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Searching for new physics in coherent neutrino scattering

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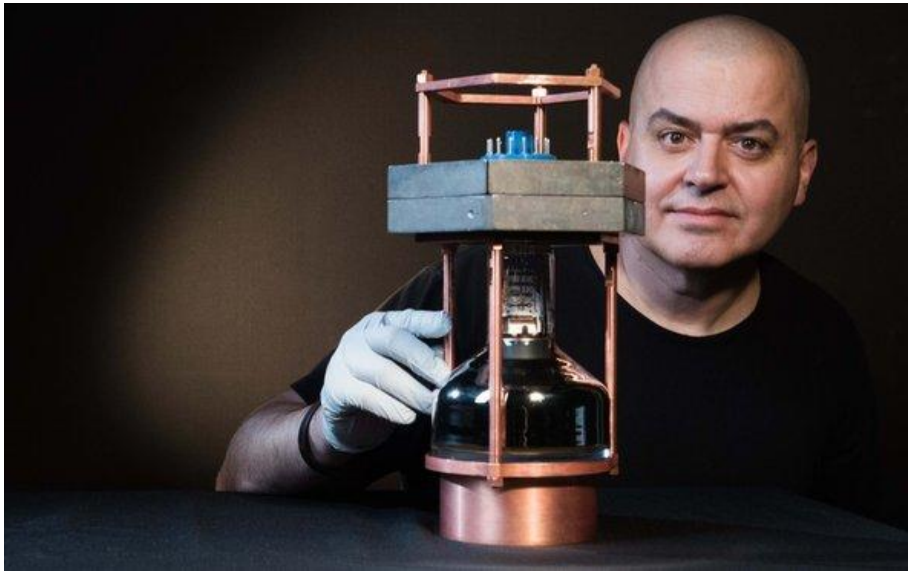
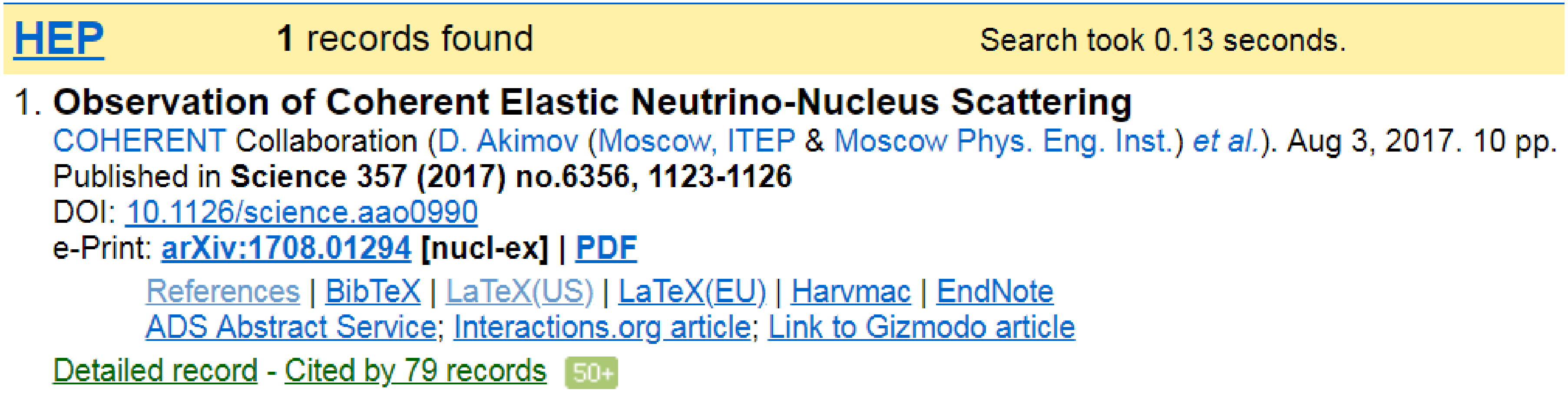
Talk at *Flavour and Dark Matter 2018*.





HEP **1** records found Search took 0.13 seconds.

1. **Observation of Coherent Elastic Neutrino-Nucleus Scattering**
COHERENT Collaboration (D. Akimov (Moscow, ITEP & Moscow Phys. Eng. Inst.) *et al.*). Aug 3, 2017. 10 pp.
Published in **Science 357 (2017) no.6356, 1123-1126**
DOI: 10.1126/science.aao0990
e-Print: **arXiv:1708.01294 [nucl-ex]** | **PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Interactions.org article; Link to Gizmodo article
Detailed record - Cited by 79 records 50+

My talk: an overview of new phy@coherent

Outline

- Introduction to (coherent) neutrino scattering
  - elastic/inelastic, coherent/non-coherent
- New physics
  - NSI (Non-Standard Interaction)
  - SPVAT $(1, \gamma^5, \gamma^\mu, \gamma^\mu\gamma^5, \sigma^{\mu\nu})$
  - Sterile neutrinos
  - light mediators
  - Neutrino magnetic moments
  - Dark matter
- Summary

Neutrino scattering

Elastic

$$\nu + X \to \nu + X$$

e.g. $X = e^-$, $^{76}\mathrm{Ge}$. Only recoil observable. CHARM II, TEXONO, COHERENT

Quasi-elastic

$$\nu + X \to \ell + Y$$

e.g. $\overline{\nu}_e + p \to e^+ + n$ (IBD, Daya Bay, RENO), $\nu_\mu +^{18}\mathrm{O} \to \mu^- +^{18}\mathrm{F}$ (CCQE, T2K)

Deep inelastic

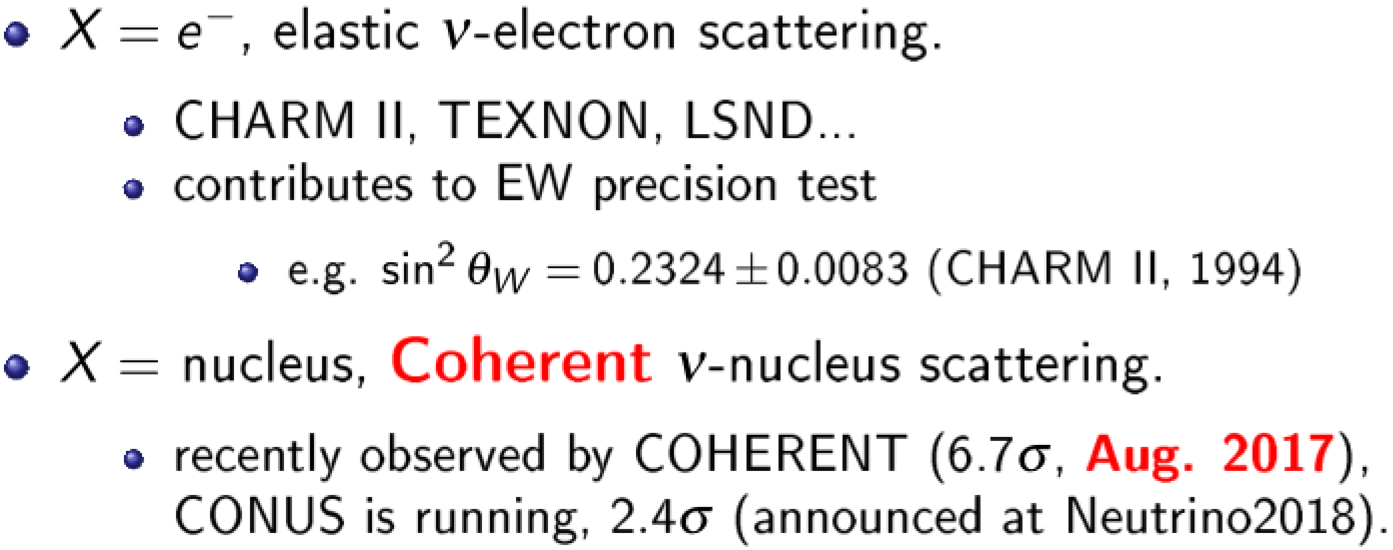
$$\nu + X \to \cdots (\text{dirty final states!!})$$

e.g. IceCube. using μ track to identify ν_μ.

