Neutrino Measurements and Their Connection to Electron Beam Measurements From Facilities Like Jefferson Lab

Kate Scholberg,

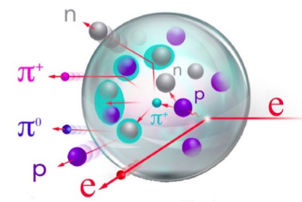
Duke University

JLab Hall A Collaboration Meeting
January 22, 2026

craiyon.ai's concept of this talk title

Two main areas I will discuss:

Area 1: electron-nucleus scattering to **inform understanding of neutrino-nucleus interactions**, primarily for ν oscillation physics (~GeV scale)



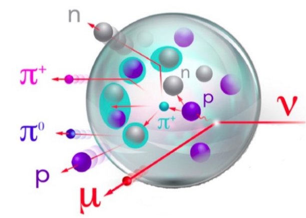
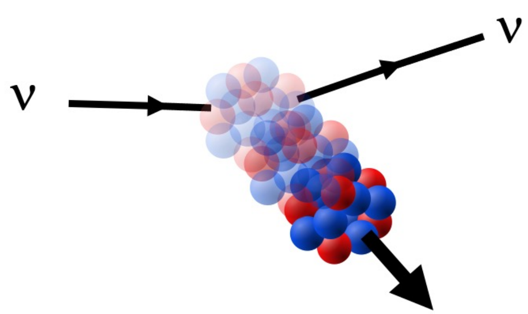


Image credit: J. Vidal



Area 2: neutrino-nucleus elastic scattering for **electroweak physics, BSM and nuclear structure**, complementary to PVES (~10s of MeV scale)

But first... **big picture of neutrino physics**

Science Drivers in Neutrino Physics

Three-flavor paradigm: filling in the remaining pieces

Hunting down **anomalies**

Searching for **BSM** physics

Understanding **astrophysics** and **cosmology**

What do we know about neutrinos?

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

← neutral partners to the charged leptons

- **They have mass and mix**

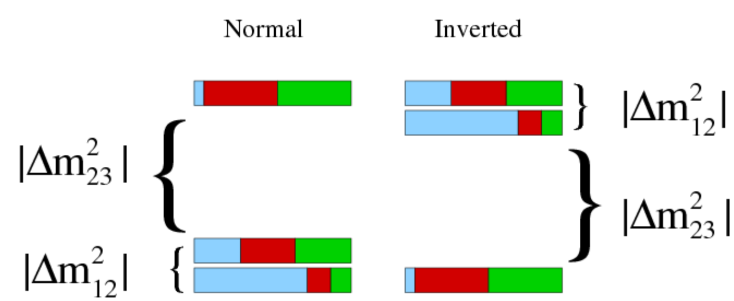
  3 flavor states, 3 mass states describe flavor change

$$|\nu_f\rangle = \sum_{i=1}^{N} U^*_{fi} |\nu_i\rangle$$

- **The mass is tiny...** from lab experiments, $\Sigma m < 2.4$ eV

3 masses	m_1, m_2, m_3 (2 mass differences + absolute scale)
3 mixing angles	$\theta_{23}, \theta_{12}, \theta_{13}$
1 CP phase	δ
(2 Majorana phases)	α_1, α_2

} signs of the mass differences matter



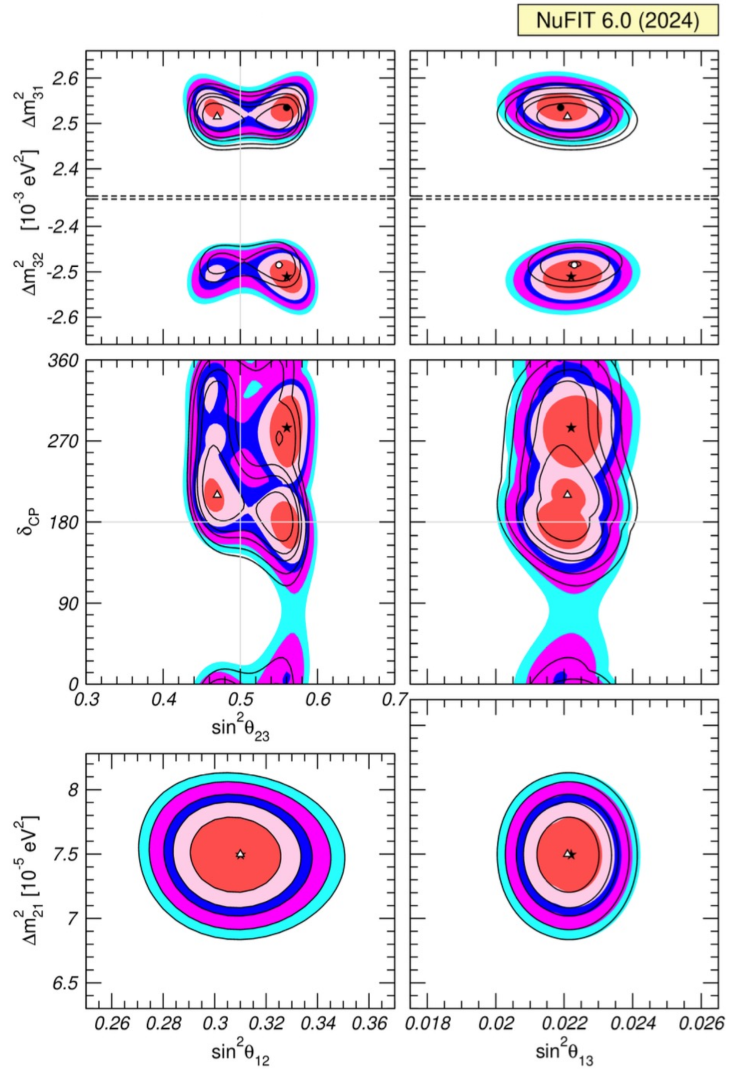
The three-flavor picture fits the data well

Global three-flavor fits to all data

IC24 with SK atmospheric data	Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 6.1$)	
	bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	$0.308^{+0.012}_{-0.011}$	$0.275 \to 0.345$	$0.308^{+0.012}_{-0.011}$	$0.275 \to 0.345$
$\theta_{12}/^\circ$	$33.68^{+0.73}_{-0.70}$	$31.63 \to 35.95$	$33.68^{+0.73}_{-0.70}$	$31.63 \to 35.95$
$\sin^2\theta_{23}$	$0.470^{+0.017}_{-0.013}$	$0.435 \to 0.585$	$0.550^{+0.012}_{-0.015}$	$0.440 \to 0.584$
$\theta_{23}/^\circ$	$43.3^{+1.0}_{-0.8}$	$41.3 \to 49.9$	$47.9^{+0.7}_{-0.9}$	$41.5 \to 49.8$
$\sin^2\theta_{13}$	$0.02215^{+0.00056}_{-0.00058}$	$0.02030 \to 0.02388$	$0.02231^{+0.00056}_{-0.00056}$	$0.02060 \to 0.02409$
$\theta_{13}/^\circ$	$8.56^{+0.11}_{-0.11}$	$8.19 \to 8.89$	$8.59^{+0.11}_{-0.11}$	$8.25 \to 8.93$
$\delta_{CP}/^\circ$	212^{+26}_{-41}	$124 \to 364$	274^{+22}_{-25}	$201 \to 335$
$\frac{\Delta m^2_{21}}{10^{-5}\ \text{eV}^2}$	$7.49^{+0.19}_{-0.19}$	$6.92 \to 8.05$	$7.49^{+0.19}_{-0.19}$	$6.92 \to 8.05$
$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \text{eV}^2}$	$+2.513^{+0.021}_{-0.019}$	$+2.451 \to +2.578$	$-2.484^{+0.020}_{-0.020}$	$-2.547 \to -2.421$

$$\Delta m^2_{3\ell} \equiv \Delta m^2_{31} > 0 \text{ for NO and } \Delta m^2_{3\ell} \equiv \Delta m^2_{32} < 0 \text{ for IO.}$$

Esteban et al., JHEP 12 (2024) 216, 2410.05380 [hep-ph]



Extensive flavor-change data from the Sun, reactors, atmospheric neutrinos & beams*

*Some experimental anomalies...hints of new states or interactions in the data ...?

What do we *not* know about the 3-flavor paradigm?

IC24 with SK atmospheric data

	Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 6.1$)	
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$\Delta m^2_{3\ell} \equiv \Delta m^2_{31} > 0$ for NO and $\Delta m^2_{3\ell} \equiv \Delta m^2_{32} < 0$ for IO.

Is θ_{23} non-negligibly greater or smaller than 45 deg?

poor knowledge

sign of Δm^2 unknown (ordering of masses)

These questions can be answered by future osc expts

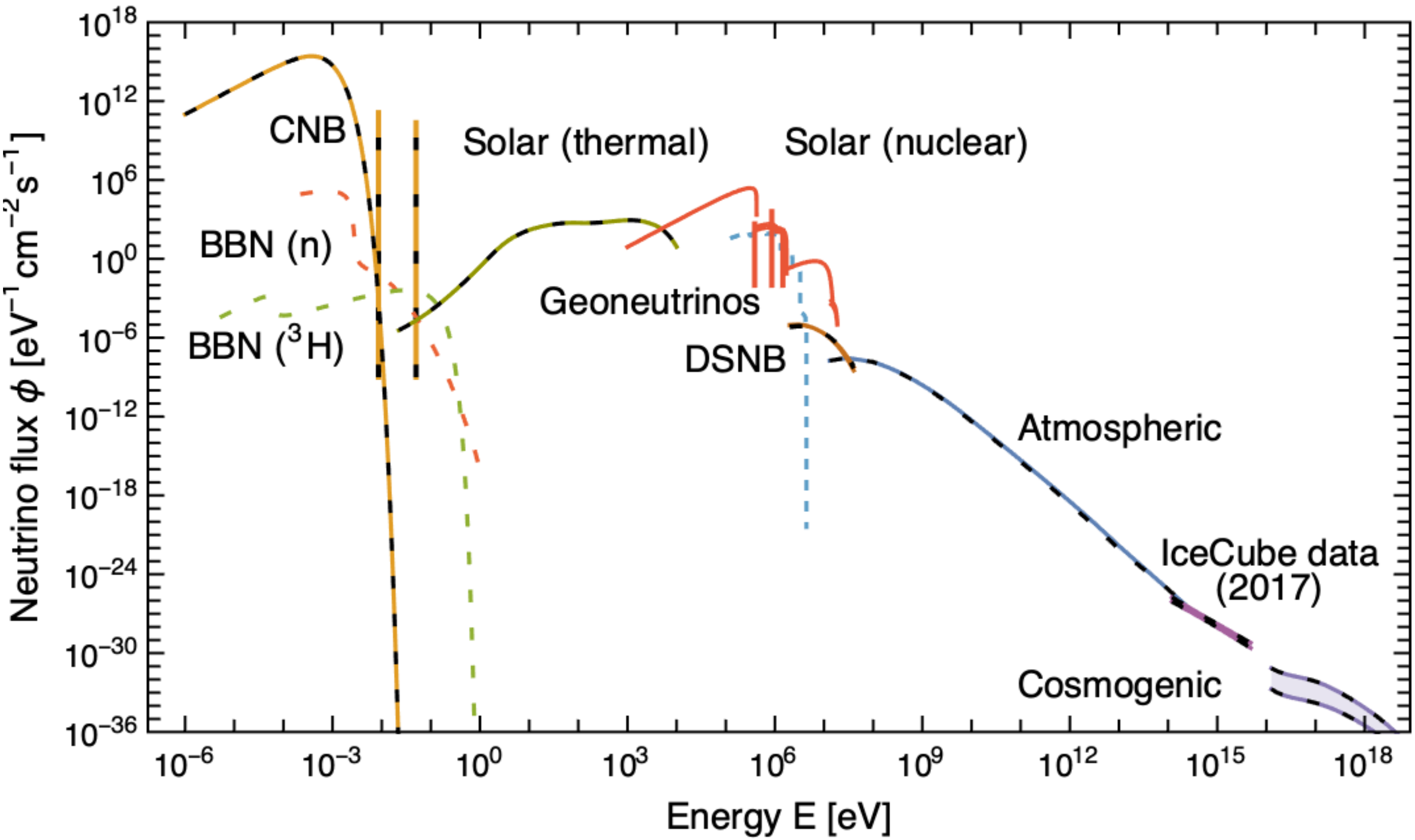
(long-baseline beams, reactors, astrophysical sources)

<u>Other unknowns</u>: (cannot answer w/osc expts)

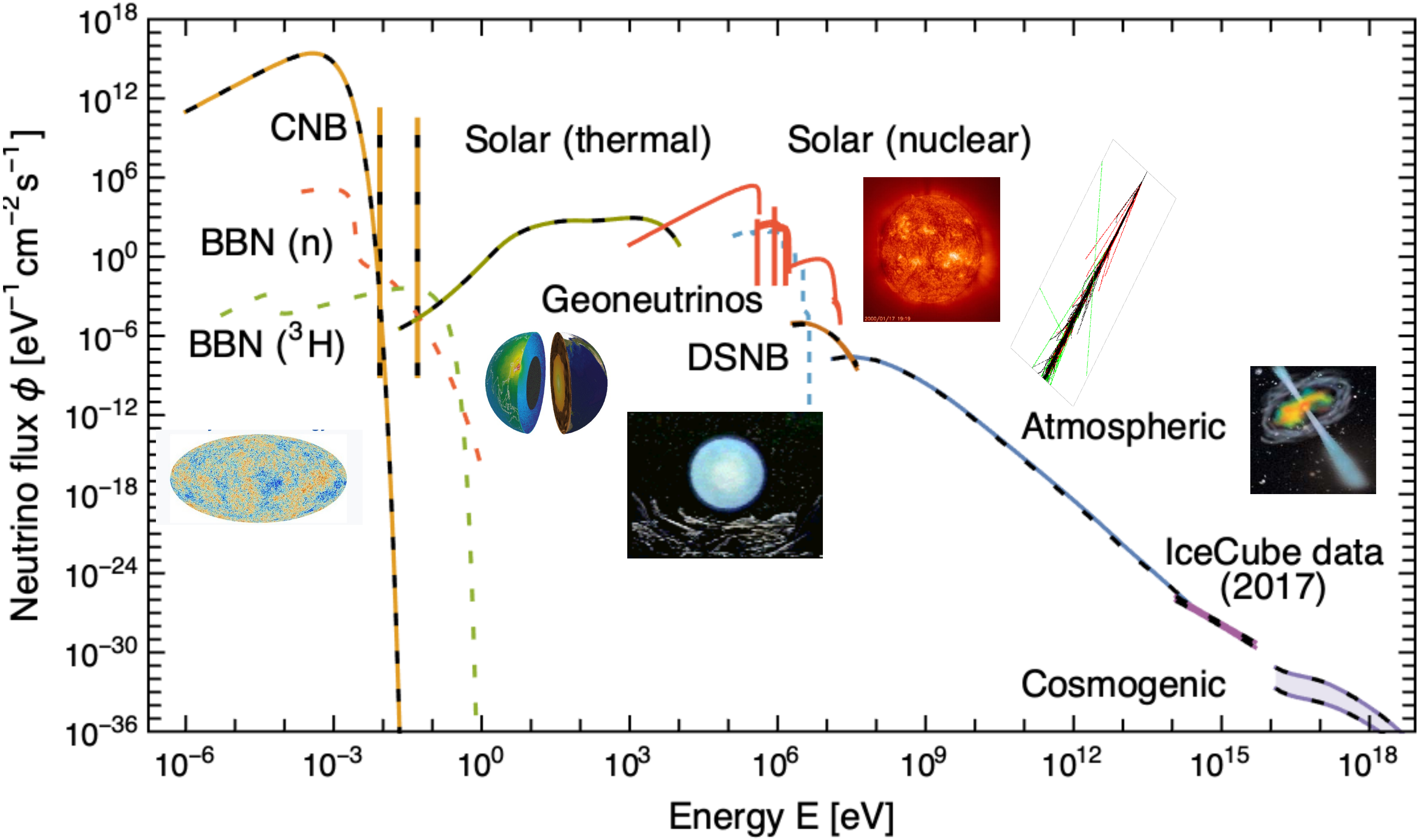
- absolute mass scale (kinematic endpoints & cosmology)
- Majorana vs Dirac nature ($0\nu\beta\beta$)

Neutrinos pervade the Universe....

Grand Unified Neutrino Spectrum at Earth
Edoardo Vitagliano, Irene Tamborra, Georg Raffelt. Oct 25, 2019. 54 pp.
MPP-2019-205
e-Print: arXiv:1910.11878 [astro-ph.HE] | PDF

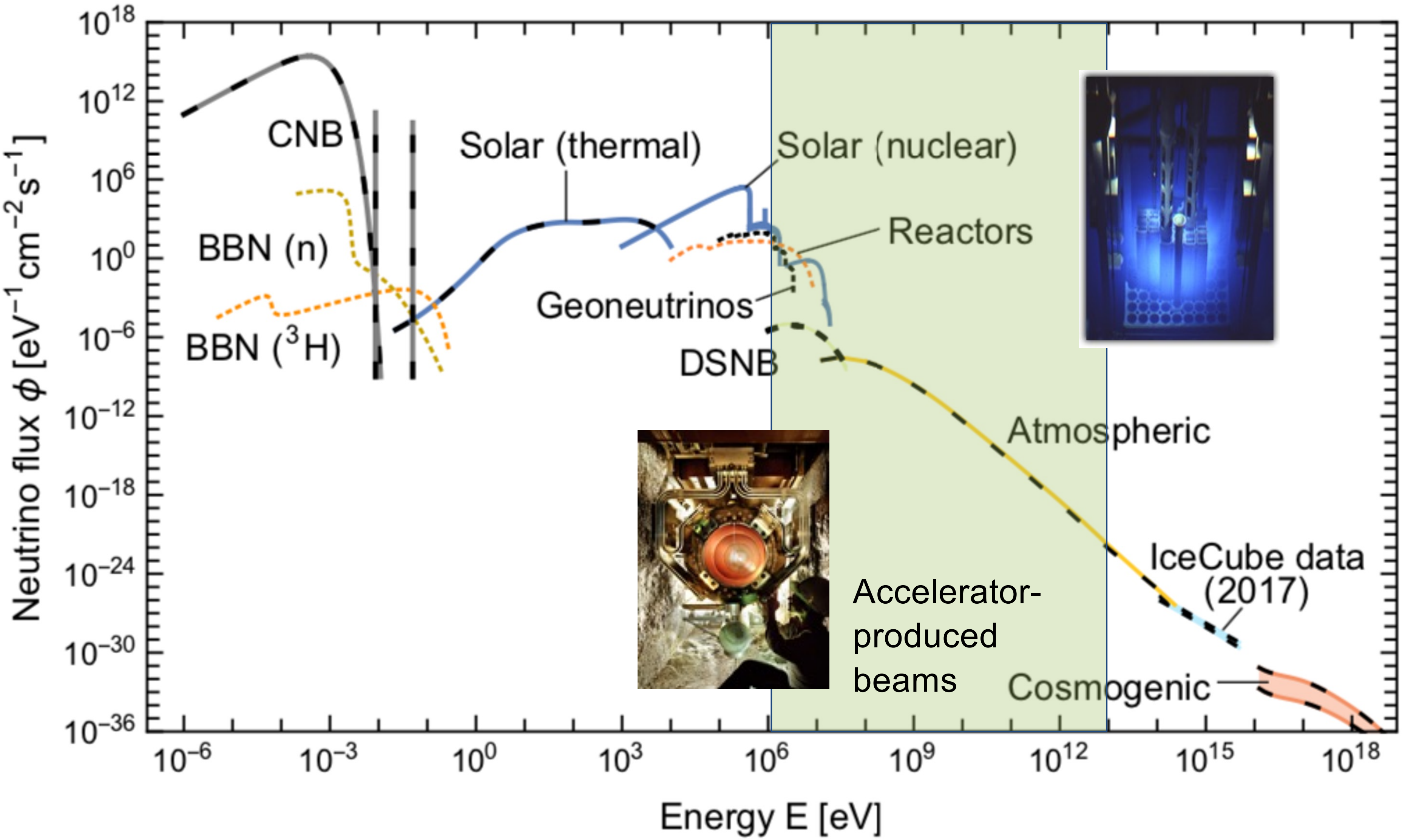


Neutrinos from natural sources



- Information from deep inside astronomical objects
- Neutrino physics using well understood fluxes

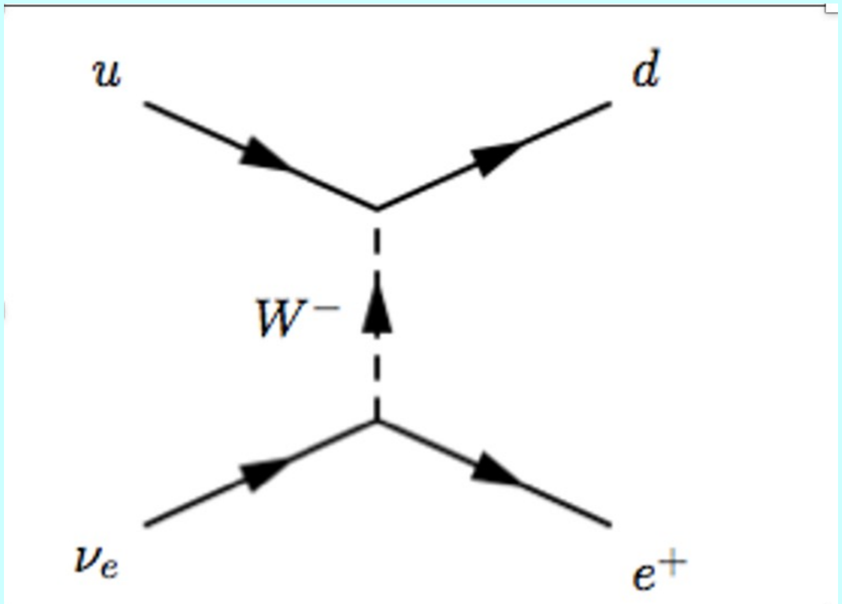
Neutrinos from artificial sources



To do physics, **need to understand neutrino interactions w/ matter** over many orders of magnitude

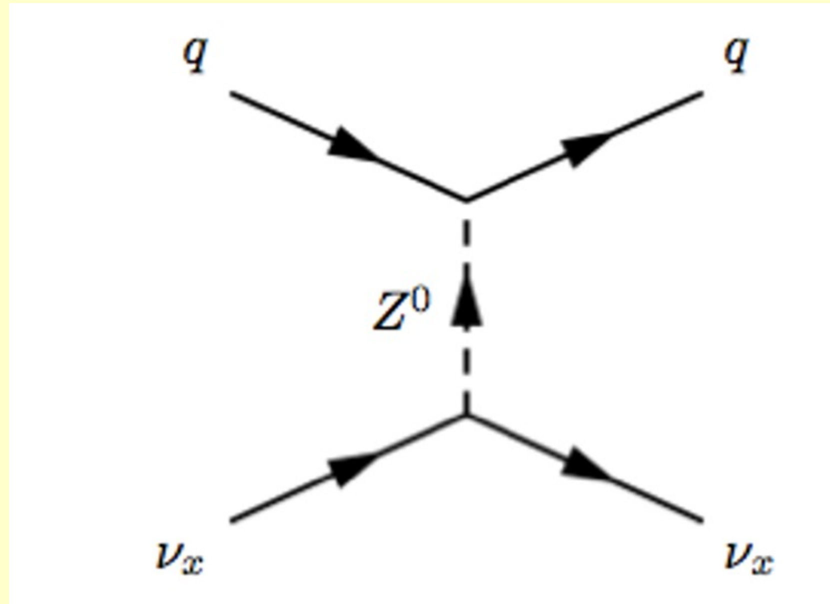
Neutrino Interactions with matter in the SM

Charged Current (CC)



Cares about ν flavor
→ lepton in final state
has same flavor as ν
(must be kinematically allowed)

Neutral Current (NC)



flavor-blind

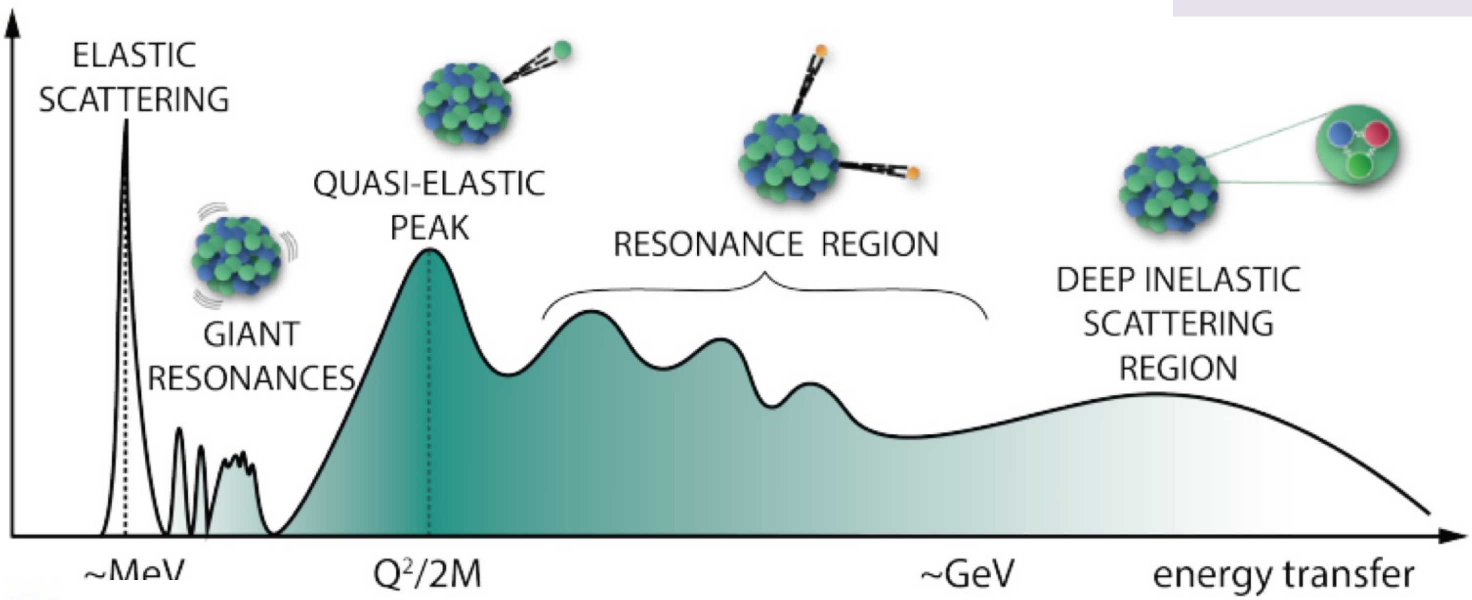
Neutrino Interactions with Nuclei

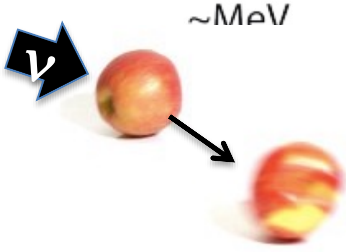
Coherent elastic neutrino-nucleus scattering

