Constraints on light vector mediators through COHERENT data

Chair of Galileo, from which, according to tradition, he gave lectures - Credits: Univ. of Padova - M. Pistore

Speaker:

Emmanuele Picciau

Constraints on light vector mediators through coherent elastic neutrino nucleus scattering data from COHERENT

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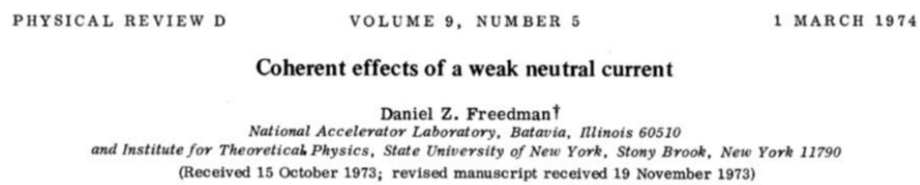
Coherent Elastic Neutrino Nucleus Scattering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Coherent effects of a weak neutral current

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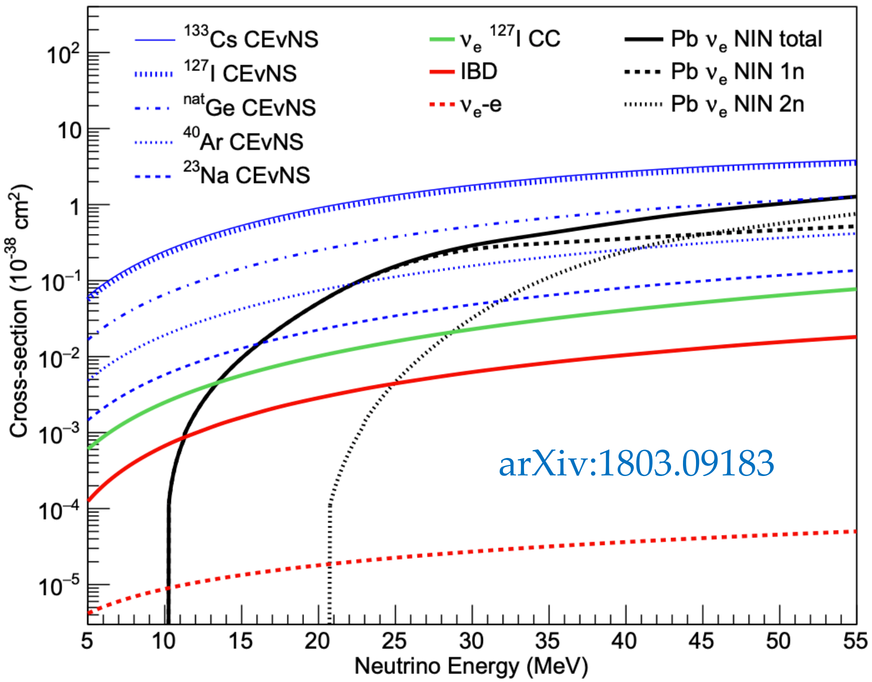
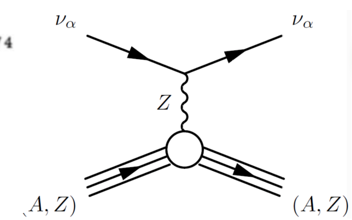
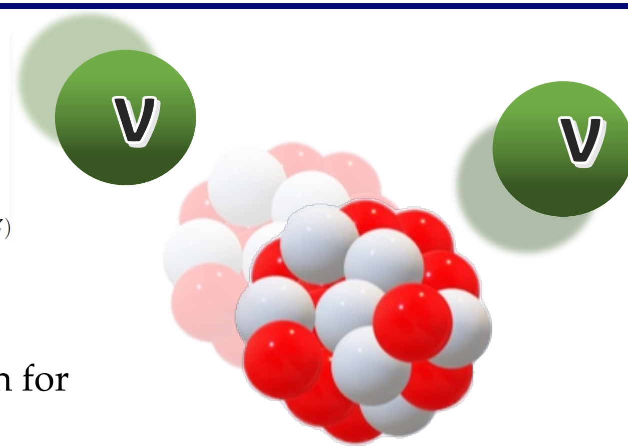






Kinematic condition for CEvNS

$$|\vec{\mathbf{q}}| \cdot R_{\mathrm{N}} \ll 1$$

VERY CHALLENGING DETECTION!

