TEVATRON 2011:

At the time of LHC TSUNAMI

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- Since more than ***4 decades***, the collider machines have been major discovery tools in H.E.P.
- They were first called dirty and “discovery machines”.
- They have proven to be indeed ***fantastic discovery machines*** but also ***high precision measurement machines***, competing with e+ e- (including B or charm factories) machines.
- This is due to continuous progress in Physics at hadron collider together with continuous detector upgrades, based on the most advanced technologies.
- The Tevatron experiments and especially CDF have been covering 25 years of this impressive success story.
- The Tevatron will close on September 30 this year

This lecture tries to point out a few of the major success with emphasis on the latest results and remaining puzzles.

Collider machines story

70's

ISR: (1971-1983) pp, 34 up to 63 GeV cm, up to 1.4x 10^{32} cm^2/s, CERN,
First hadron collider machine, instrumental training camp for collider machine & Physics
First direct evidence for jets, first high Pt Physics, rising total xcross section…

(SPEAR (SLAC) and PETRA (DESY) e+e- colliders: 30-40 GeV)

ISABELLE † (1978-1983)(BNL-USA): pp collider, 400 GeV cm, cancelled before machine achieved

80's

SppbarS (1981-1991), ppbar, 546 ->630 GeV cm, 10^{27}->2x10^{30} $/cm^2/s$, CERN, UA1 and UA2
Discovery of W & Z, precursor: B Physics at hadron colliders (first indirect evidence of B0-B0bar mixing), Top search, QCD and BSM. Has opened the road to LHC

Tevatron 0 (1985-1989), ppbar, FNAL, 1.8 TeV, CDF only (since 85):
Search for top (eμ and all-jets channels), EWK and QCD Physics, construction of the 1st vertex detector in hadron colliders, new developments on triggers & tracking

90's

(LEP (1989-2000): e+e- machine: 90 to 200 GeV cm, CERN)

Tevatron I(1992-1995), ppbar, FNAL, 1.8 TeV, up to 5x$10^{31}$$cm^2/s$,CDF &D0
Discoveries: **Top**
First vertex detector successfully installed in hadron collider (CDF in 1992)
Pioneering work on: Top, B, EWK Physics, BSM searches

SSC † (Texas-USA): pp collider, 40 TeV cm, 10^{33} $/cm^2/s$ cancelled 1992 before machine achieved

Collider machines story (cont'd)

2000

1st decade

Tevatron II(2001-2011), 1.96TeV, up to $4.2x10^{32}$/cm^2/s
Discoveries & Major breaktroughs: **Single top, Bs mixing, Top & W precise mass mst**
in Top, B, and EWK/dibosons Physics, pioneering Higgs and BSM searches
First triggering with tracking (CDF: L1 COT and L2 SVT)

2nd decade

LHC (2010-): pp, 7 TeV->14TeV c.m., $2x10^{34}$/cm^2/s, ATLAS, CMS, LHCb;

See lectures from P. Jenni and De Roeck

Higgs yes or ????????????????

What's next???

sLHC (towards 2020-_): higher Lum and or increase in energy, major detector upgrades

=> Future LC under study: ILC, CLIC projects
a very high energy LHC (VLHC?)

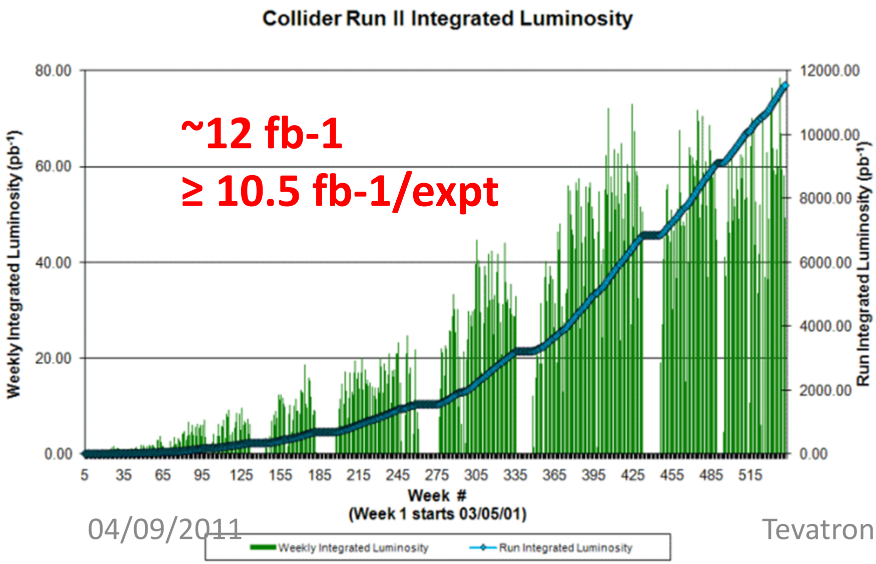
TEVATRON vs LHC 2011

Tevatron

- 2 experiments (CDF since 1985, D0 since 1992 , BTeV aborted 07-2005)
- ppbar collider (qqbar dominance)
- Started 1985 *(run0-1989 vs SppbarS')*

  Ends September 30 2011
- Ecm=2TeV
- Luminosity:peak: 4.2x10^{33}/cm/s

  ~ 60pb-1/week



~12 fb-1

≥ 10.5 fb-1/expt

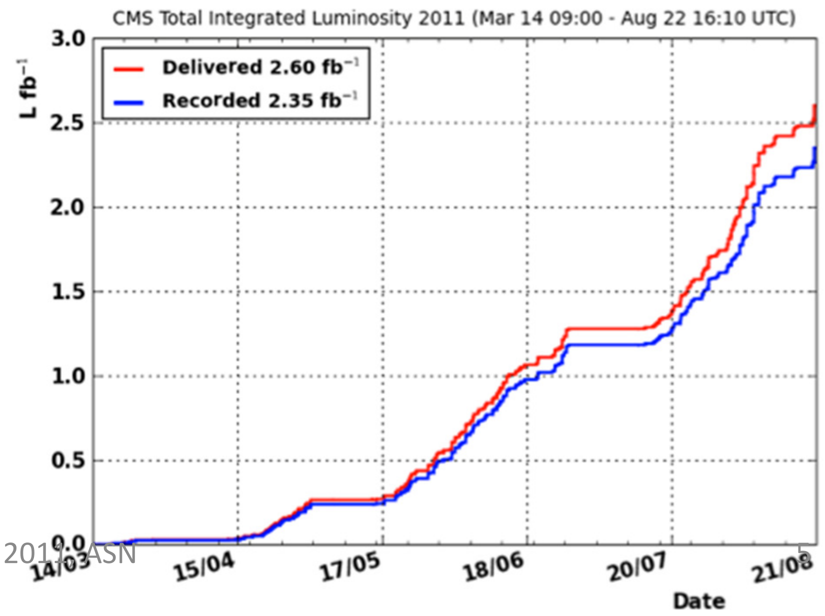
LHC

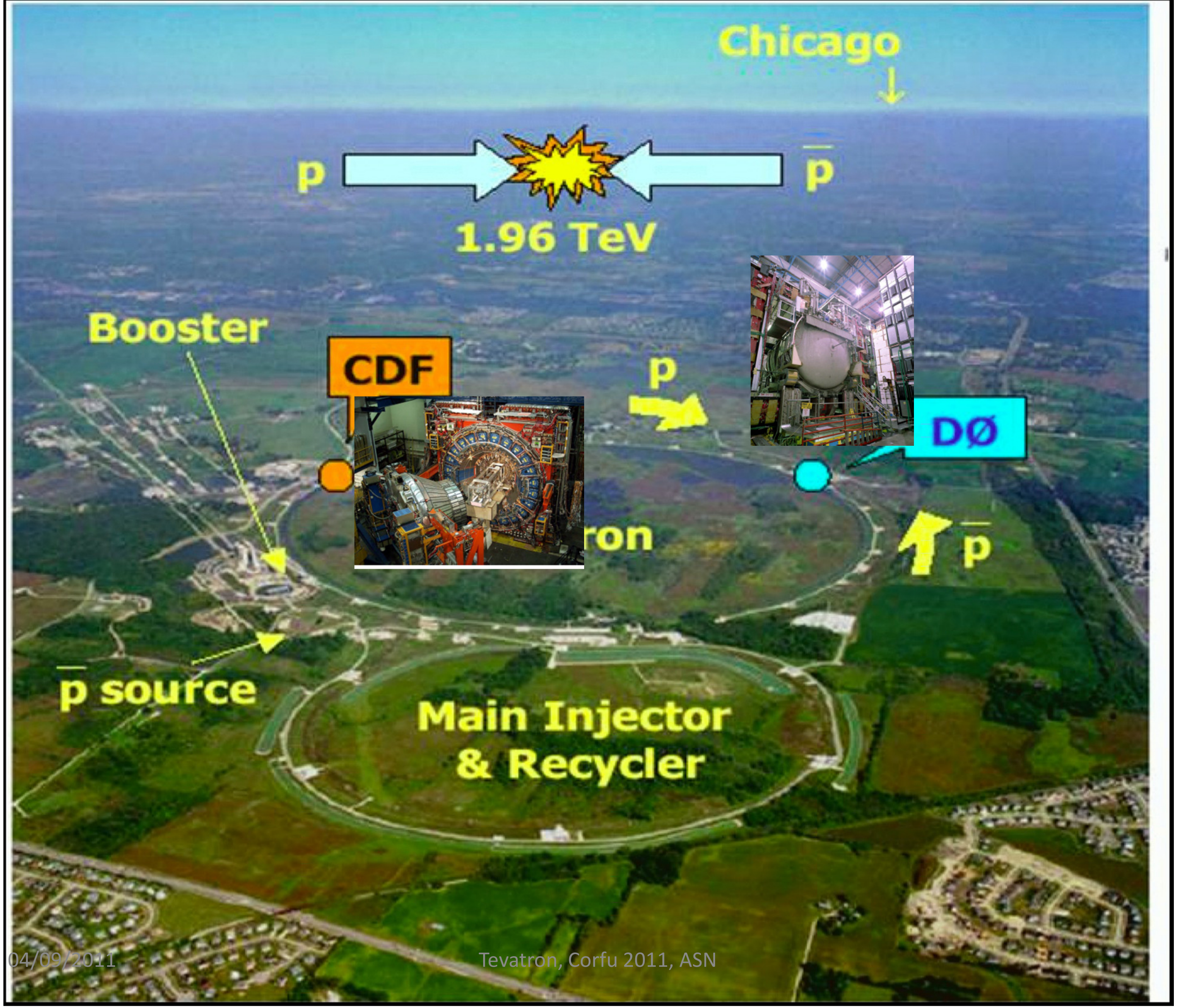
- 3 experiments (ATLAS, CMS, LHCb

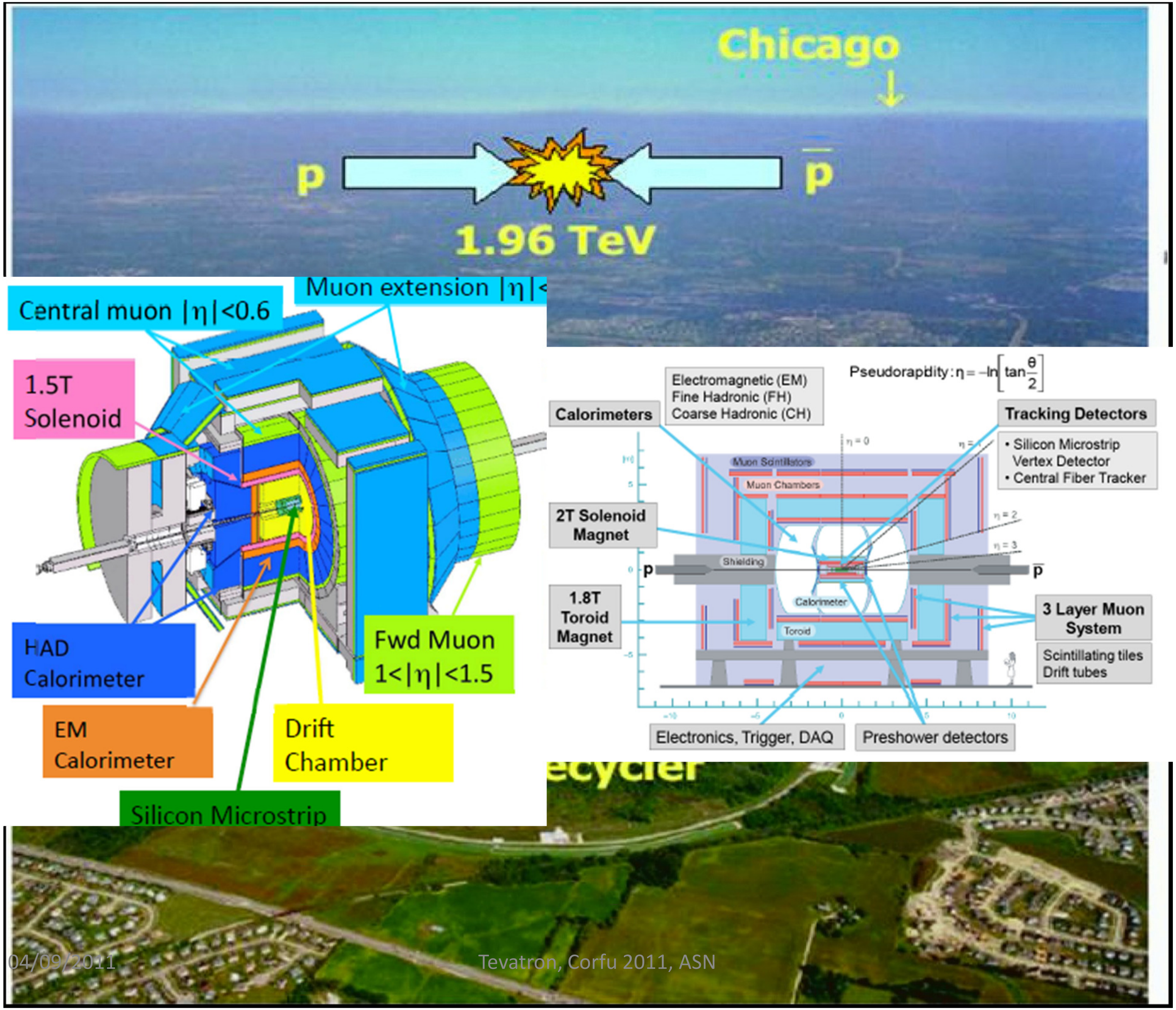
  + Heavy Ion dedicated experiment: ALICE)
- pp collider (gg dominance)
- Started 2010 *(2008)*

  First long shutdown 2013-part 2014
- Ecm= 7 TeV -> 14 TeV
- Luminosity: peak~ 2.4x 10^{33}/cm/s

  ~ 250 pb-1 /week




Chicago
p
1.96 TeV
$\bar{p}$
Booster
CDF
p
DØ
ron
$\bar{p}$
$\bar{p}$ source
Main Injector
& Recycler


Chicago
p
p̄
1.96 TeV
Central muon |η|<0.6
Muon extension |η|<
1.5T Solenoid
HAD Calorimeter
EM Calorimeter
Silicon Microstrip
Drift Chamber
Fwd Muon 1<|η|<1.5
Calorimeters
Electromagnetic (EM)
Fine Hadronic (FH)
Coarse Hadronic (CH)
Pseudorapidity: $\eta = -\ln\left[\tan\frac{\theta}{2}\right]$
Tracking Detectors
• Silicon Microstrip Vertex Detector
• Central Fiber Tracker
2T Solenoid Magnet
1.8T Toroid Magnet
3 Layer Muon System
Scintillating tiles
Drift tubes
Electronics, Trigger, DAQ
Preshower detectors
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
η = 0
η = 1
η = 2
η = 3
p
p̄
ecycler

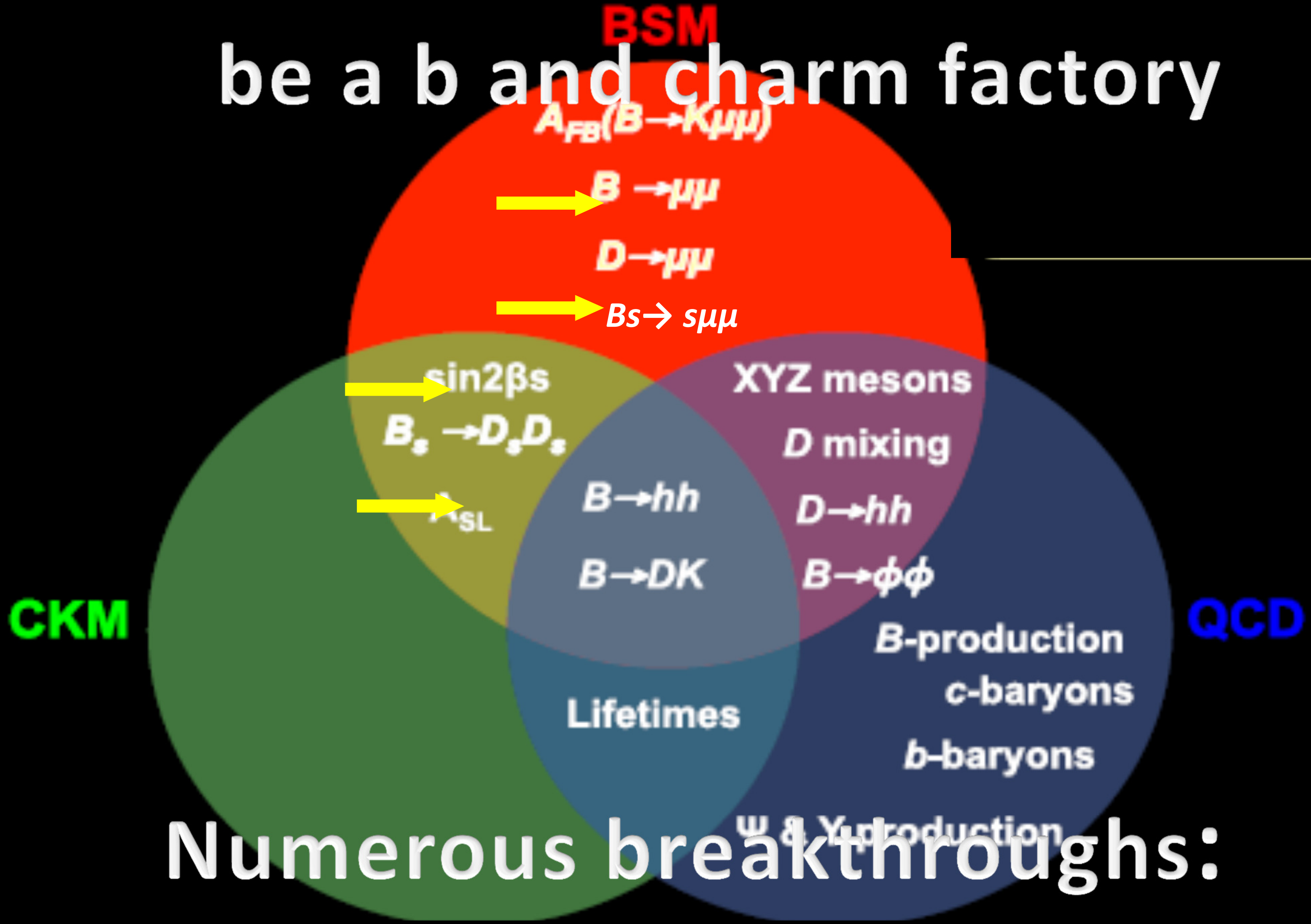
Outline

A few latest results of the Tevatron on:

- HEAVY FLAVOURS: B and Top Physics.
- HIGGS SECTOR Exploration
- BSM

LEGACY will be underlined in a few words in these different topics and in the concluding remarks…

Tevatron has demonstrated to be a b and charm factory



Numerous breakthroughs:

Bs mixing 1st precise measurement & much more

B Physics and the BSM exploration:

Let’s concentrate on 3 flagship measurements:

1) rare B decays with:

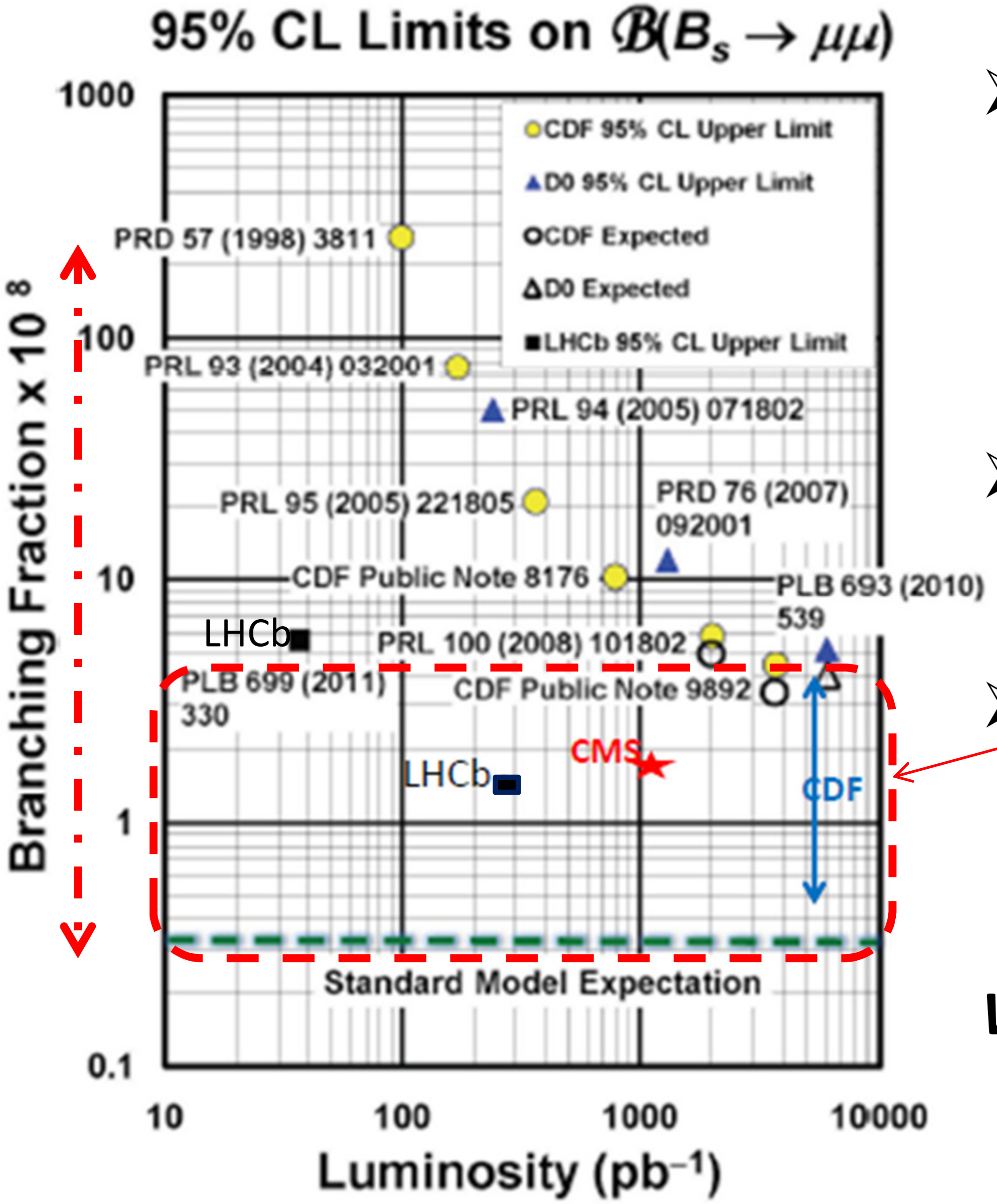
$Bs \rightarrow \mu\mu$

2) CP violation study in Bs sector with:

$B_s \rightarrow J/\Psi\varphi$

Dimuon charge asymmetry

$B_s \to \mu+\mu-$



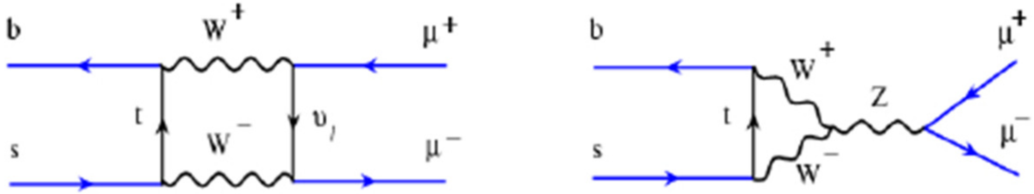
- At start of Run II, one decade ago, the limit set by CDF at Run I, on Br(Bs→μμ) was 3 orders of magnitude above the SM expected value.
- Tevatron (mainly CDF) decreased by more than 2 orders of magnitude this limit.
- We are now in the last round => near to get the final answer on: SM= Si or No?

What can the Tevatron still say?

=> see next…

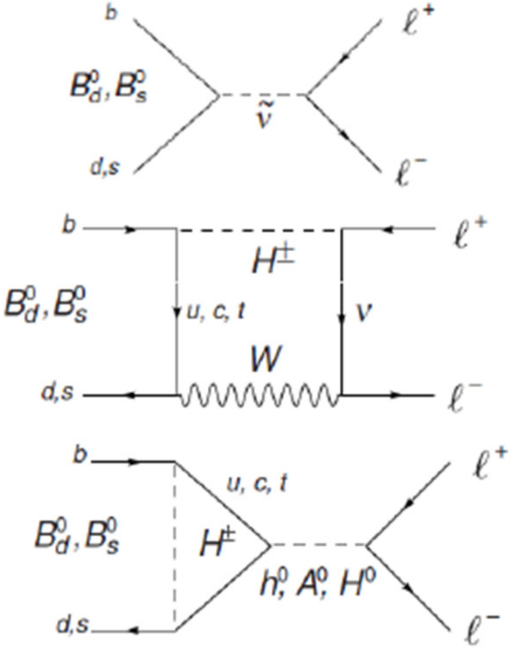
The $B_s \rightarrow \mu+\mu-$ case

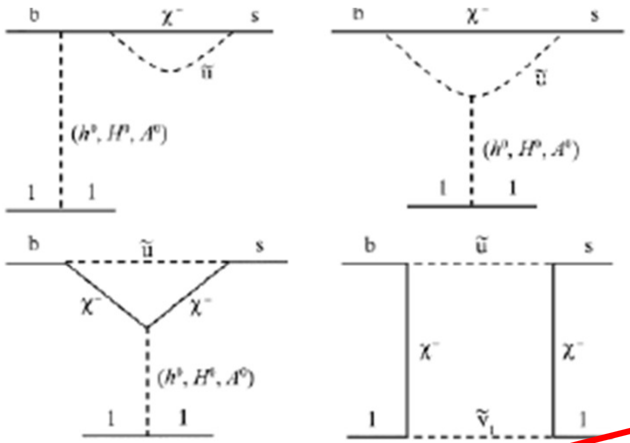
FCNC decays predicted to be very rare in the SM due to GIM & helicity suppression
Forbidden at tree level, proceed through loop diagrams



S,M, expectation: Buras => $Br(Bs \rightarrow \mu\mu) = (3.2 \pm 0.2)x10^{-9}$

New Physics will give a higher Br value:





$\mathcal{B}^{SUSY}(B \rightarrow \mu\mu) \propto (\tan\beta)^6$

New Physics can appear:
at tree level or through loops:

MFV –SM extensions
or SUSY:

New search for $B_s \rightarrow \mu\mu$ at CDF with 7fb^{-1}

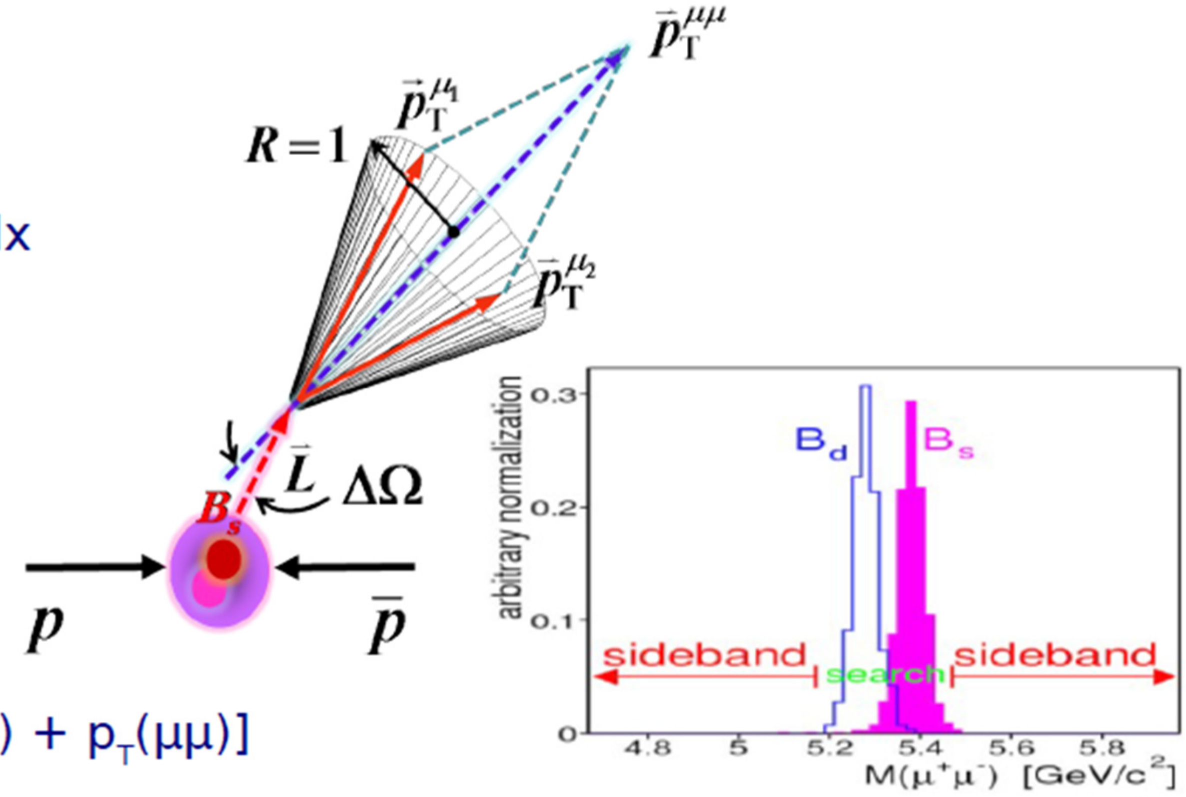
The events are searched in a sample of dimuon triggered events, but:
7 fb^{-1} data (x 2 Lum.) & acceptance improved by 20%, adding CC and CF dimuon triggered events plus refined pre-selection and upgraded analysis (next slide)

Forward (F)	Central (C)
$0.6 < \lvert\eta\rvert < 1$	$\lvert\eta\rvert < 0.6$
$p_T > 2$ GeV	$p_T > 1.5$ GeV

Preselection:

3D vertex fit and baseline cuts on

- Track quality
- Muon likelihood, dE/dx
- $p_T(\mu\mu)$
- $p_T(\mu)$
- Proper decay time significance
- Pointing angle
- Isolation: $p_T(\mu\mu) / [\sum_{R<1} p_T(\text{track}) + p_T(\mu\mu)]$



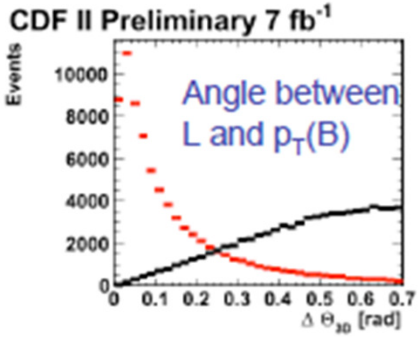
Blinded search region: 5.169 – 5.469 GeV

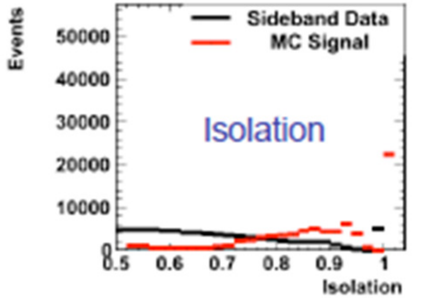
With extended sidebands in the new analysis

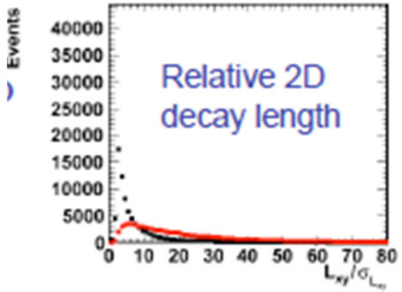
$B_s \to \mu\mu$ analysis

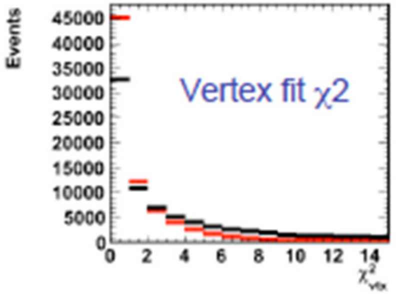
A set of 14 discriminating variables, comparing data (sidebands, black)=bkgd with MC generated events (red) = signal are studied and trained in a NN; 6 most sensitive variables are shown here:

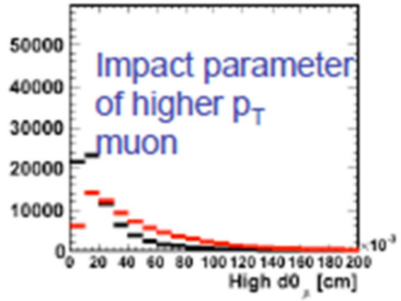
CDF II Preliminary 7 fb^{-1}

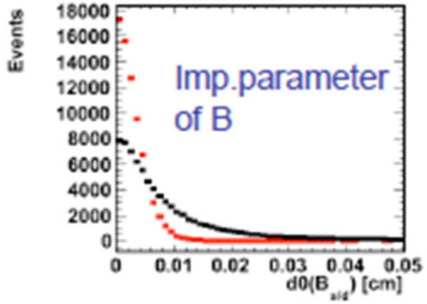












NN

Signal region determined by 5.169<Mμμ (GeV/c^2)<5.469
Previous sideband regions to estimate the background (here below)
$4.669 < M_{\mu\mu} < 5.169\,\mathrm{GeV}/c^2$ and $5.469 < M_{\mu\mu} < 5.969\,\mathrm{GeV}/c^2$ have bee extended.

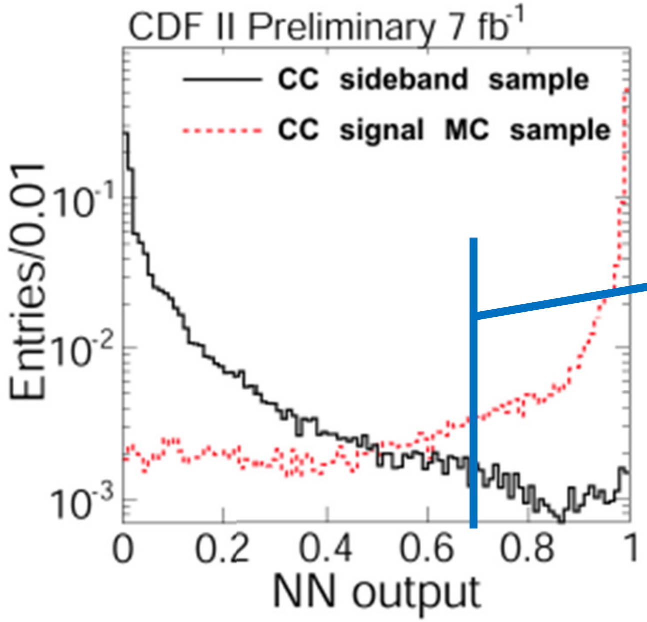
The Branching fraction is obtained by normalizing to the number of $B^+ \to J/\Psi K^+ \to \mu+\mu- K^+$

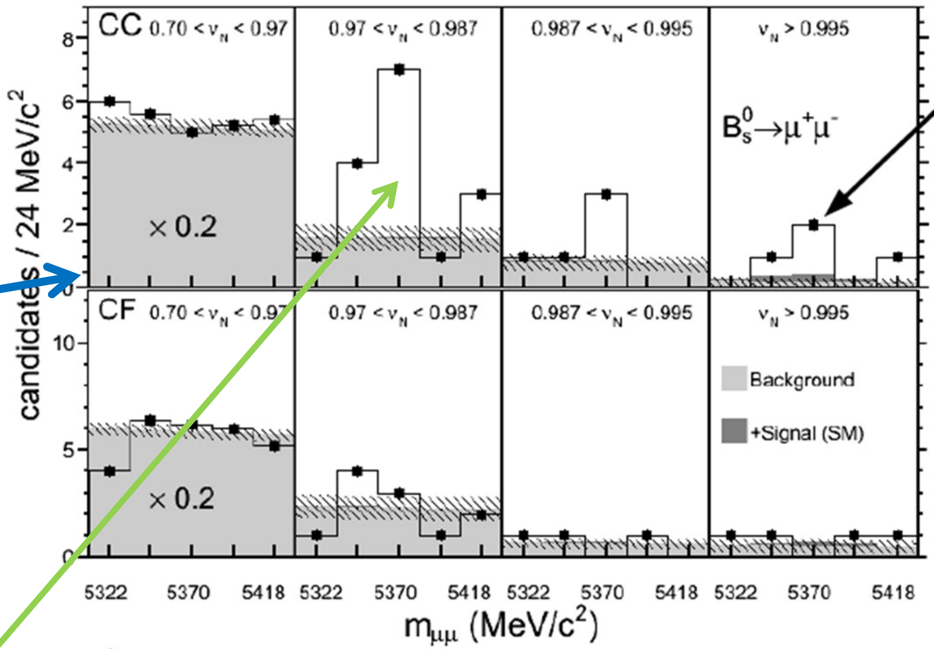
$$\mathcal{B}(B^0_{s,d}\to\mu^+\mu^-) = [N_{s,d}/N_+] \text{ x } [\alpha_+/\alpha_s] \text{ x } [\varepsilon_+/\varepsilon_{s,d}] \text{ x } [1/\varepsilon^{NN}_{s,d}] \text{ x } f_u/f_{s,d} \text{ x } \mathcal{B}(B^+\to J/\Psi\, K^+)$$

Where N_s=number of $B^0_s \to \mu+\mu-$ at 95%CL for N observed and N_b expected backg.
α stands for the acceptance, ε for efficiency and f for fragmentation function

RESULTS:

Suppress background with NN trained on MC/sideband data

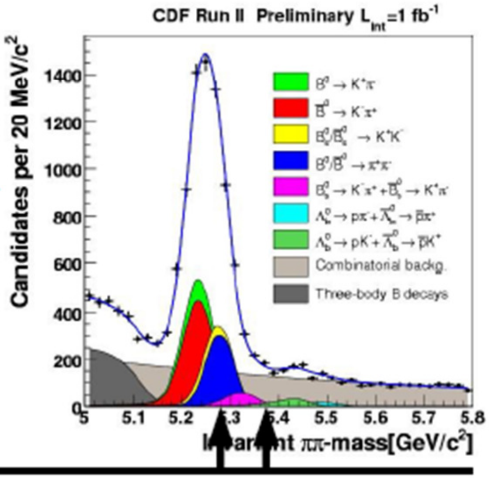




Example:
Obs: 2
Exp:
0.16±0.12

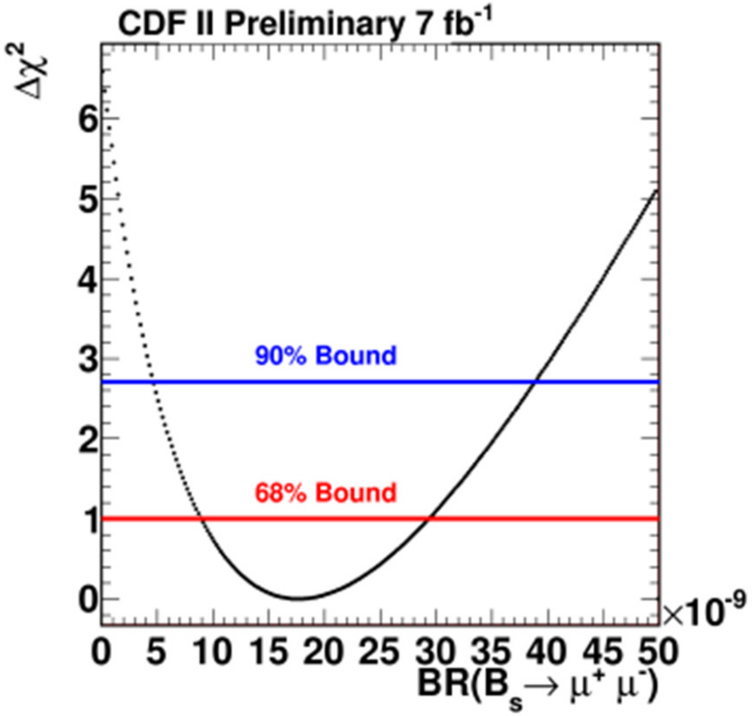
Reason for excess in 3rd highest NN bin of CC sample?

- Peaking background (B → h⁺h'⁻)?
  - ⇨ Unlikely, not seen in B⁰
- $B^0_{(s)} \to \mu^+\mu^-$ signal?
  - ⇨ Unlikely, NN well described for B⁺
- Combinatorial background?
  - ⇨ Unlikely, no NN bias observed
- Statistical fluctuation?
  - ⇨ Can happen in one out of 80 bins



CDF 2011 new result

- 90% CL region: $4.6 \times 10^{-9} < BR(B^0_s \rightarrow \mu^+\mu^-) < 3.9 \times 10^{-8}$



- Central value:
  - $BR(B^0_s \rightarrow \mu^+\mu^-) = 1.8^{+1.1}_{-0.9} \times 10^{-8}$
- Central value using only the highest two NN bins:
  - $BR(B^0_s \rightarrow \mu^+\mu^-) = 1.4^{+1.0}_{-0.8} \times 10^{-8}$

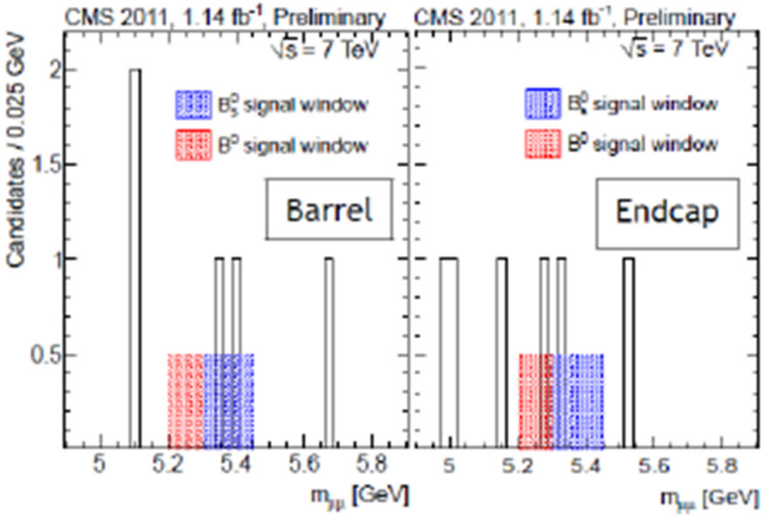
First double sided confidence region on Br(Bs→μμ)

"Although of moderate statistical significance this is the first indication of a Bs→μμ signal"

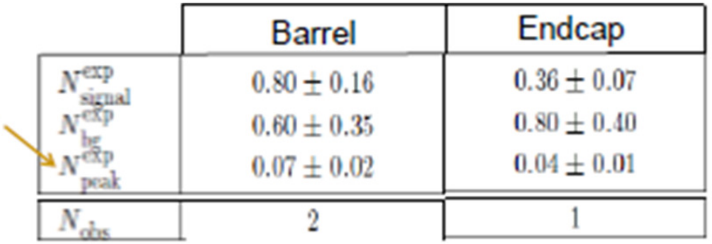
➡ ***May be the first glimpse of exciting times ahead?***

EPS 2011

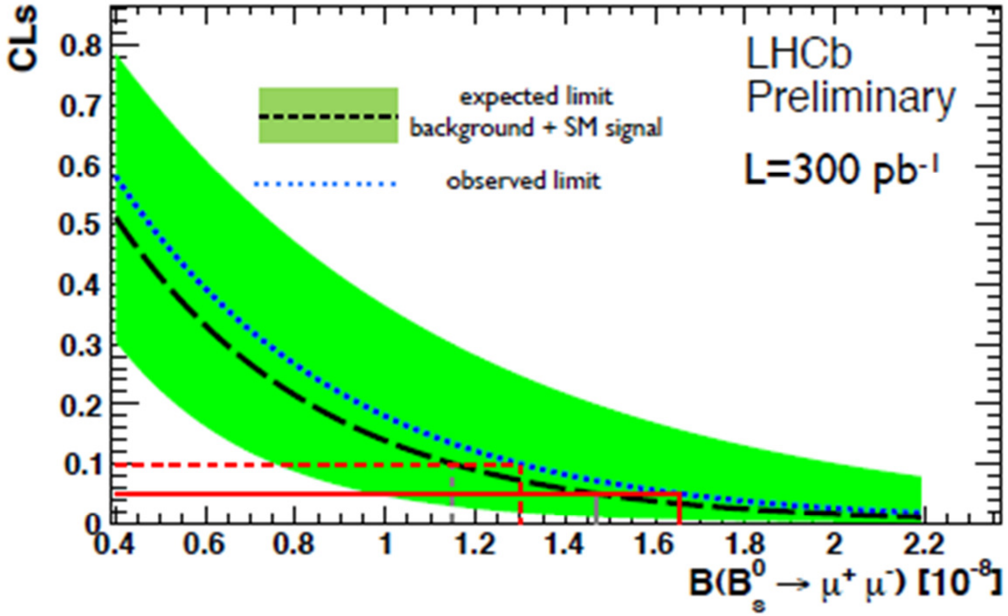
CMS, LHC*b*: $B_s \rightarrow \mu\mu$ Limits



this is B→hh



	Barrel	Endcap
N^{exp}_{signal}	0.80 ± 0.16	0.36 ± 0.07
N^{exp}_{bg}	0.60 ± 0.35	0.80 ± 0.40
N^{exp}_{peak}	0.07 ± 0.02	0.04 ± 0.01
N_{obs}	2	1



CMS-BPH-11-002

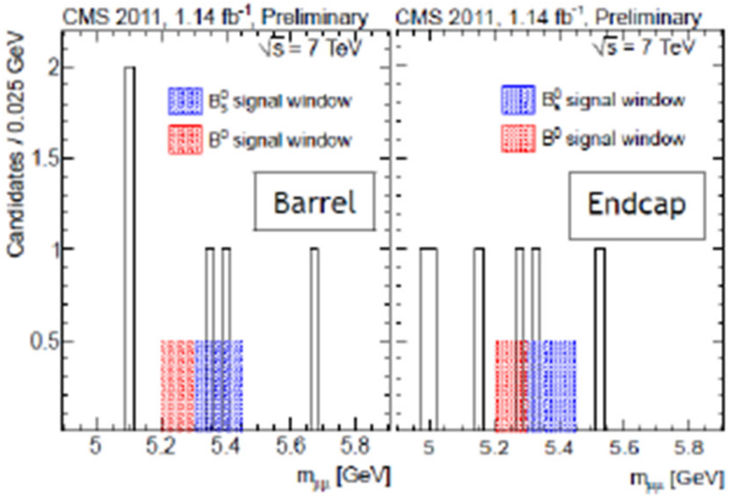
- Expected Limit: $< 1.8 \times 10^{-8}$ @ 95%CL
- p-value background only: 11%
- $Br(B_s \rightarrow \mu\mu) < 1.9 \times 10^{-8}$ @ 95% CL
- using $f_s/f_u = 0.282 \pm 0.037$ [pdg]

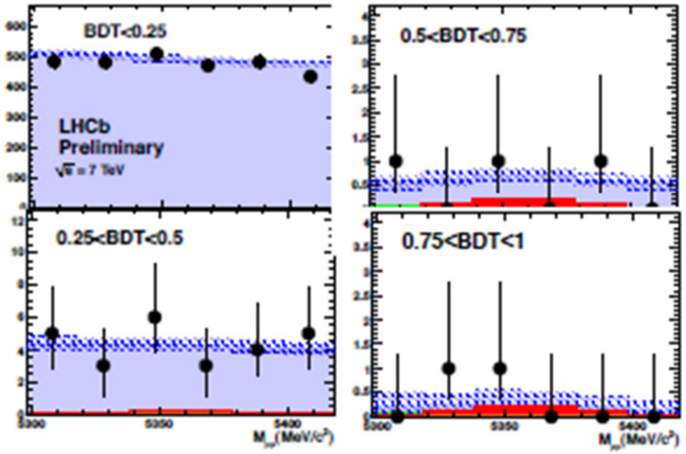
LHCb-CONF-2011-037

- Expected Limit: $< 1.5 \times 10^{-8}$ @ 95%CL
- p-value background only: 14%
- $Br\ (B_s \rightarrow \mu\mu) < 1.6 \times 10^{-8}$ @ 95% CL
- combined with 2010: $< 1.5 \times 10^{-8}$ @ 95% CL

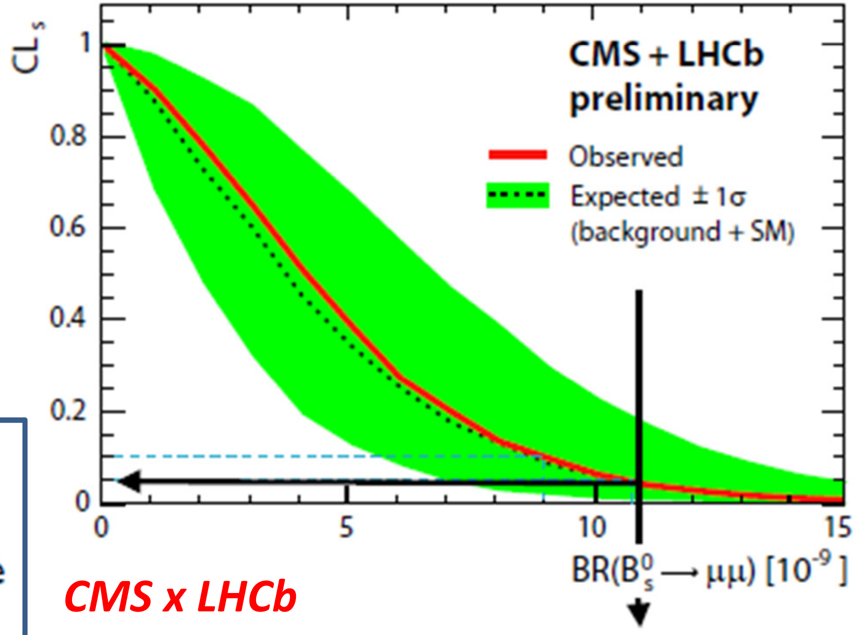
LEPTON PHOTON 2011:
CMS+LHC*b*: Combined $B_s \to \mu\mu$ Limit

LHCb-CONF-2011-047= CMS-PAS-BPH-11-019



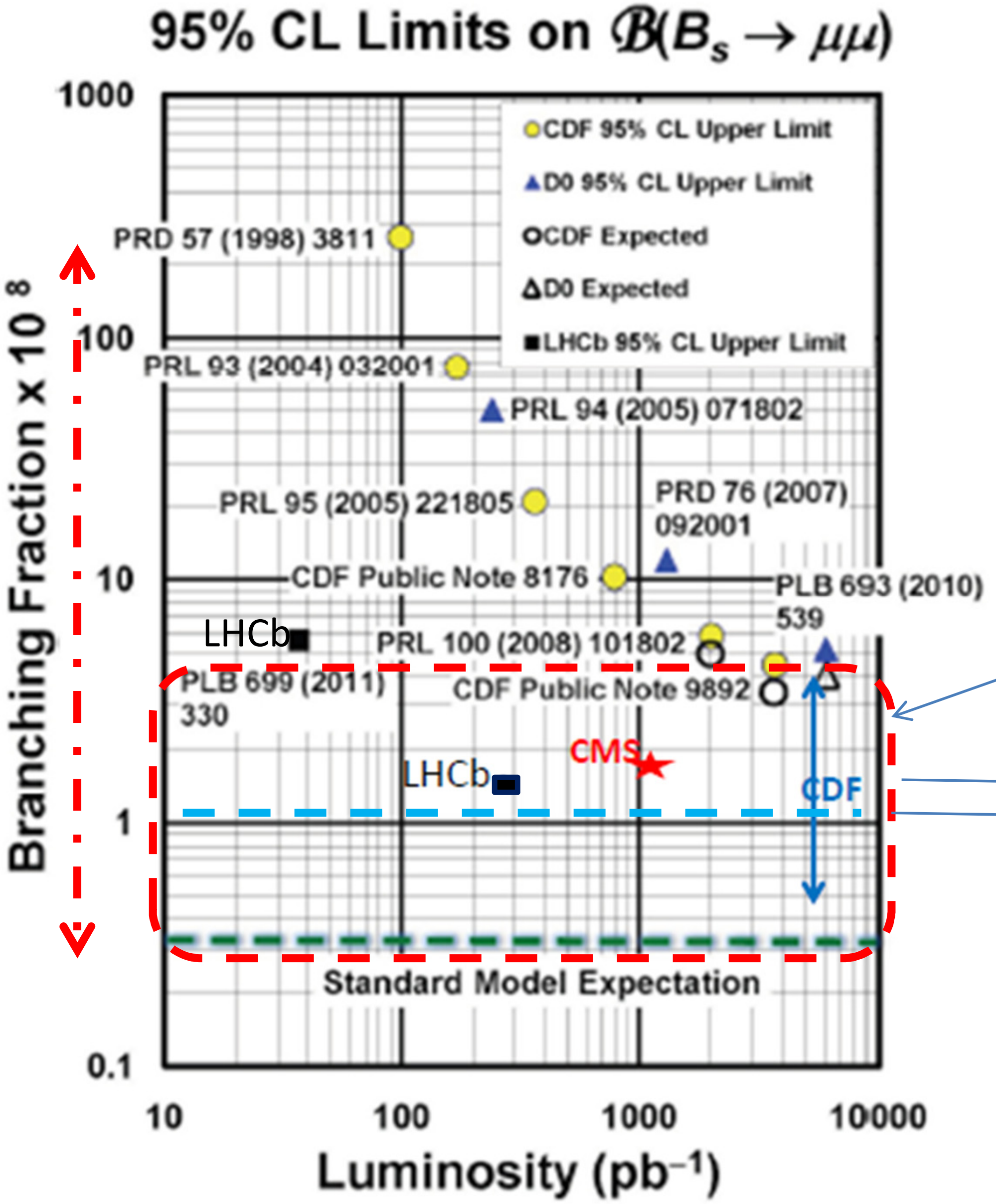


- Use $(f_s/f_d)_{LHCb} = 0.267^{+0.021}_{-0.020}$
- p-value background only: 8%
- p-value background + SM BR: 55%
- $Br(B_s \to \mu\mu) < 11 \times 10^{-9}$ @ 95% CL
- Given that the 95% CL is still 3.4 x SM, there remains plenty of room for NP, keep an eye in the near future!



