DSU 2024, Corfu, September 11

Implications of Recent Experimental & Theoretical Results on Electroweak Precision Tests

Jens Erler

JG|U

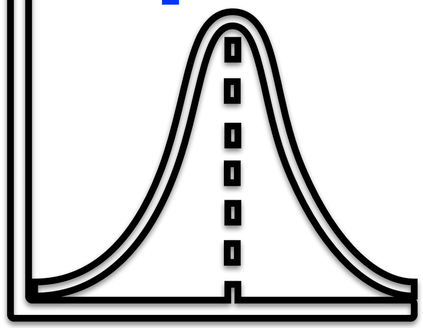
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Overview

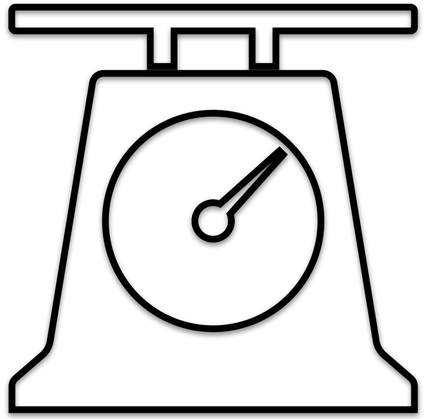
* Introduction
  * the over-constrained Standard Model
  * the weak mixing angle
* Latest developments
  * M_Z (CDF)
  * M_W (ATLAS and CDF)
  * Γ_W (update)
* Hadronic vacuum polarization
  * $\alpha(M_Z)$
  * $\sin^2\theta_W(0)$
  * g–2
* α_S and N_ν from the Z pole

The over-constrained SM

Z pole

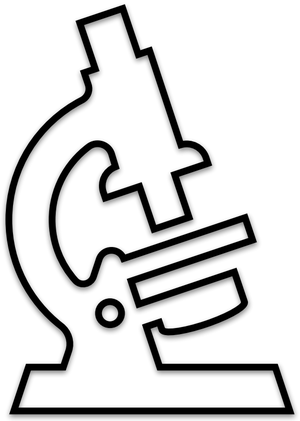


M_H, m_t
M_W, Γ_W

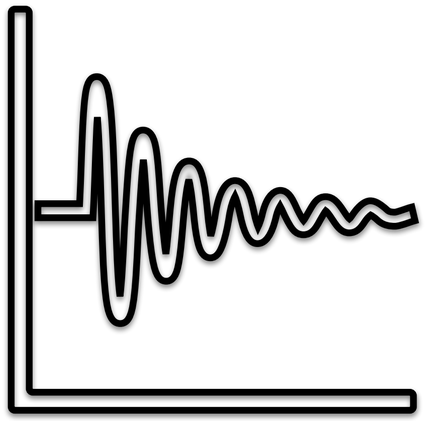


Fits to
SM & BSM

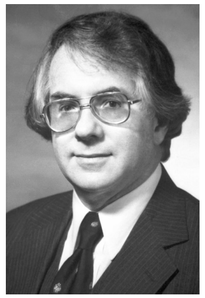
low-energy
precision



m_c, m_b, $\Delta\alpha$...



The E = mc² of the SM





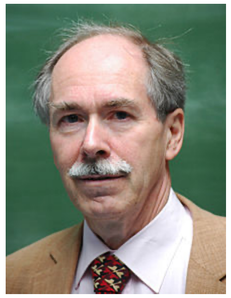
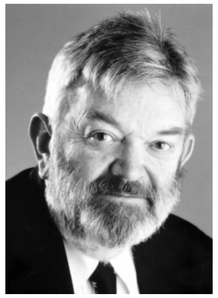
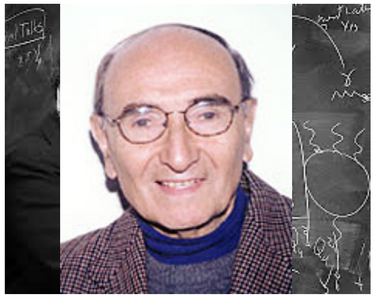
$$\sin^2\theta_W = \frac{g'^2}{g^2 + g'^2} = 1 - \frac{M_W^2}{M_Z^2} = \frac{\pi\alpha}{\sqrt{2}G_F M_W^2}$$

Radiative corrections

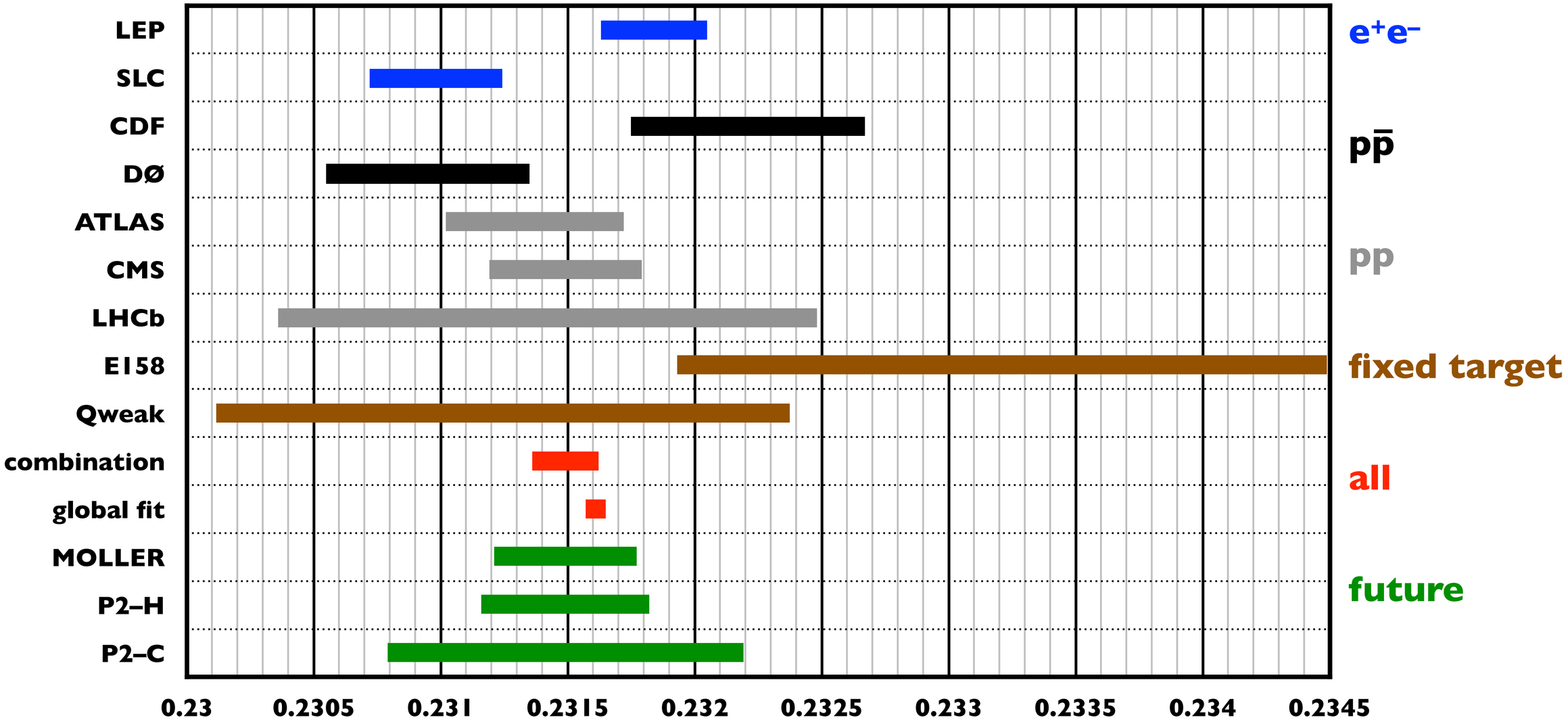
$$\frac{\sin^2\theta^e_{\text{eff}}}{1+\Delta\hat{k}} = \frac{\hat{g}'^2}{\hat{g}^2+\hat{g}'^2} = 1 - \frac{(1-\Delta\hat{\rho})M_W^2}{M_Z^2} = \frac{\pi\alpha}{(1-\Delta\hat{r})\sqrt{2}G_F M_W^2}$$

$$\propto \frac{\alpha m_t^2}{M_W^2}$$

$$\Delta\hat{\alpha} + \ldots$$


$\sin^2\theta^{\ell}_{\text{eff}}$ anno 2024



Parity Violating e⁻ Scattering (PVES) — Elastic

Qweak @ CEBAF (JLab)

hydrogen (completed)

