A Light Dilaton at the Muon Collider

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Outline

- Motivation about a light dilaton particle
- Constraints about this particle
- How to distinguish it from the SM Higgs
- The role of the muon collider
- Conclusions

$$-\mathcal{L} = -\frac{1}{2}\partial_\mu h \partial^\mu h + \frac{1}{2}M_h^2 h^2 + \frac{M_h^2}{2\,v}\,h^3 + \frac{M_h^2}{8v^2}\,h^4$$

There are two destinies about the SM Higgs boson at the end of this year run of the LHC

No Higgs found → Non-standard decays of Higgs

No Higgs found → No Higgs at all; a sign of strong dynamical models like Technicolor

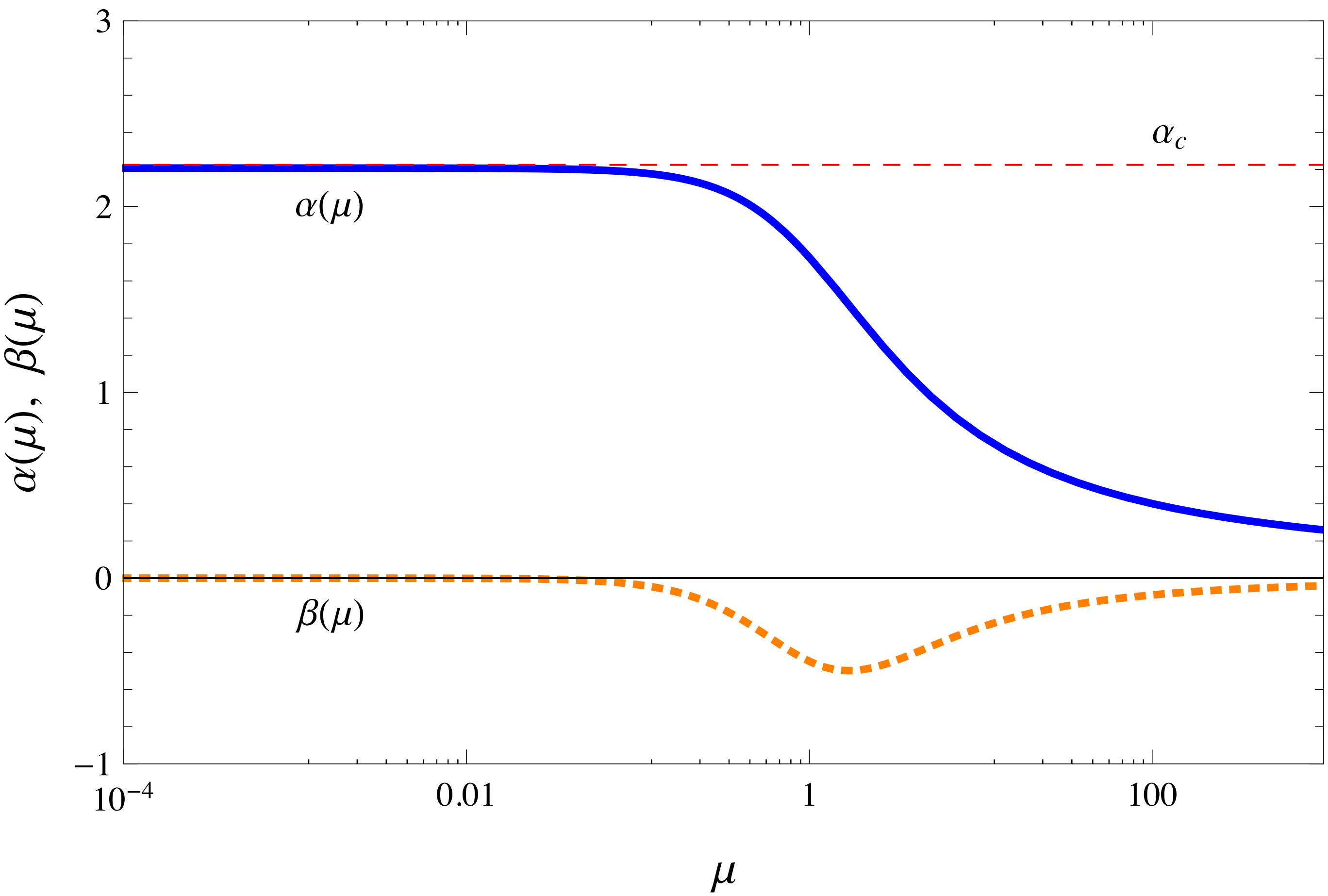
found Higgs → Are we sure that it is "the Higgs"?