CMS x LHCb

$< 11 \times 10^{-9}$ @ 95% CL



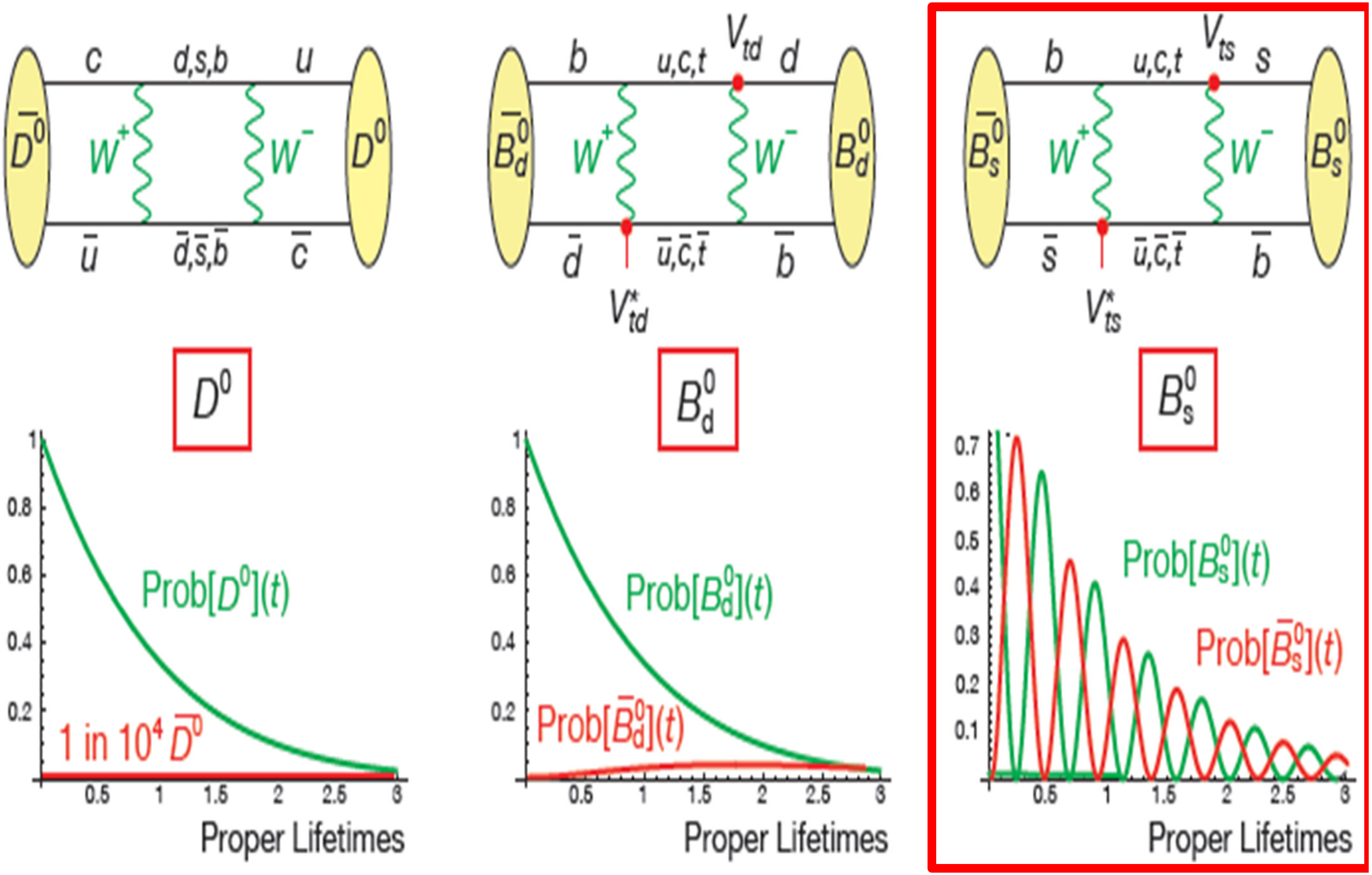
$B_s \rightarrow \mu+\mu-$ by Aug 2011

CDF: $4.6\times10^{-9} < Br < 3.9\times10^{-8}$, 90% CL

LHC: CMSxLHCb: $Br < 1.1\times10^{-8}$,95%CL

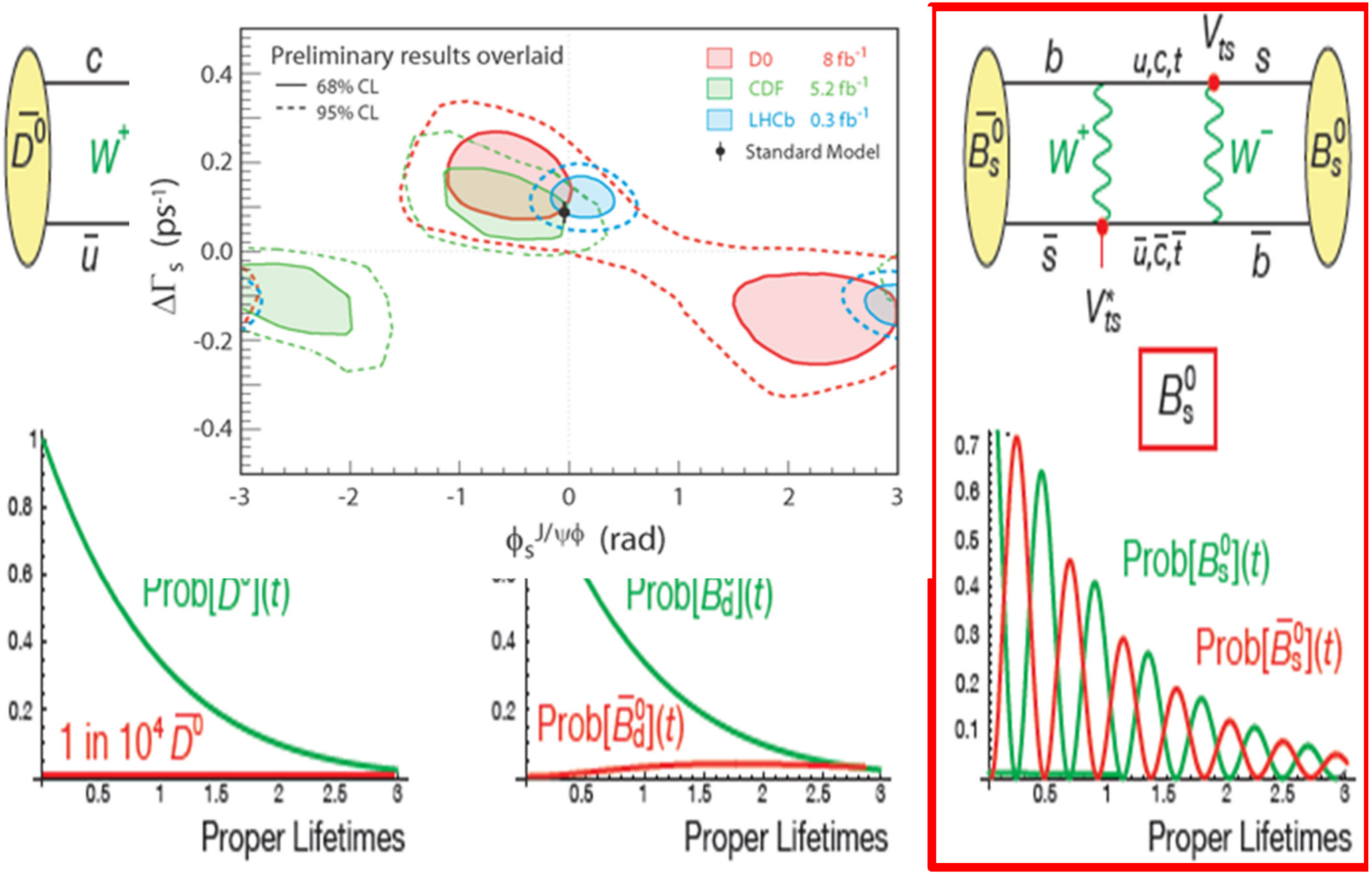
Still some very little room for BSM

Exploring the Bs CP Violation sector



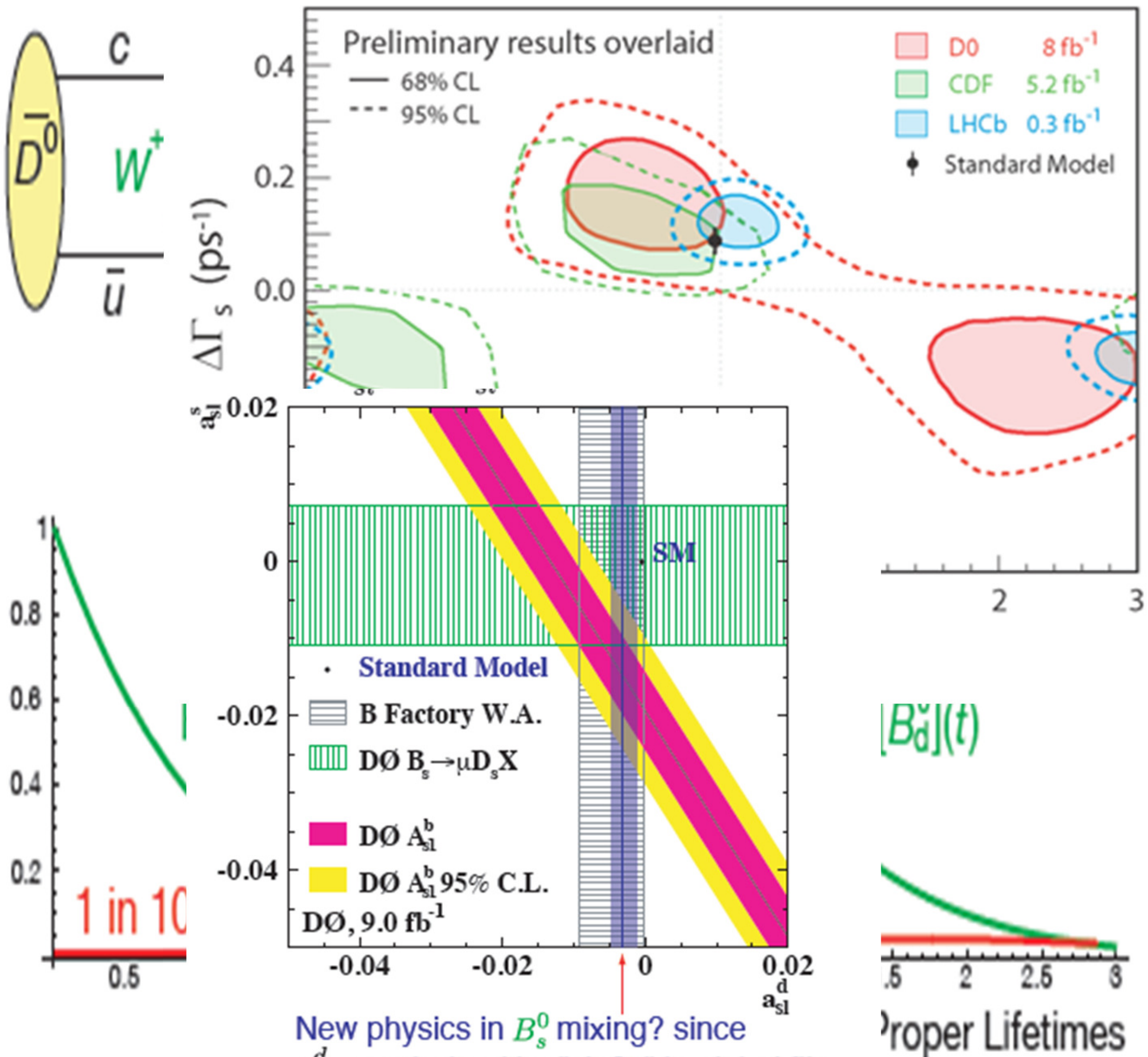
Heavy mesons oscillations

Exploring the Bs CP Violation sector



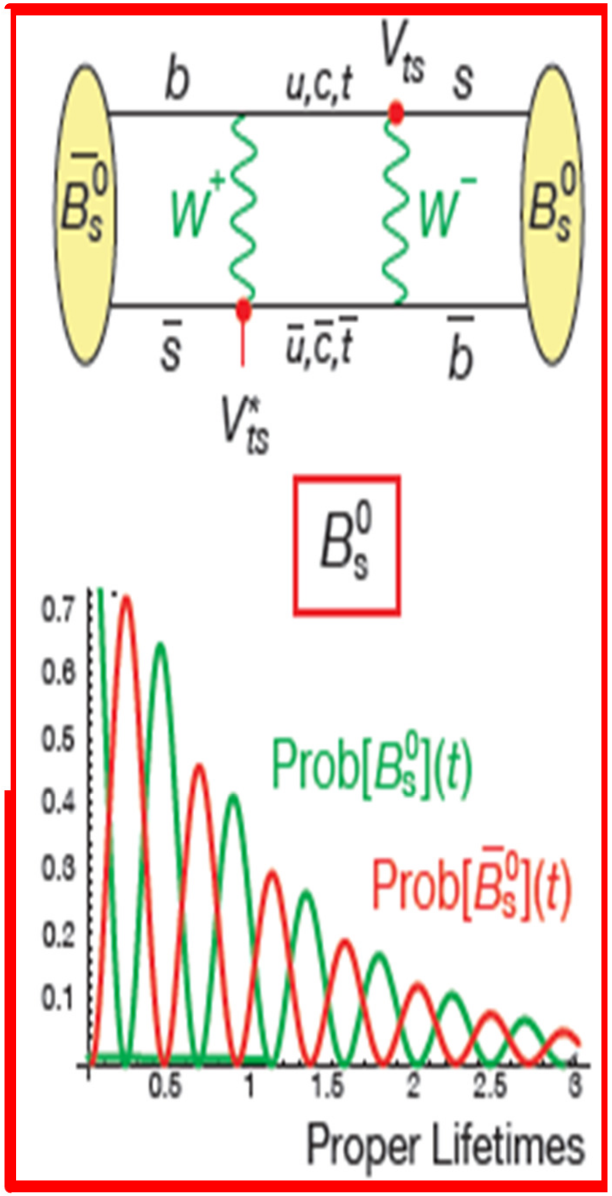
Heavy mesons oscillations

Exploring the Bs CP Violation sector



New physics in B^0_s mixing? since a^d_{sl} constrained by "sin2β" in global fits:

$a^d_{sl}(\text{pred.}) = (-36^{+23}_{-11}) \times 10^{-4}$ PRD **83**, 036004 (2011)

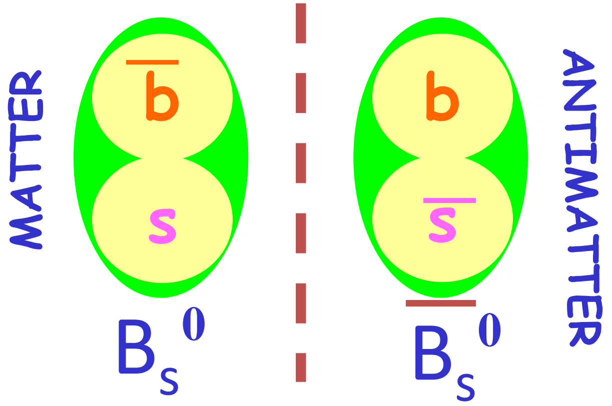


ns oscillations

Neutral B_s System: Recap!

- Time evolution of B_s flavor eigenstates described by Schrodinger equation:

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle\\ |\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M} - \frac{i}{2}\mathbf{\Gamma}\right)\begin{pmatrix}|B_s^0(t)\rangle\\ |\bar{B}_s^0(t)\rangle\end{pmatrix}$$



-Diagonalize mass (M) and decay (Γ) matrices

→ mass eigenstates :

$$|B_s^H\rangle = p\,|B_s^0\rangle - q\,|\bar{B}_s^0\rangle \qquad |B_s^L\rangle = p\,|B_s^0\rangle + q\,|\bar{B}_s^0\rangle$$

- Flavor eigenstates differ from mass eigenstates and mass eigenvalues are also different:

$\Delta m_s = m_H - m_L \approx 2|M_{12}|$

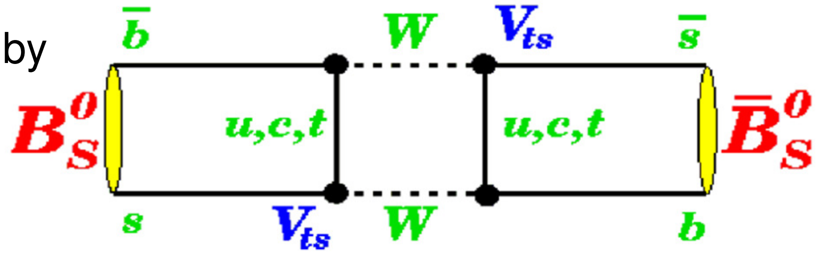
→ B_s oscillates with frequency $\Delta m_{s,}$ precisely measured by

CDF $\Delta m_s = 17.77 \pm 0.12\ ps^{-1}$

2006: first & unprecedently precise measurement (1fb^{-1})

DØ $\Delta m_s = 18.56 \pm 0.87\ ps^{-1}$

And now LHCb (see later)



- Mass eigenstates have different decay widths

$$\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos(\Phi_s) \qquad \text{where} \qquad \phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4 \times 10^{-3}$$

β_s vs ϕ_s

- Up to now, introduced two different phases:

$\phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4x10^{-3}$ and $\beta_s^{\mathrm{SM}} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$

- New Physics affects both phases by same quantity ϕ_s^{NP}

$$2\beta_s = 2\beta_s^{\mathrm{SM}} - \phi_s^{\mathrm{NP}}$$

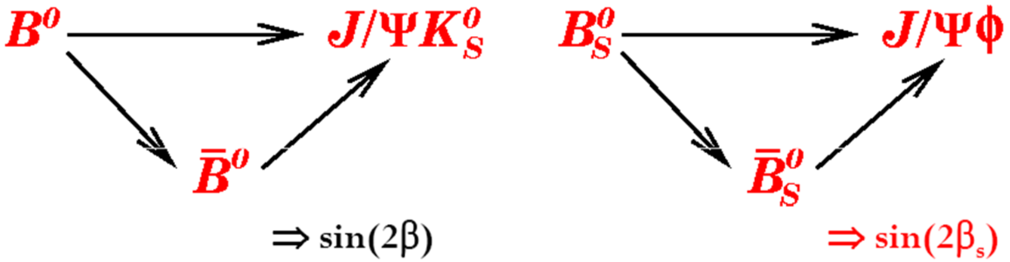
$$\phi_s = \phi_s^{\mathrm{SM}} + \phi_s^{\mathrm{NP}}$$

- If the new physics phase ϕ_s^{NP} dominates over the SM phases $2\beta_s^{\mathrm{SM}}$ and ϕ_s^{SM}
→ neglect SM phases and obtain:

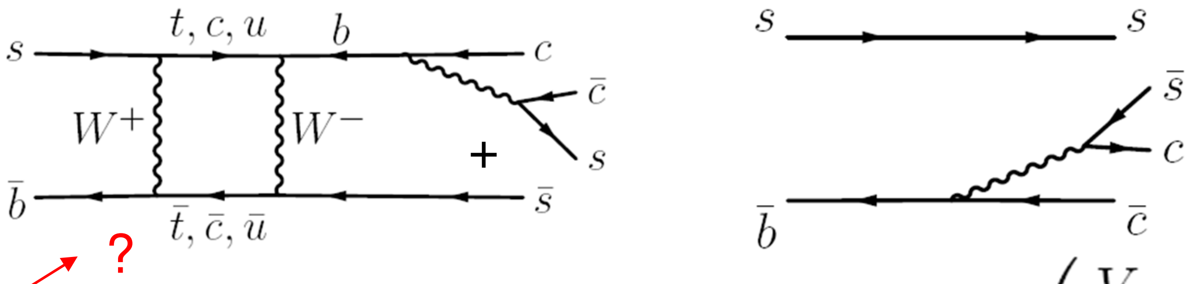
$$2\beta_s = -\phi_s^{\mathrm{NP}} = -\phi_s$$

CP Violation in $B_s \rightarrow J/\Psi\Phi$ Decays

- Analogously to the neutral B^0 system, *CP* violation in B_s system occurs through interference of decays with and without mixing:



dominant
contribution
from top quark



New Physics
particles ?

$$\beta_s^{\text{SM}} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- *CP* violation phase β_s in SM is predicted to be very small, $O(\lambda^2)$
- New physics particles running in the mixing diagram may enhance β_s
  - large β_s → clear indication of New Physics !

$B_s \rightarrow J/\Psi\Phi$ Decays

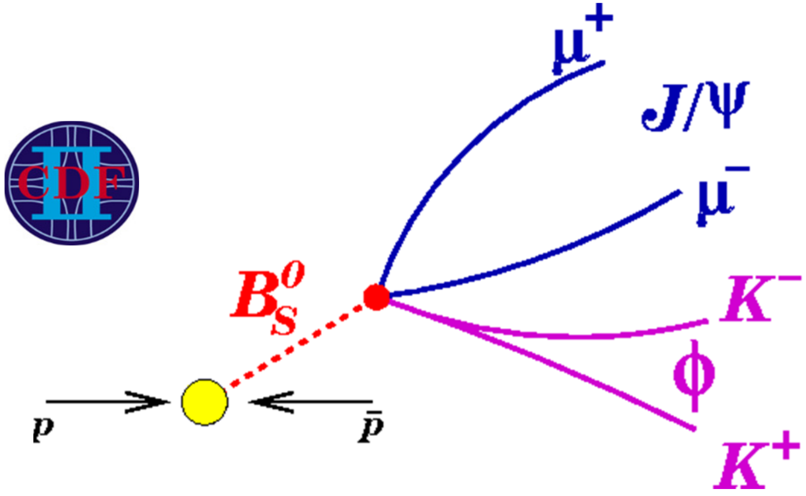
- Extremely physics rich decay mode

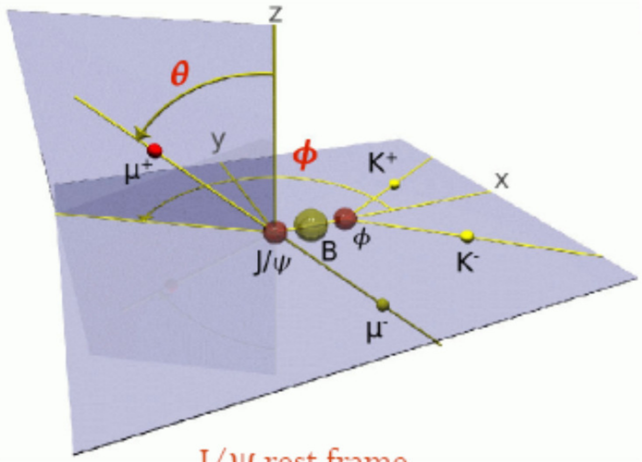
- Can measure lifetime, decay width difference $\Delta\Gamma$ and *CP* violating phase β_s

- Decay of B_s (spin 0) to J/Ψ (spin 1) and Φ (spin 1) leads to three different angular momentum final states:

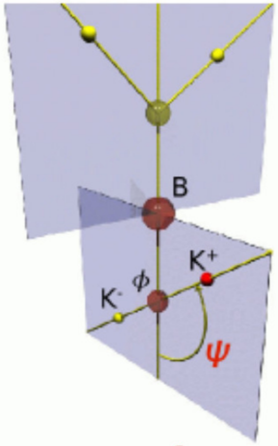
  $L = 0$ (s-wave), 2 (d-wave) → *CP even* (= short lived or light B_s if no *CPV*)

  $L = 1$ (p-wave) → *CP odd* (= long lived or heavy B_s if no *CPV*)





J/ψ rest frame



φ rest frame

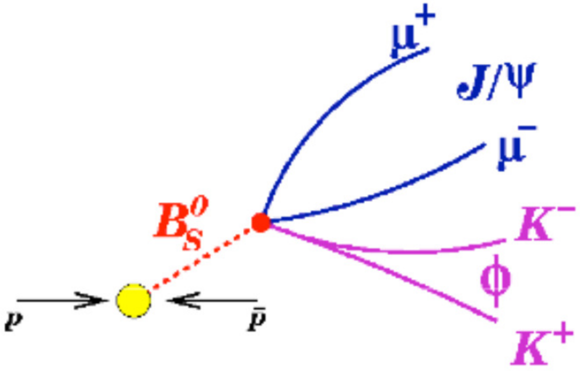
- Three decay angles $\rho = (\theta,\phi,\psi)$ describe directions of final decay products
  $\mu^+ \mu^- K^+ K^-$

Caveat: Bs→J/Ψφ is golden mode, but additional experimental complications:

- J/ψφ: a mix of CP-even and CP-odd eigenstates, treat them separately
- B_s oscillates ~ 35 times faster than B^0
- sin2β~0.7, sin2β_s expected about 20 times smaller

ANALYSIS OUTLINE

Reconstruct Bs→J/ψ(→μ+μ-) ϕ(→K+K-)



DIMUONS TRIGGER

NN SELECTION

Simultaneous mass, angular, time dependent, flavour tagged fit:

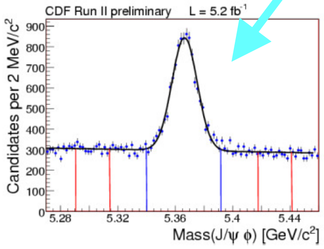
$$f_s P_s(m|\sigma_m) P_s(t,\vec{\rho},\xi|\mathcal{D},\sigma_t) P_s(\sigma_t) P_s(\mathcal{D})$$

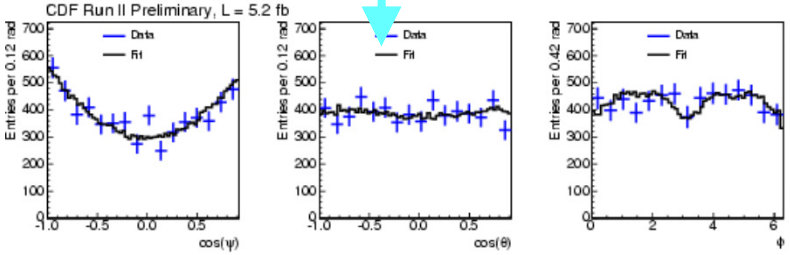
Bs mass fit to Separate signal from background

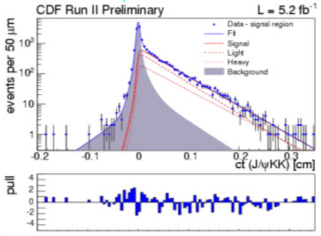
Angular separation of CP eigenstates

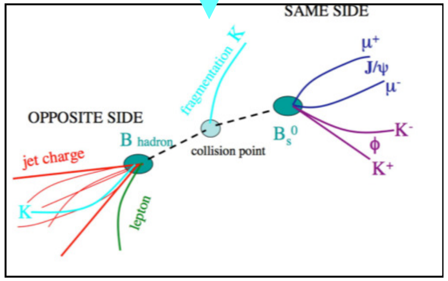
Time dependence of decay

Flavour tagging to separate Bs and Anti-Bs decays



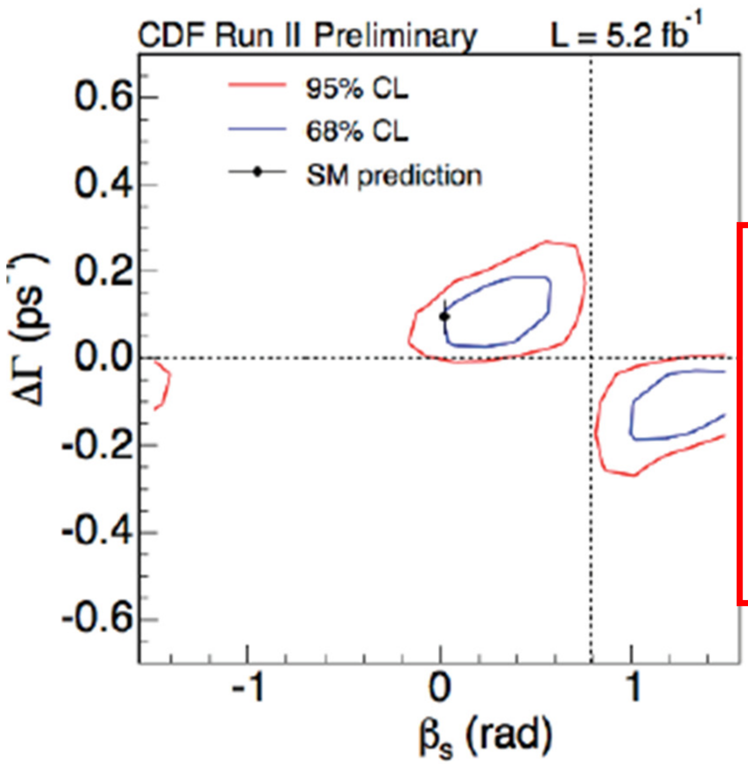






N.B. All based on quantities directly derived from data!!

RESULTS in 2010 still the latest one from CDF



Flavour tagged fit with sin2βs set to 0 (i.e. SM)

PDG value: $\tau_s = 1.47^{+0.026}_{-0.027}$ ps

$$
\begin{aligned}
c\tau_s &= 458.6 \pm 7.5\ (\text{stat.}) \pm 3.6\ (\text{syst.})\ \mu\text{m} \\
\Delta\Gamma &= 0.075 \pm 0.035\ (\text{stat.}) \pm 0.01\ (\text{syst.})\ ps^{-1} \\
|A_{\parallel}(0)|^2 &= 0.231 \pm 0.014\ (\text{stat}) \pm 0.015\ (\text{syst.}) \\
|A_0(0)|^2 &= 0.524 \pm 0.013\ (\text{stat}) \pm 0.015\ (\text{syst.}) \\
\phi_{\perp} &= 2.95 \pm 0.64\ (\text{stat}) \pm 0.07\ (\text{syst.})
\end{aligned}
$$

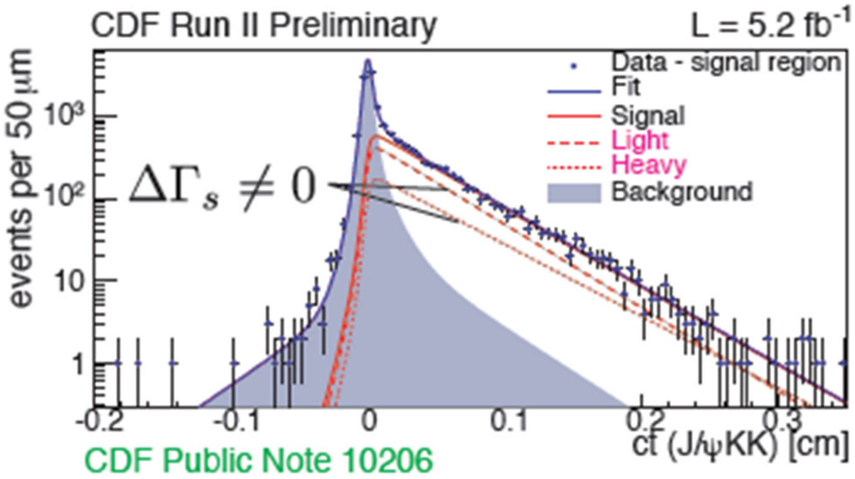
World's more precise single measurement of Bs lifetime and decay width difference (2010)

P-value for SM point: 44% ***(0.8σ dev.)***

[0.02,0.52]U[1.08,1.55] 68% C.L.

[-0.13,0.68]U[0.89,π/2]U[-π/2, -1.44] 95% C.L.

- ***Agreement with SM expectation increases with higher statistics***
- ***β_s and $\Delta\Gamma$ allowed parameter space greatly reduced***



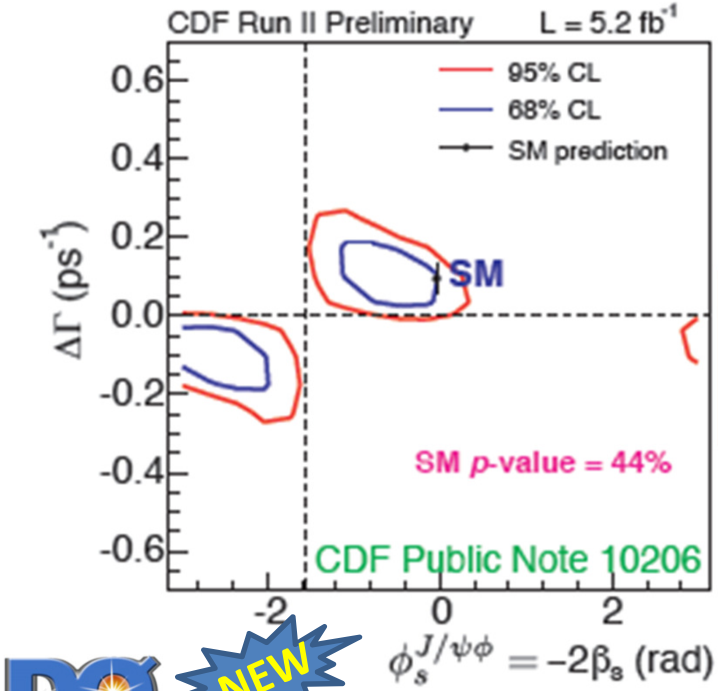
CDF Public Note 10206

CP Violation in B_s^0 Mixing

$B_s^0 \to J/\psi\phi$

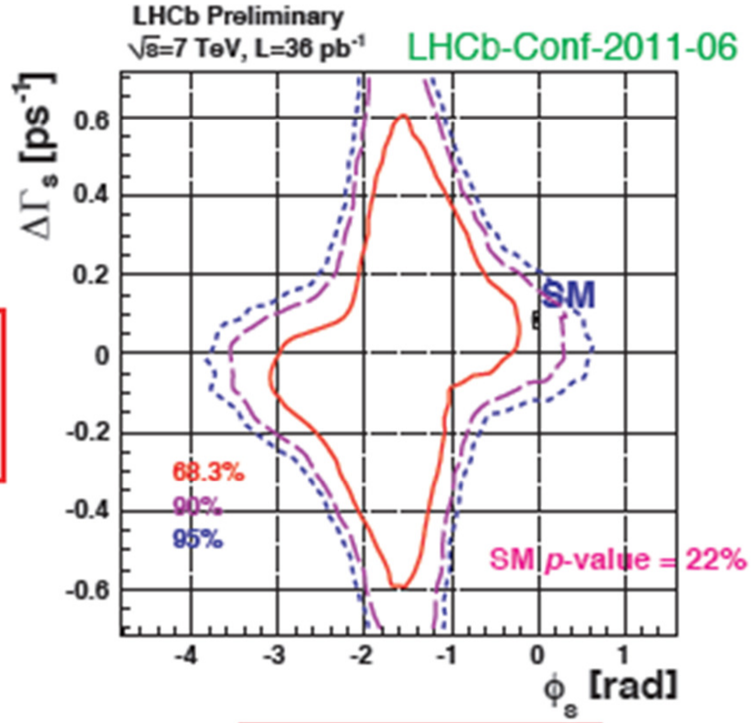
Status before Lepton Photon 2011

- Constraints in $(\Delta\Gamma_s, \phi_s)$ plane



Plots all scaled to have identical axis unit sizes

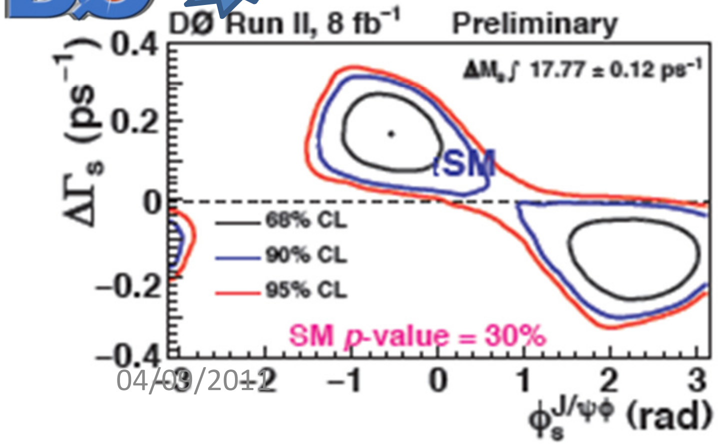
$\phi_s \in [-3.10, -2.16]$
$\cup [-1.04, -0.04]$
68% CL



$\phi_s \in [-2.7, -0.5]$
68% CL

Tevatron: with less data, was previously at ≳2σ deviation from SM

NEW



NEW from D0 in 2011: Less significant deviation now, but all still showing same trend...

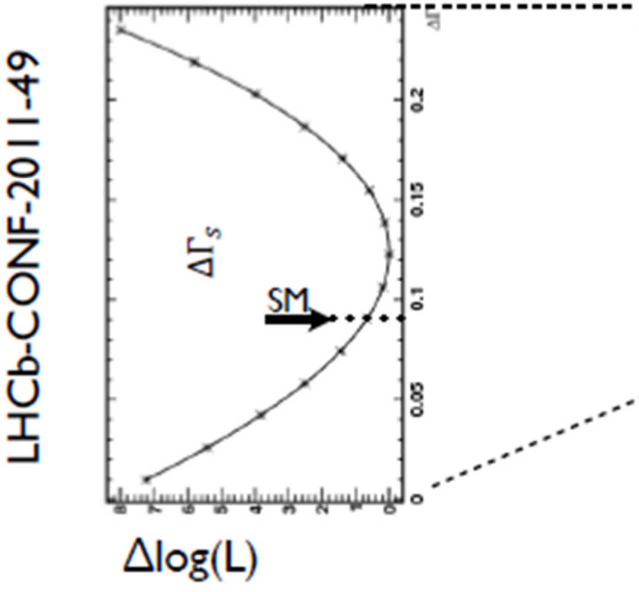
$\phi_s = -0.55^{+0.38}_{-0.36}$

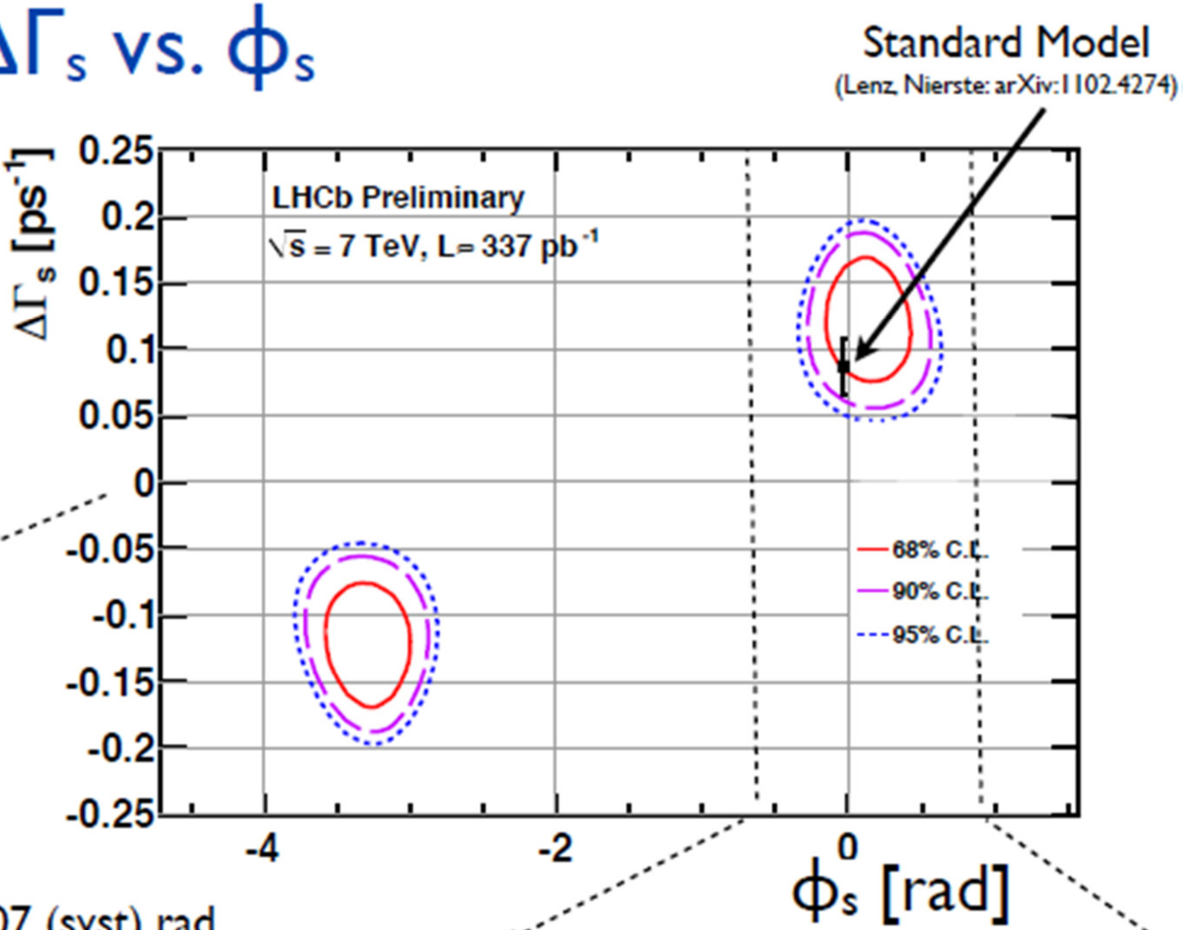
Lenz, Nierste, arXiv:1102.4274
$\Delta\Gamma_s^{SM} = 0.087 \pm 0.021\,\mathrm{ps}^{-1}$

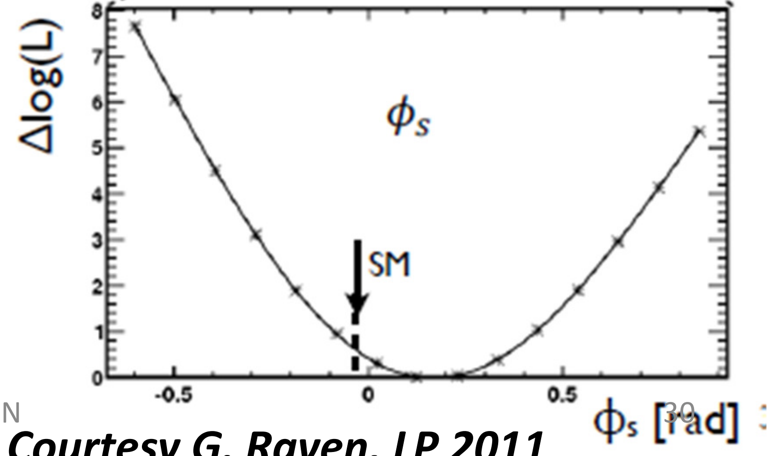
CKMfitter, indirect measure.
$\phi_s^{SM} = -0.0363 \pm 00017$

2

$B_s \rightarrow J/\psi\varphi$: $\Delta\Gamma_s$ vs. ϕ_s







Latest from LHCb:

Most precise measurement of ϕ_s

- ϕ_s = 0.13 ± 0.18 (stat) ± 0.07 (syst) rad
- Consistent with SM

4 σ Evidence for $\Delta\Gamma_s \neq 0$:

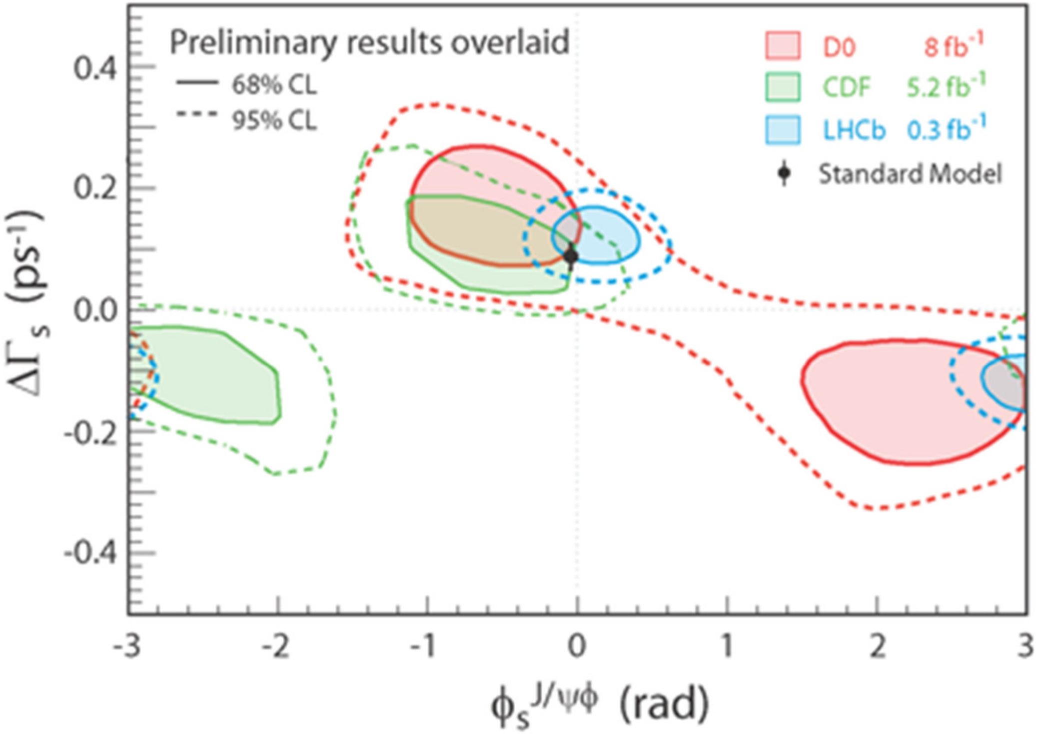
- $\Delta\Gamma s$ = 0.123 ± 0.029 (stat) ± 0.008 (syst) ps^{-1}
- Γ_s = 0.656 ± 0.009 (stat) ± 0.008 (syst) ps^{-1}

Courtesy G. Raven, LP 2011

http://public.web.cern.ch/public

August 30th 2011

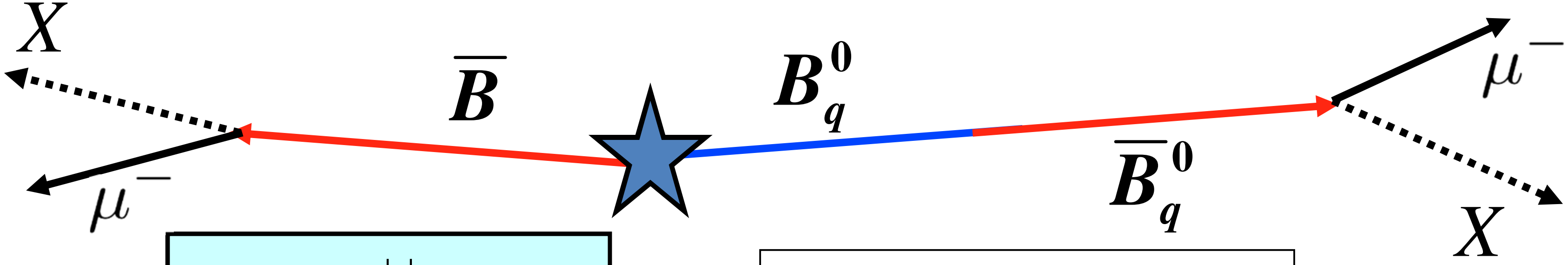
Lepton-photon conf. 2011: LHC data shedding new light



“A data visualization from the LHCb experiment's results. LHCb's measurements of B meson decay correlate with Standard Model predictions – but they also indicate that there is still room for a contribution from new physics. **IMAGE: LHCb collaboration”**

NEW RESULTS from LHCb and CDF very soon ; by end of this year important result!!!!

