COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING AND ITS IMPLICATIONS IN THE SEARCH OF NEW PHYSICS

GONZALO SANCHEZ GARCIA
DEPARTMENT OF PHYSICS, CINVESTAV, MEXICO
NBIA SUMMER SCHOOL – JULY 8, 2021
gsanchez@fis.cinvestav.mx

OUTLINE

- Introduction
- Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)
- The COHERENT experiment
- Constraining Standard Model and Nuclear parameters
- Constraining Non-Standard Interactions
- Conclusions

CURRENT PICTURE OF NEUTRINOS

- Neutrinos are massive:

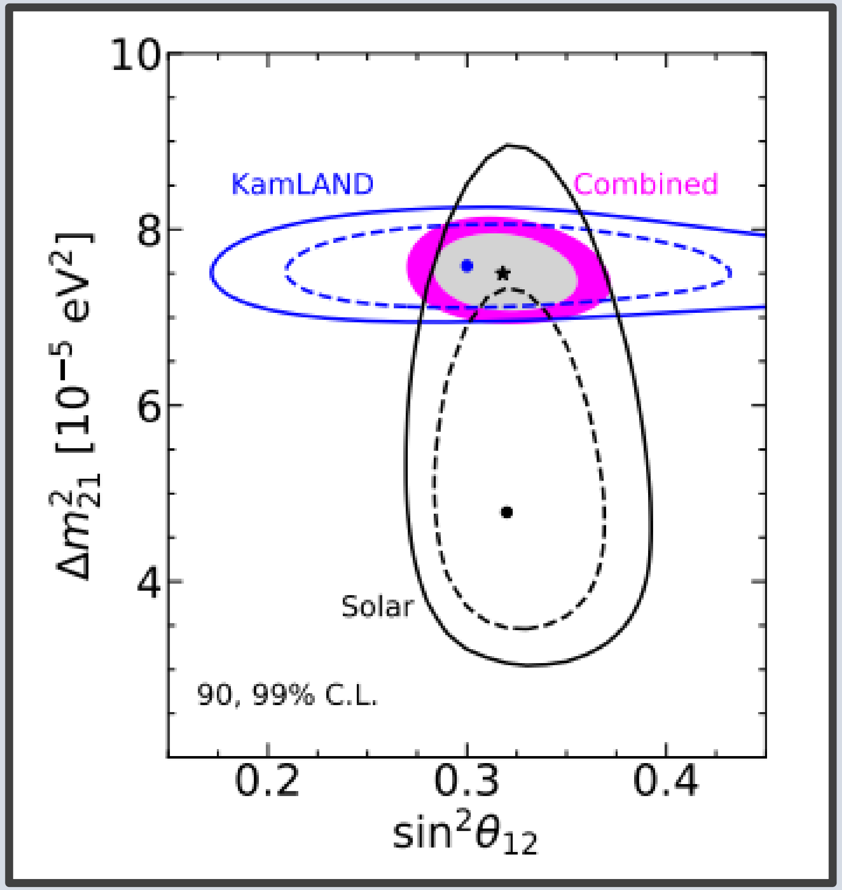
$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

Parametrized by 3 mixing angles $\theta_{12}, \theta_{13}, \theta_{23}$ and a CP phase δ

- They oscillate with a transition probability :

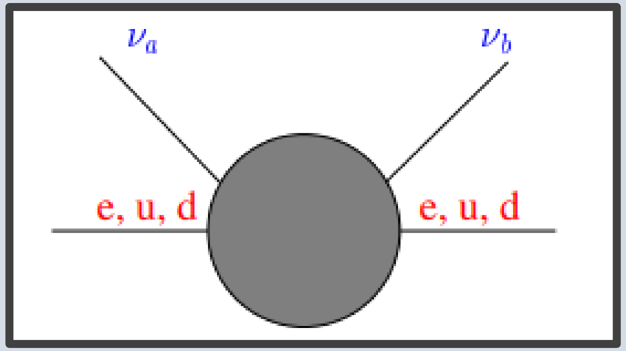
$$P_{\nu_\alpha \to \nu_\beta}(L,E) = \sum_{k,j} U^*_{\alpha k} U_{\beta k} U_{\alpha j} U^*_{\beta j} \exp\left(-i \frac{\Delta m^2_{kj} L}{2E}\right)$$

- Current experiments are sensitive to different oscillation parameters.



P. de Salas, D. Forero, S. Gariazzo, P. Martinez, O. Mena, C. Ternes, M. Tortola, and J. Valle, arXiv:2006.11237

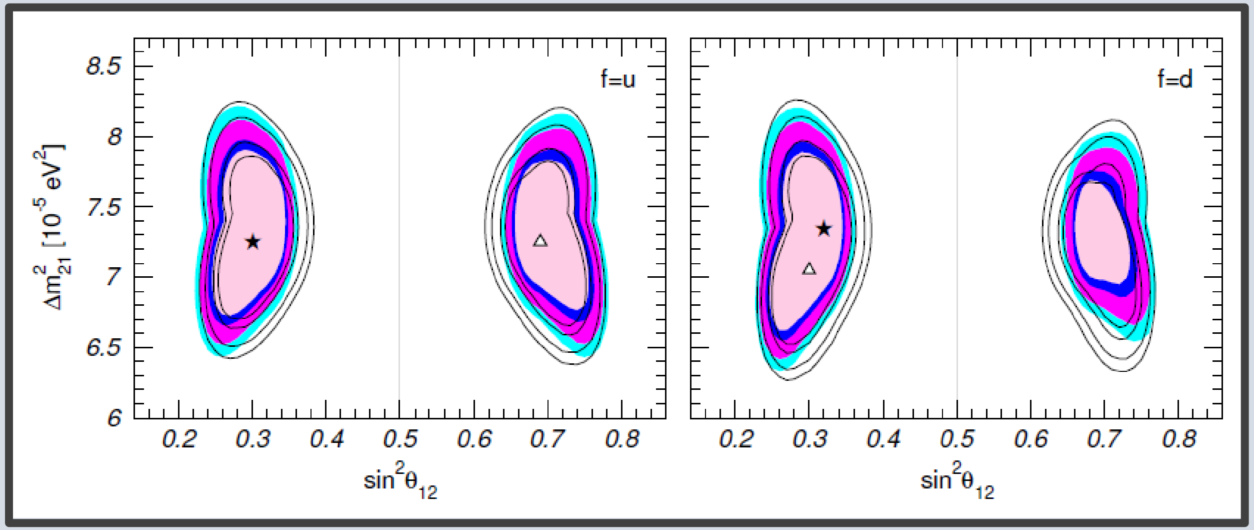
- There is a necessity to look for extensions of the Standard Model
- Many mass generation models naturally give rise to couplings of the form:



$$\mathcal{L}_{NSI} = -\epsilon_{\alpha\beta}^{fP} 2\sqrt{2} G_F \left(\bar{\nu}_\alpha \gamma_\mu L \nu_\beta\right)\left(\bar{f}\gamma^\mu P f\right)$$

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

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

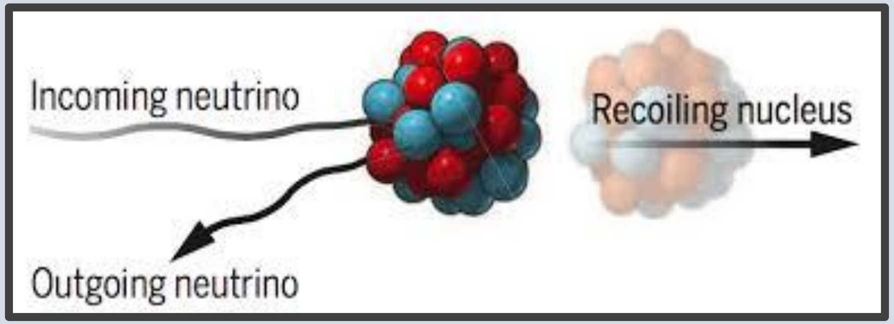


M. C. Gonzalez-Garcia and M. Maltoni, JHEP 09 (2013) 152
O. G. Miranda, M. A. Tortola, and J. W. F. Valle, JHEP 10 (2006) 008

