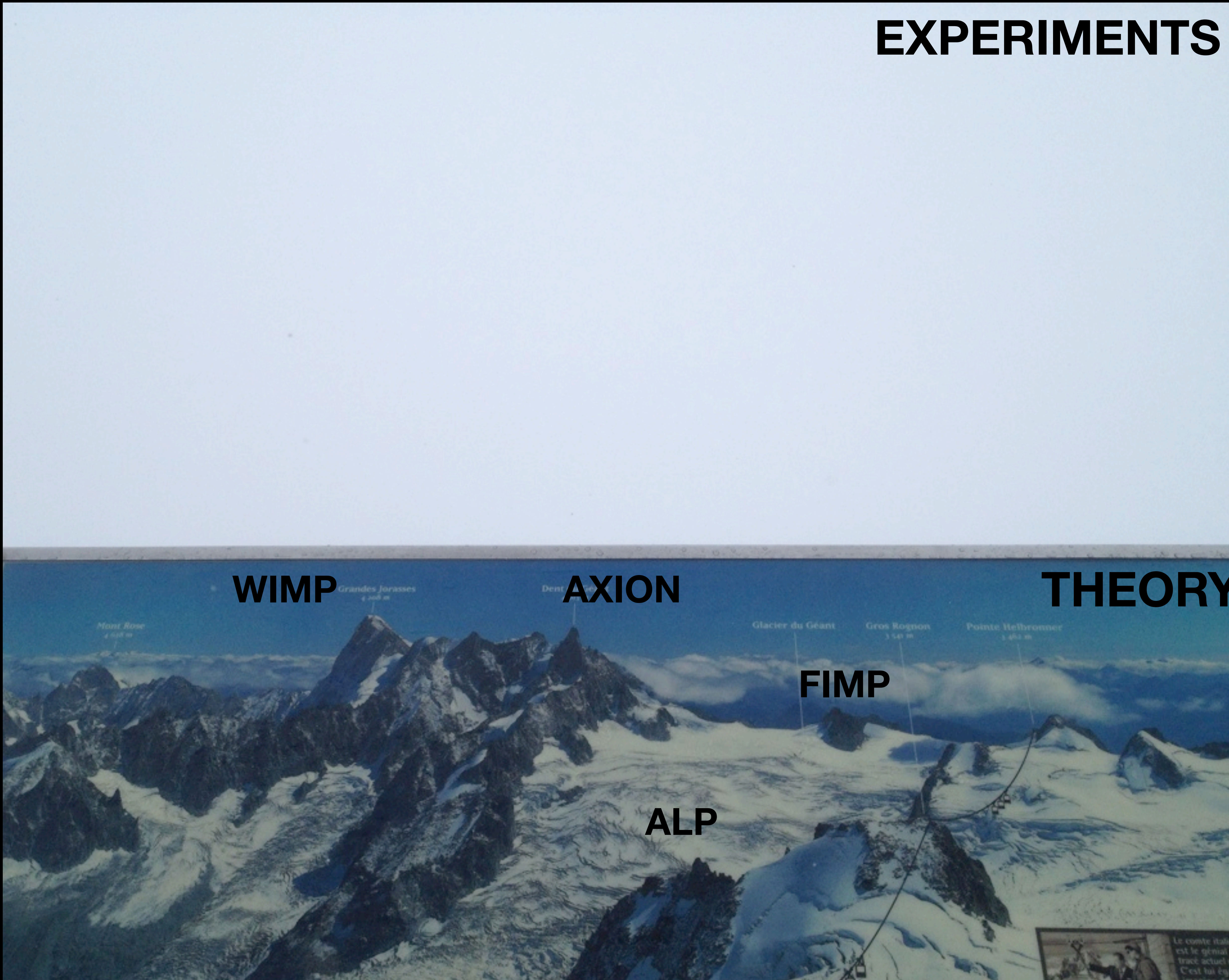
AIGUILLE DU MIDI

3842 M.
12602 FT.

CHAMONIX-MONT-BLANC
FRANCE


EXPERIMENTS
WIMP
Grandes Jorasses
AXION
THEORY
Mont Rose
Glacier du Géant
Gros Rognon
Pointe Helbronner
FIMP
ALP

