New interactions in Coherent Elastic Neutrino-Nucleus Scattering measurements

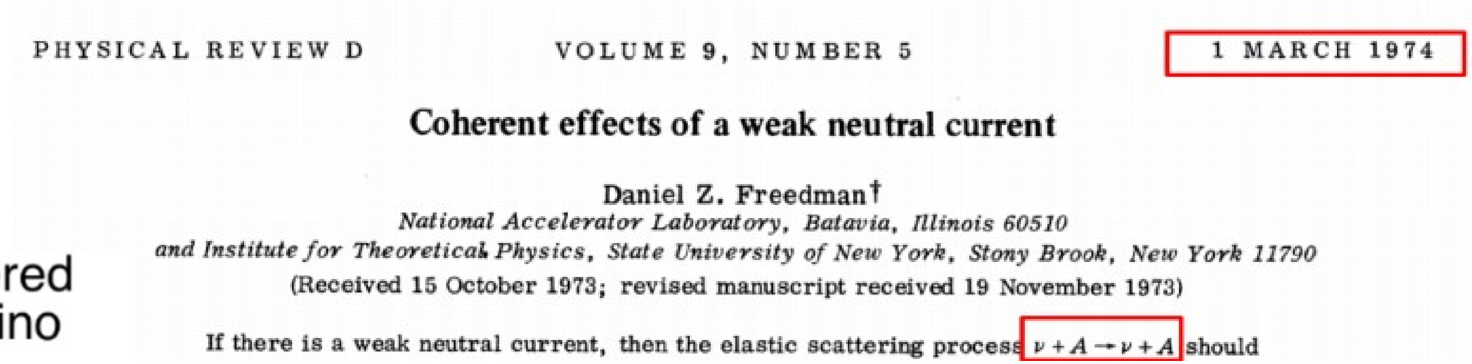
Luis Jorge Flores

In collaboration with E. Peinado and N. Nath

Outline

- Coherent elastic neutrino-nucleus scattering (CEvNS)
- Nonstandard neutrino interactions (NSI)
- U(1)’ producing NSI
- Final remarks

What is CEvNS?


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

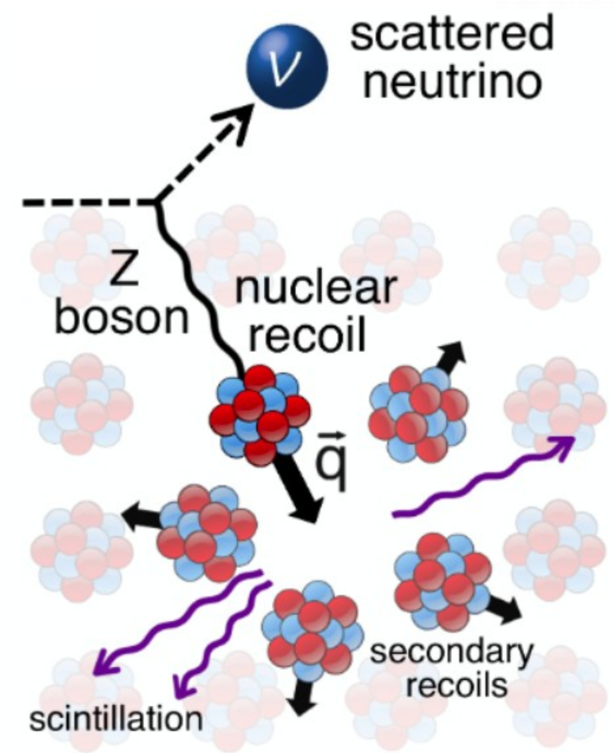
Daniel Z. Freedman†

National Accelerator Laboratory, Batavia, Illinois 60510

and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \rightarrow \nu + A$ should



$$E_\nu \lesssim 50\,\mathrm{MeV}$$

$$QR \ll 1$$

Cross section

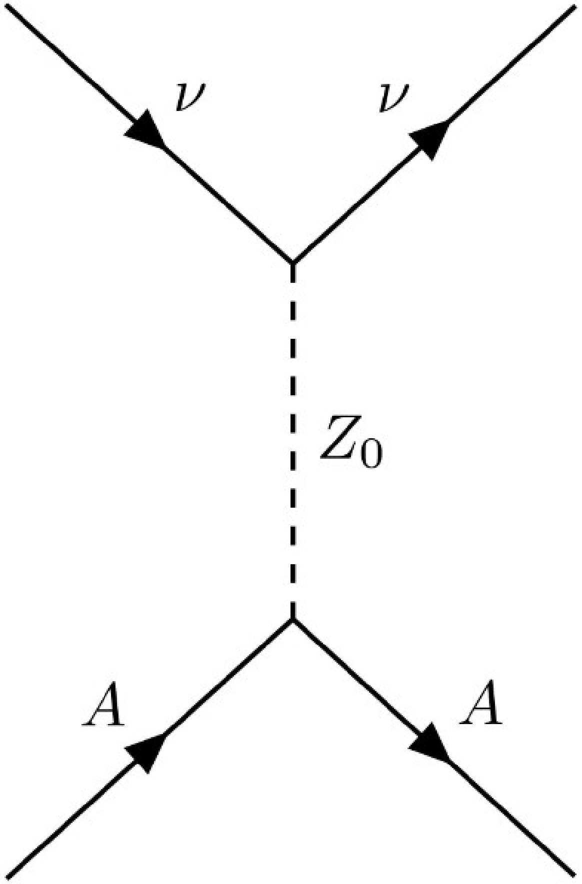
Cross section

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right)$$

$$Q_w^2 = \left[Z g_p^V F_Z(q^2) + N g_n^V F_N(q^2)\right]^2$$

Weak charge

$$\frac{d\sigma}{dT} \propto N^2$$



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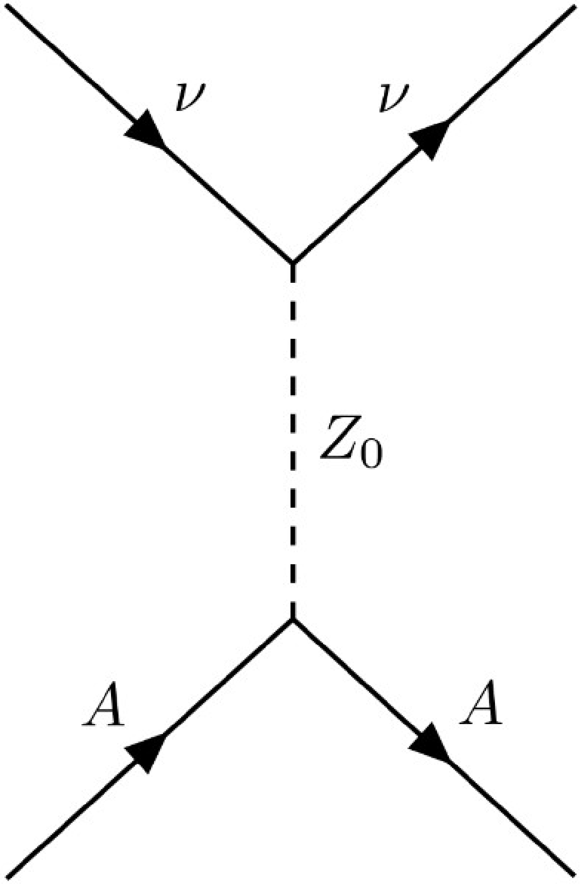