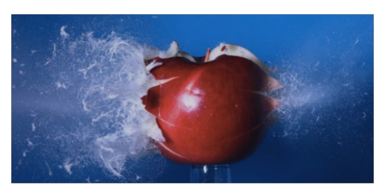
Interactions with nuclei, minimally disruptive of the nucleus

Interactions with nucleons inside nuclei, often disruptive, hadroproduction

Deep Inelastic Scattering

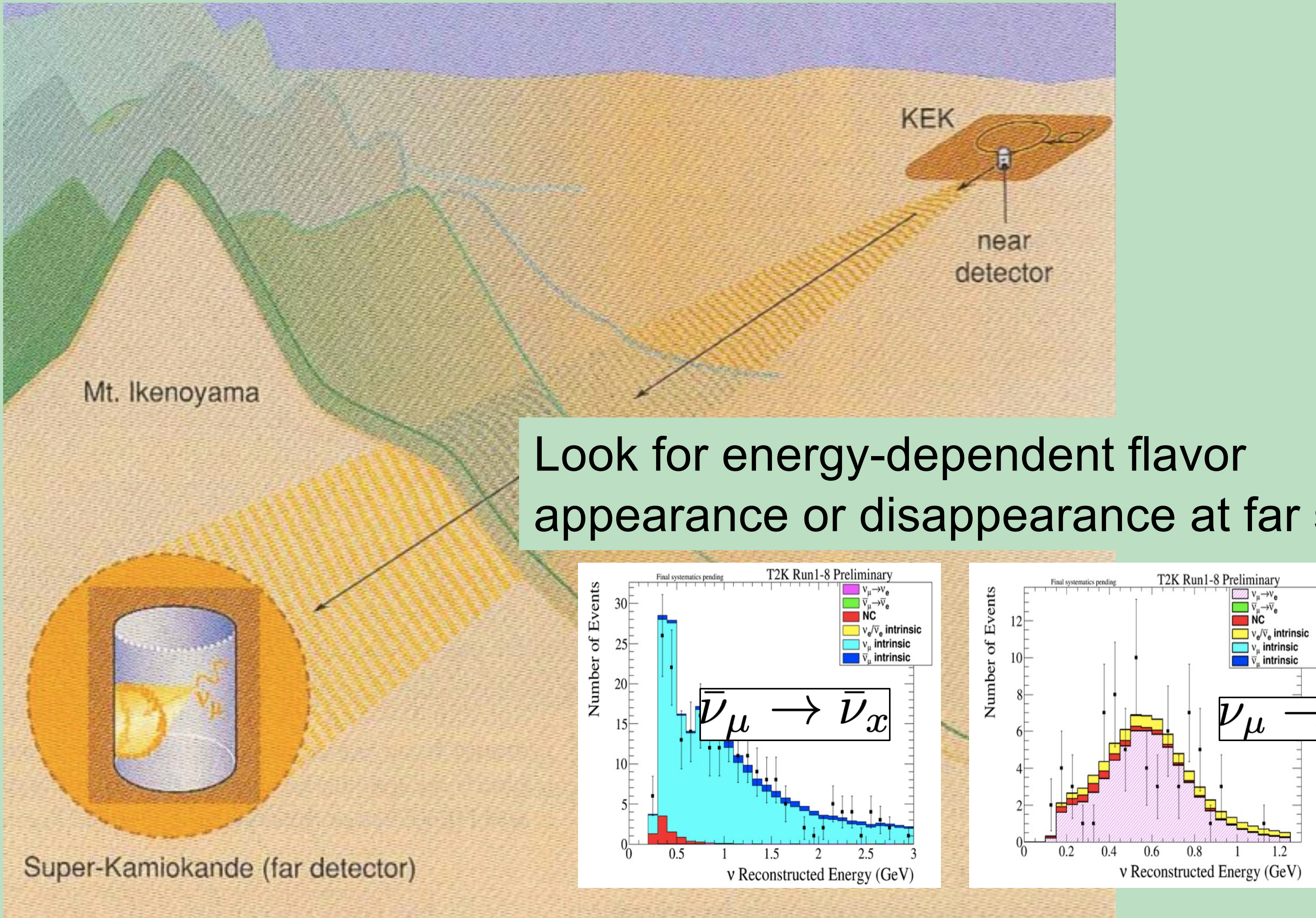






L.Munteanu energy transfer plot

The outstanding neutrino oscillation questions can be answered with ~few GeV neutrinos over long (~100-1000 km) baselines



Look for energy-dependent flavor appearance or disappearance at far site

$\bar{\nu}_\mu \rightarrow \bar{\nu}_x$

$\nu_\mu \rightarrow \nu_e$

American Scientist magazine

Long-baseline neutrino oscillation experiments

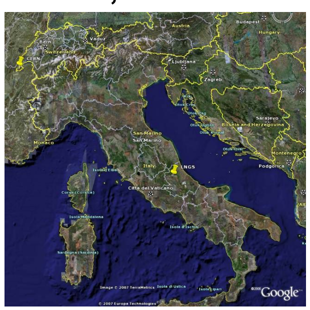
Past → **Current** → **Future**

K2K

KEK to Kamioka
250 km, 5 kW

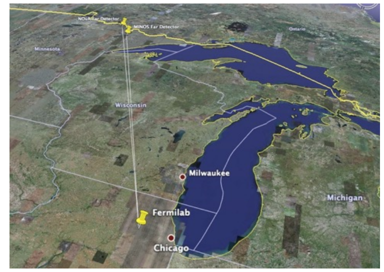
MINOS (+)

FNAL to Soudan
734 km, 400+ kW



CNGS

CERN to LNGS
730 km, 400 kW



NOνA

FNAL to Ash River
810 km, 400-900+ kW

T2K

J-PARC to Kamioka
295 km, 380-830 kW ➔>1 MW

LBNF/DUNE

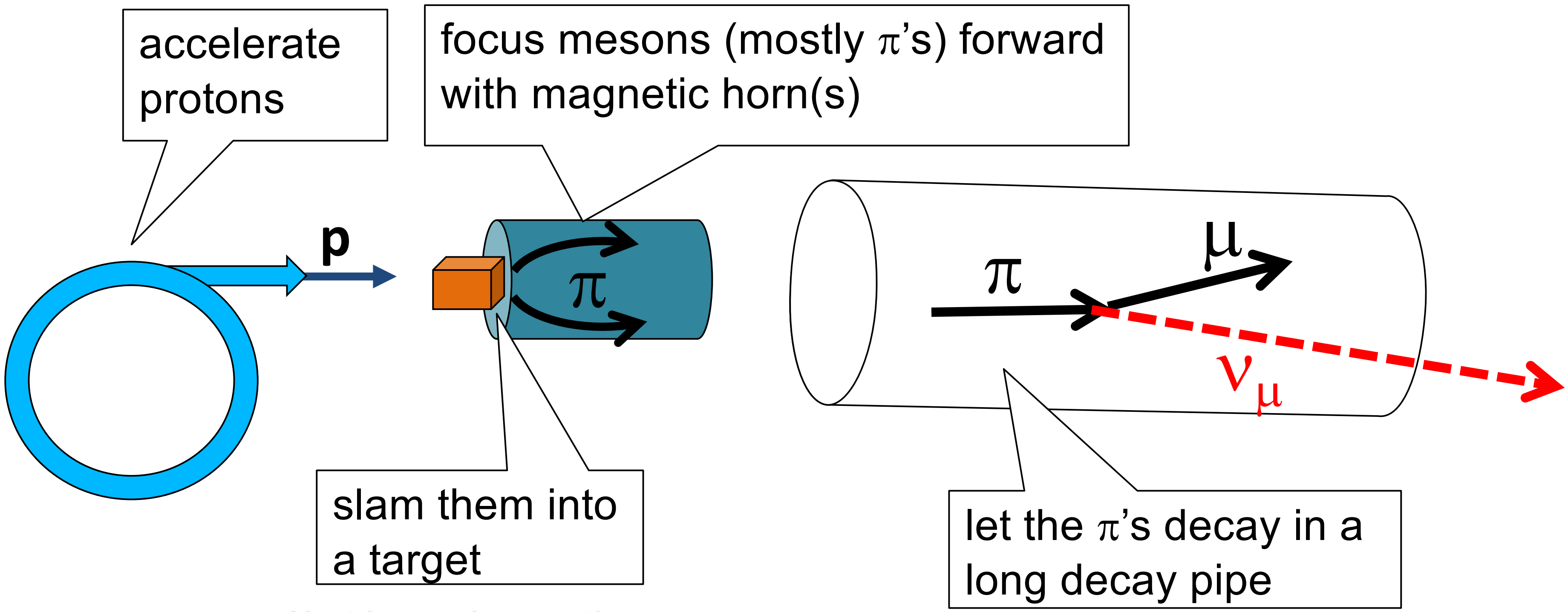
FNAL to Homestake
1300 km, 2-2.4 MW tunable

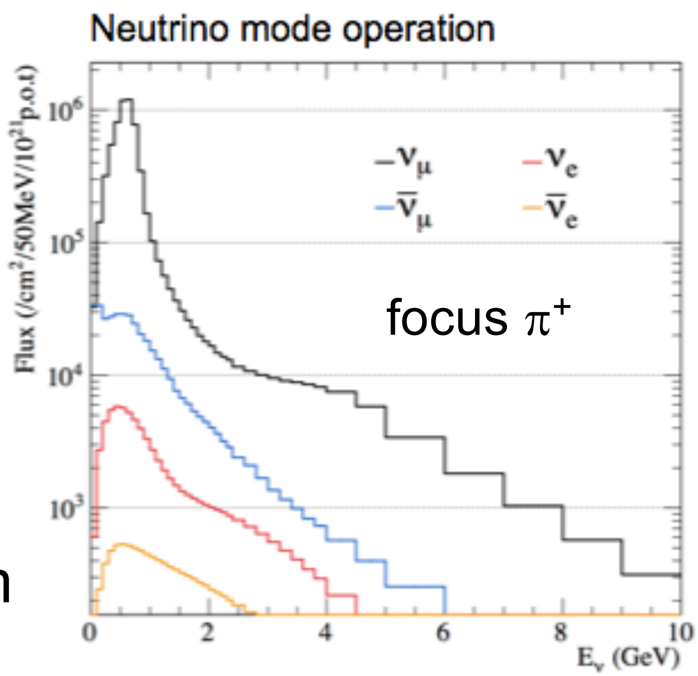
Hyper-K

J-PARC to Kamioka
295 km, 750 kW
(➔1.3 MW)

+ ESSνSB
+ farther future
nu factories...

These make use of ~GeV neutrinos from π decay in flight

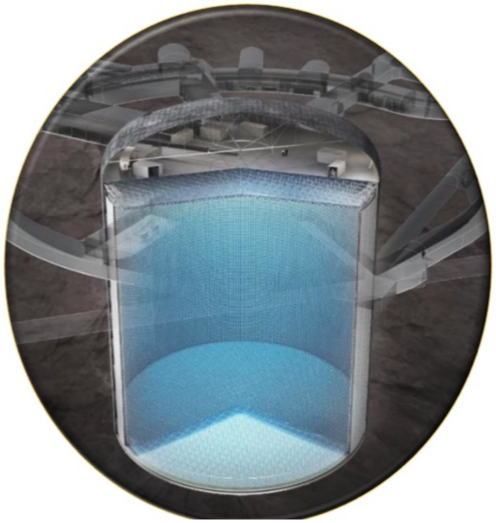


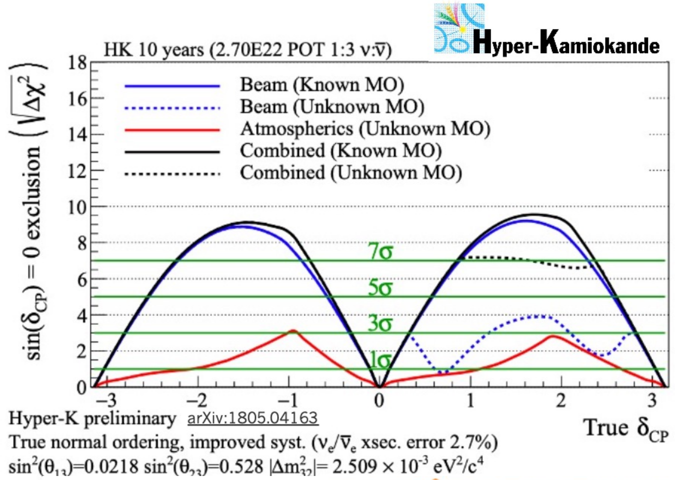


T2K beam

Non-negligible uncertainties on flux normalization and spectrum…

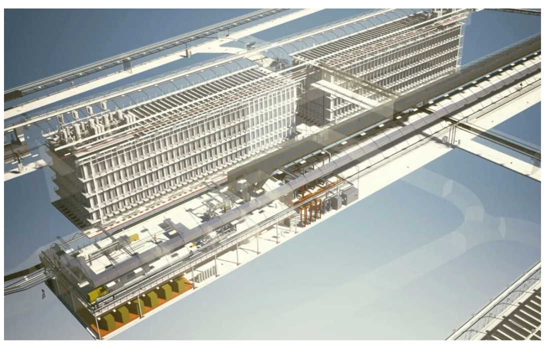
Next-generation long-baseline beam experiments

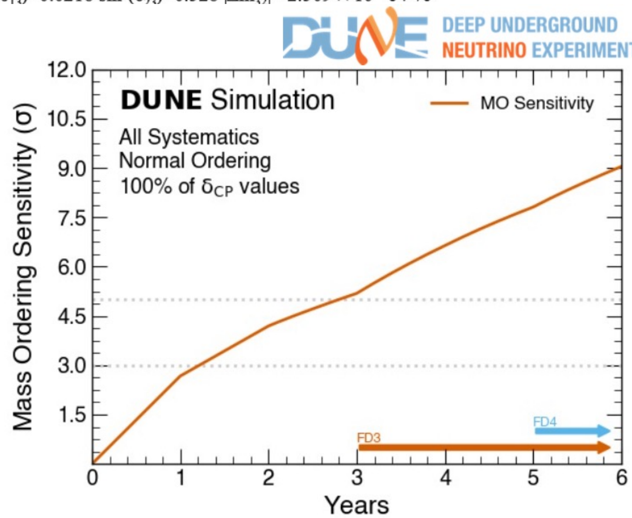




Water Cherenkov

- 187 kt water
- Cavern completed
- Excellent CPV but CPV/MO degeneracy





Liquid Argon TPC

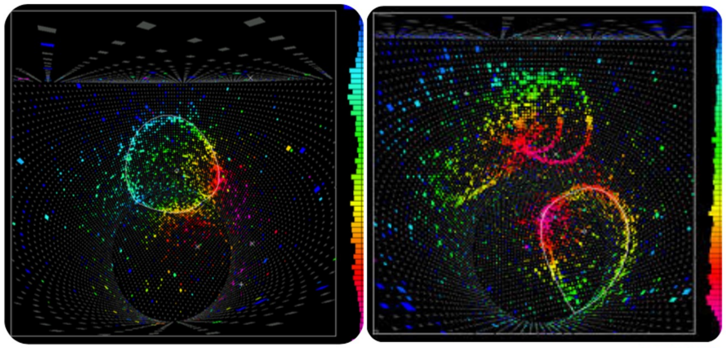
- 20-40 kt LAr
- Cavern completed
- Excellent MO sensitivity

- both can also use atmospheric neutrinos*
- both have suite of diverse near detectors
- both will measure precision 2-3 parameters
- both have broad non-oscillation physics programs

* Also KM3NeT, IceCube atmnus

Neutrino event reconstruction (energy, flavor)

Water Cherenkov

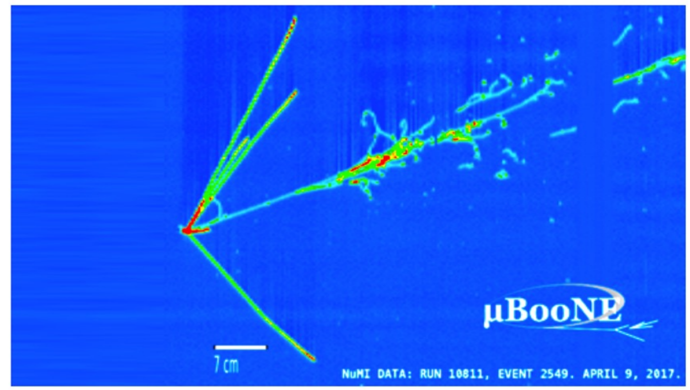


Heavy final-state particles
lost due to Cherenkov threshold

Emphasis on QE interactions
(just lepton in final state)

$$E_{QE} = \frac{2M\epsilon + 2ME_l - m_l^2}{2(M - E_l + |k_l|\cos\theta_l)}$$

Liquid Argon TPC



Better calorimetric final-state
particle reconstruction

$$E_{\text{cal}} = E_l + E_p^{\text{kin}} + \epsilon$$

[1p0π]

ϵ is the nucleon separation energy ~ 20 MeV

In all cases, **understanding of (exclusive and inclusive) ν interaction cross-sections differential in energy and angle** matters for interpretation

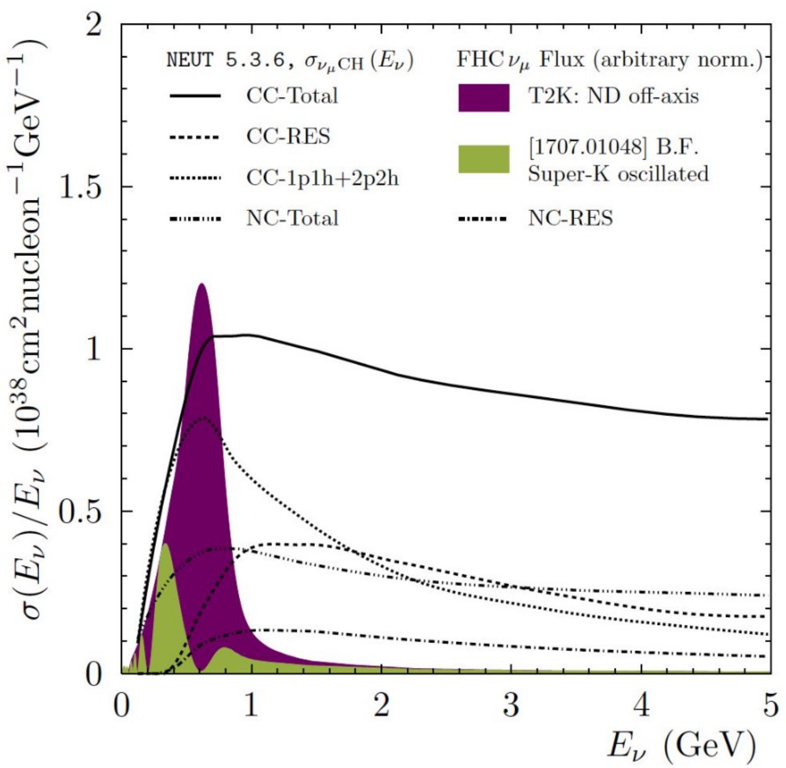
Graphics from rom A. Ashkenazi, NuInt 2025

Oscillation depends on true ν energy...

→ **must reconstruct ν energy from observed final state particles**

The game is to compare observed ν flavor and energy spectrum at near and far sites

(observable is wiggles as a function of L and E)



K. Mahn, Snowmass Neutrino Colloquium

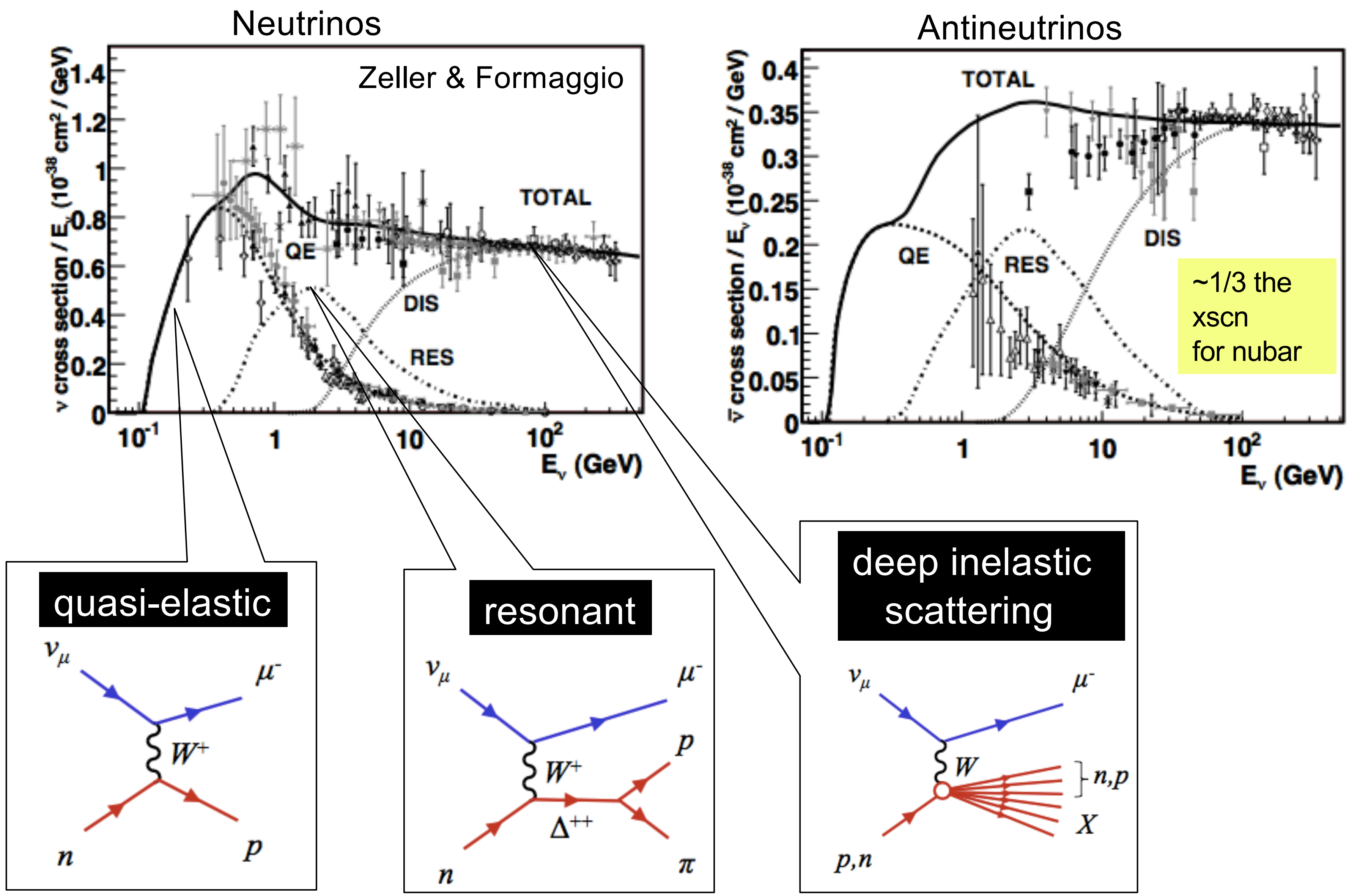
$$N_{FD}^{\alpha\to\beta}(E_{reco}) = \sum_i \phi_\alpha(E_{true}) \times \sigma_\beta^i(E_{true}) \times P_{\alpha\beta}(E_{true}) \times \epsilon_\beta(E_{true}) \times R_i(E_{true}; E_{reco})$$

It's *critically important* to understand neutrino interactions with nuclei for interpretation of oscillation experiments

(there are near detector tricks to mitigate uncertainties, but it's hard to get away from needing good understanding)

