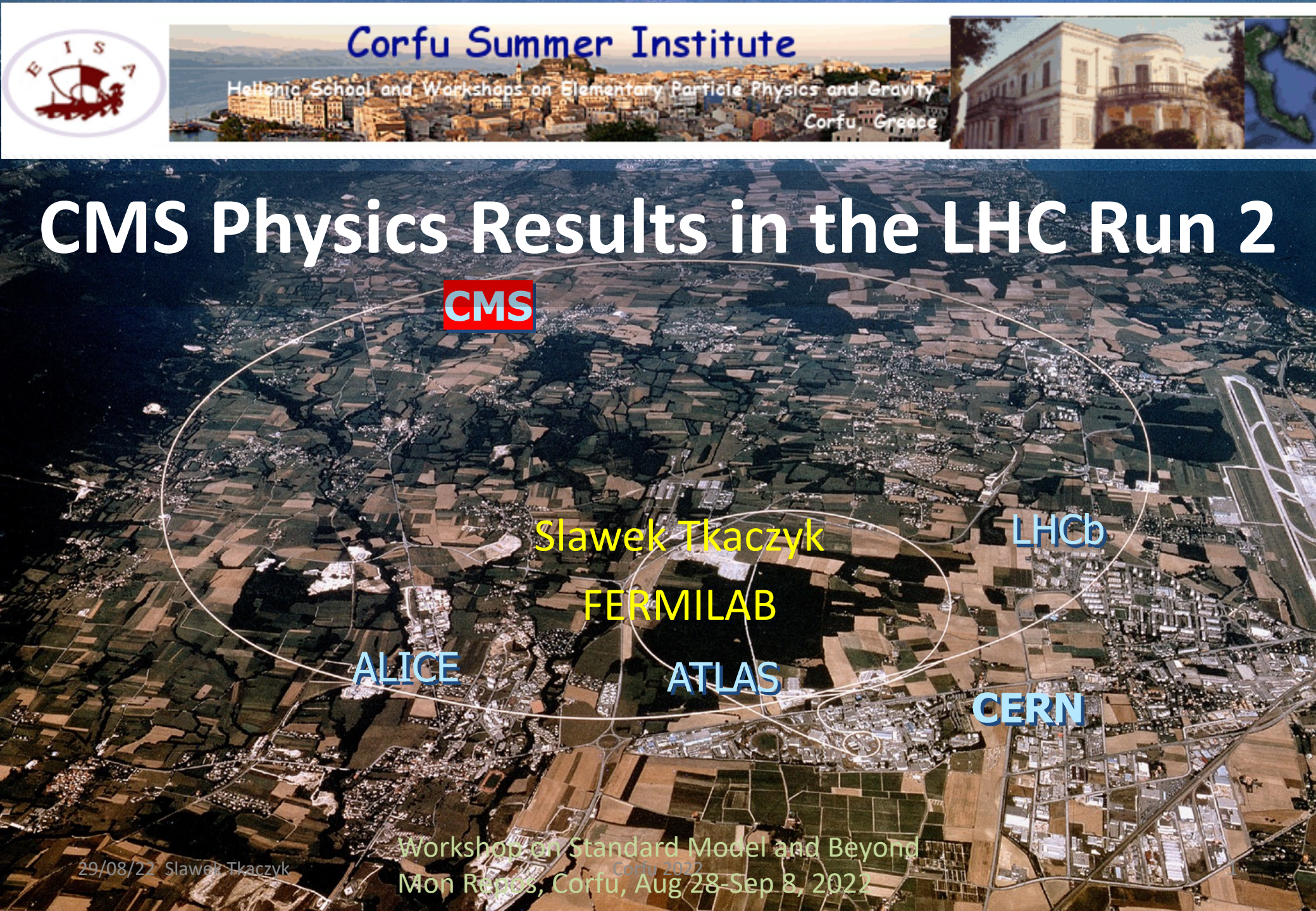


CMS Physics Results in the LHC Run 2

CMS

Slawek Tkaczyk

FERMILAB

LHCb

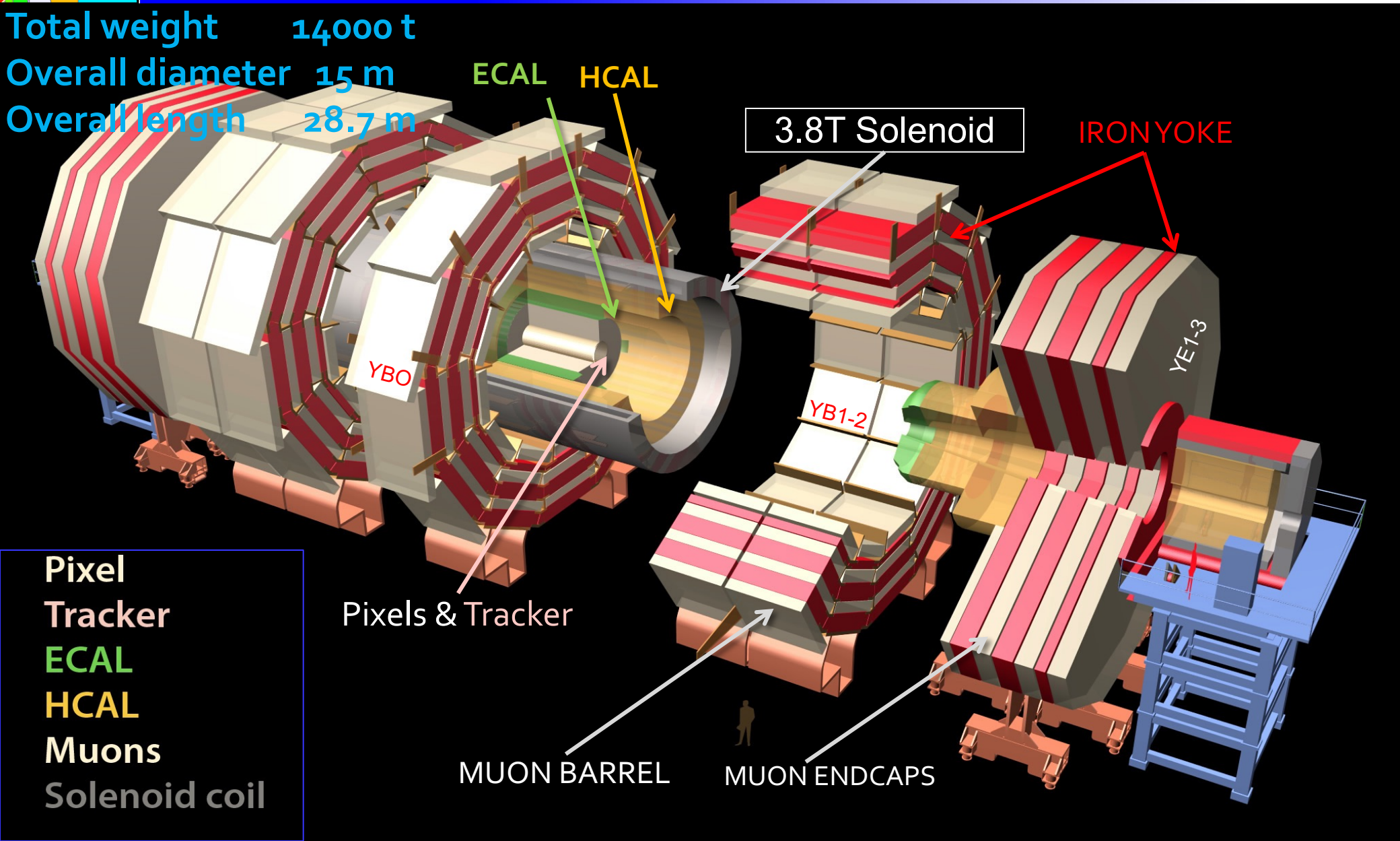
ALICE

ATLAS

CERN

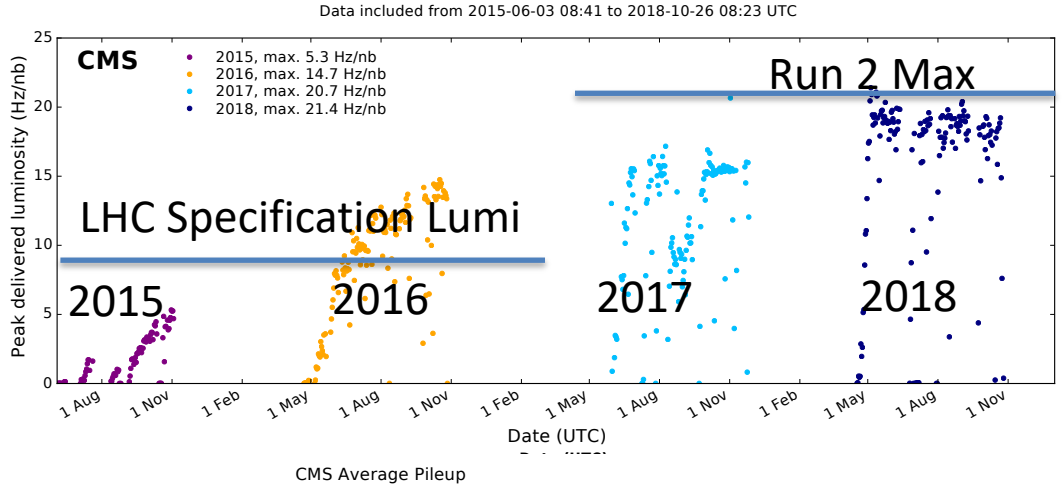
Workshop on Standard Model and Beyond
Mon Repos, Corfu, Aug 28-Sep 8, 2022

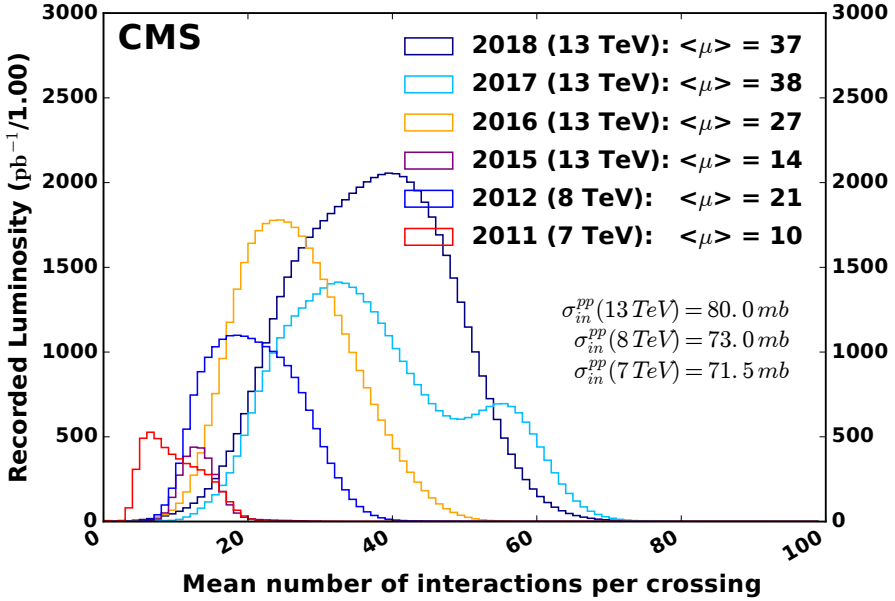
CMS Detector

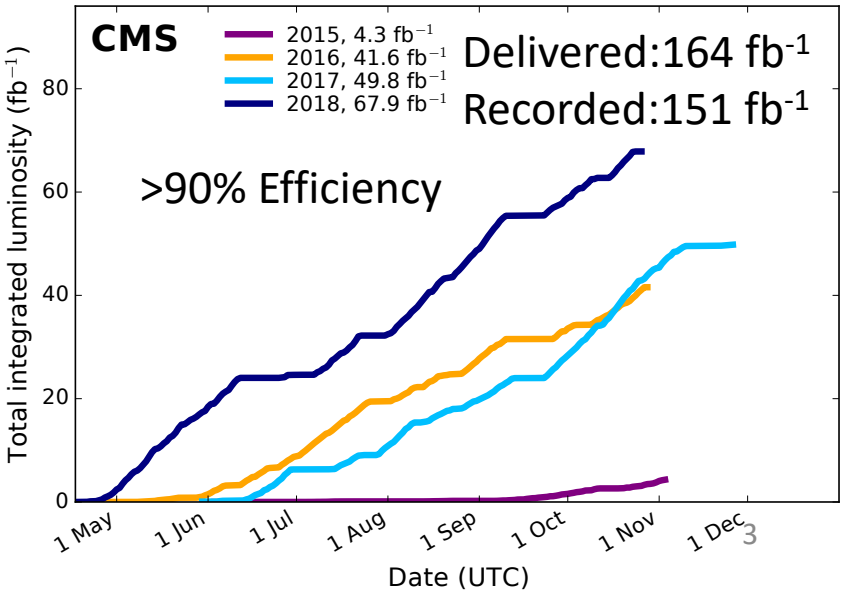


LHC in Run 2 (2015-2018)

- Spectacular performance of the LHC since turn on!





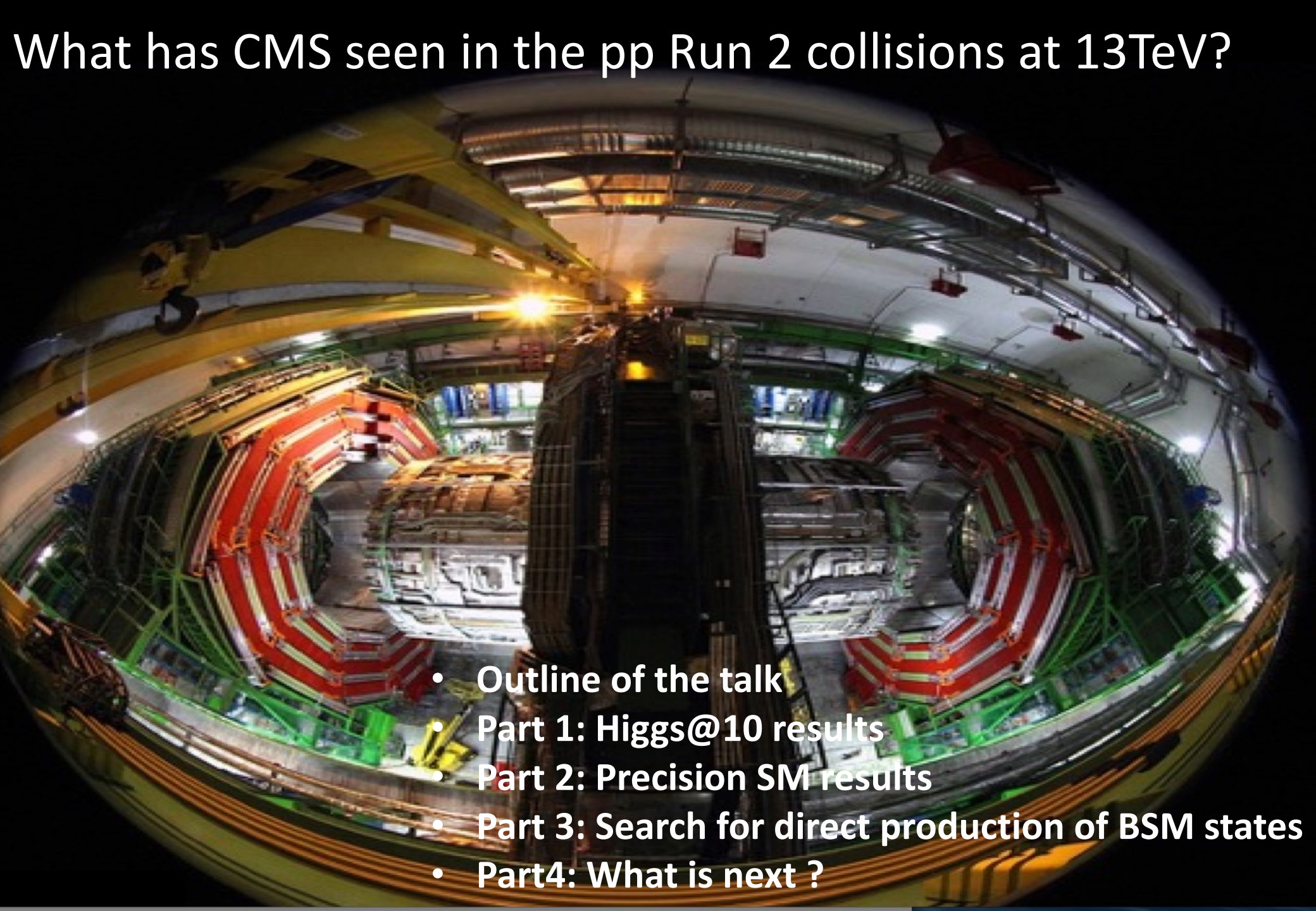


CMS Measurements from Run 2

- Many **new** or **precision** measurements enabled with large data sets collected in 2015-2018 (~151 fb^{-1})

- Amazing measurements with the Higgs
- Most precise Branching ratio $B_{(s)} \rightarrow \mu\mu$ measurements
- New top mass measurements and tt+V(W,Z),H cross-sect.
- Multiple interesting and intriguing results of searches for the BSM resonances

What has CMS seen in the pp Run 2 collisions at 13TeV?



- Outline of the talk
- Part 1: Higgs@10 results
- Part 2: Precision SM results
- Part 3: Search for direct production of BSM states
- Part4: What is next ?

Higgs Results 10 y after Discovery

Higgs Bosons — H^0 and $H^\pm$, Searches for **2012**

The July 2012 news about Higgs searches is described in the addendum to the Higgs review in the data listings, but is not reflected here.

The limits for H_1^0 and A^0 refer to the m_h^{max} benchmark scenario for the supersymmetric parameters.

H^0 Mass $m > 115.5$ and none 127–600 GeV, CL = 95%

H_1^0 in Supersymmetric Models ($m_{H_1^0} < m_{H_2^0}$)

Mass $m >$ 92.8 GeV, CL = 95%

HTTP://PDG.LBL.GOV Page 4 Created: 6/18/2012 15:05

VII. Addendum

Updated July 12, 2012.

On July 4, 2012, the ATLAS and CMS collaborations simultaneously announced observation of a new particle produced in pp collision data at high energies [363–366]. The data samples used correspond to between 4.6 and 5.1 fb^{-1} of collision data collected at $\sqrt{s} = 7$ TeV in 2011, and between 5.3 and 5.9 fb^{-1} of collisions collected at $\sqrt{s} = 8$ TeV in 2012. The observed decay modes indicate that the new particle is a boson. The evidence is strong that the new particle decays to $\gamma\gamma$ and ZZ with rates consistent with those predicted for the Standard Model (SM) Higgs boson. There are indications that the new particle might also decay to W^+W^-, and decays to $b\bar{b}$ and $\tau^+\tau^-$ are being sought as well.

H^0 $J = 0$ **2022**

Mass $m = 125.25 \pm 0.17$ GeV (S = 1.5)

Full width $\Gamma = 3.2^{+2.8}_{-2.2}$ MeV (assumes equal on-shell and off-shell effective couplings)

H^0 Signal Strengths in Different Channels

Combined Final States $= 1.13 \pm 0.06$

$WW^* = 1.19 \pm 0.12$

$ZZ^* = 1.01 \pm 0.07$

$\gamma\gamma = 1.10 \pm 0.07$

$c\bar{c}$ Final State $= 37 \pm 20$

$b\bar{b} = 0.98 \pm 0.12$

$\mu^+\mu^- = 1.19 \pm 0.34$

$\tau^+\tau^- = 1.15^{+0.16}_{-0.15}$

$Z\gamma < 3.6$, CL = 95%

$\gamma^*\gamma$ Final State $= 1.5 \pm 0.5$

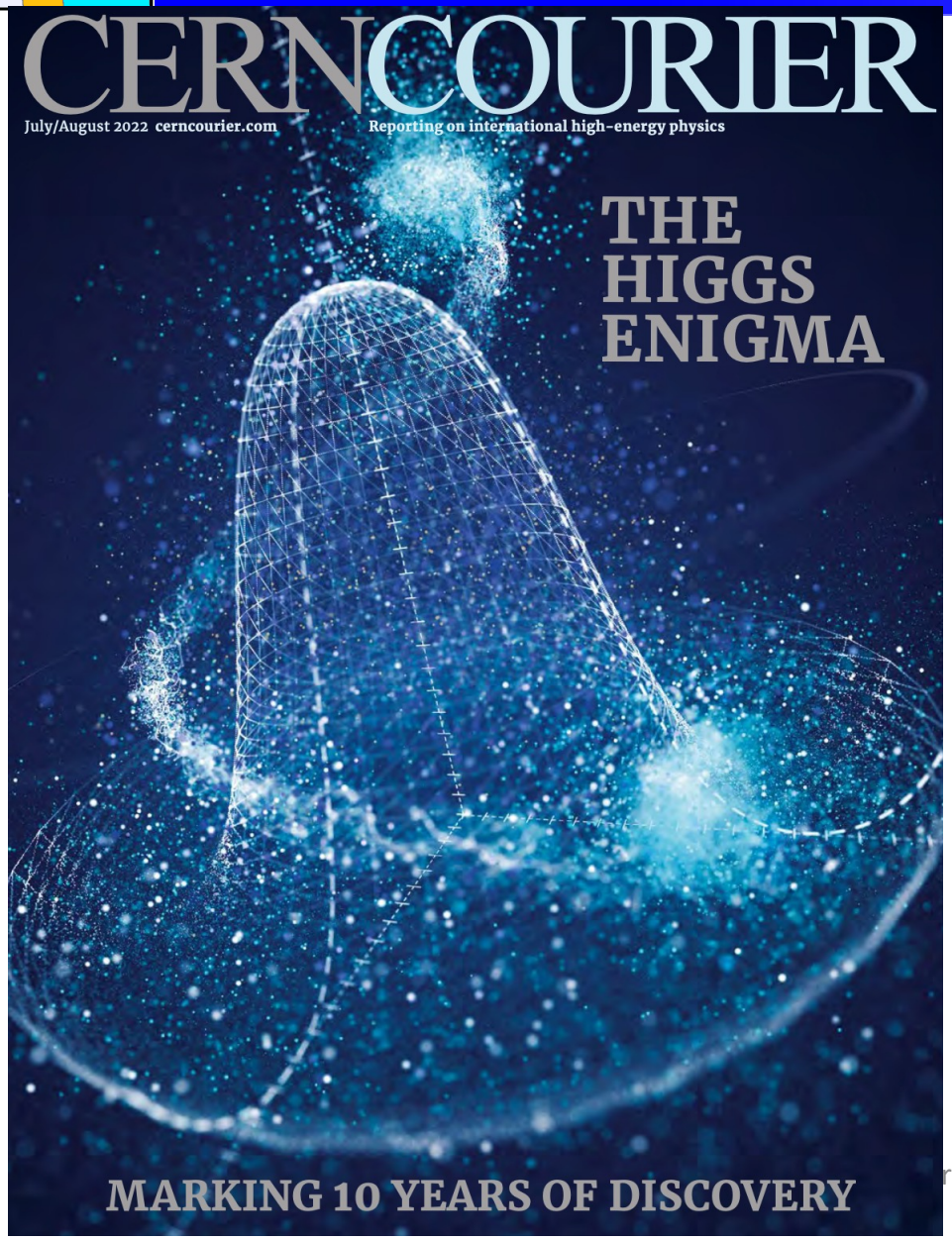
$t\bar{t}H^0$ Production $= 1.10 \pm 0.18$

tH^0 production $= 6 \pm 4$

H^0 Production Cross Section in pp Collisions at $\sqrt{s} = 13$ TeV $= 56 \pm 4$ pb

$e\mu$	LF	$< 6.1 \times 10^{-5}$	95%	62625
$e\tau$	LF	$< 2.2 \times 10^{-3}$	95%	62612
$\mu\tau$	LF	$< 1.5 \times 10^{-3}$	95%	62612
invisible		<19 %	95%	–

