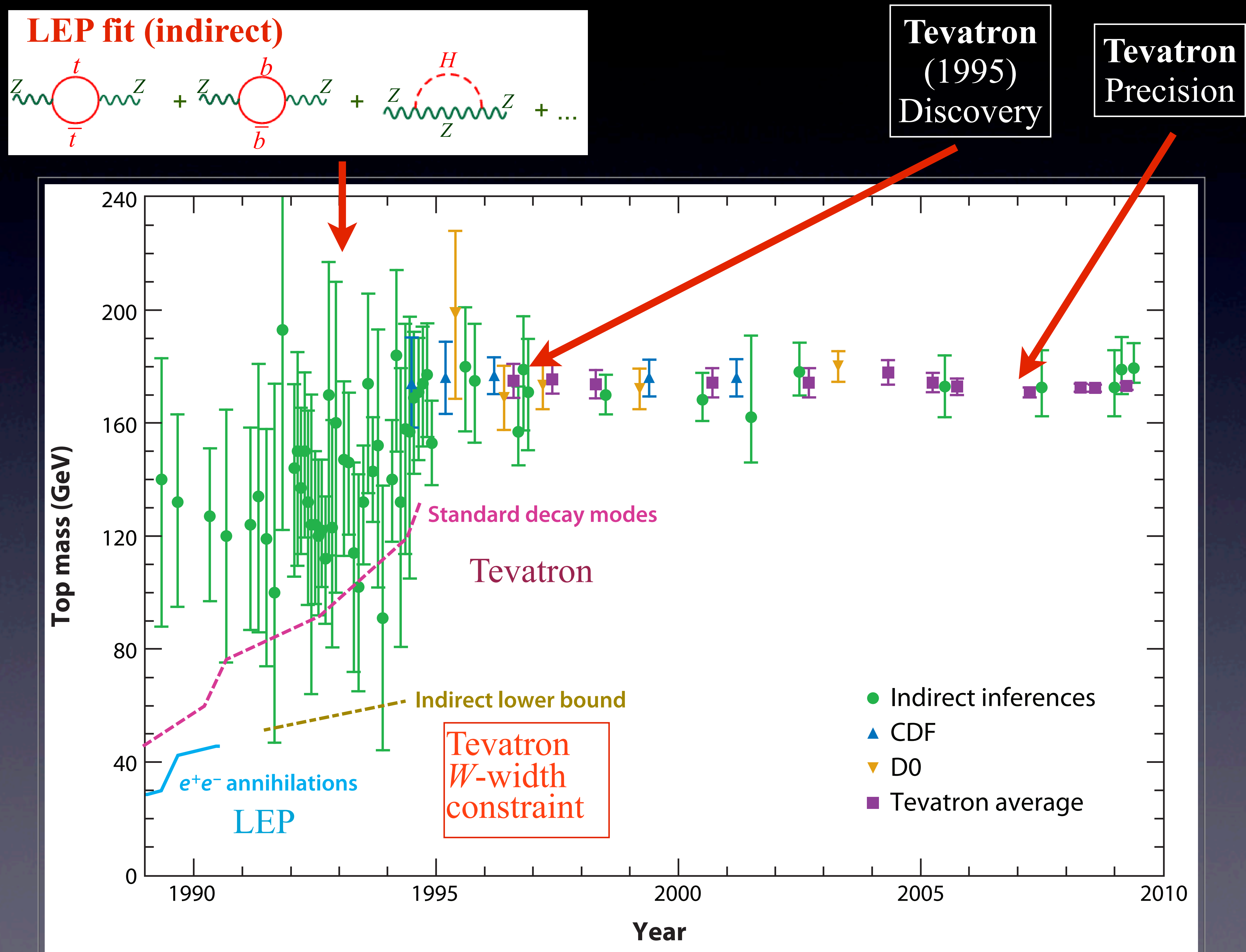
# Electroweak Precision at CHF and SppC

1. Testing the consistence of the SM
2. Indirect search of NP beyond the SM


Qing-Hong Cao (曹庆宏)
Peking University

On behalf of
Chong Sheng Li, Zhao Li, Li-Lin Yang, Shou-Hua Zhu

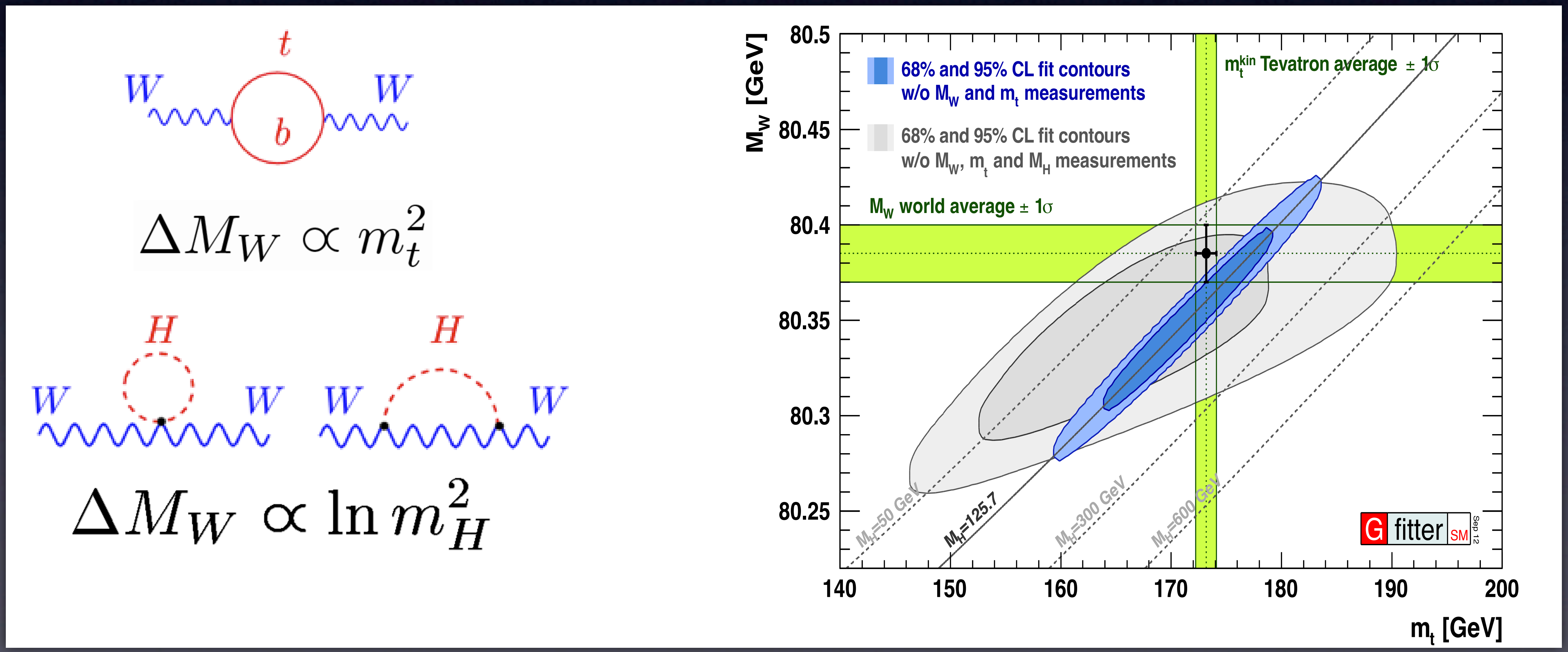
# Top discovery: EW theory tests at Loop level