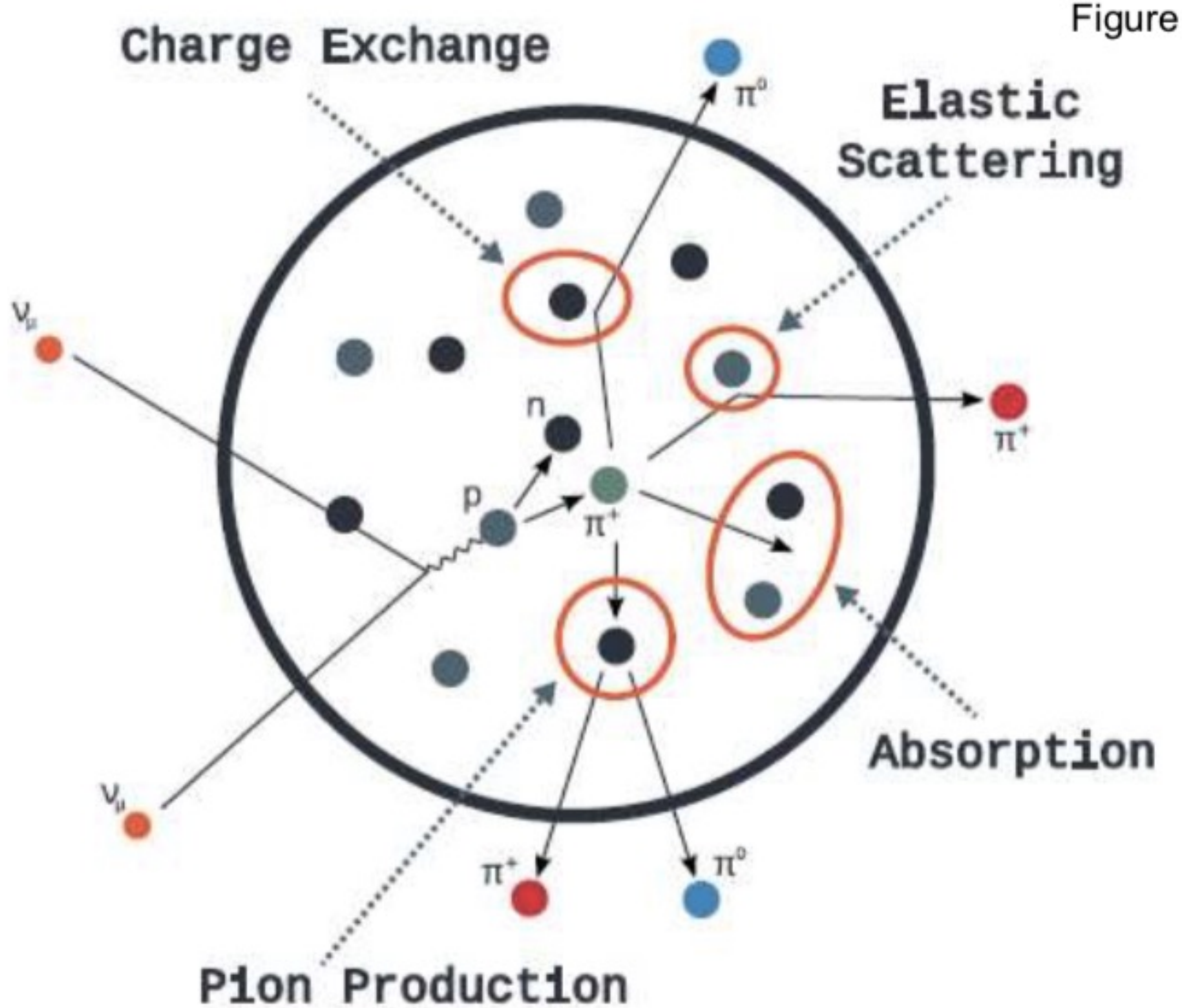
Interactions of neutrinos in the few-GeV range

scattering off nucleons, but can blow up the nucleus & create new particles



For neutrino-nucleus interactions in this regime have **final-state interactions matter**

Figure by Tomasz Golan



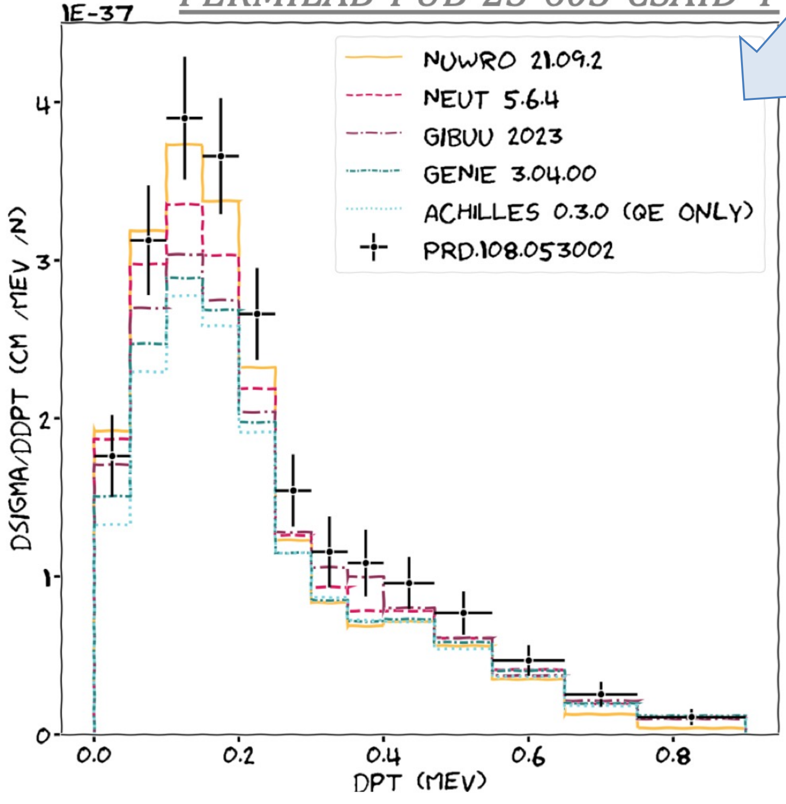
D. Ruterbories, Nu2018

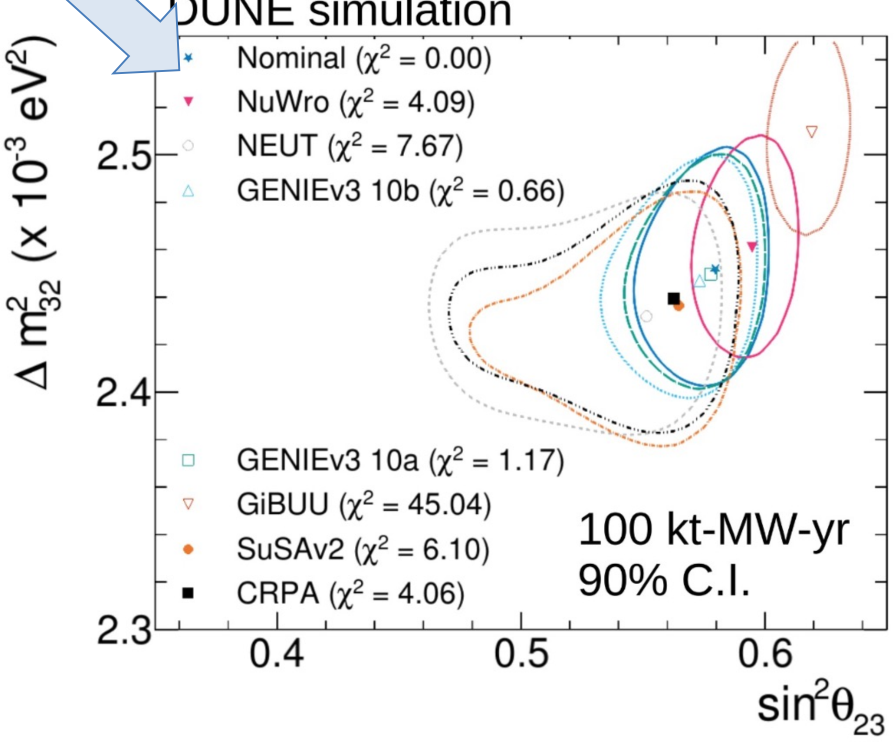
Cross section uncertainties are limiting

for oscillation parameter fits

Effect of different neutrino interaction generators

FERMILAB-PUB-23-603-CSAID-T





Example from J. Wolcott, NuInt 2025

L. Munteanu, ECT* 2024

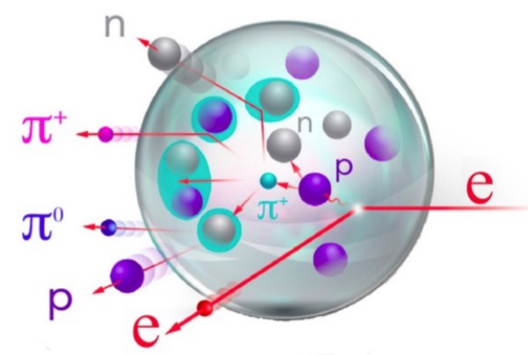
Electrons for neutrinos (e4ν)

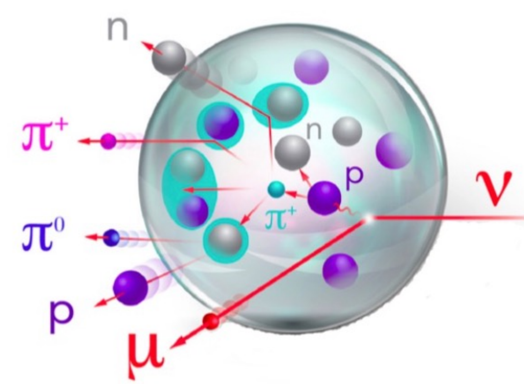
- **Same nuclear ground state**
- **Same Final State Interactions(FSI)**
- **Similar interactions with nuclei**
  - CC weak current [vector + axial]
    - $j_\mu^{\pm} = \bar{u}\frac{-ig_W}{2\sqrt{2}}(\gamma^\mu - \gamma^\mu\gamma^5)u$
  - EM current [vector]
    - $j_\mu^{em} = \bar{u}\gamma^\mu u$

Useful to constrain ν –A model uncertainties

- **Monochromatic beam**
- **High statistics**

Useful to test energy reconstruction methods





Slide from J. Vidal, Neutrino 2025

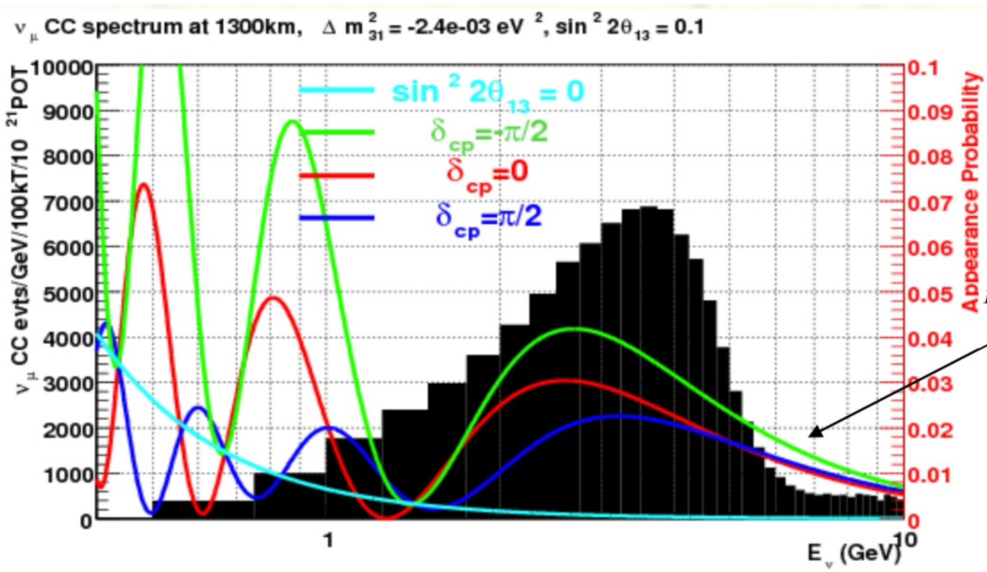
Electron scattering experiments relevant for neutrino cross sections

Collaborations	Kinematics	Targets	Scattering	Publications
E12-14-012 (JLab) (Data collected: 2017)	$E_e = 2.222$ GeV $\theta_e = 15.5, 17.5, 20.0, 21.5$ $\theta_p = -39.0, -44.0, -44.5, -47.0, -50.0$	Ar, Ti Al, C	(e, e') $(e, e'p)$	Phys. Rev. C **99**, 054608 Phys.Rev.D **105** 112002
e4nu/CLAS (JLab) (Data collected: 1999, 2022)	$E_e = 1, 2, 4, 6$ GeV $\theta_e > 5$	H, D, He, C, Ar, ^{40}Ca, ^{48}Ca, Fe, Sn	(e, e') e, p, n, π, γ in the final state	Nature **599**, 565 Phys.Rev.D **103** 113003
A1 (MAMI) (Data collected:2020) (More data planned)	$E_e = 1.6$ GeV	H, D, He C, O, Al Ca, Ar, Xe	(e, e') 2 additional charged particles	
LDMX (SLAC) (Planned)	$E_e = 4.0$ GeV $\theta_e < 40$		(e, e') e, p, n, π in the final state	
eALBA (Planned)	$E_e = 500$ MeV - few GeV	C, CH Be, Ca	(e, e')	

Adaptation from Proceedings of the US Community Snowmass2021
arXiv:2203.06853v1 [hep-ex]

Slide from A. Ashkenazi, NuInt 2025

Relevant coverage for DUNE oscillation physics



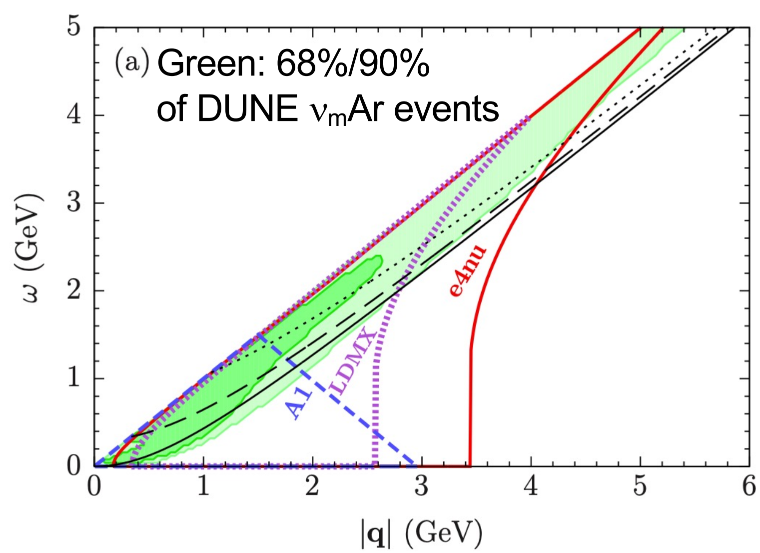
Cross sections needed in few GeV range for CPV

$$P(\nu_\mu \to \nu_e) \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{32}L}{4E}\right)\left(1+\frac{4\sqrt{2}G_F n_e E}{\Delta m^2_{31}}(1-2\sin^2\theta_{13})\right)$$

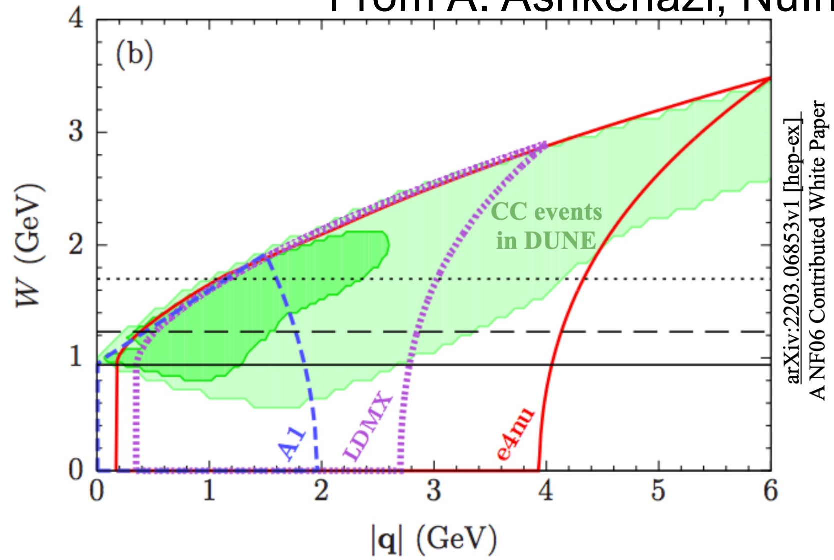
← Leading term

$$- \sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13}\cos\theta_{13}\sin\delta\,\sin\left(\frac{\Delta m^2_{32}L}{4E}\right)\sin\left(\frac{\Delta m^2_{31}L}{4E}\right)\sin\left(\frac{\Delta m^2_{21}L}{4E}\right)$$

↖ CP violating term

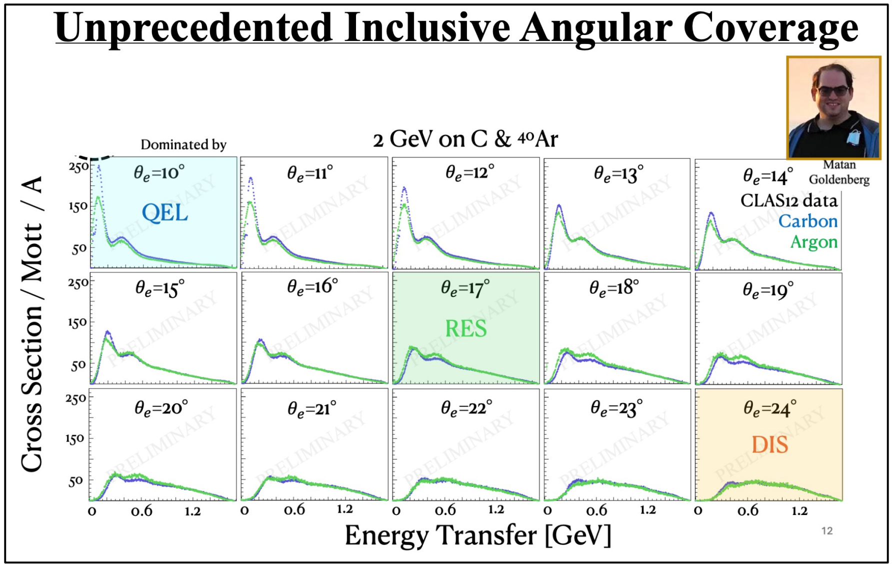


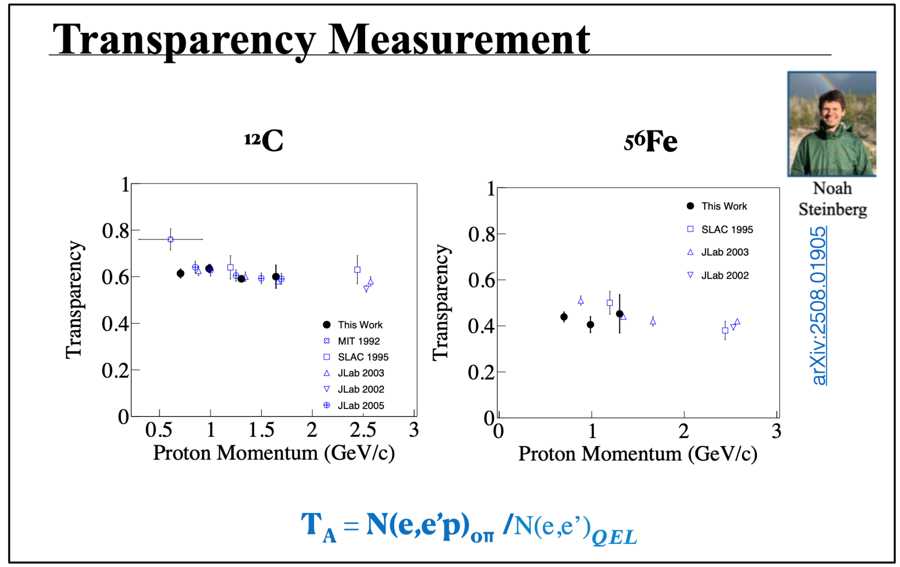
From A. Ashkenazi, NuInt 2025

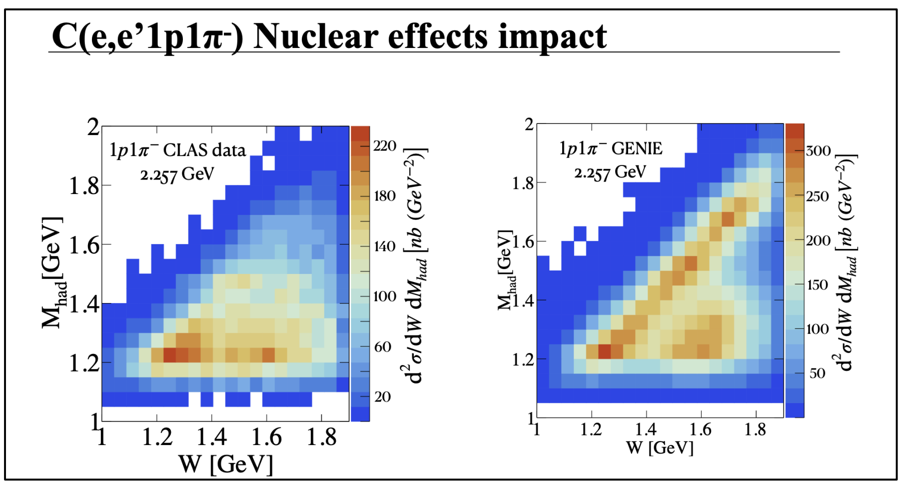


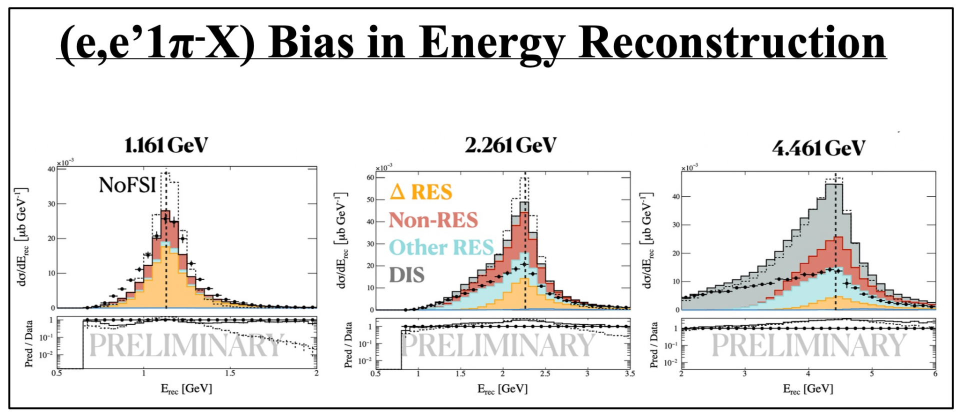
Good relevant kinematic coverage with existing electron-beam facilities

Examples of electron scattering measurements used to inform and tune neutrino event generators





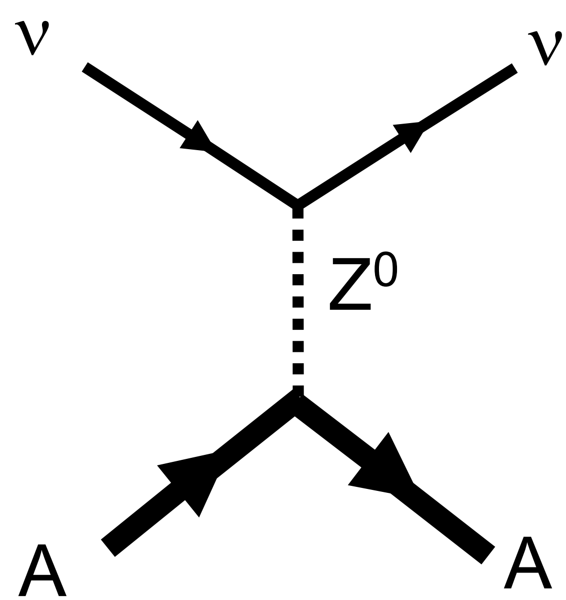




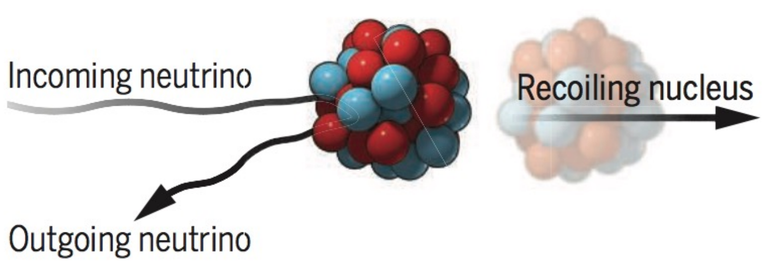
Among many: from J. Vidal, Neutrino 2025; A. Ashkenazi, NuInt 2025

Topic 2: **Coherent elastic neutrino-nucleus scattering (CEvNS)**

$$\nu + A \rightarrow \nu + A$$



A neutrino smacks a nucleus via exchange of a Z, and the nucleus recoils as a whole; **coherent** up to E_ν~ 50 MeV



Nucleon wavefunctions in the target nucleus are **in phase with each other** at low momentum transfer

For $QR << 1$, [total xscn] ~ A^2 * [single constituent xscn]

A: no. of constituents

Image: J. Link *Science* Perspectives

$$\frac{d\sigma}{dT} \simeq \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$

