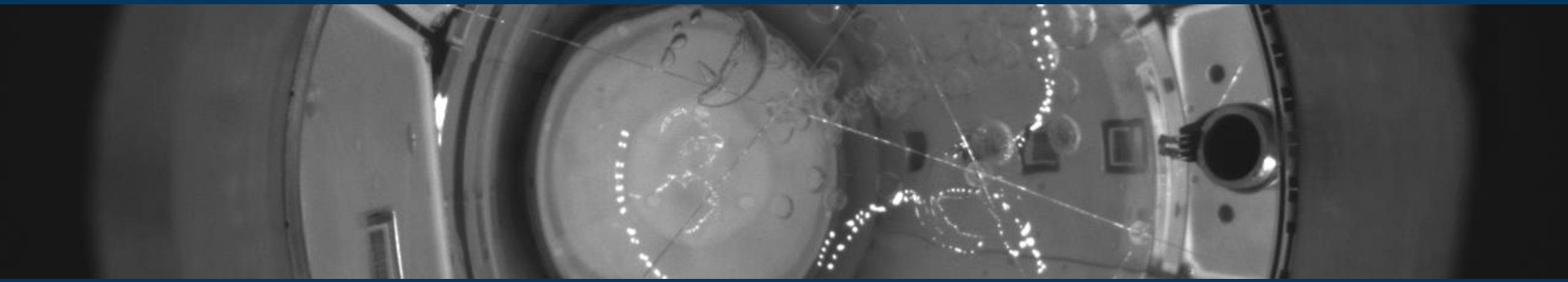
First Results from the Scintillating Bubble Chamber Liquid Argon 10 kg (SBC-LAr10) Detector

Ryan Zhang
representing SBC collaboration

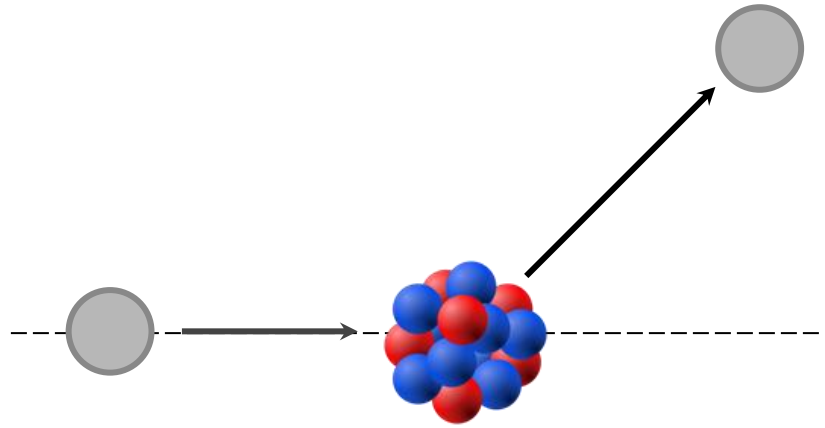
CPAD
October 20, 2026



UC SANTA BARBARA

Introduction

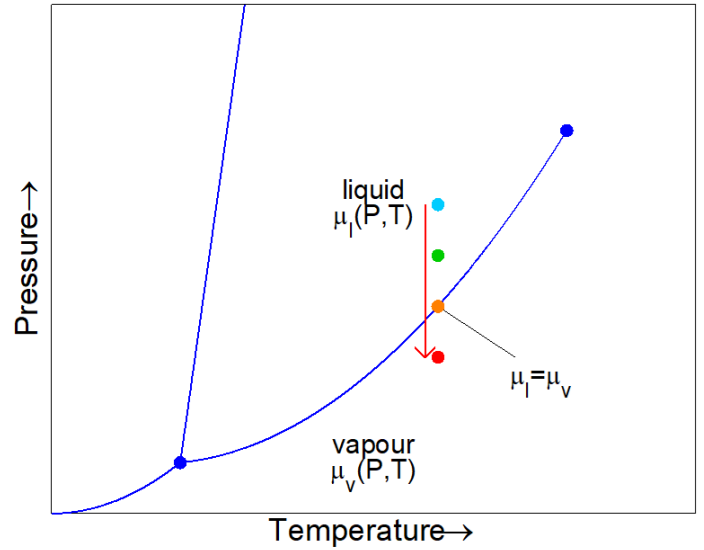
- Scintillating Bubble Chamber
  - Scintillation: high energy background discrimination
  - Bubble: O(100) eV nuclear recoil (NR) detection
    - Dark matter via elastic scattering: M_χ ~ GeV
    - Neutrino via Coherent elastic neutrino-nucleus scattering (CEνNS): E_ν ~ MeV

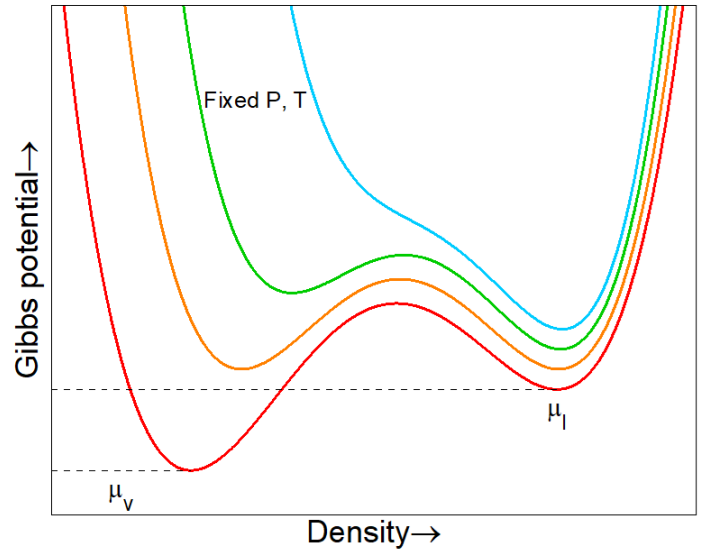


Signals in Bubble Chamber

- Superheated fluid
  - NR > energy threshold ($E_{\mathrm{th}} \approx Q_{\mathrm{Seitz}}$)
  - Bubble nucleates

- Advantage
  - Electron Recoil (ER):
    - Dominant background
    - Low nucleation efficiency
  - Strong gamma rejection

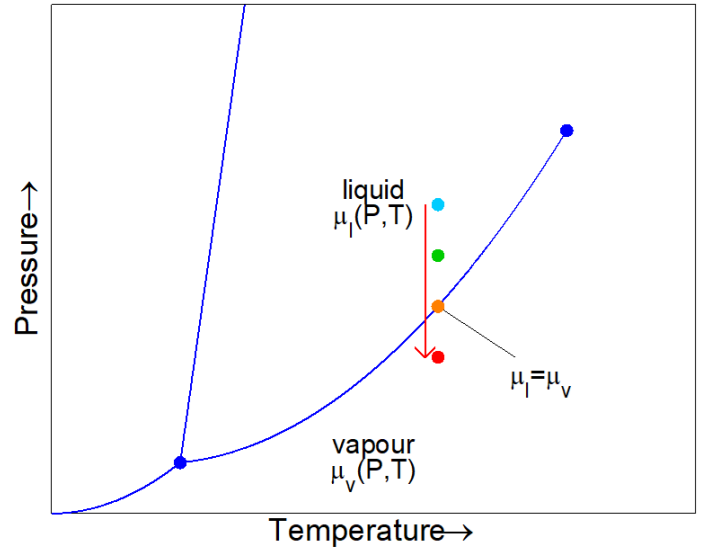


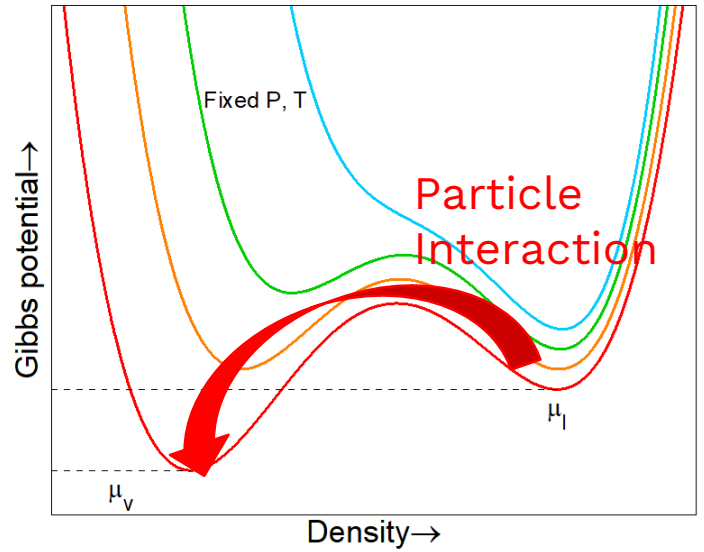


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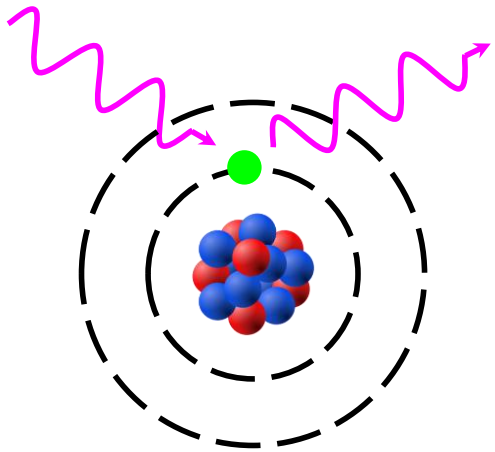
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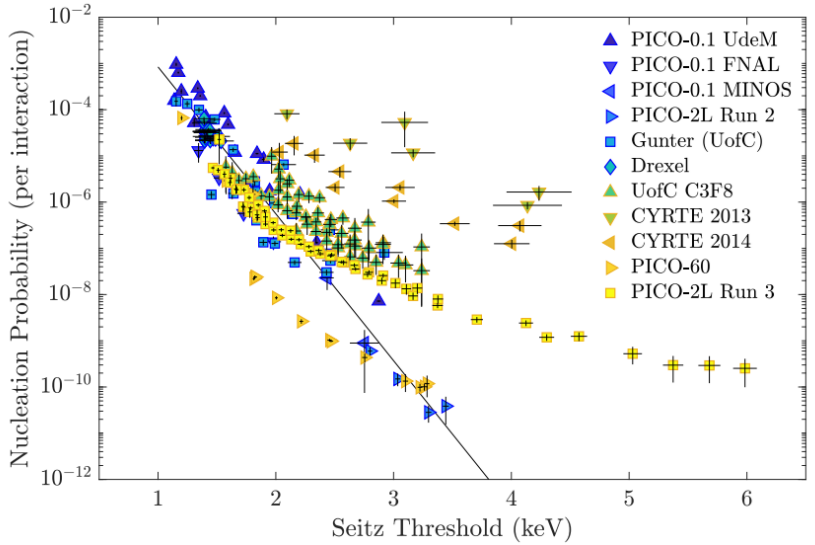


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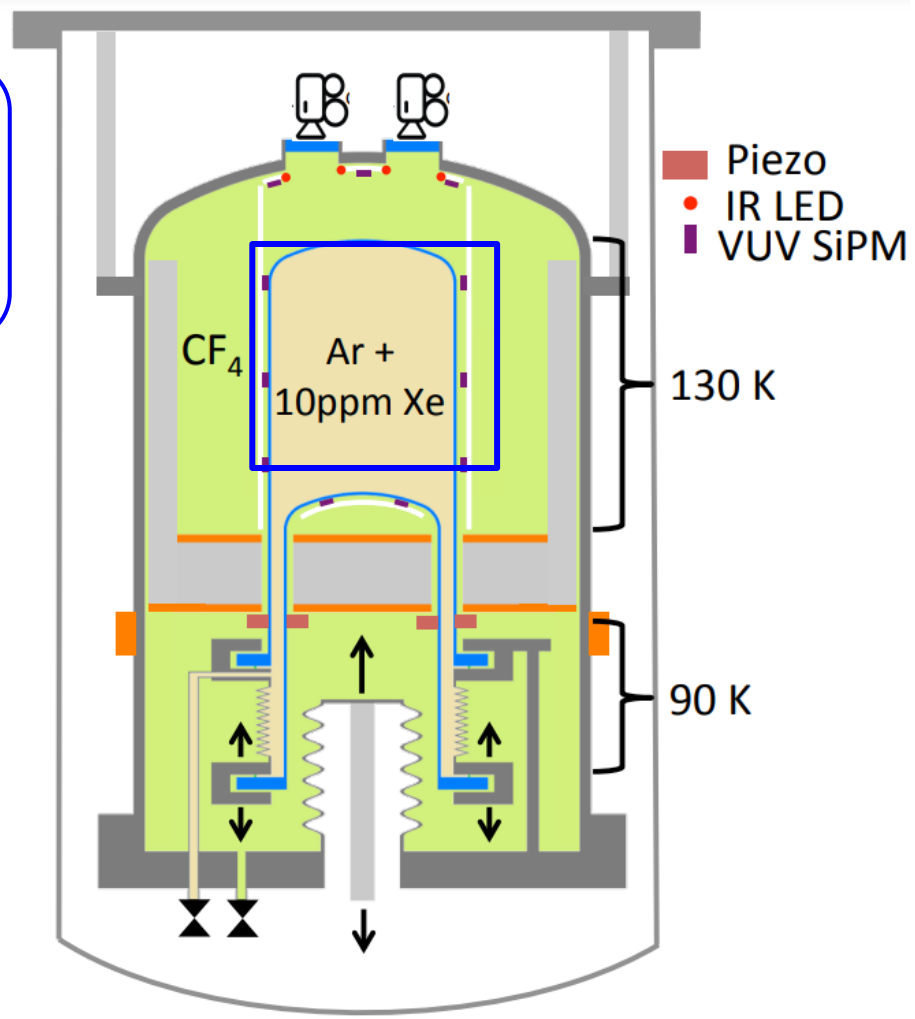
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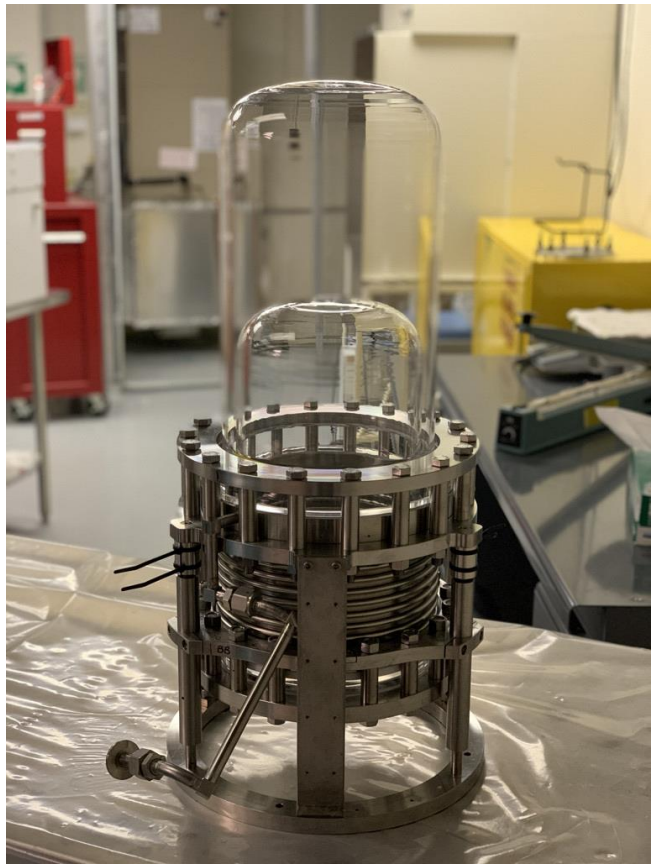


PICO: https://arxiv.org/pdf/1905.12522

SBC Structure

- Sensitive volume - liquid argon
  - Heat -> bubble
  - Scintillation light

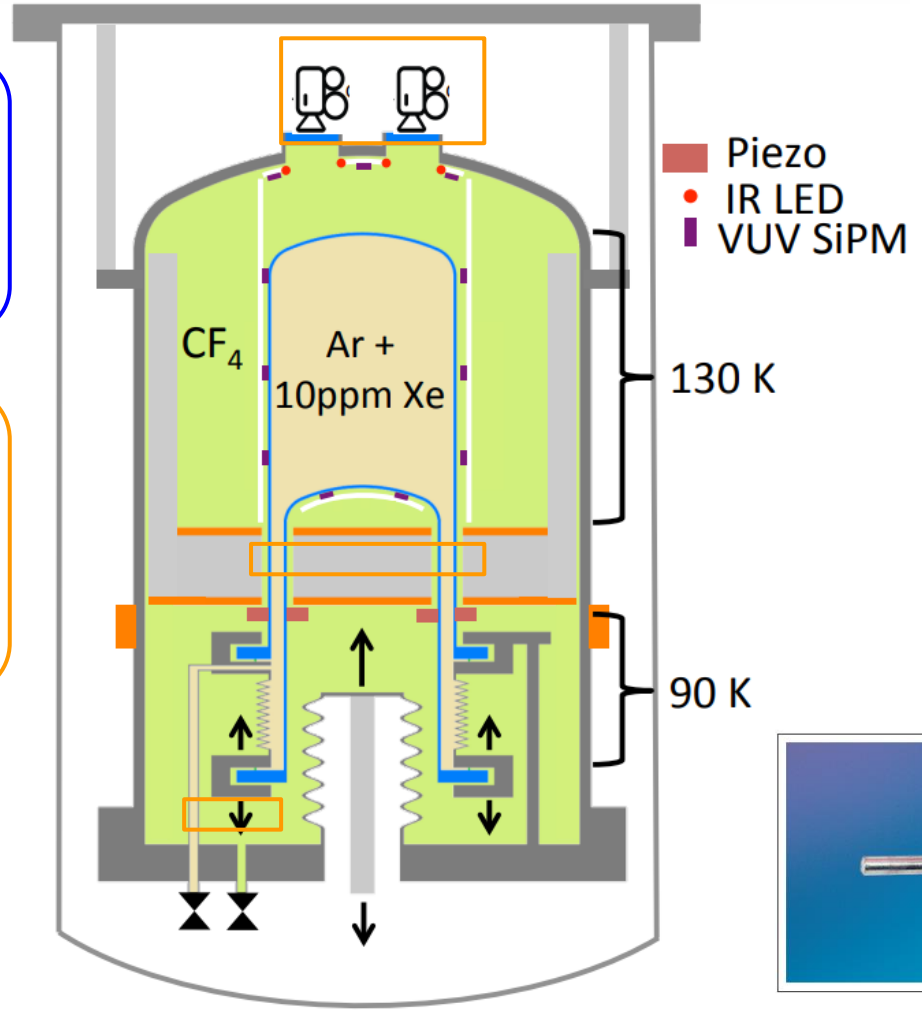




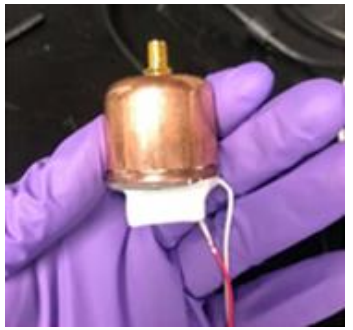
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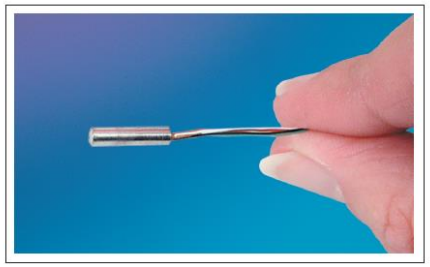
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- Bubble detection
  - Camera
  - Acoustic sensor
  - Pressure transducer









