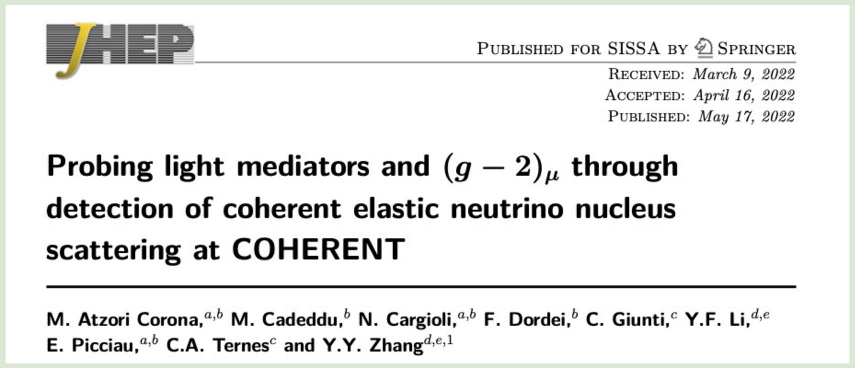
NOW 2022

Neutrino Oscillation Workshop

Probing light mediators, muon (g-2) and nu's with CEvNS

Presentation based on:

"Probing light mediators and $(g-2)_\mu$ through detection of coherent elastic neutrino nucleus scattering at COHERENT", J. High Energ. Phys. **2022**, 109 (https://doi.org/10.1007/JHEP05(2022)109)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Probing light mediators and $(g-2)_\mu$ through detection of coherent elastic neutrino nucleus scattering at COHERENT

M. Atzori Corona,[a,b] M. Cadeddu,[b] N. Cargioli,[a,b] F. Dordei,[b] C. Giunti,[c] Y.F. Li,[d,e] E. Picciau,[a,b] C.A. Ternes[c] and Y.Y. Zhang[d,e,1]

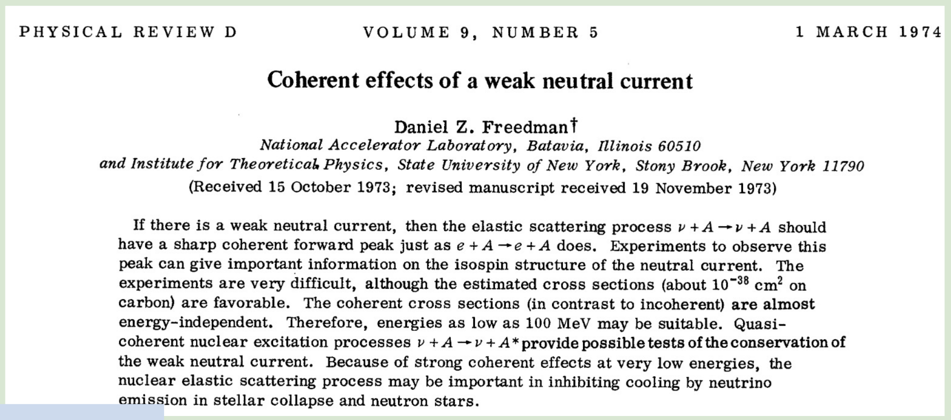
On behalf of:

M. Atzori Corona, M. Cadeddu, N. Cargioli*, F. Dordei, C. Giunti, Y.F. Li, E. Picciau, C.A. Ternes and Y.Y. Zhang

*Speaker: Nicola Cargioli nicola.cargioli@ca.infn.it
INFN Cagliari and University of Cagliari

Coherent Elastic Neutrino-Nucleus Scattering

- **Coherent elastic neutrino-nucleus scattering** (CEνNS): a neutrino scatters off a nucleus via the exchange of a **Z** boson, and the nucleus recoils as a whole (**coherently**)
- $\boldsymbol{\nu_\alpha + (A,Z) \rightarrow \nu_\alpha + (A,Z)}$
- Coherency condition: $q \cdot R \ll 1$ (q~ tens of MeV)



PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

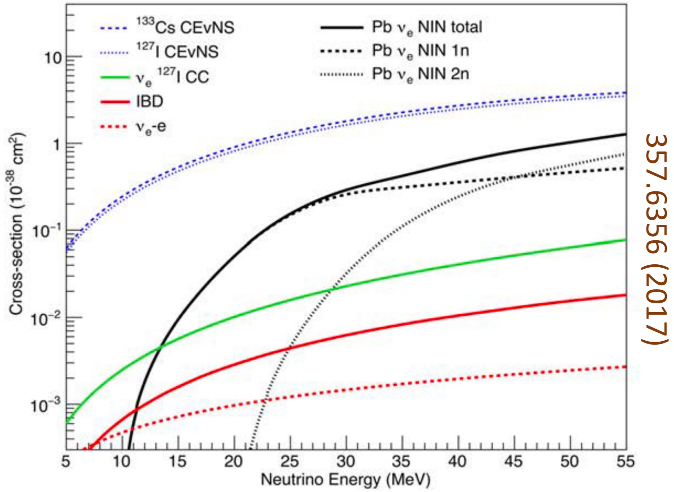
Daniel Z. Freedman†

National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

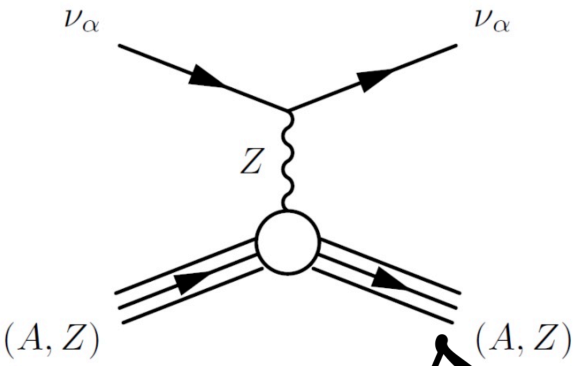
(Received 15 October 1973; revised manuscript received 19 November 1973)

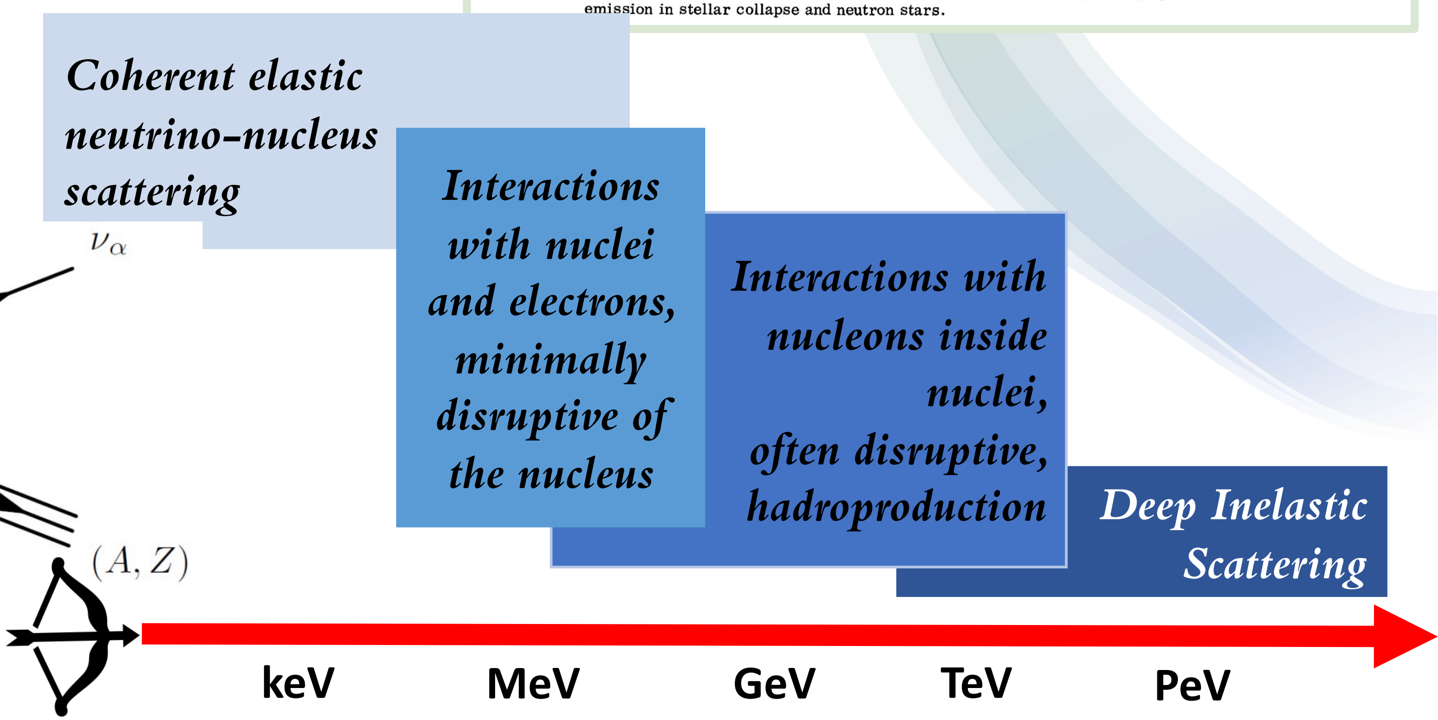
If there is a weak neutral current, then the elastic scattering process $\nu + A \rightarrow \nu + A$ should have a sharp coherent forward peak just as $e + A \rightarrow e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \rightarrow \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

- Predicted in **1974** by Freedman
- Observed for the first time in **2017** by **the COHERENT Collaboration**
- Very challenging to detect due to **tiny nuclear recoils** (tens of keV)
- **Low-Energy Regime (**E_ν~few tens MeV)
- **Large cross section** (**σ** ∝ $\boldsymbol{N^2}$)



