

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) ?

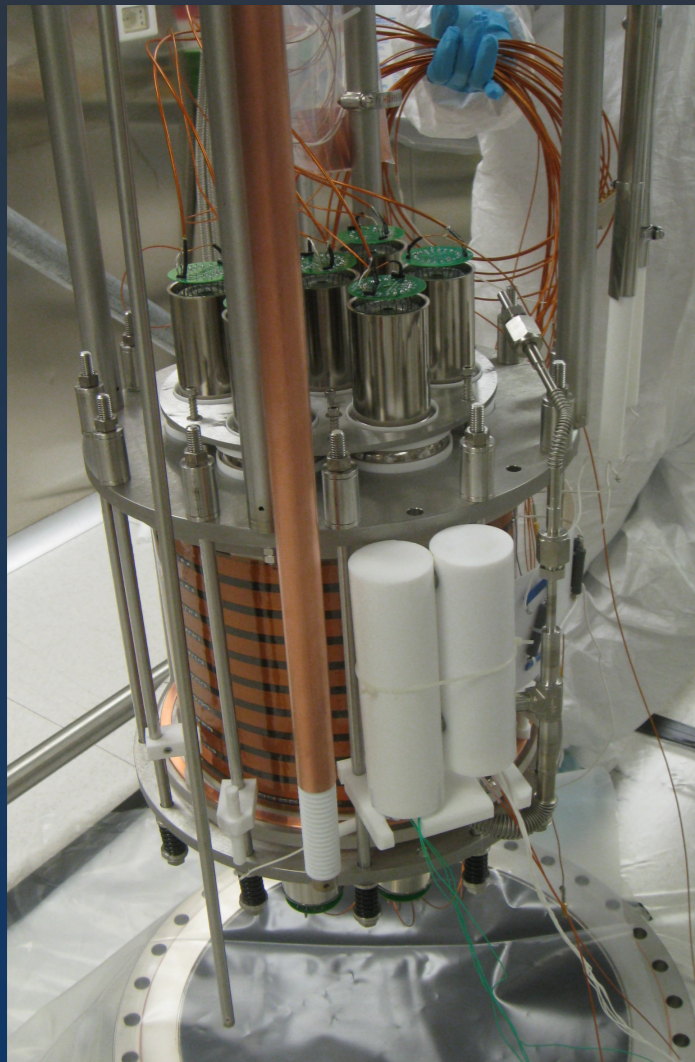
LAr advantages

- **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.

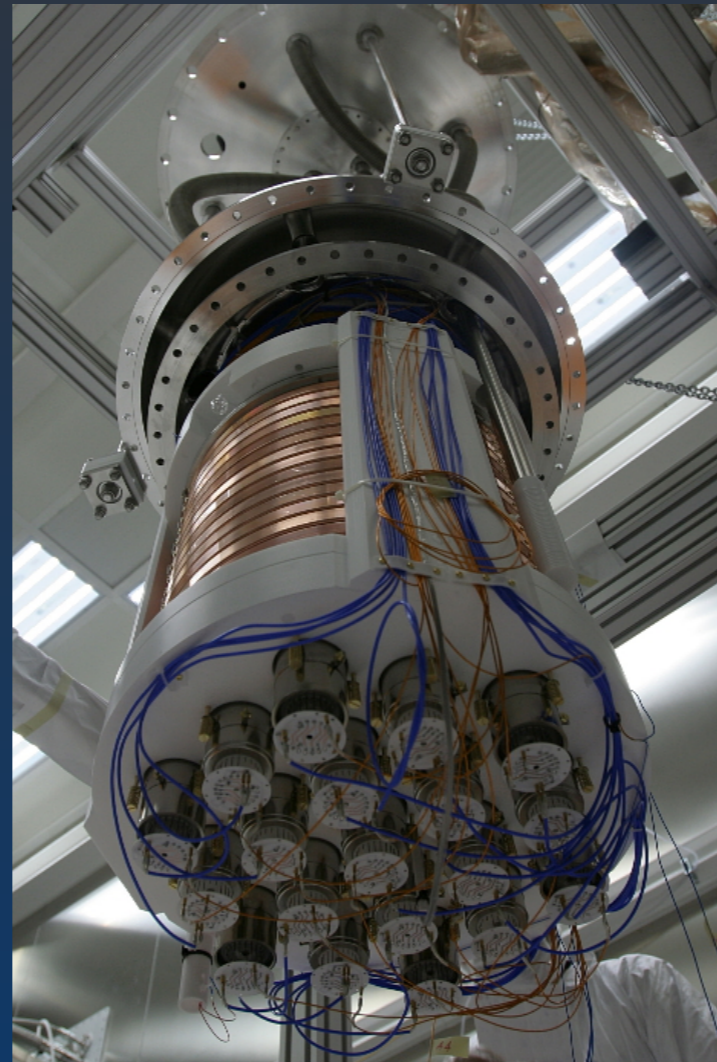
LAr disadvantages

- 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

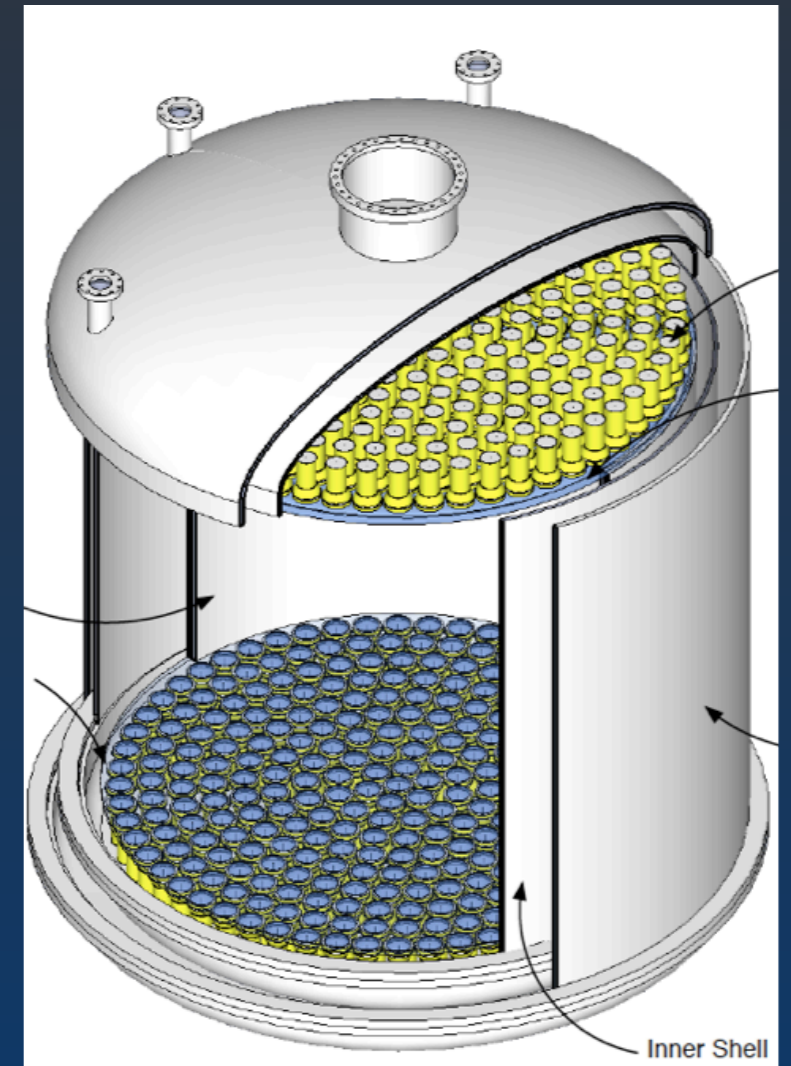
DarkSide Multi-stage Program



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

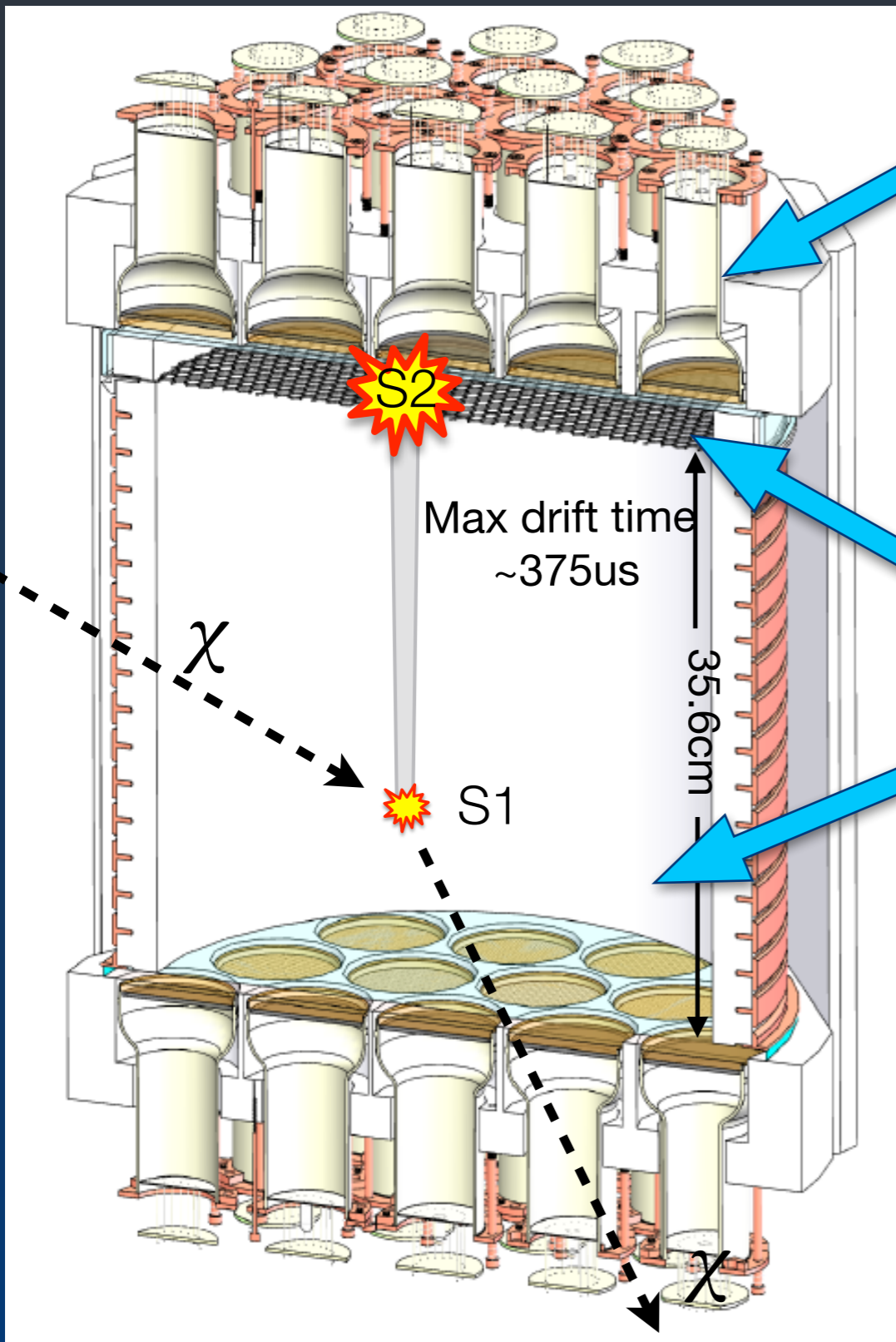


DarkSide-50
First physics detector
recently commissioned
 $\sim 10^{-45} \text{cm}^2 @ 100 \text{GeV}$