Can we totally discard new strong dynamics models?

The muon collider may answer those questions

Walking Technicolor

A new strong dynamics has different properties from QCD



Physics Report,
Volume 381, page 235-402

Strong Dynamics and Electroweak Symmetry Breaking

Christopher T. Hill[1]
and
Elizabeth H. Simmons[2,3]

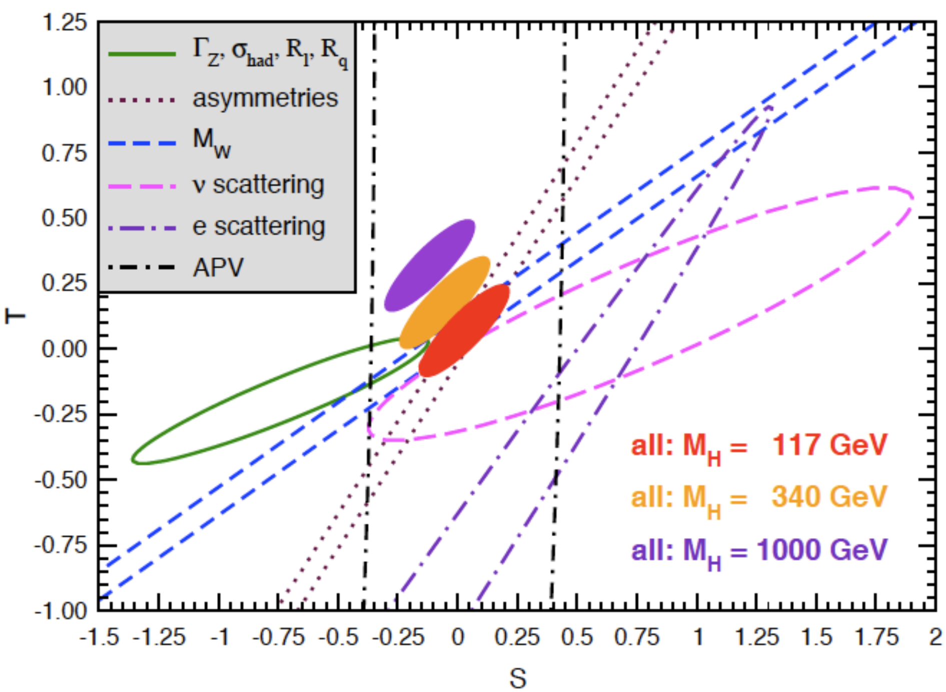
A modification of the dynamics of the Technicolor gauge theory itself can produce smaller oblique corrections than naively estimated above. In Walking Technicolor models (Section 3.4), where the Technicolor gauge coupling remains strong between the TC and ETC scales[21], the theory is intrinsically non-QCD-like and conventional chiral lagrangian, or chiral constituent techniquark estimates are expected to fail. Models of this type would

[21] This could be engineered, for instance, by including many vectorial techniquarks which would affect the β function without adding to S.