D. Akimov et al. **Science** 357.6356 (2017)

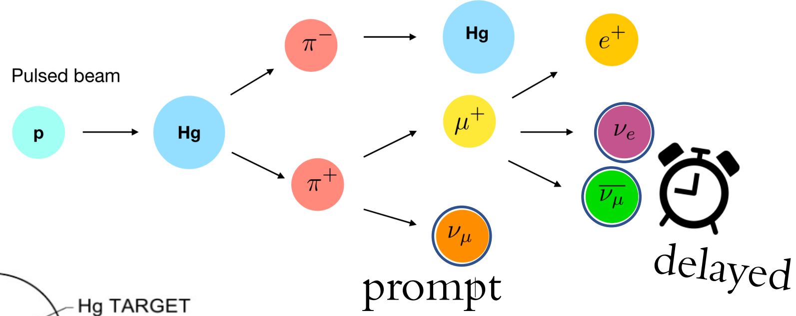


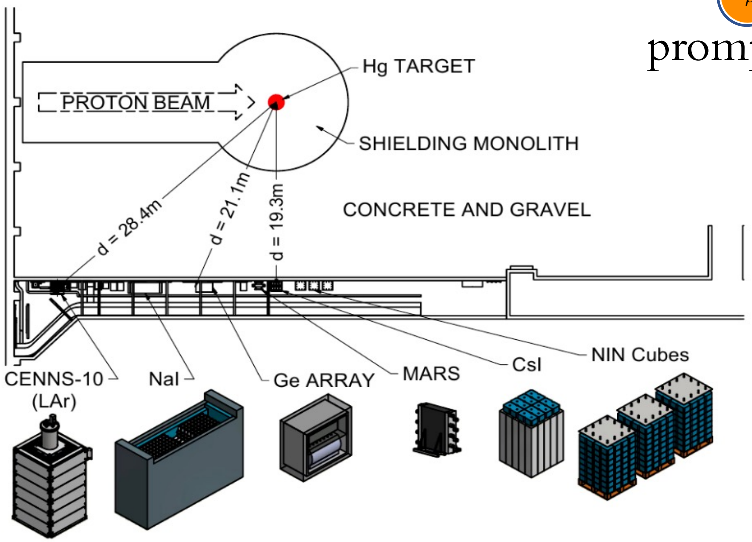


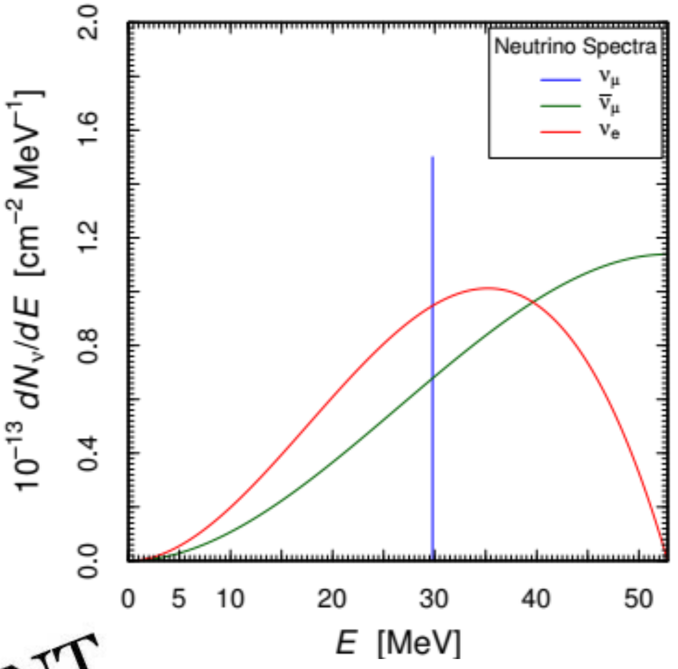
The COHERENT experiment: CsI and LAr detectors

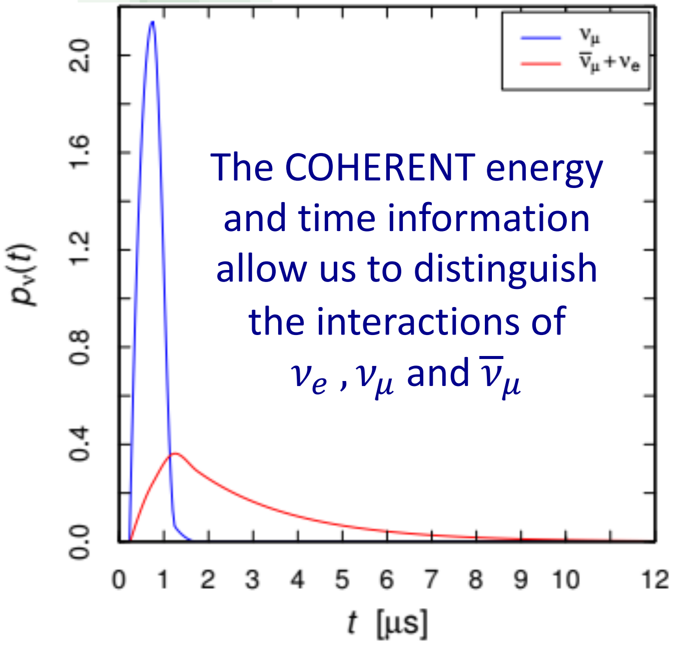
An appropriate **source of neutrinos** is needed: high flux, well understood (low uncertainties), pulsed for background rejection, multiple flavors, etc.

Spallation neutron source:
neutrinos produced from the decay of pions/muons









The COHERENT energy and time information allow us to distinguish the interactions of ν_e , ν_μ and $\overline{\nu}_\mu$

COHERENT neutrinos spectra, both **energy** and **arrival time** informations

See Igor Bernardi talk

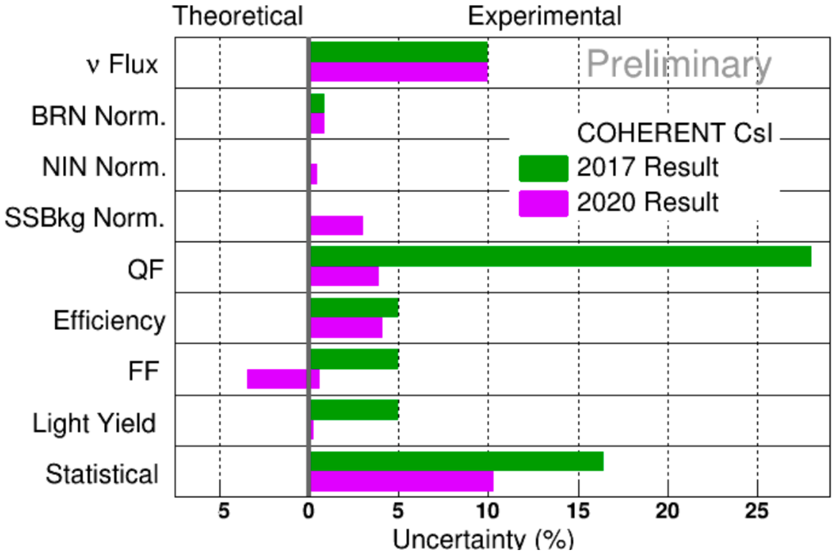
The COHERENT experiment: CsI and LAr detectors

I. COHERENT has observed for the **first time** CEνNS with a 14.6 kg CsI scintillating crystal (D. Akimov et al. **Science** 357.6356 (2017))

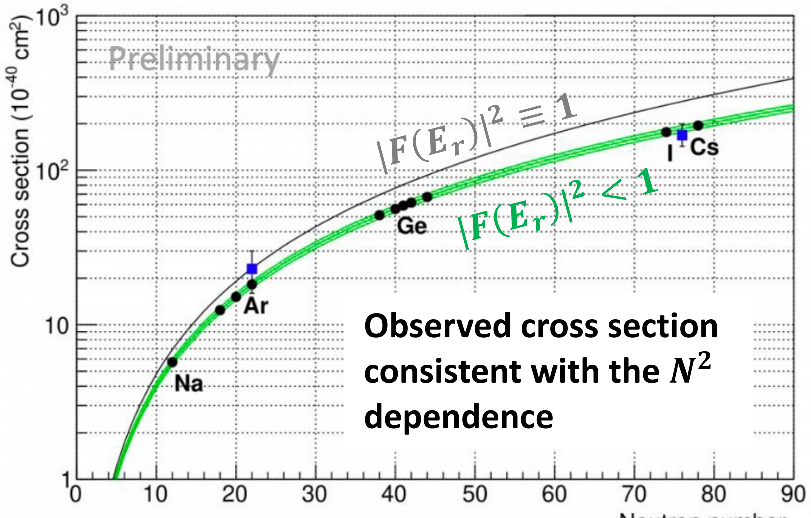
II. New observation in 2020 with 24 kg LAr detector (upgrade to 750 kg), with >3σ CEvNS detection significance (D. Akimov et al. **Phys.Rev.Lett.** 126 (2021) 1, 012002)

III. In 2020 presented the updated results on the CsI detector (D. Akimov et al. **Phys.Rev.Lett**. 129 (2022) 8, 081801):

- ✓ Increased statistics (more than 2x!)
- ✓ 2D Likelihood fit in numbers of photoelectrons and reconstructed time
- ✓ Result consistent with SM prediction at 1σ
- ✓ **Flux uncertainty** now dominates the systematic
- ✓ Overall systematic uncertainty reduced: 28%→13%



No-CEνNS rejection	11.6σ
SM CEνNS prediction	333±11(th)±42(ex)
Fit CEνNS events	306±20
Fit χ^2/dof	82.4/98
CEνNS cross section	$169^{+30}_{-26} \times 10^{-40}\,\mathrm{cm}^2$
SM cross section	$189 \pm 6 \times 10^{-40}\,\mathrm{cm}^2$

