

Current and future sensitivities to Non-Standard Interactions using CEvNS

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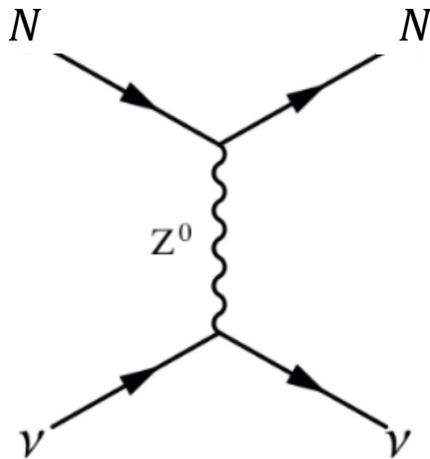
Conselleria d'Educació,
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Outline

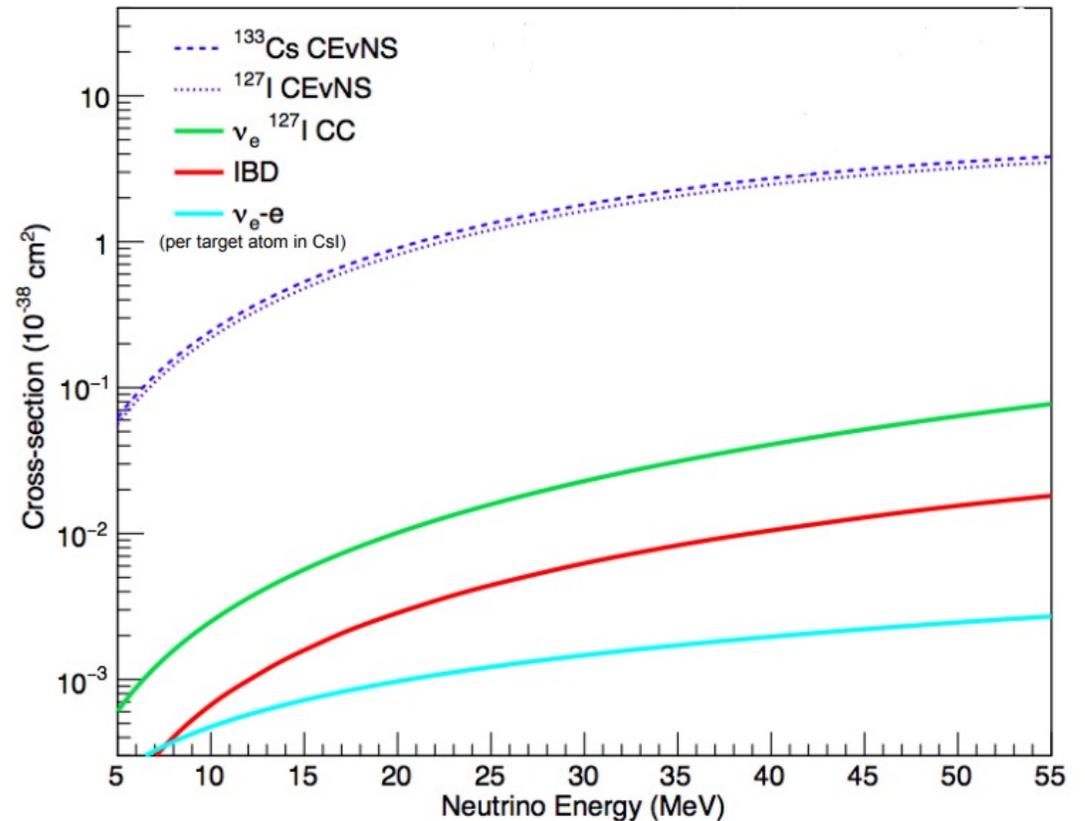
- Introduction
 - Non-Standard Interactions (NSI)
- Current status of CEvNS NSI
 - Constraints from CsI + LAr COHERENT data.
- Future sensitivities
 - The European Spallation Source proposal.

Coherent Elastic Neutrino-Nucleus Scattering

Neutral current process predicted in the Standard Model



$$\left(\frac{d\sigma}{dT}\right)_{\text{SM}} = \frac{G_F^2 M}{\pi} \left[1 - \frac{MT}{2E_\nu^2}\right] [Zg_V^p F_Z(q^2) + Ng_V^n F_N(q^2)]^2$$



D. Akimov et al. Science, 357(6356) 1123–1126 (2017).

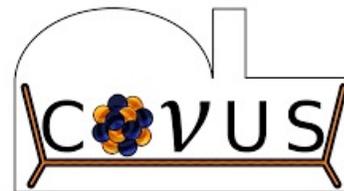
Where to study CEvNS:

- Spallation Neutron Sources:
 - COHERENT (CsI, LAr, Ge, NaI)
 - Captain Mills Experiment
 - European Spallation Source



<https://neutrons.ornl.gov/sns>

- Reactor Sources:
 - CONUS (Ge)
 - CONNIE (Si)
 - nuGeN (Ge)
 - RED-100 (Xe)



What can we study with CEvNS?

- Standard Model physics tests.
M. Cadeddu, et al. Phys. Rev. D 102 (2020)
- Neutron distribution of the target material.
M. Cadeddu, C. Giunti, et al. Rev. Lett. 120, 072501 (2018),
- Study new physics scenarios:
 - Non-Standard interactions.
V. De Romeri, et al. arxiv 2211.11905. S. S. Chatterjee, et al. Phys. Rev. D 107 (2023)
 - Neutrino Electromagnetic properties.
M. Atzori Corona, C. A. Ternes, et al. JHEP 09 (2022) 164
 - Generalized neutrino interactions.
O. G. Miranda, D. K. Papoulias, et al. JHEP 07, 103 (2019)
 - Light Mediators.
M. Abdullah, et al. Phys. Rev. D 98 (2018) L. J. Flores, et al. JHEP 06 (2020) 045
 - Transition to sterile neutrinos.
O. G. Miranda, et al. JHEP 12 (2021) 191

And many more!

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This talk!

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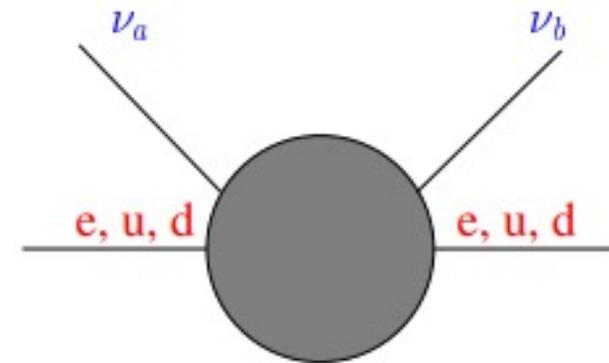
Non-Standard Interactions

- Different extensions of the SM give rise to interactions of the form:

$$\mathcal{L}_{NC}^{NSI} = -2\sqrt{2}G_F(\bar{\nu}_\alpha\gamma^\mu P_L\nu_\beta)(\epsilon_{\alpha\beta}^{fL}\bar{f}\gamma_\mu P_L f + \epsilon_{\alpha\beta}^{fR}\bar{f}\gamma_\mu P_R f)$$

