Experimental program of the COHERENT collaboration

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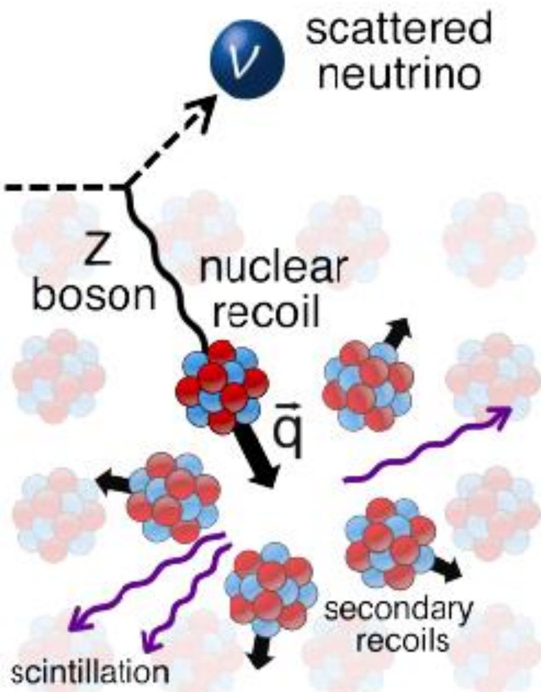
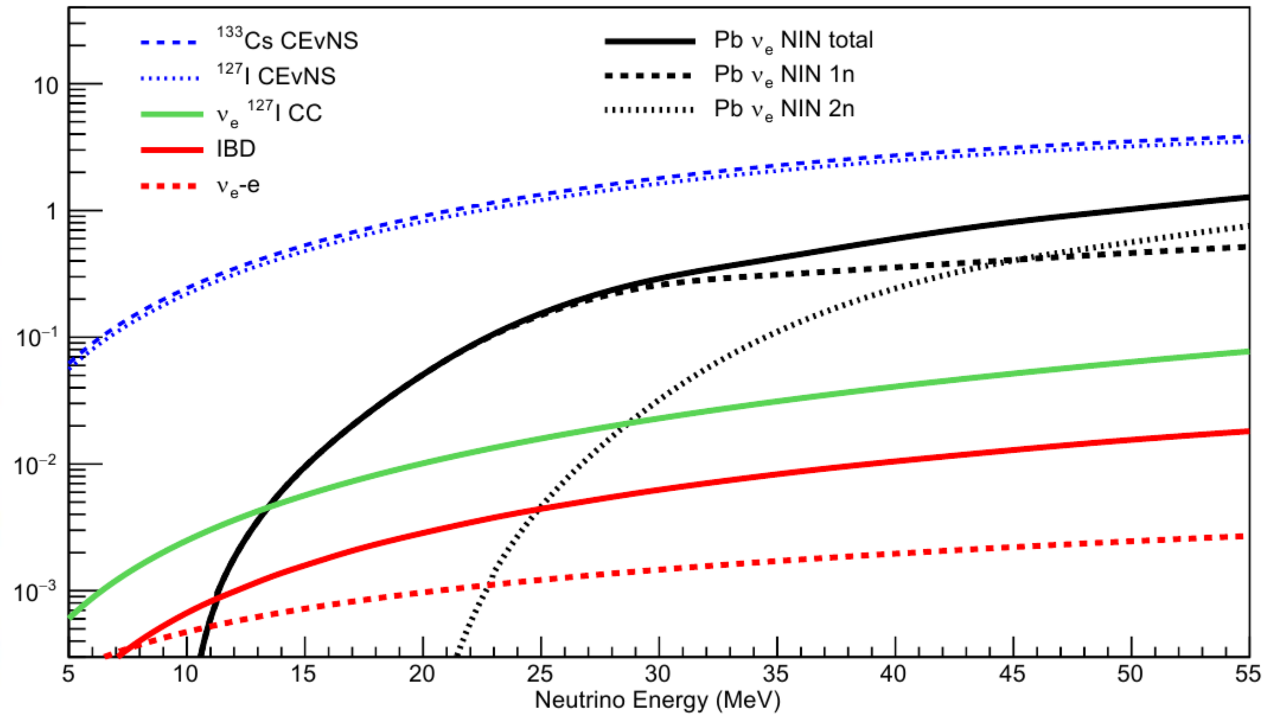
Collaboration

Carnegie Mellon University
THE UNIVERSITY OF CHICAGO
Duke UNIVERSITY
UF UNIVERSITY of FLORIDA
KAIST
Laurentian University Université Laurentienne
Los Alamos NATIONAL LABORATORY EST. 1943
MEPhI
NORTH CAROLINA CENTRAL UNIVERSITY
NC STATE UNIVERSITY
NM STATE UNIVERSITY
OAK RIDGE National Laboratory
Sandia National Laboratories
UNIVERSITY OF SOUTH DAKOTA
THE UNIVERSITY of TENNESSEE UT KNOXVILLE
SIGILLUM UNIVERSITATIS TUFTENSIS PAX ET LUX 1852
TUNL
VT VIRGINIA TECH
W UNIVERSITY of WASHINGTON

The main goal is to look for new physics using coherent elastic ν–nucleus scattering

Coherent elastic neutrino-nucleus scattering (CEvNS)





CEvNS cross section in the SM:

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi}\Big([1 - 4\sin^2\theta_W]Z - N\Big)^2\left[1 - \frac{T}{T_{max}}\right]F_{nucl}^2(q^2)$$

Dominating type of interaction for heavy nuclei and E_ν< 50 MeV!

Coherent elastic neutrino-nucleus scattering (CEvNS)

Predicted in 1974…

"Coherent effect of a weak neutral current", D. Freedman, PRD v.9, n.5 (1974)

"Isotopic and chiral structure of neutral current", V.Kopeliovich, L. Frankfurt, ZhETF. Pis. Red., v.19 n.4 (1974)

…with first observation 43 years after

Low energy recoil nucleus in a final state: $T_{max} = 2E_\nu^2/(M + 2E_\nu)$

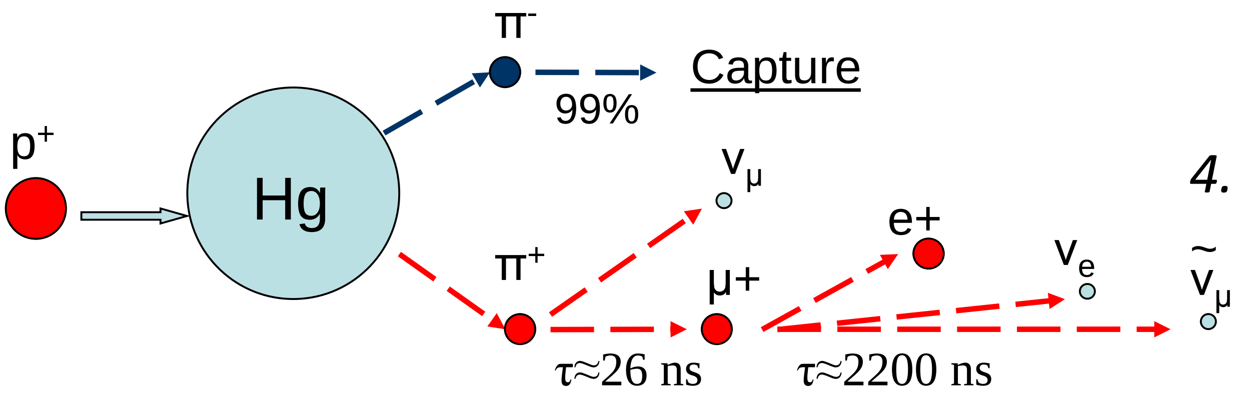
Nucleus	T_{max}, keV (E_ν =5 MeV)	T_{max}, keV (E_ν =30 MeV)
^{12}C	4.44	159.0
^{23}Na	2.32	83.2
^{40}Ar	1.33	47.9
^{74}Ge	0.72	25.9
^{133}Cs	0.40	14.4

Observation requires combination of a large flux of neutrino with proper E_ν and a low-threshold detector

