New analysis and thermodynamic parameter estimation from the upgraded optics system of PICO-60

Pitam Mitra
University of Alberta

TAUP 2017
Laurentian University
Sudbury

Monday July 24, 2017

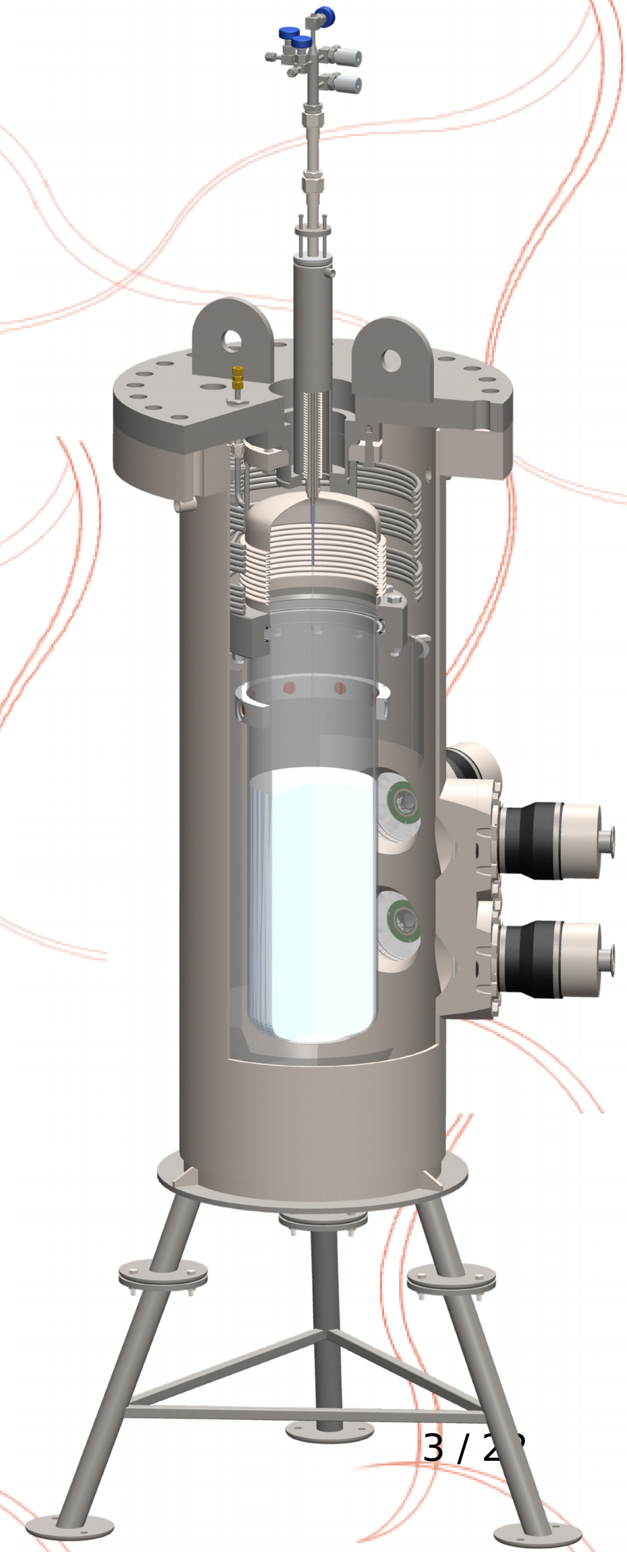
Overview

- Introduction to PICO-60
- PICO-60 imaging analysis and tracking
- Using bubble track information for physics analysis
- Using the bubble growth rate to understand the thermodynamic properties of the active liquid.

PICO-60 overview

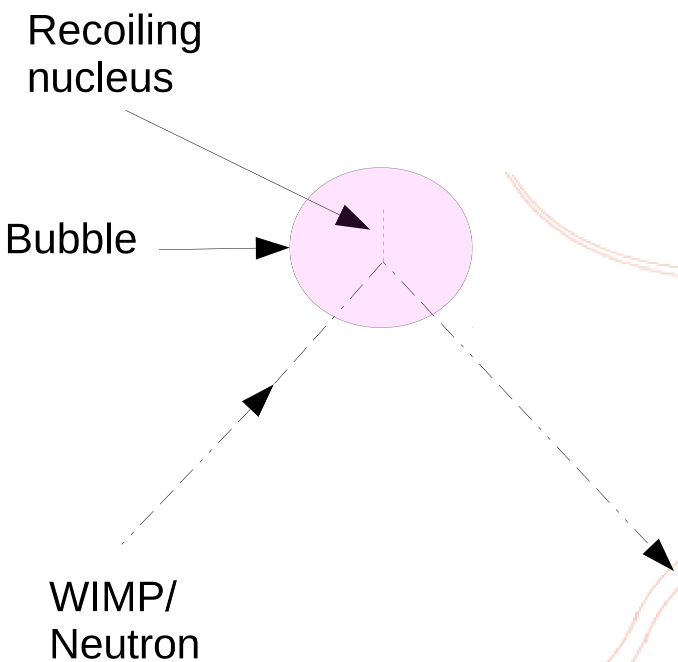
PICO-60 is a **direct dark matter search** experiment, **using superheated liquid** C_3F_8 as a target material.

The detector is a glass jar that sits inside a pressure vessel. The liquid is **superheated** under **normal operating conditions**, and **pressurized otherwise**.

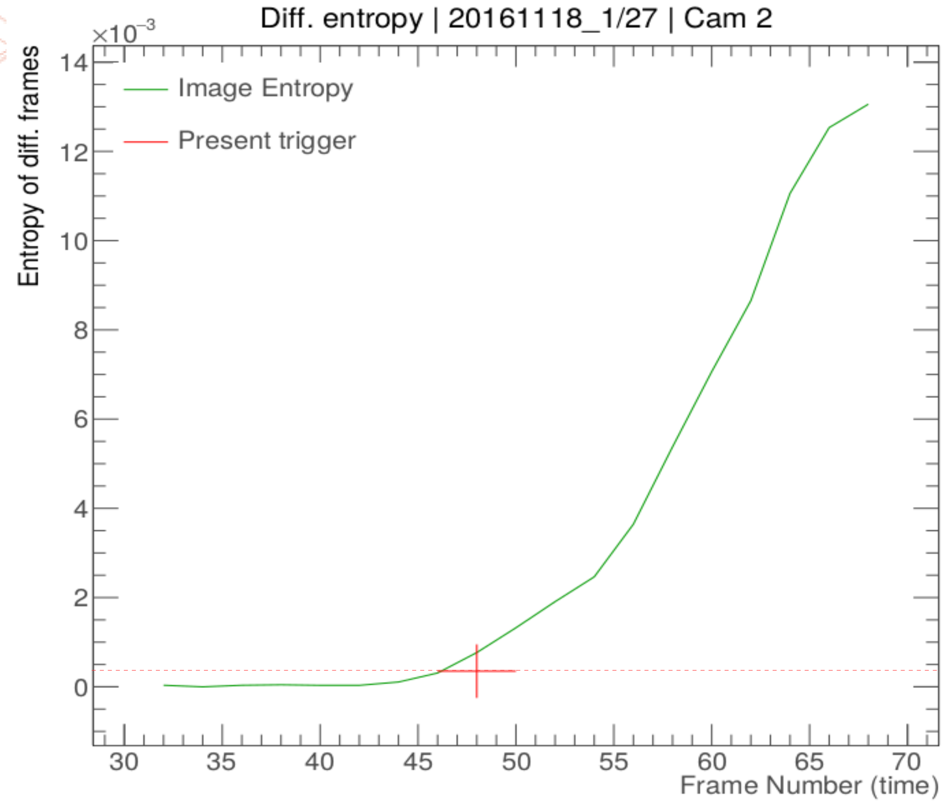


*PICO Results and Outlook by C. Krauss, plenary talk on Tuesday 9:50am

PICO-60 triggering



Cameras are used to **monitor the detector**. They compute the "**image entropy***", and issues a trigger when it rises above a threshold.