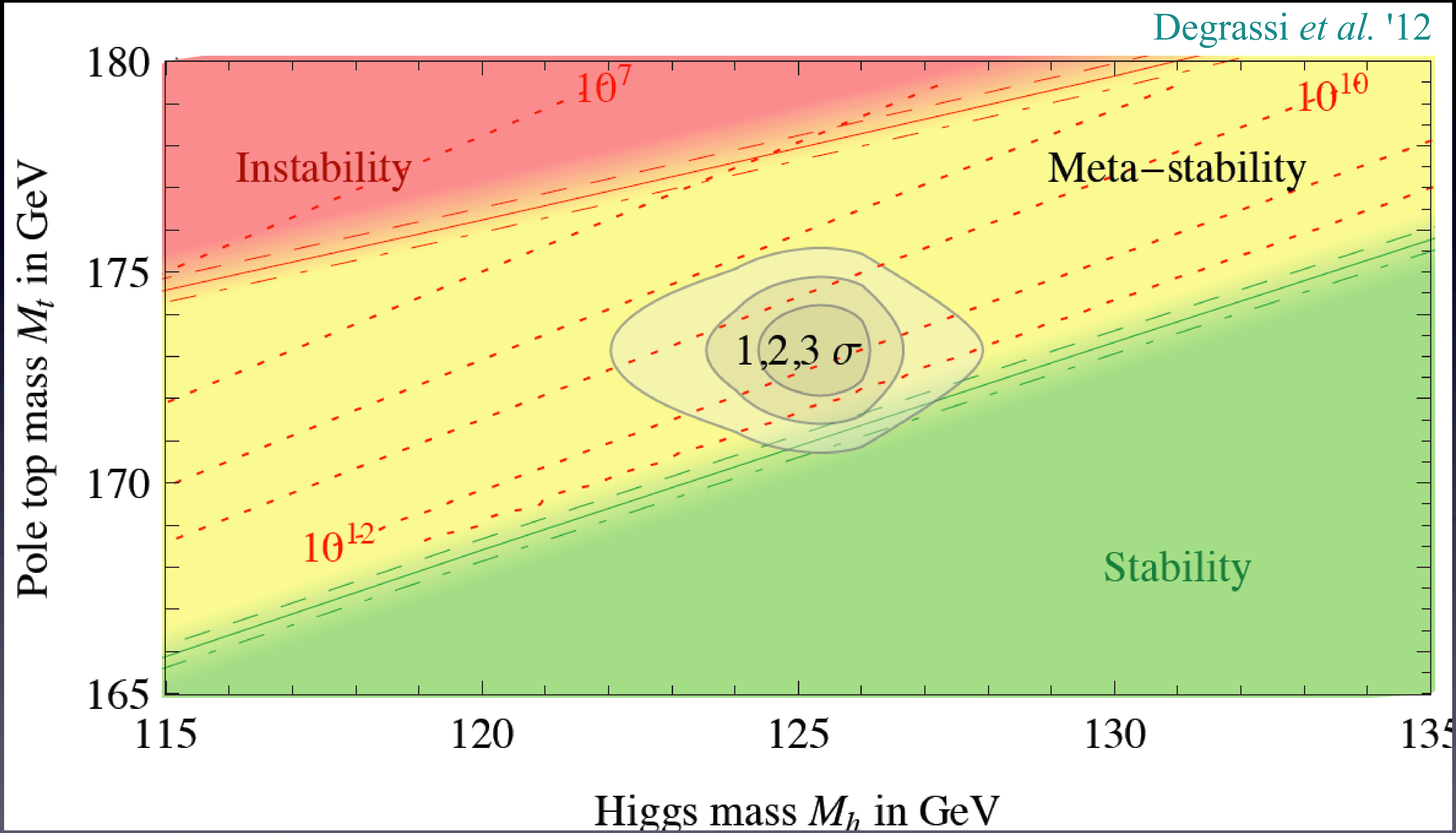
# $W$-boson, Top-quark and Higgs boson

- Highly correlated at the quantum level

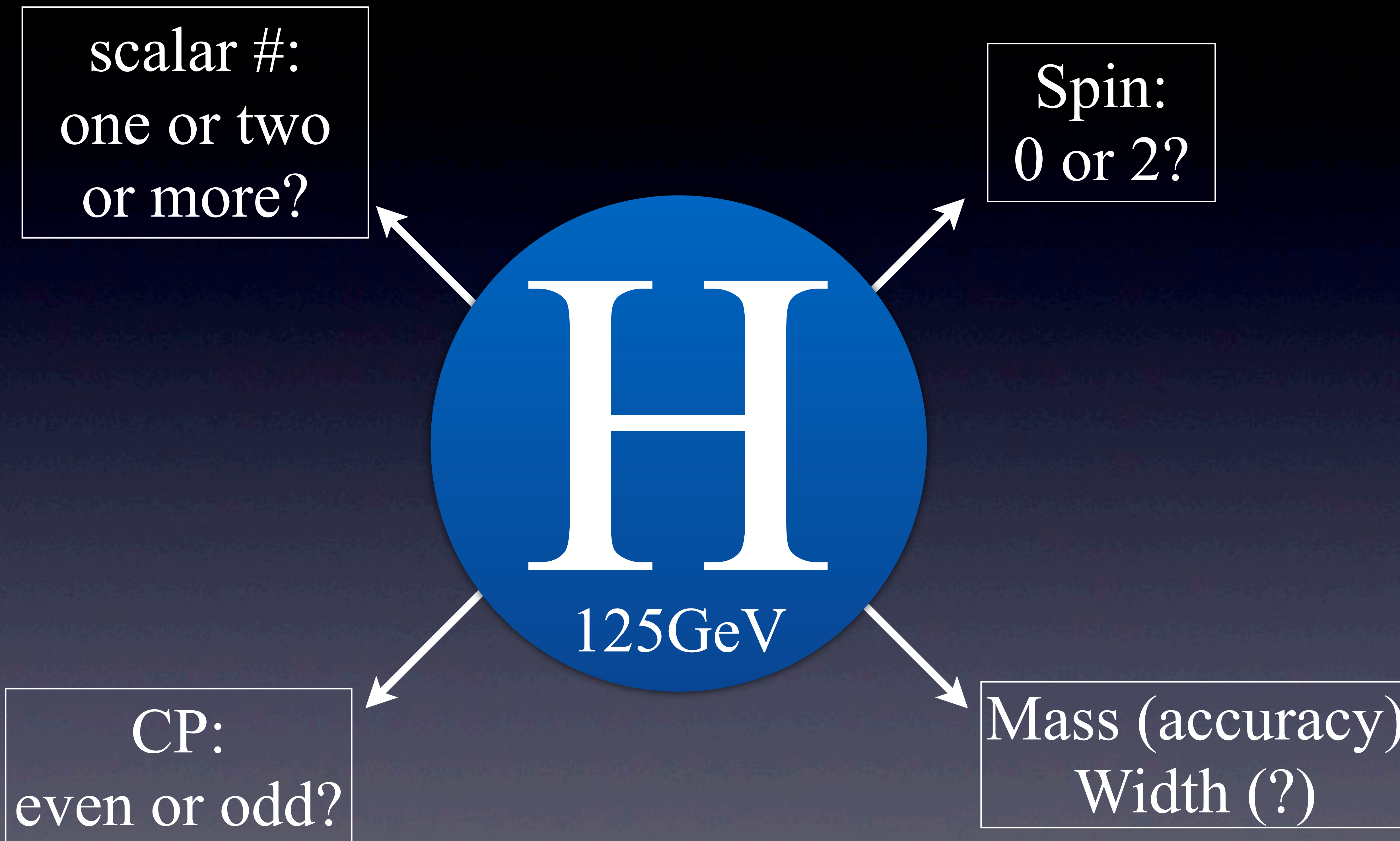
$$M_W = 80.3827 - 0.0579 \ln\left(\frac{M_H}{100\ \mathrm{GeV}}\right) - 0.008 \ln^2\left(\frac{M_H}{100\ \mathrm{GeV}}\right)$$
$$+0.543\left(\left(\frac{m_t}{175\ \mathrm{GeV}}\right)^2 - 1\right) - 0.517\left(\frac{\Delta\alpha^{(5)}_{had}(M_Z)}{0.0280} - 1\right) - 0.085\left(\frac{\alpha_s(M_Z)}{0.118} - 1\right)$$



# Top quark and 125GeV Higgs boson



# Questions of the top priority



# Higgs boson couplings

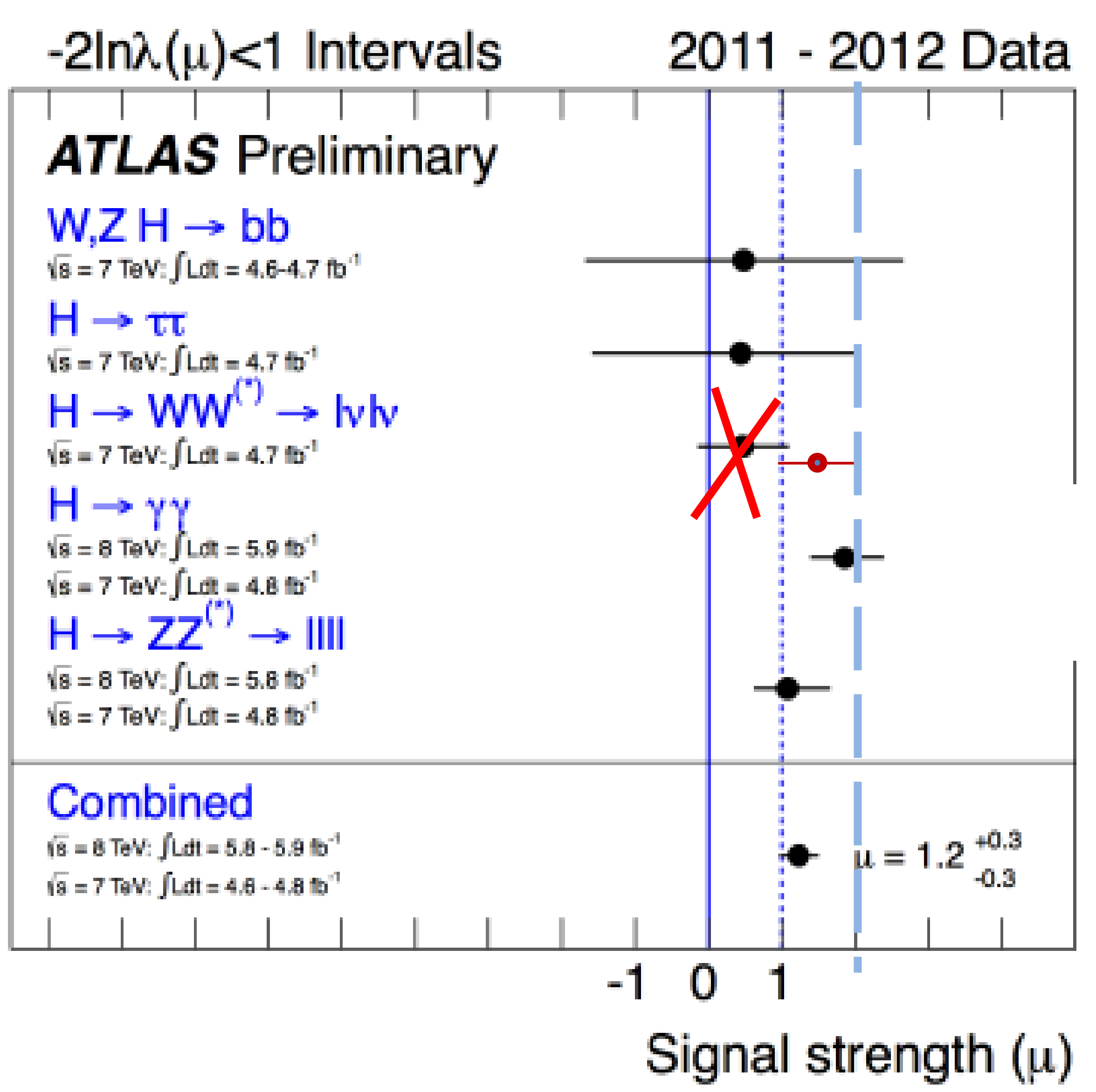
- New set of reference SM parameters

$m_H \sim 126$ GeV $\quad \Gamma_H = 4.2$ MeV $\quad \lambda = (m_H/v)^2/2 = 0.131$

