Probing novel scalar and tensor interactions at the TeV scale

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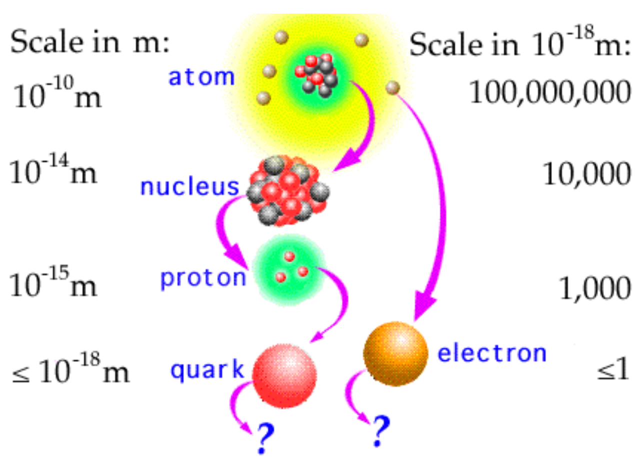

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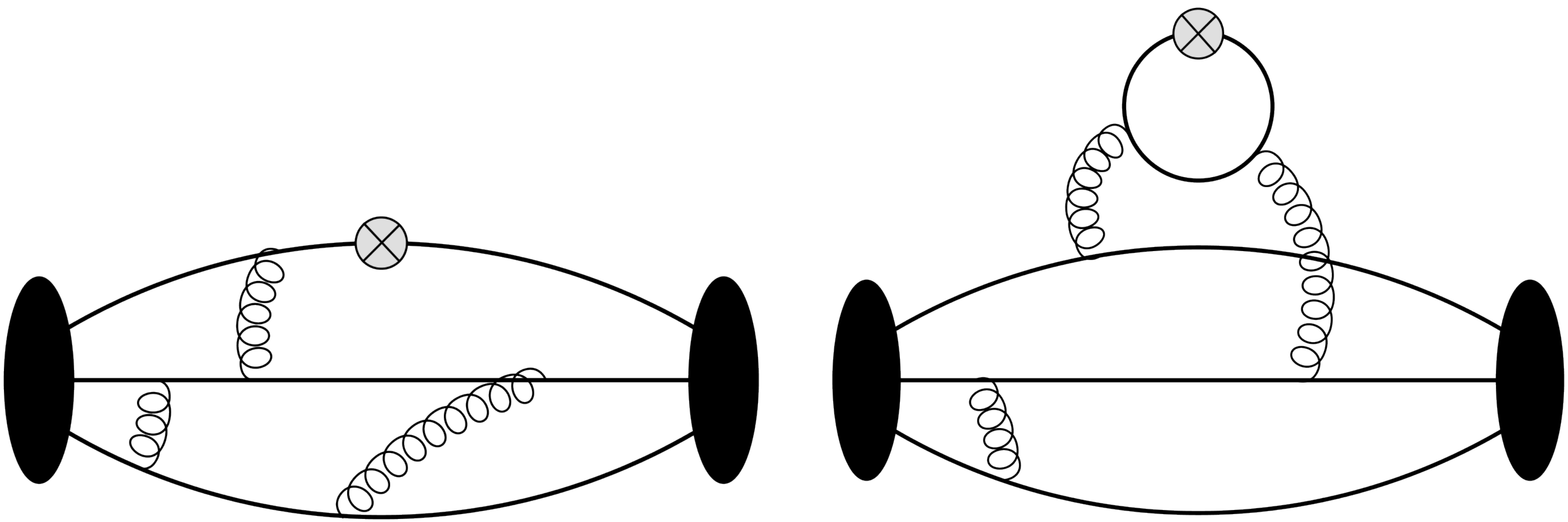
Snowmass 2021, EF04

High precision estimates of the matrix elements of quark bilinear operators within the nucleon state, obtained from "connected" and "disconnected" 3-point correlation functions, address a number of important physics questions

