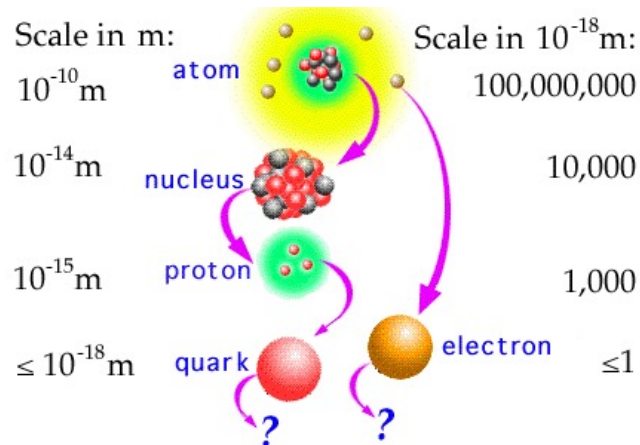


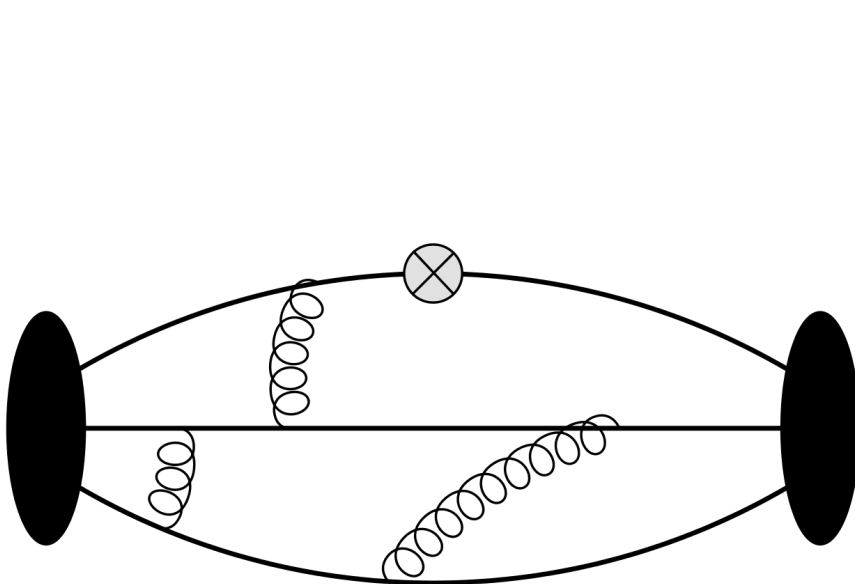
Probing novel scalar and tensor interactions at the TeV scale

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Huey-Wen Lin, Emanuele Mereghetti, Santanu Mondal,
Sungwoo Park, Saori Pastore, Frank Petriello,
Boram Yoon, Albert Young

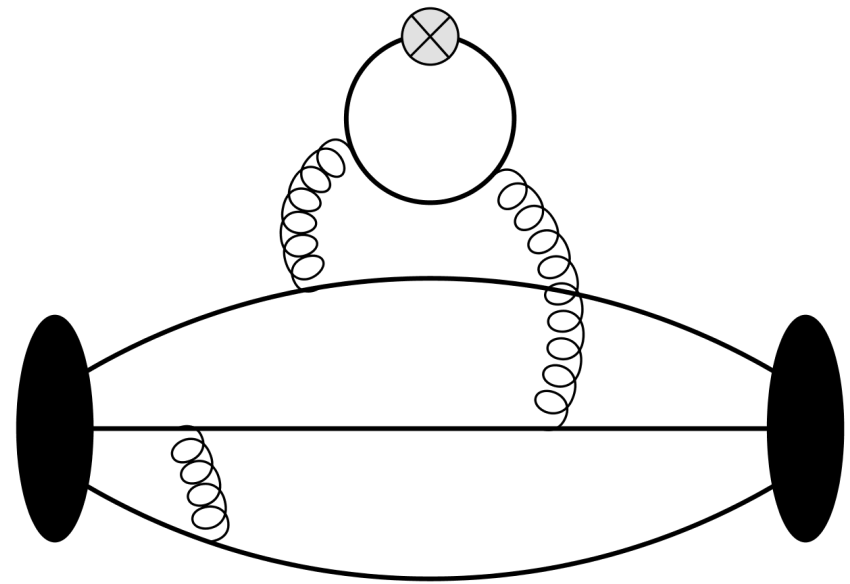


High precision estimates of the matrix elements of quark bilinear operators within the nucleon state, obtained from “connected” and “disconnected” 3-point correlation functions, address a number of important physics questions

