Magnificent CEνNS 2020

17 November

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

Presentation based on arXiv: 2008.0522
M. Cadeddu, N. Cargioli, F. Dordei,
C. Giunti, Y.F. Li, E. Picciau and Y.Y. Zhang

Speaker: Nicola Cargioli

Outline of the talk

- Coherent Elastic Neutrino Nucleus Scattering
- COHERENT experiment
- Light vector mediators in CEνNS
- Limits on new physics models using COHERENT data

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

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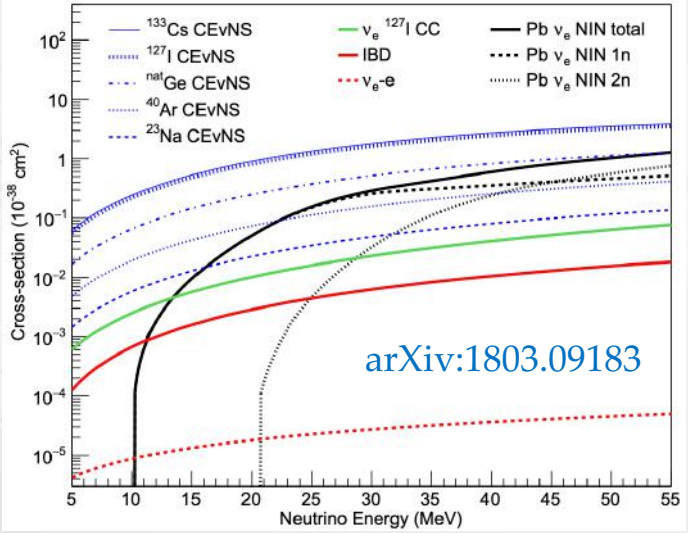
Reference paper: arXiv:2008.05022 [hep-ph]

Coherent Elastic Neutrino Nucleus Scattering

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

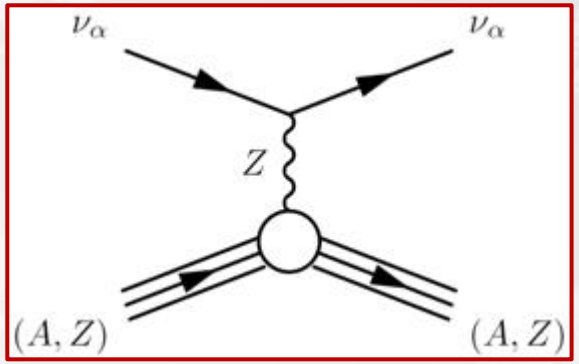
Coherent effects of a weak neutral current

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)



Kinematic condition for CEvNS $|\vec{q}| \cdot R_N \ll 1$

$$R \simeq 10fm \rightarrow q \leq \frac{\hbar c}{R} \simeq \frac{200MeVfm}{10fm} \sim 20MeV$$



VERY CHALLENGING DETECTION

Small momentum transfer means small **recoil energy**:

MeV-neutrinos produce recoil energy around O(1-10) **keV.**

$$T \simeq \frac{q^2}{2M} \qquad T \simeq \frac{2E_\nu^2}{M}$$

E = 30 MeV Cs: 14 keV Xe: 15 keV Ar: 48 keV

Coherent Elastic Neutrino Nucleus Scattering

The differential cross section as a function of the recoil energy for a spinless target is :

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

Tree Level

$$g_V^p = \frac{1}{2} - 2\sin^2\vartheta_W, \qquad g_V^n = -\frac{1}{2}$$

*Even if the target is not spin zero, the axial part remains negligible with respect to the vector part. The ratio of axial to vector contributions is expected to be of order of 1/A.

With radiative corrections

$$g_V^p(\nu_\ell) = \rho\left(\frac{1}{2} - 2\sin^2\vartheta_W\right) - \frac{\hat{\alpha}_Z}{4\pi\hat{s}_Z^2}\left(1 - 2\frac{\hat{\alpha}_s(m_W)}{\pi}\right) + \frac{\alpha}{6\pi}\left(3 - 2\ln\frac{m_\ell^2}{m_W^2}\right)$$

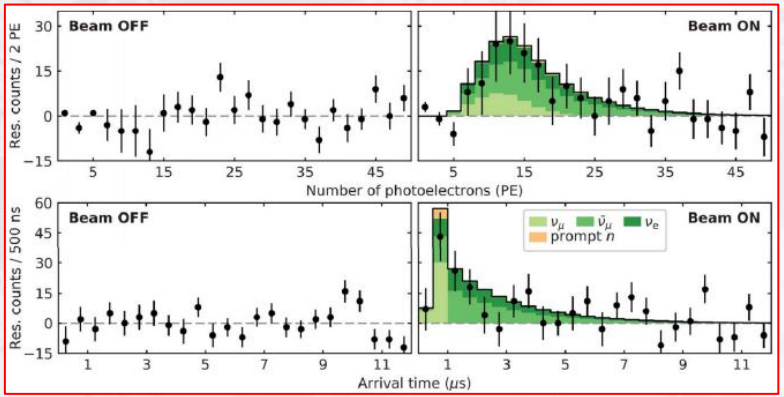
$$g_V^n = -\frac{\rho}{2} - \frac{\hat{\alpha}_Z}{8\pi\hat{s}_Z^2}\left(7 - 5\frac{\hat{\alpha}_s(m_W)}{\pi}\right)$$

J. Erler & S. Su - Prog.Part.Nucl.Phys. 71 (2013)
M. Cadeddu et al. - Phys.Rev.D 102 (2020) 1, 015030

Parameters included in the cross section

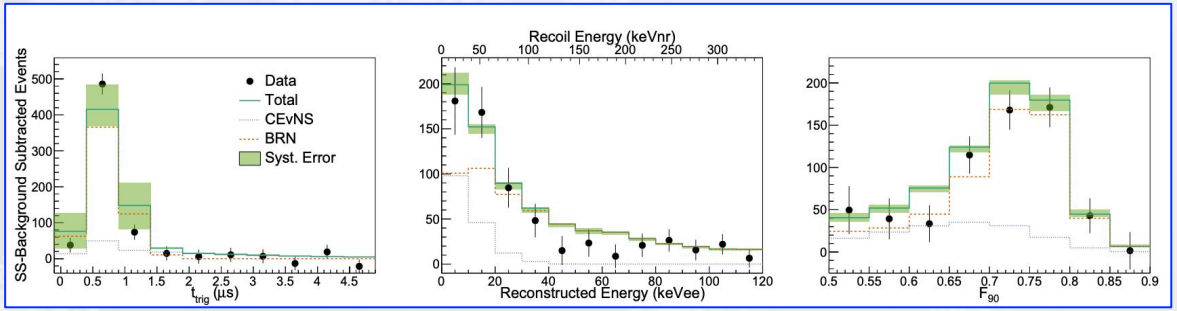
- G_F = Fermi constant
- M = Mass of the target nucleus
- T_{nr} = Recoil energy of the nucleus
- E = Neutrino energy
- g_V^p = Vector coupling with protons
- g_V^n = Vector coupling with neutrons
- Z = Number of protons
- N = Number of neutrons
- F_Z = Proton form factor
- F_N = Neutron form factor
- q = Momentum transfer
- ϑ_W = Weinberg Angle
- $\hat{\alpha}_s(m_W)$ = Strong coupling constant at W mass
- $\hat{\alpha}_Z$ = Fine structure constant at Z-mass
- ρ = Low-energy NC parameter
- m_W = Mass of W boson
- m_ℓ = Mass of the lepton
- $\hat{s}_Z = \sin^2\vartheta_W$ at the Z-boson mass

COHERENT experiment



Cesium-Iodide **6.7σ** C.L. 14.6 kg detector

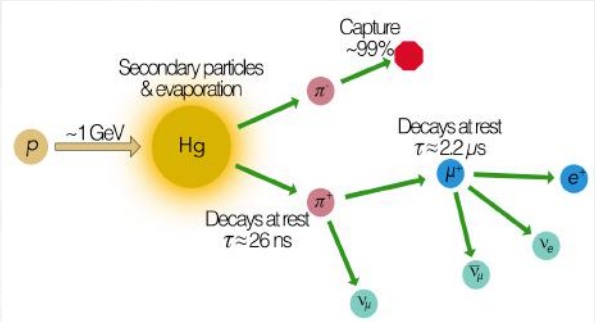
Observation of Coherent Elastic Neutrino-Nucleus Scattering - COHERENT Collaboration (Akimov, D. et al.) Science 357 (2017) no.6356

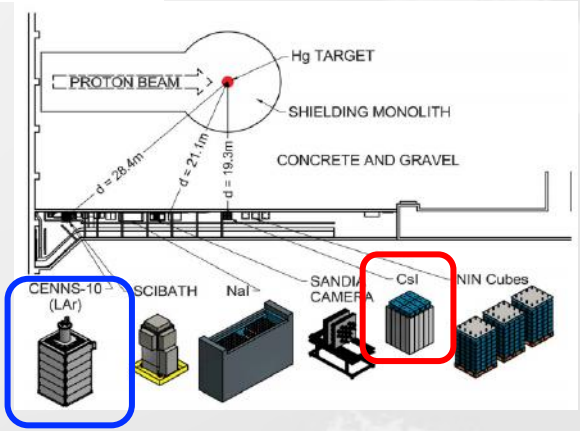


Argon **3.5σ** C.L. 24 kg detector

First Detection of Coherent Elastic Neutrino-Nucleus Scattering on Argon - COHERENT Collaboration (Akimov, D. et al.) arXiv:2003.10630 [nucl-ex]

Neutrino production at Spallation Neutron Source





COHERENT experiment

The expected CEvNS signal is given by:

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

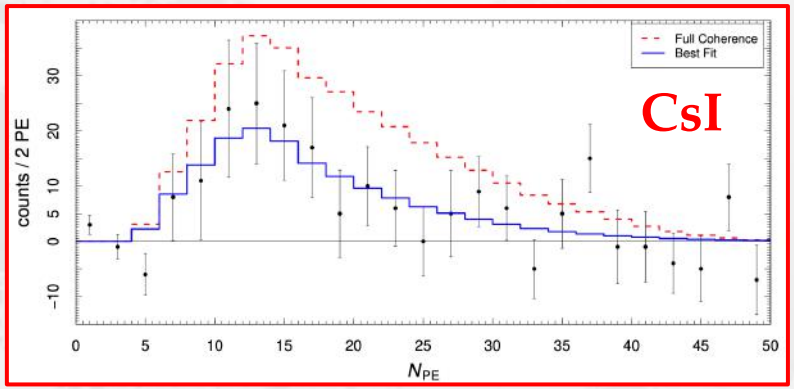
$N(X)$: Number of nuclei in the active volume of the detector

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

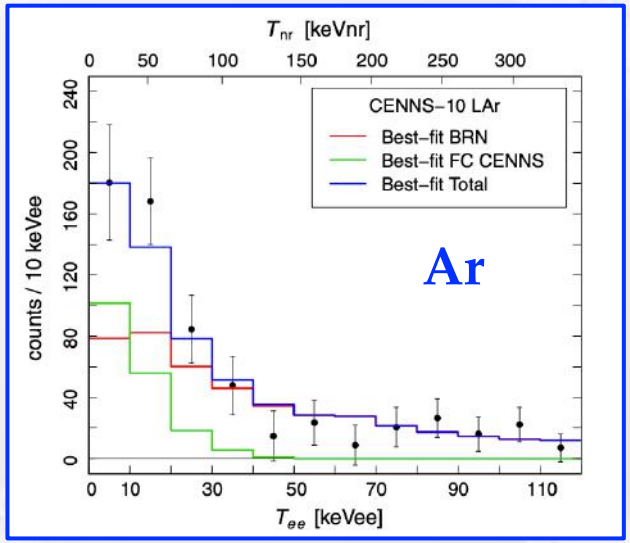
dN_ν/dE : Neutrino fluxes at SNS

$d\sigma/dT_{nr}$: 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

Light vector mediators in CEνNS

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

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

SM electroweak vector contribution

$$\left[g_V^p Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right]^2$$

General NSI electroweak vector contribution

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

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):