E_e = 1149 MeV

|Q| = 158 MeV (θ = 7.9°)

$A_{PV} = 2.3 \times 10^{-7}$

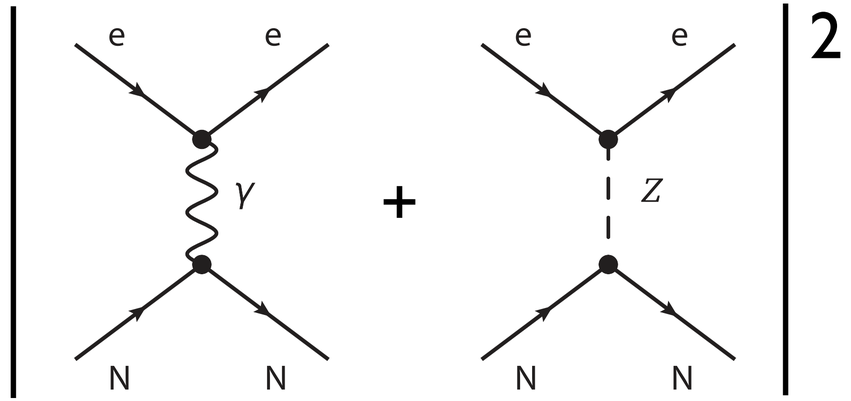
$\Delta A_{PV} = \pm 4.1\%$

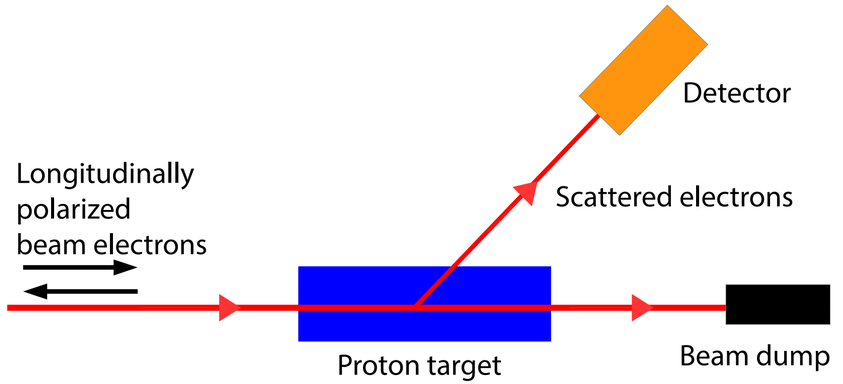
$\Delta Q_W(p) = \pm 6.25\%$

$\sin^2\theta_W = 0.2383 \pm 0.0011$

FFs from fit to ep asymmetries

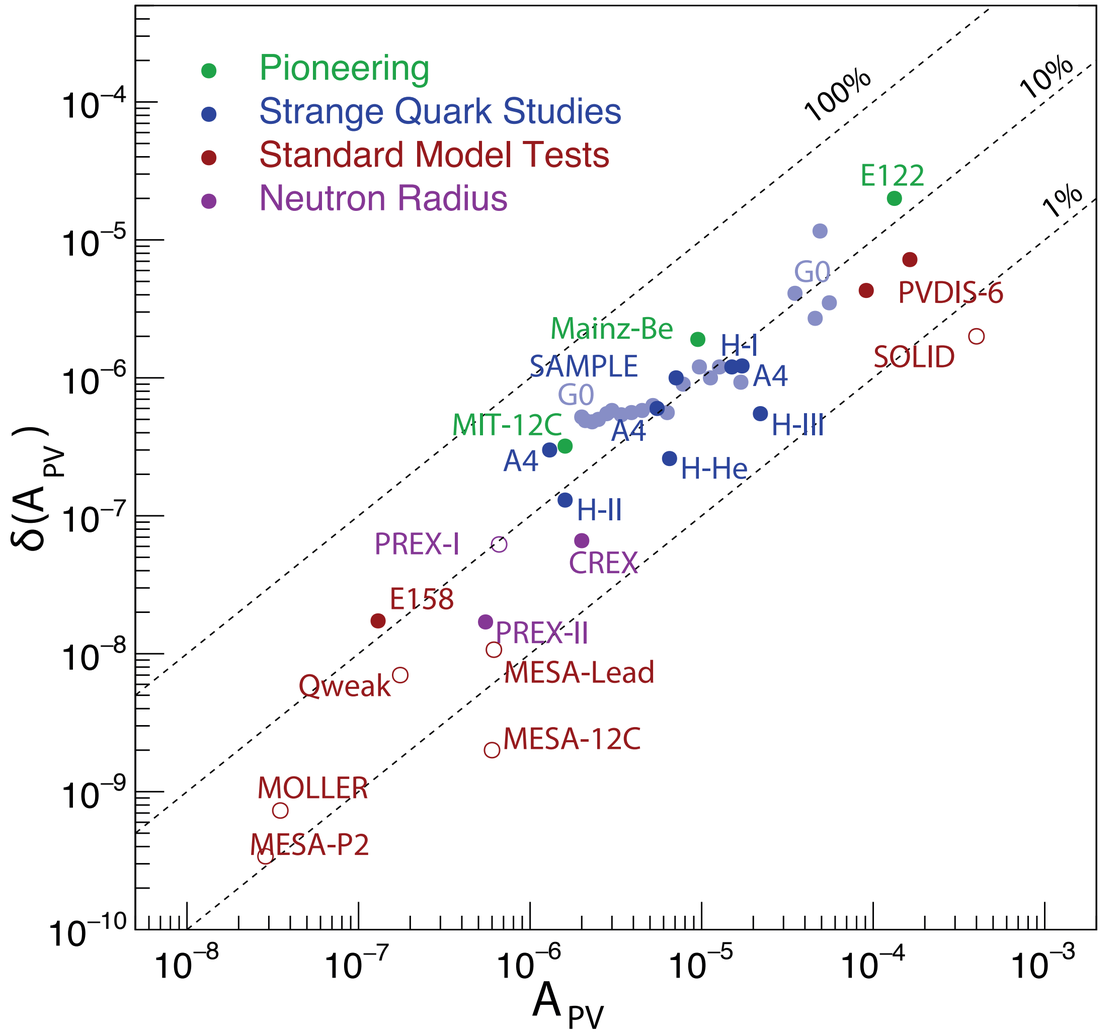