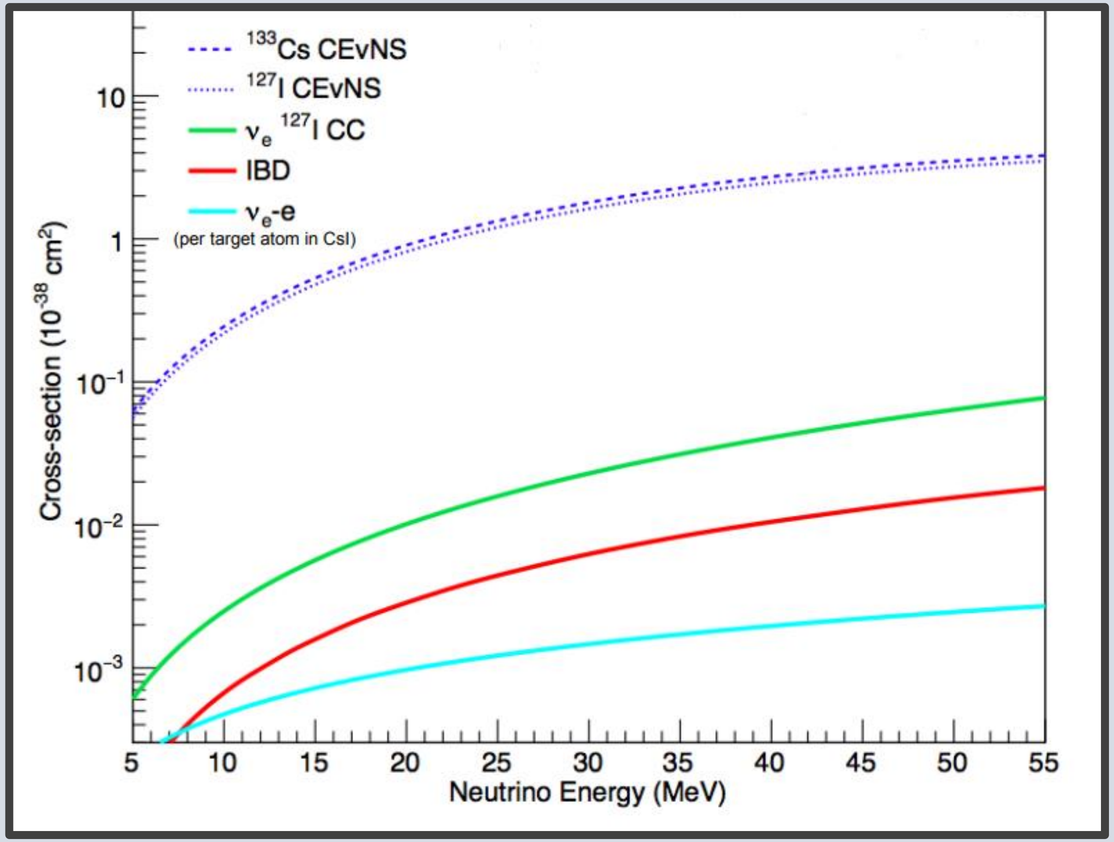
WHAT PROCESSES ARE SENSITIVE TO NSI?

COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING

- Neutral current process by which a neutrino interacts with a nucleus.
- Proposed by **Friedman** in 1974 and measured by the **COHERENT** collaboration in 2017 (CsI) y 2020 (LAr).
- Very low thresholds are required.



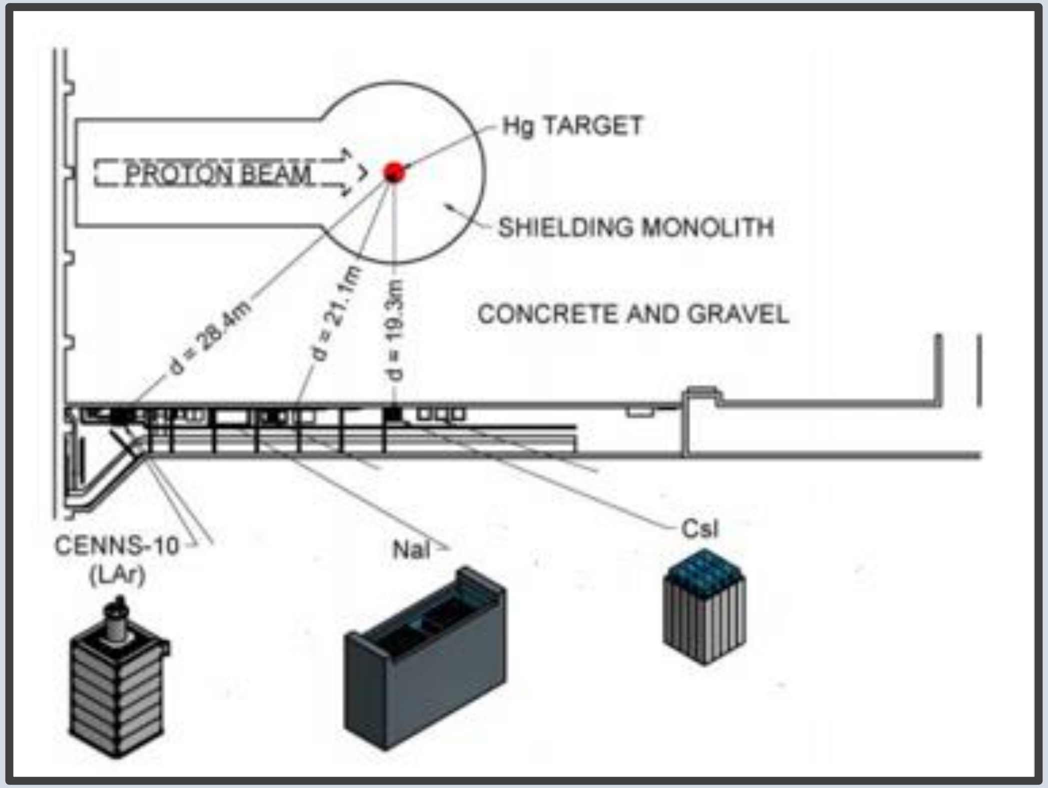
$$qR \ll 1$$

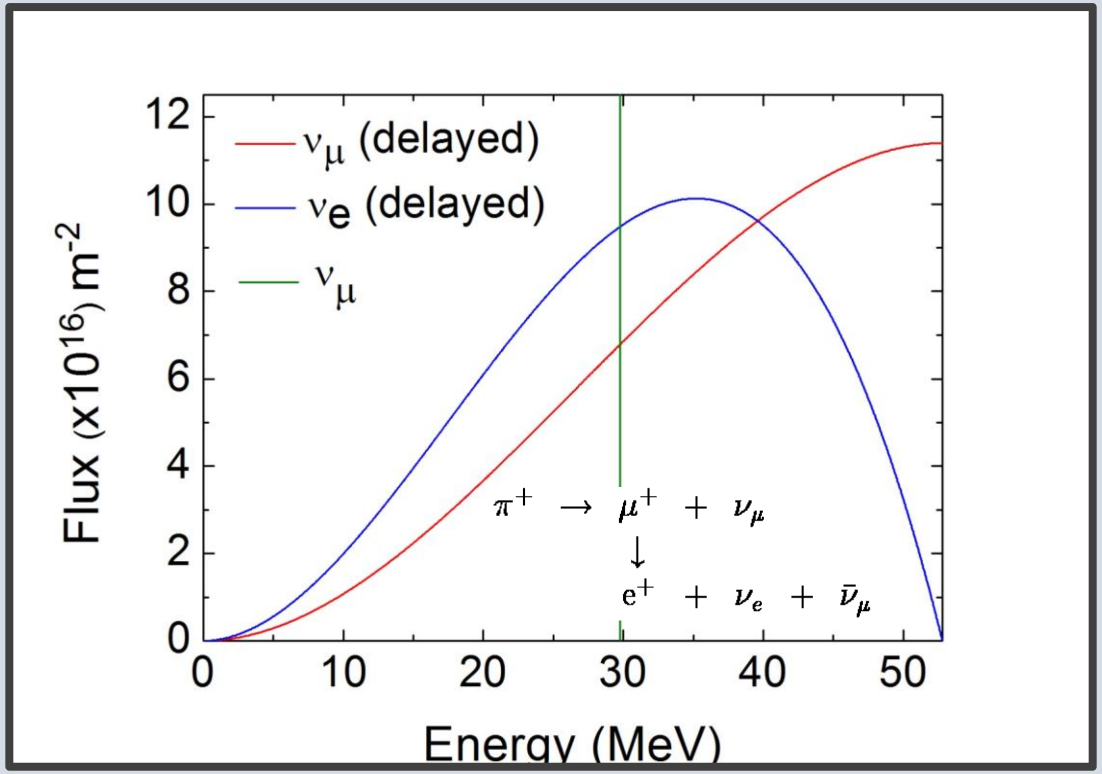


D. Akimov et al. Science 357.6356 (2017)

THE COHERENT EXPERIMENT

- Neutrino beam production by the collision of high energy protons with Hg nuclei at the Spallation Neutron Source (Oak Ridge National Laboratory).





