Probing scalar and tensor interactions at the TeV scale

Emanuele Mereghetti

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Los Alamos
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Snowmass2021 - Letter of Interest
Probing Scalar and Tensor Interactions at the TeV Scale

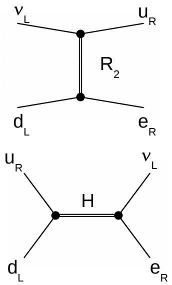
Topical Groups:

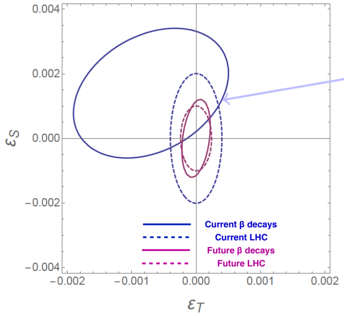
- ■ (EF04) EW Physics: EW Precision Physics and constraining new physics
- ■ (EF05) QCD and strong interactions:Precision QCD
- ■ (EF09) BSM: More general explorations
- ■ (EF10) BSM: Dark Matter at colliders
- ■ (RF02) BSM: Weak decays of strange and light quarks
- ■ (RF03) Fundamental Physics in Small Experiments
- ■ (TF02) Effective field theory techniques
- ■ (TF05) Lattice gauge theory
- ■ (TF06) Theory techniques for precision physics
- ■ (CompF2) Theoretical Calculations and Simulation

Contact Information:
Rajan Gupta (Los Alamos National Laboratory) [rajan@lanl.gov]:
Emanuele Mereghetti (Los Alamos National Laboratory) [emereghetti@lanl.gov]
Collaboration: Precision Neutron Decay Matrix Elements (PNDME) and Nucleon Matrix Elements (NME)

Authors:
Simone Alioli (Universita' degli Studi di Milano-Bicocca) [simone.alioli@unimib.it]
Tanmoy Bhattacharya (Los Alamos National Laboratory) [tanmoy@lanl.gov]
Radja Boughezal (Argonne National Laboratory) [rboughezal@anl.gov]
Vincenzo Cirigliano (Los Alamos National Laboratory) [cirigliano@lanl.gov]
Rajan Gupta (Los Alamos National Laboratory) [rajan@lanl.gov]
Yong-Chull Jang (Brookhaven National Laboratory) [ypj@bnl.gov]
Huey-Wen Lin (Michigan State University) [hwlin@pa.msu.edu]
Emanuele Mereghetti (Los Alamos National Laboratory) [emereghetti@lanl.gov]
Santanu Mondal (Los Alamos National Laboratory) [santanu@lanl.gov]
Sungwoo Park (Los Alamos National Laboratory) [sungwoo@lanl.gov]
Saori Pastore (Washington University, St. Louis) [saori@wustl.edu]
Frank Petriello (Northwestern University) [f-petriello@northwestern.edu]
Boram Yoon (Los Alamos National Laboratory) [boram@lanl.gov]
Albert Young (North Carolina State University) [aryoung@ncsu.edu]

link to LOI





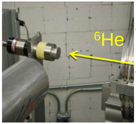
$\Lambda \sim 5$ TeV

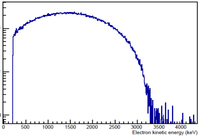
$$\mathcal{L}_{\rm CC} = -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}} \left[\epsilon_S \, \bar{e}(1-\gamma_5)\nu_\ell \cdot \bar{u}d + \epsilon_T \, \bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu}(1-\gamma_5)d \right] .$$

- no charged-current scalar or tensor interactions in SM
- … but they arise in several BSM models (leptoquarks, charged Higgs, …)
- probe scalar and tensor interactions up to $\Lambda \gtrsim 10$ TeV

collider, neutron and nuclear β decays
& improvement in lattice QCD and nuclear theory

High Precision Spectroscopy Experiments to Probe for Exotic Couplings



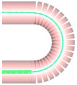


46 MeV/nucleon
after degrader

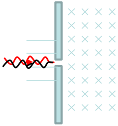
(Naviliat group)