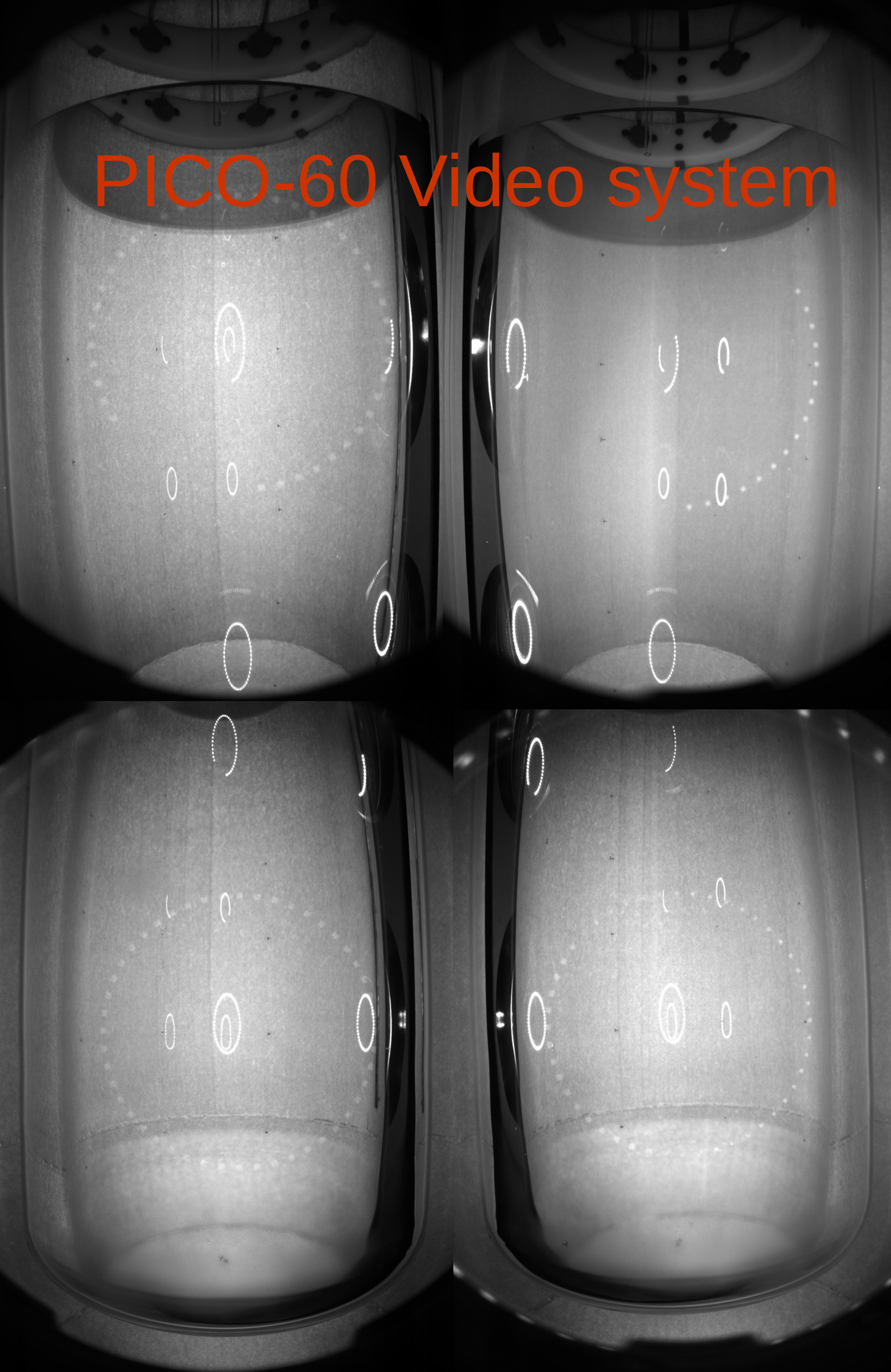


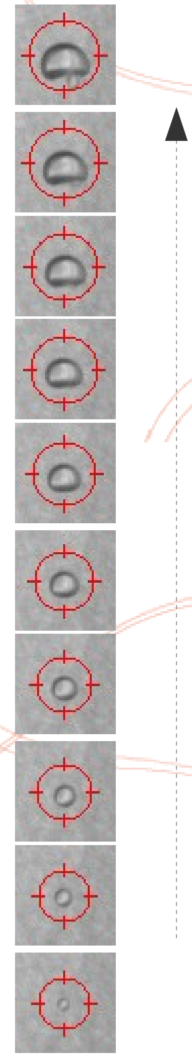
A WIMP or a neutron **recoils** off of a **nucleus**, depositing some energy. The **recoiling nucleus produces a bubble** .

Pitam

Klassen K. Galileo Solid-State Imaging Subsystem Calibration Report: Part 2

PICO-60 Video system

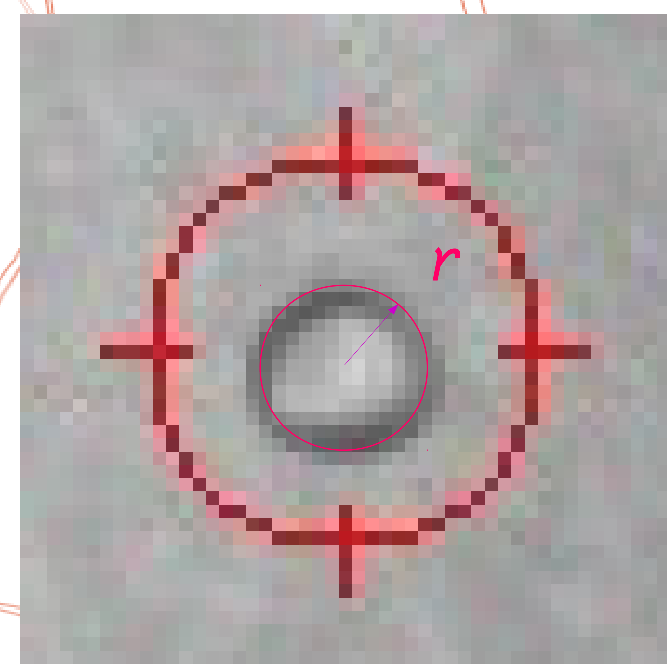




Four Basler ace acA-340km cameras running at **340 fps.**

Tracked by “Autobub”, **detecting** and **tracking** the bubble across **10 frames** after genesis.

The average distance from the centre to the contour is used as the “radius” of the bubble.