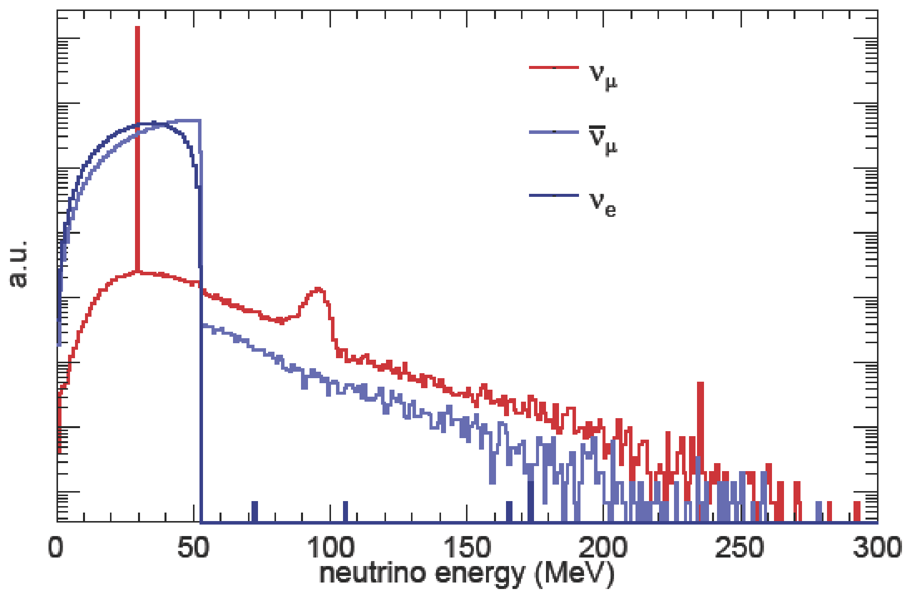
SNS facility at ORNL

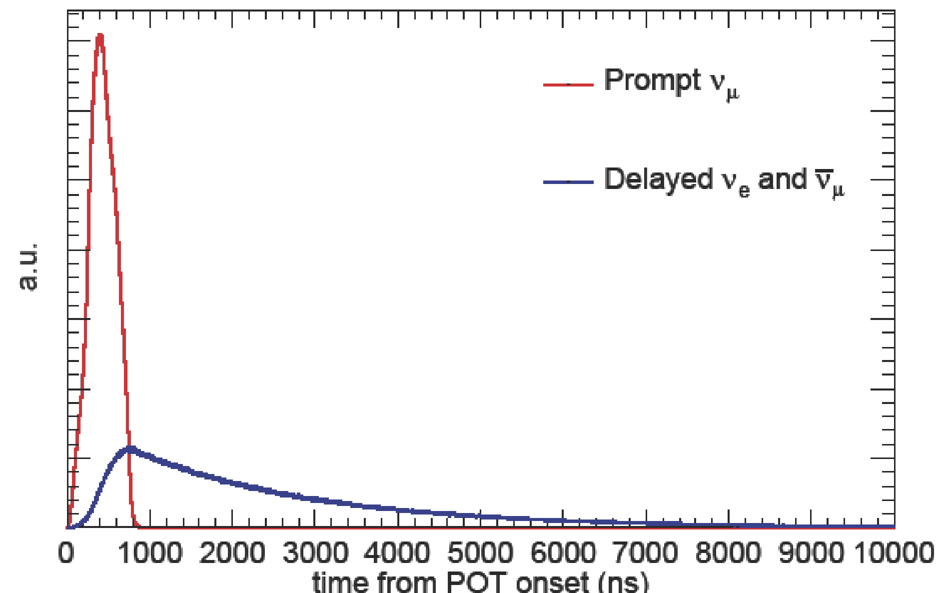
Bunches of ~1 GeV protons on the Hg target with 60 Hz frequency

Proton bunch time profile with FWHM of ~350 ns



Total neutrino flux
$4.3 \cdot 10^7$ $cm^{-2} * s^{-1}$ at 20m



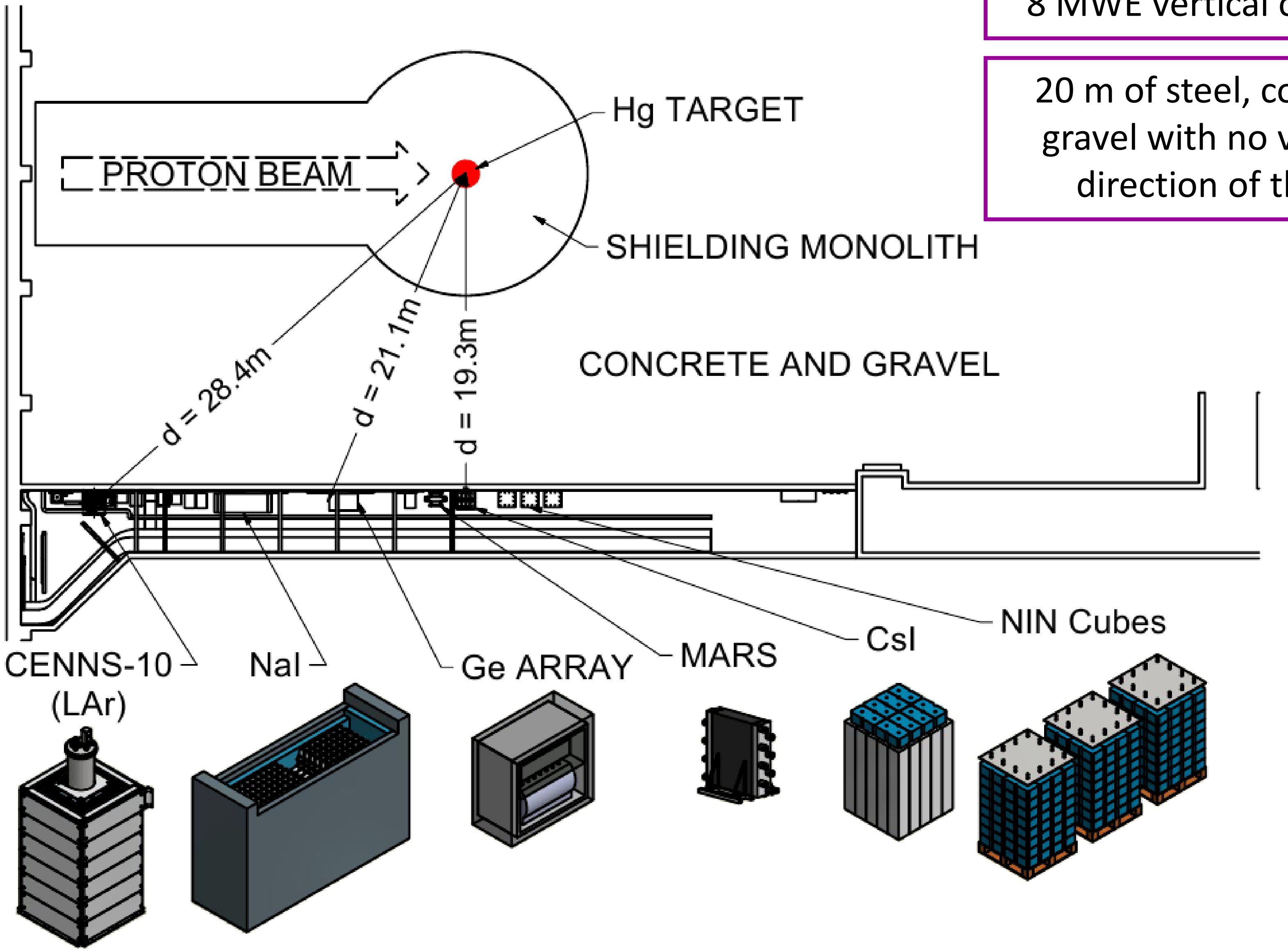


"Neutrino alley"

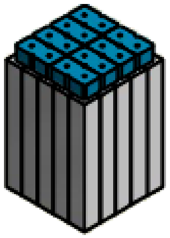
COHERENT detectors are hosted by the target building basement

8 MWE vertical overburden

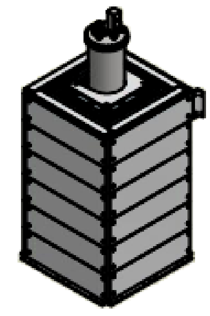
20 m of steel, concrete and gravel with no voids in the direction of the target



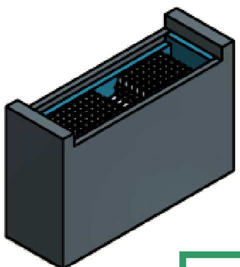
Detector subsystems



CsI[Na], deployed→decommisioned: 14.5 kg crystal, single PMT readout, LY of 13.4 PE/keV, ~8 keV_{nr} threshold

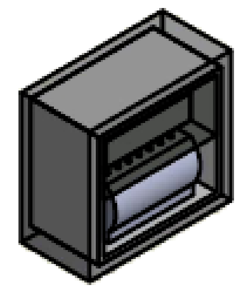


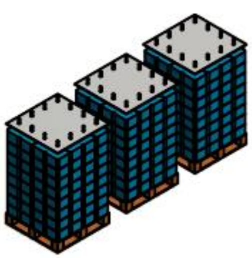
CENNS-10, deployed: 22 kg liquid argon detector, 2 PMTs readout, LY of 4.5 PE/keV, ~20 keV_{nr} threshold



NaI[Tl]: segmented 185 kg, deployed →2T, ~13 keV_{nr} threshold (Na recoils)

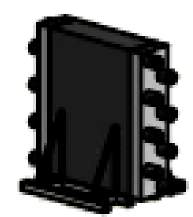
HPGe PPC: 5 kg (cryostat ready, funding secured) →16 kg, ~150 eVee threshold expected (~1keV_{nr})





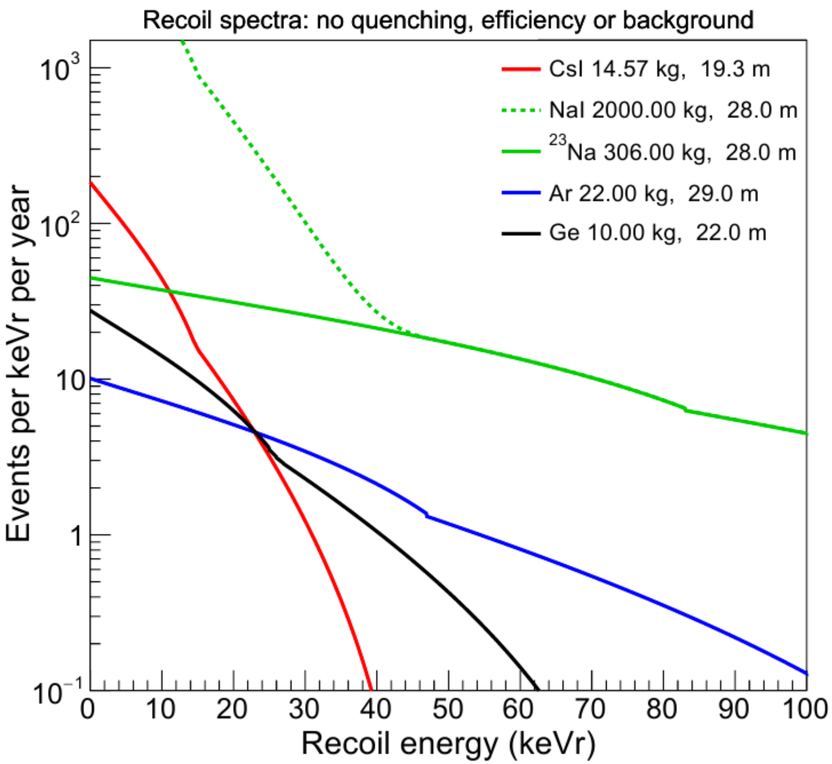
Nubes: 4 LS cells/cube (2*2L+2*1.3L, EJ-301 –PSD capability), surrounded by lead (deployed) / iron (deployed) / copper

MARS, deployed: BC-408 plastic scintillator interleaved with Gd coated Mylar sheets



Physics sensitivity

Topic	CsI	Ar	NaI	Ge	Nubes	D_2O
Non-standard neutrino interactions	✓	✓	✓	✓		
Weak mixing angle	✓	✓	✓	✓		
Neutrino magnetic moment				✓		
Inelastic CC/NC cross-section for supernova		✓			✓	✓
Inelastic CC/NC cross-section for weak physics		✓	✓		✓	✓
Nuclear form factors	✓	✓	✓	✓		
Accelerator-produced dark matter	✓	✓	✓	✓		
Sterile oscillations	✓	✓	✓	✓		



$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi}\left([1 - 4\sin^2\theta_W]Z - N\right)^2\left[1 - \frac{T}{T_{max}}\right]F_{nucl}^2(q^2)$$

Study of some of these benefits from the multi-detector approach!

