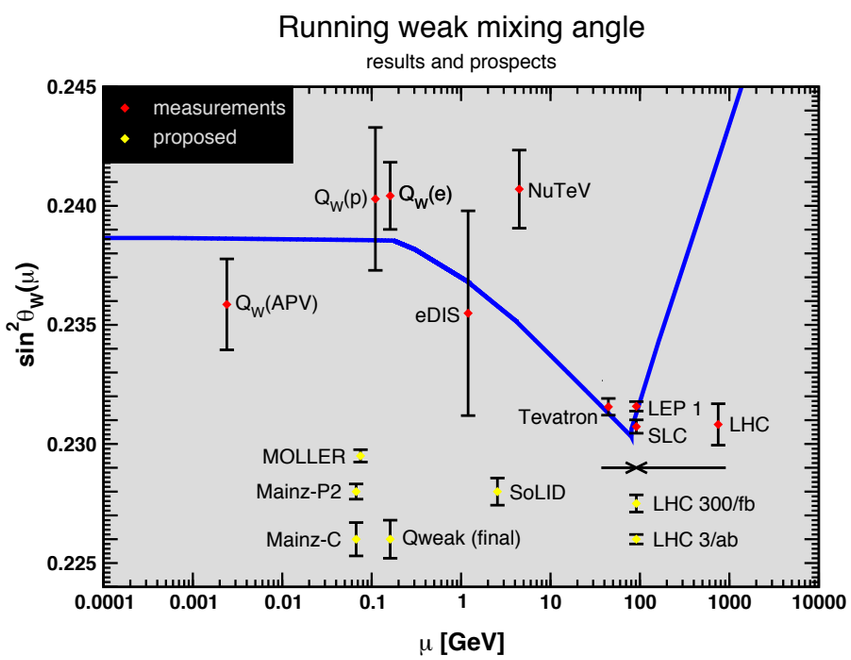
Electroweak Precision Physics

Jens Erler (IF-UNAM)



WIN 2017 — UC Irvine

June 19–24, 2017

Upcoming scientific program

Bridging the Standard Model to New Physics with the Parity Violation Program at MESA

Mainz Institute for Theoretical Physics

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

April 23 — May 4, 2018

https://www.mitp.uni-mainz.de/625.php

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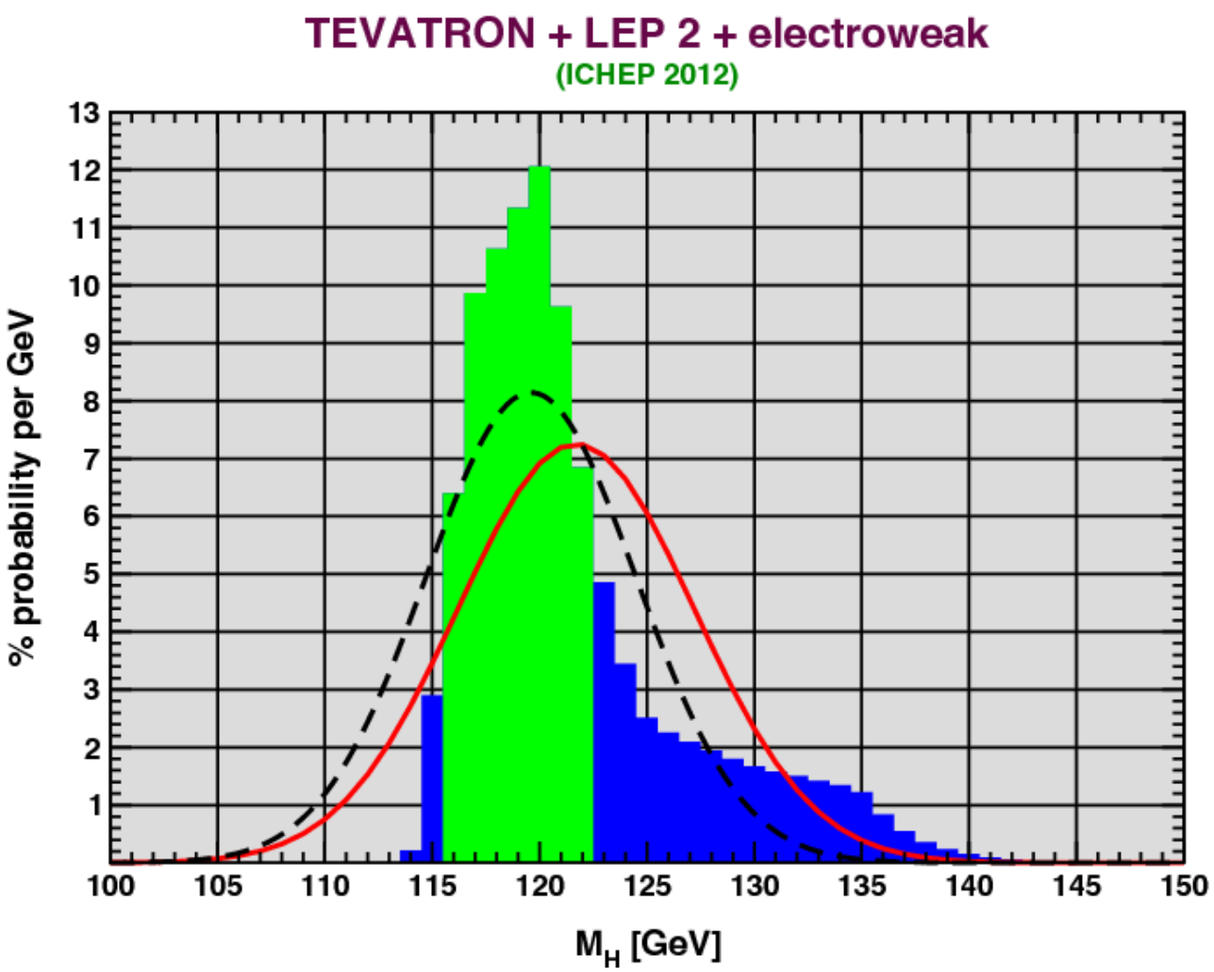

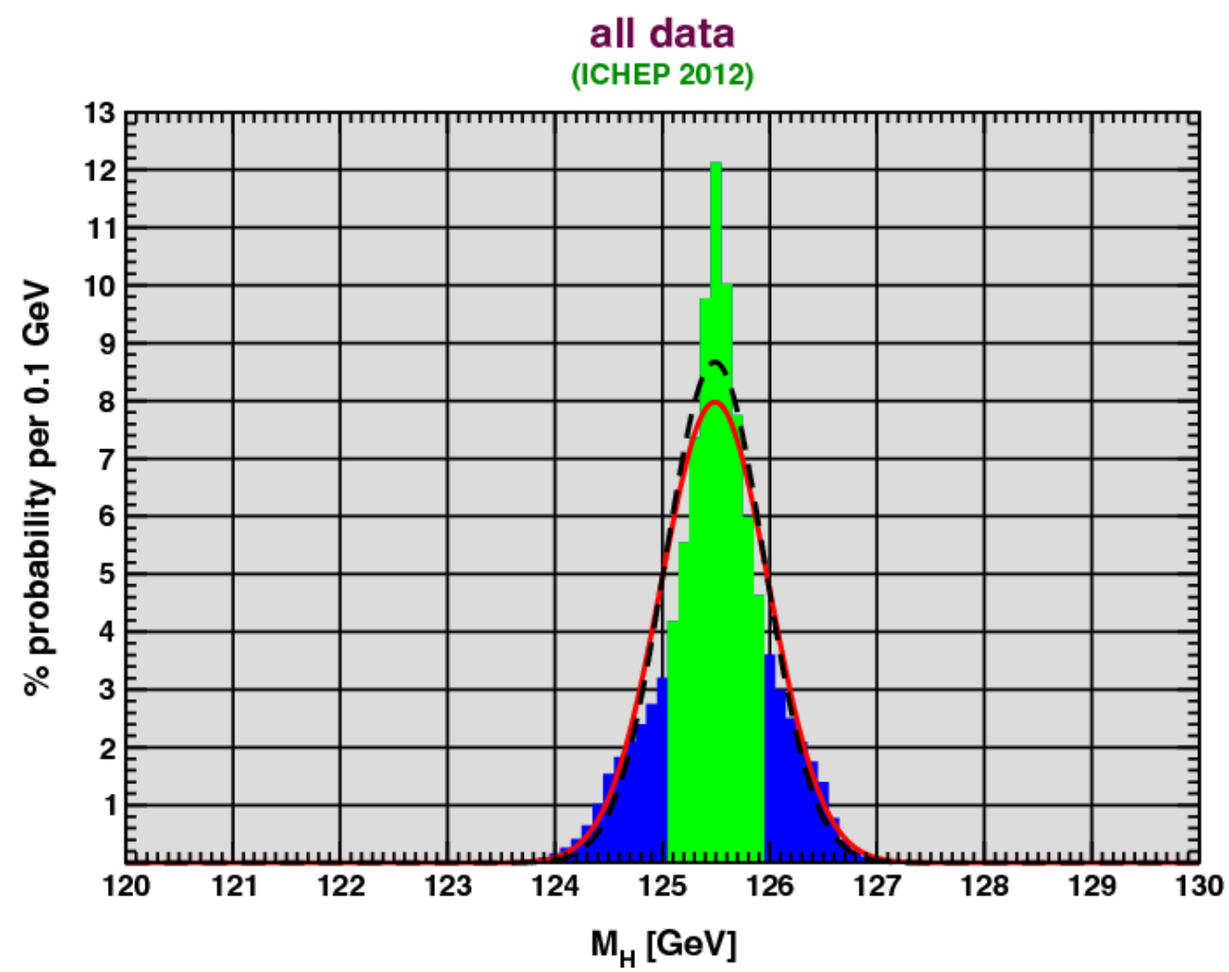

Outline

- Aspects of the Global Electroweak Fit with GAPP
- Weak Mixing Angle at high and low energies
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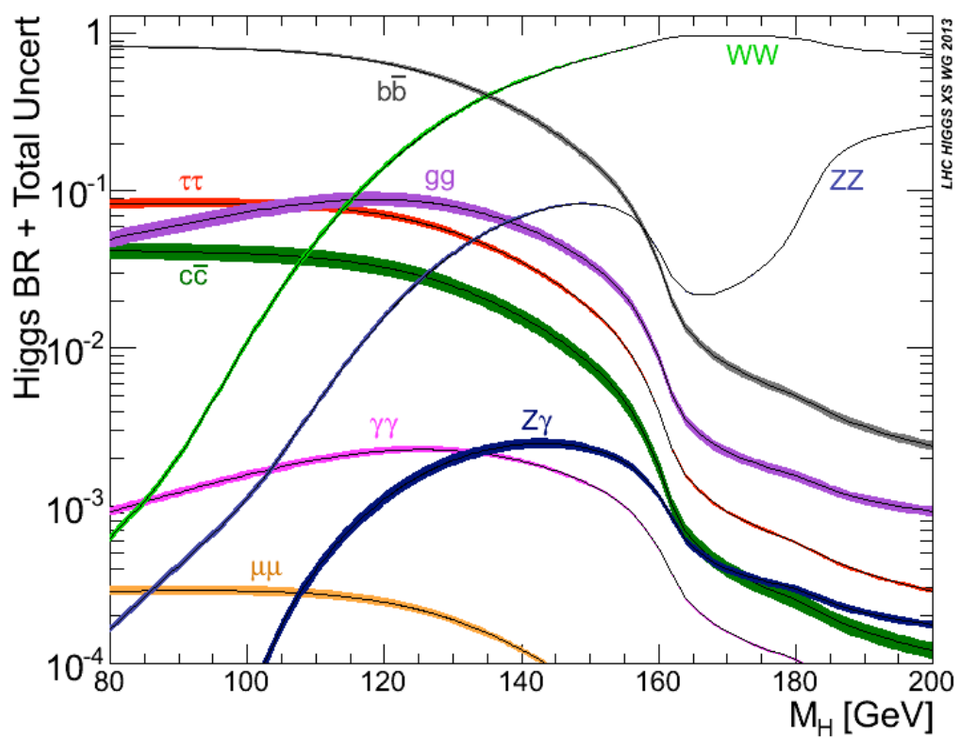
M_H

event kinematics ATLAS, CMS 2015	**125.09 ± 0.24 GeV**
Higgs BRs Freitas, JE (PDG 2016)	**126.1 ± 1.9 GeV**
updated electroweak fit	**94^{+18}_{-16} GeV**



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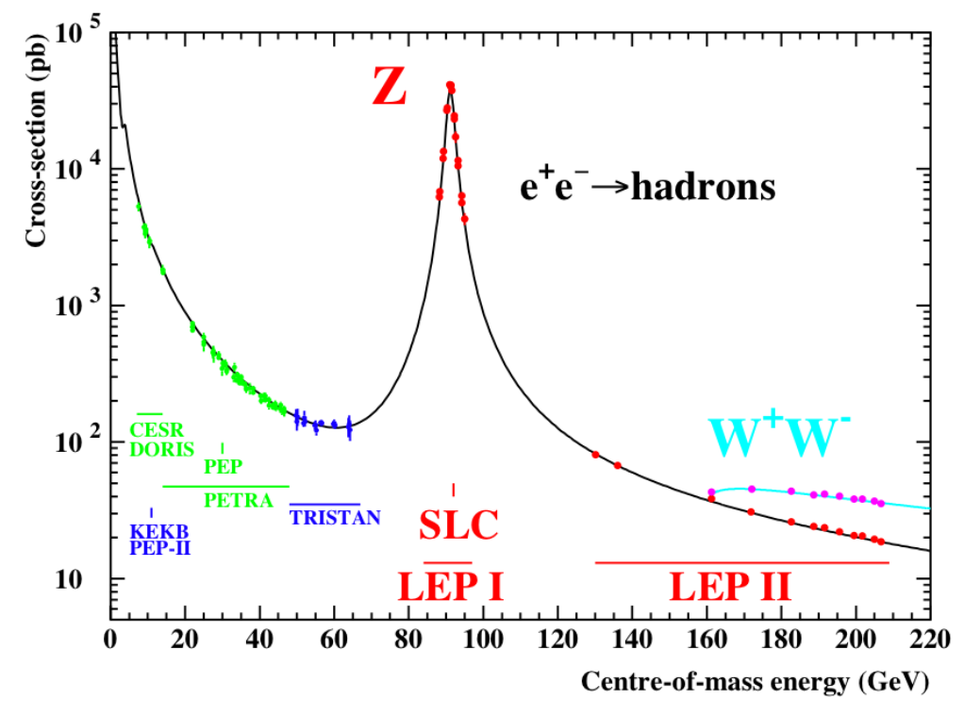
- strong coupling: $\alpha_s(M_Z)$ extracted to ±1.4% from EW fit

Weak probes of the strong coupling



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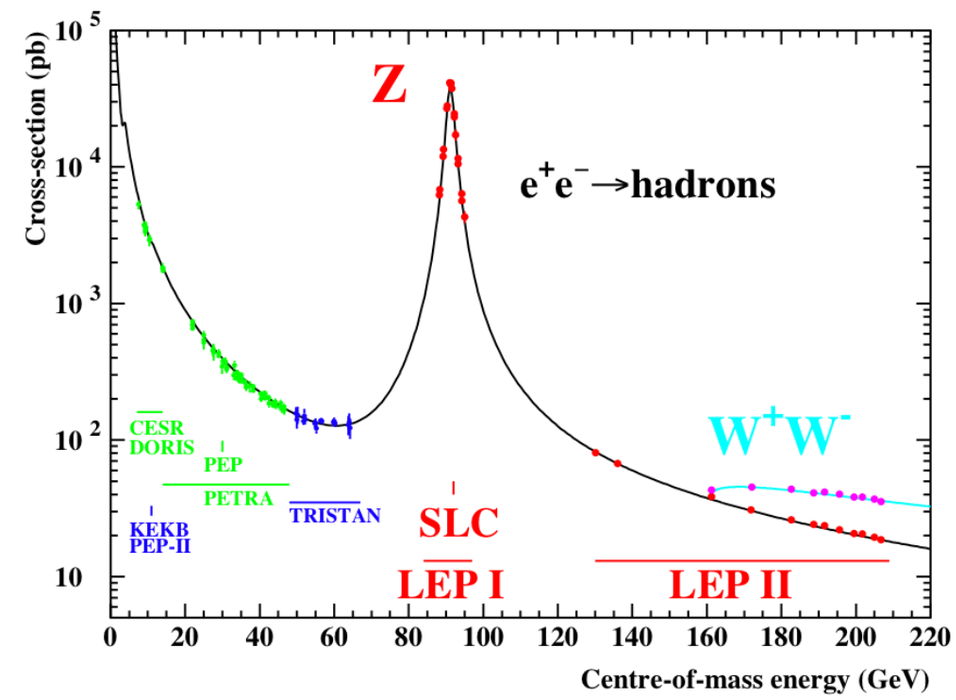

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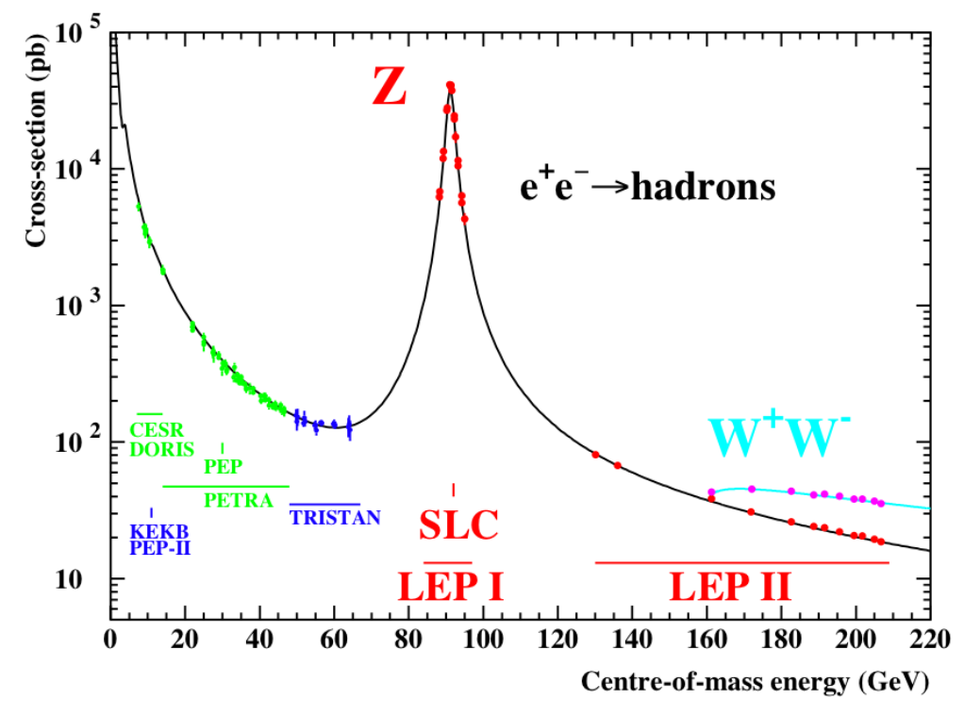

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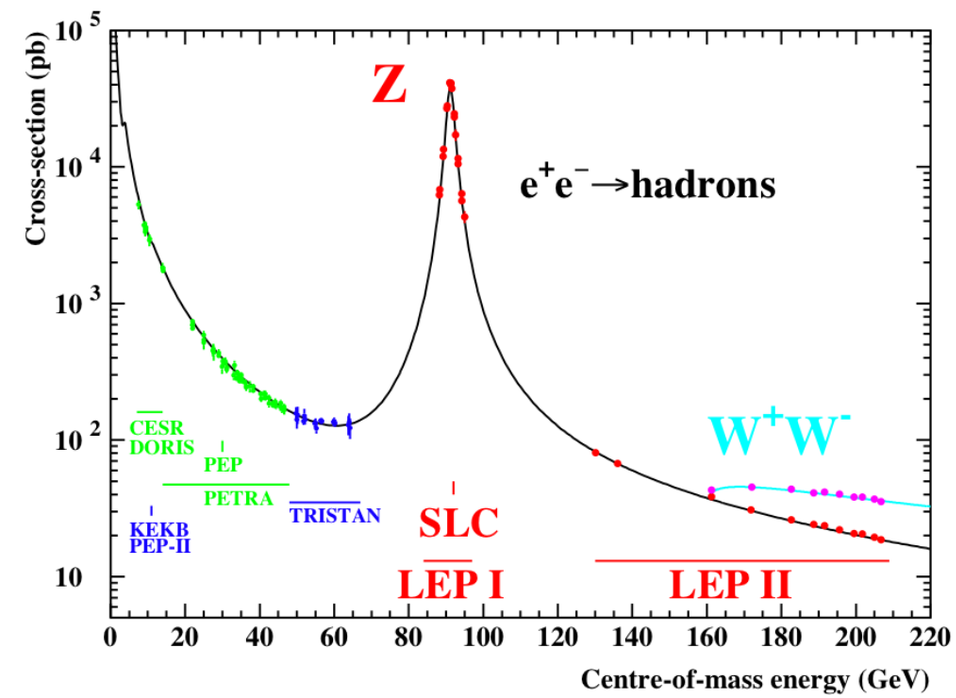

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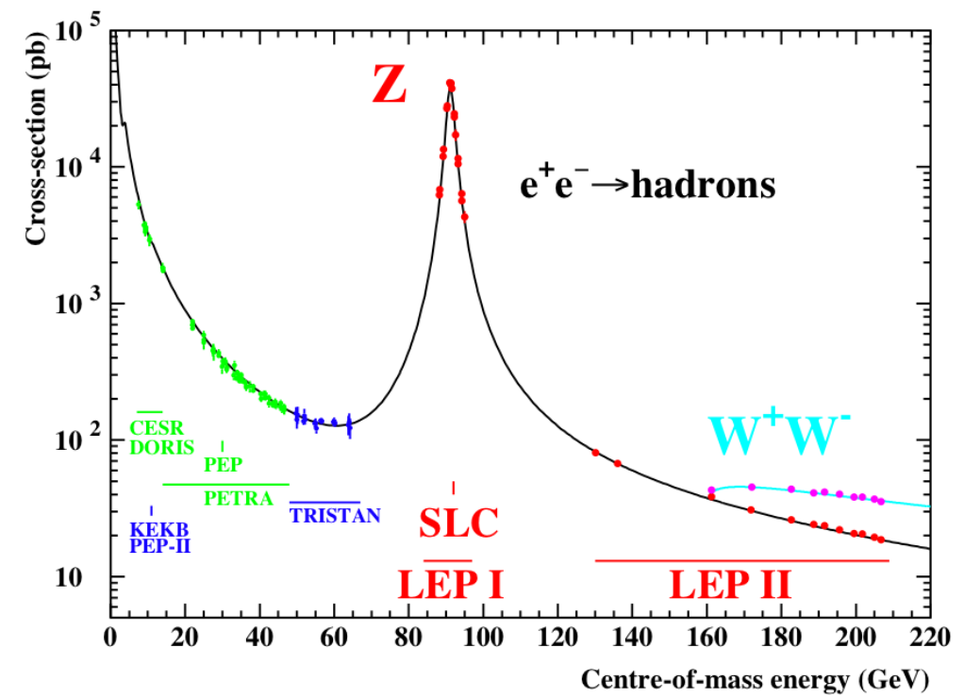

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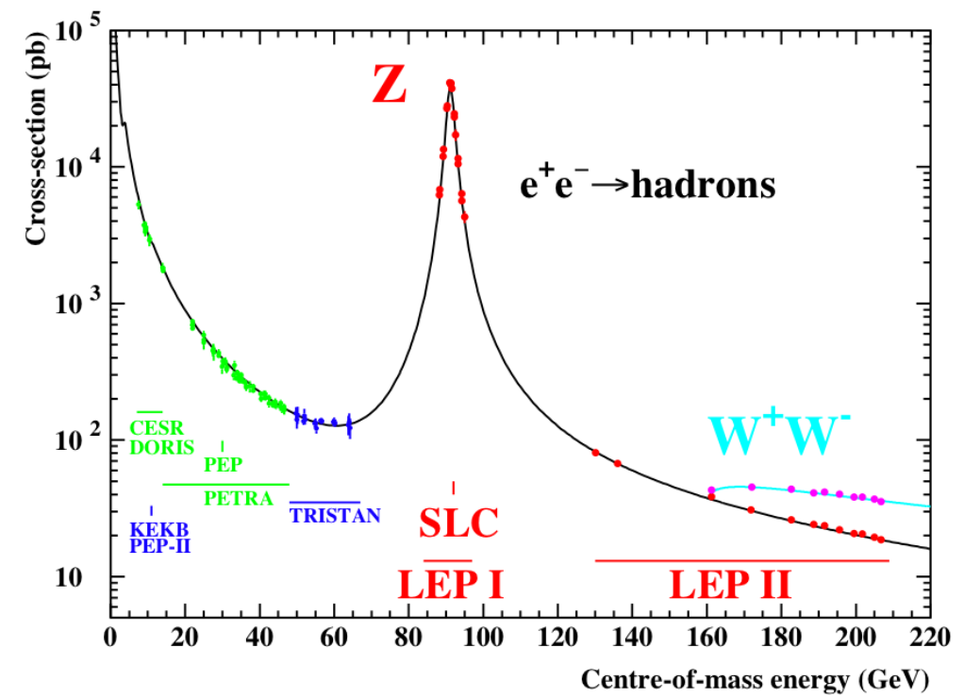

