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

Dr. Pietro Giampa

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ICHEP 2020
Dark Matter Detection Session

29 July 2020

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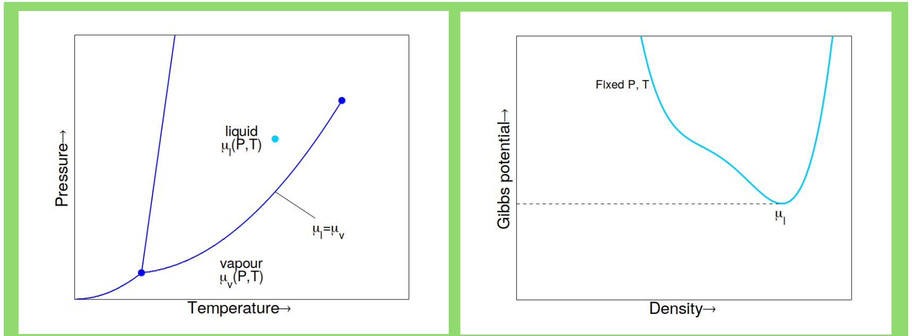
Overview

- The SBC Strategy
- The SBC Experiment
- Current Status & Timeline
- Conclusions

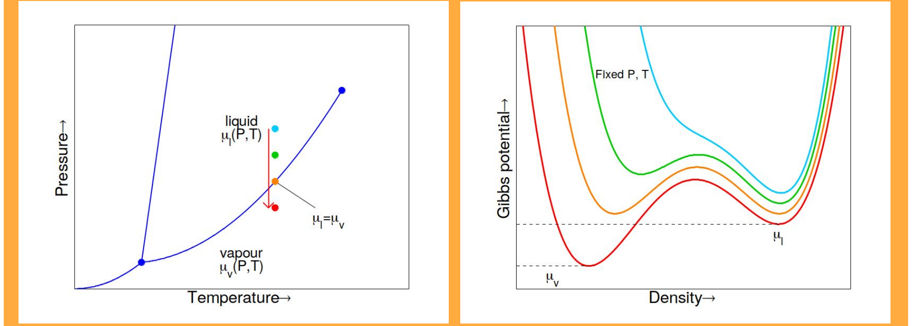
Discovery,
accelerated

The SBC Strategy

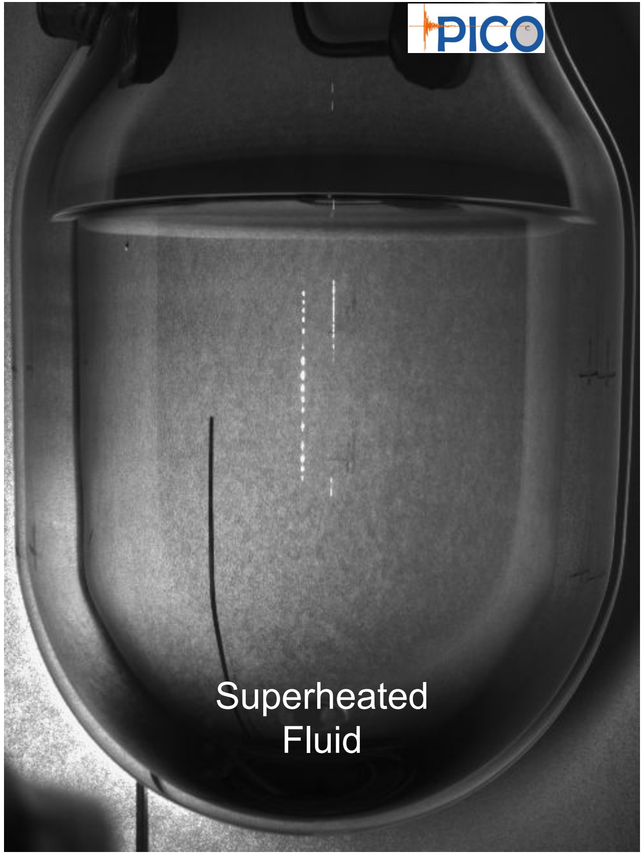
How Bubble Chambers Work



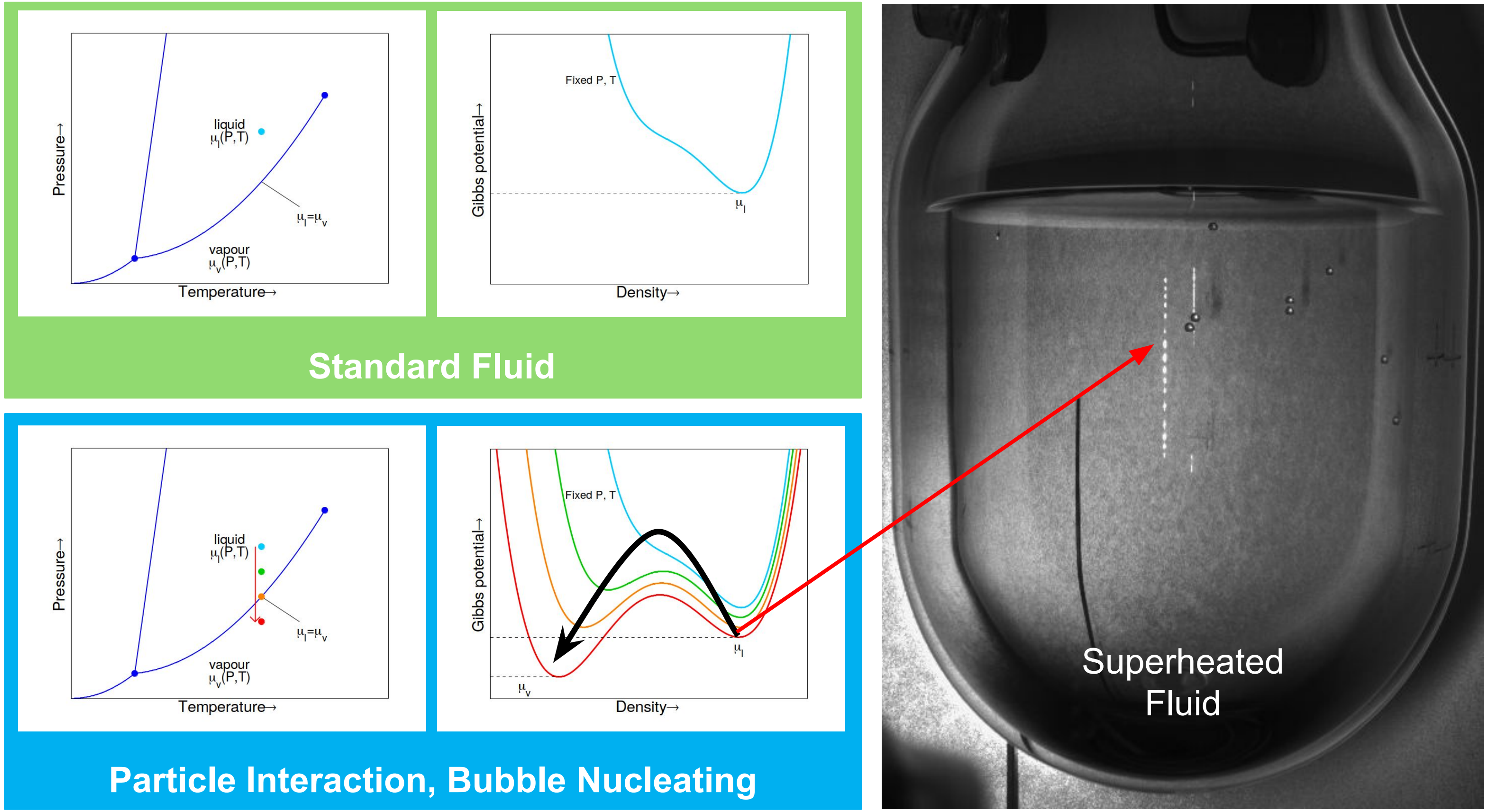
Standard Fluid



Superheated Fluid

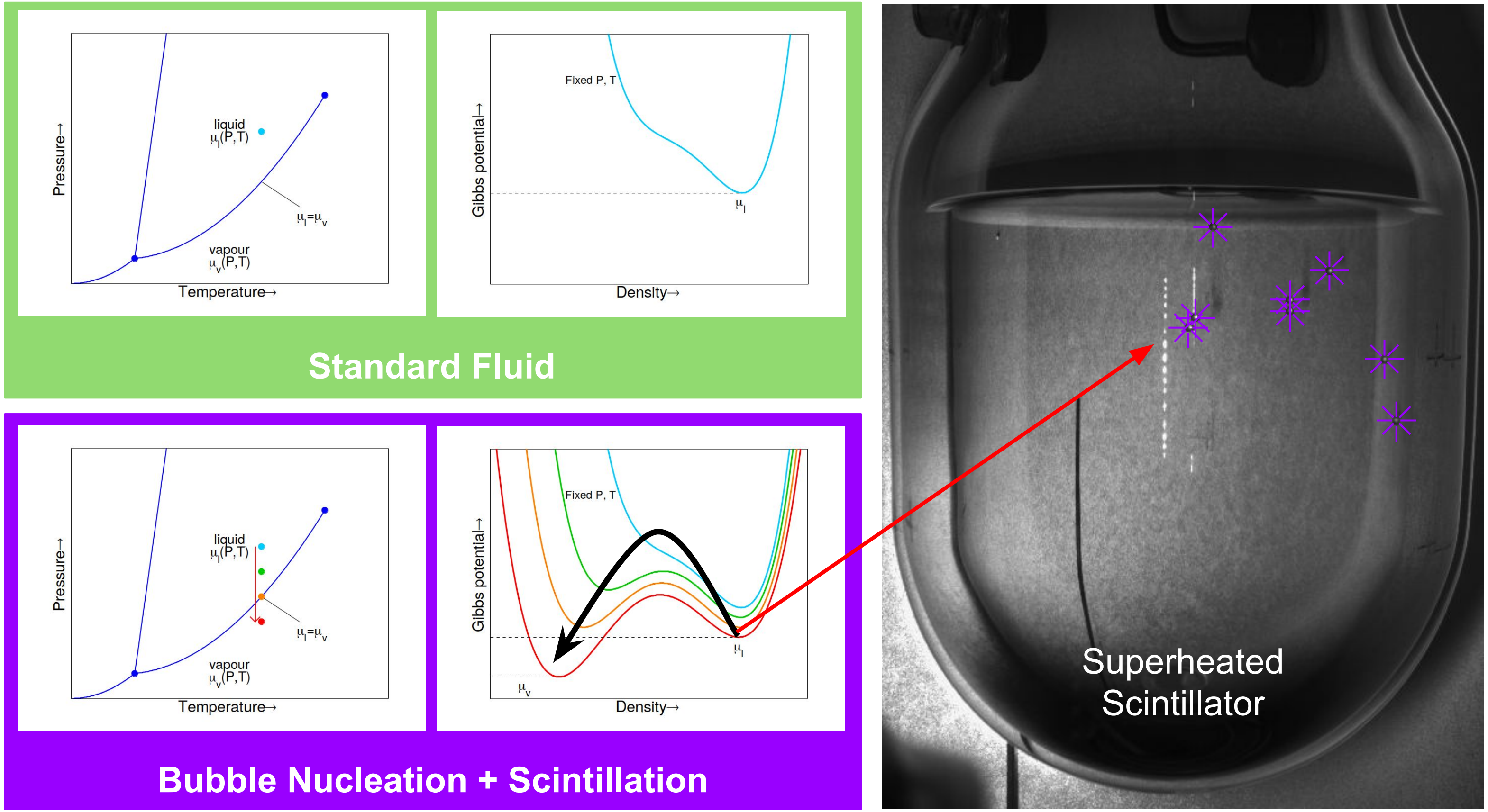


