



中山大學 物理与天文学院
SUN YAT-SEN UNIVERSITY SCHOOL OF PHYSICS AND ASTRONOMY

Constraints on neutrino nonstandard interactions from COHERENT, PandaX-4T and XENONnT

Gang Li (李刚)

School of Physics and Astronomy,
Sun Yat-sen University, Zhuhai

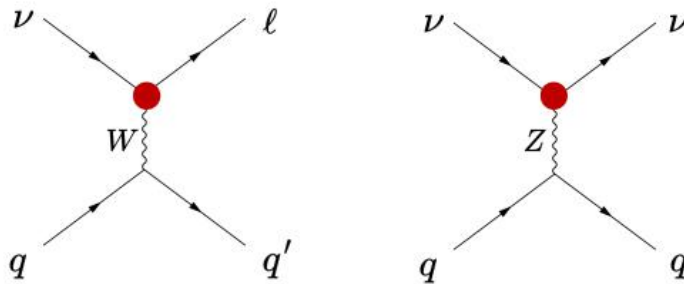
GL, Chuan-Qiang Song, Feng-Jie Tang, Jiang-Hao Yu, 2409.04703 (PRD)

Dark Matter and Neutrino Focus Week

TDLI, Shanghai , August 23, 2025

Neutrino Non-standard Interactions

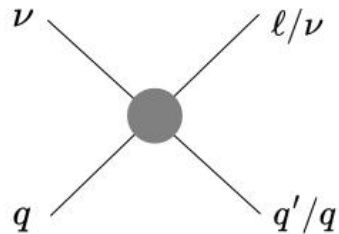
Neutrino-quark interactions:



+

other contributions from
BSM particles (W' , Z' ,
new scalar, leptoquark)

$\mu < M_W, M_Z$



four-fermion interactions

Neutrino Non-standard Interactions

Parameterization of neutrino NSIs:

- charged current:

$$\mathcal{L}_{\text{CC}} \supset -2\sqrt{2}G_F V_{ud}^{\text{SM}} \left\{ [\mathbf{1} + \epsilon_L]_{\alpha\beta}^{ij} (\bar{u}_i \gamma^\mu P_L d_j) (\bar{\ell}_\alpha \gamma_\mu P_L \nu_\beta) + [\epsilon_R]_{\alpha\beta}^{ij} (\bar{u}_i \gamma^\mu P_R d_j) (\bar{\ell}_\alpha \gamma_\mu P_L \nu_\beta) \right. \\ \left. + \frac{1}{2} [\epsilon_S]_{\alpha\beta}^{ij} (\bar{u}_i d_j) (\bar{\ell}_\alpha P_L \nu_\beta) - \frac{1}{2} [\epsilon_P]_{\alpha\beta}^{ij} (\bar{u}_i \gamma_5 d_j) (\bar{\ell}_\alpha P_L \nu_\beta) + \frac{1}{4} [\epsilon_T]_{\alpha\beta}^{ij} (\bar{u}_i \sigma^{\mu\nu} P_L d_j) (\bar{\ell}_\alpha \sigma_{\mu\nu} P_L \nu_\beta) + \text{H.c.} \right\}$$

- neutral current:

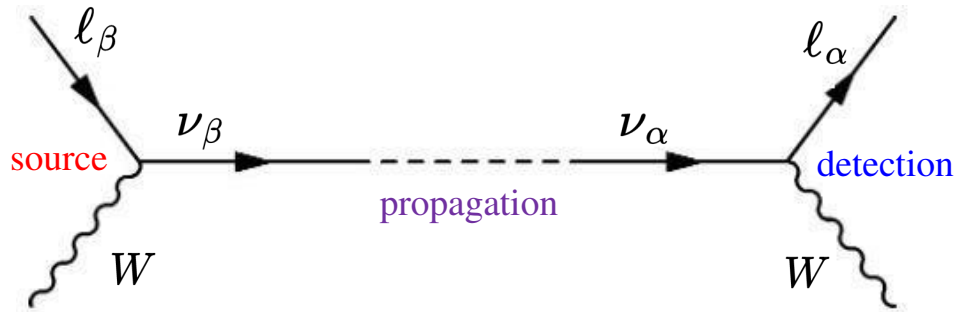
$$\mathcal{L}_{\text{NC}} \supset 2\sqrt{2}G_F [\epsilon_{\alpha\beta}^{fL} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) (\bar{f} \gamma_\mu P_L f) + \epsilon_{\alpha\beta}^{fR} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) (\bar{f} \gamma_\mu P_R f)] + \text{H.c.}$$

matched to dimension-6 operators in the SMEFT

Yong Du, Hao-Lin Li, Jian Tang, Sampsa Vihonen,
Jiang-Hao Yu 2106.15800 (PRD)

Neutrino Non-standard Interactions

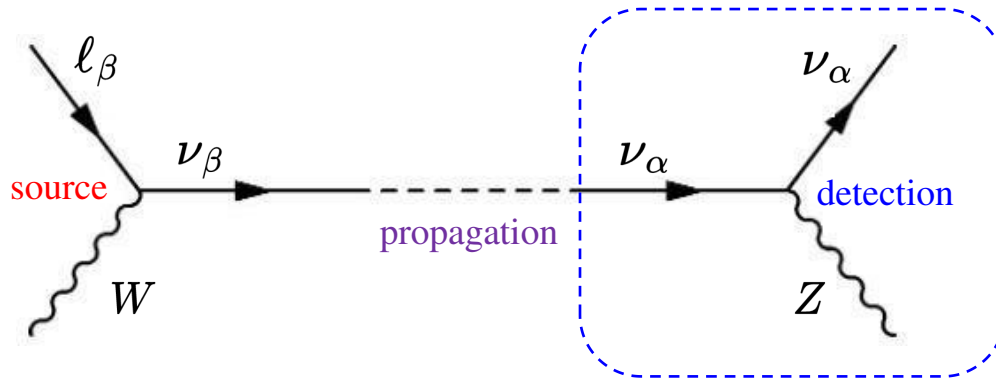
Measurements of neutrino NSIs in **oscillation** experiments:



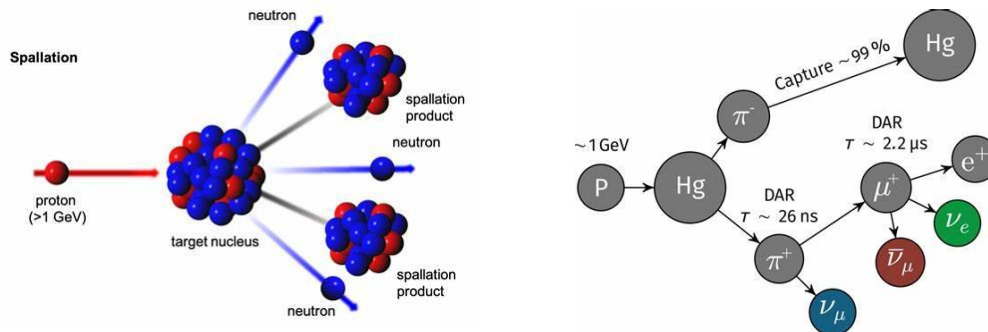
- Neutrino charged-current NSIs affect the **source** (production) and **detection** (scattering) of neutrinos
- Neutrino neutral-current NSIs affect the **propagation** of neutrinos

Neutrino Non-standard Interactions

Measurements of neutrino NSIs in **scattering** experiments:



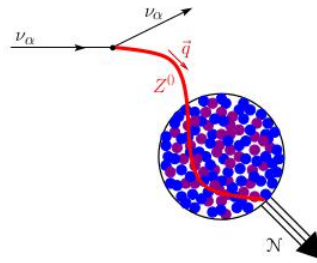
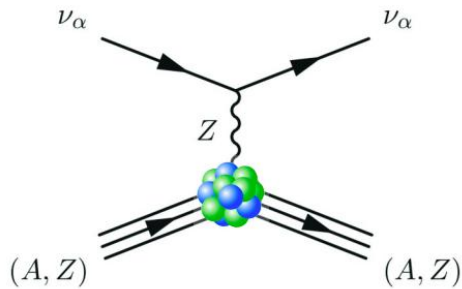
- Neutrino neutral-current NSIs can also affect the **detection** (scattering) of neutrinos



Neutrino source: Spallation Neutron Source

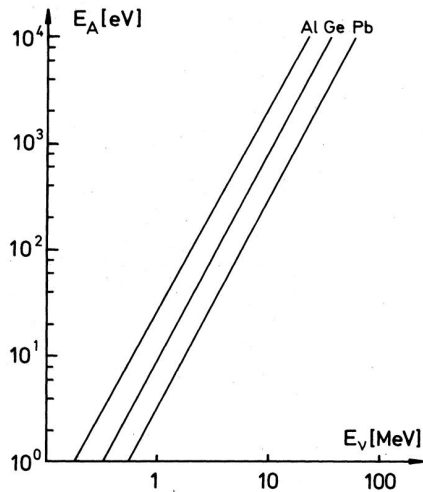
Coherent elastic neutrino-nucleus scattering

CEvNS: what is it?



$$\frac{d\sigma}{dT_{nr}} \propto Z^2 \quad Z: \text{atomic number}$$

D. Z. Freedman, Phys.Rev.D 9 (1974) 1389



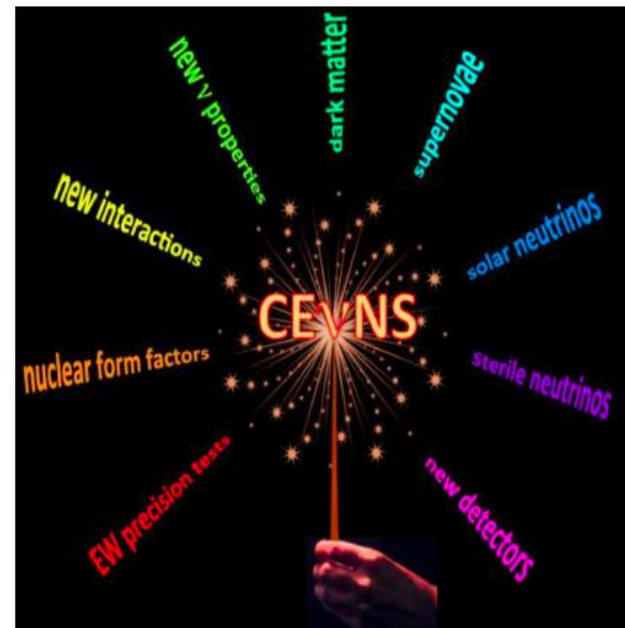
$$E_A = \frac{2}{3A} (E_\nu / 1 \text{ MeV})^2 \text{ keV}$$

Drukier, Stodolsky, Phys.Rev.D 30 (1984) 2295

Coherent elastic neutrino-nucleus scattering

CEvNS: physical potential

- EW precision tests: weak mixing angle, electroweak charges;
- Neutrino physics: neutrino magnetic moment, charge radius, sterile neutrinos,
- New interactions: nonstandard interactions, light mediators, generalized interactions; light dark matter;
- Nuclear Physics: neutron radius, quenching factor, reactor neutrino flux;
- Astroparticle physics: supernova, solar, atmospheric neutrinos, DSNB;...