$\mathrm{Br}(H \to WW^*) = 23\%$ ★
$\mathrm{Br}(H \to ZZ^*) = 2.9\%$ ★

$\mathrm{Br}(H \to bb) = 56\%$ ★
$\mathrm{Br}(H \to cc) = 2.8\%$
$\mathrm{Br}(H \to \tau\tau) = 6.2\%$ ★
$\mathrm{Br}(H \to \mu\mu) = 0.021\%$

$\mathrm{Br}(H \to gg) = 8.5\%$ ★
$\mathrm{Br}(H \to \gamma\gamma) = 0.23\%$ ★
$\mathrm{Br}(H \to \gamma Z) = 0.16\%$ ★



# Higgs boson couplings at LC

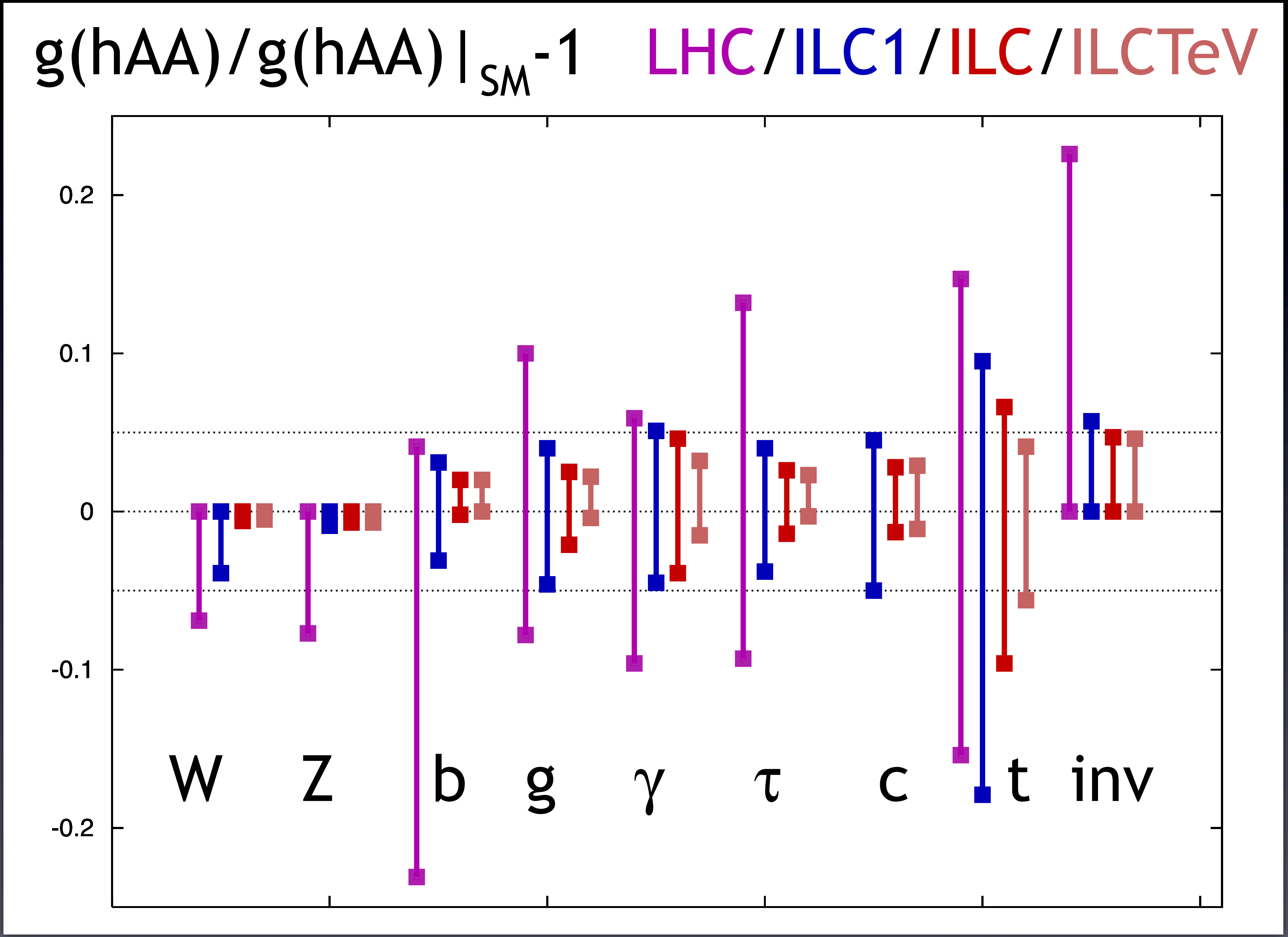
Peskin, 1208.5152

LHC:
14TeV
$300fb^{-1}$

ILC1:
250GeV
$250fb^{-1}$

ILC:
500GeV
$500fb^{-1}$

ILC TeV:
1000GeV
$1000fb^{-1}$

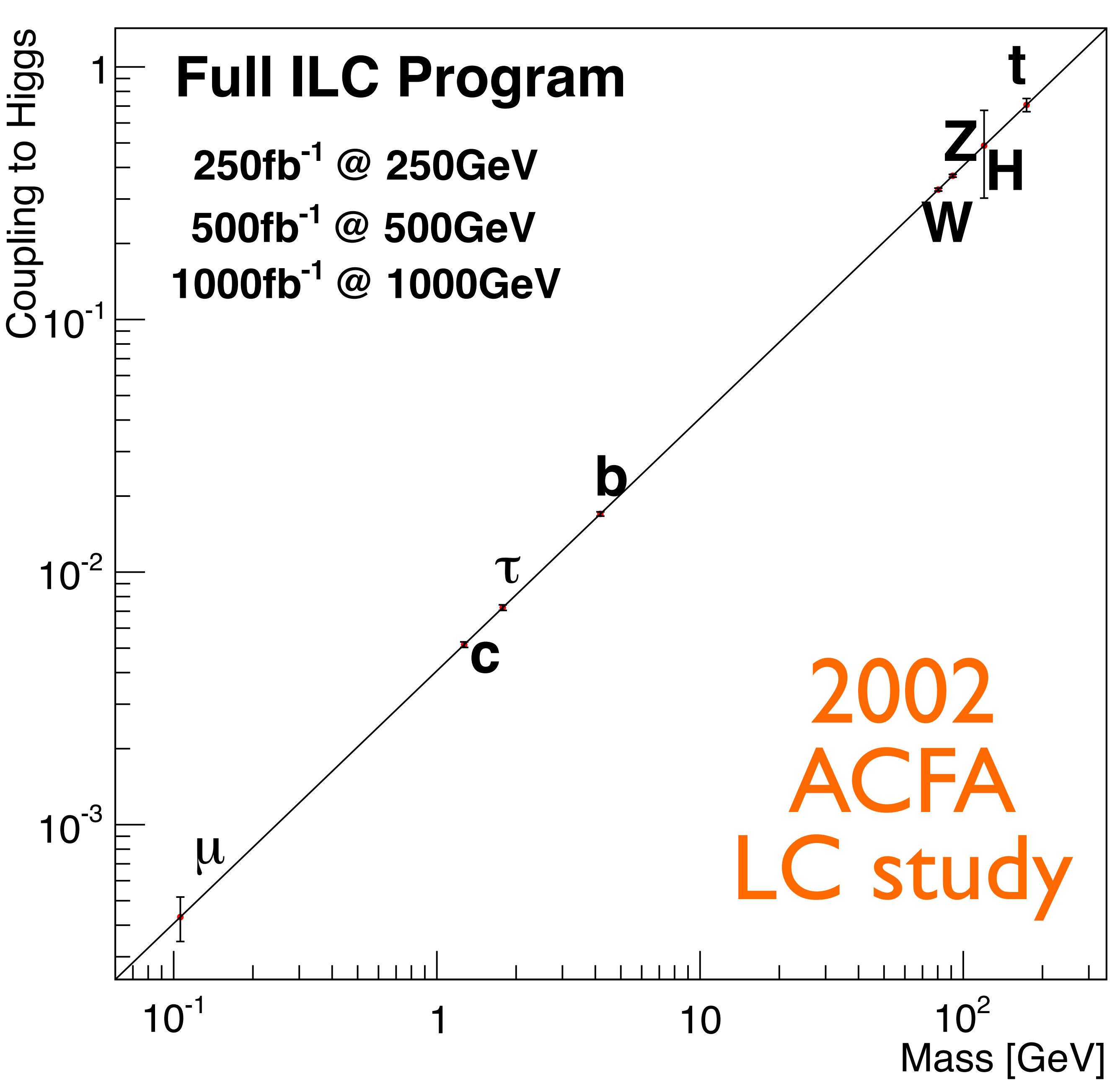


# $e^+e^-$ collider at 250 GeV

- The LHC 7-8TeV results imply no need for a LEP above 500 GeV.