Dimuon charge asymmetry & CPV



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

N_b^{++} (N_b^{--}) – number of same-sign $\mu^+\mu^+$ ($\mu^-\mu^-$) events from $B \to \mu X$ decay

- Both B_d and B_s contribute in A^b_{sl} at Tevatron :

$$A_{sl}^b = (0.506 \pm 0.043) a_{sl}^d + (0.494 \pm 0.043) a_{sl}^s$$

B_d contribution

B_s contribution

- a^q_{sl} is the charge asymmetry of "wrong sign" semileptonic B^0_q ($q = d,s$) decays:

$$a_{sl}^q \equiv \frac{\Gamma(\overline{B}_q^0 \to \mu^+ X) - \Gamma(B_q^0 \to \mu^- X)}{\Gamma(\overline{B}_q^0 \to \mu^+ X) + \Gamma(B_q^0 \to \mu^- X)}; \quad q = d, s$$

and is related to CP violating

$$a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta M_q} \tan(\phi_q)$$

SM prediction

- SM predicts very small values of ϕ_q and $A^b{}_{\mathrm{sl}}$:

$$\boxed{\begin{aligned} \phi_d^{SM} &= -0.091^{+0.026}_{-0.038} \\ \phi_s^{SM} &= 0.0042 \pm 0.0014 \\ A_{sl}^{b,SM} &= (-2.3^{+0.5}_{-0.6}) \times 10^{-4} \end{aligned}}$$

A. Lenz, U. Nierste, J. High Energy Phys. 0706, 072 (2007)

  - These values are below current experimental sensitivity

- New physics contribution can significantly change these values

$$\boxed{\begin{aligned} \phi_d &= \phi_d^{SM} + \phi_d^{NP} \\ \phi_s &= \phi_s^{SM} + \phi_s^{NP} \end{aligned}}$$

Non-zero $A^b{}_{\mathrm{sl}}$ would indicate the presence of new physics

Remember:

$\phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$ ≈ *4x10*$^{-3}$ and $\beta_s^{\mathrm{SM}} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$

$2\beta_s = 2\beta_s^{\mathrm{SM}} - \phi_s^{\mathrm{NP}}$ & $\phi_s = \phi_s^{\mathrm{SM}} + \phi_s^{\mathrm{NP}} \longrightarrow 2\beta_s = -\phi_s^{\mathrm{NP}} = -\phi_s$

Measurement strategy

- Measure two raw asymmetries (include μ's from all sources):

raw dimuon charge asymmetry

$$\boxed{A \equiv \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = (0.564 \pm 0.053)\%}$$

raw inclusive muon charge asymmetry

$$\boxed{a \equiv \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)} = (0.955 \pm 0.003)\%}$$

- Both asymmetries contain contributions from A^b_{sl} and detector-related background asymmetries

$$\boxed{A = K\,A^b_{sl} + A_{bkg}}$$

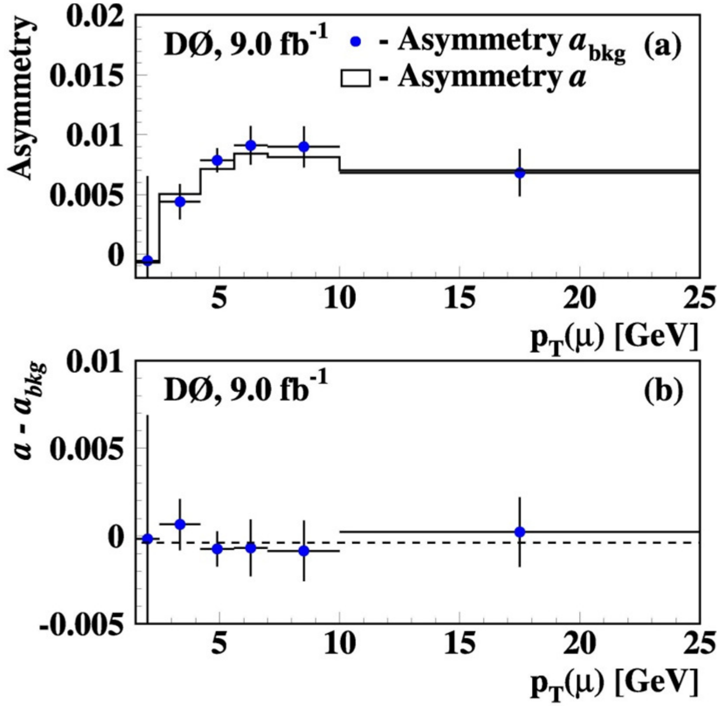
$$\boxed{a = k\,A^b_{sl} + a_{bkg}}$$

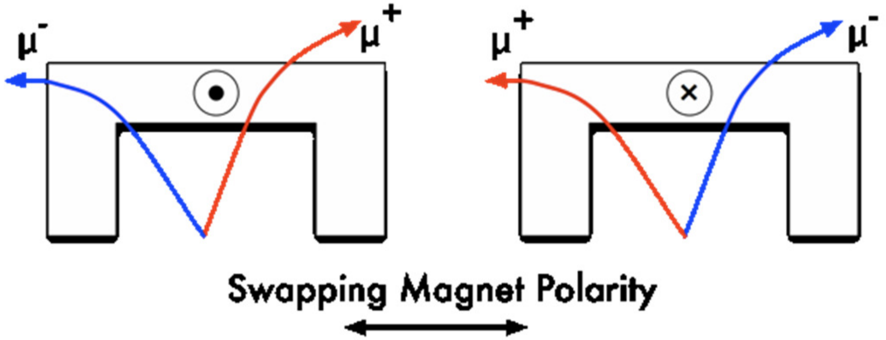
  - contribution from A^b_{sl} to a is strongly suppressed by k=0.041±0.003
- Determine background contributions A_{bkg} and a_{bkg} using data with minimal input from simulation
- Exploit the correlation of background content in raw asymmetries to reduce the uncertainty on A^b_{sl}

Some experimental remarks

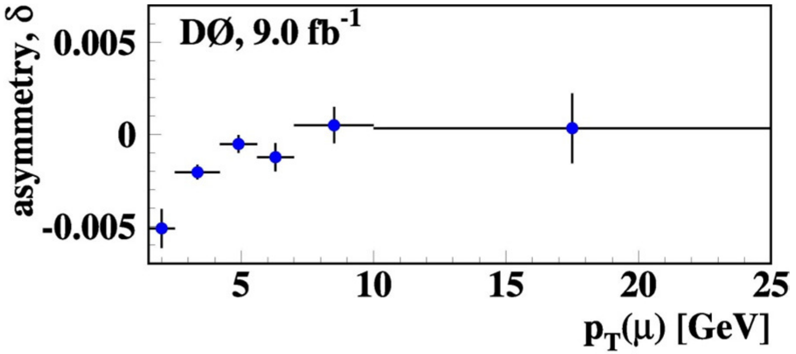
1) Test of background description

- Raw inclusive muon asymmetry *a* is dominated by the background asymmetry a_{bkg}
- a_{bkg} is measured in data
- Compare *a* and a_{bkg} to verify the background description as f(Pt(μ))





Muon reconstruction asymmetry



2) Original experimental technique

Polarities of DØ solenoid and toroid are reversed every ~2 weeks => *difference in reconstruction efficiency between positive & ne gative particles minimized*

Reconstruction asymmetries reduced from ~1% to <0.1%

To be compared with raw dimuon asymmetry A= (0.564±0.053)%

Updated measurement of the anomalous like-sign dimuon charge asymmetry for b-hadron semi-leptonic decays, 9fb^{-1}

A^b_{sl}=(-0.787±0.172(stat) ±0.093(sys))%

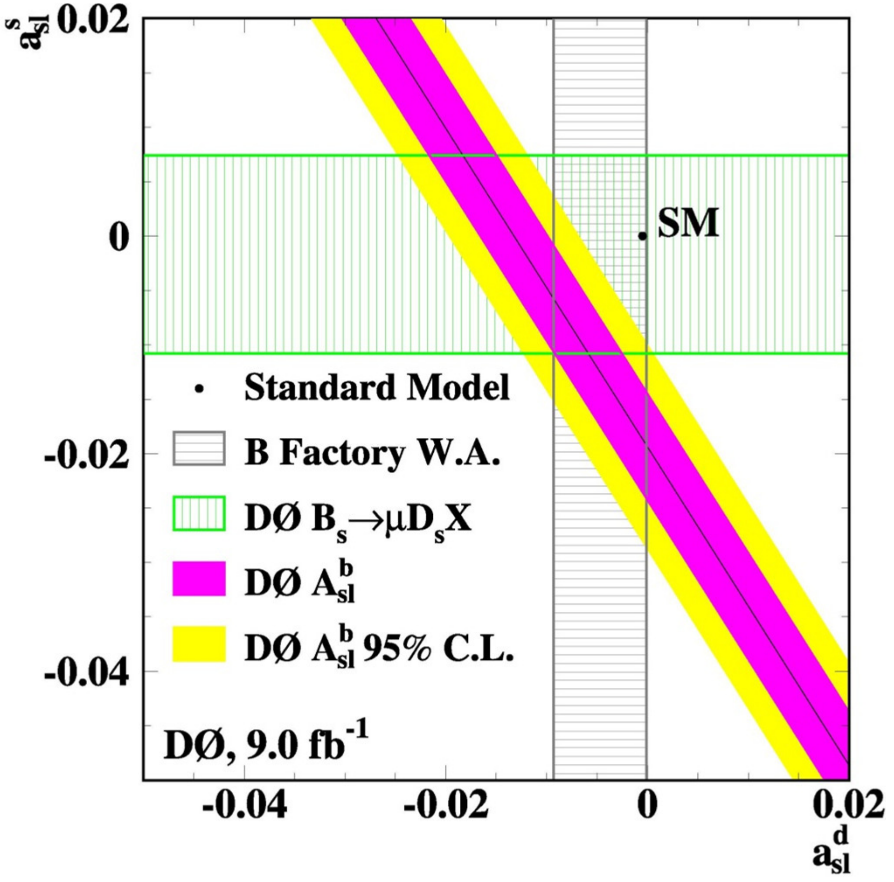
Was =(-0.957±0.0251(stat) ±0.146(sys))% with 6.1fb^{-1}

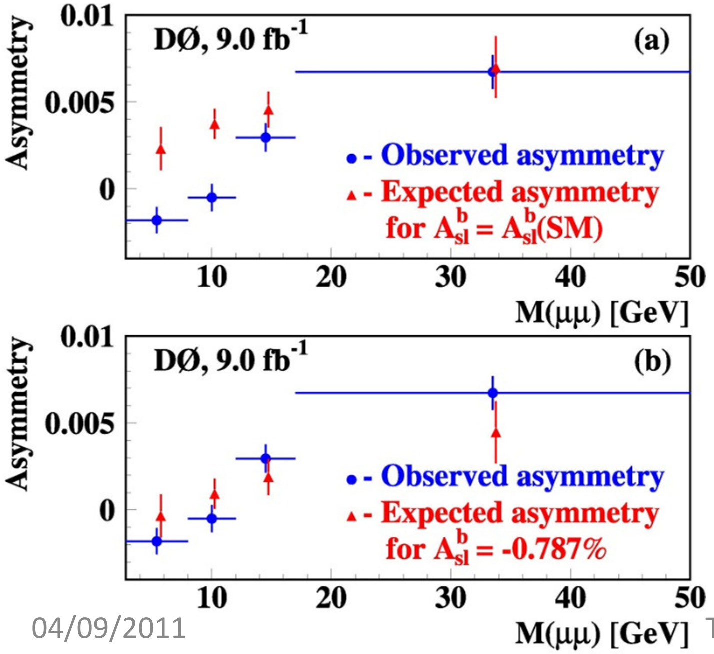
~3.9 σ deviation from SM (previously 3.2σ)

- A^b_{sl} produces a band in a^d_{sl} v.s. a^s_{sl} plane:

$$A^b_{sl} = (0.506 \pm 0.043)a^d_{sl} + (0.494 \pm 0.043)a^s_{sl}$$

- Obtained result agrees well with other measurements of a^d_{sl} and a^s_{sl}





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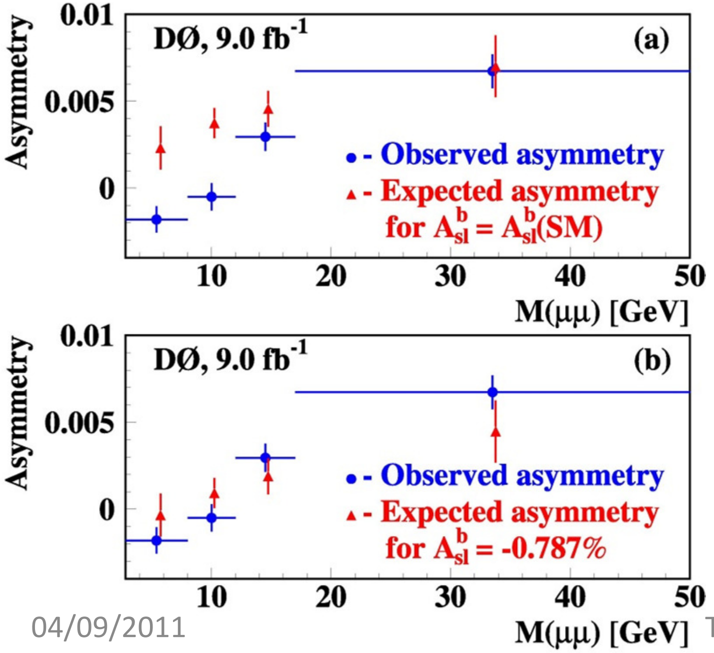
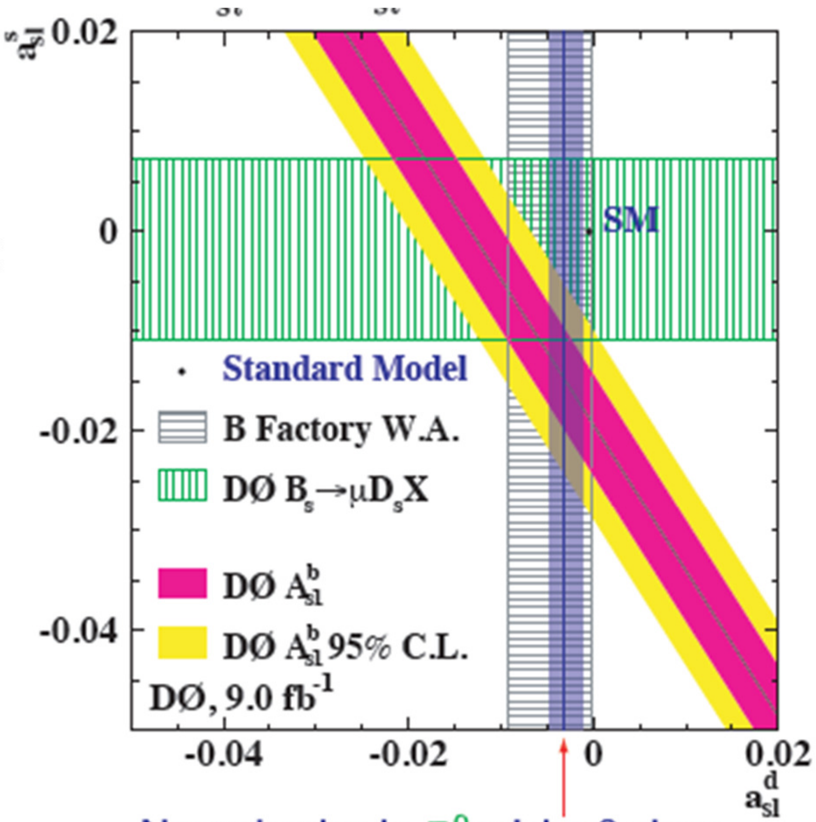




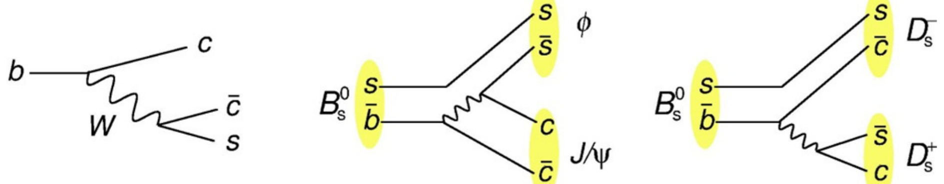
New physics in B^0_s mixing? since a^d_{sl} constrained by "sin2β" in global fits:

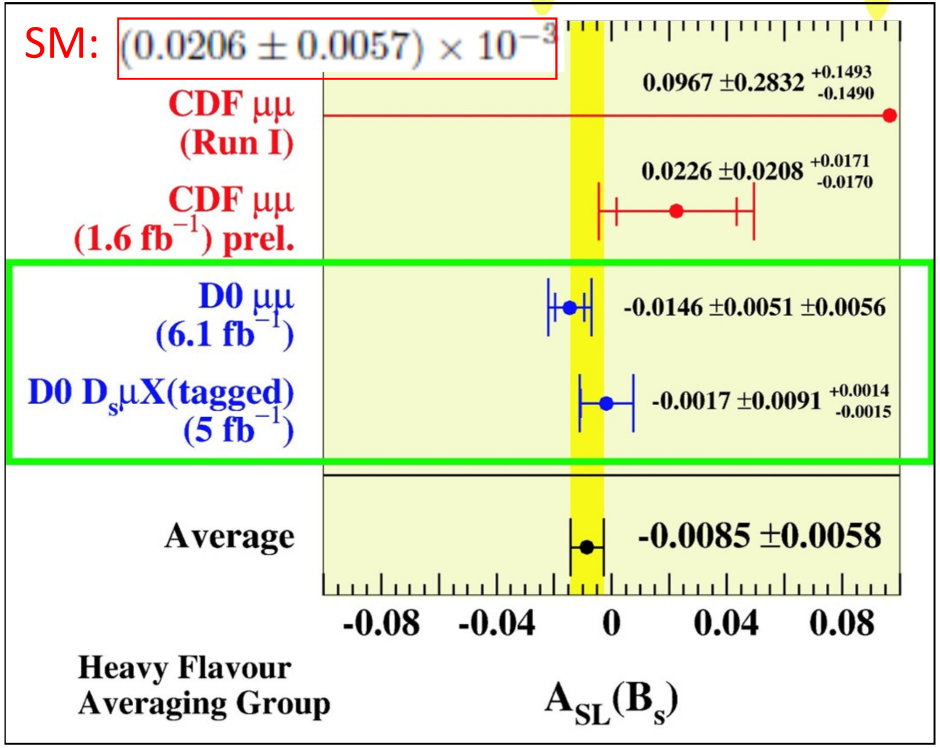
$a^d_{sl}(\text{pred.}) = (-36^{+23}_{-11}) \times 10^{-4}$ PRD **83**, 036004 (2011)

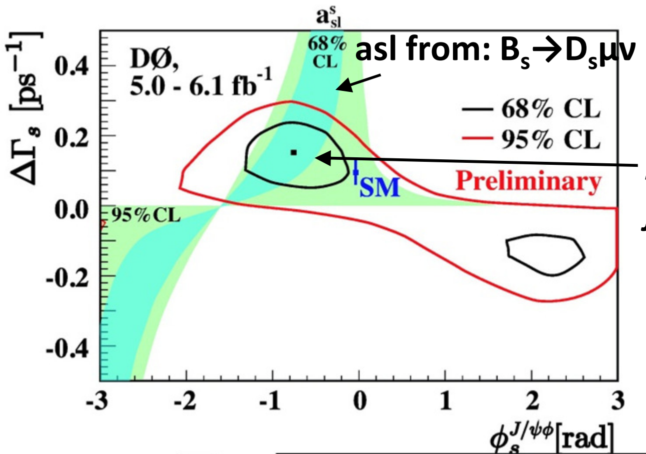
CDF is trying to perform this measurement if not impeded by systematics ("Central tracking Asymmetry" to be corrected) and personpower…

Combining results $^{(2010)}$ on ΔΓs & CPV phase from various analyses by D0

Bs decays giving rise to non zero Γ12:

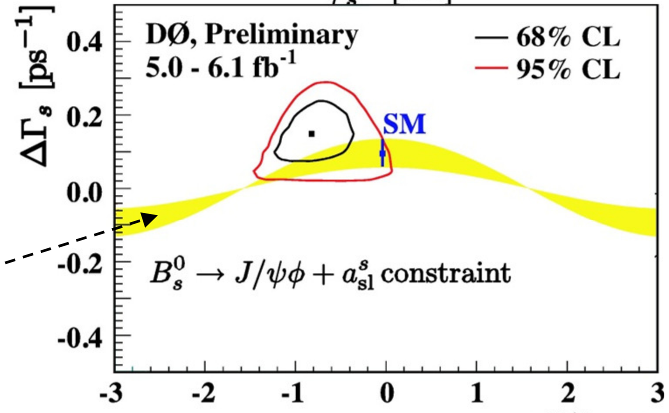




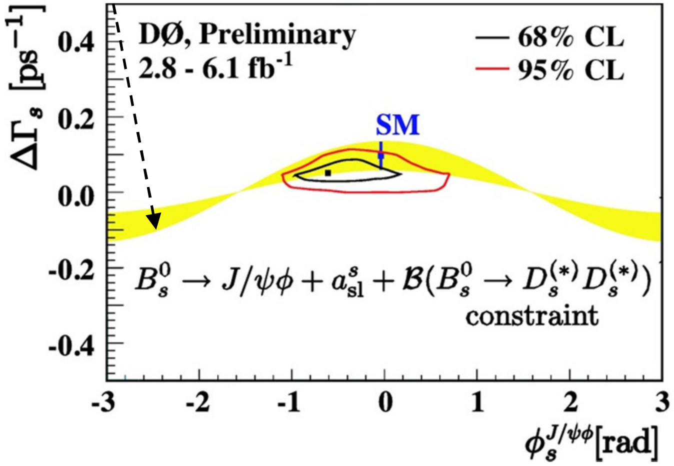


asl from: $B_s \rightarrow D_s \mu \nu$

New best fit value



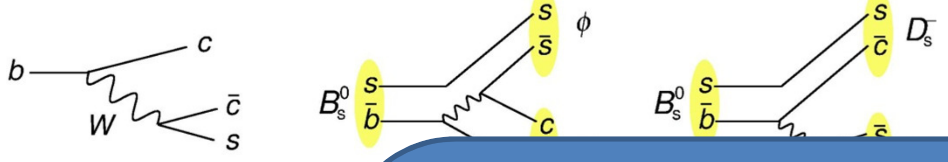
Region allowed in NP models given by: $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\phi_s$

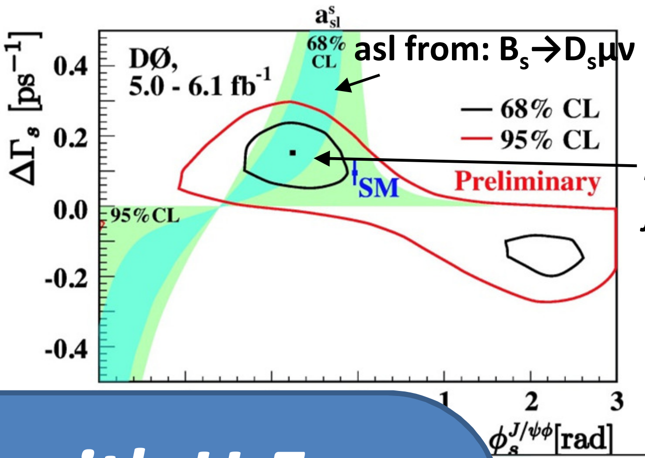


A_{sl} measurement from 2010 & asl from $B_s \rightarrow D_s \mu \nu$ => constraints on $\Delta\Gamma_s$ & $\Phi_s^{J/\Psi\phi}$ consistent with the 2010 results from $B_s \rightarrow J/\Psi\phi$. When combining p-value at SM point is: 7.5%. When adding $Br(B_s \rightarrow D_s^* D_s^*)$ p-value decreases to 6%.

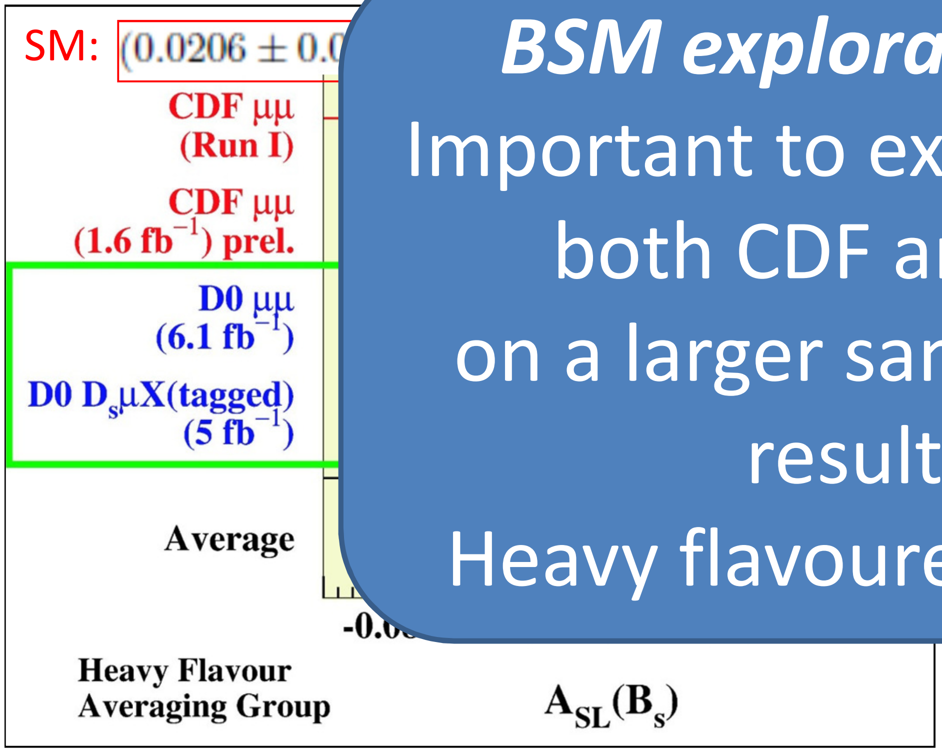
Combining results $^{(2010)}$ on ΔΓs & CPV phase from various analyses by D0

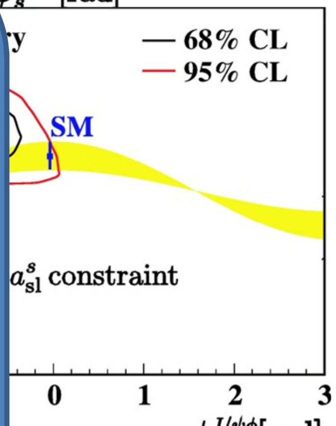
Bs decays giving rise to non zero Γ12:

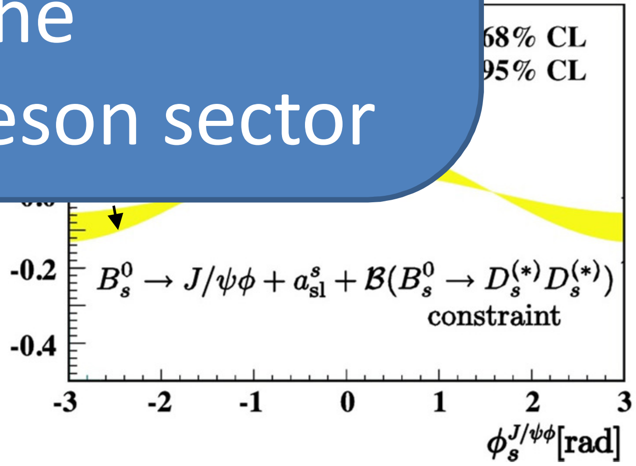




New best fit value







BSM exploration with H.F.:

Important to extend this work to both CDF and D0 results on a larger sample of relevant results in the Heavy flavoured meson sector

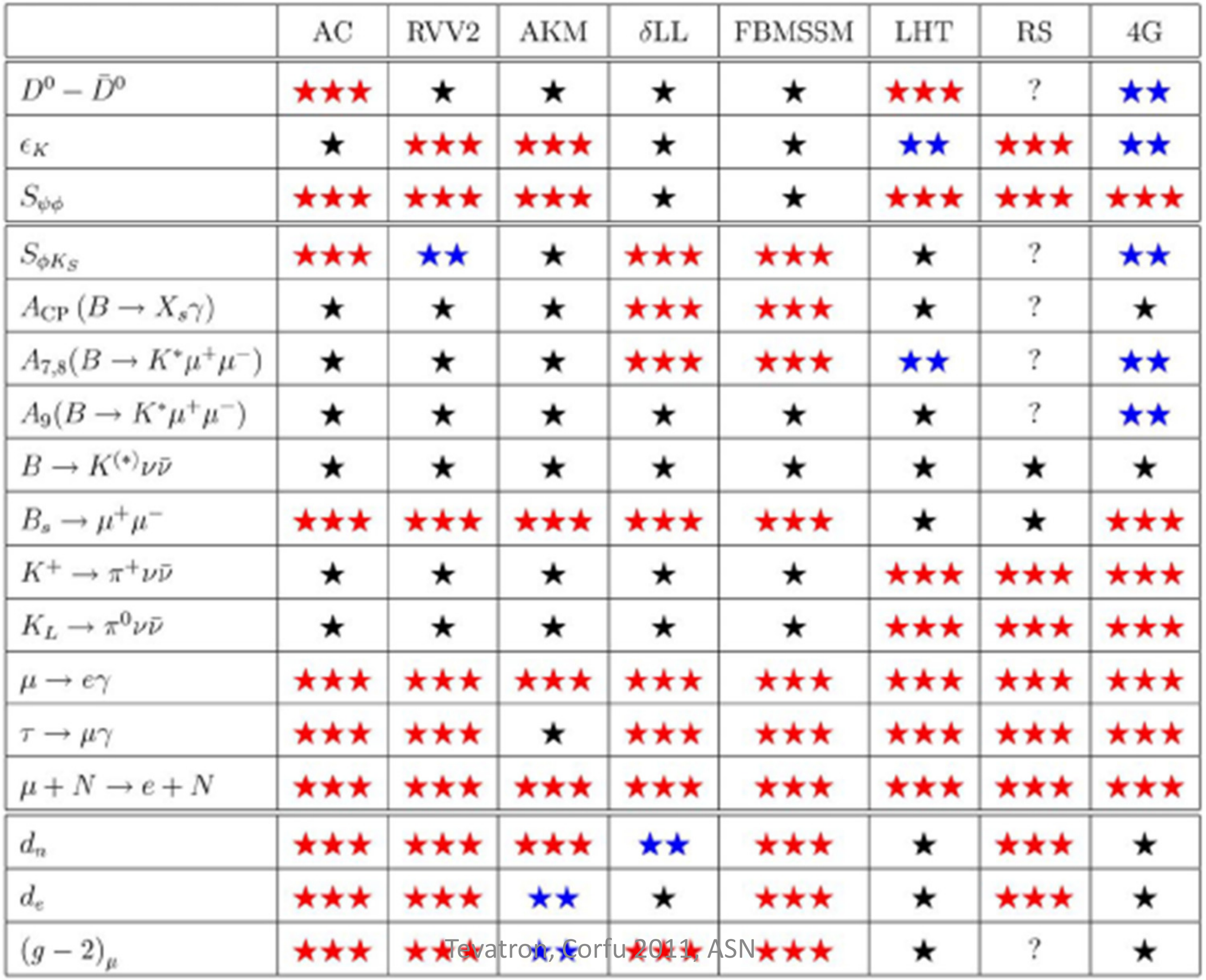
A_{sl} measurement from 2010 & asl from $B_s \to D_s \mu\nu$ => constraints on $\Delta\Gamma_s$ & $\Phi_s^{J/\Psi\phi}$ consistent with the 2010 results from $B_s \to J/\Psi\phi$. When combining p-value at SM point is: 7.5%. When adding Br($B_s \to D_s^* D_s^*$) p-value decreases to 6%.

How the Bs measurements impact on the BSM Models:
a summary from Buras and collaborators (Beauty 2010-11).

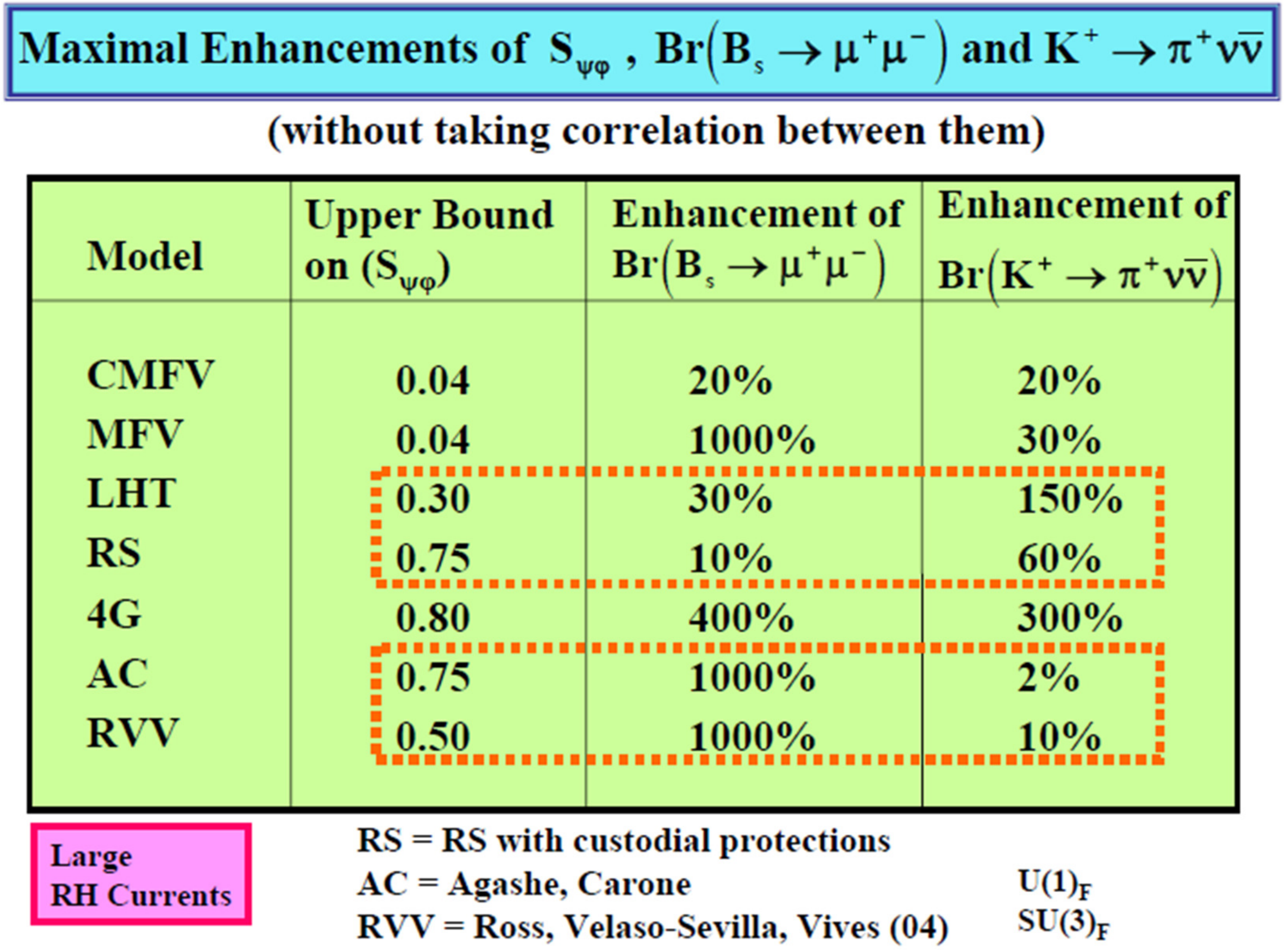
ABGPS

DNA Tests of Flavour Models

0909.1333



	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS	4G
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?	★★
ϵ_K	★	★★★	★★★	★	★	★★	★★★	★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?	★★
$A_{\rm CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?	★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?	★★
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?	★★
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★	★★★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★	★
d_e	★★★	★★★	★★	★	★★★	★	★★★	★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?	★



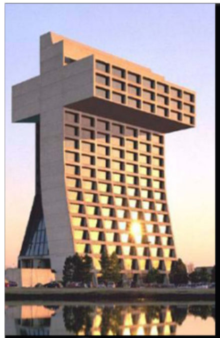
Maximal Enhancements of $S_{\psi\varphi}$, $Br\left(B_s \to \mu^+\mu^-\right)$ and $K^+ \to \pi^+\nu\bar{\nu}$

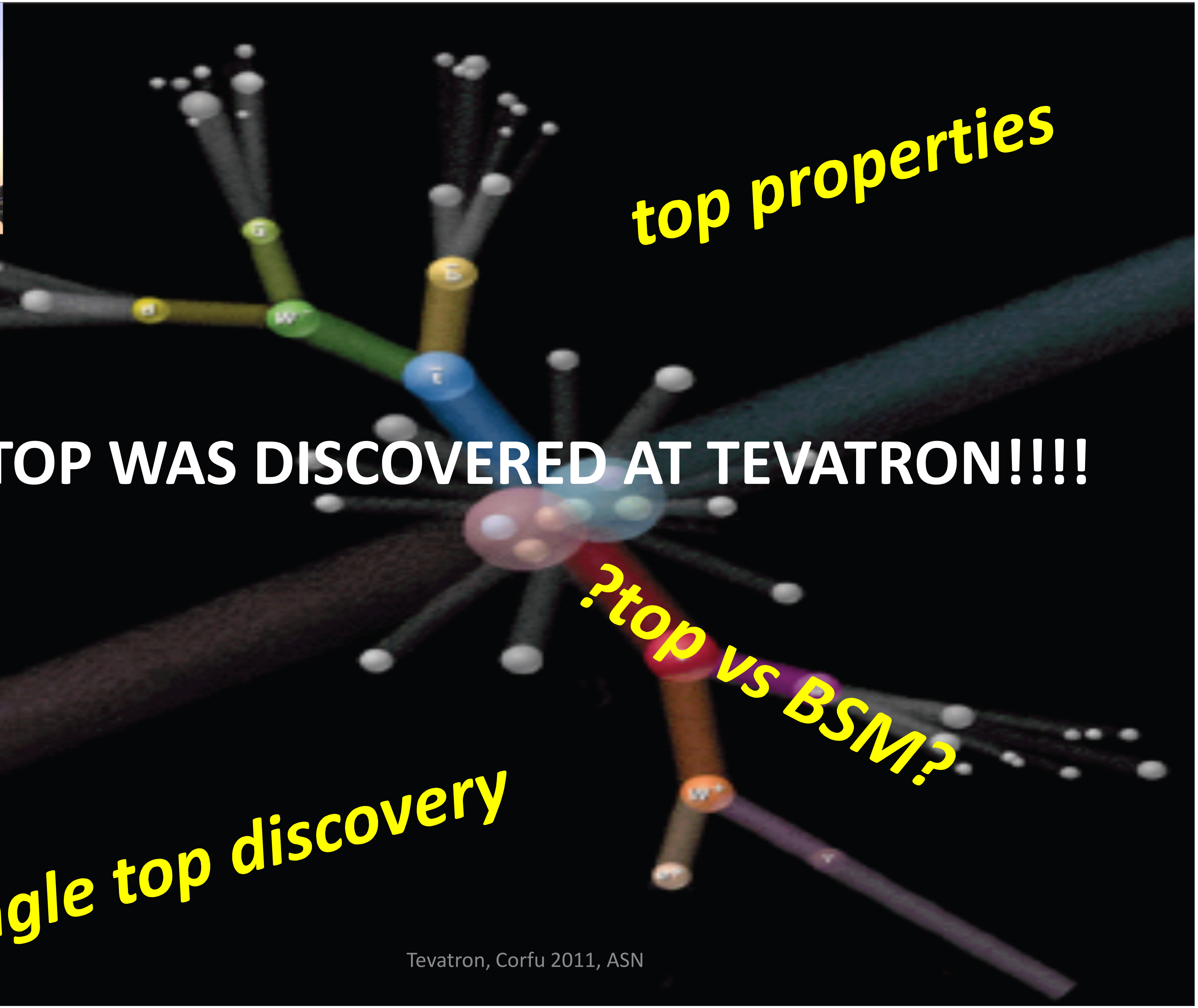
(without taking correlation between them)

Model	Upper Bound on ($S_{\psi\varphi}$)	Enhancement of $Br\left(B_s \to \mu^+\mu^-\right)$	Enhancement of $Br\left(K^+ \to \pi^+\nu\bar{\nu}\right)$
CMFV	0.04	20%	20%
MFV	0.04	1000%	30%
LHT	0.30	30%	150%
RS	0.75	10%	60%
4G	0.80	400%	300%
AC	0.75	1000%	2%
RVV	0.50	1000%	10%

Large RH Currents

RS = RS with custodial protections
AC = Agashe, Carone $U(1)_F$
RVV = Ross, Velaso-Sevilla, Vives (04) $SU(3)_F$





top properties

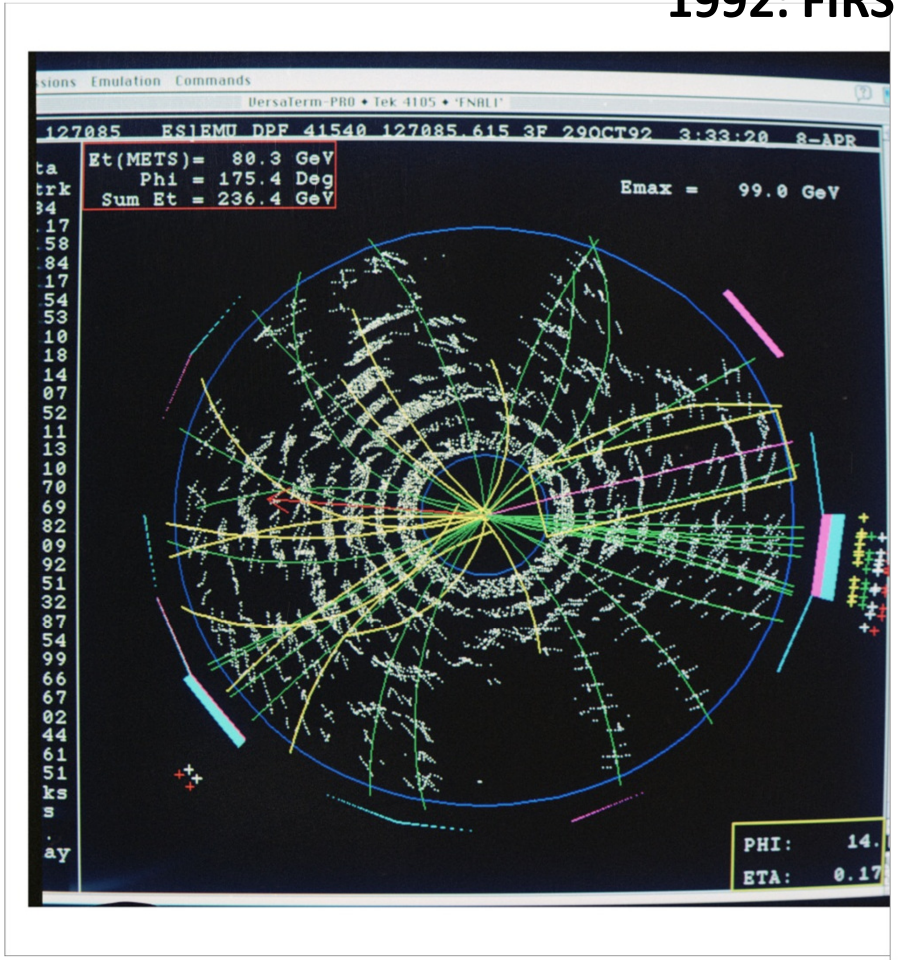
TOP WAS DISCOVERED AT TEVATRON!!!!

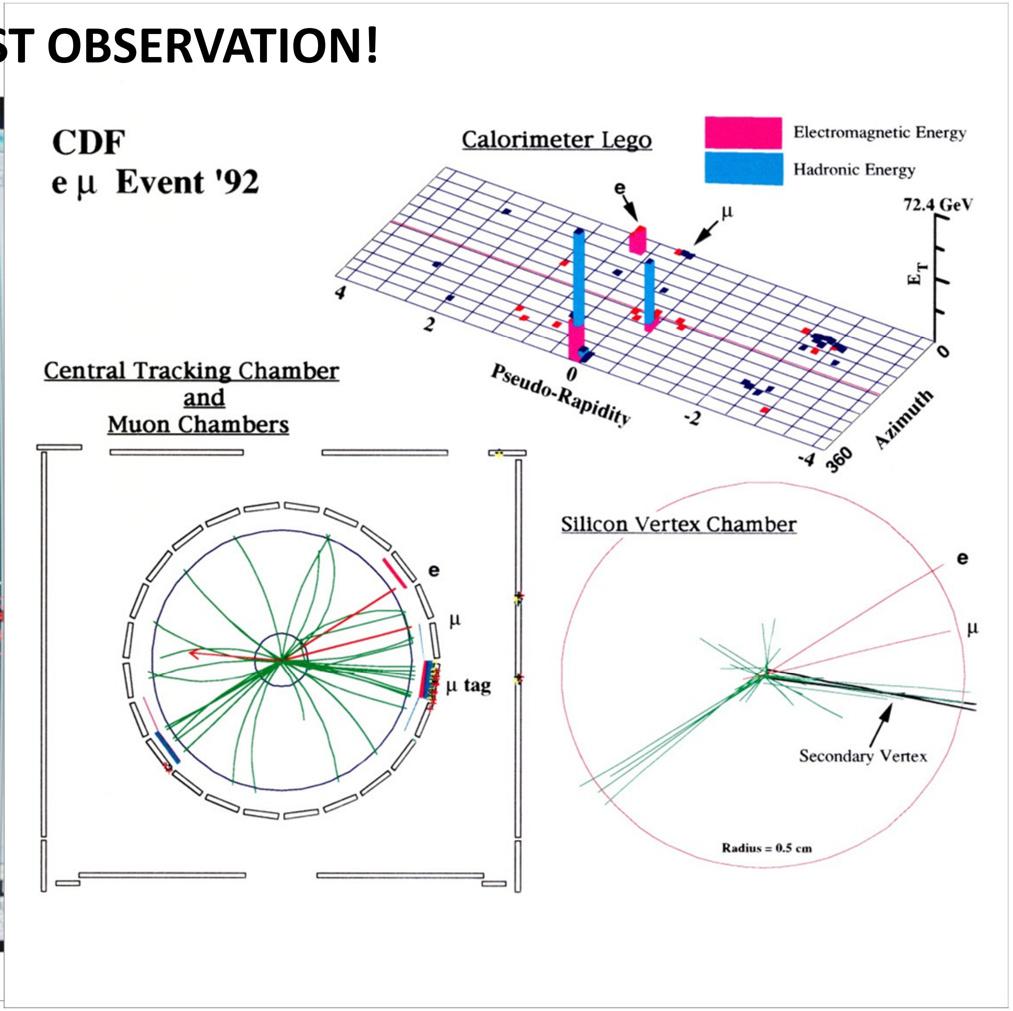
?top vs BSM?

Single top discovery

TOP: A little bit of history…

1992: FIRST OBSERVATION!