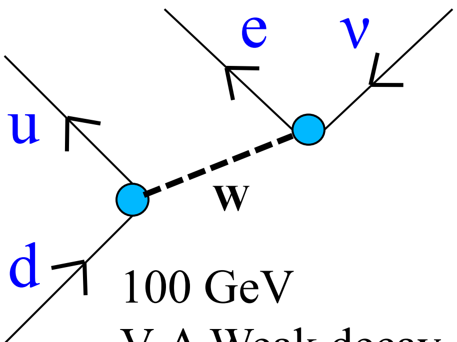
Nucleon charges g_A, g_S, g_T obtained from $\langle N | \bar{q}_i \, \Gamma \, q_j \, | N \rangle$



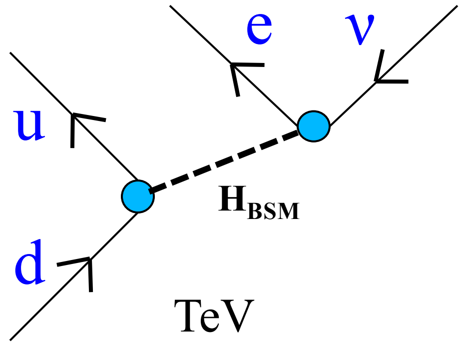
Connected **Disconnected**

Probing New Interactions: $M_{BSM} >> M_W >> 1$ GeV

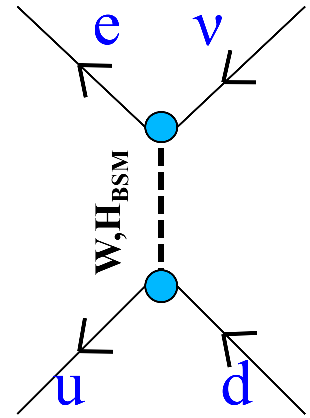
Many BSM possibilities for novel Scalar & Tensor interactions: Higgs-like, leptoquark, loop effects, …



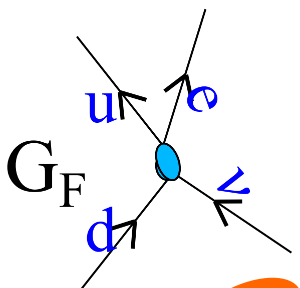
100 GeV
V-A Weak decay
e_L with a ν_L



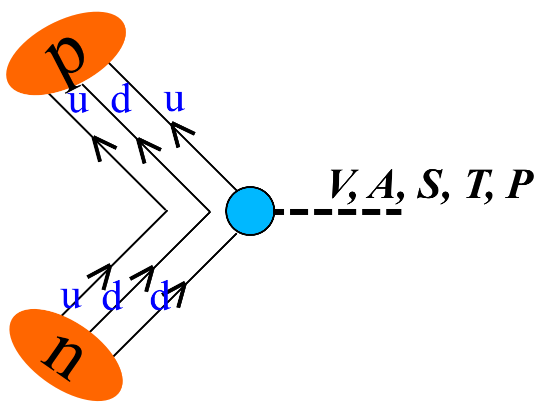
TeV
Novel S,T Interactions
e_R with a ν_L



LHC



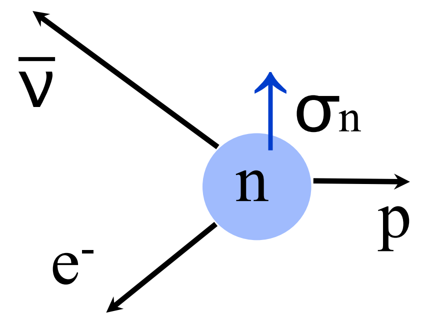
Neutron
Decay



Effective Theory @ ~2 GeV
V-A (g_A, g_V) Weak interactions
S, T (g_S, g_T) New Interactions