- If the simple scalar Higgs model is correct, the Higgs couplings to each particle is proportional to its mass.

We can test this hypothesis to high accuracy.




2002 ACFA LC study

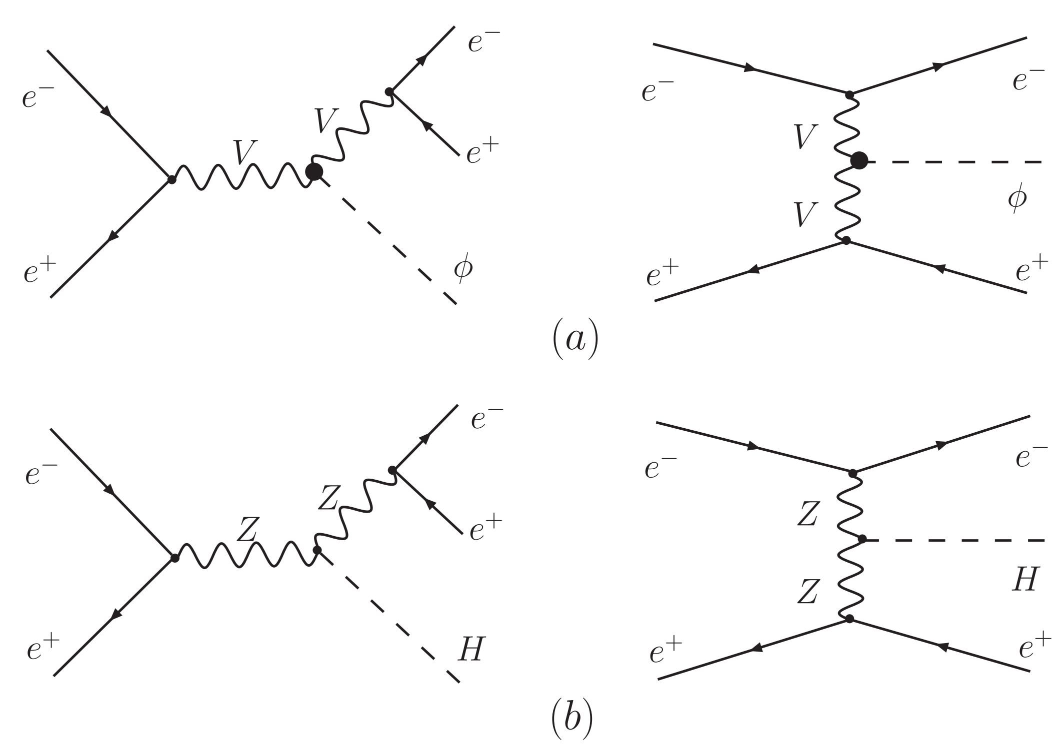
# Higgs effective coupling

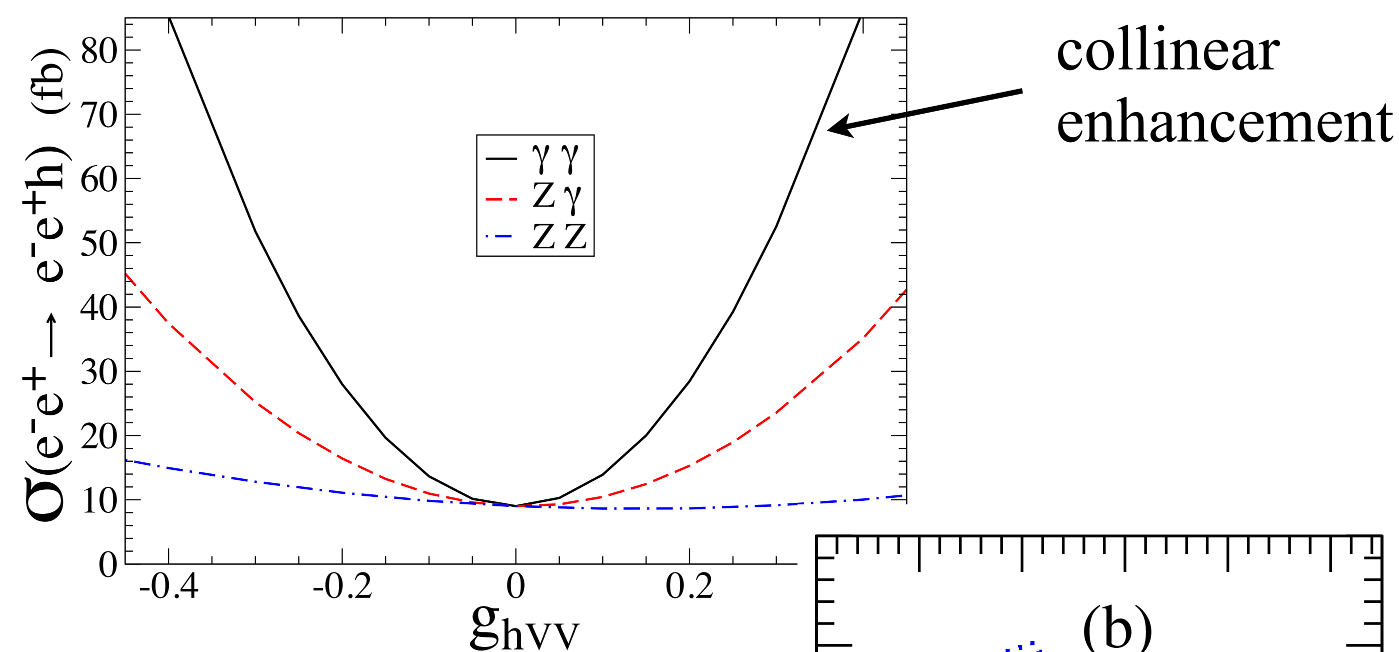
$$\mathcal{O}_{BW} = \Phi^\dagger B_{\mu\nu} W^{\mu\nu} \Phi,$$

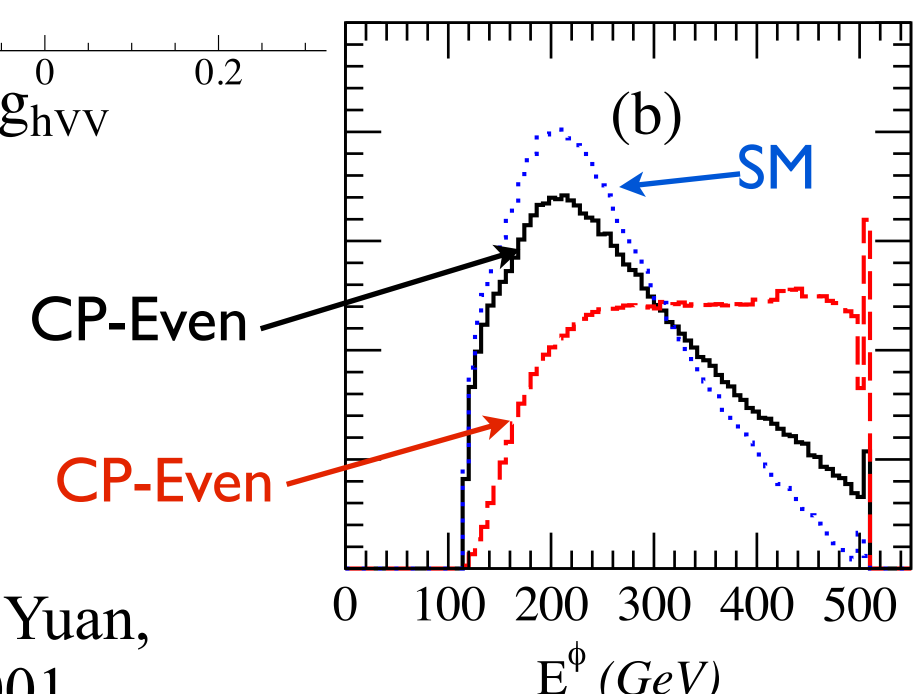
$$\mathcal{O}_{WW} = \Phi^\dagger W_{\mu\nu} W^{\mu\nu} \Phi,$$

$$\mathcal{O}_{BB} = \Phi^\dagger B_{\mu\nu} B^{\mu\nu} \Phi,$$

$$\Gamma^{\mu\nu}_{\phi VV} = i\, a_{\phi ZZ}\, g^{\mu\nu} + i\, \frac{g_{\phi VV}}{v} \left( p_2^\mu p_1^\nu - g^{\mu\nu}\, p_1 \cdot p_2 \right) + i\, \frac{\tilde{g}_{\phi VV}}{v}\, \varepsilon^{\mu\nu\rho\sigma}\, p_{1\rho} p_{2\sigma}$$



