DarkSide-50
Results from first Argon run

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DarkSide Keywords

- ➡ Direct detection of dark matter
- ➡ Wimp-nucleus scattering in liquid Argon
- ➡ Dual-phase Time Projection Chambers (TPC)
- ➡ Multi-stage approach
- ➡ At Laboratori Nazionali del Gran Sasso (LNGS) in central Italy:

  rock coverage ~3500m w.e.
- ➡ Very low intrinsic background levels
- ➡ Electron recoil discrimination
- ➡ Neutron active suppression

→ **Background-free operation**

Why Liquid Argon (LAr) ?

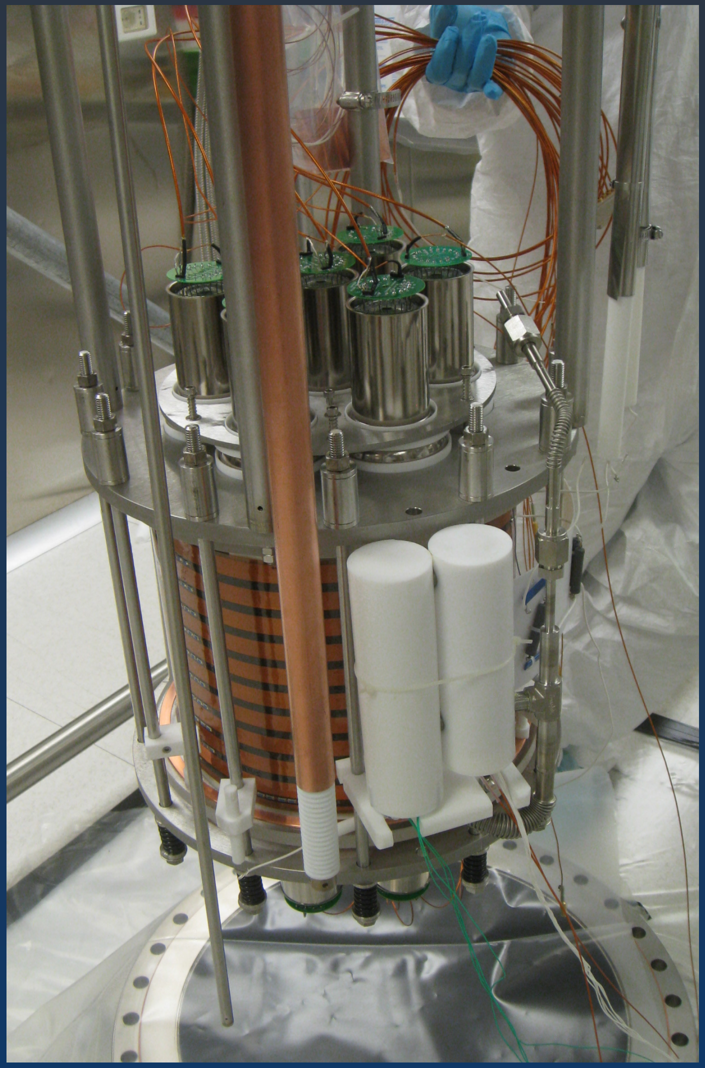
LAr advantages

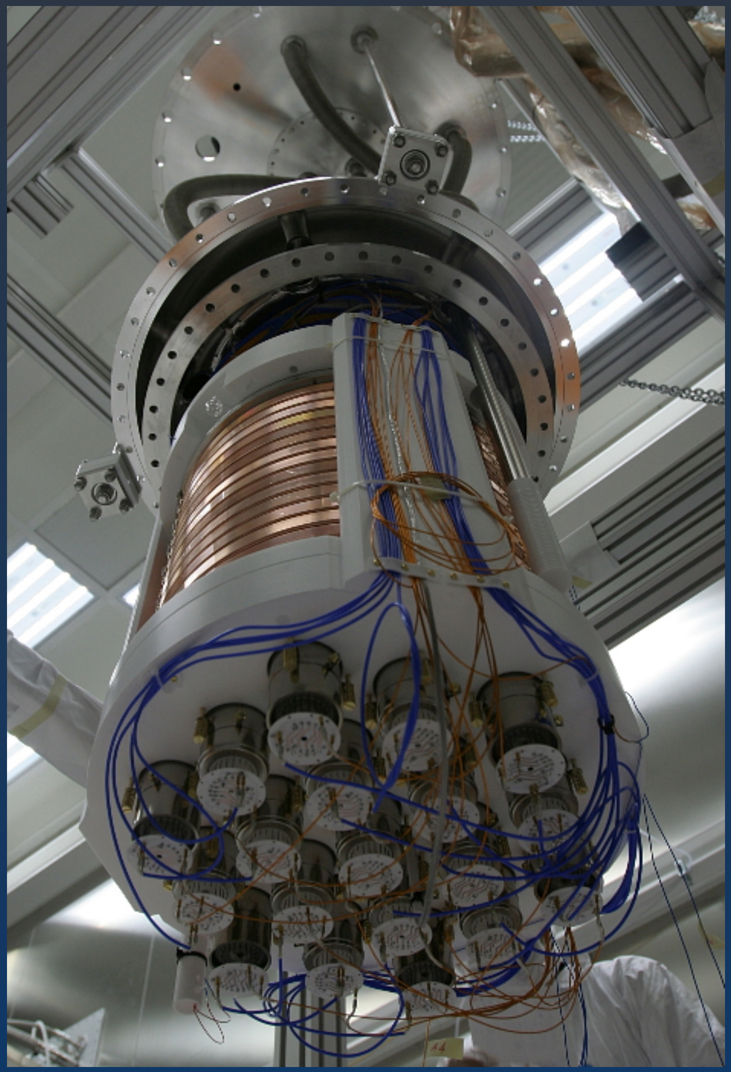
- Bright scintillator -> low energy threshold:
  ~40 photons/keVee
  ~8-10 pe/keVee possible
- Powerful PSD in scintillation signal separates background from ER from WIMP induced NR.
- Moderate cryogenic requirements
- Good ionization detector for TPC
  - Well defined fiducial volume is possible.
  - S2/S1 helpful for discrimination.
- Easily scalable to large masses.
- Liquids and gasses can be radio-pure. Internal background reduced by online purification.

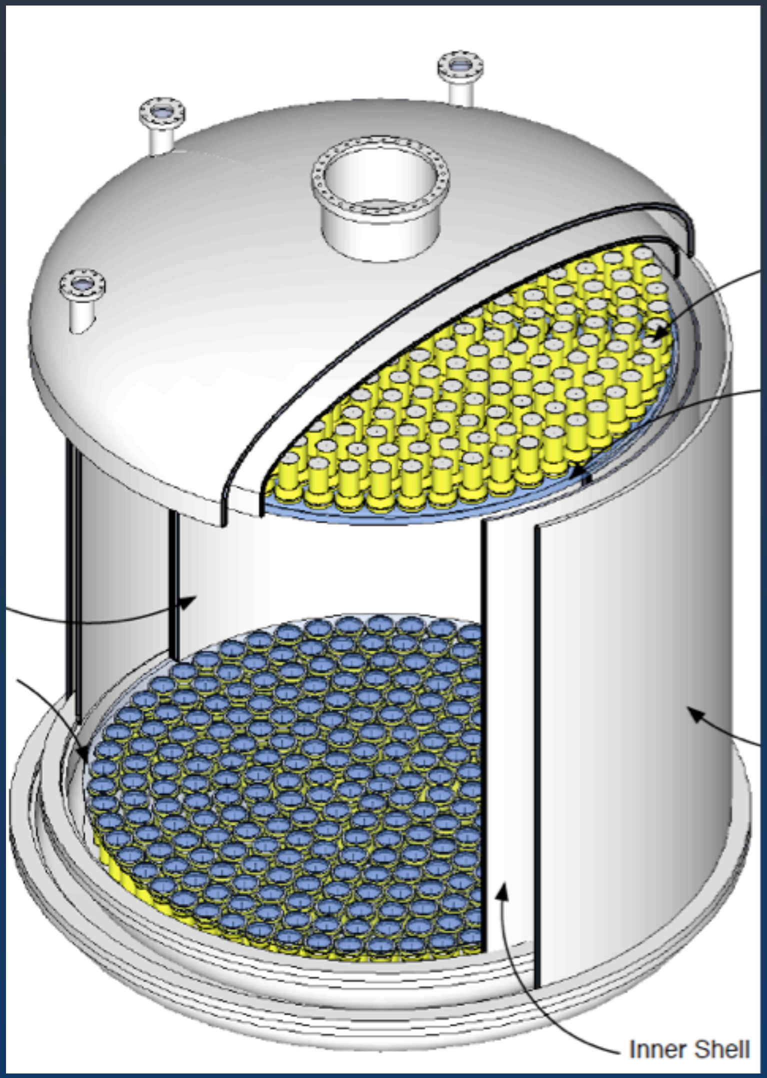
LAr disadvatanges

- Cosmogenic radioactive ^{39}Ar:
  Atmospheric argon (AAr) 1 Bq/kg
  Underground argon (UAr) has low ^{39}Ar but:
- AAr is cheap, UAr is not.
- Scintillation light at 128 nm.
  - Need wavelength shifters.
- Special PMTs developed:
  - low radioactivity
  - working at LAr temperature

DarkSide Multi-stage Program





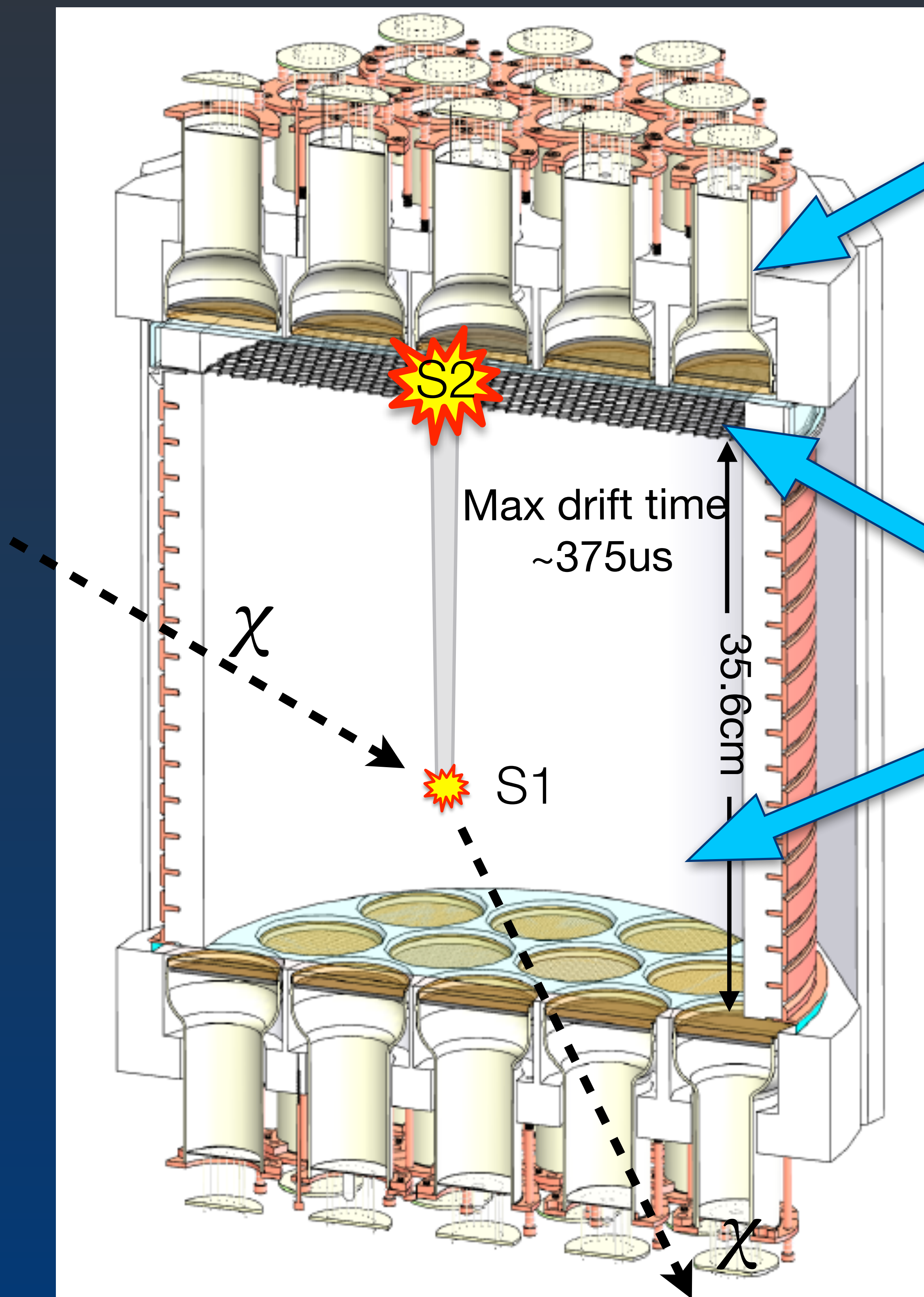


DarkSide-10
Prototype detector
Astropart.Phys. 49 (2013) 44-51

DarkSide-50
First physics detector
recently commissioned
$\sim 10^{-45} cm^2$ @100GeV