Elastic Neutrino Scattering

- Not so well measured as the other types

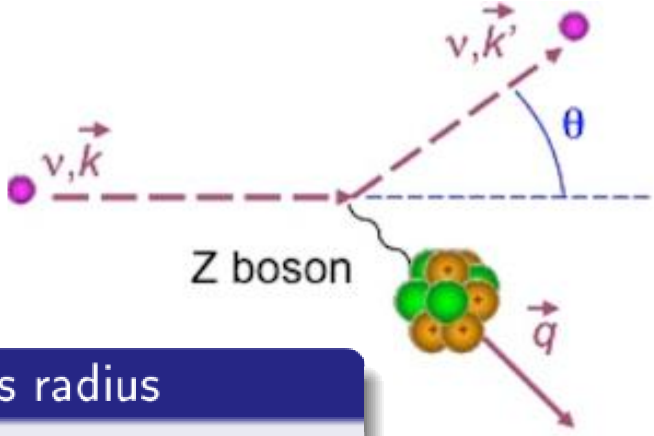
- Advantage: precision measurement of SM interactions



- $X = e^-$, elastic ν-electron scattering.
  - CHARM II, TEXNON, LSND...
  - contributes to EW precision test
    - e.g. $\sin^2\theta_W = 0.2324 \pm 0.0083$ (CHARM II, 1994)
- $X =$ nucleus, **Coherent** ν-nucleus scattering.
  - recently observed by COHERENT (6.7σ, **Aug. 2017**), CONUS is running, 2.4σ (announced at Neutrino2018).

Coherent Elastic Neutrino-Nucleus Scattering

What is "Coherent"?



Without Coherency: neutrino wavelength $\ll$ nucleus radius

Sum over cross sections

$$\sigma_{\text{tot}} = \sigma_p + \sigma_p + \cdots + \sigma_n + \sigma_n + \cdots$$

With Coherency: neutrino wavelength $\gg$ nucleus radius

Sum over amplitude, then square

$$i\mathscr{M} = i\mathscr{M}_p + i\mathscr{M}_p + \cdots + i\mathscr{M}_n + i\mathscr{M}_n + \cdots$$

$$\sigma_{\text{tot}} = |i\mathscr{M}_p + i\mathscr{M}_p + \cdots + i\mathscr{M}_n + i\mathscr{M}_n + \cdots|^2$$

Macroscopic coherence also possible, see E. Akhmedov et al, 1806.10962

Cross section

$$\frac{d\sigma}{dT} = \frac{G_F^2 \left[N - (1-4s_W^2)Z\right]^2 M_{\mathrm{nucleus}}}{4\pi} \left(1 - \frac{T}{T_{\max}}\right)$$

T: recoil energy, $N\&Z$: neutron&proton numbers

$$T_{\max}(E_\nu) = \frac{2E_\nu^2}{M + 2E_\nu}\,.$$

- Large cross section for large N
  - because $1 - 4s_W^2 \approx 0$, $\frac{d\sigma}{dT} \propto N^3$.
- Although large, difficult to detect, T too low,
  - $T_{\max}$ determined by kinetics, 1 MeV neutrino $\Rightarrow$ $T_{\max} \approx 0.1$ keV
- Modern tech: ultra-low threshold detection
  - thanks to dark matter experiments

Coherency requires $E_\nu < 50$ MeV.
Two suitable neutrino sources:

SNS

pros: higher E_ν & T, larger σ, $T_{\rm thre} = \mathcal{O}(10)$ keV enough.

cons: lower ν flux, future reducing $T_{\rm thre}$ cannot help.

Reactor neutrino

pros: intensive ν flux, high statistics if 0.1 keV achieved

cons: needs very low $T_{\rm thre}$, quenching factor unknown.

Example:

100 kg Ge

Threshold: 0.1 keV

1GW nuclear reactor

Distance: 10m

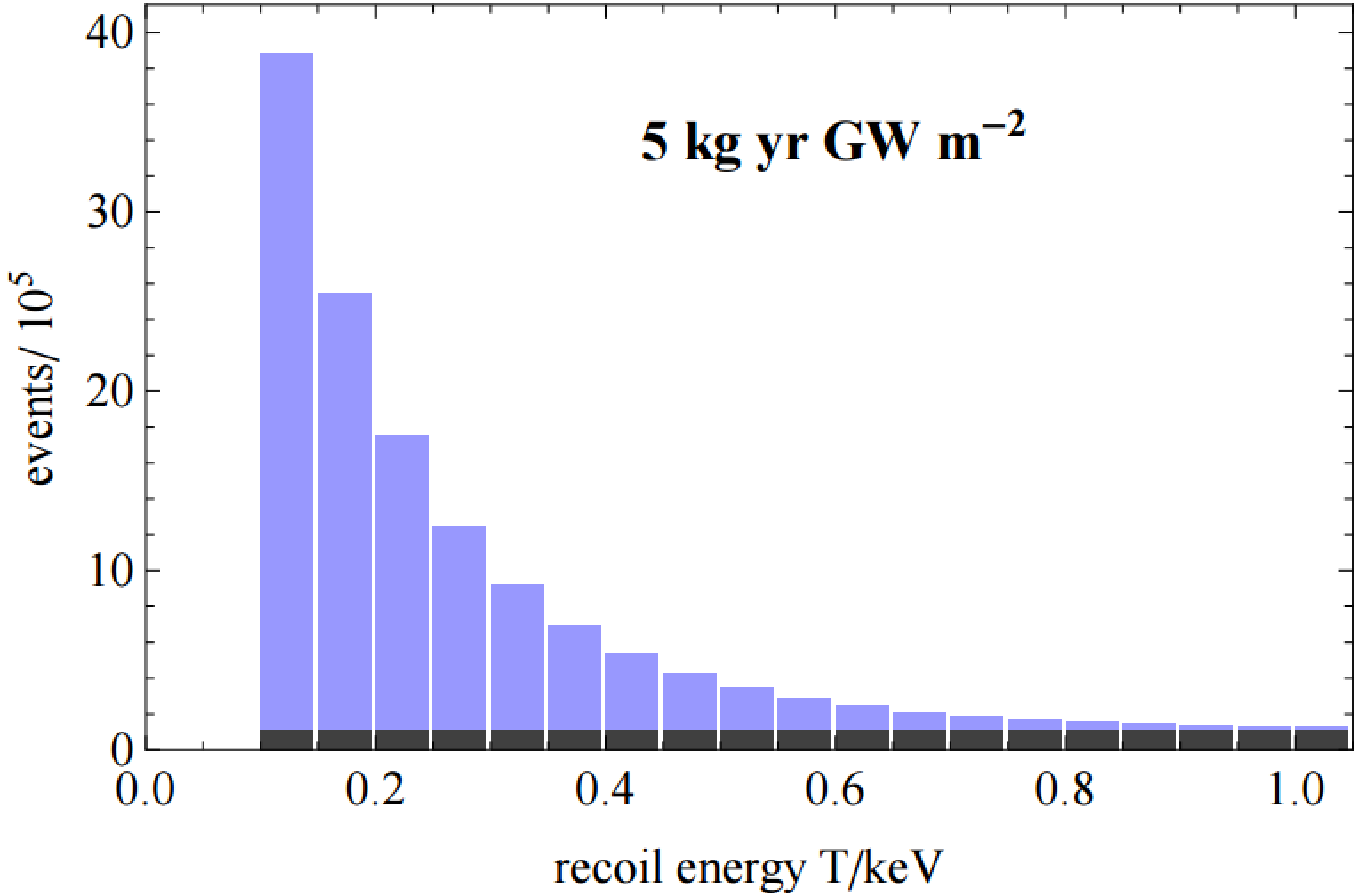
⇨

Event number:

$7.6 \times 10^6/\text{yr}$

Distribution

7.6×10^6 in total!