arXiv:1905.08283



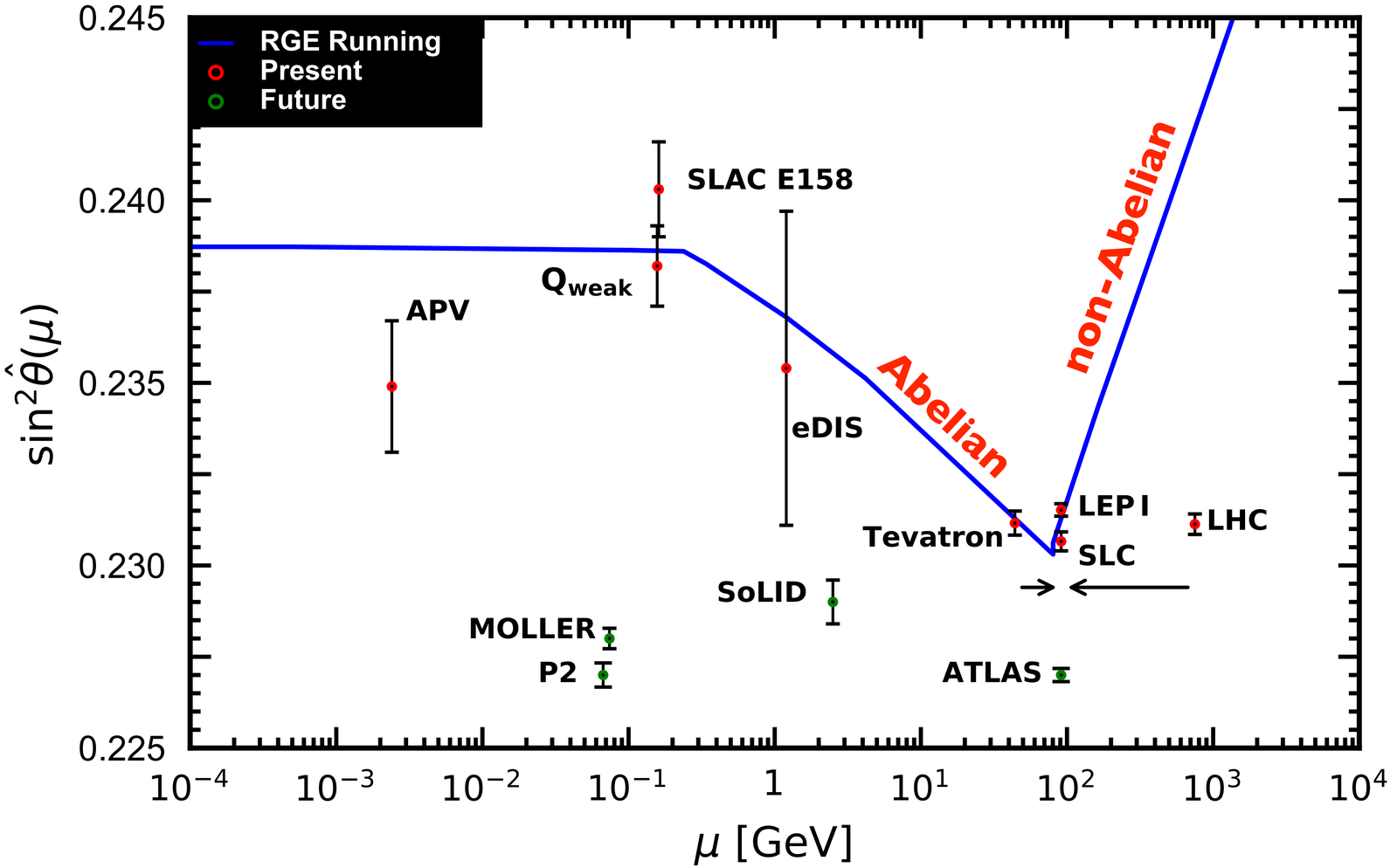


$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \sim \frac{Q^2}{e^2 v^2} \sim 10^{-4}\, Q^2\ [\mathrm{GeV}^2]$$

Parity Violating e⁻ Scattering (PVES)



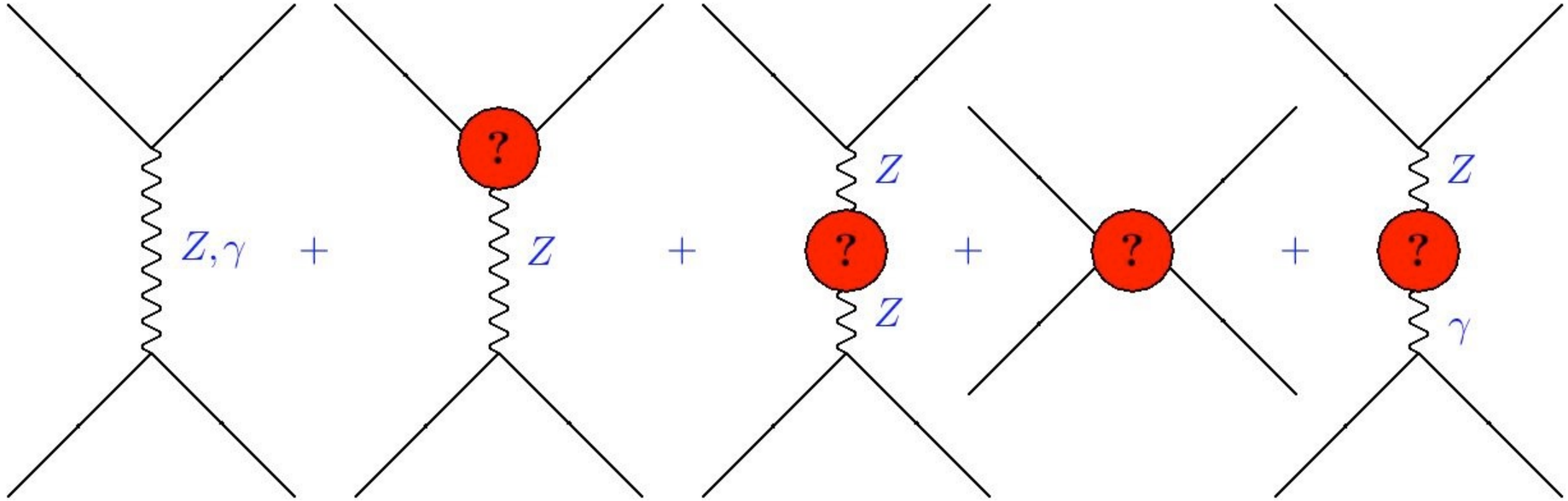
Running $\overline{\text{MS}}$ weak mixing angle



