Unitarity Bounds for New Physcis from Axial Coupling at LHC

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Based on the work:

Jing Shu, arXiv: 0711.2516 [hep-ph]

Outline

- Motivation
- Unitarity bound from an axial coupling
- Two two-site moose UV completions
- A stronger bound from 2 to n.
- Experimental discovery and applications
- Summary

Motivation

In QFT, if the tree level unitarity is violated in the scattering ampiltude, we know it must come from

- Our theory becomes strongly coupled

M.S. Chanowitz and M.K. Gaillard, Nucl. Phys. B 261, 379 (1985)

- There is no gauge symmetry assciated with the massive spin one particles

J.M. Cornwall, D.N. Levin, and G.Tiktopoulos, Phys. Rev. D 10, 1145 (1974)

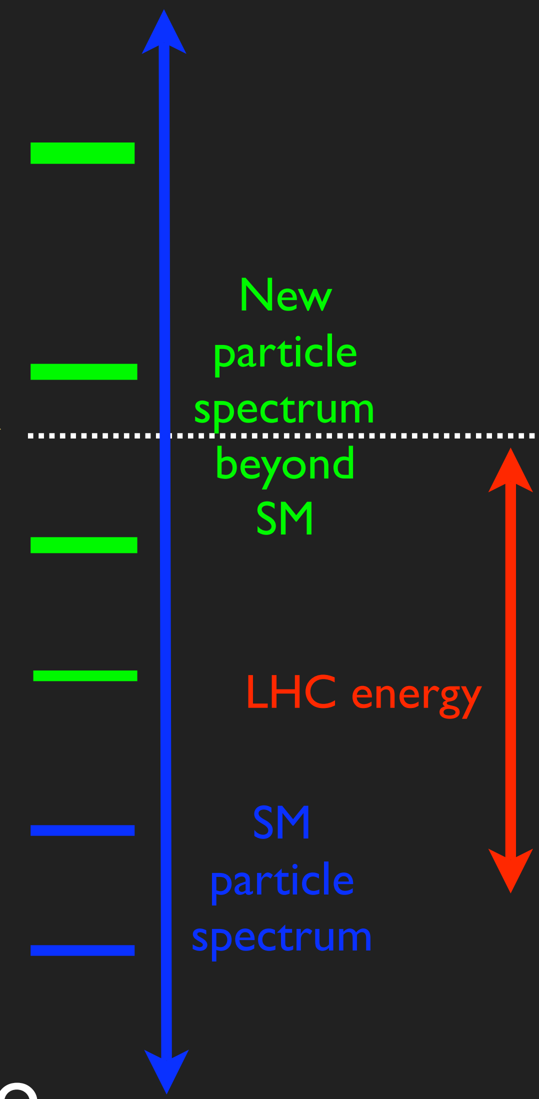
B.W. Lee, C. Quigg, H.B. Thacker, Phys. Rev. Lett. 38, 883 (1977); Phys. Rev. D 16, 1519 (1977)

Applying to SM, and considering we haven't discovered higgs yet, we know that SM higgs mass must be light, or ....

Motivation

At the LHC, if there are new physics beyond SM, very probabally we won't see the full sector of new physics.

Then perhaps the gauge symmetry in the underlying theory is apparantly violated in the incomplete theory that we can recontruct from LHC observables.

