First Demonstration of a Scintillating Xenon Bubble Chamber for Dark Matter and CEvNS Detection

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Outline

- Motivation: GeV WIMPs and reactor neutrinos

- The scintillating bubble chamber technique

- Results from a 30-gram xenon prototype
  - arXiv:1702.08861 [PRL **118**, 231301]

- Current status and next steps: lowering thresholds, liquid Argon target

# What could you do with a liquid-noble bubble chamber?

- Discriminating
  - Only sensitive to nuclear recoils (neutrons, neutrinos, and WIMPs), $\sim 10^{10}$ ER discrimination
  - Scintillation channel eliminates bubble-nucleating backgrounds at other energies (e.g alpha decays, surface wetting phenomena)

- Scalable
  - Largest bubble chamber to date: 35 m^3 (BEBC)
  - Ton-scale low-background bubble chamber in works (PICO)

- Low threshold
  - Sub-keV recoil energy threshold is moving from "plausible" to "realistic"

What could you do with an argon bubble chamber?
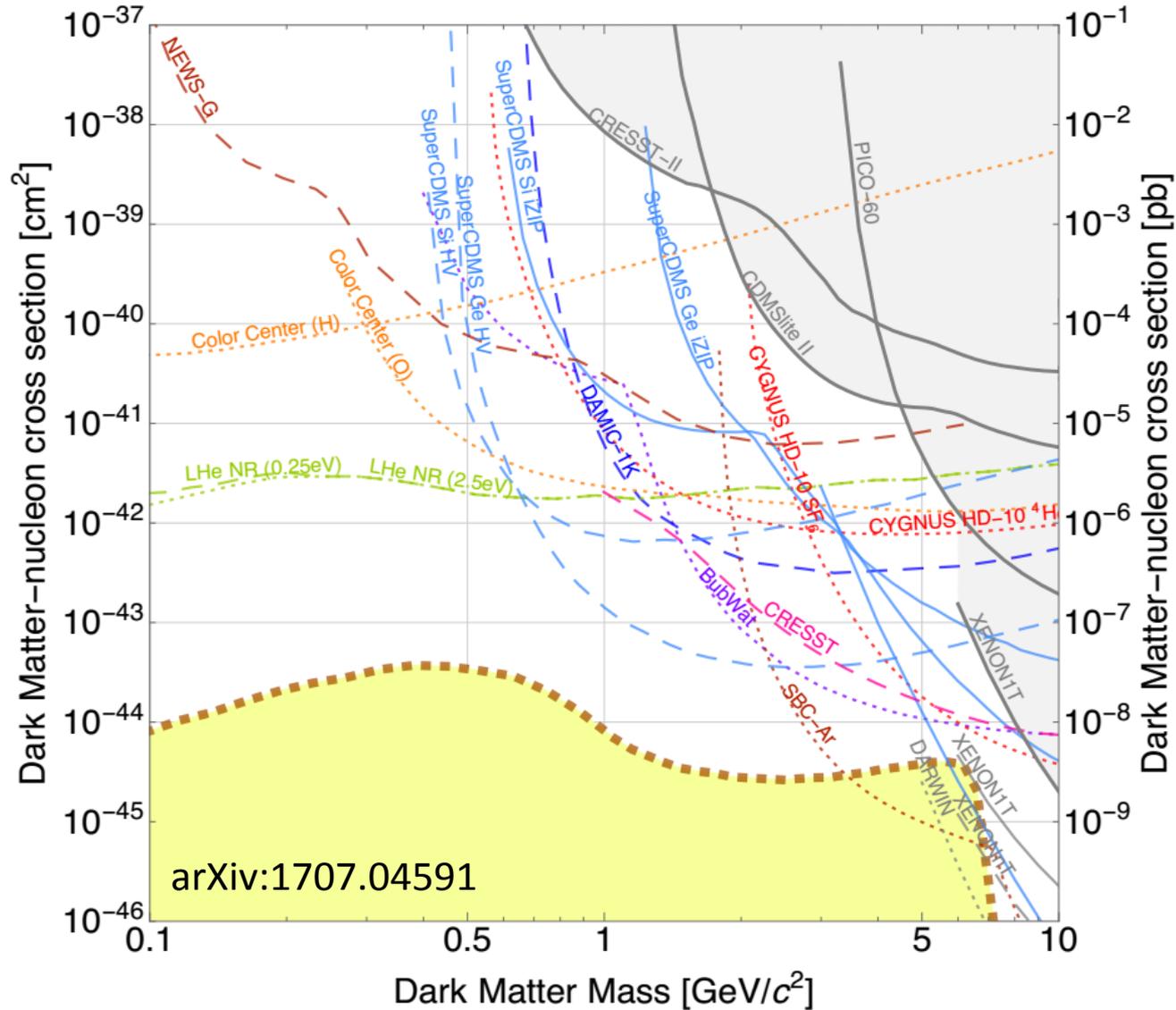
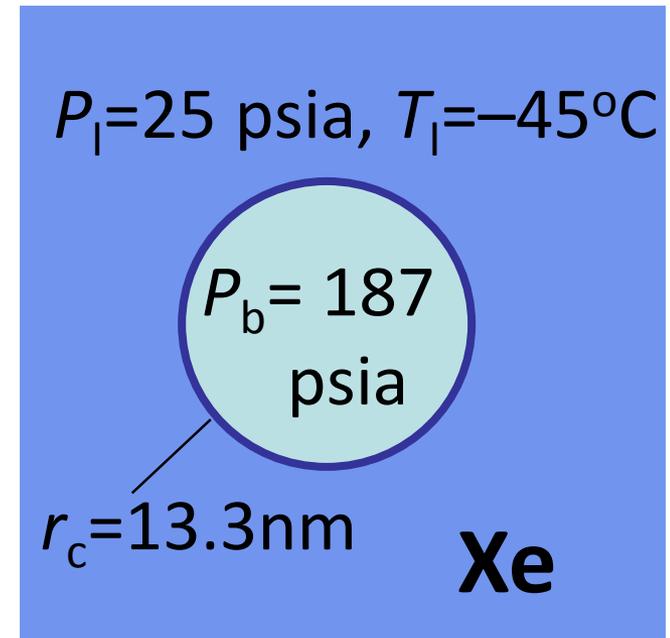1 ton-year at 1-keVr threshold (76 ^{8}B neutrino events expected)

arXiv:1707.04591

What could you do with an argon bubble chamber?