29 Oct 1992, first observation of TOP by CDF in the Run I in a golden e μ event and the vertex detector signing b-jet!

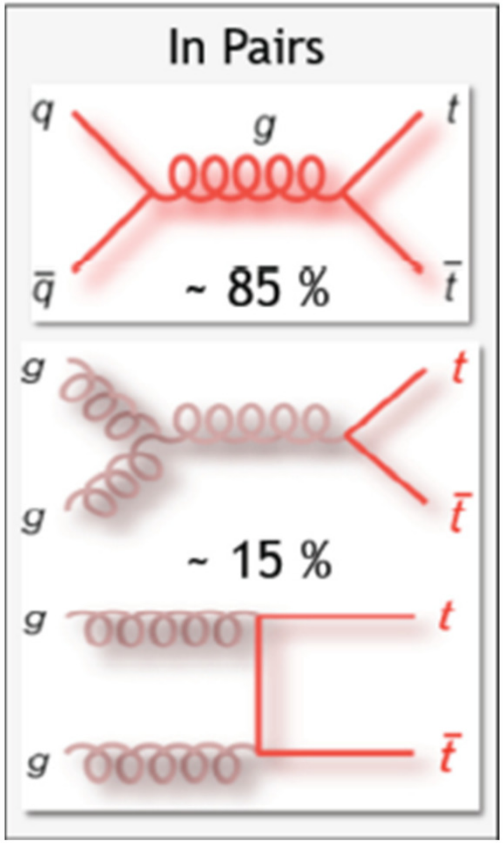
Thanks to the first vertex detector successfully built for a hadron collider experiment

Top production at Tevatron

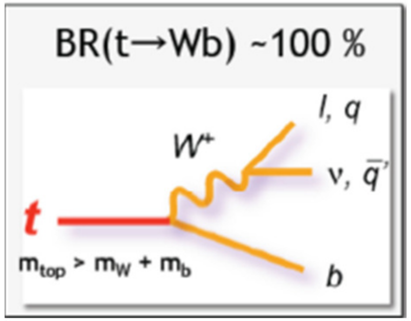
Top pair

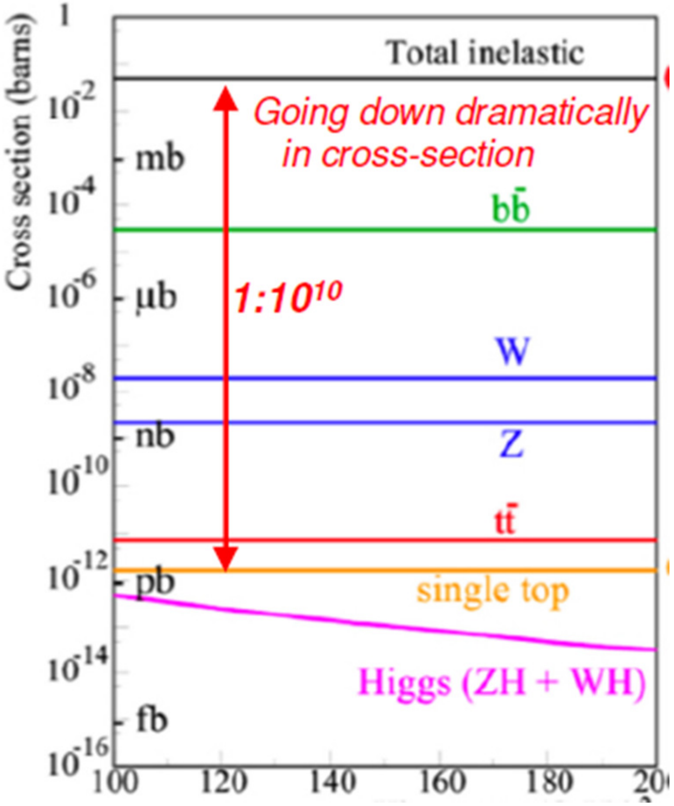
$$\sigma(pp \to t\bar{t})_{NNLOapprox} = 7.46^{+0.48}_{-0.67}\ \mathrm{pb}$$

At 1.96TeV c.m. and M_t=172.5GeV
(about 22 times lower than at 7TeV)

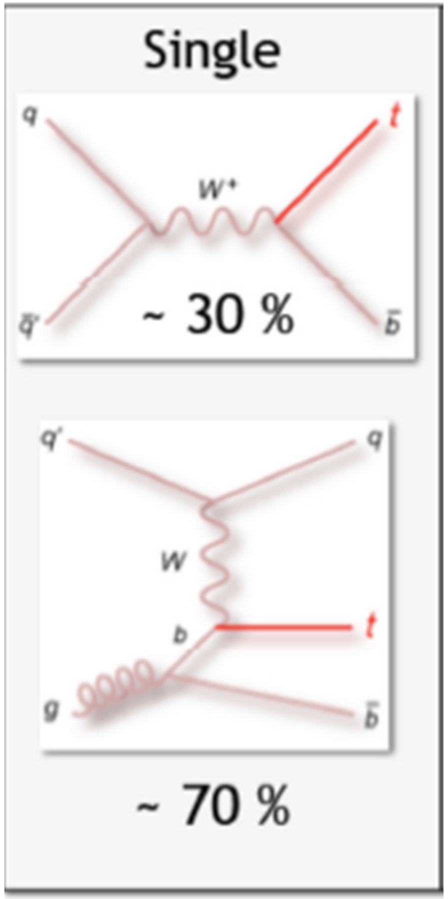


SM:


BR(t→Wb) ~100 %



Single top

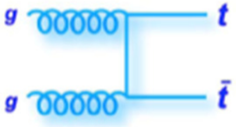


Tevatron & LHC complementarity in Top sector

1 fb-1 at LHC => 4 times more top paires than 5 fb-1 at Tevatron => Tevatron still interesting for some top Physics aspects.

- Gluon fusion (dominant at LHC)

90%

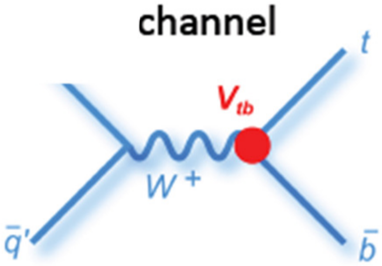


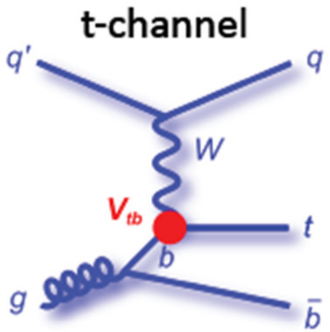
- Quark-antiquark annihilation

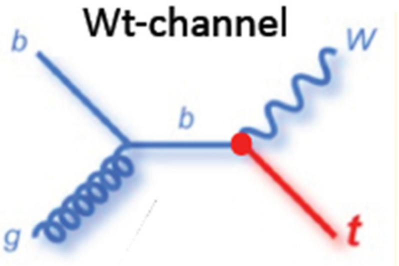
10%

Tevatron is a quark-antiquark annihilation machine whereas LHC is gluon fusion machine
=> many interesting consequences (see for instance A_{BF} asymmetry).

AND:





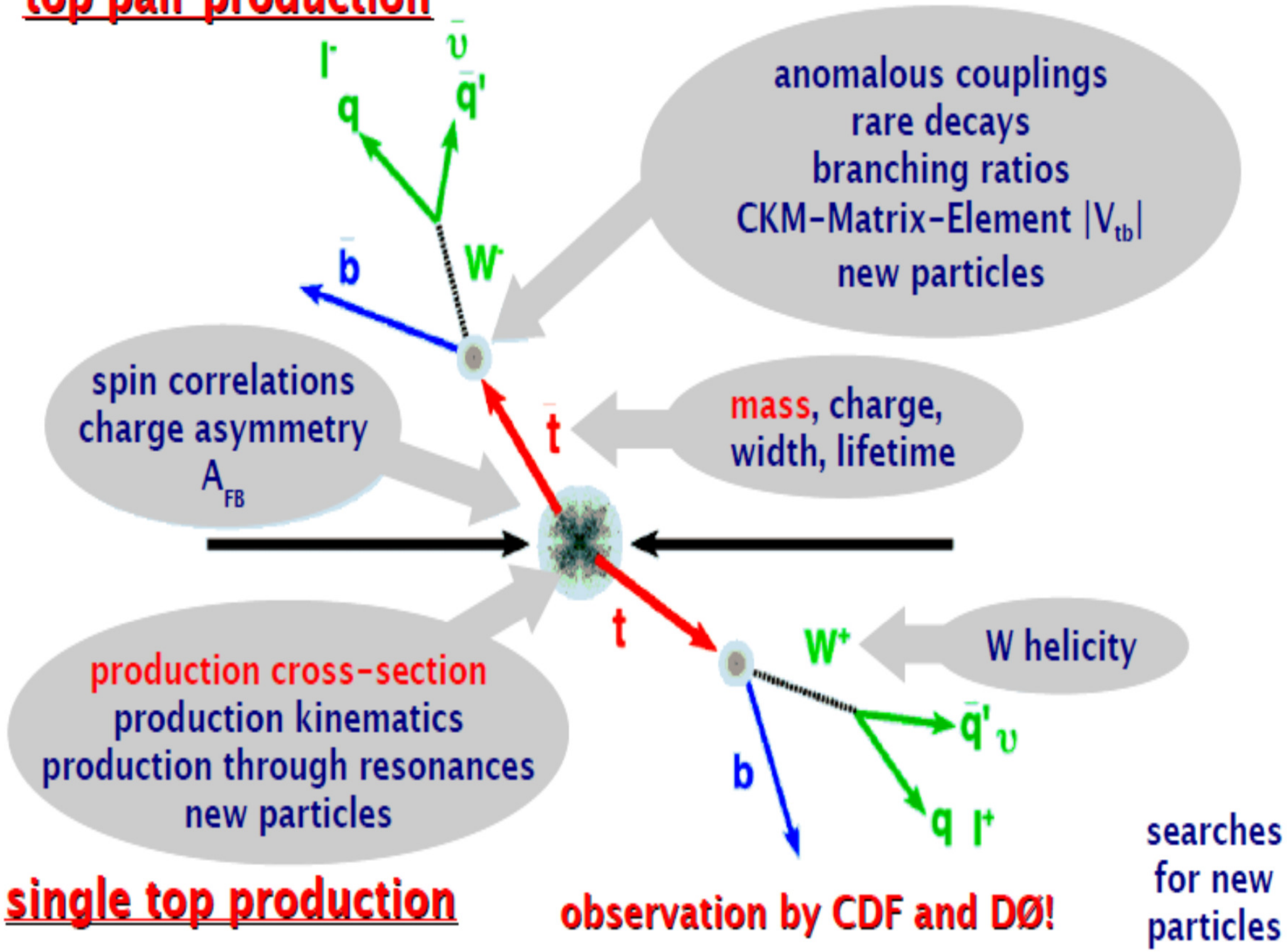


For M_t = 172.5 GeV	σ_{tb}	σ_{tqb}	σ_{tW}
$p\bar{p}$ @ 1.96 TeV	1.04 ± 0.04 pb	2.26 ± 0.12 pb	0.28 ± 0.06 pb
pp @ 7 TeV	4.6 ± 0.3 pb	64.6 +3.3 -2.6 pb	15.7 ± 1.4 pb

Challenging at
LHC

Not possible at
Tevatron

TEVATRON has performed a complete SCAN of TOP PHYSICS



top pair production

anomalous couplings
rare decays
branching ratios
CKM-Matrix-Element $|V_{tb}|$
new particles

spin correlations
charge asymmetry
A_{FB}

mass, charge,
width, lifetime

W helicity

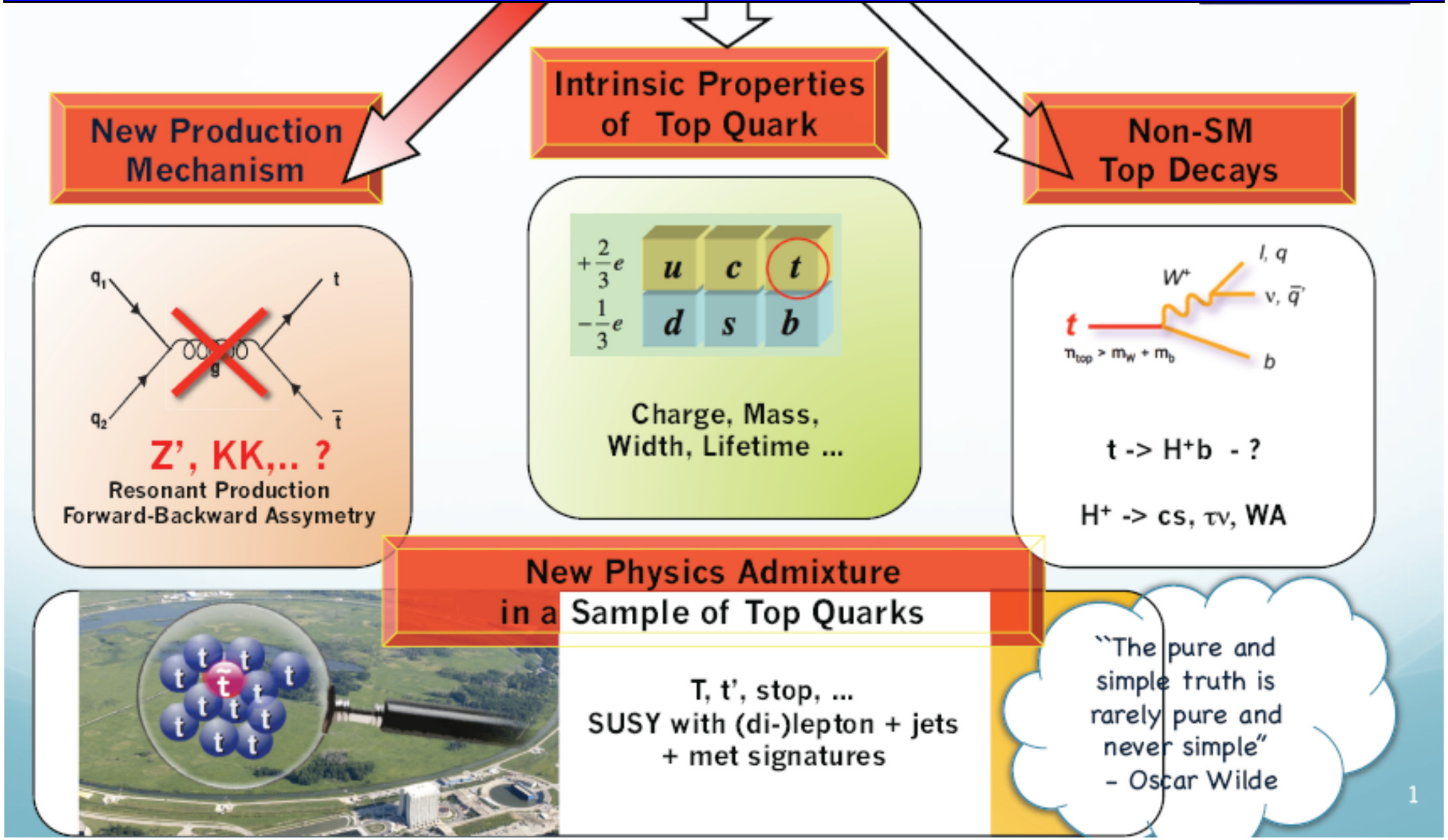
production cross-section
production kinematics
production through resonances
new particles

single top production

observation by CDF and DØ!

searches
for new
particles

The Many ways to find N.P. with the Top explored at Tevatron



New Production Mechanism

Intrinsic Properties of Top Quark

Non-SM Top Decays

Z', KK,.. ?

Resonant Production

Forward-Backward Assymetry

Charge, Mass,

Width, Lifetime ...

t -> H⁺b - ?

H⁺ -> cs, τν, WA

New Physics Admixture in a Sample of Top Quarks

T, t', stop, ...

SUSY with (di-)lepton + jets

+ met signatures

"The pure and simple truth is rarely pure and never simple"

– Oscar Wilde

Property	Measurement		SM Prediction	Luminosity (fb^{-1})
$\sigma_{t\bar{t}}$ (for $M_t = 172.5$ GeV)	$p\bar{p} \to t\bar{t}$	CDF: $7.5 \pm 0.31(\mathrm{stat}) \pm 0.34(\mathrm{syst}) \pm 0.15(\mathrm{theory})$ pb	$7.46^{+0.48}_{-0.67}$ pb	up to 4.6
		D0: $7.56^{+0.63}_{-0.56}$ (stat + syst + lumi) pb		5.6
	$pp \to t\bar{t}$	Atlas: $180 \pm 9(\mathrm{stat}) \pm 15(\mathrm{syst}) \pm 6(\mathrm{lumi})$ pb	$164.6^{+11.4}_{-15.7}$ pb	up to 0.7
		CMS: $158 \pm 10(\mathrm{uncor.}) \pm 15(\mathrm{cor.}) \pm 6(\mathrm{lumi})$ pb		0.036
σ_{tbq} (for $M_t = 172.5$ GeV)	$p\bar{p} \to t\bar{t}$	CDF: 0.8 ± 0.4 pb ($M_t = 175$ GeV)	2.26 ± 0.12 pb	3.2
		D0: 2.90 ± 0.59 pb		5.4
	$pp \to t\bar{t}$	Atlas: 90^{+32}_{-22} pb	$64.6^{+3.3}_{-2.6}$ pb	0.7
		CMS: $83.6 \pm 29.8(\mathrm{stat+syst}) \pm 3.3(\mathrm{lumi})$ pb		0.035
σ_{tb} (for $M_t = 172.5$ GeV)	$p\bar{p} \to t\bar{t}$	CDF: $1.8^{+0.7}_{-0.5}$ pb ($M_t = 175$ GeV)	1.04 ± 0.04 pb	3.2
		D0: $0.68^{+0.38}_{-0.35}$ pb		5.4
σ_{Wt} (for $M_t = 172.5$ GeV)	$pp \to t\bar{t}$	Atlas: < 39.1 pb	15.7 ± 1.4 pb	0.7
$\lvert V_{tb} \rvert$		CDF: $\lvert V_{tb} \rvert = 0.91 \pm 0.11(\mathrm{stat+sys}) \pm 0.07(\mathrm{theory})$	1	3.2
		D0: $\lvert V_{tb} \rvert = 1.02^{+0.10}_{-0.11}$		5.4
$R = B(t \to Wb)/B(t \to Wq)$		CDF: > 0.61 @ 95% CL	1	0.2
		D0: 0.90 ± 0.04		5.4
$\sigma(gg \to t\bar{t})/\sigma(p\bar{p} \to t\bar{t})$	$p\bar{p} \to t\bar{t}$	CDF: $0.07^{+0.15}_{-0.07}$	0.18	1
M_t		Tev: 173.2 ± 0.9 GeV	-	up to 5.8
		Atlas: 169.3 ± 6.3 GeV	-	0.035
		CMS: 173.4 ± 3.3 GeV	-	0.036
$M_t - M_{\bar{t}}$		CDF: $-3.3 \pm 1.4(\mathrm{stat}) \pm 1.0(\mathrm{syst})$ GeV	0	5.6
		D0: $0.8 \pm 1.8(\mathrm{stat}) \pm 0.5(\mathrm{syst})$ GeV		3.6
W helicity fraction		Tev: $f_0 = 0.732 \pm 0.063(\mathrm{stat}) \pm 0.052(\mathrm{syst})$	0.7	up to 5.4
		Atlas: $f_0 = 0.59 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{syst})$	0.7	0.035
Charge		CDF: -4/3 excluded @ 95% CL	2/3	5.6
		D0: 4/3 excluded @ 92% CL		0.37
Γ_t		CDF: < 7.6 GeV @ 95% CL	1.26 GeV	4.3
		D0: $1.99^{+0.69}_{-0.55}$ GeV		up to 2.3
spin correlation	C_{beam}	CDF: $0.72 \pm 0.64(\mathrm{stat}) \pm 0.26(\mathrm{syst})$	$0.777^{+0.027}_{-0.042}$	5.3
		D0: $0.57 \pm 0.31(\mathrm{stat+sys})$		5.4
Charge asymmetry	$p\bar{p} \to t\bar{t}$	CDF: 0.158 ± 0.074	0.06	5.3
		D0: 0.196 ± 0.065		5.4
	$pp \to t\bar{t}$	Atlas: $A_C^y = -0.024 \pm 0.016(\mathrm{stat}) \pm 0.023(\mathrm{syst})$	0.006	0.7
		CMS: $A_C^\eta = -0.016 \pm 0.030(\mathrm{stat})^{+0.010}_{-0.019}(\mathrm{syst})$	0.013	1.1

CDF

CDF

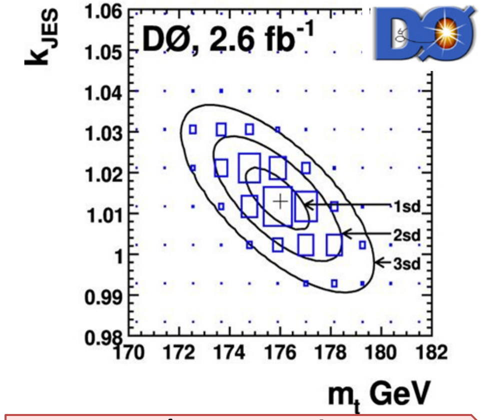
Single top

CDF

D0

Courtesy Deliot
EPS 2011

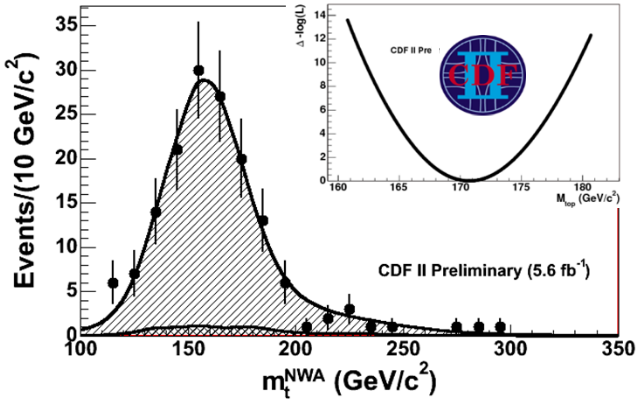
New Top Mass Measurements at Tevatron



- DØ, **3.6fb^{-1}**
- ℓ+jets
- Matrix element
- in-situ JES calib.

$$m_t = 174.9 \pm 1.5 \text{ GeV}$$

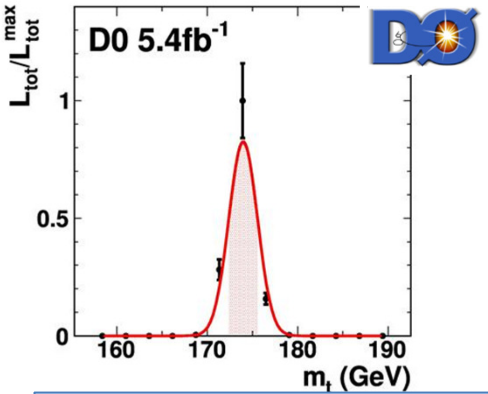
PRD84,032004(2011)



- CDF, **5.6fb^{-1}**
- dilepton
- Assume $\eta_{\nu,\bar{\nu}}$ (NWA)

$$m_t = 170.3 \pm 3.7 \text{ GeV}$$

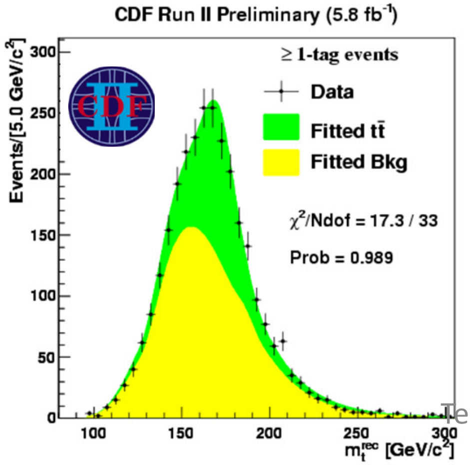
PRD83,111101R(2011)



- DØ, **5.4fb^{-1}**
- dilepton
- Matrix element

$$m_t = 174.0 \pm 3.0 \text{ GeV}$$

arXiv:1105.0320



- CDF, **5.8fb^{-1}**
- All-hadronic
- Kinematic fit + Template method
- in-situ JES calibration

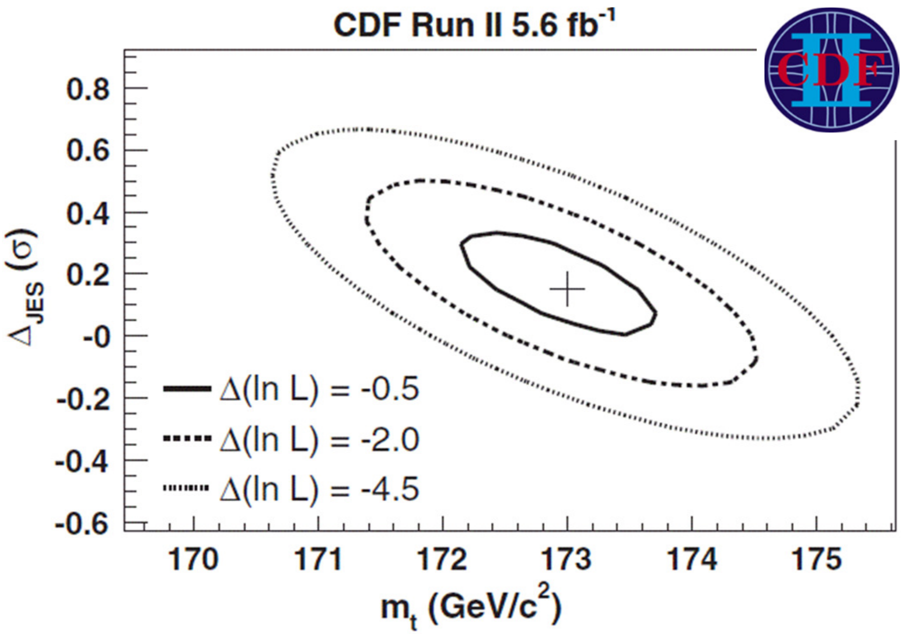
$$m_t = 172.5 \pm 2.0 \text{ GeV}$$

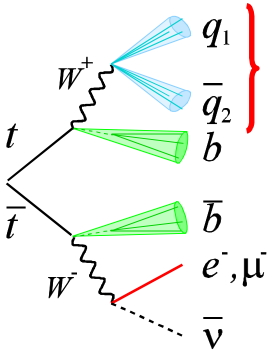
CDF-10456

Top Mass Measurement in CDF ℓ+jets

Still world best single measurement

- CDF ℓ+jets channel
  - e,μ+ ≥4jets, ≥1b-tag
  - 1016(1b-tag), 247(≥2b-tag)
- Matrix element method
- in-situ JES calibration
  - $L_i(\vec{y}\mid m_t,\Delta_{\mathrm{JES}})$ for each event
  - $L(m_t,\Delta_{\mathrm{JES}}) = \prod_i L_i(\vec{y}\mid m_t,\Delta_{\mathrm{JES}})$





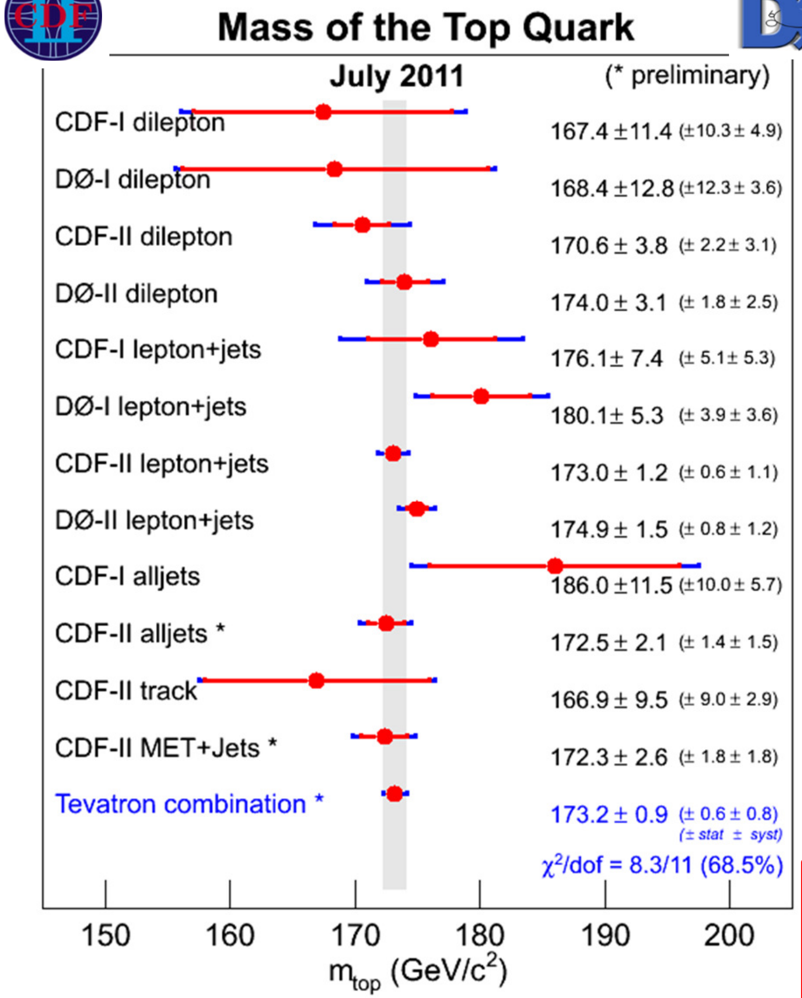
Mjj→M_W

$$M_t = 173.0 \pm 0.7_{\mathrm{stat}} \pm 0.6_{\mathrm{JES}} \pm 0.9_{\mathrm{syst}}\ \mathrm{GeV}$$
$$= 173.0 \pm 1.2\ \mathrm{GeV}$$
$\Delta m_t/m_t \sim 0.7\%$

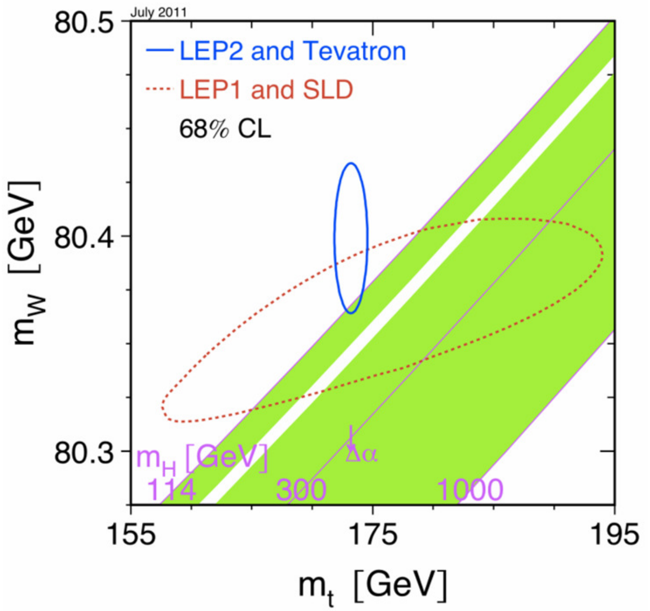
5.6fb^{-1}

PRL105,252001(2010)

Latest Top Mass Measurement at Tevatron



http://lepewwg.web.cern.ch/LEPEWWG/plots/summer2011/



$m_{\mathrm{H}} = 92^{+34}_{-26}$ GeV (68%CL)

or

< 161 GeV (95%CL)

$m_t = 173.2 \pm 0.9$ GeV

$\Delta m_t < 1\mathrm{GeV},\ \Delta m_t/m_t \sim 0.5\%$ ➡

Measured with 3.6-5.8fb^{-1}

Remark:

m_{top}=(173.2 ± 0.9) GeV (0.5%)

m_W=(80.399±0.023) GeV (0.028%)

$\Delta m_W \sim 0.005 \times \delta m_{top} \sim 5$ MeV =>mission impossible

for equal weights in Higgs limits

Tevatron W Mass current status

Currently about 7 M W's/expt ($9fb^{-1}$)

- **Last Tevatron combination:**

  m_W=80420±31MeV (0.038%)

  – Update previous CDF result to modern PDFs

  – Correct to same Γ_W

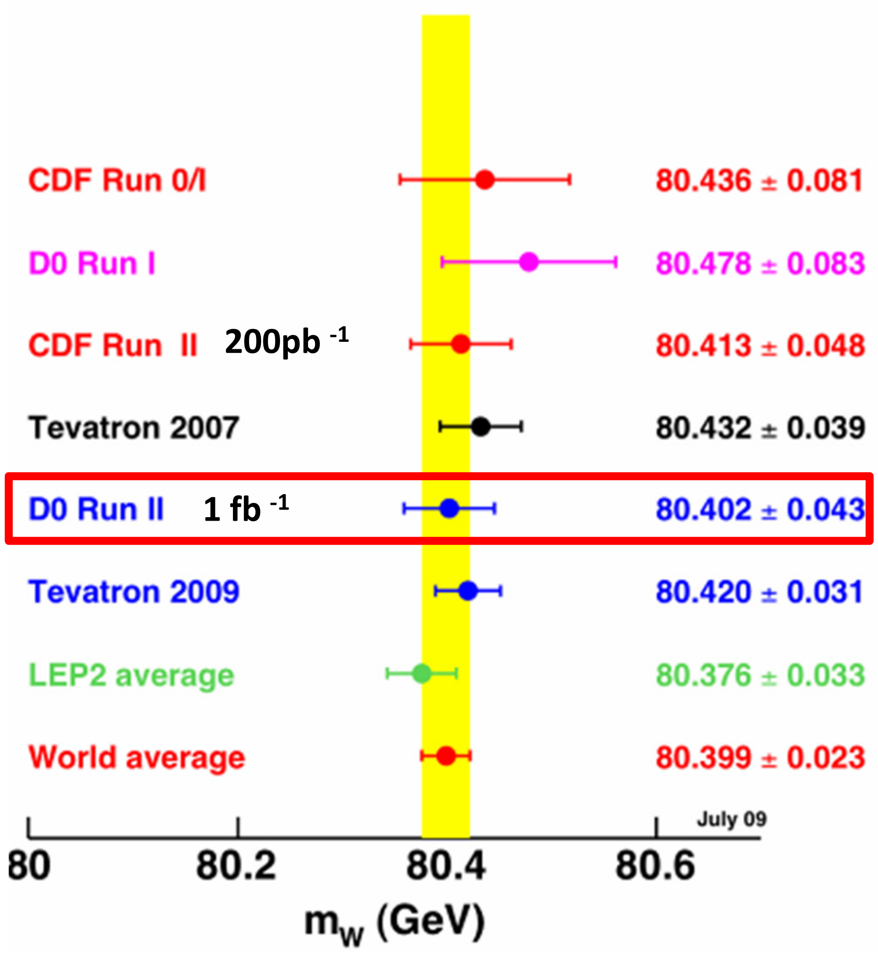
  – PDF, QED, Γ_W uncertainties correlated

- **More precise than LEPII legacy:**

  80.367±0.033 GeV (0.04%)

- **Current World average (2009):**

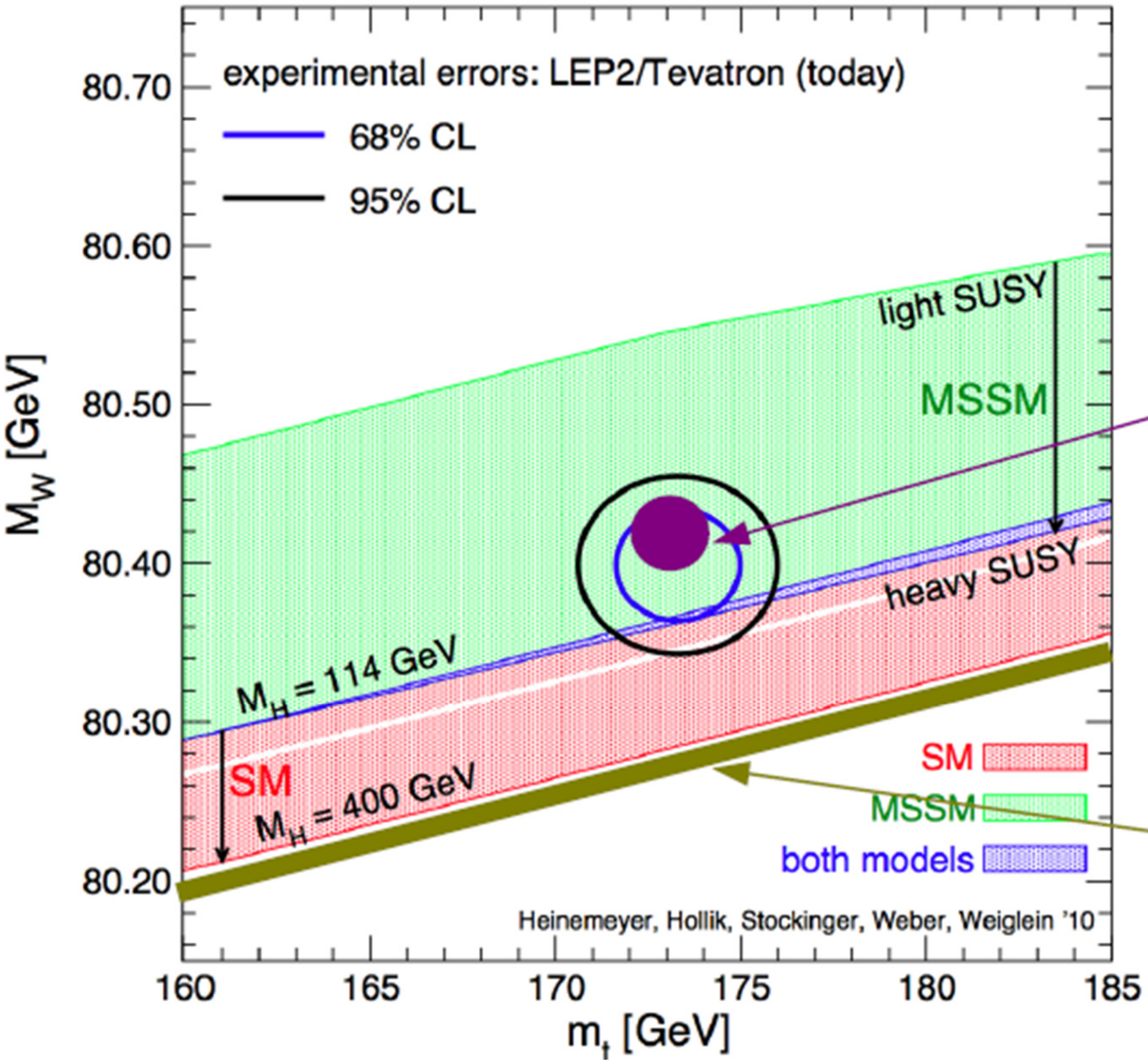
  m_W=80399 ± 23 MeV



CDF (2.4 fb^{-1}) and D0 ($5fb^{-1}$) are working on updates with improved analyses
⇒ expect to reach ≤ 25 MeV per experiment
-> 15 MeV combining both experiments

=> W-MASS: ONE of the OUTSTANDING LEGACY OF THE TEVATRON

Best possible scenario in about 2 years?



ΔM_t = 0.7 GeV
ΔM_W = 15 MeV

Higgs discovery at a large mass

Courtesy J. Stark LP 2011

Top quark charge asymmetry

!!Not Forward Backward Asymmetry!!

As teached by German Rodrigo (EPS11)

At O(α_s^2): top and antitop quarks have identical angular distributions

A charge asymmetry arises at O(α_s^3)

Interference of ISR with FSR
LO for ttbar+jet
negative contribution (ttbar+1 jet)

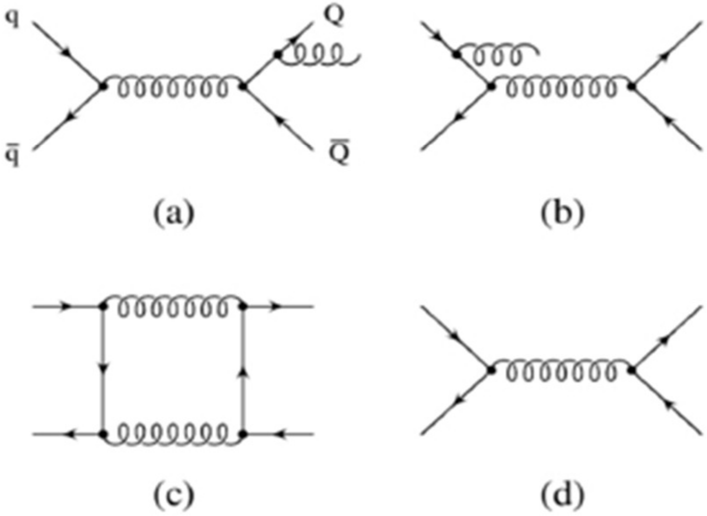
Interference of box diagrams with Born
positive contribution (ttbar+0 jet)

- color factor d_{abc}^2 : pair in color singlet

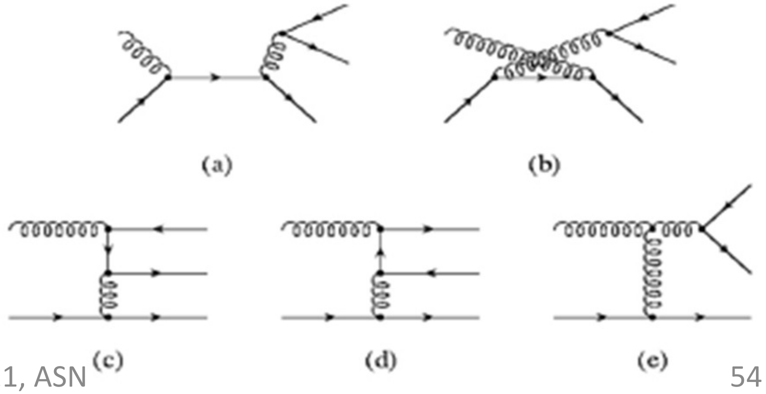
- Loop contribution larger than tree level

top quarks are preferentially emitted in the direction of the incoming quark

[Kühn, GR,1998]



Flavor excitation (qg channel) much smaller



Inclusive asymmetry at Tevatron

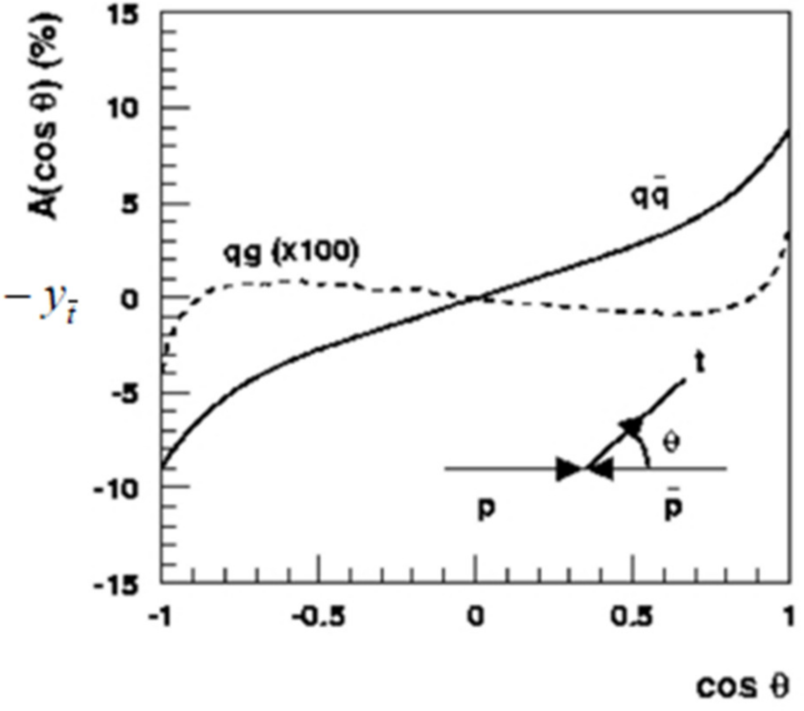
Charge conjugation symmetry* ($N_{\bar{t}}(y) = N_t(-y)$)

forward-backward

$$A^{p\bar{p}} = \frac{N_t(y>0) - N_{\bar{t}}(y>0)}{N_t(y>0) + N_{\bar{t}}(y>0)} = 0.051(6)$$

$$A^{t\bar{t}} = \frac{N(\Delta y>0) - N(\Delta y<0)}{N(\Delta y>0) + N(\Delta y<0)} = 0.078(9) \quad \Delta y = y_t - y_{\bar{t}}$$

[Kühn, GR,1998; Antuñano, Kühn, GR, 2008]



- mixed QCD-EW interference: factor 1.09 included [Hollik, Pagani, claim 1.19]
- stable to NLL threshold resummations (one per mille) [Almeida,Sterman,Vogelsang]
- NNLL threshold resummations [Ahrens,Ferroglia,Neubert,Pecjak,Yang] Not expanding the asymmetry in α_S : the asymmetry decreases by 20% at NLO (K factor), but only by 5% at NLO+NNLL

* CP violation arising from electric or chromoelectric dipole moments do not contribute to the asymmetry

The asymmetry increases with Mttbar because of gluon fusion

TOP Forward-Backward Asymmetry

Compare the number of top and antitop produced with momentum in a given direction:

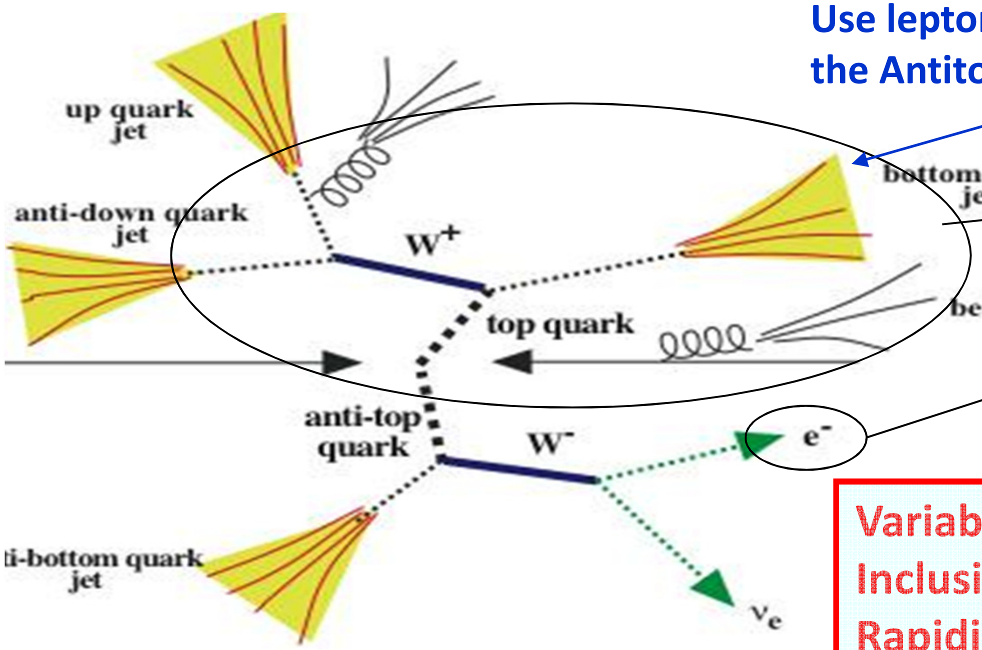
$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

Top (antitop) moving against or in the same direction in the Lab or the ttbar rest frames

$$A_{fb} = \frac{N_t(\cos(\theta) > 0) - N_t(\cos(\theta) < 0)}{N_t(\cos(\theta) > 0) + N_t(\cos(\theta) < 0)}$$

Choose to express it with θ the angle between the Top momentum and the p beam direction.