Higgs Results 10y after Discovery

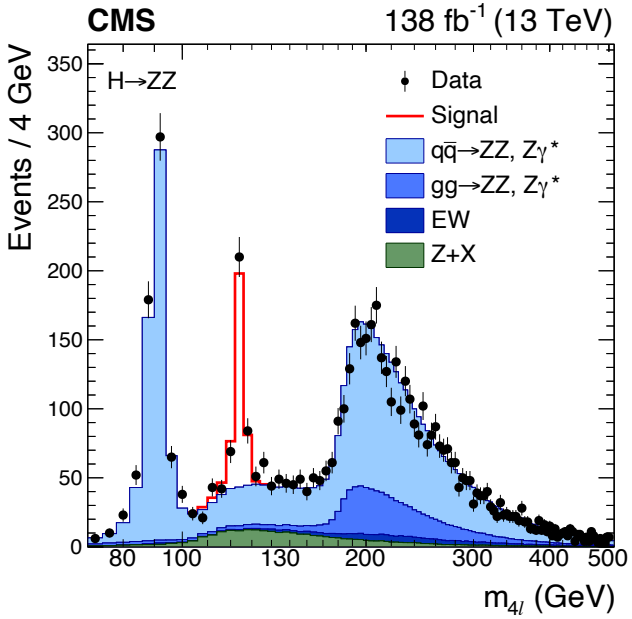


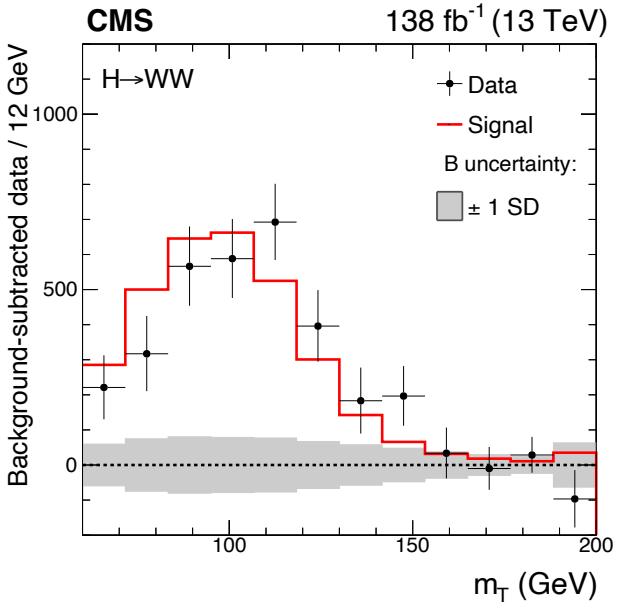
- Differential cross sections
- Rare decays or not allowed in SM: LFV H→τe/μe/τμ
- Couplings to vector bosons, quarks and leptons and ttH (H→bb/ττ/γγ)
- HH resonance studies (bb + bb/γγ/ττ)
- Decays to non-SM particles: H→*invisible* or light pseudo- or scalar-particles

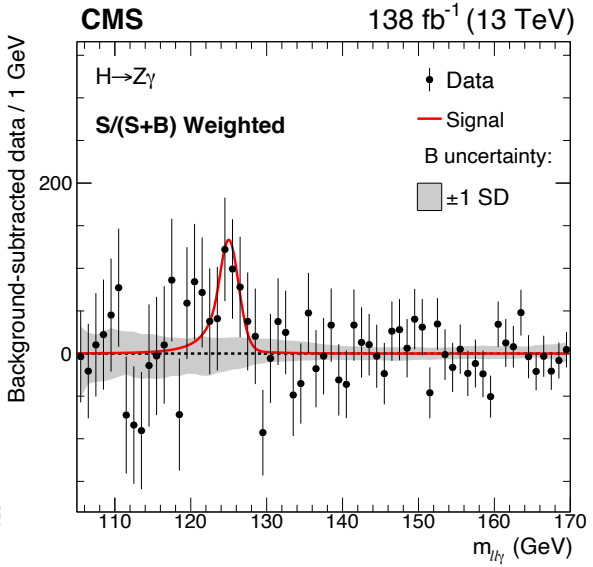
A portrait of the Higgs boson by the CMS experiment ten years after the discovery
Nature **volume 607**, pages 60–68 (2022)

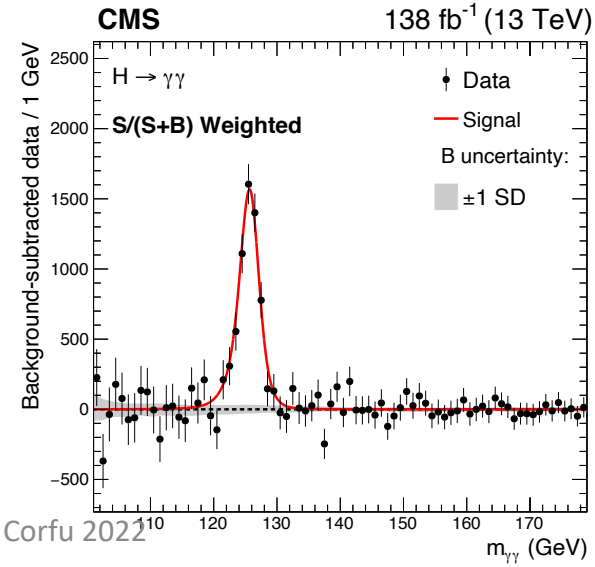
Higgs Mass Peaks in Run 2

CMS PAS HIG-22-001



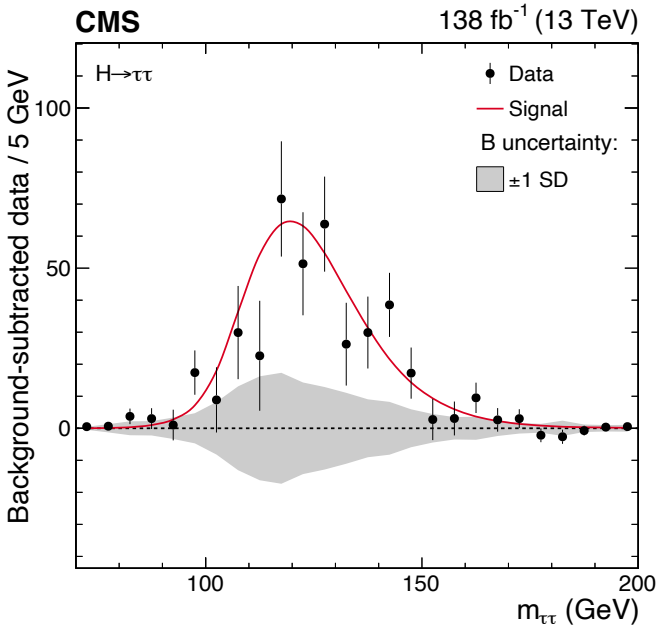


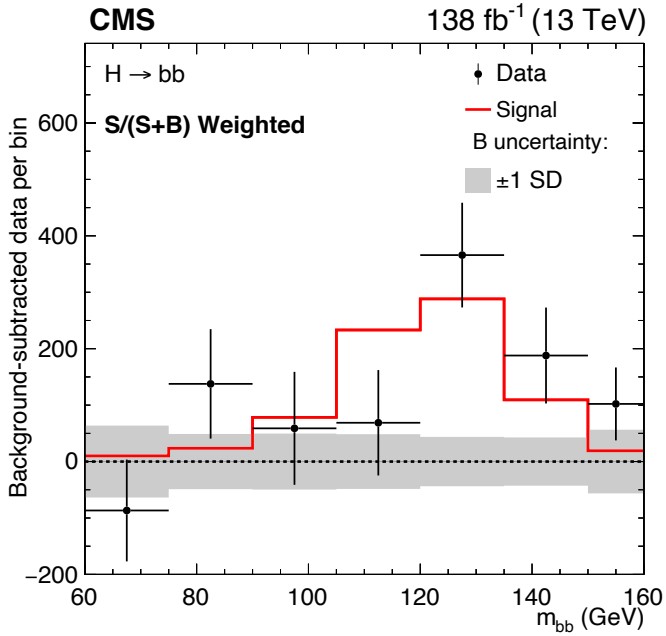


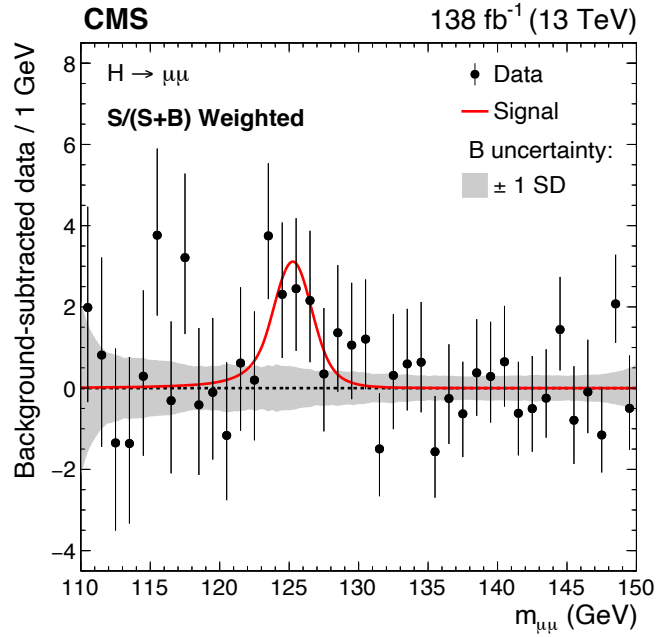


Higgs Mass Peaks in Run 2

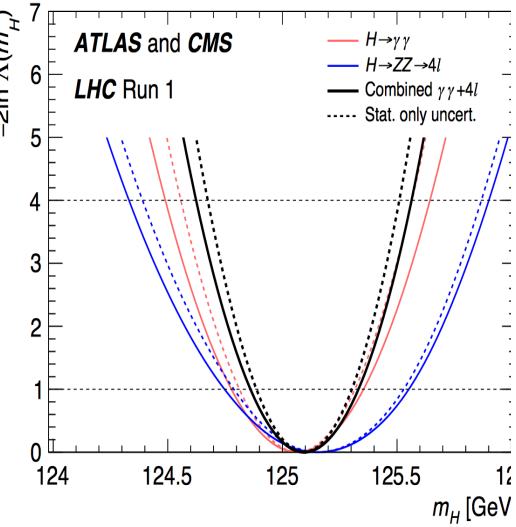
CMS PAS HIG-22-001

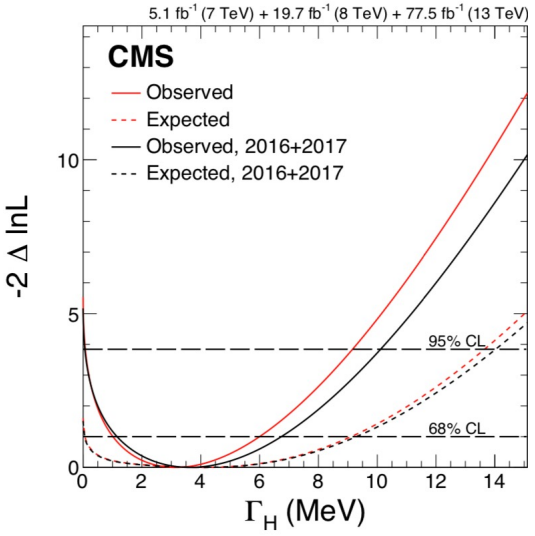


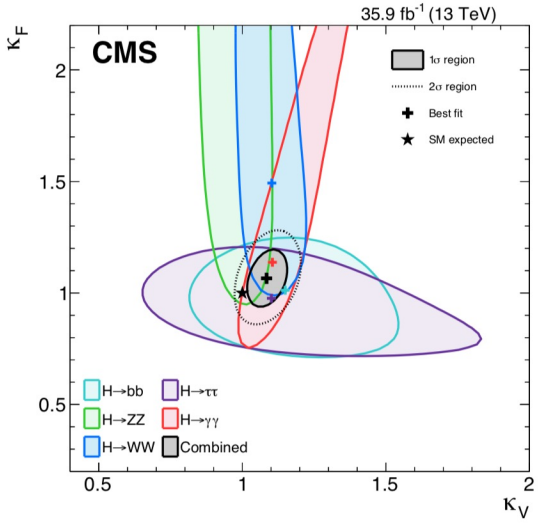


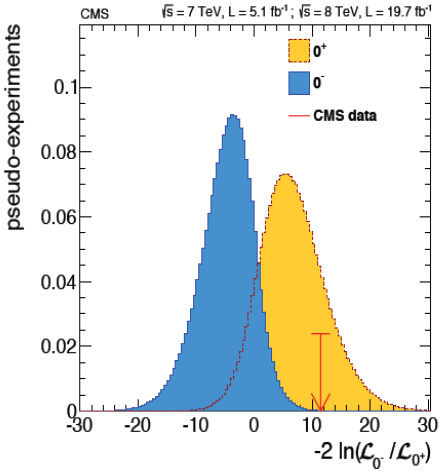


Higgs Measurements from Run 2









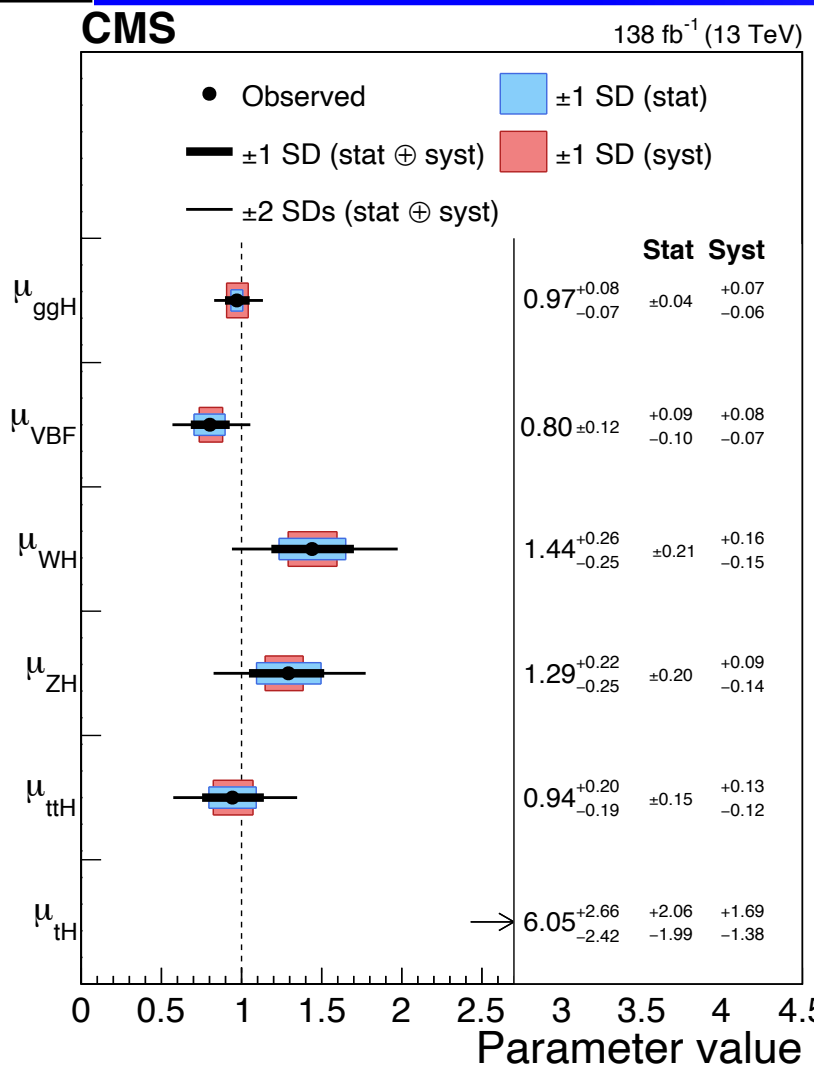
Mass = CMS+ATLAS
125.09 ±0.21(stat)
±0.11(syst) GeV

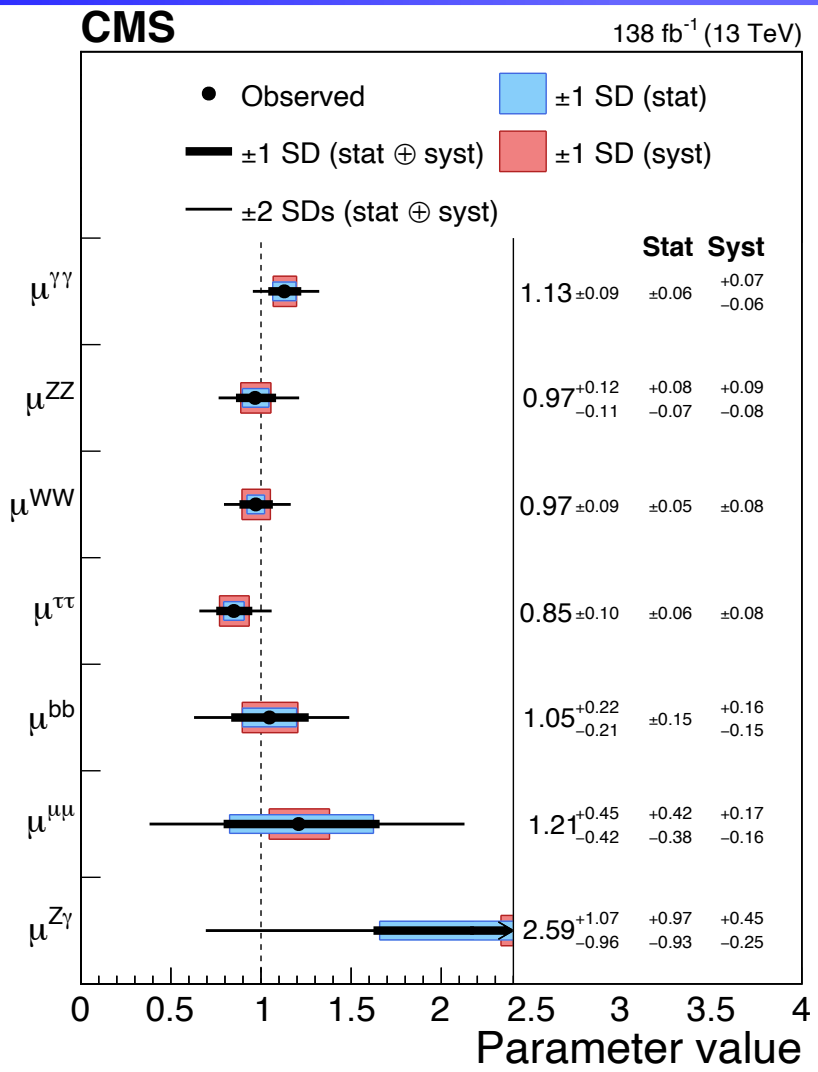
Width
< 9 MeV (95%CL)

Couplings
within ~15-20%
of the SM values

Spin
$0^{+(+)}$ preferred
over 0^-,1,2

Higgs Measurements from Run 2

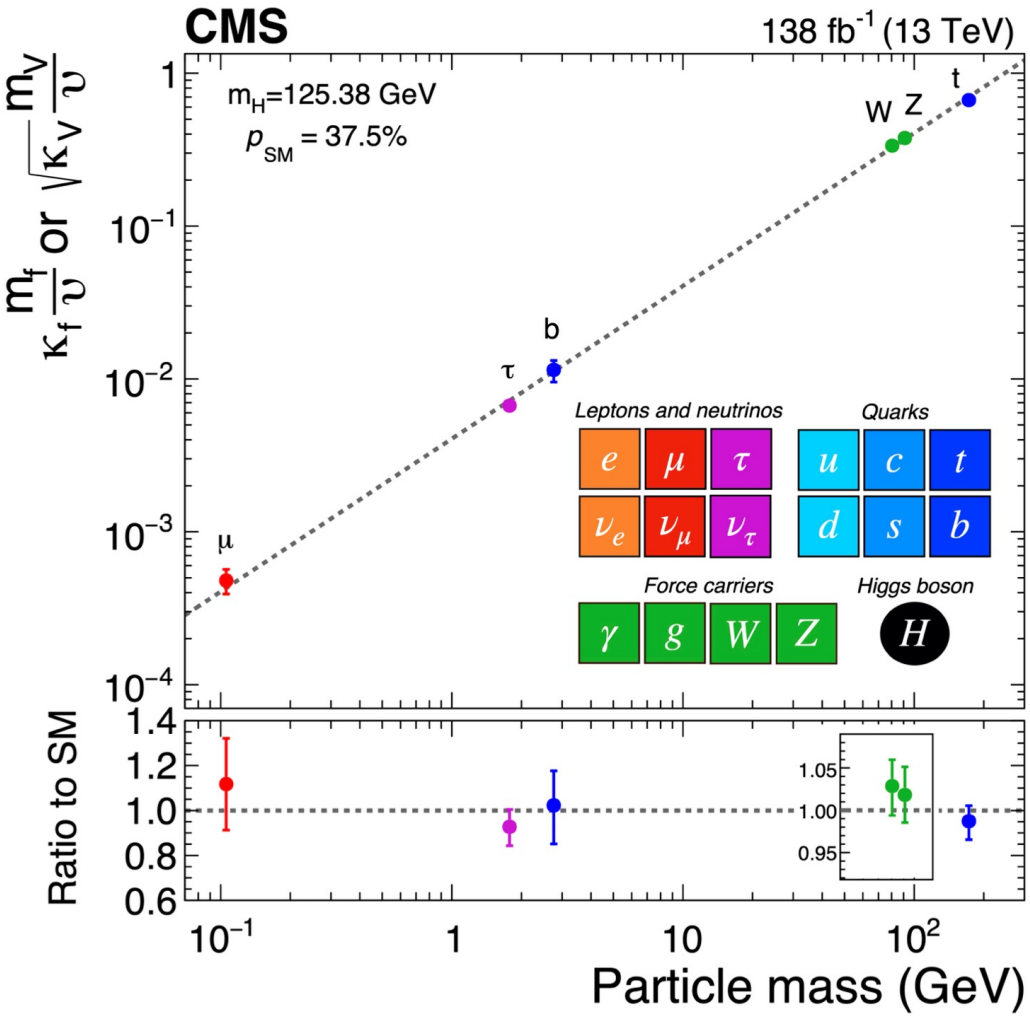


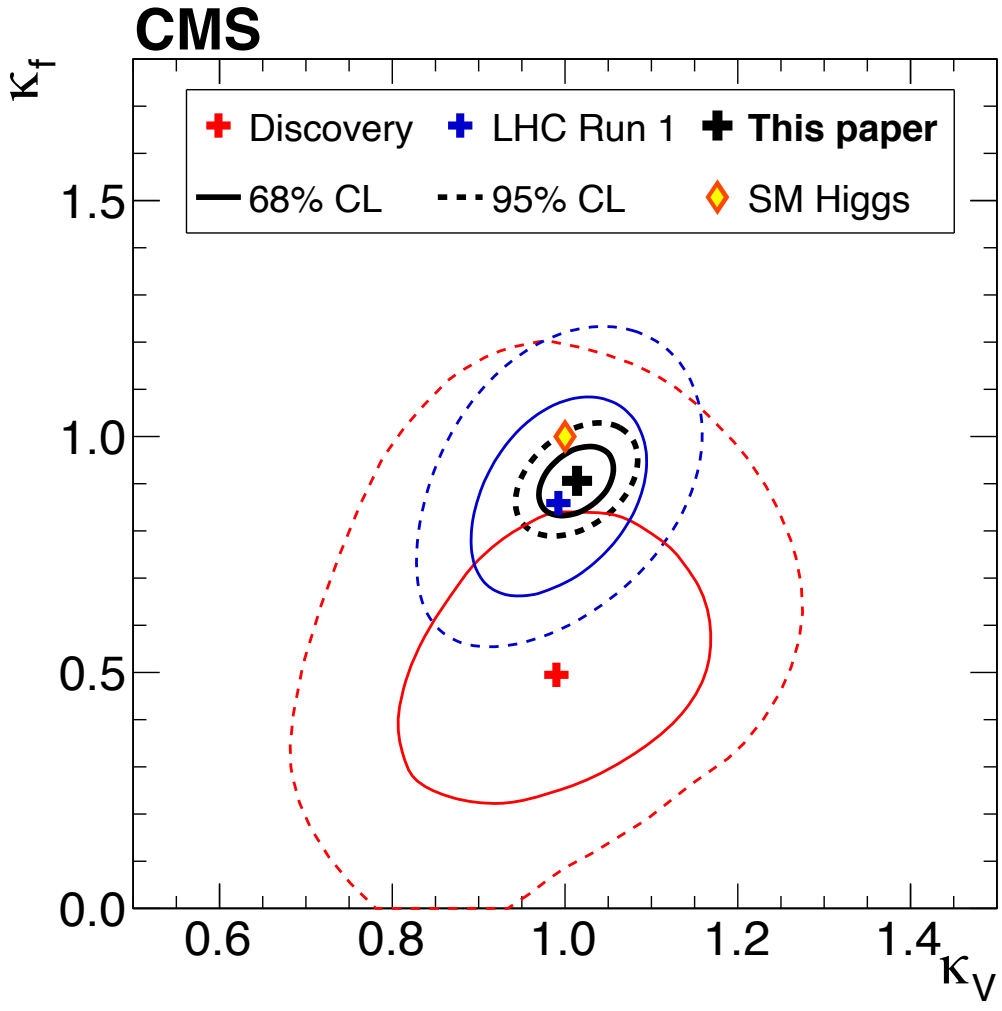


Agreement with the SM production modes and decays channels

Higgs Couplings Run 2 Results

[Nature 607 (2022) 60-68]