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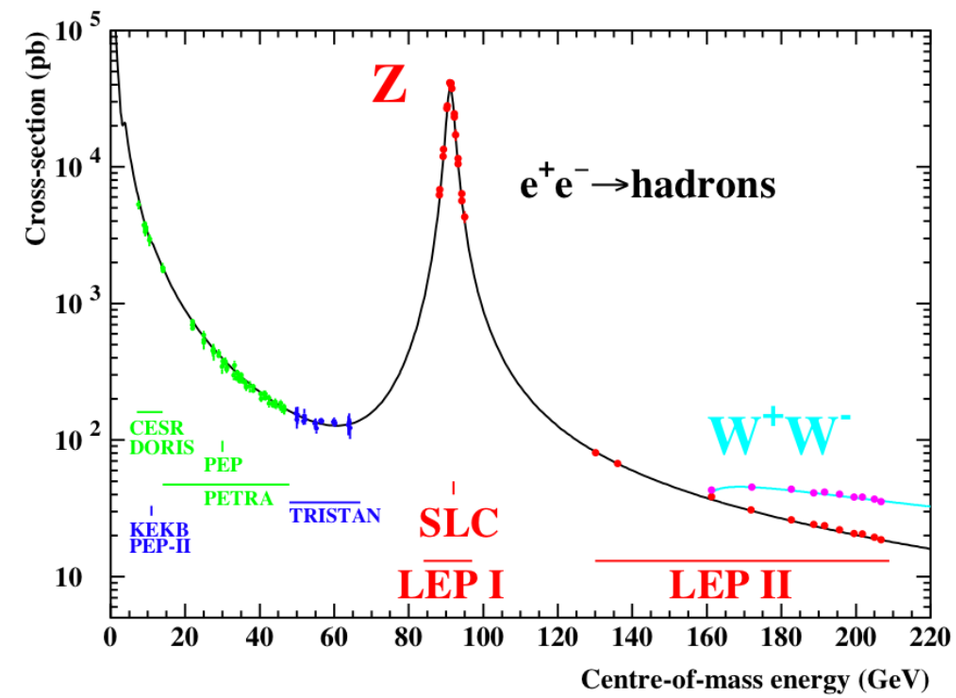

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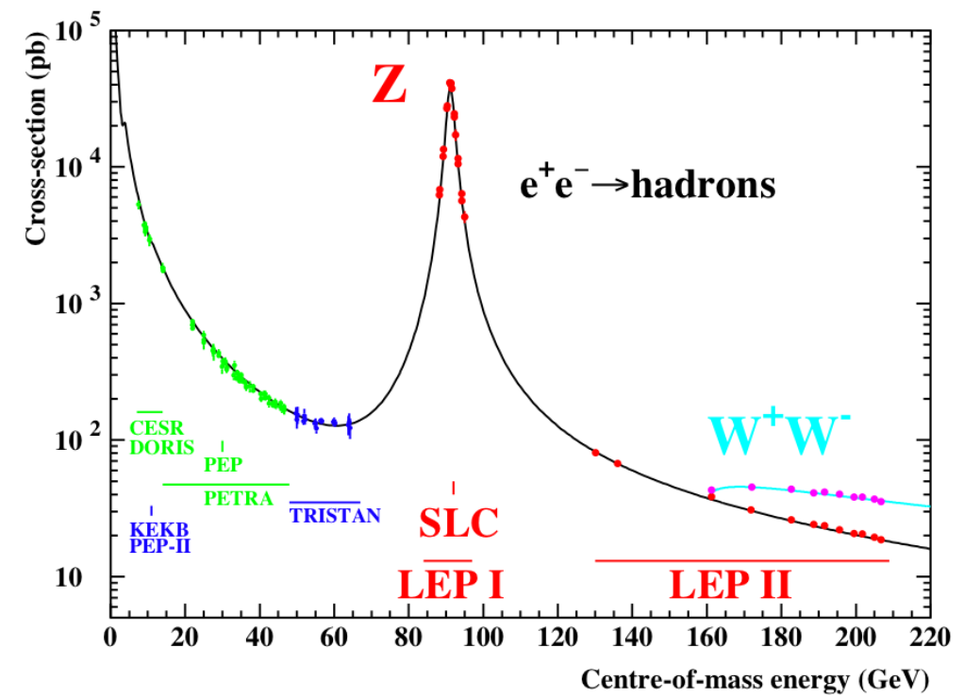

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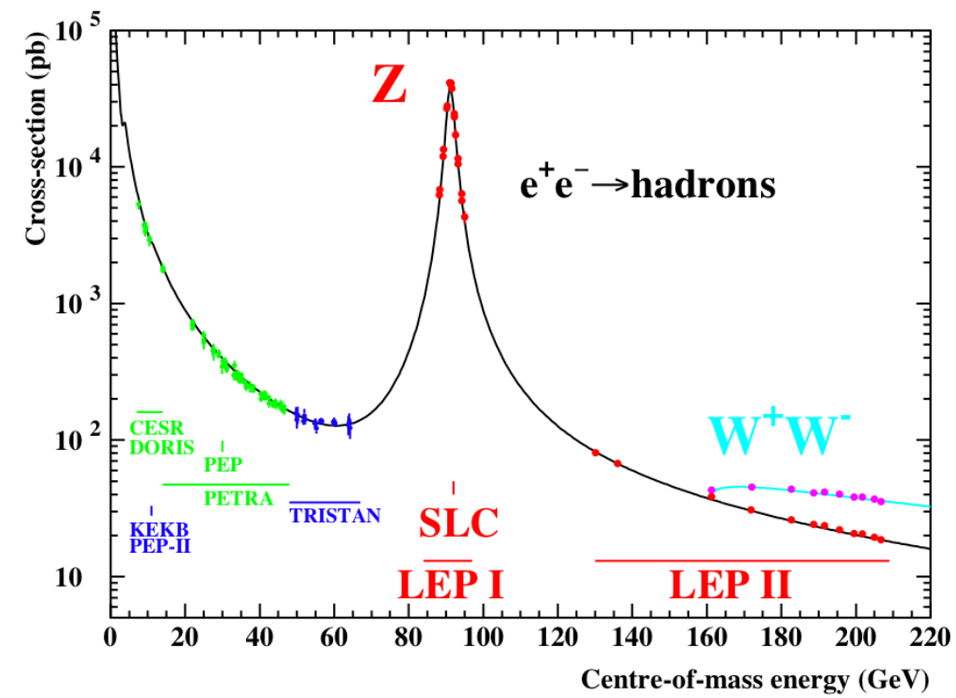
- W width: lacks precision, but $1^{st} + 2^{nd}$ row CKM unitarity test



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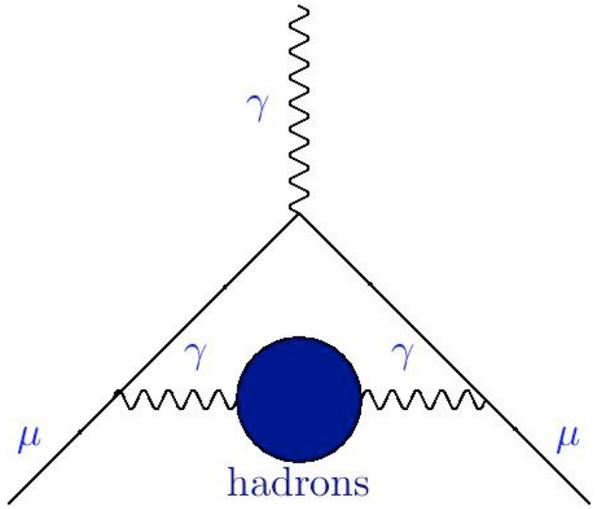

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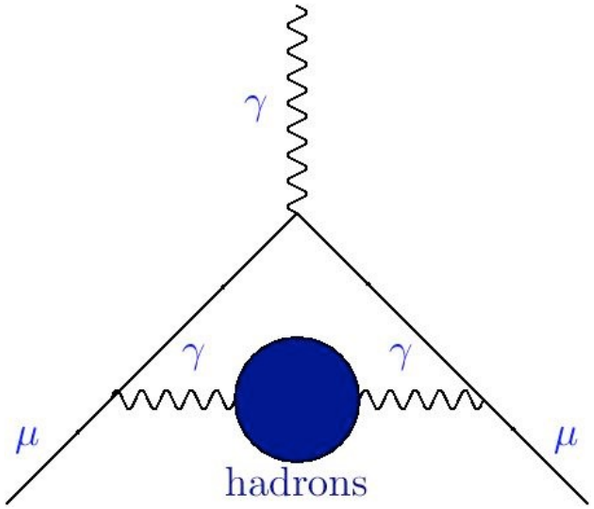

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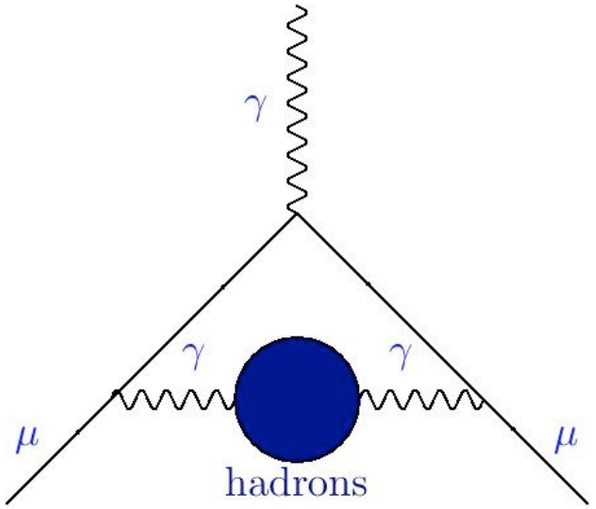

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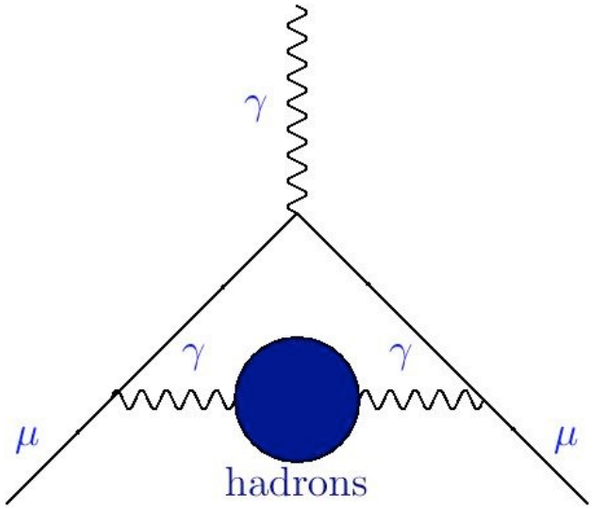

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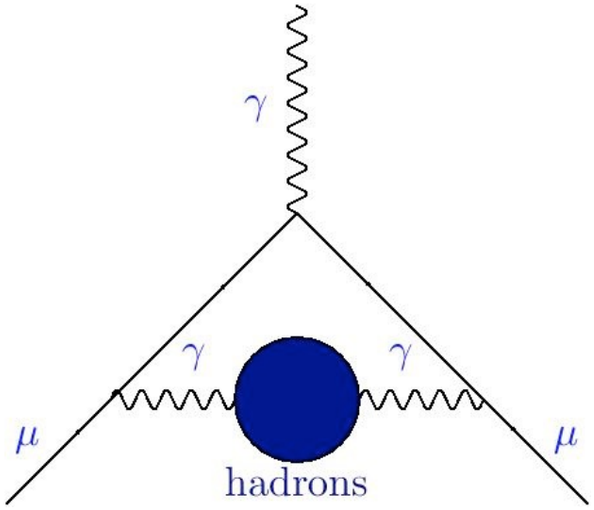

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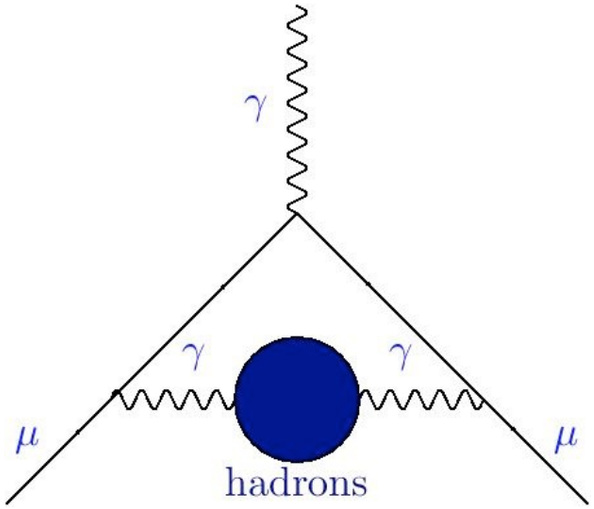

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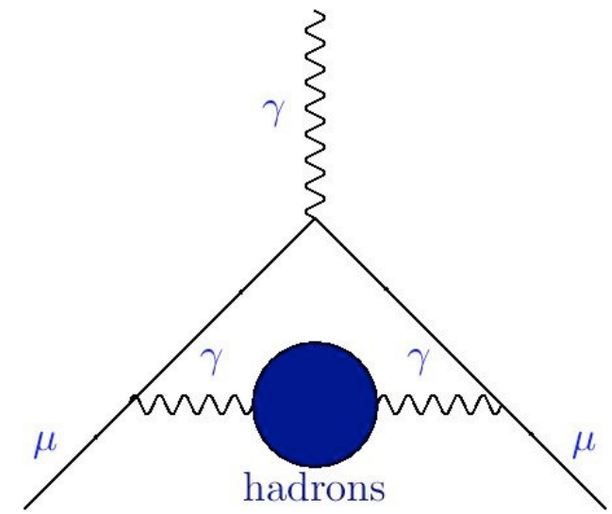

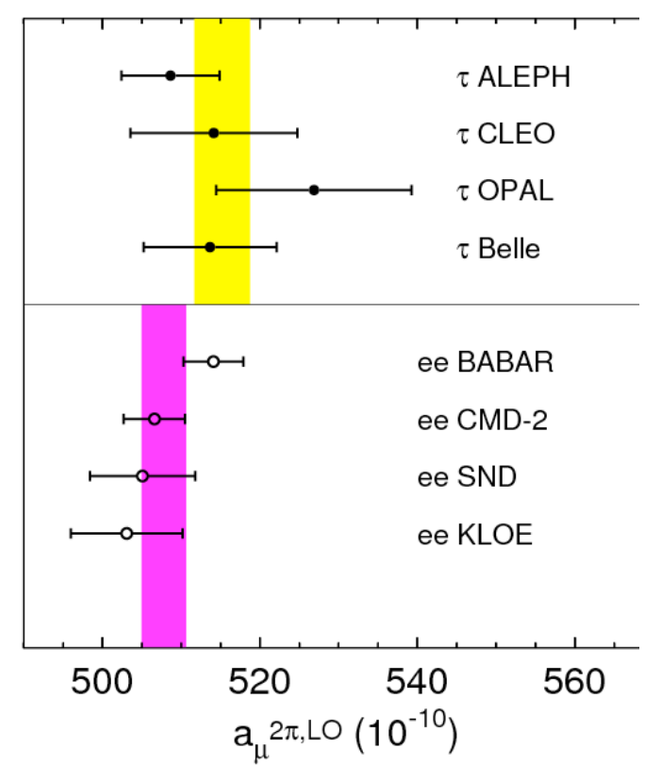

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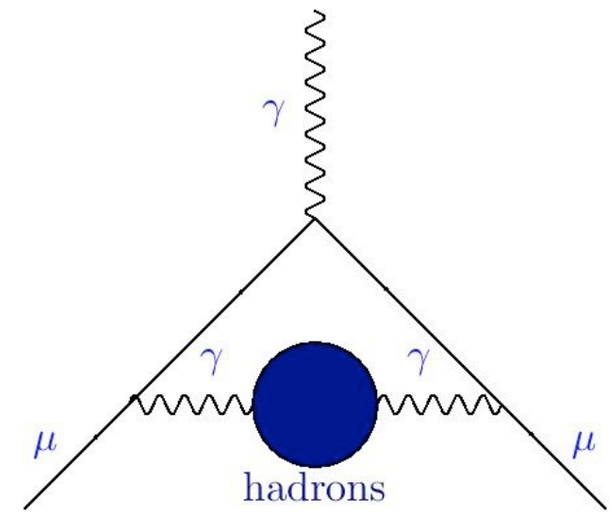

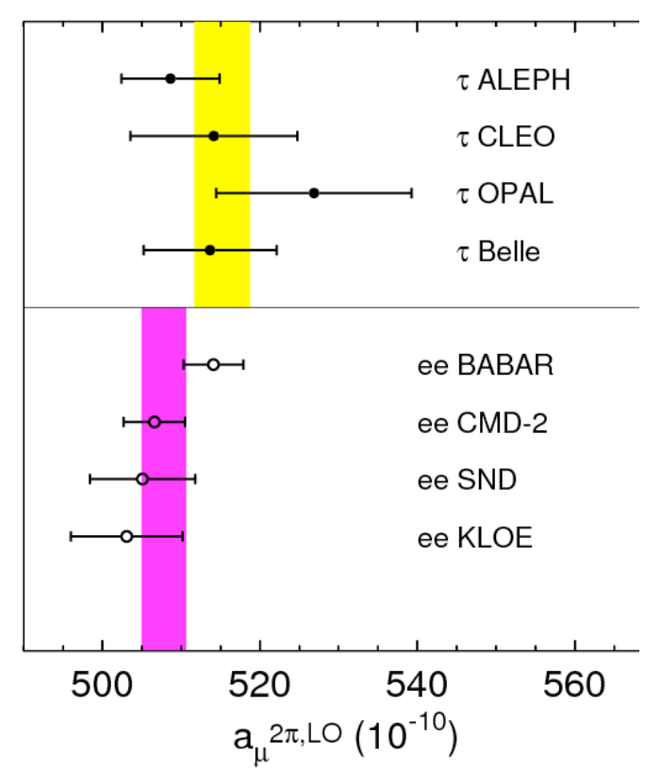

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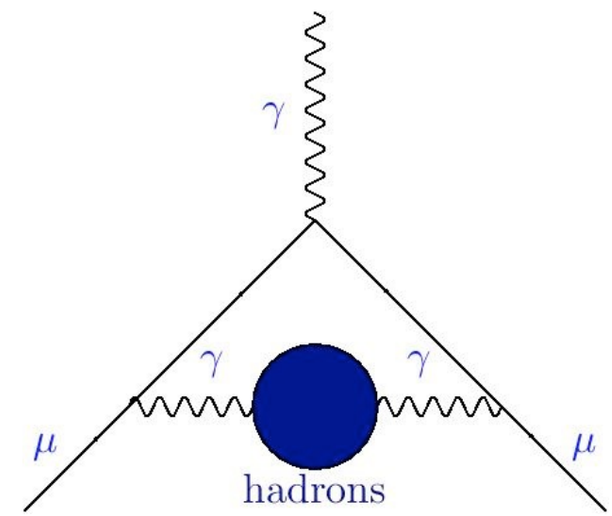

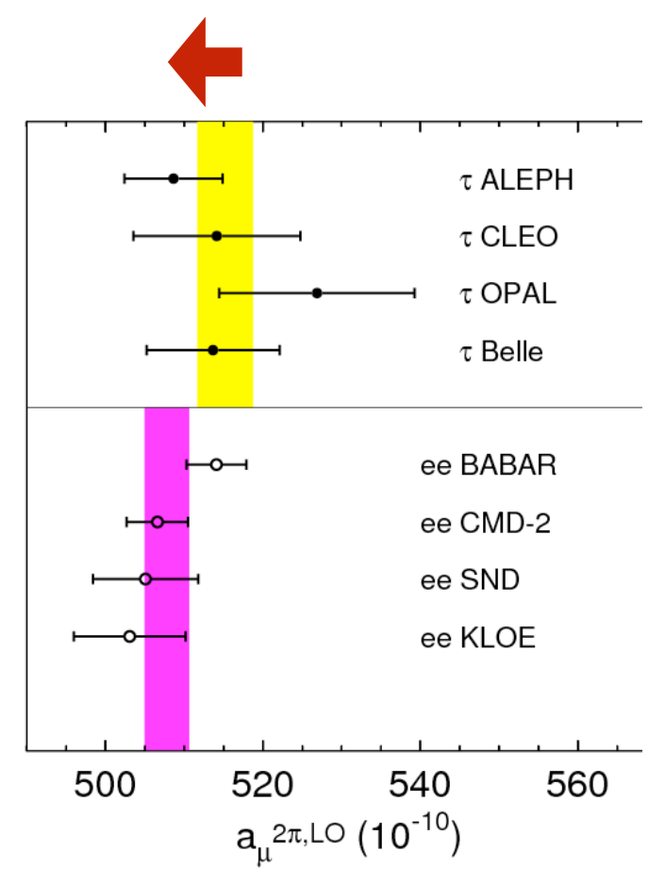

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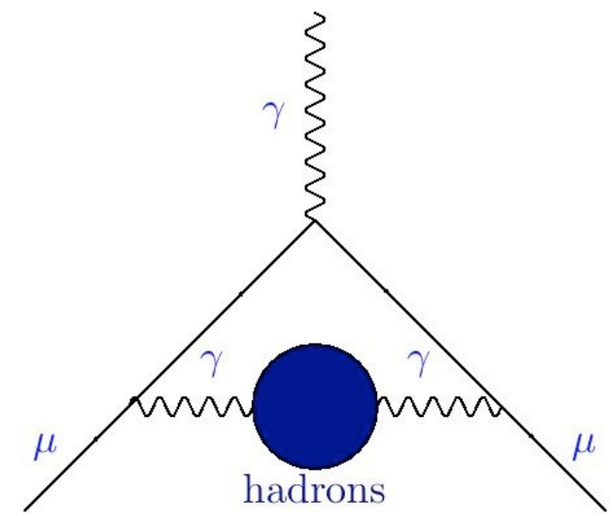
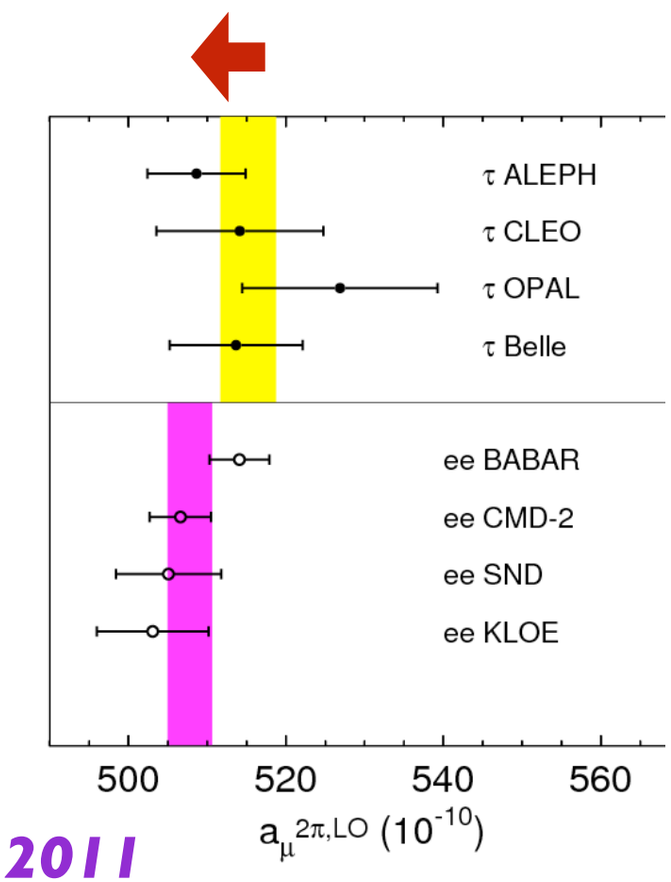
  - 1.9 σ conflict between *KLOE* and *BaBar*