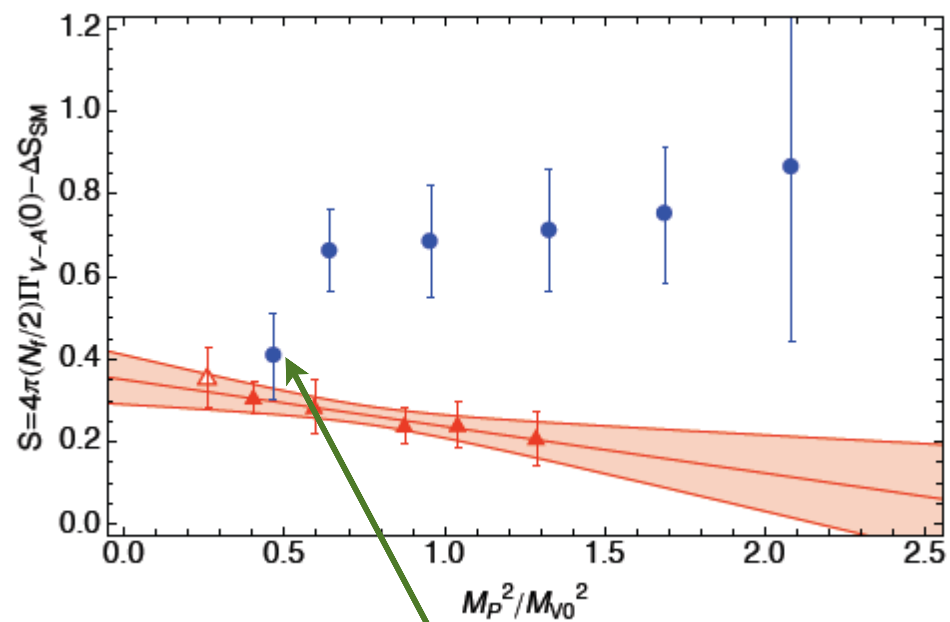
Walking Technicolor

Unfortunately, I don't know how to make a reliable calculation with a very strong coupling in the theory

Fortunately, the lattice theorists know how to study QCD as well as walking dynamics



Appelquist, Fleming, Neil, et al. (LSD);1009.5967



$$S = \frac{0.42}{3} = 0.14$$

Prediction of WTC

In QCD, the pions are much lighter than vector meson masses

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

Pions are pseudo-Goldstone bosons and their masses are protected by the chiral symmetry

In the walking technicolor model, we have a spontaneously breaking of a conformal symmetry

$$SO(4,2) \to \text{Poincare}$$

The Goldstone boson is called "dilaton"

From Ads/CFT correspondence: $\text{dilaton} \leftrightarrow \text{radion}$

4 d 5 d

For pions, we can have the partially conserved axial current (PCAC) and have the pion mass proportional to bare quark masses.

$$\partial^\mu j_\mu^{5a} = 2m j^{5a} \qquad\qquad m_\pi^2 = -\frac{2m\langle 0|\bar{\psi}\psi|0\rangle}{f_\pi^2}$$

Appelquist, YB; Phys.Rev.D82 (2010)

For a dilaton, we have the PCDC with its mass proportional to how fast the gauge coupling runs at a scale around the confinement scale

$$\partial_\mu D^\mu = \theta_\nu^\mu = \frac{\beta(\alpha)}{4\alpha} G_{\mu\nu}^a G^{a\,\mu\nu} \qquad\qquad m_\sigma^2 \simeq \frac{\alpha^* - \alpha^c}{\alpha_c}\Lambda^2 \simeq \frac{N_f^c - N_f}{N_f^c}\Lambda^2$$

The dilaton mass is parametrically lighter than other particles

Grinstein, Goldberger, Skiba; Phys.Rev.Lett, 100 (2008)