Nuclear form-factors

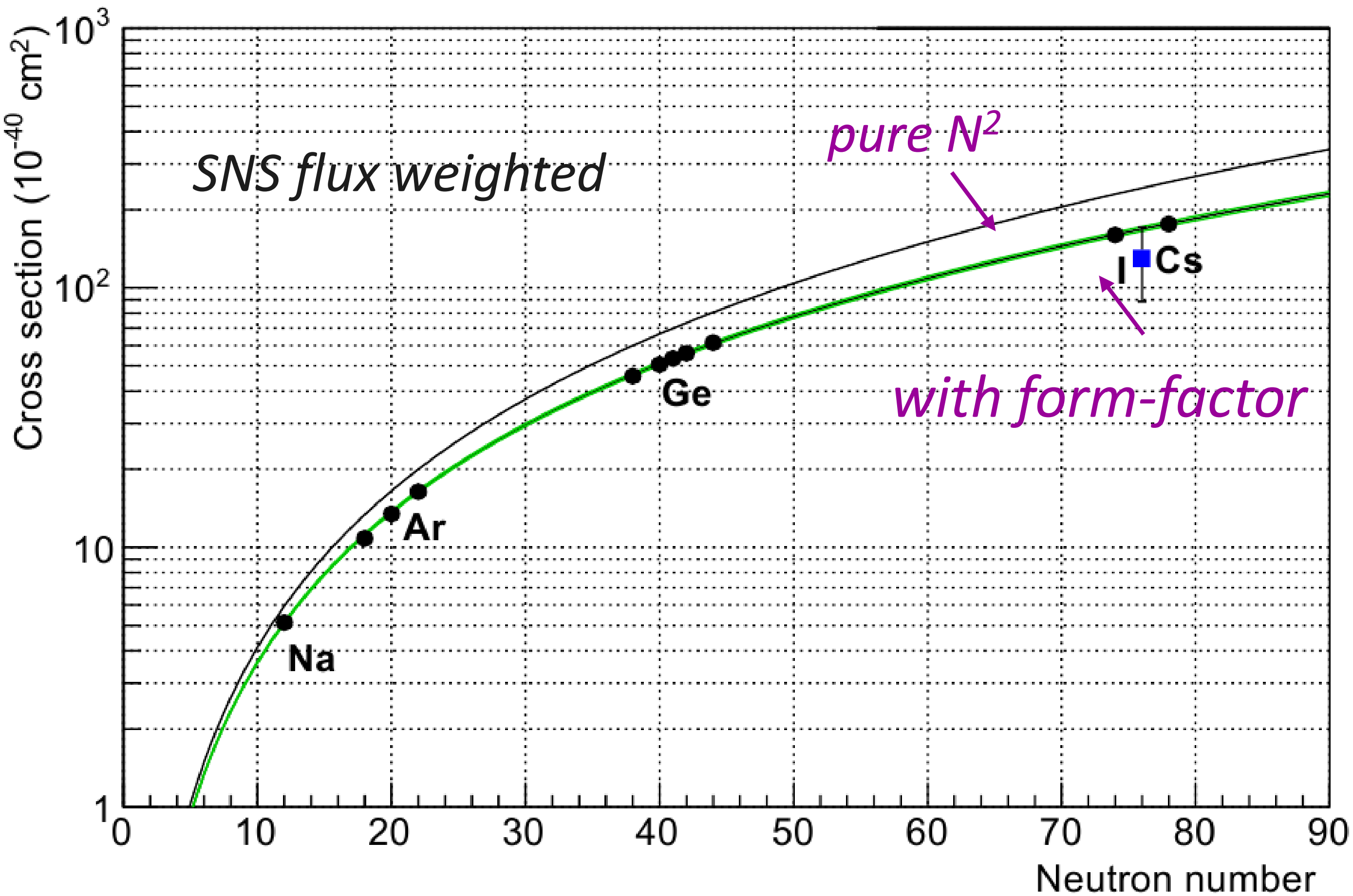
See talks by X. Huang and M. Cadeddu

Vector current neutron form-factor studies with CEvNS suggested in

Amanik P., McLaughlin G., Journal of Physics G (2009)

K. Patton et al., PRC 86 (2012)

May be less precise than e-nucleus PV experiments but will be available for larger set of nuclei + not model dependent as hadron-nucleus scattering



COHERENT results utilized in:

M. Caddedu et al., arXiv: 1710.02730

Xu-Run Huang, Lie-Wen Chen, arXiv: 1902.07625

D. Papoulias et al., arXiv:1903.03722

ν-quark non-standard interactions

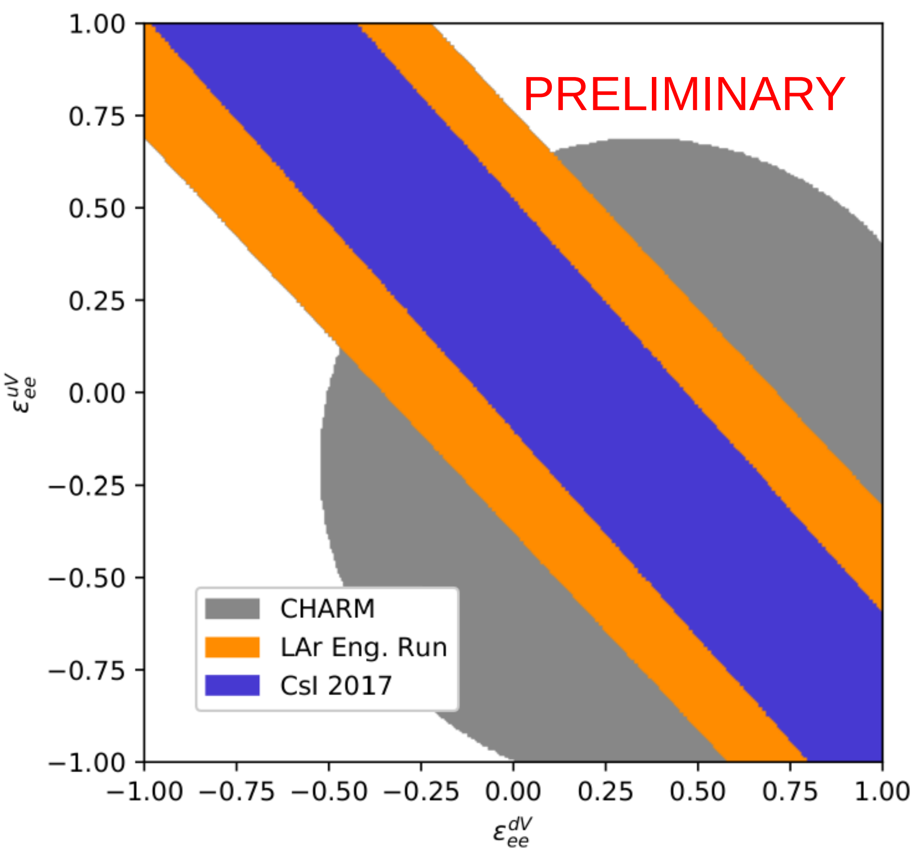
See talk by D. Marfatia

Various ν-quark NSI contributions may indicate themselves in a CEvNS rate

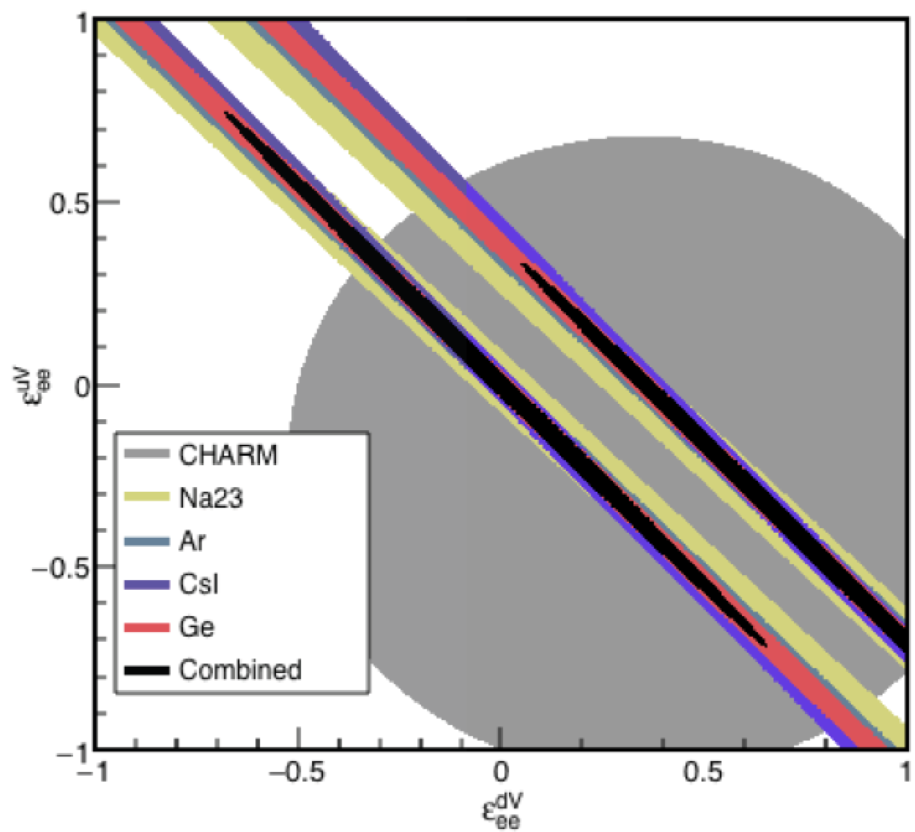
E.g. vector current-like: $(g_V^p + 2\epsilon_{ee}^{uV} + \epsilon_{ee}^{dV})\ Z + (g_V^n + \epsilon_{ee}^{uV} + 2\epsilon_{ee}^{dV})N$