DarkSide
Future multi-ton
detector
$\sim 10^{-47} cm^2$ @100GeV

Detecting WIMPs

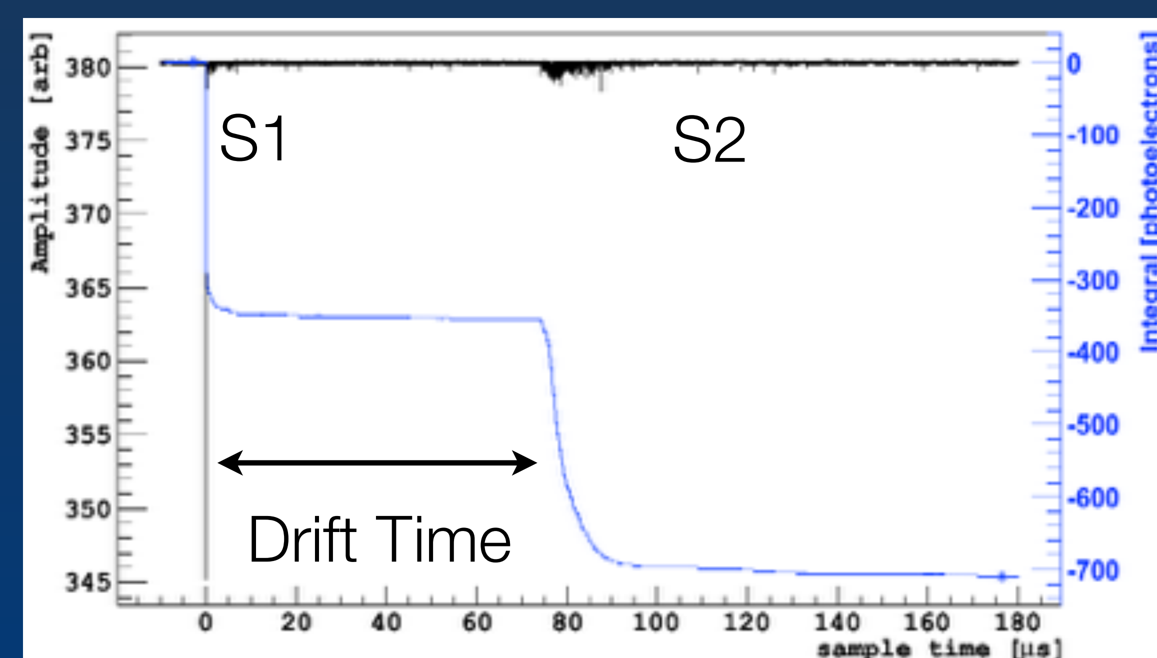


19x2 3” Photomultiplier Tubes
(Top & Bottom)
~20% photocathode coverage
~60% of end plate surface

Total mass: 145kg
Active mass: 49.4kg
Fiducial mass: 44.9kg

Gas Ar (E_{lum} ~ 4200 V/cm)

Liquid Ar (E_{drift} ~ 200 V/cm)



DarkSide 50

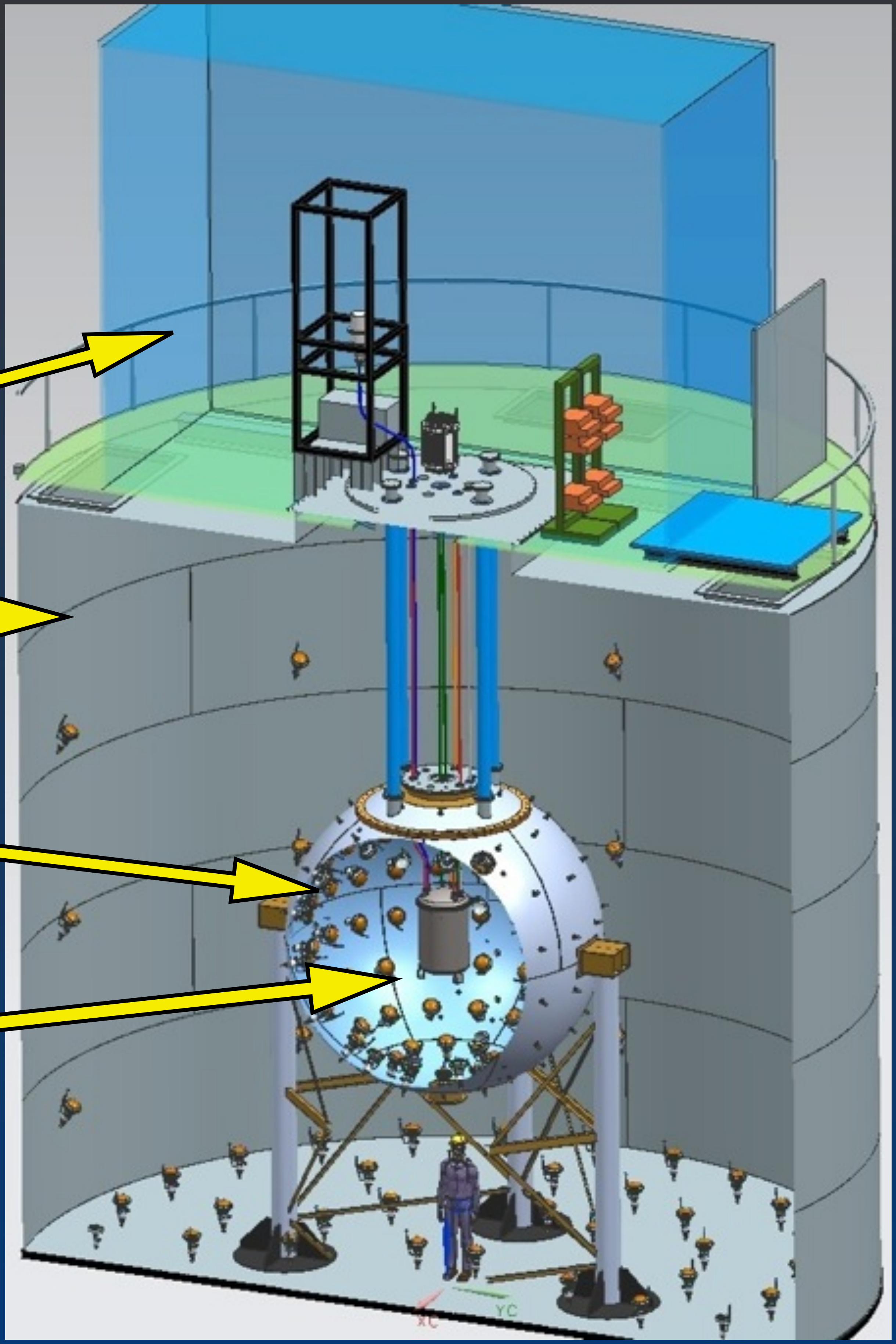
Housed in CTF
Borexino Counting Test Facility

Radon-free clean room

Instrumented water tank

Organic liquid scintillator

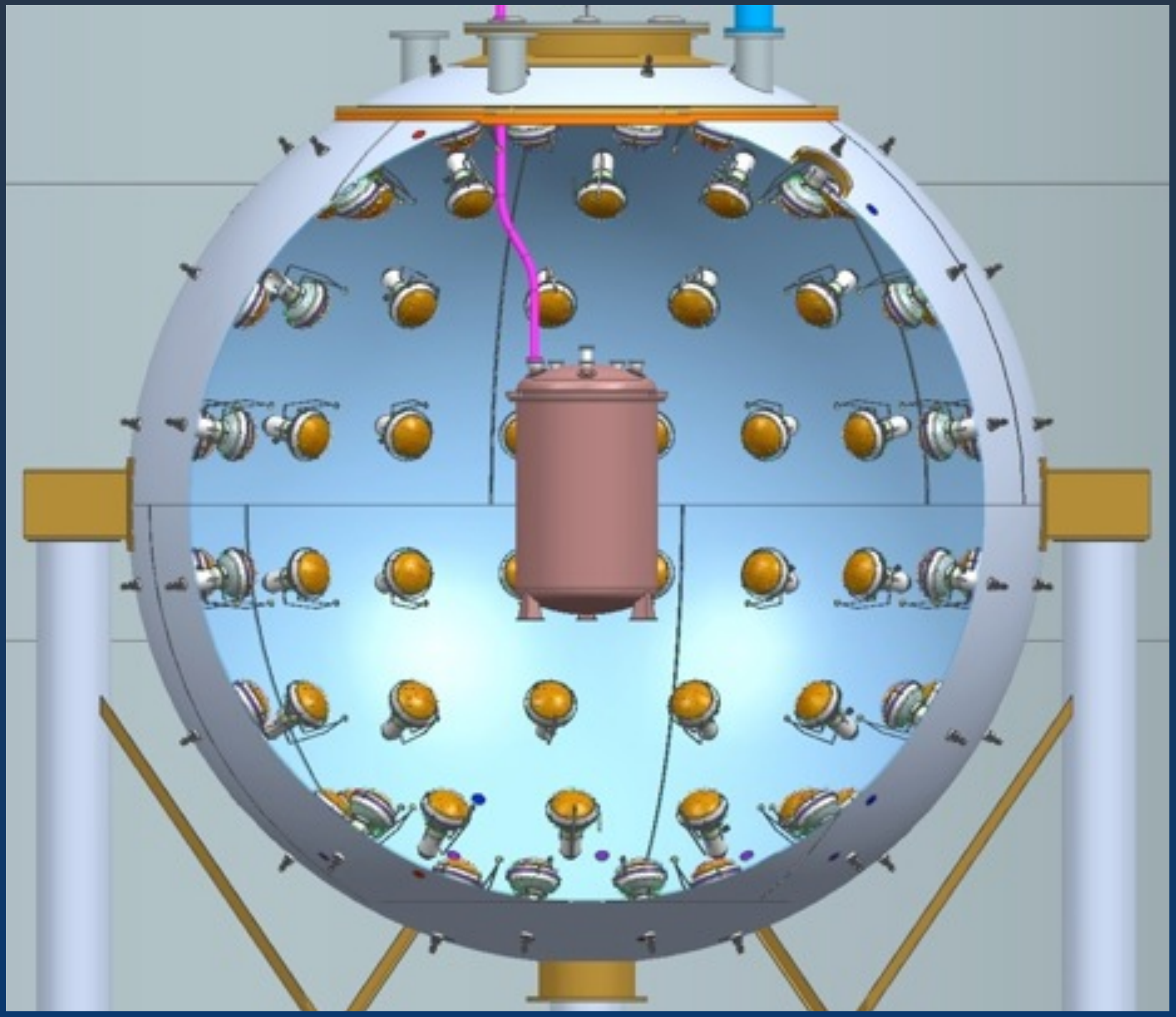
Inner detector TPC



Designed to hold a 5t TPC
within the same Veto system

Liquid Scintillator Veto

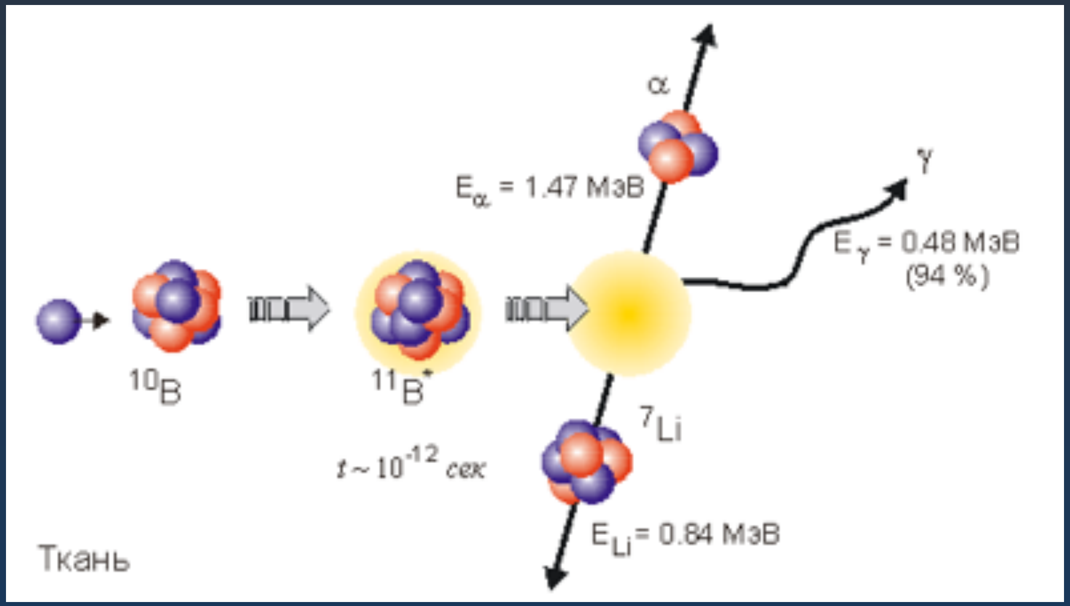
- 4 m diameter sphere containing 1:1 PC + TMB scintillator
- Instrumented with 110 8” PMTs



1. Coincident veto of neutrons in the TPC
2. in situ measurement of the neutron background rate

Borated Liquid Scintillator

- High neutron capture cross section on boron allows for compact veto size
- Short capture time (2.3 μs) reduces dead time loss
- Capture results in 1.47 MeV α particle, quenched to ~50 keV: it must be detected with high efficiency!