CEνNS rate on Argon at existing/proposed reactor sites
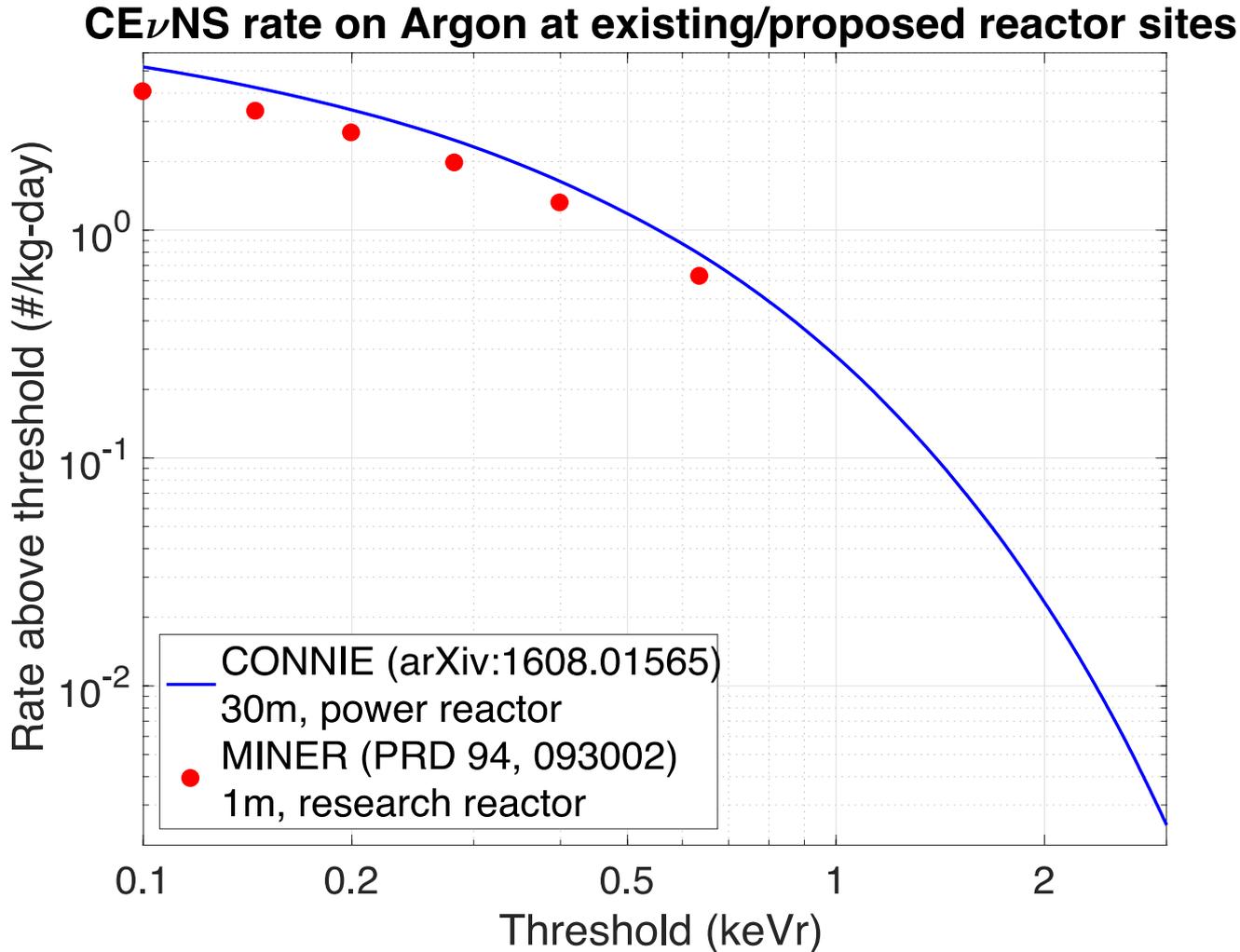
Up to an event-per-minute in a m^3 target, only background is neutrons

Bubble Chamber Thermodynamics

- What does it take to nucleate a bubble?