$\epsilon_{\alpha\beta}^{fP} \neq 0$ Flavor changing

$\epsilon_{\alpha\alpha}^{fP} \neq 0$ Non-universal



CEvNS cross section is now modified

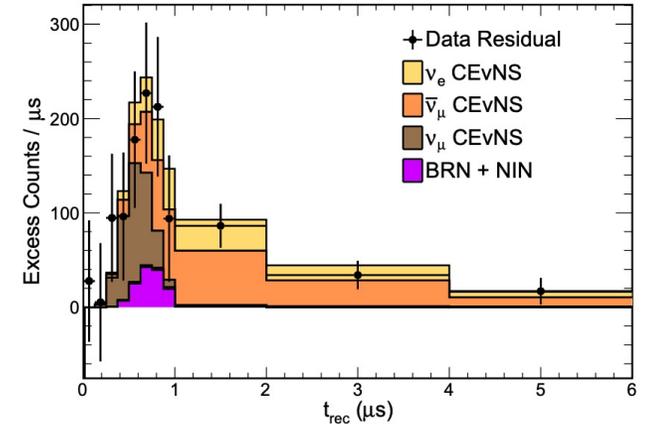
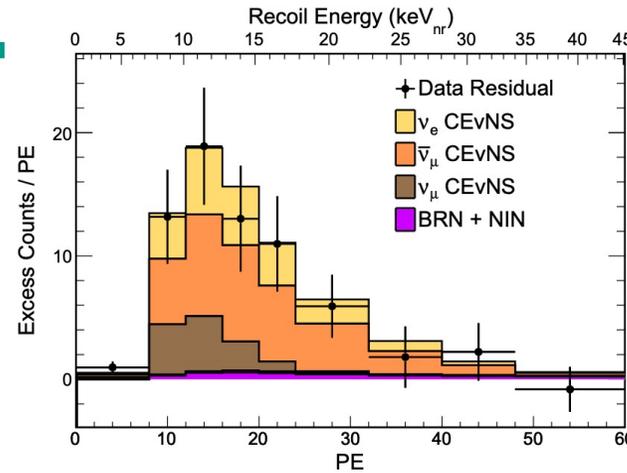
$$\frac{d\sigma}{dT}(E_\nu, T) \simeq \frac{G_F^2 M}{\pi} \left(1 - \frac{MT}{2E_\nu^2}\right) \left\{ \left[Z (g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}) F_Z^V(q^2) + N (g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV}) F_N^V(q^2) \right]^2 + \sum_\alpha \left[Z (2\varepsilon_{\alpha e}^{uV} + \varepsilon_{\alpha e}^{dV}) F_Z^V(q^2) + N (\varepsilon_{\alpha e}^{uV} + 2\varepsilon_{\alpha e}^{dV}) F_N^V(q^2) \right]^2 \right\}$$

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

- This allows to study different combinations of NSI and set bounds to them.
- We assume one or two non-zero NSI at a time.

Analysis using COHERENT

- Available data sets: CsI and LAr
- Analysis using a Poissonian least-squares function:



COHERENT Collaboration, Phys. Rev. Lett. 129 no. 8, (2022) 081801

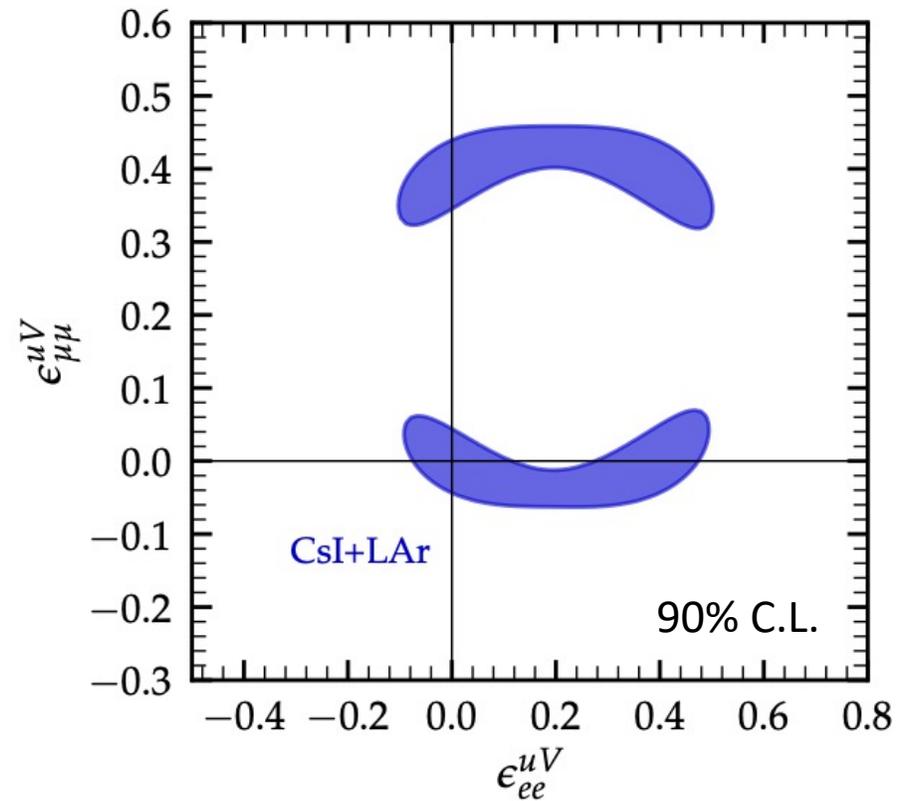
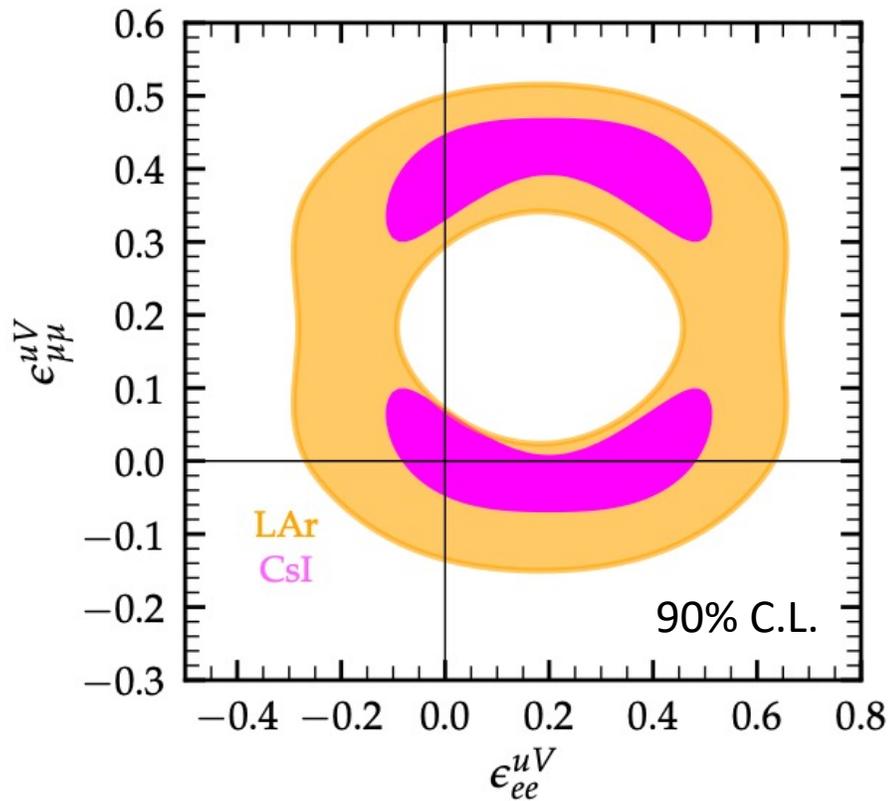
$$\chi^2_{\text{CsI}} \Big|_{\text{CE}\nu\text{NS}(+\text{ES})} = 2 \sum_{i=1}^9 \sum_{j=1}^{11} \left[N_{\text{th}}^{\text{CsI}} - N_{ij}^{\text{exp}} + N_{ij}^{\text{exp}} \ln \left(\frac{N_{ij}^{\text{exp}}}{N_{\text{th}}^{\text{CsI}}} \right) \right] + \sum_{k=0}^{4(5)} \left(\frac{\alpha_k}{\sigma_k} \right)^2 .$$

$$N_{\text{th}}^{\text{CsI,CE}\nu\text{NS}} = (1 + \alpha_0) N_{ij}^{\text{CE}\nu\text{NS}}(\alpha_4, \alpha_6, \alpha_7) + (1 + \alpha_1) N_{ij}^{\text{BRN}}(\alpha_6) + (1 + \alpha_2) N_{ij}^{\text{NIN}}(\alpha_6) + (1 + \alpha_3) N_{ij}^{\text{SSB}} .$$

σ_0	Flux + QF
σ_1	BRN
σ_2	NIN
σ_3	SSB
σ_4	RMS Radius
α_6	Efficiency
α_7	Timing

- PE and timing information were considered for the analysis.