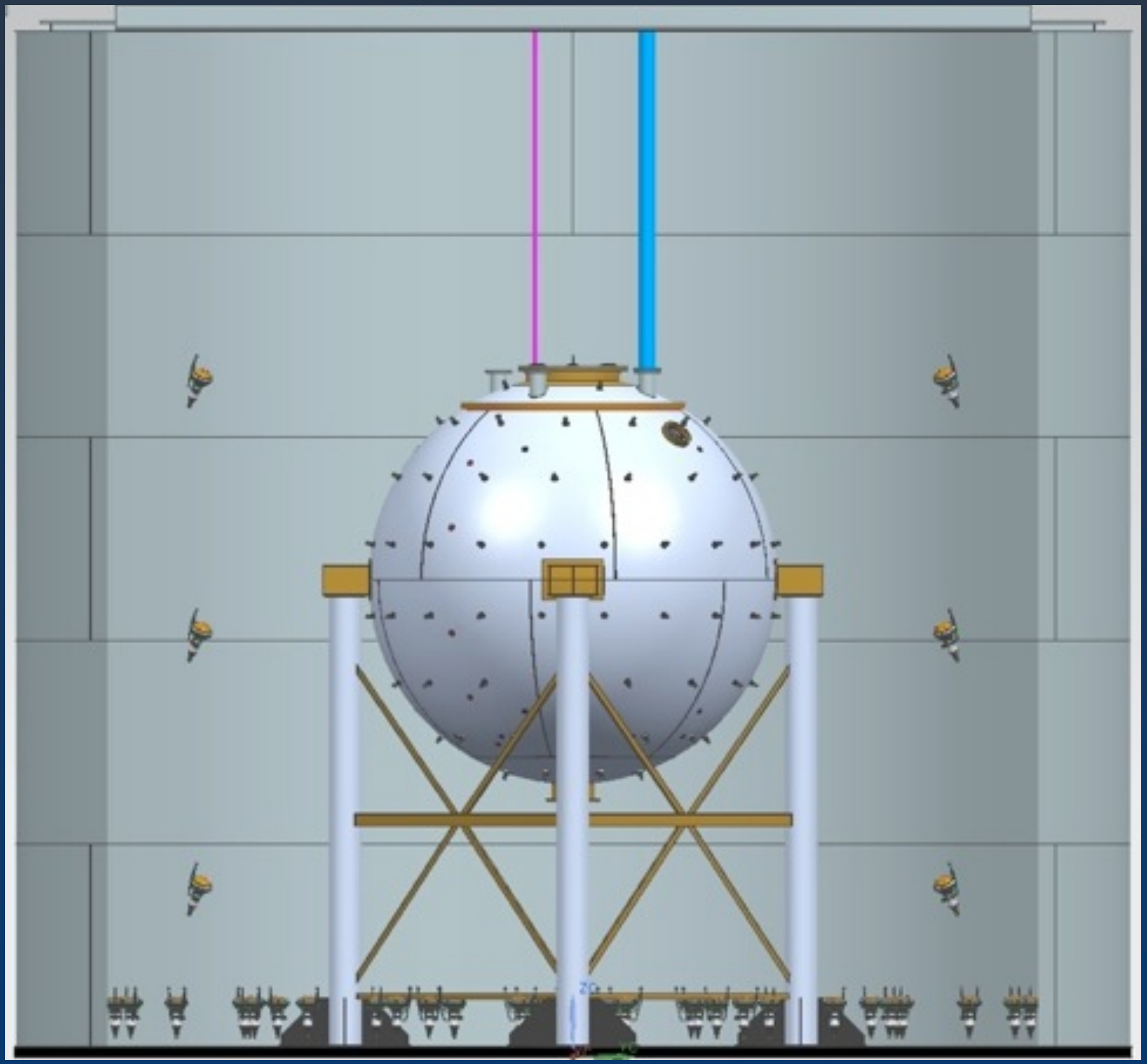


	Veto Efficiency (MC)
Radiogenic Neutrons	> 99%
Cosmogenic Neutrons	> 95%

Nuclear Instruments and Methods A 644, 18 (2011)

External Water tank

- Ultra-pure Water Cherenkov detector (11m dia. x 10 m high)
- 80 8” PMTs from Borexino’s CTF
- Acts as a muon and cosmogenic veto (~ 99% efficiency)
- Provides passive gamma and neutron shielding



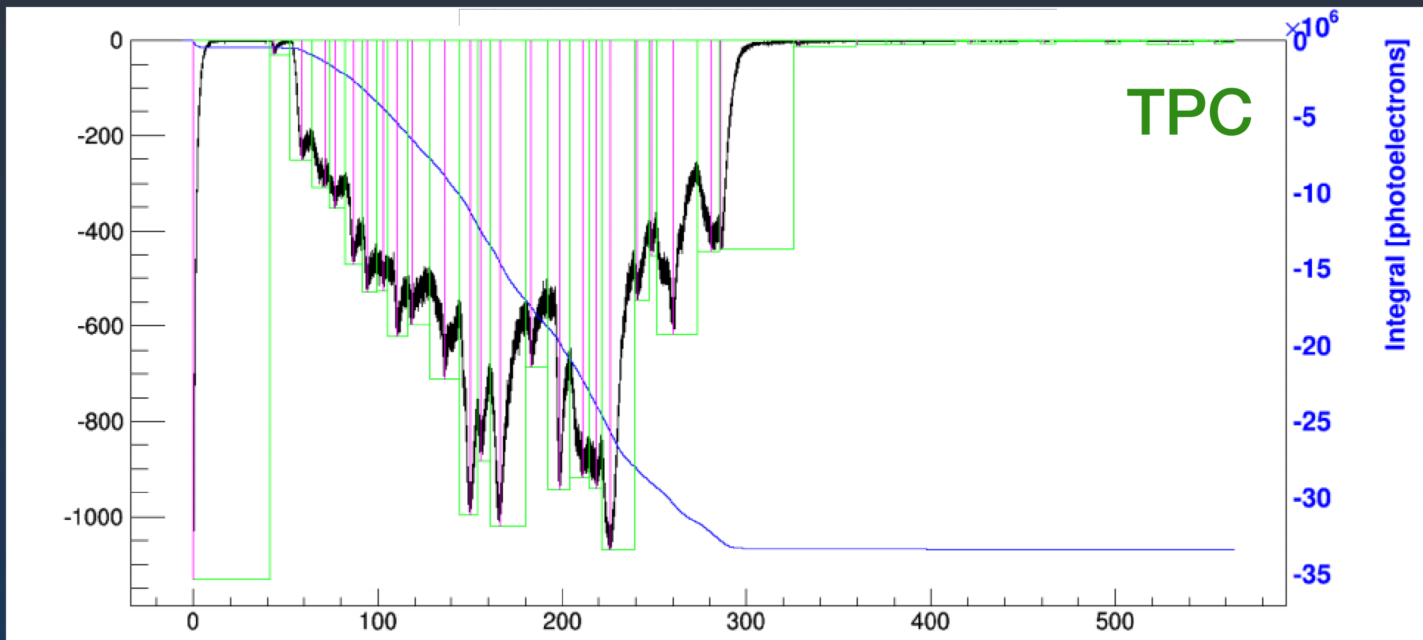
DS-50 Assembly

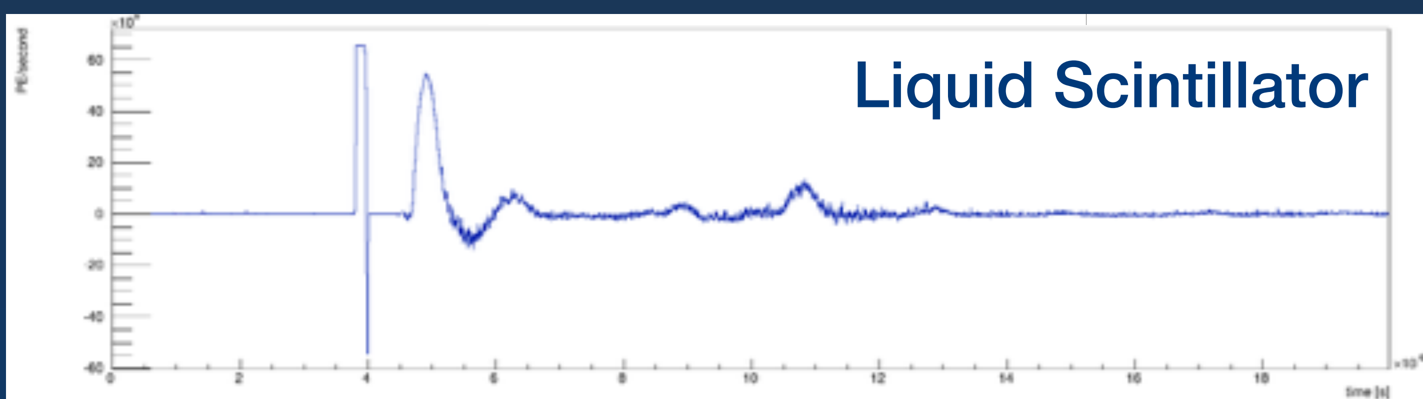
Sept - Oct 2013

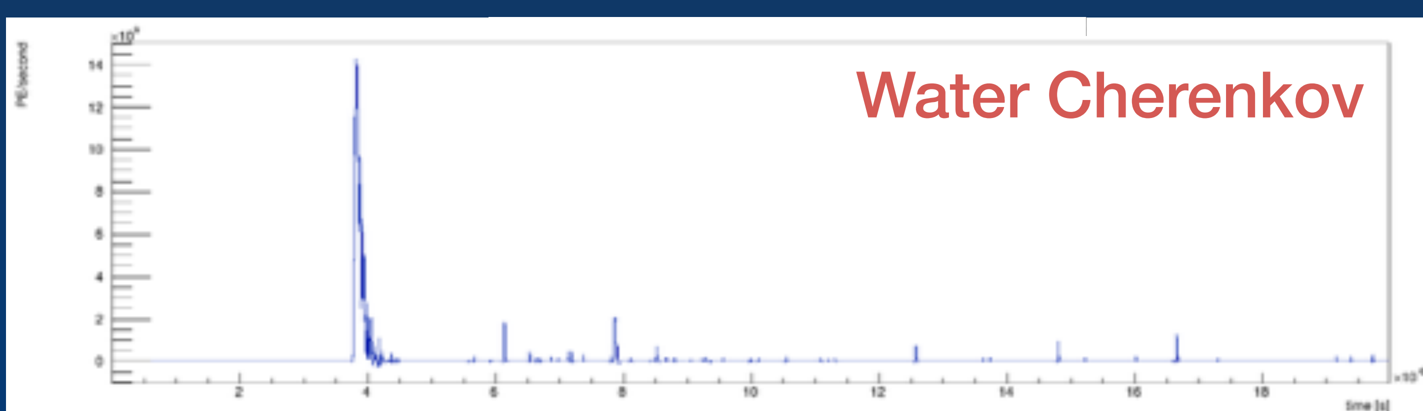
PMTs with cold-amplifiers

- 3” PMTs
- Hamamatsu R11065 series
- The “/20” have good background levels but show problems at nominal gain at LAr temperature
- Require low PMT Gain ~ 4 x 10^5
- Custom cold amplifiers: Noise ~3 μV on 200 MHz