Davier et al. 2011

Charm and bottom quark masses

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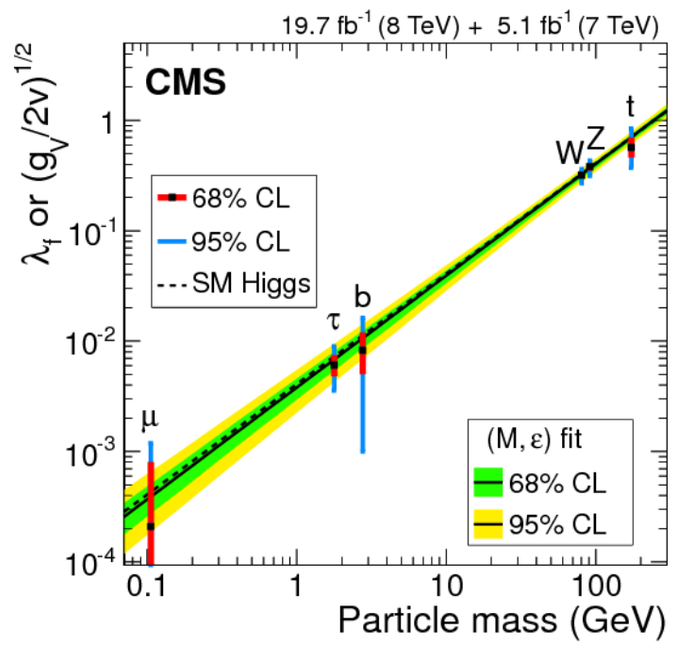

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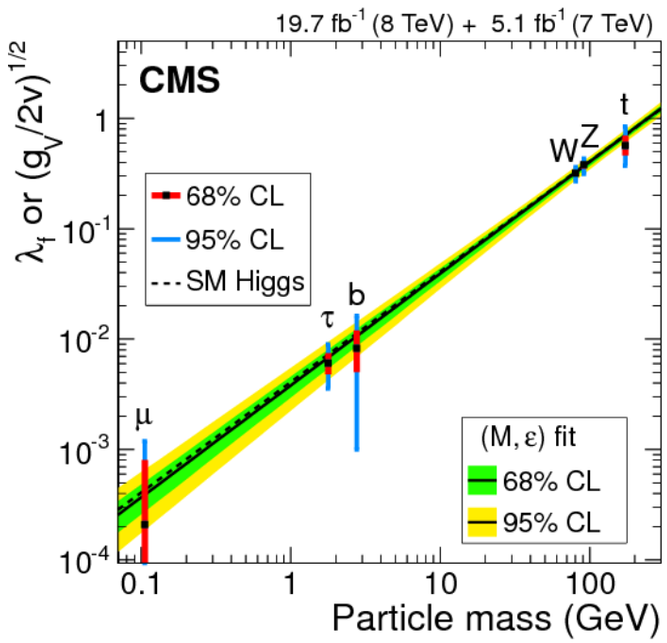

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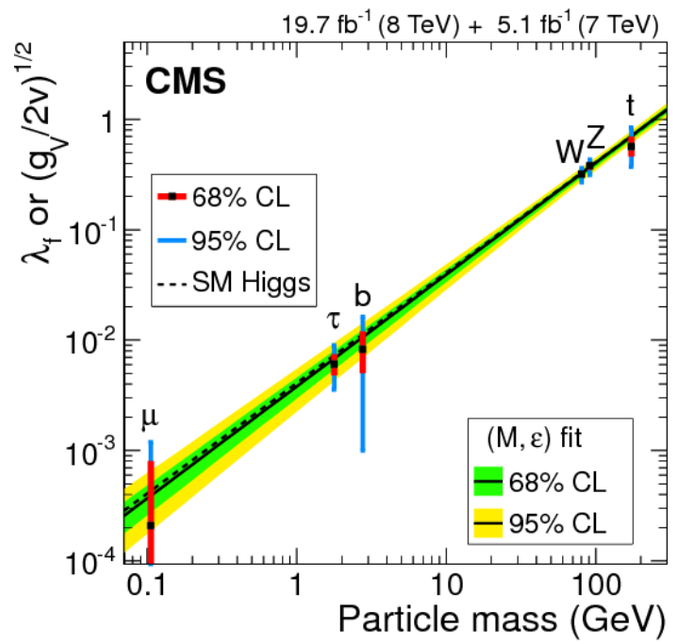

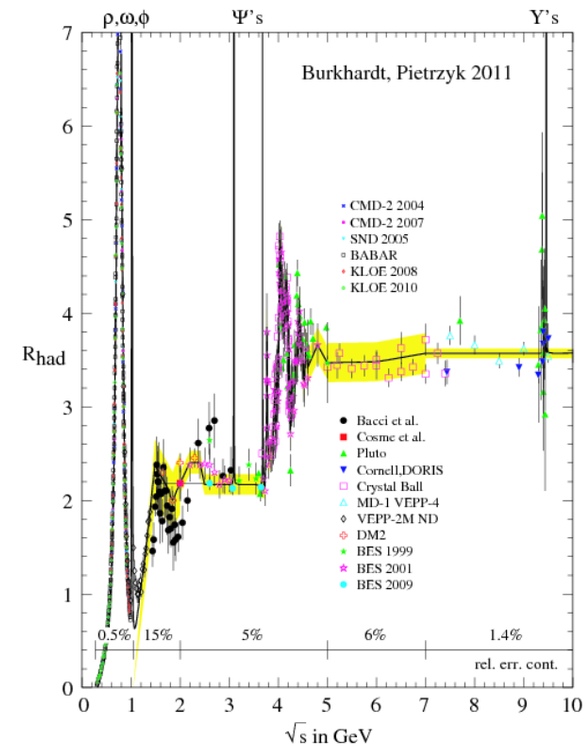

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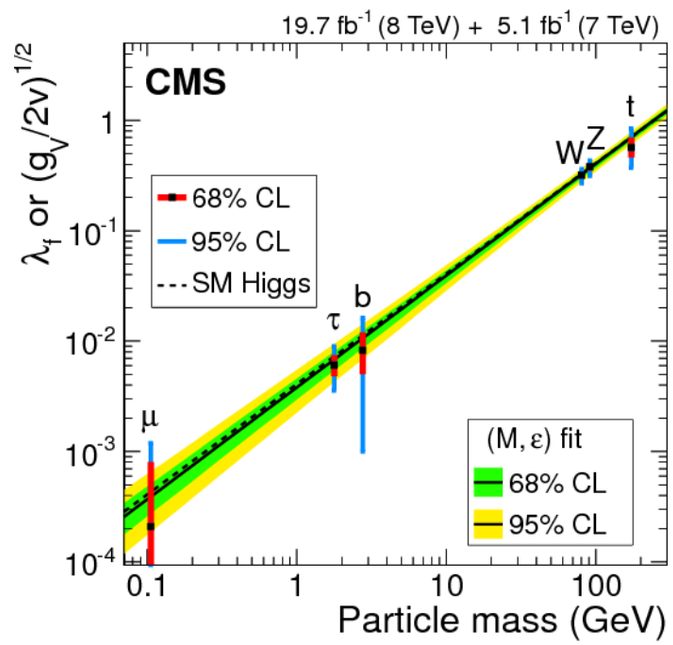

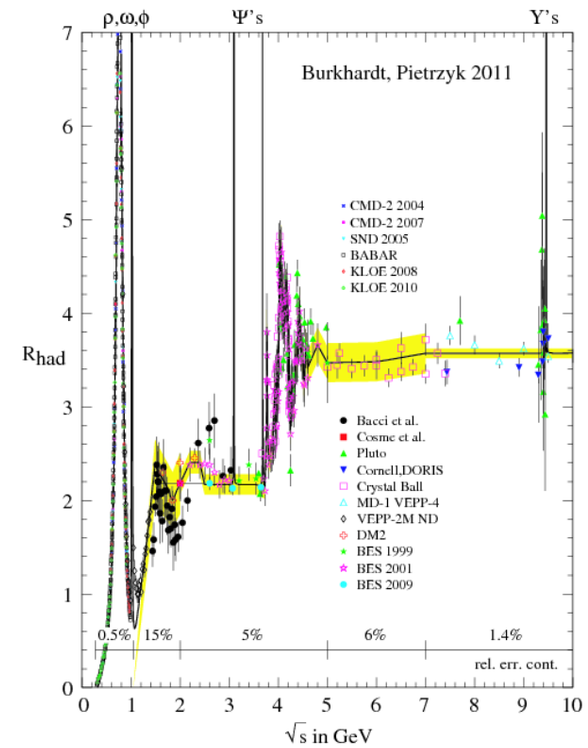

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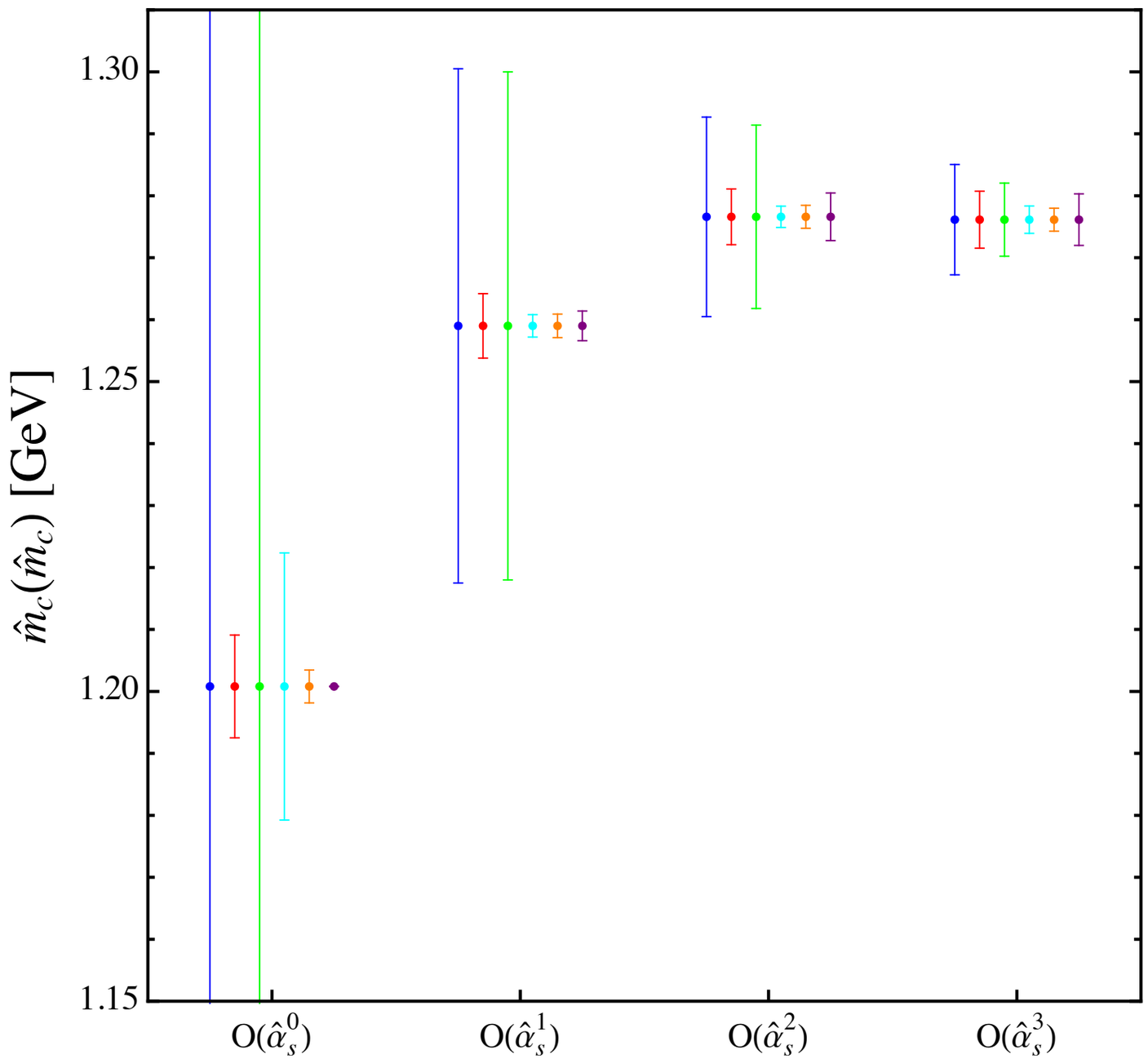
- Sum rule: $m_c = 1272 \pm 8 \pm 4\ (\alpha_s)$ MeV
  Masjuan, Spiesberger, JE 2016
  (expect about twice the error for m_b)

Charm quark mass uncertainty



total error
resonances
PQCD truncation
method
(OPE truncation, …)
gluon condensate
α_s

JE, Masjuan, Spiesberger 2016

Top quark mass

	central value	statistical error	systematic error	total error
ATLAS	172.84	0.34	0.61	0.70
Tevatron	174.30	0.35	0.54	0.64
CMS	172.43	0.13	0.46	0.48
grand average	172.97	0.13	0.38	0.41

JE, Eur. Phys. J. C 75 (2015)

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JE, Eur. Phys. J. C 75 (2015)

- $m_t = 172.97 \pm 0.28_{\text{uncorr.}} \pm 0.29_{\text{corr.}} \pm 0.50_{\text{QCD}}$ GeV

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	central value	statistical error	systematic error	total error
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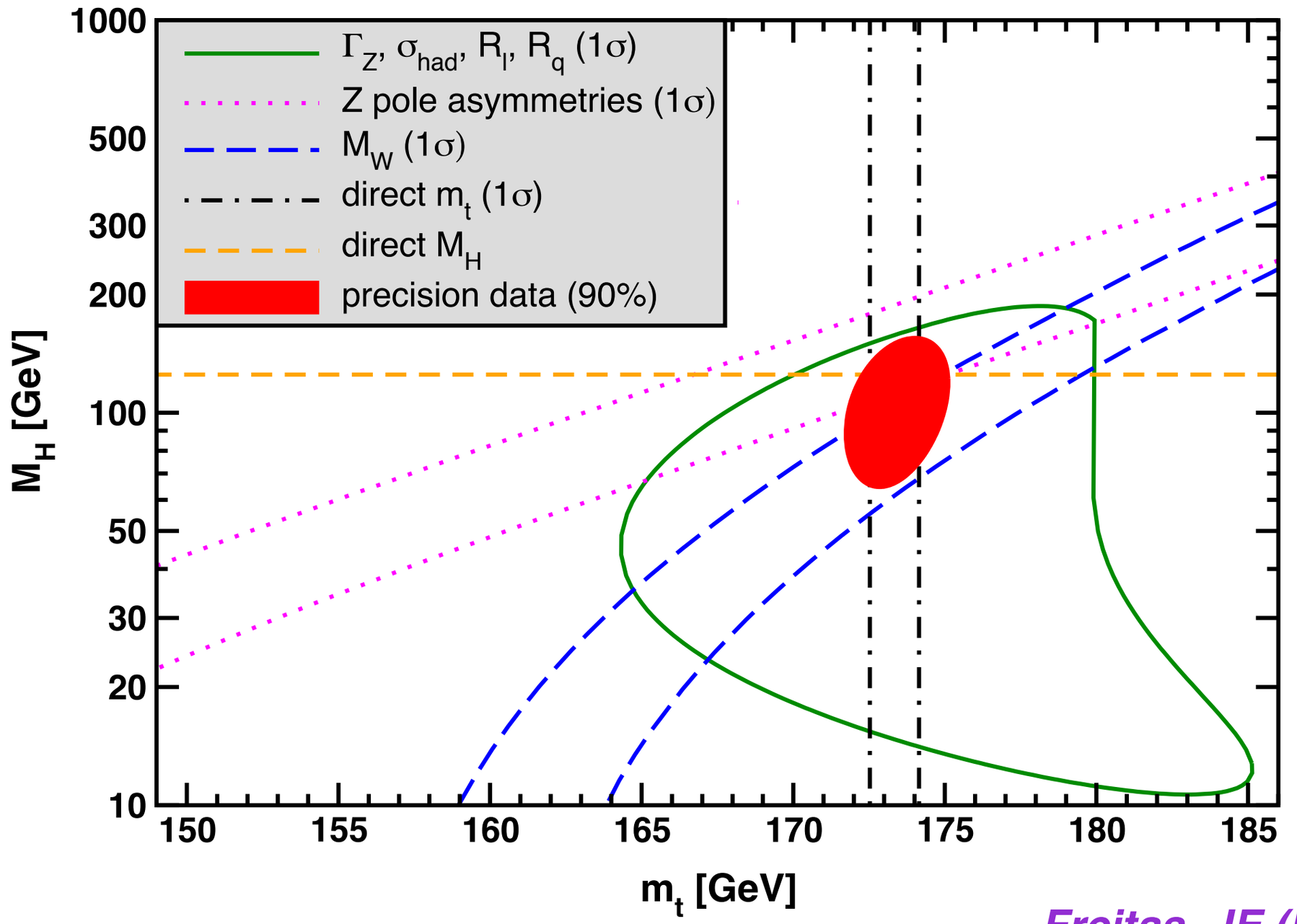
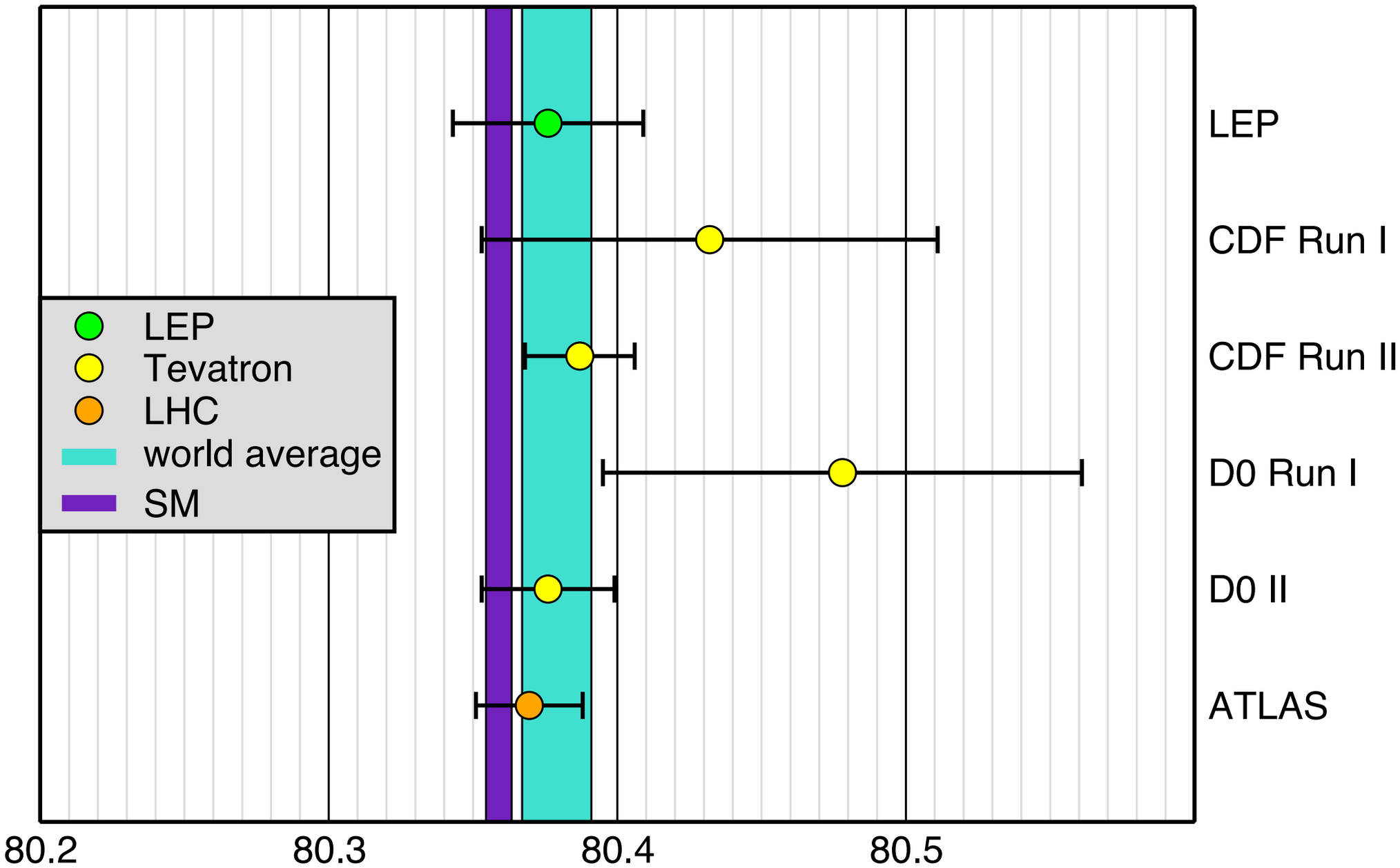
- top mass still matters: change from previous
  $m_t = 173.34 \pm 0.81$ GeV reduces indirect M_H by 3 GeV

M_H — m_t

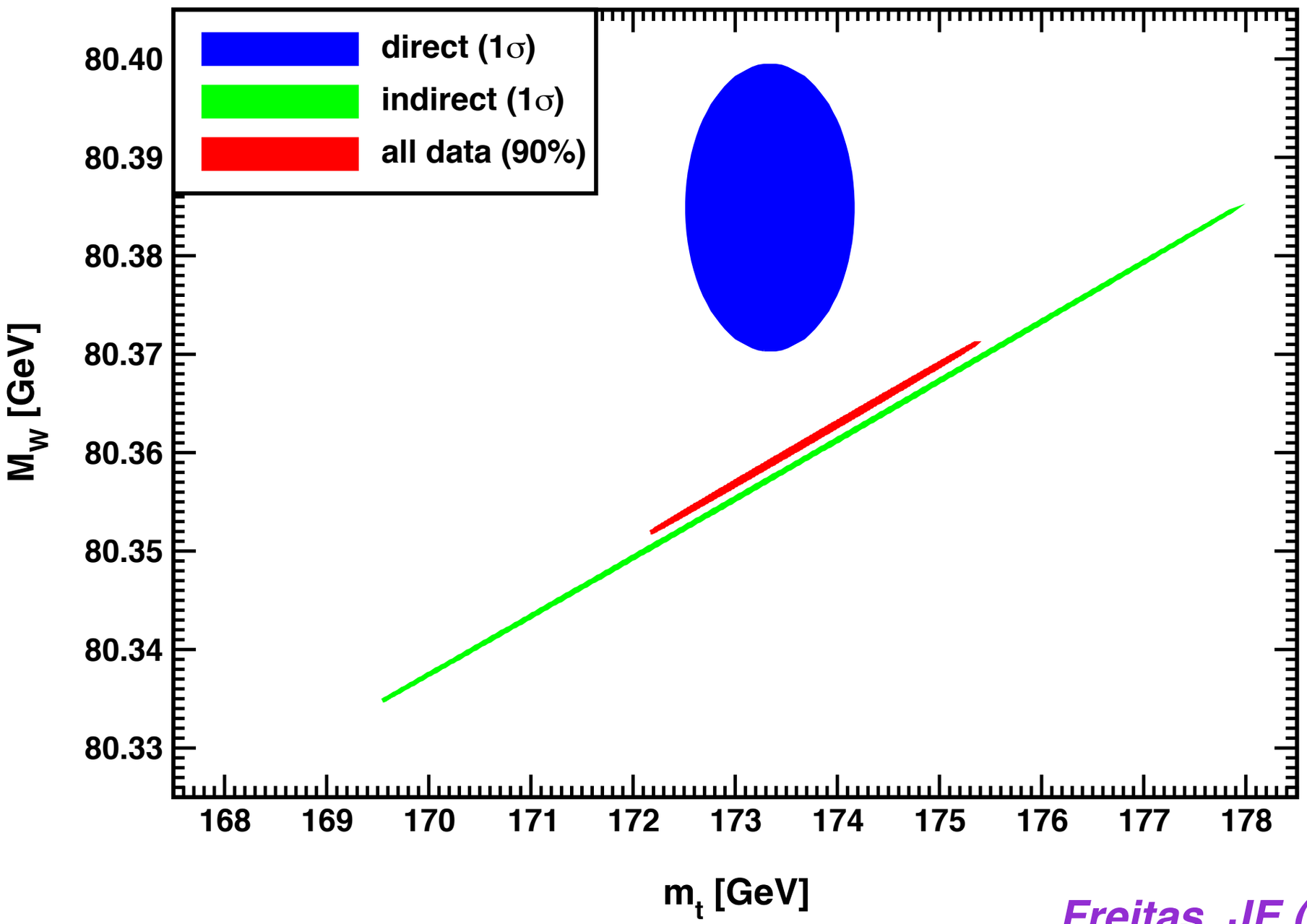


Freitas, JE (PDG 2016)

