Testing the SM through Dijets

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Introduction

- **<u>Why we want to test the SM at the LHC?</u>**

(i) Strong hints that NP must appear at the TeV scale:

Naturalness problems due to the large hierarchy of scales

$$\underbrace{m_H^2}_{\sim\Lambda_{EW}^2} = (m_H^{(0)})^2 + \underbrace{(\Delta m_H)^2}_{\sim M_P^2}$$

(ii) Some directions in the SM poorly tested.

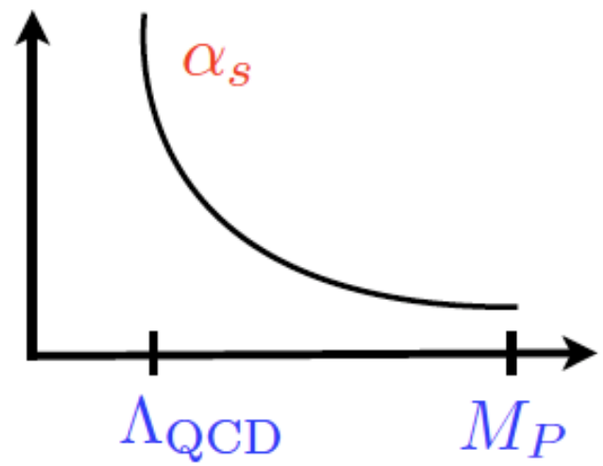
Introduction

What New Physics at the TeV?

Strongly Interacting Sector *(analogous to QCD)*

Dynamical generation of the EW scale:

"Dimensional Transmutation"



Composite Higgs → Prevents from receiving Planckian corrections

- If the Higgs is Composite, why not the whole plethora of SM particles?
- What do we know about the SM so far?

Introduction

Legacy from past experiments

- LEP ⟶ Properties of leptons very well measured through e+ e- collisions (per mille level)

- KLOE ⟶ Quark-Lepton Universality $\frac{G_F|_{\text{quarks}}}{G_F|_{\text{leptons}}} - 1 < 10^{-3}$ ⇒ LH-quarks as elementary as leptons

- Tevatron ⟶ Tests the RH-quark sector. This direction is "*poorly measured*"

Framework

RH-quark sector has not been well tested so far

LHC can do better!

Model Independent approach

We parametrize the NP effects with a set of higher dimensional operators:

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \underbrace{\frac{c_i}{\Lambda^2}\mathcal{O}_i^{d=6}}_{\text{NP effects}} + \cdots$$

Framework

Two classes of Operators in the expansion $\frac{c_i}{\Lambda^2}\mathcal{O}_i$

1. Extra Derivatives: $c_i \sim \mathcal{O}(1)$

$\psi\gamma_\mu\psi D_\nu F^{\mu\nu}$, $\psi\psi D_\mu D^\mu H$, ...

2. Extra Fields: $0 < c_i < g_\rho^2 \simeq 16\pi^2$

$(\bar{\psi}\gamma_\mu\psi)(H^\dagger D^\mu H)$, $(\bar{\psi}\gamma_\mu\psi)^2$

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Contribute to couplings to W, Z
Already measured at LEP & KLOE

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2. Extra Fields: $0 < c_i < g_\rho^2 \simeq 16\pi^2$

$(\bar{\psi}\gamma_\mu\psi)(H^\dagger D^\mu H)$, $(\bar{\psi}\gamma_\mu\psi)^2$ → Parametrize Quark Compositeness

↓

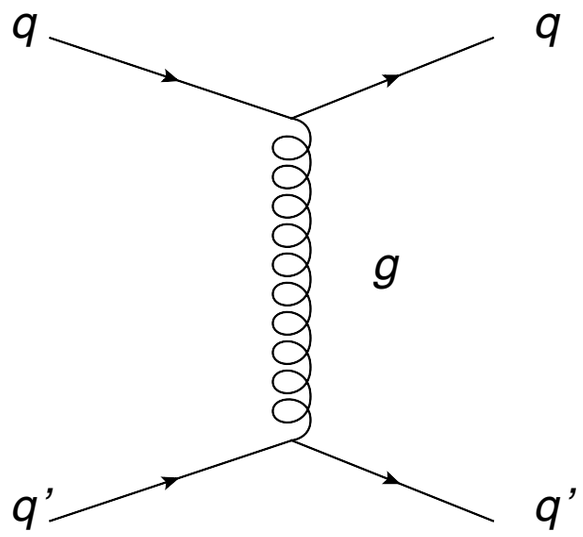
Contribute to couplings to W, Z
Already measured at LEP & KLOE