P_l=25 psia, T_l=−45ºC

P_b= 187 psia
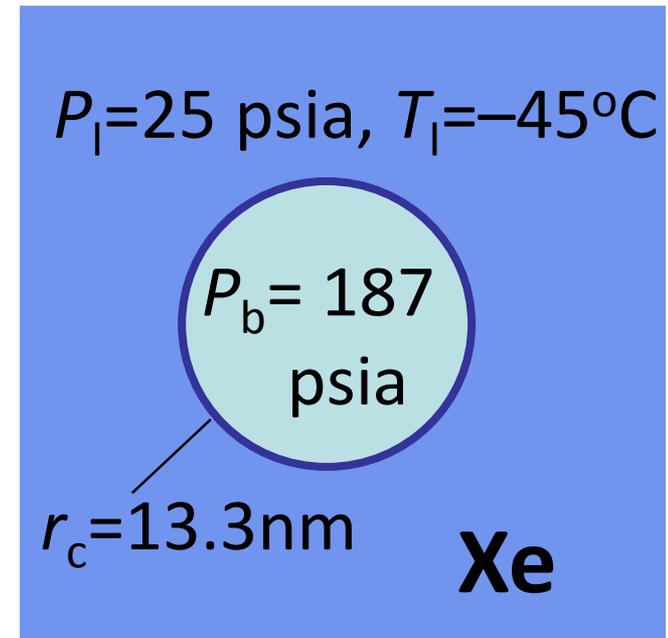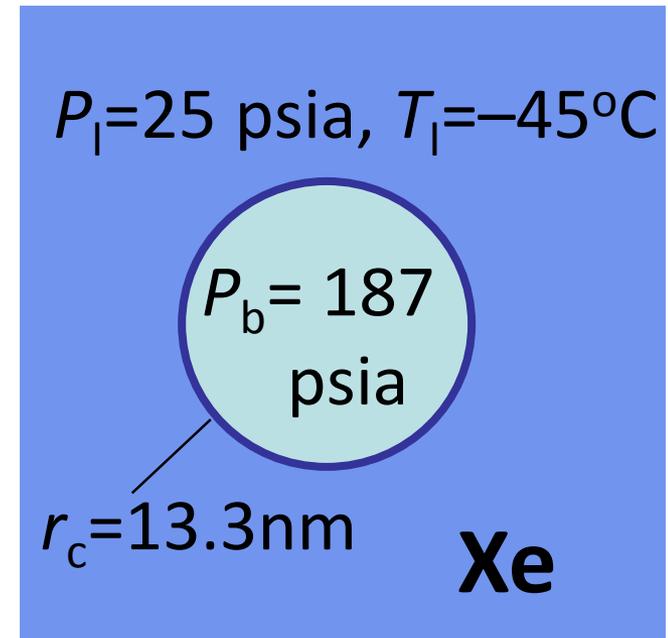
r_c=13.3nm

Xe

Bubble Chamber Thermodynamics

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$$E_T = 4\pi r_c^2 \left(\sigma - T \left(\frac{\partial \sigma}{\partial T} \right)_\mu \right)$$ 0.55 keV

$$+ \frac{4\pi}{3} r_c^3 \rho_b \left(h_b - h_l \right)$$ 0.61 keV

$$- \frac{4\pi}{3} r_c^3 \left(P_b - P_l \right)$$ -0.07 keV

= 1.09 keV total

Surface energy, Bulk energy, Reversible Work

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6

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More in other PICO talks & posters, e.g., Carsten Krauss on Jul 25

6

Bubble Chamber Discrimination

Electron recoil sensitivity in C_3F_8 and CF_3I from various PICO calibration and dark-matter chambers

