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Hunting for Low-Mass WIMPs with the Scintillating Bubble Chamber (SBC) Experiment

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New Techniques for Dark Matter Discovery - Workshop

August 2019

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Overview

- Towards Low-Mass WIMPs
- Introduction to (Scintillating) Bubble Chambers
- The SBC Experiment
- Conclusions

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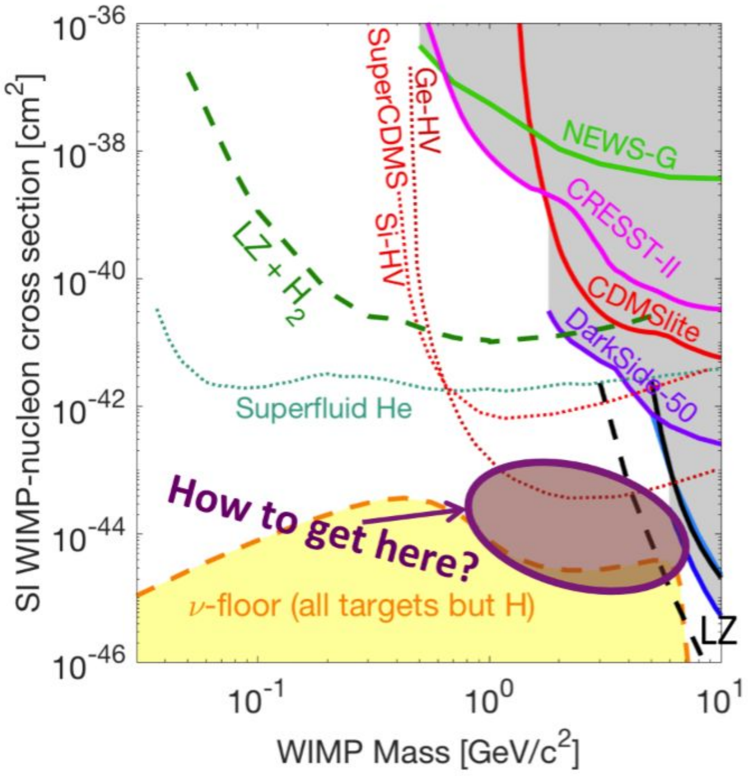
Towards Low-Mass WIMPs

Towards Low-Mass WIMPs

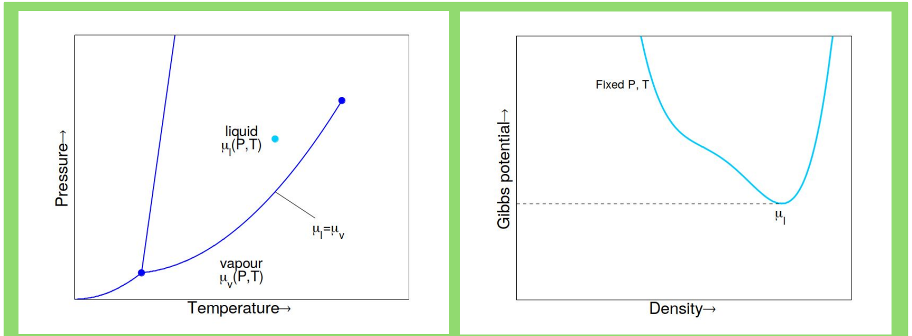


<u>Requirements for Low-Mass WIMP Detectors:</u>

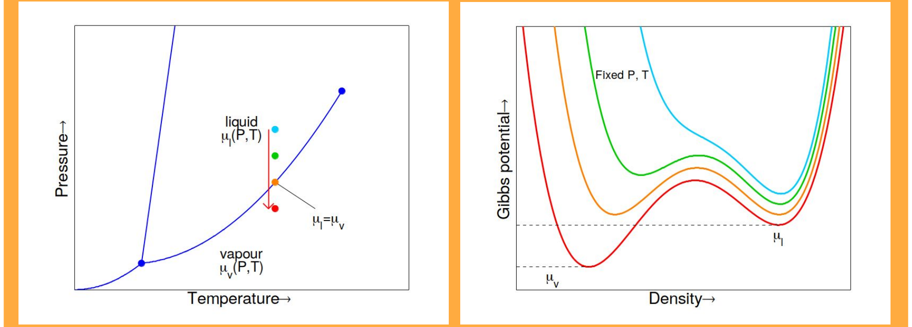
- **Low Threshold:**
  - sub-keV NR's
- **Exposure:**
  - Scalable to O(100) kg
- **Backgrounds:**
  - Strong ER/NR Discrimination (10E-6 or stronger)

