GENERALIZED NEUTRINO INTERACTIONS IN DARK MATTER and CEvNS EXPERIMENTS

XV SILAFAE @ CINVESTAV, México City

Nov 4-8, 2024

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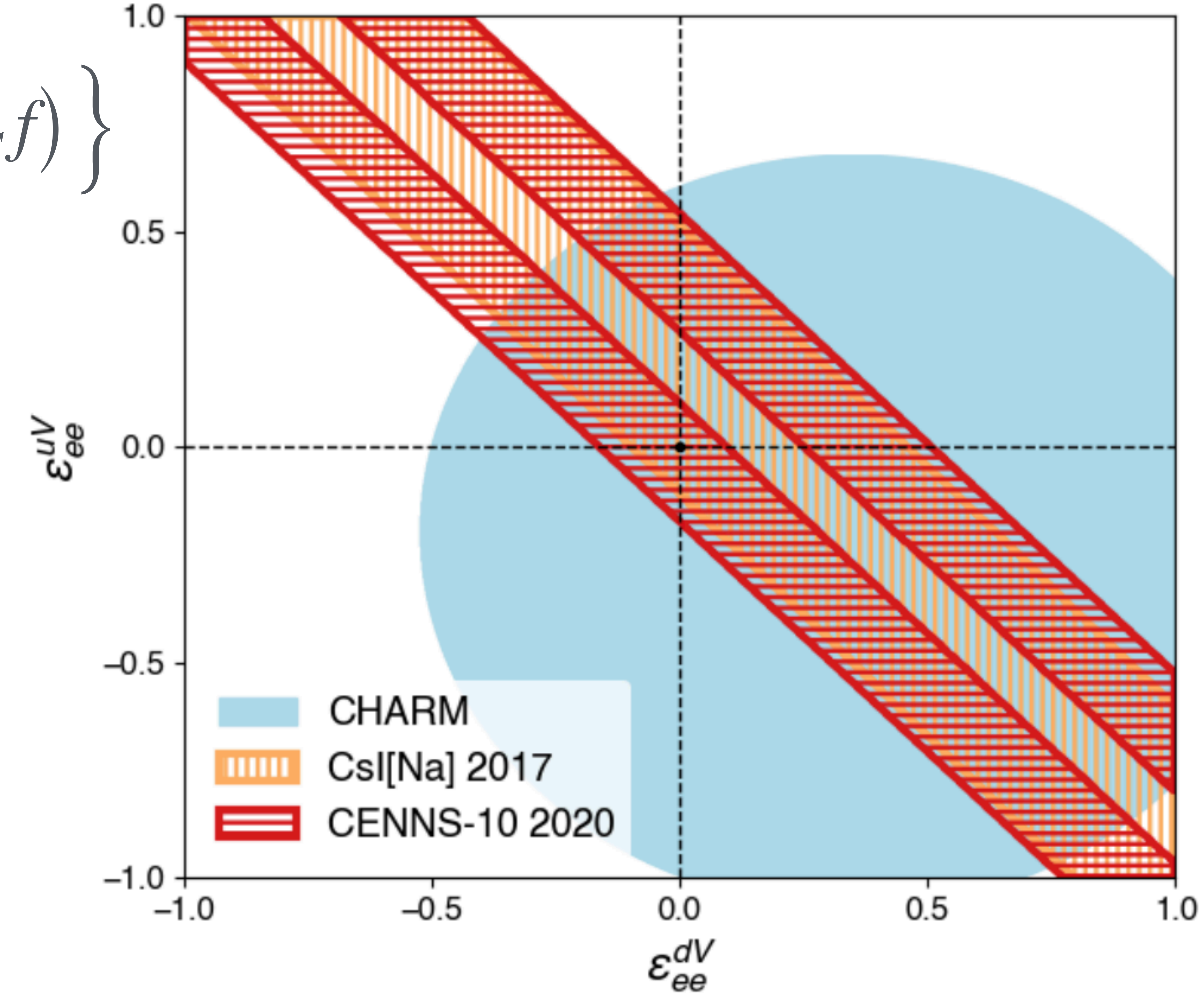
NON STANDARD NEUTRINO INTERACTIONS (NSI)

$$\mathscr{L}_{\rm NSI} = - \; 2\sqrt{2}G_F \sum_{\alpha,\beta,f,C} \left\{ \varepsilon^{fC}_{\alpha\beta} \left(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta\right)\left(\bar{f}\gamma_\mu P_C f\right) \right\}$$

Useful to study new *vector* interactions in a model independent way

Could have sizable effects in:

- Production
- Detection
- Propagation in matter



COHERENT Collaboration•D. Akimov(Moscow, ITEP and Moscow Phys. Eng. Inst.) et al. (Apr 3, 2020)
Published in: *Phys.Rev.Lett.* 126 (2021) 1, 012002 • e-Print: 2003.10630 [nucl-ex]

GENERALIZED NEUTRINO INTERACTIONS (GNI)

- Also referred to as NGI

$$\mathscr{L}_{\rm GNI} = -\frac{G_F}{\sqrt{2}} \sum_{\alpha,\beta,f} \Big\{ \epsilon^{fS}_{\alpha\beta} \left(\bar{\nu}_\alpha (1-\gamma^5) \nu_\beta\right) \left(\bar{f} f\right) + \tilde{\epsilon}^{fS}_{\alpha\beta} \left(\bar{\nu}_\alpha (1+\gamma^5) \nu_\beta\right) \left(\bar{f} f\right)$$

$$- \epsilon^{fP}_{\alpha\beta} \left(\bar{\nu}_\alpha (1-\gamma^5) \nu_\beta\right) \left(\bar{f} \gamma^5 f\right) - \tilde{\epsilon}^{fP}_{\alpha\beta} \left(\bar{\nu}_\alpha (1+\gamma^5) \nu_\beta\right) \left(\bar{f} \gamma^5 f\right)$$

$$+ \epsilon^{fT}_{\alpha\beta} \left(\bar{\nu}_\alpha \sigma^{\mu\nu} P_L \nu_\beta\right) \left(\bar{f} \sigma_{\mu\nu} P_L f\right) + \tilde{\epsilon}^{fT}_{\alpha\beta} \left(\bar{\nu}_\alpha \sigma^{\mu\nu} P_R \nu_\beta\right) \left(\bar{f} \sigma_{\mu\nu} P_R f\right) \Big\}$$

$$+ \mathrm{h.c.},$$

$$-\mathscr{L}_{\rm GNI} = \frac{G_F}{\sqrt{2}} \sum_X \bar{\nu} \Gamma^X \nu \bar{q} \Gamma_X \left(C^{qX}_{\alpha\beta} + i\gamma^5 D^{qX}_{\alpha\beta} \right)$$

$$f = e, u, d$$

Ingolf Bischer , Werner Rodejohann, (2019)
Nucl.Phys.B 947 (2019) 114746 • e-Print: 1905.08699 [hep-ph]

GNI framework features

- Can describe new interactions in Model-indepent framework
- Low-energy Effective Field Theory
- Naturally includes RH neutrinos
- Suitable for low-energy experiments (below the EW scale)
- Not as robust as SMEFT