Measure in [Ultra]Cold Neutron Decay: Parameters sensitive to new physics

Neutron decay can be parameterized as



$$d\Gamma \propto F(E_e)\left[1 + b\frac{m_e}{E_e} + \left(B_0 + B_1\frac{m_e}{E_e}\right)\frac{\vec{\sigma}_n \cdot \vec{p}_\nu}{E_\nu} + \cdots\right]$$

b: Deviations from the leading order electron spectrum: Fierz interference term

B_1: Energy dependent part of correlation of antineutrino momentum with the neutron spin

Relating b, B_1 to $g_{S,T}$ & BSM couplings $\varepsilon_{S,T}$

$$H_{eff} \supset G_F \left[\varepsilon_S \bar{u}d \; \bar{e}(1-\gamma_5)\nu_e + \varepsilon_T \bar{u}\sigma_{\mu\nu}d \; \bar{e}\sigma^{\mu\nu}(1-\gamma_5)\nu_e \right]$$

$$g_S = Z_S \langle p | \bar{u} d | n \rangle \qquad g_T = Z_T \langle p | \bar{u}\, \sigma_{\mu\nu}\, d | n \rangle$$

Lattice QCD

Leading order in $\varepsilon_{S,T}$

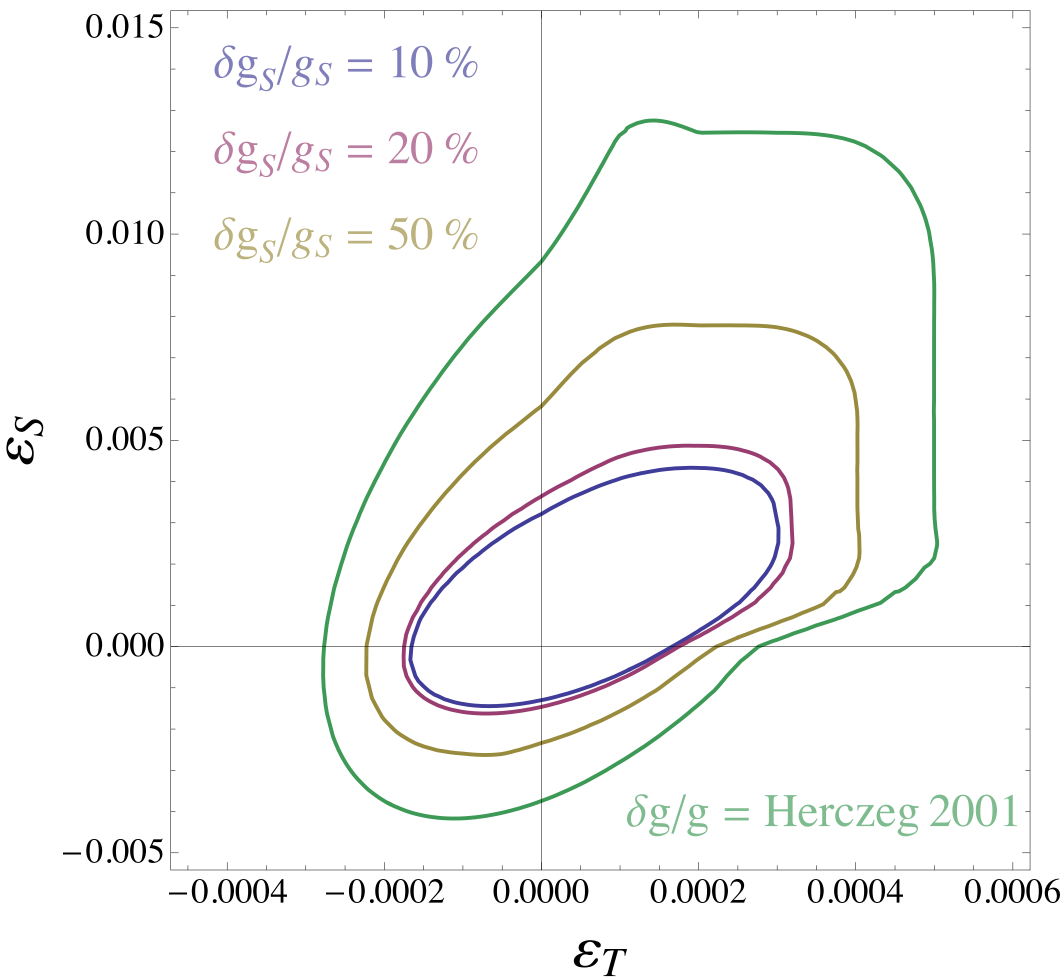
$n \rightarrow p\, e\, \bar{\nu}$ decay gives the linear relations