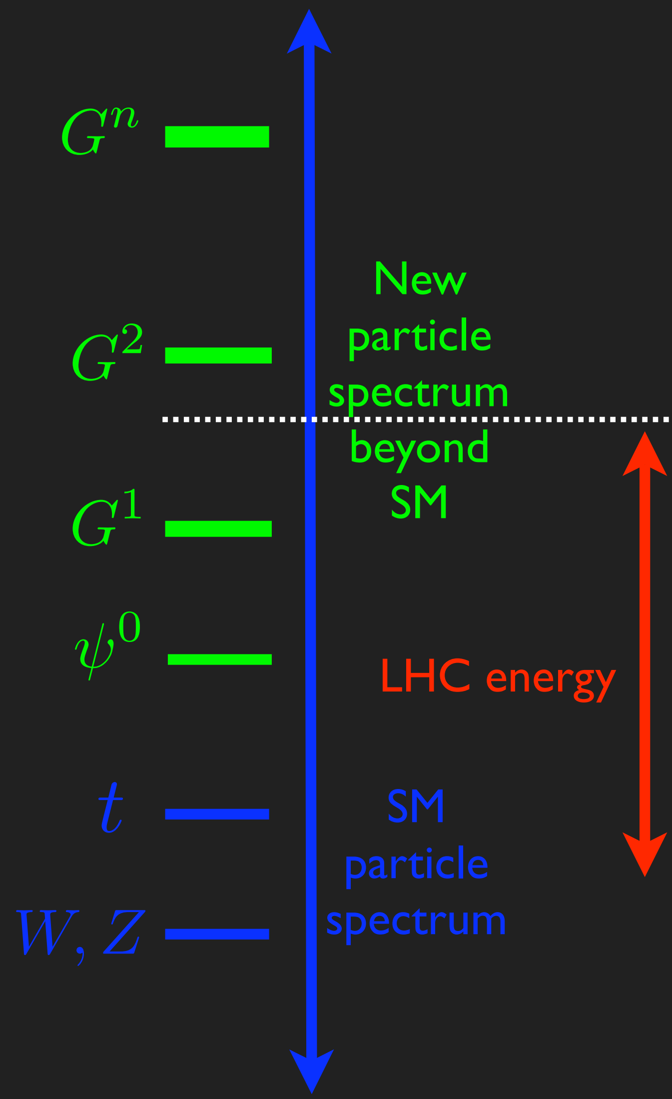


A new spin one particle G^1 with a nonzero axial coupling to fermions ψ^0 is such a case.

Motivation

Then tree-level unitarity is violated in $\bar{\psi}^0 \psi^0 \to G^1 G^1$, and we can predict the scale of new physics beyond the reach of LHC in a model-independent way!

Perhaps one of the first scientific reasons to build the next generation colliders (VLHC, muon collider, etc).