Framework

- 4-Quark operators $\mathcal{O}_{4q} = \frac{c_i}{\Lambda^2}(\bar{\psi}\gamma_\mu\psi)^2$

  can be constrained through Dijet processes: (p p ⟶ j j)

$\mathcal{M}|_{qq'\to qq'} \propto$



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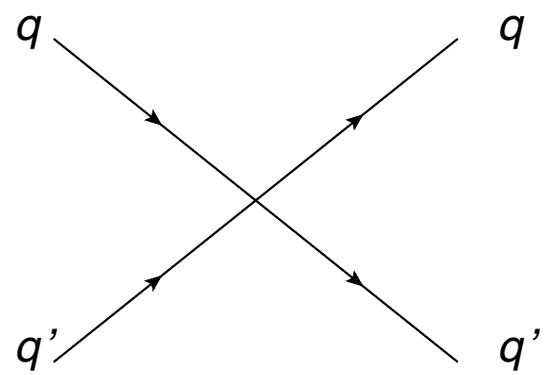


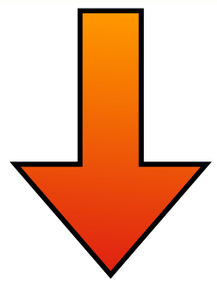
QCD

4-Quark Op.

Framework

How many Independent 4-Quark Operators?

- $U(3)_{q_L} \times U(3)_{d_R} \times U(2)_{u_R}$ global symmetry of the strong sector.
- Only 1st family quarks are relevant for Dijets



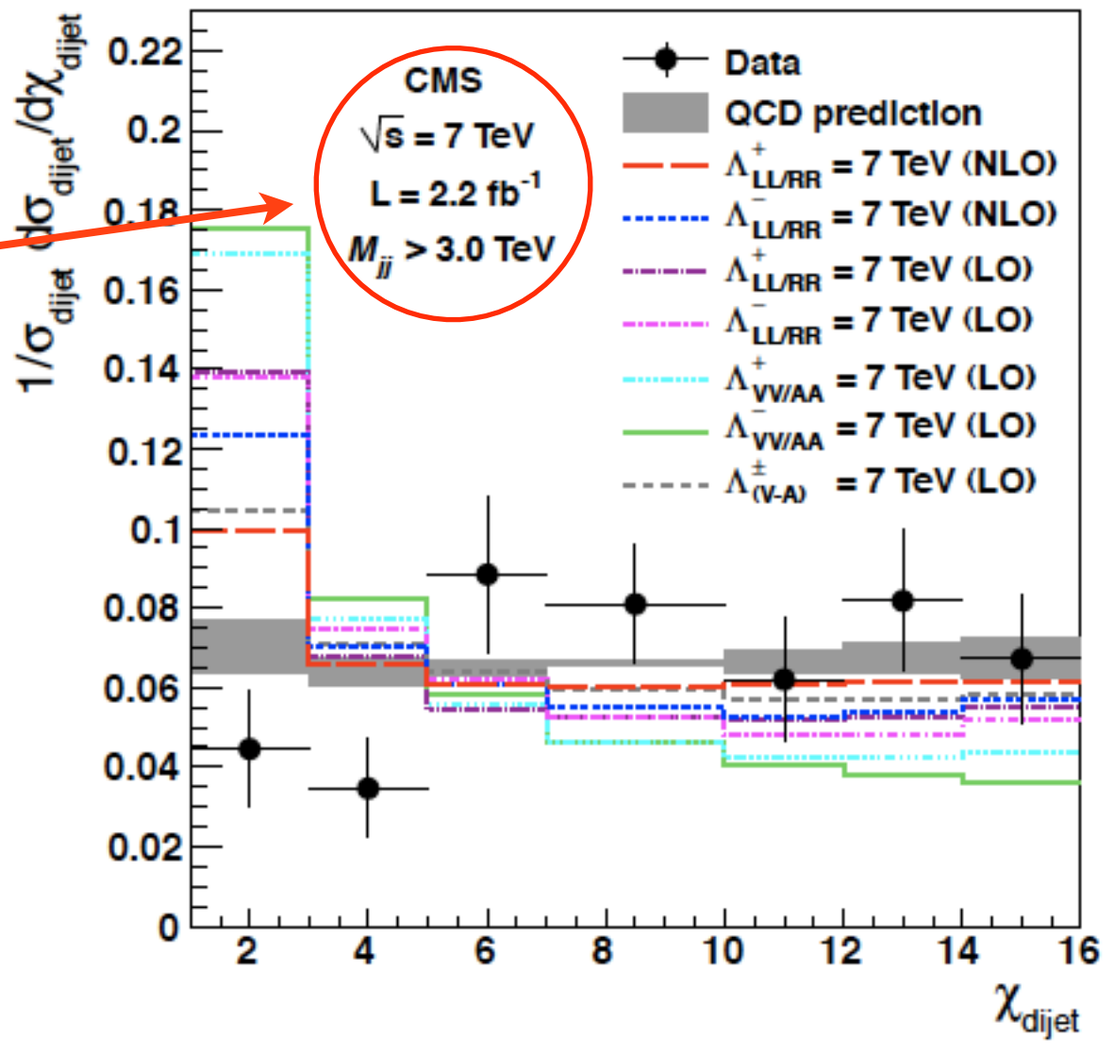
10 independent 4-Quark operators!