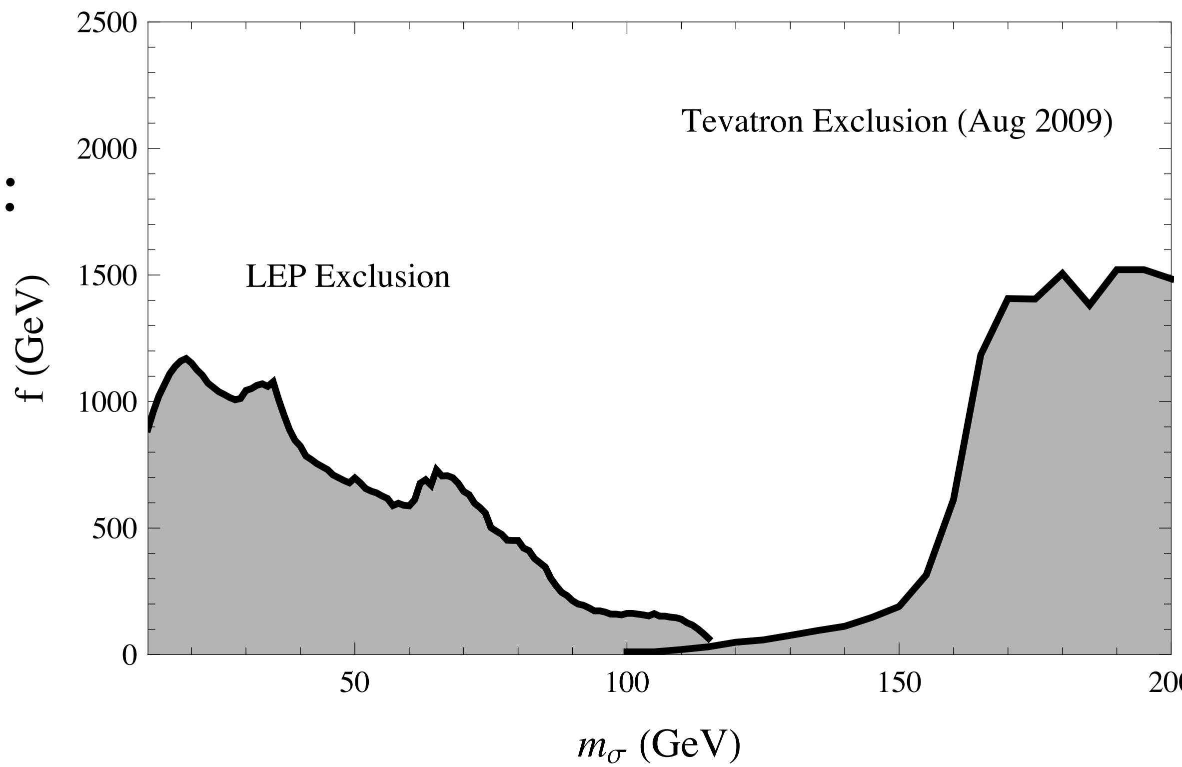
The general couplings of dilaton to SM particles are

$$\mathcal{L} \supset \frac{\sigma}{f}\left[2\,M_W^2\,W^{\mu+}\,W_{\mu-} + M_Z^2\,Z^\mu\,Z_\mu - \sum_\psi m_\psi\,\bar{\psi}\,\psi\; - \frac{\alpha_{em}\,b_{em}}{8\,\pi}\,F_{\mu\nu}F^{\mu\nu} - \frac{\alpha_s\,b_{QCD}}{8\,\pi}\,G_{a\mu\nu}G^{a\mu\nu}\right]$$

If QCD is also imbedded into the conformal sector:

$$b_{QCD} = -11 + \frac{2}{3}\,n_f$$

otherwise $\quad -\dfrac{2}{3}$



YB, Carena, Lykken; Phys.Rev.Lett, 103 (2009)

For the dilaton from the WTC, the QCD is not embedded in the conformal sector.

The dilaton field couplings to SM fermions, weak gauge bosons and gluons are identical to the Higgs couplings in the SM.

"Higgs look-alikes at the LHC", De Rujula, Lykken et al., 1001.5300

"Higgs friends and counterfeits at hadron colliders", Fox, Tucker-Smith and Weiner, 1104.5450

This dilaton field is more confusing with the Higgs boson at hadron colliders than those cases

The "**discovered**" dilaton at the LHC will be misidentified as the Higgs boson

The muon collider is unique to break this degeneracy

For the SM Higgs:

$$-\mathcal{L} = -\frac{1}{2}\partial_\mu h \partial^\mu h + \frac{1}{2} M_h^2 h^2 + \frac{M_h^2}{2\,v}\, h^3 + \frac{M_h^2}{8v^2}\, h^4$$