$$b^{BSM} \approx 0.34\, g_S \varepsilon_S - 5.22\, g_T \varepsilon_T$$

$$b_\nu^{BSM} \equiv B_1^{BSM} = E_e \frac{\partial B^{BSM}(E_e)}{\partial m_e} \approx 0.44\, g_S \varepsilon_S - 4.85\, g_T \varepsilon_T$$

Impact of reducing errors in g_S and g_T from 50→10%

Allowed region in [ε_S , ε_T] (90% contours)



Experimental input

$|B_1\text{-}b| < 10^{-3}$

$|b| < 10^{-3}$

$b_{0+} = 2.6\ (4.3) * 10^{-3}$

Impact limited by precision of ME from Lattice QCD

$$g_S = Z_S \langle p | \bar{u} d | n \rangle$$

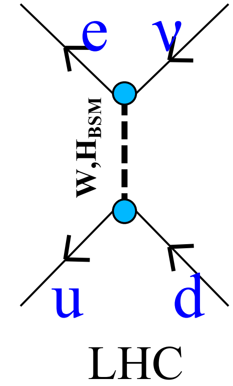
$$g_T = Z_T \langle p | \bar{u} \sigma_{\mu\nu} d | n \rangle$$

Goal: 10% accuracy in g_S and g_T

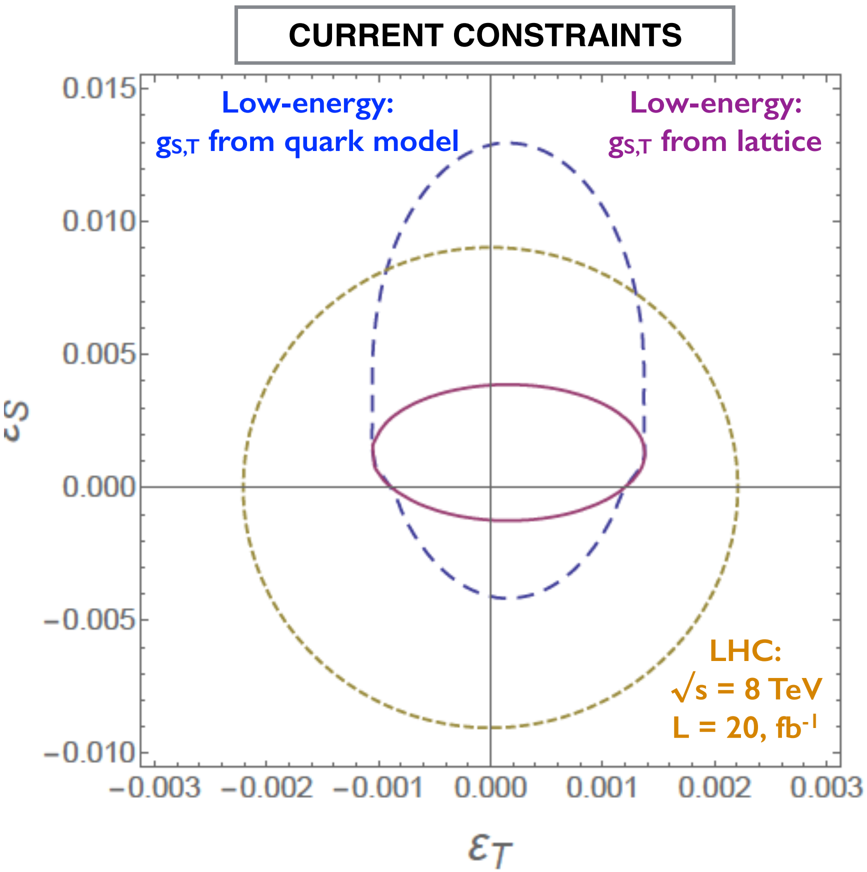
Constraints on [ε_S ,ε_T]: β-decay versus LHC