Event number:

$7.6 \times 10^6/\mathrm{yr}$

1. Small, portable detector

2. Precise measurement of neutrino interactions and EW parameters

$$\text{E.g. } \sin^2\theta_W = 0.238 \pm 0.0022$$

(Optimistic estimation in 1612.04150)

See also: B.C. Cañas et al 1806.01310

3. Finding new physics

New physics

- NSI
  - 1804.03660, 1711.09773 , 1711.03521, 1708.04255 , 1708.02899, 1612.04150, 1805.01798
- SPVAT
  - 1806.07424, 1711.09773, 1612.04150
- Sterile neutrinos
  - 1703.00054, 1711.09773, 1511.02834
- light mediators (scalar, Z’, dark photon…)
  - 1803.05466, 1803.01224, 1803.00060, 1802.05171, 1711.09773, 1711.04531, 1710.10889, 1612.06350, 1805.01798, 1508.07981,
- Neutrino magnetic moments
  - 1510.01684, 1706.02555, 1711.09773, 1805.01798

NSI (Non-Standard Interaction)

If mediated by a new gauge boson (e.g. Z'), integrated out $\Rightarrow$ NSI

NSI (Non-Standard Interaction)

$$\mathscr{L} \supset \frac{G_F}{\sqrt{2}} \sum_{q=u,d} \overline{\nu}_\alpha \gamma^\mu (1-\gamma^5) \nu_\beta \left[\overline{q} \gamma^\mu (\varepsilon^{qV}_{\alpha\beta} + \varepsilon^{qA}_{\alpha\beta} \gamma^5) q \right],$$

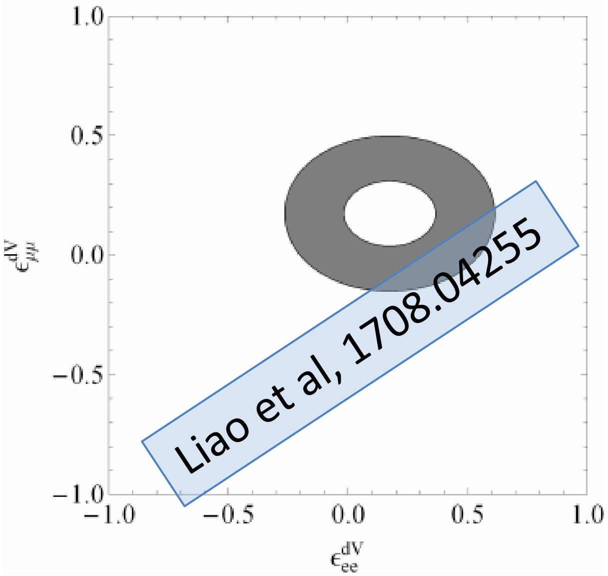
Loop-induced NSI: 1807.08102

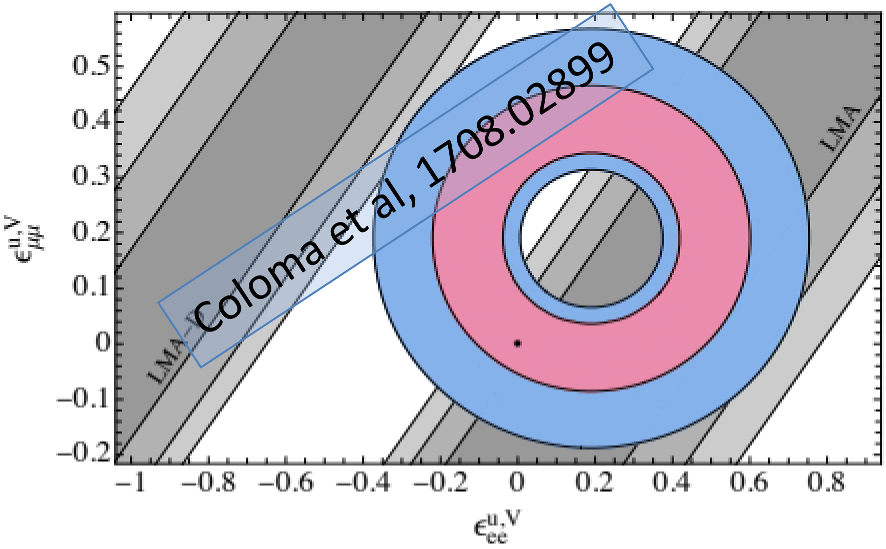
- Lepton Flavor Violation (LFV)
- Still V-A in $\overline{\nu}_\alpha \gamma^\mu (1-\gamma^5) \nu_\beta$, because only left-handed ν
- the only change in $d\sigma/dT$, $Q^2 : Q^2_{\mathrm{SM}} \to Q^2_{\mathrm{NSI}}$

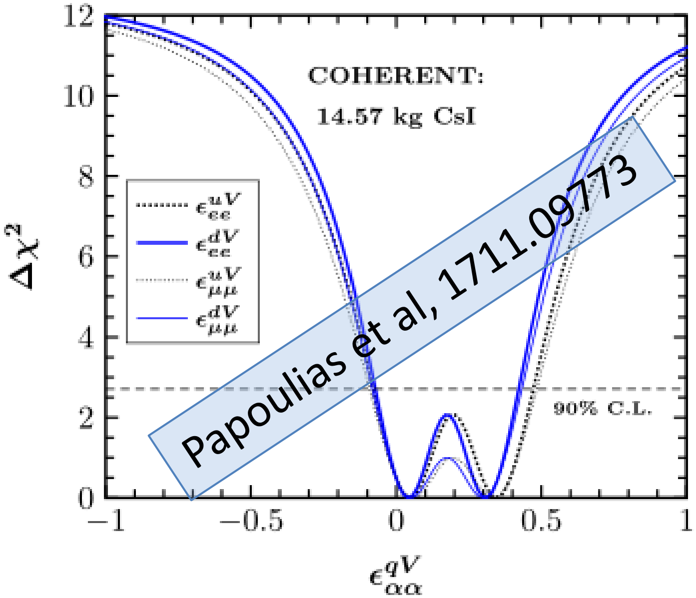
$$\frac{d\sigma}{dT} = \frac{G_F^2 Q^2 M_{\mathrm{nucleus}}}{4\pi} \left(1 - \frac{T}{T_{\mathrm{max}}}\right)$$

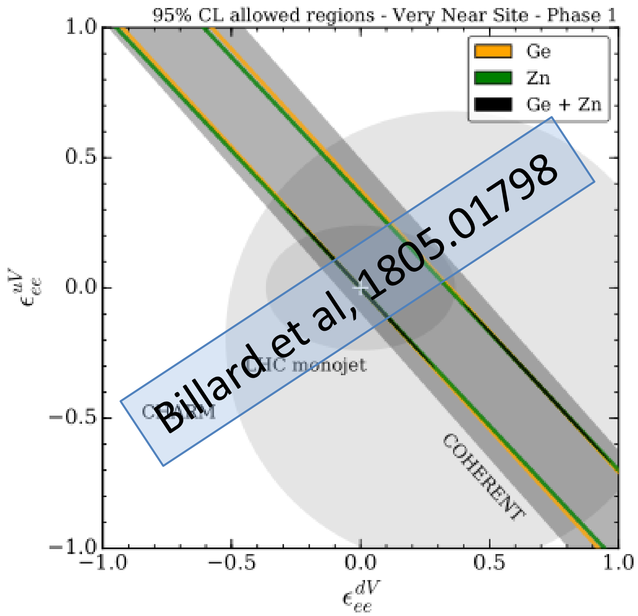
$$Q^2_{\mathrm{NSI}} \equiv 4 \left[N \left(\cdots + \varepsilon^{uV}_{ee} + 2\varepsilon^{dV}_{ee} \right) + Z \left(\cdots + 2\varepsilon^{uV}_{ee} + \varepsilon^{dV}_{ee} \right) \right]^2 + \cdots$$

NSI (Non-Standard Interaction)