D. Akimov et al. Science 357.6356 (2017)

THE CEVNS CROSS SECTION

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

- The cross section can provide information about SM and nuclear parameters

SM PARAMETERS

$$g_V^p = \frac{1}{2} - 2\sin^2\theta_W$$

$$g_V^n = -\frac{1}{2}$$

NUCLEAR PARAMETERS

$$F_N^{\rm Helm}(q^2) = 3\,\frac{j_1(qR_0)}{qR_0}\,e^{-q^2 s^2/2}$$

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

- We can calculate the predicted number of events for a given experiment through the expression:

$$N_i^{th} = N_{CsI} \int_{T_i}^{T_{i+1}} dT \int_{E_{min}}^{52.8MeV} dE A(x(T)) \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \frac{\mathrm{d}\sigma}{\mathrm{d}T}$$

- So far, we have two experimental measurements: CsI and LAr
- There is a slight discrepancy between experimental and theoretical results.

Detector	Expected Events	Measured events
CsI	171	136 ± 31
LAr	132	159 ± 43

THE ANALYSIS

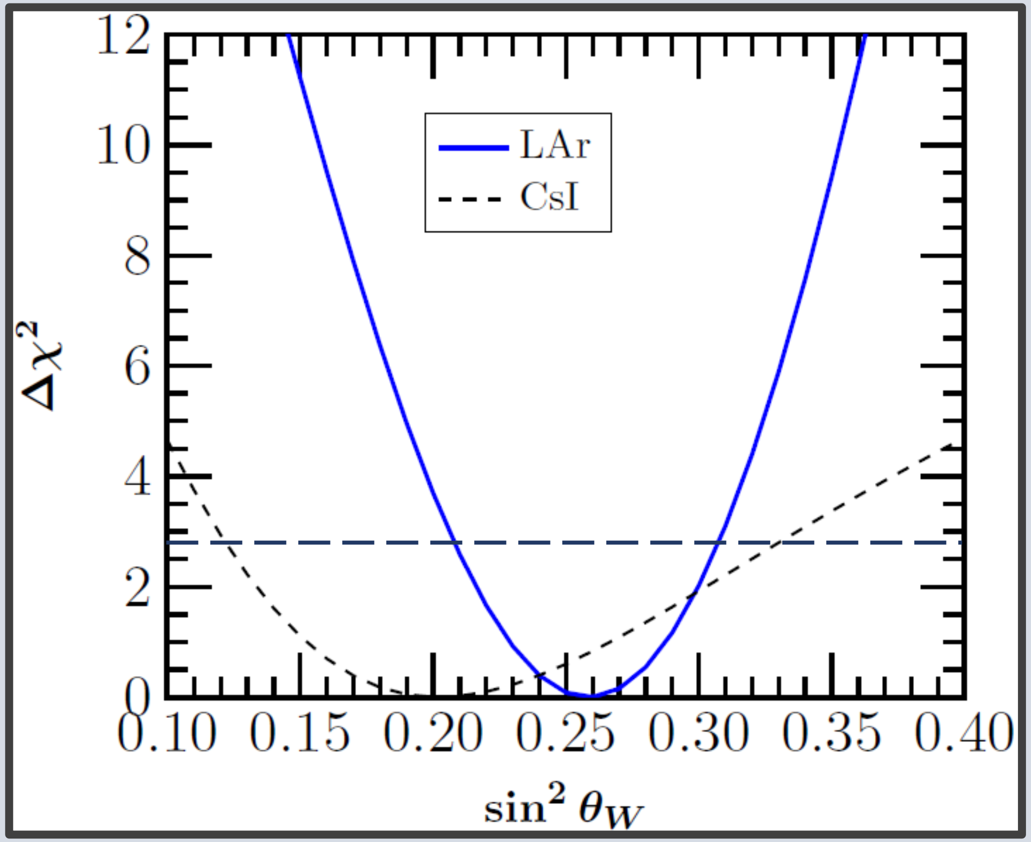
- We compare the results with experimental ones by performing a χ analysis

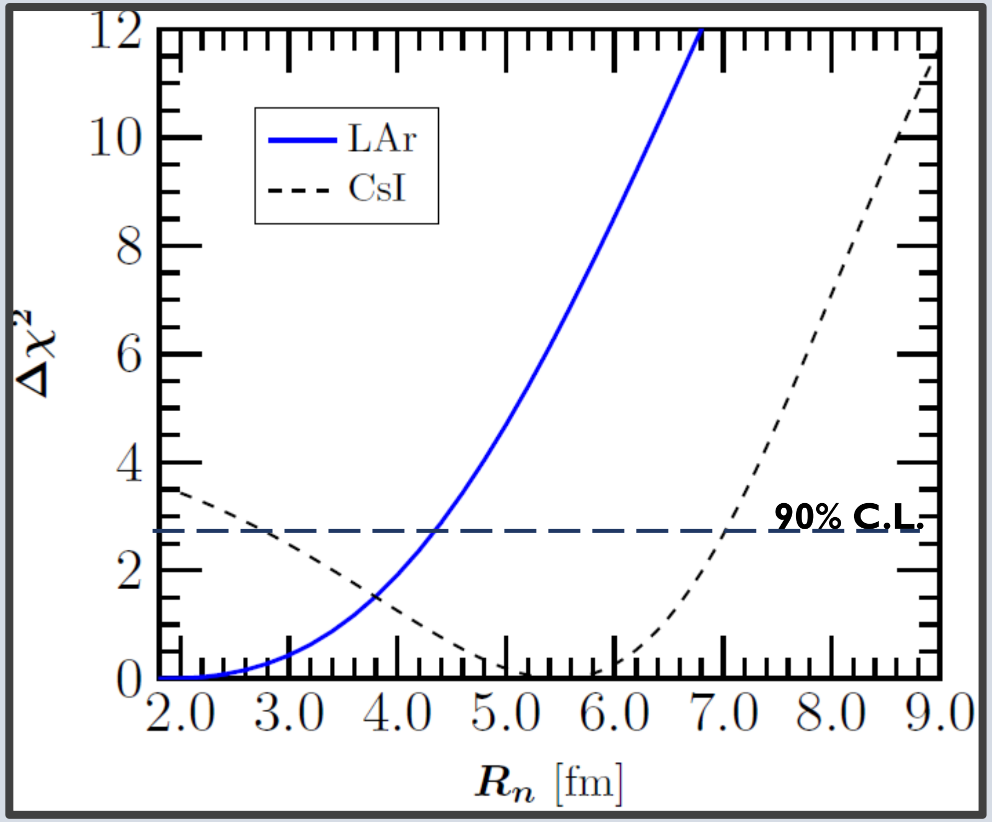
$$\chi^2 = \sum_{i=1}^{n} \frac{\left(N_i^{exp} - (1+\alpha)N_i^{th}(X) - (1+\beta)N_i^{bg}\right)^2}{\sigma_i^2} + \frac{\alpha^2}{\sigma_\alpha^2} + \frac{\beta^2}{\sigma_\beta^2}$$

- Where *X* stands for the set of parameters under study, which will include:

- ❑ Weak mixing angle (*Standard Model test*)
- ❑ Neutron RMS (*Nuclear target information*)
- ❑ NSI Parameters. (*New Physics*)

