# CE$\nu$NS

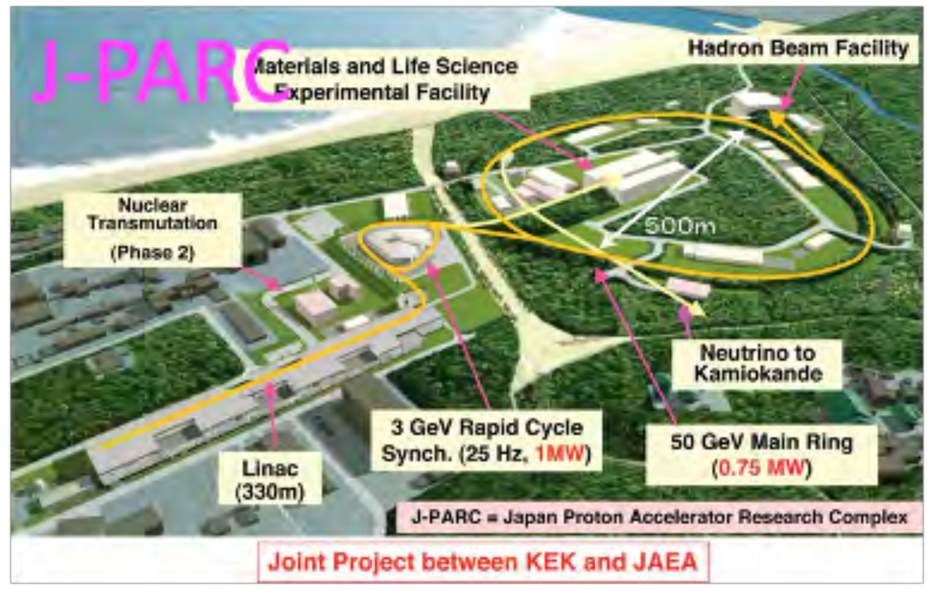
## Coherent Elastic Neutrino-Nucleus Scattering
## Status and Prospects

Enectalí
Figueroa-Feliciano
Northwestern

# Neutrino Sources at NuInt

**Neutrino Energy**

See Lucas' talk




$E(\nu)$

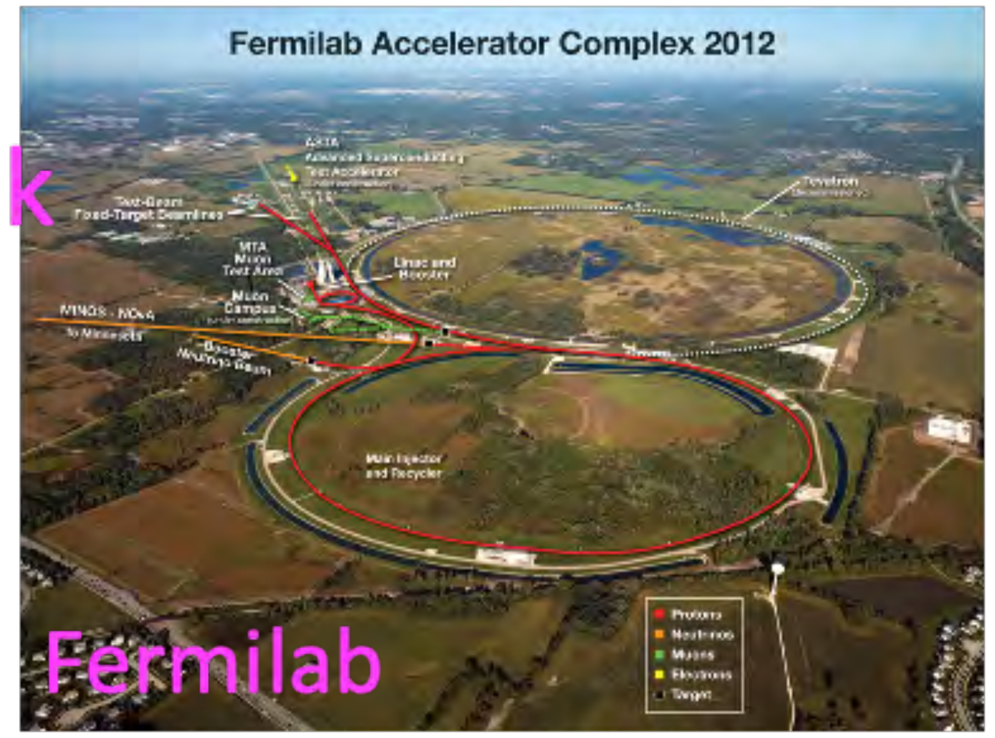
1 GeV

100 MeV

10 MeV

Accelerator based neutrinos

See Zarko's talk




Spallation neutrinos

Reactor neutrinos


See Yuri's talk


Credit: Katsuya Yonehara

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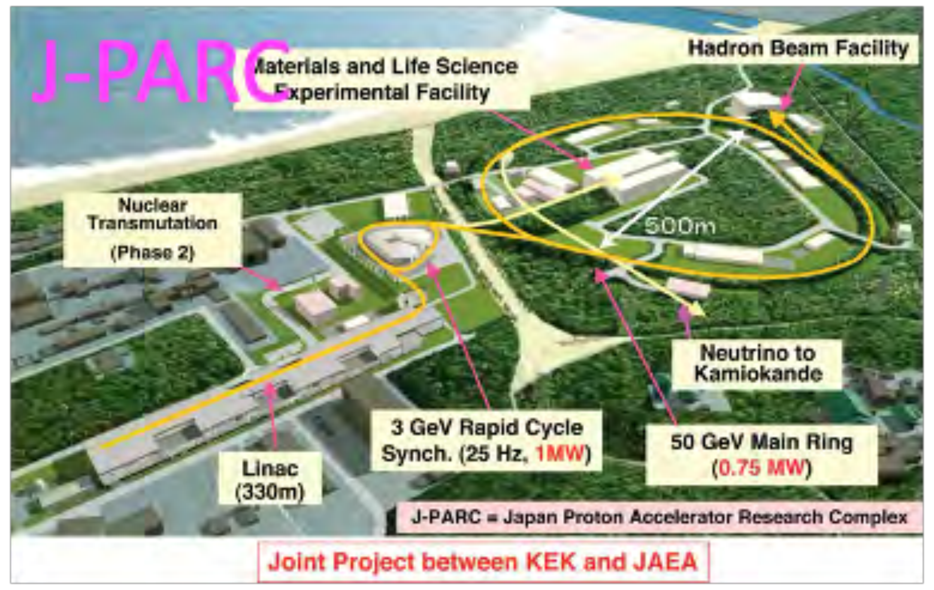


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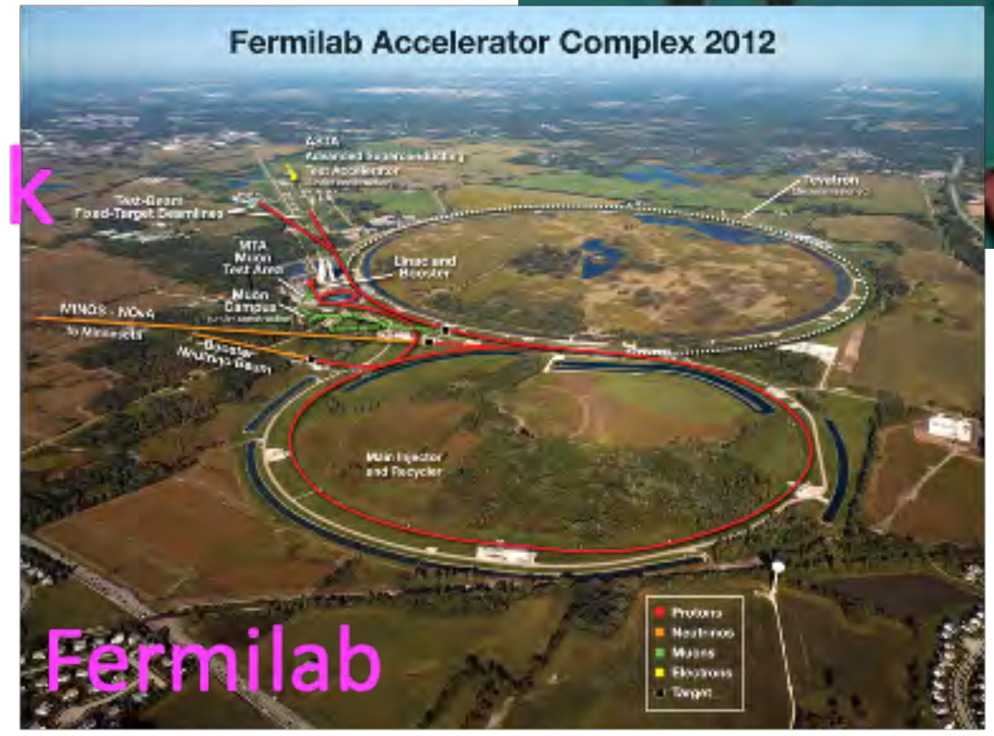


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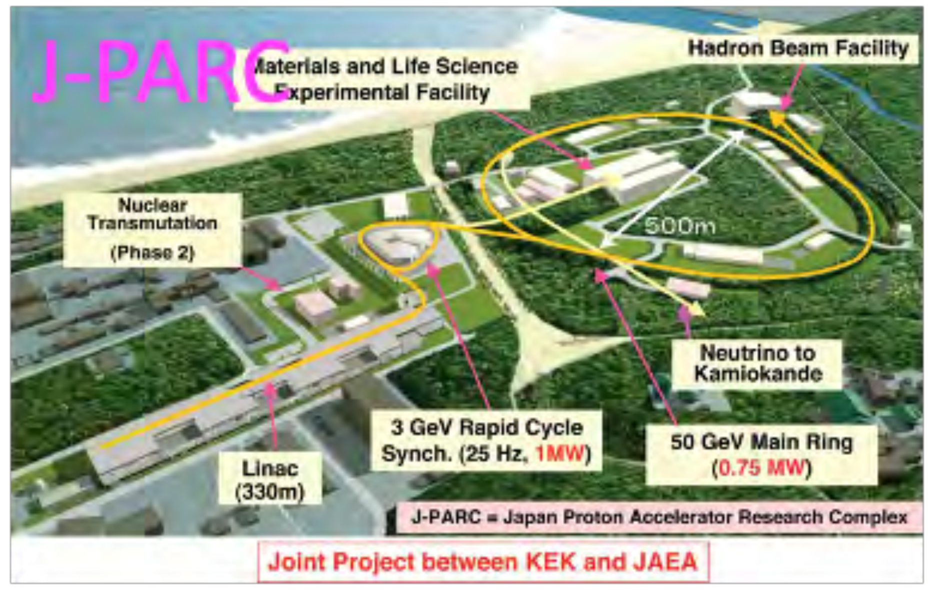


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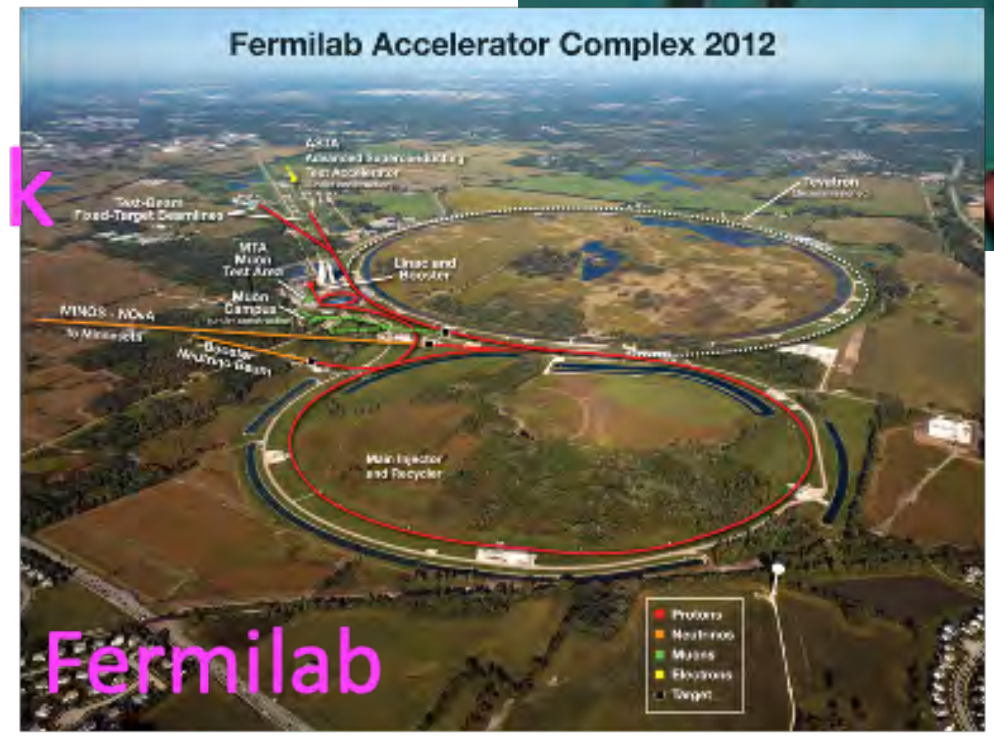


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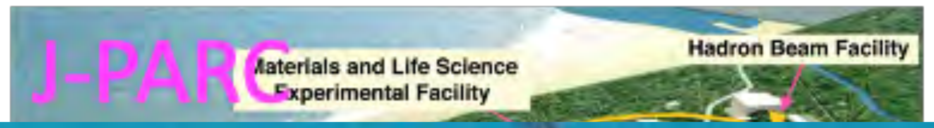
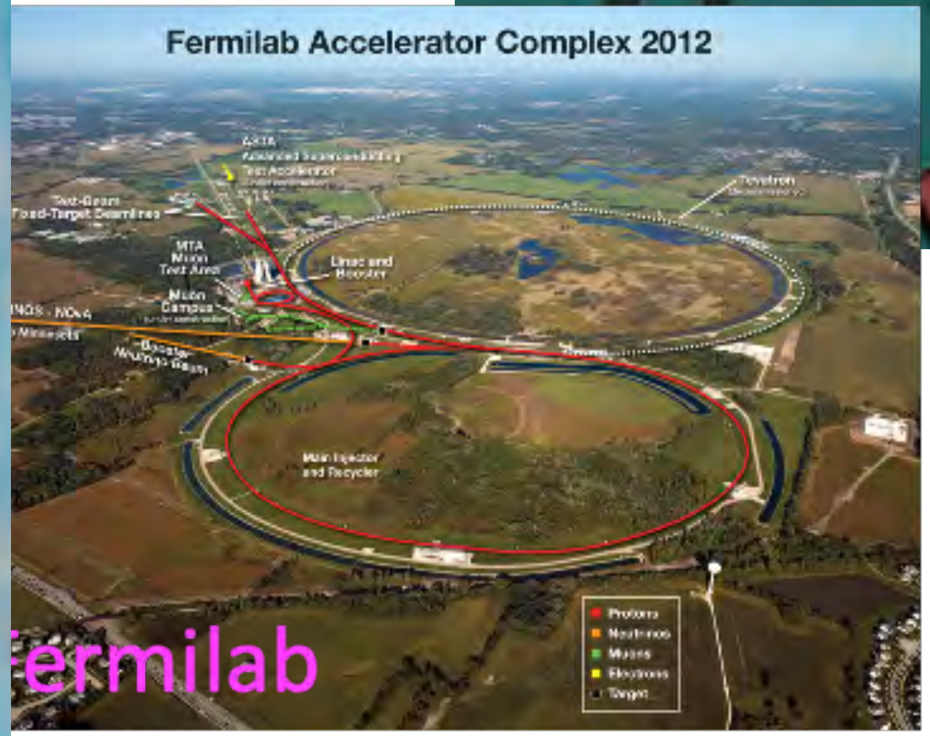



$E(\nu)$

r based neutrinos


Credit: Netflix Stranger Things




ermilab

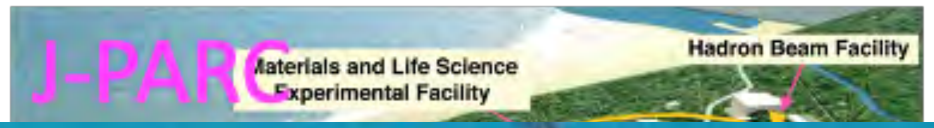
Yuri's talk

Credit: Katsuya Yonehara

# Neutrino Sources at NuInt

## Neutrino Energy

See Lucas' talk




$E(\nu)$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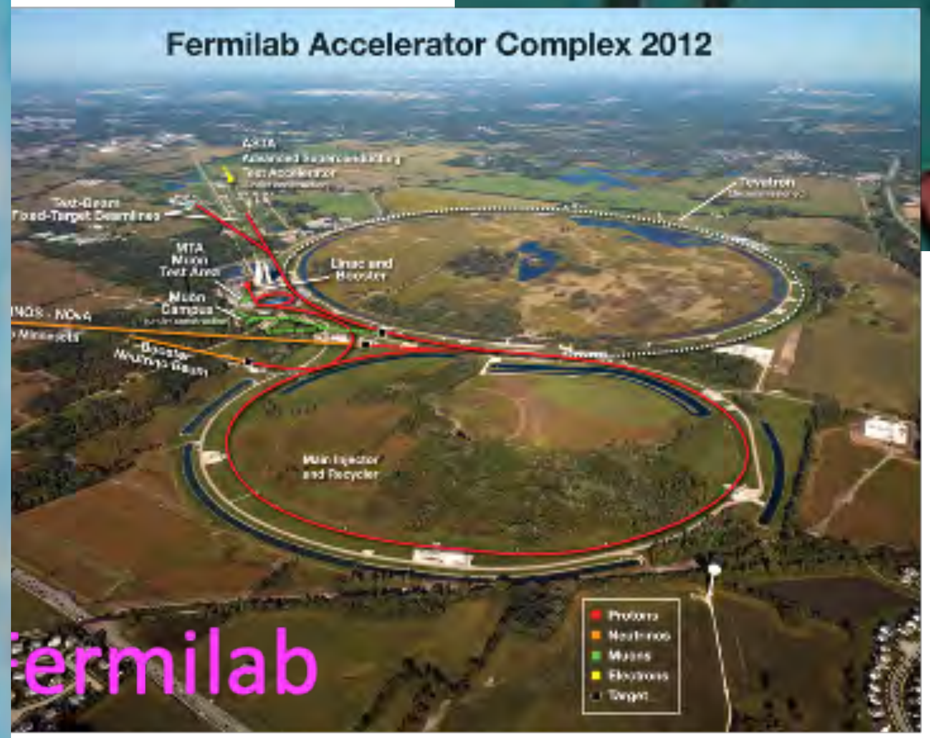
r based neutrinos

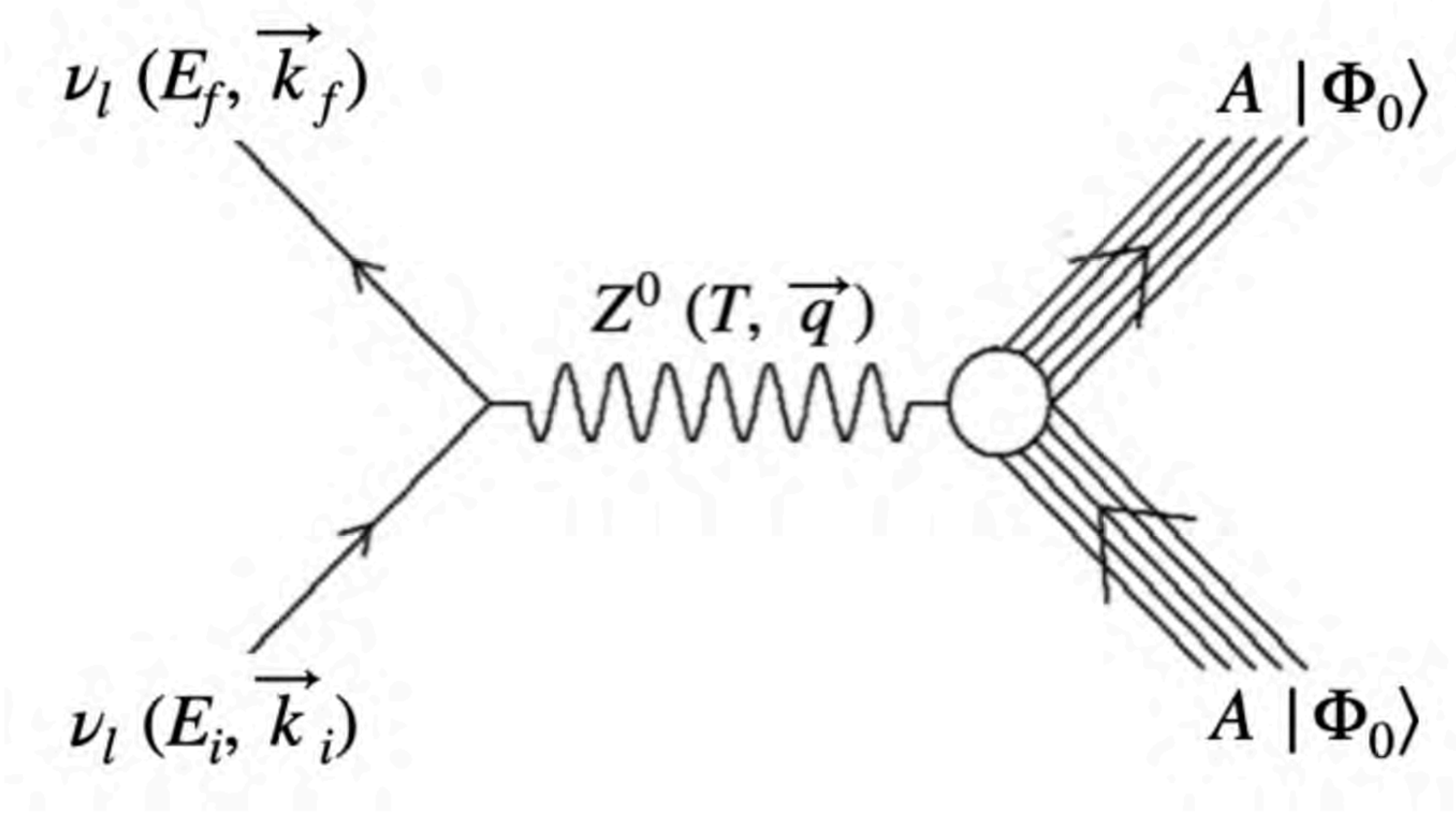



ermilab

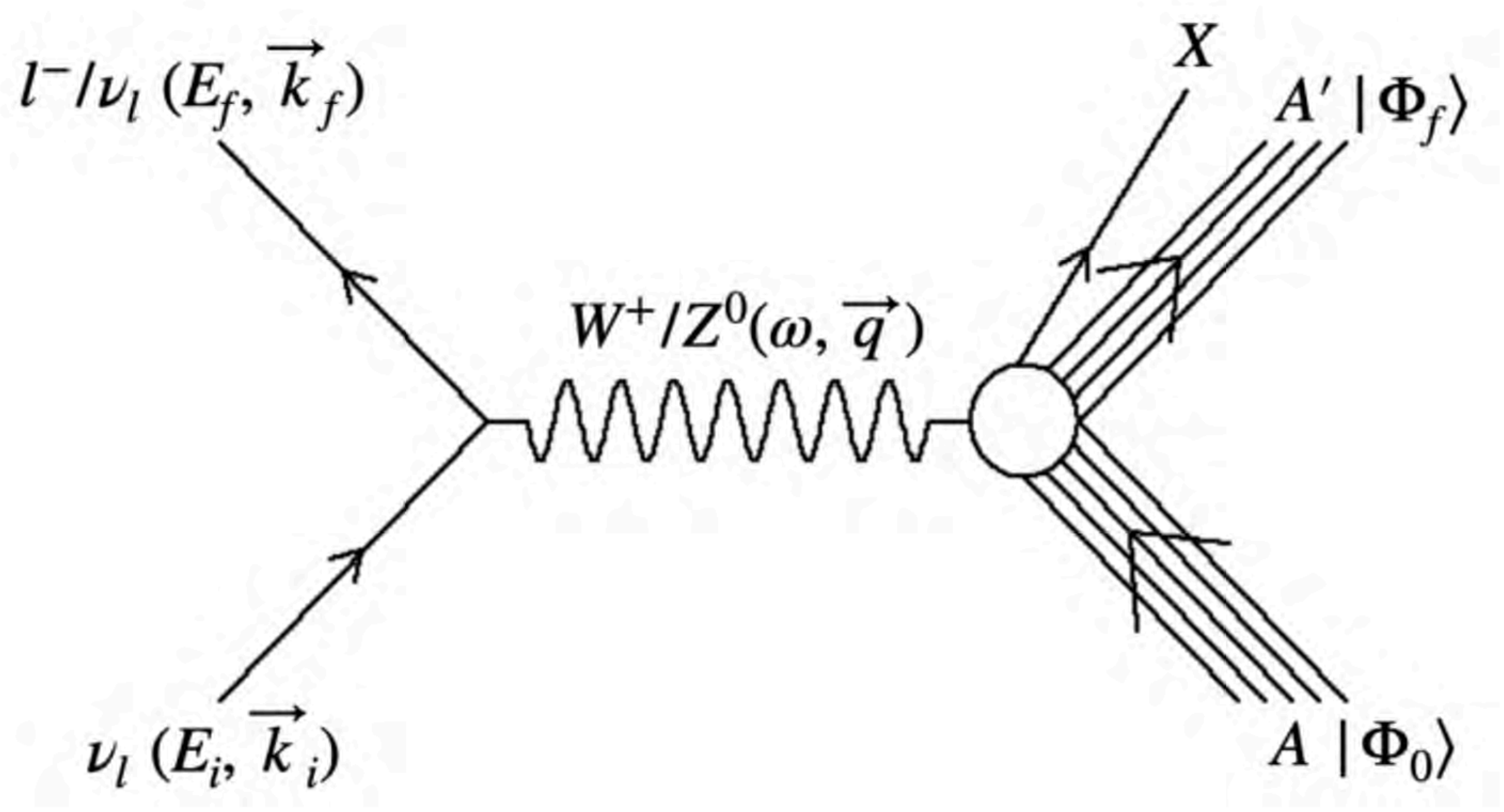

Yuri's talk

Credit: Katsuya Yonehara

# Life is simple at low energies




$$\mathrm{CE}\nu\mathrm{NS}$$




$$\mathrm{CCQE, NCQE}$$

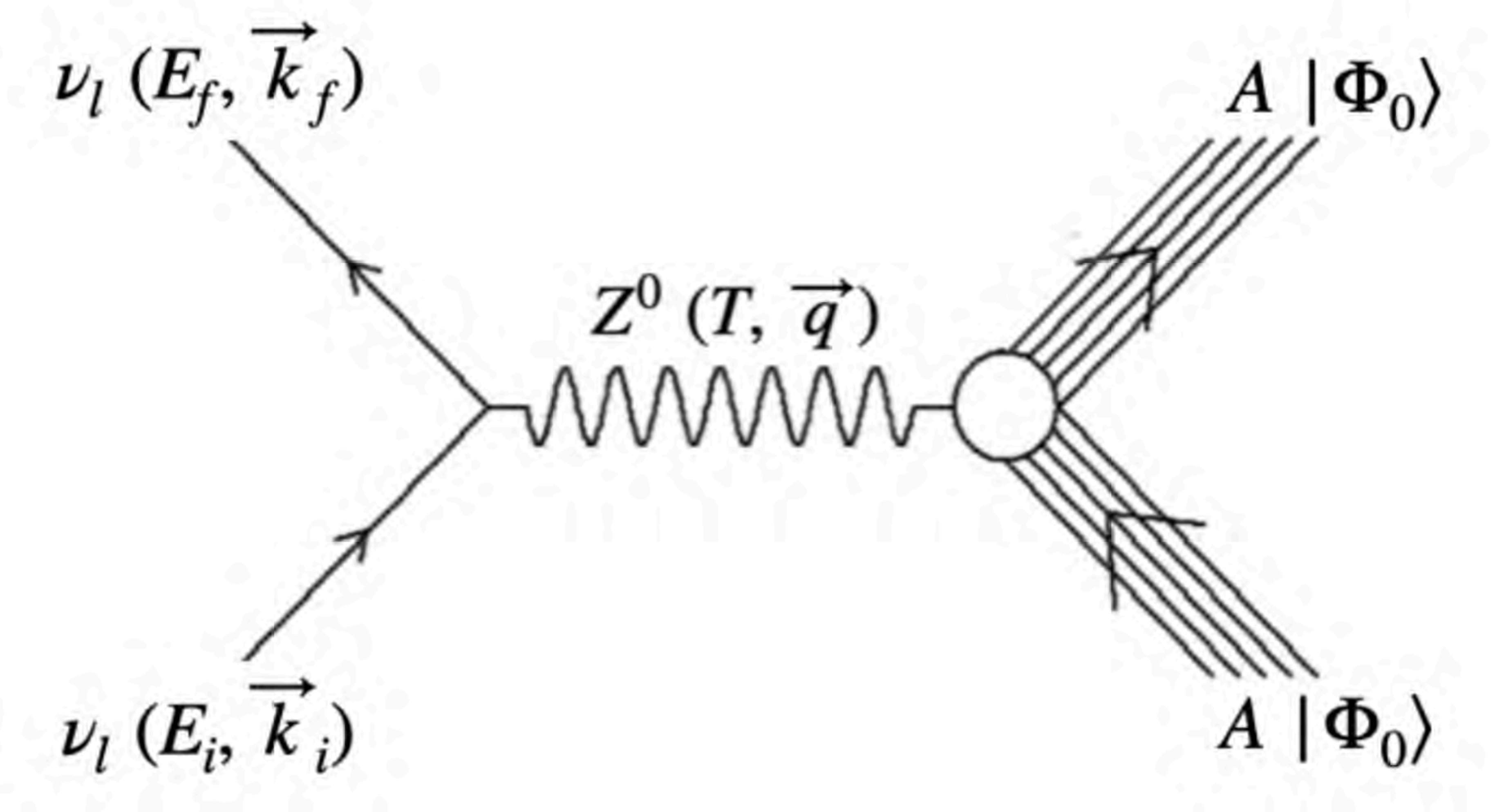
**Dessel et al.**, *Universe* **2023**, *9*(5), 207; https://doi.org/10.3390/universe9050207

# Coherent Elastic ν-Nucleus Scattering

## CEνNS

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) F_W(q^2)^2$$

- σ: Cross Section
- T: Recoil Energy
- $E_\nu$: Neutrino Energy
- $G_F$: Fermi Constant
- $Q_W$: Weak Charge
- $M_A$: Atomic Mass
- $F_W$: Form Factor




No flavor-specific terms!!!
Same rate for $\nu_e$, $\nu_\mu$, and $\nu_\tau$

# Coherent Elastic ν-Nucleus Scattering

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PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

**Coherent effects of a weak neutral current**

Daniel Z. Freedman†
*National Accelerator Laboratory, Batavia, Illinois 60510*
*and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790*
(Received 15 October 1973; revised manuscript received 19 November 1973)

Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.

Also: D. Z. Freedman et al., "The Weak Neutral Current and Its Effect in Stellar Collapse", Ann. Rev. Nucl. Sci. 1977. 27:167-207

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VOLUME 55, NUMBER 1 PHYSICAL REVIEW LETTERS 1 JULY 1985

**Bolometric Detection of Neutrinos**

Blas Cabrera, Lawrence M. Krauss, and Frank Wilczek
*Department of Physics, Stanford University, Stanford, California 94305*
*Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 01238*
*Institute for Theoretical Physics, University of California, Santa Barbara, California 93106*
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CEνNS

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) F_W(q^2)^2$$

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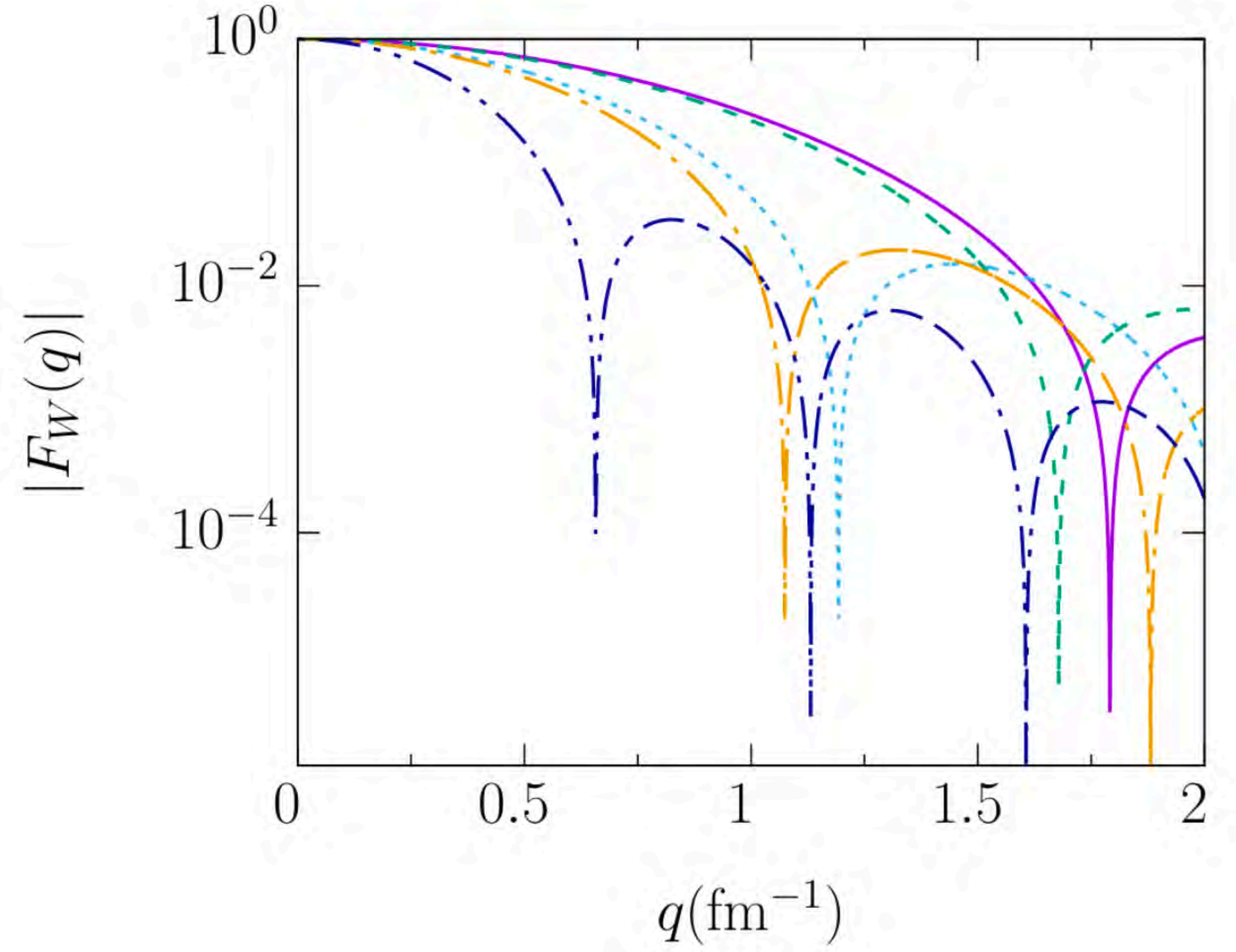
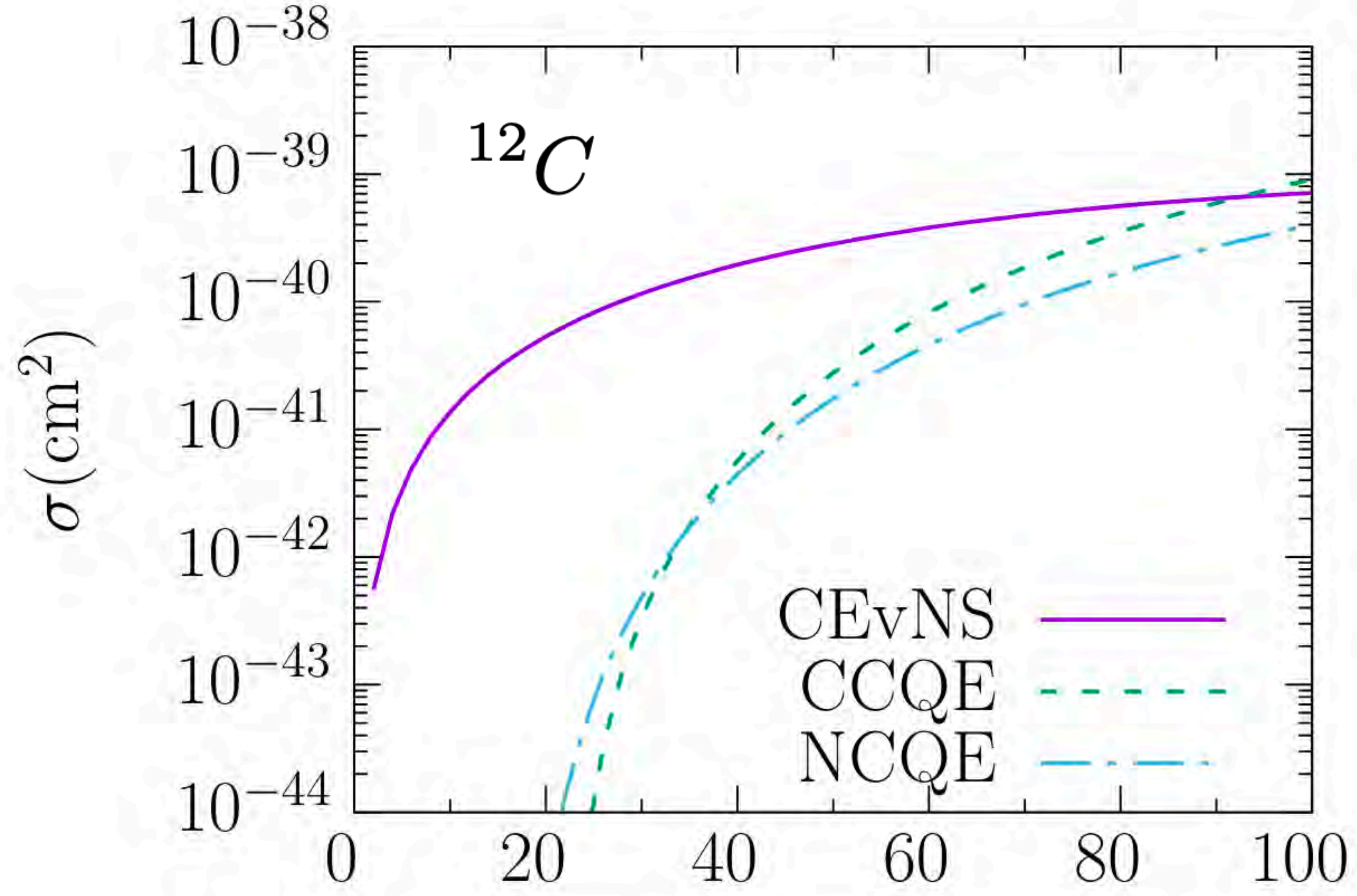
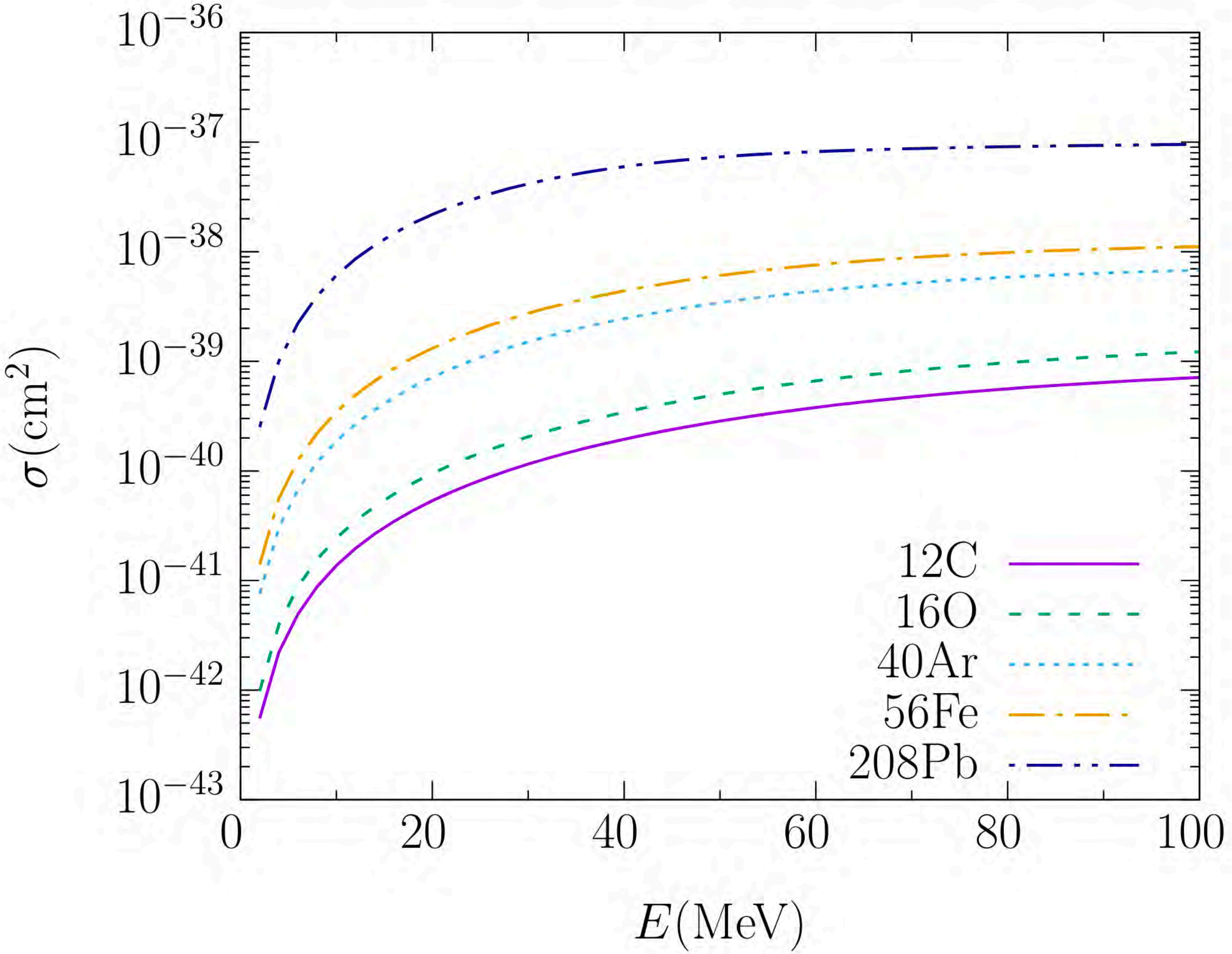
# Form factor means you want to look at low energies



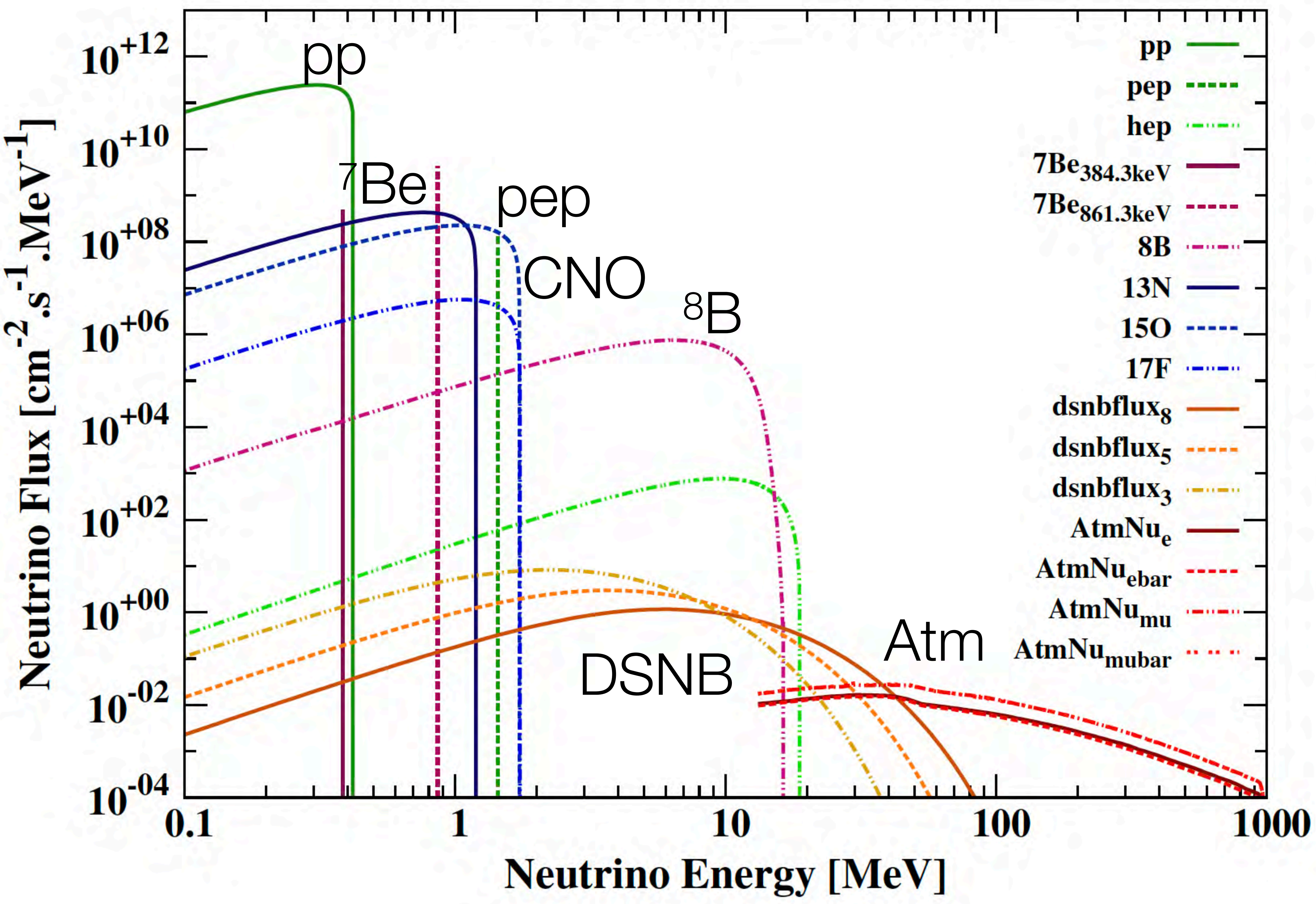



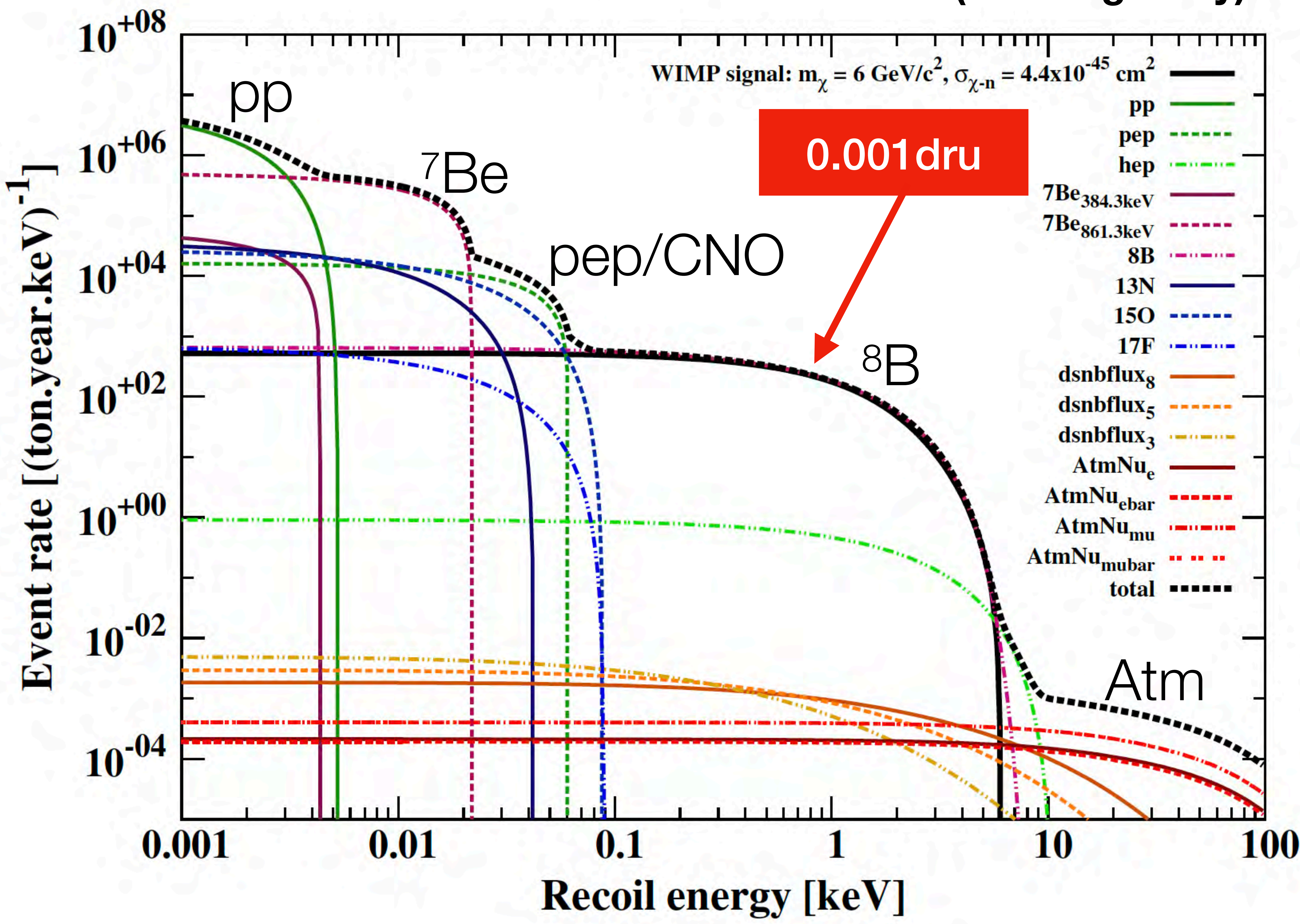

**Dessel et al.**, *Universe* **2023**, *9*(5), 207; https://doi.org/10.3390/universe9050207

# Neutrino Sources: the Sun & other cosmic sources

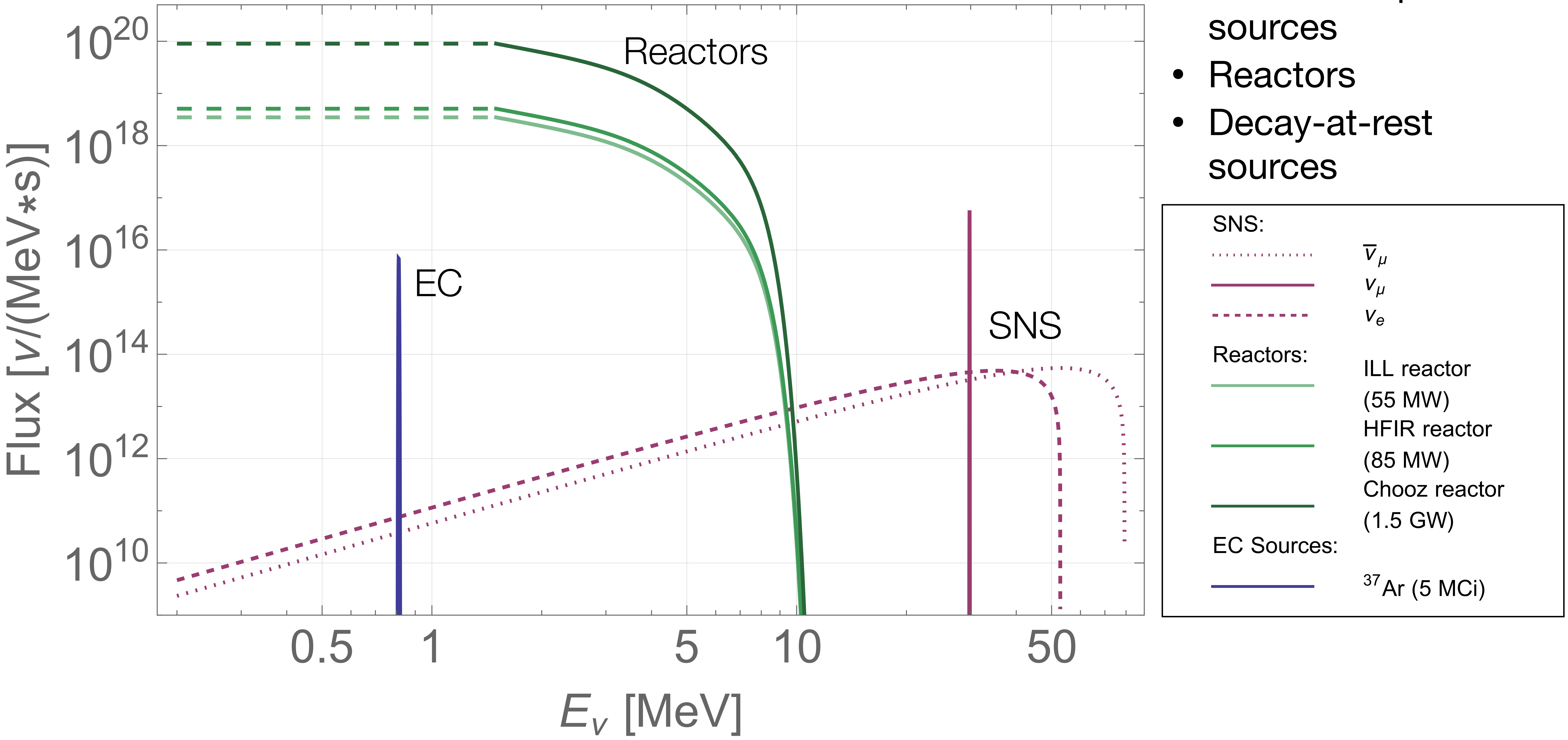
- Need lots of exposure (mass * time)
- Probably need to do this underground…
- We'll leave these to the dark matter experiments

**dru = evt/(keV * kg * day)**



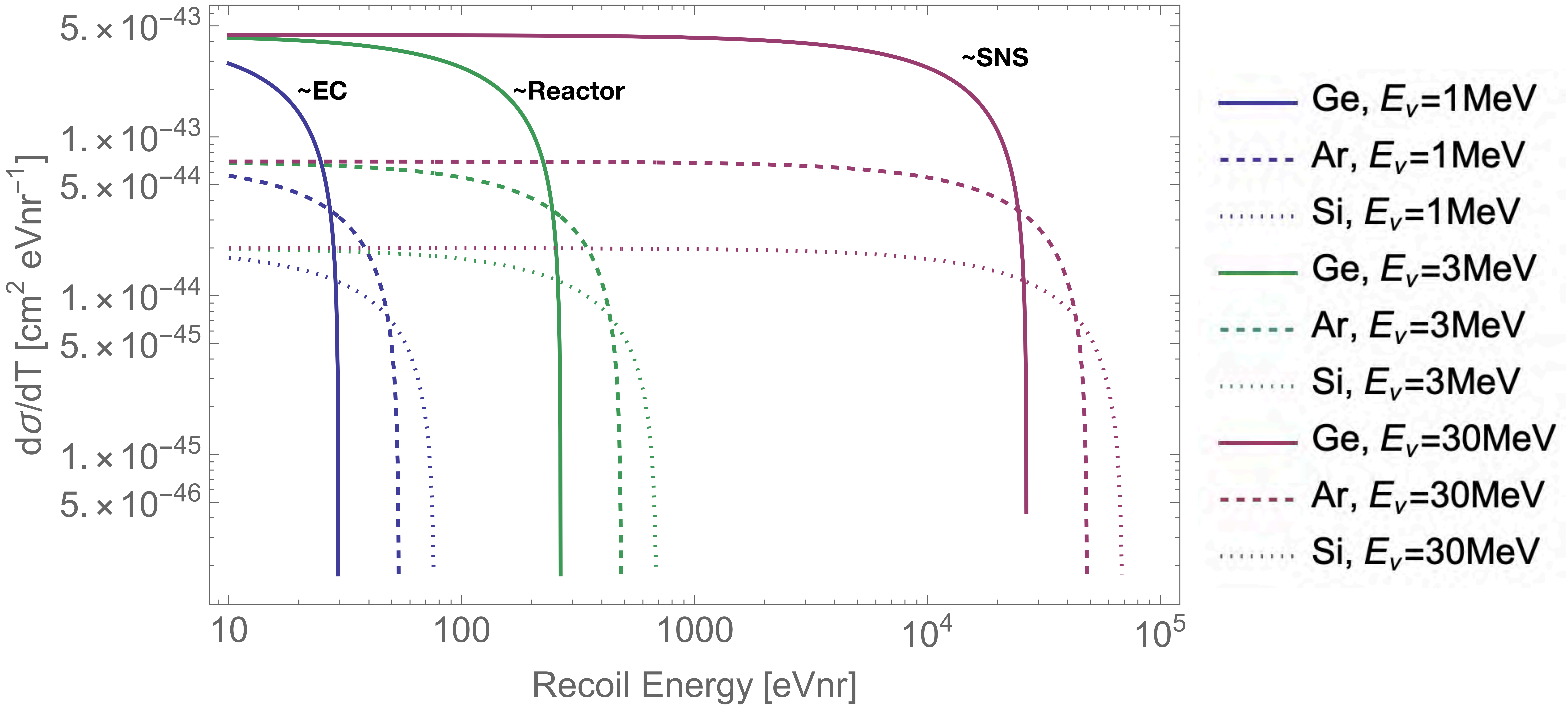



# Neutrino Sources for CEνNS



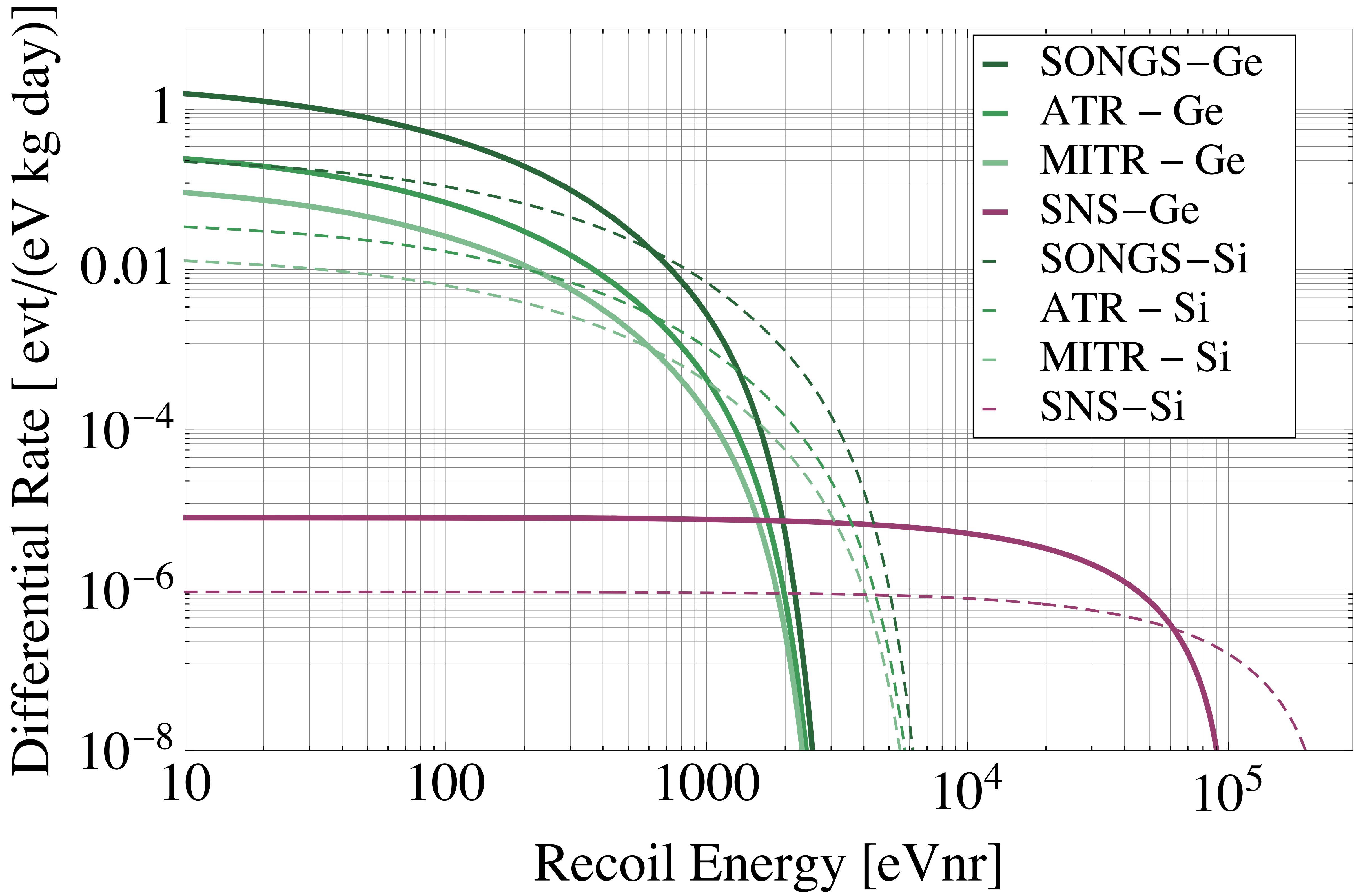

- Electron-capture sources
- Reactors
- Decay-at-rest sources

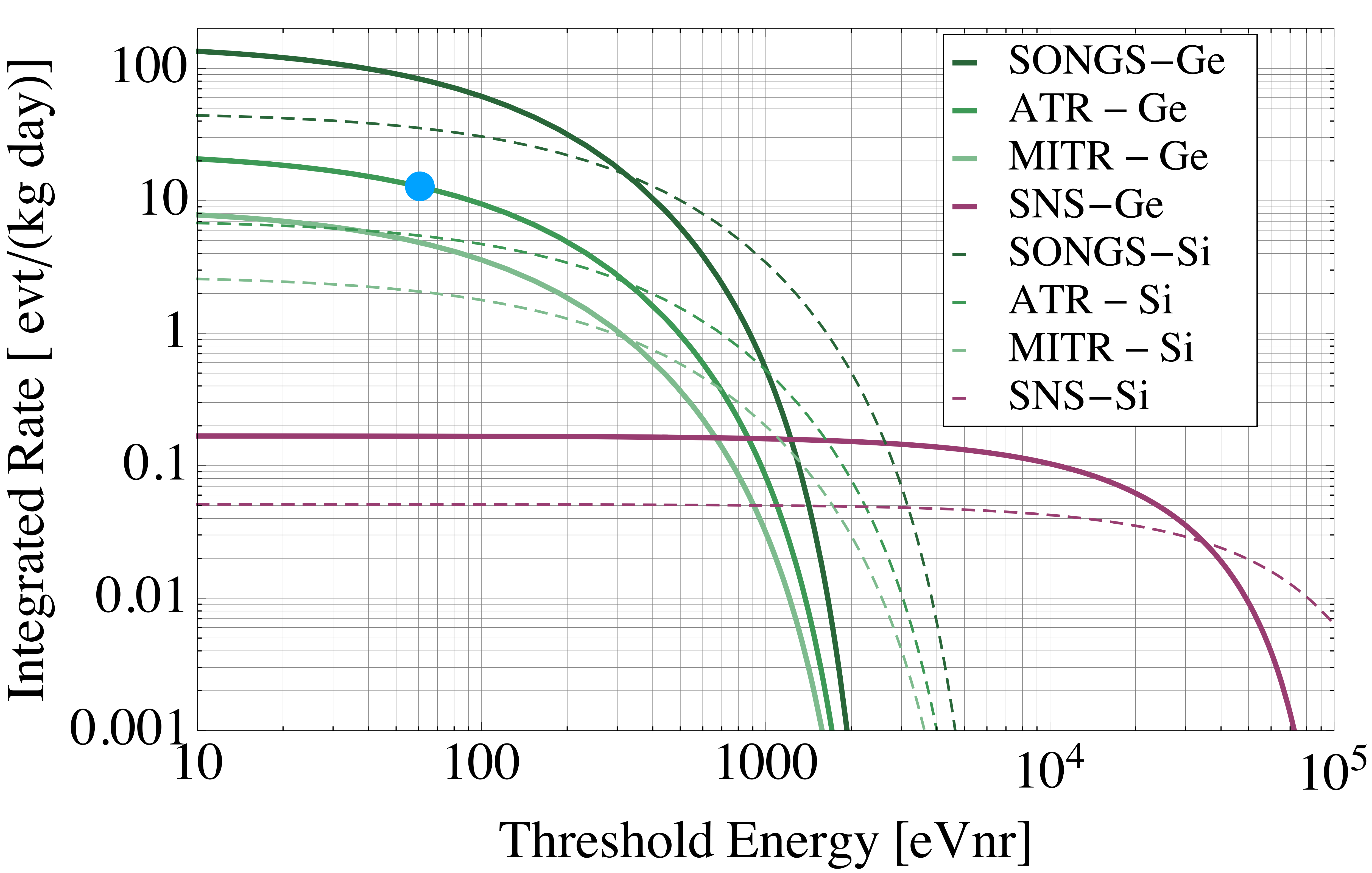
# Energy Thresholds Needed for mono-energetic Neutrinos



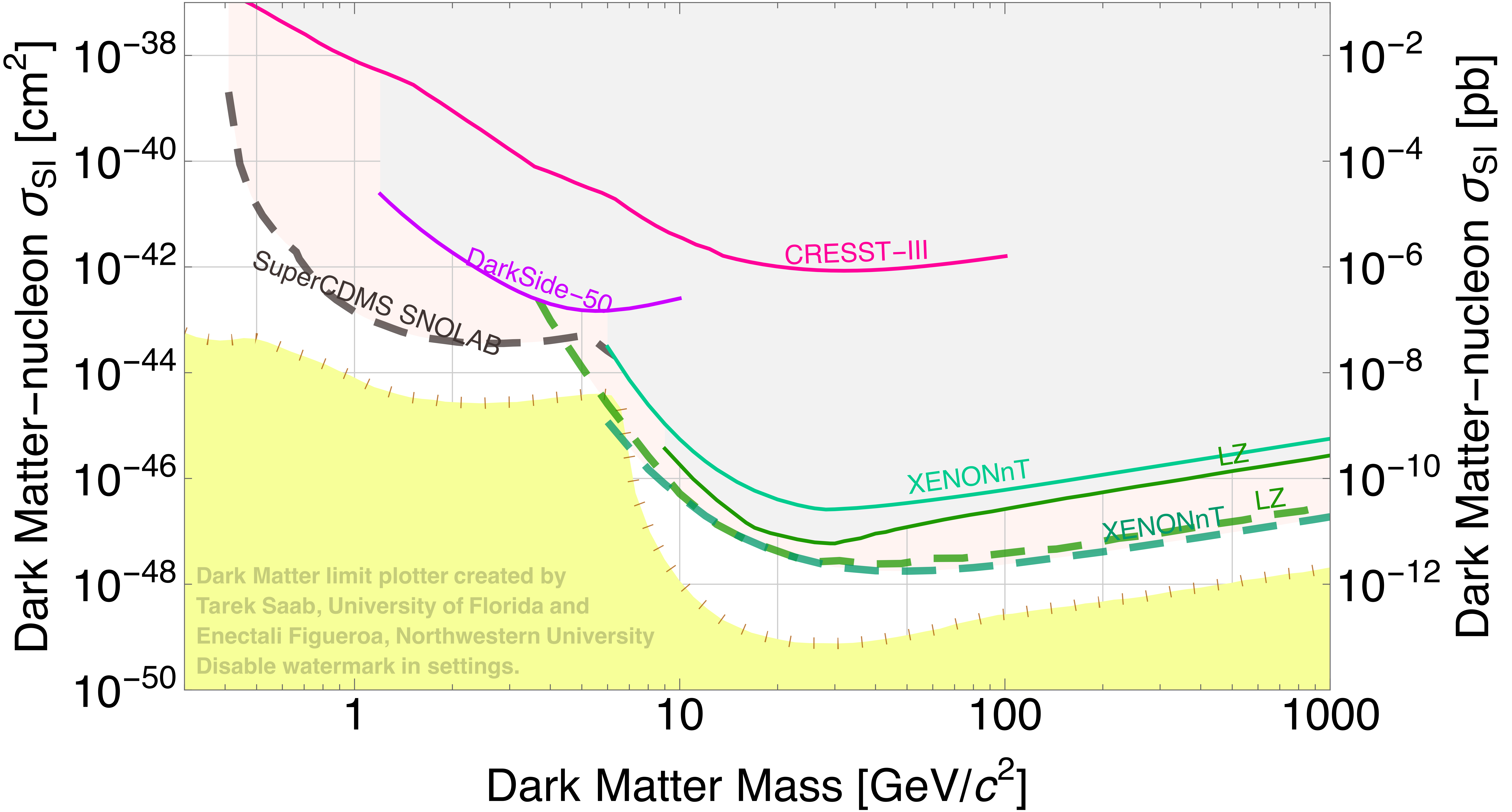
# Detector Response: Need Low-thresholds!