W boson mass [GeV]

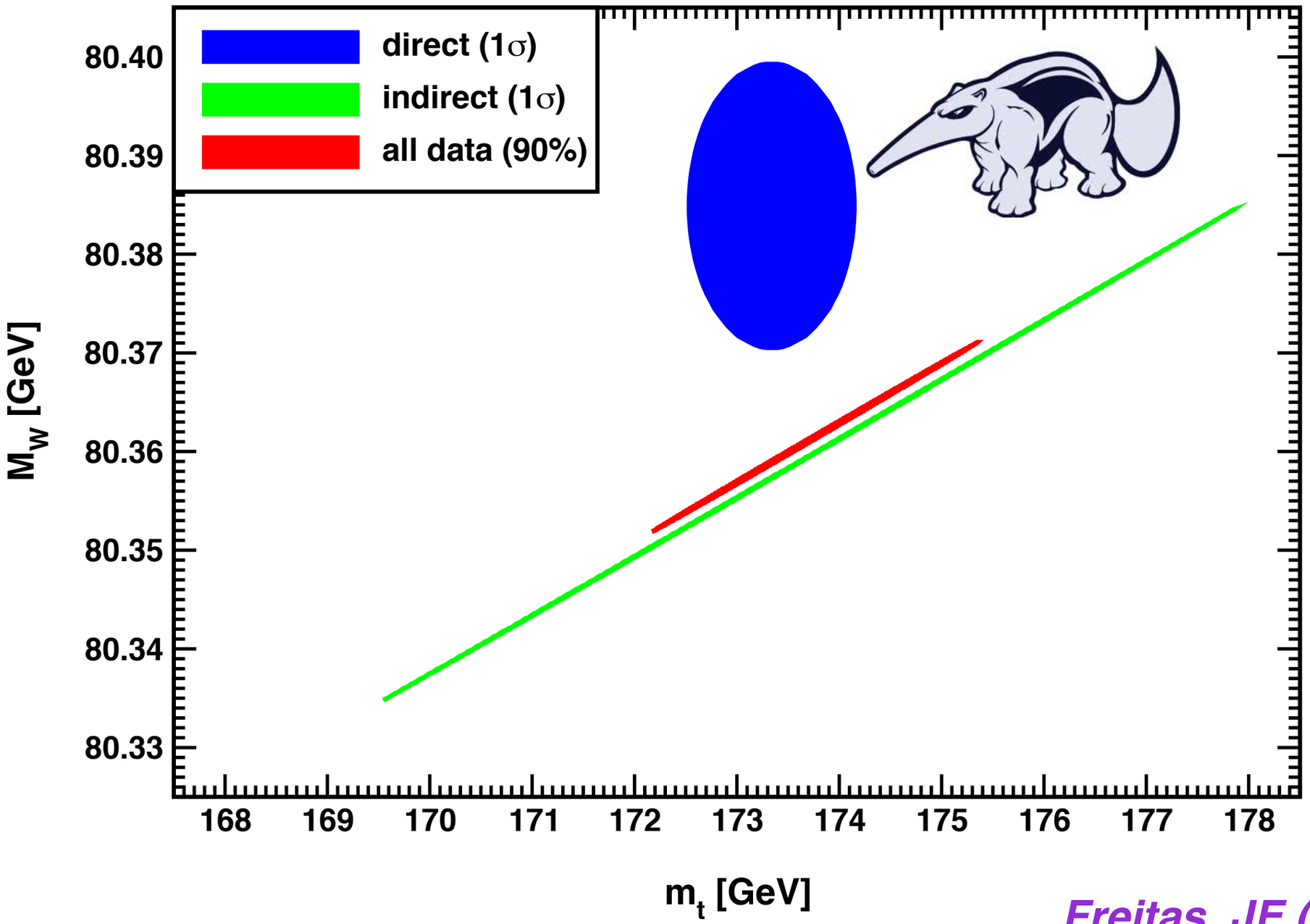


M_W — m_t



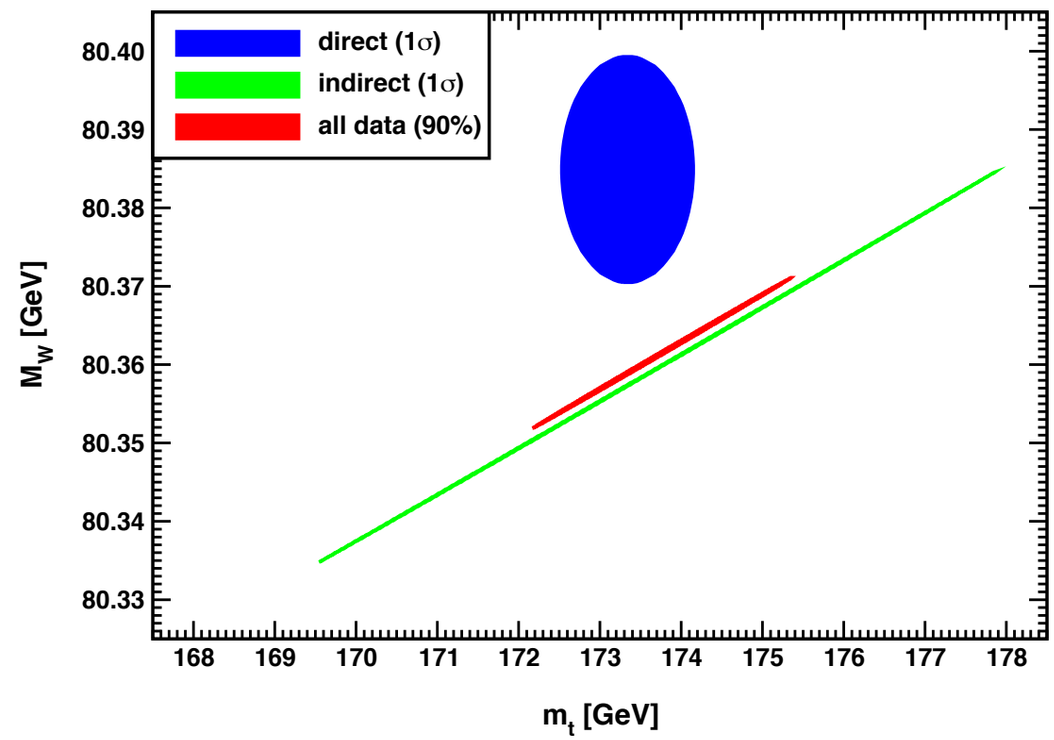
Freitas, JE (PDG 2016)

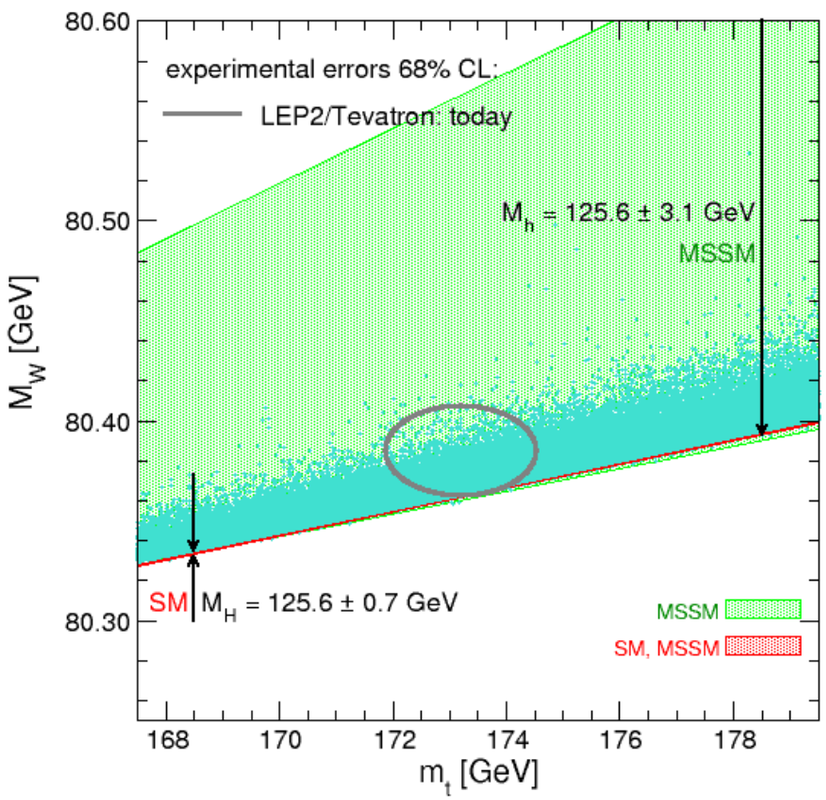
M_W — m_t

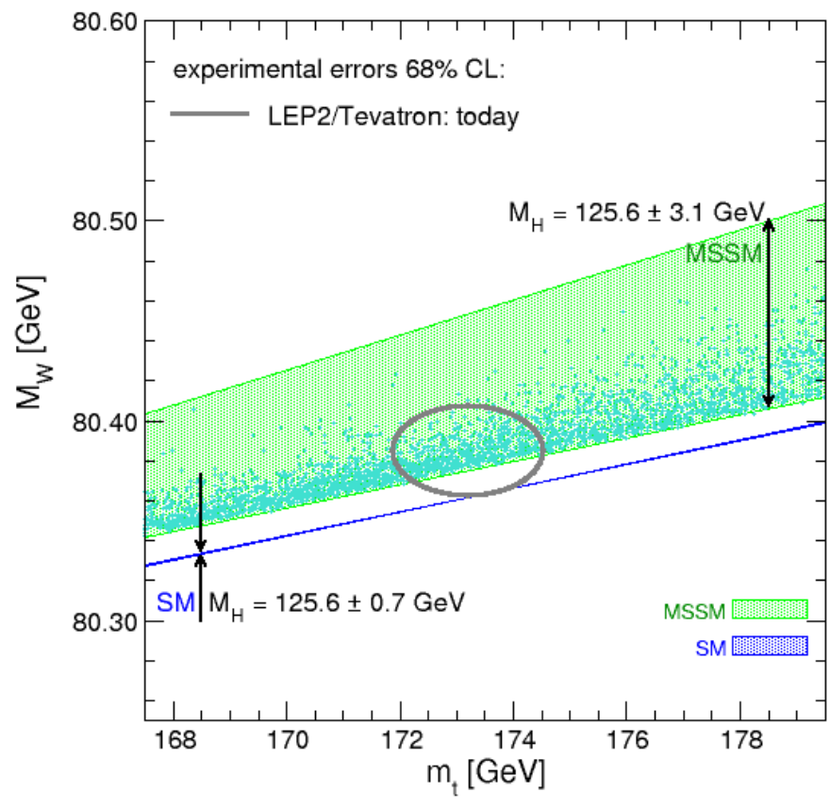


Freitas, JE (PDG 2016)

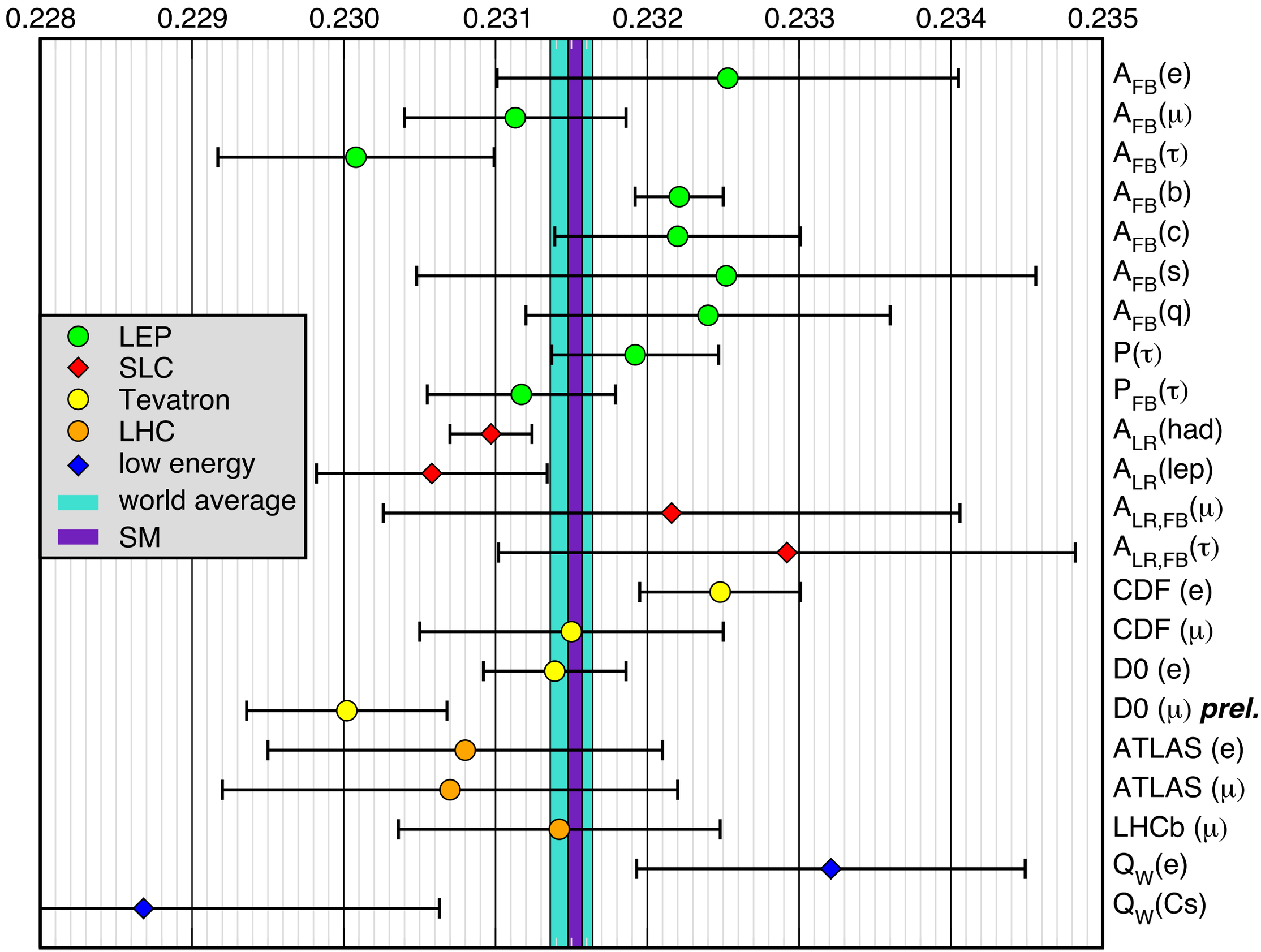
M_W in the MSSM

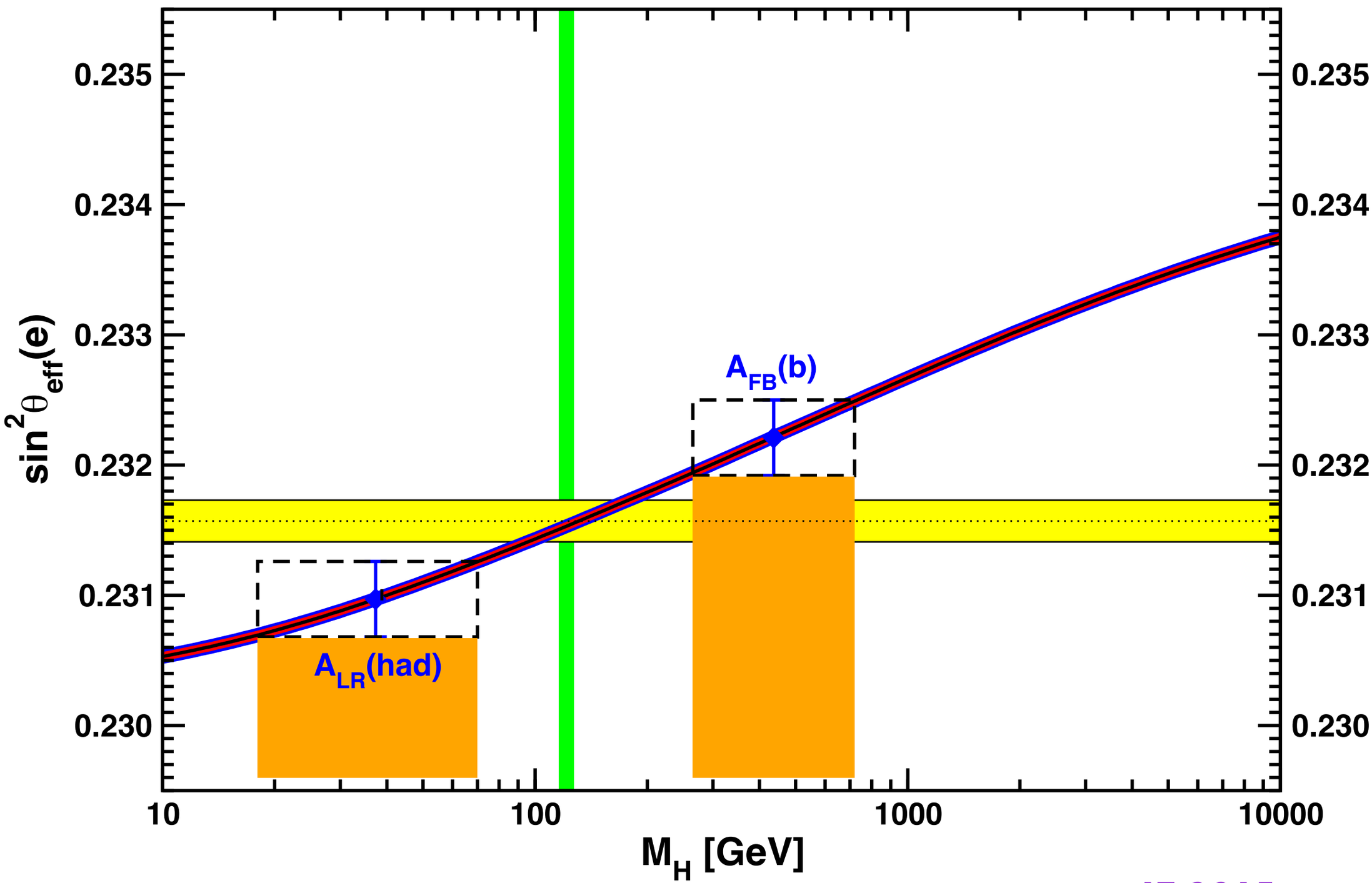






Heinemeyer, Hollik, Weiglein, Zeune 2013

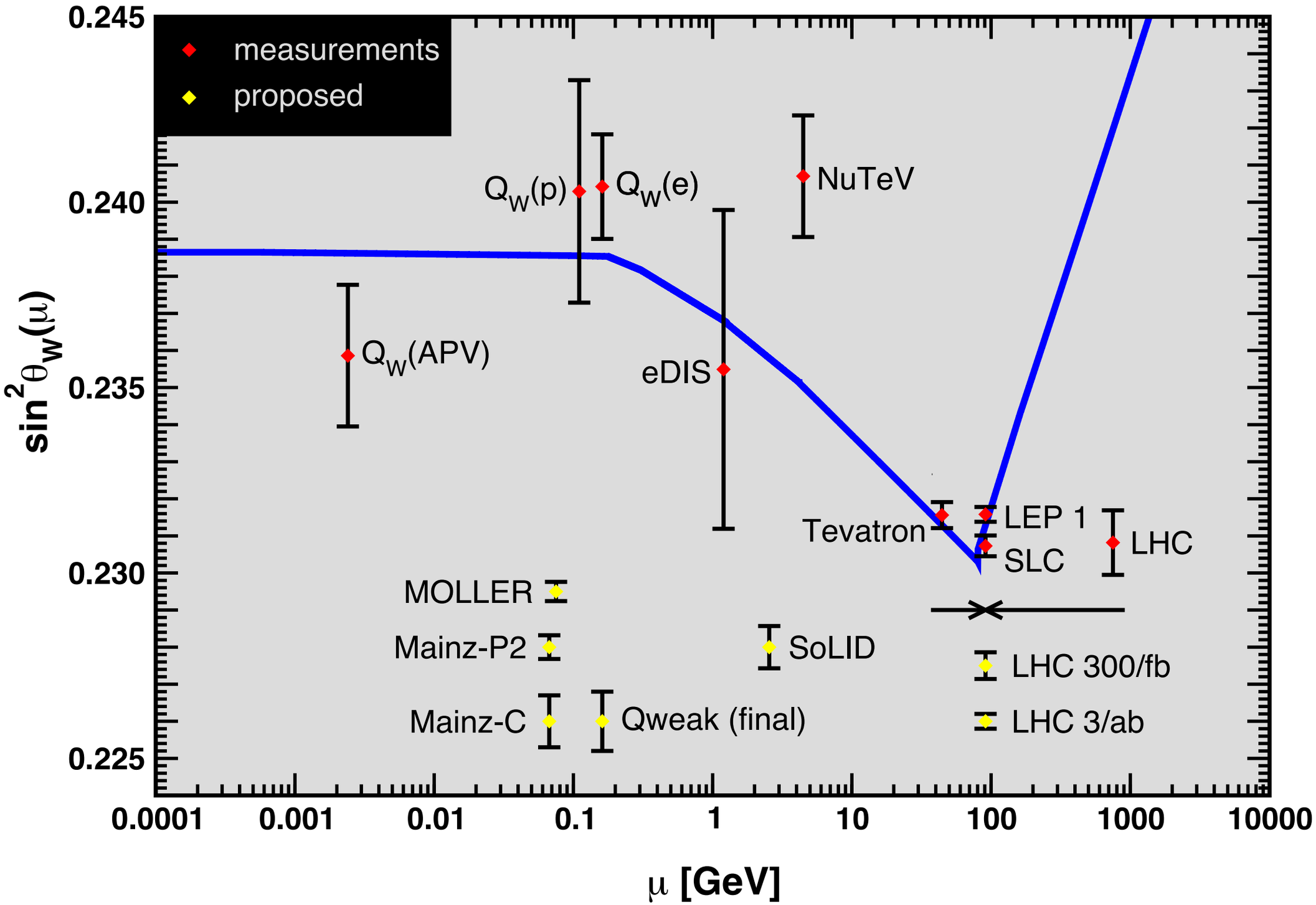

0.228
0.229
0.230
0.231
0.232
0.233
0.234
0.235
LEP
SLC
Tevatron
LHC
low energy
world average
SM
$A_{FB}(e)$
$A_{FB}(\mu)$
$A_{FB}(\tau)$
$A_{FB}(b)$
$A_{FB}(c)$
$A_{FB}(s)$
$A_{FB}(q)$
$P(\tau)$
$P_{FB}(\tau)$
$A_{LR}(had)$
$A_{LR}(lep)$
$A_{LR,FB}(\mu)$
$A_{LR,FB}(\tau)$
CDF (e)
CDF (μ)
D0 (e)
D0 (μ) ***prel.***
ATLAS (e)
ATLAS (μ)
LHCb (μ)
$Q_W(e)$
$Q_W(Cs)$


0.235
0.234
0.233
0.232
0.231
0.230
$\sin^2\theta_{eff}(e)$
$A_{FB}(b)$
$A_{LR}(had)$
10
100
1000
10000
M_H [GeV]

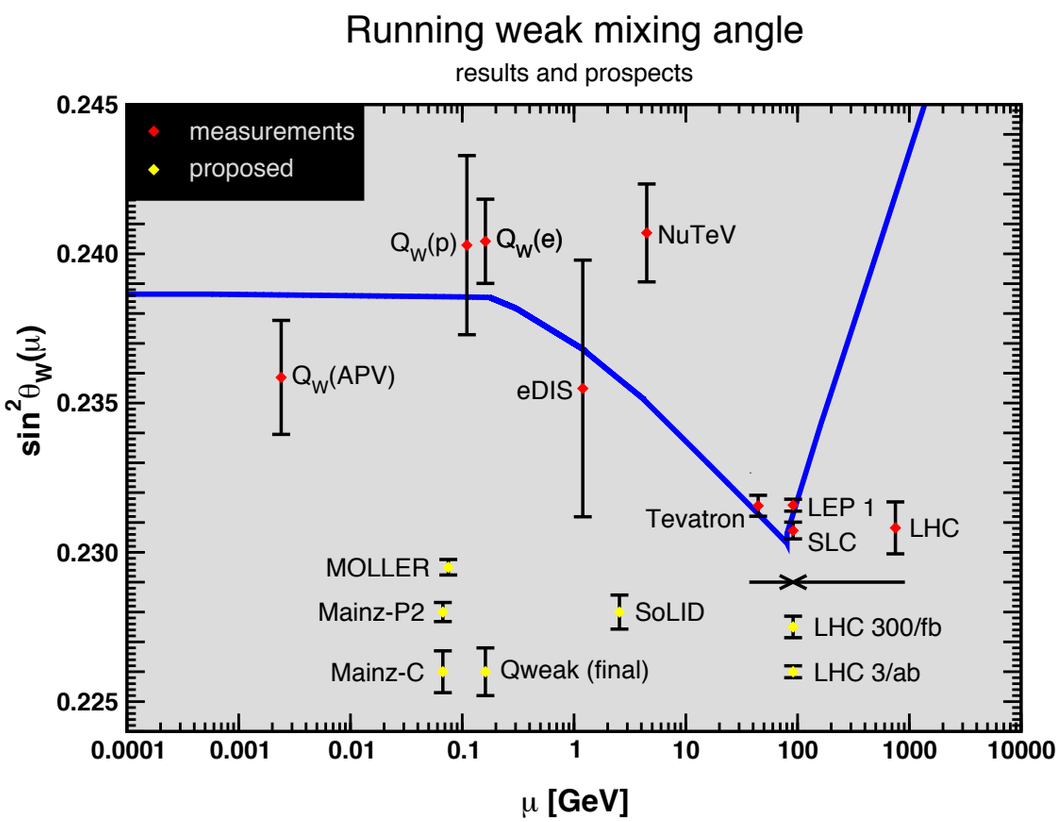
JE 2015

Running weak mixing angle

results and prospects



Precision $\sin^2\theta_W(0)$: issues



Rodolfo Ferro, JE
(in preparation)