Introduction to (Scintillating) Bubble Chambers

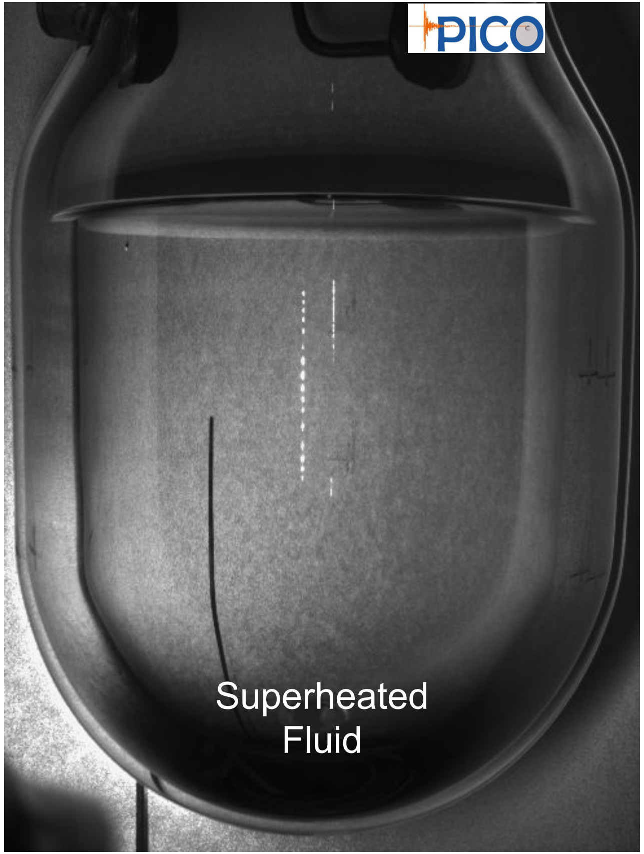
How Bubble Chambers Work



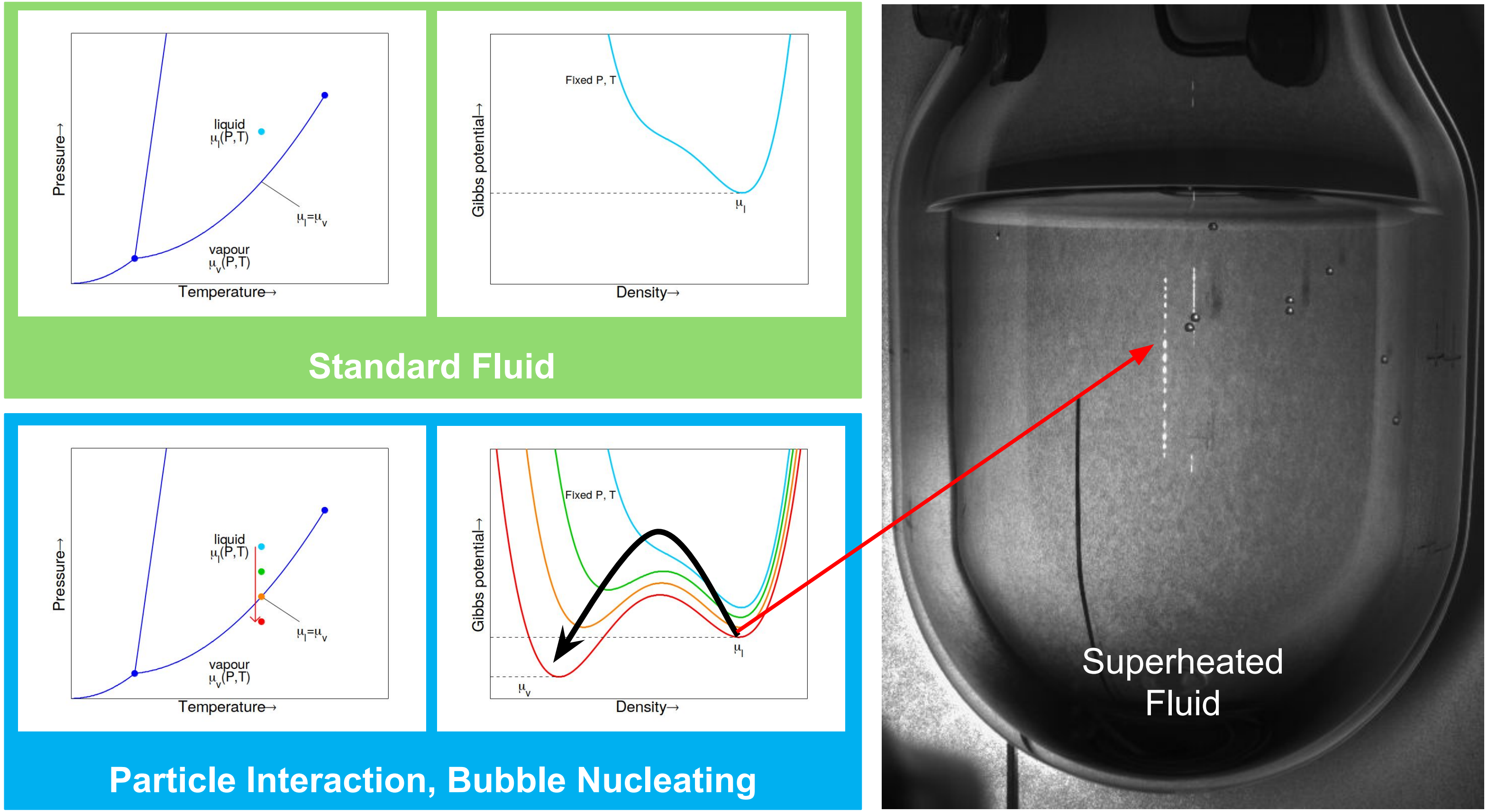
Standard Fluid



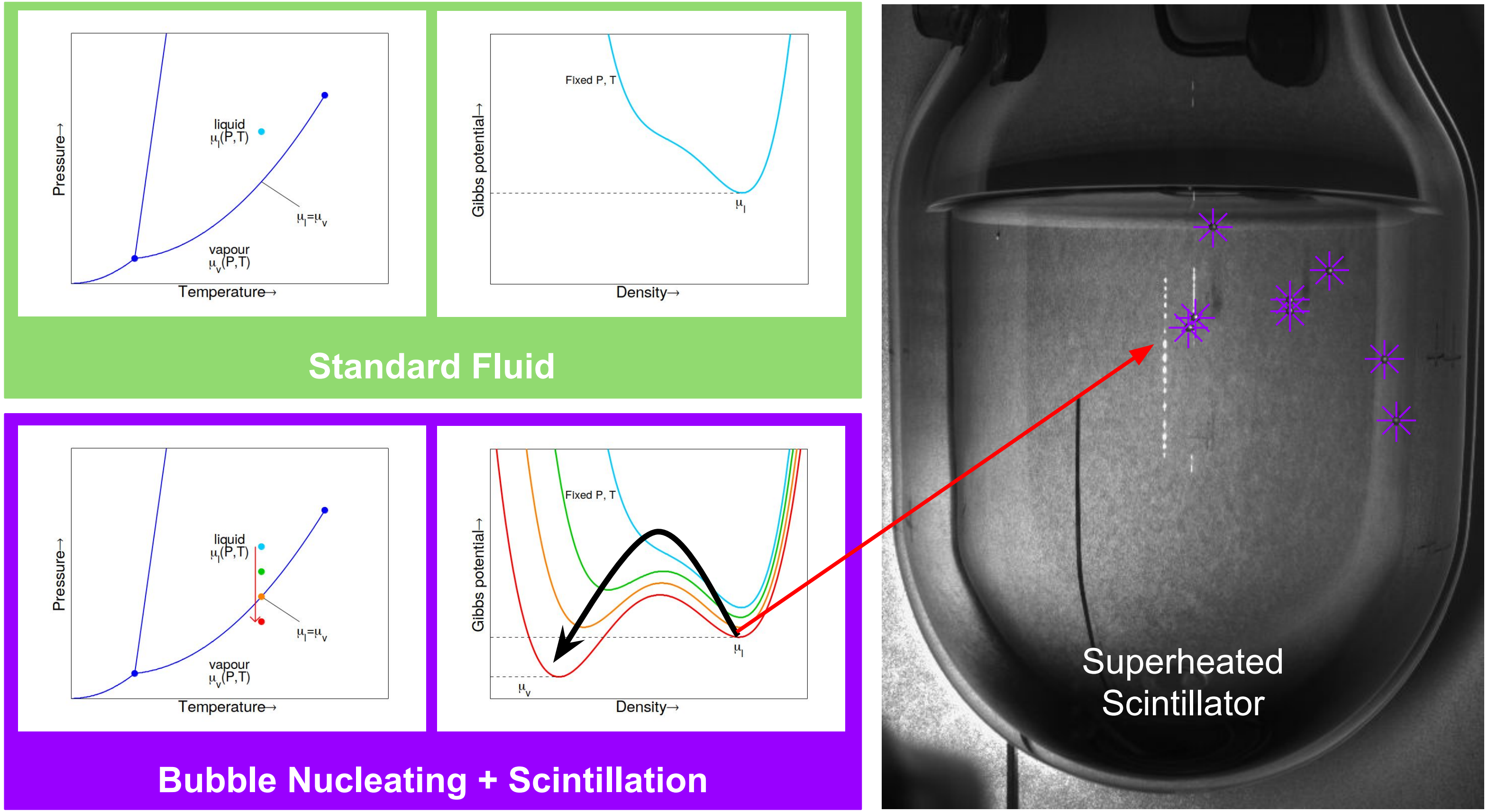
Superheated Fluid



How Bubble Chambers Work



How (Scintillating) Bubble Chambers Work



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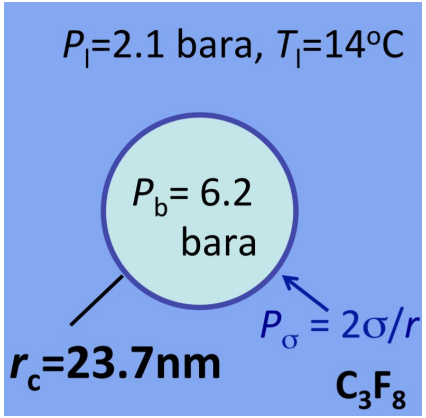
Key Considerations

- **Critical Radius:**
  Smallest vapor bubble that will spontaneously grow in a superheated liquid.



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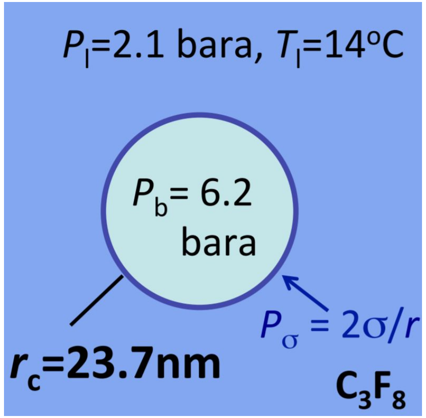