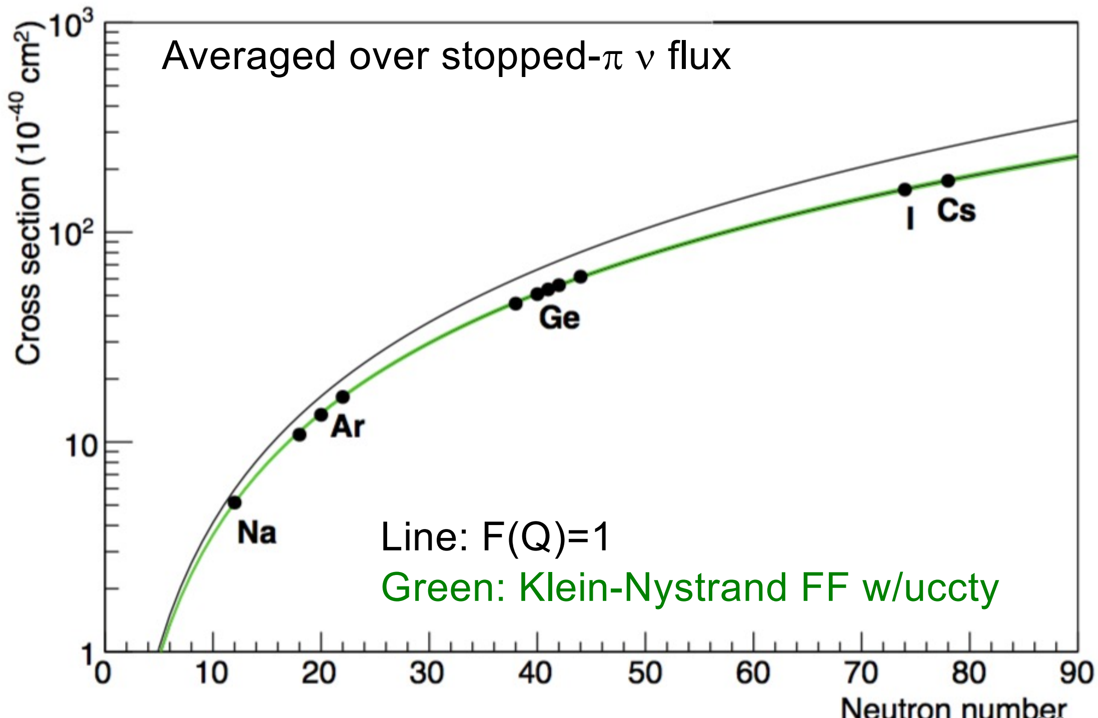
E_ν: neutrino energy
T: nuclear recoil energy
M: nuclear mass
Q = √ (2 M T): momentum transfer

weak nuclear charge

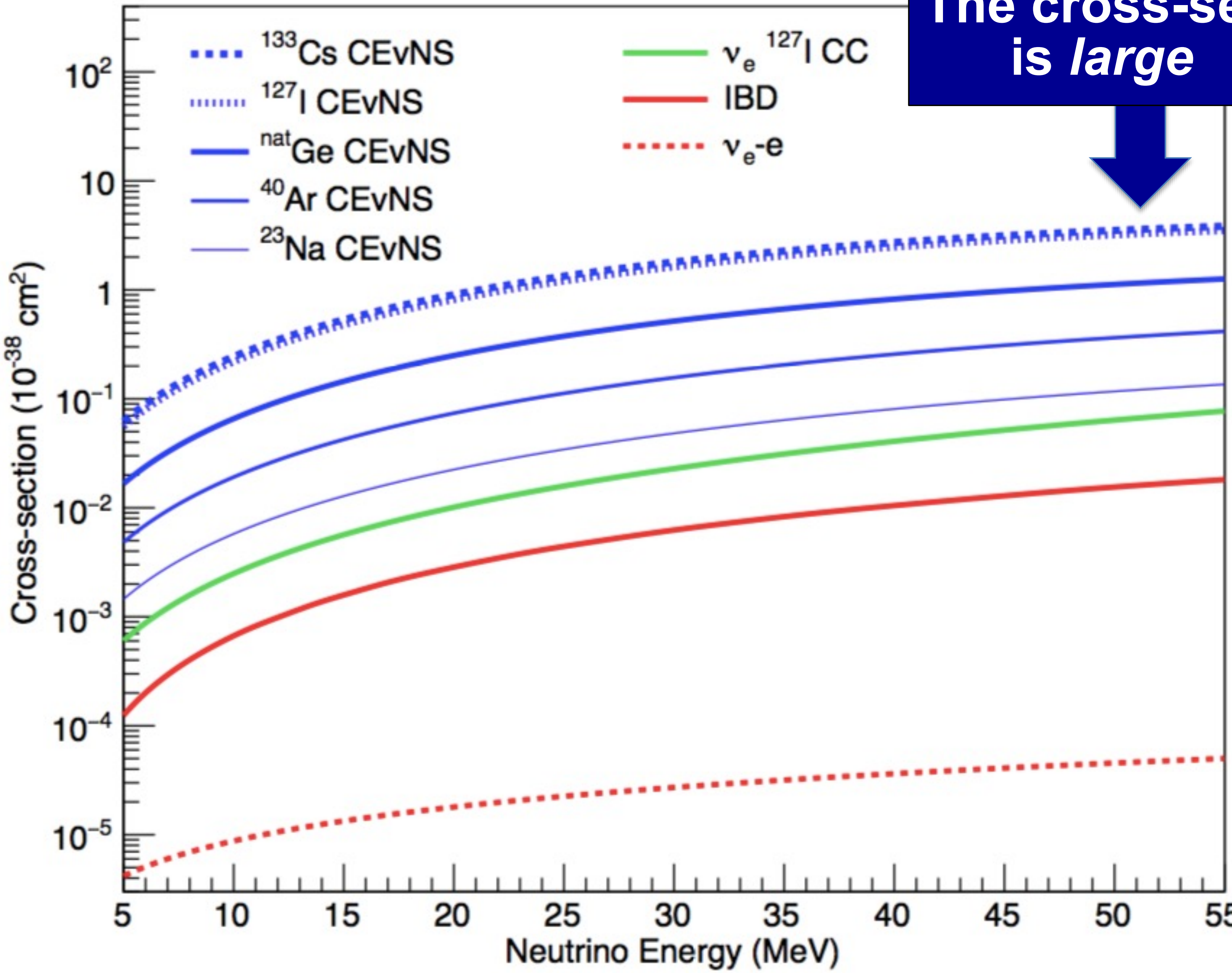
Form factor: F=1 ➔ full coherence

$$Q_W = (1 - 4\sin^2\theta_W)Z - N$$

$$\Rightarrow \boxed{\frac{d\sigma}{dT} \propto N^2}$$



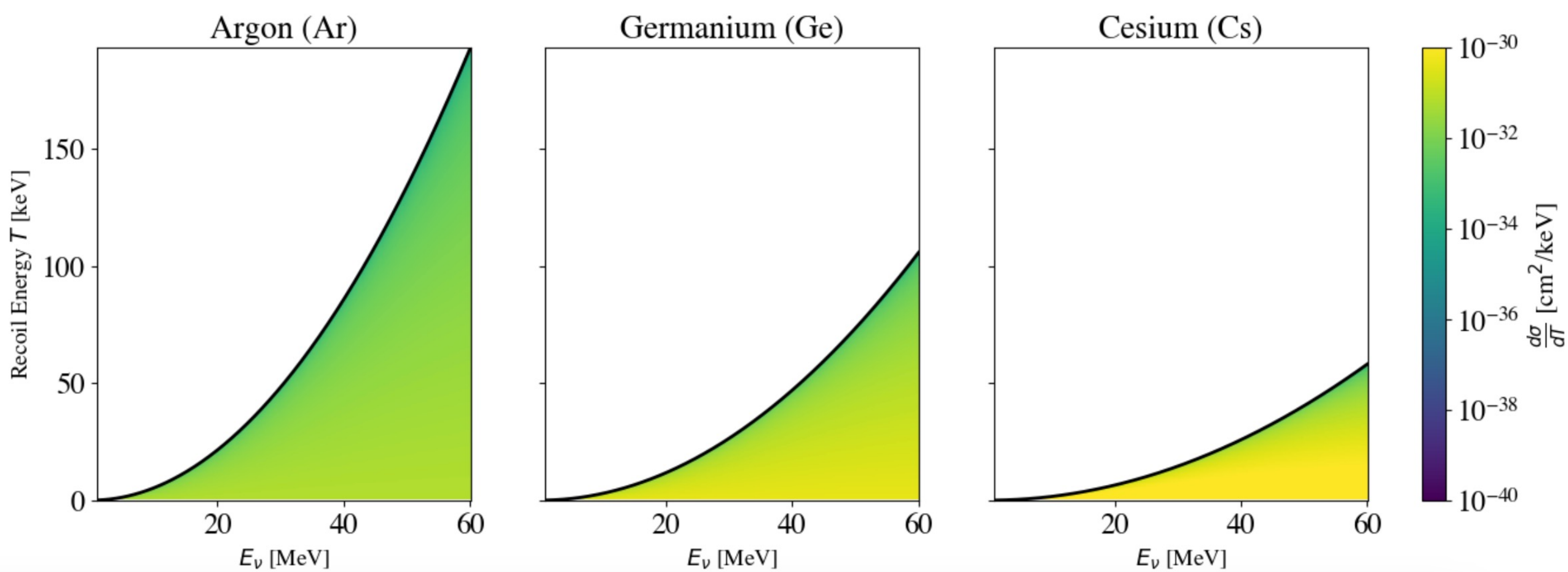
The cross-section is *large*



Large cross section (by neutrino standards) but hard to observe due to **tiny nuclear recoil energies:**

Nuclear recoil energy spectra

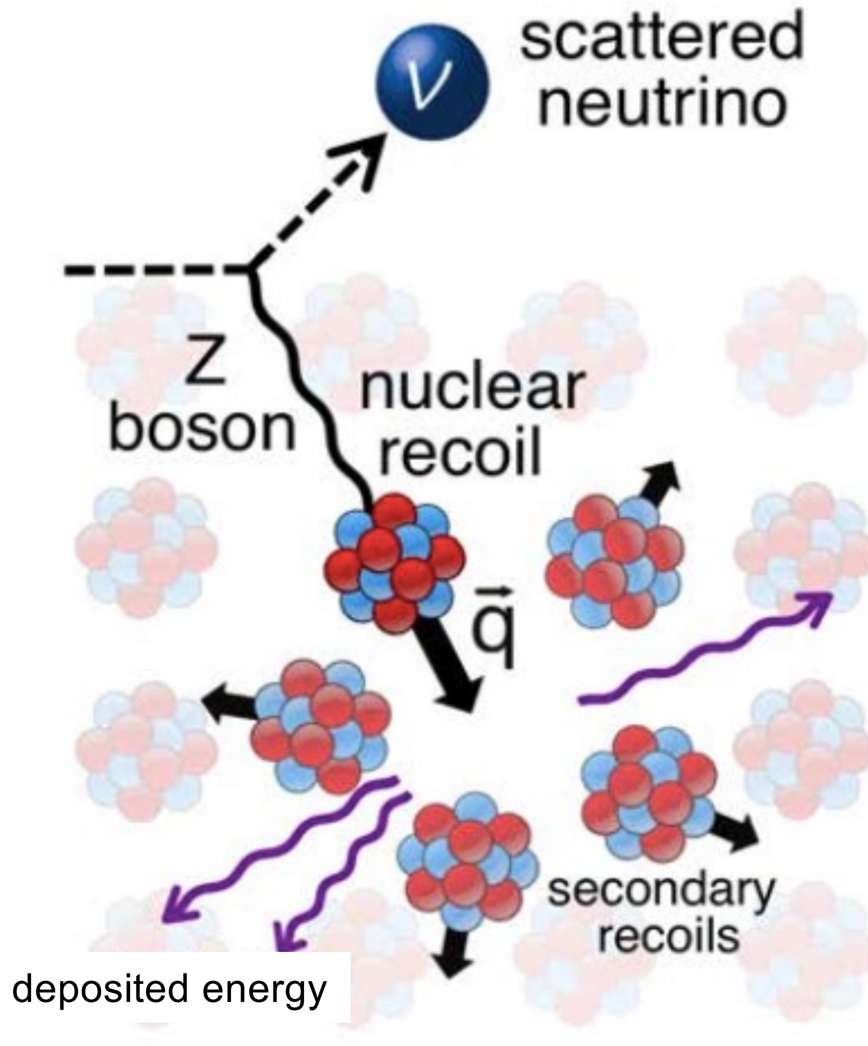
$$\frac{d\sigma}{dT} \simeq \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$



Few to ~tens of keV recoils in the regime where CEvNS dominates. E_ν <~ 50 MeV

The only experimental signature:

tiny energy deposited by nuclear recoils in the target material



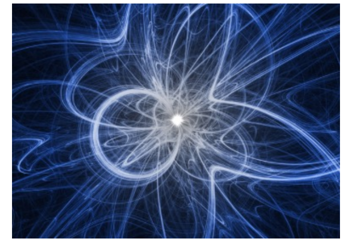
➔ **WIMP dark matter detectors** developed over the last ~decade are sensitive to ~ keV to 10's of keV recoils

CEvNS: what's it good for?

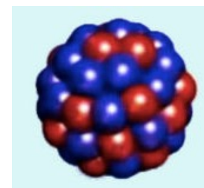
!

(not a complete list!)

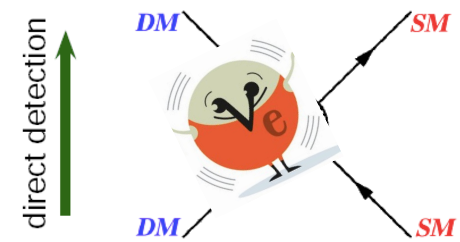
CEvNS as a **signal**
for signatures of *new physics*



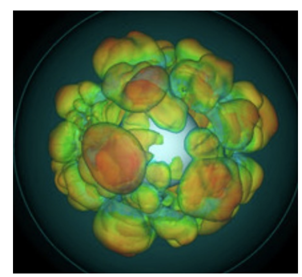
CEvNS as a **signal**
for understanding of "old" physics



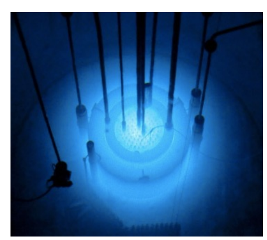
CEvNS as a **background**
for signatures of new physics



CEvNS as a **signal** for *astrophysics*



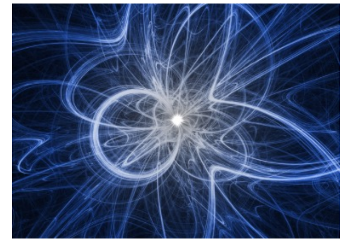
CEvNS as a **practical tool**



CEvNS: what's it good for?

! (not a complete list!)

CEvNS as a **signal**
for signatures of *new physics*



CEvNS as a **signal**
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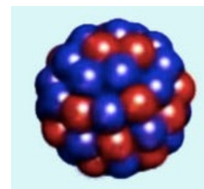
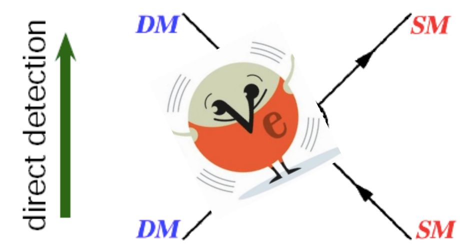
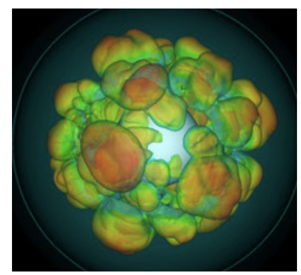


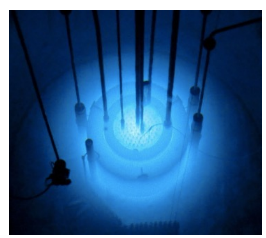
CEvNS as a **background**
for signatures of new physics



CEvNS as a **signal** for *astrophysics*



CEvNS as a **practical tool**



CEvNS cross section in the Standard Model

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{\pi} F^2(Q) \left[(G_V + G_A)^2 + (G_V - G_A)^2 \left(1 - \frac{T}{E_\nu}\right)^2 - (G_V^2 - G_A^2) \frac{MT}{E_\nu^2} \right]$$

E_ν: neutrino energy
T: nuclear recoil energy
M: nuclear mass
$Q = \sqrt{(2 M T)}$: momentum transfer

G_V, G_A: SM weak parameters

vector $G_V = g_V^p Z + g_V^n N,$ ← dominates

axial $G_A = g_A^p (Z_+ - Z_-) + g_A^n (N_+ - N_-)$ ← small for most nuclei, zero for spin-zero

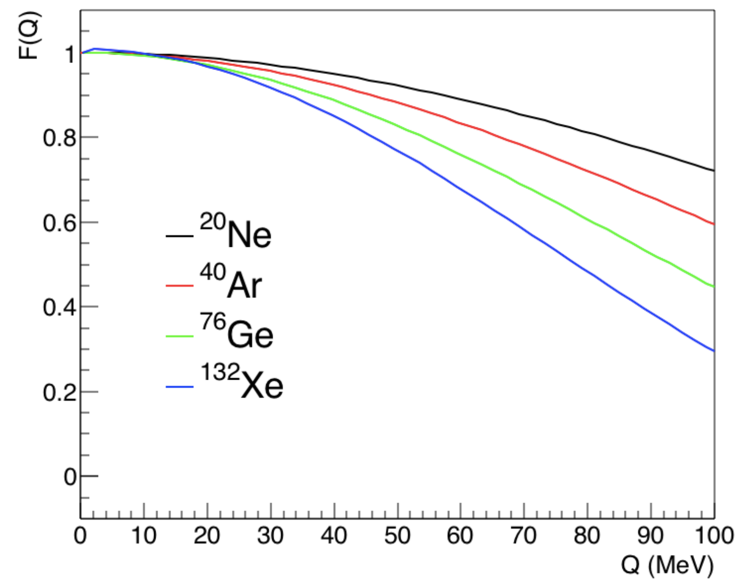
$$g_V^p = 0.0298$$
$$g_V^n = -0.5117$$
$$g_A^p = 0.4955$$
$$g_A^n = -0.5121.$$

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$

SM electroweak in here

nuclear physics in here, with ~percent uncertainties

$$Q_W = (1 - 4\sin^2\theta_W)Z - N$$



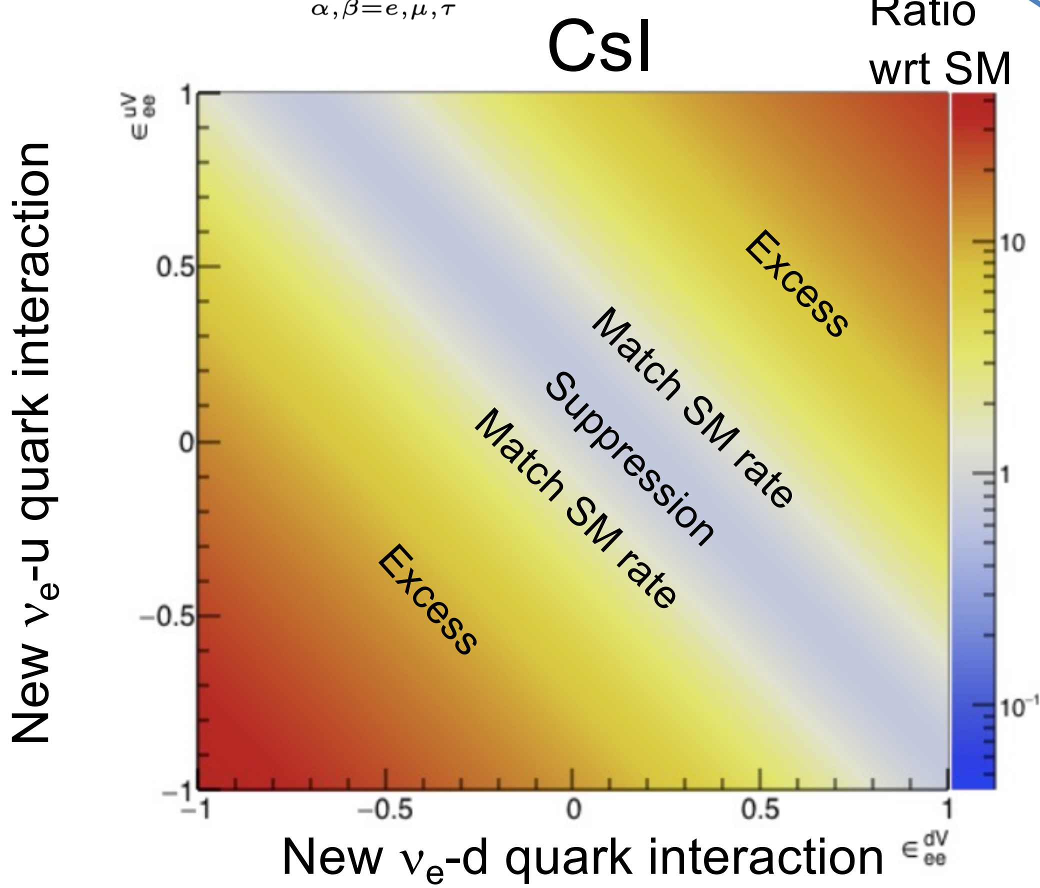
- In the context of the SM, measure $\sin^2\theta_W$ at low Q
- Look for anomalies in rate, N or Q distribution to search for BSM

- Bigger suppression for for larger Q and larger nucleus

Non-Standard Interactions of Neutrinos:

new interaction **specific to ν's**

$$\mathcal{L}_{\nu H}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5)\nu_\beta] \times (\varepsilon_{\alpha\beta}^{qL}[\bar{q}\gamma_\mu(1-\gamma^5)q] + \varepsilon_{\alpha\beta}^{qR}[\bar{q}\gamma_\mu(1+\gamma^5)q])$$



If these ε's are ~unity, there is a new interaction of ~Standard-model size... many not currently well constrained

For heavy mediators, expect ***overall scaling*** of CEvNS event rate, depending on N, Z

Non-Standard Interactions of Neutrinos:

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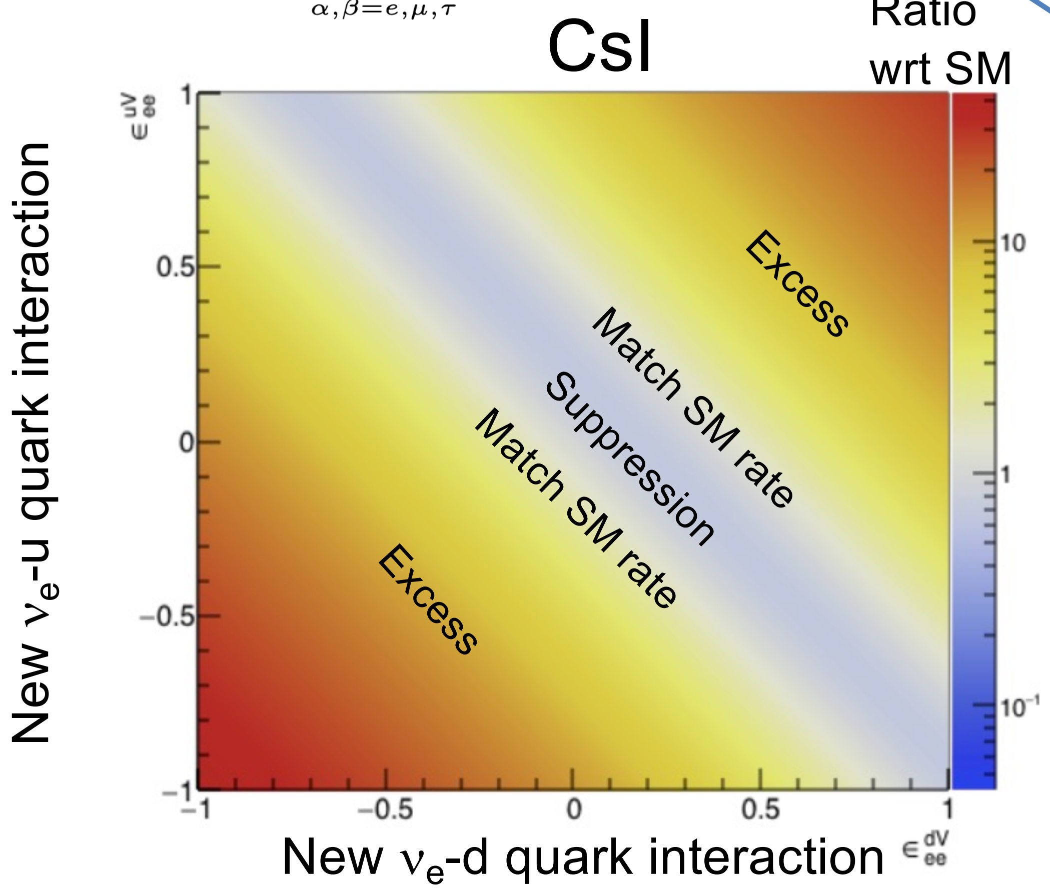


If these ε's are ~unity, there is a new interaction of ~Standard-model size... many not currently well constrained

For heavy mediators, expect ***overall scaling*** of CEvNS event rate, depending on N, Z

Observe less or more CEvNS than expected?
...could be beyond-the-SM physics!

Other new physics results in a
distortion of the recoil spectrum (Q dependence)

BSM Light Mediators

SM weak charge

$$Q^2_{\alpha,\mathrm{SM}} = (Z g_p^V + N g_n^V)^2$$

Effective weak charge in presence of light vector mediator Z'

$$Q^2_{\alpha,\mathrm{NSI}} = \left[Z\left(g_p^V + \frac{3g^2}{2\sqrt{2}G_F(Q^2 + M_{Z'}^2)} \right) + N\left(g_n^V + \frac{3g^2}{2\sqrt{2}G_F(Q^2 + M_{Z'}^2)} \right) \right]^2$$

specific to neutrinos and quarks

e.g. arXiv:1708.04255

Neutrino (Anomalous) Magnetic Moment

e.g. arXiv:1505.03202, 1711.09773

$$\left(\frac{d\sigma}{dT}\right)_m = \frac{\pi\alpha^2\mu_\nu^2 Z^2}{m_e^2}\left(\frac{1 - T/E_\nu}{T} + \frac{T}{4E_\nu^2}\right)$$

Specific ~1/T upturn at low recoil energy

Sterile Neutrino Oscillations

$$P^{\mathrm{SBL}}_{\nu_\alpha \to \nu_\alpha}(E_\nu) = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2\left(\frac{\Delta m^2_{41} L}{4E_\nu}\right)$$

"True" disappearance with baseline-dependent Q distortion

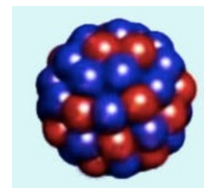
e.g. arXiv: 1511.02834, 1711.09773, 1901.08094

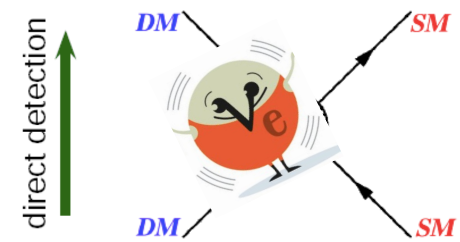
CEvNS: what's it good for?

