2022/02/15

The Scintillating Bubble Chamber (SBC) Experiment For Dark Matter and Reactor CEvNS

Dr. Pietro Giampa
Research Scientist

@PietroGiampa

SNOLAB

Overview

1. Concept
2. Experiment Design
3. Physics Program
4. Conclusions

1. Concept

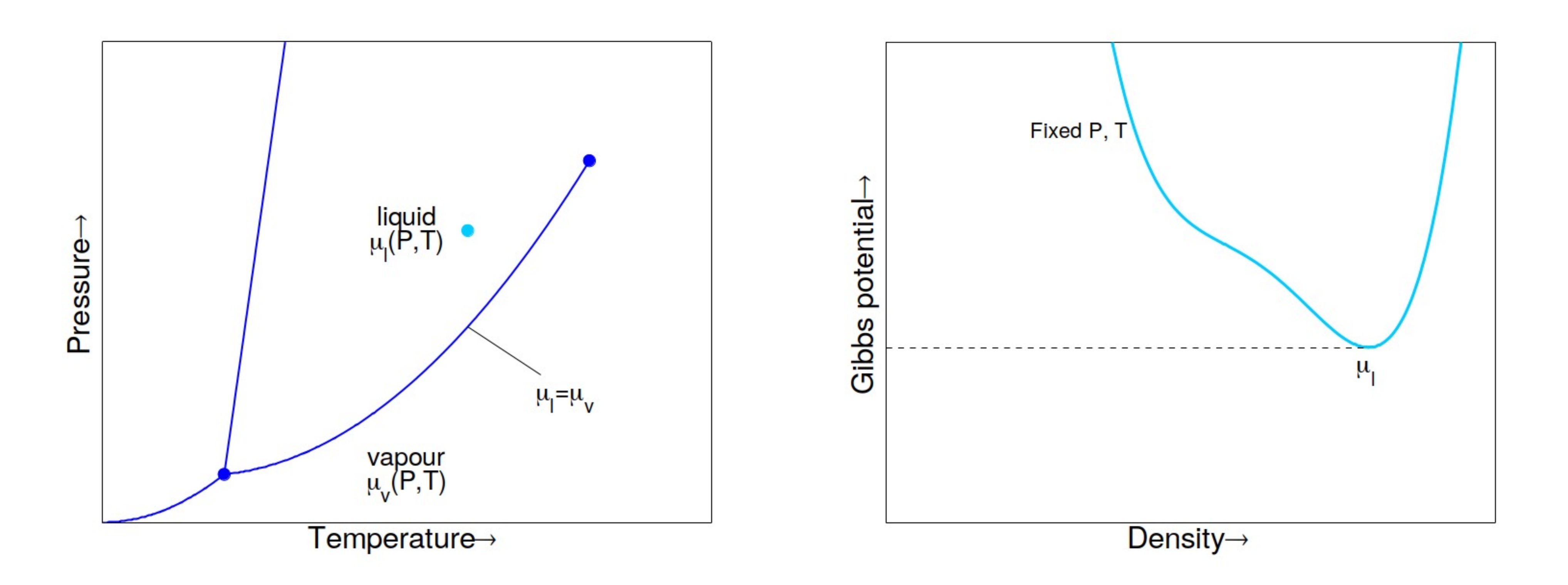
Goals

Key items to consider when designing an experiment to study Dark Matter & CEvNS neutrinos:

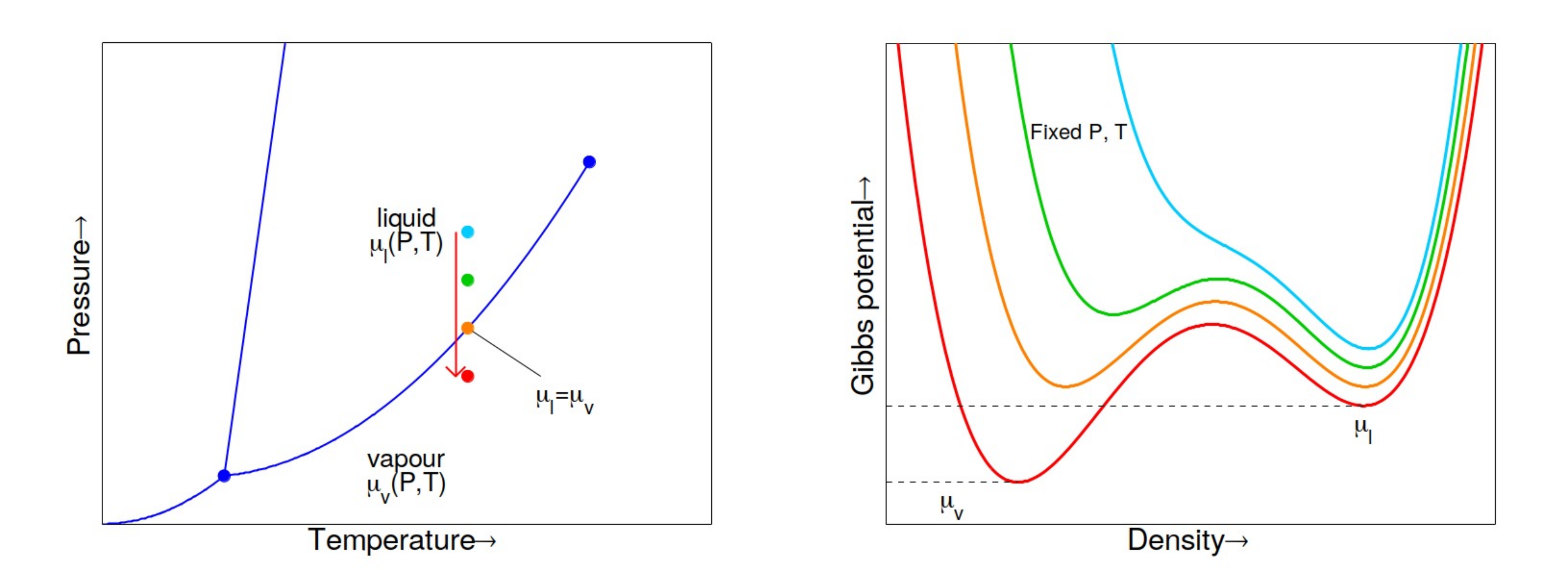
- Good identification of interactions with the nucleus.
- Great ability to distinguish nuclear interaction (n, α, etc.) from electronic interactions (β, γ, etc.).
- Ability to operate the experiment at low energy thresholds (eV-keV).
- Good position reconstruction for interactions occurring within the experiment active volume.
- Scalable technique.

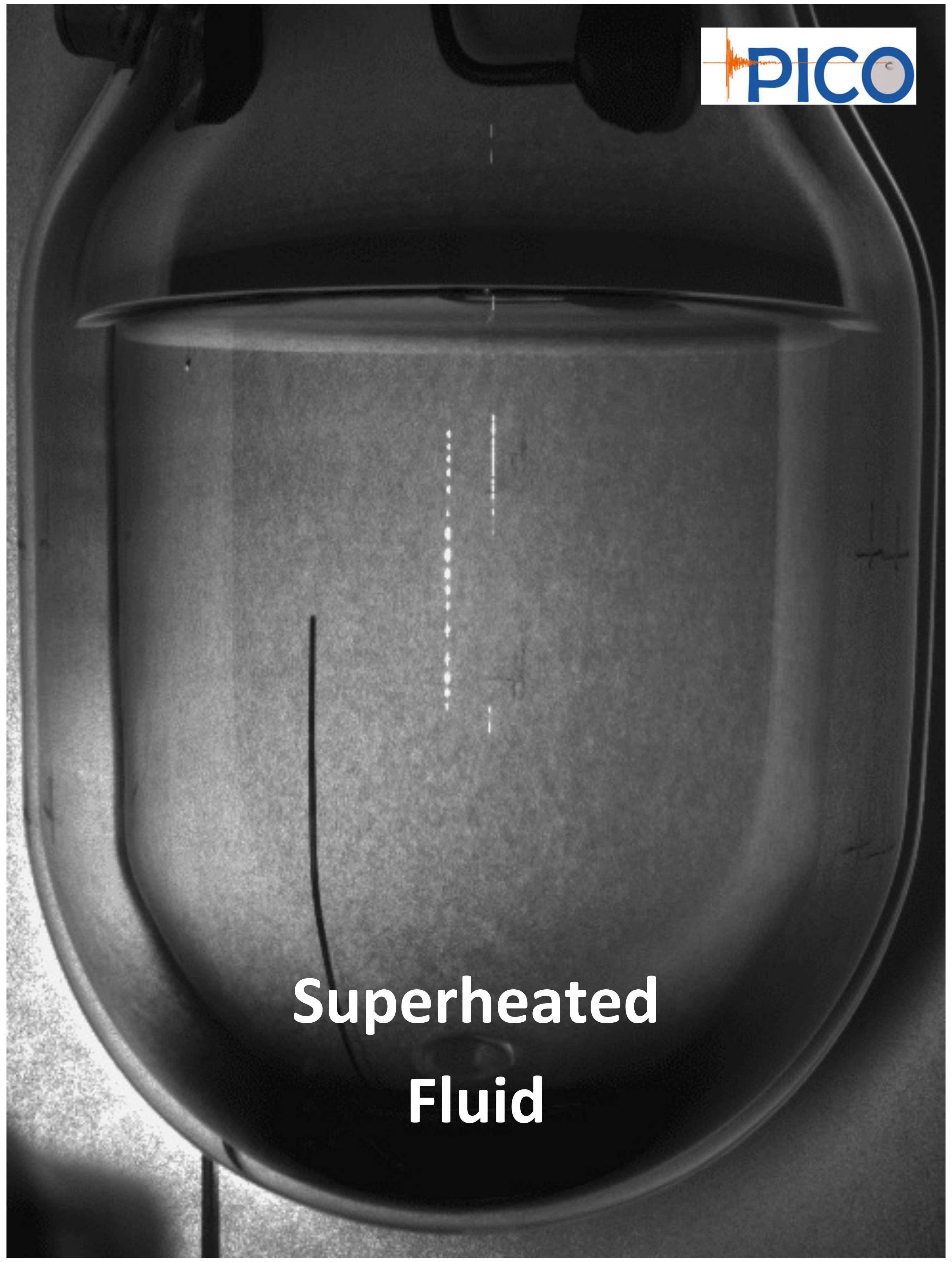
Bubble Chamber Technique

Standard Fluid



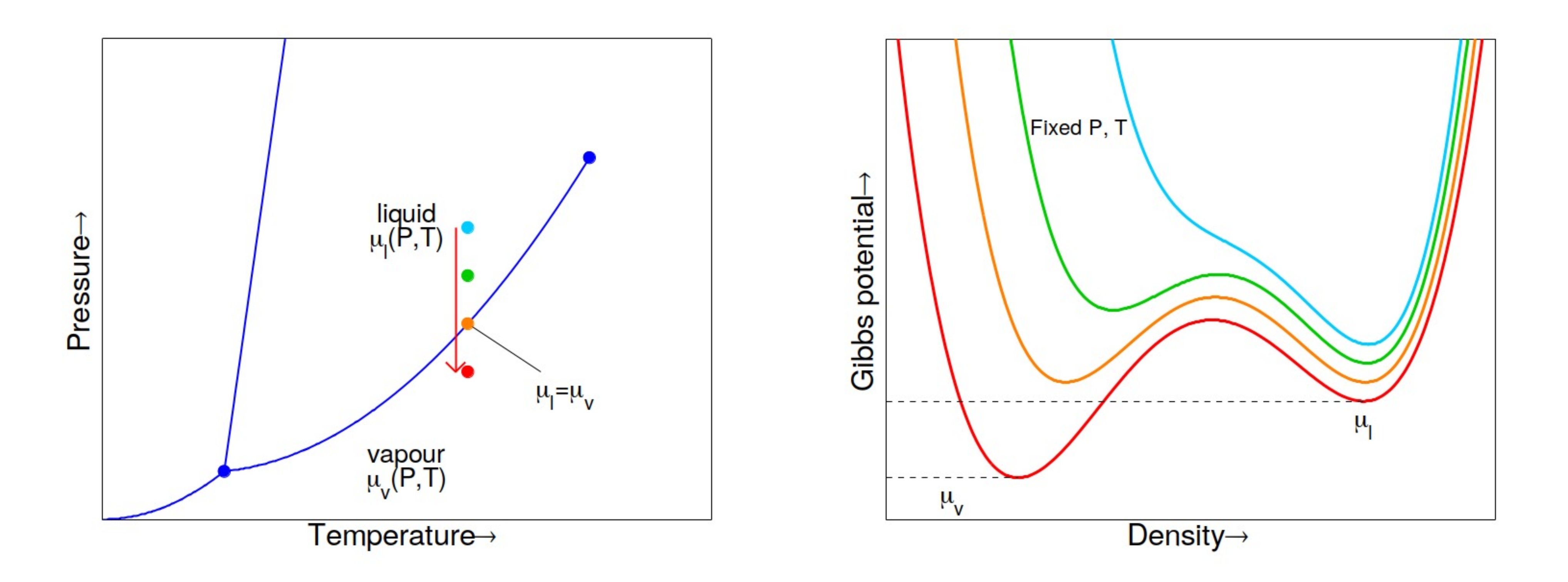
Superheated Fluid



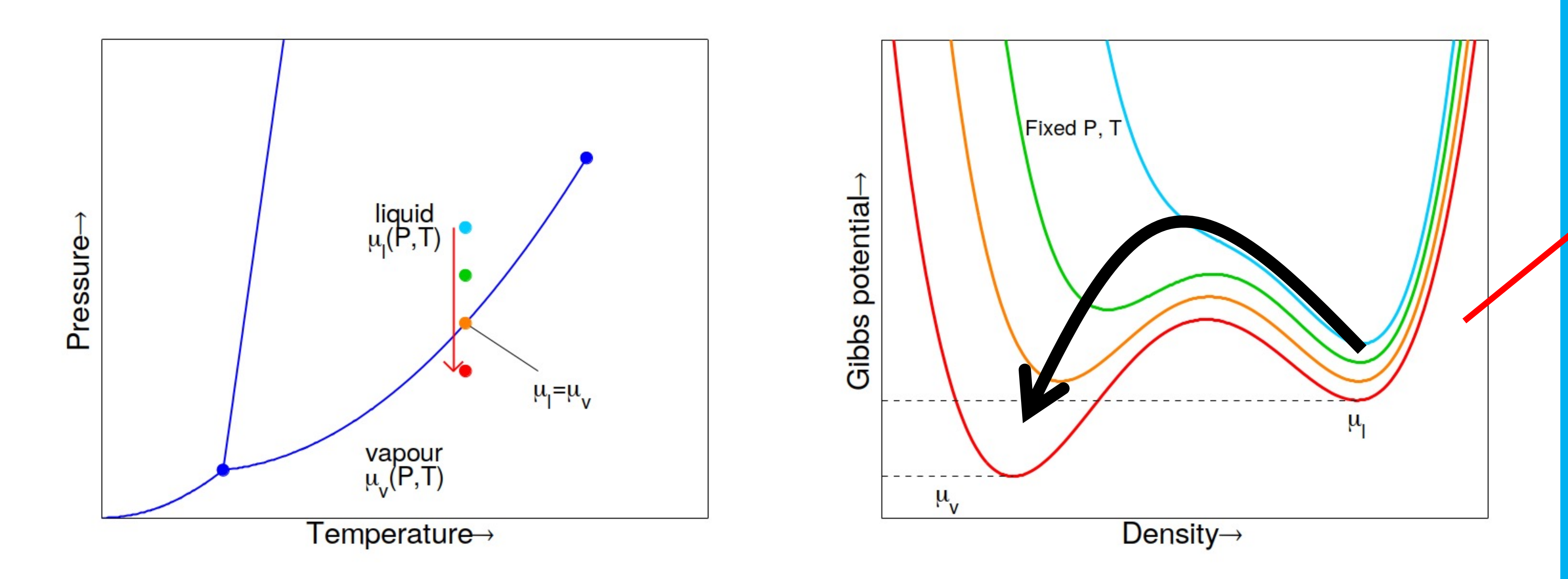


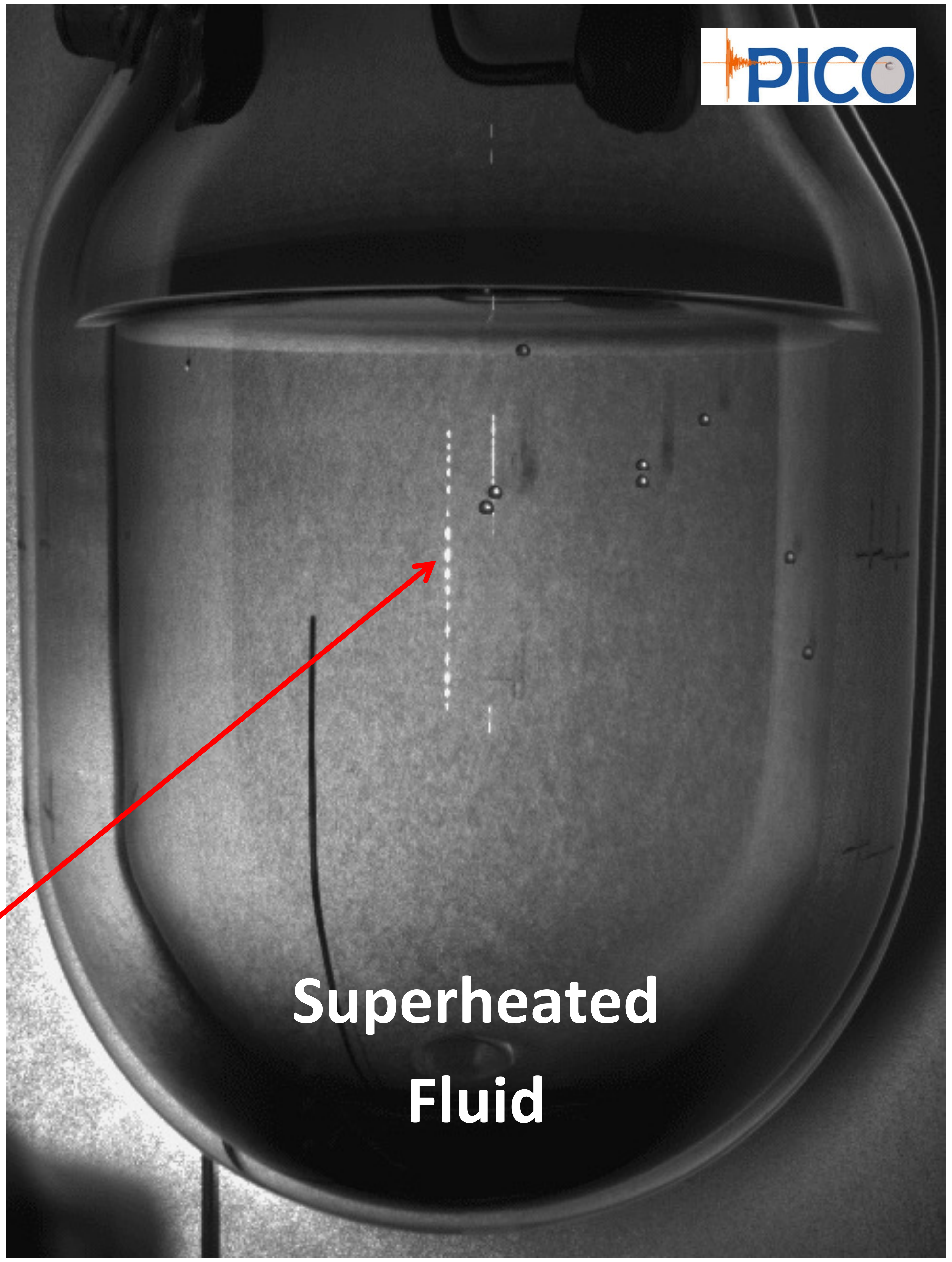
Bubble Chamber Technique

Superheated Fluid



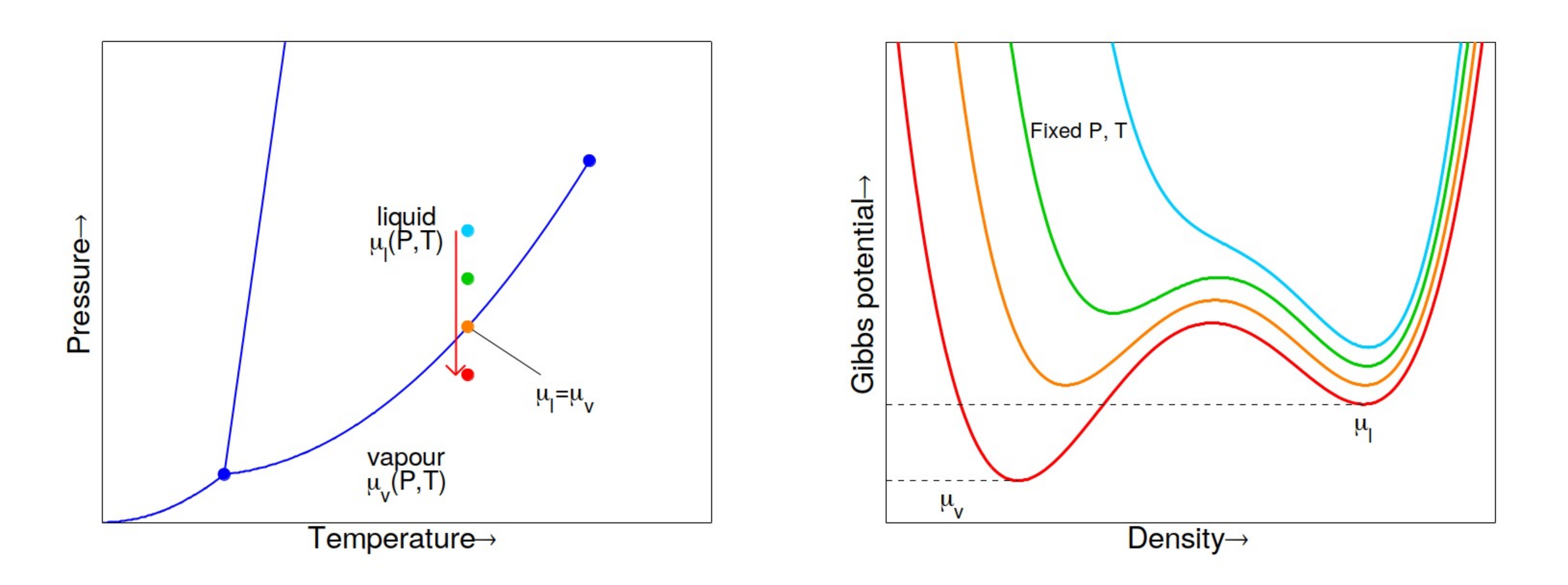
Particle Interaction -> Bubble Formation