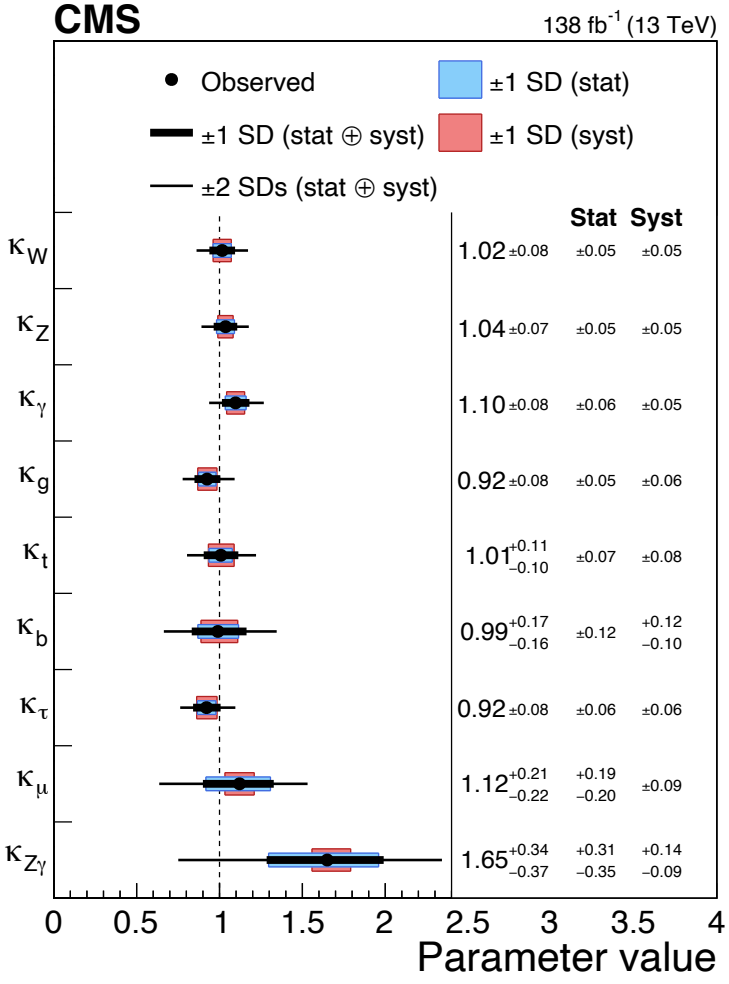


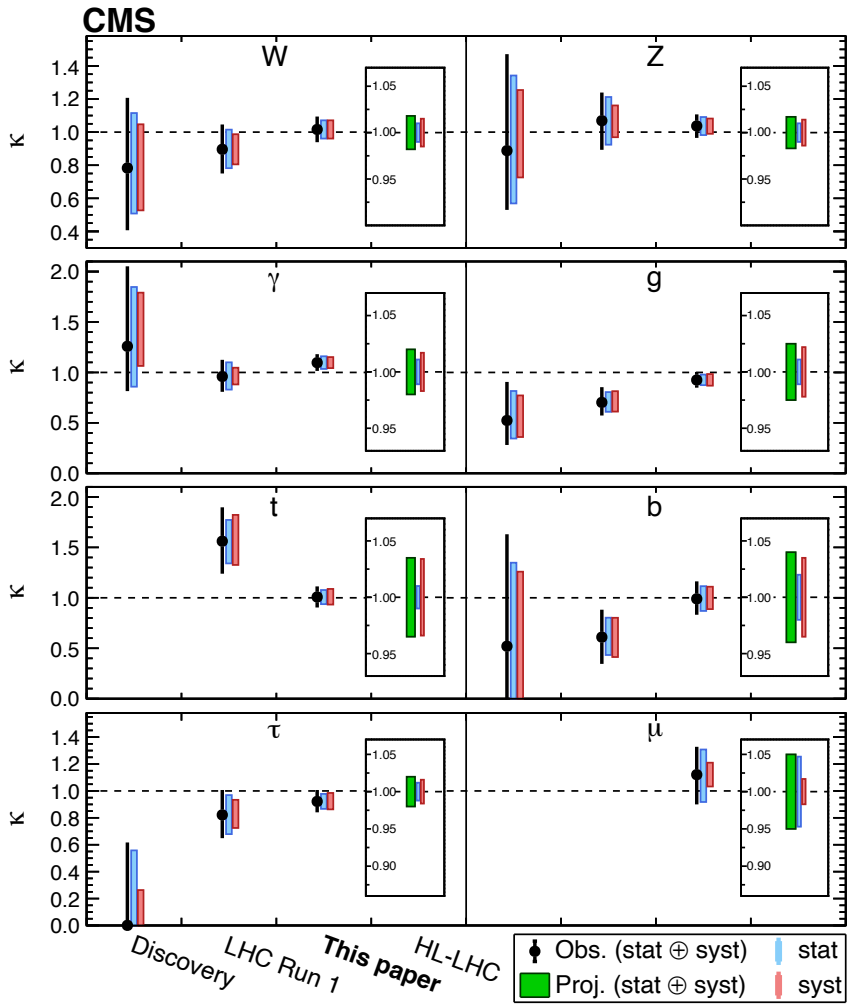


Higgs Couplings Run 2 and Beyond

[Nature 607 (2022) 60-68]

[Run1 JHEP 08 (2016) 045]

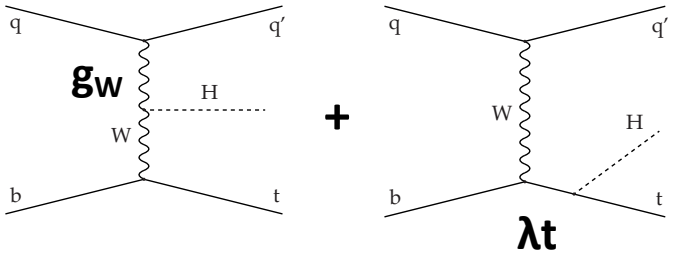




Higgs Coupling to Top in Run 2

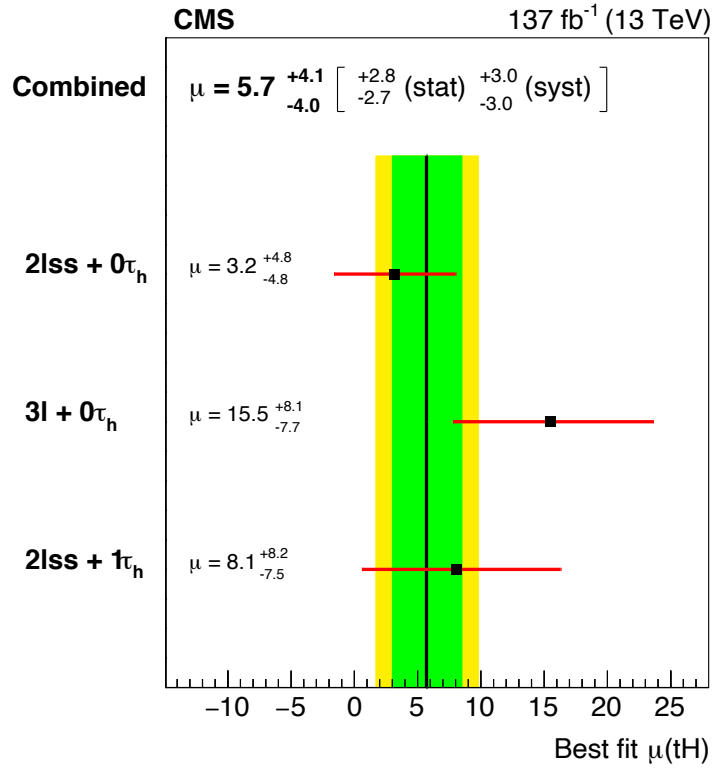
Eur. Phys. J. C 81 (2021) 378

ttH - a direct probe to Top Yukawa **λt** cplg while **tH** - a unique channel to study the relative sign of couplings while



- tHV + tHq + ttH with tt decays to multi-ℓ or all-jet final states
- H→WW*,ZZ*,ττ – channels in 10 signatures depending on lepton multiplicity
- MVA, ML and ME techniques to separate ttV and tt+jets backgrounds from signals

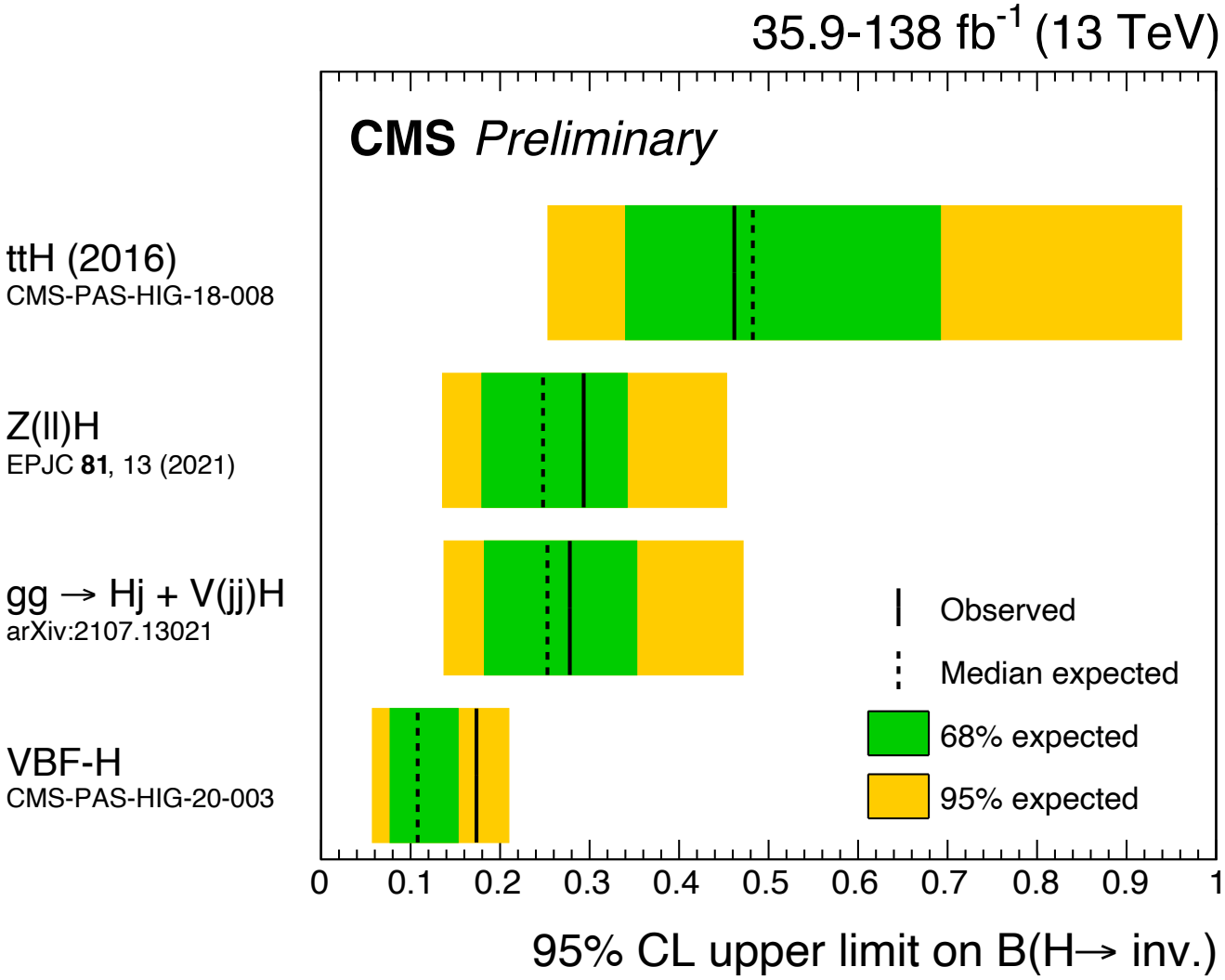
Constructive interference when **λt** and g_W have opposite sign
Large increase in the cross section



Significance for **tH** with M_h=125 GeV:
Observed: **1.4** σ Expected: **0.3** σ

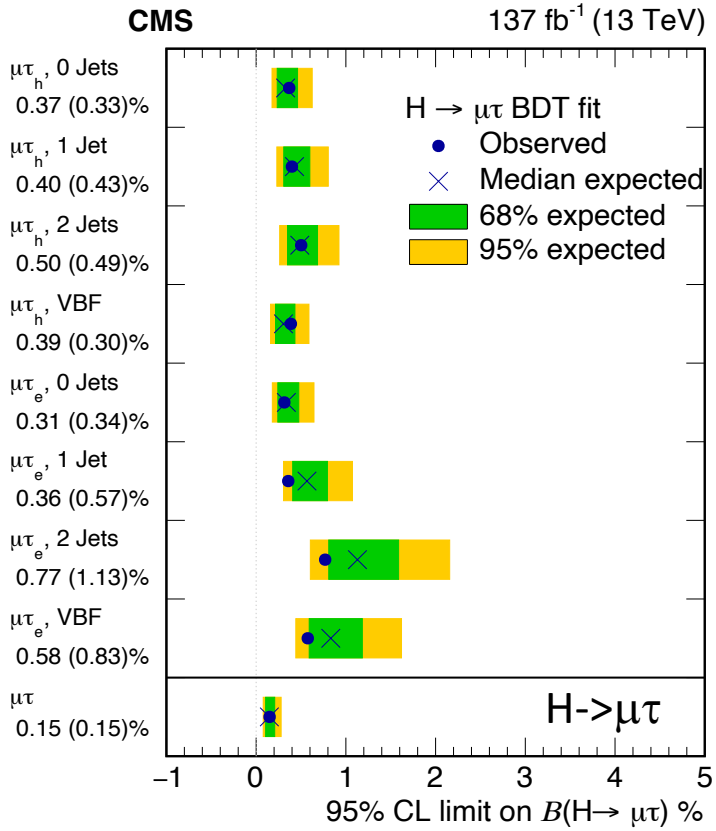
Significance for ttH with M_h=125 GeV:
Observed: **4.7** σ Expected: 5.2 σ

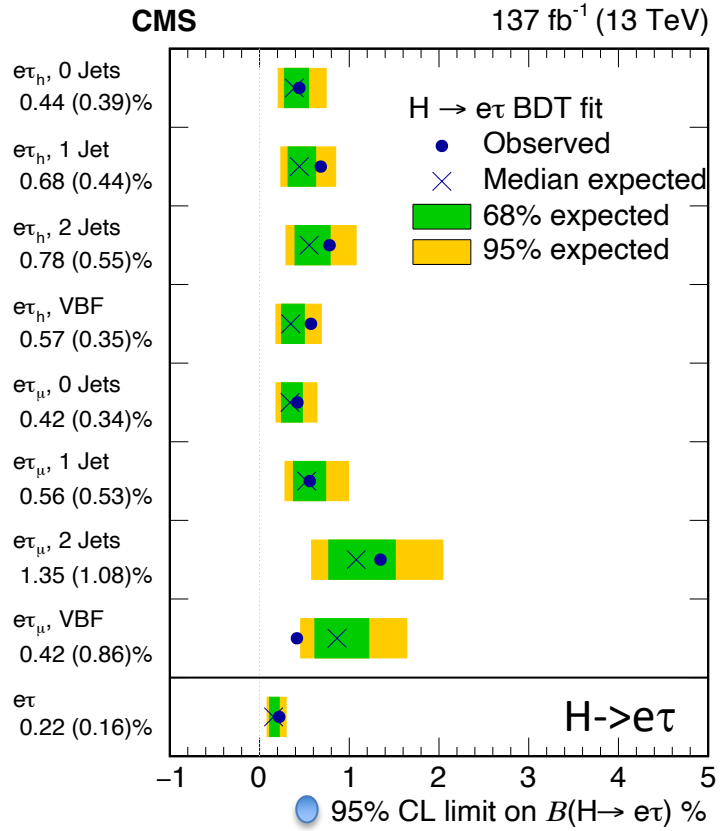
Higgs Width to Invisible Run 2



LFV Higgs Decays Run 2

Phys. Rev. D 104 (2021) 032013



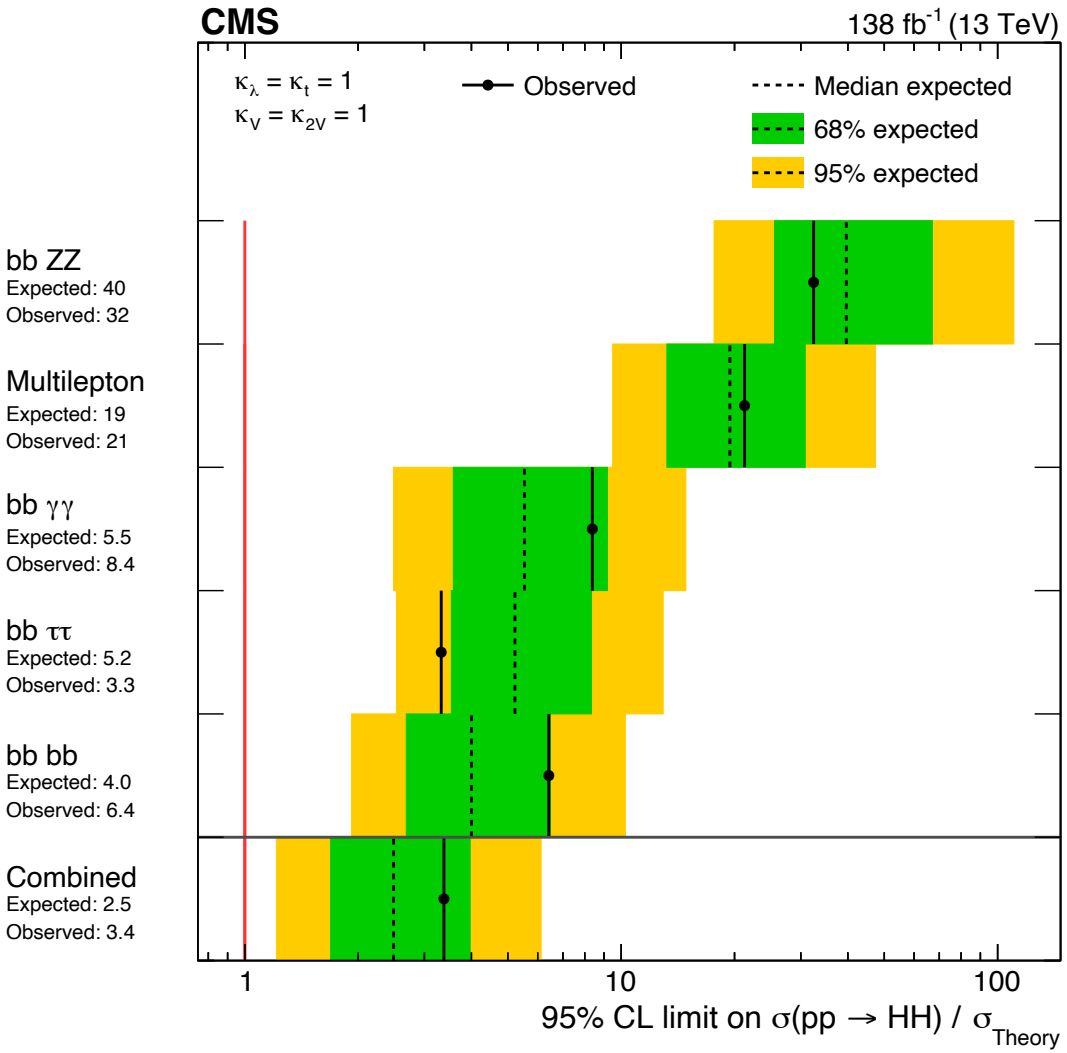


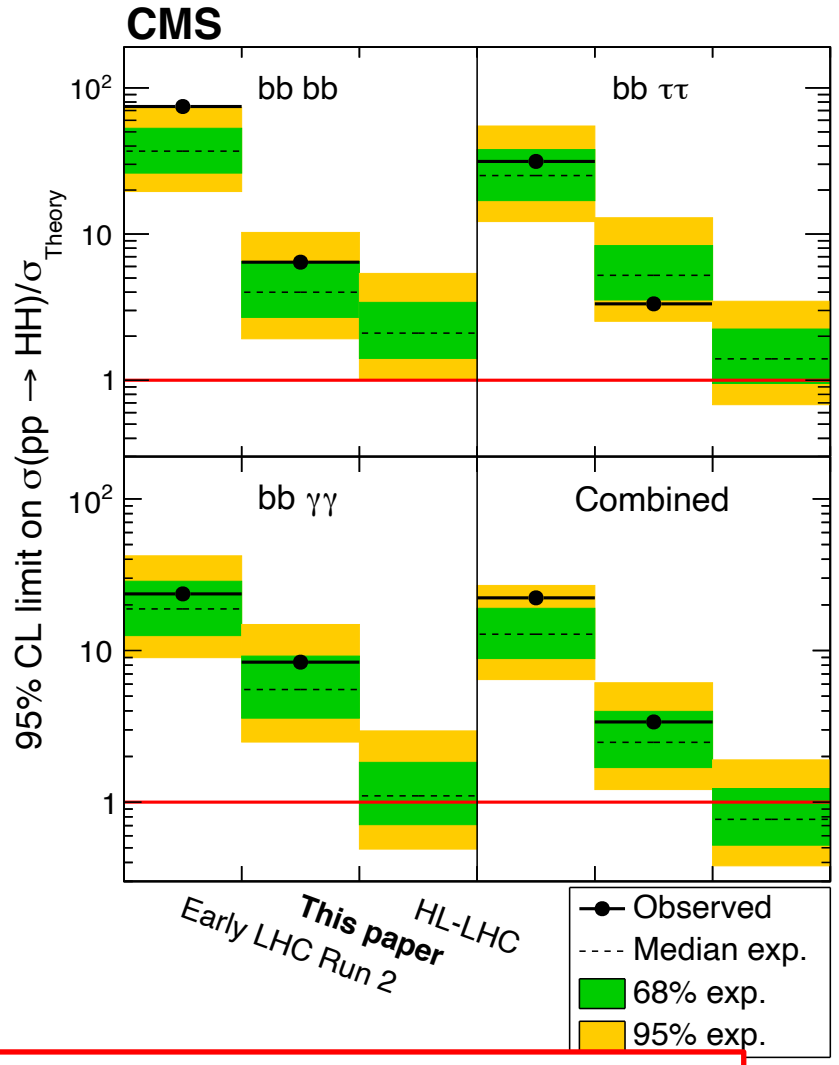
	Observed (expected) upper limits (%)	Best fit branching fractions (%)	Yukawa coupling constraints
$H \to \mu\tau$	<0.15 (0.15)	0.00 ± 0.07	$< 1.11\,(1.10) \times 10^{-3}$
$H \to e\tau$	<0.22 (0.16)	0.08 ± 0.08	$< 1.35\,(1.14) \times 10^{-3}$