Large cross section allows for "tabletop" neutrino experiments with kg-scale mass!



# CE$\nu$NS Requires Dark Matter Sensitivity On the Surface!



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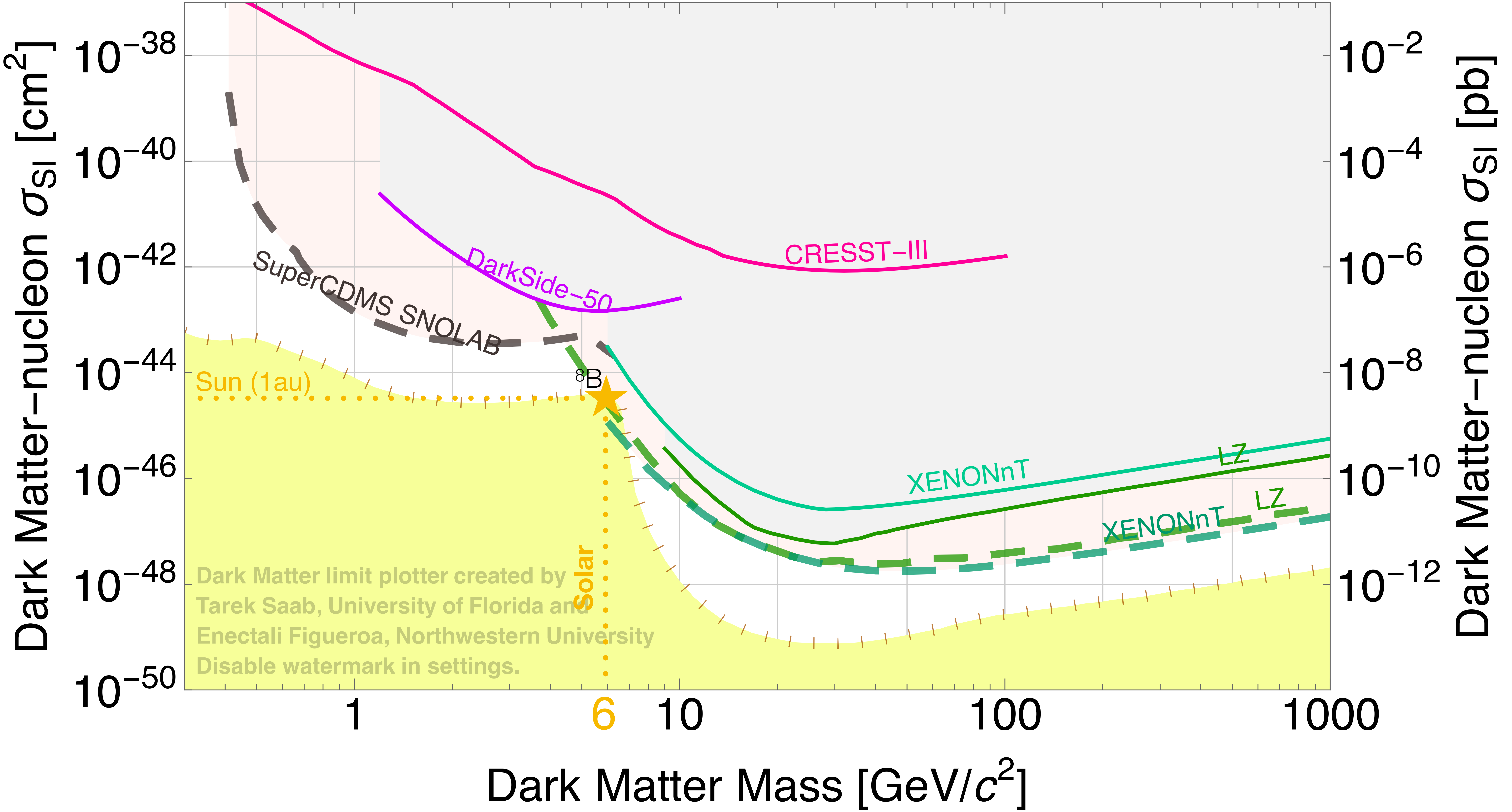

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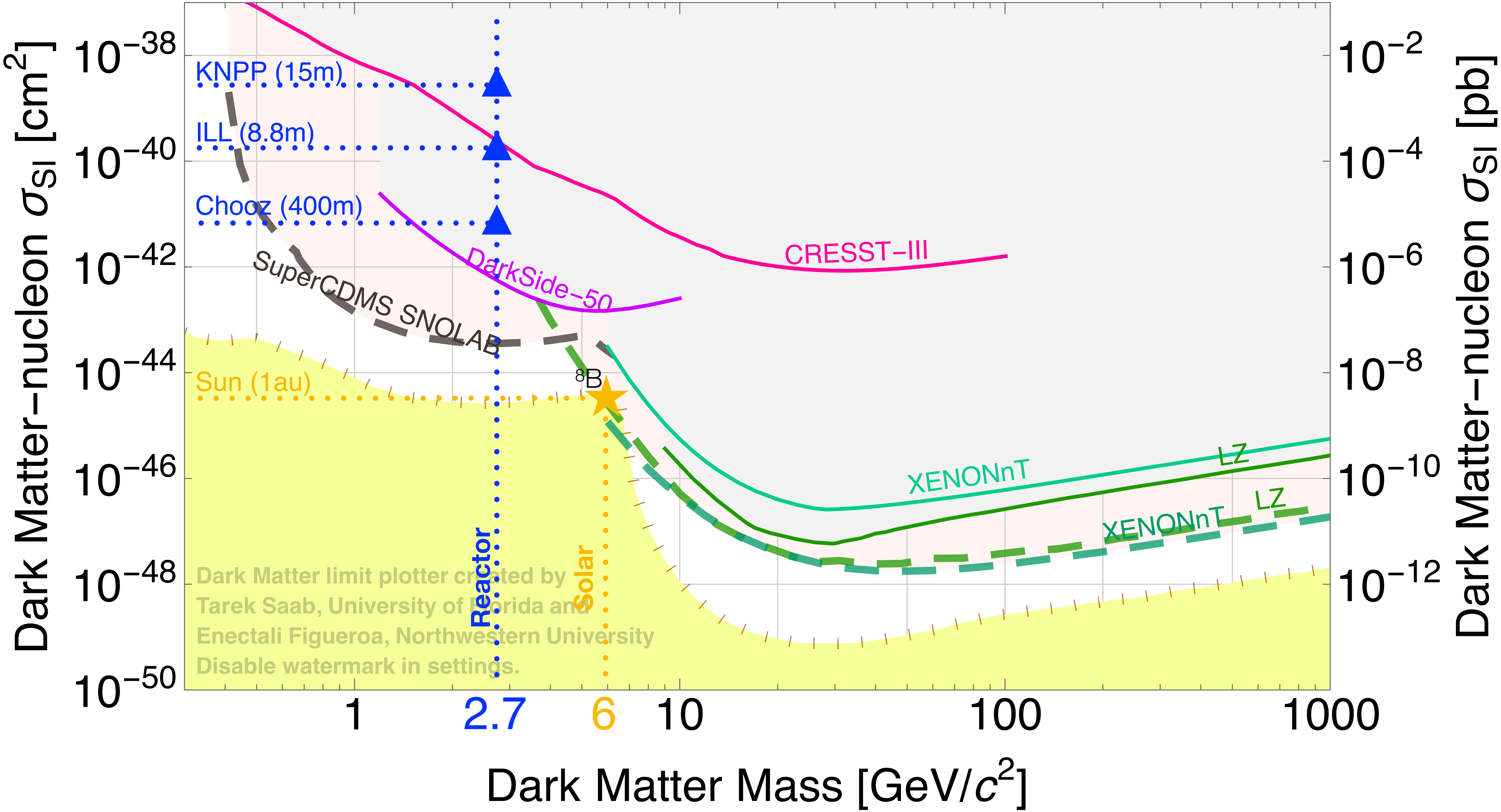

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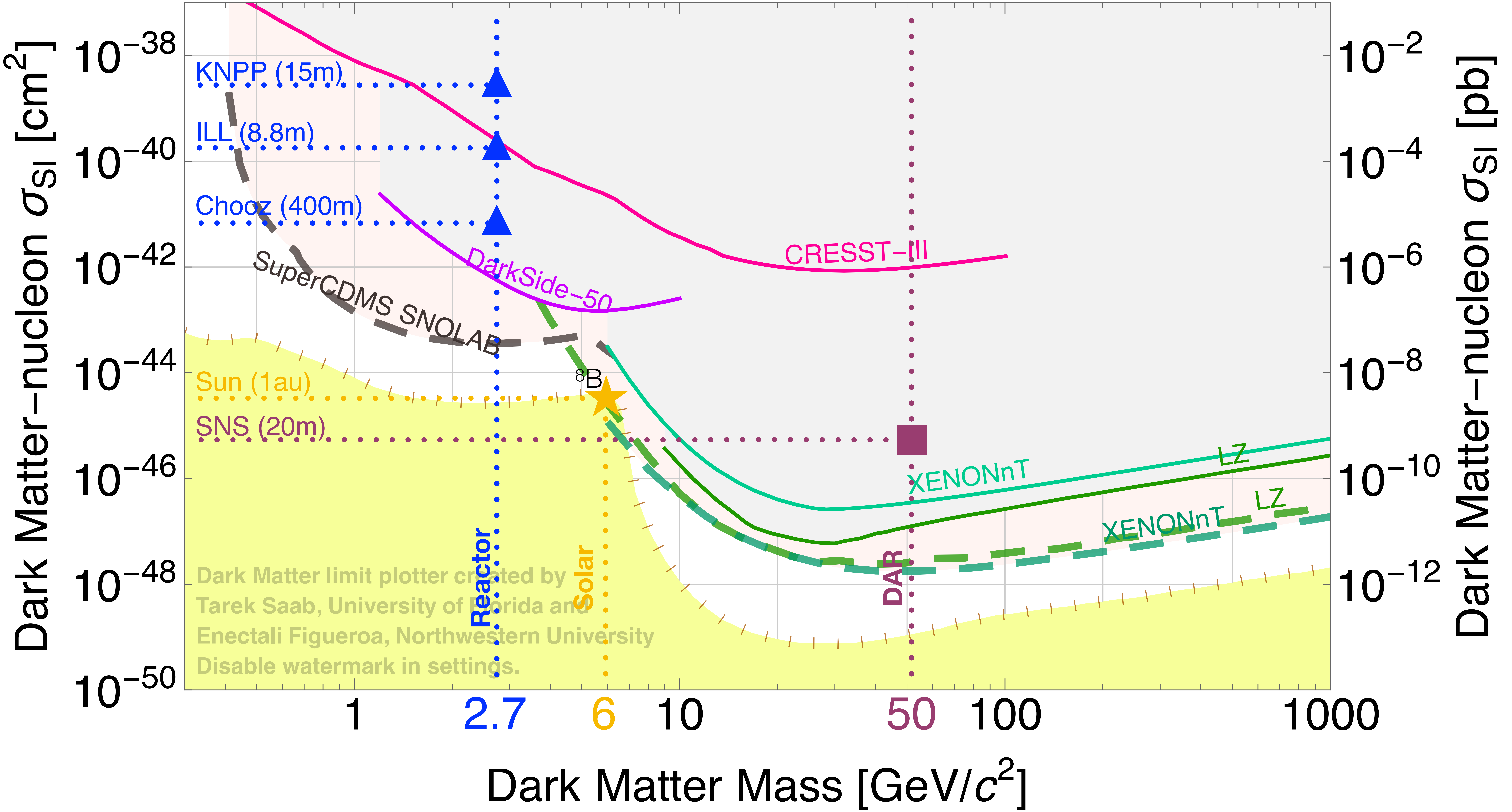


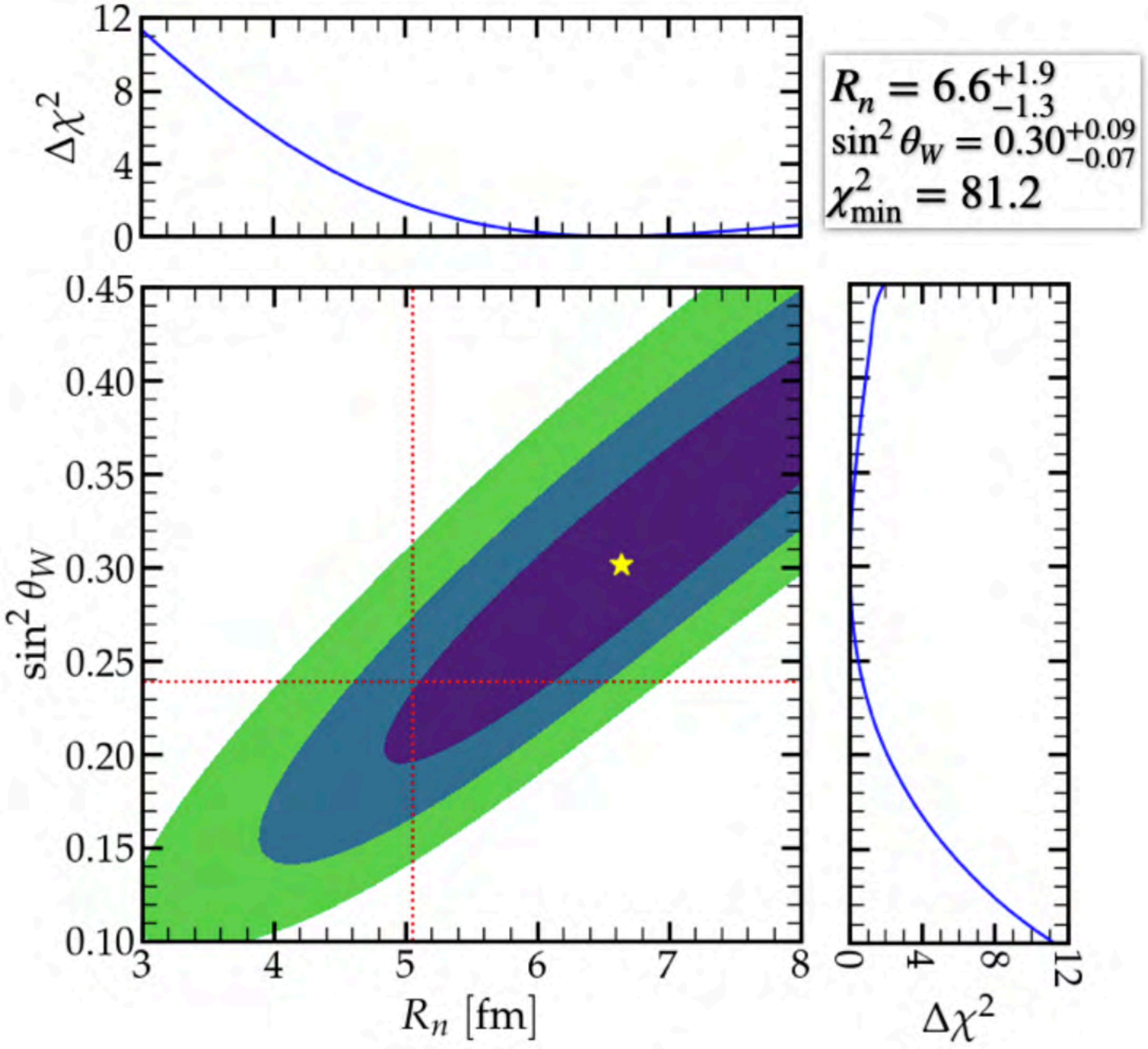
# CE$\nu$NS Science

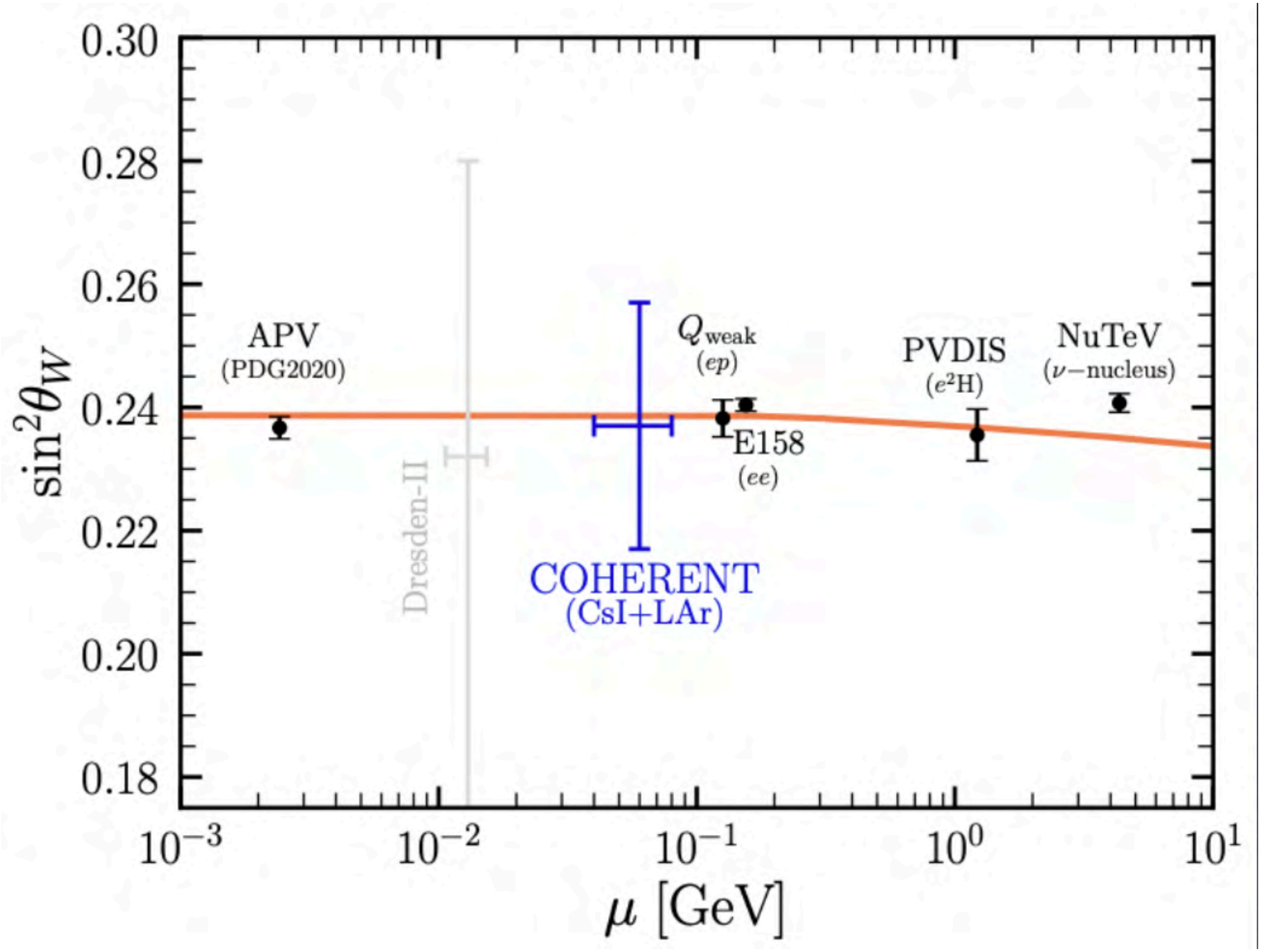
Slide from Valentina De Romeri

- EW Precision tests:
  - Weak Mixing Angle
- New neutrino interactions
  - Non-standard interactions
  - Generalised interactions
  - New mediators
- Neutrino Properties
  - Neutrino Charge Radius
  - Magnetic Moments
- Nuclear Physics
  - Nuclear form factors
  - Neutron radius and “skin”
- Solar Neutrinos
- Dark Matter
- Sterile Neutrinos
- Supernovae

Brdar and Rodejohann, arXiv:1810.03626; Chang and Liao, arXiv:2002.10275; Li et al, arXiv:2005.01543; CONUS, arXiv:2110.02174; Cadeddu et al, arXiv:1710.02730, arXiv:2005.01645, arXiv:1908.06045; Aristizabal Sierra et al, arXiv:1902.07398; Huang and Chen, arXiv:1902.07625; Papoulias et al, arXiv:1903.03722, arXiv:1907.11644; Miranda et al, arXiv:2003.12050; Papoulias et al, arXiv:1711.09773, arXiv:1907.11644; Cadeddu et al, arXiv:1808.10202, arXiv:2005.01645, arXiv:1908.06045, arXiv:2205.09484; Huang and Chen, arXiv:1902.07625; Miranda et al, arXiv:1902.09036, arXiv:2003.12050; Khan and Rodejohann, arXiv:1907.12444; COHERENT, arXiv:2110.07730; Papoulias and Kosmas, arXiv:1711.09773; Blanco et al, arXiv:1901.08094; Miranda et al, arXiv:1902.09036, Cerdeño et al, arXiv:1604.01025; Farzan et al, arXiv:1802.05171; Aristizabal Sierra et al, arXiv:1806.07424; Khan and Rodejohann, arXiv:1907.12444; Aristizabal Sierra et al, arXiv:1910.12437; Miranda et al, arXiv:2003.12050; Aristizabal Sierra et al, JHEP 09 (2019) 069; Suliga and Tamborra, arXiv:2010.14545; CONUS, arXiv:2110.02174; Li and Xia, arXiv:2201.05015; Atzori Corona et al, arXiv:2202.11002; Liao et al, arXiv:2202.10622; Coloma et al, arXiv:2202.10829; Lindner et al, arXiv:1612.04150; Aristizabal Sierra et al, arXiv:1806.07424; Aristizabal Sierra et al, JCAP 01 (2022) 01, 055

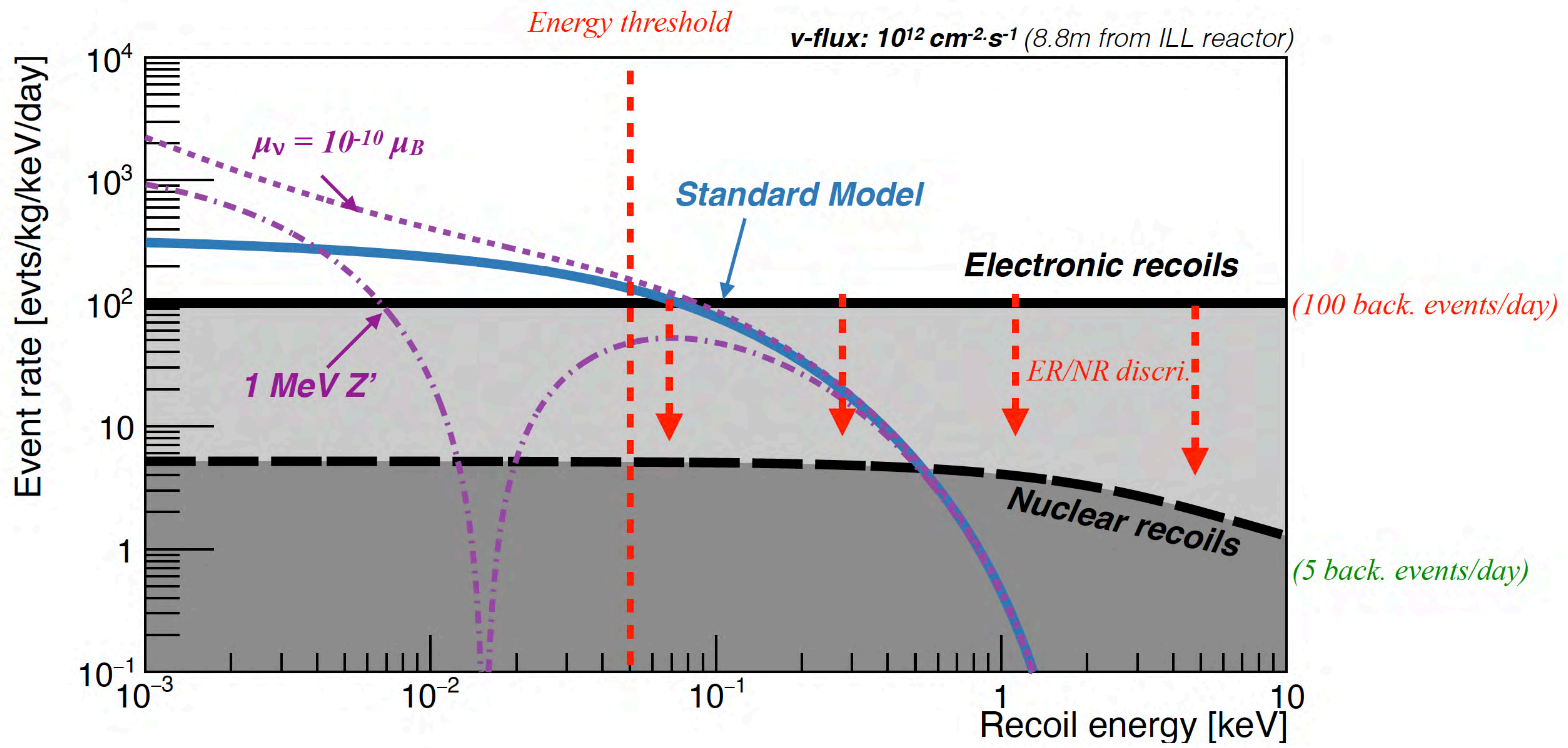
# COHERENT Limits on Weak Mixing Angle and Skin Radius




**De Romeri, Miranda, DKP, Sanchez, Tortola, Valle: arXiv: 2211.11905**

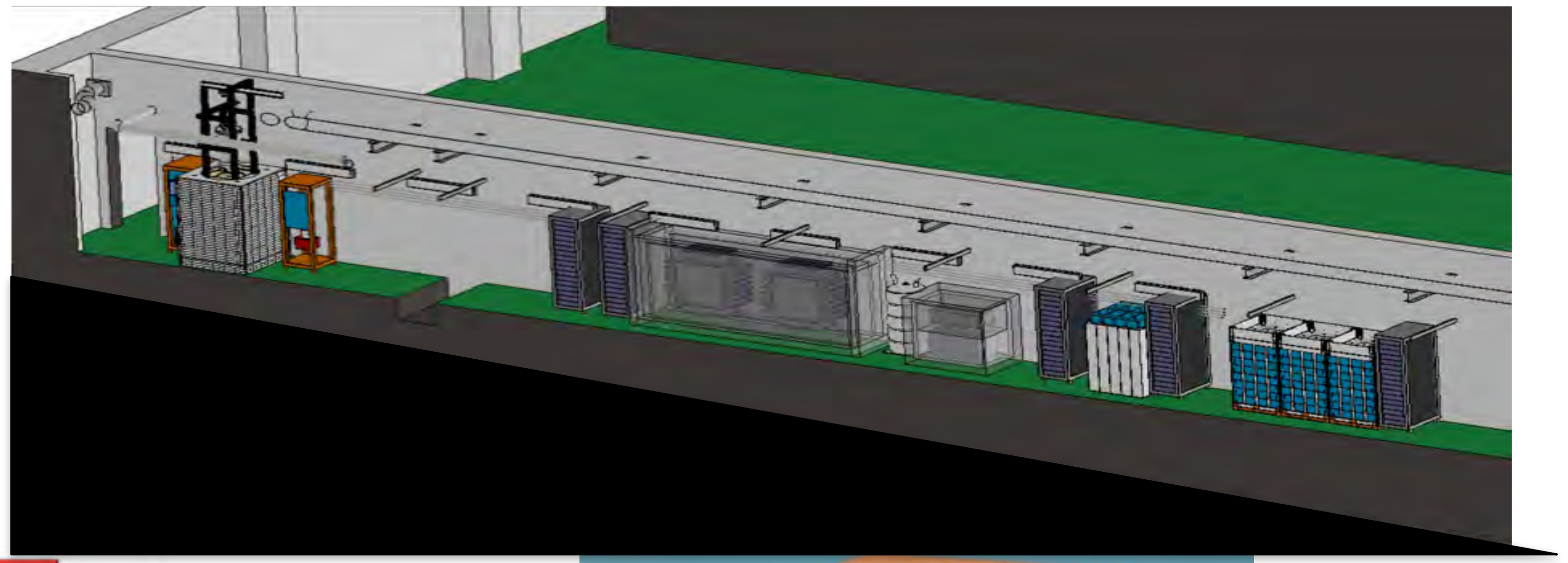
# CE$\nu$NS Future Science Example: Ricochet

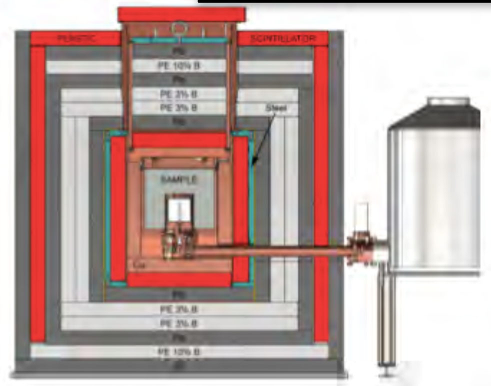
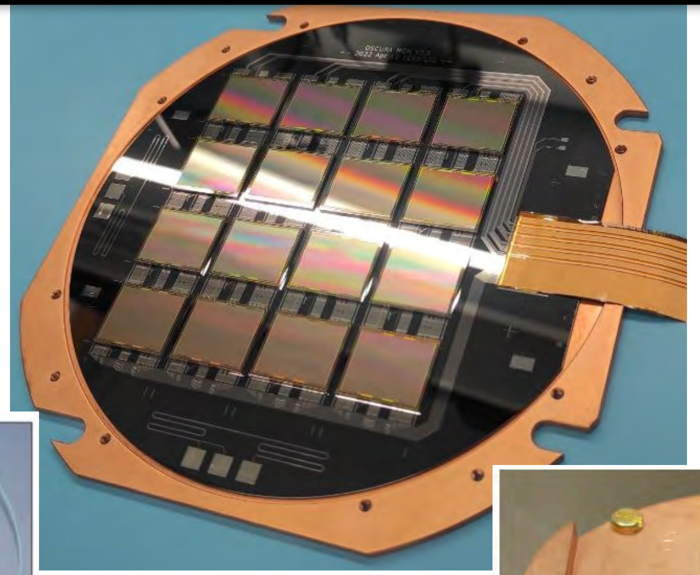
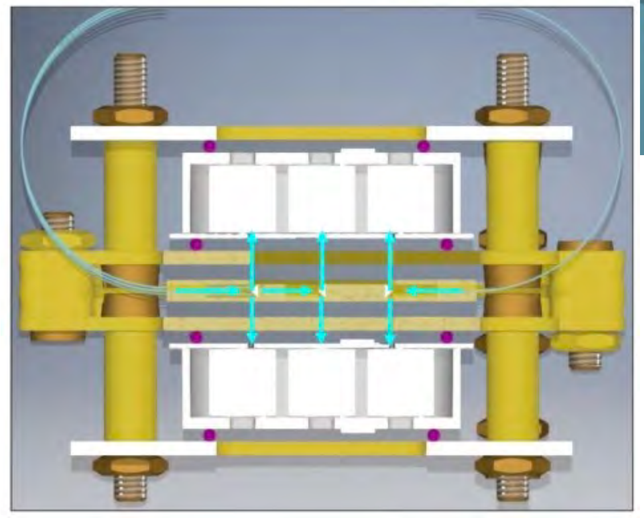
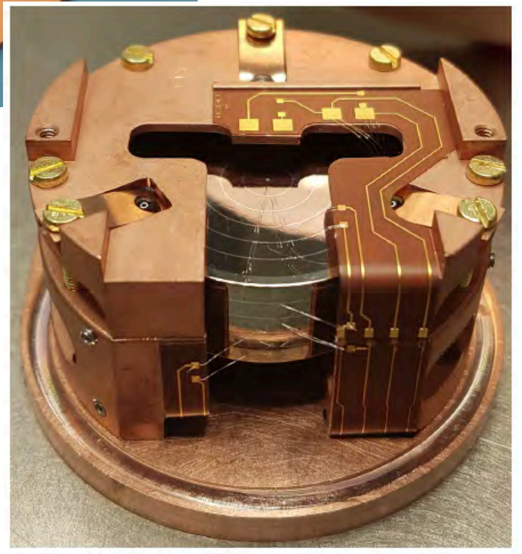
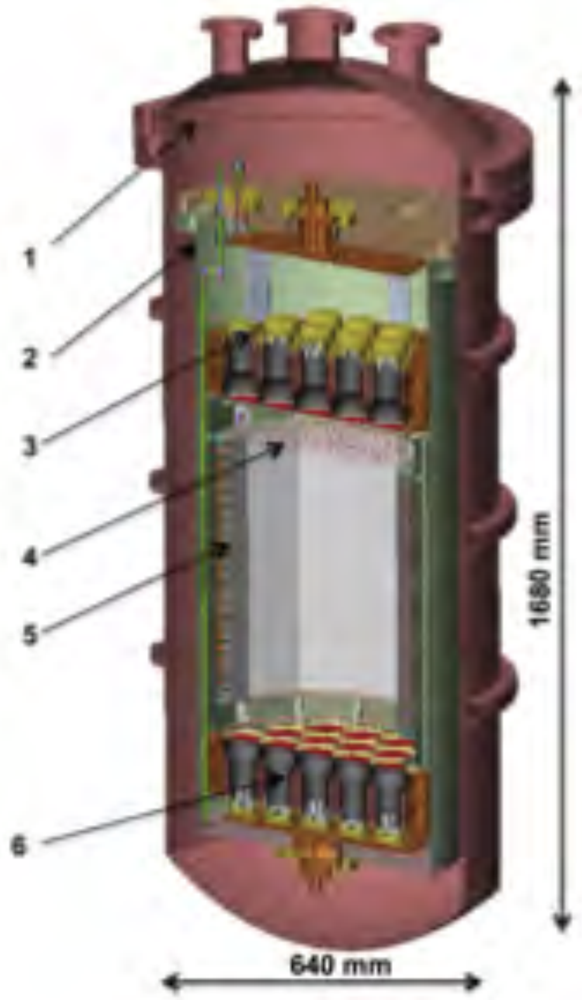


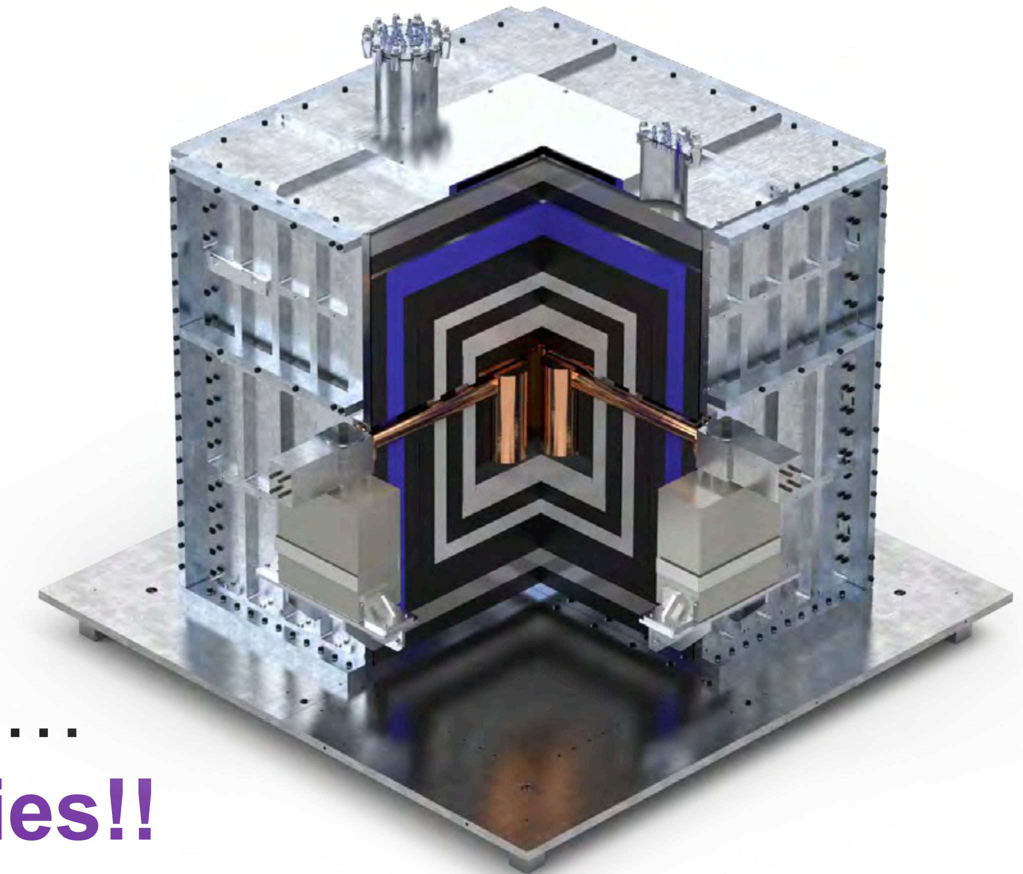
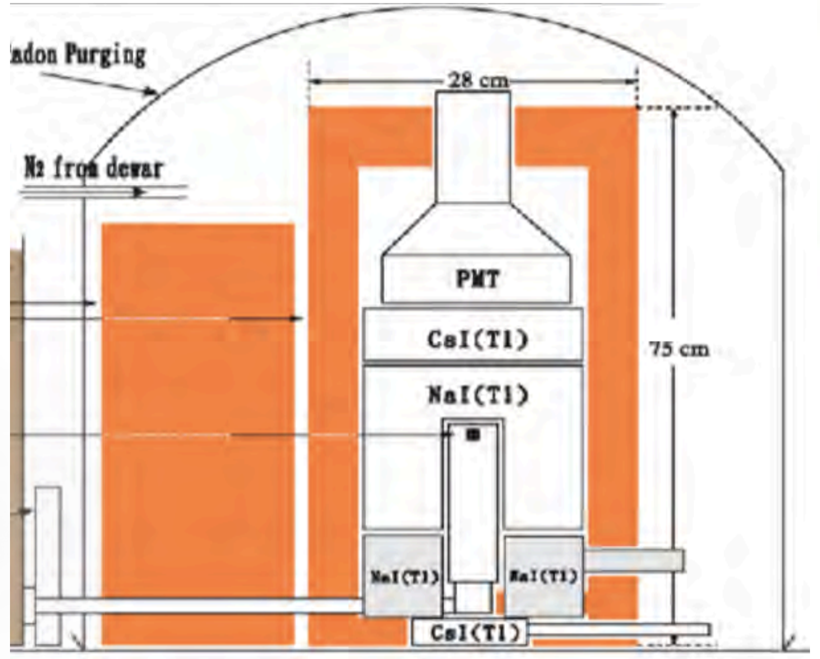

**Spectral information improves searches for new physics!**

# Many CEvNS Efforts Worldwide [incomplete]

| Experiment | Technology | Location | Source |
|---|---|---|---|
| **COHERENT** | CsI, Ar, Ge, NaI | USA | $\pi$DAR |
| **CCM** | Ar | USA | $\pi$DAR |
| **ESS** | CsI, Si, Ge, Xe | Sweden | $\pi$DAR |
| **BULLKID** | Si/Ge | Italy | Reactor |
| **CONNIE** | Si CCDs | Brazil | Reactor |
| **CONUS** | HPGe | Germany | Reactor |
| **NEWS-G** | Ar+2%CH4 | Canada | Reactor |
| **MINER** | Ge/Si cryogenic | USA | Reactor |
| **NEON** | NaI(Tl) | Korea | Reactor |
| **NUCLEUS** | $CaWO_4$ , $Al_2O_3$ cryogenic | Europe | Reactor |
| **$\nu$GEN** | Ge PPC | Russia | Reactor |
| **RED-100** | LXe dual phase | Russia | Reactor |
| **Ricochet** | Ge, Zn, Al, Sn cryogenic | France | Reactor |
| **TEXONO** | p-PCGe | Taiwan | Reactor |
| **Dresden II** | PCGe | USA | Reactor |
| **SBC** | Scintillating Bubble Chamber | Fermilab (R&D) | Reactor |



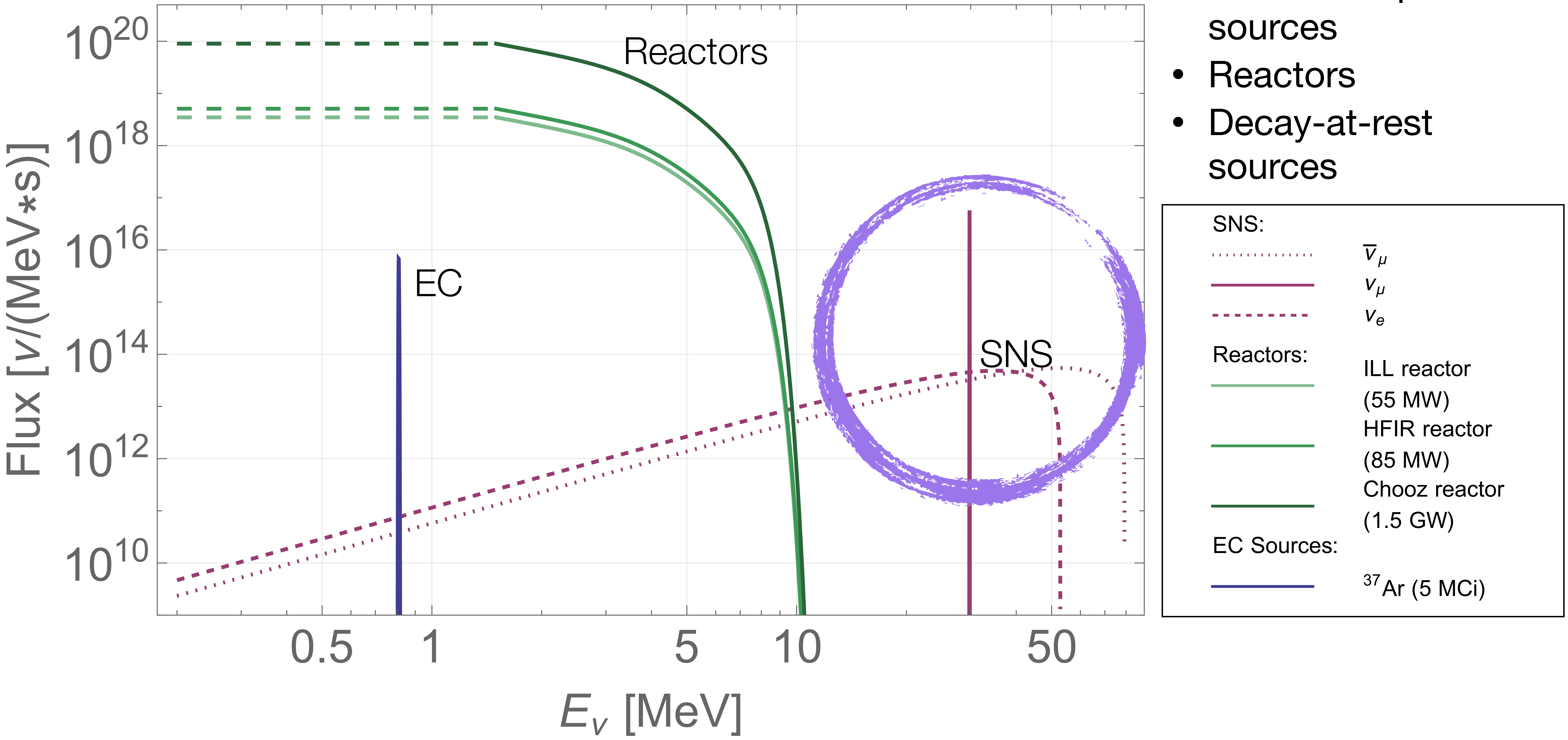







+DM detectors, +directional detectors +Solar/SN detectors…

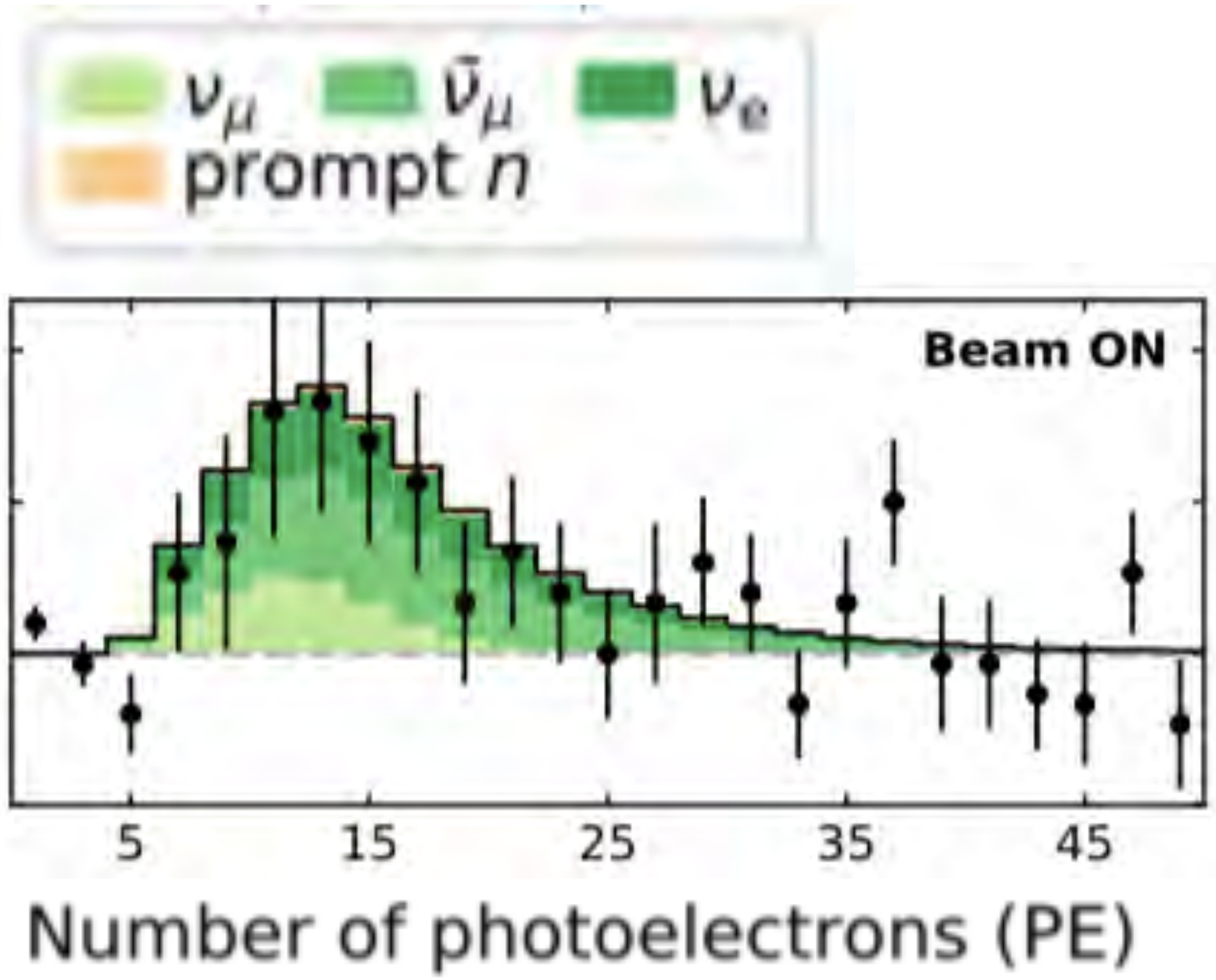
**many novel low-background, low-threshold technologies!!**

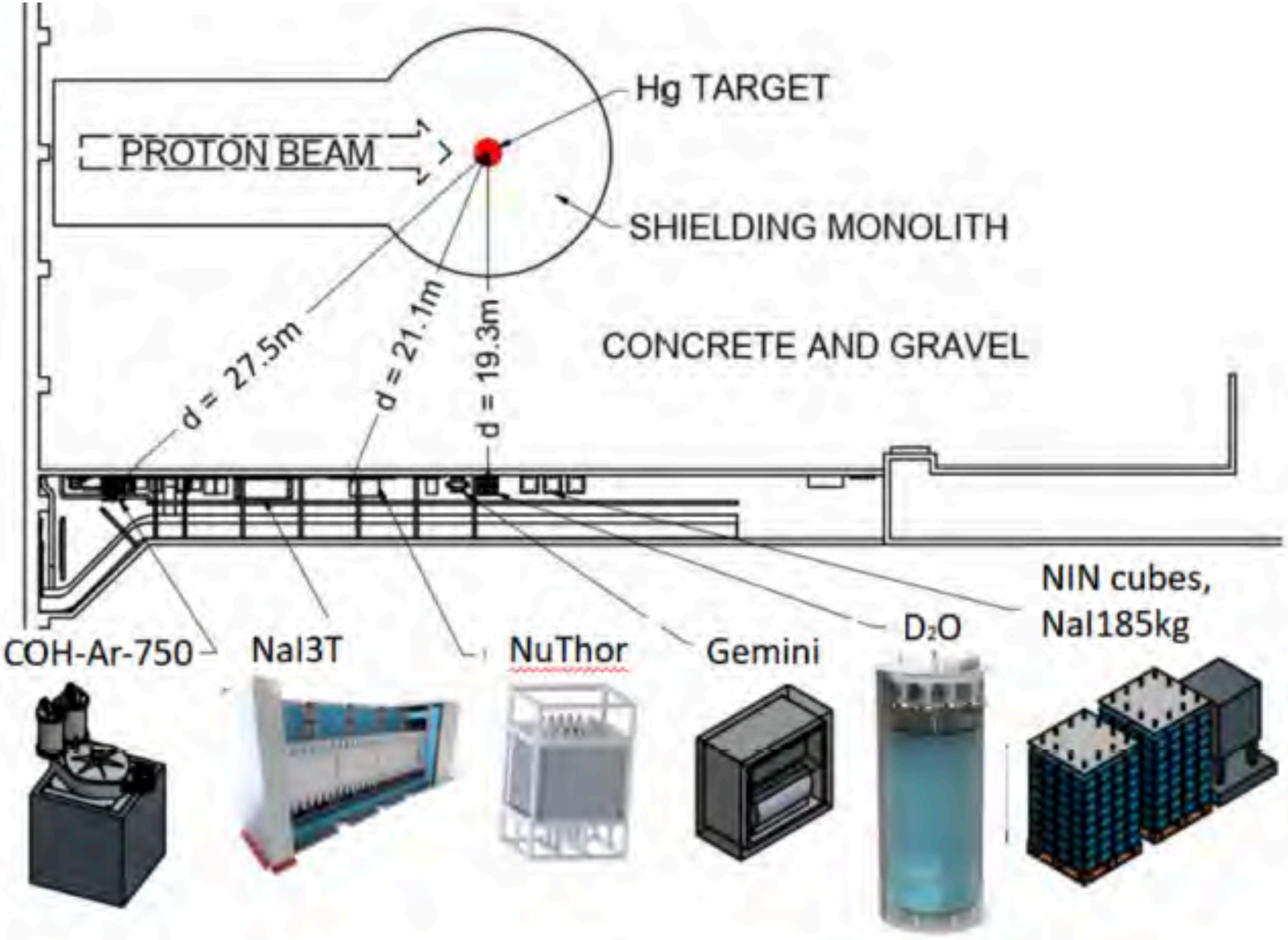
# DAR Experiments




- Electron-capture sources
- Reactors
- Decay-at-rest sources

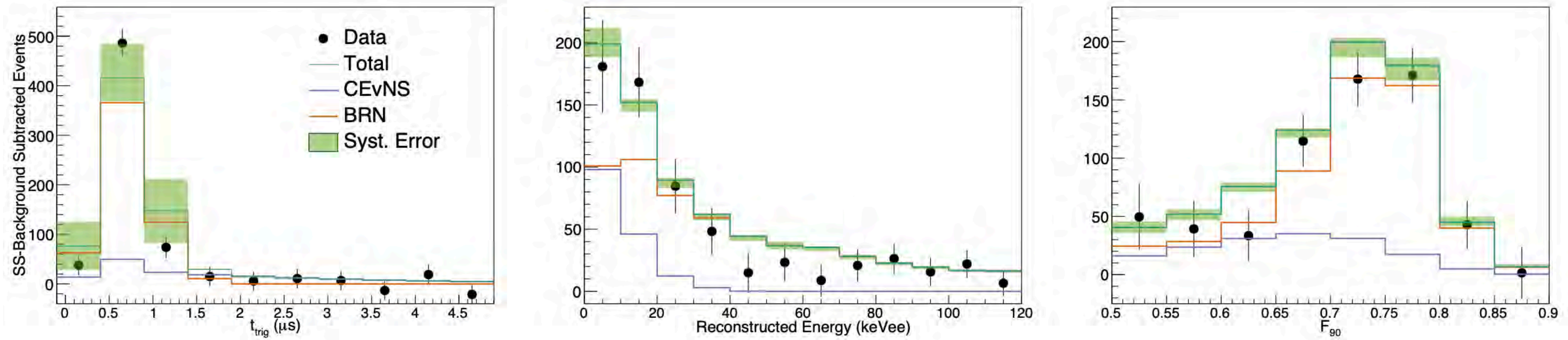
**See Yuri Efremenko’s Talk from Tuesday**

