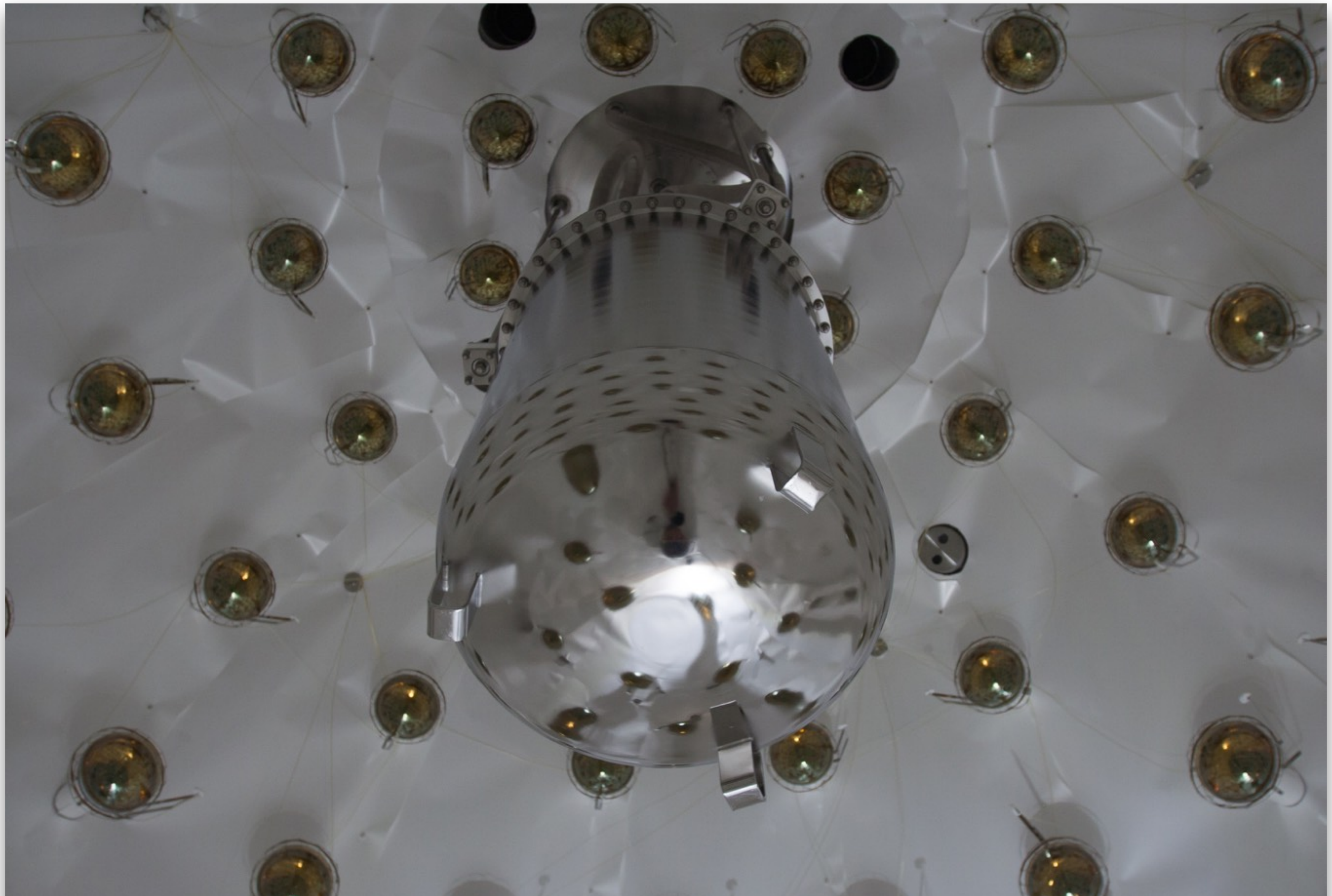
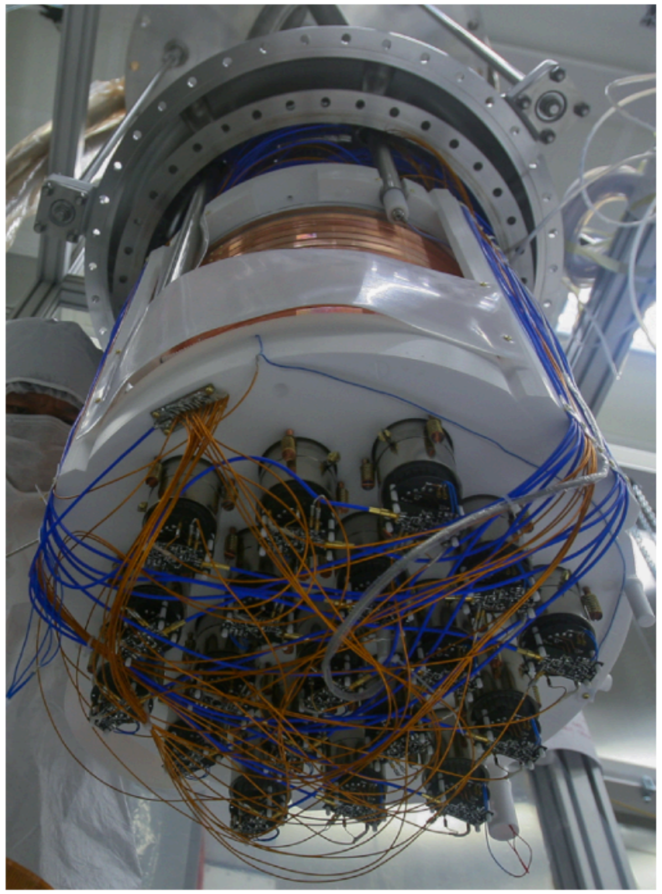
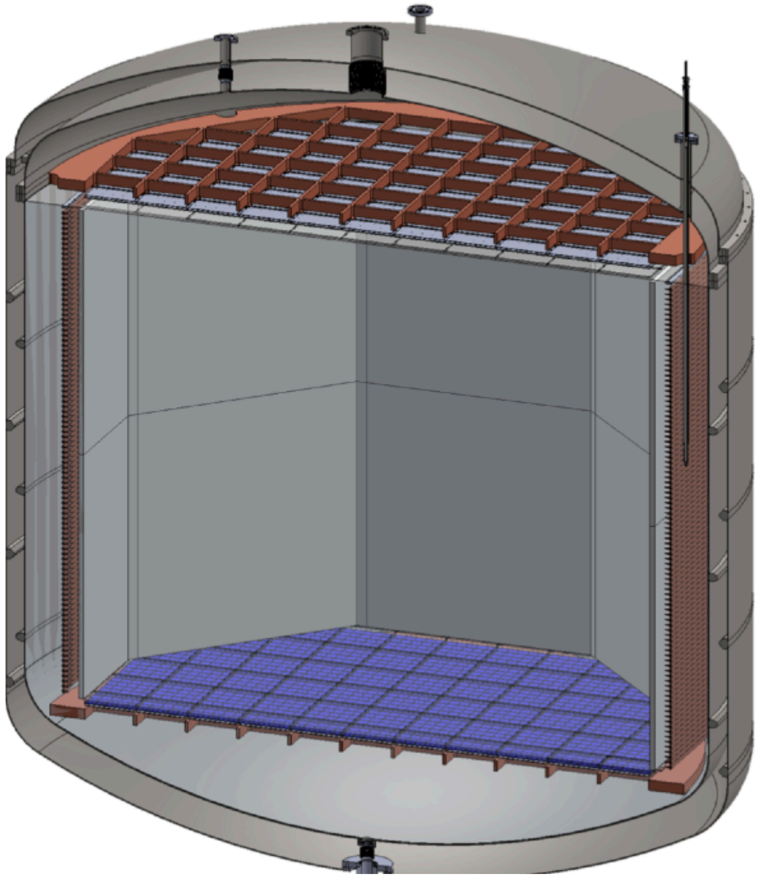
DarkSide: Status and Prospects



Xin Xiang
Princeton University
On behalf of DarkSide Collaboration
Sept 3rd, 2017

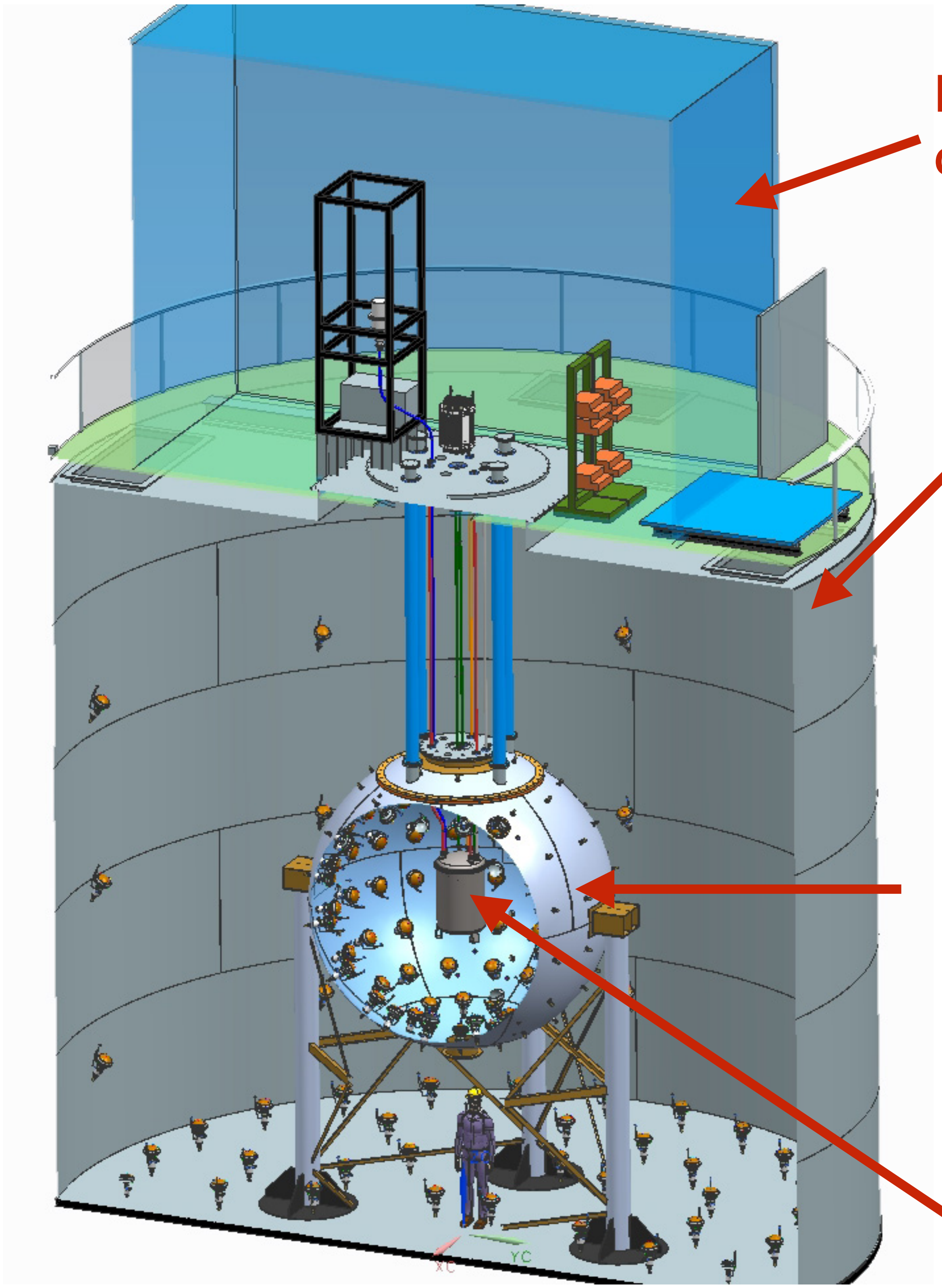
The DarkSide Program

Past	Present	Future
		
DarkSide-10	DarkSide-50	DarkSide-20k

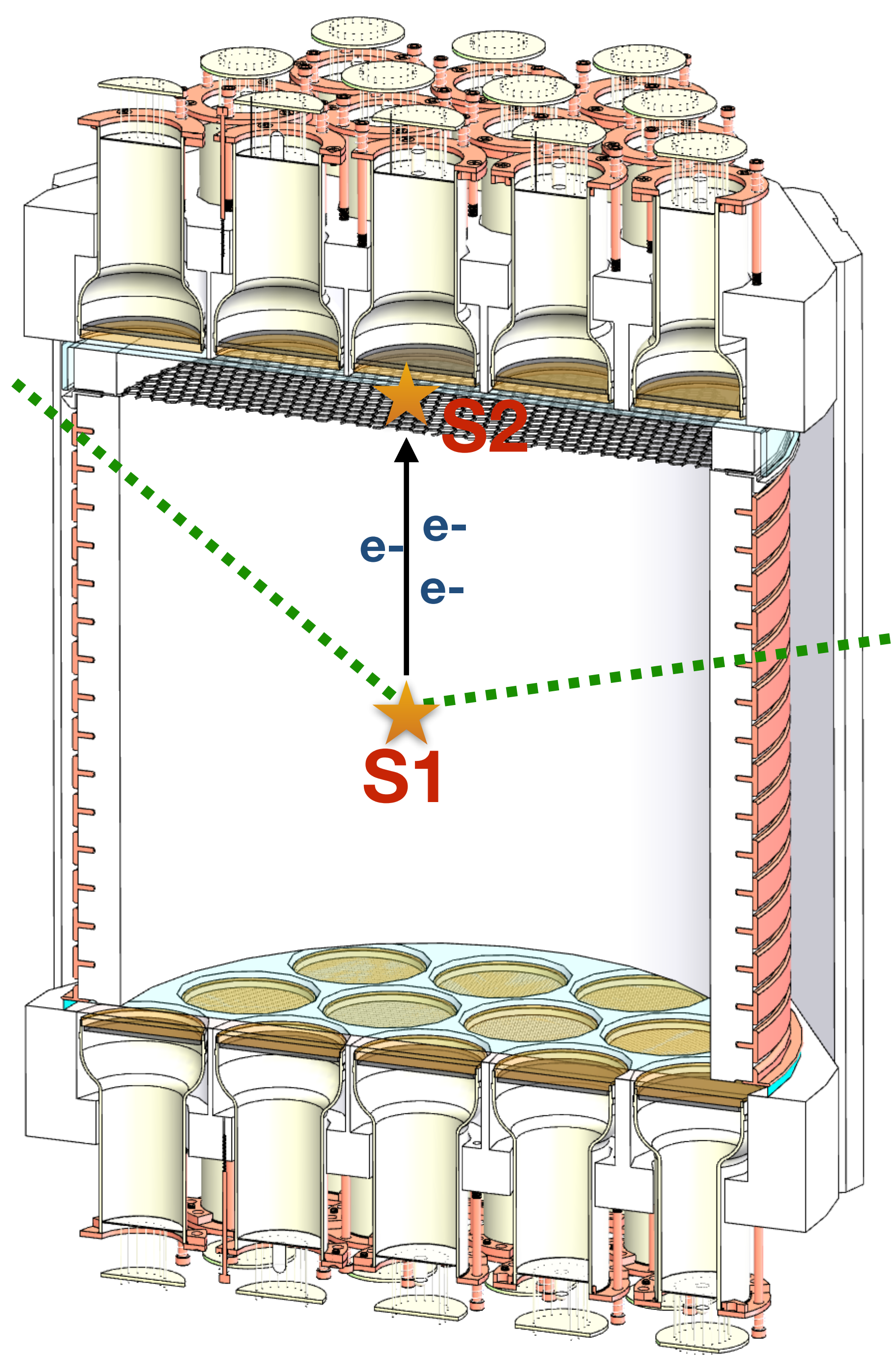
- WIMP direct detection at LNGS
- Dual-phase argon TPC as the WIMP detector at center
- Background free operation with active background suppression