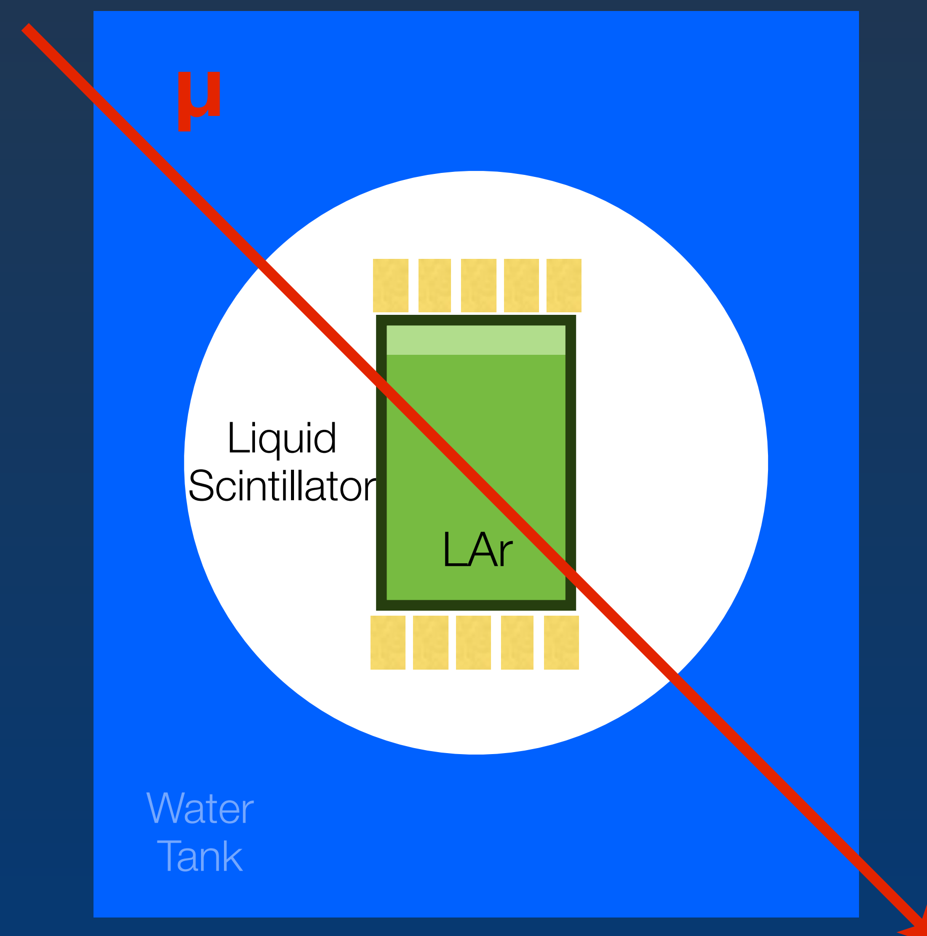
DS-50 Status



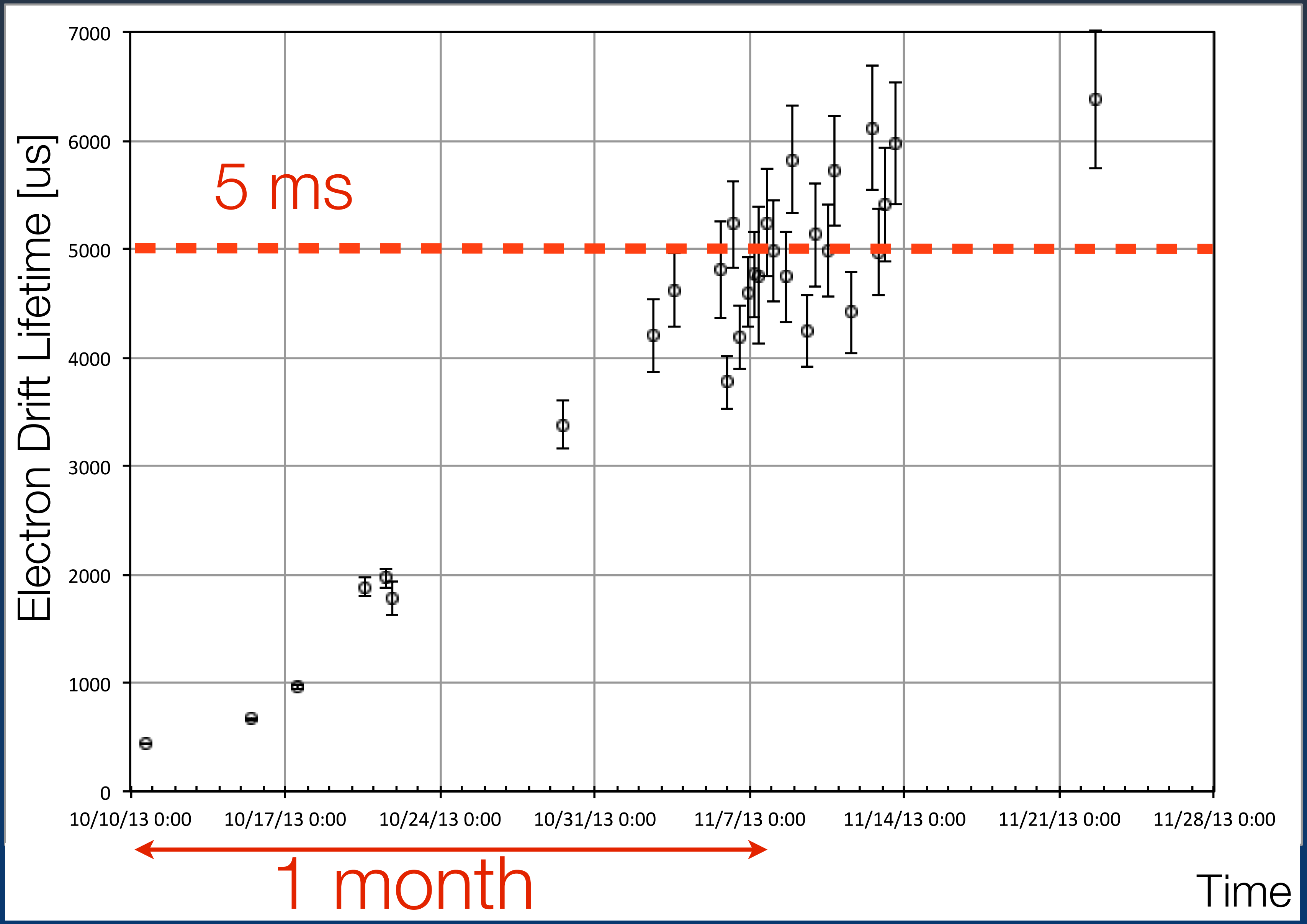




All 3 detectors are filled and currently operating



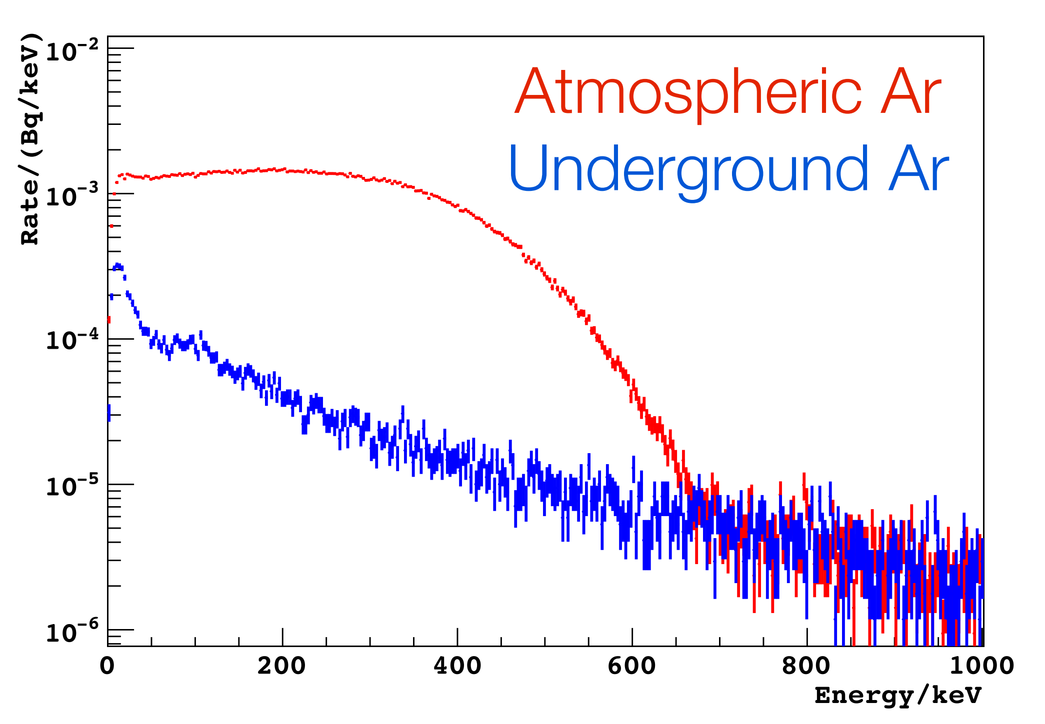
Ar purification: electron lifetime



Electron lifetime **> 5 ms >>** max. drift time ~ **375 us**

^{39}Ar

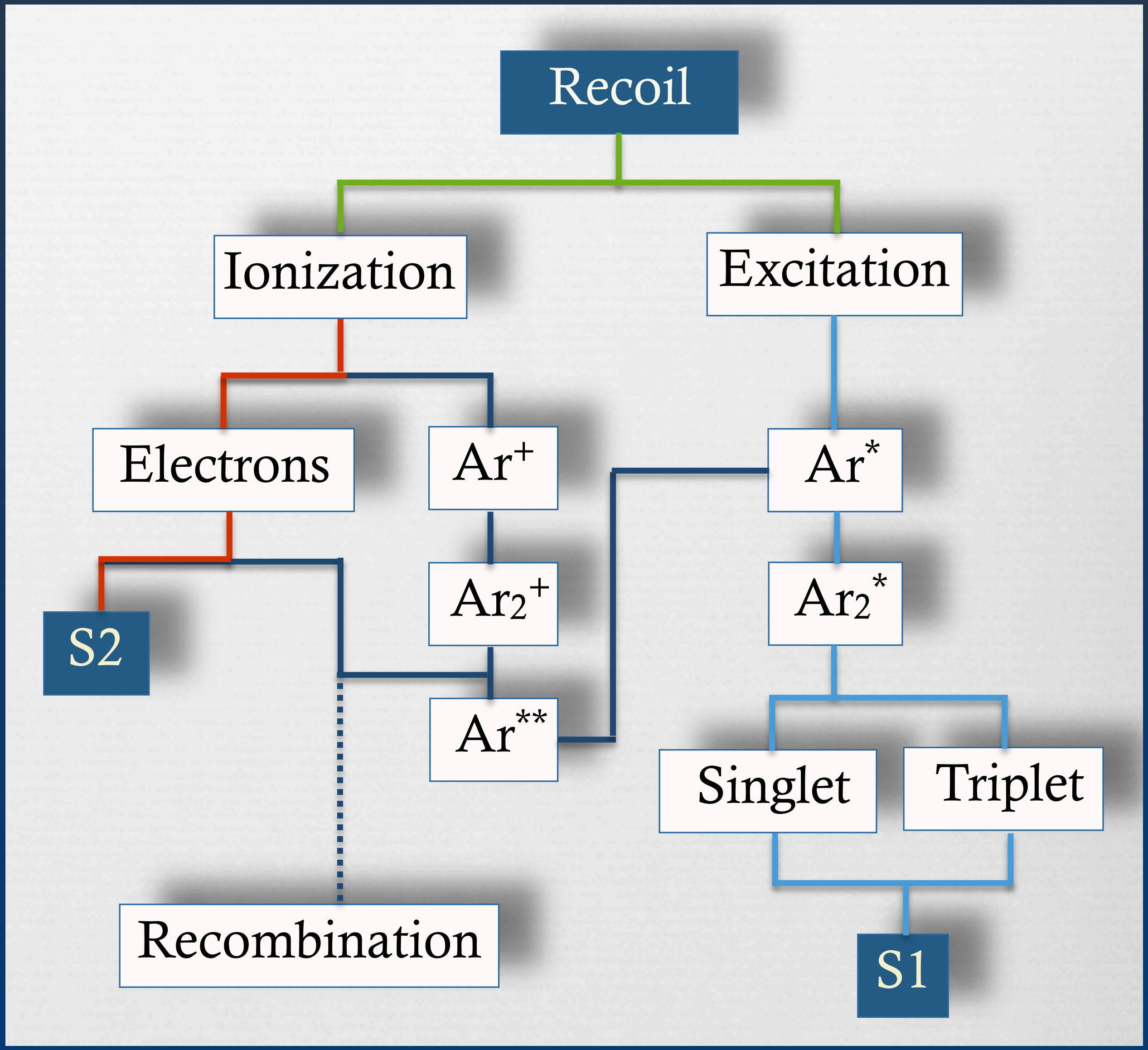
- ~1 Bq/kg in atmospheric argon:
  - primary background for argon-based detectors!
- β emitter with Q_β=565 keV and $T_{1/2}$=269 years
- Cosmogenic via $^{40}Ar(n,2n)^{39}Ar$:
  - in argon from underground sources it can be significantly reduced



Identified source of underground argon in Colorado measured to have <6.5mBq/kg
i.e. > 150 times lower rate compared to atmospheric argon
Plant (including cryogenic distillation at FNAL) produces ~0.5 kg/d