updated from
Ferro-Hernández & JE
arXiv:1712.09146

for dark Z interpretation
👉 Eduardo Peinado's talk tomorrow

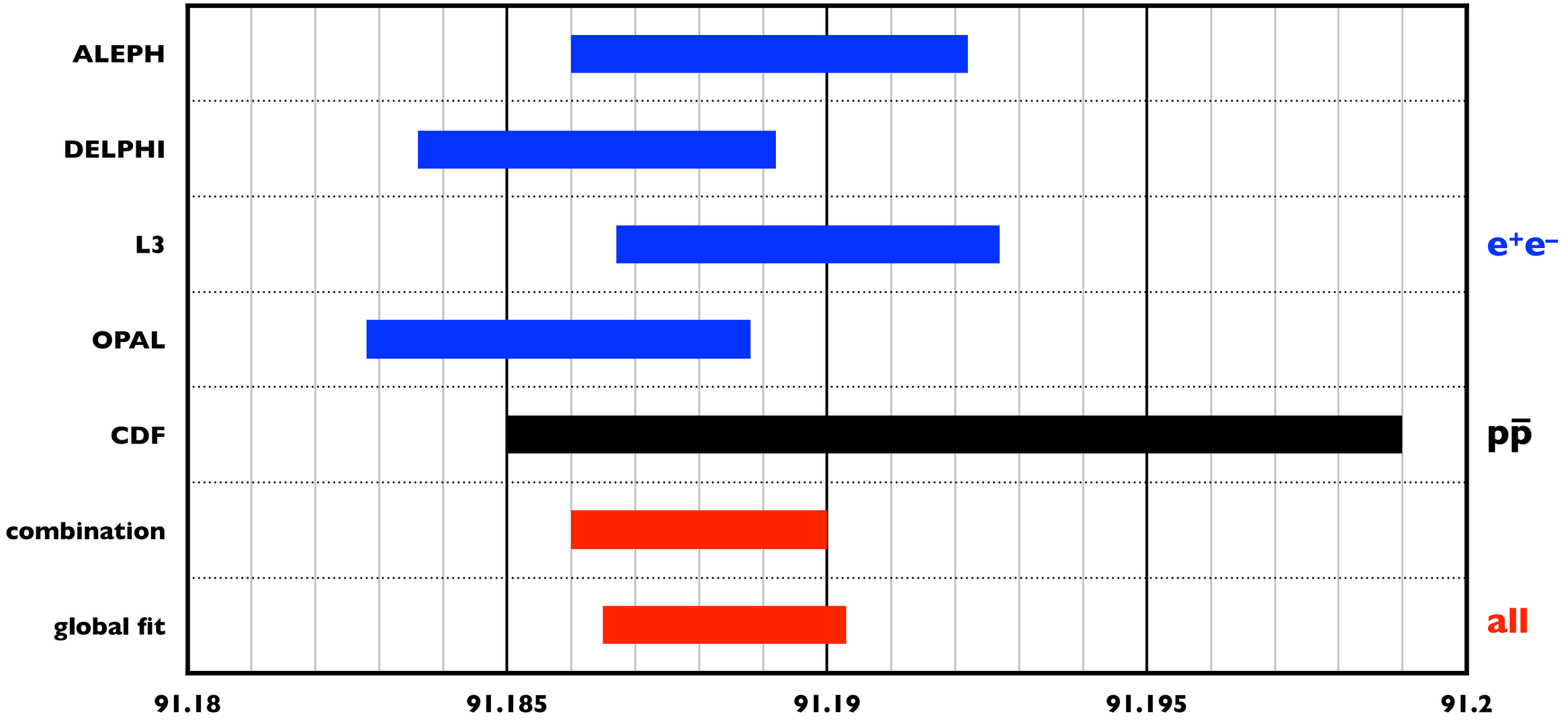
Discriminating new physics



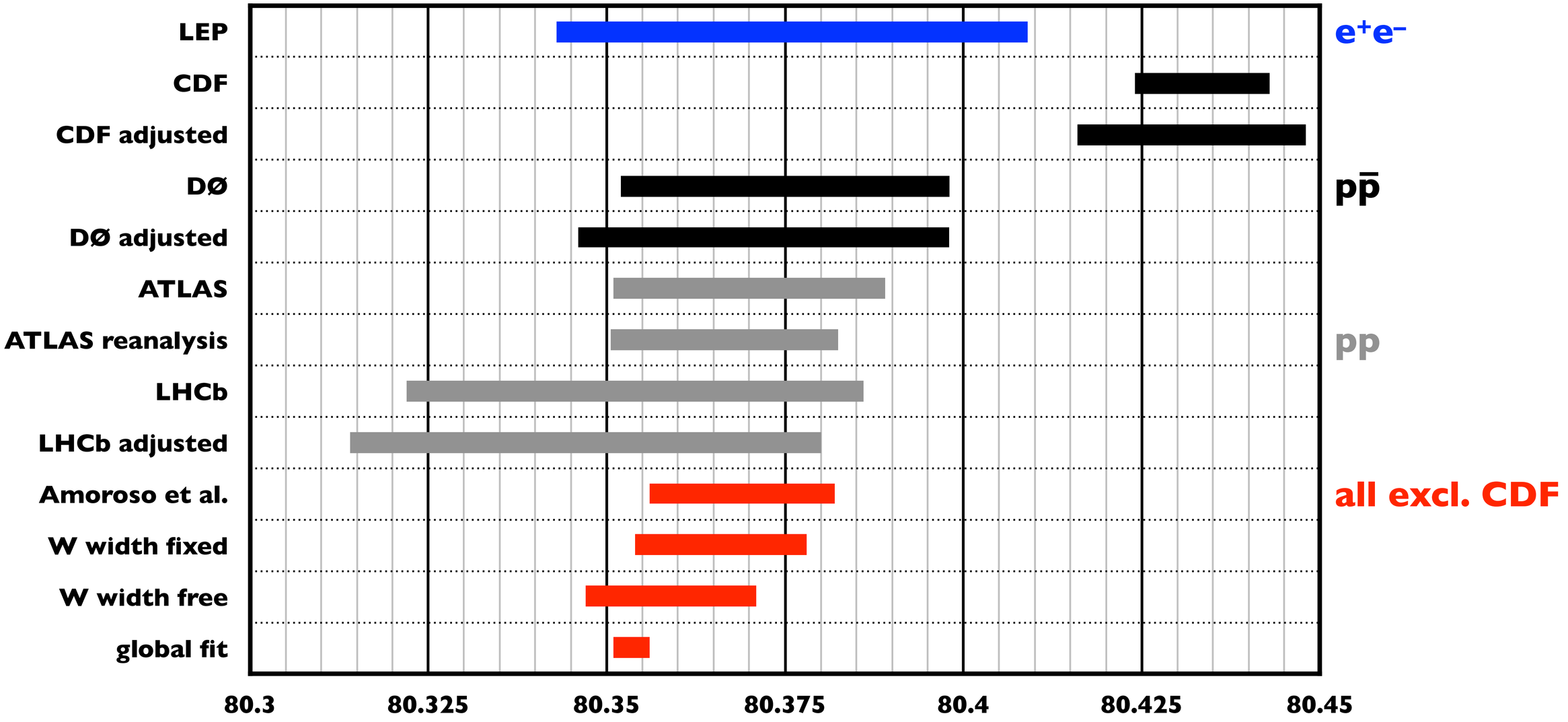
* Z-Z′ mixing: modification of Z vector coupling
* oblique parameters: STU (also need M_W and Γ_Z)
* new amplitudes: off- versus on-Z pole measurements (e.g. heavy Z′)
* dark Z: renormalization group evolution (low versus very low energy measurements)