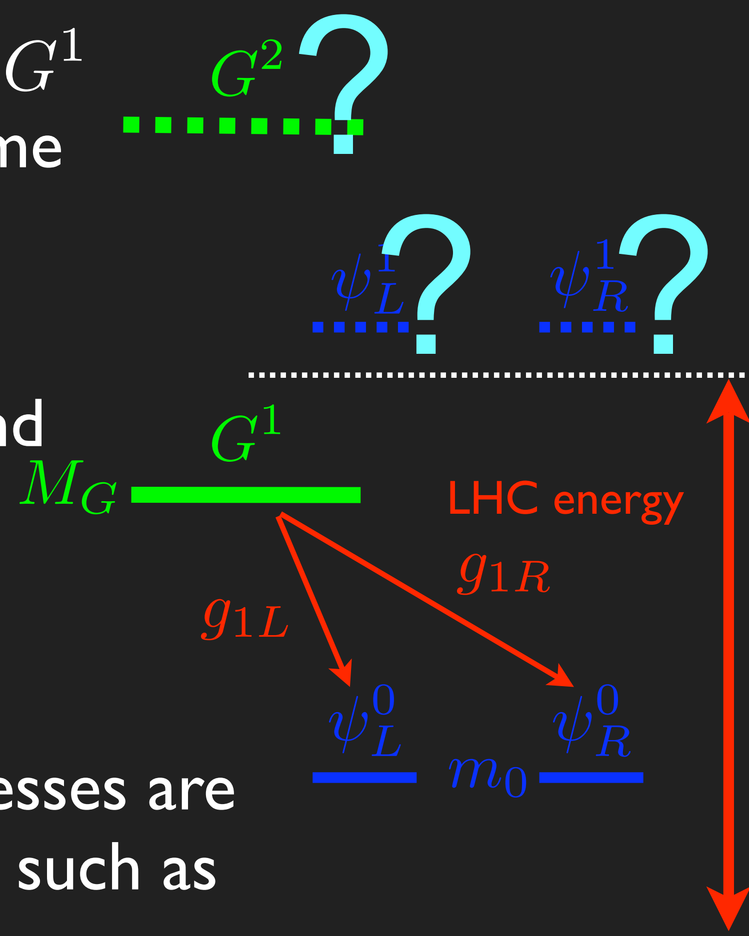


Unitarity bounds

Suppose we observe a new spin one particle G^1 with mass M_G at LHC, and G^1 decays into some fermion ψ^0 with mass m_0.

We can measure the G^1 couplings to the left and right components of ψ^0 and we find the axial coupling $g_A \equiv (g_{1L} - g_{1R})/2$ is nonzero.

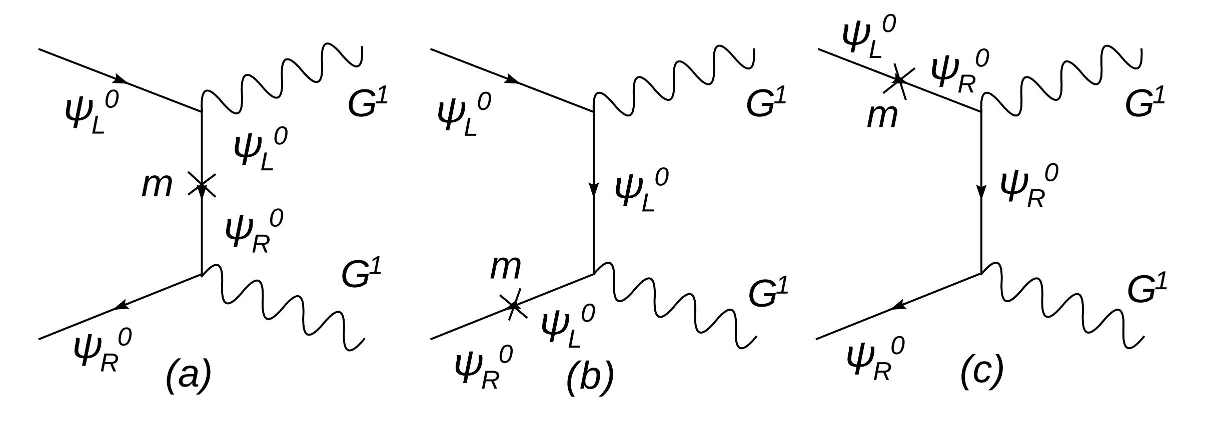
If $g_A \neq 0$, the leading order bad behaved processes are coming from chirality-nonconserving channels such as $\bar{\psi}^0_L \psi^0_L \rightarrow G^1 G^1$ and it is $\propto m_0\sqrt{s}$



Here we focus on the J=0 partial wave amplitude and drop out the irevelant pieces that are related to G^1 self-interaction that perhaps could be measured at LHC.

Unitarity bounds

$$\mathcal{M} = 4g_A^2 \frac{m_0}{M_G^2}\sqrt{s} \qquad\qquad s \gg m_0^2 \; M_G^2$$