Pulse Shape Discrimination

Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

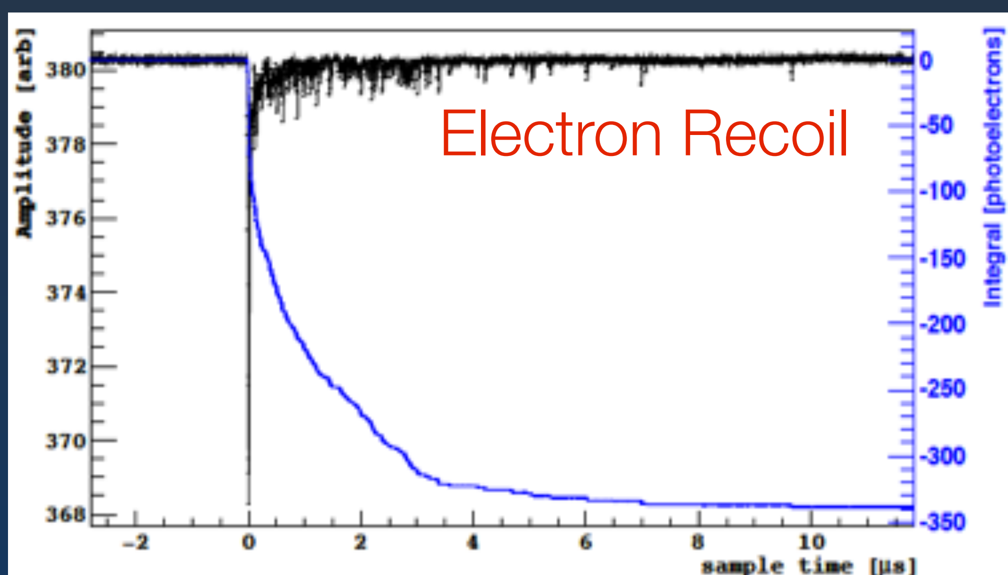


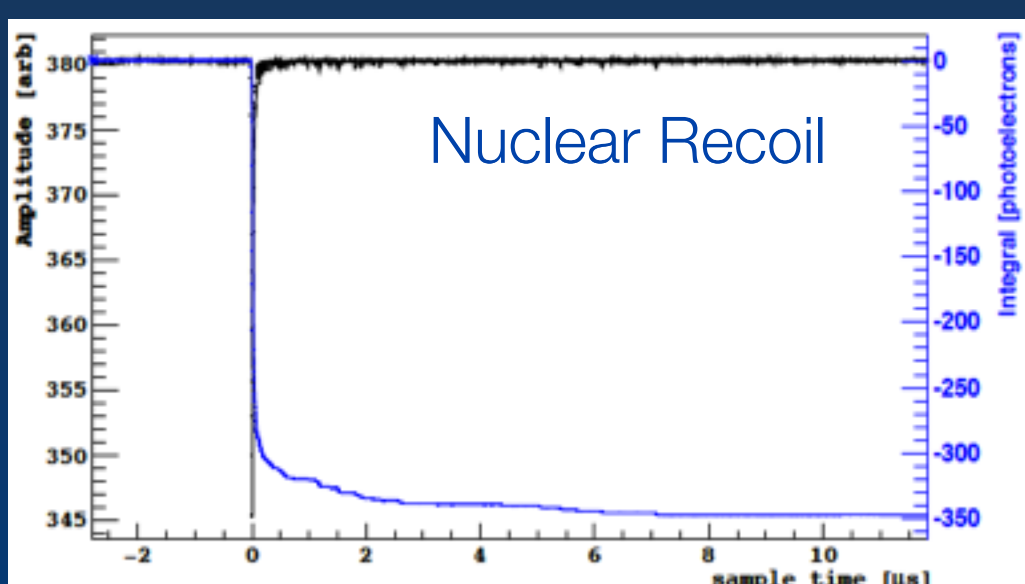
$\tau_{singlet} \sim 7$ ns

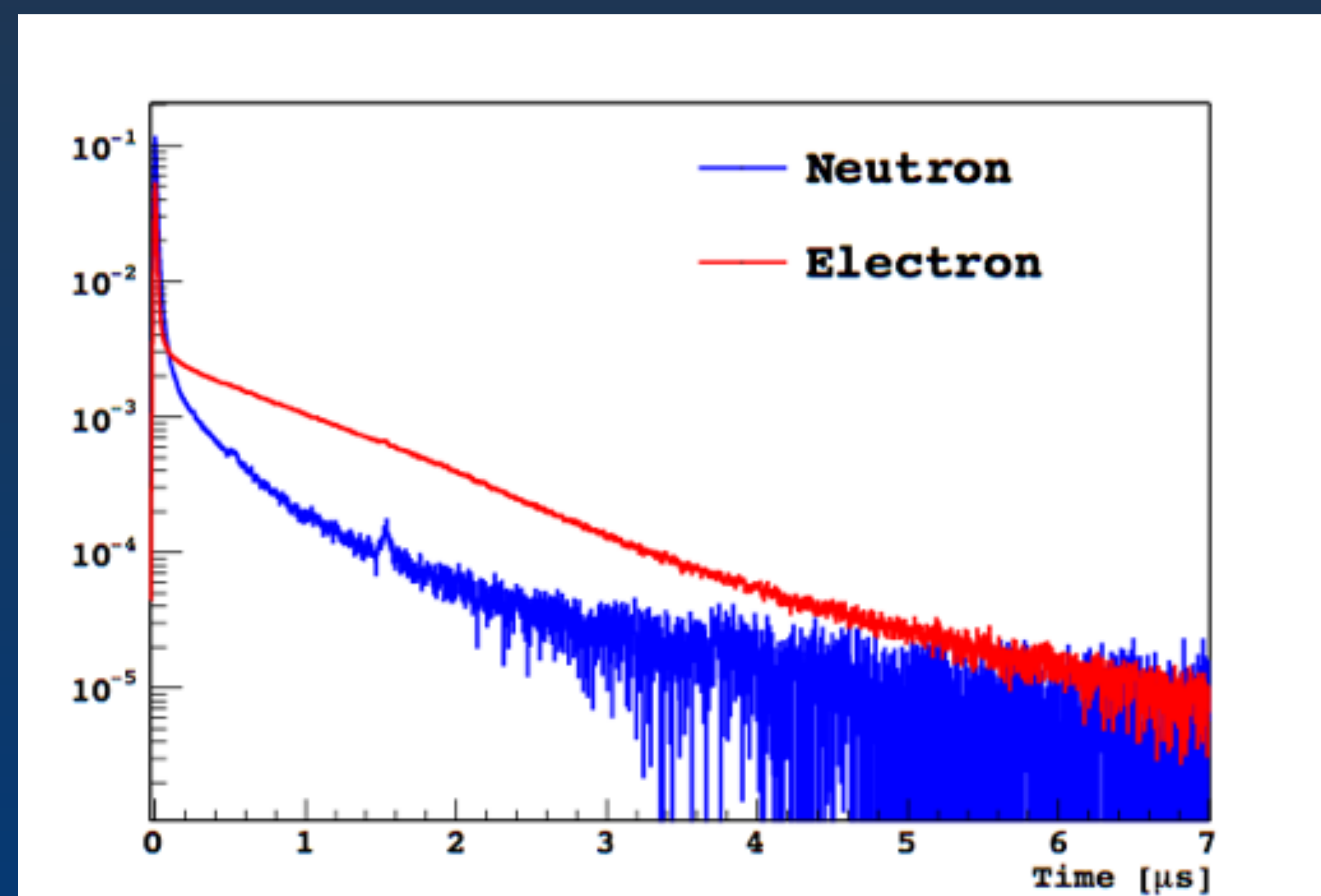
$\tau_{triplet} \sim 1600$ ns

Pulse Shape Discrimination

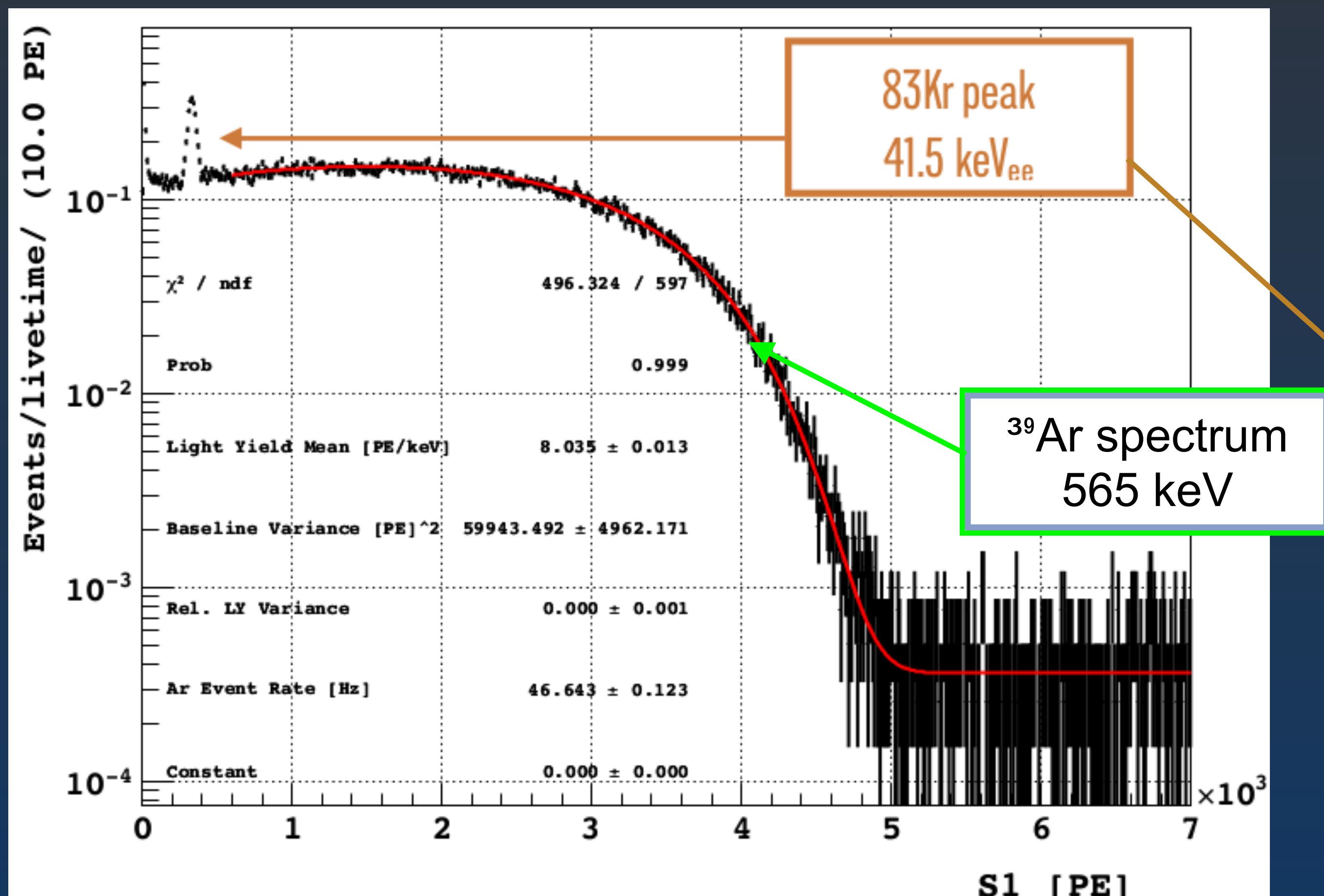
$$F_{90} = \frac{\int_0^{90ns} dt\, f(t)}{\int_0^{\infty} dt\, f(t)} = \begin{cases} 0.3 \text{ ER} \\ 0.7 \text{ NR} \end{cases}$$







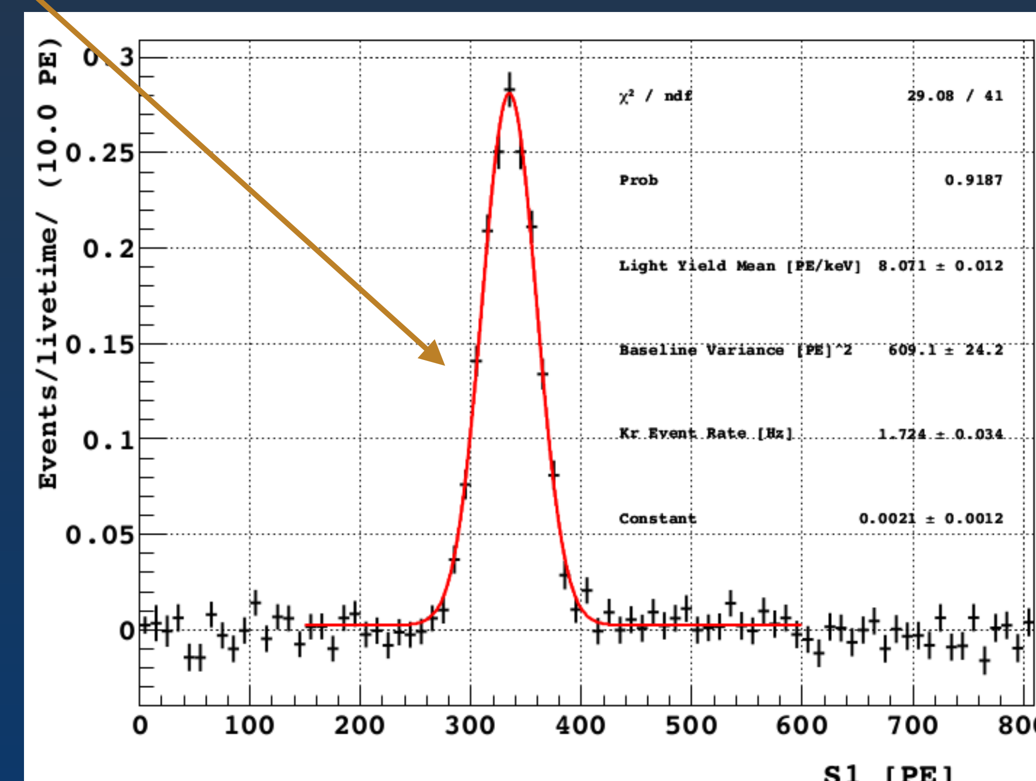
ER Light Yield



^{83m}Kr spike in the recirculation system

$\tau_{1/2}$ ~1.8h

(possibly concentrated near the cathode where S1 light collection is higher)



