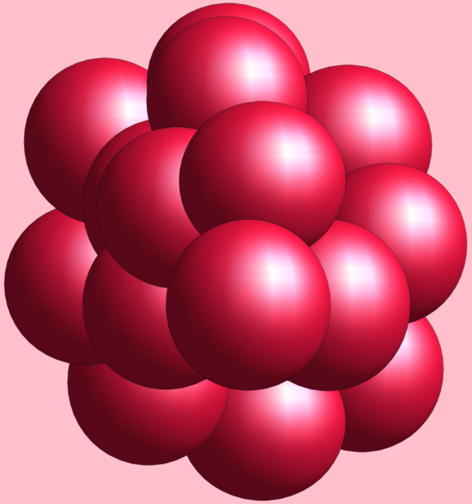


Review on coherent elastic neutrino nucleus scattering (CEvNS)

Janina Hakenmüller

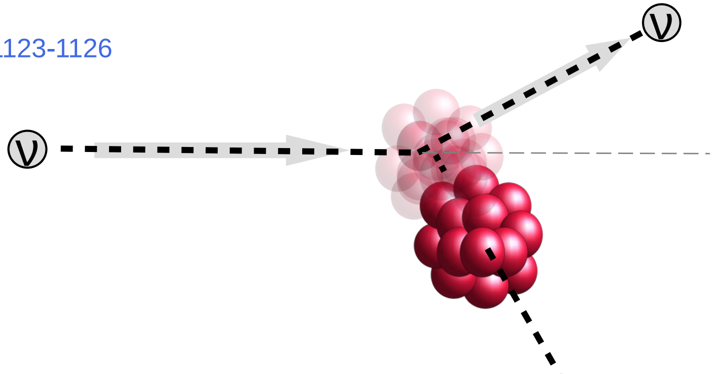
MARIETTA BLAU INSTITUTE FOR PARTICLE PHYSICS (MBI, Vienna, Austria)

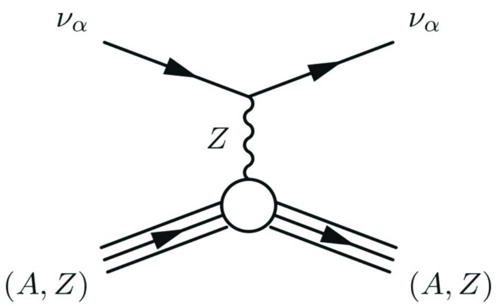
22nd June 2026, Neutrino Conference 2026, Irvine, CA

Coherent elastic neutrino nucleus scattering (CEvNS)

- standard model weak interaction, flavor blind, no energy threshold
- predicted in 1974: D.Z. Freedmann Phys. Rev. D 9, 1389 (1974) 5
- first observed in 2017 by COHERENT Science 357 (2017) 6356, 1123-1126
- **coherence condition:**
  λ(mom. transfer Q) > size of atom
  => σ ~ (#scatter targets)^2
  => large cross section at low E!

E_{max}≤50 MeV
(for medium A)





neutrino energy

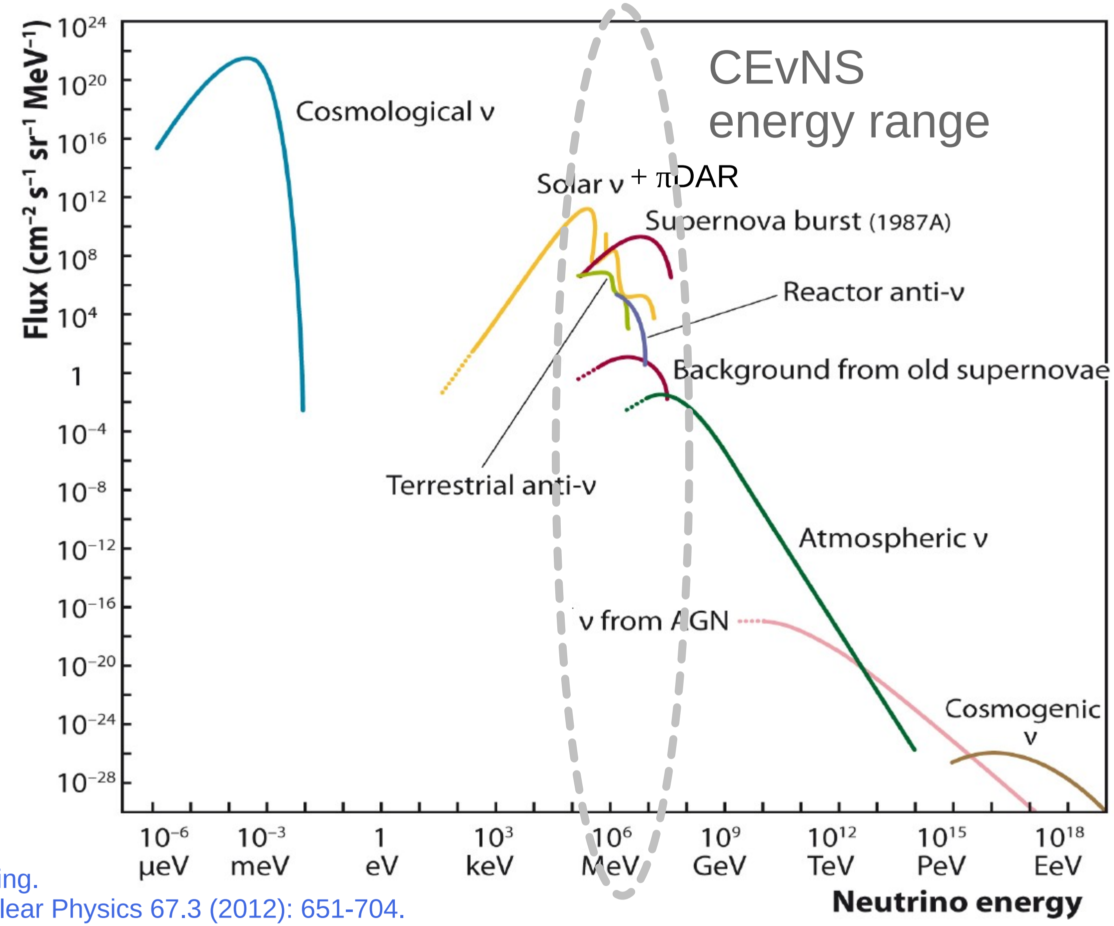
$$\frac{d\sigma}{d\Omega} = \frac{G_f^2}{16\pi^2}(N - (1 - 4\sin^2\theta_W)Z)^2 E_\nu^2 (1 + \cos\,\theta) F(Q^2)$$

nucleus ~N^2

nuclear form factor
F(Q^2) → 1 for Q^2 → 0

Physics motivation

too low energetic recoil to detect



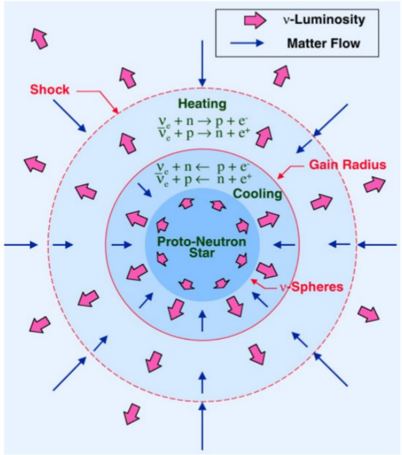
too high energy for coherence

Katz, Ulrich F., and Ch Spiering.
Progress in Particle and Nuclear Physics 67.3 (2012): 651-704.

Physics motivation

stellar collapse:
99% energy released in neutrinos
→ burst modeling
→ detect on Earth

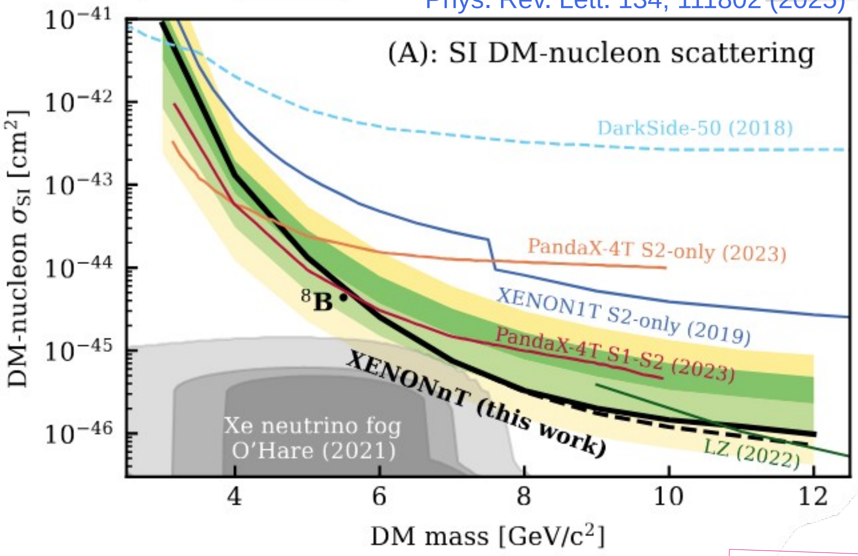
Poster 67



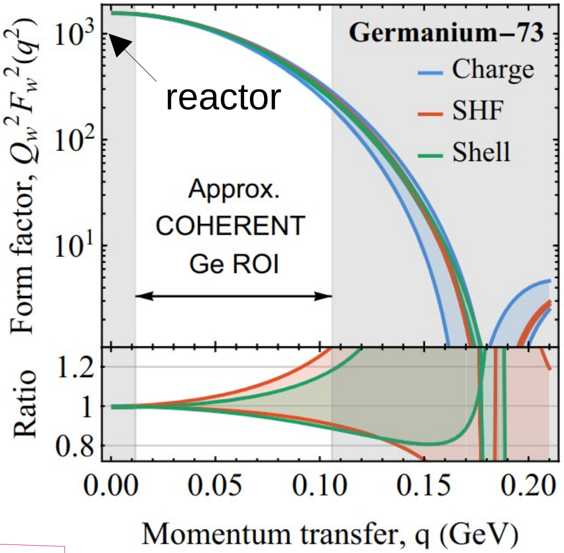
Credit: TeraScale Supernova Initiative

dark matter neutrino floor/fog:
inevitable background
detector understanding

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



nuclear physics:
- neutron form factor
- neutron radius and skin



PRD 111, 033003 (2025)

reactor spectrum/monitoring:
Poster 81

threshold less interaction → detect ^{239}Pu neutrinos

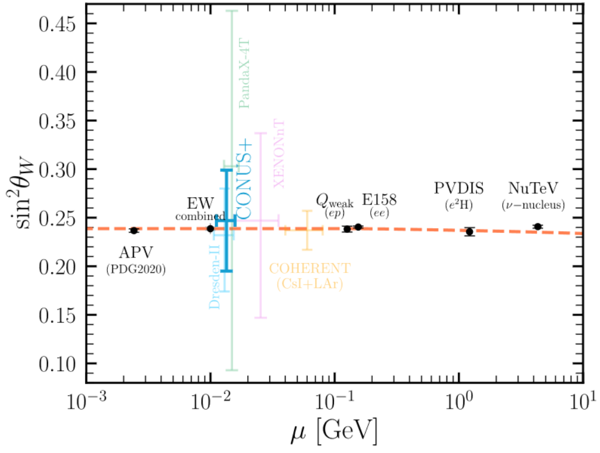
Precision test of the standard model

ν

N² dependence cross section for a wide range of nuclei

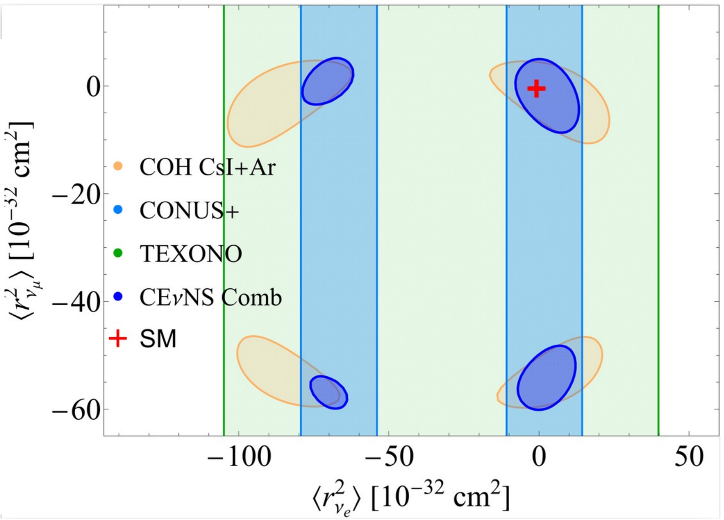
Weinberg angle at low momentum transfer

$$\frac{d\sigma}{d\Omega} \propto (N-(1-4\sin^2\theta_W)Z)^2$$



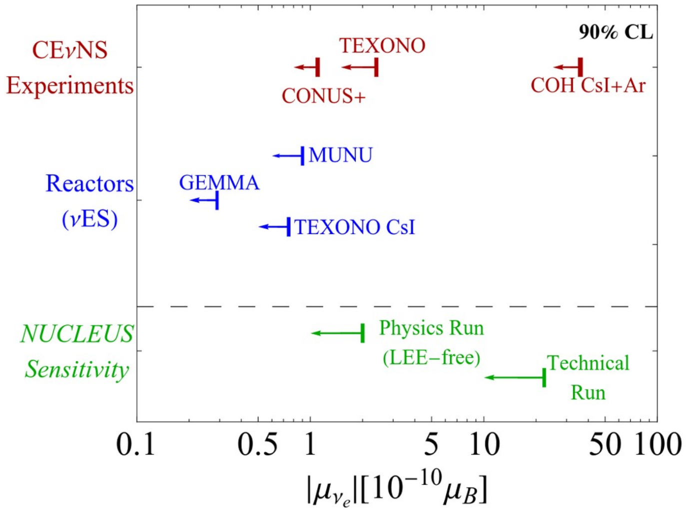
PRD 111 (2025) 7, 075025

neutrino charge radius: SM: O(10^{-32}cm²)



PRD 112 (2025) 1, 015007

neutrino magnetic moment: recoil spectrum and elastic e- scattering

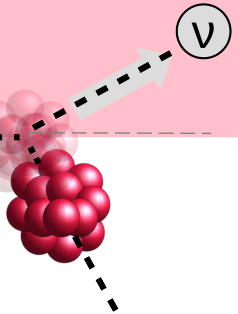


arXiv:2603.24450

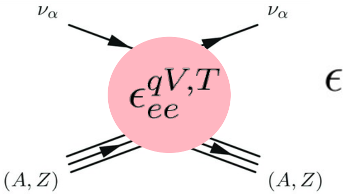
→ any deviations point to physics beyond the standard model