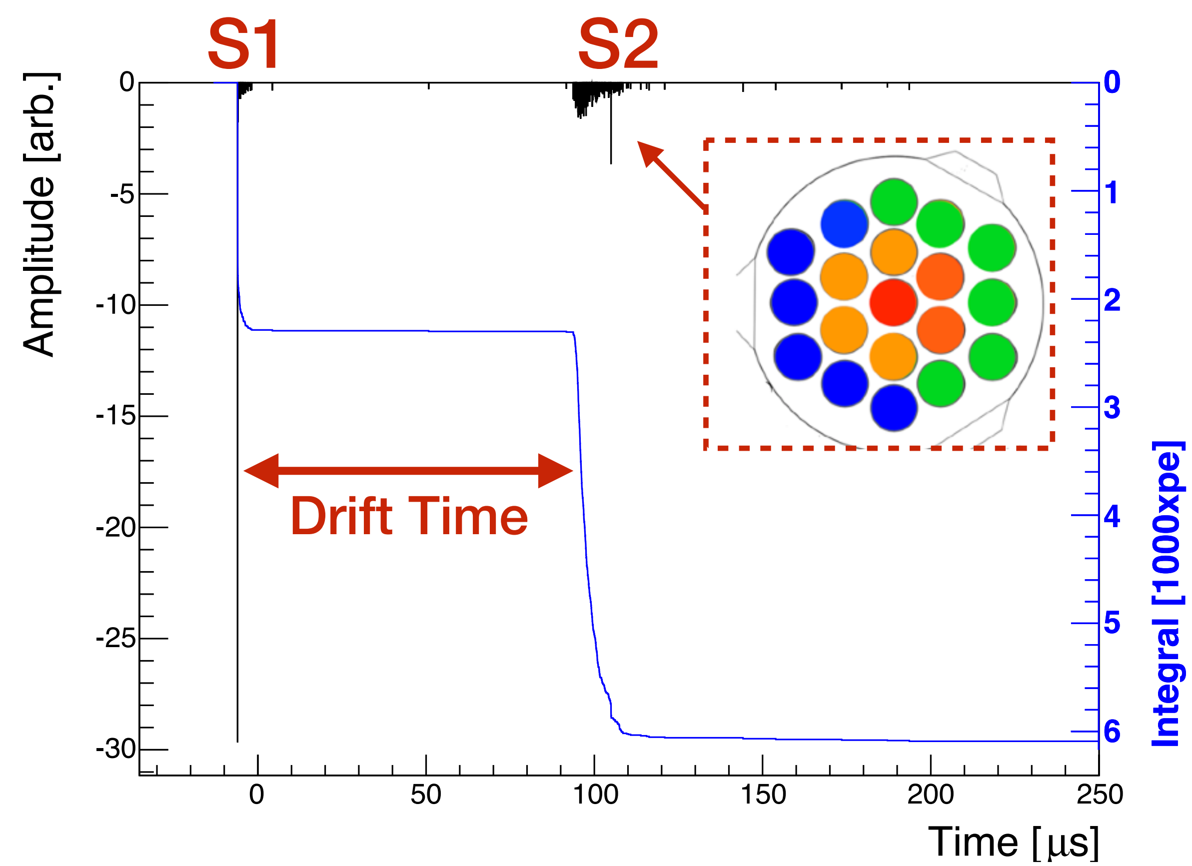
DarkSide-50 Overview

- Current detector has ~50 kg active mass.
- TPC was previously loaded with atmospheric argon, now loaded with low radioactive underground argon
- Neutron veto (4 m diameter) is filled with boron-loaded liquid scintillator (95% PC+ 5% TMB)
- Active neutron veto with veto efficiency above 99.5% (see H. Qian's talk)
- Designed to be background-free with various active techniques to reject backgrounds



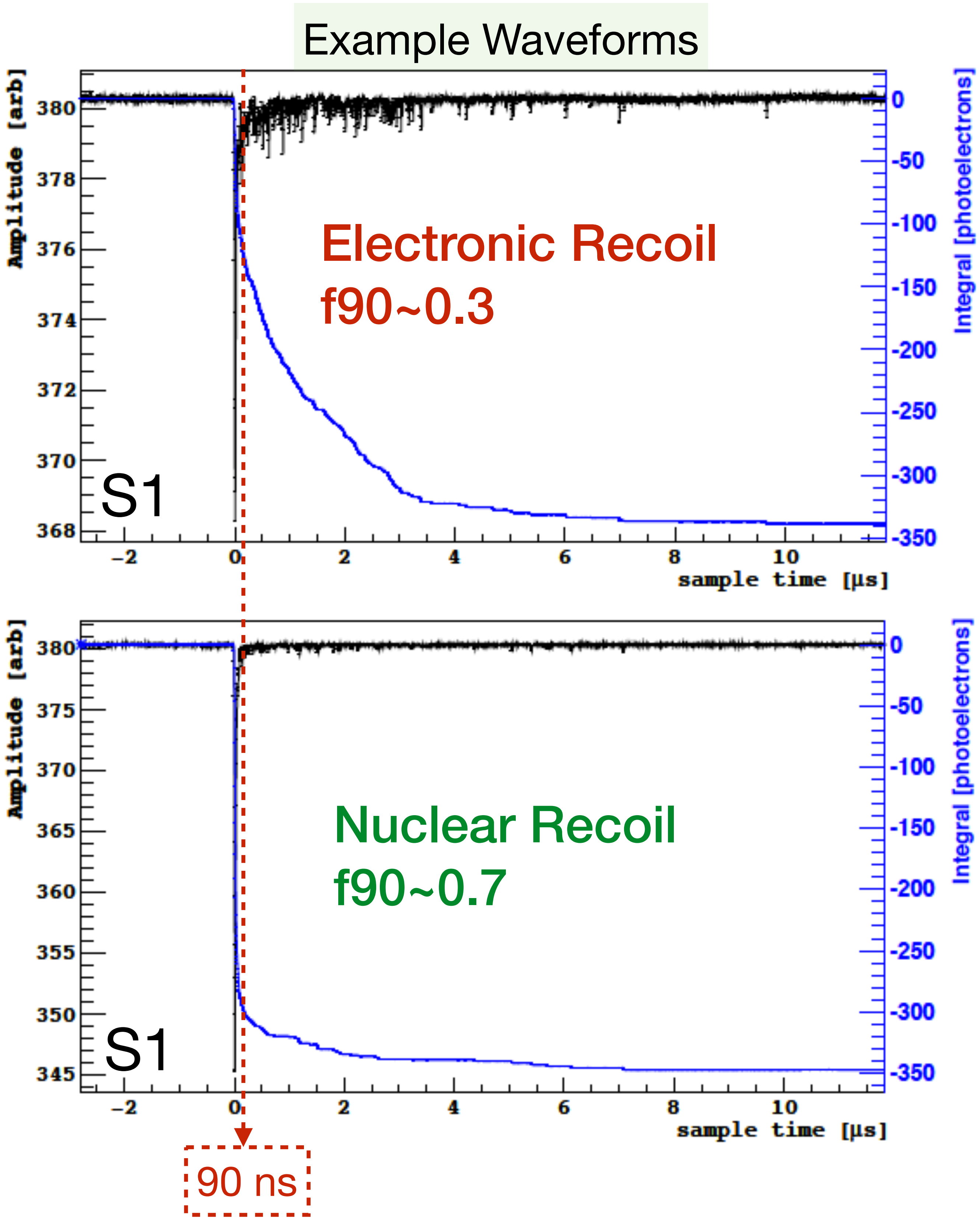
Dual-phase TPC

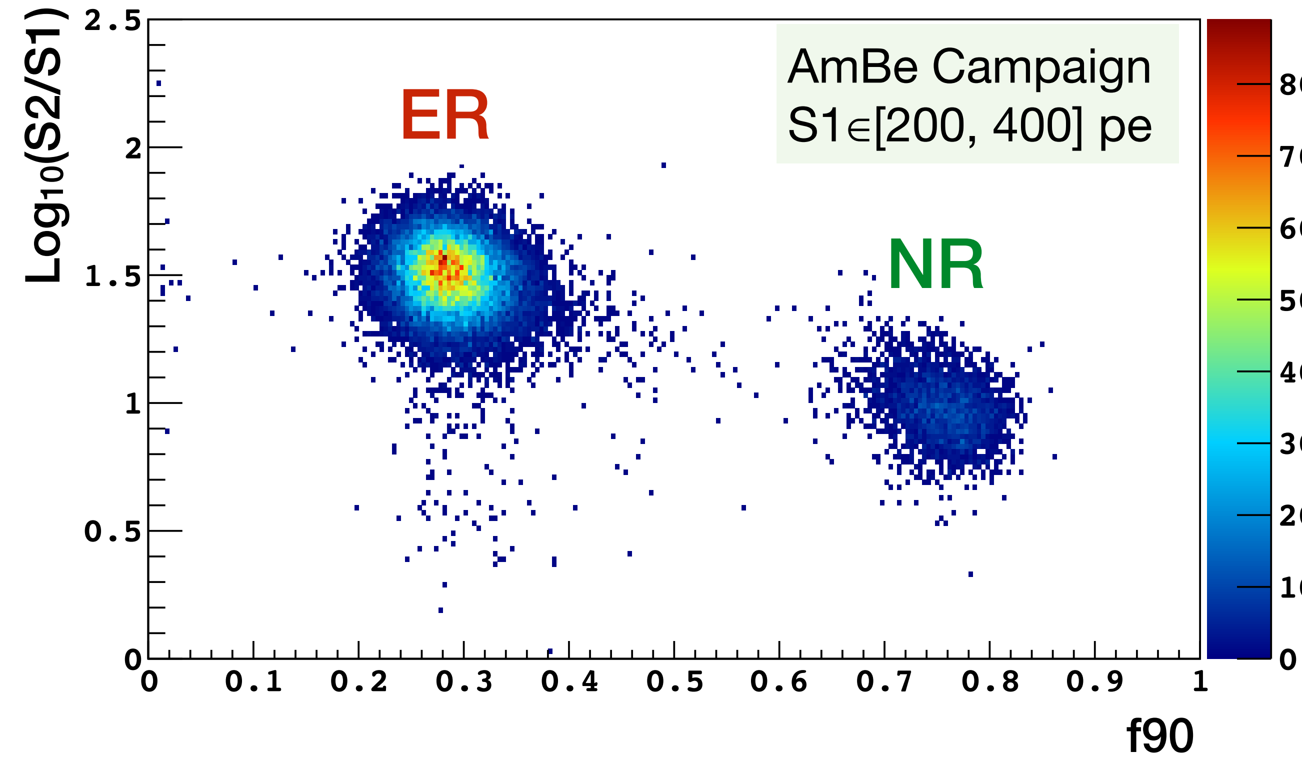




- Light collected by top and bottom PMT arrays
- S1 := Primary scintillation in liquid Ar
- S2 := Secondary scintillation in Ar gas pocket
- S1 & S2 –> full energy deposition
- Drift time –> vertical (z) position
- S2 Channel light pattern –> transverse position (xy)

Why Argon?





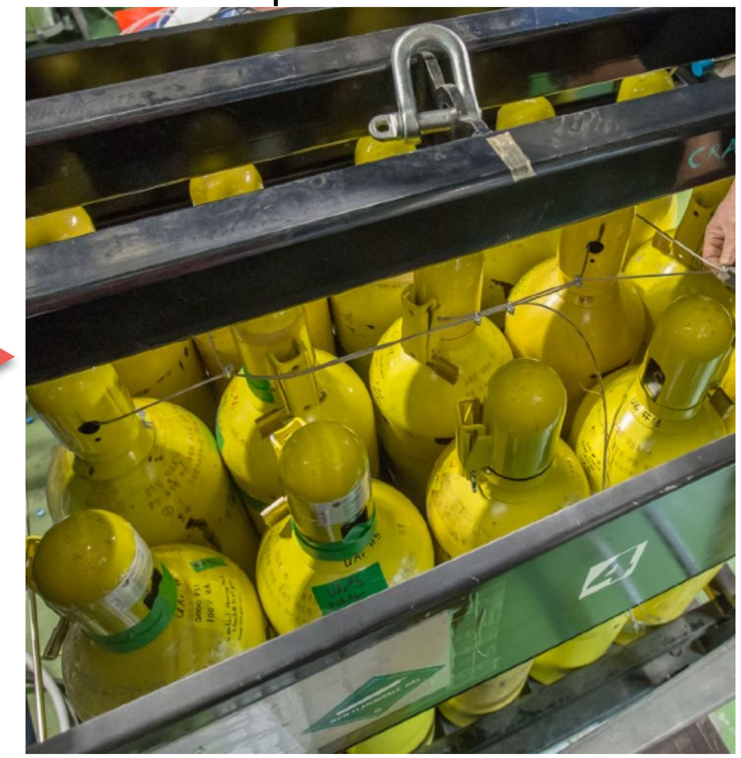
- Discrimination: Ionization to Scintillation ratio (S2/S1), **Pulse Shape Discrimination (PSD)**
- Ar scintillation decays with 2 states, $\tau_{singlet}$ ~7 ns and $\tau_{triplet}$ ~1600 ns. NR produces more $\tau_{singlet}$ and less $\tau_{triplet}$ states than ER.
- **f_{90} := the fraction of S1 light in the first 90 ns.**
- f90 rejection ~10^7 for single scatter ER
- Challenge: intrinsic ^{39}Ar β-decay ($T_{1/2}$: 269 yr, Q: 565 keV). ~1 Bq/kg in atmospheric argon.
- **Solution: extract low radioactivity argon from underground source!**