LY_{null} ~ 8 pe/keV from ^{39}Ar
(energy independent within 3%)

quenching factor from ^{83m}Kr and used to scale the LY_{null}

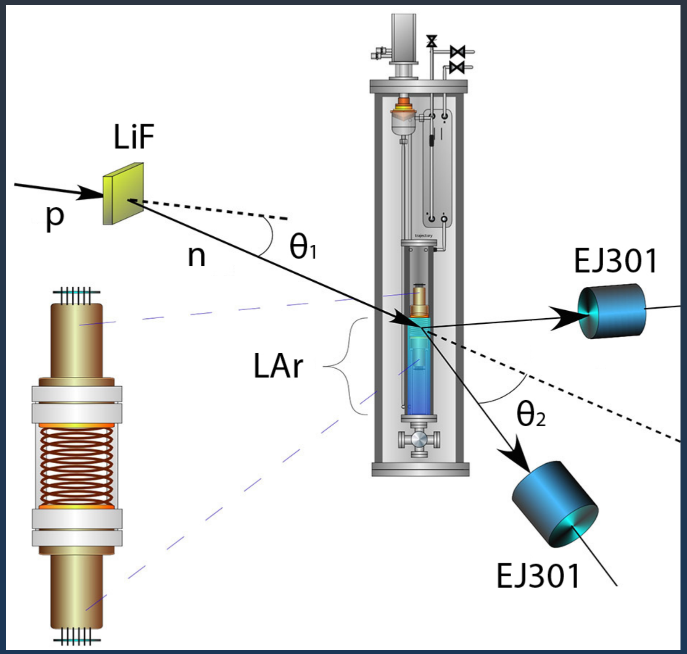
LY_{200} ~7.2 pe/keV at 200 V/cm

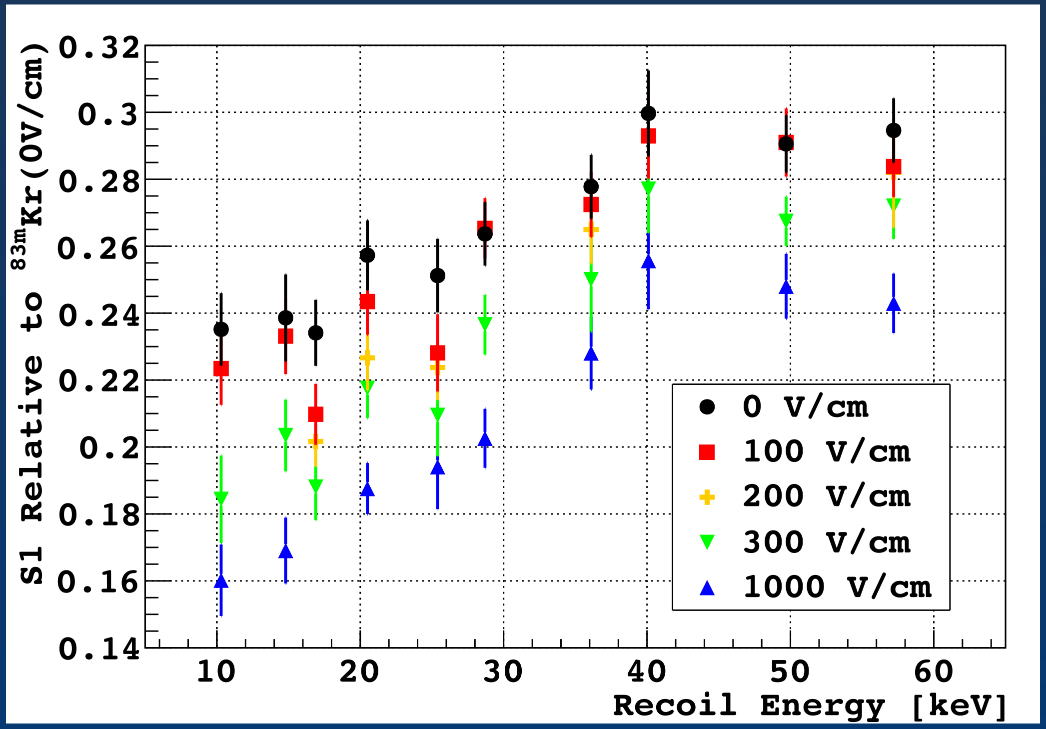
Nuclear Recoil

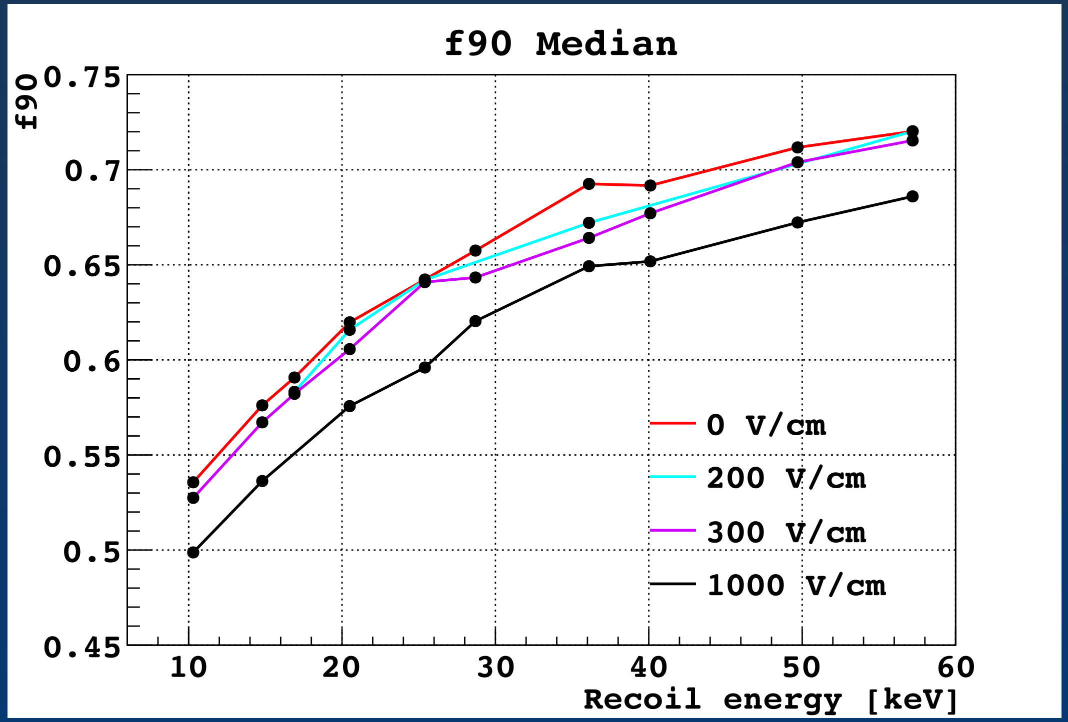
From **SCENE** (SCintillation Efficiency of Noble Elements):

1. nuclear recoil quenching
2. the F90 distribution

by processing SCENE data with DS-50 code and extrapolated to DS-50 detector along with the systematics.



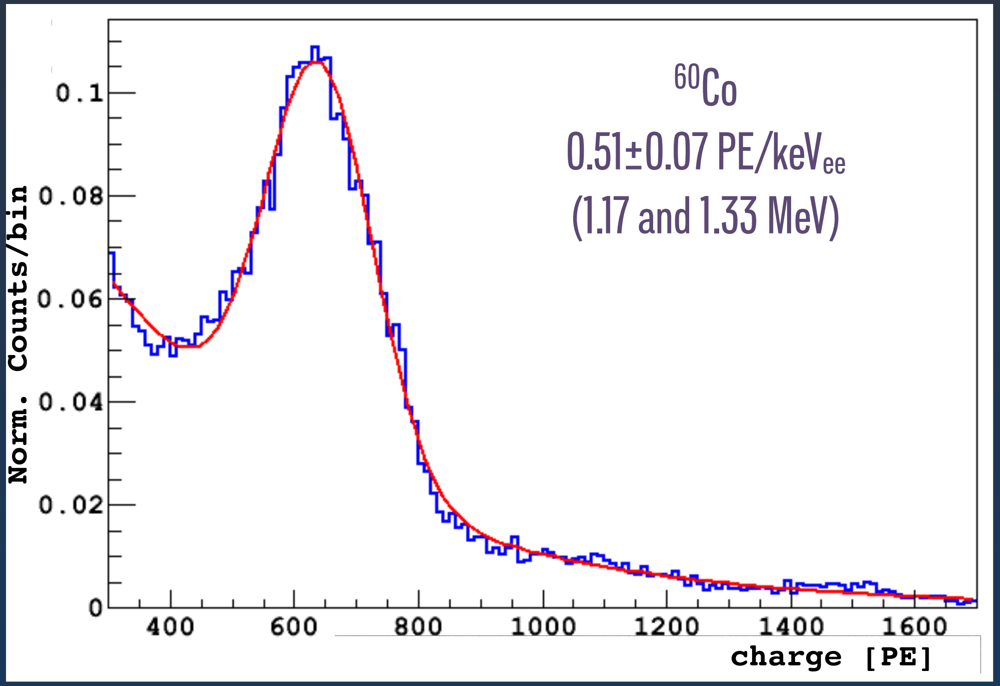




arXiv:1406.4825

Neutron Veto Commissioning

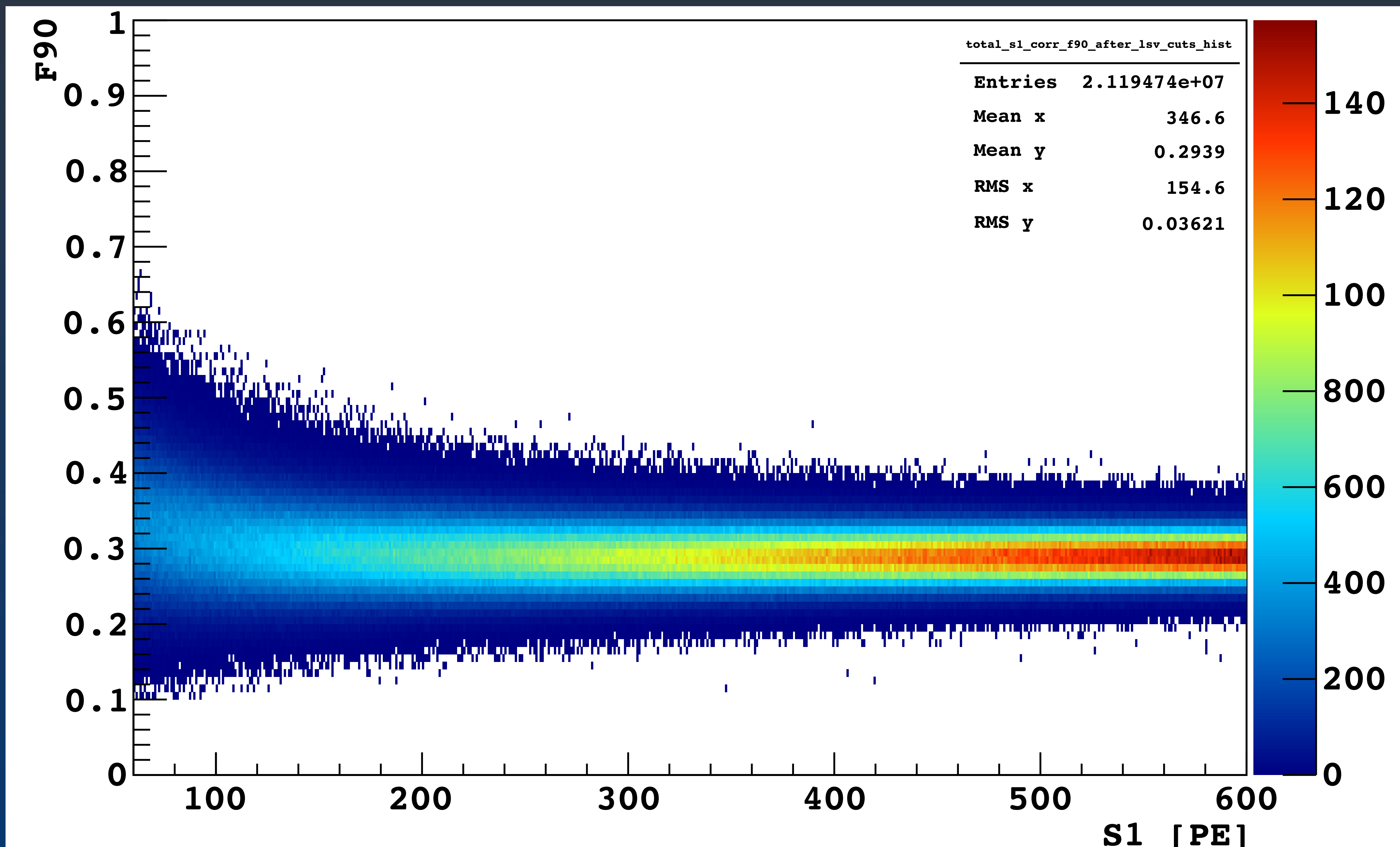
Use high energy coincident ^{60}Co events from cryostat stainless steel to evaluate Light Yield in scintillator.
Confirmed by ^{14}C and ^{208}Tl fits.