RESULTS FOR STANDARD MODEL PARAMETERS





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

INCORPORATING NSI

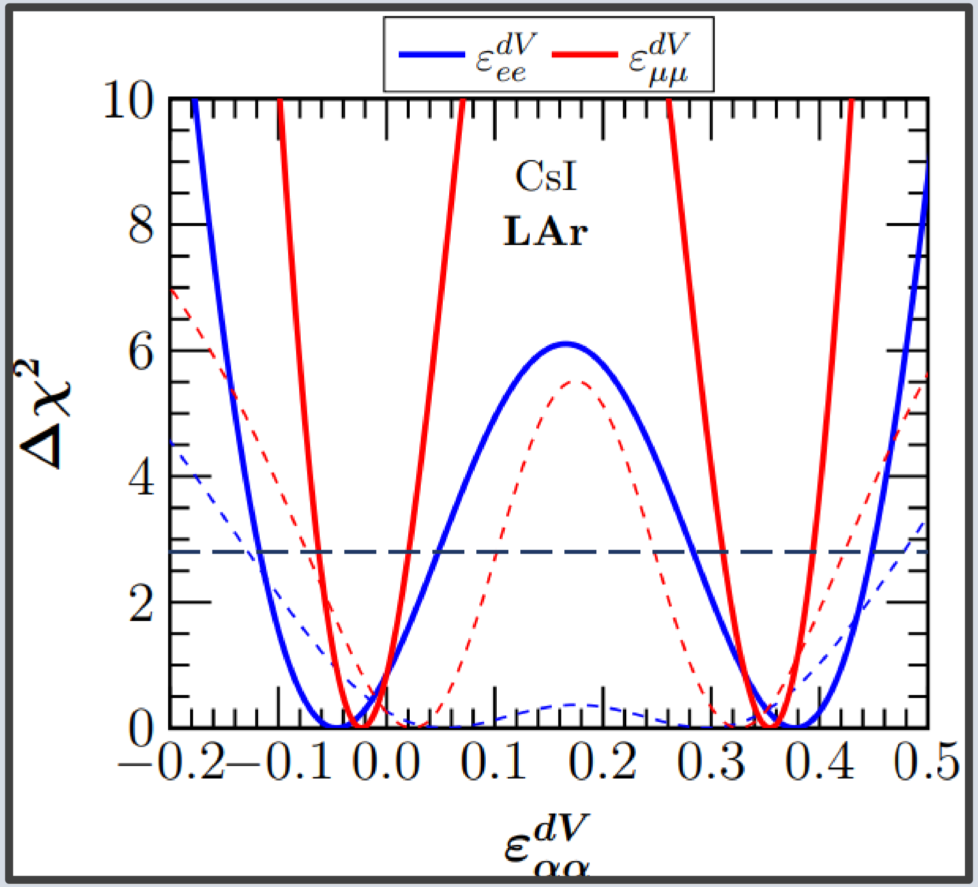
- The cross section now reads:

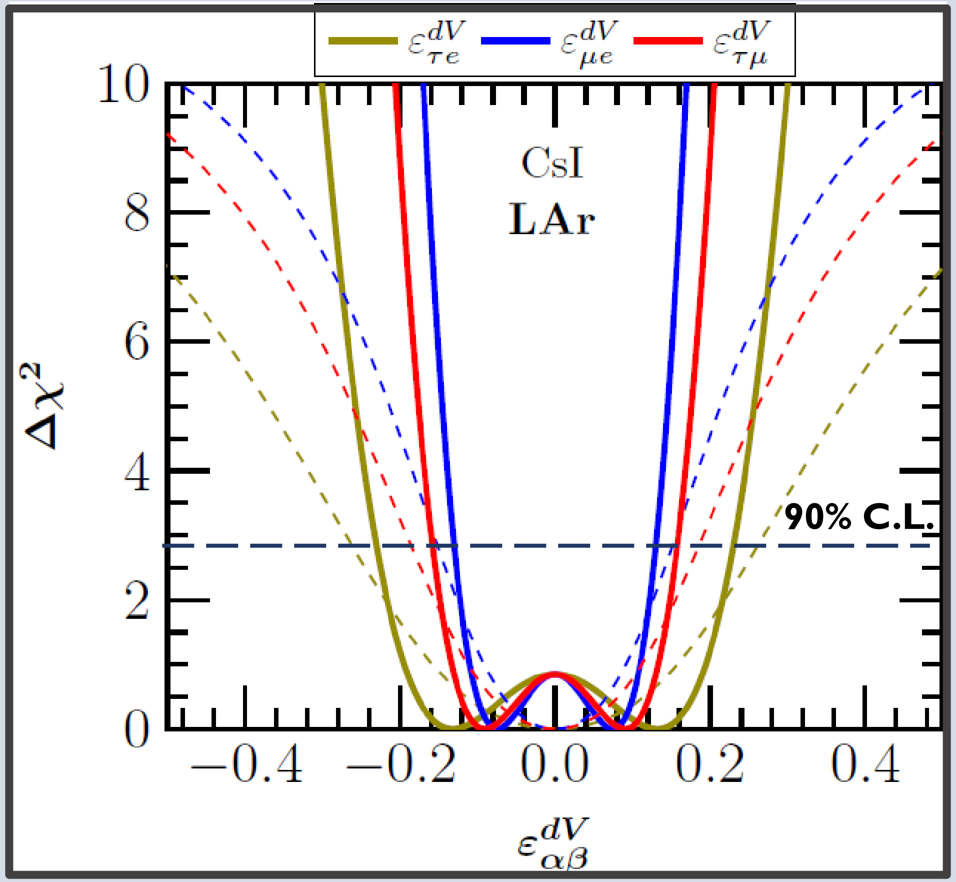
$$\frac{d\sigma}{dT}(E_\nu, T) \simeq \frac{G_F^2 M}{\pi}\left(1 - \frac{MT}{2E_\nu^2}\right)\left\{\left[Z\left(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}\right)F_Z^V(q^2) + N\left(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV}\right)F_N^V(q^2)\right]^2 + \sum_\alpha \left[Z\left(2\varepsilon_{\alpha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

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

- We begin the analysis by considering one of them to be non-zero at a time.