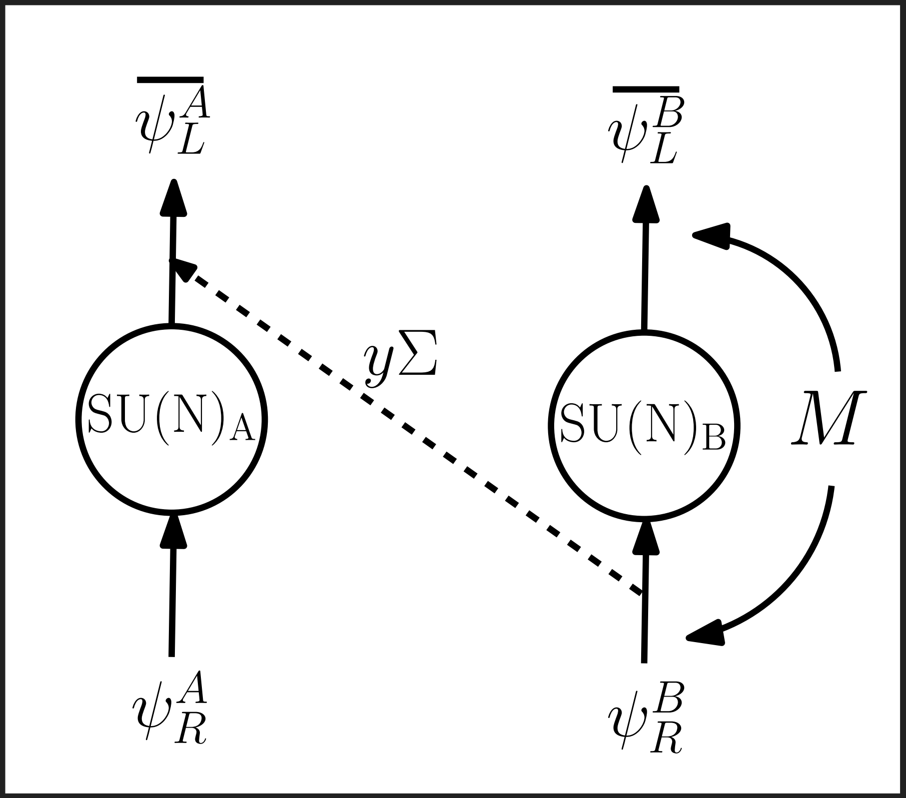
$$a_0 = \frac{1}{32\pi}\int_{-1}^{1} d\cos\theta \mathcal{M} = \frac{C g_A^2 m_0 \sqrt{s}}{4\pi M_G^2} \leqslant \frac{1}{2}$$

$$\sqrt{s} \lesssim E_U = \frac{\sqrt{2}\pi M_G^2}{C g_A^2 m_0}$$

assume we define the spin-singlet combination for the inital states

C represents the color factor where C=1 is for the Abelian case and $C = (N^2-1)/2N$ is for the SU(N) case.

Two-site UV completion (A)



Could be viewed as a two site deconstructed "KK gluon" (N=3) and top quark

After the link field gets a vev $\langle \Sigma_{i\bar{k}} \rangle = u\delta_{i\bar{k}}$ the mass eigenstates of the gauge bosons and left-handed fermions become mixture of their gauge eigenstate.

$$\begin{pmatrix} G^0_\mu \\ G^1_\mu \end{pmatrix} = \begin{pmatrix} c_g & s_g \\ s_g & -c_g \end{pmatrix} \begin{pmatrix} A_\mu \\ B_\mu \end{pmatrix}$$

$$\begin{pmatrix} \psi^0_L \\ \psi^1_L \end{pmatrix} = \begin{pmatrix} -c_f & s_f \\ s_f & c_f \end{pmatrix} \begin{pmatrix} \psi^A_L \\ \psi^B_L \end{pmatrix}$$