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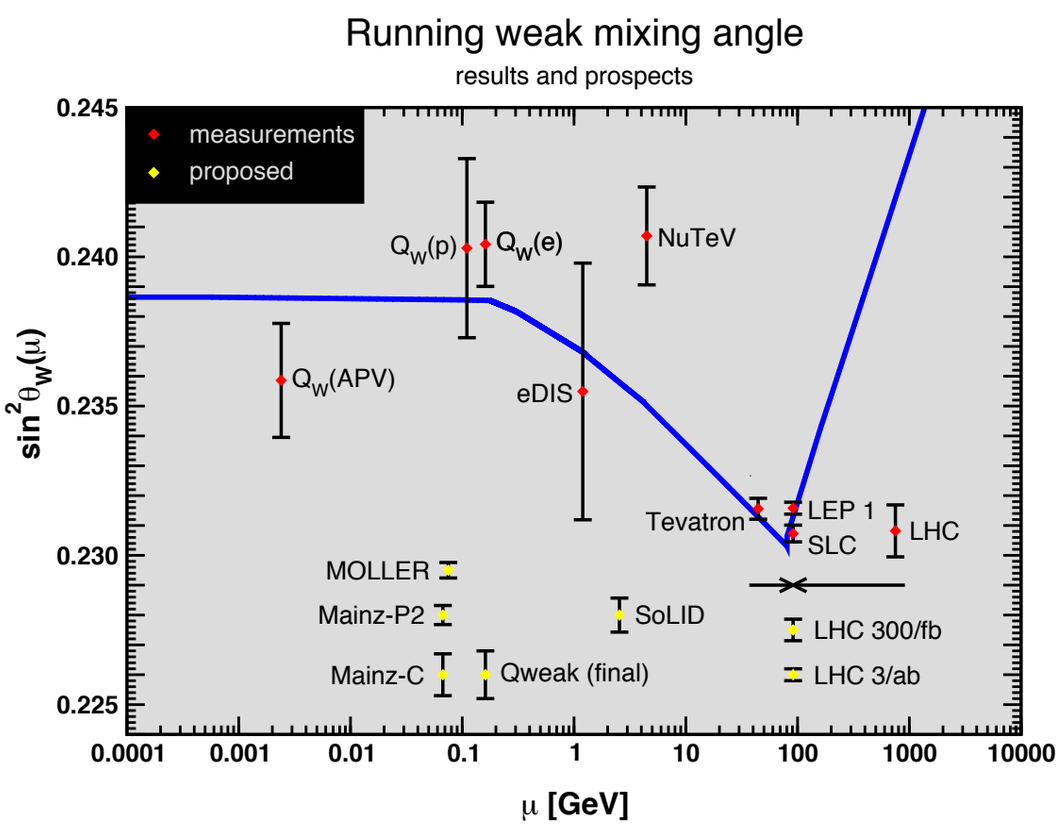

- use PQCD where possible (m_c and m_b needed)

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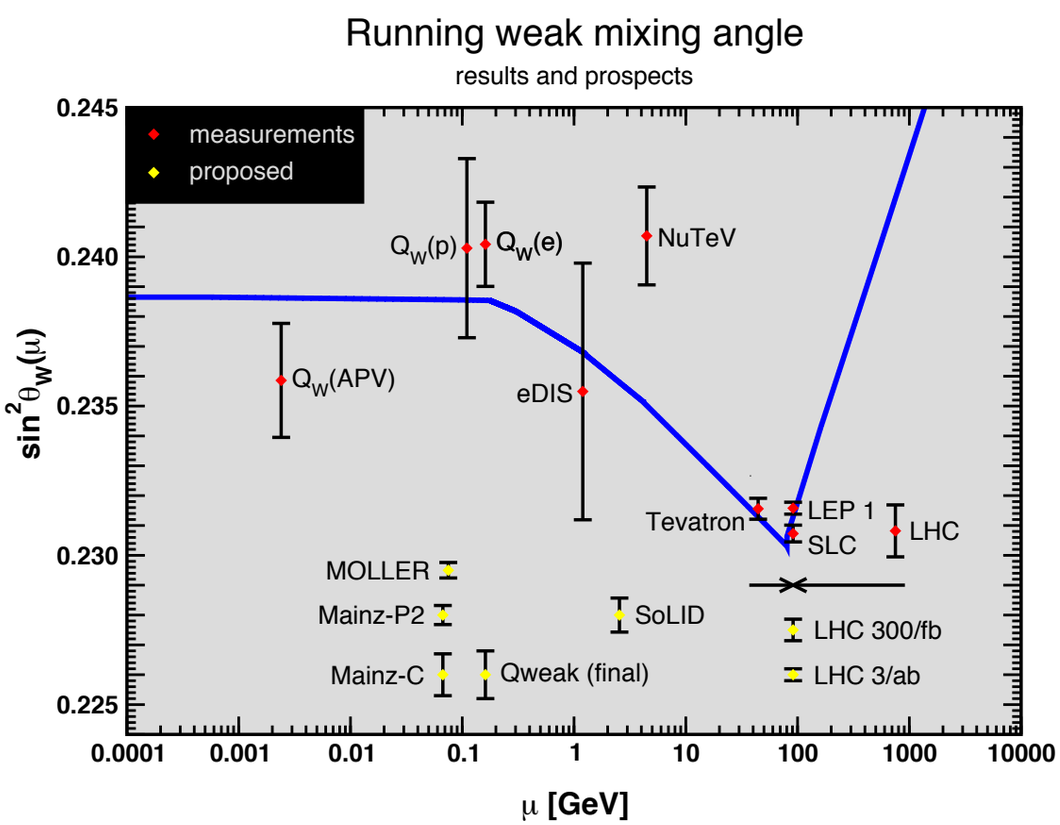

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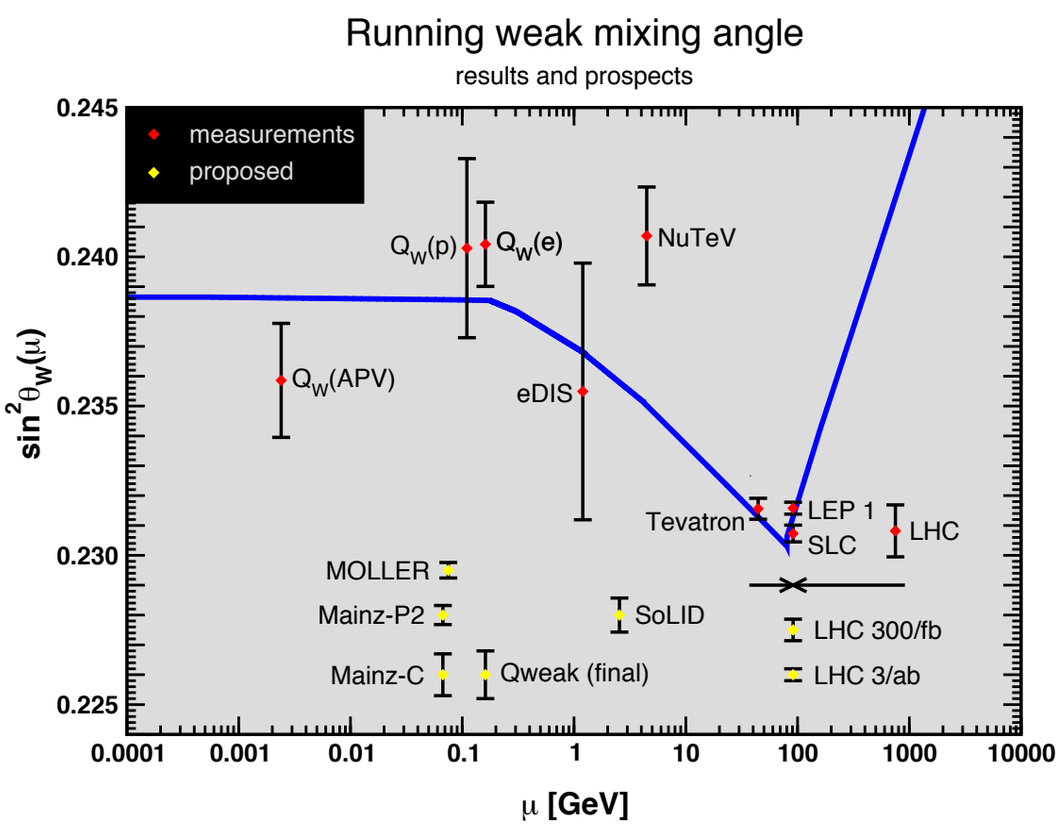

Rodolfo Ferro, JE (in preparation)

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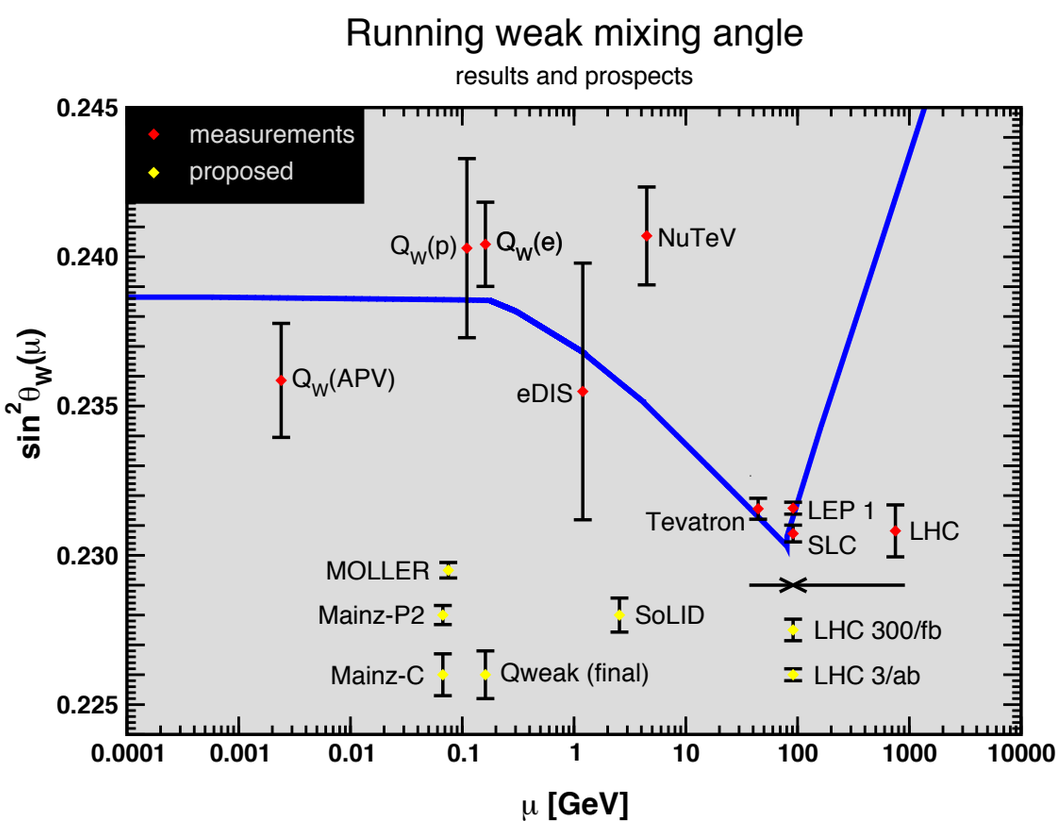

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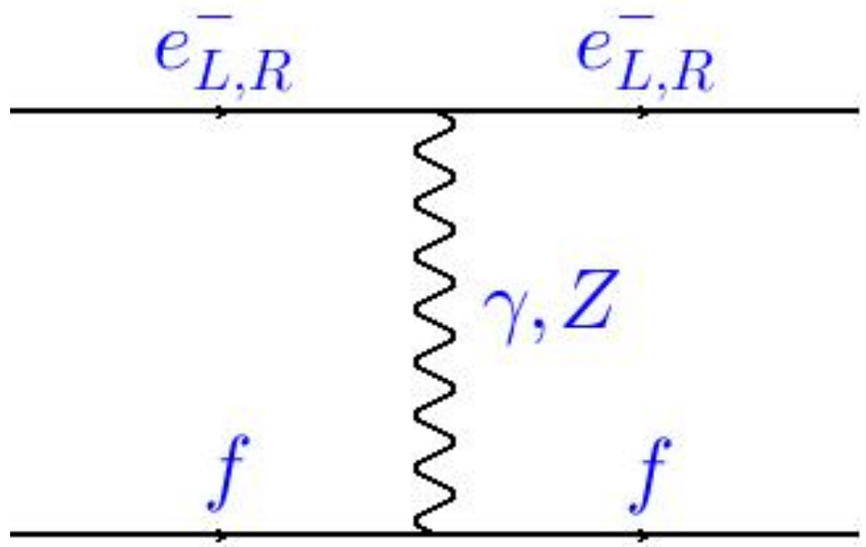
- flavor separation: construction of upper and lower limits on strange quark contribution
- singlet separation: adaptation of lattice result for $g_\mu-2$

Parity violating electron scattering



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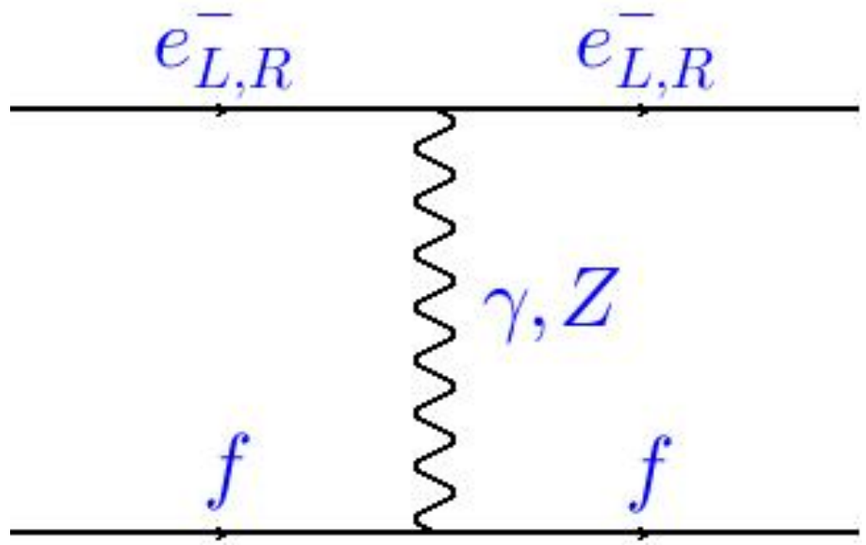

- NC couplings: $g^{ef}_{AV}\ \bar{e}\gamma^{\mu}\gamma^{5} e\ \bar{f}\gamma_{\mu} f$ $\quad g^{ef}_{VA}\ \bar{e}\gamma^{\mu} e\ \bar{f}\gamma_{\mu}\gamma^{5} f$

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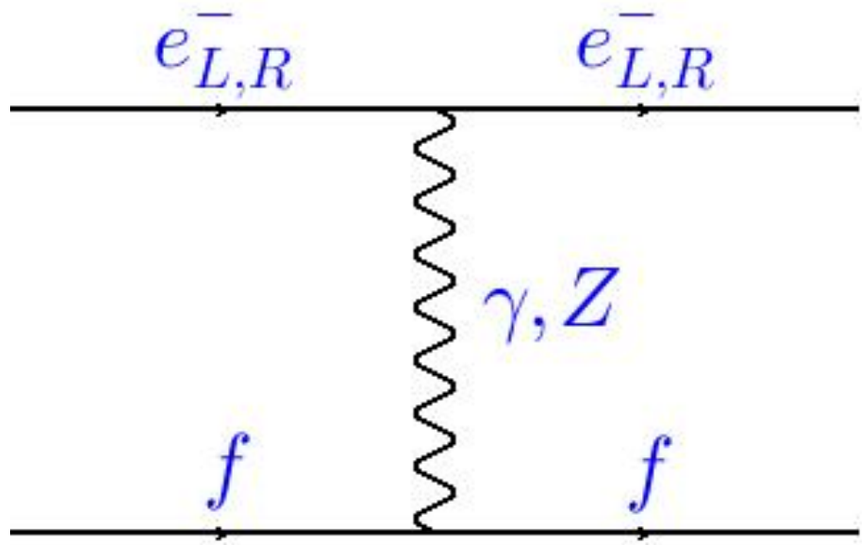

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- $|g^{ef}_{AV}| = \frac{1}{2} - 2\,|Q_f|\,\sin^2\theta_W$ $\qquad$ $|g^{ef}_{VA}| = \frac{1}{2} - 2\sin^2\theta_W$

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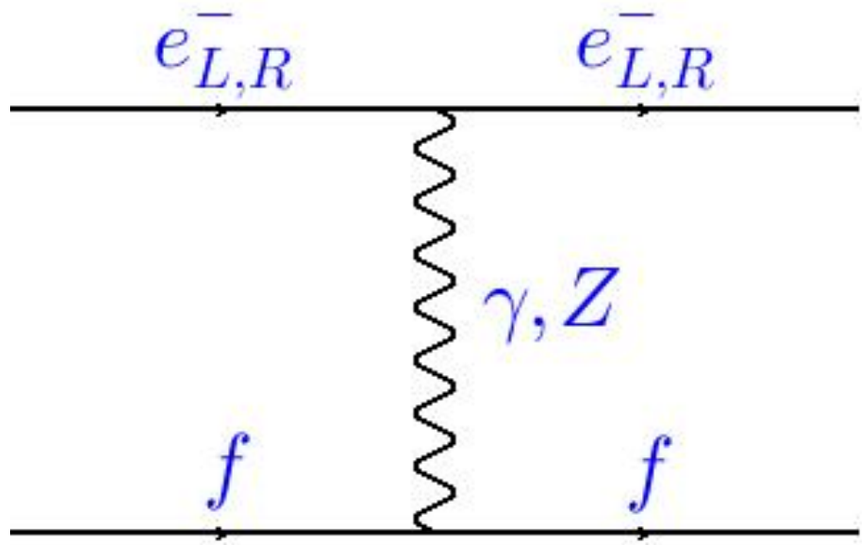

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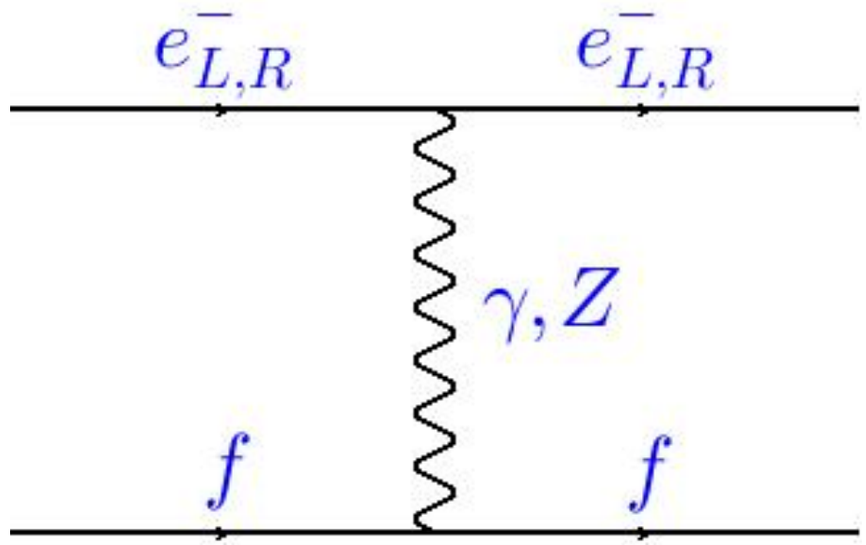

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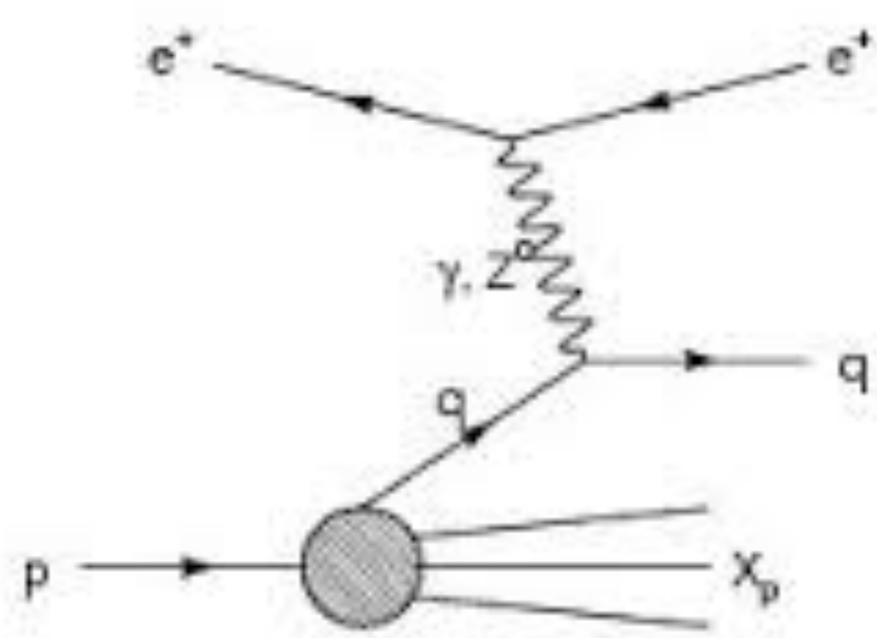
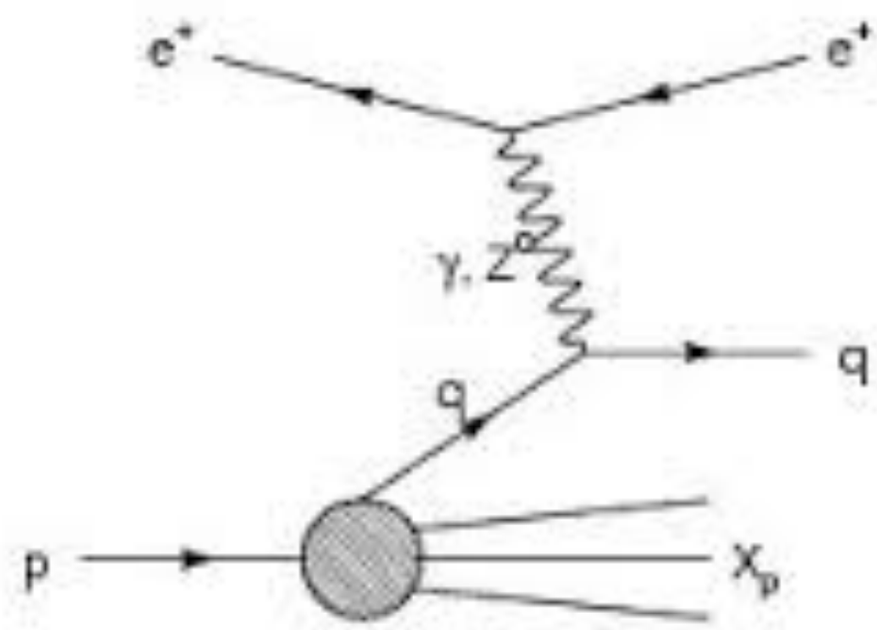
- $\Delta\sin^2\theta_W = (\sin^2\theta_W - 1/4 + N/4Z)\,\Delta Q_W/Q_W$