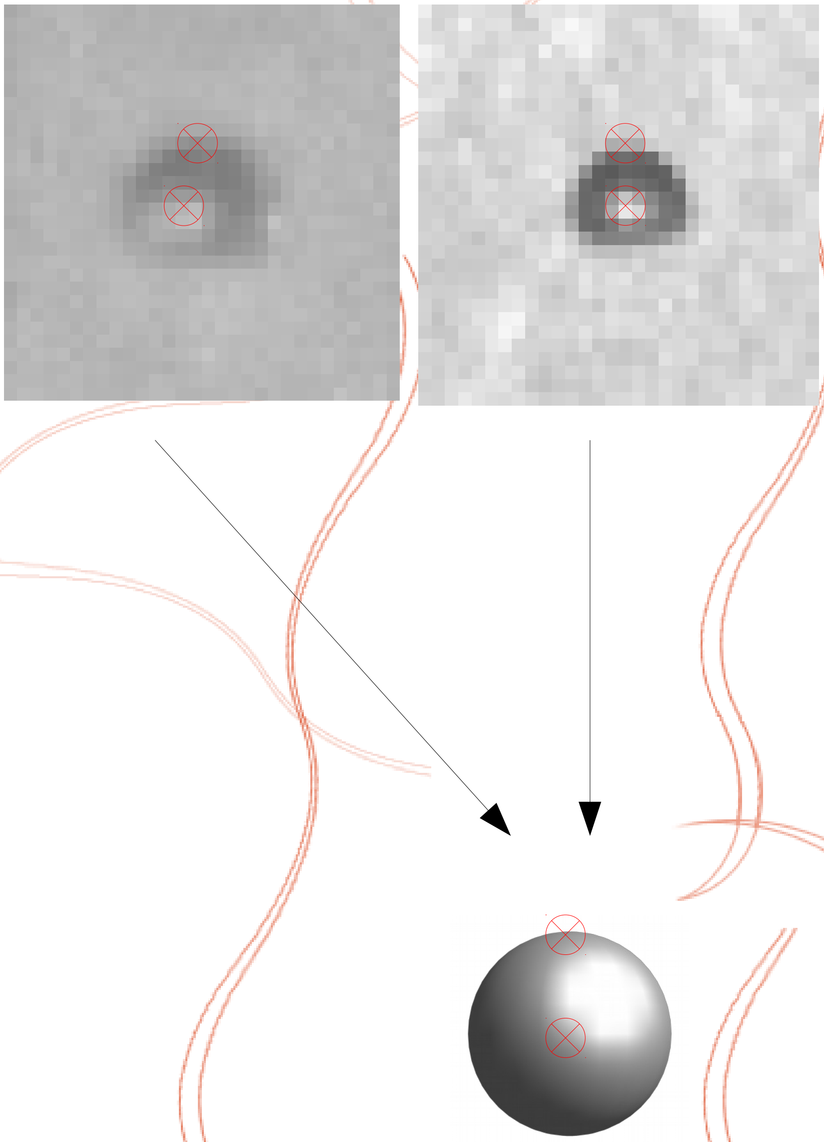


From 2D bubble to 3D bubble

The **top** , **centre** and **bottom** points are used to construct a 3D bubble from a stereo image.

Each 2D point is reconstructed as a ray in 3D. Two or more rays provide the stereo required to re-construct the 3D bubble.

Each bubble is approximated as a **sphere**.



Updated physics analysis with new optics

Most of the events during a dark matter search **are wall events** (radon progeny). We wish to **exclude** these **with a fiducial cut**. With the updated optics and the new analysis algorithms, we have

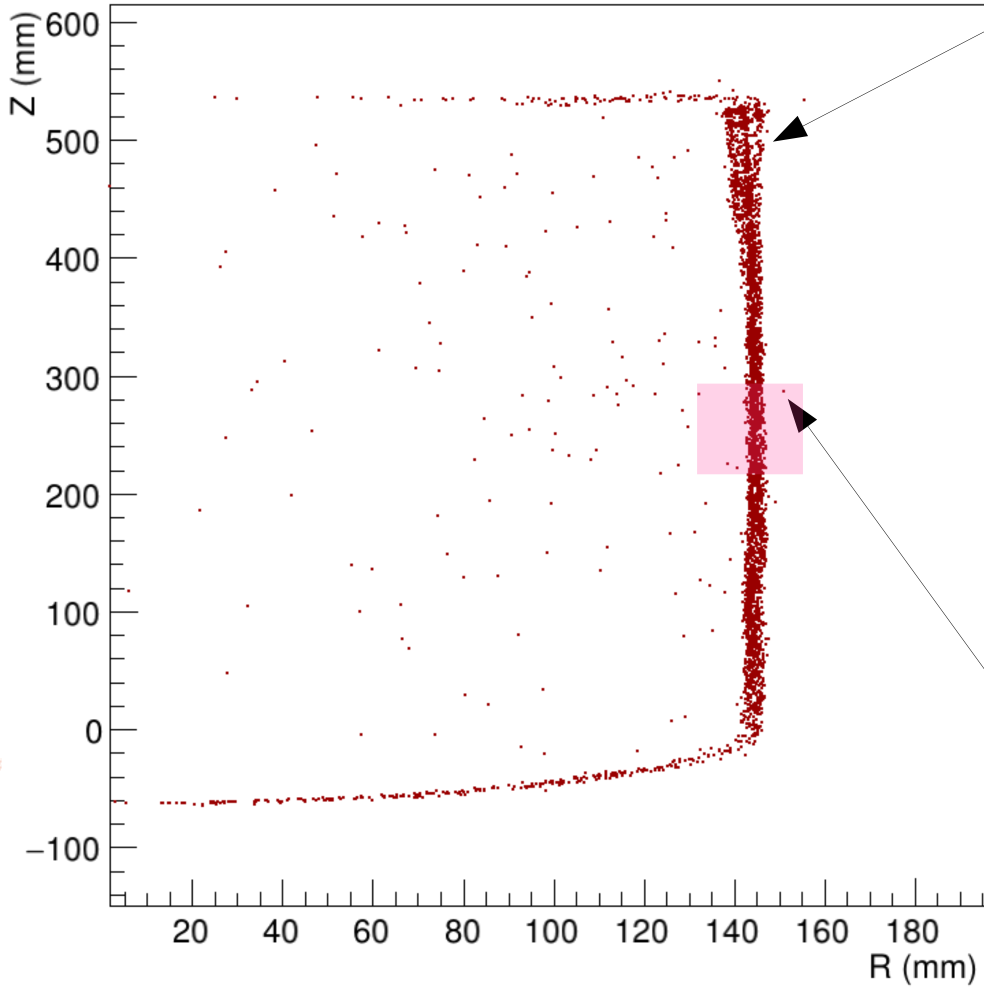
1. Improved the accuracy of the position reconstruction

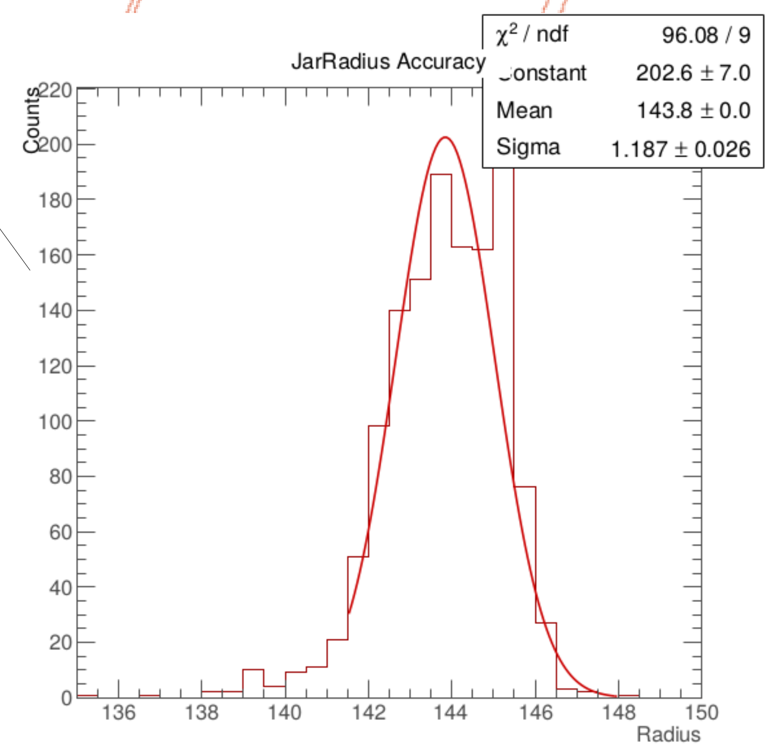
2. Used the track / motion of the bubble for better fiducial cuts (and thus increase the fiducial volume and dark matter sensitivity)