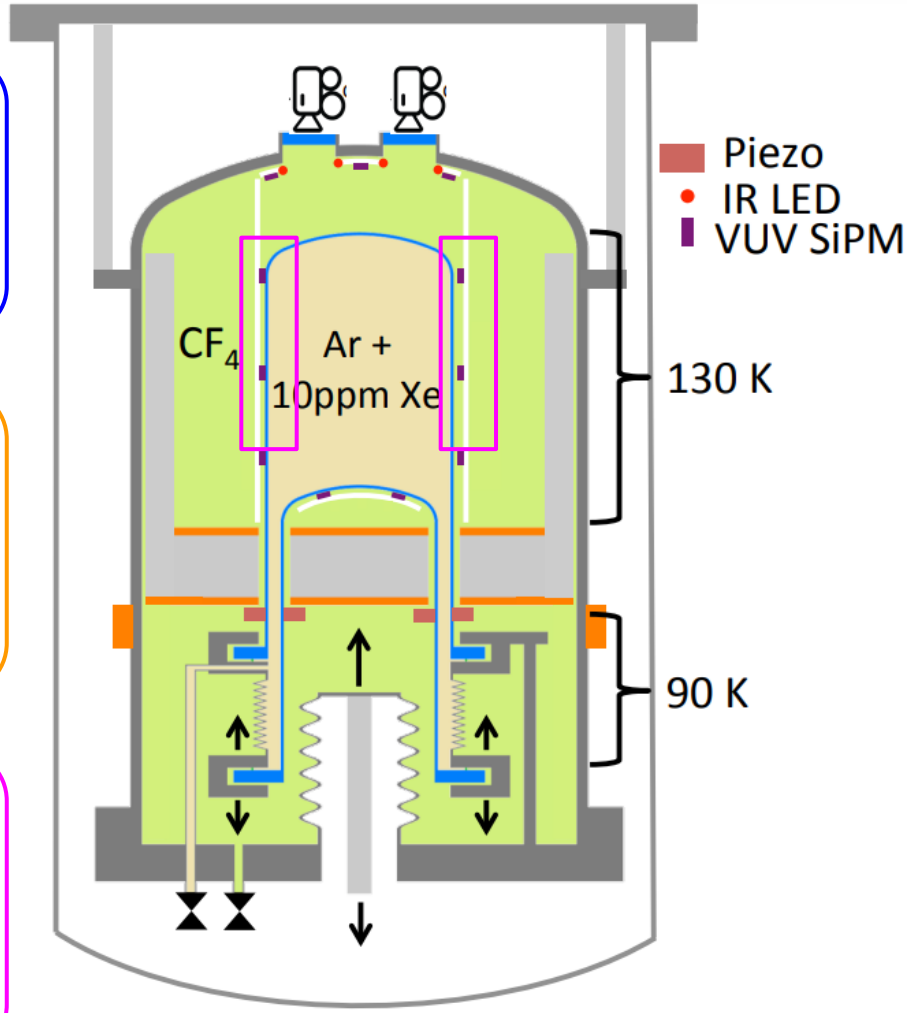


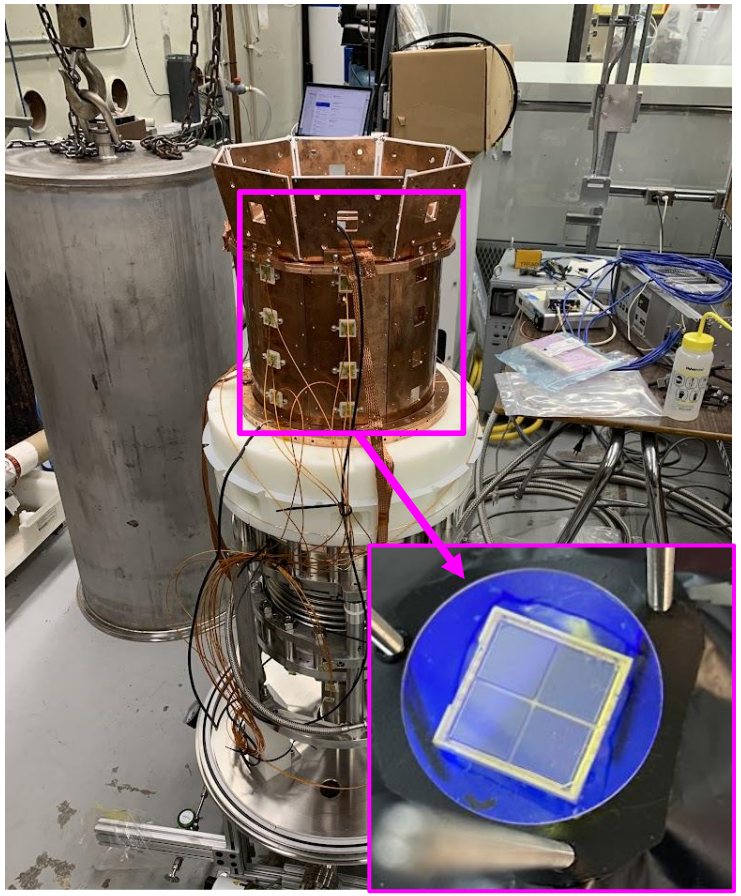
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- Scintillation detection
  - Silicon PhotoMultiplier (SiPM)
  - Xenon doping



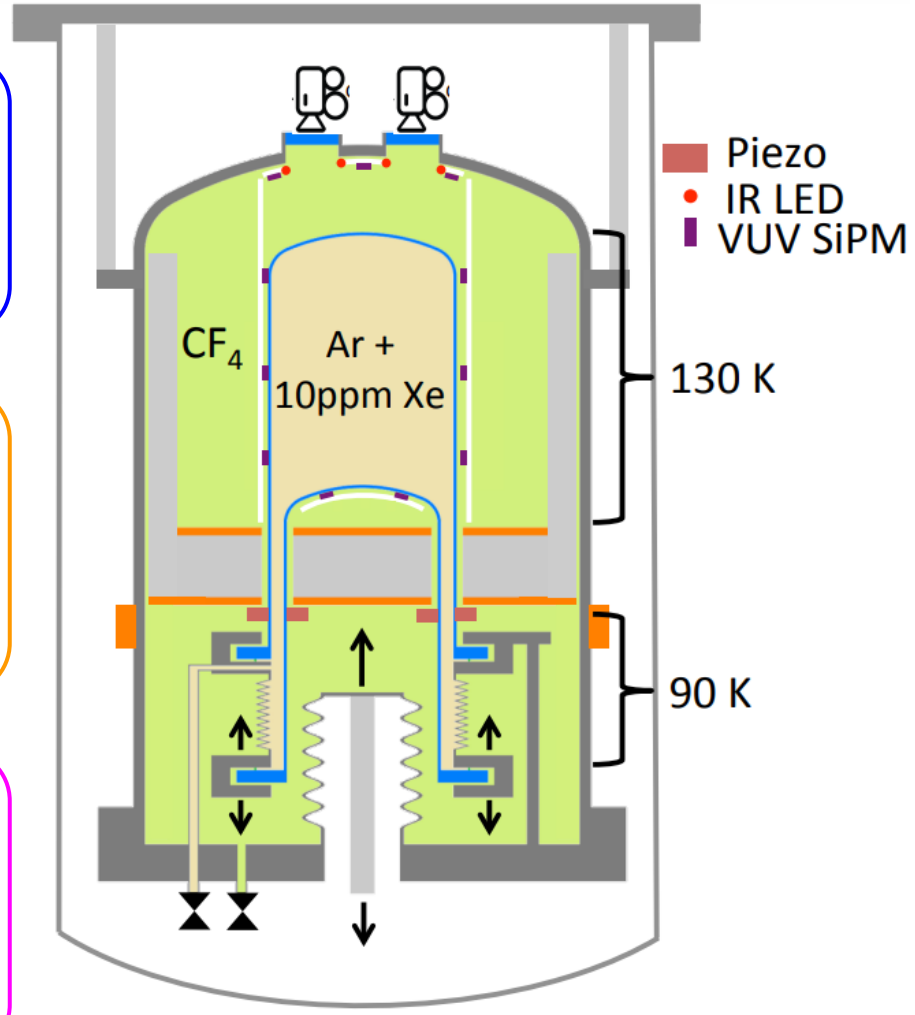


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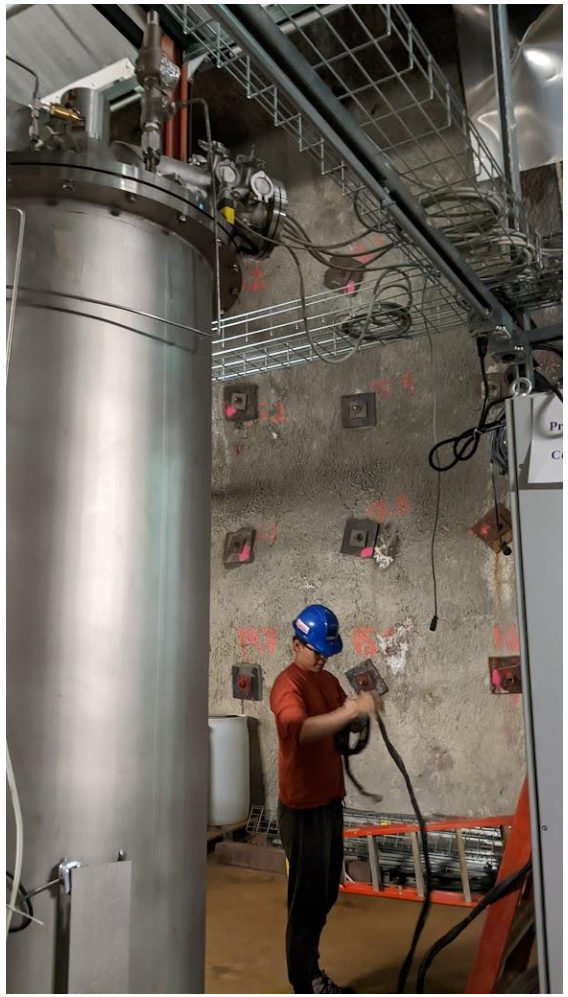


SBC Projects

- SBC-LAr10
  - 10kg calibration chamber
  - MINOS, Fermilab

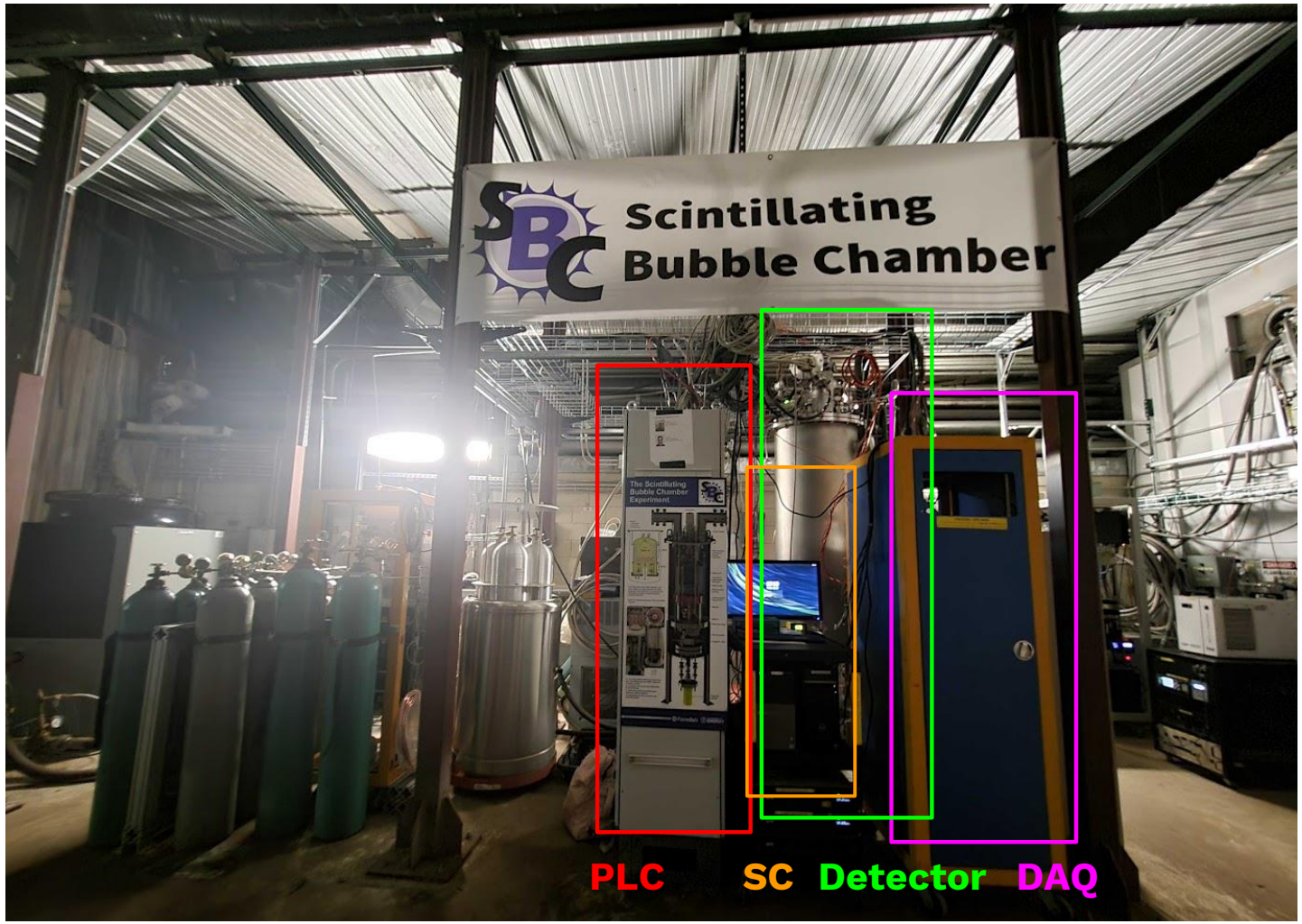
- SBC-SNOLAB
  - Identical detector
  - SNOLAB
  - Dark matter search

SBC-LAr10 First Operation





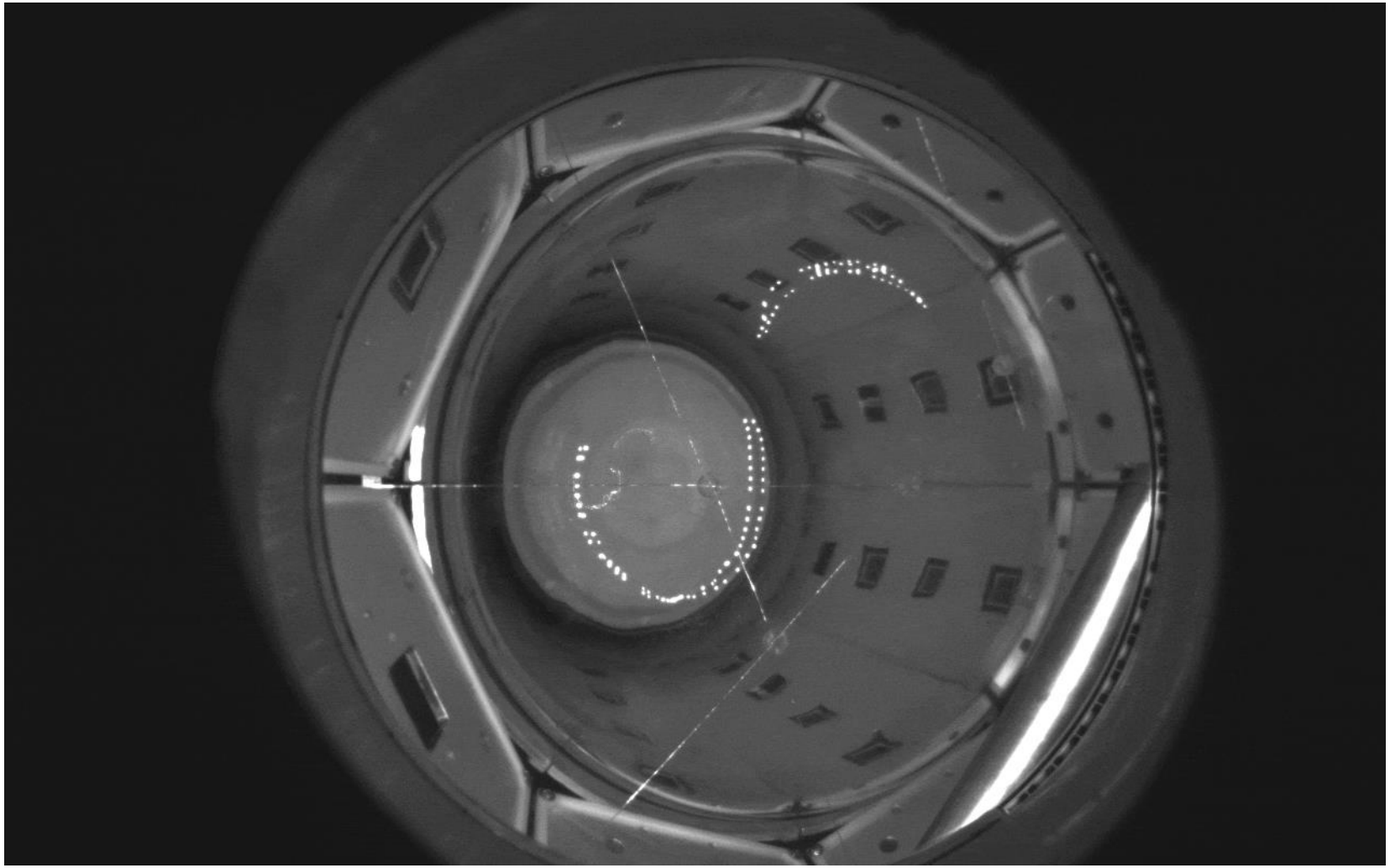

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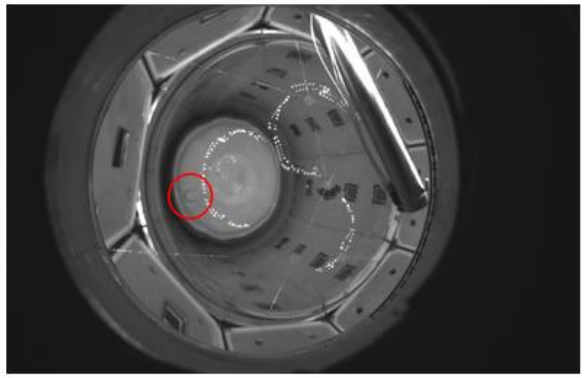
- Programmable Logic Controller (PLC)
- Slow Control (SC)
- Data Acquisition (DAQ)

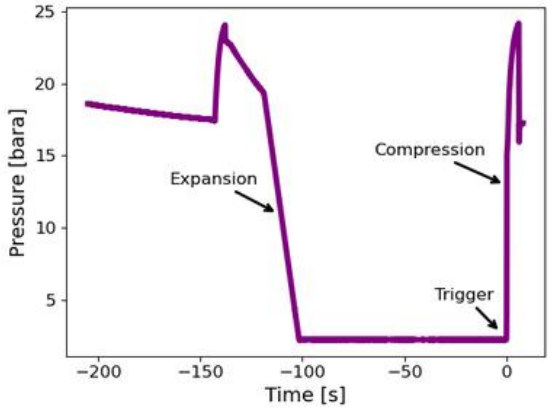
- The first run began in the fall of 2025