Polarized DIS



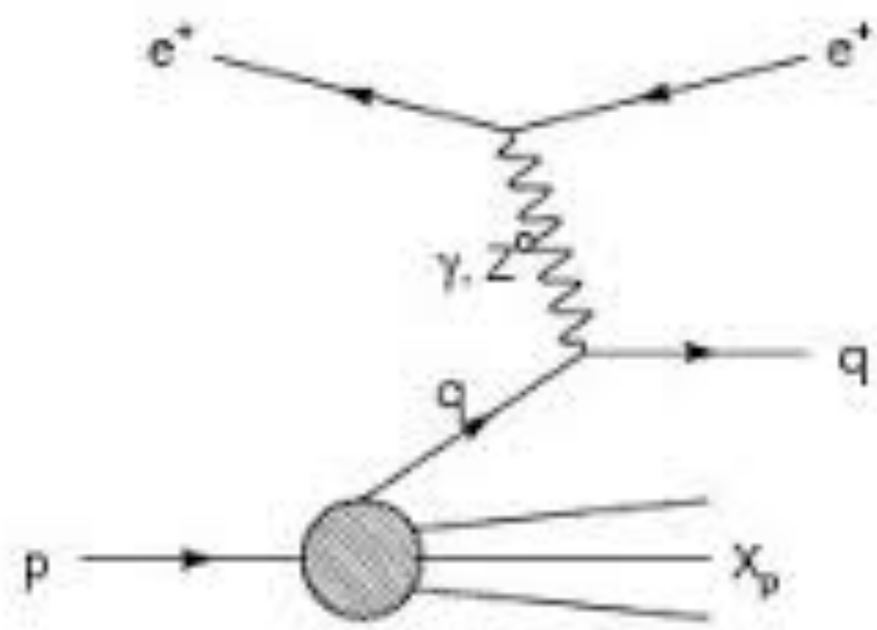
Polarized DIS

- E122 (SLAC) & PVDIS (Jefferson Lab)



Polarized DIS

- E122 (SLAC) & PVDIS (Jefferson Lab)
- deuterium target (isoscalar and simple nucleus)



Polarized DIS

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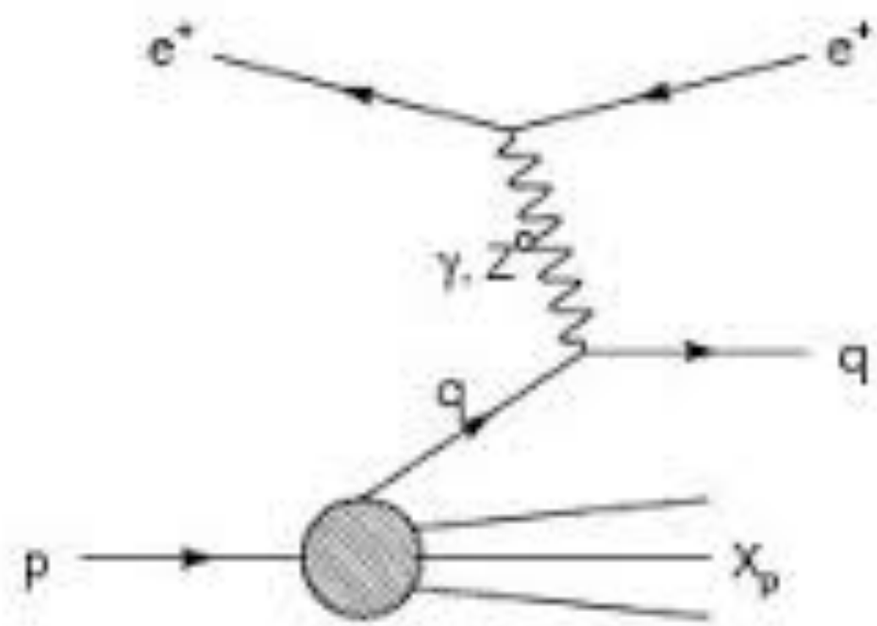

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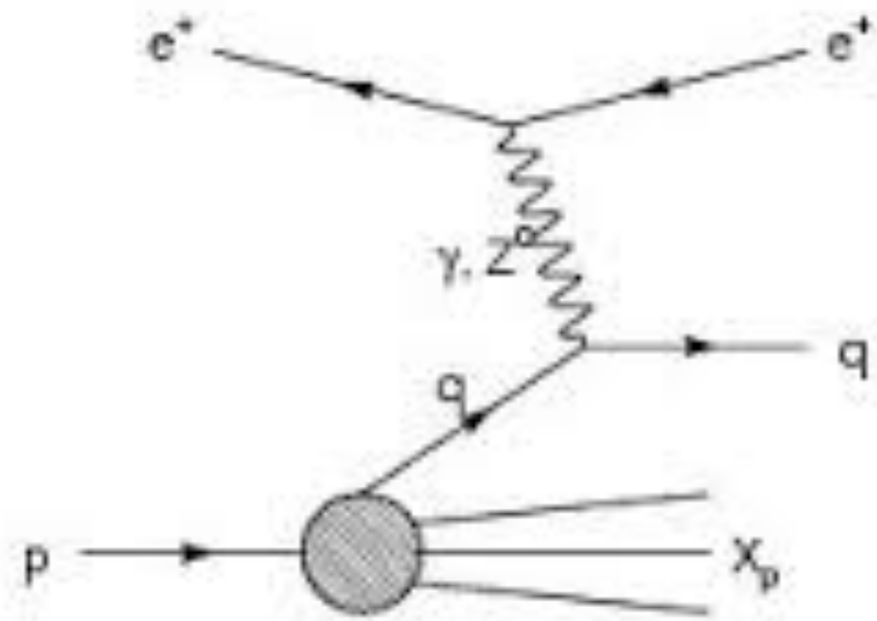

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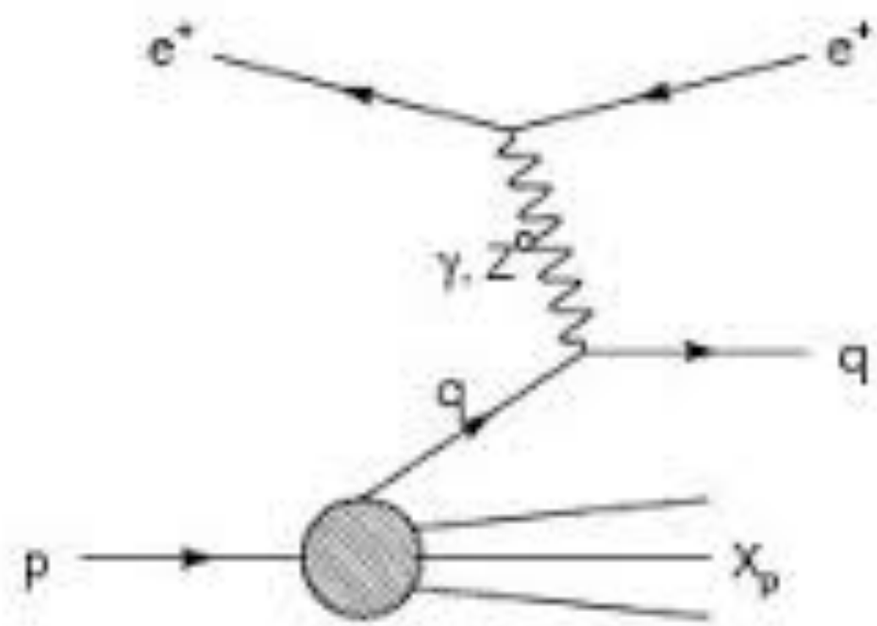
- large $y \Longrightarrow g^{eq}_{AV}$ and g^{eq}_{AV}



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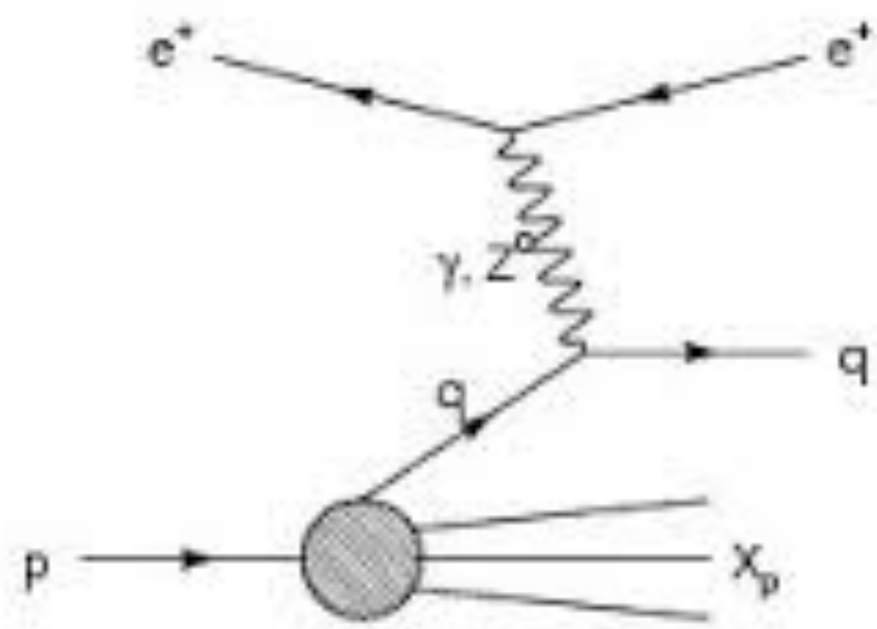
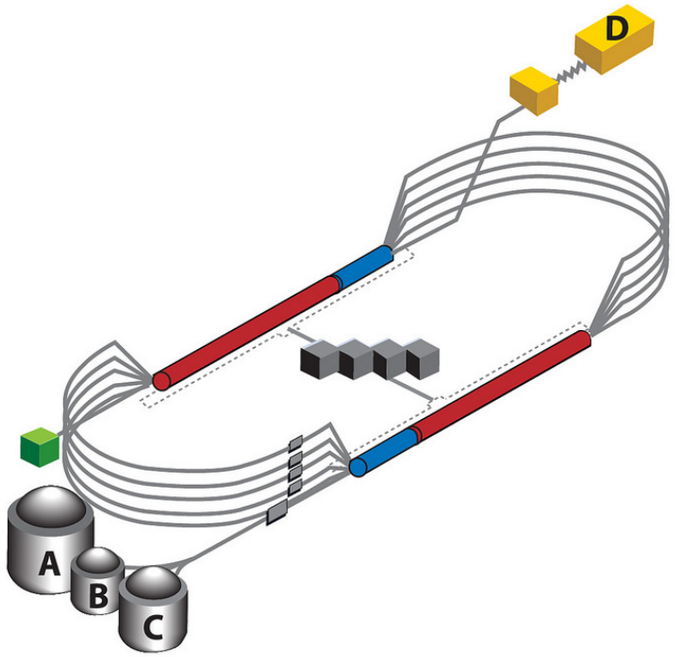
- large $y \Longrightarrow g^{eq}_{AV}$ and g^{eq}_{AV}
- Q_q weighted (γ-Z interference)

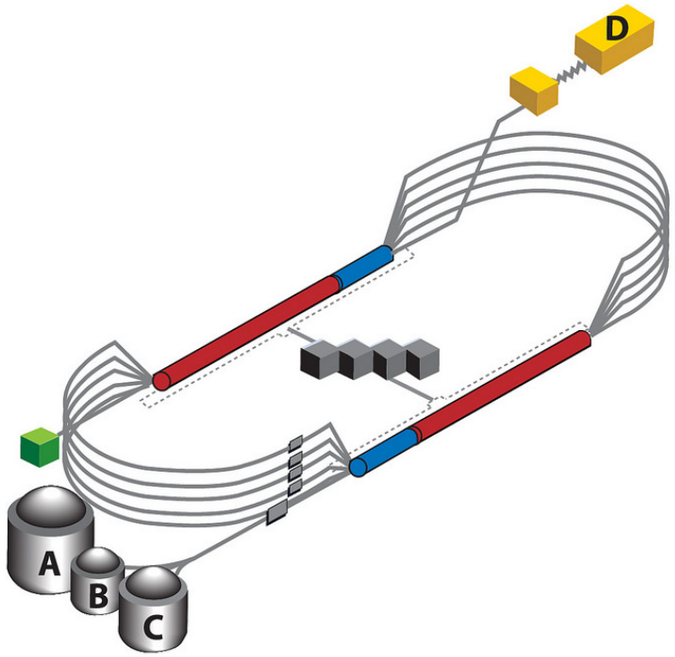


Polarized Møller scattering



Polarized Møller scattering

- E158 (SLAC) & MOLLER (Jefferson Lab)



Polarized Møller scattering

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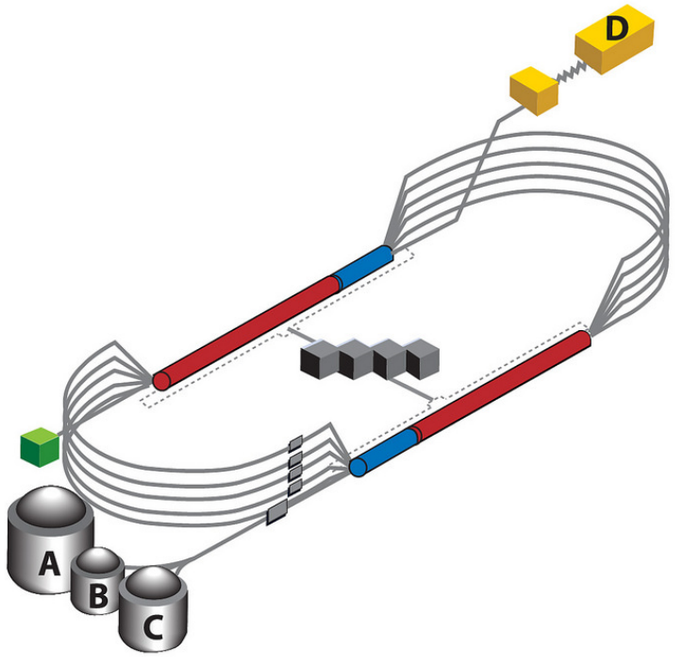

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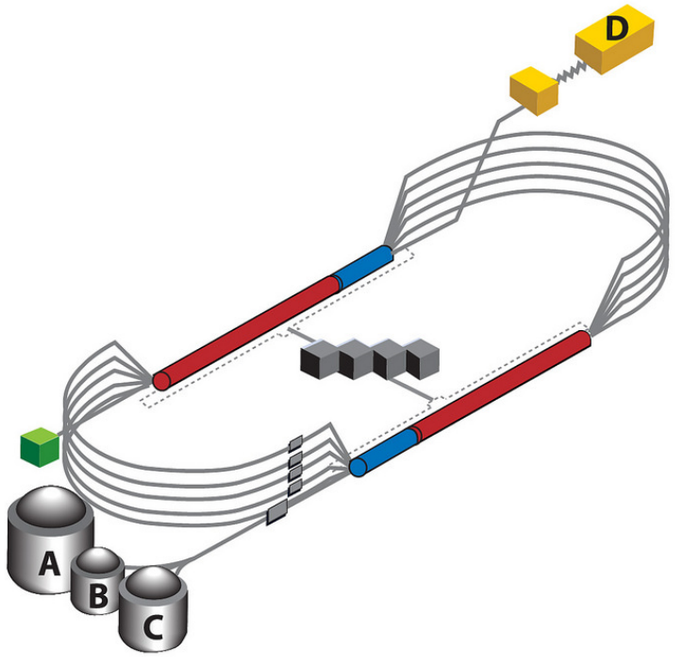

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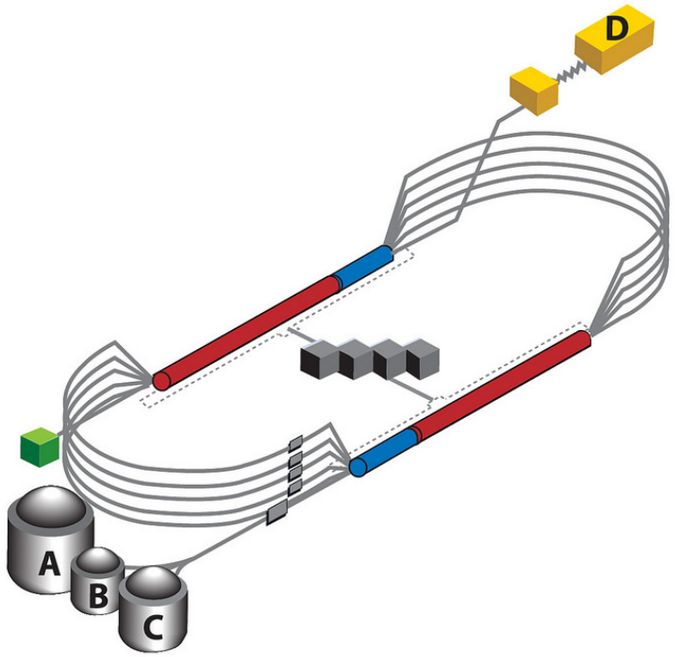

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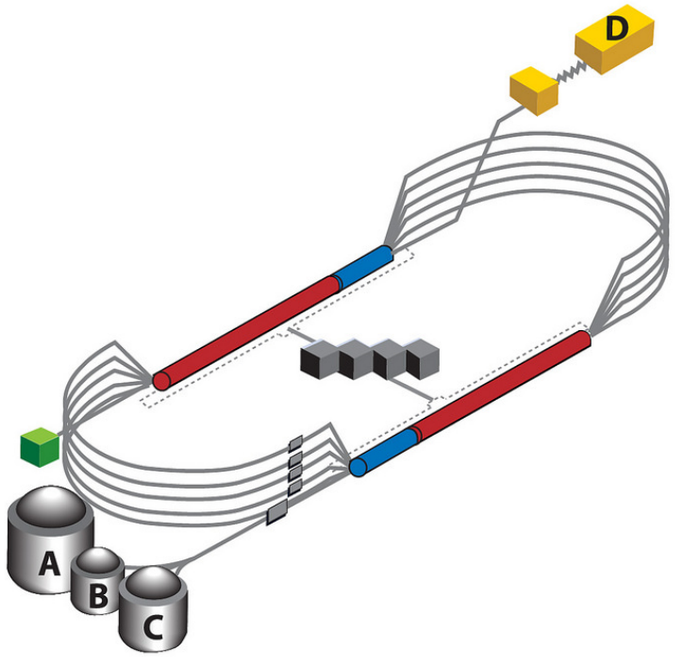

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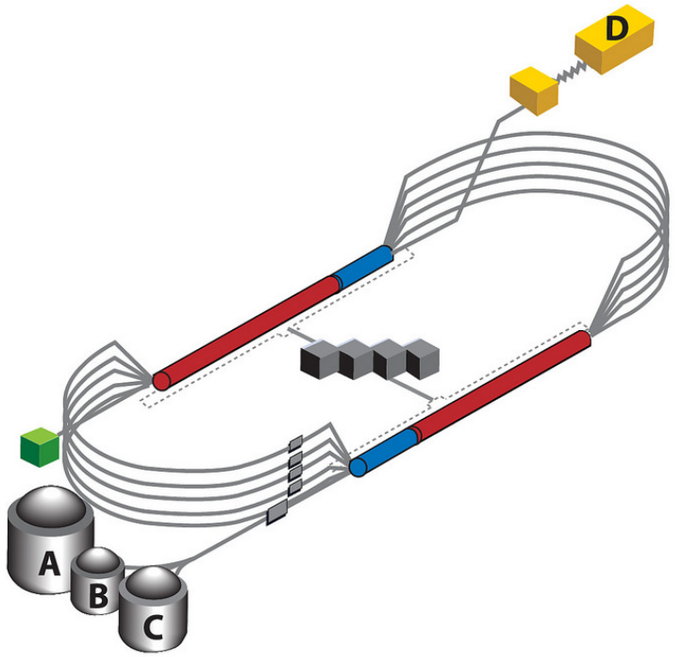
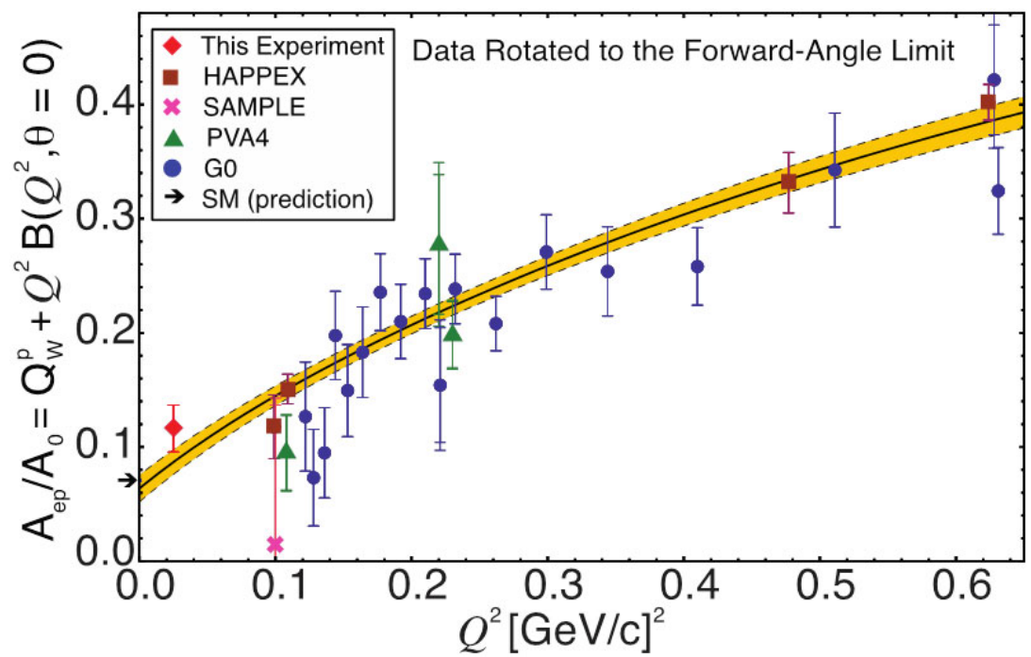
➡ need at least one 2-loop electroweak calculation ***Aleksejevs, Barkanova***



Polarized elastic scattering

- $A_{LR} \propto Q_W(p) + Q^2 B(Q^2, \theta)$
- Qweak (Jefferson Lab):
  - $Q^2 = 0.025\ GeV^2$
  - extrapolation to $Q^2 = 0$
  - large γ-Z box ***Gorchtein, Horowitz, Ramsey-Musolf; Rislow, Carlson; Hall, Blunden, Melnitchouk, Thomas, Young***



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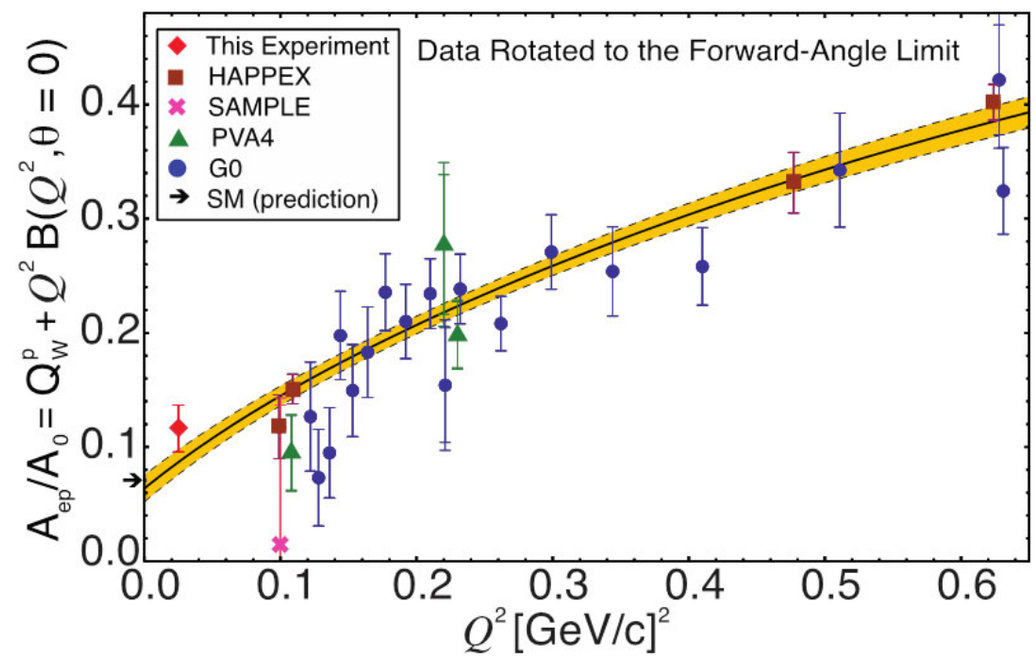