SM couplings *NSI contributions*

Current status



Realistic goal

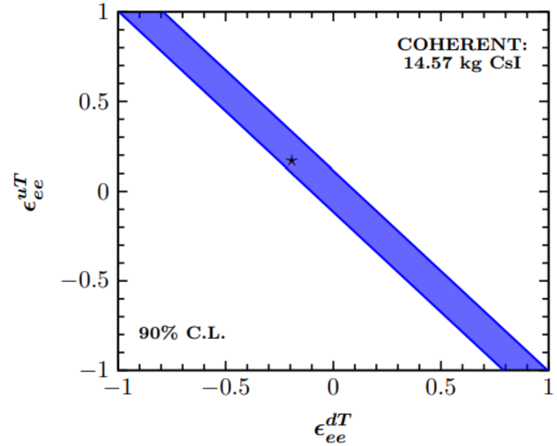


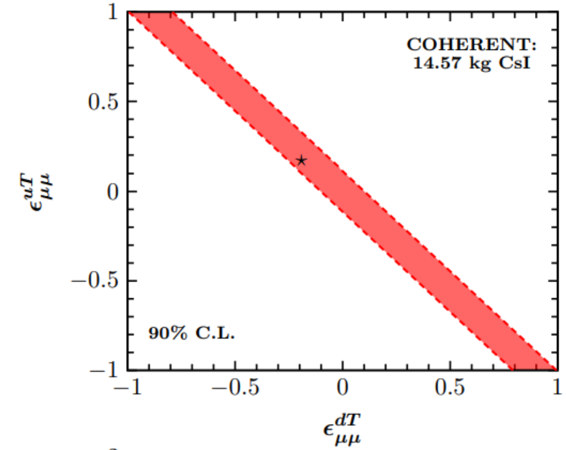
For details see: D. Akimov et al., Science v.357 (2017) + M. Heath PhD Thesis (IU, 2019) + arXiv:1803.09183

Impact of COHERENT data on ν-quark NSI discussion

Tensor current contributions

D. Papoulias and T. Kosmas, PRD 97 (2018)



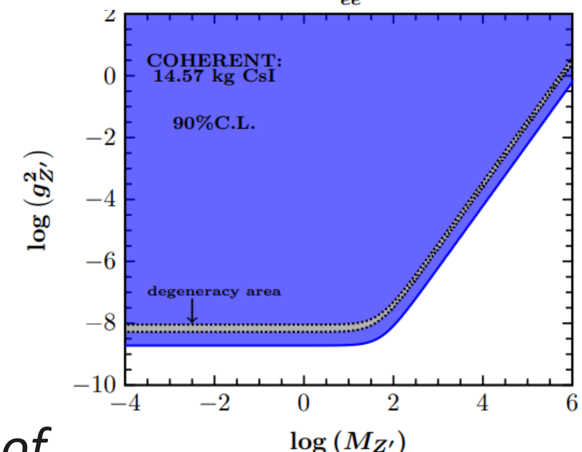


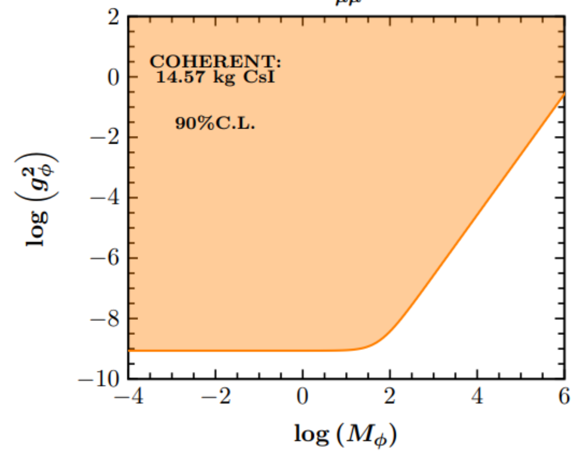
Light vector and scalar mediators

J.Liao, D. Marfatia., PLB 775 (2017)

D. Papoulias, T. Kosmas, PRD 97 (2018)

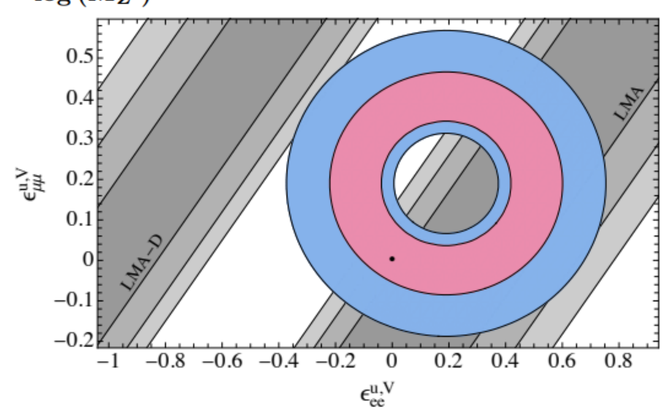
Y. Farzan et al., JHEP 66 (2018)





Effect of NSI on interpretation of oscillation data (LMA-D solution)

P.Coloma et al., PRD 96 (2017)

