PROBING NUCLEAR RECOILS IN LIQUID ARGON

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NEW PERSPECTIVES CONFERENCE
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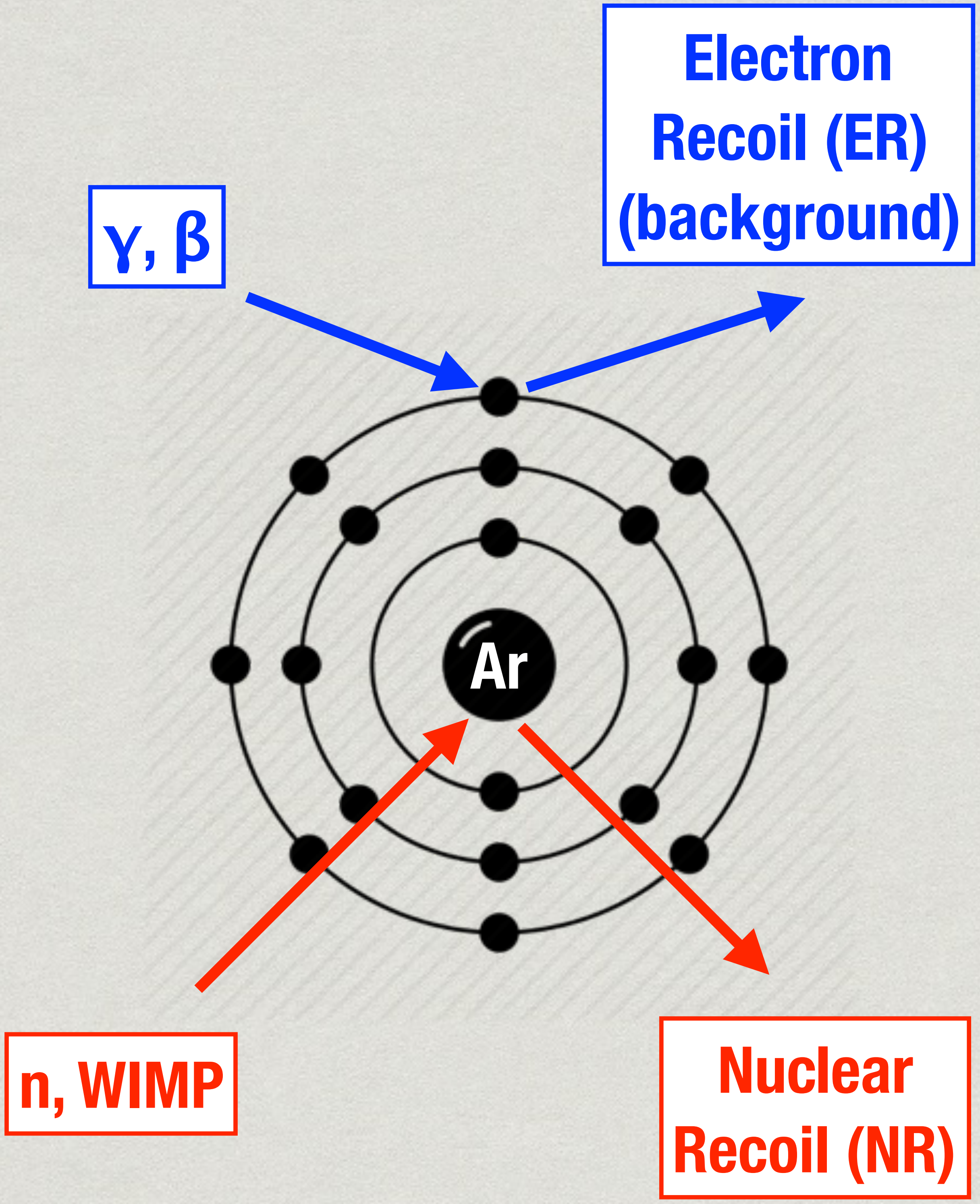
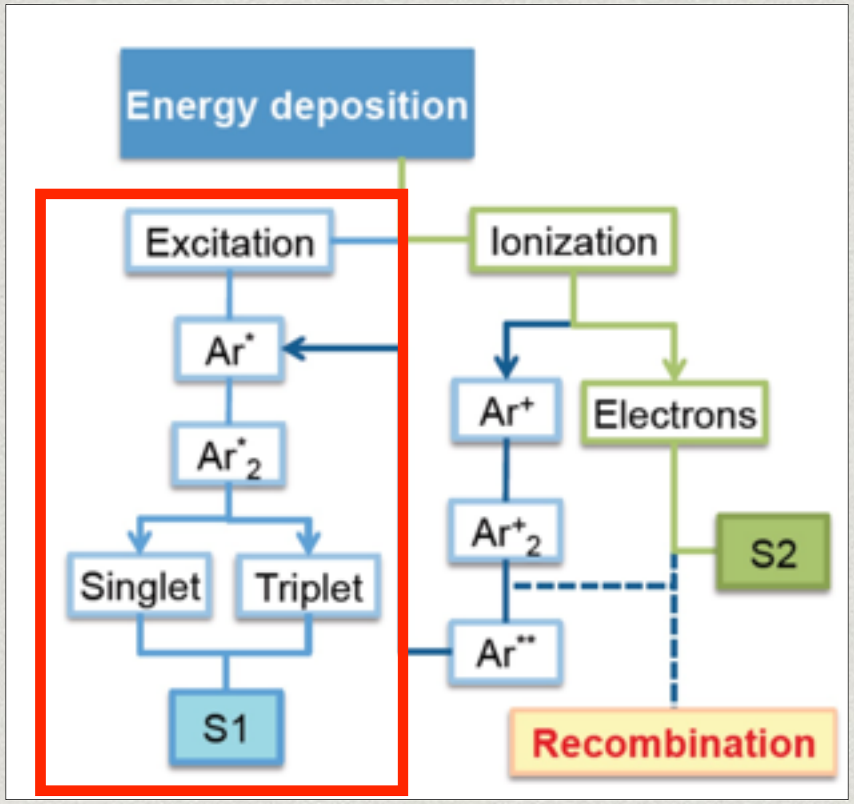
Introduction

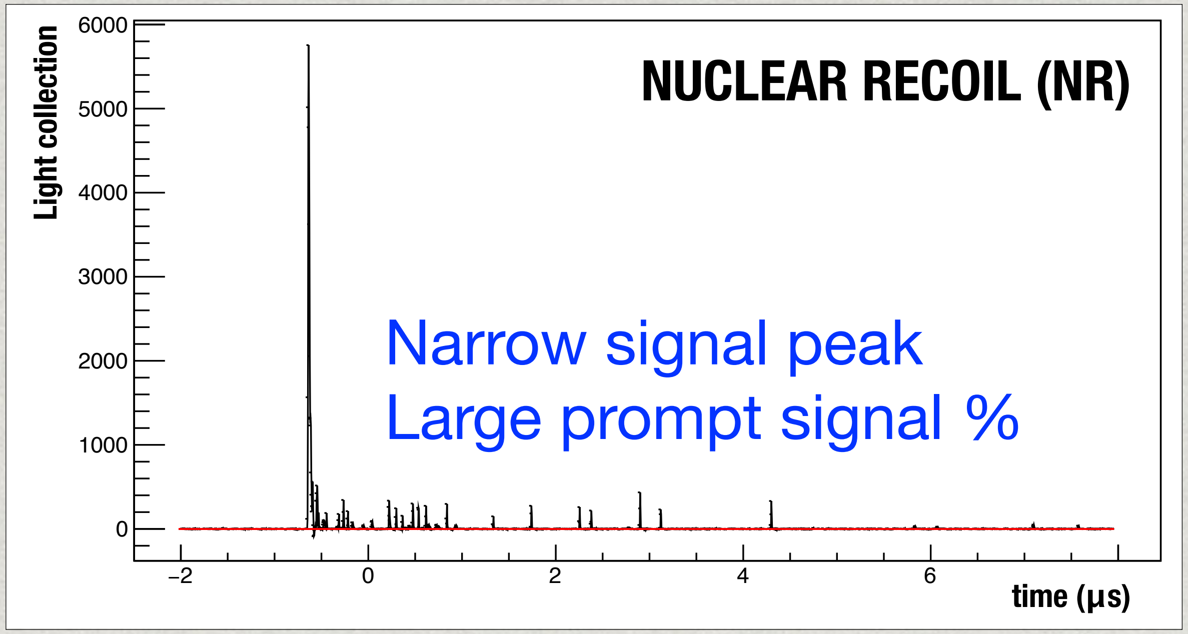
- The DarkSide collaboration utilizes liquid argon (LAr) as a target medium for a direct dark matter search
- A **W**eakly **I**nteracting **M**assive **P**article (WIMP) would scatter elastically with the nucleus, so our target signal is a nuclear recoil. It is critical to characterize these signals in LAr.

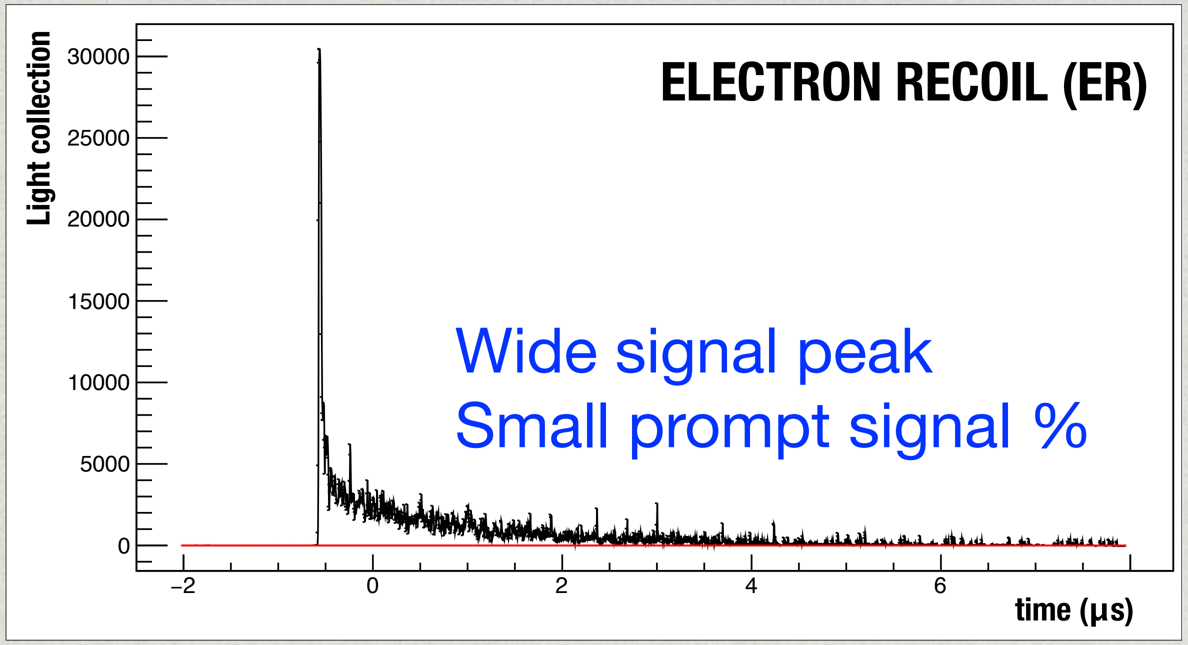


Liquid Argon Target

- Liquid argon is an attractive medium for a direct dark matter search experiment.
- The time profile of primary scintillation light (S1) depends strongly on particle type. We can use **pulse shape discrimination** for extremely powerful background rejection.