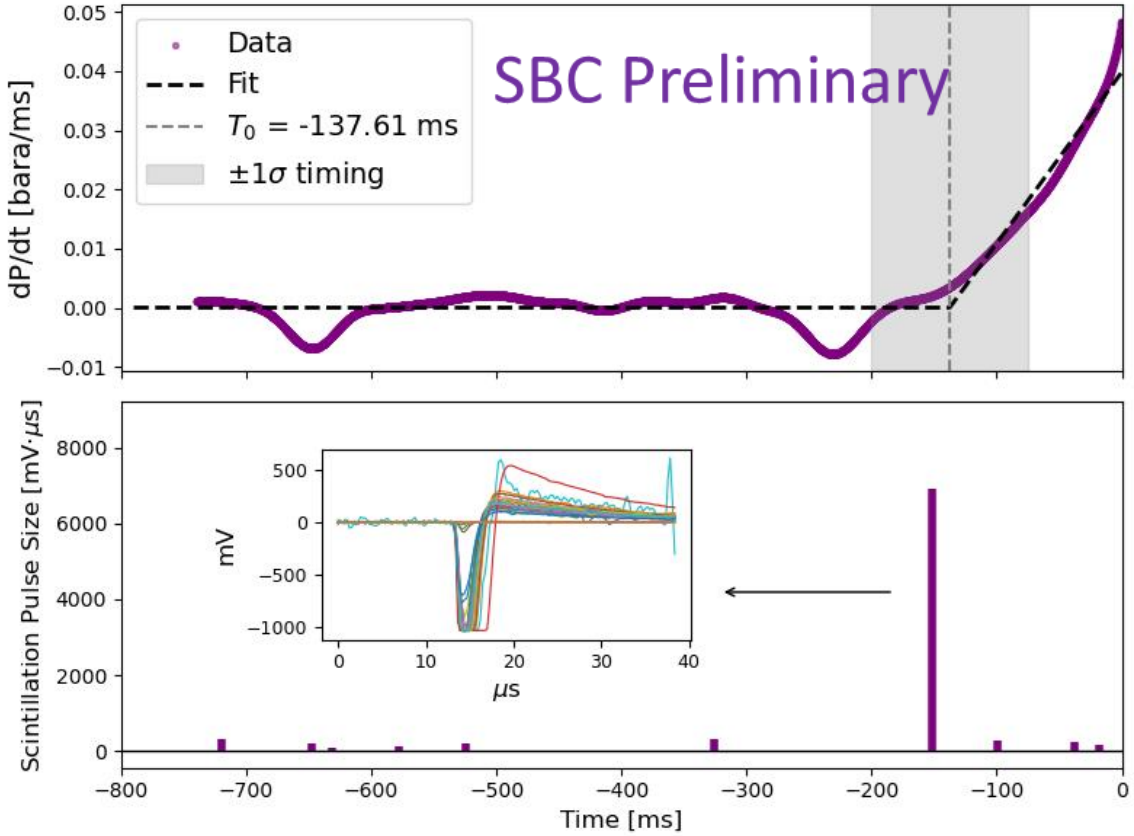
We See Bubbles!



Multi-channel Signals



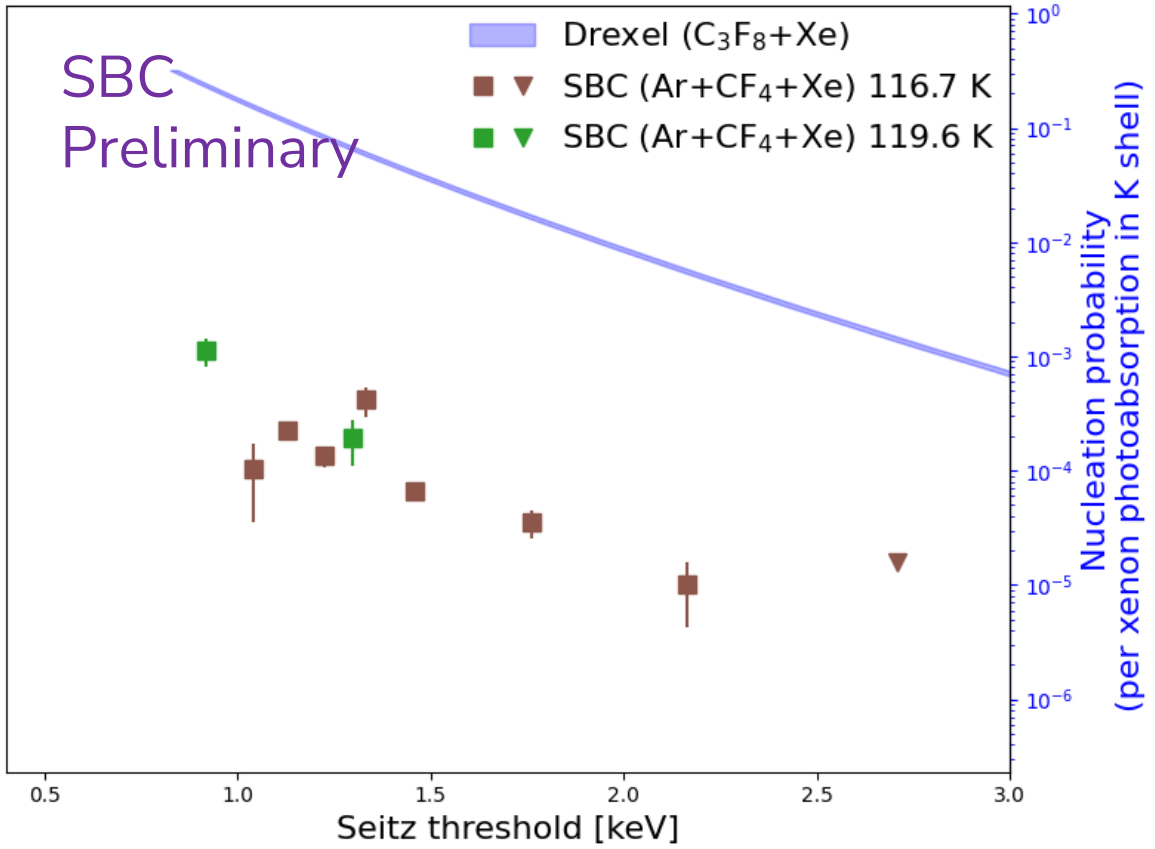




- Camera
- Pressure
- Scintillation

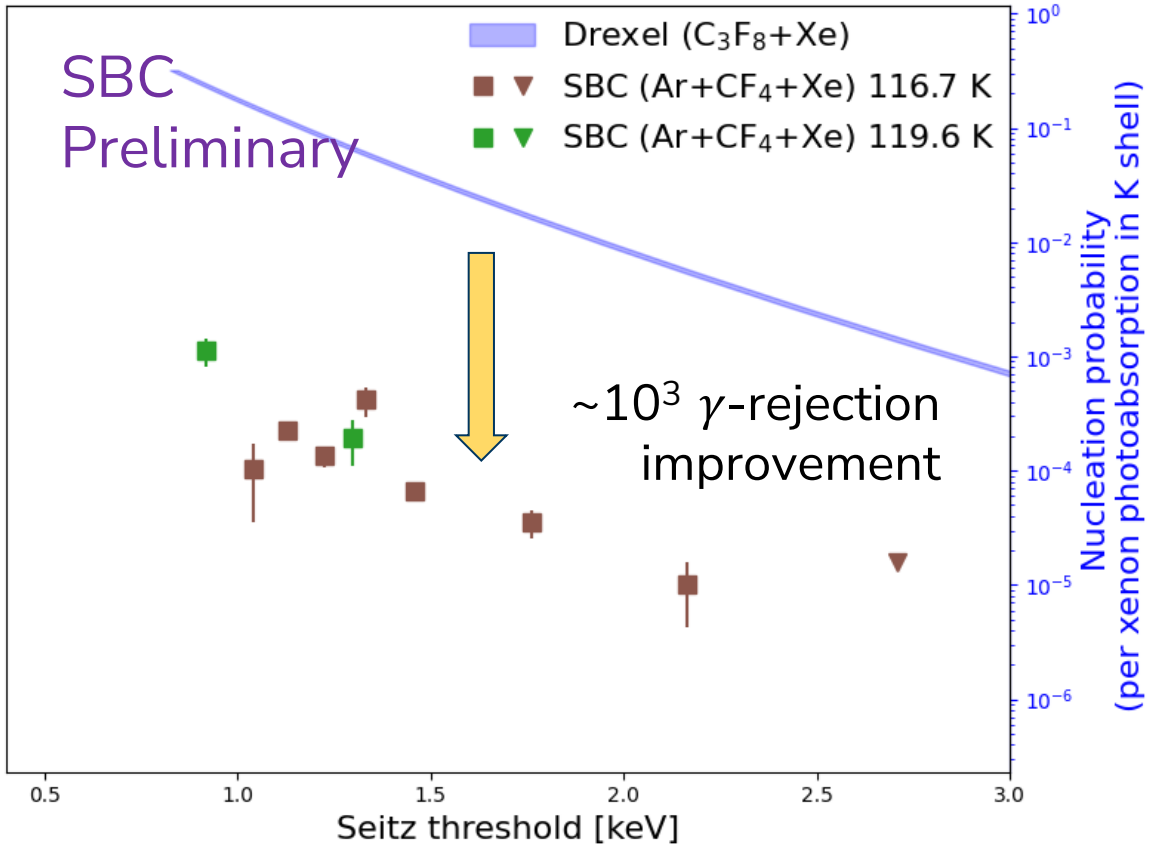
Gamma Rejection Analysis

- Bubble chamber
  - Strong ER background rejection
  - Depends on the liquid thermodynamic properties Q_{Seitz}
- SBC ER nucleation
  - Driving mechanism
    - Xe photoabsorption induced
  - Performance evaluation
    - Good at 1 keV: 10^{-7} per keV
  - Future improvement
    - Remove CF_4 hydraulic fluid contamination
    - Estimated to reach 10^{-6} per xenon photoabsorption



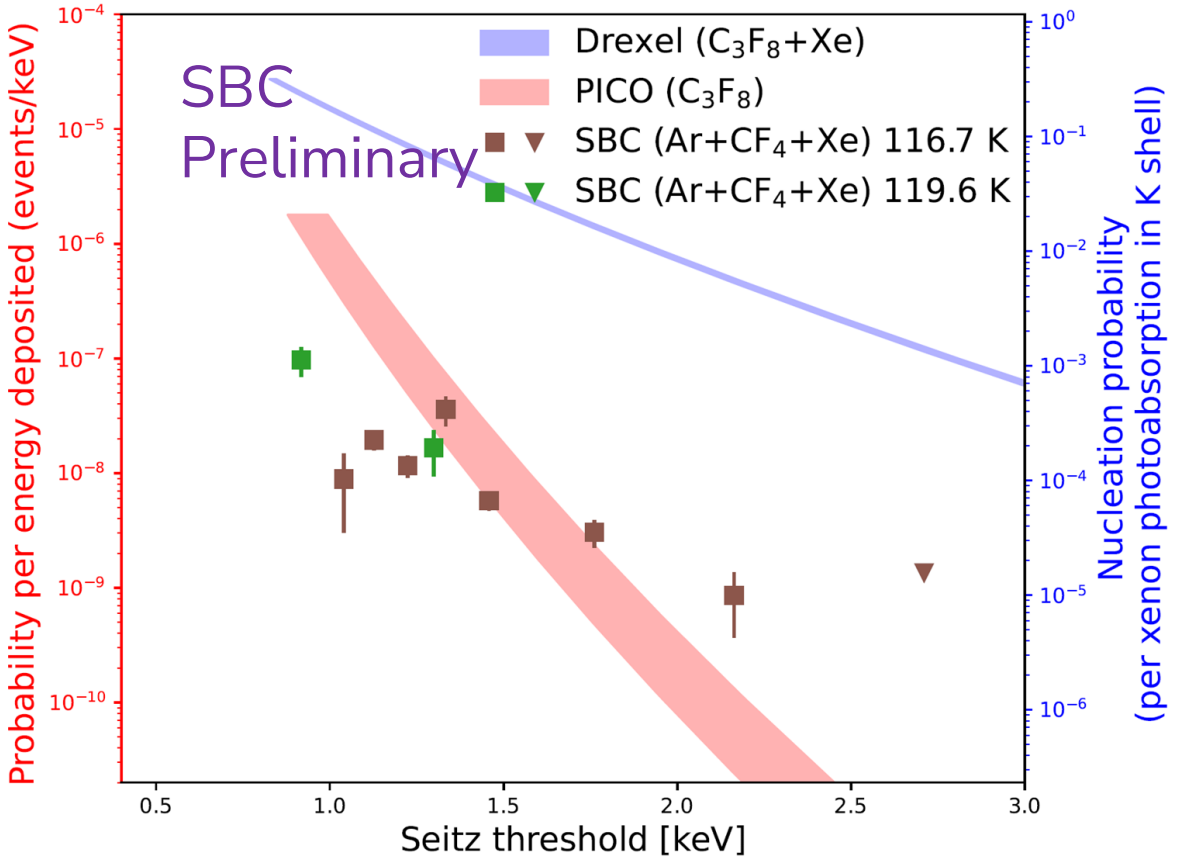
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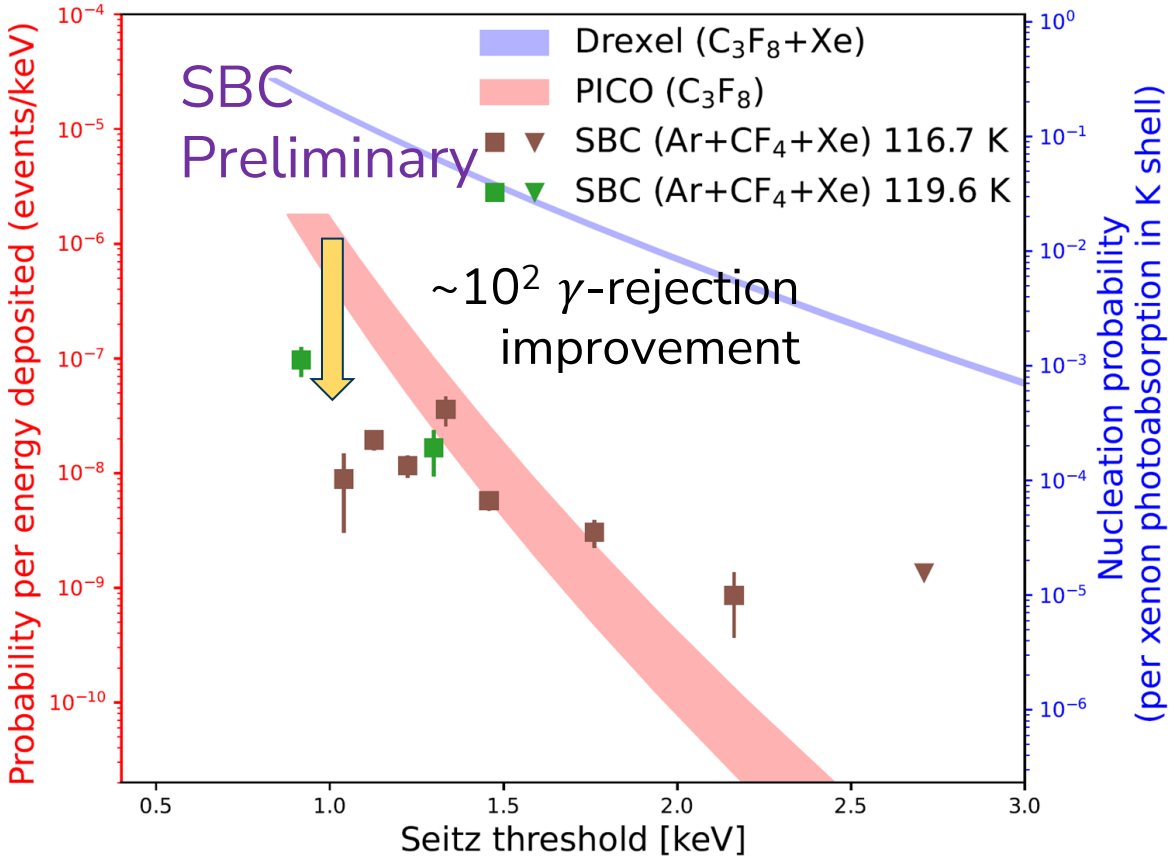
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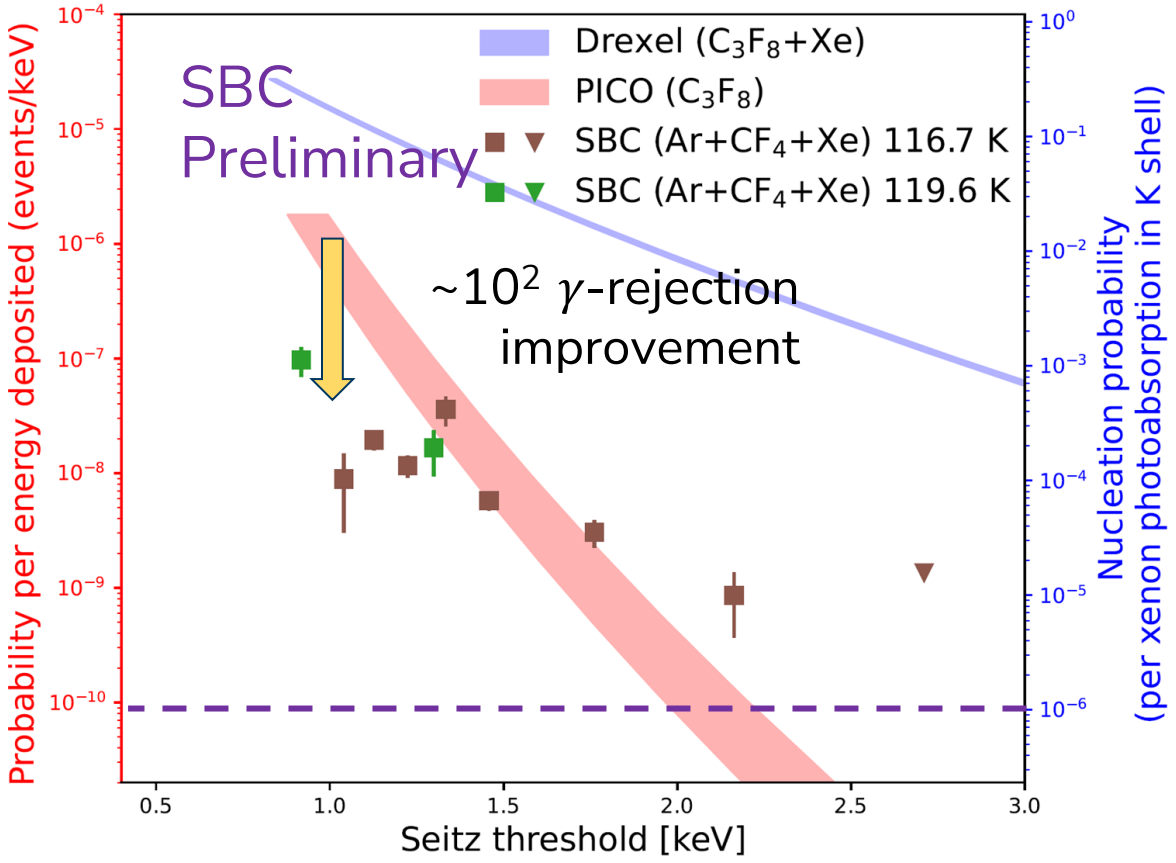
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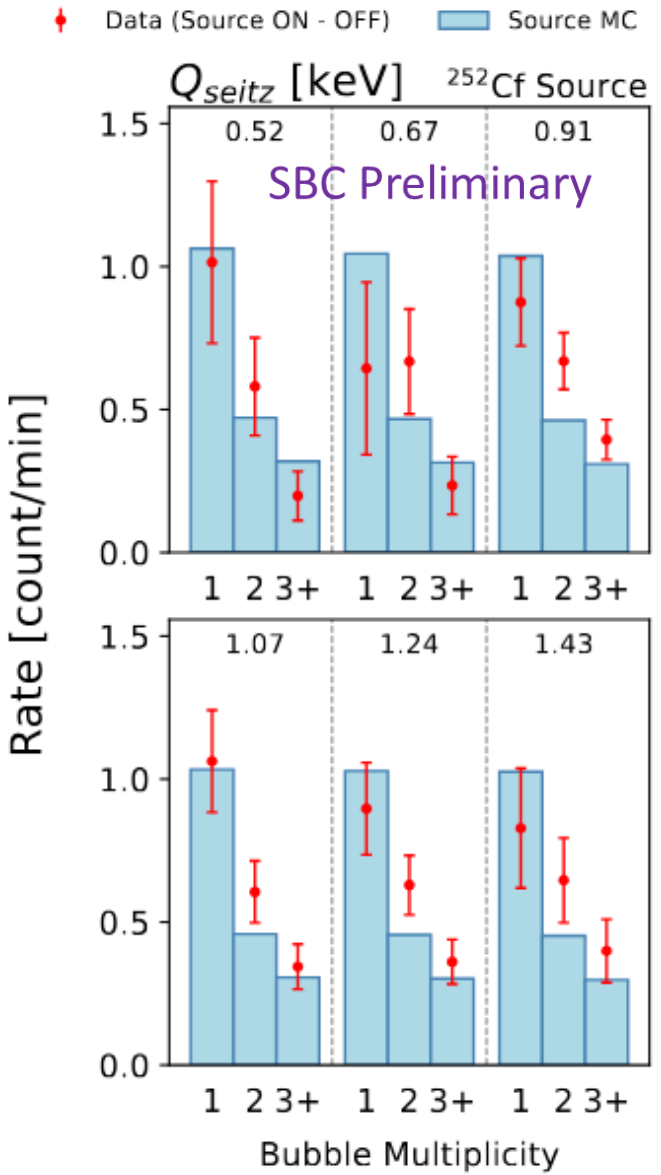
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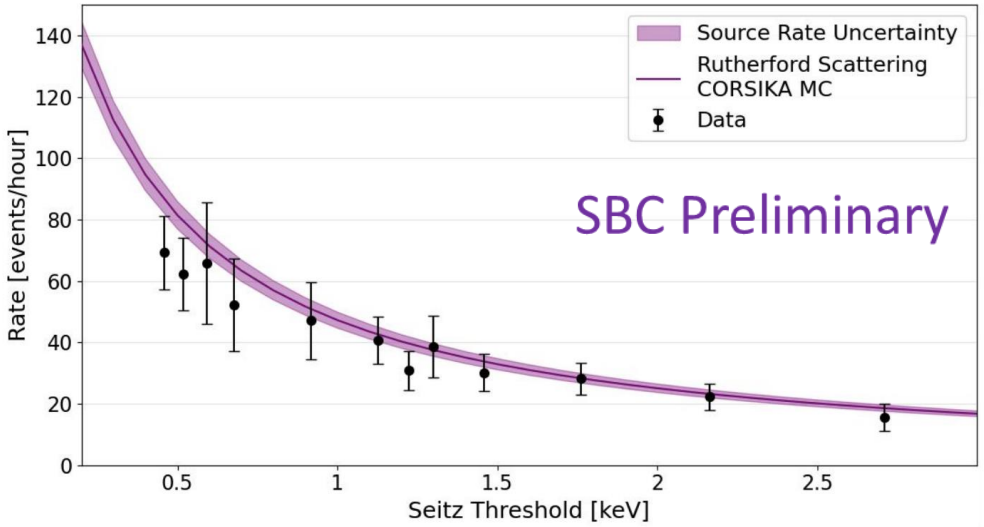
Sensitivity to ^{252}Cf Neutrons