Dijets

- **How can we constrain the 4-Quark operators?**

Through Dijet distributions

Latest data from CMS
(arXiv:1202.5535)



Dijets

- **How can we constrain the 4-Quark operators?**

Through Dijet distributions

Latest data from CMS
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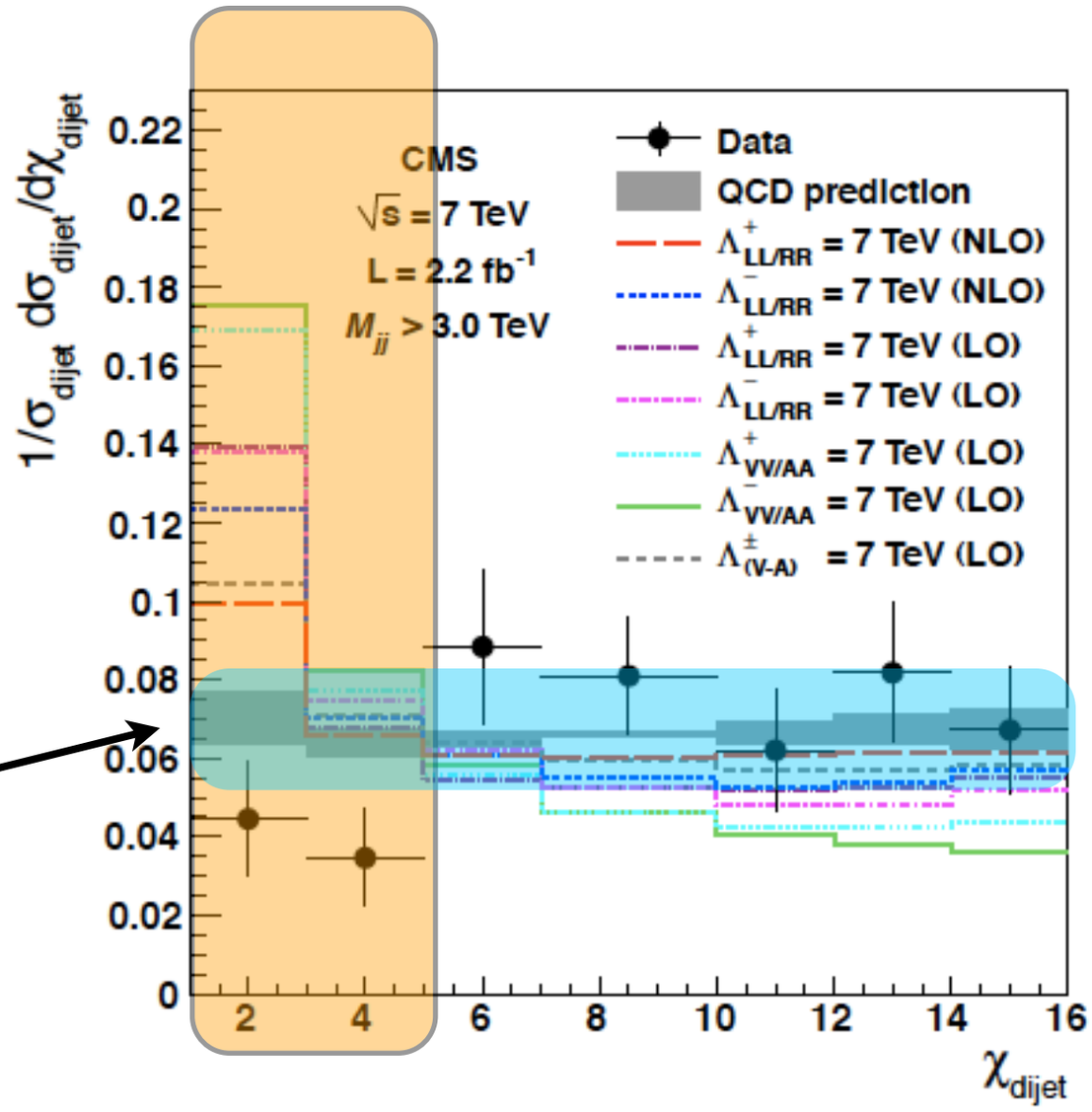
NP peaked at low χ