For the dilaton in WTC, with the explicitly breaking of CFT coming from a marginal operator:

$$-\mathcal{L} = -\frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma + \frac{1}{2} M_\sigma^2 \sigma^2 + \frac{5\,M_\sigma^2}{6\,v}\, \sigma^3 + \cdots$$

Actually, the operator in the non-linear sigma model:

$$\frac{c}{(4\pi\chi)^4} (\partial_\mu \chi \partial^\mu \chi)^2 \qquad\qquad \sigma \equiv \chi - v$$

It contributes to σ^3 $\quad W_\mu W^\mu \sigma$

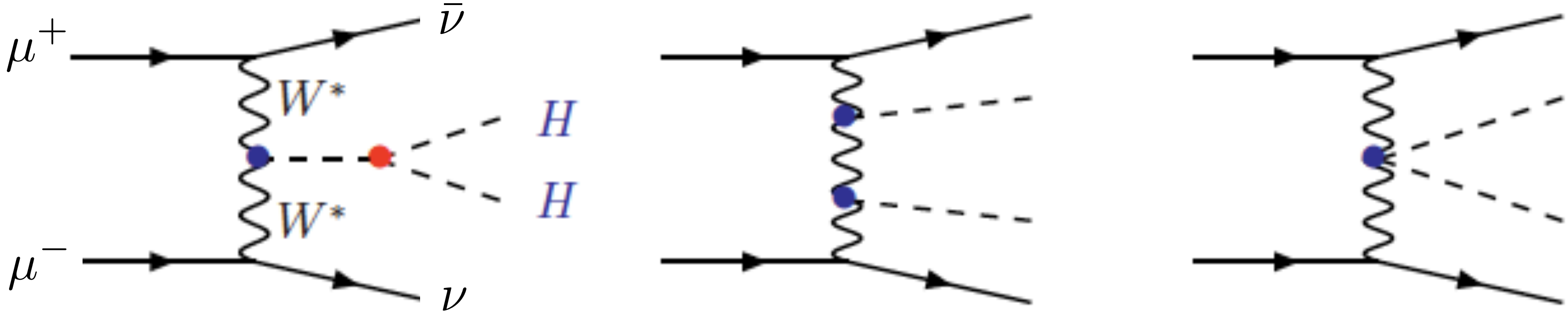
Barger, Han, Langacker, McElrath, Zerwas, hep-ph/0301097

From Barger, Han, Langacker, McElrath, Zerwas, hep-ph/0301097

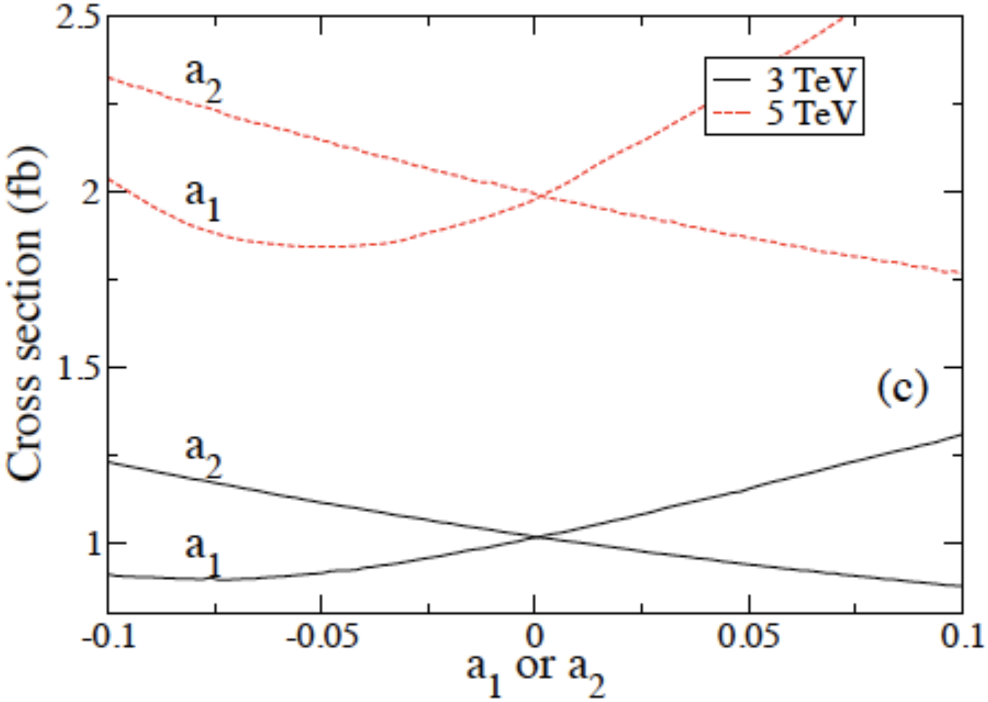
$$\mathcal{L}_{H^3} = -\frac{m_H^2}{2v}\left((1 - \frac{a_1}{2} + \frac{2a_2}{3}\frac{v^2}{m_H^2})H^3 - \frac{2a_1 H\partial_\mu H \partial^\mu H}{m_H^2}\right)$$