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

No flavor changing NSI electroweak vector contribution

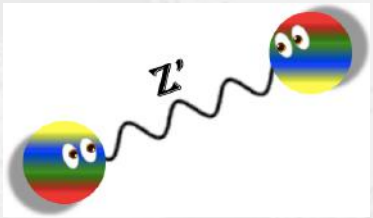
$$Q^2_{\ell} = [(g_V^p(\nu_\ell) + 2\epsilon^{uV}_{\ell\ell} + \epsilon^{dV}_{\ell\ell}) Z F_Z(|\vec{q}|^2) + (g_V^n + \epsilon^{uV}_{\ell\ell} + 2\epsilon^{dV}_{\ell\ell}) N F_N(|\vec{q}|^2)]^2$$

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

Light vector mediators in CEνNS

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, namely assuming a value for Q'_ℓ and Q'_f it is possible to explore several models, for instance the following three:

Universal model

$Q'_l = Q'_f = 1$

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

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

B-L model

$Q'_l = 1,$
$Q'_f = -Q'_l/3$

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

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

L_μ-L_τ model

$$\left(\frac{d\sigma}{dT_{nr}}\right)^{\nu_\ell\text{-}\mathcal{N}}_{L_\mu - L_\tau}(E, T_{nr}) = \frac{G_F^2 M}{\pi}\left(1 - \frac{MT_{nr}}{2E^2}\right)\cdot$$

$$\left\{\left[g_V^p(\nu_\ell) - \frac{\alpha_{\text{EM}}\,(g_{Z'})^2}{3\sqrt{2}\pi G_F}\log\left(\frac{m_\tau^2}{m_\mu^2}\right)\frac{1}{|\vec{q}|^2 + M_{Z'}^2}\right] ZF_Z(|\vec{q}|^2) + g_V^n NF_N(|\vec{q}|^2)\right\}^2$$

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

Light vector mediators in CEνNS

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

Universal model

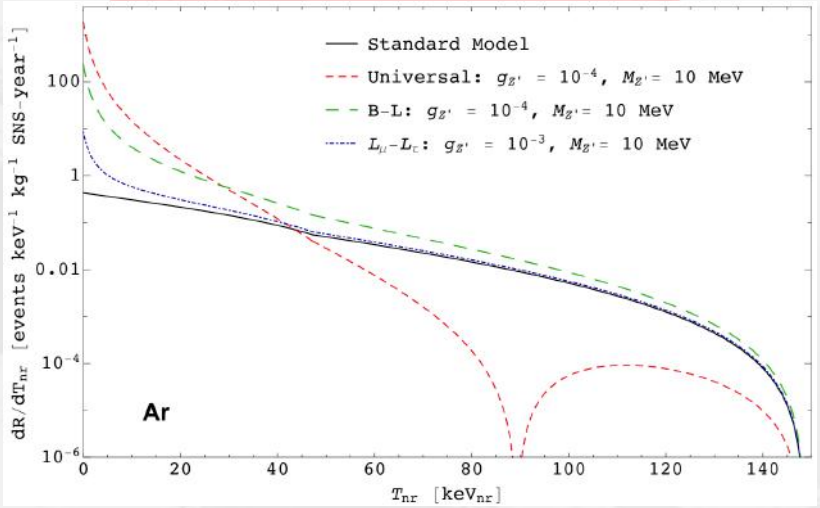
Low energy:
Enhancement of the rate

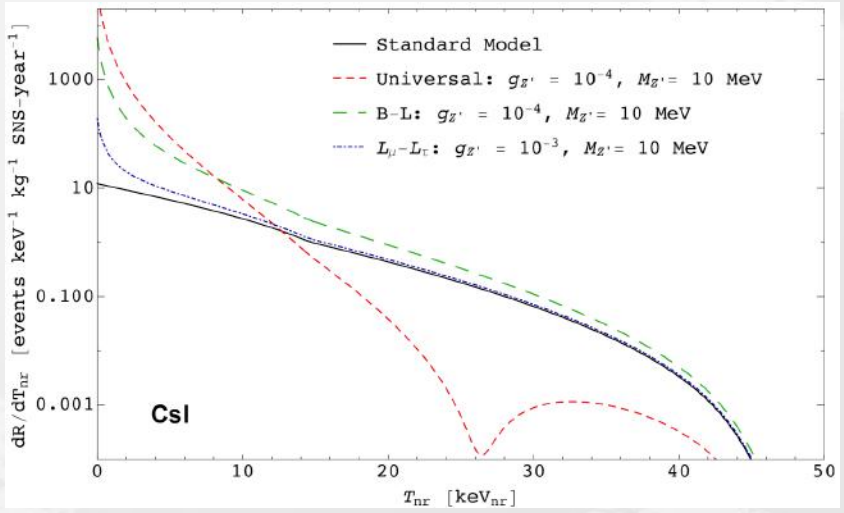
High energy:
Drop of the rate due the cancellation of the cross section

B-L model

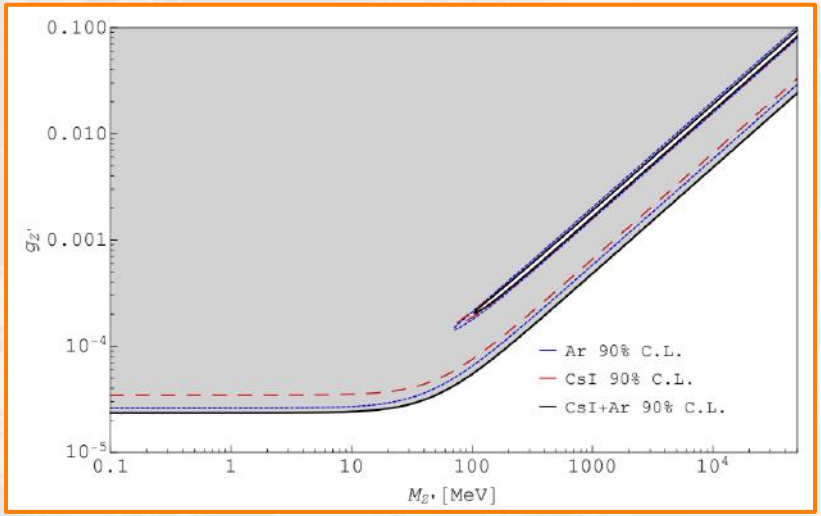
L_μ-L_τ model

Overall enhancement of the event rate



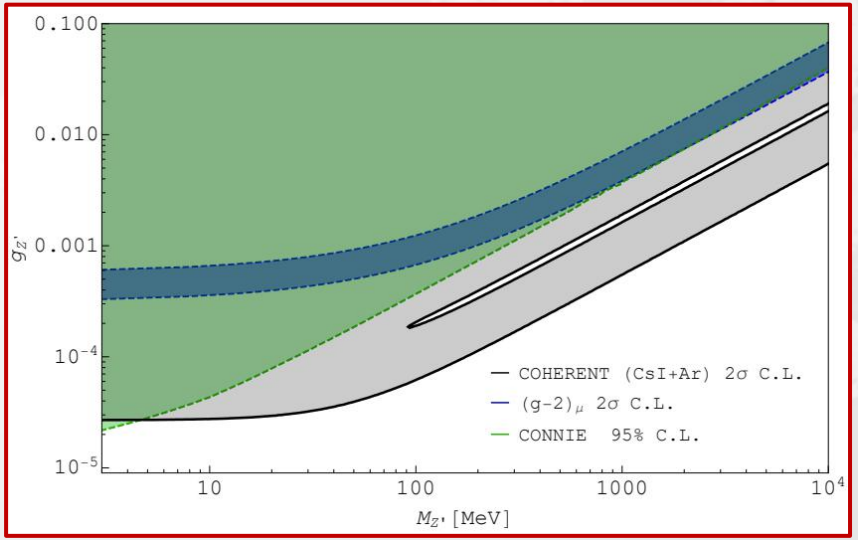


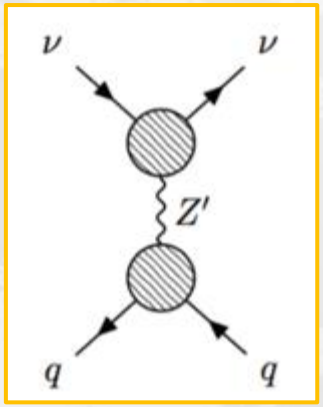
Limits on new physics models using COHERENT data



Same coupling with all the fermions

$$Q'_\ell \equiv Q'_f = 1,$$





Universal model

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

CONNIE collaboration - JHEP 04 (2020) 054

A. Drukier and L. Stodolsky - Phys. Rev. D30 (1984) 2295

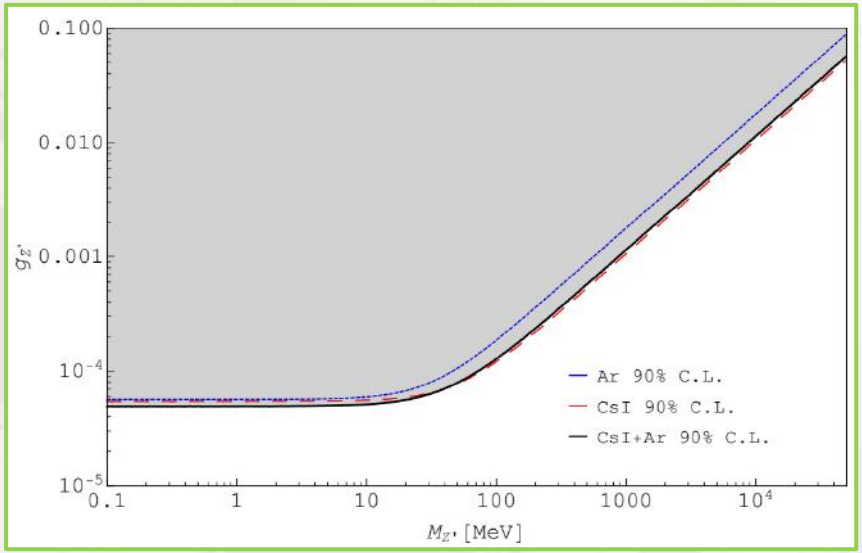
J. Barranco, O. Miranda and T. Rashba - JHEP 12 (2005) 021

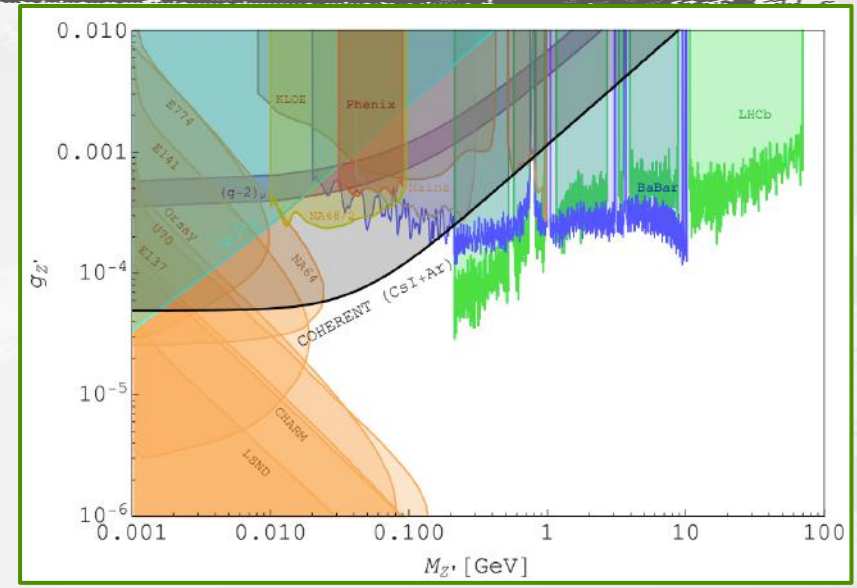
Limits on new physics models using COHERENT data

The second model that we consider is the so-called $B - L$ (baryon number minus lepton number) extension of the SM [20, 21]. In this case the gauge charges are determined by imposing that the theory is anomaly free. In particular, in this model the boson couples universally to the quarks, as well as to the neutrinos, but with different charges, namely $Q'_\ell \neq Q'_f$. In particular, in the $B - L$ model the gauge charges are such that $Q'_\ell = 1$ and $Q'_f = -Q'_\ell/3$.