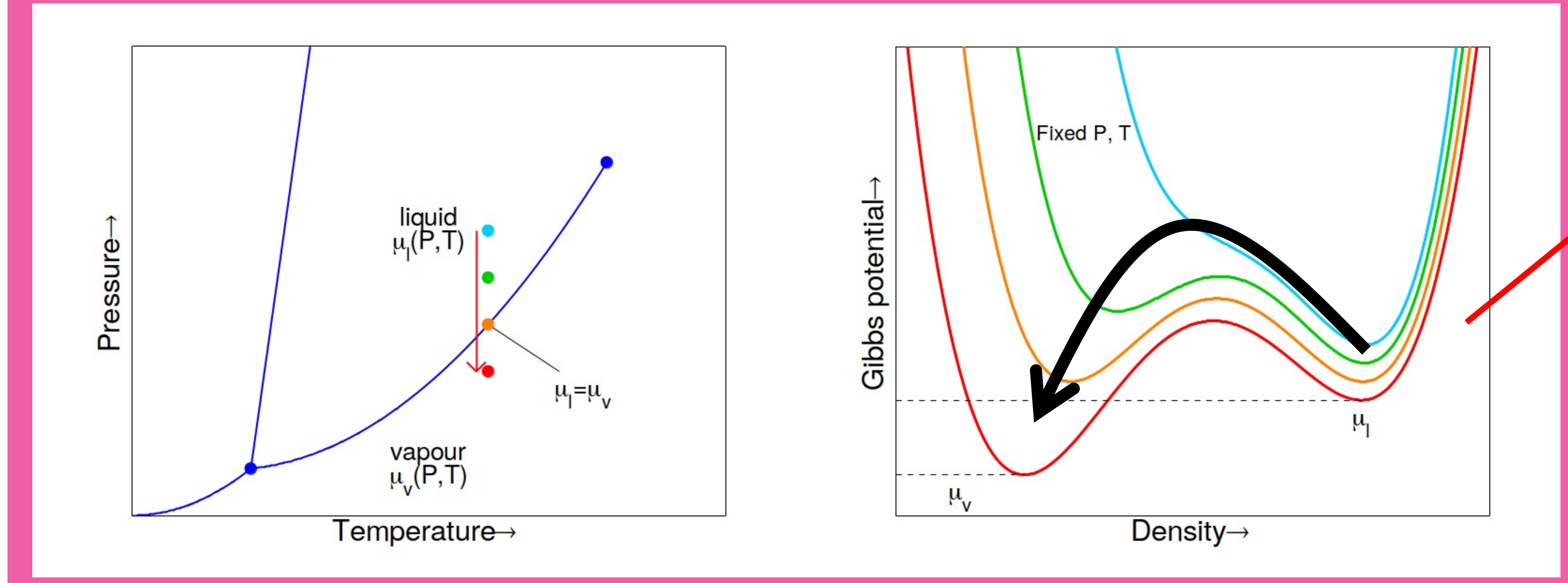


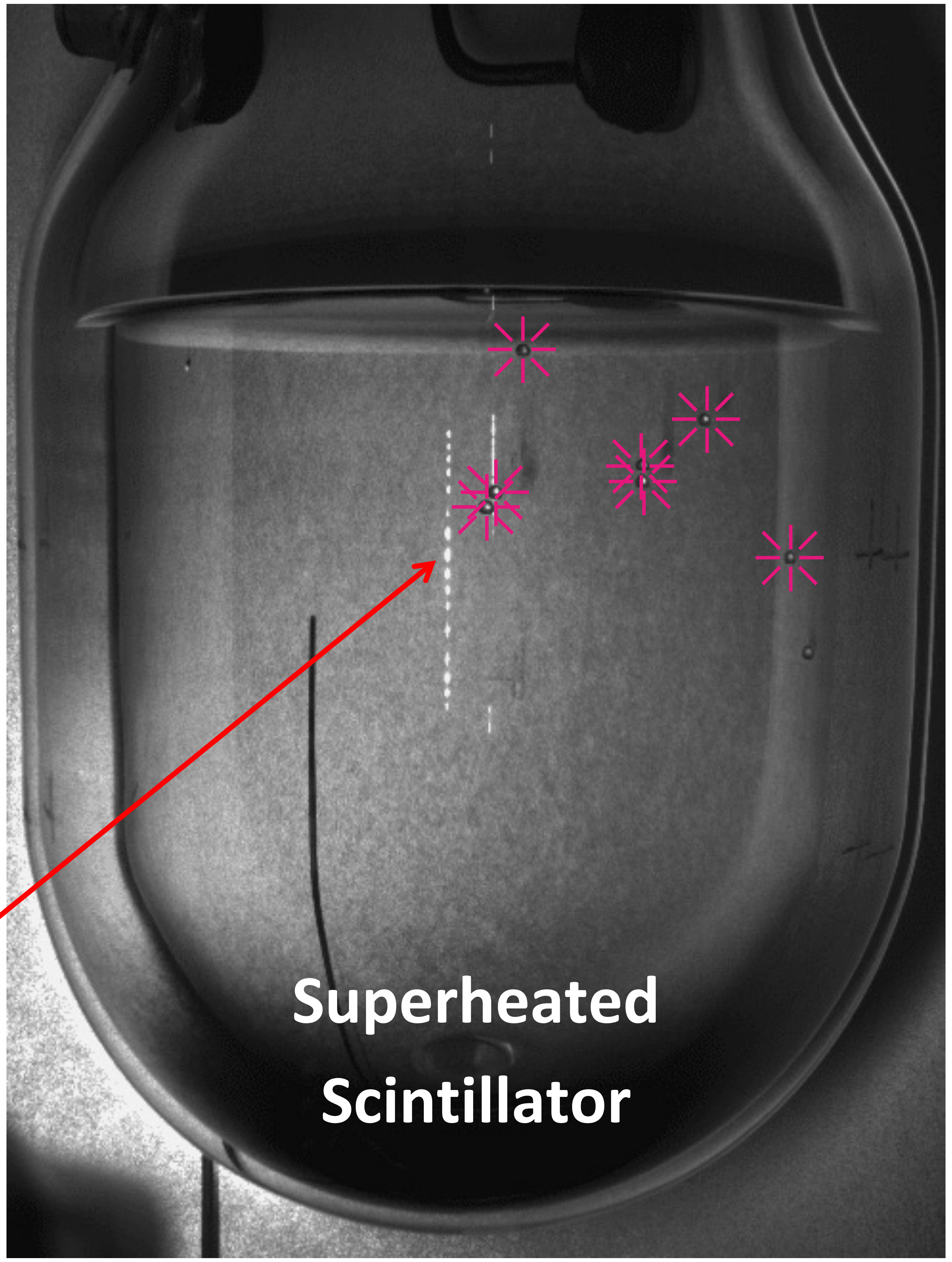
Bubble Chamber Technique

Superheated Fluid

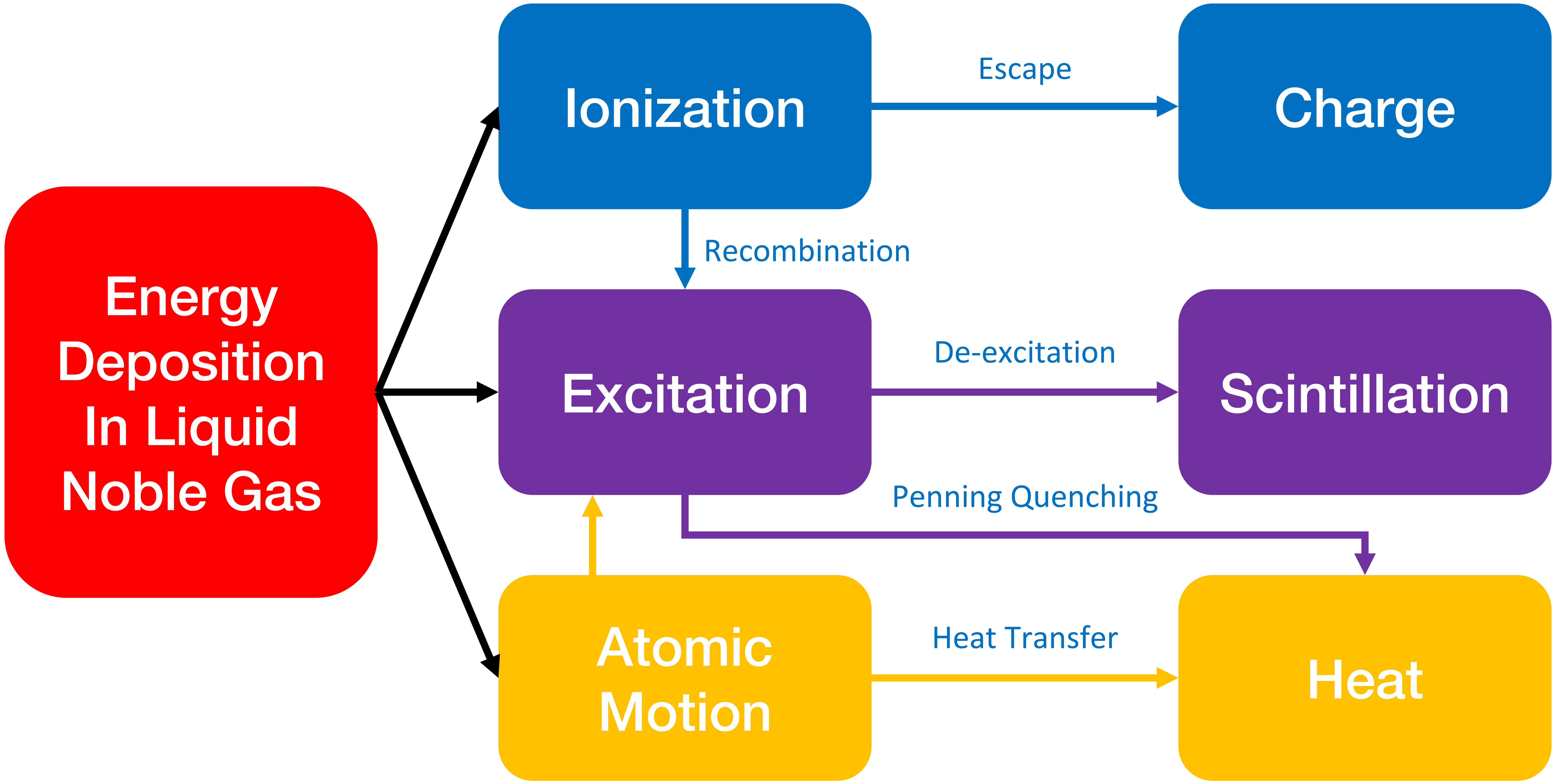


Nucleation + Scintillation Light

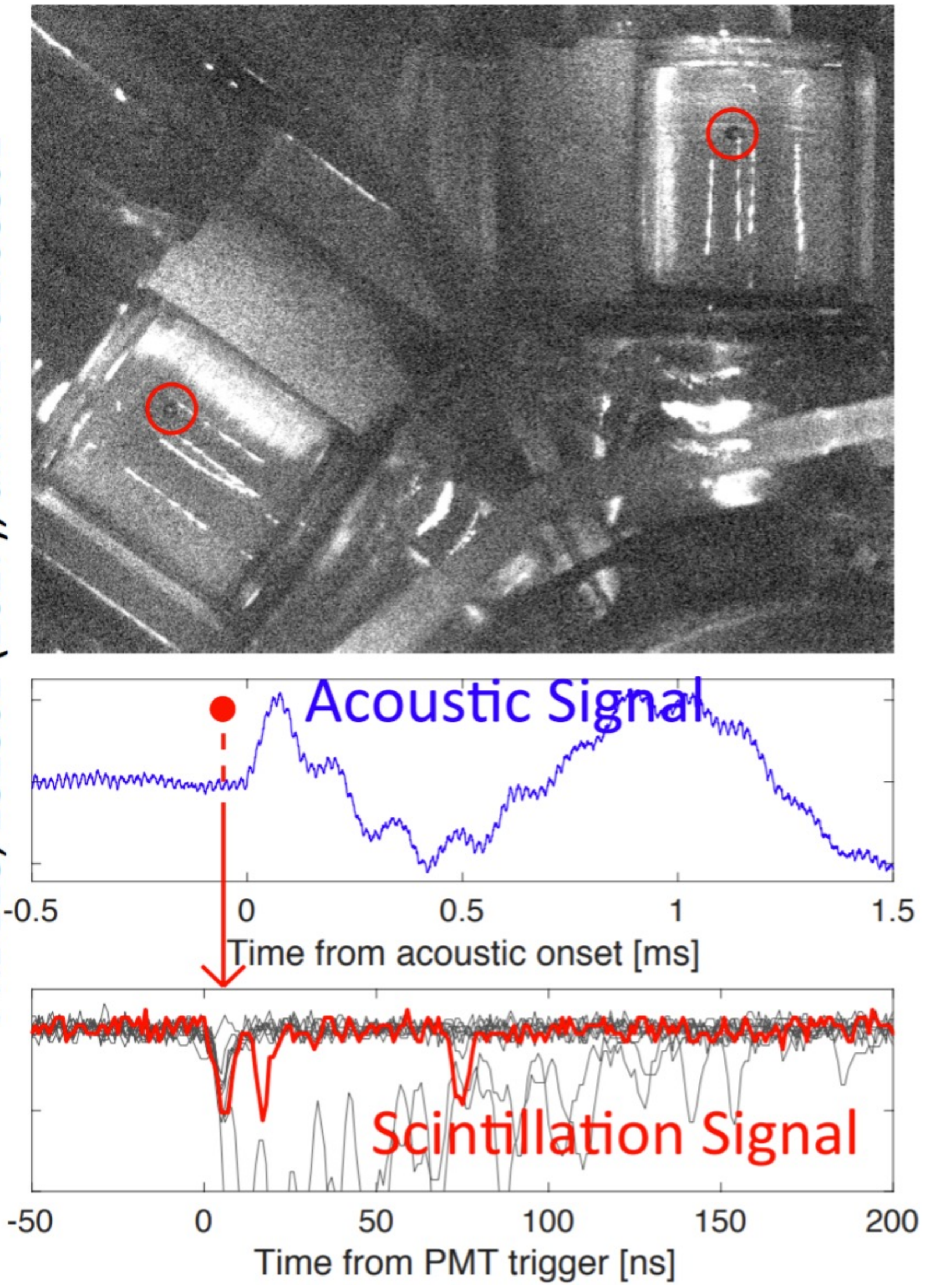




Energy Loss in Liquid Nobles

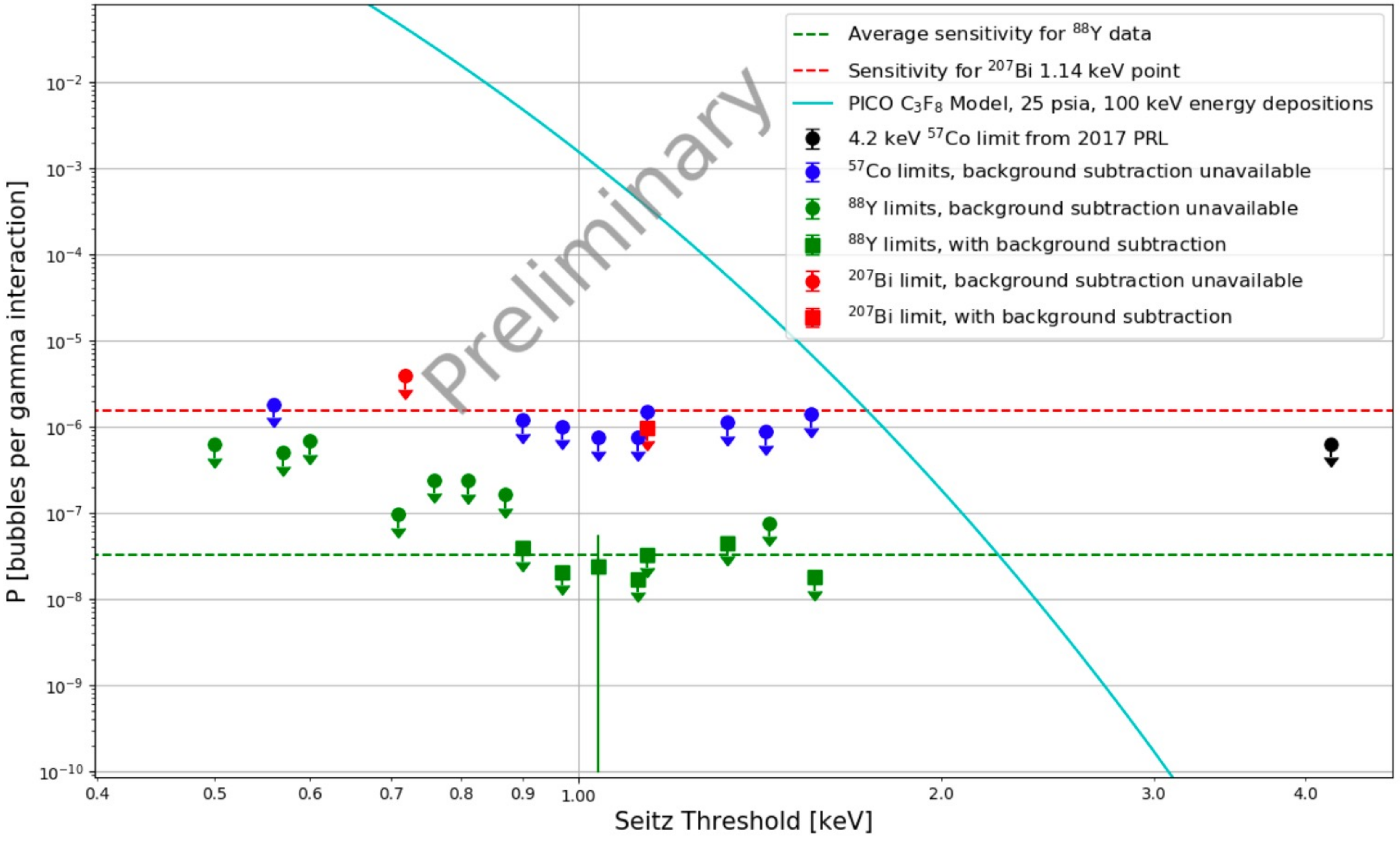


Scintillating Bubble Chamber



PRL 118, 231301 (2017), arXiv:1702.08861

30g of LXe, 30% Overall Light Collection Efficiency

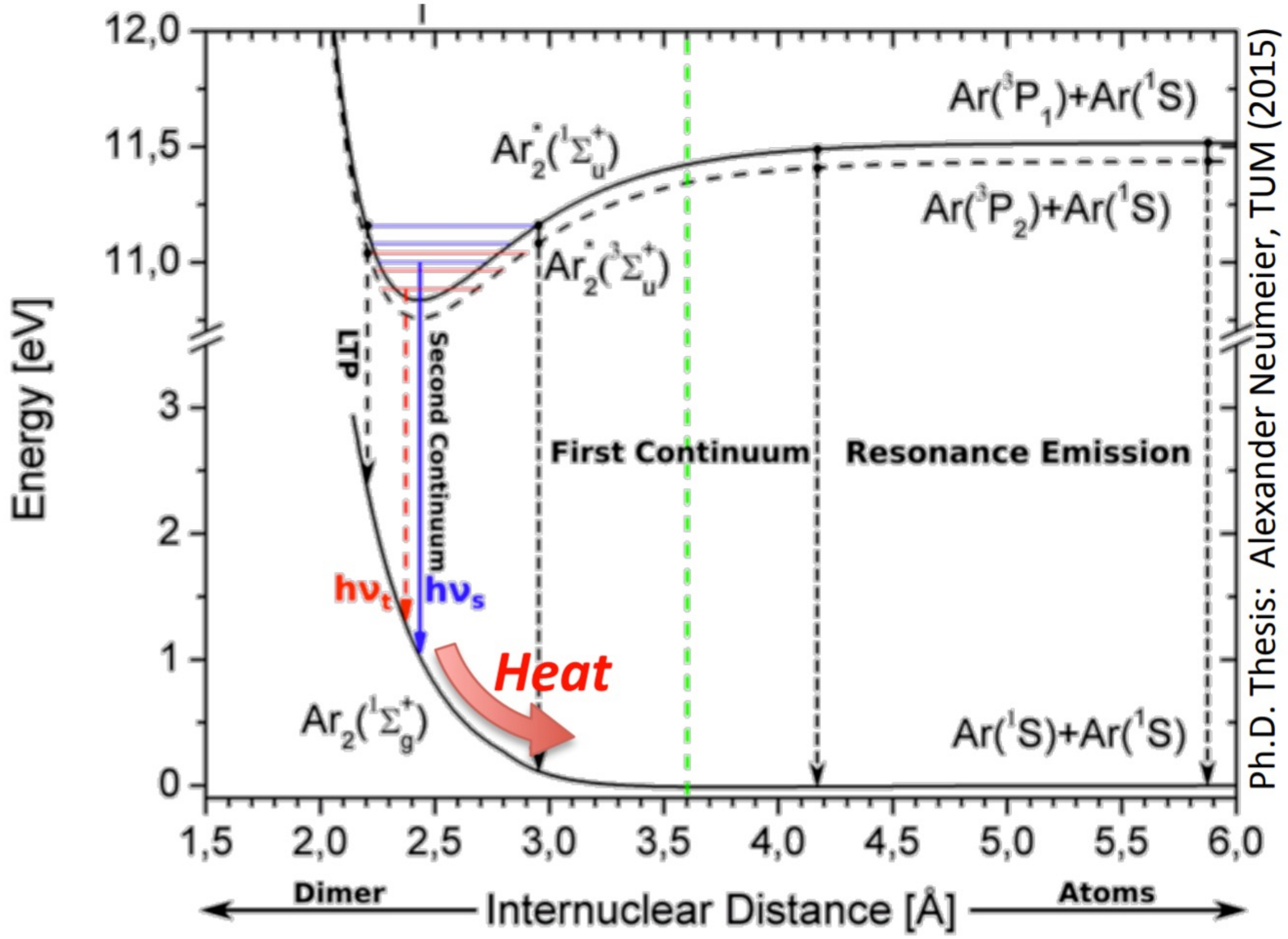


Energy Threshold In LAr

- ER's can lose ~10% energy to heat. Consistent with historic results from LAr bubble chamber, with tracks at *O*(10) eV in threshold.

- Thermal Fluctuations must be considered at *O*(10) eV in threshold.