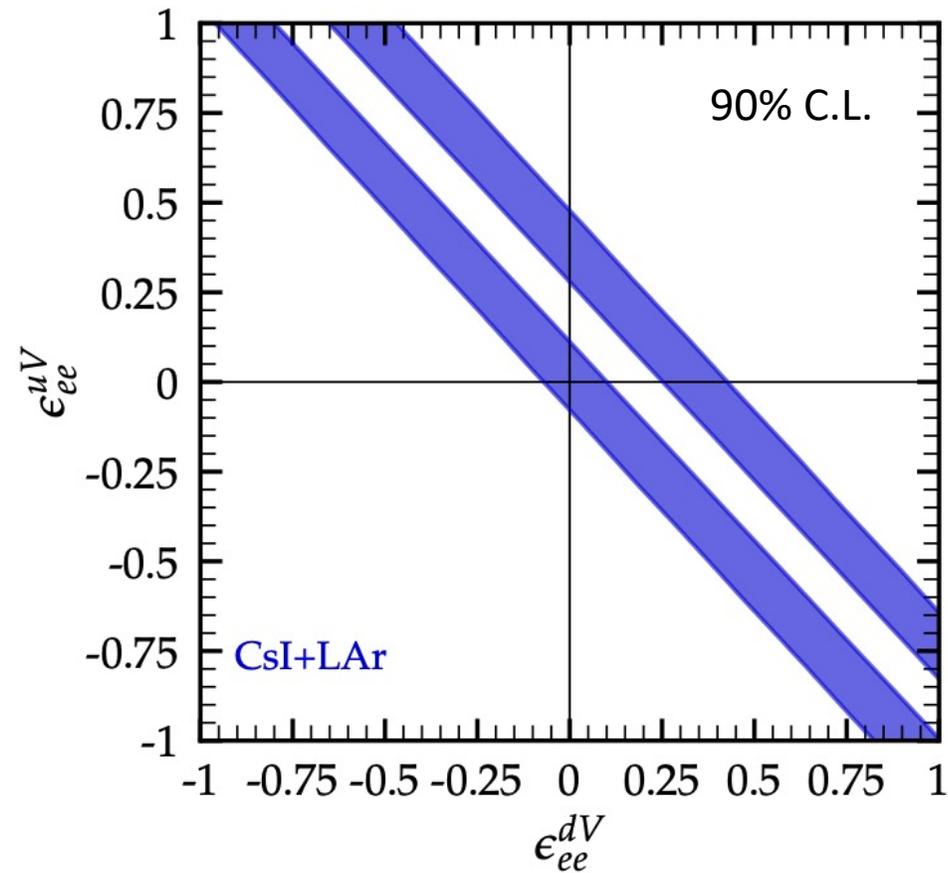
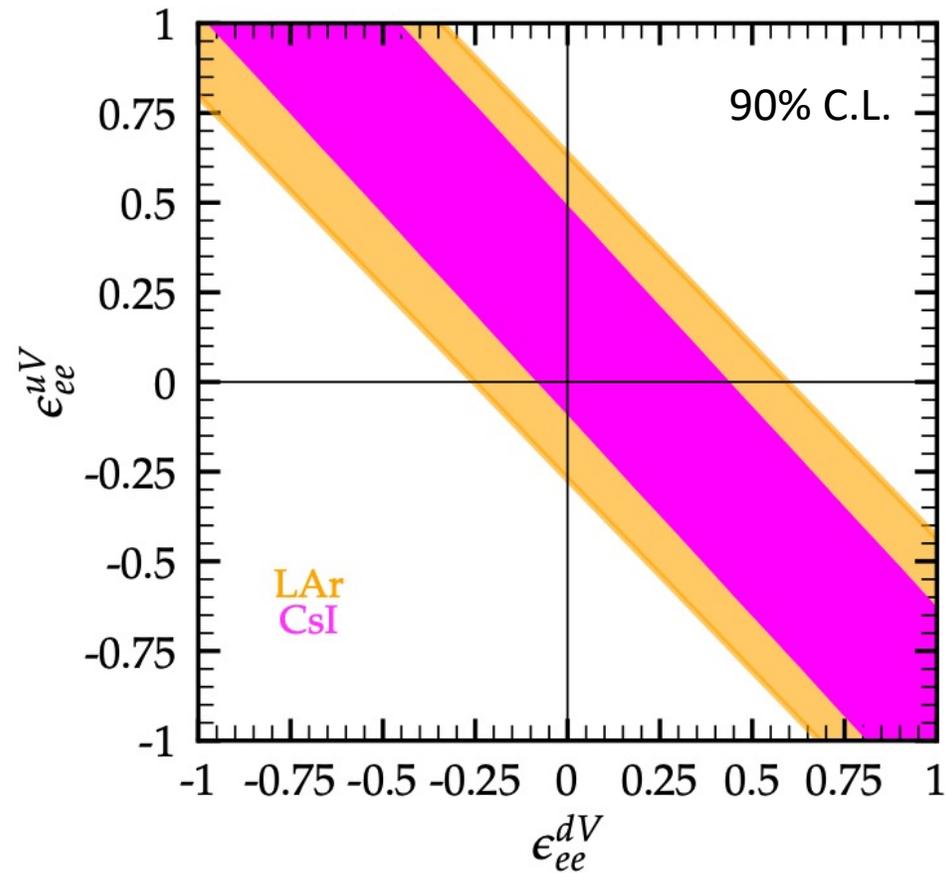
Non-universal NSI