SM distribution is flat



Dijets

We define: $$F_\chi^{3\mathrm{TeV}} = \frac{N(\chi < 3, m_{jj} > 3\mathrm{TeV})}{N(\chi < 16, m_{jj} > 3\mathrm{TeV})}$$

When including 4-Quark Operators:

$$F_\chi^{3\mathrm{TeV}} \simeq (F_\chi^{3\mathrm{TeV}})_{SM} - \frac{1}{\Lambda^2} f(c_i) + \frac{1}{\Lambda^4} g(c_i \cdot c_j)$$

That we compare with the experimental value

$$0.003 \lesssim (F_\chi^{3\ \mathrm{TeV}})_{\mathrm{exp}} \lesssim 0.15 \quad \text{at } 95\% \text{ C.L.}$$

Results

- Bounds on 4-Quark Operators:

Constructive Interference SM-NP

Destructive Interference SM-NP

Operator	$\Lambda_-/\sqrt{c_i}$	$\Lambda_+/\sqrt{c_i}$ (TeV)
$\mathcal{O}_{uu}^{(1)}$	4.5	3.0
$\mathcal{O}_{dd}^{(1)}$	2.4	2.0
$\mathcal{O}_{ud}^{(1)}$	2.2	2.2
$\mathcal{O}_{ud}^{(8)}$	1.8	1.3
$\mathcal{O}_{qq}^{(1)}$	5.0	3.5
$\mathcal{O}_{qq}^{(8)}$	3.4	2.0
$\mathcal{O}_{qu}^{(1)}$	2.5	2.5
$\mathcal{O}_{qu}^{(8)}$	1.9	1.5
$\mathcal{O}_{qd}^{(1)}$	1.9	1.9
$\mathcal{O}_{qd}^{(8)}$	1.4	1.2