Latest developments

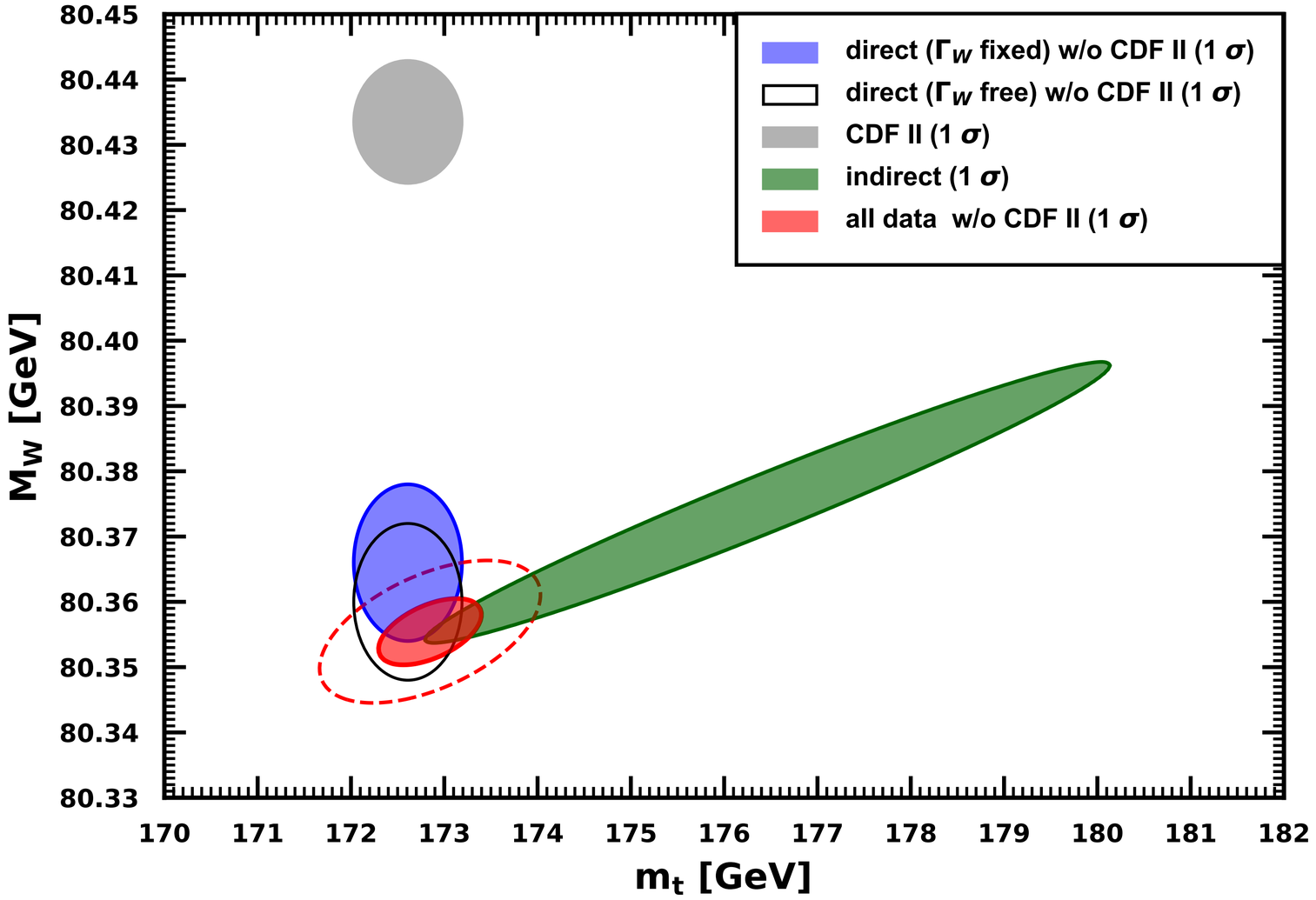
M_Z anno 2024 [GeV]



M_W anno 2024 [GeV]



$M_W - m_t$



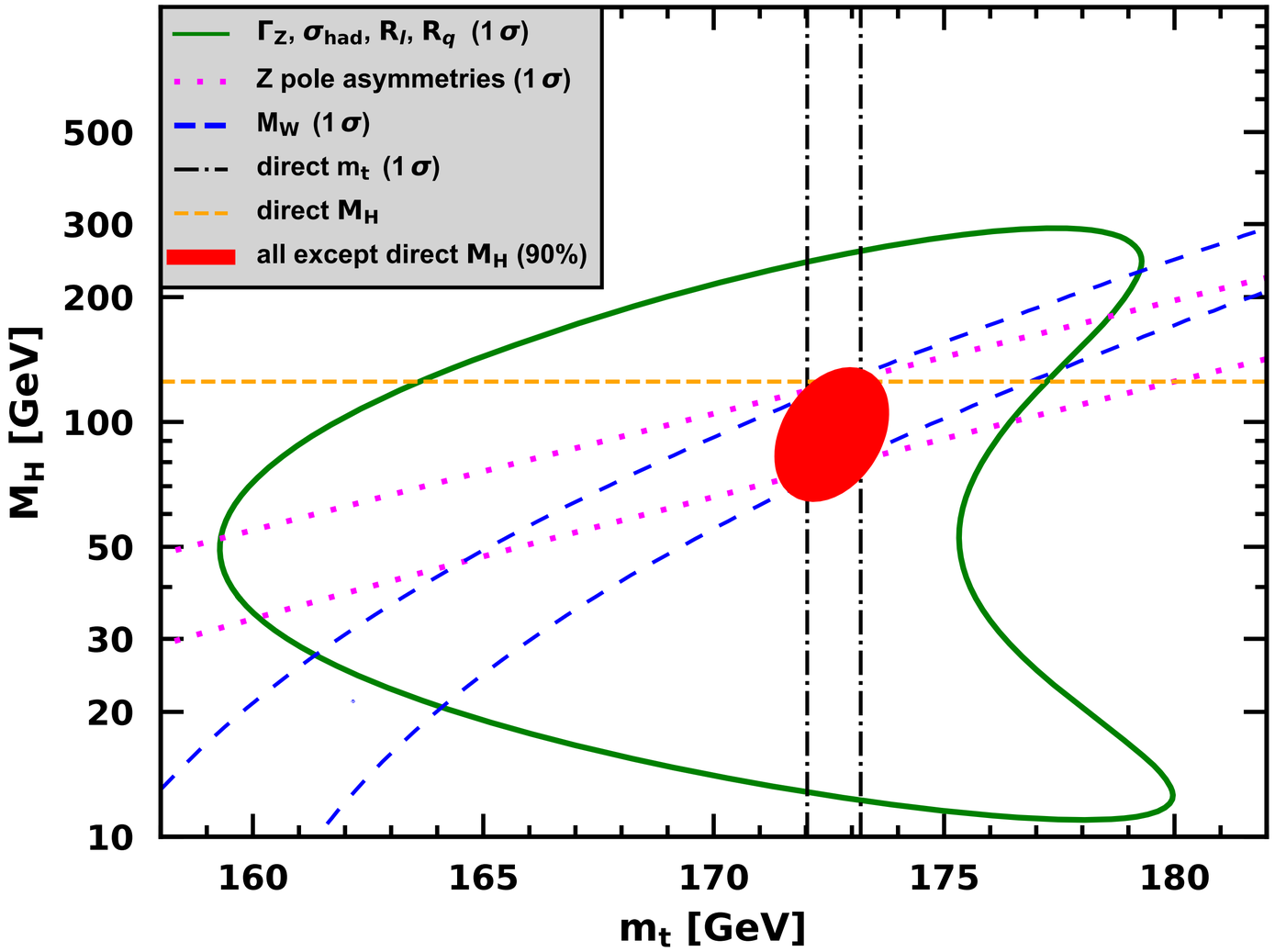
m_t = 175.2 ± 1.8 GeV (indirect)

1.4 σ above

m_t = 172.61 ± 0.58 GeV (Tevatron + LHC)

Freitas & JE, PDG (2024)
figure: Rodolfo Ferro

$M_H - m_t$



χ^2 / d.o.f. = 49.5 / 47

(p-value = 37%)