Poster 372, 59

...and beyond

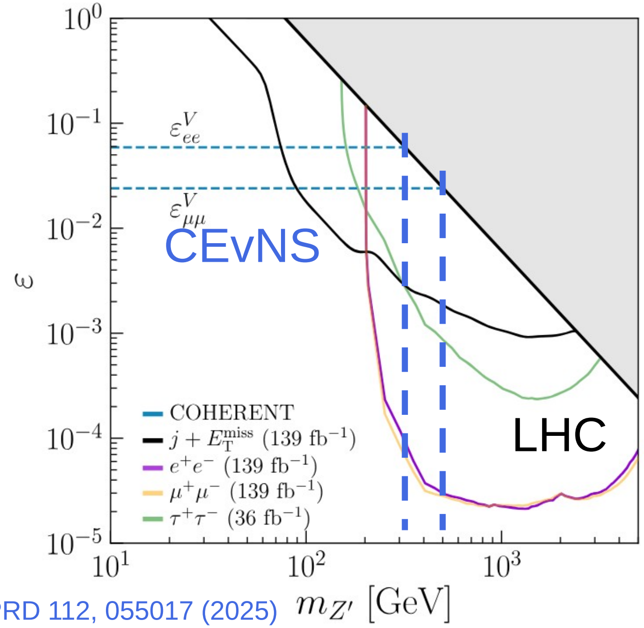


Non-standard interactions



$$\epsilon \approx \frac{g_x^2}{g^2}\frac{M_W^2}{M_x^2}$$

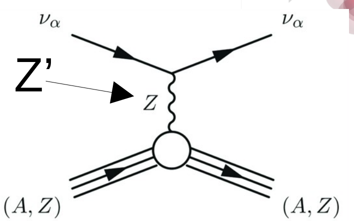
new exchange boson

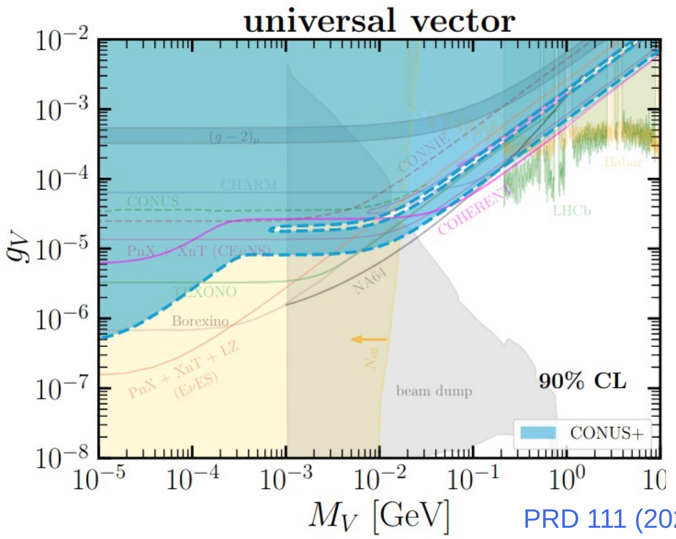


PRD 112, 055017 (2025)

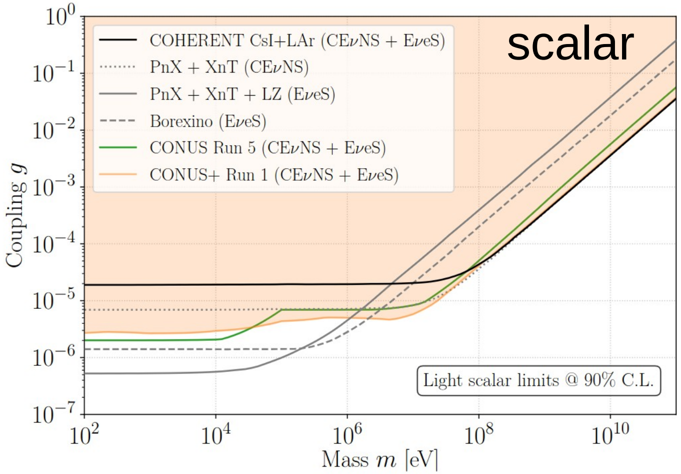
Light mediator models:

vector, scalar, tensor,...





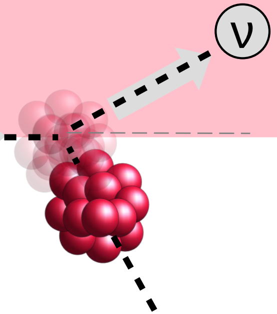
PRD 111 (2025) 7, 075025



arXiv:2605.22815

+ generalized interactions,…
+ more physics opportunities for CEvNS experiments:
  dark matter, sterile neutrinos,...

How to detect CEvNS



coherence $\sigma \propto N^2 E_\nu^2$

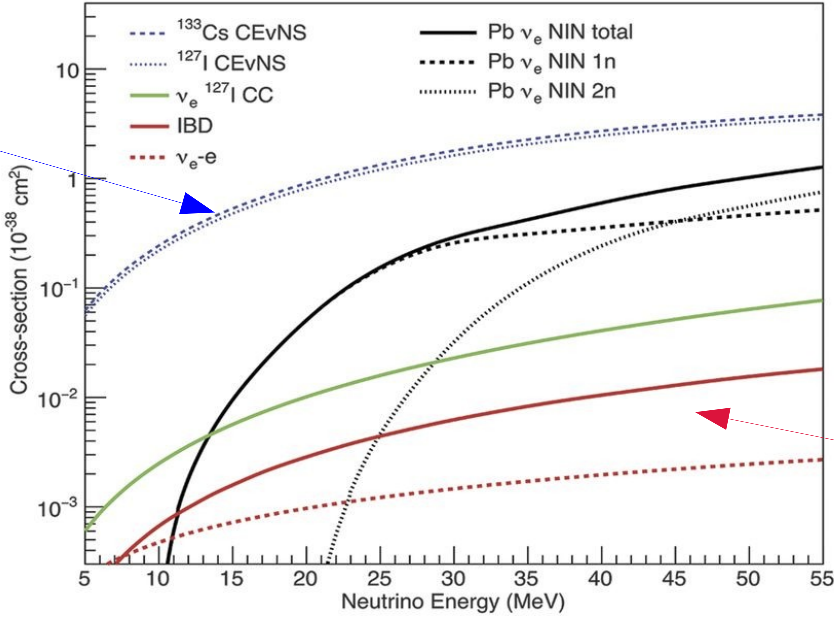
→ large cross section

→ **kg-sized detectors** and **below**

BOREXINO

~100 t fiducial mass

COHERENT CsI 14.6 kg



D. Akimov et al., Science 10.1126/science.aao0990, 2017

How to detect CEvNS

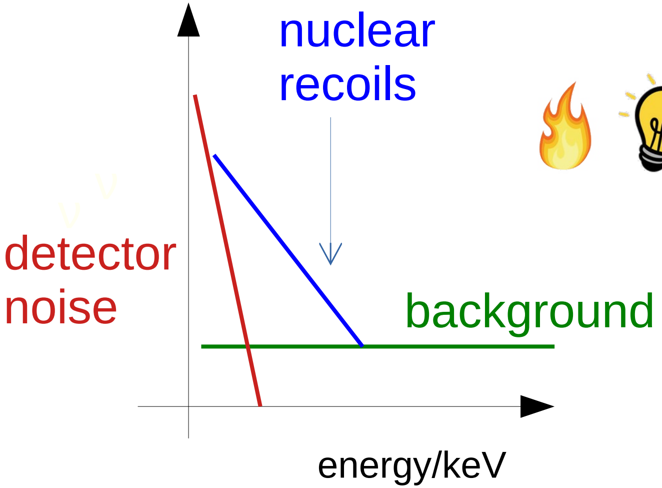
coherence $\sigma \propto N^2 E_\nu^2$

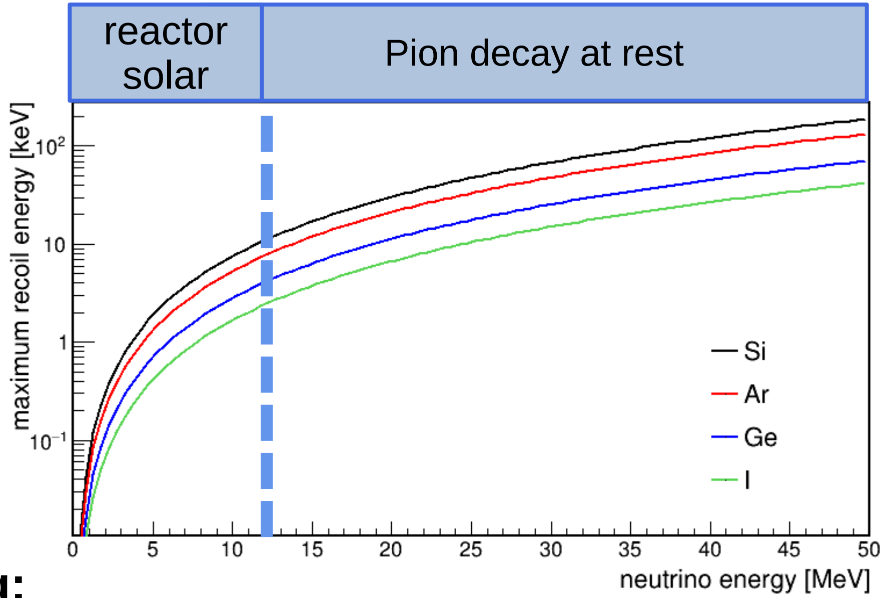
→ large cross section

→ **kg-sized detectors** and **below**

→ **signature in the detector:**

nuclear recoil $T_{max} \approx \frac{2E_\nu^2}{m_n(N+Z)}$



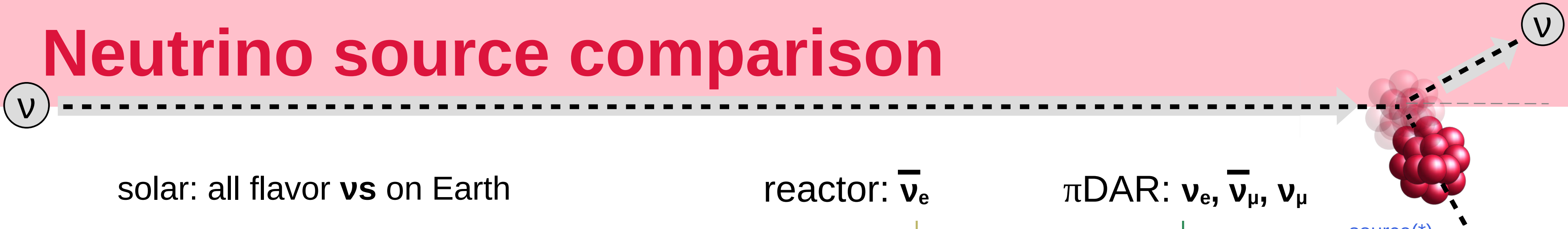


Quenching:

Quenching factor: Q=E(meas)/$E_{\text{nuclear recoil}}$

→ major systematic for detector technologies that does not observe the phonon signal directly

Neutrino source comparison

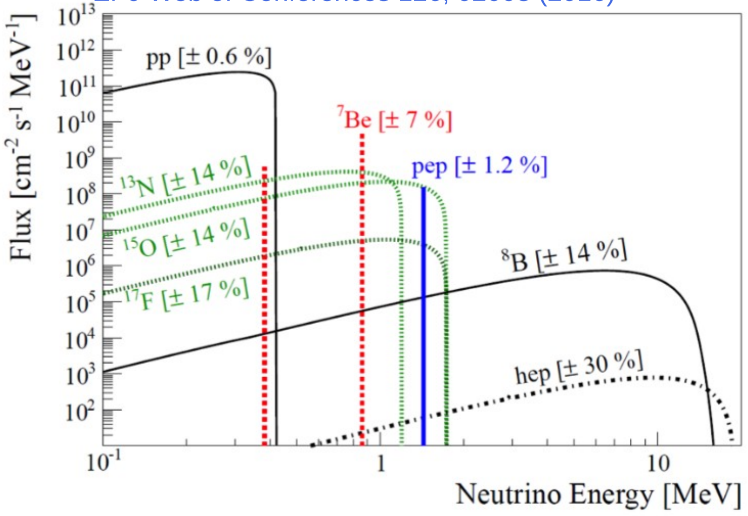


solar: all flavor **νs** on Earth

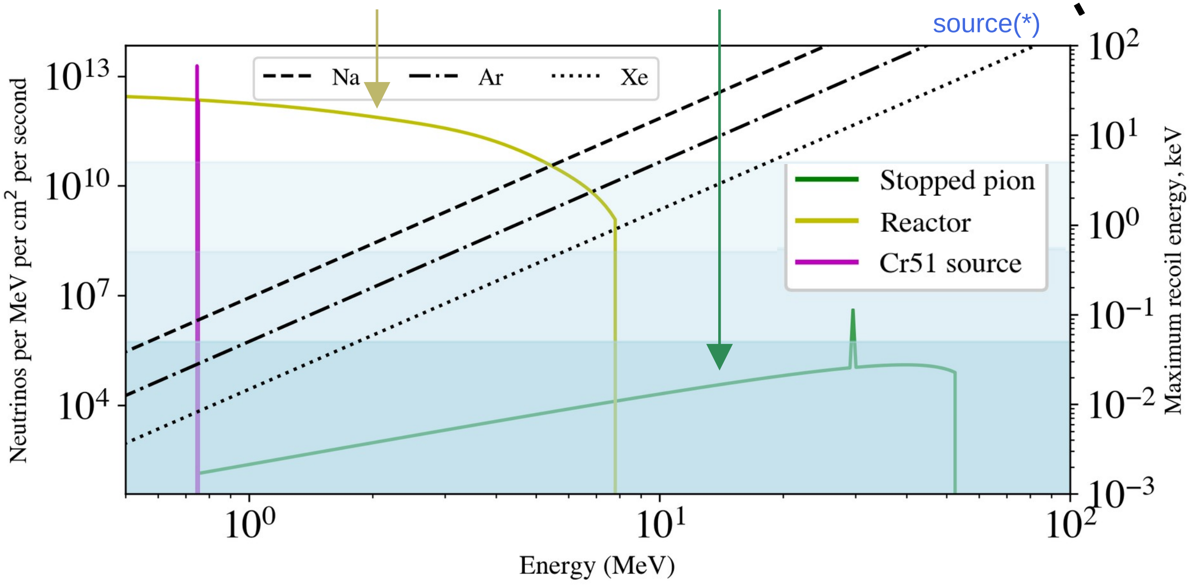
reactor: **$\bar{\nu}_e$**

πDAR: **ν_e, $\bar{\nu}_\mu$, ν_μ**

EPJ Web of Conferences 126, 02008 (2016)



source(*)



form factor ~1, (almost) fully coherent regime

form factor <1

(*) From: Reference Collection in Material Science and Materials Engineering
https://doi.org/10.1016/B978-0-443-26598-3.00067-5