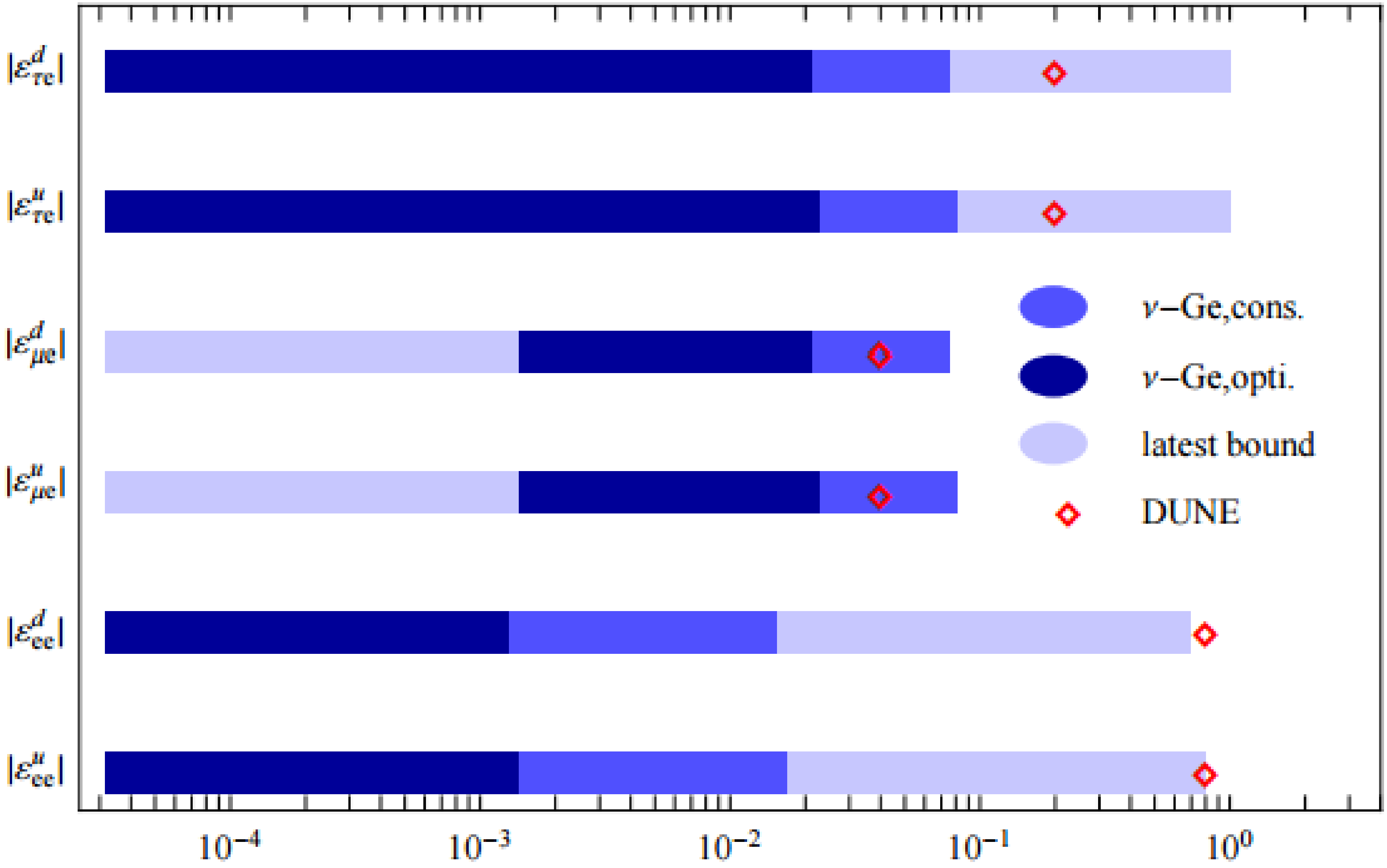

Liao et al, 1708.04255


Coloma et al, 1708.02899


Papoulias et al, 1711.09773


Billard et al, 1805.01798

NSI (Non-Standard Interaction)



From 1612.04150

SPVAT Interaction

If mediated by any kinds of forces, integrated out ⇒ SPVAT

SPVAT (Scalar, Pseudo-S, Vector, Axial-V, Tensor)

$$\mathscr{L} \supset \frac{G_F}{\sqrt{2}} \sum_{a=S,P,V,A,T} \overline{\nu}\Gamma^a \nu \left[\overline{\psi}\Gamma^a (C_a + D_a i\gamma^5)\psi\right],$$

$$\Gamma^a = \{1, i\gamma^5, \gamma^\mu, \gamma^\mu\gamma^5, \sigma^{\mu\nu} \equiv \frac{i}{2}[\gamma^\mu, \gamma^\nu]\}.$$

- Scalar (Pseudo-S) mediator ⇒ 1 ($i\gamma^5$)
- Charged scalar (Pseudo-S) mediator ⇒ 1 ($i\gamma^5$)+$\sigma^{\mu\nu}$
- Vector (Axial-V) mediator ⇒ $\gamma^\mu, \gamma^\mu\gamma^5$
- contains all possible Lorentz-invariant interactions

SPVAT Interaction

SM cross section:

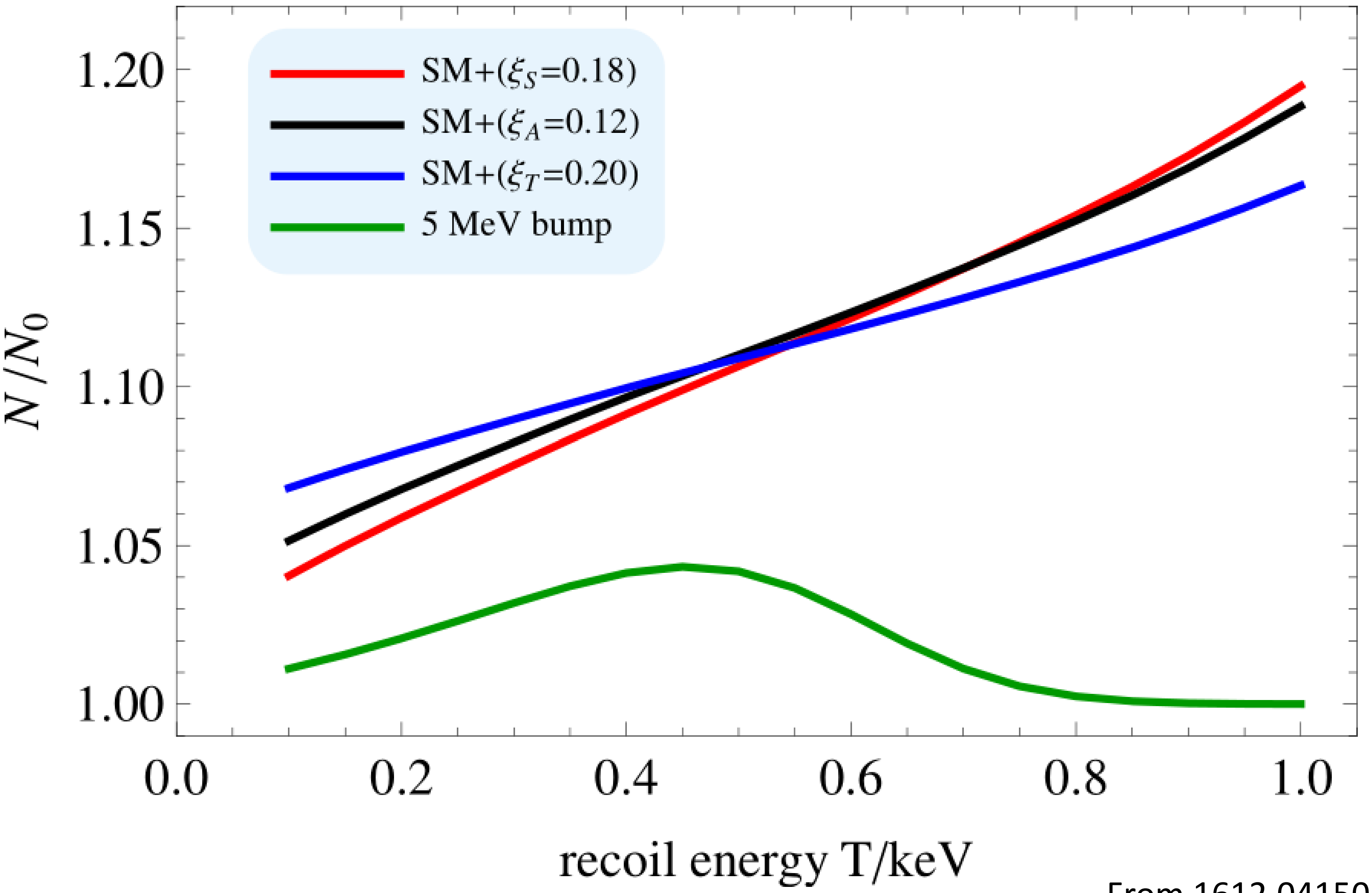
$$\frac{d\sigma}{dT} = \frac{G_F^2 Q^2 M}{4\pi}\left(1 - \frac{T}{T_{\mathrm{max}}}\right)$$