- **Seitz Threshold:**
  Minimum amount of energy required to create a vapor bubble with a critical radius.

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

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

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

= 3.19 keV

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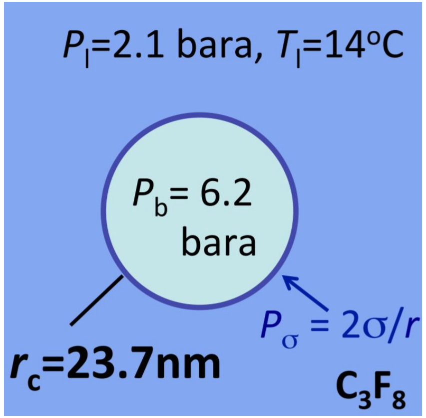

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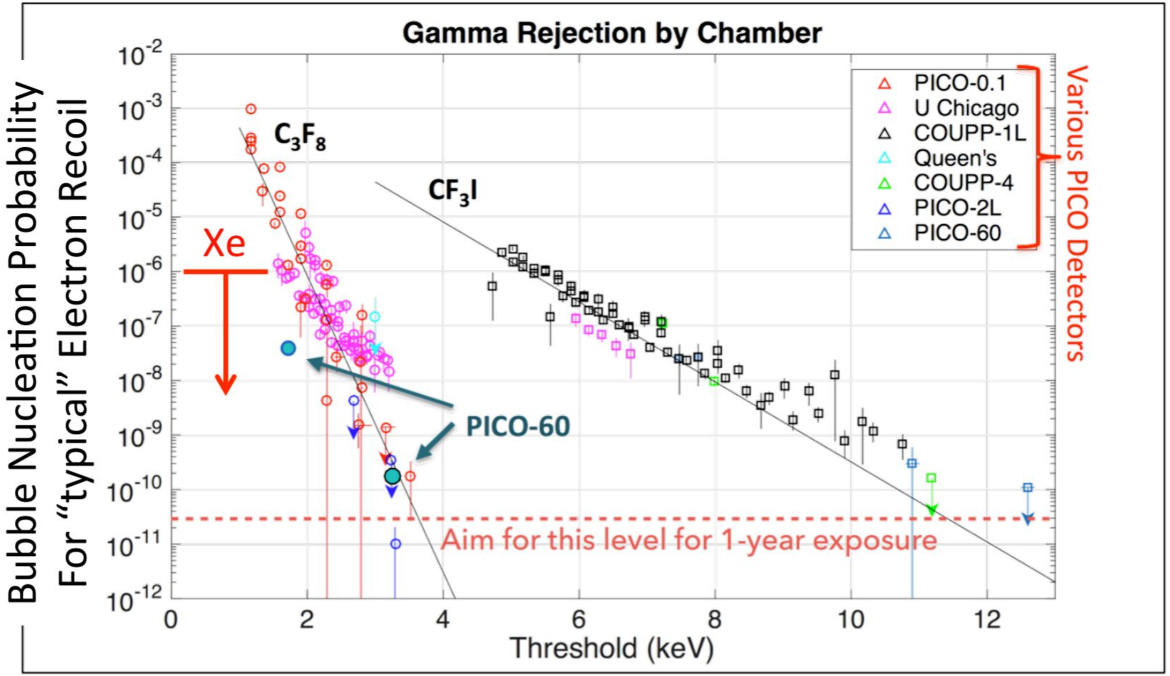
- **NR/ER Response:**
  NR leads to Nucleation, can ER also induce Nucleation?