- Target **threshold of 100 eV (LAr)** with controlled background levels



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2. Experiment Design

SBC Collaboration

Northwestern University

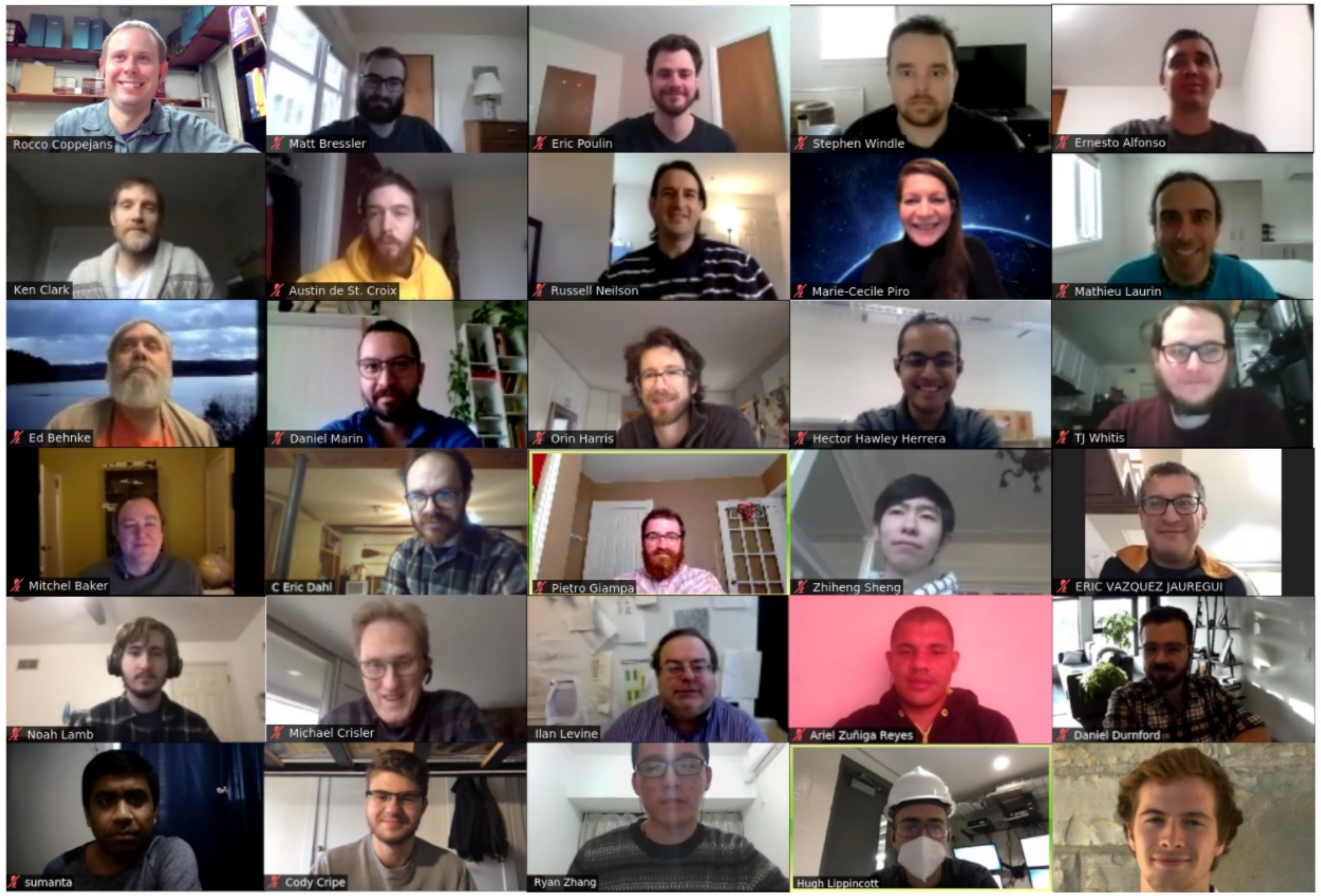
- **Eric Dahl**
- Rocco Coppejans
- Zhiheng Sheng
- Aaron Brandon
- David Velasco
- Ari Sloss
- Mahebub Khatri
- Dishen Wang
- Shishir Bandapalli

Queen's University

- **Ken Clark**
- Hector Hawley
- Patrick Hatch
- Austin De St Croix

University of Alberta

- Marie-Cécile Piro
- Carsten Krauss
- Daniel Durnford
- Sumanta Pal
- Youngtak Ko
- Mitchel Baker



Universidad Nacional Autónoma de México

- Eric Vázquez-Jáuregui
- Ernesto Alfonso-Pita
- Ariel Zuniga-Reyes
- Daniel Lámbarri

Drexel University

- Russell Neilson
- Matt Bressler
- Noah Lamb
- Stephen Windle

Indiana University South Bend

- Ilan Levine
- Ed Behnke
- Cody Cripe

UC Santa Barbara

- Hugh Lippincott
- TJ Whitis
- Runze Zhang

SNOLAB

- Pietro Giampa
- Eric Poulin

Université de Montréal

- Mathieu Laurin

Northeastern Illinois University

- Orin Harris

Pacific Northwest National Laboratory

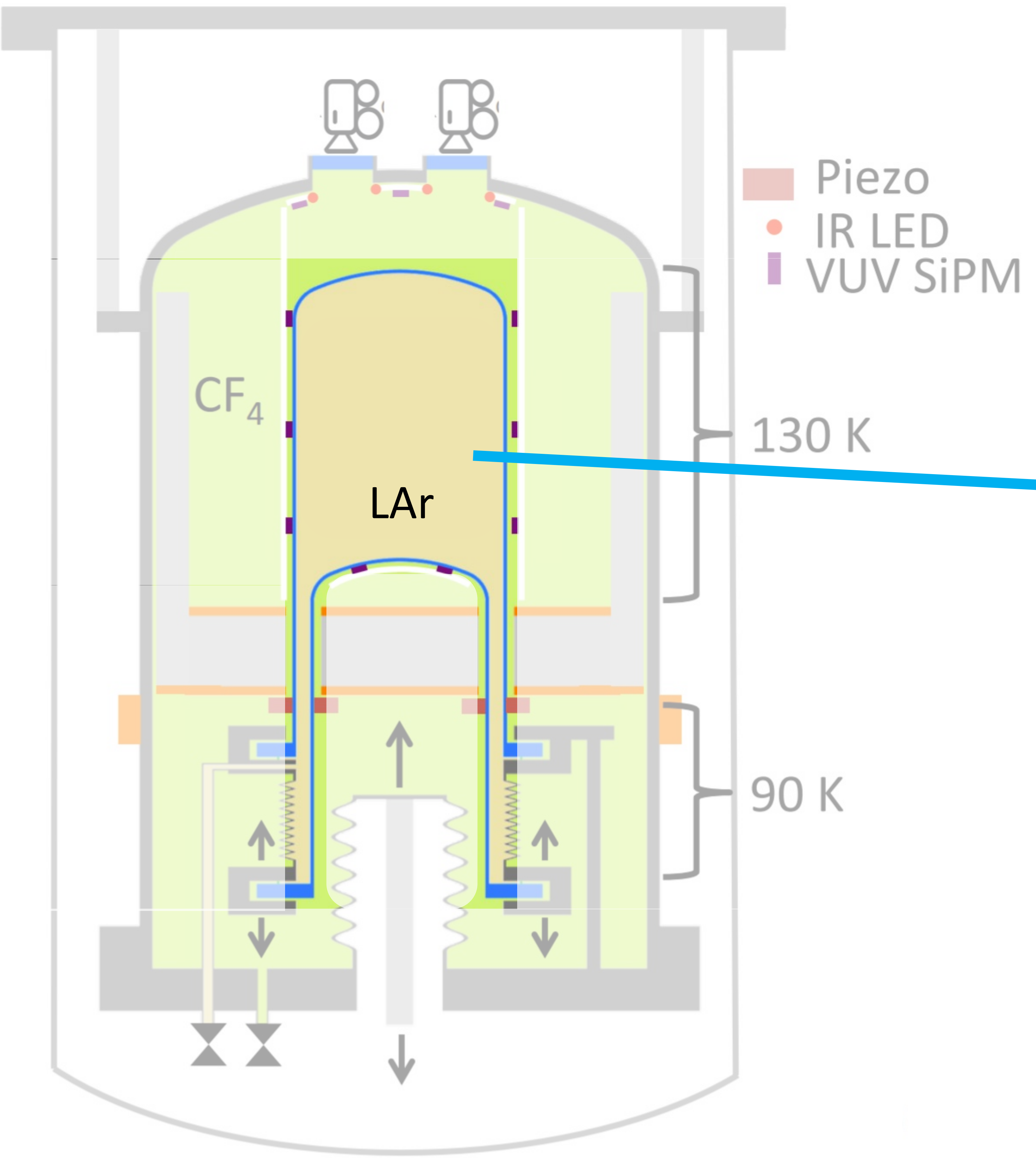
- Chris Jackson

Fermilab

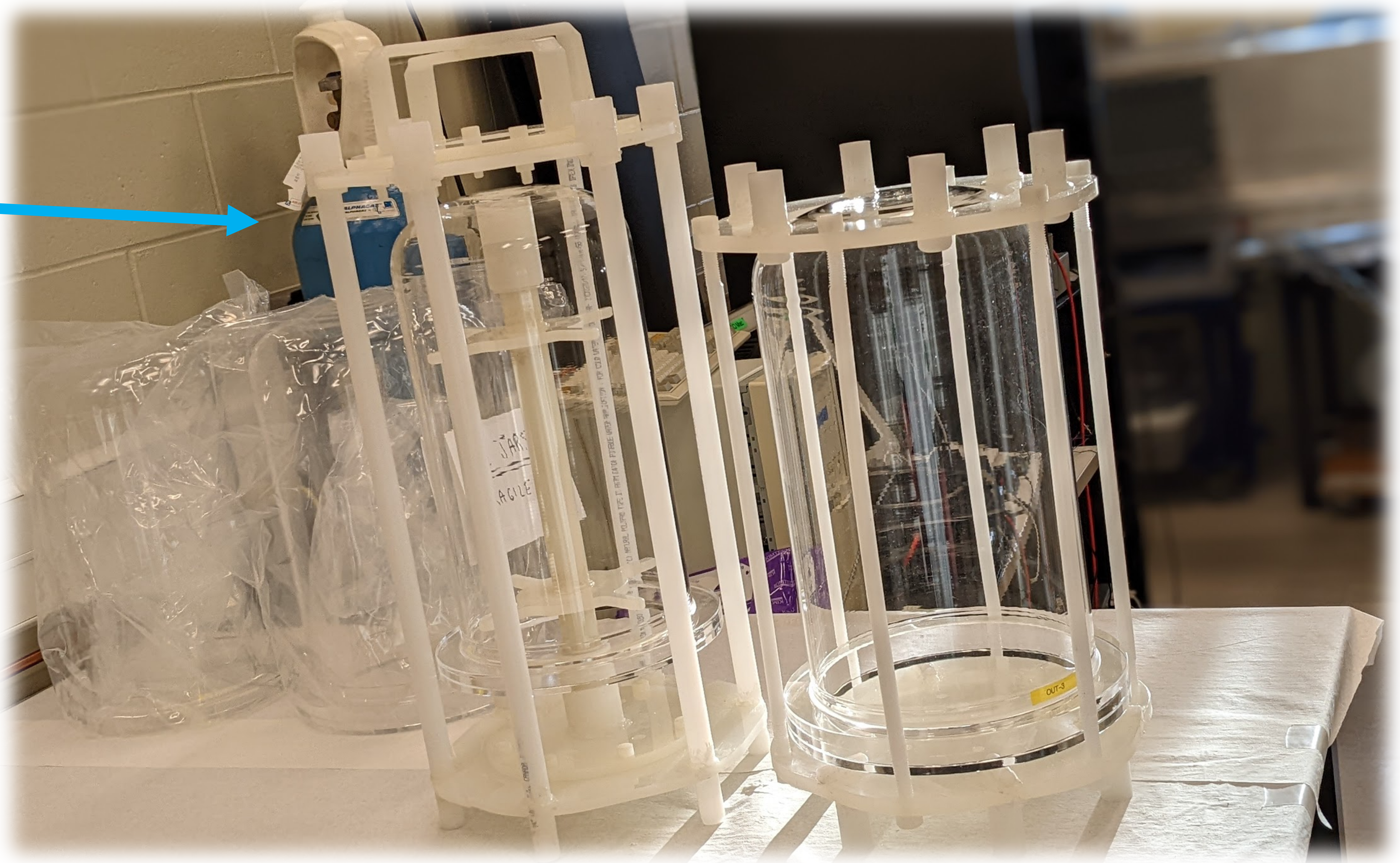
- Mike Crisler

SBC At Glance

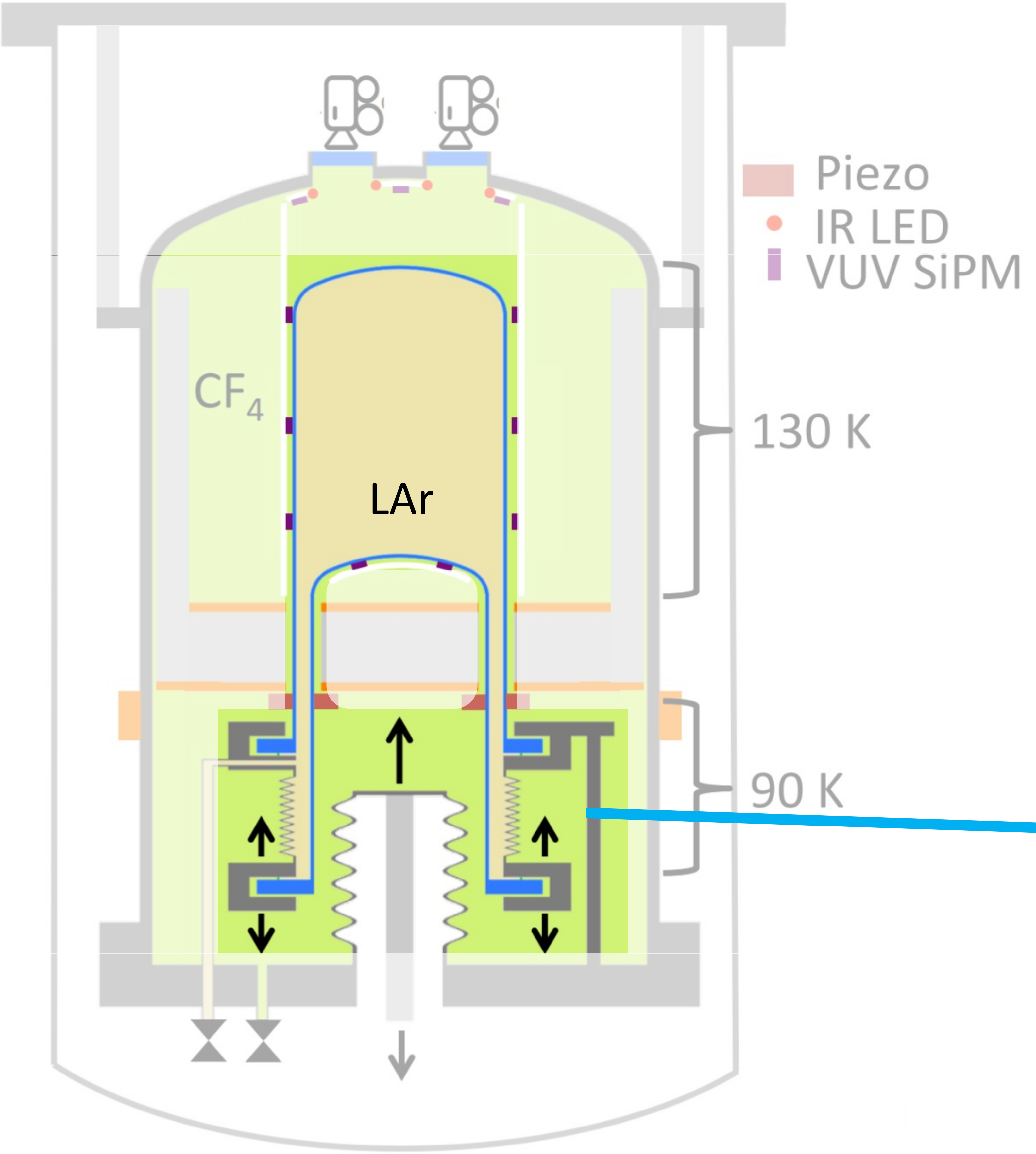
SBC Experiment Design



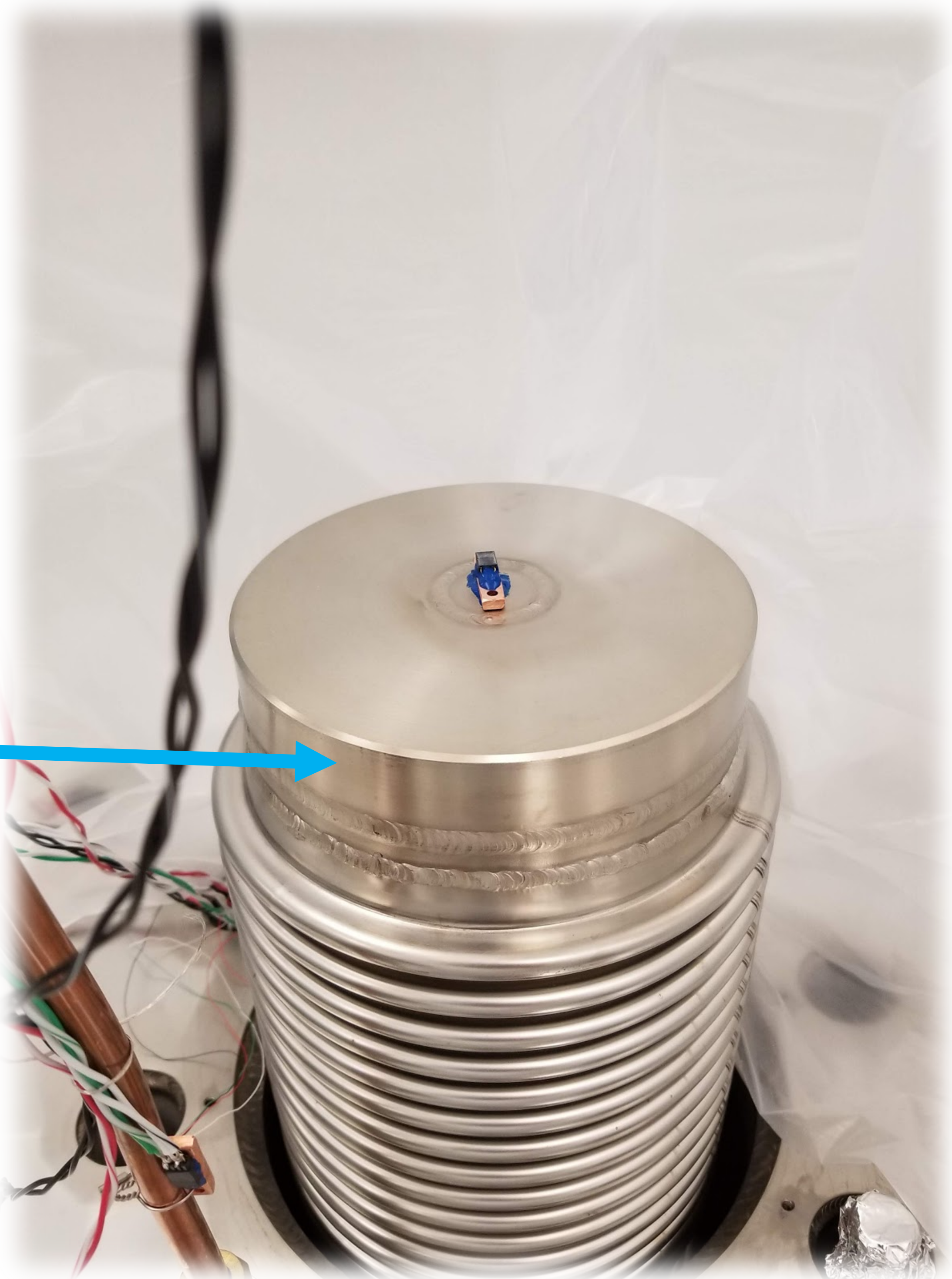
O(10 kg) LAr contained within two fused silica jars, inner and outer jars. The Inner jar is used to “push” on the Lar.

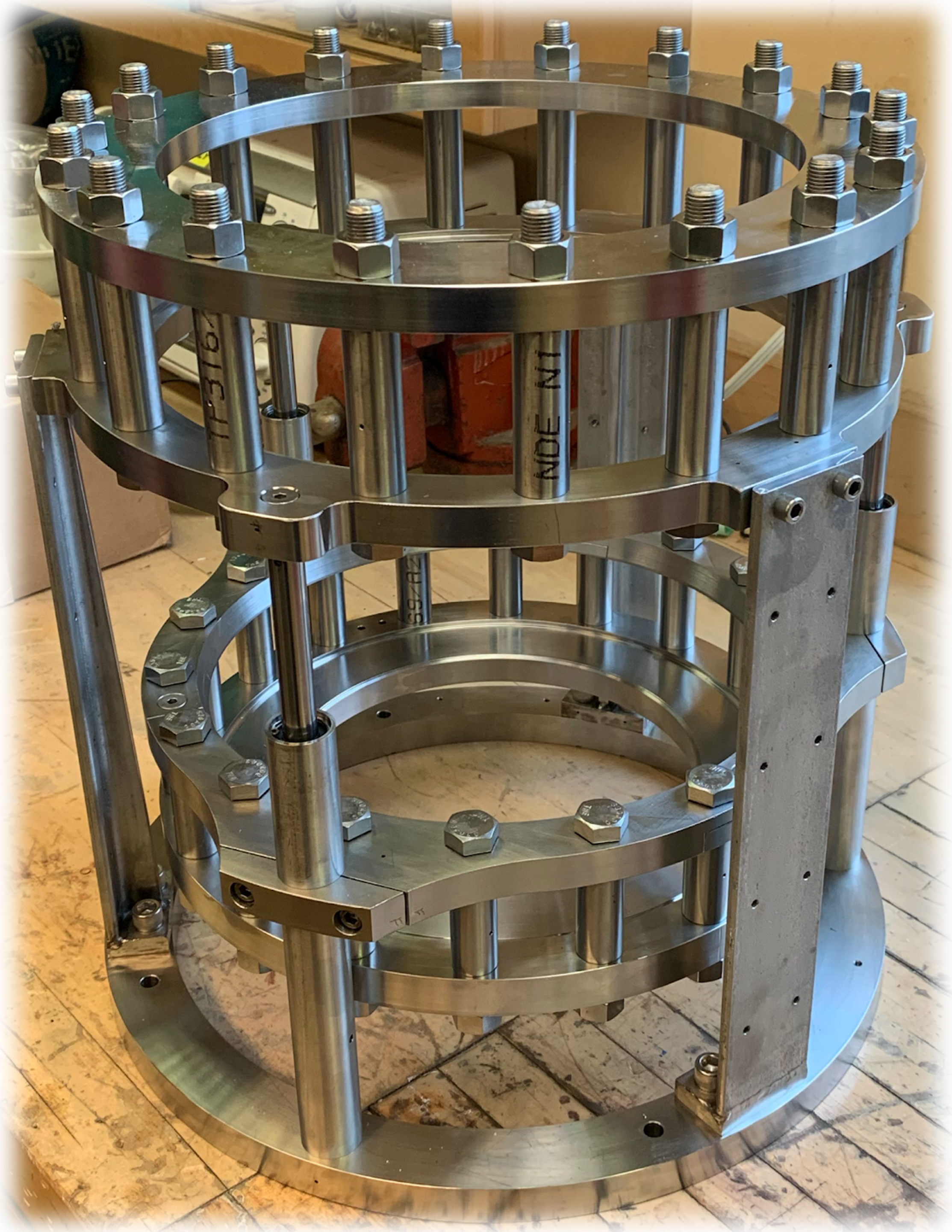


SBC Experiment Design

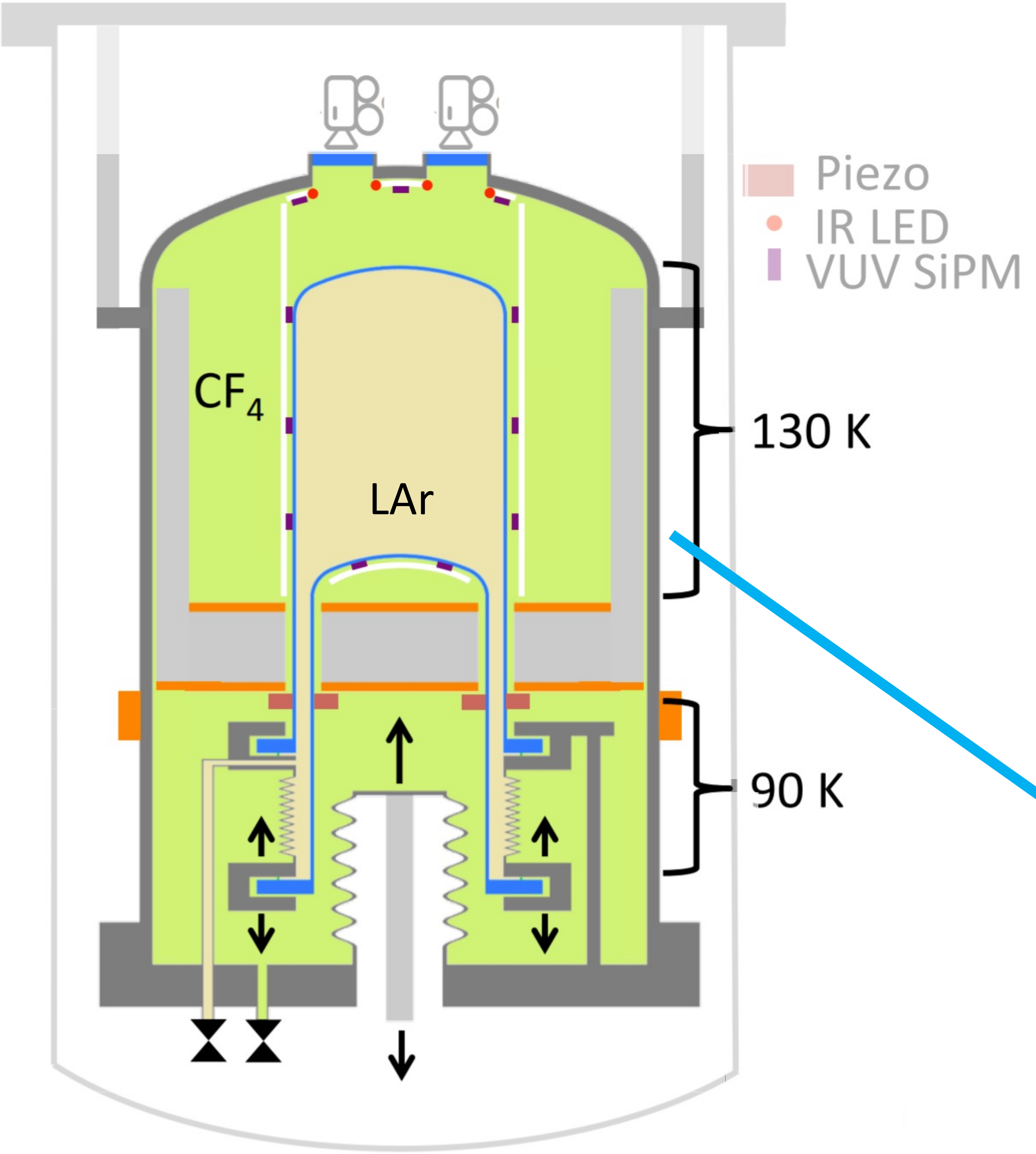


Hydraulic Piston Controls The Inner Jar Position
Compressing/Decompressing The Target Fluid