SPVAT cross section:

$$\frac{d\sigma}{dT} = \frac{{G_F}^2 Q^2 M}{4\pi}\left(\boxed{\cdots} \times 1 - \boxed{\cdots} \times \frac{T}{T_{\mathrm{max}}} + \boxed{\cdots} \times \frac{MT}{4E_\nu^2}\right)$$

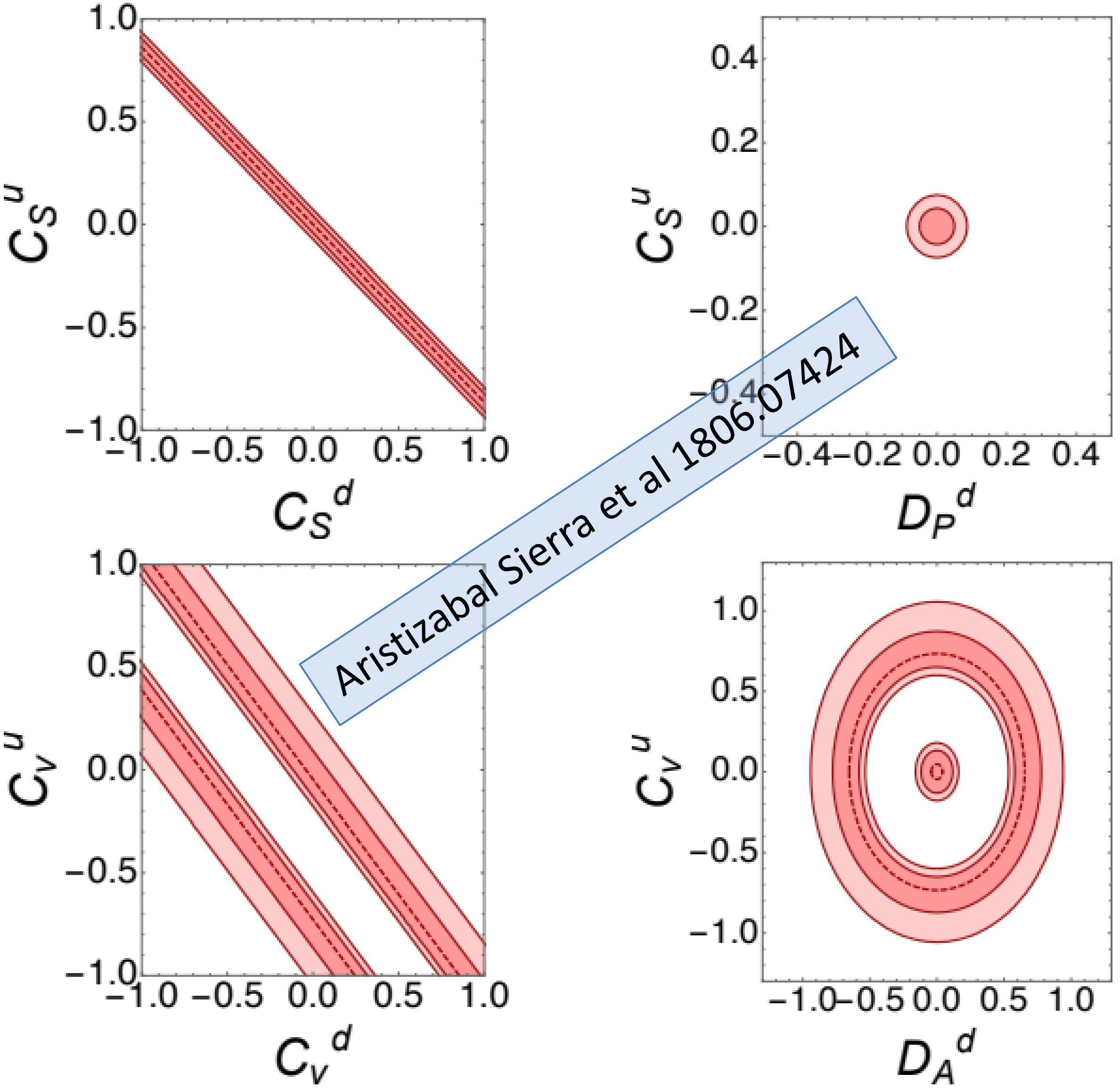
$\Rightarrow$ distortion of the recoil spectrum