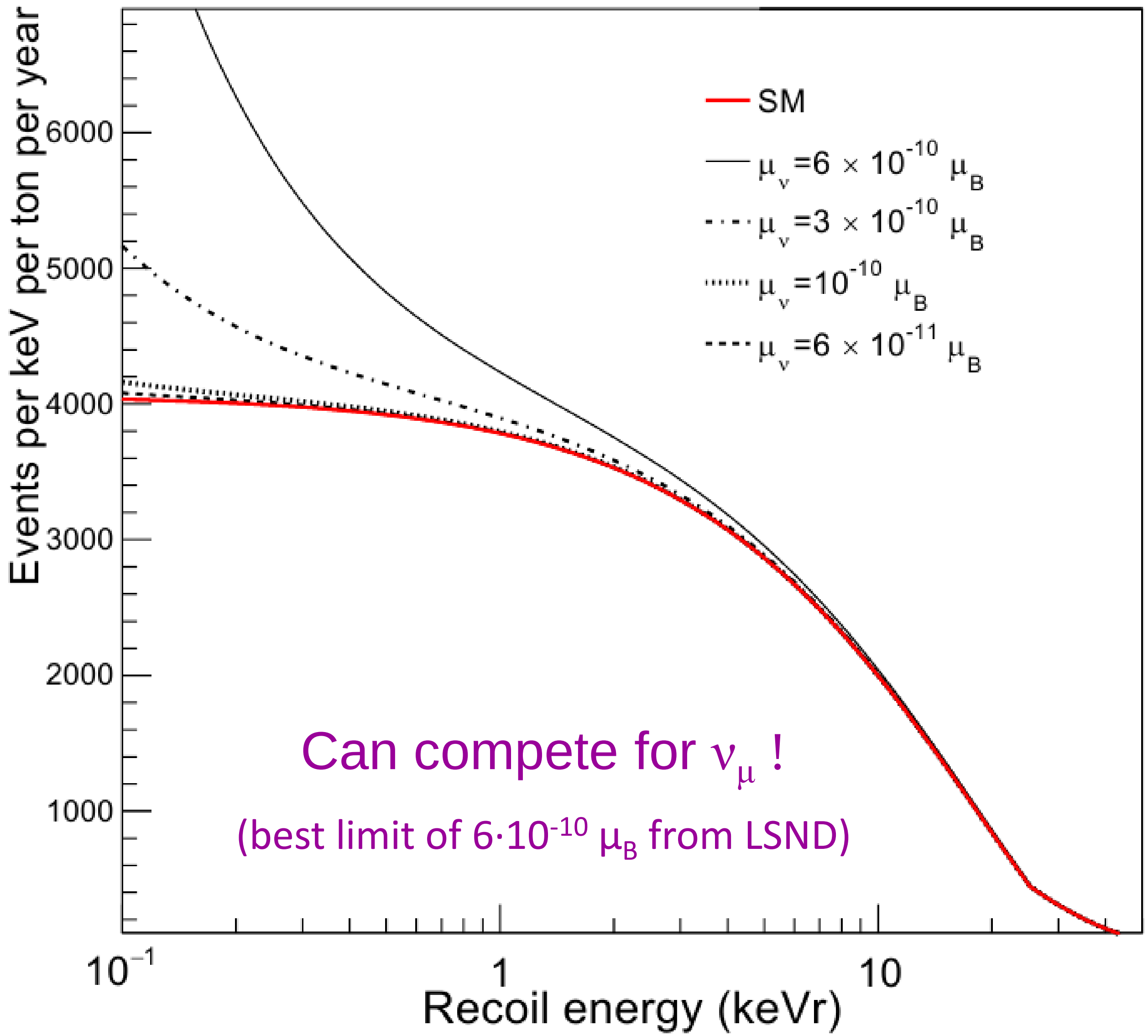


Majorana ν TMM

O. Miranda et al., arXiv:190503750 (2019)

Neutrino magnetic moment

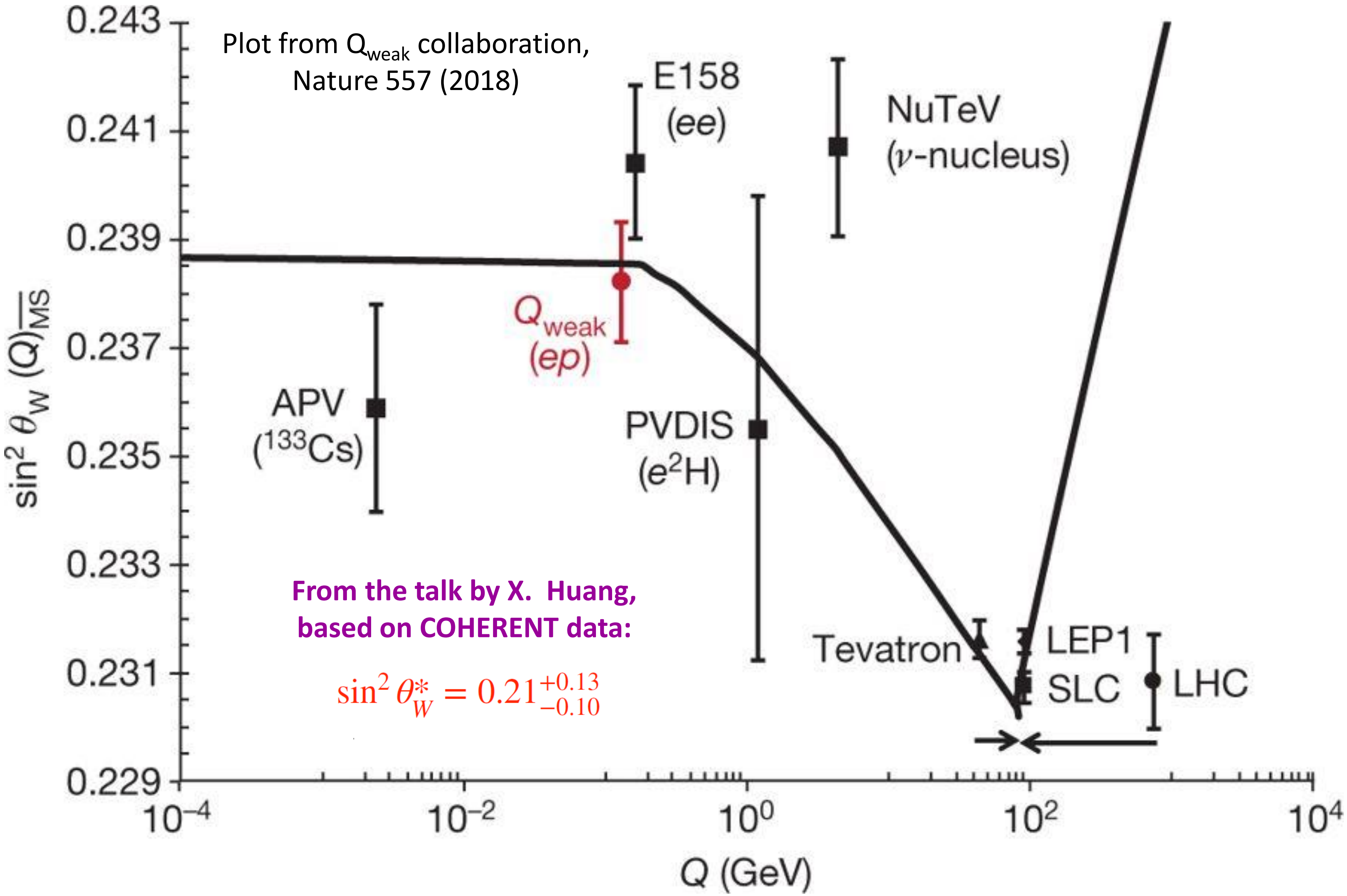
Possible with 15 kg of low threshold HPGe PPC, however can hardly be competitive with ν-e scattering results for ν_e (current limit ~$3\cdot10^{-11}\ \mu_B$)



Electroweak mixing angle

See talks by X. Huang and M. Cadeddu

New channel, but need sub-percent precision to compete with PV ES



Plot from Q_{weak} collaboration, Nature 557 (2018)

From the talk by X. Huang, based on COHERENT data:

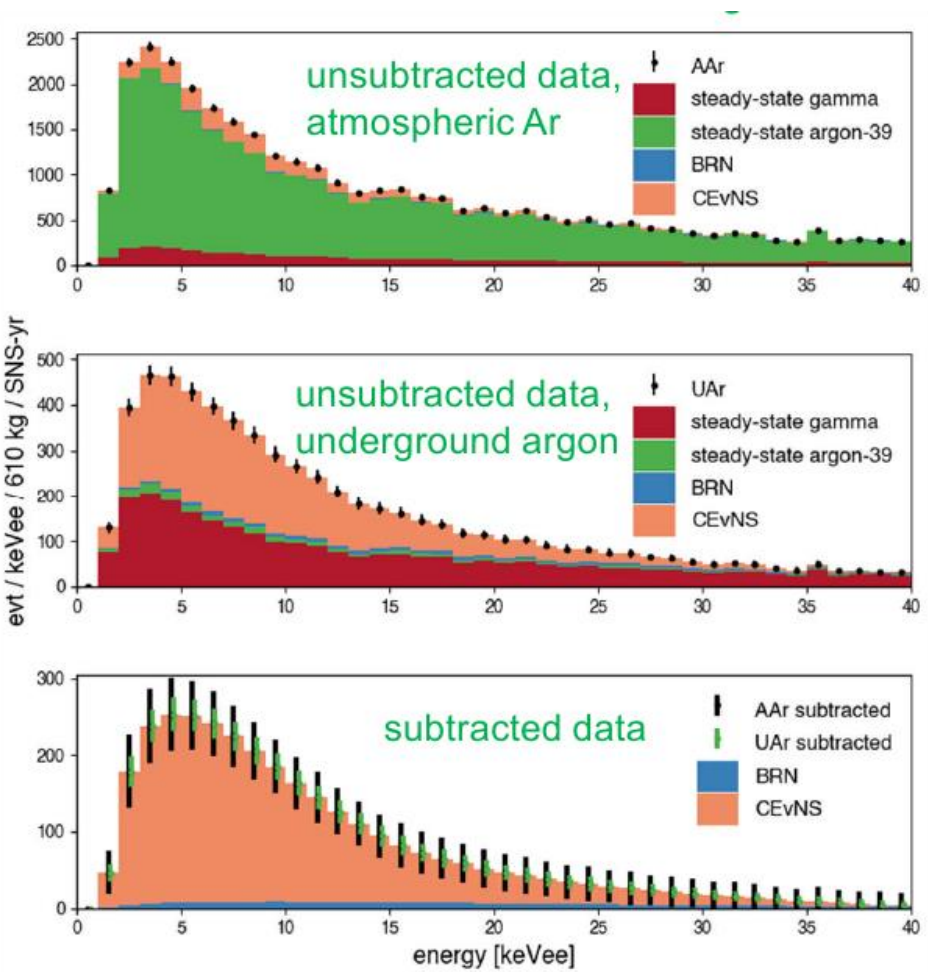
$$\sin^2 \theta_W^* = 0.21^{+0.13}_{-0.10}$$

COHERENT future

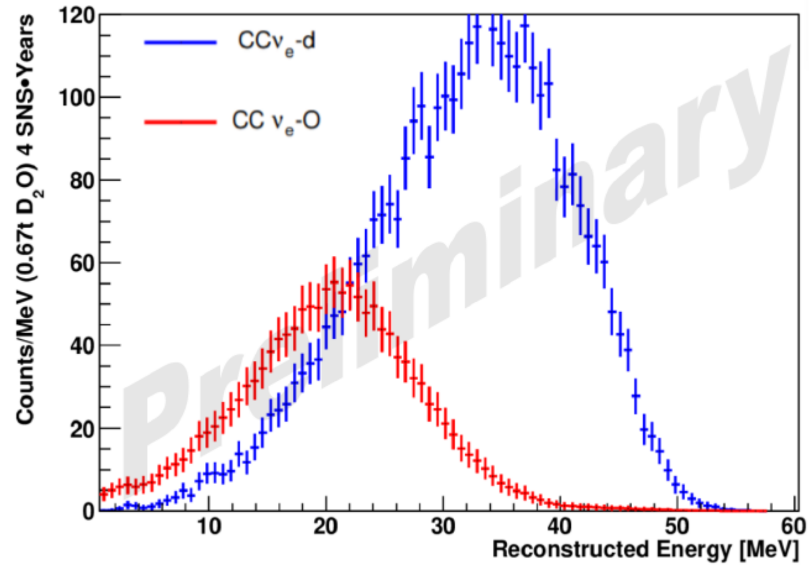
See talks by D. Rudik and A. Kumpan

LAr-750 (R&D, proposals pending): 750/610 kg (tot./fiducial), underground (low ^{39}Ar) argon