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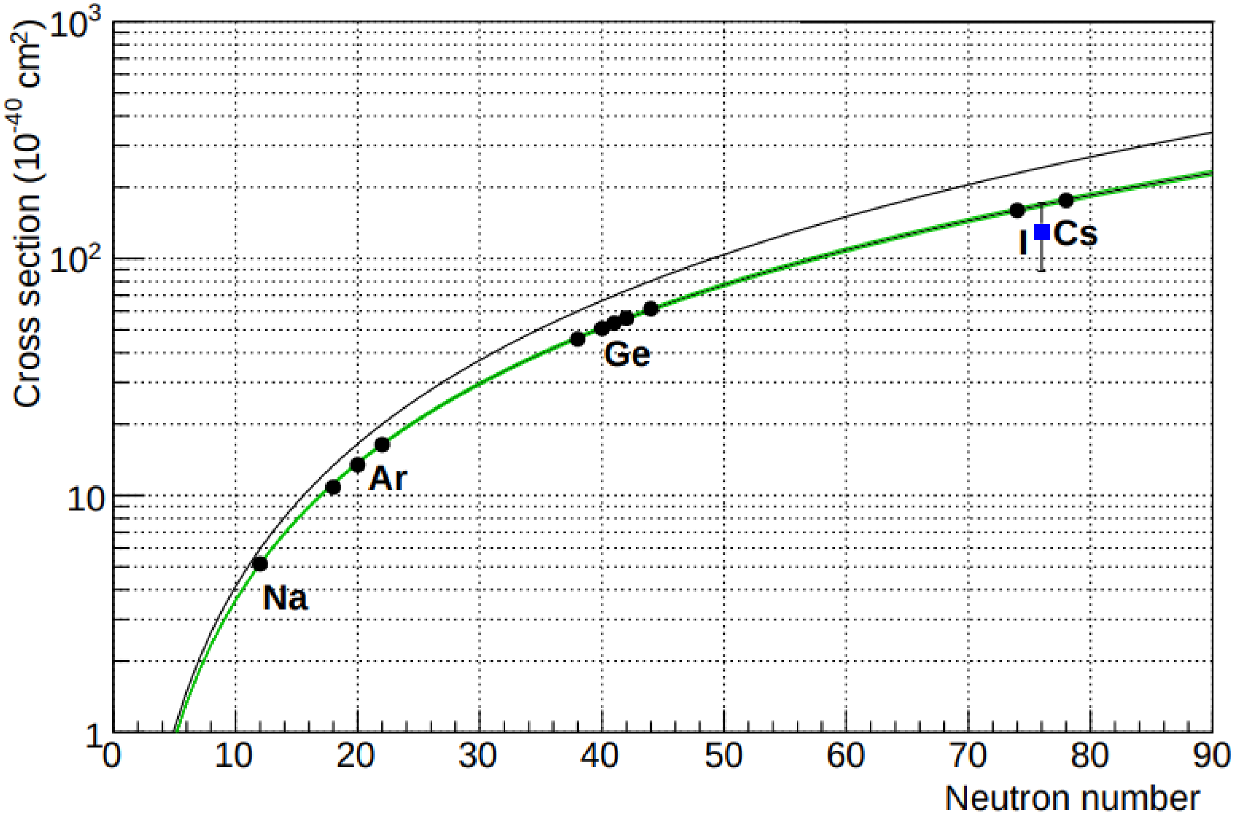

COHERENT Collaboration, Science 357,1123 (2017)

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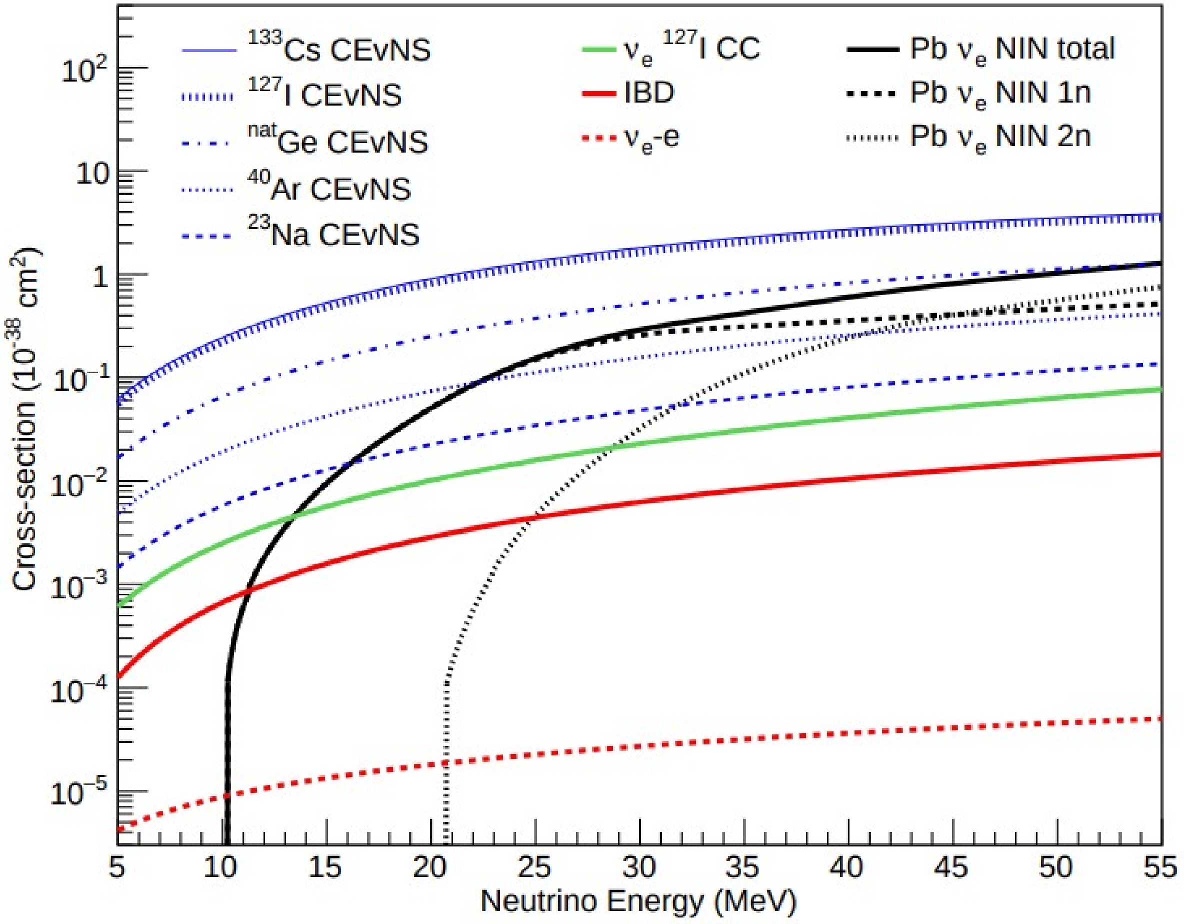
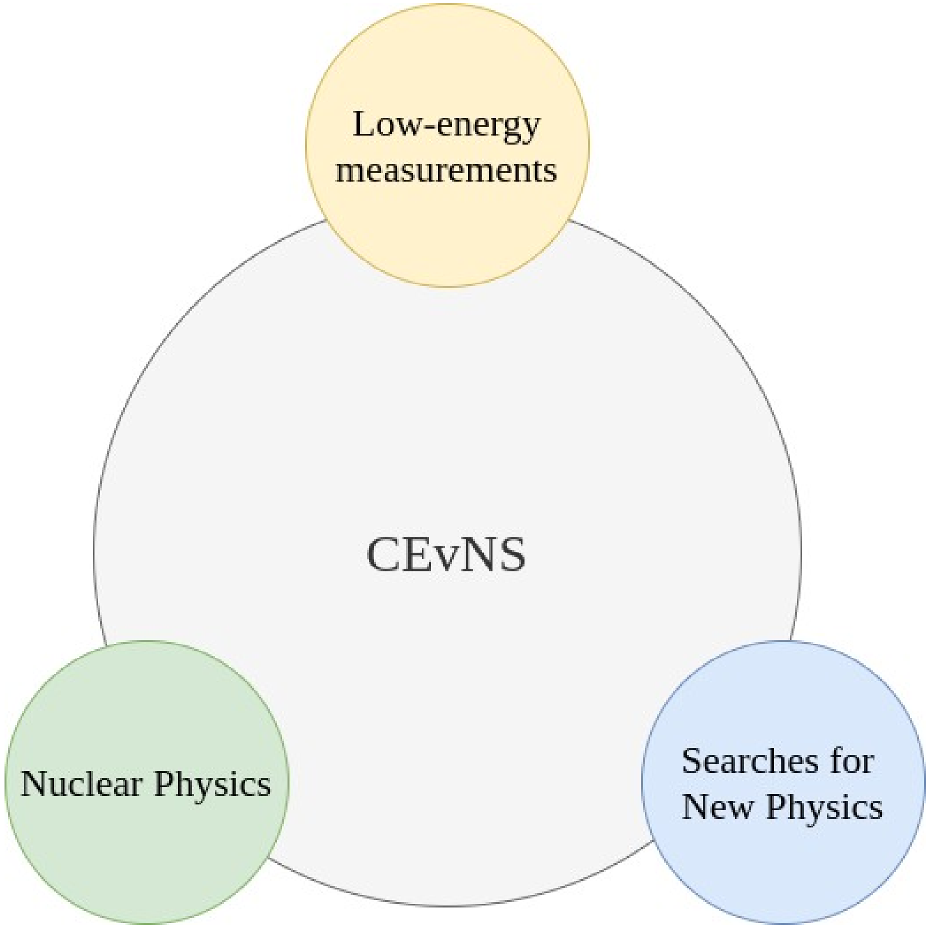