No excess observed in Run 2 data

HH Production Limits Run 2

Nature 607 (2022) 60-68



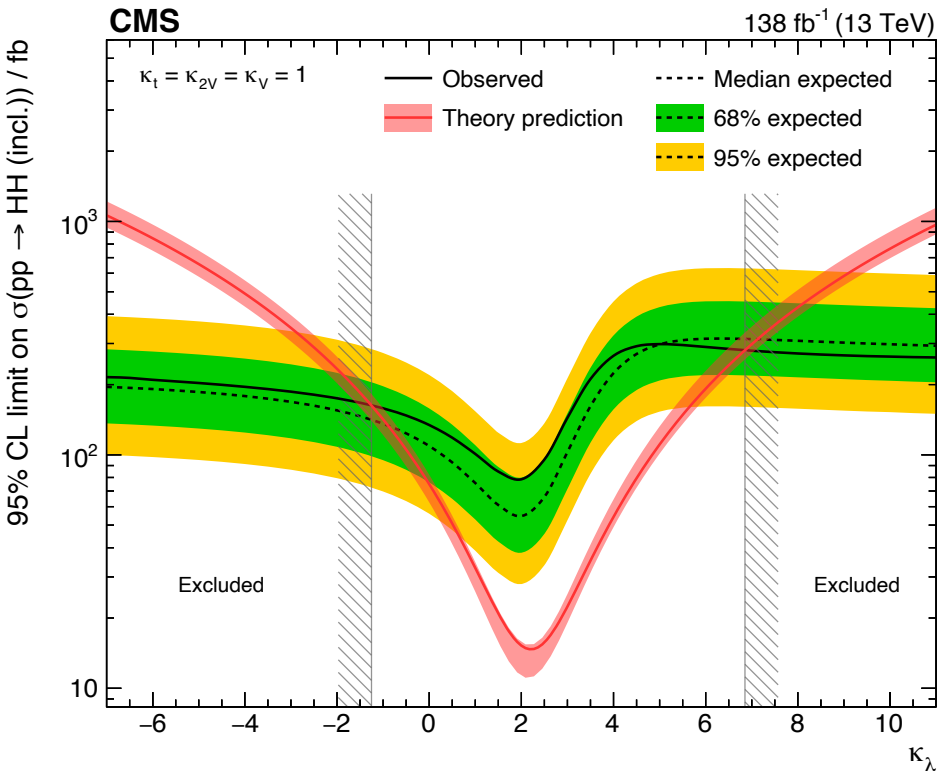


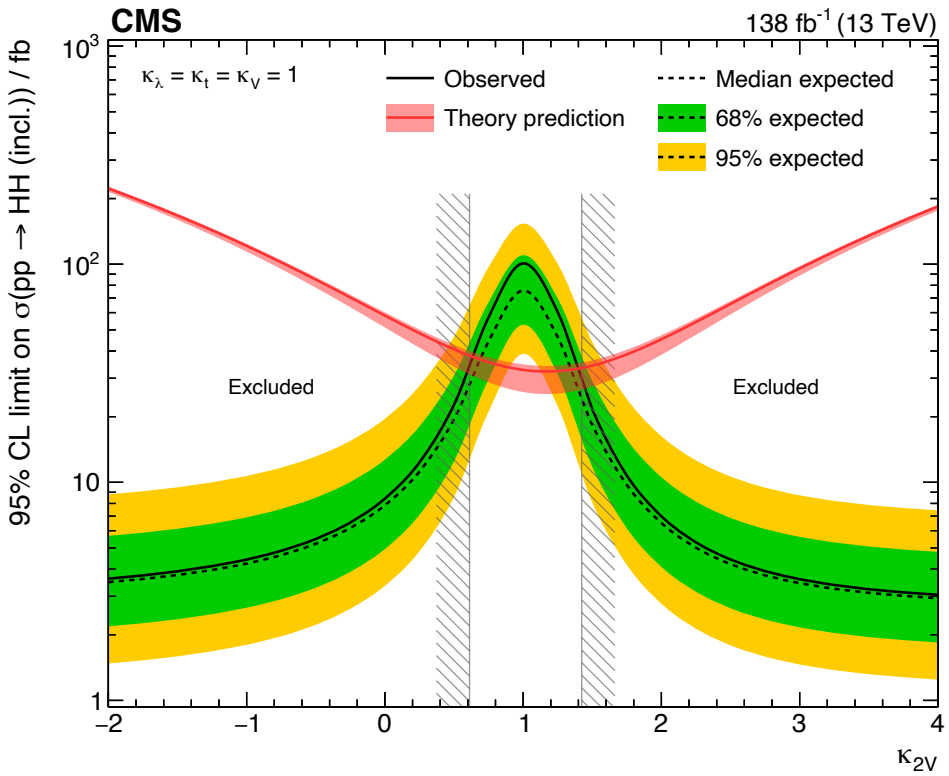
HH Discovery expected at the HL-LHC

HH Production Limits Run 2

Nature 607 (2022) 60-68

Limits on Higgs boson self-interaction κ_λ and quartic coupling κ_{2V} (VVHH)





SM values assumed for H modifier couplings to t and V

Summary of Higgs Measurements

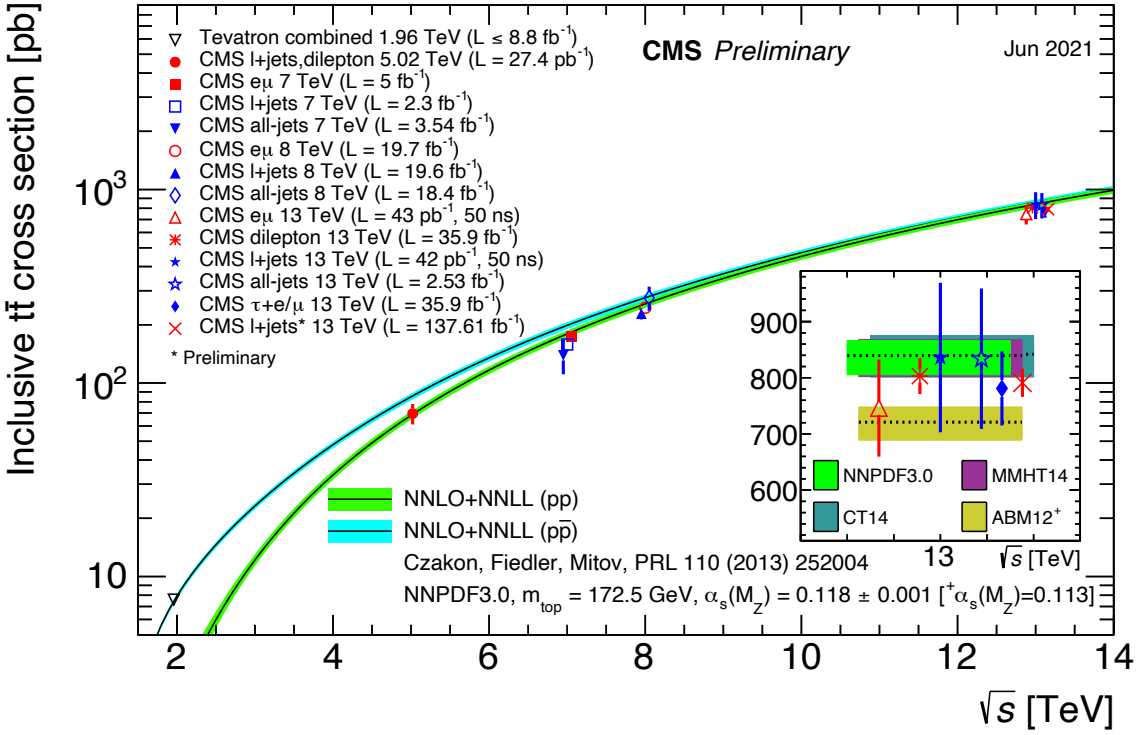
- Proud discover the Higgs and performing many original precision measurements elucidating its properties
- Higgs may play a role as a portal to new physics theories
  - Still large uncertainties on the parameters
- Crux of precision physics measurements in Run 3 and beyond

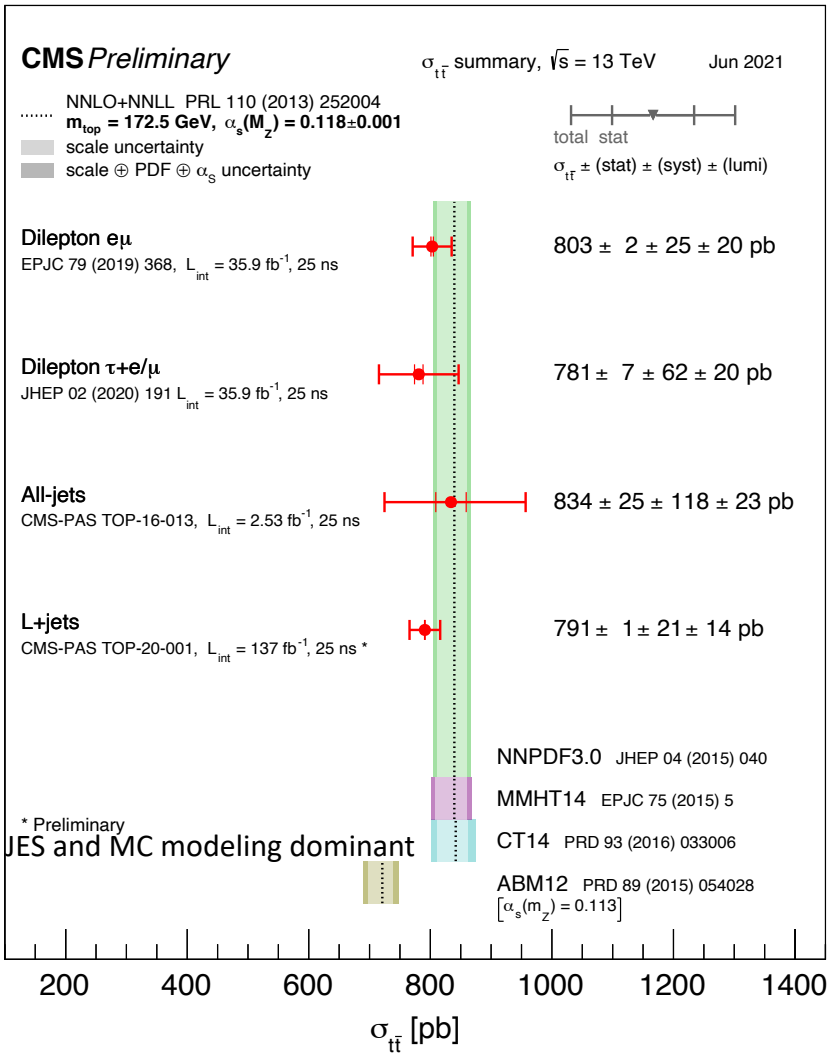
TOP Quark Properties

- TOP Production and Mass

ttbar Production

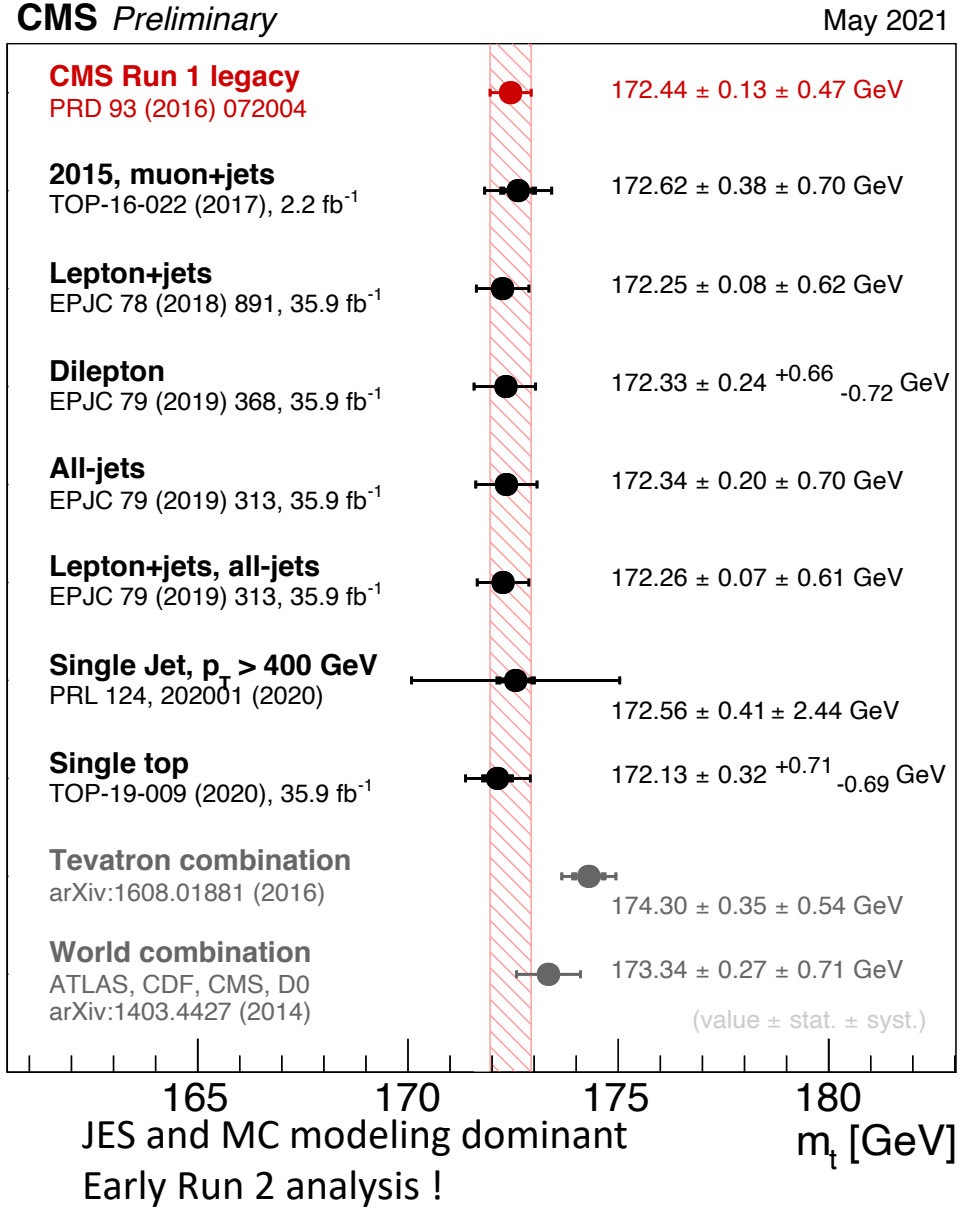
[Phys. Rev. D 104 (2021) 092013]





$\sigma_{tt} = 791 \pm 1(\text{stat.}) \pm 21(\text{syst.}) \pm 14(\text{lumi.})$ pb

TOP Mass Determination Run 2



JES and MC modeling dominant

Early Run 2 analysis !

CMS-PAS-TOP-020-008

- Direct measurement with 5d-fit constraining the jet uncertainty from W-peak in the ML fit
- **m_t = 171.77±0.38 GeV**(stat.0.04GeV)

CMS-PAS-TOP-021-008

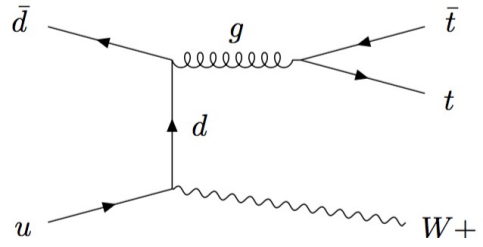
- Measurement from tt-jet cross section
- m_t^{pole} = 172.94±1.37 GeV

CMS-PAS-TOP-021-012

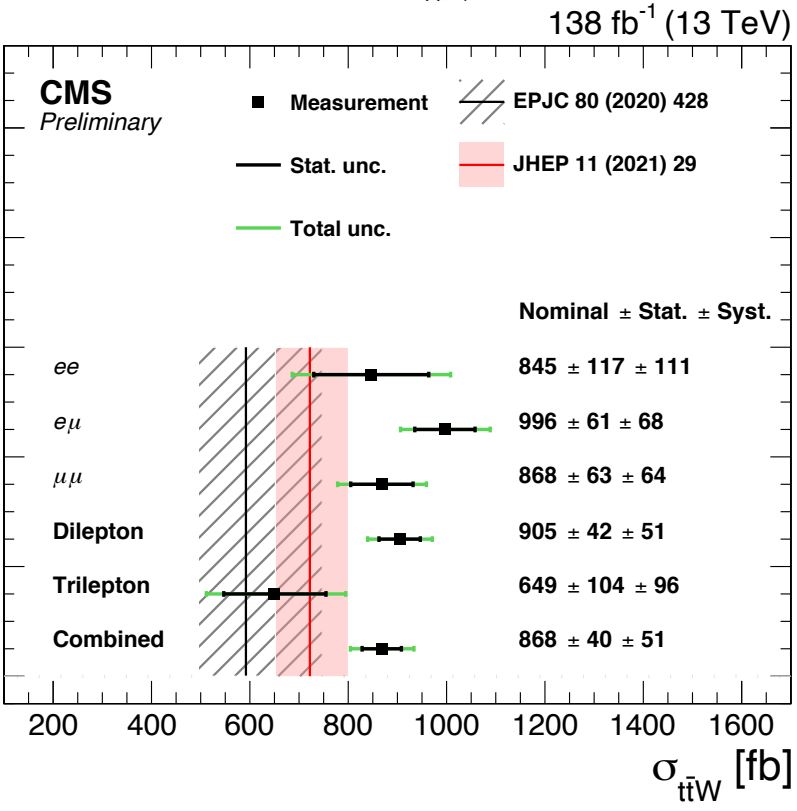
- Measurement of mass distribution and m_t in hadronic decays to boosted jets
- m_t = 172.76±0.81 GeV

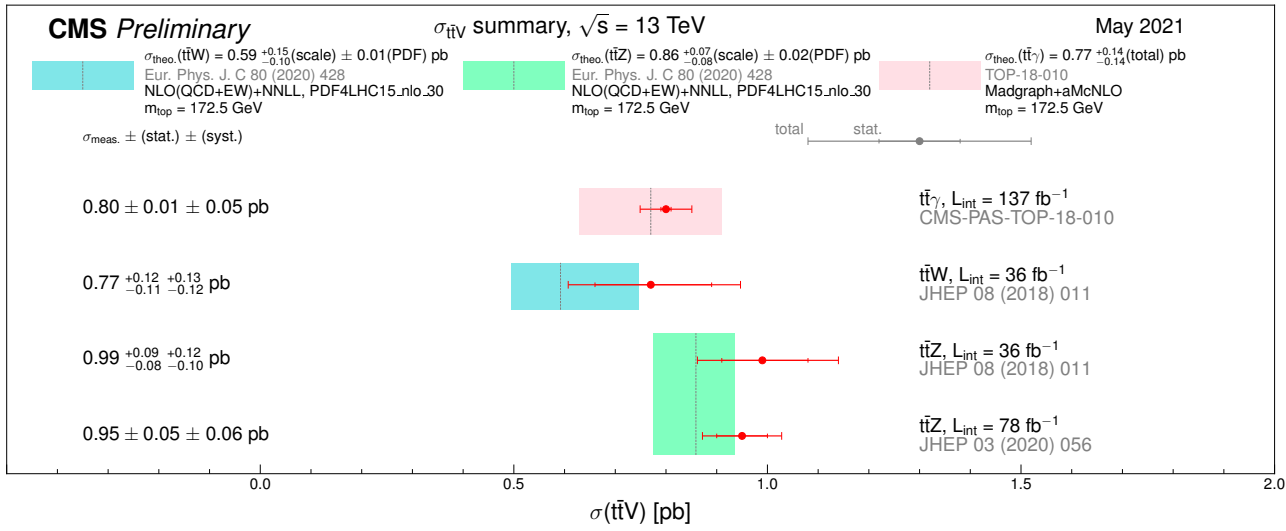
ttV Production in Run 2

CMS-TOP-021-011



ttW: Same sign 2- and 3-lepton channels





σ_{ttW} = 0.868± 0.040(stat.) ±0.051(syst.) pb

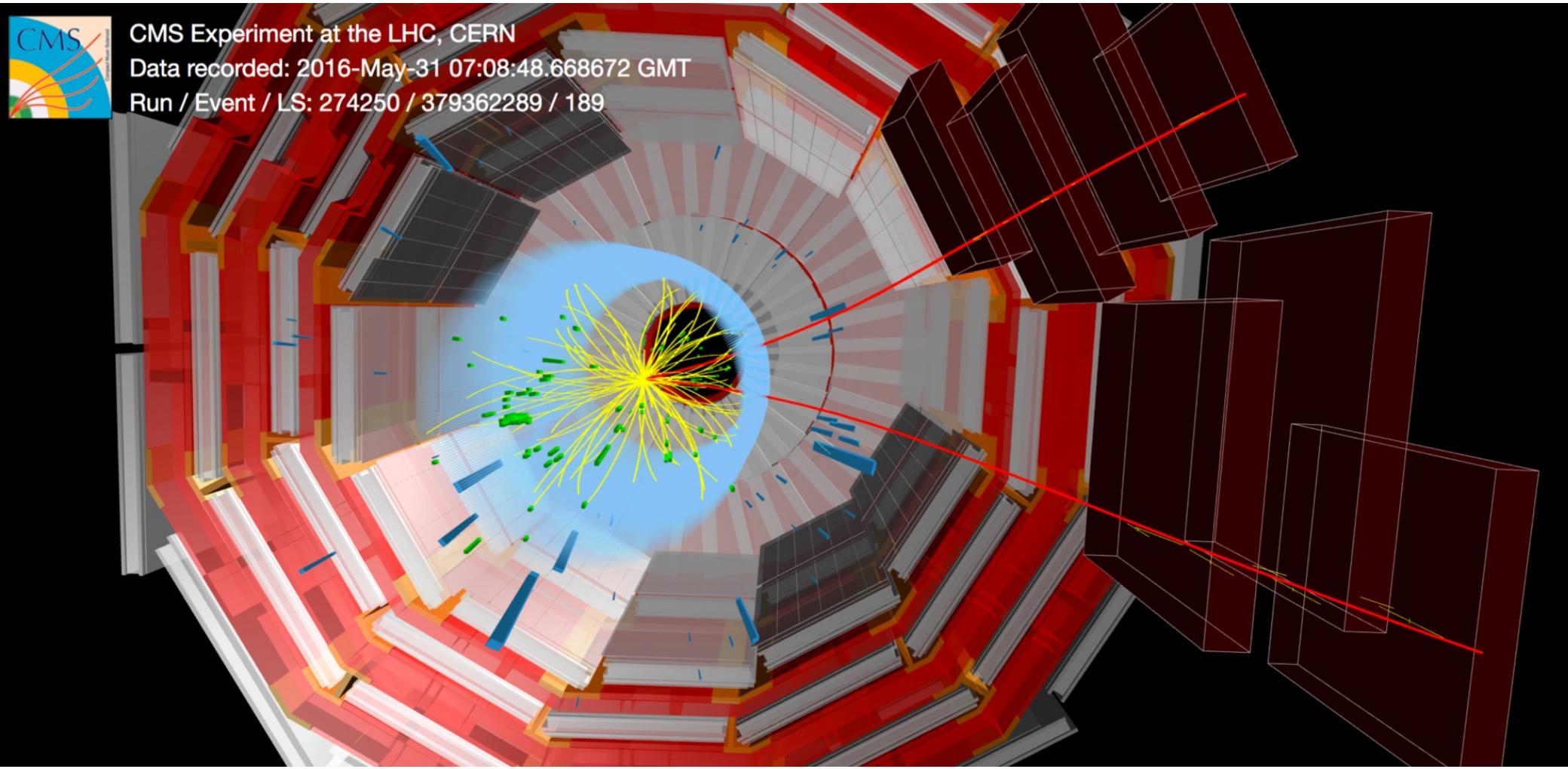
σ_{ttW+}(W+) = 0.553±0.030(stat.) ±0.030(syst.)pb

σ_{ttW-}(W-) = 0.343±0.026(stat.)±0.025(syst.) pb

Most precise values to date

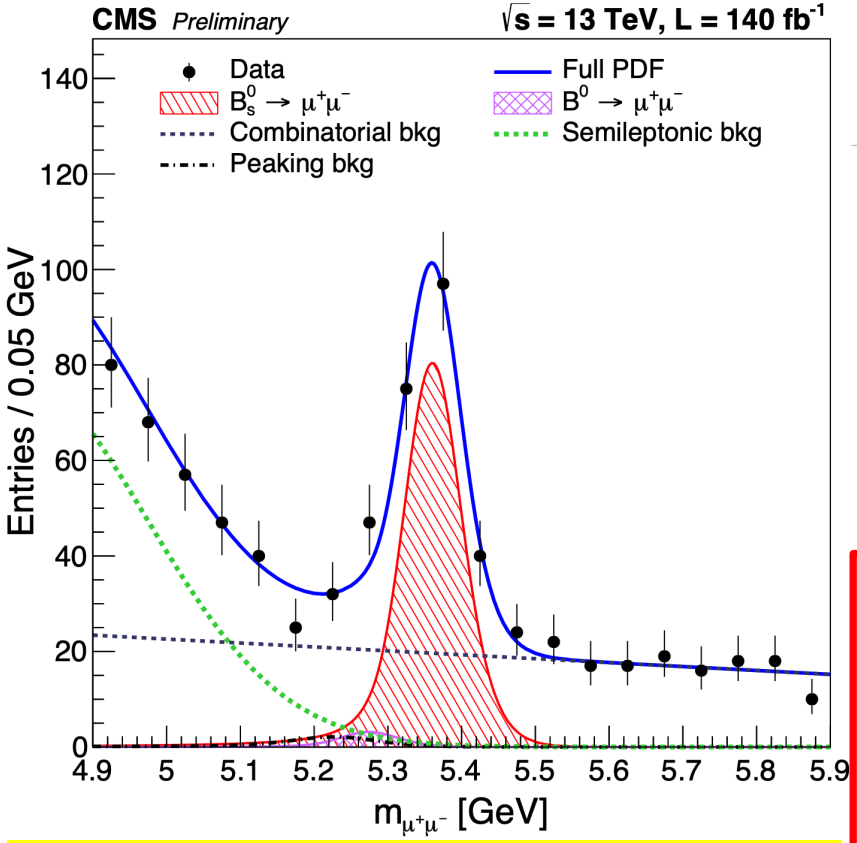
Results consistent with the SM predictions