Use lepton +jet to distinguish between the Top and the Antitop signature in the same event



Use the hadronic side to measure top rapidity. → Y_{had}

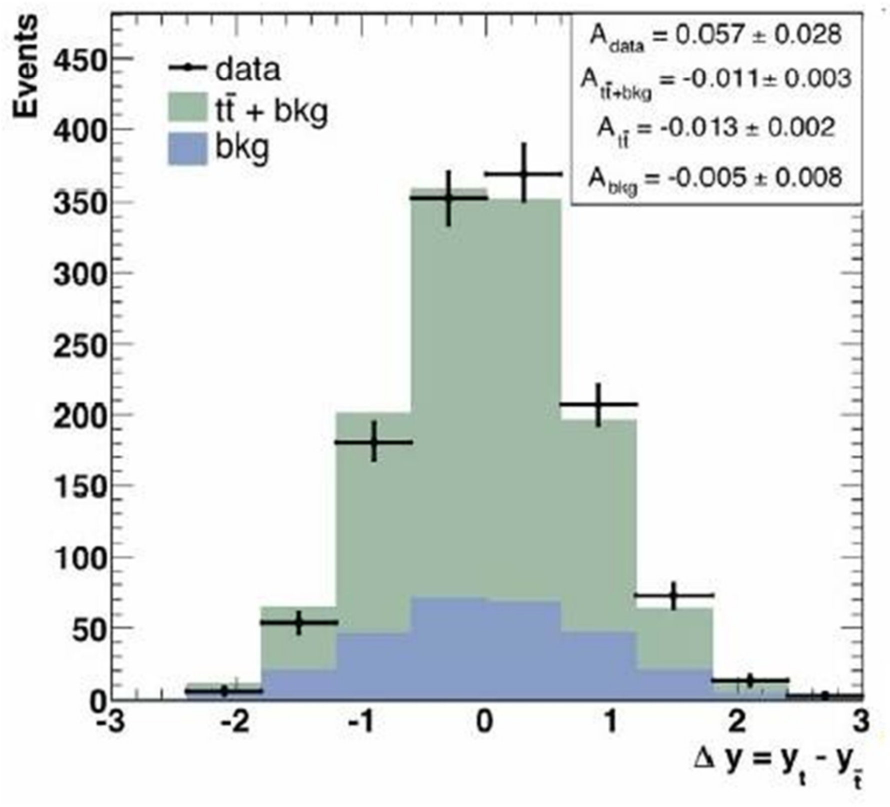
Tag top vs tbar with lepton charge. → Q_l

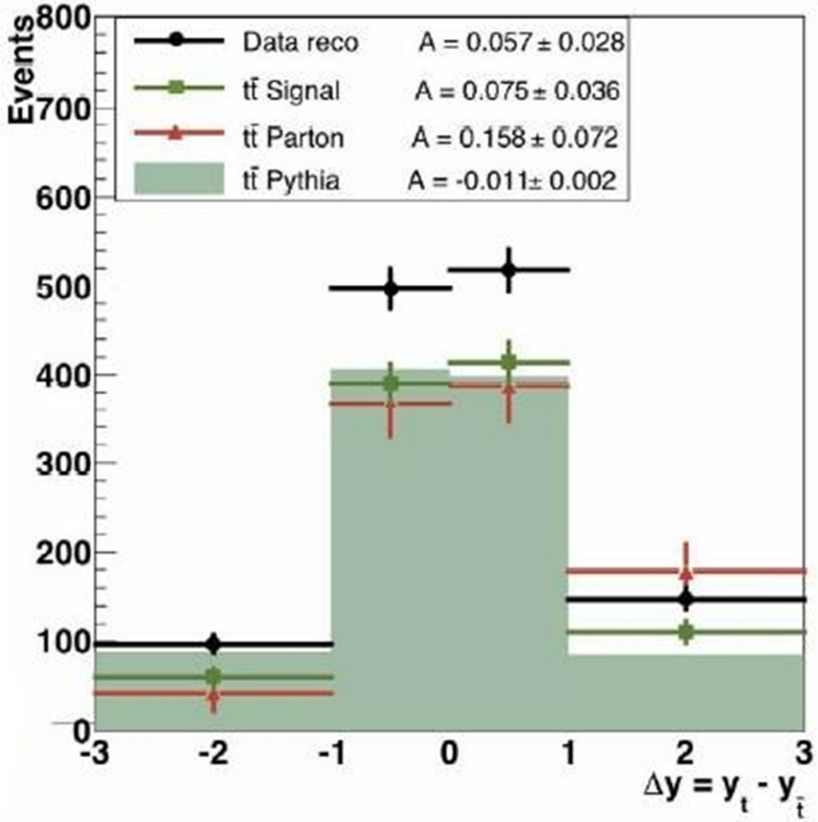
q_l	t_{lep}	t_{had}
+	t	$\bar{t}$
−	$\bar{t}$	t

Variables => calculate A_{FB}
Inclusive: $-QY_{had}=Y_{top}=-Y_{antitop}$
Rapidity-dependent:
$Q(Y_{lep}-Y_{had})=Q\Delta Y=Y_{top}-Y_{antitop}$

Lepton+jets result (5.3fb^{-1})

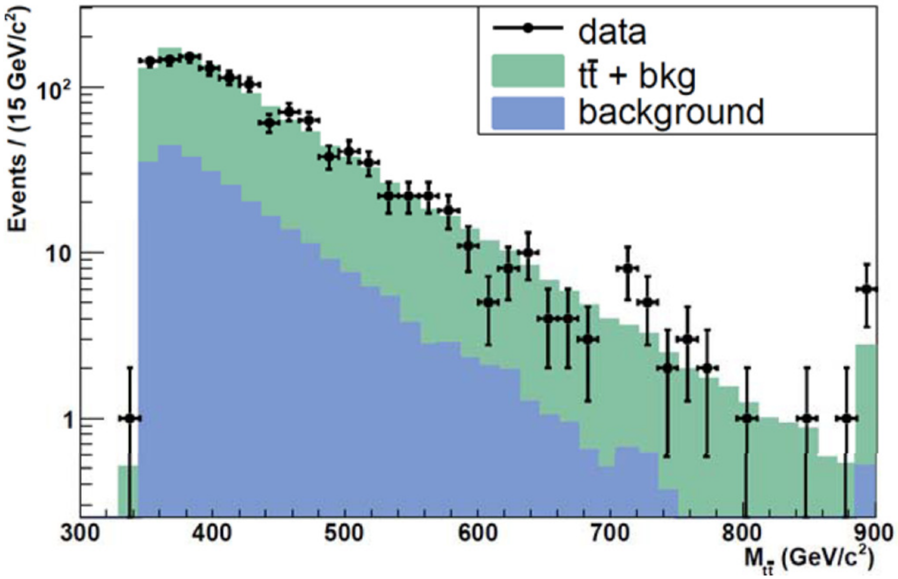
- $\Delta Y(= y_t - y_{tbar})$
- *Background subtracted, then unfolded back to parton level*
- $A^{ttbar} = 0.158 \pm 0.074$ *(2σ deviation)*

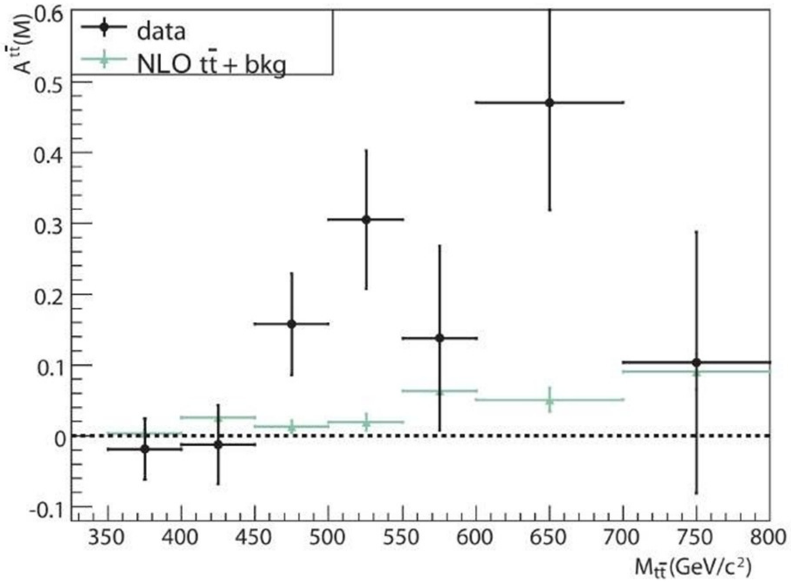


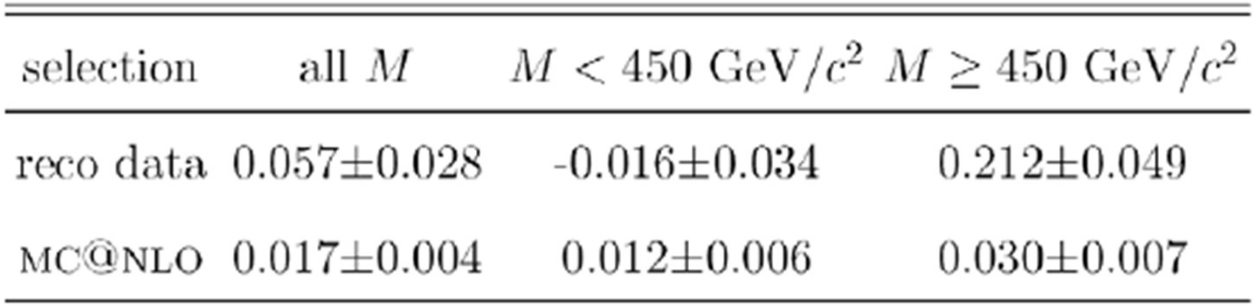


Lepton+jets result (5.3 fb^{-1})

- Found A_{FB} has a strong dependence on M_{tt}
- Many possible theoretical scenarios where A_{FB} depends on M_{tt}



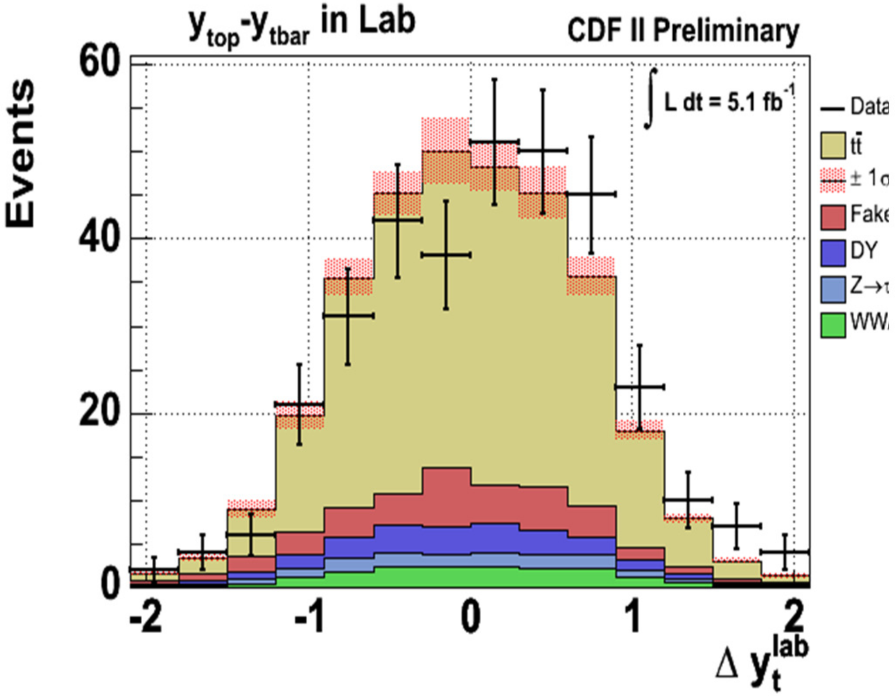


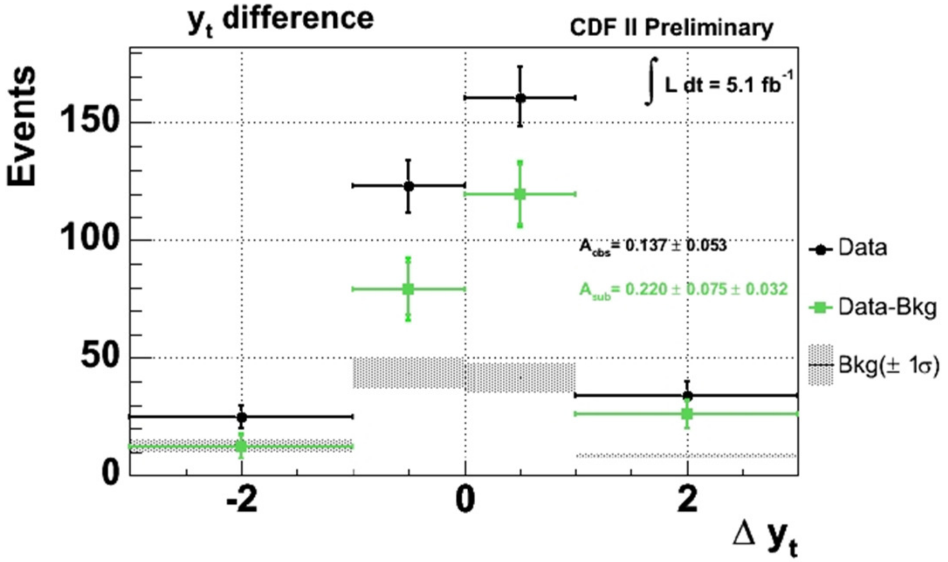


selection	all M	$M < 450$ GeV/c^2	$M \geq 450$ GeV/c^2
reco data	0.057±0.028	-0.016±0.034	0.212±0.049
MC@NLO	0.017±0.004	0.012±0.006	0.030±0.007

(3.4σ deviation)

Dilepton results (5.1fb^{-1})





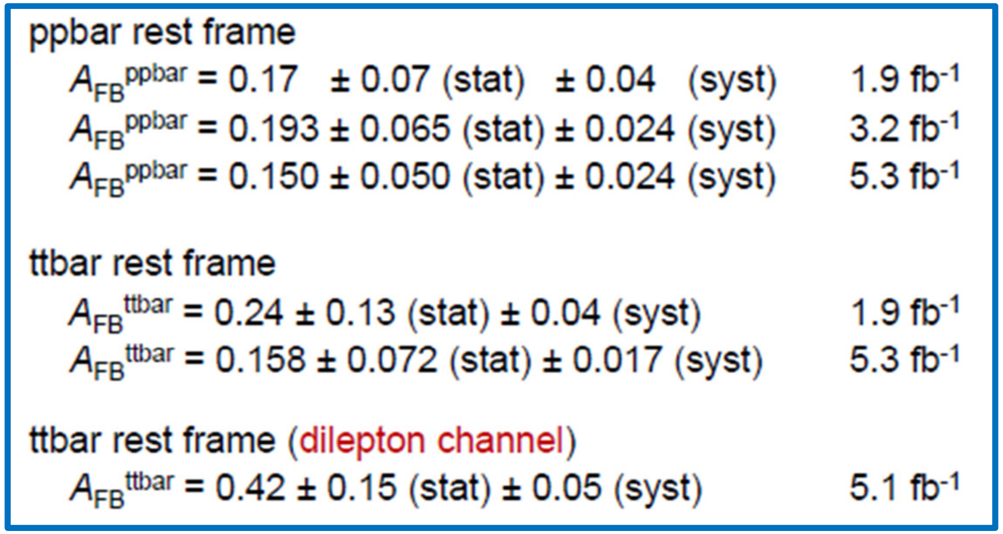
- $A_{\rm obs} = 0.137 \pm 0.053(\text{stat.})$
- $A_{\rm sub} = 0.220 \pm 0.075(\text{stat.}) \pm 0.032(\text{bkg shape})$

⇩

$$A_{\rm true} = 0.445 \pm 0.152(\text{stat.}) \pm 0.065(\text{bkg shape})$$ (2.3σ)

Confirms observation in Lepton+jets !!

CDF Top Asymmetry results



ppbar rest frame

A_{FB}^{ppbar} = 0.17 ± 0.07 (stat) ± 0.04 (syst) 1.9 fb^{-1}

A_{FB}^{ppbar} = 0.193 ± 0.065 (stat) ± 0.024 (syst) 3.2 fb^{-1}

A_{FB}^{ppbar} = 0.150 ± 0.050 (stat) ± 0.024 (syst) 5.3 fb^{-1}

ttbar rest frame

A_{FB}^{ttbar} = 0.24 ± 0.13 (stat) ± 0.04 (syst) 1.9 fb^{-1}

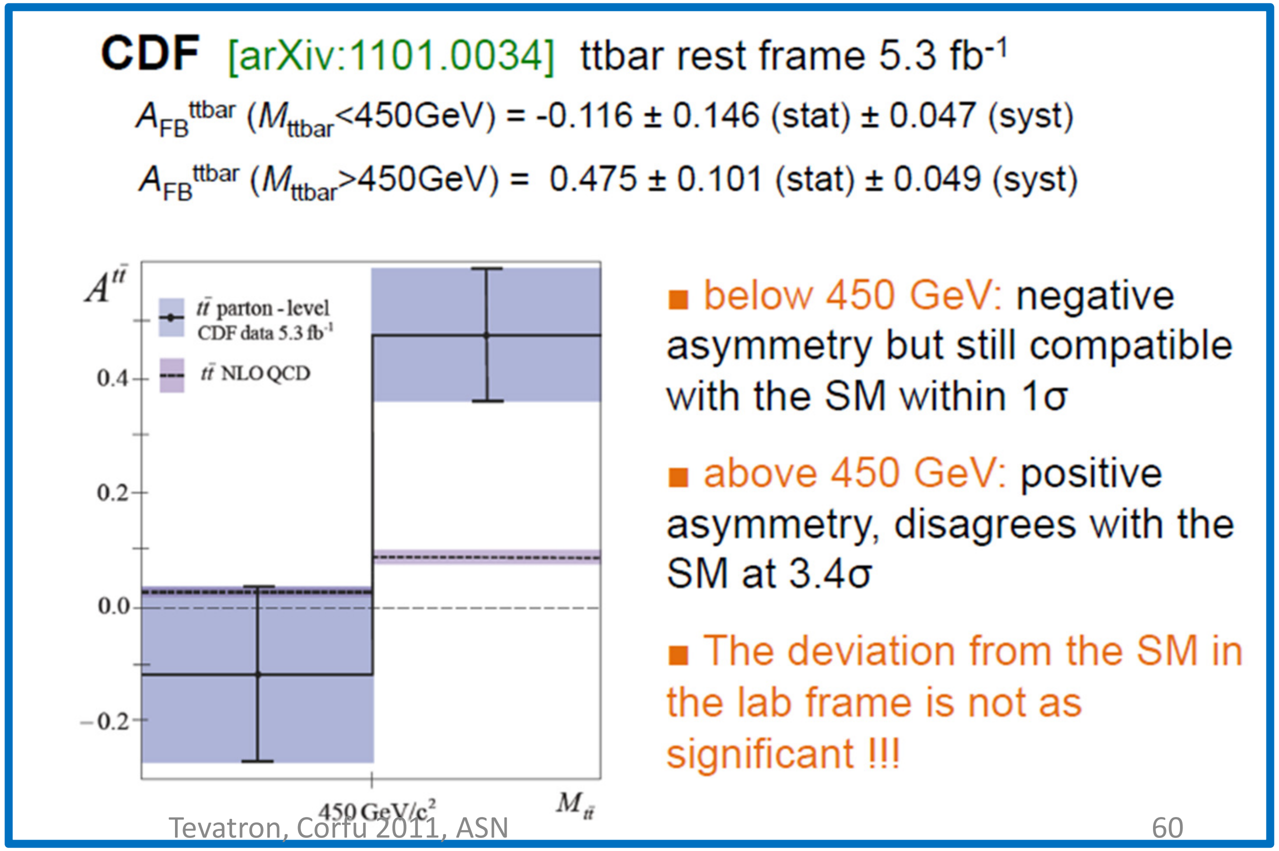
A_{FB}^{ttbar} = 0.158 ± 0.072 (stat) ± 0.017 (syst) 5.3 fb^{-1}

ttbar rest frame (dilepton channel)

A_{FB}^{ttbar} = 0.42 ± 0.15 (stat) ± 0.05 (syst) 5.1 fb^{-1}

About 3σ above zero room for positive BSM within 2σ

Invariant mass charge dependent asymmetry



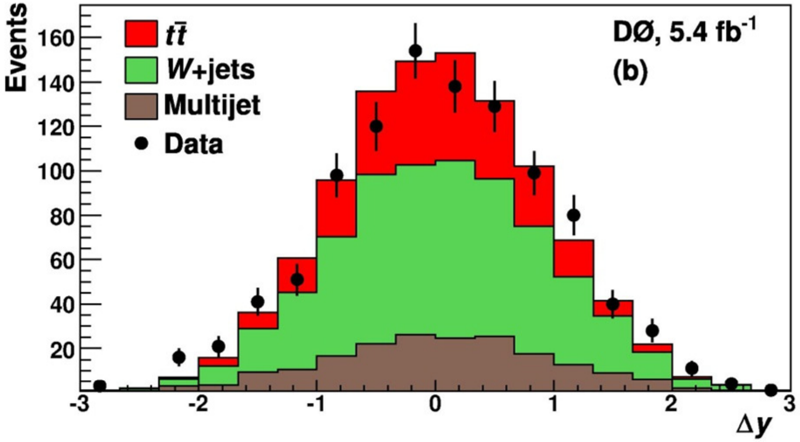
CDF [arXiv:1101.0034] ttbar rest frame 5.3 fb^{-1}

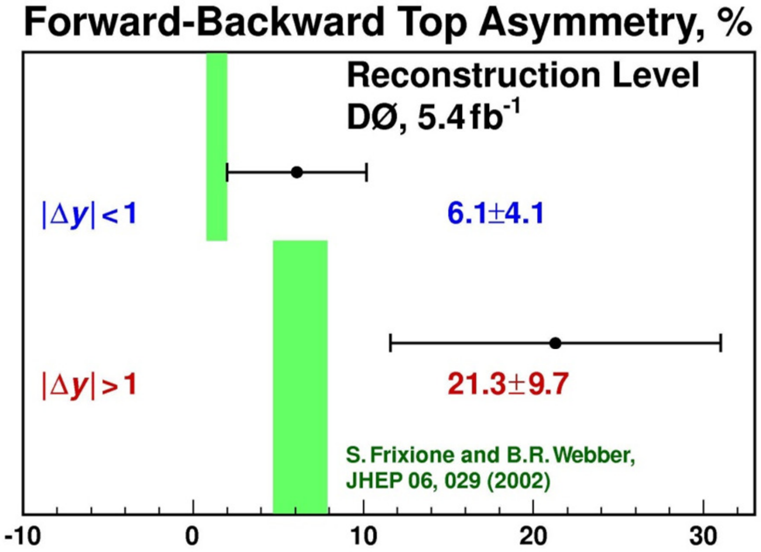
A_{FB}^{ttbar} (M_{ttbar}<450GeV) = -0.116 ± 0.146 (stat) ± 0.047 (syst)

A_{FB}^{ttbar} (M_{ttbar}>450GeV) = 0.475 ± 0.101 (stat) ± 0.049 (syst)

- below 450 GeV: negative asymmetry but still compatible with the SM within 1σ
- above 450 GeV: positive asymmetry, disagrees with the SM at 3.4σ
- The deviation from the SM in the lab frame is not as significant !!!

Top AFB Asymmetry: new D0 results





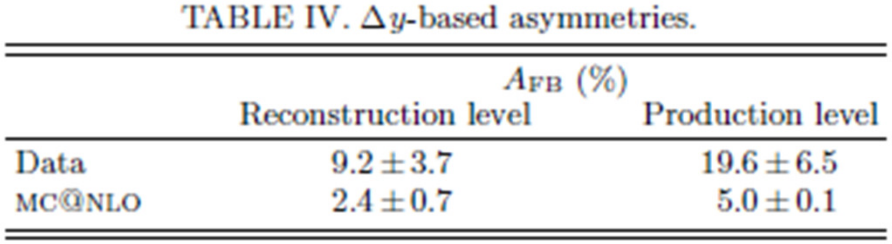


TABLE IV. Δy-based asymmetries.

	A_{FB} (%) Reconstruction level	Production level
Data	9.2 ± 3.7	19.6 ± 6.5
MC@NLO	2.4 ± 0.7	5.0 ± 0.1

2.4σ measured vs expected at prod level
1.9σ at reconstruction level

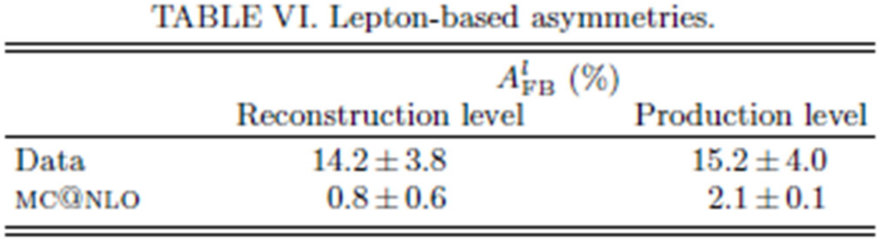


TABLE VI. Lepton-based asymmetries.

	A^{l}_{FB} (%) Reconstruction level	Production level
Data	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	0.8 ± 0.6	2.1 ± 0.1

3σ effect for lepton based Asymmetry

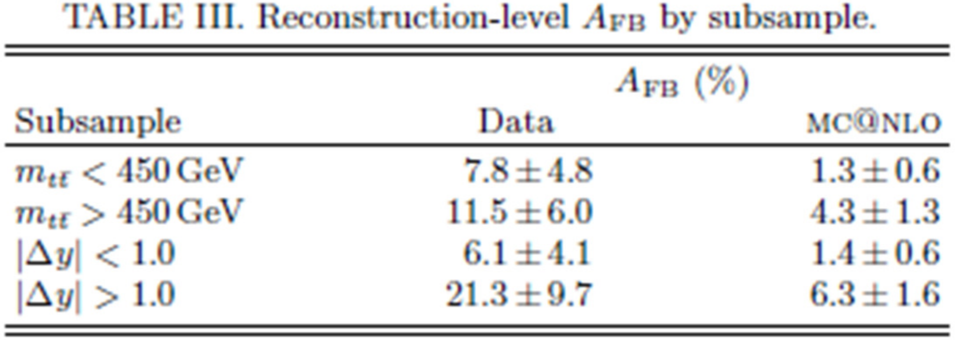
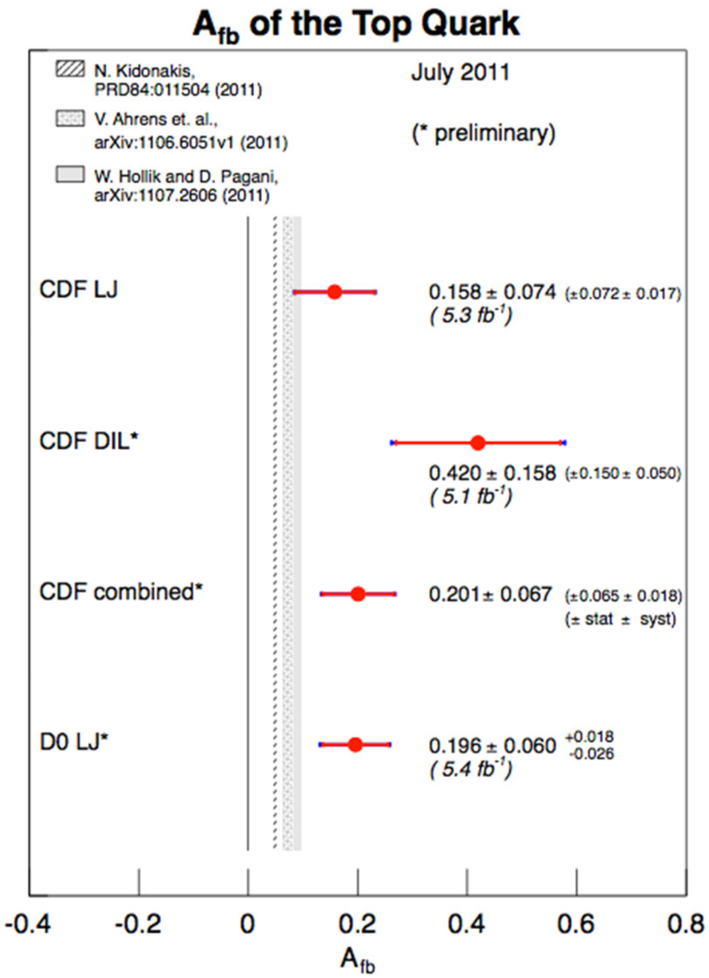
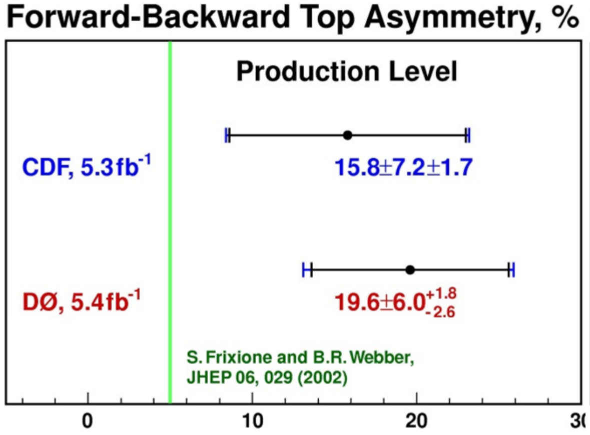


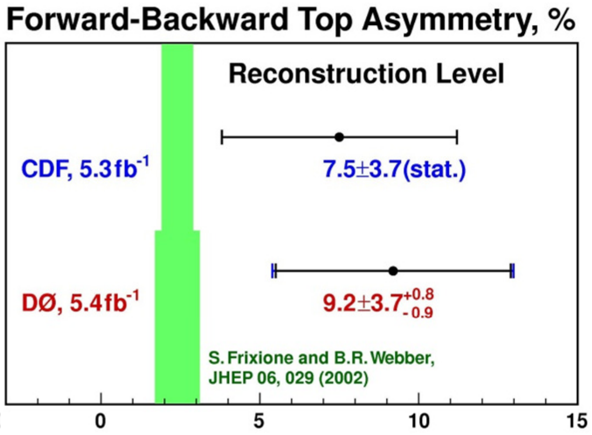
TABLE III. Reconstruction-level A_{FB} by subsample.

Subsample	A_{FB} (%) Data	MC@NLO
$m_{t\bar{t}} < 450$ GeV	7.8 ± 4.8	1.3 ± 0.6
$m_{t\bar{t}} > 450$ GeV	11.5 ± 6.0	4.3 ± 1.3
$\lvert\Delta y\rvert < 1.0$	6.1 ± 4.1	1.4 ± 0.6
$\lvert\Delta y\rvert > 1.0$	21.3 ± 9.7	6.3 ± 1.6

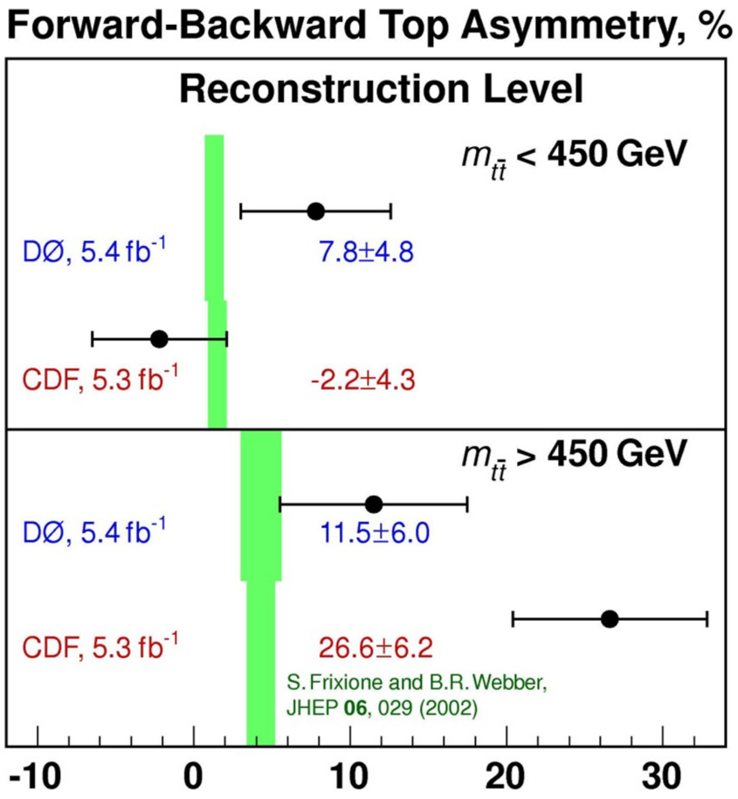
No statistical enhancement of Afb with
Δy or m(ttbar)







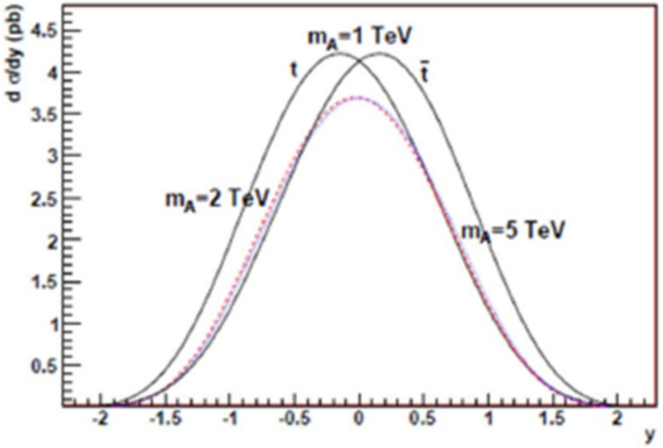
Afb: Comparison CDF vs D0



Both experiments are pursuing their analysis with the full set of recorded data and will combine then at the end.

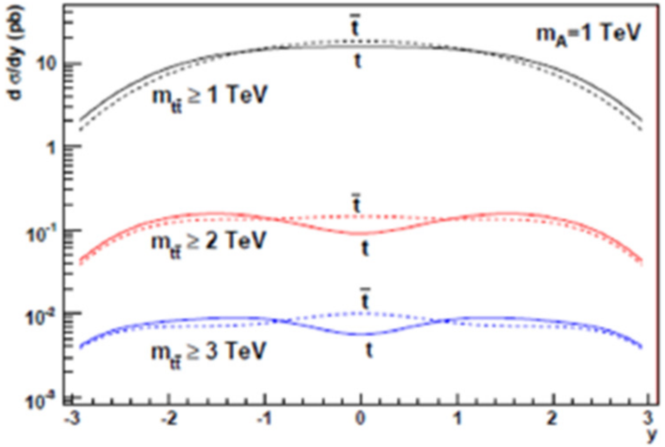
From Tevatron to LHC

Tevatron



LHC

Courtesy German Rodrigo



$$A_C = \frac{N_t(|y|<y_C)-N_{\bar{t}}(|y|<y_C)}{N_t(|y|<y_C)+N_{\bar{t}}(|y|<y_C)}$$

central charge asymmetry

$$A_{\bar{C}} = \frac{N_t(|y|>y_C)-N_{\bar{t}}(|y|>y_C)}{N_t(|y|>y_C)+N_{\bar{t}}(|y|>y_C)}$$

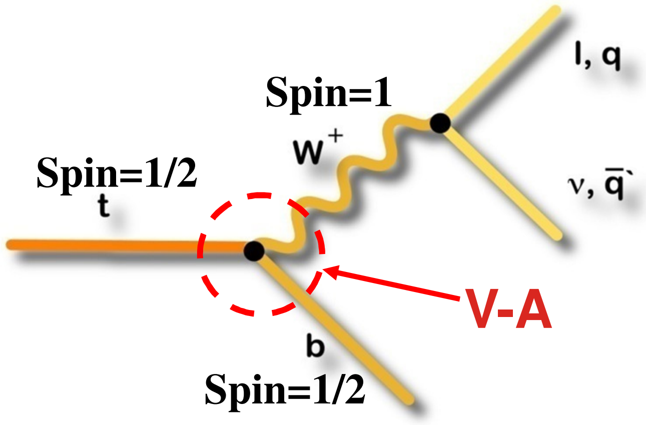
anti-central charge asymmetry
[Edge charge asymmetry,
Forward charge asymmetry]

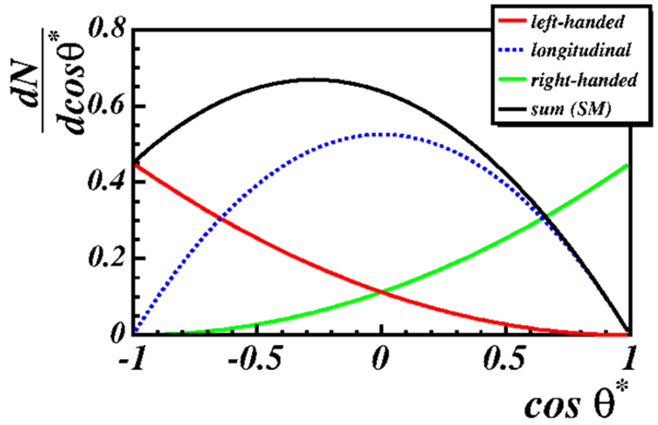
$$A_\Delta = \frac{N(\Delta>0)-N(\Delta<0)}{N(\Delta>0)+N(\Delta<0)}$$

$\Delta = |\eta_t| - |\eta_{\bar{t}}|$ or $\Delta = |y_t| - |y_{\bar{t}}|$

Interesting competition and complementary information from both sides that will be essential for a final conclusion whether or not there is a BSM effect there. Should get soon more about it, stay tuned!

W boson polarization in top decay

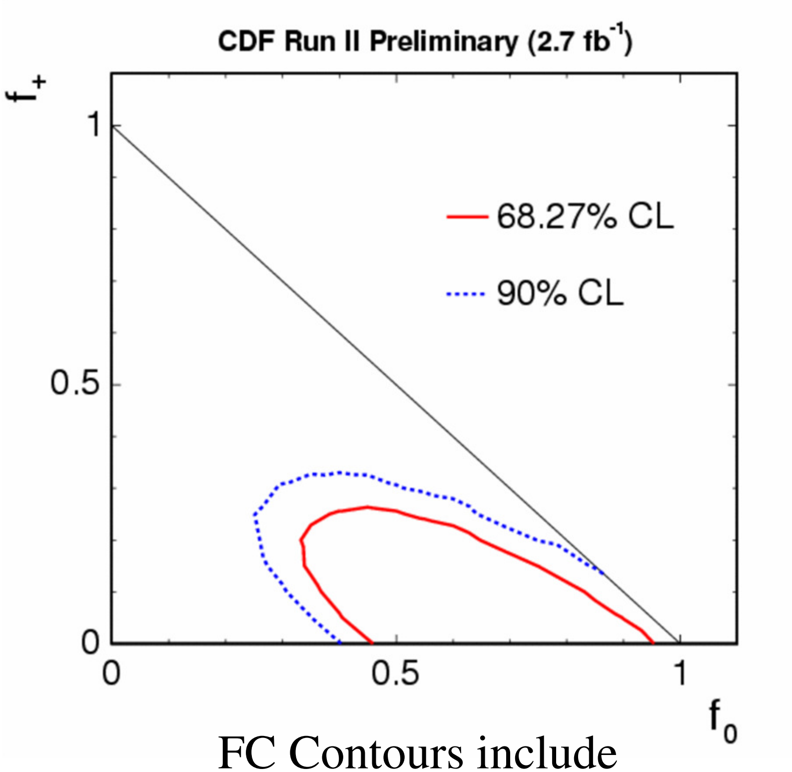




- *The SM top decays via EW interaction: Br($t \rightarrow bW$) ~ 100%*
    - *Top decays as a bare quark (no hadronization) ⇒ spin info transferred to final states*
- *V-A coupling in the SM ⇒* $F_0 \equiv BR(t \rightarrow W_0 b) \approx \frac{m_t^2}{m_t^2 + 2M_W^2} \approx 70\%,\quad F_- \approx 30\%,\quad F_+ \approx 0\%$
    - *longitudinal fraction f0 ~ 70%*
    - *left-handed fraction f- ~ 30%*
    - *right-handed fraction f+ ~ 0%*
- *The SM prediction modified in various new physics models*
- *W polarization fractions are sensitive to non-SM tWb couplings*
- *Use cosθ* : Angle between lepton (down-type quark) in W rest frame and the momentum of the W in the top-quark rest frame*

Result from lepton+jets events

- *Simultaneous measurement:*
  - $f_0 = 0.88 \pm 0.11$ *(stat)* ± 0.06 *(sys)*
  - $f_+ = -0.15 \pm 0.07$ *(stat)* ± 0.06 *(syst)*
  - *Correlation coefficient of -0.59*
  - *As measured central values are unphysical use Feldman Cousins (FC) method to obtain confidence level intervals*
- *Model dependent measurements:*
  - $f_0 = 0.70 \pm 0.07$ *(stat)* ± 0.04 *(syst)* *constraining* $f_+ = 0.0$
  - $f_+ = -0.01 \pm 0.02$ *(stat)* ± 0.05 *(syst)* *constraining* $f_0 = 0.7$
    - *Upper limit at 95% CL :* $f_+ < 0.12$

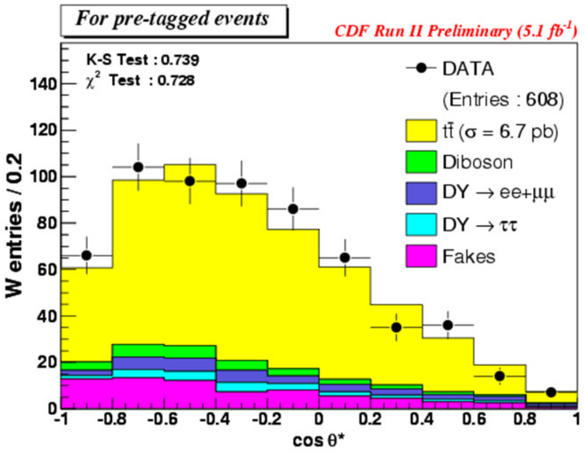


FC Contours include stat+syst uncertainties

Published for PRL publication FERMILAB-PUB-10-041-E,
Phys. Rev. Lett. **105**, 042002 (2010)

Result from dilepton events

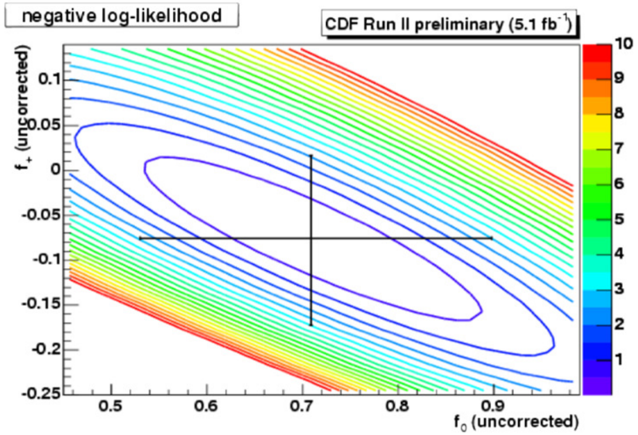
- Used 343 pre-tagged di-lepton candidates (304 passed reconstruction) with 5.1 fb^{-1} and 137 b-tagged events (118 passed reconstruction) with 4.8 fb^{-1}



- *Simultaneous measurement:*
  - *Before b-tagging :* $f_0^{2D} = 0.73 \,^{+\,0.18}_{-\,0.17}(\text{stat}) \pm 0.06(\text{syst})$

    $f_+^{2D} = -0.08 \pm 0.09(\text{stat}) \pm 0.03(\text{syst})$
  - *After b-tagging :* $f_0^{2D} = 0.78 \,^{+\,0.19}_{-\,0.20}(\text{stat}) \pm 0.06(\text{syst})$

    $f_+^{2D} = -0.12 \,^{+\,0.11}_{-\,0.10}(\text{stat}) \pm 0.04(\text{syst})$



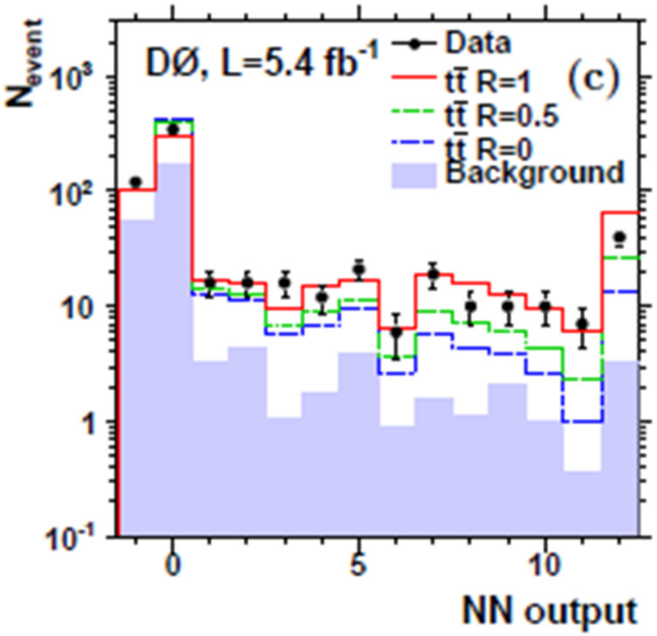
- *Model dependent measurements:*
  - *Before b-tagging :* $f_0^{1D} = 0.60 \pm 0.09(\text{stat}) \pm 0.06(\text{syst})$

    $f_+^{1D} = -0.06 \pm 0.04(\text{stat}) \pm 0.03(\text{syst})$
  - *After b-tagging A* $f_0^{1D} = 0.62 \pm 0.11(\text{stat}) \pm 0.06(\text{syst})$

    $f_+^{1D} = -0.07 \,^{+\,0.06}_{-\,0.05}(\text{stat}) \pm 0.03(\text{syst})$
  - *Determined upper limit on f+<0.07 at 95% CL*

Well in agreement with SM expextations

Precision measurement of ratio B(t →Wb)/B(t→Wq) by D0 with 5.4fb^{-1}



$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{\mid V_{tb} \mid^2}{\mid V_{tb} \mid^2 + \mid V_{ts} \mid^2 + \mid V_{td} \mid^2} .$$

Assuming Unitarity of 3x3 CKM Matrix, IVtbI is highly constrained to:

$$|V_{tb}| = 0.999152^{+0.000030}_{-0.000045}$$

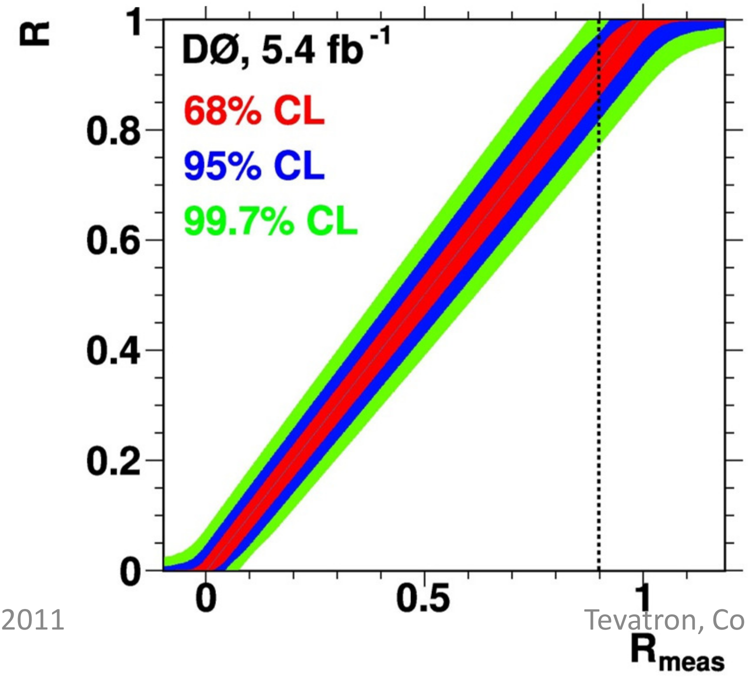
Thus if R≠ 1 => indication of BSM; indeed:

If 4th generation of quarks => no more such constraint.

A smaller value of IVtbI can be directly observed in single top production and also affects xcross(ttbat production.

Measure of R with q=d, s or b-quark in dilepton and lepton+jets channels .

Distinguishing ttbar with 2 b tags or 1 or none

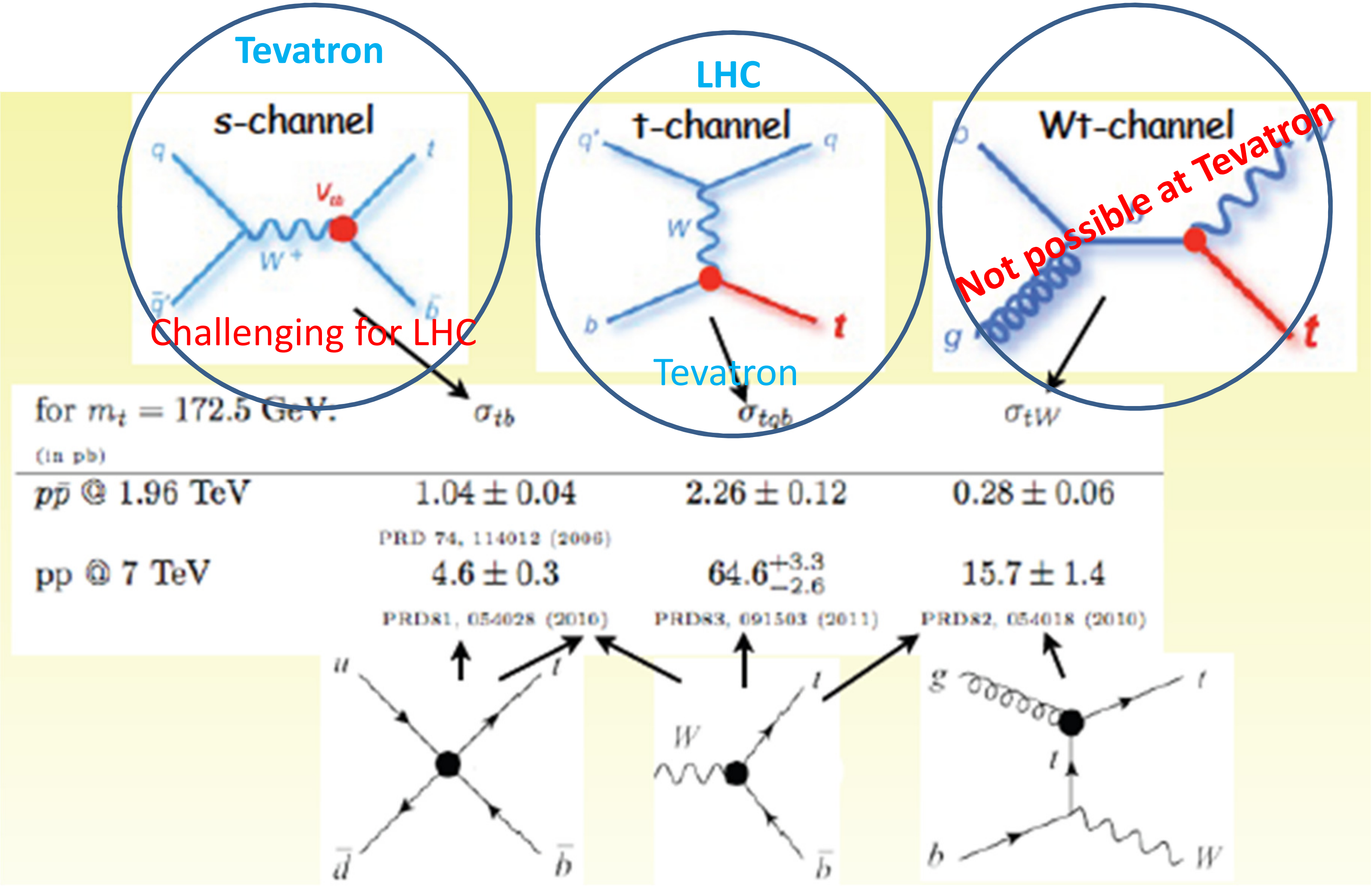


$$R = 0.90 \pm 0.04 \text{ (stat+syst)}$$
$$\sigma_{t\bar{t}} = 7.74^{+0.67}_{-0.57} \text{ (stat+syst) pb.}$$

R agrees within 2.5σ with SM

CDF is pursuing the analysis done so far with only 160 pb^{-1}

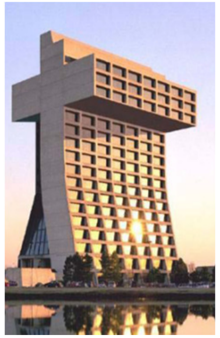
SINGLE TOP: TEVATRON versus LHC



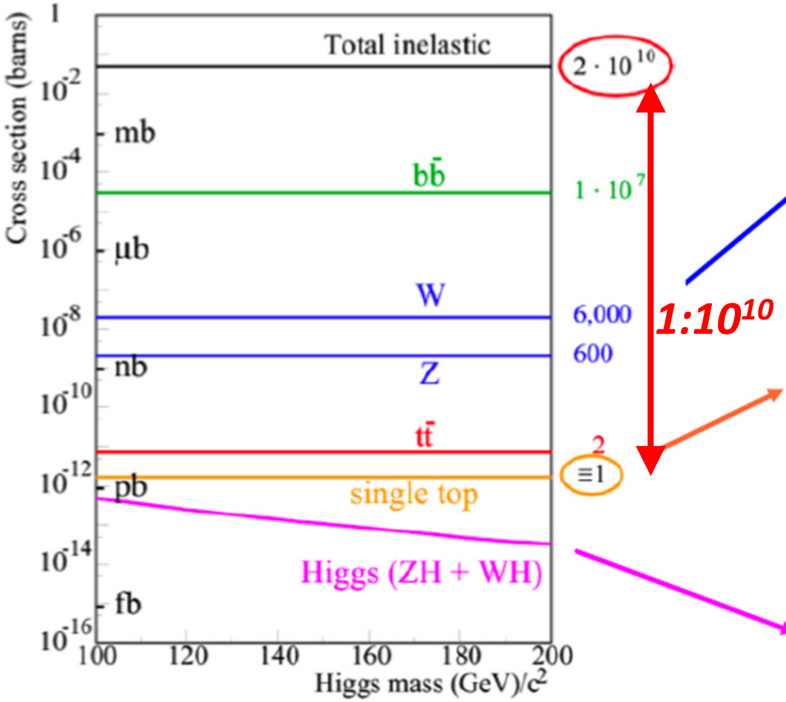
for $m_t = 172.5$ GeV: (in pb)	σ_{tb}	σ_{tqb}	σ_{tW}
$p\bar{p}$ @ 1.96 TeV	1.04 ± 0.04	2.26 ± 0.12	0.28 ± 0.06
	PRD 74, 114012 (2006)		
pp @ 7 TeV	4.6 ± 0.3	$64.6^{+3.3}_{-2.6}$	15.7 ± 1.4
	PRD81, 054028 (2010)	PRD83, 091503 (2011)	PRD82, 054018 (2010)

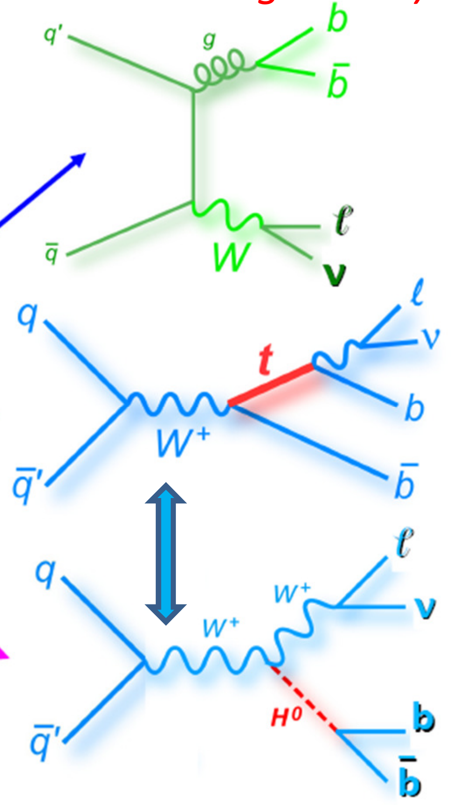
Single top: after 15 years of search...