How Bubble Chambers Work



Discovery, accelerated

How (Scintillating) Bubble Chambers Work



The SBC Overview

Combine the **electron recoil discrimination** of bubble chambers +
the **event-by-event energy resolution** and **low-thresholds** of liquid noble scintillation detectors.

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Bubble Chambers:

- Tunable Threshold O(keV).
- ER Blindness.
- mm-scale Position Resolution.
- Scalable Technology.

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- Calorimetry abilities, through scintillation.
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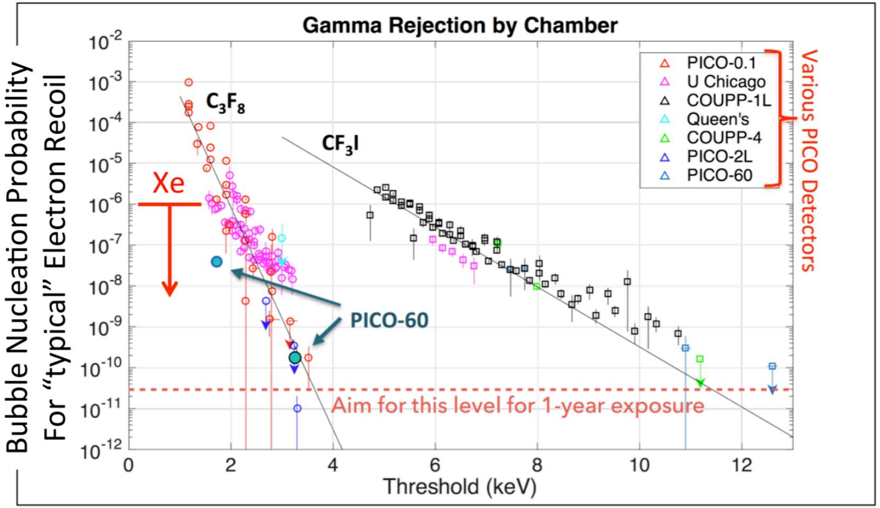