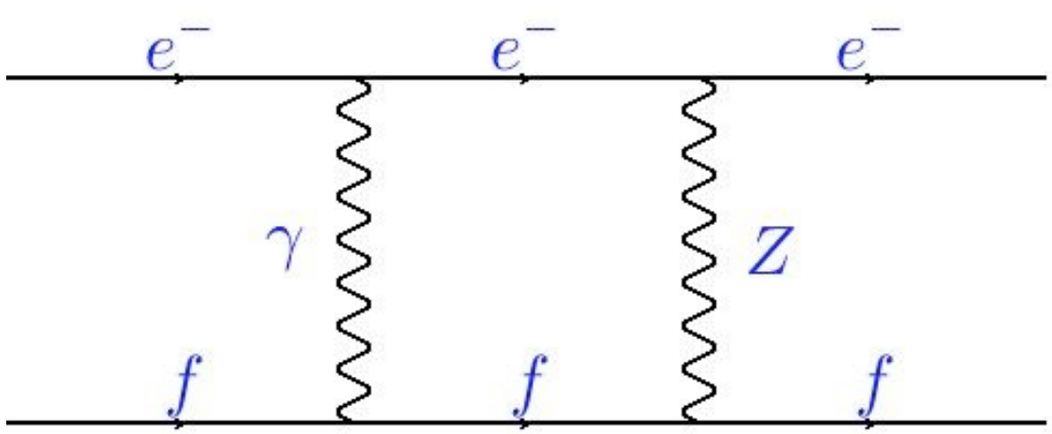

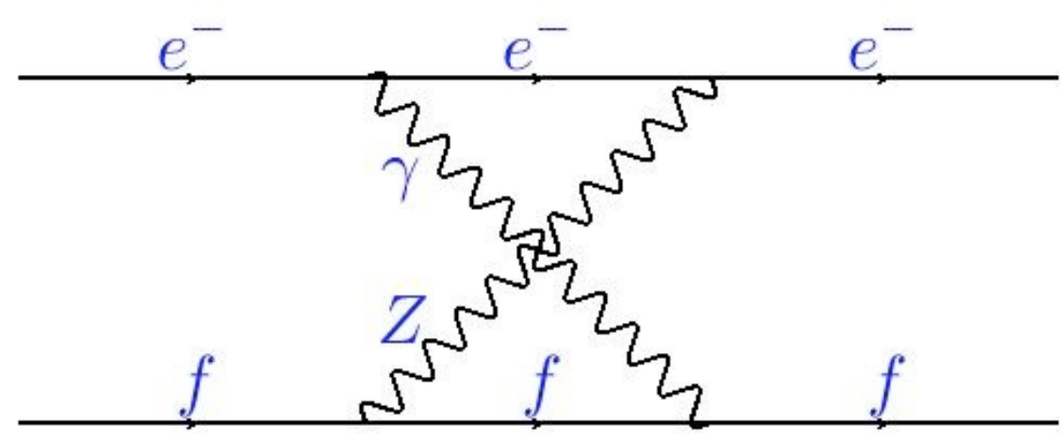

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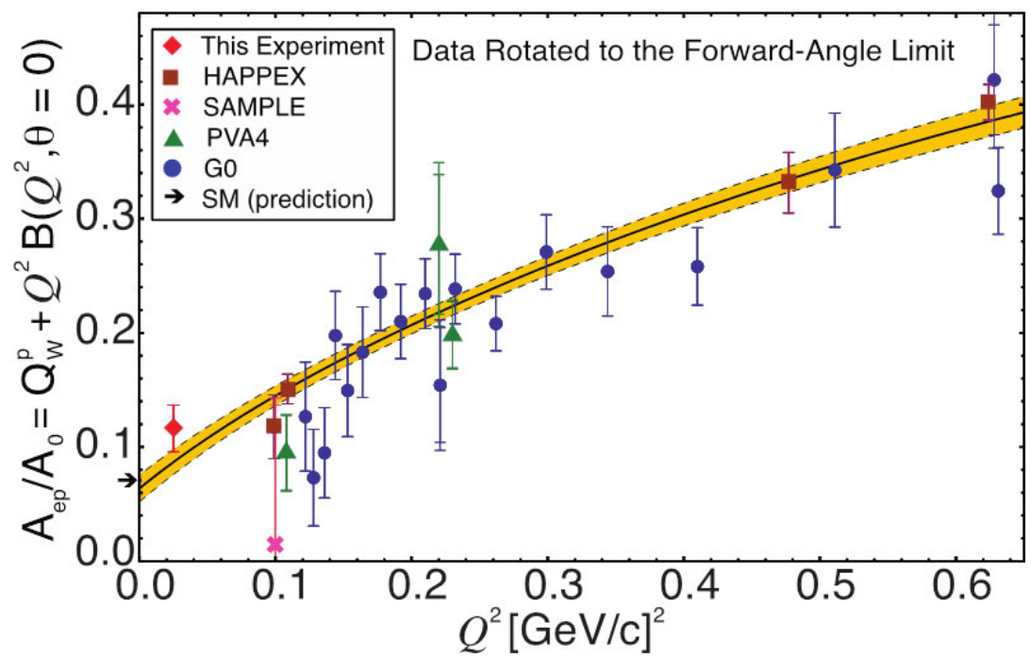
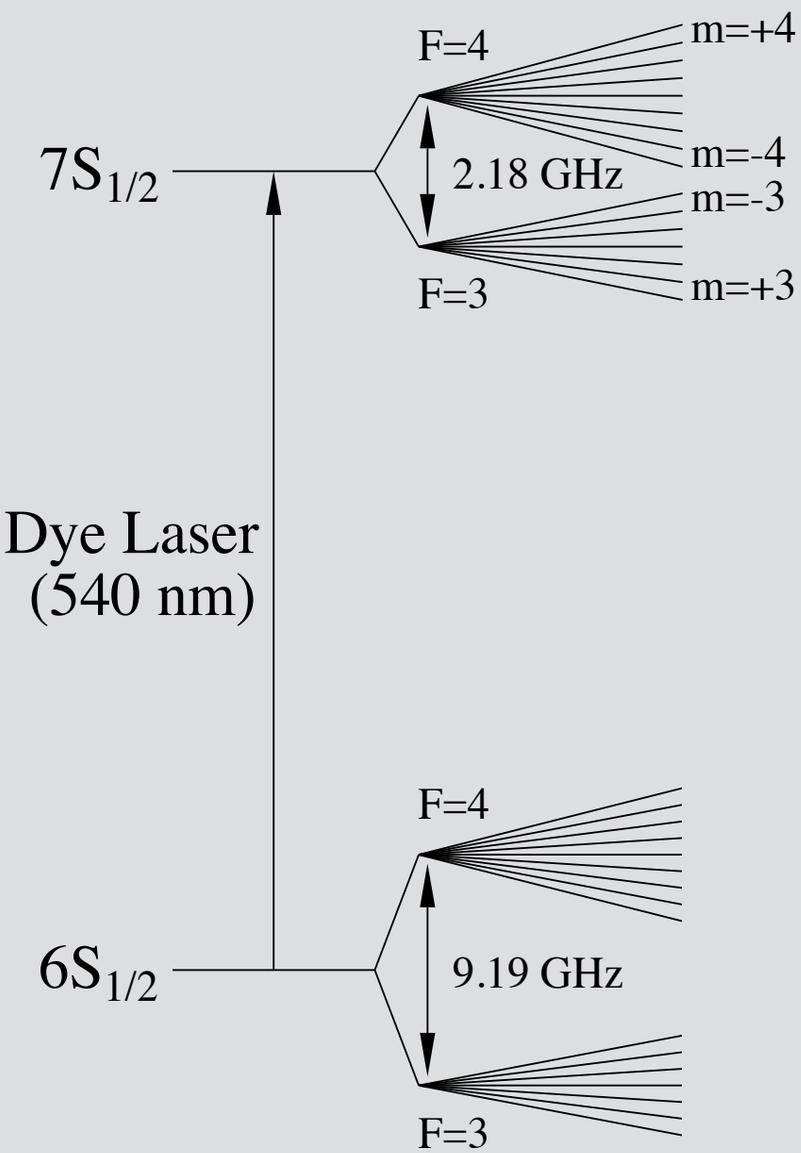


- P2 (JGU Mainz): $Q^2 = 0.0045\ GeV^2$ ($A_{LR} \sim 10^{-8}$)
  - γ-Z box correction (error) factor of 8 (5) smaller

Atomic parity violation



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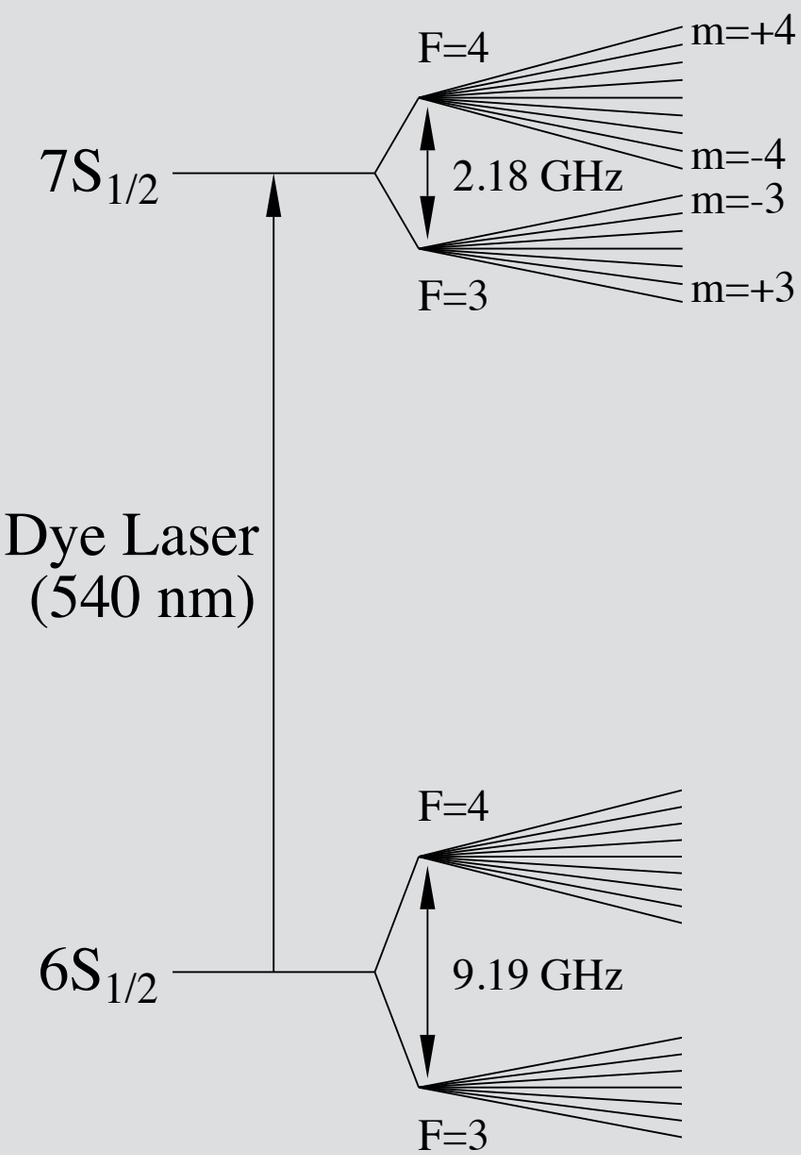
- g^{eq}_{AV} (coherent) Stark induced-Z interference amplitude dominant (spin-independent)



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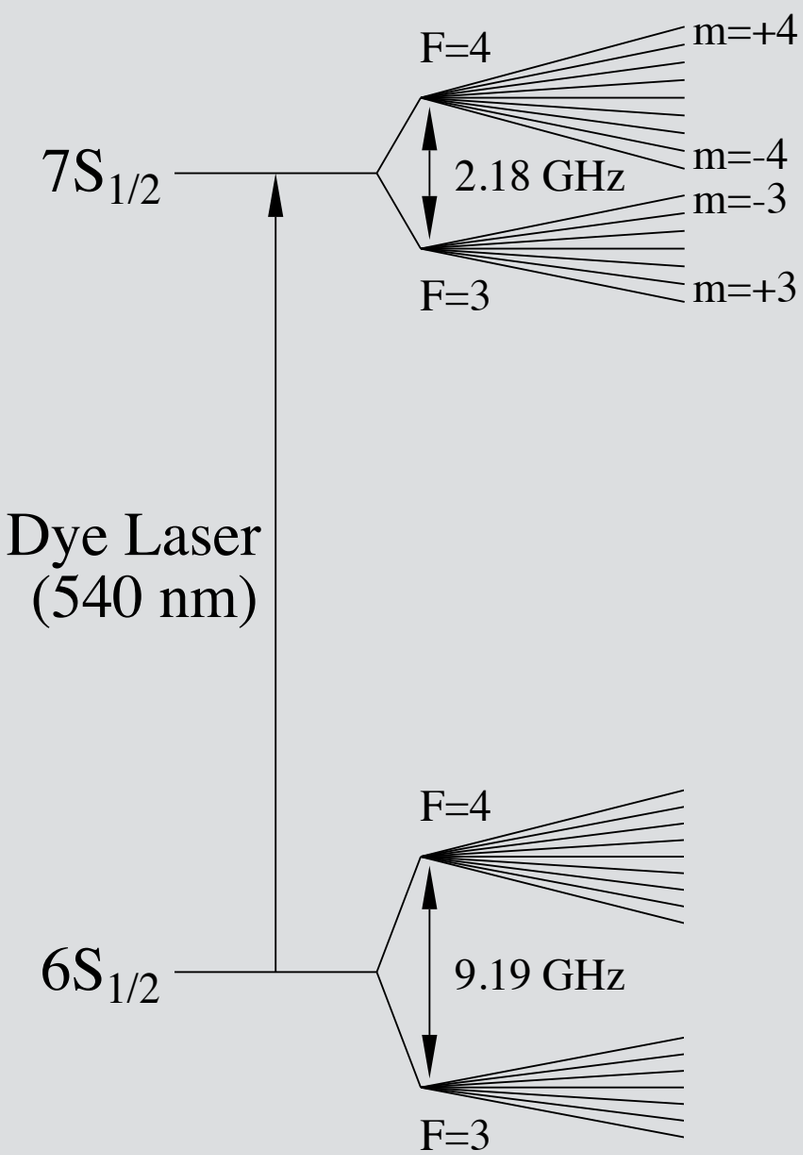

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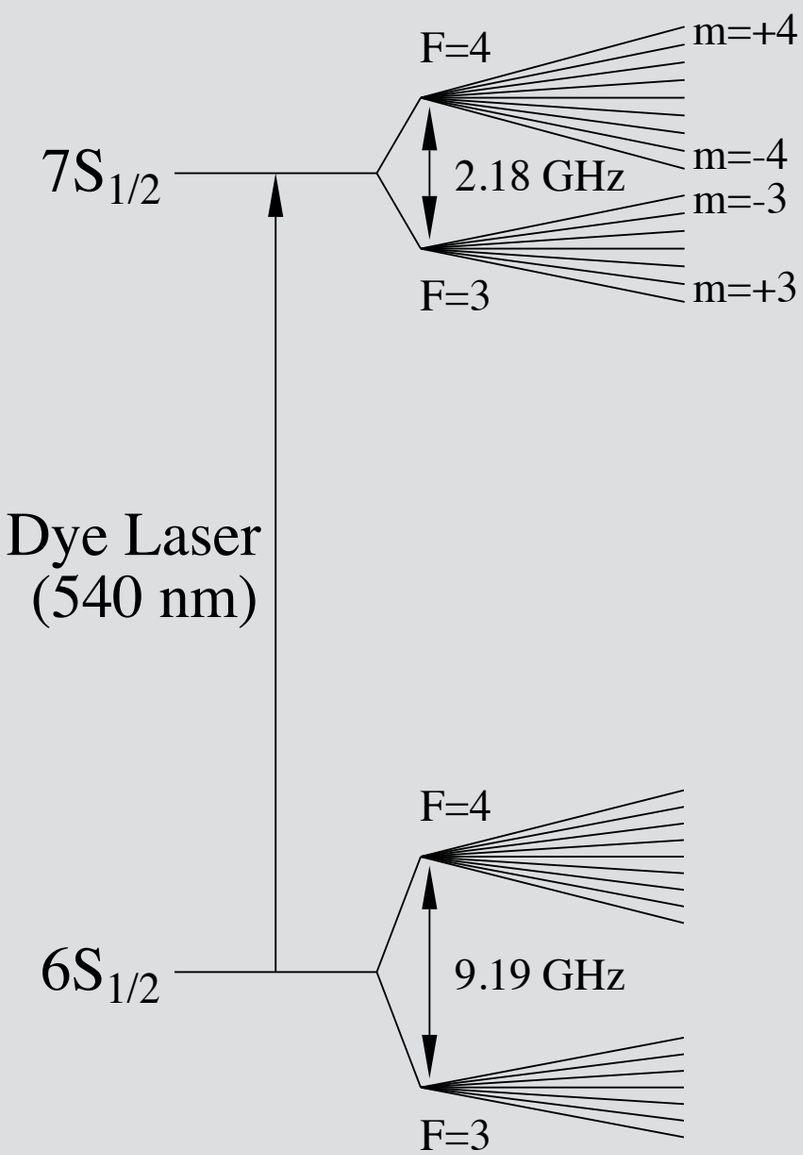
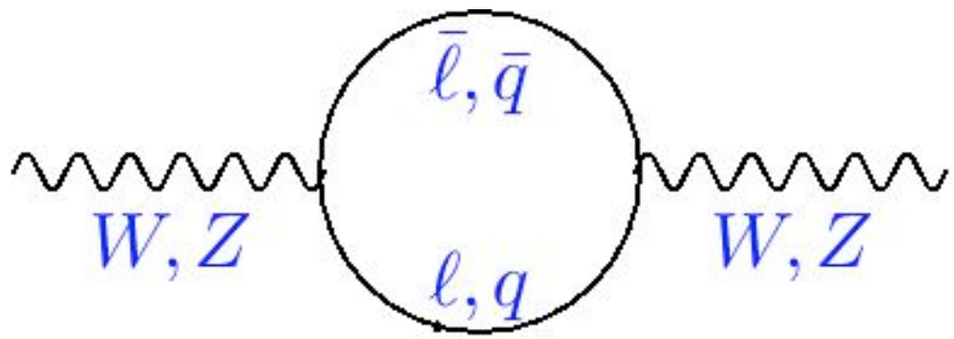
- spin-dependent nuclear anapole moment through difference in hyperfine transitions

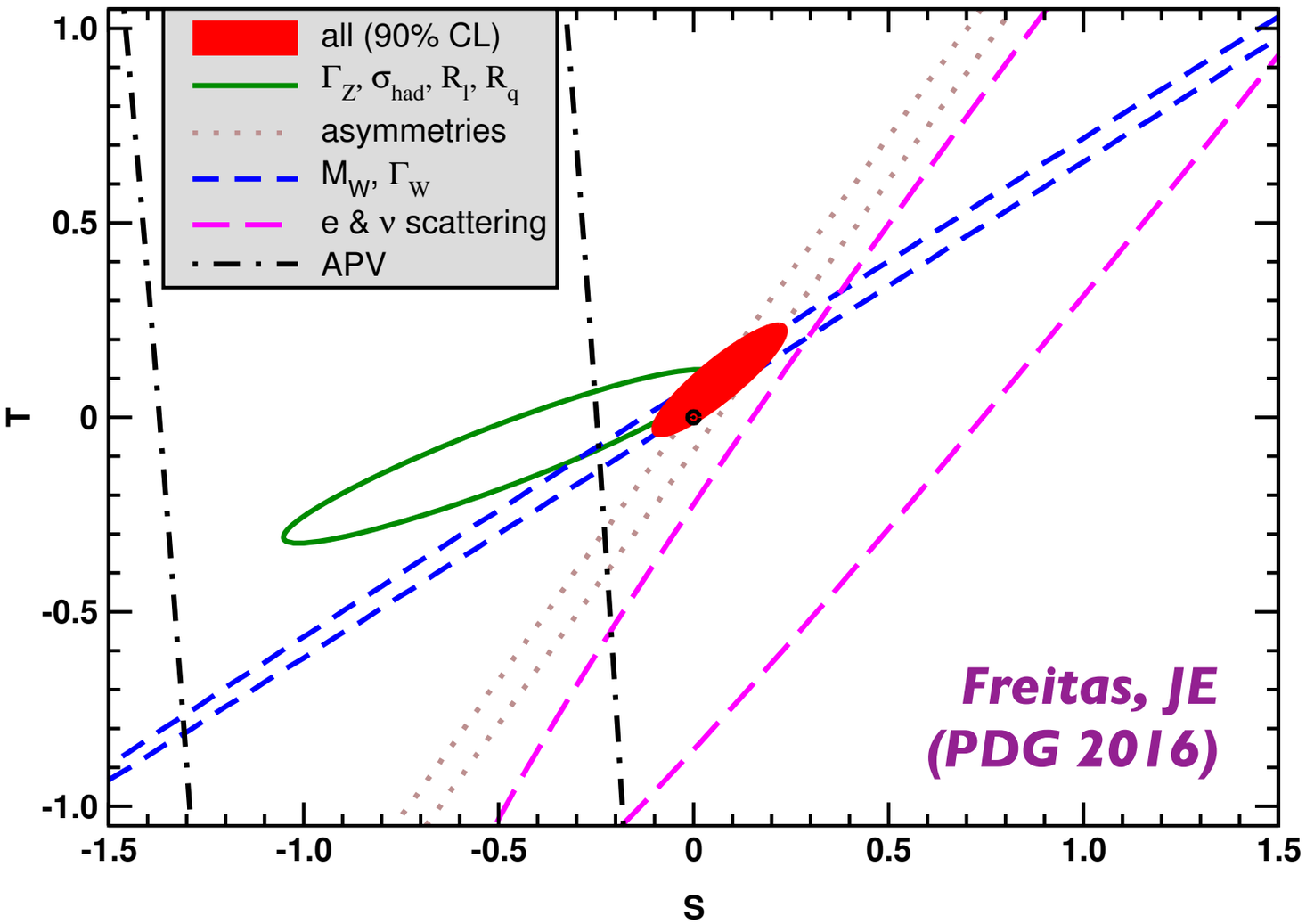


Oblique physics beyond the SM

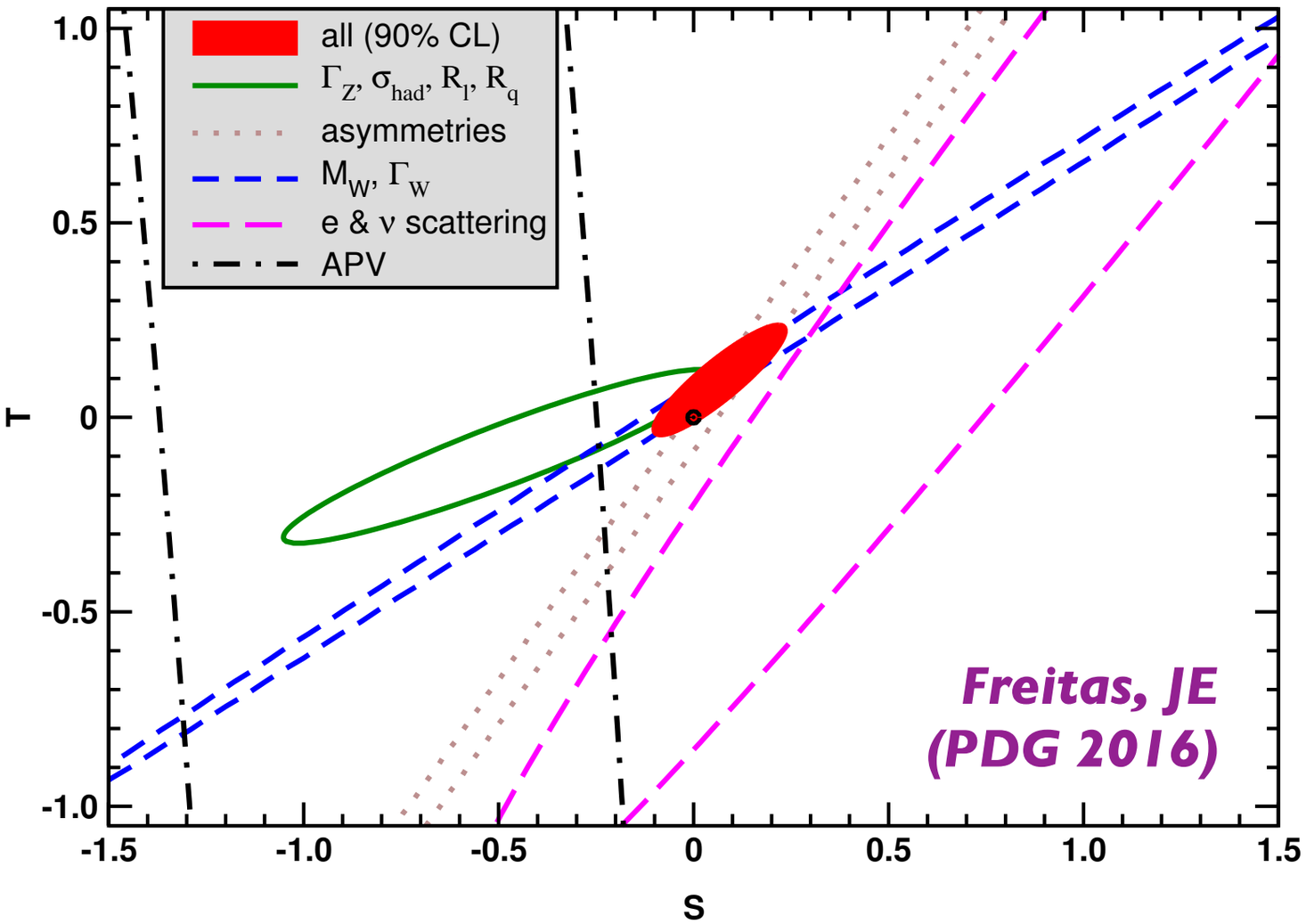


- STU describe corrections to gauge-boson self-energies
- T breaks custodial SO(4)
- a multiplet of heavy degenerate chiral fermions contributes $\Delta S = N_C/3\pi \sum_i [t_{3L}^i - t_{3R}^i]^2$
- extra degenerate fermion family yields $\Delta S = 2/3\pi \approx 0.21$
  - S and T (U) correspond to dimension 6 (8) operators