D20 (R&D, d_2O secured): 670 kg Cherenkov detector to reduce flux unc-ty



~3000 CEvNS events/year



now: 10% ν flux uncertainty

↓

4 years run time to get few % statistical precision

CC and NC inelastic ν interactions

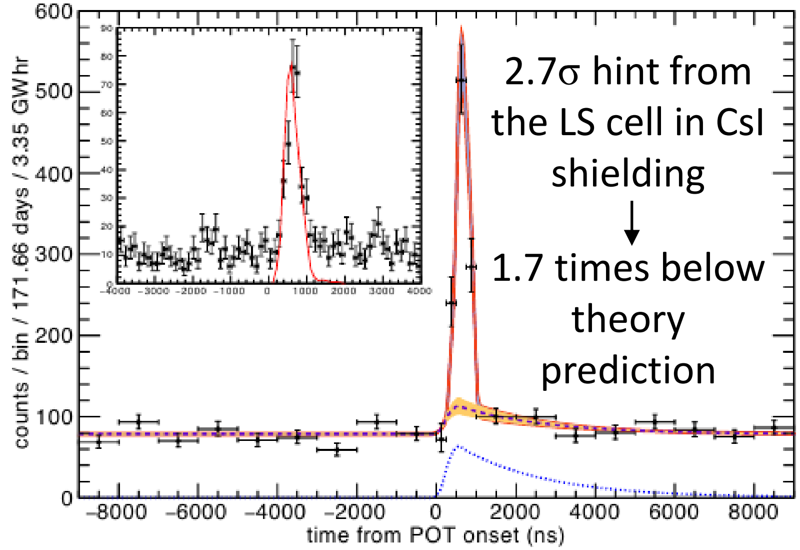
Nubes:

$$\nu_e + {}^{208}Pb \rightarrow e^- + {}^{208}Bi,$$
$$\nu + {}^{208}Pb \rightarrow \nu + {}^{208*}Pb$$

+ decay of a nucleus with neutrons in the final state

…and reactions of the same kind for Fe, Cu

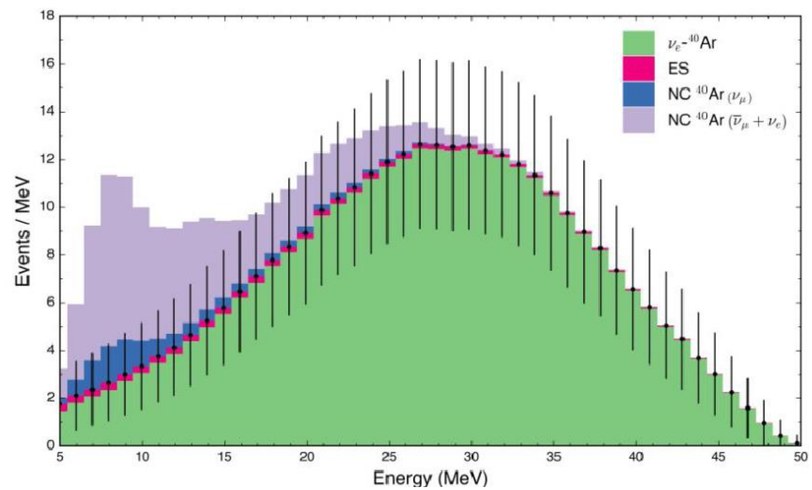
Interesting for HALO and as backg. for CEvNS



LAr-750: $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K$

~440 CC/NC inelastic events/year expected

Interesting for Duve (supernova signature)



NaI[Tl]: $\nu_e + {}^{127}I \rightarrow e^- + {}^{127}Xe$ *- compare to LAMPF result*

^{127}I	^{127}I$(\nu_e, e^-)^{127}$Xe	Stopped π/μ	LSND	284 ± 91(stat) ± 25(sys)	210-310 [Quasi-particle] (Engel *et al.*, 1994)

Accelerator produced Dark Matter at SNS

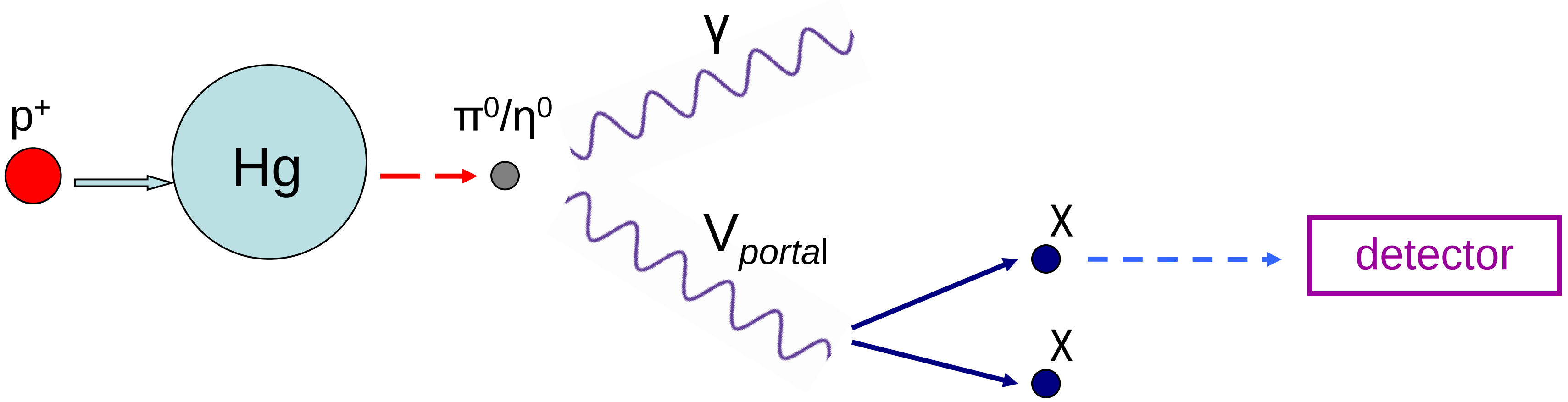
Vector portal: mixing of the vector mediator with photons in π^0/η^0 decays

P. deNiverville et al., PRD 95 (2017)

B. Batell et al., PRD 90 (2014)

Leptophobic portal: mediator coupling only to baryons

+ decay into "DM"-like χ



χ arrives to the detector with prompt ν and beam-related neutrons

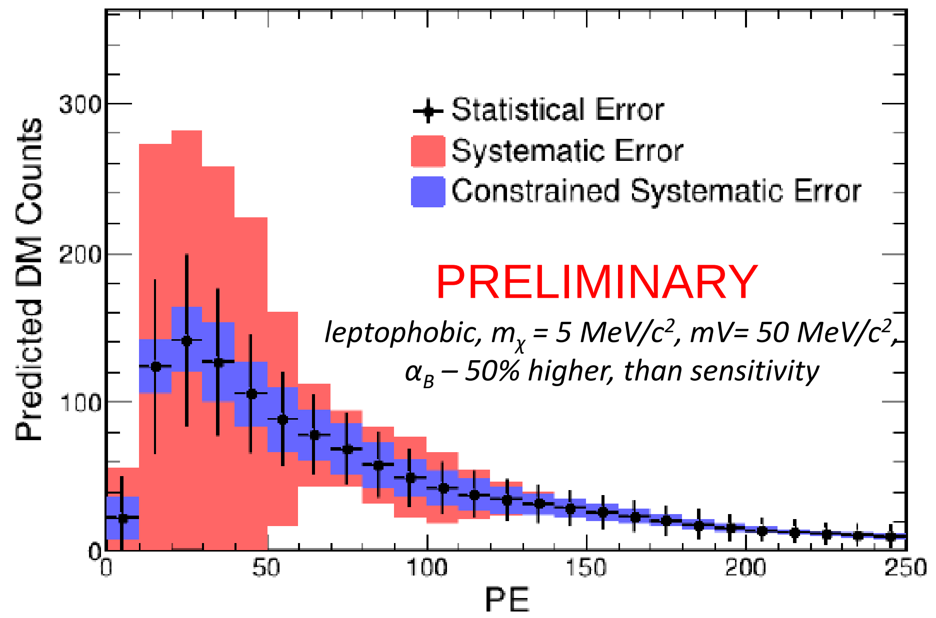
may be constrained by "delayed" ν CEvNS

constrained from the dedicated measurements

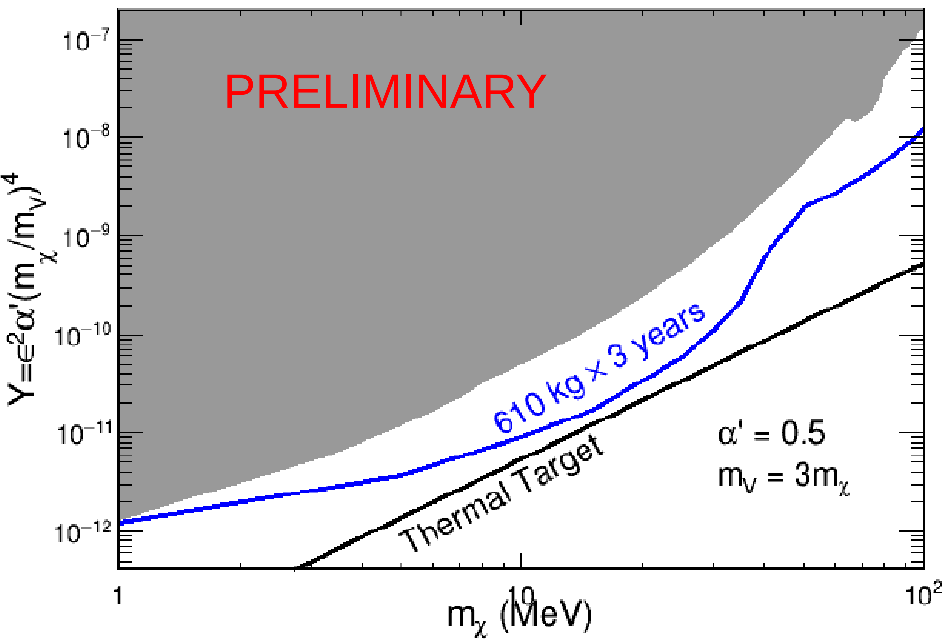
A "DM" particle interact with the target [detector nuclei] coherently → σ enhancement!