(Dan Baxter, Conference on Science at SURF, May 14, 2017)

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

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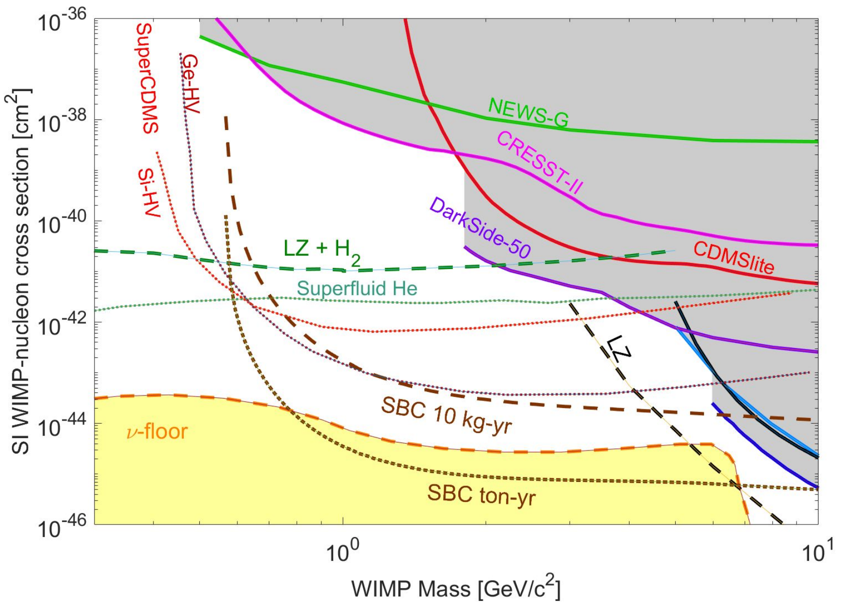
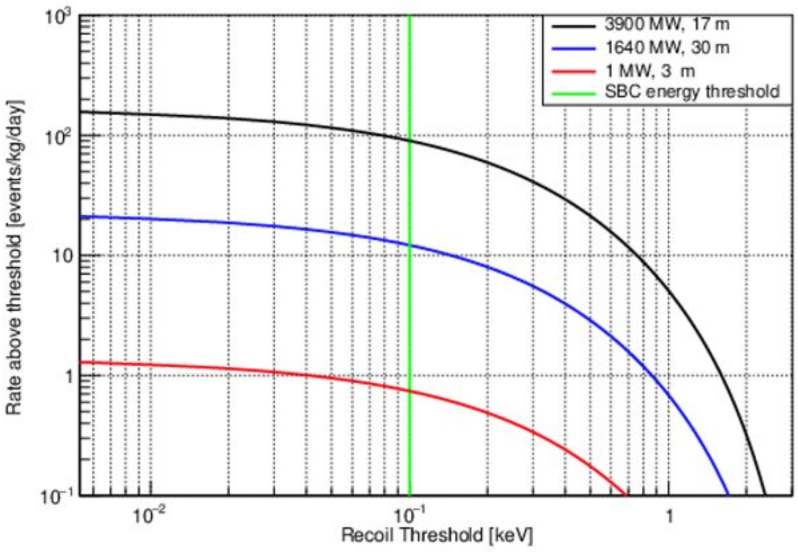
The Physics Reach

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



Location = SNOLAB

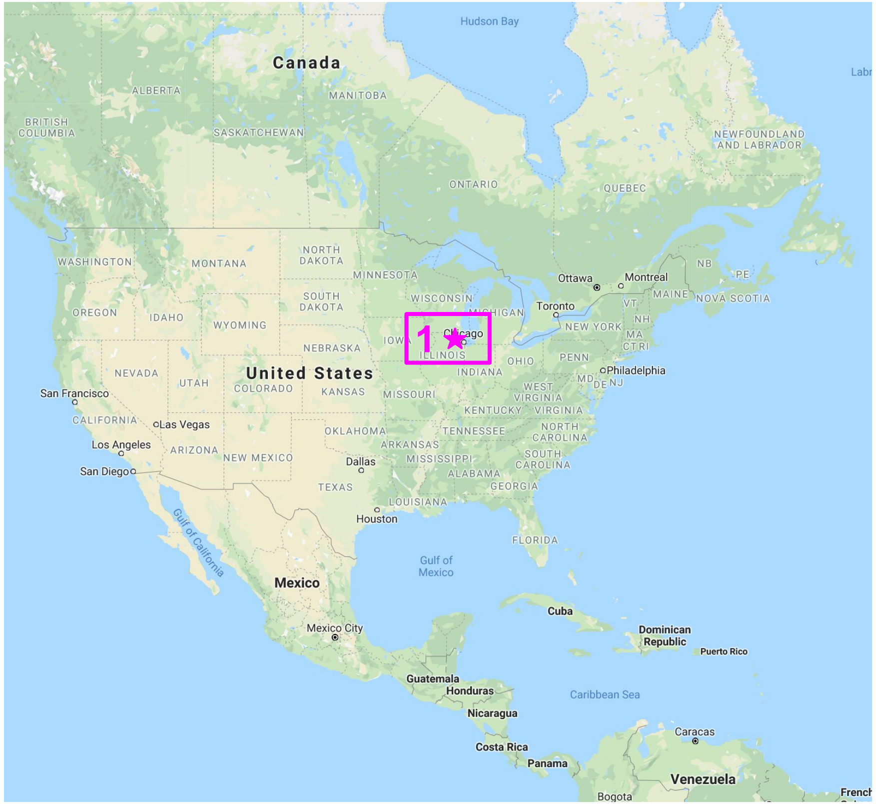
Precision study of **reactor CEvNS** interactions for Argon and Xenon



Collaborating with UNAM to identify reactor site

Discovery, accelerated

The SBC Strategy



SBC-Fermilab - Phase 1

Build and commission the first detector at Fermilab.