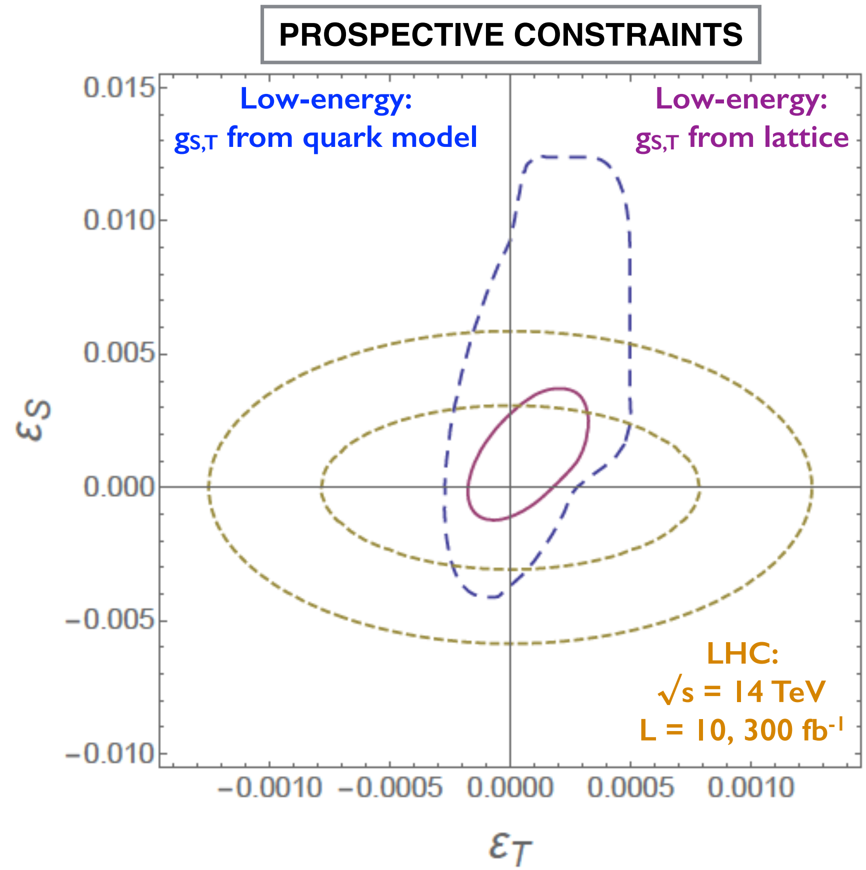
- LHC: (u+d → e+ν) look for events with an electron and missing energy at high transverse mass