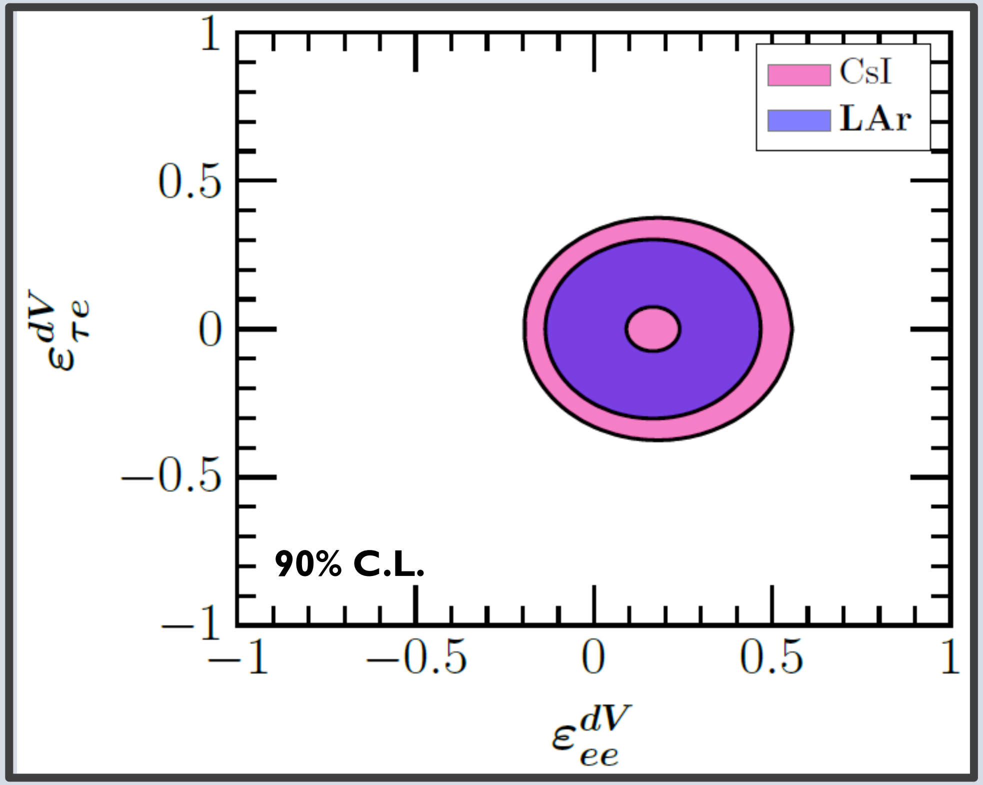
NON-UNIVERSAL AND FLAVOR CHANGING RESULTS

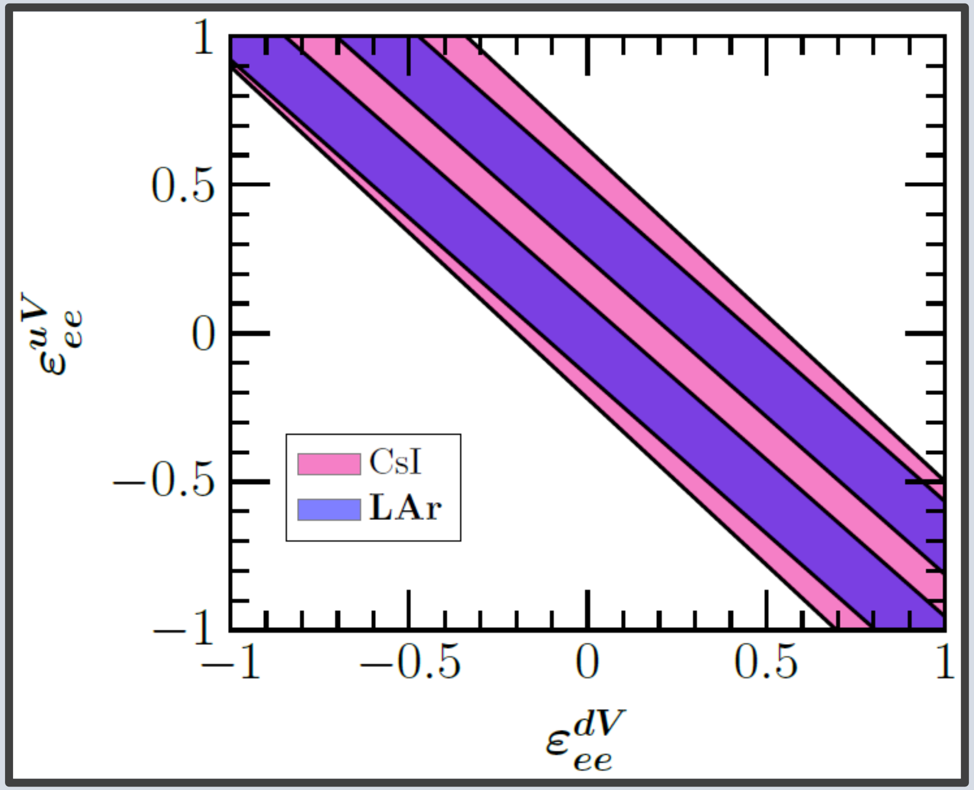




O. Miranda, D. Papoulias, **GSG**, O. Sanders, M. Tórtola, and J. Valle, JHEP 05 (2020) 130

CORRELATION BETWEEN TWO PARAMETERS

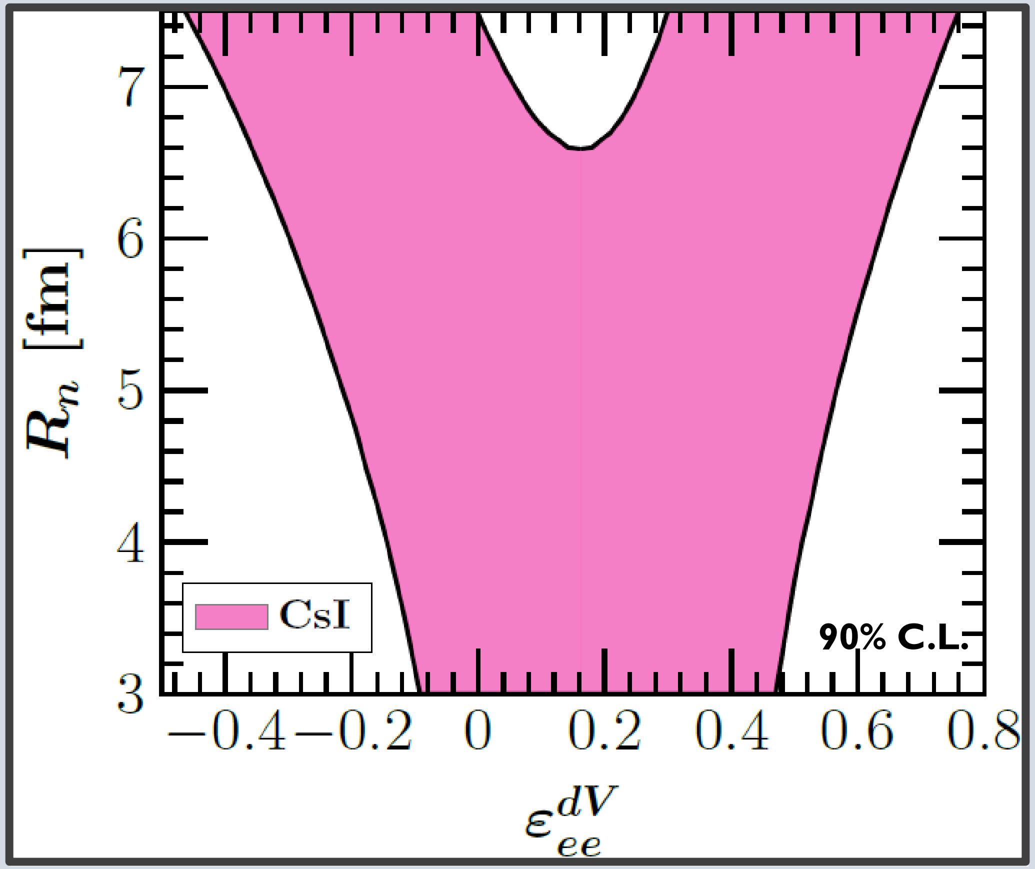


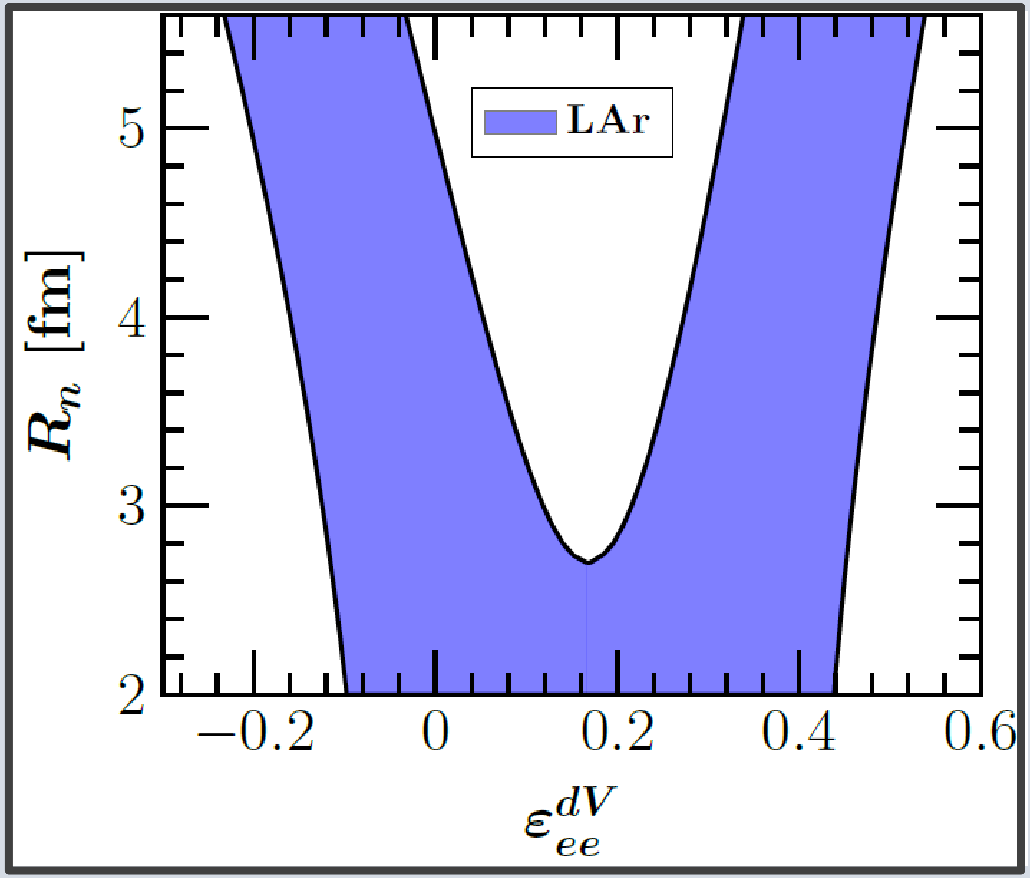


O. Miranda, D. Papoulias, **GSG**, O. Sanders, M.Tórtola, and J. Valle, JHEP 05 (2020) 130

CONSTRAINING NUCLEAR PARAMETERS AND NSI

- The deviation from the predicted value can be due to NSI or nuclear unknowledge.





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

THE FUTURE FOR CEVNS

- Different detection technologies such as Ge and NaI detectors have been proposed to measure CEvNS.

- Reactor neutrinos as a source of neutrinos to study CEvNS

- DM experiments will be sensitive to this process.