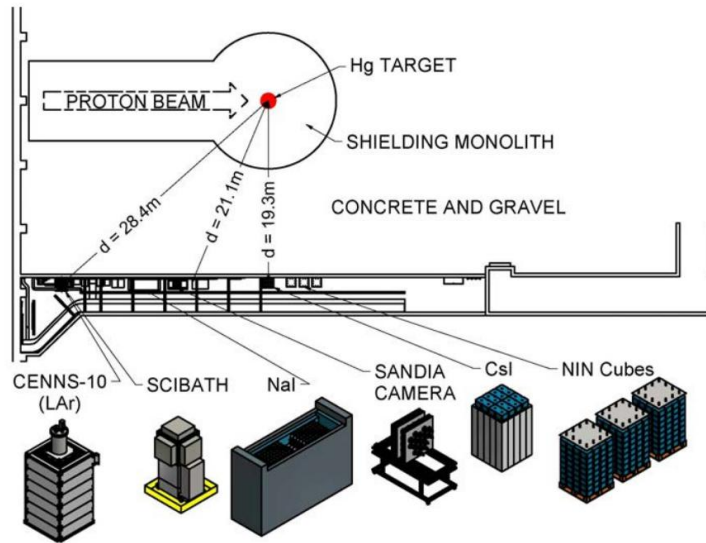


E. Lisi, Neutrino 2018

credit: Jiajun Liao

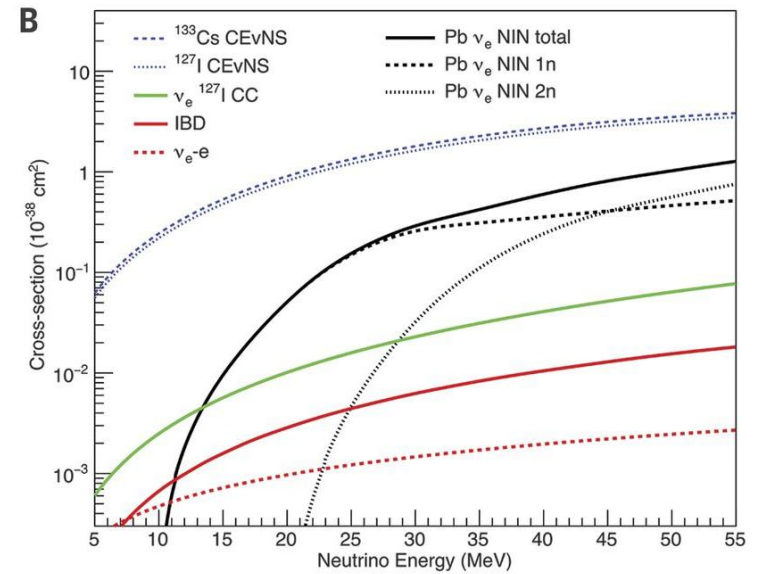
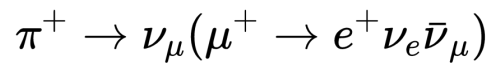
Coherent elastic neutrino-nucleus scattering

First observation of CEvNS by COHERENT:



CsI[Na] or CsI detector

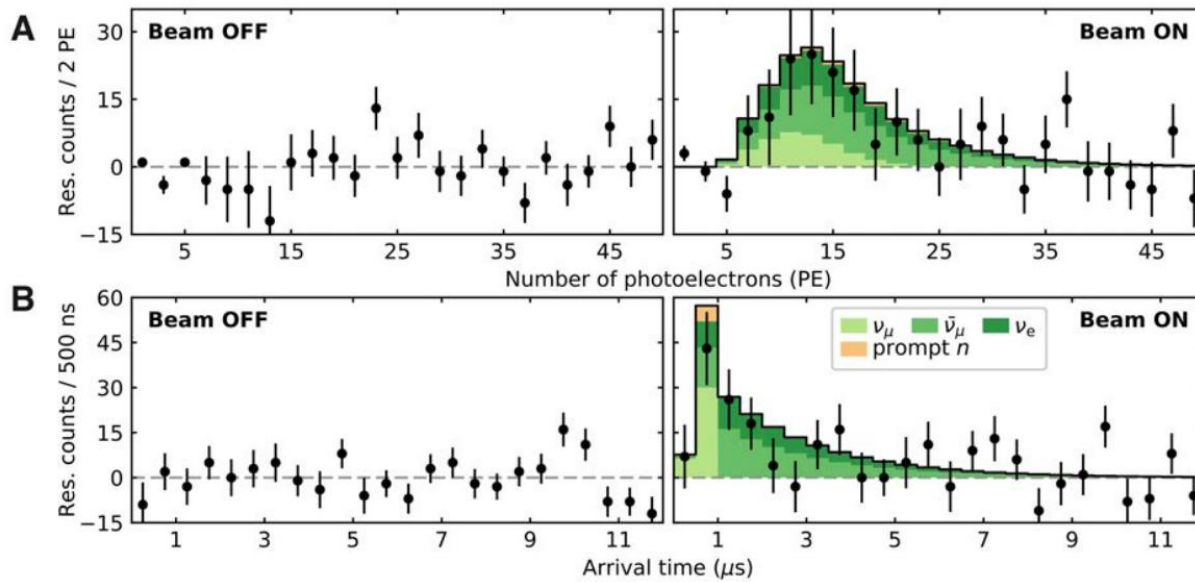
neutrinos produced in



Science 357 (2017) 6356, 1123

Coherent elastic neutrino-nucleus scattering

First observation of CEvNS by COHERENT:



Science 357 (2017) 6356, 1123

$$n_{\text{PE}} \longleftarrow T_{ee} \longleftarrow T_{\text{nr}}$$

Constraint on NSIs from COHERENT

From CEvNS events to neutrino NSIs:

- Number of PEs in i -th bin

$$N_{\nu_\alpha}^i = n_N \sum_{x=\text{Cs,I}} \eta_x \langle \varepsilon_T \rangle_{\nu_\alpha} \int_{n_{\text{PE}}^i}^{n_{\text{PE}}^{i+1}} dn_{\text{PE}} \varepsilon(n_{\text{PE}}) \\ \times \int_{T_{\text{nr,min}}}^{T_{\text{nr,max}}} dT_{\text{nr}} P(n_{\text{PE}}) \left. \frac{dR_{\nu_\alpha}}{dT_{\text{nr}}} \right|_x$$

- Differential event rate

$$\frac{dR_{\nu_\alpha}}{dT_{\text{nr}}} = \int_{E_{\nu,\text{min}}}^{E_{\nu,\text{max}}} dE_\nu \Phi_{\nu_\alpha}(E_\nu) \frac{d\sigma}{dT_{\text{nr}}}$$

total neutrino flux

number of target nuclei: n_N

fraction of Cs/I: η_x

average time efficiency: $\langle \varepsilon_T \rangle_{\nu_\alpha}$

detector efficiency: $\varepsilon(n_{\text{PE}})$

detector energy resolution: $P(n_{\text{PE}})$

$$\Phi_{\nu_e}(E_\nu) = \mathcal{N} \frac{192E_\nu^2}{m_\mu^3} \left(\frac{1}{2} - \frac{E_\nu}{m_\mu} \right)$$