ε^A ε^V ε^S ε^P ε^T

DIS

CHARM

CDHS

NuTev

CEvNS

COHERENT-CsI

COHERENT-LAr

COHERENT-Ge

DM DD

LUX ZEPLIN

PANDAX-4T

XENONnT

CHARM II

Texono

LEP

Interactions with Nuclei

$\mathcal{N}$

Interaction with Electrons

e

to name a few…

DARK MATTER DIRECT DETECTION EXPERIMENTS

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

LUX-ZEPLIN (LZ)
DARK MATTER SEARCH

XENON

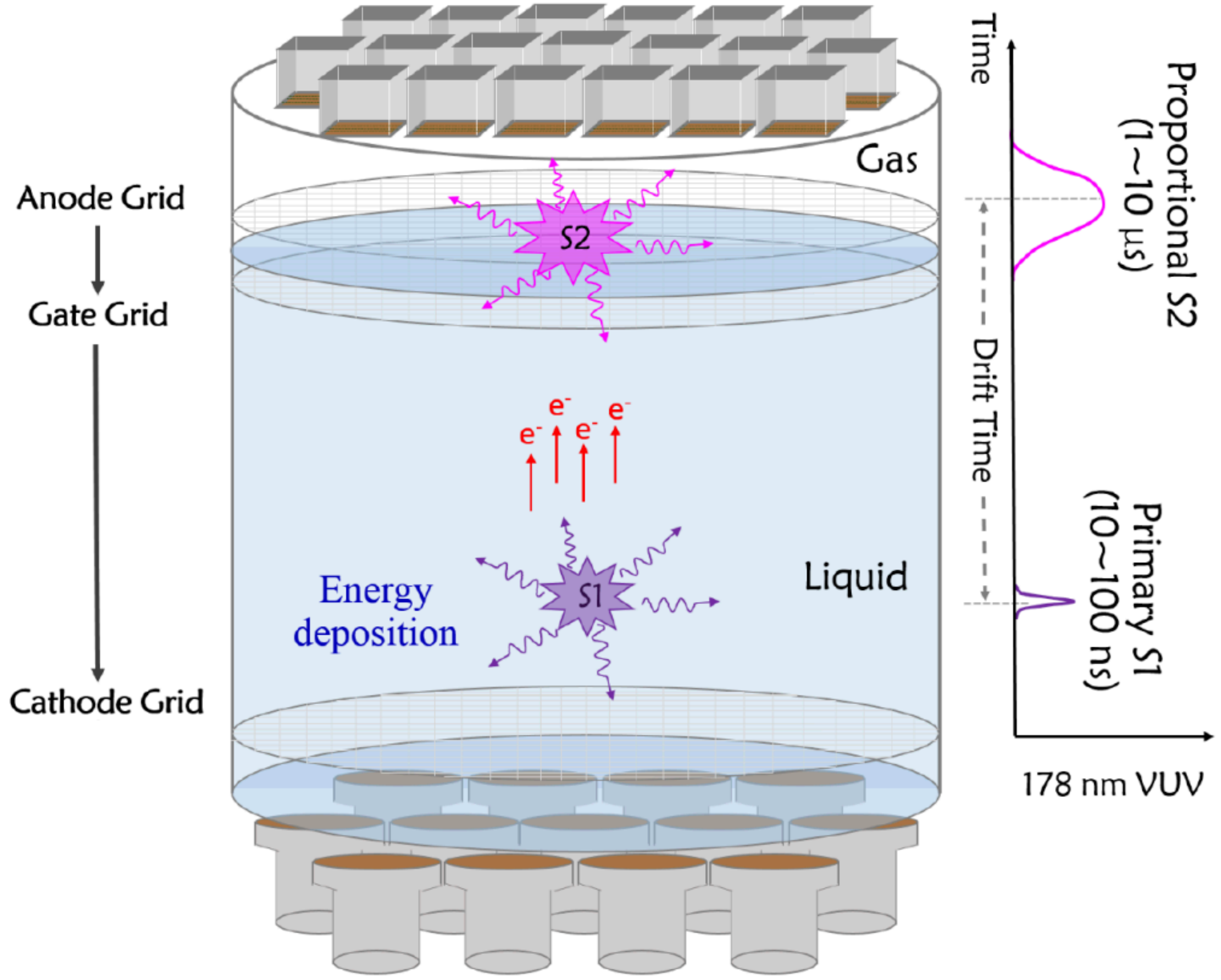
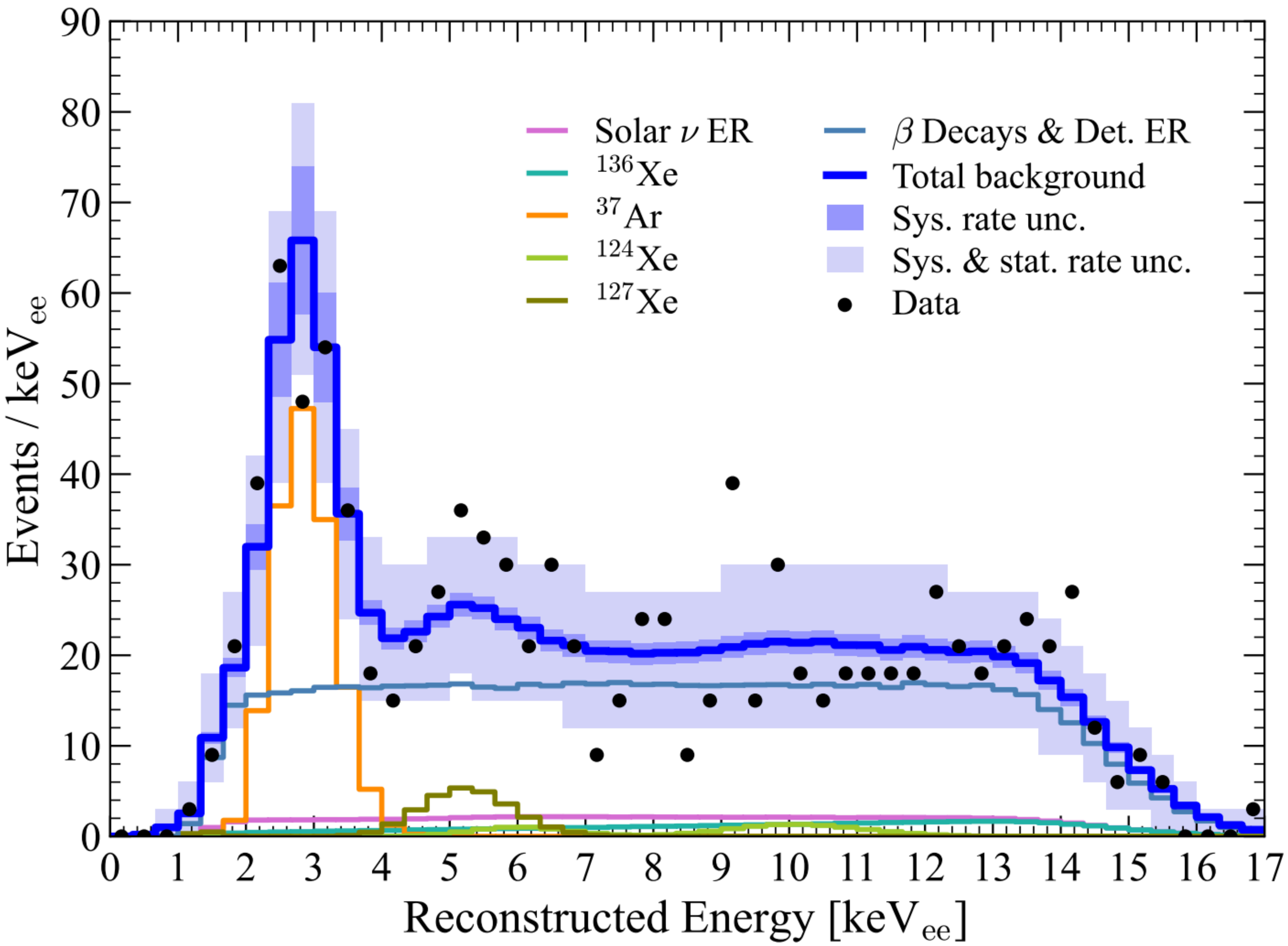


Fig. 1. Working principle of a two-phase TPC.