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Electron recoil sensitivity in C_3F_8 and CF_3I from various PICO calibration and dark-matter chambers
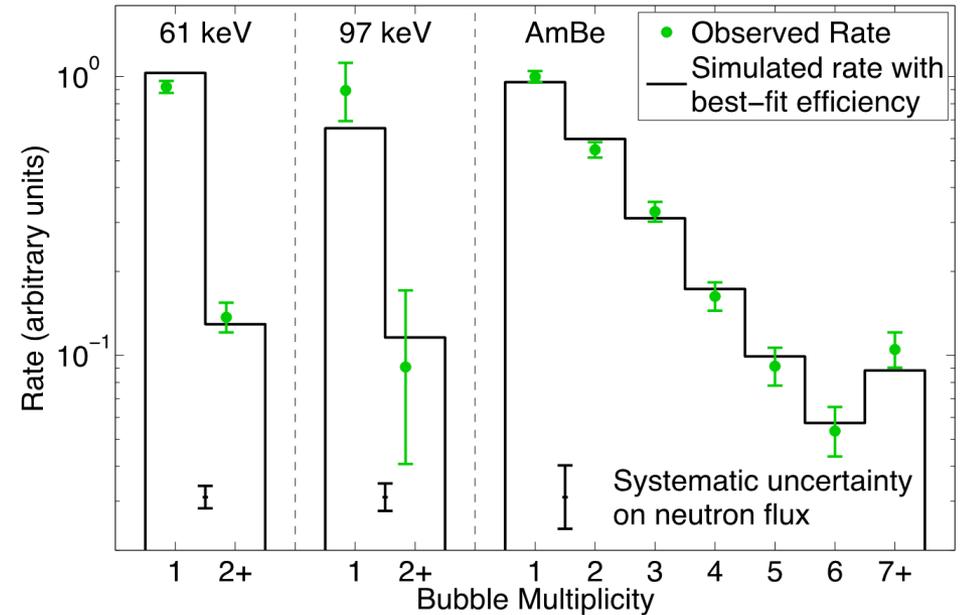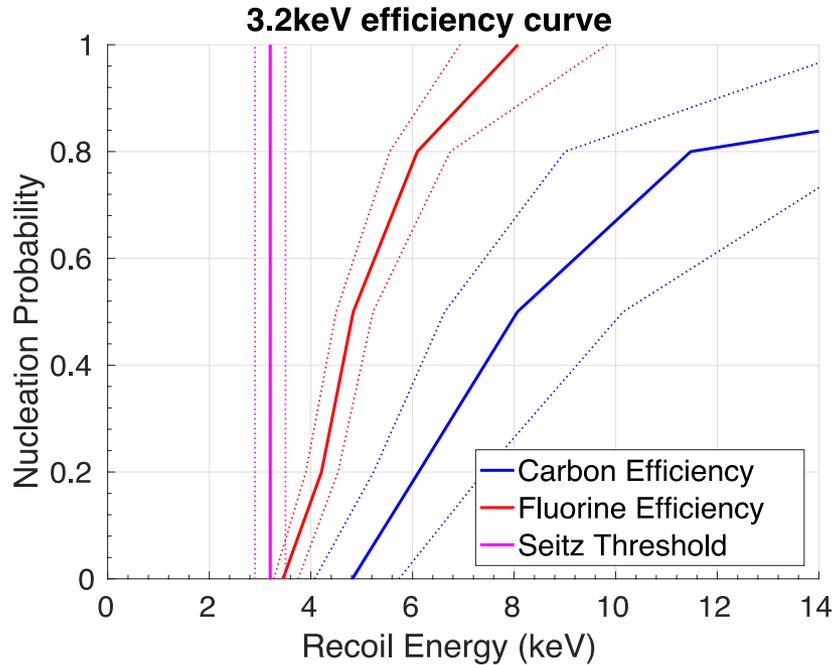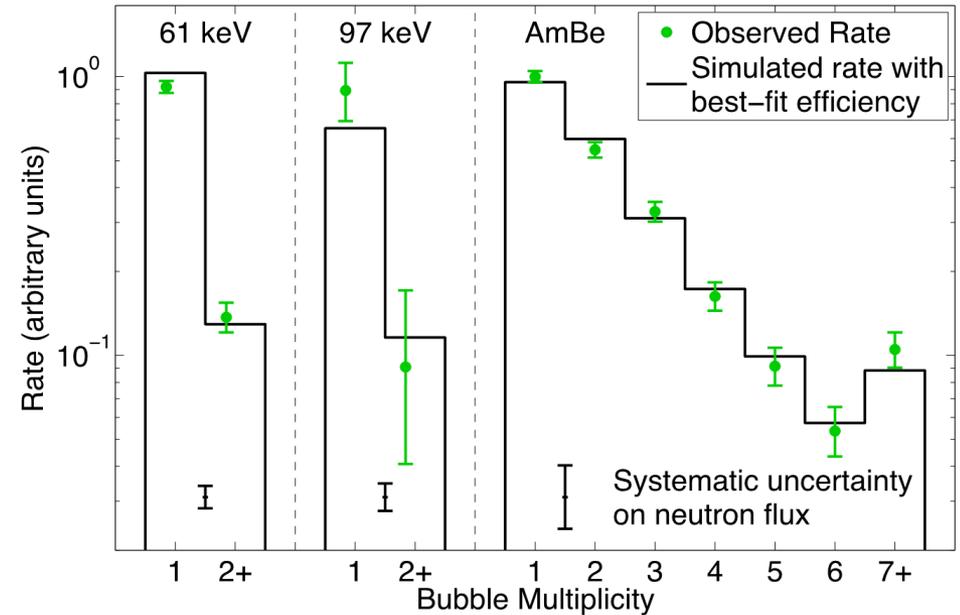
More on electron recoil calibration: Daniel Baxter on Jul 25
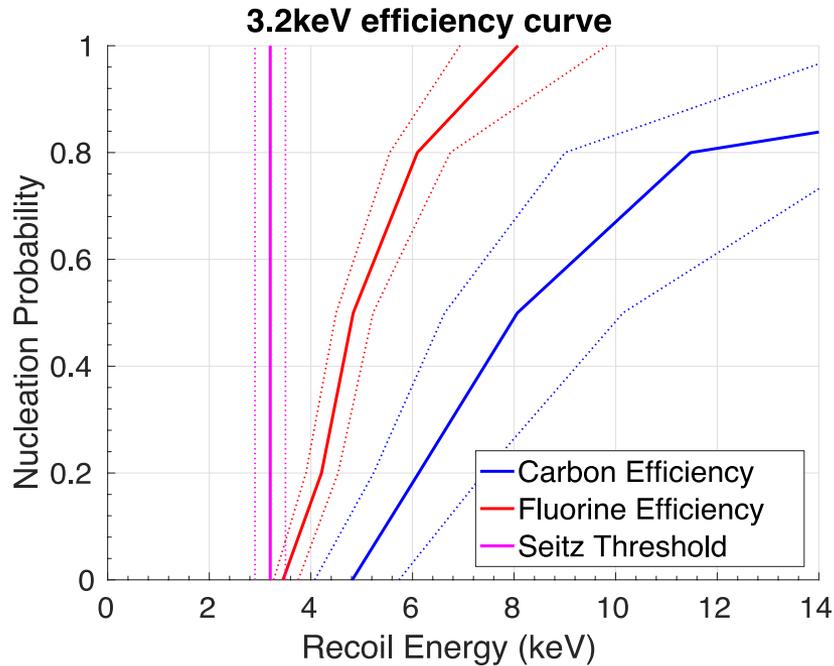
Nuclear Recoil Sensitivity
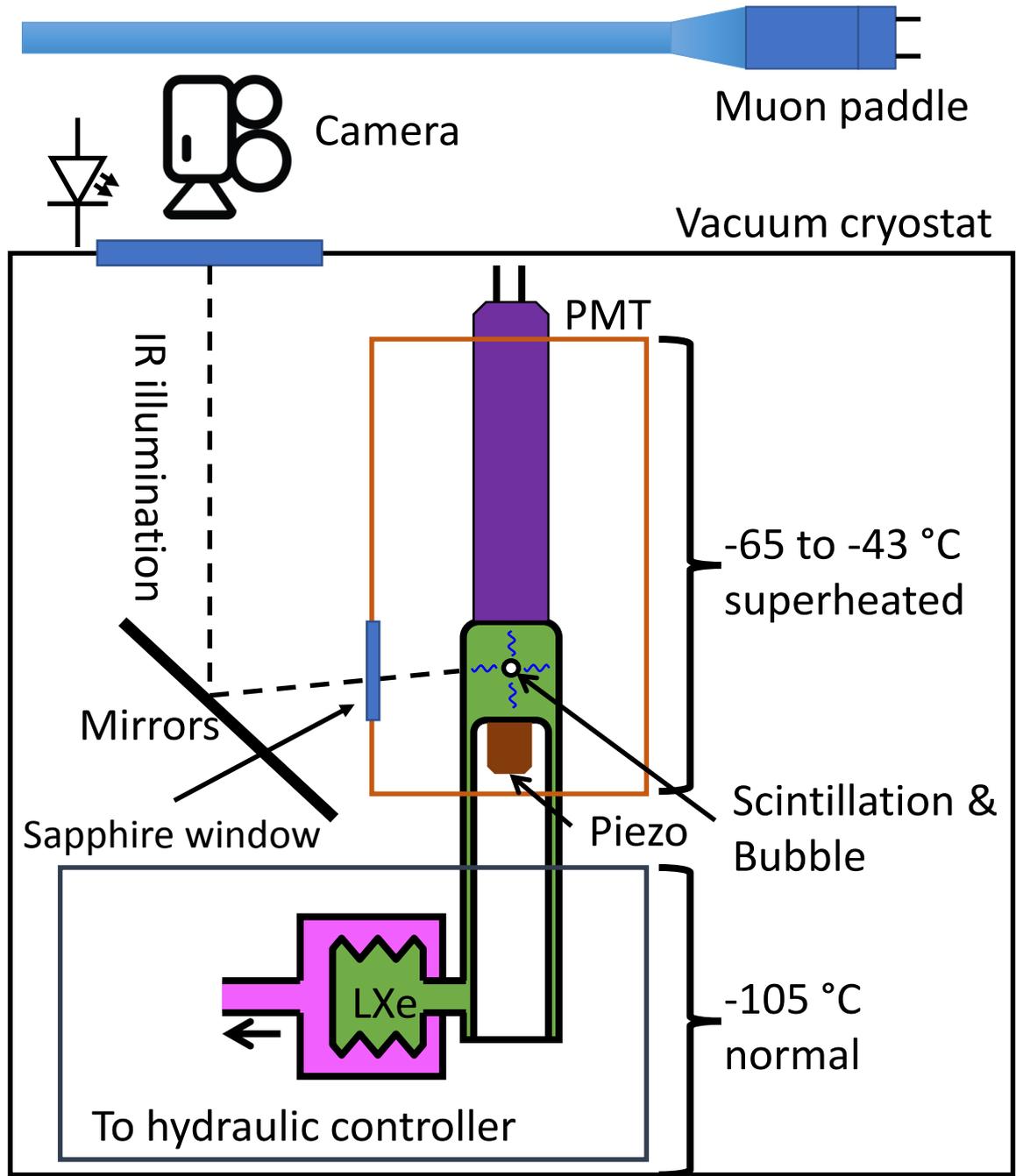
Neutron Calibrations in C_3F_8 @ E_T = 3.2 keV