$B_{d(s)} \rightarrow \mu\mu$ Candidate Event



$B_{(s)} \rightarrow \mu\mu$ Results in Run 2

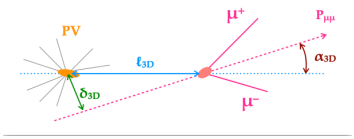
CMS-BPH-21-006



Summer 2020 combination of $B_{(s)} \rightarrow \mu\mu$ (ATLAS, CMS and LHCb)

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.69^{+0.37}_{-0.35}) \times 10^{-9}$$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{\mathrm{SM}} = (3.66 \pm 0.23) \times 10^{-9}$$



Summer 2022 $B_{s(d)} \rightarrow \mu\mu$ CMS result

- BF normalized using B → J/psi K (nominal) and B → J/psi Phi (alternative)
- New Multivariate Analysis (MVA_B) used to suppress backgrounds
- Fake rates in control samples Ks→ππ and Φ →KK
- New MVA based muon identification to improve Kaon decays in flight

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}\ (\mathrm{stat})\ ^{+0.19}_{-0.16}\ (\mathrm{syst})\ ^{+0.14}_{-0.13}\ (f_s/f_u)\right] \times 10^{-9}$$

Alternative using Bs→J/ψϕ: $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[3.95^{+0.39}_{-0.37}\ (\mathrm{stat})\ ^{+0.27}_{-0.22}\ (\mathrm{syst})\ ^{+0.21}_{-0.19}\ (\mathrm{BF})\right] \times 10^{-9}$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left[0.37^{+0.75}_{-0.67}\ (\mathrm{stat})\ ^{+0.08}_{-0.09}\ (\mathrm{syst})\right] \times 10^{-10}$$

The results are compatible with the SM predictions

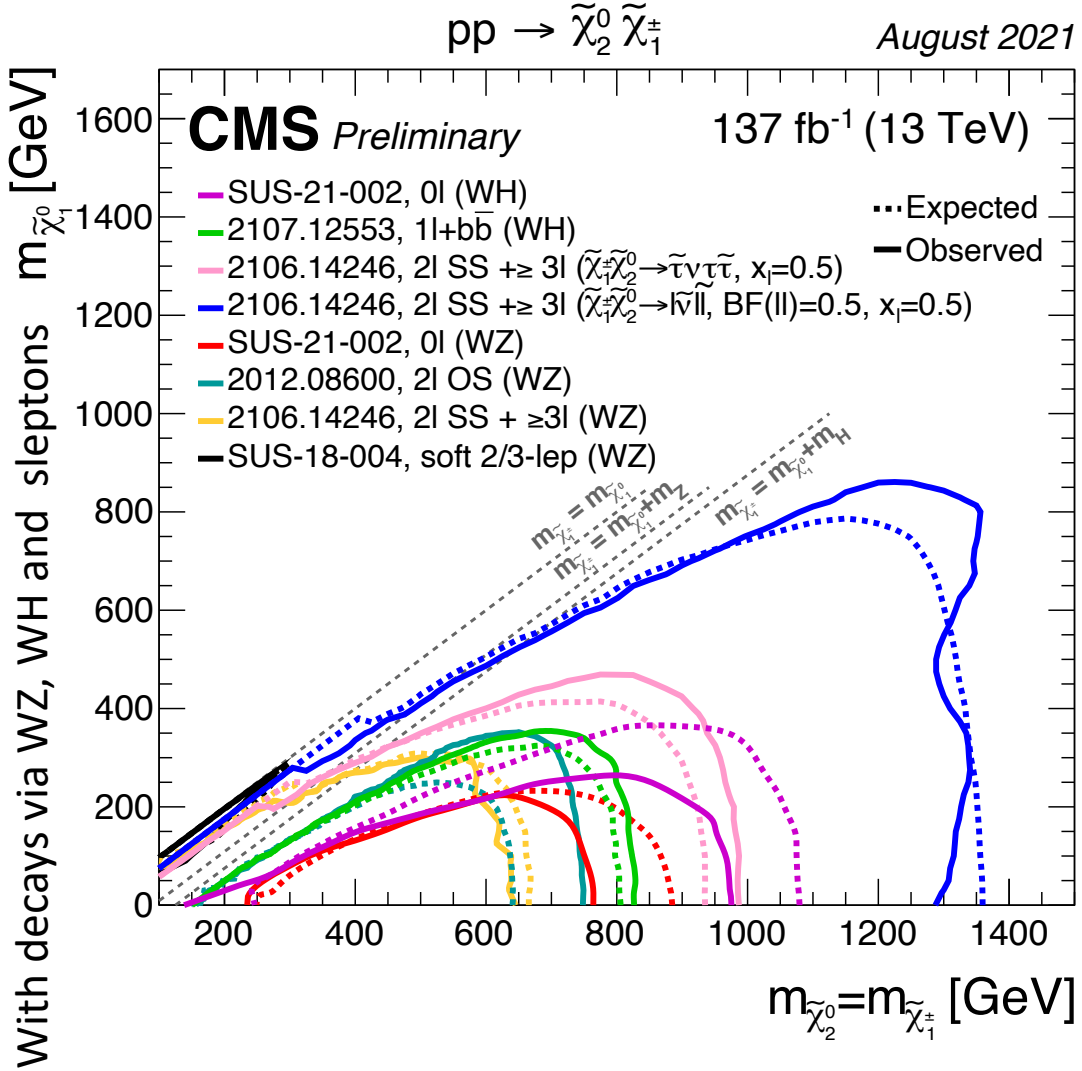
Most precise measurement from a single experiment

Part 3- Searches for direct production

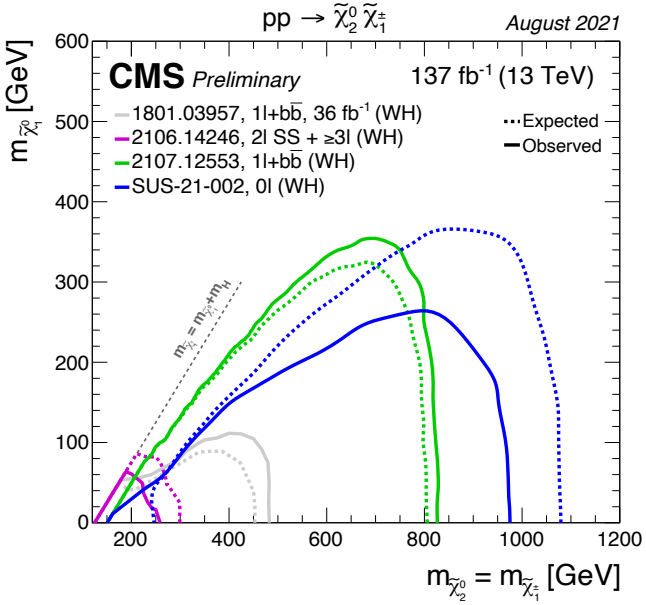
- What else is being seen in Run 2 data ?
  - Or else…what have not been seen … yet
- A set of Universal Measurements serving many original phenomenological analysis needs in a variety of models
- Examples of such results – selected today:
  - SUSY Phenomenology
  - Search for new higgs particles neutral or charged $H^{+/-}$, H^{++}
  - Di-boson resonances in VV, Vγ, VH, HH channels
  - Z', W', LQ, excited quarks, resonances in di-jets
- Many improvements observed in existing Run 2 results compared to Run 1 using new highly optimized ML techniques

Search for SUSY EWKinos in Run 2

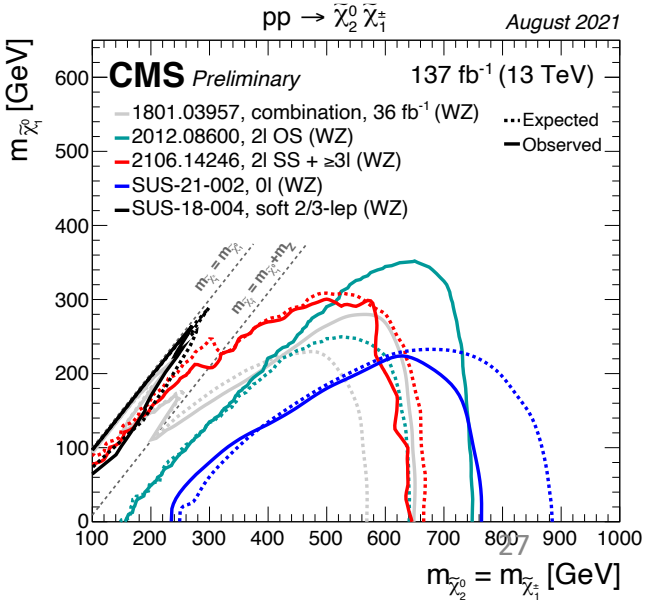
EWK production of chargino-neutralino pair



With decays via W/H

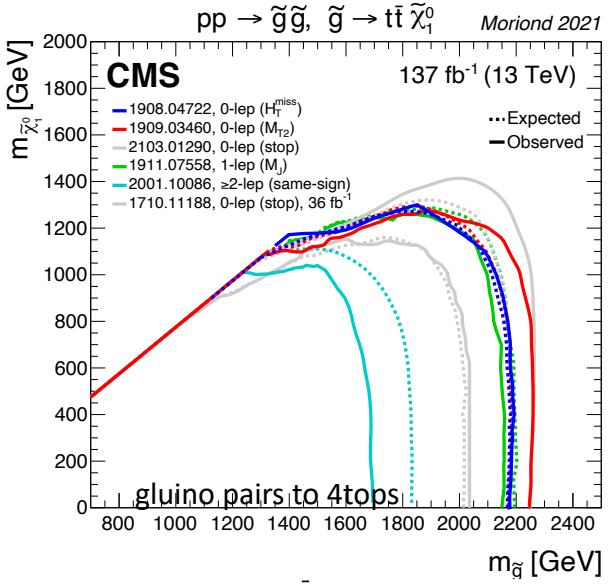


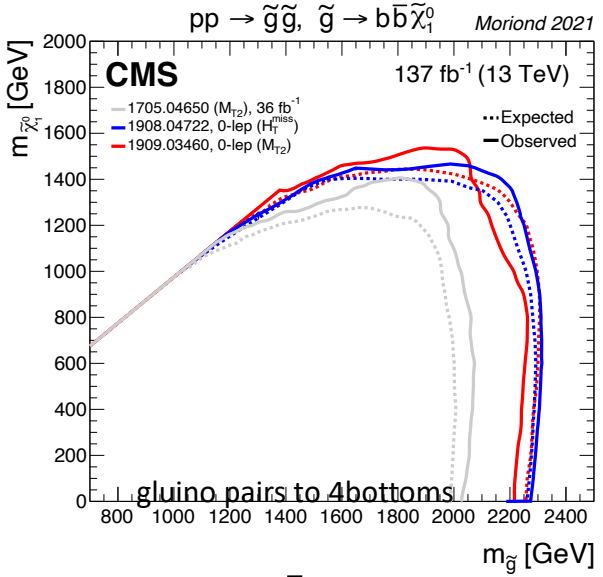
With decays via W/Z/H

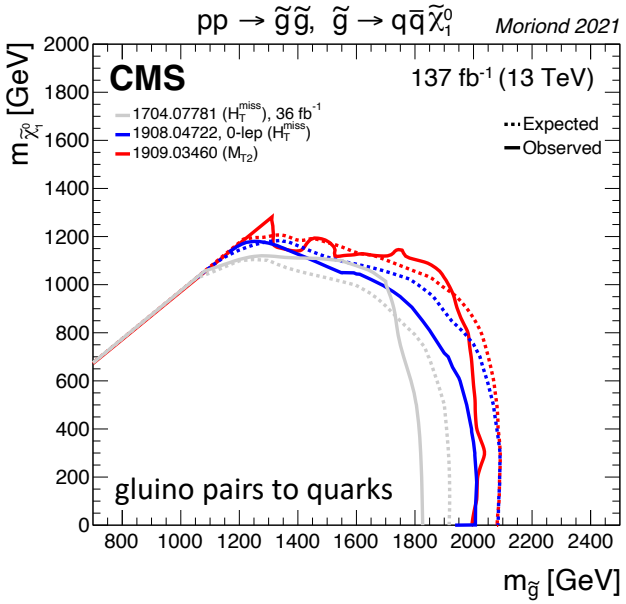


Search for colored SUSY in Run 2

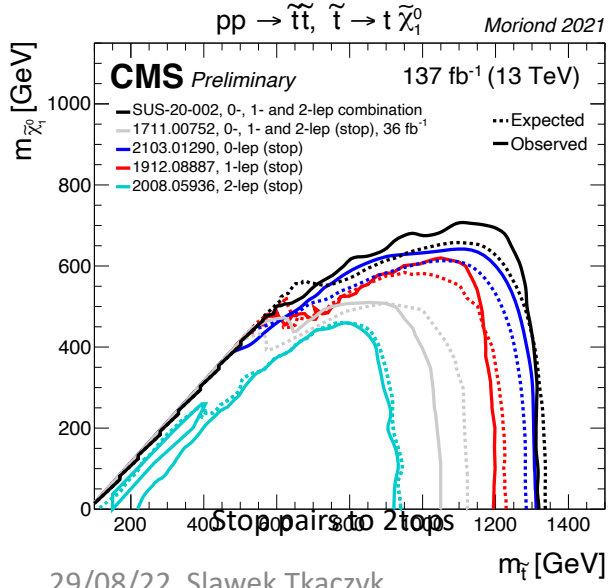
gluinos

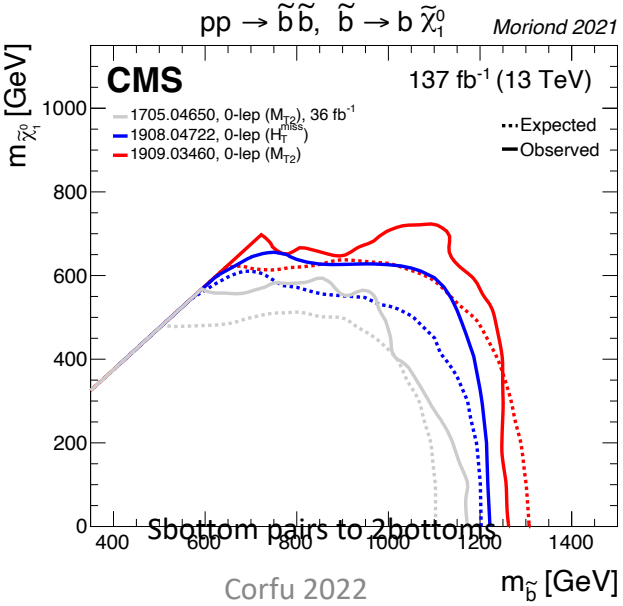


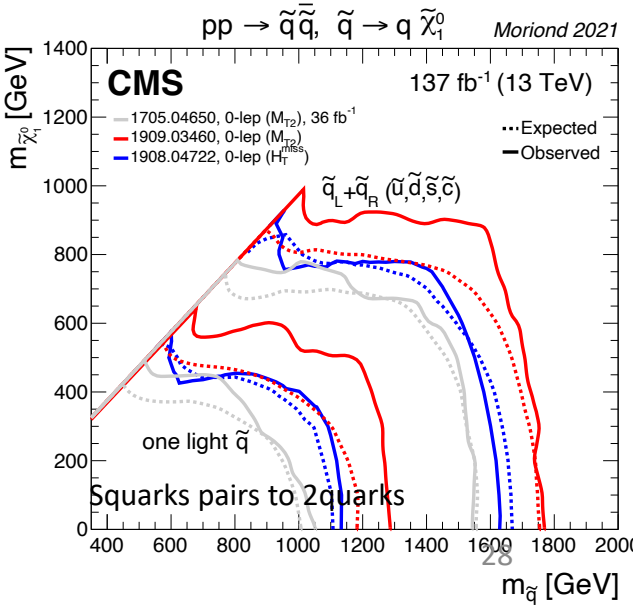




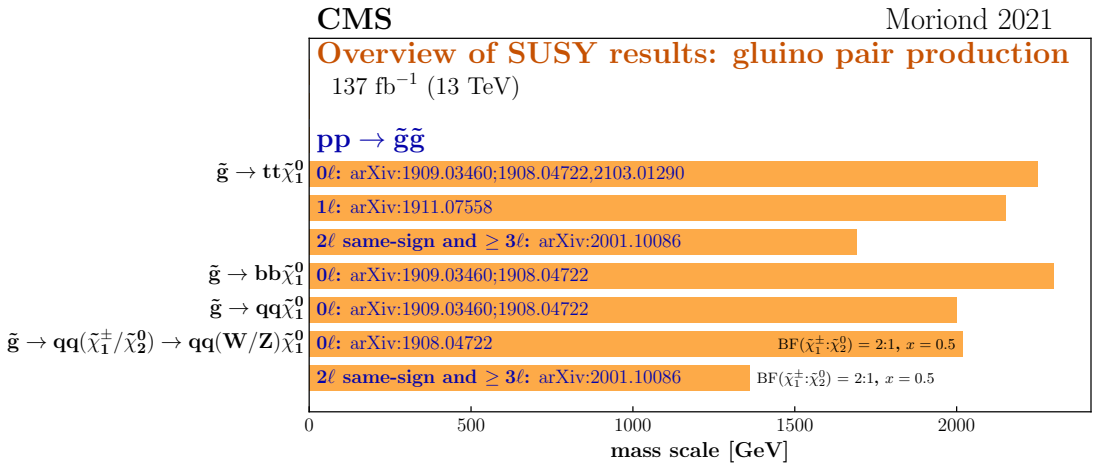
Stop, sbottom, squarks



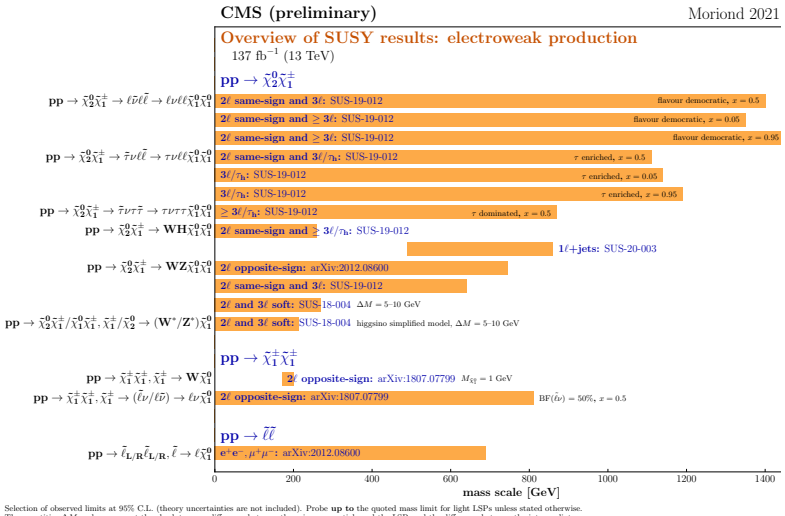




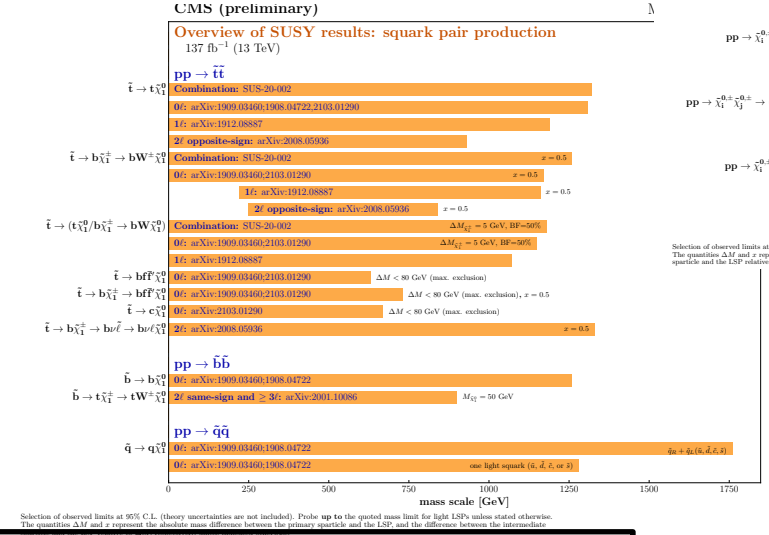
SUSY Searches Summary



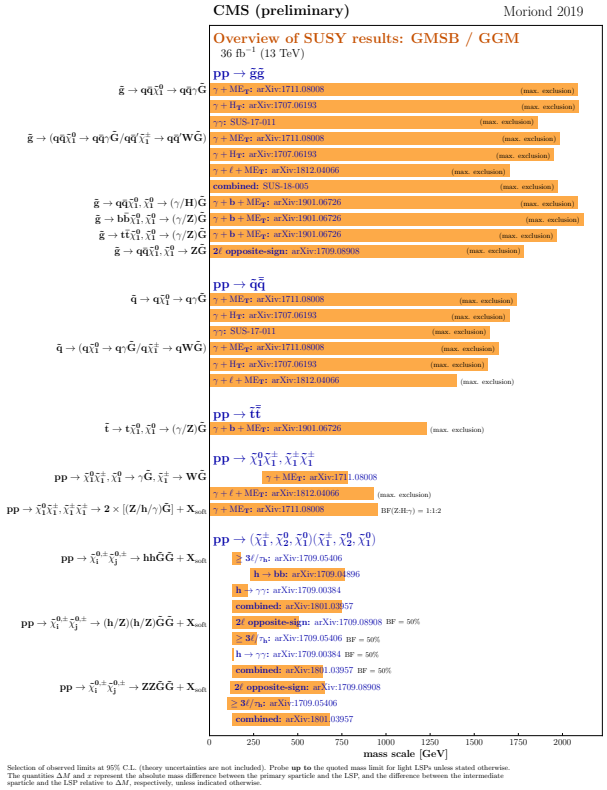
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.