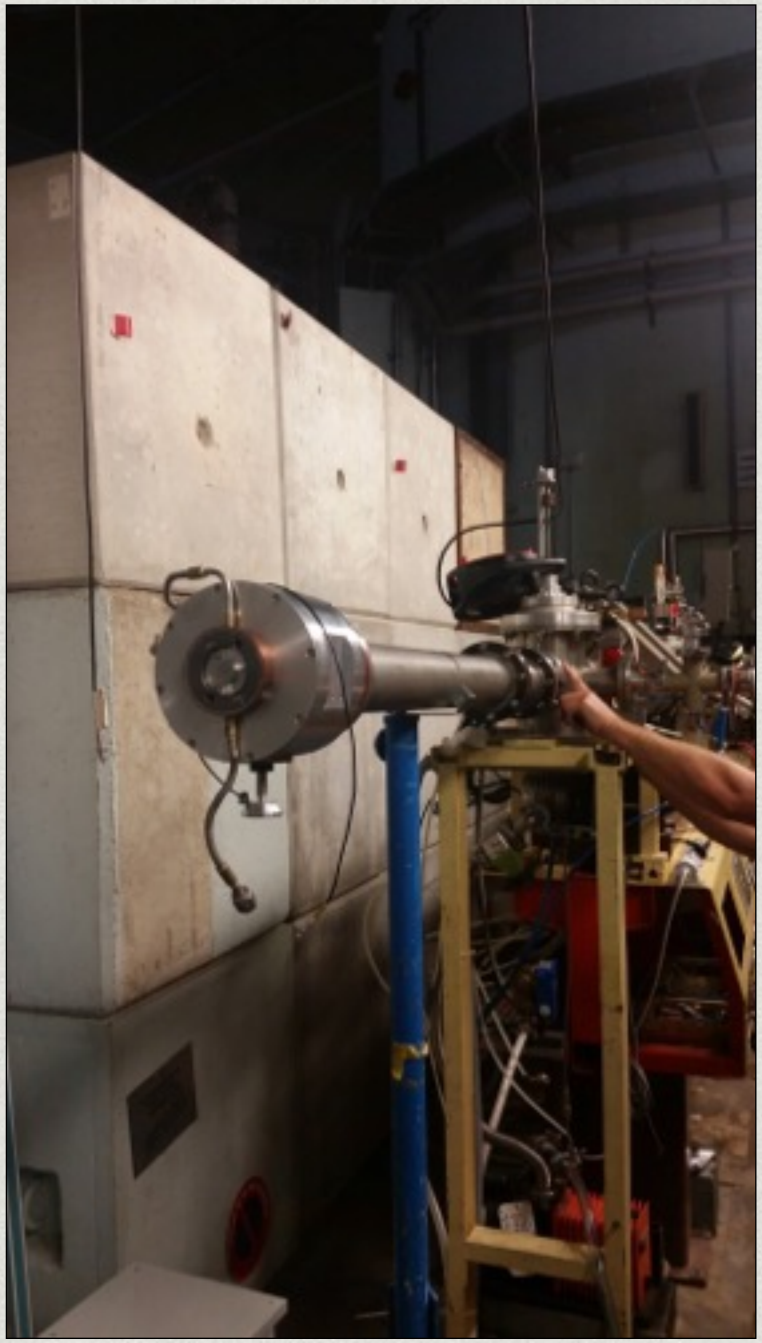


The ARIS experiment

We exposed a LAr scintillation chamber to a 1.4 MeV neutron beam to produce many nuclear recoil (NR) events.

Physics goals—characterize:

1. **L_{eff}**: How does the light yield of a NR compare to an ER of the same energy?
2. **Prompt Signal**: What is the time-profile of scintillation light from a NR?
3. **Recombination**: What fraction of free electrons recombine with ions after a NR?

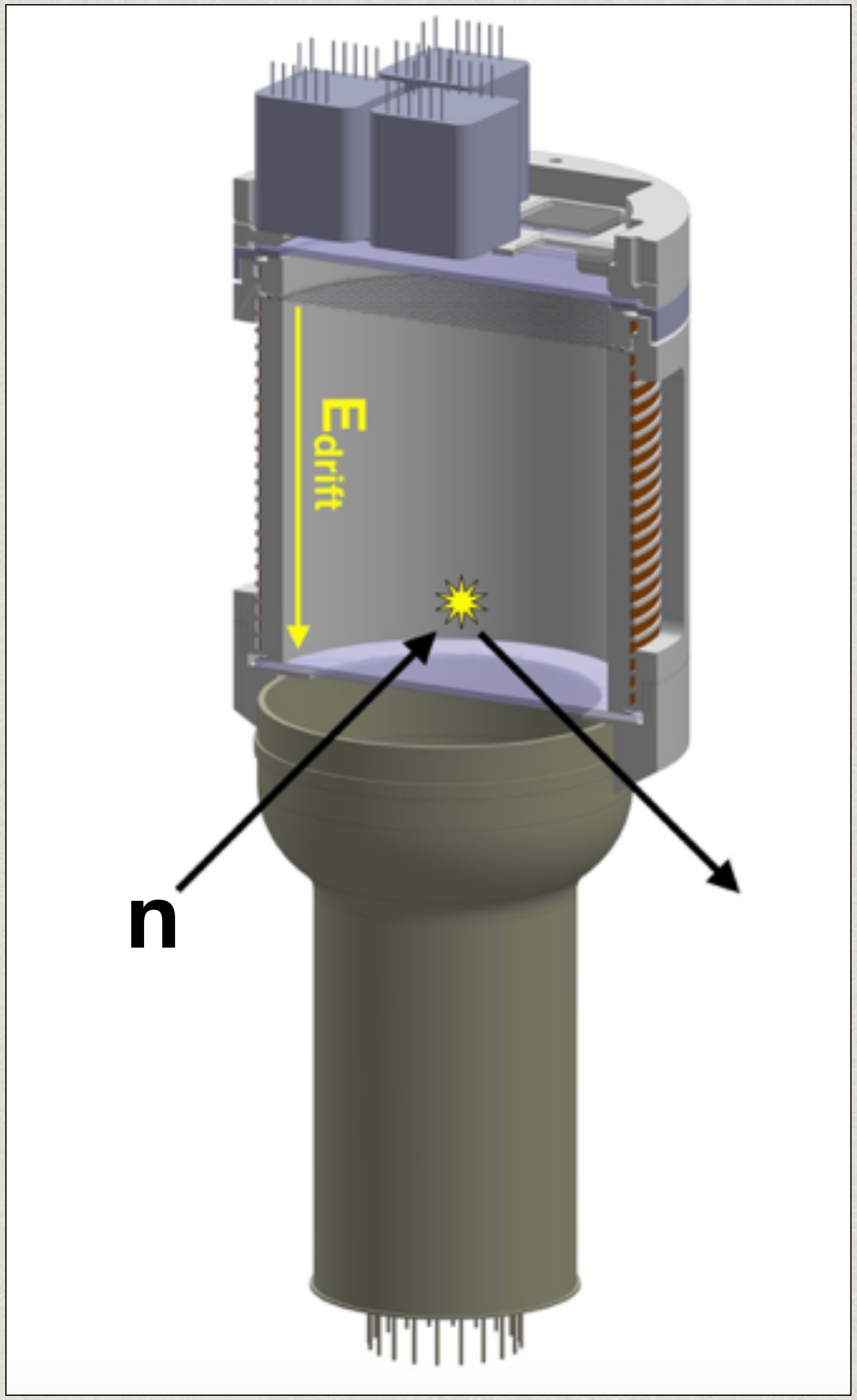


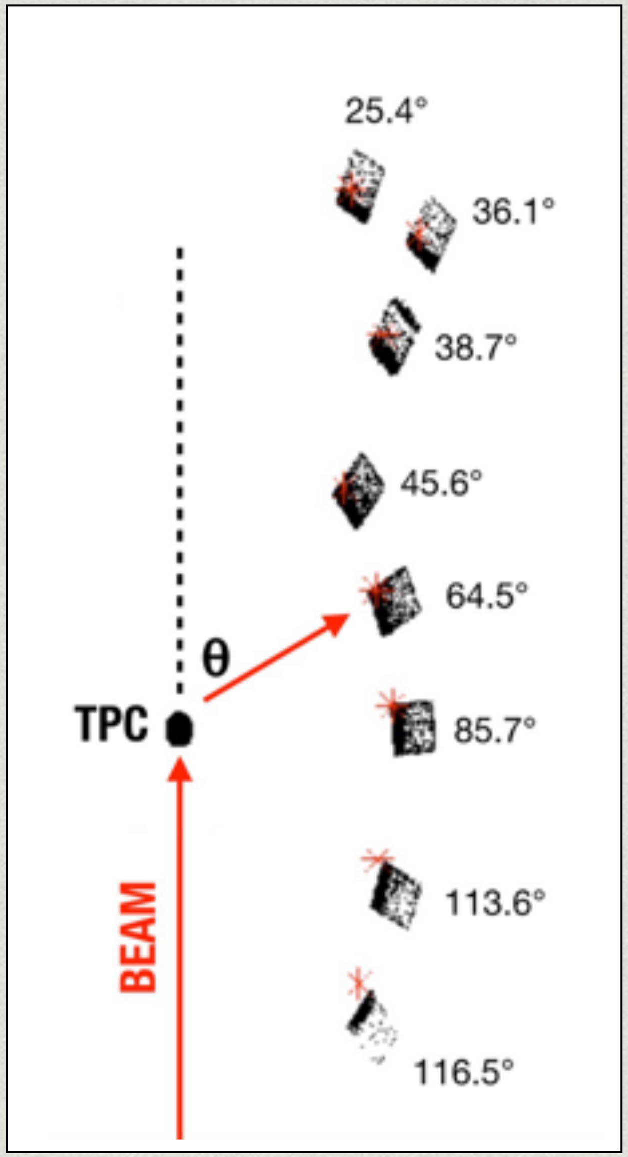
LICORNE Neutron Beam

ARIS Setup

Scintillation chamber:

- Simplify: remove gas pocket to focus on scintillation yield.
- Seven cryogenic 1” PMTs above chamber, one 3” PMT below.
- Active volume: ~0.5 kg of LAr
- Tunable electric field: 0 V/cm→ 500 V/cm



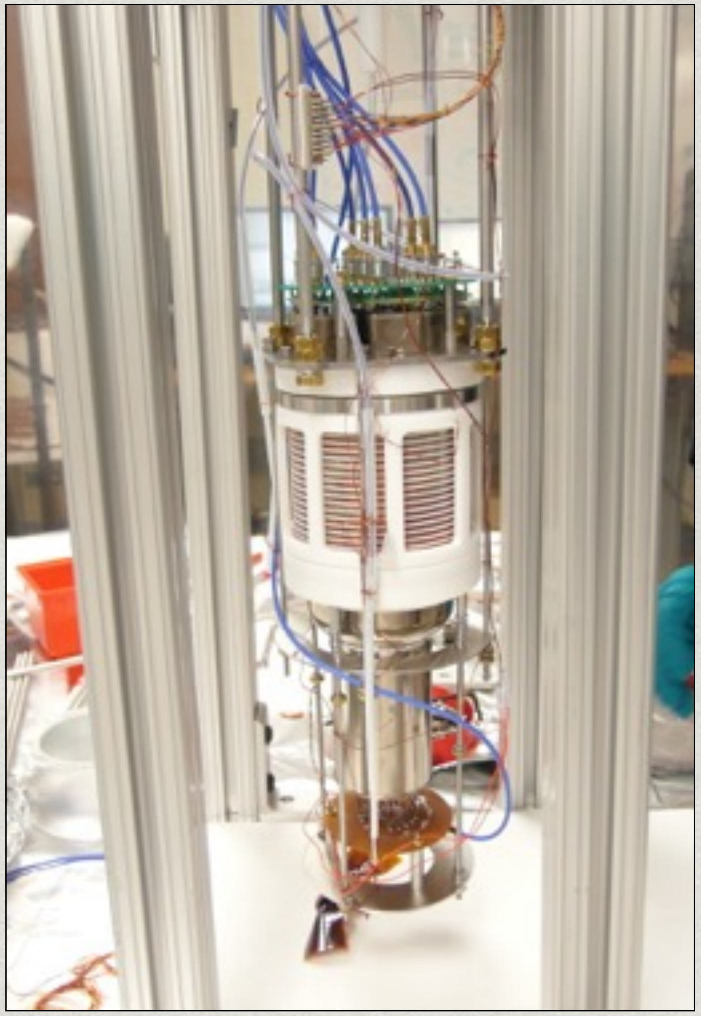


Scattering Geometry:

Look for a scattered neutron in a neutron detector to constrain energy deposited in TPC

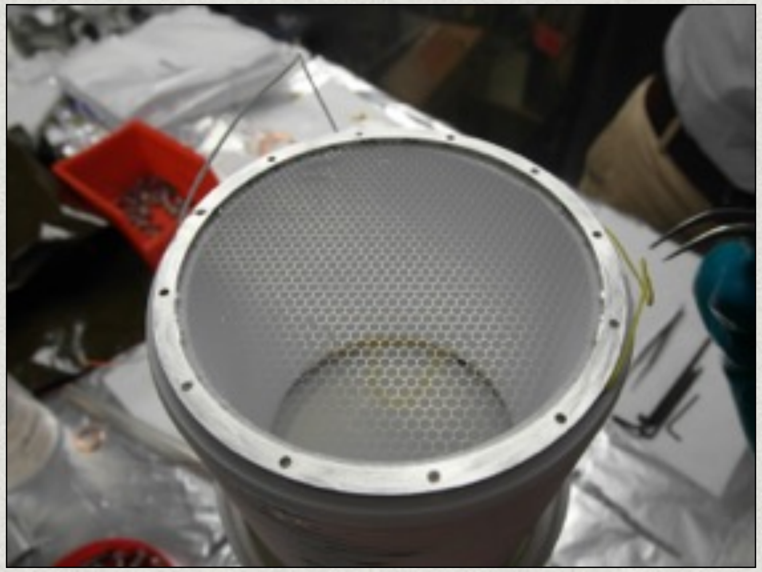
ARIS Hardware

Neutron Detector

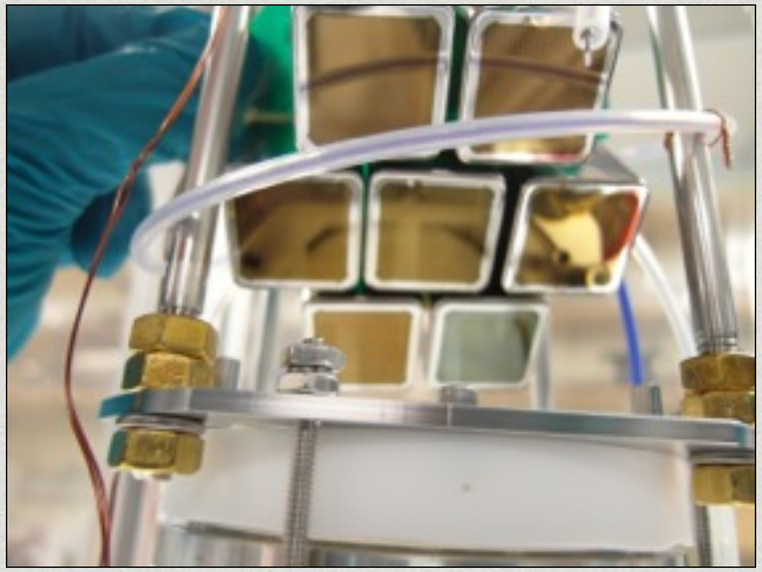


Full TPC

Circulation System



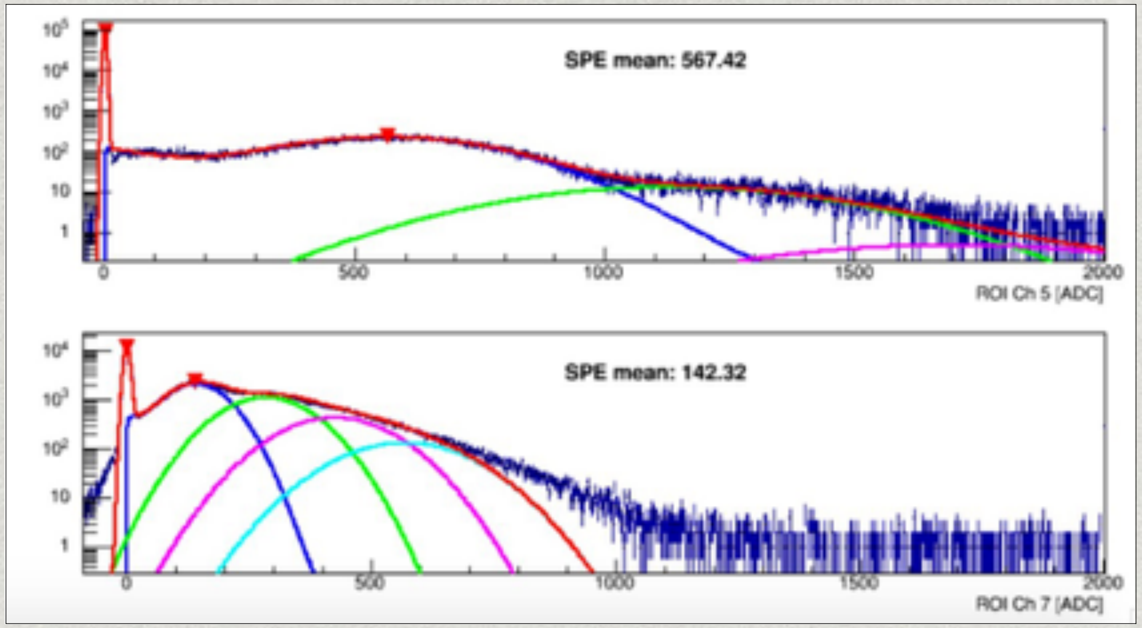
Grid Cathode



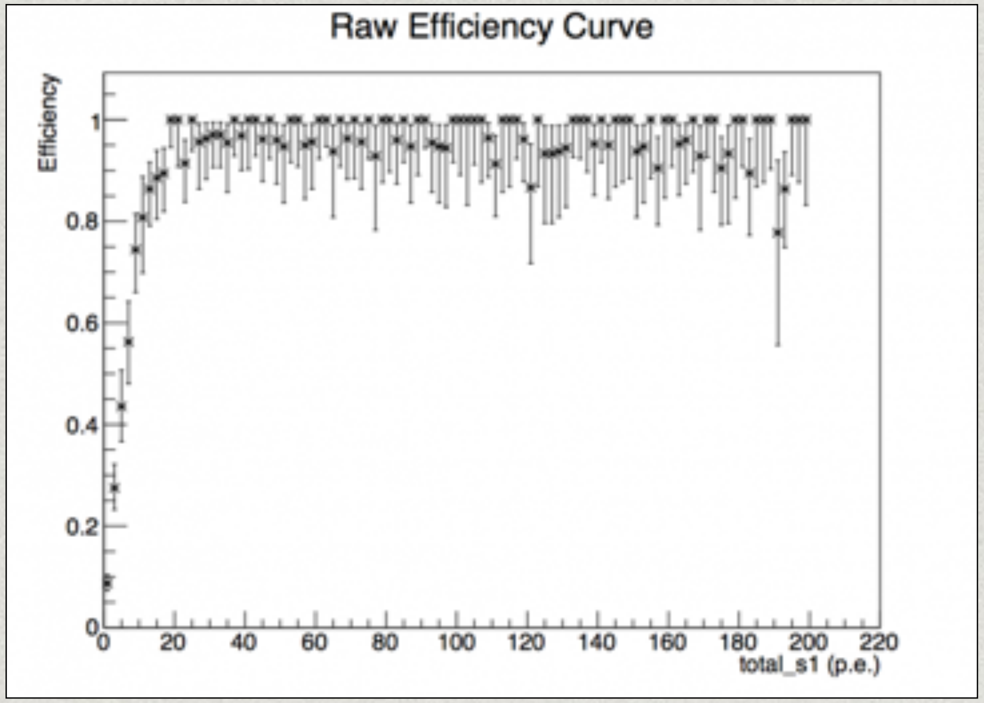
Top 1” PMT Array

ARIS Detector Calibration

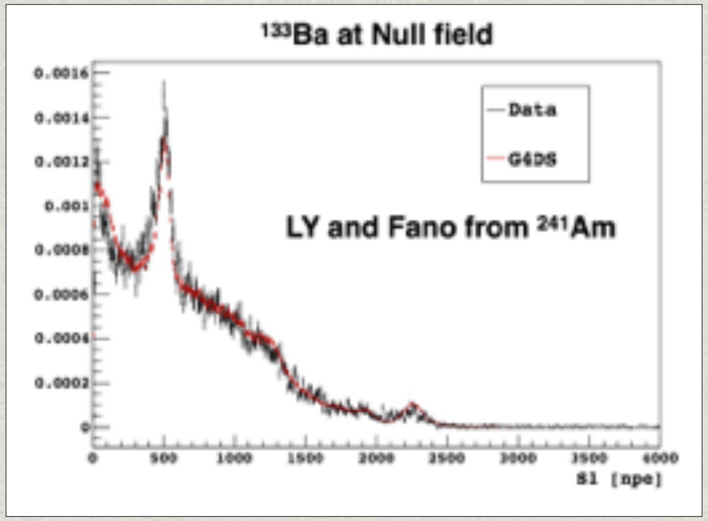
- During data taking, we continuously performed calibrations in order to quantify the detector response.
- Characterize PMT gain, detector light yield, trigger efficiency