DARK MATTER DIRECT DETECTION EXPERIMENTS

LUX-ZEPLIN (LZ)
DARK MATTER SEARCH

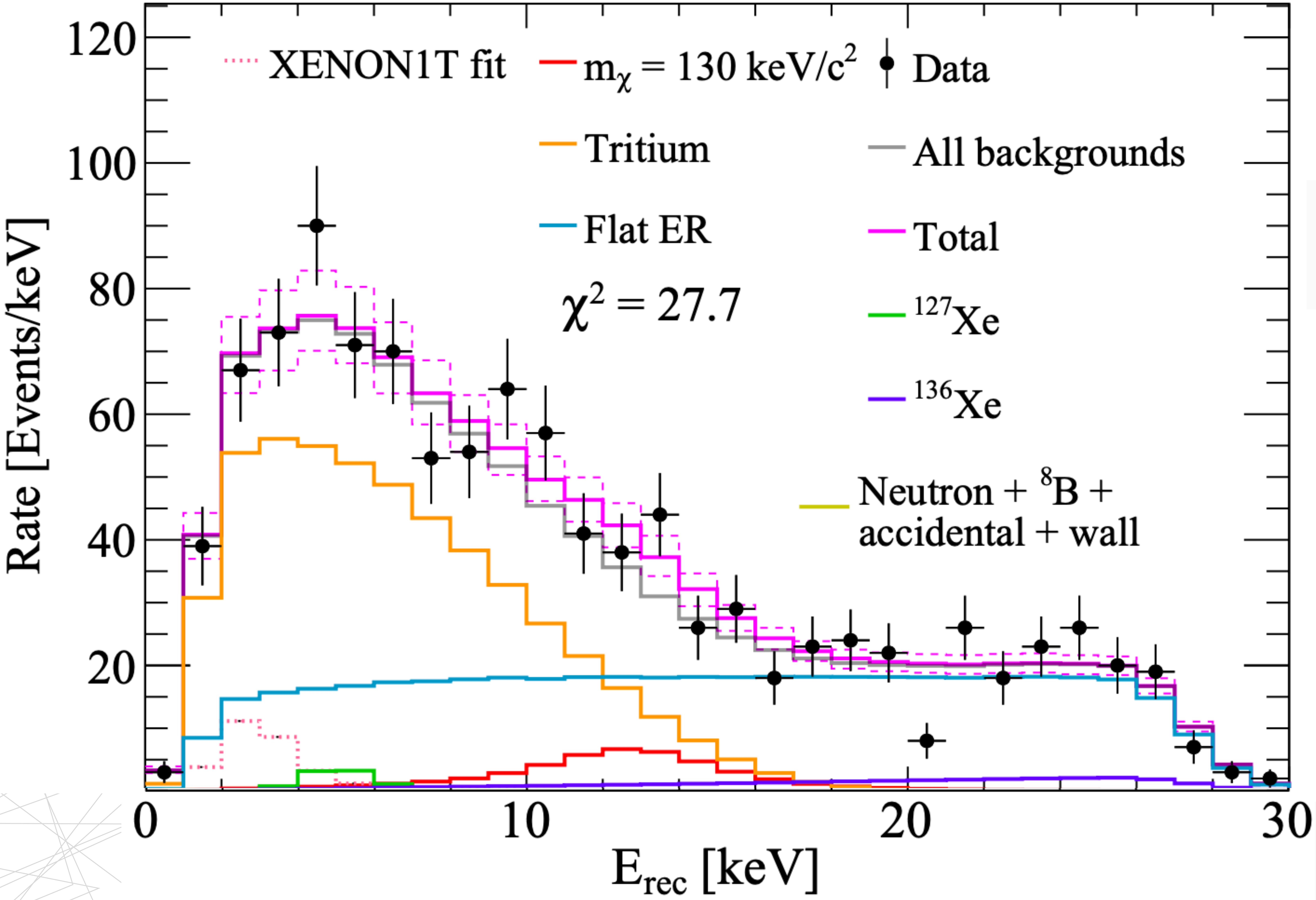
~ 27 solar $\nu\ (ER)$



DARK MATTER DIRECT DETECTION EXPERIMENTS

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

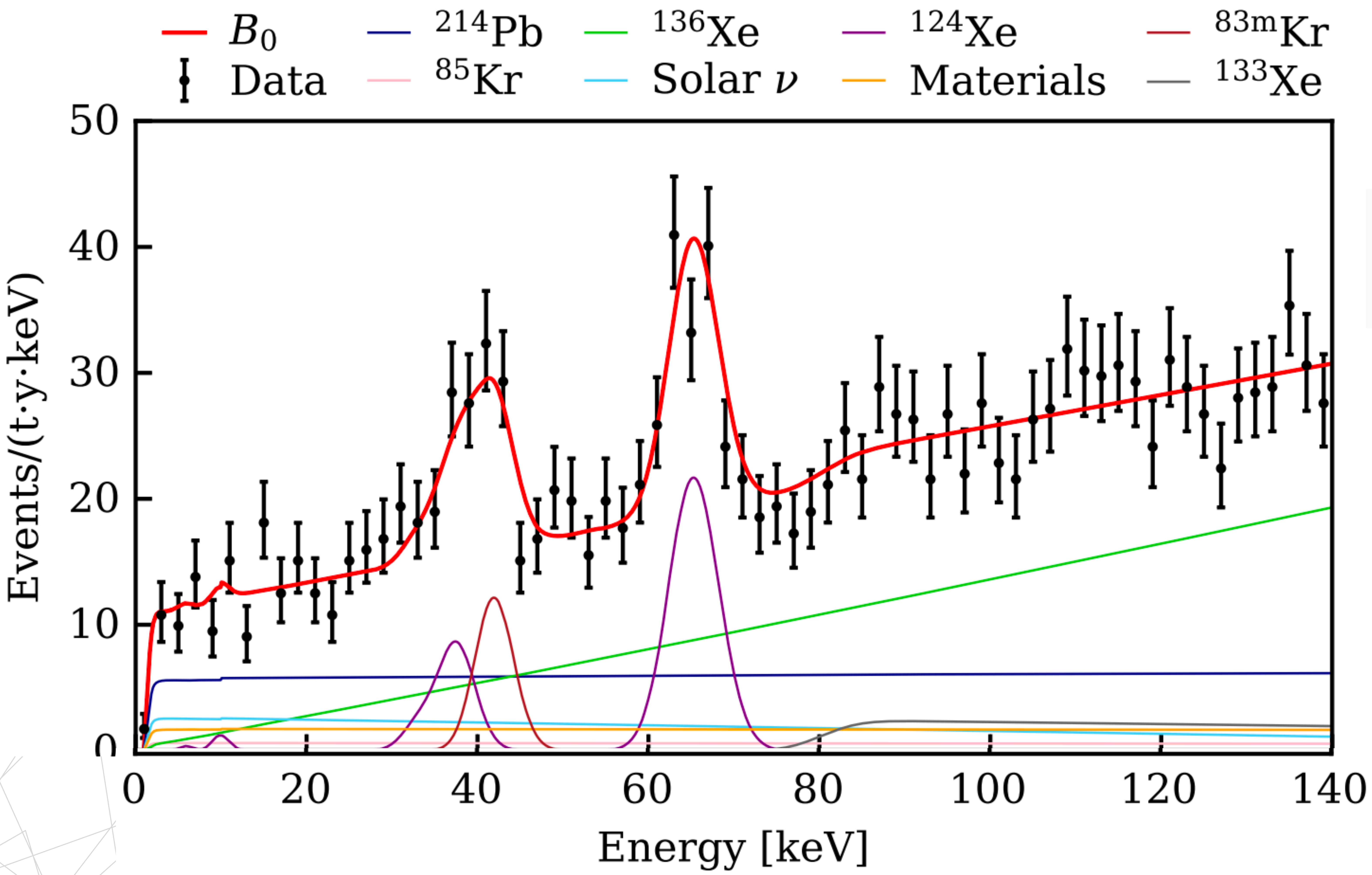
$\sim 36\,\text{solar}\,\nu\,(ER)$



DARK MATTER DIRECT DETECTION EXPERIMENTS

XENON

~ 300 solar $\nu\,(ER)$



Neutrino-electron cross section

$$\frac{d\sigma}{dT}(\nu_\alpha + e^- \to \nu_\beta + e^-) = \frac{G_F^2 m_e}{2\pi}\left[A_{\alpha\beta} + 2B_{\alpha\beta}\left(1-\frac{T}{E_\nu}\right) + C_{\alpha\beta}\left(1-\frac{T}{E_\nu}\right)^2 + D_{\alpha\beta}\frac{m_e T}{4E_\nu^2}\right]$$

$$A = \frac{1}{4}\left|\epsilon^A + \epsilon^V - \tilde{\epsilon}^A - \tilde{\epsilon}^V + 2g^L\right|^2 + \frac{1}{8}\left|\epsilon^S + i\tilde{\epsilon}^P\right|^2 + \frac{1}{8}\left|\epsilon^P + i\tilde{\epsilon}^S\right|^2$$
$$+\left|\epsilon^T - i\tilde{\epsilon}^T\right|^2 + \frac{1}{2}\mathrm{Re}\left[\left(\epsilon^T - i\tilde{\epsilon}^T\right)^*\left(\epsilon^P + i\tilde{\epsilon}^S - \epsilon^S - i\tilde{\epsilon}^P\right)\right],$$