3. Using the growth / radius of the bubble to understand thermodynamics of the detector.

Initial reconstruction vs optimized

1. Uncorrected jar motion
2. Asymmetry between two sides of the detector

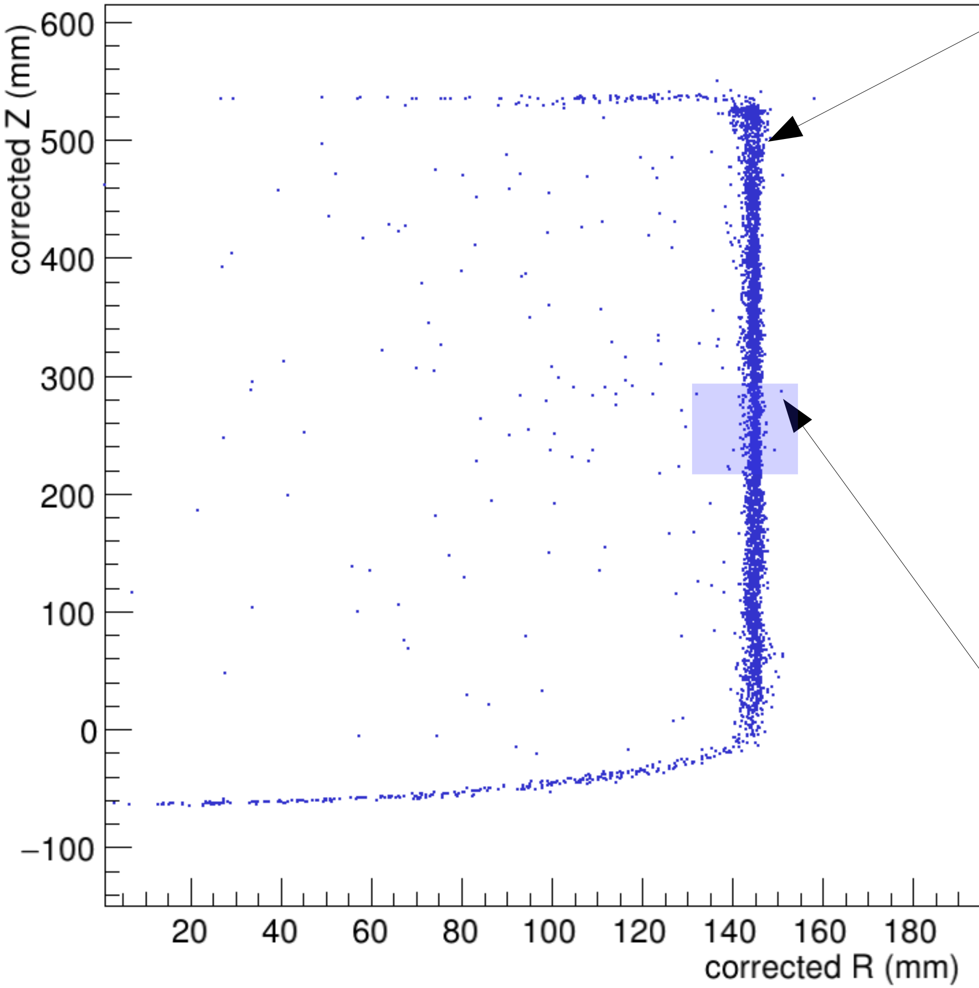


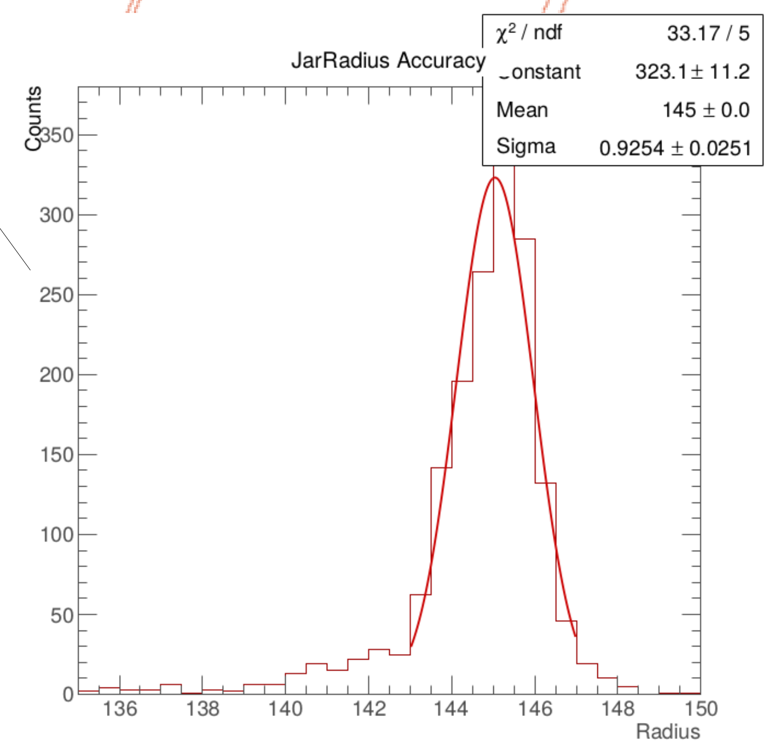


Initial reconstruction vs **optimized**

Corrected for jar motion solves these problems.

Heuristic camera choices improve accuracy





Pitam Mitra

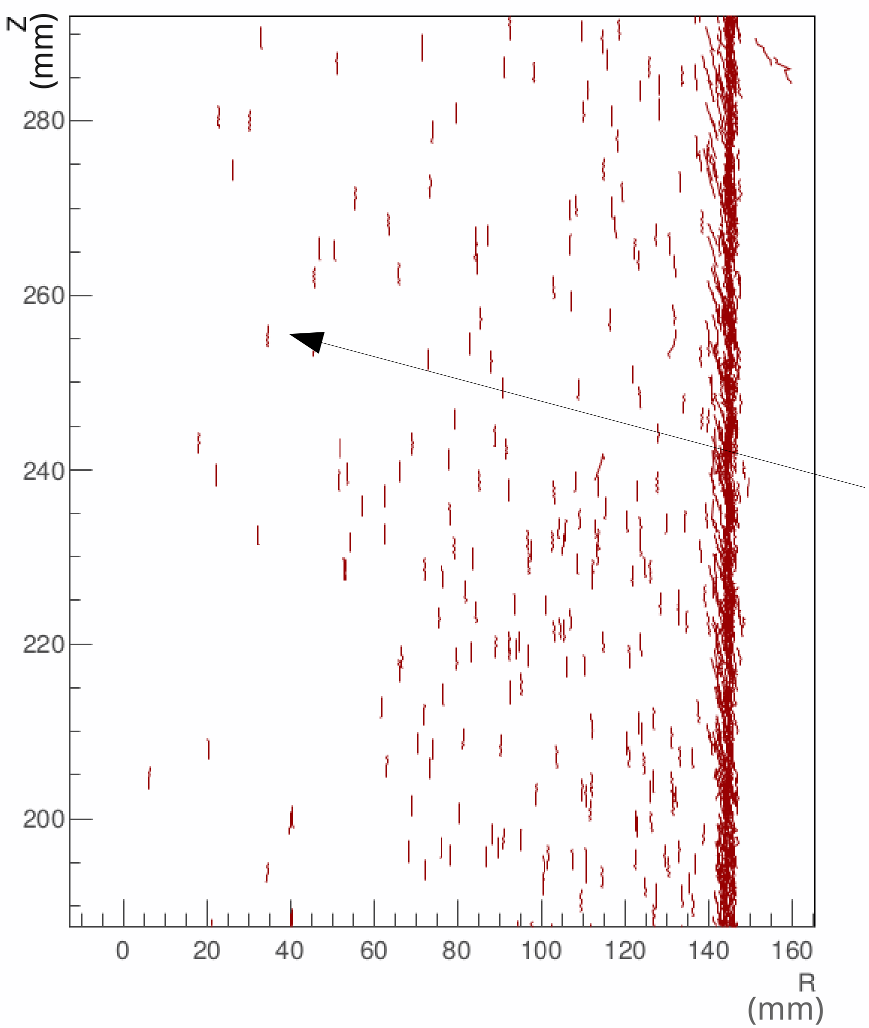
Can we do better?