V. De Romeri, O.G. Miranda, D.K. Papoulias, **GSG**, M. Tórtola and J.W.F. Valle arxiv 2211.11905.

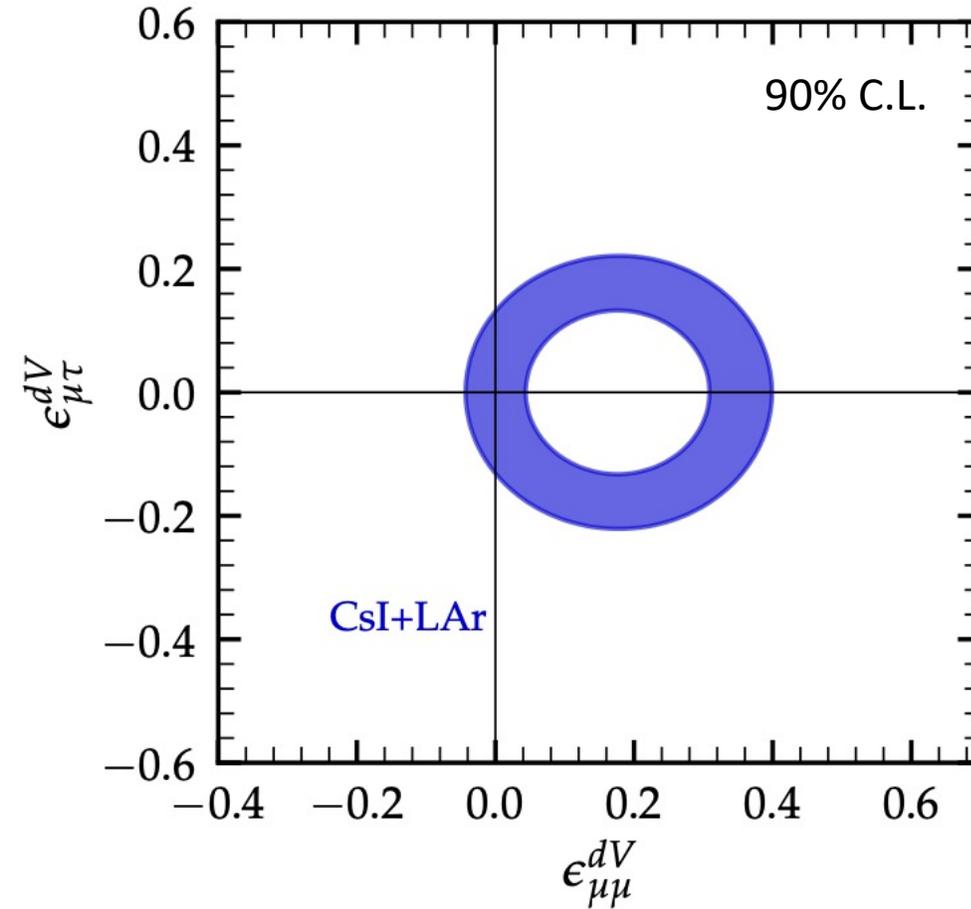
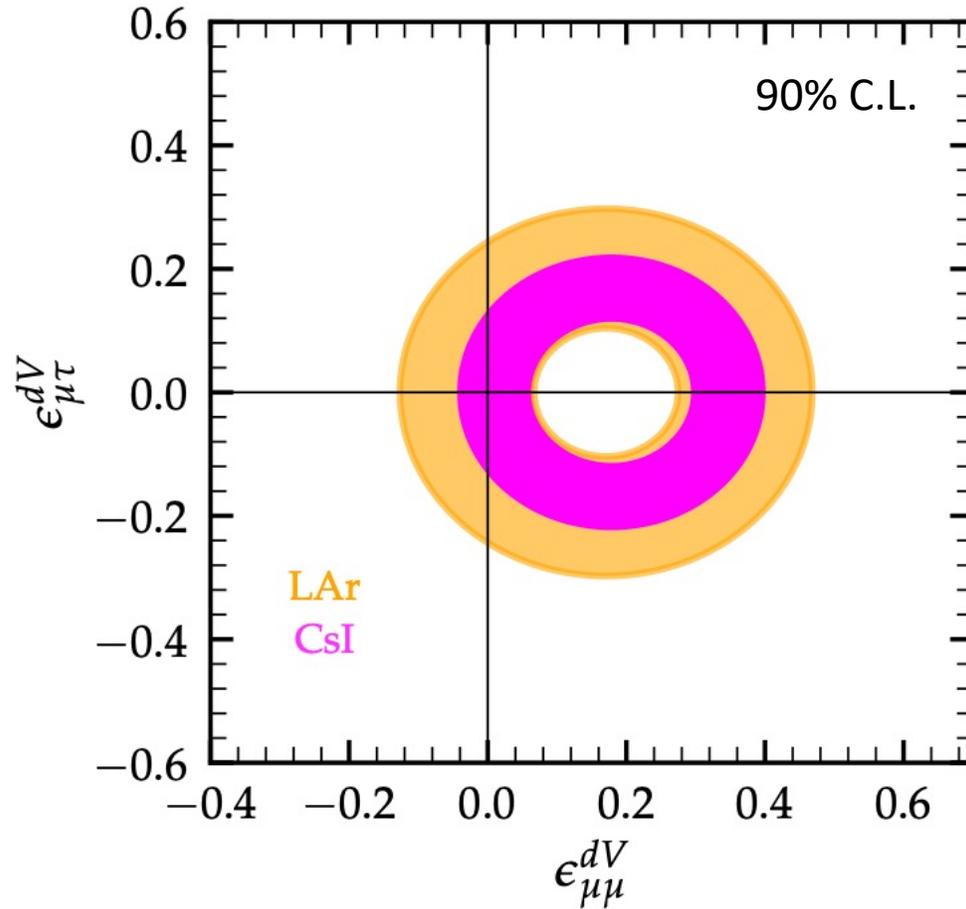
COHERENT Collaboration, Phys. Rev. Lett. 129 no. 8, (2022) 081801

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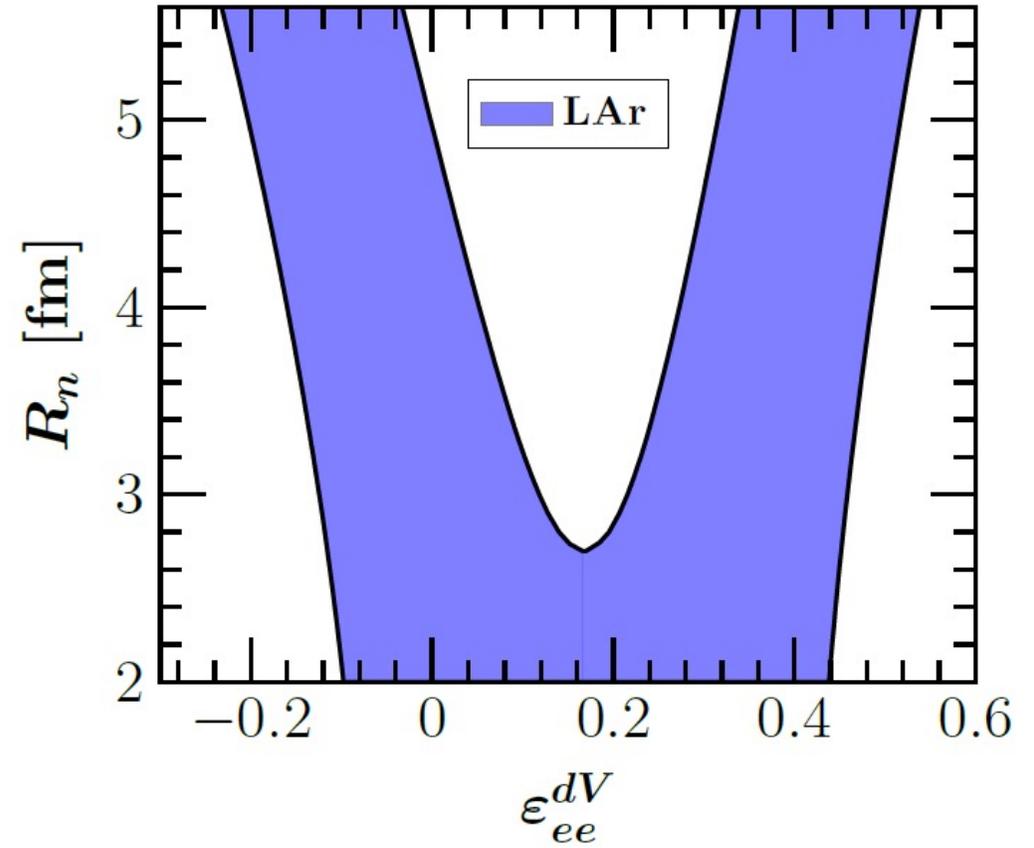
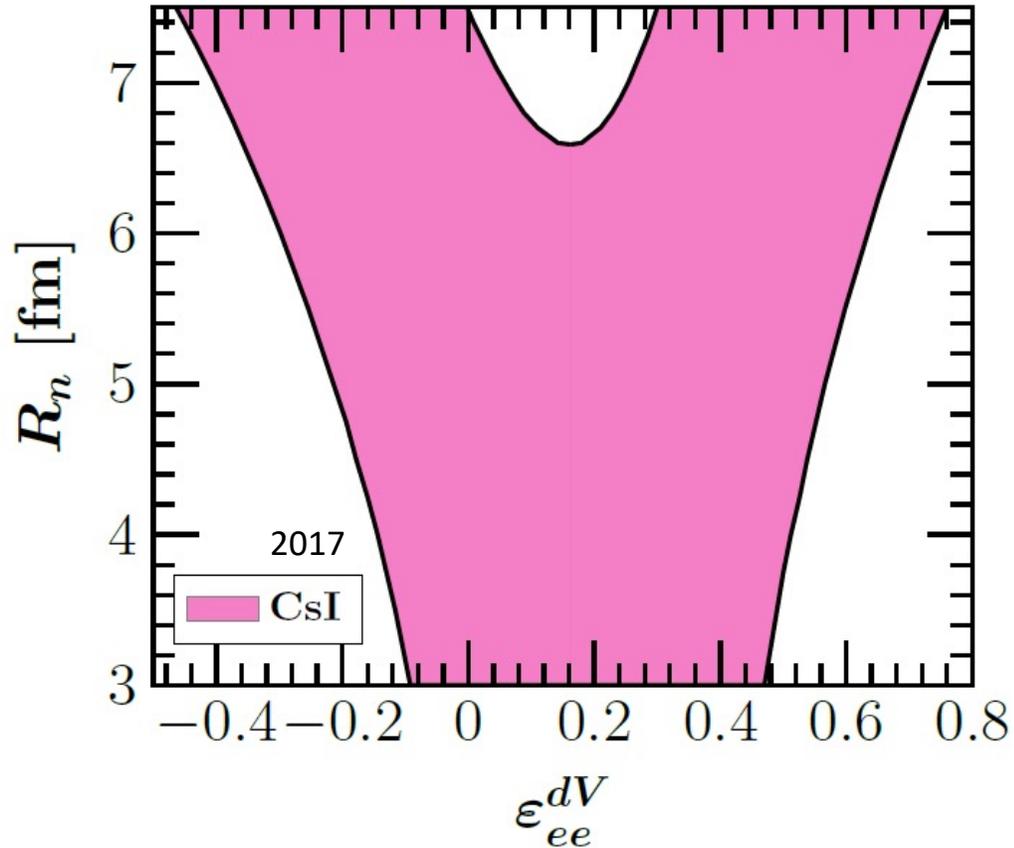
V. De Romeri, O.G. Miranda, D.K. Papoulias, **GSG**,
M. Tórtola and J.W.F. Valle arxiv 2211.11905.