The Underground Argon

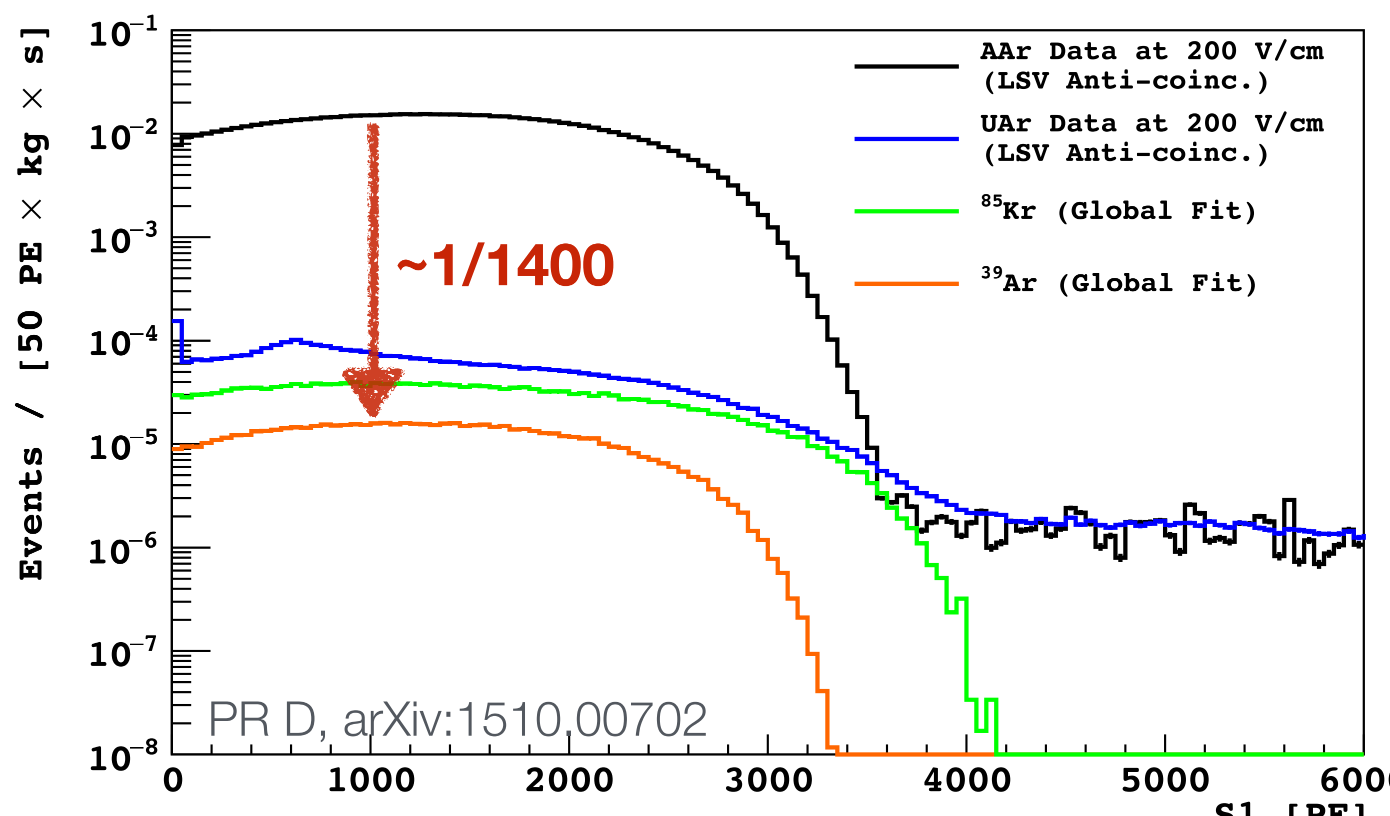
Extraction in Colorado

Distillation at Fermilab

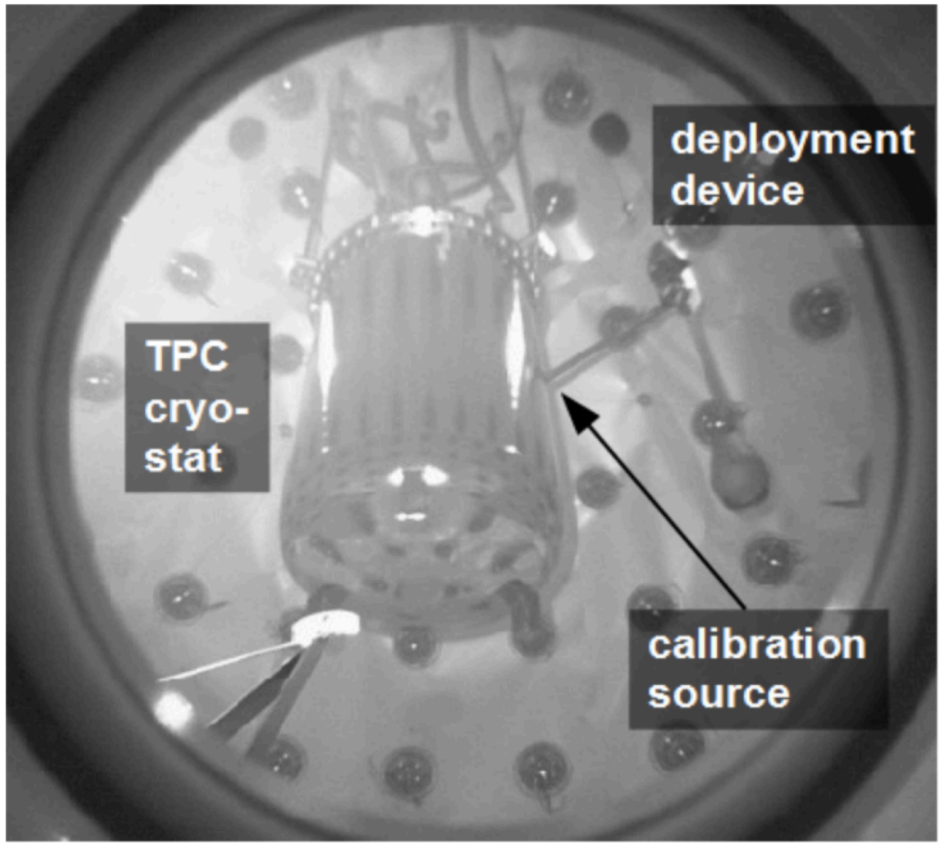
Transport to LNGS

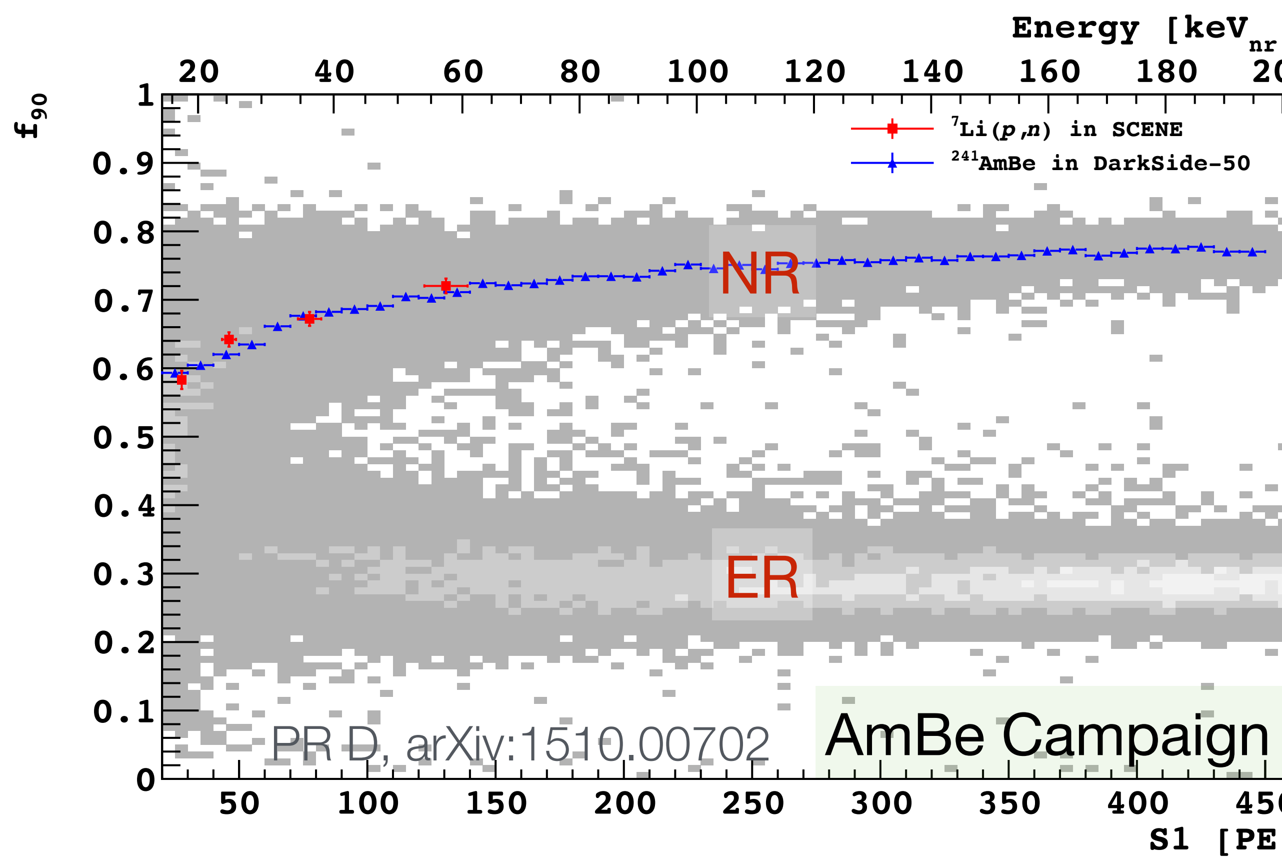


- Extract crude Ar and He gas from a CO_2 well in Colorado, purified at FermiLab.
- 155 kg produced, 6 years of effort
- β-decays is reduced by ~1/300
- The estimated ^{39}Ar depletion factor is ~1400 (PR D, arXiv: 1510.00702)

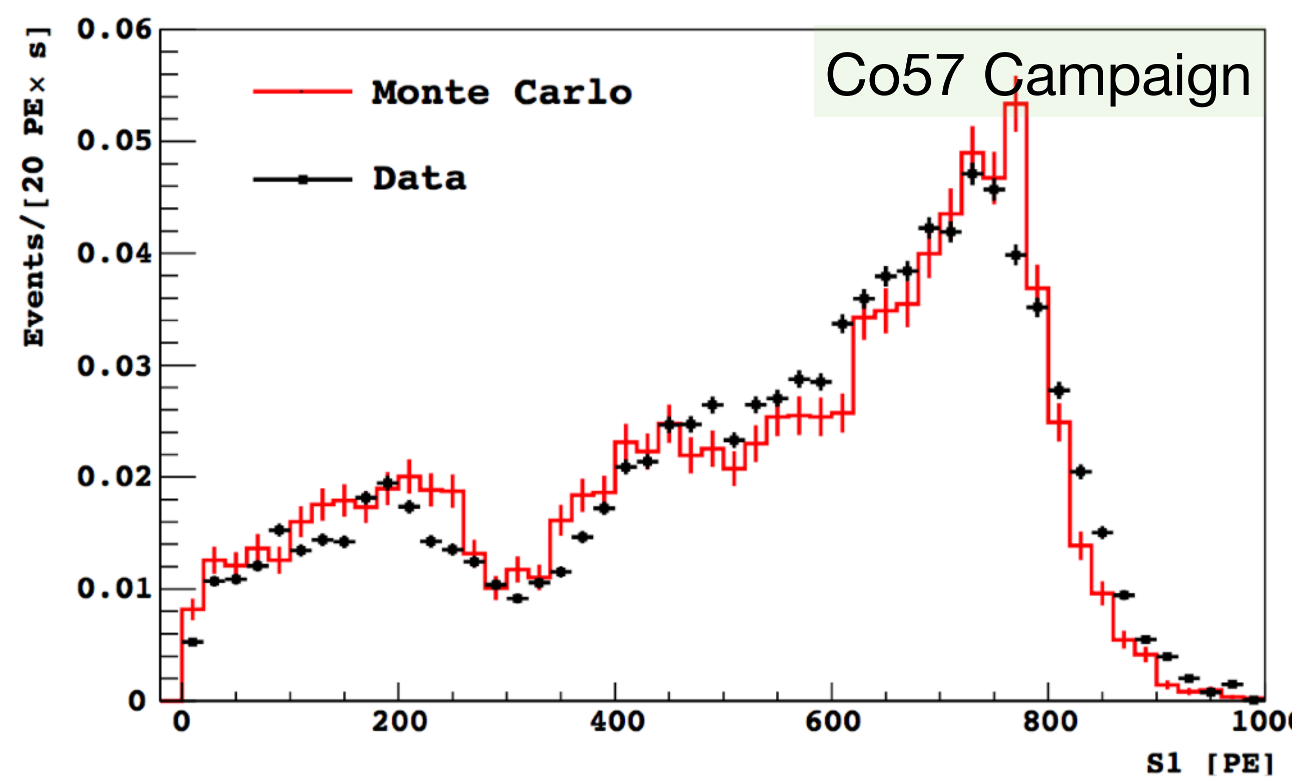


In-situ External Calibrations

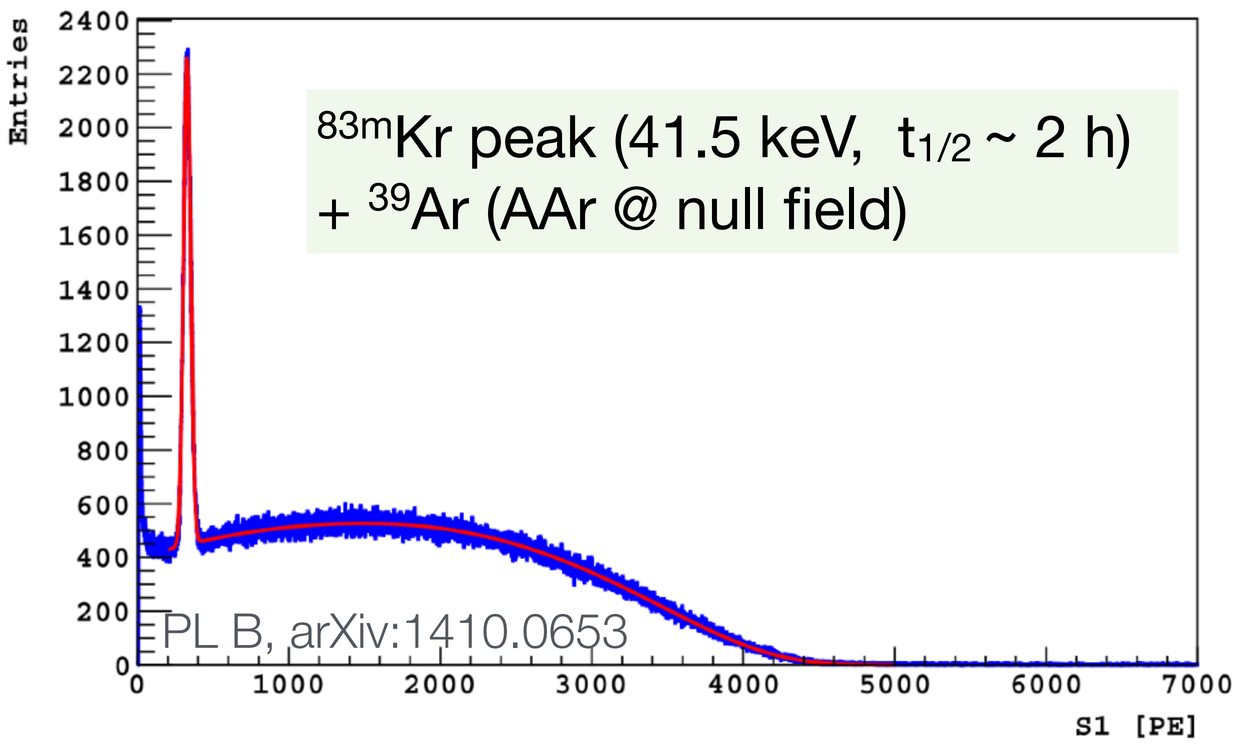


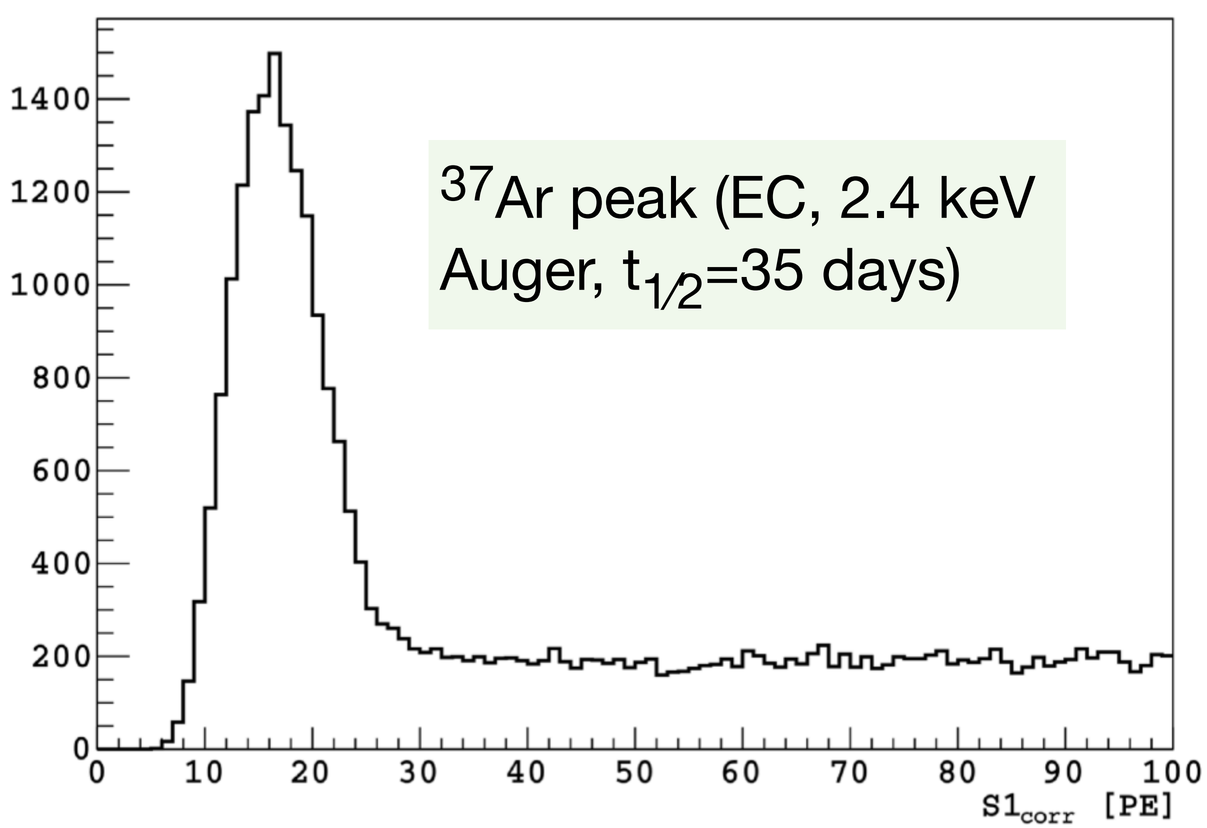


- **CAL**ibration source **I**nsertion **S**ystem (CALIS).
- Neutron sources:
  - **AmC, AmBe**
  - Veto efficiency, cross-check f90 contours
- γ-ray sources:
  - **^{57}Co (122 keV), ^{133}Ba (356 keV), ^{137}Cs (663 keV), ^{22}Na (550 keV, 1.27 MeV)**
  - ER energy calibration, MC tuning (right plot), Cherenkov background modeling