(1) So (2) Many (3) Things **!** (not a complete list!)

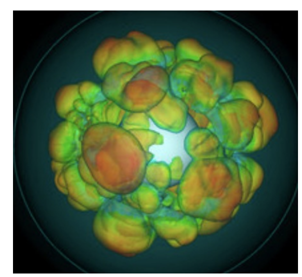
CEvNS as a **signal**
for signatures of *new physics*

CEvNS as a **signal**
for understanding of "old" physics



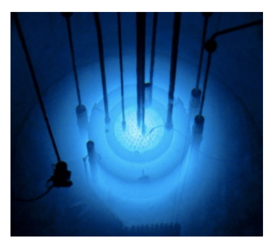


CEvNS as a **background**
for signatures of new physics

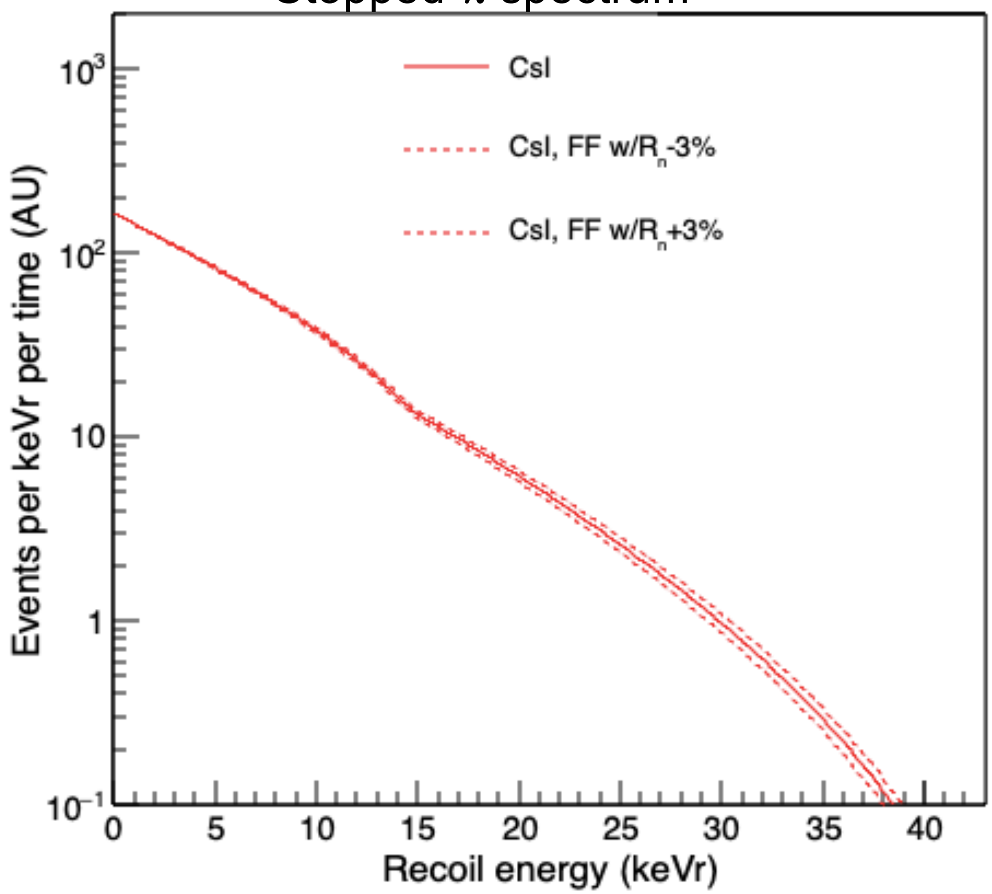


CEvNS as a **signal** for *astrophysics*

CEvNS as a **practical tool**



What can we learn about **nuclear physics** with CEvNS**?**

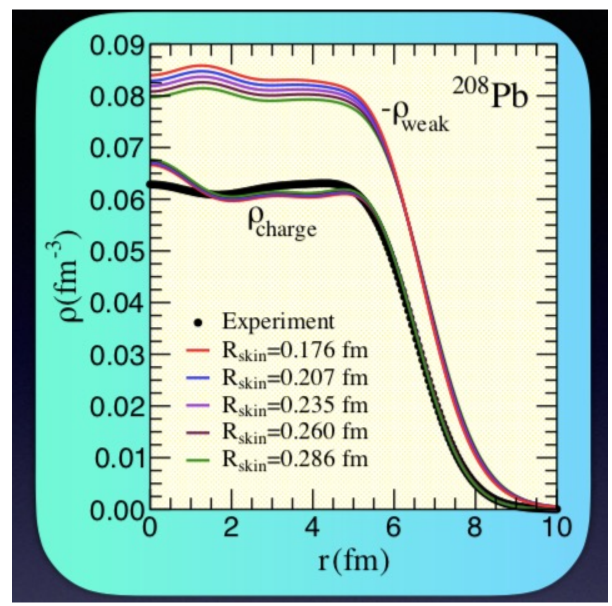


P S Amanik and G C McLaughlin 2009
J. Phys. G: Nucl. Part. Phys. 36 015105

K. Patton et al., Phys.Rev. C86 (2012) 024612

Observable is
recoil spectrum shape
(Q-dependent suppression)

Neutron radius and "skin" (R_n-R_p) relevant for understanding of neutron star EOS



J. Piekarewicz

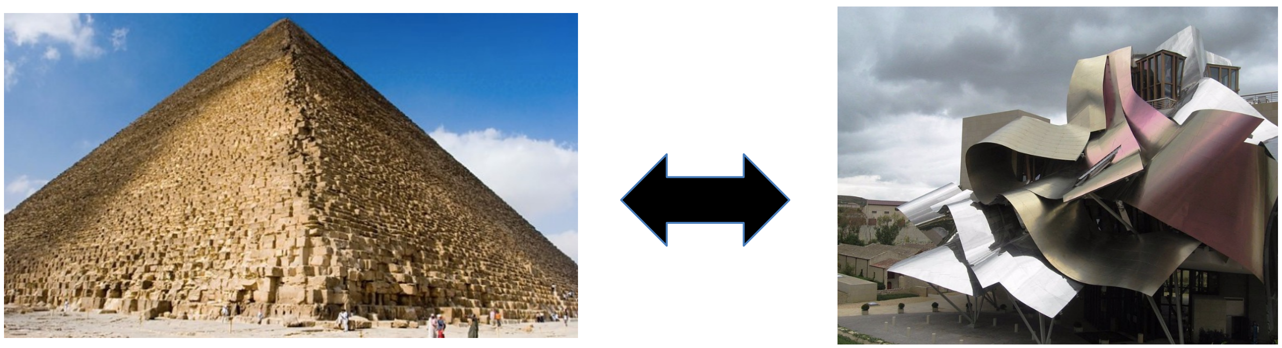
So: if you are hunting for BSM physics

as a distortion of the recoil spectrum

… **uncertainties in the form factor are a nuisance!**

There are degeneracies in the observables between

“old” (but still mysterious) physics



and “new” physics

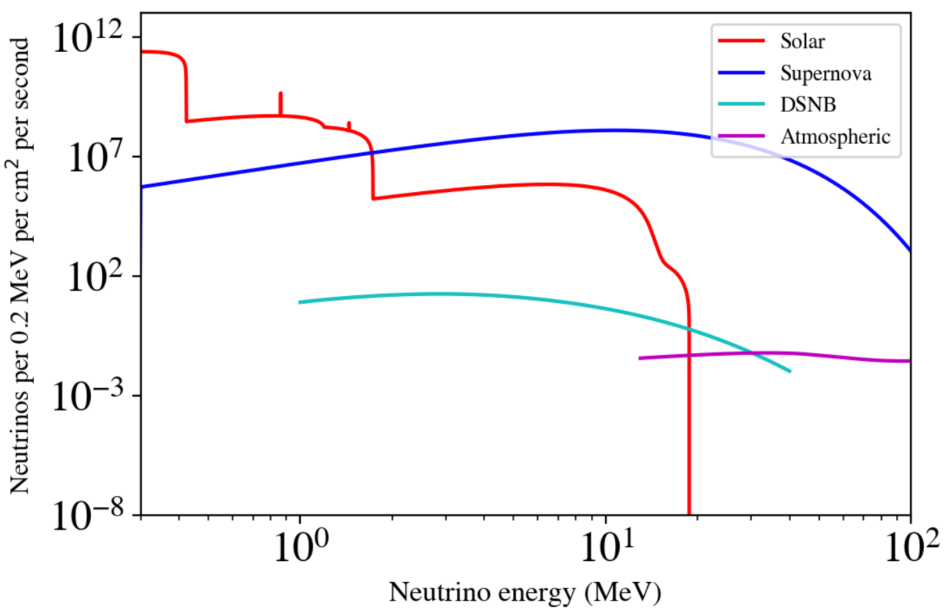
At current level of precision,

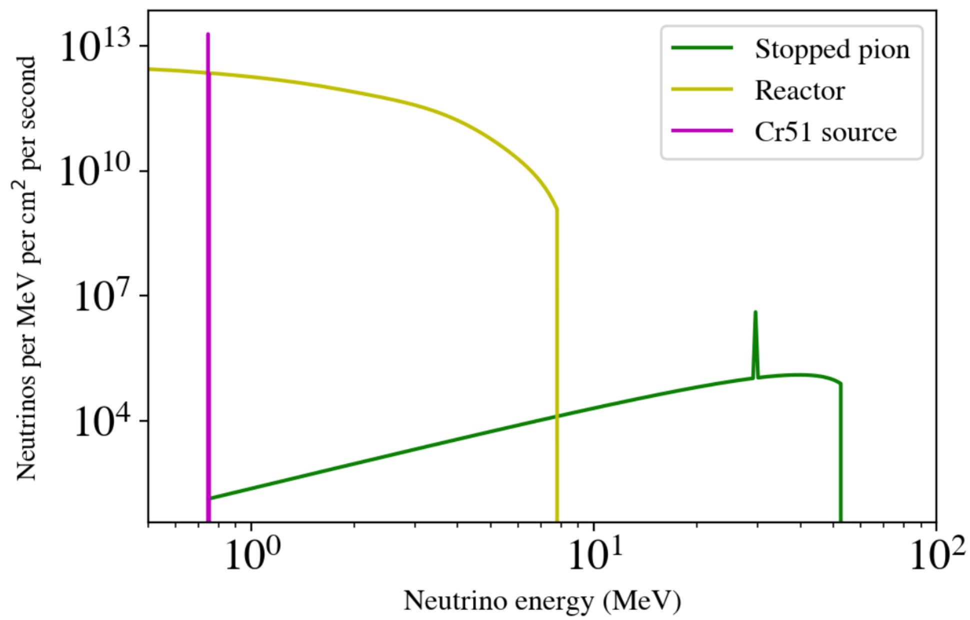
form factor shape is **not a dominant effect**

... but we will need to think carefully about

how to disentangle these effects for the longer term

Neutrino sources for CEvNS, below ~100 MeV

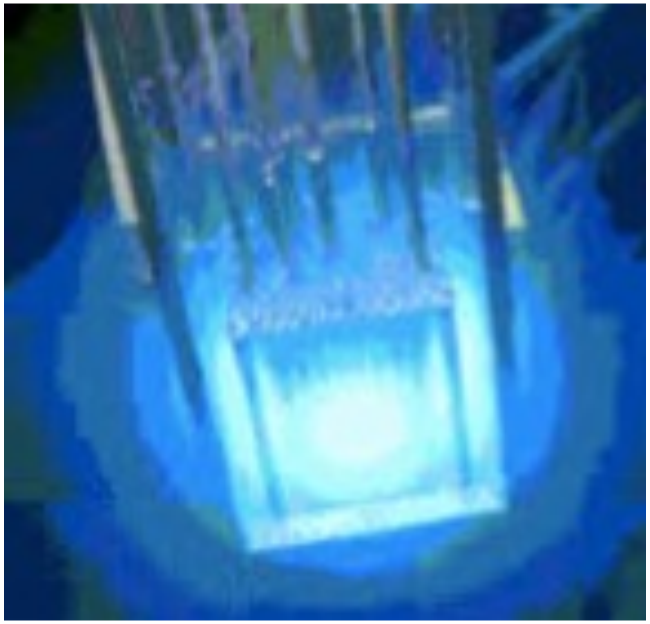


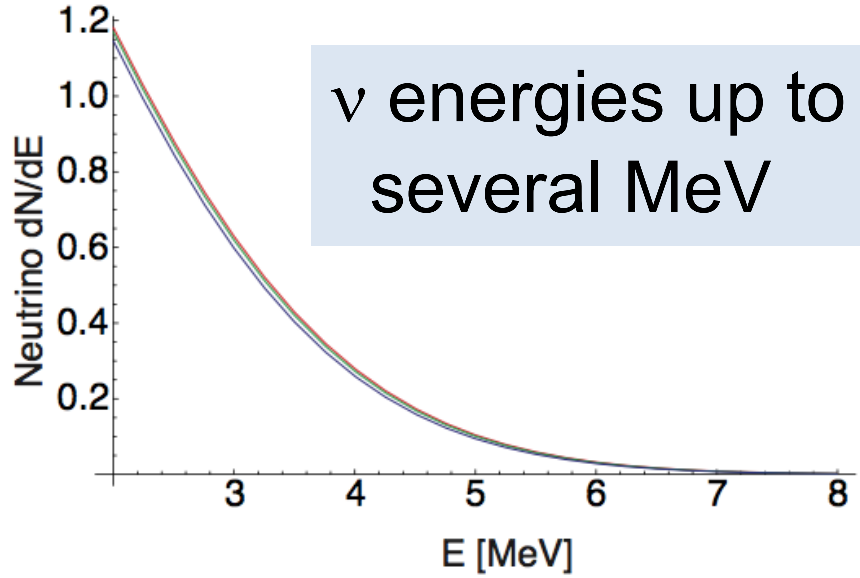


Physics motivations for both wild & tame ν's:

- 3-flavor parameters
- BSM
- astrophysics & cosmology
- nuclear physics

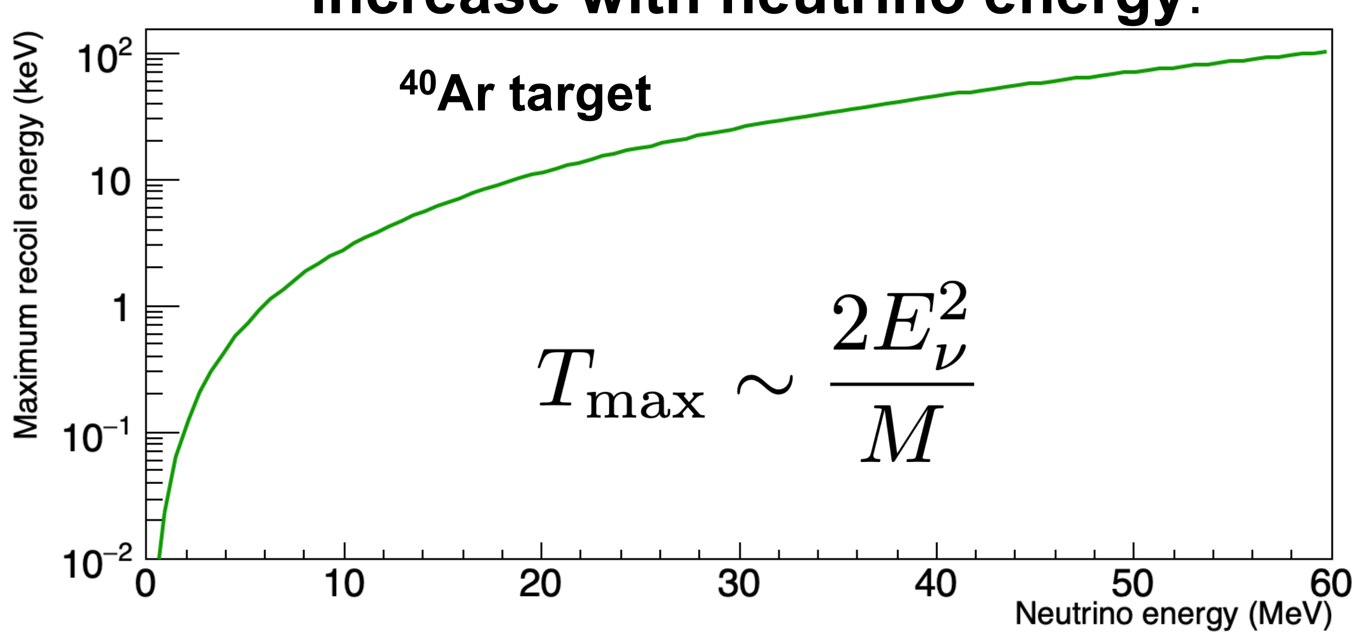
Neutrinos from nuclear reactors





- ν_e-bar produced in fission reactions (one flavor)
- **huge fluxes possible**: ~2×10^{20} s^{-1} per GW
- several CEvNS searches past, current and future at reactors, but **recoil energies<keV** and backgrounds make this very challenging

Both **cross-section** and **maximum recoil energy increase with neutrino energy**:

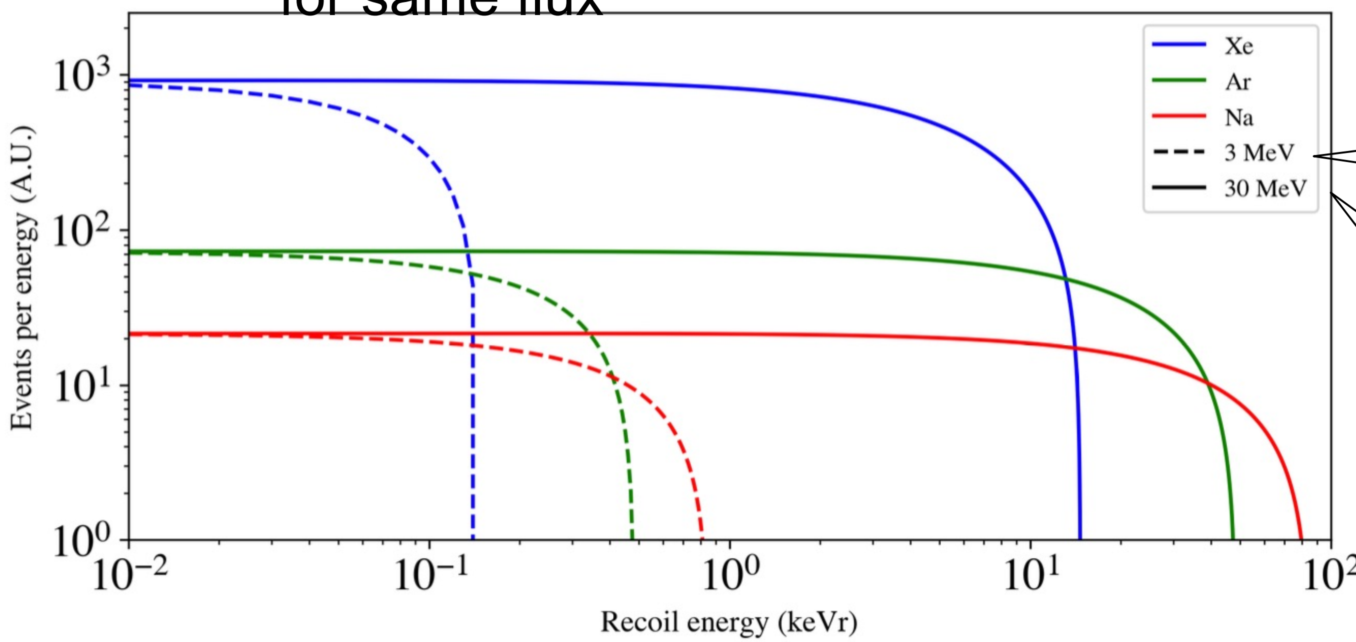


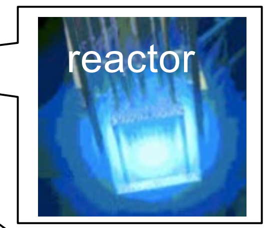
Want energy as large as possible while satisfying coherence condition

$$Q \lesssim \frac{1}{R}$$

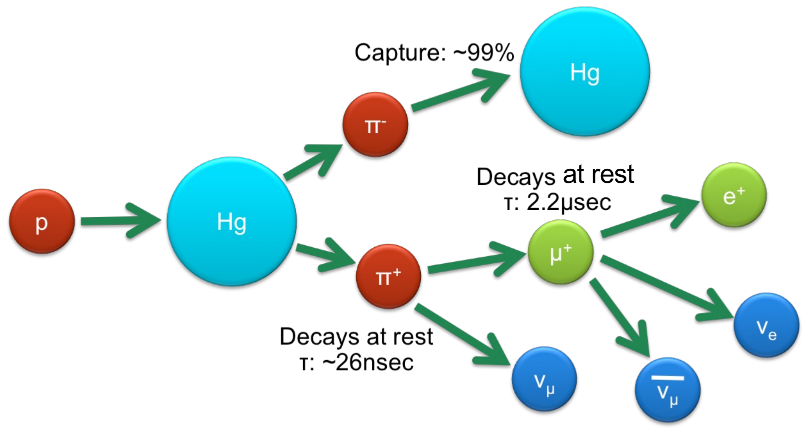
(<~ 50 MeV for medium A)

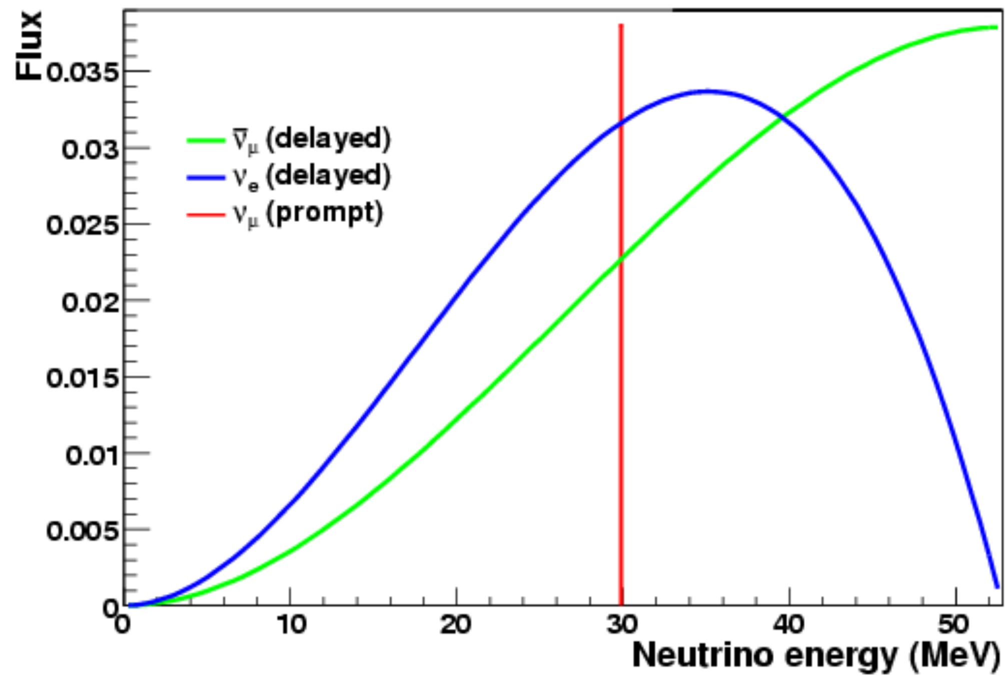
for same flux





Stopped-Pion (πDAR) Neutrinos





$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

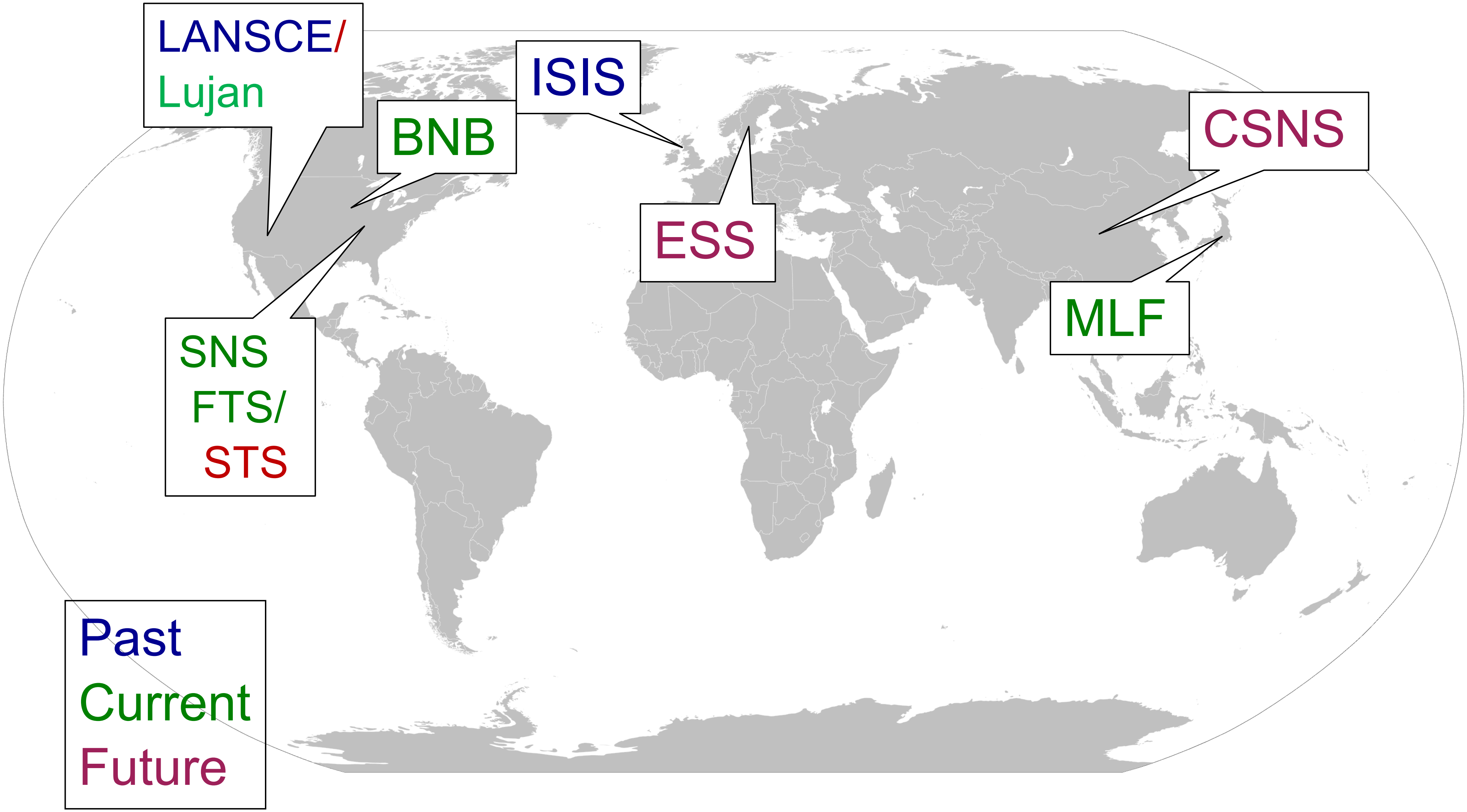
2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