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

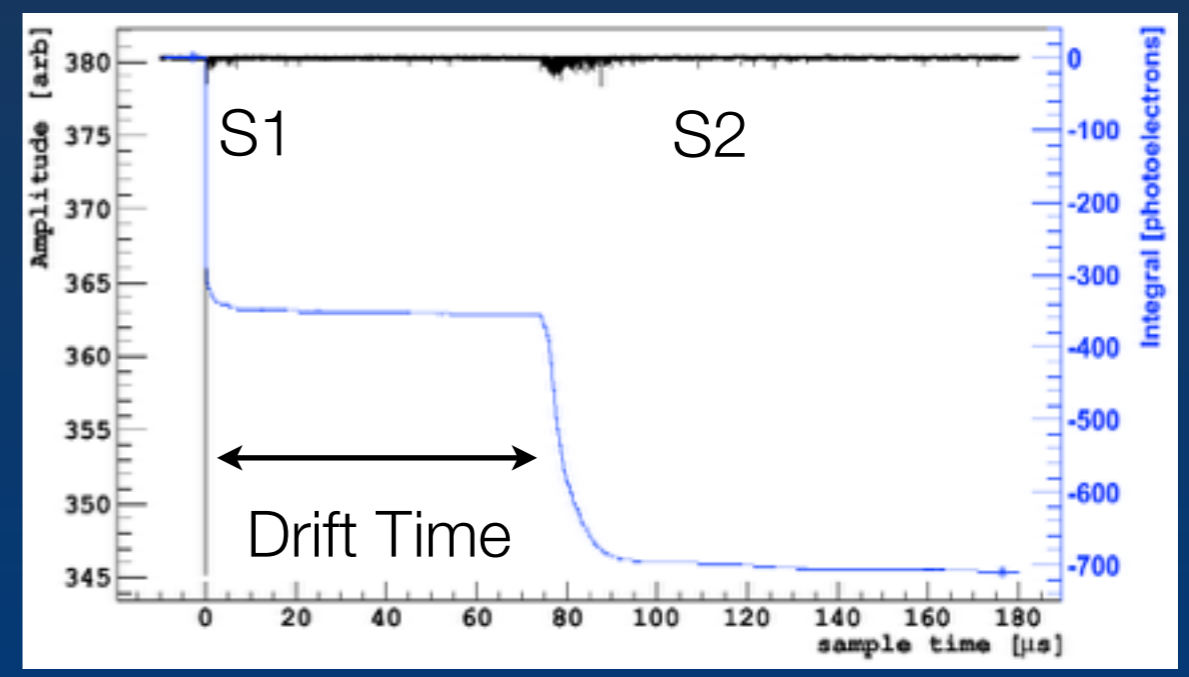
Detecting WIMPs



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 ($E_{lum} \sim 4200$ V/cm)
Liquid Ar ($E_{drift} \sim 200$ V/cm)



DarkSide 50

Housed in CTF
Borexino Counting Test Facility

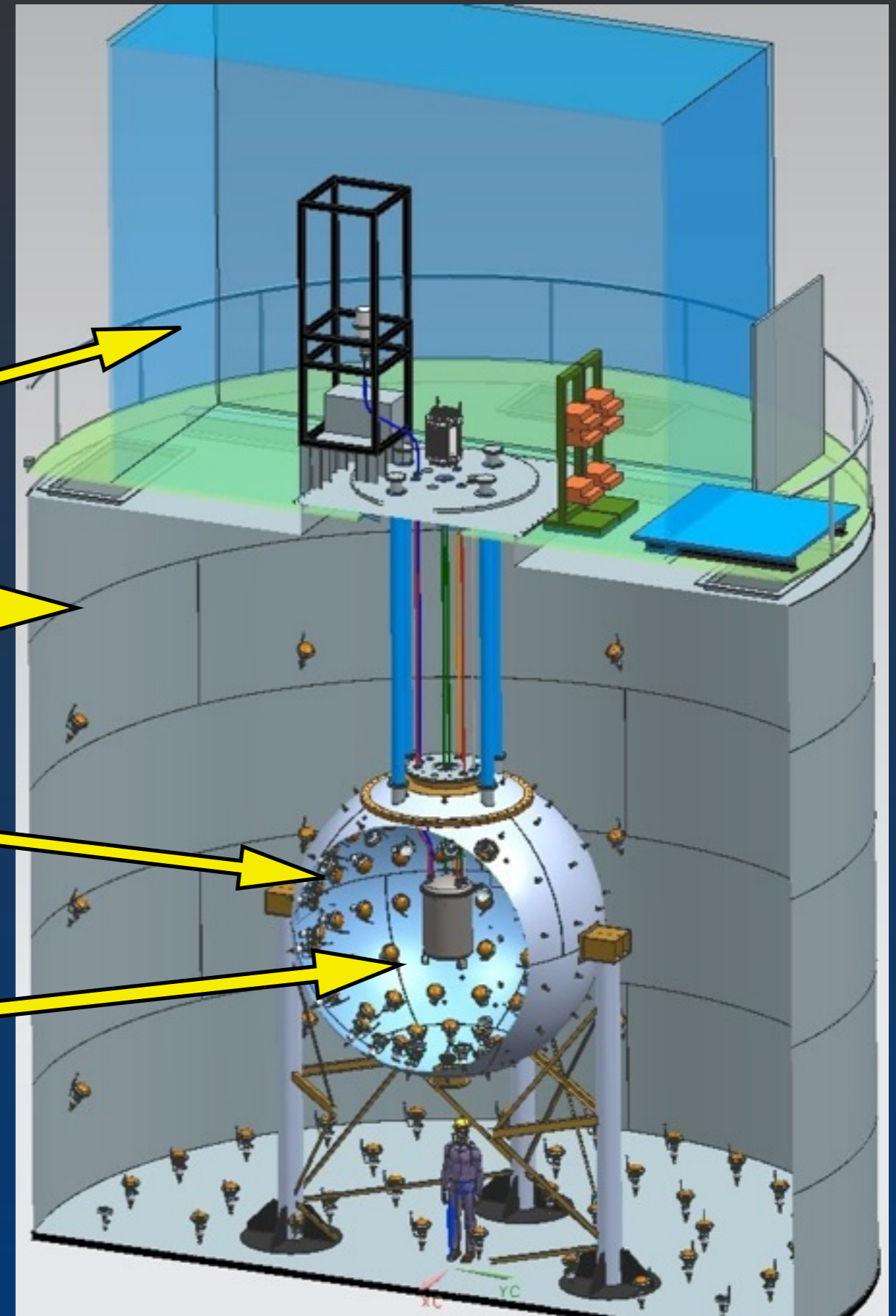
Radon-free clean room

Instrumented water tank

Organic liquid scintillator

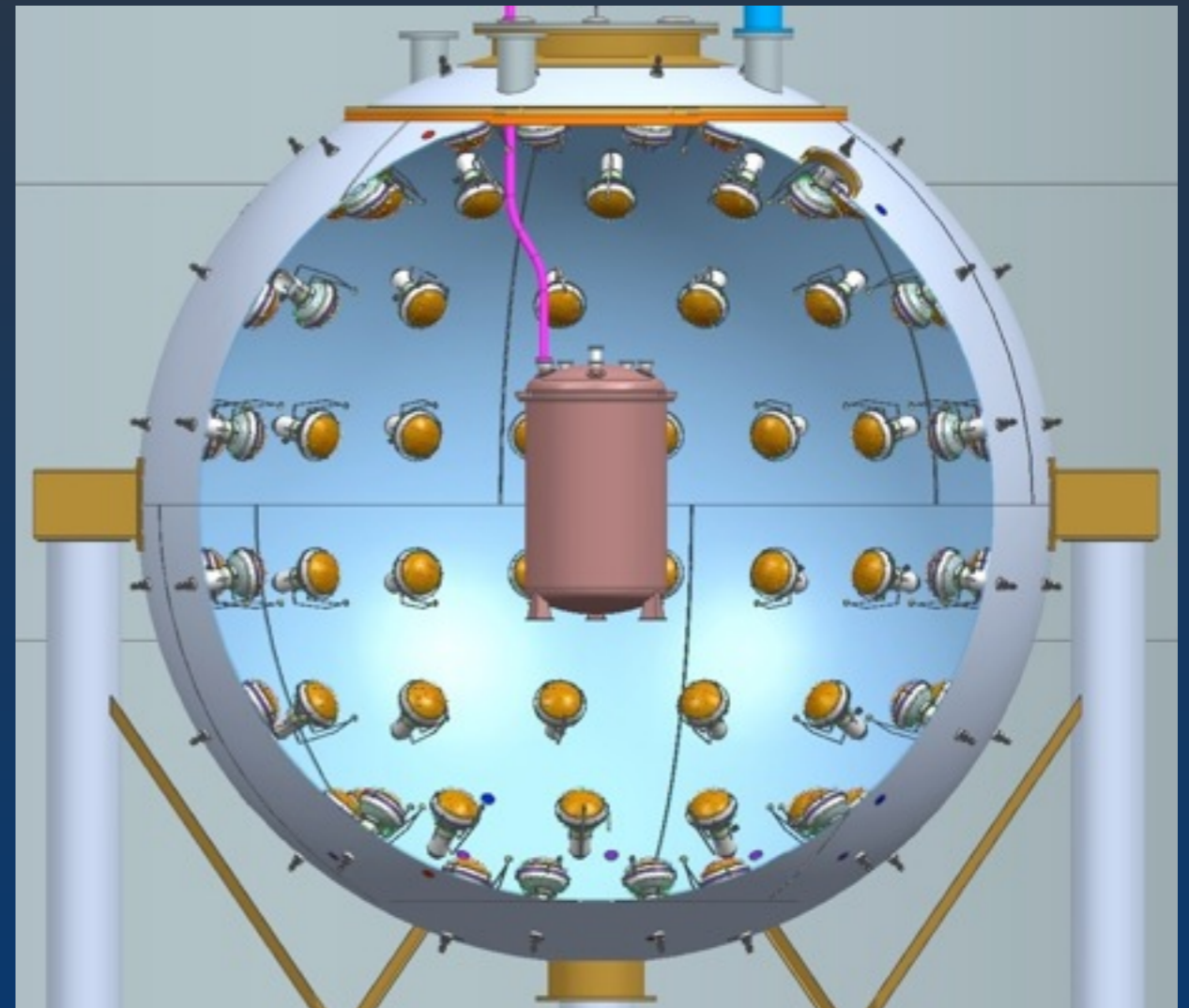
Inner detector TPC

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



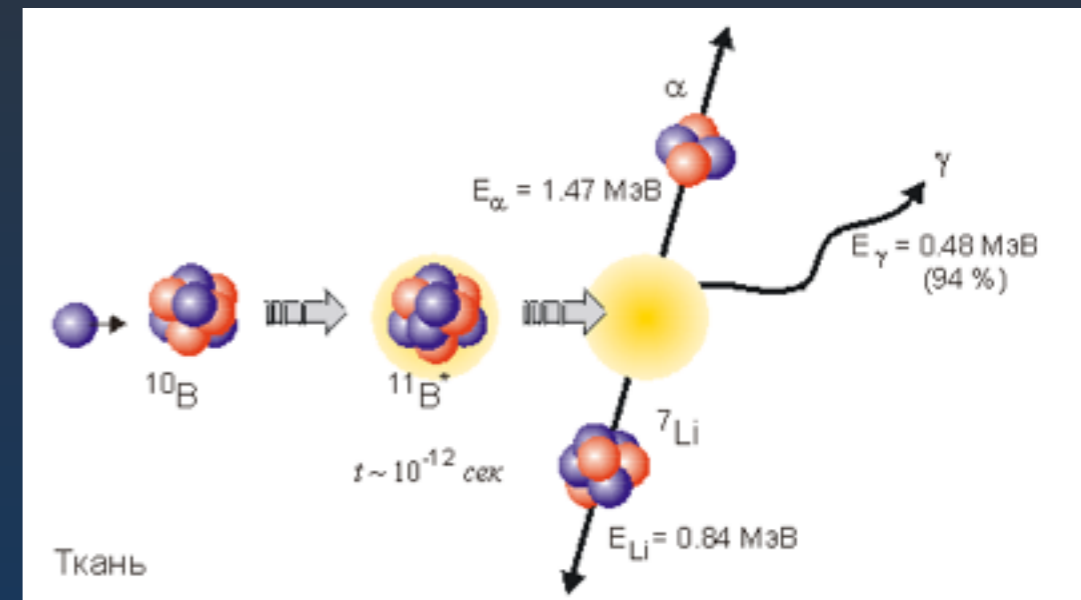
Liquid Scintillator Veto

- 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!