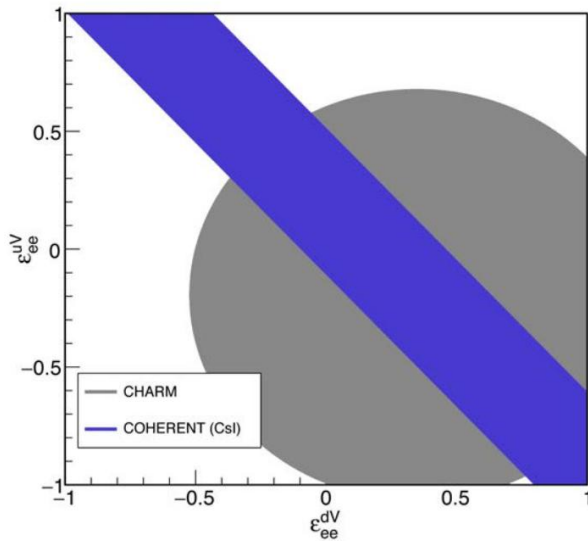
$$\Phi_{\bar{\nu}_\mu}(E_\nu) = \mathcal{N} \frac{64E_\nu^2}{m_\mu^3} \left(\frac{3}{4} - \frac{E_\nu}{m_\mu} \right)$$

$$\Phi_{\nu_\mu}(E_\nu) = \mathcal{N} \delta \left(E_\nu - \frac{m_\pi^2 - m_\mu^2}{2m_\pi} \right)$$

Constraint on NSIs from COHERENT

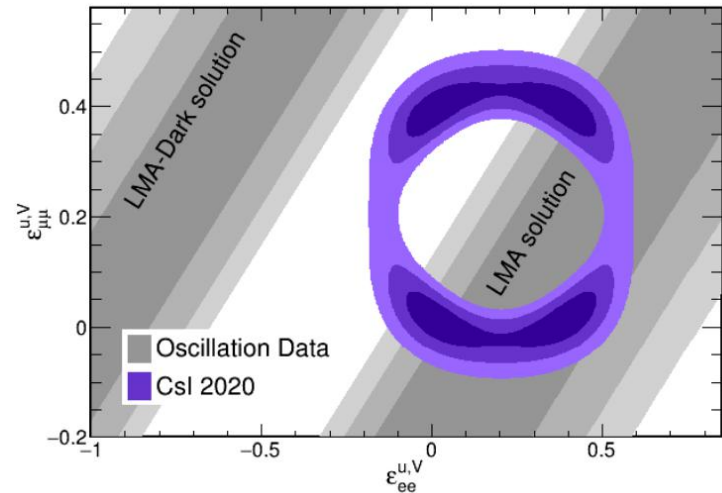
From CEvNS events to neutrino NSIs:

$$\mathcal{L}_{\text{NC}} \supset -2\sqrt{2}G_F \left[\epsilon_{\alpha\beta}^{qL} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) (\bar{q} \gamma_\mu P_L q) + \epsilon_{\alpha\beta}^{qR} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) (\bar{q} \gamma_\mu P_R q) \right] \quad \epsilon_{\alpha\beta}^{qV} = \epsilon_{\alpha\beta}^{qL} + \epsilon_{\alpha\beta}^{qR}$$



COHERENT, Science
357 (2017) 6356, 1123

measurement by LAr detector
combined result of CsI+LAr



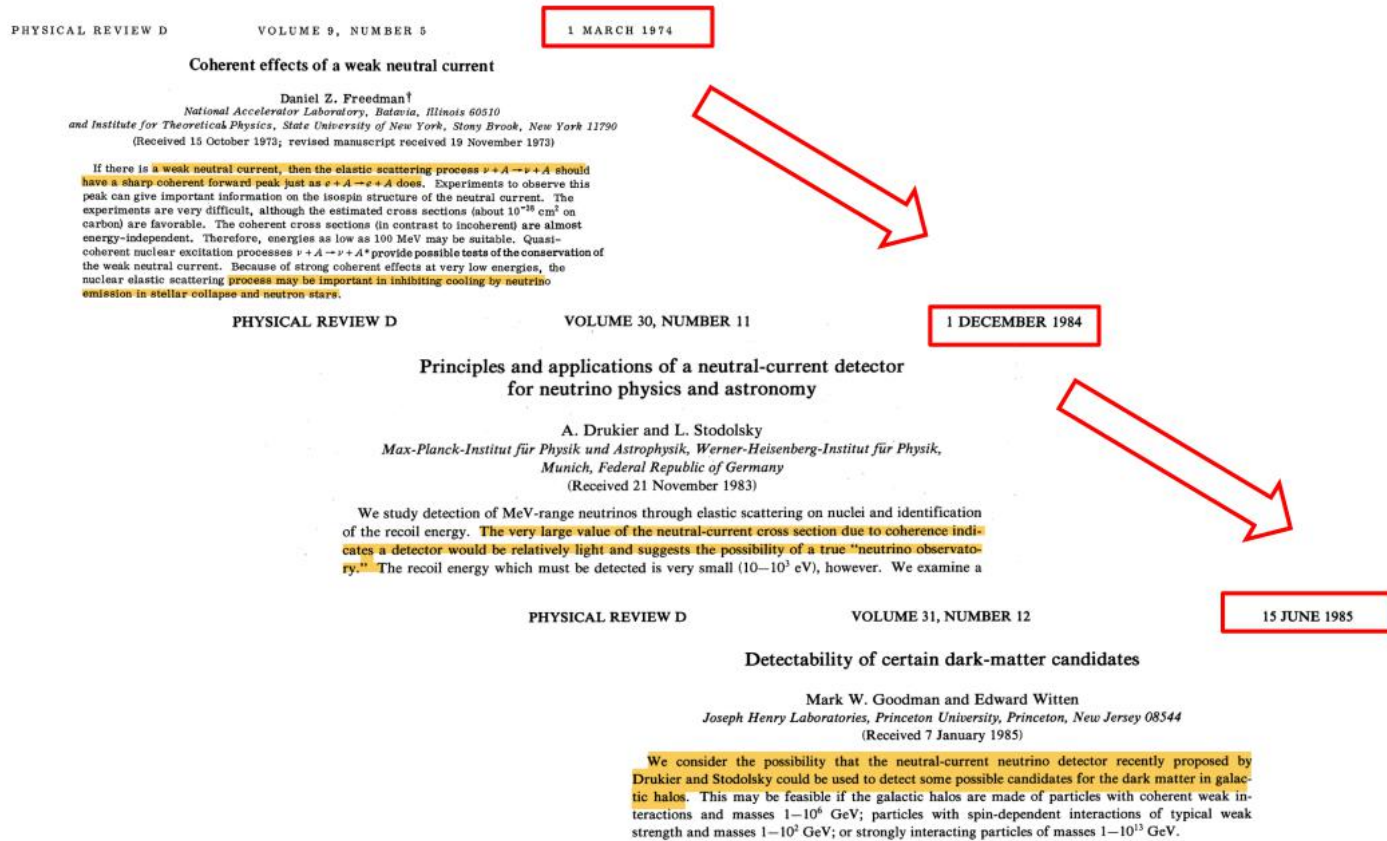
COHERENT, 2110.07730 (PRL)