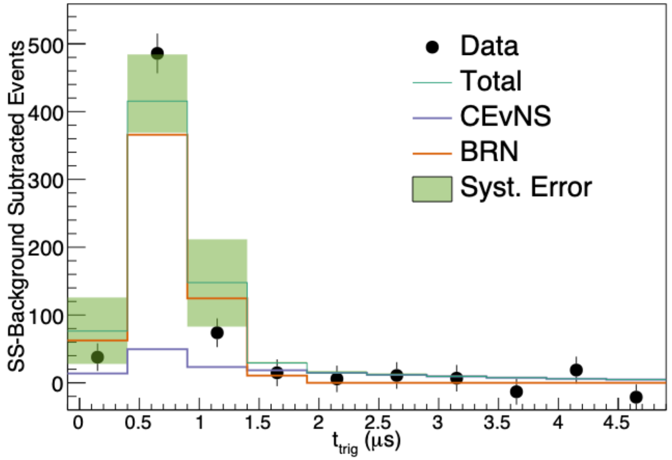


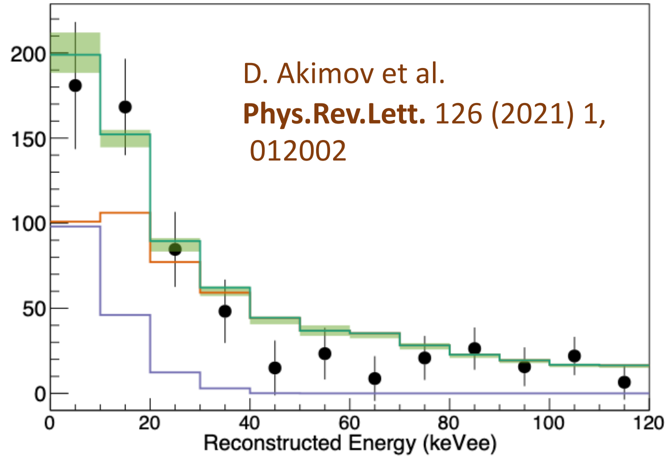
Observed cross section consistent with the N^2 dependence

Pershey, talk @Magnificent CEνNS '20

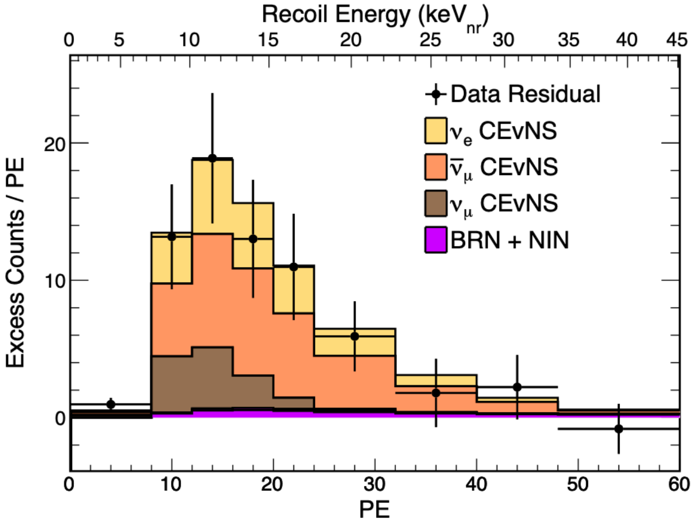
The COHERENT experiment: CsI and LAr detectors

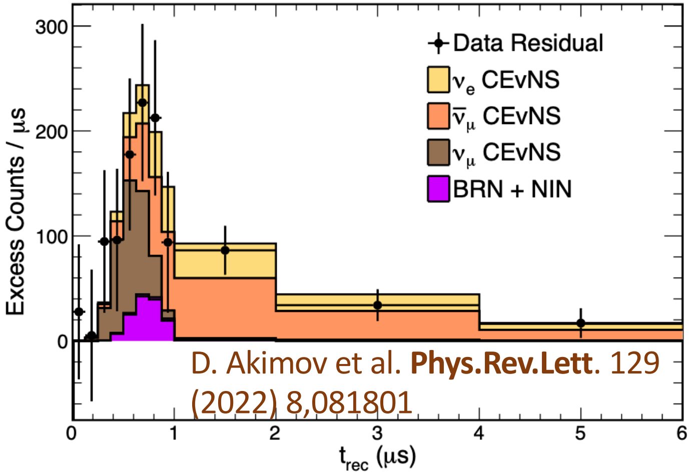
- Liquid argon detector made of an active mass of **24 kg** of atmospheric argon
- **27.5 m** from the SNS target
- Single phase only (scintillation), thr. 20 keV$_{nr}$
- Global quenching factor fit with a linear model
- new data are expected to be presented soon
- Plans of upgrade to a tonne-scale LAr





D. Akimov et al. **Phys.Rev.Lett.** 126 (2021) 1, 012002





D. Akimov et al. **Phys.Rev.Lett.** 129 (2022) 8,081801

- **14.6 kg** CsI scintillating crystal
- **19.3 m** from the SNS target
- Redefined quenching factor wrt 2017 (new measurements and global fit)
- Dismissed detector
- Possible new low-threshold cryogenic CsI detectors in future

CEνNS cross section

C. Giunti, A. Studenikin, Rev Mod Phys, 87, 531 (2015)
Cadeddu et al, PRD 102, 015030 (2020)
Cadeddu et al, PRD 101, 033004 (2020)
Miranda et al, JHEP 05 (2020) 130
M. Atzori Corona et al, arxiv:2205.09484
Coloma et al, JHEP 05(2022) 037

M. Cadeddu et al, JHEP 01 (2021) 116
P. Coloma et al, JHEP 01 (2021) 114
Miranda et al, JHEP 05 (2020) 130
M. Atzori Corona et al, JHEP 05 (2022) 109

This talk!

New ν interaction

New ν properties

Neutrino energy

Mass of the nucleus

SM vector proton coupling

SM vector neutron coupling

$$\frac{d\sigma^{CE\nu NS}(E_\nu, E_r)}{dE_r} \cong \frac{G_F^2\, m_N}{\pi}\left(1 - \frac{m_N E_r}{2E_\nu^2}\right)\left[\underbrace{g_V^p\left(\sin^2(\vartheta_W)\right) Z\, F_Z(|\vec{q}|^2) + g_V^n\, N\, F_N(|\vec{q}|^2)}_{}\right]^2 + \dots$$

Nuclear recoil energy

Nuclear weak charge Q_W

Weinberg angle

Proton Form Factor

Neutron Form Factor

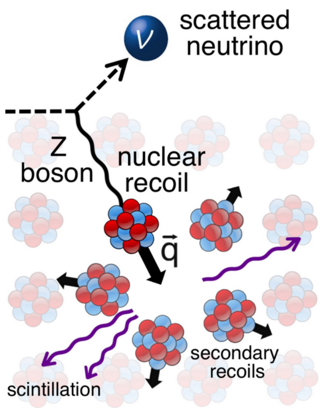
EW precision

Nuclear physics

Cadeddu et al, *Phys.Rev.D* 101 (2020) 3, 033004
M. Cadeddu and F. Dordei, Phys. Rev. D **99**, 033010
M. Atzori Corona et al, arxiv:2205.09484
D. Aristizabal Sierra et al, arxiv:2203.02414

Cadeddu et al., PRD 101, 033004 (2020)
Papoulias, PRD 102, 113004 (2020)
Khan and Rodejohann, PRD 100, 113003 (2019)
Coloma et al, JHEP 08:030 (2020)
Cadeddu et al., PRC 104, 065502 (2021)

Light Mediators from $U(1)'$ extensions of the SM



The interaction between neutrinos and the nucleus happens through the exchange of a Z boson in the SM

We might want to search for new physic signatures in CEvNS data

The easiest extension we can think of: **Non-standard neutrino interactions (NSI)**

- General vector neutral-current neutrino non-standard interactions described by the effective four-fermion Lagrangian
- Modification of the neutrino-nucleon coupling
- Energy-independent correction
- The nuclear weak charge for an α-flavor neutrino interaction becomes

$$Q_\alpha^2 = \left[\left(g_V^p + 2\varepsilon_{\alpha\alpha}^{uV} + \varepsilon_{\alpha\alpha}^{dV}\right) Z F_Z(|\vec{q}|^2) + \left(g_V^n + \varepsilon_{\alpha\alpha}^{uV} + 2\varepsilon_{\alpha\alpha}^{dV}\right) N F_N(|\vec{q}|^2)\right]^2 + \sum_{\beta\neq\alpha} \left|\left(2\varepsilon_{\alpha\beta}^{uV} + \varepsilon_{\alpha\beta}^{dV}\right) Z F_Z(|\vec{q}|^2) + \left(\varepsilon_{\alpha\beta}^{uV} + 2\varepsilon_{\alpha\beta}^{dV}\right) N F_N(|\vec{q}|^2)\right|^2,$$

J. Barranco et al, JHEP 0512:021 (2005)
C. Giunti, PRD 101, 035039 (2020)

*$\boldsymbol{\varepsilon_{\alpha\beta}}$ = size of NSI relative to SM

Light Mediators from $U(1)'$ extensions of the SM

The neutrino NSI can be induced by a gauge Z'-vector boson with mass $M_{Z'}$ and coupling $g_{Z'}$ associated with a new U(1)' symmetry:

$$\varepsilon_{\ell\ell}^{fV} = \frac{g_{Z'}^2 Q'_\ell Q'_f}{\sqrt{2}G_F(|\vec{q}|^2 + M_{Z'}^2)}$$

*$\boldsymbol{Q'_\ell}$=gauge charge of the lepton ℓ
$\boldsymbol{Q'_f}$=gauge charge of the fermion f

$$Q_{\ell,\mathrm{SM+V}}^V = Q_{\ell,\mathrm{SM}}^V + \frac{g_{Z'}^2 Q'_\ell}{\sqrt{2}G_F\left(|\vec{q}|^2 + M_{Z'}^2\right)}\left[\left(2Q'_u + Q'_d\right) Z F_Z(|\vec{q}|^2) + \left(Q'_u + 2Q'_d\right) N F_N(|\vec{q}|^2)\right]$$