ER Discrimination vs Threshold

- **NR's Nucleate Bubbles:**
  Superheat = NR single/multiple bubbles.
- **ER's don't Nucleate Bubbles:**
  Superheat = dE/dx threshold for ER's
- **No Evidence of Nucleation by ER in Xenon:**
  900 eV Threshold.



(Dan Baxter, Conference on Science at SURF, May 14, 2017)

More in PRD 100, 082006 (2019), arXiv:1910.09124

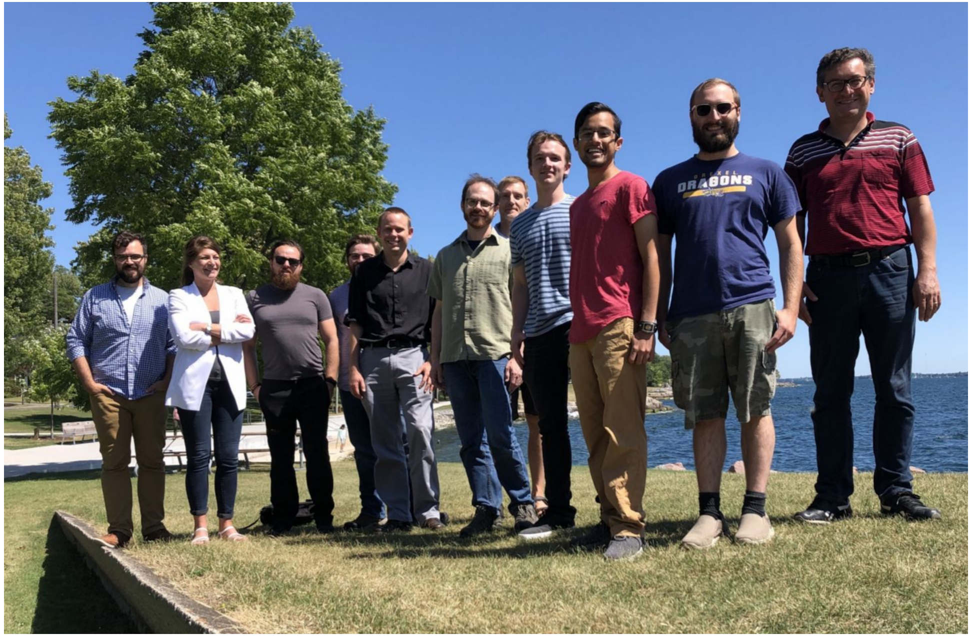
The SBC Experiment

The SBC Collaboration

Northwestern University
- **Eric Dahl**
- Rocco Coppejans
- Runze Zhang
- Jason Phelan
- Will Reinhardt
- Lawrence Luo
- Zhiheng Sheng
- Fangjun Zhu
- Aaron Brandon

Queen's University
- **Ken Clark**
- Hector Hawley

University of Alberta
- Marie-Cécile Piro
- 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

Indiana University South Bend
- Ilan Levine
- Ed Behnke
- Nathan Walkowski
- Kelly Allen

UC Santa Barbara
- Hugh Lippincott
- TJ Whitis

TRIUMF
- Pietro Giampa

Université de Montréal
- Mathieu Laurin

Northeastern Illinois University
- Orin Harris

Pacific Northwest National Laboratory
- Chris Jackson

Fermilab
- Mike Crisler

The Experimental Strategy

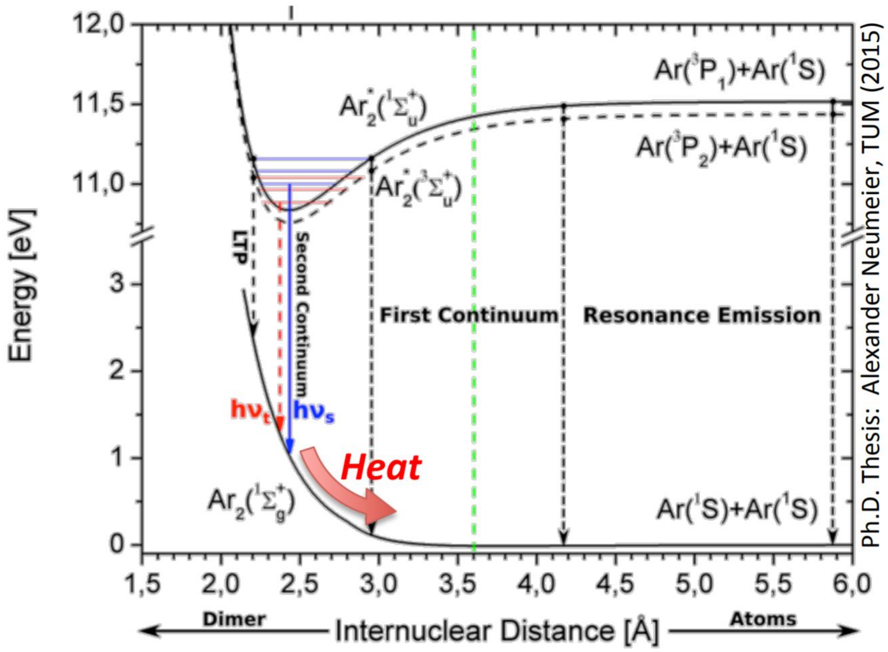
Combine the **electron recoil discrimination** of bubble chambers

+

the **event-by-event energy resolution** and **low-thresholds** of scintillation detectors.