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



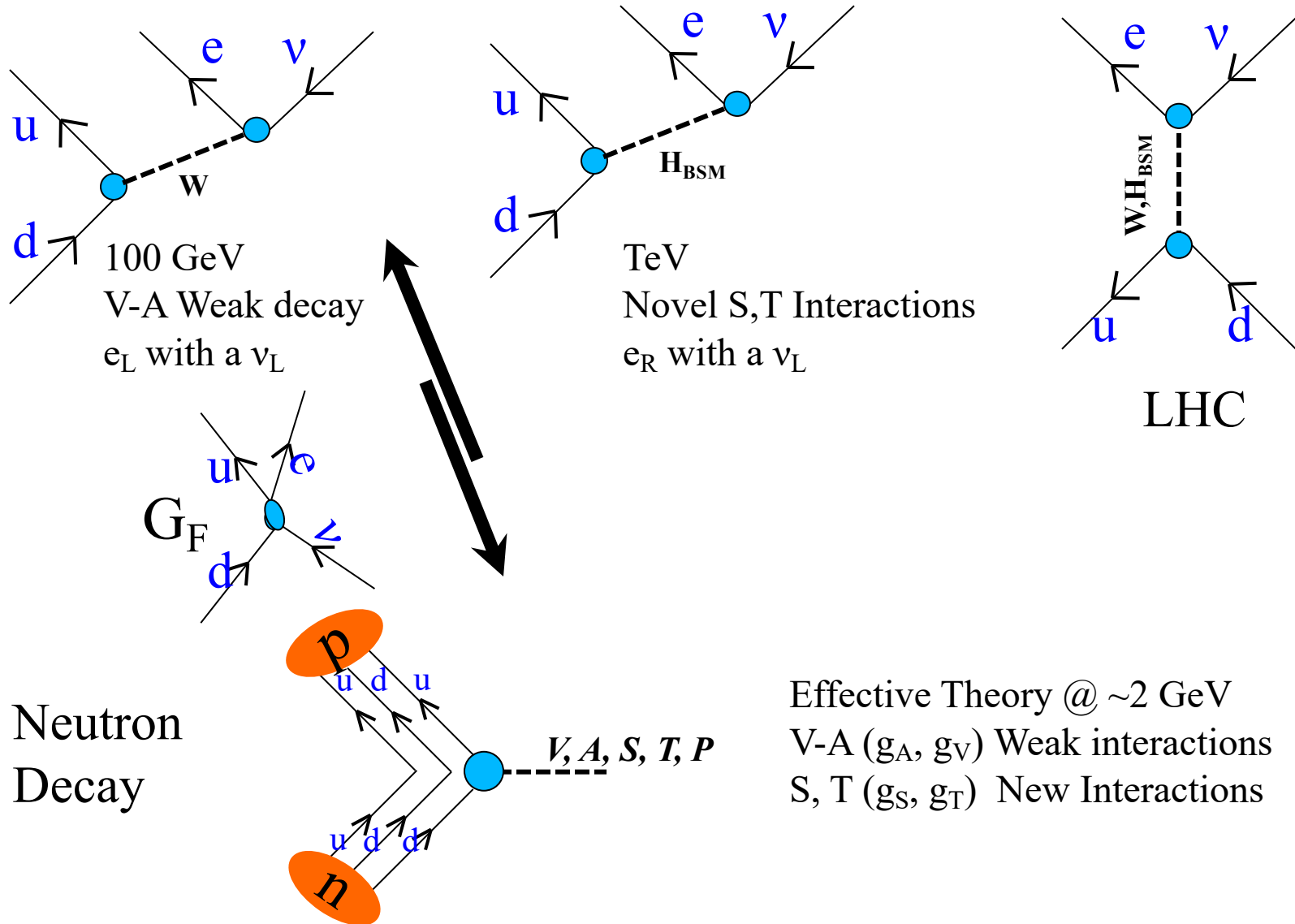
Connected



Disconnected

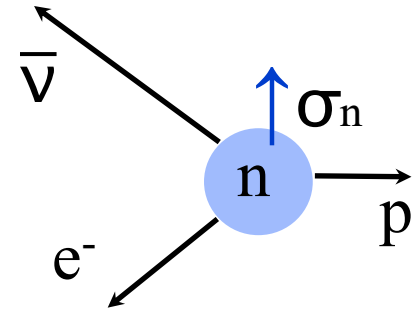
Probing New Interactions: $M_{\text{BSM}} \gg M_W \gg 1 \text{ GeV}$