Nuclear Recoil Sensitivity

Neutron Calibrations in C_3F_8 @ E_T = 3.2 keV

More on nuclear recoil calibration: Miaotianzi Jin's poster

NU Xenon Bubble Chamber

Muon paddle

Camera

Vacuum cryostat

IR illumination

PMT

-65 to -43 °C superheated

Mirrors

Sapphire window

Piezo

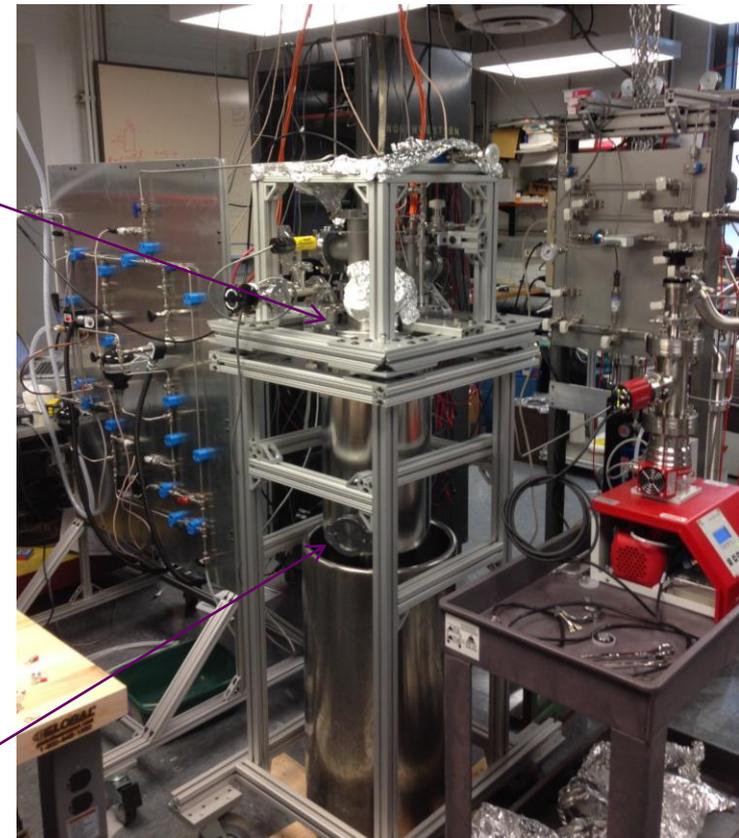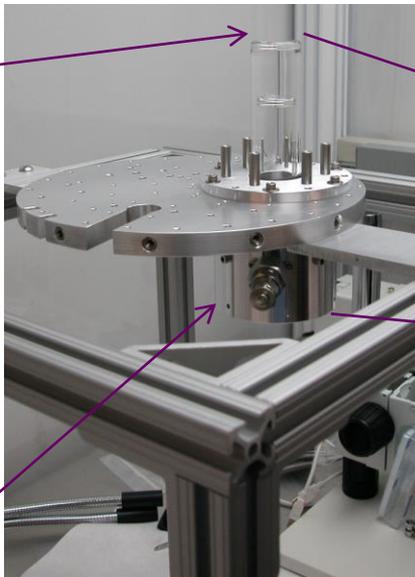Scintillation & Bubble