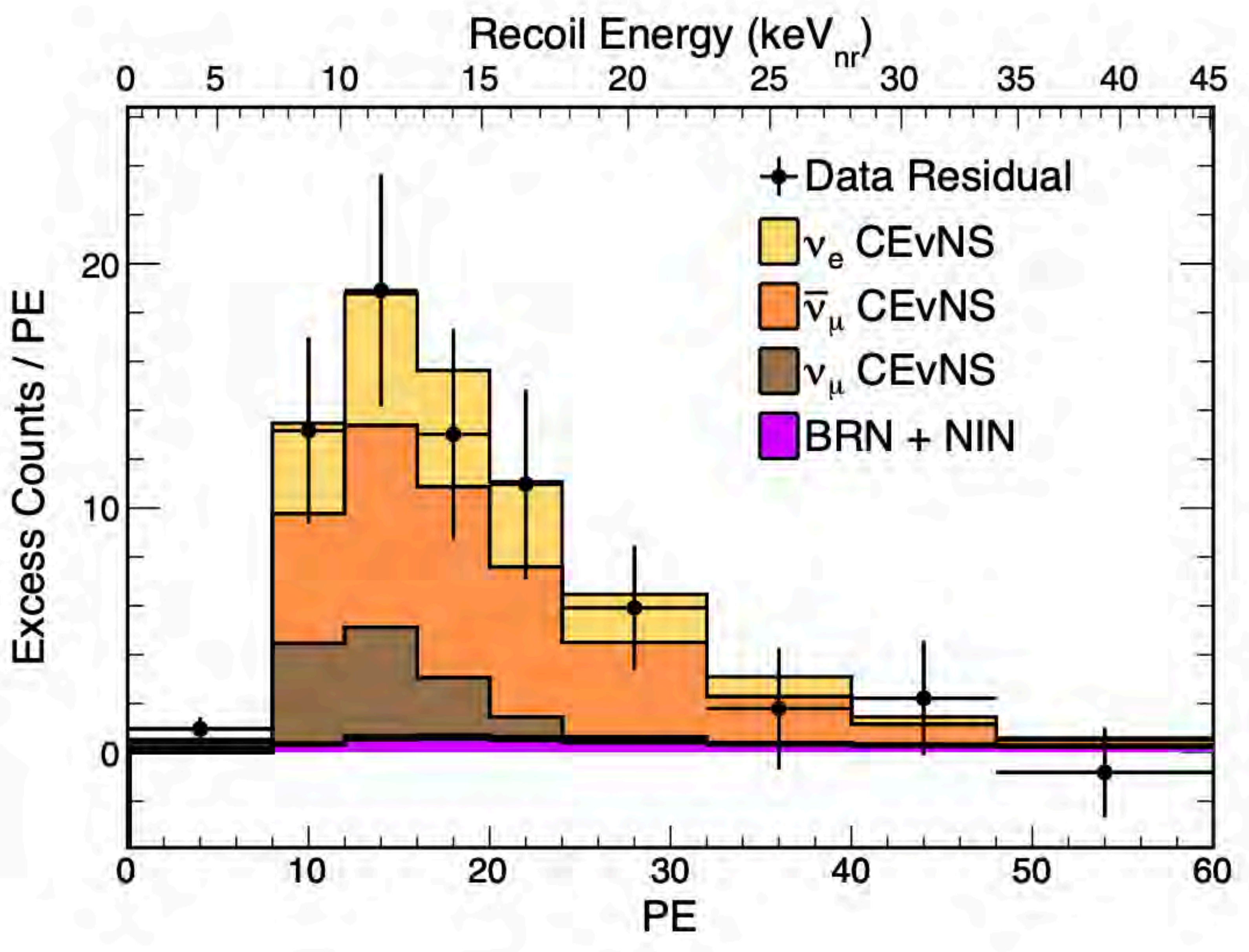


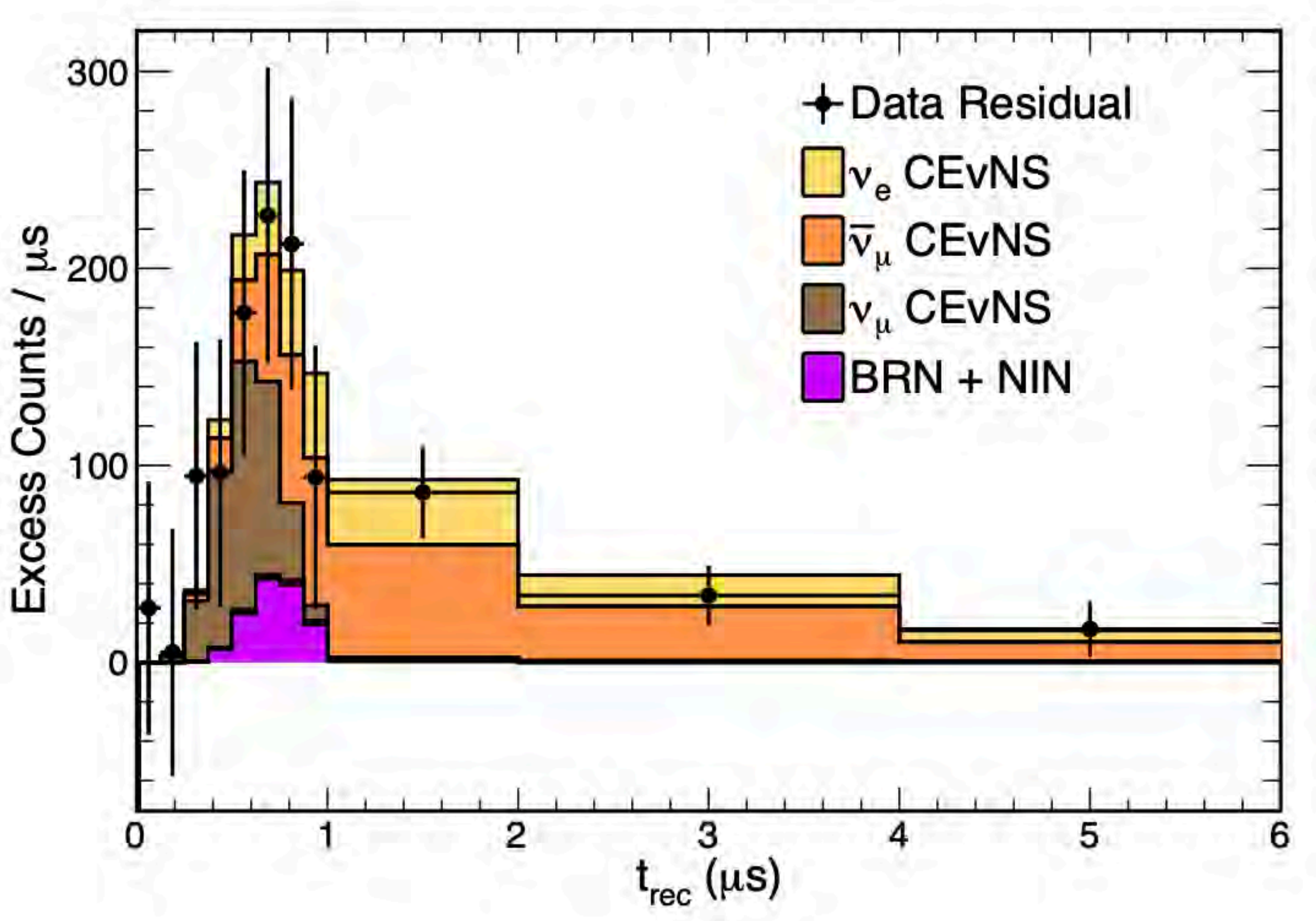




D. Akimov et al. (COHERENT). Science 357, 1123–1126 (2017)

# COHERENT Measurements on Ar and CsI



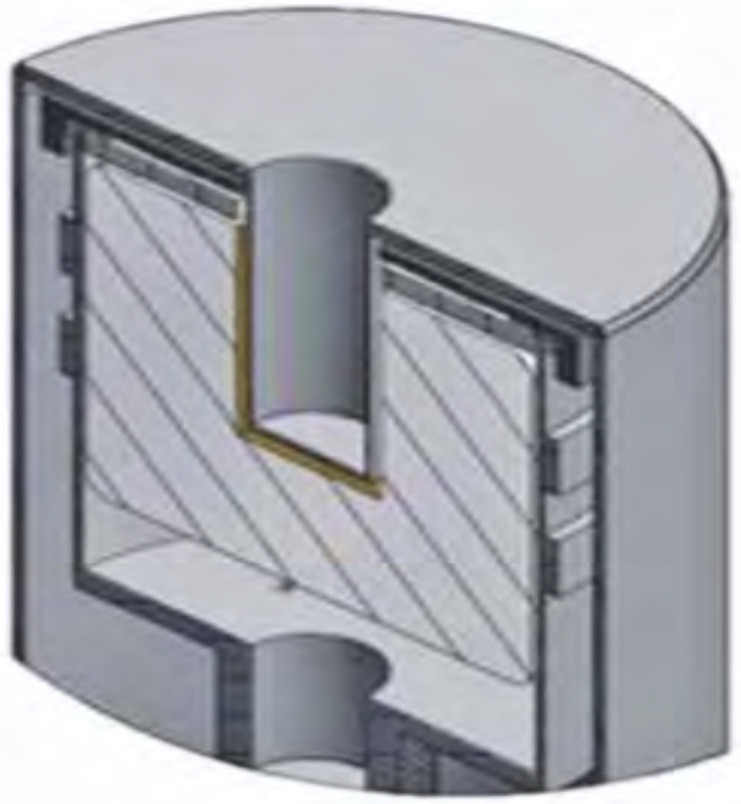



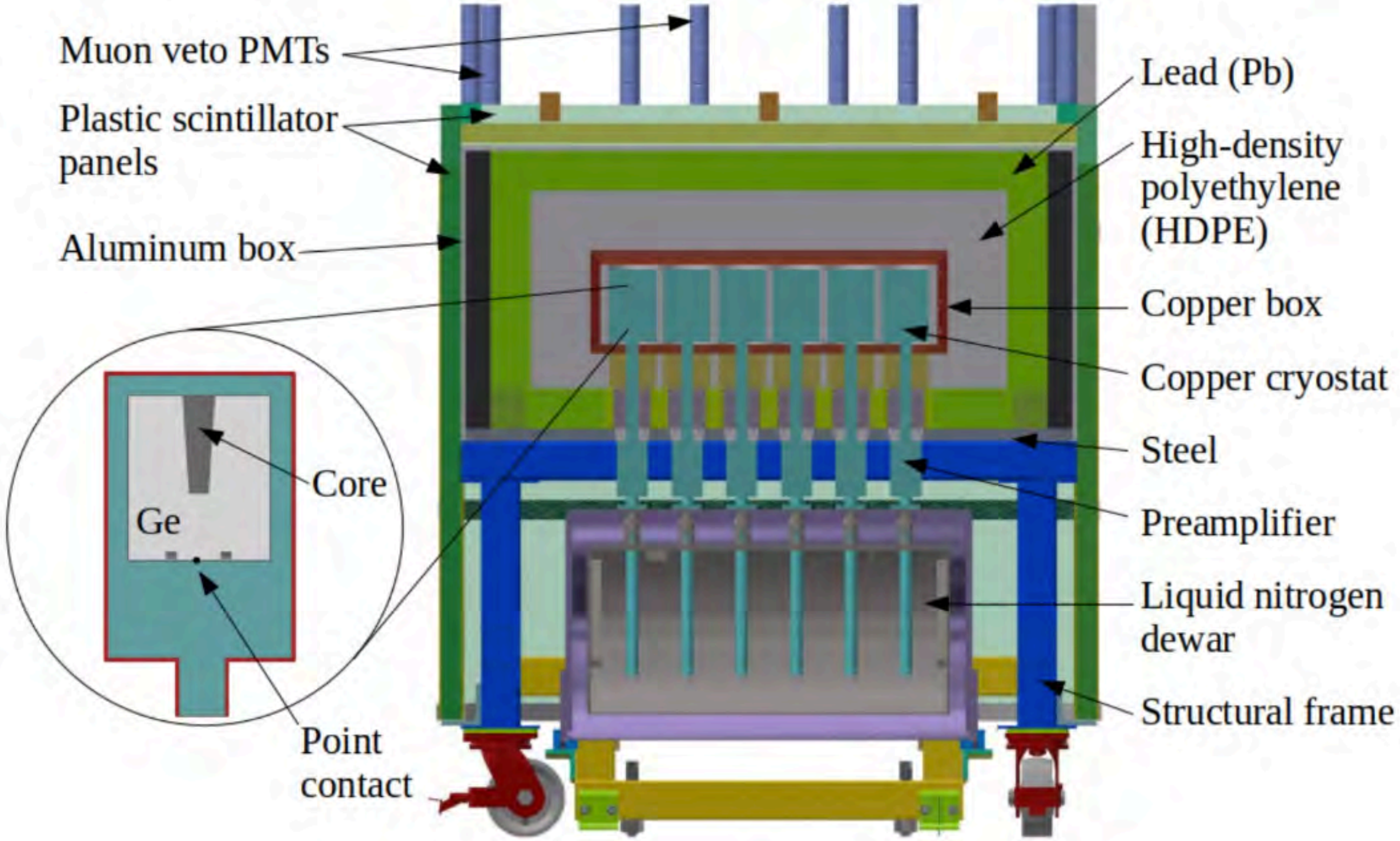



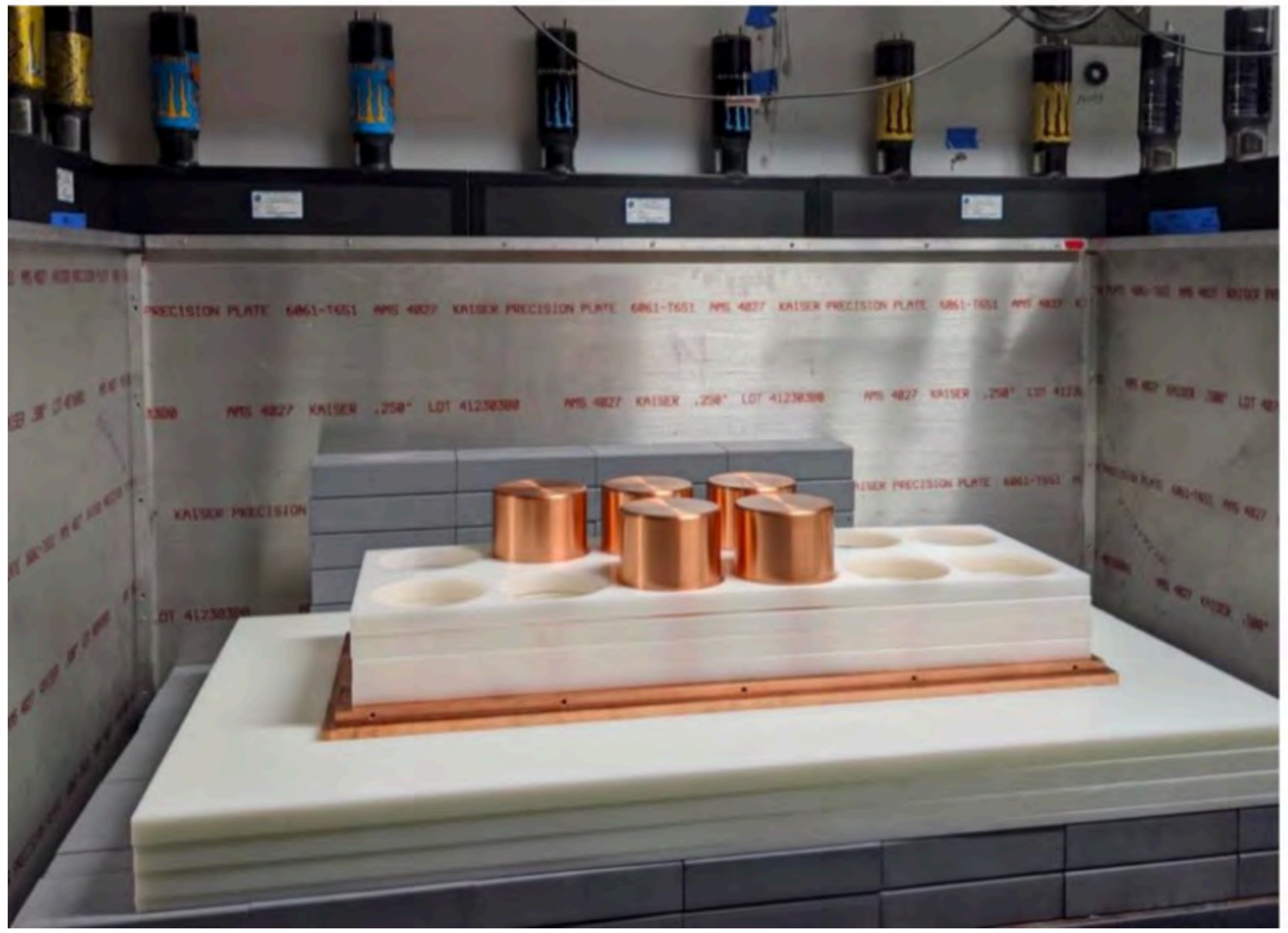

**https://doi.org/10.48550/arXiv.2003.10630**
**https://doi.org/10.48550/arXiv.2110.07730**

# COHERENT Germanium Detectors

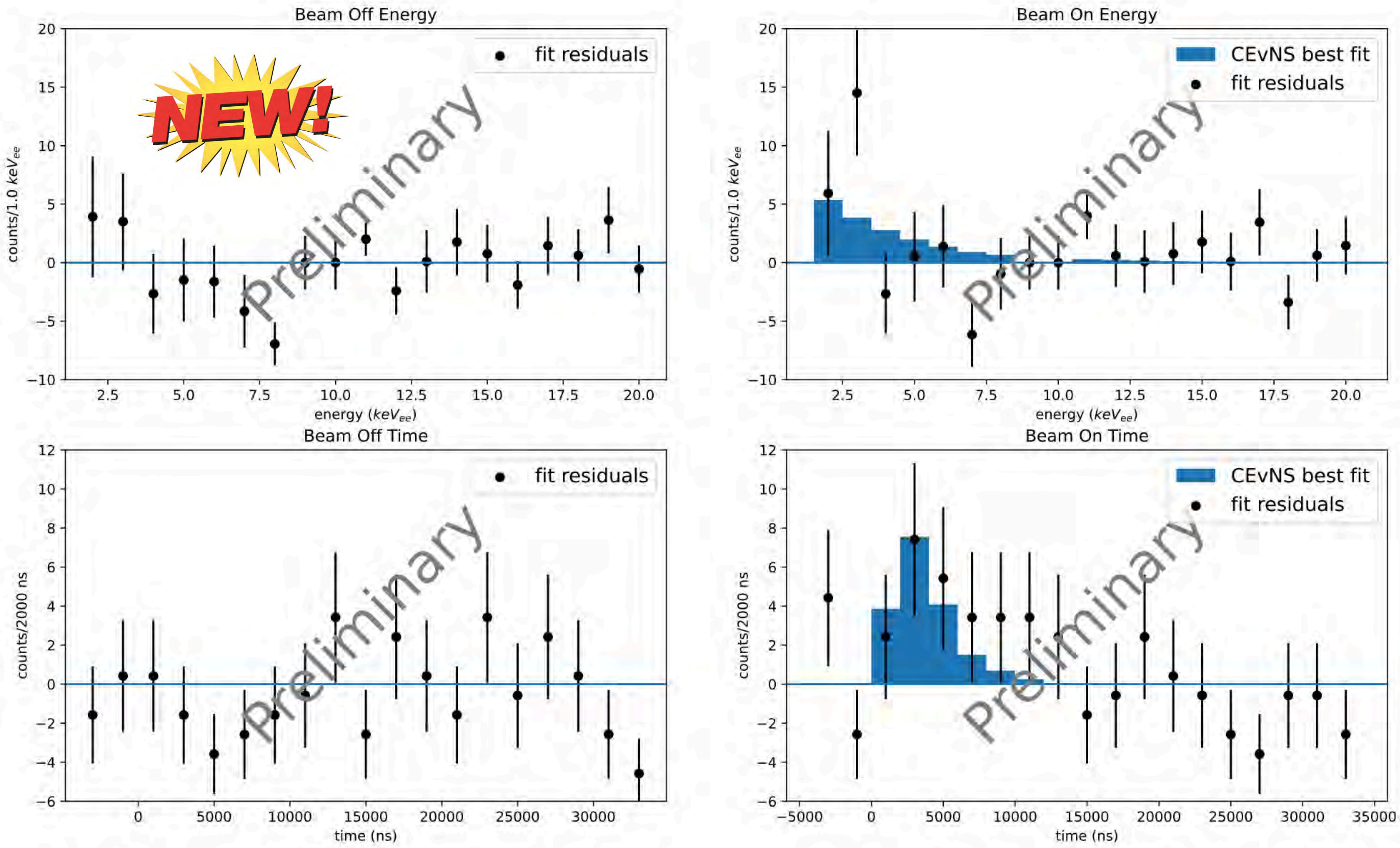
- 8 2.2-kg Ge PPC detectors from Mirion
- First deployment 2022
- Physics run 2023
- 110-150 eV FWHM pulser resolution/noise

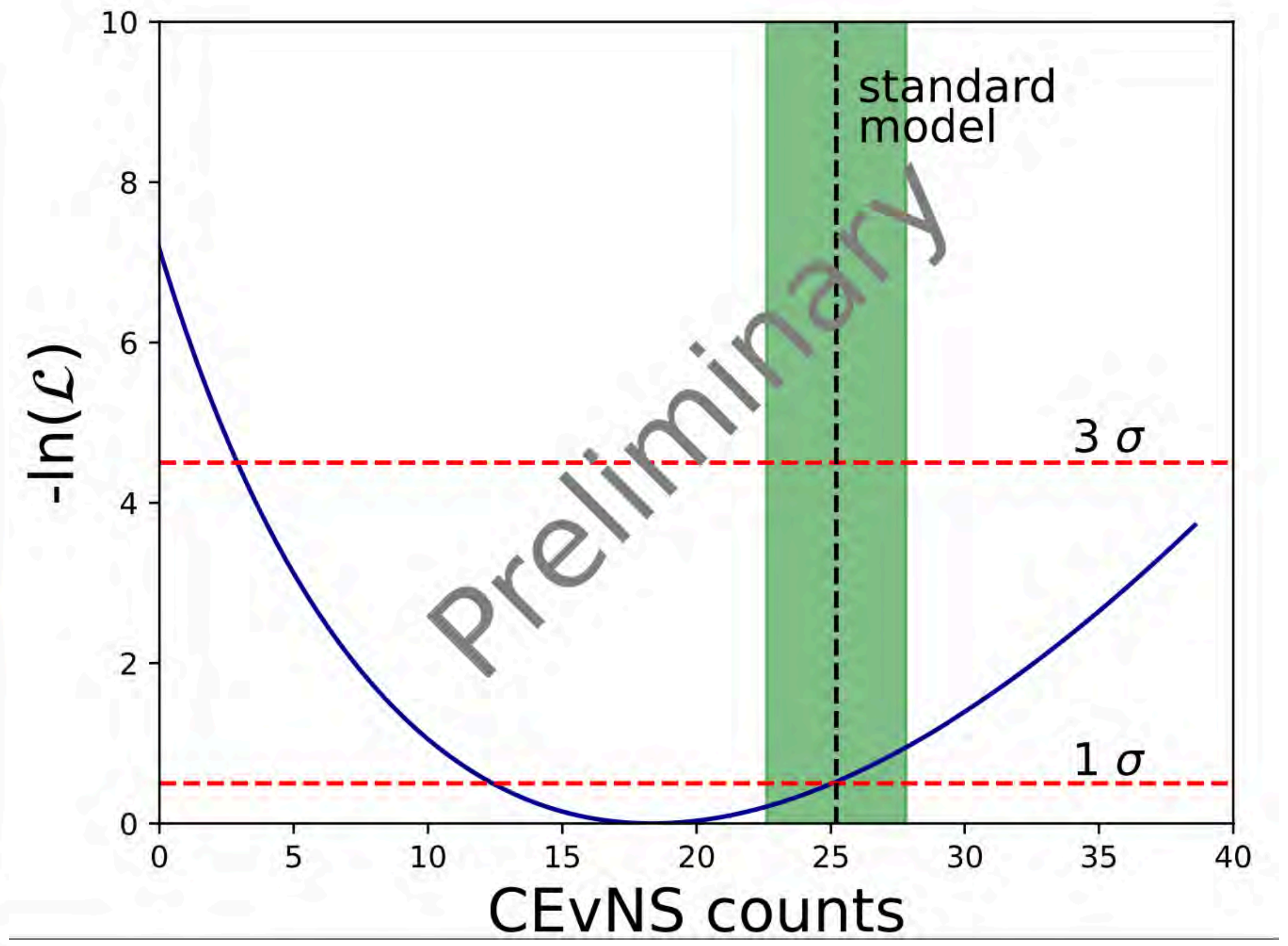


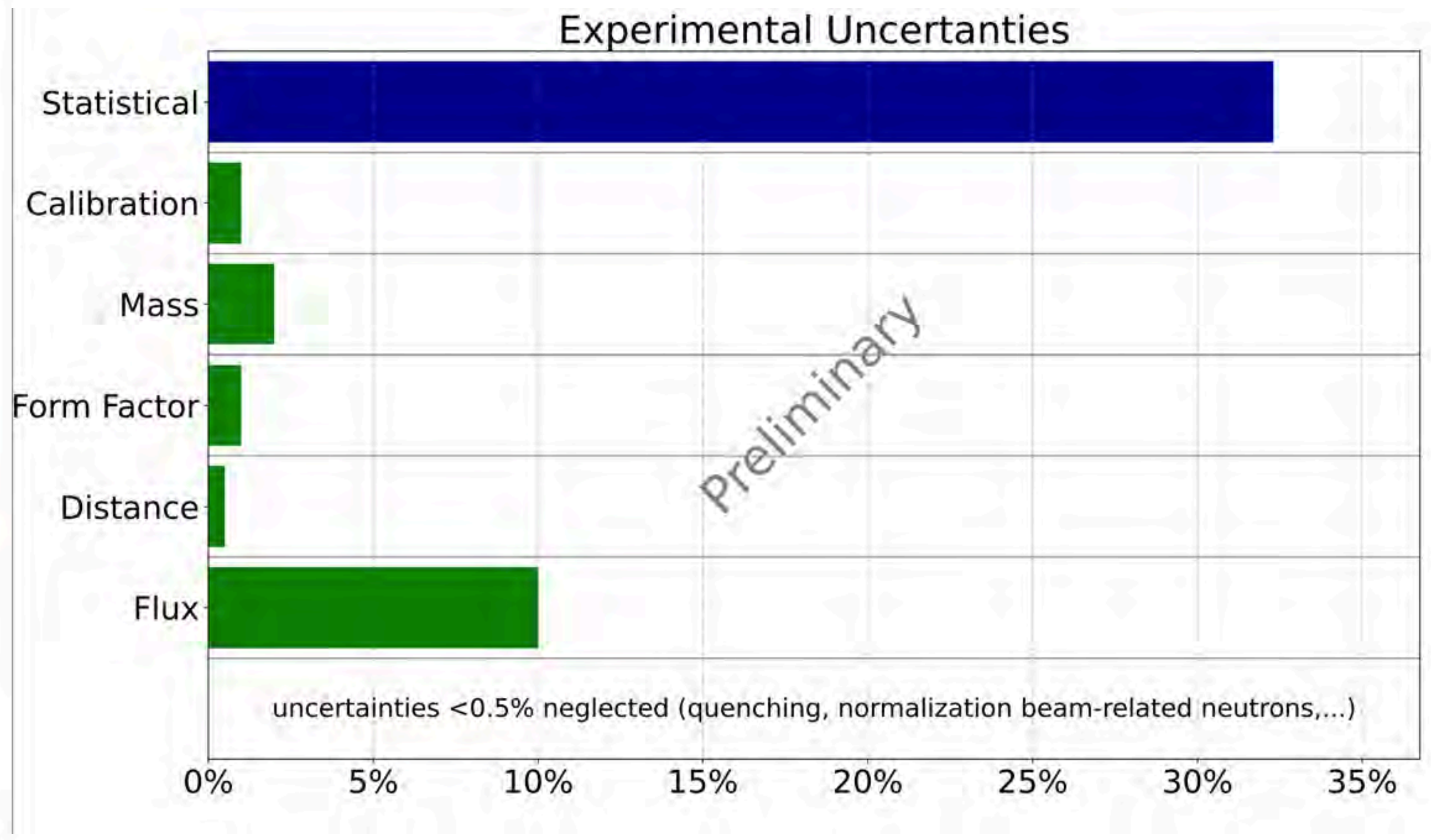


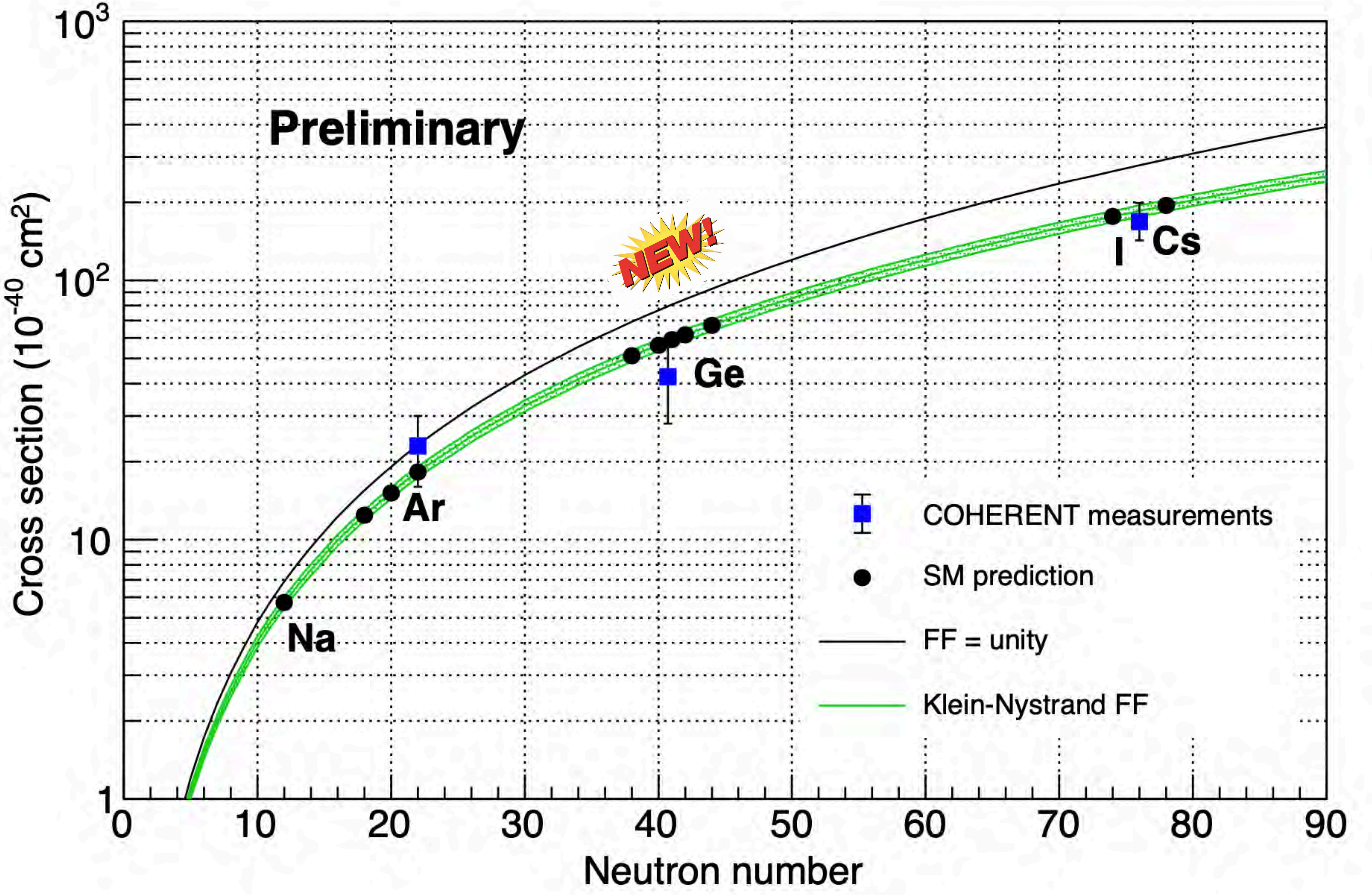
# First Ge Results (preprint soon!)



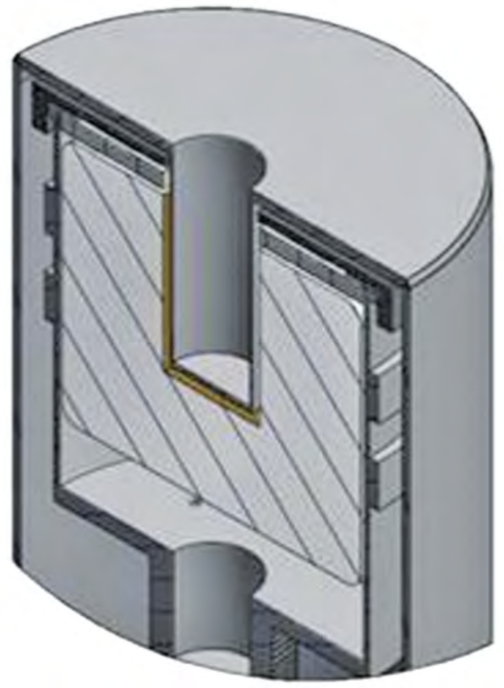



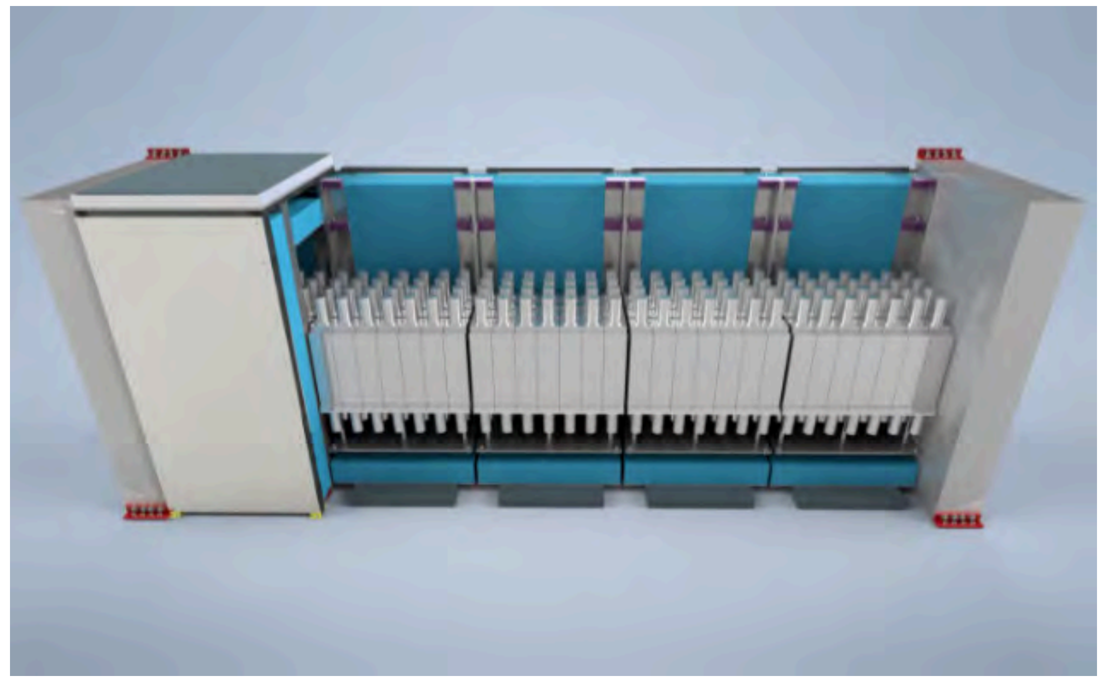
# COHERENT Cross Sections: Filling Out the Curve!

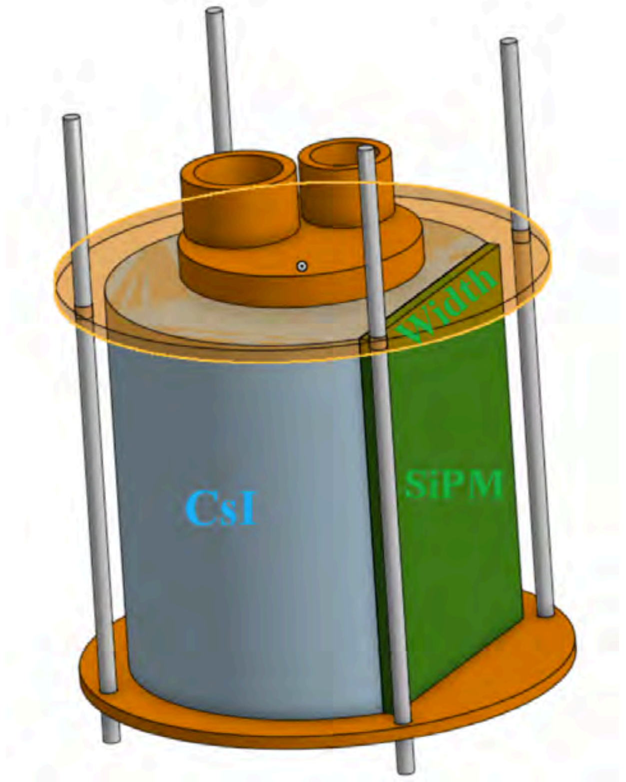


# COHERENT **CEvNS** Detector Status

| Nuclear Target | Technology | Mass (kg) | Distance from source (m) | Status |
|---|---|---|---|---|
| **CsI[Na]** | Scintillating crystal | 14.6 | 19.3 | First result 2017; final result 2021; decommissioned |
| **COH-Ar-10 (CENNS-10)** | Single-phase LAr | 24 | 27.5 | First result 2020; x2 data analysis underway; decommissioned |
| **COH-Ge-18 (GeMini)** | HPGe PPC | 18 | 22 | First result 2023/24; continued running |
| **COH-NaI-3000 (NaIvETe)** | Scintillating NaI[Tl] crystal | 3400 | 25 | Staged deployment up to 3400 kg; first modules taking commissioning data |
| **COH-Ar-750** | Single-phase LAr | 750 | 27.5 | First data expected 2025 |
| **COH-CryoCsI-10** | Cryogenic scintillating CsI crystal | 10-15 | ~20 | Proposed |

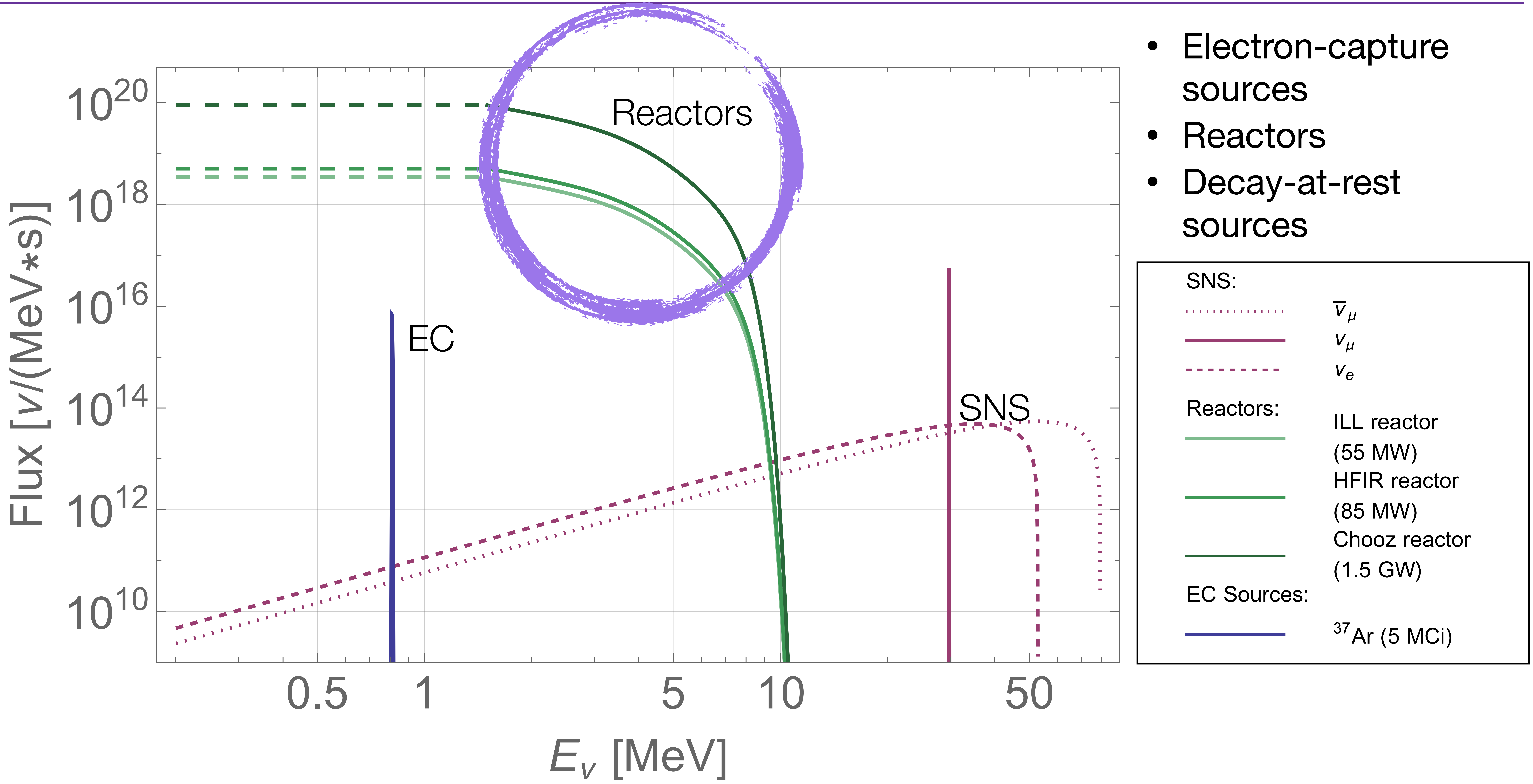







+$D_2O$ for flux normalization

# Reactor Experiments




- Electron-capture sources
- Reactors
- Decay-at-rest sources

# CONNIE

COherent Neutrino-Nucleus Interaction Experiment

NEW

Searches for CEνNS and Physics beyond the Standard Model using Skipper-CCDs [**arXiv: 2403.15976**]

Results from engineering run [JINST 11 (2016), P07024]

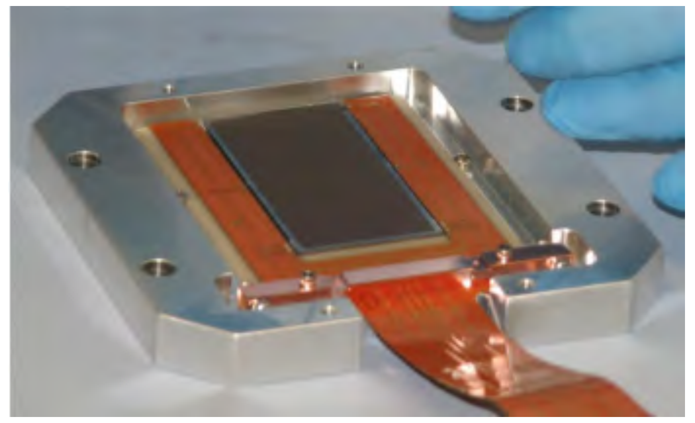
Results from 2016-2018 run [**PRD 100 (2019), 092005**]

Results from 2019 run [**JHEP 05 (2022), 017**]

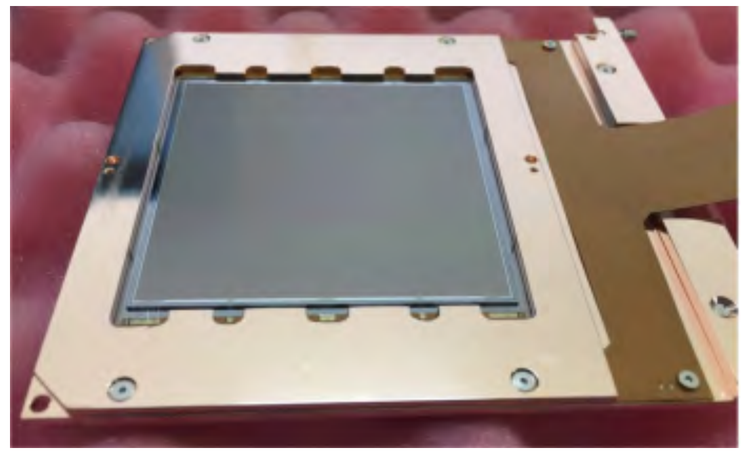
2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024

Engineering run | 2016-2018 (1x1) run | 2019 (1x5) run | Skipper-CCD run

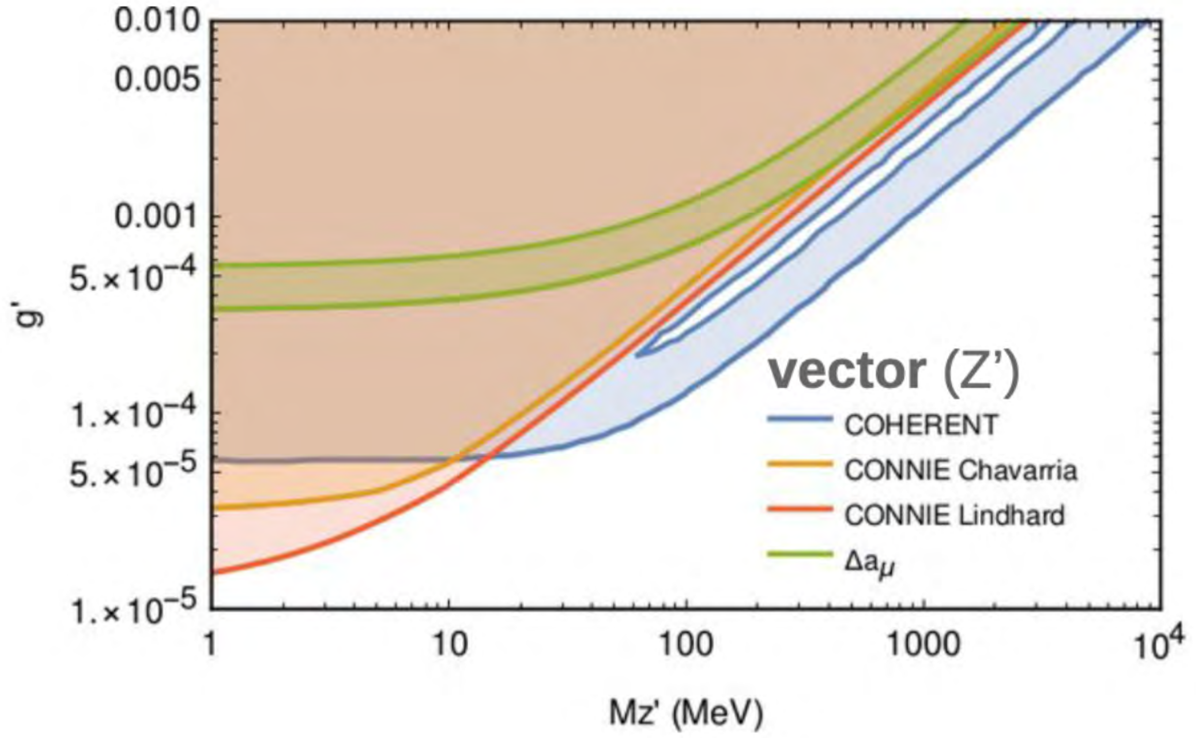
Installation at Angra



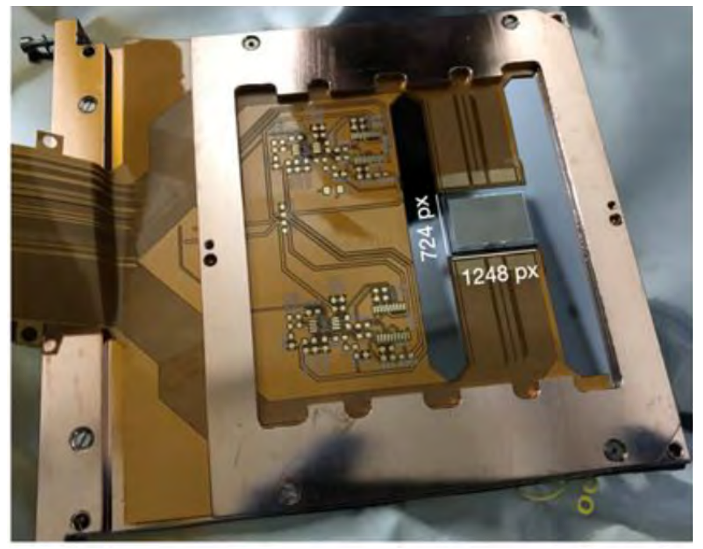
Installation of scientific CCDs

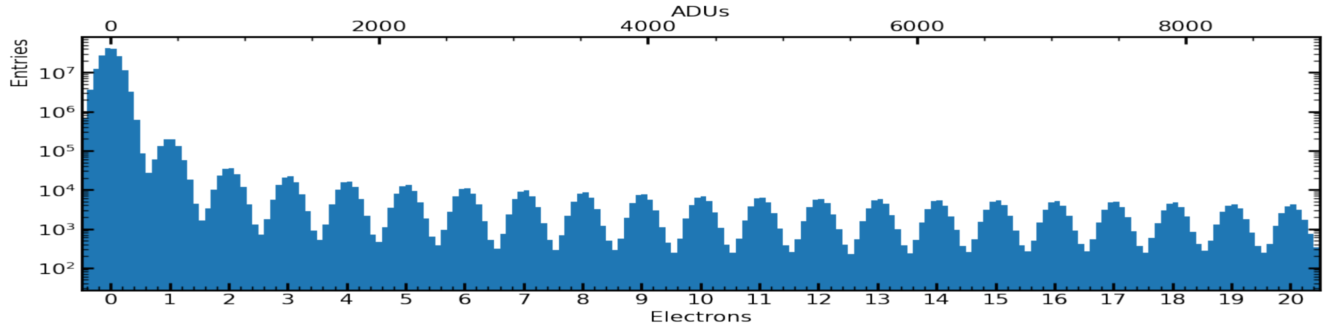


Limits on SM extensions with light mediators [**JHEP 04 (2020), 054**]

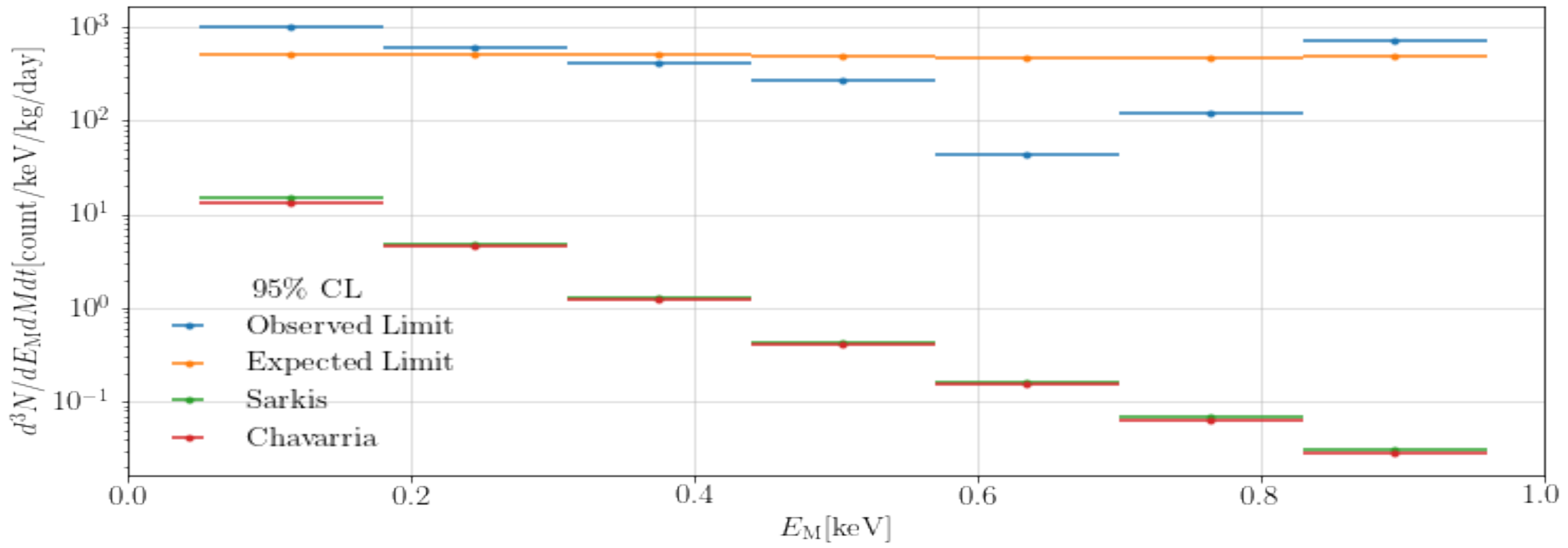



Installation of Skipper-CCDs

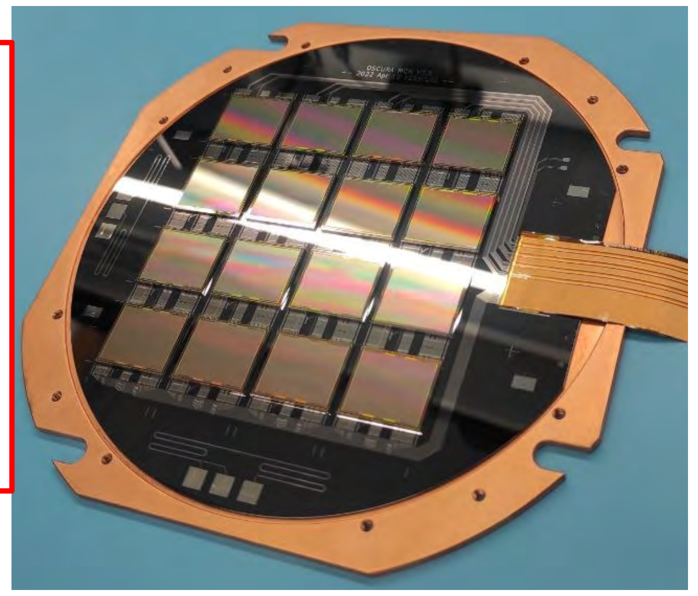



Upper limits at 90% C.L. on the measured neutrino rate vs predictions




Next: Installation of a Multi-Chip Module with Skipper-CCDs, May 2024. 33x increase in mass.