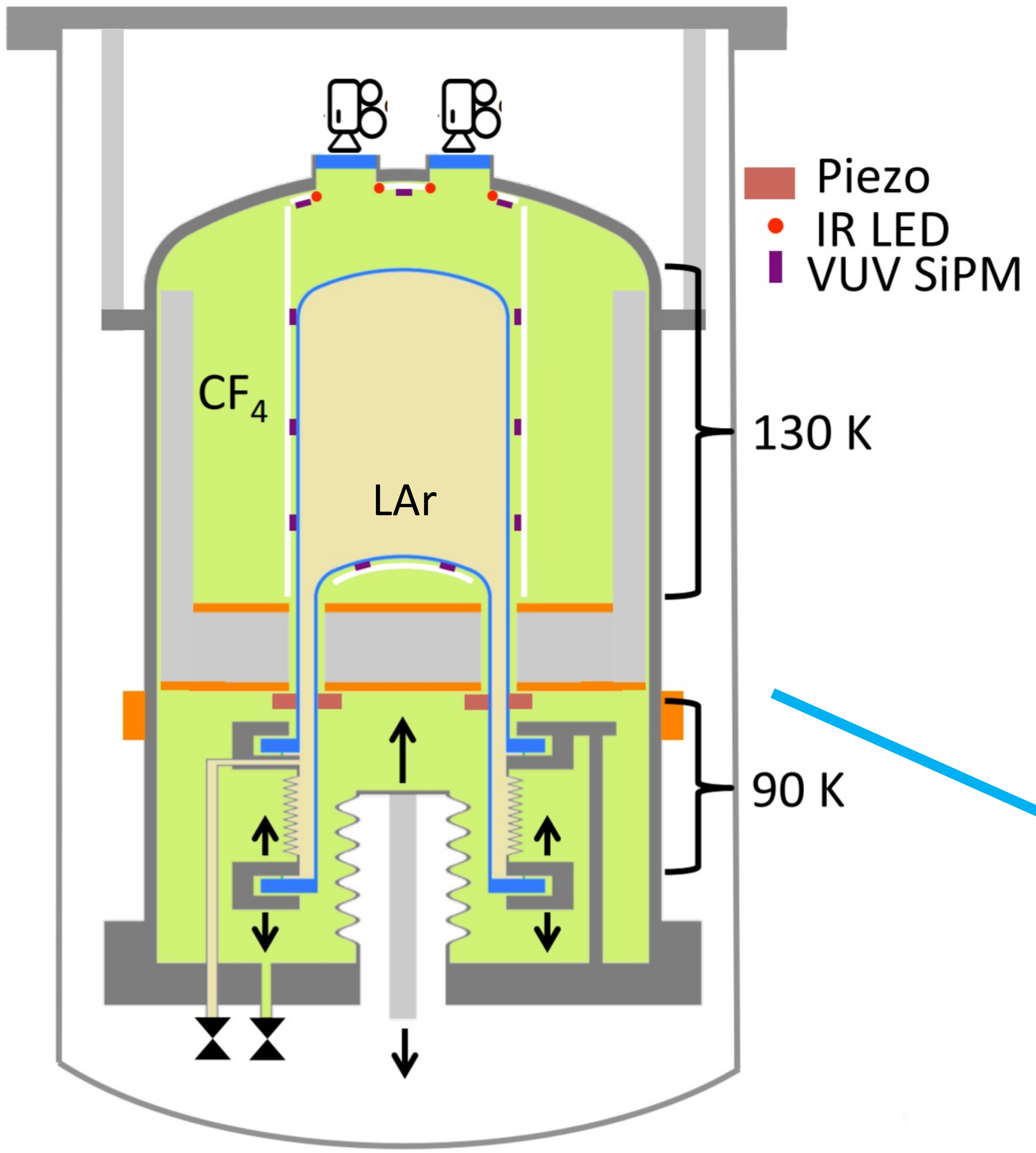


SBC Experiment Design



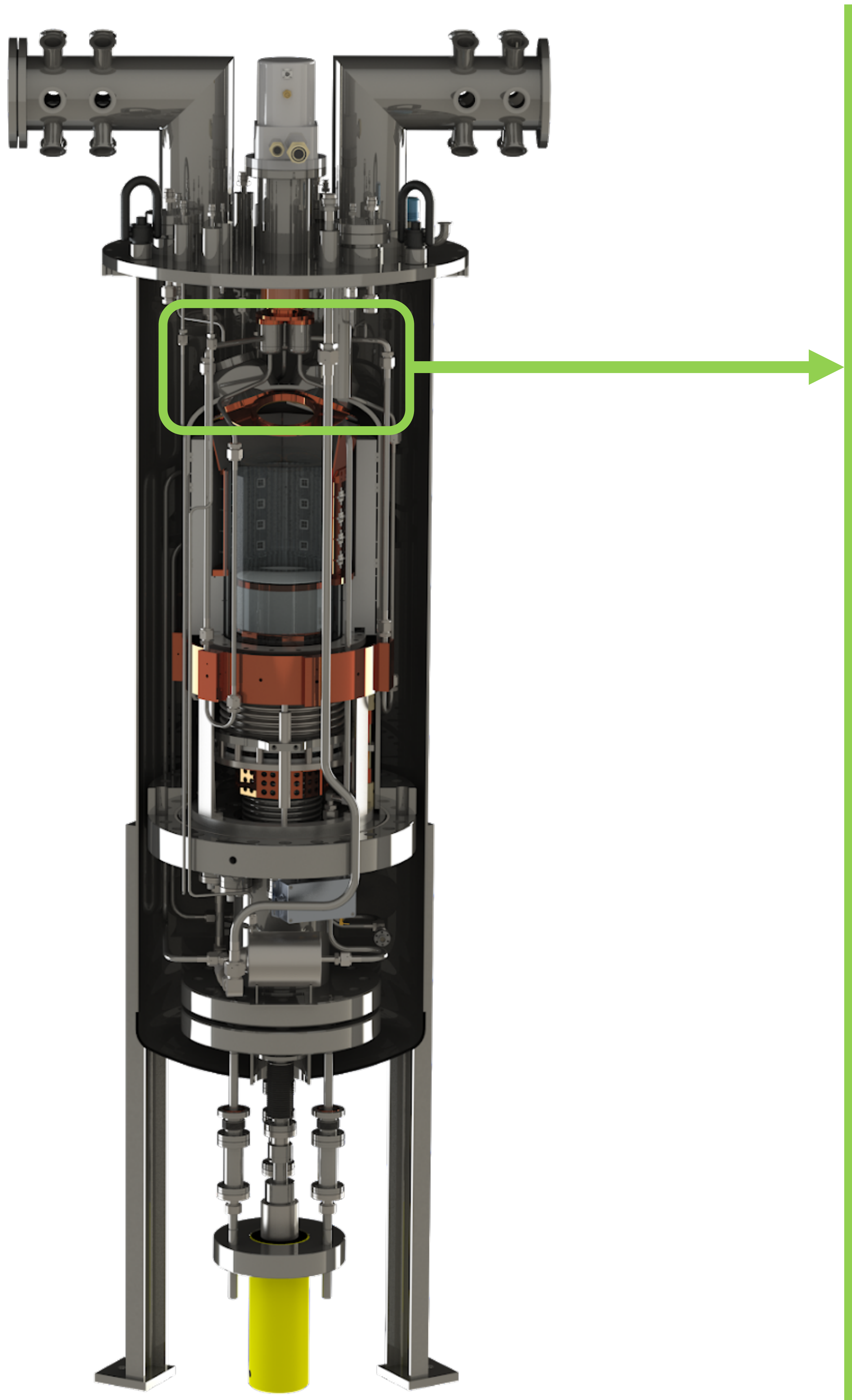
Liquid CF4 Cryogenic Hydraulic Fluid, within a Stainless-Steel Pressure Vessel. HDPE Castle for thermal gradient.

SBC Experiment Design



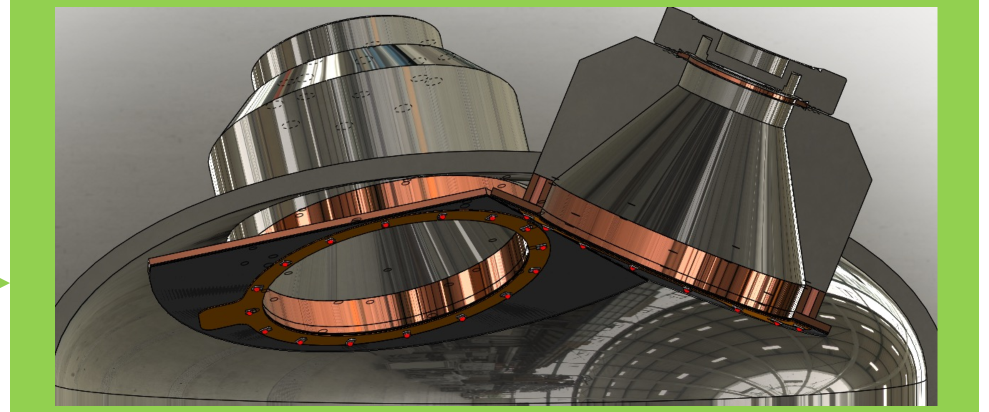
The Full Inner Assembly Is Placed Inside a Stainless-Steel Vacuum Jacket Vessel

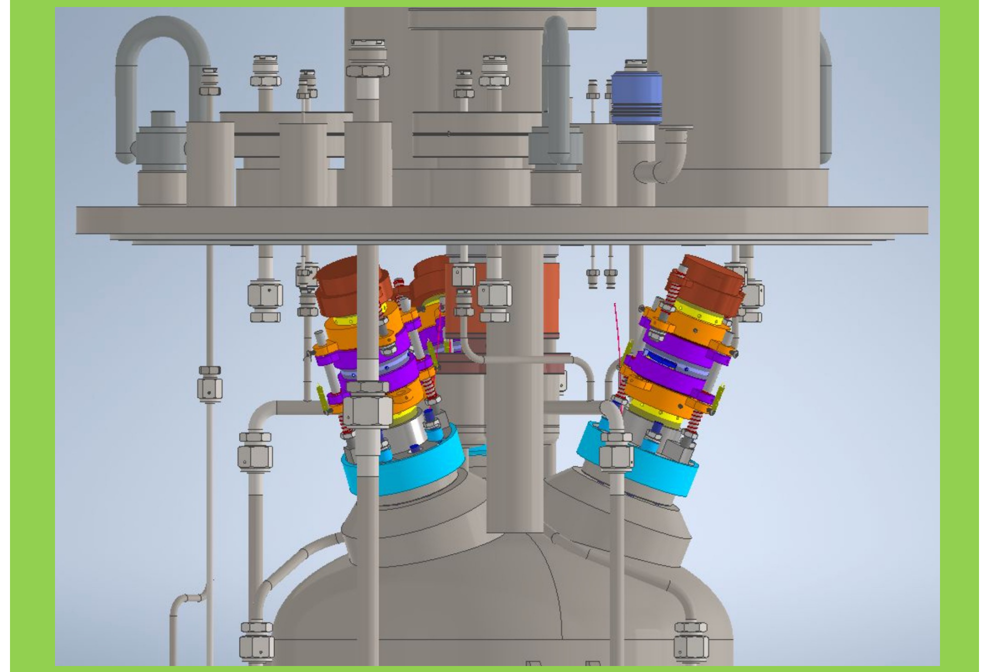
Readout Systems

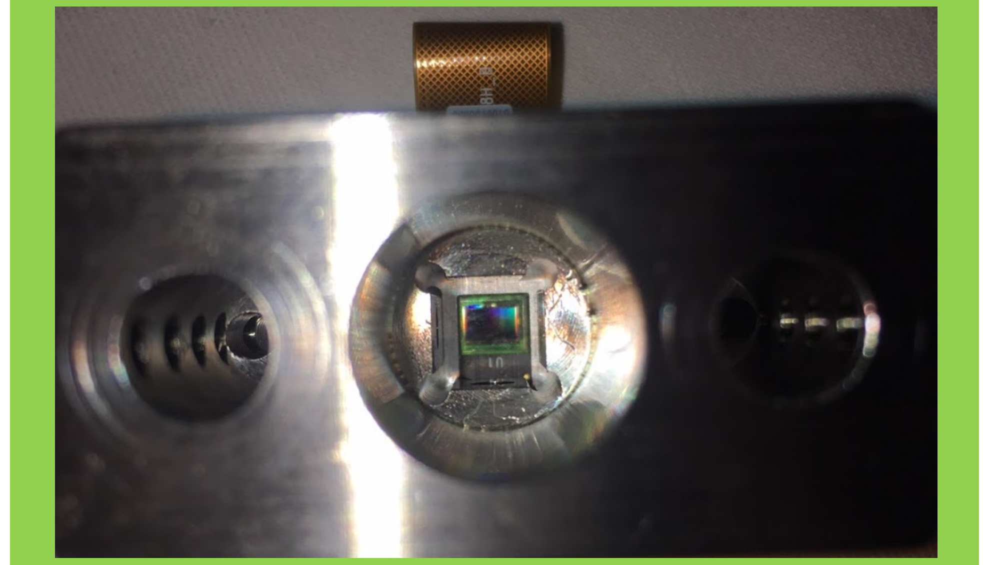


Bubble Imaging

3 Raspberry-Pi Cameras + LEDs







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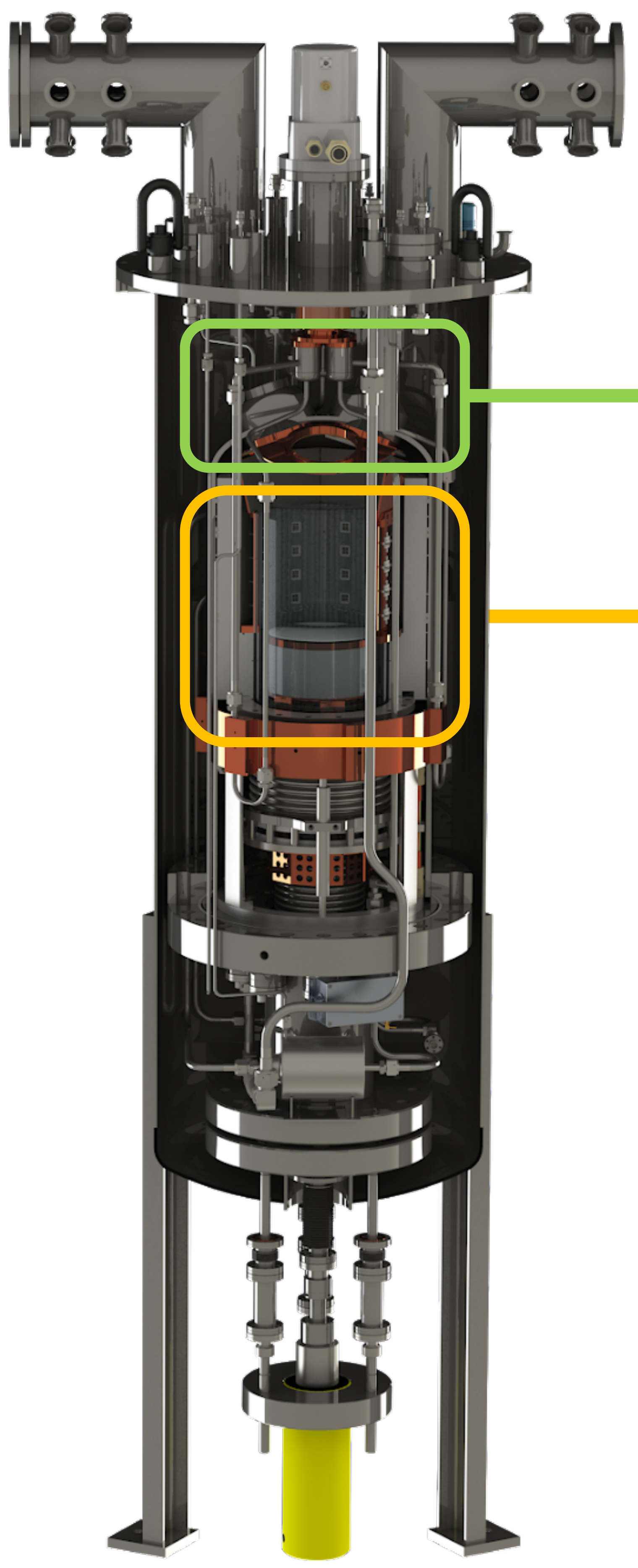

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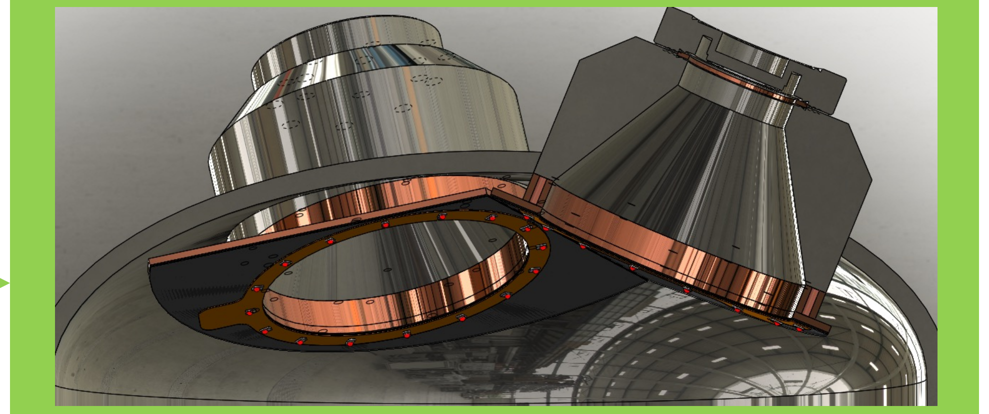
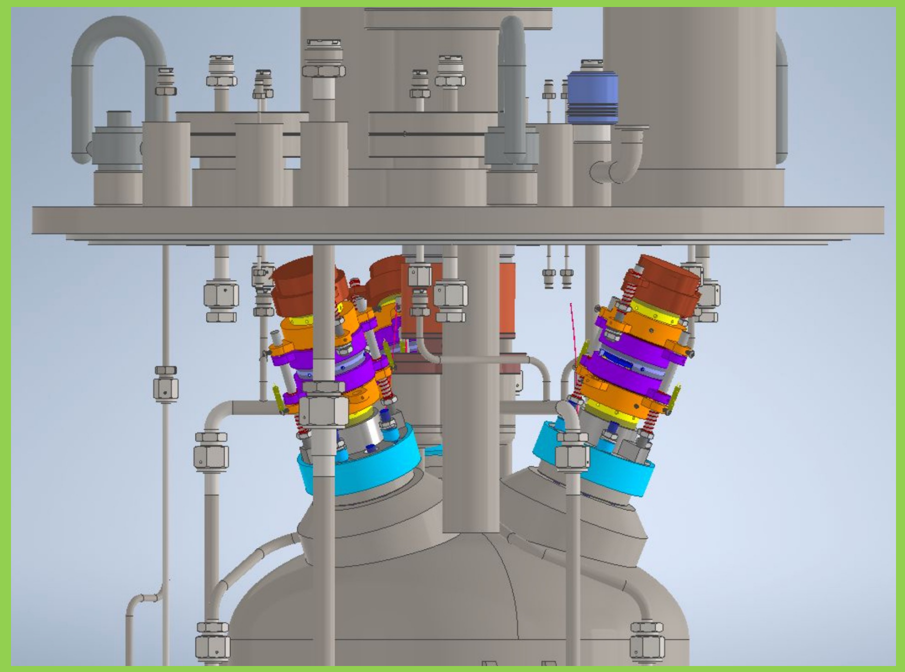
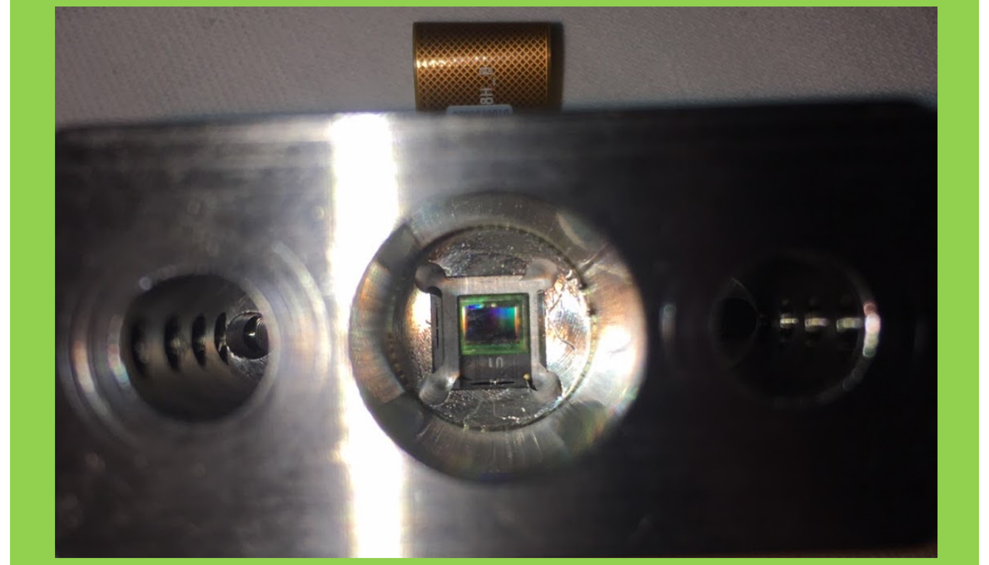
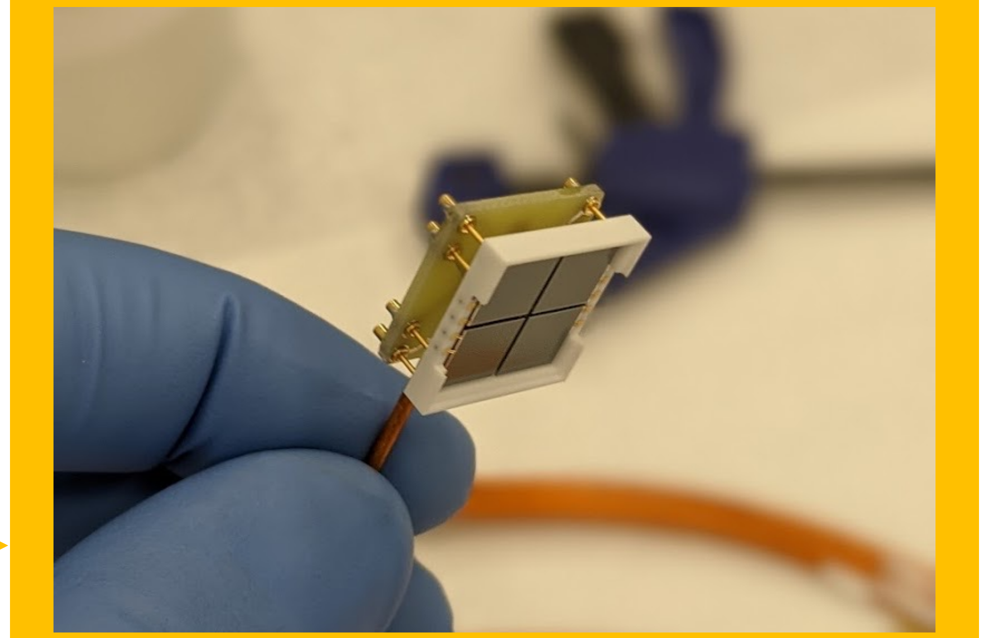