$$\downarrow$$

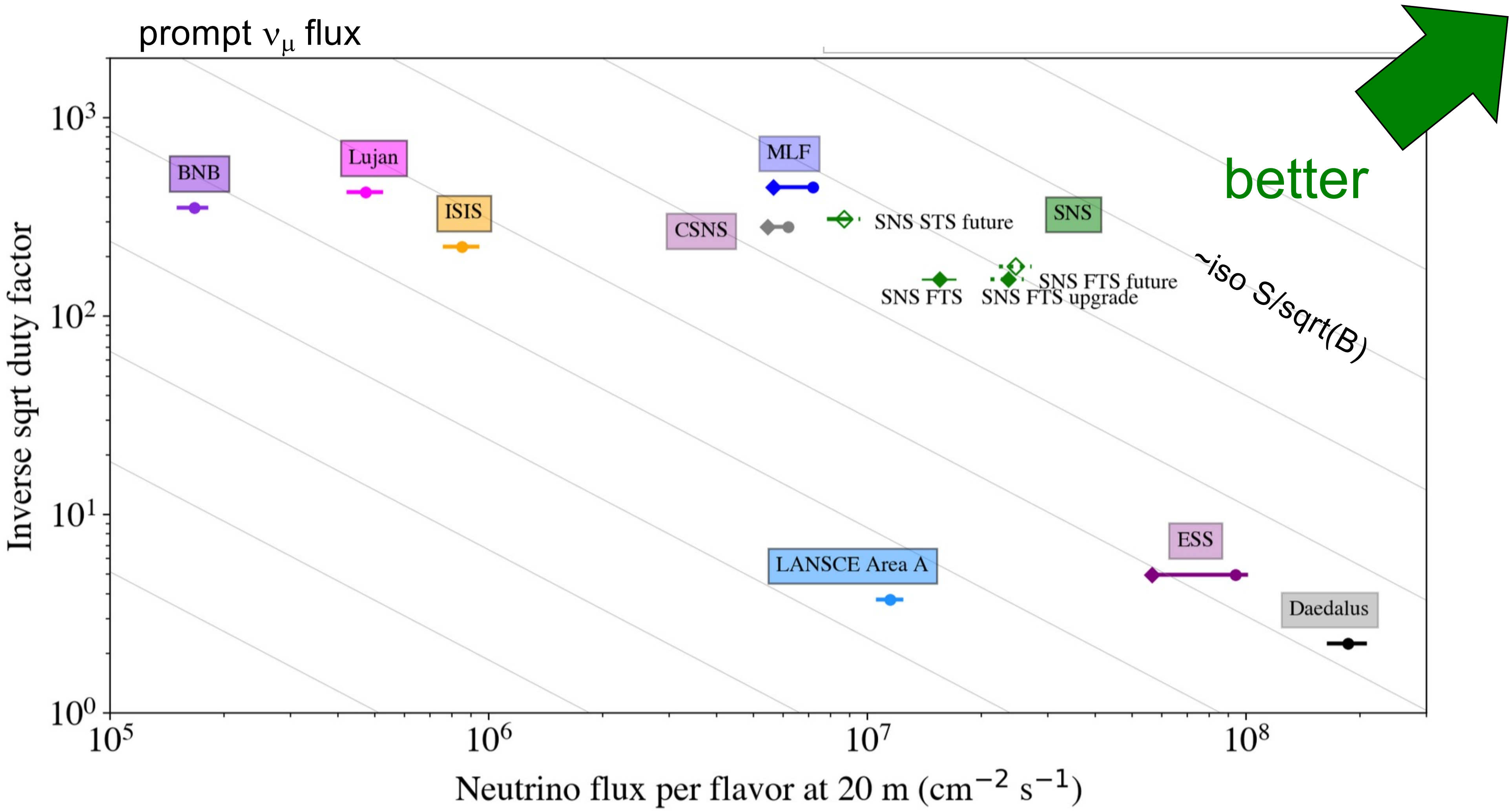
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies between 0 and $m_\mu/2$
DELAYED (2.2 μs)

Stopped-Pion Neutrino Sources Worldwide



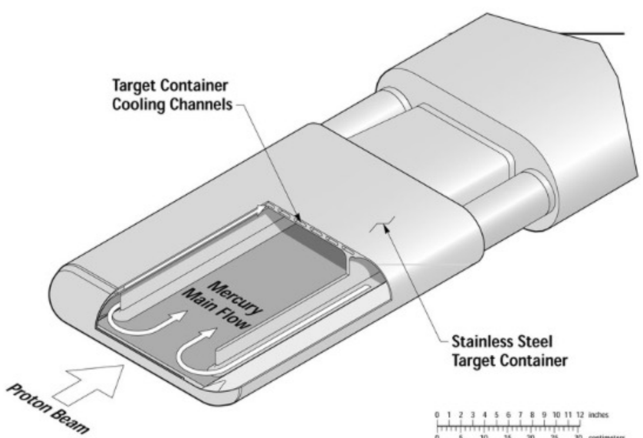
Comparison of stopped-pion ν sources



rough figure of merit: ~flux/sqrt(duty cycle) (~S/sqrt(B))

[does not capture all relevant characteristics]

[could add JLab beam dump to this plot!]



Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.9 MW (increasing)
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target

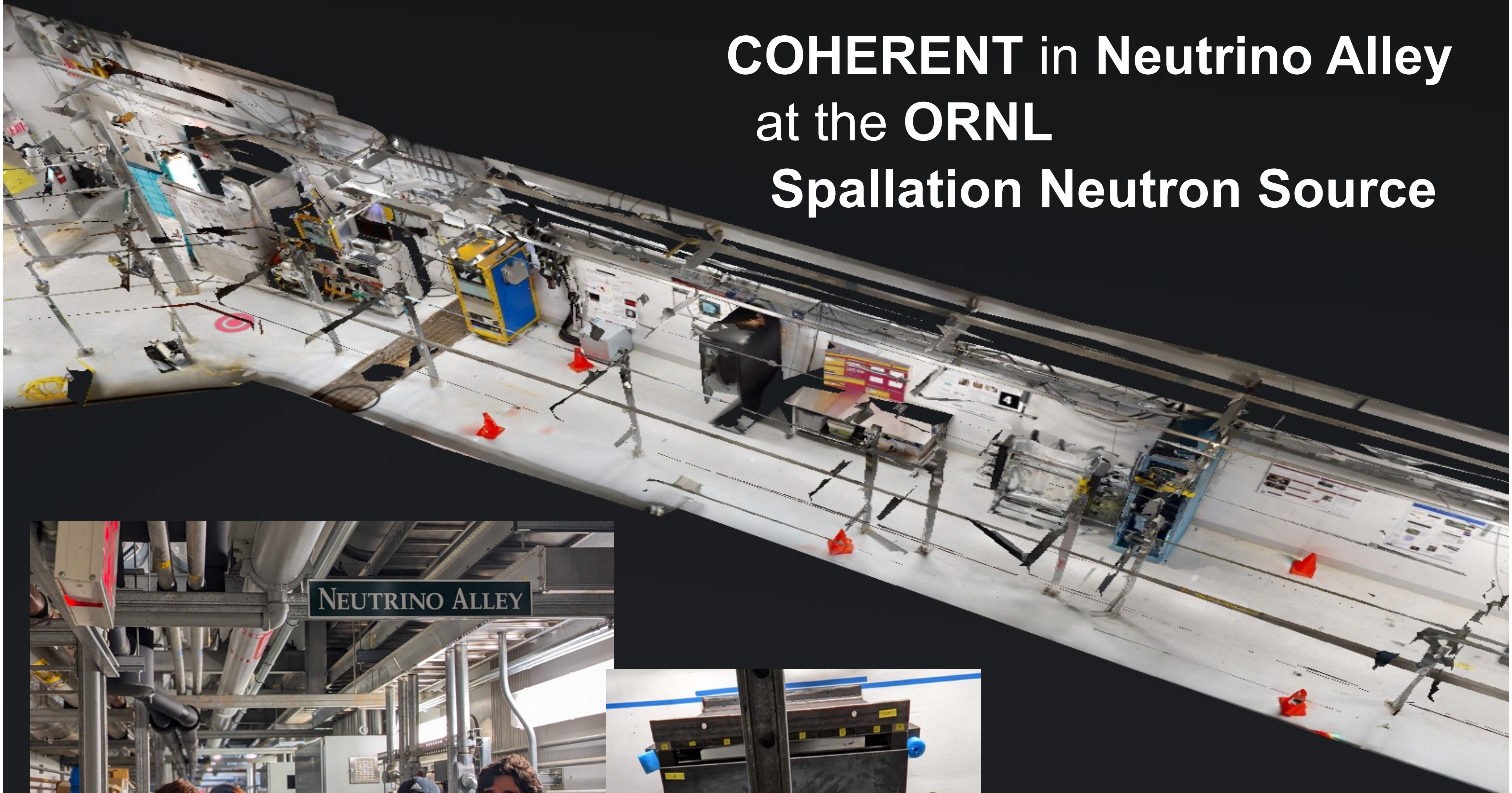
The neutrinos are free!

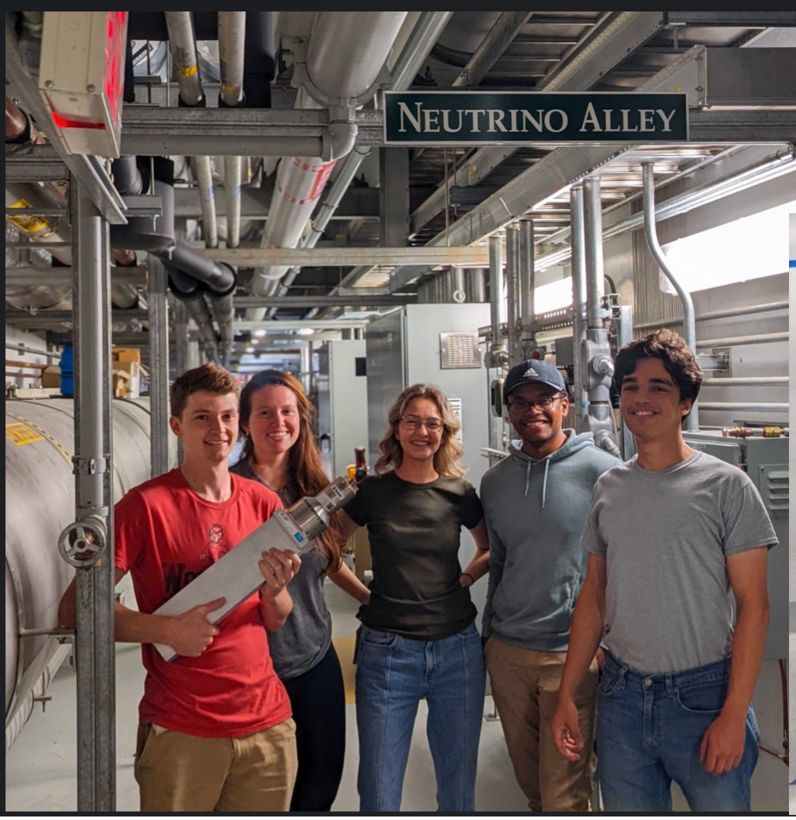
The COHERENT collaboration

http://sites.duke.edu/coherent

~100 members,
25 institutions
5 countries

COHERENT in Neutrino Alley at the ORNL Spallation Neutron Source



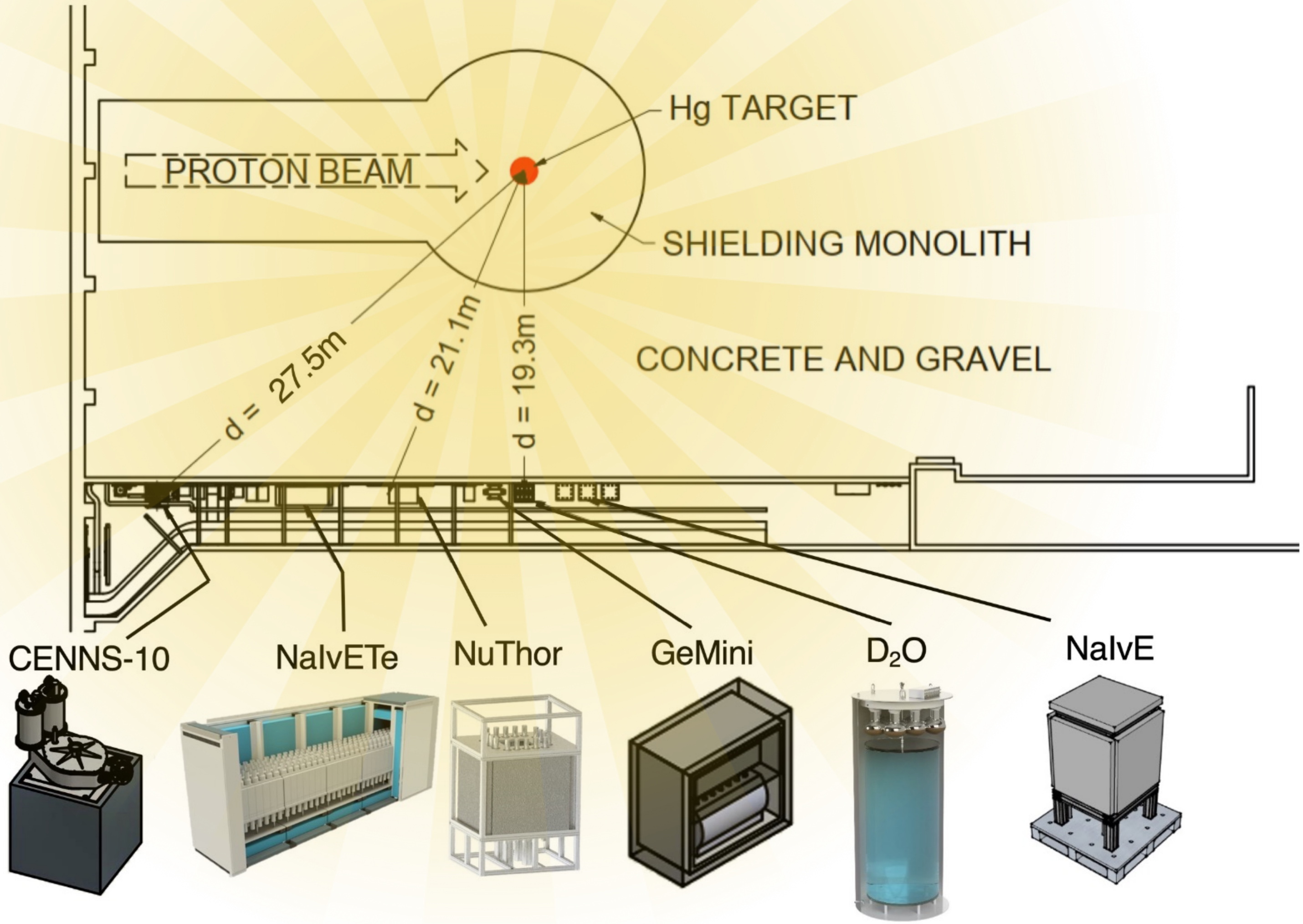


COHERENT
SNS
SPALLATION NEUTRON SOURCE

Siting for deployment in SNS basement

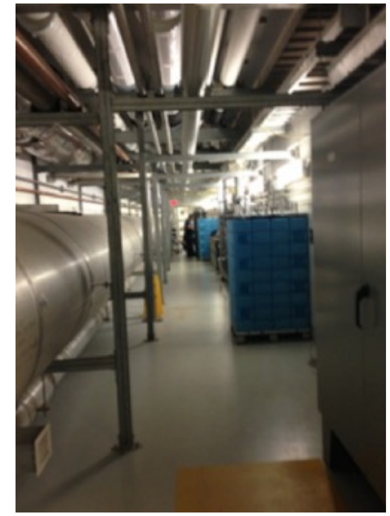
(measured neutron backgrounds low,

~ 8 mwe overburden)

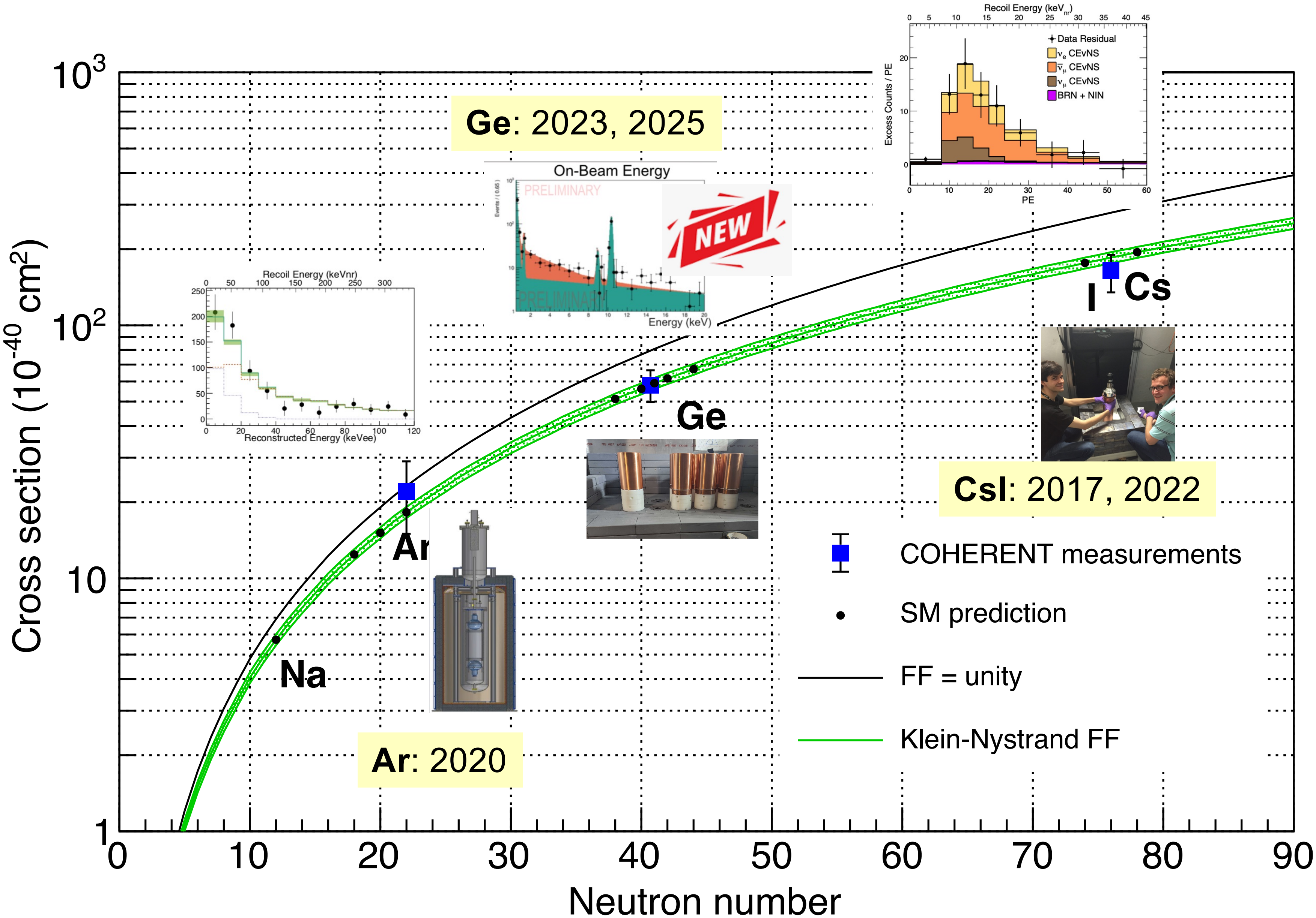


Isotropic ν glow from Hg SNS target

View looking down "Neutrino Alley"

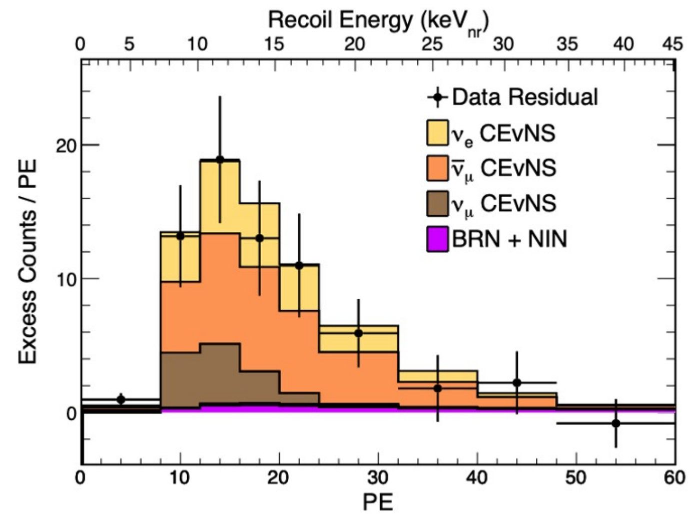


Measurements in 3 targets from COHERENT



Example physics interpretations from COHERENT CsI CEvNS

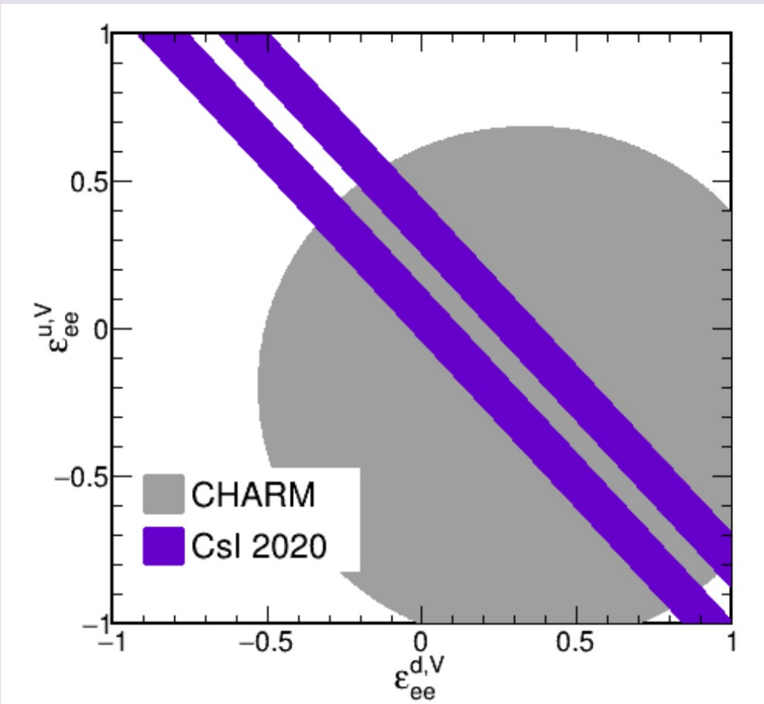
Phys.Rev.Lett. 129 (2022) 8, 081801 • e-Print: 2110.07730 [hep-ex]