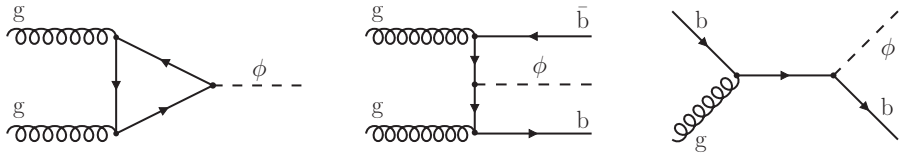
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

No sign of SUSY found at the LHC Run 2
continue probing the TeV scale using Simplified models

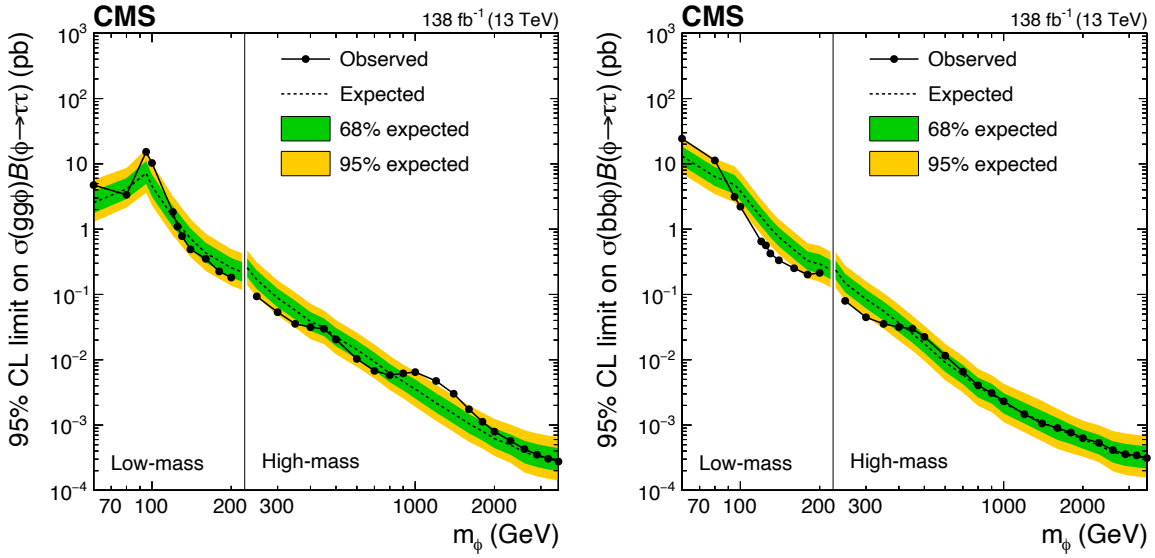
Search for neutral higgs ϕ

CMS-HIG-21-001
arXiv:2208.02717

Neutral higgs ϕ in ggF or in association with b-quark(s)



ϕ → ττ decays in lepton or hadron decays



Limits set [60 - 2000 GeV] ranging from 10pb to 0.3fb
e.g. two excesses in ggϕ at 0.1 and 1.2 TeV with ~3σ

In MSSM scenarios M_h^{125} & $M_{h,\,EFT}^{125}$ additional Higgs bosons with masses below 350 GeV excluded

Search for heavy higgs to WW decays

CMS-PAS-HIG-020-016

ggF and VBF production considered
Fully leptonic final states (ee, μμ, eμ)

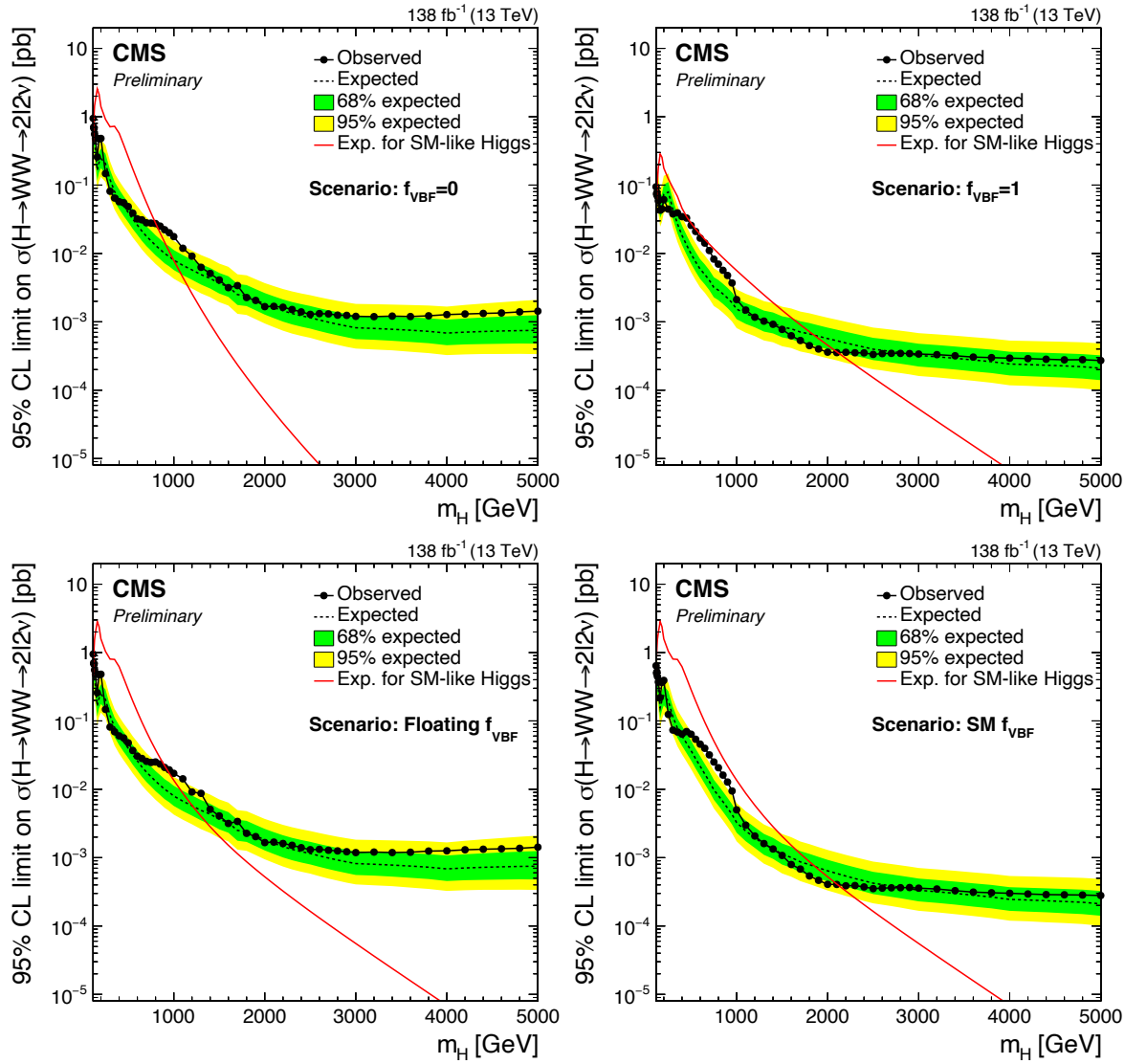
New analysis techniques implemented
Various width hypothesis considered

Heavy higgs excluded up to 2100TeV @95% CL depending on the production model

Upward fluctuation observed in data over the expected background

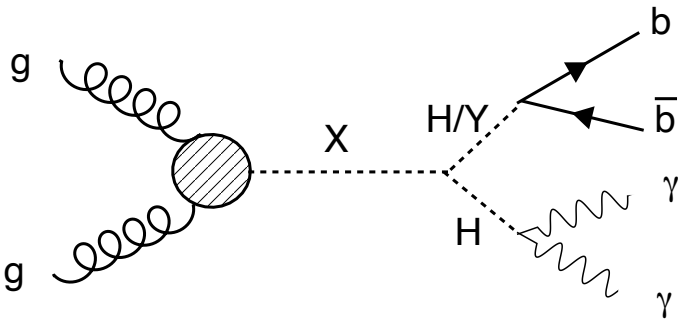
Signal hypothesis at mass of 650 GeV with highest global significance of 2.6σ for VBF production only

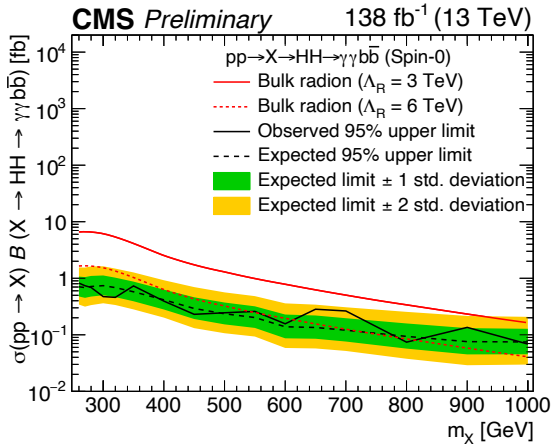
Additional exclusion limits obtained on MSSM and 2HDM scenarios

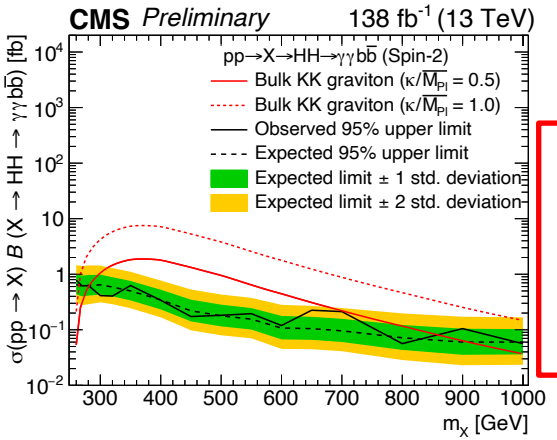


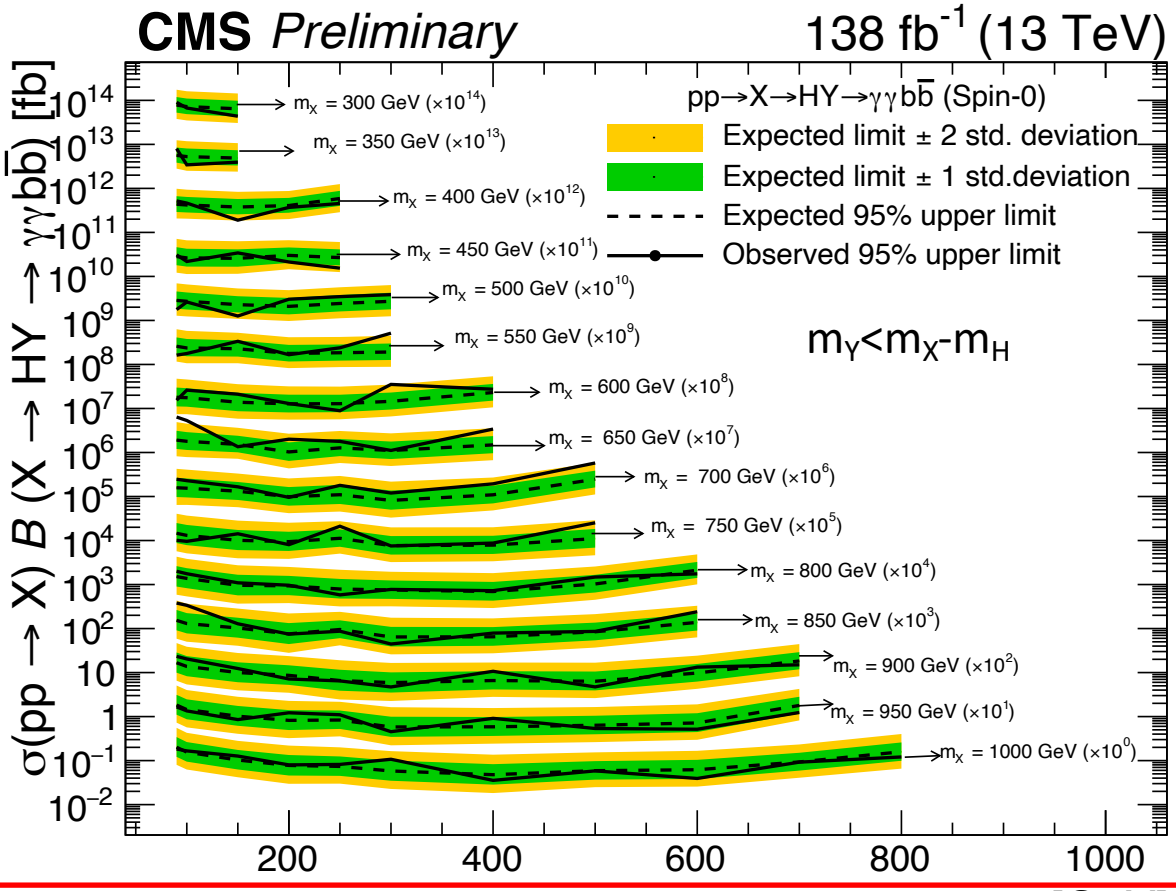
Search for X → H/Y(bb)H(γγ)

CMS-PAS-HIG-021-011









Overall agreement with the SM

Data compatible with background-only-hypothesis

Largest deviation M_X=650GeV and M_Y=90GeV w/ Local (Global)3.8σ(2.8σ)

Search for charged Higgs

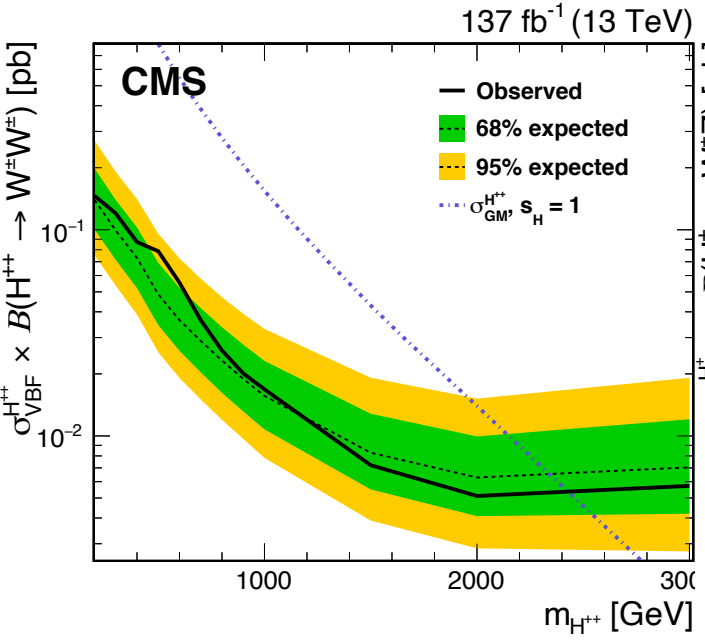
CMS HIG-20-017

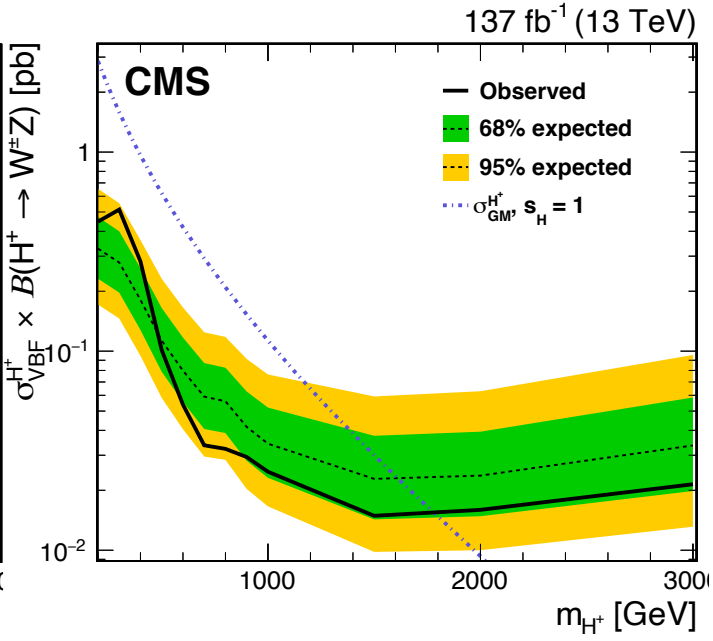
Eur. Phys. J. C 81 (2021) 723

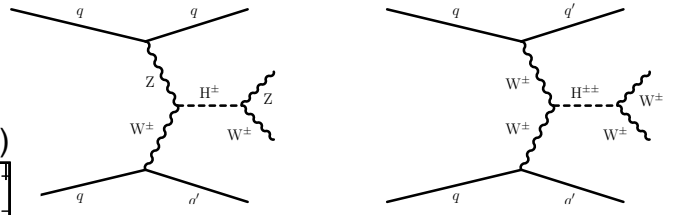
VBF production of charged Higgs:$H_5(H^+, H^{++})$ – degenerated in mass@LO

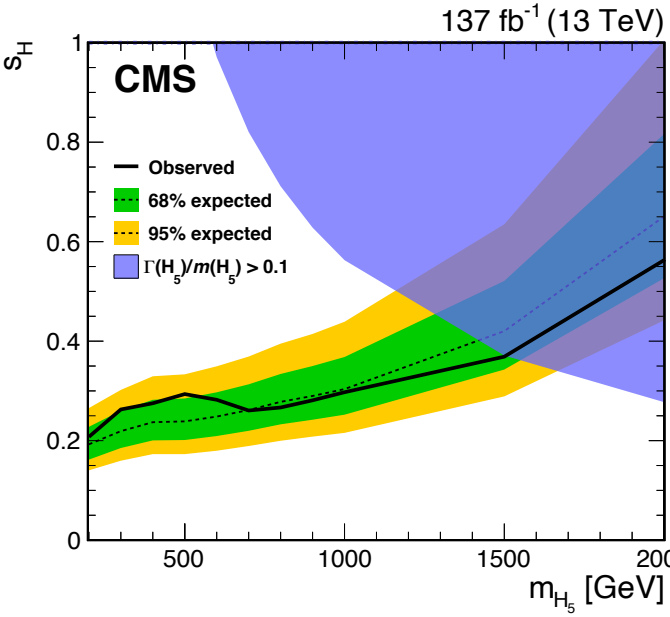
Leptonic decays of VV and VBS selection

Interpretation using **Georgi-Machacek** model with additional triplets









Most stringent limits on production **of GM charged higgses to** date

GM particles as a resolution of tensions in EWK fits with new CDF m_W e.g.Ellis et al. arXiv:2204.05260 - list tree-level single field extensions that include EFT dim-6 operators providing a better fit than SM alone among them 2.9TeV Ξ– triplet

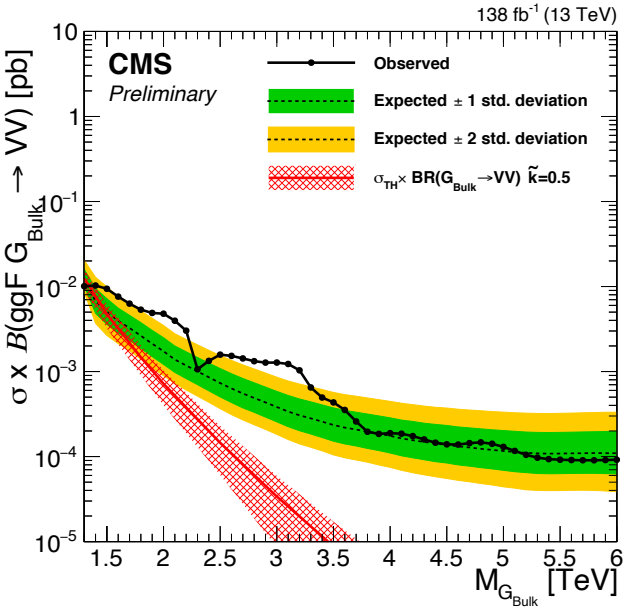
Exclusion of model parameter S_H for masses 200-1500GeV: 0.2-0.35@95%CL

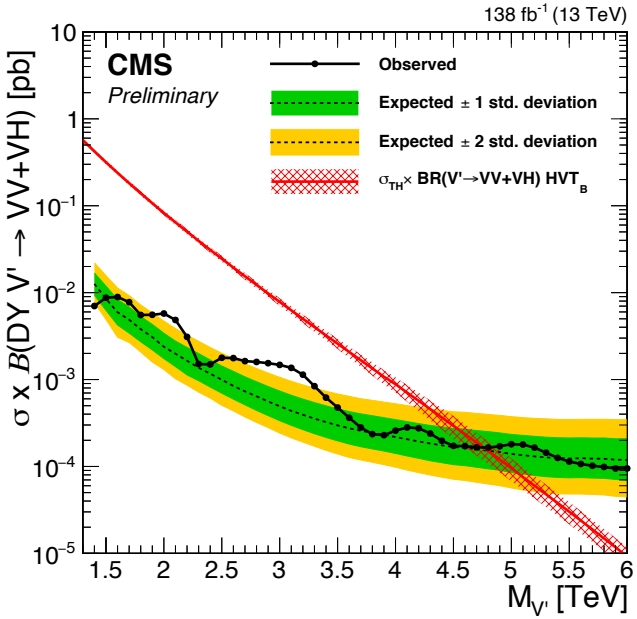
Search for VV,VH All-Hadronic Resonance

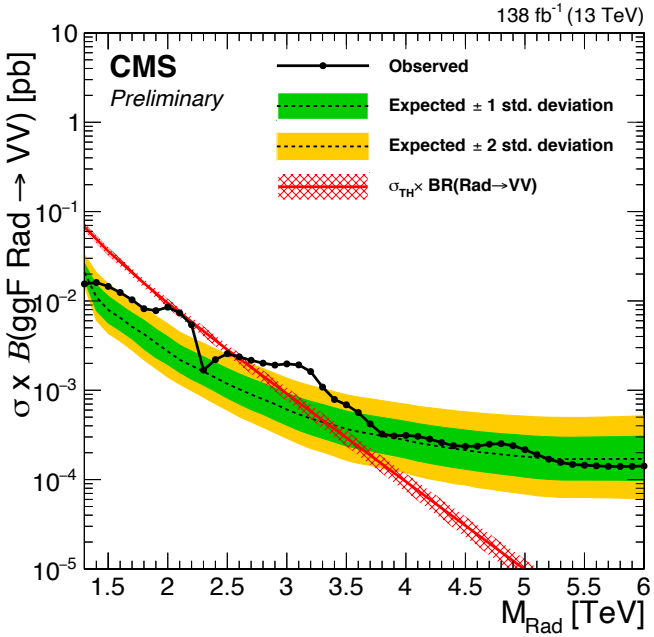
CMS PAS B2G-20-009

Models: Gravitons, heavy spin-1 bosons (W', Z') and spin-0 radions

Decay channels: Bosons highly boosted reconstructed as 1 super-jet with a new algorithm







G_{bulk} Limit: Upper Limit on x-section and branching ratio

Limits on the Heavy Vector Triplet "B" type model:
V': 4.8 TeV at 95%CL

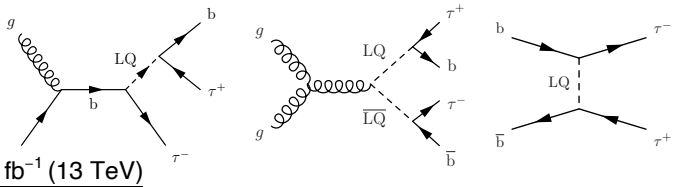
Limits on Radion mass:
rad: 2.7 TeV at 95%CL

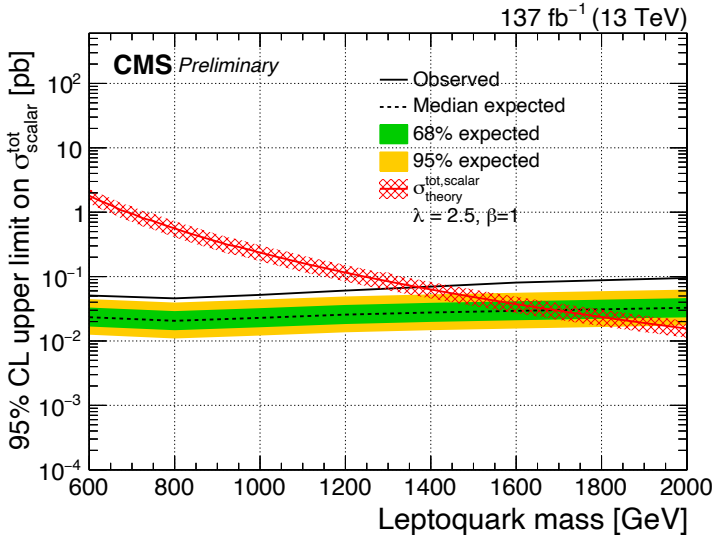
Mild excesses observed @2.1&2.9TeV with 3.6σ(2.3σ) local (global) significance

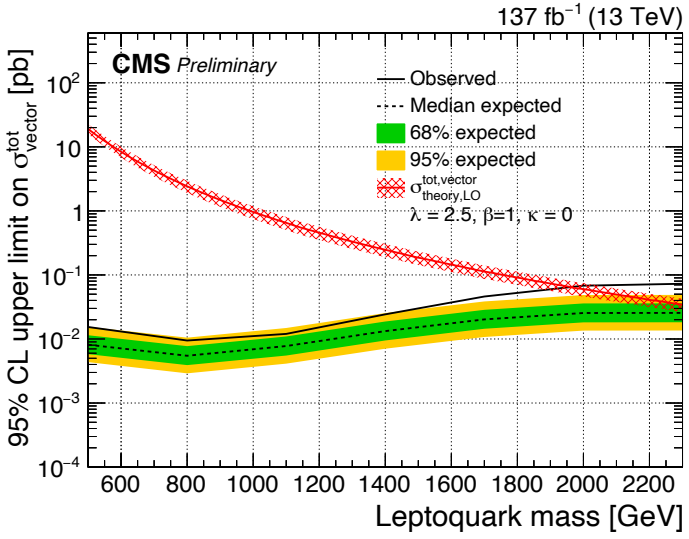
Search for 3rd-Gen LeptoQuarks

CMS-PAS-EXO-19-016

3rd gen. LQ with a pair of ττ and b-quark in the final state
LQ predicted by many extensions of the SM







95%CL Limits set on LQ coupled to b-quark and τ lepton with LQ masses excluded :

LQ^{scalar} — below 1.25 (1.37)TeV with λ=1(λ=2.5)