Model	Q'_u	Q'_d	Q'_e	Q'_μ	Q'_τ
universal	1	1	1	1	1
$B-L$	1/3	1/3	-1	-1	-1
$B-3L_e$	1/3	1/3	-3	0	0
$B-3L_\mu$	1/3	1/3	0	-3	0
$B-2L_e-L_\mu$	1/3	1/3	-2	-1	0
$B-L_e-2L_\mu$	1/3	1/3	-1	-2	0
L_e-L_μ	0	0	1	-1	0
L_e-L_τ	0	0	1	0	-1
$L_\mu-L_\tau$	0	0	0	1	-1

Different kind of models:

- Universal
- Anomaly Free hadrophilic: $B - c_e L_e - c_\mu L_\mu - c_\tau L_\tau$
- Anomaly Free leptophilic (hadrophobic): $L_\alpha - L_\beta$

$$G(c_1, c_2, c_3, c_e, c_\mu, c_\tau) = c_1 B_1 + c_2 B_2 + c_3 B_3 - c_e L_e - c_\mu L_\mu - c_\tau L_\tau,$$

Condition for anomaly freedom

$$c_1 + c_2 + c_3 - c_e - c_\mu - c_\tau = 0.$$

*often $c_1 = c_2 = c_3 = c_B$ to avoid unobserve flavor-changing neutral currents in the quark sector

Light Mediators from $U(1)'$ extensions of the SM: Hadrophilic Models

$$G(c_1, c_2, c_3, c_e, c_\mu, c_\tau) = c_1 B_1 + c_2 B_2 + c_3 B_3 - c_e L_e - c_\mu L_\mu - c_\tau L_\tau,$$

Model	Q'_u	Q'_d	Q'_e	Q'_μ	Q'_τ
universal	1	1	1	1	1
$B-L$	$1/3$	$1/3$	-1	-1	-1
$B-3L_e$	$1/3$	$1/3$	-3	0	0
$B-3L_\mu$	$1/3$	$1/3$	0	-3	0
$B-2L_e-L_\mu$	$1/3$	$1/3$	-2	-1	0
$B-L_e-2L_\mu$	$1/3$	$1/3$	-1	-2	0
L_e-L_μ	0	0	1	-1	0
L_e-L_τ	0	0	1	0	-1
$L_\mu-L_\tau$	0	0	0	1	-1

$$c_1 + c_2 + c_3 - c_e - c_\mu - c_\tau = 0.$$

Condition for anomaly freedom

UNIVERSAL MODEL:

- $c_1 = c_2 = c_3 = c_e = c_\mu = c_\tau$
- Not anomaly free
- All the gauge charges =1

B-L MODEL:

- $c_1 = c_2 = c_3 = c_B$ and $c_e = c_\mu = c_\tau = c_L$
- $c_B - c_L = 0 \rightarrow Q'_B = 1$ and $Q'_L = -1$

$\mathrm{B} - \alpha \mathrm{L}_\alpha - \beta \mathrm{L}_\beta$ MODEL:

- $c_1 = c_2 = c_3 = c_B$ and $c_\gamma = 0$
- $\mathrm{B} - 2\mathrm{L}_e - \mathrm{L}_\mu \rightarrow Q'_B = 1$ and $Q'_e = -2, Q'_\mu = -1, Q'_\tau = 0$

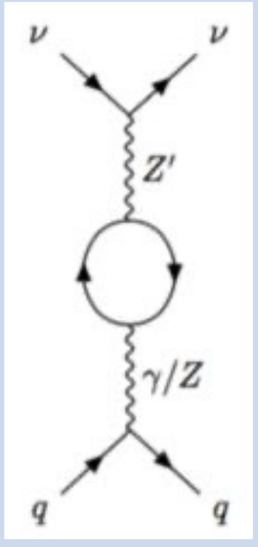
*These models are anomaly free if the SM is extended with right-handed neutrinos

Light Mediators from $U(1)'$ extensions of the SM: Leptophilic Models

Models with no direct coupling to hadrons: $c_B = 0$

Composition of two leptonic flavours: $c_\alpha = 1, c_\beta = -1, c_\gamma = 0$

- In the context of the CEνNS process, the new boson can't couple directly to the nucleus (no tree-level contribution)
- Interaction happens through kinetic mixing of the Z' and the γ at loop-level

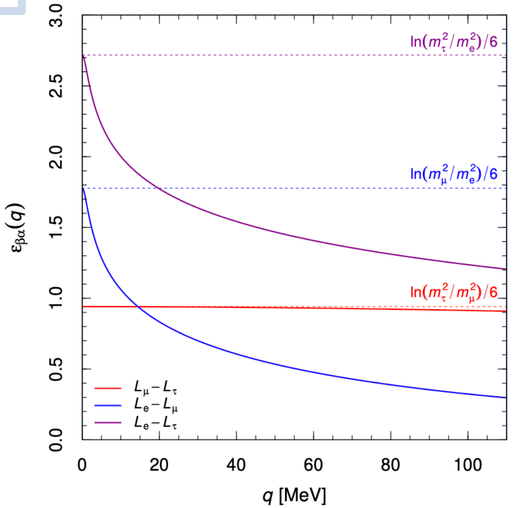


Model	Q'_u	Q'_d	Q'_e	Q'_μ	Q'_τ
universal	1	1	1	1	1
$B-L$	1/3	1/3	−1	−1	−1
$B-3L_e$	1/3	1/3	−3	0	0
$B-3L_\mu$	1/3	1/3	0	−3	0
$B-2L_e-L_\mu$	1/3	1/3	−2	−1	0
$B-L_e-2L_\mu$	1/3	1/3	−1	−2	0
L_e-L_μ	0	0	1	−1	0
L_e-L_τ	0	0	1	0	−1
$L_\mu-L_\tau$	0	0	0	1	−1

$$\left(\frac{d\sigma}{dT_{\rm nr}}\right)^{\nu_\ell-\mathcal{N}}_{L_\alpha-L_\beta}(E,T_{\rm nr}) = \frac{G_F^2 M}{\pi}\left(1-\frac{MT_{\rm nr}}{2E^2}\right) \times \left\{\left[g_V^p(\nu_\ell) + \frac{\sqrt{2}\alpha_{\rm EM} g_{Z'}^2\left(\delta_{\ell\alpha}\varepsilon_{\beta\alpha}(|\vec{q}|)+\delta_{\ell\beta}\varepsilon_{\alpha\beta}(|\vec{q}|)\right)}{\pi G_F\left(|\vec{q}|^2+M_{Z'}^2\right)}\right] Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right\}^2$$

One-loop kinetic mixing coupling

$$\varepsilon_{\beta\alpha}(|\vec{q}|) = \int_0^1 x(1-x)\ln\left(\frac{m_\beta^2 + x(1-x)|\vec{q}|^2}{m_\alpha^2 + x(1-x)|\vec{q}|^2}\right)dx$$



*These models are anomaly free and do not need right-handed neutrinos

Light Mediators from $U(1)'$ extensions of the SM: Scalar Model

If the SM is extended with the addition of right-handed neutrinos, NSI mediated by a scalar boson ϕ are also possible

- The contribution of the scalar boson to the CEνNS is incoherent
- We assume a scalar boson with $g_\phi^{\nu_e} = g_\phi^{\nu_\mu} = g_\phi^{\nu_\ell}$ and $g_\phi^u = g_\phi^d = g_\phi^q$

$$\left(\frac{d\sigma_{\nu_\ell\text{-}\mathcal{N}}}{dT_{\rm nr}}\right)_{\rm scalar} = \frac{M^2 T_{\rm nr}}{4\pi E^2}\frac{(g_\phi^{\nu_\ell})^2 \mathcal{Q}_\phi^2}{(|\vec{q}|^2 + M_\phi^2)^2} \longrightarrow \mathcal{Q}_\phi = g_\phi^q \left[Z F_Z(|\vec{q}|^2)\langle p|\bar{u}u + \bar{d}d|p\rangle + N F_N(|\vec{q}|^2)\langle n|\bar{u}u + \bar{d}d|n\rangle\right]$$

Considering the isospin approximation: $\langle p|\bar{u}u + \bar{d}d|p\rangle = \langle n|\bar{u}u + \bar{d}d|n\rangle = \langle N|\bar{u}u + \bar{d}d|N\rangle = \dfrac{\sigma_{\pi N}}{\overline{m}_{ud}}$,

$\left(\dfrac{\sigma_{\pi N}}{\overline{m}_{ud}}\right)_{\rm ref} = 17.3$, REFERENCE value M. Hoferichter, J. Ruiz de Elvira, B. Kubis and U.-G. Meißner, *Phys. Rev. Lett.* **115** (2015) 092301
Particle Data Group collaboration, *PTEP* **2020** (2020) 083C01

*$\sigma_{\pi N}$ is the pion-nucleon σ-term that has been determined in literature (pionic atoms and pion-nucleon scattering, lattice calculations)

$$\left(\frac{d\sigma_{\nu_\ell\text{-}\mathcal{N}}}{dT_{\rm nr}}\right)_{\rm scalar} = \frac{M^2 T_{\rm nr}}{4\pi E^2}\frac{\tilde{g}_\phi^4}{(|\vec{q}|^2 + M_\phi^2)^2}\left(\frac{\sigma_{\pi N}}{\overline{m}_{ud}}\right)_{\rm ref}^2 \left[Z F_Z(|\vec{q}|^2) + N F_N(|\vec{q}|^2)\right]^2$$

$$\tilde{g}_\phi^2 = g_\phi^{\nu_\ell} g_\phi^q \frac{\sigma_{\pi N}/\overline{m}_{ud}}{(\sigma_{\pi N}/\overline{m}_{ud})_{\rm ref}}.$$