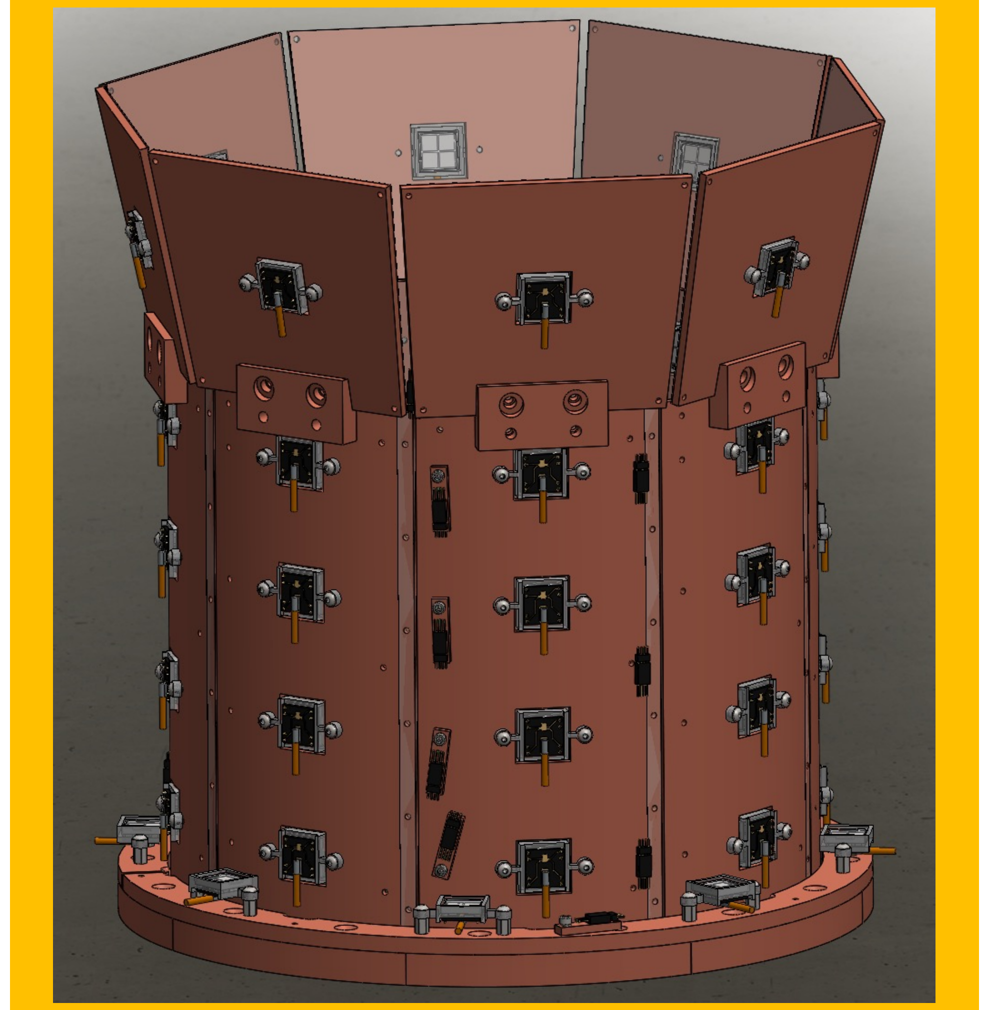




Scintillation System

32 VUV4 Hamamatsu SiPMs





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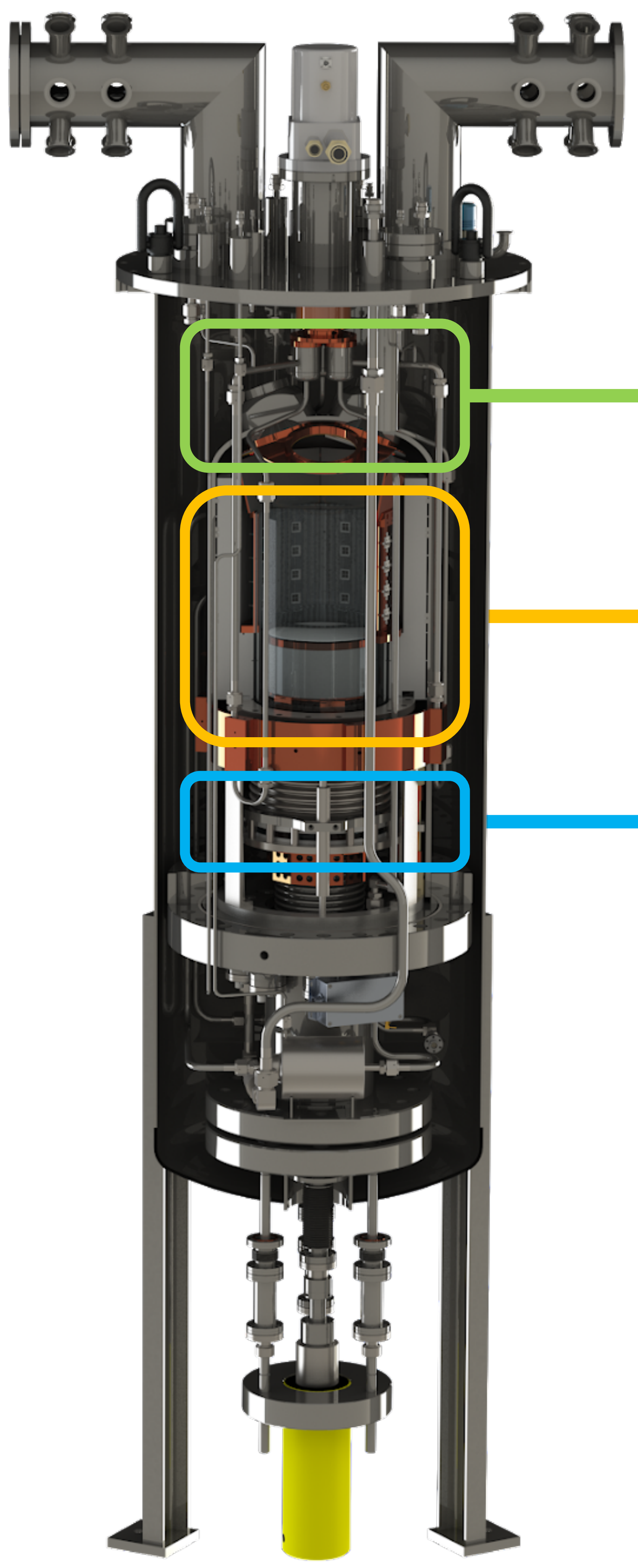
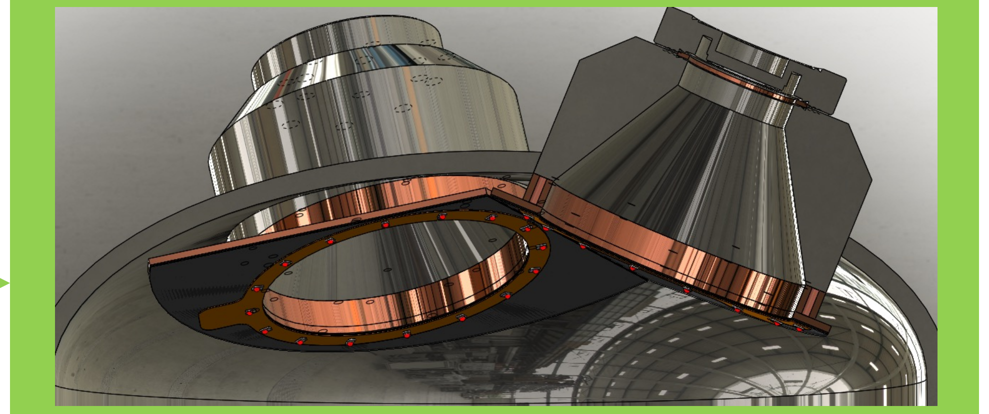
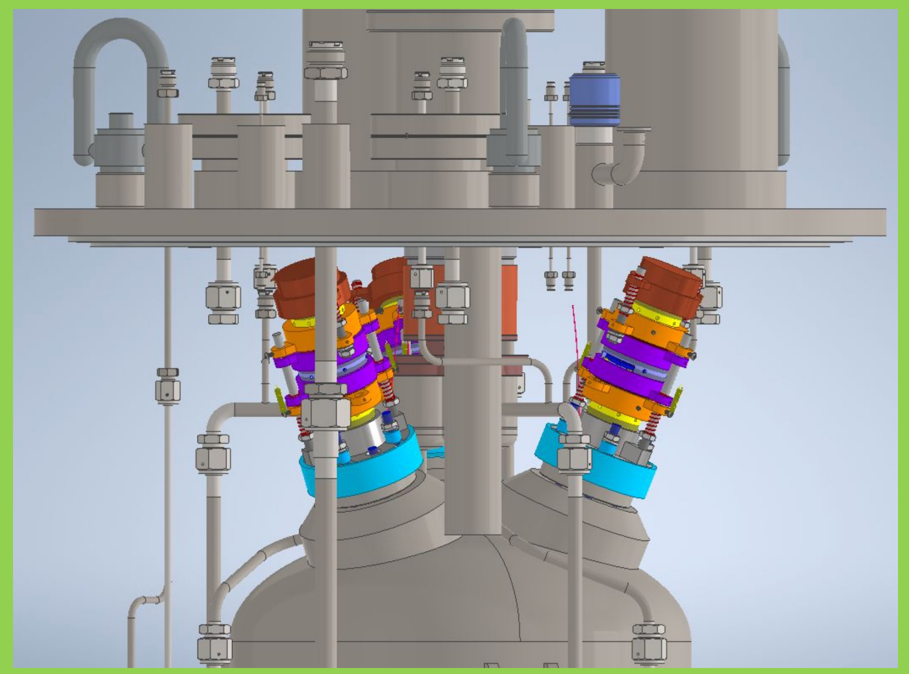
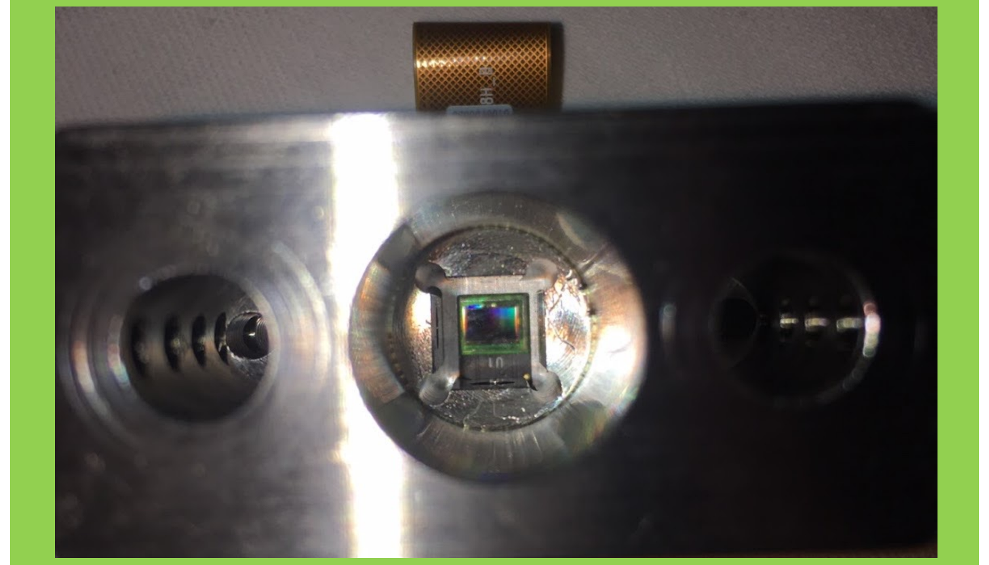


Bubble Imaging

3 Raspberry-Pi Cameras + LEDs







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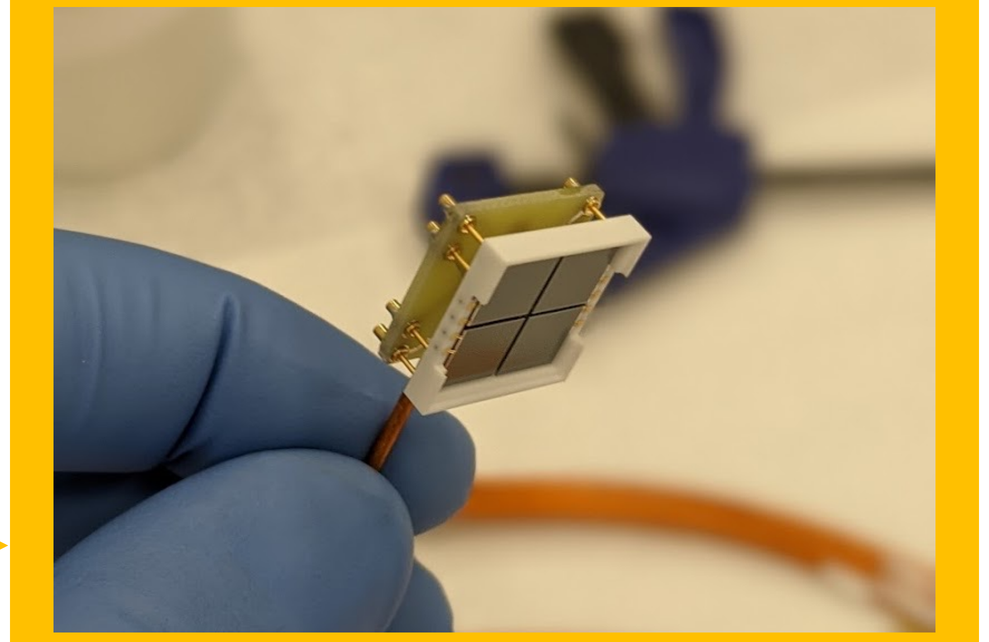
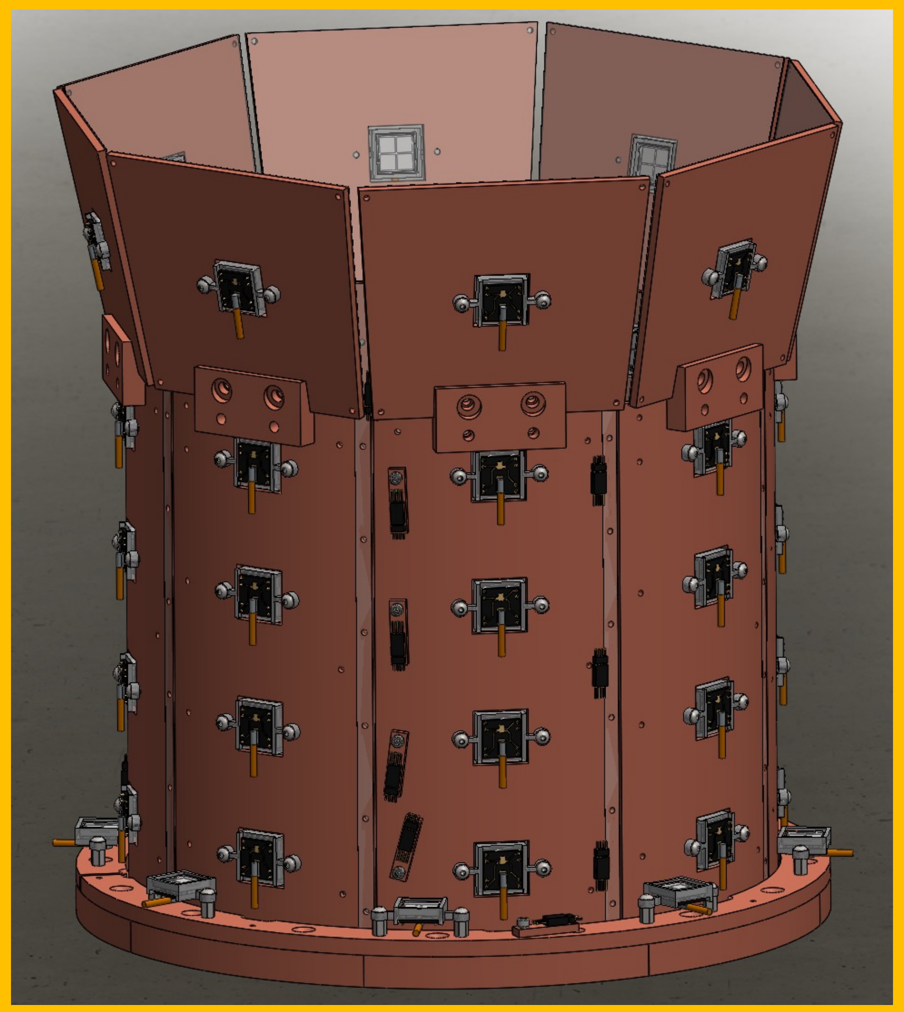
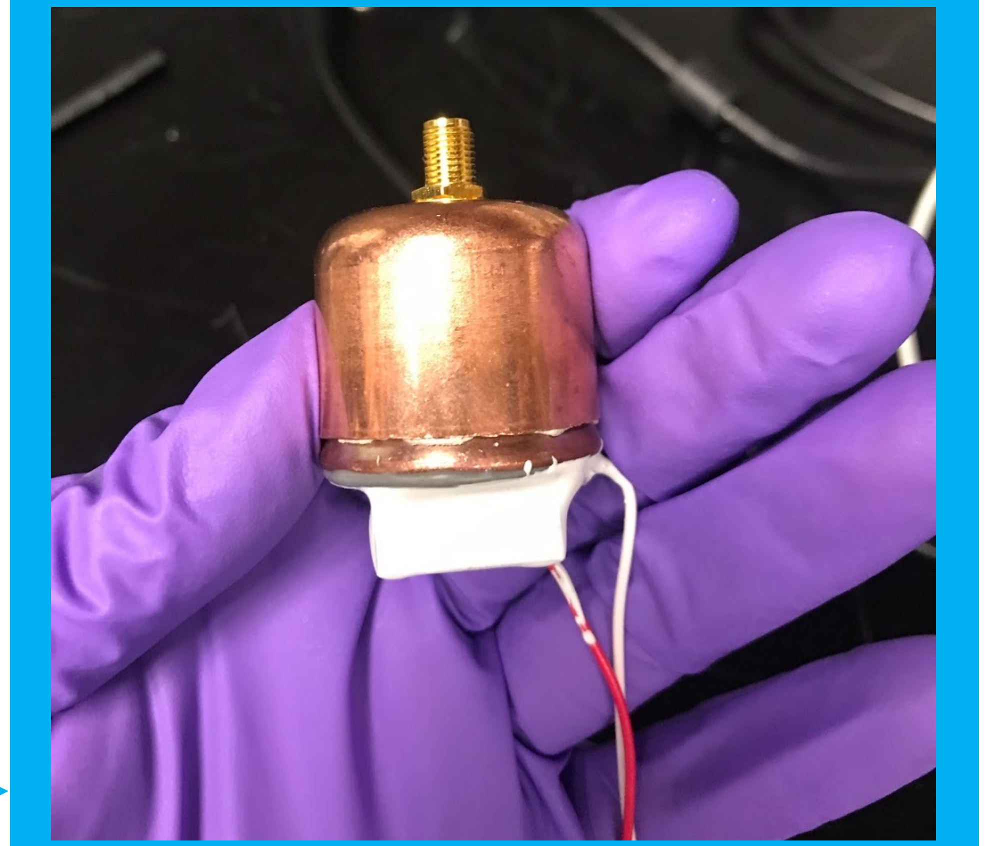
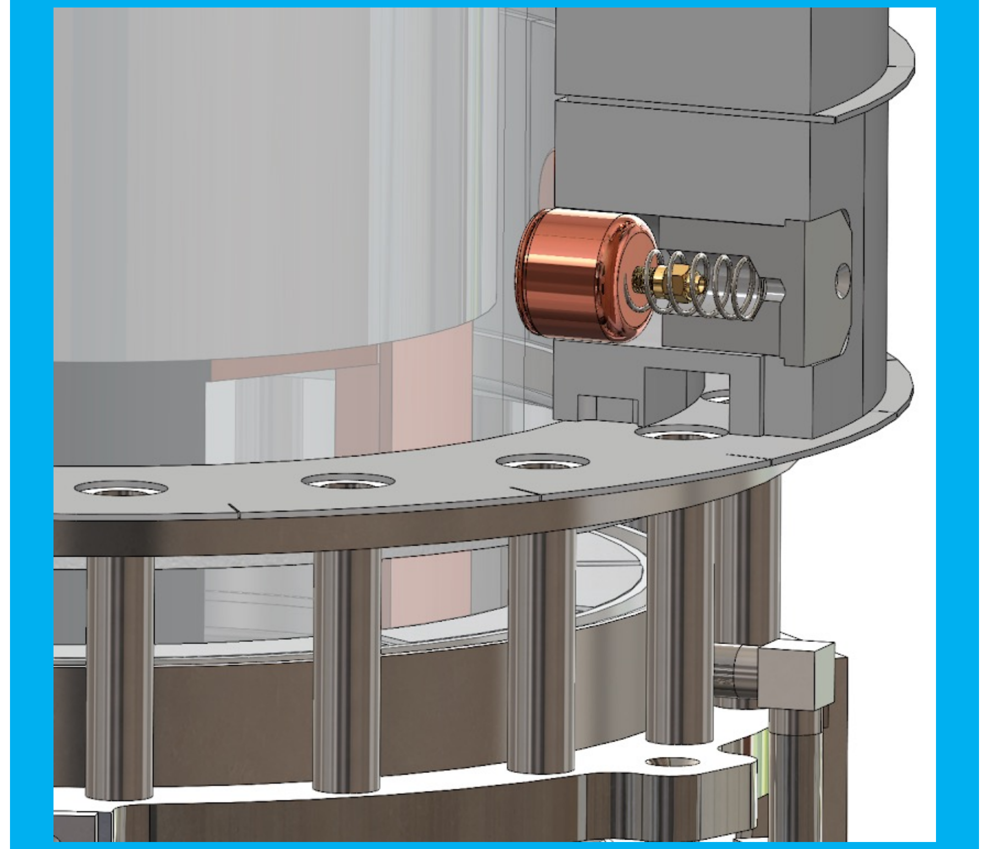




Acoustic Sensors

8 Piezoelectric Transducers





3. Physics Program

Dark Matter & Reactor CEvNS

SBC-Fermilab - Phase 1

Build and commission the first detector at Fermilab.