LXe

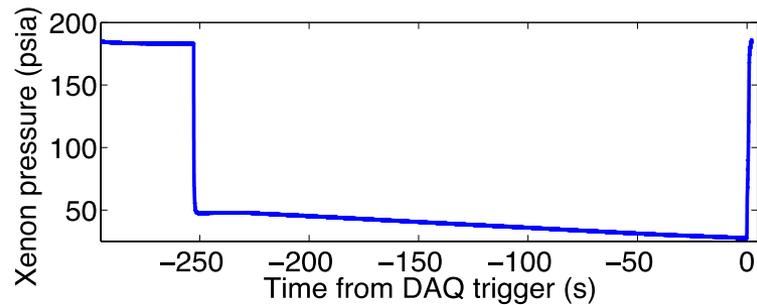-105 °C normal

To hydraulic controller

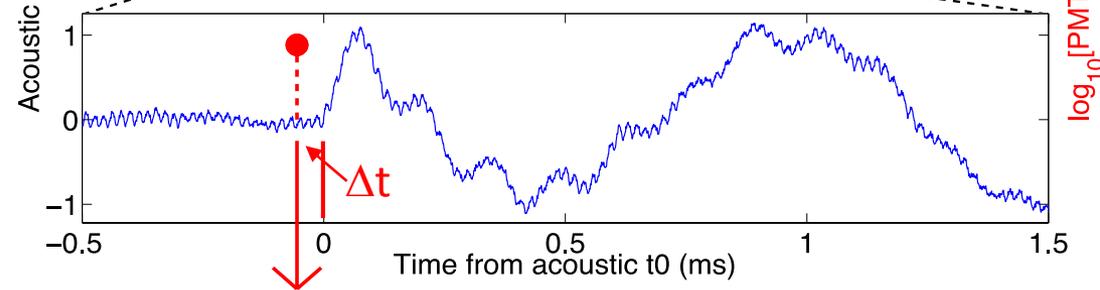# NU Xenon Bubble Chamber

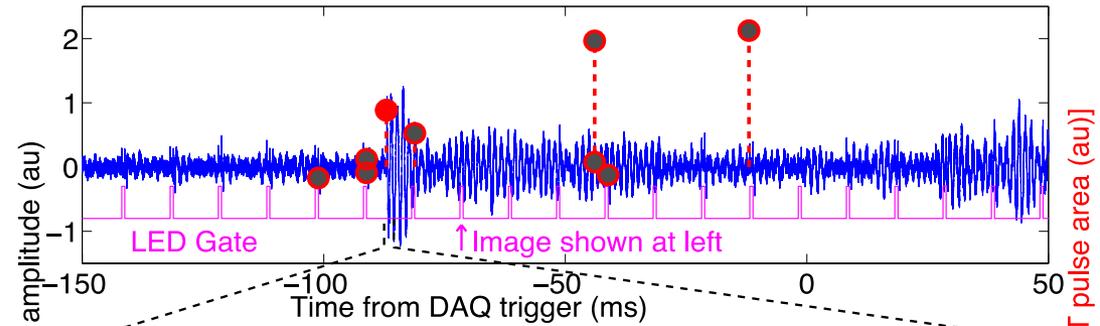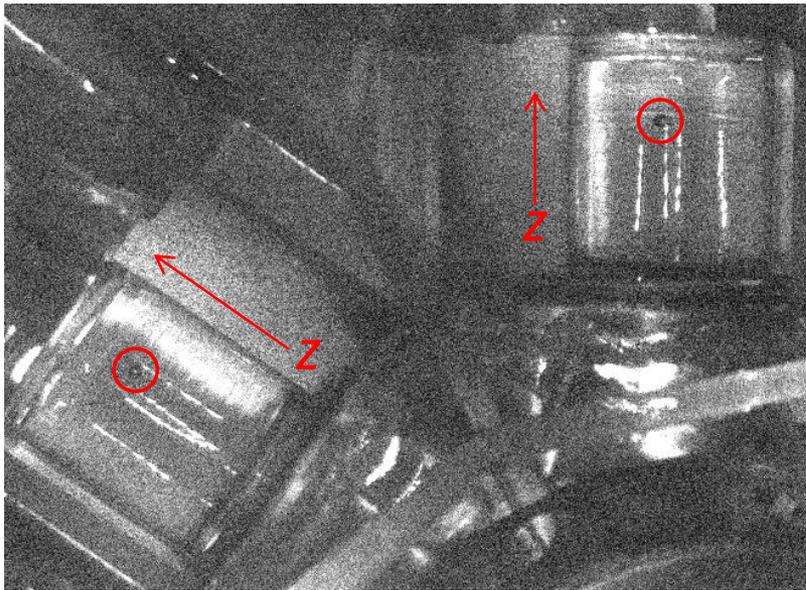- First Bubbles June 2016