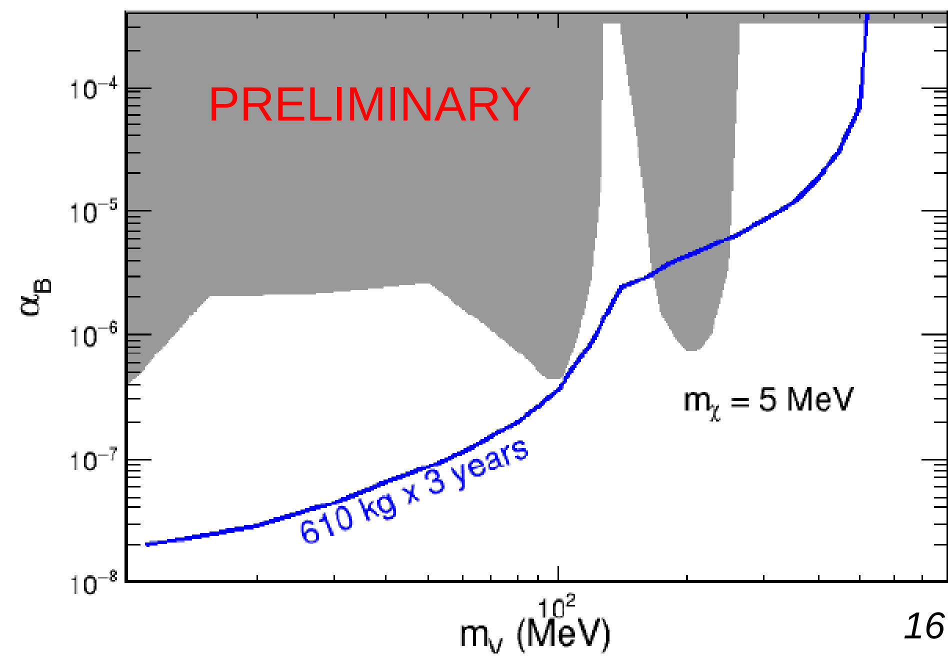
Accelerator produced Dark Matter at SNS

LAr-750 could put better limits on the parameter space of these models [1-100 MeV m_χ]

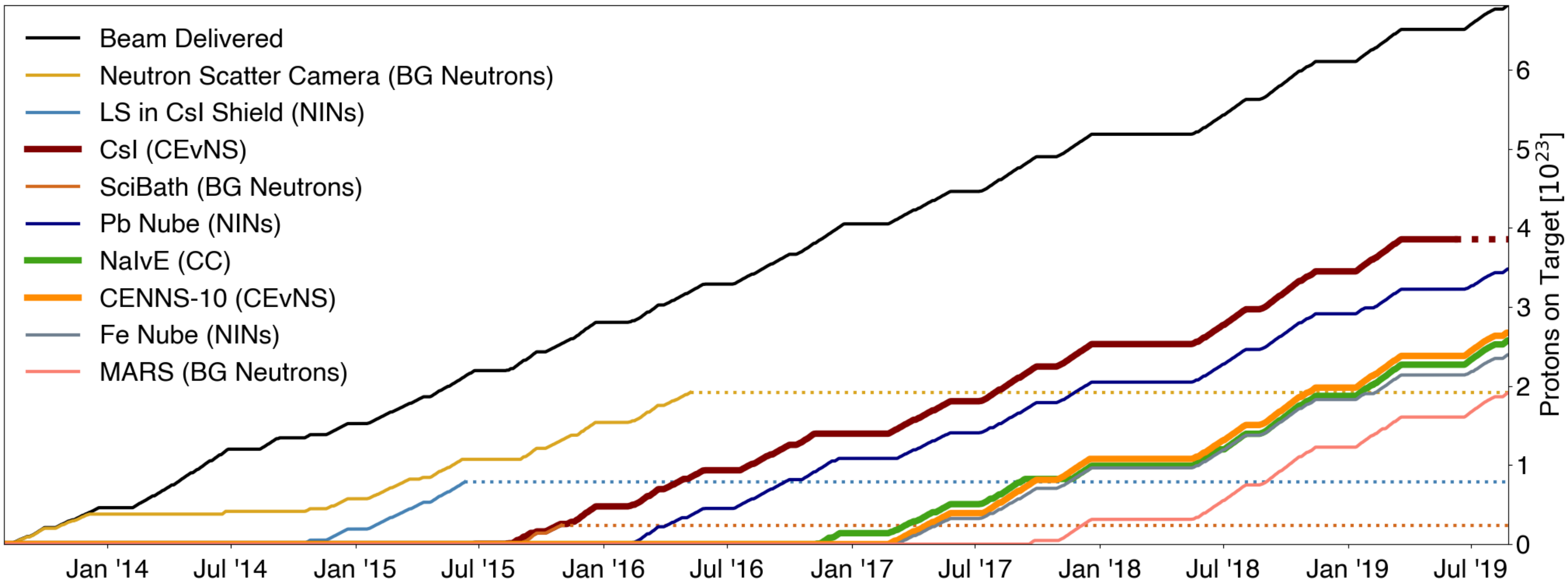


Plots by D. Pershey, pub. in draft





Near-term future



- *CsI[Na] has 2x statistics more than by the time of the first observation*

  ongoing analysis and discussions regarding quenching factor values, please use older values till the new QF publication by collaboration

- *LAr "box" is about to be opened, SM predicts ~130 events for this data set*

Summary

Studying CEvNS:

- *the first result has impact on nuclear physics and ν-quark NSI*
- *multiple detectors continue data taking → new isotopes, stricter limits*

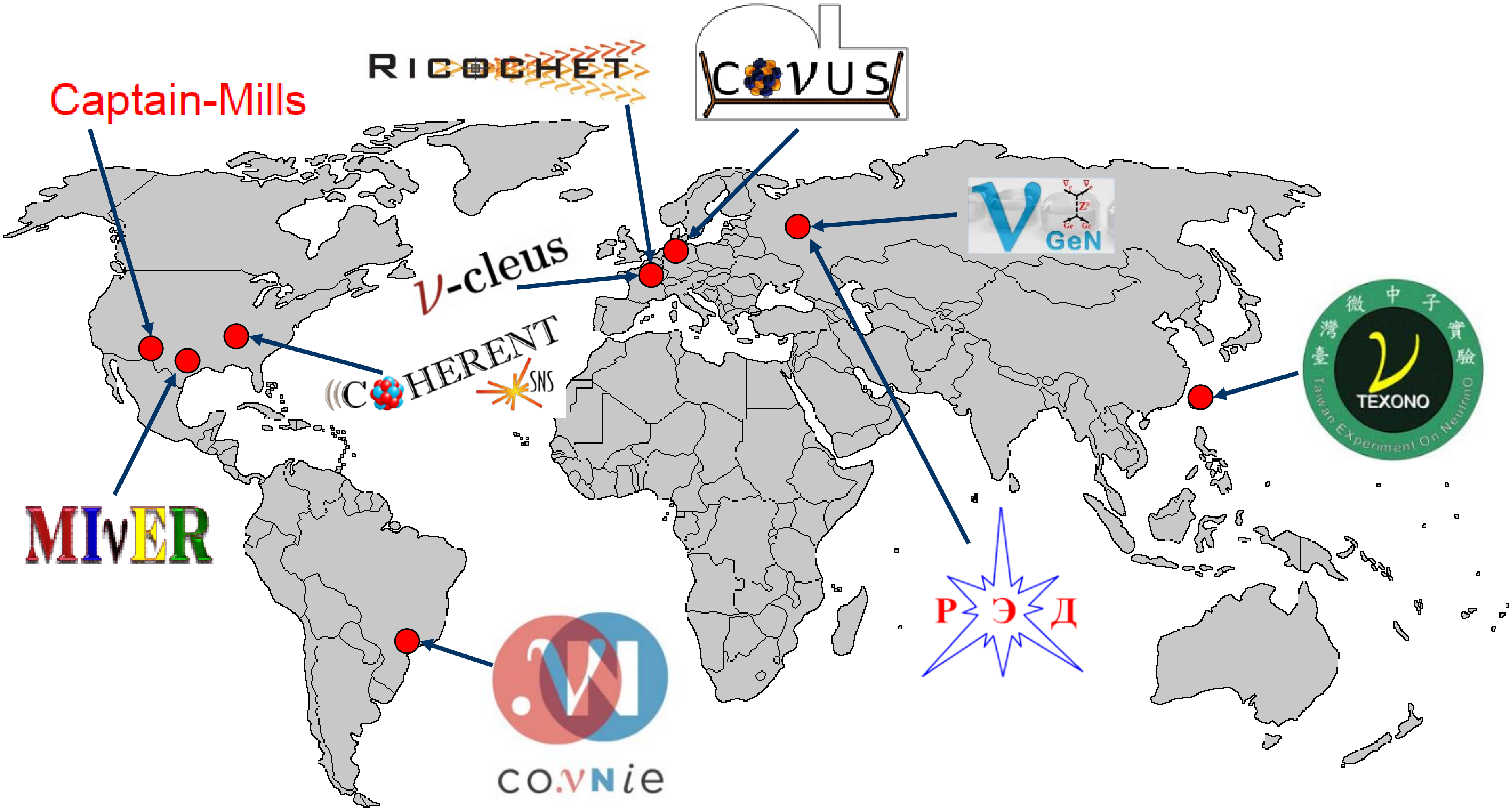
Working on systematics:

- *ongoing analysis of quenching factor data for the target elements*
- *R&D of D_2O to reduce ν flux uncertainty*