Dark Matter & Reactor CEvNS

SBC-Fermilab - Phase 1

Build and commission the first detector at Fermilab.

SBC-SNOLAB - Phase 2

Build and install a second detector at SNOLAB for low-mass dark matter searches.

Dark Matter & Reactor CEvNS

SBC-Fermilab - Phase 1

Build and commission the first detector at Fermilab.

SBC-SNOLAB - Phase 2

Build and install a second detector at SNOLAB for low-mass dark matter searches.

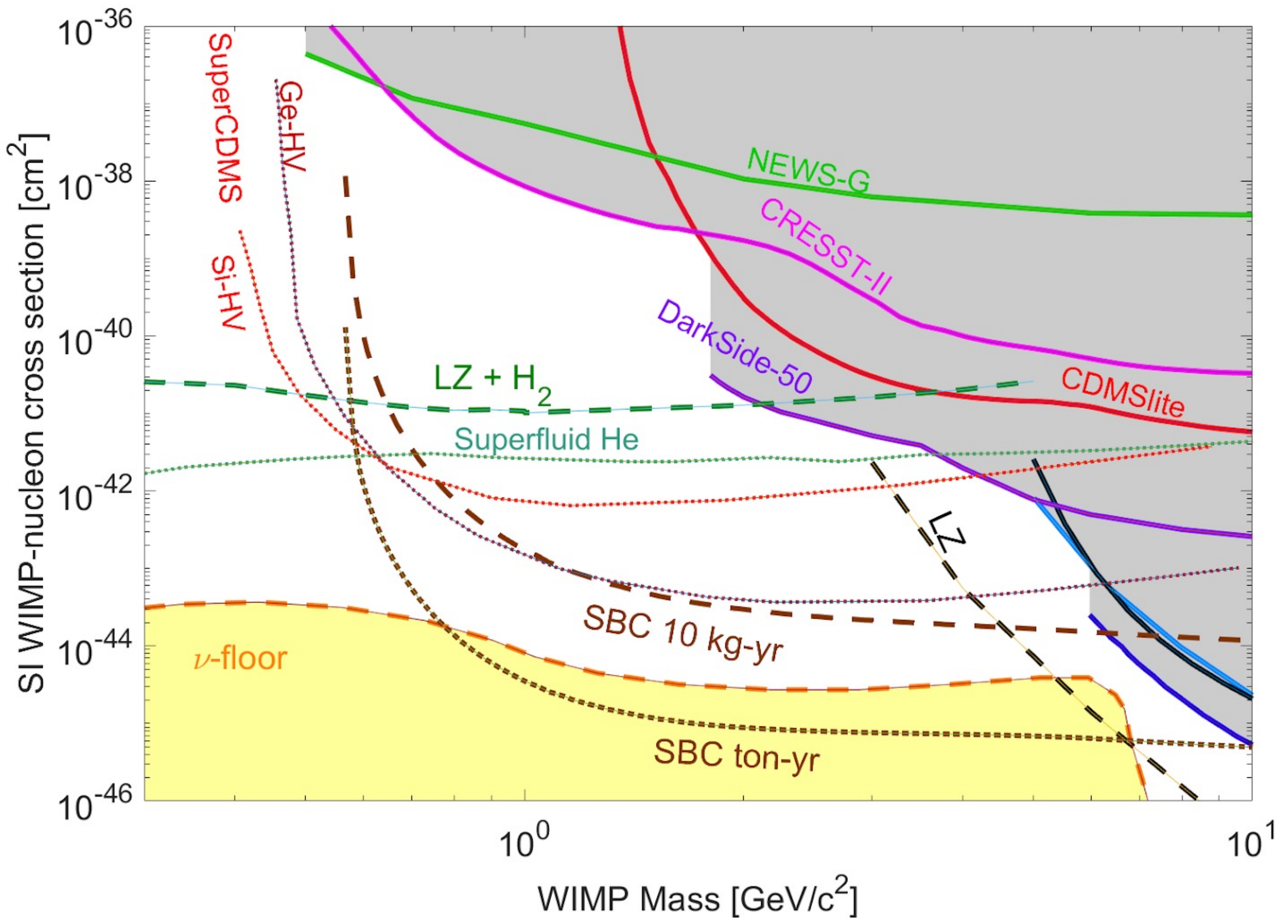
SBC-CEvNS - Phase 3

Upgrade and install detector from (1) at a reactor site for CEvNS studies.

Dark Matter Search @ SNOLAB

DOI: https://doi.og/10.22323/1.390.0632

Perform competitive **Low-Mass WIMP** search
(0.7-7 GeV/c2)

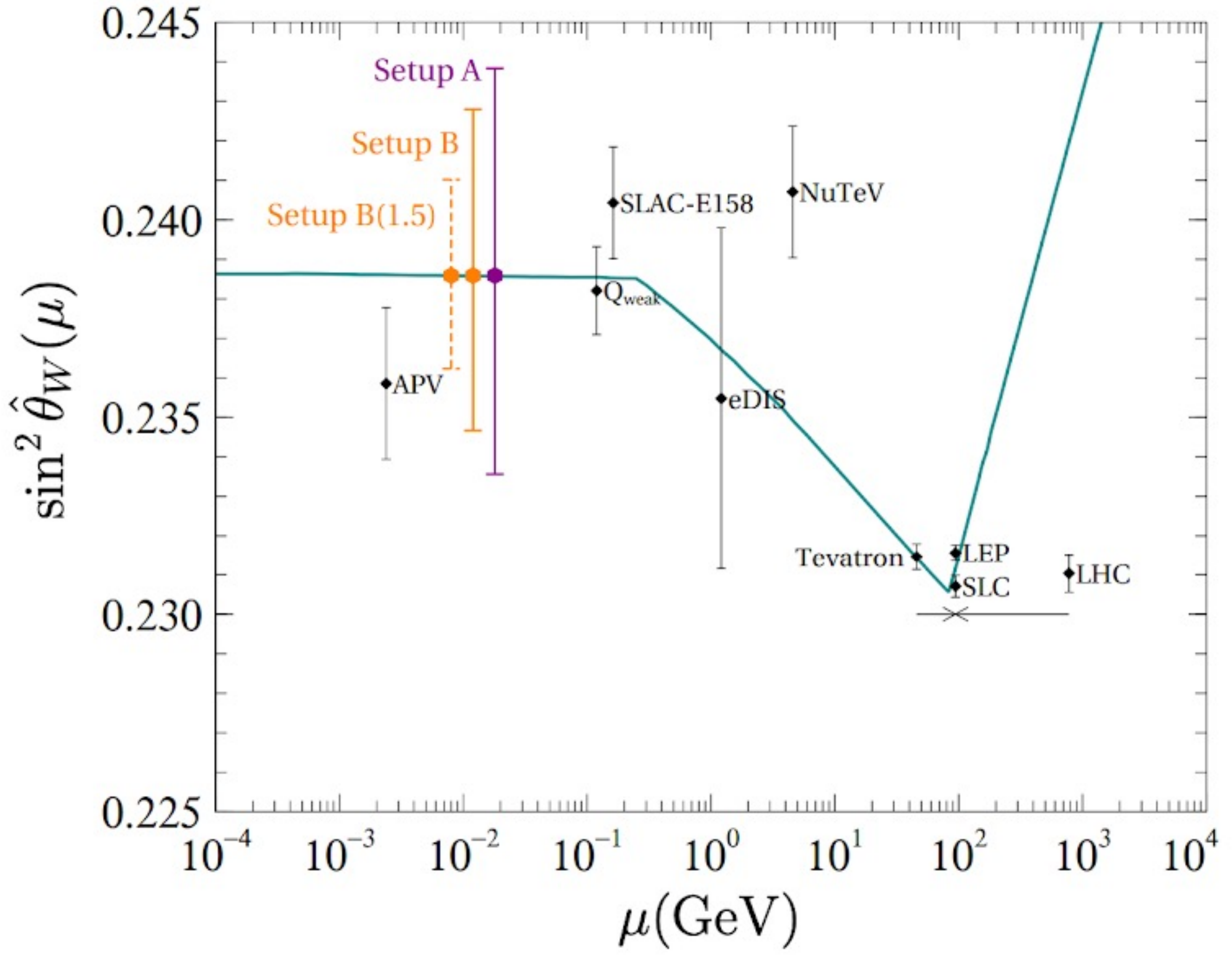


- Projected sensitivity to WIMP-like Dark Matter, with an energy threshold set at 100 eV, and a background budget target of 1 event/year.
- Primary background challenge are neutrons generated in (α,n) reactions in the bulk of the detector materials. Material screen crucial for the development of this detector.

CEvNS Physics Reach

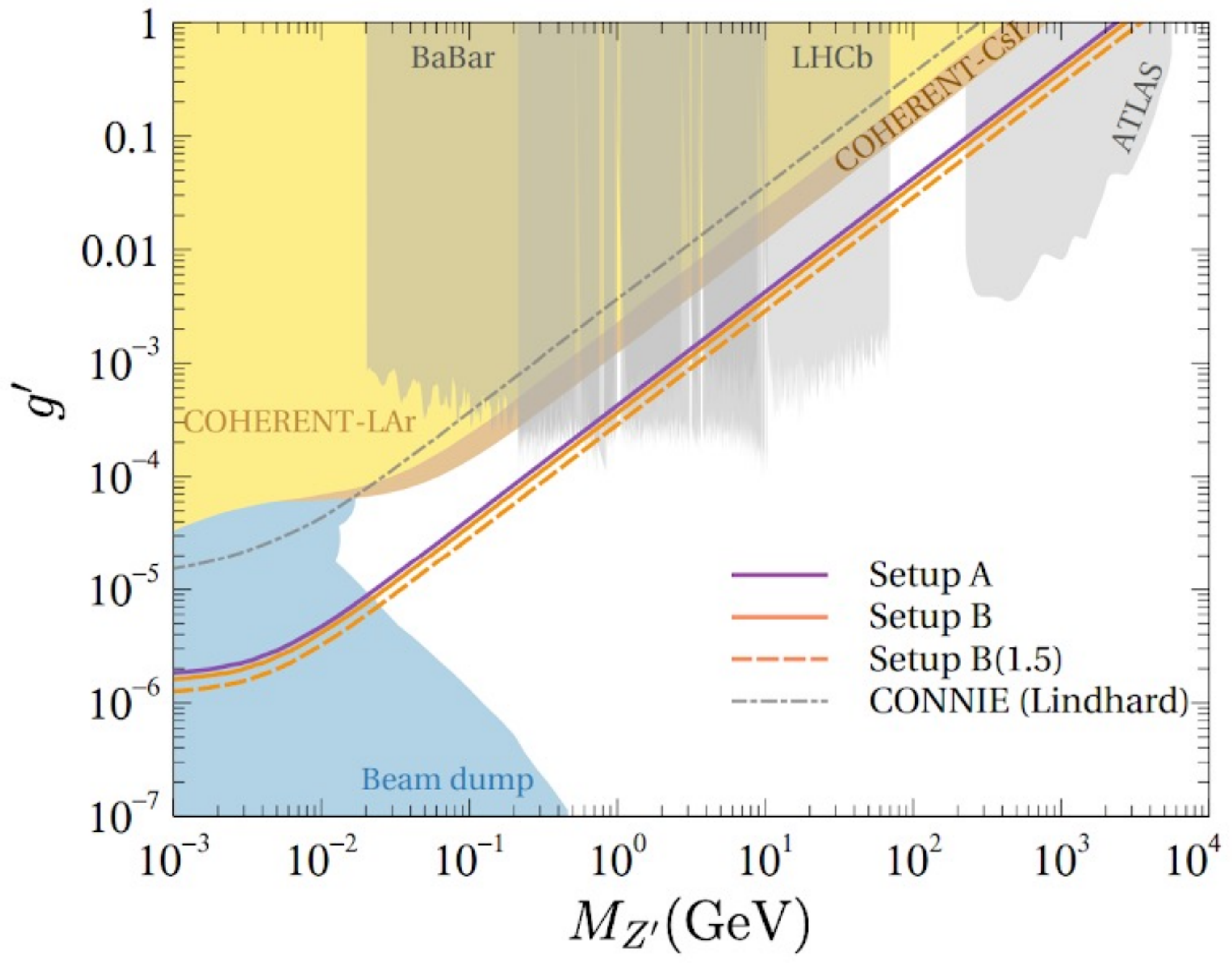
Phys. Rev. D 103, L091301

Weak-Mixing Angle



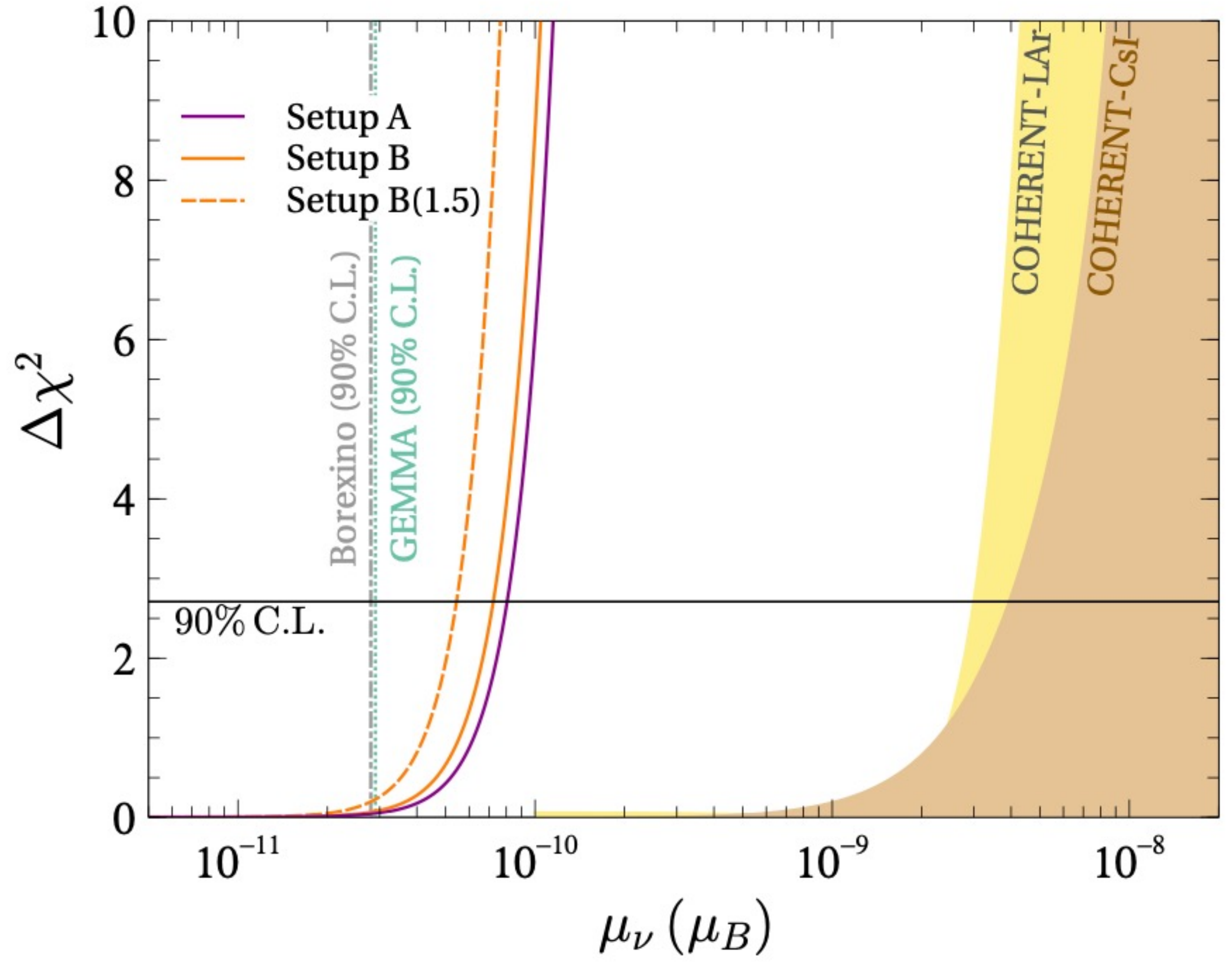
$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right) F^2(q^2),$$

Dark Mediator Z'



$$\mathcal{L}_{\text{eff}} = -\frac{g'^2 Q_l Q_q}{q^2 + M_{Z'}^2} \left[\sum_\alpha \bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha\right] \left[\sum_q \bar{q}\gamma_\mu q\right],$$

Neutrino Magnetic Moment



$$\frac{d\sigma}{dT} = \pi \frac{\alpha_{\text{EM}}^2 Z^2 \mu_\nu^2}{m_e^2} \left(\frac{1}{T} - \frac{1}{E_\nu} + \frac{T}{4E_\nu^2}\right) F^2(q^2),$$

5. Conclusions

Conclusions

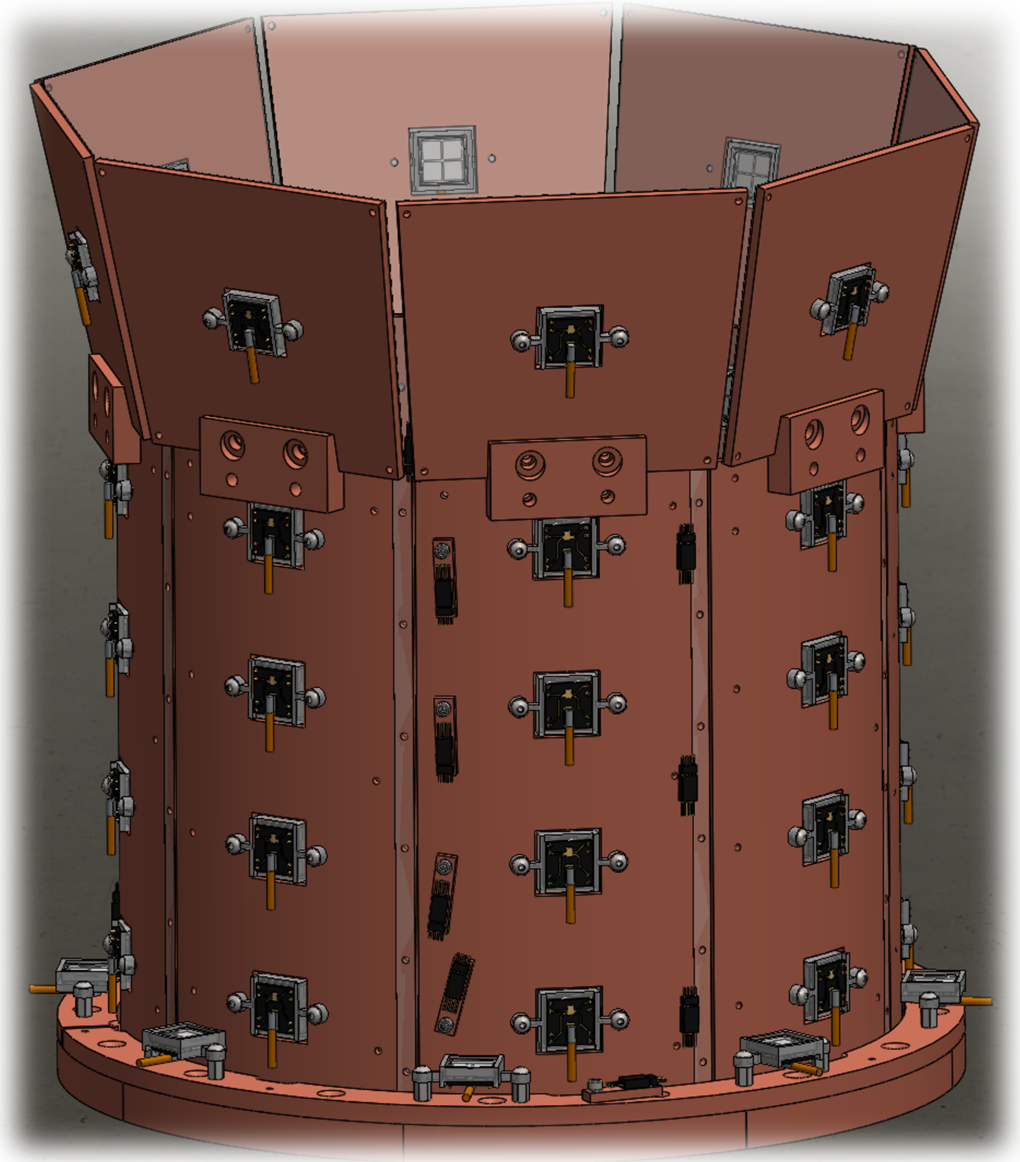
- Introduced scintillating bubble chambers technique, with good potential for low threshold [O(100 eV)] and optimal ER rejection power [$<10^6$].
- Discussed the SBC design and scientific program with two detectors optimized, respectively, for Dark Matter (SBC-SNOLAB) and neutrino (SBC-CEvNS) studies (SBC-CEvNS).
- Presented the projected sensitivity for the Dark Matter search. Discussed CEvNS studies, for different reactor configurations, with projected sensitivities for the weak-mixing angle, dark mediator Z' and the neutrino magnetic moment.