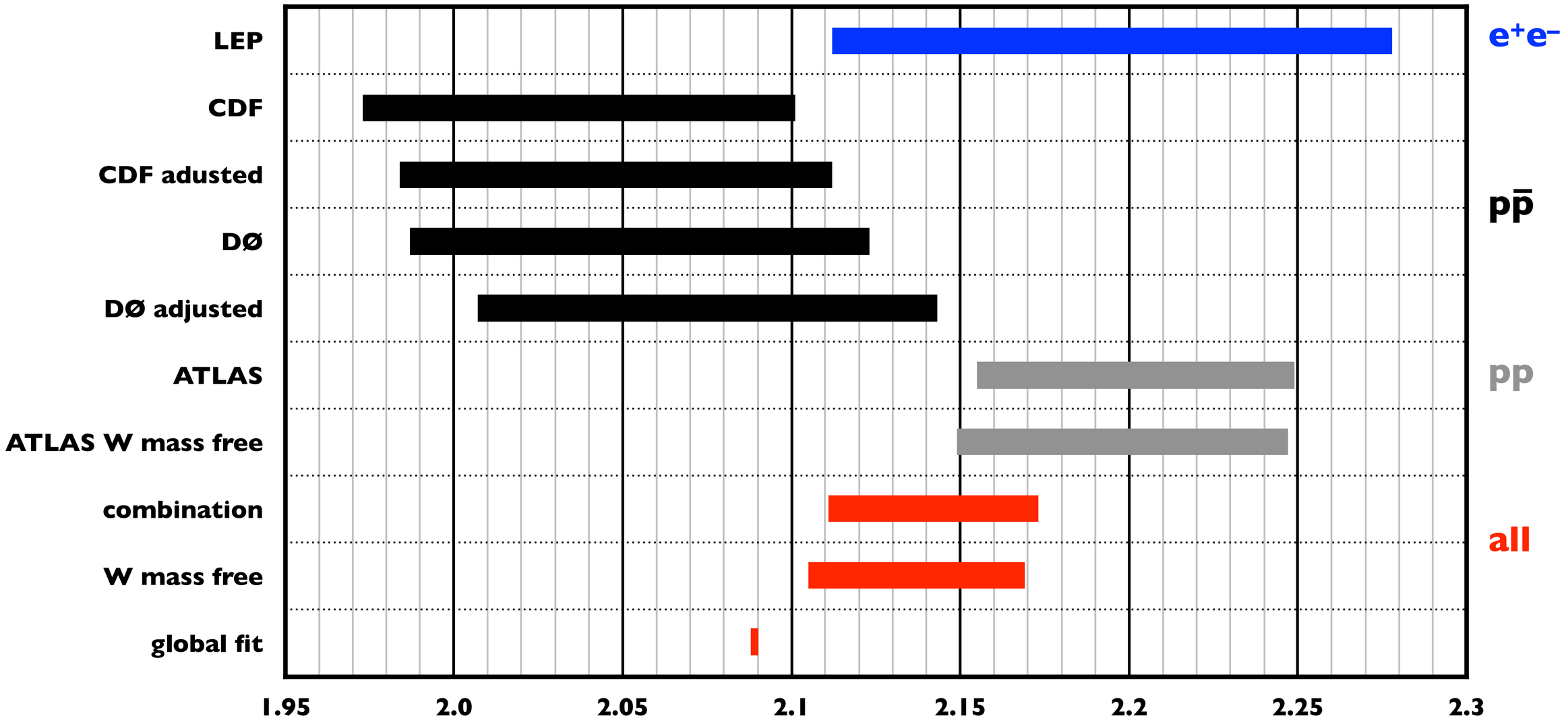
$M_H = 97^{+18}_{-16}$ GeV (indirect)

1.6 σ below

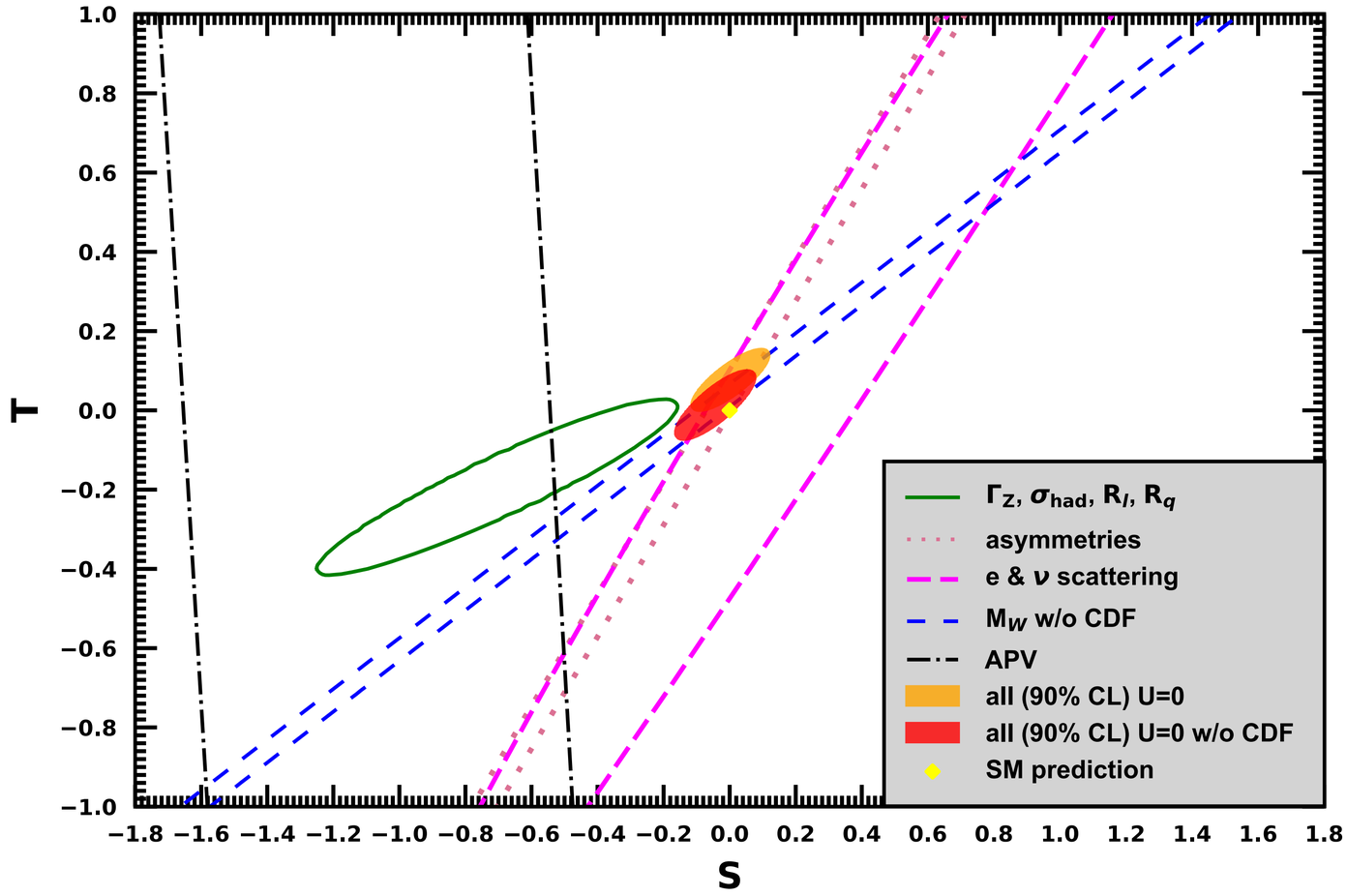
$M_H = 125.10 \pm 0.09$ GeV (LHC)

Freitas & JE, PDG (2024)
figure: Rodolfo Ferro

Γ_W anno 2024 [GeV]