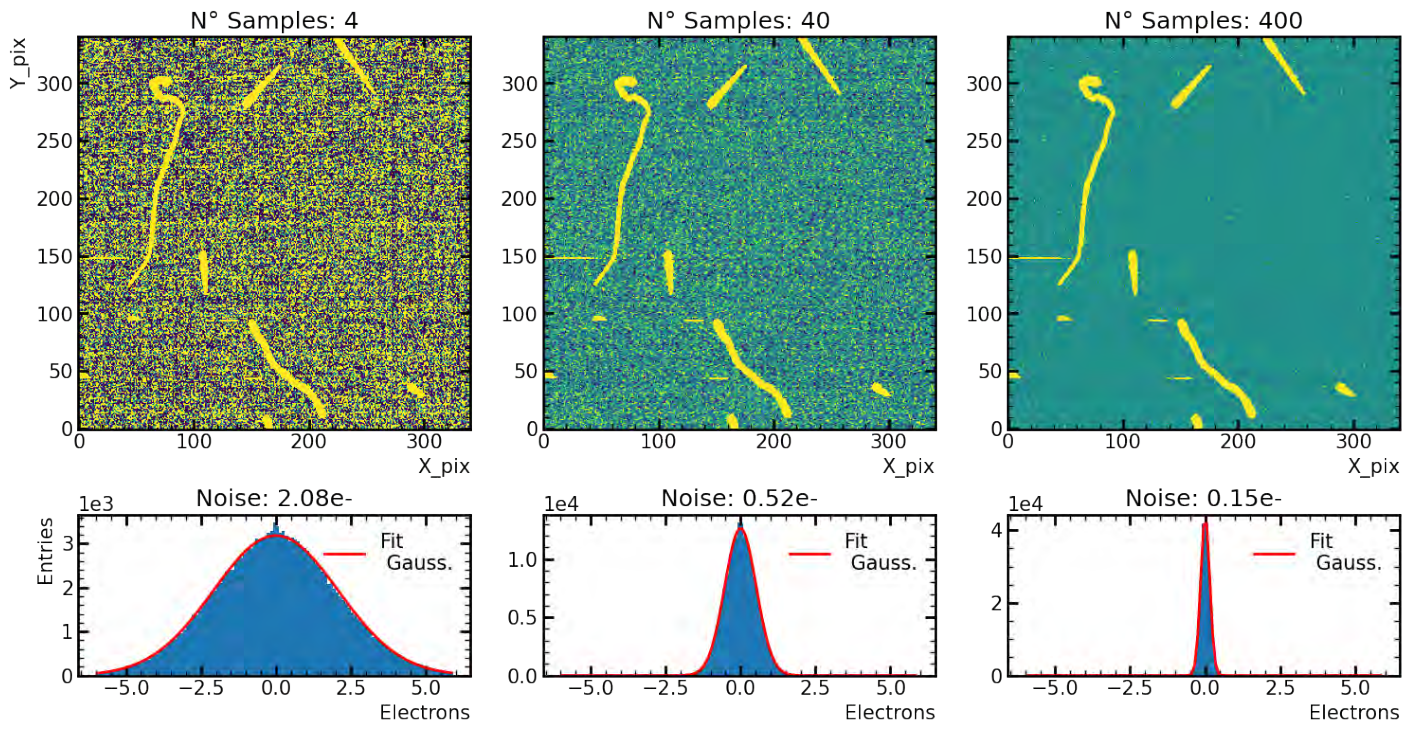


# CONNIE Skipper-CCD results

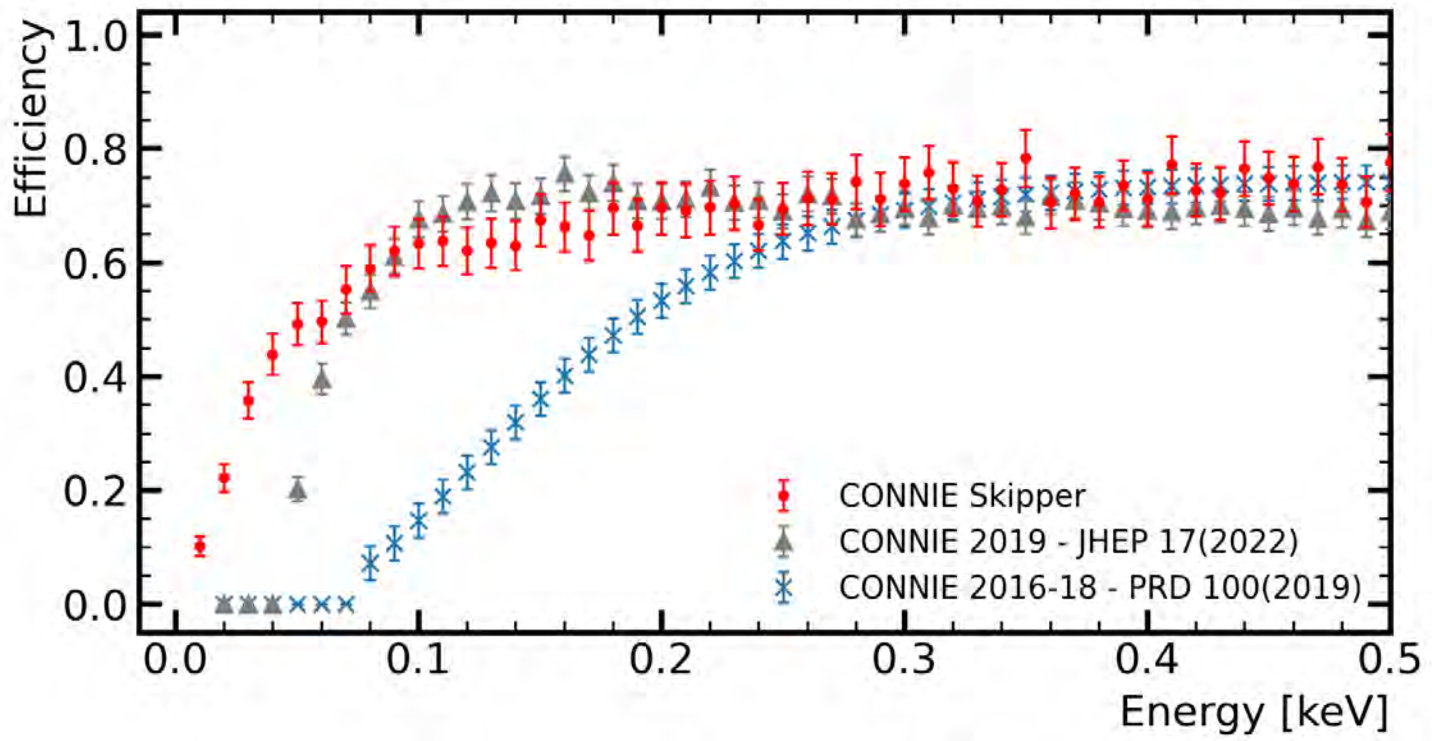
NEW
[arXiv: 2403.15976]

**See Poster by Pedro Ventura**

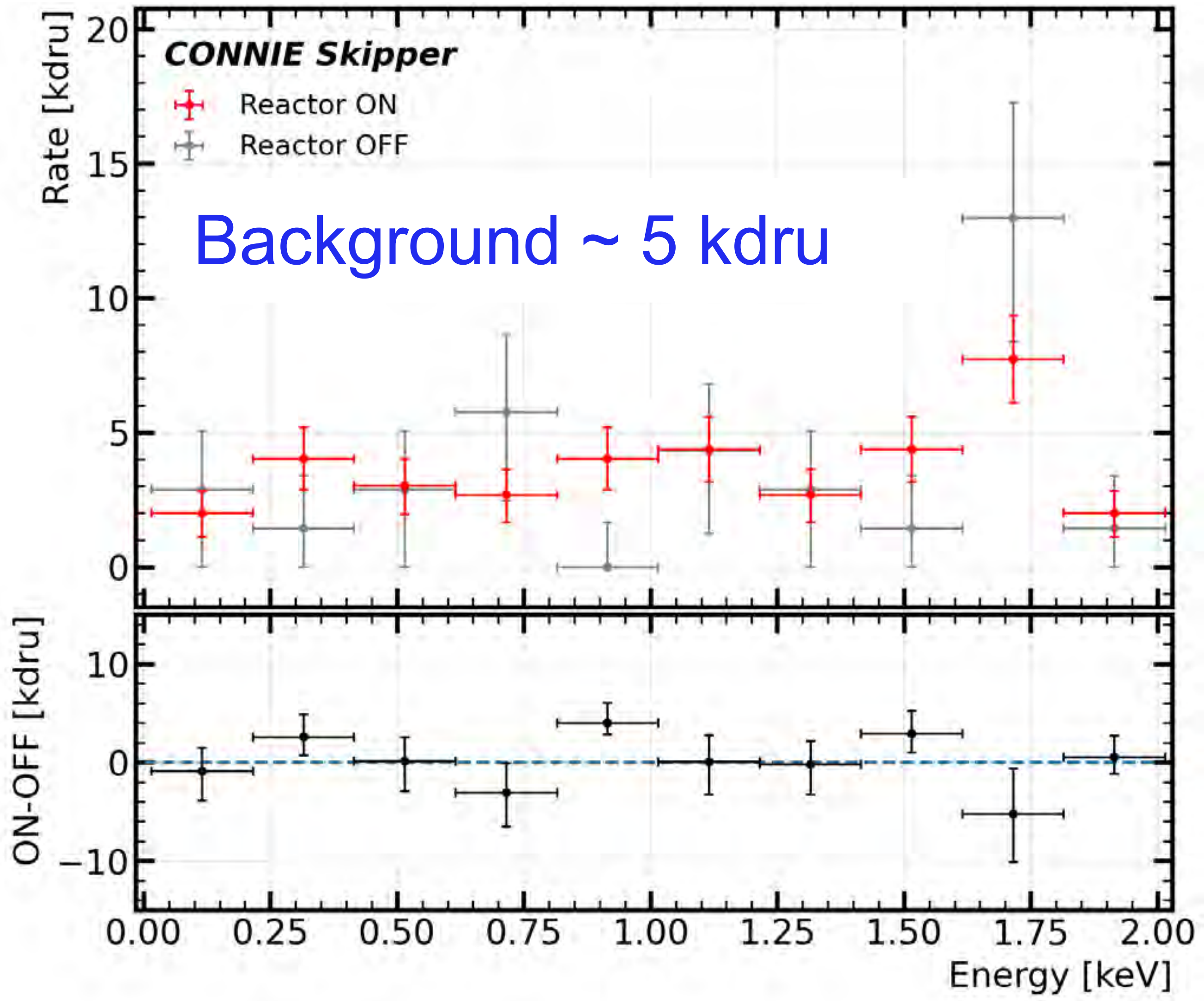
- 2 Skipper-CCDs (0.4 g mass), exposure 18.4 g-days.
- Readout noise reduced with N samples:



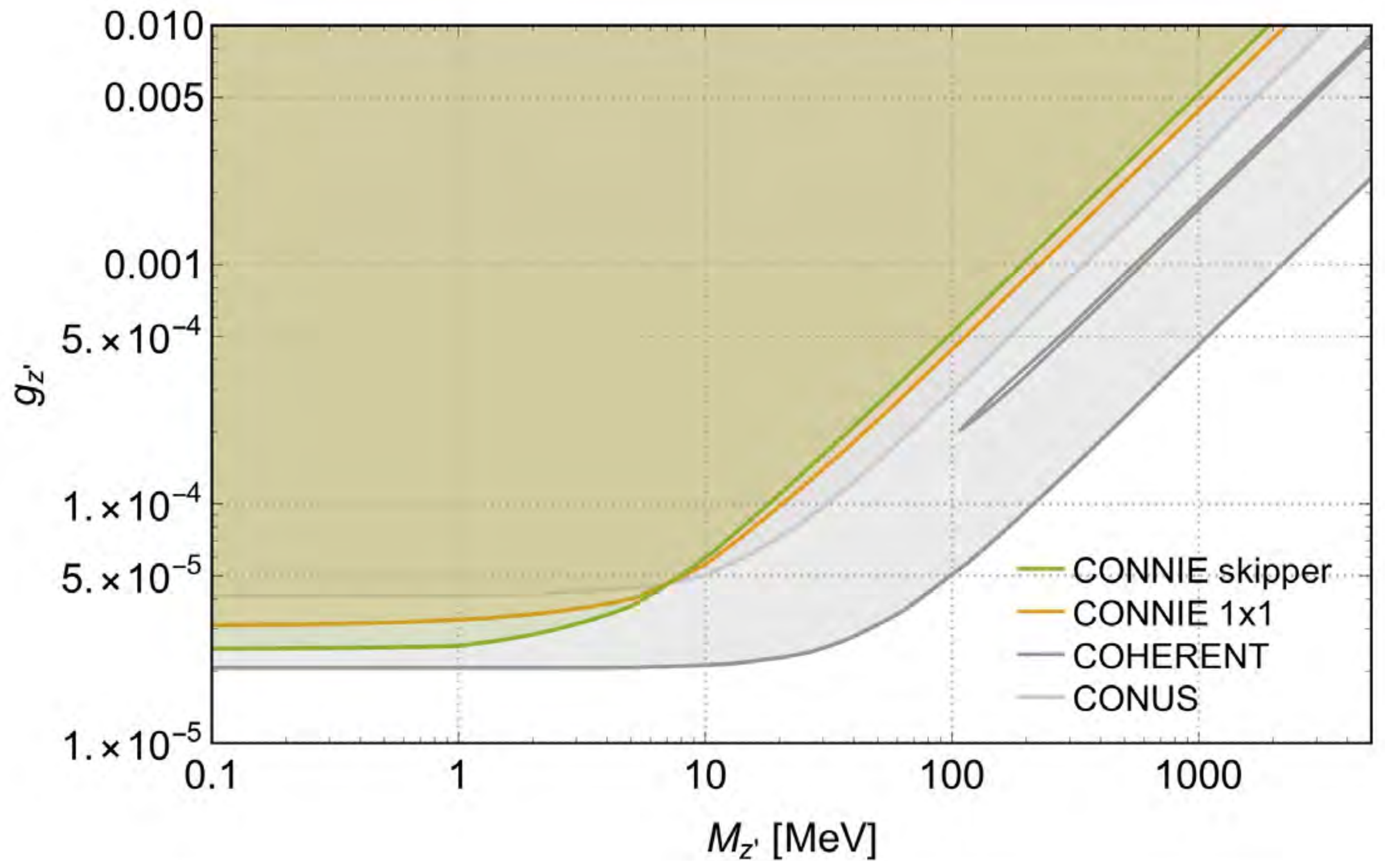

Efficiency extended to lower energies



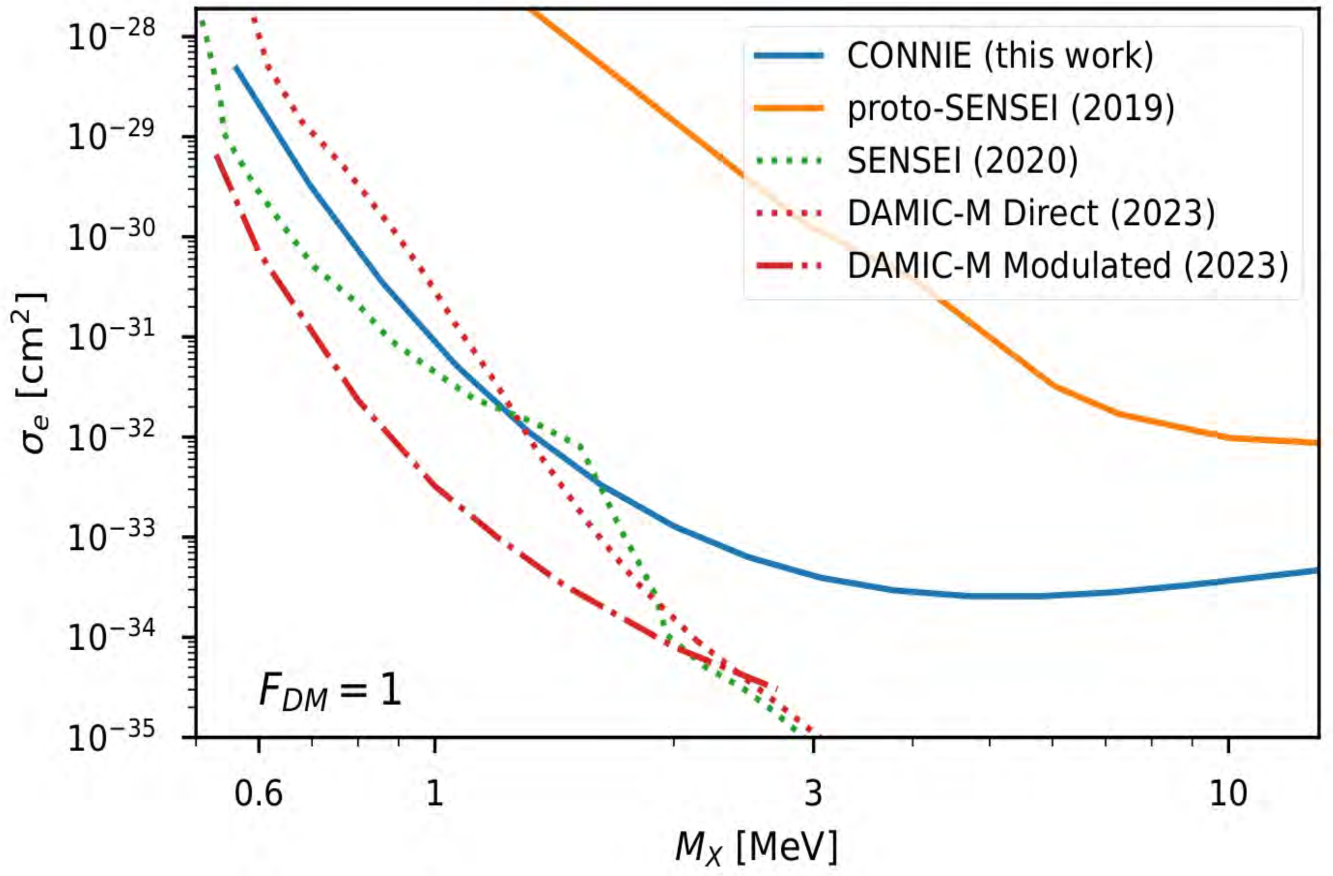

Limit on CEvNS from Reactor-On - Off spectra

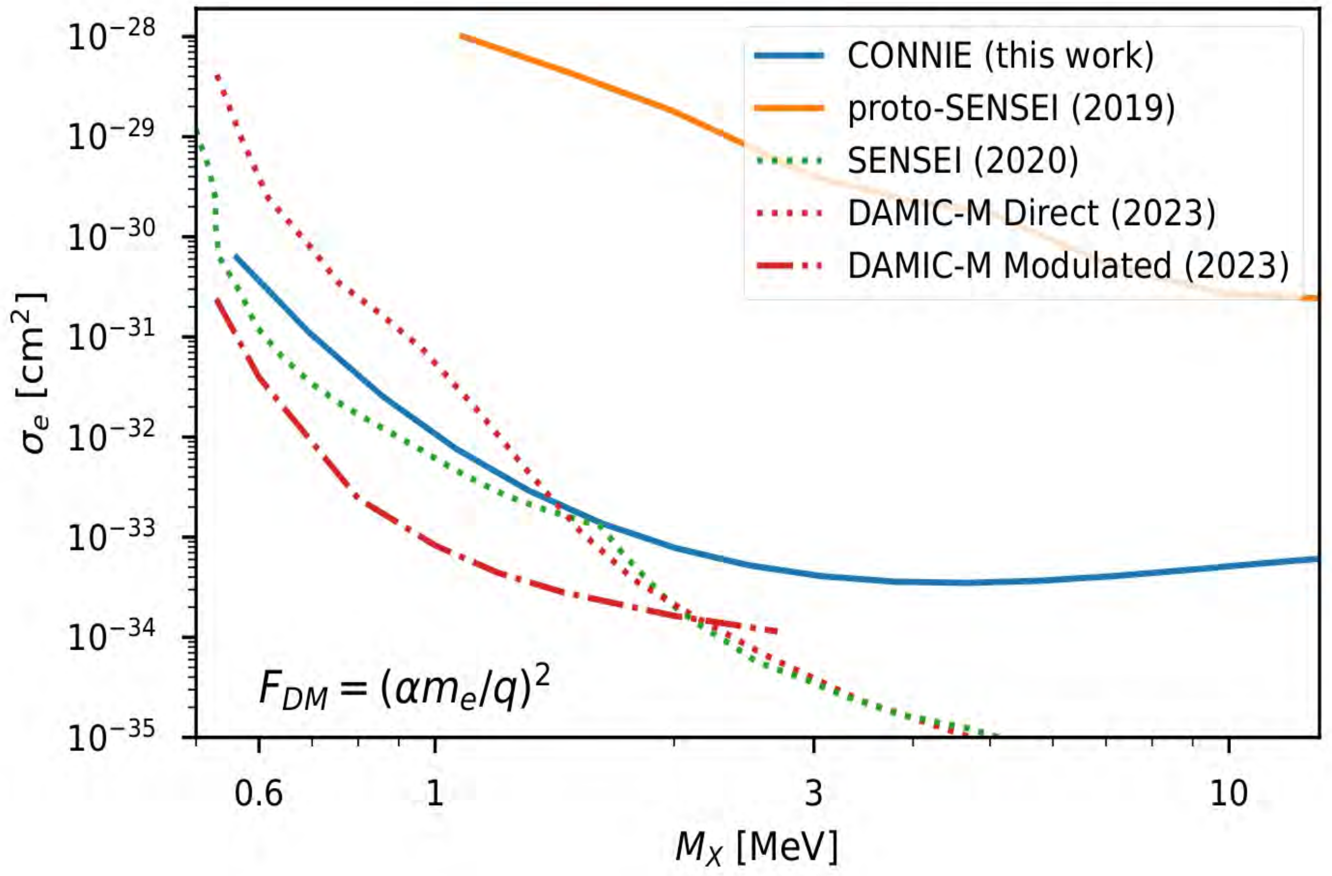



- Threshold = 15 eV – lowest of any CEvNS experiment.
- Searches for Physics beyond the Standard Model:




Improved limit on a simplified model with a new vector mediator Z’



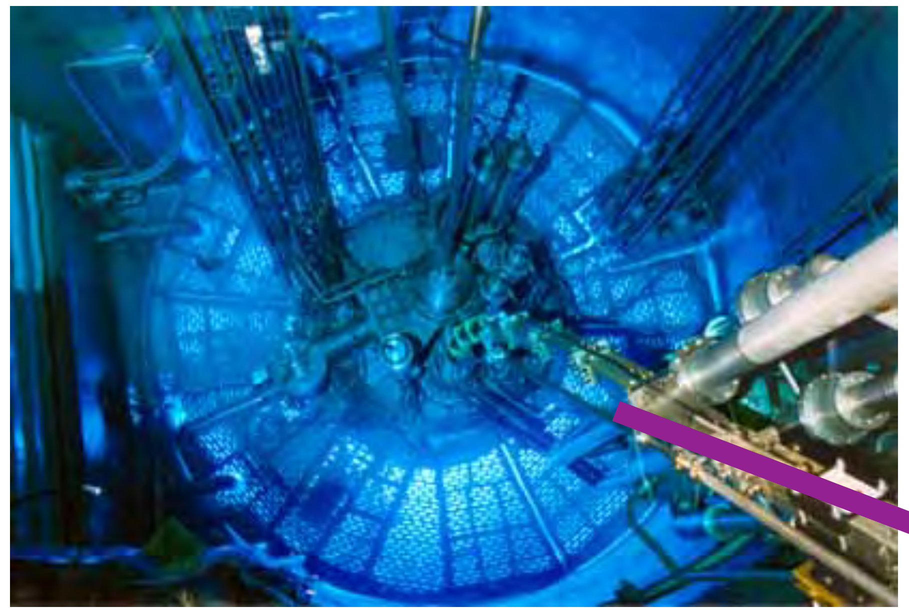



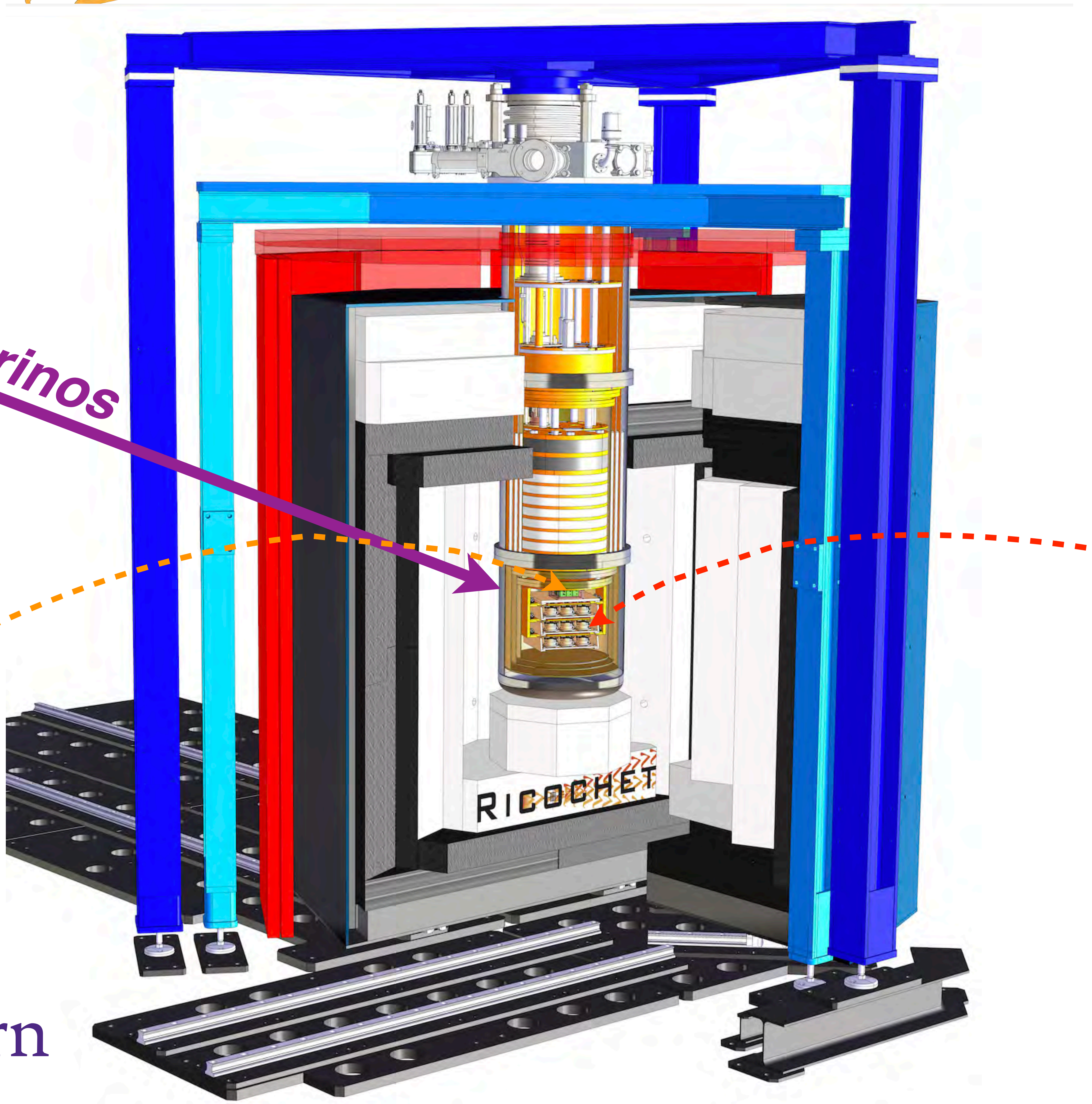

First DM search by diurnal modulation: best limits on the DM-electron scattering cross-section, obtained by a surface-level experiment.

# RICOCHET

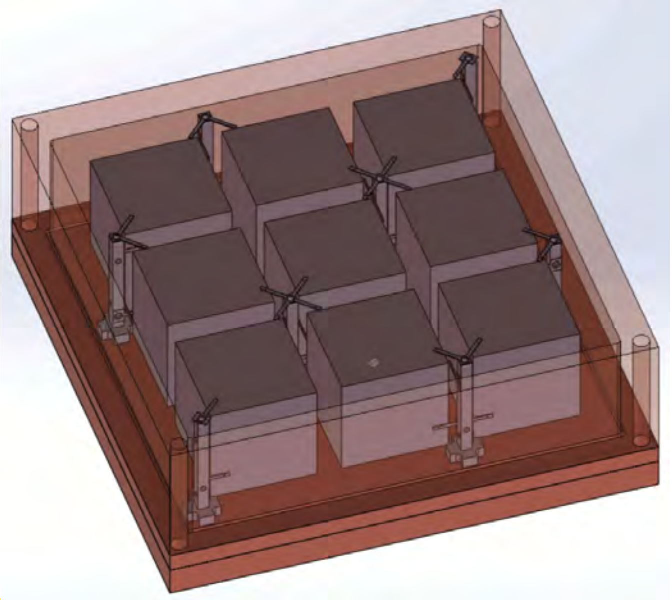
10.1140/epjc/s10052-022-11150-x
10.1140/epjc/s10052-024-12433-1

ANR AGENCE NATIONALE DE LA RECHERCHE

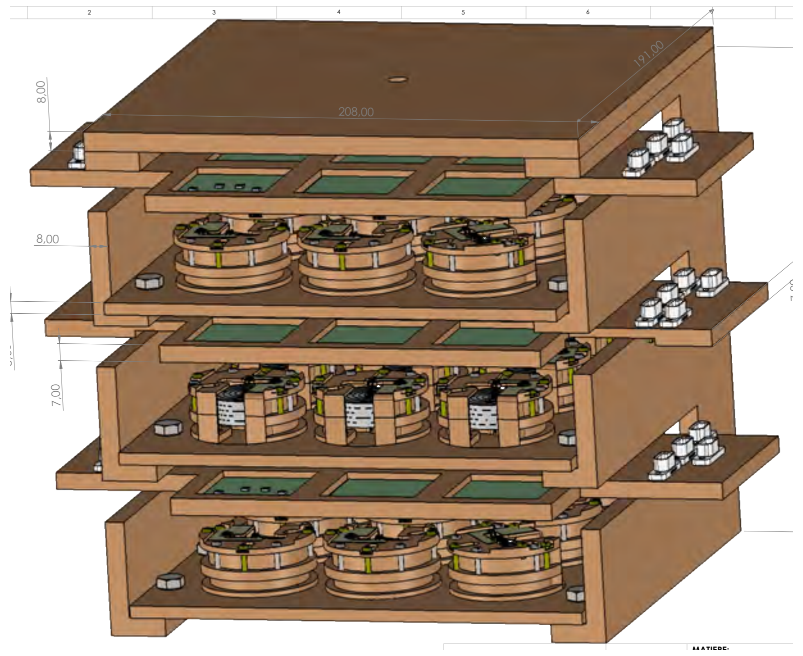





**Q-ARRAY**
Sn & Al



**CRYOCUBE**
Ge (& Si?)



erc
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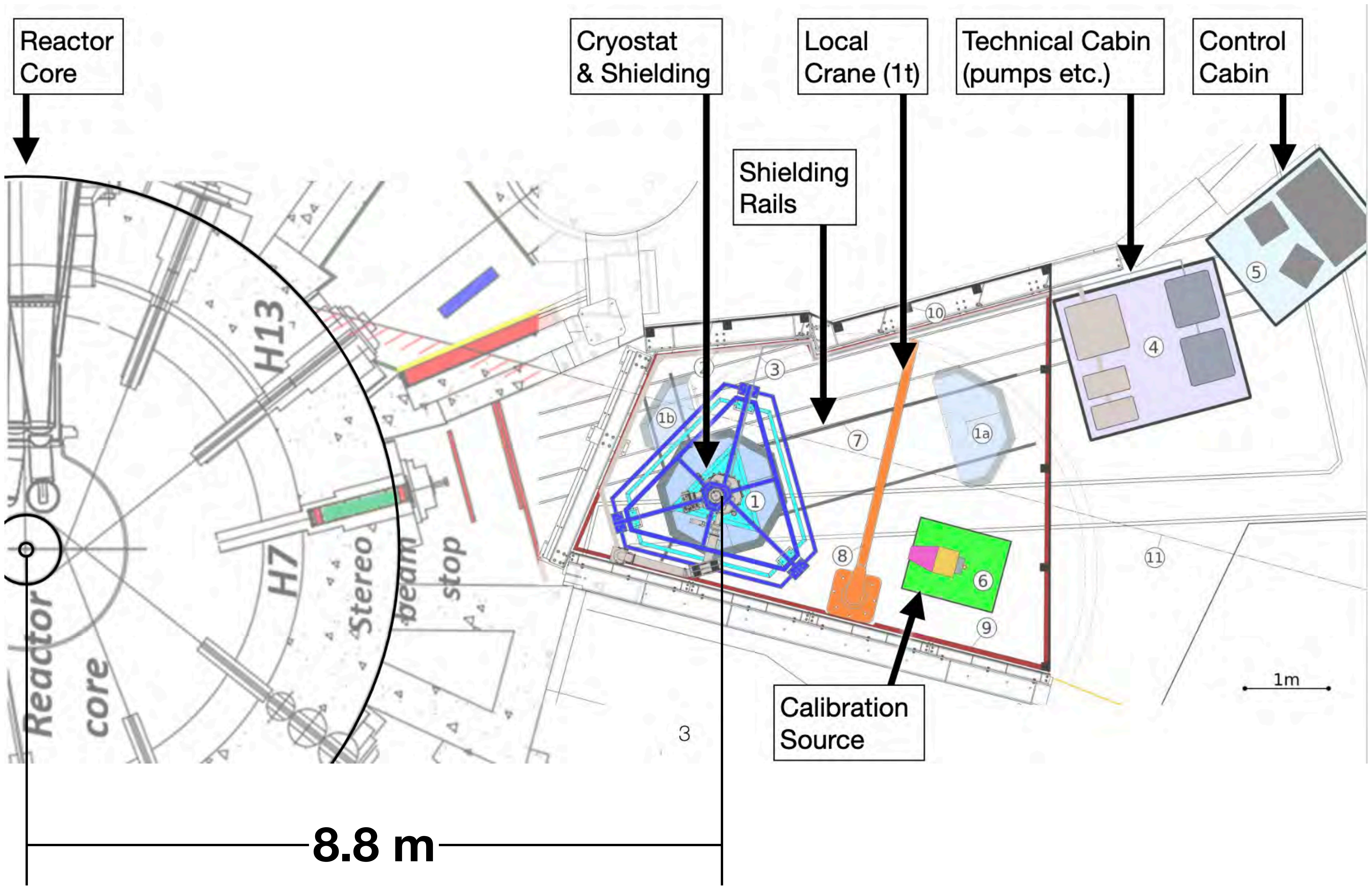
Northwestern
NÉEL
THE UNIVERSITY of WISCONSIN MADISON
ill
LPSC Grenoble
IJCLab Irène Joliot-Curie
iP2i LES 2 INFINIS LYON
MIT
UMASS AMHERST
UNIVERSITY OF TORONTO

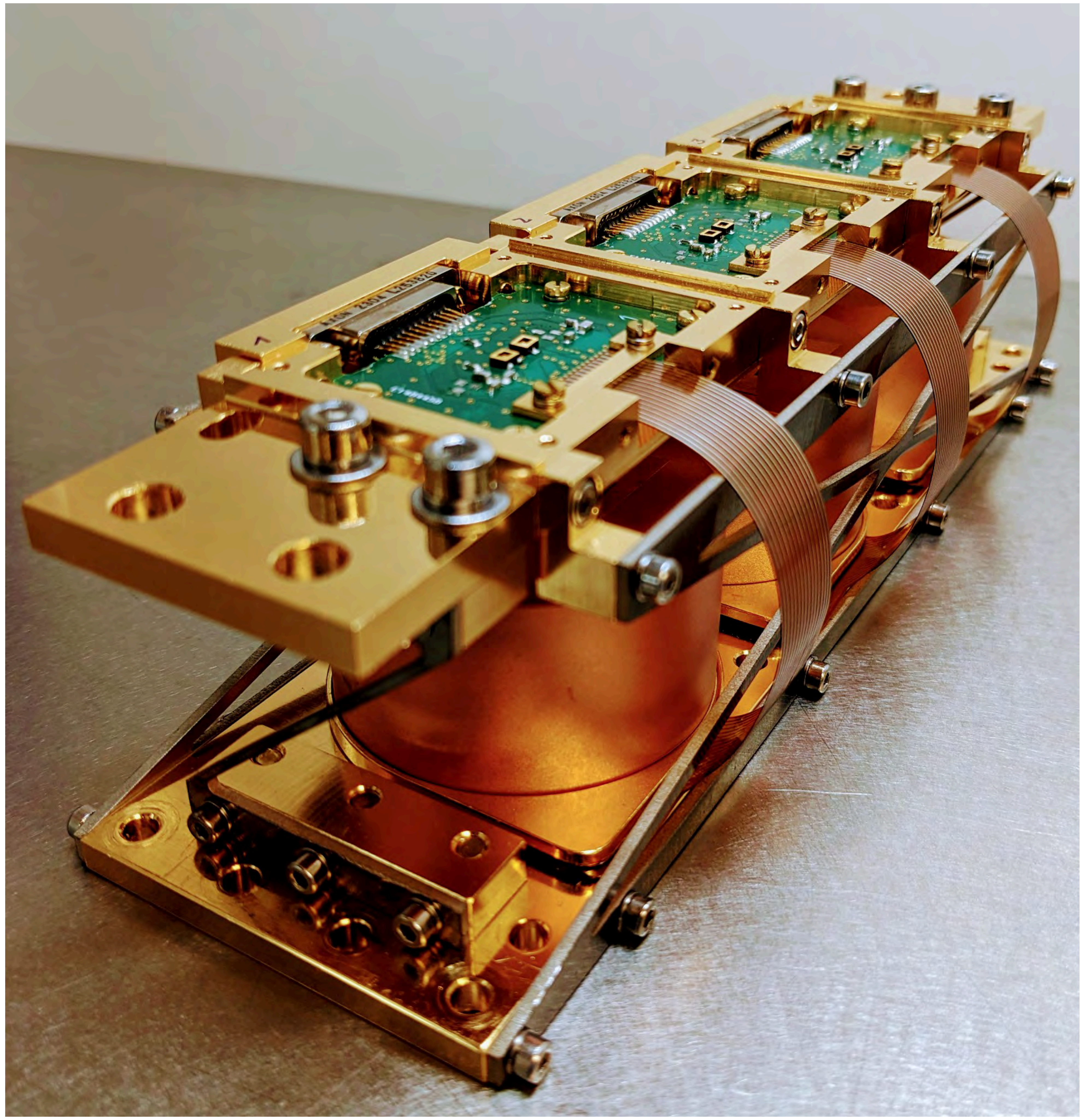
10.1140/epjc/s10052-022-11150-x
10.1140/epjc/s10052-024-12433-1

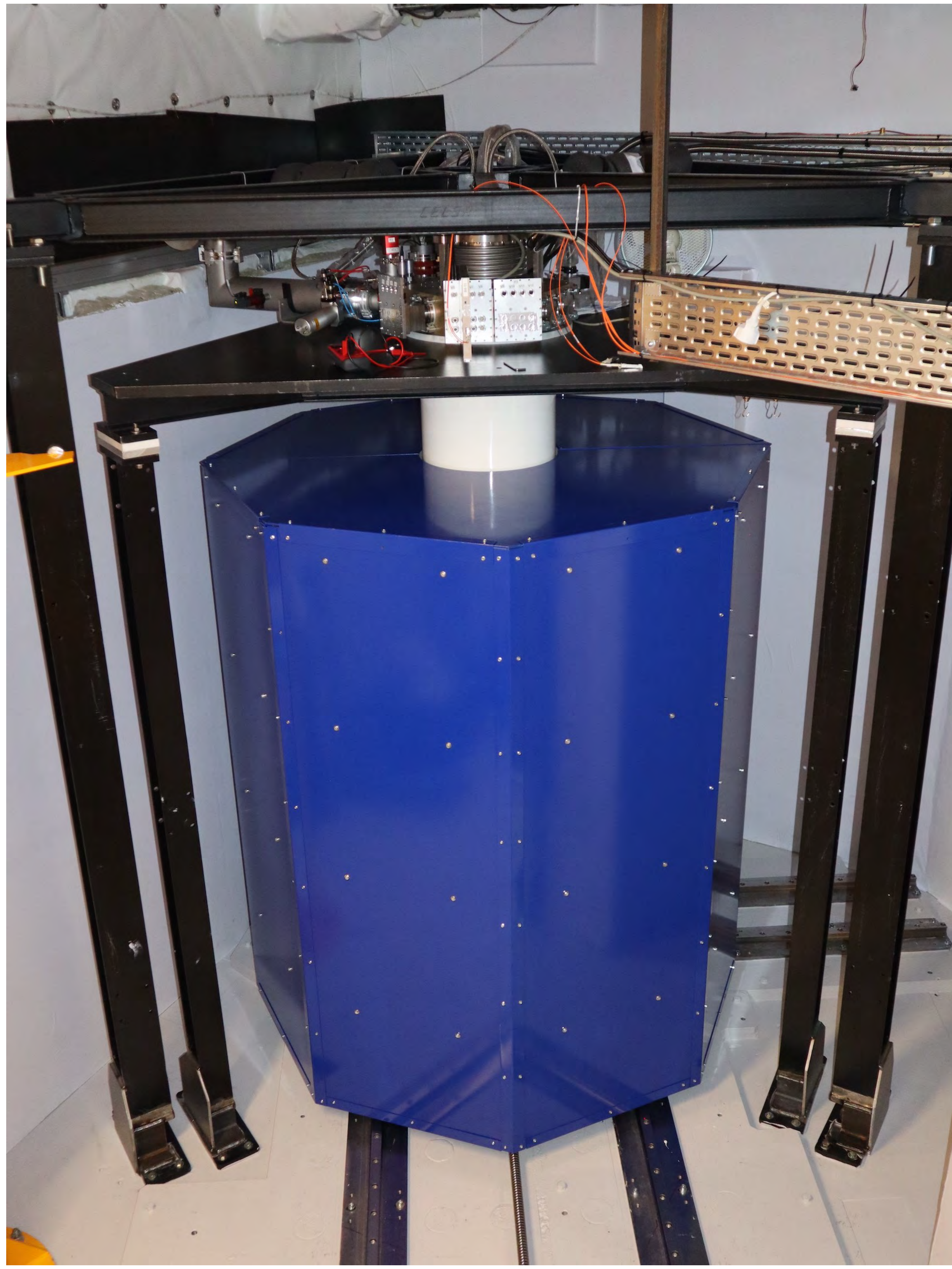
# Institut Laue-Langevin (ILL) Nuclear Research Reactor




- 58 MW nominal thermal power
- Located ~9 m from reactor core
- ~11 evts/day/kg (50 eV threshold)
- 3 to 4 cycles per year: *excellent ability to subtract uncorrelated backgrounds*
- Significant overburden (~15 m.w.e) to reduce cosmics
- **Ricochet commissioning at ILL started February 2024!**

# Ricochet Detectors Installed and Taking Data!





**11 CEvNS events/day and $10^3$ Electron-recoil rejection factor**

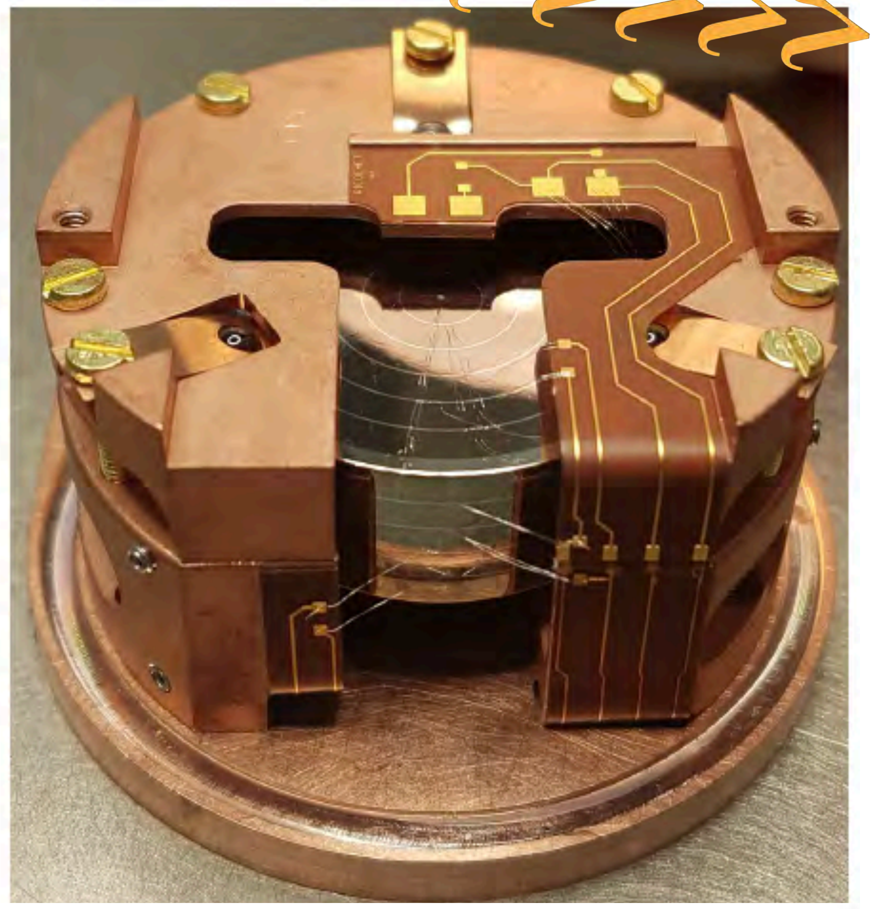
**~4 (20) sigma CEvNS detection after one reactor cycle including low-energy excess background (or not)**

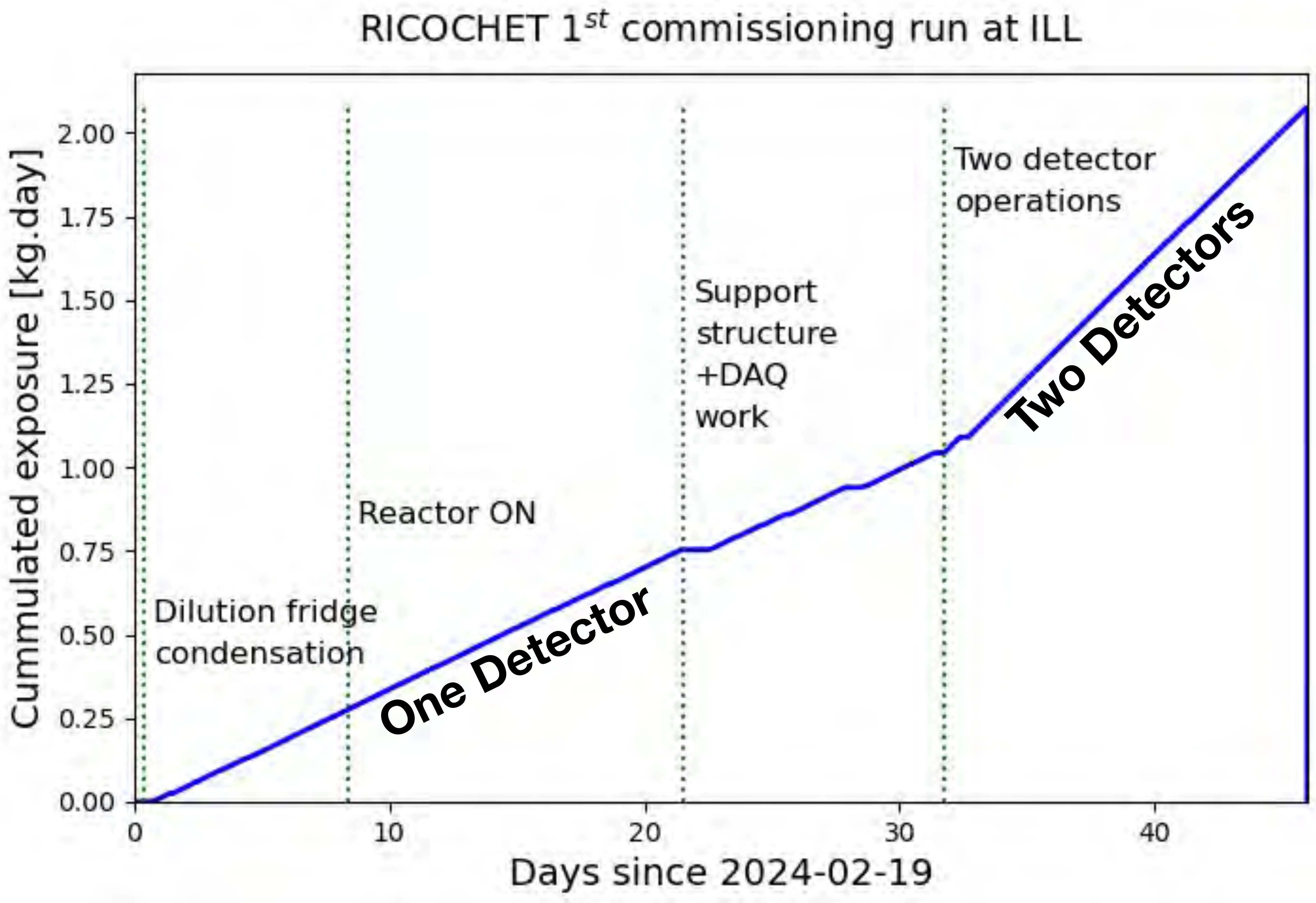
# Commissioning Underway

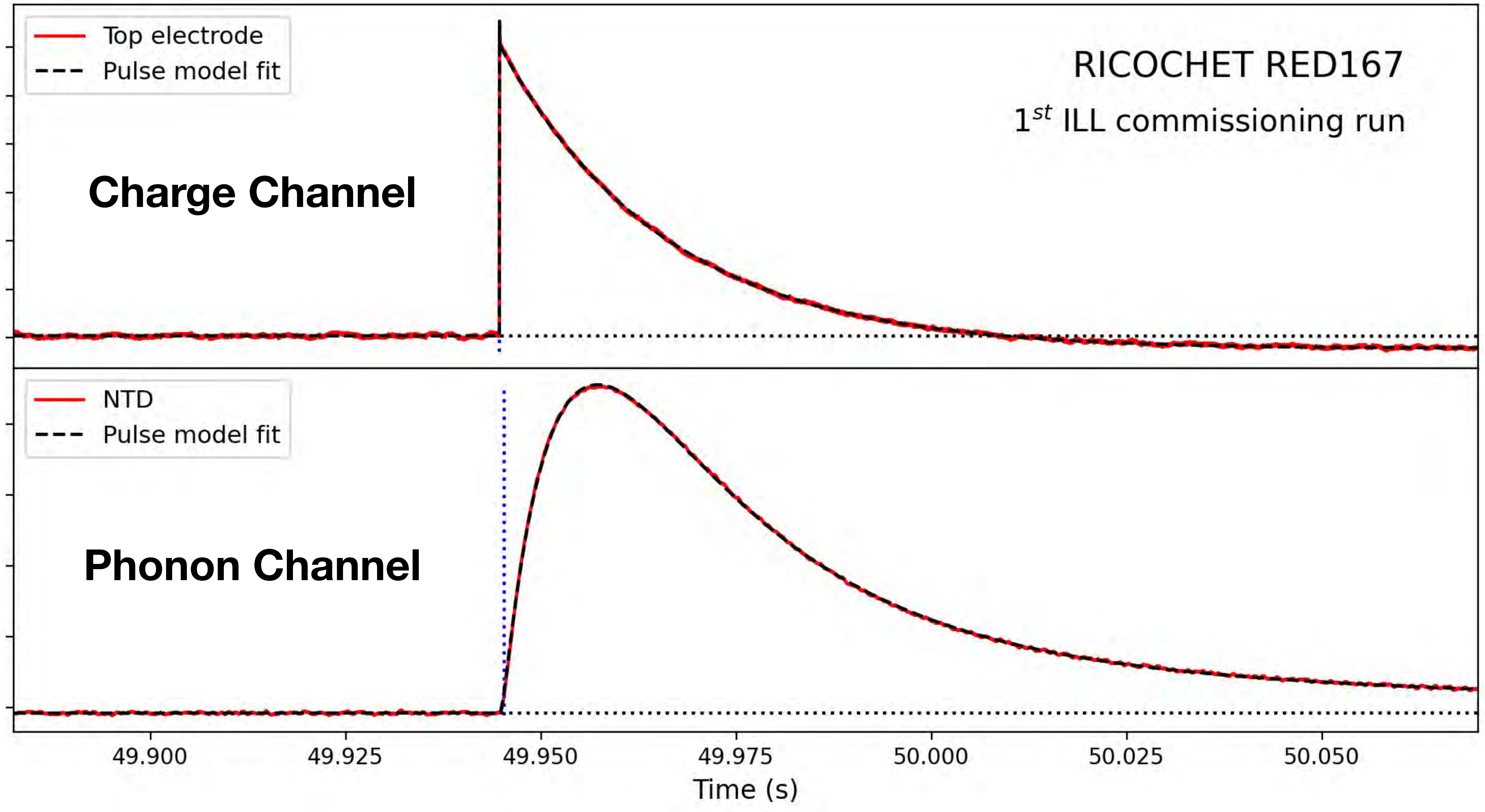
RICOCHET

- Array of 38 g detectors
- Operated at 10 mK
- Dual Charge and Phonon Readout Provides gamma discrimination

- Aim to perform a %-level measurement of the CEvNS spectrum
- Spectral measurement very complimentary to COHERENT!

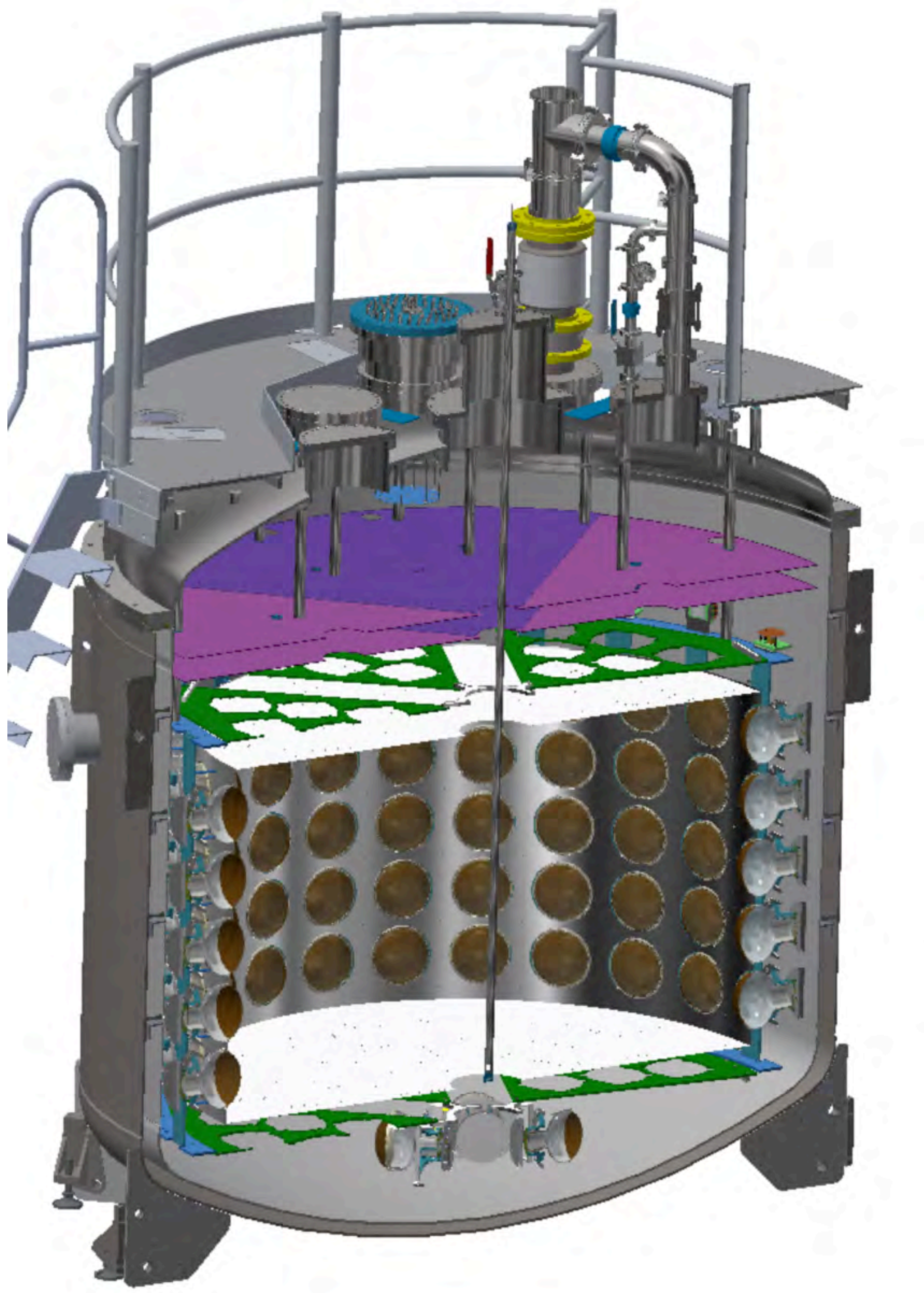




# Other DAR Experiments

**CCM**
**Coherent CAPTAIN-Mills**
**At LANSCE proton beam**

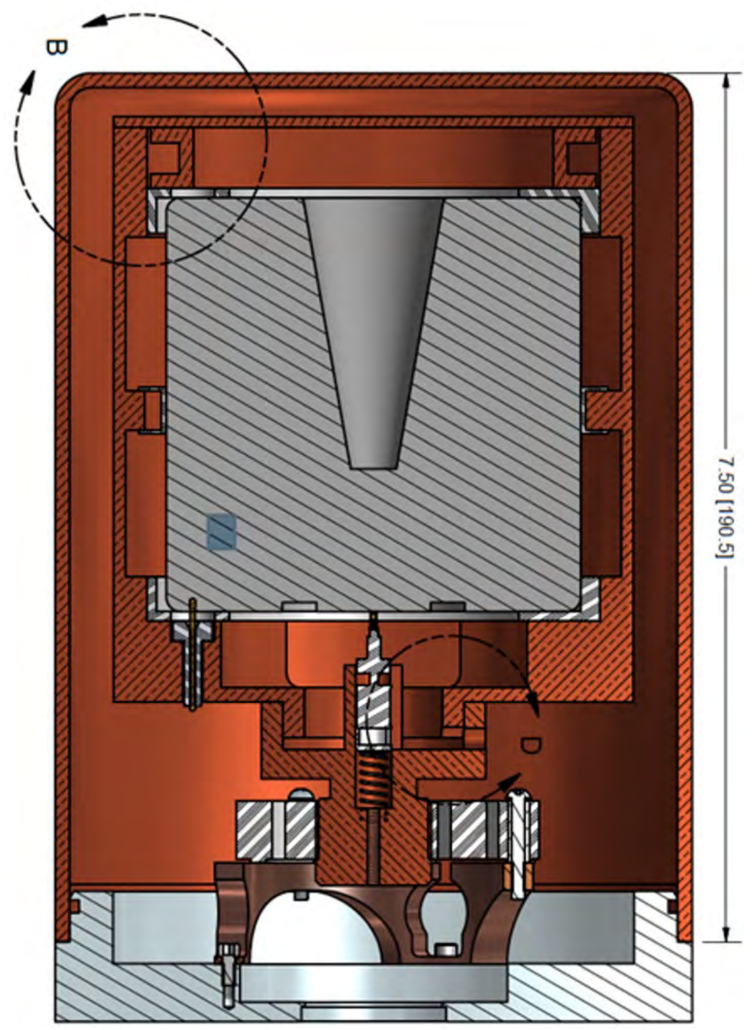


# ESS & NCC-1701

- Three fully-funded technologies for CEνNS@ESS. Start of onsite activities summer of 2025.
- Reinstallation of upgraded NCC-1701 in Vandellós' tendon gallery in progress. Expected signal/bckg of >40 (~1/4 @ Dresden)
- Additional QF measurement at OSURR (1E5 Ge NRs below 700 eVnr collected)
- Update: https://indico.ess.eu/event/3495/

European Research Council

ikur estrategia

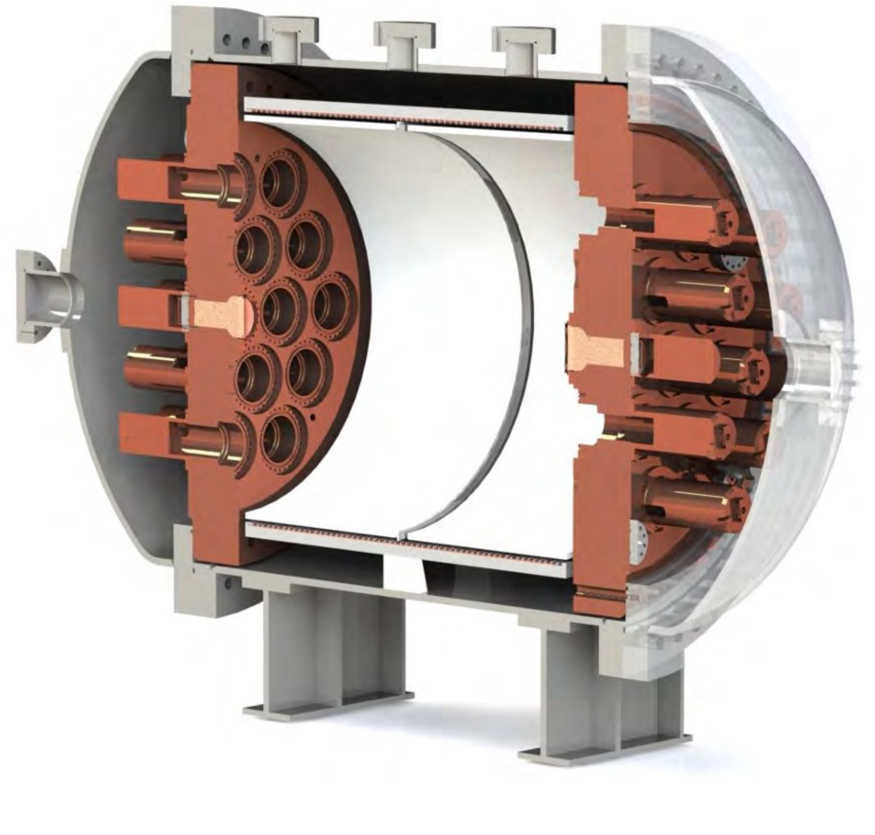


**Cryogenic undoped CsI**

**p-type point contact Ge**

ERC-Advanced grant

100 MEUR/ 10 yr IKERBASQUE program. "Neutrionics" one of four concentrations.

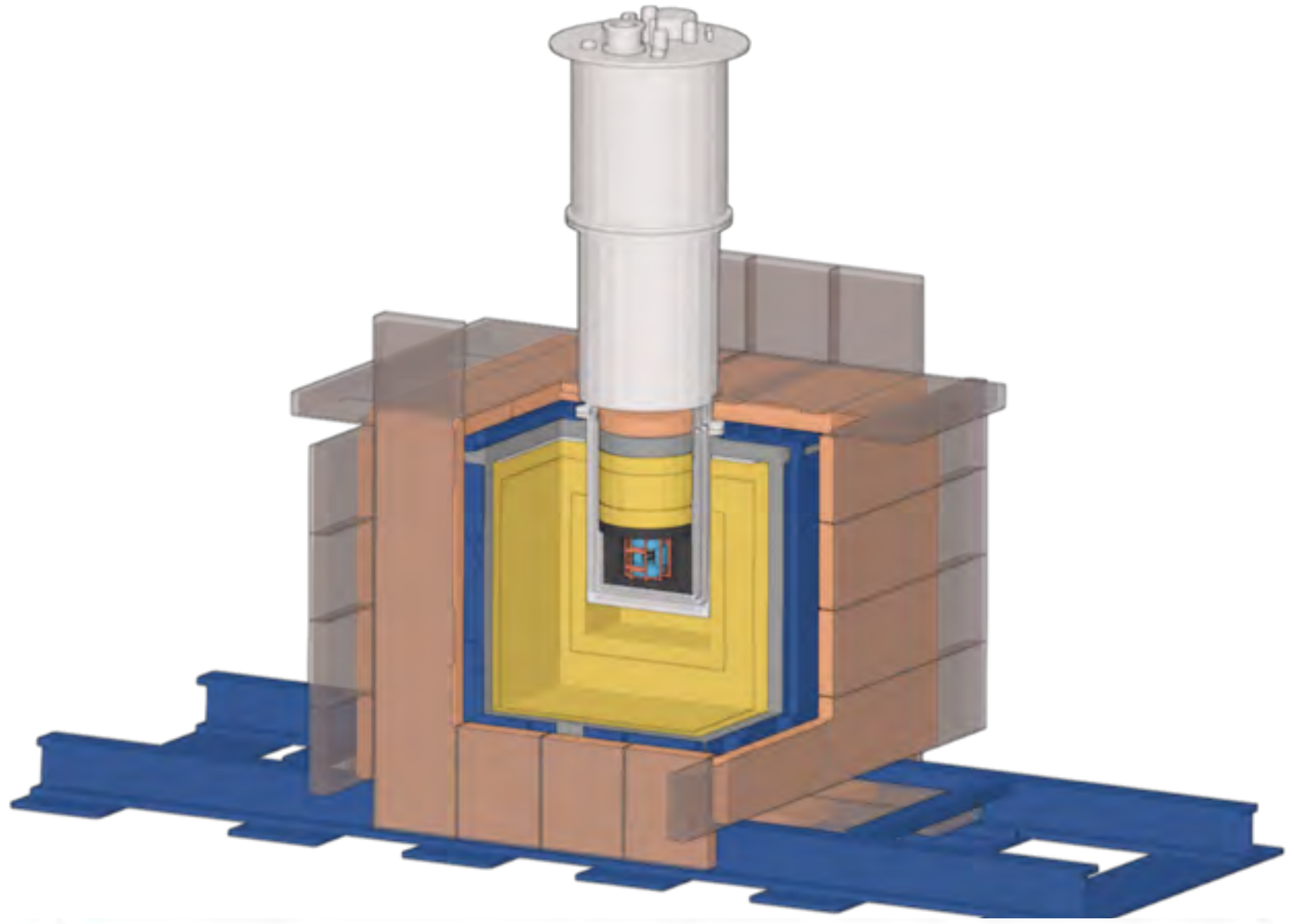


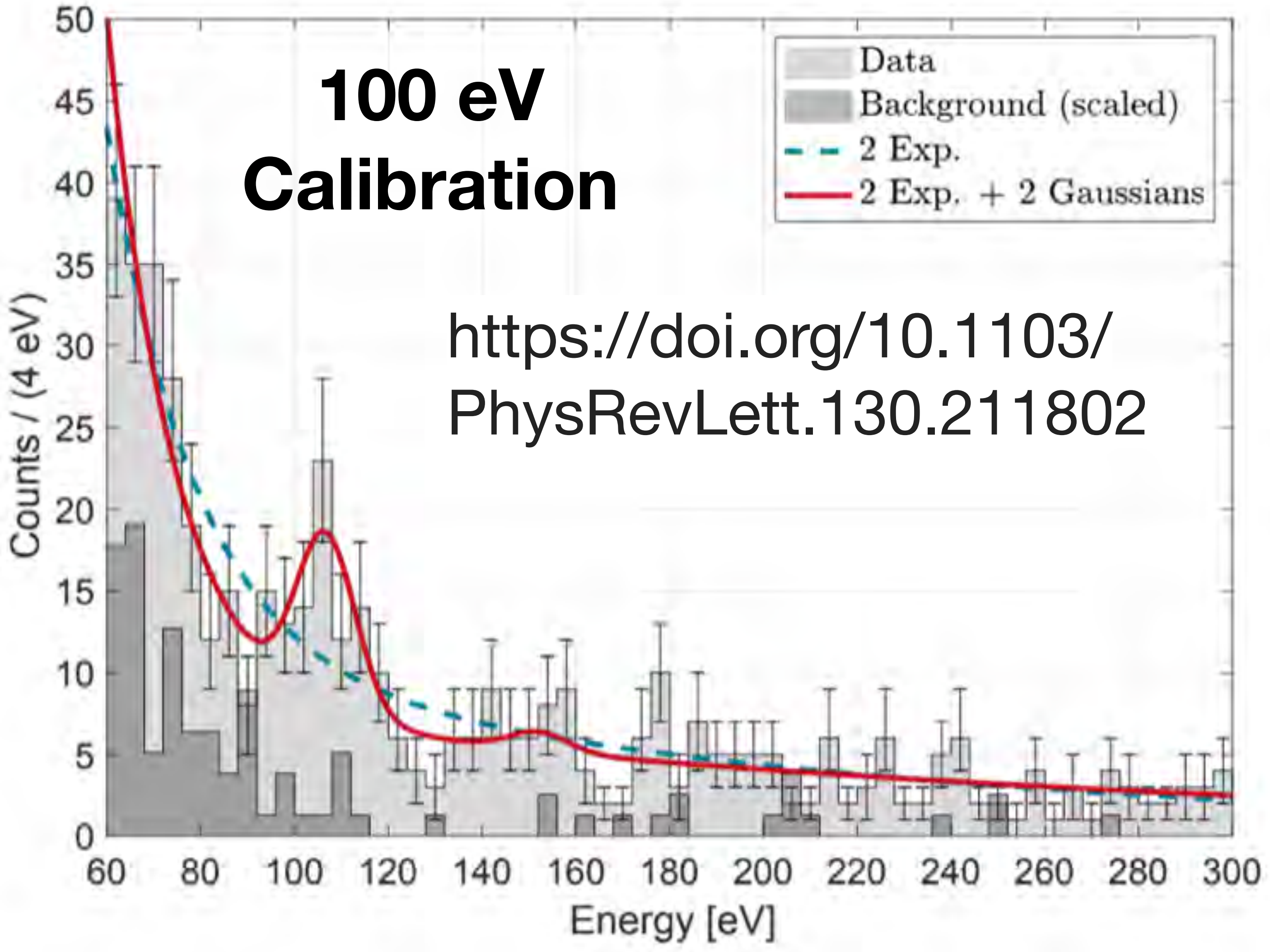
**high pressure gas TPC**

ERC-Starting grant

# Other Reactor Experiments

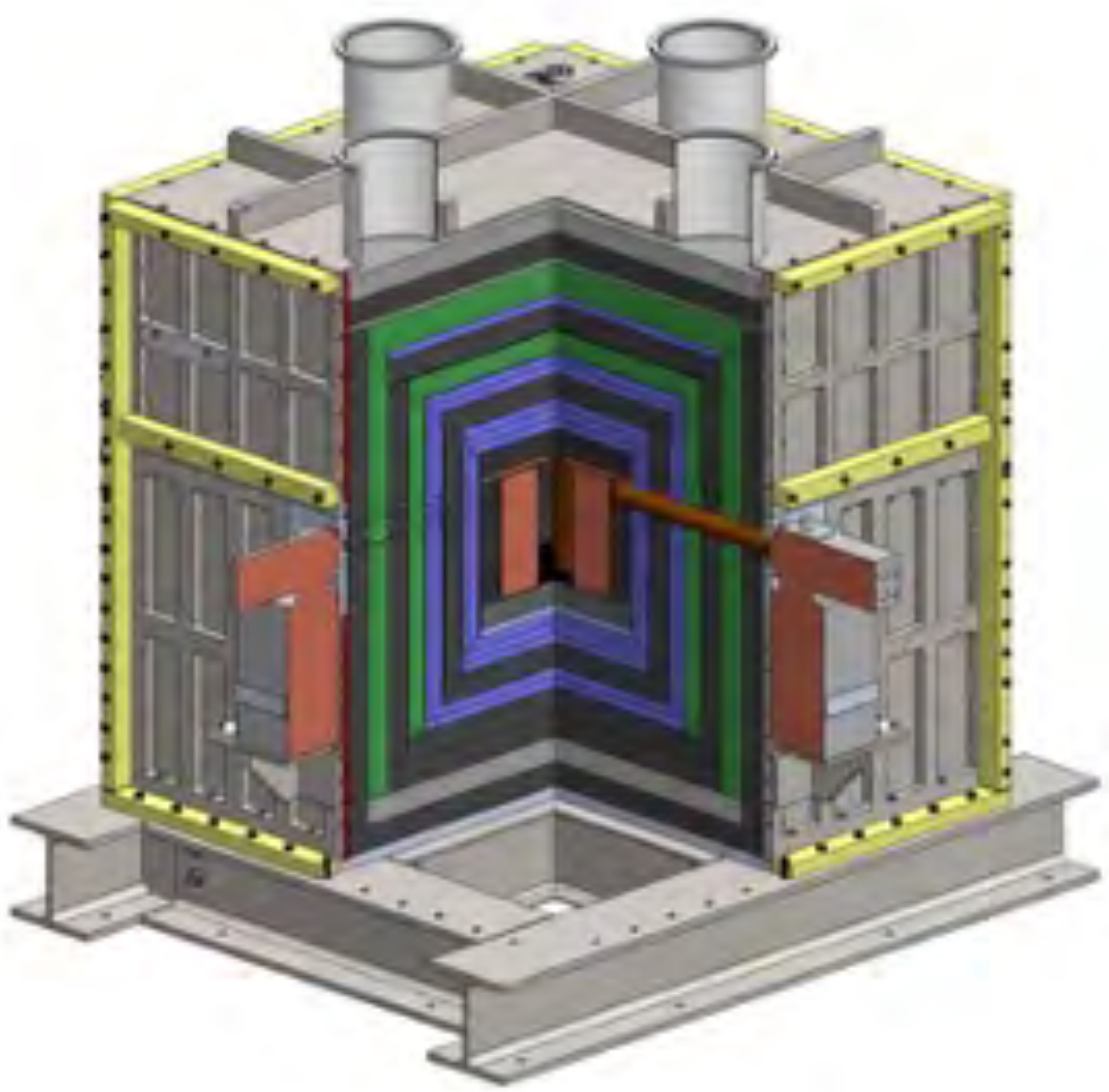
**NUCLEUS**
**10g, 20eV Cryogenic Detector at Chooz**
**Installation to start in 2024!**