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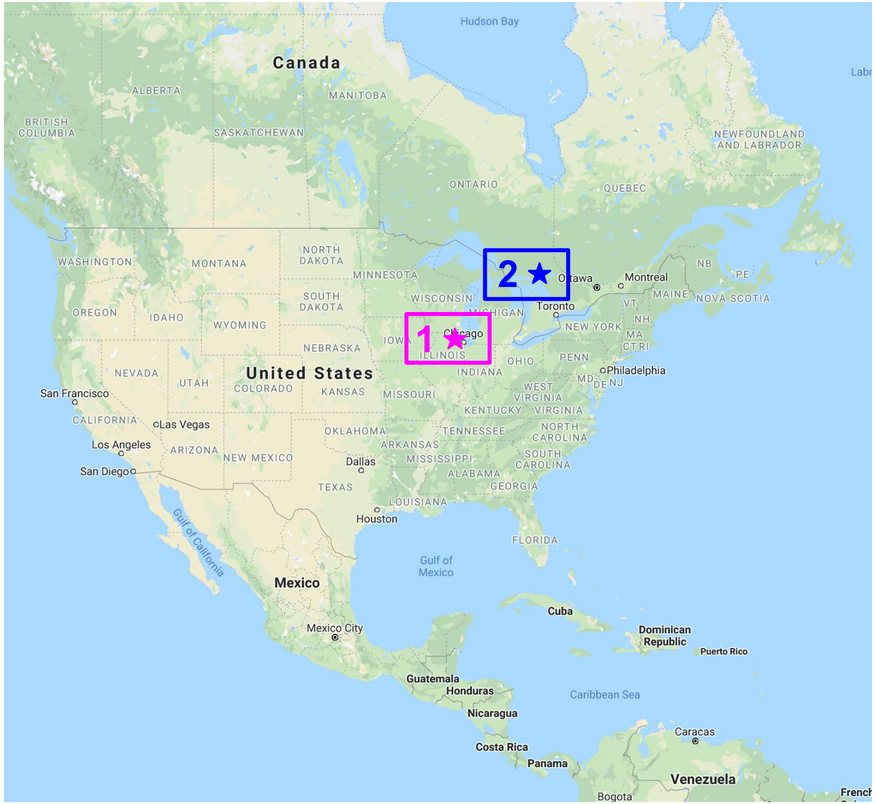
The SBC Strategy



SBC-Fermilab - Phase 1

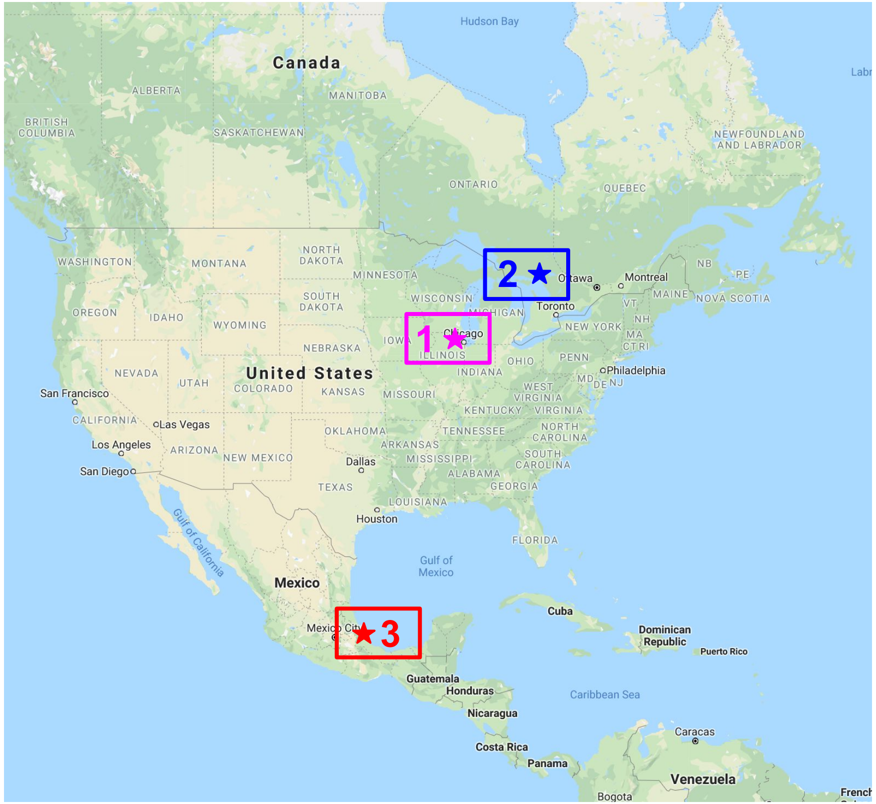
Build and commission the first detector at Fermilab.

SBC-SNOLAB - Phase 2

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

Discovery, accelerated

The SBC Strategy



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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 (currently considering Laguna Verde Mexico).

The SBC Experiment

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The SBC Collaboration

Northwestern University

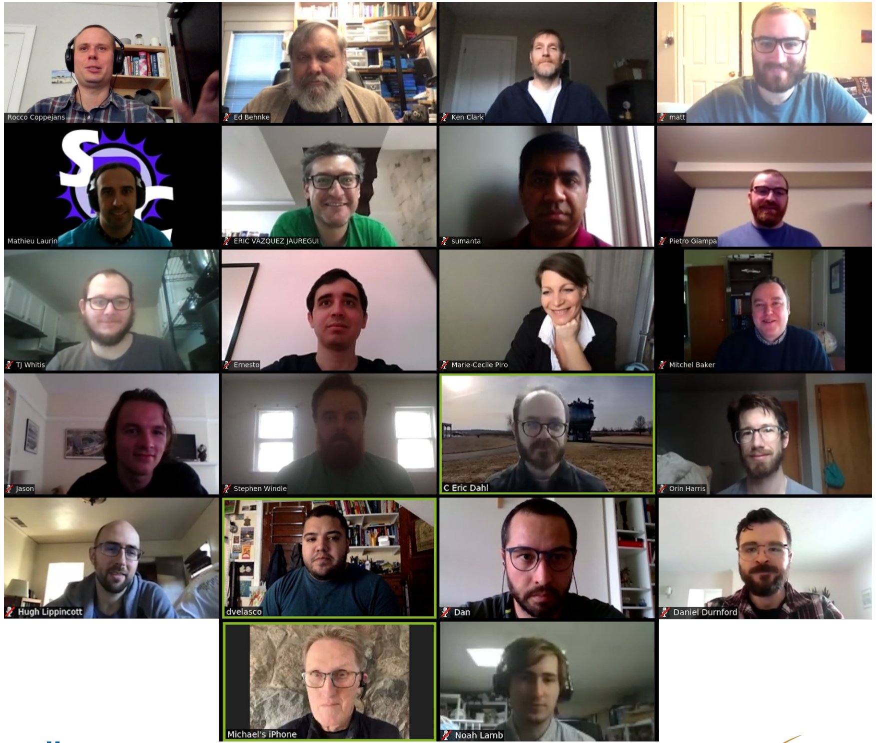
- **Eric Dahl**
- Rocco Coppejans
- Runze Zhang
- Jason Phelan
- Will Reinhardt
- Lawrence Luo
- Zhiheng Sheng
- Fangjun Zhu
- Aaron Brandon