S – T



Freitas & JE, PDG (2024)
figure: Rodolfo Ferro

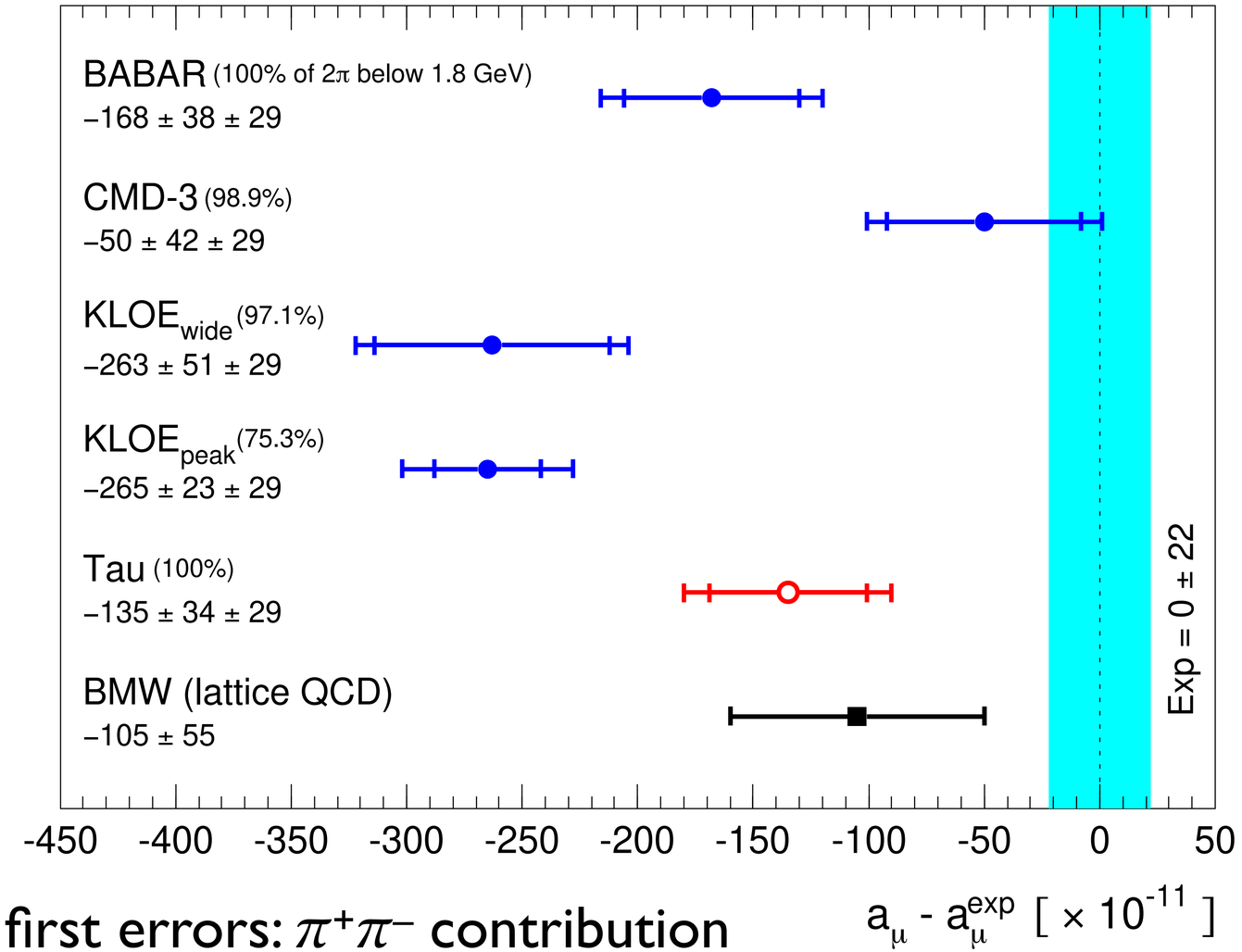
S	–0.05 ± 0.07
T	0.00 ± 0.06

T constrains
doublet mass splittings
👉 Spyros Argyropoulos' talk
Monday afternoon

$$(2\ \mathrm{GeV})^2 < \sum_i \frac{N_C^i}{3}\,\Delta m_i^2 < (44\ \mathrm{GeV})^2$$

Hadronic vacuum polarization

Hadronic vacuum polarization



first errors: $\pi^+\pi^-$ contribution

BaBar and earlier data based on
Davier et al. arXiv:1908.00921

CMD–3 and figure from
Davier et al., arXiv:2312.02053

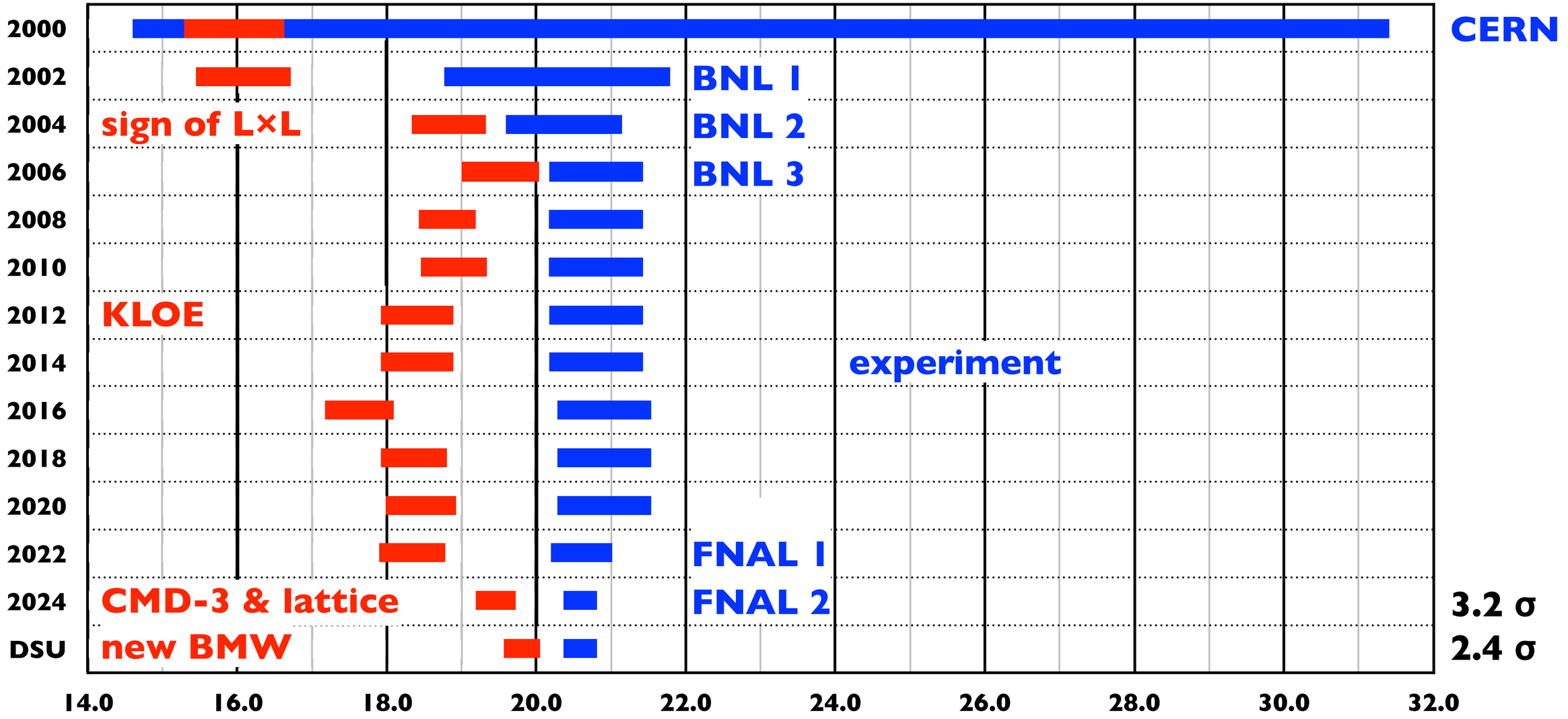
KLOE based on
Davier et al. arXiv:1908.00921