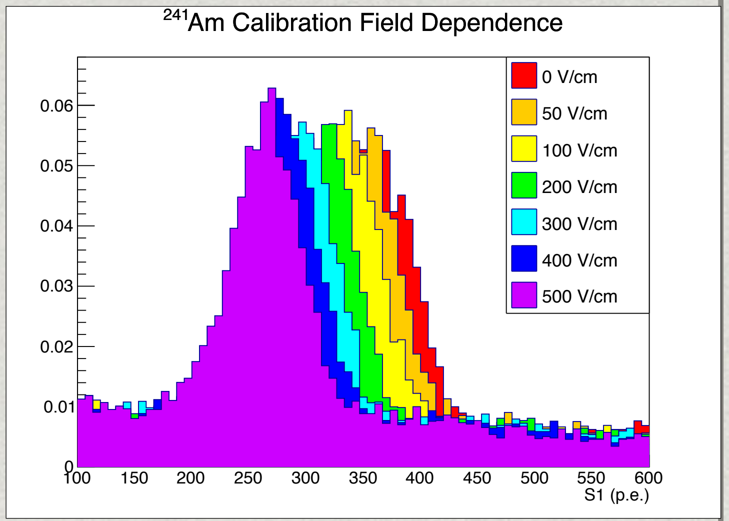


What is the PMT response for a single photoelectron?



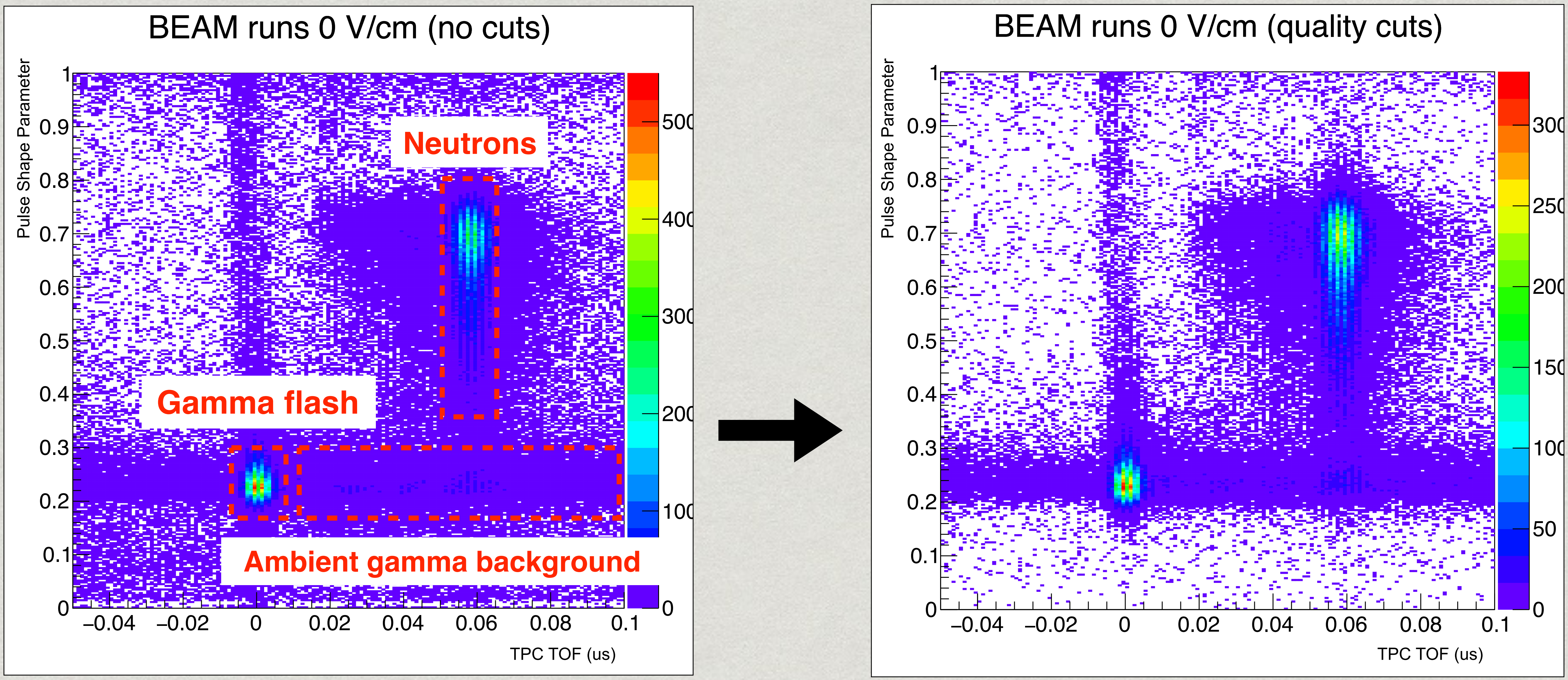
How often does our trigger correctly identify an event in the chamber?





How much light will an event of a certain energy produce?

Data Analysis: Quality Cuts

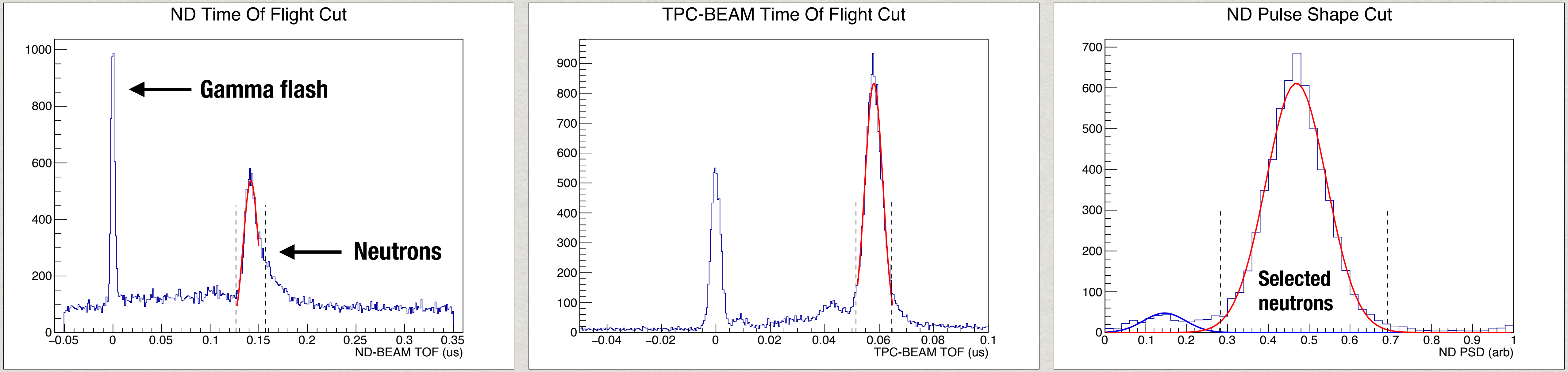


We design some basic quality cuts to remove an event if:

- PMT is saturated
- PMT shows over 80% of the signal
- The rise-time of the scintillation signal is especially long

Neutron Selection

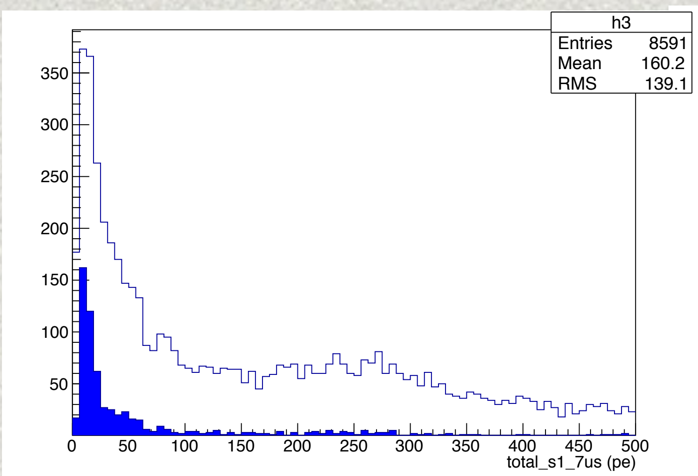
- Next we isolate neutron events by selecting on the particle time-of-flight and neutron detector pulse-shape:
  - Gammas from the neutron beam travel faster than neutrons.
  - Neutrons have a longer pulse-shape than gammas.
- After selection cuts, less than 0.02% of events are estimated to be background events