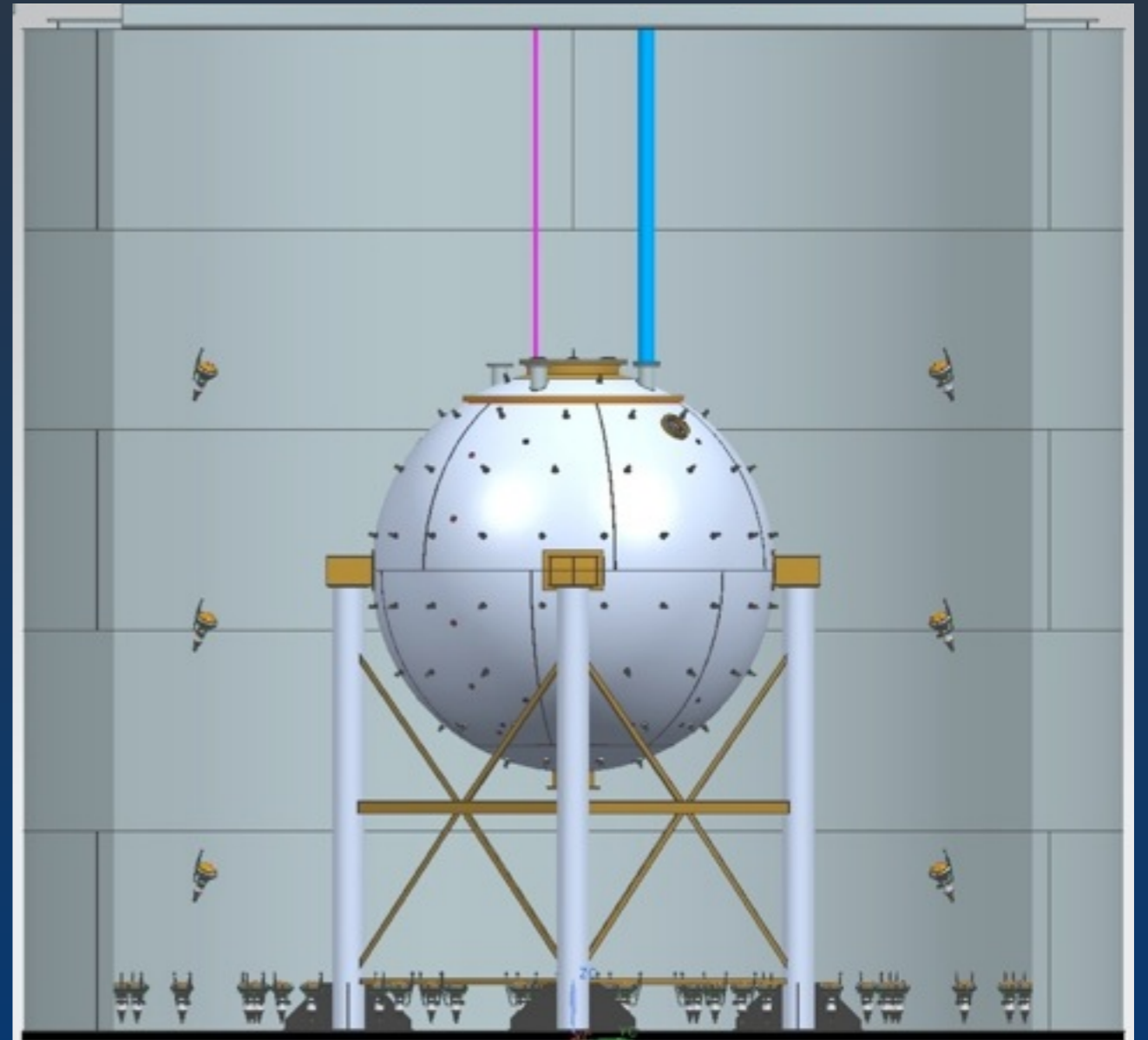


	Veto Efficiency (MC)
Radiogenic Neutrons	> 99%
Cosmogenic Neutrons	> 95%

Nuclear Instruments and Methods A 644, 18 (2011)

External Water tank

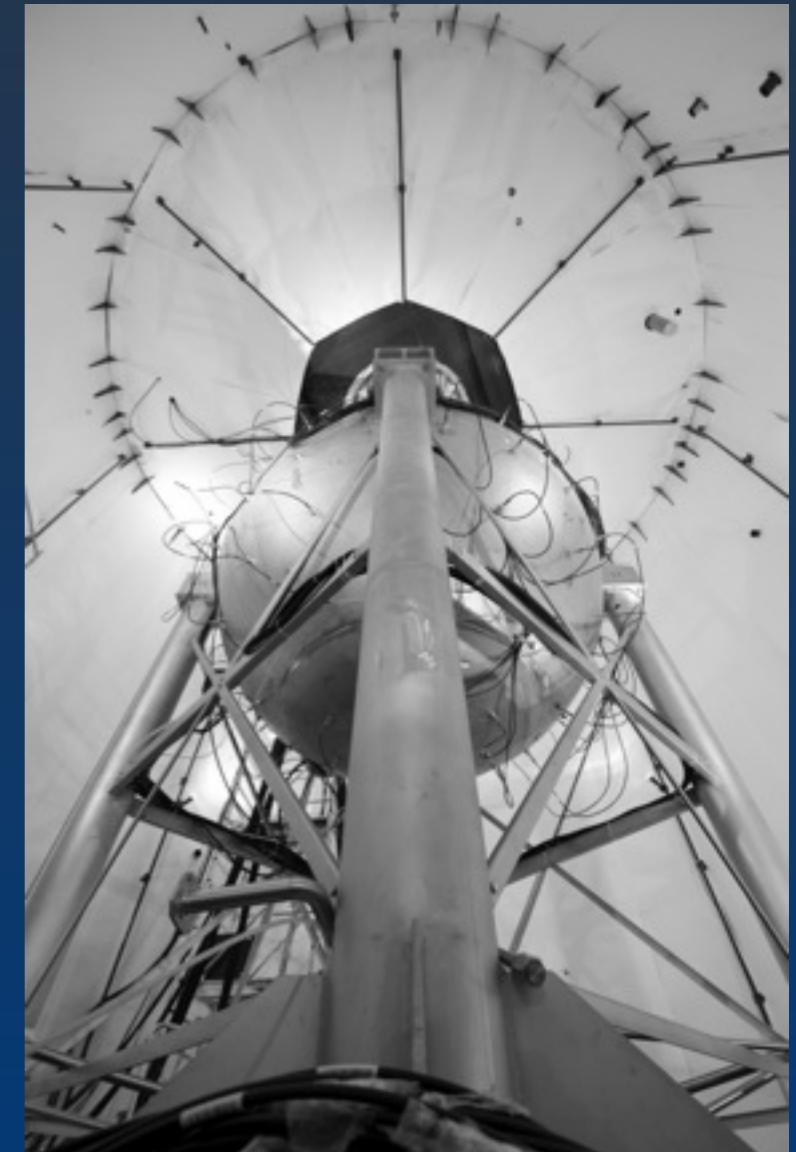
- Ultra-pure Water Cherenkov detector (11m dia. x 10 m high)
- 80 8" PMTs from Borexino's CTF
- Acts as a muon and cosmogenic veto (~ 99% efficiency)
- Provides passive gamma and neutron shielding



DS-50 Assembly



Sept - Oct 2013

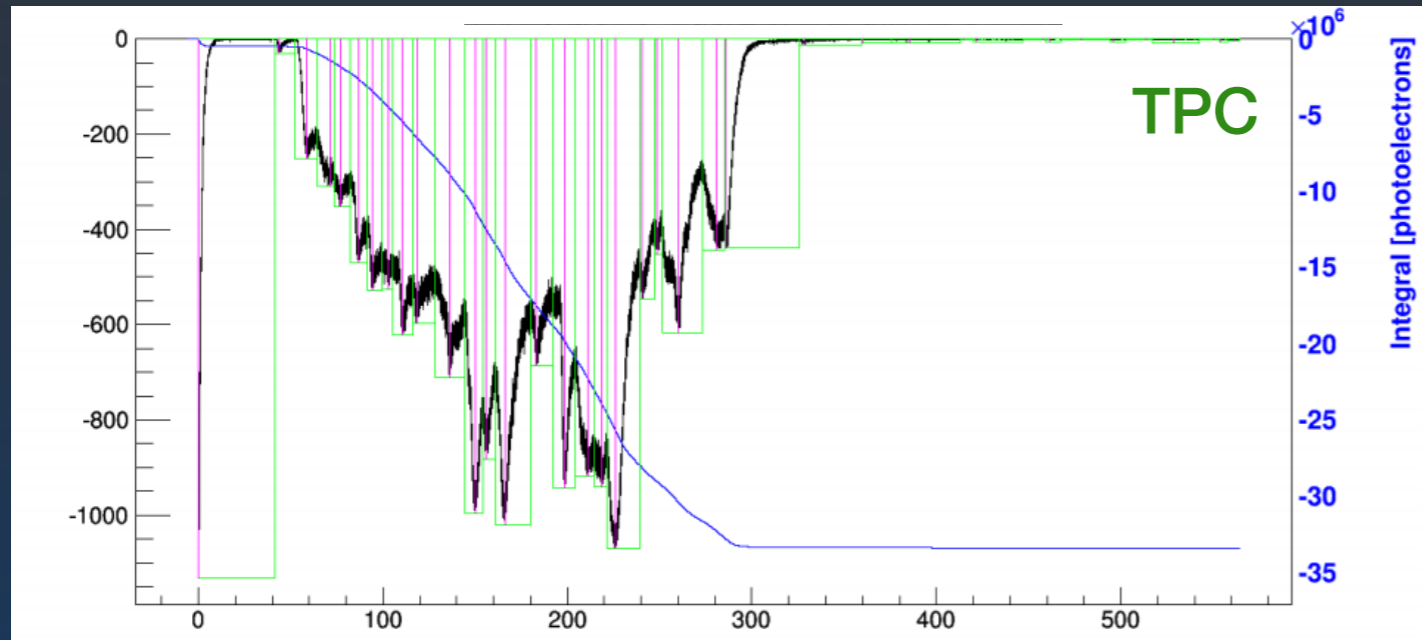


PMTs with cold-amplifiers

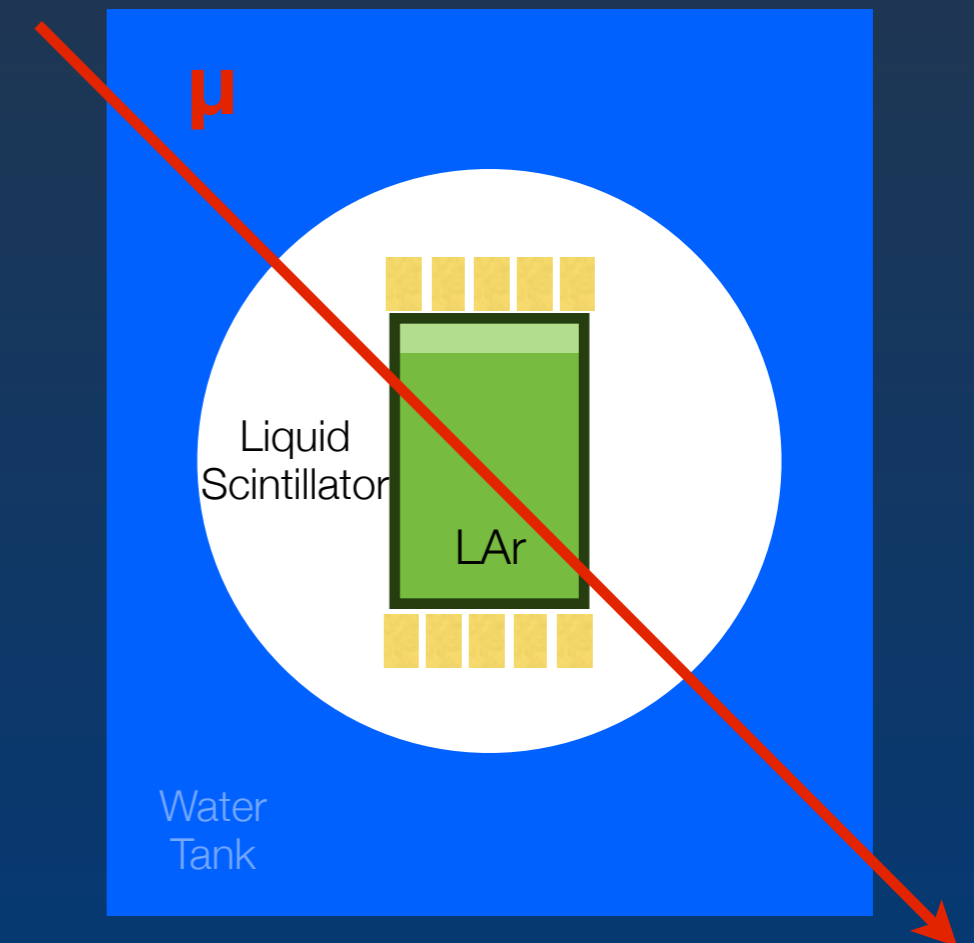
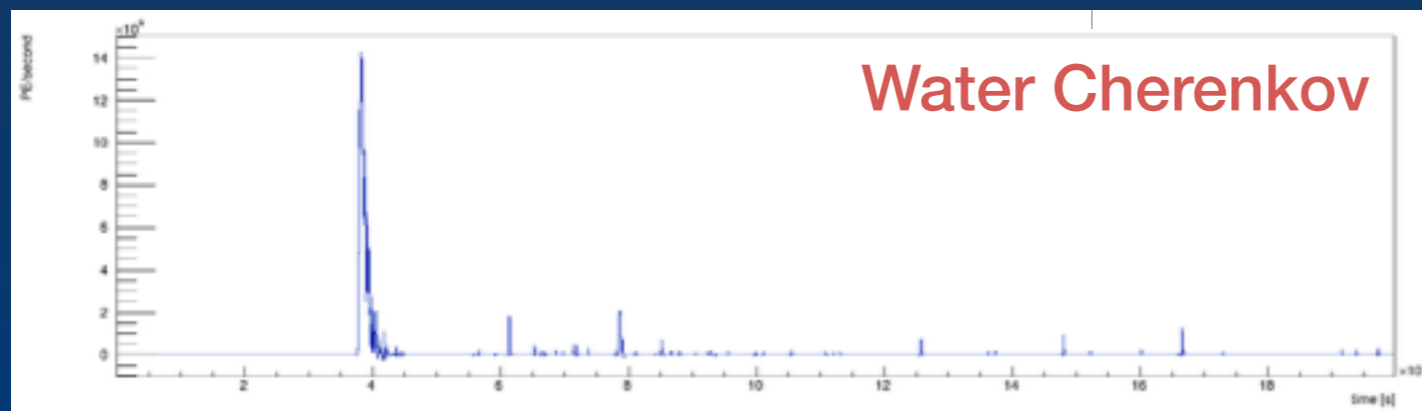
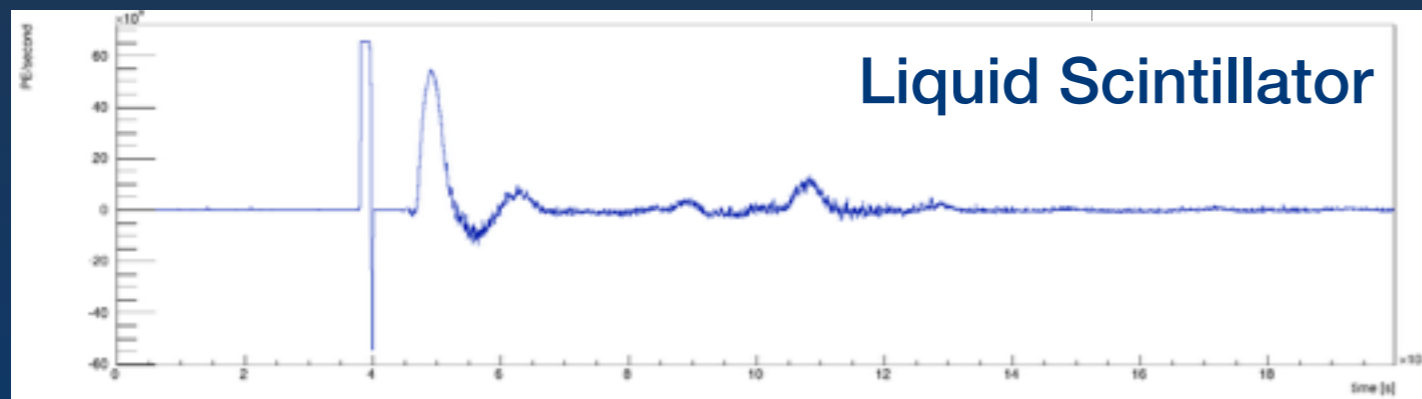
- 3" PMTs
- Hamamatsu R11065 series
- The “/20” have **good background levels** but show problems at nominal gain at LAr temperature
- Require **low PMT Gain**
 $\sim 4 \times 10^5$
- Custom cold amplifiers:
Noise $\sim 3 \mu\text{V}$ on 200 MHz