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



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

Neutron decay can be parameterized as



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

- b***: Deviations from the leading order electron spectrum:
Fierz interference term
- B₁***: Energy dependent part of correlation of antineutrino
momentum with the neutron spin

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

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

$$g_S = Z_S \langle p | \bar{u}d | n \rangle \quad g_T = Z_T \langle p | \bar{u}\sigma_{\mu\nu}d | n \rangle \quad \boxed{\text{Lattice QCD}}$$

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

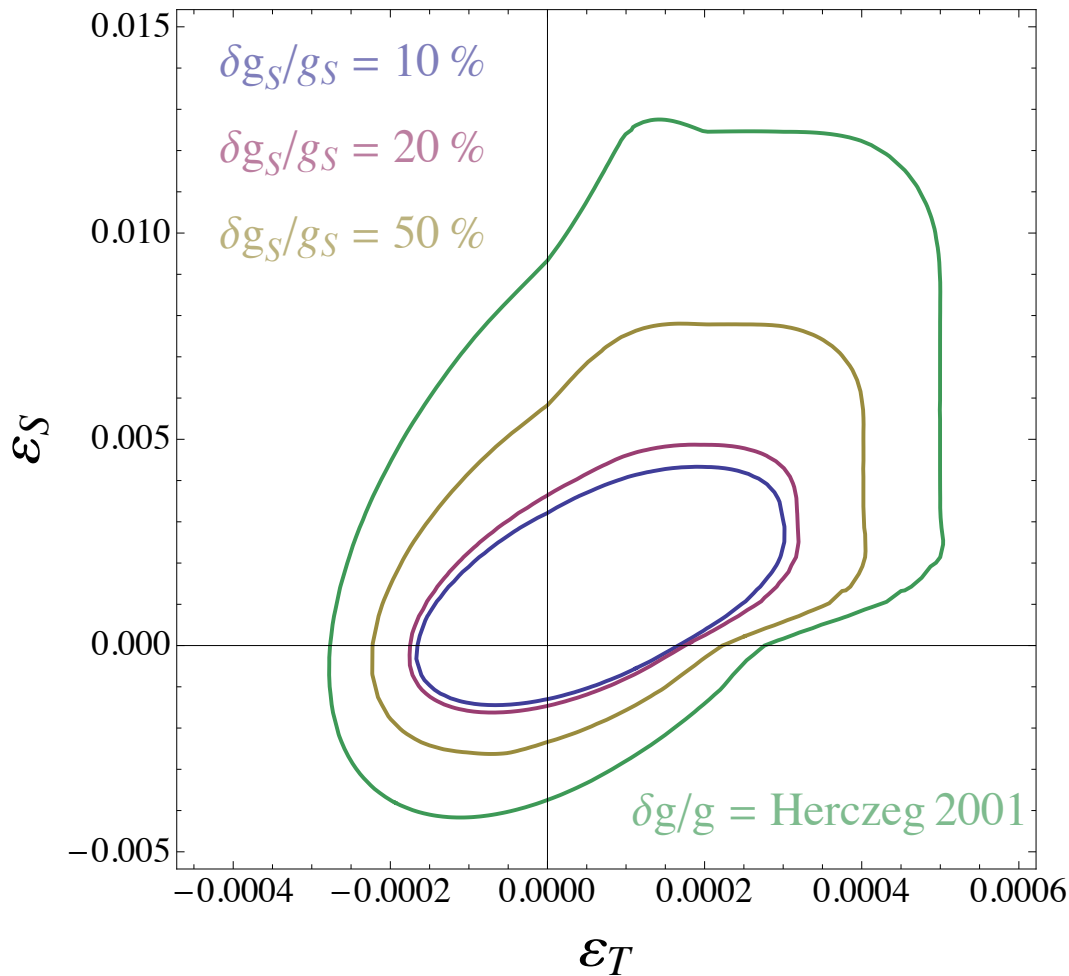
$n \rightarrow p e \bar{\nu}$ decay gives the linear relations