Small momentum transfer => small **recoil energy**:
MeV-neutrinos produce recoil energy around O(1-10) **keV.**

E = 30 MeV CsI: 14 keV Ar: 48 keV

Standard Model cross section for CEvNS

$$\frac{d\sigma_{\nu_\ell\text{-}\mathcal{N}}}{dT_{\mathrm{nr}}}(E, T_{\mathrm{nr}}) = \frac{G_{\mathrm{F}}^2 M}{\pi}\left(1 - \frac{M T_{\mathrm{nr}}}{2E^2}\right)\left[g_V^p Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right]^2$$

How to compare model with COHERENT data

The expected CEvNS signal is given by:

See also Y. Zhang parallel talk

$$N_i^{\mathrm{CE}\nu\mathrm{NS}} = N(X) \int_{T_{\mathrm{nr}}^{i}}^{T_{\mathrm{nr}}^{i+1}} dT_{\mathrm{nr}} A(T_{\mathrm{nr}}) \int_{E_{\min}}^{E_{\max}} dE \sum_{\nu=\nu_e,\nu_\mu,\bar{\nu}_\mu} \frac{dN_\nu}{dE} \frac{d\sigma_{\nu-\mathcal{N}}}{dT_{\mathrm{nr}}}(E, T_{\mathrm{nr}})$$

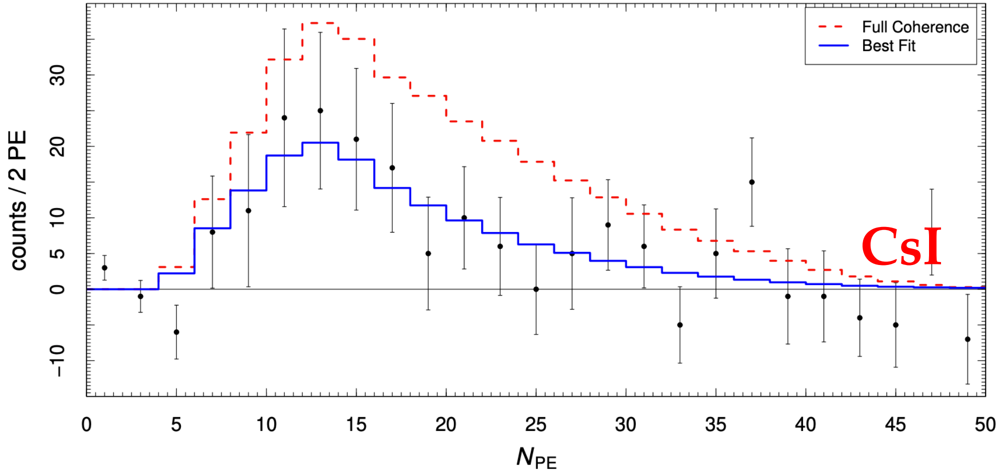
$N(X)$: Number of nuclei in the active volume of the detector