In-situ Internal Calibrations



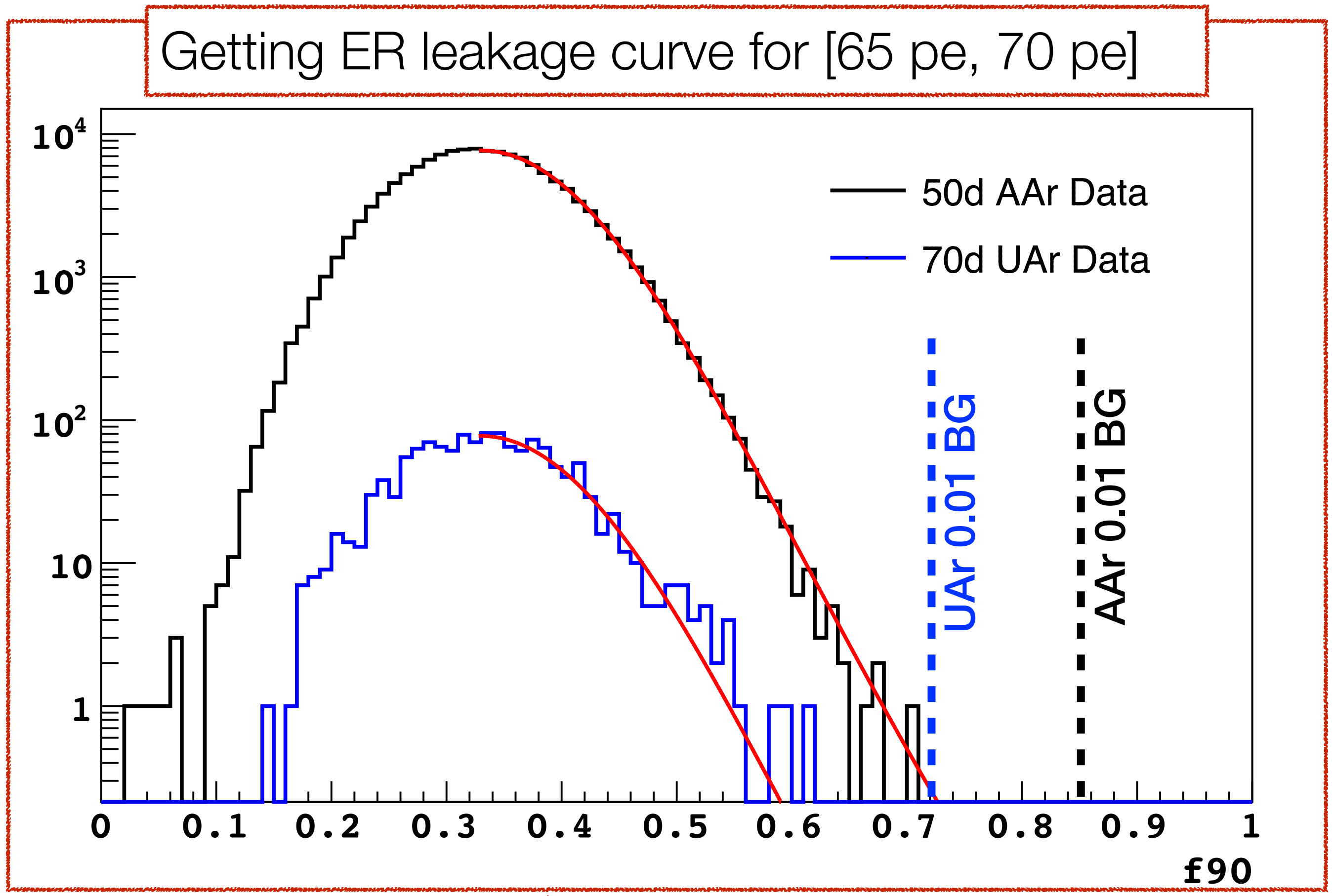


- Introduced ^{83m}Kr Calibration
    - LY = 7.0 ± 0.3 pe/keV (@ 200V/cm) ,
    - LY = 7.9 ± 0.3 pe/keV (@ null field)
    - Electron drift lifetime (> 5000 μs)
        - Maximum drift time is ~ 373 us
    - xyz dependent corrections for S1, S2
- Residual ^{37}Ar in UAr
    - LY ~ 7 pe/keV (@200V/cm)
    - Pulse finder efficiency
    - Cosmic ray activation. Possibly created during UAr transportation.
    - Harmless, now gone.

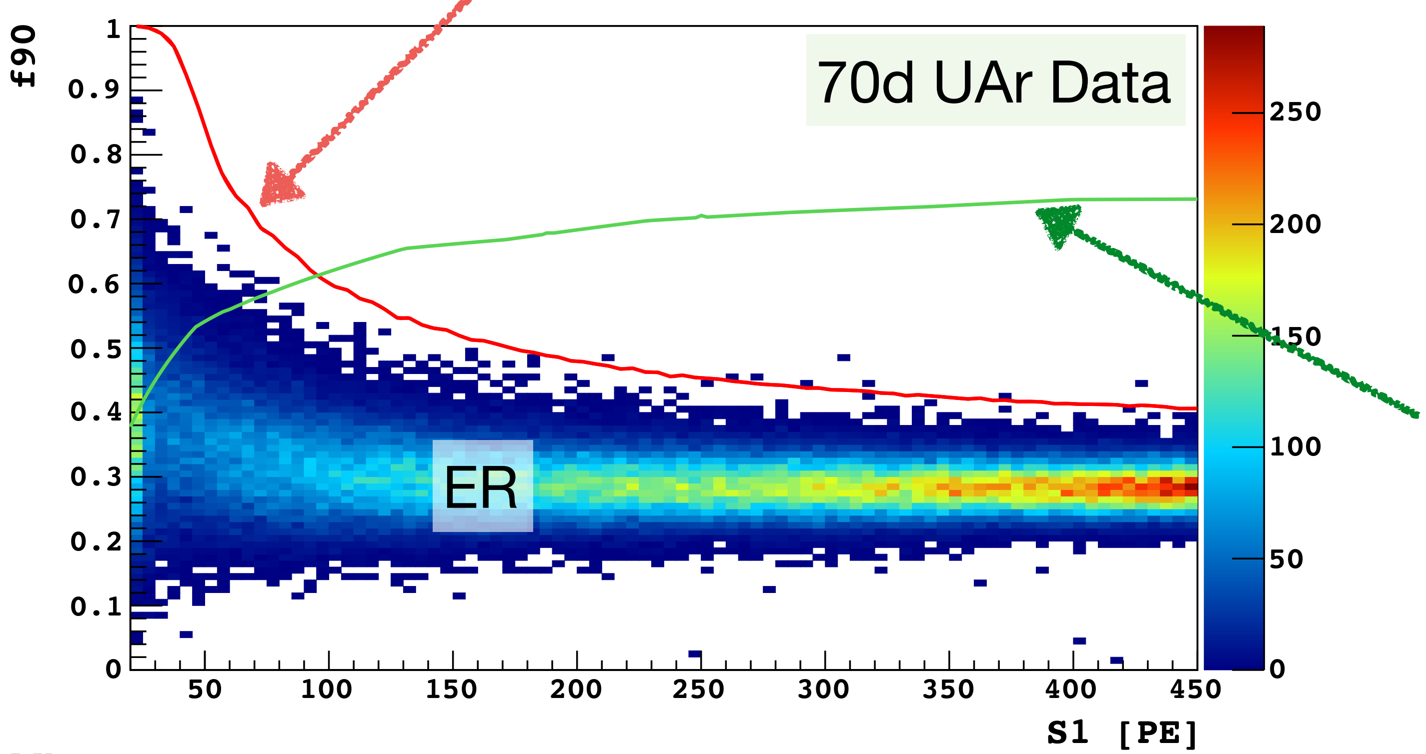
Non-blinded WIMP Analysis

- Two open data sets:
  - 50-day with AAr target (October 2013 - June 2014)
  - 70-day with UAr target (April 2015 - August 2015)
- WIMP search analysis cuts*:
  - Single-scatter (one S1 pulse and one S2 pulse)
  - Neutron veto cuts (no coincidence signal in veto)
  - Cosmogenics cut (no muon-like signal in the WCD)
  - Drift time (z) fiducial cut (no radial fiducial cut)
  - S1 light channel pattern (for Cherenkov + ER background)
  - Define WIMP ROI (next page)

Define WIMP ROI

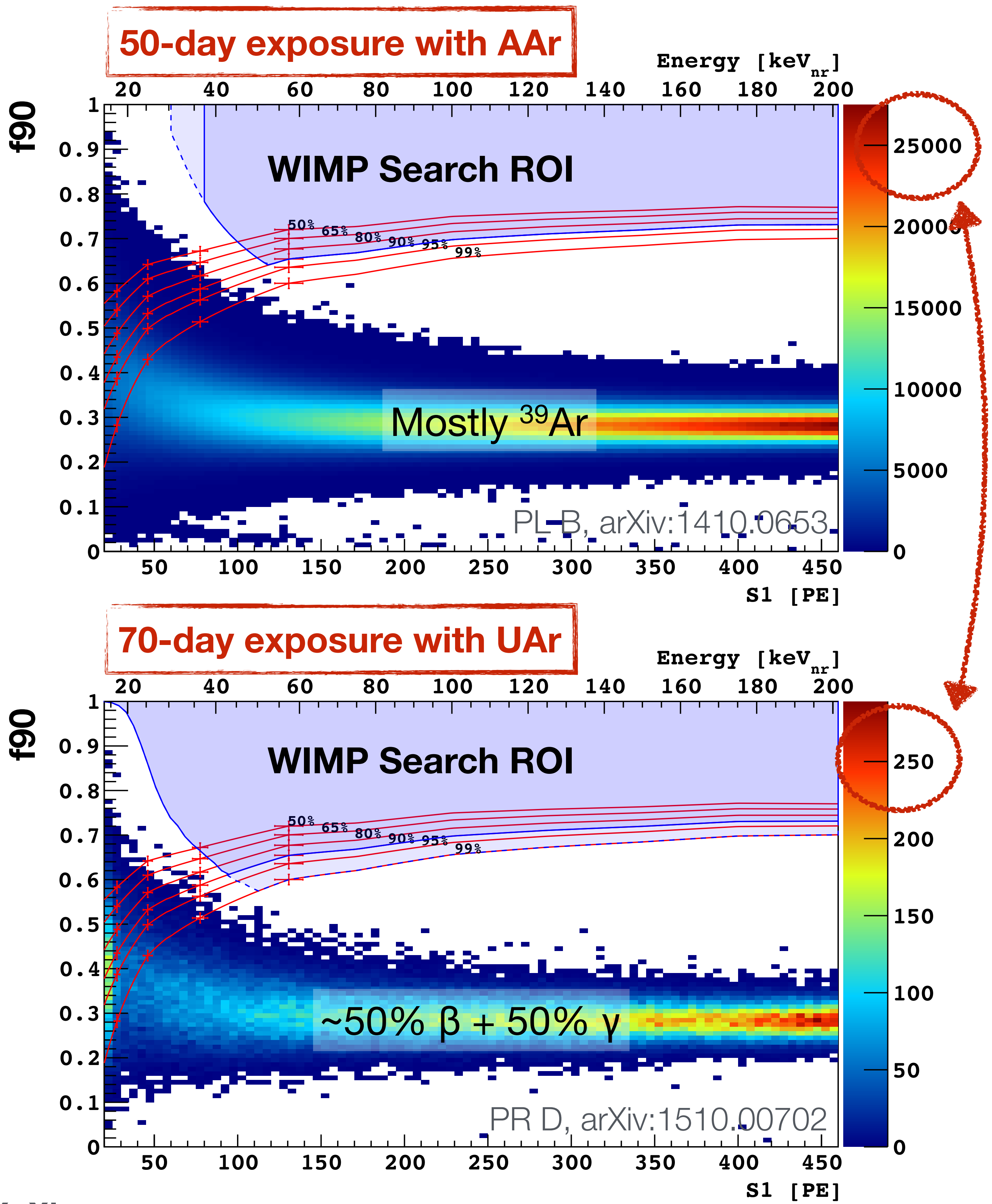


- Fit an analytic f90 model for single-sited ERs to AAr data
- Extrapolate ER leakage of 0.01 events from the fit
- Repeat above for all s1 bins
- Hint of multi-sited background in UAr data. Scale the fit of AAr down to UAr statistics for single-sited ER leakage.



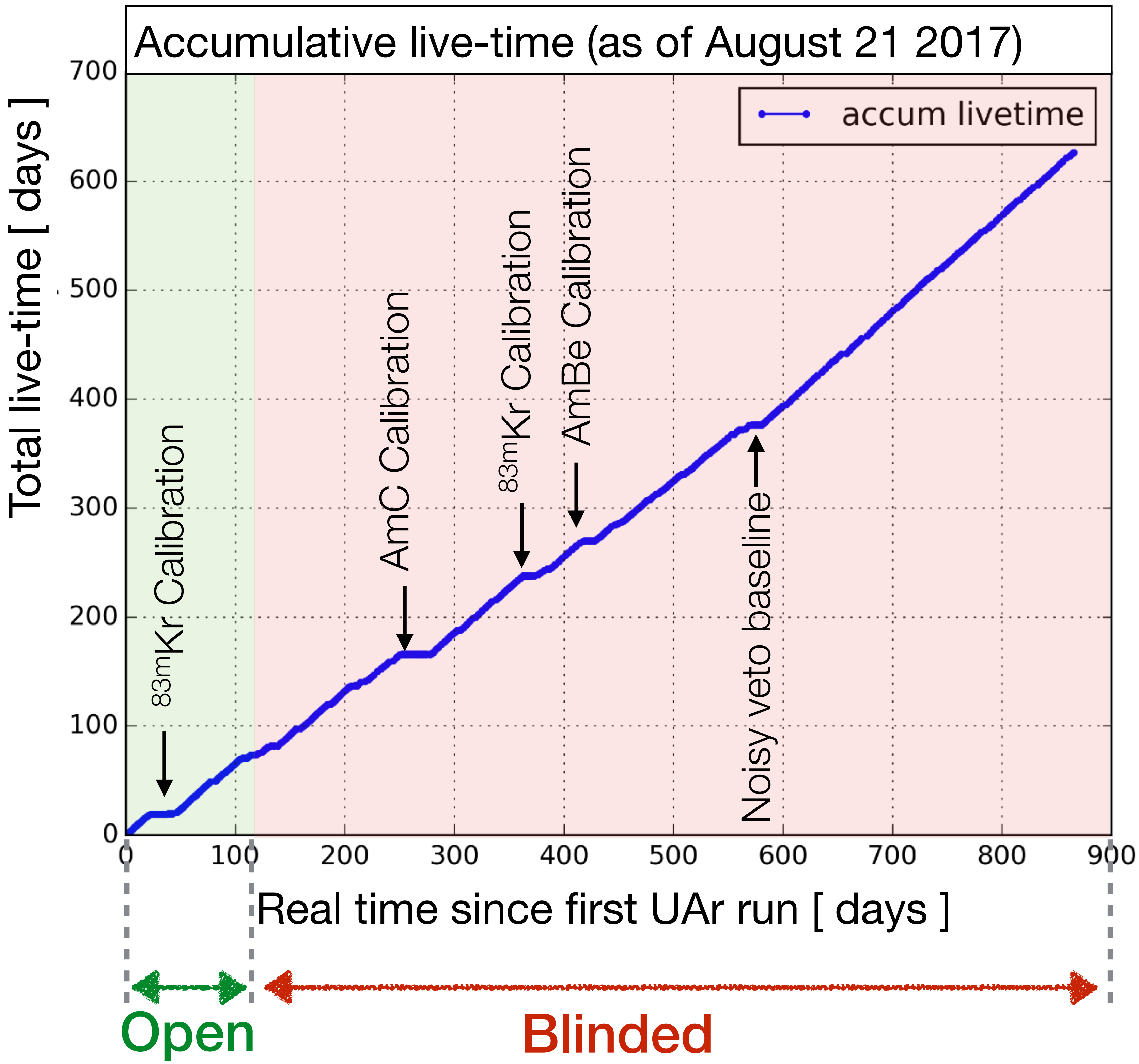
The 90% NR acceptance curve follows the same procedure (data from SCENE experiment, and cross-check with AmBe calibration)

Non-blinded WIMP Results



- 0 observed events in WIMP search ROI in both data sets
- Lower ER threats in UAr => bigger WIMP box at the low energy than AAr