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

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

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

Allowed region in $[\varepsilon_S, \varepsilon_T]$ (90% contours)



Experimental input

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

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

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

Impact limited by precision of ME from Lattice QCD

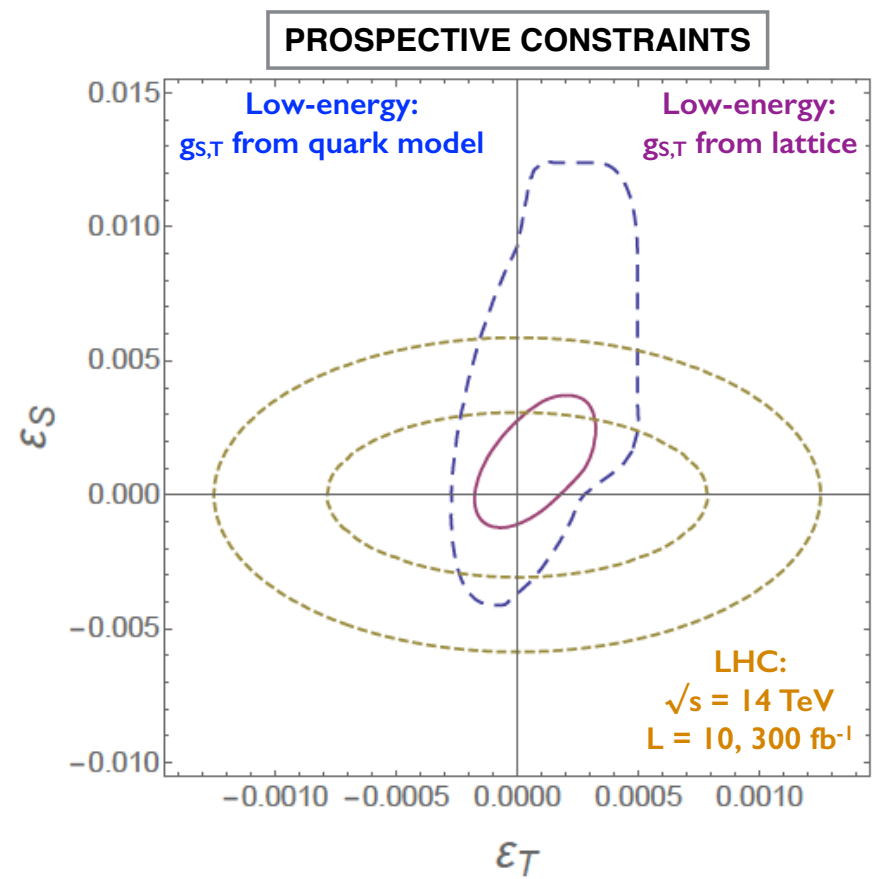
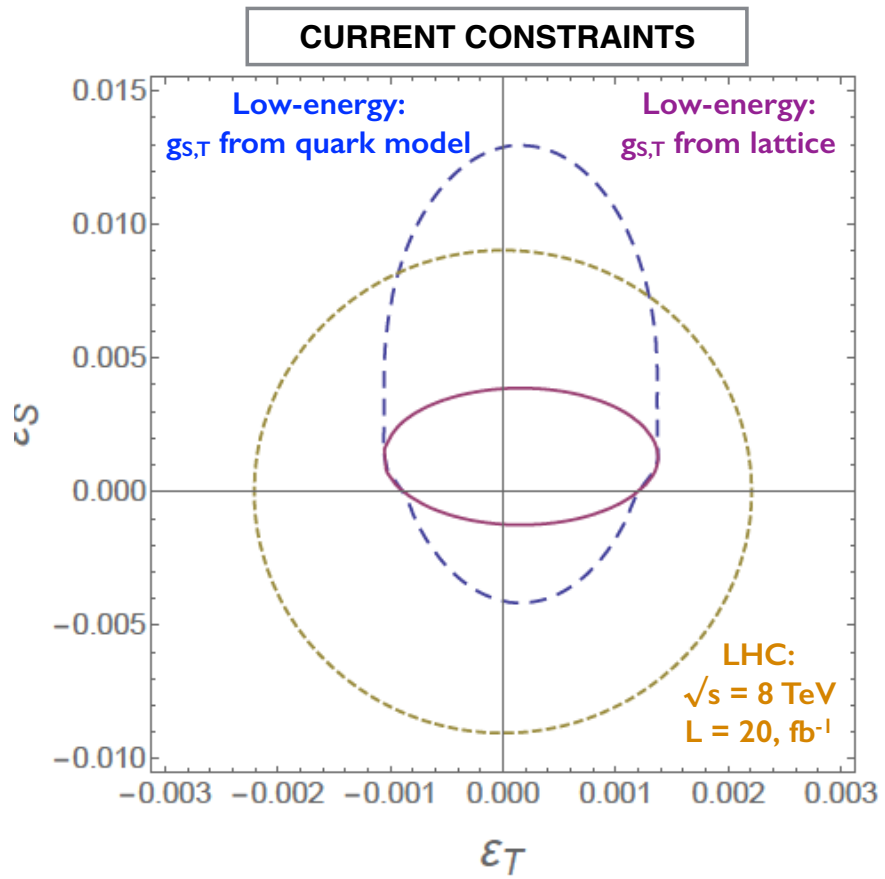
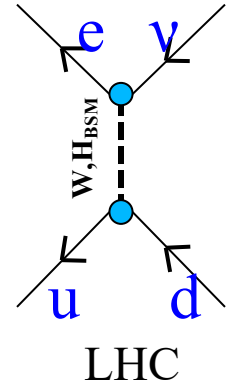
$$g_S = Z_S \langle p | \bar{u} d | n \rangle$$