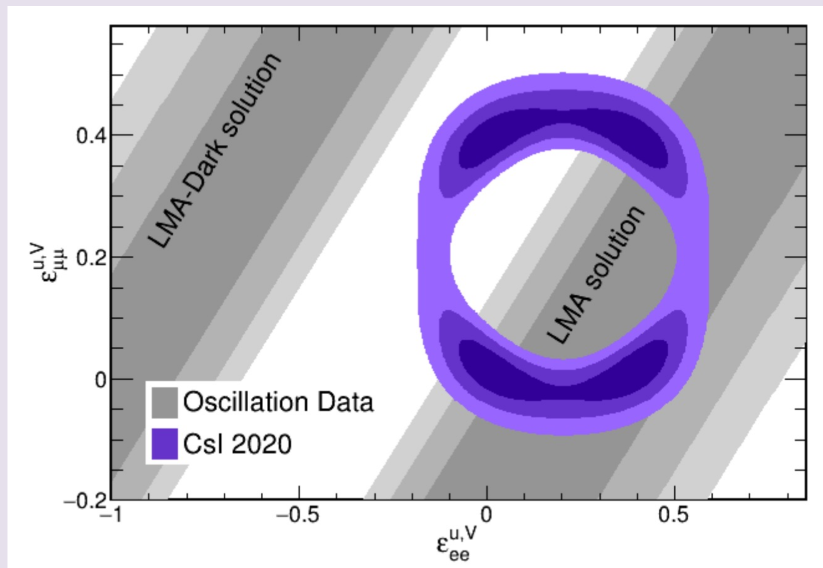


Weak Mixing Angle

$$\sin^2\theta_W = 0.220^{+0.028}_{-0.026}$$

NSI constraints



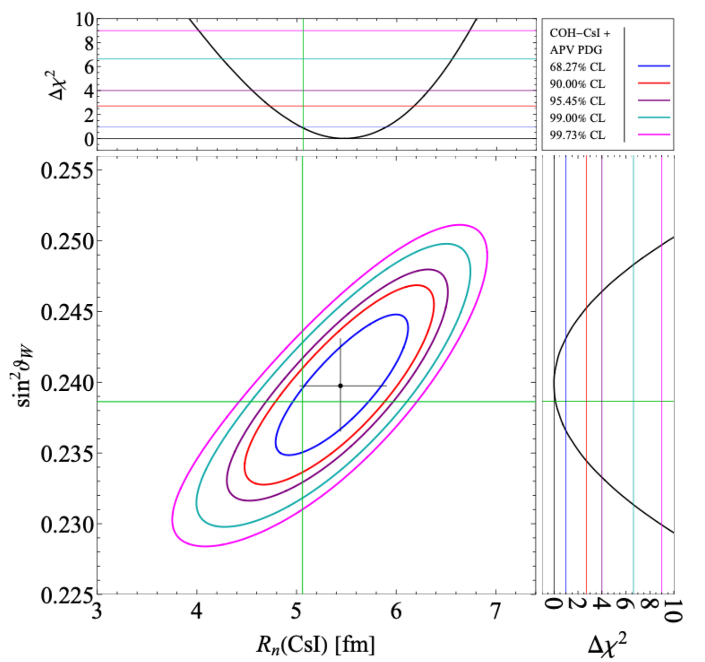


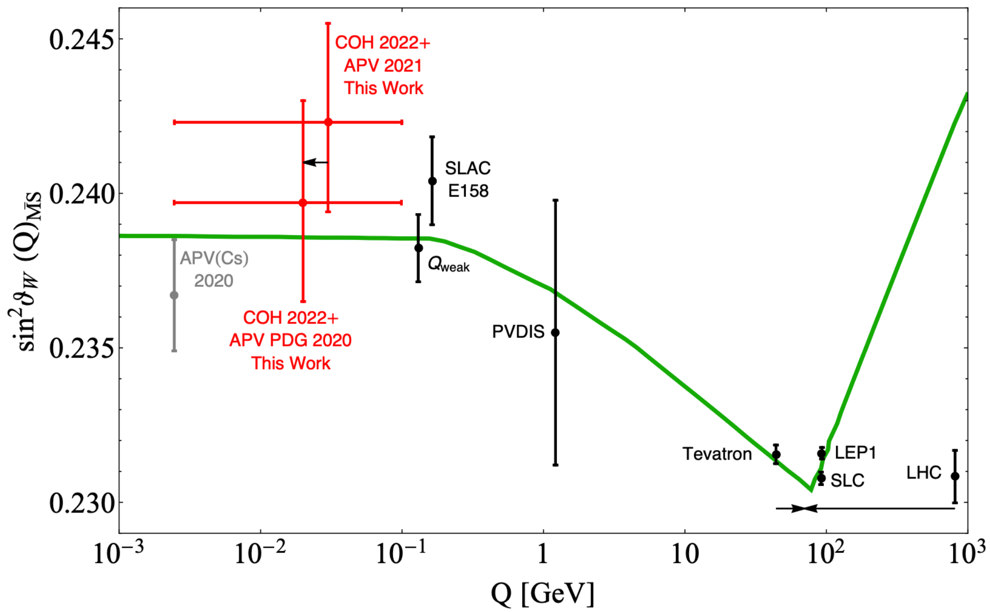
WMA and Neutron Radius from COHERENT CsI data

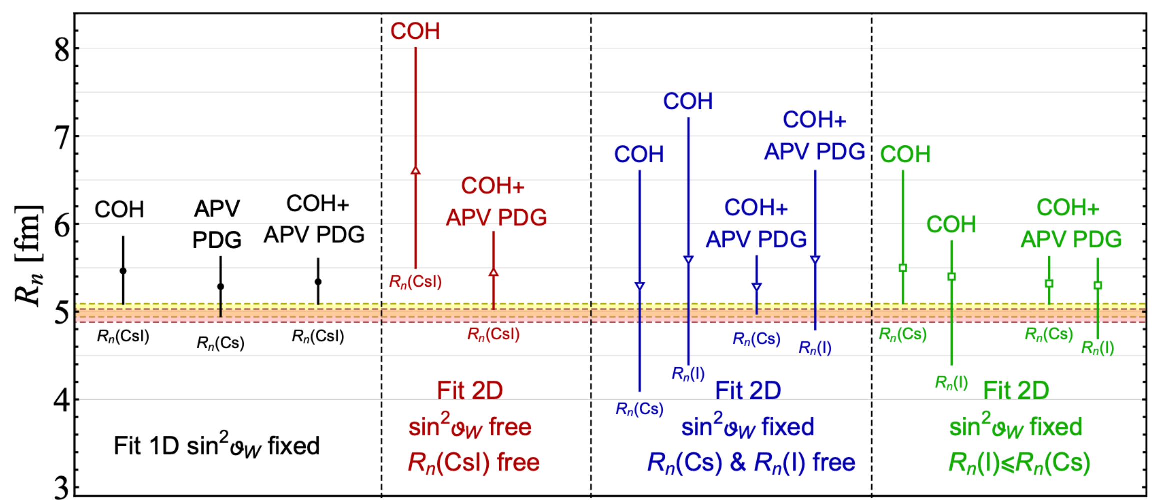
: *Eur.Phys.J.C* 83 (2023) 7, 683 • e-Print: 2303.09360 [nucl-ex]

COHERENT combined w/APV result

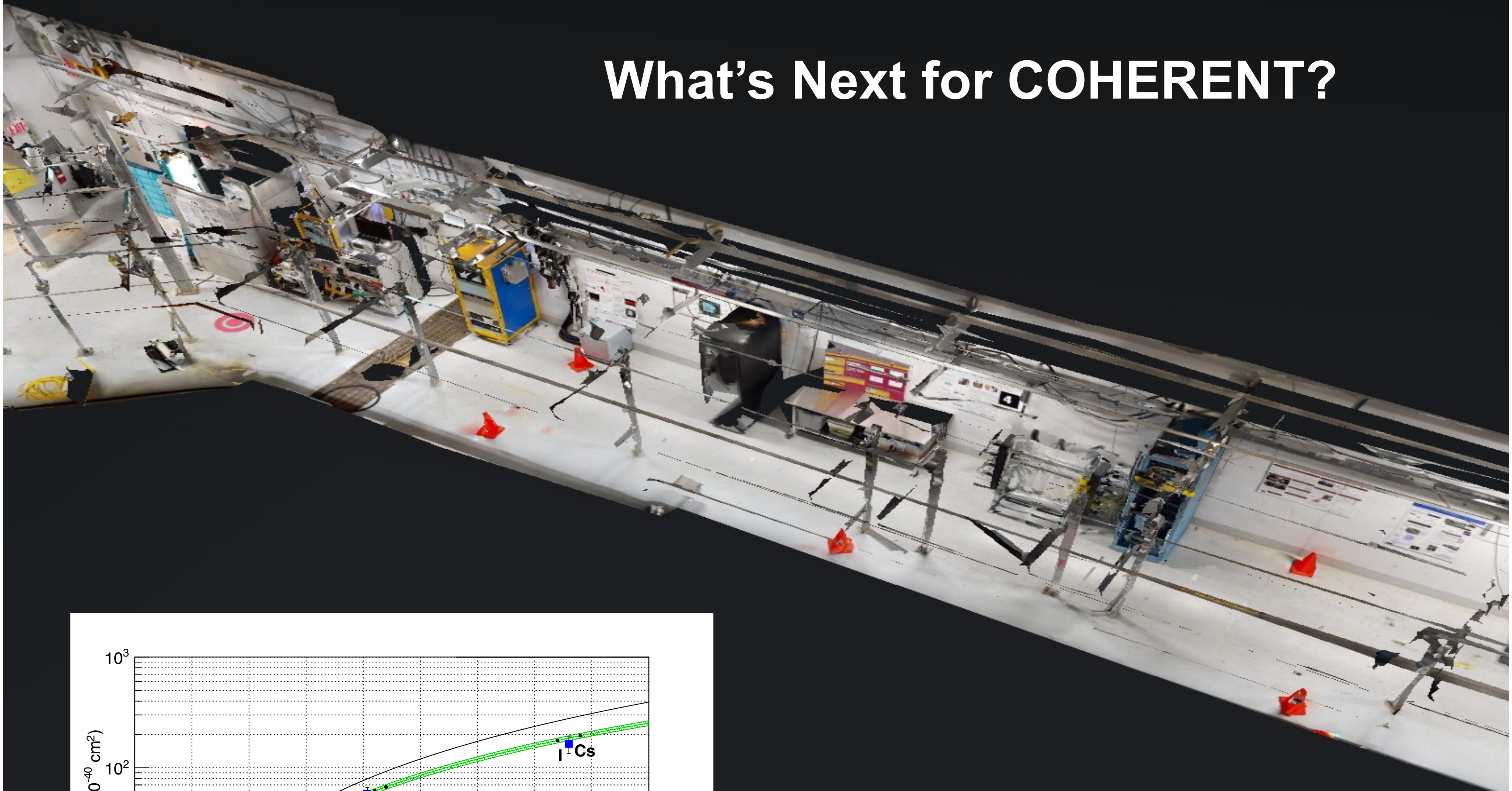
R_n (CsI)=$5.4^{+0.5}_{-0.4}$ fm $\sin^2\vartheta_W$=$0.2397^{+0.0033}_{-0.0032}$ χ^2_{min}= 85.2

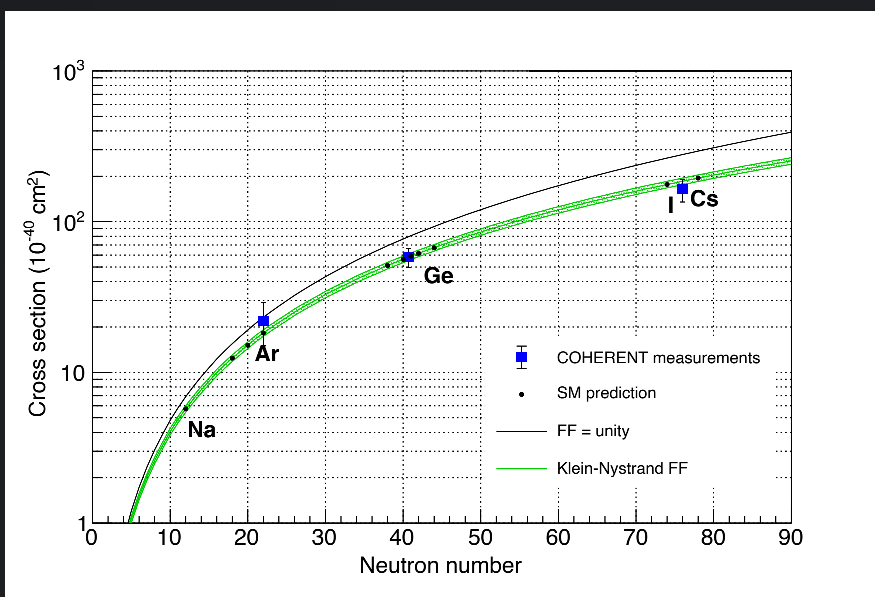






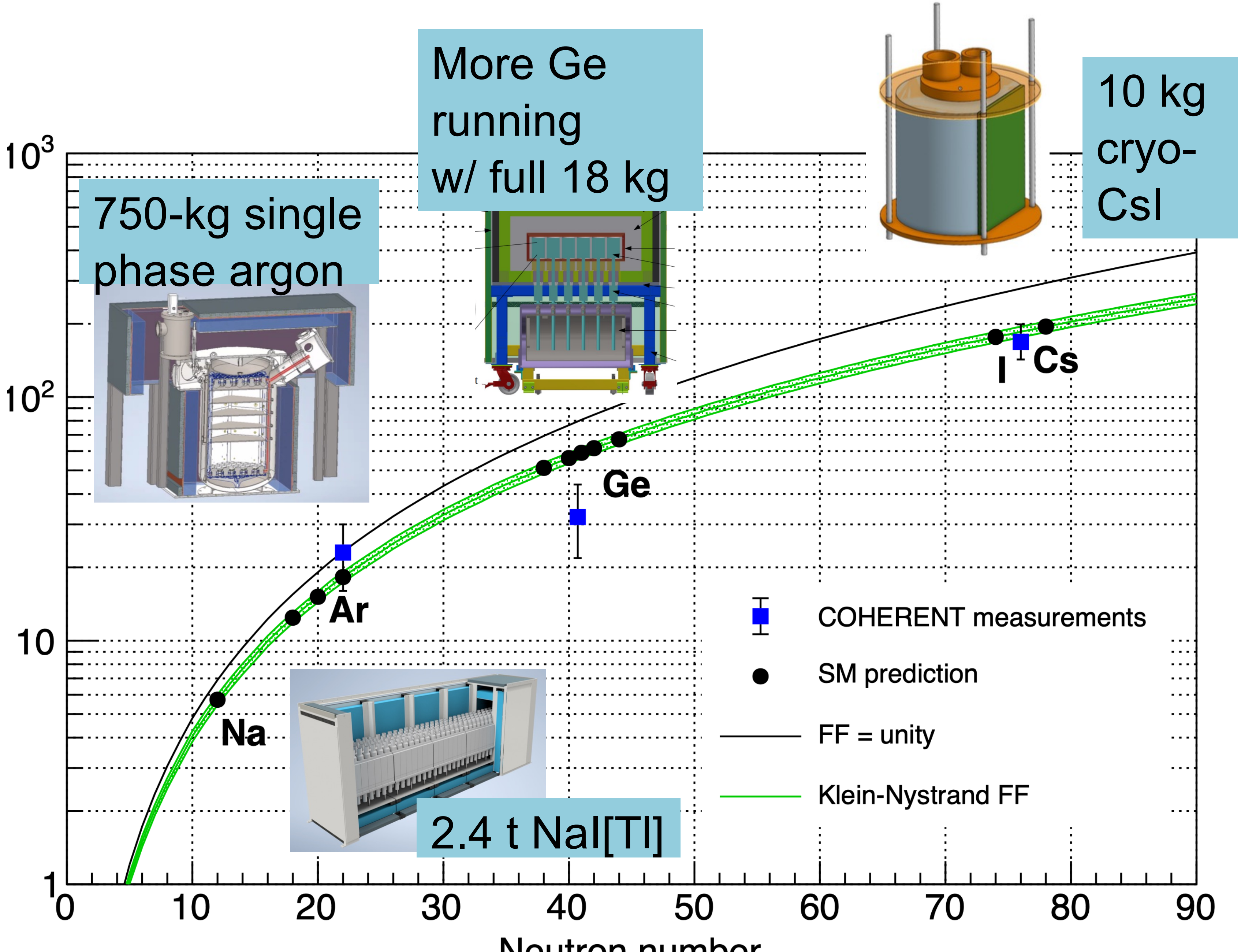
What's Next for COHERENT?





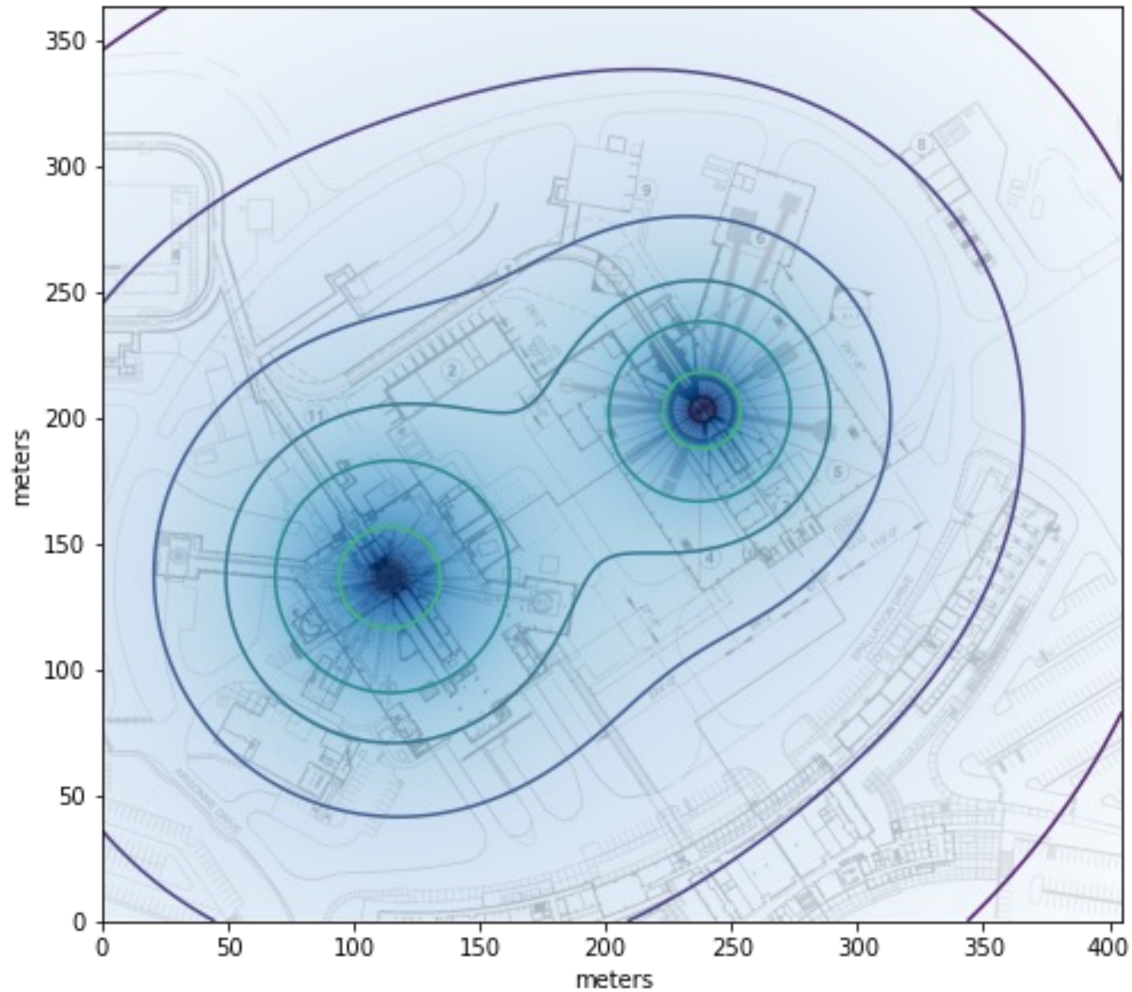
Three down!
But still more
to go!

Ongoing CEvNS in Neutrino Alley



(... and more inelastics)

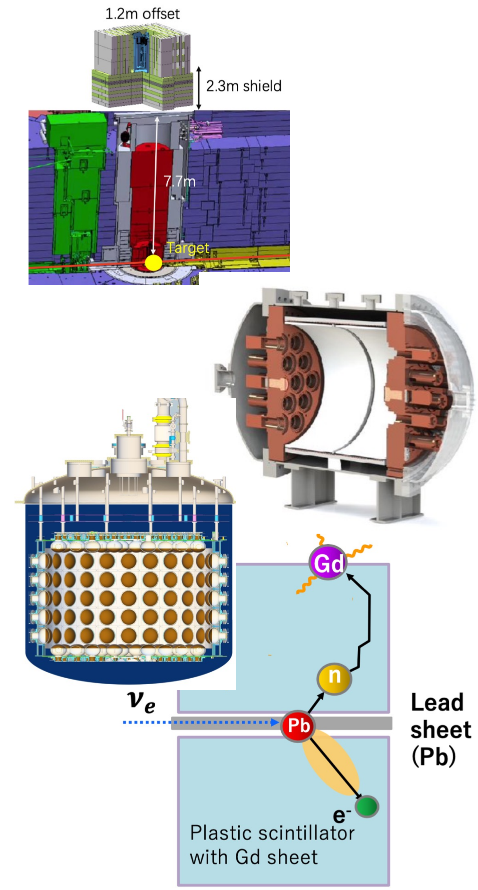
SNS power upgrade to 2 MW underway,
Second Target Station upgrade to 2.8 MW ~2030's



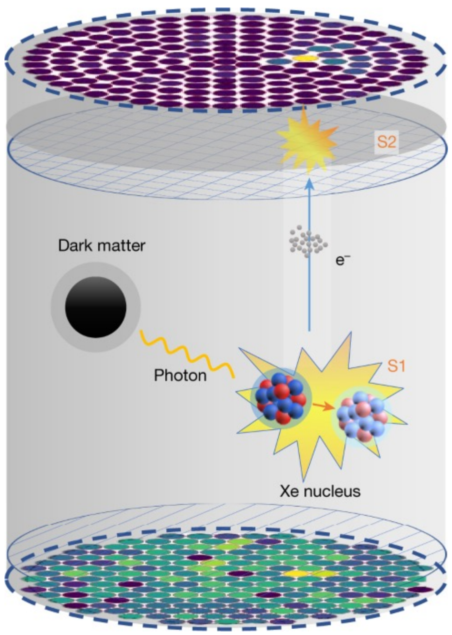
Many exciting possibilities for ν's + DM!

Other Experiments at Stopped-Pion Sources

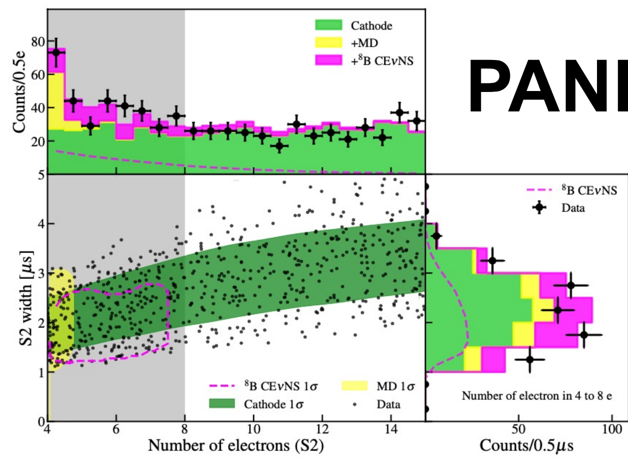
Facility	Country	Experiment(s)
China Spallation Neutron Source	China	CLOVERS
European Spallation Source	Sweden	NuESS (several)
Lujan, LANL	USA	Coherent Captain Mills
Materials and Life Science Facility, J-PARC	Japan	JSNS^2, DArVeX [not CEvNS]
Spallation Neutron Source, ORNL	USA	COHERENT, (EOS)



Dark matter experiments starting to descend through the neutrino "fog" (or "glare")

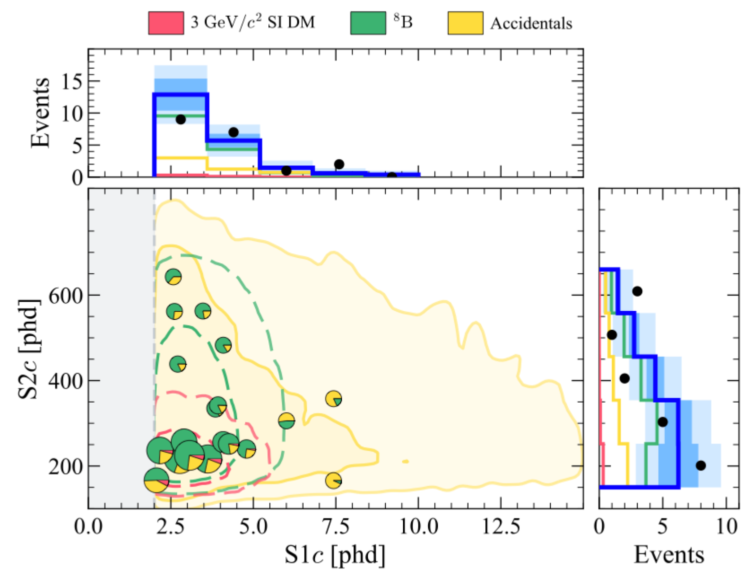


Dual-phase low-energy TPCs

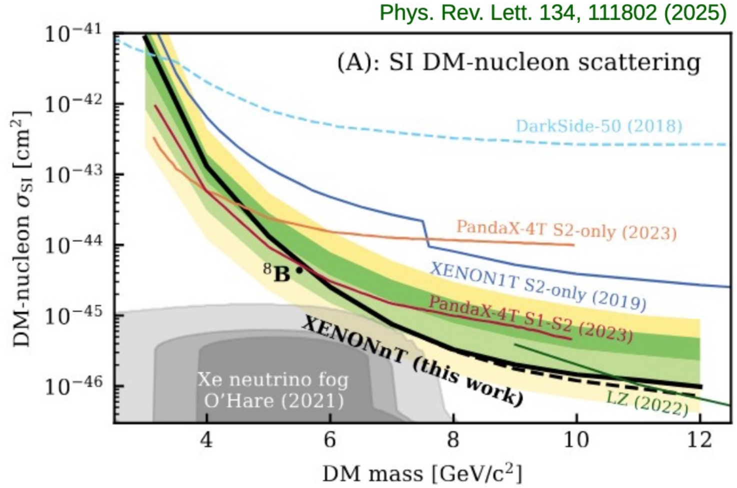


PANDA-X

Solar ν CEνNS in three DM experiments



Phys. Rev. Lett. 134, 111802 (2025)



LZ NEW

[arXiv:2512.08065v2]