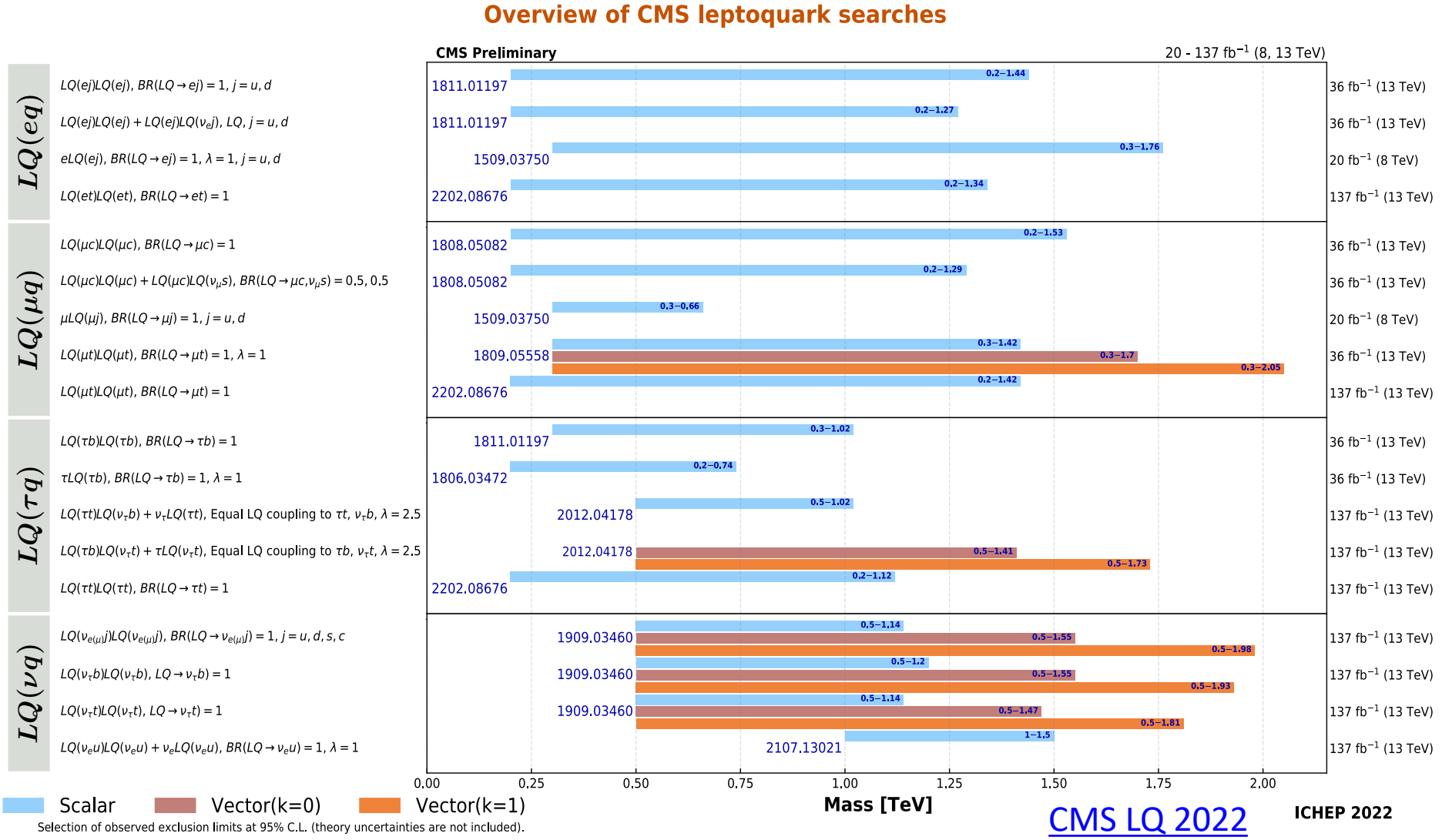
LQ^{vector} – below 1.53(1.86)TeV for κ=0(1) and λ=1

LQ^{vector} – below 1.86(1.96)TeV for κ=0(1) and λ=2.5

ULimits set on LQ coupling strength to b-quark and τ lepton:
e.g. excluded portion of the parameter space that can explain b-physics anomalies

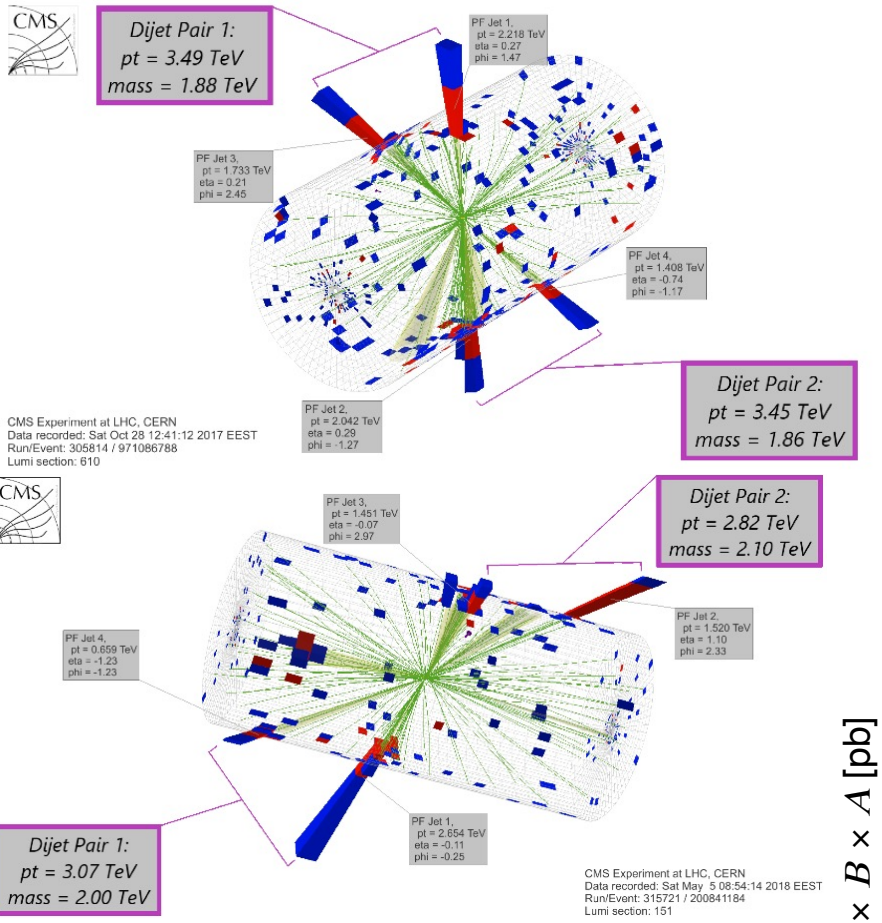
For LQ mass of 2TeV an excess of ~3.4σ observed in the t-channel LQ exchange

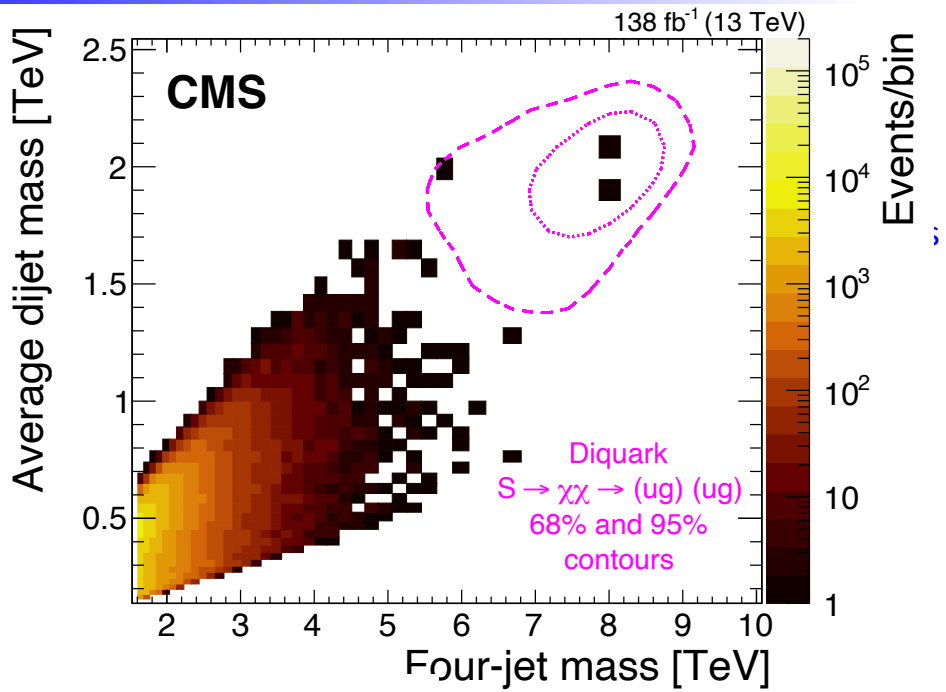
Summary of LQ Searches

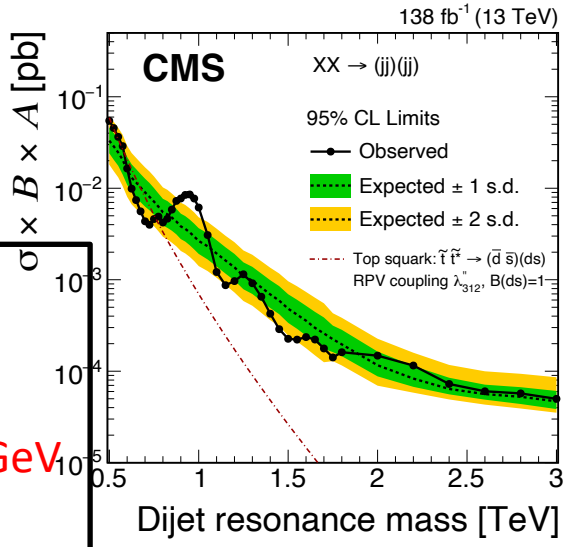


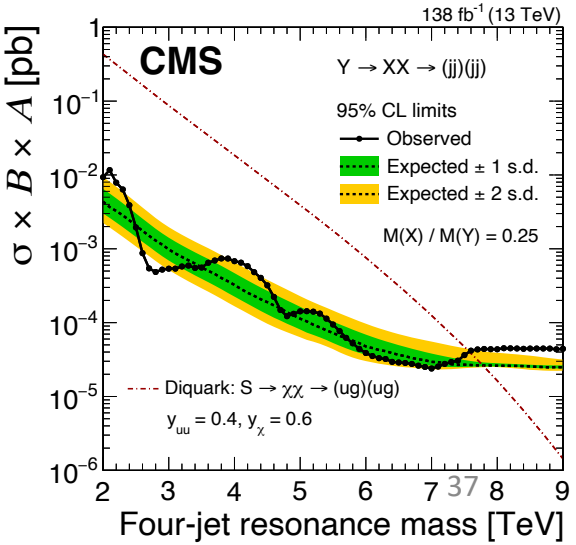
Search for new physics in 4-jets - Run2

CMS PAS EXO-21-010







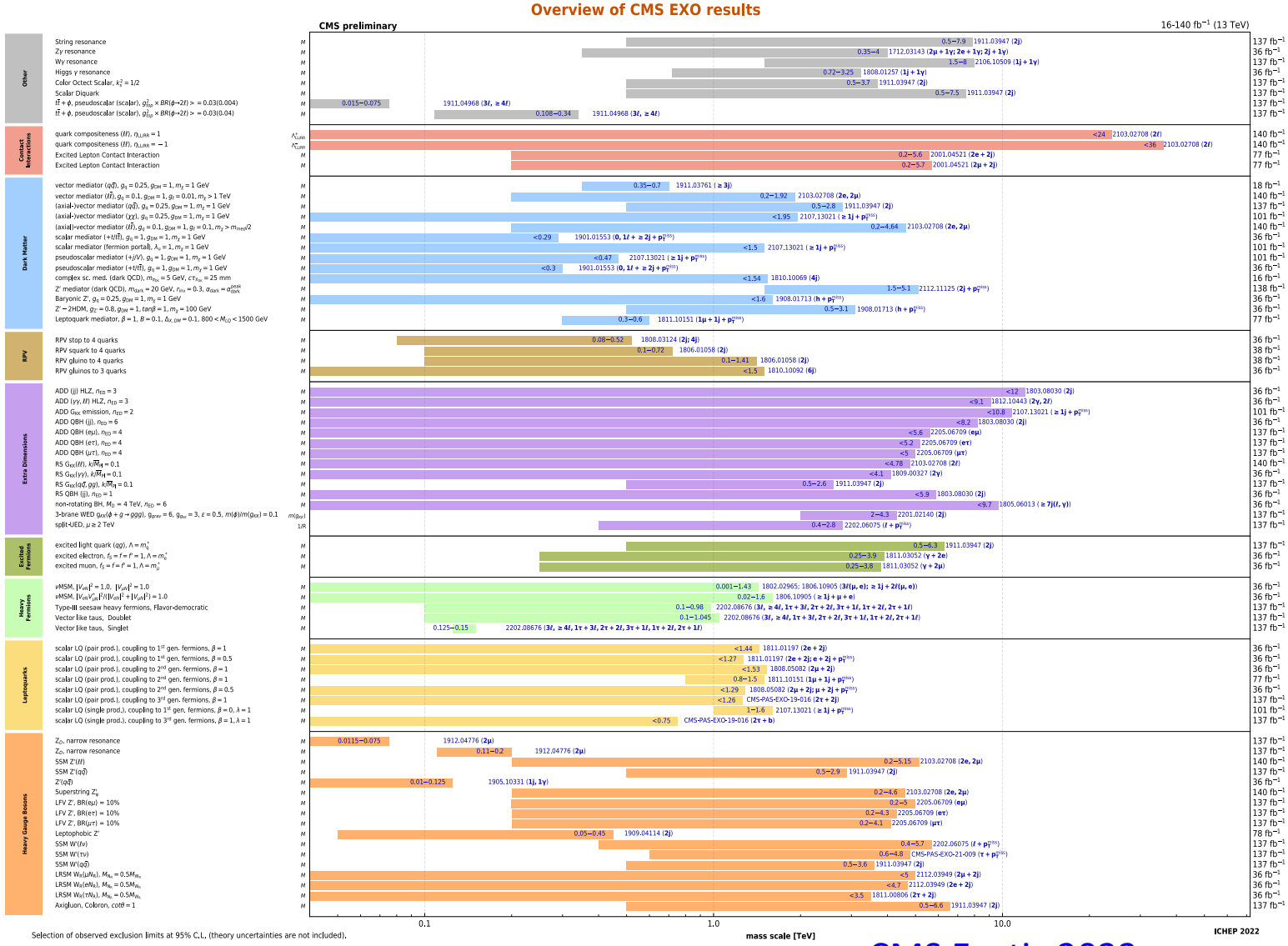


Resonant: 2 events in tails (8,2)GeV

3.9σ(1.6σ) local (global)

Non-resonant: extended limits on stop in RPV SUSY 3.6σ(2.5σ) local (global) @950GeV

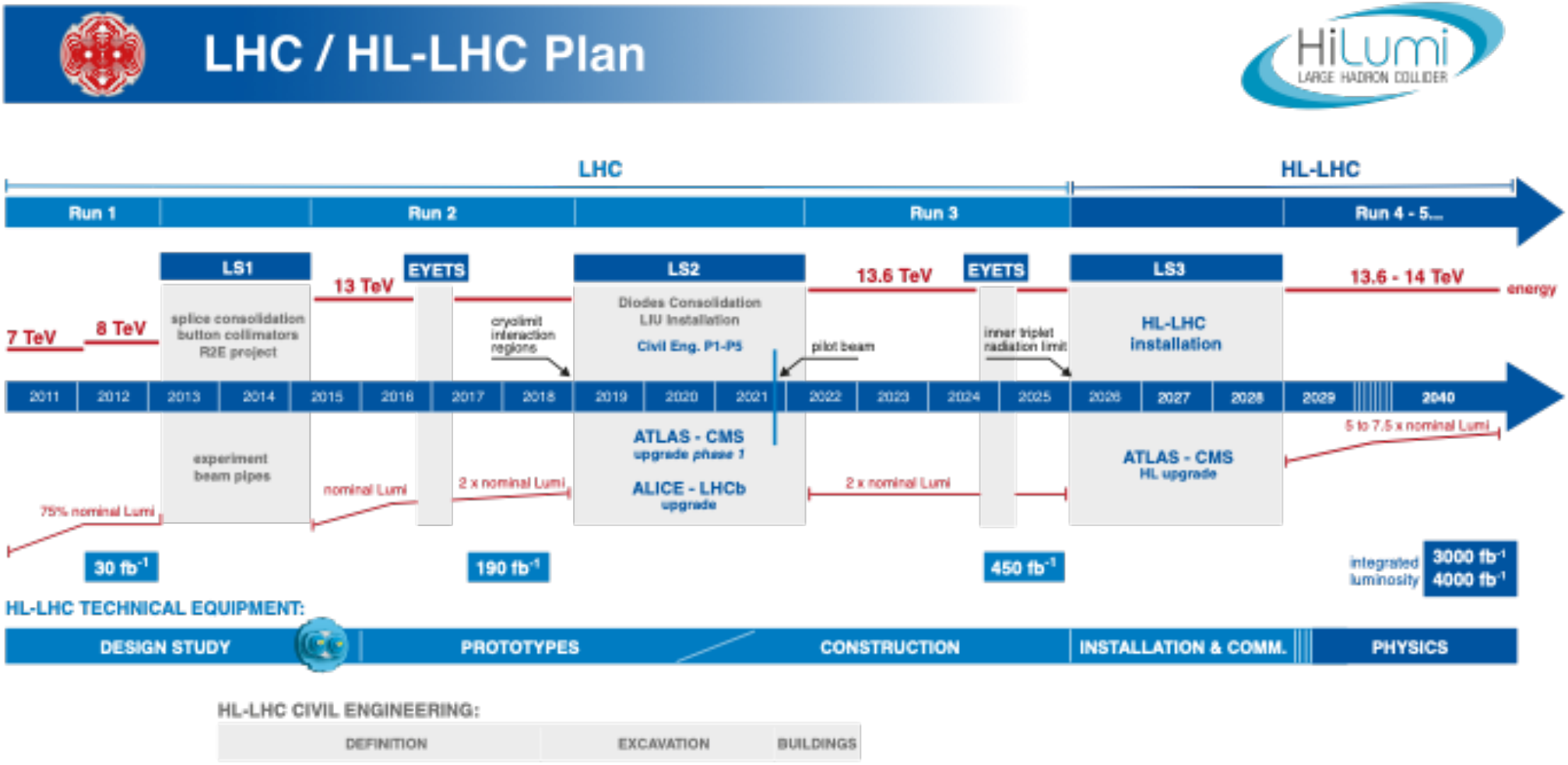
Summary of Exotic Searches



[CMS Exotic 2022]

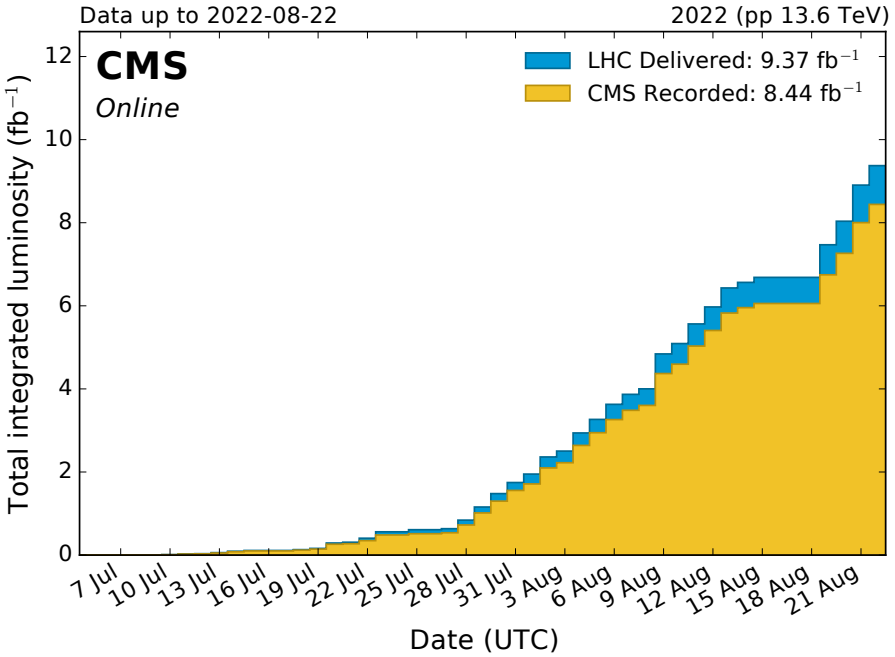
Part 4 – What is next ?

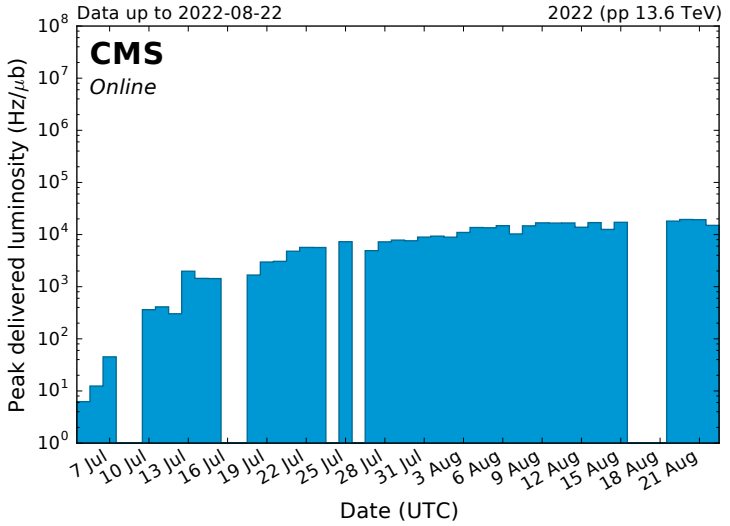
Beyond Run 2

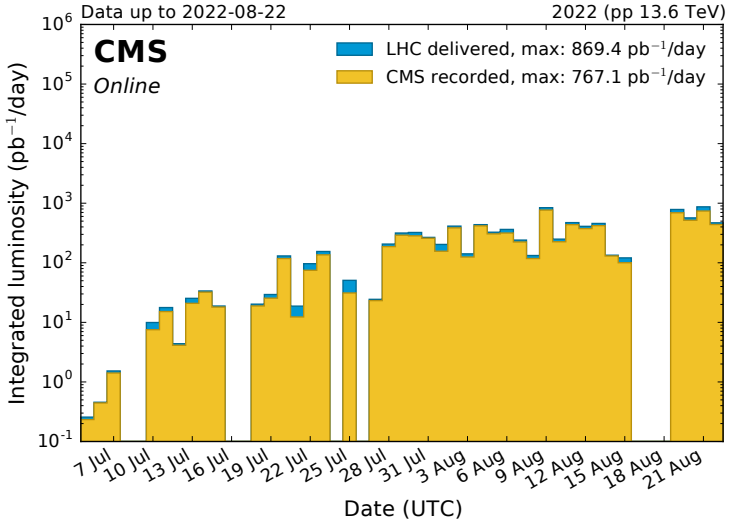

LHC / HL-LHC Plan
HiLumi
LARGE HADRON COLLIDER
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
pilot beam
inner triplet
radiation limit
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1
HL-LHC TECHNICAL EQUIPMENT:
DESIGN STUDY
PROTOTYPES
CONSTRUCTION
INSTALLATION & COMM.
PHYSICS
HL-LHC CIVIL ENGINEERING:
DEFINITION
EXCAVATION
BUILDINGS

Start of Run 3 at 13.6 TeV

- **Run 3** has just started – 2022-2025 following minor detector improvements during LS2 (2019-2021)







- After Run 3 : Major LHC detector upgrades during LS3 (2026-2028)
- HL-LHC running in Run 4 + from 2029 onwards

CONCLUSIONS

- Many precise and important measurements from Run2 already available:
  - Higgs boson, Top quark and gauge boson measurements
  - Direct searches for new physics
- No signs of physics beyond standard model yet, but Run2 analyses continue and Run3 has just started
- Improved limits on new particles produced directly can be used to further constrain the model building !
- The well known open questions still remain!