Implantation into scintillators at NSCL

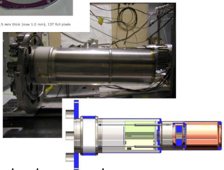
R×B
spectrometer



Magnetic
spectrometer



Magnetic spectroscopy at PERC

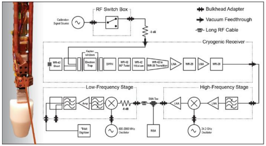


Nab and UCNB

Si detector spectroscopy
In magnetic spectrometers

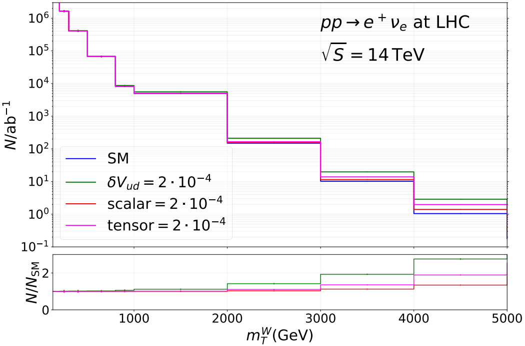
+
Energy dependence of $\tilde{a}_{\beta\nu}$ for pure Fermi decays (TAMU)

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



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

Scalar and tensor interactions at colliders

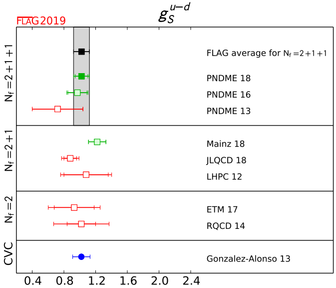


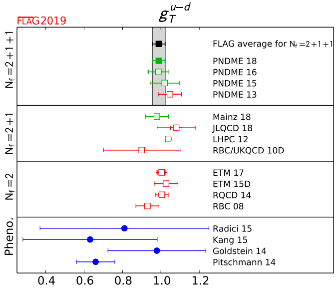
- high-luminosity LHC will reach $\epsilon_{S,T} \sim 10^{-4}$, $\Lambda \sim 20$ TeV
- angular distributions provide smoking-gun observables

$$\frac{d\sigma}{dm^2 dy d\Omega} = \frac{d\sigma_{\mathrm{SM}}}{dm^2 dy d\Omega} + |f_S(m,\Omega,y)\epsilon_S + f_T(m,\Omega,y)\epsilon_T|^2$$

need to consistently add dimension-eight operators!

Lattice QCD

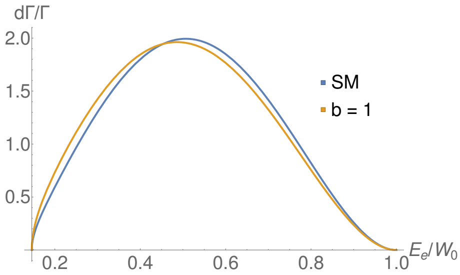




$\langle p|\bar{u}d|n\rangle$ $\langle p|\bar{u}\sigma^{\mu\nu}d|n\rangle$

- interpretation of neutron decay requires hadronization of weak currents
- great LQCD progress in last ten years

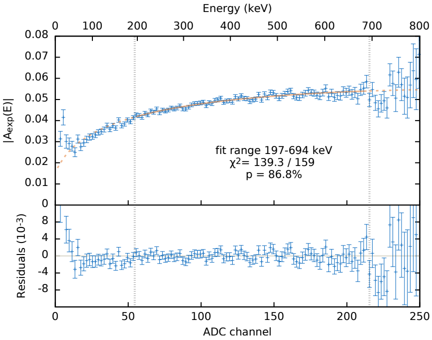
  from order-of-magnitude to $\delta g_T = \mathcal{O}(5\%)$, $\delta g_S = \mathcal{O}(10\%)$
- reduce by a factor of 2 in 2-3 years, $< 1\%$ in next ten years



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

- Fierce interference term b in the β spectrum induced by S/T interactions
- need control over SM background at the 10^{-4} level
- first *ab initio* calculations of recoil corrections to β spectrum of ^{6}He

Neutron decay experiments



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

$$-0.018 < b < 0.052$$

H. Saul *et al.*, '19

PERKEO III

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

PERKEO III, UCNA

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

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