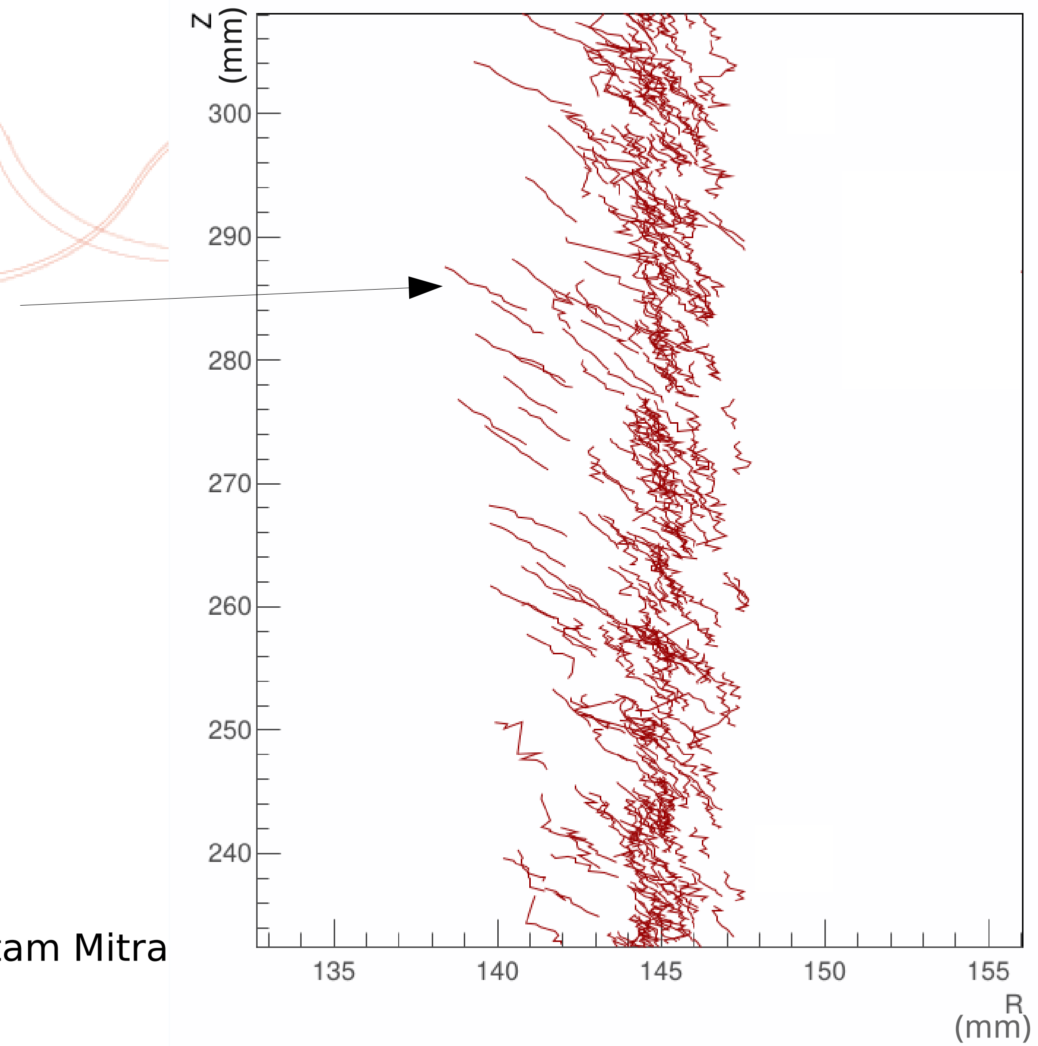
Jar correction and heuristic camera choices improve the location and the accuracy of events

They do not solve the problem of determining **if a bulk event is close to the wall** or an actual wall event.

Updated physics analysis with new optics

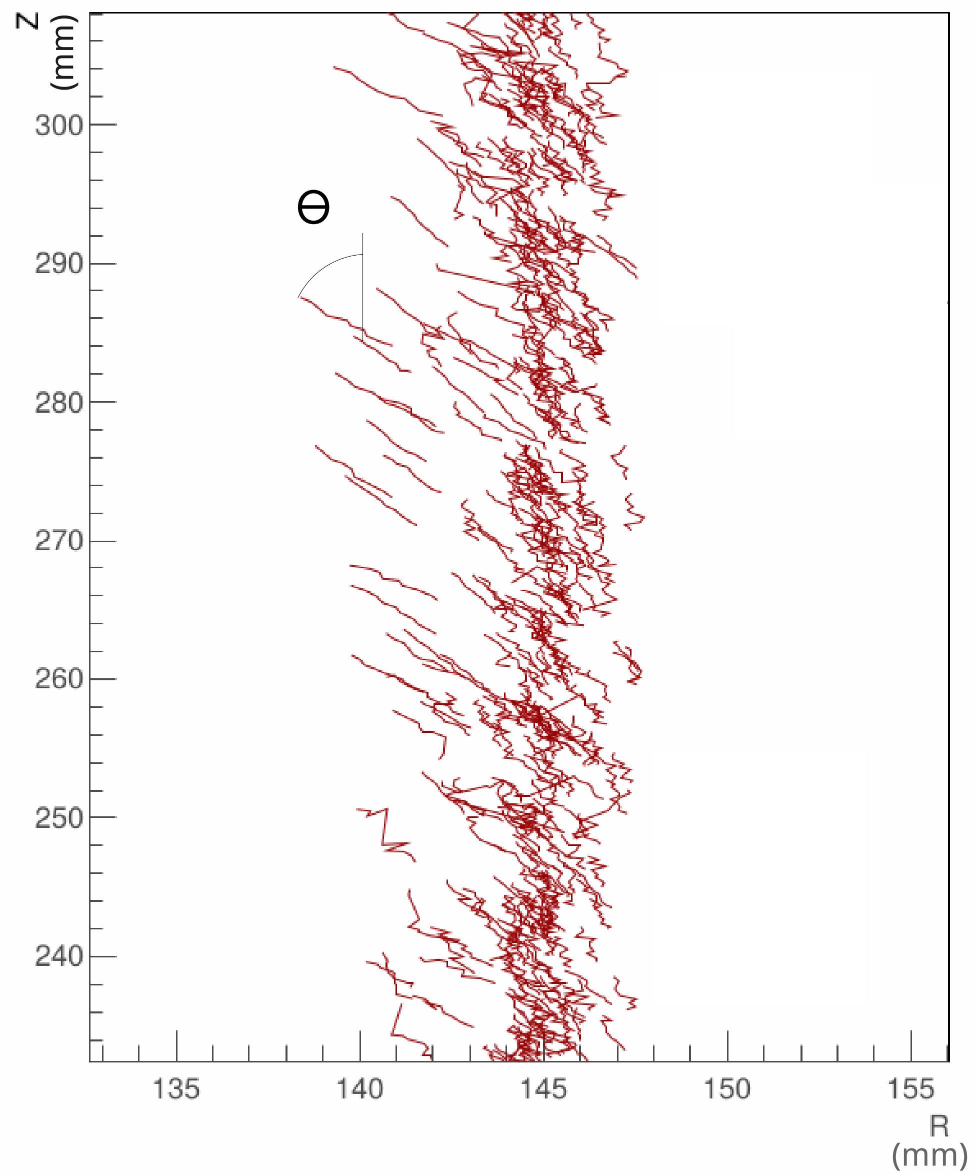
We can use the track / motion of the bubble to **tell bulk events apart from wall events** → bigger fiducial volume without wall leakage