S and T



Moriond 2017 update	
S	0.06 ± 0.08
T	0.09 ± 0.06
$\Delta\chi^2$	–4.0



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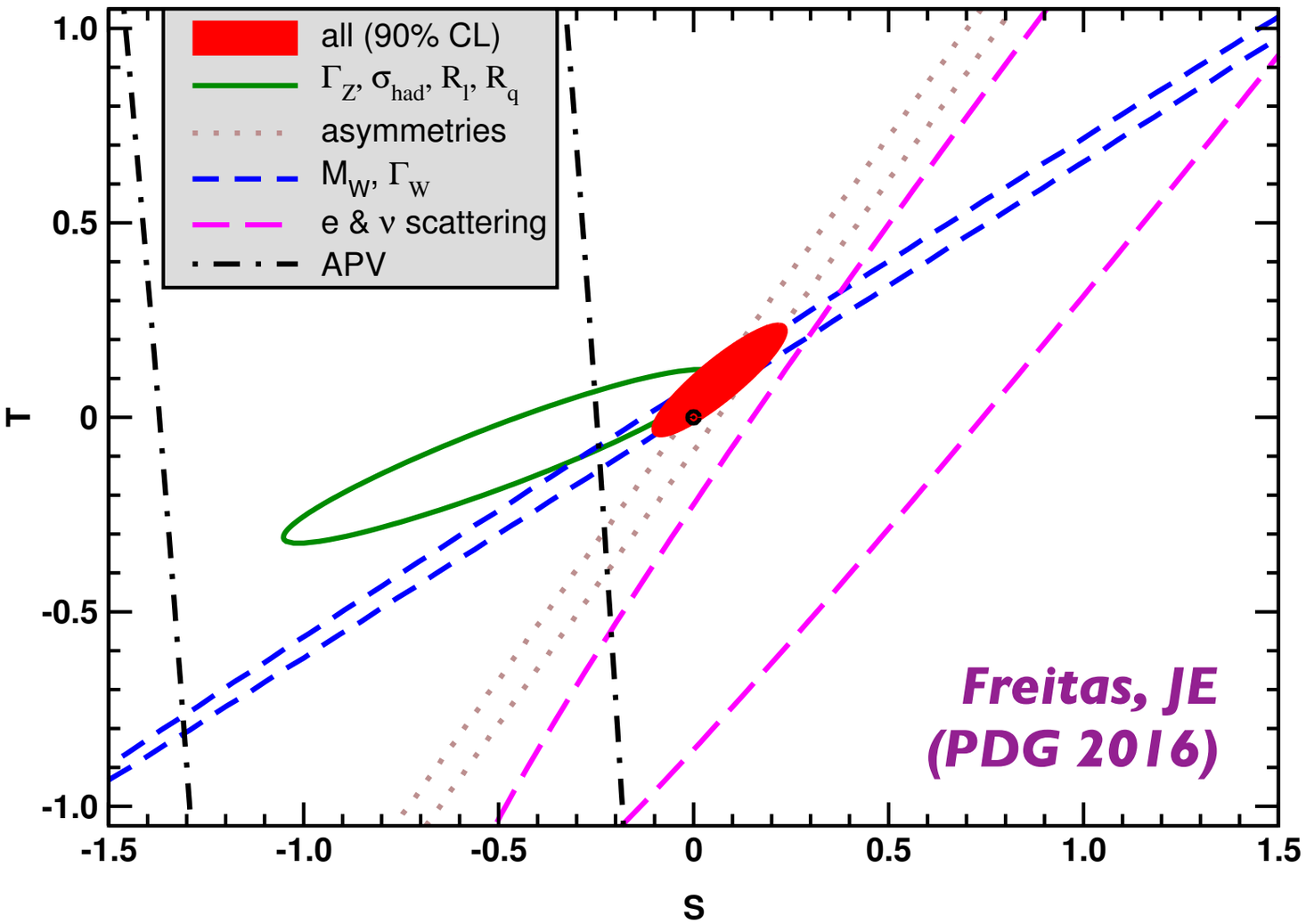

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- S rules out:
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  - degenerate 4th generation

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- LHC@150 fb^{-1}:
  - no SM deviation: $\rho_0 = 1 \pm 0.00014 \Longrightarrow \Sigma_i C_i / 3 \Delta m_i^2 \leq (27 \text{ GeV})^2$
  - assuming no change in central value:
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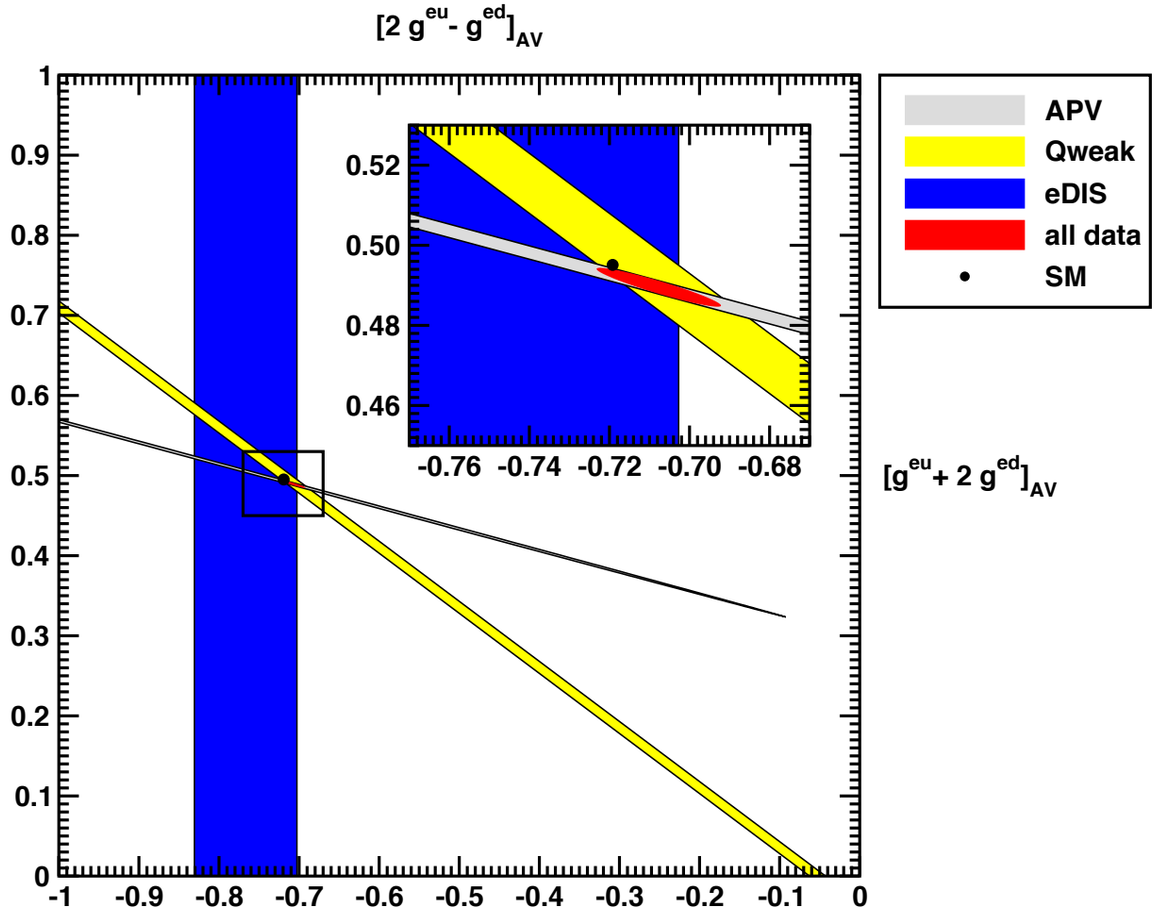
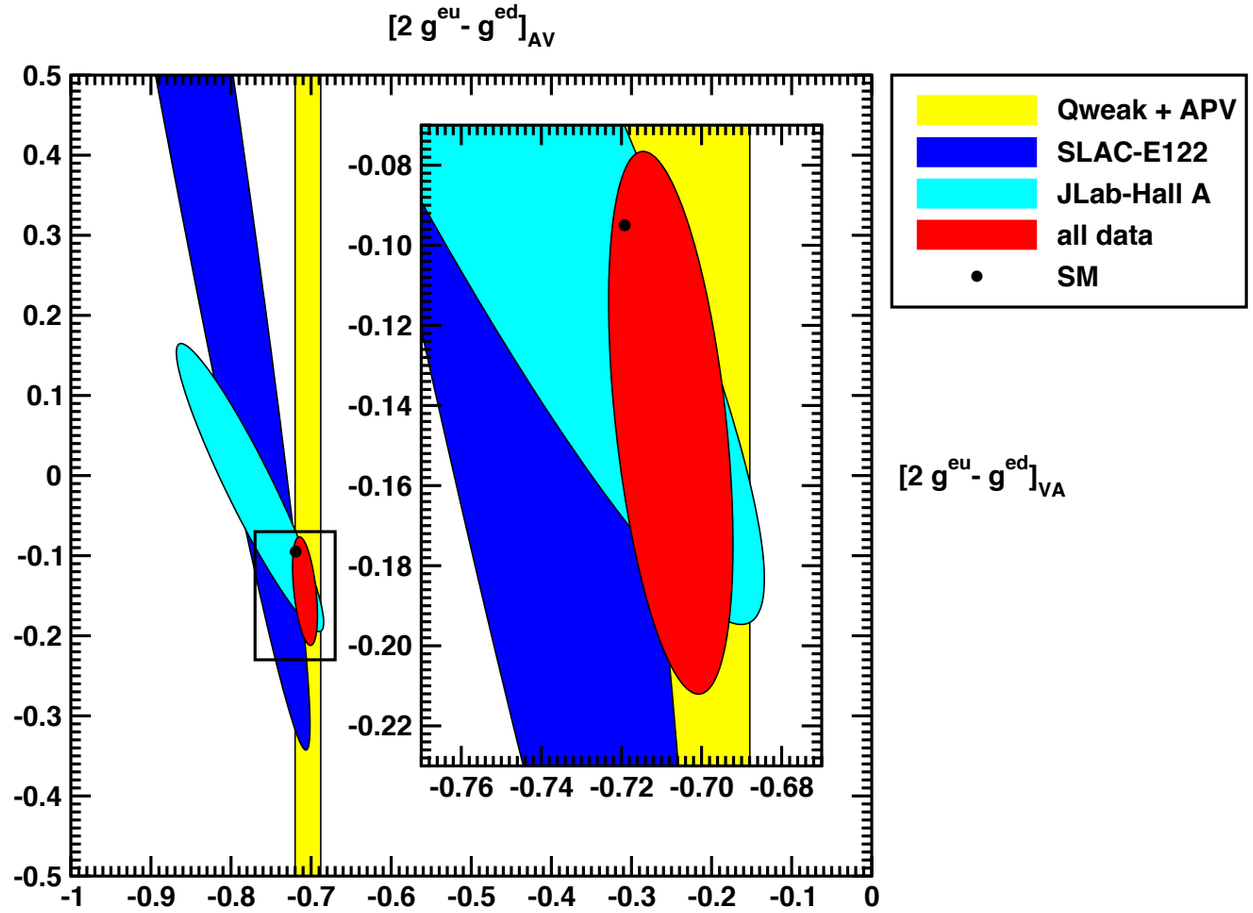
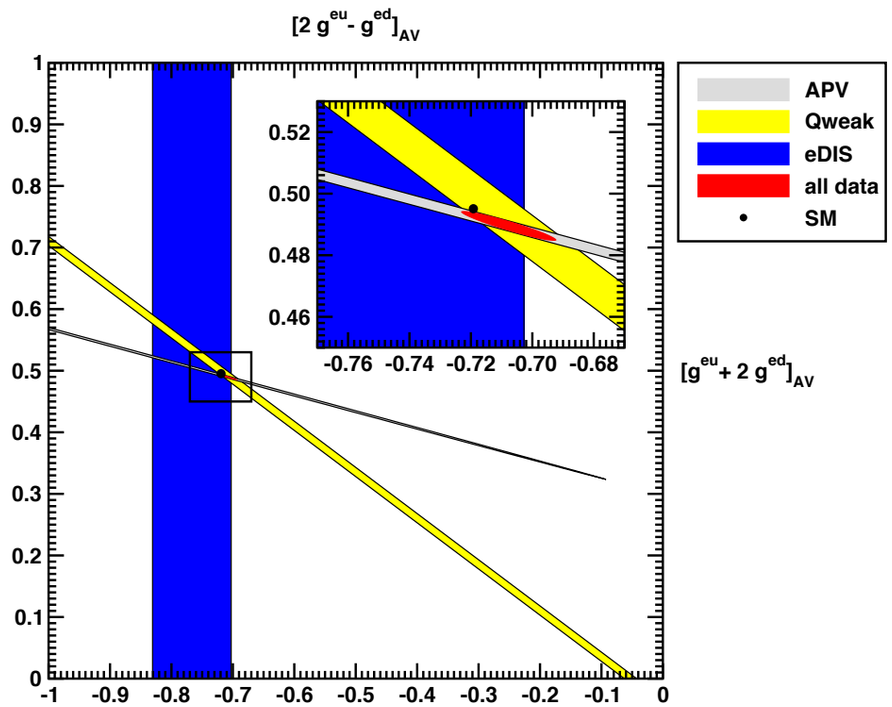
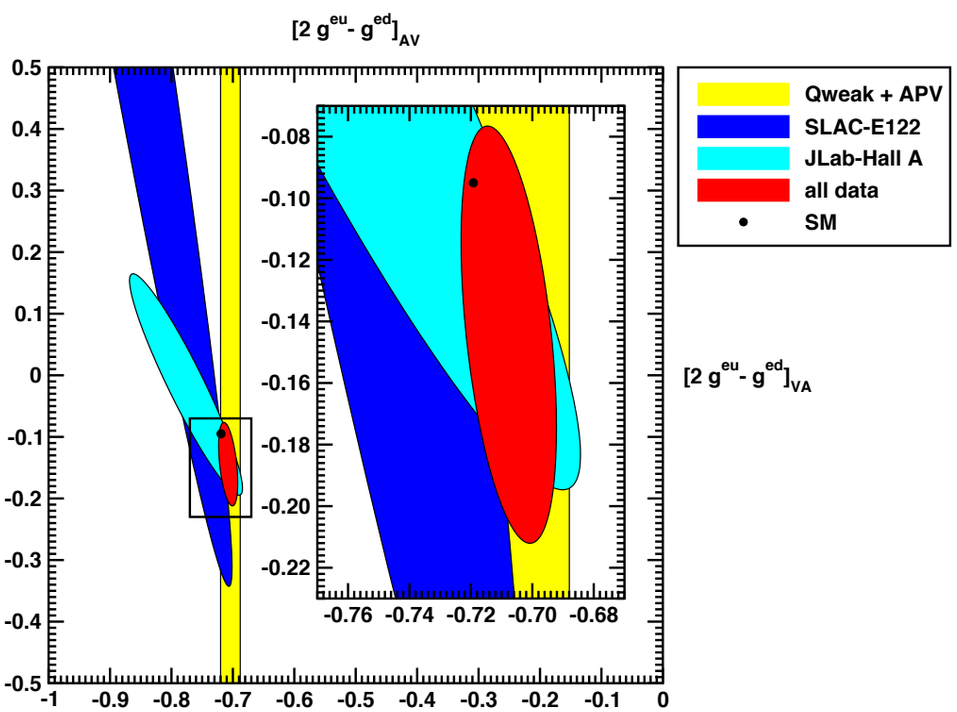
Effective parity-violating couplings

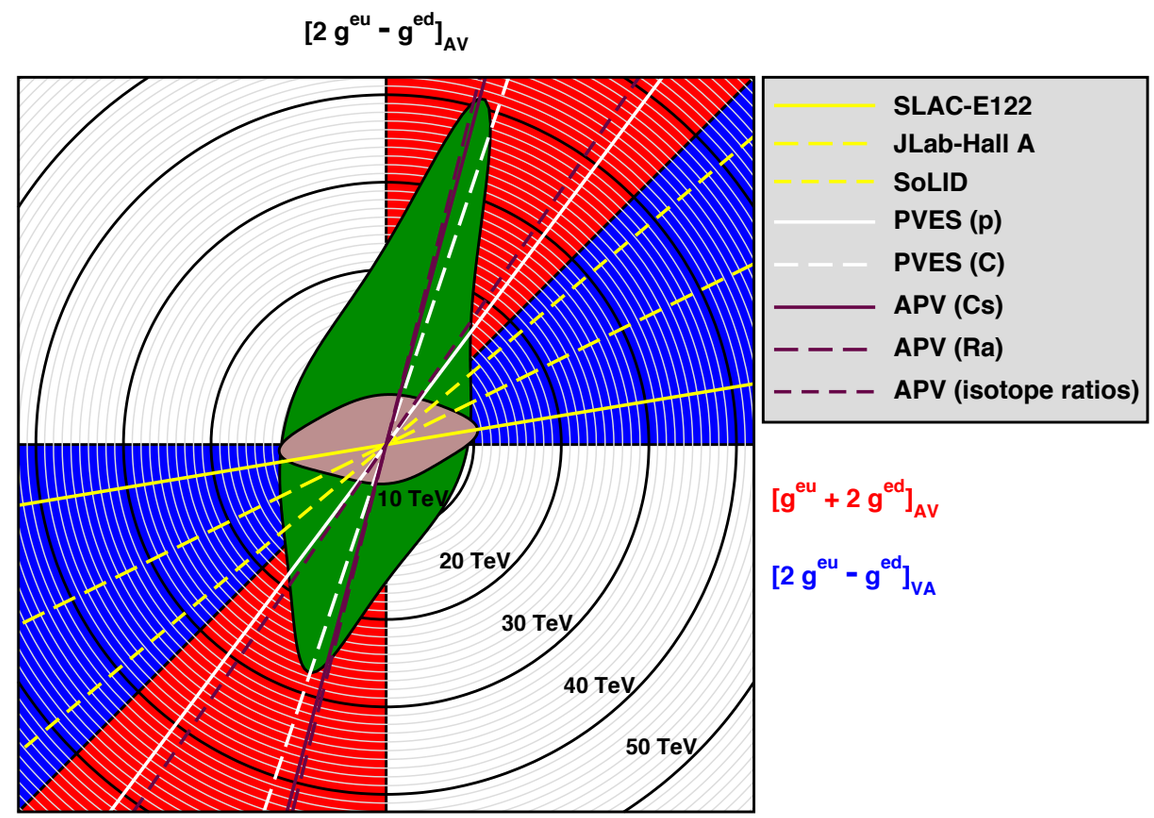






Compositeness scales from low energies





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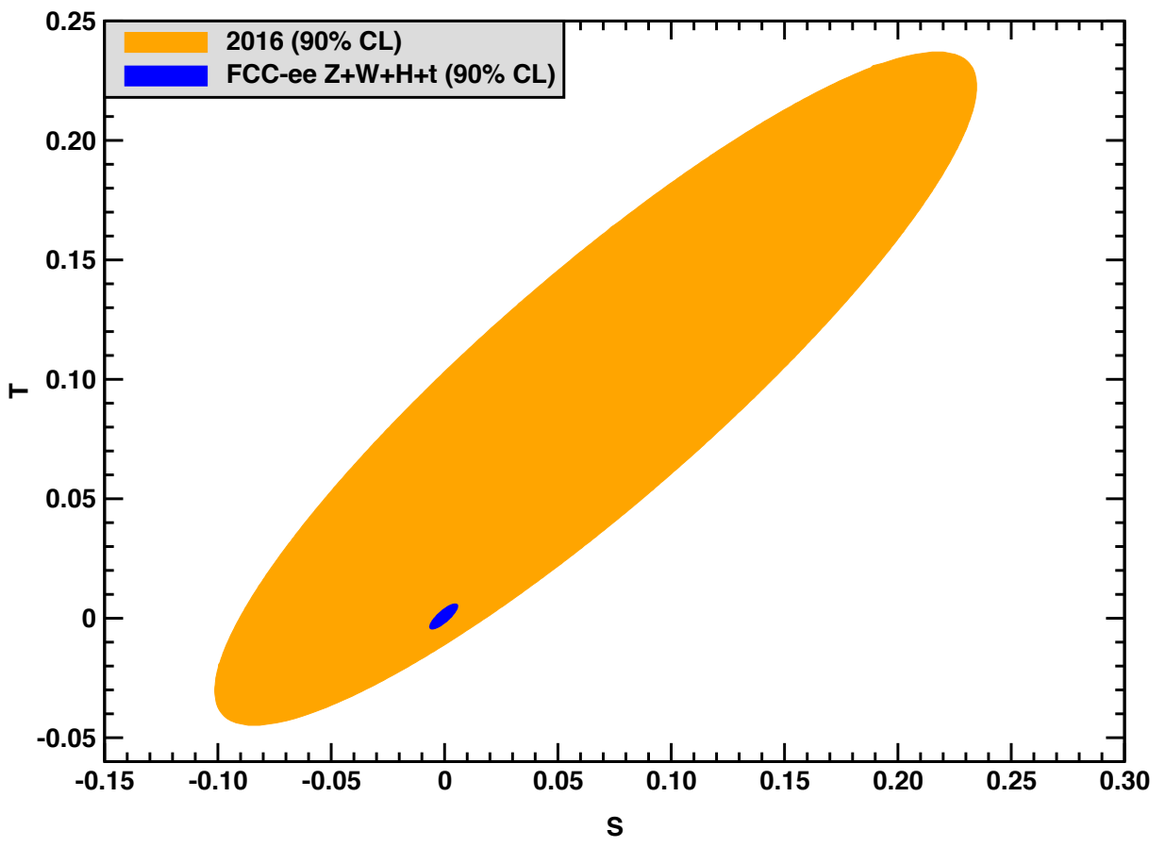
BACKUP

STU



	current	FCC-ee
S	± 0.099	± 0.005
T	± 0.116	± 0.007
U	± 0.095	± 0.005
S	± 0.078	± 0.003
T	± 0.066	± 0.003
T	± 0.030	± 0.002

FCC-ee

M_Z ± 2.1 MeV ➡ < 100 keV

Γ_Z ± 2.3 MeV ➡ < 100 keV

R_μ ± 0.025 ➡ < 0.001

R_b ± 0.00066 ➡ $< 6\times10^{-5}$

m_t ± 810 MeV (incl. QCD) ➡ ± 15 MeV

σ_{had} ± 37 pb ➡ ± 4 pb (assumes 0.01% luminosity error)

A_{LR} ± 0.0022 ➡ $\pm 2\times10^{-5}$ (needs 3-loop EW to be useful, 4-loop to match exp.)

$A_{LR}^{FB}(b)$ ± 0.020 ➡ ± 0.001 (using similar b-tagging improvements as for R_b)

M_W ± 33 MeV (LEP); ± 16 MeV (Tevatron) ➡ ± 0.6 MeV

Γ_W ± 42 MeV ➡ 1st + 2nd row CKM unitarity test