How Low (In Threshold) Can SBC Go?

- 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 have to be considered at *O*(10) eV in threshold.
  - SBC design target is 1 bubble / ton-year at a **threshold of 40 eV (LAr).**



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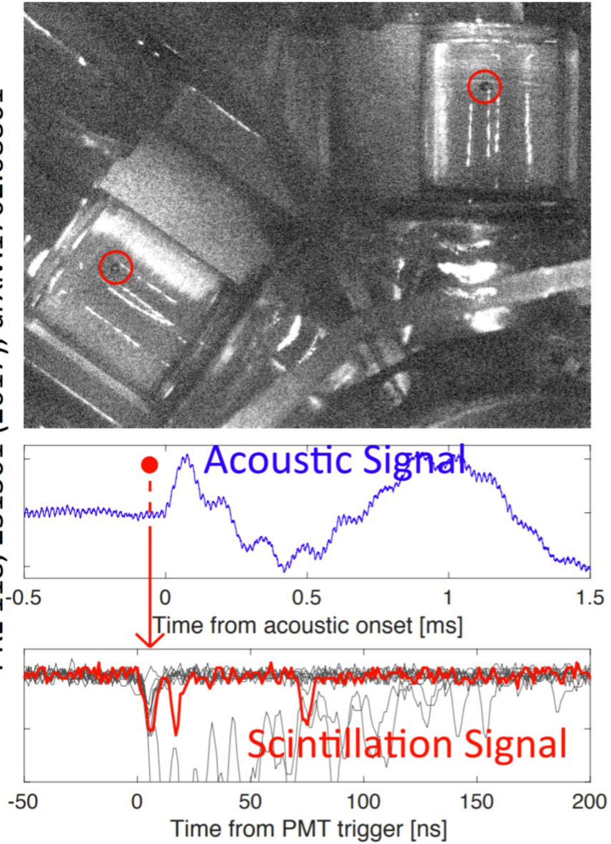
SBC Detector Goals

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
      (thermal fluctuations)
    - 2% Overall Photon Collection Efficiency
      (1-photon ~ 5 keVr)

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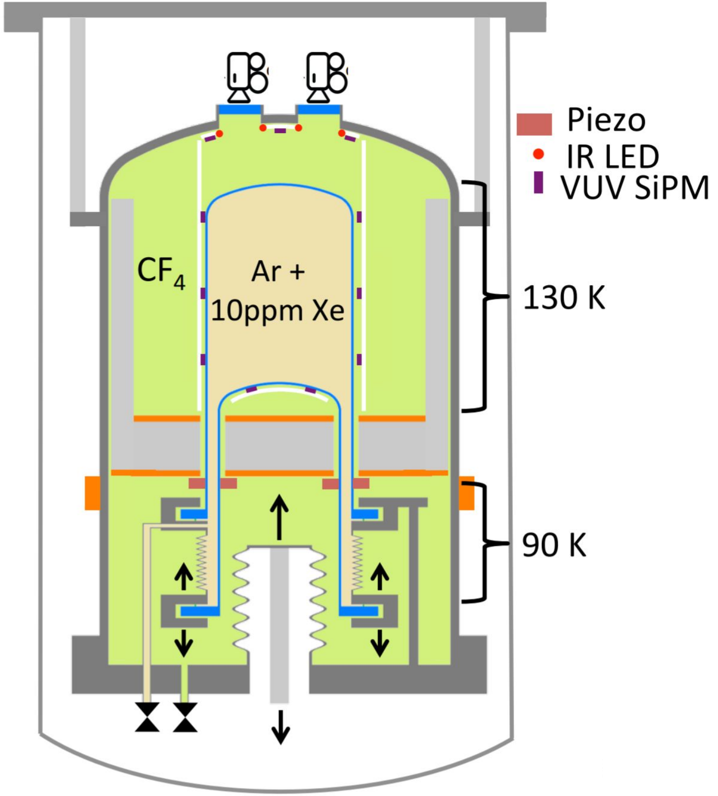
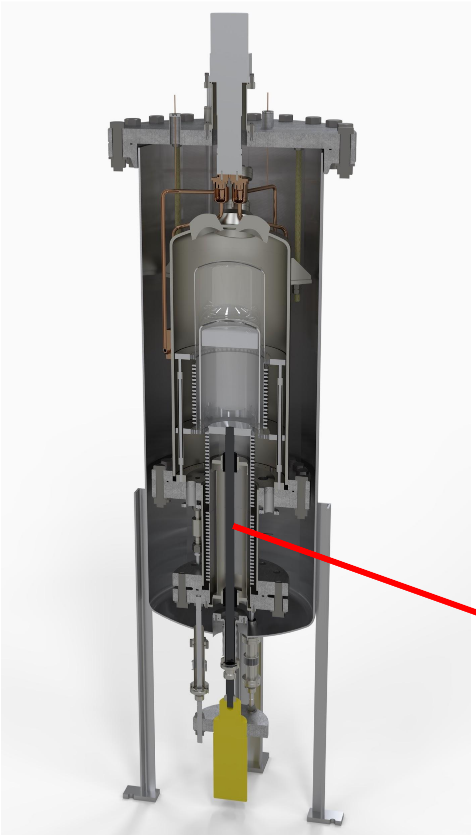
SBC Detector Overview

- Single fluid, “right-side-up” geometry with thermal gradient.
- Target is 10 kg of LAr + O(100) ppm Xe. (178 nm).
- Pressure cycles 20-360 PSIA.
- Events detected by: Cameras, Piezos acoustic sensors, Si-Photomultipliers (SiPMs).
- SiPMs immersed in hydraulic fluid (CF4 at 130 K)