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

Goal: 10% accuracy in g_S and g_T

Constraints on $[\epsilon_S, \epsilon_T]$: β -decay versus LHC

- LHC: $(u+d \rightarrow e+\nu)$ look for events with an electron and missing energy at high transverse mass
- low-energy experiments + lattice with $\delta g_S/g_S \sim 10\%$



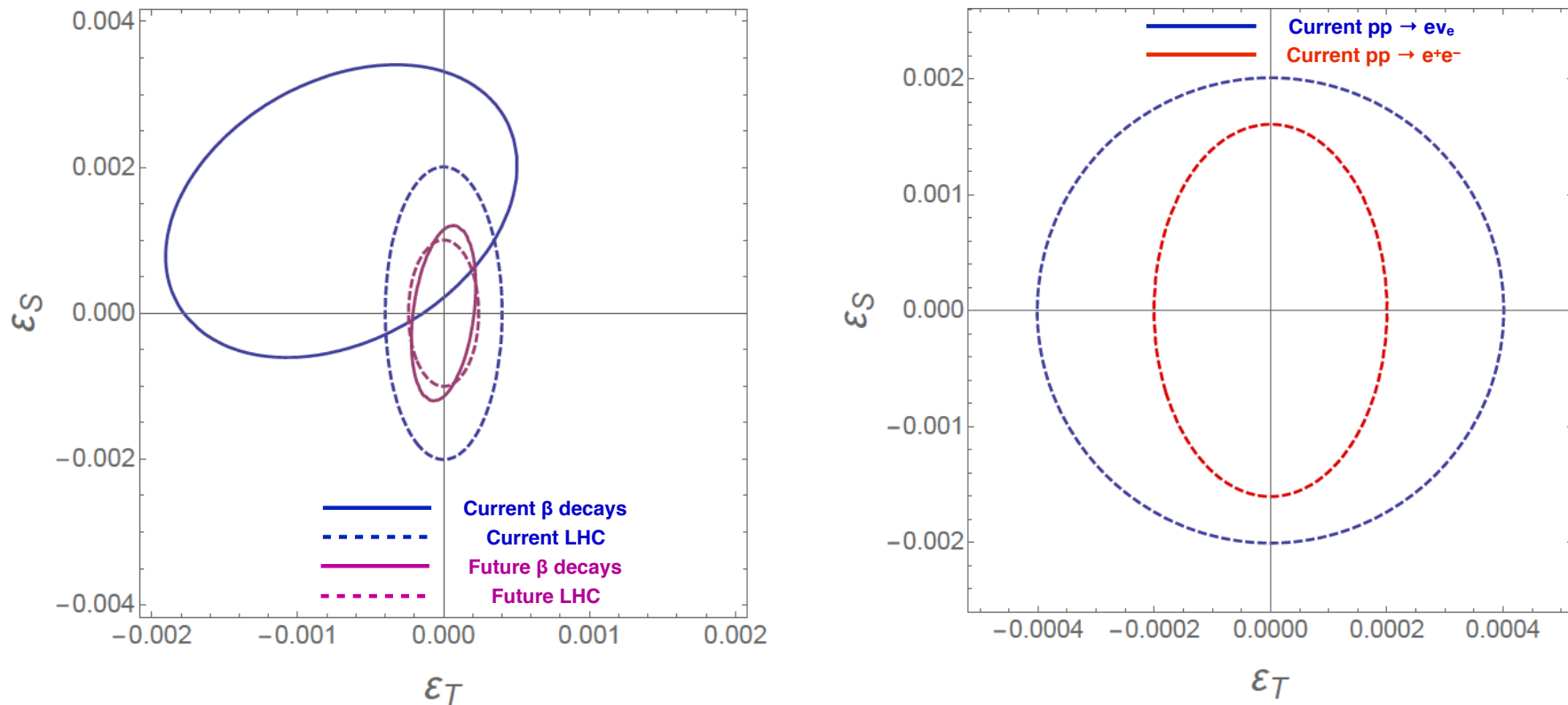
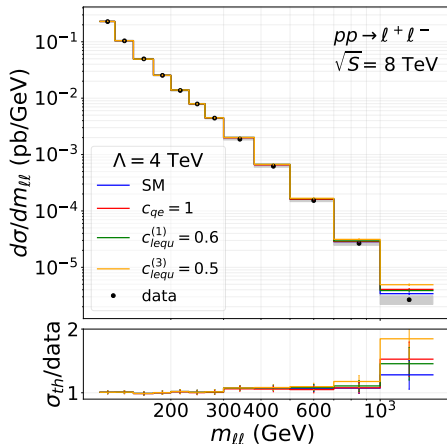