B-L

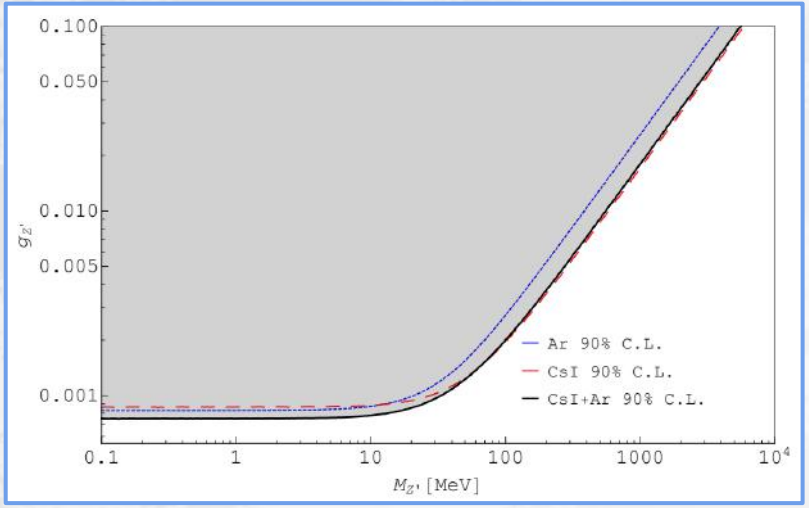
Improved limits for 20 MeV < $M_{Z'}$ < 200 MeV





BaBar collaboration, Phys. Rev. Lett. 113 (2014) 201801
LHCb collaboration, Phys. Rev. Lett. 124 (2020) 041801
PHENIX Collaboration - Phys. Rev. C 91 (2015) 031901
ALICE collaboration - Phys. Lett. B 720 (2013) 52
NA48/2 collaboration - Phys. Lett. B 746 (2015) 178
A1 Collaboration collaboration - Phys. Rev. Lett. 106 (2011) 251802.
R. Harnik, J. Kopp and P.A. Machado - JCAP 07 (2012) 026
Muon g-2 collaboration -, Phys. Rev. D 73 (2006) 072003
H. Davoudiasl and W.J. Marciano - Phys. Rev. D 98 (2018) 075011

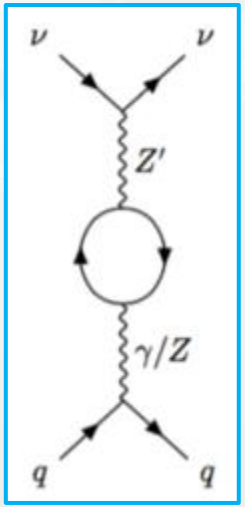
Limits on new physics models using COHERENT data

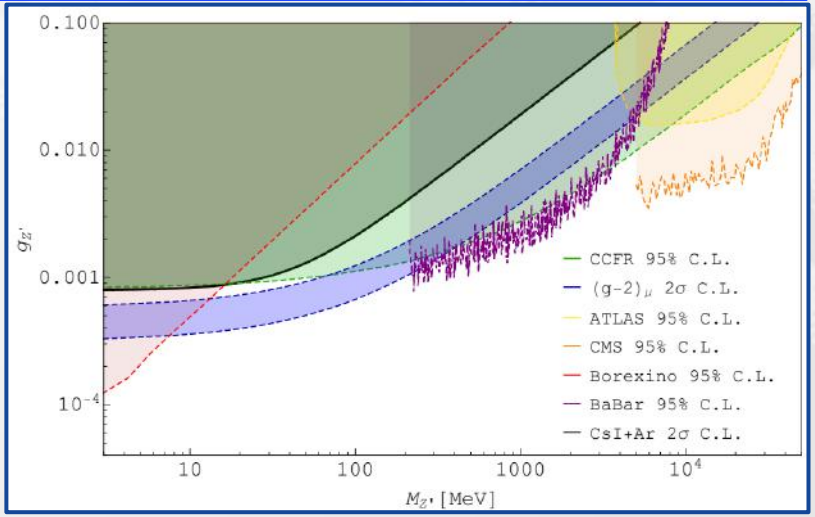


W. Altmannshofer et al. - Phys. Rev. Lett. 113 (2014) 091801
ATLAS collaboration - Phys. Rev. Lett. 112 (2014) 231806
CMS collaboration-Phys. Lett. B 792 (2019) 345
BaBar collaboration - Phys. Rev. D 94 (2016) 011102
S. Gninenko and D. Gorbunov - arXiv:2007.16098
Muon g-2 collaboration -, Phys. Rev. D 73 (2006) 072003

L_μ-L_τ

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





- Gauged Lμ − Lτ symmetry model.
- The new Z′ boson can couple directly only to muonic or tauonic flavour.
- CEνNS through kinetic loops of muons and tauons involving photons

Conclusions

General

- Description of CEνNS process and COHERENT experiment
- COHERENT CsI and LAr data
- Introduction of three different Z′ models

Results

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 your attention

Back Up Slides

Coherent Elastic Neutrino Nucleus Scattering

The differential cross section as a function of the recoil energy for a spinless target is :

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Electroweak vector coupling

$$C_V = g_V^p Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)$$

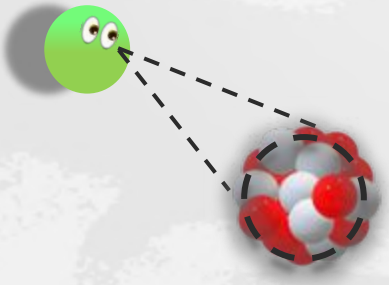
$$= \frac{1}{2}\left[(1-4\sin^2\vartheta_W) Z F_Z(|\vec{q}|^2) - N F_N(|\vec{q}|^2)\right]$$

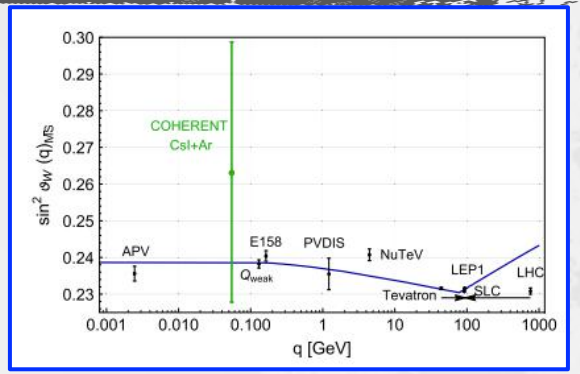
Weak mixing angle

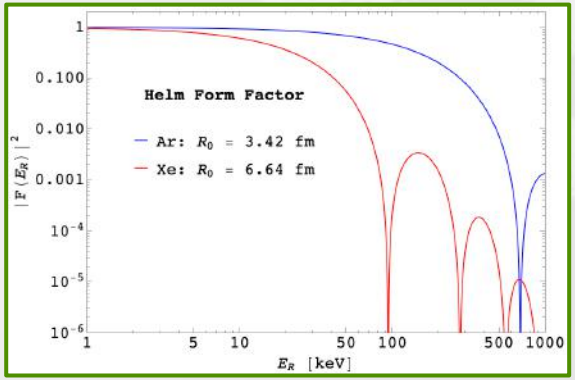
Neutron Form Factor

$$F(q)^{\rm Helm} = 3\frac{j_1(qR_0)}{qR_0} e^{-\frac{(qs)^2}{2}}$$

$$R_n \simeq R_p + 0.1 \text{ fm.}$$





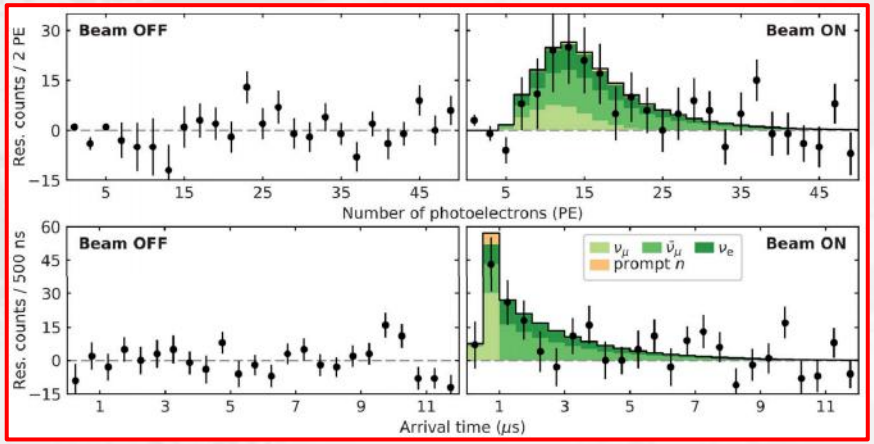


Measurements:

ϑ_W gives information about weak interactions

R_0 gives information about how neutrons are distributed in the nucleus

COHERENT experiment



Oct 1973: **Prediction**
Aug 2017: **Discovery**

Observation of the process at **6.7σ** CL using 14.6 kg CsI low-background scintillator as a target

First detection ever

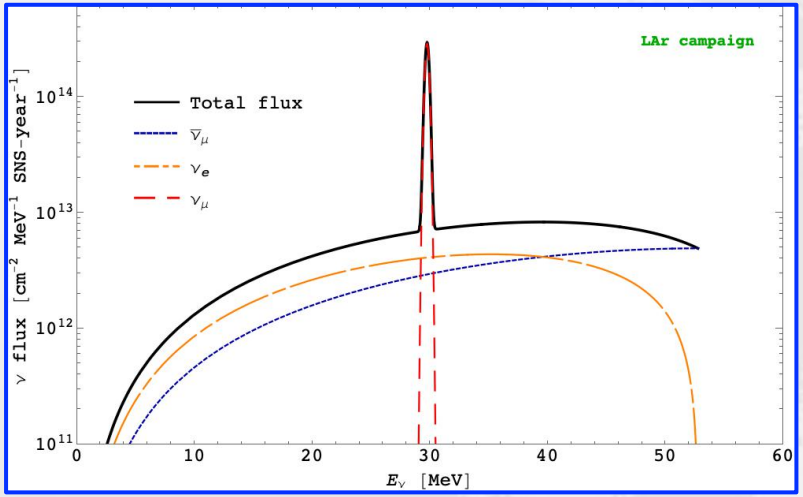
Three neutrino fluxes:

- **Muonic anti-neutrinos**
- **Electron neutrinos**
- **Muonic neutrinos**

$$\frac{dN_{\nu_\mu}}{dE_\nu} = \frac{rN_{POT}}{4\pi L^2}\,\delta\left(E_\nu - \frac{m_\pi^2 - m_\mu^2}{2m_\pi}\right)$$

$$\frac{dN_{\nu_\mu}}{dE_\nu} = \frac{rN_{POT}}{4\pi L^2}\frac{64E_\nu^2}{m_\mu^3}\left(\frac{3}{4} - \frac{E_\nu}{m_\mu}\right) \text{ per } E_\nu \le \frac{m_\mu}{2}$$

$$\frac{dN_{\nu_e}}{dE_\nu} = \frac{rN_{POT}}{4\pi L^2}\frac{192E_\nu^2}{m_\mu^3}\left(\frac{1}{2} - \frac{E_\nu}{m_\mu}\right) \text{ per } E_\nu \le \frac{m_\mu}{2}$$



COHERENT experiment

In 2020 also COHERENT LAr detector has seen CEvNS!