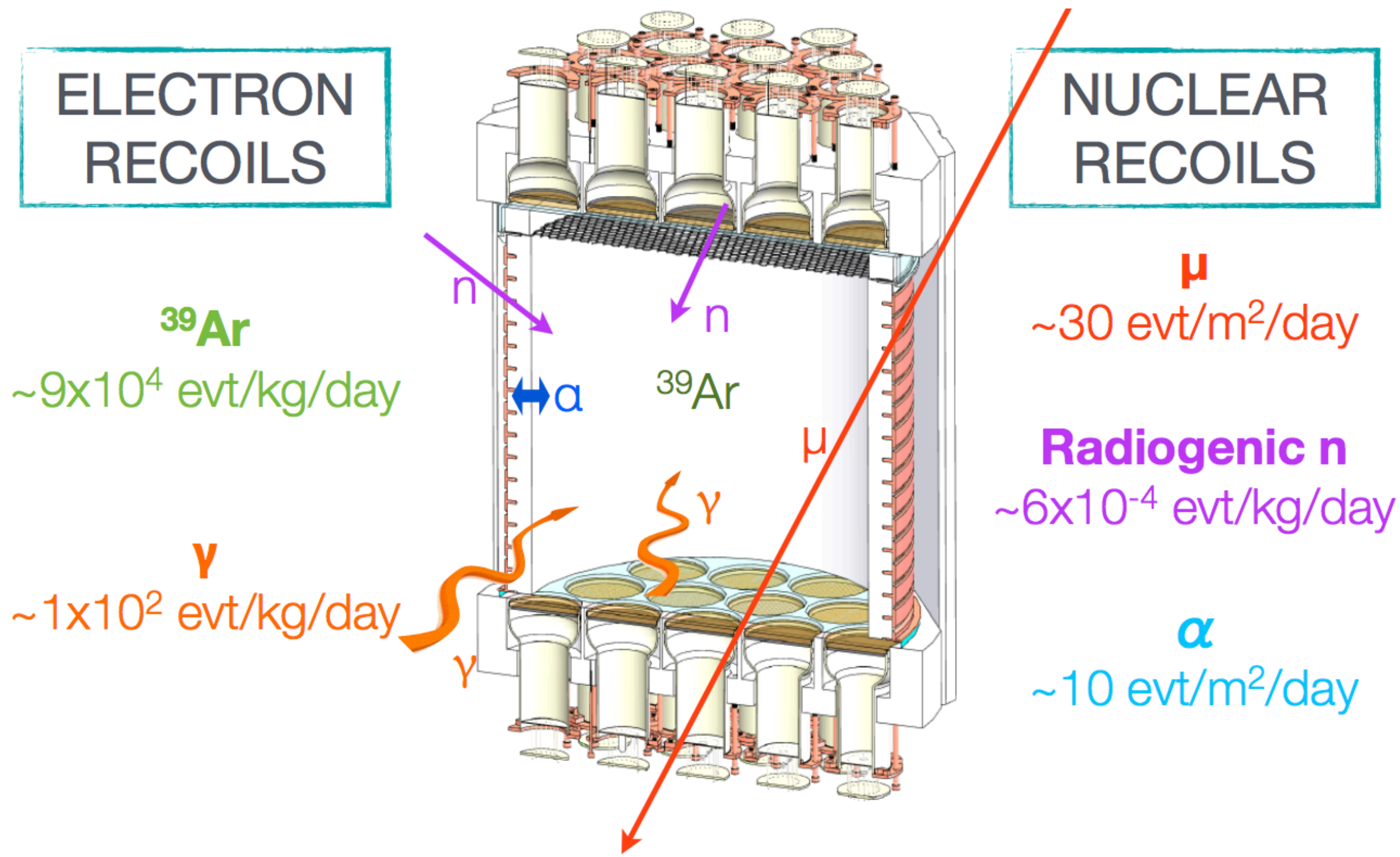
Blinded UAr Analysis



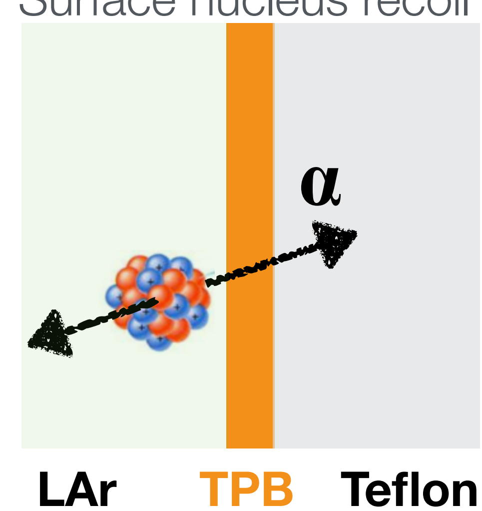
Accumulated **extra 500+ days** of blinded data since the 70-day UAr results

Toward Background Free

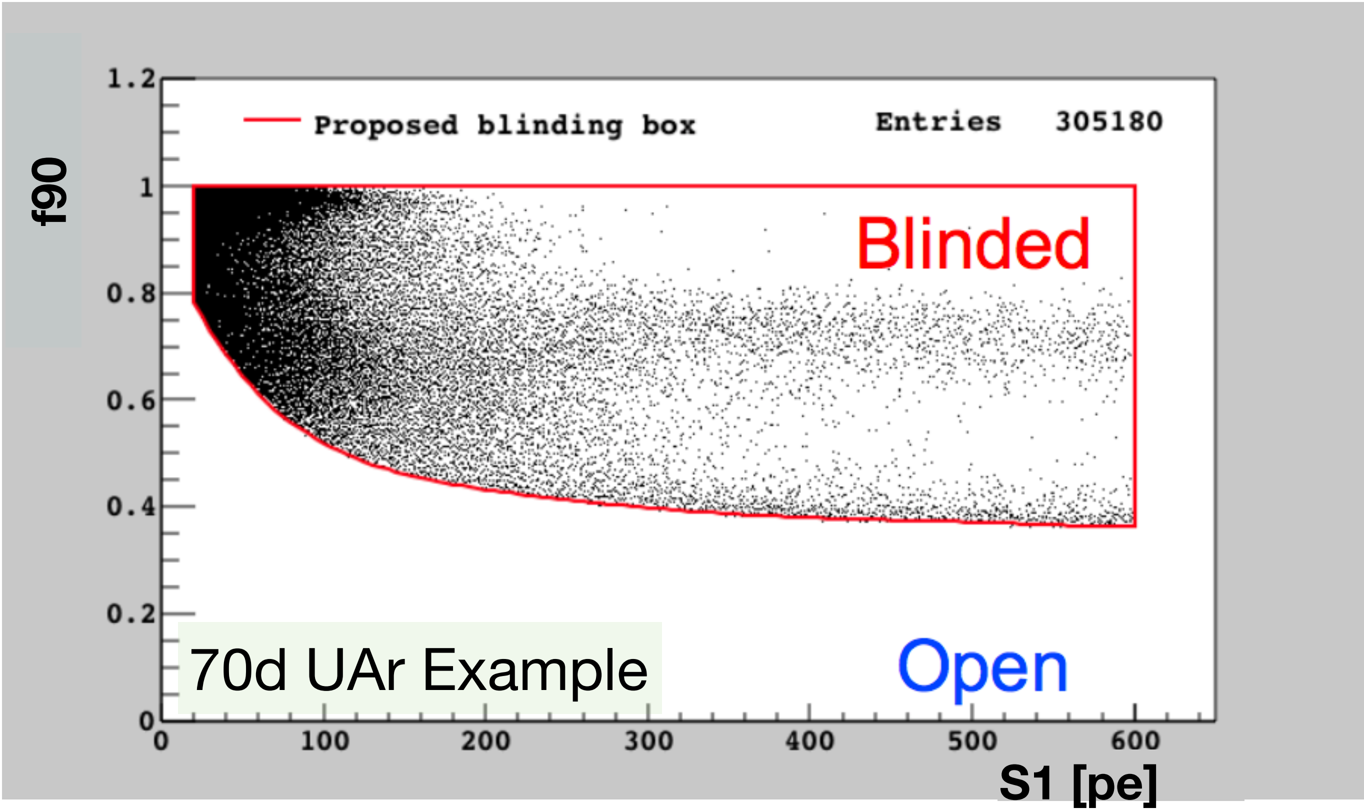
- Single and multiple ERs in LAr
  - ☑ LAr PSD, single-scatter cut, UAr,
- Radiogenics neutron
  - ☑ high efficiency neutron veto (>99.5%)
- Cosmogenics neutron
  - ☑ neutron veto, and water-Cherenkov muon veto
- Surface background
  - ☑ fiducial cut, TPB millisecond long tail
- ER + Cherenkov coincidence
  - ☑ fiducial cut, light pattern, etc (**work in progress**)

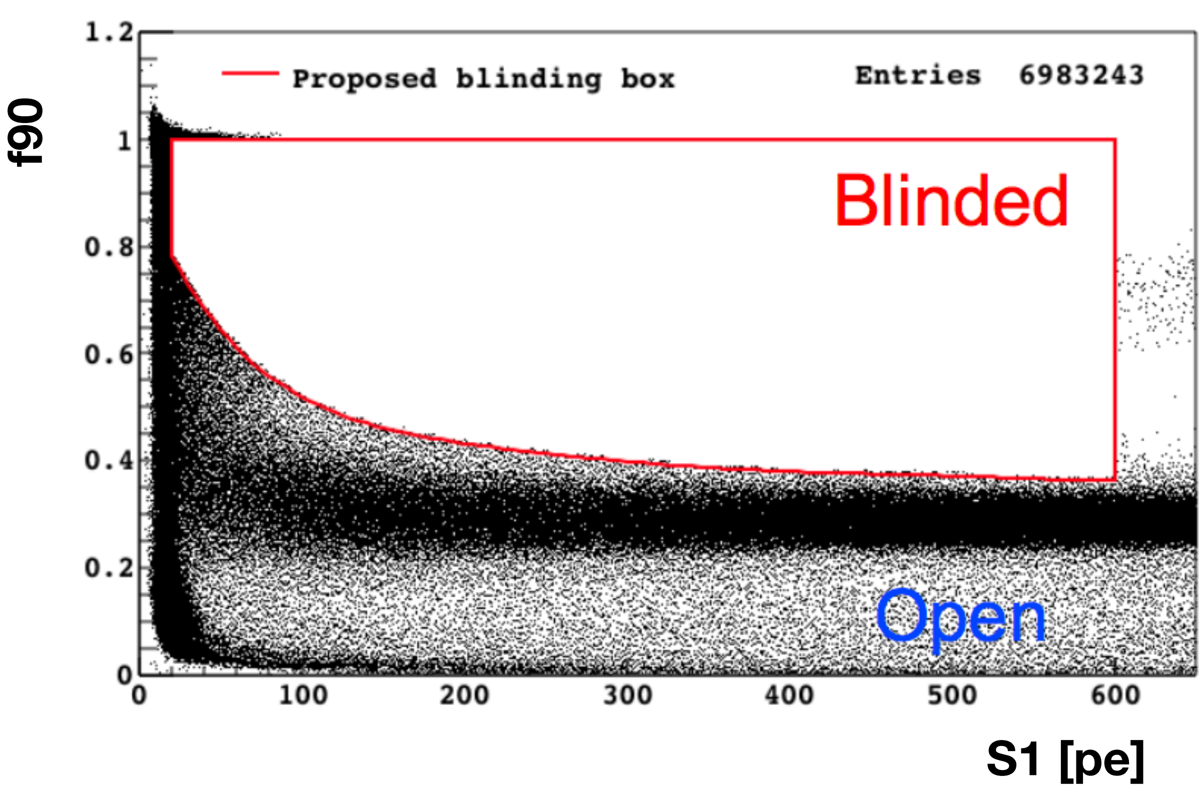


Surface nucleus recoil



Blinded Analysis Scheme



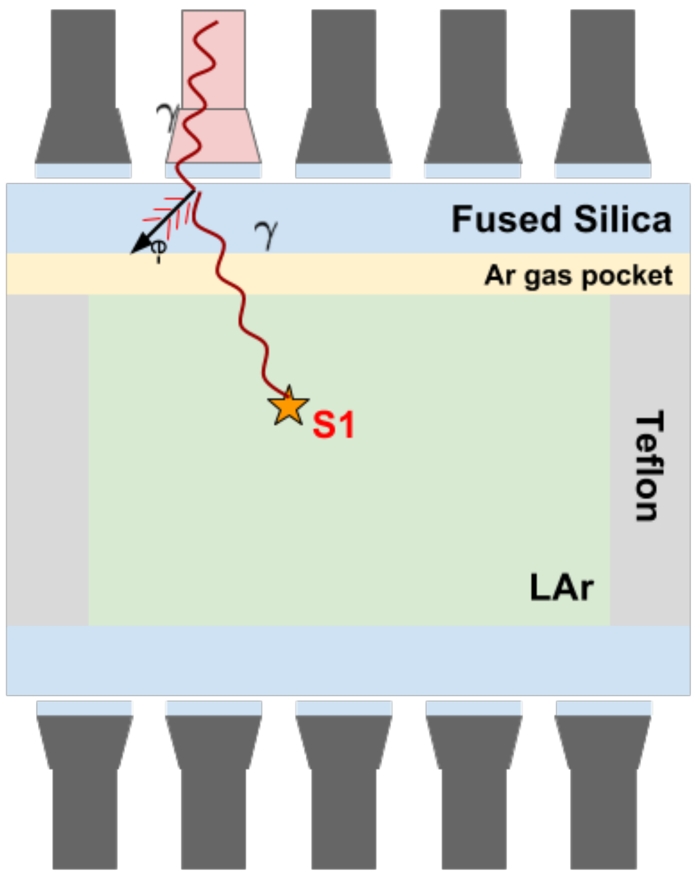


- Process raw data **hiding all events in the blinded box** (>> 70d WIMP box) + a tiny random fraction (~1/50000).
- 50d AAr, 70d UAr, and calibration data are all open
  - left plots are made from 70d UAr open data as an example.
- Use open data to develop cuts and predict backgrounds.
- Once ready, **open test-strips** to verify background predictions and cuts.
  - open veto tagged, multiple-sited, etc
- Choose cuts and final search box to give **<0.1 event of predicted background** after all cuts.

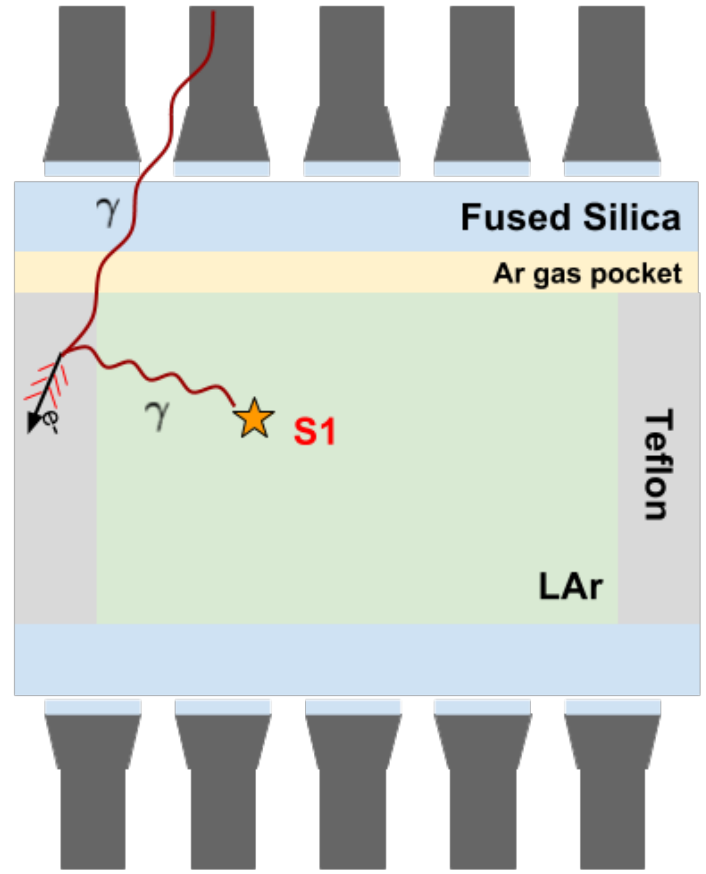
Example: Radiogenics Neutron

1. Measure the neutron veto efficiency (see H. Qian's talk)
   - Select events passing TPC WIMP cuts from AmC calibration data, and calculate the fraction has veto signal (veto efficiency **~99.3%**).
   - Make MC-based corrections for the origin and spectrum (veto efficiency ~**99.8%**).
2. Calculate the final background
   - Unblind events with neutron-veto signal
   - Count the number of neutron passing TPC WIMP cuts (~99% neutron tagging, ER is negligible)
   - Use the efficiency in step 1 to make the final prediction