Making the most of opportunities

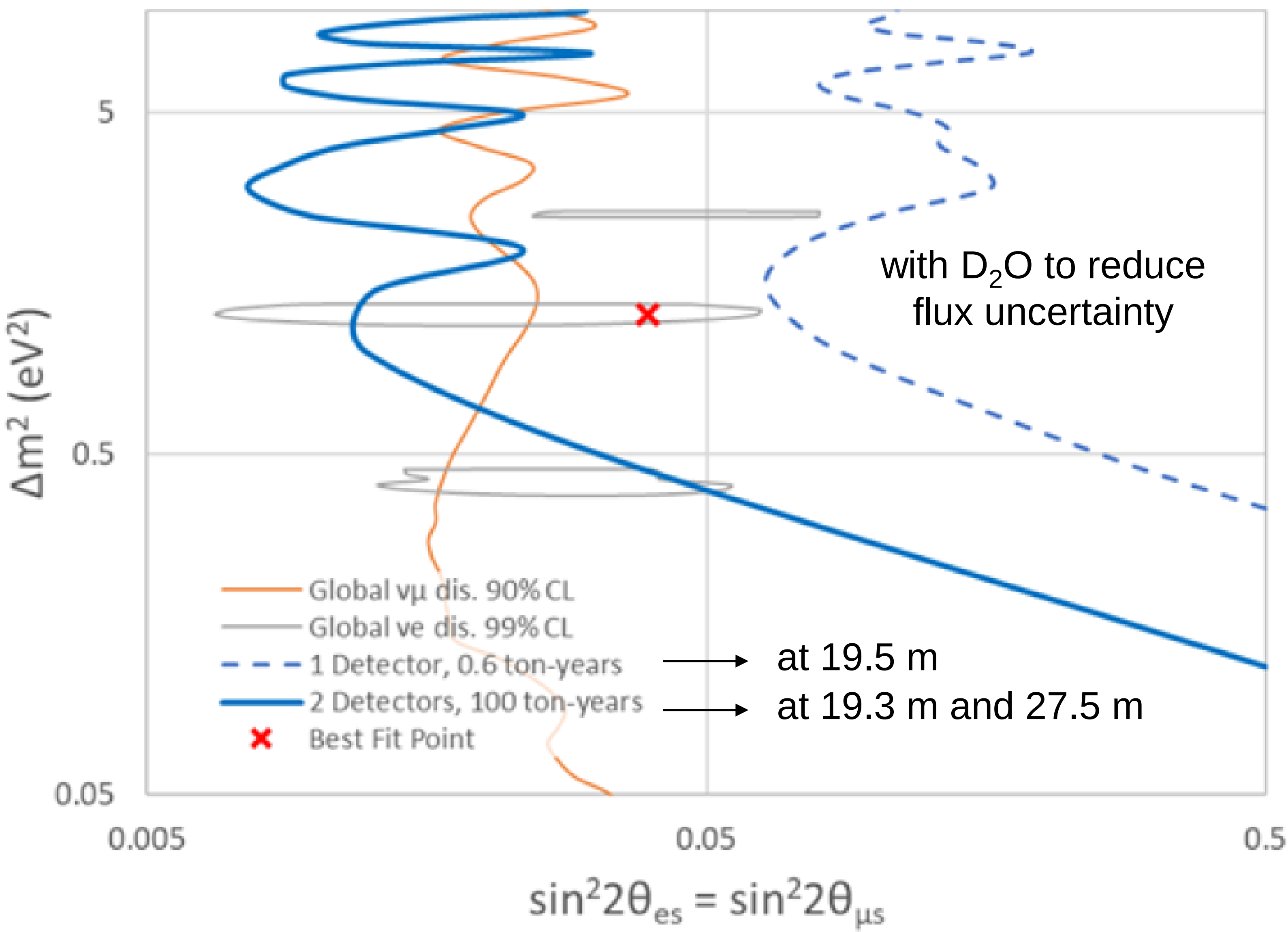
- *looking for CC/NC interactions*
- *testing the sensitivity to accelerator produced DM*

CEvNS search activities around the world



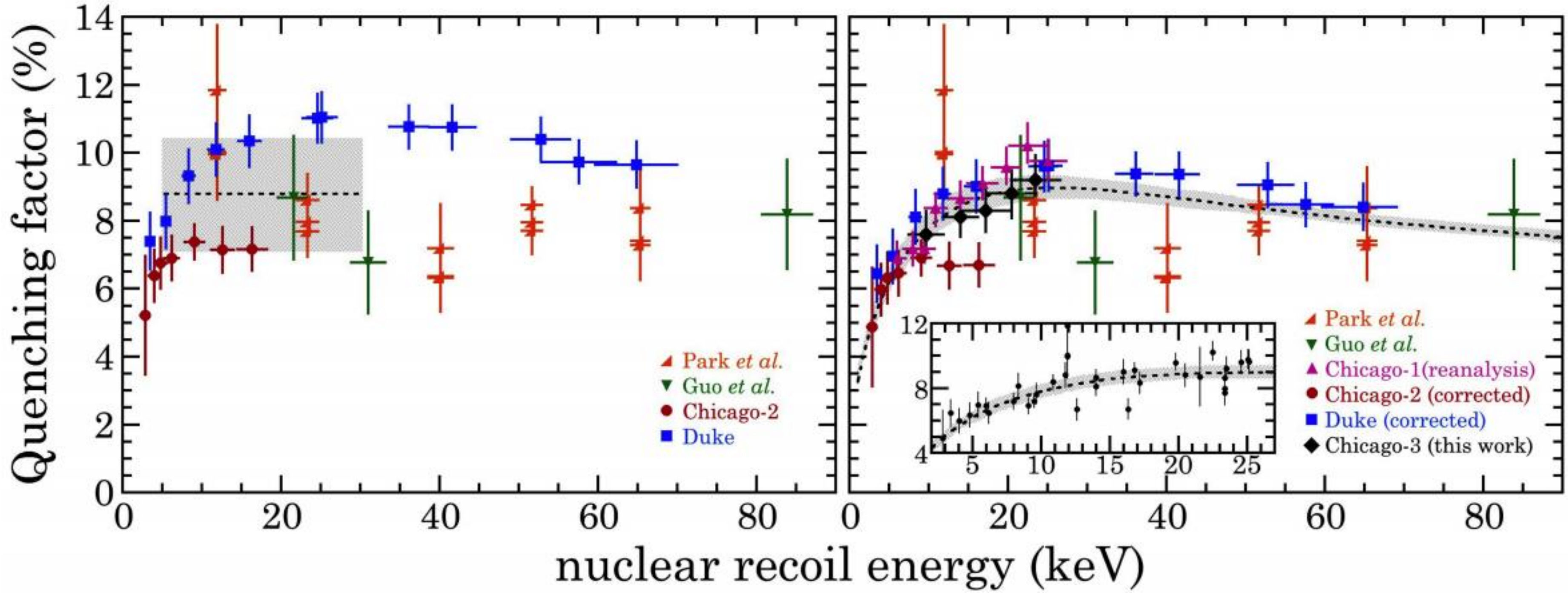
Thank you for your attention!

Backup-1: Sterile neutrinos



Backup-2: QF

J. Collar et al., PRD 100 (2019)



Ongoing analysis and discussions regarding QF, please use older values [D. Akimov et al., Science v.357, 2017] till the new QF publication by collaboration

Backup-3: prompt neutron backgrounds

Measurement of total flux and energy distribution of neutrons:

- Scibath
- Sandia Camera

→ The spectrum is power-law in 1-100 MeV energy region + estimate on the flux: $1.5 \cdot 10^{-7}$ $cm^{-2}s^{-1}$

Neutron flux measurement within the shielding:

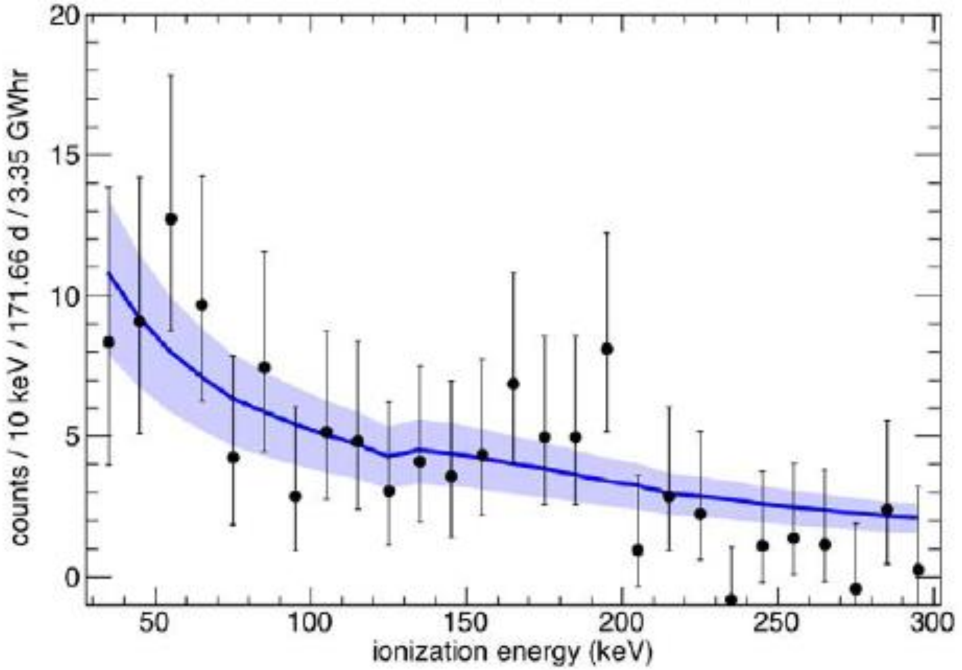
- LS EJ-301 with PSD capability

 - 3 liters of LS

 - taking data for half a year

Fit procedure:

1. Power-law spectrum on the input
2. Propagation through the shielding
3. Fit of the E_{dep} distribution



Result: $1.09 \cdot 10^{-7}$ $cm^{-2}s^{-1}$, power law exponent $\alpha = -1.6$