Queen's University

- **Ken Clark**
- Hector Hawley
- Patrick Hatch

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

Indiana University South Bend

- Ilan Levine
- Ed Behnke
- Nathan Walkowski
- Kelly Allen

UC Santa Barbara

- Hugh Lippincott
- TJ Whitis

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- Pietro Giampa

Université de Montréal

- Mathieu Laurin

Northeastern Illinois University

- Orin Harris

Pacific Northwest National Laboratory

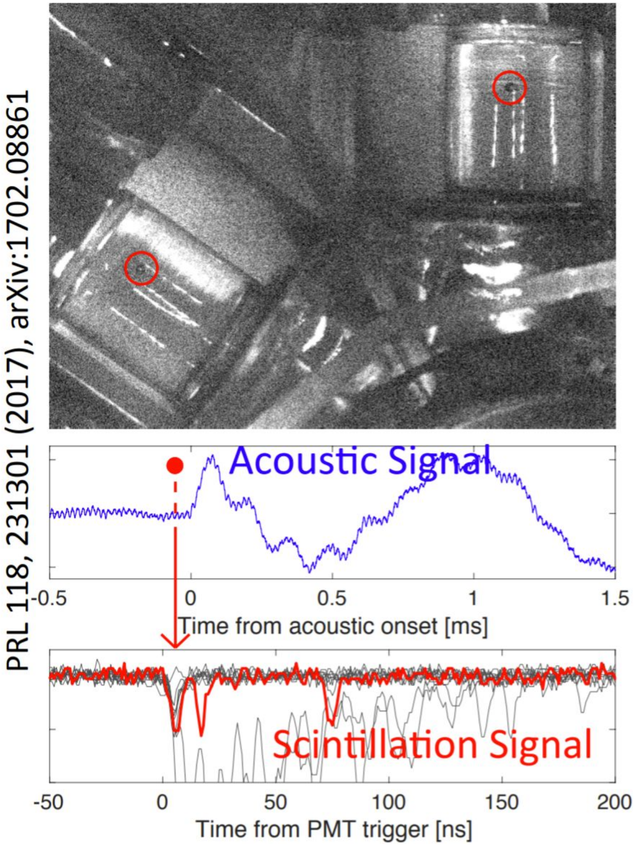
- Chris Jackson

Fermilab

- Mike Crisler

Discovery, accelerated

SBC Detector Goals



- **Demonstrated**
  - Liquid Xenon Bubble Chamber at 500 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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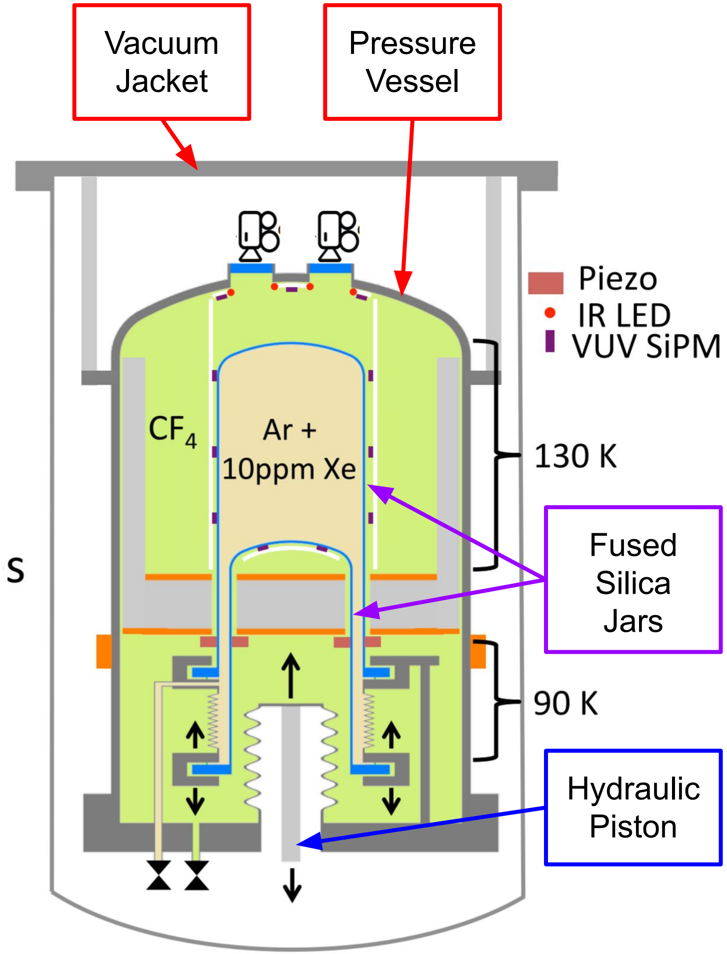
SBC Detector Overview

- "Right-side-up" geometry with thermal gradient.
- 10 kg of LAr + O(100) ppm Xe target contained within fused-silica Jar.
- Pressure cycles 20-360 PSIA.
- Events detected by: Cameras, Piezos acoustic sensors, Si-Photomultipliers (SiPMs).
- SiPMs immersed in hydraulic fluid (liquid CF_4 at 130 K)