Results

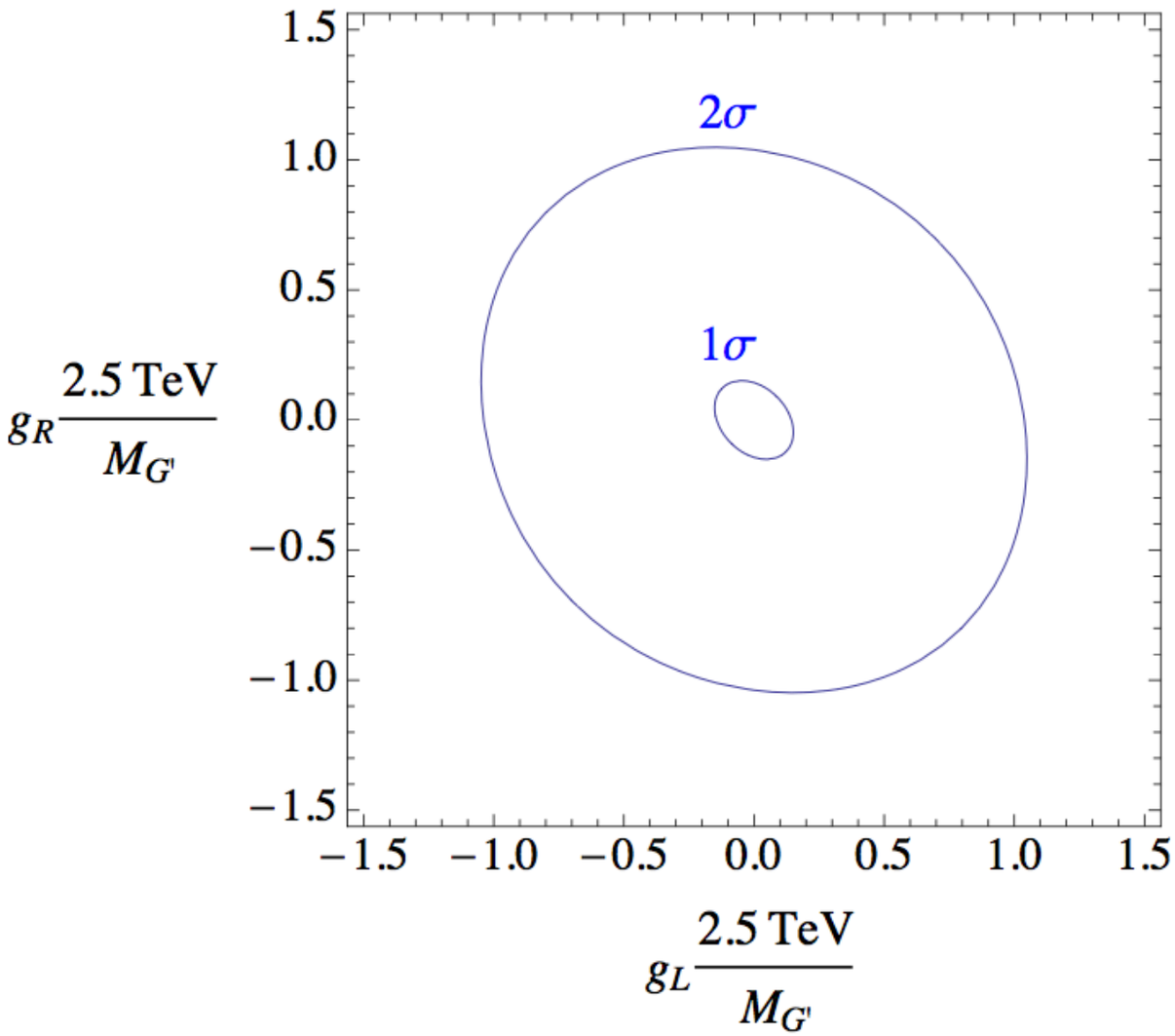
- Composite scenarios:

Composite States	$f\,(\mathrm{TeV})$
d_R	1.5
u_R	3.2
u_R, d_R	3.6
q_L	3.8
q_L, d_R	4.0
q_L, u_R	4.9
q_L, u_R, d_R	5.2

Results

- Heavy Gluon resonances:

$$\mathcal{L}_{int} = G'^{A}_{\mu} \left[g_L \bar{q}_L T^A \gamma^\mu q_L + g_R \bar{q}_R T^A \gamma^\mu q_R \right]$$



Summary

- RH-Quark sector has been poorly explored so far
  - Only explored by Tevatron at E = 1 TeV
  - Dijets at the LHC can do a better job

- From the Dijet analysis we can bound:
  - 4-Quark operators
  - Composite scenarios
  - Models of heavy particles coupled to quarks
  - EWP Parameters: *W, Y* and *Z*