Flavor Changing and Non-Universal NSI



V. De Romeri, O.G. Miranda, D.K. Papoulias, **GSG**,
M. Tórtola and J.W.F. Valle arxiv 2211.11905.

Interplay between nuclear physics and NSI



O. Miranda, D. Papoulias, **GSG**, O. Sanders, M. Tórtola, and J. Valle, JHEP 05 (2020) 130

What is next for NSI?

- Future detectors will be more sensitive to NSI parameters.
- We can use different detector combinations to break some degeneracies.

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As a working example we explore the expected ESS sensitivity to NSI



Why the ESS?

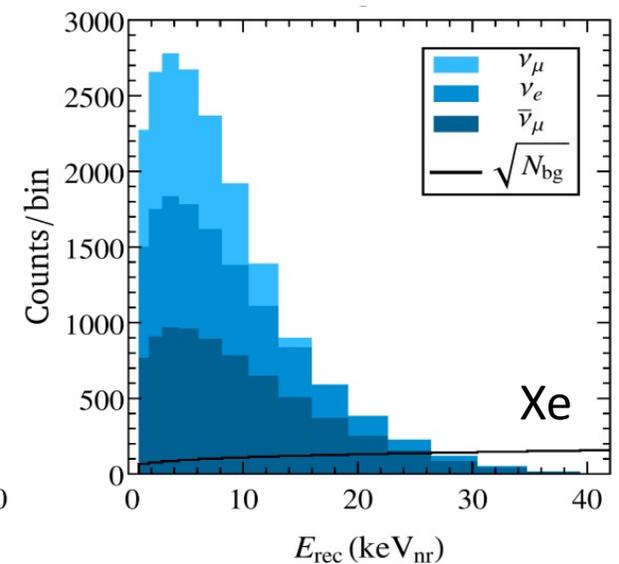
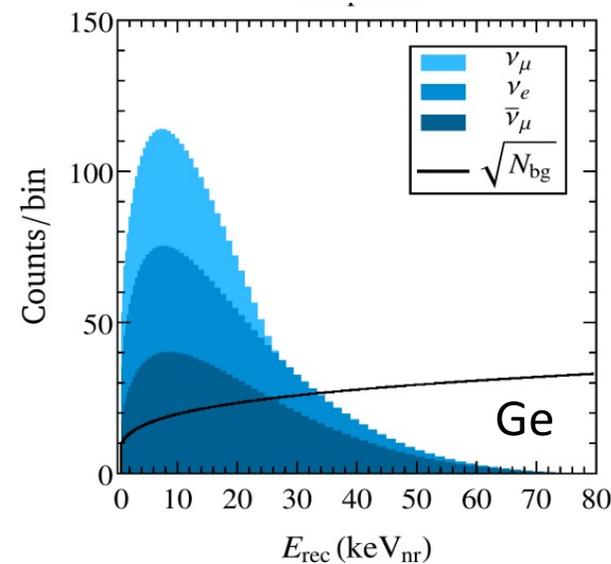
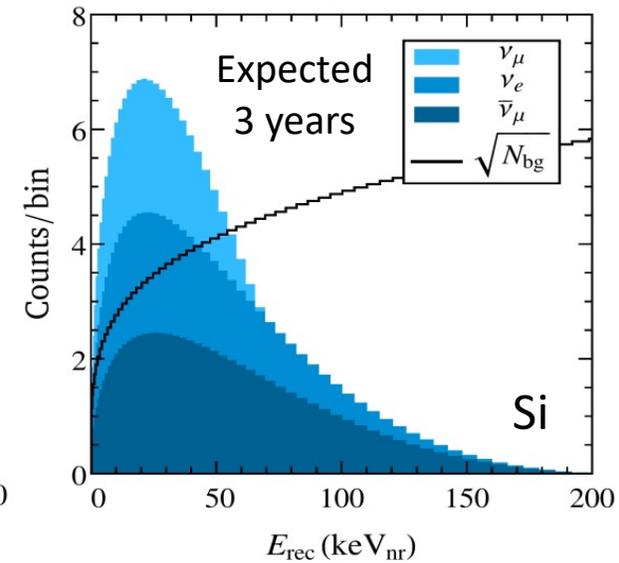
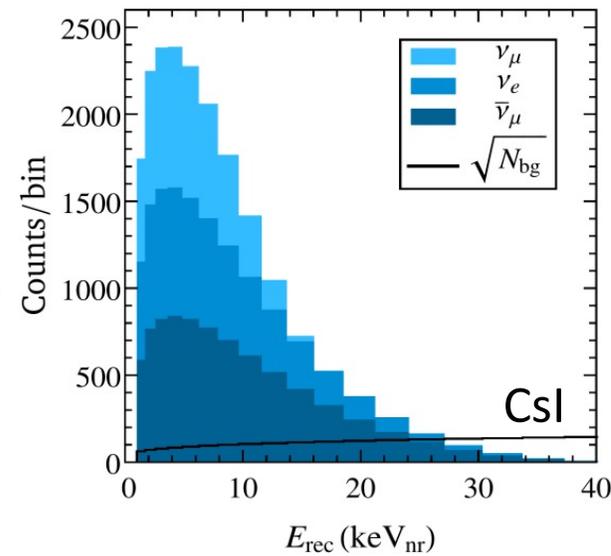
- Currently under construction in Sweden.
- Will become the most powerful neutron beam source.

$\sim 2.8 \times 10^{23}$ POT per calendar year!