Ongoing Construction



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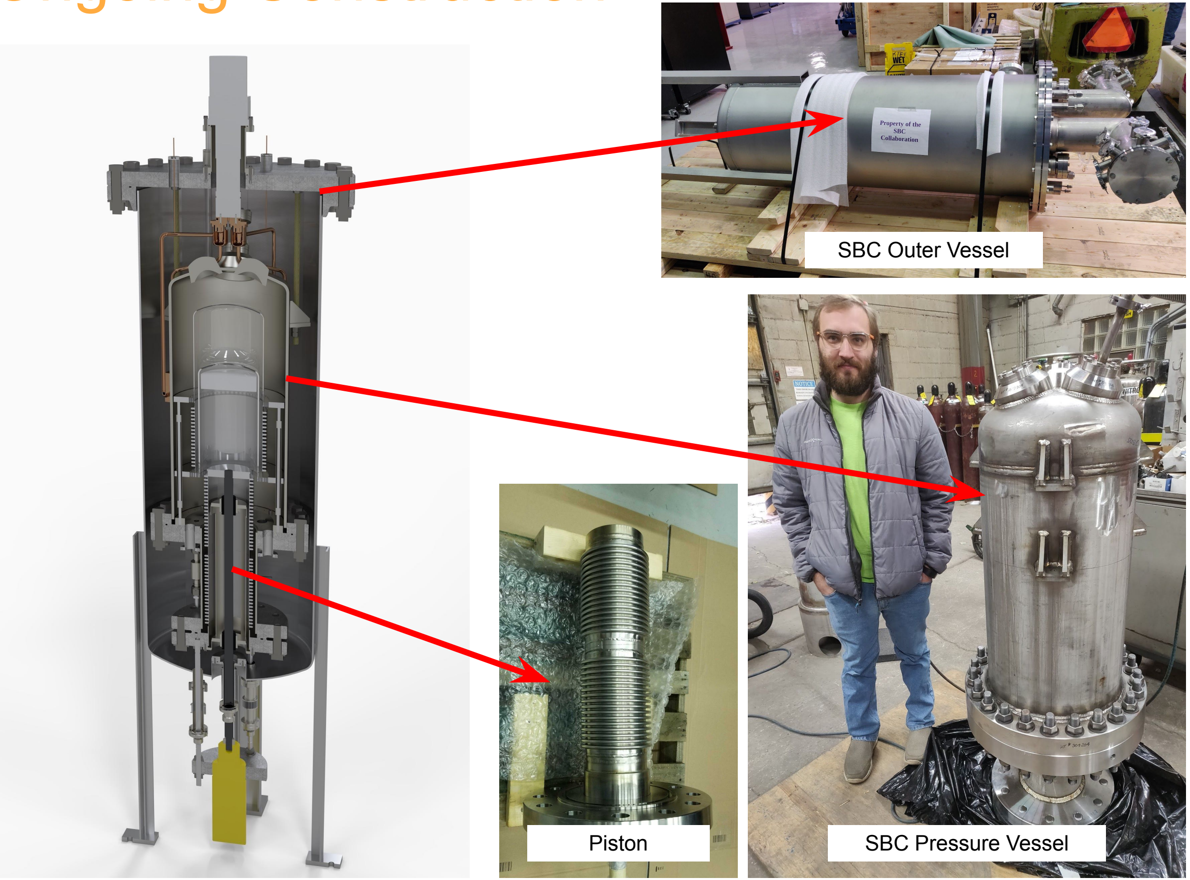

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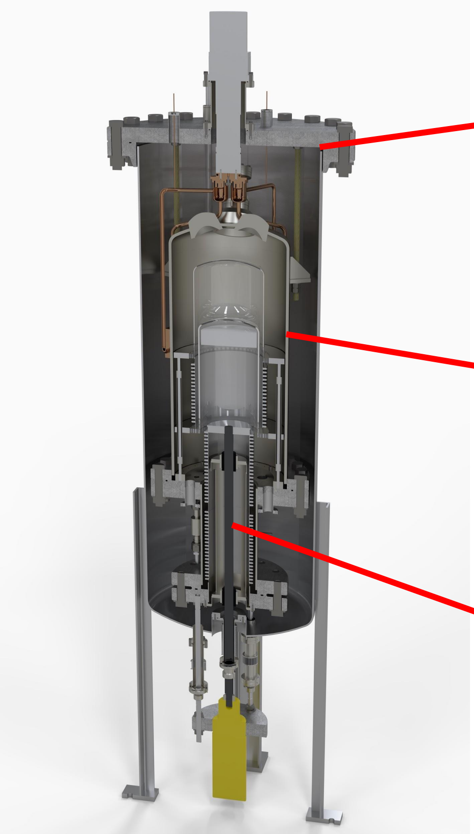
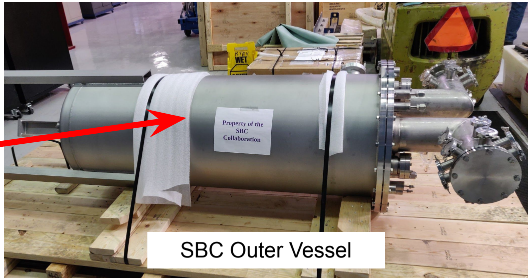
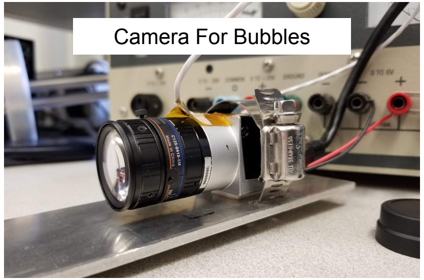
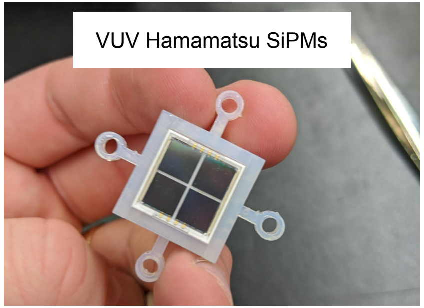
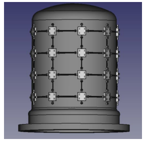
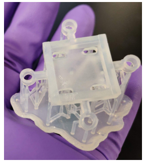