Experimentally very challenging and same as WH (signatures & backgrounds)



Going down
Dramatically
in cross-section





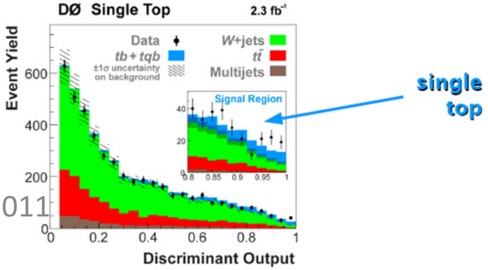
⇒ **multivariate analysis techniques**

Boosted Decision Trees

Boosted Neural Networks

Matrix Elements

combine up to 12 different analysis channels:

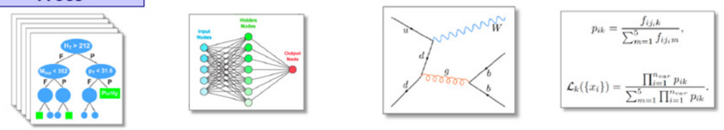


Boosted Decision Trees

Neural Networks

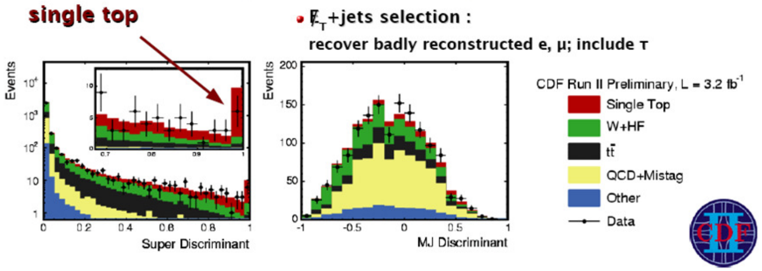
Matrix Elements

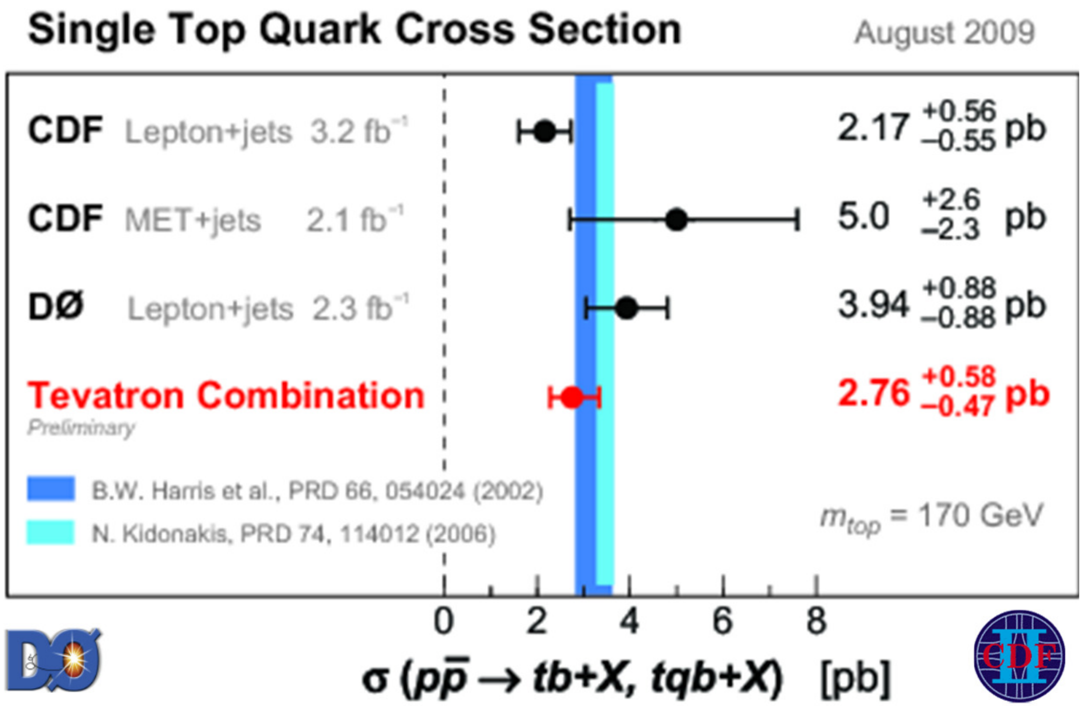
Likelihood

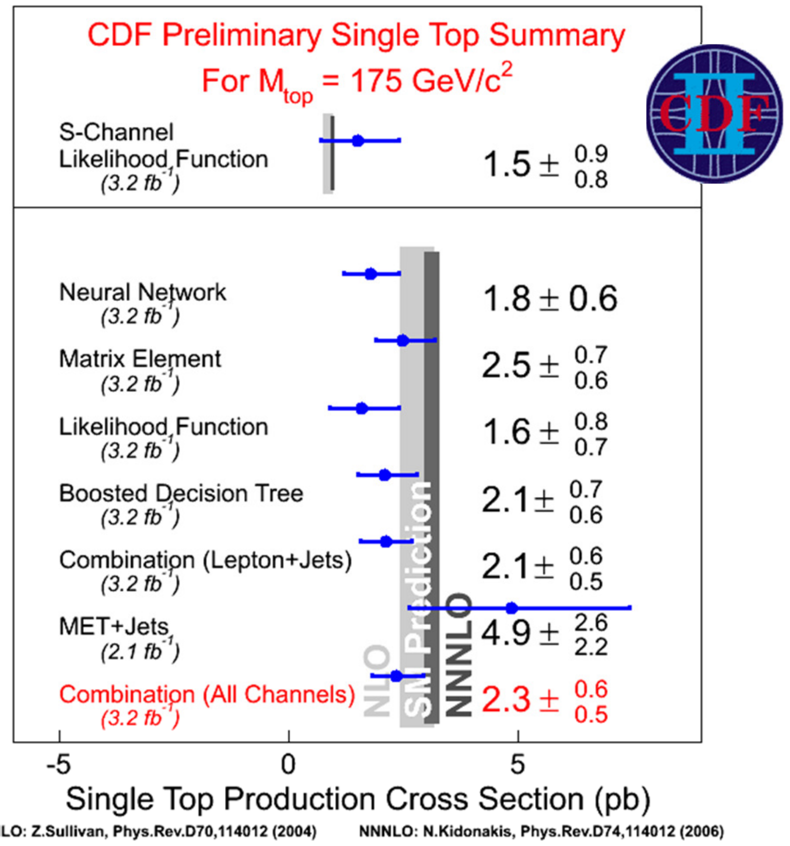


combine up to 8 different analysis channels:

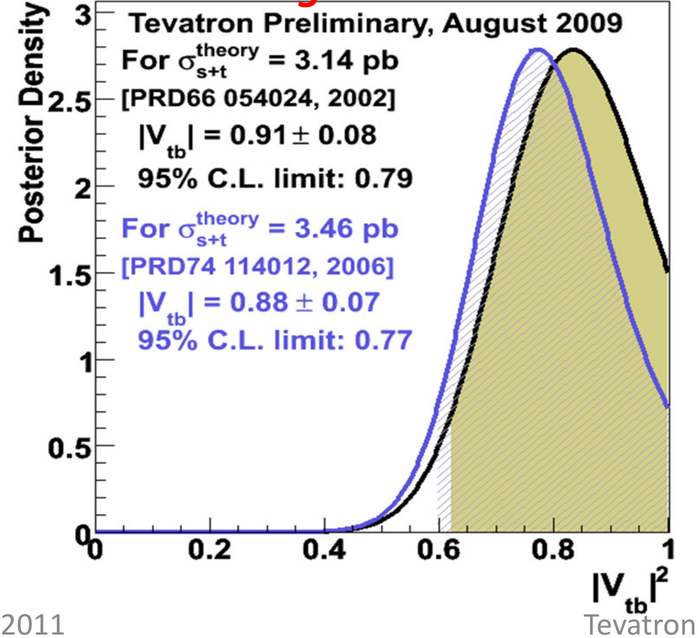
- $\not{E}_T$+jets selection :
recover badly reconstructed e, μ; include τ

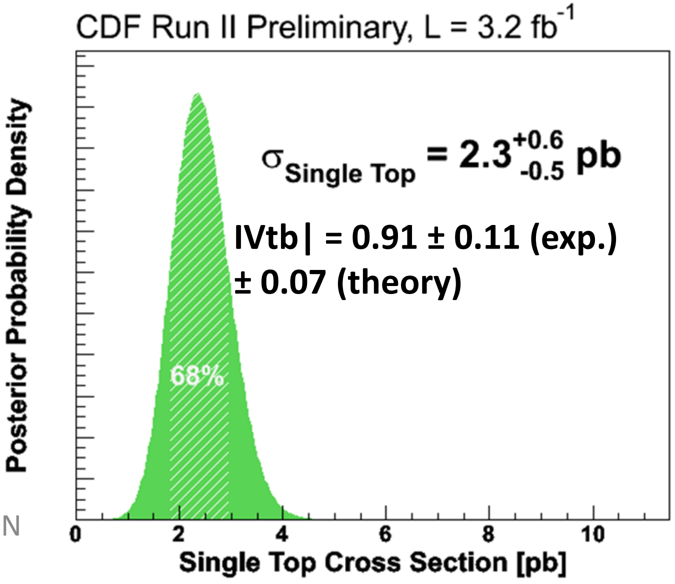






Combining CDF & D0



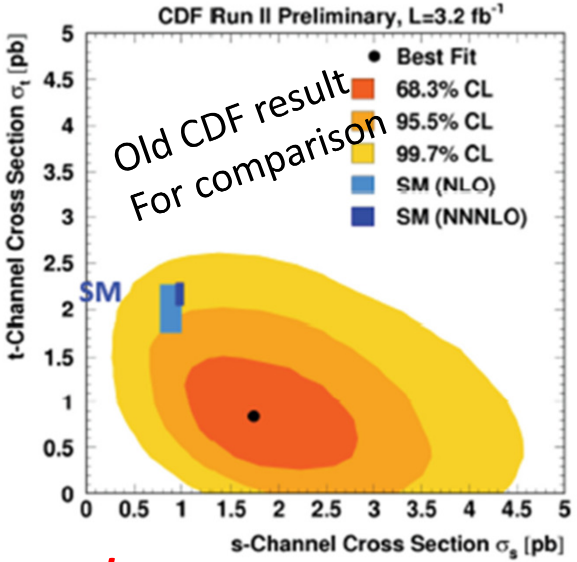


IVtb| = 0.91 ± 0.11 (exp.)
± 0.07 (theory)

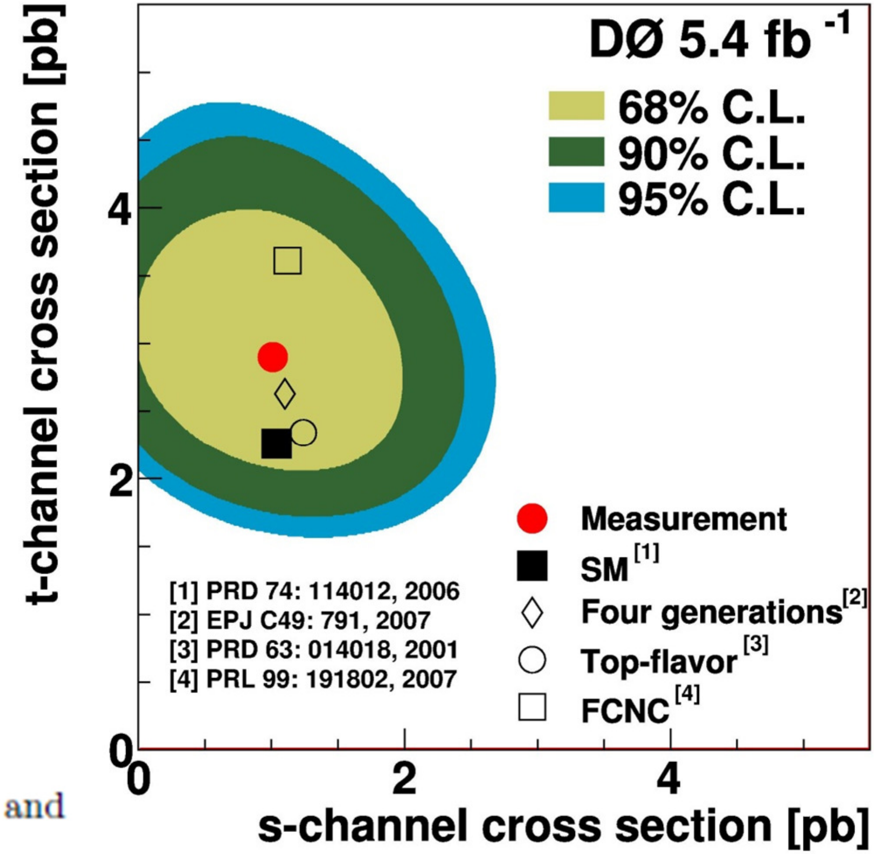
Latest results on single top: D0

Interest to measure the tb and tbq production cross-sections separatly, in an independent way from theoretical assumptions about their relative Rates (as previously done by CDF and D0).

⇒ will allow to see if any deviation wrt SM.



Old CDF result
For comparison



DO new results:

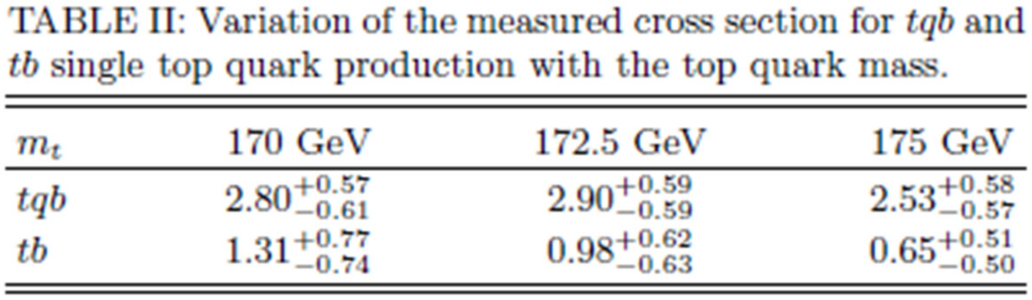


TABLE II: Variation of the measured cross section for tqb and tb single top quark production with the top quark mass.

m_t	170 GeV	172.5 GeV	175 GeV
tqb	$2.80^{+0.57}_{-0.61}$	$2.90^{+0.59}_{-0.59}$	$2.53^{+0.58}_{-0.57}$
tb	$1.31^{+0.77}_{-0.74}$	$0.98^{+0.62}_{-0.63}$	$0.65^{+0.51}_{-0.50}$

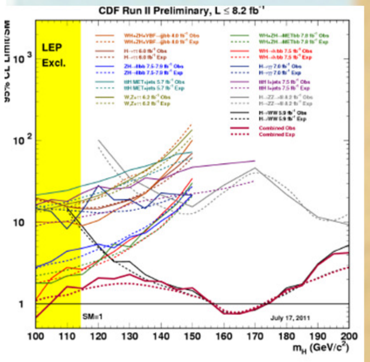
σ(ppbar→tqb + X) = 2.90 ± 0.59 pb

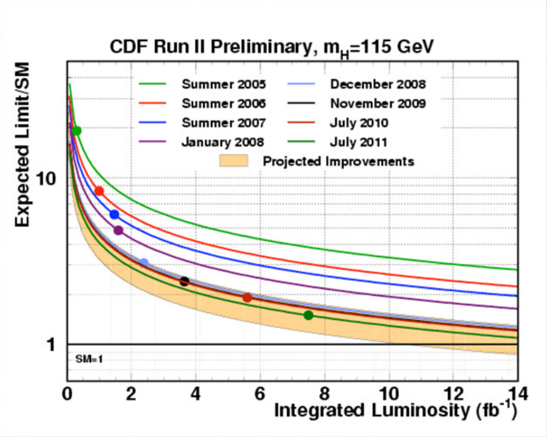
in good agreement with SM

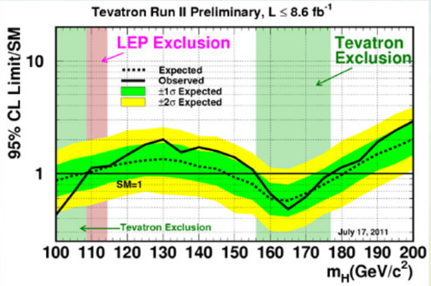
!!Most precise to date!!

Probability of the background to fluctuate & produce a signal as large as the one observed is: 1.6 x10^{-8}, corresponding to a significance of 5.5 σ deviation

Search for Higgs(ses)@ FNAL







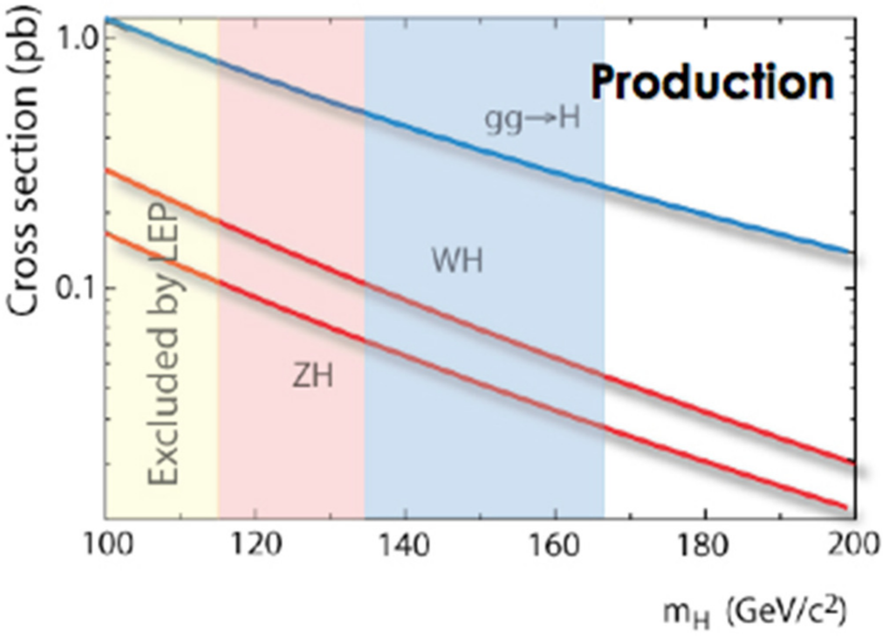
Observed Exclusion : 100-109 and 156-177 GeV/c²

Expected Exclusion : 100-108 and 148-181 GeV/c²

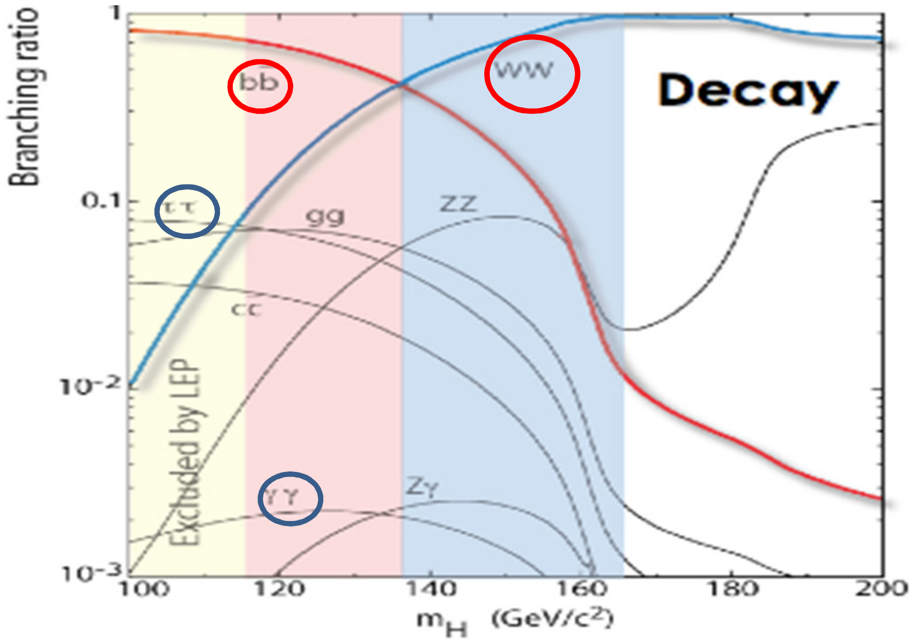
After LEP II, Tevatron has performed an impressive very complete Higgs(ses) search in all possible standard or beyond standard ways

Two main goals and challenges: low mass Higgs & especially H-> bbbar

LOW MASS HIGGS:



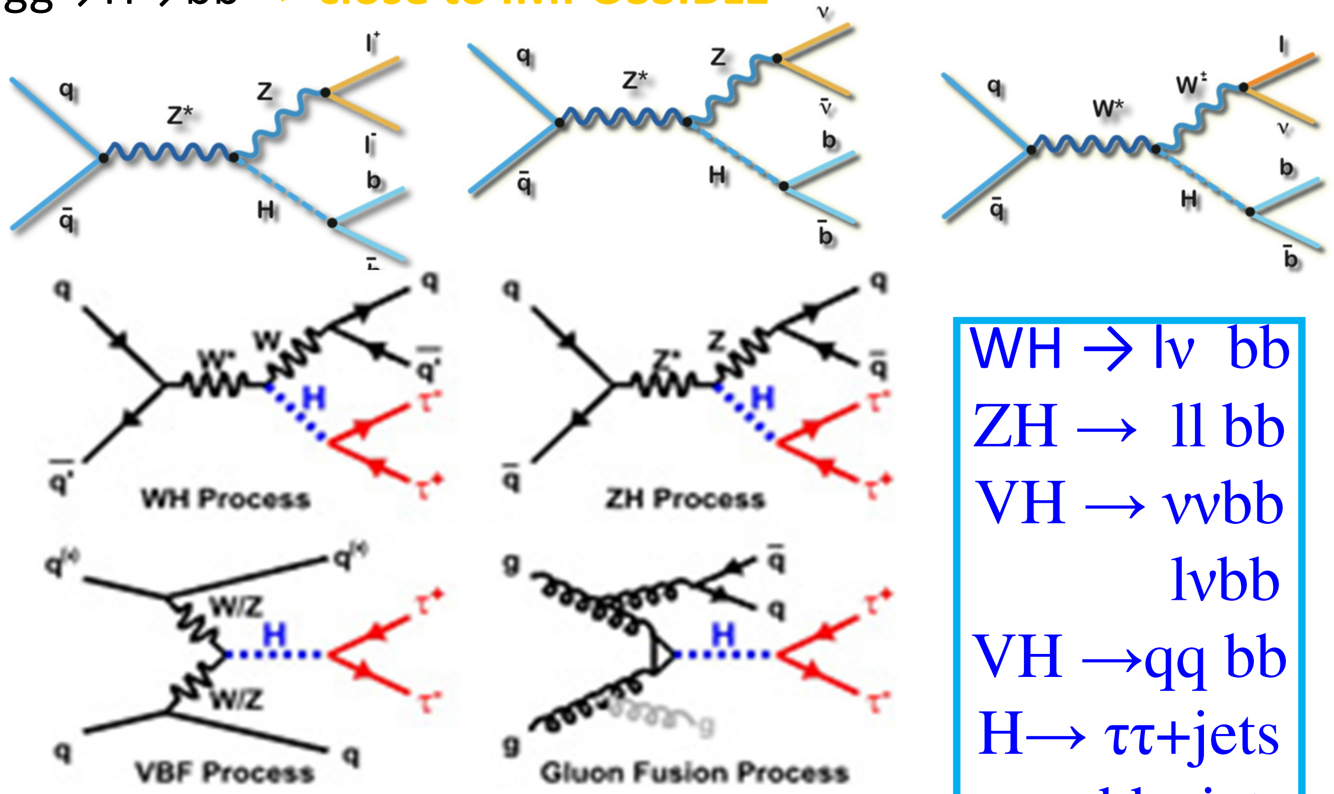
Production and Decay at the Tevatron



The many ways to produce a light Higgs at the Tevatron

m_H<135GeV

gg→H→bb => close to IMPOSSIBLE



WH → lν bb

ZH → ll bb

VH → ννbb

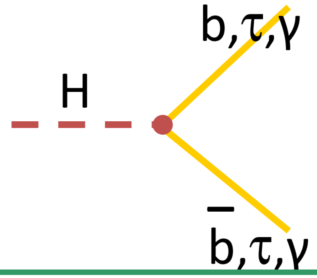
lνbb

VH →qq bb

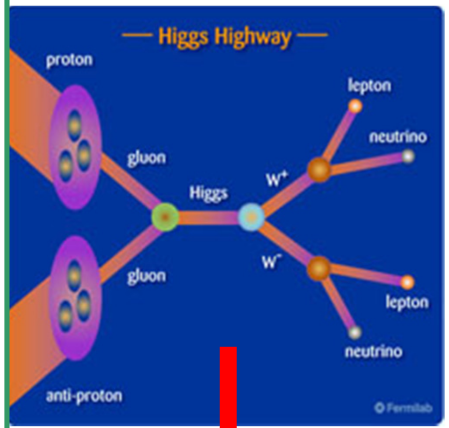
H→ ττ+jets

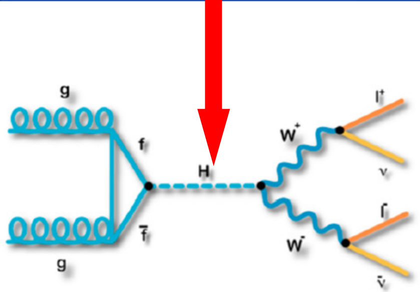
bb+jets

γγ

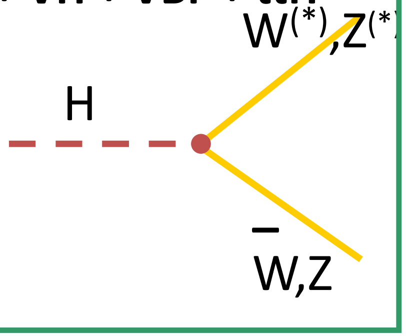


m_H>135GeV





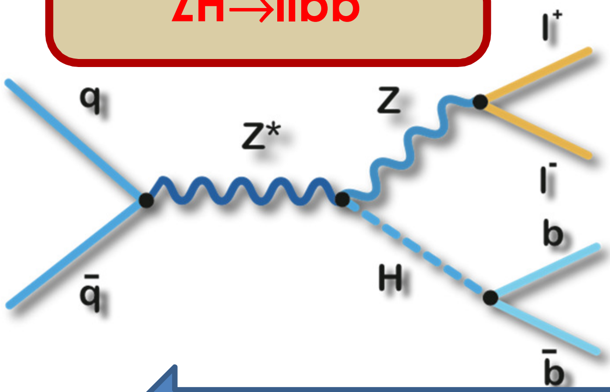
+ VH + VBF + ttH



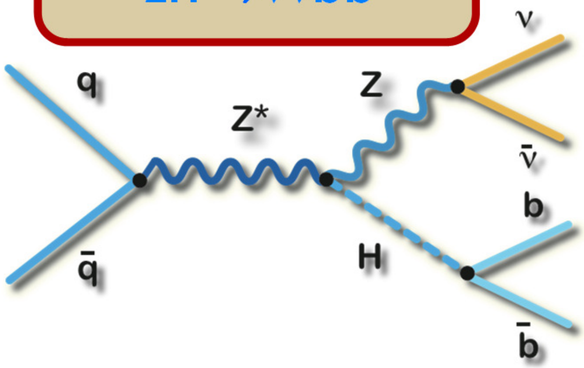
Higgs Production at the Tevatron: *the main channels*

Tevatron unique for finding H into bbar channel

ZH→llbb



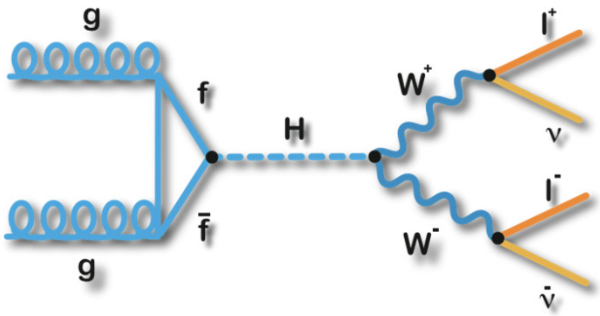
ZH →ννbb



WH → lνbb

Higgs into bb: provides best sensitivity, in mass region above LEP bounds

H →WW → lνlν



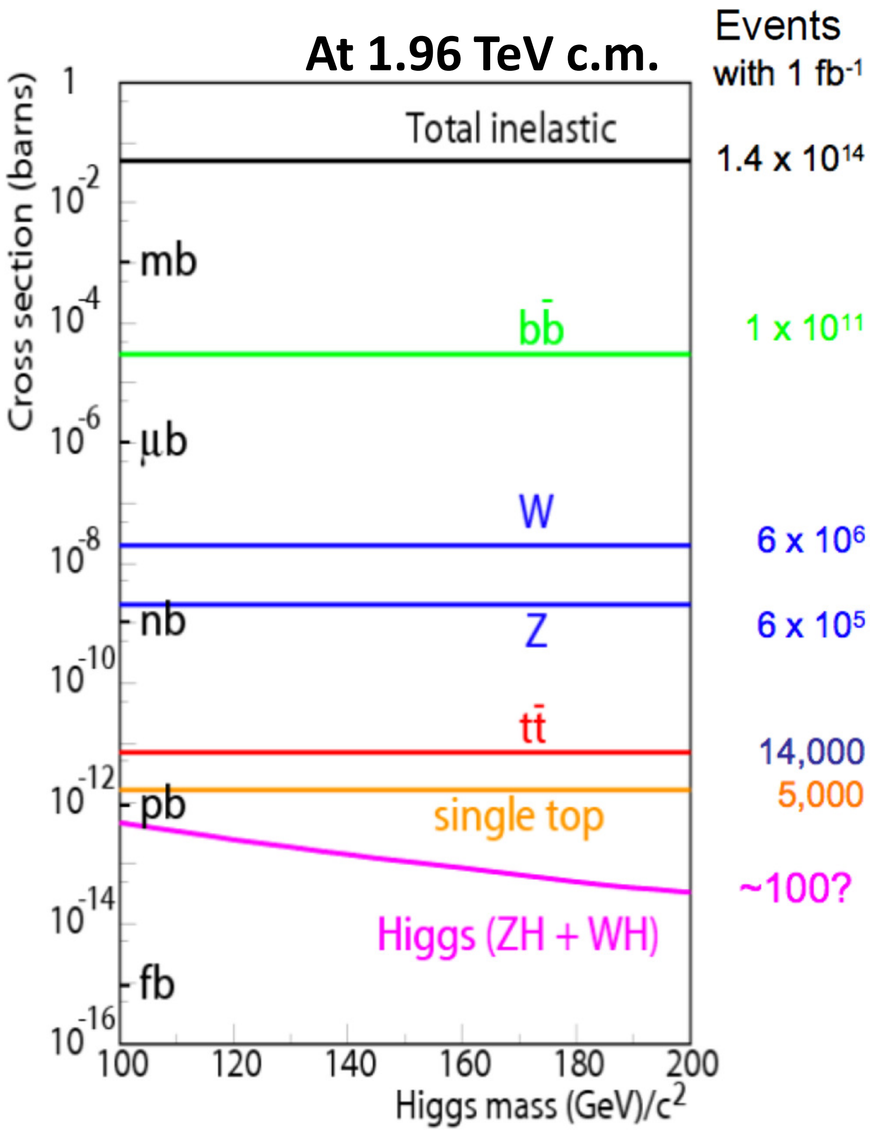
Expected number of events per fb^{-1} per experiment

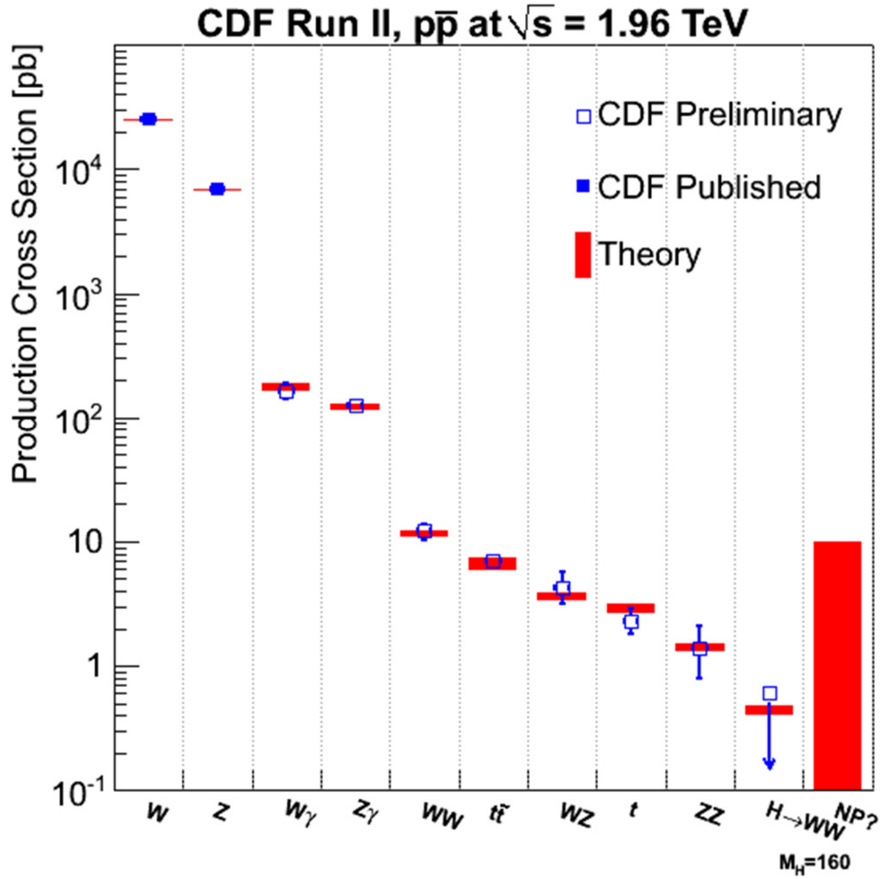
Higgs Mass (GeV/c^2)	WH→lνbb	ZH→ννbb	ZH→llbb	H→WW→lνlν
120	25	12	4	13
135	10	5	2	26
150	3	2	1	32

reconstruction/selection/tagging efficiencies ~ 10% in H→bb channels and ~25% in H→WW channels

On the path to the Higgs sector at Tevatron:

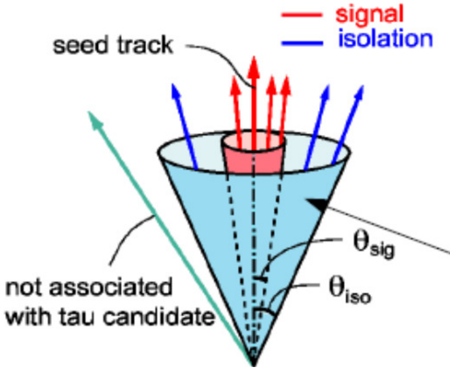
- Search for very low cross section processes
- Measure/discover new processes instrumental
- for discovering possible H0
- Fight against very huge SM backgrounds
- Handle very accurately ALL systematics





This is not only a matter of developing smarter & smarter analysis tools ! (see next)

Higgs sector demands it all from the detectors



Etmiss

electron ID

Jet energy scale

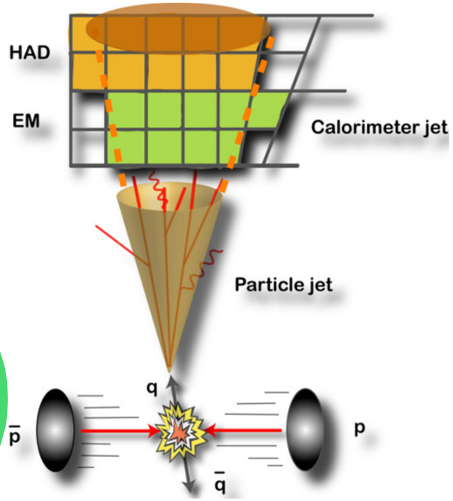
Jets ID

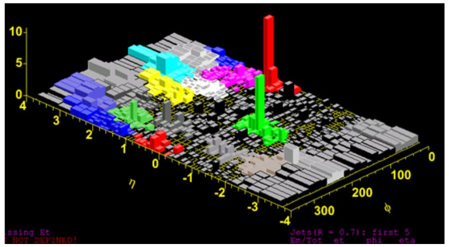
b-tagging

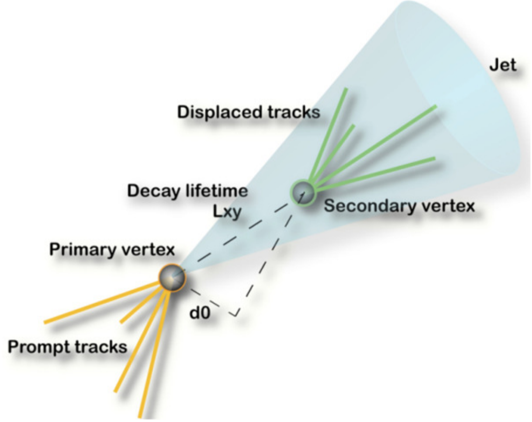
μ ID

τ lepton ID

HIGGS



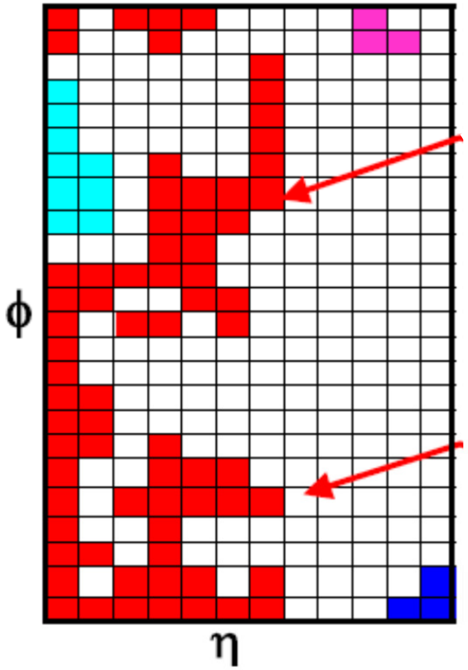


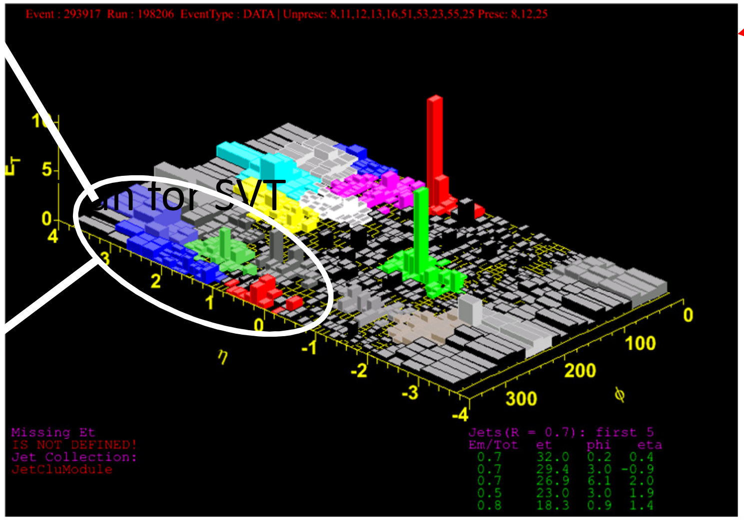


WITH STRONG TRIGGERING POWER

A dedicated new Higgs trigger & N.P. searches (2008)

High luminosity gives large calorimeter occupancy (pile up) => fake clusters/cluster merging (ex: red towers seen as one single cluster)



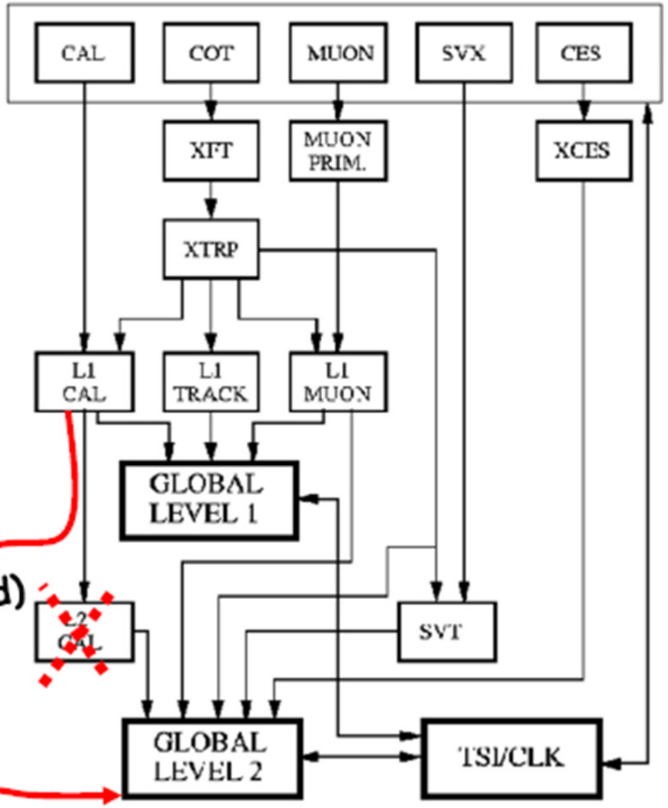


```
Event : 293917  Run : 198206  EventType : DATA | Unpresc: 8,11,12,13,16,51,53,23,55,25 Presc: 8,12,25
```

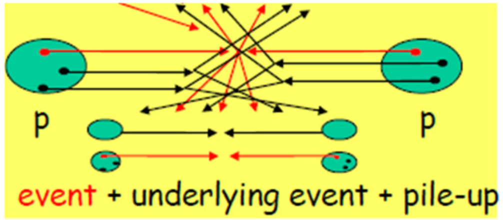
```
Missing Et
IS NOT DEFINED!
Jet Collection:
JetCluModule
```

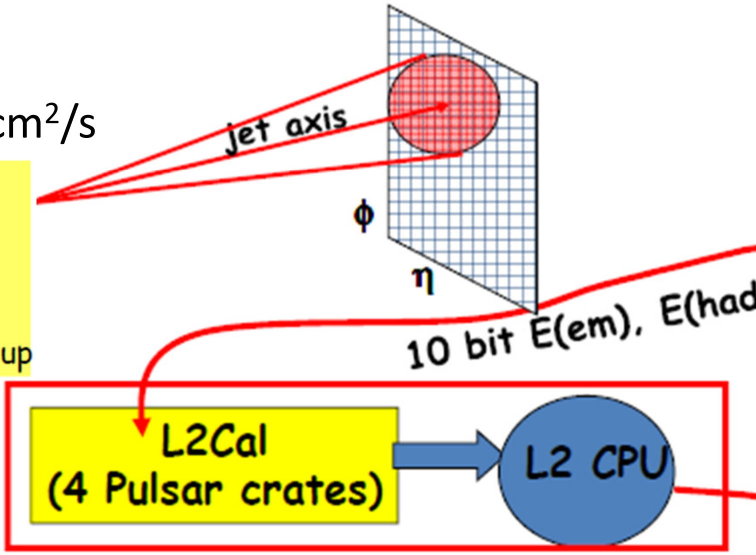
```
Jets(R = 0.7): first 5
Em/Tot  et    phi  eta
 0.7    32.0  0.2  0.4
 0.7    29.4  3.0 -0.9
 0.7    26.9  6.1  2.0
 0.5    23.0  3.0  1.9
 0.8    18.3  0.9  1.4
```

CDF Uses same processing strategy than for SVT: A.M. and pulsars



5-6 pile ups at 4x10^{32}/cm^2/s

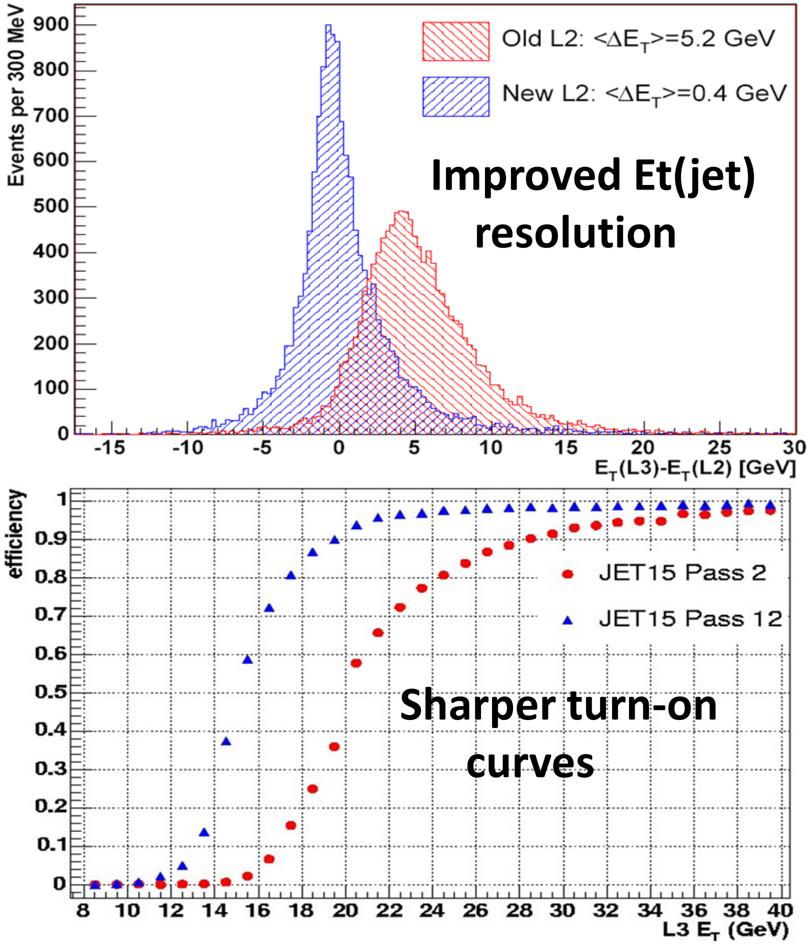




New trigger strategies for the Higgs (by 2008)

The calorimeter trigger upgrade together with XFT-3D, SVT upgrades significantly improves CDF reach for the Higgs (and lots of Physics topics)

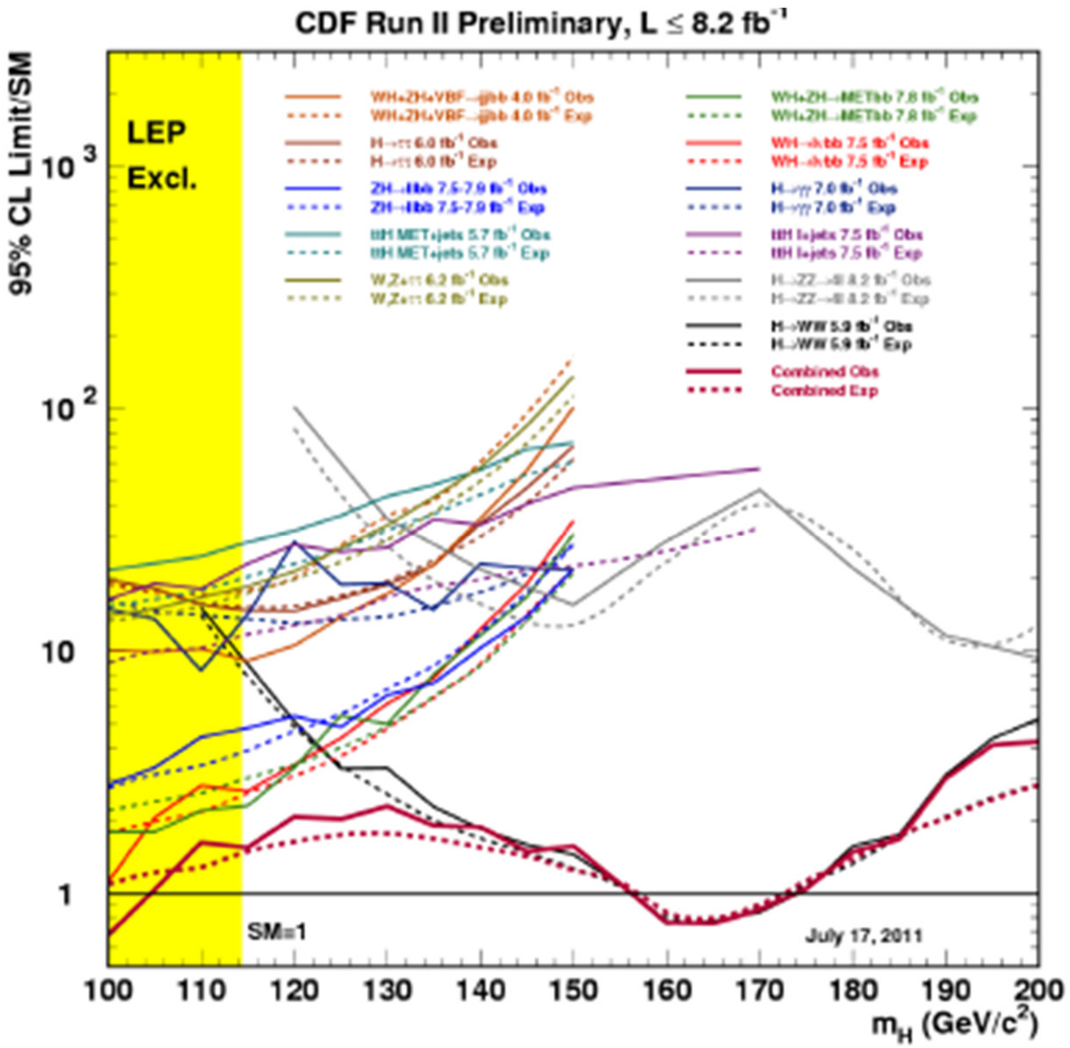
Ex: New Jet clustering provides



Mode	Acceptance increase
WH → eνbb	+97 %
WH → μνbb	+110 %
ZH → e+e-bb	+27 %
ZH → μ+μ-bb	+60 %
ZH → ννbb	+30 %
H → lνlν	+24 %

Goal: to leave NO HIGGS event behind.