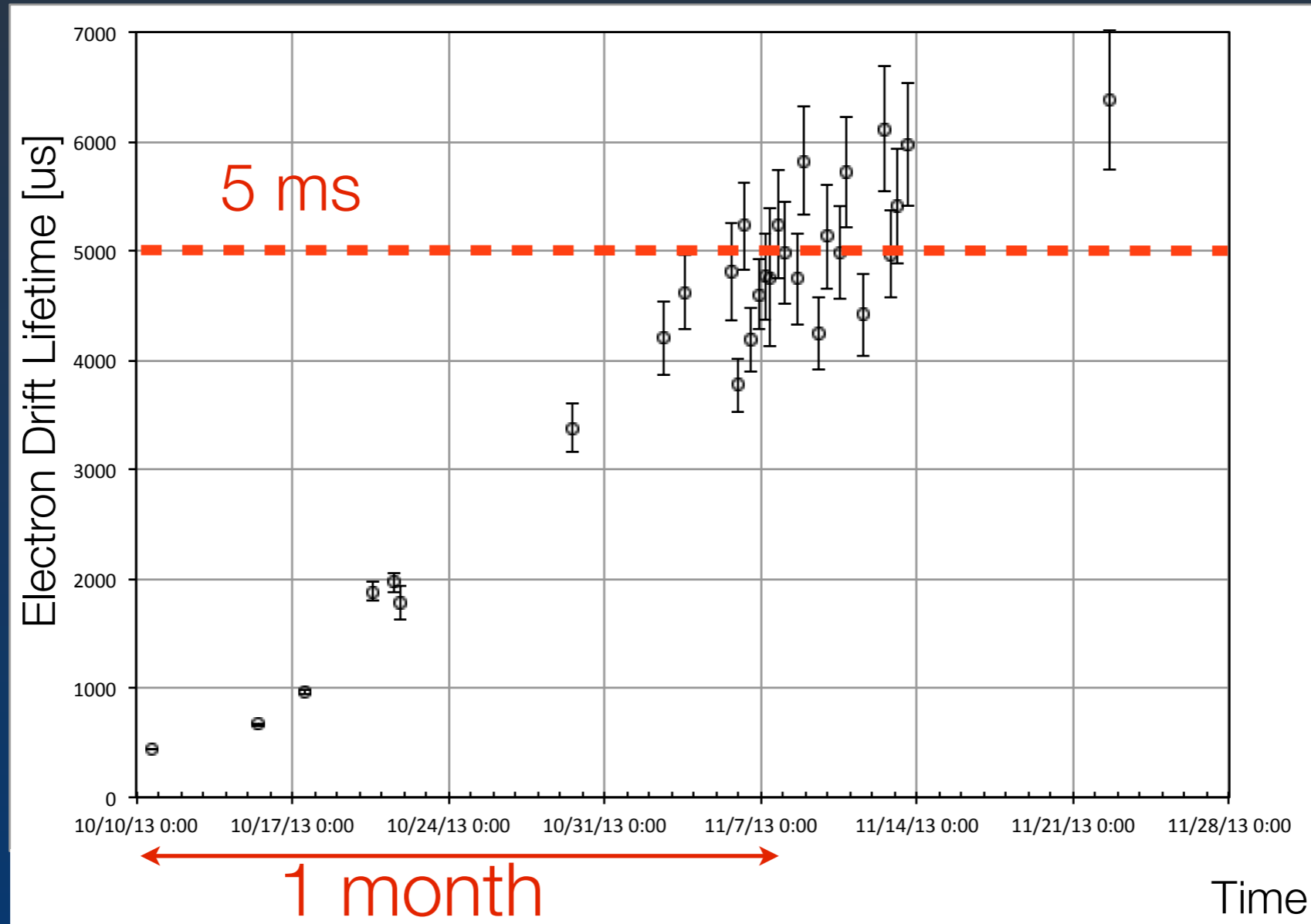
DS-50 Status



All 3 detectors are filled and currently operating



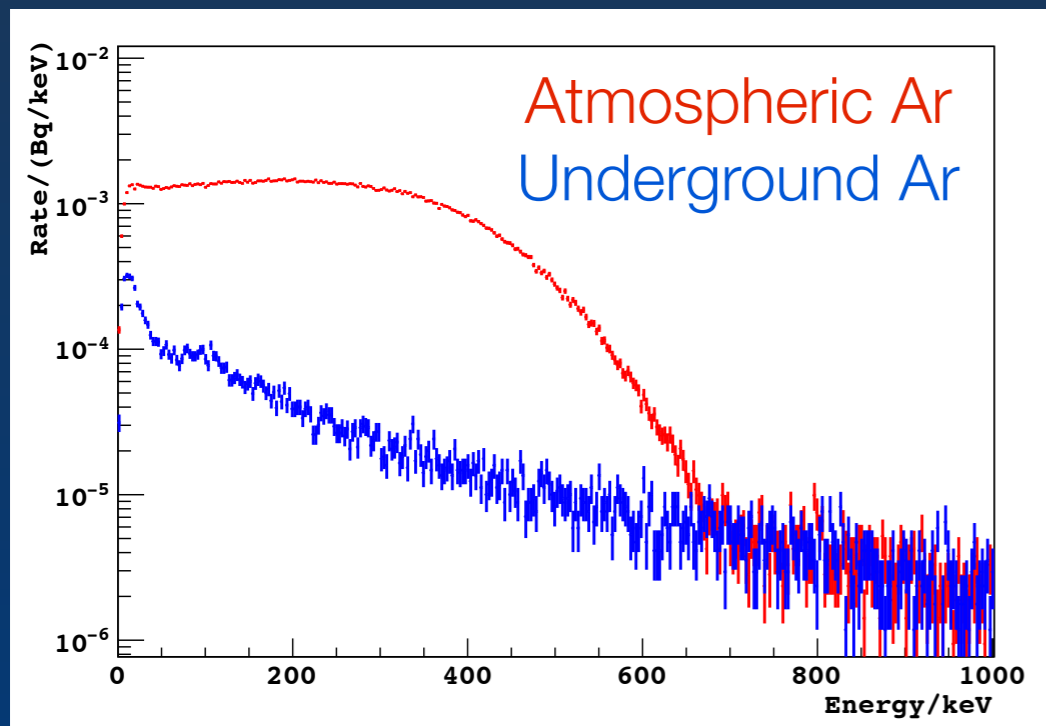
Ar purification: electron lifetime



Electron lifetime $> 5 \text{ ms} \gg$ max. drift time $\sim 375 \text{ us}$

^{39}Ar

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

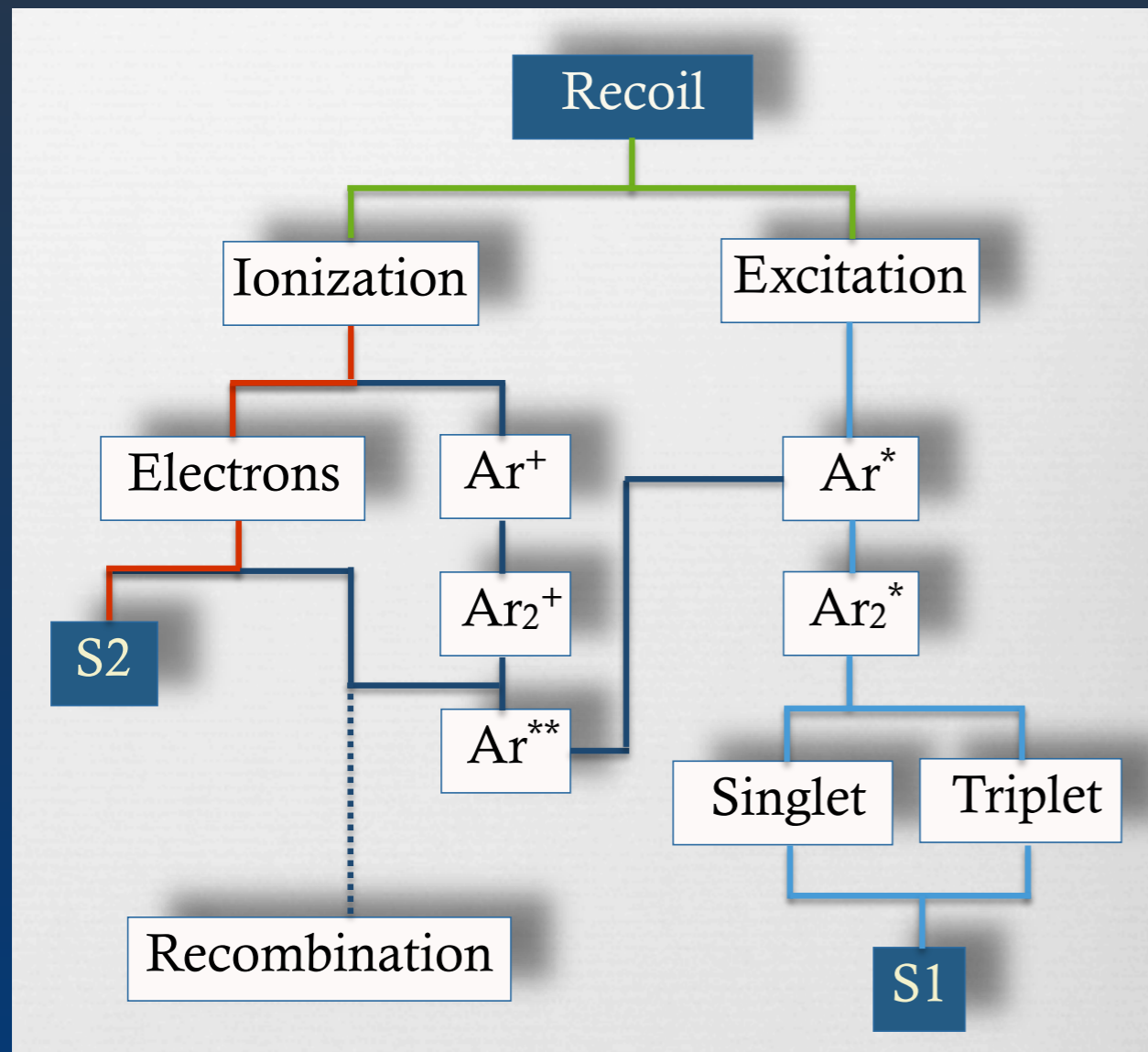


Identified source of underground argon in Colorado measured to have $<6.5\text{mBq/kg}$ i.e. > 150 times lower rate compared to atmospheric argon