- Produce bubbles via ^{252}Cf NR
- Multiplicity rates gives threshold information
  - Consistent with Monte Carlo simulation



Sensitivity to Cosmic Muon Rutherford Scattering





- Cosmic muons
  - Bright events observed by SiPMs
  - Bubble rate
    - Rutherford scattering

$$\lambda_{\mu}^{LAr} \approx 40\ cm \times \frac{T_{th}}{1\ keV}$$

- Calibrate data:

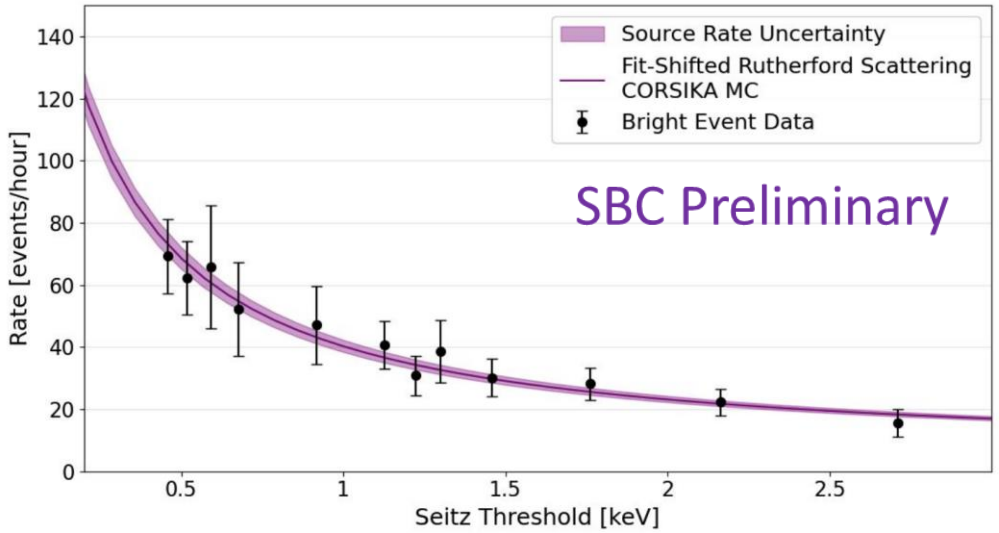
$$R_{\text{data}}(T_{th}) = R_{\text{MC}}(A \times T_{th}) + B$$

$$A = 1.40 \pm 0.31$$

$$B = 5.11 \pm 5.38\ \text{events/hr}$$

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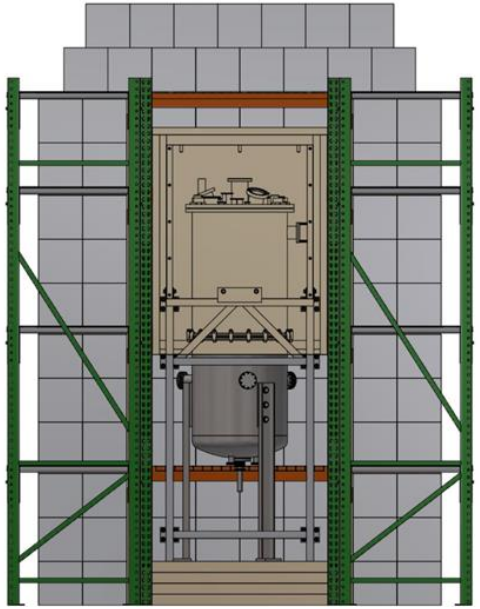
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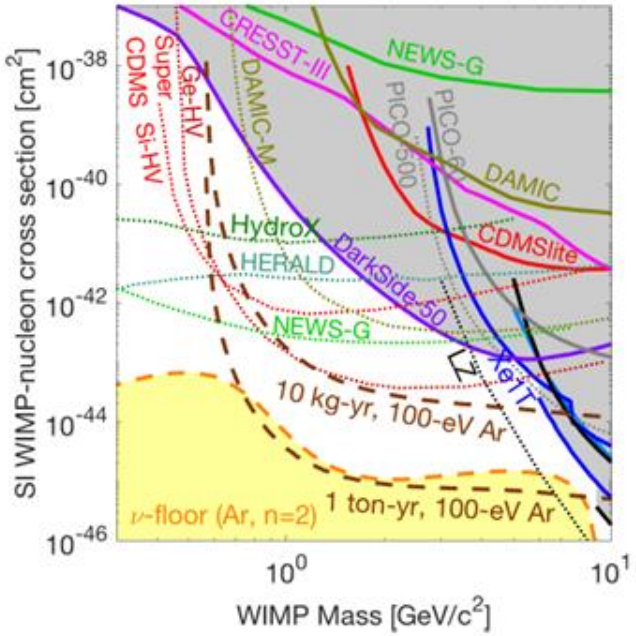
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SBC-SNOLAB

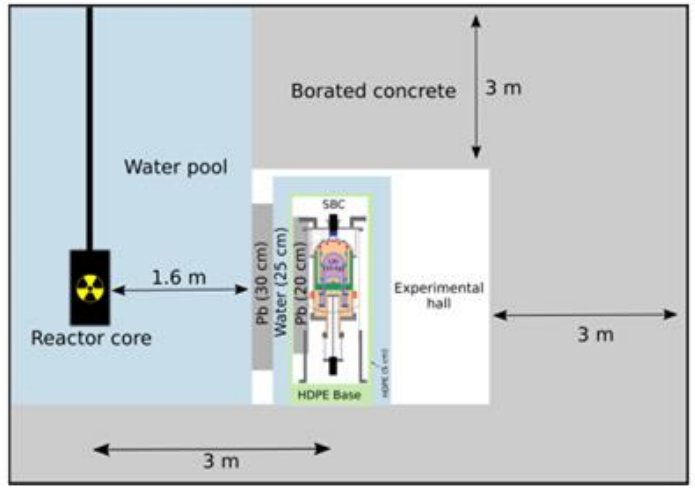
- SBC-LAr10: calibration
- SBC-SNOLAB:
  - SNOLAB, 2 km / 6,800 ft underground, Canada
  - Improved design and better shielding
  - Formal run searching for WIMPs
    - 100 eV energy threshold

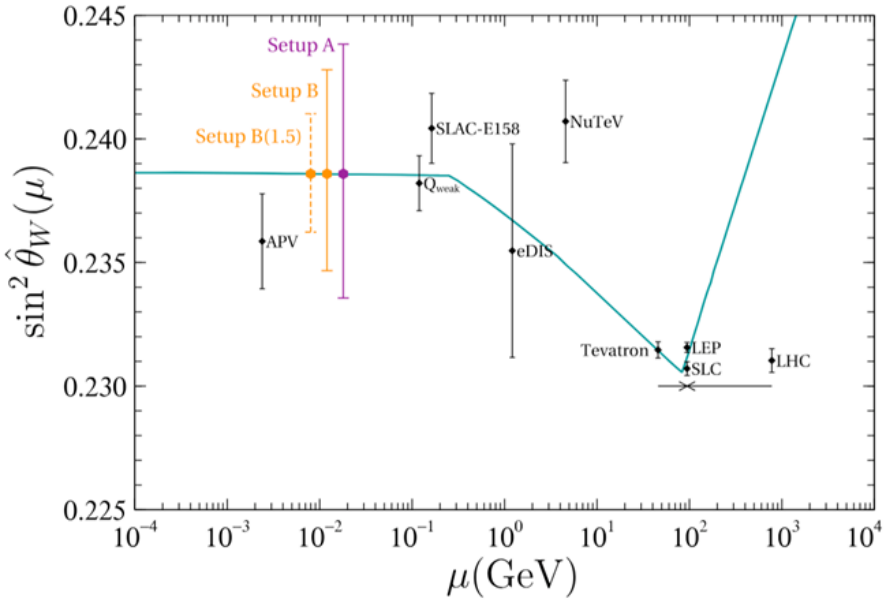




CEνNS Detection via SBC

- 100 eV energy threshold allows CEνNS detection
  - Reactor at National Institute for Nuclear Research (ININ) near Mexico City
  - Weak mixing angle
- Phys. Rev. D 103, L091301





Conclusion

- SBC can reach O(100) eV energy threshold NR detection
  - Dark matter via elastic scattering: M_χ ~ GeV
  - Neutrino via CEνNS: E_ν ~ MeV
- SBC-LAr10 at Fermilab has completed the first calibration run
  - Gamma rejection: 10^{-7} per keV energy deposited at 1 keV threshold
  - Bubble multiplicity calibration
  - Threshold calibration based on cosmic muon Rutherford scattering
- Paper on the first results is in preparation!
- SBC prospects:
  - Dark matter search in SNOLAB
  - CEνNS measurement from reactor

U.S. DEPARTMENT OF ENERGY
Office of Science

NSF

NSERC CRSNG

INNOVATION
Canada Foundation for Innovation
Fondation canadienne pour l'innovation

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Ilan Levine
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Ken Clark
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Carter Garrah
Gary Sweeney
Jonathan Corbett
Ezri Wyman
Jack Walker
Lydia Magurn
Sean Hughson
Koby Dering
Nicholas Moss
Carsten Krauss