Neutrino source comparison

ν

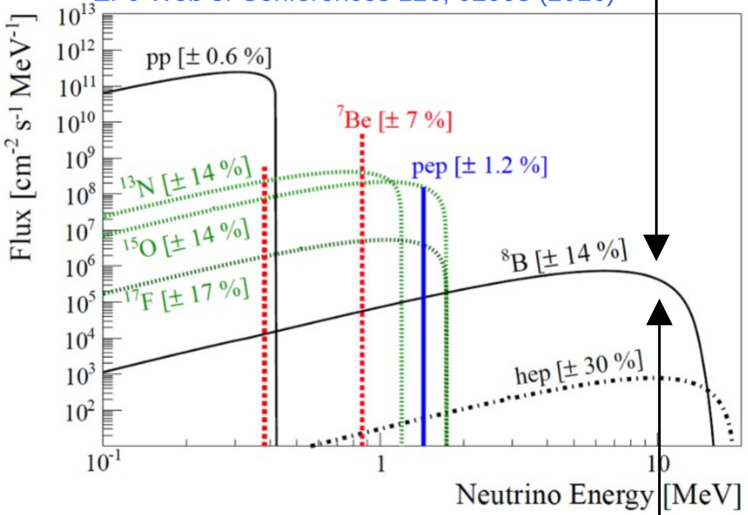
ν

O(10^{7} $cm^{-2}s^{-1}$) ^{8}B on Earth

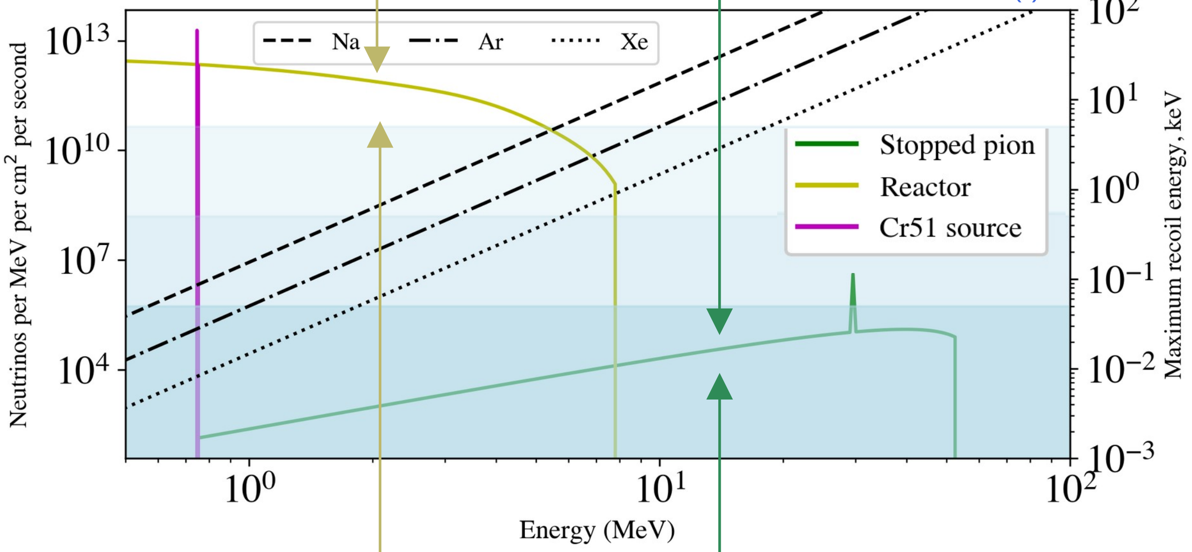
O(10^{12-13} $cm^{-2}s^{-1}$)
close to GW reactors (10-100) m

O(10^{7} $cm^{-2}s^{-1}$) at 20 m
at 1.4 MW, 1 GW proton energy

EPJ Web of Conferences 126, 02008 (2016)



source(*)



experiments deep
Underground,
large mass

(sparse) outages to
measure background

background suppression
by beam correlation: 10^{-3}-10^{-4} (SNS)

(*) From: Reference Collection in Material Science and Materials Engineering
https://doi.org/10.1016/B978-0-443-26598-3.00067-5

CEvNS around the world

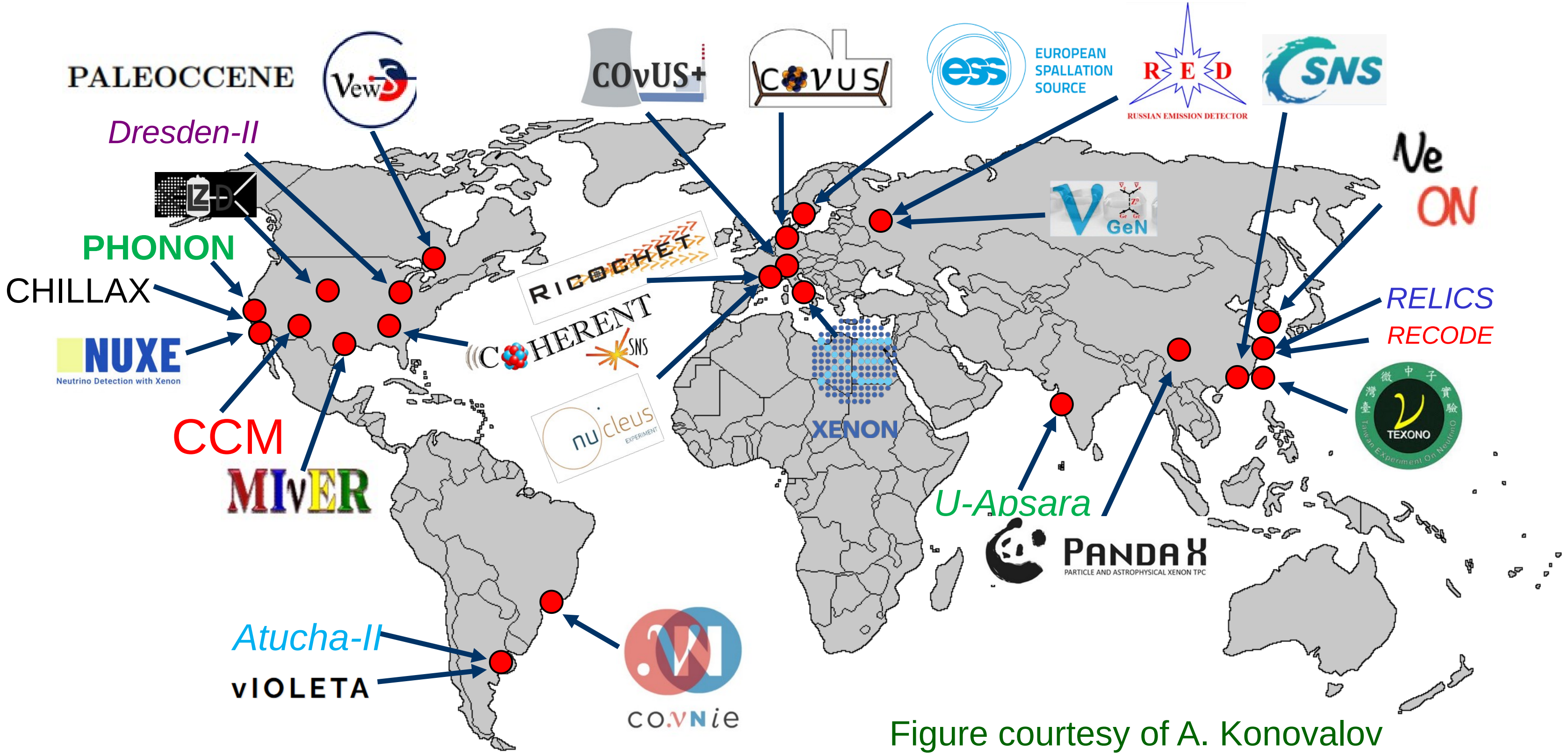
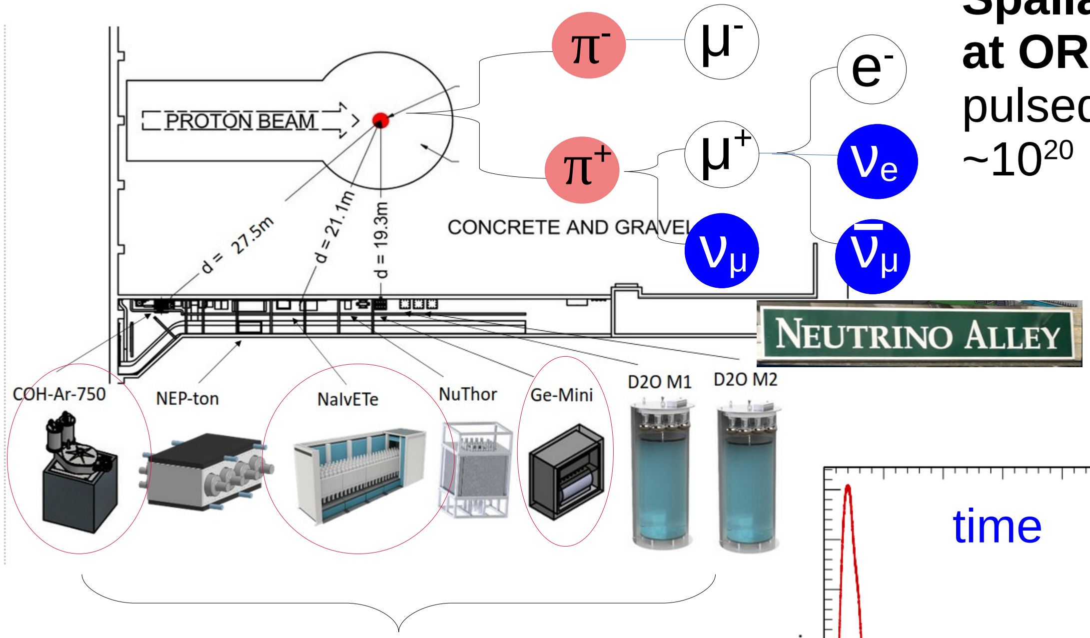


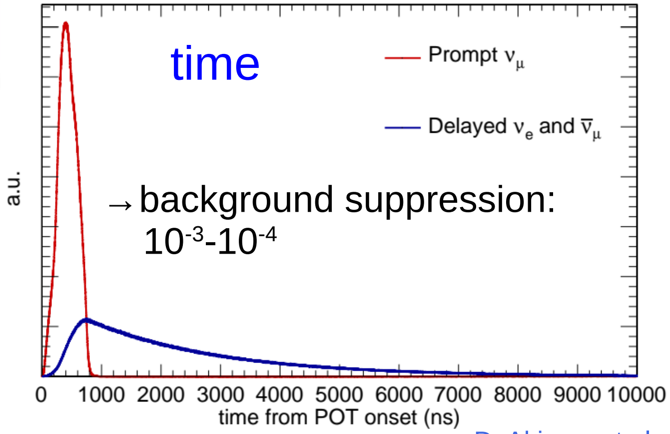
Figure courtesy of A. Konovalov

Pion decay-at-rest CEvNS

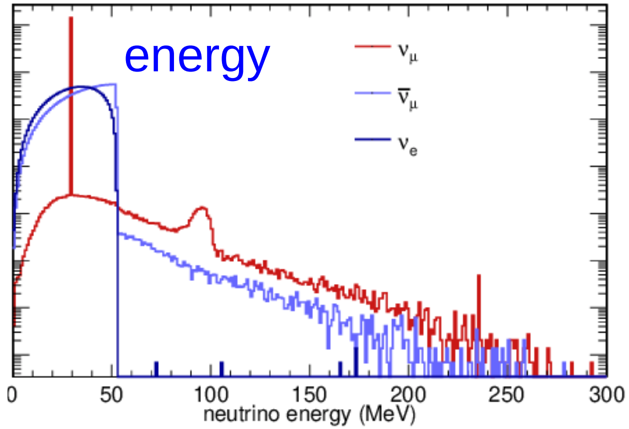
Spallation neutron source (SNS) at ORNL, US: Pion-decay at rest source pulsed beam with 60 Hz, ~10^{20} protons on target/d, max. beam power: 2 MW



multitude of detector technologies and target materials



→ background suppression: 10^{-3}-10^{-4}



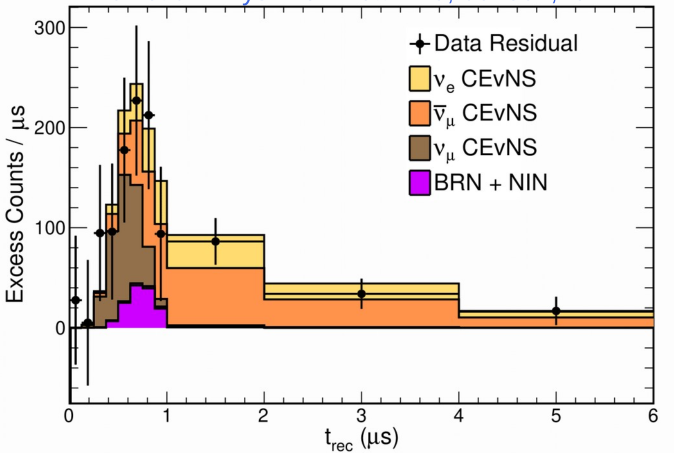
D. Akimov et al., Science 10.1126/science.aao0990, 2017

CsI + CryoCsI

14.6 kg scintillating CsI crystal
Threshold: 5 keV_{nr}
First ever observation of CEvNS in a detector!
→ full dataset: 11.6 σ

D. Akimov et al., Science 10.1126/science.aao0990, 2017

D. Akimov et al. Phys. Rev. Lett. 129, 081801,2022



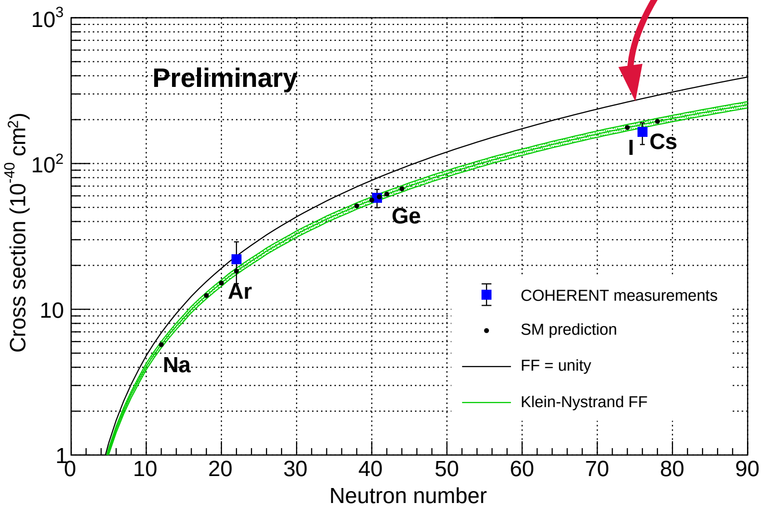
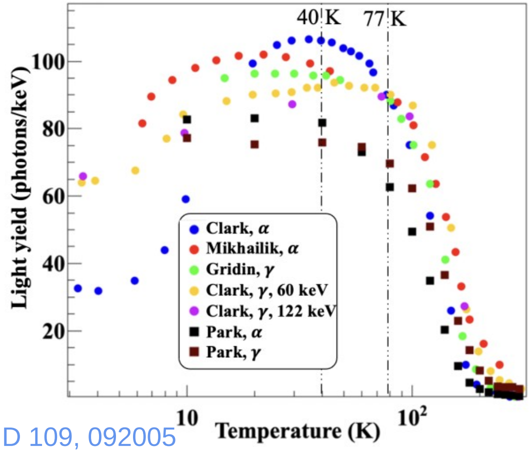


Figure by K. Scholberg

Future: **CryoCsI** in 2027
undoped CsI at 40 K
→ threshold: 0.5 keV_{nr} in reach