Plant (including cryogenic distillation at FNAL) produces ~ 0.5 kg/d

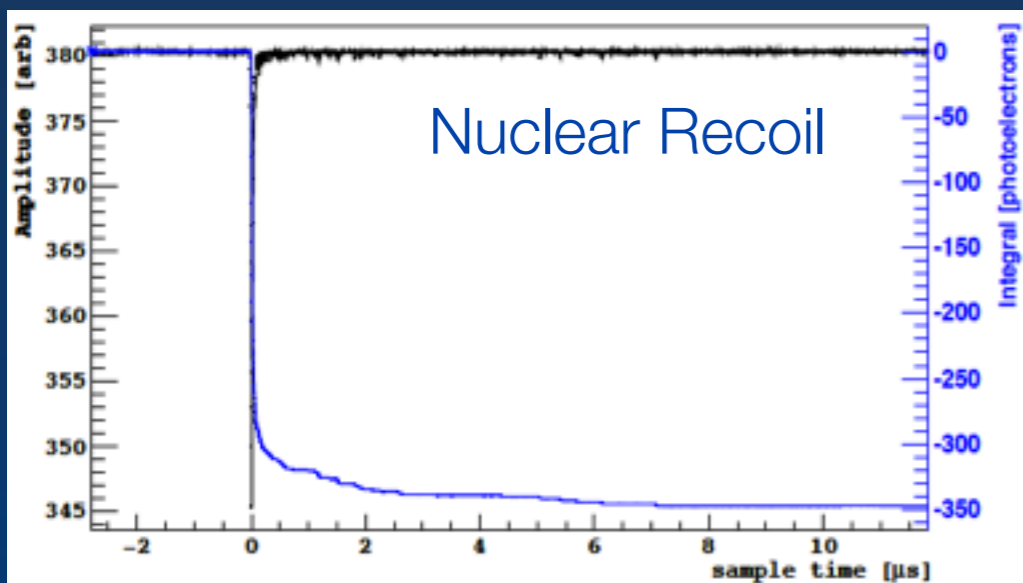
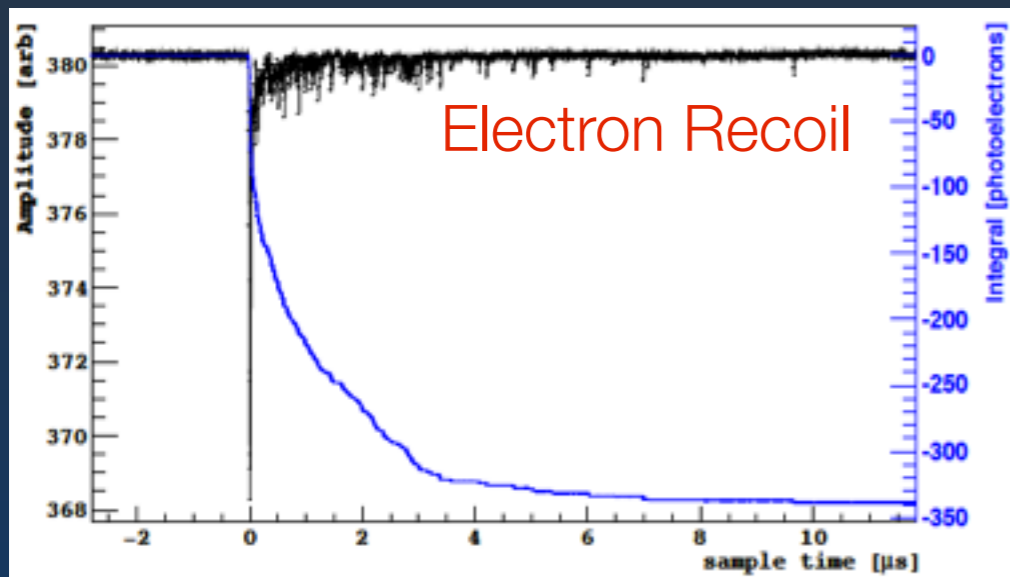
Pulse Shape Discrimination

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

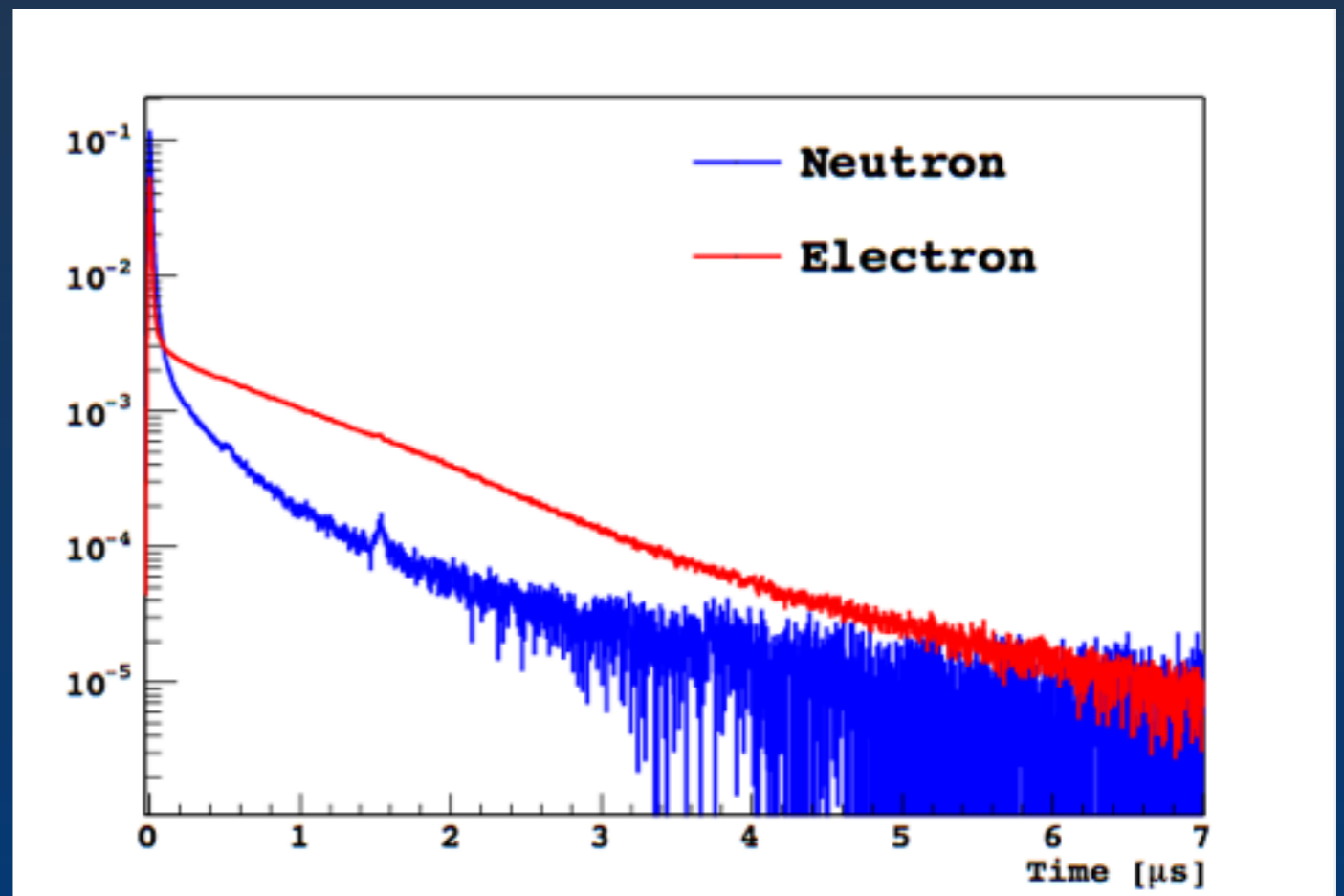


$\tau_{\text{singlet}} \sim 7 \text{ ns}$
 $\tau_{\text{triplet}} \sim 1600 \text{ ns}$