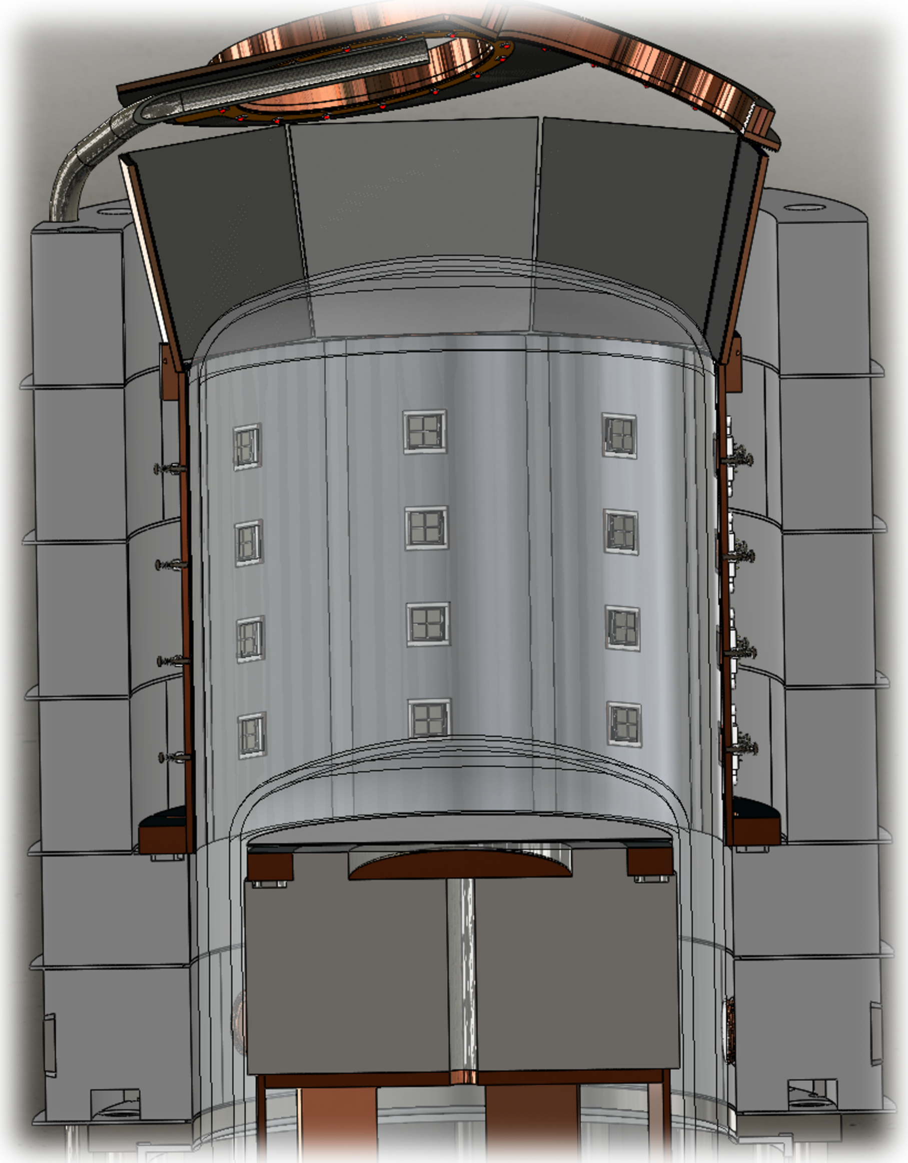
Thank You,
Merci

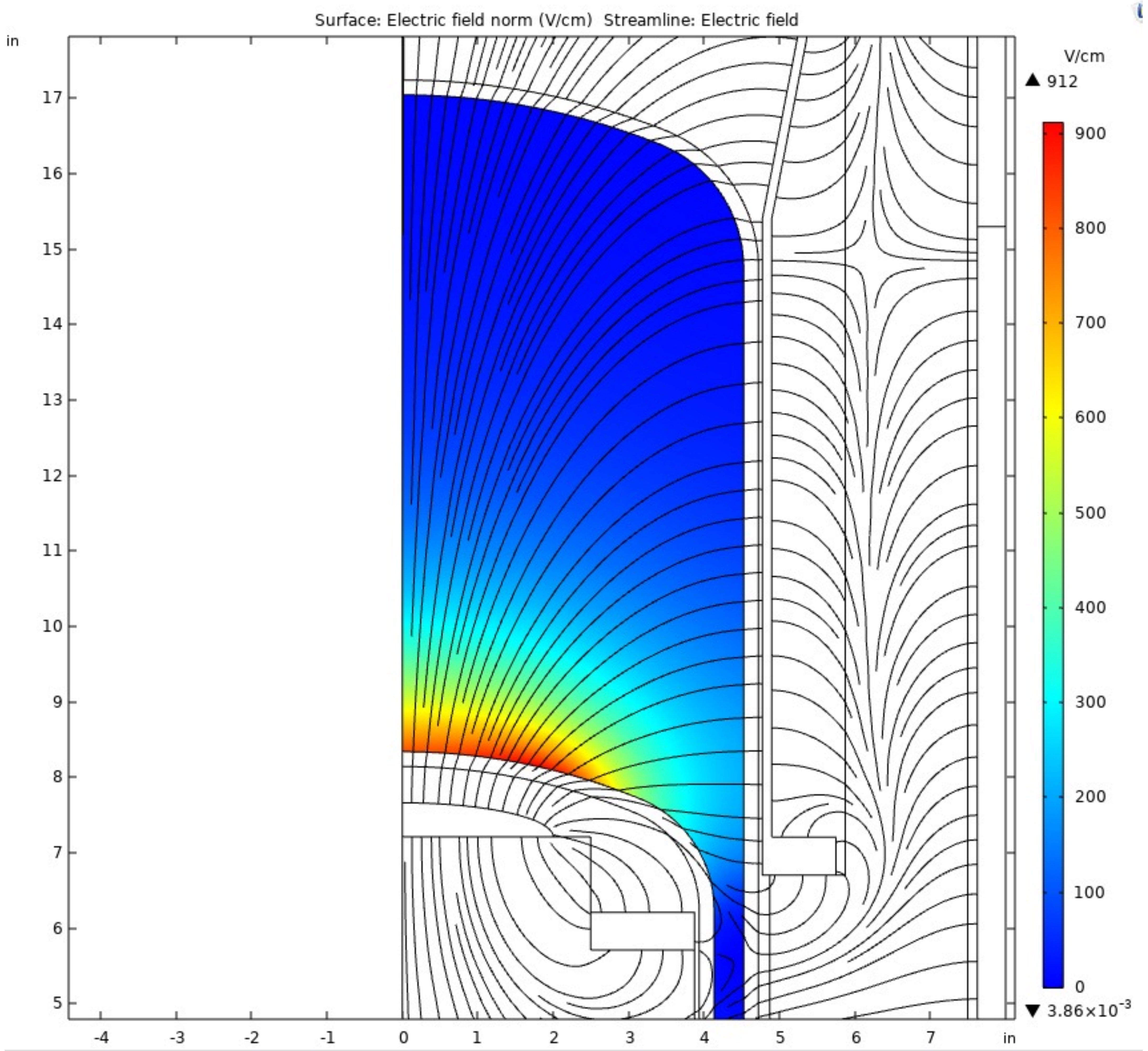
@SNOLABscience

Backup Slides

HV System

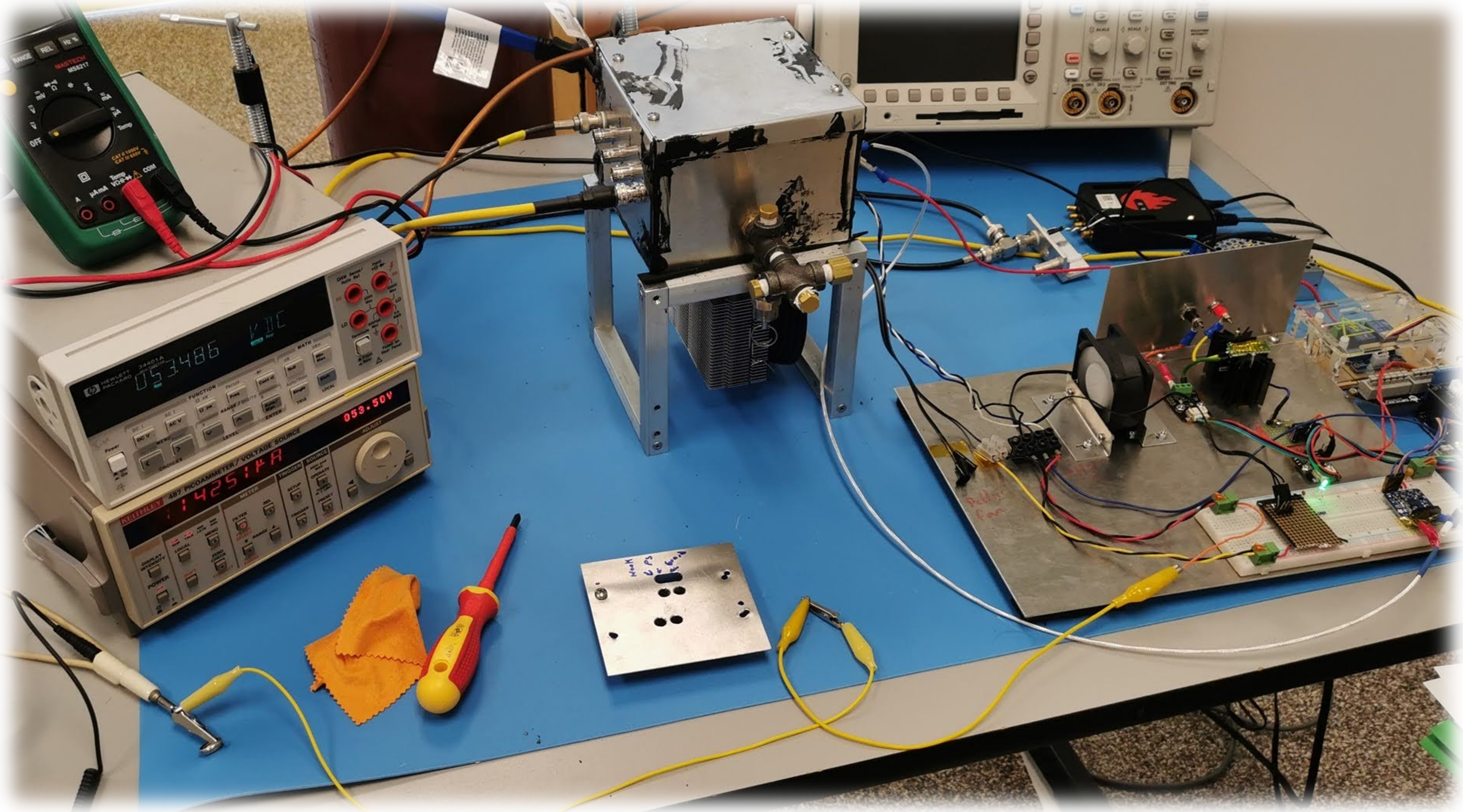


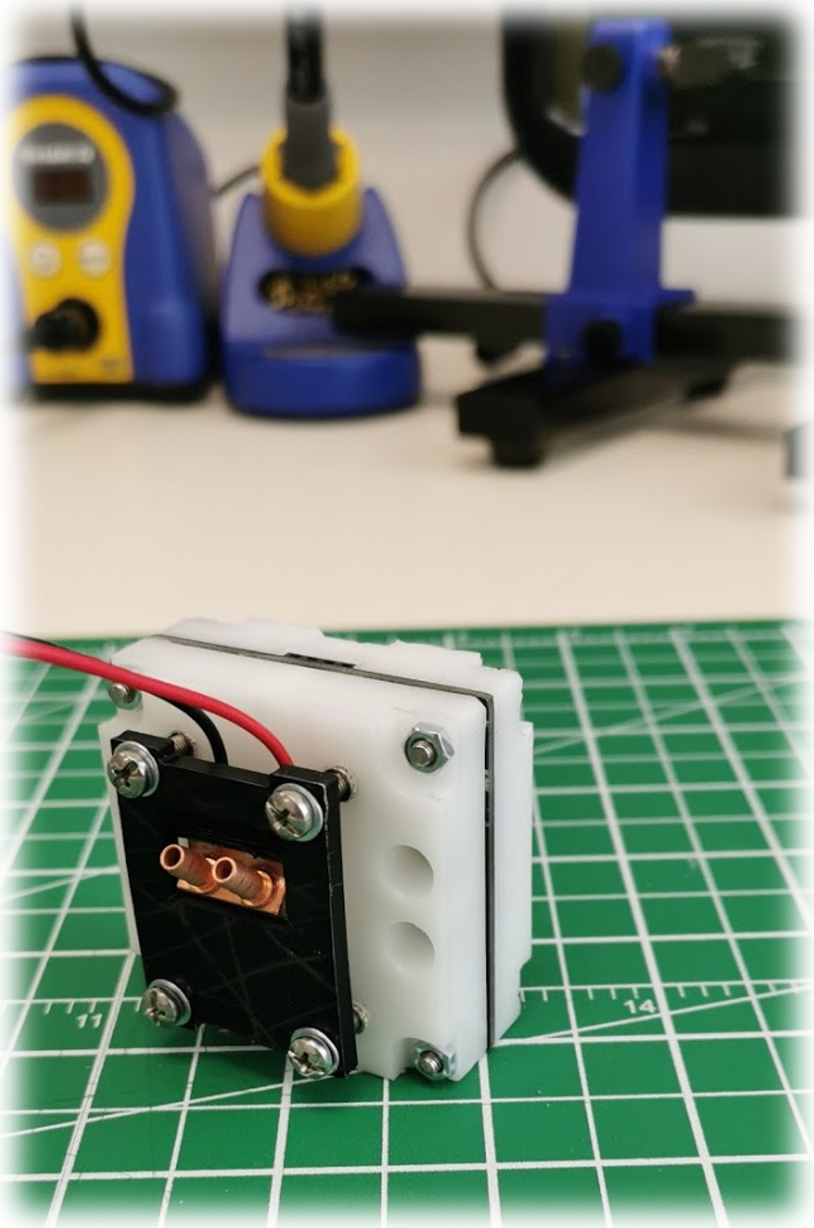


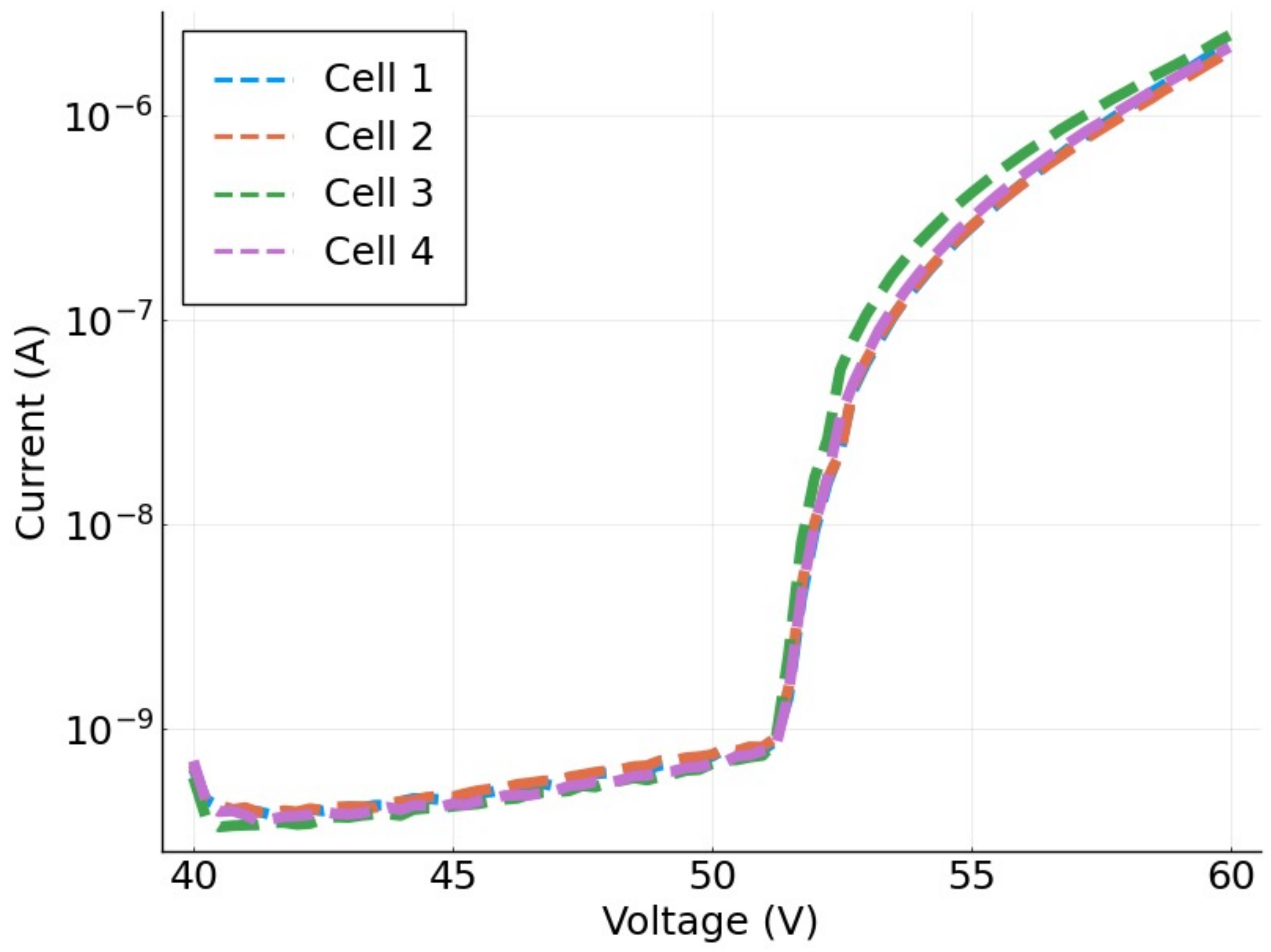


5 kV applied on the Cu plate under the inner jar.
Grounded reflector around the outer jar.