Considerably higher than other processes

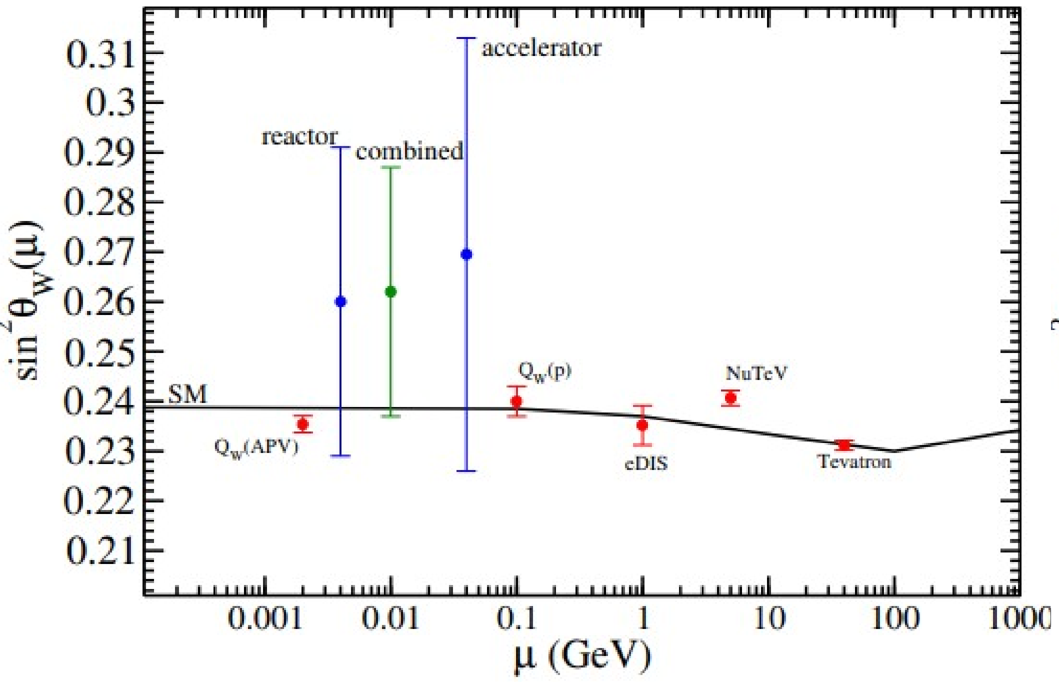
COHERENT Collaboration, Science 357,1123 (2017)

Why is it important?

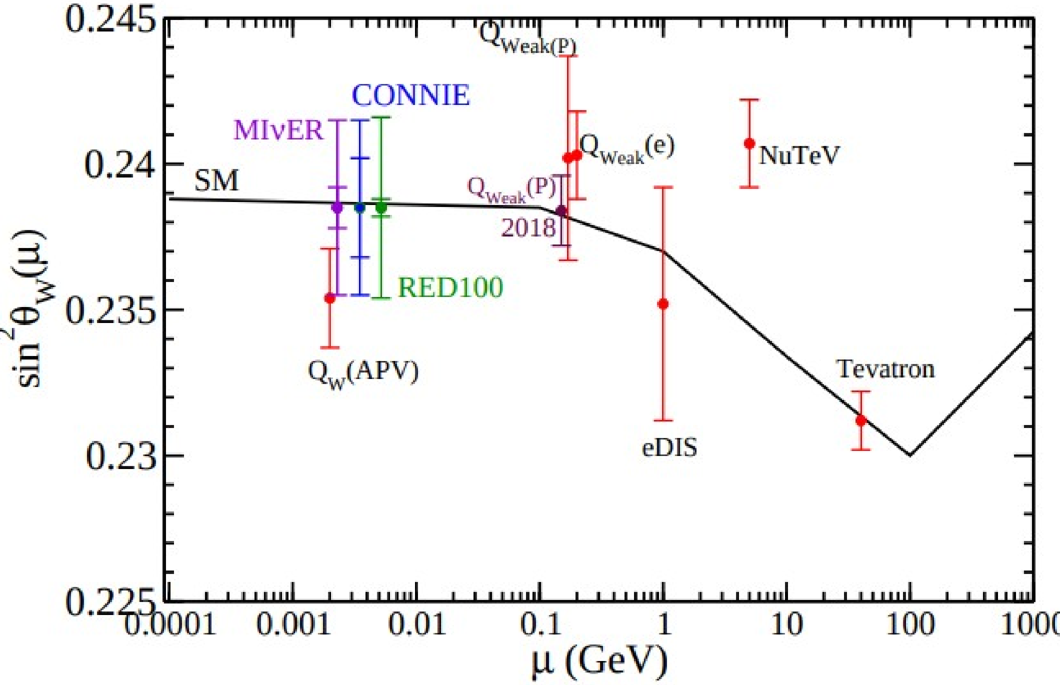


Low-energy measurements

$\nu_e - e$



CEνNS



Cañas, et al, Phys. Lett. B 761, 450 (2016)
Cañas, Garcés, Miranda, Parada, Phys.Lett. B784, 159 (2018)

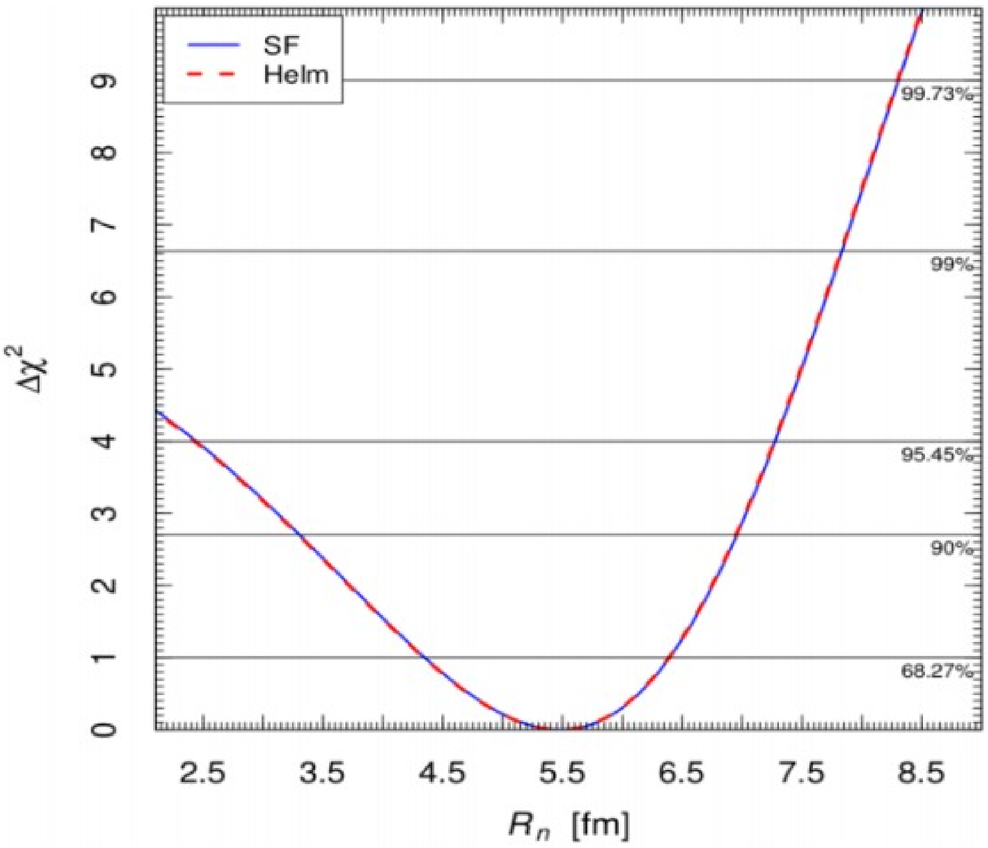
Nuclear physics

Helm form factor

$$F(q^2) = 3\frac{j_1(qR_0)}{qR_0}e^{-q^2s^2/2}$$

Neutron rms radius

$$R_n^2 = \frac{3}{5}R_0^2 + 3s^2$$



R. H. Helm, Phys. Rev. 104, 1466 (1956)
Cadeddu, Giunti, Li, Zhang, Phys. Rev. Lett. 120, 072501 (2018)

Searches for new physics

To name a few:

- Sterile neutrinos
- NSI
- Neutrino magnetic moment
- Dark matter

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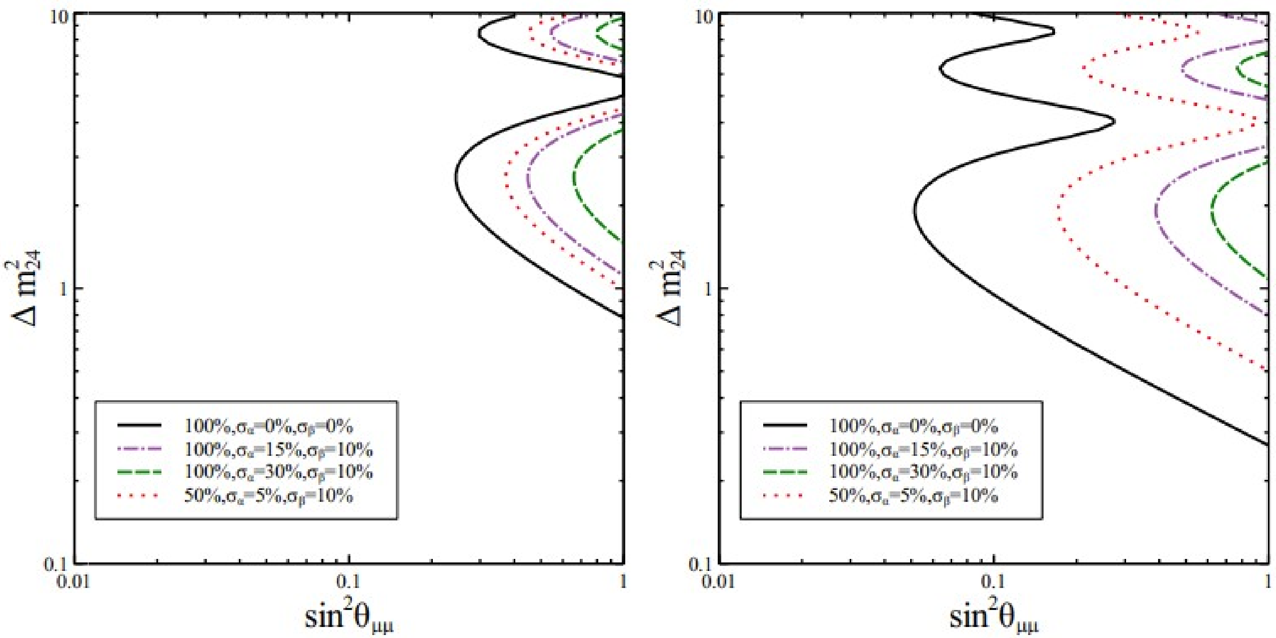

O.G. Miranda, G. Sanchez Garcia and O. Sanders, Adv. High Energy Phys. 2019, 3902819 (2019)

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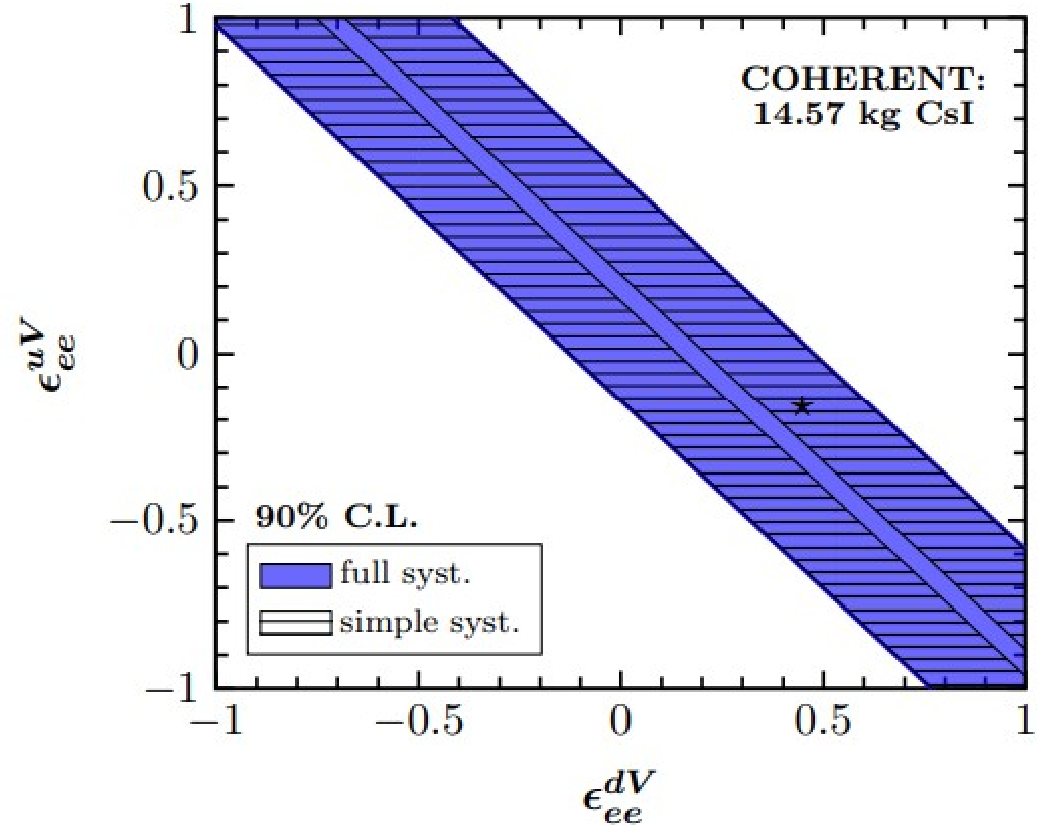

D.K. Papoulias, T. S. Kosmas and Y. Kuno, Front. in Phys. 7, 191 (2019)