Searching for the DarkSide

Richard Saldanha on behalf of the DarkSide Collaboration

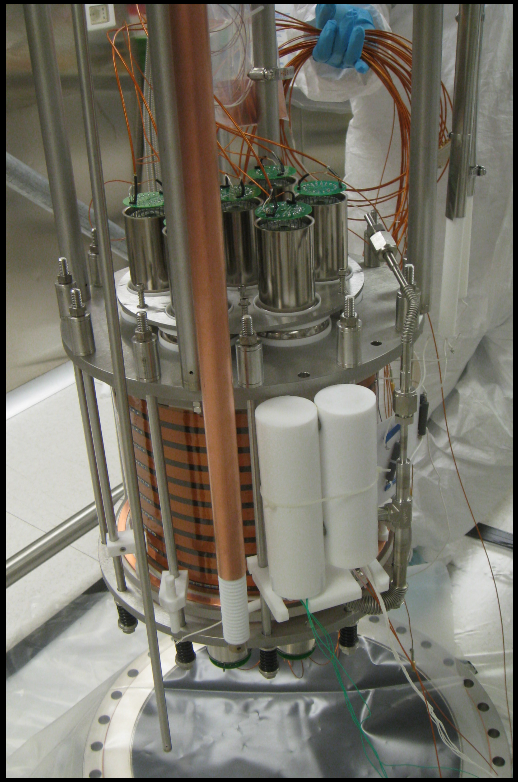
4th July 2014

DarkSide Program

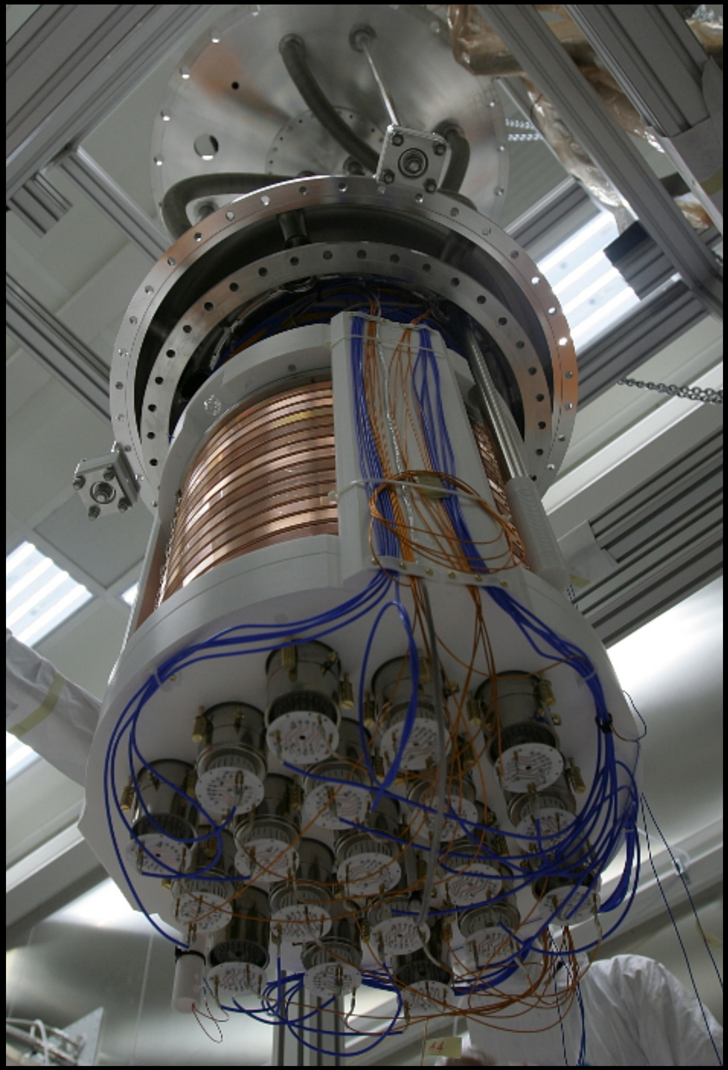
- Direct detection search for WIMP dark matter
- Based on a two-phase argon time projection chamber (TPC)
- Design philosophy based on having very low background levels that can be further reduced through **active** suppression, for background-free operation