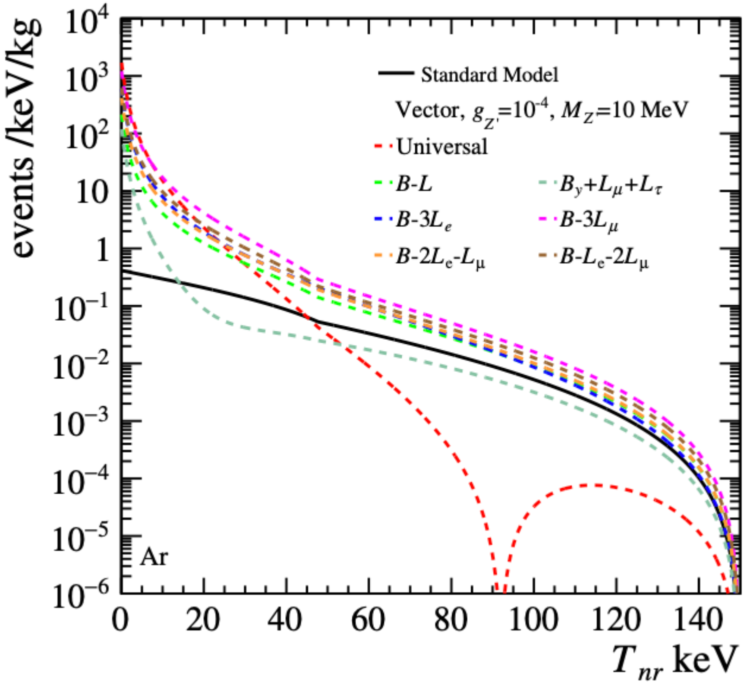
COHERENT rates in BSM scenarios

Expected rate of events at COHERENT for the LAr detector considering energy resolution, acceptance, etc..

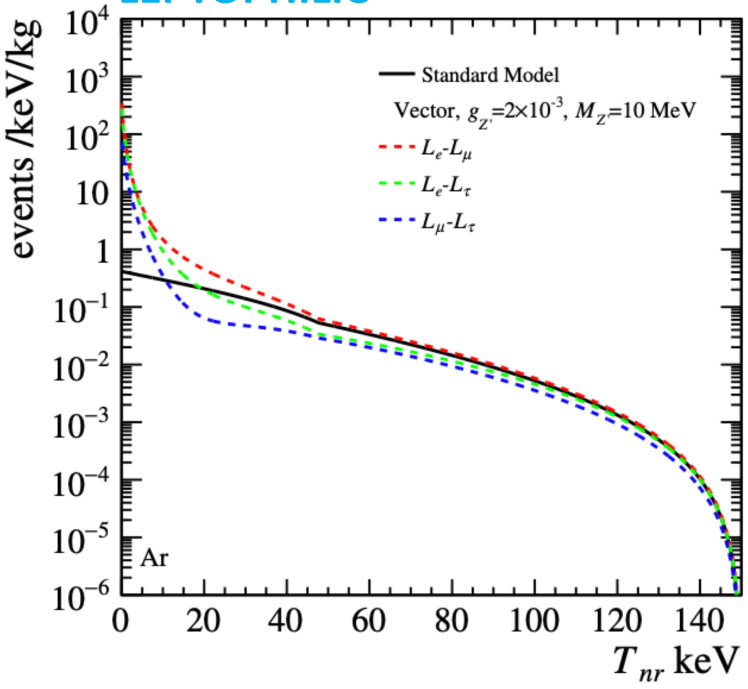
$$N_i^{\mathrm{CE}\nu\mathrm{NS}} = N(\mathcal{N}) \int_{T_{\mathrm{nr}}^{i}}^{T_{\mathrm{nr}}^{i+1}} dT_{\mathrm{nr}} A(T_{\mathrm{nr}}) \int_0^{T_{\mathrm{nr}}^{\prime\max}} dT'_{\mathrm{nr}} R(T_{\mathrm{nr}}, T'_{\mathrm{nr}}) \int_{E_{\min}(T'_{\mathrm{nr}})}^{E_{\max}} dE \sum_{\nu=\nu_e,\nu_\mu,\bar{\nu}_\mu} \frac{dN_\nu}{dE}(E) \frac{d\sigma_{\nu-\mathcal{N}}}{dT_{\mathrm{nr}}}(E, T'_{\mathrm{nr}})$$

Some models produce a positive contribution inside the nuclear weak charge (which is negative) leading to a cancellation in the cross section

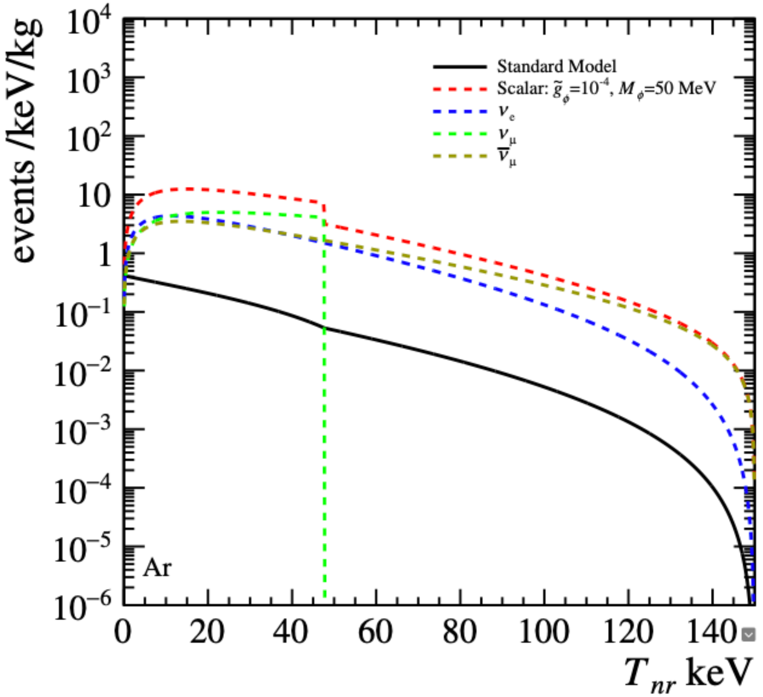
HADROPHILIC



LEPTOPHILIC



SCALAR

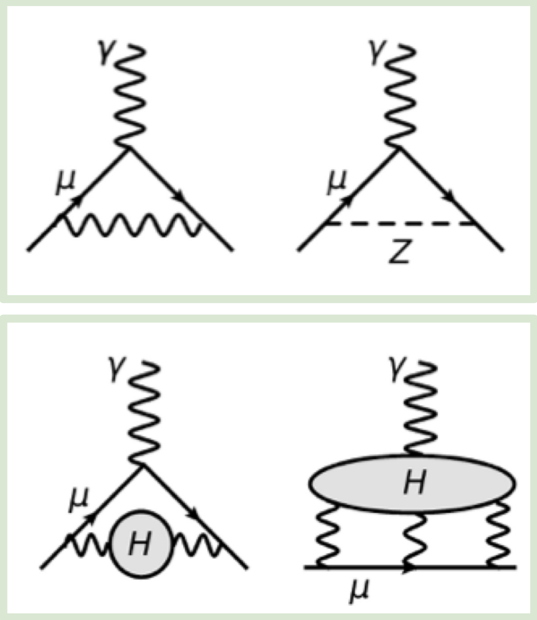


Muon anomalous magnetic moment $(g-2)_\mu$

$$a_\mu = (g-2)_\mu/2$$

•Improvement of the loop calculations: T. Aoyama et al., Phys. Rept. 887, 1 (2020)
•Muon g-2 experimentc(FNAL): B. Abi et al. (Muon g−2 Collaboration), Phys. Rev. Lett. 126, 141801 (2021)
•Confirmed the long-Standing deviation of the experimental determination of a_μ (BNL in 2004).

World average gives: $\Delta a_\mu = 251(59)\times 10^{-11}(4.2\sigma)$

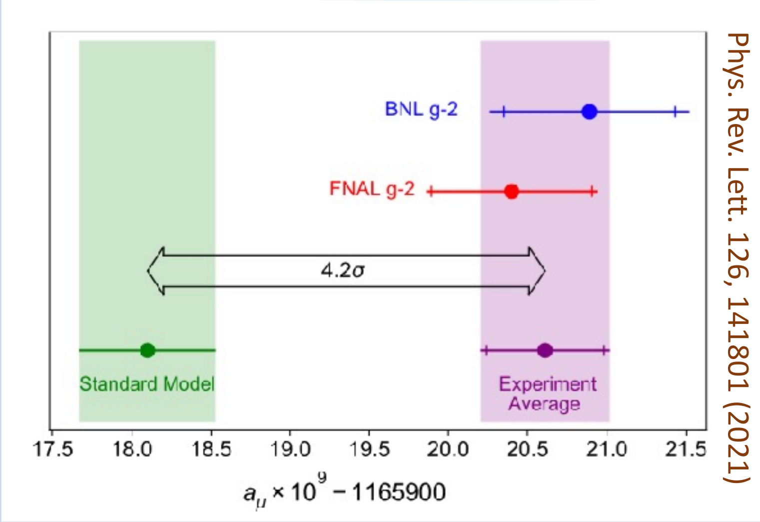


- In BSM theories with a neutral boson B with mass M_B, which interacts with muons with coupling g_B, there is an additional contribution to the muon anomalous magnetic moment:

- $\delta a_\mu^B = \frac{g_B^2}{8\pi^2}\int_0^1 dx \frac{Q(x)}{x^2+(1-x)M_B^2/m_\mu^2}$ S.J. Brodsky and E. De Rafael, Phys. Rev. **168** (1968) 1620

- With $Q(x) = \begin{cases} x^2(2-x) & \text{(scalar)} \\ 2x^2(1-x). & \text{(vector)} \end{cases}$

Could a Z' boson be the solution?