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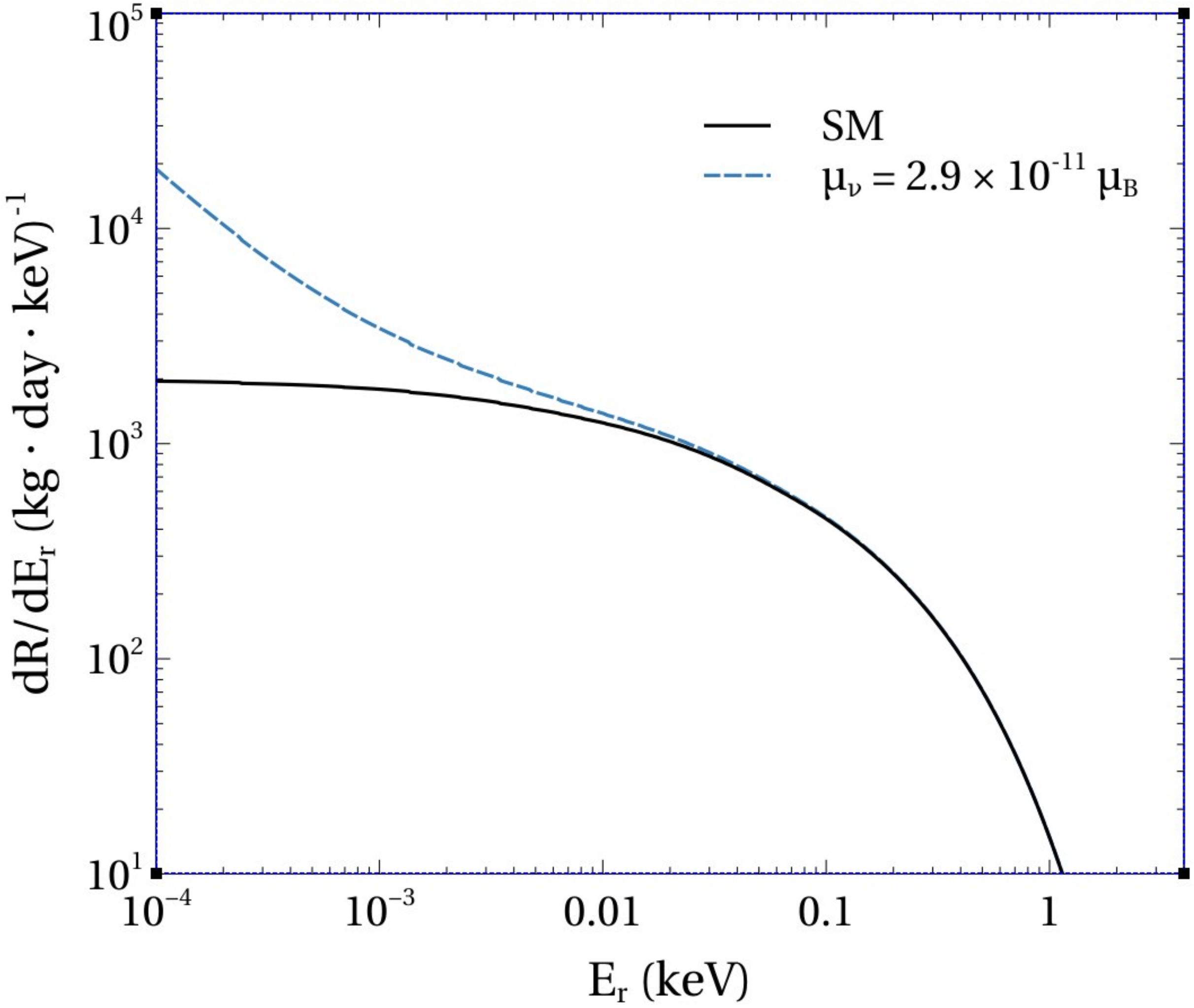
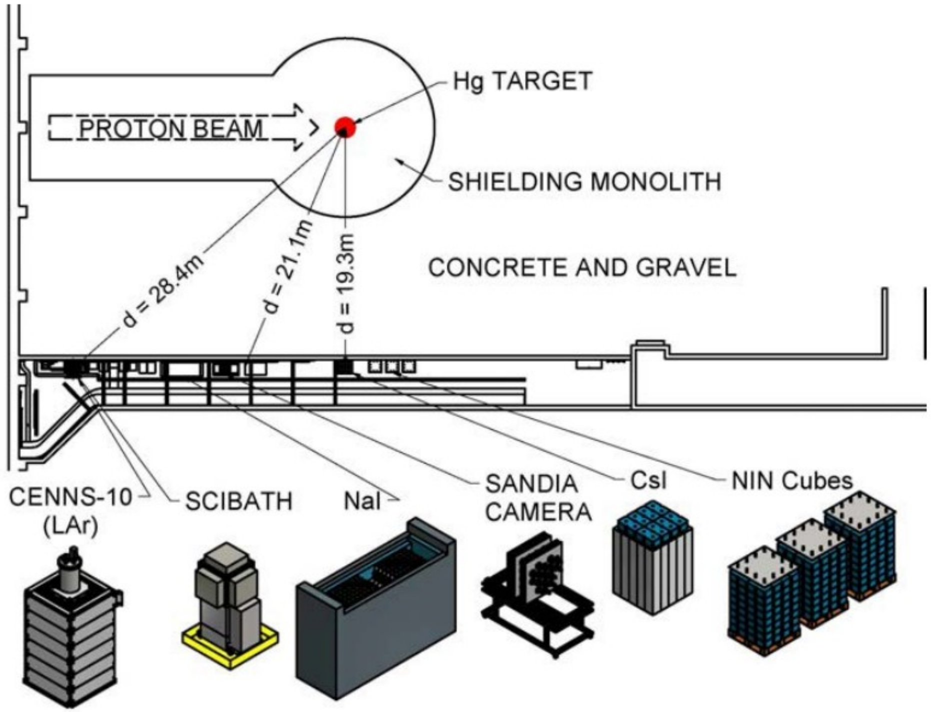


First measurements:



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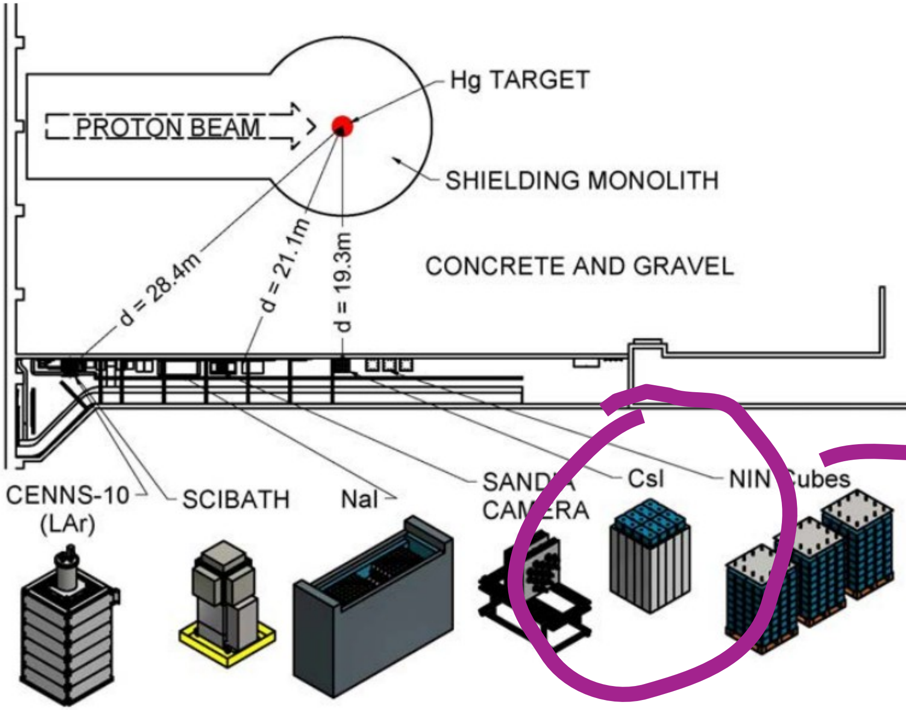