FIG. 8. Current and projected 90% C.L. constraints on ϵ_S and ϵ_T defined at 2 GeV in the \overline{MS} scheme. (Left) The beta-decay constraints are obtained from the recent review article Ref. [80]. The current and future LHC bounds are obtained from the analysis of the $pp \rightarrow e + MET + X$. 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 $pp \rightarrow e + MET + X$ versus $pp \rightarrow e^+e^- + X$.

Scalar and tensor interactions at colliders



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

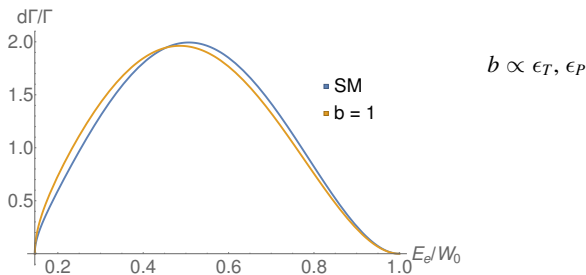
reach few $\times 10^{-4}$ @ 13 TeV
 $< 10^{-4}$ @ HL-LHC

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

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

- need to include dim8 SMEFT operators

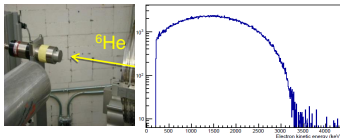
Scalar and tensor interactions in light nuclei



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

- 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 ${}^6\text{He}$ in chiral EFT
- radiative corrections?

High Precision Spectroscopy Experiments to Probe for Exotic Couplings



46 MeV/nucleon
after degrader

(Naviliat group)

Implantation into scintillators at NSCL

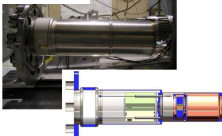
First Prototype Silicon Detector



Nab and UCNB



1" x 6" x 1/8" Silicon Detector



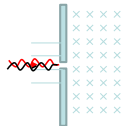
Si detector spectroscopy
In magnetic spectrometers

+
Energy dependence
of $\tilde{a}_{\beta\nu}$ for pure Fermi
decays (TAMU)

R×B
spectrometer

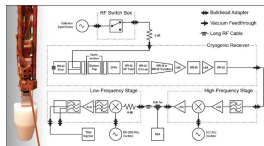


Magnetic
spectrometer



Magnetic spectroscopy at PERC

Cyclotron Resonance Spectroscopy on
 ${}^6\text{He}$ at UW (Garcia)



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