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Constraints on light mediators through COHERENT data

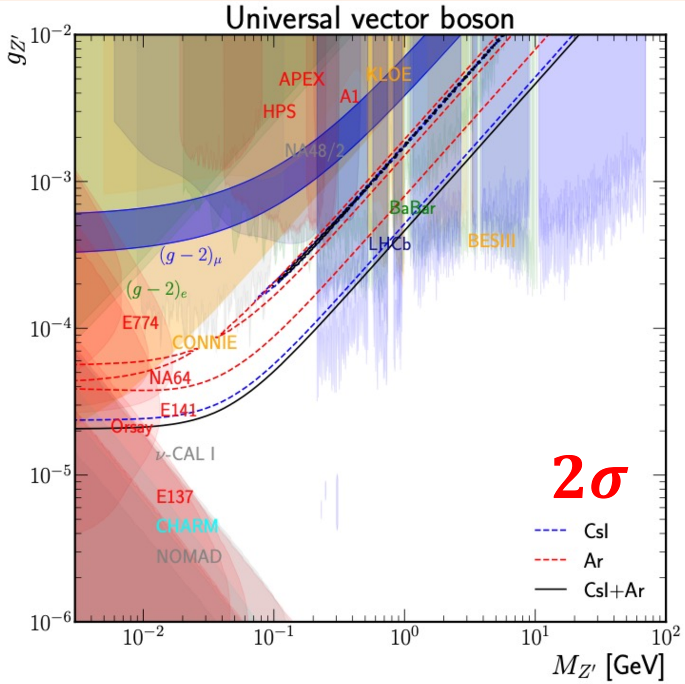
χ^2 analysis of COHERENT data with both time and spectral information

Universal: improved the existing limits for:

$$20 \lesssim M_{Z'} \lesssim 200 \text{ MeV}$$
$$\rightarrow 2\times10^{-5} \lesssim g_{Z'} \lesssim 10^{-4}$$

Excluding $(\mathbf{g-2})_\mu$

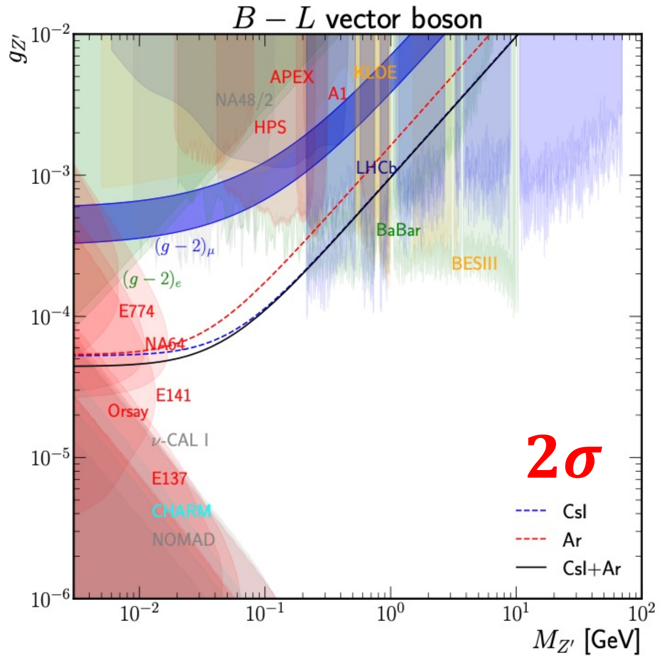
Degeneracy strip



B-L: improved the existing limits for:

$$10 \lesssim M_{Z'} \lesssim 200 \text{ MeV}$$
$$\rightarrow 5\times10^{-5} \lesssim g_{Z'} \lesssim 3\times10^{-4}$$

Excluding $(\mathbf{g-2})_\mu$



$\mathbf{B-2L_e-L_\mu}$: improved the existing limits for:

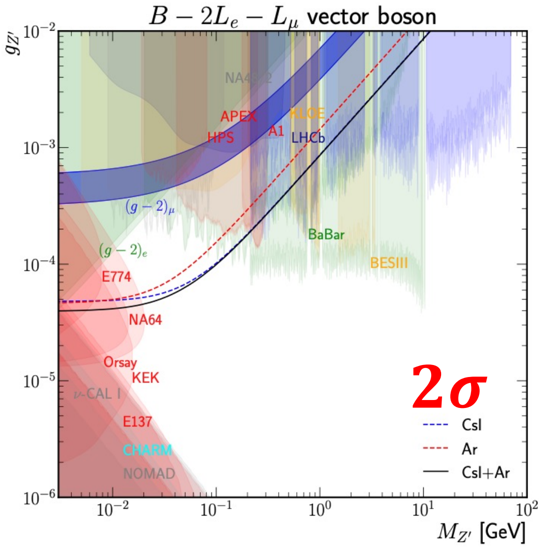
$10 \lesssim M_{Z'} \lesssim 100 \text{ MeV} \rightarrow$
$5\times10^{-5} \lesssim g_{Z'} \lesssim 2\times10^{-4}$

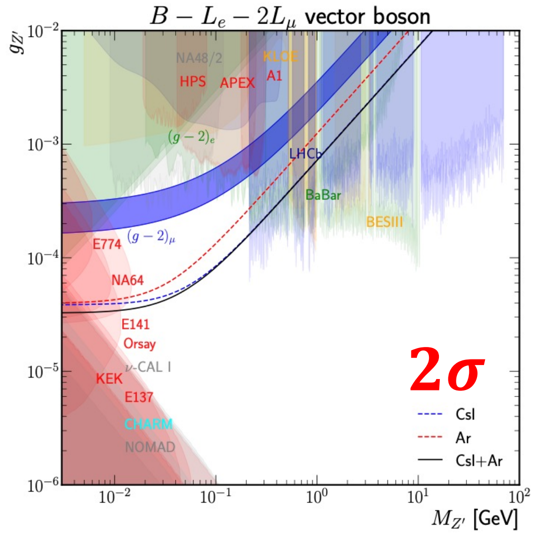
Excluding $(\mathbf{g-2})_\mu$

$\mathbf{B-L_e-2L_\mu}$: improved the existing limits for:

$10 \lesssim M_{Z'} \lesssim 200 \text{ MeV} \rightarrow$
$3\times10^{-5} \lesssim g_{Z'} \lesssim 3\times10^{-4}$

Excluding $(\mathbf{g-2})_\mu$





Constraints on light mediators through COHERENT data

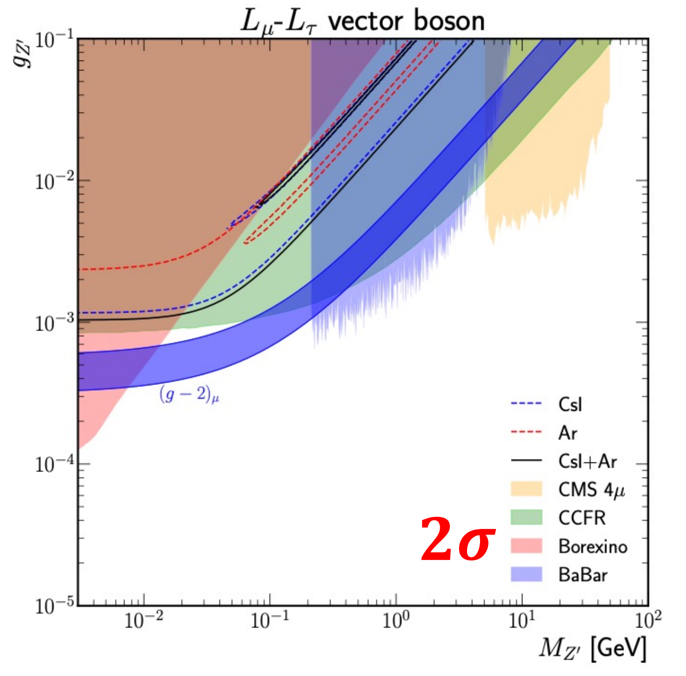
χ^2 analysis of COHERENT data with both time and spectral information

$\mathbf{L_\mu - L_\tau}$: not competitive with existing limits

$\mathbf{(g-2)_\mu}$ **still unconstrained for:**

$$10 \lesssim M_{Z'} \approx 200\text{MeV}$$
$$3\times10^{-4} \lesssim g_{Z'} \lesssim 10^{-3}$$

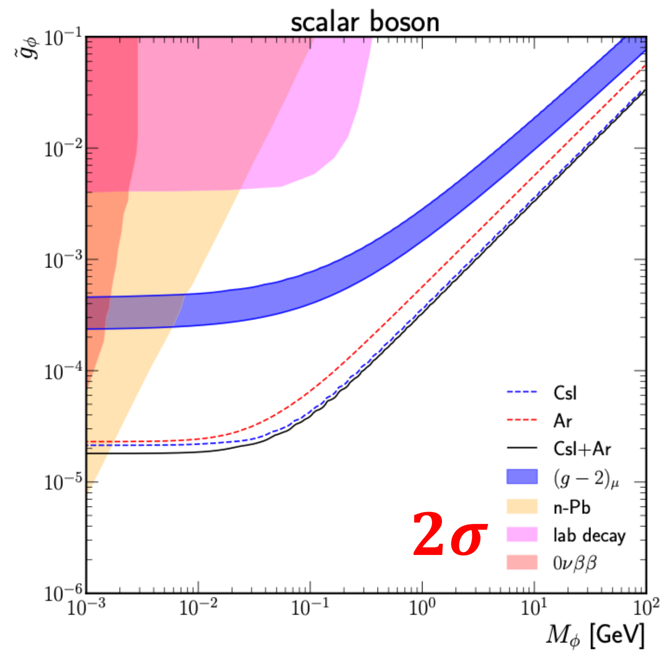
Degeneracy strip



Scalar: much more stringent limits obtained through CEνNS for:

$$M_\phi \gtrsim 2\text{ MeV}$$

Excluding $\mathbf{(g-2)_\mu}$

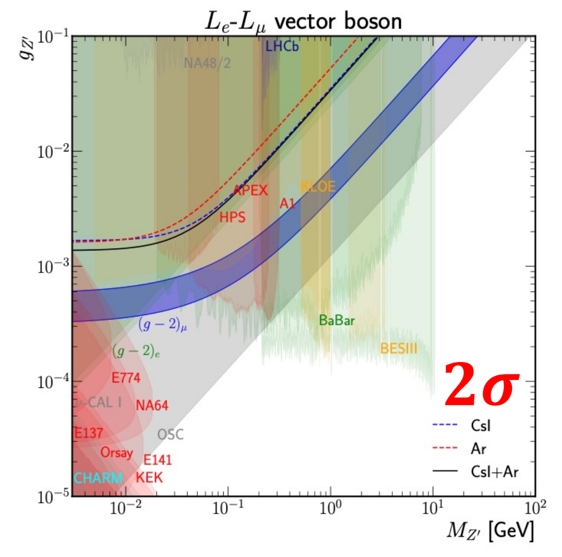


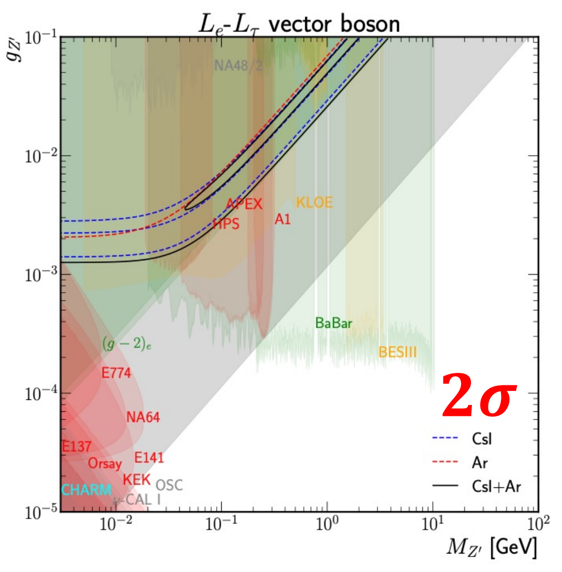
$\mathbf{L_e - L_\mu}$: not competitive with existing limits $\mathbf{(g-2)_\mu}$ **explanation still available for:**

$$M_{Z'} \approx 20-30\text{MeV}$$
$$g_{Z'} \approx (4-7)\times10^{-4}$$

$\mathbf{L_e - L_\tau}$: not competitive with existing limits

No possible $\mathbf{(g-2)_\mu}$ **explanation (no coupling to muons)**





Conclusions

- We analysed the **COHERENT data** for both CsI and LAr detectors to derive constraints on the coupling and mass of a non-standard light vector or scalar boson mediator
- **Hadrophilic models** (B-L, etc)
- **Hadrophobic models** ($L_\alpha - L_\beta$)
- Comparison with non-CEνNS constraints and with $\boldsymbol{(g-2)_\mu}$ allowed region
- Total exclusion of $(g-2)_\mu$ for universal, B-L, B$-3\mathrm{L_e}$, B$-2\mathrm{L_e} - \mathrm{L_\mu}$ and B$-\mathrm{L_e} - 2\mathrm{L_\mu}$
- $L_\alpha - L_\beta$ models do not lead to stringent constraints, still room for $(g-2)_\mu$ allowed region
- Really strong constraints for the **scalar model**, excluding the explanation of $(g-2)_\mu$

- Future data will allow us to improve the current constraints

INFN Istituto Nazionale di Fisica Nucleare

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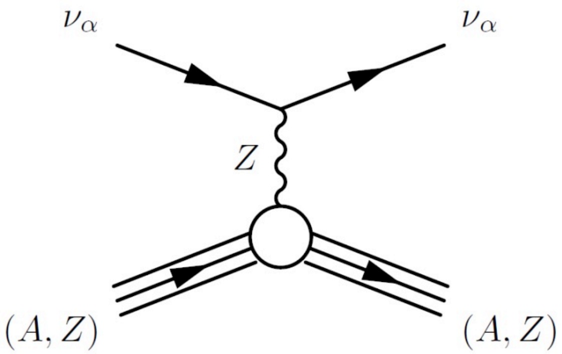
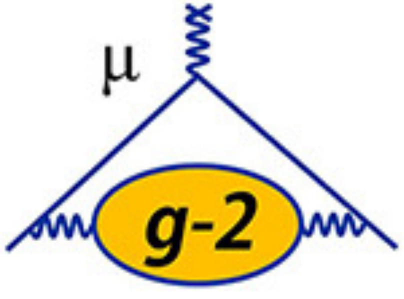
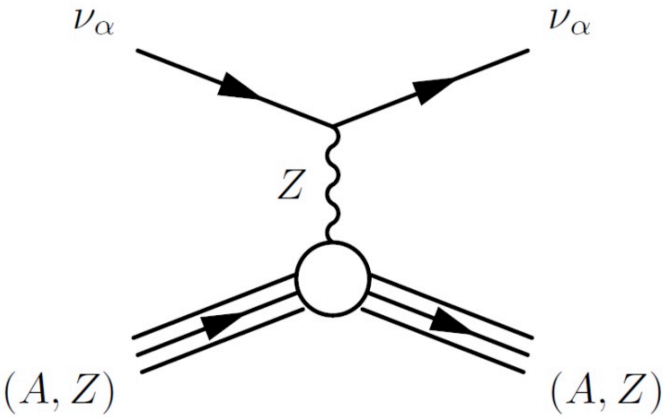
Dipartimento Interateneo di Fisica Michelangelo Merlin

Dipartimento di Matematica e Fisica "Ennio De Giorgi"

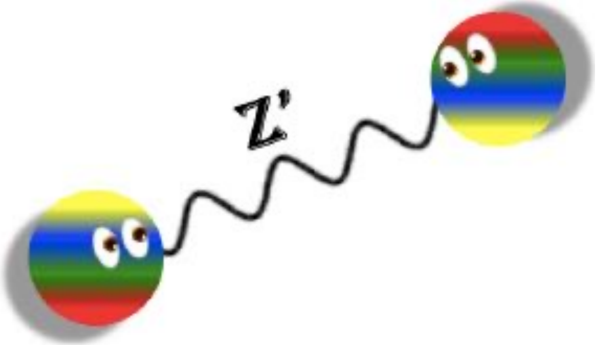




THANKS FOR YOUR ATTENTION!



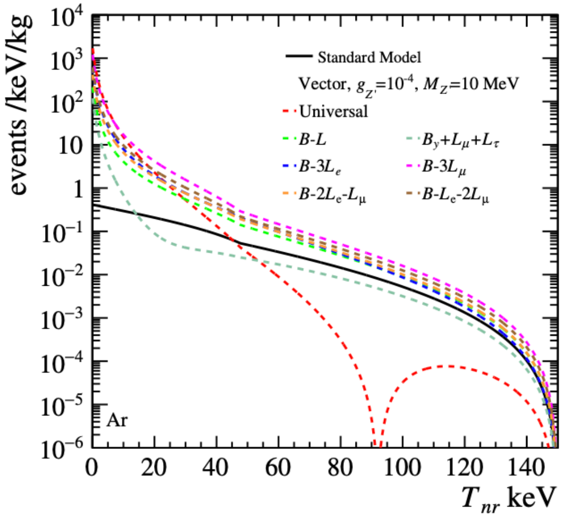
Back UP slides

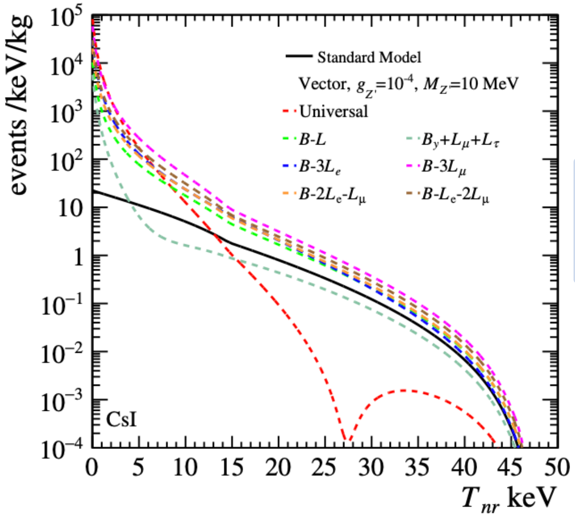


Light Mediators from U(1)′ extensions of the SM

Model	Q'_u	Q'_d	Q'_e	Q'_μ	Q'_τ
universal	1	1	1	1	1
$B-L$	$1/3$	$1/3$	-1	-1	-1
$B-3L_e$	$1/3$	$1/3$	-3	0	0
$B-3L_\mu$	$1/3$	$1/3$	0	-3	0
$B-2L_e-L_\mu$	$1/3$	$1/3$	-2	-1	0
$B-L_e-2L_\mu$	$1/3$	$1/3$	-1	-2	0
$B_y+L_\mu+L_\tau$	$1/3$	$1/3$	0	1	1
L_e-L_μ	0	0	1	-1	0
L_e-L_τ	0	0	1	0	-1
$L_\mu-L_\tau$	0	0	0	1	-1