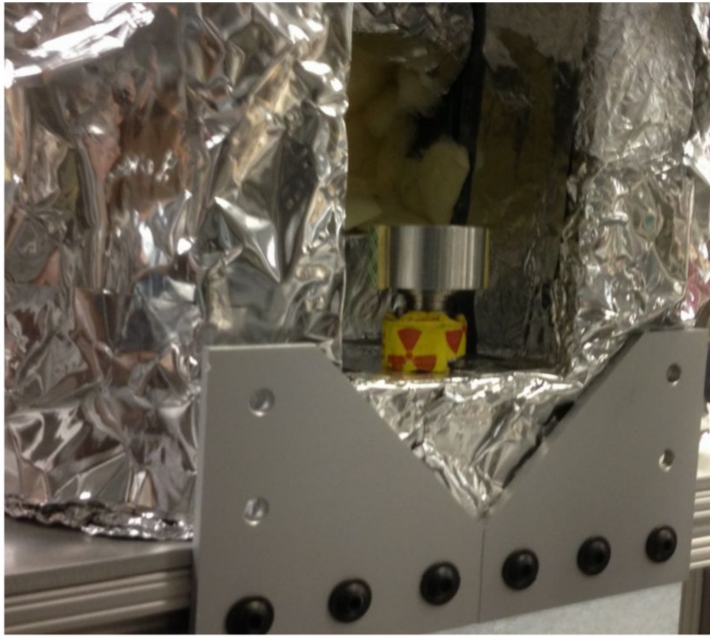




SBC Calibration Program

- **Challenges:**
  - Maximum rate ~1k bubbles / day
  - No energy information below 5 keVr (with current SiPM coverage)

- **Advantages:**
  - Ability to go gamma-blind, using a photo-neutron source.
  - mm-resolution spatial reconstruction
(use multiple scattering)



^{9}Be(γ,n), Q=1664.5 keV

arXiv:1602.05911

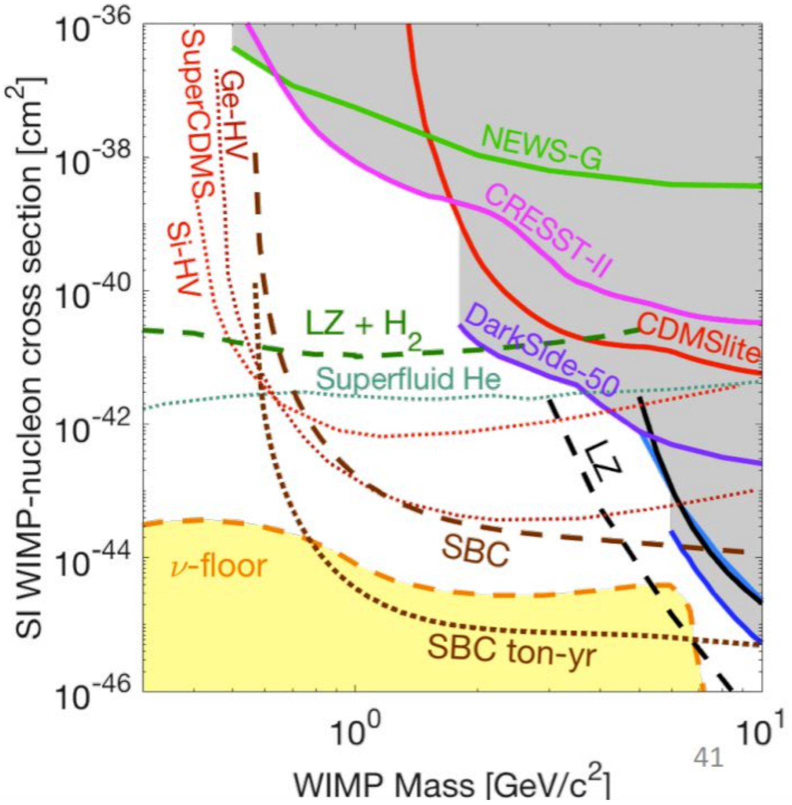
SBC Strategy: Building Two Detectors

- Construct two SBC detectors.

- **Fermilab (now-2022):**
  - Measure the bubble nucleation probability for ER's.
  - Determina nuclear recoil sensitivity.

- **SNOLAB (2021-2023):**
  - Low-Mass Search

- **SBC-CEvNS (2022-2024):**
  - Reactor CEvNS demonstrator.
  - Use Fermilab chamber.
  - Investigating reactor sites (Mexico)



Conclusions

Conclusions

- Scintillating Bubbles Chambers provide a scalable, ER blind, detection technique for low-mass WIMPs (with sub-keVnr thresholds).
- Calibration studies of the next LAr (+100 ppm Xe) Bubble Chamber (Fermilab) expected by 2021/2022.
    - Designed target threshold of 40 eV.
- The preparation at SNOLAB as started, with the second Bubble Chamber expected to be commissioned underground in 2021.
    - First WIMPs results by 2022.
- Investigating possible sites for reactor CEvNS demonstrator.
- Gearing up for future tonne-scale SBC-SNOLAB.

Backup Slides

Scintillating Bubble Chamber History

- 1956 - Glaser finds pure xenon doesn't work (for tracks).
- 1962 - Stump & Pellett and in 1981 Harigel, Linser and Schenk tried Ar / N2 chamber prototypes. Pure argon requires *O*(10 ev) threshold to observe tracks.
- 2016 - First observation of simultaneous bubbles + scintillation in pure xenon (NR's only).
- 2017 - Xenon chamber pushed to 900 eV thresholds, still no evidence of ER induced nucleation. 10-kg Argon chamber is proposed to Fermilab LDRD.
- 2018 - SBC collaboration is formed, and the 10-kg Arcon chamber conceptual design is completed.
- 2019 - 10-kg Argon chamber technical design completed, start of construction.