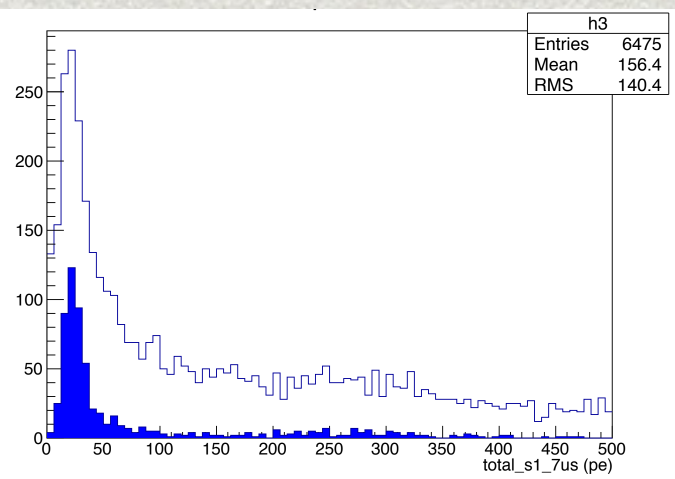
= events passing quality cuts

= events passing quality cuts & neutron cuts

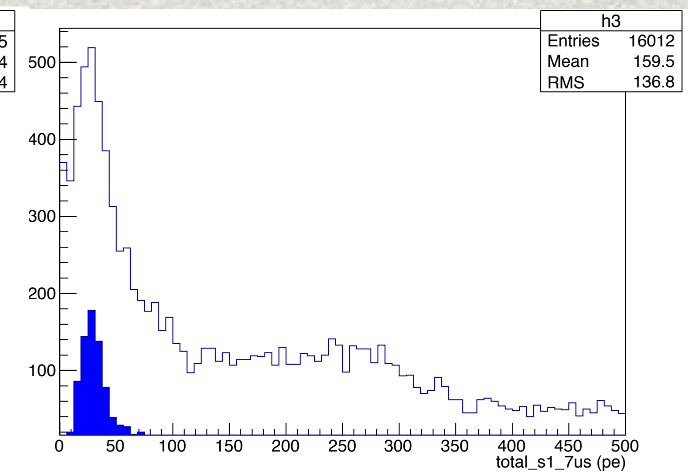
6.69 keV



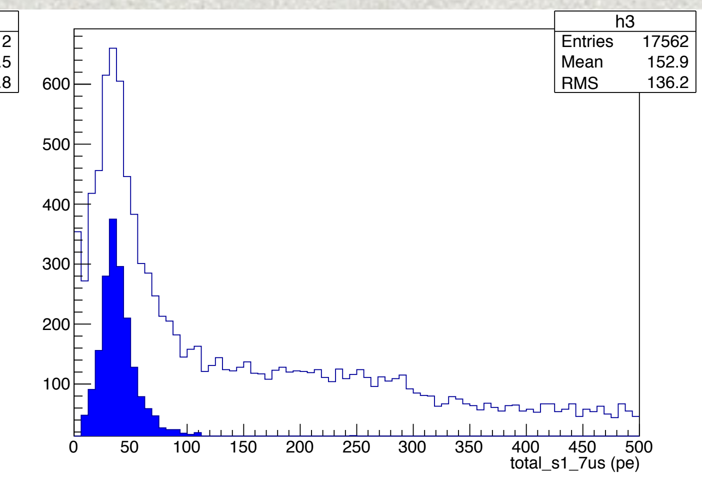
13.27 keV



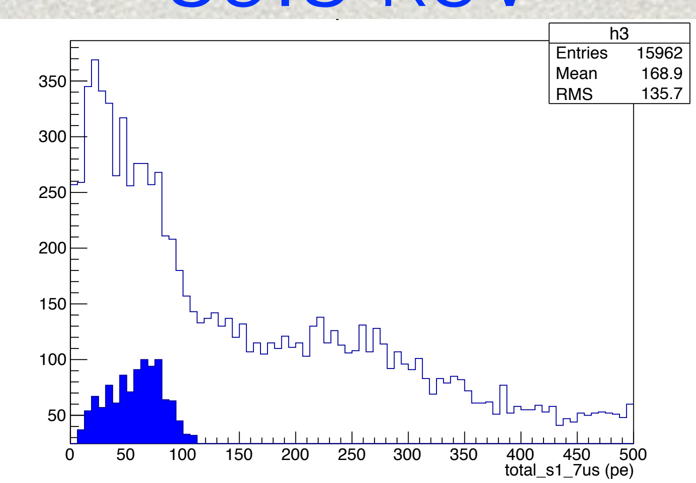
15.22 keV



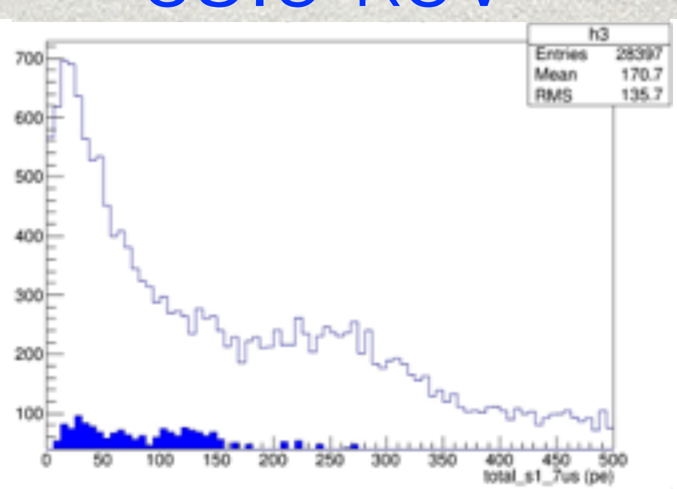
20.7 keV



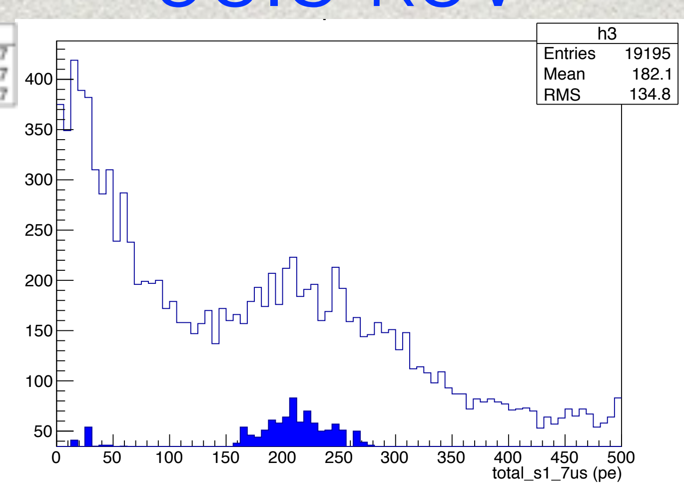
39.3 keV



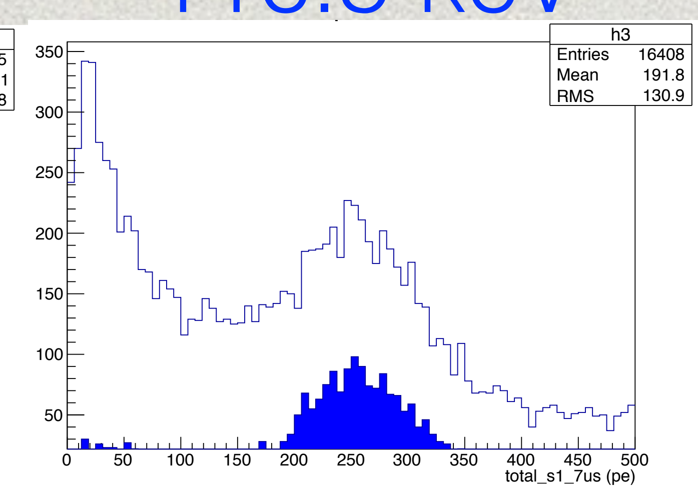
63.9 keV



96.5 keV



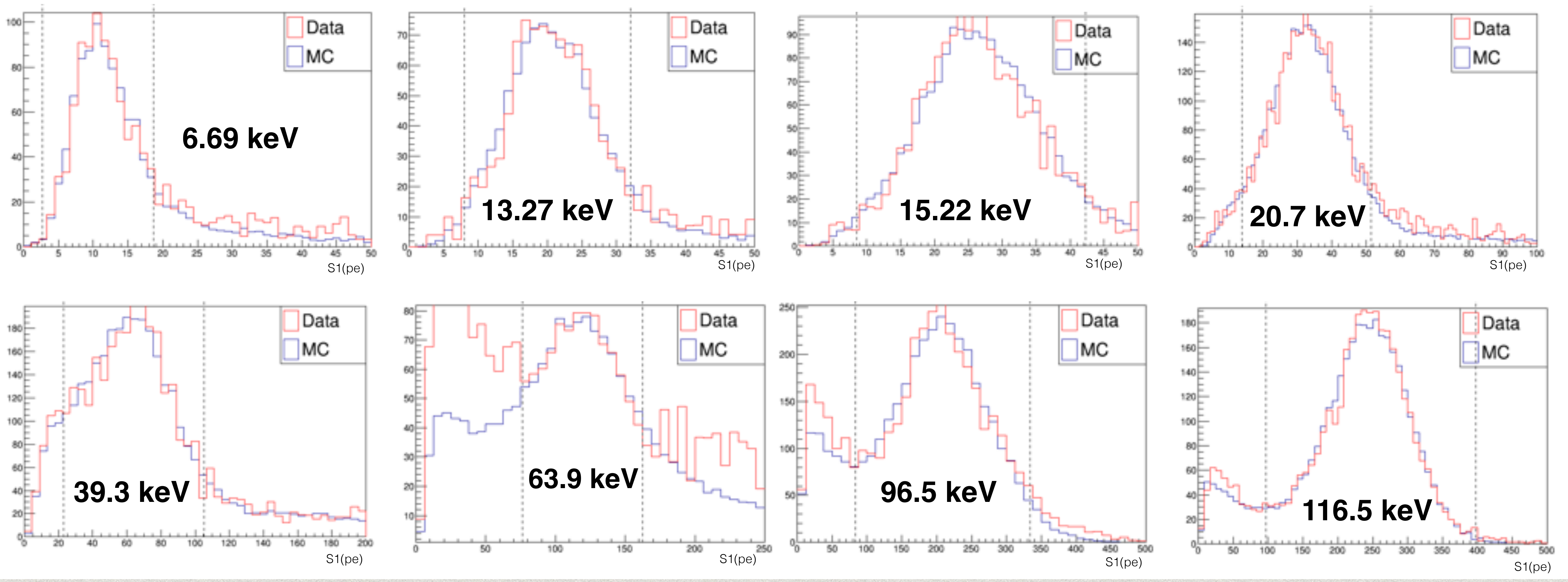
116.5 keV



Matching Monte Carlo To Data

Our light yield (LY) is measured with a source which produces electronic recoils. By varying the L_{eff} parameter and matching the measured neutron data to simulated MC events, we can make a measurement of the relative scintillation of NR events compared to ER events.

$$S1[\mathrm{pe}] = \mathrm{Energy}[\mathrm{keV_{nr}}] \times \mathrm{LY}[\frac{\mathrm{pe}}{\mathrm{keV_{ee}}}] \times L_{\mathrm{eff}}[\frac{\mathrm{keV_{ee}}}{\mathrm{keV_{nr}}}]$$