For the WTC dilaton,

$$a_1 \approx 0 \qquad\qquad a_2 = \frac{m_H^2}{v^2}$$

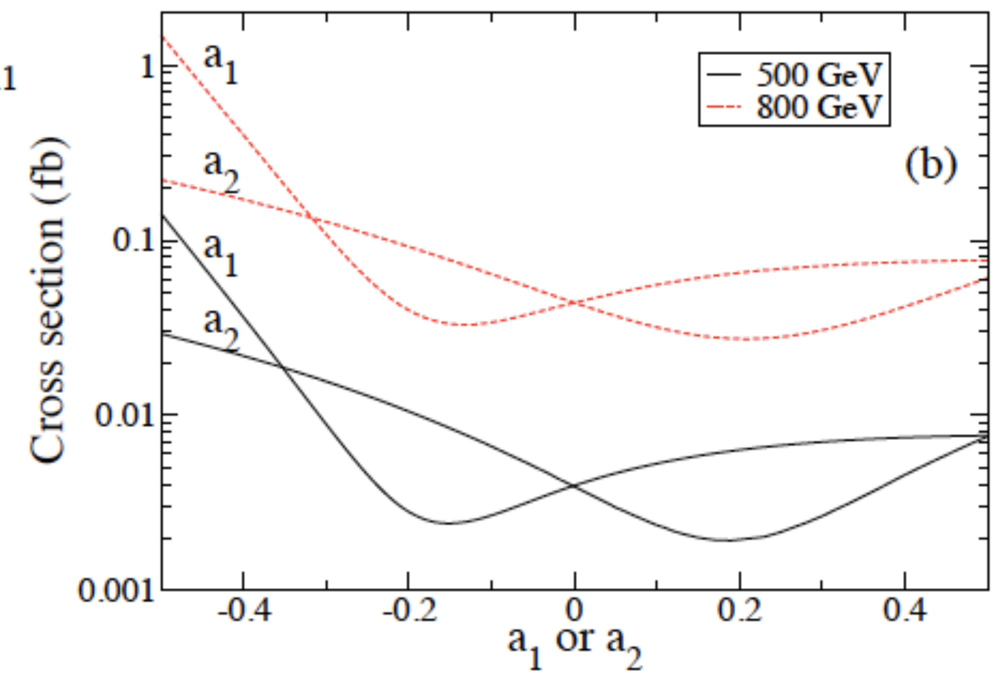


Barger, Han, Langacker, McElrath, Zerwas, hep-ph/0301097

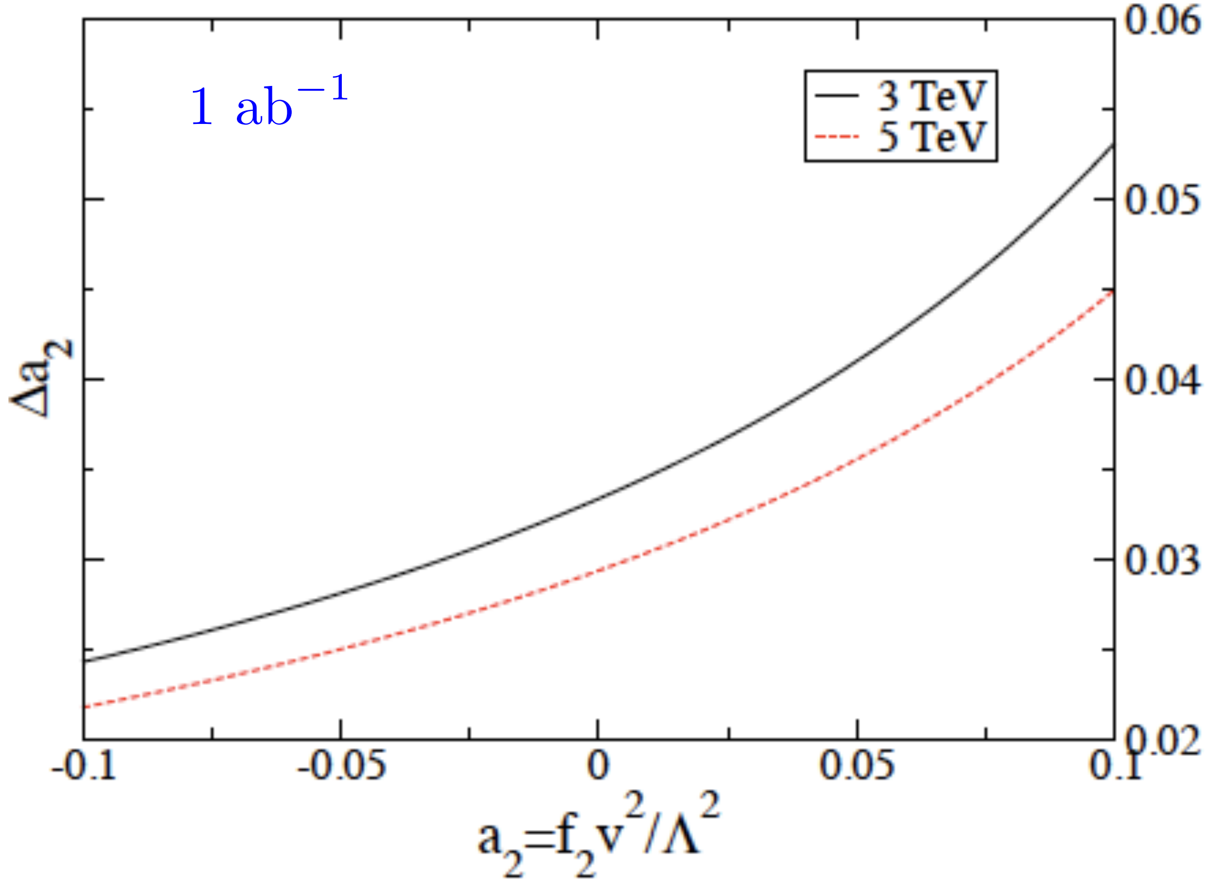


$M_\sigma = 120 \text{ GeV}$

$a_2 = 0.24$



Barger, Han, Langacker, McElrath, Zerwas, hep-ph/0301097



$M_\sigma = 120\ \mathrm{GeV}$

$a_2 = 0.24$

$p_T(b) > 20\ \mathrm{GeV}, \quad |\cos\theta_b| < 0.8, \quad M_{missing} > 70\ \mathrm{GeV}, \quad |m_H - m(bb)| < 10\ \mathrm{GeV}$

80% b-tagging efficiency and require 3 b-tagging

Conclusions

- Discovery of a "Higgs boson" at the LHC may not confirm the Higgs mechanism
- The dilaton in WTC is extremely similar to the Higgs boson
- A muon collider with a center-of-mass energy 3 TeV or above is the unique machine to confirm or disconfirm the Higgs mechanism