Drexel University

Russell Neilson
Daniel Pyda
Jake Curran
Olivia Chiarini

UC Santa Barbara

Hugh Lippincott
Ryan Zhang

Fermilab

Gray Putnam
Daniel

SNOLAB

Jeter Hall
Reg Castilloux

Pacific Northwest NATIONAL LABORATORY

Christopher Jackson

PennState

Shashank Priya

UC RIVERSIDE

Shawn Westerdale

Northeastern ILLINOIS UNIVERSITY

Orin Harris

Université de Montréal

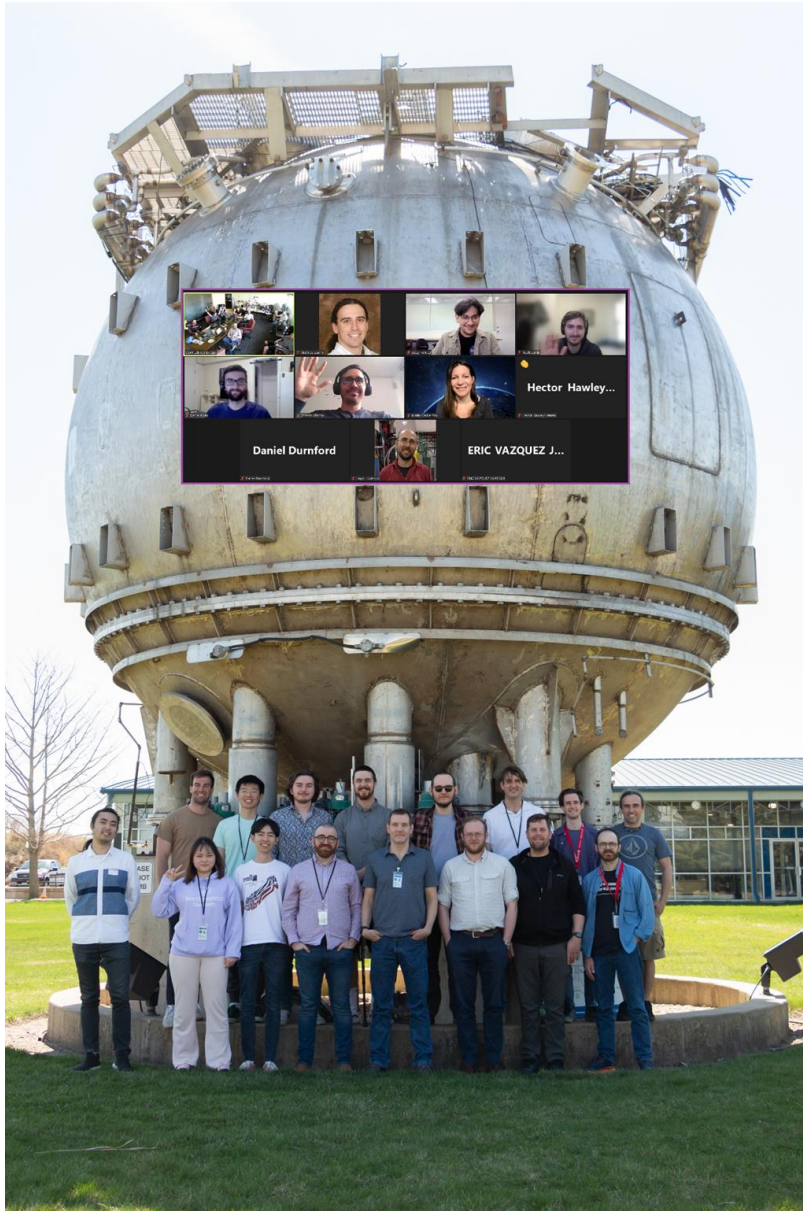
Mathieu Laurin

TRIUMF

Pietro Giampa

UNIVERSITY OF ALBERTA

Carsten Krauss

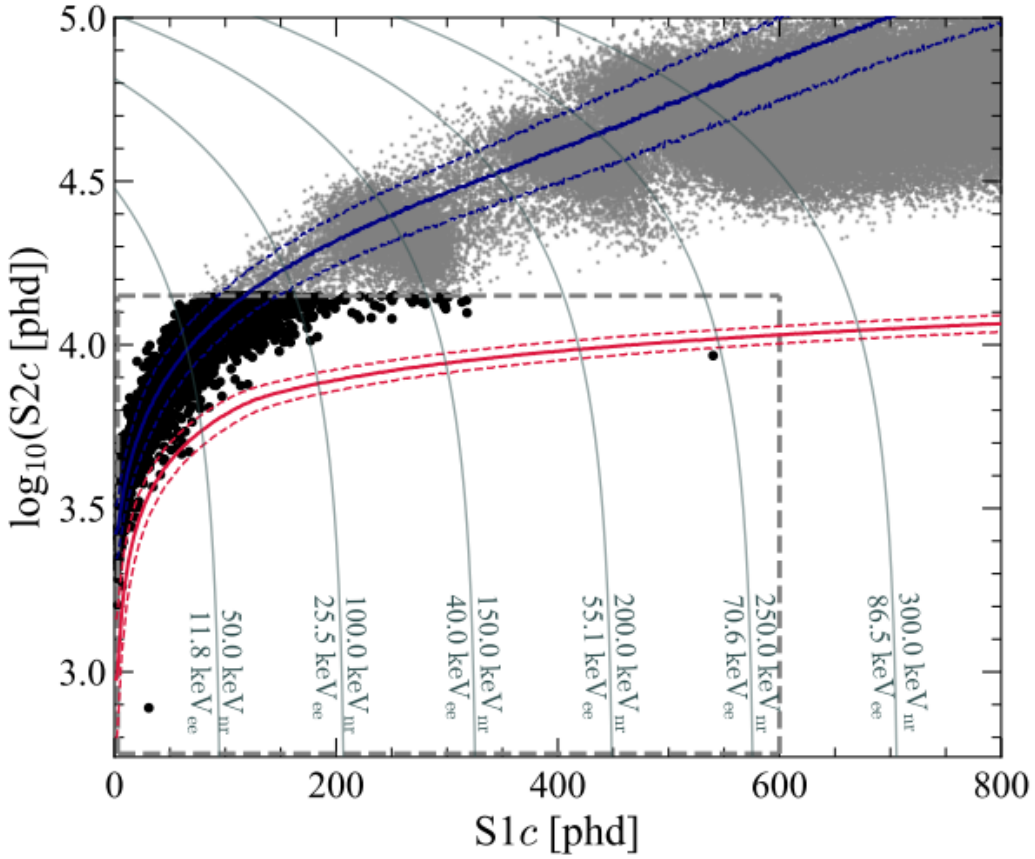


CPAD 2026

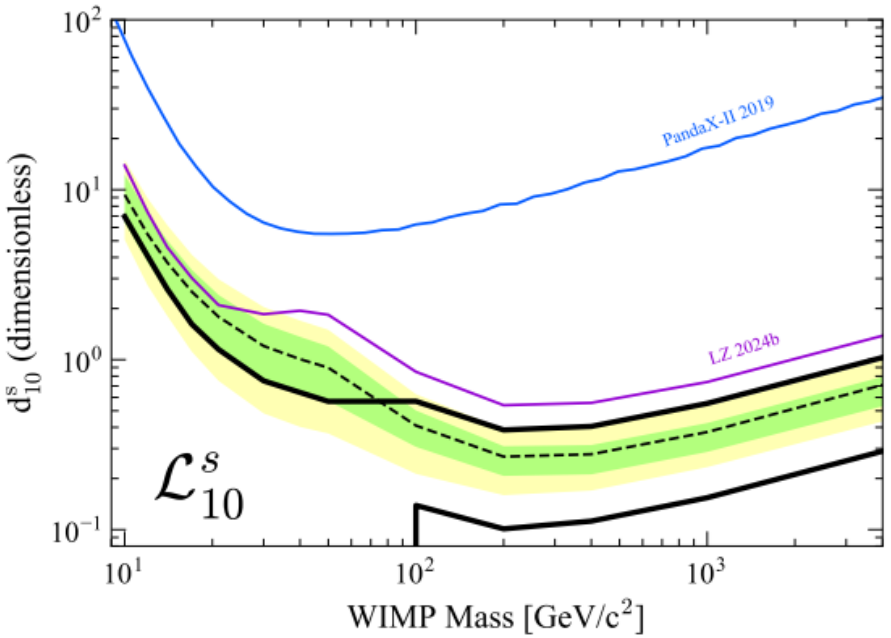
UC SANTA BARBARA

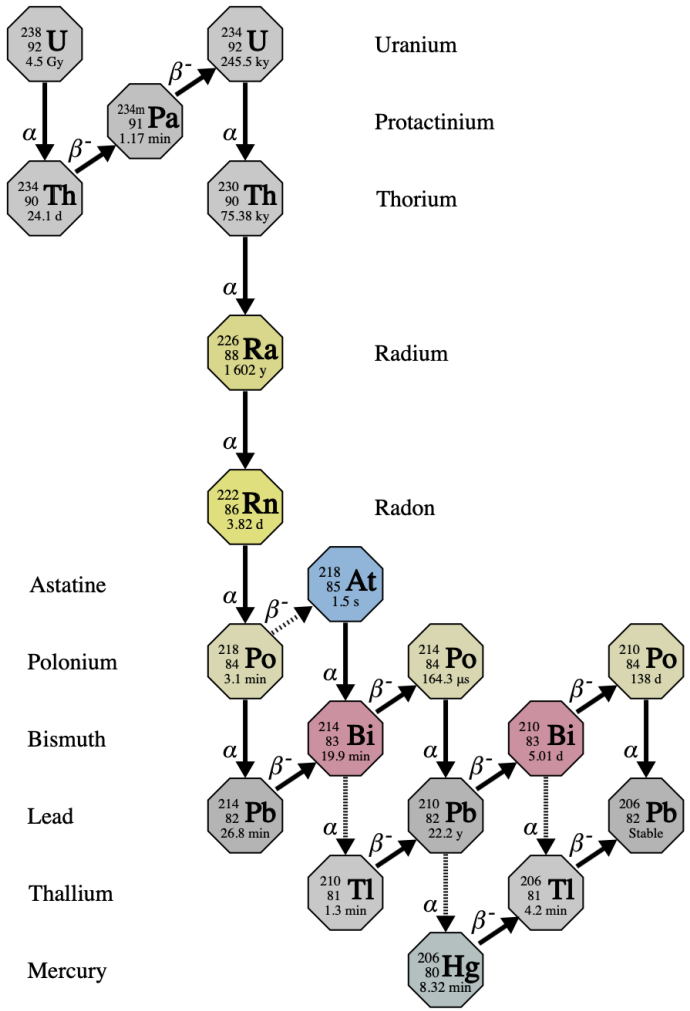
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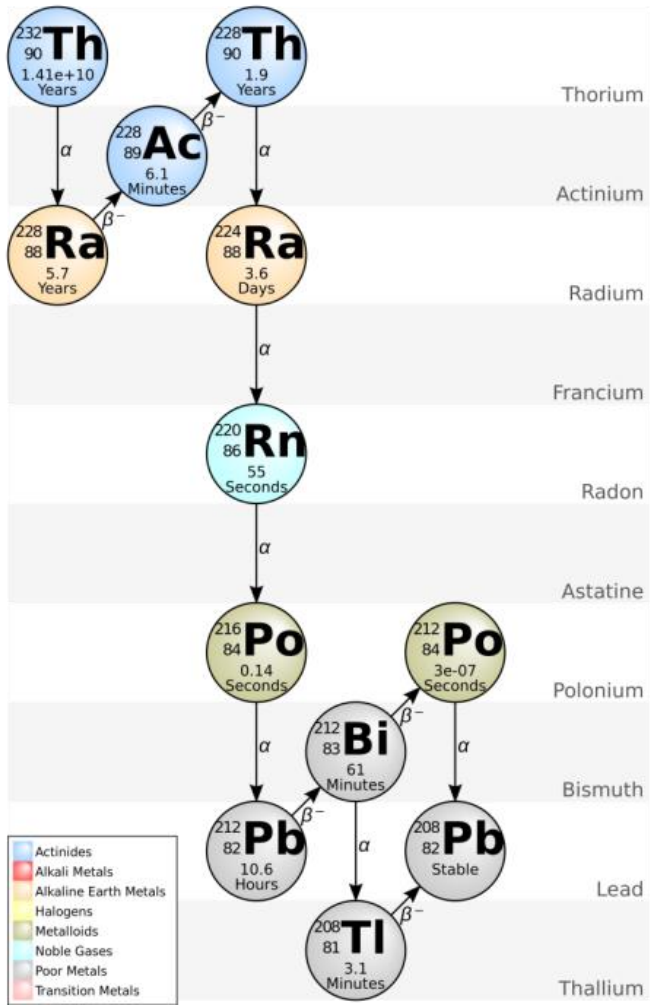
Backup Slides

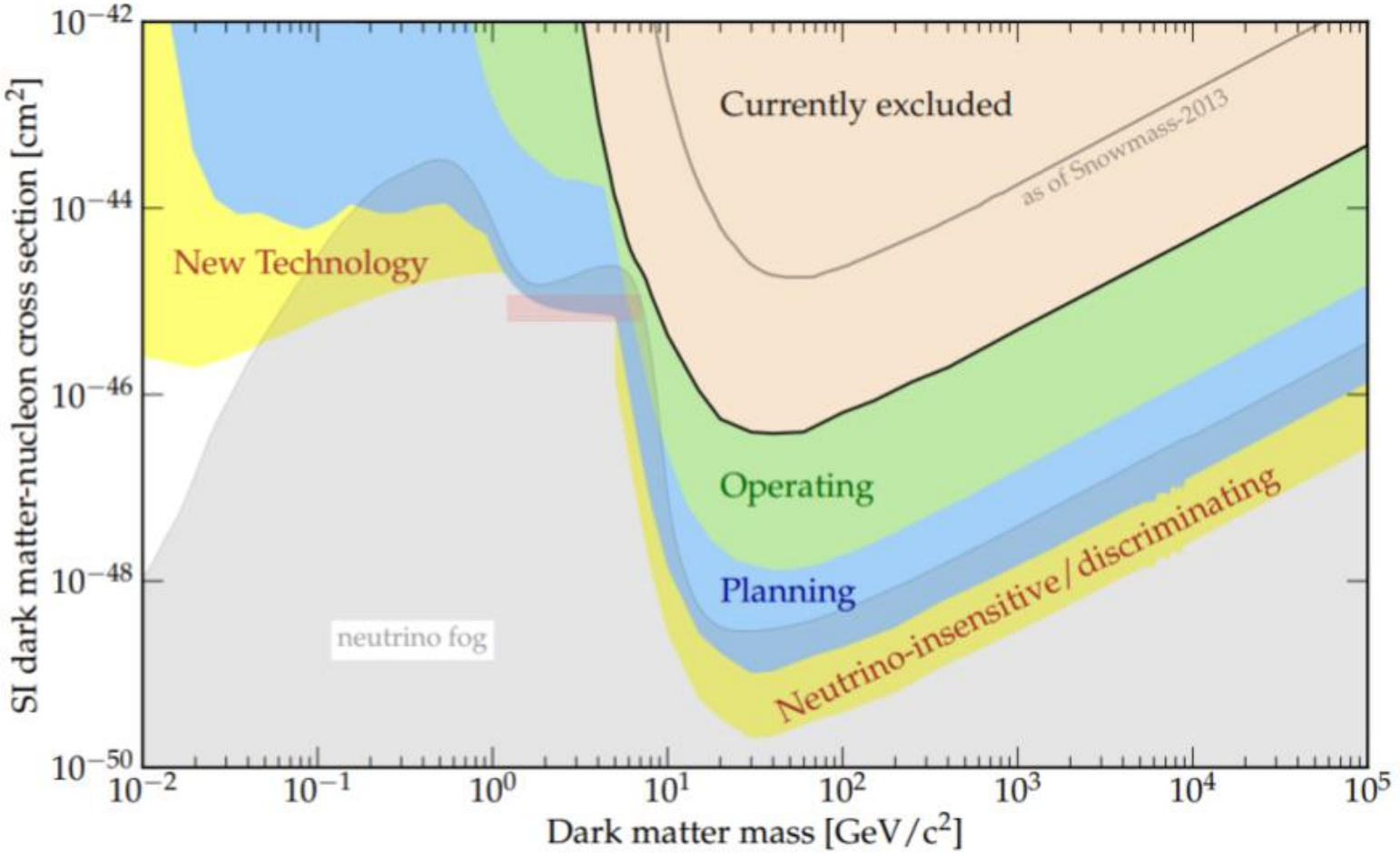


100 GeV/c*2 DM elastic scattering:
~ 200 keV NR SBC able to detect it




238 92 U 4.5 Gy
234m 91 Pa 1.17 min
234 92 U 245.5 ky
234 90 Th 24.1 d
230 90 Th 75.38 ky
226 88 Ra 1 602 y
222 86 Rn 3.82 d
218 85 At 1.5 s
218 84 Po 3.1 min
214 84 Po 164.3 µs
210 84 Po 138 d
214 83 Bi 19.9 min
210 83 Bi 5.01 d
214 82 Pb 26.8 min
210 82 Pb 22.2 y
206 82 Pb Stable
210 81 Tl 1.3 min
206 81 Tl 4.2 min
206 80 Hg 8.32 min
Uranium
Protactinium
Thorium
Radium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Mercury

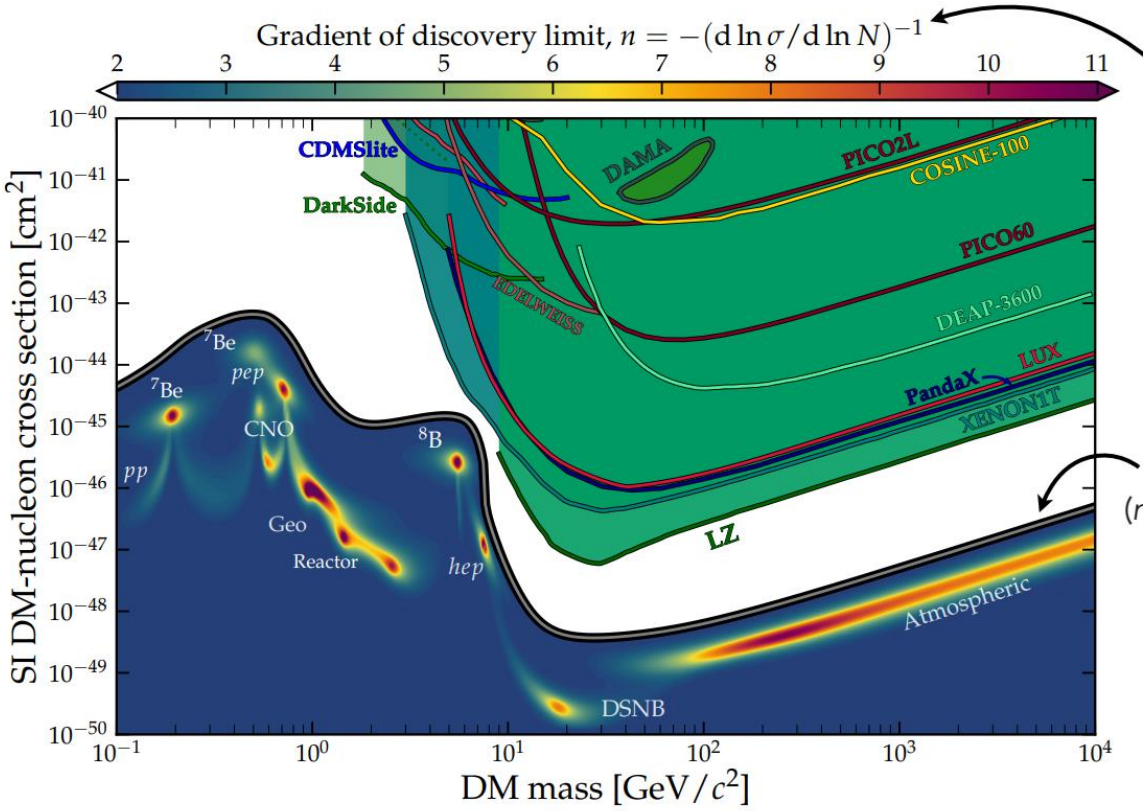

232 90 Th 1.41e+10 Years
228 90 Th 1.9 Years
228 89 Ac 6.1 Minutes
228 88 Ra 5.7 Years
224 88 Ra 3.6 Days
220 86 Rn 55 Seconds
216 84 Po 0.14 Seconds
212 84 Po 3e-07 Seconds
212 83 Bi 61 Minutes
212 82 Pb 10.6 Hours
208 82 Pb Stable
208 81 Tl 3.1 Minutes
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Actinides
Alkali Metals
Alkaline Earth Metals
Halogens
Metalloids
Noble Gases
Poor Metals
Transition Metals

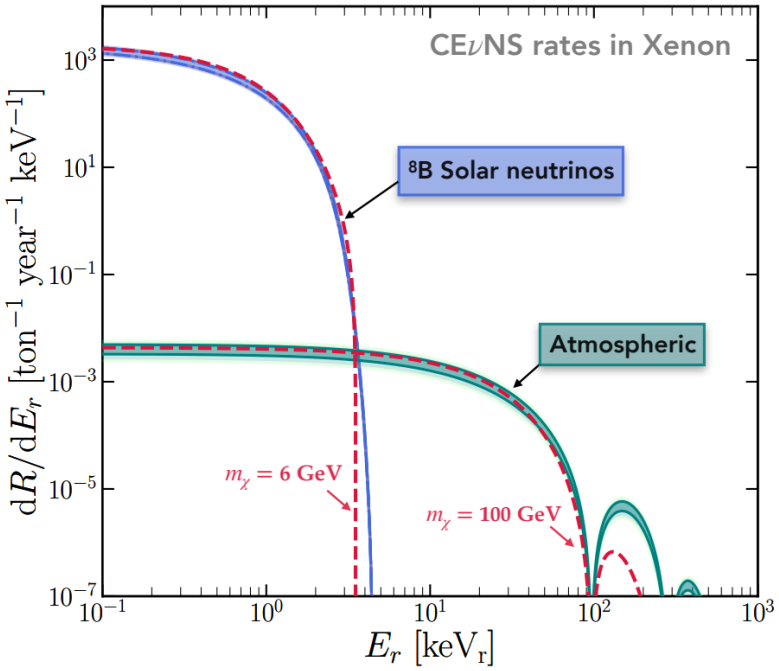


$$\frac{dR}{dE} = \frac{\rho_{DM}\sigma_i|F(E)|^2}{2m\mu^2}\int_{v>v_{min}}\frac{f(\vec{v},t)}{v}d^3v$$

$$v_{min} = \sqrt{ME/2\mu^2}$$

https://indico.global/event/6083/contributions/50030/attachments/24952/42709/nufog.pdf

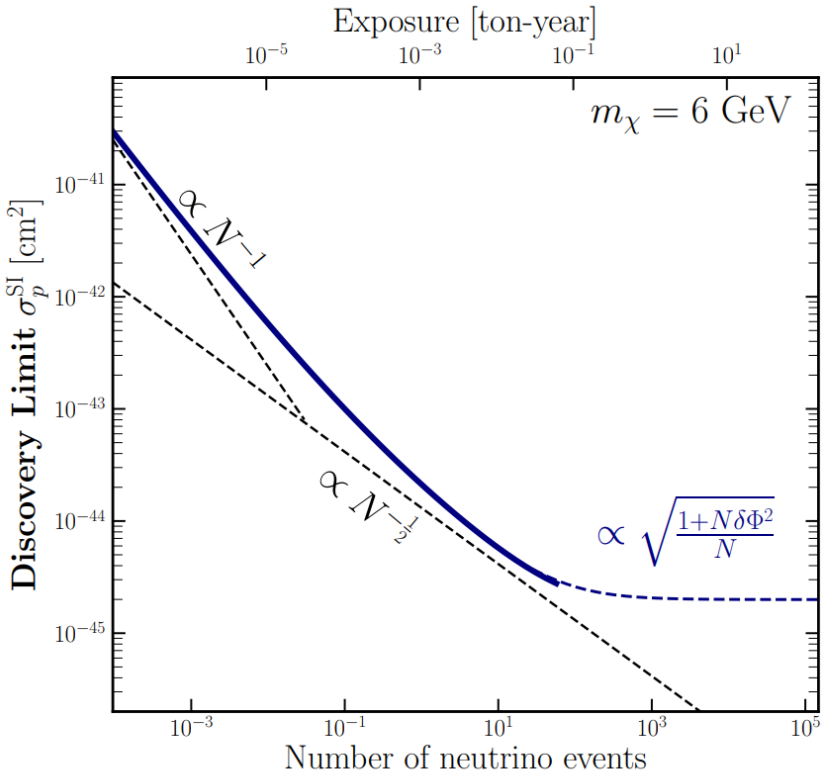




Why is there a neutrino "floor"?