Best sensitivity obtained by combining MANY INDEPENDENT search channels

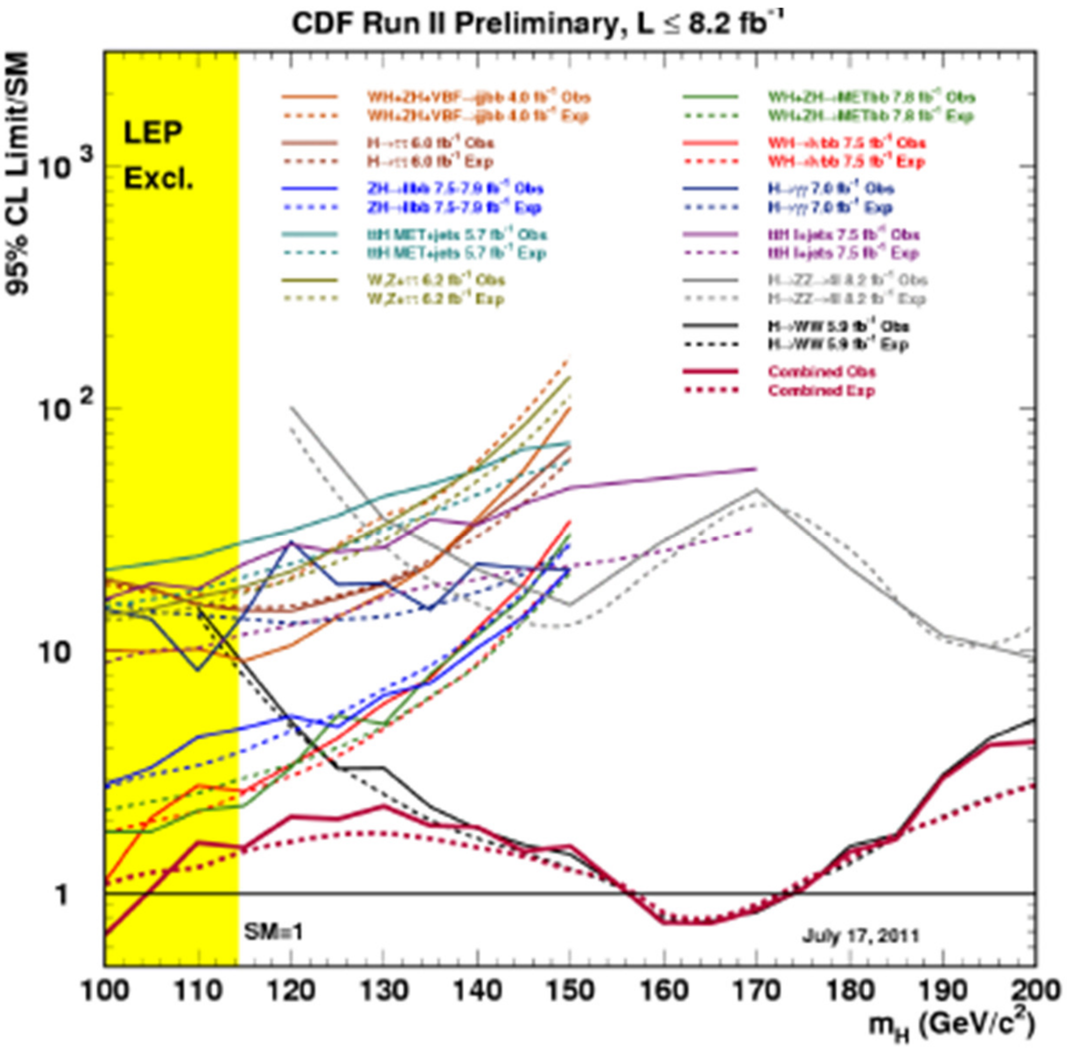


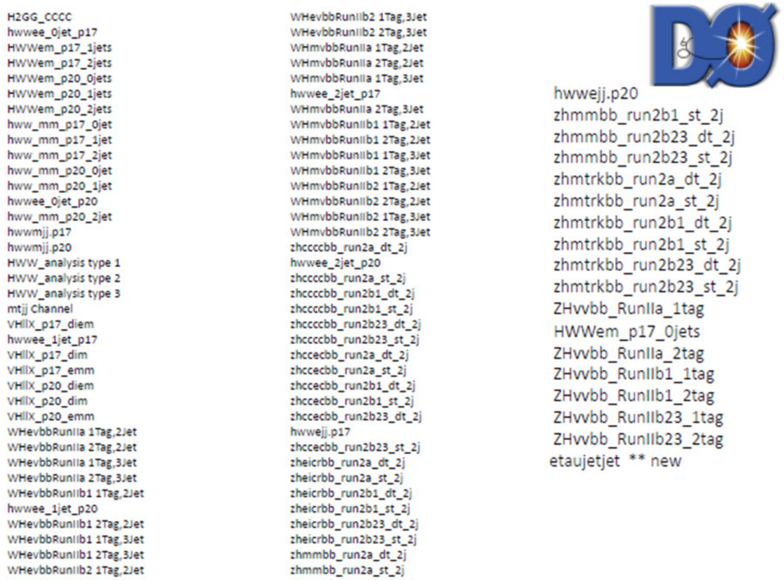
WH→lνbb
ZH→ννbb
ZH→llbb
WH/ZH→jjbb
ttH→WbWbbb
H→γγ
H→ττ
WH→lνττ / ZH→llττ
H→WW→lνlν
H→WW→lνjj
WH→WWW / ZH→ZWW
H→ZZ

Not mentioned here ALL the BSM Higgs that are looked for as well!

Goal: to leave NO HIGGS event behind.

Best sensitivity obtained by combining MANY INDEPENDENT search channels



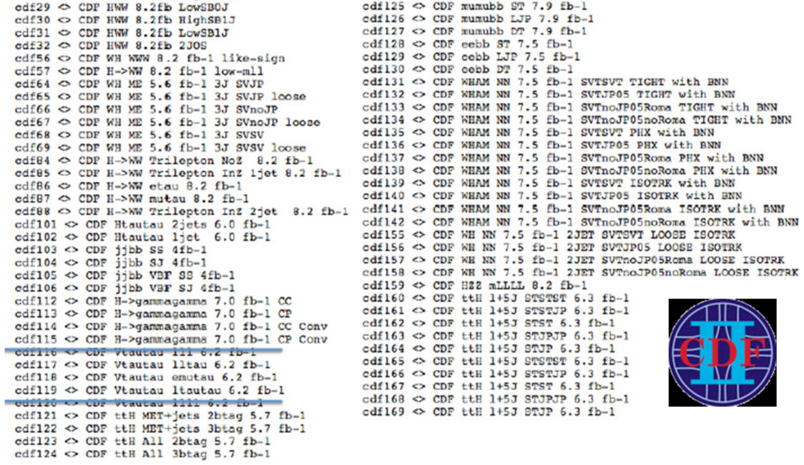


```
H2GG_CCCC
hwwee_0jet_p17
HWWem_p17_1jets
HWWem_p17_2jets
HWWem_p20_0jets
HWWem_p20_1jets
HWWem_p20_2jets
hww_mm_p17_0jet
hww_mm_p17_1jet
hww_mm_p17_2jet
hww_mm_p20_0jet
hww_mm_p20_1jet
hwwee_0jet_p20
hww_mm_p20_2jet
hwwmjj.p17
hwwmjj.p20
HWW_analysis type 1
HWW_analysis type 2
HWW_analysis type 3
mtjj Channel
VHllX_p17_diem
hwwee_1jet_p17
VHllX_p17_dim
VHllX_p17_emm
VHllX_p20_diem
VHllX_p20_dim
VHllX_p20_emm
WHevbbRunIIa 1Tag,2Jet
WHevbbRunIIa 2Tag,2Jet
WHevbbRunIIa 1Tag,3Jet
WHevbbRunIIa 2Tag,3Jet
WHevbbRunIIb1 1Tag,2Jet
hwwee_1jet_p20
WHevbbRunIIb1 2Tag,2Jet
WHevbbRunIIb1 1Tag,3Jet
WHevbbRunIIb1 2Tag,3Jet
WHevbbRunIIb2 1Tag,2Jet
WHevbbRunIIb2 2Tag,2Jet
```

```
WHevbbRunIIb2 1Tag,3Jet
WHevbbRunIIb2 2Tag,3Jet
WHmvbbRunIIa 1Tag,2Jet
WHmvbbRunIIa 2Tag,2Jet
WHmvbbRunIIa 1Tag,3Jet
hwwee_2jet_p17
WHmvbbRunIIa 2Tag,3Jet
WHmvbbRunIIb1 1Tag,2Jet
WHmvbbRunIIb1 2Tag,2Jet
WHmvbbRunIIb1 1Tag,3Jet
WHmvbbRunIIb1 2Tag,3Jet
WHmvbbRunIIb2 1Tag,2Jet
WHmvbbRunIIb2 2Tag,2Jet
WHmvbbRunIIb2 1Tag,3Jet
WHmvbbRunIIb2 2Tag,3Jet
zhccccbb_run2a_dt_2j
hwwee_2jet_p20
zhccccbb_run2a_st_2j
zhccccbb_run2b1_dt_2j
zhccccbb_run2b1_st_2j
zhccccbb_run2b23_dt_2j
zhccccbb_run2b23_st_2j
zhccecbb_run2a_dt_2j
zhccecbb_run2a_st_2j
zhccecbb_run2b1_dt_2j
zhccecbb_run2b1_st_2j
zhccecbb_run2b23_dt_2j
hwwejj.p17
zhccecbb_run2b23_st_2j
zheicrbb_run2a_dt_2j
zheicrbb_run2a_st_2j
zheicrbb_run2b1_dt_2j
zheicrbb_run2b1_st_2j
zheicrbb_run2b23_dt_2j
zheicrbb_run2b23_st_2j
zhmmbb_run2a_dt_2j
zhmmbb_run2a_st_2j
zhmmbb_run2b1_dt_2j
```

```
hwwejj.p20
zhmmbb_run2b1_st_2j
zhmmbb_run2b23_dt_2j
zhmmbb_run2b23_st_2j
zhmtrkbb_run2a_dt_2j
zhmtrkbb_run2a_st_2j
zhmtrkbb_run2b1_dt_2j
zhmtrkbb_run2b1_st_2j
zhmtrkbb_run2b23_dt_2j
zhmtrkbb_run2b23_st_2j
ZHvvbb_RunIIa_1tag
HWWem_p17_0jets
ZHvvbb_RunIIa_2tag
ZHvvbb_RunIIb1_1tag
ZHvvbb_RunIIb1_2tag
ZHvvbb_RunIIb23_1tag
ZHvvbb_RunIIb23_2tag
etaujetjet ** new
```

List of CDF & D0 channels to be combined as of July 14 2011



```
cdf15 <> CDF VH->MET bb 1S 7.8 fb-1
cdf16 <> CDF VH->MET bb SS 7.8 fb-1
cdf17 <> CDF VH->MET bb SJ 7.8 fb-1
cdf28 <> CDF HWW 8.2fb HighSB0J
cdf29 <> CDF HWW 8.2fb LowSB0J
cdf30 <> CDF HWW 8.2fb HighSB1J
cdf31 <> CDF HWW 8.2fb LowSB1J
cdf32 <> CDF HWW 8.2fb 2JOS
cdf56 <> CDF WH WWW 8.2 fb-1 like-sign
cdf57 <> CDF H->WW 8.2 fb-1 low-mll
cdf64 <> CDF WH ME 5.6 fb-1 3J SVJP
cdf65 <> CDF WH ME 5.6 fb-1 3J SVJP loose
cdf66 <> CDF WH ME 5.6 fb-1 3J SVnoJP
cdf67 <> CDF WH ME 5.6 fb-1 3J SVnoJP loose
cdf68 <> CDF WH ME 5.6 fb-1 3J SVSV
cdf69 <> CDF WH ME 5.6 fb-1 3J SVSV loose
cdf84 <> CDF H->WW Trilepton NoZ  8.2 fb-1
cdf85 <> CDF H->WW Trilepton InZ 1jet 8.2 fb-1
cdf86 <> CDF H->WW etau 8.2 fb-1
cdf87 <> CDF H->WW mutau 8.2 fb-1
cdf88 <> CDF H->WW Trilepton InZ 2jet  8.2 fb-1
cdf101 <> CDF Htautau 2jets 6.0 fb-1
cdf102 <> CDF Htautau 1jet  6.0 fb-1
cdf103 <> CDF jjbb SS 4fb-1
cdf104 <> CDF jjbb SJ 4fb-1
cdf105 <> CDF jjbb VBF SS 4fb-1
cdf106 <> CDF jjbb VBF SJ 4fb-1
cdf112 <> CDF H->gammagamma 7.0 fb-1 CC
cdf113 <> CDF H->gammagamma 7.0 fb-1 CP
cdf114 <> CDF H->gammagamma 7.0 fb-1 CC Conv
cdf115 <> CDF H->gammagamma 7.0 fb-1 CP Conv
~~cdf116 <> CDF Vtautau 111 6.2 fb-1~~
cdf117 <> CDF Vtautau lltau 6.2 fb-1
cdf118 <> CDF Vtautau emutau 6.2 fb-1
cdf119 <> CDF Vtautau ltautau 6.2 fb-1
~~cdf120 <> CDF Vtautau 1111 6.2 fb-1~~
cdf121 <> CDF ttH MET+jets 2btag 5.7 fb-1
cdf122 <> CDF ttH MET+jets 3btag 5.7 fb-1
cdf123 <> CDF ttH All 2btag 5.7 fb-1
cdf124 <> CDF ttH All 3btag 5.7 fb-1
```

```
cdf125 <> CDF mumubb ST 7.9 fb-1
cdf126 <> CDF mumubb LJP 7.9 fb-1
cdf127 <> CDF mumubb DT 7.9 fb-1
cdf128 <> CDF eebb ST 7.5 fb-1
cdf129 <> CDF eebb LJP 7.5 fb-1
cdf130 <> CDF eebb DT 7.5 fb-1
cdf131 <> CDF WHAM NN 7.5 fb-1 SVTSVT TIGHT with BNN
cdf132 <> CDF WHAM NN 7.5 fb-1 SVTJP05 TIGHT with BNN
cdf133 <> CDF WHAM NN 7.5 fb-1 SVTnoJP05Roma TIGHT with BNN
cdf134 <> CDF WHAM NN 7.5 fb-1 SVTnoJP05noRoma TIGHT with BNN
cdf135 <> CDF WHAM NN 7.5 fb-1 SVTSVT PHX with BNN
cdf136 <> CDF WHAM NN 7.5 fb-1 SVTJP05 PHX with BNN
cdf137 <> CDF WHAM NN 7.5 fb-1 SVTnoJP05Roma PHX with BNN
cdf138 <> CDF WHAM NN 7.5 fb-1 SVTnoJP05noRoma PHX with BNN
cdf139 <> CDF WHAM NN 7.5 fb-1 SVTSVT ISOTRK with BNN
cdf140 <> CDF WHAM NN 7.5 fb-1 SVTJP05 ISOTRK with BNN
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cdf142 <> CDF WHAM NN 7.5 fb-1 SVTnoJP05noRoma ISOTRK with BNN
cdf155 <> CDF WH NN 7.5 fb-1 2JET SVTSVT LOOSE ISOTRK
cdf156 <> CDF WH NN 7.5 fb-1 2JET SVTJP05 LOOSE ISOTRK
cdf157 <> CDF WH NN 7.5 fb-1 2JET SVTnoJP05Roma LOOSE ISOTRK
cdf158 <> CDF WH NN 7.5 fb-1 2JET SVTnoJP05noRoma LOOSE ISOTRK
cdf159 <> CDF HZZ mLLLL 8.2 fb-1
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cdf161 <> CDF ttH l+5J STSTJP 6.3 fb-1
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cdf167 <> CDF ttH l+5J STST 6.3 fb-1
cdf168 <> CDF ttH l+5J STJPJP 6.3 fb-1
cdf169 <> CDF ttH l+5J STJP 6.3 fb-1
```

Do-not-leave-any-Higgs-event-behind flow diagram

Optimize event selection (including triggers), reconstruction and tagging/identification algorithms

Maximize sensitivity:

- ✓ Combine all possible decay channels
- ✓ Use all production modes

Maximize acceptance to Higgs signal:

- ✓ Be inclusive for selecting candidat sample
- ✓ Improve e,μ ID efficiency
- ✓ Improve and further develop the τ-lepton ID *(fake rate estimate)*
- ✓ Improve b-tagging
- ✓ Improve jet tagging
- ✓ Handle the increase of pile ups (Lum) on some more sensitive variables

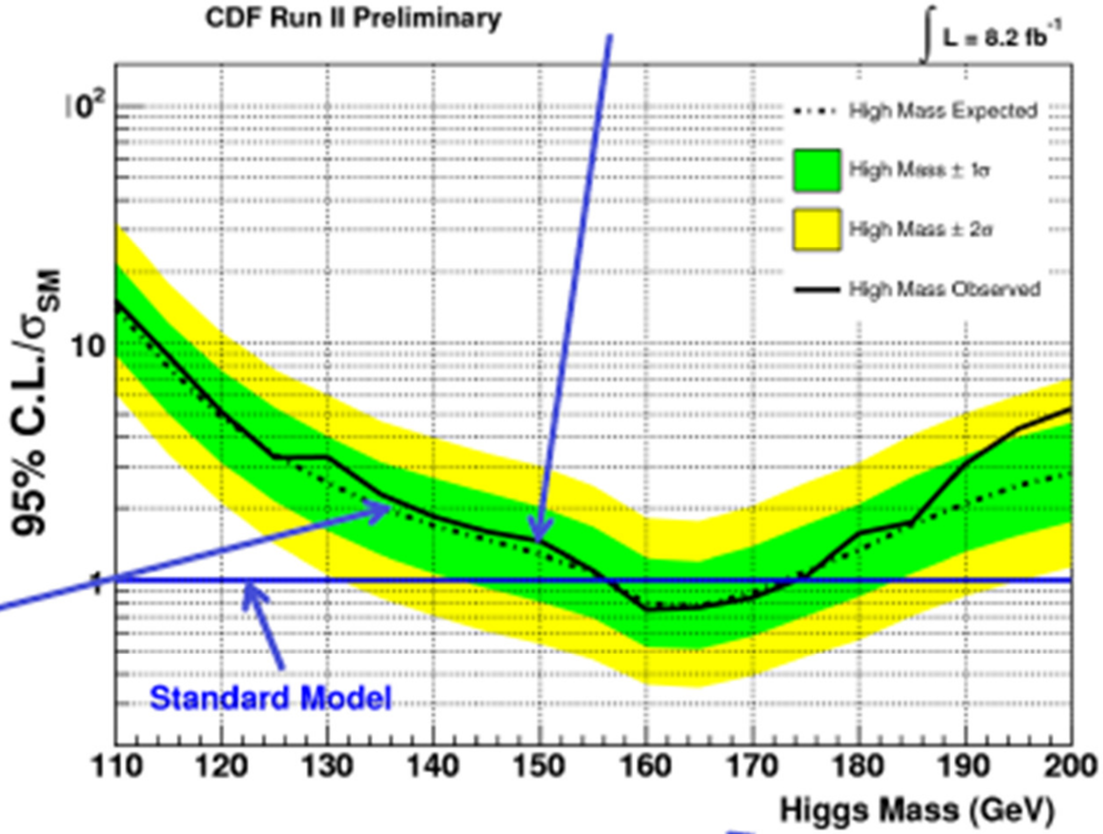
Model Backgrounds

- ✓ Cross-checks using control regions in data
- ✓ Measure xcross section for SM processes

Signal/background separation

Multivariate techniques

Determination of limits: Limit plot example



Observed limit (solid line) from data

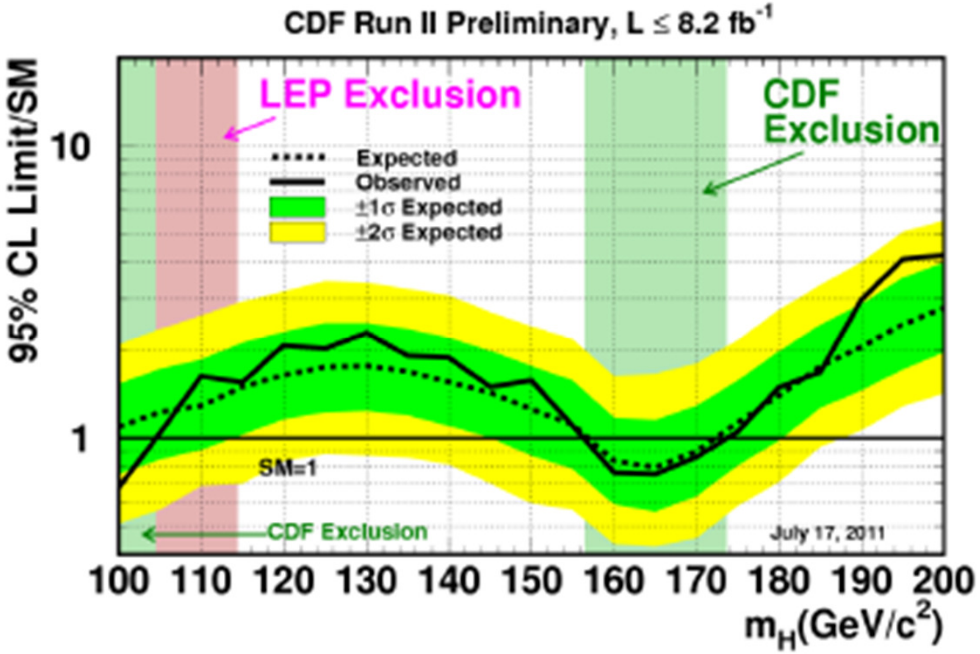
Upper cross section limit for Higgs production relative to SM prediction

Median expected limit (dot-dashed line) and predicted 1σ/2σ (green/yellow bands) excursions from background only pseudo-experiments

Analysis repeated using different signal templates for each m_H between 100 and 200 GeV in 5 GeV steps

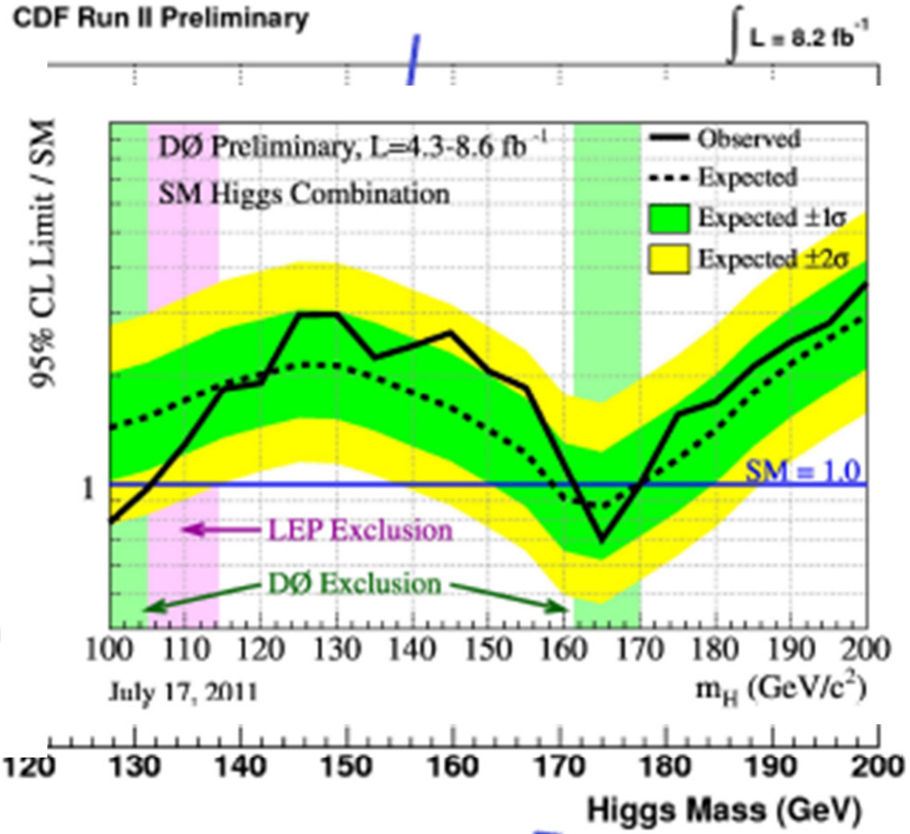
Courtesy Eric James

Upper cross section limit for

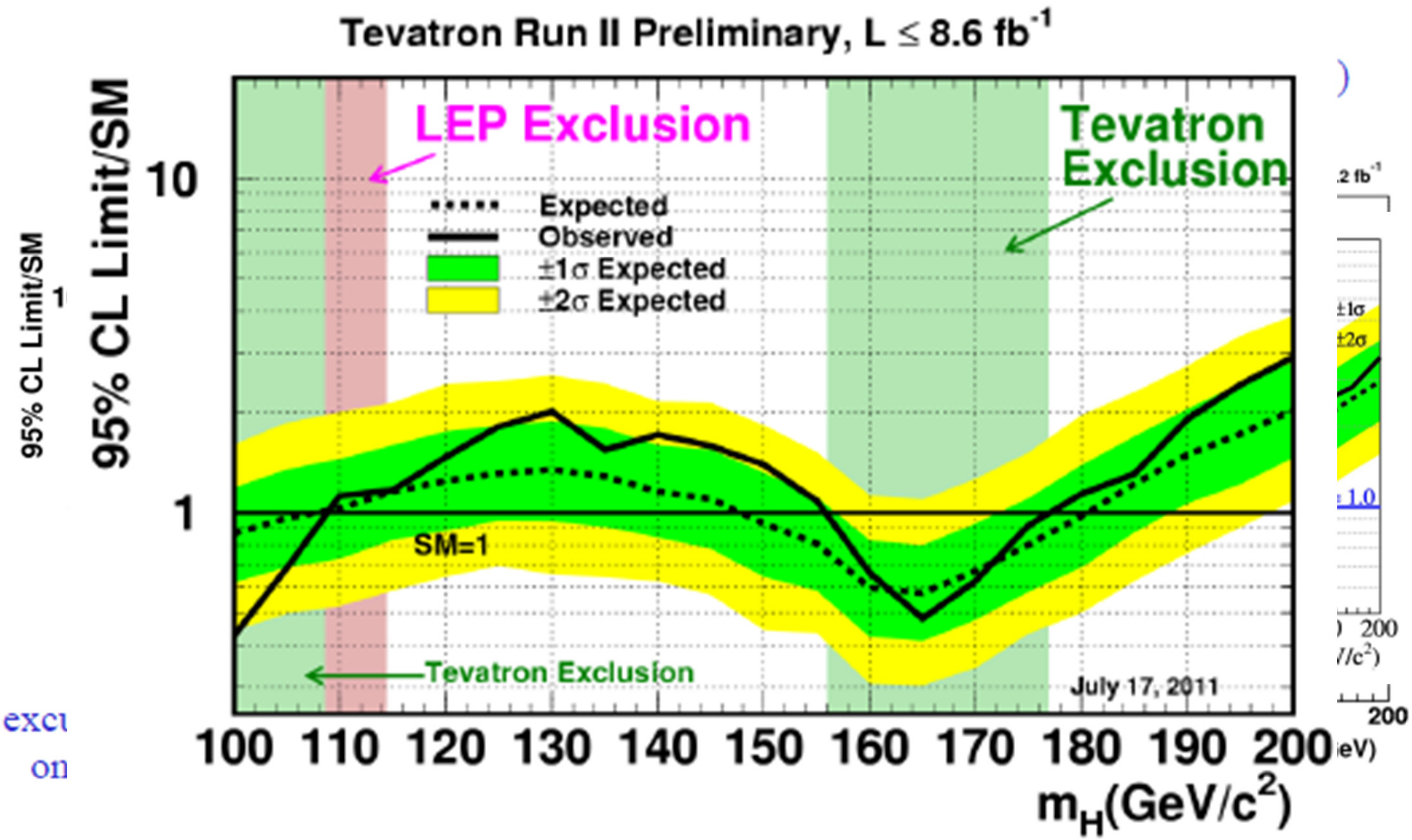


excursions from background only pseudo-experiments

Observed limit (solid line) from data



Analysis repeated using different signal templates for each m_H between 100 and 200 GeV in 5 GeV steps



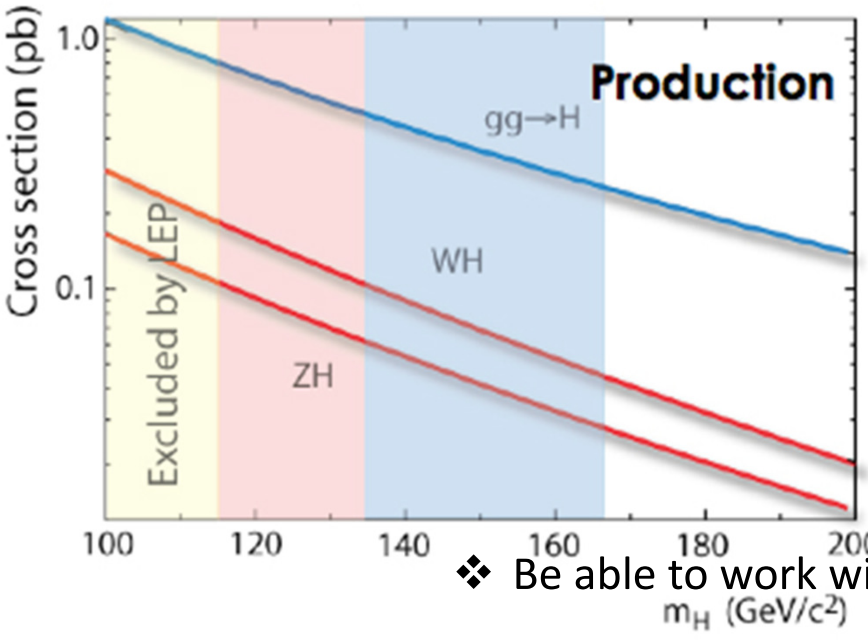
excı

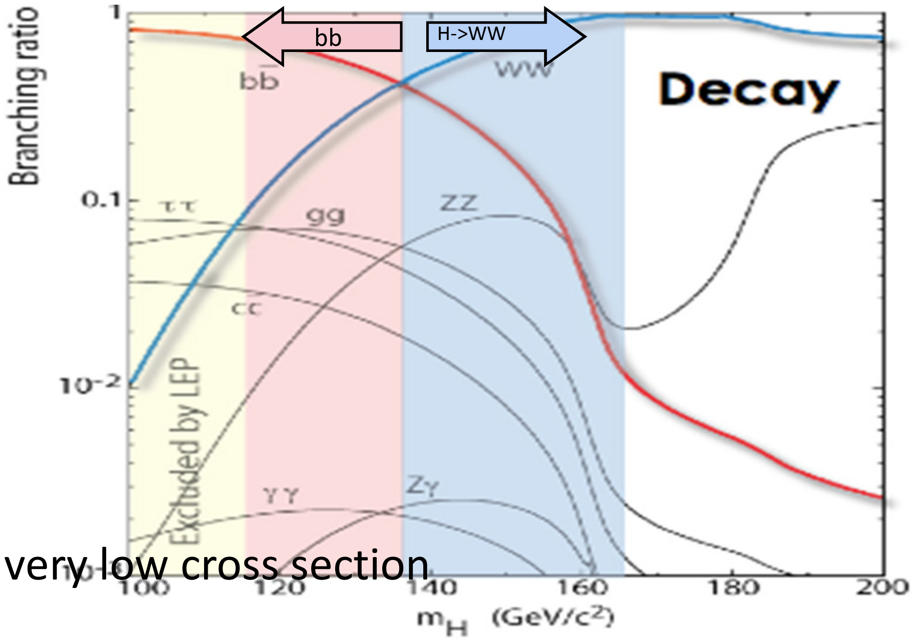
on

Observed Exclusion : 100-109 and 156-177 GeV/c^2

Expected Exclusion : 100-108 and 148-181 GeV/c^2

LOW MASS HIGGS: search for Higgs into bb





- Be able to work with very low cross section

Low Mass Final States

$WH \to \ell\nu b\bar{b}$ → 1 High P_T Lepton + $\not{E}_T$ + b jets

$ZH \to \ell\ell b\bar{b}$ → 2 High P_T Leptons + b jets

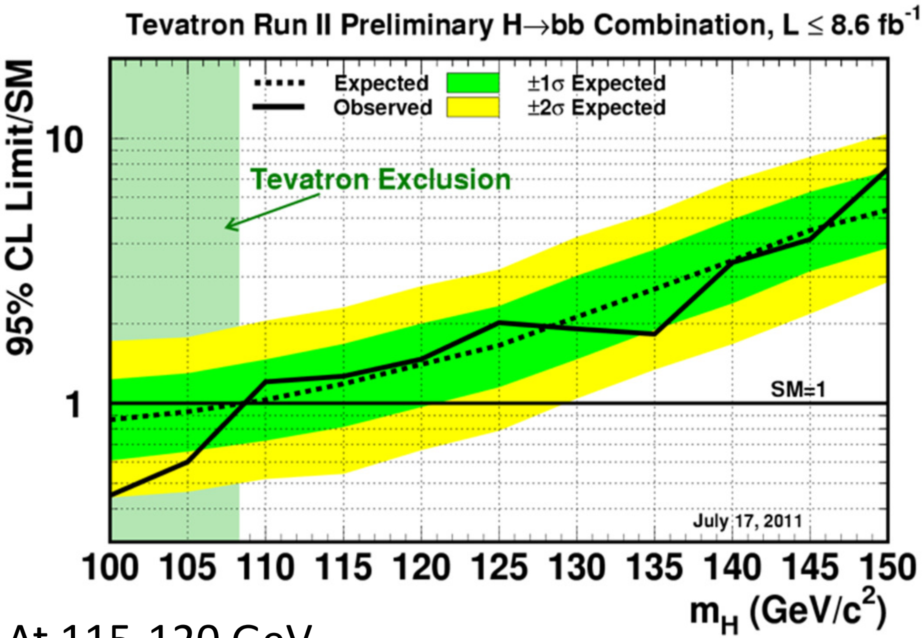
$ZH \to \nu\nu b\bar{b}$
$WH \to (\ell)\nu b\bar{b}$ → 0 High P_T Leptons + $\not{E}_T$ + b jets

Efficiency for tagging b-quark jets is critical as well as rate for mis-tagging light quark jets

Searching for H→bb

95% CL Limits at m_H = 115 GeV

Channel	Exp/obs Limit (σ/SM)
WH→lνbb (7.5 fb^{-1})	2.7/2.6
ZH→ννbb (7.8 fb^{-1})	2.9/2.3
ZH→l^+l^-bb (7.9 fb^{-1})	3.9/4.8
WH→lνbb (8.5 fb^{-1})	3.5/4.6
ZH→ννbb (8.4 fb^{-1})	4.0/3.2
ZH→l^+l^-bb (8.6 fb^{-1})	4.8/4.9
WH→lνbb (1.0 fb^{-1})	~25/20
ZH→l^+l^-bb (1.0 fb^{-1})	~25/20
VH/VBF→jjbb (4.0 fb^{-1})	17.8/9.1
ttH→l+jets (7.5 fb^{-1})	11.722.9
ttH→jets (5.7 fb^{-1})	20.2/28.1



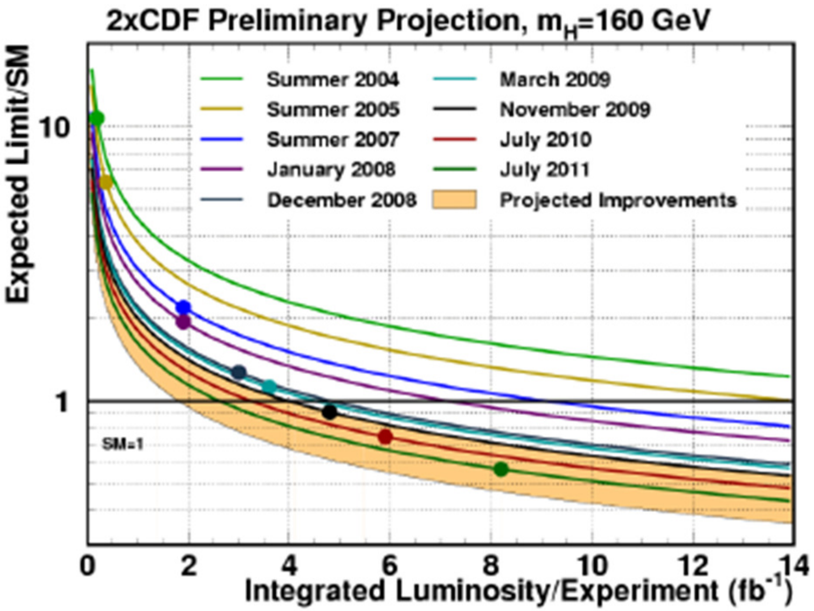
At 115-120 GeV

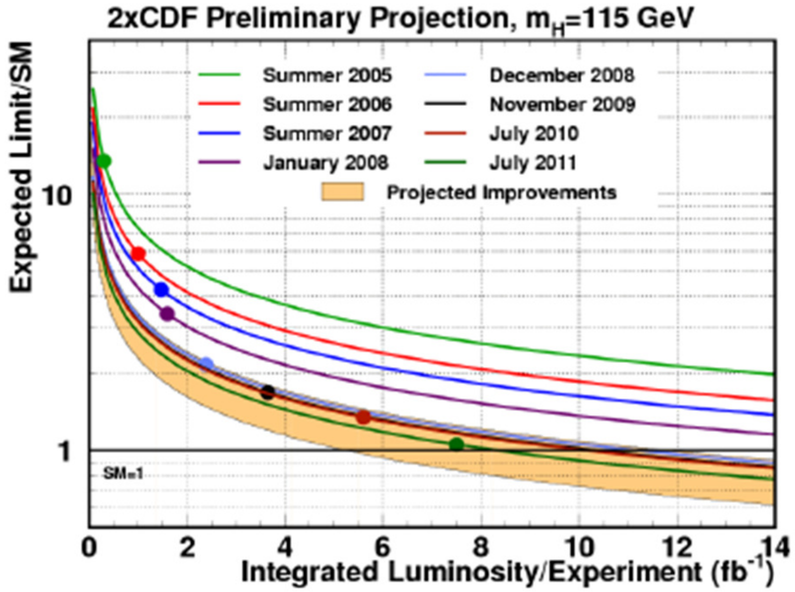
- Almost at 1xSM sensitivity
- No excess seen

At 130-140 GeV

- 2xSM-3xSM sensitivity
- No excess seen

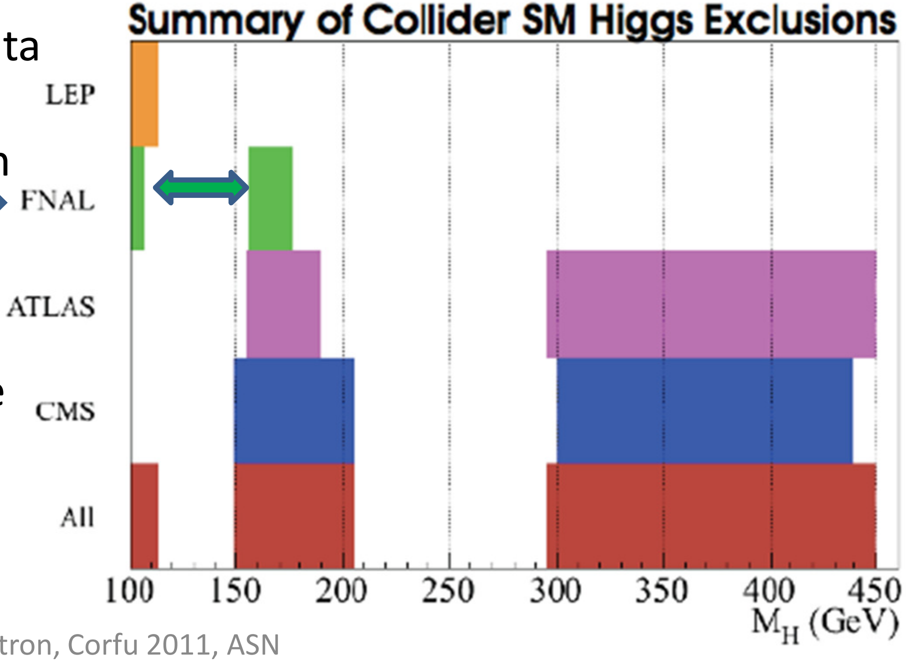
This channel is important as "Higgs reference channel => to ensure the Higgs identity of other Higgs like signal.

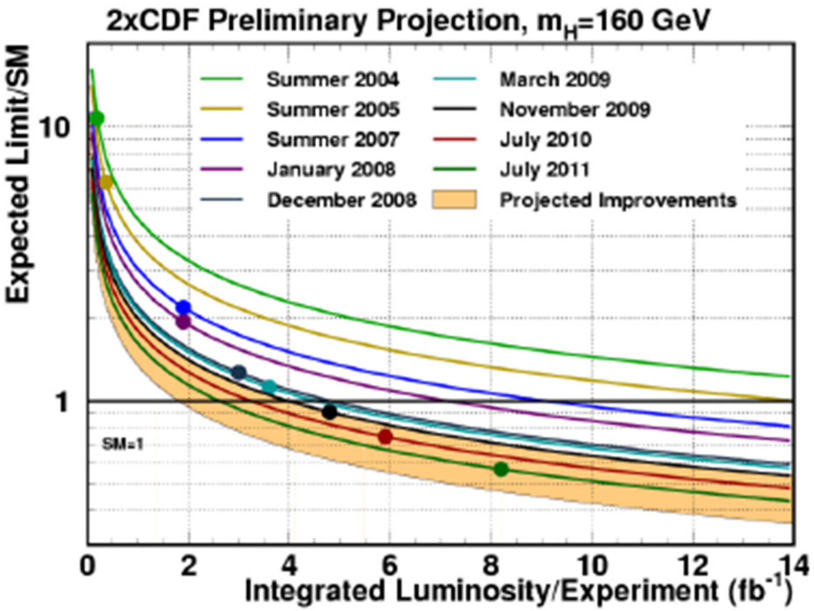


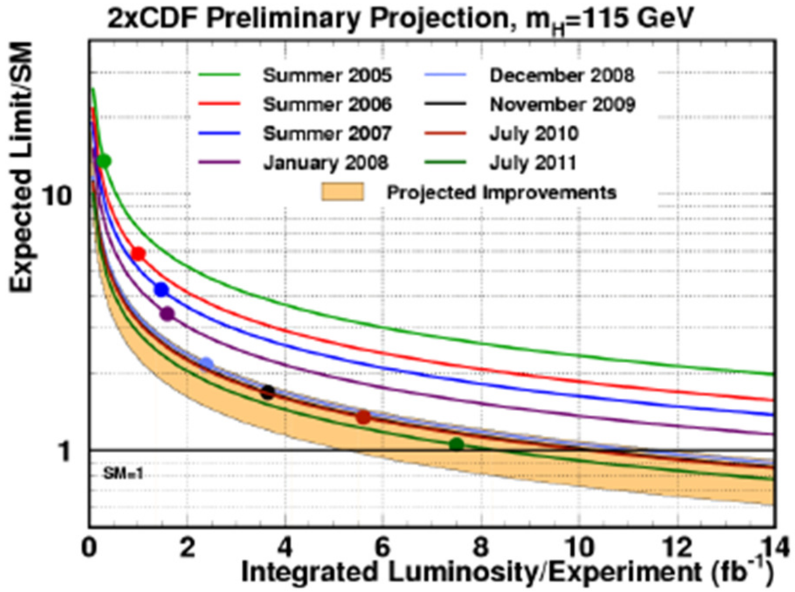


Tevatron Higgs final word

- CDF and D0 will collect over 10 fb-1 data on track to reach 95% CL exclusion
- Sensitivity over entire m(H) range from 100-185 GeV/c2
- Best current sensitivity to bb Higgs decay mode
- Overall Tevatron Higgs searches will be completed by Spring 2012.







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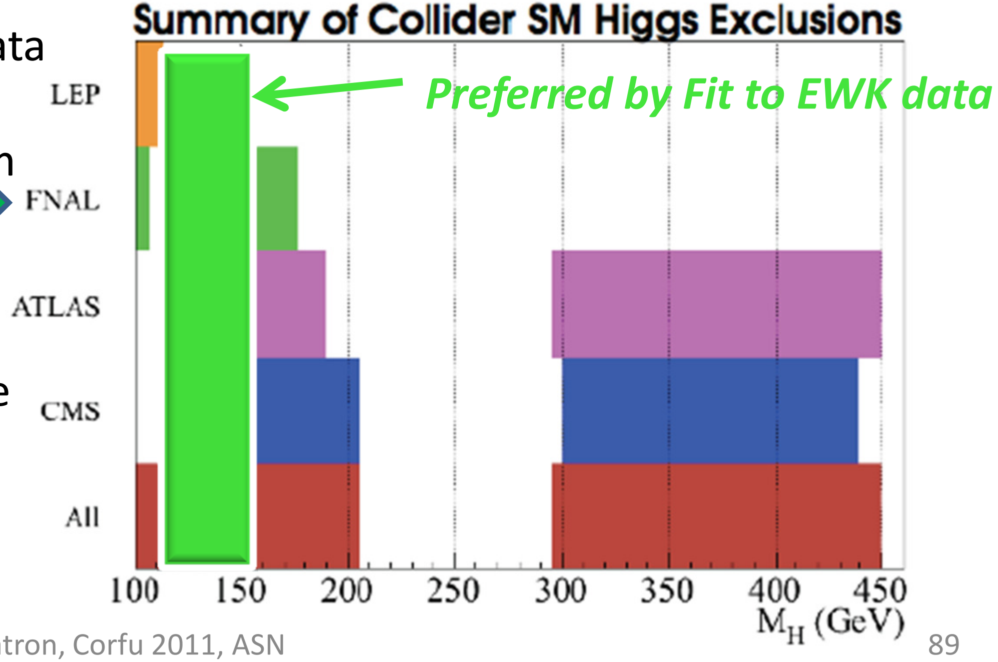


Preferred by Fit to EWK data

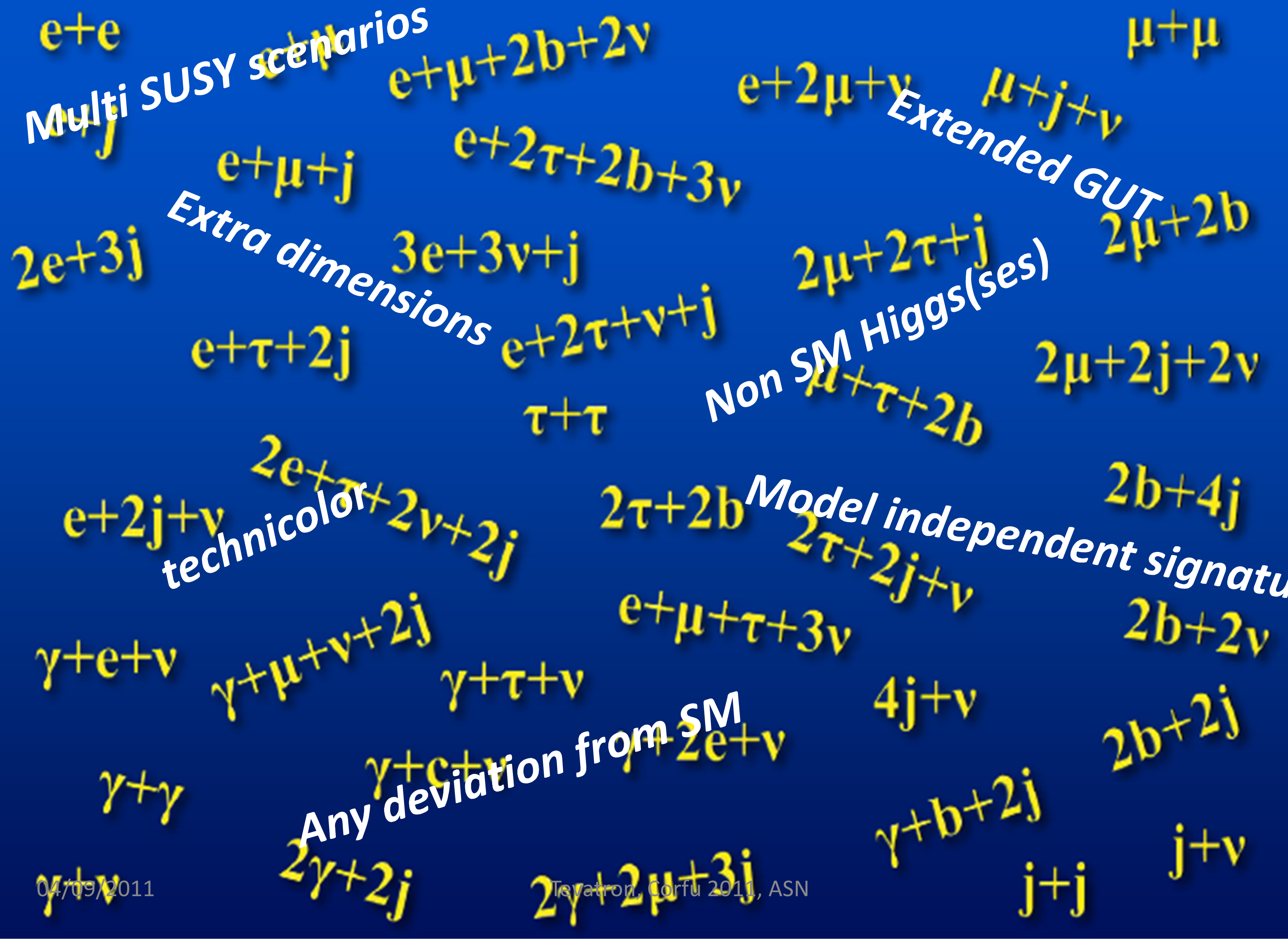
BSM::What are we looking for ?

Tevatron looked for

Courtesy Duperrin, EPS2011

$e+e$
$e+\mu$
$e+\mu+2b+2\nu$
$e+2\mu+\nu$
$\mu+j+\nu$
$\mu+\mu$
$e+j$
$e+\mu+j$
$e+2\tau+2b+3\nu$
$2e+3j$
$3e+3\nu+j$
$2\mu+2\tau+j$
$2\mu+2b$
$e+\tau+2j$
$e+2\tau+\nu+j$
$\mu+\tau+2b$
$2\mu+2j+2\nu$
$\tau+\tau$
$e+2j+\nu$
$2e+\tau+2\nu+2j$
$2\tau+2b$
$2\tau+2j+\nu$
$2b+4j$
$\gamma+e+\nu$
$\gamma+\mu+\nu+2j$
$\gamma+\tau+\nu$
$e+\mu+\tau+3\nu$
$2b+2\nu$
$4j+\nu$
$\gamma+2e+\nu$
$2b+2j$
$\gamma+\gamma$
$\gamma+c+\nu$
$\gamma+b+2j$
$j+\nu$
$\gamma+\nu$
$2\gamma+2j$
$2\gamma+2\mu+3j$
$j+j$

Tevatron exploration of BSM



Multi SUSY scenarios

Extended GUT

Extra dimensions

Non SM Higgs(ses)

technicolor

Model independent signatures

Any deviation from SM

Remaining puzzles or hints to BSM from Tevatron?

Charles et la chanson

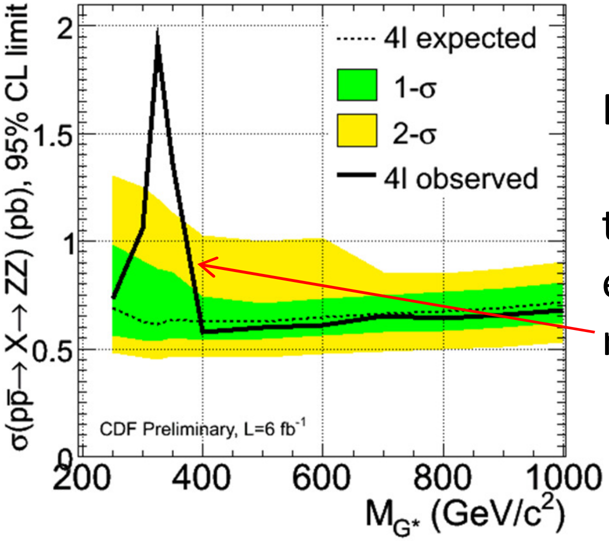
Que reste t'il de nos amours…?