Discovery, accelerated

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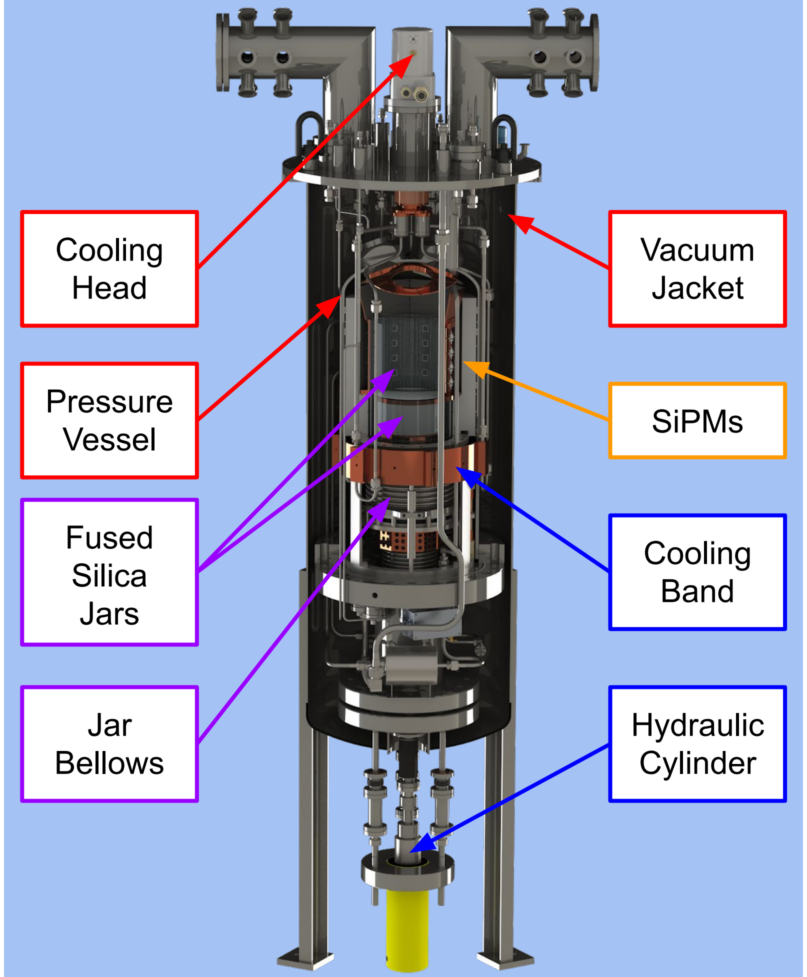
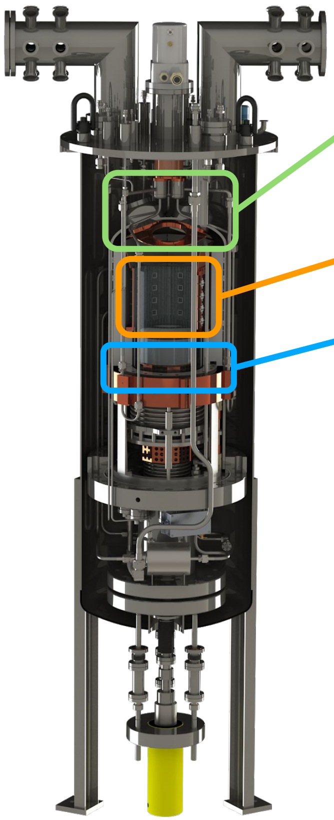


M. Laurin, Université de Montréal

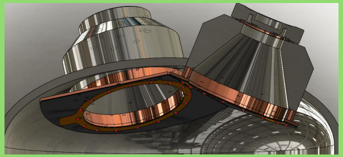
Discovery, accelerated

Readout Systems



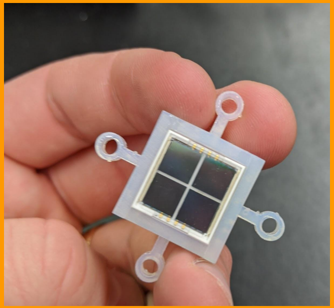
3 High-Speed Cameras

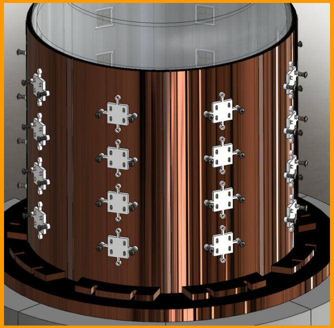
Speed of 100 fps and resolution of 1.0 MP



32 Hamamatsu VUV4 Quad SiPMs

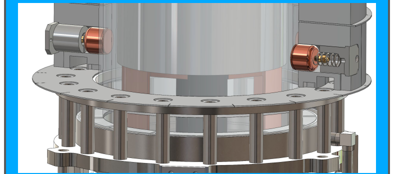
detection of scintillation light down to ~5 keVnr interactions

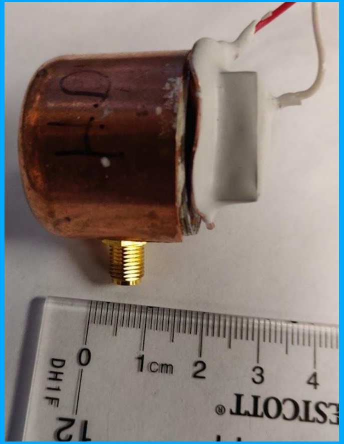




8 Piezoelectric Transducer

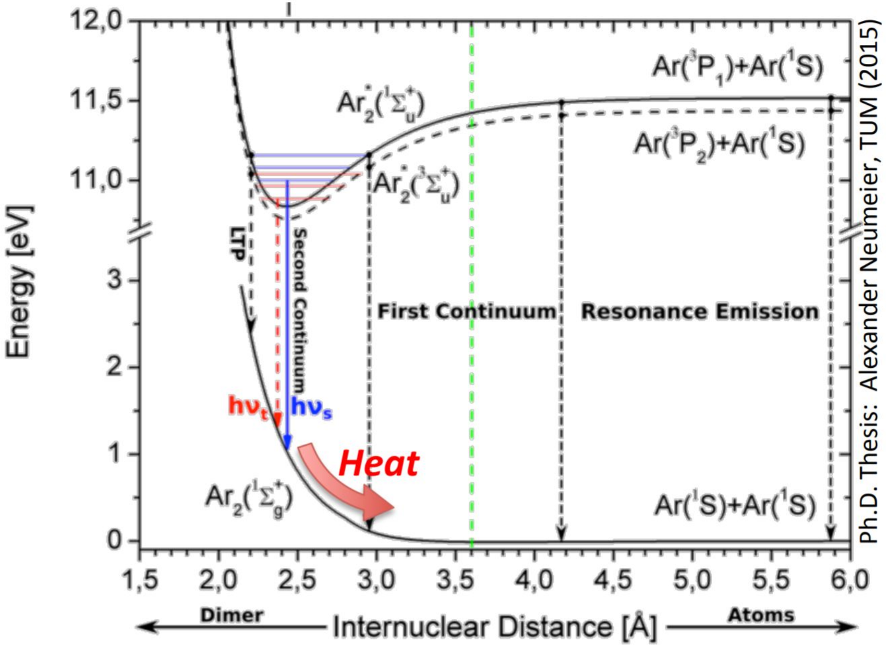
spring-held against the outside of the jar





How Low (In Threshold) Can SBC Go?