DarkSide Program

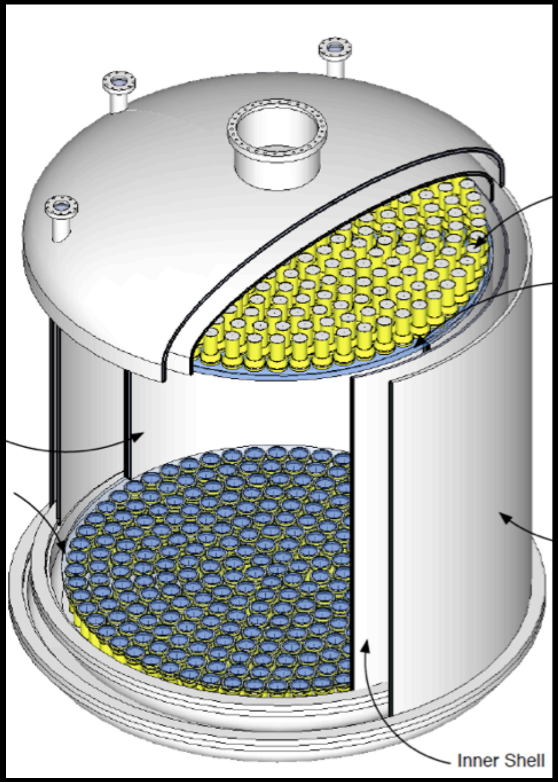
Multi-stage program at Gran Sasso National Laboratory



DarkSide 10
Prototype detector



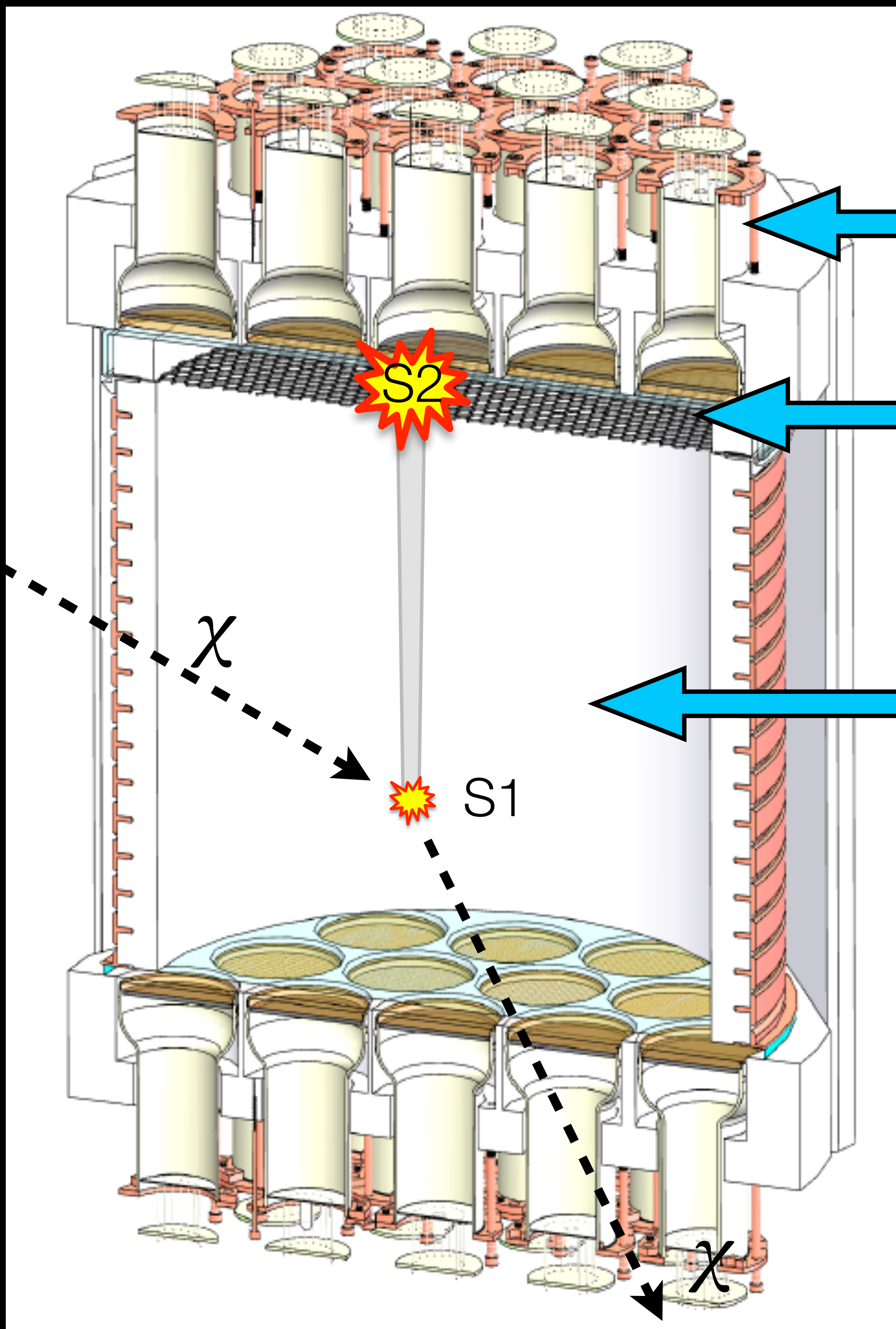
DarkSide 50
First physics detector
Recently commissioned