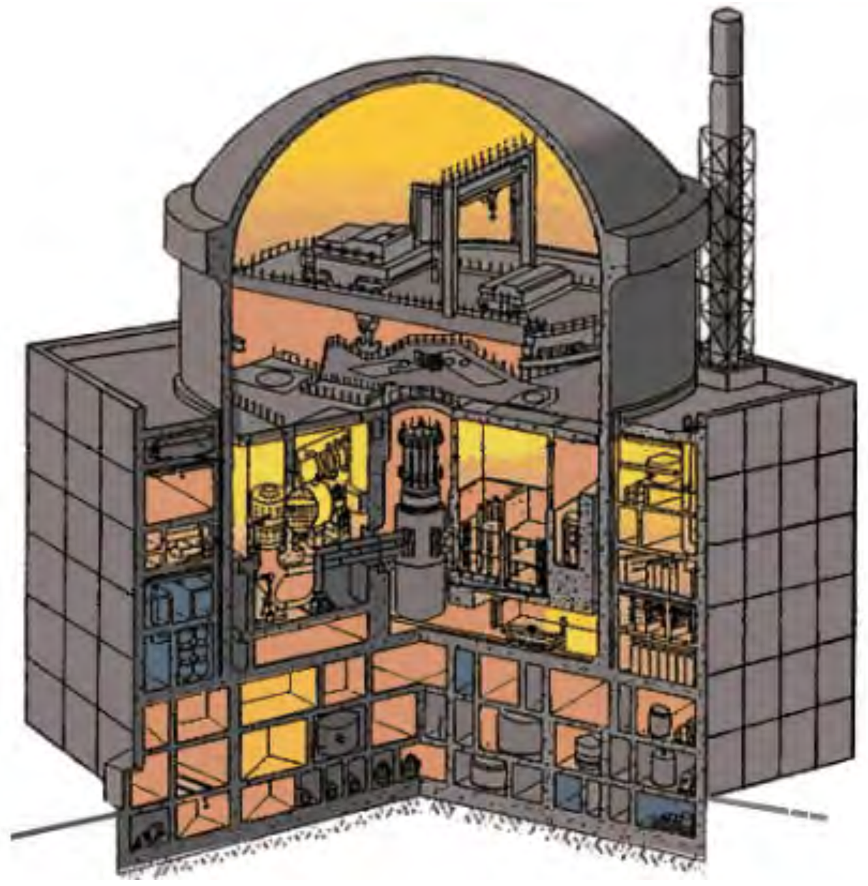

**CONUS+**
**21 m from KKL Power Plant**

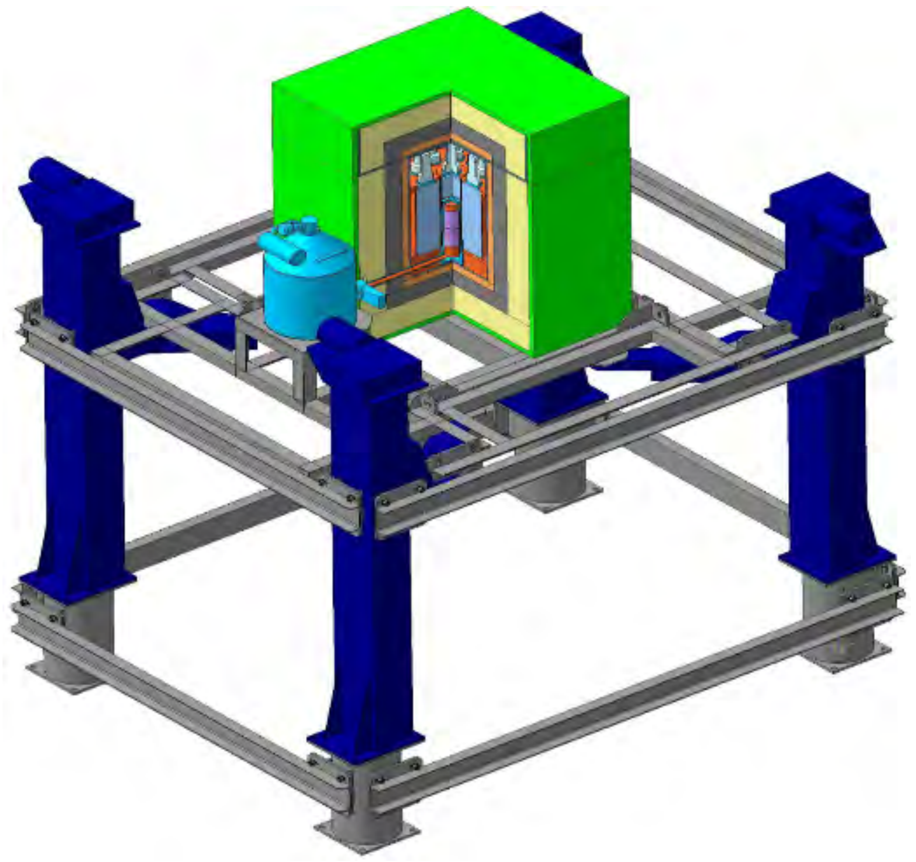
- CONUS shield modified to include additional second muon veto.
- CONUS Ge detectors upgraded. Energy resolution and threshold improved.



**νGEN**
**11.5 m from KNPP Power Plant**

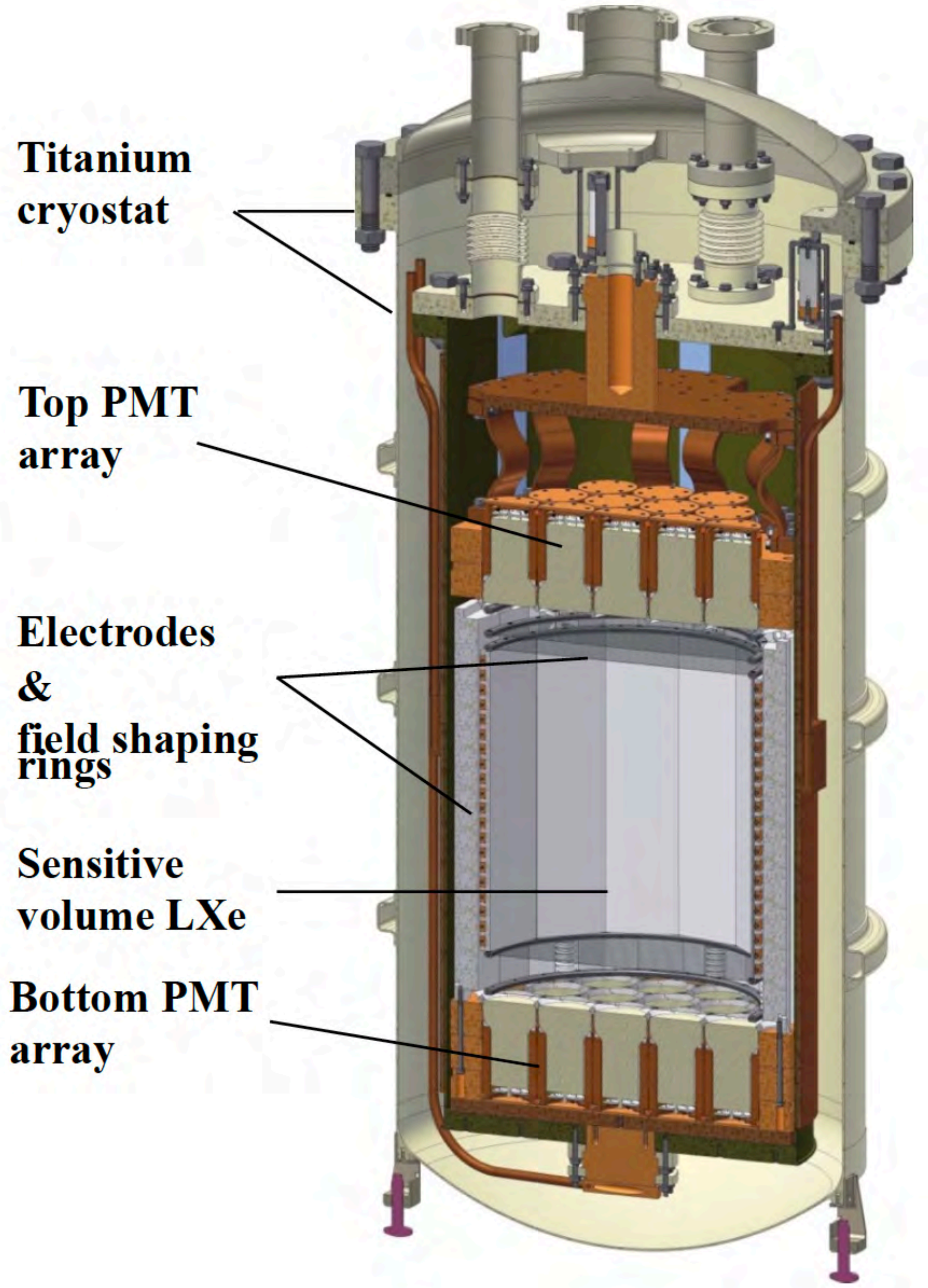
- New results with more statistics and optimized measurement modes are expected soon. Search for evidence of other effects in data are ongoing.



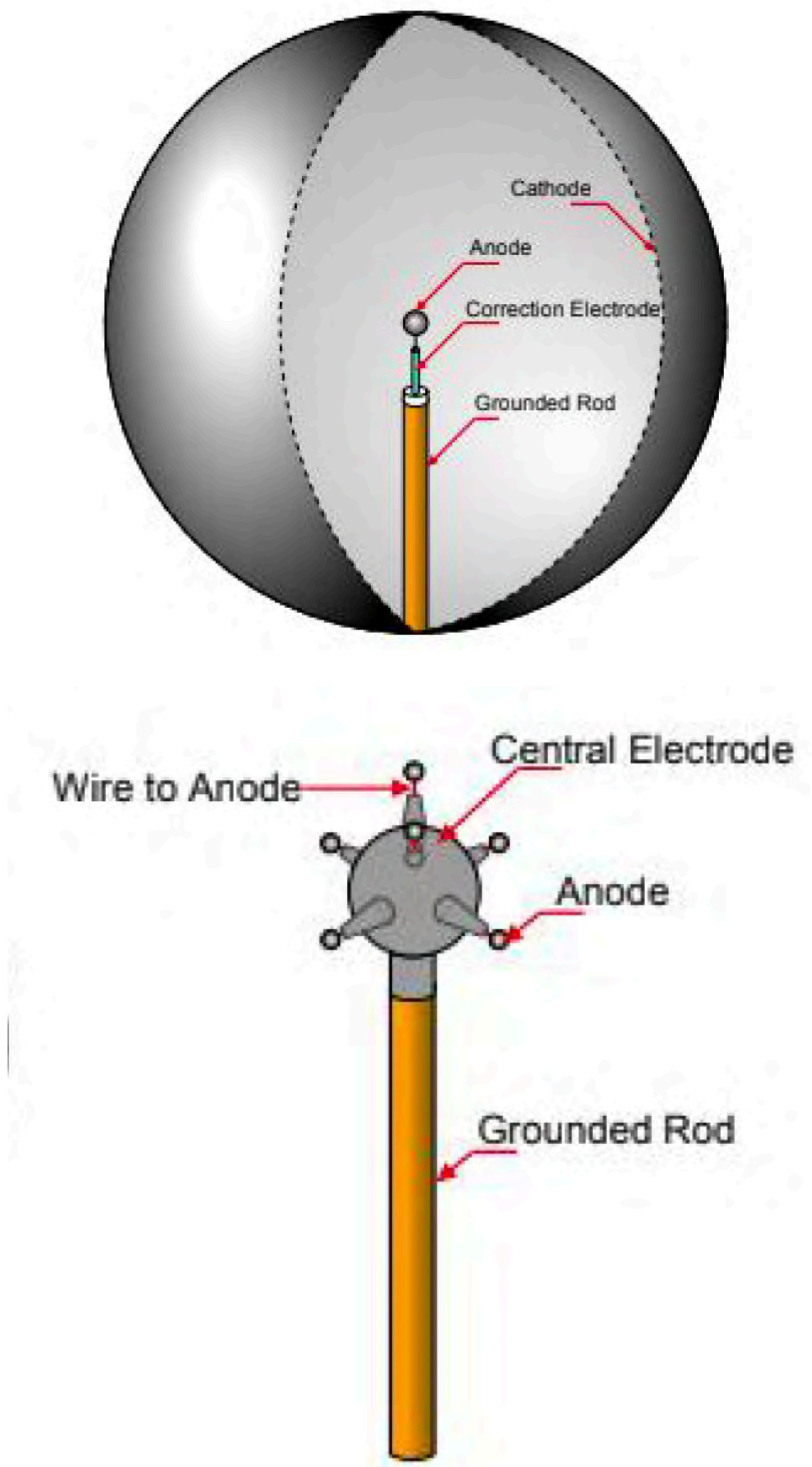


# Other Reactor Experiments

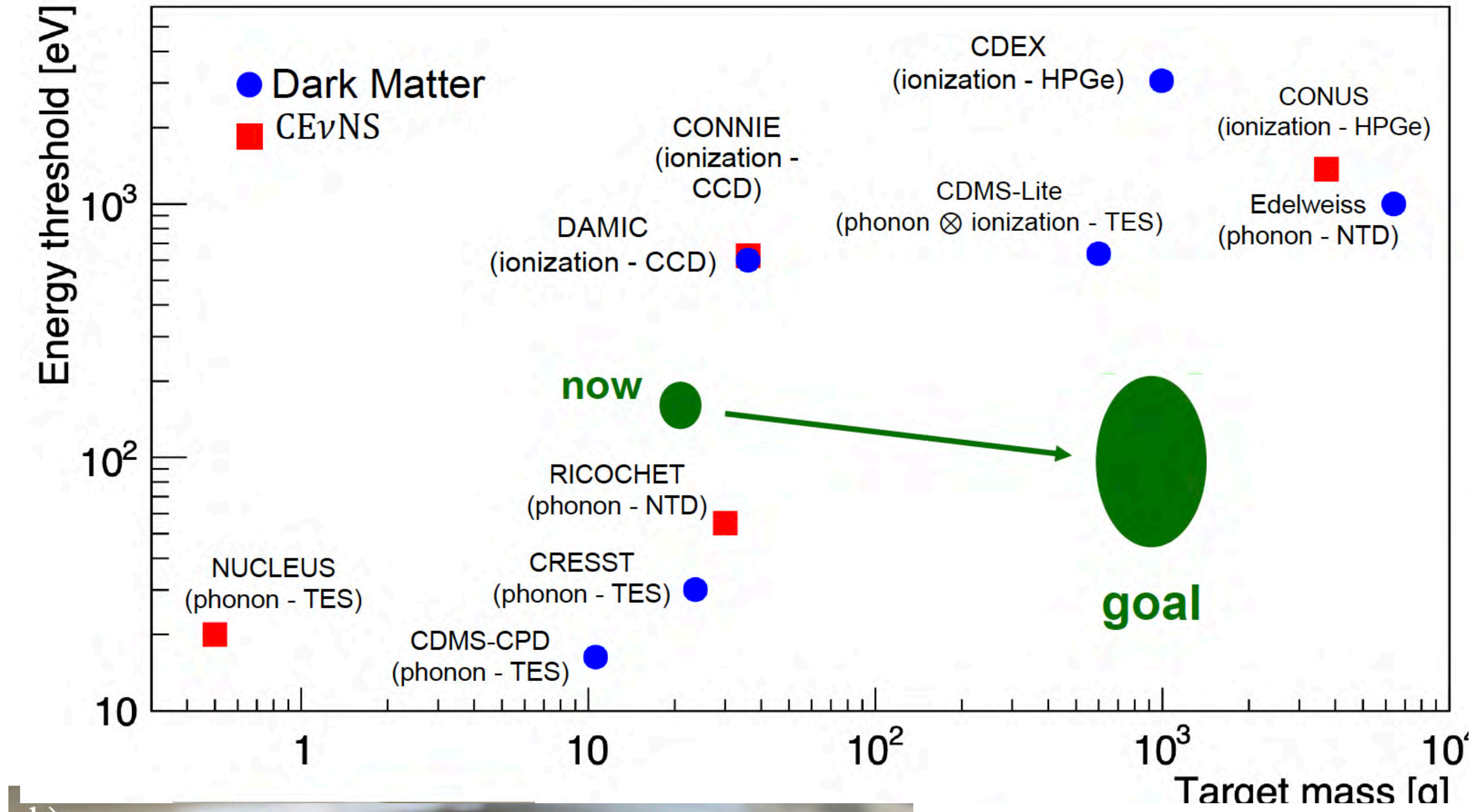
**RED-100**
**Successful Data run with Xe**
**Moving from Xe to Argon**

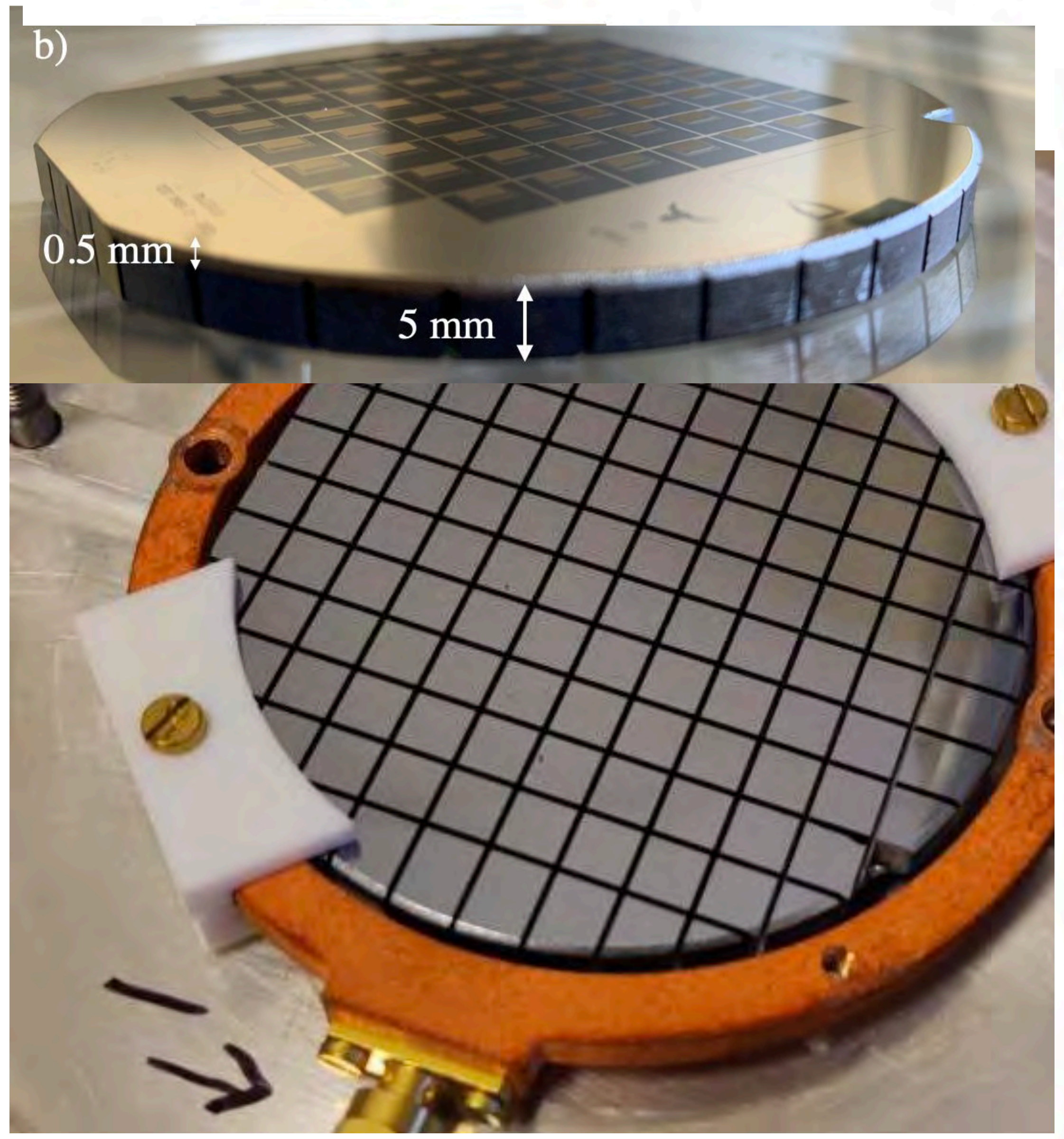


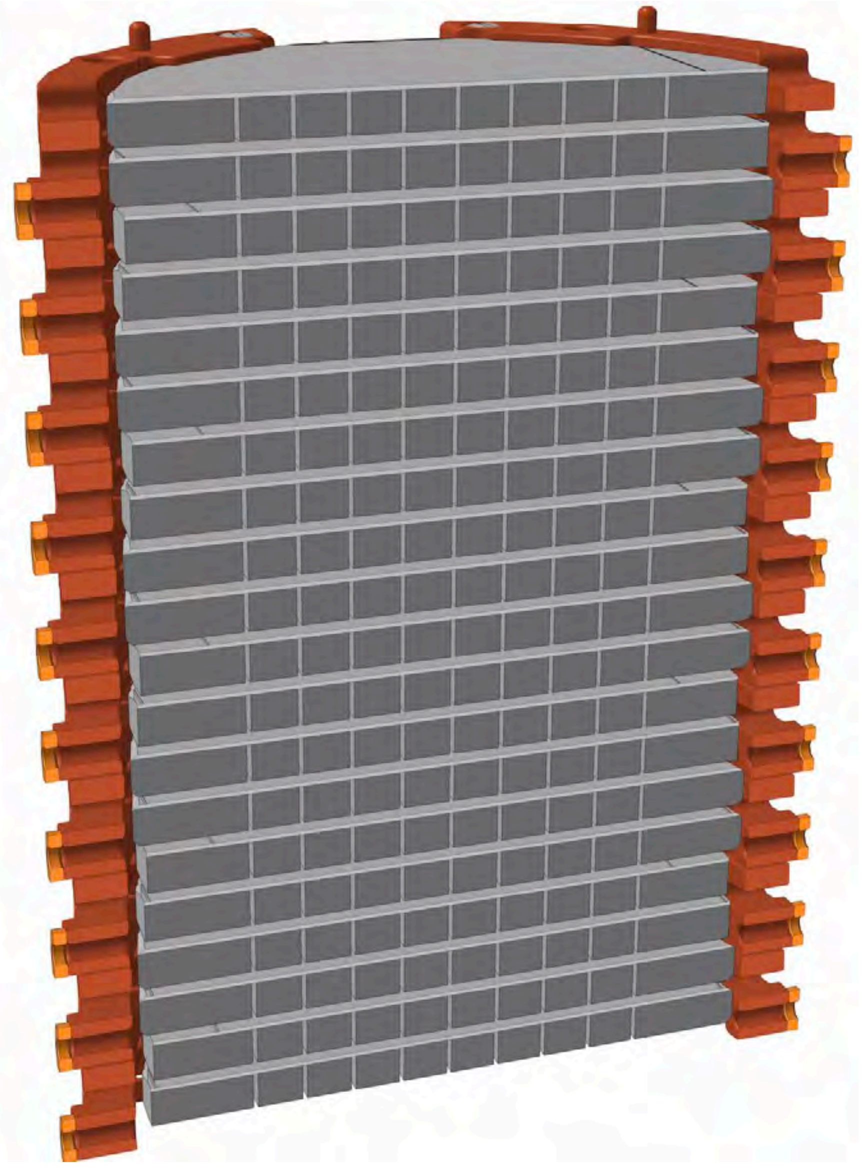

**NEWS-G3**
**Spherical Proportional Counter**
**Working on final design**




**BULLKID**
**Si/Ge with MKIDS**



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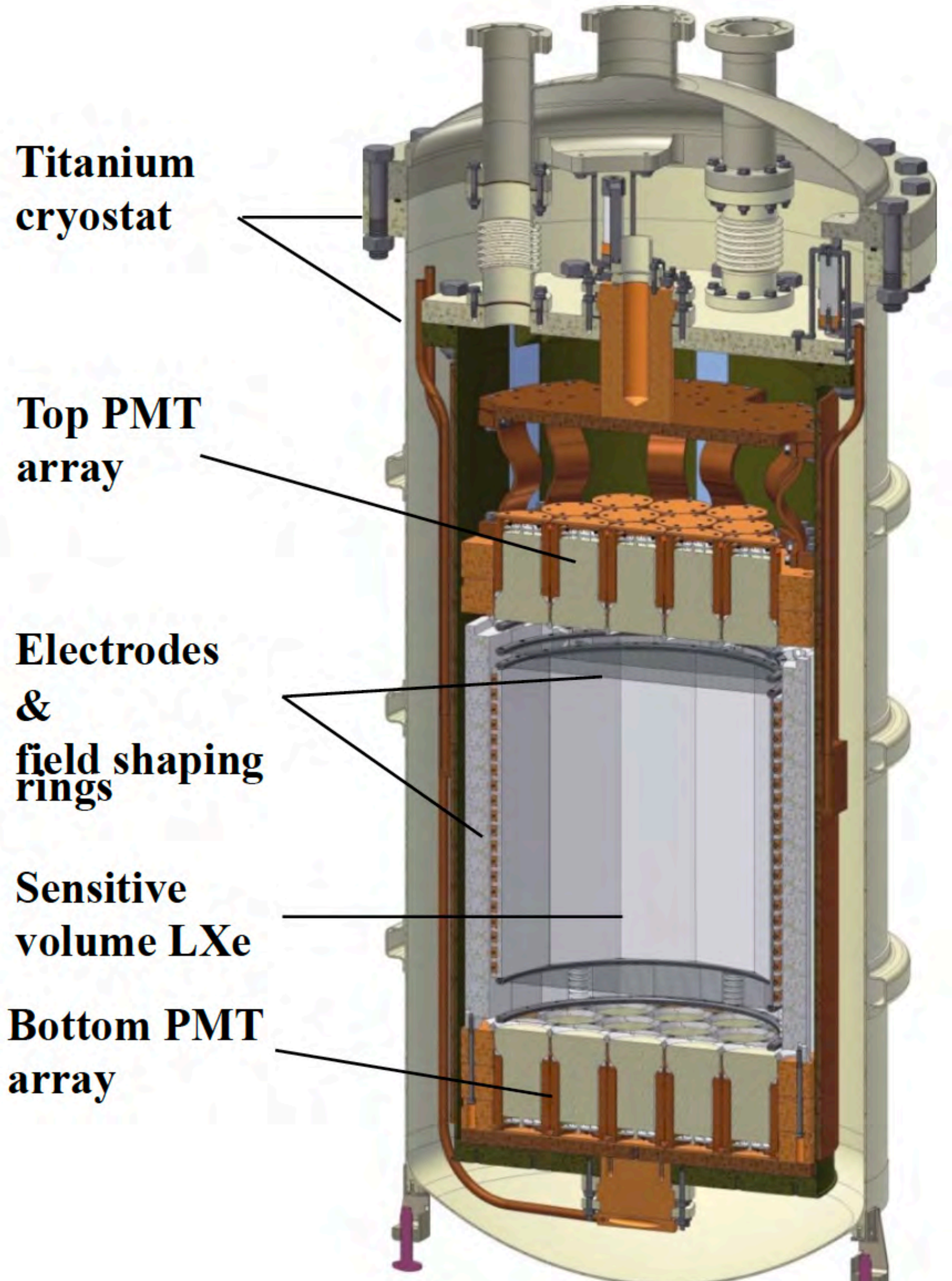


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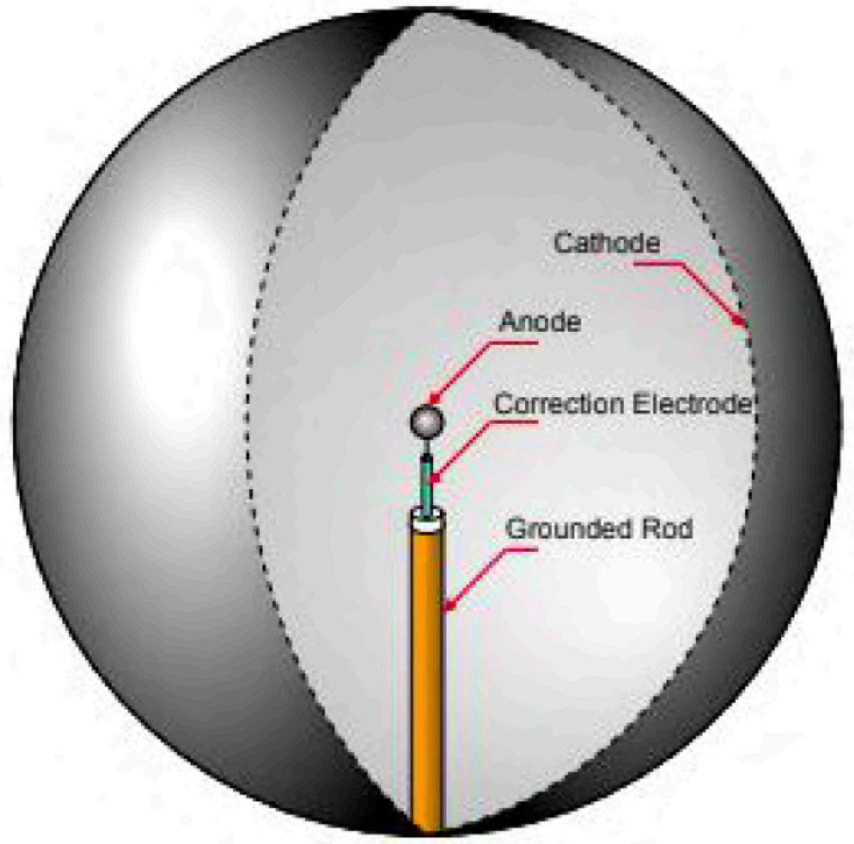


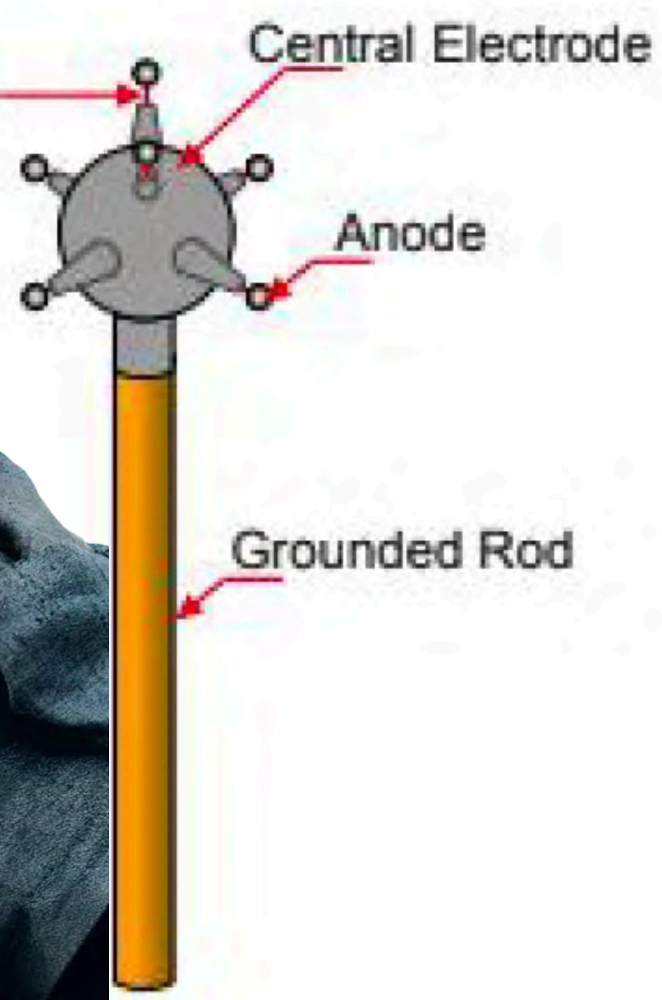


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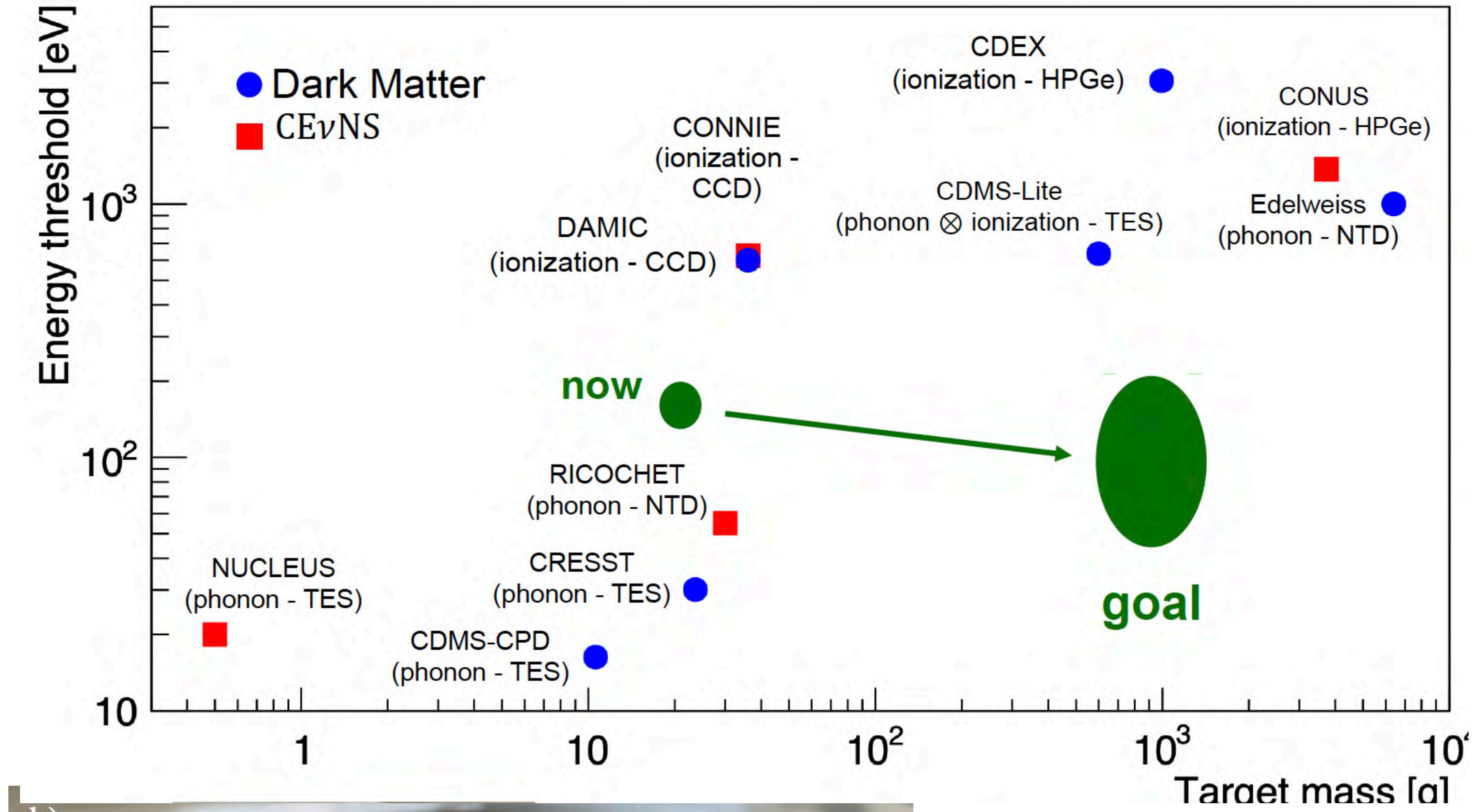


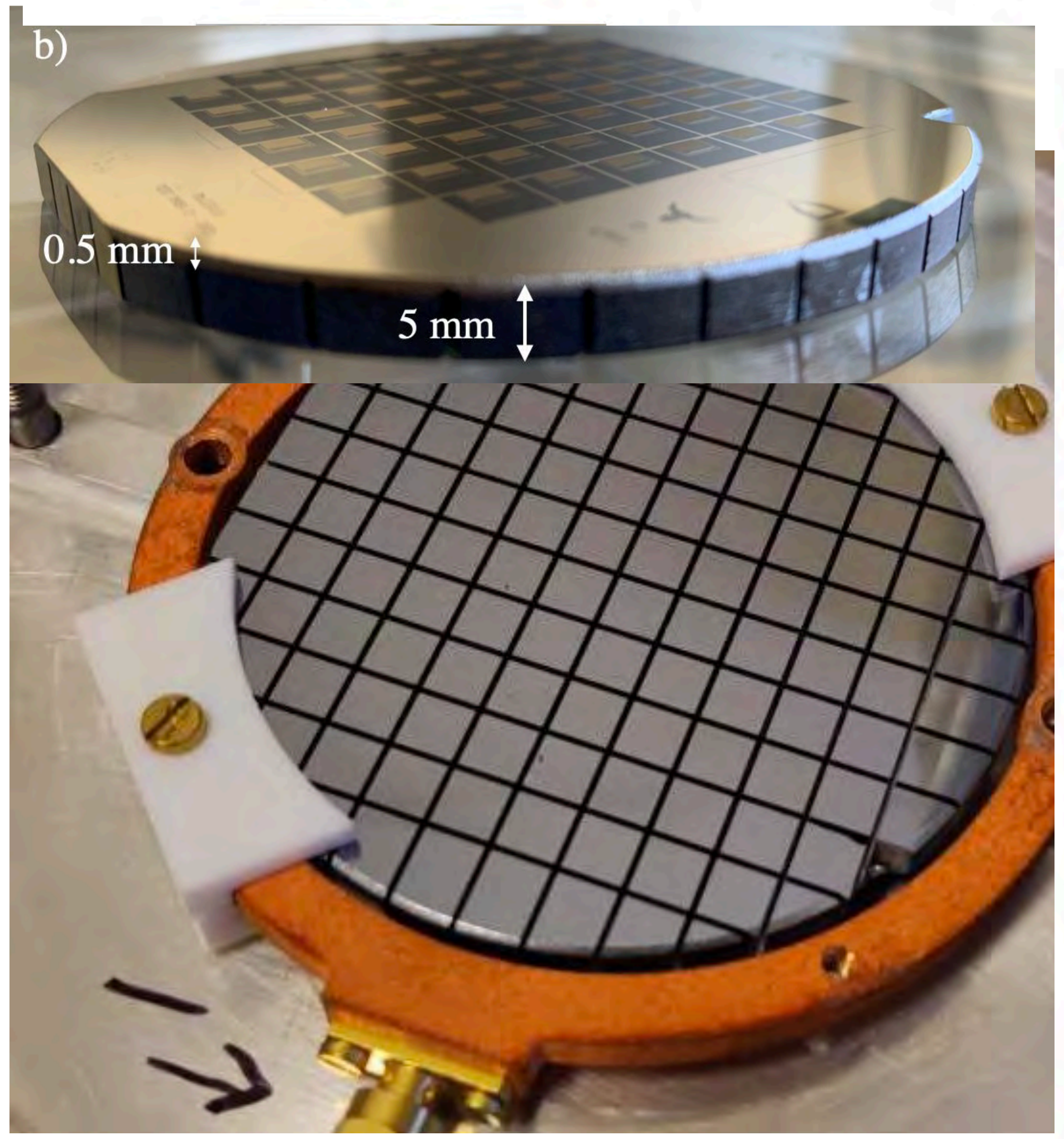


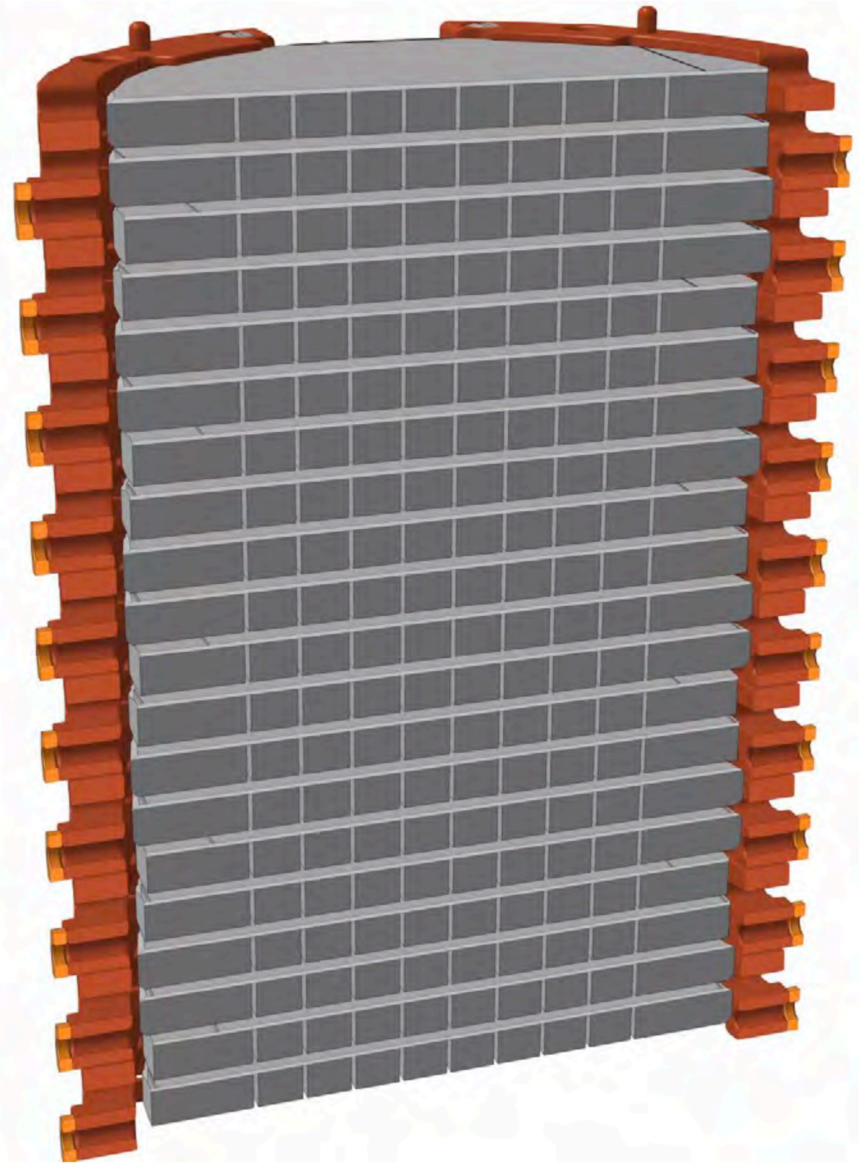

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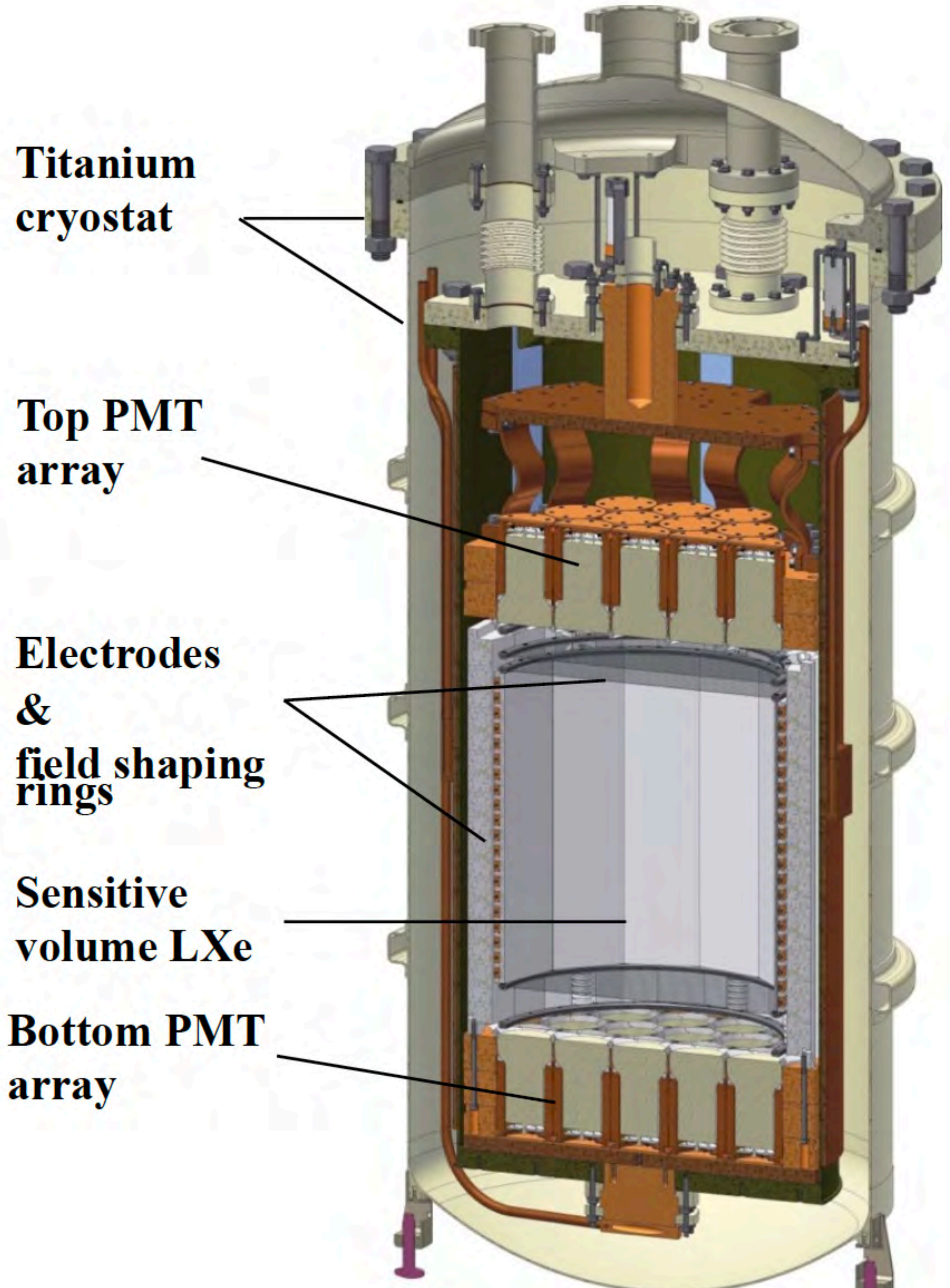


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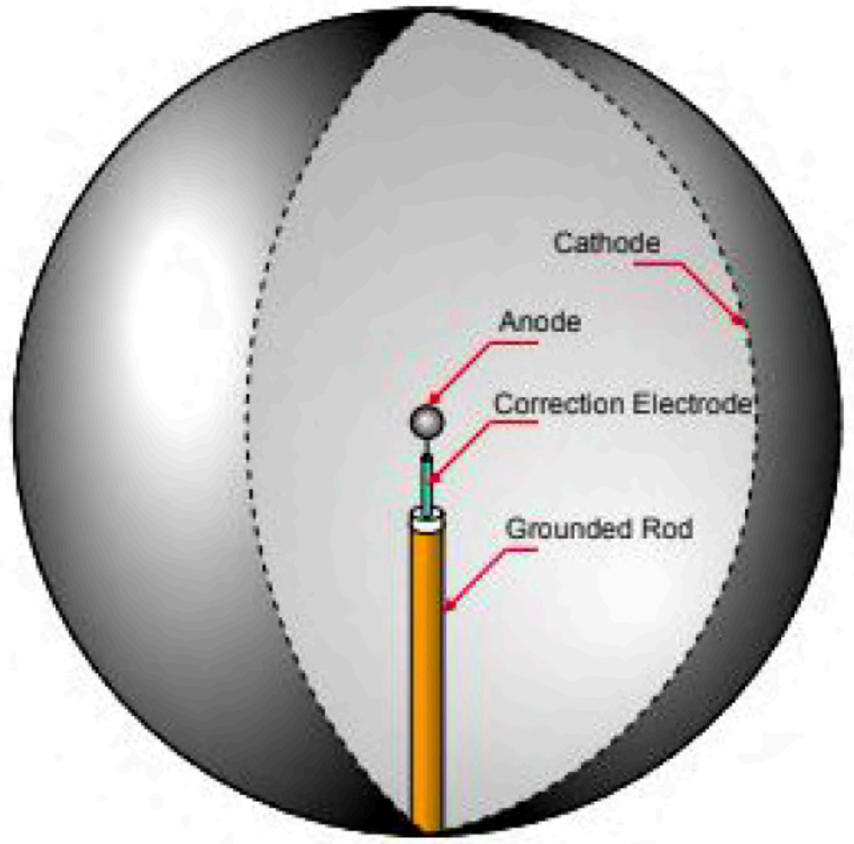


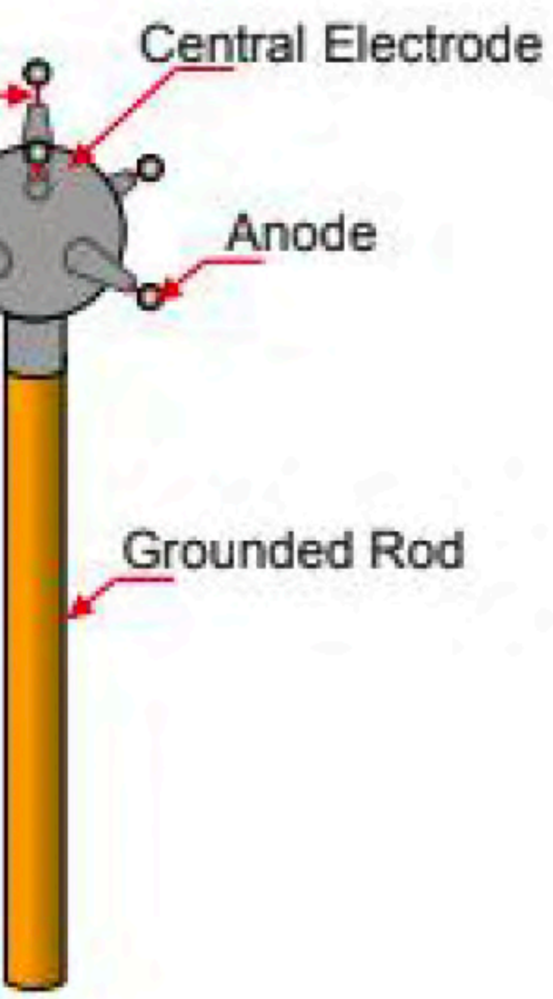


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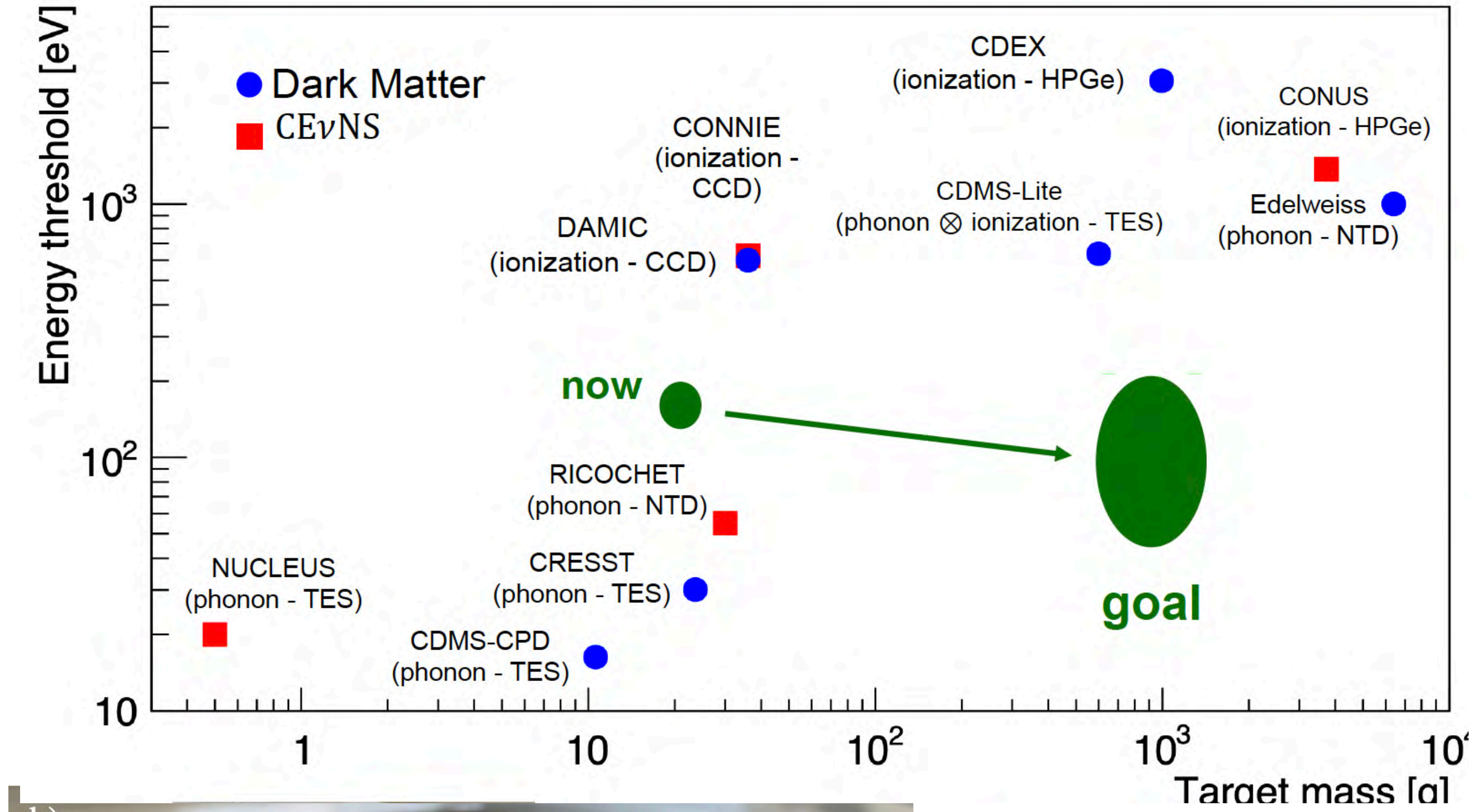
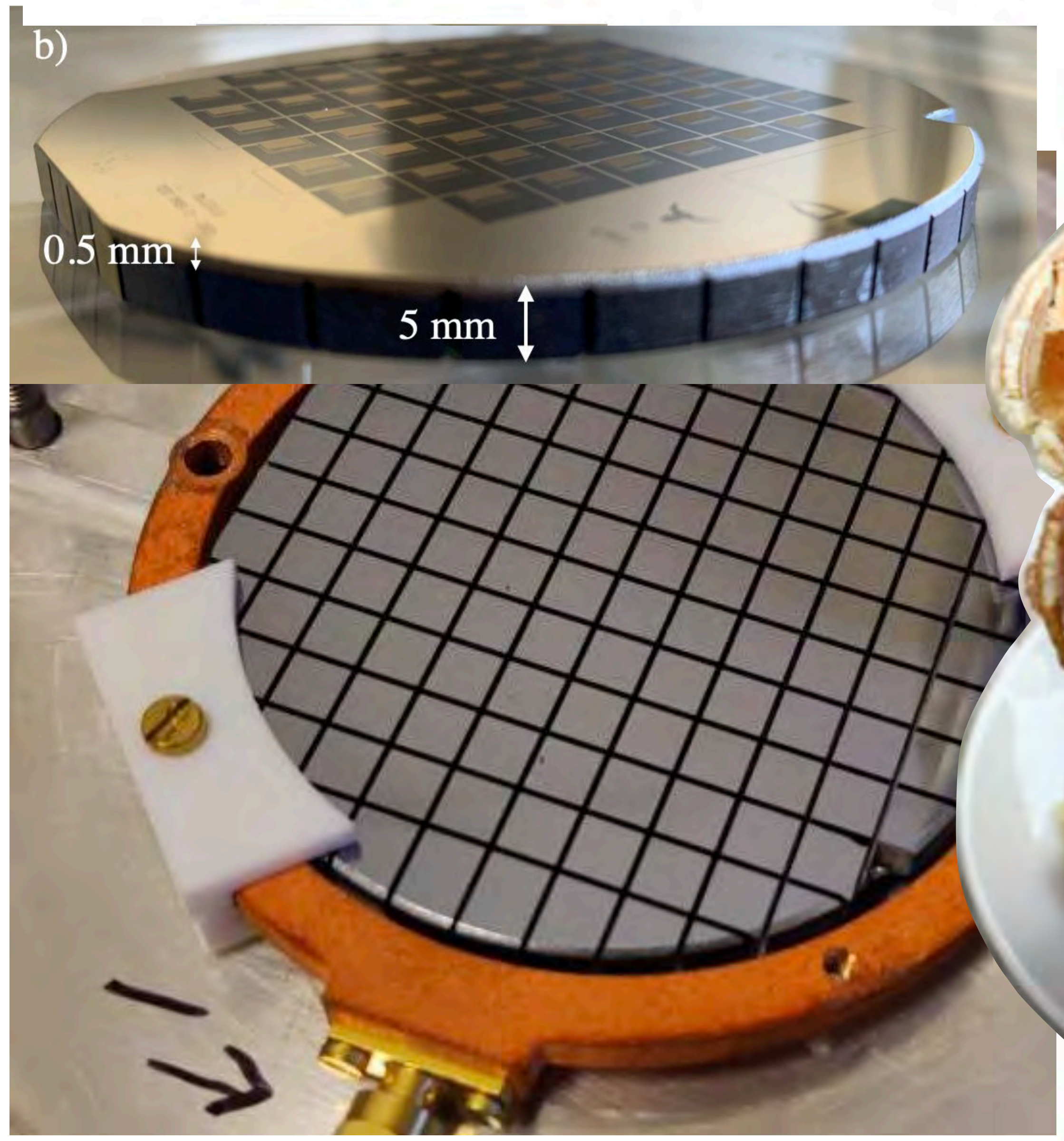
**Si/Ge with MKIDS**




# Conclusions

- COHERENT is leading the way with detections in CsI, Ar, and Ge! Physics impact already very strong.