^{8}B solar and atmospheric neutrinos generate NR spectra through CEνNS that look near-identical to O(1) GeV and O(100) GeV mass DM respectively

https://indico.global/event/6083/contributions/50030/attachments/24952/42709/nufog.pdf



The neutrino "floor"

← Scaling of sensitivity as experiment's exposure increases. If there are no problematic backgrounds this should go like $\sigma \sim 1/\sqrt{N}$ for $N \gtrsim 1$ background events

→ Experiment can't claim discovery of a DM model that creates an excess in events smaller than the expected level of systematic background fluctuations

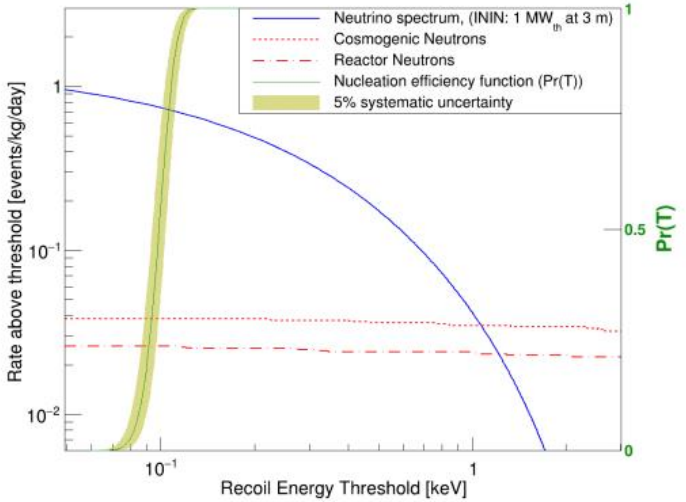
(Billard et al. 2013)

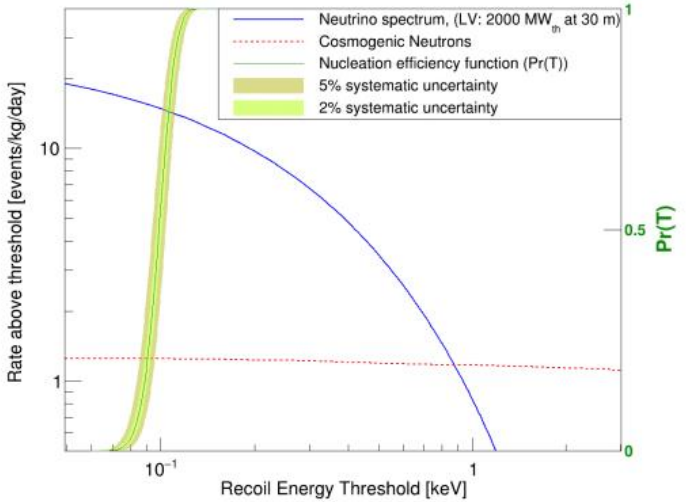
The physics reach of the setups described above is investigated for a one-year exposure. The SM cross-section for CEνNS, after neglecting the axial contribution, is:

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right) F^2(q^2), \qquad (2)$$

where T is the nuclear recoil energy, E_ν the incoming neutrino energy, $F(q^2)$ the nuclear form factor, $Q_w = Zg_p^V + Ng_n^V$ is the weak nuclear charge and M_N, Z, N are the nuclear mass, proton, and neutron number of the detector material, respectively. The cross-section uncertainty. The weak mixing angle can be extracted from the CEνNS differential cross-section through the SM weak coupling $g_p^V = 1/2 - 2\sin^2\theta_W$. A fit using

$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos\theta_w & \sin\theta_w \\ -\sin\theta_w & \cos\theta_w \end{pmatrix} \begin{pmatrix} B^0 \\ W^0 \end{pmatrix}.$$ [3]





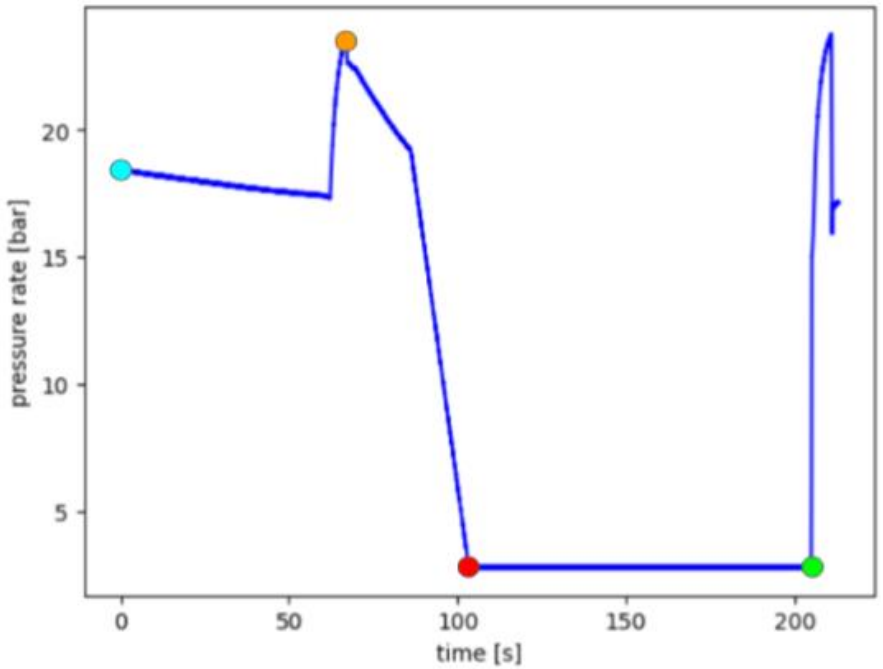
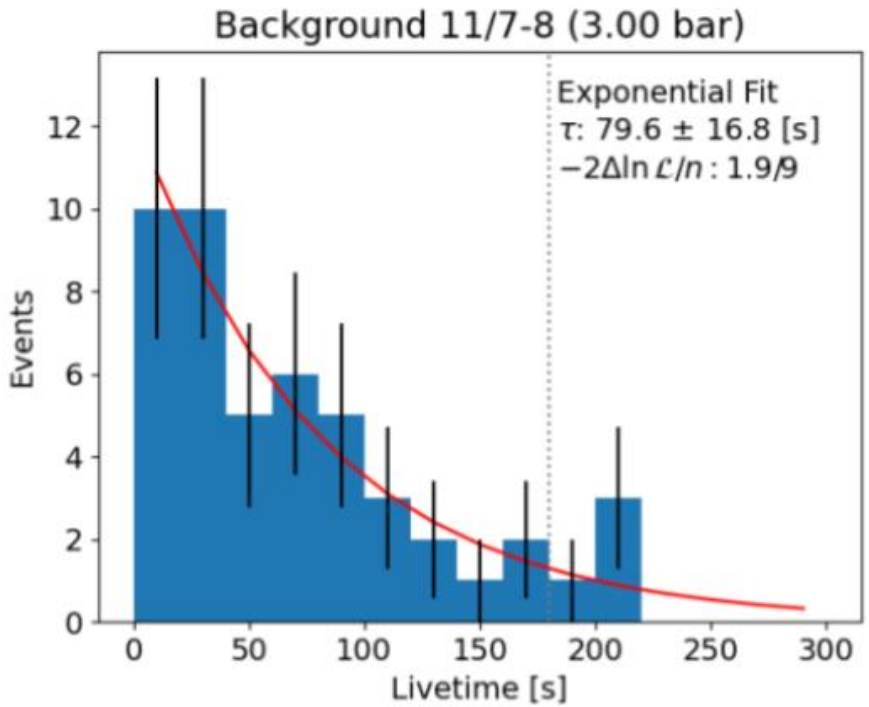


Figure 3.3: An example of pressure cycling. Expansion begins at the orange dot; the pressure is reduced until the chamber achieves superheated status, denoted by the red dot at ($t_{\text{superheated}}$). The bubble chamber stays in the superheated fluid until bubble formation at t_0 (green dot). The control system responds immediately and rapidly compresses the bubble chamber up to 25 bara. The pseudo expansion state starts at cyan dot to monitor the residual micro-bubble growth and dissipate energy by fast compression. Then the system is re-compressed to be ready for expansion in the next pressure cycle.

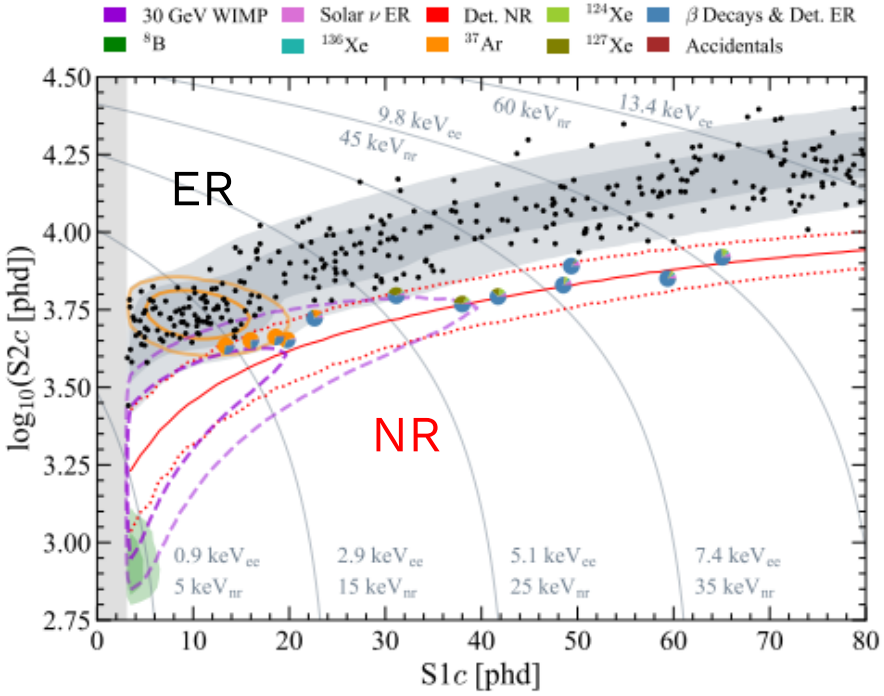
$$P(N;T_{\text{live}}) = \frac{(RT_{\text{live}})^N e^{-RT_{\text{live}}}}{N!}$$



- Electron recoil (ER) is a huge background for dark matter search

- Bubble chamber has inherent advantages for the ER rejection
  - ER cannot deposit enough energy locally -no bubbles

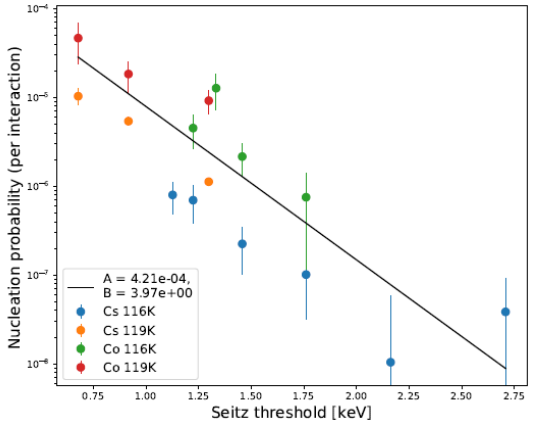
- Important to evaluate the gamma rejection rate

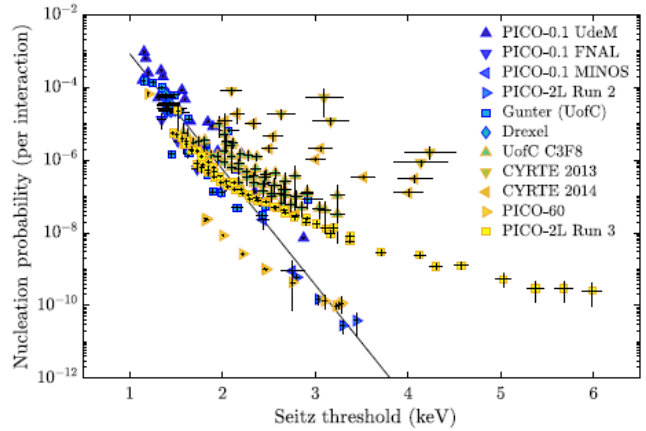


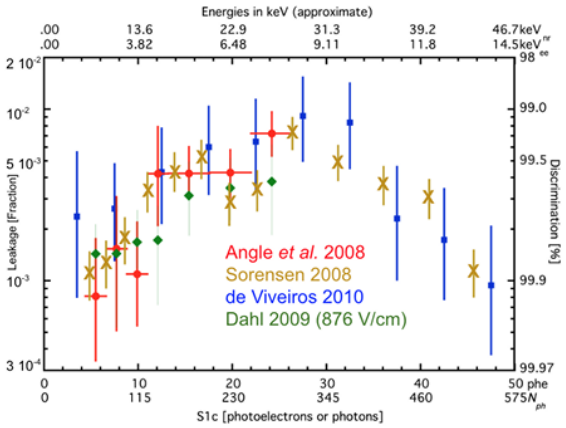
LZ: arxiv.org/abs/2211.17120

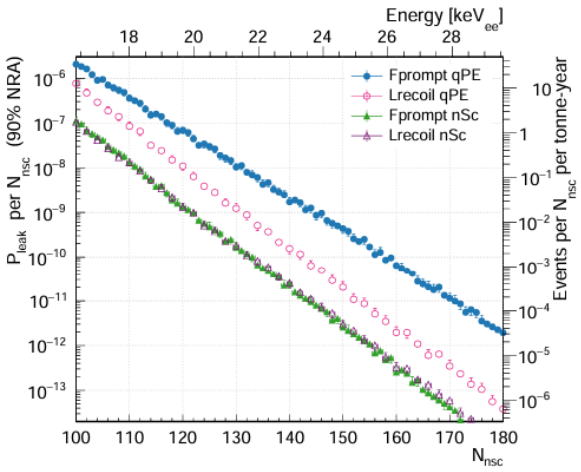
Gamma Rejection Analysis

- Still world leading rejection under keV than any other other experiments so far
  - Current SBC 10^{-5}
  - PICO 10^{-3}
  - LZ ~ 10^{-3} at ~ 5 keV
  - DarkSide 10^{-6} at 72 keV_{nr} [12] (18 keV_{ee}).
- Cannot proceed to neutron calibrations without solving it
  - Requires 10^{-8} gamma rejection rates



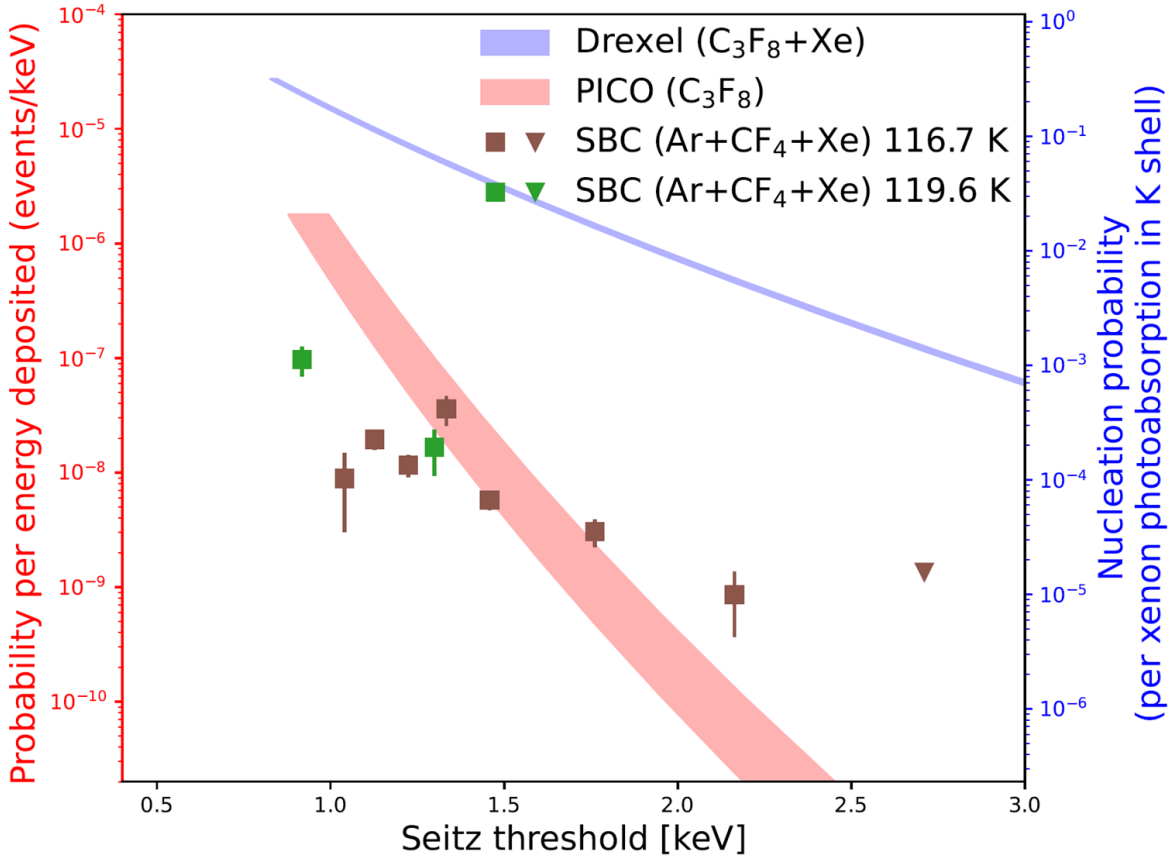


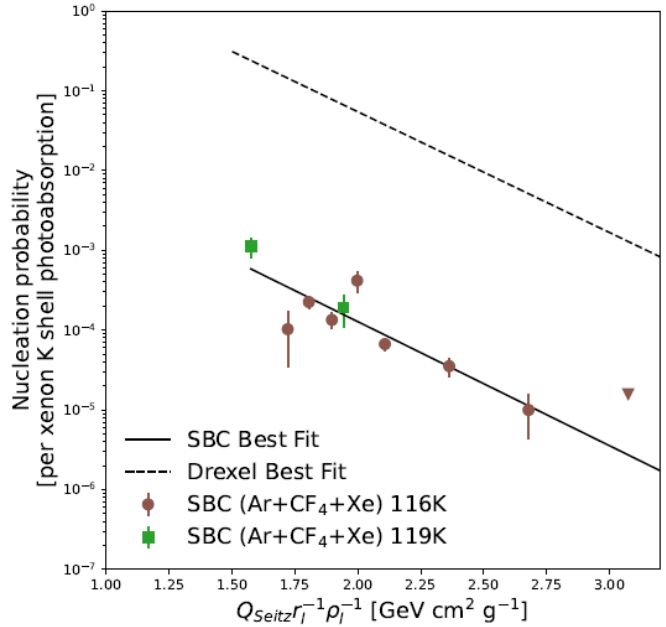




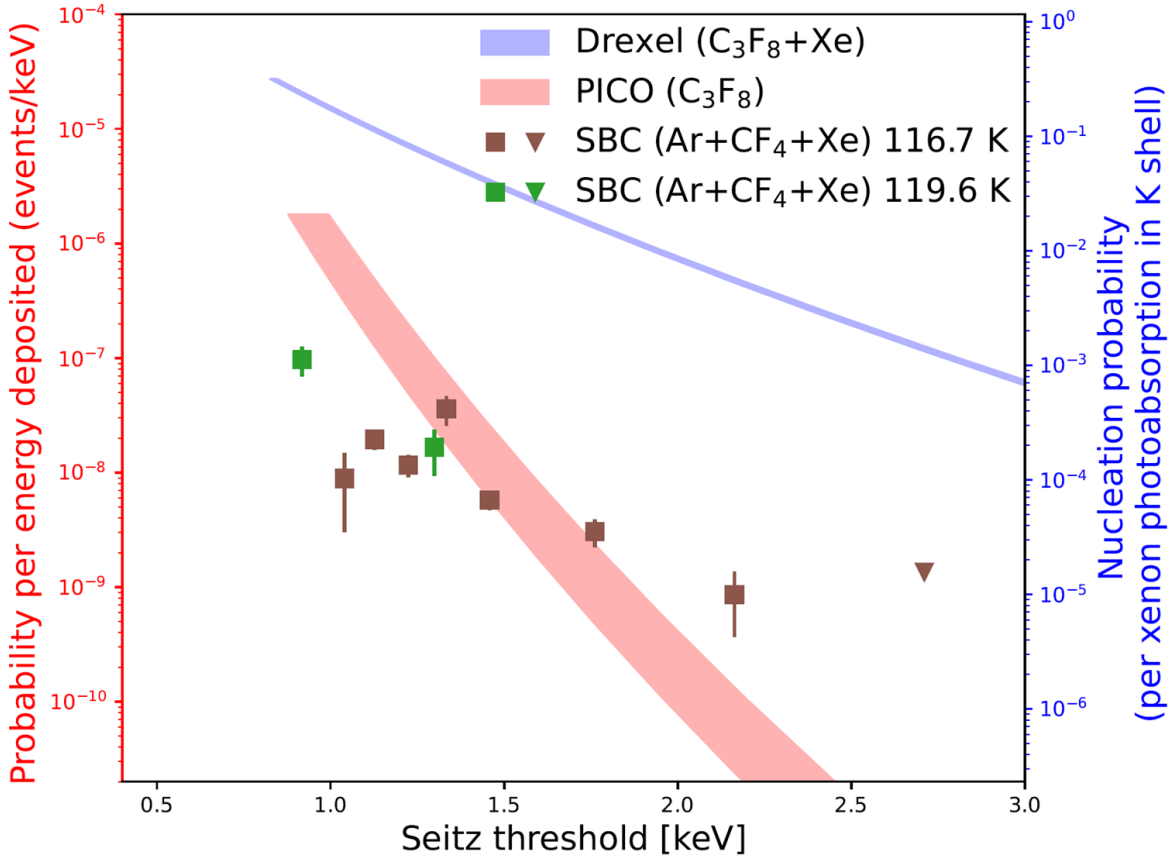
SBC ER rejection (top left); PICO ER rejection (top right); LZ ER leakage (bottom left); DarkSide ER leakage (bottom right)