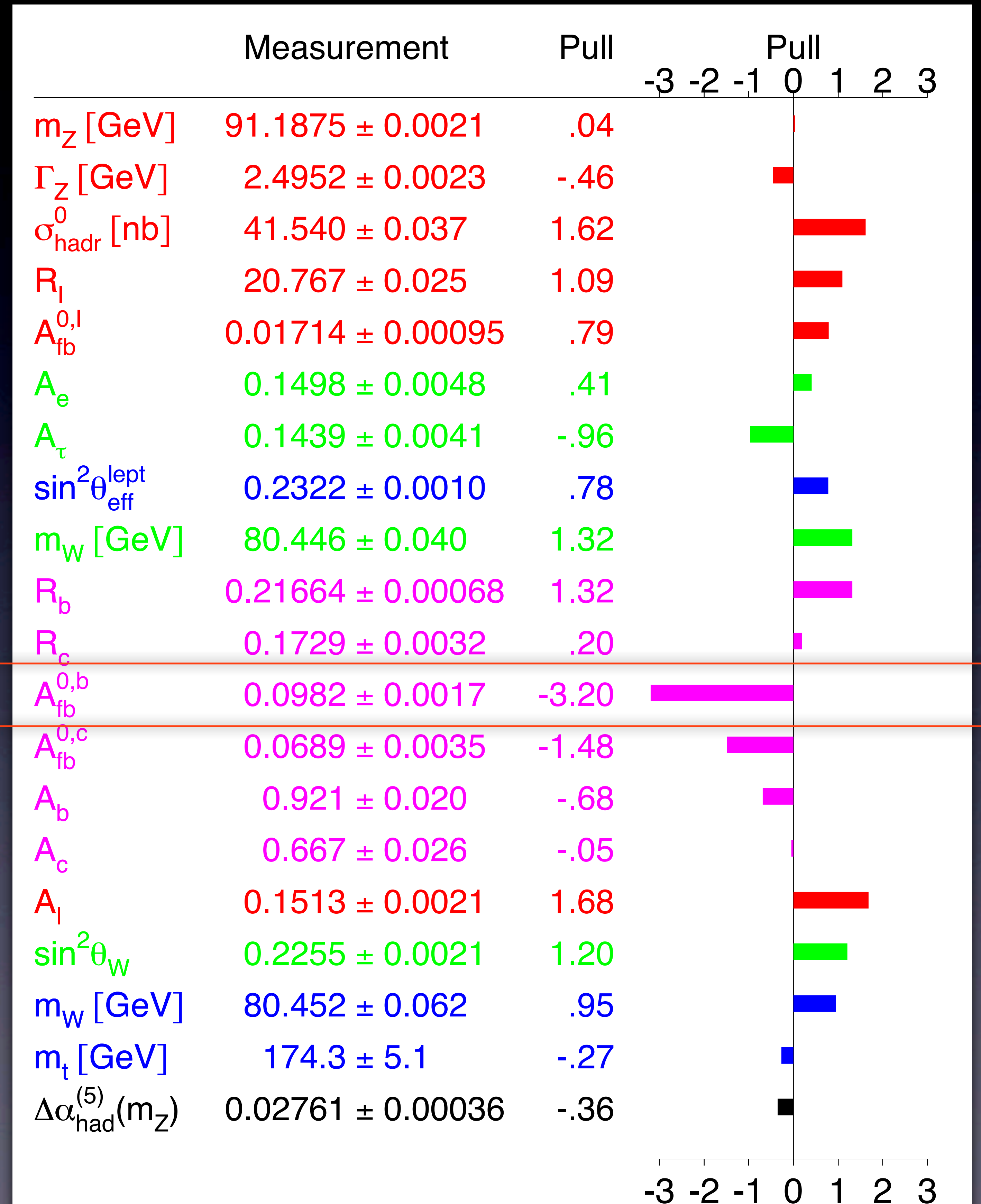

QHC, Larios, Tavares-Velasco, Yuan,
Phys. Rev. D74 (2006) 056001

# CHF at 250 GeV

- Test the notorious 3 sigma deviation in the AFB of bottom quark

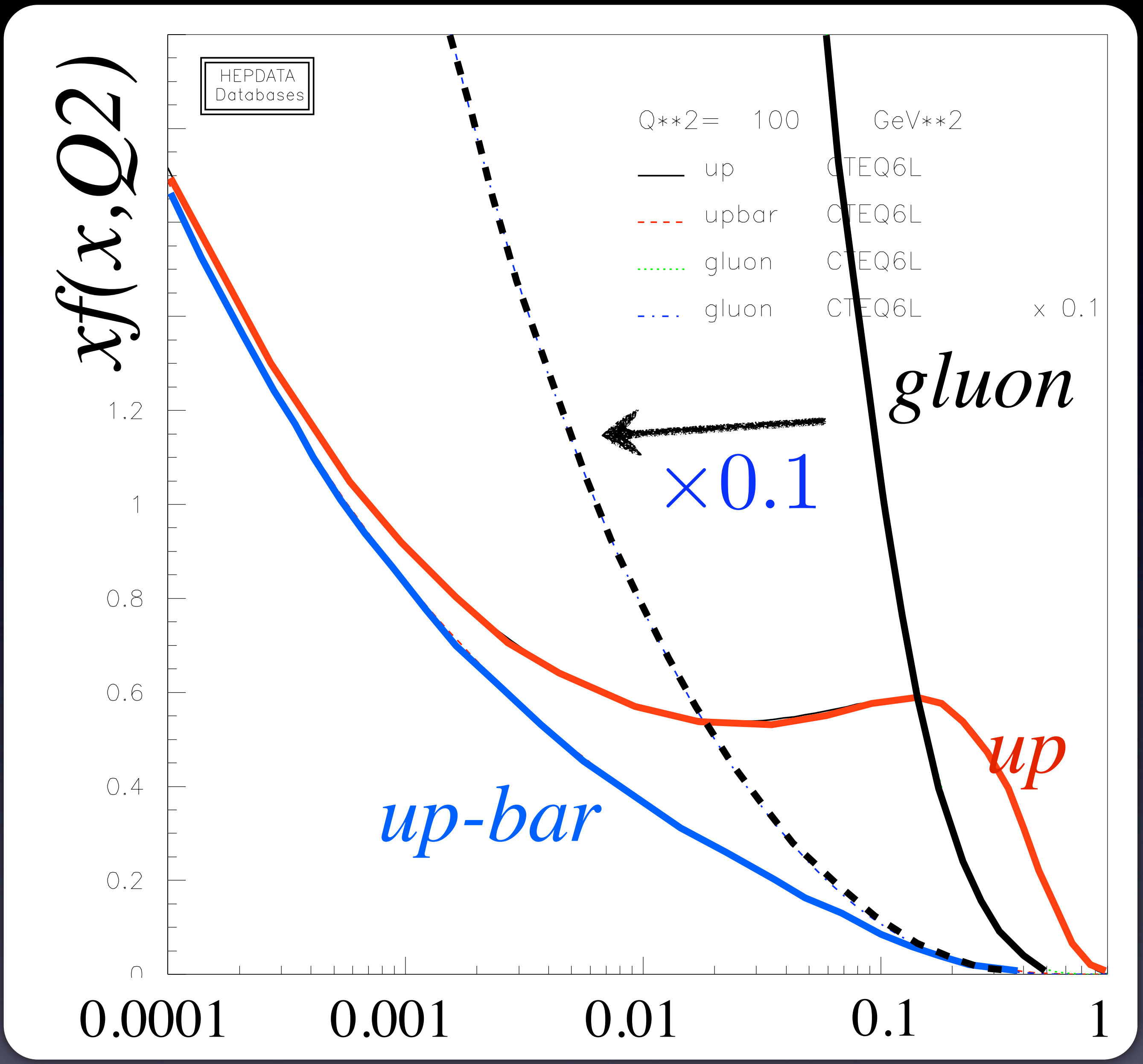
- Measure three-gauge-boson coupling

7 effective couplings



# 50 TeV versus 14 TeV

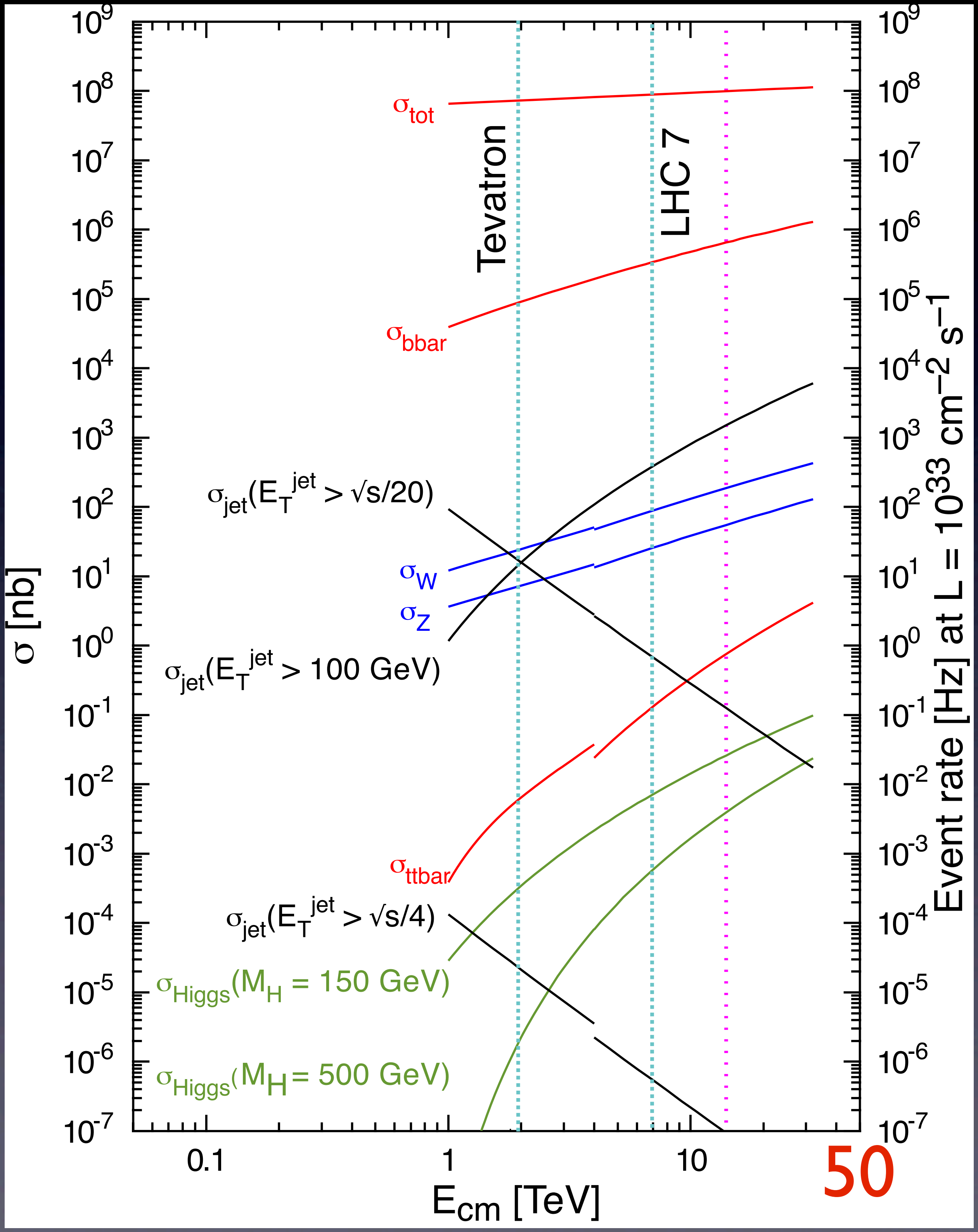
# Parton distribution function




$$\langle x \rangle \sim \frac{m_X}{\sqrt{S}}$$

- Gluon induced channels are highly suppressed, while the quark-antiquark channels are less suppressed.
- For heavy resonance production, the quark-(anti)quark initial states dominate.

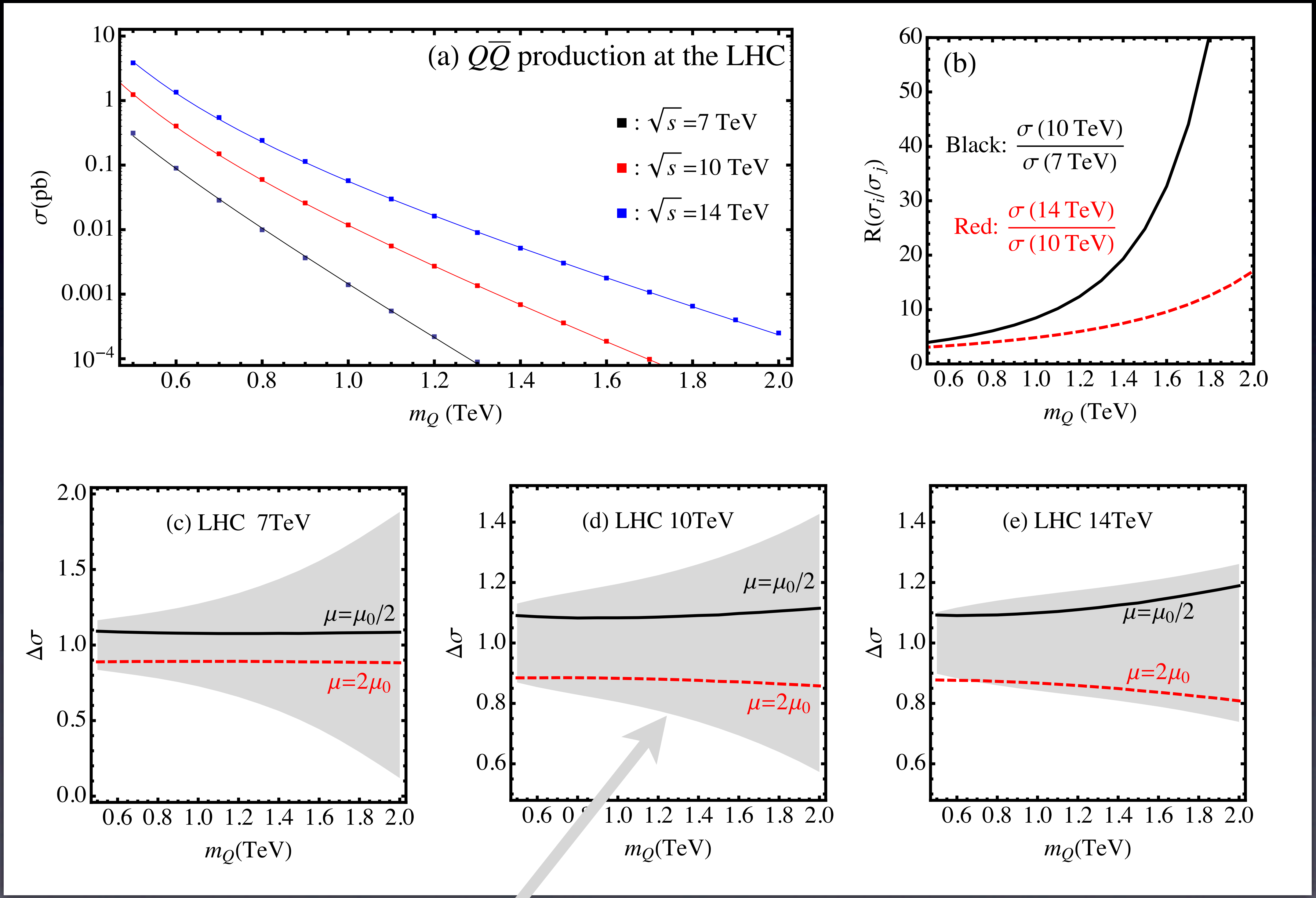