SPVAT Interaction



From 1612.04150

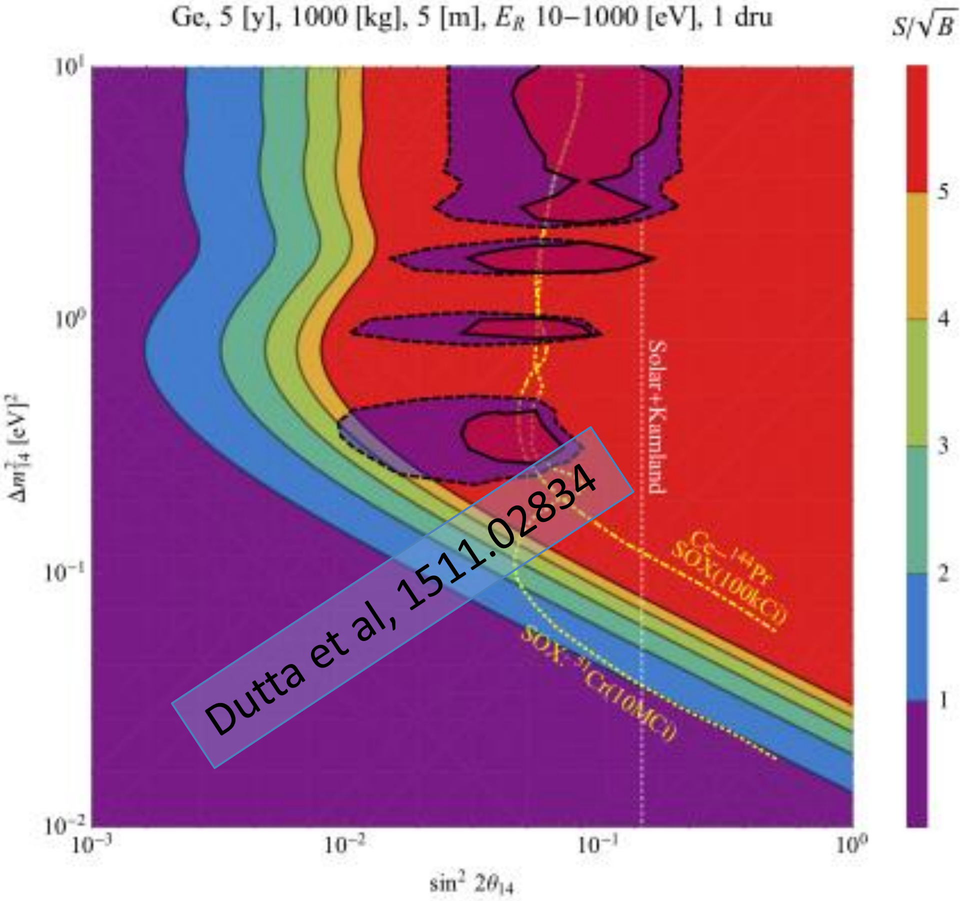
SPVAT Interaction



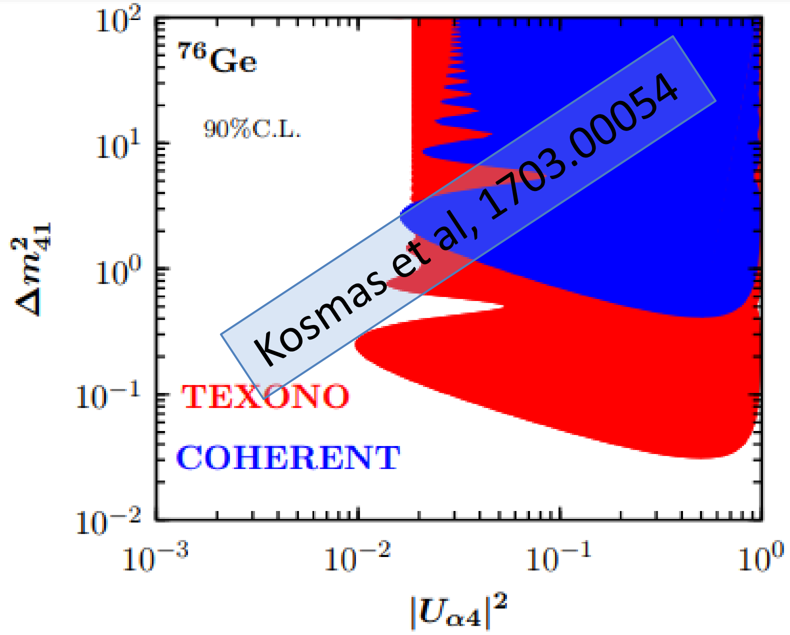
Aristizabal Sierra et al 1806.07424

Sterile neutrinos

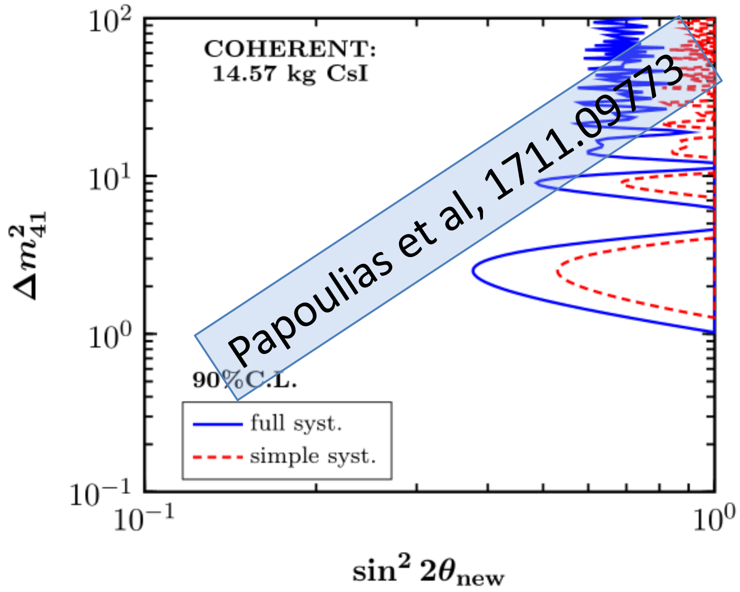
$$P_{ee} = 1 - \sin^2 2\theta_{14} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E_\nu}\right)$$



Dutta et al, 1511.02834

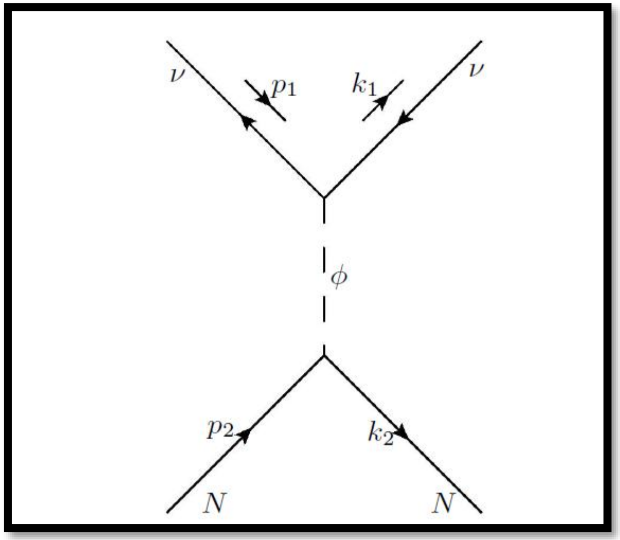


Kosmas et al, 1703.00054



Papoulias et al, 1711.09773

Light mediators (scalar, Z’, dark photon…)



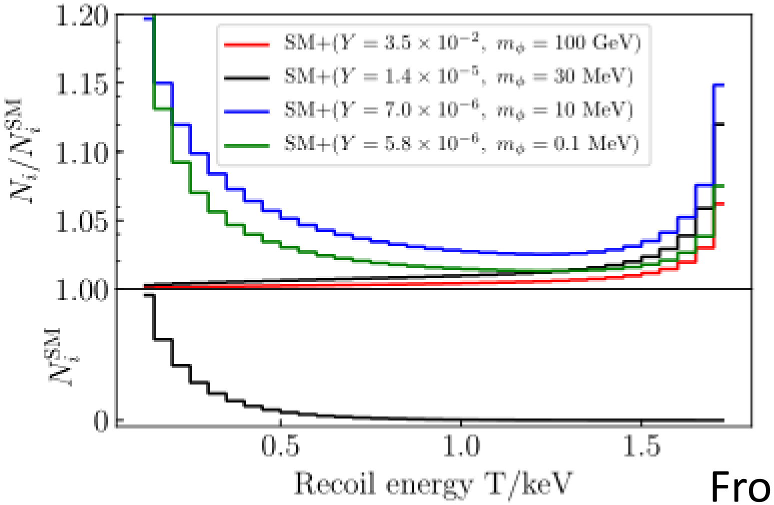
$$\frac{d\sigma_\phi}{dT} = \frac{MY^4}{4\pi\underbrace{(2MT+m_\phi^2)^2}_{\text{(2) Effect of propagator}}}\overbrace{\left[\cdots\frac{MT}{E_\nu^2}+\cdots\right]}^{\text{(1) Depending on scalar/vector}}$$

M: nucleus mass;

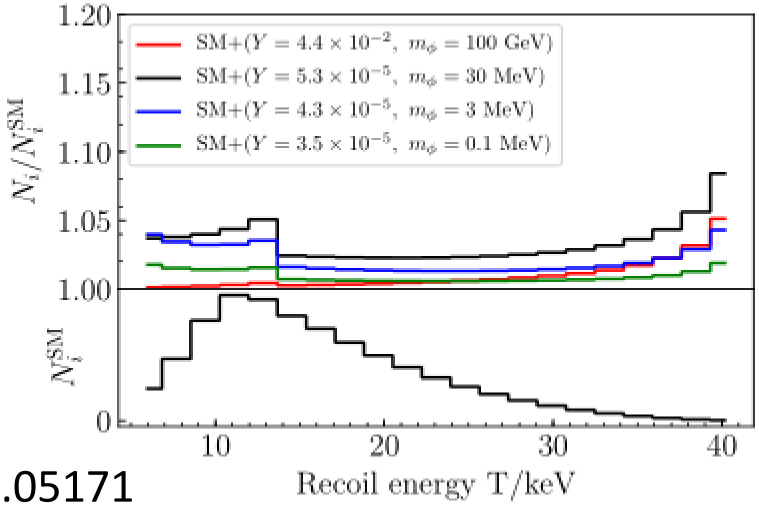
E_ν: neutrino energy;

T: recoil energy.