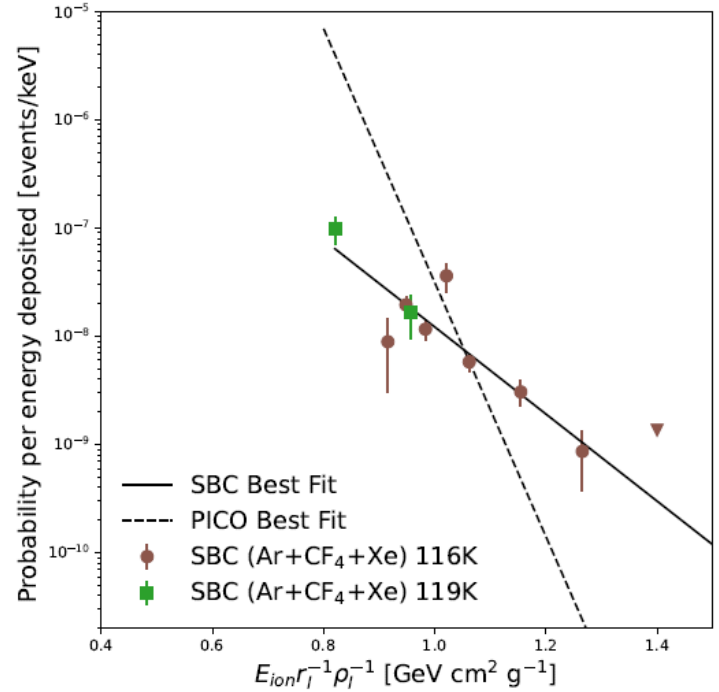
[9] arxiv.org/abs/1905.12522
[10] https://arxiv.org/pdf/2211.10726v3
[11] https://arxiv.org/pdf/2103.12202





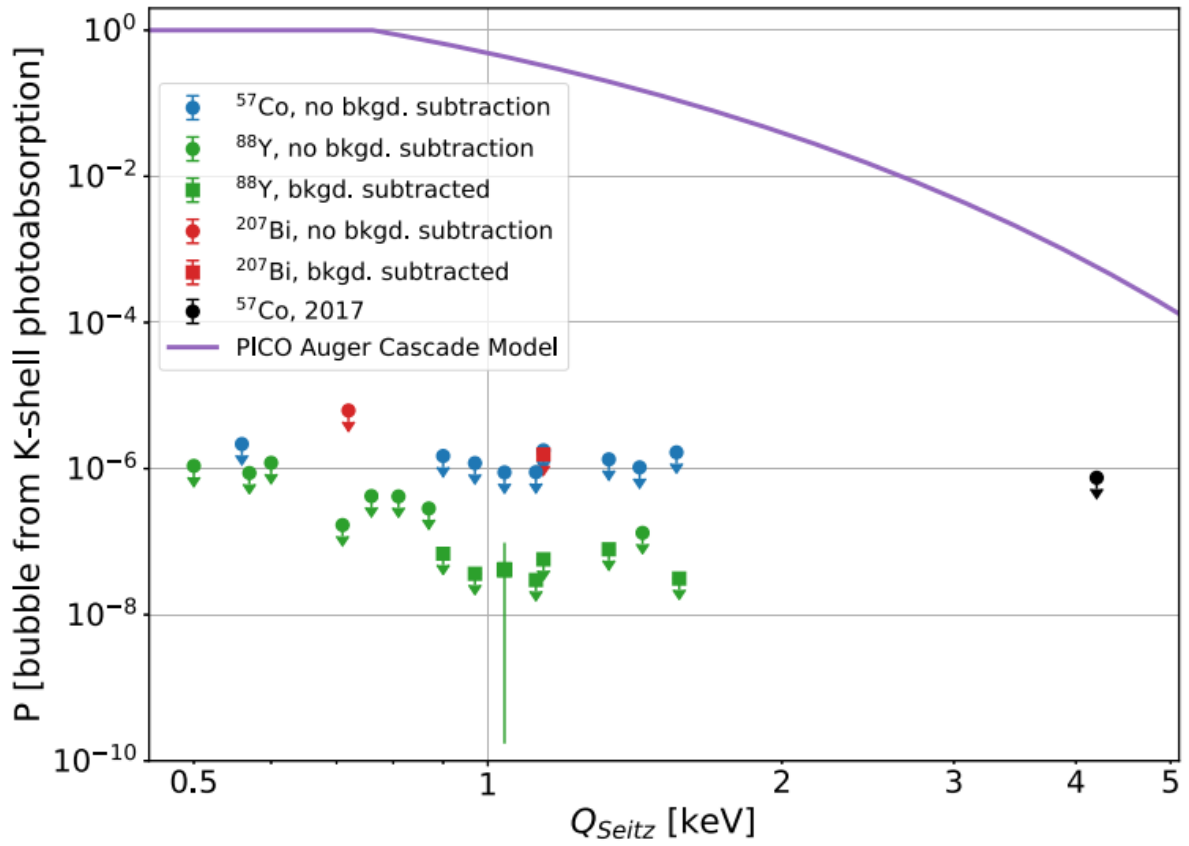
Q stopping power vs per xenon photoabsorption	A [K phot^{-1}]	B^{-1}[GeV cm^2 g^{-1}]	A - DBC [K phot^{-1}]	B^{-1}-DBC [GeV cm^2 g^{-1}]
Values	$1.6*10^{-1}$	0.28	58	0.29
Uncertainty	$10^{\pm 0.66}$	0.07	30	0.02





Eion stopping power vs per keV	A [probability per keV]	B^{-1} [GeV cm^2 g^{-1}]	A -PICO [probability per keV]	B^{-1}-PICO [GeV cm^2 g^{-1}]
Values	$1.3*10^{-4}$	0.11	$1.7*10^{4}$	$3.7*10^{-2}$
Uncertainty	$10^{\pm 0.79}$	0.02	$10^{\pm 0.36}$	$2*10^{-3}$

XeBC gamma rejection:



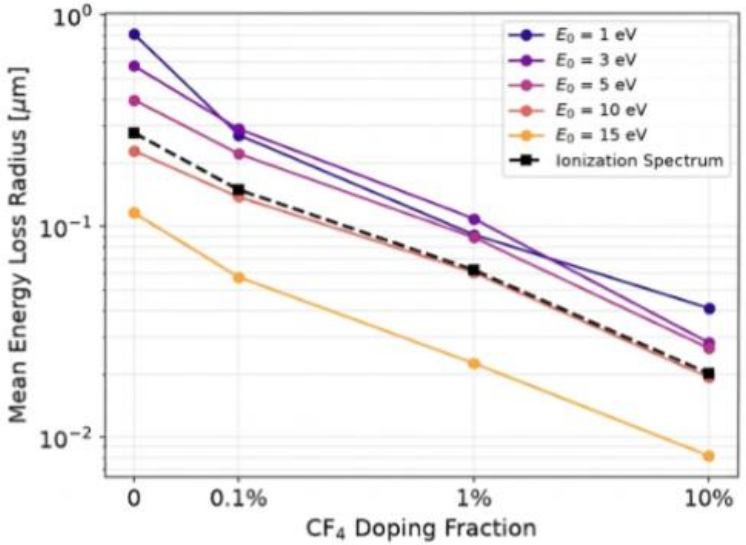
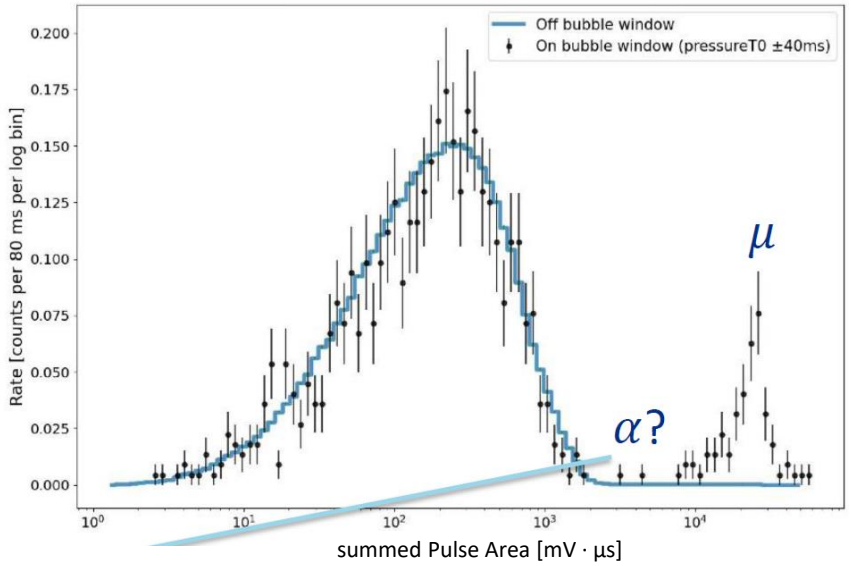
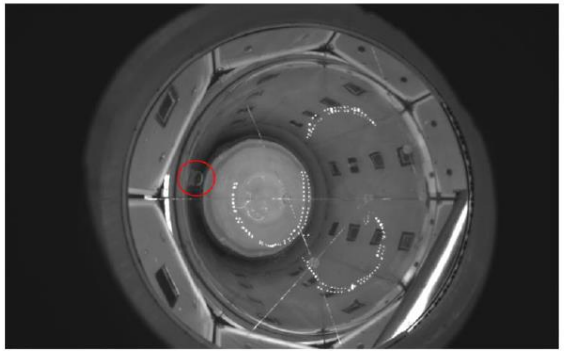


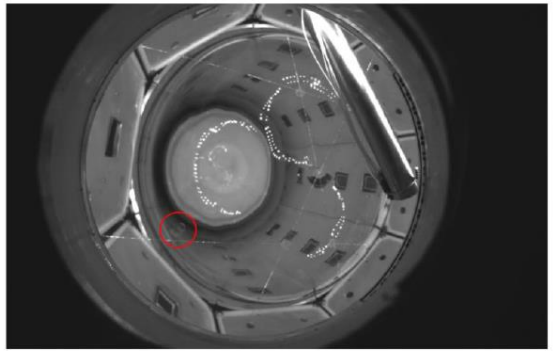
Figure 4.19: Thermalization radius (Mean energy loss radium) as a function of CF_4 doping fraction at different initial δ electron kinetic energy (E_0). The dashed black line (ionization spectrum) represents the averaged δ electron initial kinetic energy taking into account the ionization electron energy spectrum [72].

- Thermalization: CF_4 has shorter thermalization range ; recombine quickly -> higher local energy deposition -> higher bubble production
- TRANSLATE simulation by Gray Putnam
- Y thermal radius

Backgrounds in Scintillation Channel







- Bright muon events
- Wall events by alpha decay
- Rutherford Scattering

$$\frac{d\sigma}{dT} = \frac{2\pi Z_{Ar}^2 e^4 c^2}{M_{Ar}\beta^2 T^2}$$

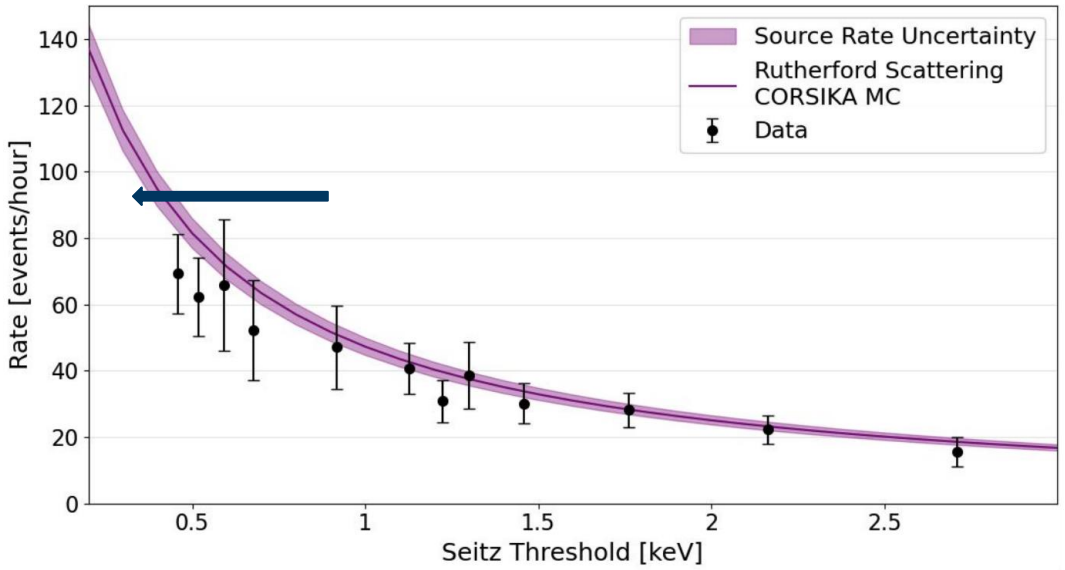
T: recoil energy

β: muon velocity

M_{Ar}: argon mass

Z_{Ar} : argon charge number

Before Fitting:

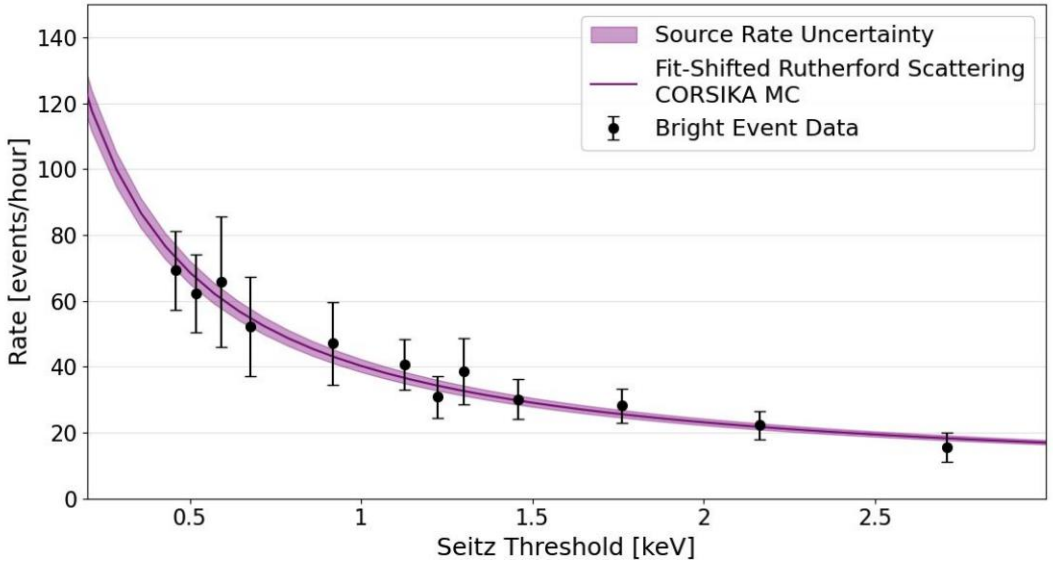


$$R_{\text{data}}(T) = R_{\text{MC}}(A \times T) + B$$

$$A = 1.40 \pm 0.31$$

$$B = 5.11 \pm 5.38$$

After Fitting:



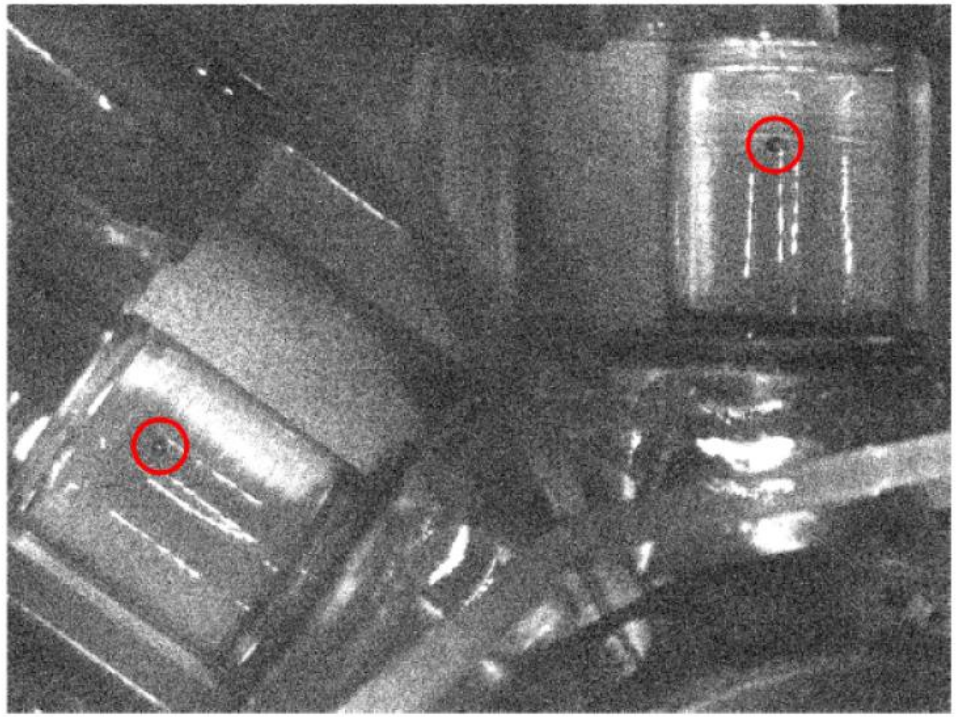
Threshold shift:

- can be caused by the heat dissipation

XeBC Calibration

- Prototype - XeBC
  - 20 g of superheated LXe
  - Calibrated using ^{252}Cf, ^{88}Y-Bi, ^{207}Bi-Be