Updated physics analysis with new optics

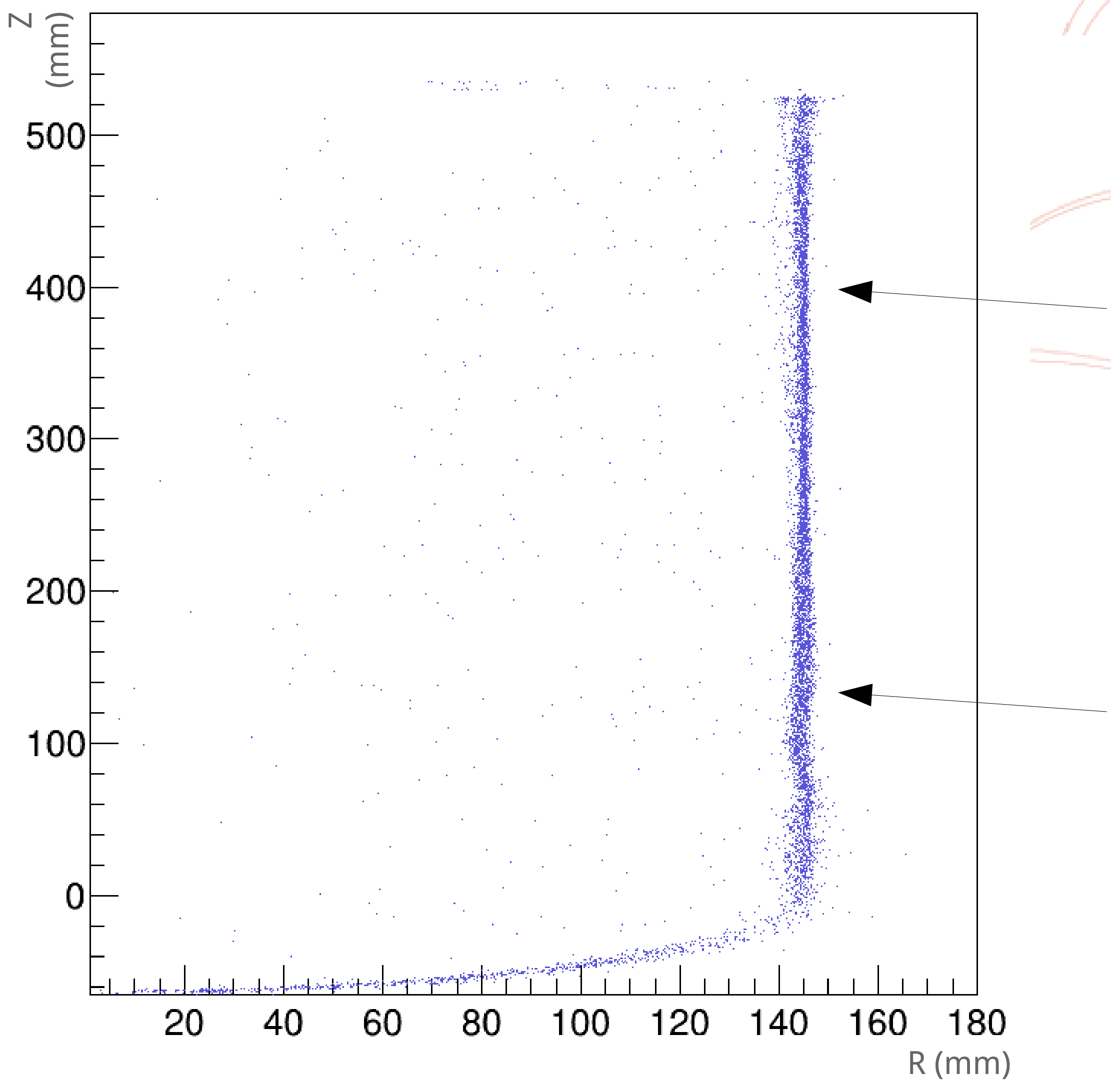
Can use the **zenith angle theta** to discriminate between **wall** and **bulk** events → Better definition of the wall... bigger fiducial volume?

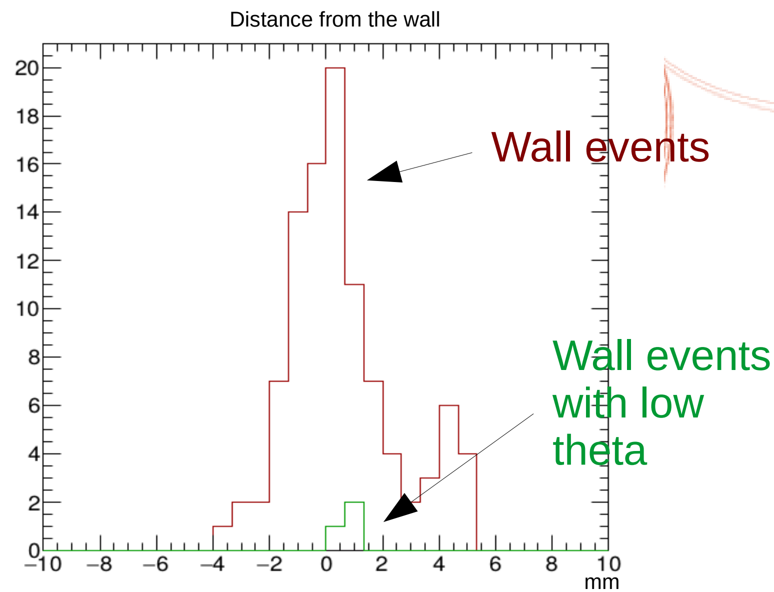


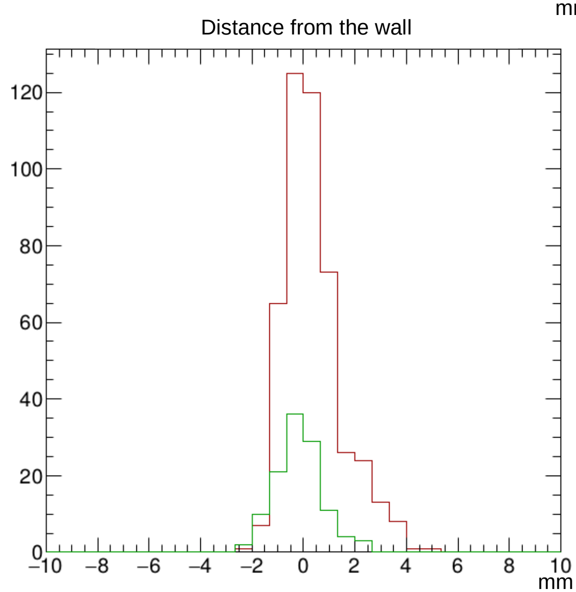
Pitam

Updated physics analysis with new optics

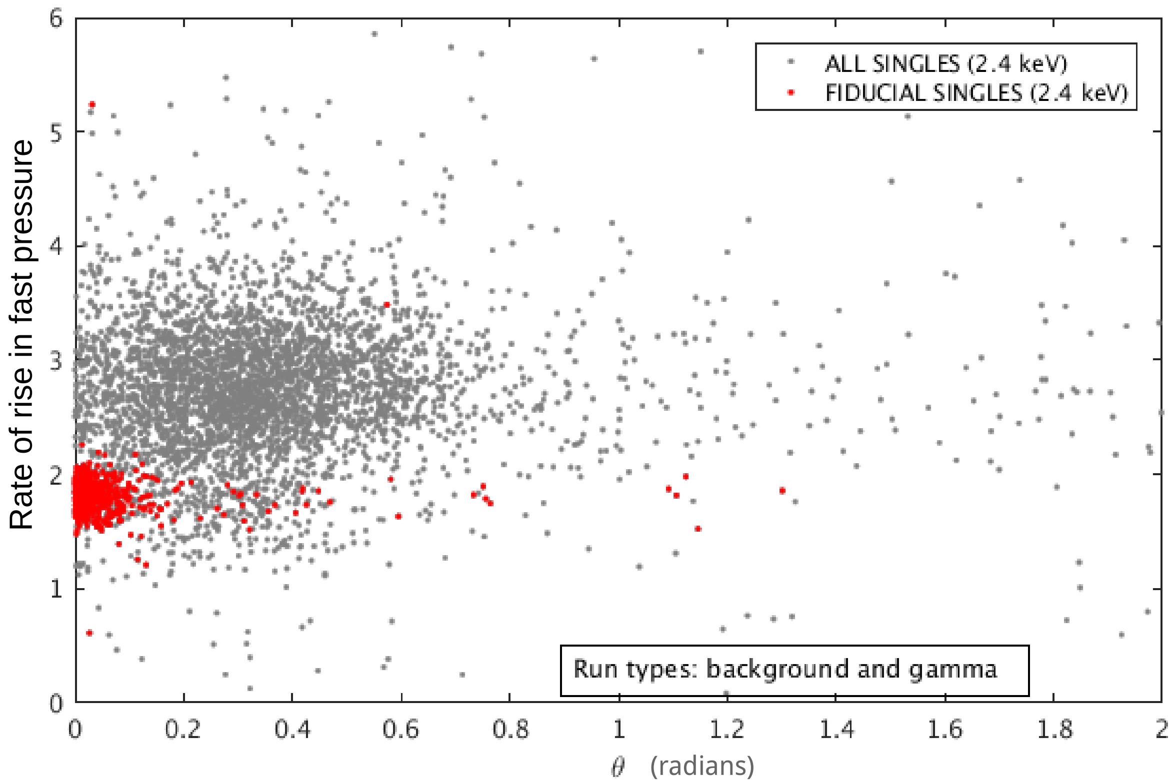
Better fiducial definitions, ~5-6% fiducial mass gain