CONCLUSIONS

- ✓ The CEvNS process is sensitive to the study of non-universal and flavor changing NSI's.
- ✓ Current results give good constraints to these parameters.
- ✓ Many experiments are under development and will be sensitive to other new physics scenarios.
- ✓ Improvement in systematic uncertainties is important to get more robust constraints.


Thank you

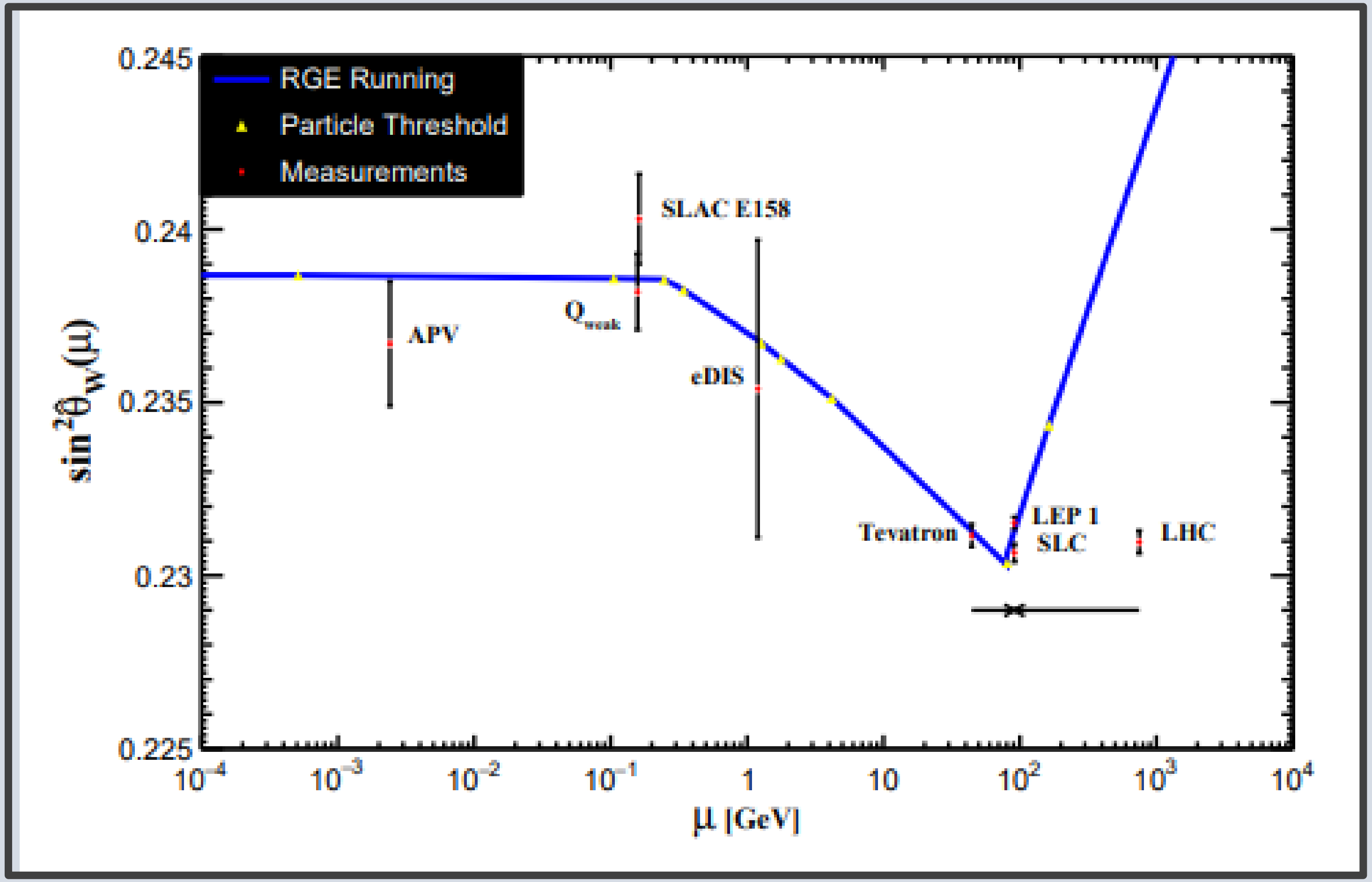
BACKUP

OTHER NSI CONSTRAINTS

Experiment	Parameter	Bounds	Reference
CHARM	$\epsilon_{e\tau}^{qL}, \epsilon_{e\tau}^{qR}$	[-0.5,0.5]	[1]
CHARM	ϵ_{ee}^{dL}	[-0.3,0.3]	[1]
CHARM	ϵ_{ee}^{dR}	[-0.6,0.5]	[1]
CHARM + NuTeV	$\epsilon_{\mu\mu}^{dV}$	[-0.042,0.042]	[2]
CHARM + NuTeV	$\epsilon_{\mu\tau}^{qV}$	[-0.007,0.007]	[2]

[1] S. Davidson, C. Pena-Garay, N. Rius, and A. Santamaria, JHEP 03 (2003) 011
[2] F. J. Escrihuela, M. Tortola, J. W. F. Valle, and O. G. Miranda, Phys. Rev. D83 (2011) 093002

Scale dependence of the weak mixing angle.