DarkSide G2
Future multi-ton detector

+ multiple smaller test setups and prototypes

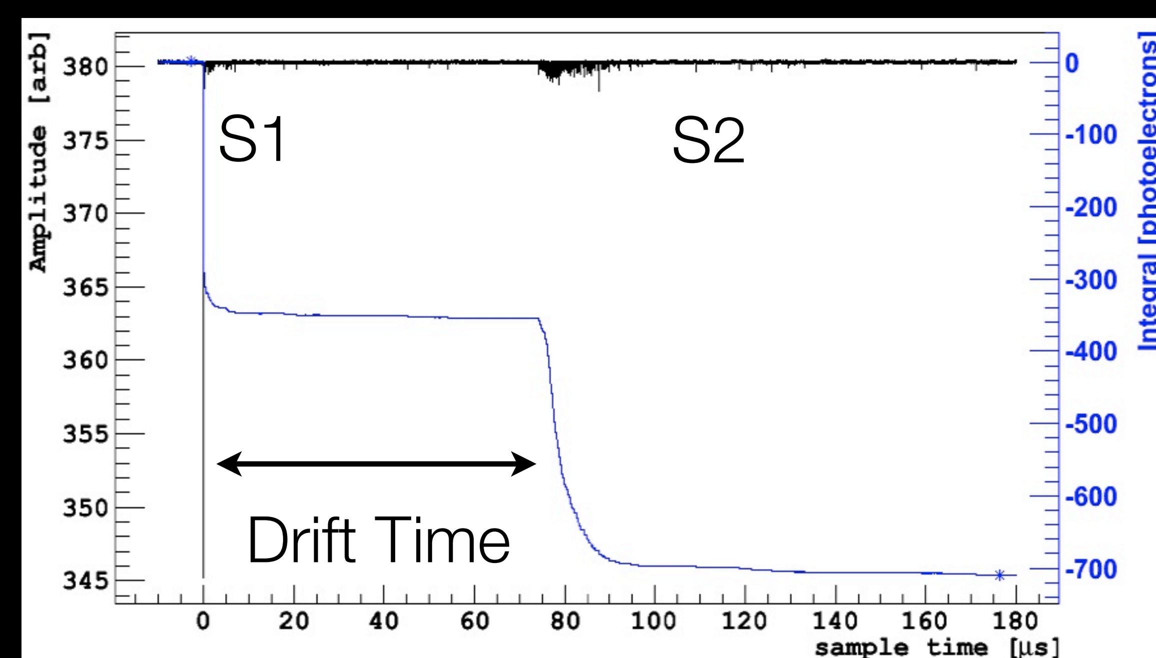
Detecting WIMPs



19 3” Photomultiplier Tubes (Top & Bottom)