- New upgrades in the COHERENT program plus other DAR sources (ESS) will bring lots of new data in the coming years.

- Reactor experiments have made some contested claims of detection, but we will have several definitive measurements with higher statistics within a year or two(ish).

- Quenching factor measurements are crucial for the interpretation of reactor data, and many new measurements are being done to provide clarity on QF values (especially for Ge).

- New technologies are being brought to bear, and we can look forward to future percent-precision measurements of CEvNS spectra.

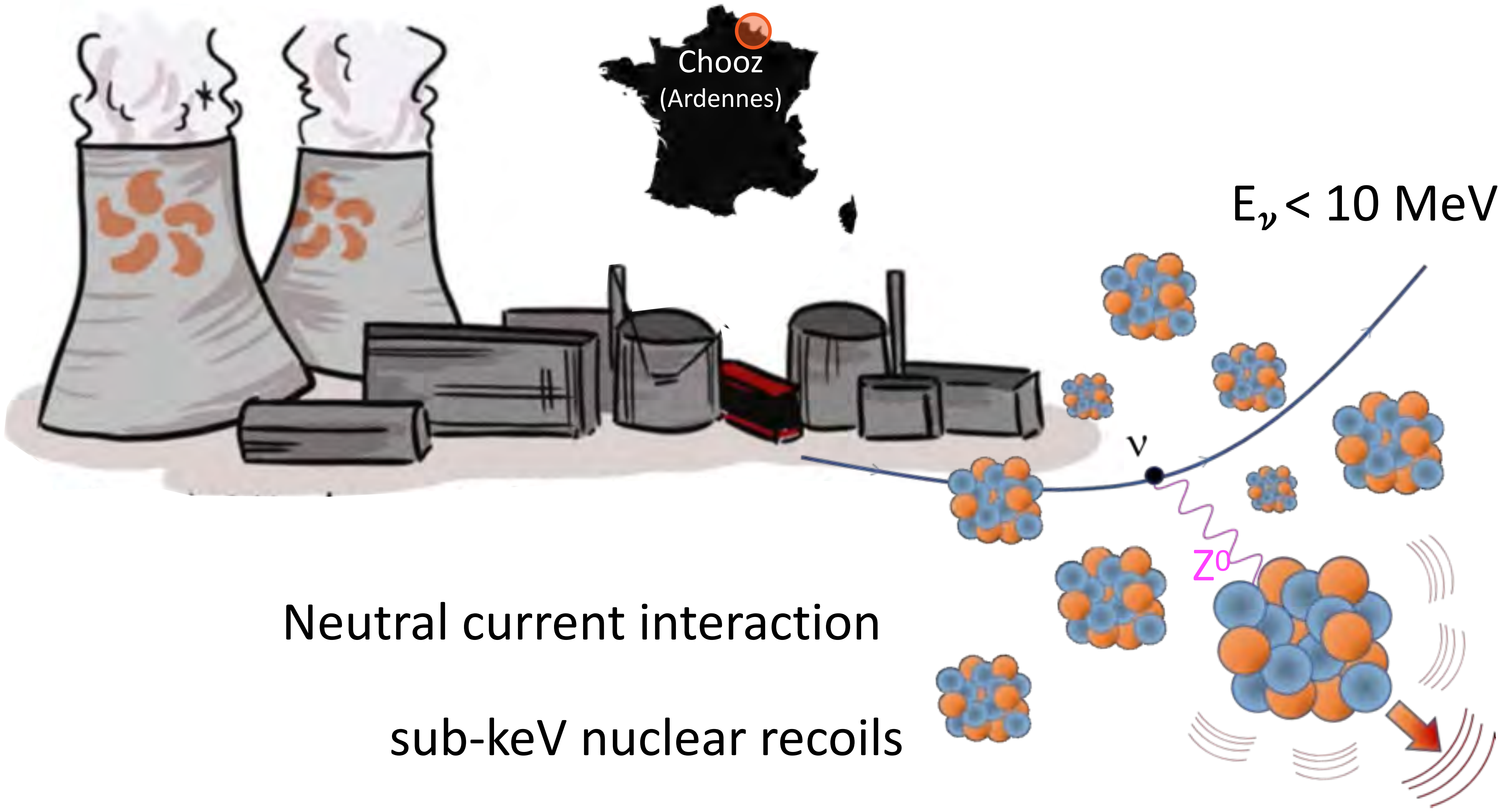
# Additional Slides on Specific Experiments

# NUCLEUS

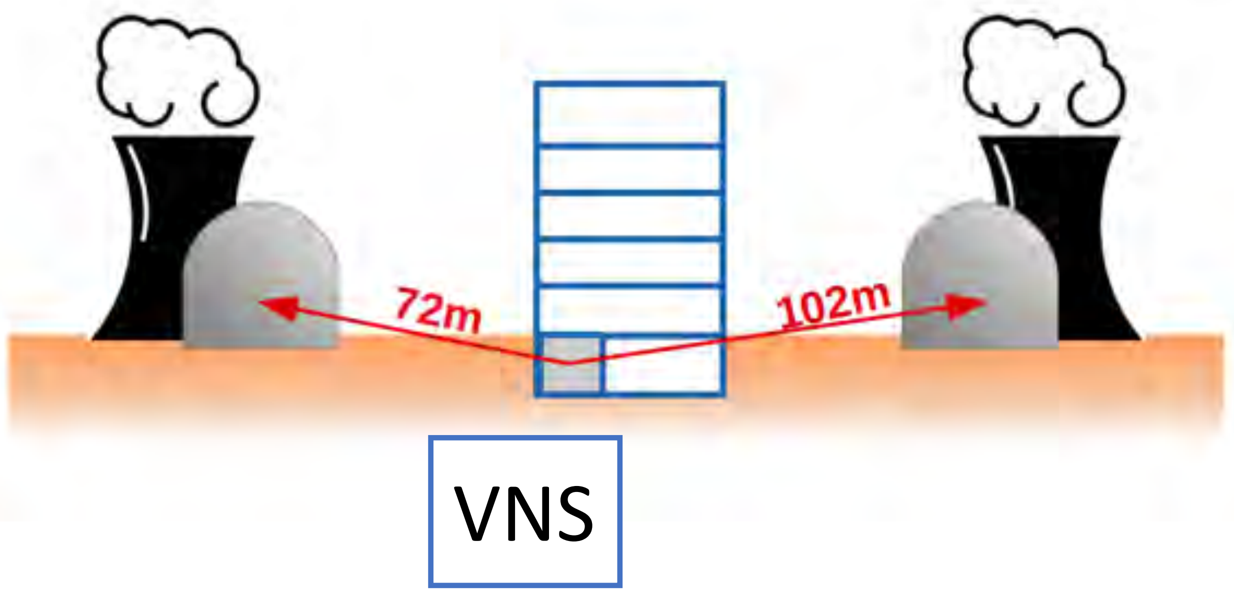
# NUCLEUS: Study CE$\nu$NS from reactor antineutrinos

**Chooz B** nuclear power plant:
Thermal power of 2 x 4.25 $GW_{th}$

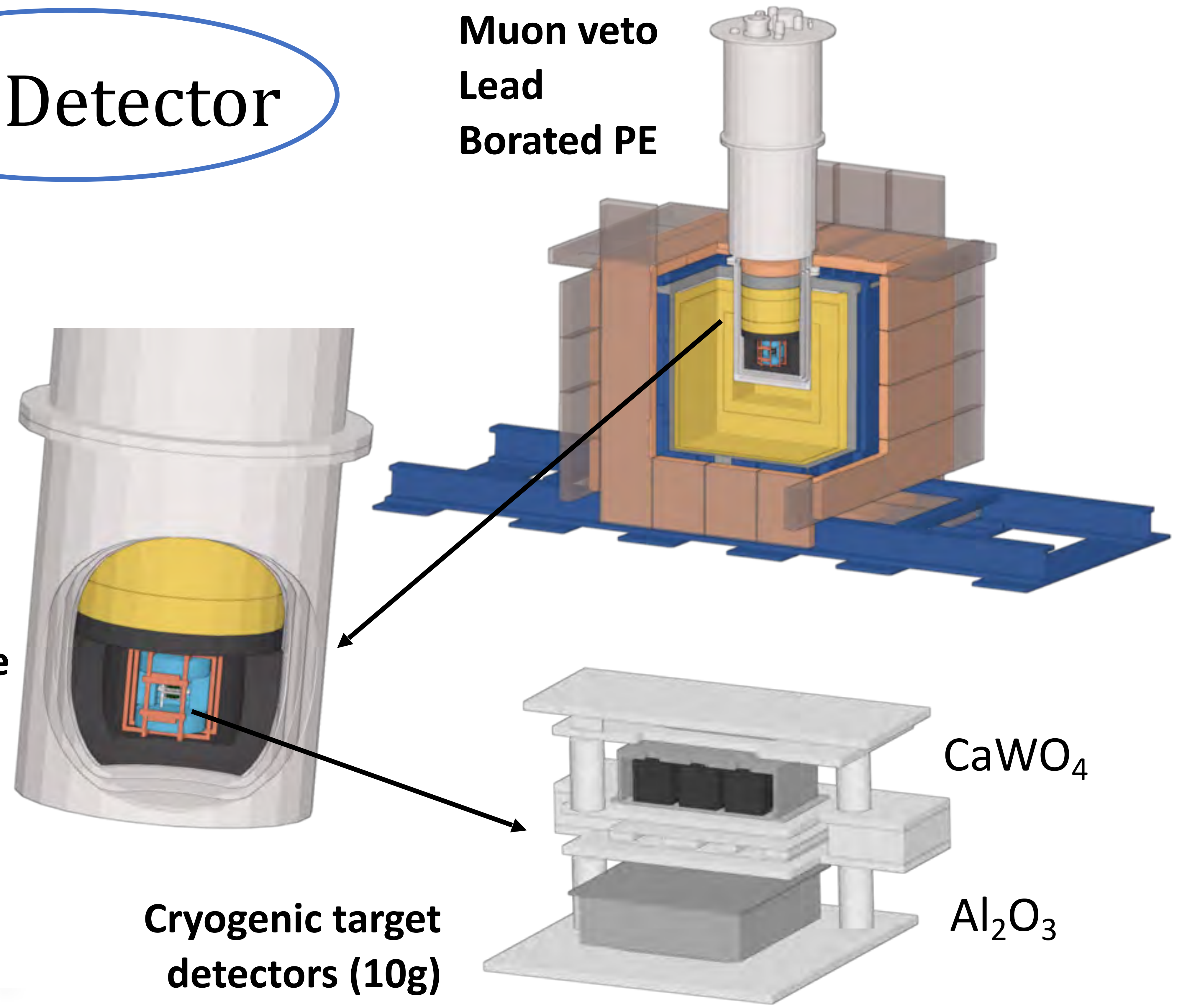
## The Site




**Experimental site: the "Very Near Site" (VNS)**
102m and 72m from the two reactor cores
Expected neutrino flux : $1.7\times10^{12}\ \bar{\upsilon}/(s.cm^2)$




## The Detector



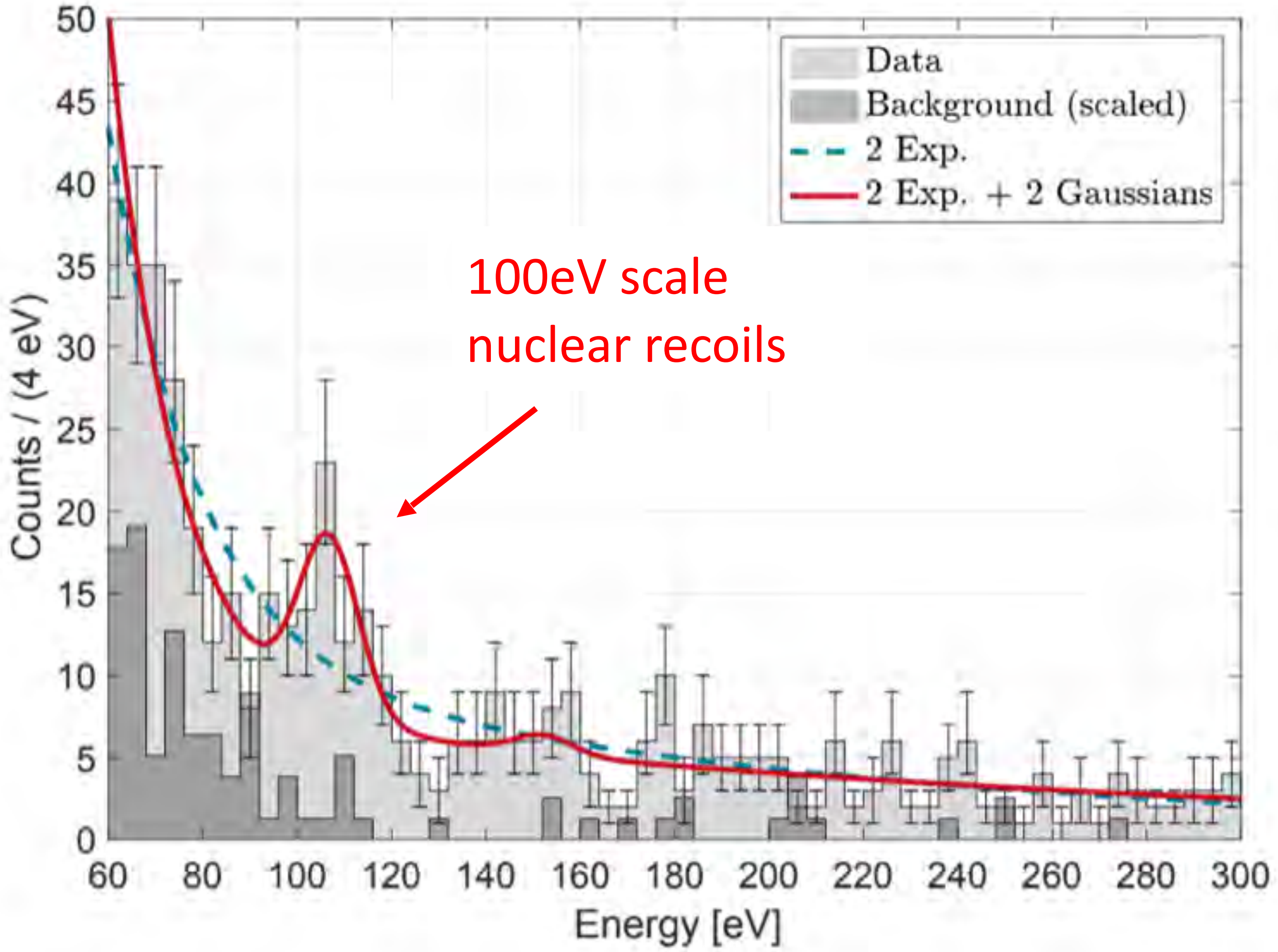

Low energy threshold: 20 eV
Measure neutrinos with a 10g detector!

*Comics courtesy Chloe Goupy, CEA, 2022

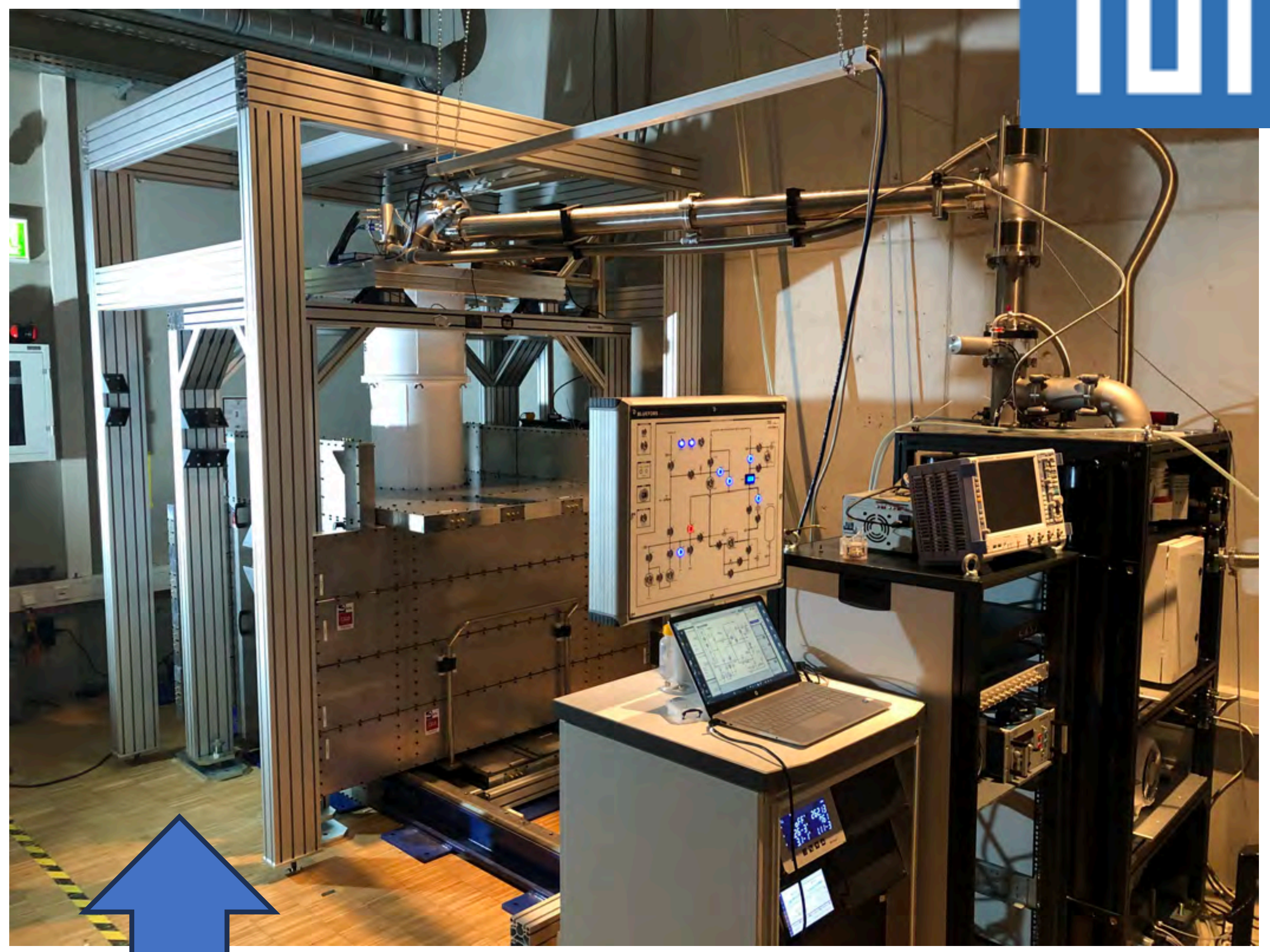
# Status and prospects of NUCLEUS

**Milestone result in 2022: Calibration at 100 eV by observing the capture of thermal neutrons on a NUCLEUS target crystal**

→ First observation of a 100eV scale nuclear recoil peak




Published in PRL

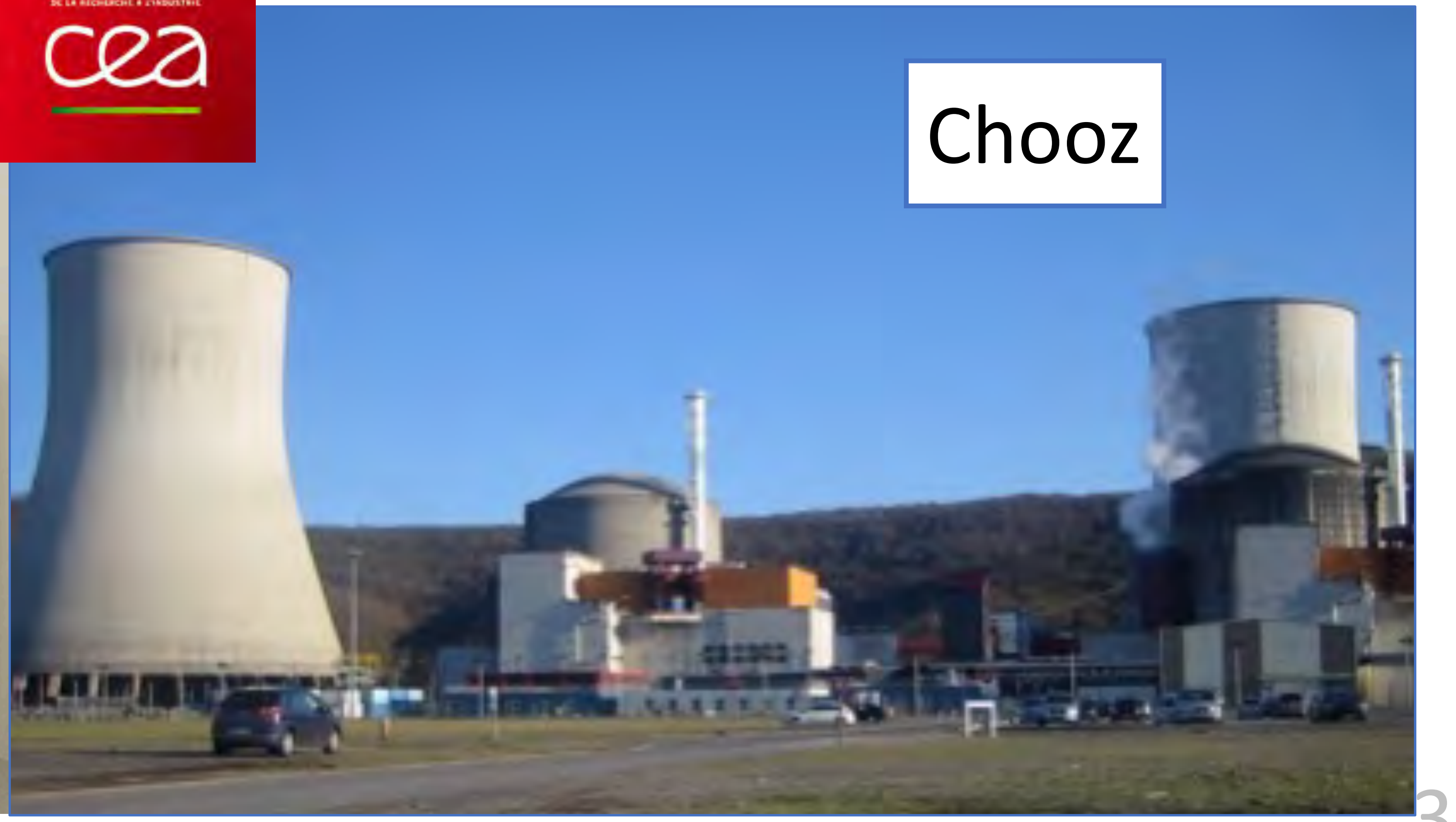


**Spring 2023** – Full setup started commissioning in the TUM-UGL

- Mechanical integration tests
- Calibrations at keV energies and below
- Detector performance

Experimental room at the CHOOZ Power Plant ready

On-site installation starting end of 2024



# The NUCLEUS collaboration

nu|cleus EXPERIMENT

Please check out the NUCLEUS homepage for further info:
[https://nucleus-experiment.org/](https://nucleus-experiment.org/)

≈ 50 collaborators

TUM (Munich) - April 2024


TUM LMU ORIGINS Excellence Cluster

SFB 1258 Neutrinos Dark Matter Messengers

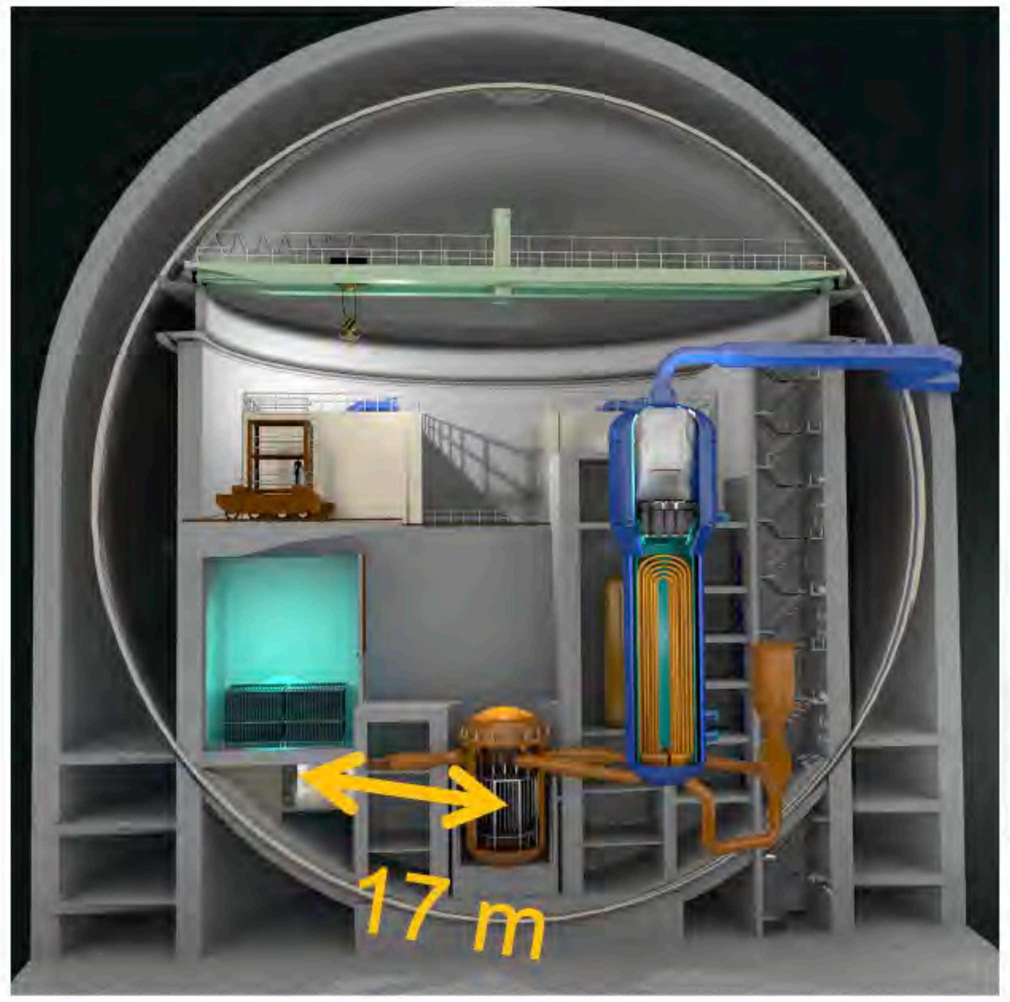
erc European Research Council Established by the European Commission

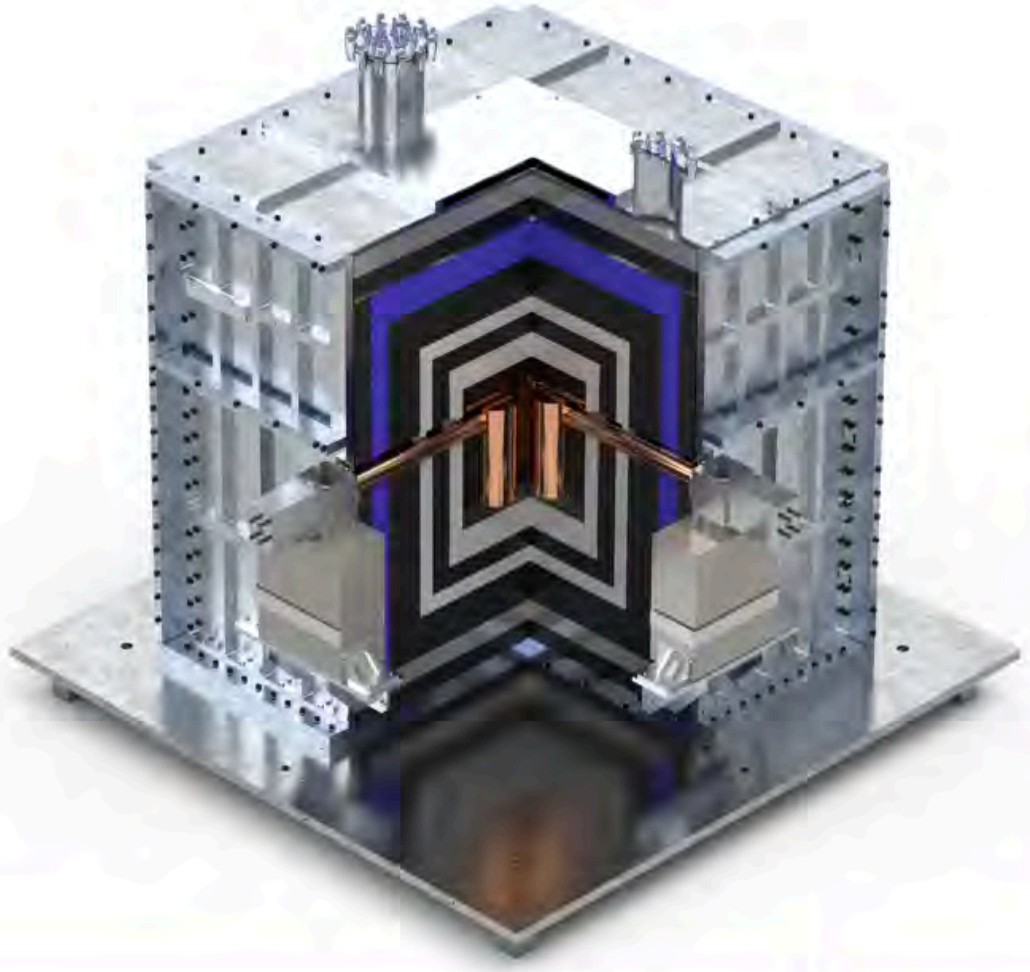
P2IO Physique des 2 Infinis et des Origines

TUM · cea · EDF · INFN · SAPIENZA UNIVERSITÀ DI ROMA · TU WIEN · MAX-PLANCK-INSTITUT FÜR PHYSIK · HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

# CONUS

# CEvNS search at Brokdorf nuclear power plant with CONUS



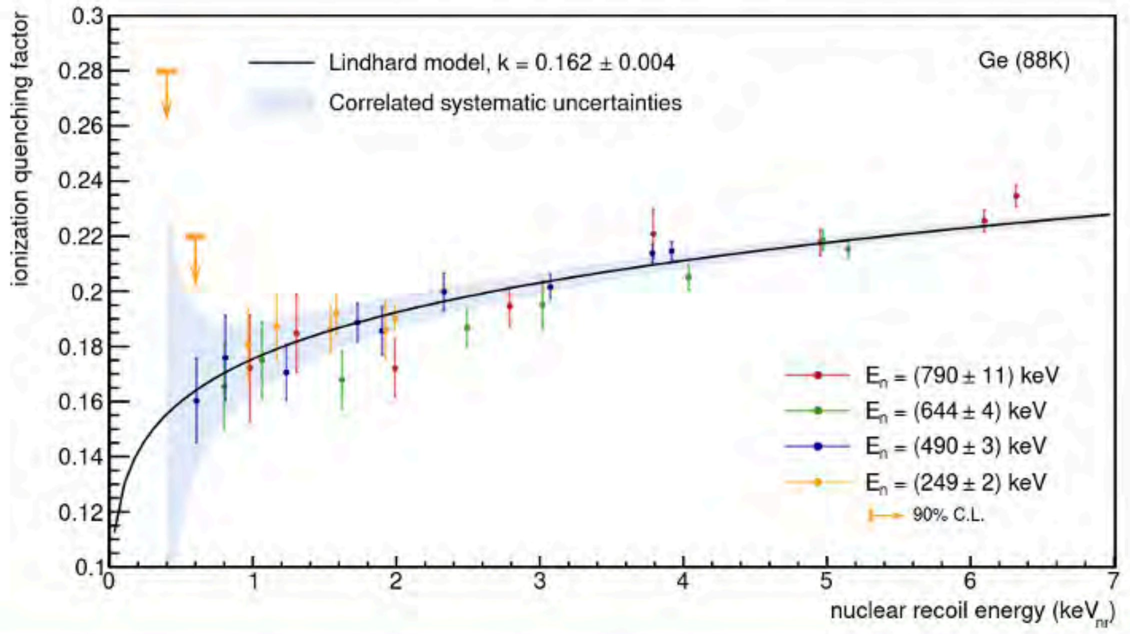



5 years of successful operation of
4 x 1kg Ge detectors @ 17 m distance
from a 3.9 $GW_{th}$ reactor core center

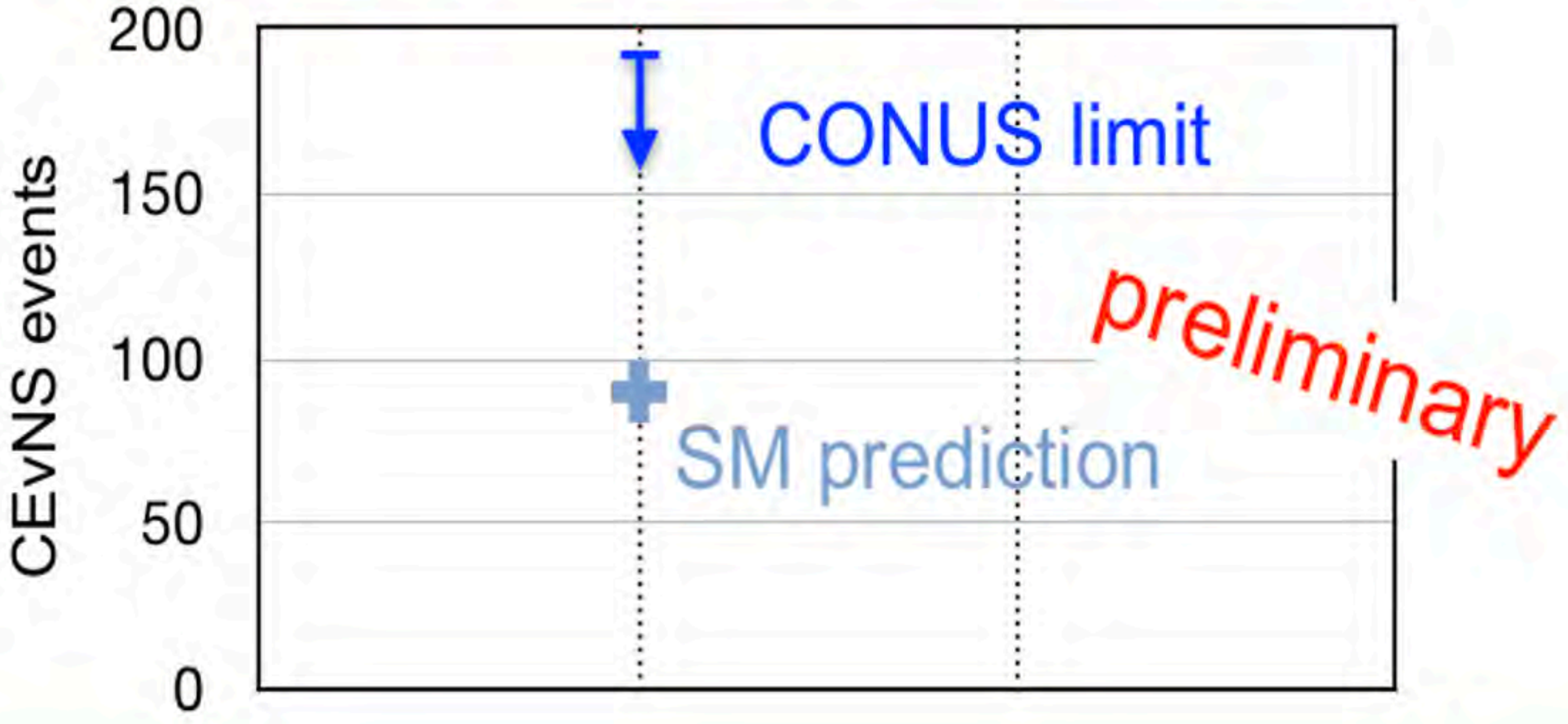
2110.02174
2112.09585
arXiv:2201.12257

<u>Key parameters:</u>
intense neutrino flux: Φ=2.3 x 10^13 ν/s/cm²
ultra low energy threshold: ~200 $eV_{ee}$
ultra low bkg in ROI: O(10) cts/d/kg

- full background decomposition
- reactor thermal power correlated neutrons negligible inside CONUS shield
- precise quenching measurement in Ge at 88 K:
  - validity of Lindhard confirmed in (0.4-6.3) $keV_{nr}$
  - quenching factor k=0.162+-0.04 (stat. + syst.)

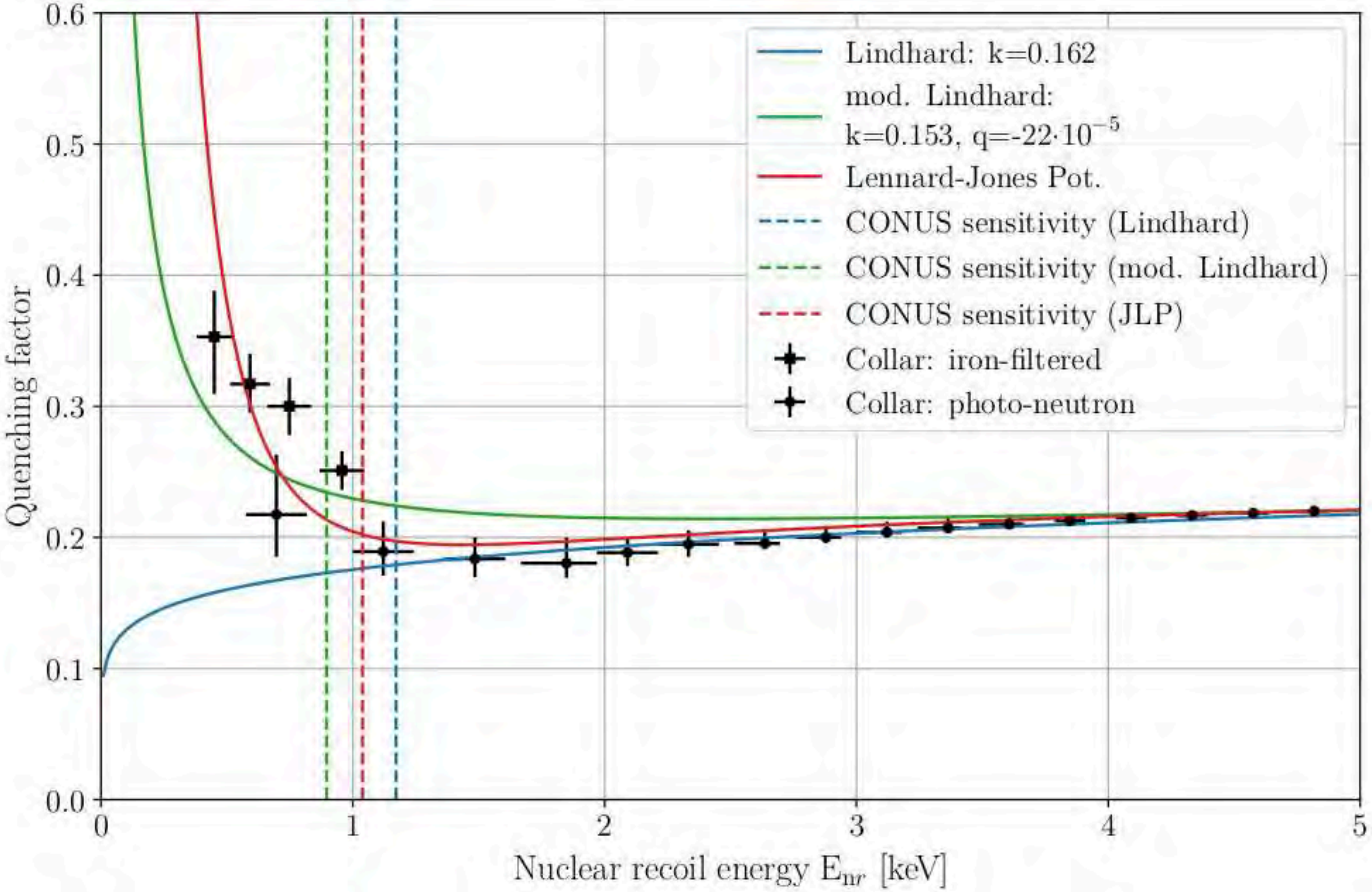


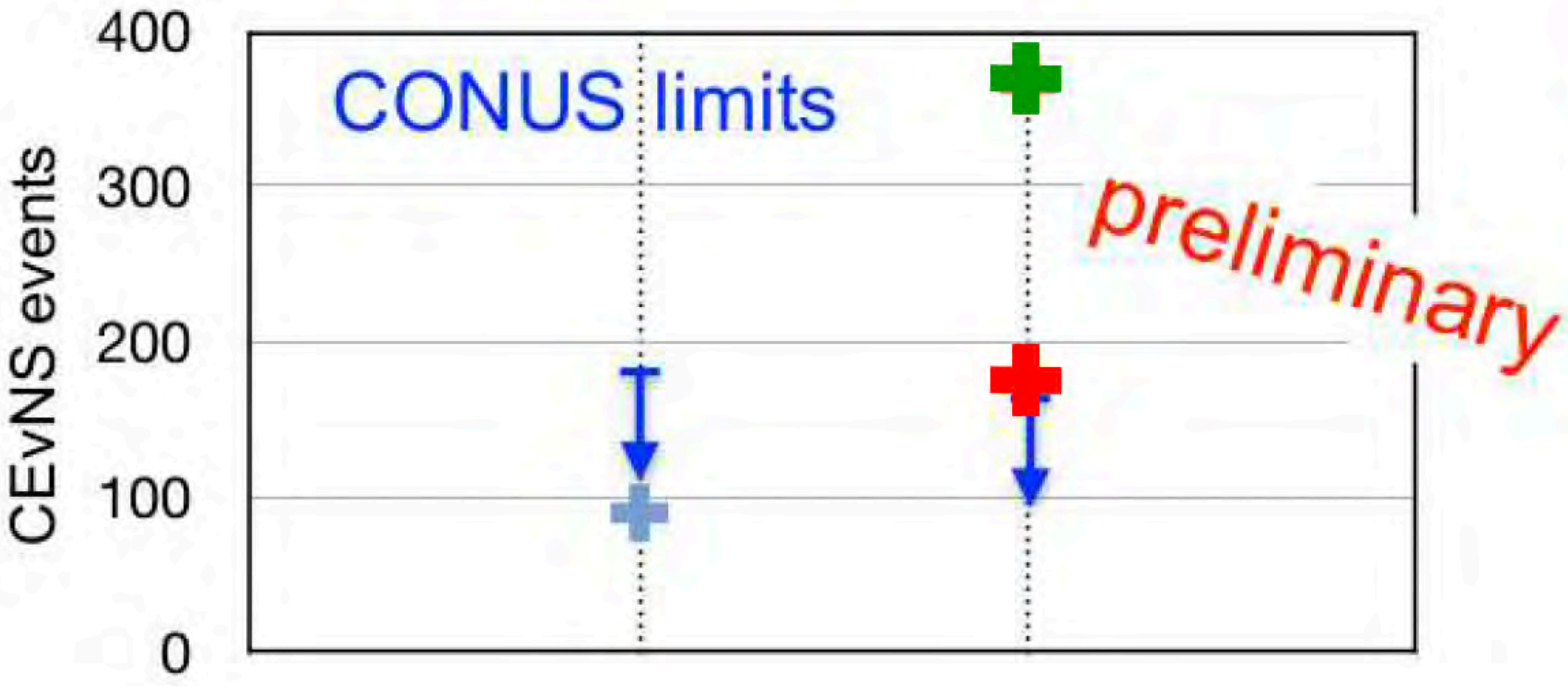

- competitive constraints on BSM models
- new limit on CEvNS signal from reactor neutrinos:
  **factor ~2 (90% C.L.) above SM prediction assuming Lindhard theory with k=0.162**



# CONUS and Dresden-II

*Test NCC-1701 signal with CONUS data*




**green**/**red** cross:
2 parametrisations Lindhard+Migdal like measured in Phys. Rev. D 103, 122003 (2021)

**blue** cross:
Lindhard, k=0.162
CONUS meas.

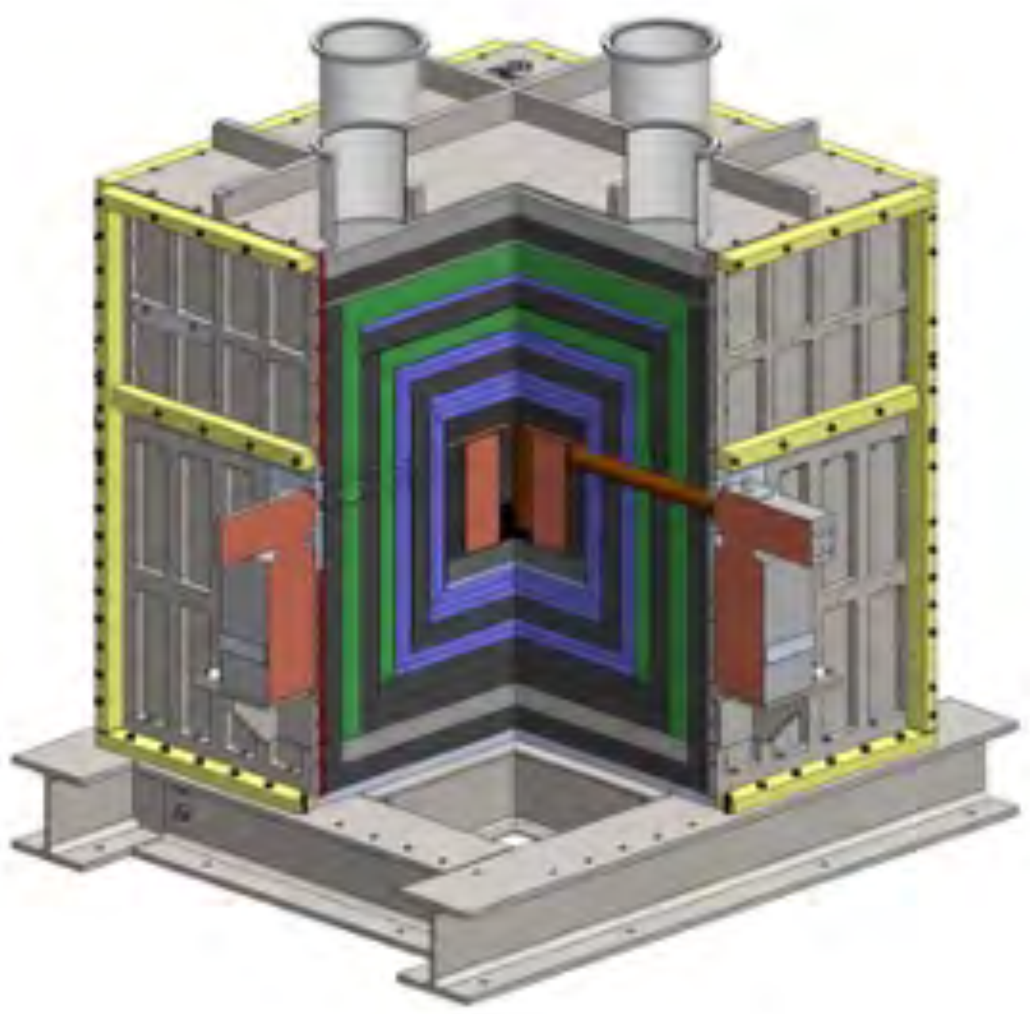
# CONUS+

CONUS+ will be installed KKL power plant during summer 2023.

4 upgraded x 1kg Ge detectors @ 21 m distance from a 3.6 $GW_{th}$ reactor core center

**Key parameters:**
intense neutrino flux: $\Phi$=1.5 x 10^13 v/s/cm²
ultra low energy threshold: <200 $eV_{ee}$

- Full background characterization of detector location:
- Gamma background with HPGe detector. Contribution over 2.7 MeV → 25 times smaller than in KBR.
- Neutron background measured with Bonner Sphere array. Neutron flux 30 times larger than in KBR. Correlated with thermal power.
- Cosmic muons measured with liquid scintillator detector. 4 times larger than in KBR → overburden on 6 m.w.e.
- Radon level 200 Bq/cm3 → radon filtering system for detector chamber flushing.

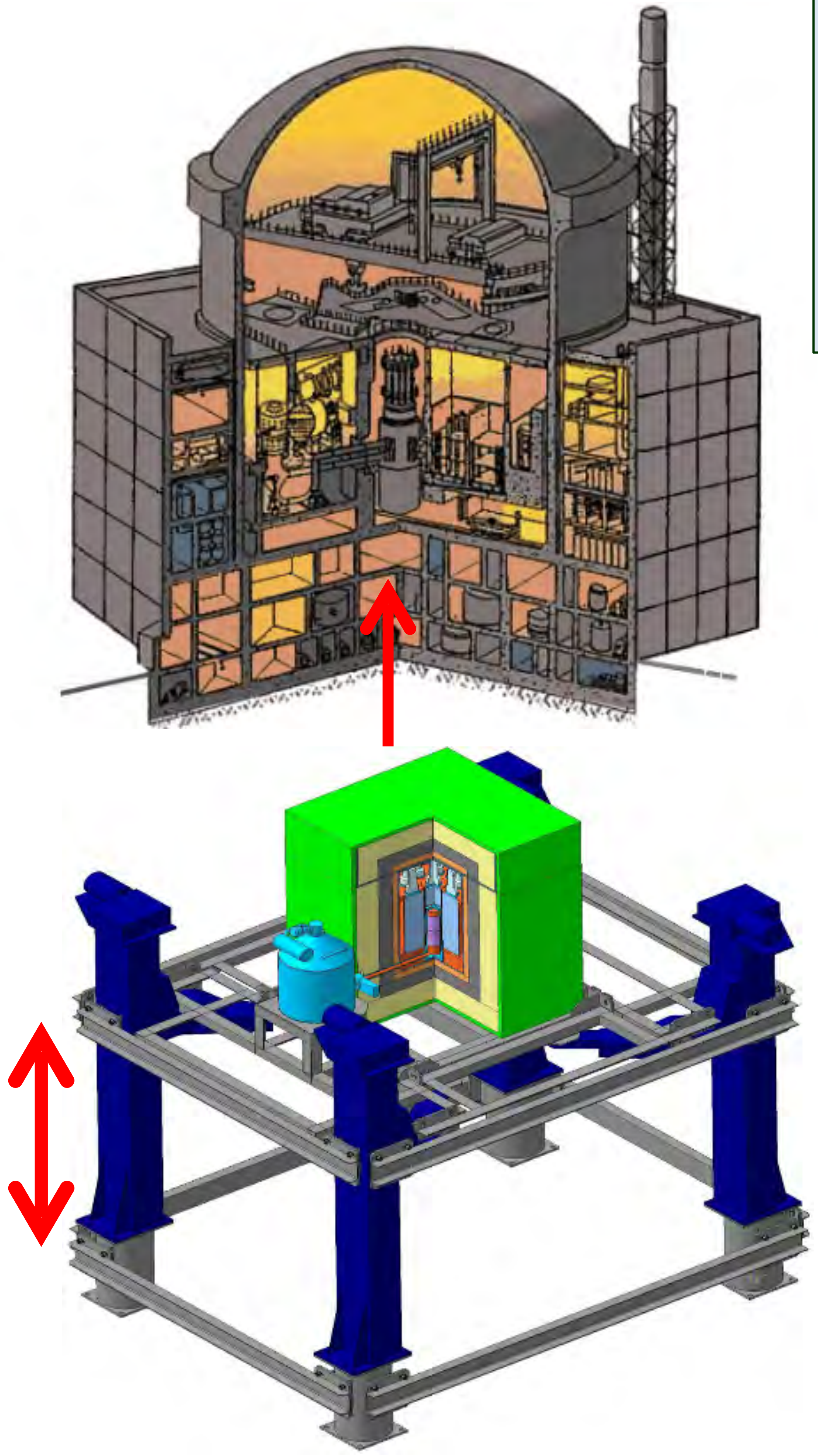


- - CONUS shield modified to include additional second muon veto.
- - CONUS Ge detectors upgraded. Energy resolution and threshold improved.

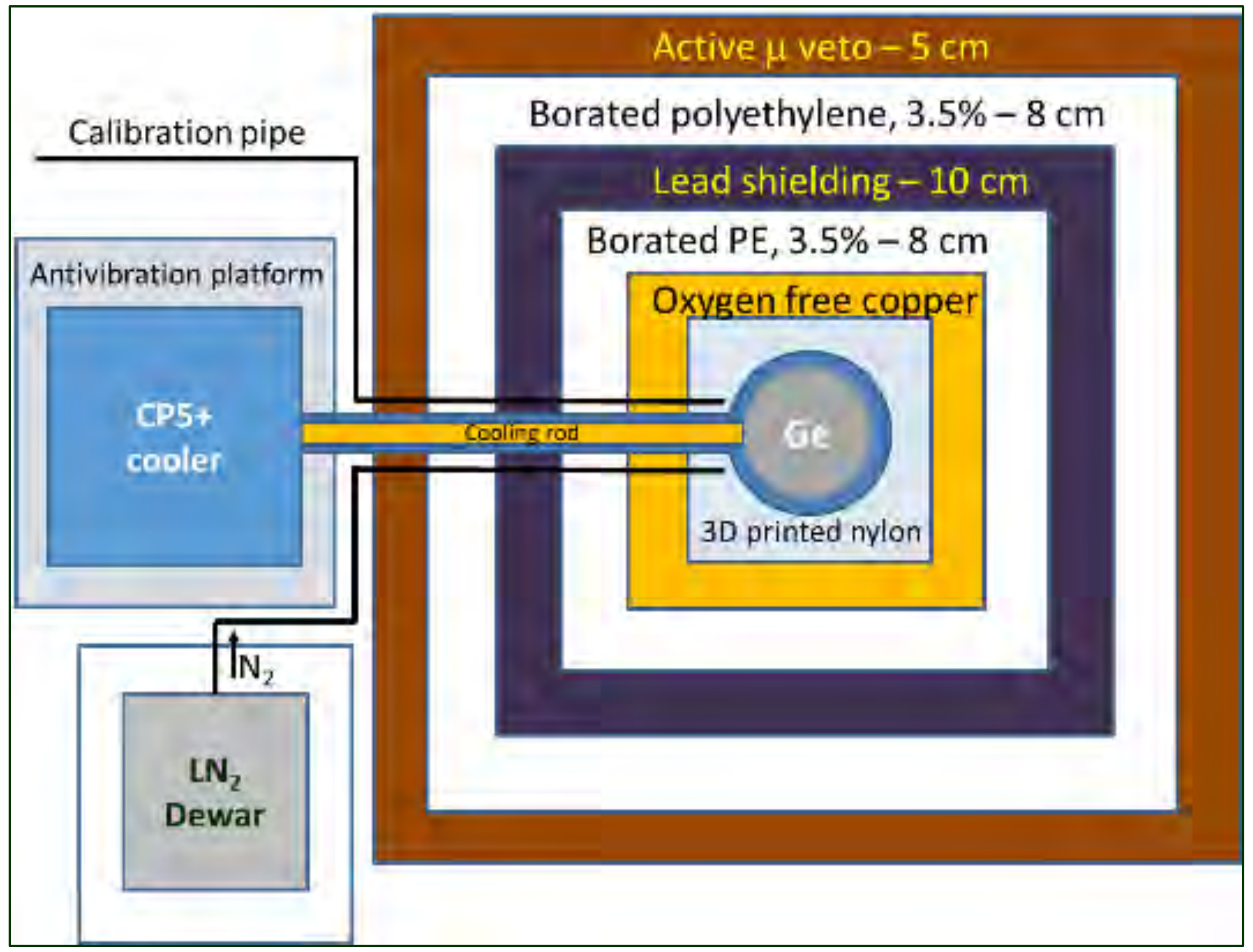
$$\nu_{\mathrm{GeN}}$$

# νGeN experiment at Kalinin nuclear power plant

- ✓ The νGeN project studies neutrino scattering at Kalinin Nuclear Power Plant (KNPP, Russia). Main interests: **coherent elastic neutrino-nucleus scattering (CEνNS)**, the search for the **magnetic moment of neutrino (MMN)**, search for New Physics beyond the SM, and many other applications, including reactor monitoring.
- ✓ The experimental setup is constructed under reactor unit #3 of KNPP at a distance of **11.1-12.5 m** from the center of the **3.1 $GW_{th}$** core under enormous antineutrino flux **$(4.4\text{-}3.6)\times10^{13}$ ν/cm²/s** at **~50 m w.e.** overburden. The low-threshold HP Ge detector with a mass of 1.4 kg is used to detect desired signals.



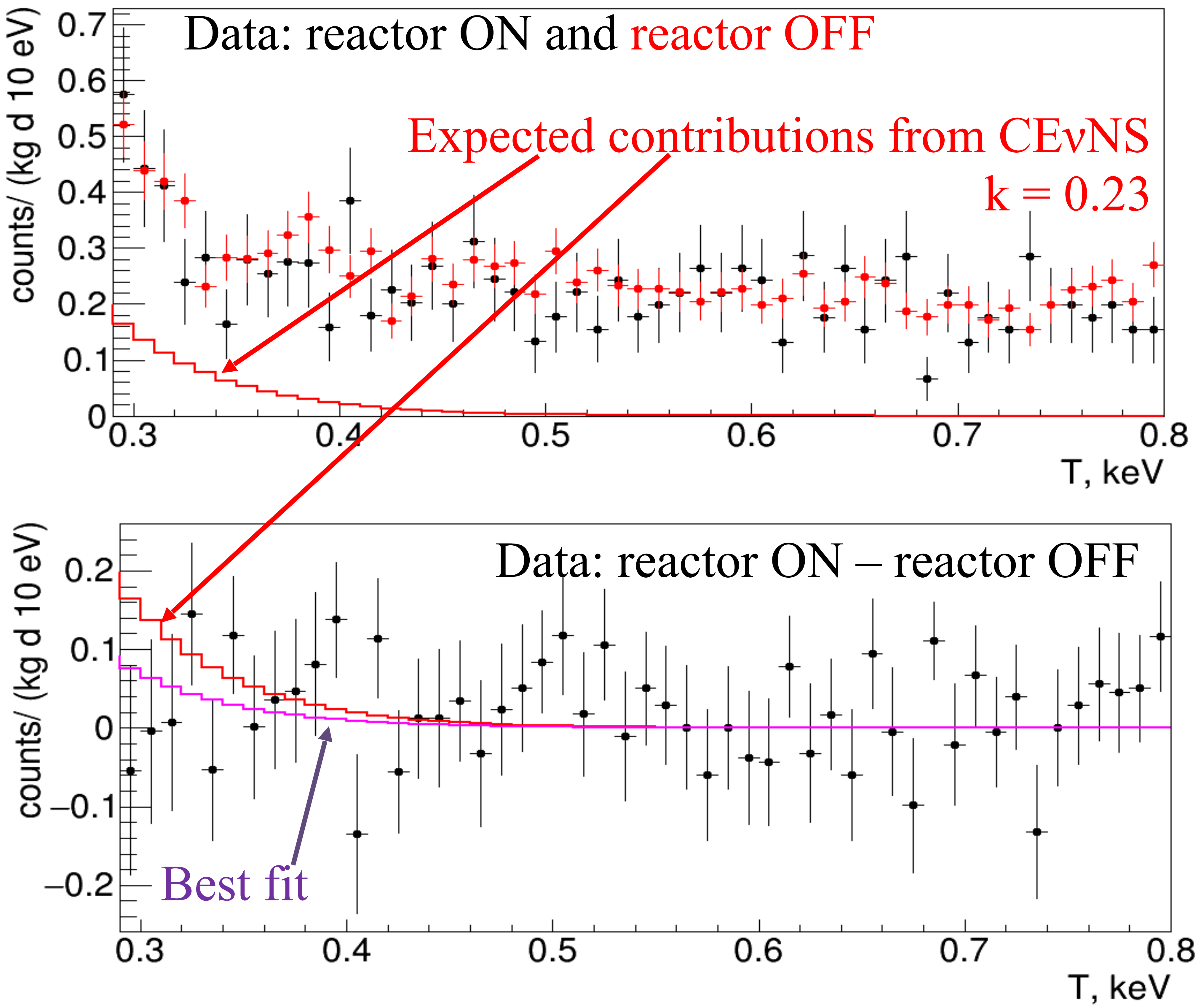
- ✓ The passive and active shielding covers detectors from all sides suppressing backgrounds.
- ✓ Active antivibration platform suppresses microphonic noises.
- ✓ Nitrogen flushing decrease background from radon.
- ✓ Movable platform allows to change the distance to the reactor, thus changing the ν flux.
- ✓ Special acquisition system was developed to suppress noise and achieve energy resolution of 101.6(5) eV (FWHM).