Complementary to existing wall discriminator



The orthogonality allows selection of a **much purer sample of fiducial** events.

Without this variable, it is **almost impossible to get such accuracy near the wall** even by looking at the events **manually**.

Rate of rise in fast pressure (y-axis in the plot) may be used to discriminate wall from bulk, but it has leakages.

New thermodynamic parameters with faster optics

The active liquid is meta-stable. **Instrumentation** of this region is **impossible**.

Growth / time evolution **of the radius** of the bubble could be used to understand the **thermodynamics** of the chamber (work in progress)

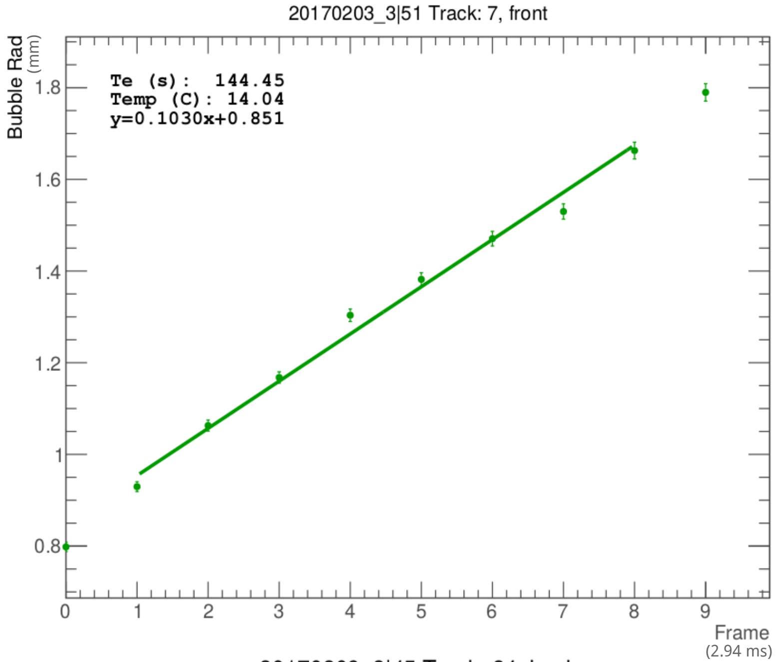
Terminologies

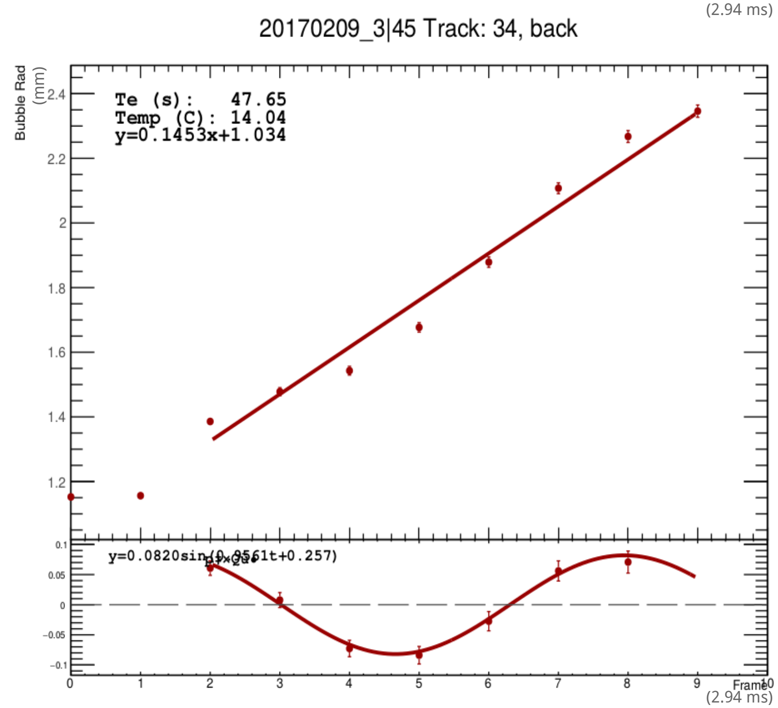
For each single nucleation event in the bulk, the **radius** of the bubble is plotted **over time.**

Slope = Speed of bubble growth

Intercept = initial size at detection

The residuals havent been fully studied yet.