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

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



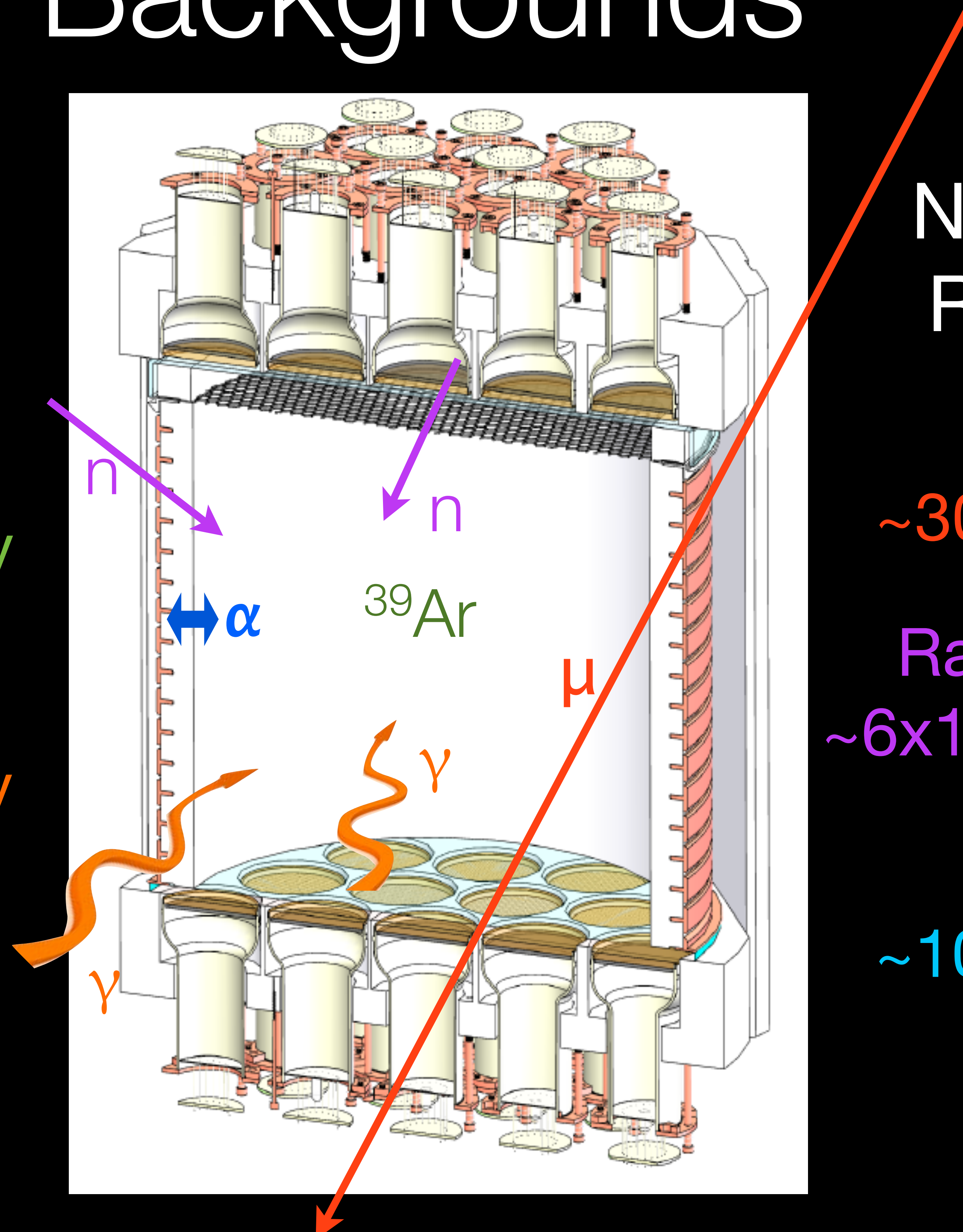
Backgrounds

[30-200]keVr

ELECTRON RECOILS

^{39}Ar
~1x10^{4} ev/kg/day

γ
~1x10^{2} ev/kg/day