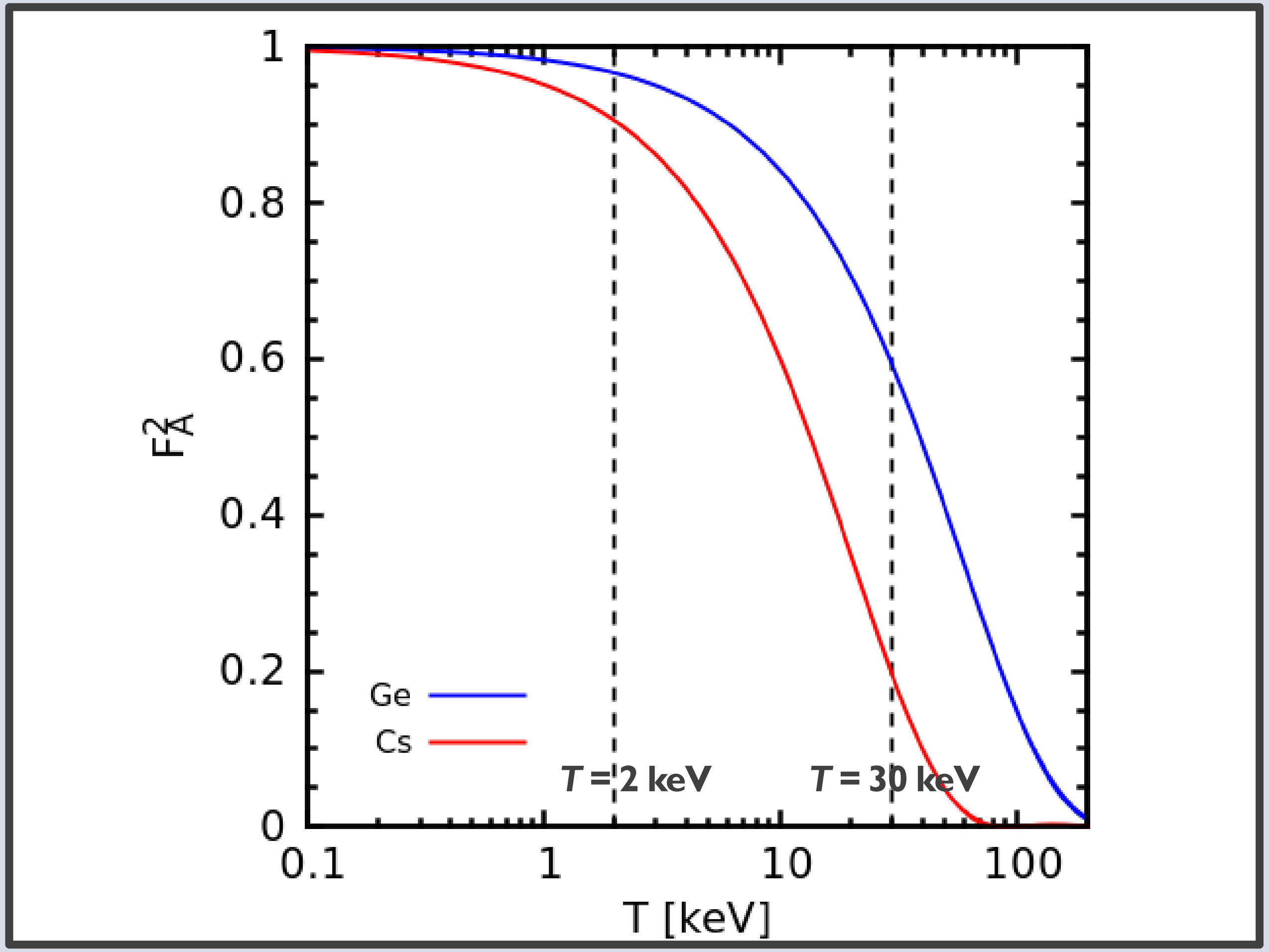


P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

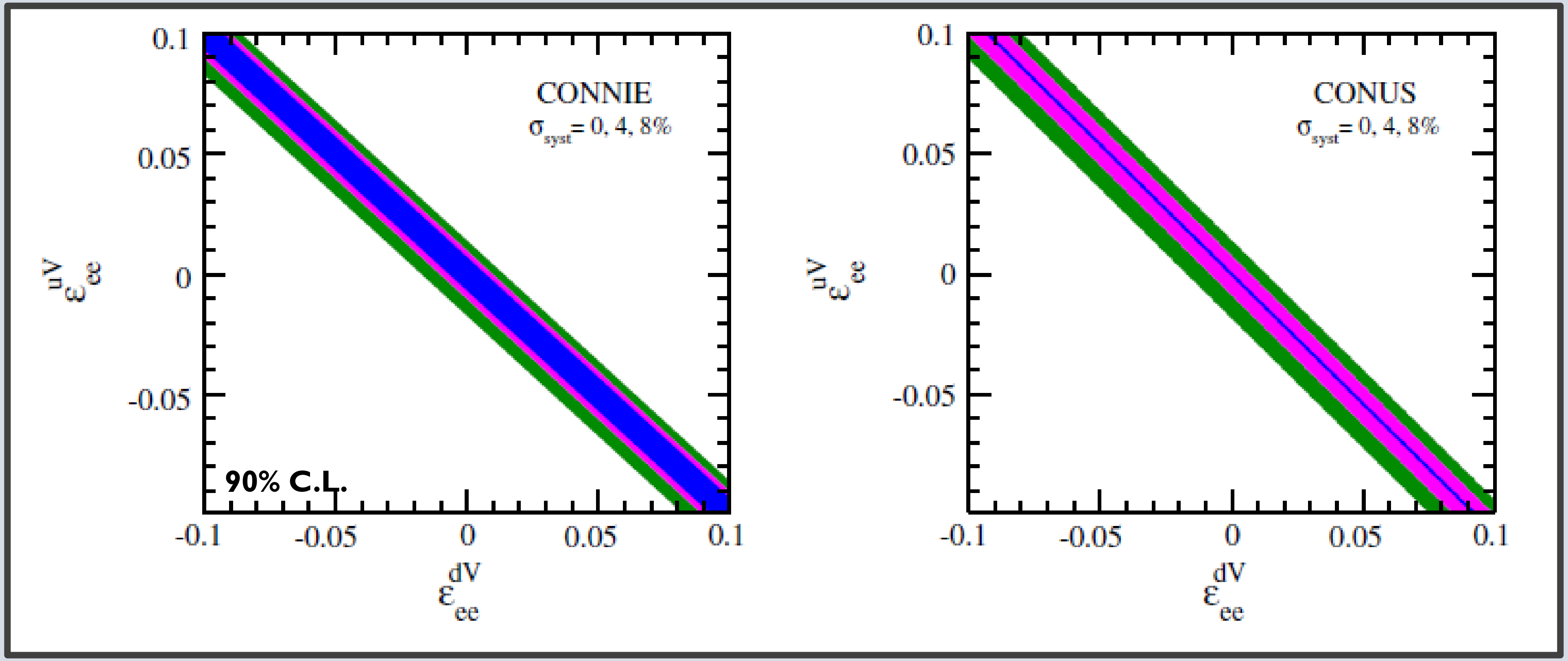
FUTURE REACTOR NEUTRINOS

- Form factors do not play a significant roll in this energy regime

$$N_{\text{events}} = t\phi_0 \frac{M_{\text{detector}}}{M} \int_{E_{\nu\,\text{min}}}^{E_{\nu\,\text{max}}} \lambda(E_\nu) dE_\nu \times \int_{T_{\text{min}}}^{T_{\text{max}}(E_\nu)} \left(\frac{d\sigma}{dT}\right)^{\text{coh}} dT$$