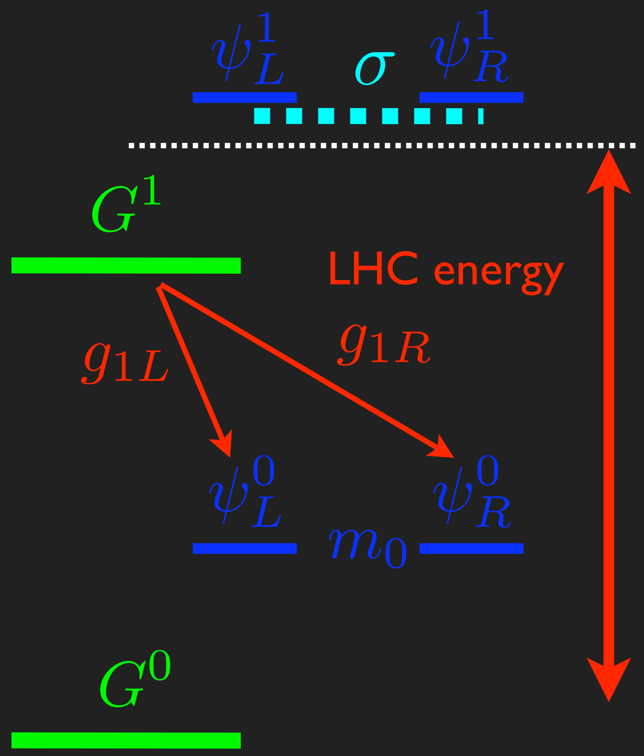
The "0-mode" fermion is massless, we can introduce a gauge invaraint mass term $M'\bar{\psi}^A\psi^A$ to give the mass. We work in the limit $M' \ll yu, M$

M' could come from another SGSB sector like $y'\bar{\psi}^A\psi^A\phi$

Two-site UV completion (A)

In this limit, the "KK-modes" G^1, ψ^1 gain their mass from the link field condensation (compactification in 5D case). The "0-mode" ψ^0 , on the other hand, gains their mass differently (like top quark from EWSB) and does not couple to the link field.

The tree level unitarity in $\bar{\psi}^0\psi^0 \to G^1 G^1$ scattering is recovered if one consider ψ^1 in the t, u-channel.



The full results for maintainning tree-level unitarity is shown based on mass insertion techniques.

Two-site UV completion (A)

If we miss ψ^1, which is not a gauge eigenstate, its mass term and interactions are also not in a gauge invariant form.

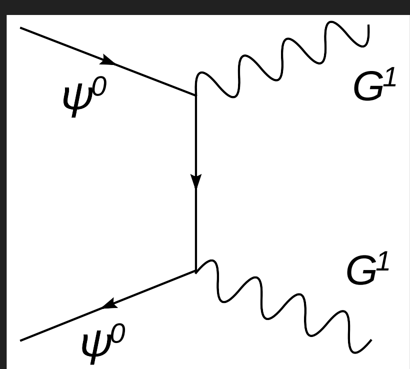
→ Apprent explicit violation of gauge invariance!

Violation of Goldstone equivalence principle,

→ Violation of Wald Identity.

Without ψ^1,

ψ^0 does not couple to π, as it doesn't couple to Σ



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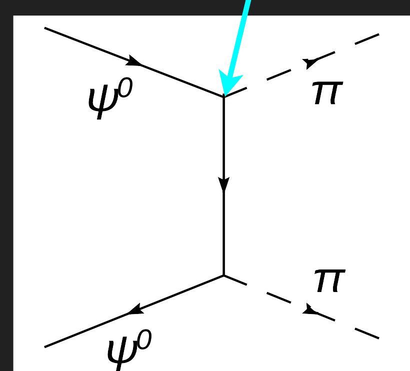