SIGNAL: CEvNS interaction with Ar nuclei → Nuclear recoils

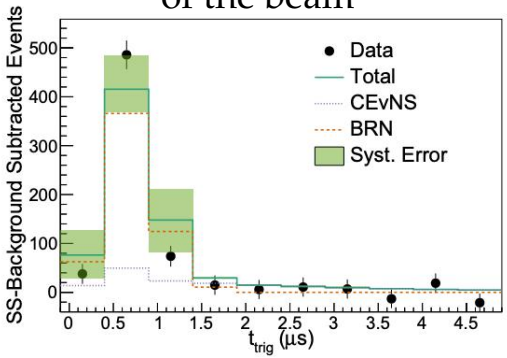
BACKGROUND: Neutrons interaction with Ar nuclei → Nuclear recoils

Gamma and beta interaction with Ar → Electron recoils

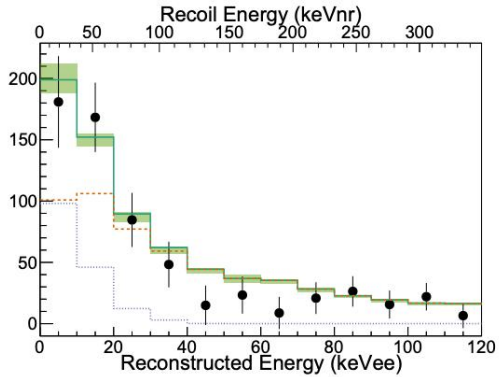
DATA RELEASE

With LAr detectors it is possible to exploit a very powerful tool (Pulse Shape Discrimination) that allows to reject most of the background produced by electron recoils

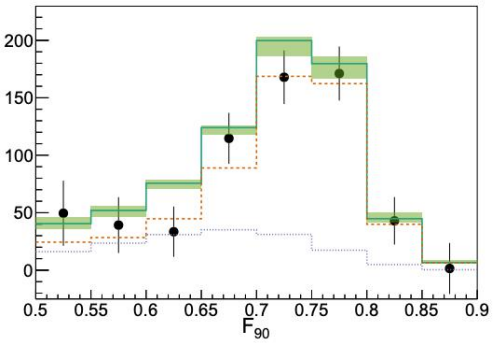
Time of the event with respect to the start time of the beam



Recoil energy of the event



PSD value of the event



Evidence of the process at **3.5σ** CL using 24 kg of atmospheric ^{40}Ar.

COHERENT experiment

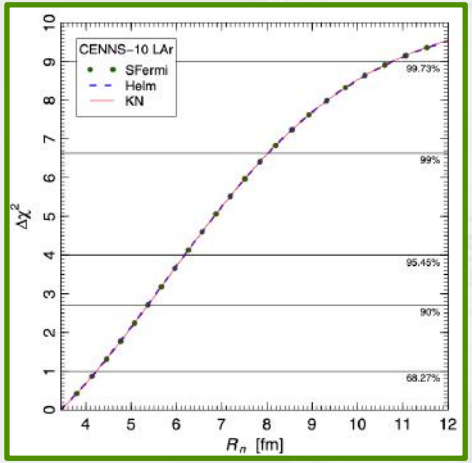
We performed a χ^2 fit of the data measuring:

Neutron distribution radius

The neutron form factor embeds the neutron distribution radius

Nuclear models prediction:

Our result $R_n(^{40}\mathrm{Ar}) < 4.2(1\sigma), 6.2(2\sigma), 10.8(3\sigma)$ fm



Weak Mixing Angle

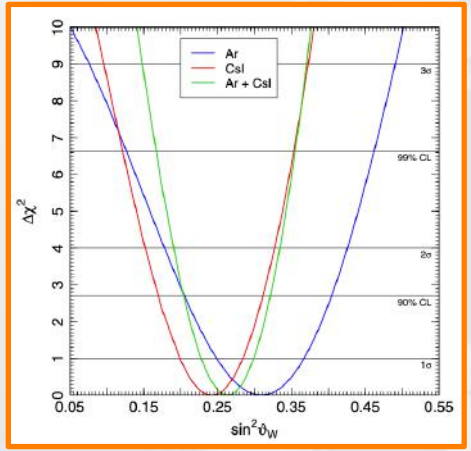
Theoretical prediction: $\sin^2\vartheta_{\mathrm{W}} = 0.23857 \pm 0.00005$

Our result

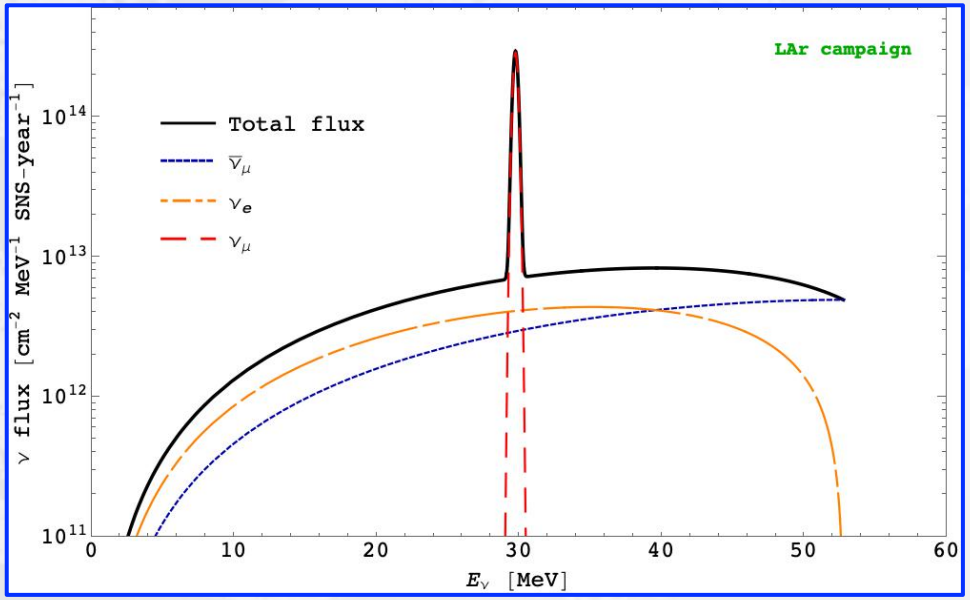
$$\sin^2\vartheta_{\mathrm{W}}(\mathrm{Ar}) = 0.31 \pm 0.06\,(1\sigma), {}^{+0.11}_{-0.13}\,(2\sigma), {}^{+0.18}_{-0.23}\,(3\sigma)$$

$$\sin^2\vartheta_{\mathrm{W}}(\mathrm{CsI}) = 0.24 \pm 0.04\,(1\sigma), \pm 0.09\,(2\sigma), {}^{+0.13}_{-0.14}\,(3\sigma)$$

$$\sin^2\vartheta_{\mathrm{W}}(\mathrm{CsI}+\mathrm{Ar}) = 0.26^{+0.04}_{-0.03}\,(1\sigma), \pm 0.07\,(2\sigma), \pm 0.11\,(3\sigma)$$



COHERENT experiment



$$\frac{dN_{\nu_\mu}}{dE} = \eta\delta\left(E - \frac{m_\pi^2 - m_\mu^2}{2m_\pi}\right),$$

$$\frac{dN_{\nu_{\bar{\mu}}}}{dE} = \eta\frac{64E^2}{m_\mu^3}\left(\frac{3}{4} - \frac{E}{m_\mu}\right),$$

$$\frac{dN_{\nu_e}}{dE} = \eta\frac{192E^2}{m_\mu^3}\left(\frac{1}{2} - \frac{E}{m_\mu}\right),$$

$$\eta = rN_{\mathrm{POT}}/4\pi L^2$$

$$r = (9 \pm 0.9) \times 10^{-2}$$

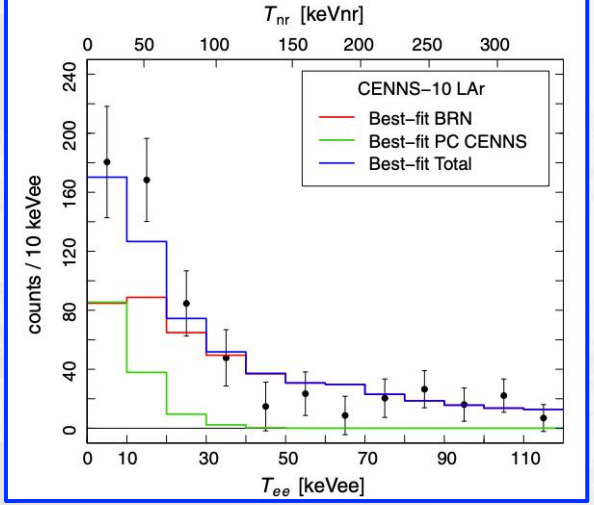
L_{Ar} = 27.5 m $N_{POT,Ar} = 13.7\times10^{22}$

L_{CsI} = 19.3 m $N_{POT,CsI} = 17.6\times10^{22}$

Spallation Neutron Source, ORNL

COHERENT experiment

$$\chi^2_S = \sum_{i=1}^{12} \left(\frac{N_i^{\text{exp}} - \eta_{\text{CE}\nu\text{NS}} N_i^{\text{CE}\nu\text{NS}} - \eta_{\text{PBRN}} B_i^{\text{PBRN}} - \eta_{\text{LBRN}} B_i^{\text{LBRN}}}{\sigma_i} \right)^2 + \left(\frac{\eta_{\text{CE}\nu\text{NS}} - 1}{\sigma_{\text{CE}\nu\text{NS}}} \right)^2 + \left(\frac{\eta_{\text{PBRN}} - 1}{\sigma_{\text{PBRN}}} \right)^2 + \left(\frac{\eta_{\text{LBRN}} - 1}{\sigma_{\text{LBRN}}} \right)^2$$



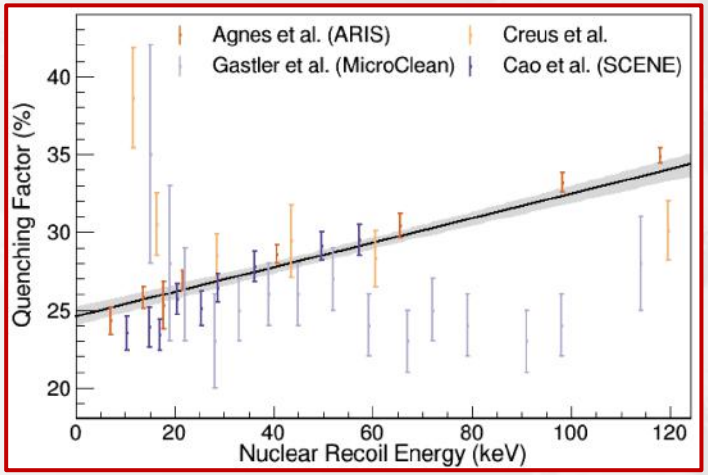
$$\sigma_i^2 = (\sigma_i^{\text{exp}})^2 + [\sigma_{\text{BRNES}}(B_i^{\text{PBRN}} + B_i^{\text{LBRN}})]^2,$$

$$\sigma_{\text{BRNES}} = \sqrt{\frac{0.058^2}{12}} = 1.7\%,$$

$$\sigma_{\text{CE}\nu\text{NS}} = 13.4\% \text{ for fixed } R_n, \text{ or } 13.2\% \text{ for free } R_n,$$