- low-energy experiments + lattice with $\delta g_S/g_S$ ~10%



LHC





2018 Analysis

PhysRevD.98.034503

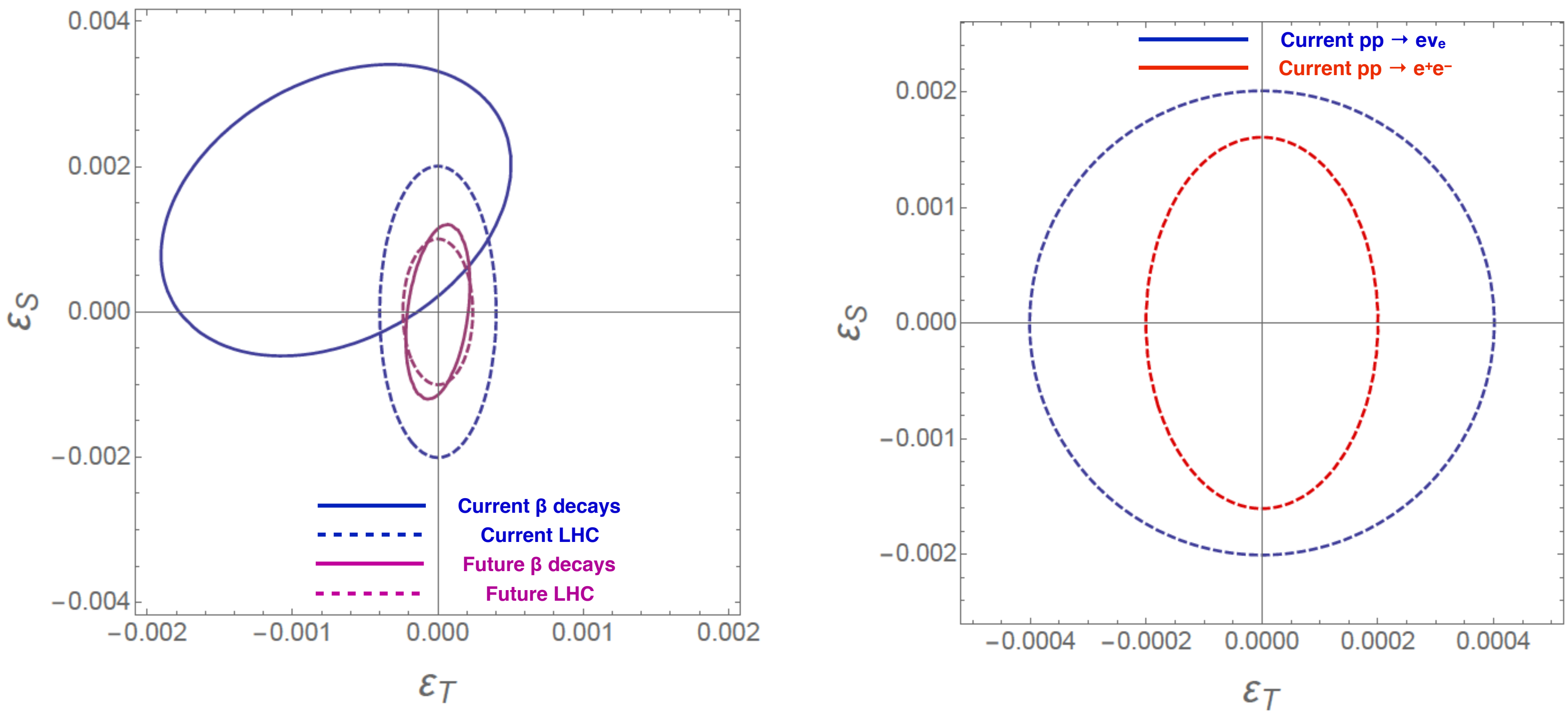
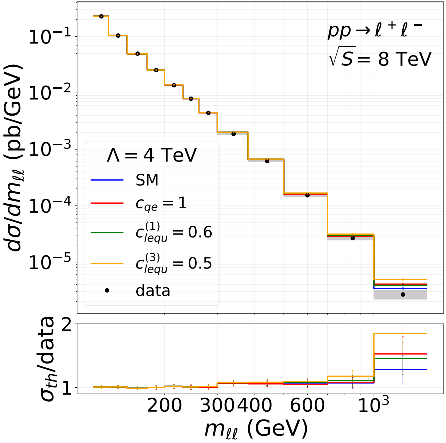