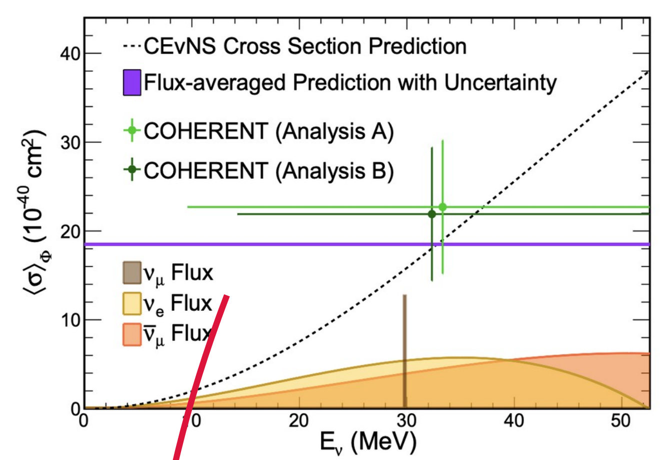


Phys. Rev. D 109, 092005

LAr

Coh-Ar-10:
Single phase Lar 24 kg
Threshold: 20 keV_{nr}
LAr (1st data set): 3.5 σ

3x more exposure under analysis
→ O(500 CEvNS)



D. Akimov et al. Phys. Rev. Lett. 126, 012002, 2021

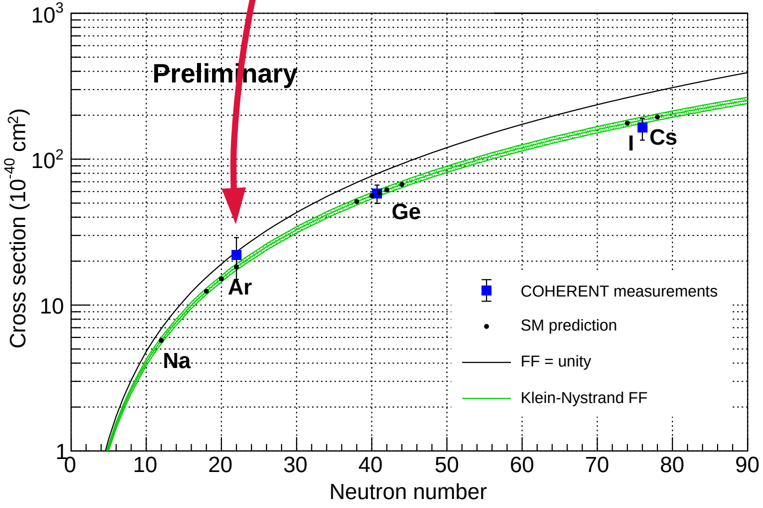


Figure by K. Scholberg

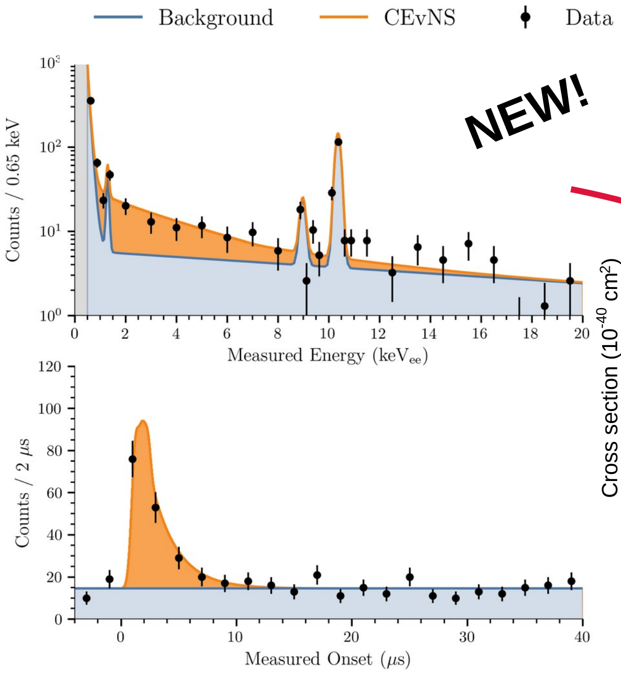
Future: more mass

Coh-Ar-750: ~476 kg
→ O(5000 CEvNS) per SNS year

Ge-Mini

HPGe inverse coax detectors
total mass: 18 kg
threshold: 1.5 keV_{ee} → 0.5 keV_{ee}
→ new result: **~10 σ**

NEW!



Second result: arXiv:2603.17951
First result: PRL 134, 231801

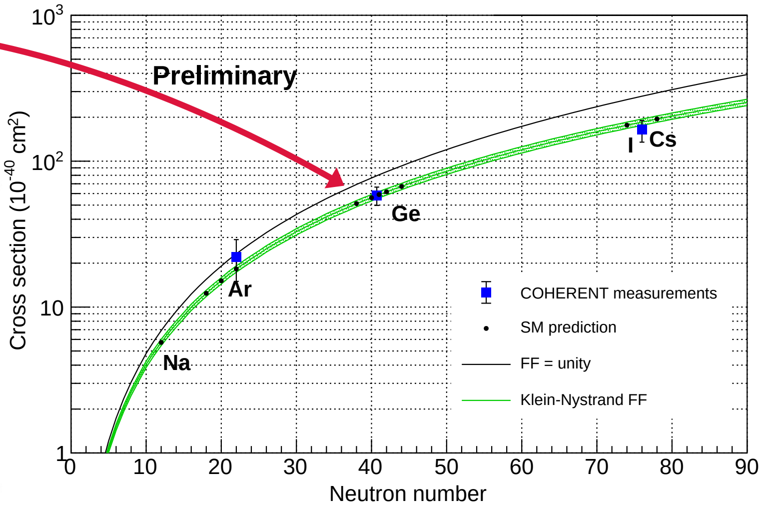


Figure by K. Scholberg

statistical uncertainties ~ systematic uncertainties

Future:
more exposure is collected
→ precision measurement

NaI

Lightest nuclei to detect CEvNS on (+ Ne efforts)
NaI scintillating crystal
→ **NaIvETe:** total mass 2.4t under commissioning

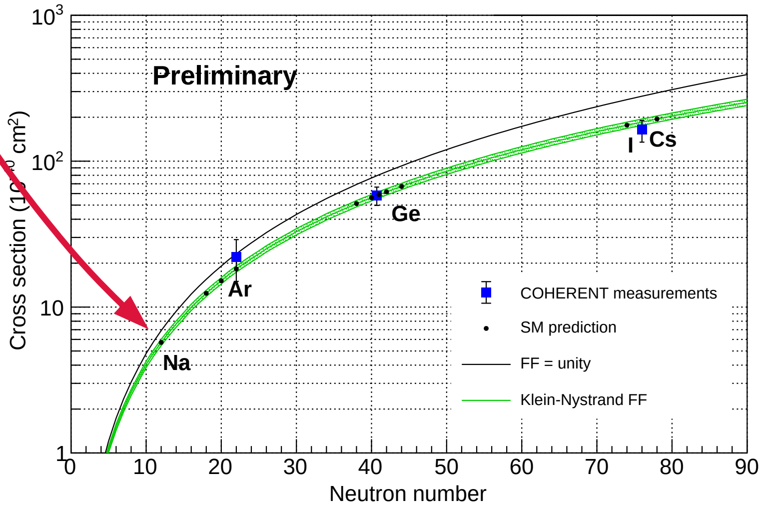
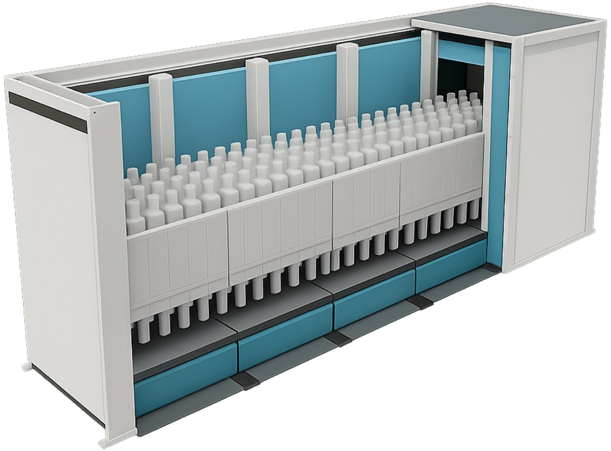


Figure by K. Scholberg



Much more information on COHERENT in the talk by Sam Hedges + many posters!

More stopped pion sources

<u>SNS reference:</u> current max 2 MW at 60 Hz, <1 μs beam width, mercury target

EUROPEAN SPALLATION SOURCE

at Lund (Sweden) under construction,
first neutron production planned in 2027
full capacity of 5 MW at 14 Hz: 2030s
beam width: 2.86 ms
target material: tungsten

Planned CEvNS projects:
- Cryogenic undoped CsI
- Point contact HPGe detectors
- High-pressure TPC (GanESS) with Ar, Kr, Xe

(exploration of j-PARC as alternative)

SNS

located at Dongguan, upgrade to 0.5 MW
at 25 Hz set to be completed this year
beam width: 0.5 ms
target material: tungsten

Planned CEvNS project: CICENNS
with 300 kg of CsI crystals,
Commissioning this year

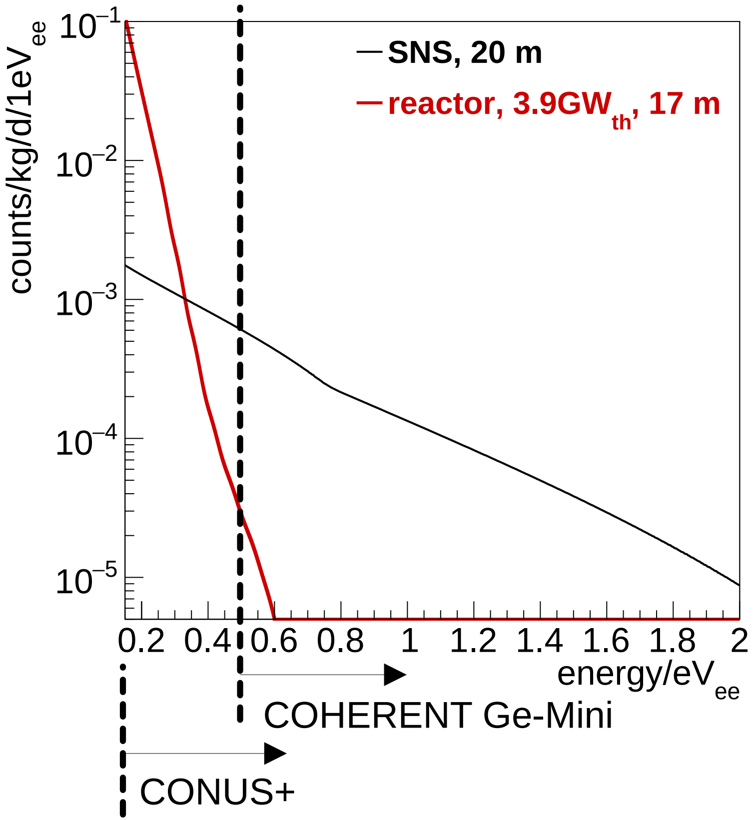
Posters 49, 85, 351

By Roger Eriksson/ESS - https://dam.esss.lu.se/asset-bank, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=124035847

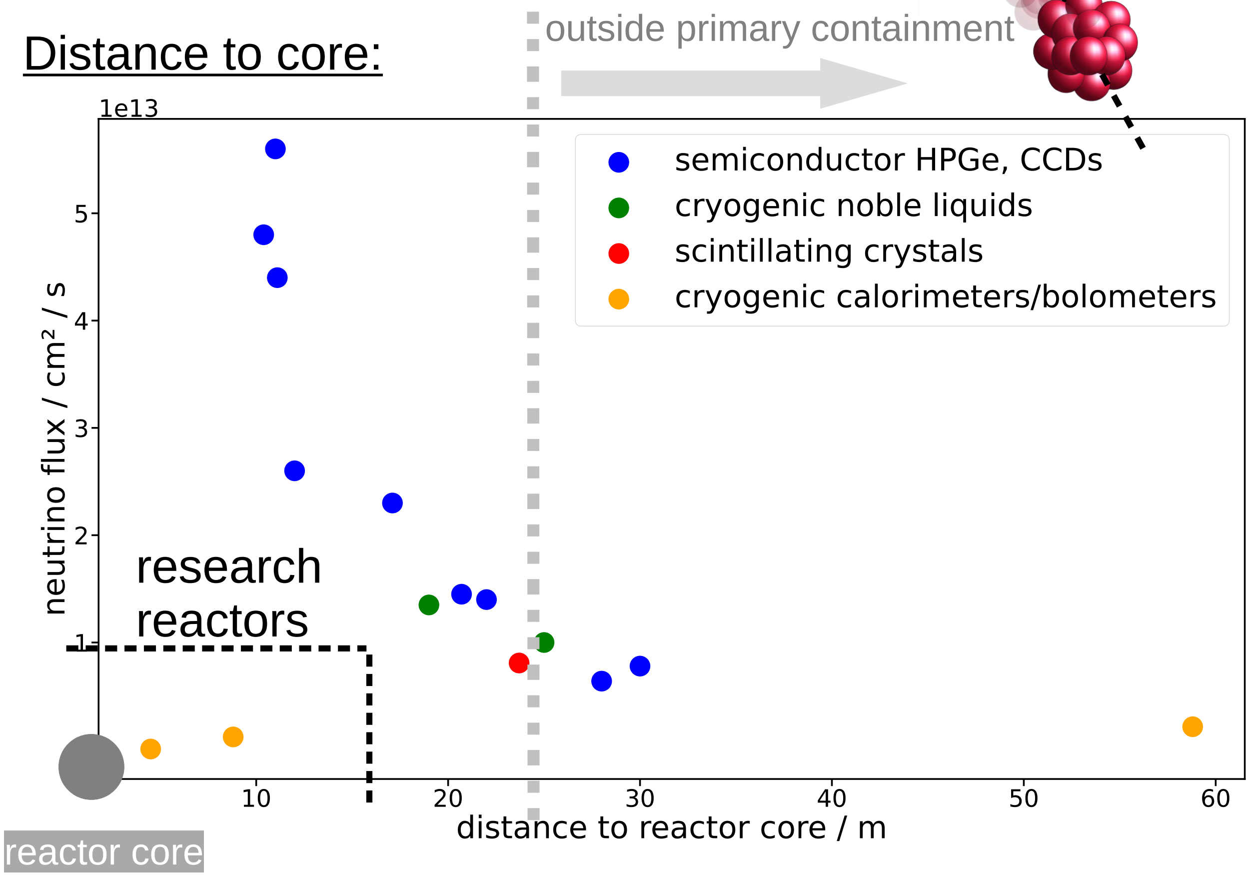
Reactor CEvNS

CEvNS at reactor site

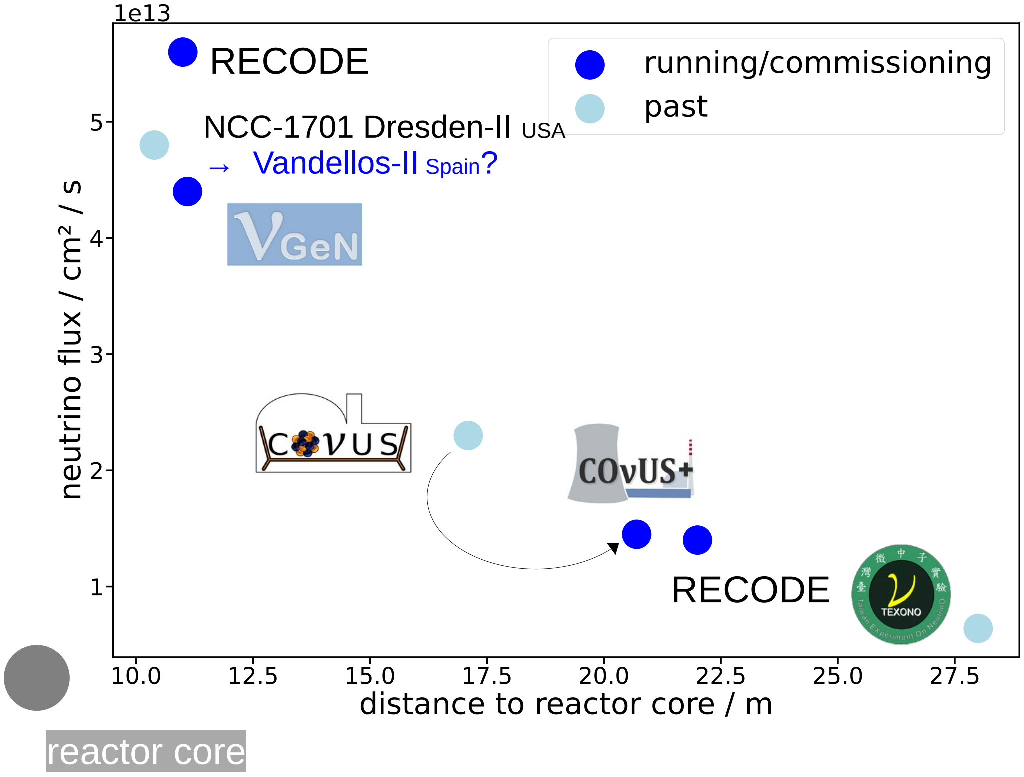
Signal expectation HPGe



Distance to core:

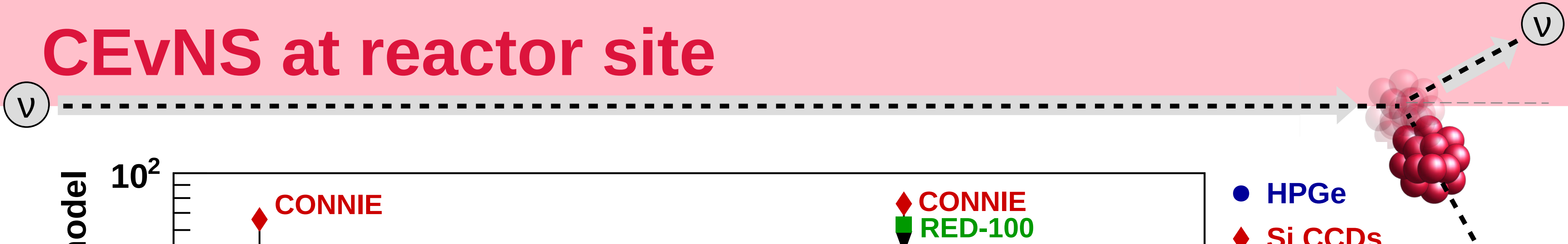


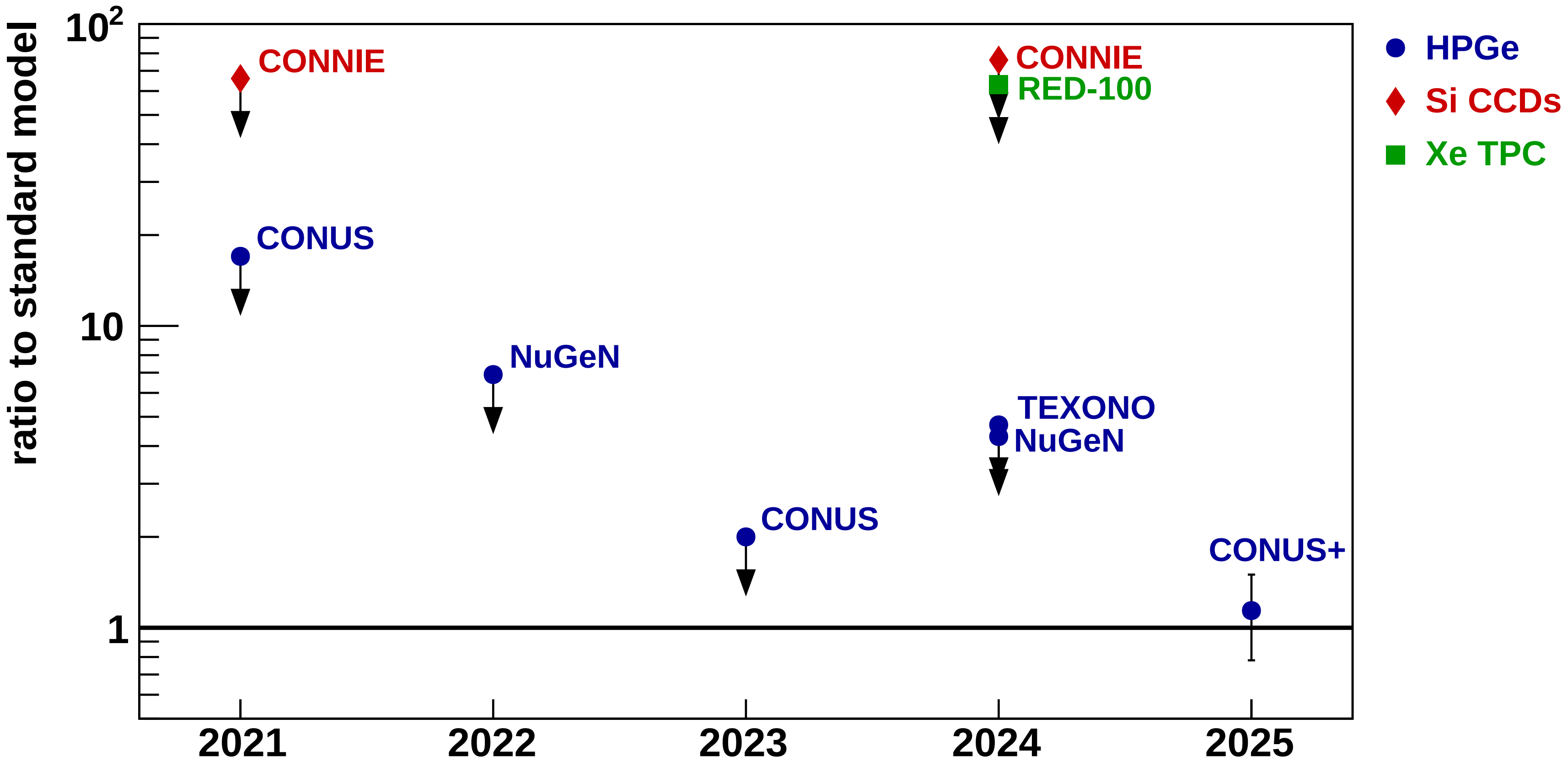
HPGe detectors at reactor site



	threshold eV$_{ee}$ (trigger eff.)	**bkg level ROI** cts/d/kg/keV
NCC-1701	200 (>0%)	~2000 ON, ~500 OFF
NuGen	290 (~85%)	~30
CONUS **CONUS+**	210 (>20%) ~160 (>95%)	~20 ~80 ON, ~70 OFF
TEXONO **RECODE**	200 (~100%) Aim 160 (tbd)	~50 tbd

CEvNS at reactor site



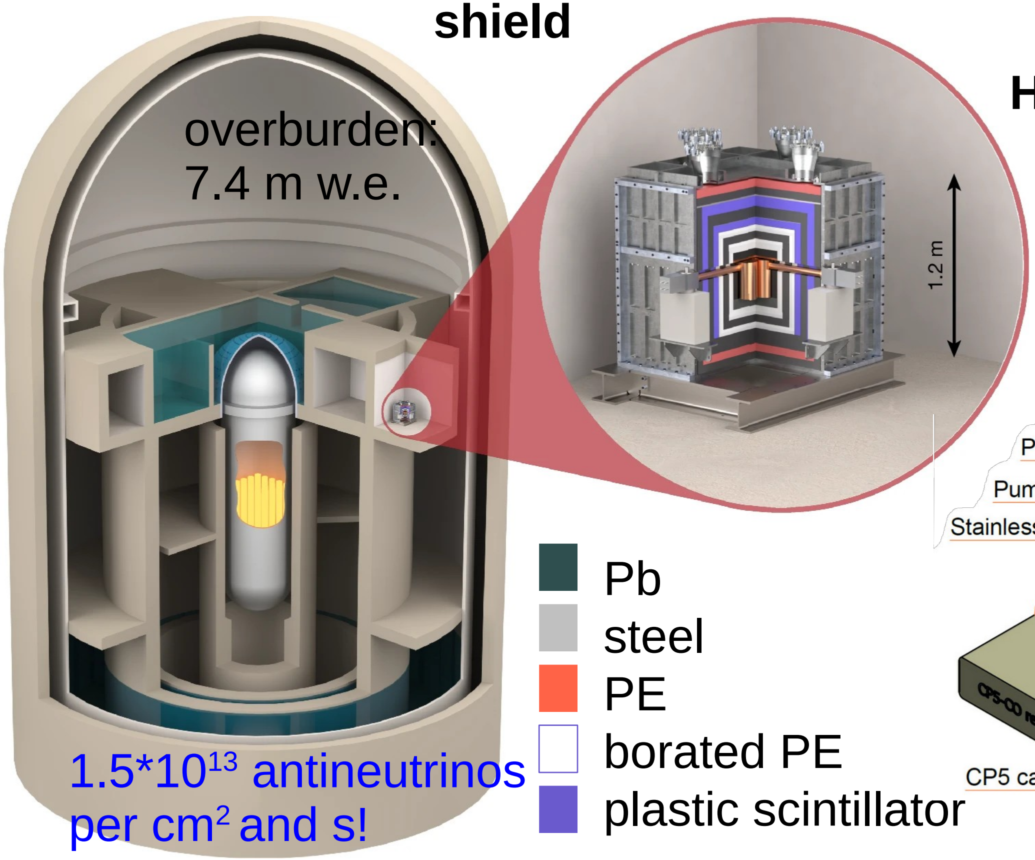


CONUS+ experiment

2018-2022
Brokdorf reactor,
17.1 m to core

2023++
Leibstadt reactor,
20.7 m to core
Detector upgrade

shield



overburden:
7.4 m w.e.

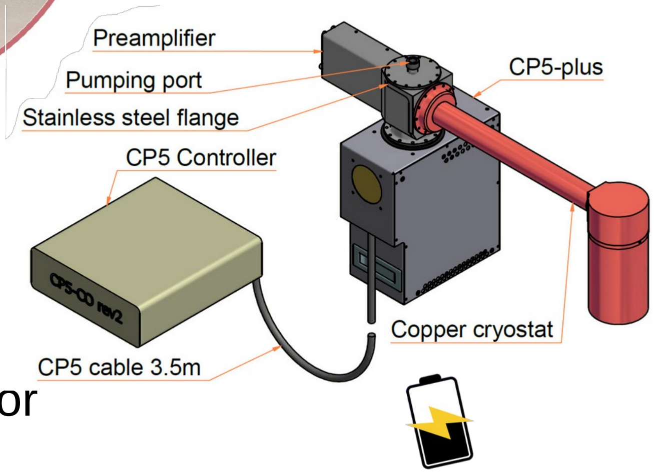
$1.5 \cdot 10^{13}$ antineutrinos per cm^2 and s!

- Pb
- steel
- PE
- borated PE
- plastic scintillator

HPGe detectors

4 detectors in shield
threshold:
CONUS: 210 eV_{ee}
CONUS+: 160-180 eV_{ee}

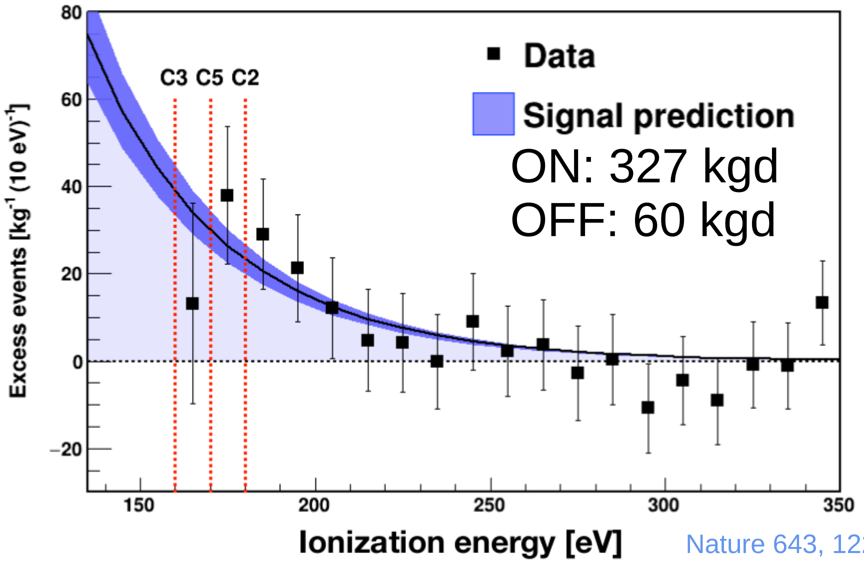
Eur. Phys. J. C (2024) 84:1265



CONUS+ CEvNS result

Simultaneous binned log likelihood fit of:
reactor OFF (→ bkg model) and reactor ON data (→ bkg model + CEvNS)

Figure: bkg model subtracted



Nature 643, 1229–1233 (2025)

Quenching:
EPJC, 82(9):815, 2022

detectable with HPGe

recoil → ionization energy + phonons

(about 16% at 1 keV$_{nr}$)

Total active mass: (2.83+-0.02) kg
Signal events data: **395+-106**
Signal predicted: 347+-59

Ratio to SM: 1.14+-0.36

3.7 σ significance!

Upgrade since Nov. 2024:
1 kg → 2.4 kg detector mass → ~4 times more exposure at similar energy threshold!

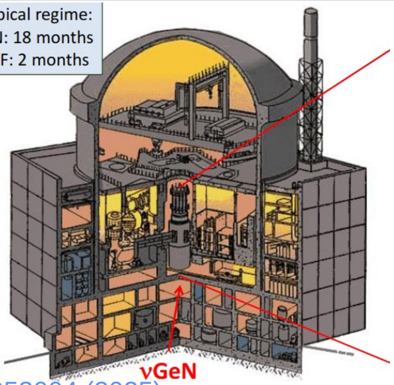
STAY TUNED!