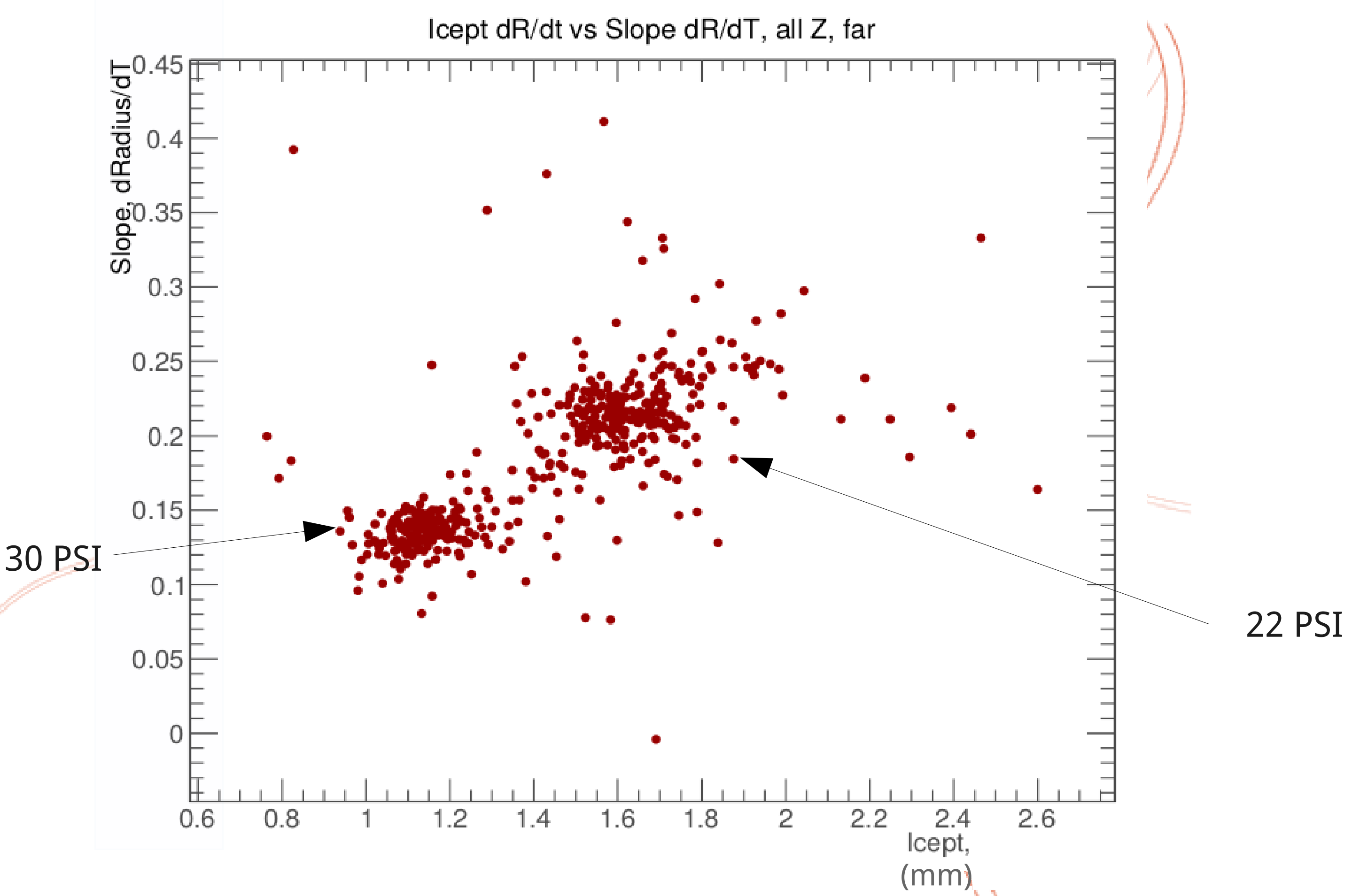




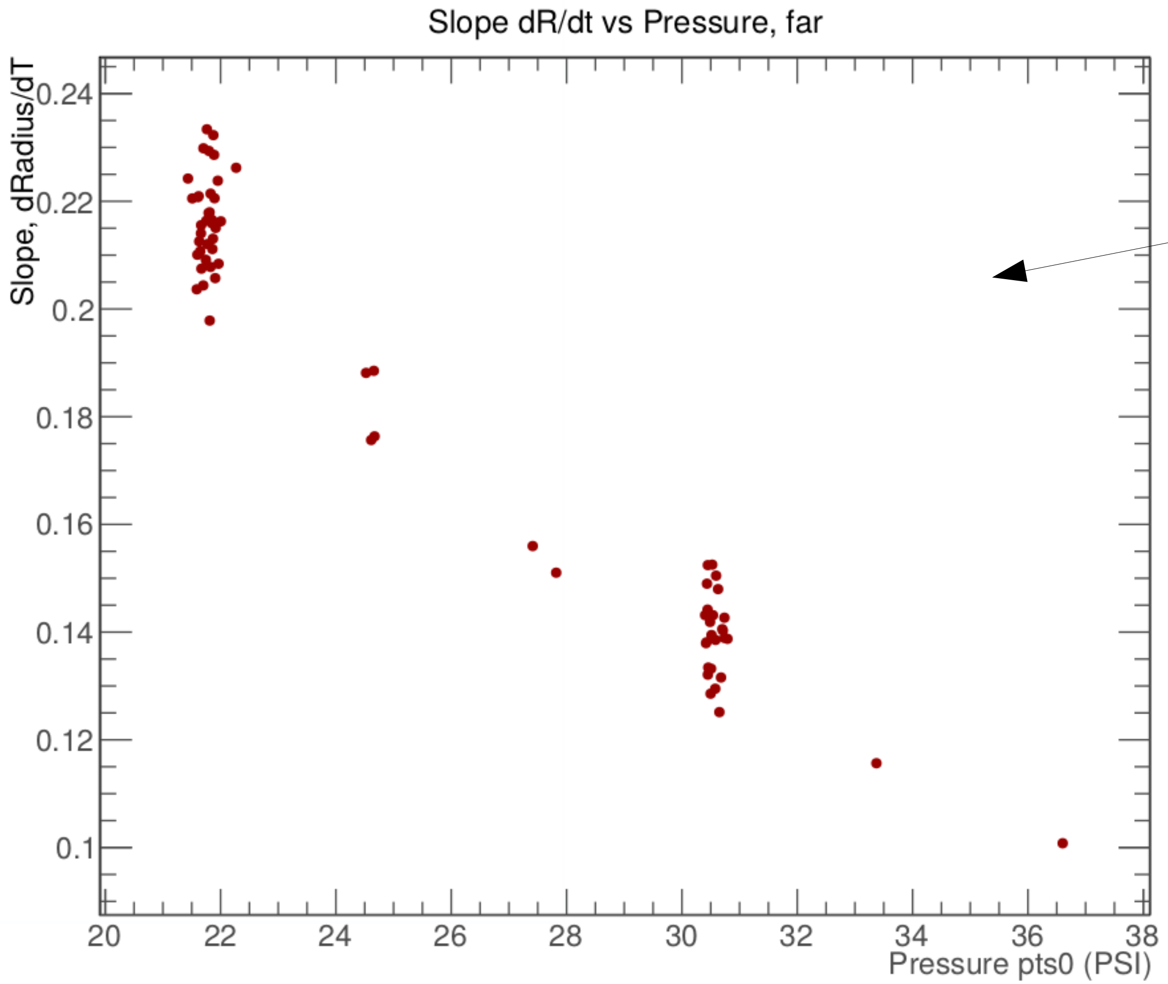
Constant temperature

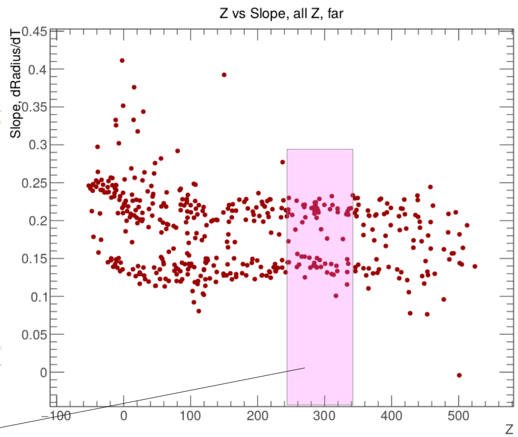
Studying the effects of pressure on bubble growth

Growth rate vs initial size in the “far” part of the detector.



Growth rate vs pressure (far side)
250 < Z <350





Bubbles grow faster as pressure drops.

We have a calibration for pressure vs growth.

Studying the effects of temperature is more difficult and is work in progress.

The end goal is to determine the **local pressure and temperature inside the active volume.** This has never been done before and will be a powerful tool to **understand the threshold** in the detector with much better accuracy.

Summary

1. New optical system in PICO-60 allows for **video data** at **340 fps**

2. New optical analysis algorithms are being used to **track the movement** and the **growth** of bubbles in PICO.

3. The **movement** of the bubbles can be used as a **discriminator** of **fiducial events from non-fiducial wall events,** increasing the fiducial volume (by ~6%).

4. The growth rate of the bubble is inversely proportional to pressure. We have a calibration pending verification.

5. **Work is in progress** to understand the effects of temperature on bubble growth.

6. The **objective** of the study is to calibrate the **bubble growth** with respect to **temperature** and **pressure** and thus allow for a measurement of the superheat (and **threshold**) inside the PICO detector volume.

Thank You!

Other PICO talks:

- **PICO Results and Outlook** by C. Krauss, **plenary** talk on Tuesday 9:50am

- First Demonstration of a Scintillating Xenon Bubble Chamber for Dark Matter and CEνNS Detection by Jianjie Zhang on Monday 1:15pm
- Toward a next-generation dark matter search with the PICO-40L bubble chamber by Scott Fallows on Monday 4:45pm
- Calibrating Inner-Shell Electron Recoils in a Xenon Time Projection Chamber by Daniel Baxter on Tuesday 1:15pm
- PICO-500L: Simulations for a 500L Bubble Chamber for Dark Matter Search by Eric Vázquez Jáuregui on Tuesday 4:30pm

- Nuclear recoil calibration for PICO bubble chambers by Miaotianzi Jin at the poster session
- PICO-60: World's largest bubble chamber for dark matter detection by U. Chowdhury at the poster session
- The PICO-40L Detector Design by B. Loer at the poster session