- All these bounds can be improved if Luminosity &/or Energy increase

Backup Slides

- Independent 4-Quark operators:

$$
\begin{aligned}
\mathcal{O}_{uu}^{(1)} &= (\bar{u}_R\gamma^\mu u_R)(\bar{u}_R\gamma_\mu u_R) \\
\mathcal{O}_{dd}^{(1)} &= (\bar{d}_R\gamma^\mu d_R)(\bar{d}_R\gamma_\mu d_R) \\
\mathcal{O}_{ud}^{(1)} &= (\bar{u}_R\gamma^\mu u_R)(\bar{d}_R\gamma_\mu d_R) \\
\mathcal{O}_{ud}^{(8)} &= (\bar{u}_R\gamma^\mu T^A u_R)(\bar{d}_R\gamma_\mu T^A d_R) \\
\mathcal{O}_{qq}^{(1)} &= (\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) \\
\mathcal{O}_{qq}^{(8)} &= (\bar{q}_L\gamma^\mu T^A q_L)(\bar{q}_L\gamma_\mu T^A q_L) \\
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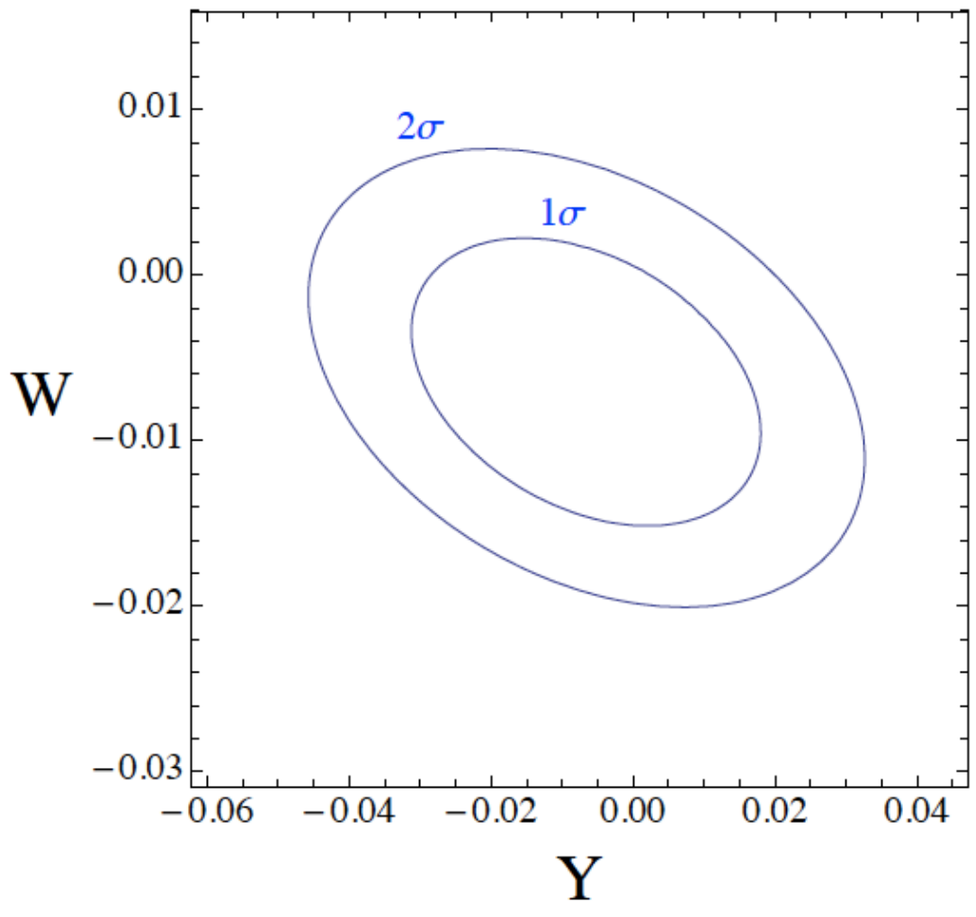
\mathcal{O}_{qu}^{(8)} &= (\bar{q}_L\gamma^\mu T^A q_L)(\bar{u}_R\gamma_\mu T^A u_R) \\
\mathcal{O}_{qd}^{(1)} &= (\bar{q}_L\gamma^\mu q_L)(\bar{d}_R\gamma_\mu d_R) \\
\mathcal{O}_{qd}^{(8)} &= (\bar{q}_L\gamma^\mu T^A q_L)(\bar{d}_R\gamma_\mu T^A d_R)
\end{aligned}
$$

Backup Slides

- Oblique parameters:



$$-3 \times 10^{-3} \lesssim Z \lesssim 6 \times 10^{-4}$$

Best bound for Z up to date