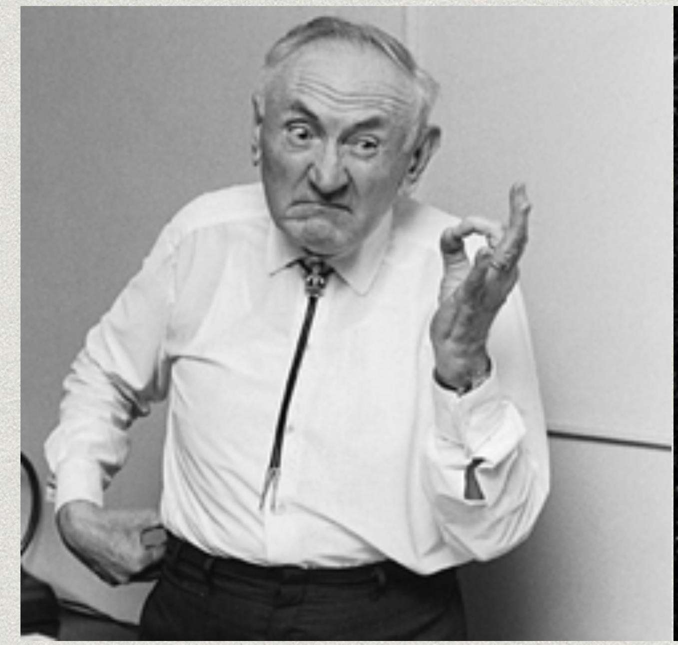
Conclusion

- The ARIS experiment successfully gathered neutron beam data in a scintillation chamber over 8 nuclear recoil energies and 5 electric drift fields.
- The collaboration has designed cuts to isolate neutron events which we will use to make measurements of nuclear recoils.
- Monte Carlo and data agreement now show we have an accurate understanding of our detector resolution, experiment geometry, and neutron energy spectra.

BACKUP

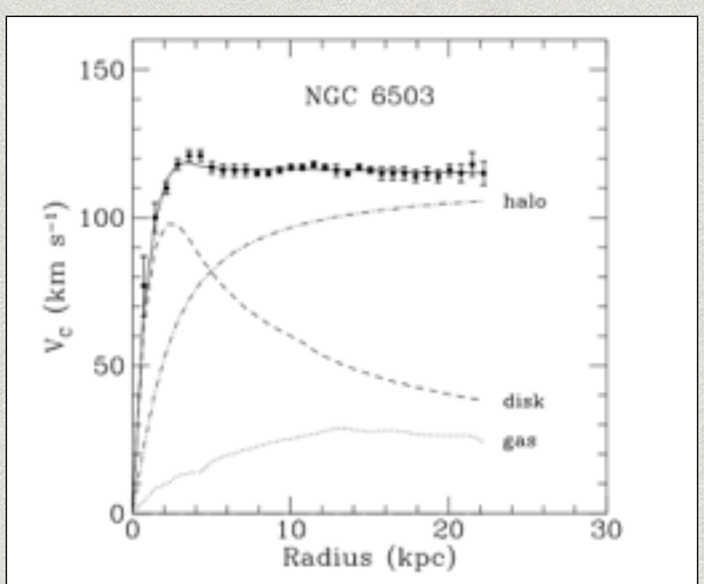
The Dark Matter Hypothesis

There is substantial evidence for a new form of matter which accounts for about 80% of the mass density of the universe.

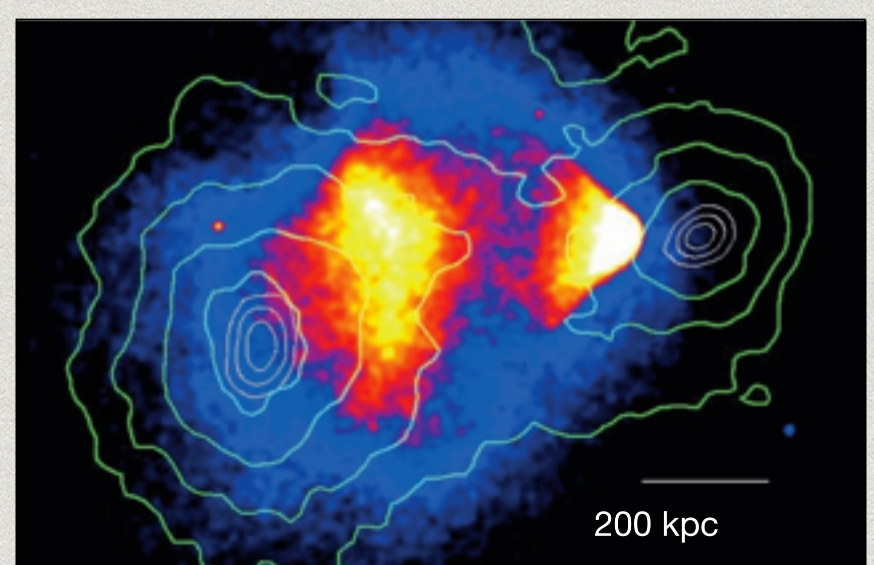


THE COMA CLUSTER

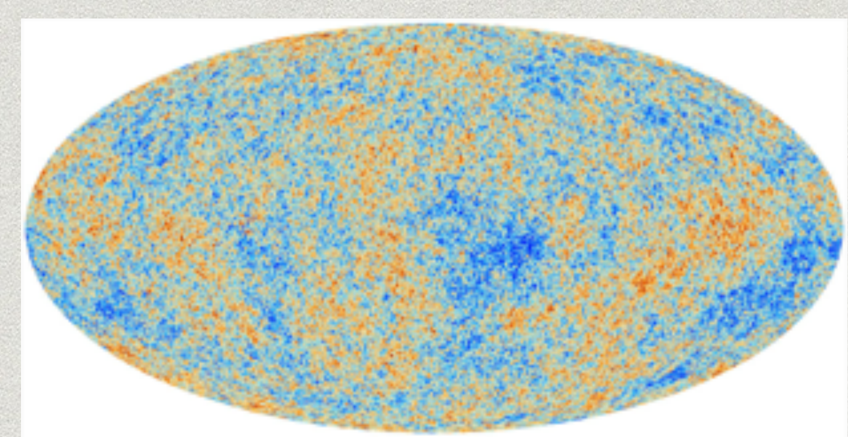
GALACTIC ROTATION CURVES



THE BULLET CLUSTER

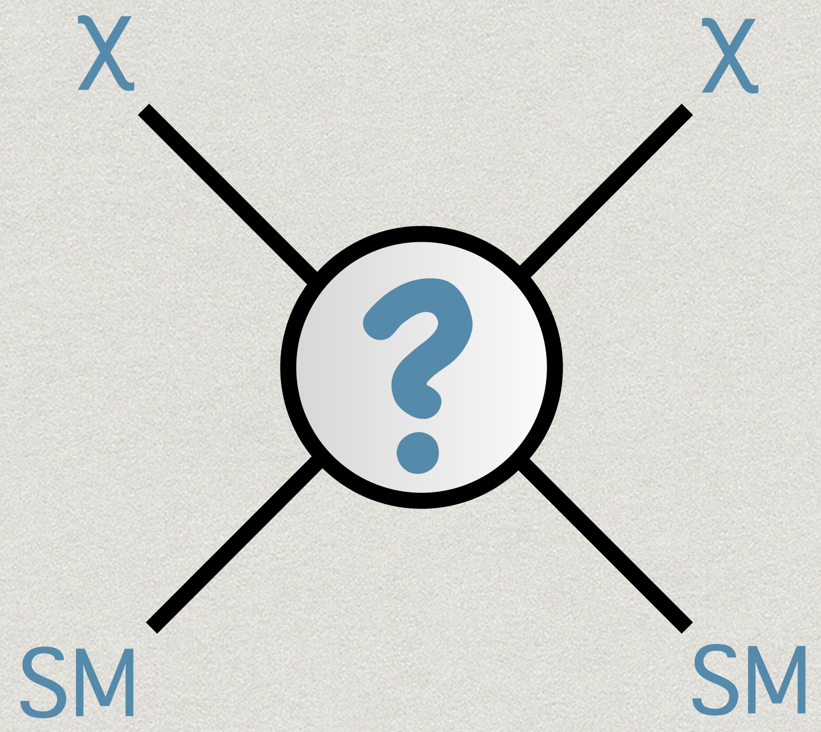


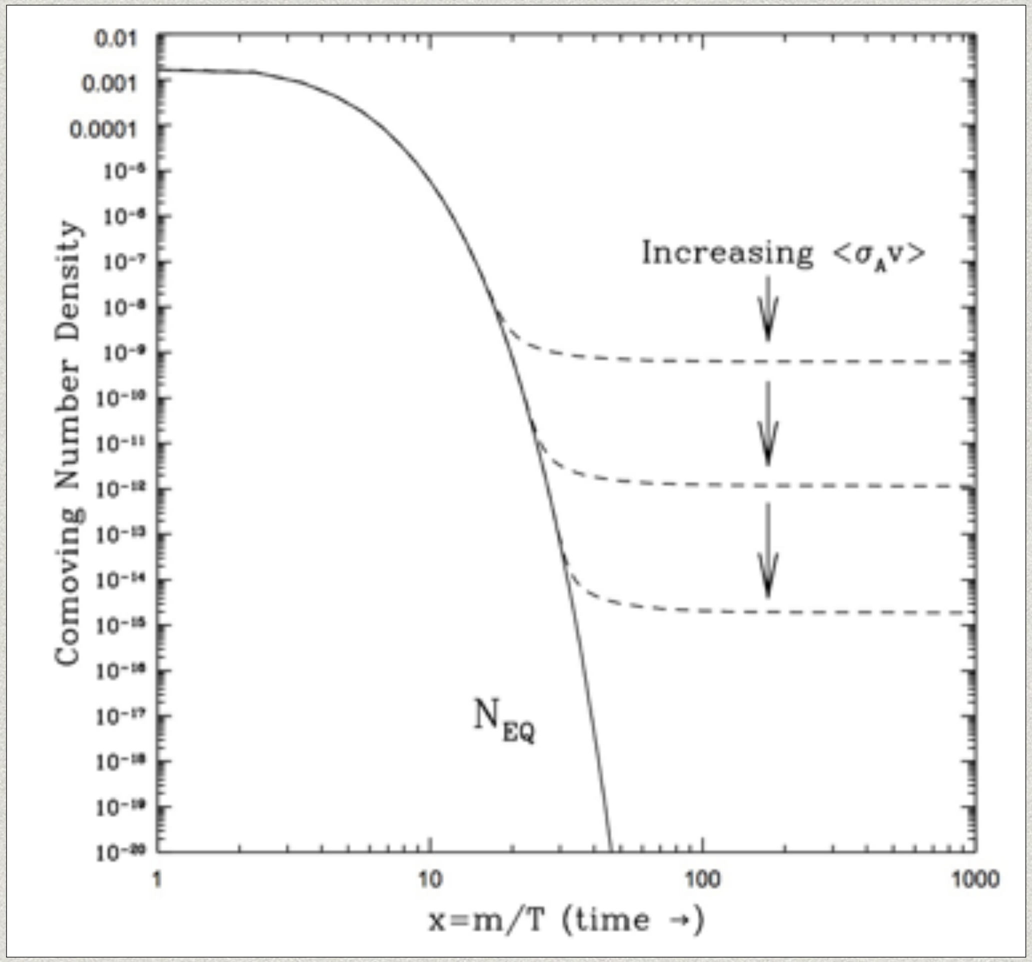
COSMIC MICROWAVE BACKGROUND



Detecting Dark Matter

- How can we look for dark matter? One option is "direct detection."