HPGe detectors at reactor site

νGeN

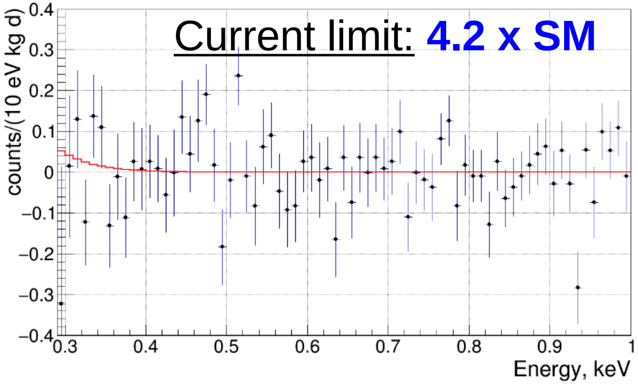
Typical regime:
ON: 18 months
OFF: 2 months

KNPP, Russia, 1.4 kg



Chin. Phys. C 49 053004 (2025)

Current limit: **4.2 x SM**

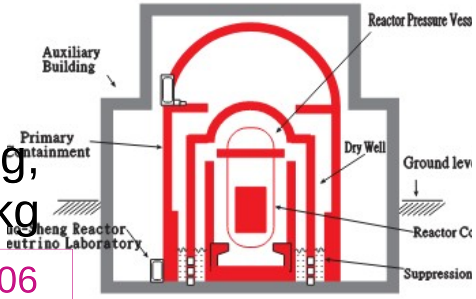


Planned upgrades: internal NaI veto, DAQ waveform collection

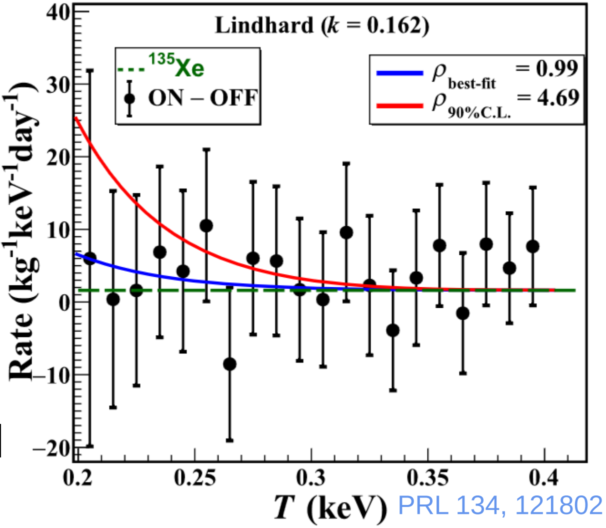
TEXONO

Final data set: **4.7 x SM**

Kuo-Sheng, Taiwan, 2kg

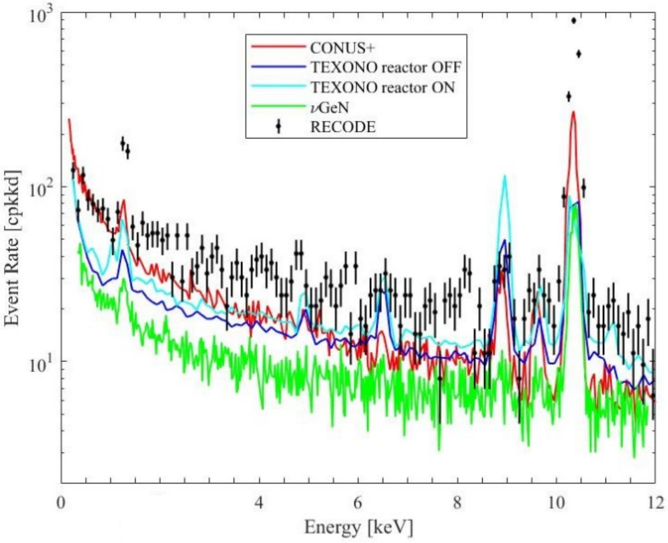


Poster 106



PRL 134, 121802

RECODE
Sanmen, China
different distances to the reactor core (11 m, 22 m, (7 m))
Start of data taking: Oct 2025
Current achieved threshold: 210/220 eV_{ee} (Taup 2025)



More detector technologies at reactors

high mass O(100 kg)
+ higher threshold: 1-2 keV_{nr}

NaI

RED
RUSSIAN EMISSION DETECTOR

RELICS
REactor neutrino LIquid xenon Coherent elastic Scattering

NUXE

Xe, Ar

low mass gram-sized
+ low threshold 10-100 eV_{nr}

CONNIE

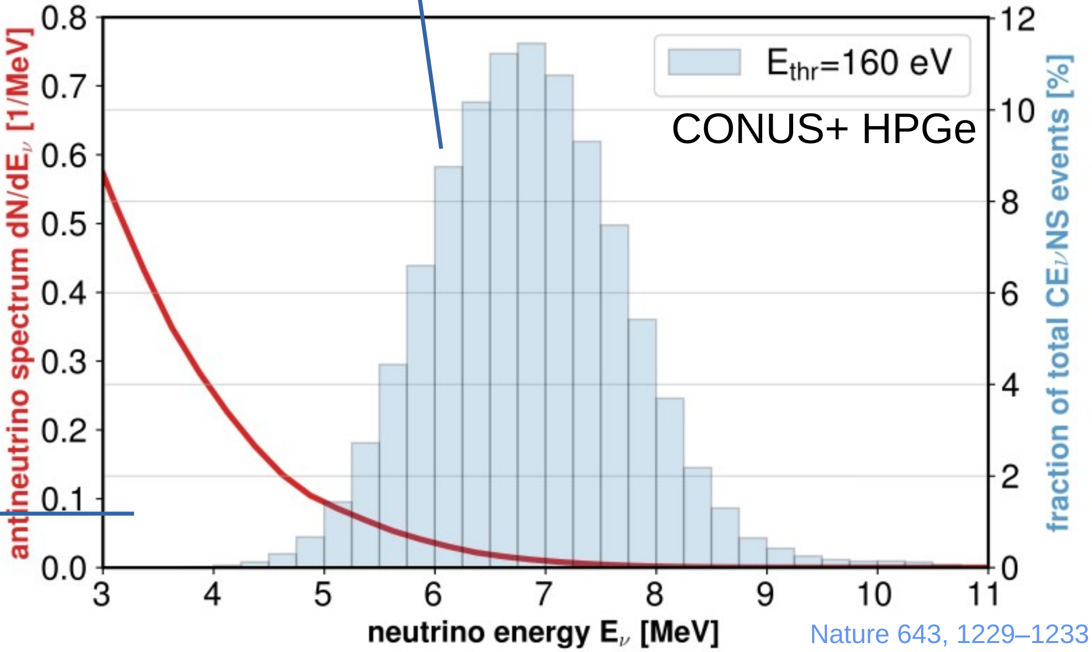
Si

Atucha-II

RICOCHET Ge, Zn

$CaWO_4$,
Al_2O_3

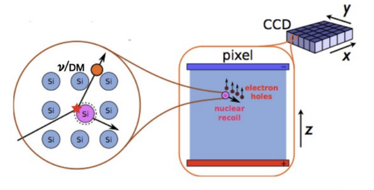
nucleus EXPERIMENT



Nature 643, 1229–1233 (2025)

Si Charge coupled devices CCDs

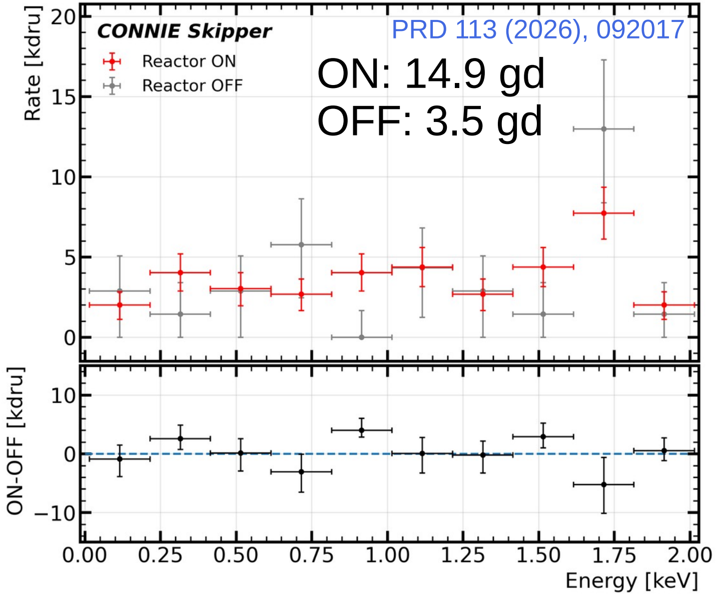
imaging detector with pixelated readout
- ionization energy → quenching
- slow readout O(10 min)



CONNIE

30 m from Angra-2 reactor core
2016-2020: CCDs 8 x 6 g
2021-2023: skipper CCDs 2 x 0.5 g
→ 15 eV_{ee} threshold!

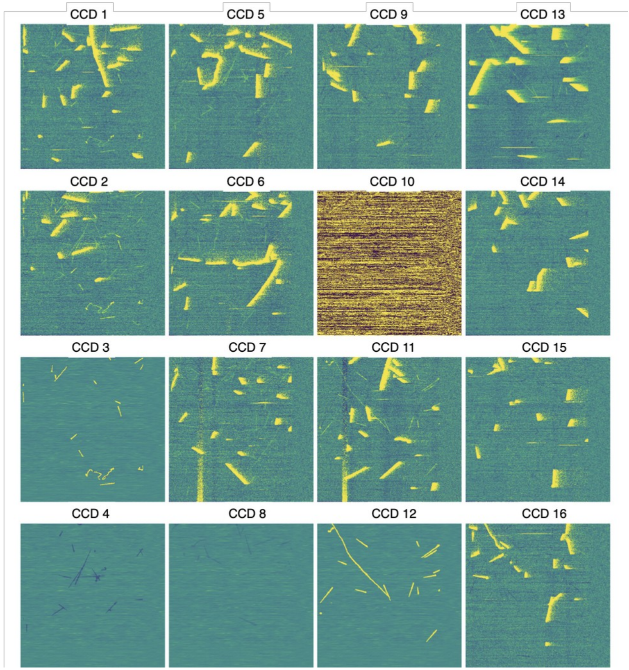
Limit from Reactor ON-OFF rates: **SM x76**
(5 orders of magnitude less exposure than CONUS+!)



(thanks to I. Nasteva for providing input!)

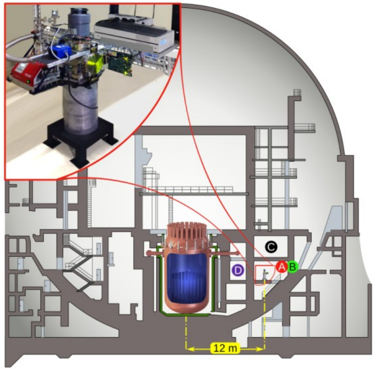
Si Charge coupled devices CCDs

Mass upgrade: MCM with 9 skipper CCDs 8 g total
→ analysis ongoing



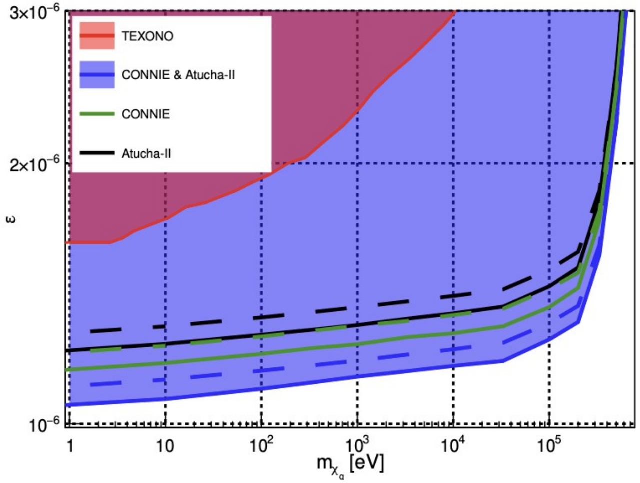
(500 x 500 pixels)

Combined analysis of CONNIE and Atucha-II data:



Atucha-II, Argentinia, 12 m Skipper CCDs

PRL 134, 071801 (2025)



→ world-leading limits on milli charged particles at reactors over 6 orders of mass

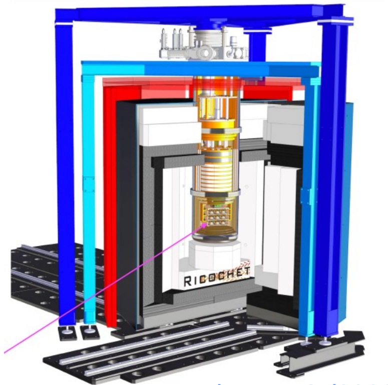
(thanks to I. Nasteva for providing input!)

Bolometers/cryogenic calorimeters

recoil-incuded temperature change in gram-sized crystals

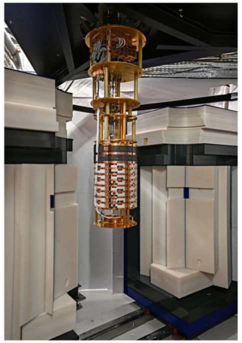
→ O(10 mK) temperatures required

RICOCHET

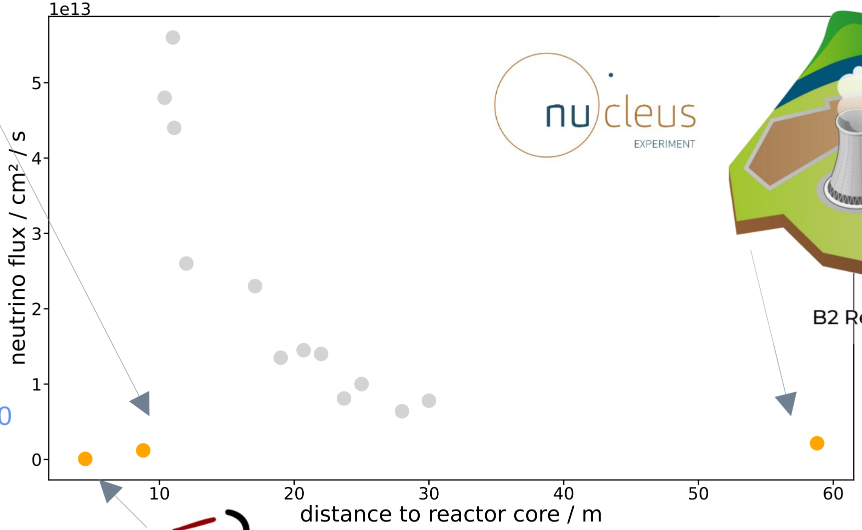


CryoCube

Eur. Phys. J. C (2023) 83:20



Research reactor ILL, France
58 MW

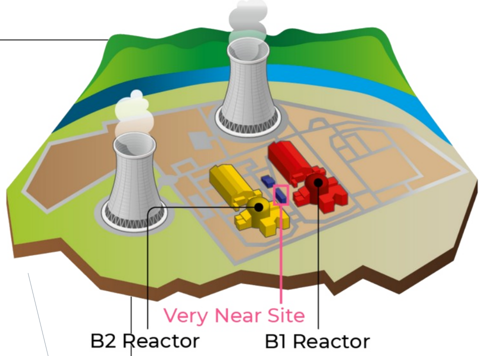


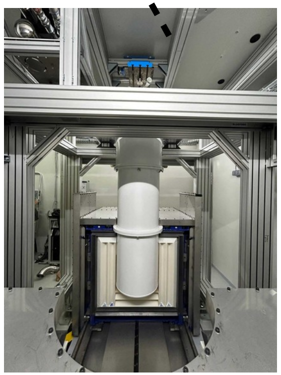
(Miner)