$A(T_{nr})$: Acceptance of the detector

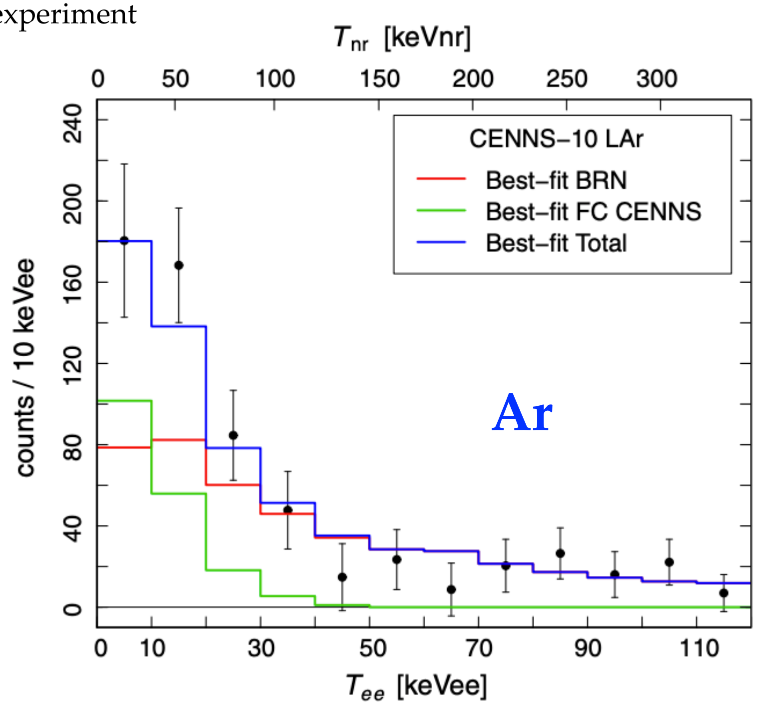
dN_ν/dE : Neutrino fluxes at SNS

$d\sigma/dT_{nr}$: CEvNS cross section

*The conversion between nuclear recoil and the measured observable includes the presence of **quenching factor,** a very challenging quantity to be measured, that for both CsI and Ar detectors is one of the parameter that affects the sensitivity of the experiment



M. Cadeddu et al. - Phys.Rev.D 101 (2020) 3, 033004



M. Cadeddu et al. - Phys.Rev.D 102 (2020) 1, 015030

For the **very latest analysis** with 2020 CsI data see: arXiv: 2102.06153

Non Standard Interactions

The general vector neutral-current neutrino non standard interactions described by the effective four-fermion Lagrangian is:

$$\mathcal{L}_{\mathrm{NSI}}^{\mathrm{NC}} = -2\sqrt{2}G_{\mathrm{F}} \sum_{\alpha,\beta=e,\mu,\tau} (\overline{\nu_{\alpha L}}\gamma^{\rho}\nu_{\beta L}) \sum_{f=u,d} \varepsilon_{\alpha\beta}^{fV} (\bar{f}\gamma_{\rho}f)$$

SM electroweak vector contribution

$$\boxed{Q_{\alpha}^{2} = \left[g_{V}^{p} Z F_{Z}(|\vec{q}|^{2}) + g_{V}^{n} N F_{N}(|\vec{q}|^{2})\right]^{2}}$$

General NSI electroweak vector contribution

$$\begin{aligned} Q_{\alpha}^{2} = & \left[\left(g_{V}^{p} + 2\varepsilon_{\alpha\alpha}^{uV} + \varepsilon_{\alpha\alpha}^{dV}\right) Z F_{Z}(|\vec{q}|^{2}) + \left(g_{V}^{n} + \varepsilon_{\alpha\alpha}^{uV} + 2\varepsilon_{\alpha\alpha}^{dV}\right) N F_{N}(|\vec{q}|^{2})\right]^{2} \\ & + \sum_{\beta\neq\alpha} \left|\left(2\varepsilon_{\alpha\beta}^{uV} + \varepsilon_{\alpha\beta}^{dV}\right) Z F_{Z}(|\vec{q}|^{2}) + \left(\varepsilon_{\alpha\beta}^{uV} + 2\varepsilon_{\alpha\beta}^{dV}\right) N F_{N}(|\vec{q}|^{2})\right|^{2}, \end{aligned}$$

C. Giunti - Phys.Rev.D 101 (2020) 3, 035039

Assuming that neutrinos don't change flavor and only electron and muon neutrinos are involved in the process (as the case of COHERENT experiment):

$$\mathcal{L}_{\mathrm{NSI}}^{\mathrm{NC}} = -2\sqrt{2}G_{F} \sum_{\ell=e,\mu} (\overline{\nu_{\ell L}}\gamma^{\rho}\nu_{\ell L}) \sum_{f=u,d} \varepsilon_{\ell\ell}^{fV} (\bar{f}\gamma_{\rho}f)$$