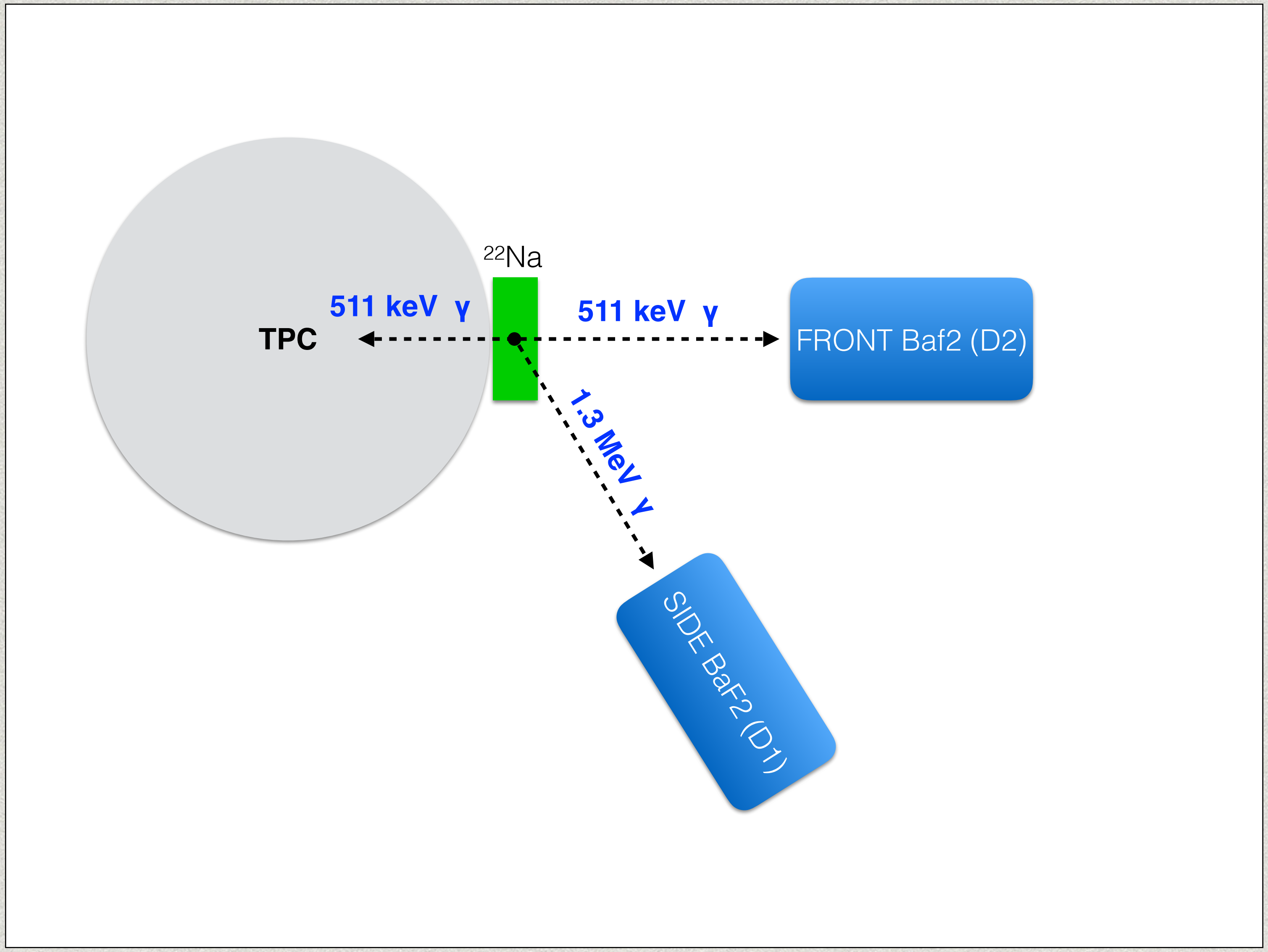




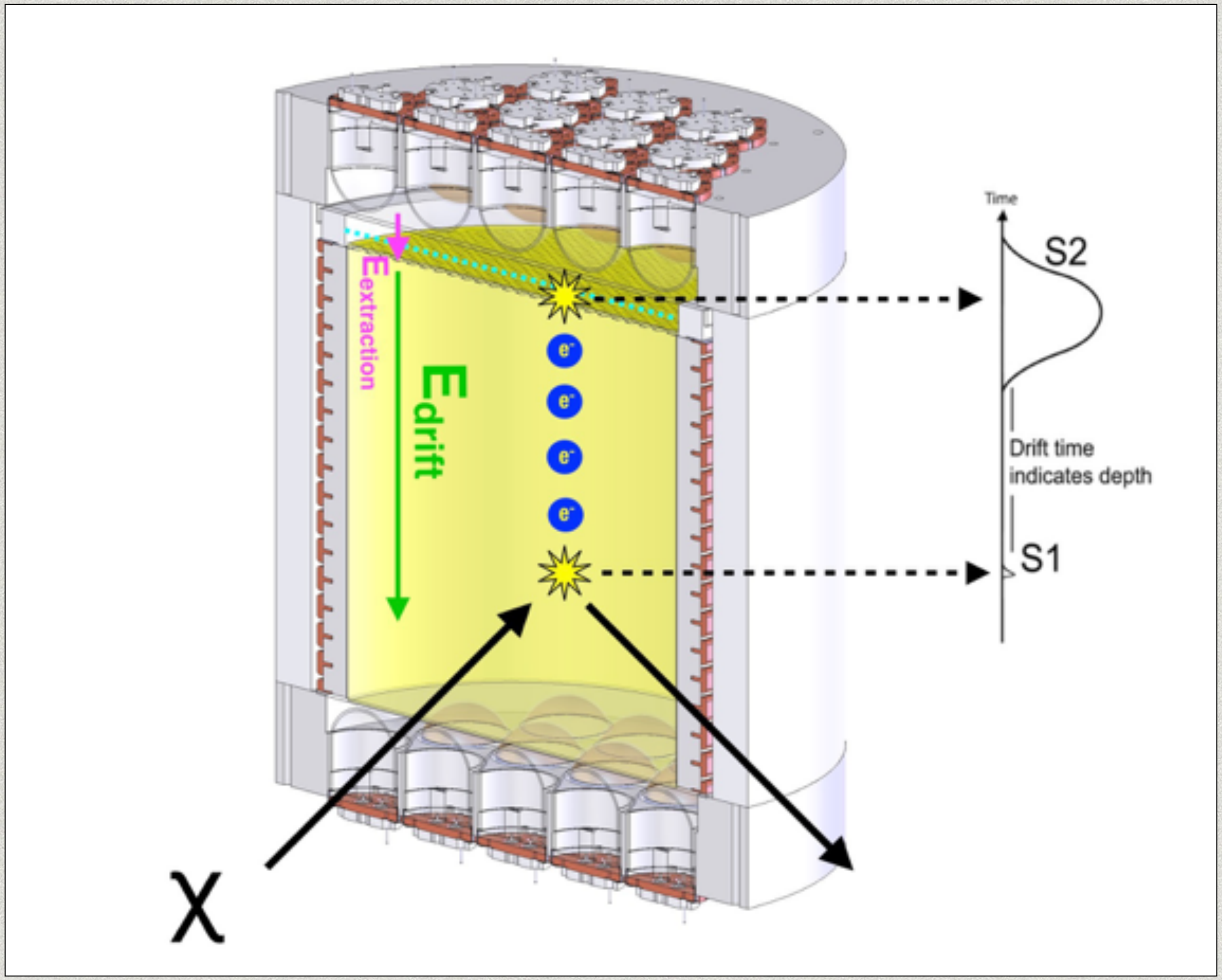
- The Weakly Interacting Massive Particle (WIMP) is an attractive dark matter candidate.

Calibration: Trigger Efficiency

- If there is an event in the detector, how often does our trigger see it?
- Design an experiment where we guarantee a 511 keV gamma ray is in the TPC, and see if the trigger fires.
- Need to correct for this energy-dependent effect in Monte Carlo comparison to data.