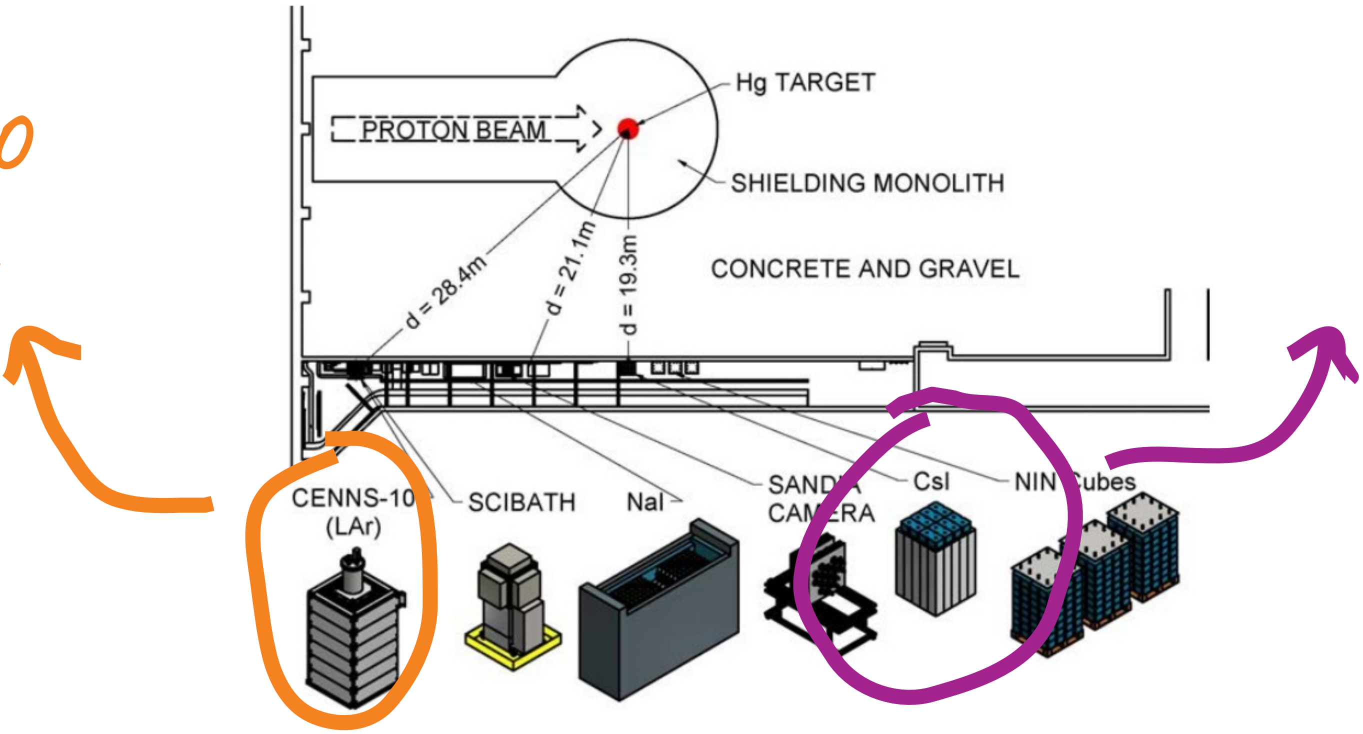
2017

6.7σ

First measurements:

2020

3.5σ



2017

6.7σ

Reactor experiments

Nonstandard neutrino interactions

NSI effective Lagrangian

$$\mathcal{L}_{eff}^{NSI} = -2\sqrt{2}G_F \sum_f \varepsilon_{\alpha\beta}^{f,P} \left[\bar{\nu}_\alpha \gamma^\mu L \nu_\beta\right] \left[\bar{f}\gamma_\mu P f\right]$$

CEvNS with NSI:

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right)$$

$$Q_{w\,\alpha}^2 = \left[Z(g_p^V + \underline{2\epsilon_{\alpha\alpha}^{uV}} + \underline{\epsilon_{\alpha\alpha}^{dV}})F_Z(q^2) + N(g_n^V + \underline{\epsilon_{\alpha\alpha}^{uV}} + \underline{2\epsilon_{\alpha\alpha}^{dV}})F_N(q^2)\right]^2$$

U(1)' producing NSI

U(1)' symmetry

Ingredients:

$U(1)_{B-2L_\alpha-L_\beta}$

3 RH neutrinos

2 U(1)' breaking scalar fields

	L_e	L_μ	L_τ	l_e	l_μ	l_τ	N_1	N_2	N_3	ϕ_1	ϕ_2
$SU(2)_L$	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
$U(1)'$	x_e	x_μ	x_τ	x_e	x_μ	x_τ	x_e	x_μ	x_τ	**1**	**2**

$U(1)'$ charges of the model. The charges x_α, with $\alpha = e, \mu, \tau$, can take the values $x_\alpha = 0, -1, -2$

LJF, N. Nath, E. Peinado, JHEP (2020)

Neutrino mass matrix

x_e	x_μ	x_τ	Neutrino mass matrix	Type	NSI parameters
0	-1	-2	$\begin{pmatrix} 0 & 0 & \times \\ 0 & \times & \times \\ \times & \times & \times \end{pmatrix}$	A_1	$\varepsilon_{\mu\mu}$ & $\varepsilon_{\tau\tau}$
0	-2	-1	$\begin{pmatrix} 0 & \times & 0 \\ \times & \times & \times \\ 0 & \times & \times \end{pmatrix}$	A_2	$\varepsilon_{\mu\mu}$ & $\varepsilon_{\tau\tau}$
-1	0	-2	$\begin{pmatrix} \times & 0 & \times \\ 0 & 0 & \times \\ \times & \times & \times \end{pmatrix}$	B_3	ε_{ee} & $\varepsilon_{\tau\tau}$
-1	-2	0	$\begin{pmatrix} \times & \times & 0 \\ \times & \times & \times \\ 0 & \times & 0 \end{pmatrix}$	B_4	ε_{ee} & $\varepsilon_{\mu\mu}$
-2	-1	0	$\begin{pmatrix} \times & \times & \times \\ \times & \times & 0 \\ \times & 0 & 0 \end{pmatrix}$	$\times$	ε_{ee} & $\varepsilon_{\mu\mu}$
-2	0	-1	$\begin{pmatrix} \times & \times & \times \\ \times & 0 & 0 \\ \times & 0 & \times \end{pmatrix}$	$\times$	ε_{ee} & $\varepsilon_{\tau\tau}$

Type I seesaw

$$m_\nu \sim -m_D^T M^{-1} m_D$$

Neutrino mass matrix

x_e	x_μ	x_τ	Neutrino mass matrix	Type	NSI parameters
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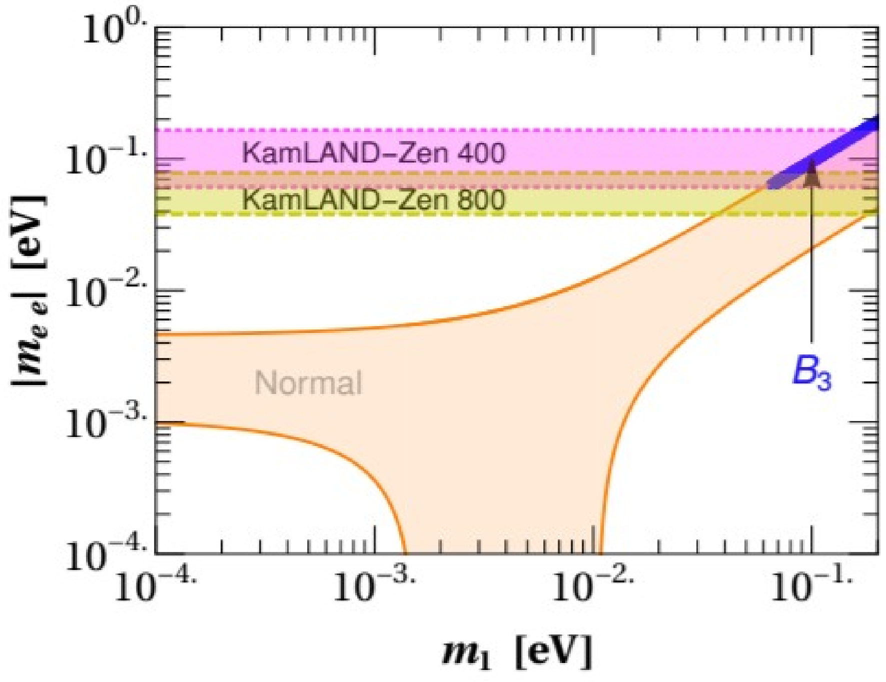
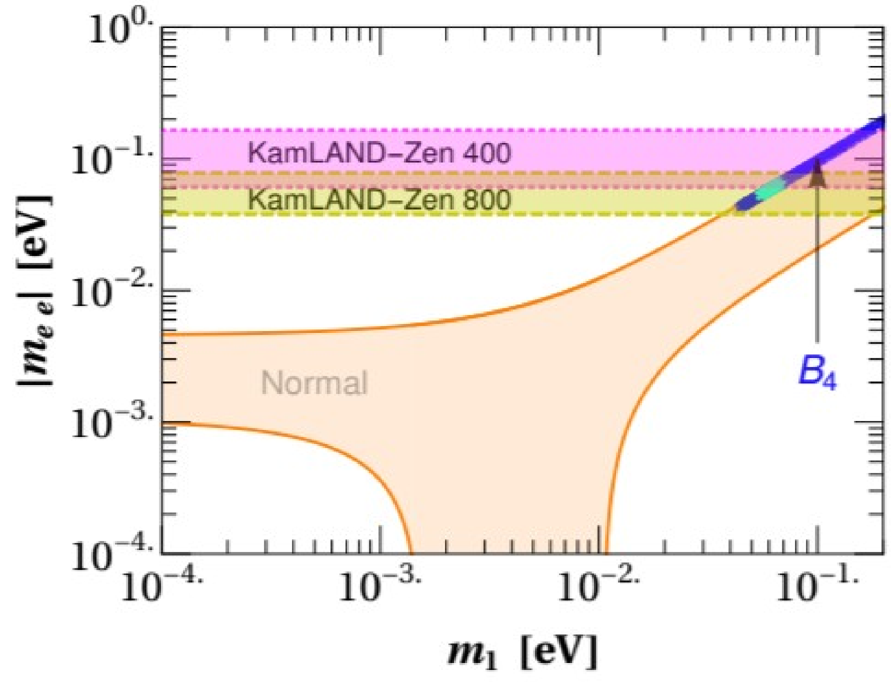
-2	0	-1	$\begin{pmatrix} \times & \times & \times \\ \times & 0 & 0 \\ \times & 0 & \times \end{pmatrix}$	$\times$	ε_{ee} & $\varepsilon_{\tau\tau}$