Light yield ~0.5 PE/keV sufficient to detect ~ 50 keV$_{ee}$

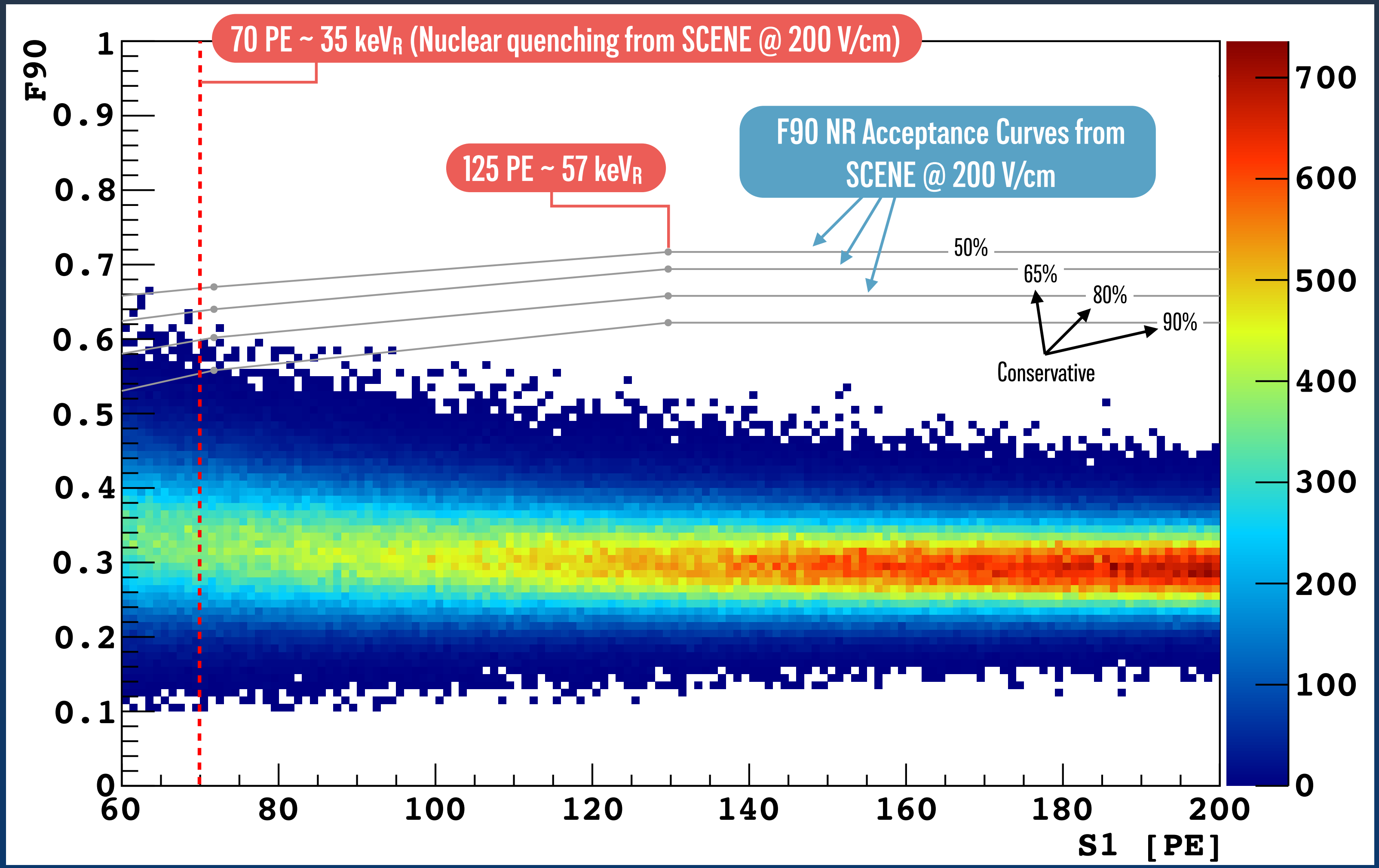
- Found high rate of intrinsic ^{14}C in (biogenic) TMB: ~10^{-13} g/g
- TMB temporarily removed via distillation: currently running in pure PC-mode
- Identified <u>new batch of low-^{14}C</u> (underground) TMB (<10^{-15}g/g) to be used in October 2014

Initial Exposure (280 kg-days)



Initial Exposure (280 kg-days)

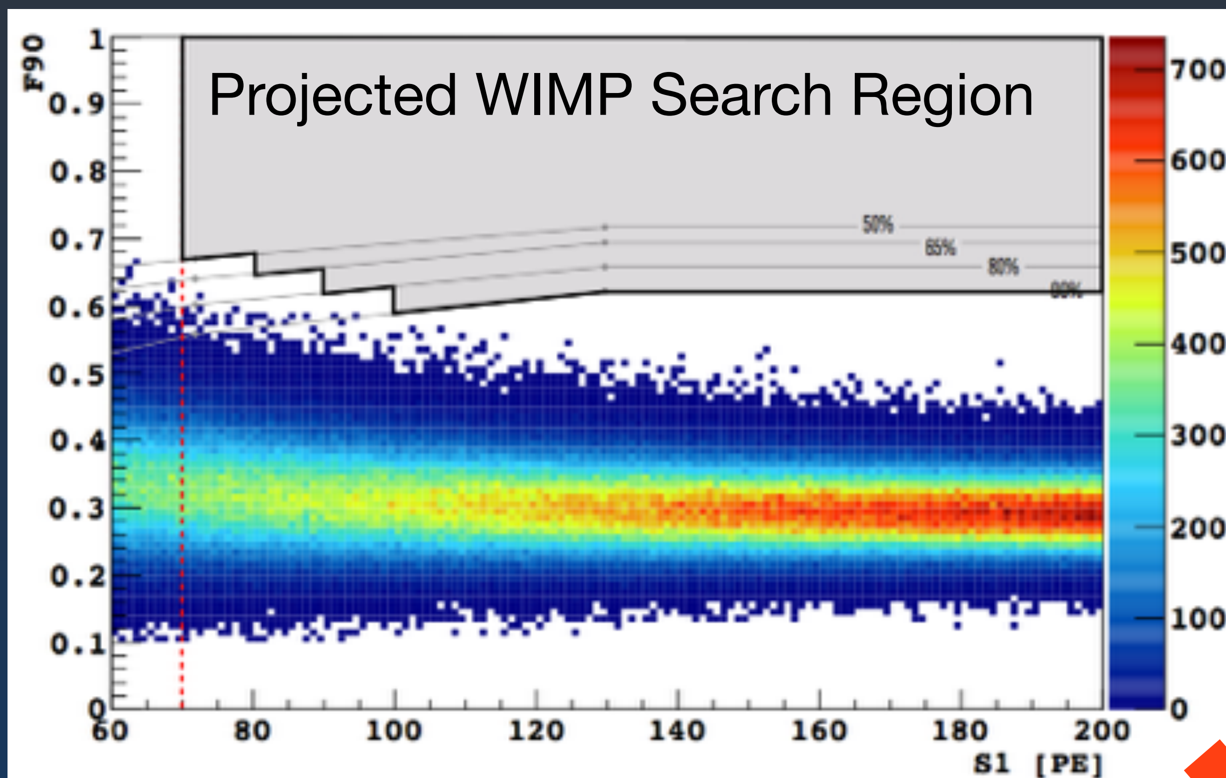
High rate of ^{39}Ar in AAr allows us to calibrate our S1-PSD with an exposure equivalent to 2.6y with UAr



- Single hit events (1 S1 and 1 S2)
- z-cuts to remove regions near grid and cathode
- No coincident energy deposition in the neutron veto

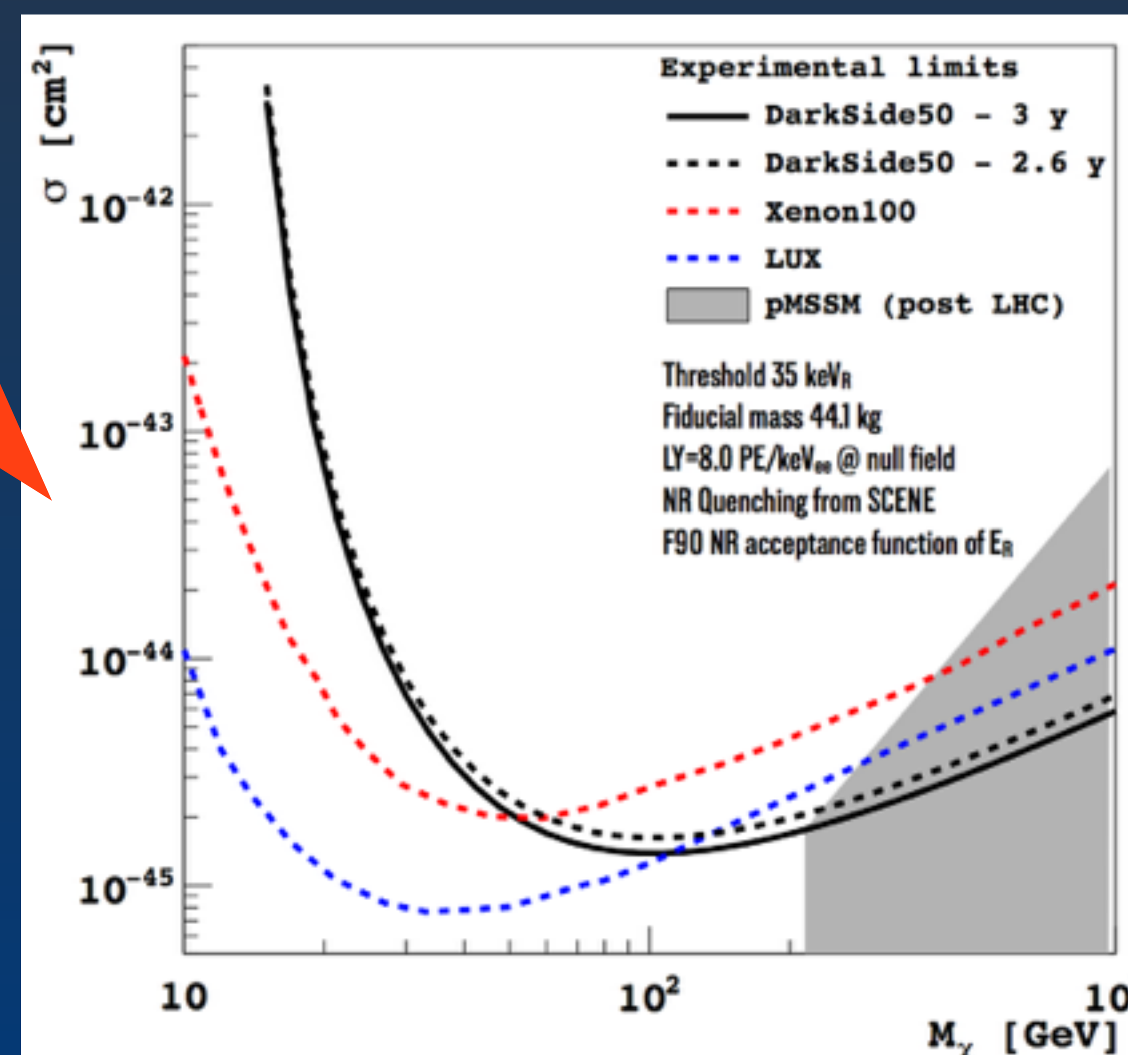
We have **PROVEN** that PSD @ 200 V/cm can efficiently suppress the dominant ER background that we expect in 2.6 years of DS-50 UAr run, while maintaining high acceptance for WIMPs.