XENONnT

Many experiments worldwide in the game

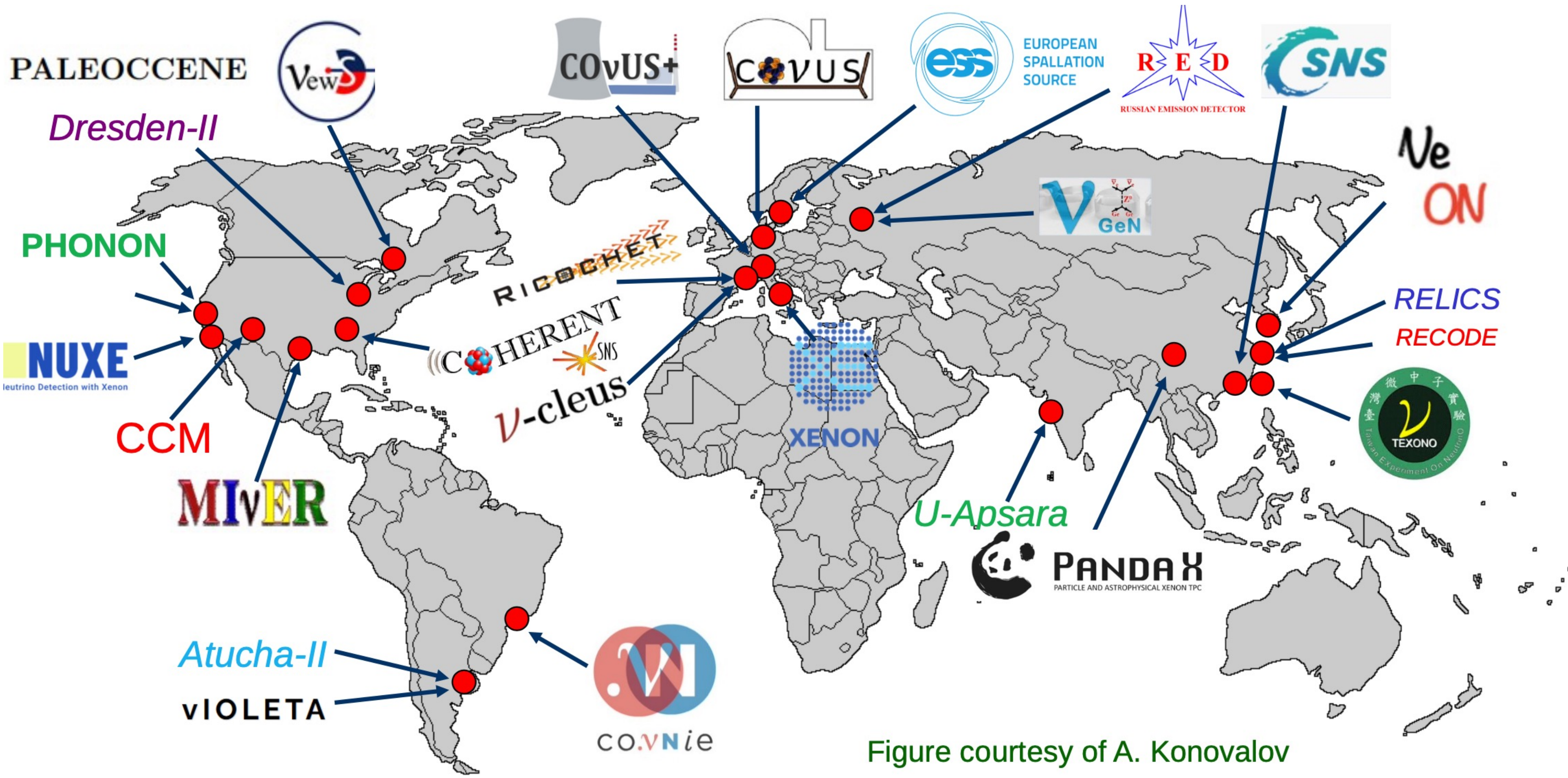


Figure courtesy of A. Konovalov

Reactor CEvNS experiments with measurements (signal or limits)

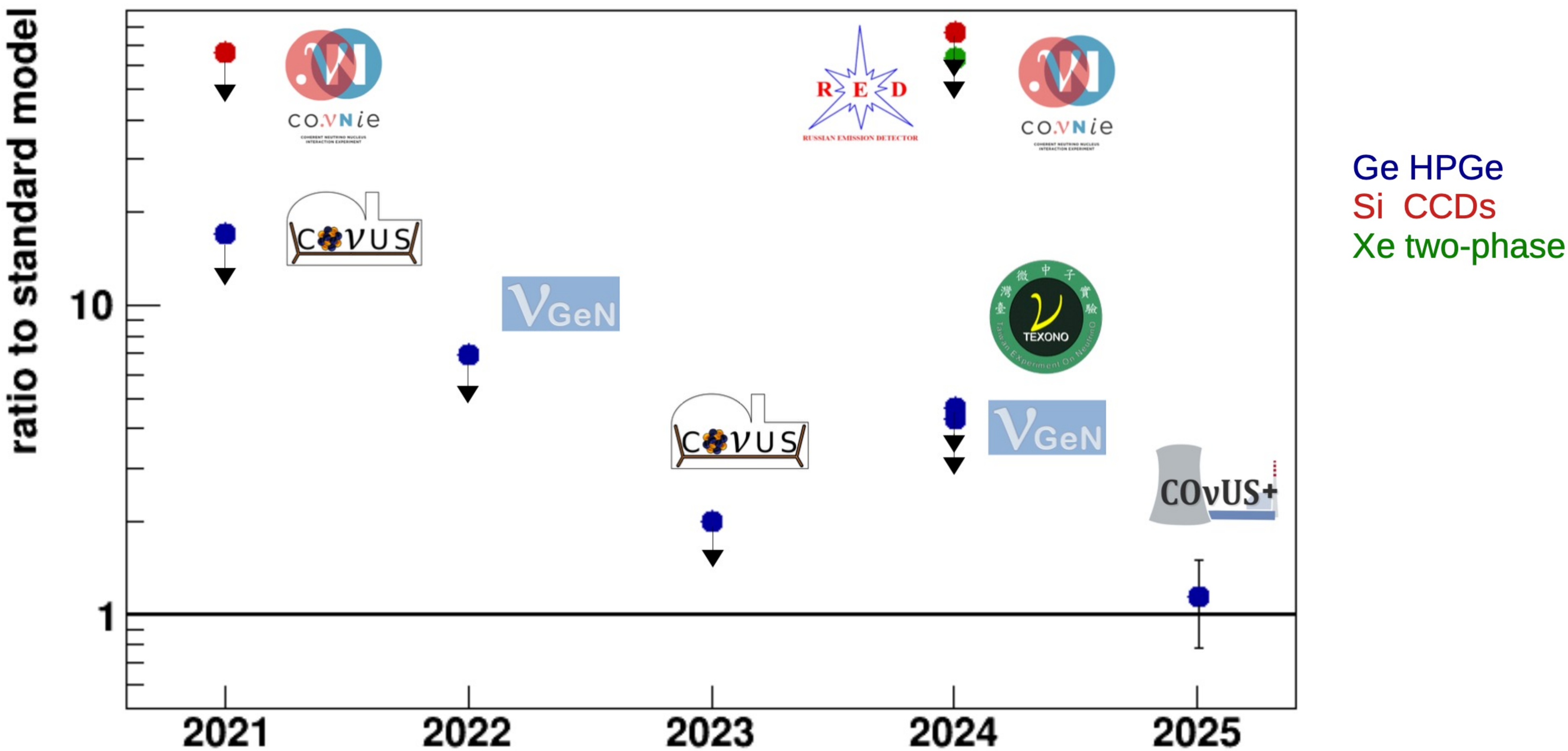
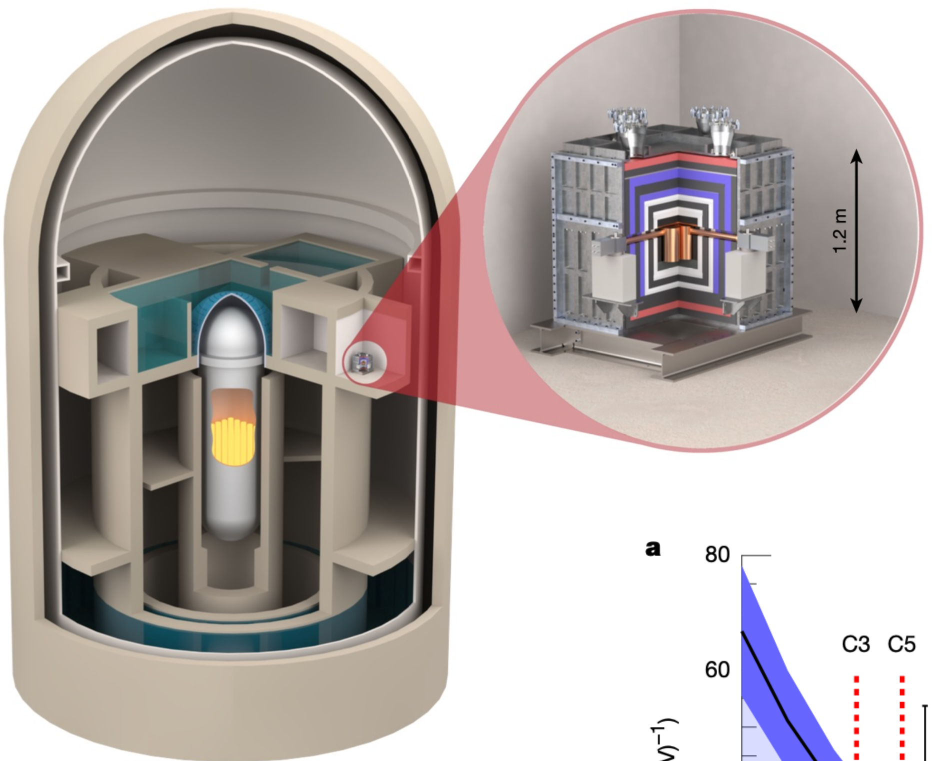


Figure from J. Hakenmüller

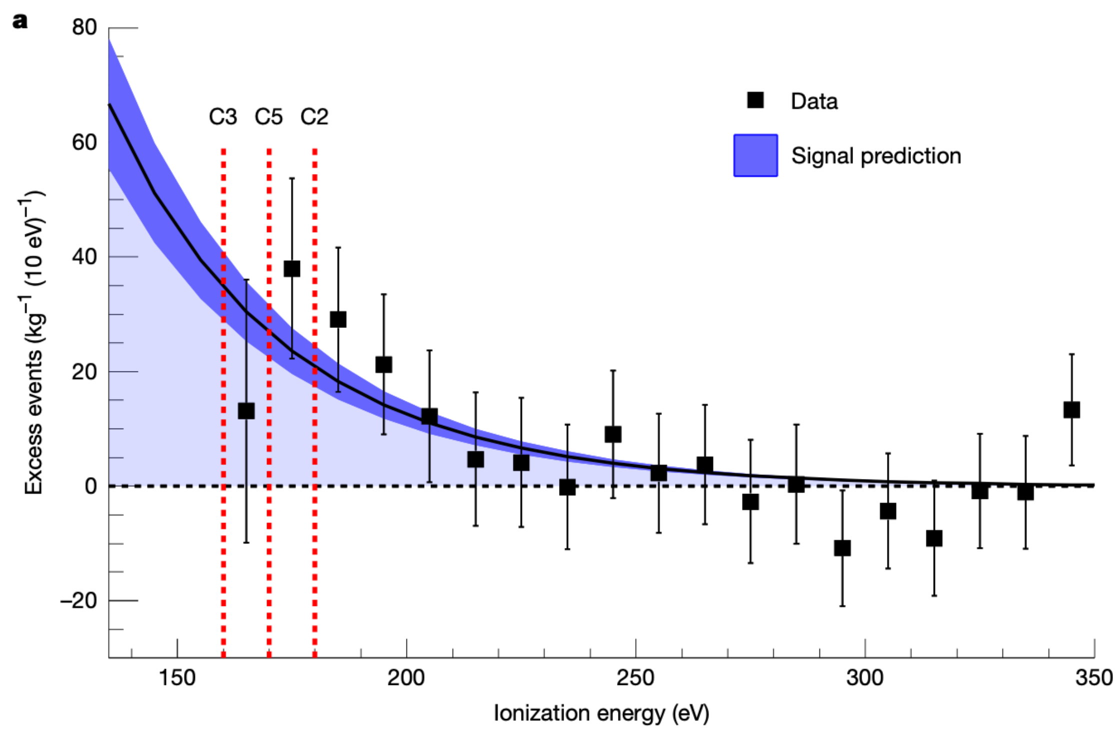
And reactor CEvNS has finally been seen!



CONUS+

4 ~1kg HPGe detectors
3.7σ measurement

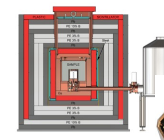
Nature 643, 1229–1233 (2025)

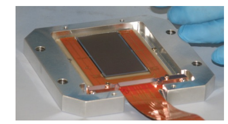
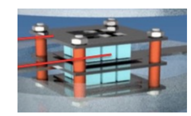
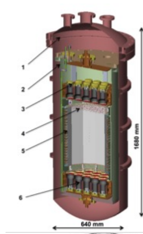


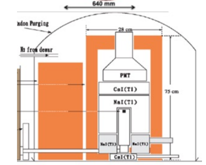
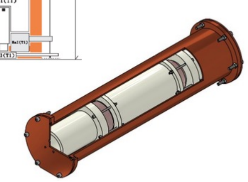
Ratio to SM:
1.14+-0.36

Many technologies in play, going for low threshold

Experiment	Distance to core (m)	max. ν flux ($cm^{-2}s^{-1}$)	Target nuclei	E_{nr} recoil best (eff.) (keVr)	Status
Semiconductor					
CONUS+ [80]	20.7	$1.5{\cdot}10^{13}$	Ge	0.9 (>95%)	running
NuGeN [122]	$11.1^{(***)}$	$4.4{\cdot}10^{13}$	Ge	1.6 (90%)	running
CONNIE [83]	30	$7.8{\cdot}10^{12}$	Si	0.24 (15%)	running
CONUS [121]	17.1	$2.3{\cdot}10^{13}$	Ge	1.2 (20%)	finished
TEXONO [123]	28	$6.4{\cdot}10^{12}$	Ge	1.1 (30%)	finished
NCC-1701 [125]	10.4	$4.8{\cdot}10^{13}$	Ge	1.1 (0%)	finished
RECODE [129]	~25	$\sim1.0{\cdot}10^{13}$	Ge	$0.9^{(**)}$	comm.
Atucha II [130]	12	$2.3{\cdot}10^{13}$	Si	0.44 (45%)	comm.
Cryogenic bolometers					
NUCLEUS [92]	72, 102	$3.0{\cdot}10^{12}$	W, Ca Al, O	$0.02^{(**)}$	comm.
RICOCHET [136]$^{(*)}$	8.8	$1.1{\cdot}10^{12}$	Ge, Zn	$0.01^{(**)}$	comm.
Noble gas/liquid					
RED-100 [89]	19	$1.4{\cdot}10^{13}$	Xe, Ar	2 (15%)	running
RELICS [132]	~25	$\sim1.0{\cdot}10^{13}$	Xe	$0.6\text{-}1.4^{(**)}$	comm.
Scintillating crystals					
NEON [78]	23.7	$8.1{\cdot}10^{12}$	Na, I	$2, 6^{(**)}$	running

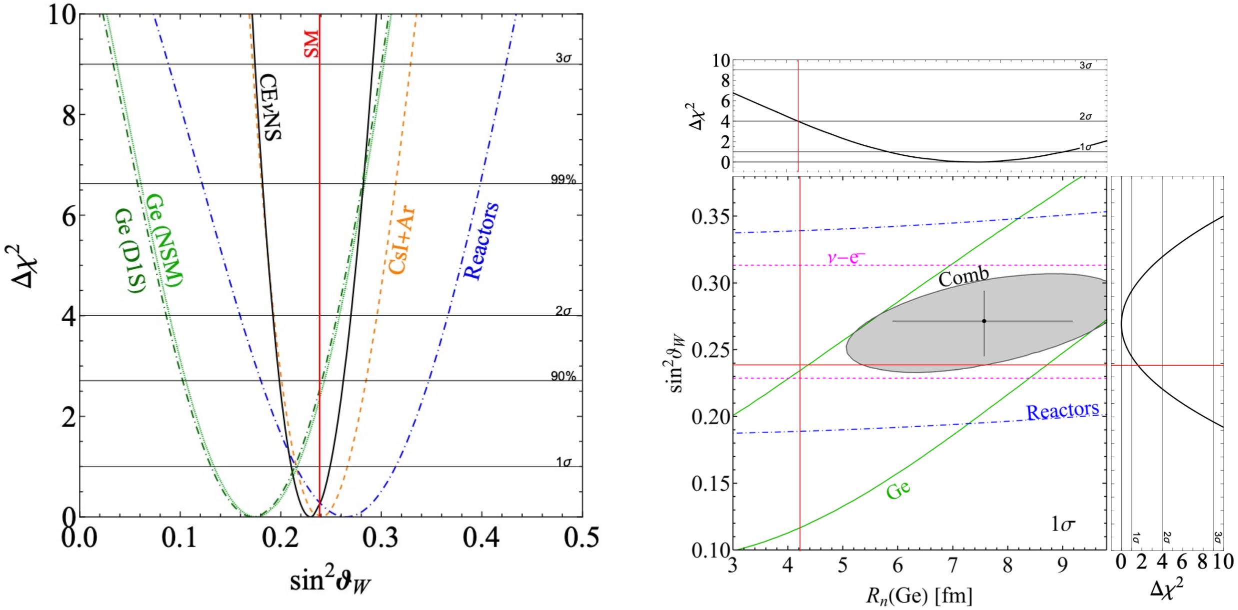


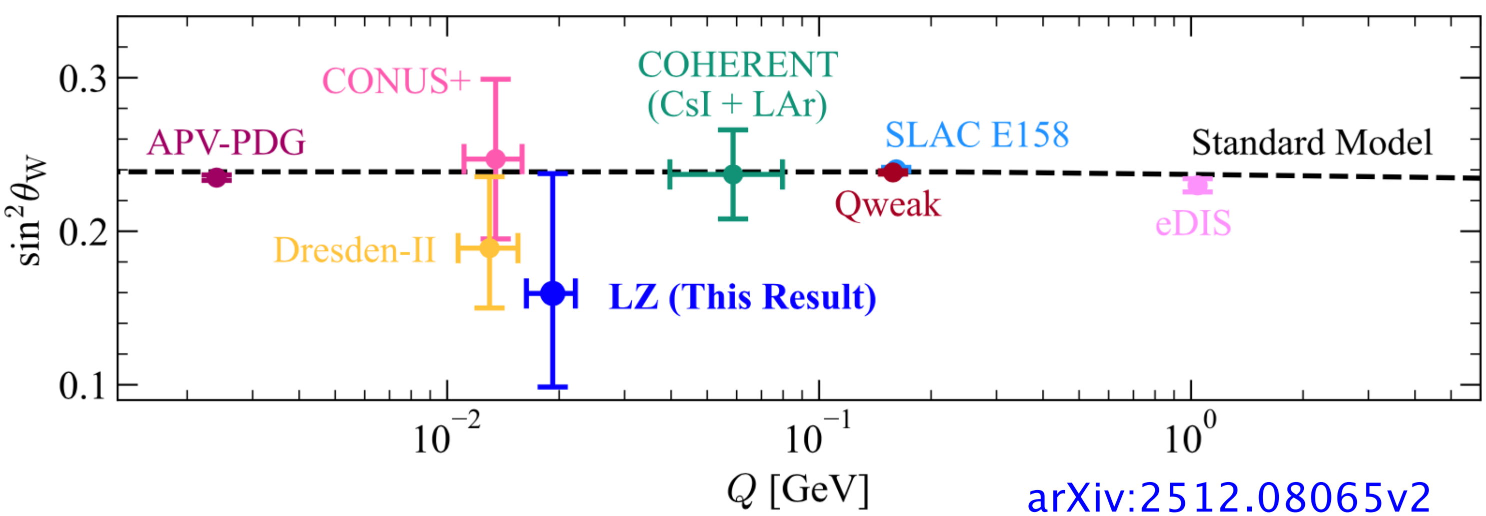
+ directional recoils (CYGNUS), mineral detection (PALEOCCENE), supernova (RES-NOVA) and more...

More interpretation with new data rolling in



Phys.Lett.B 869 (2025) 139856 • e-Print: 2506.13555 [hep-ph]

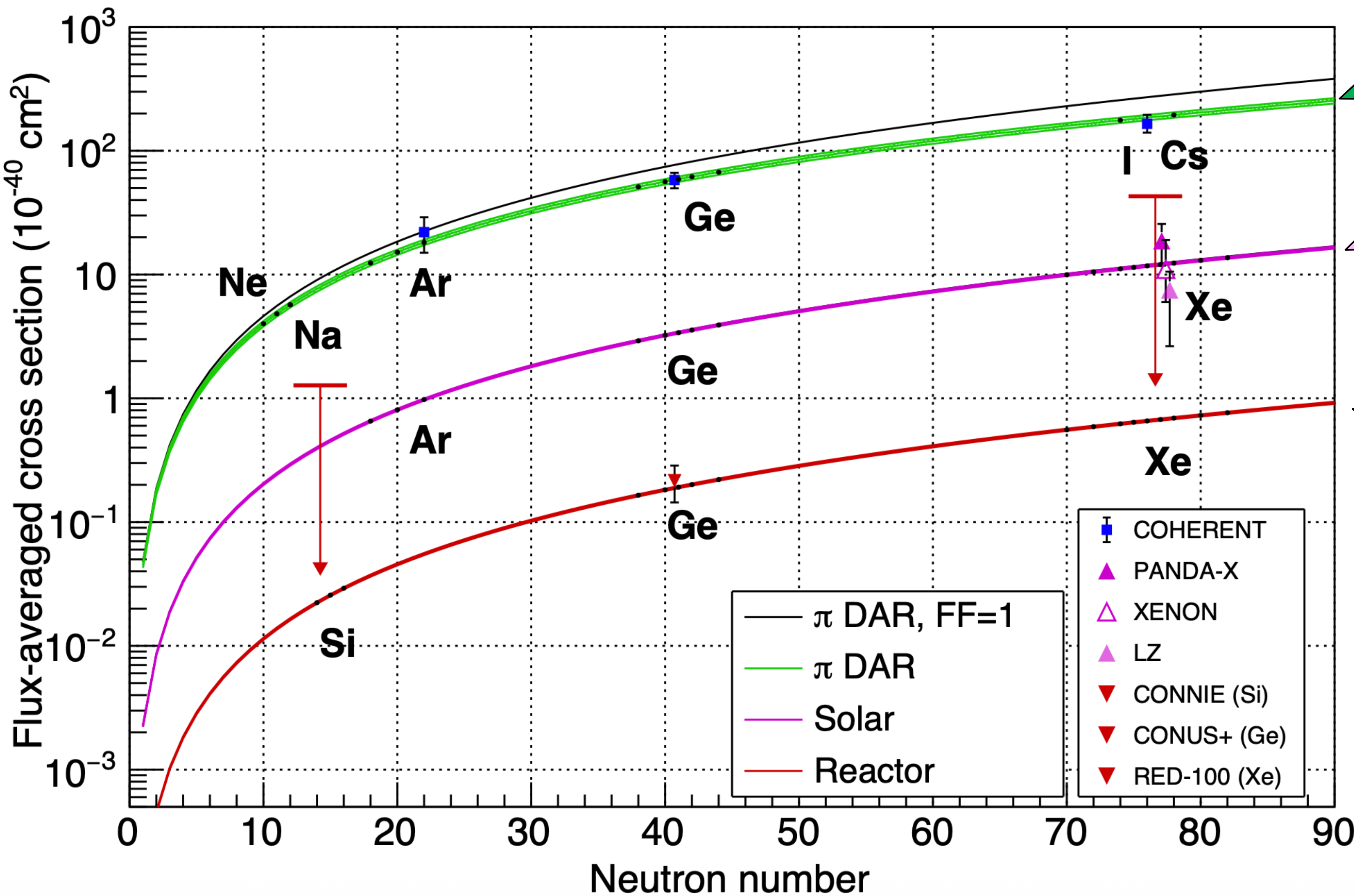
COHERENT (first Ge) and CONUS+ Ge data

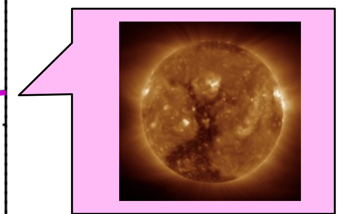


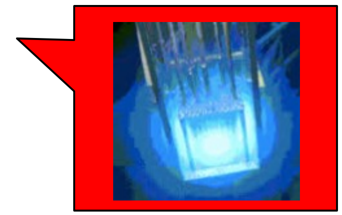
Including LZ data

arXiv:2512.08065v2

Worldwide CEvNS status





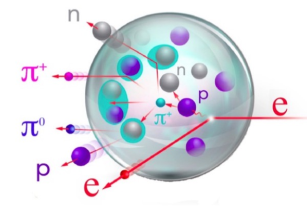


"Best" measurement for each target/source combination

Summary

Area 1: electron-nucleus scattering to **inform understanding of neutrino-nucleus interactions**, primarily for ν oscillation physics

Data under analysis to improve event generator tuning & reduce uncertainties



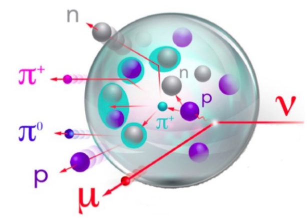
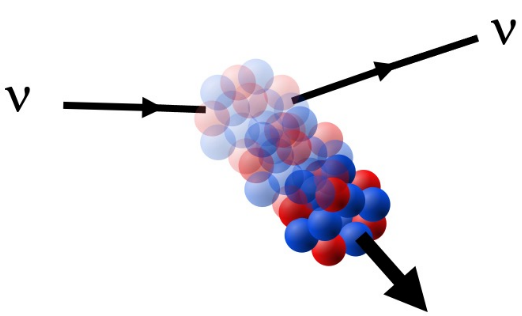


Image credit: J. Vidal



Area 2: neutrino-nucleus elastic scattering for **electroweak physics, BSM and nuclear structure**, complementary to PVES

Rich program of CEvNS experiments w/ initial R_n, $\sin^2\theta_W$ measurements; not (yet) as precise as PVES but different approach

And more connections out there...!

Extras/Backups