# Proton-Proton at $50^+$ TeV




The cross sections of quark-quark initial state increase by a factor of 3-5 while the cross sections of gluon-gluon initial state increase by a factor 5-10.

# NLO QCD corrections to heavy quark production

- QQ production via the QCD Interaction




PDF uncertainties

Berger and QHC,
Phys. Rev. D81 (2010) 035006

# Pros and Cons of 50 TeV SppC

- The effective $\langle x \rangle$ is lowered by a factor of 3.5 when machine energy increases from 14TeV to 50TeV. For a TeV resonance,

$$\langle x \rangle_{14} \sim \frac{\text{TeV}}{14\ \text{TeV}} \sim 0.07 \qquad \langle x \rangle_{50} \sim \frac{\text{TeV}}{50\ \text{TeV}} \sim 0.02$$

The gluon PDF exhibits a larger uncertainty.

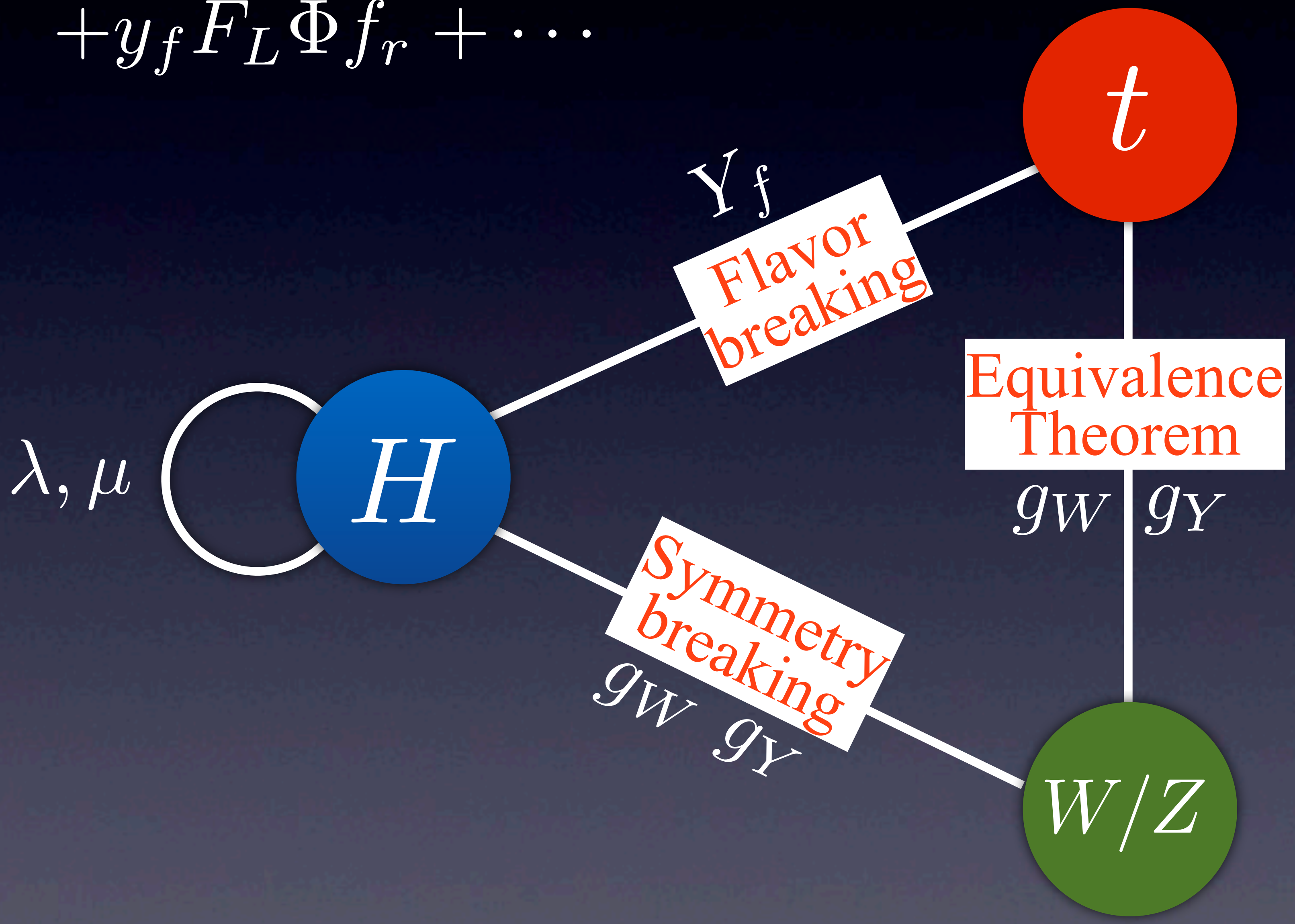
New Data $\longrightarrow$ Proton structure in small *x*