Potential Cherenkov BG



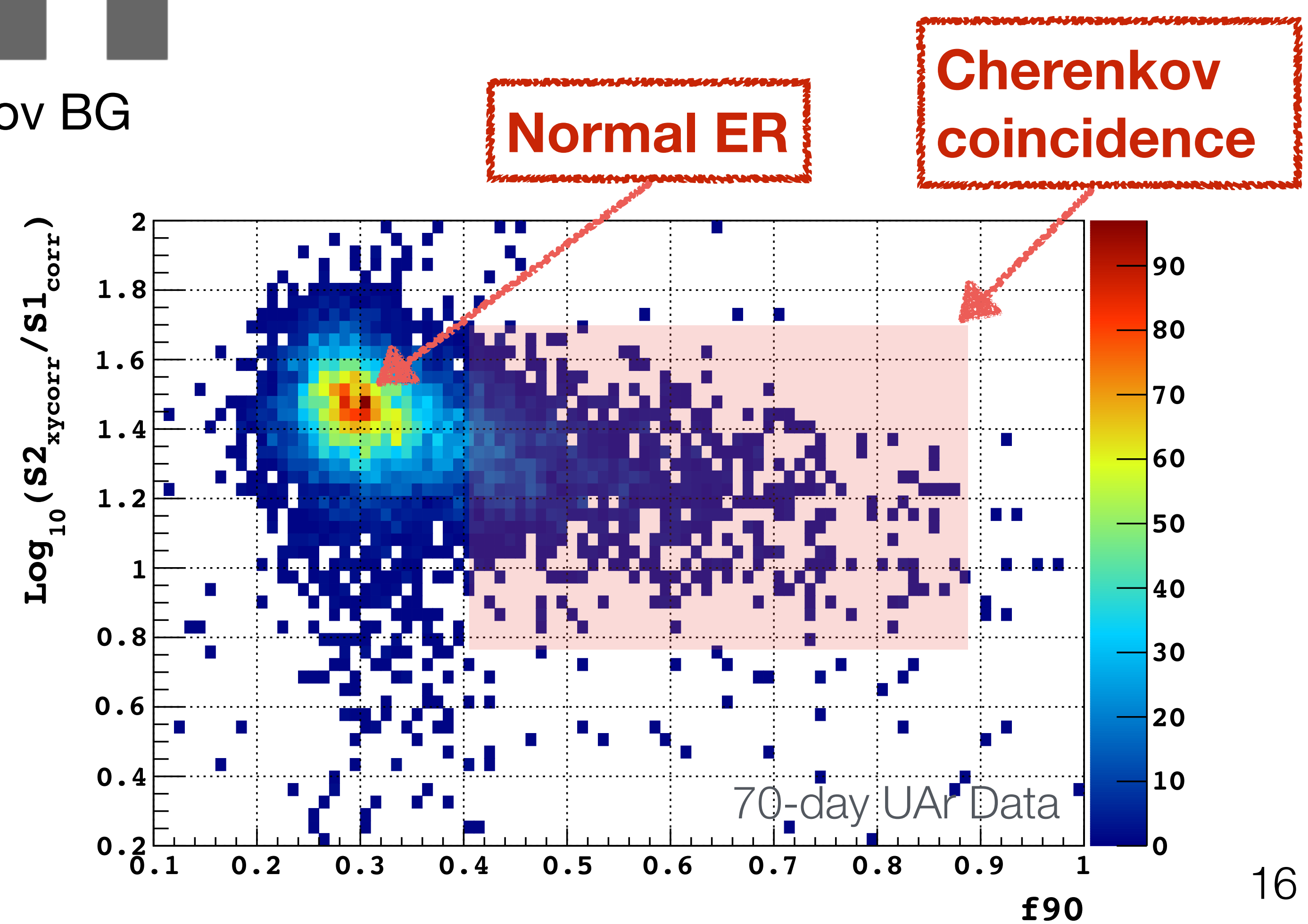
Fused Silica Cherenkov BG



Teflon Cherenkov BG

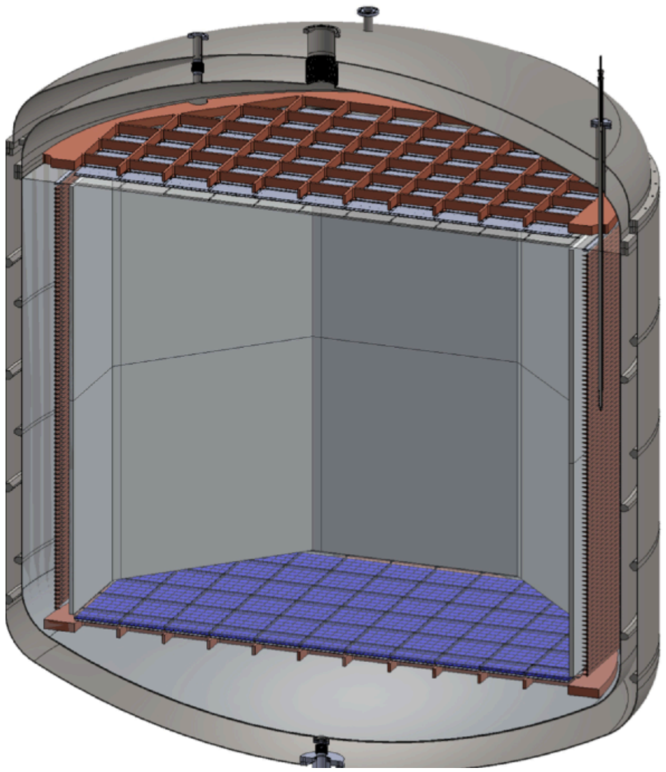
- Main mechanism: γ multi-scatter in LAr and Cherenkov radiator (fused silica, Teflon)
- Cherenkov in FS gives abnormally large amount of light in one PMT - easy to tag/cut
- Teflon Cherenkov is a challenge

- Cherenkov process is fast and doesn't produce S2 => **the coincidence makes an event NR-like in both f90 and S2/S1 axis (red shadow)**
- **Developed a MC model for this BG.** Test with pure-Cherenkov events and γ events tagged with veto signals.

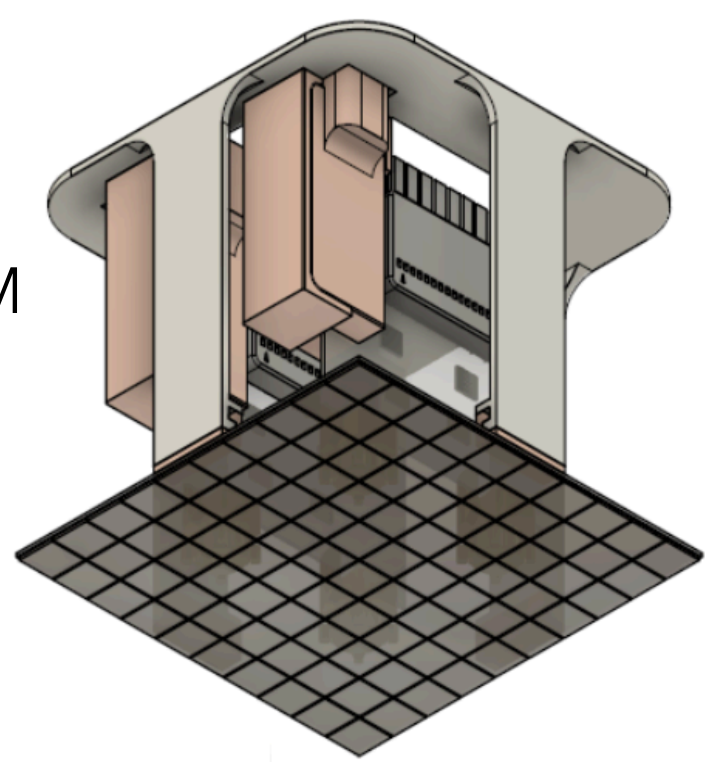


DarkSide-20k Overview

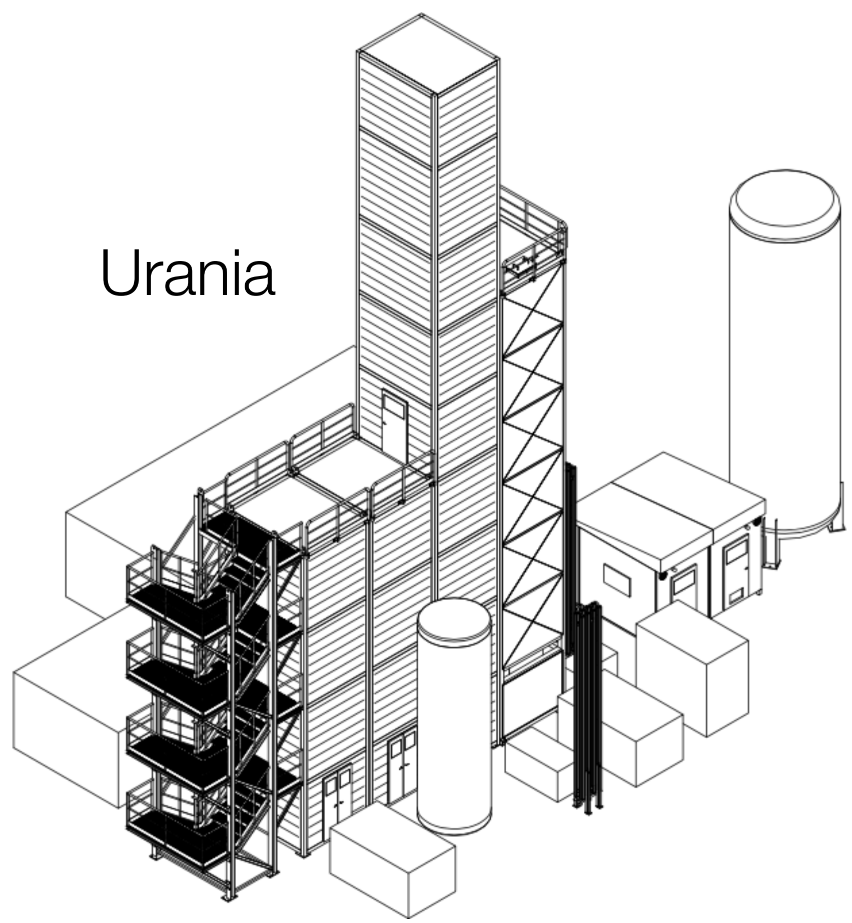
- Joint collaboration: **DarkSide + DEAP + MiniClean + ArDM**
- Sensitivity reaches **10^{-47} for 1 TeV/c^2 WIMP** mass and 100 t yr exposure
- Plan to take data in 2021
- New **SiPM** technology to replace PMT
- Extended Ar project:
  - **Urania** - scale up UAr production
  - **Aria** - distillation column to further remove ^{39}Ar



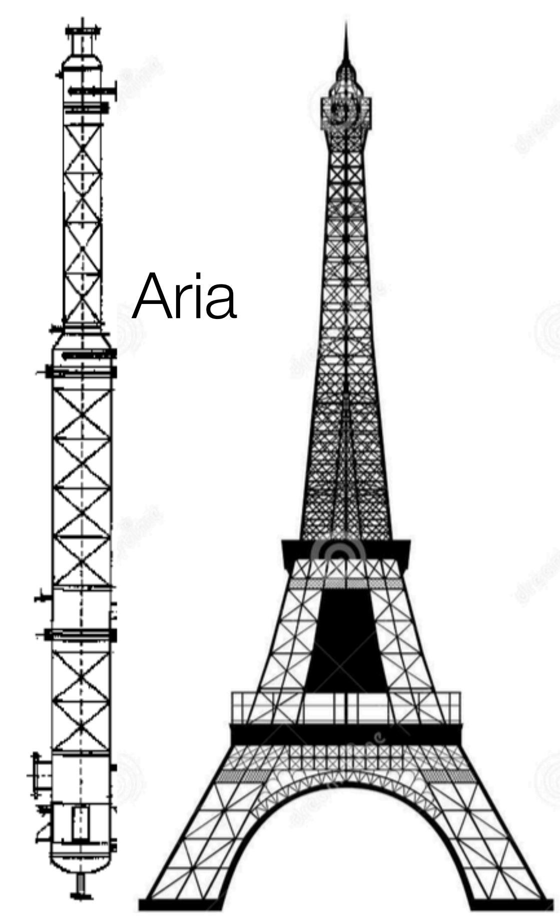
SiPM



Urania

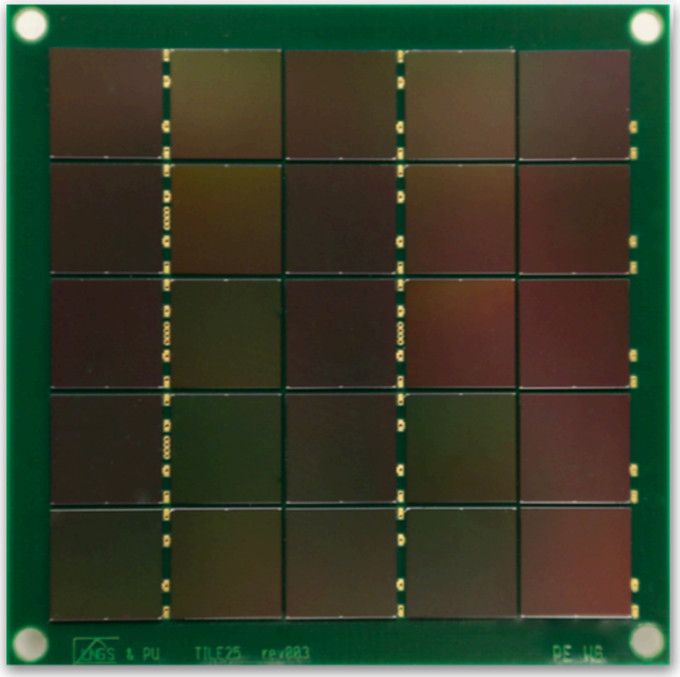


Aria



SiPM

single-channel, 24 cm^2 detector

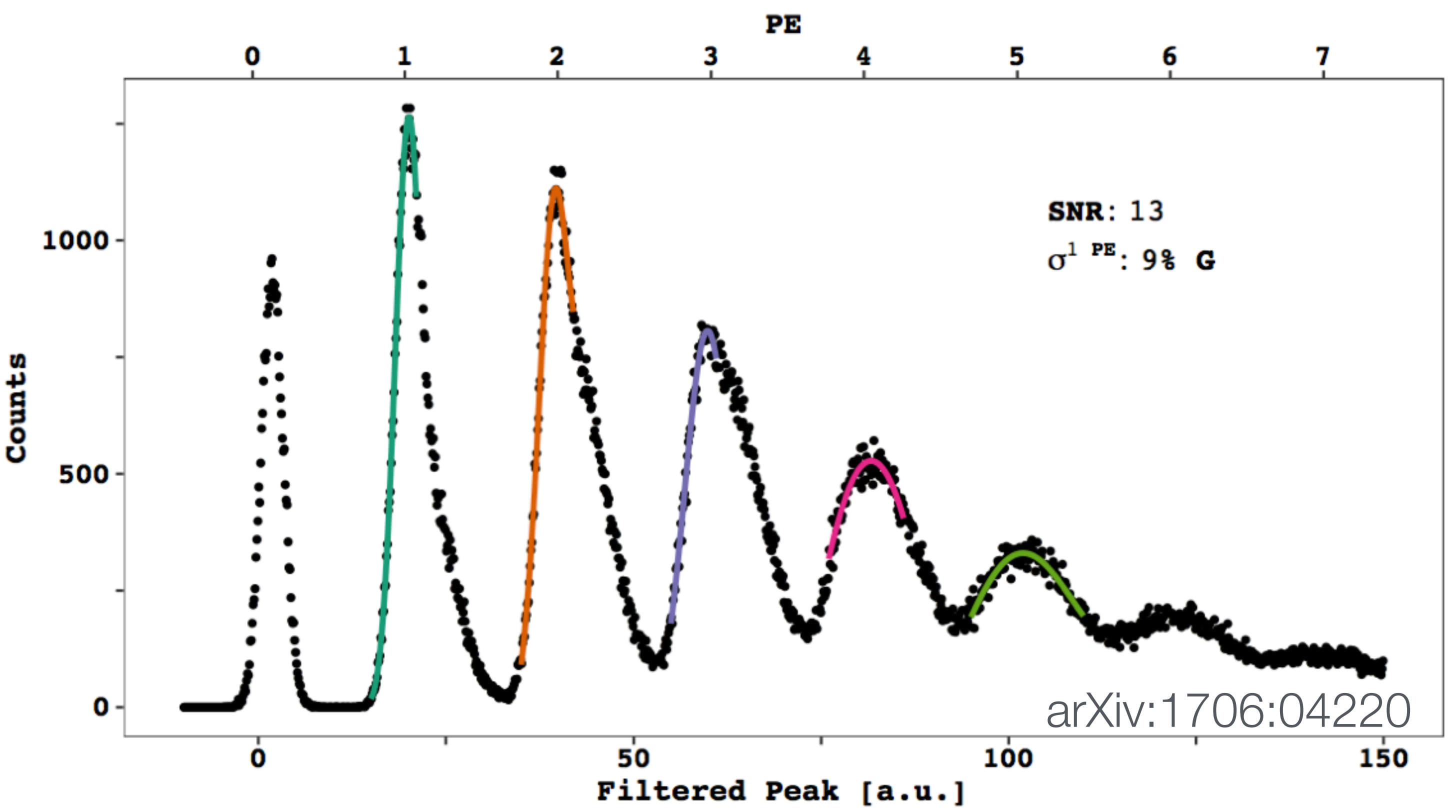


Advantages over PMTs:

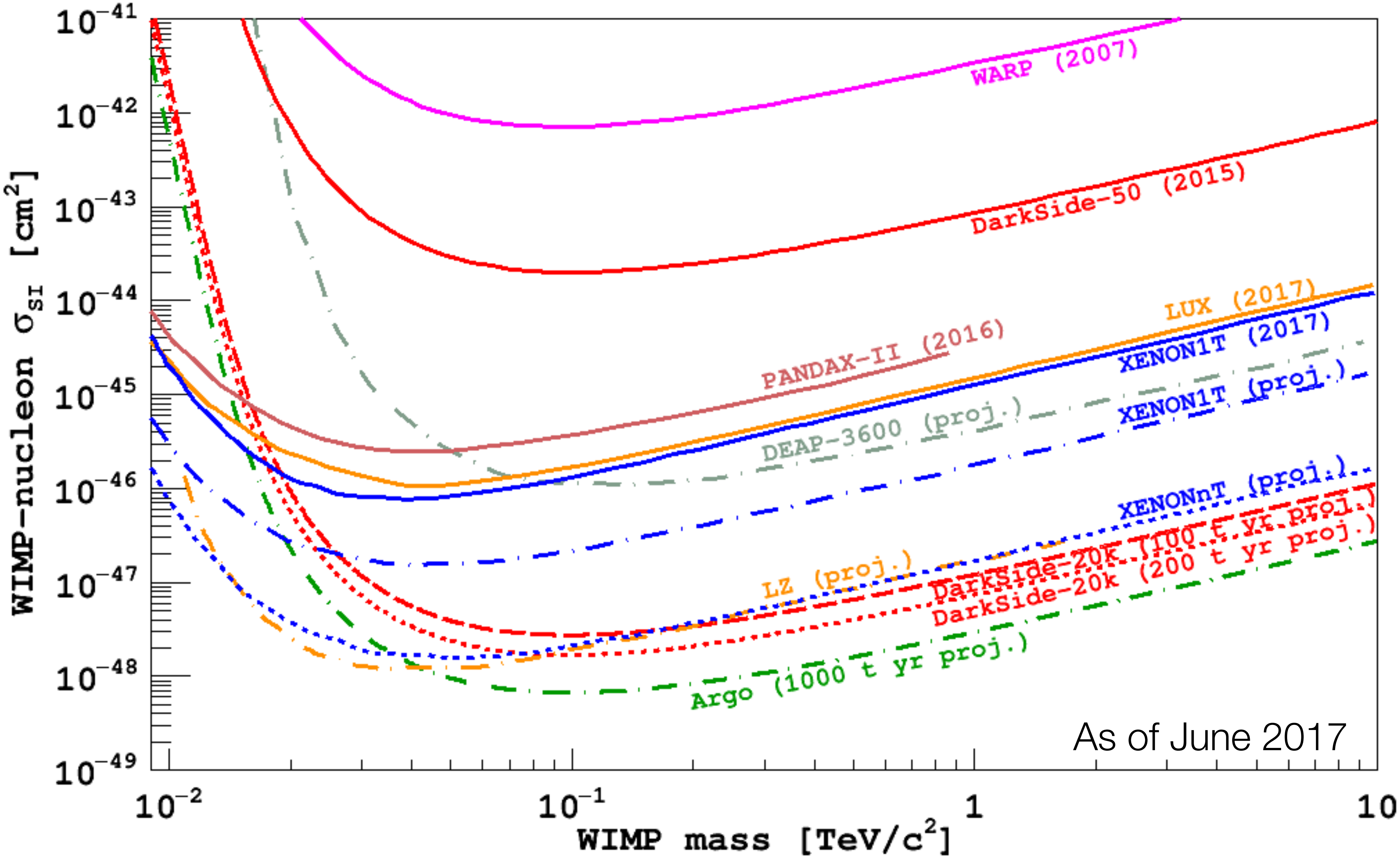
- Lower cost
- Higher photon detection efficiency (>40%)
- Better single photon resolution
- Lower background (lower mass)

Challenges:

- High capacitance per unit area
  - Solution: novel cryogenic preamplifier (arXiv:1706.04213)
- High dark noise and correlated noise
  - Solution: cryogenic SiPMs optimized for DarkSide-20k (arXiv:1610.01915)



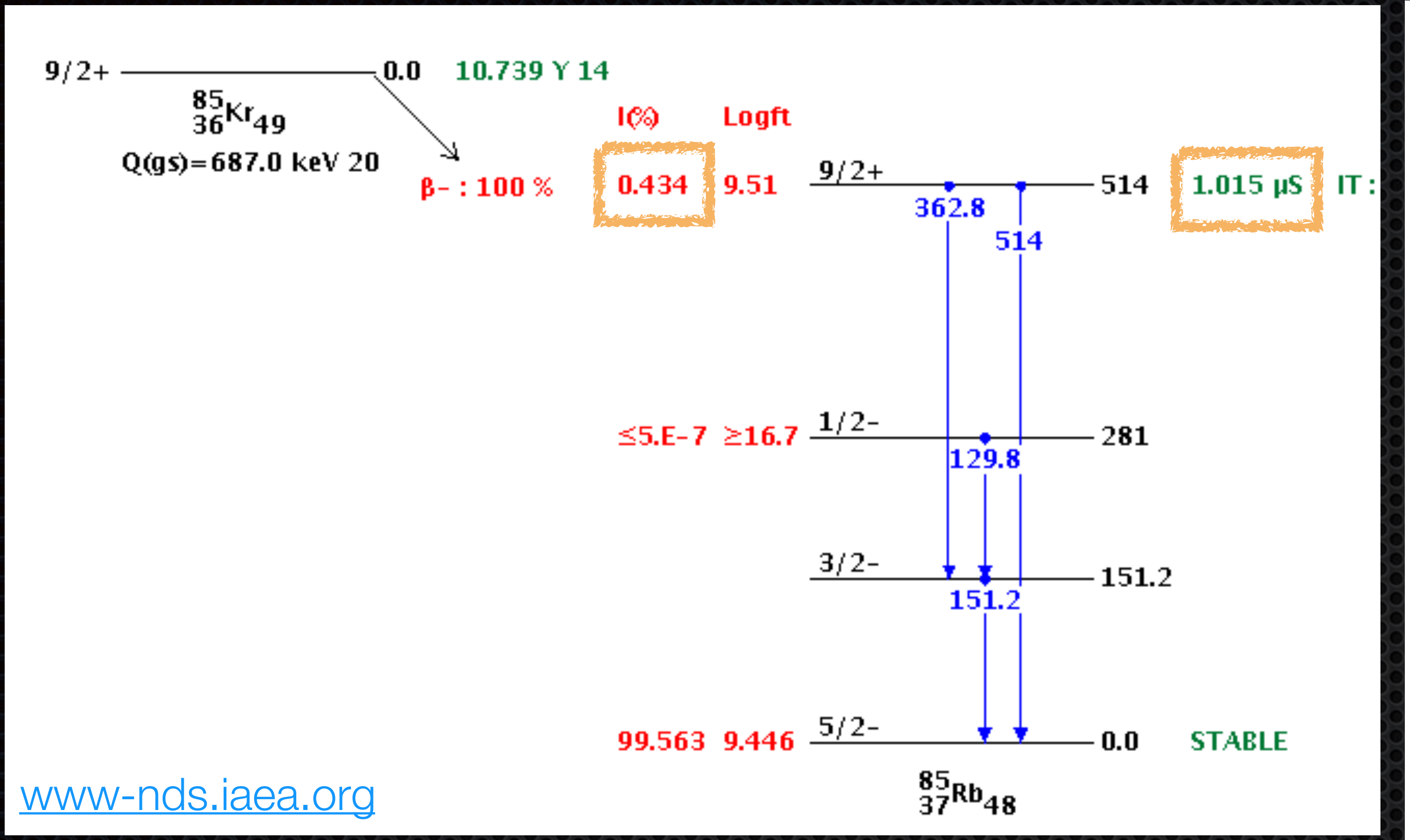
Exclusion Curves

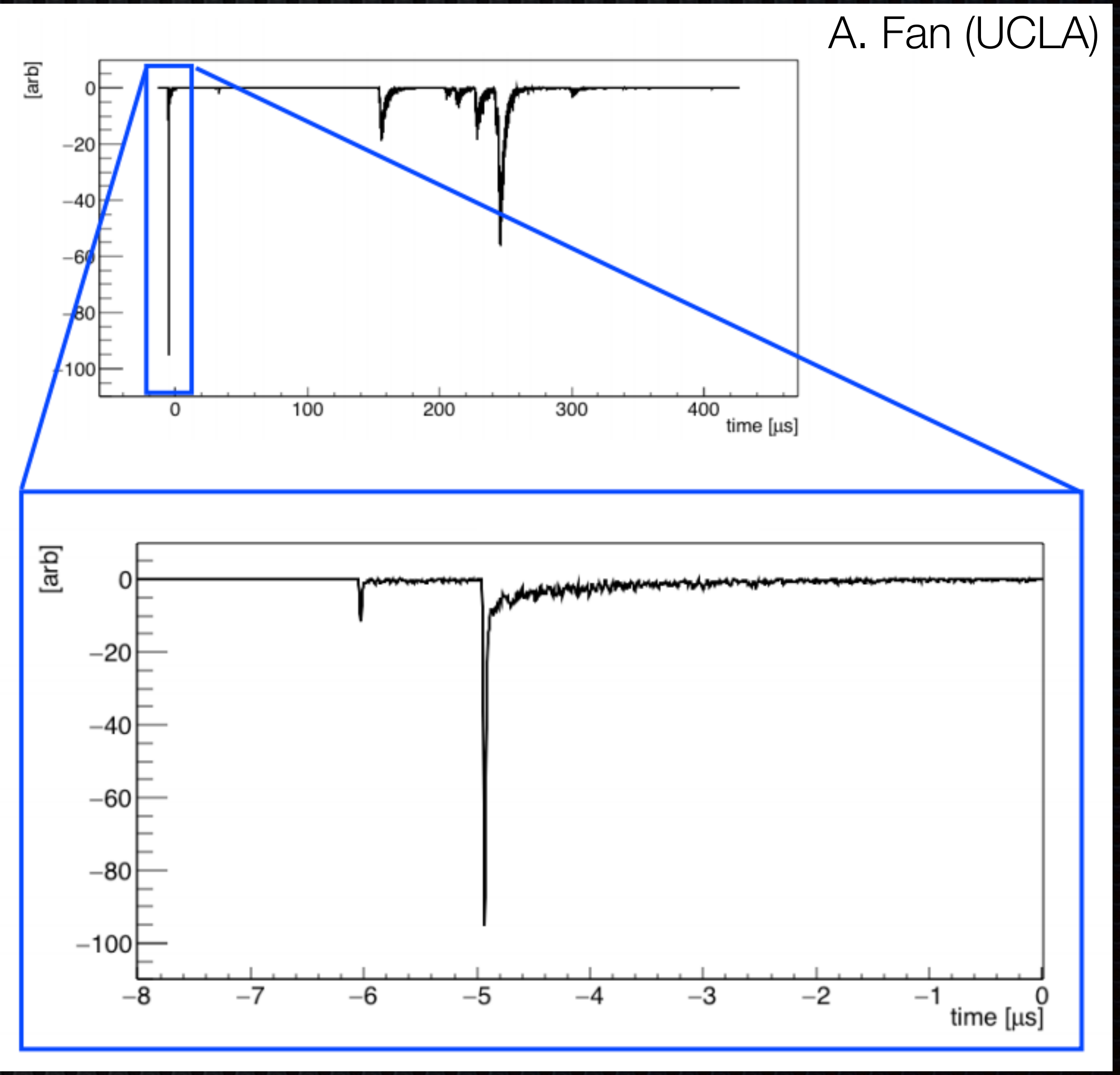


Summary

- DarkSide-50 has demonstrated background free operations.
- Null results from the two non-blinded data sets were reported.
- Blind analysis is ongoing.
- R&D for DarkSide-20k is underway.