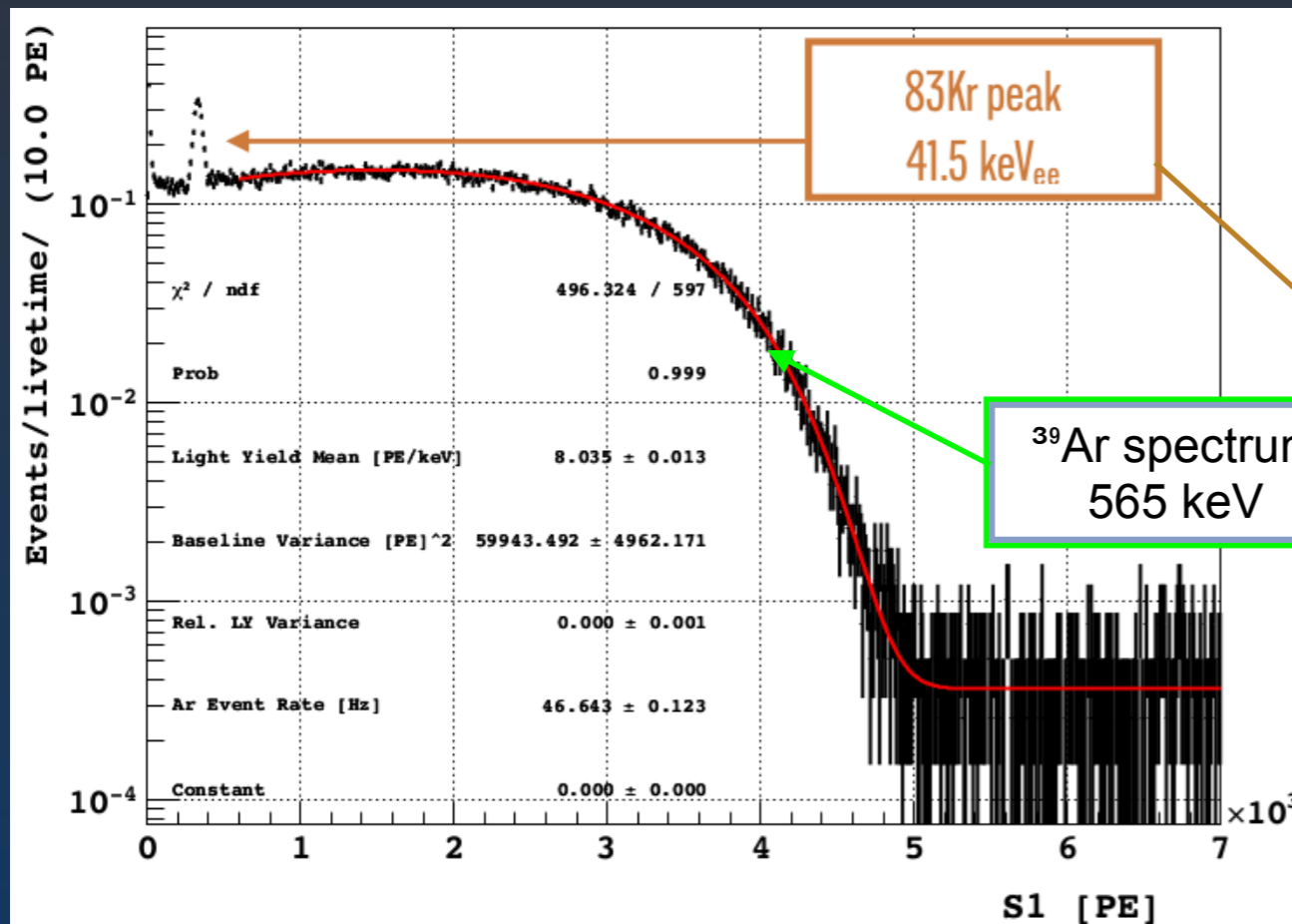
Pulse Shape Discrimination



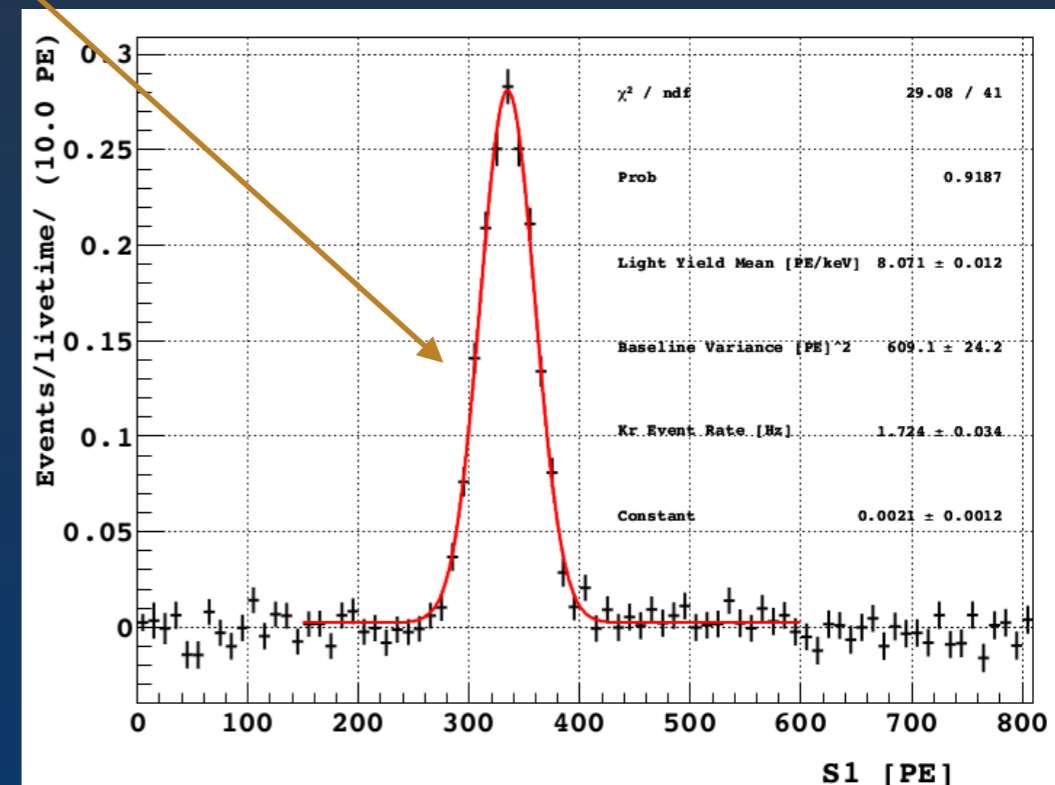
$$F_{90} = \frac{\int_0^{90ns} dt f(t)}{\int_0^{\infty} dt f(t)} = \begin{cases} 0.3 \text{ ER} \\ 0.7 \text{ NR} \end{cases}$$



ER Light Yield



$^{83\text{m}}\text{Kr}$ spike in the recirculation system
 $\tau_{1/2} \sim 1.8\text{h}$
 (possibly concentrated near the cathode where S1 light collection is higher)



$LY_{\text{null}} \sim 8 \text{ pe/keV}$ from ^{39}Ar
 (energy independent within 3%)

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

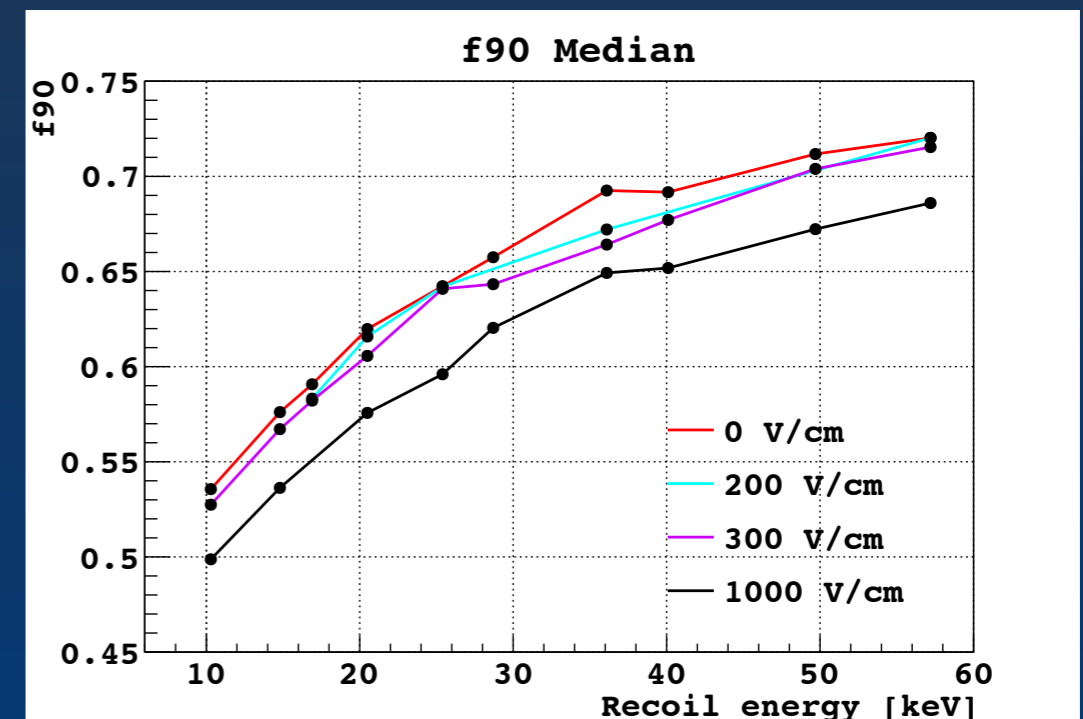
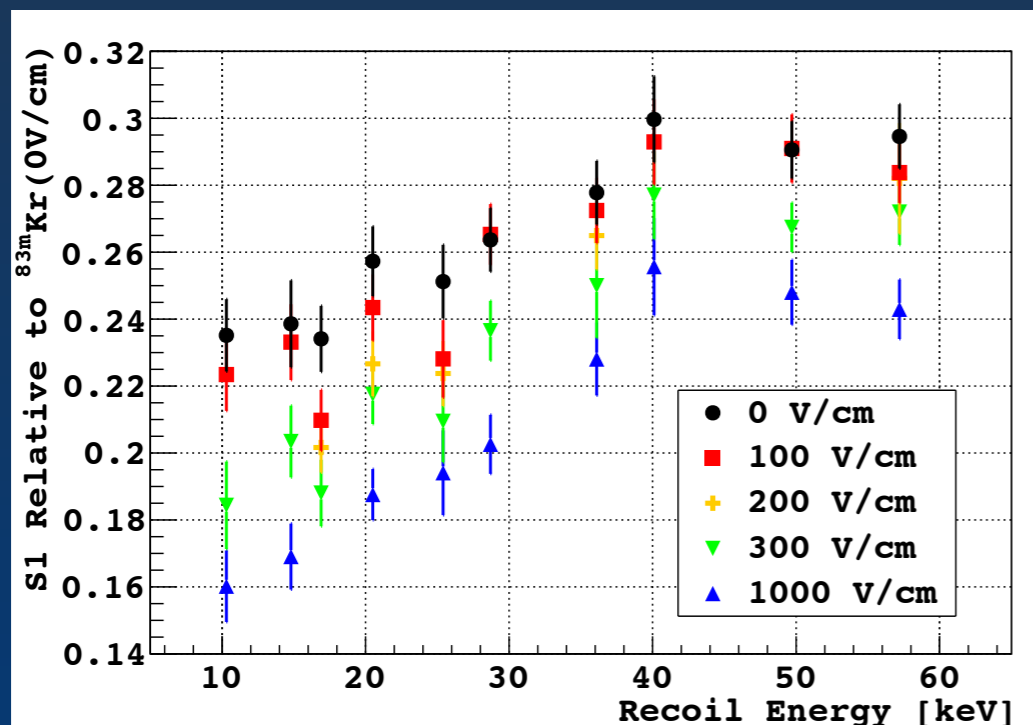
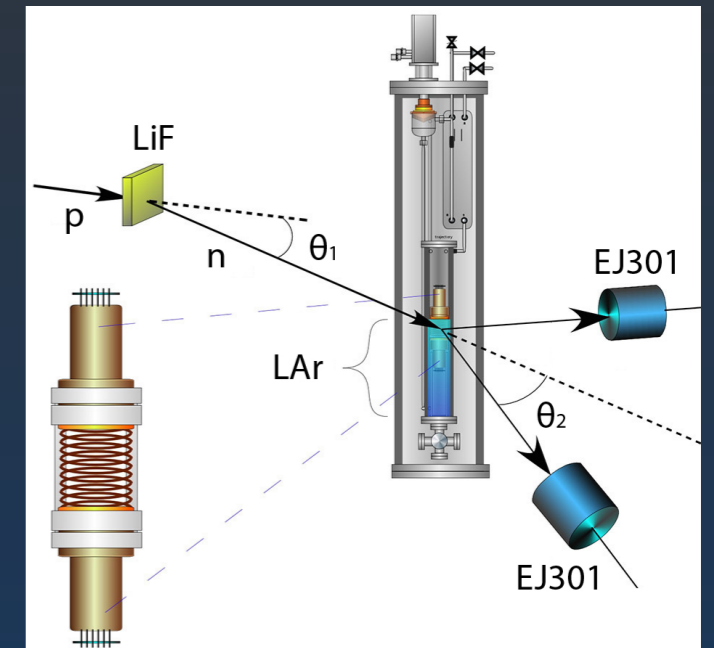
$LY_{200} \sim 7.2 \text{ pe/keV}$ at 200 V/cm

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.