GOOD

BETTER





-1	0	-2	$\begin{pmatrix} \times & 0 & \times \\ 0 & 0 & \times \\ \times & \times & \times \end{pmatrix}$	B_3	ε_{ee} & $\varepsilon_{\tau\tau}$
-1	-2	0	$\begin{pmatrix} \times & \times & 0 \\ \times & \times & \times \\ 0 & \times & 0 \end{pmatrix}$	B_4	ε_{ee} & $\varepsilon_{\mu\mu}$
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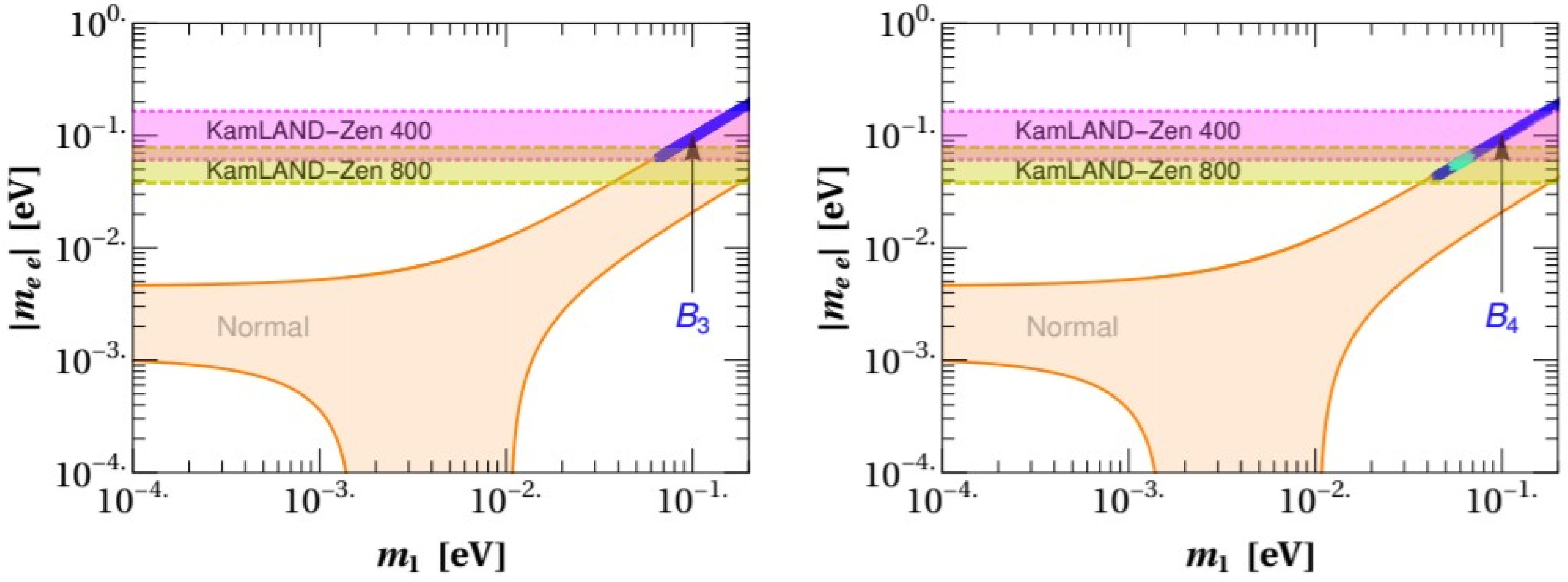
GO



Texture	$(m_1, m_2, m_3) \times 10^{-2}$ [eV]	$\sum m_\nu$ [eV]	$(\delta, \alpha, \beta)^\circ$
$A_1(\theta_{23}^{\rm bf})$	$(0.650, 1.067, 5.054)$	0.067	(260, 97, 55)
$A_1(\theta_{23}^{\rm max})$	$(0.564, 1.047, 5.017)$	0.066	(213, 94, 76)
$A_1(\theta_{23}^{\rm T2K})$	$(0.570, 1.067, 4.990)$	0.063	(267, 97, 51)
$A_2(\theta_{23}^{\rm bf})$	$(0.466, 0.984, 5.097)$	0.065	(262, 80, 133)
$A_2(\theta_{23}^{\rm max})$	$(0.577, 1.071, 5.001)$	0.066	(267, 81, 130)
$A_2(\theta_{23}^{\rm T2K})$	$(0.504, 1.010, 4.988)$	0.065	(237, 81, 145)

Limits on g’ & $M_{Z'}$

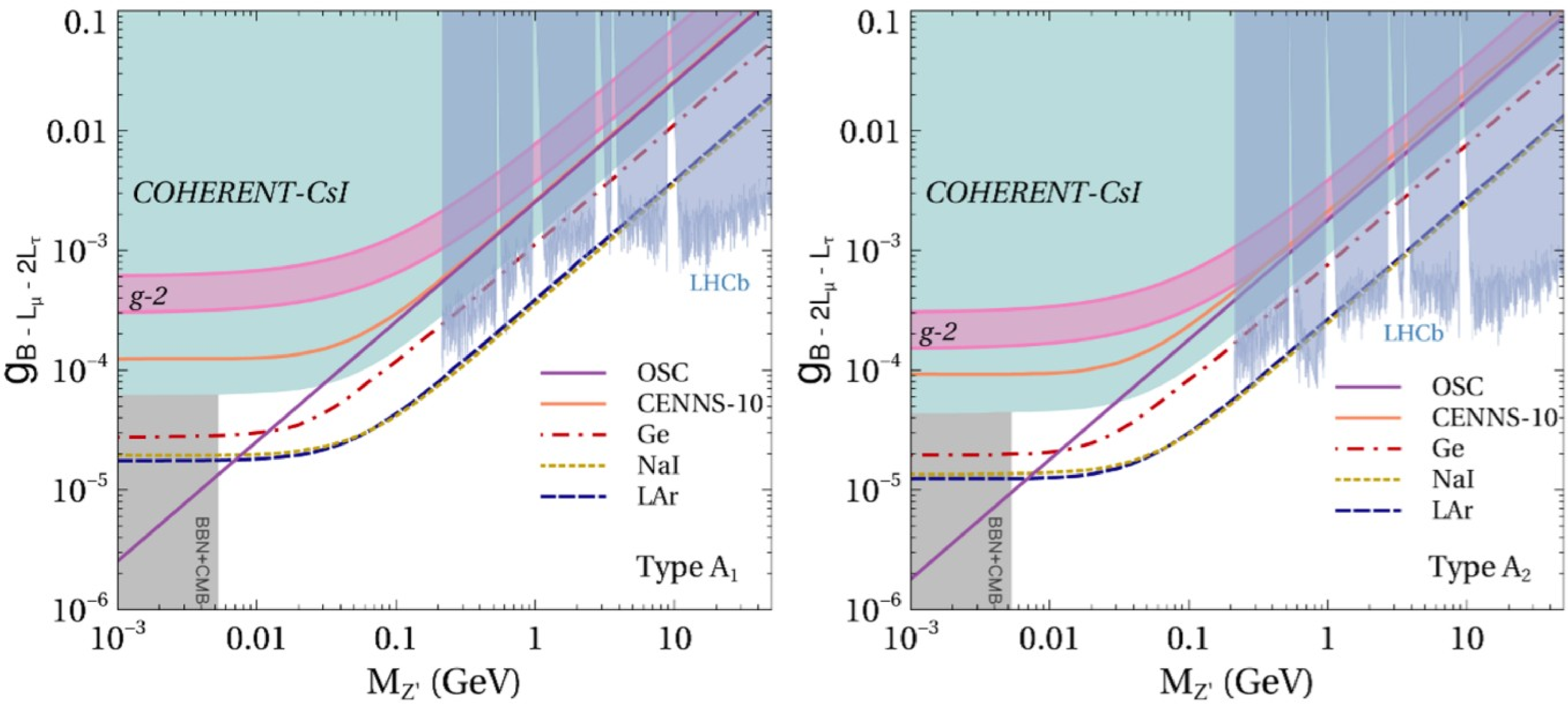
$$Z' \Leftrightarrow U(1)'$$

$$\mathcal{L}_{\text{eff}} = -\frac{g'^2}{q^2 + M_{Z'}^2}\left[\sum_\alpha x_\alpha \bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha\right]\left[\sum_q x_q \bar{q}\gamma_\mu q\right]$$

$$\epsilon_{\alpha\alpha}^{qV} = \frac{g'^2 x_\alpha x_q}{\sqrt{2}G_F(q^2 + M_{Z'}^2)}$$