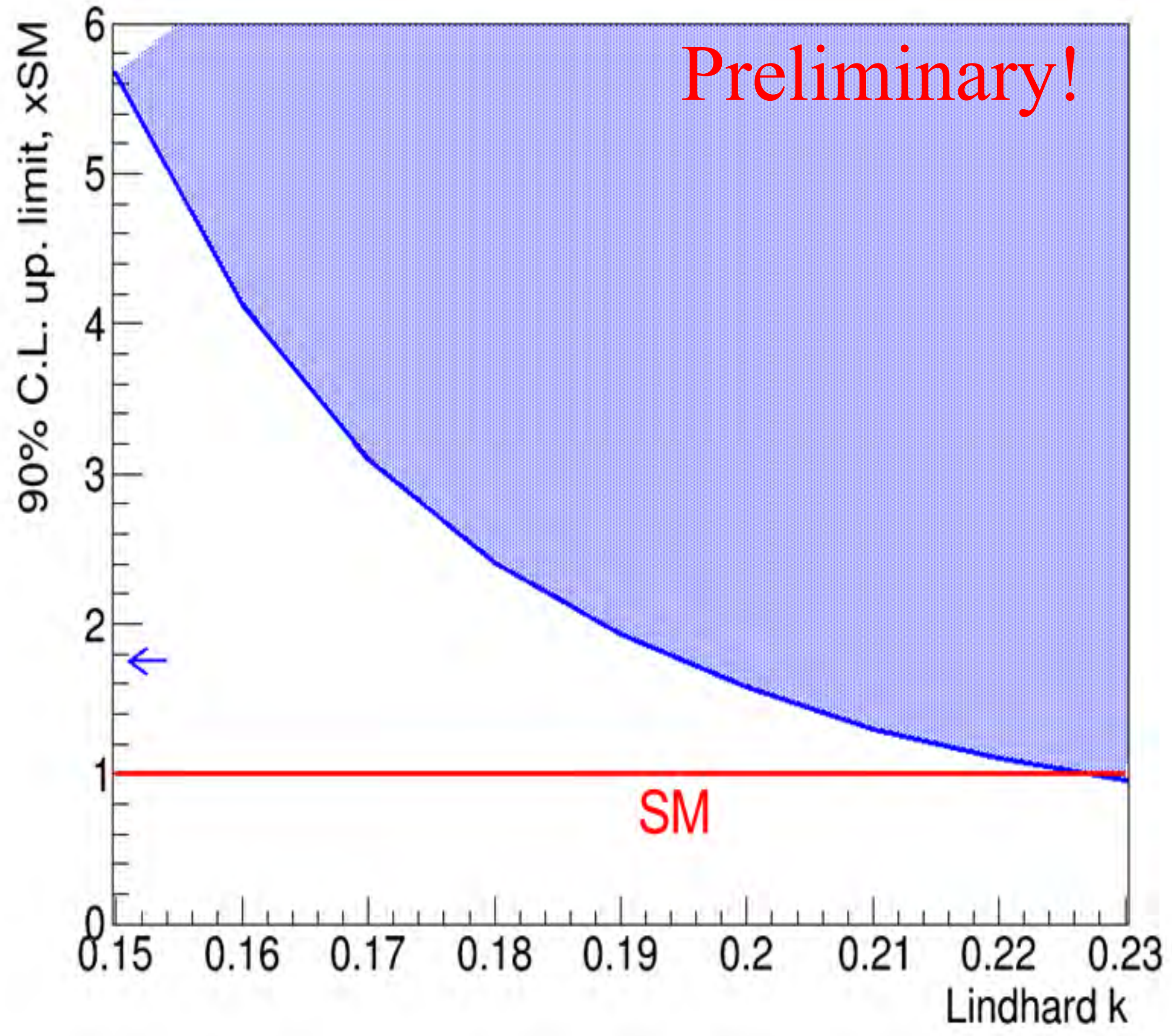


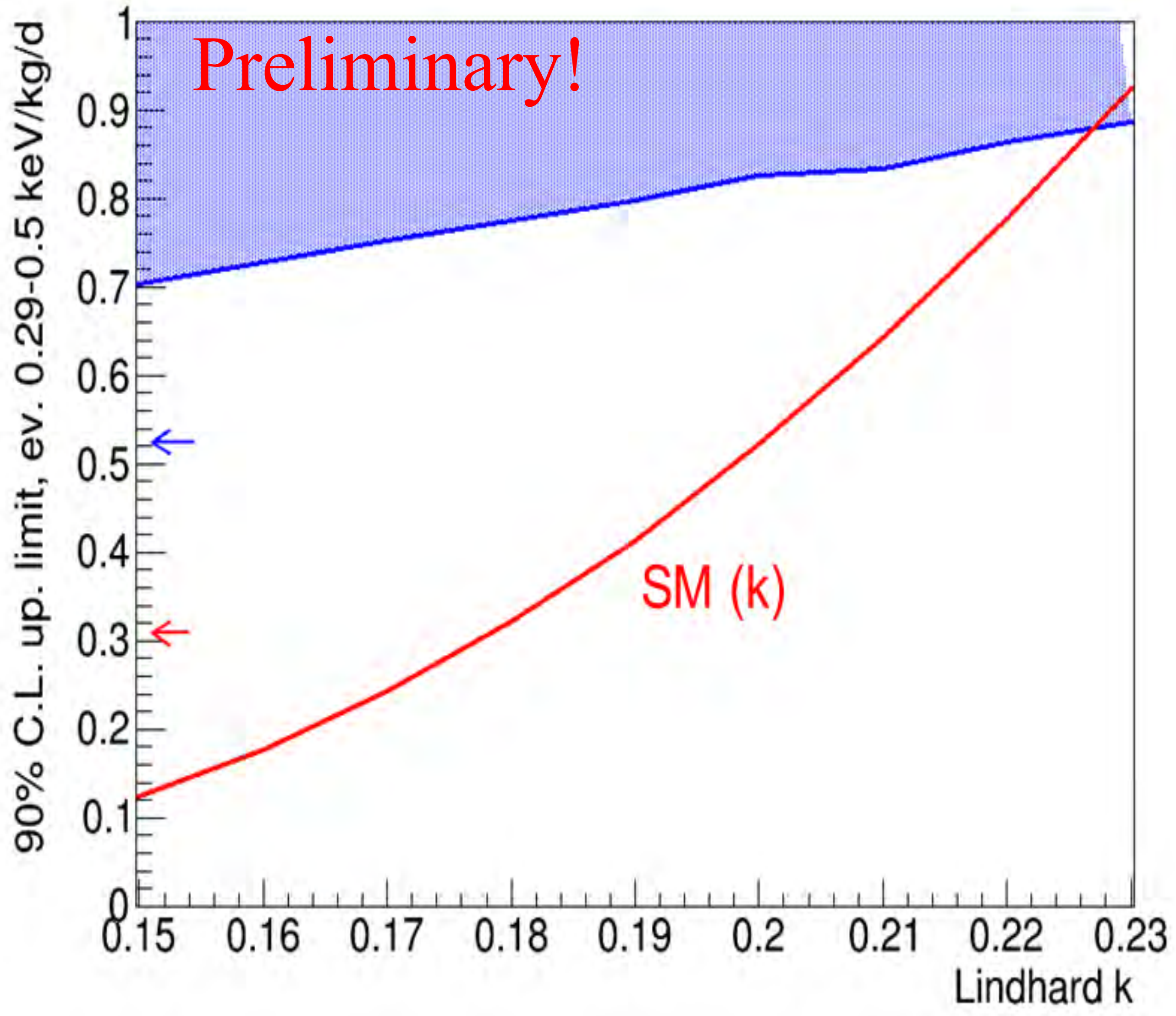

**Alekseev et al.,Phys. Rev. D 106, L051101 (2022)**

# νGeN experiment at Kalinin nuclear power plant

- ✓ No significant difference between regimes with reactor ON and OFF has been observed in first data taken in 2021. The limit on the quenching parameter in germanium has been obtained (k<0.26).
- ✓ Later measurements at a closer distance from the reactor (**11.1 m** instead of **12.2 m**) with higher flux started in September 2022. No difference in BI between regimes with reactor ON and OFF was found as well. A preliminary limit on the quenching parameter **k<0.23** was obtained with 154 days ON and 39 days OFF statistics.
- ✓ We continued data taking, and so far we accumulated more than **1600 kgd** raw data.



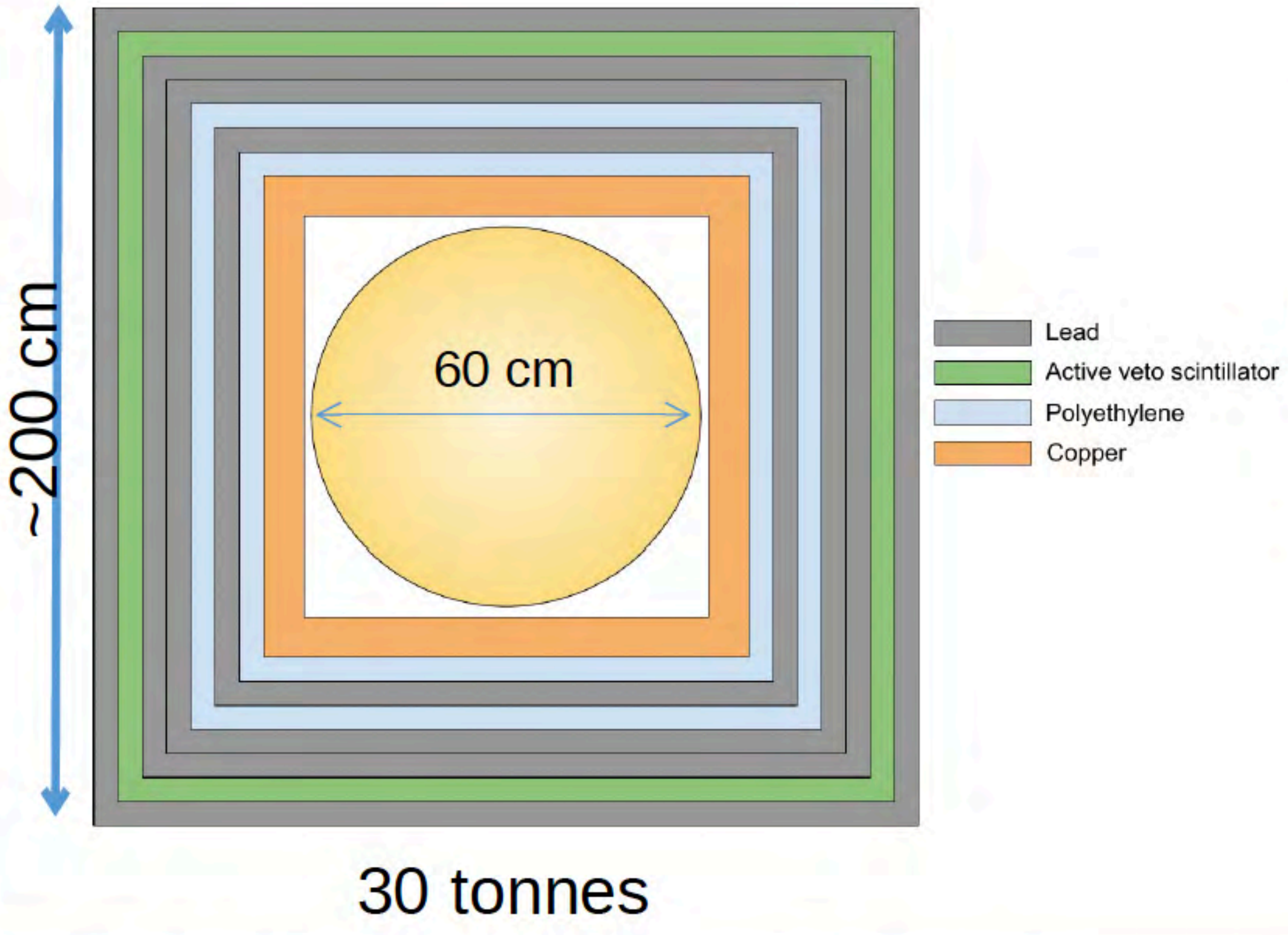

- ✓ New results with more statistics and optimized measurement modes are expected soon. Search for evidence of other effects in data are ongoing.
- ✓ Some improvements are done or planned: additional muon vetoes, the internal shielding and new better detectors to improve sensitivity of experiment.

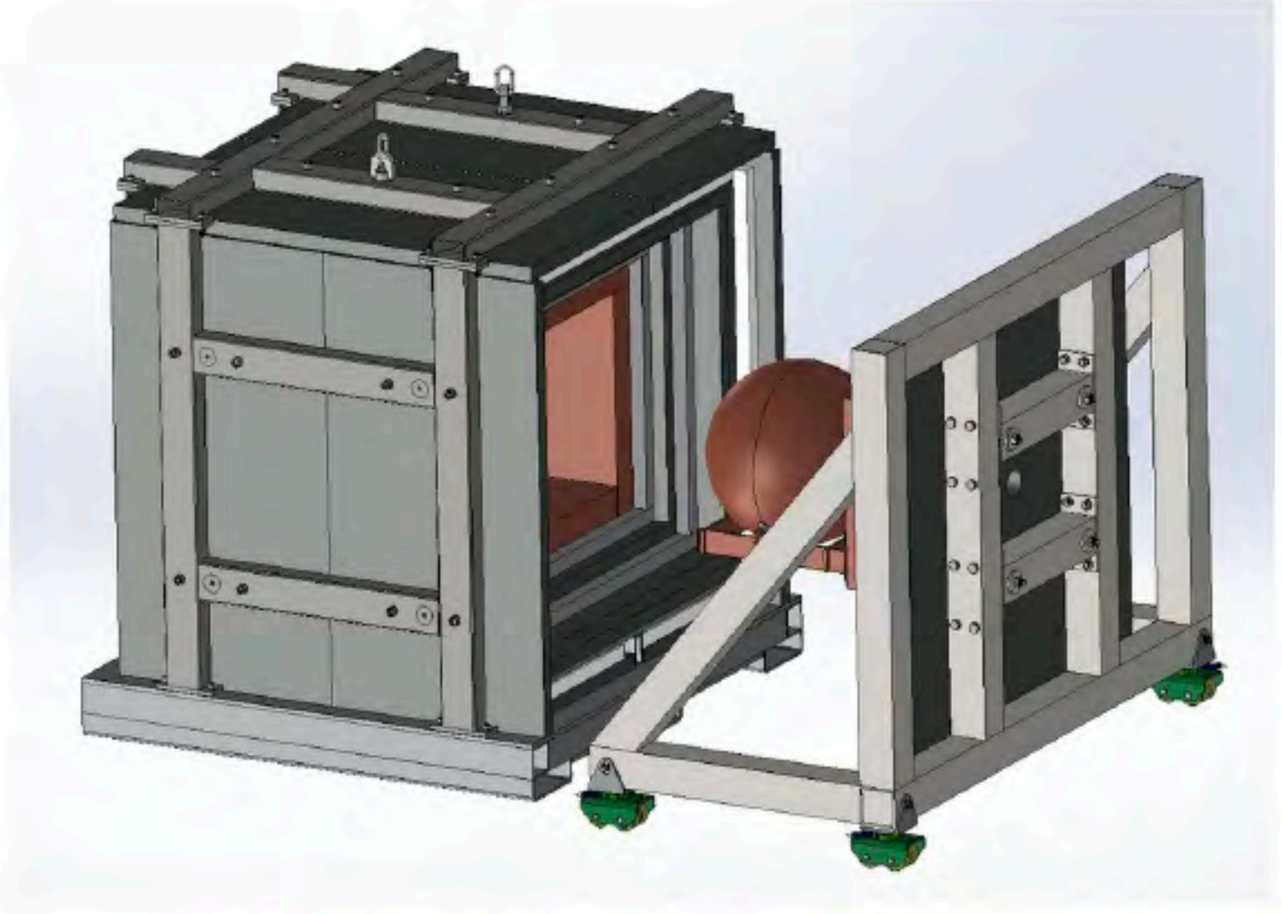
# NEWS-G3

# The NEWS-G3 detector

### Compact Shield

- Lead
- Active muon veto
- Polyethylene
- Copper



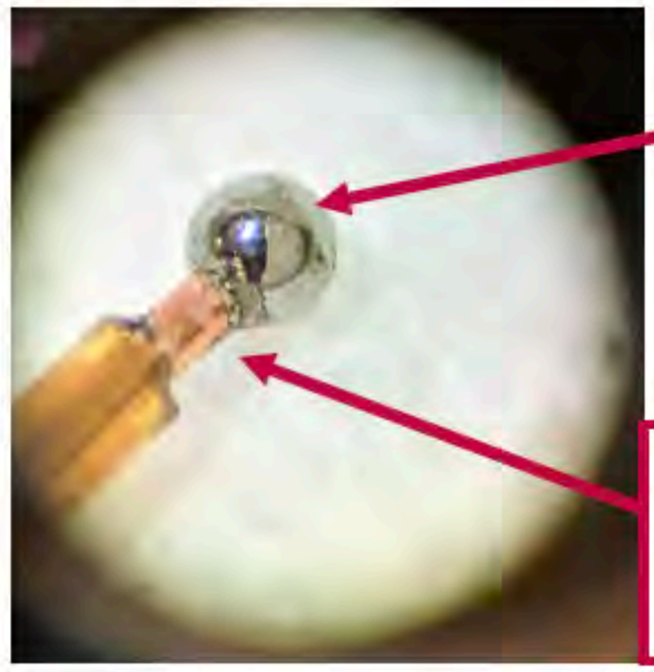



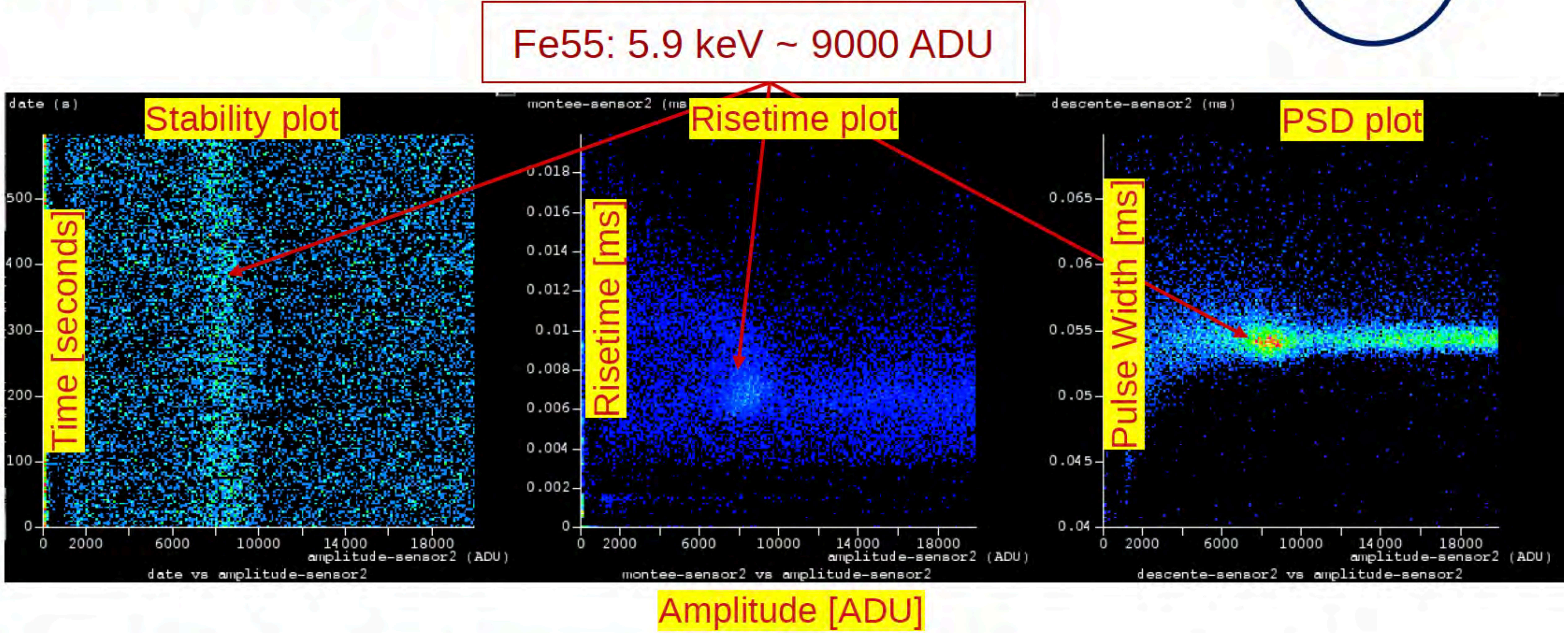

### SPC (Spherical Proportional Counter)

- $\Phi = 60$ cm
- Aiming for 20 bar pressure
- Candidate detector materials: copper (C10100), stainless steel
- Candidate gas targets: Ar, Ne, Xe

Queen's UNIVERSITY

# First successful detector operation at 10 bar



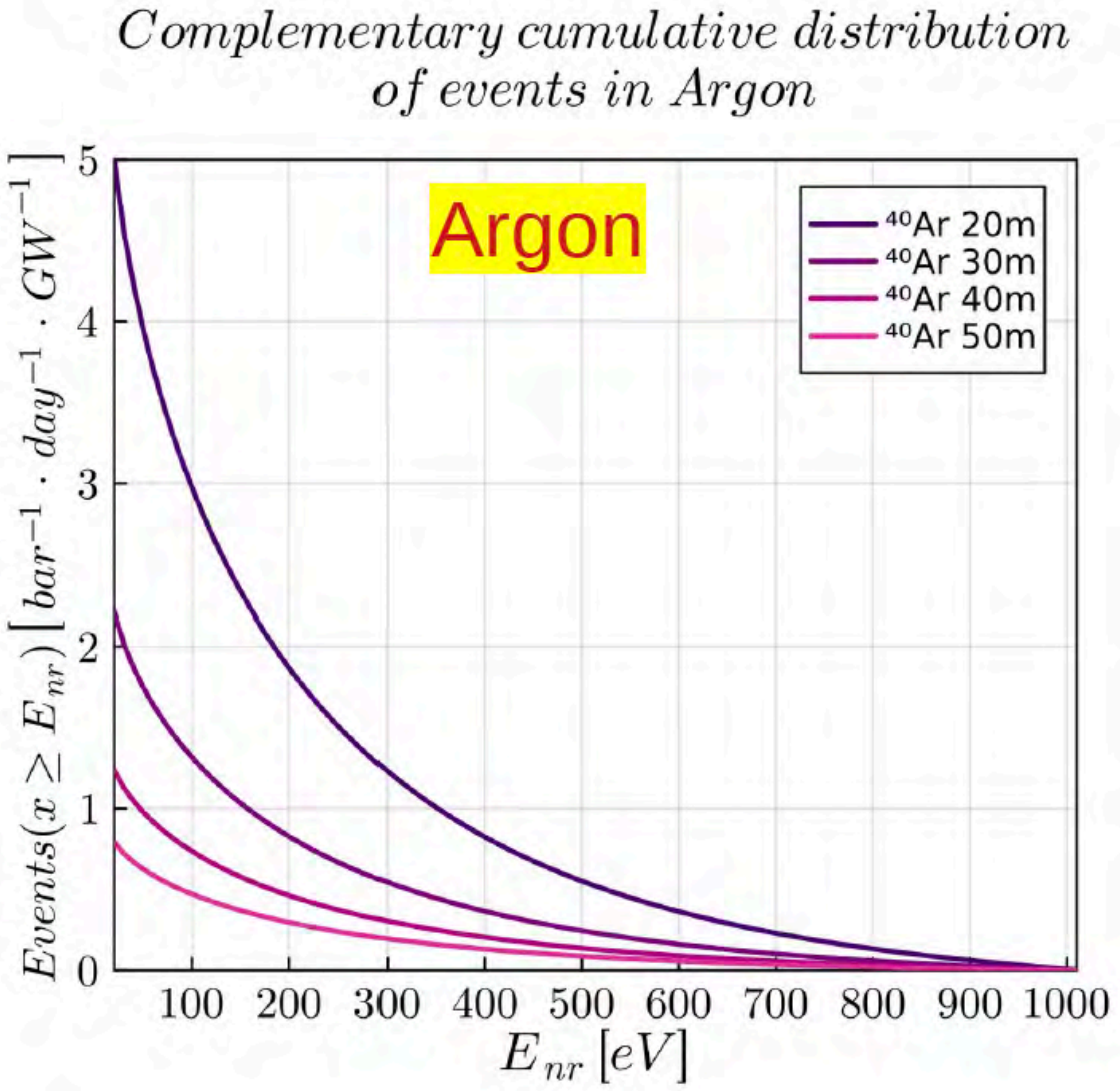

**Calibration Conditions**

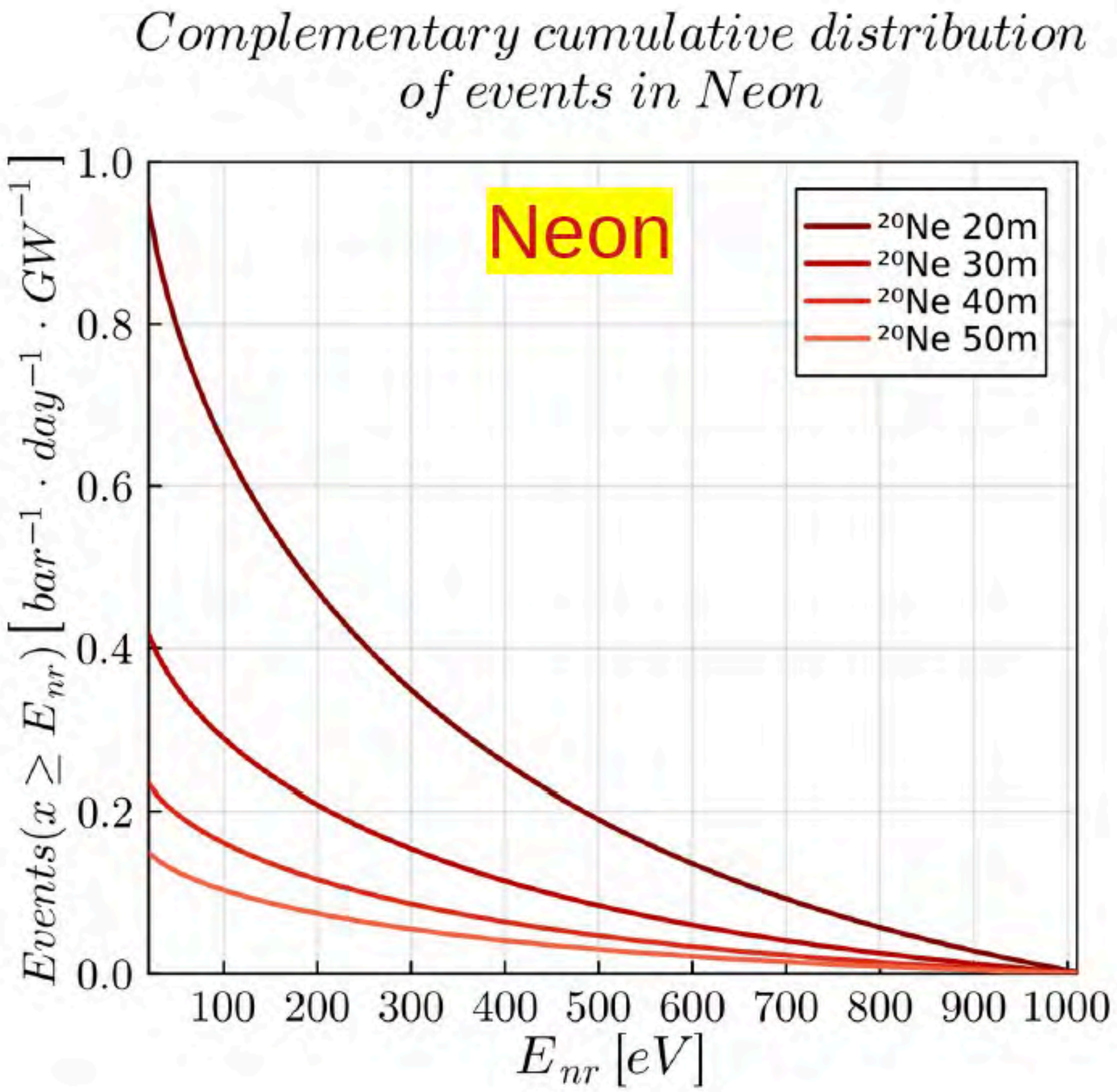
- 0.5 mm anode
- Pressure = 10 bar
- Gas = Ar+2%CH4
- HV = 4920 V

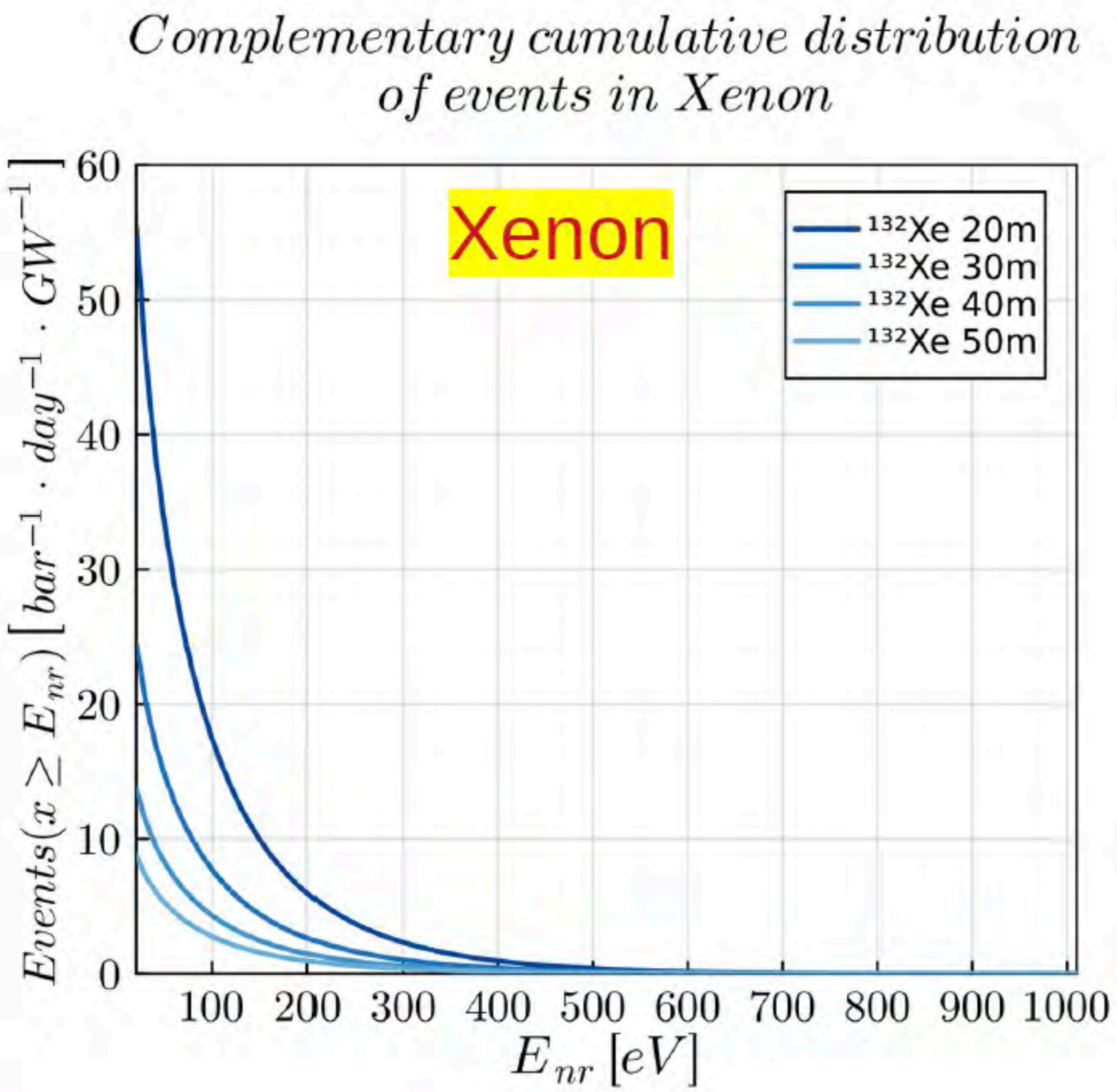
- First successful operation at 10 bar
- No sparks, no instabilities

# Expected number of CEvNS events in at various detector-reactor distances for three candidate gas targets

- In all cases, 60cm diameter detector is considered



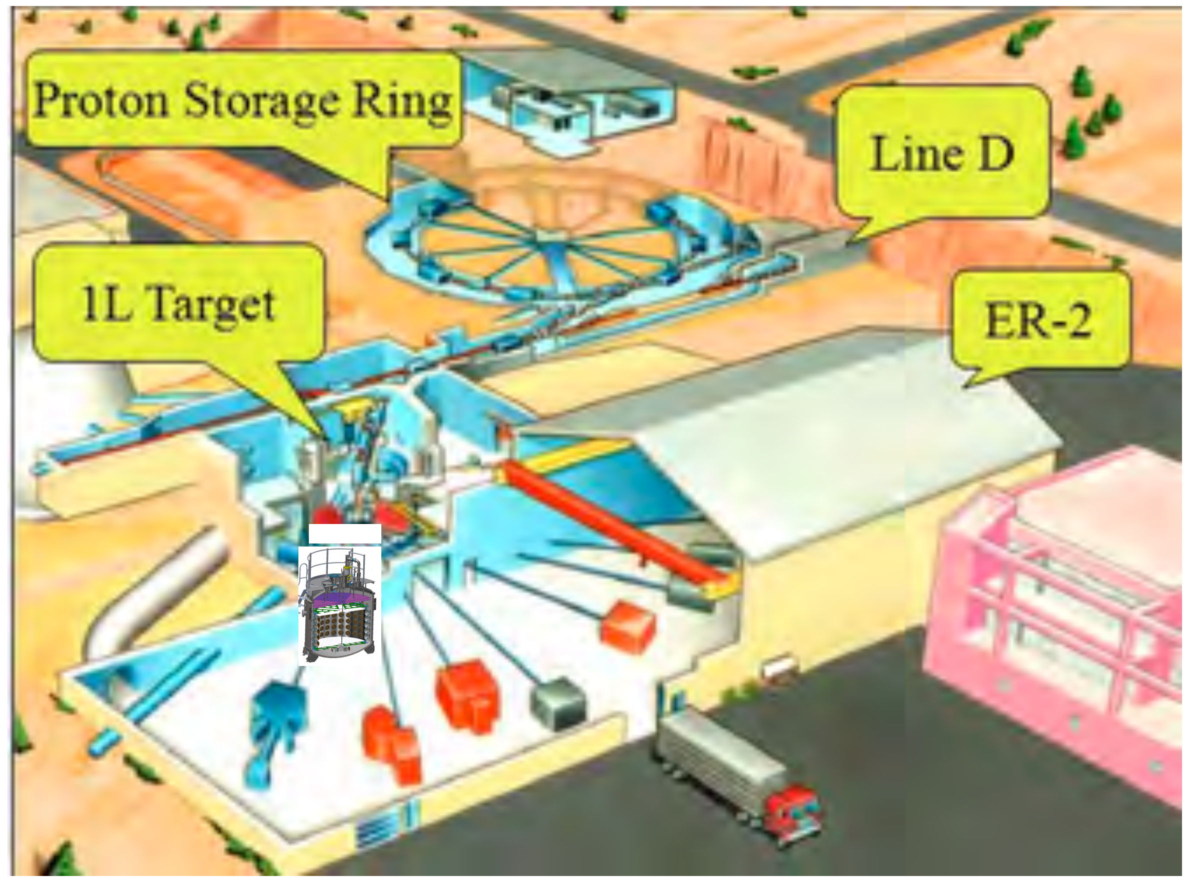



# CCM (Coherent CAPTAIN-Mills)

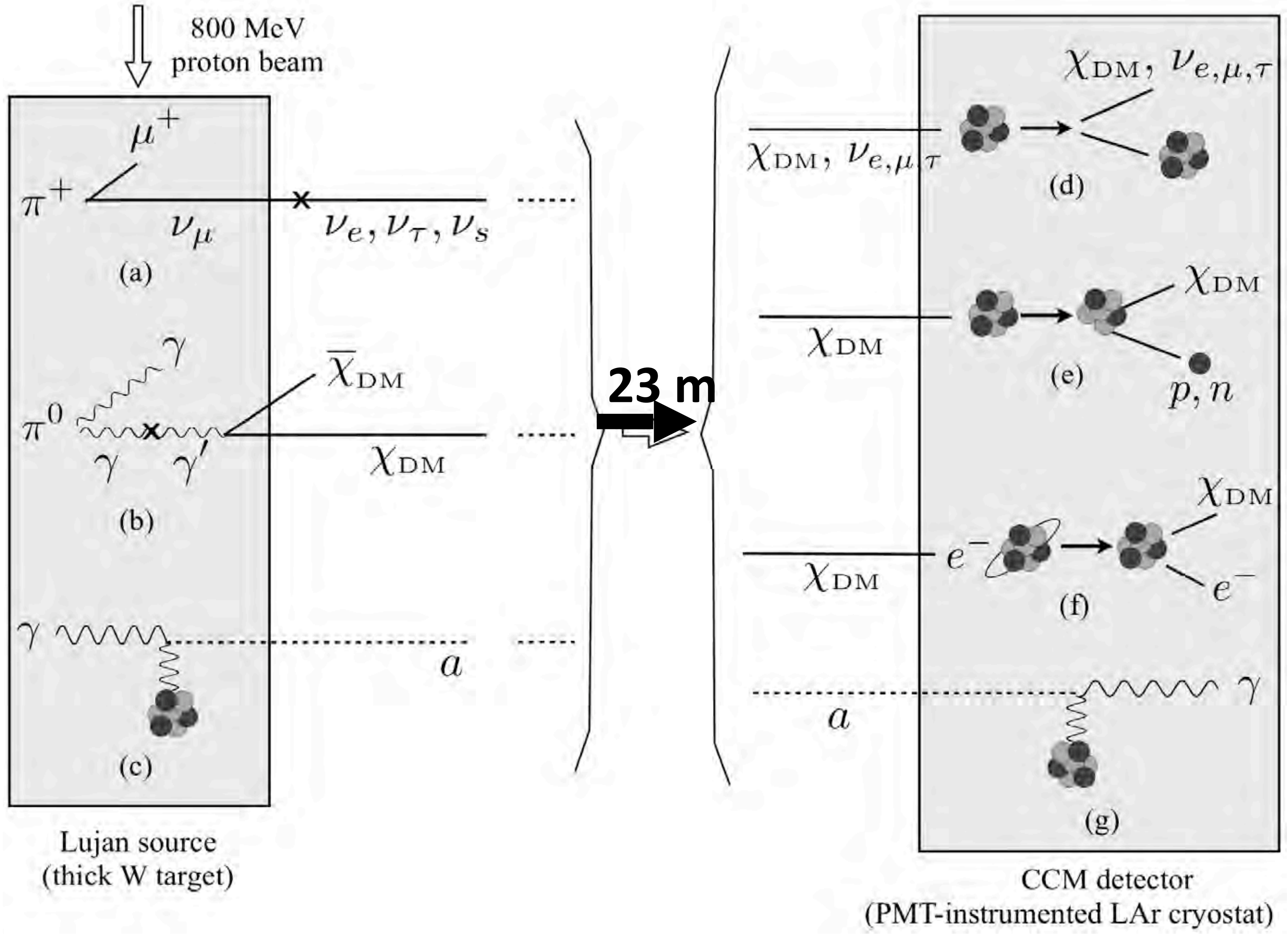
# Impactful Neutrino Physics and Dark Sector Searches at LANSCE with the Coherent CAPTAIN-Mills (CCM) Experiment

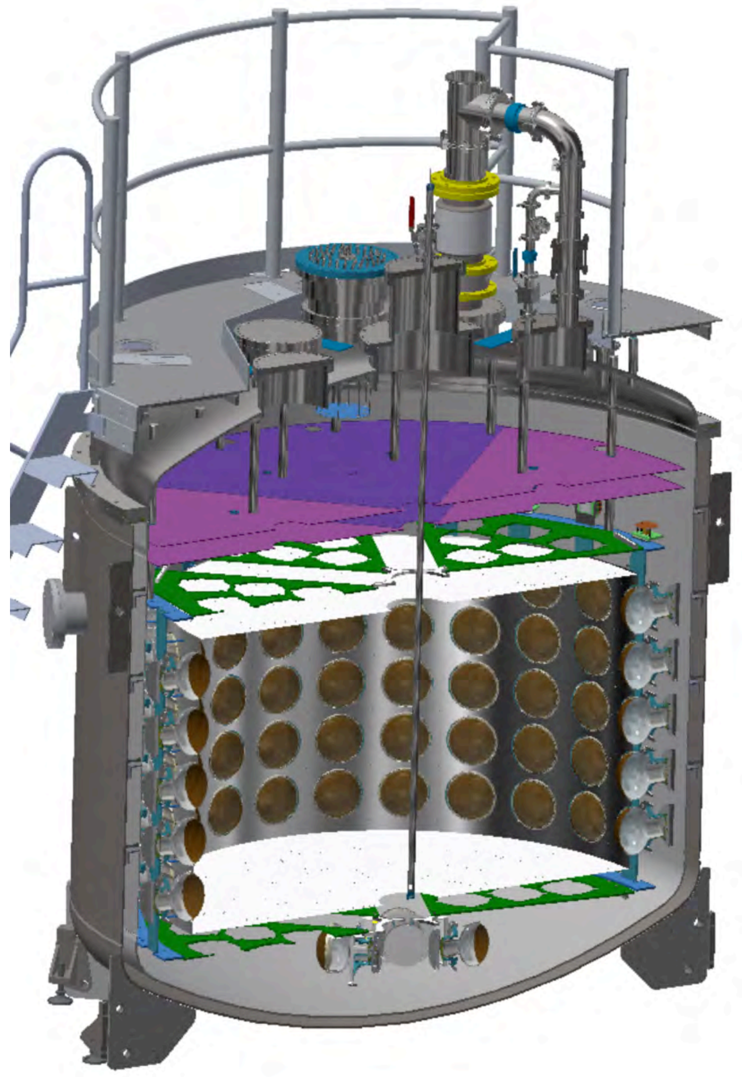
(LANL, FNAL, Columbia, MIT, TAMU, UNM, UFlorida, ERAU, UNAM-Mexico, Edinburgh-UK)

**800 MeV protons, 100kW, 285 nsec pulsed beam**




**LANSCE-PSR-Lujan Target:** Prolific source of charged/neutral pion and photons that produce neutrinos and potential dark sector particles.



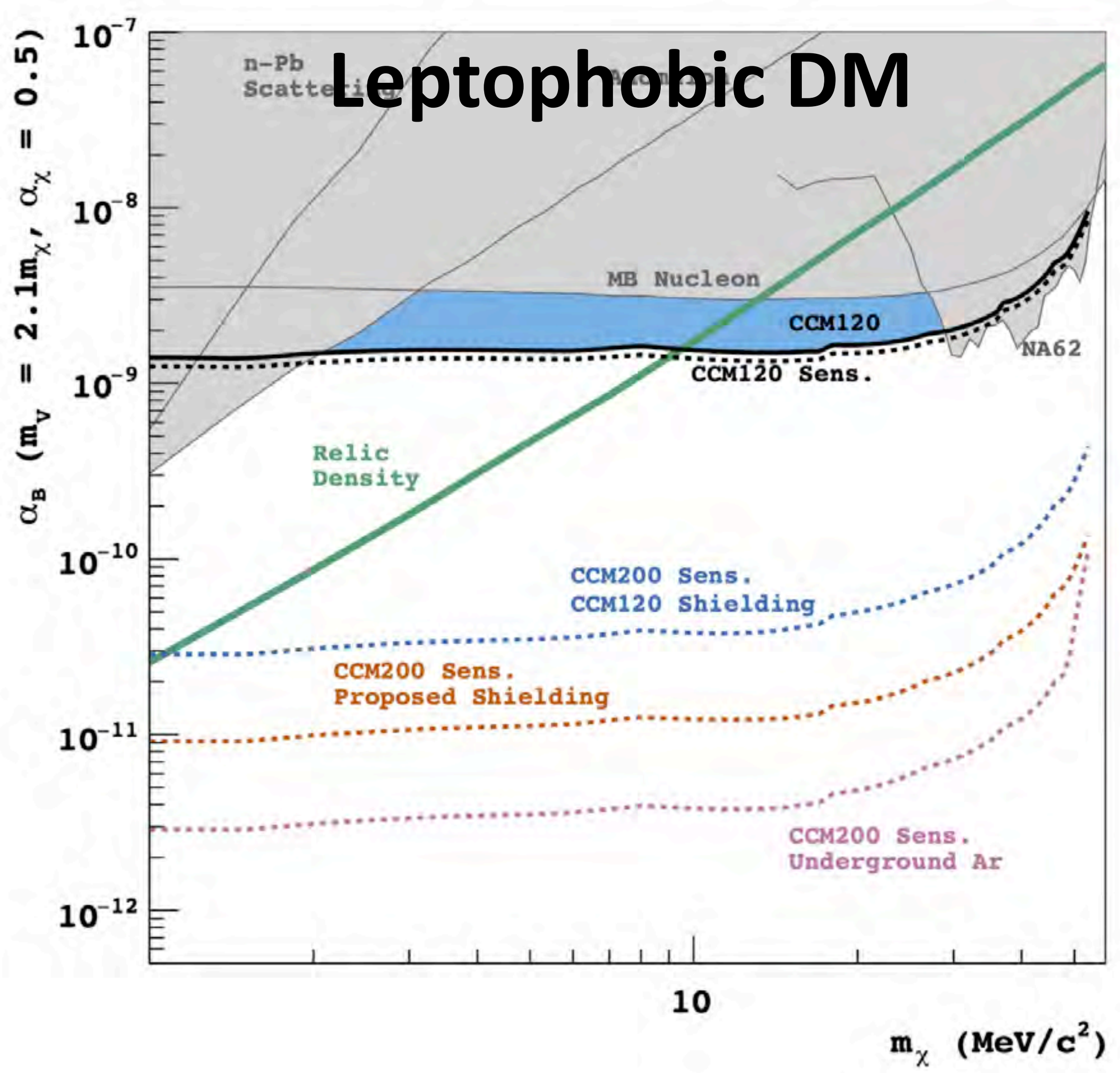



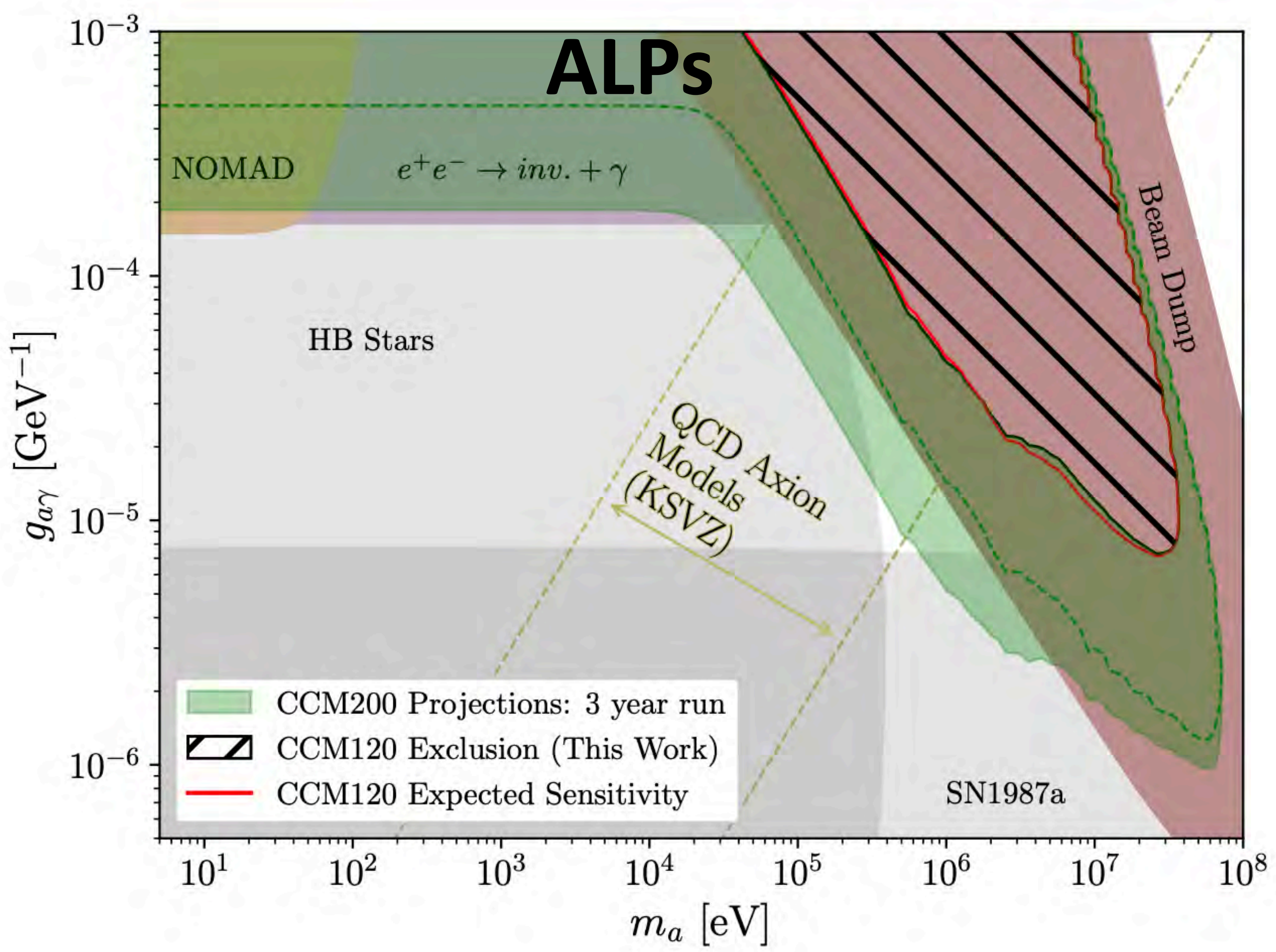
**CCM:** 10-ton Liquid Argon (LAr) scintillation detector instrumented with 200 8" Photo-multiplier tubes, veto region, shielding, fast electronics.

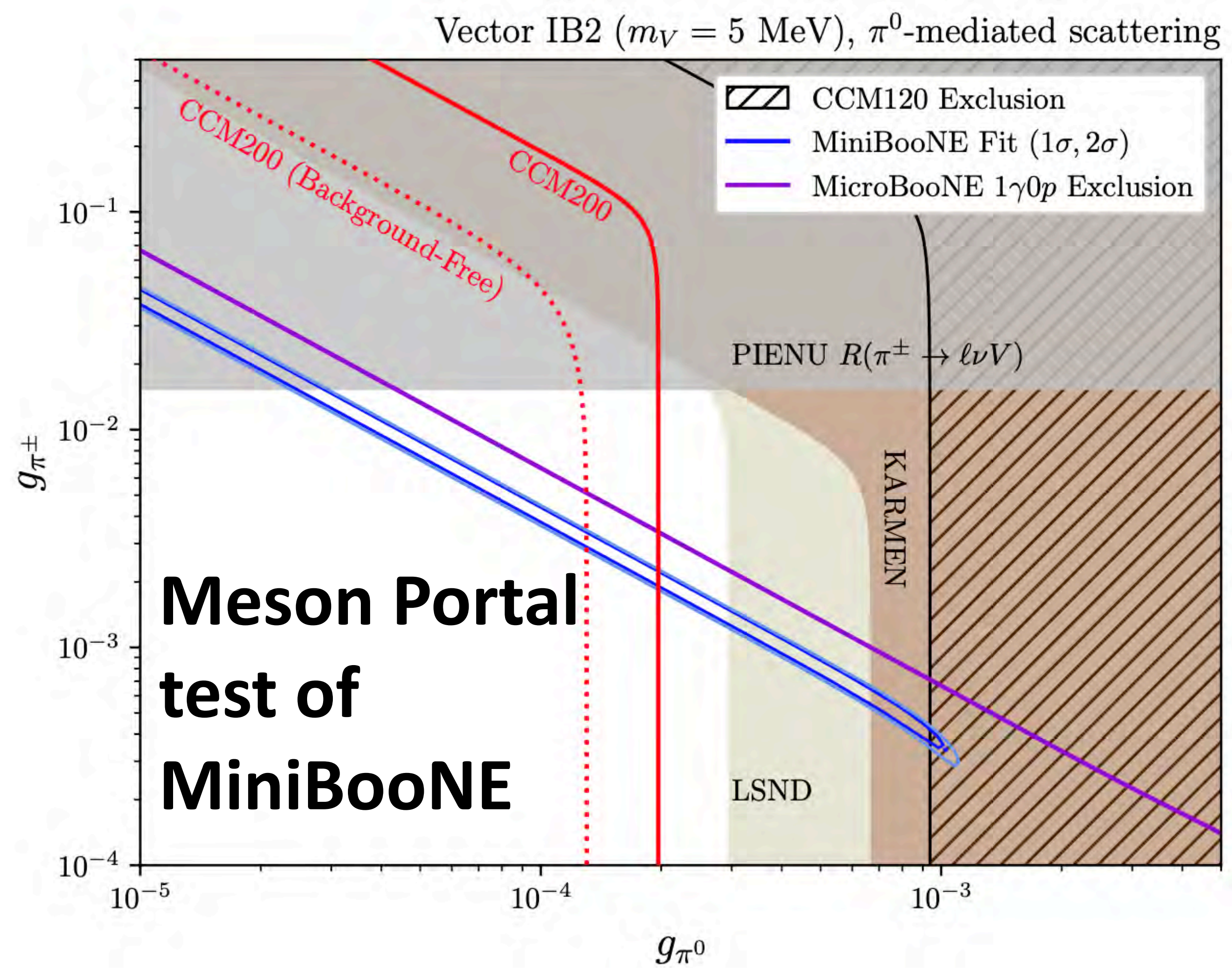
- Successfully built and commissioned CCM detector at Lujan 800 MeV stopped pion source (FY2019-FY2022 LDRD, and HEP-DMNI funding). Have begun HEP funded three-year beam run (2023-25) to collect 20E21 Protons on Target (POT).
- Large energy dynamic range (100 keV to 10 GeV) with fast beam and ~nsec detector response can probe unexplored parameter space for dark matter, axions, and meson portal model test of MiniBooNE. Expect to complete beam run end of 2025 with ~20E21 POT.

# Recent CCM@LANL Highlights Feb 2024

- CCM has three papers published, and one accepted by PRD (based on 2019 CCM120 data - 1.8E21 POT)
  - *Physical Review Letters* Vol. 129, No. 2 (2022), “First Leptophobic Dark Matter Search from Coherent CAPTAIN-Mills“ (51 citations).
  - *Physical Review D* 106, 1, (2022), “First dark matter search results from Coherent CAPTAIN-Mills” (23 citations).
  - *Physical Review D* 107, 9, (2023), “Prospects for Detecting Axionlike Particles at the Coherent CAPTAIN-Mills Experiment” (21 citations).
  - *arXiv:2309.20599* (accepted by PRD) , “Testing Meson Portal Dark Sector Solutions to the MiniBooNE Anomaly at CCM” (1 citation).



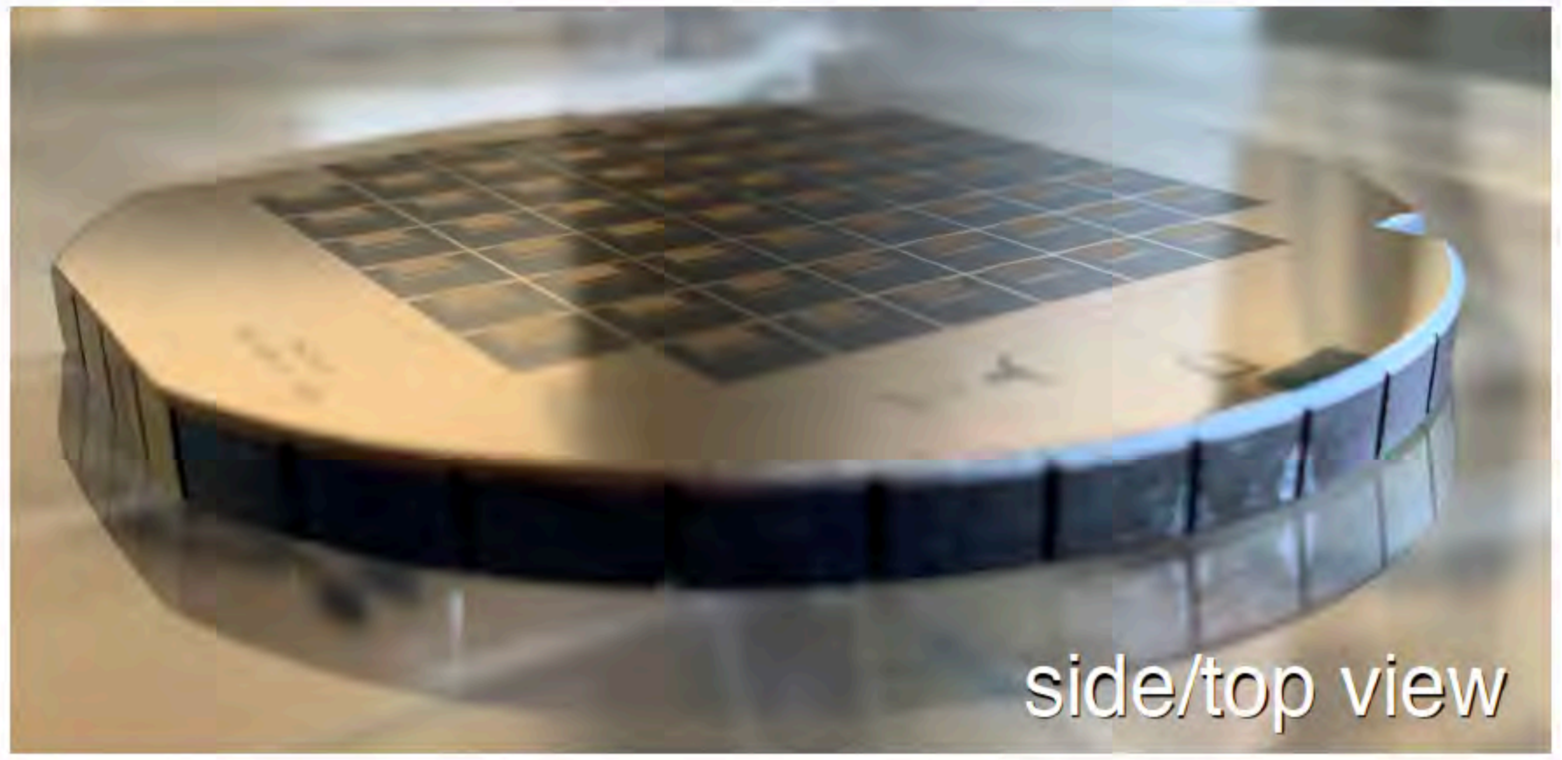

- CCM200 detector is running well and has collected 9E21 POT beam data from 2021-2023. Expect new preliminary results on ALP, DM, and meson portal model test of MiniBooNE by Fall 2024.
- Expect six to eight impactful dark sector publications and >3 Phd thesis based on final data set (20E21 POT).
- Continue collaborating with theorists developing new dark sector models to test. Contemplating follow-on dark sector search beam experiments at LANL and/or FNAL with order magnitude improved reach.