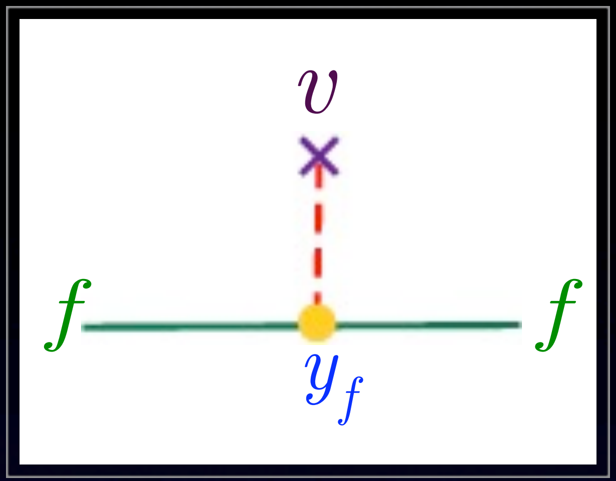
- The cross section of New physics resonance (in the large $\langle x \rangle$ region) production increases less than the cross section of the SM backgrounds (in the small $\langle x \rangle$ region).

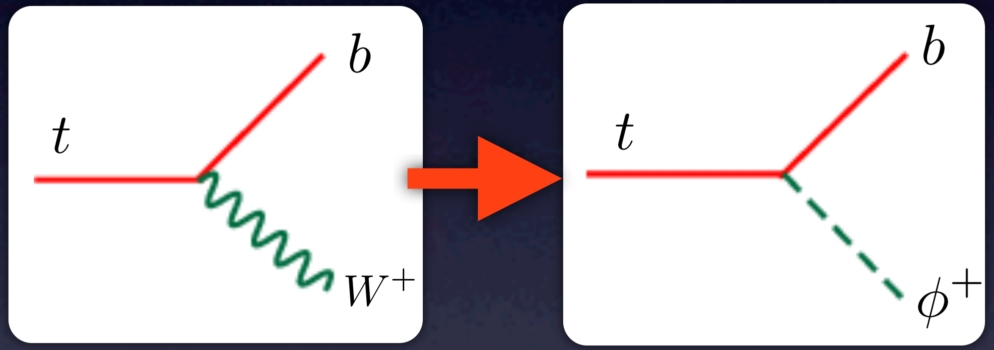
# Electroweak triangle

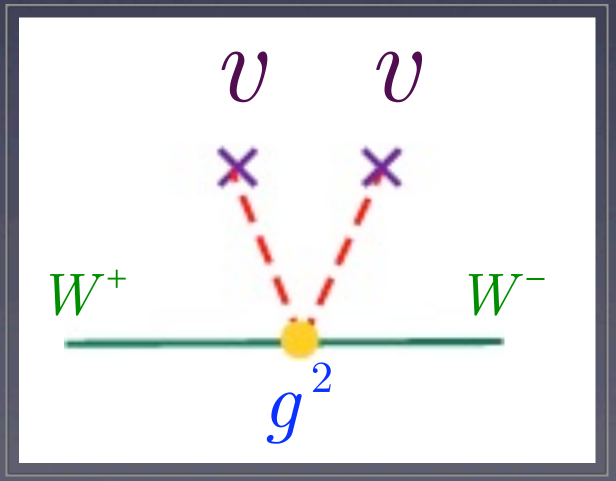
$$\mathcal{L} = \left(D_\mu \Phi\right)^\dagger \left(D^\mu \Phi\right) - \mu^2 \Phi^\dagger \Phi + \lambda \left(\Phi^\dagger \Phi\right)^2$$

$$+ y_f \bar{F}_L \Phi f_r + \cdots$$



# What is not measured yet

- One last not-measured fermion gauge coupling

$$g_{Zt\bar{t}}$$

- $V_{tb}$

  It always comes together with W-t-b coupling.

- Neutrino: Dirac or Majorana

- Higgs self interaction coupling

# EWPT: Bottom-Up approach

- Effective Field Theory
  - Gauge invariant (less model independent)
  - Easy to track the origin and order of NP
  - Too many operators

- Effective Lagrangian (effective coupling)
  - More general (Lorentz invariant)
  - Tree and loop effects messed up.

# Tree-level induced dim-6 operators

$$\mathcal{O}^{(1)}_{\phi q} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{q}\gamma^\mu q\right),$$

$$\mathcal{O}^{(3)}_{\phi q} = i\left(\phi^\dagger \tau^I D_\mu \phi\right)\left(\bar{q}\gamma^\mu \tau^I q\right),$$

$$\mathcal{O}_{\phi t} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{t}_R\gamma^\mu t_R\right),$$

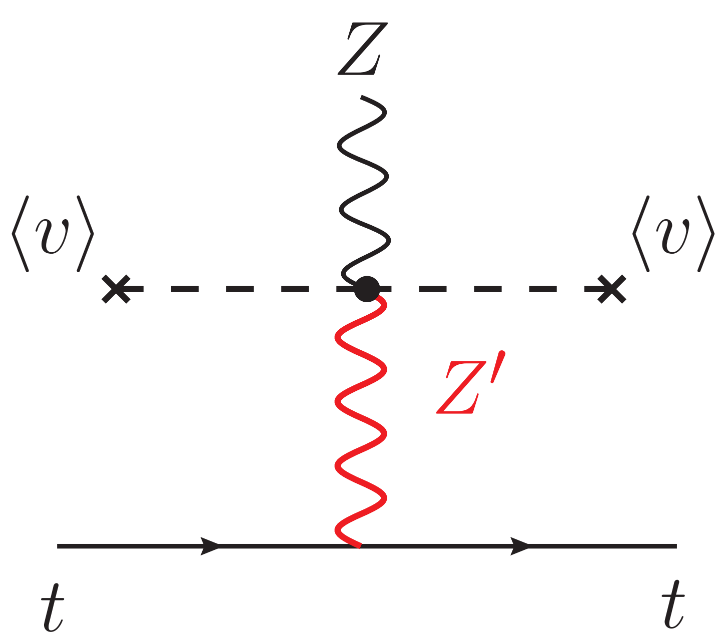
$$\mathcal{O}_{\phi b} = i\left(\phi^\dagger D_\mu \phi\right)\left(\bar{b}_R\gamma^\mu b_R\right),$$