after isospin rotation according to
Davier et al., arXiv:2312.02053

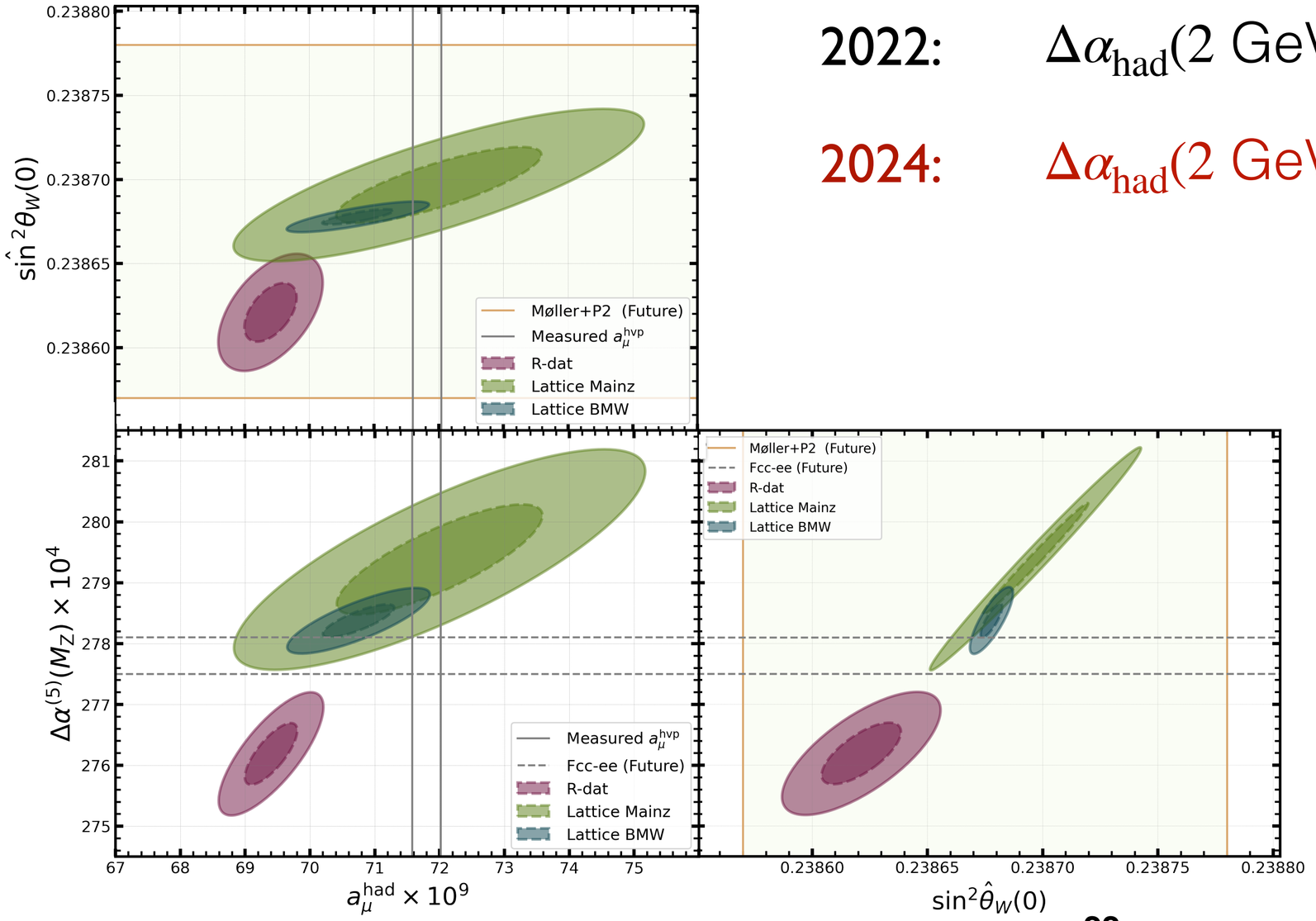
Borsanyi et al., arXiv:2002.12347

Δα from Cè et al., arXiv:2203.08676
also enters through correlations

chronology of a_μ [$\times 10^9$ – 1165900]



$g_\mu - 2$, $\alpha(M_Z)$ and $\sin^2\theta_W(0)$



2022: $\Delta\alpha_{\rm had}(2\ {\rm GeV}) = (58.84 \pm 0.51) \times 10^{-4}$

2024: $\Delta\alpha_{\rm had}(2\ {\rm GeV}) = (60.30 \pm 0.43) \times 10^{-4}$

$\Delta M_W = -2.7$ MeV

$\Delta M_H = -7.0$ MeV

Ferro-Hernàndez, Kuberski & JE, arXiv:2406.16691

. . . if there is time . . .

α_s from the Z pole

observable	$\alpha_s(M_Z)$	comment
Γ_Z = 2495.5 ± 2.3 MeV	0.1215 ± 0.0048	update: Γ_Z = +0.3 MeV
σ_{had} = 41.481 ± 0.033 nb	0.1201 ± 0.0065	update: $\Delta\sigma_{had}$ = –60 pb
$R_e = \Gamma_{had}/\Gamma_e$ = 20.804 ± 0.050	0.1295 ± 0.0082	
$R_\mu = \Gamma_{had}/\Gamma_\mu$ = 20.784 ± 0.034	0.1264 ± 0.0054	$m_\mu \neq 0$
$R_\tau = \Gamma_{had}/\Gamma_\tau$ = 20.764 ± 0.045	0.1157 ± 0.0072	$m_\tau \neq 0$
B_W(had) = 0.6736 ± 0.0018	0.098 ± 0.025	recent (LEP 2 + CMS)
combination	0.1223 ± 0.0028	future lepton collider ~ 10^{-4}
global fit	0.1185 ± 0.0016	includes τ decays

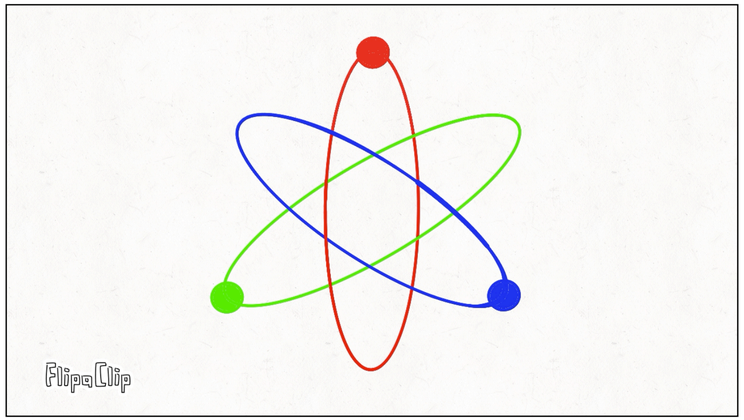
electromagnetic beam-beam effects
improved Bhabha X section (luminosity)

Voutsinas et al., arXiv:1908.01704

Janot & Jadach, arXiv:1912.02067

Conclusions

* *after more than 50 years of electroweak precision physics, still no conclusive evidence for BSM*
  * M_W, M_Z, m_t, M_H (and m_c) have all been successfully predicted before their discoveries
  * the infamous conflict in muon g–2 reduced to about 2.4 σ
  * recent *LEP* luminosity update confirms $N_\nu = 3$ active neutrinos, but α_s somewhat high
  * new CDF M_W result ~ 7 σ higher than other measurements !!!
* *outlook*
  * high precision PVES (*P2, MOLLER, SoLID*) competitive alternatives to high energy frontier
  * leap in precision expected from future lepton collider(s)
    ILC, CEPC, FCC–ee, CLIC, μ collider



Thank You