Suitable for the study of CEvNS through different detectors: CsI, Xe, Si, Ge, Ar, C_3F_8

D. Baxter et al., "Coherent Elastic Neutrino-Nucleus Scattering at the European Spallation Source," JHEP 02 (2020) 123

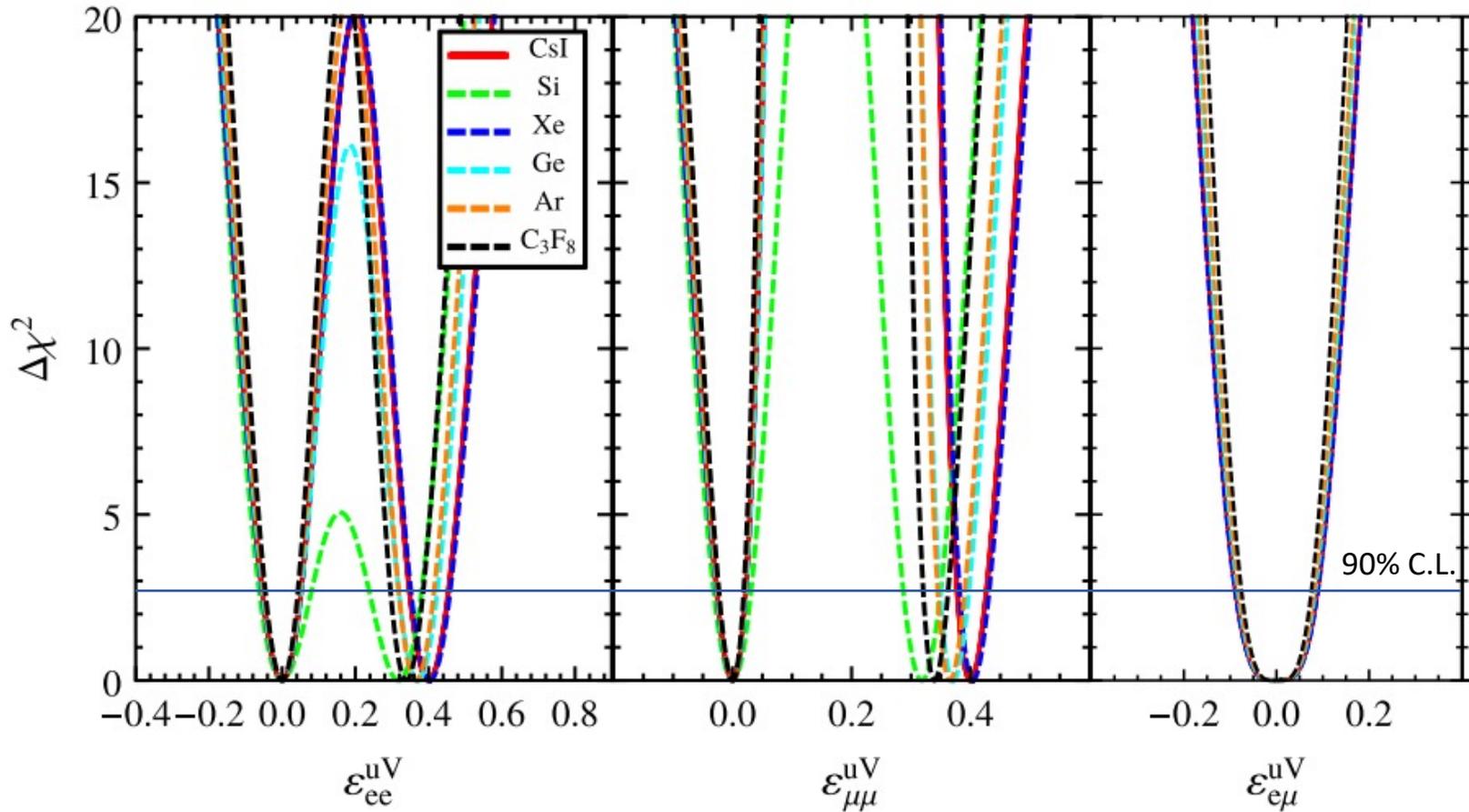
- We use a Poissionan least-squares function.



D. Baxter et al., "JHEP 02 (2020) 123

S. S. Chatterjee, S. Lavignac, O. G. Miranda, and GSG
Phys.Rev.D 107 (2023) 5, 055019

Single NSI parameter analysis

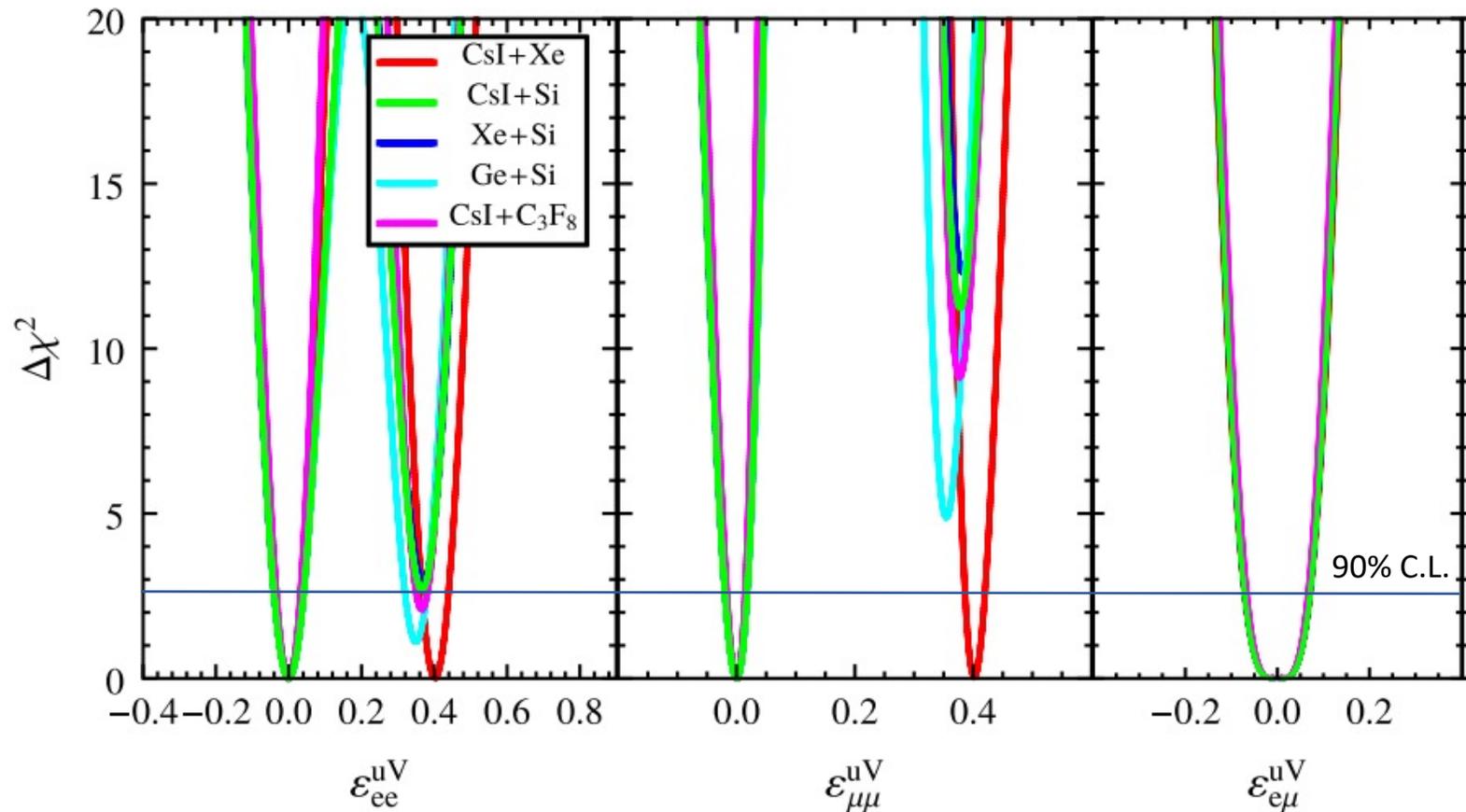


Detector	ϵ_{ee}^{uV} Expected 90% C.L. sensitivity
CsI	(-0.055,0.051) U (0.35,0.45)
Si	(-0.063,0.080) U (0.24,0.38)
Xe	(-0.055,0.052) U (0.35,0.46)
Ge	(-0.054,0.054) U (0.32,0.42)
Ar	(-0.050,0.047) U (0.32,0.42)
C_3F_8	(-0.046,0.043) U (0.30,0.39)

S. S. Chatterjee, S. Lavignac, O. G. Miranda, and **GSG** Phys.Rev.D 107 (2023) 5, 055019

Combined analysis

- Different proton to neutron ratios allow to break degeneracies by combining the results.