$$\sigma_{\text{PBRN}} = 32\%,$$

$$\sigma_{\text{LBRN}} = 100\%.$$



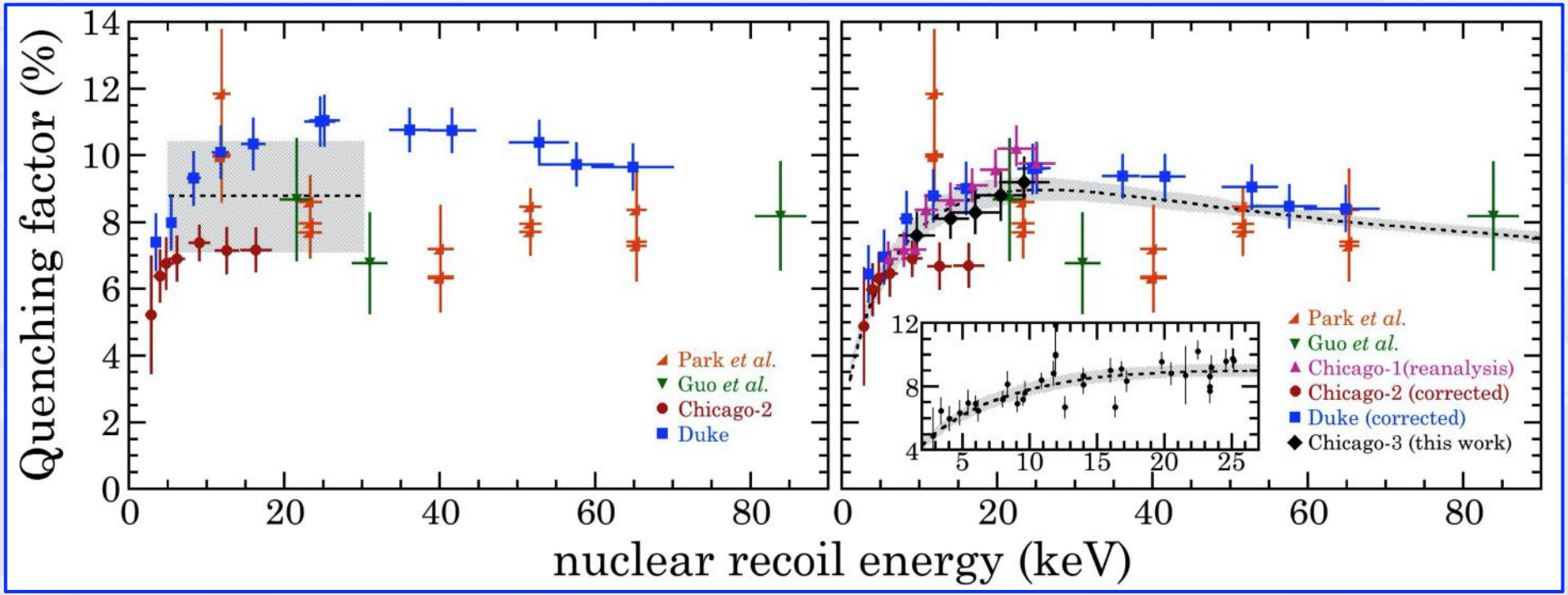
$$T_{ee} = f_Q(T_{\text{nr}})T_{\text{nr}}$$

Gives information about the number of photoelectrons released and the nuclear recoil energy

$$f_Q(T_{\text{nr}}) = (0.246 \pm 0.006\,\text{keV}_{\text{nr}}) + ((7.8 \pm 0.9) \times 10^{-4})T_{\text{nr}}$$

Here, f_Q is the quenching factor, which is the ratio between the scintillation light emitted in nuclear and electron recoils and determines the relation between the number of detected photoelectrons and the nuclear recoil kinetic energy.