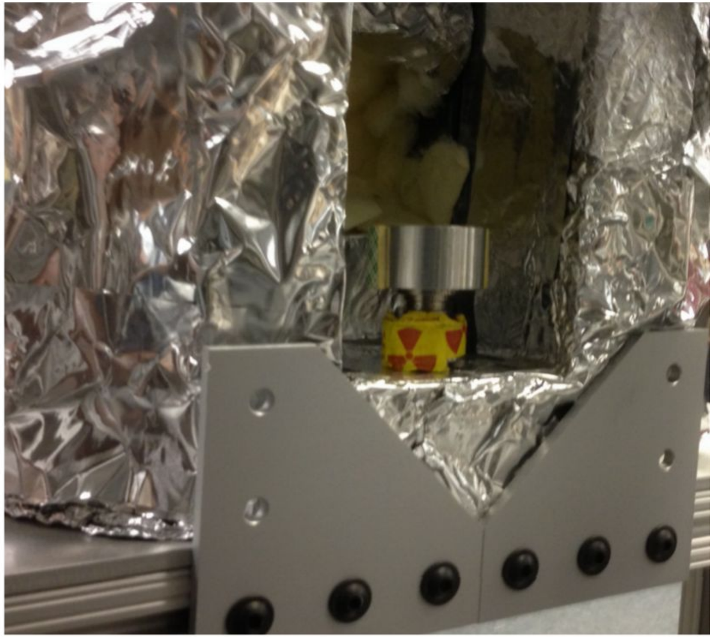
- ER's can lose ~10% energy to heat.
  - Consistent with historic results from LAr bubble chamber, with tracks at *O*(10) eV in threshold.
- Thermal Fluctuations have to be considered at *O*(10) eV in threshold.
  - SBC design target is 1 bubble / ton-year at a **threshold of 40 eV (LAr).**



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.

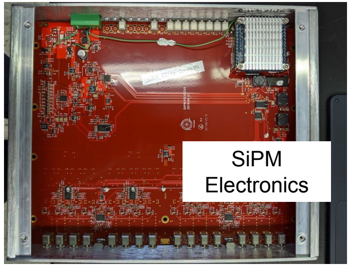


$^{9}Be(\gamma,n)$, Q=1664.5 keV

arXiv:1602.05911

Current Status and Timeline

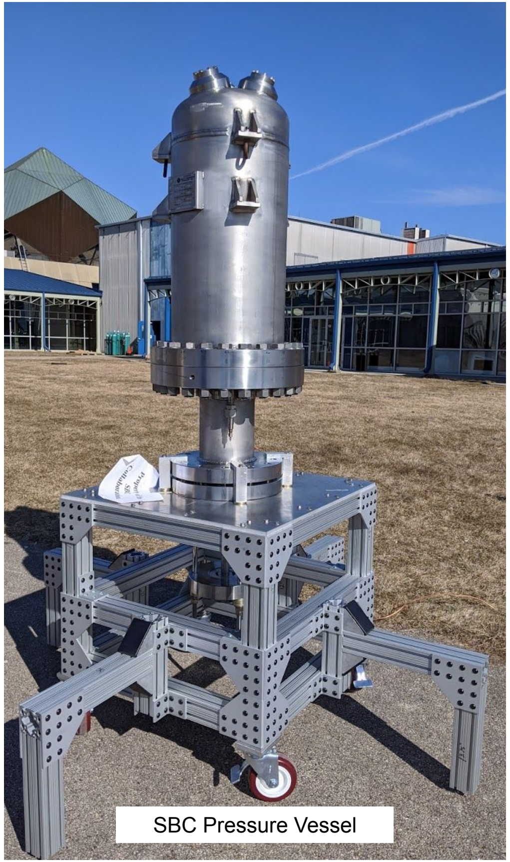
Ongoing Construction


SiPM Electronics


SBC Vacuum Jacket


Pressure Vessel Weldment


SBC Pressure Vessel


SBC Pressure Vessel


Process System

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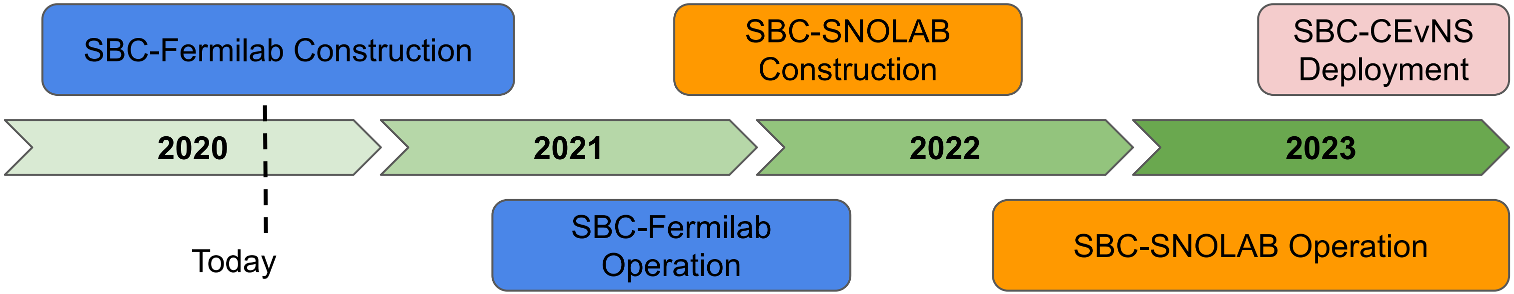
Collaboration Goals & Plan

Very tentative schedule !

- Install, commission, operate SBC-Fermilab.
- In parallel, build SBC-SNOLAB.
- Commission and operate SBC-SNOLAB.
- Upgrade and install SBC-CEvNS at reactor site.

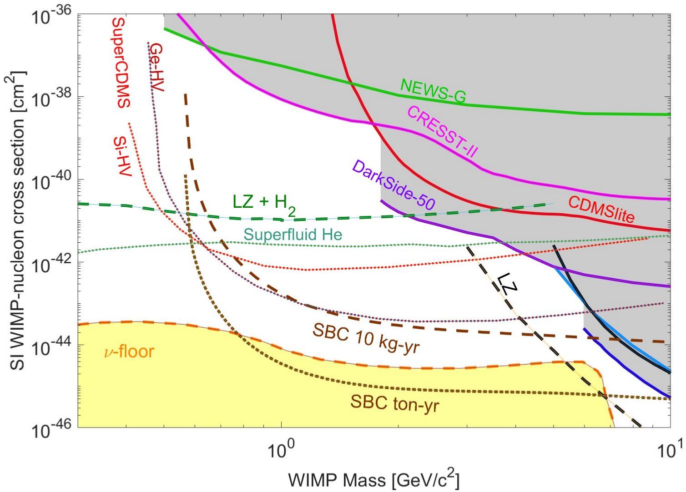


Discovery, accelerated

Conclusions

Conclusions

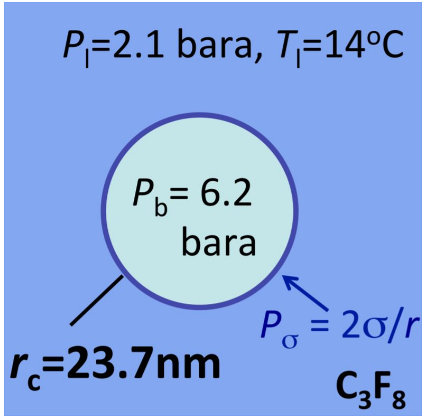
- Scintillating Bubble Chambers provide a scalable, ER blind, detection technique for low-mass WIMPs.
- Calibration studies of the next LAr (+*O*(100 ppm) Xe) Bubble Chamber (SBC-Fermilab) expected by 2021.
    - Designed target threshold of 40 eV.
- The preparation at SNOLAB as started for the second detector (SBC-SNOLAB), with underground construction anticipated to start in late-2021.
    - First WIMPs results by 2022.
- Currently investigating possible sites for reactor CEvNS demonstrator.
- Gearing up for future tonne-scale SBC-SNOLAB.