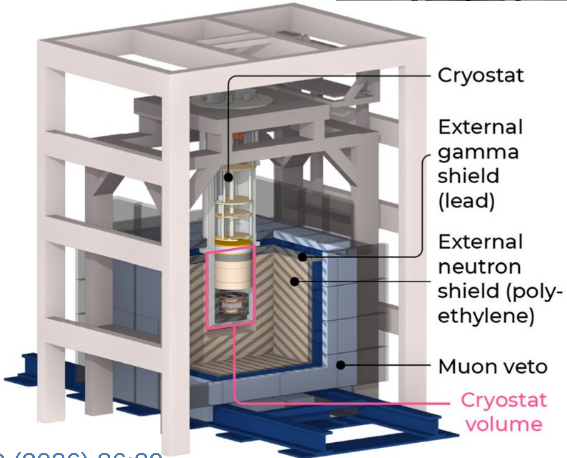
gram-scale mass, threshold: O(10 eV_{nr})

Challenge: Low energy excess (LEE) in phonon channel

Chooz reactor, France
2 x 4.25 GW at 70 and 102 m







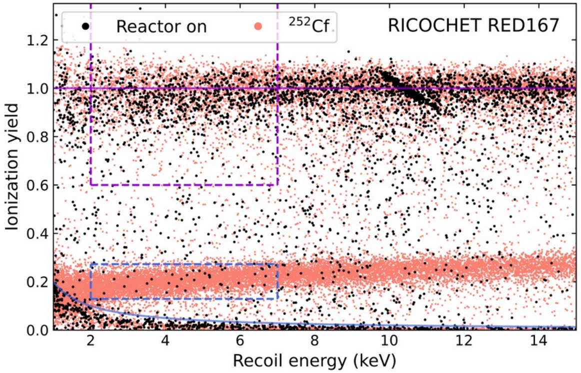
Eur. Phys. J. C (2026) 86:29

Bolometers/cryogenic calorimeters

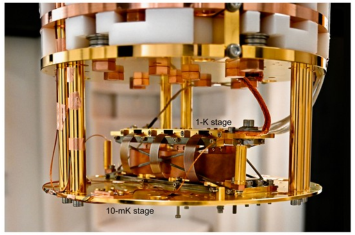
RICOCHET

ionization **and** phonon channel → bkg rejection

PRD 112, 112019 (2025)



Mini CryoCube:
3 x 42 gr of Ge with NDT thermistors



baseline resolution commssioning:
Ionization: **40 eV,** Phonon: **50-80 eV**

Posters 131, 222

July 2025: begin physics run with 18 det.

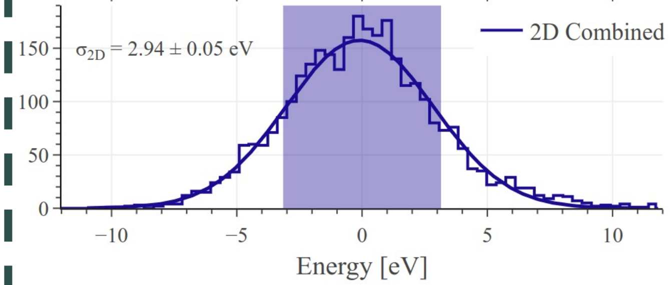
R&D: Q-Array Zn, Al, Sn with TES sensors

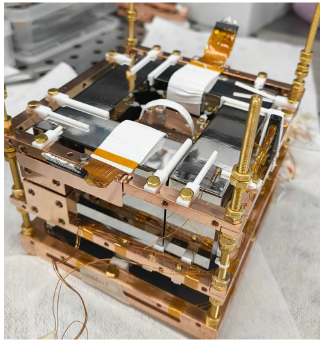
nucleus EXPERIMENT

direct recoil detection via phonons

MDM2:
~7 gr $CaWO_4$, 8 double TES

arXiv:2603.28276v1





baseline resolution at lab: **3-4 eV**
→ threshold **$O(20eV_{nr})$** in reach

March 2026: begin commissioning at Chooz

LEE mitigation: double TES readout, instrumented detector holder R&D

Cryo noble liquids

two-phase gas emission detectors

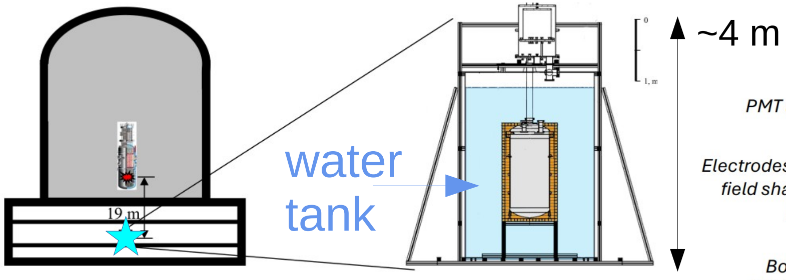
- sensitivity to CEvNS driven by S2 (electroluminisence)
- large mass O(100 kg), threshold: 0.5-2 keV_{nr}

<u>Challenge:</u> large delayed single electron noise bkg related to high cosmic ray rate at Earth surface

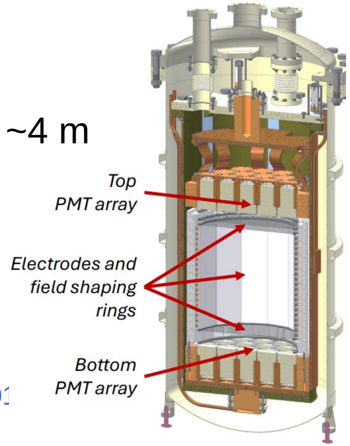
RUSSIAN EMISSION DETECTOR

RED-100: KNPP, Russia, 19 m
100 kg liquid Xe (fiducial volume)
threshold: 2 keV_{nr}

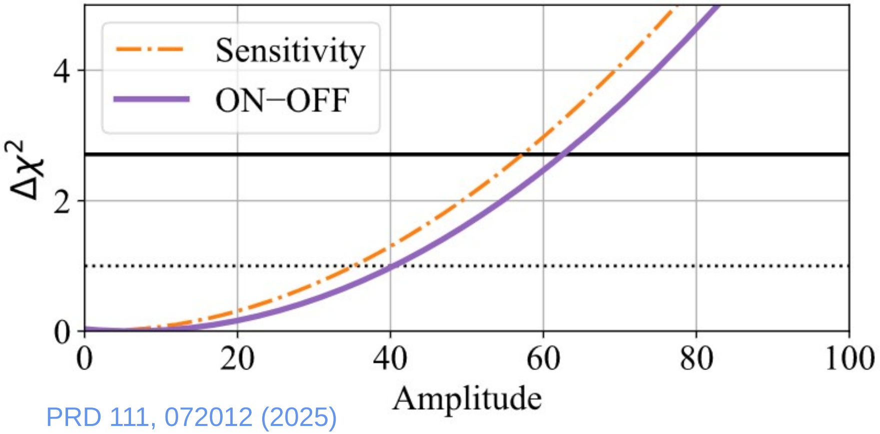
→ bkg reduction in analysis, first result: **63x SM**



JINST 17.11 (2022), T110:



PRD 111, 072012 (2025)



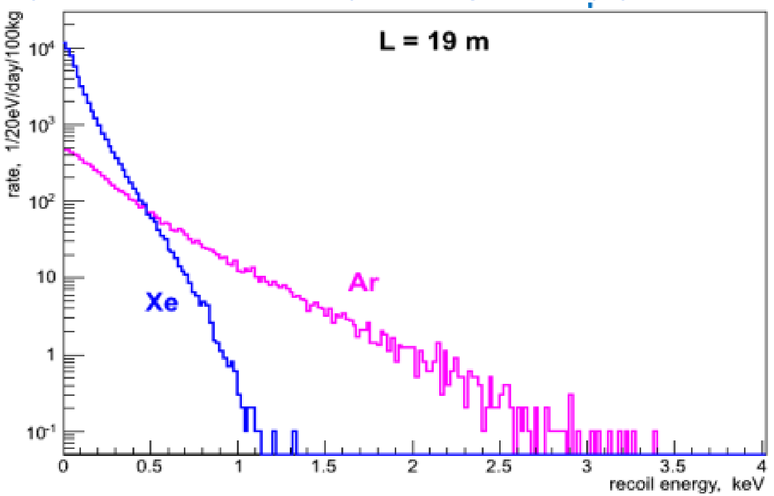
PRD 111, 072012 (2025)

Cryo nobel liquids

RED — RUSSIAN EMISSION DETECTOR

Planned upgrade:
replace Xe with Ar →
requires modifications

Physics 2023, 5, 492–498. https://doi.org/10.3390/physics5020034



Current:
laboratory tests ongoing at MEPhI with Ar
→ lower SE rate, but afterglow and ^{39}Ar

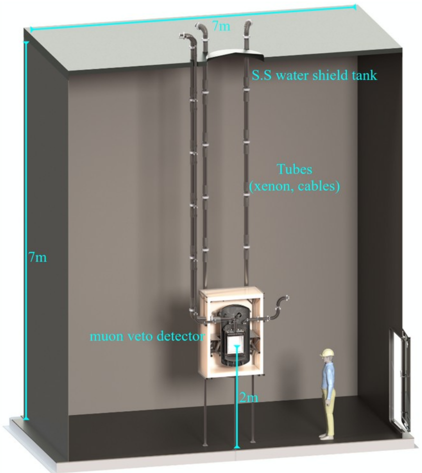
(thanks to A. Konovalov for the input)

RELICS
REactor neutrino LIquid xenon Coherent elastic Scattering

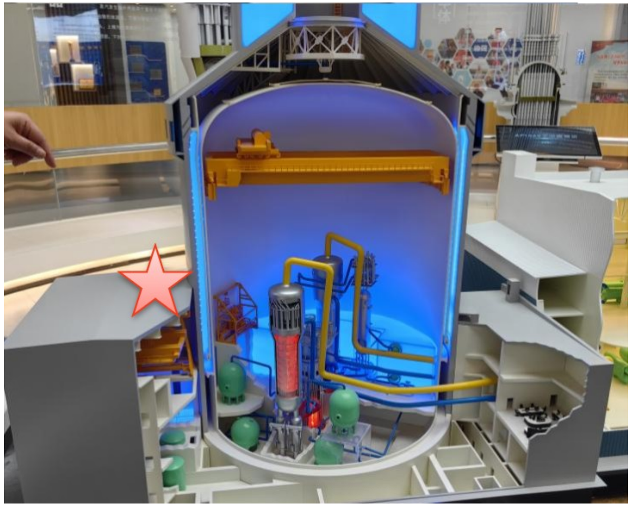
32 kg liquid Xe , Sanmen, China
outside containment, at 25 m

status: successful operation of prototype at lab with single electron gain of ~34 PE/e- Eur. Phys. J. C (2026) 86:348
Planned data taking at reactor: 2026

Poster 12



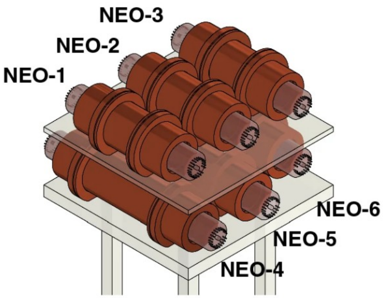
PRD 110, 072011 (2024)



M7 2025 Shengchao Li

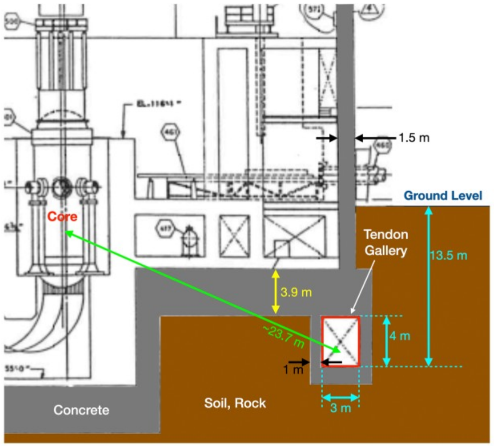
Scintillating crystals

Scintillating crystals:
- modular and scalable
- quenching applies
- background levels might be challenging



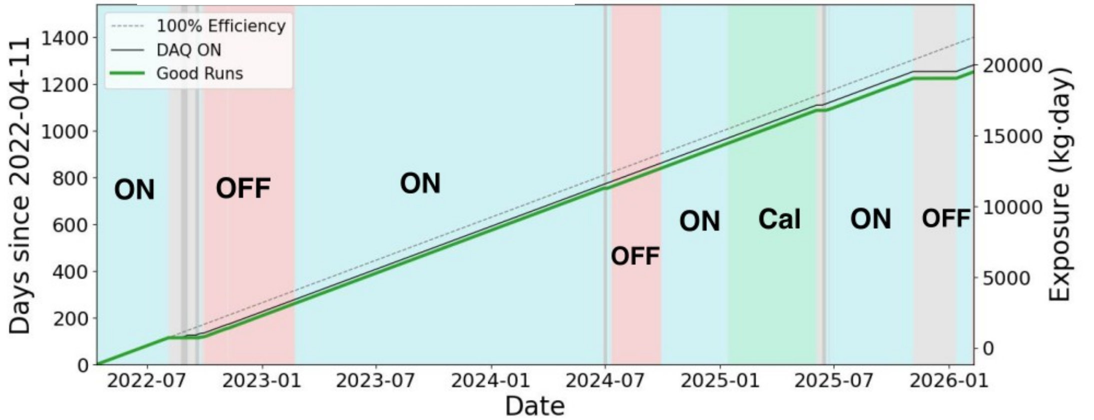
6 NaI crystals
with PMT readout
(total 12.5 kg)

aimed threshold for CEvNS detection:
5 PE → ~0.2 keV_{ee}



Eur.Phys.J.C 83 (2023) 3, 226

Hanbit, Korea, 24 m



Poster 20

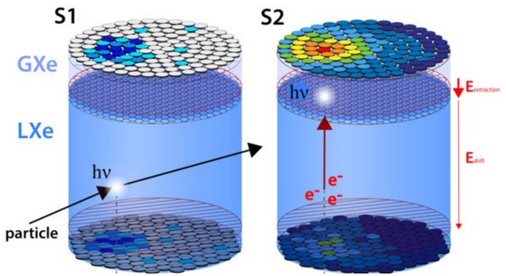
reactor data since May 2021: 886 ON days, 226 OFF days
→ deep learning noise selection for low and stable threshold

Solar CEvNS

Solar and Supernova

two-phase liquid Xe TPCs for dark matter detection

→ S2 only and S1/S2 paired analyses, thresholds below 1 keV_{nr}!