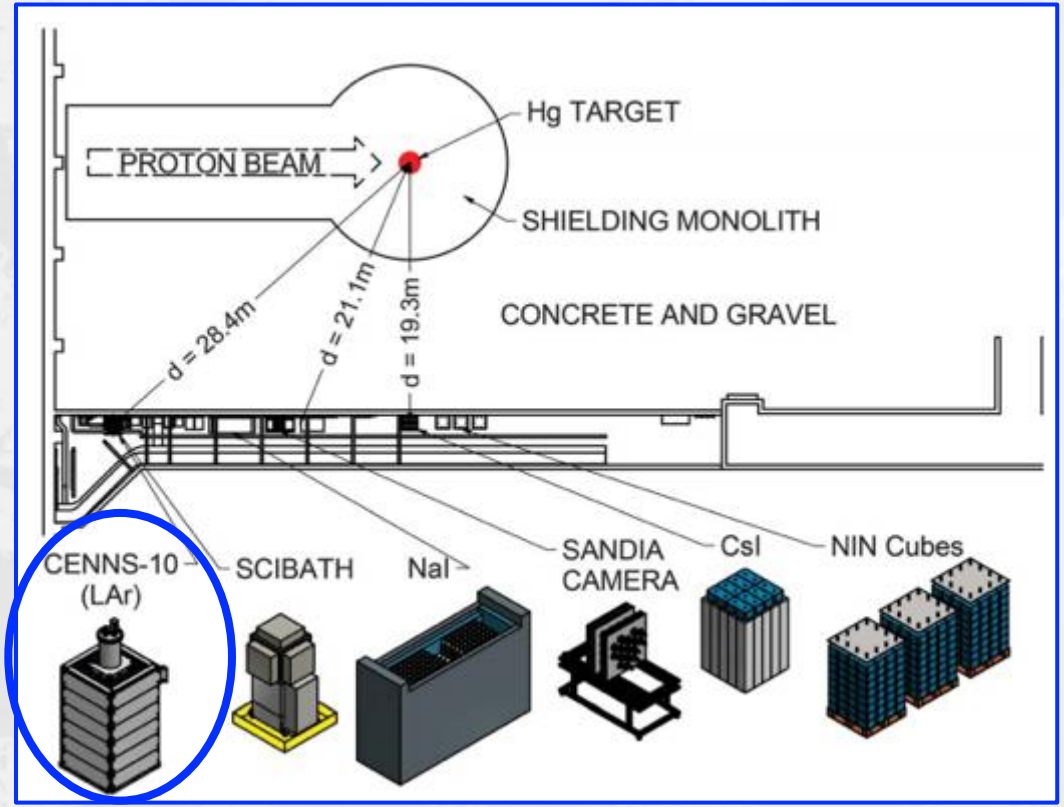
COHERENT experiment

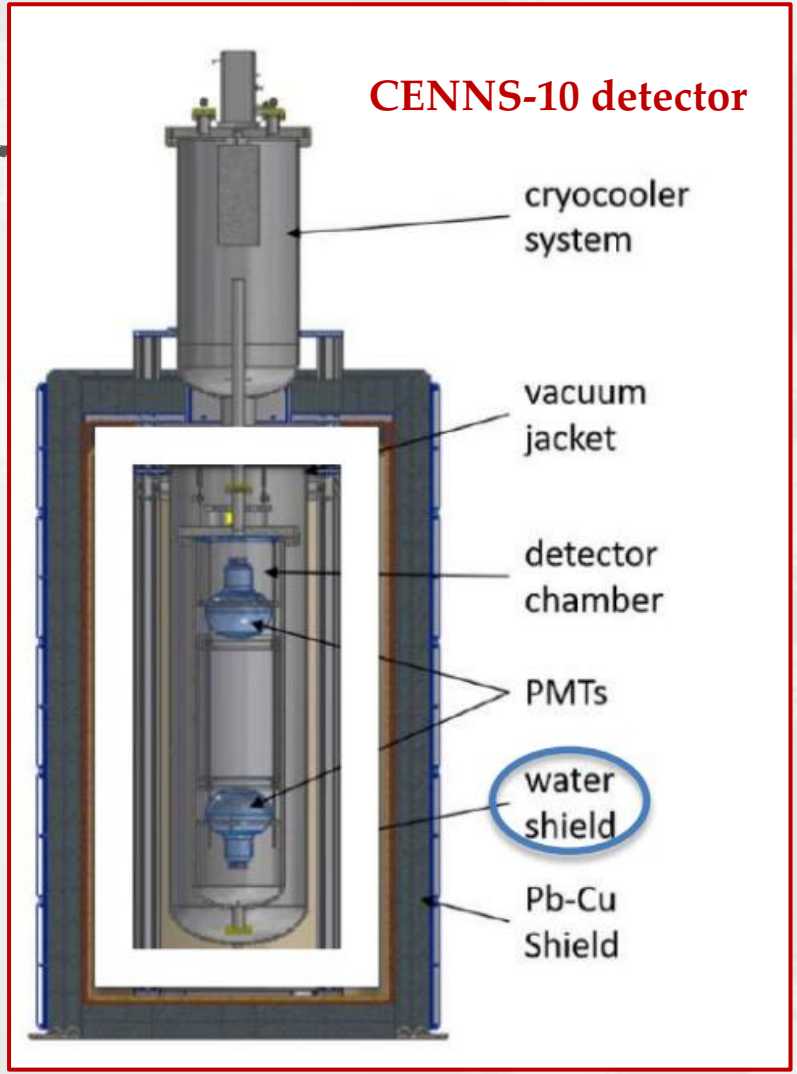


COHERENT Collaboration, arXiv:1708.01294

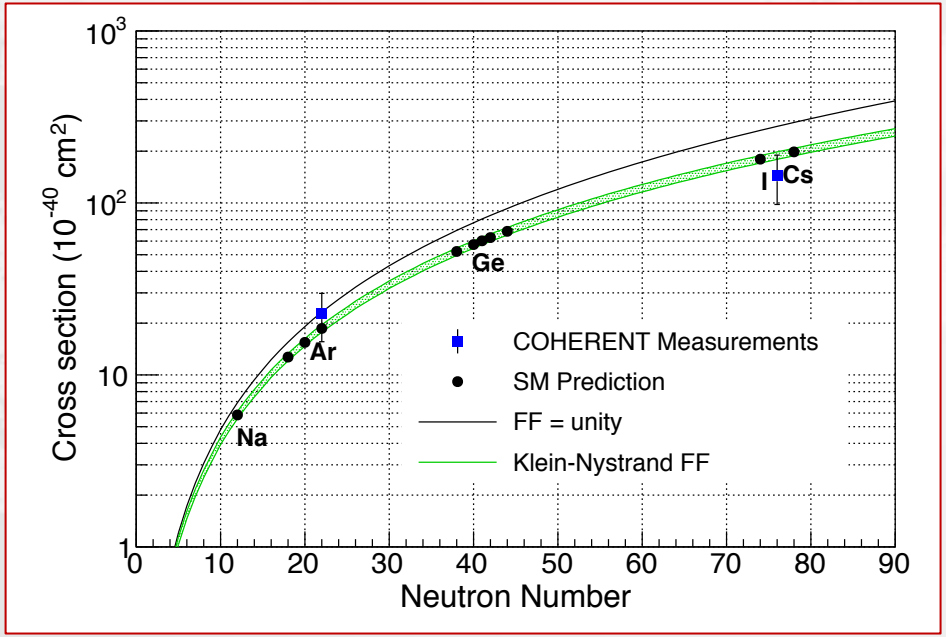
Collar, Kavner, Lewis, arXiv:1907.04828

COHERENT experiment

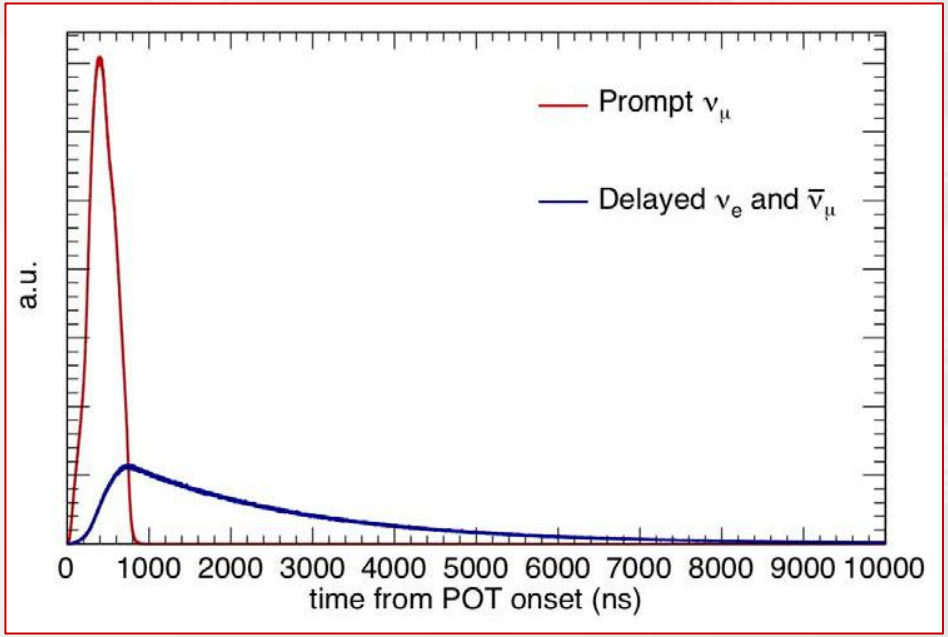




COHERENT experiment



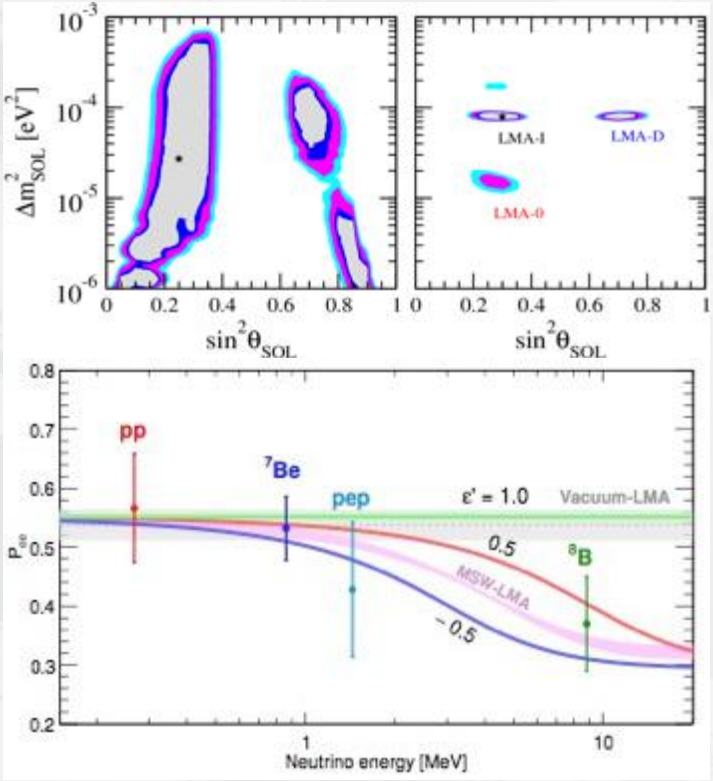
arXiv:2003.10630v1 [nucl-ex] 24 Mar 2020

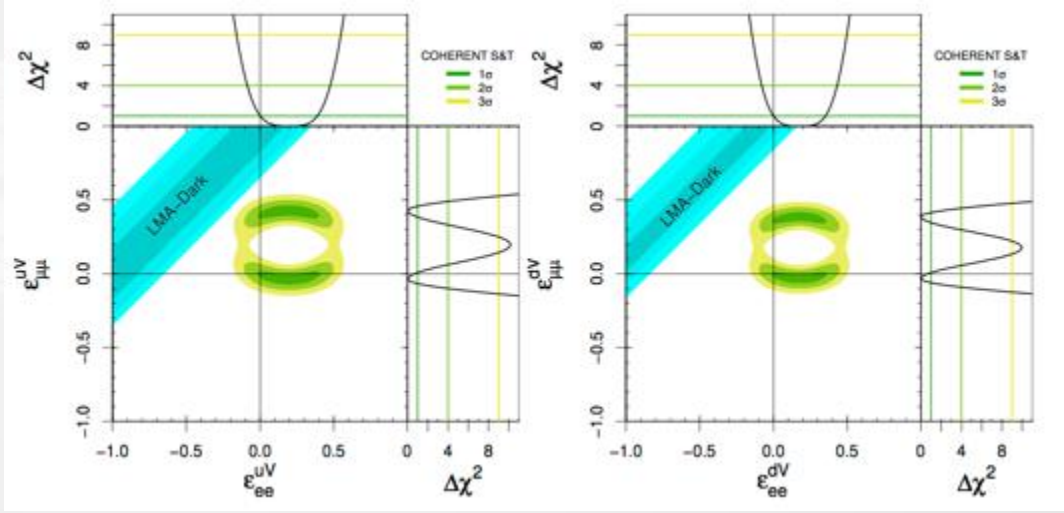


Science 357, 1123–1126 (2017). 1708.01294.

Light vector mediators in CEνNS

Non-standard neutrino interactions modify neutrino oscillation inside the matter
In presence of NSI oscillation data are affected by a degeneracy: LMA-D solutions of solar mixing angle





arXiv:1909.00466v2 [hep-ph] 5 Feb 2020

Light vector mediators in CEνNS

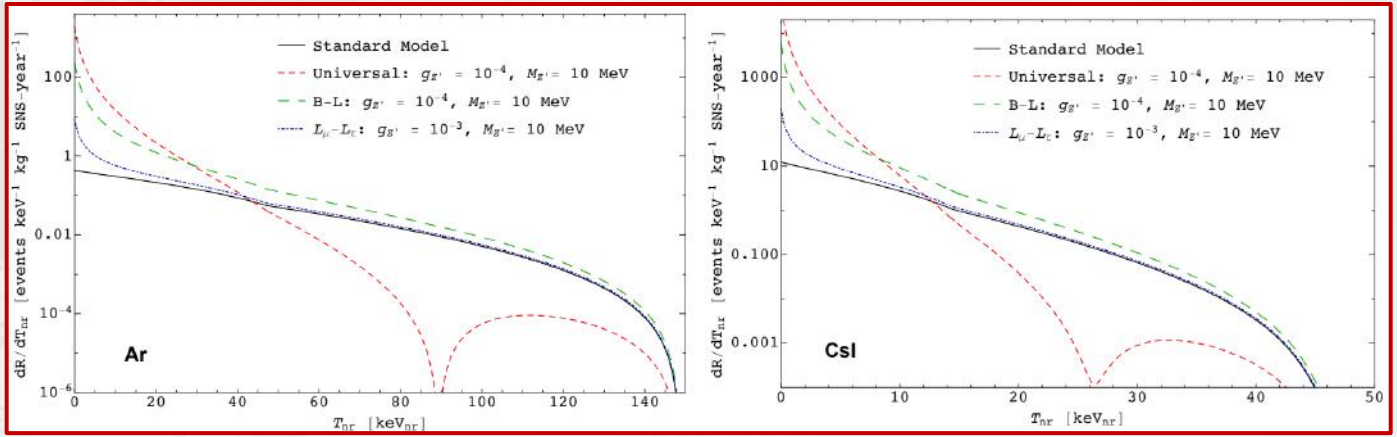
- U(1)' extension of SM: a new boson mediator is introduced through mixing with photon and Z boson
- $$\begin{pmatrix} B_\mu \\ W_\mu^3 \\ X_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\epsilon\sin\alpha - \sin\theta_W\cos\alpha & \sin\theta_W\sin\alpha - \epsilon\cos\alpha \\ \sin\theta_W & \cos\theta_W\cos\alpha & -\cos\theta_W\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} A_\mu \\ Z_\mu \\ Z'_\mu \end{pmatrix}$$
- 3 kind of models

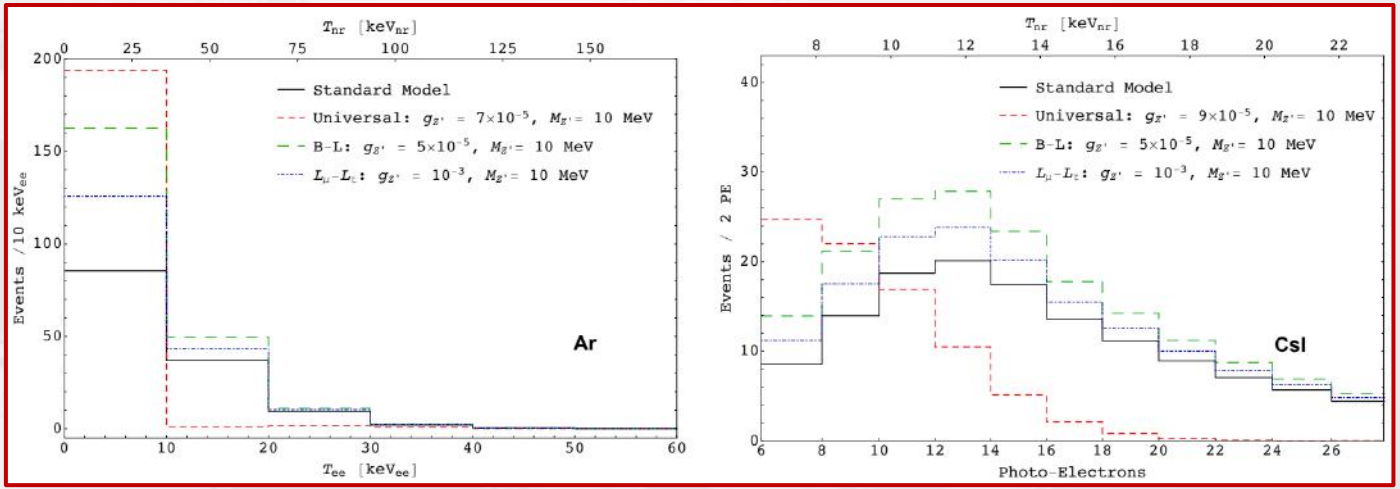
Dark photon γ_d o A'	Z prime Z'	Z dark Z_d
• coupling similar to standard photon • suppression by the mixing parameter ϵ • coupling proportional to electric charge	• kinetic mixing dominates • $\alpha \ll 1$	• mass mixing dominates • $\epsilon = 0$

Light vector mediators in CEνNS

- General gauge simmetry: $X = Q'_1 B_1 + Q'_2 B_2 + Q'_3 B_3 + Q'_e L_e + Q'_\mu L_\mu + Q'_\tau L_\tau$
- To build an anomaly free theory:
  - $3(Q'_1 + Q'_2 + Q'_3) + Q'_e + Q'_\mu + Q'_\tau = 0$
- $L_{eff} = -\frac{(g')^2}{Q^2 + M^2_{Z'}} [\sum_q Q'_q \bar{q}\gamma^\mu q][\sum_\alpha Q'_\alpha \overline{\nu_\alpha}\gamma^\mu P_L \nu_\alpha]$
- Compairing to the NSI we get the coupling forms:
- $\epsilon^{qV}_{\alpha\alpha} = \frac{(g')^2 Q'_\alpha Q'_q}{\sqrt{2}\, G_F (Q^2 + M^2_{Z'})}$
- Weak charge becomes:
- $\left(Q_V^{BSM}\right)_\alpha = (g^p_V + 2\epsilon^{uV}_{\alpha\alpha} + \epsilon^{dV}_{\alpha\alpha}) Z\, F_Z(q^2) + (g^n_V + \epsilon^{uV}_{\alpha\alpha} + 2\epsilon^{dV}_{\alpha\alpha}) N F_N(q^2)$