Backup Slides

Key Considerations

- **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.

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

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

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

= 3.19 keV

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

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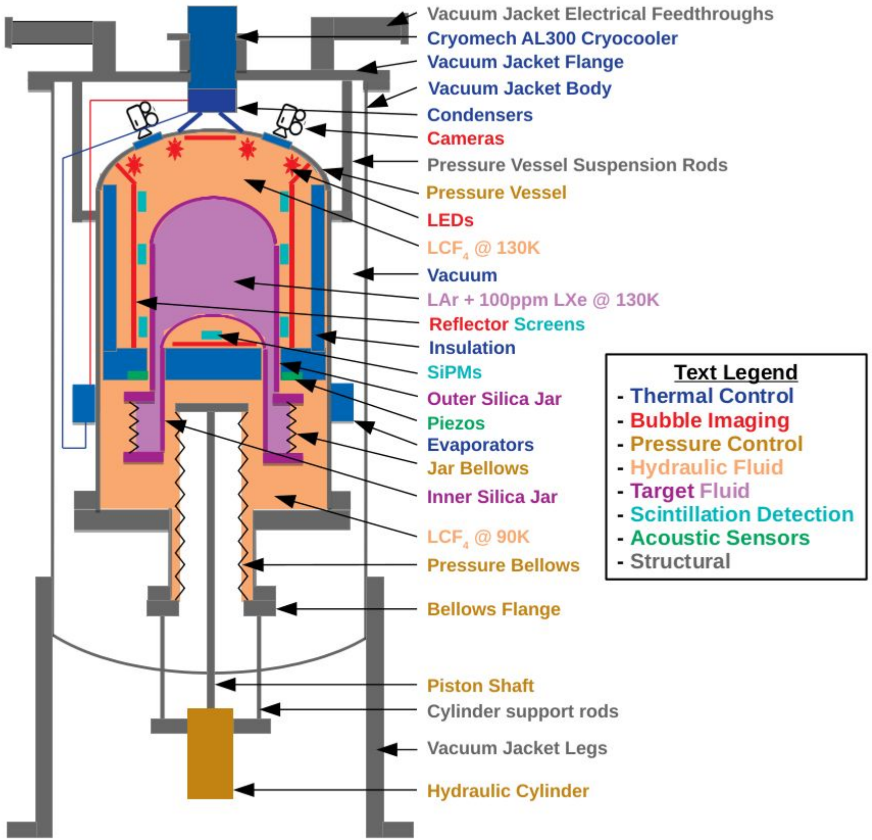
Scintillating Bubble Chamber History

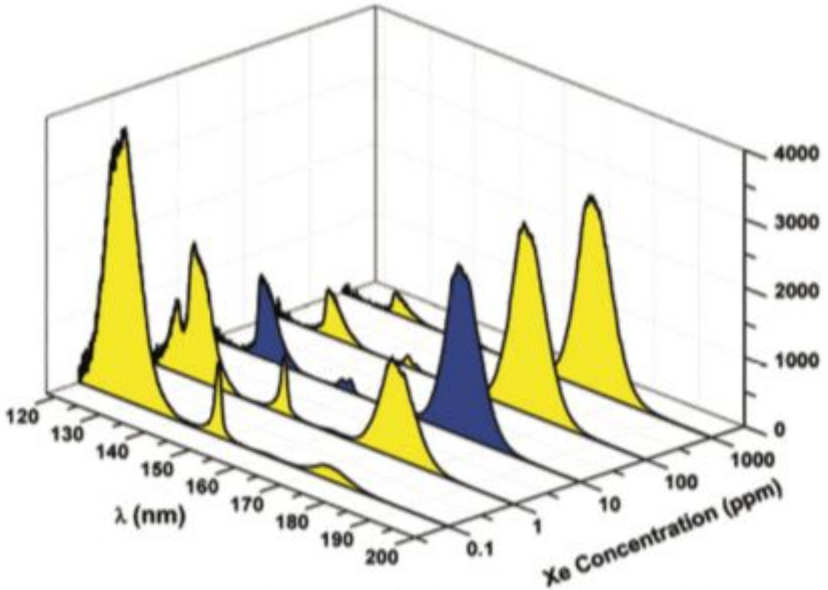
- 1956 - Glaser finds pure xenon doesn’t work (for tracks).
- 1962 - Stump & Pellett and in 1981 Harigel, Linser and Schenk tried Ar / N2 chamber prototypes. Pure argon requires *O*(10 ev) threshold to observe tracks.
- 2016 - First observation of simultaneous bubbles + scintillation in pure xenon (NR’s 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.

The SBC Detector



LAr + Xe Doping

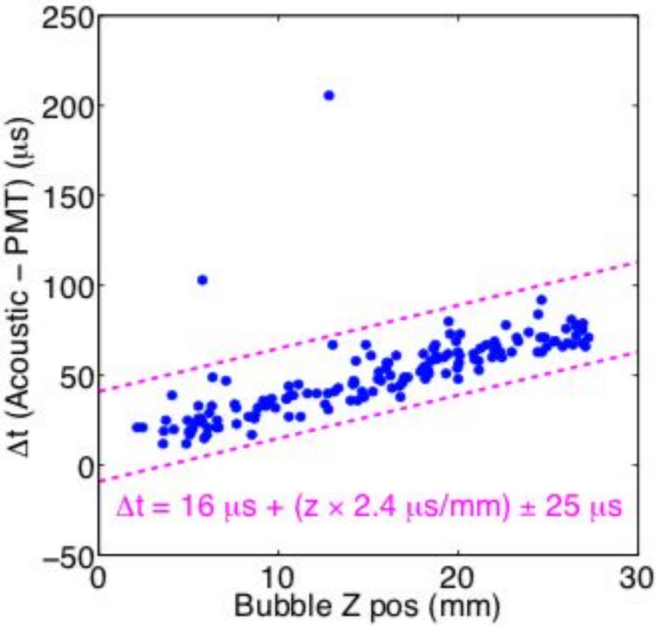
- Silica jars opaque to 128nm Ar scintillation
- 10ppm Xe sufficient to exchange Ar_2^* for Xe_2^*
  - 175nm, jars transparent
  - Side-effect: lose pulse-shape discrimination



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%)



SiPM System Layout