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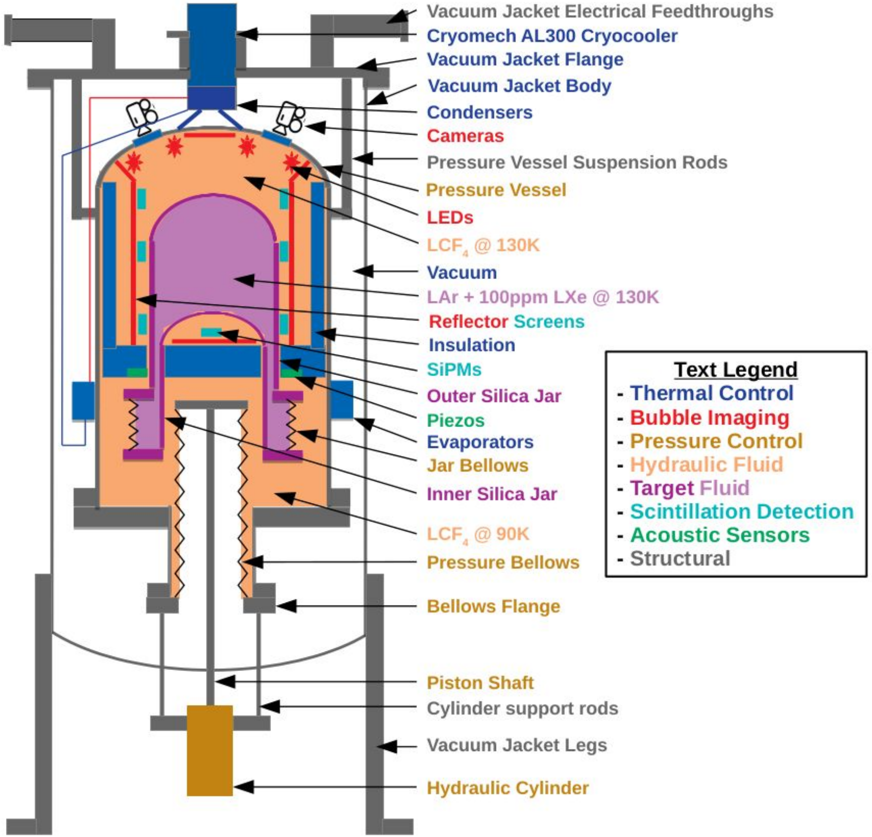
The SBC Detector



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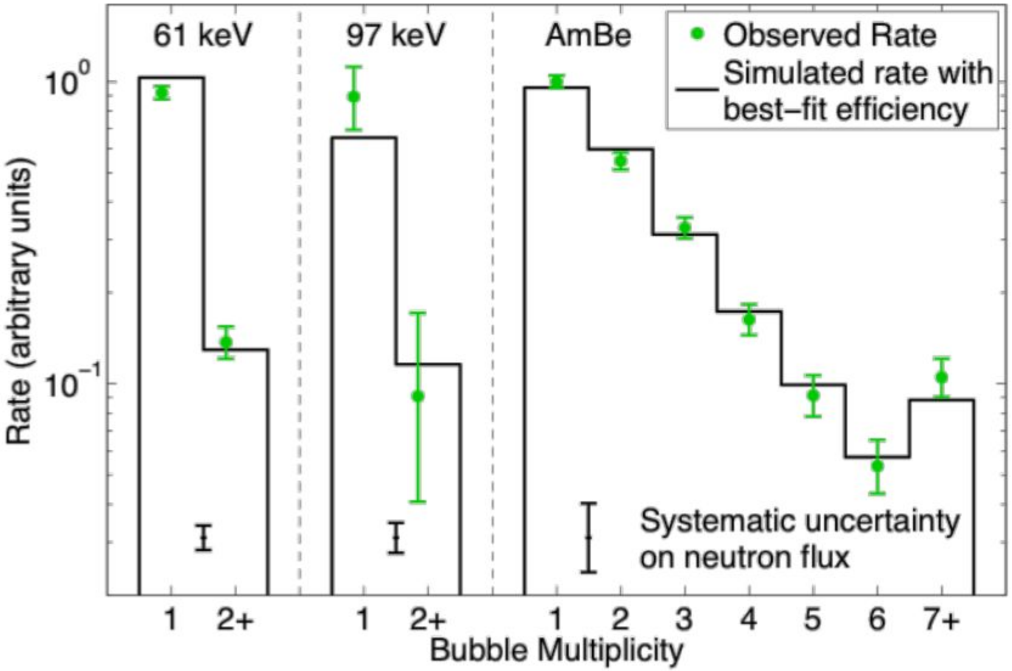
NR Single/Multiple Bubble Nucleation



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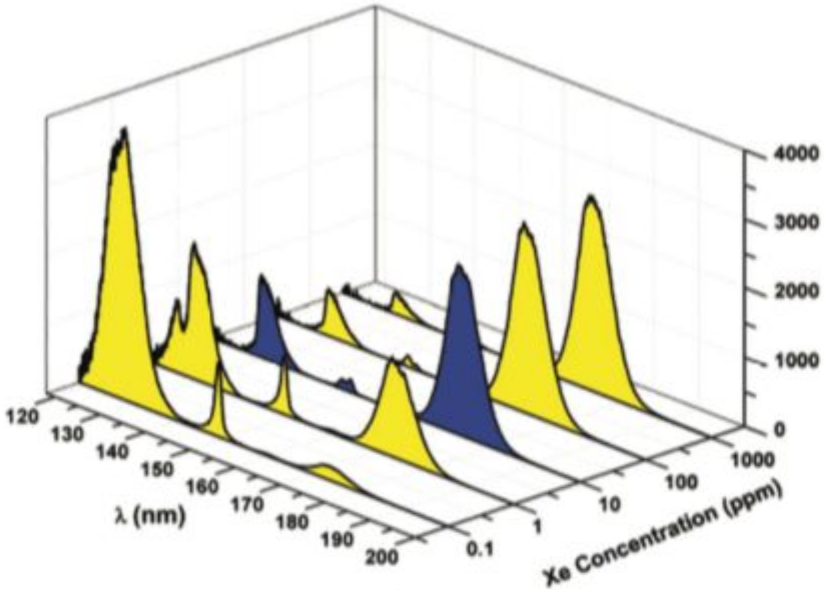
LAr + Xe Doping

- Silica jars opaque to 128nm Ar scintillation
- 10ppm Xe sufficient to exchange Ar_2^* for Xe_2^*
  - 175nm, jars transparent
  - Side-effect: lose pulse-shape discrimination



A. Neumeier *et al* 2015 *EPL* **109** 12001

Acoustic-Scintillation Coincidence

- $< 1\%$ accidental coincidence rate in calibration data
- Slope = speed of sound in xenon (to 20%)