Universe 2021, 7(8), 313

XENON

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

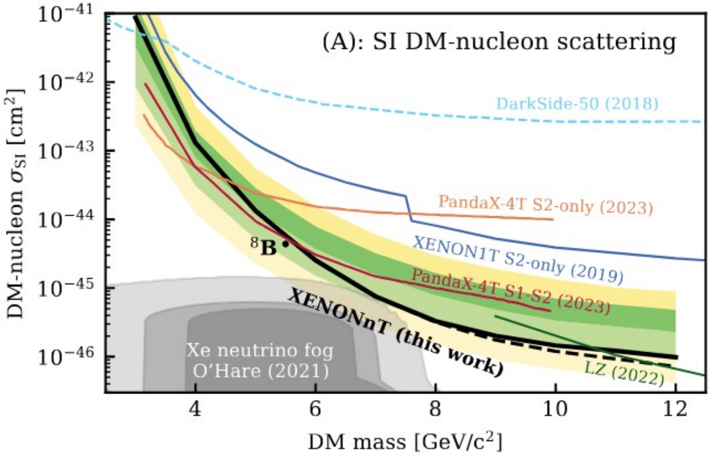
LZ

Talk on LZ by Dongqing Huang!

small flux ^{8}B neutrinos → tonscale detectors

no “OFF” data/no beam correlation → deep underground

Large distance to source → **tau** neutrinos (not available at piDar or reactor)



XenonNT: arXiv:2604.06002v1 (updated statistics)

Significance: 3.3 σ

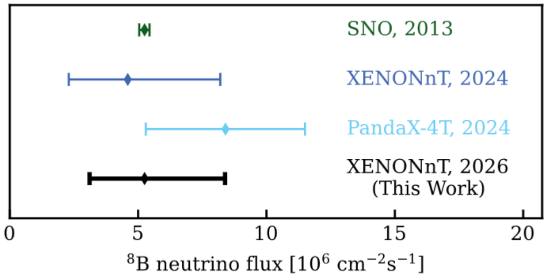
PandaX: Phys. Rev. Lett. 133, 191001 (2024)

Significance: 2.6 σ

LUX-ZEPLIN (LZ): arXiv:2512.08065v2

Significance: 4.5 σ

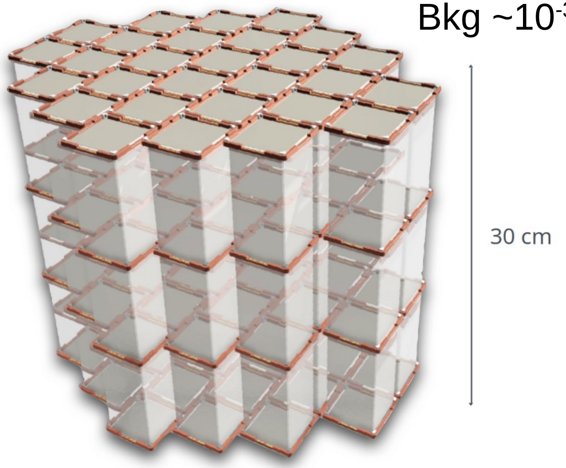
Posters 280, 11



Supernova

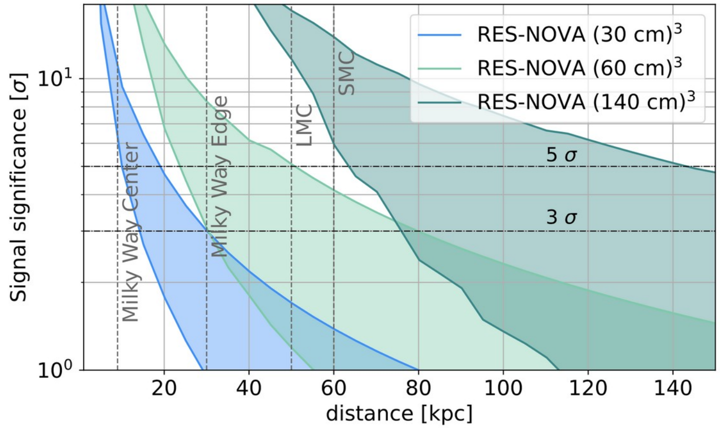
RES-Nova:
- Pb-based cryogenic calorimeters from ancient lead
- threshold: ~1keV$_{nr}$
- detector production started
- first prototype operating at end of 2026 at LNGS

Bkg ~10^{-3}/keV/ton/s



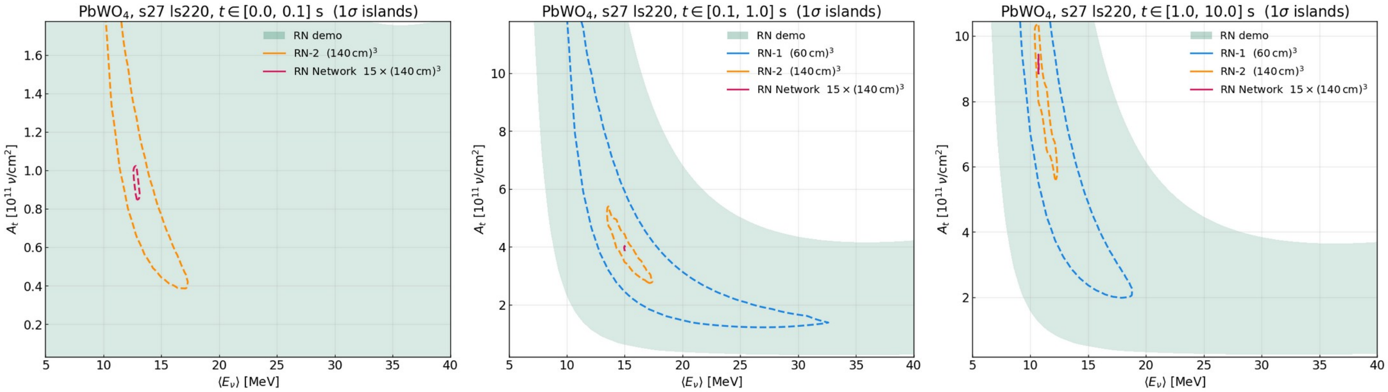
(thanks to L. Pattavina for the input)

Sensitivity to core collapse supernovae



Poster 280

UPDATED from: L. Pattavina et al., *JCAP* 10 (2021) 064

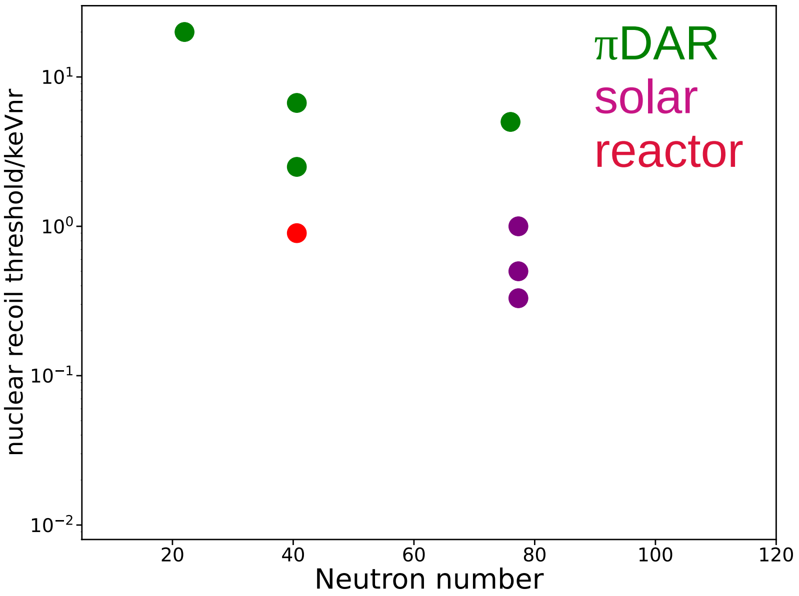


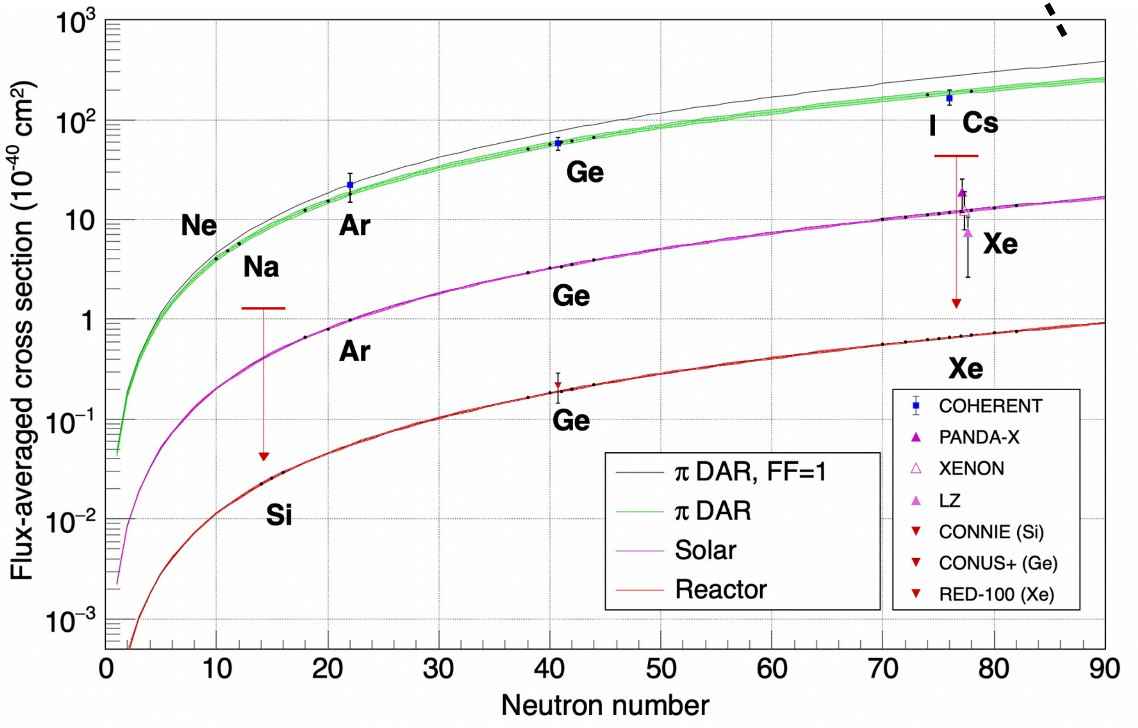
UPDATED from: L. Pattavina et al., Phys. Rev. D 102, 063001 (2020)

Conclusions

Overview results

Parameter space:

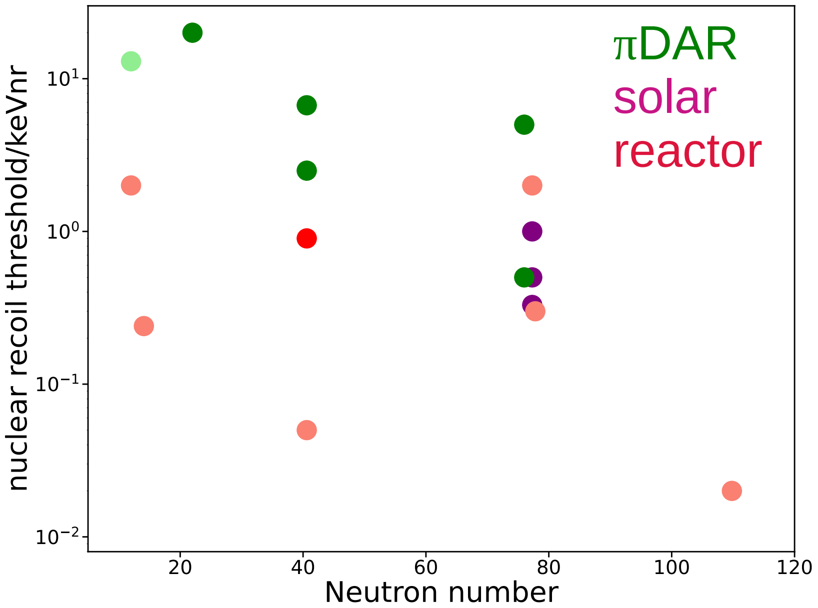




(figure by K. Scholberg)

Overview and future

Parameter space:

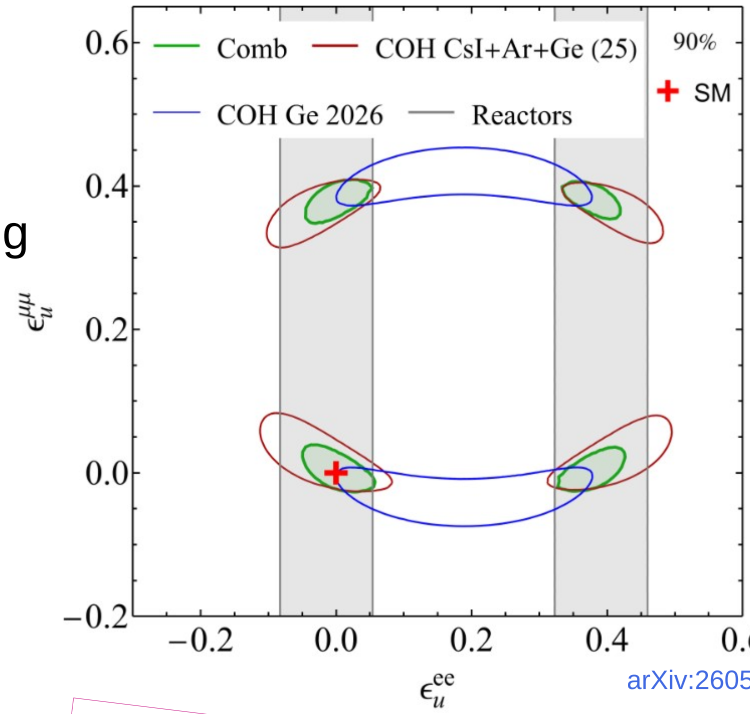


Light color= threshold goal

+ upscaling of mass

→ more CEvNS events

Combined analyses

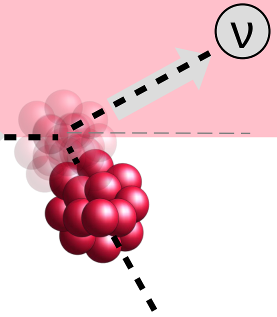


arXiv:2605.07975

Posters 79, 366 , 429, 22

+ **R&D efforts:** NEWS-G3, SBC, Paleoccene, LArCADe, DELight, PHONON, directional detection (nuBDX-DRIFT, CYGNUS), NUXE...

Summary and outlook



CEvNS is fast growing field with many recent detections:

SNS pion decay-at-rest (pulsed): COHERENT
first detection of CEvNS in 2017 with CsI, followed by LAr (2021) and HPGe (2023, 2025)

Reactor (lower energies): first detection in 2024 by CONUS+ with HPGe
multitude of efforts with different technologies at reactors:
CCDs (CONNIE,..), cryogenic bolometers (NUCLEUS, Ricochet), twophase TPCs (RED-100,..),…

first evidence on CEvNS from **solar neutrinos** (XenonNT, PandaX, Lux-Lz)

20 CEvNS related posters at NEUTRINO!

More mass! Lower threshold! Combined analyses! More exposure!
→ start of precision era of CEvNS detection to probe the SM and beyond

Next **M7 workshop** in Heidelberg 13th -15th July https://plan.events.mpg.de/event/603/

Thank you for your attention!