DS-50 Projected Sensitivity



Systematics

Estimates of systematics on NR quenching and pulse shape cause a ~10% variation at 100 GeV/c^2

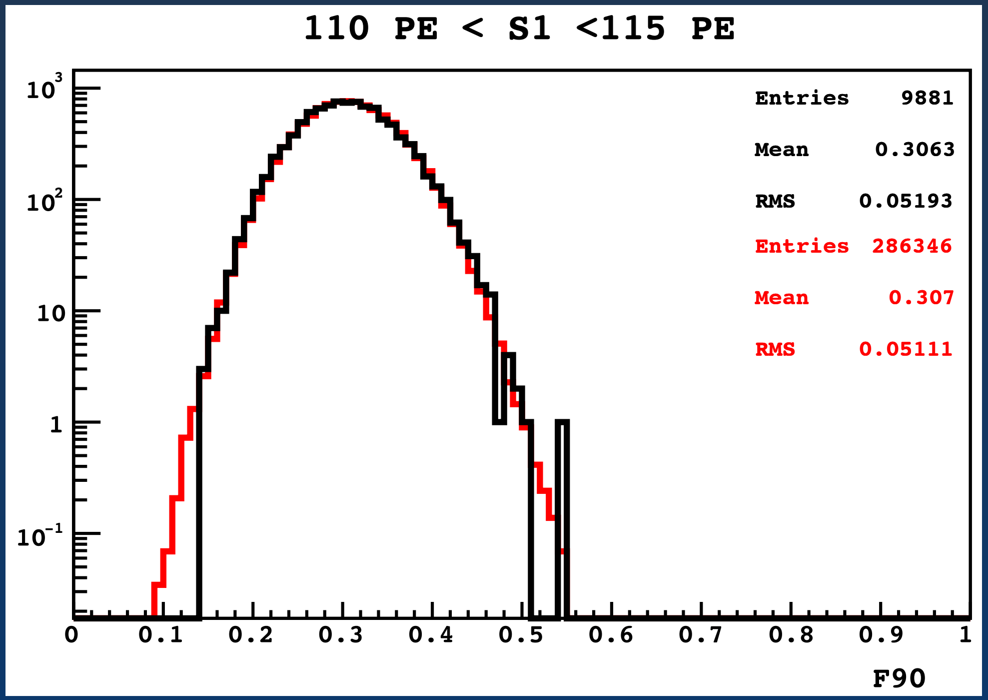


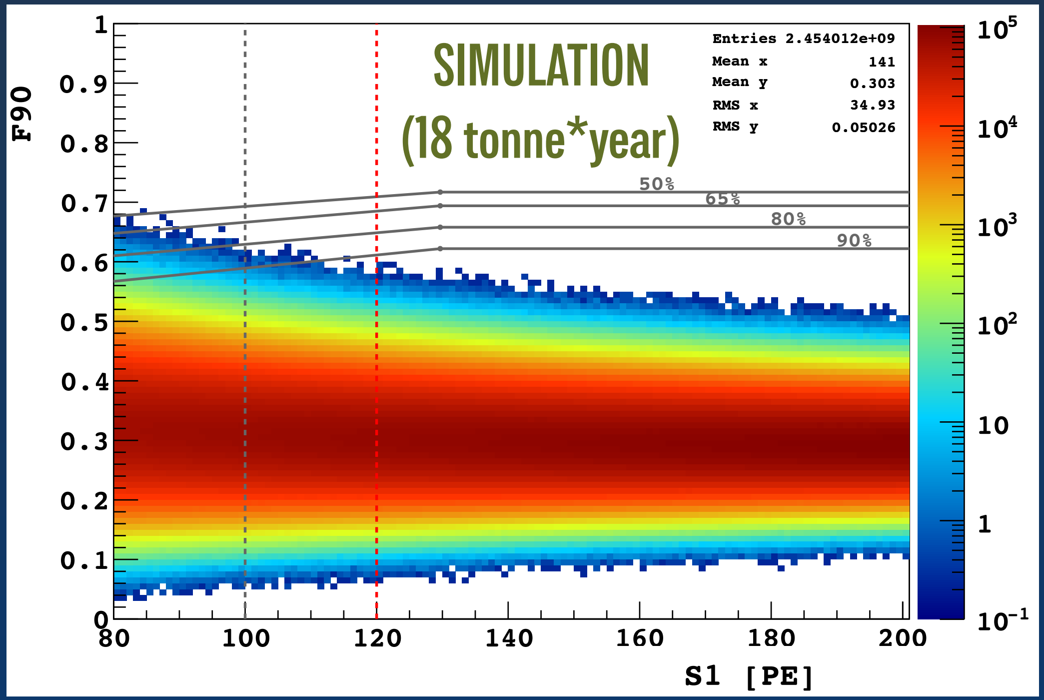
Assumptions

- PSD as demonstrated
- No S2/S1 rejection
- Fiducial mass ~ 44 kg (z-cut only)
- NR energy & pulse shape taken from SCENE

PSD Model

Model the **statistical** properties of F90 using statistical distributions of the underlying processes with parameters taken from data.
The model accounts for macroscopic effects related to argon micro-physics, detector properties, reconstruction and noise effects.

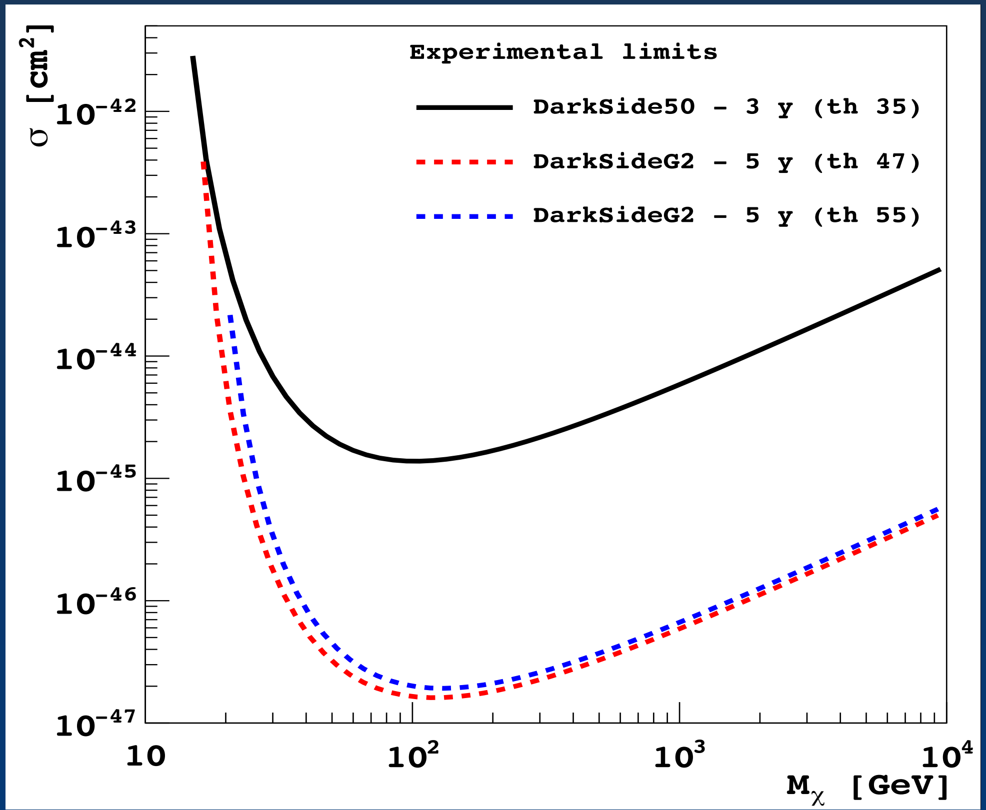


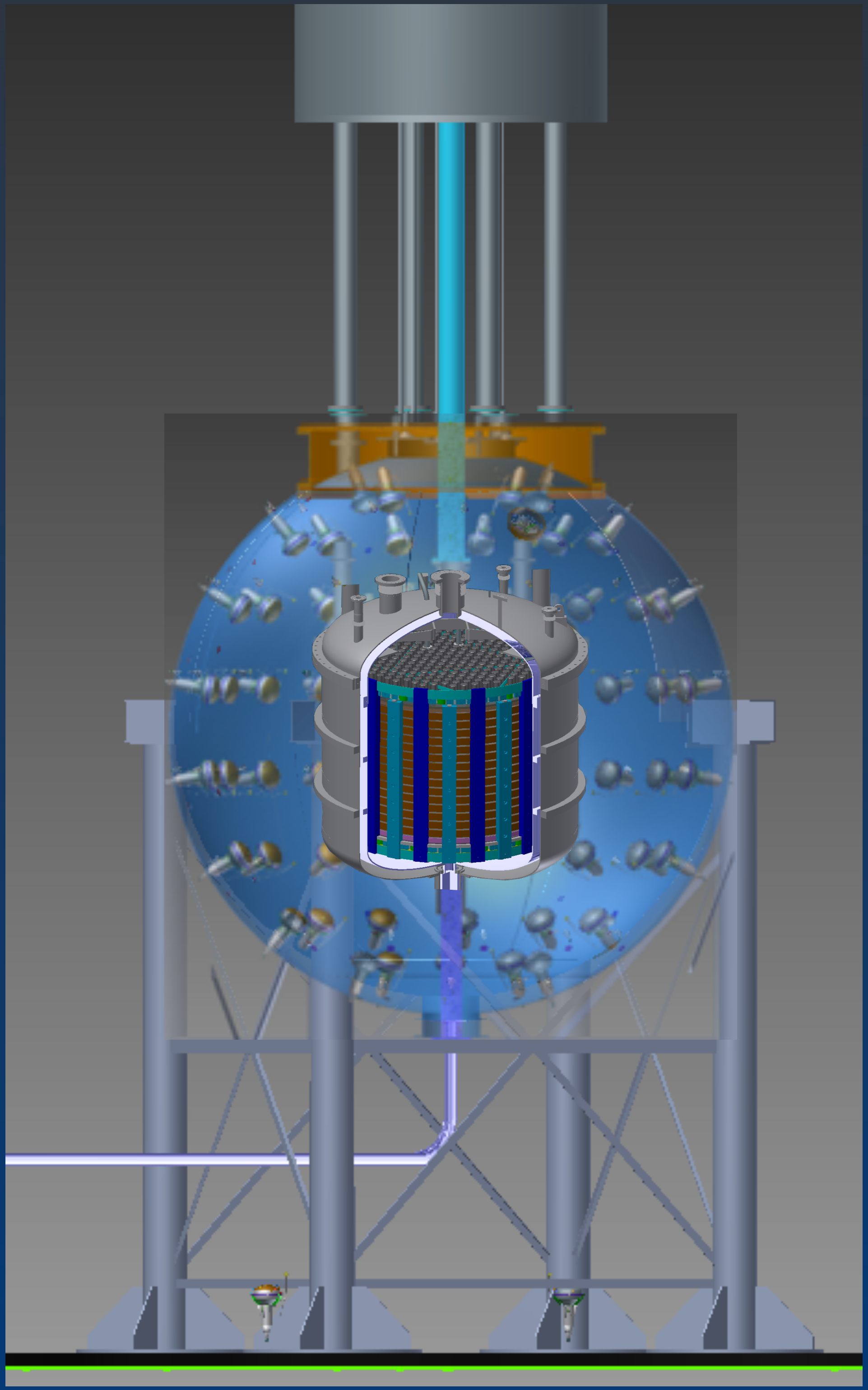


Simulated F90 distribution for a DS upgrade of 3.8t fiducial mass and 5 years run, assuming the ER bkg will be dominated by ^{39}Ar at its present upper limit.

DarkSide multi-ton

- Next generation experiment designed to have up to 3.8 ton active mass
- Neutron veto and water tank were sized to hold the new detector
- Modest upgrade of cryogenic and gas handling system required





Conclusions

- ➡ DS-50 TPC and Vetoes are fully operational at LNGS:
  1. Long electron lifetime achieved
  2. Exceeded desired light yield
  3. Excellent discrimination power from PSD
     (including z fiducialization, multi-hit cut and vetoes).
- ➡ Currently acquired ~5000 kg·d of AAr data with TPC (50% with Veto);
  under study:
  1. improve understanding of backgrounds,
  2. S2 signal
  3. x-y position reconstruction,
  4. S1-S2 correlations
- ➡ High ^{14}C in TMB in Neutron Veto, currently operating in pure PC mode:
  low-^{14}C TMB in October 2014
- ➡ Source calibration
  Gamma and neutron data in september 2014
- ➡ Underground argon
  Switch to using underground argon foreseen at the end of 2014

THE END

Sensitivity Comparison