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right)$$

Limits on g’ & $M_{Z'}$



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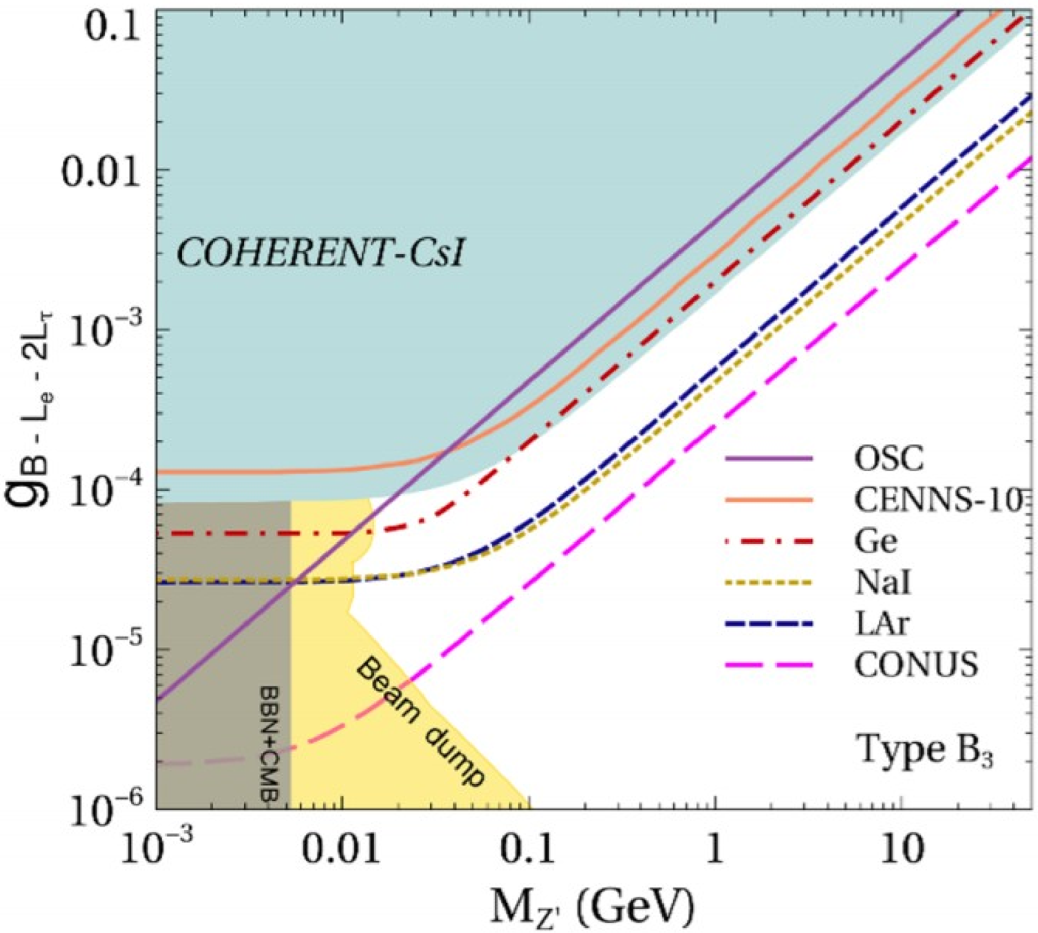

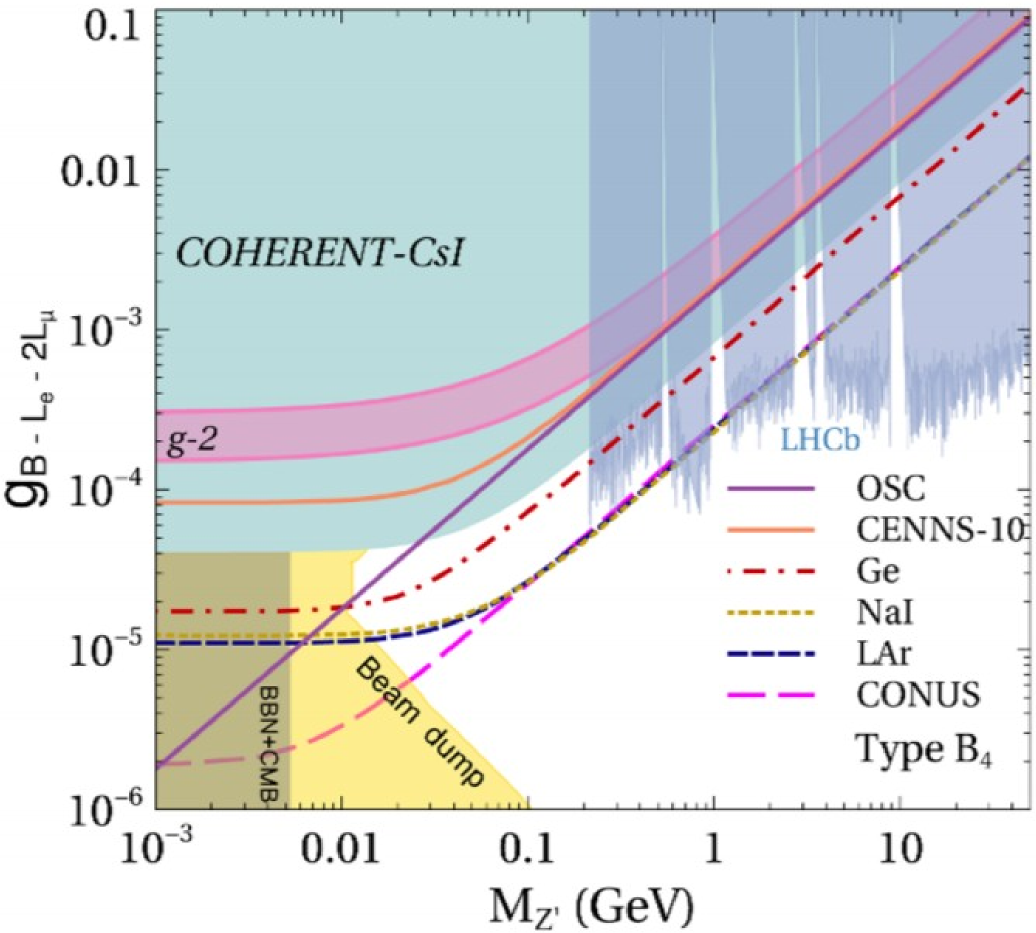

Final remarks

- CEvNS is a powerful tool for low-energy measurements
- Possibility to find a signal for new physics
- Future COHERENT upgrades and reactor experiments can improve the current limits for new interactions

For the model:

- Consistent with current oscillation data
- Four different easy-to-study scenarios
- Provides predictions for *neutrinoless double beta decay* and for oscillation parameters.

Thank you!

Backup

Breaking scale

$$\frac{1}{2}M_{Z'}^2 = g'^2 \ \frac{1}{2}(v_1^2 + 4v_2^2)$$

$\langle\phi_1\rangle$ $\langle\phi_2\rangle$

Choosing the values:

$$M_{Z'} = 0.1\,\mathrm{GeV} \quad g' = 2.8 \times 10^{-5}$$

$$v_1 \approx 3\,\mathrm{TeV} \quad v_2 \approx 1\,\mathrm{TeV}$$