Light vector mediators in CEνNS



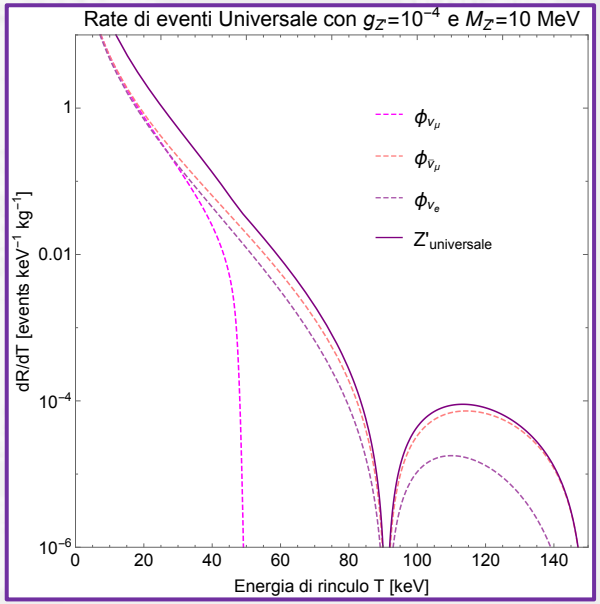


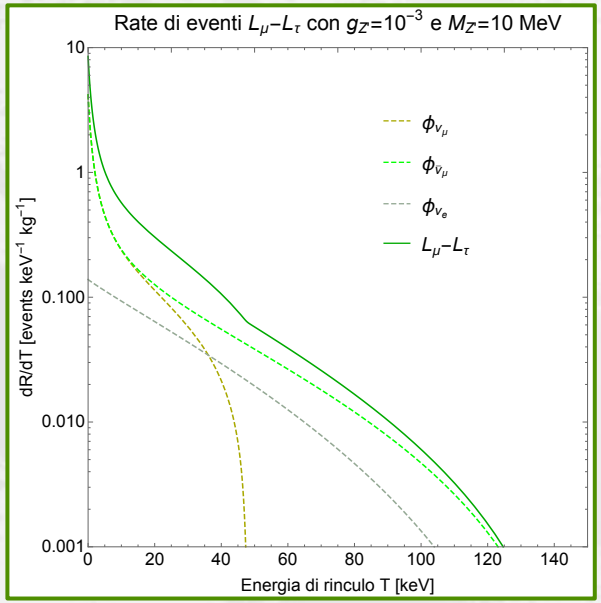
Z′ contribution to the rate

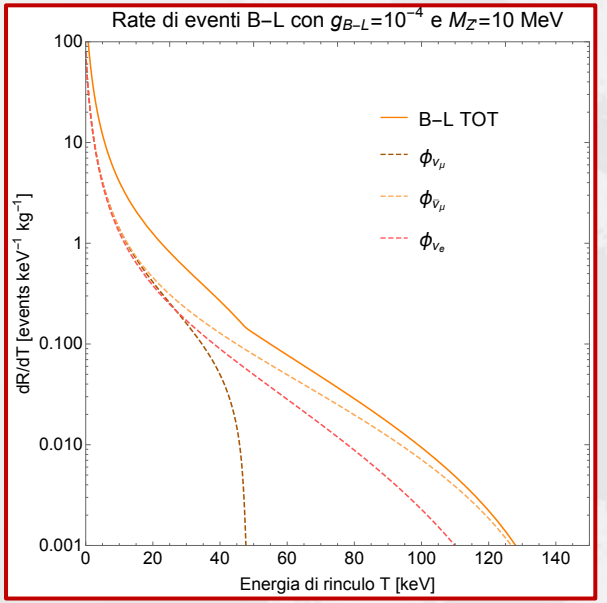
Limits on new physics models using COHERENT data

- We used a minimization of χ^2 method to determine the exclusion limits in the parameter space
- $\chi^2_s = \sum_{i=1}^{12} \left(\frac{N_i^{exp} - \eta_{CE\nu NS} N_i^{CE\nu NS} - \eta_{PBRN} B_i^{PBRN} - \eta_{LBRN} B_i^{LBRN}}{\sigma_i} \right)^2 + \left(\frac{\eta_{CE\nu NS} - 1}{\sigma_{CE\nu NS}} \right)^2 + \left(\frac{\eta_{PBRN} - 1}{\sigma_{PBRN}} \right)^2 + \left(\frac{\eta_{LBRN} - 1}{\sigma_{LBRN}} \right)^2$
  - PBRN= Prompt Beam-Related Background
  - LBRN=Late Beam-Related Neutron Background
  - BRNES= Beam Related Neutron Energy Shape
- $\sigma_i^2 = (\sigma_i^{exp})^2 + [\sigma_{BRNES}(B_i^{PBRN} + B_i^{LBRN})]^2$
- $\sigma_{CE\nu NS} = 13.4\%$ for fixed R_n or 13.2% for free R_n
- $\sigma_{PBRN} = 32\%$
- $\sigma_{LBRN} = 100\%$
- $\eta_{CE\nu NS}, \eta_{PBRN}, \eta_{LBRN}$= nuisance parameters, they quantify, respectively, the systematic uncertainty on the rate signal, on the PBRN background and the LBRN background.

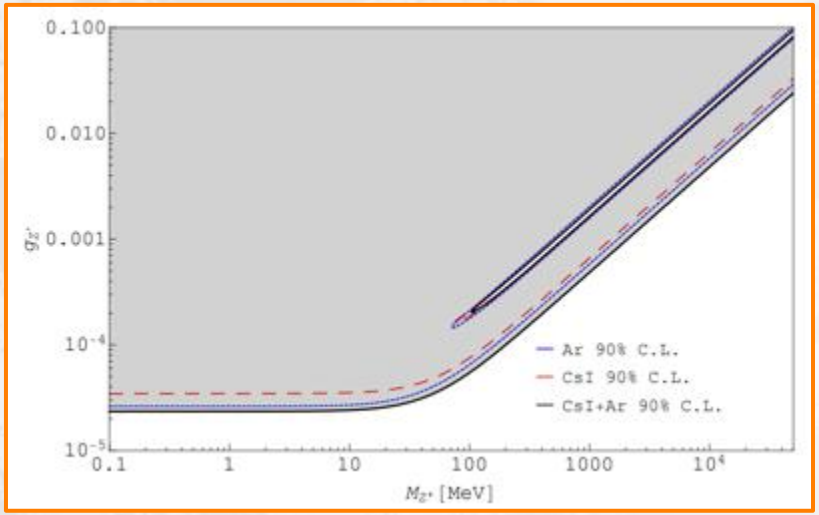
Limits on new physics models using COHERENT data





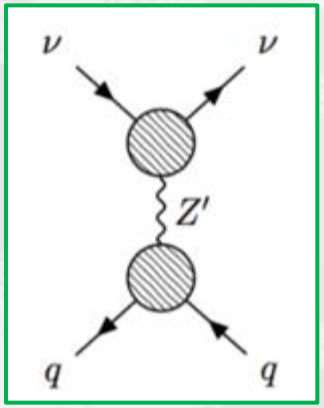


Limits on new physics models using COHERENT data



$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4} Z'^{\mu\nu} Z'_{\mu\nu} + \frac{1}{2} M^2_{Z'} Z'^{\mu} Z'_{\mu} + Z'_{\mu} J^{\mu}_{X}$$

$$J^{\mu}_{X} = g' \left[\sum_{q} Q'_q \bar{q} \gamma^{\mu} q + \sum_{L_l = \nu_{lL}, l} Q'_l \bar{L}_l \gamma^{\mu} L_l \right]$$



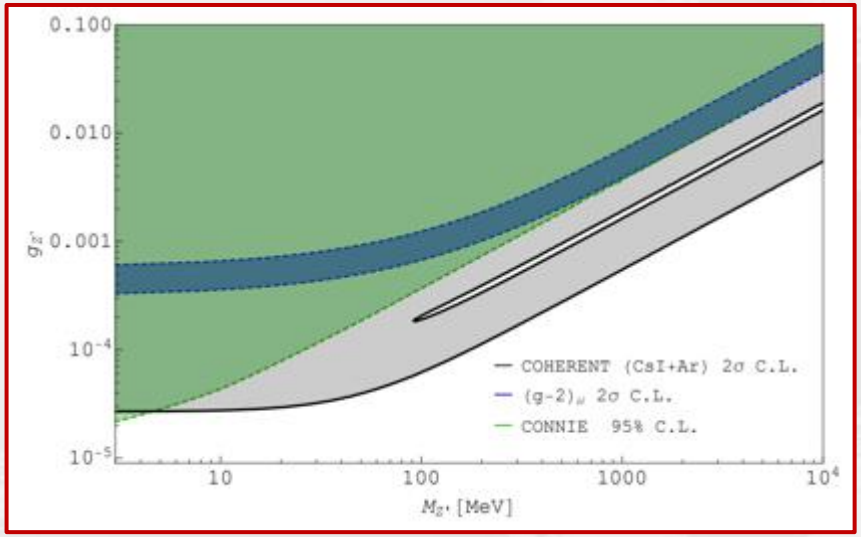
$$Q'_\ell \equiv Q'_f = 1,$$

Same coupling with all the fermions

CONNIE collaboration - JHEP 04 (2020) 054

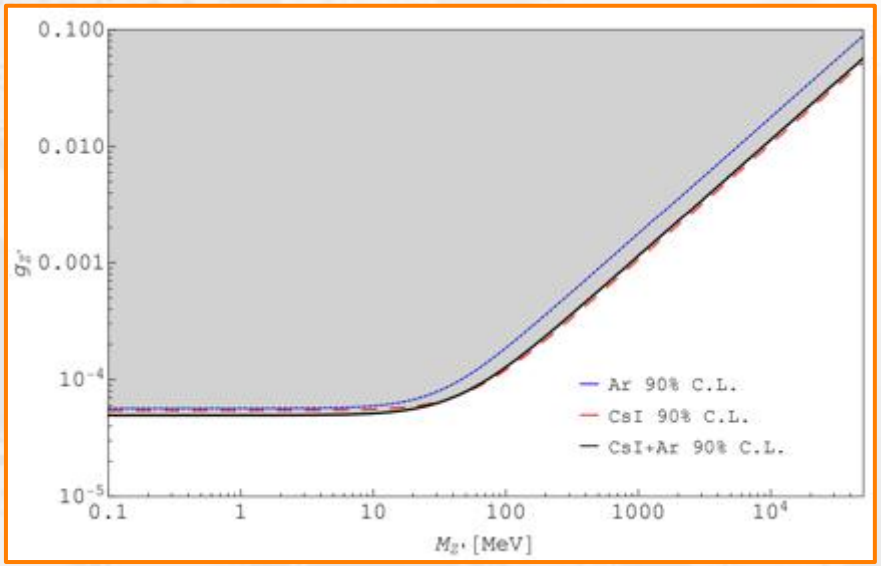
A. Drukier and L. Stodolsky - Phys. Rev. D30 (1984) 2295

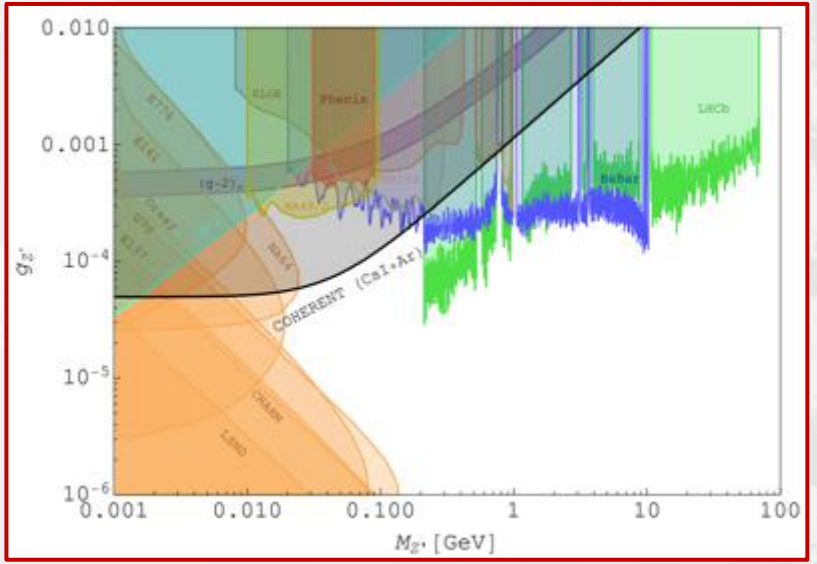
J. Barranco, O. Miranda and T. Rashba - JHEP 12 (2005) 021