The confirmation of ^{85}Kr

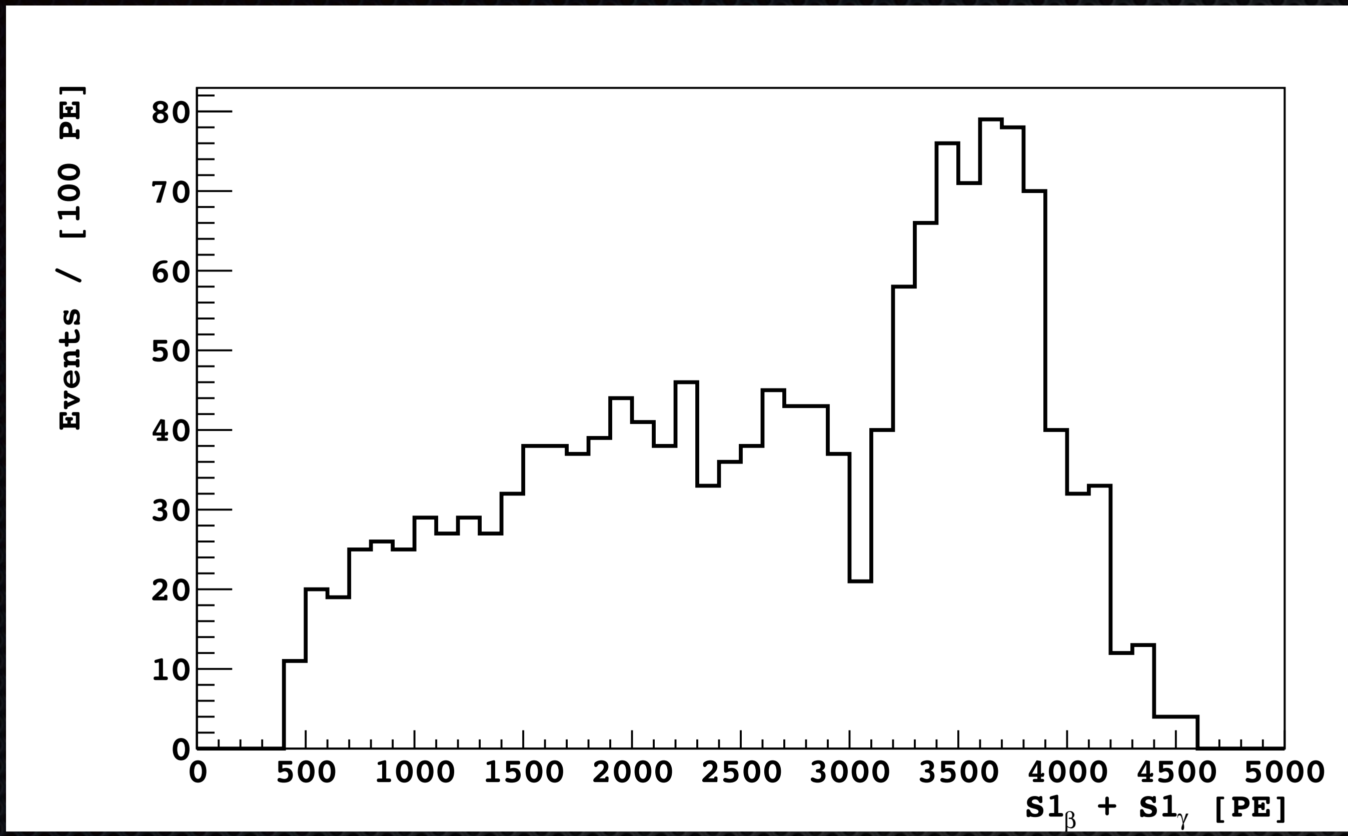


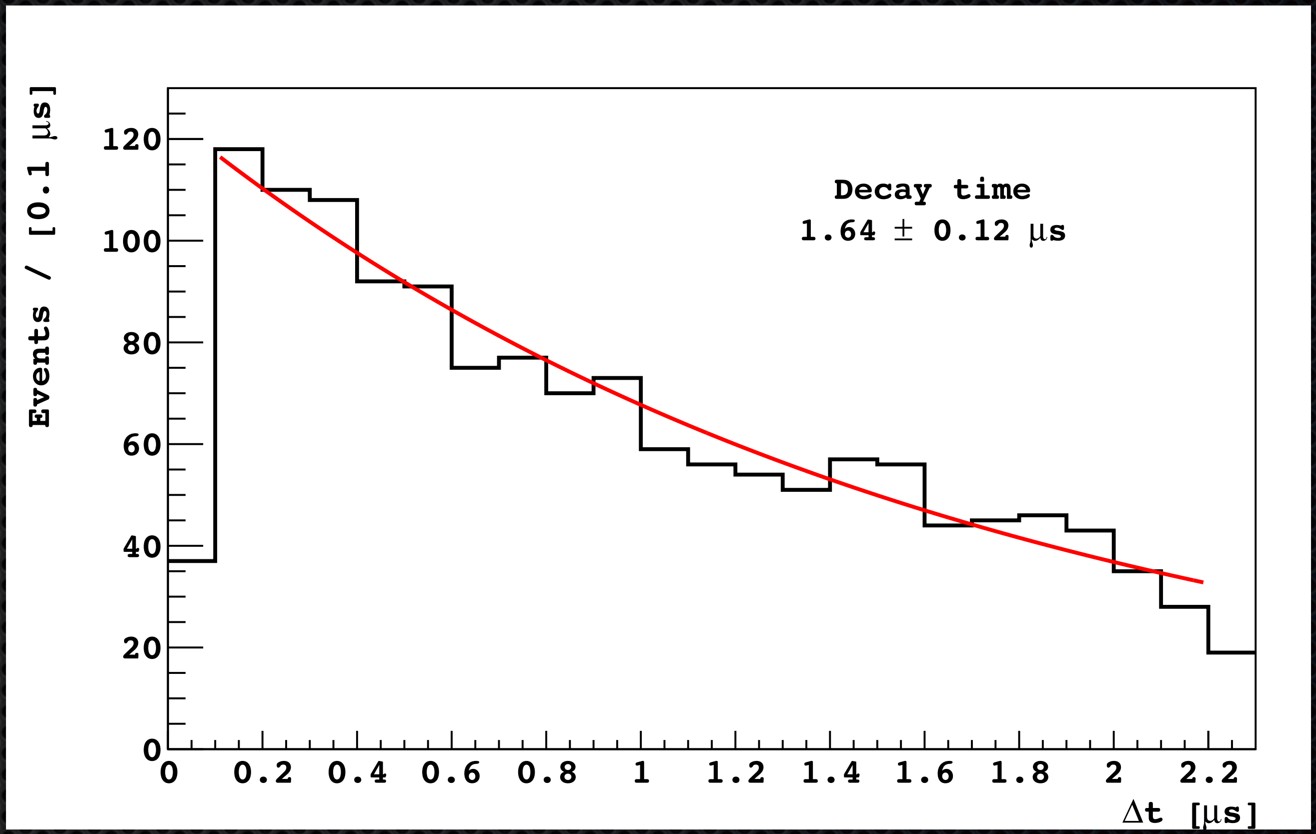


- 0.4% branch from ^{85}Kr decay follow by a 514 keV γ to ^{85}Rb
- **Signature I: ~1 μs (β-γ) delay S1 coincidence**
- **Signature II: multiple S2 pulses**
- Customized algorithm to search for events with these signatures

- Use MC to estimate the inefficiency from escaping γ and algorithm search failing.

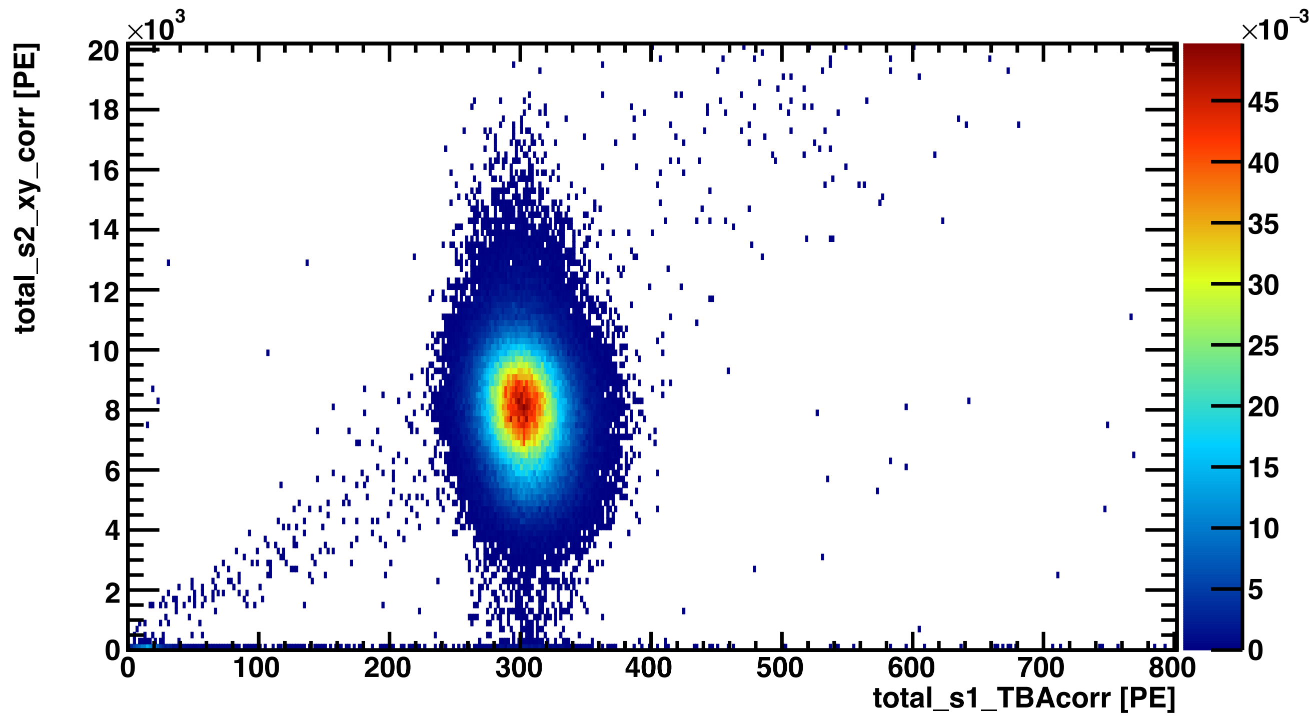
The confirmation of ^{85}Kr

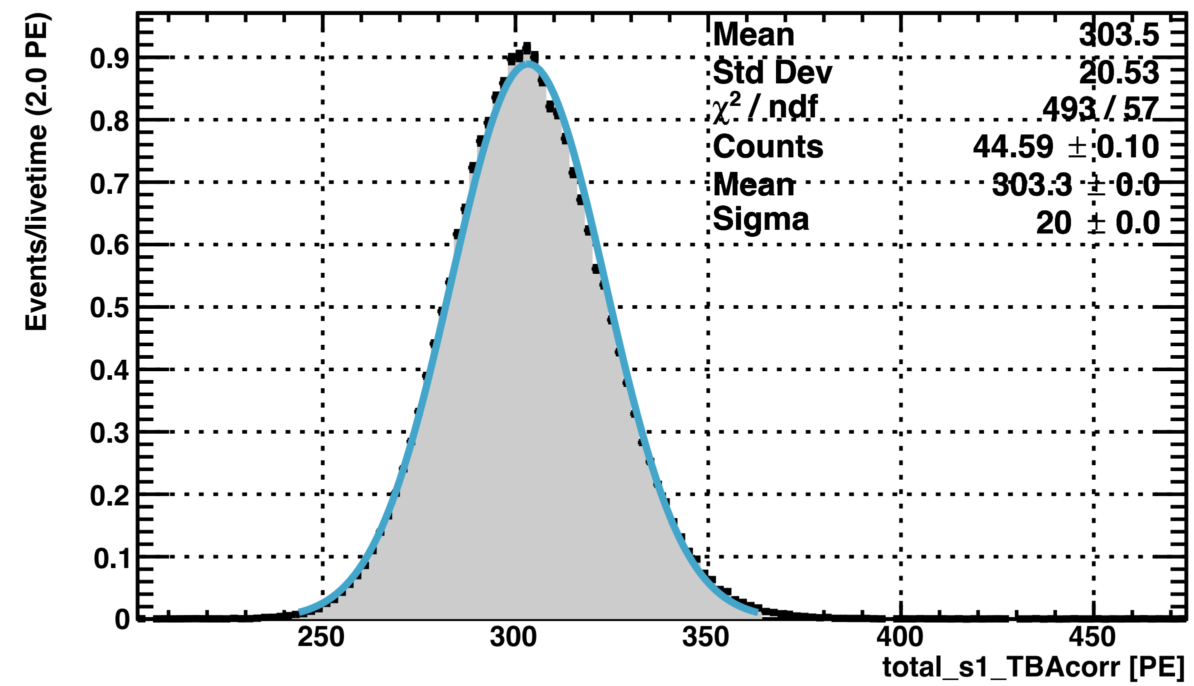


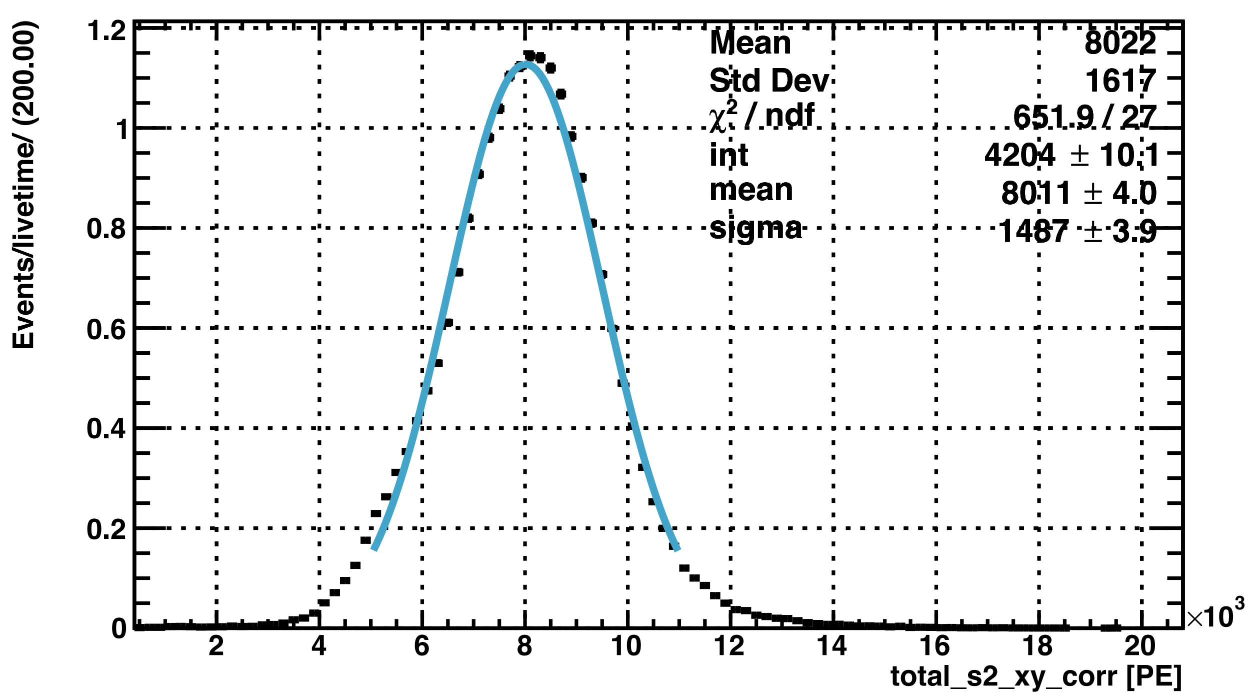


- Expect (from MC fit): 35.3±2.2 event/day
- Observe (from data): 33.1 ± 0.9 events/day
- Decent agreement with the expected τ~1.46 μs
- Possible origin: deep underground natural fission. They could have been easily removed via cryogenic distillation

Kr Calibration with UAr







# of Event (Source events): 547

S1 mean: 303.285821 ± 0.045477

S1 resolution: 0.065948 ± 0.000114

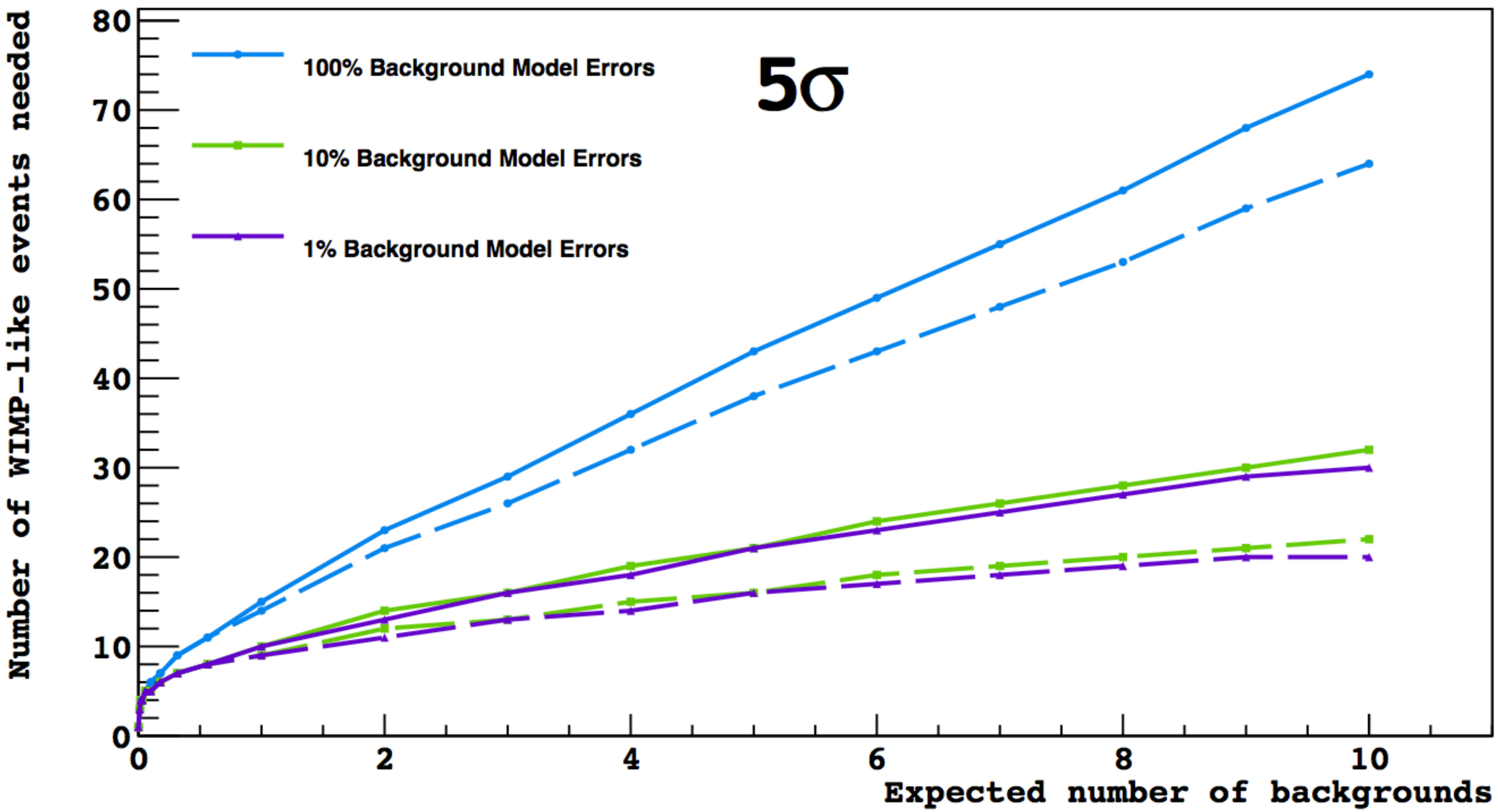
S2 mean: 8011.340241 ± 3.963675

S2 resolution: 0.185666 ± 0.000501

Bg fraction under S1 Source peak: 0.000000

LY($S1_{mean}$/41.5keV): 7.308092 ± 0.001096

Why background-free?



S. Westerdale, PhD Thesis (Princeton 2016) https://www.osti.gov/scitech/biblio/1350520