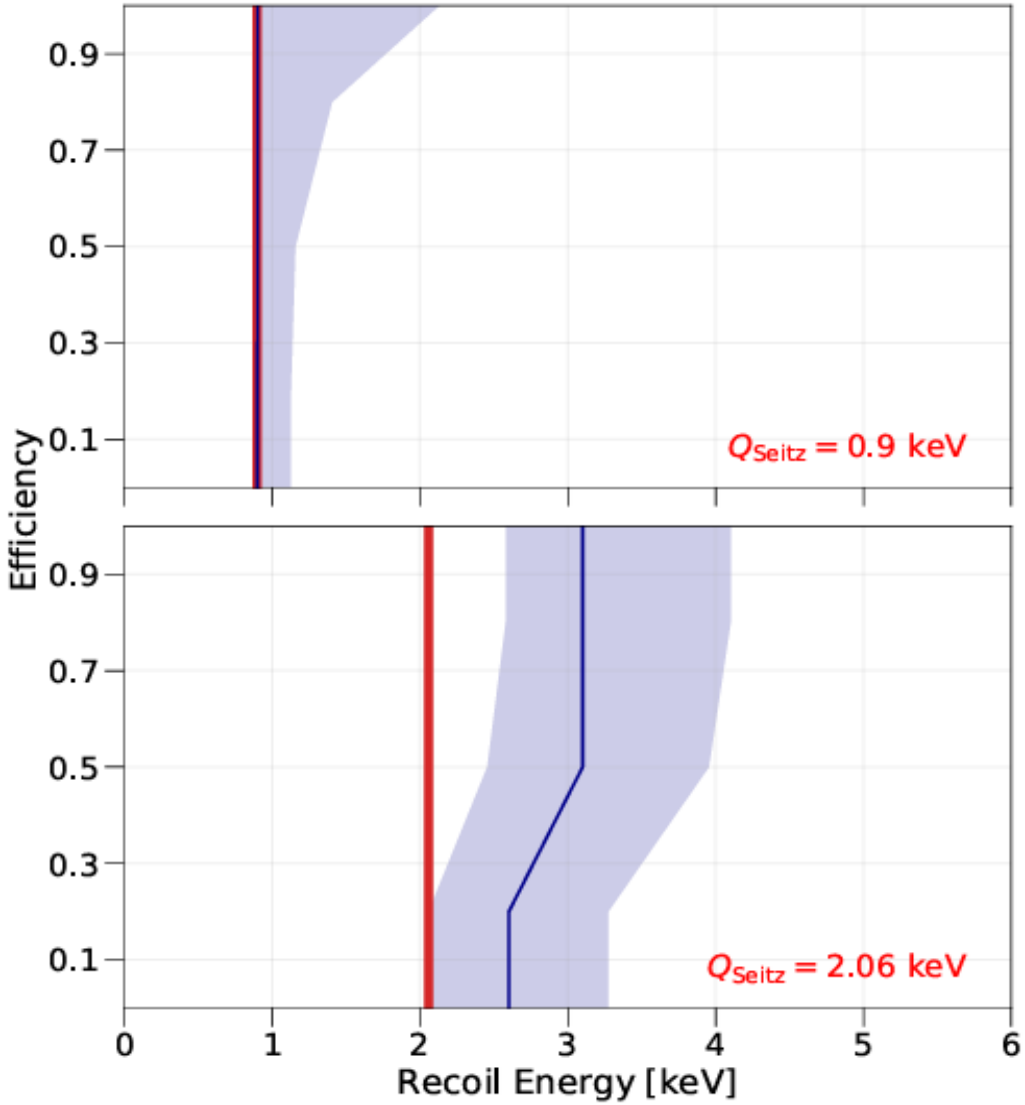
- achieved results to ~1 keV level as displayed at right: arXiv:2410.07241v1



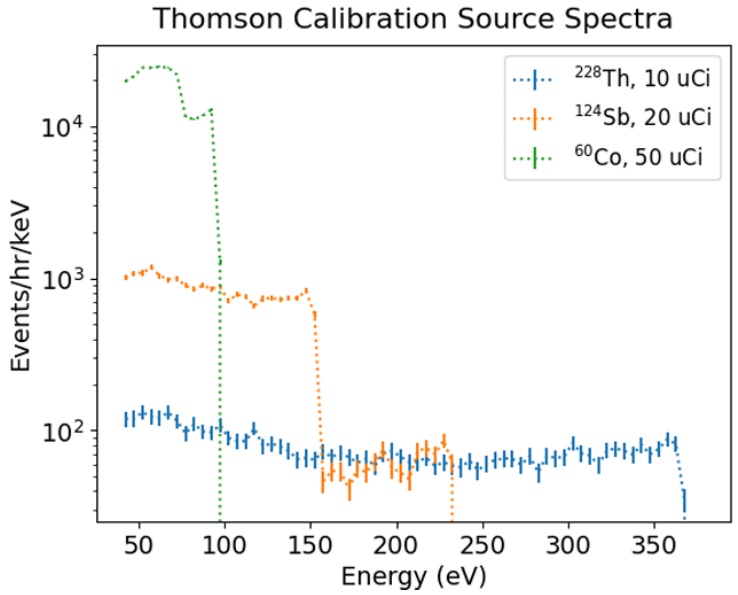
XeBC Calibration

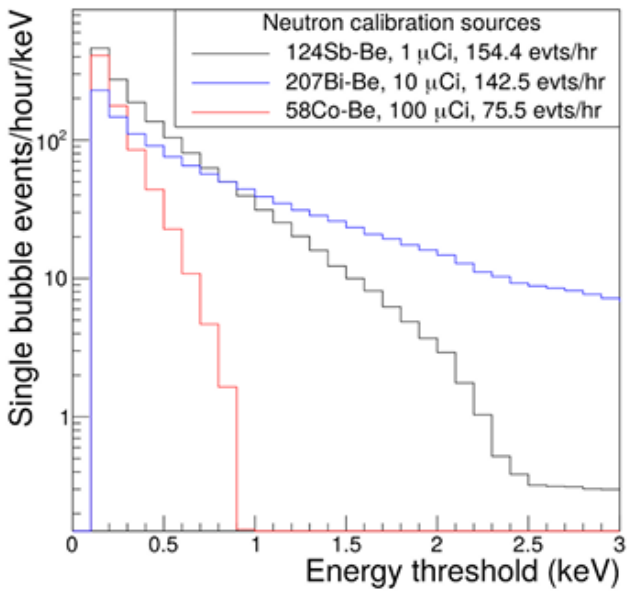
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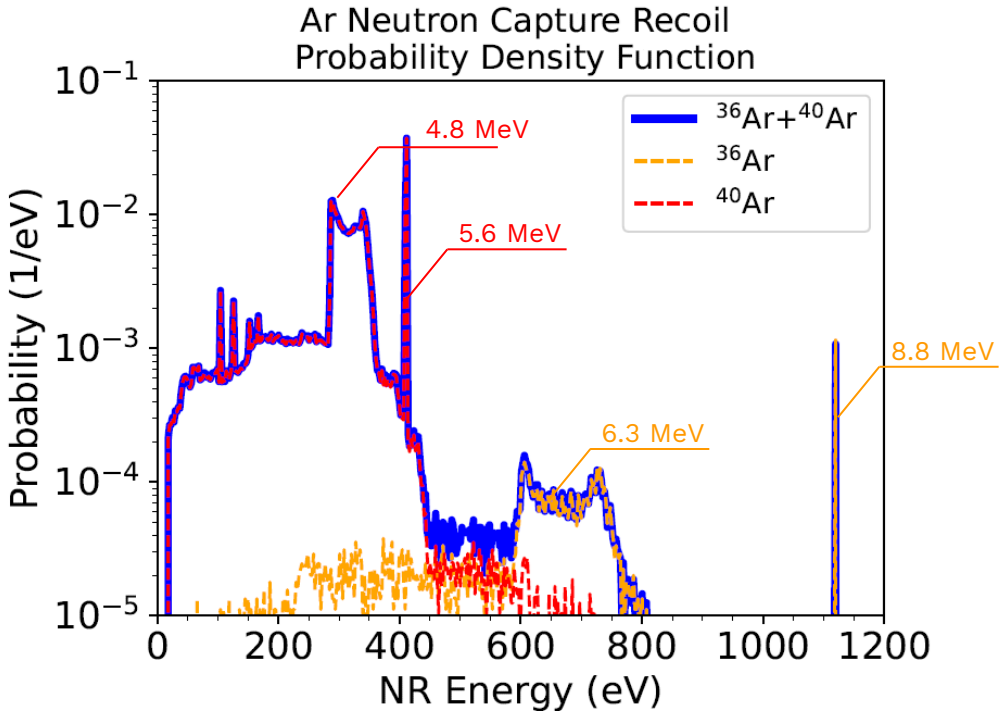
- achieved results to ~1 keV level as displayed at right: arXiv:2410.07241v1



NR Calibration Sources

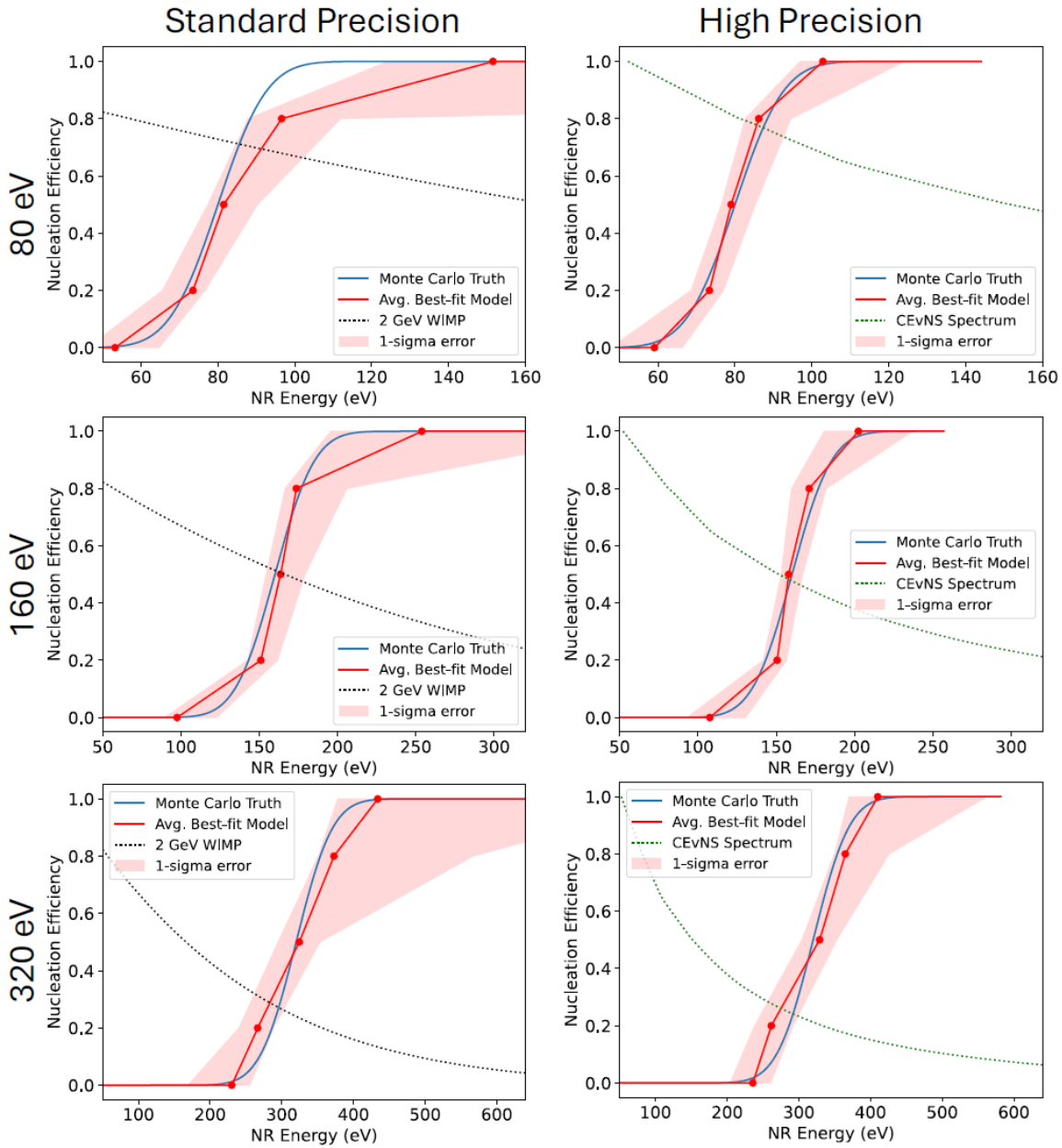






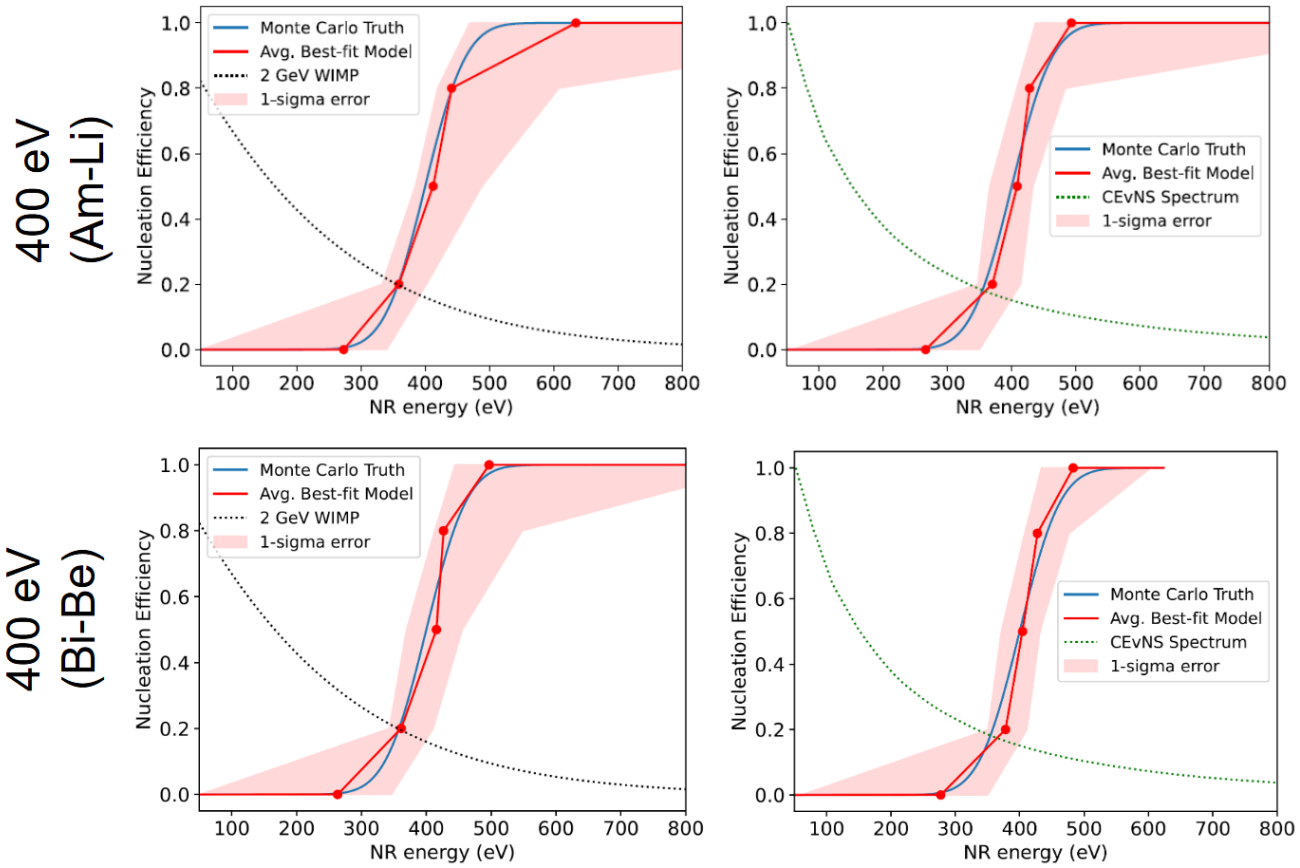
Calibration Robustness Validation

- 5% uncertainty source strength
- External backgrounds: 500 bubble events in 100 hours
- Uncertainty on the predicted dark matter rate
  - Am-Li: 3.7 %
  - Bi-Be: -2 %
- Published on JINST:
  - DOI: 10.1088/1748-0221/21/03/P03020



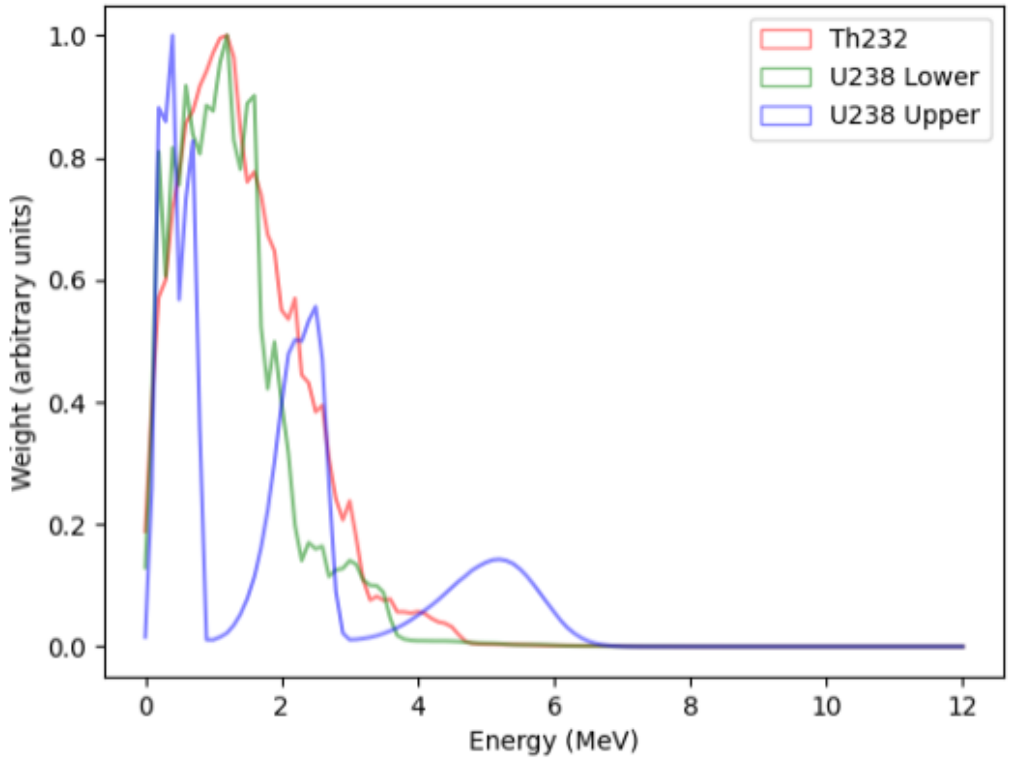
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  - DOI: 10.1088/1748-0221/21/03/P03020



Neutron Backgrounds from Geant4

- Background for Thomson and photo-neutron sources
- Neutron Backgrounds Source:
  - Rock Neutron
    - ^{232}Th
    - ^{238}U
  - Muon-Induced Neutrons
- 1.368- 1.618 single bubble events/hour for MINOS (no shield)




EPO


FPO


FPO