$$B = -\frac{1}{8}\left|\epsilon^P + i\tilde{\epsilon}^S\right|^2 - \frac{1}{8}\left|\epsilon^S + i\tilde{\epsilon}^P\right|^2 + \left|\epsilon^T - i\tilde{\epsilon}^T\right|^2,$$

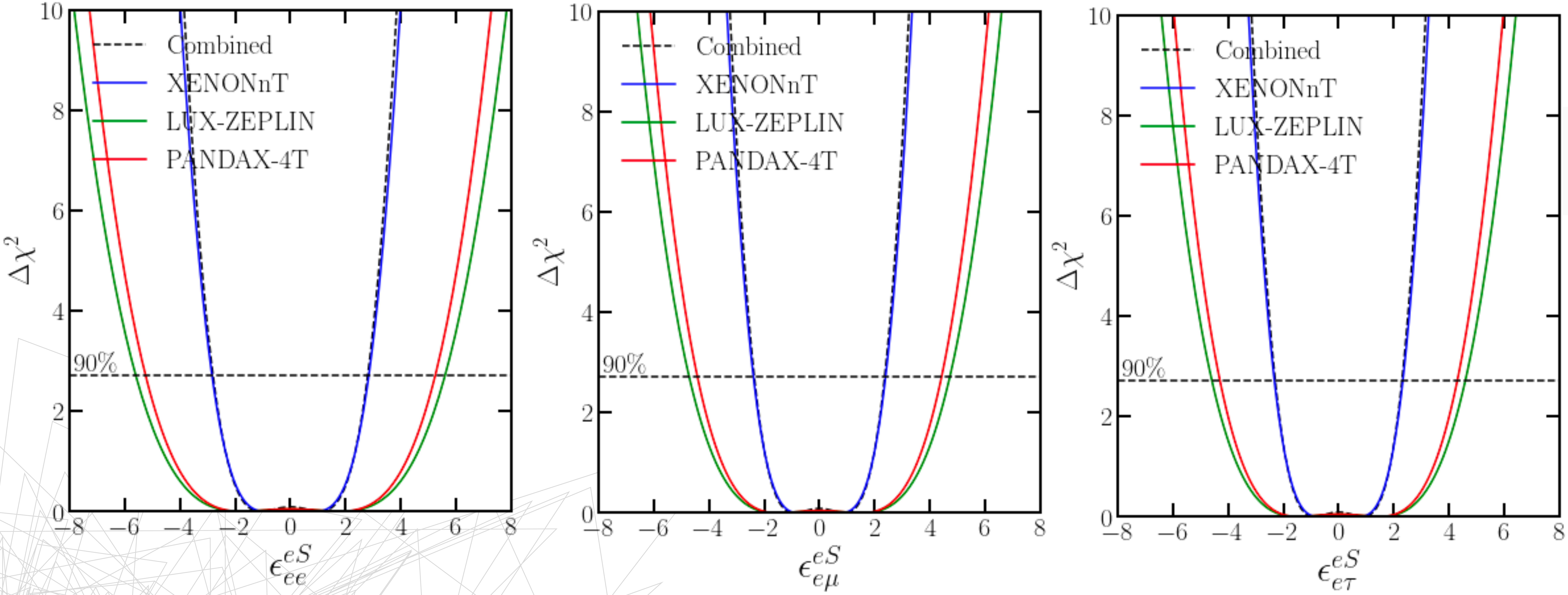
$$C = \frac{1}{4}\left|\epsilon^A + \tilde{\epsilon}^A - \epsilon^V - \tilde{\epsilon}^V - 2g^R\right|^2 + \frac{1}{8}\left|\epsilon^S + i\tilde{\epsilon}^P\right|^2 + \frac{1}{8}\left|\epsilon^P + i\tilde{\epsilon}^S\right|^2$$
$$+\left|\epsilon^T - i\tilde{\epsilon}^T\right|^2 - \frac{1}{2}\mathrm{Re}\left[\left(\epsilon^T - i\tilde{\epsilon}^T\right)^*\left(\epsilon^P + i\tilde{\epsilon}^S - \epsilon^S - i\tilde{\epsilon}^P\right)\right],$$

$$D = \mathrm{Re}\left[\left(\epsilon^A + \epsilon^V - \tilde{\epsilon}^A - \tilde{\epsilon}^V + 2g^L\right)\left(\epsilon^A + \tilde{\epsilon}^A - \epsilon^V - \tilde{\epsilon}^V - 2g^R\right)^*\right]$$
$$-4\left|\epsilon^T - i\tilde{\epsilon}^T\right|^2 + \left|\epsilon^S + i\tilde{\epsilon}^P\right|^2.$$

RESULTS FOR ε^{eS}

In collaboration with:

Jesus Celestino, Francisco Escrihuela,
Omar Miranda, Ricardo Sánchez



RESULTS FOR ε^{eT}

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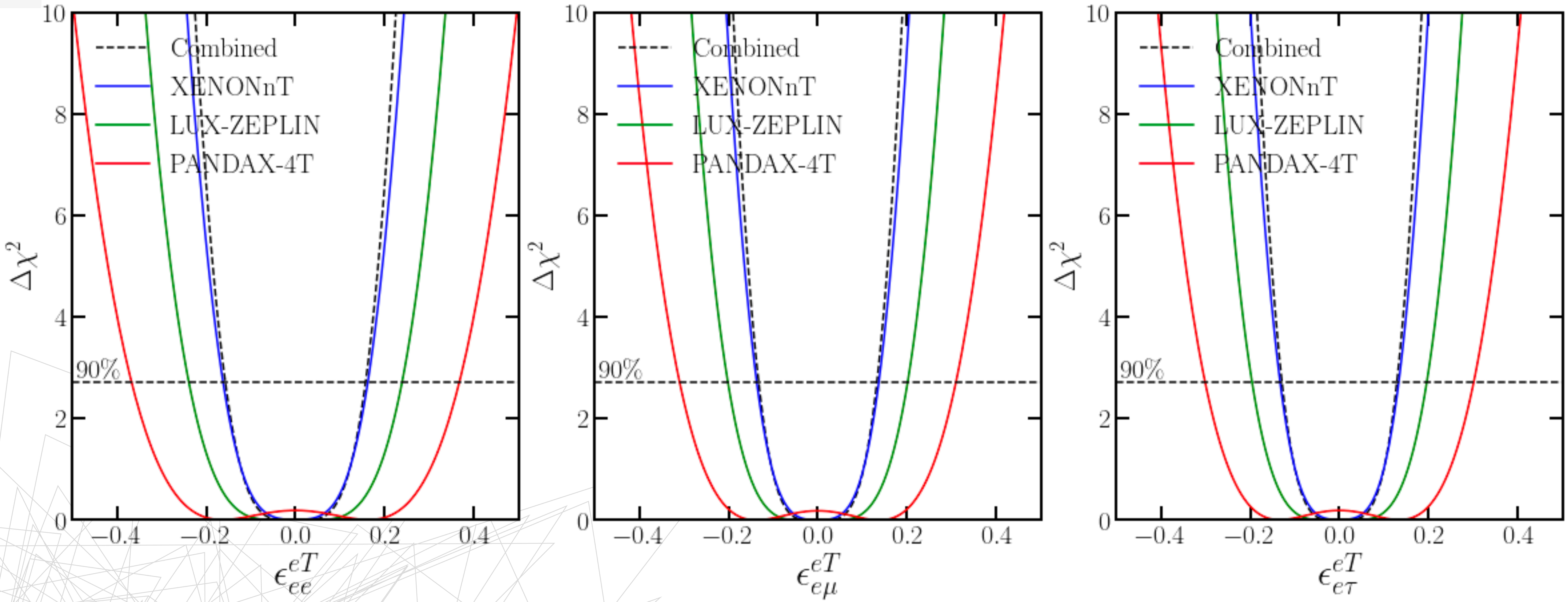
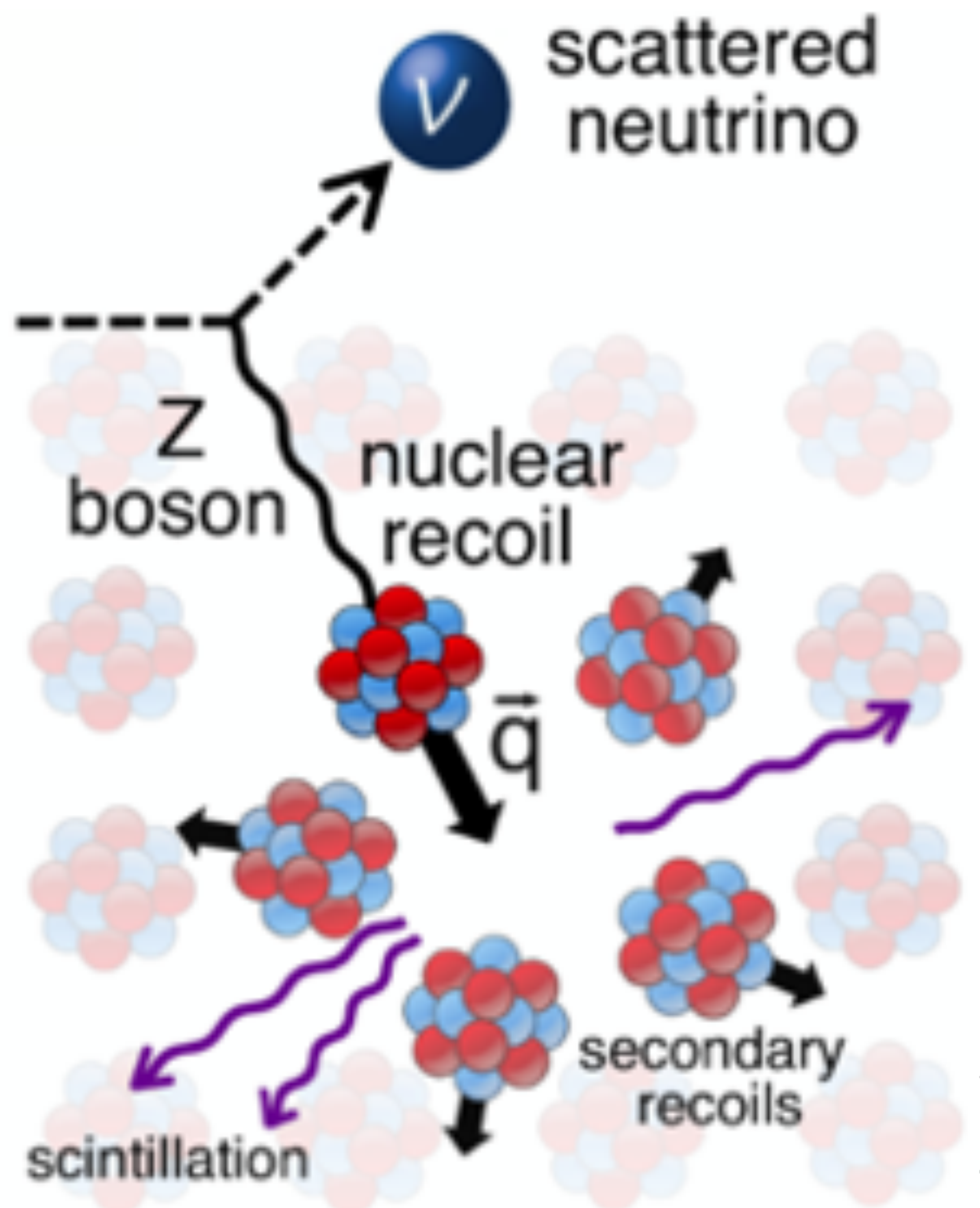
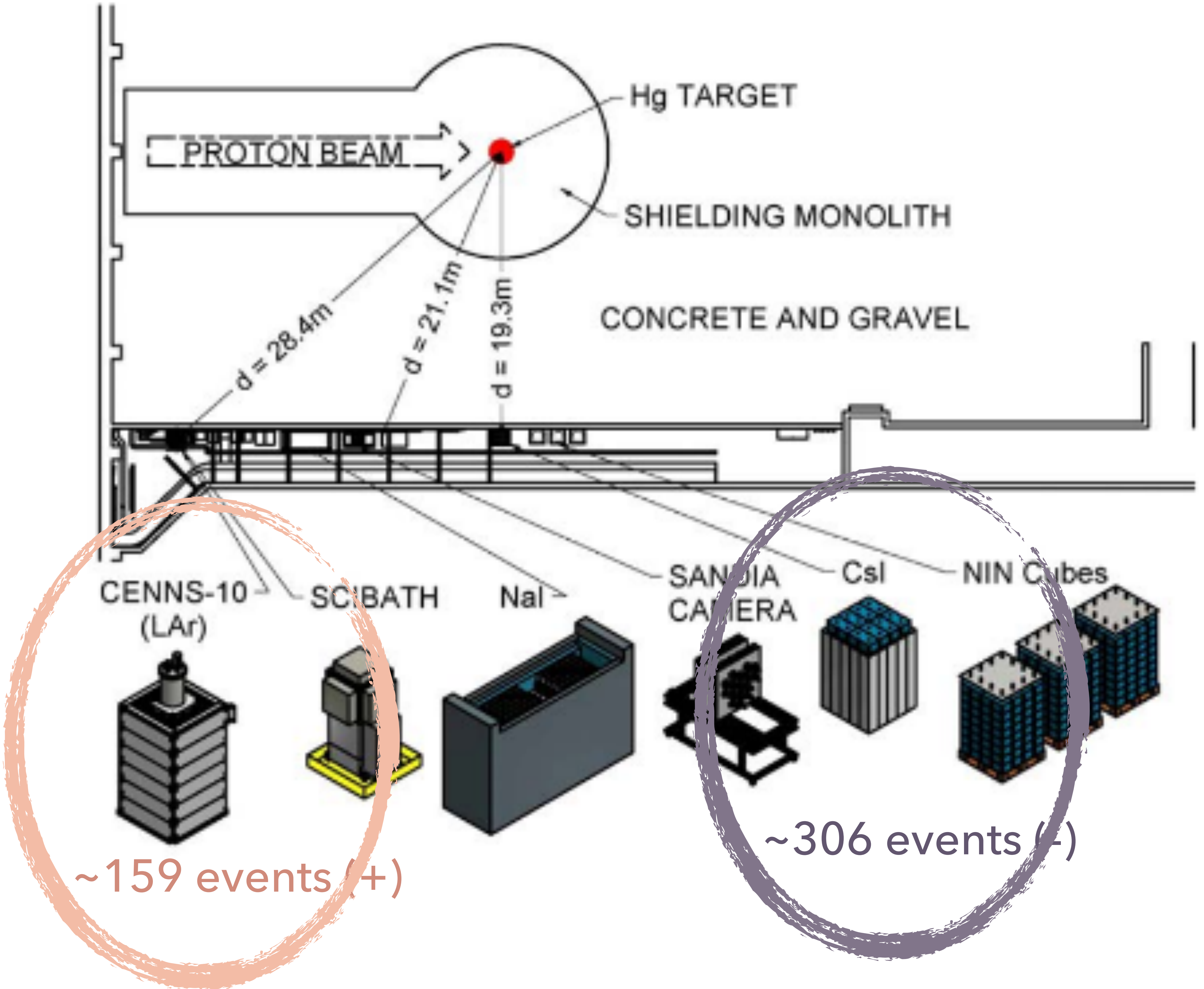


COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING EXPERIMENTS



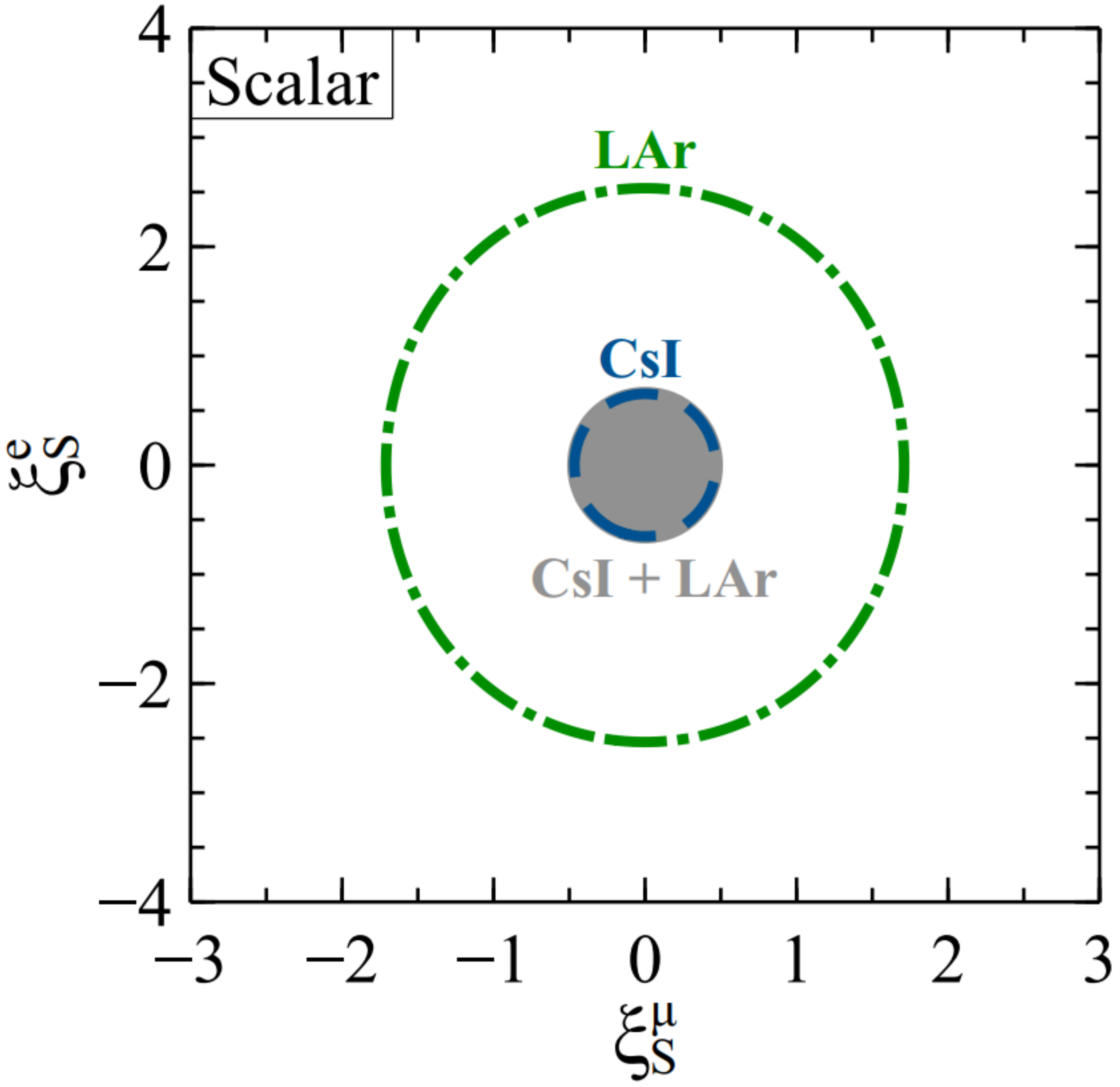
COHERENT SNS

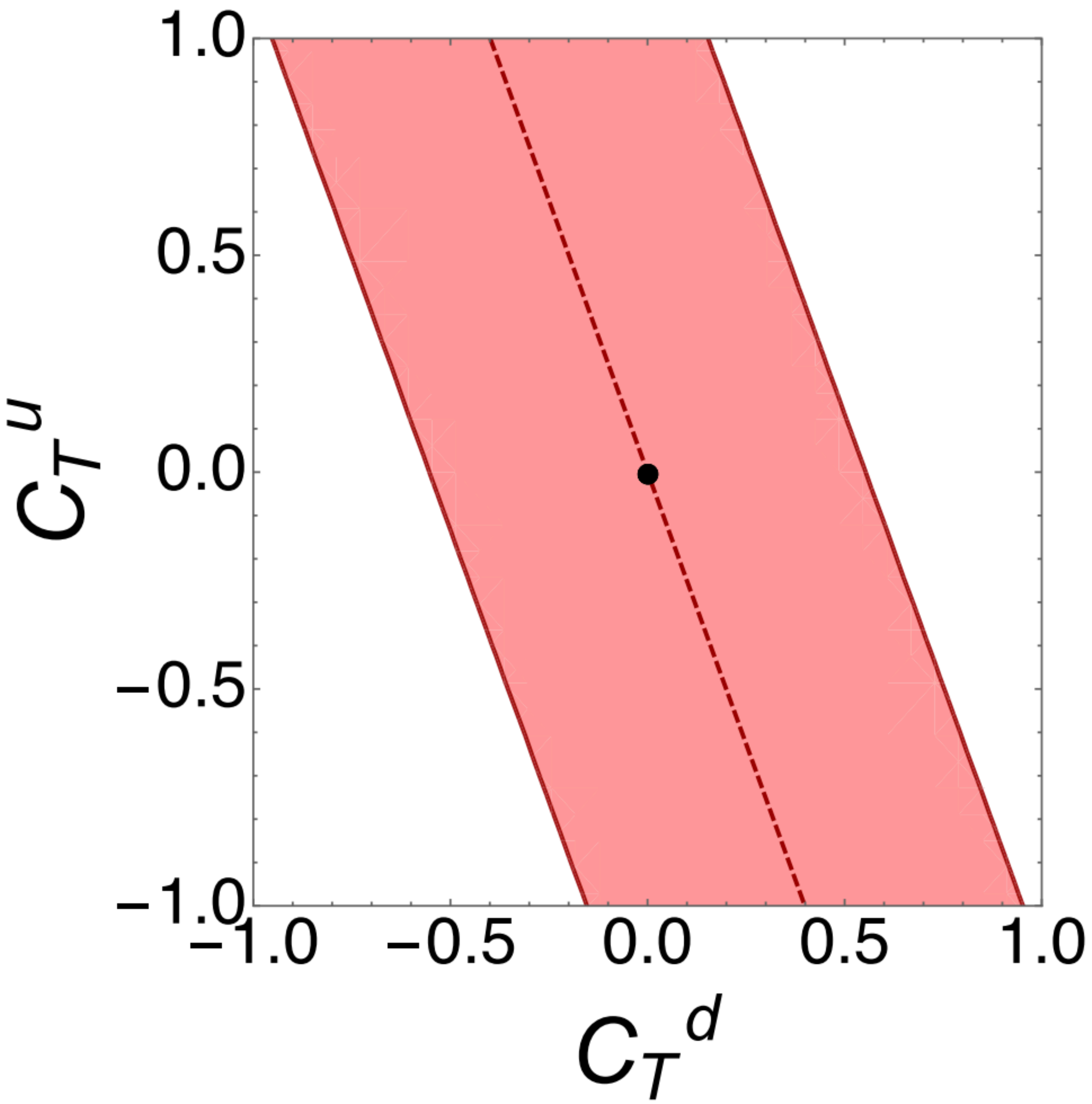


COHERENT Collaboration, Science 357,1123 (2017) & Phys.Rev.Lett. 126 (2021) 1, 012002

CEvNS cross section

$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2 M}{\pi} F^2(|\vec{q}|^2) \sum_{\beta=e,\mu,\tau} \left[\left|\xi^S_{\alpha\beta}\right|^2 \frac{MT}{8E_\nu^2} + \left|\frac{\xi^V_{\alpha\beta}}{2} + Q_{W,\alpha}\delta_{\alpha\beta}\right|^2 \left(1 - \frac{MT}{2E_\nu^2}\right) + 2\left|\xi^T_{\alpha\beta}\right|^2 \left(1 - \frac{MT}{4E_\nu^2}\right) - \frac{1}{2} R_{\alpha\beta}\frac{T}{E_\nu} \right]$$





L.J. Flores, Newton Nath, Eduardo Peinado (2021)
Phys.Rev.D 105 (2022) 5, 055010 • e-Print: 2112.05103 [hep-ph]

D. Aristizabal Sierra, Valentina De Romeri, N. Rojas (2018)
Phys.Rev.D 98 (2018) 075018 • e-Print: 1806.07424 [hep-ph]

GNI couplings

From Lagrangian

C's and D's

$$C^S_{\alpha\beta} = \sum_{q=u,d}\left(Z\,\frac{m_p}{m_q} f^p_q + N\,\frac{m_n}{m_q} f^n_q\right) C^{qS}_{\alpha\beta}\,,$$

$$C^V_{\alpha\beta} = (2Z+N)\, C^{uV}_{\alpha\beta} + (Z+2N)\, C^{dV}_{\alpha\beta}\,,$$

$$C^T_{\alpha\beta} = \sum_{q=u,d}\left(Z\delta^p_q + N\delta^n_q\right) C^{qT}_{\alpha\beta}\,,$$