April 2016

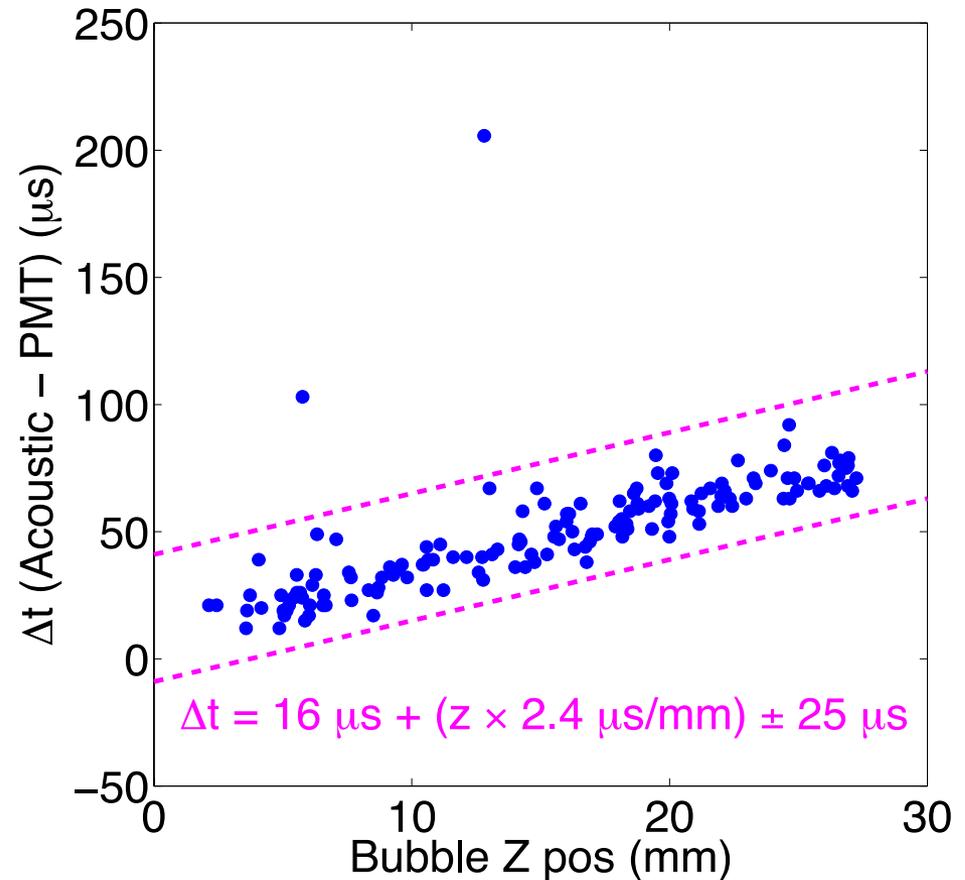Feb 2016
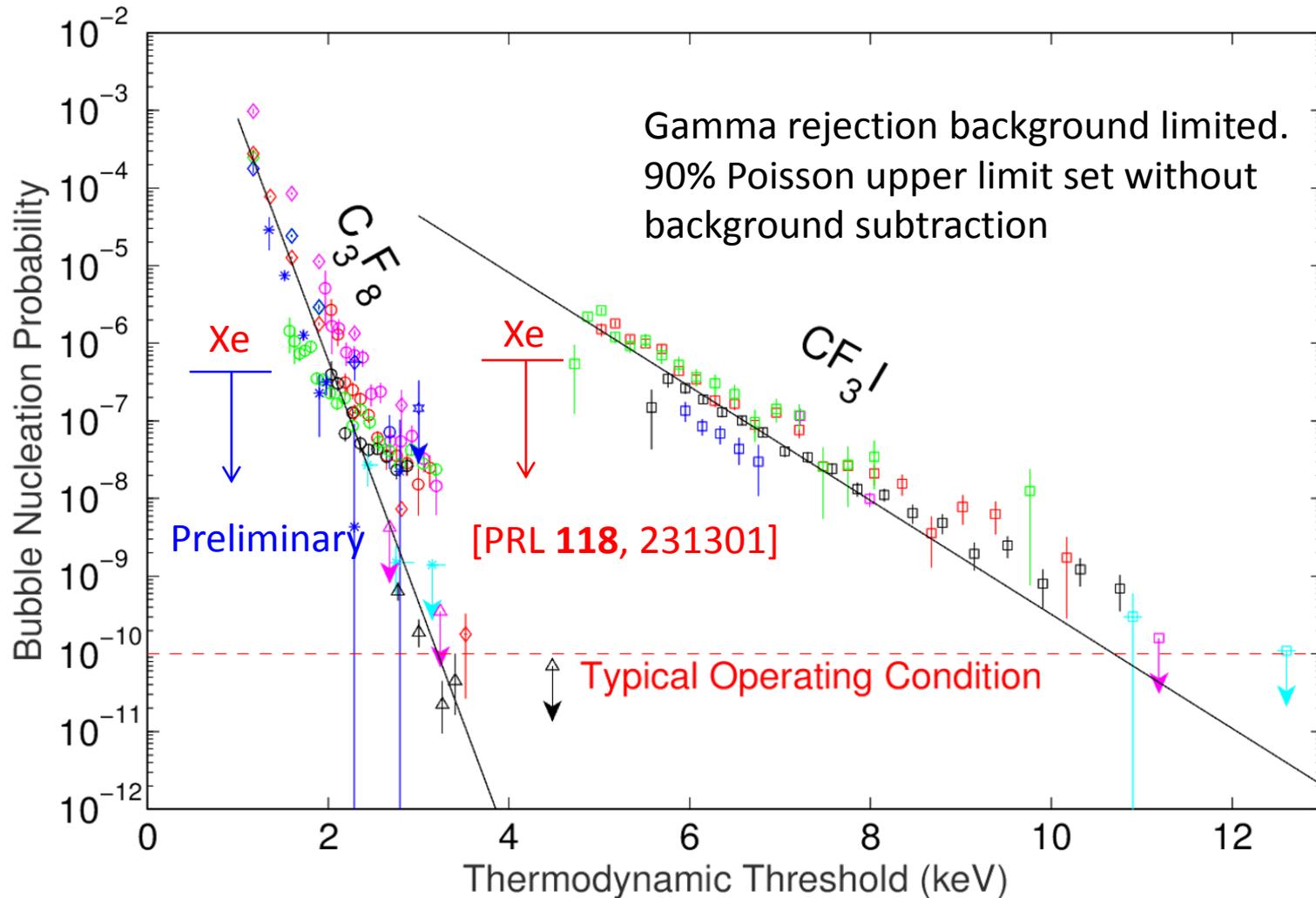
Sept 2015