COHERENT, 2003.10630 (PRL)

V. De Romeri, et al., 2211.11905 (JHEP)

Experimental Synergy

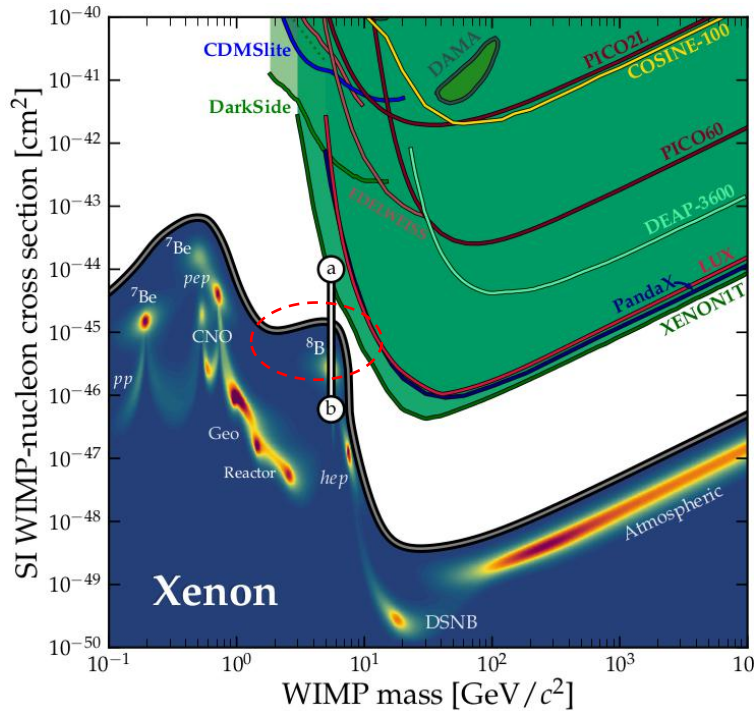
From neutrino measurement to dark matter detection



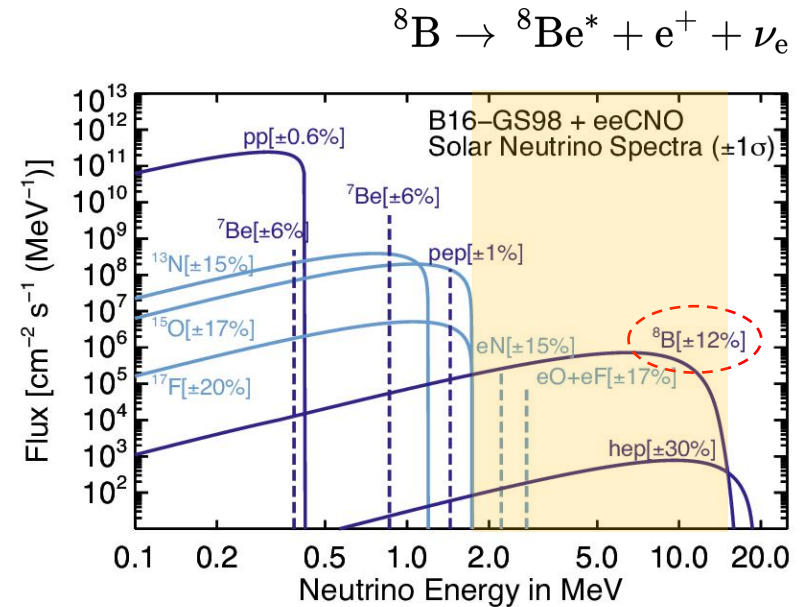
credit: Jiajun Liao

Experimental Synergy

Neutrino floor/frog:



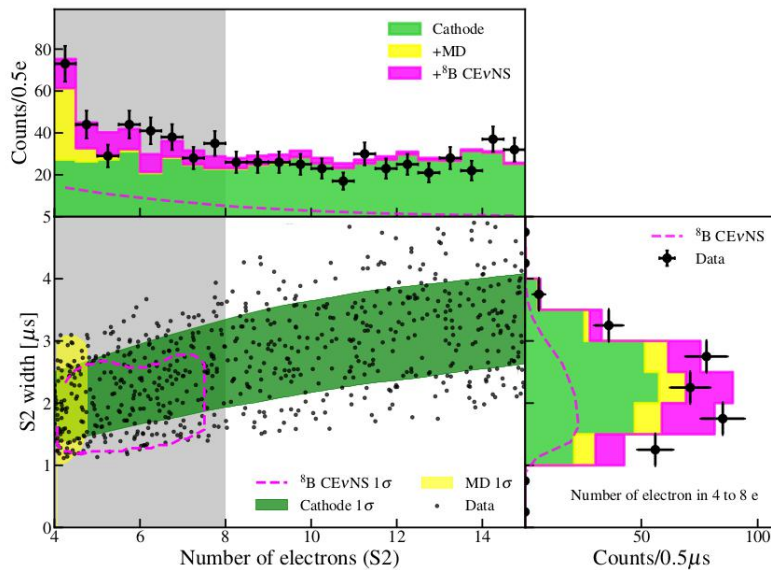
C. A. J. O'Hare, 2109.03116 (PRL)
 J. Tang, B.-L. Zhang, 2304.13665 (PRD)