Limits on new physics models using COHERENT data

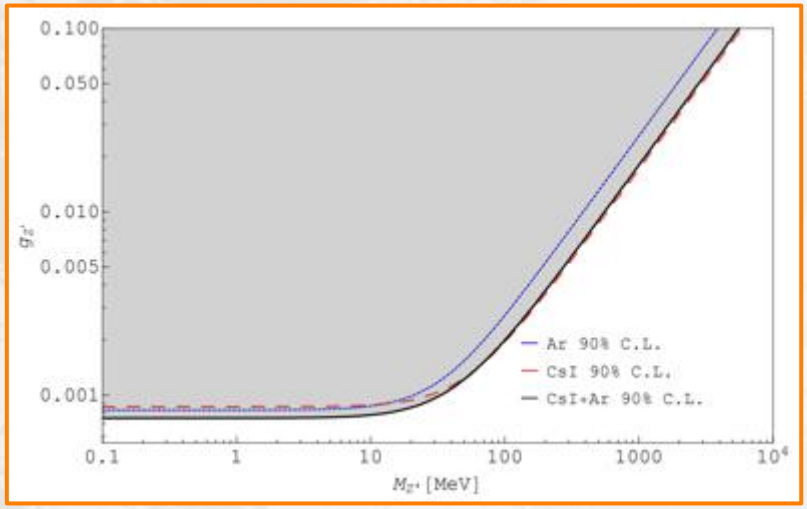
The second model that we consider is the so-called $B - L$ (baryon number minus lepton number) extension of the SM [20, 21]. In this case the gauge charges are determined by imposing that the theory is anomaly free. In particular, in this model the boson couples universally to the quarks, as well as to the neutrinos, but with different charges, namely $Q'_\ell \neq Q'_f$. In particular, in the $B - L$ model the gauge charges are such that $Q'_\ell = 1$ and $Q'_f = -Q'_\ell/3$.

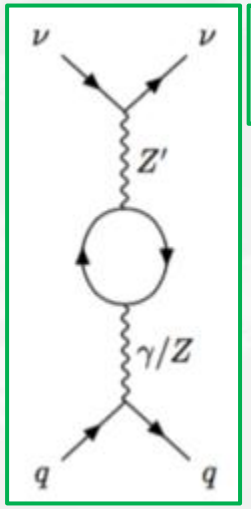




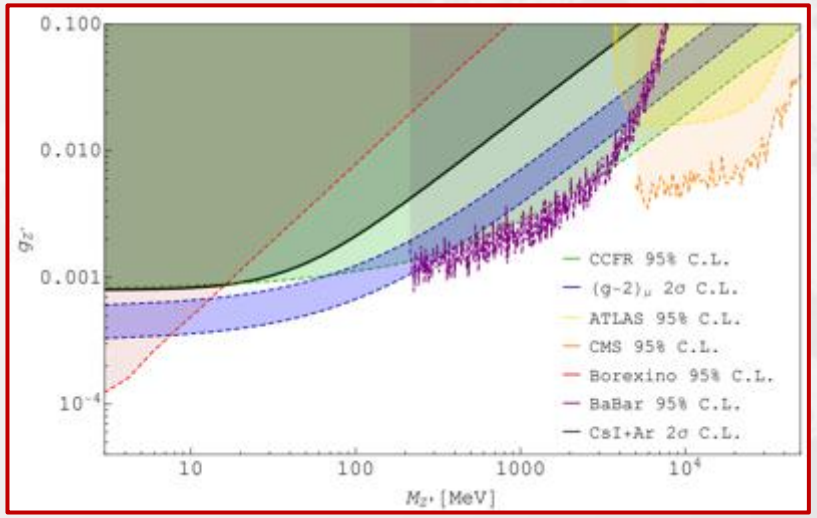
BaBar collaboration, Phys. Rev. Lett. 113 (2014) 201801
LHCb collaboration, Phys. Rev. Lett. 124 (2020) 041801
PHENIX Collaboration - Phys. Rev. C 91 (2015) 031901
ALICE collaboration - Phys. Lett. B 720 (2013) 52
NA48/2 collaboration - Phys. Lett. B 746 (2015) 178
A1 Collaboration collaboration - Phys. Rev. Lett. 106 (2011) 251802.
R. Harnik, J. Kopp and P.A. Machado - JCAP 07 (2012) 026
Muon g-2 collaboration -, Phys. Rev. D 73 (2006) 072003
H. Davoudiasl and W.J. Marciano - Phys. Rev. D 98 (2018) 075011

Limits on new physics models using COHERENT data





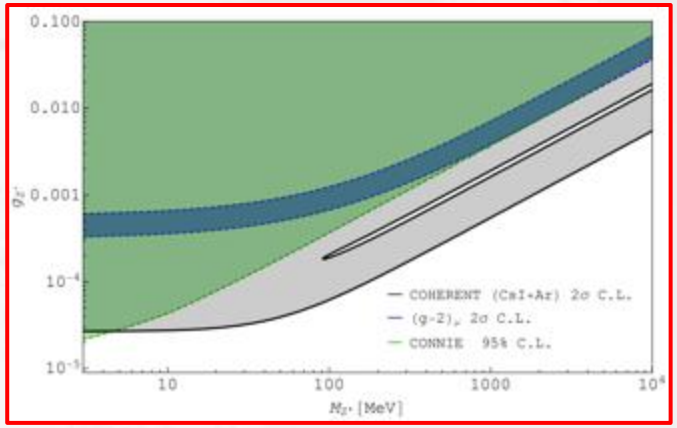
$$\mathcal{L}_{int}^{\mu\tau} \supset g_{Z'} Q_{\alpha\beta} (\bar{l}_\alpha \gamma^\mu l_\beta + \bar{\nu}_{L\alpha} \gamma^\mu \nu_{L\beta}) Z'_\mu$$



- Gauged Lμ − Lτ symmetry model.
- The new Z′ boson can couple directly only to muonic or tauonic flavour
- There is no tree-level coupling to the quark sector.
- This model can be studied through the CEvNS process by considering the interaction between the new boson and quarks via kinetic loops of muons and tauons involving photons

W. Altmannshofer et al. - Phys. Rev. Lett. 113 (2014) 091801
ATLAS collaboration - Phys. Rev. Lett. 112 (2014) 231806
CMS collaboration-Phys. Lett. B 792 (2019) 345
BaBar collaboration - Phys. Rev. D 94 (2016) 011102
S. Gninenko and D. Gorbunov - arXiv:2007.16098
Muon g-2 collaboration -, Phys. Rev. D 73 (2006) 072003

Limits on new physics models using COHERENT data

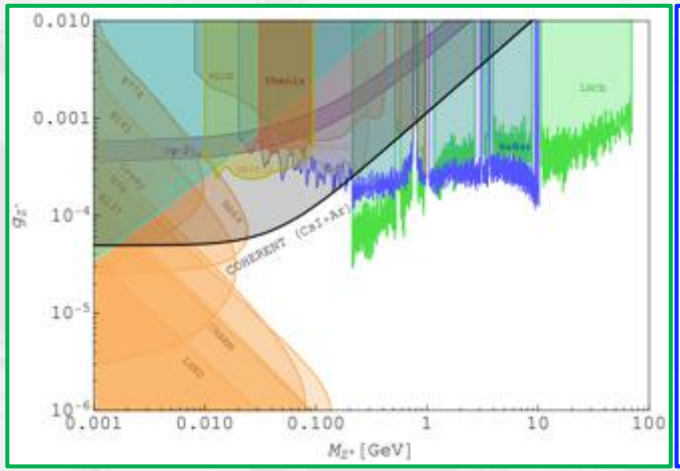


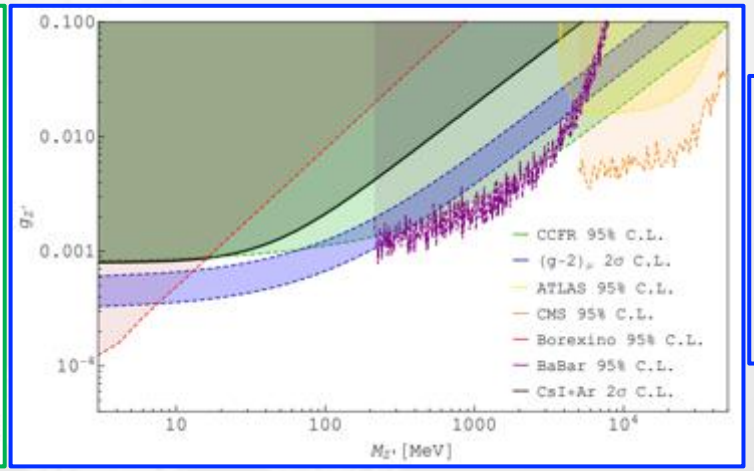
Universal model

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

B-L

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



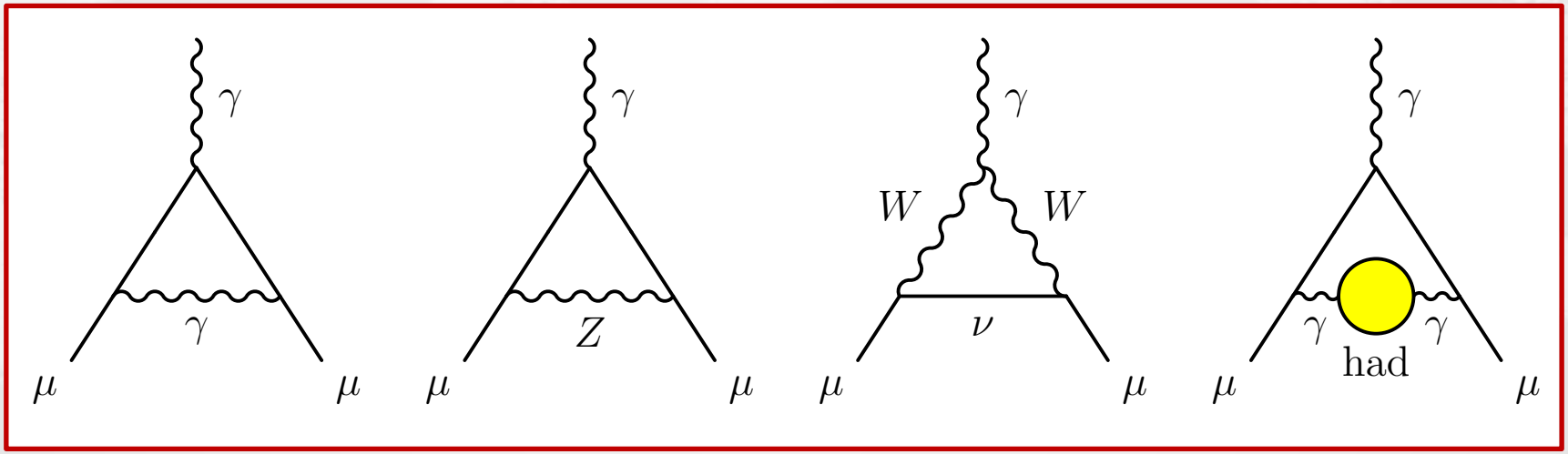


L_μ-L_τ

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

Limits on new physics models using COHERENT data

Muon Magnetic Anomalous Momentum



$$\Delta a_\mu = 261(63)(48)\times 10^{-11}$$

$$\Delta a_\mu^{new} = 279(76)\times 10^{-11}$$