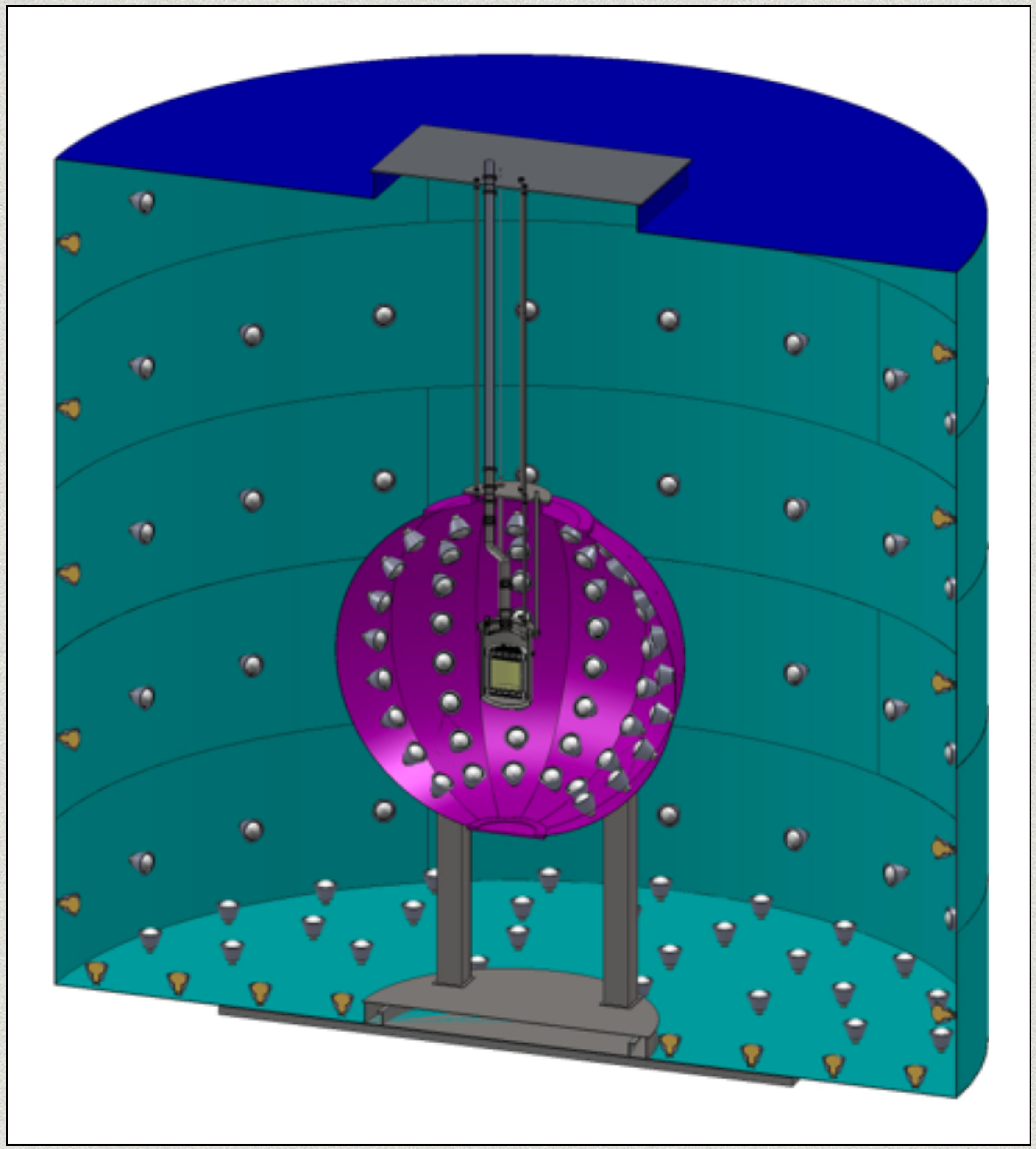
The DarkSide-50 Detector



DARKSIDE COLLABORATION

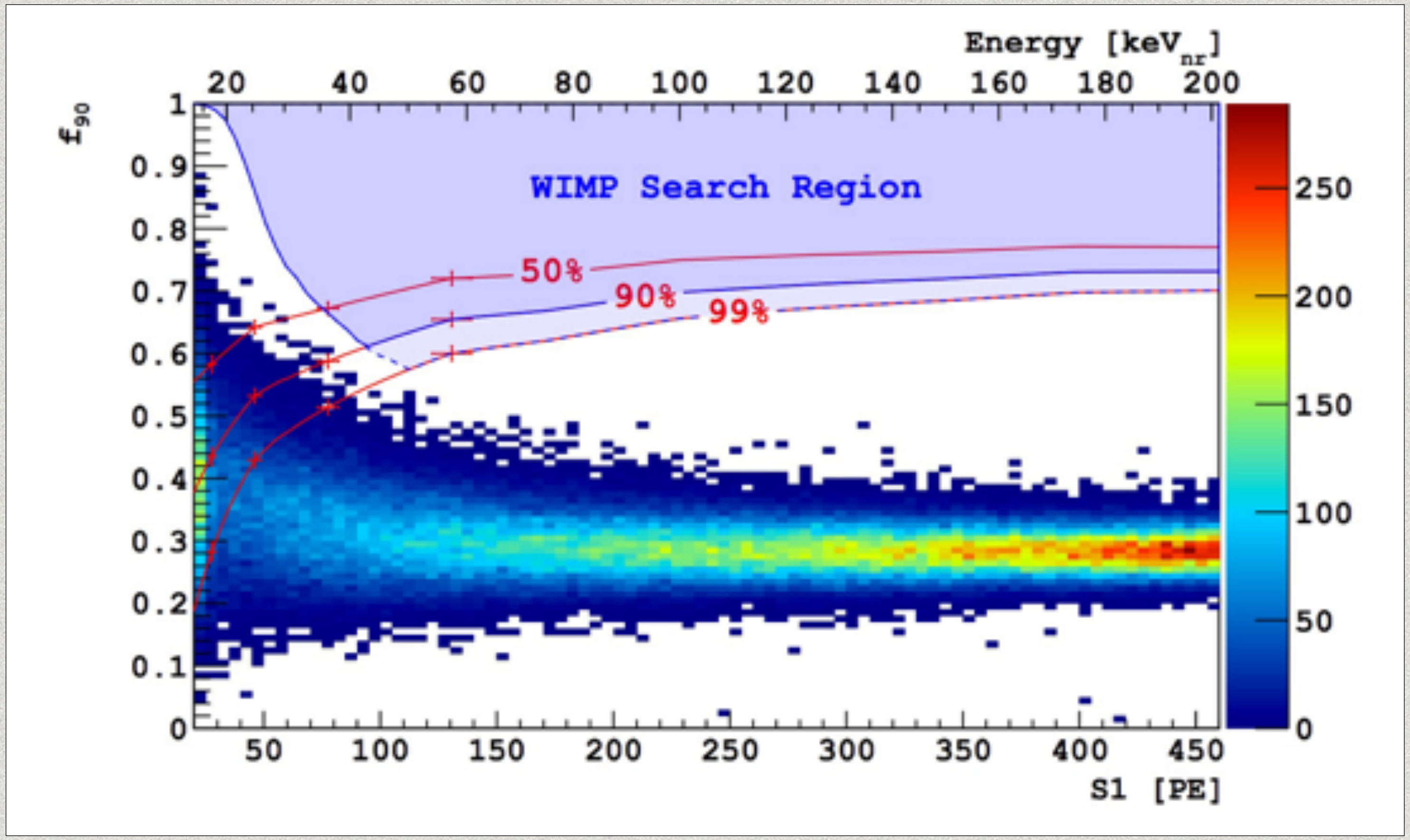
DS-50 Full System

- Water Cherenkov veto
- LSV muon veto
- Inner TPC



DS-50 Data and WIMP Search Region

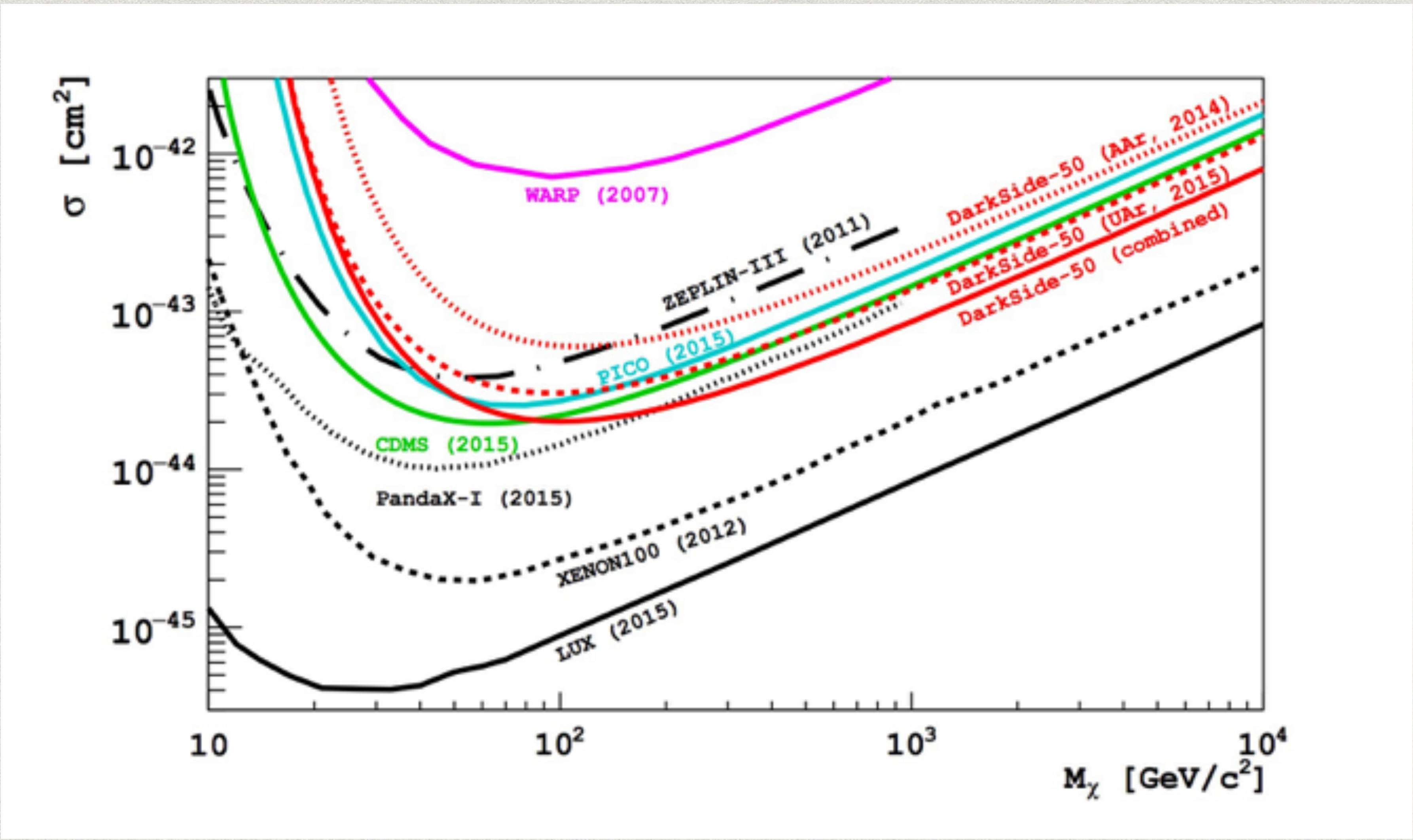
- Create a WIMP search region using neutron experiments
- Once data taking is complete, plot in energy (S1) vs pulse shape (f90) space. Look for events in the WIMP search box.
- Detector is calibrated to ER energy scale, so we need to convert signal to NR energy scale:



RESULTS FROM THE DARKSIDE-50 DARK MATTER EXPERIMENT

$$\mathrm{S1[pe]} = \mathrm{Energy[keV_{nr}]} \times \mathrm{LY}[\frac{\mathrm{pe}}{\mathrm{keV_{ee}}}] \times \mathrm{L_{eff}}[\frac{\mathrm{keV_{ee}}}{\mathrm{keV_{nr}}}]$$

Setting An Interaction Limit



Data from the most recent DS-50 analysis and the cross section limit compared to some other dark matter search experiments.