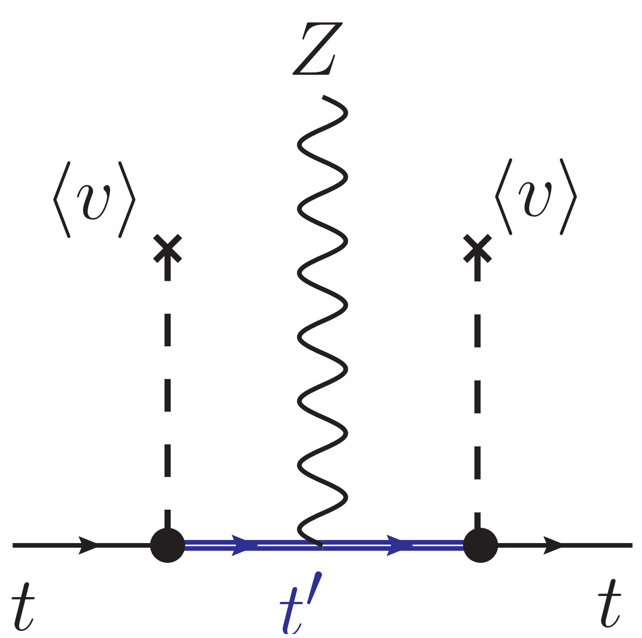
$$\mathcal{O}_{\phi\phi} = \left(\phi^\dagger \epsilon D_\mu \phi\right)\left(\bar{t}_R\gamma^\mu b_R\right),$$

$$q = \begin{pmatrix} t \\ b \end{pmatrix}_L$$

$t_R \quad b_R$

$\phi$: Higgs doublet



# Effective *wtb*, *ztt* and *zbb* couplings

$b \to s\gamma$

$$-0.0007 < \frac{c_{\phi\phi} v^2}{2\Lambda^2} < 0.0025$$

B. Grzadkowski and M. Misiak, Phys. rev. D78, 077501 (2008)

$$\mathcal{O}_{Wtb} = \frac{c_{\phi q}^{(3)} v^2}{\Lambda^2} \frac{g_2}{\sqrt{2}} W_\mu^+ \bar{t}_L \gamma^\mu b_L - \frac{c_{\phi\phi} v^2}{2\Lambda^2} \frac{g_2}{\sqrt{2}} W_\mu^+ \bar{t}_R \gamma^\mu b_R + h.c.$$

$$\mathcal{O}_{Zt\bar{t}} = \frac{\left(c_{\phi q}^{(3)} - c_{\phi q}^{(1)}\right) v^2}{\Lambda^2} \frac{\sqrt{g_1^2 + g_2^2}}{2} Z_\mu \bar{t}_L \gamma^\mu t_L - \frac{c_{\phi t} v^2}{\Lambda^2} \frac{\sqrt{g_1^2 + g_2^2}}{2} Z_\mu \bar{t}_R \gamma^\mu t_R$$

$$\mathcal{O}_{Zb\bar{b}} = -\frac{\left(c_{\phi q}^{(1)} + c_{\phi q}^{(3)}\right) v^2}{\Lambda^2} \frac{\sqrt{g_1^2 + g_2^2}}{2} Z_\mu \bar{b}_L \gamma^\mu b_L - \frac{c_{\phi b} v^2}{\Lambda^2} \frac{\sqrt{g_1^2 + g_2^2}}{2} Z_\mu \bar{b}_R \gamma^\mu b_R$$

$R_b$ and $A_{FB}^{(b)}$

$$\frac{\delta g_{Z b_L b_L}}{g_{Z b_L b_L}^{\mathrm{SM}}} \leq 0.25\%$$

→

$$c_{\phi q}^{(3)} + c_{\phi q}^{(1)} \simeq 0$$

J. Alcaraz et al, arXiv:hep-ex/0511027

# Effective Wtb, Ztt, Zbb couplings

- New parameterization of couplings

$$\mathcal{O}_{Wtb} = \frac{g}{\sqrt{2}} \mathcal{F}_L W_\mu^+ \bar{t}_L \gamma^\mu b_L + h.c. \ ,$$

$$\mathcal{O}_{Zt\bar{t}} = \frac{g}{2c_w} Z_\mu \left( 2\mathcal{F}_L \bar{t}_L \gamma^\mu t_L + \mathcal{F}_R \bar{t}_R \gamma^\mu t_R \right)$$

- The coefficients of the left-handed neutral and charged currents are related,

$$g^L_{Zt\bar{t}} = 2 g^L_{Wtb} = 2\mathcal{F}_L$$

which is predicted by the EW gauge symmetry

after the stringent constraint on $Zb_Lb_L$ imposed.

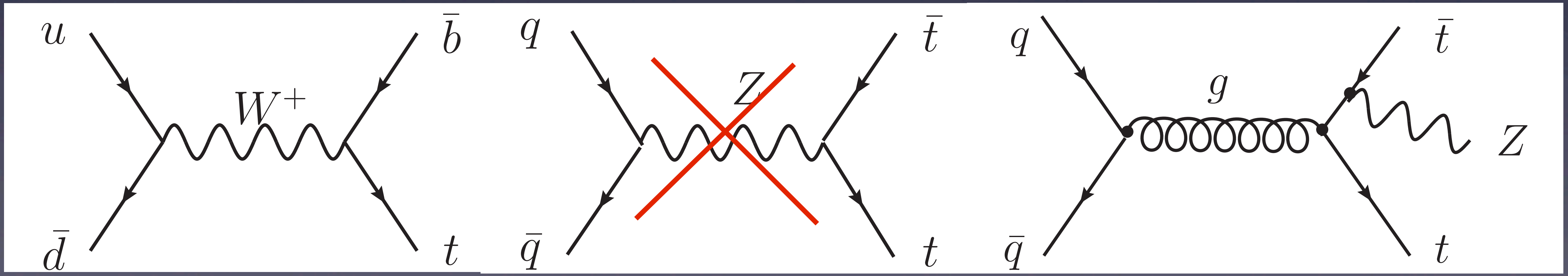
# How to probe such a correlation

$$\mathcal{O}_{Wtb} = \frac{g}{\sqrt{2}} \mathcal{F}_L \, W^+_\mu \bar{t}_L \gamma^\mu b_L + h.c. \,,$$

$$\mathcal{O}_{Zt\bar{t}} = \frac{g}{2c_w} Z_\mu \left( 2\mathcal{F}_L \, \bar{t}_L \gamma^\mu t_L + \mathcal{F}_R \, \bar{t}_R \gamma^\mu t_R \right)$$

- At the Hadron Collider

U. Baur, A. Juste, L.H. Orr, D. Rainwater
Phys.Rev.D71:054013,2005;
Phys. Rev.D73:034016,2006



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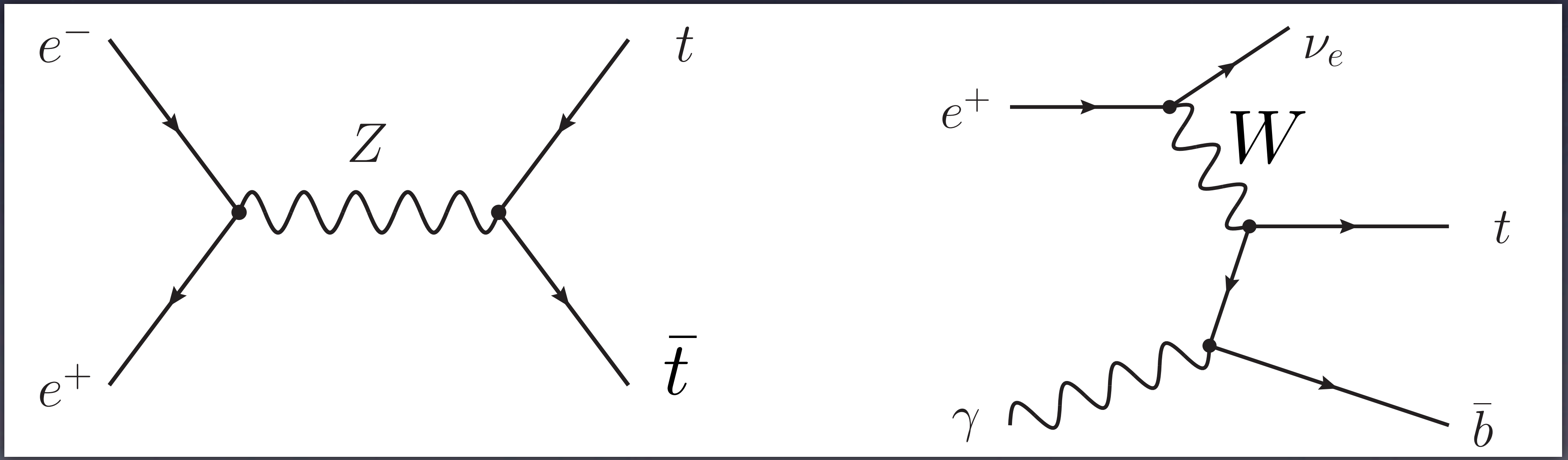
- At the Linear Collider

P. Batra, T. Tait,
Phys.Rev.D74:054021,2006

QHC, J. Wudka,
Phys.Rev.D74: 094015, 2006



# Impact of anomalous couplings on $\sigma_t$ and $\sigma_{t\bar{t}}$

- Inclusive cross sections of single-t and Ztt productions:

$$\sigma_t = \sigma_t^0 \left[1 + 2\mathcal{F}_L + 2\delta V_{tb} + \mathcal{O}\left(\mathcal{F}_L^2, \delta V_{tb}^2\right)\right],$$

$$\sigma_{Zt\bar{t}} = \sigma_{Zt\bar{t}}^0 \left[1 + 4.4\mathcal{F}_L - 1.5\mathcal{F}_R + \mathcal{O}\left(\mathcal{F}_L^2,\ \mathcal{F}_R^2,\ \mathcal{F}_L\mathcal{F}_R\right)\right]$$

$$\delta\sigma = (\sigma - \sigma^0)/\sigma^0 \qquad \delta V_{tb} = |V_{tb}|^{(\mathrm{exp})} - |V_{tb}|^{(\mathrm{SM})}$$

$$\delta V_{tb} = -0.23\delta\sigma_{Zt\bar{t}} + 0.5\delta\sigma_t - 0.34\mathcal{F}_R$$

Ed L. Berger, QHC, Ian Low, Phys.Rev.D80: 074020 (2009)

Note: Vtb cannot be extracted out from single top production alone.

# Experiments versus Theories

- Physics is associated with many scales

WEAK | TeV | GUT | PLANCK

Hierarchy

EWSB
Dark Matter

SUSY

Unification,
Neutrino See-Saw

Quantum
Gravity


**Higgs Factory**