No flavor changing NSI electroweak vector contribution

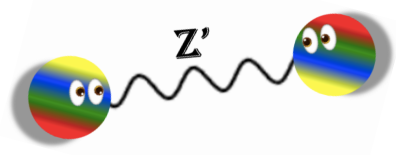
$$\boxed{Q_{\ell}^{2} = [(g_{V}^{p}(\nu_{\ell}) + 2\varepsilon_{\ell\ell}^{uV} + \varepsilon_{\ell\ell}^{dV}) Z F_{Z}(|\vec{q}|^{2}) + (g_{V}^{n} + \varepsilon_{\ell\ell}^{uV} + 2\varepsilon_{\ell\ell}^{dV}) N F_{N}(|\vec{q}|^{2})]}$$

*In principle we should also consider an axial contribution but in experiments looking for coherent scattering the axial contribution is negligible

Interactions mediated by non standard bosons

What if neutrino NSI are induced by a gauge Z′-boson with mass $M_{Z'}$ and coupling $g_{Z'}$ associated with a new U(1)′ symmetry?

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



Depending on how the **new light vector mediator** couples to the SM, so assuming a value for Q_ℓ and Q_f it is possible to explore several models, for instance:

Universal model

J. Liao and D. Marfatia- *Phys.Lett.B* 775 (2017)

$$\left(\frac{d\sigma}{dT_{\rm nr}}\right)^{\nu_\ell\text{-}\mathcal{N}}_{\rm univ}(E, T_{\rm nr}) = \frac{G_F^2 M}{\pi}\left(1 - \frac{M T_{\rm nr}}{2E^2}\right) \cdot \left[Q_{\ell,\rm SM} + \frac{3(g_{Z'})^2}{\sqrt{2} G_F} \frac{Z F_Z(|\vec{q}|^2) + N F_N(|\vec{q}|^2)}{|\vec{q}|^2 + M_{Z'}^2}\right]^2$$

B-L model

T. Han, J. Liao, H. Liu and D. Marfatia - JHEP 11 (2019) 028
J. Billard, J. Johnston and B.J. Kavanagh - JCAP 11 (2018) 016

$$\left(\frac{d\sigma}{dT_{\rm nr}}\right)^{\nu_\ell\text{-}\mathcal{N}}_{\rm B-L}(E, T_{\rm nr}) = \frac{G_F^2 M}{\pi}\left(1 - \frac{M T_{\rm nr}}{2E^2}\right) \cdot \left[Q_{\ell,\rm SM} - \frac{(g_{Z'})^2}{\sqrt{2} G_F} \frac{Z F_Z(|\vec{q}|^2) + N F_N(|\vec{q}|^2)}{|\vec{q}|^2 + M_{Z'}^2}\right]^2$$

L_μ-L_τ model

W. Altmannshofer et al. - Phys. Rev. D 100 (2019) 115029

$$\left(\frac{d\sigma}{dT_{\rm nr}}\right)^{\nu_\ell\text{-}\mathcal{N}}_{L_\mu - L_\tau}(E, T_{\rm nr}) = \frac{G_F^2 M}{\pi}\left(1 - \frac{M T_{\rm nr}}{2E^2}\right) \cdot$$
$$\left\{\left[g_V^p(\nu_\ell) - \frac{\alpha_{\rm EM}\,(g_{Z'})^2}{3\sqrt{2}\pi G_F} \log\left(\frac{m_\tau^2}{m_\mu^2}\right) \frac{1}{|\vec{q}|^2 + M_{Z'}^2}\right] Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right\}^2$$

Interactions mediated by non standard bosons

How does the COHERENT theoretical rate of events change with Z' contributions?