COHERENT rates in BSM scenarios

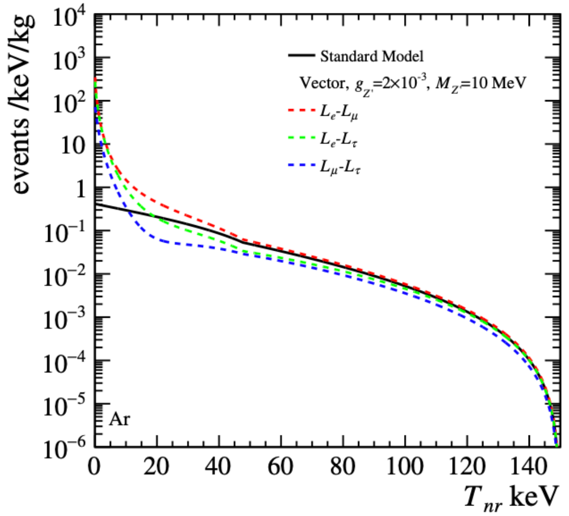


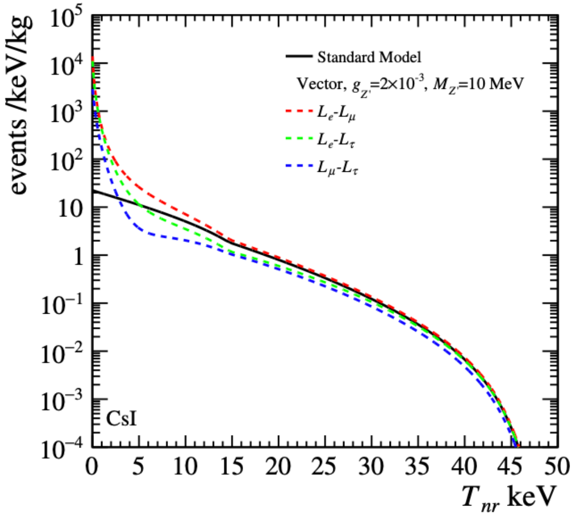


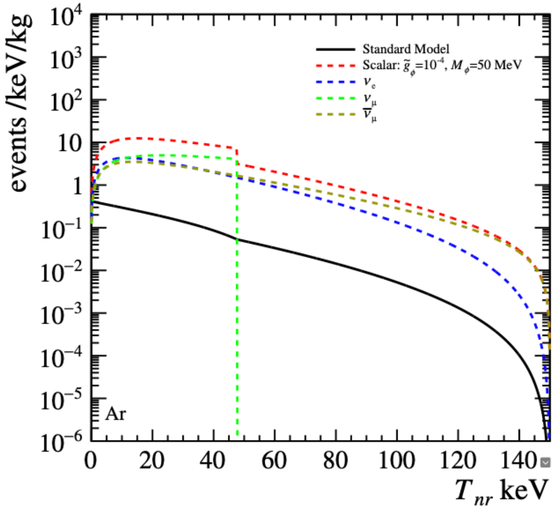
Expected rate of events at COHERENT for both CsI and LAr detectors considering energy resolution, acceptance, etc..

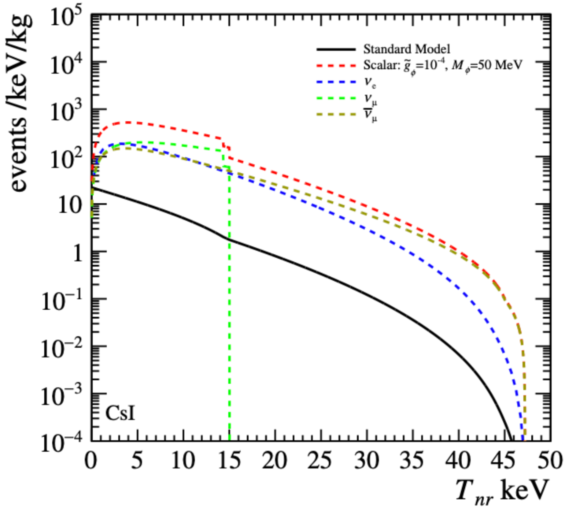
$$N_i^{\mathrm{CE\nu NS}} = N(\mathcal{N}) \int_{T_{\mathrm{nr}}^{i}}^{T_{\mathrm{nr}}^{i+1}} dT_{\mathrm{nr}} A(T_{\mathrm{nr}}) \int_0^{T'^{\mathrm{max}}_{\mathrm{nr}}} dT'_{\mathrm{nr}} R(T_{\mathrm{nr}}, T'_{\mathrm{nr}}) \int_{E_{\mathrm{min}}(T'_{\mathrm{nr}})}^{E_{\mathrm{max}}} dE \sum_{\nu=\nu_e,\nu_\mu,\bar{\nu}_\mu} \frac{dN_\nu}{dE}(E) \frac{d\sigma_{\nu-\mathcal{N}}}{dT_{\mathrm{nr}}}(E, T'_{\mathrm{nr}})$$

Some models produce a positive contribution inside the nuclear weak charge (which is negative) leading to a cancellation in the cross section









Constraints on light mediators through COHERENT data

We analysed the COHERENT data through a χ^2 analysis

D. Akimov et al. **Phys.Rev.Lett.** 126 (2021) 1, 012002
D. Akimov et al. **Phys.Rev.Lett**. 129 (2022) 8,081801

- Gaussian χ^2 for COHERENT LAr

$$\chi^2_{\mathrm{Ar}} = \sum_{i=1}^{12}\sum_{j=1}^{10}\left(\frac{N_{ij}^{\mathrm{exp}} - \sum_{z=1}^{4}(1+\eta_z+\sum_l \eta_{zl,ij}^{\mathrm{sys}})N_{ij}^z}{\sigma_{ij}}\right)^2 + \sum_{z=1}^{4}\left(\frac{\eta_z}{\sigma_z}\right)^2 + \sum_{z,l}(\epsilon_{zl})^2$$

  - i=energy bin
  - j=time bin
  - z=1,2,3,4 → CEνNS prediction, Steady-State,Prompt Beam-Related Neutron and Delayed Beam-Related Neutron backgrounds
  - $\sigma_{CE\nu NS} = 0.13, \sigma_{PBRN} = 0.32, \sigma_{DBRN} = 1, \sigma_{SS} = 0.0079$
  - Also considered the systematic uncertainties of the shapes of CEνNS and PBRN spectra using the information in the data release

- Poissonian χ^2 for COHERENT CsI

$$\chi^2_{\mathrm{CsI}} = 2\sum_{i=1}^{9}\sum_{j=1}^{11}\left[\sum_{z=1}^{4}(1+\eta_z)N_{ij}^z - N_{ij}^{\mathrm{exp}} + N_{ij}^{\mathrm{exp}}\ln\left(\frac{N_{ij}^{\mathrm{exp}}}{\sum_{z=1}^{4}(1+\eta_z)N_{ij}^z}\right)\right] + \sum_{z=1}^{4}\left(\frac{\eta_z}{\sigma_z}\right)^2$$

  - i=energy bin
  - j=time bin
  - z=1,2,3,4 → CEνNS prediction, beam-related neutron, neutrino-induced neutron and steady-state backgrounds
  - $\sigma_{CE\nu NS} = 0.12, \sigma_{BRN} = 0.25, \sigma_{NIN} = 0.35, \sigma_{SS} = 0.021$

Constraints on light mediators through COHERENT data

2σ constraints for the low and high mass approximations

- **Low mass: $\propto g'$**
- **High mass: $\propto \frac{g'}{M'}$**

model	Ar		CsI		CsI+Ar	
	$g_{Z'}$(low $M_{Z'}$)	$\frac{g_{Z'}}{M_{Z'}}$(high $M_{Z'}$)	$g_{Z'}$(low $M_{Z'}$)	$\frac{g_{Z'}}{M_{Z'}}$(high $M_{Z'}$)	$g_{Z'}$(low $M_{Z'}$)	$\frac{g_{Z'}}{M_{Z'}}$(high $M_{Z'}$)
universal	3.91×10^{-5}	0.82×10^{-3}	2.36×10^{-5}	0.53×10^{-3}	2.07×10^{-5}	0.48×10^{-3}
$B-L$	5.35×10^{-5}	1.67×10^{-3}	5.27×10^{-5}	1.00×10^{-3}	4.42×10^{-5}	0.99×10^{-3}
$B_y+L_\mu+L_\tau$	10.4×10^{-5}	3.58×10^{-3}	4.97×10^{-5}	1.14×10^{-3}	4.47×10^{-5}	1.04×10^{-3}
$B-3L_e$	4.91×10^{-5}	1.55×10^{-3}	5.16×10^{-5}	0.96×10^{-3}	4.34×10^{-5}	0.95×10^{-3}
$B-3L_\mu$	3.45×10^{-5}	1.09×10^{-3}	3.21×10^{-5}	0.64×10^{-3}	2.76×10^{-5}	0.63×10^{-3}
$B-2L_e-L_\mu$	4.62×10^{-5}	1.48×10^{-3}	4.79×10^{-5}	0.89×10^{-3}	3.95×10^{-5}	0.88×10^{-3}
$B-L_e-2L_\mu$	3.97×10^{-5}	1.28×10^{-3}	3.86×10^{-5}	0.75×10^{-3}	3.26×10^{-5}	0.74×10^{-3}
L_e-L_μ	161×10^{-5}	54.2×10^{-3}	166×10^{-5}	36.1×10^{-3}	137×10^{-5}	34.9×10^{-3}
L_e-L_τ	204×10^{-5}	71.1×10^{-3}	140×10^{-5}	29.9×10^{-3}	125×10^{-5}	26.6×10^{-3}
$L_\mu-L_\tau$	234×10^{-5}	80.9×10^{-3}	116×10^{-5}	26.6×10^{-3}	103×10^{-5}	24.2×10^{-3}
	$\tilde{g}_\phi$(low M_ϕ)	$\frac{\tilde{g}_\phi}{M_\phi}$(high M_ϕ)	$\tilde{g}_\phi$(low M_ϕ)	$\frac{\tilde{g}_\phi}{M_\phi}$(high M_ϕ)	$\tilde{g}_\phi$(low M_ϕ)	$\frac{\tilde{g}_\phi}{M_\phi}$(high M_ϕ)
scalar	2.30×10^{-5}	0.58×10^{-3}	1.80×10^{-5}	0.31×10^{-3}	1.68×10^{-5}	0.30×10^{-3}