???: will probably not be confirmed

Process	Experiment	Luminosity (fb^{-1})	significance	My personal opinion
ZZ→ 4 leptons	CDF	6.0	~ 3 σ	**Solved: no excess**
t' → qW	D0	5.3	2.5σ	**???**
W + jj excess	CDF	7.3	4.1σ	**???**
bbb excess	CDF	2.6	2.8σ	**???**
Dimuon asymmetry	D0	9.0	3.9σ	**?**
$B^{0}s \rightarrow \mu+\mu-$	CDF	7.0	3σ	**?? Soon**
ttbar forward backward asymmetry	CDF	5.1	3.4σ	**?**
Br(t→Wb)/Br(t→Wq)	D0	5.4	2.5σ	**???**

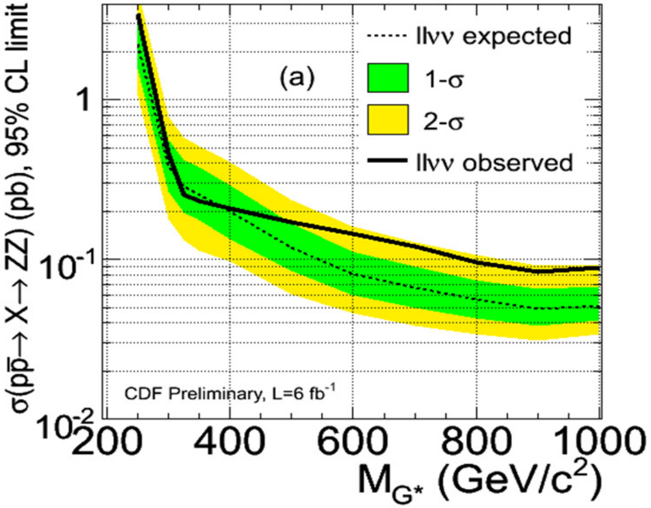
N.B. We indicate in this Table the Tevatron experiment that has found some deviation wrt SM. It does not mean that the other experiment didn't perform or is performing the analysis too.

SEARCH for HIGH MASS ZZ RESONANCES at CDF (6fb-1)

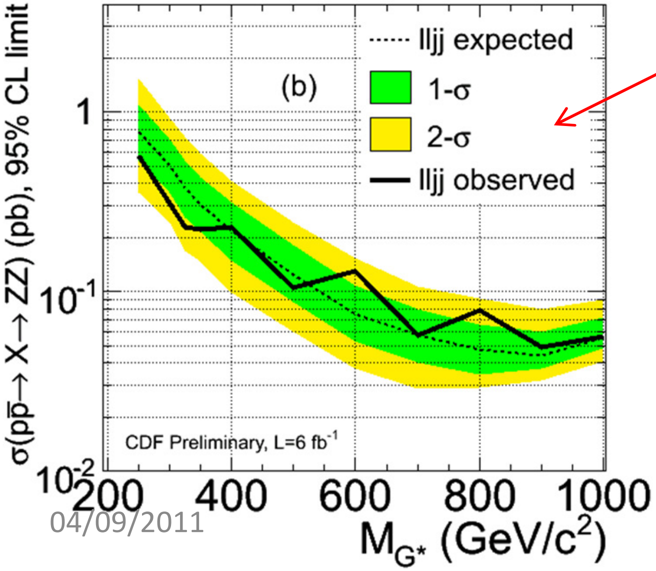


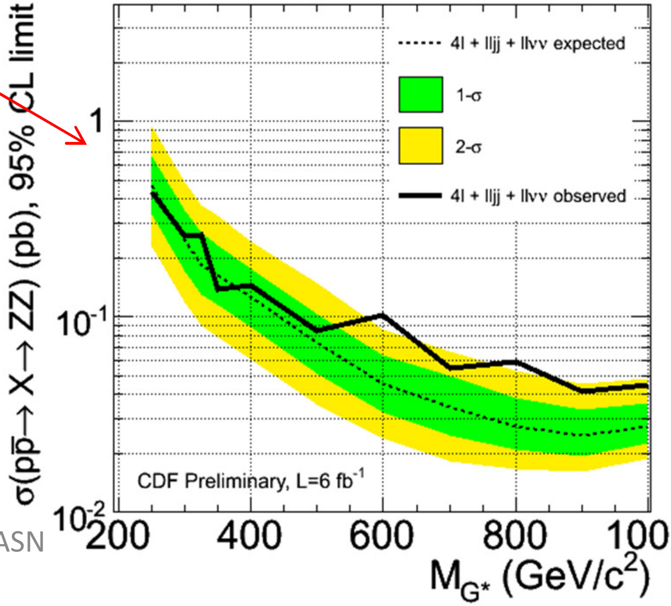
Expected and observed 95% CL limits on σ(pp → X → ZZ) from the Z → $l^+l^-l^+l^-$ channel; the 4 events with M_{ZZ}=327 GeV/c^2 result in a deviation from the expected limit

BUT:

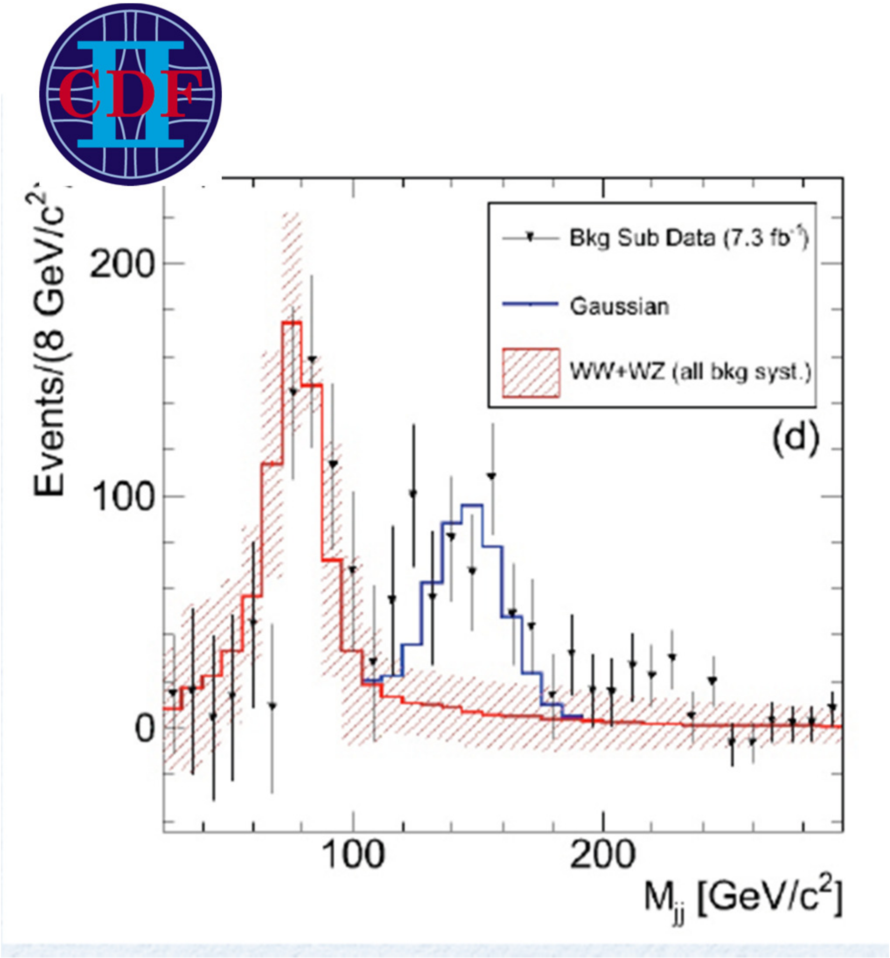


Analysis of pp → ZZ → ll+MET & pp → ZZ → lljj final states does not confirm a heavy resonance decaying into a pair of Z bosons. 95% CL upper limits are set on the production cross section x BR σ(pp → X → ZZ) at 0.26 pb and 0.28 pb for two signal models.

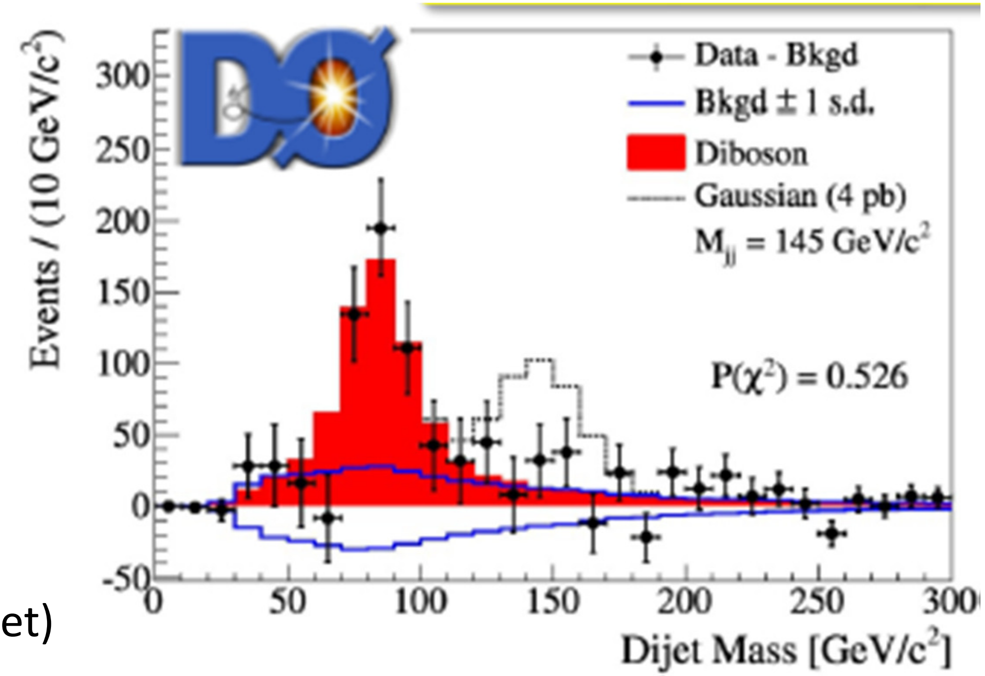




“CDF Wjj excess”: one of the action-packed serials of this summer

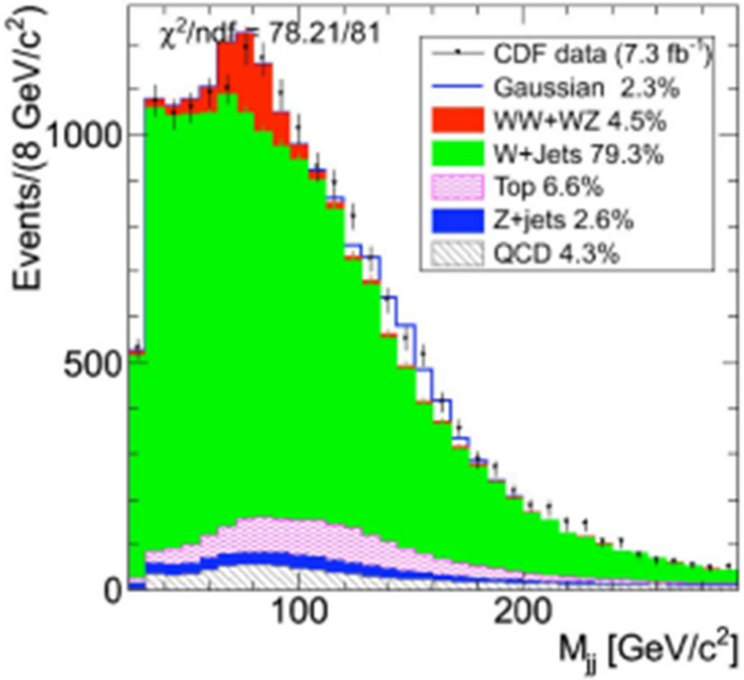


CDF SEES AN EXCESS INCREASING with increasing statistics
D0 “mirrors” the analysis and does not see any such signal with 4.3fb-1



ATLAS and CMS have performed this search each with 1fb-1 of data: not such a signal (yet)

SM Templates + Gaussian



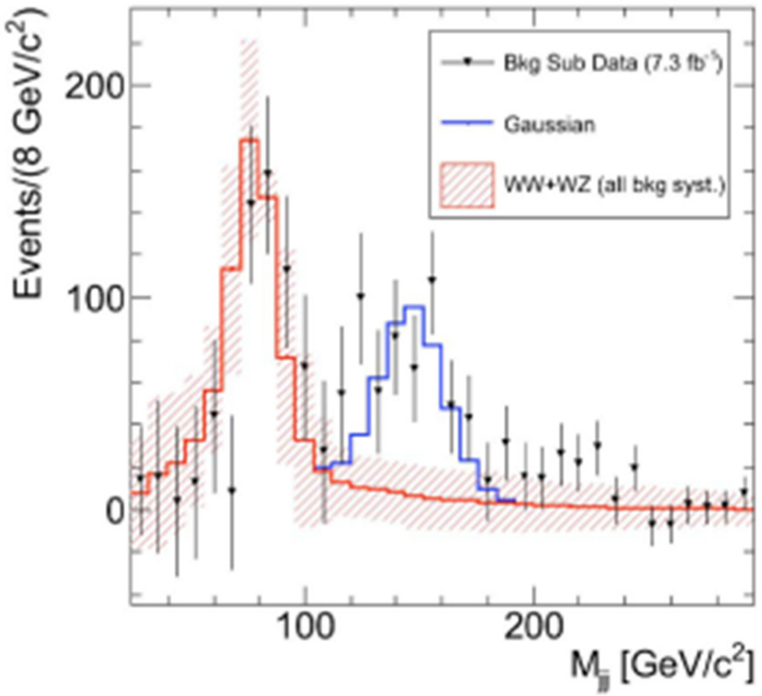
- Statistical significance (no systematics) 4.8σ, including trial factor

- Shape systematics on:
  - QCD, Jet Energy Scale
  - W+jets renorm. scale
  - The largest p-value is $1.9 * 10^{-5}$
  - significance of 4.1 s. d.
  - was 3.2 s. d. in 4.3 fb^{-1}

- Measured cross-section 3.0 ± 0.7 pb
  - cross-section model dependence
  - use W+Higgs $m_H(150)$ acceptance * efficiency

	muons	**electrons**
Excess events	158 +- 46	240 +- 55
Excess/exp. WW+WZ	42% +- 12%	47% +- 10%
Gaussian mean	147 +- 5 GeV (stat. only)	

SM Templates + Gaussian



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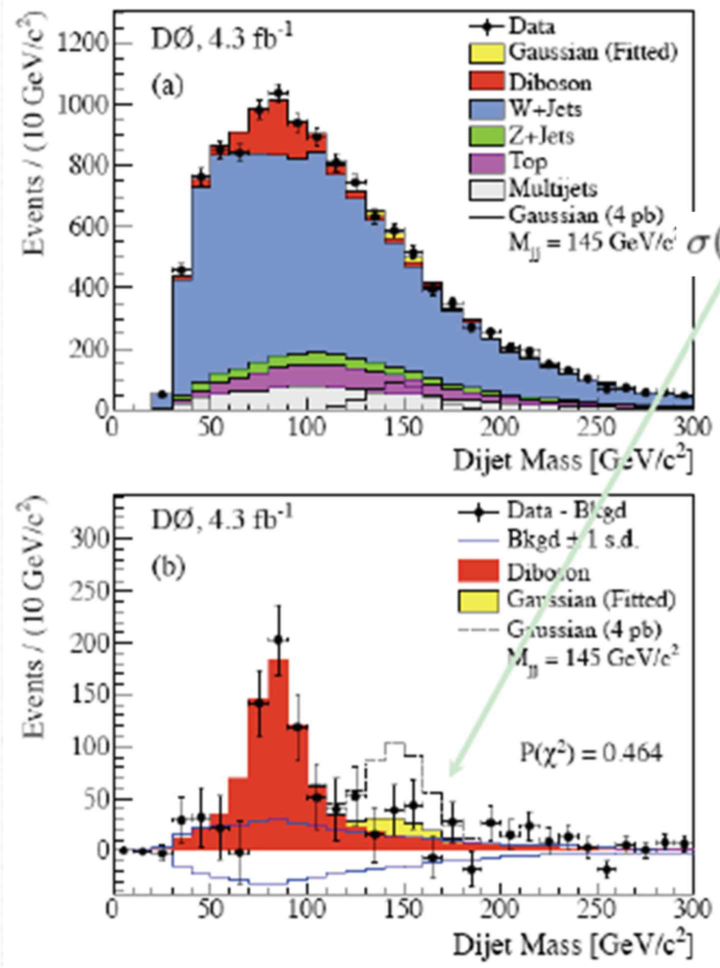
On the other side of the Ring: D0 => controversy



$$\sigma(p\bar{p} \rightarrow WX) = 0.82^{+0.83}_{-0.82}\ \text{pb}$$

✓ D0 “mirrors what was done in the CDF analysis” => *“No evidence for such an excess, ruling out a particle with 4.3 pb-1 at the 4.1 σ level*” (EPS 2011)

✓ CDF identifies some differences:
- D0 jets corrected for out-of-cone:
- effective jet threshold lower
- Double QCD contamination from low purity electrons
- Fit procedure morphs Mjj to correct for systematics
- Quantitative effect on Mjj templates not available

✓ D0 excludes a 4pb signal at 4.3σ level
Does not account for uncertainty on CDF number: O(4pb)

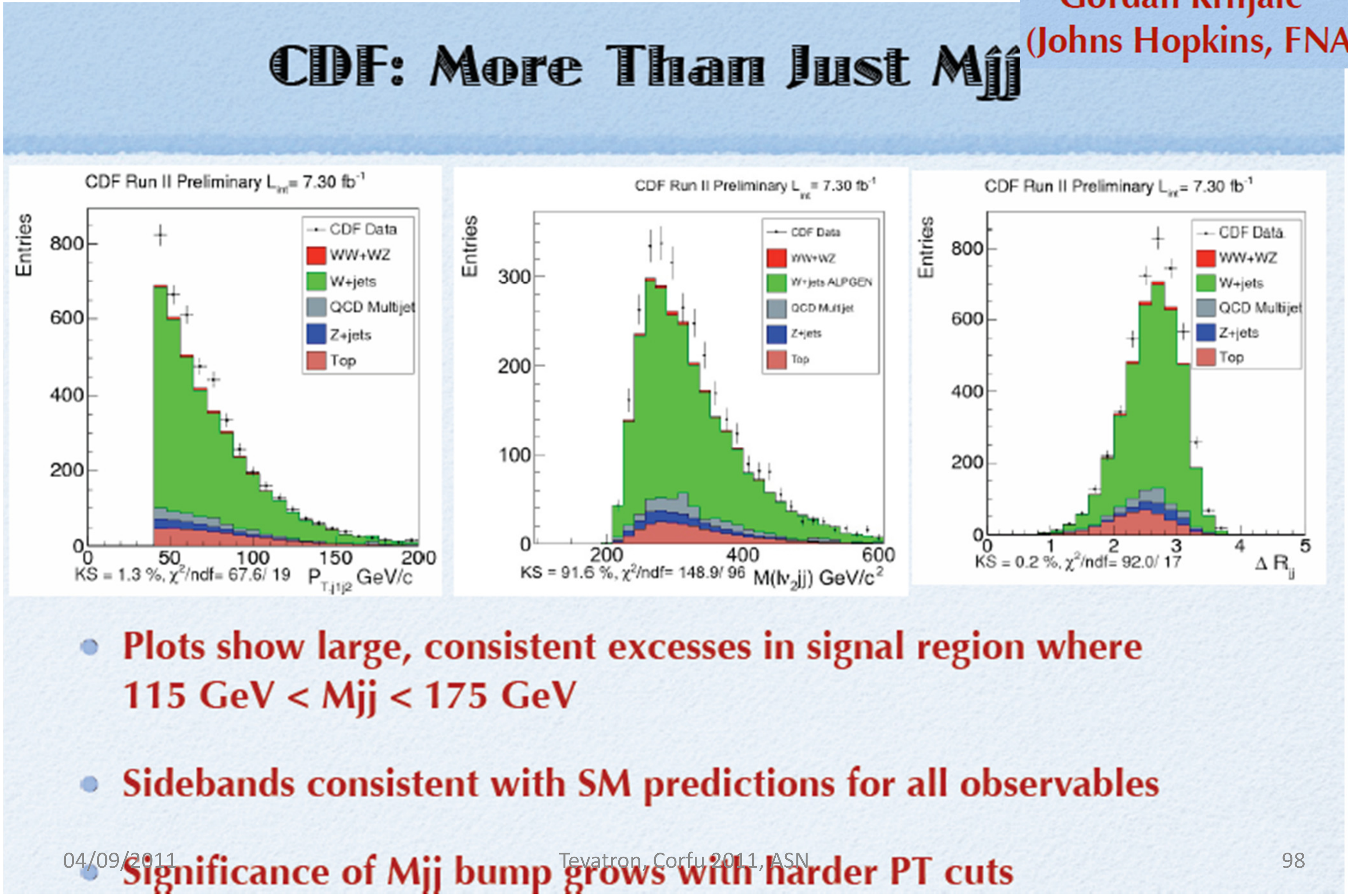
✓ Evaluated xsec using D0 procedure:
3.1 ± 0.8 pb (with 4.3fb-1 data)
3.0 ± 0.7 pb (with 7.3 fb-1 data)

✓ To be compared with 0.82 ± 0.83 pb

The two results are about 2σ apart. Need of clarification on both sides.

CDF Wjj excess: as viewed by a young theoretician

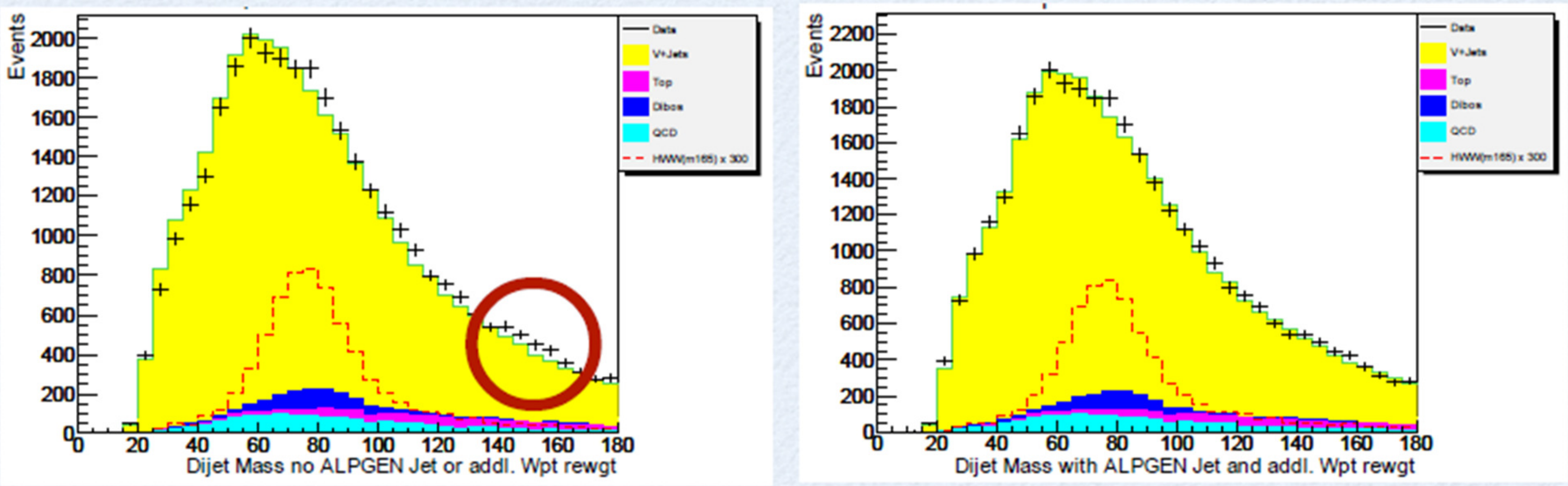
Gordan Krnjaic
(Johns Hopkins, FNAL)



CDF: More Than Just Mjj

- Plots show large, consistent excesses in signal region where 115 GeV < Mjj < 175 GeV
- Sidebands consistent with SM predictions for all observables
- Significance of Mjj bump grows with harder PT cuts

DO Claims Null Result, BUT …

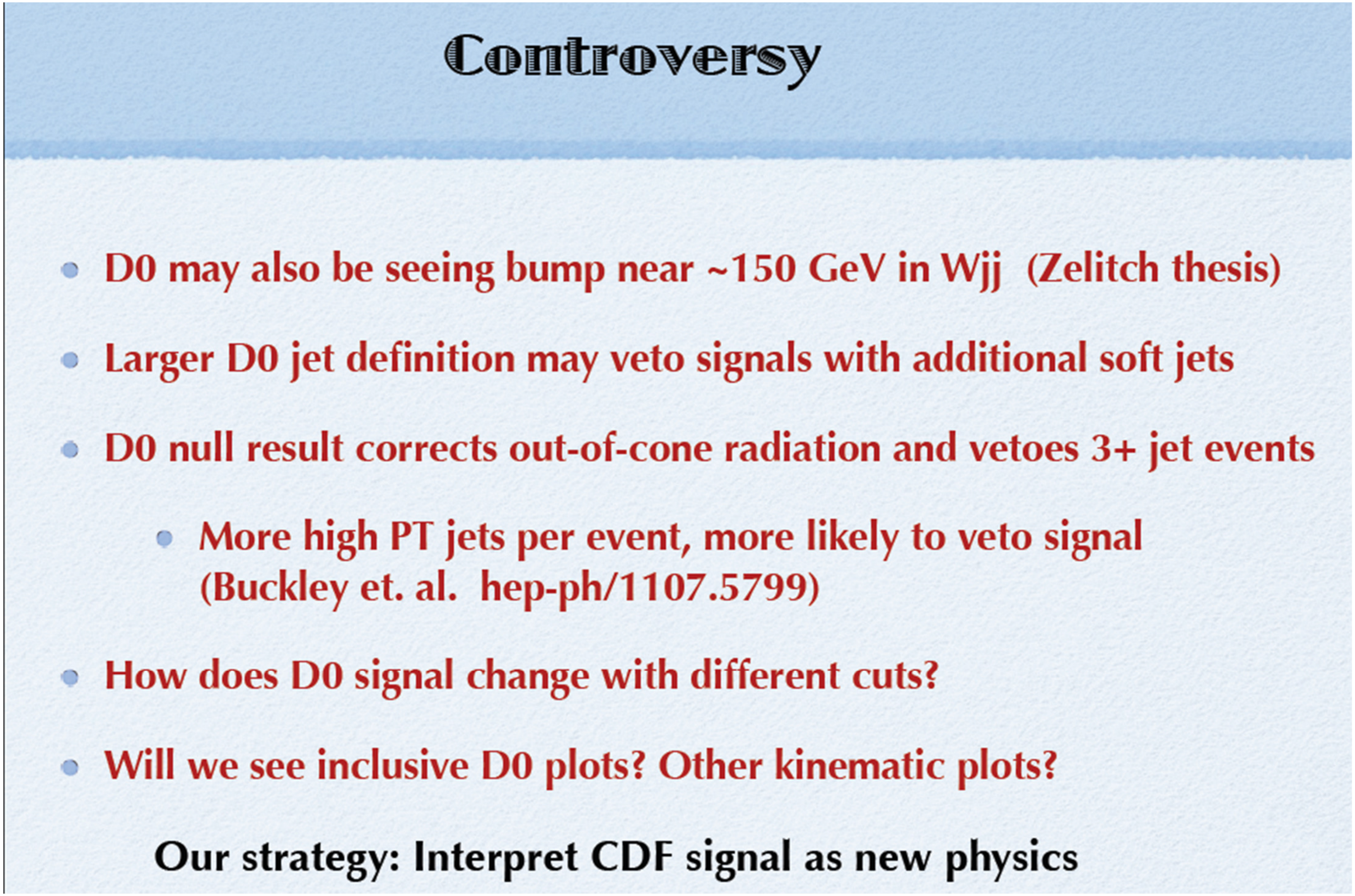


unreweighted

reweighted

D0 Higgs search has similar feature near Mjj ≈ 150 GeV
(S. Zelitch PhD thesis 2010)

~3 sigma above BG in *unreweigted* sample with 5.4/fb



Controversy

- D0 may also be seeing bump near ~150 GeV in Wjj (Zelitch thesis)
- Larger D0 jet definition may veto signals with additional soft jets
- D0 null result corrects out-of-cone radiation and vetoes 3+ jet events
    - More high PT jets per event, more likely to veto signal (Buckley et. al. hep-ph/1107.5799)
- How does D0 signal change with different cuts?
- Will we see inclusive D0 plots? Other kinematic plots?

Our strategy: Interpret CDF signal as new physics

Several other theoretical nice explanations also showing why this is not found (yet) at LHC => Committee at FNAL and wait and see for more luminosity at LHC….

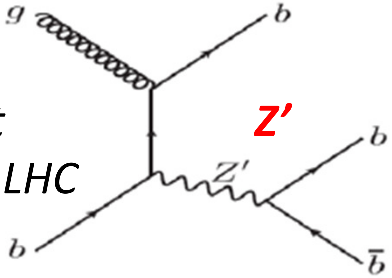
OCTO-TRIPLETS

$$\Theta^{a\alpha} : (8, 3, 0)$$

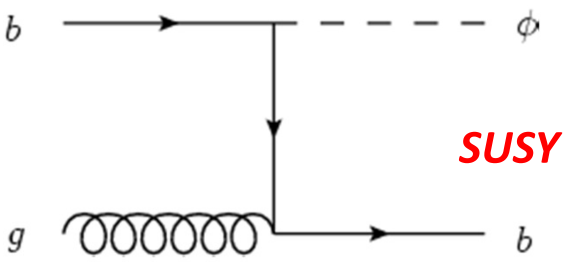
$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

Search for a bb resonance associated to b

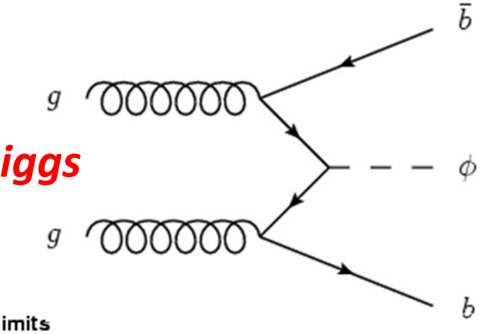
Challenging final state not accessible at LHC

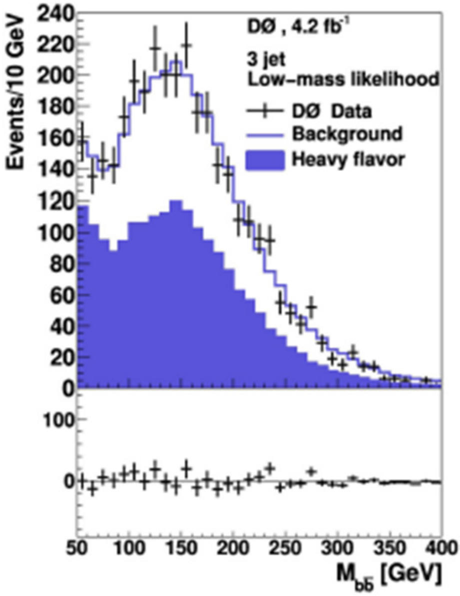


Z’



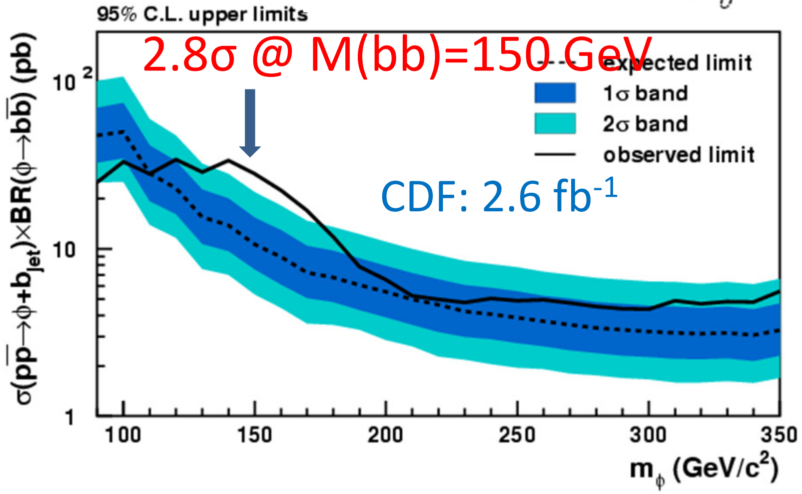
SUSY Higgs





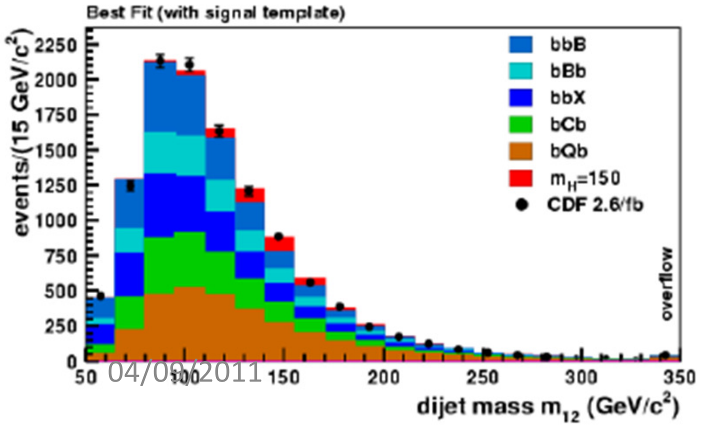
ANALYSIS:

- Cannot rely on MC to model Multijet background
- Data driven background predictions
- Fit of templates to data provides normalization



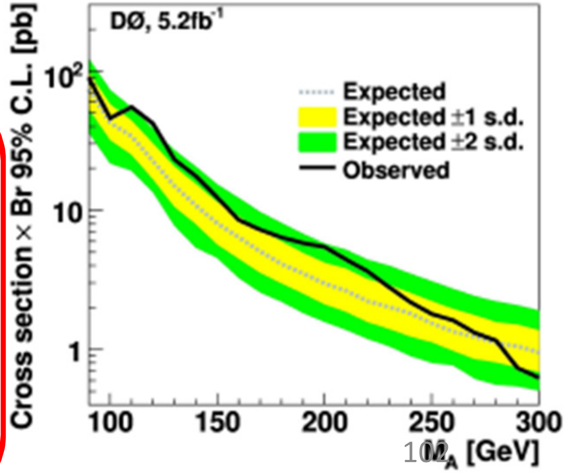
2.8σ @ M(bb)=150 GeV

CDF: 2.6 fb^{-1}



RESULTS:

- CDF & D0 => about 2σ excess at 120-150 GeV.
- Still compatible with background expectations
- Work in progress on the overall data sample



Conclusions & Legacy

❖**CDF & D0 have produced a tremendous amount of important results in all topics:**
QCD, B Physics (competing with B & charm factories) with some unique features (Bs), Top (scan of all Top properties and beyond), EWB (W properties:Mass, helicity…), dibosons, large scan of BSM models in a large parameter space.

❖**Pioneering searches with new ideas & improved tools (hardware & software)**

❖**Continuously upgrading/innovating (especially CDF: longuest-life expt.) and the MACHINE! The electron cooling has saved Run II at the Tevatron allowing dramatic increase in L&perf.**

❖**Some major breakthrough or discoveries**: in Bs Mixing & Bs-CPV, Bs in μμ, Single Top, unprecedented precision on Top and W mass.

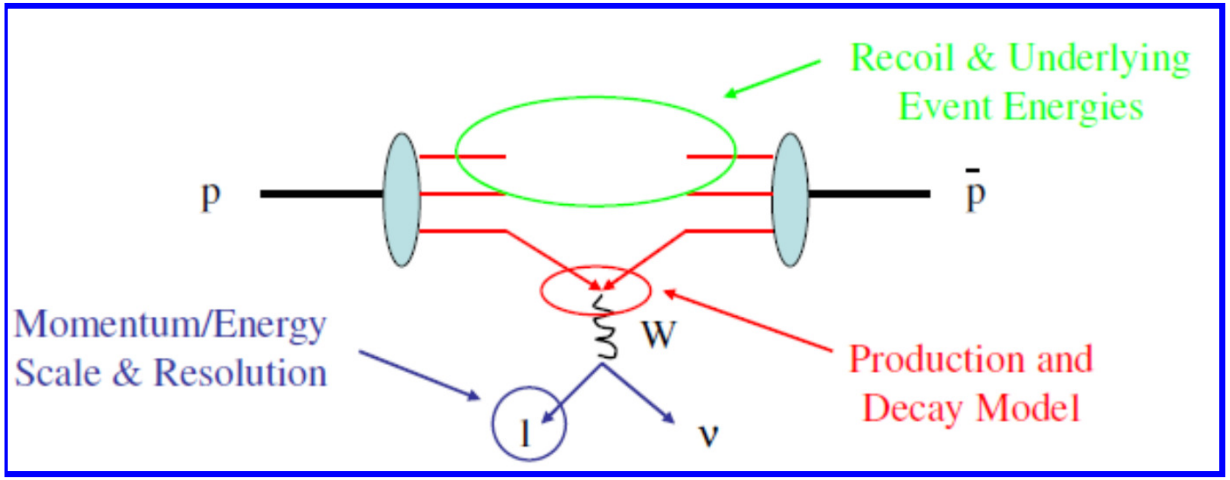
A number of analyses are still undergoing..

❖ **A new era in HEP has started:**
The LHC experiments and the LHC have entered in the game at very high speed after a long waiting time

VERY EXCITING TIME!
IMPORTANT TO SUCCEED THE OVERLAP:
Tevatron x LHC
And thus to conclude the analyses where the Tevatron is still valuable or even unique.

BACKUP slides

W detection at Tevatron

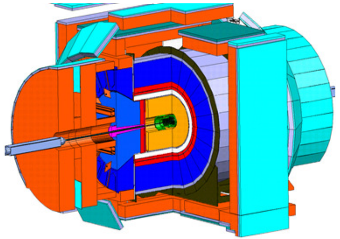


On tape ~ 7.5 fb^{-1} /expt
=> ~6 Mio W's per expt

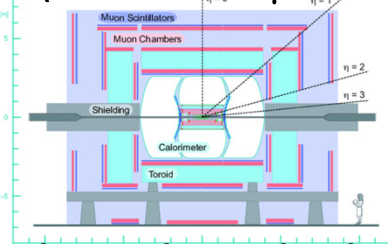
W events:

- single charged lepton
  - high p_T
  - isolated
- missing E_T from neutrino (W→μν or eν).
  - p_T^ν is inferred

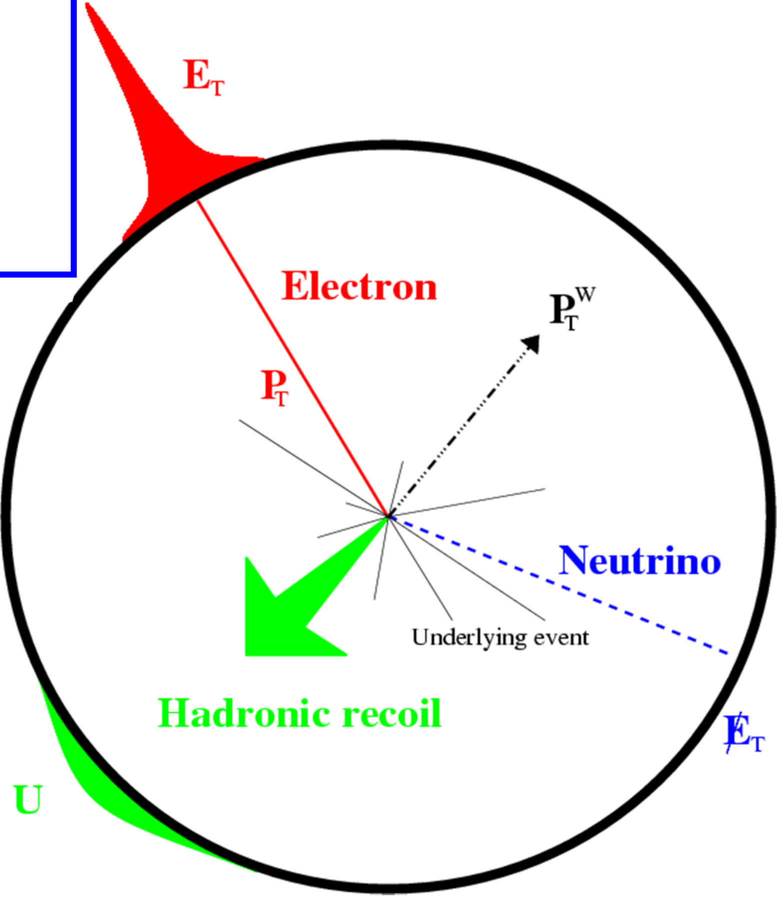
.



$|\eta_{e(trk}| < 2.8$, $|\eta_\mu| < 1$



$|\eta_{e(trk)}| < 3.2$, $|\eta_\mu| < 2$



- Muons: central tracker + muon detectors
- Electrons: central tracker + calorimeter

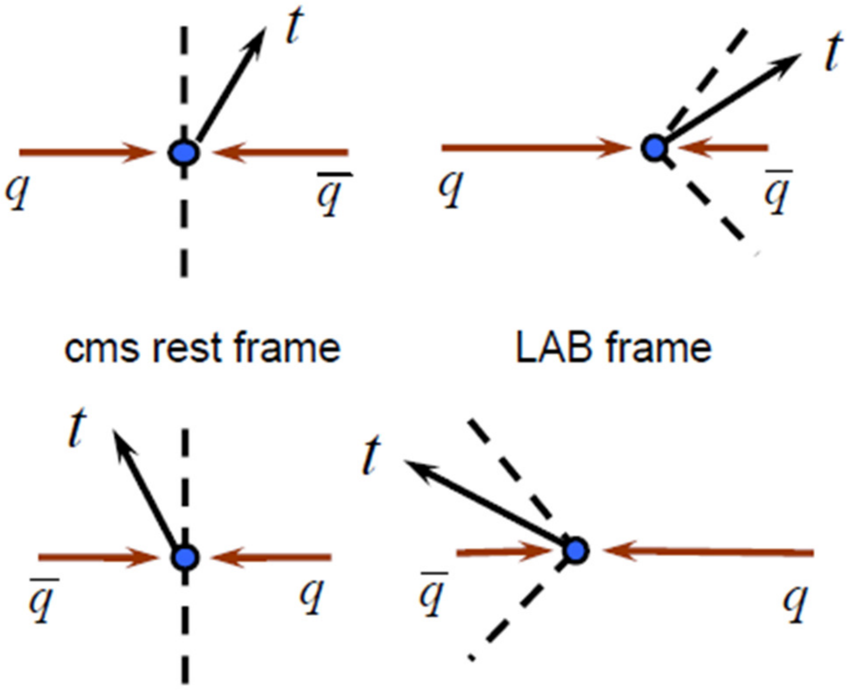
Detailed understanding (~10MeV) of all aspects of W is required.

Charge asymmetry at LHC

LHC is symmetric ⇨ no forward-backward

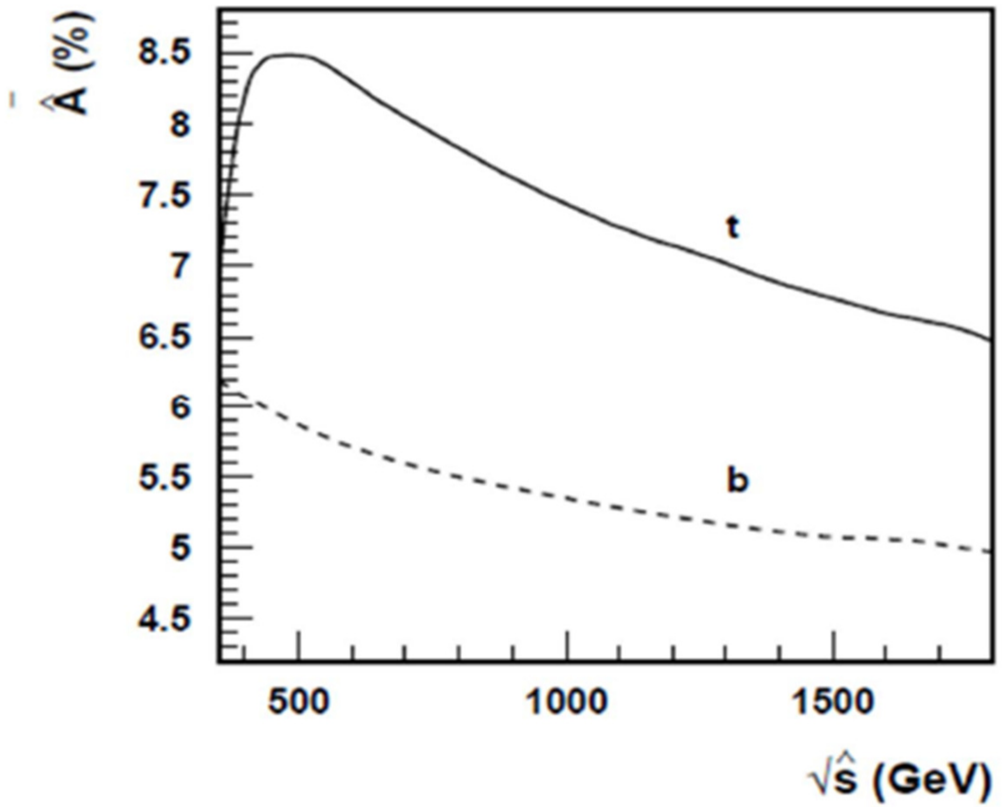
But suppose that there is a charge asymmetry at parton level
(QCD predicts that tops are preferentially emitted in the direction of incoming quark, BSM asymmetry can be positive or negative)

quarks carry more momenta than antiquarks



- Excess of tops (or antitops) in the forward and backward regions
- Top cross section is gg dominated, which is symmetric; but gg can be suppressed by selecting pairs with large invariant mass

Partonic asymmetry and dependence on M_{ttbar}

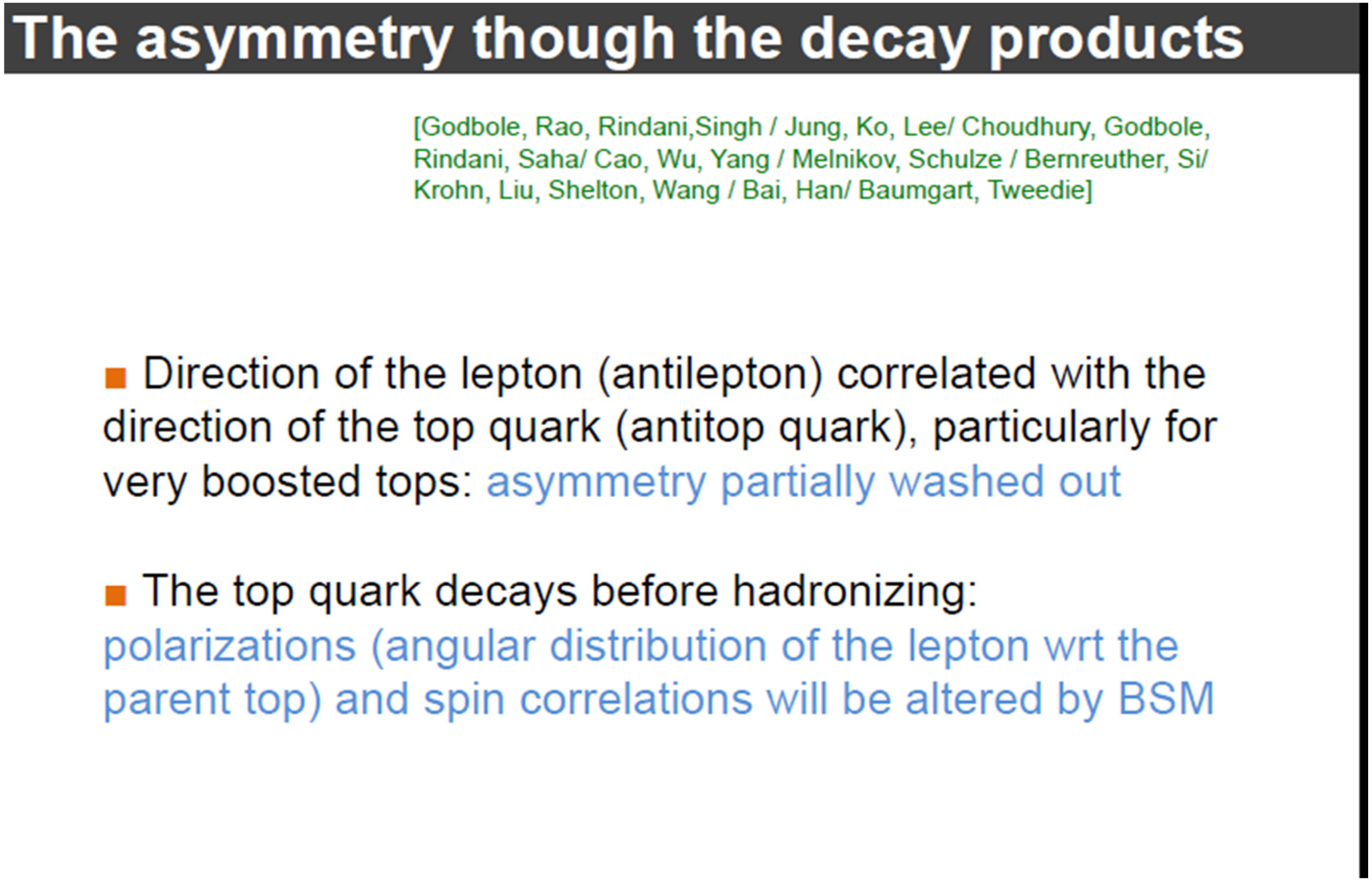


[Kühn, GR,1998]

- The asymmetry increases with M_{ttbar} because gluon fusion get supressed.
- Same effect for **bottom production**, but much more supressed by gluon fusion: inclusive asymmetry almost vanishes

A=4.3%-5.1% for M_{bbar}>300 GeV |cos θ|<0.9

Very challenging experimentally.



The asymmetry though the decay products

[Godbole, Rao, Rindani,Singh / Jung, Ko, Lee/ Choudhury, Godbole, Rindani, Saha/ Cao, Wu, Yang / Melnikov, Schulze / Bernreuther, Si/ Krohn, Liu, Shelton, Wang / Bai, Han/ Baumgart, Tweedie]

- Direction of the lepton (antilepton) correlated with the direction of the top quark (antitop quark), particularly for very boosted tops: asymmetry partially washed out

- The top quark decays before hadronizing: polarizations (angular distribution of the lepton wrt the parent top) and spin correlations will be altered by BSM