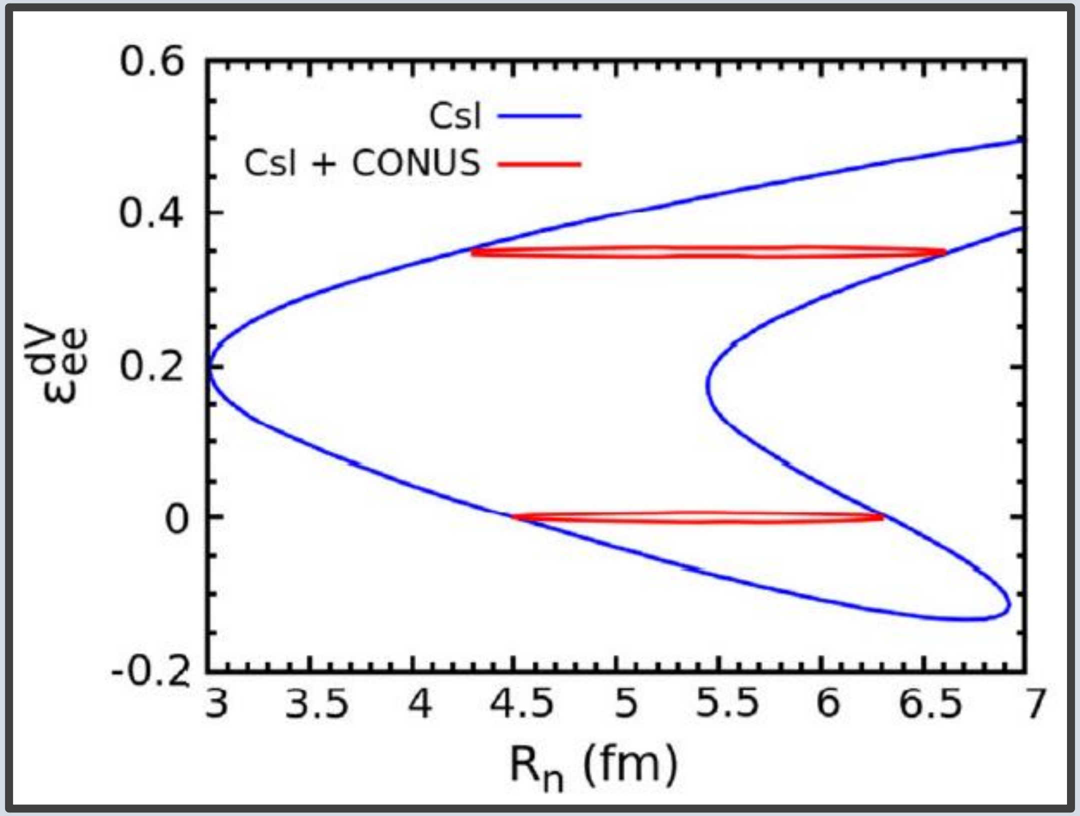


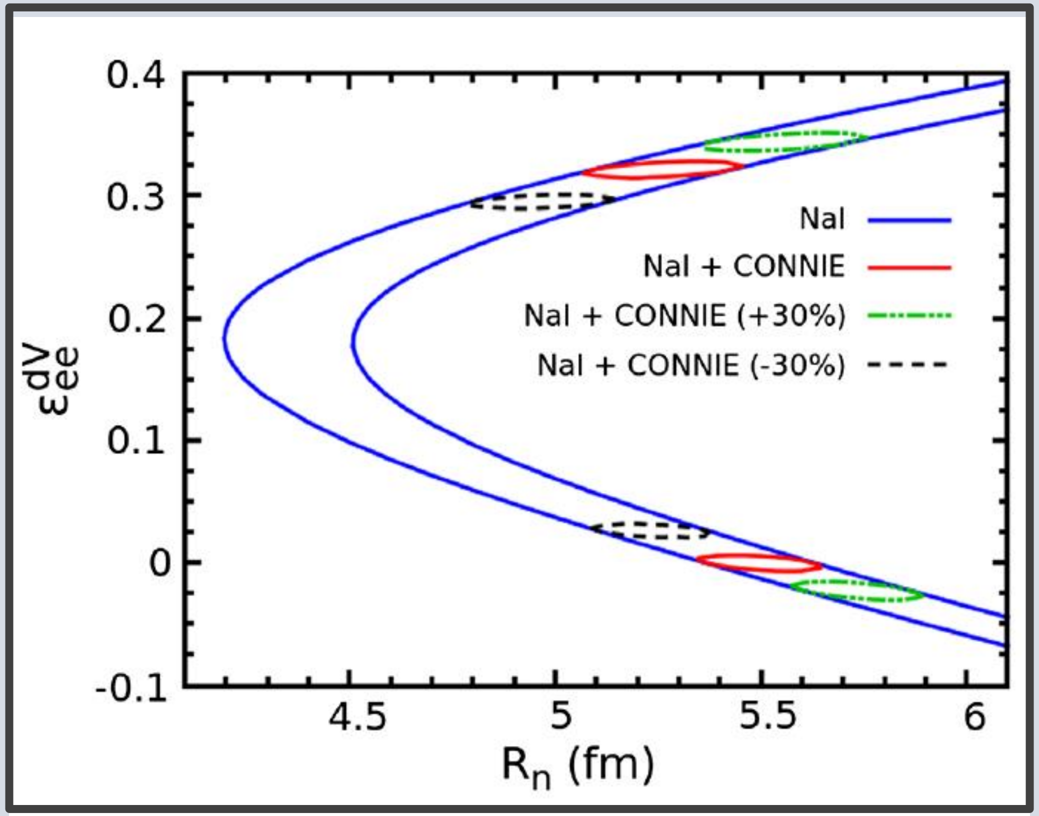
NON-UNIVERSAL NSI



B. Canas, E. Garces, O. Miranda, A. Parada, and **GSG**, *Phys. Rev. D* 101 (2020) 3 035012

COMBINED ANALYSIS

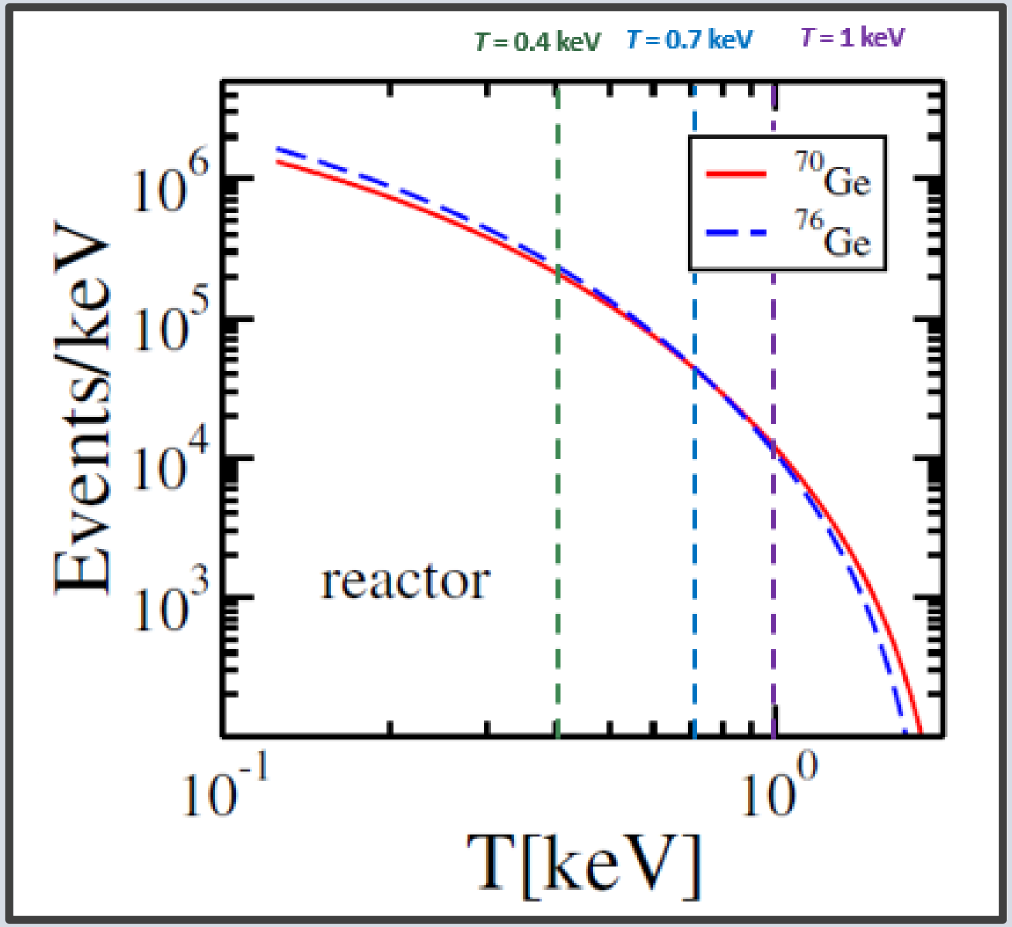




B. Canas, E. Garces, O. Miranda, A. Parada, and G. Sanchez Garcia, *Phys. Rev. D* 101 (2020) 3 035012

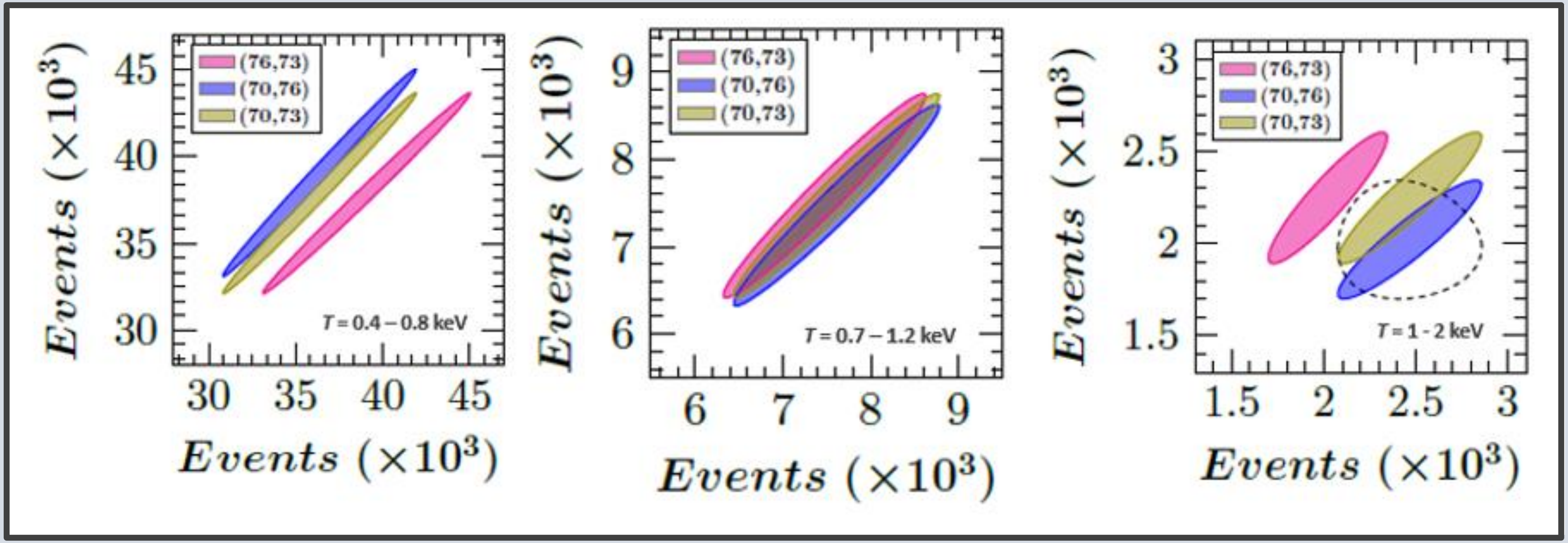
OTHER PROPOSALS TO STUDY CEVNS

- Use an array of detectors of different isotopes[1] to perform a simultaneous measurement.
- Systematic effects will be *common to all the detectors*.
- Nuclei of different isotopes only differ by the number of neutrons, *leading to a correlation of systematic uncertainties* of form factors and quenching factors.
- The idea is applicable to elements like Ge.



A. Galindo-Uribarri, O. G. Miranda, and **GSG**, (2020), arXiv:2011.10230

Expected number of events for such an array



A. Galindo-Uribarri, O. G. Miranda, and **GSG**, (2020), arXiv:2011.10230

- Different behavior of the allowed regions depending on the recoil energy interval under study.