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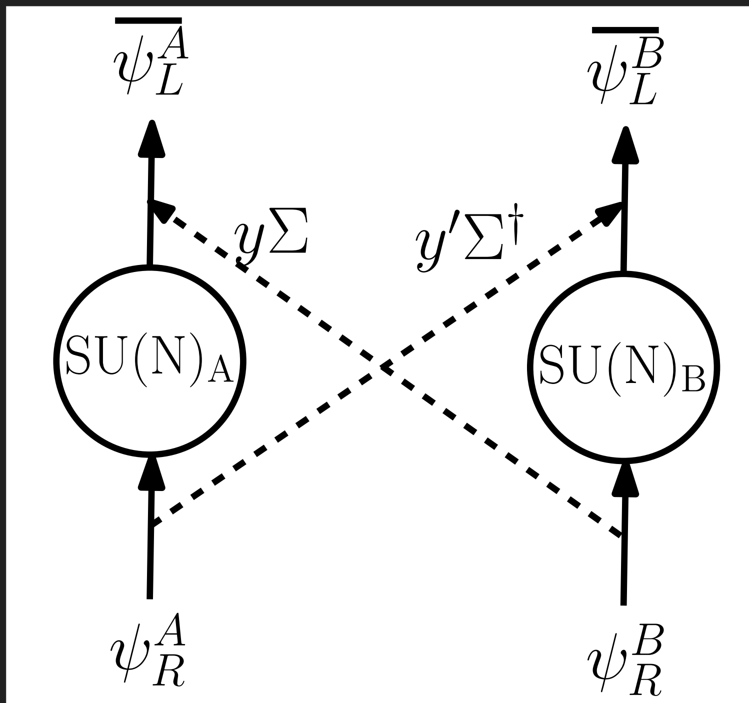
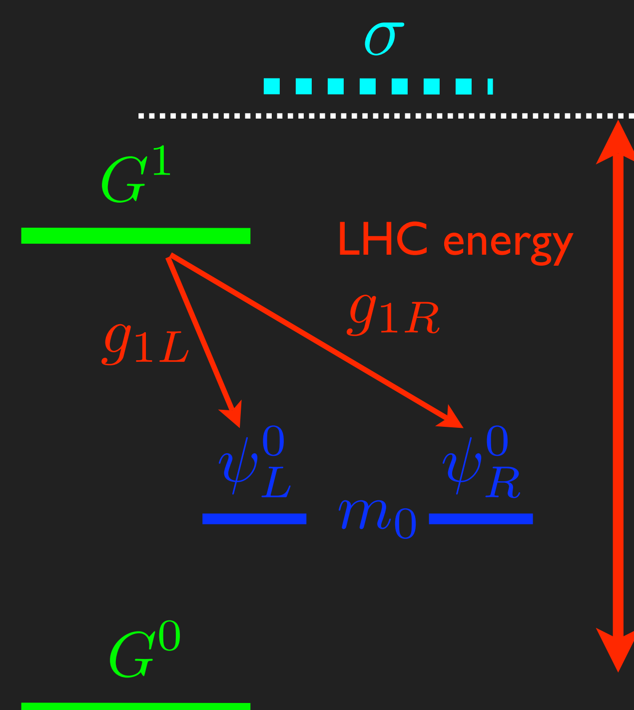
↓ Violation of tree-level unitaity.

Two-site UV completion (B)



Sending $y' \to \infty$, with a WZW term left to cancel the gauge anomaly. No Dirac mass term in moose A and B.

For fermions, the mass eigenstate is the gauge eigenstate. No mixing! Like the case in SM, no violation of gauge invaraince.



The tree level unitaity in $\bar{\psi}^0\psi^0 \to G^1G^1$ scattering is recovered from the s-channel σ exchange, or our symmetry breaking is triggered by strong dynamics.

Very similar to $\bar{t}t \to ZZ$ in SM.

A stronger bound from 2-->n

It is discovered that unitarity bounds from 2 to n process will give a stronger than the 2 to 2 process because of the growing of the phase space in the final state.

F. Maltoni, J.M. Niczyporuk and S. Willenbrock, Phys. Rev. D 65, 033004 (2002)

D.A. Dicus and H.J. He, Phys. Rev. Lett. 94, 221802 (2005); Phys. Rev. D 71, 093009 (2005).

For a 2 to n inelastic collision, the total cross section is bounded by

$$\sigma_{inel}[2 \to n] \leqslant \frac{4\pi}{s}$$

We assume that the corresponding 2 to 2 elastic channel is dominated by s-partial wave.