June 2015

Sample Nuclear Recoil Event

11
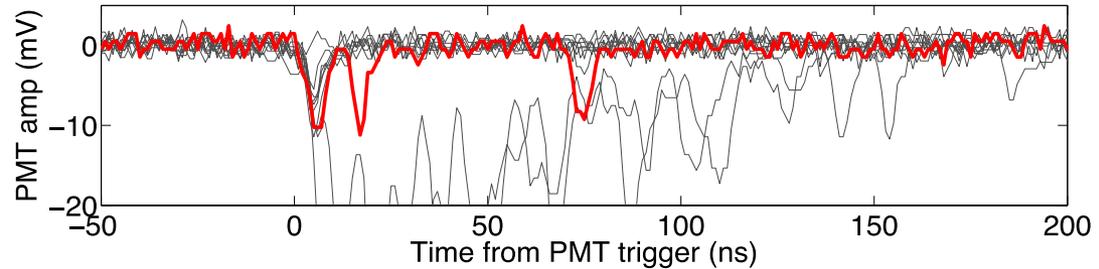
Acoustic – Scintillation Coincidence

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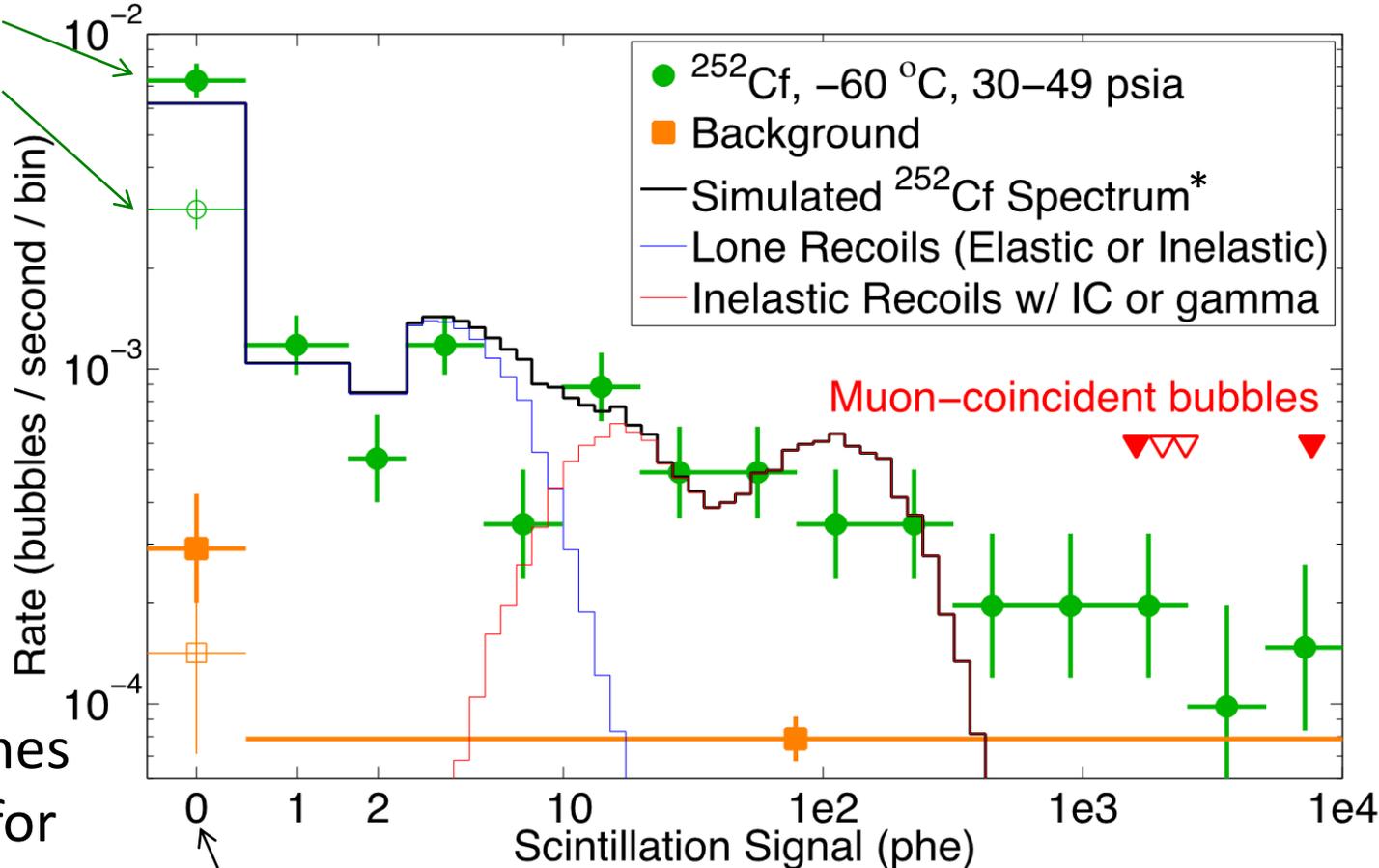
- Slope = speed of sound in xenon (to 20%)

$\Delta t = 16 \ \mu s + (z \times 2.4 \ \mu s/mm) \pm 25 \ \mu s$

Gamma Rejection

Gamma rejection background limited. 90% Poisson upper limit set without background subtraction

Scintillation Spectrum for Bubble Events

$E_T = 8.2 - 8.6$ keV
$E_T = 8.6 - 15$ keV

No E_T dependence observed in other bins

*Simulation assumes 15-keV threshold for bubble nucleation

Based on rate alone, NR threshold is 19 ± 6 keV

Legend:
- ● ^{252}Cf, −60 °C, 30–49 psia
- ■ Background
- — Simulated ^{252}Cf Spectrum*
- — Lone Recoils (Elastic or Inelastic)
- — Inelastic Recoils w/ IC or gamma

Muon−coincident bubbles

Rate (bubbles / second / bin)

Scintillation Signal (phe)

Bubbles with no PMT Trigger

14

Current Status and Next Steps

- Simultaneous bubble nucleation and scintillation for nuclear recoils demonstrated
- Bubble nucleation by gammas $<10^{-6}$ at $E_T=1.0$ keV

- Nuclear threshold analysis ongoing at $E_T=1.0$ keV
  - Now calibrating sensitivity to low-energy nuclear recoils using (γ,n) sources
- Reconfiguring the xenon chamber to use liquid Ar as target fluid
- Ready to scale up soon