Neutrino source: sun

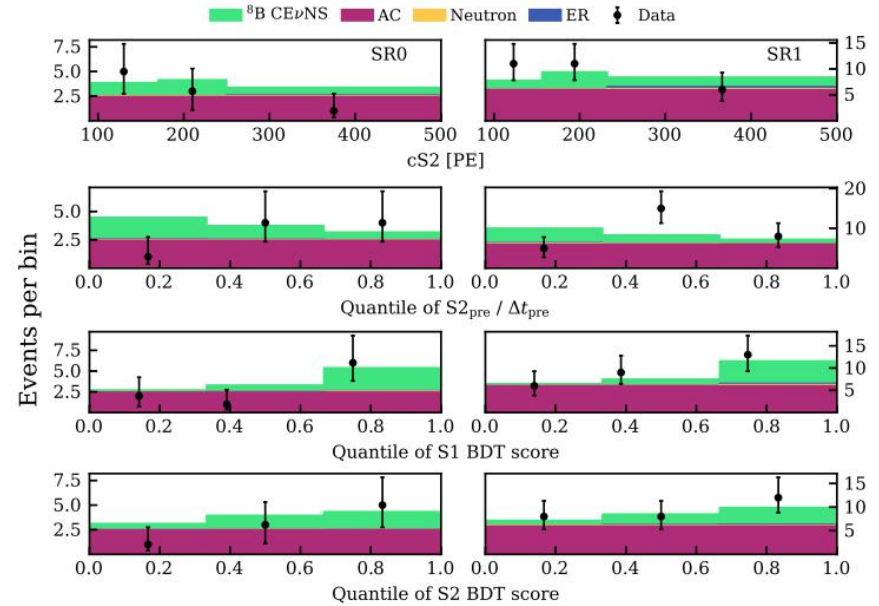
Solar ^8B neutrinos

First measurements of solar ^8B neutrinos via CEvNS:



PandaX-4T, 2407.10892 (PRL)

US2 (75), paired (3.5),
background-only hypothesis
is rejected with 2.64σ



XENONnT, 2408.02877 (PRL)

37 signal events, background-only
hypothesis is rejected with 2.73σ

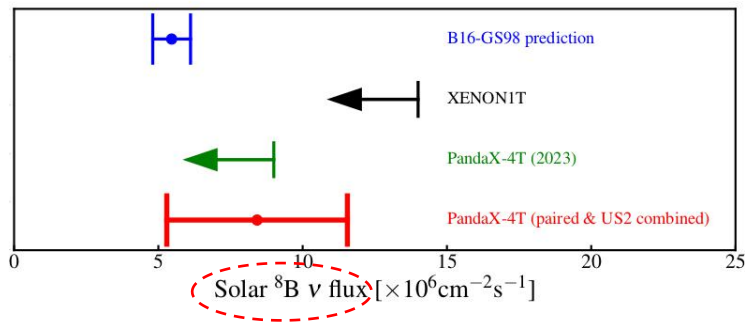
see Ning Zhou's talk

Solar ^8B neutrinos

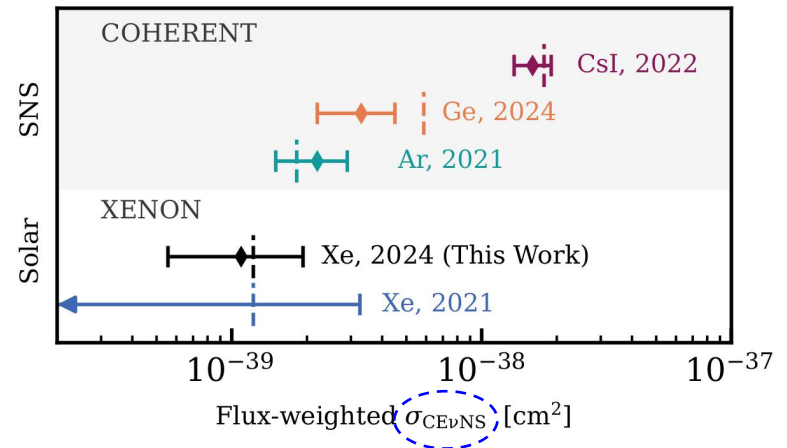
First measurements of solar ^8B neutrinos via CEvNS:

Number of signal events

= solar ^8B neutrino flux \otimes CEvNS cross section



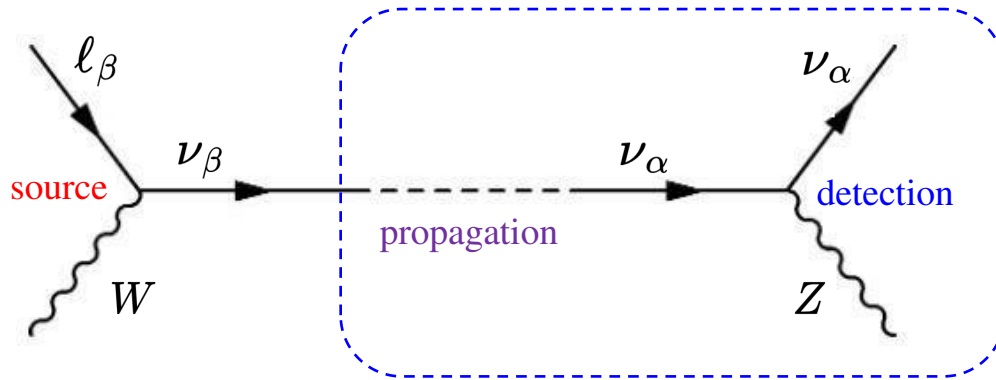
PandaX-4T, 2407.10892 (PRL)



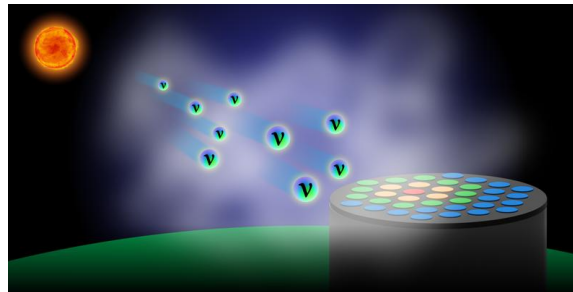
XENONnT, 2408.02877 (PRL)

Neutrino Non-standard Interactions

Measurements of neutrino NSIs in **scattering** experiments:



- Neutrino neutral-current NSIs can affect both the **propagation** and **detection** (scattering) of neutrinos



Neutrino source: sun

CEvNS events in PandaX-4T and XENONnT

From CEvNS events to neutrino NSIs:

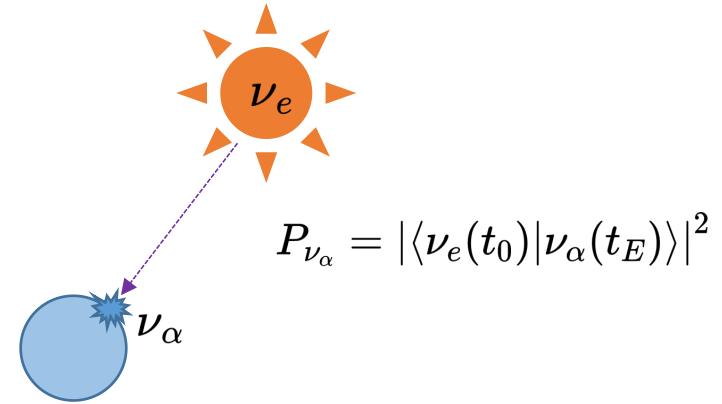
- Number of signal events

$$N_{\nu_\alpha} = n_N \int_{T_{\text{nr},\text{min}}}^{T_{\text{nr},\text{max}}} dT_{\text{nr}} \varepsilon(T_{\text{nr}}) \frac{dR_\alpha}{dT_{\text{nr}}}$$

- Differential event rate:

$$\frac{dR_{\nu_\alpha}}{dT_{\text{nr}}} = \int_{E_{\nu,\text{min}}}^{E_{\nu,\text{max}}} dE_\nu \Phi_{\nu_\alpha}(E_\nu) \frac{d\sigma}{dT_{\text{nr}}}$$

$$i \frac{d}{dr} |\nu\rangle = \left[\frac{1}{2E_\nu} U H_{\text{vac}} U^\dagger + H_{\text{mat}} \right] |\nu\rangle$$



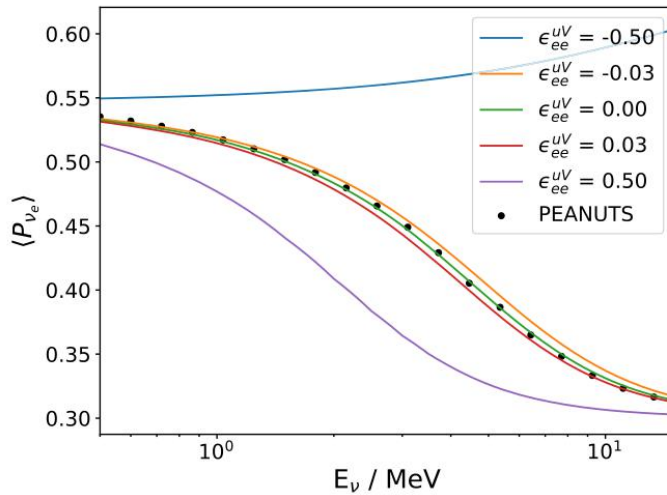
exposure

$$\Phi_{\nu_\alpha}(E_\nu) = \frac{\mathcal{E}}{M_{\text{det}}} \langle P_{\nu_\alpha} \rangle \phi({}^8\text{B})$$

$$\underline{\Delta H_{\text{mat}}} = \sqrt{2} G_F n_q \begin{pmatrix} \epsilon_{ee}^{qV} & \epsilon_{e\mu}^{qV} & \epsilon_{e\tau}^{qV} \\ \epsilon_{e\mu}^{qV*} & \epsilon_{\mu\mu}^{qV} & \epsilon_{\mu\tau} \\ \epsilon_{e\tau}^{qV*} & \epsilon_{\mu\tau}^{qV*} & \epsilon_{\tau\tau}^{qV} \end{pmatrix}$$

CEvNS events in PandaX-4T and XENONnT

From CEvNS events to neutrino NSIs:



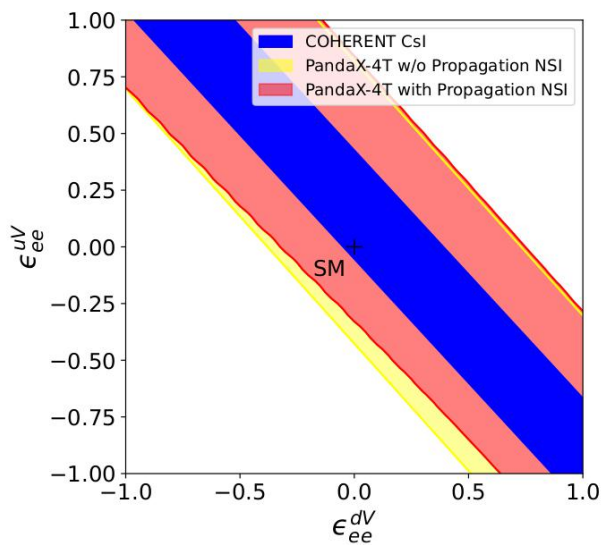
- The neutrino NSIs have **substantial** impact on the solar matter effect
- The averaged probabilities vary by a factor of 2 at most for $|\epsilon_{ee}^{uV}| \leq 0.5$

see also Aristizabal Sierra, Mishra, Strigari, 2409.02003 (PRD)

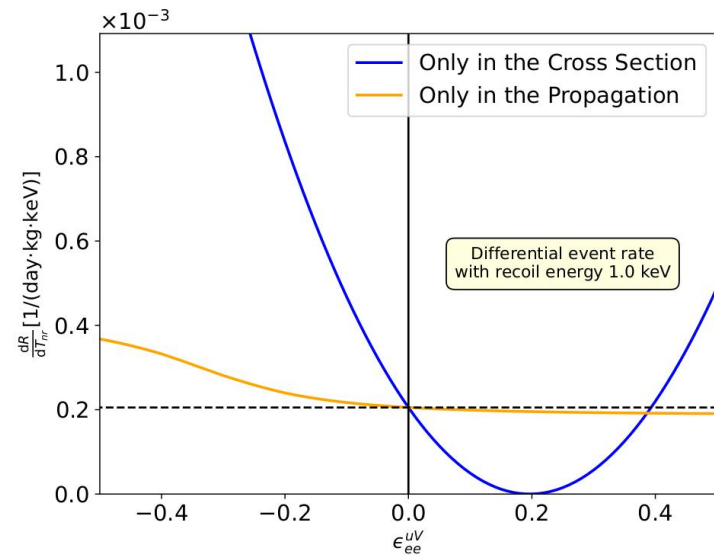
The neutrino neutral-current NSIs have impact on the solar matter effects (**propagation**) and CEvNS cross section (**scattering**)

CEvNS events in PandaX-4T and XENONnT

From CEvNS events to neutrino NSIs:



The effect of NSIs on neutrino propagation is **weaker** than that on scattering

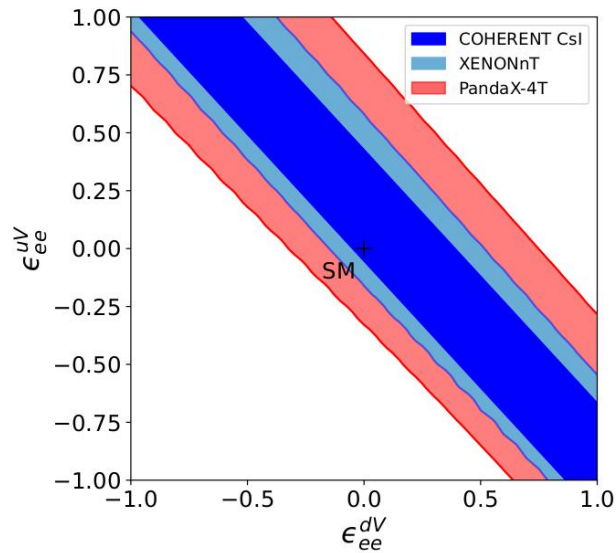


The cross section is approximated as quadratic polynomial of the NSI parameter

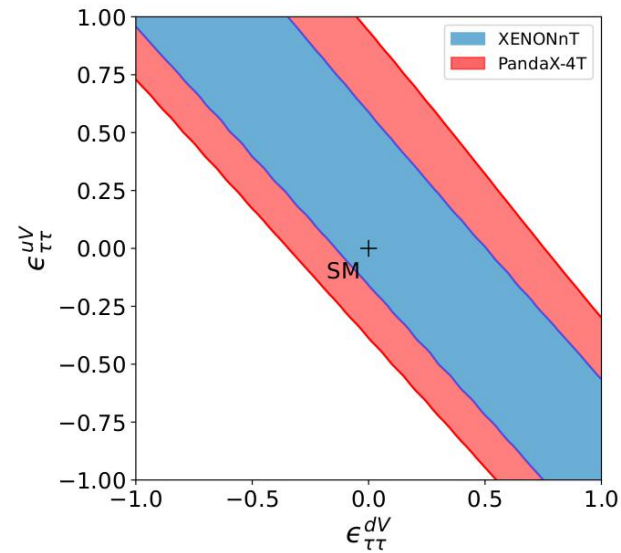
Constraint on NSIs from PandaX-4T and XENONnT

From CEvNS events to neutrino NSIs:

$$\mathcal{L}_{\text{NC}} \supset -2\sqrt{2}G_F \left[\epsilon_{\alpha\beta}^{qL} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) (\bar{q} \gamma_\mu P_L q) + \epsilon_{\alpha\beta}^{qR} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) (\bar{q} \gamma_\mu P_R q) \right] \quad \boxed{\epsilon_{\alpha\beta}^{qV} = \epsilon_{\alpha\beta}^{qL} + \epsilon_{\alpha\beta}^{qR}}$$



constraint from PandaX-4T (US2 data) is weaker than XENONnT



unique probe of tau-flavor NSIs

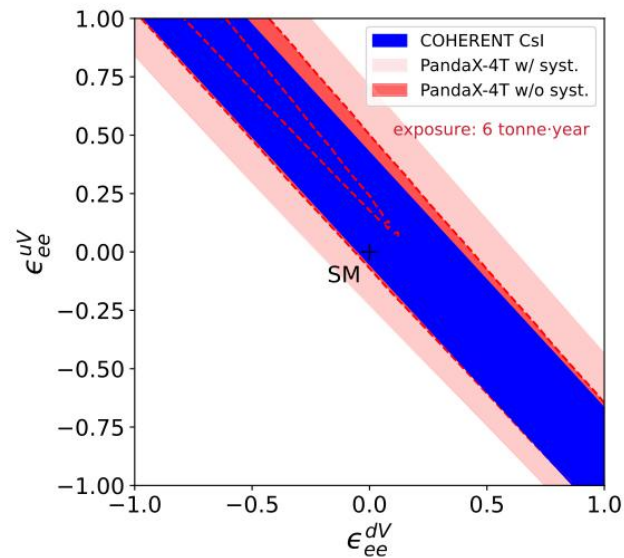
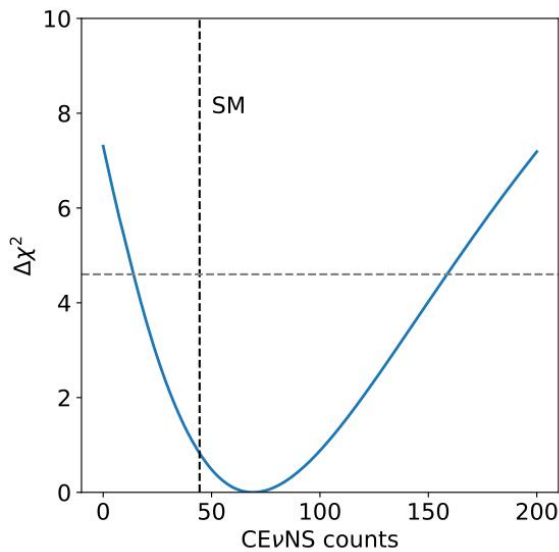
Sensitivity of PandaX-4T

chi-square analysis:

$$\chi^2 = \frac{[N_{\text{meas}} - N_{\text{CE}\nu\text{NS}}(1 + \alpha)]^2}{\sigma_{\text{stat}}^2} + \left(\frac{\alpha}{\sigma_\alpha}\right)^2$$

Sensitivity to NSIs is currently limited by

- central value (75)
- statistic uncertainties (37%)
- systematic uncertainties (24.5%)



Summary

- We investigate constraints on neutrino nonstandard interactions from COHERENT, PandaX-4T and XENONnT.
- We find that the constraints from PandaX-4T and XENONnT are **weaker than** that from COHERENT for **e- and mu-flavor NSIs**.
- PandaX-4T and XENONnT provide **unique probes** of **tau-flavor NSIs**.
- In the measurements of solar ^8B neutrinos, effect of NSIs on neutrino **propagation** is **weaker than** that on scattering.
- The sensitivity of PandaX-4T is primarily limited by the deviation of the **central value** from the SM prediction

Thank you