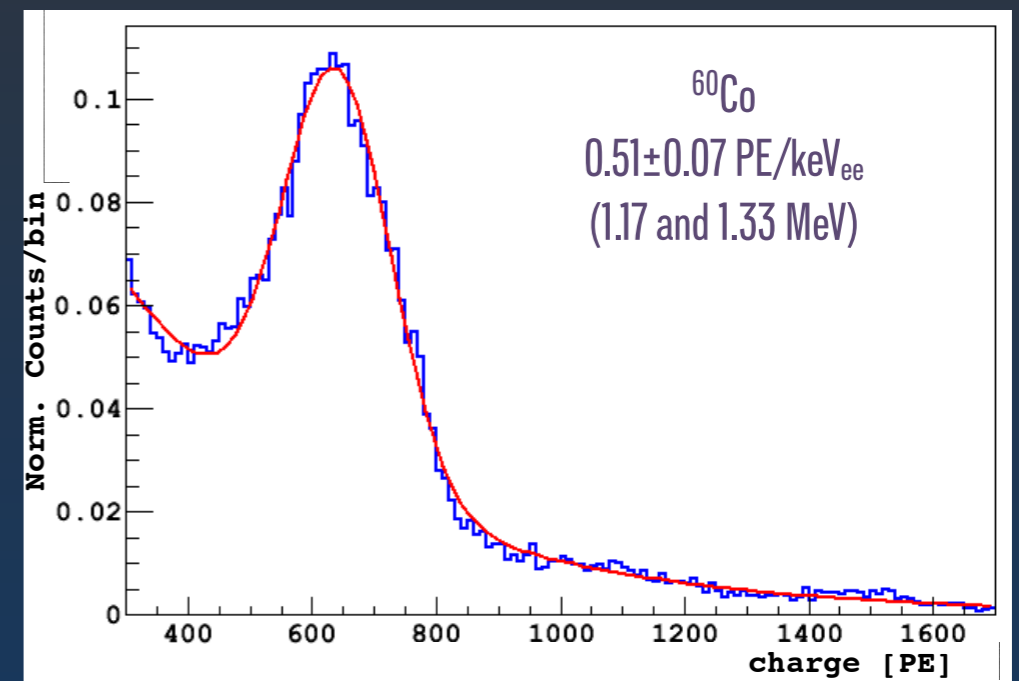


arXiv:1406.4825

Neutron Veto Commissioning

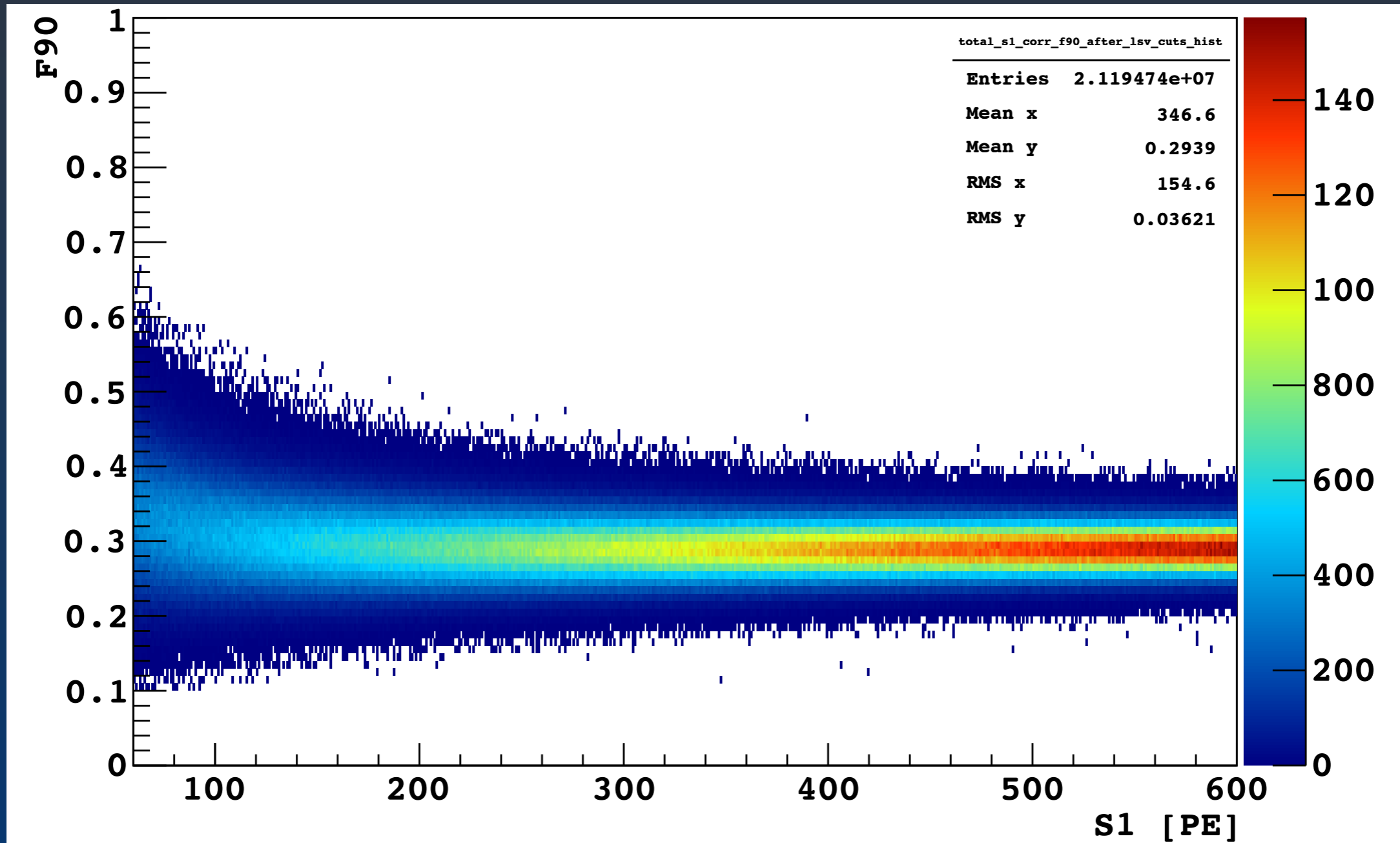
Use high energy coincident ^{60}Co events from cryostat stainless steel to evaluate Light Yield in scintillator.
Confirmed by ^{14}C and ^{208}Tl fits.

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



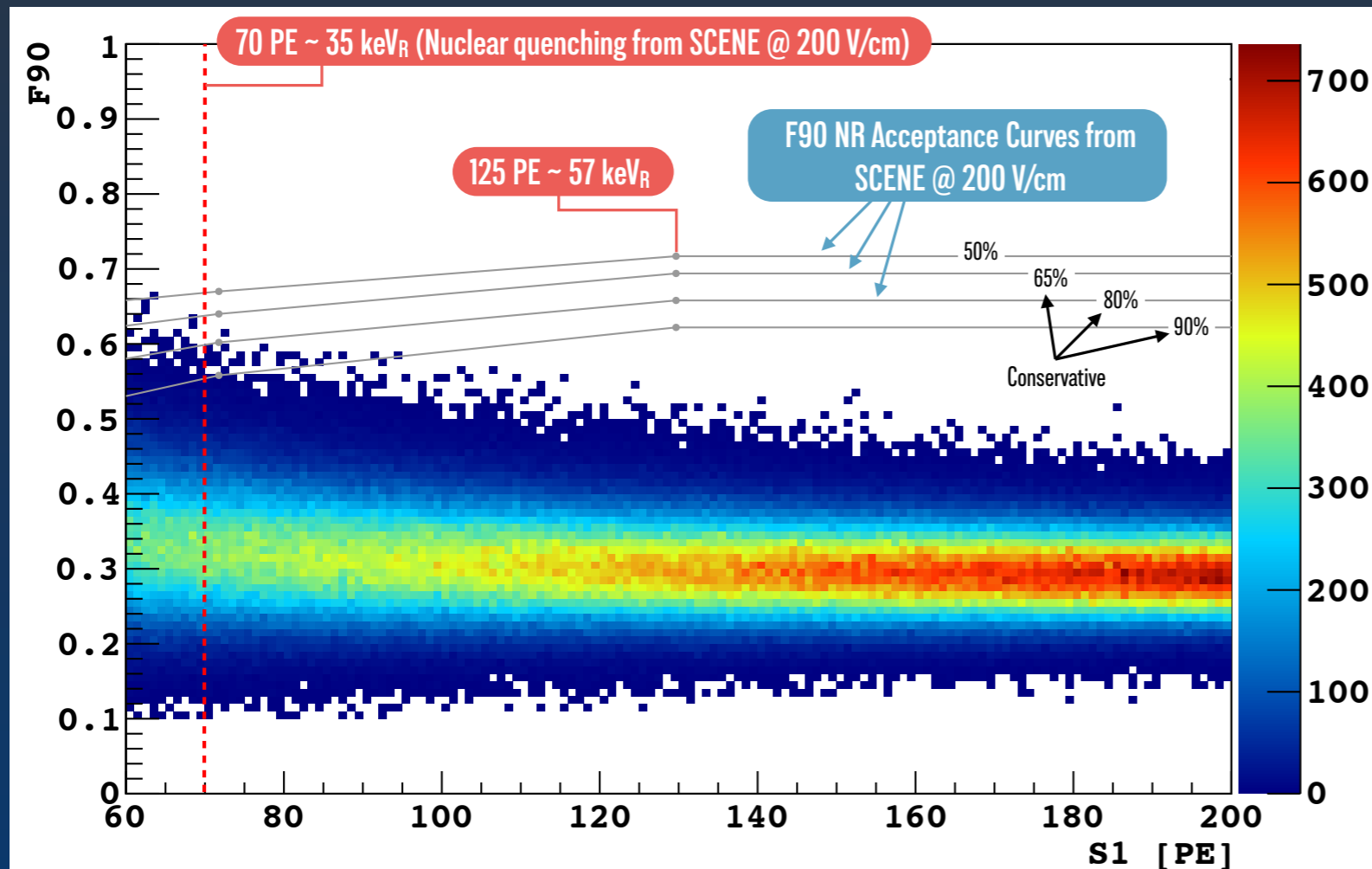
- Found high rate of intrinsic ^{14}C in (biogenic) TMB: $\sim 10^{-13}$ g/g
- TMB temporarily removed via distillation: currently running in pure PC-mode
- Identified new batch of low- ^{14}C (underground) TMB ($< 10^{-15}$ g/g) to be used in November 2014

Initial Exposure (280 kg-days)



Initial Exposure (280 kg-days)

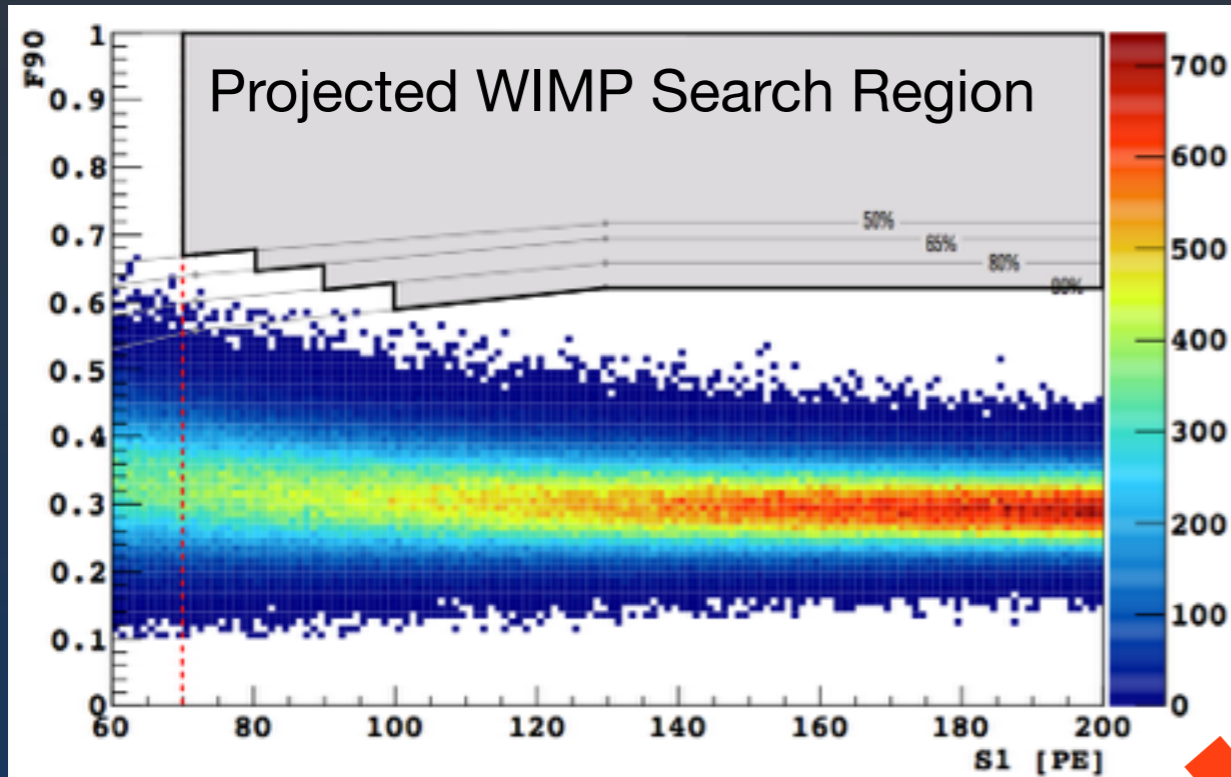
High rate of ^{39}Ar in AAr allows us to calibrate our S1-PSD with an exposure equivalent to 2.6y with UAr



- 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.

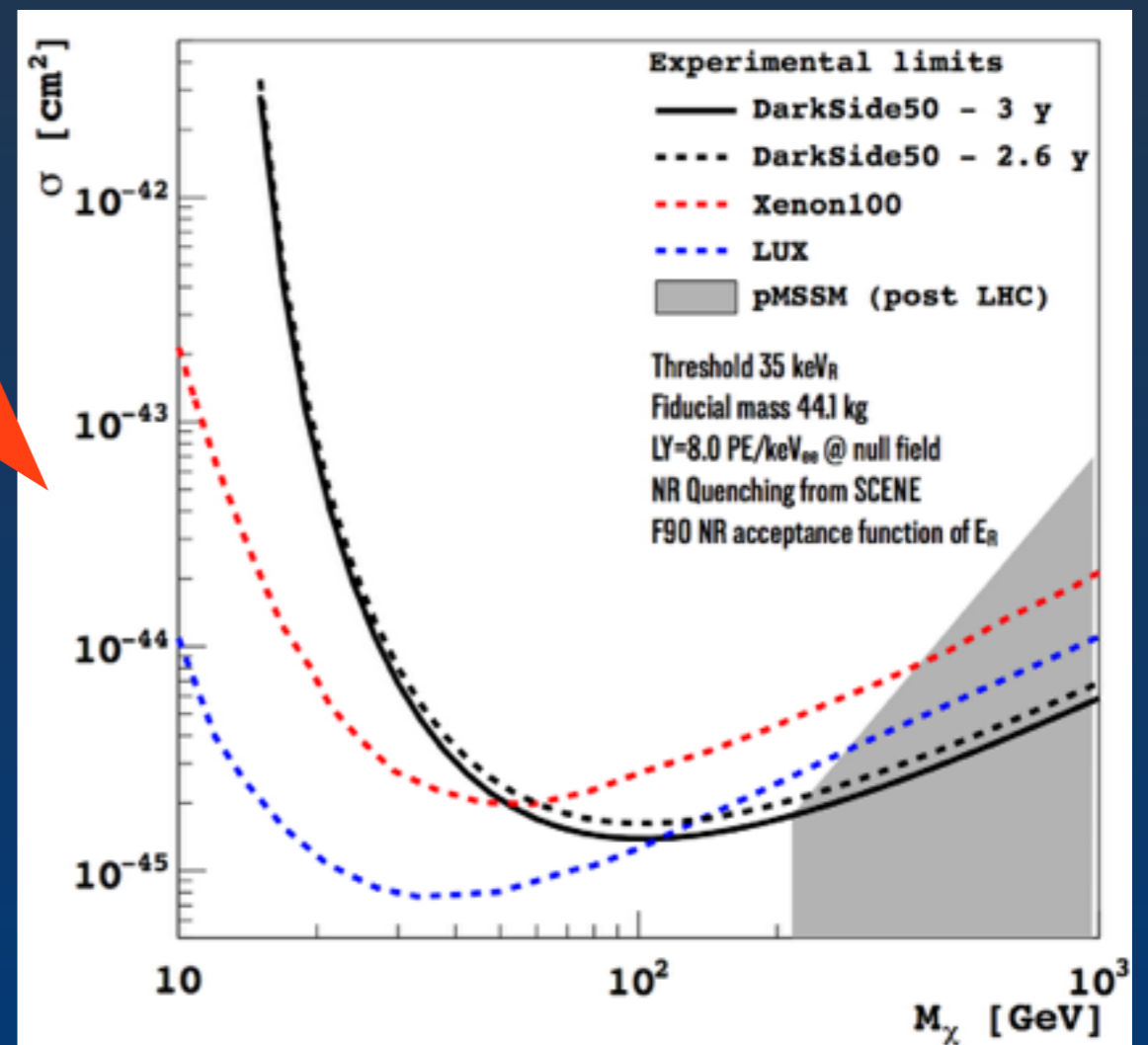
DS-50 Projected Sensitivity



Systematics
 Estimates of systematics on NR quenching and pulse shape cause a $\sim 10\%$ variation at $100 \text{ GeV}/c^2$