A stronger bound from 2-->n

We can derive a unitarity bound from $\bar{\psi}^0\psi^0 \to nG^1$ scattering.

$$E_U = \frac{2\pi M_G}{C g_A}\left[\left(\frac{M_G}{2 g_A m_0}\right)^2 \frac{1}{R}\right]^{\frac{1}{2(n-1)}}$$

$$R = \frac{2^{n-1}\left(\frac{n}{2}!\right)^2}{(n!)^2(n-1)!(n-2)!}$$

$$C = (C_F)^{n/2(n-1)}$$

We can double check the unitaity bound here by comparing with the true new physics scale in model A (ψ^1 mass) and B (σ mass) respectively.

We find that the unitarity bound here is always higher than true new physics scale as long as all couplings are weakly coupled.

Experimental discovery

In order to know g_{1L} and g_{1R}, we have to measure ψ^0 chirality, so ψ^0 must decay before it hadronize if it is colored.

$$\Gamma_{\psi^0} > \Lambda_{QCD}$$ if it is colored

top quark
t' quark (top partner)
chiral 4th generation

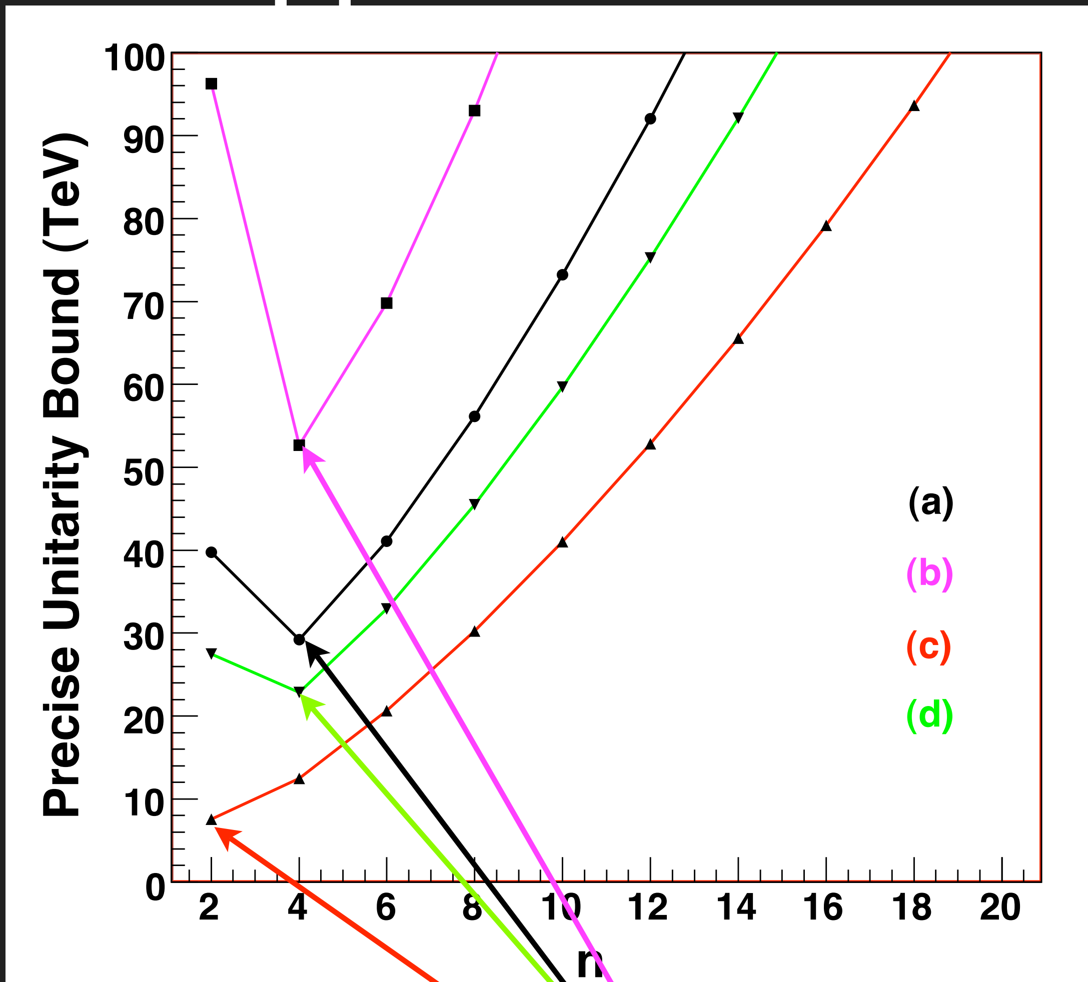
The axial coupling g_A could be measured by looking at the angular distribution of leptons from ψ^0 decay in the ψ^0 rest frame.