$$\xi^S_{\alpha\beta}{}^2 = C^S_{\alpha\beta}{}^2 + D^P_{\alpha\beta}{}^2$$

$$\xi^V_{\alpha\beta}{}^2 = C^V_{\alpha\beta}{}^2 + D^A_{\alpha\beta}{}^2$$

$$\xi^T_{\alpha\beta}{}^2 = C^T_{\alpha\beta}{}^2$$

COMMON PARAMETRIZATION

For Scalar interactions:

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{\pi} F^2(|\vec{q}|^2) \left[\left| \sum_{q=u,d} \left(Z \frac{m_p}{m_q} f_q^p + N \frac{m_n}{m_q} f_q^n \right) \left(\varepsilon_{\alpha\beta}^{qS} + \tilde{\varepsilon}_{\alpha\beta}^{qS} \right) \right|^2 + \left| \sum_{q=u,d} \left(Z \frac{m_p}{m_q} f_q^p + N \frac{m_n}{m_q} f_q^n \right) \left(\varepsilon_{\alpha\beta}^{qS} - \tilde{\varepsilon}_{\alpha\beta}^{qS} \right) \right|^2 \right] \frac{MT}{8E_\nu^2},$$

For Tensor interactions:

$$\frac{d\sigma}{dT} = \frac{2G_F^2 M}{\pi} F^2(|\vec{q}|^2) \left[4 \left| \sum_{q=u,d} \left(Z \delta_q^p + N \delta_q^n \right) \left(\varepsilon_{\alpha\beta}^{qT} + \tilde{\varepsilon}_{\alpha\beta}^{qT} \right) \right|^2 + 4 \left| \sum_{q=u,d} \left(Z \delta_q^p + N \delta_q^n \right) \left(\varepsilon_{\alpha\beta}^{qT} - \tilde{\varepsilon}_{\alpha\beta}^{qT} \right) \right|^2 \right] \left(1 - \frac{MT}{4E_\nu^2} \right),$$

RESULTS FOR ε^{qS}

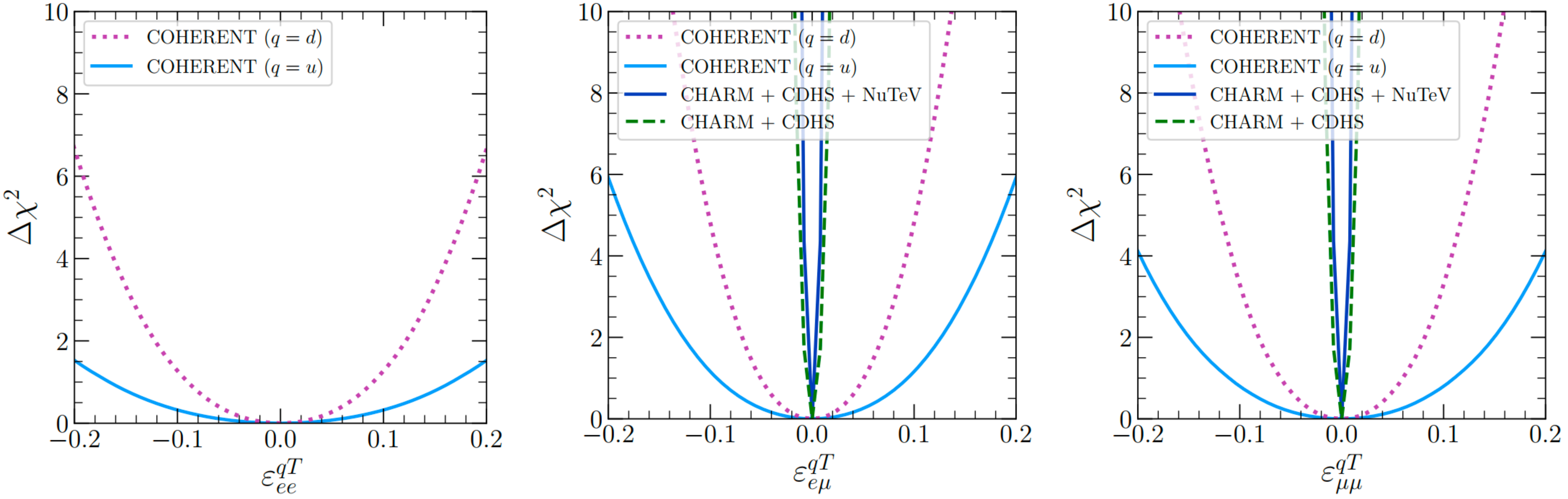
In collaboration with:

Omar Miranda, Gonzalo Sánchez

RESULTS FOR ε^{qT}

In collaboration with:

Omar Miranda, Gonzalo Sánchez



Comparing with previous limits

Experiments		Scalar	Pseudoscalar		Tensor
e^-e^+ + TEXONO	$\|\varepsilon^{eS}_{ee}\| < 2.82$	$\|\epsilon^{e,S}_{ee}\| < 0.38$	$\|\epsilon^{e,P}_{ee}\| < 0.40$	$\|\varepsilon^{eT}_{ee}\| < 0.16$	$\|\epsilon^{e,T}_{ee}\| < 0.07$
e^-e^+ + CHARM-II	$\|\varepsilon^{eS}_{\mu\mu}\| < 4.35$	$\|\epsilon^{e,X}_{\mu\mu}\| < 0.31$		$\|\varepsilon^{eT}_{\mu\mu}\| < 0.24$	$\|\epsilon^{e,T}_{\mu\mu}\| < 0.03$
e^-e^+	$\|\varepsilon^{eS}_{\tau\tau}\| < 3.98$	$\|\epsilon^{e,X}_{\tau\tau}\| < 0.40$		$\|\varepsilon^{eT}_{\tau\tau}\| < 0.22$	$\|\epsilon^{e,T}_{\tau\tau}\| < 0.12$
e^-e^+ + TEXONO + CHARM-II	$\|\varepsilon^{eS}_{e\mu}\| < 2.34$	$\|\epsilon^{e,S}_{e\mu}\| < 0.25$	$\|\epsilon^{e,P}_{e\mu}\| < 0.25$	$\|\varepsilon^{eT}_{e\mu}\| < 0.13$	$\|\epsilon^{e,T}_{e\mu}\| < 0.03$
e^-e^+ + TEXONO	$\|\varepsilon^{eS}_{e\tau}\| < 2.28$	$\|\epsilon^{e,S}_{e\tau}\| < 0.28$	$\|\epsilon^{e,P}_{e\tau}\| < 0.29$	$\|\varepsilon^{eT}_{e\tau}\| < 0.13$	$\|\epsilon^{e,T}_{e\tau}\| < 0.07$
e^-e^+ + CHARM-II	$\|\varepsilon^{eS}_{\mu\tau}\| < 2.94$	$\|\epsilon^{e,X}_{\mu\tau}\| < 0.25$		$\|\varepsilon^{eT}_{\mu\tau}\| < 0.16$	$\|\epsilon^{e,T}_{\mu\tau}\| < 0.03$
CHARM$-e$	$\|\varepsilon^{qS}_{ee}\| < 0.026$	$\|\epsilon^{q,X}_{ee}\| < 1.9$		$\|\varepsilon^{dT}_{ee}\| < 0.13$	$\|\epsilon^{q,T}_{ee}\| < 0.13$
CHARM + CDHS (+ NuTeV)	$\|\varepsilon^{qS}_{\mu\mu}\| < 0.018$	$\|\epsilon^{q,X}_{\mu\mu}\| < 0.15\,(0.1)$		$\|\varepsilon^{dT}_{\mu\mu}\| < 0.09$	$\|\epsilon^{q,T}_{\mu\mu}\| < 0.01\,(0.006)$
HARM$-e$ + CHARM + CDHS (+ NuTeV)	$\|\varepsilon^{qS}_{e\mu}\| < 0.015$	$\|\epsilon^{q,X}_{e\mu}\| < 0.15\,(0.1)$		$\|\varepsilon^{dT}_{e\mu}\| < 0.08$	$\|\epsilon^{q,T}_{e\mu}\| < 0.01\,(0.006)$
CHARM$-e$		$\|\epsilon^{q,X}_{e\tau}\| < 1.9$			$\|\epsilon^{q,T}_{e\tau}\| < 0.13$
CHARM + CDHS (+ NuTeV)		$\|\epsilon^{q,X}_{\mu\tau}\| < 0.15\,(0.1)$			$\|\epsilon^{q,T}_{\mu\tau}\| < 0.01\,(0.006)$

SUMMARY

- So far, no evidence of nonzero GNI couplings
- Dark matter experiments :
  - can improve current TENSOR GNI with electron recoils
  - will soon provide insights of GNI with nuclear recoils
- CEvNS experiments are better at constraining SCALAR GNI

Thank you

BACKUP

$$\mathcal{L} = -\frac{G_F}{\sqrt{2}} \sum_{\alpha,\beta} \sum_{j=1}^{10} \left(\overset{(\sim)j}{\epsilon} \right)_{\alpha\beta} \left(\overline{\nu}^{\alpha} \mathcal{O}_j \nu^{\beta} \right) \left(\overline{e} \mathcal{O}'_j e \right) ,$$

j	$\overset{(\sim)}{\epsilon}_j$	$\mathcal{O}_j$	$\mathcal{O}'_j$
1	ϵ_L	$\gamma_\mu(\mathbb{1} - \gamma^5)$	$\gamma^\mu(\mathbb{1} - \gamma^5)$
2	$\tilde{\epsilon}_L$	$\gamma_\mu(\mathbb{1} + \gamma^5)$	$\gamma^\mu(\mathbb{1} - \gamma^5)$
3	ϵ_R	$\gamma_\mu(\mathbb{1} - \gamma^5)$	$\gamma^\mu(\mathbb{1} + \gamma^5)$
4	$\tilde{\epsilon}_R$	$\gamma_\mu(\mathbb{1} + \gamma^5)$	$\gamma^\mu(\mathbb{1} + \gamma^5)$
5	ϵ_S	$(\mathbb{1} - \gamma^5)$	$\mathbb{1}$
6	$\tilde{\epsilon}_S$	$(\mathbb{1} + \gamma^5)$	$\mathbb{1}$
7	$-\epsilon_P$	$(\mathbb{1} - \gamma^5)$	γ^5
8	$-\tilde{\epsilon}_P$	$(\mathbb{1} + \gamma^5)$	γ^5
9	ϵ_T	$\sigma_{\mu\nu}(\mathbb{1} - \gamma^5)$	$\sigma^{\mu\nu}(\mathbb{1} - \gamma^5)$
10	$\tilde{\epsilon}_T$	$\sigma_{\mu\nu}(\mathbb{1} + \gamma^5)$	$\sigma^{\mu\nu}(\mathbb{1} + \gamma^5)$

RESULTS FOR ε^{eP}

In collaboration with:

Jesus Celestino, Francisco Escrihuela, Omar Miranda, Ricardo Sánchez