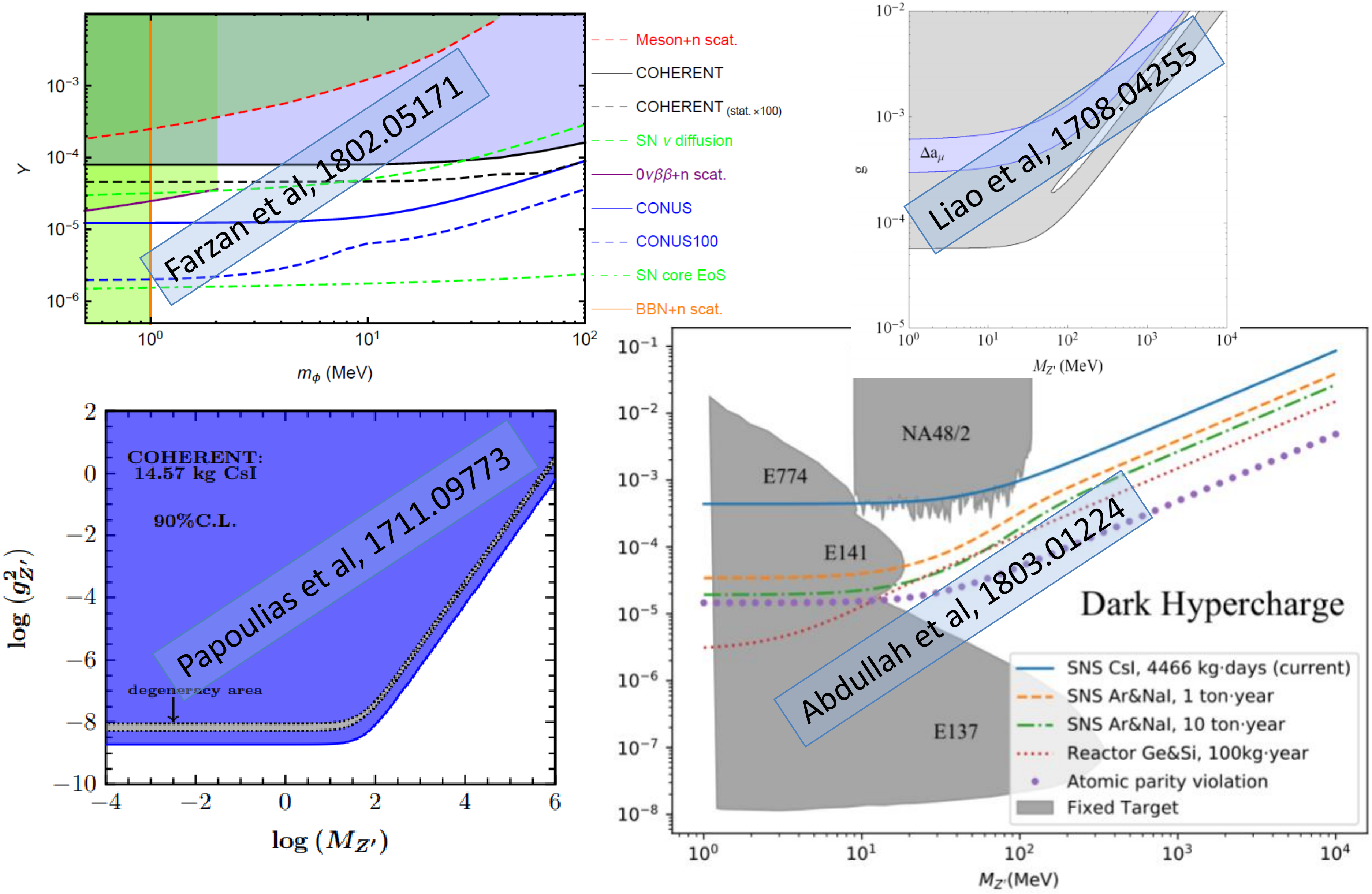
(1) and (2) both cause spectral distortions



From 1802.05171



Light mediators (scalar, Z’, dark photon…)



Farzan et al, 1802.05171

Liao et al, 1708.04255

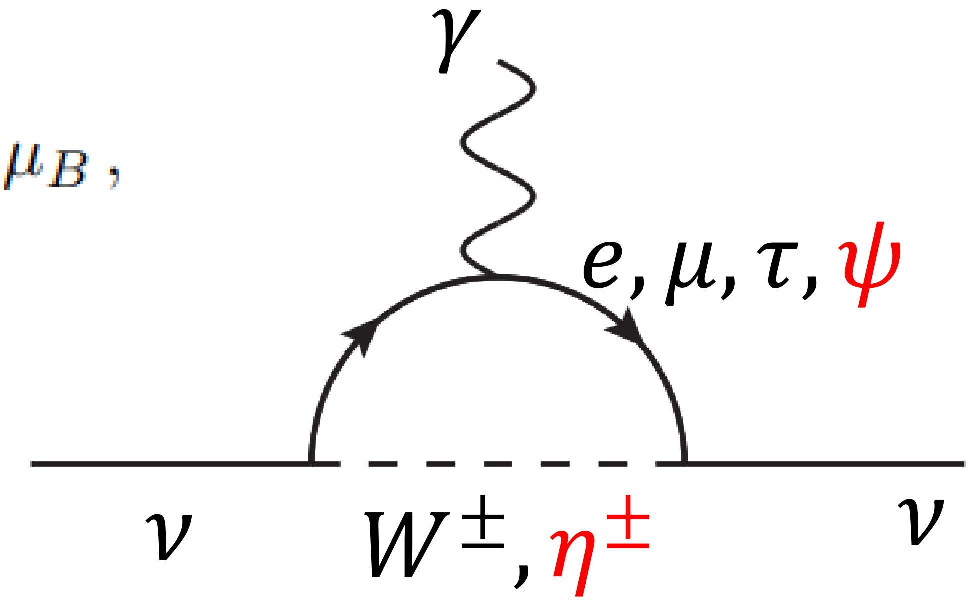
Papoulias et al, 1711.09773

Abdullah et al, 1803.01224

Neutrinos magnetic moment (μ_ν)

In SM, very small

$$\mu_\nu \approx 3.2 \times 10^{-19} \left[\frac{m_\nu}{1\ \mathrm{eV}}\right] \mu_B \, ,$$



Larger μ_ν implies new physics in the loop

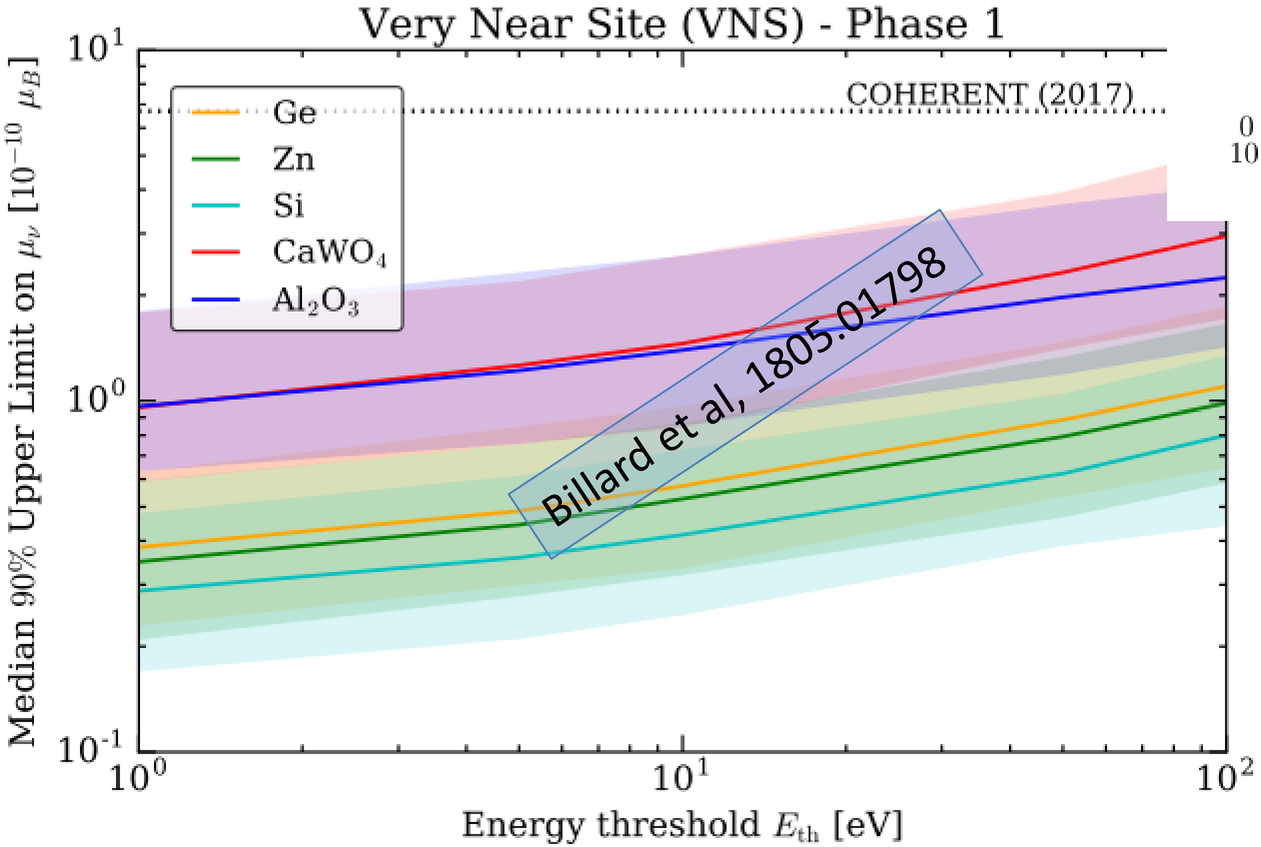
BSM particles ($\psi, \eta^\pm$)