FIG. 8. Current and projected 90% C.L. constraints on ϵ_S and ϵ_T defined at 2 GeV in the $\overline{MS}$ scheme. (Left) The beta-decay constraints are obtained from the recent review article Ref. [80]. The current and future LHC bounds are obtained from the analysis of the $pp \to e + MET + X$. We have used the ATLAS results [81], at $\sqrt{s} = 13$ TeV and integrated luminosity of 36 fb^{-1}. We find that the strongest bound comes from the cumulative distribution with a cut on the transverse mass at 2 TeV. The projected future LHC bounds are obtained by assuming that no events are observed at transverse mass greater than 3 TeV with an integrated luminosity of 300 fb^{-1}. (Right) Comparison of current LHC bounds from $pp \to e + MET + X$ versus $pp \to e^+e^- + X$.

Scalar and tensor interactions at colliders



$$\epsilon_T = \frac{v^2}{\Lambda^2} c^{(3)}_{lequ} \sim 10^{-3}$$

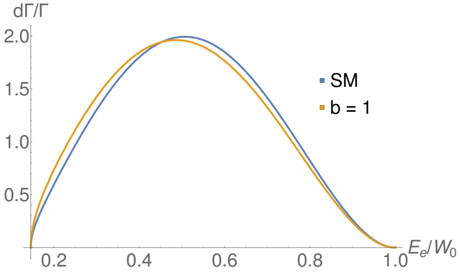
reach few $\times 10^{-4}$ @13 TeV
$< 10^{-4}$ @ HL-LHC

- large contributions from scalar/tensor interactions at large $m_{\ell^+\ell^-}$
- but no interference with SM

$$\sigma = \sigma_{\rm SM} + \frac{1}{\Lambda^4}\left| a_S c^{(1))}_{lequ} + a_T c^{(3)}_{lequ} \right|^2$$

- need to include dim8 SMEFT operators

Scalar and tensor interactions in light nuclei

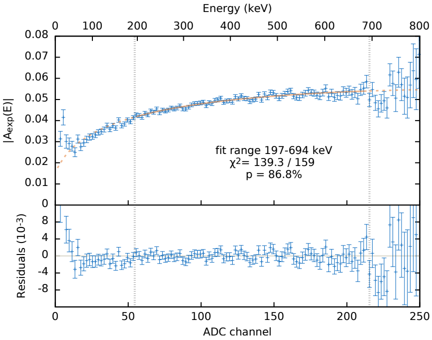


$b \propto \epsilon_T, \epsilon_P$

$$\frac{d\Gamma}{d\varepsilon} = f(W_0)\sqrt{1-\frac{\mu_e^2}{\varepsilon^2}}\,\varepsilon^2(1-\varepsilon)^2\mathcal{M}_{GT}^2\left\{1 + b\frac{m_e}{E_e} + \frac{2}{3}\frac{W_0}{m_N}\left(1-2\varepsilon-\frac{\mu_e^2}{\varepsilon}\right)\mathcal{M}_M + \dots\right\}$$

- Fierz interference term b in the β spectrum induced by S/T interactions
- need control over SM background at the 10^{-4} level
- almost complete *ab initio* calculations of β spectrum of ^{6}He in chiral EFT
- radiative corrections?

Neutron decay experiments



$$b(1+3g_A^2) = g_S\epsilon_S + 3g_Ag_T\epsilon_T$$

$$-0.018 < b < 0.052$$

H. Saul *et al.*, '19
PERKEO III

- first % level bounds on the neutron Fierz interference term via β asymmetry

PERKEO III, UCNA

$$A_{\rm exp}(E_e) = \frac{N^\uparrow(E_e) - N^\downarrow(E_e)}{N^\uparrow(E_e) + N^\downarrow(E_e)} = \frac{v(E_e)A(\lambda)P_nM}{2c\left(1 + b\frac{m_e}{E_e}\right)},$$

- Nab experiment @ Oak Ridge aims at $\delta b \sim 10^{-3}$, with measurement of decay spectrum of unpolarized neutrons