- Many more new and interesting results from Run 2 which I had no time to discuss : focus on full data set and newest results

- Other talks at this conference extend the coverage:
  - Mon 28.09 – 10:30 – Lydia Brenner – “Higgs boson property measurements at the Atlas and CMS experiments”
  - Sat 03.09 – 17:00 – Vasiliki Mitsou – “Searches for supersymmetry with the Atlas and CMS detectors”
  - Mon 05.09 – 13:00 – Nishu Nishu – “Searches for dark matter with the Atlas and CMS detectors”

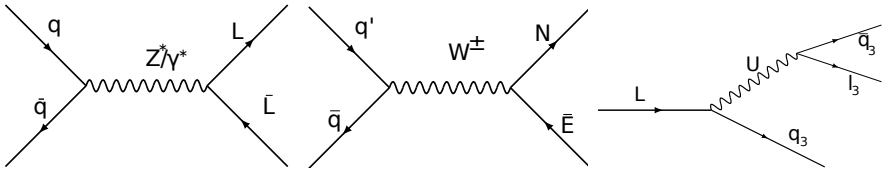
- More information about CMS publications on CMS twiki
  - CMS Preliminary Public Results

Additional Slides

Search for Vector Like Leptons

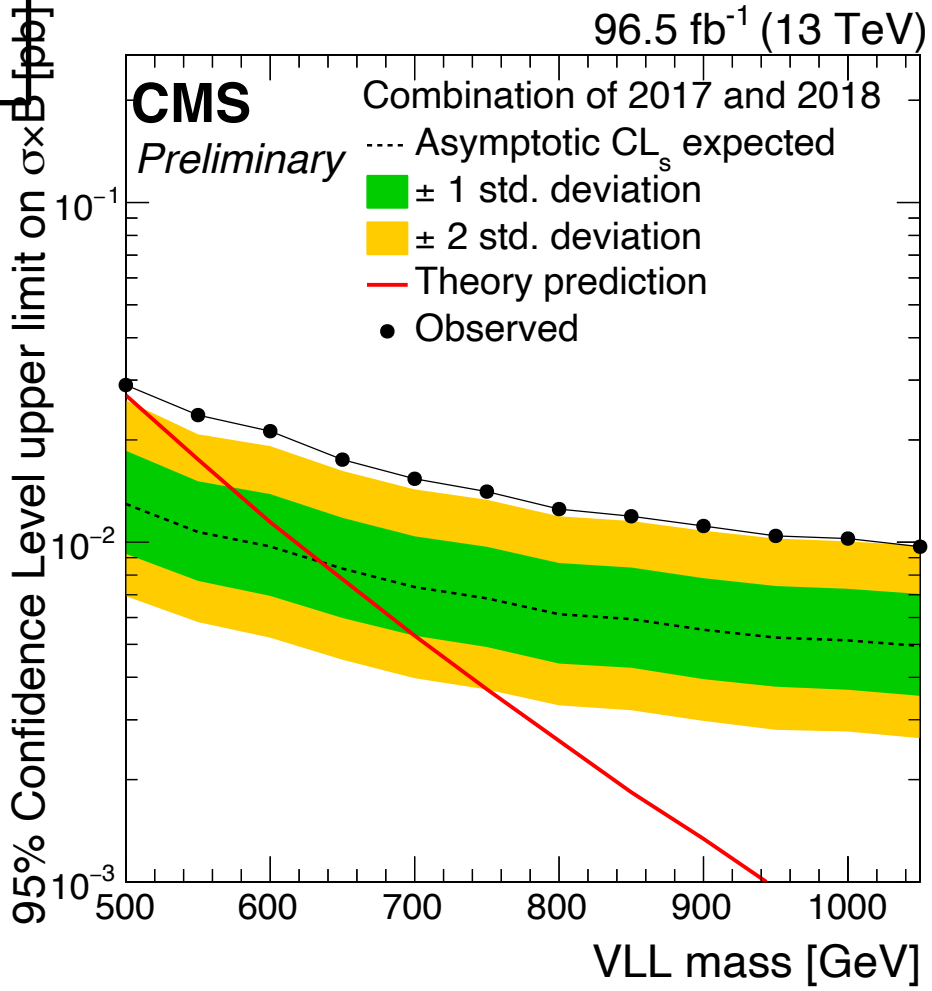
CMS-PAS-B2G-021-004

Vector Like –Leptons from 4321 UV-complete model
Potential to explain B-physics results tensions with SM



Final states with more than 3 b-jets and a pair ($\tau\nu$, $\tau\tau$, $\nu\nu$) in the final state

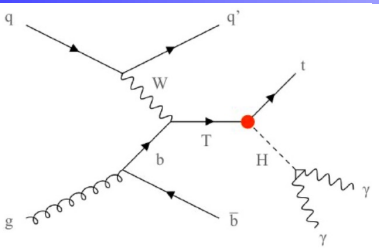
Expected exclusion of VLL masses below 640 GeV
Observed: small excess in the data !
Observed excess consistent with presence of VLL's with mass of 600 GeV at the level 2.8σ
over the background only hypothesis

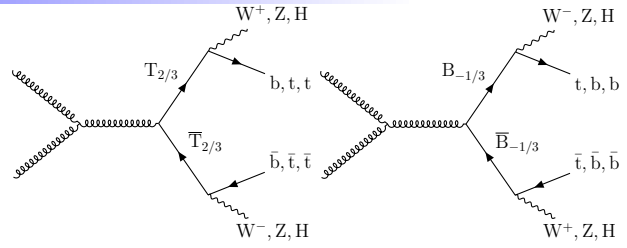


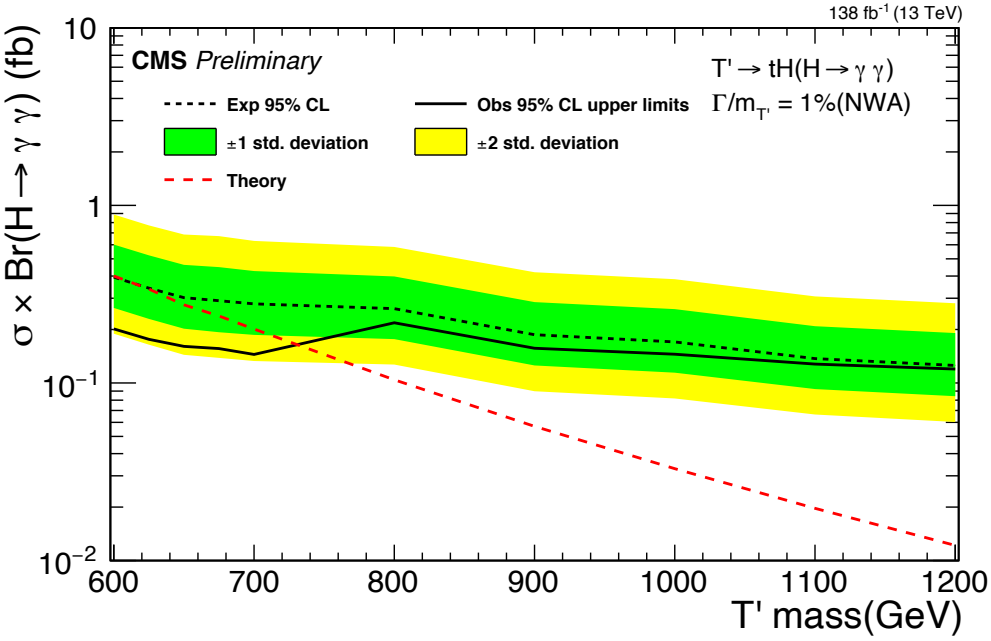
Search for Vector Like Quarks

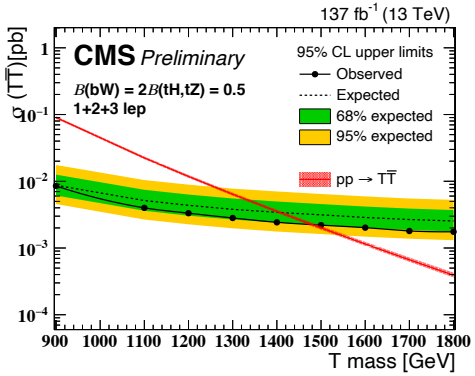
CMS-PAS-B2G-021-007 CMS-PAS-B2G-020-011

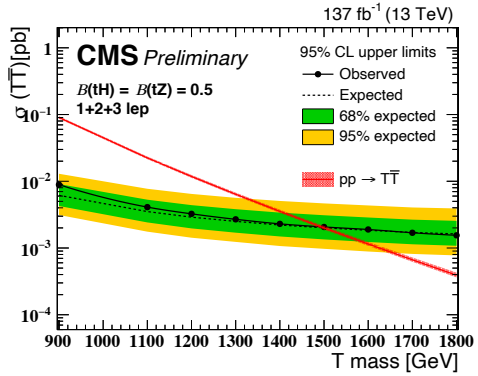
Vector Like – Quarks in single and pair production
Resonans of t/b quarks with bosons

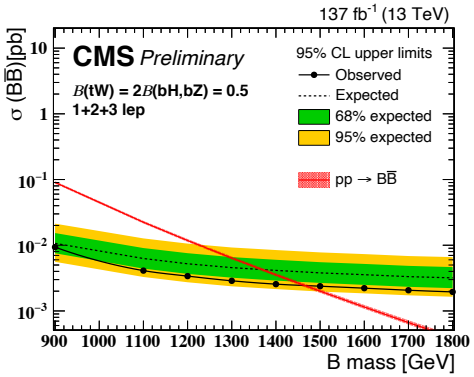


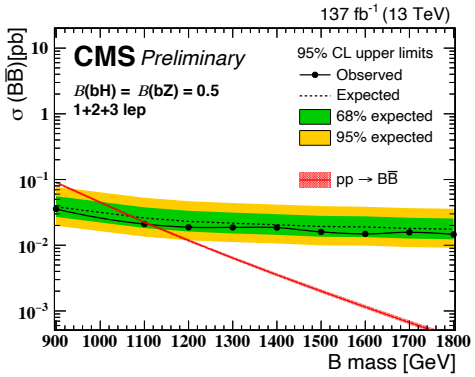












Exclusion of VLQ below 730 GeV@95%CL

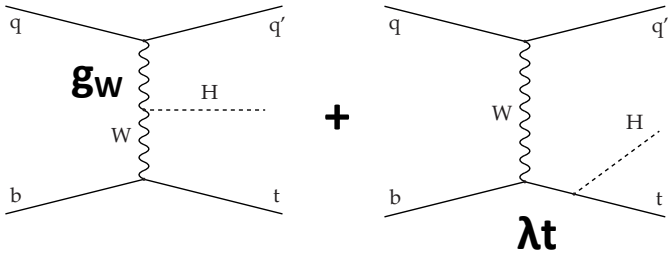
Exclusion of T VLQ below 1.54 Tev@95%CL
Exclusion of B VLQ below 1.56 Tev@95%CL

Higgs Run 2 Results tH, ttH channels

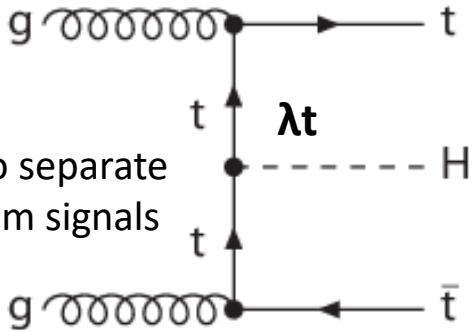
Eur. Phys. J. C 81 (2021) 378

tHV + tHq + ttH with tt decays to multi-ℓ or all-jet final states

Unique channel to study the relative sign of couplings



Direct probe of Top Yukawa cplg **λt**



MVA, ML and ME techniques to separate ttV and tt+jets backgrounds from signals

H→WW*,ZZ*,ττ – channels in 10 signatures depending on lepton multiplicity

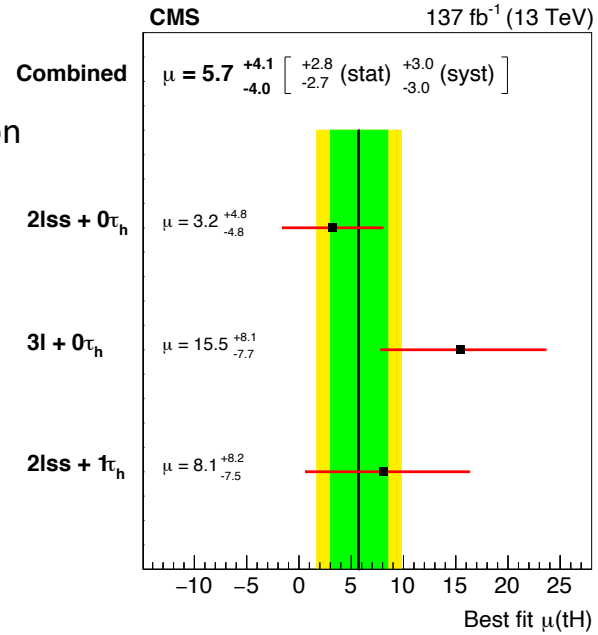
$K_t = y_t/y_t^{SM}$ top Yukawa modifier under assumption that H coupling to τ equal in strength to SM value

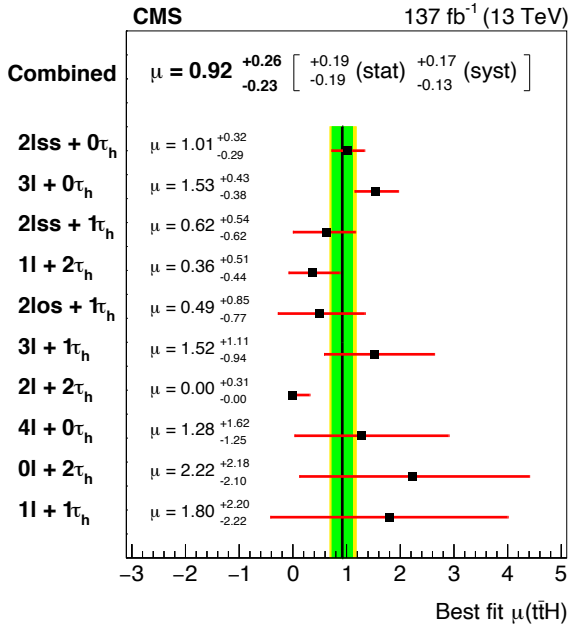
$-0.9 < K_t < -0.7$ @95%CL

$0.7 < K_t < 1.1$ @95%CL

Significance for tH with M_h=125 GeV:
Observed: **1.4** σ Expected: 0.3 σ

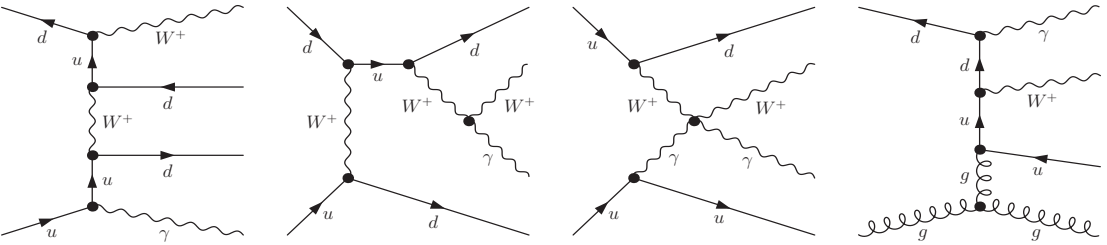
Significance for ttH with M_h=125 GeV:
Observed: **4.7** σ Expected: 5.2 σ

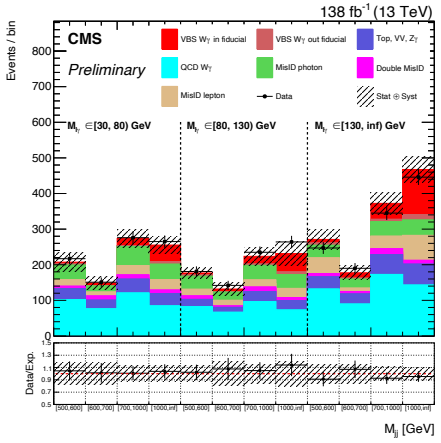




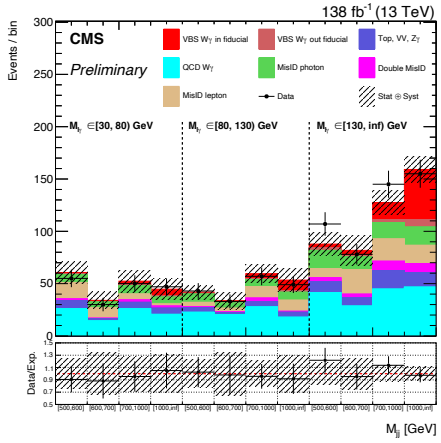
Vector Boson Scattering: Wγ

CMS-PAS-SMP-21-011





(a) Barrel



(b) Endcap

- Observation of the Wγ EWK production
- VBS Signature: 2-j w/ large m_{jj} & $\Delta\eta_{jj}$
- NLO EW corrections not included

Expected. limit	Observed. limit	U_{bound}
$-5.1 < f_{M0}/\Lambda^4 < 5.1$	$-5.6 < f_{M0}/\Lambda^4 < 5.5$	1.7
$-7.1 < f_{M1}/\Lambda^4 < 7.4$	$-7.8 < f_{M1}/\Lambda^4 < 8.1$	2.1
$-1.8 < f_{M2}/\Lambda^4 < 1.8$	$-1.9 < f_{M2}/\Lambda^4 < 1.9$	2.0
$-2.5 < f_{M3}/\Lambda^4 < 2.5$	$-2.7 < f_{M3}/\Lambda^4 < 2.7$	2.7
$-3.3 < f_{M4}/\Lambda^4 < 3.3$	$-3.7 < f_{M4}/\Lambda^4 < 3.6$	2.3
$-3.4 < f_{M5}/\Lambda^4 < 3.6$	$-3.9 < f_{M5}/\Lambda^4 < 3.9$	2.7
$-13 < f_{M7}/\Lambda^4 < 13$	$-14 < f_{M7}/\Lambda^4 < 14$	2.2
$-0.43 < f_{T0}/\Lambda^4 < 0.51$	$-0.47 < f_{T0}/\Lambda^4 < 0.51$	1.9
$-0.27 < f_{T1}/\Lambda^4 < 0.31$	$-0.31 < f_{T1}/\Lambda^4 < 0.34$	2.5
$-0.72 < f_{T2}/\Lambda^4 < 0.92$	$-0.85 < f_{T2}/\Lambda^4 < 1.0$	2.3
$-0.29 < f_{T5}/\Lambda^4 < 0.31$	$-0.31 < f_{T5}/\Lambda^4 < 0.33$	2.6
$-0.23 < f_{T6}/\Lambda^4 < 0.25$	$-0.25 < f_{T6}/\Lambda^4 < 0.27$	2.9
$-0.60 < f_{T7}/\Lambda^4 < 0.68$	$-0.67 < f_{T7}/\Lambda^4 < 0.73$	3.1

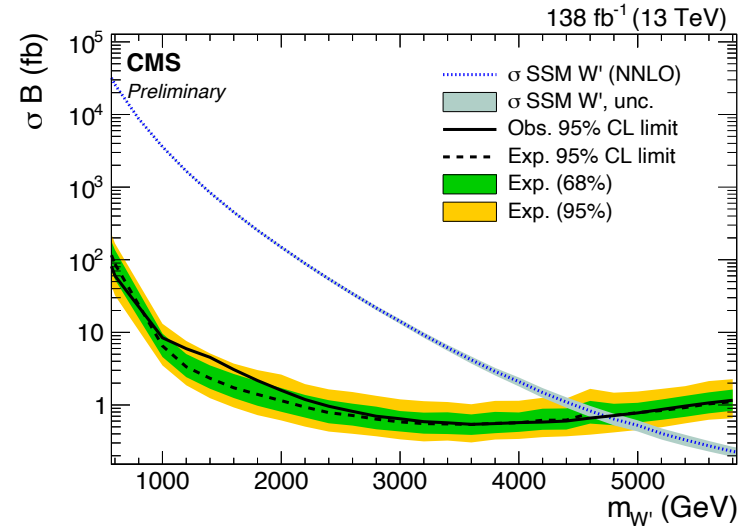
Significance: EWK
Observed: **6.0 σ**
Expected: 6.8 σ

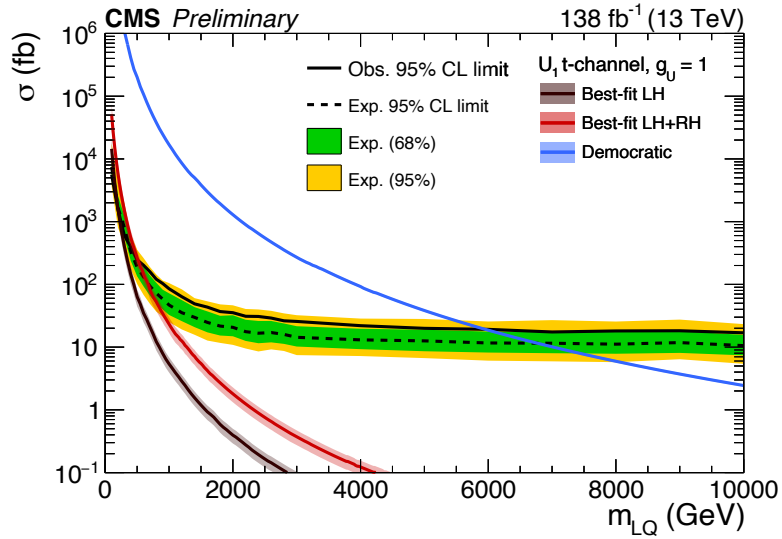
Fiducial Wγ Cross section:
Wγ EWK: σ_{fid}=19.2 ± 0.4 fb
Wγ inclusive: σ= 90 ± 11 fb

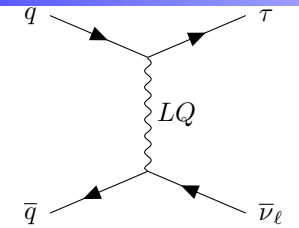
Search for 3rd-Gen LeptoQuarks

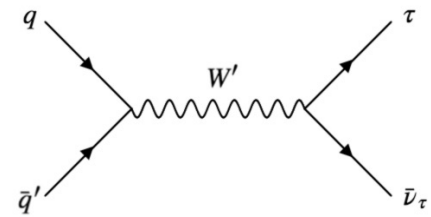
CMS-PAS-EXO-21-009

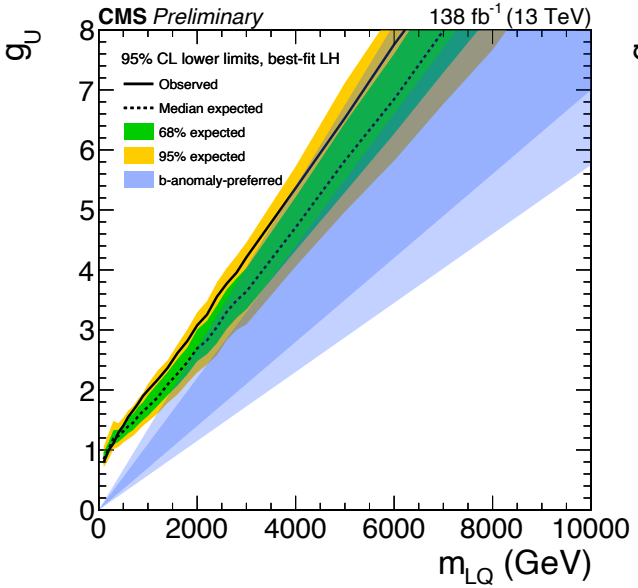
t-channel LQ exchange with τν in the final state and typical channel for W' search

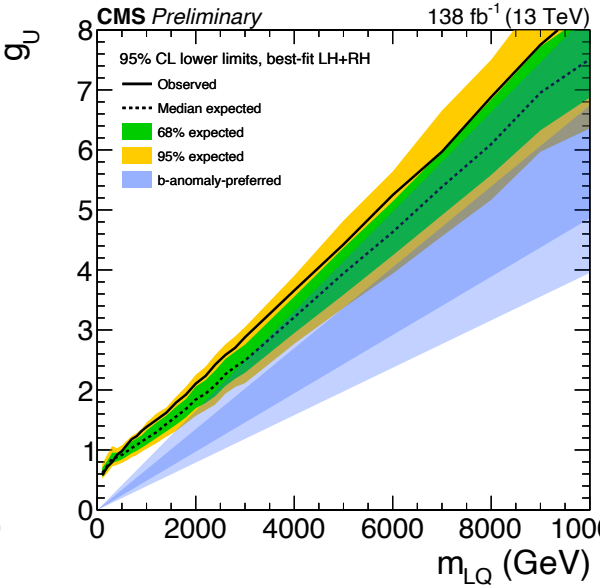












Excluded: QBH below 6.6TeV, W' below 4.6 TeV

Limits set on g_U coupling strength to quark and τ lepton as a function of its mass :

e.g. excluded portion of the parameter space that can explain b physics anomalies

Beyond Run 2

- Analysis of full Run2 and first Run3 datasets progressing rapidly
- Many big questions remain unanswered
  - Higgs Mass value at 125 GeV
  - Particle mass spectrum
  - Nature of Dark Matter
  - Origins of Neutrino masses
  - Absence of antimatter in the universe
- Higgs discovery only the first step and more precision measurements or a new discovery yet to come
  - Perhaps in some of them the Higgs may play a role as a portal to new physics theories