Effect on neutrino scattering:

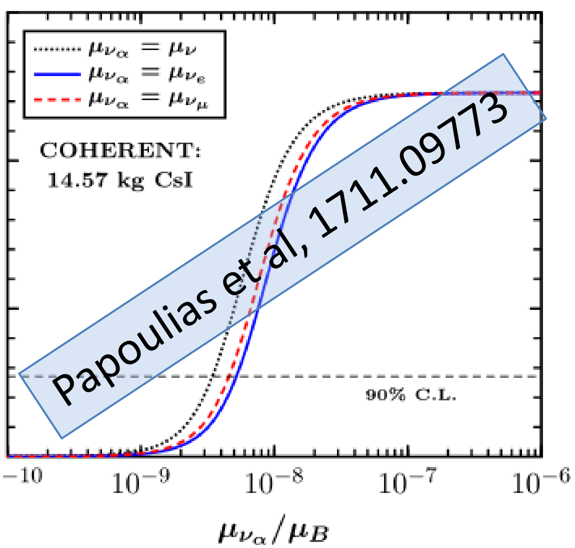
$$\frac{\mathrm{d}\sigma^{\mathrm{mag.}}_{\nu-N}}{\mathrm{d}E_R} = \frac{\pi \alpha^2 \mu_\nu^2 Z^2}{m_e^2} \left(\boxed{\frac{1}{E_R}} - \frac{1}{E_\nu} + \frac{E_R}{4E_\nu^2} \right) F^2(E_R) \, .$$

The smaller recoil, the better (soft photon)

Neutrinos magnetic moment (μ_ν)



Billard et al, 1805.01798

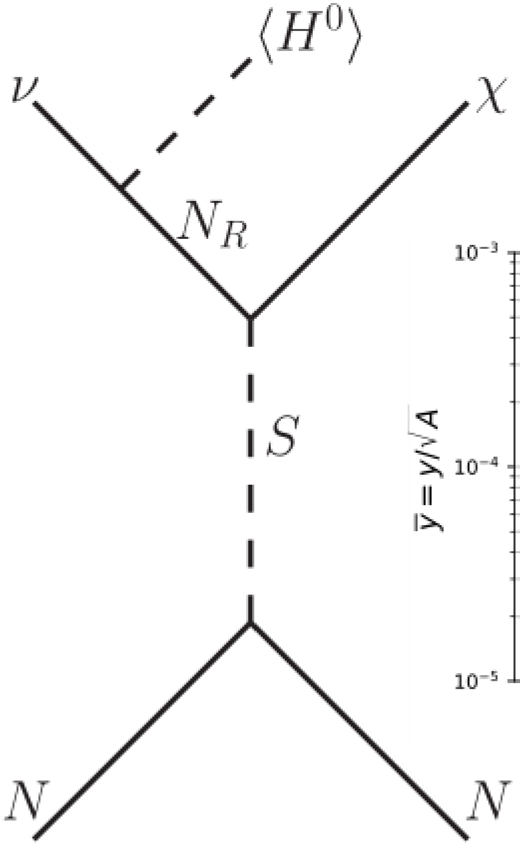


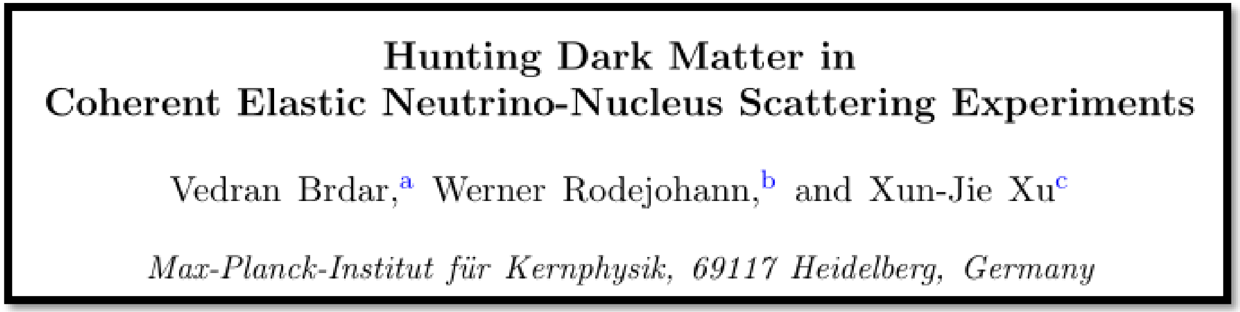
Papoulias et al, 1711.09773

Still not better than
$\nu + e$ scattering

GEMMA: $\mu_\nu < 10^{-11}\mu_B$

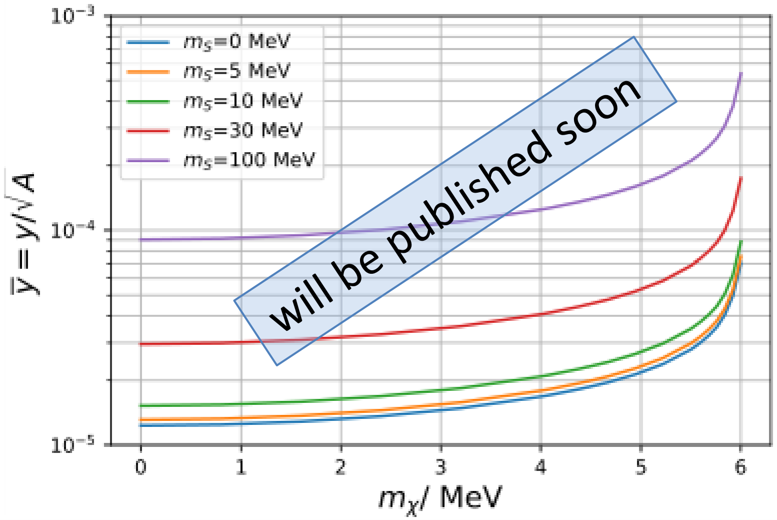
Dark matter




Hunting Dark Matter in Coherent Elastic Neutrino-Nucleus Scattering Experiments

Vedran Brdar,[a] Werner Rodejohann,[b] and Xun-Jie Xu[c]

Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany



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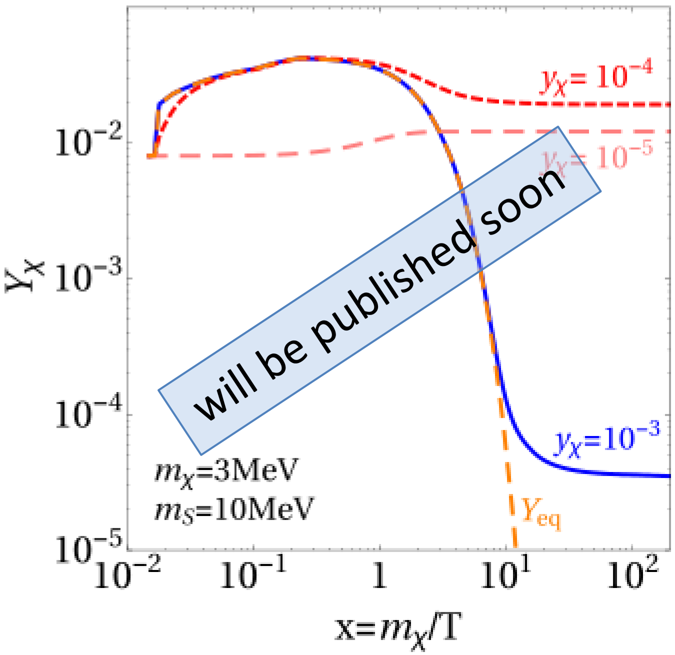

will be published soon

Summary

- Elastic neutrino scattering (including coherent) is powerful in probing both SM & BSM neutrino interaction;
- Recent coherent neutrino scattering experiments can provide leading constraints on NSI, SPVAT, Sterile neutrinos, light mediators, Neutrino magnetic moments;
- Future reactor-based coherent scattering experiments will reveal more of the unexplored space of new physics related to neutrino.