# BULLKID

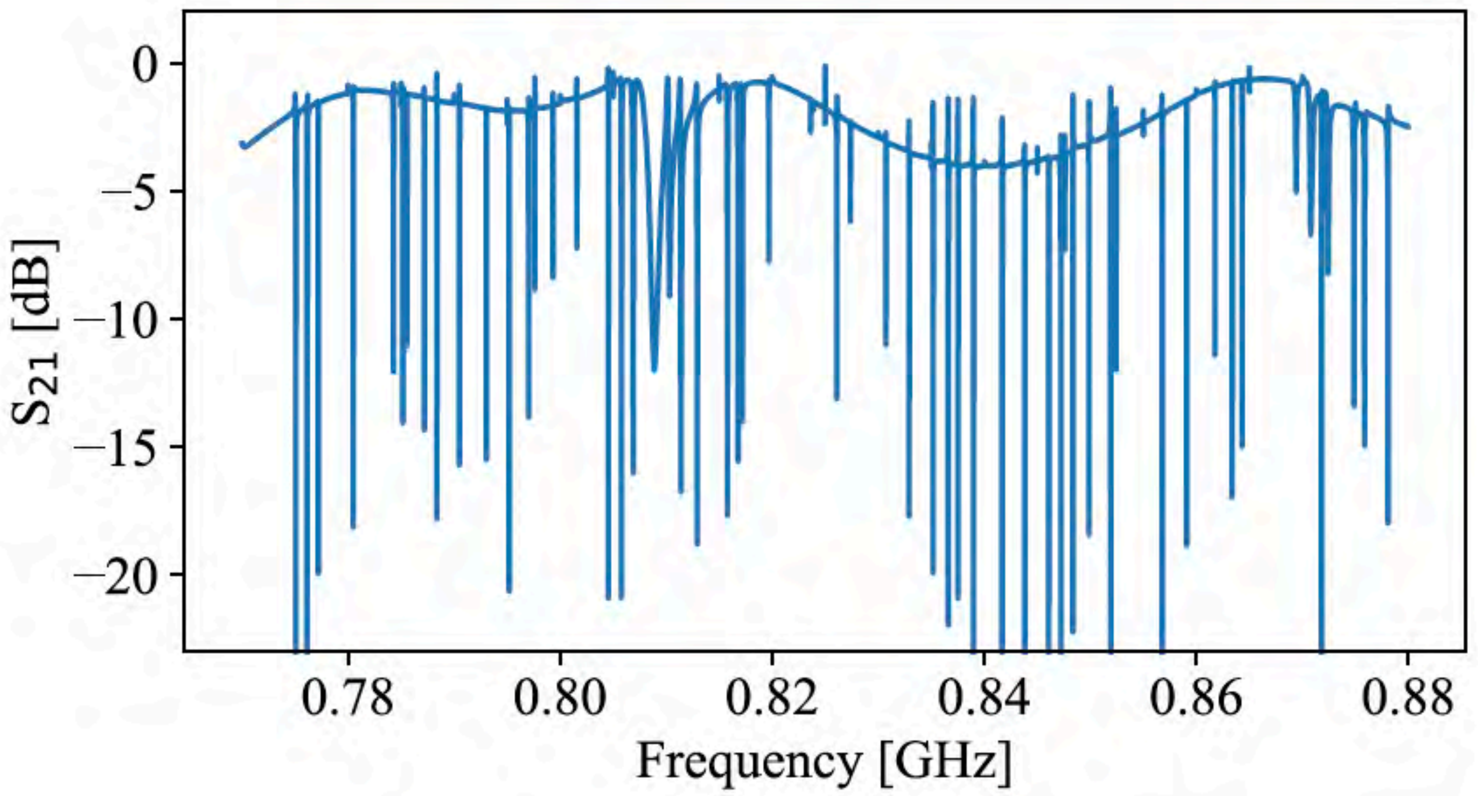
# BULLKID phonon detector array

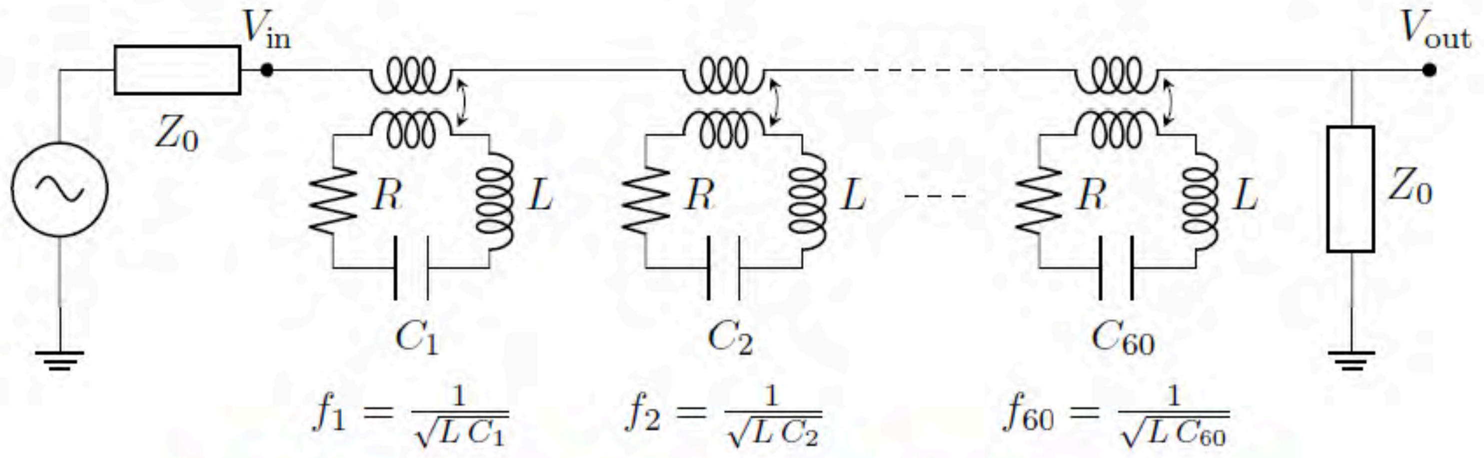
A. Cruciani, et al, Appl. Phys. Lett. 121, 213504 (2022)

D. Delicato et al, Eur. Phys. J. C 84 (2024) 353



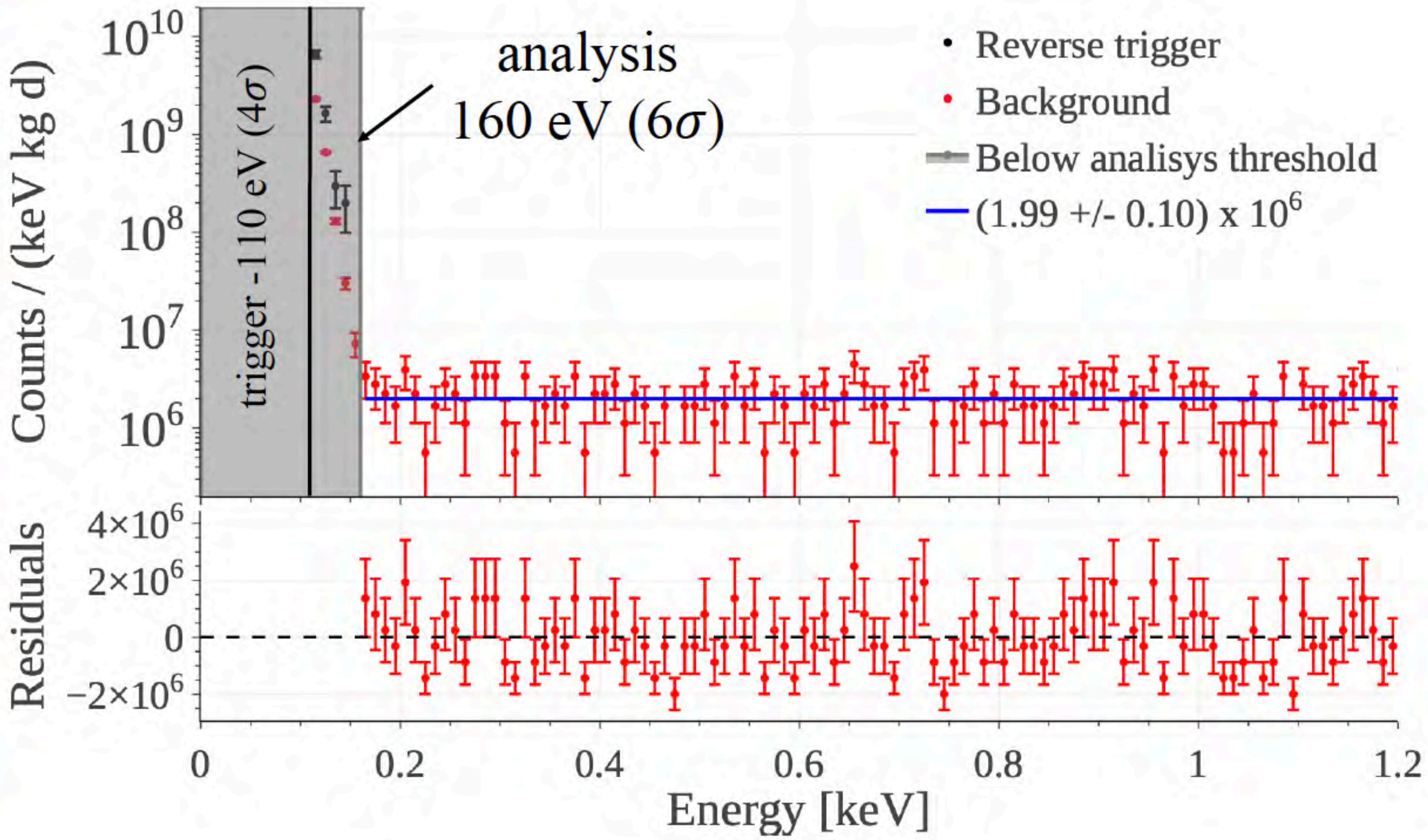

Array of silicon phonon-mediated nuclear recoil detectors sensed by KIDs



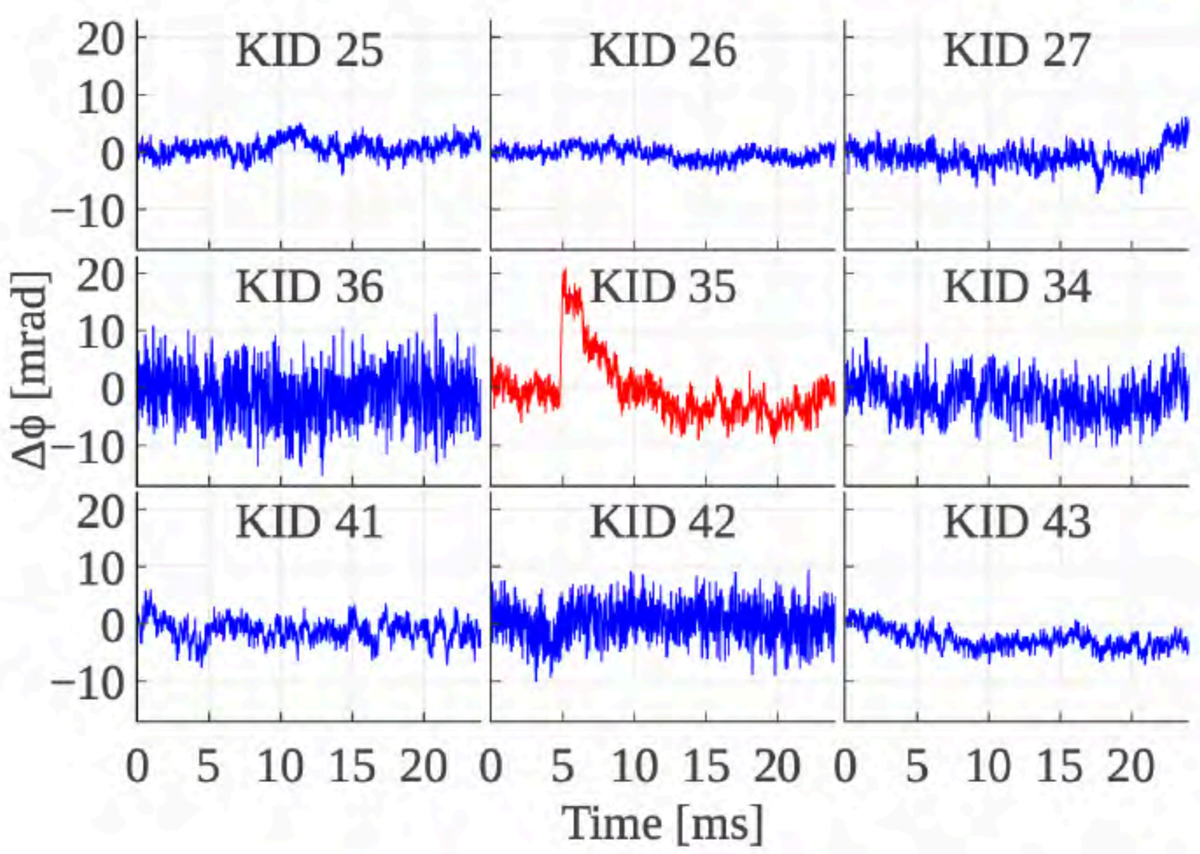




Multiplexed Kinetic Inductance Detectors (KIDs) convert the phonons from the nuclear recoil into an electronic signal

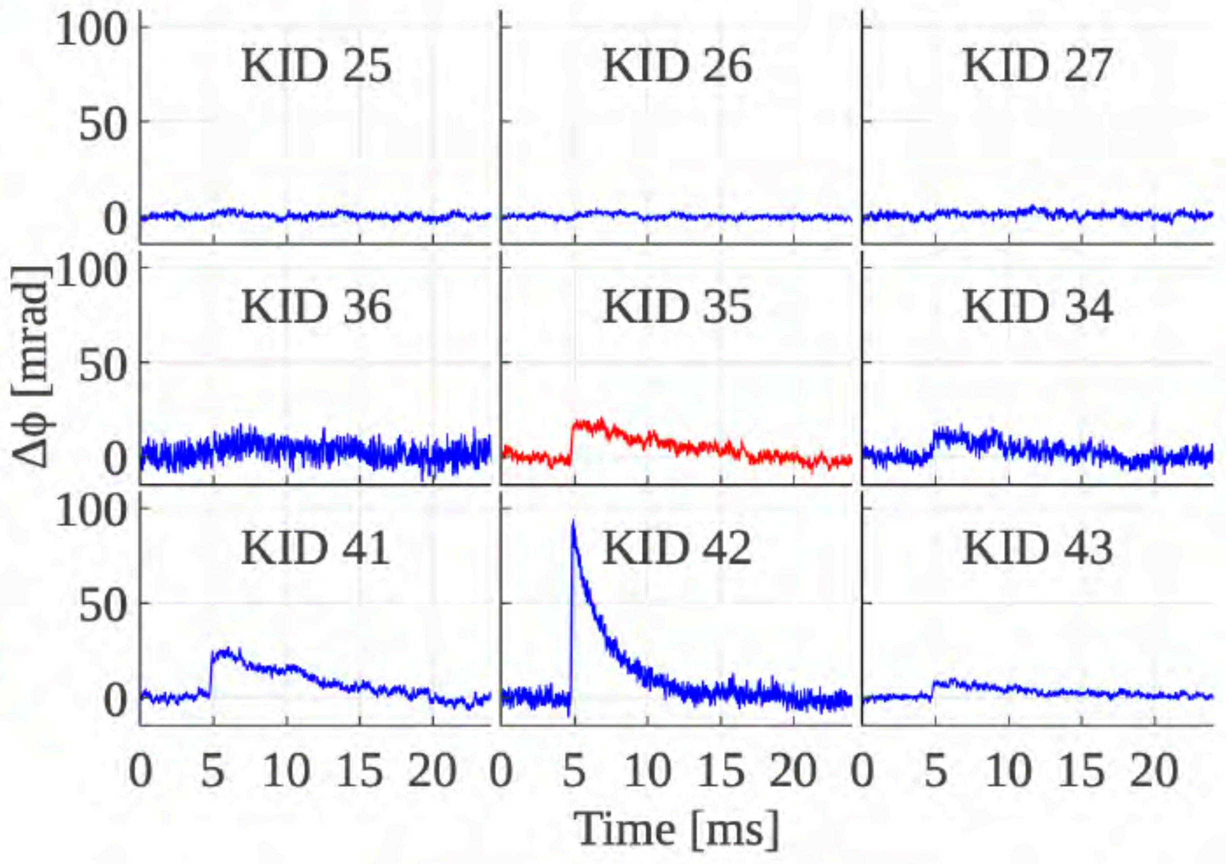
Surface background of a single die




Acquiring the neighbours of a given die allows to veto events interacting elsewhere



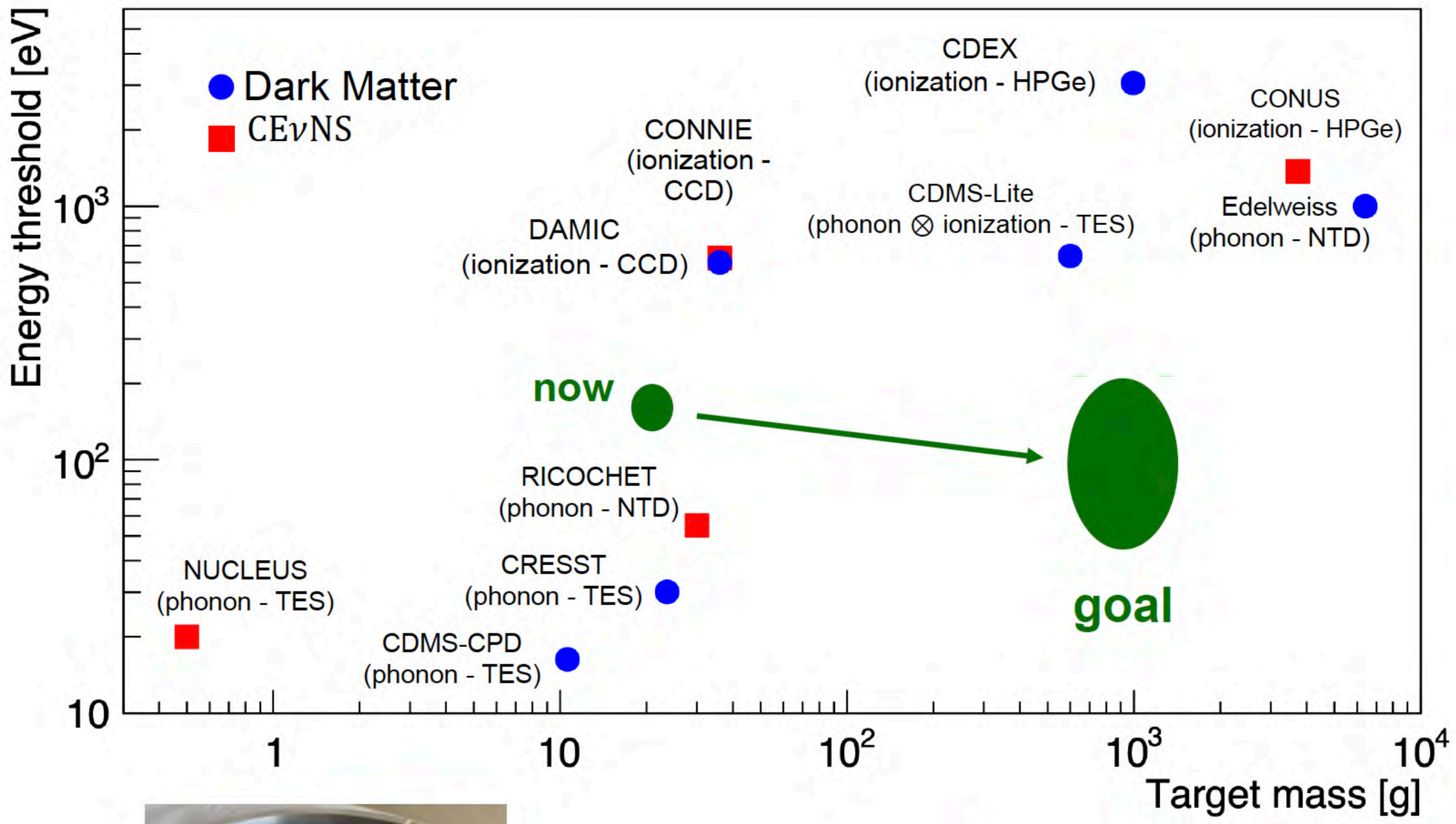

Kept event




Discarded event

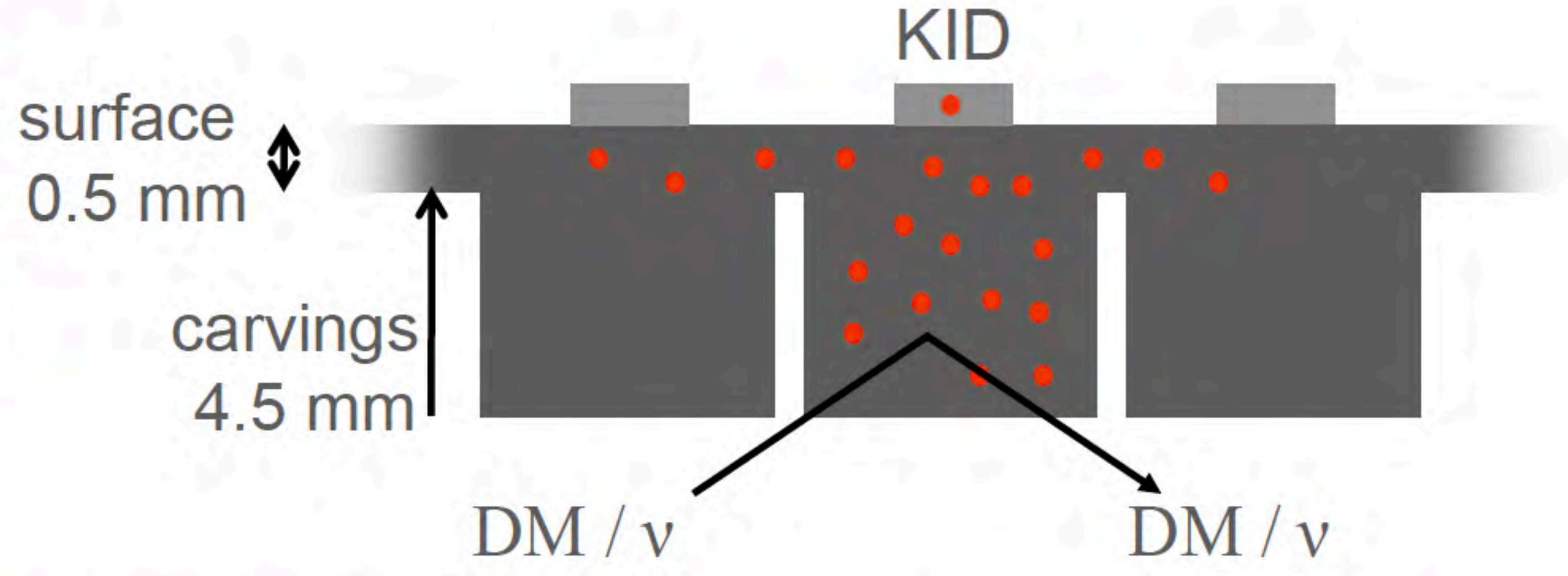
# Mass and threshold improvement

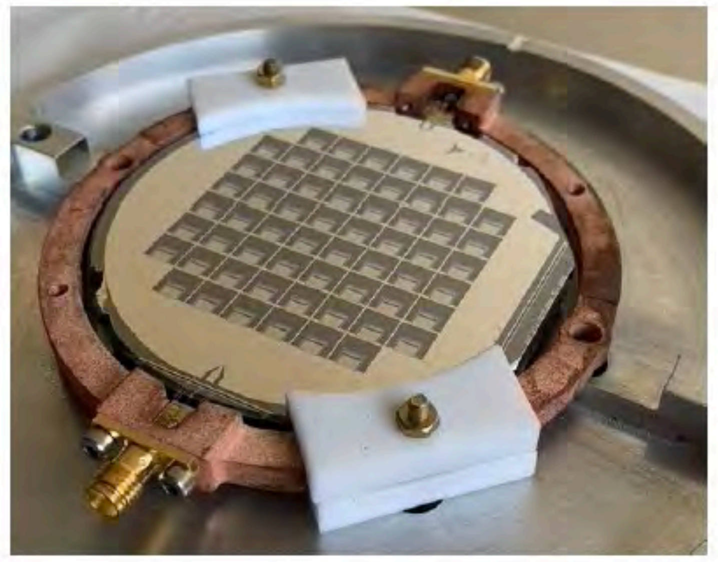
ercDANAE



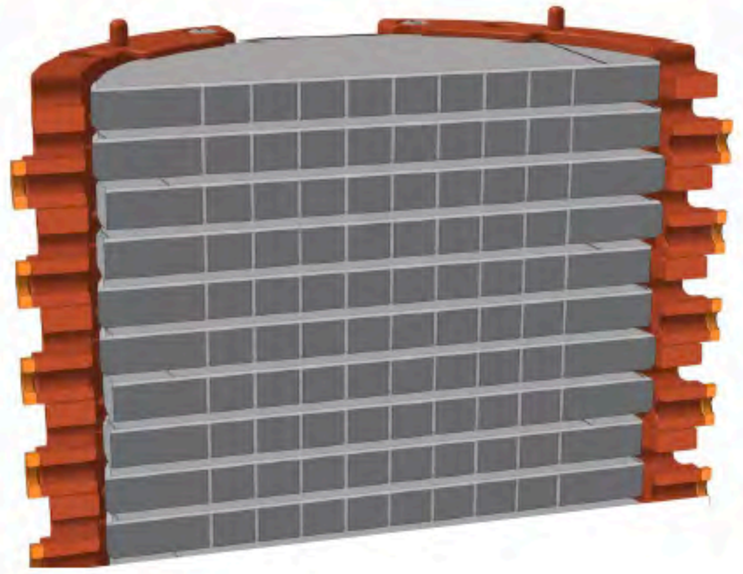

Threshold (ongoing R&D):

1. Replace Al with Al-Ti-Al KIDs - 5x inductance
2. Deeper carvings for higher phonon focussing

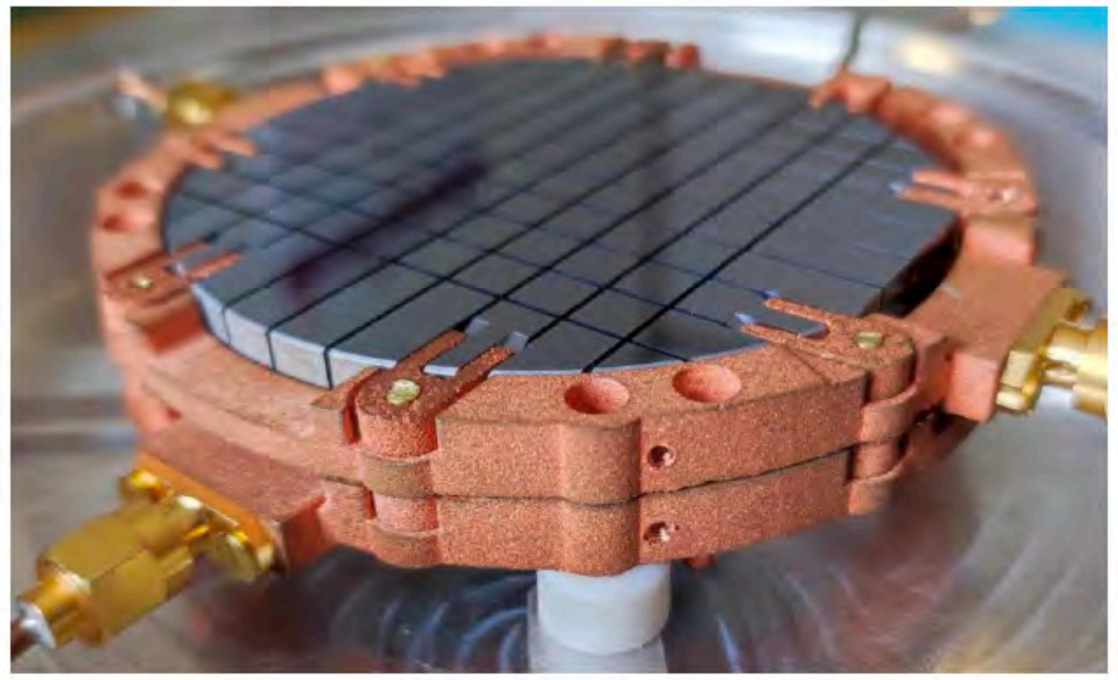


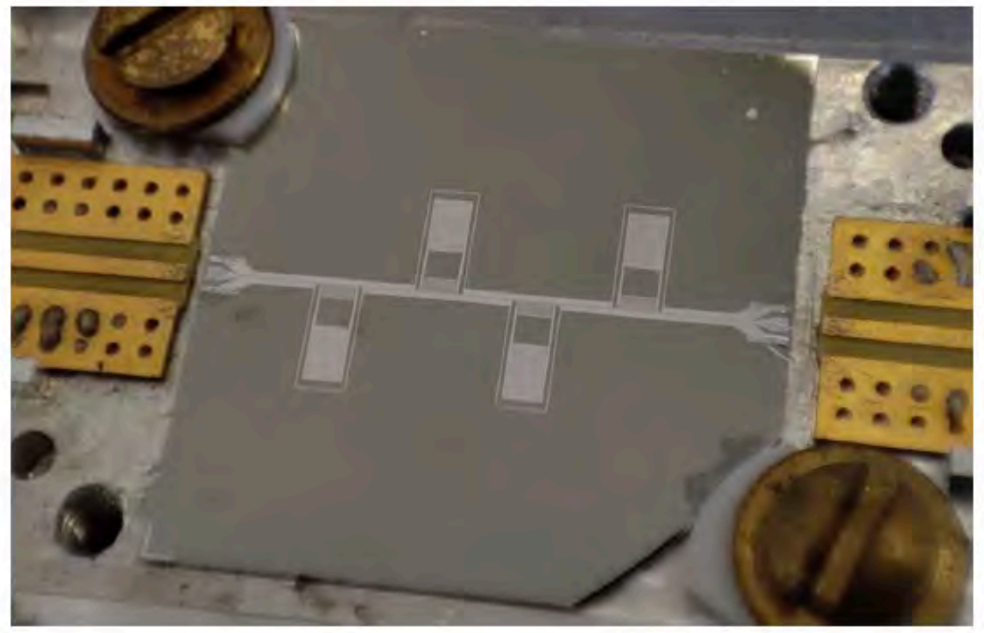
Mass:
from 3” to 4” wafers
stack of wafers



First stacking of two BULLKID detectors is operational



Sample from R&D of KIDs on Germanium for CEVENS



# SBC (Scintillating Bubble Chamber)

# Liquid Noble Bubble Chambers

Objective:

Quasi-background-free detection of sub-keV Nuclear Recoils

Signal:

Single bubble with little or no coincident scintillation

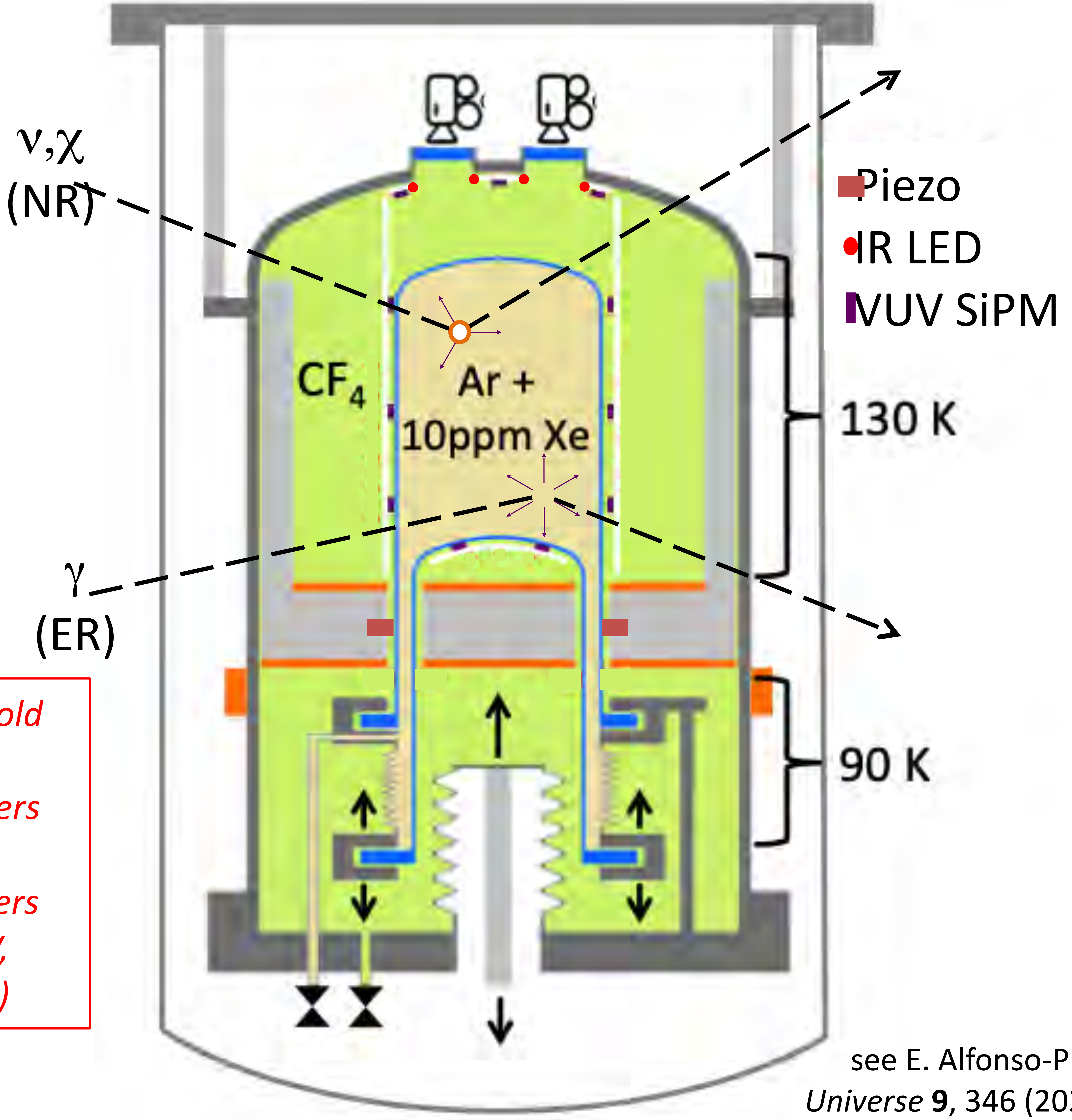
Backgrounds:

ER's (beta, gamma):
No bubbles

*Depends on NR threshold and target fluid:*

- *Freon-based chambers ER-blind @ ~3 keV*
- *Liquid-noble chambers ER-blind @ < 500 eV, (target 100 eV)*

NR's (fast neutron):
Multiple bubbles
Strong coincident scintillation

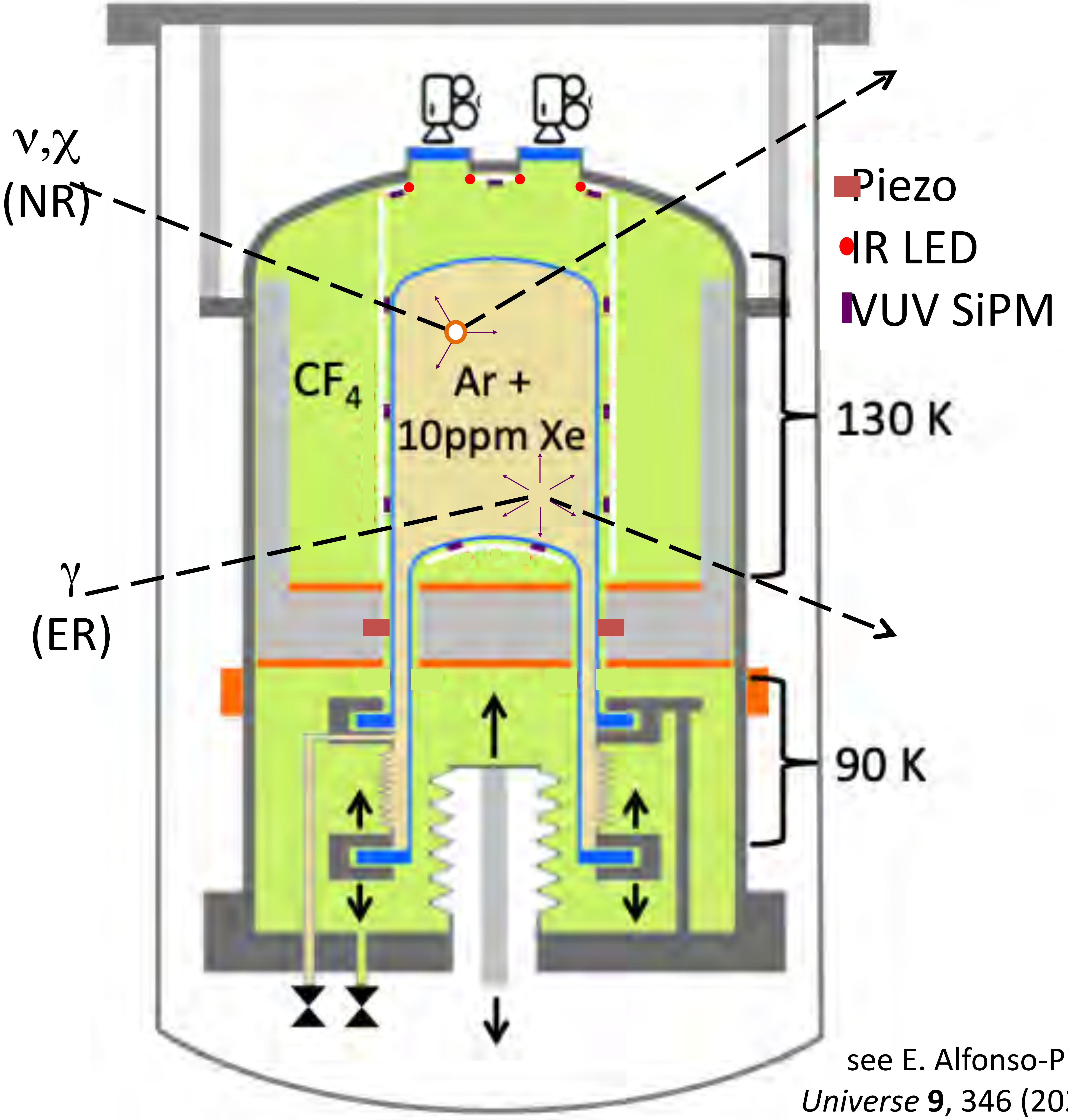



see E. Alfonso-Pita, *Universe* **9**, 346 (2023)

## Liquid Noble Bubble Chambers

Objectives for SBC-LAr10 in MINOS:

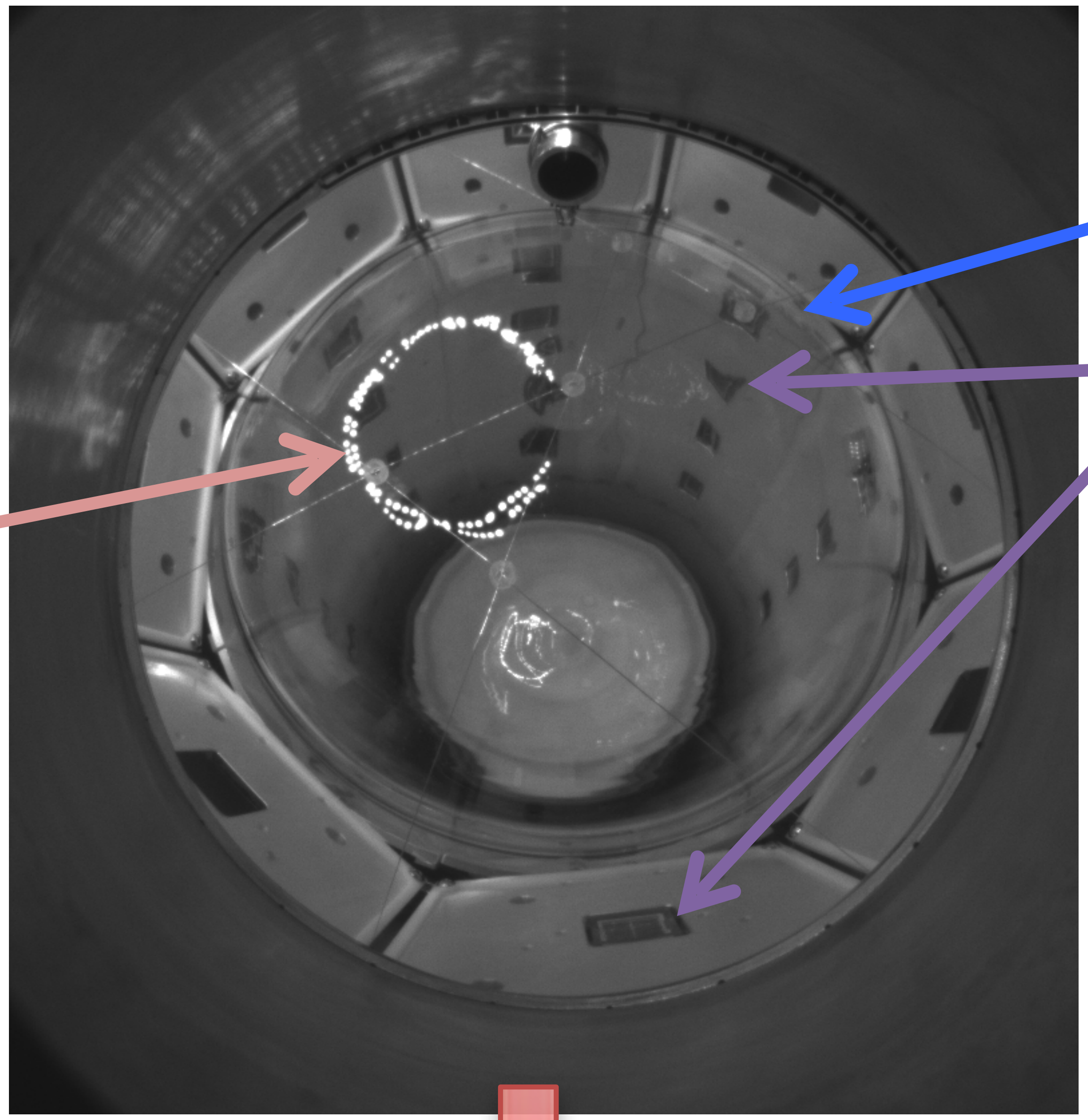
- **Demonstrate operation** of physics-scale liquid-noble bubble chamber
- **Determine maximum superheat** for ER-blind operation
- **Calibrate Threshold** for NR detection, @ 100 eV, with 10 eV resolution




see E. Alfonso-Pita, *Universe* **9**, 346 (2023)

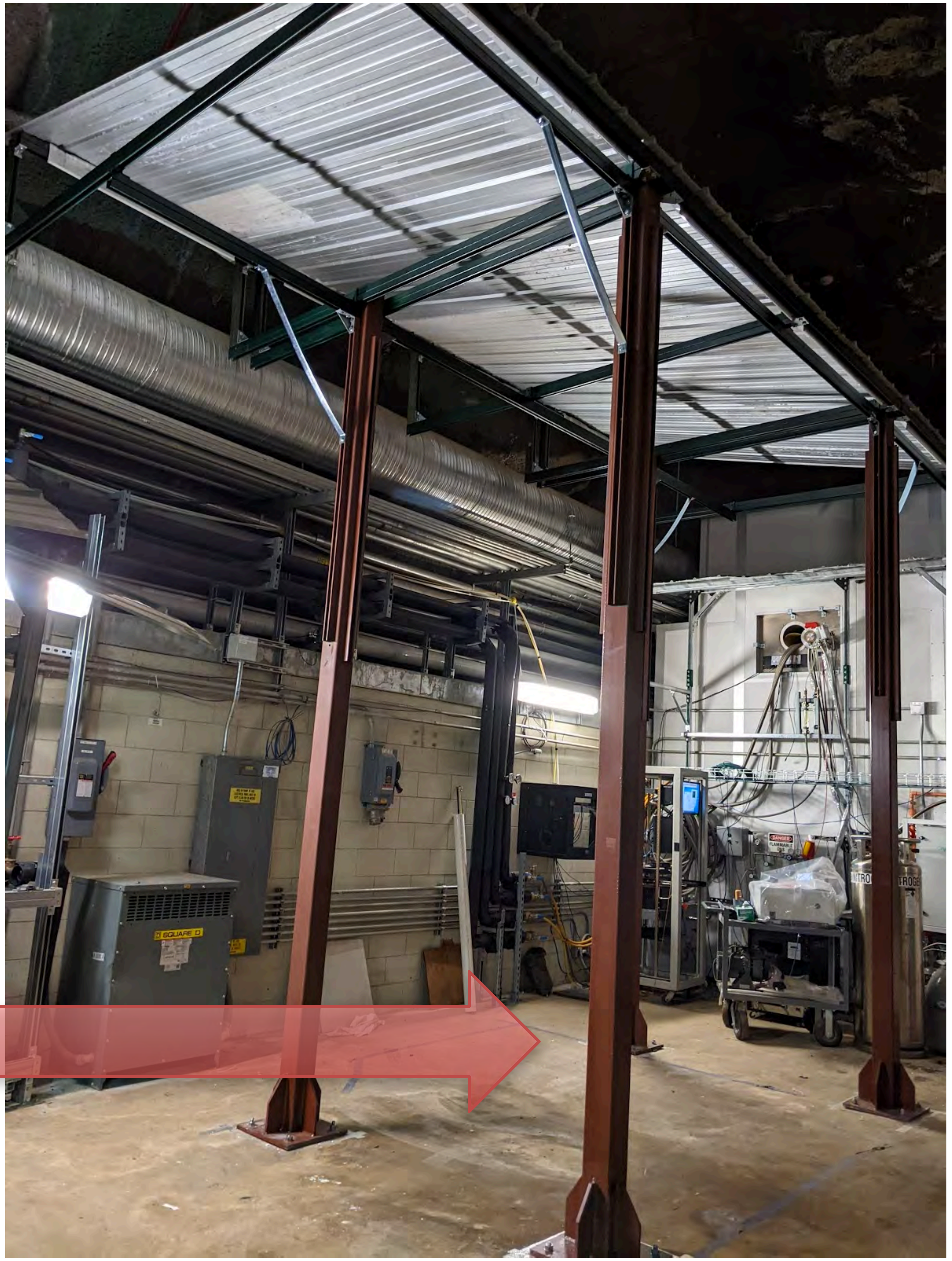
**Top-view from image acquisition system**

LED reflections (less pronounced in liquid-filled chamber)



Silica Vessel for LAr target (gas Ar in this image)

Hammamtsu VUV4 SiPMs



# Calibration Strategies
(for the ER-blind)

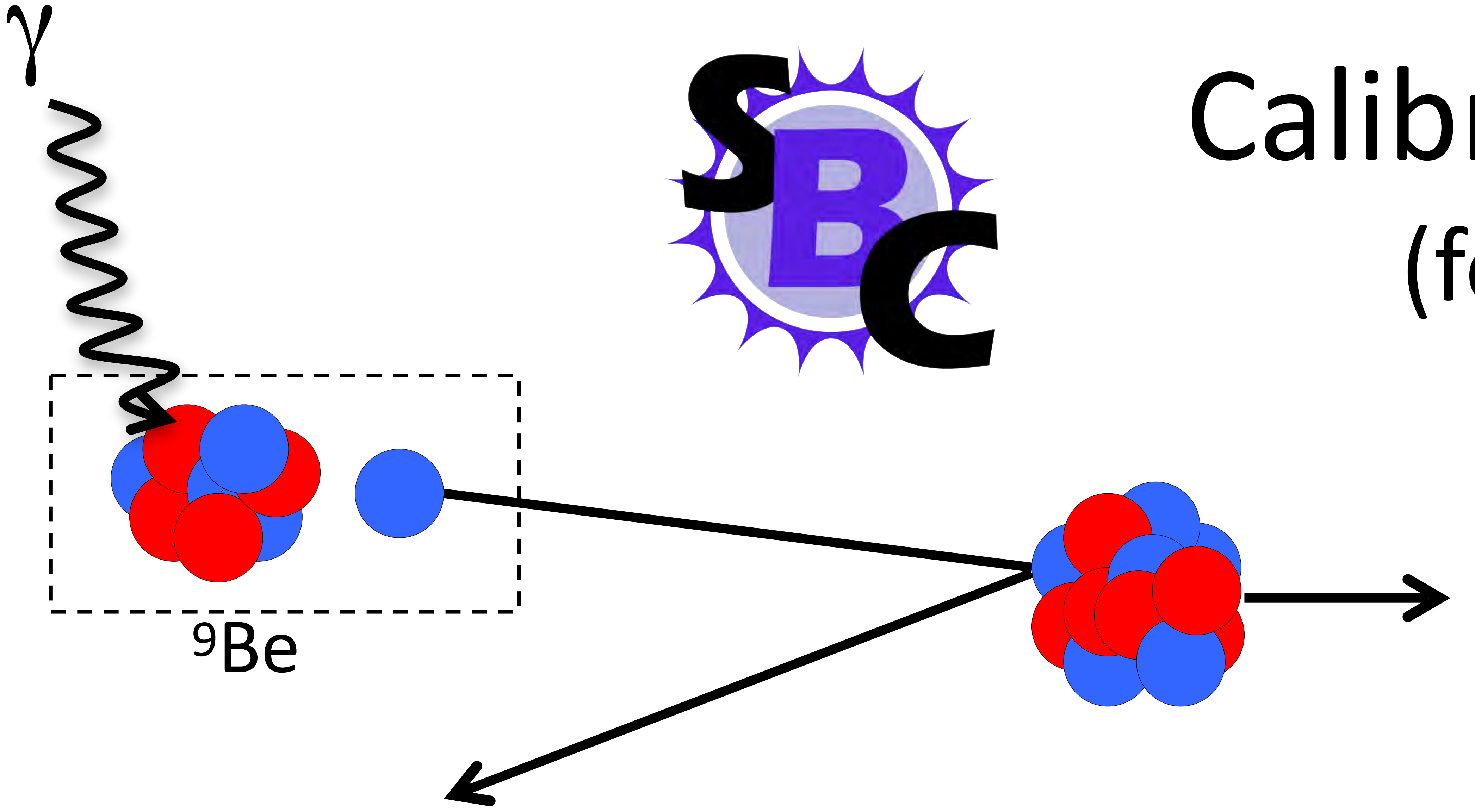
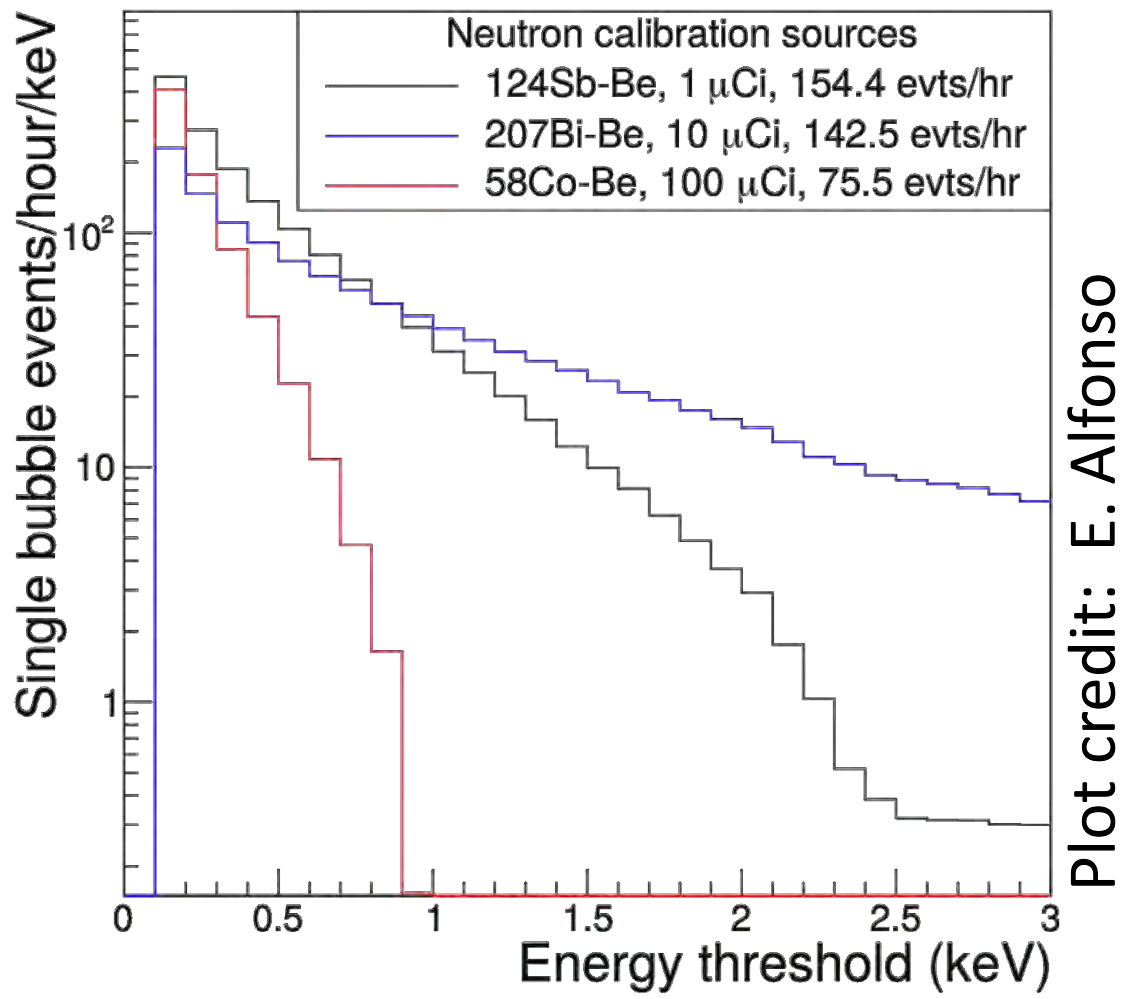
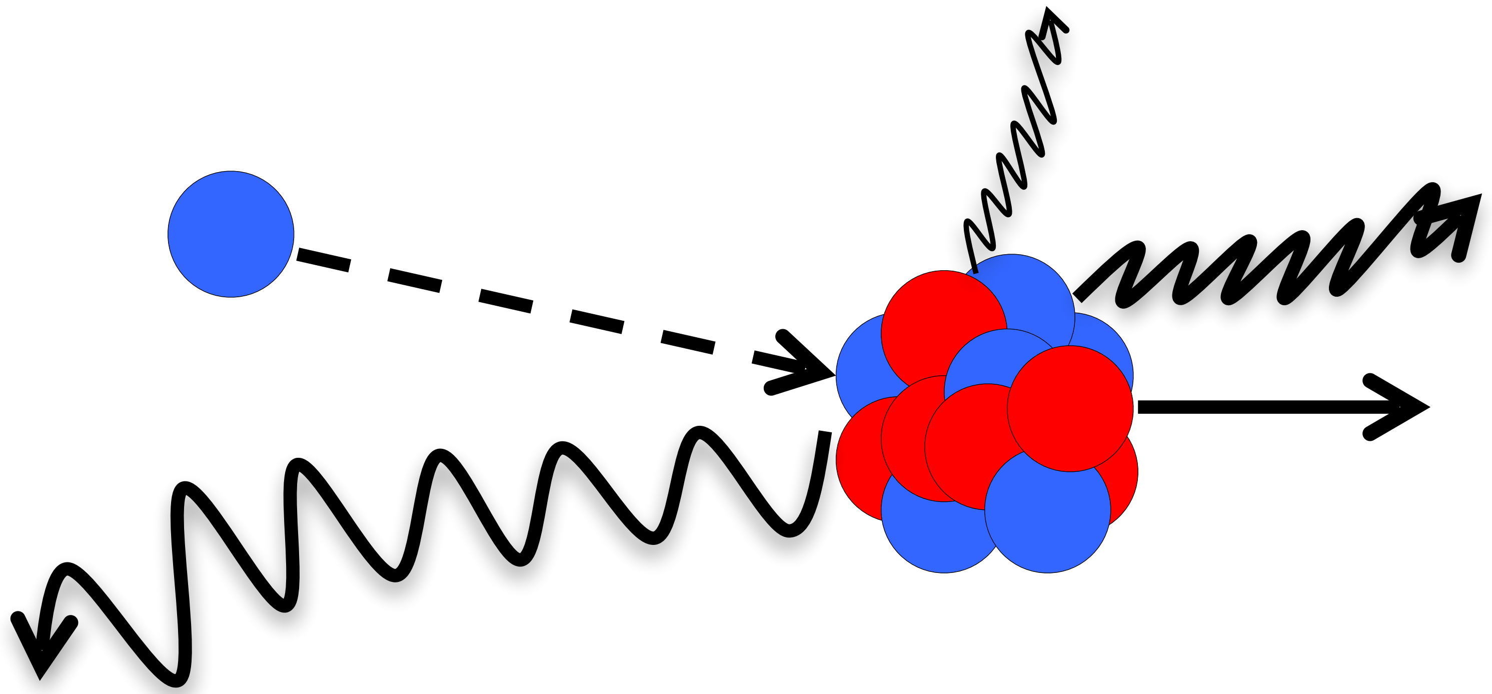
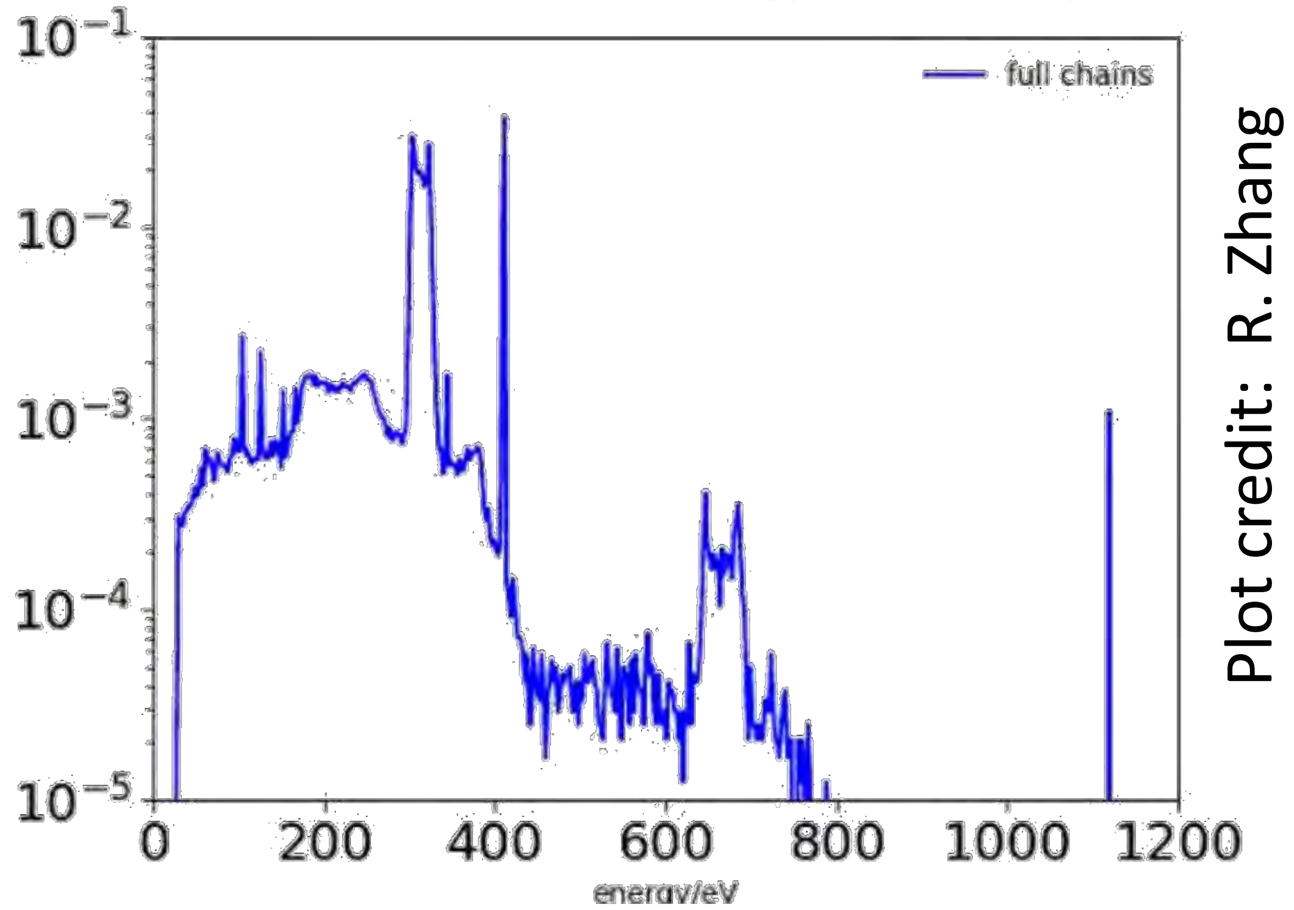


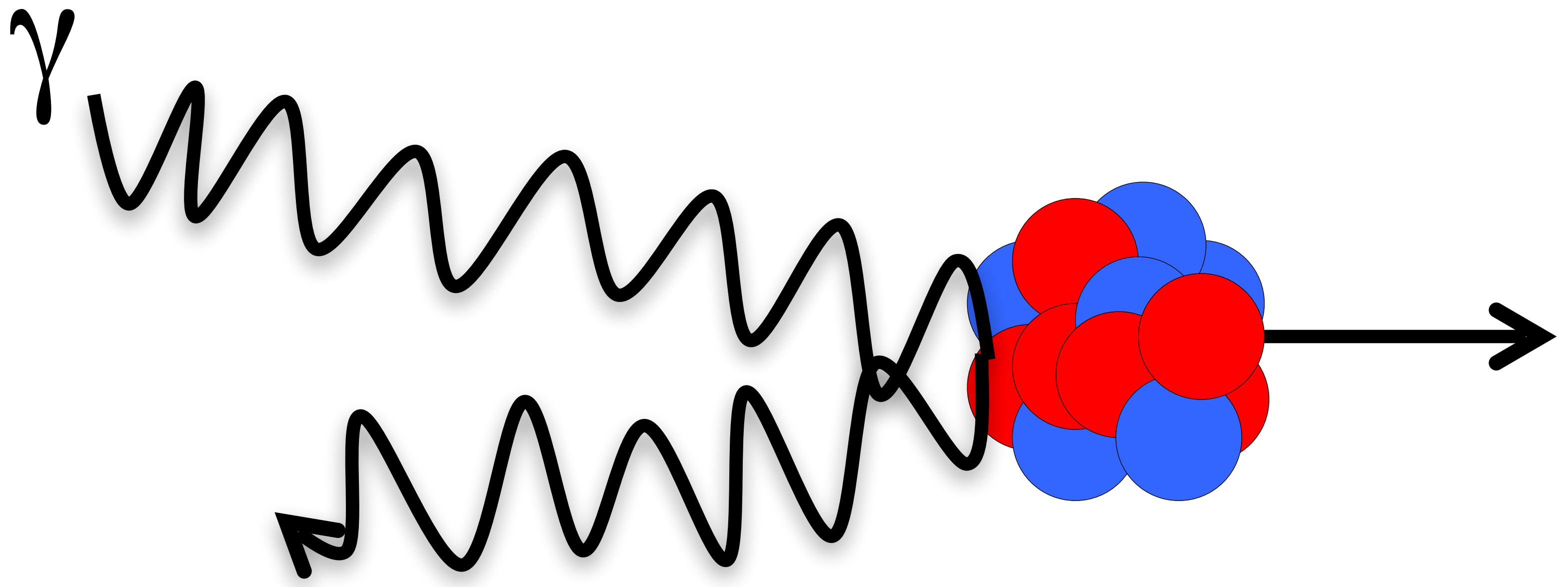

Photo-neutron Sources
( > 500 eV recoils)



Thermal neutron Capture
(200 – 500 eV recoils)




Photon-nucleus Scattering
( < 300 eV recoils)