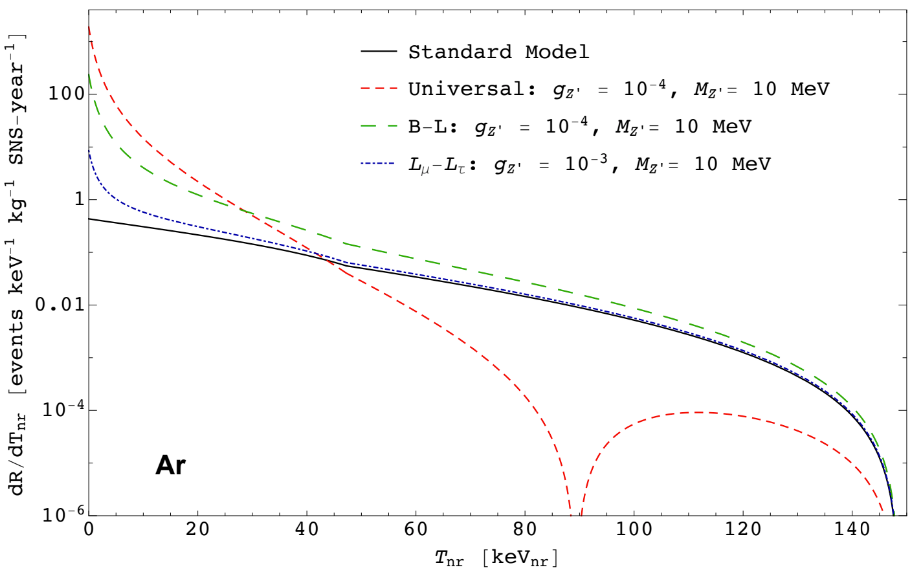
Universal model

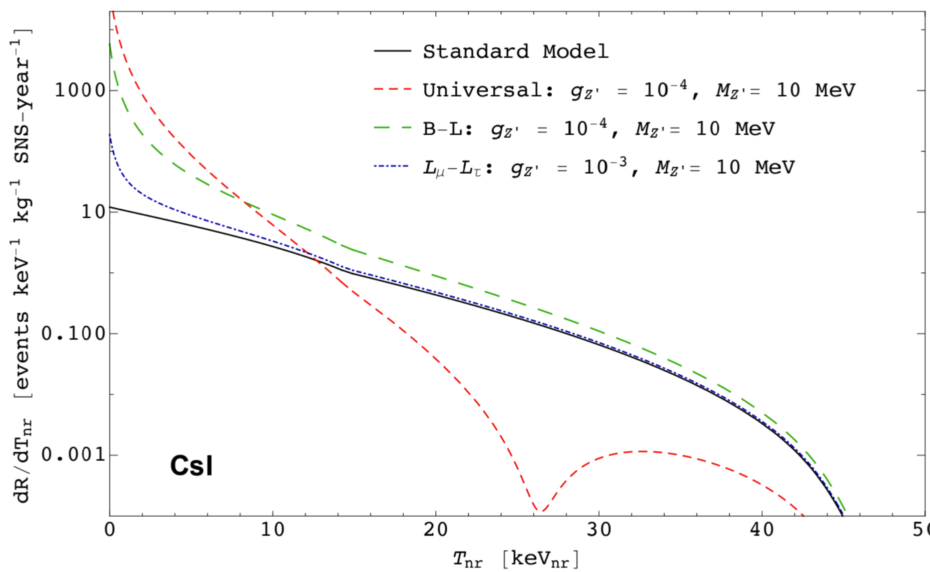
Low energy:
Enhancement of the rate

High energy:
Drop of the rate due the cancellation of the cross section

B-L model **L_μ-L_τ model**

Overall enhancement of the event rate

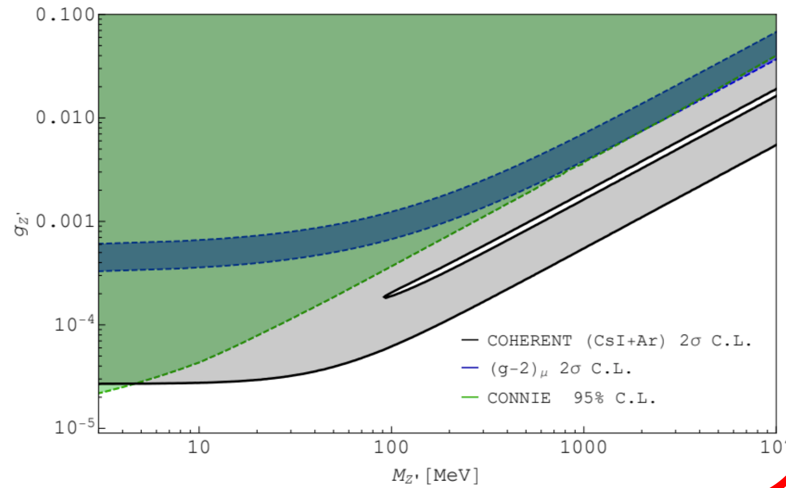




Constraints on the 3 models using COHERENT data

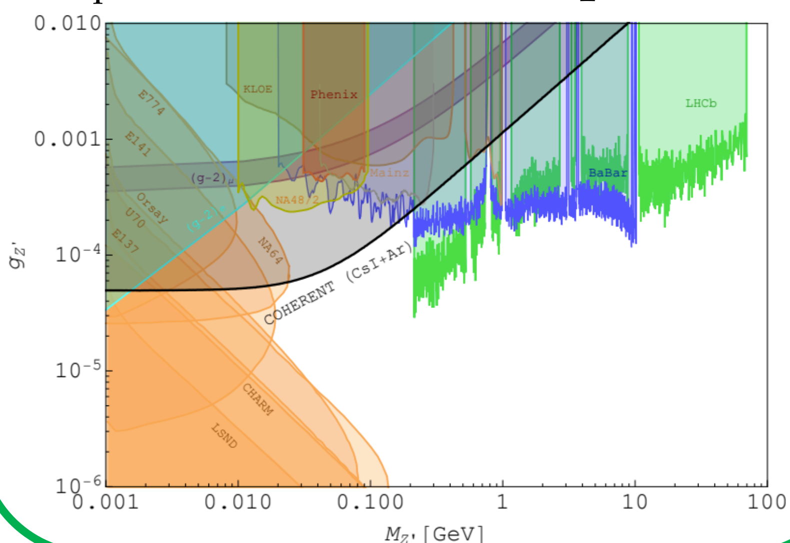