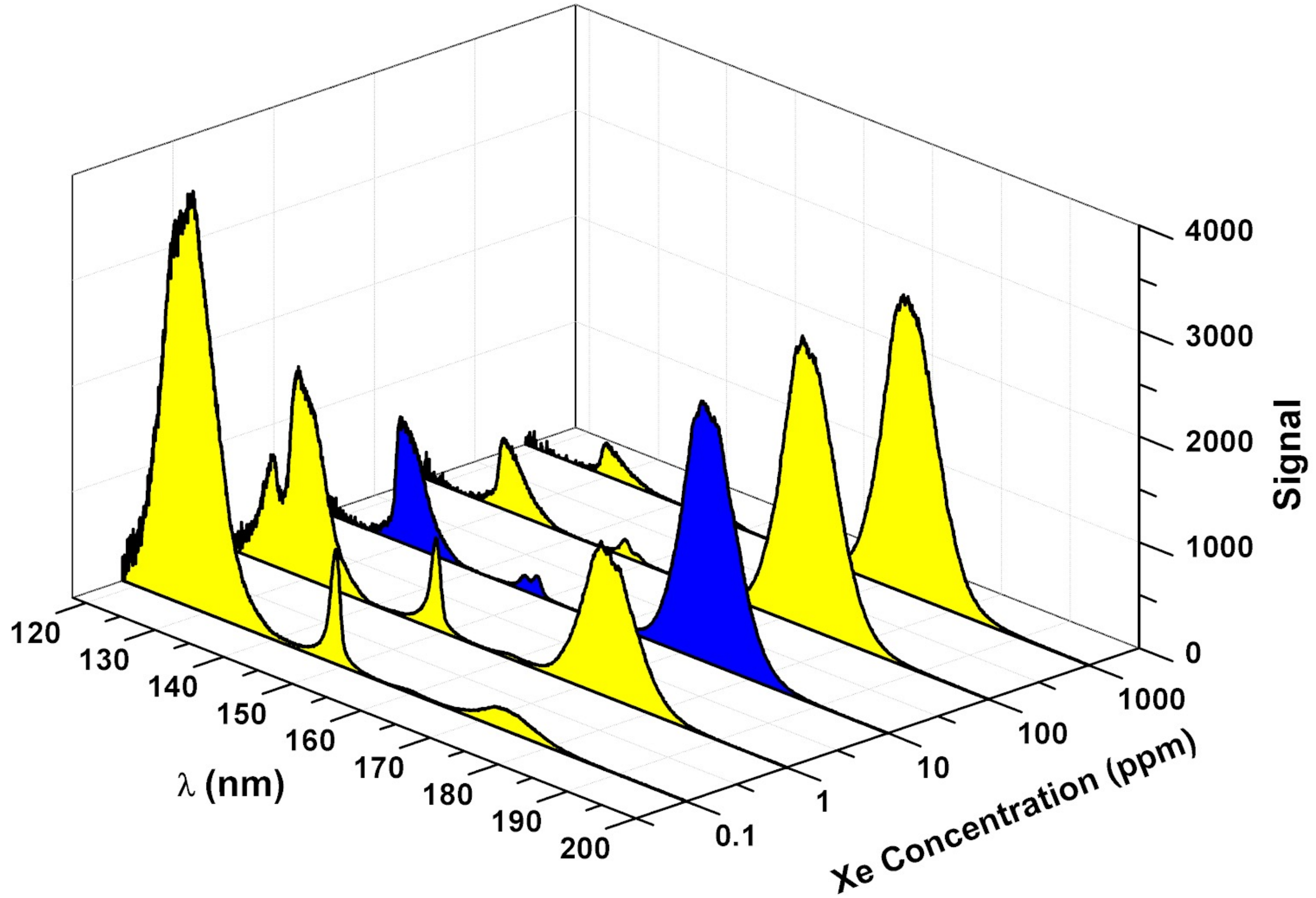
SiPM Testing @ Queen's U

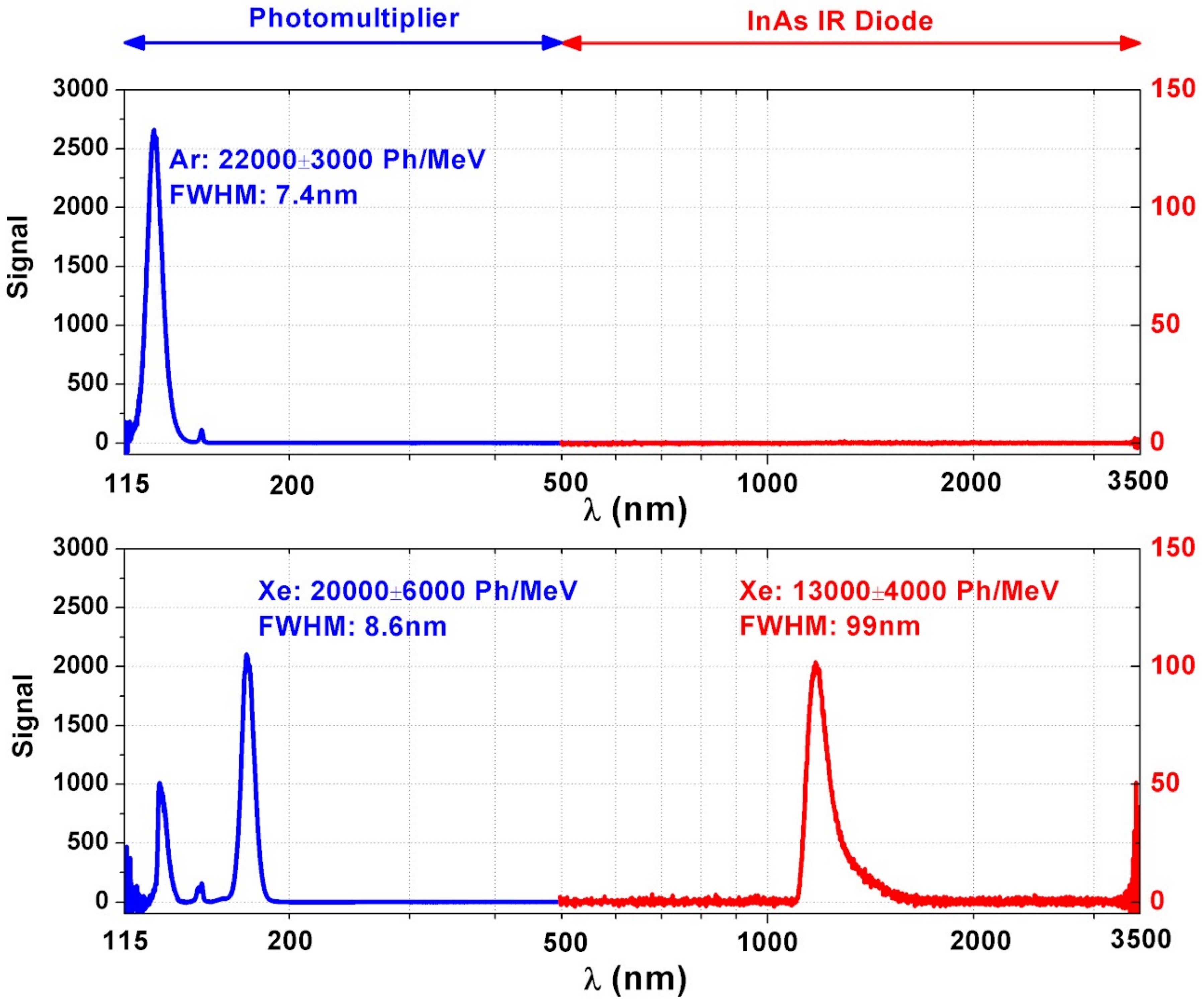






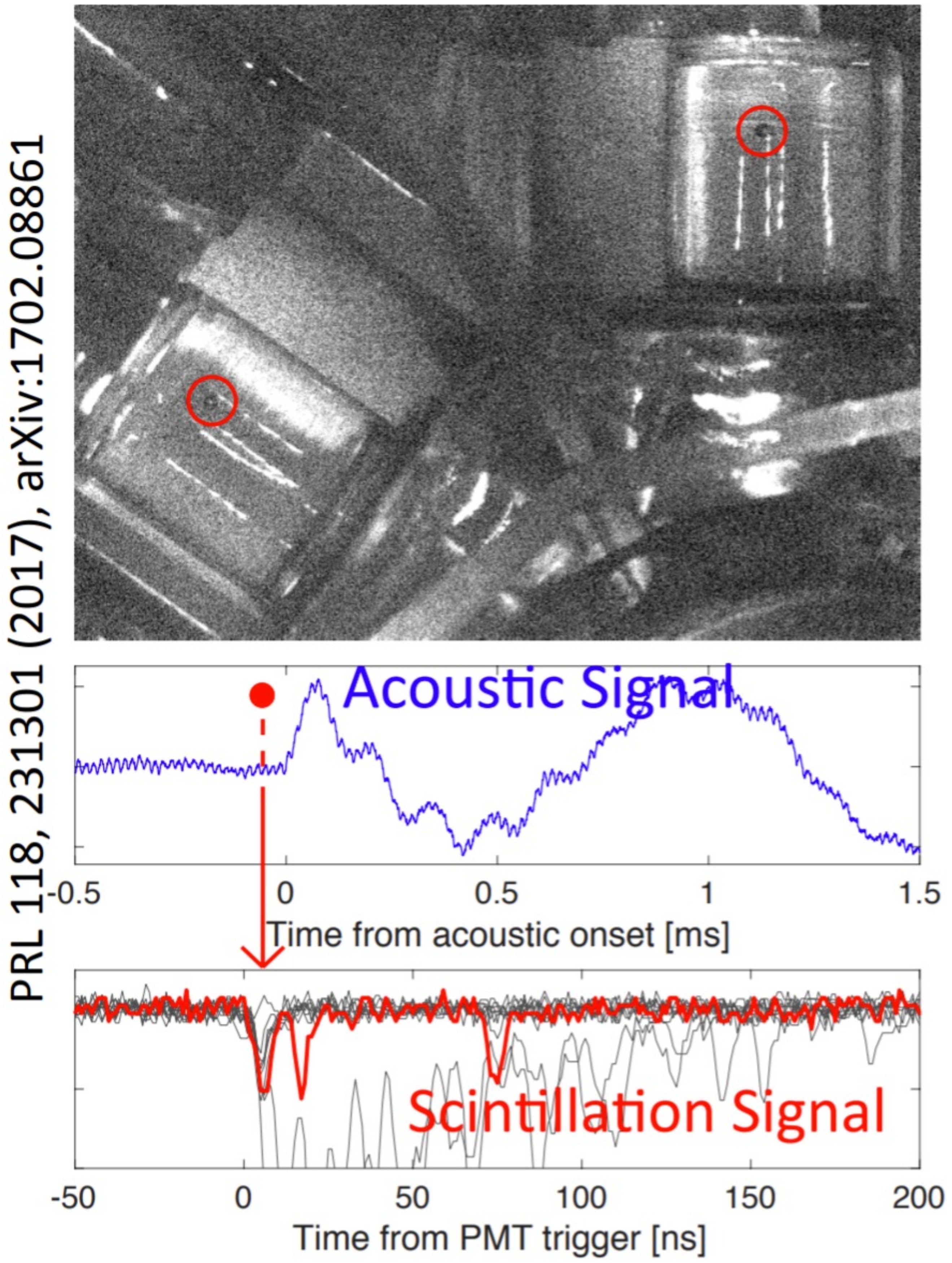
Xe-doping in LAr





Xe Bubble Chamber at NU

PRL 118, 231301 (2017), arXiv:1702.08861



Demonstrated

- Liquid Xenon Bubble Chamber at 900 eV E_{th}
- Target Mass = 30 grams
- 0.3% Overall Photon Collection Efficiency

Next Program

- Liquid Argon Bubble Chamber at 40 eV E_{th}
- Target Mass = 10 kg
- ER Background of 1 Bubble / Ton-Year
- 2% Overall Photon Collection Efficiency (1-photon ~ 5 keVr)

Bubble Chamber Physics

•Critical Radius:

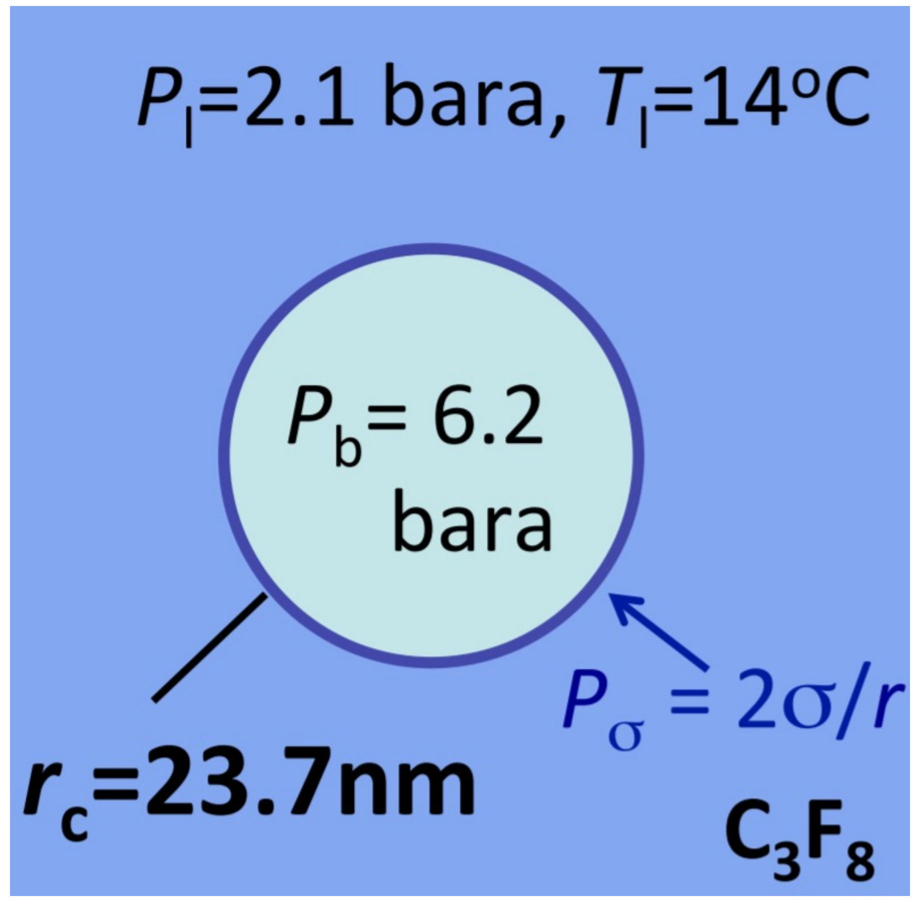
Smallest vapor bubble that will spontaneously grow in a superheated liquid.

•Seitz Threshold:

Minimum amount of energy required to create a vapor bubble with a critical radius.

•NR/ER Response:

NR leads to Nucleation, can ER also induce Nucleation?



$$E_T = 4\pi r_c^2 \left(\sigma - T\left(\frac{\partial \sigma}{\partial T}\right)_\mu\right) \quad \text{1.53 keV}$$

$$+ \frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l) \quad \text{1.81 keV}$$

$$- \frac{4\pi}{3} r_c^3 (P_b - P_l) \quad \text{-0.15 keV}$$

Reactors Setup

Setup A:

~8 CEvNS/day @ 100 eV Threshold

0.25 events/day – reactor backgrounds

0.85 events/day – cosmogenic backgrounds

Shielding – 0.3m Pb, 0.25m H_2O, 0.5m Polyethene , 0.2m Pb

Results B:

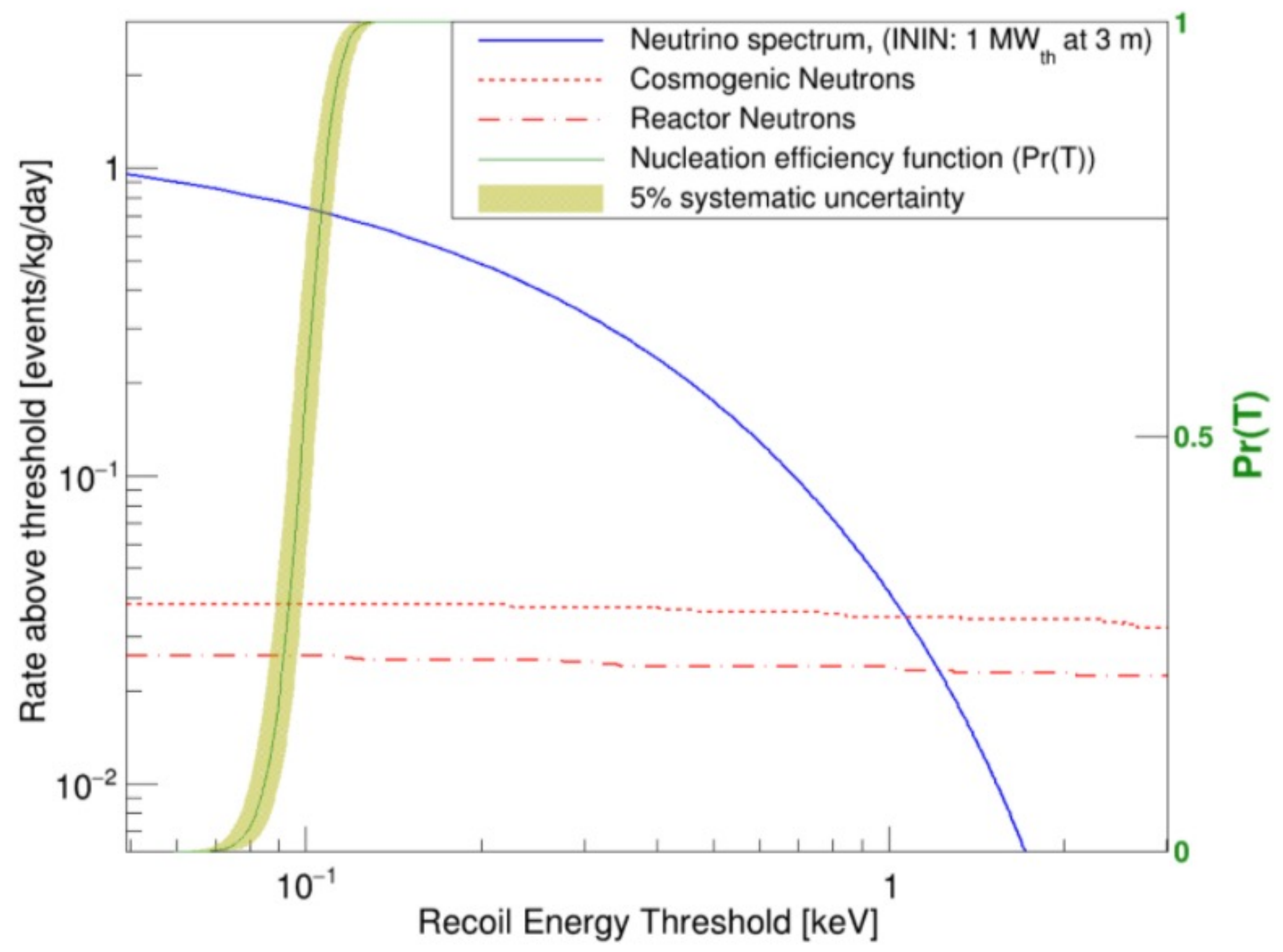
~1570 CEvNS/day 100 eV Threshold

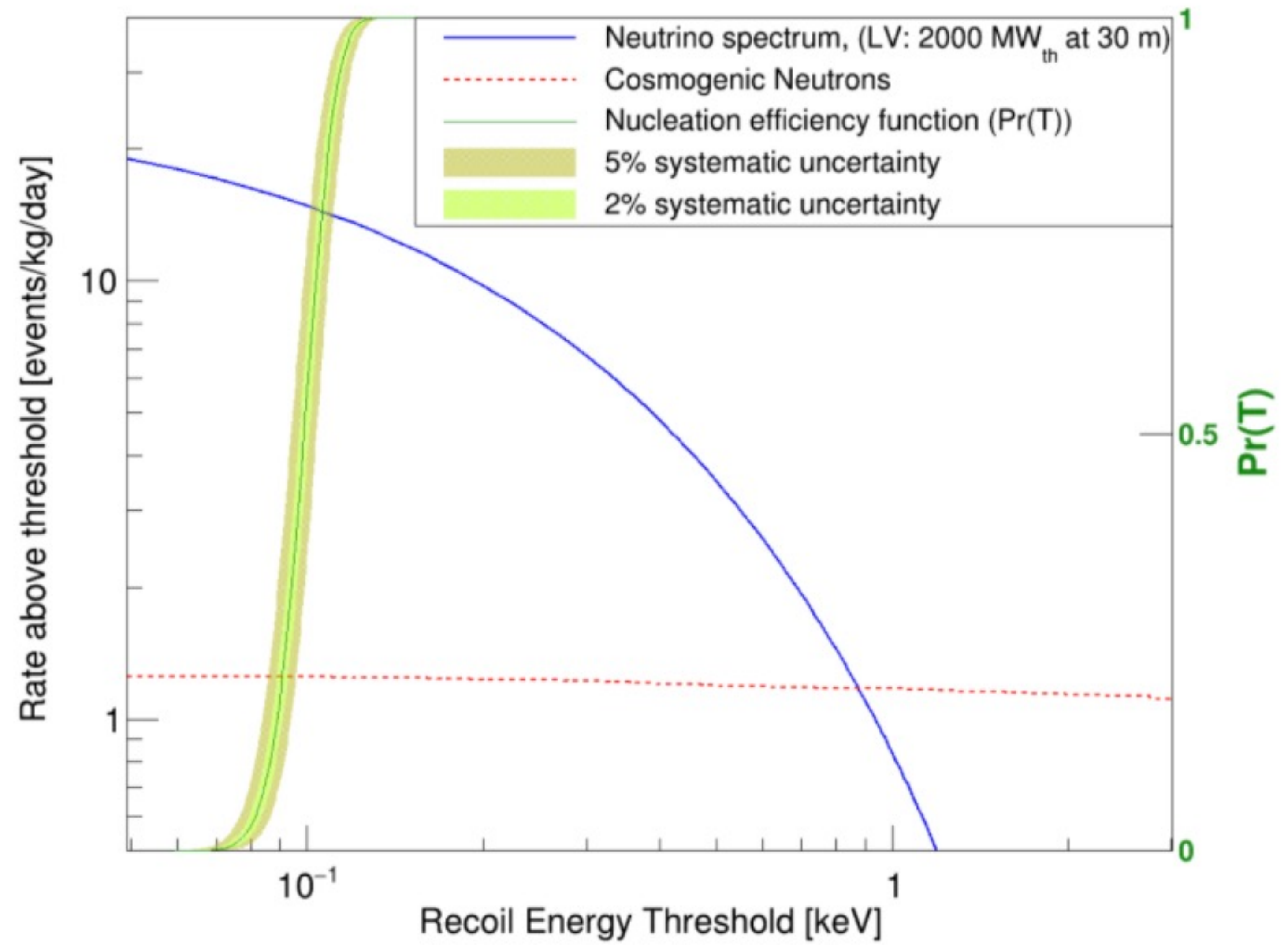
negligible – reactor backgrounds (30m + shielding)

180 events/day – cosmogenic backgrounds

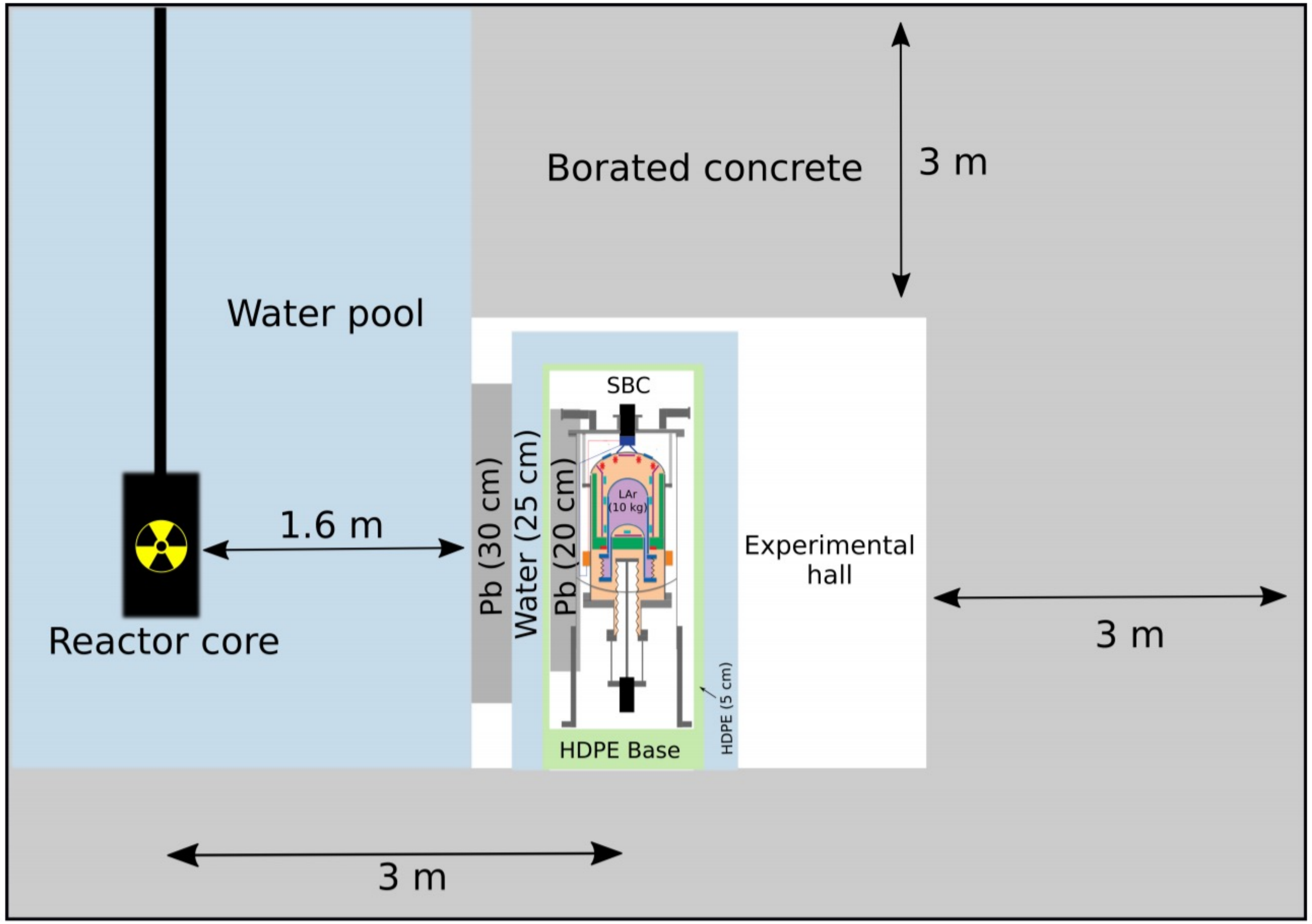
Shielding – 3m H_2O, 0.5m Polyethene

(Reactor Neutrons, ɣ-n Interactions, ɣ-n Elastic Thomason Scattering, Cosmogenic Neutrons, ɣ/β interactions negligible)





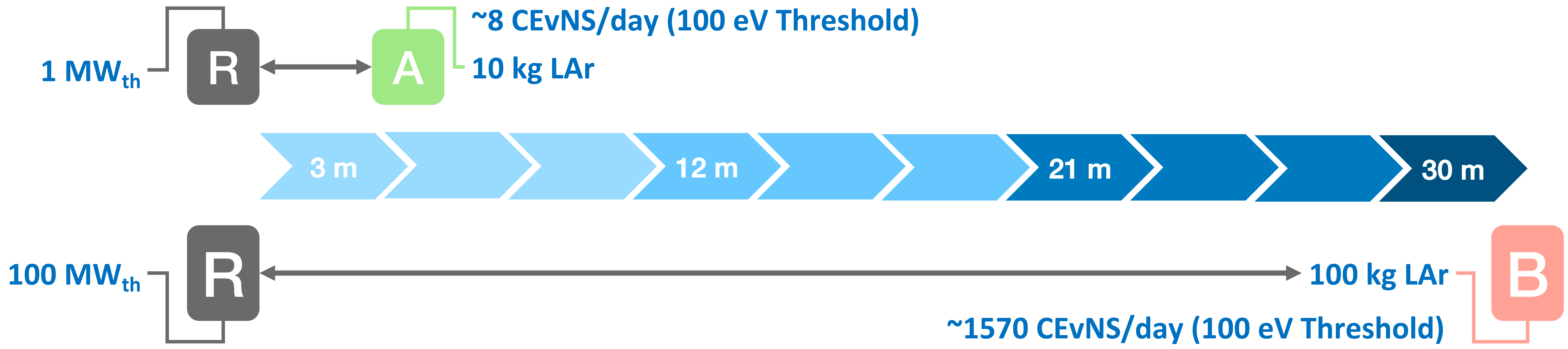
Reactor Setup B



Considered Reactor Setups

Phys. Rev. D 103, L091301

Setup	LAr Mass [kg]	Power [MW_{th}]	Distance [m]	Anti-ν Flux Uncertainty [%]	Threshold Uncertainty [%]
A	10	1	3	2.4	5.0
B	100	2000	30	2.4	5.0
B(1.5)	100	2000	30	1.5	2.0



Energy Deposition in LAr