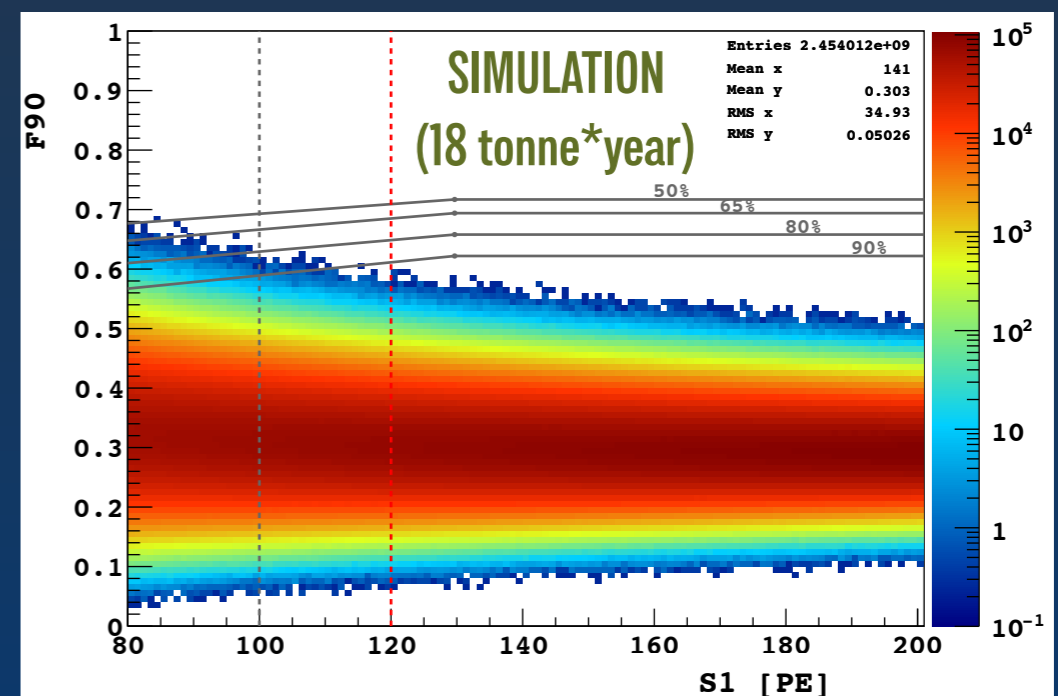
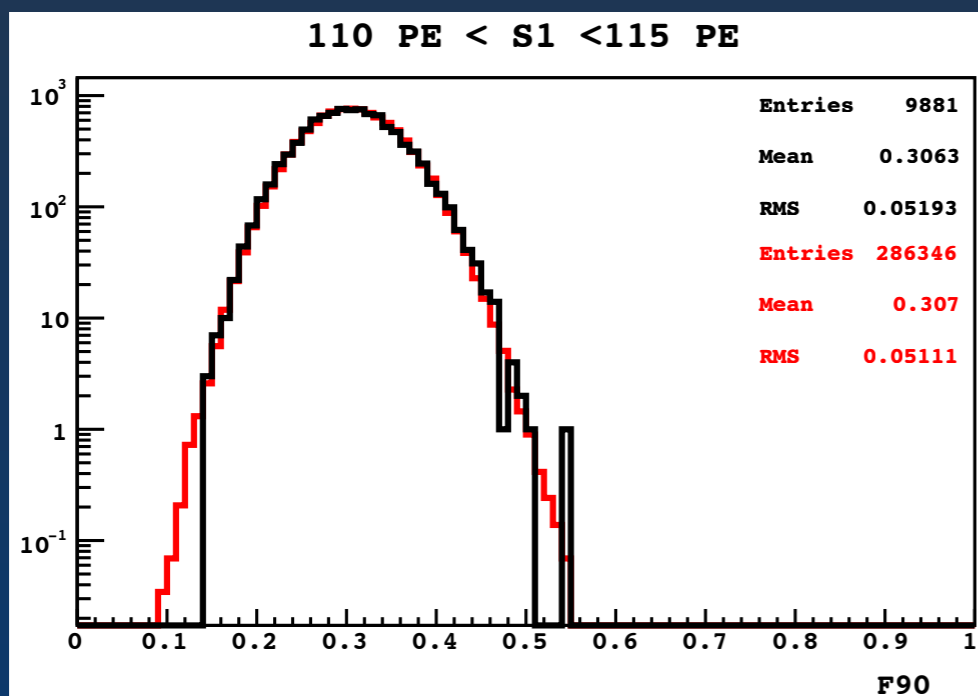
Assumptions

- PSD as demonstrated
- No S2/S1 rejection
- Fiducial mass $\sim 44 \text{ kg}$ (z-cut only)
- NR energy & pulse shape taken from SCENE



PSD Model

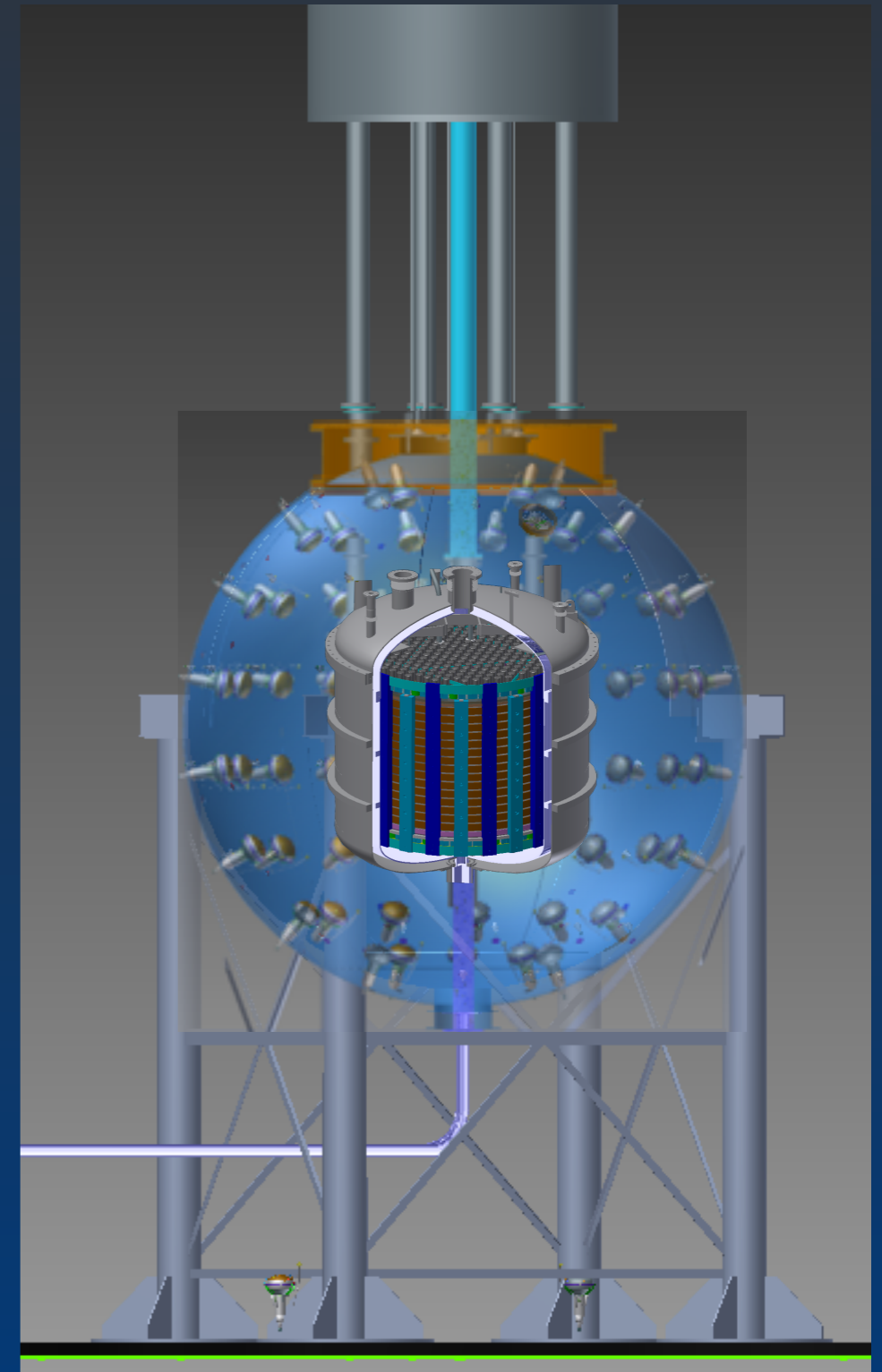
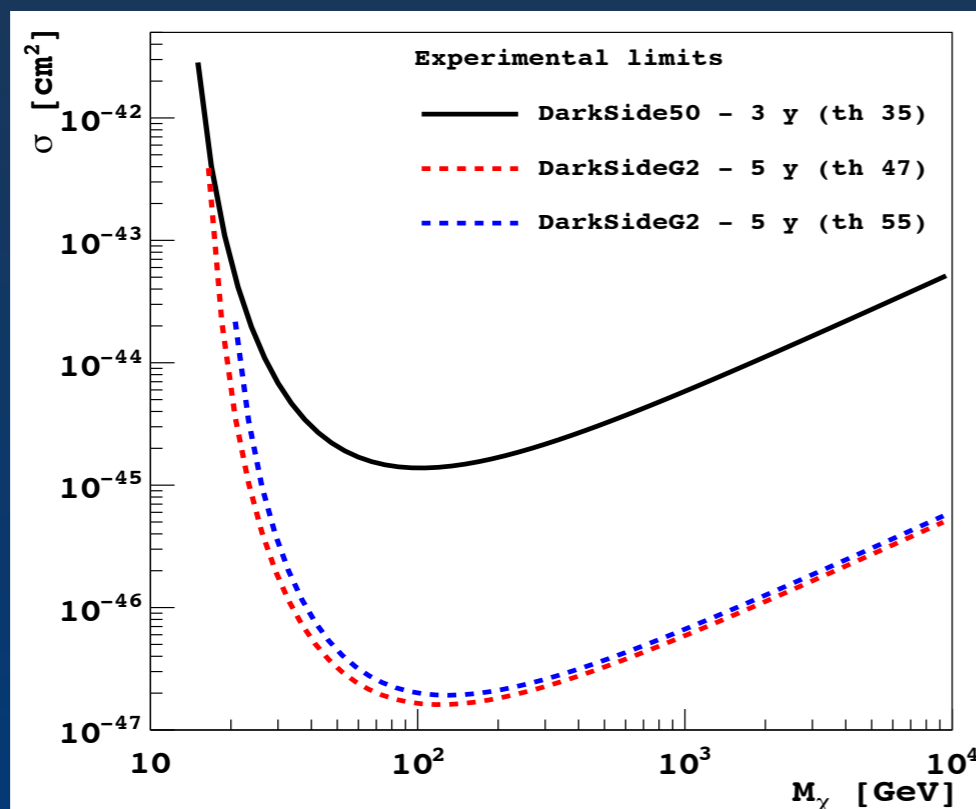
Model the **statistical** properties of F90 using statistical distributions of the underlying processes with parameters taken from data. The model accounts for macroscopic effects related to argon micro-physics, detector properties, reconstruction and noise effects.



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 November 2014
- ➔ Source calibration
Gamma and neutron data in October 2014
- ➔ Underground argon
Switch to using underground argon foreseen at the beginning of 2015

THE END

Sensitivity Comparison