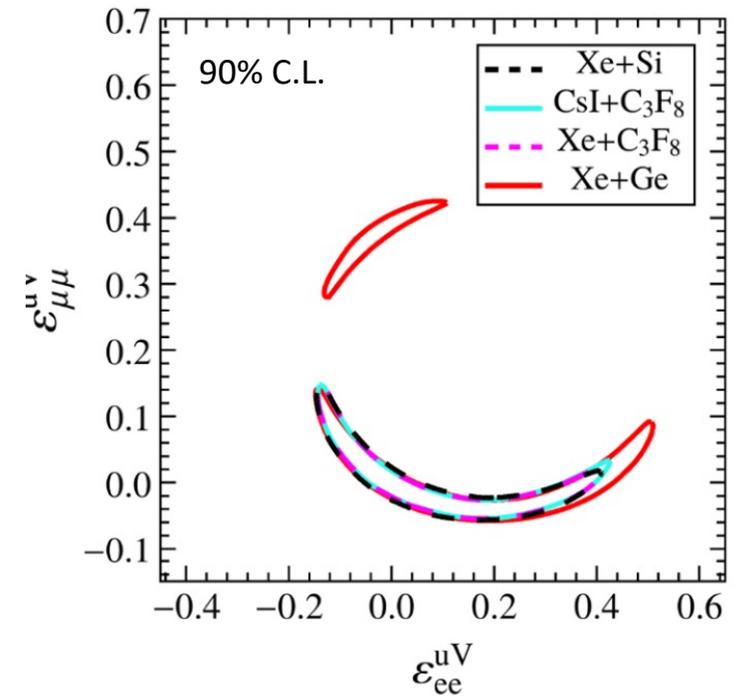
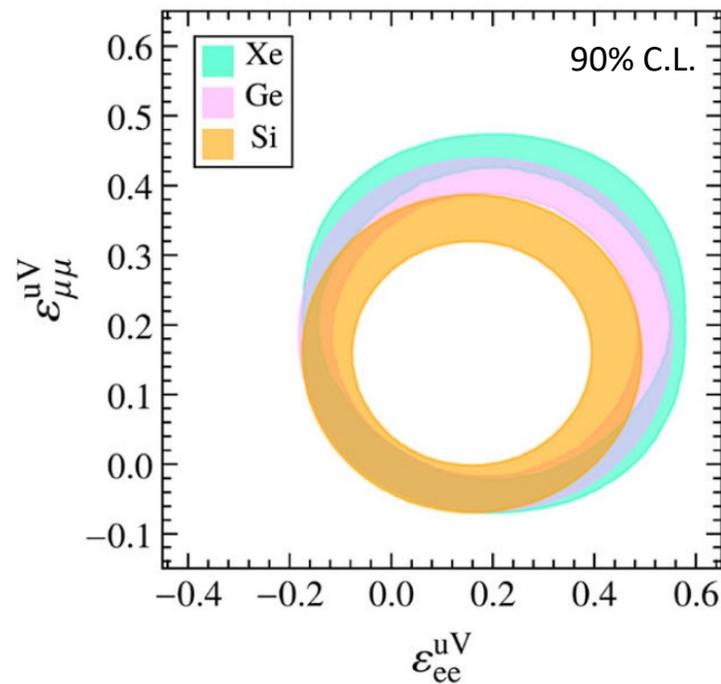
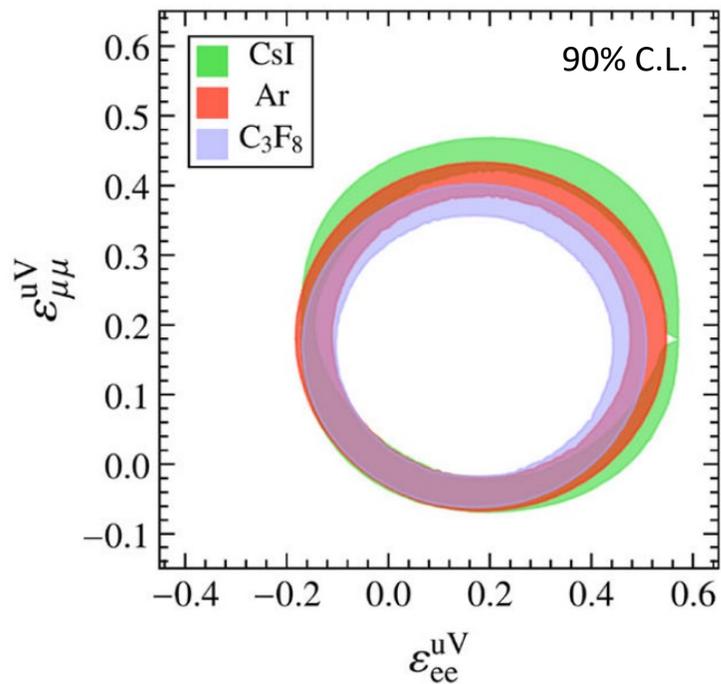
Expected 90% C.L. sensitivity for CsI + Si	
ϵ_{ee}^{uV}	(-0.041, 0.042)
$\epsilon_{\mu\mu}^{uV}$	(-0.02, 0.016)
$\epsilon_{e\mu}^{uV}$	(-0.074, 0.074)

We can remove degeneracies!

S. S. Chatterjee, S. Lavignac, O. G. Miranda, and GSG Phys.Rev.D 107 (2023) 5, 055019

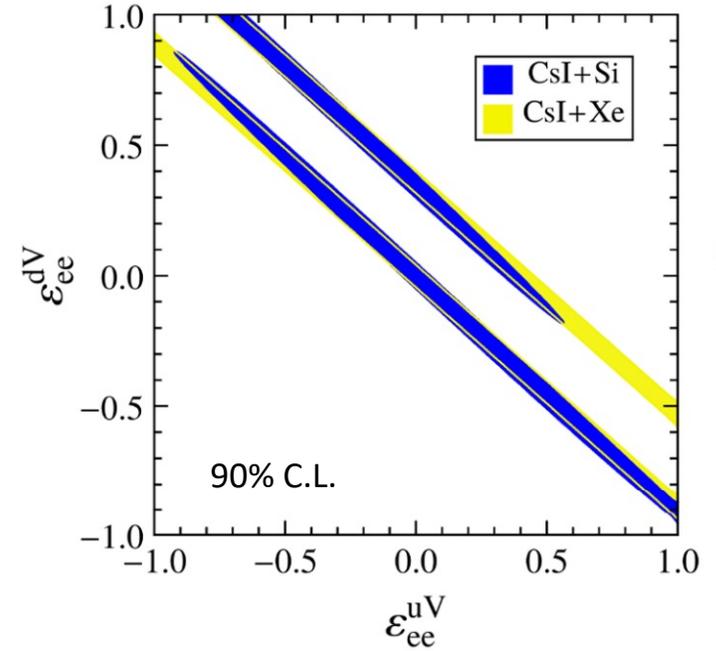
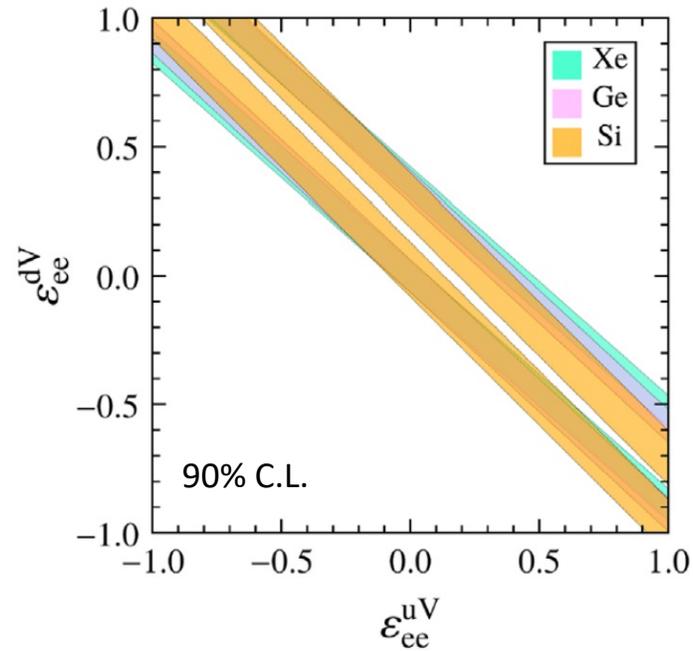
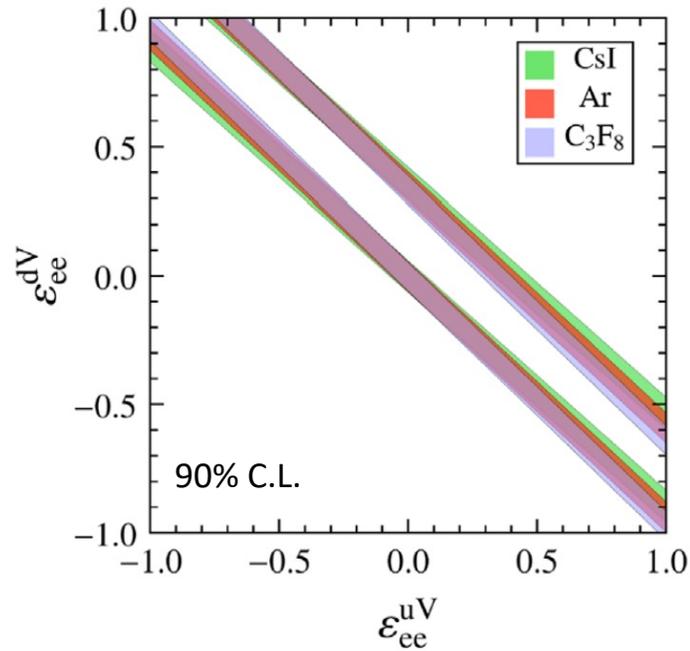
Two NSI parameter analysis:

- Assuming two non-zero NSI at a time:



S. S. Chatterjee, S. Lavignac, O. G. Miranda, and GSG
Phys.Rev.D 107 (2023) 5, 055019

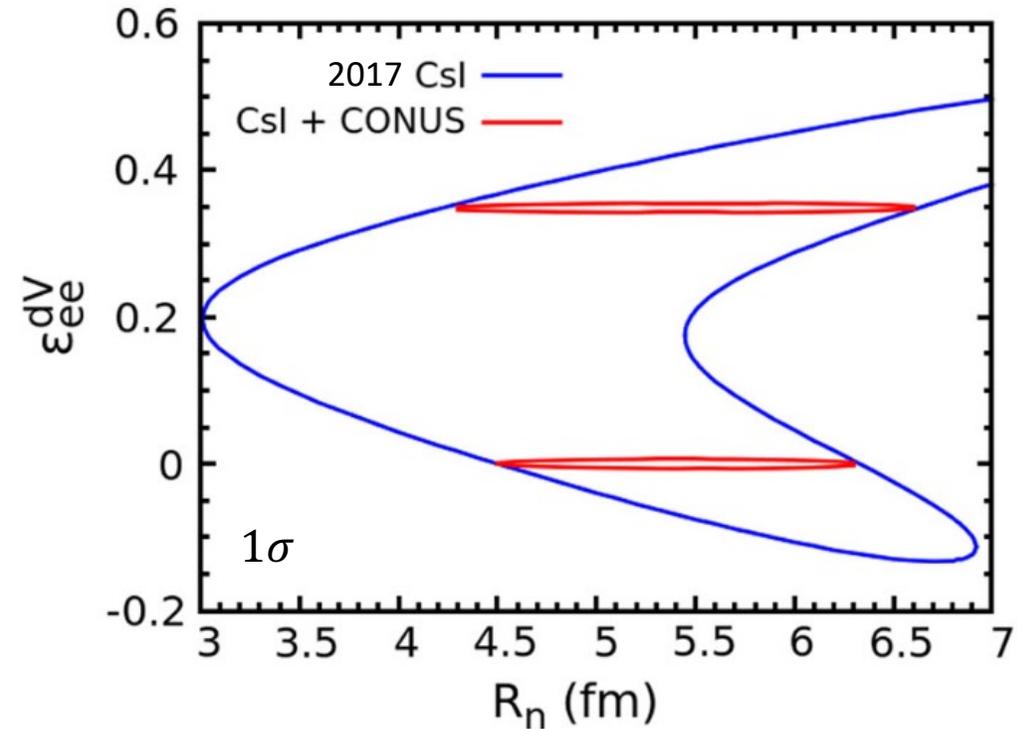
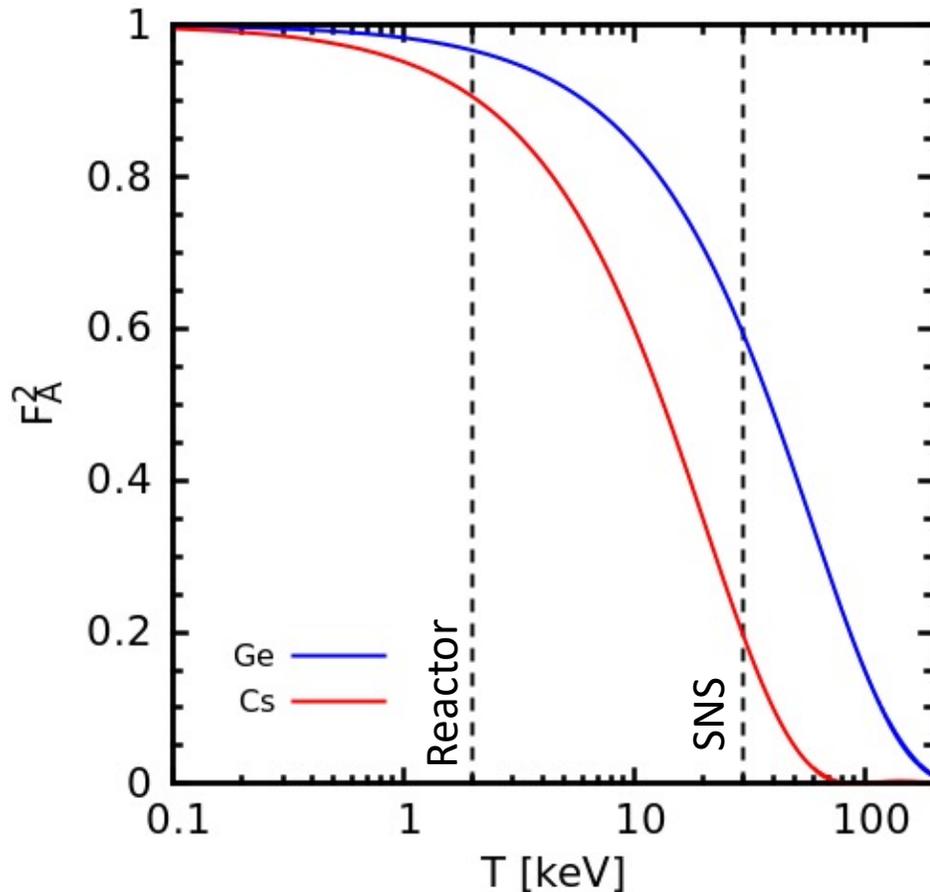
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COHERENT + Expected reactor

- We can explore the sensitivity of a combined analysis from different sources



B. C. Canas, E. A. Garces, O. G. Miranda, A. Parada, **GSG**
Phys. Rev. D 101, 035012 (2020),

Summary

- CEvNS is a powerful tool to explore new physics scenarios such as NSI.
- Sensitivities will improve as systematic uncertainties are better known.
- Combination of different detectors can help to break some degeneracies.
- Future detectors will be more sensitive to NSI.

Thank you!