Universal model

- Improved limits for $M_{Z'} > 4$ MeV
- Degeneracy line related to the cancellation in the event rate



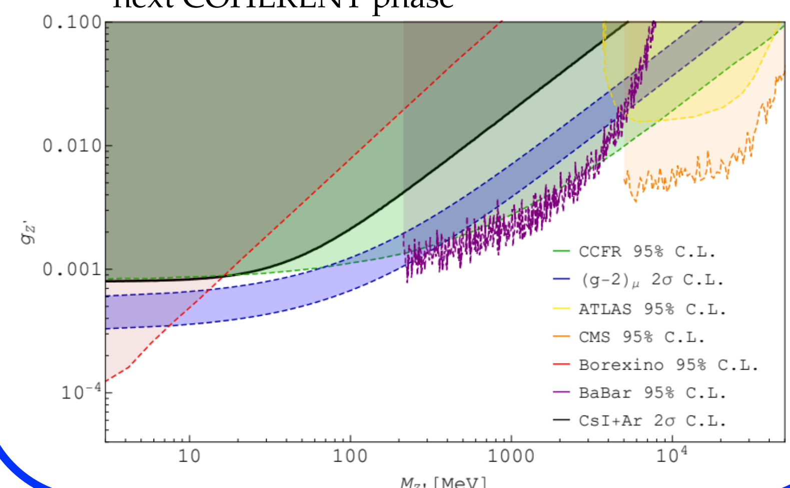
B-L

Improved limits for 20 MeV < $M_{Z'}$ < 200 MeV



L_μ-L_τ

- Confirmation of already set limits.
- Promising opportunity to improve limits with next COHERENT phase




Thanks for the attention
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