One can even define variables like "polarization asymmetry" to directly measure such g_A, which is just like A_{FB}

K. Agashe, A. Belyaev, T. Krupovnickas G. Perez and J. Virzi Phys. Rev. D 65, 033004 (2007)

Perhaps our methods can't apply to the models with discret parity as the pair produced missing E_T will make it very difficult to reconstruct ψ^0

Applications



$M_G = 3\text{TeV}$

(a) RS1 with SM in the bulk.

G^1 1st KK gluon ψ^0 top quark

(b) RS1 with O(3) extended custodial symmetry.

G^1 1st KK gluon ψ^0 top quark

(c) The same as (b) but with

G^1 1st KK gluon ψ^0 t' quark

(d) Top quark seesaw.

G^1 coloron ψ^0 top quark

We choose the typical parameters in the above models.

Unitarity bounds very LOW!

Applications

Really apply to any model without discrete parity with a large axial coupling.

Warped extra dimension models

Higgsless models

Little higgs models withour T-parity.

deconstructed moose models

models with gauge extension

etc!

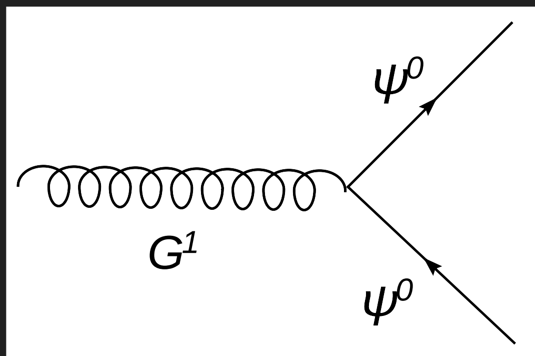
We really need the next generation colliders (VLHC?)to distinguish and study those posibilities in detail.

Generally speaking,

if $M_G/g_A < 3$ TeV ψ^0 is the top quark,

$$E_U < 78 \text{ TeV}$$

Road map



We can measure M_G, m_0 and find G^1 is spin one.

Maybe colored or not?

From ψ^0 decay, in the ψ^0 rest frame, the g_A is measured through the angular distribution of leptons

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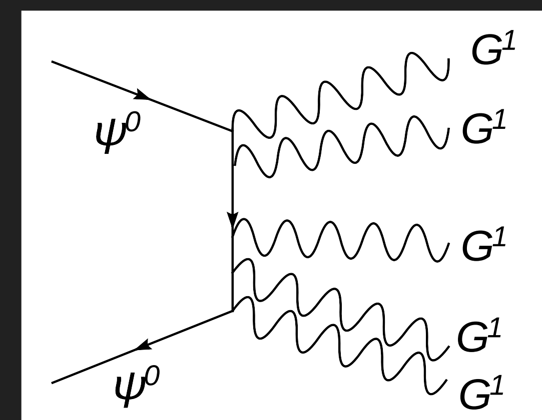

$$E_U < \; ? \; \text{TeV}$$

Build the next generation colliders?

Summary and Outlook

- Signals that are easily observed at LHC give us predictions on the energy scale of new physics.
- The new physics involves either massive fermions, scalars or a strongly coupled sector.
- A incomplete theory that we can reconstructed from LHC perhaps leads to apprent explicit violation of gauge invariance.
- Scentific reasons to build next generation colliders.
- The scattering process could be generalized here. Not nessarily restricted to our current case.