NUCLEAR RECOILS

μ
~30 ev/m^{2}/day

Radiogenic n
~6x10^{-4} ev/kg/day

α
~10 ev/m^{2}/day

100 GeV, 10^{-45}cm^{2} WIMP Rate ~ 10^{-4} ev/kg/day

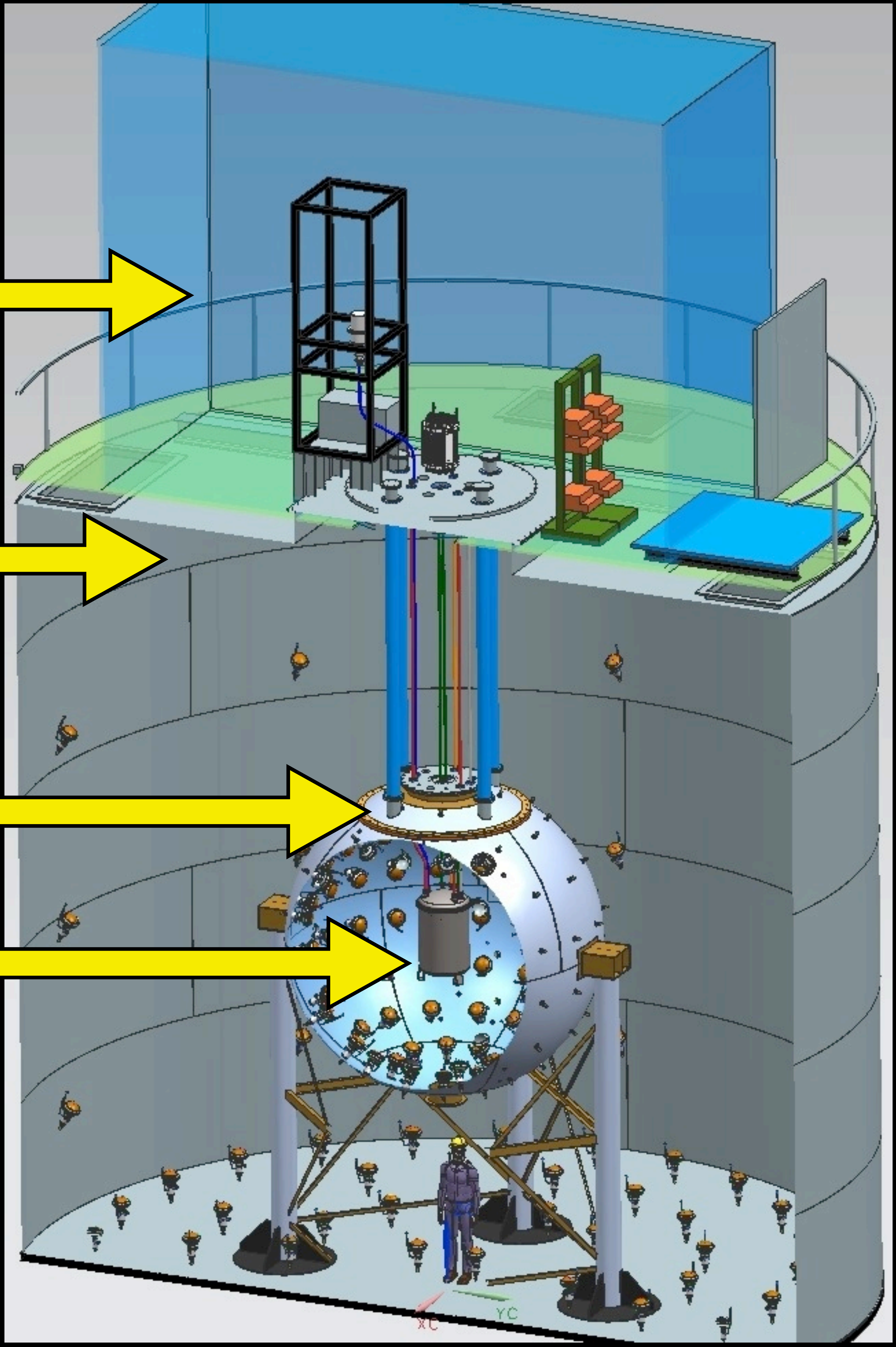
DarkSide 50

Radon-free clean room

Instrumented water tank

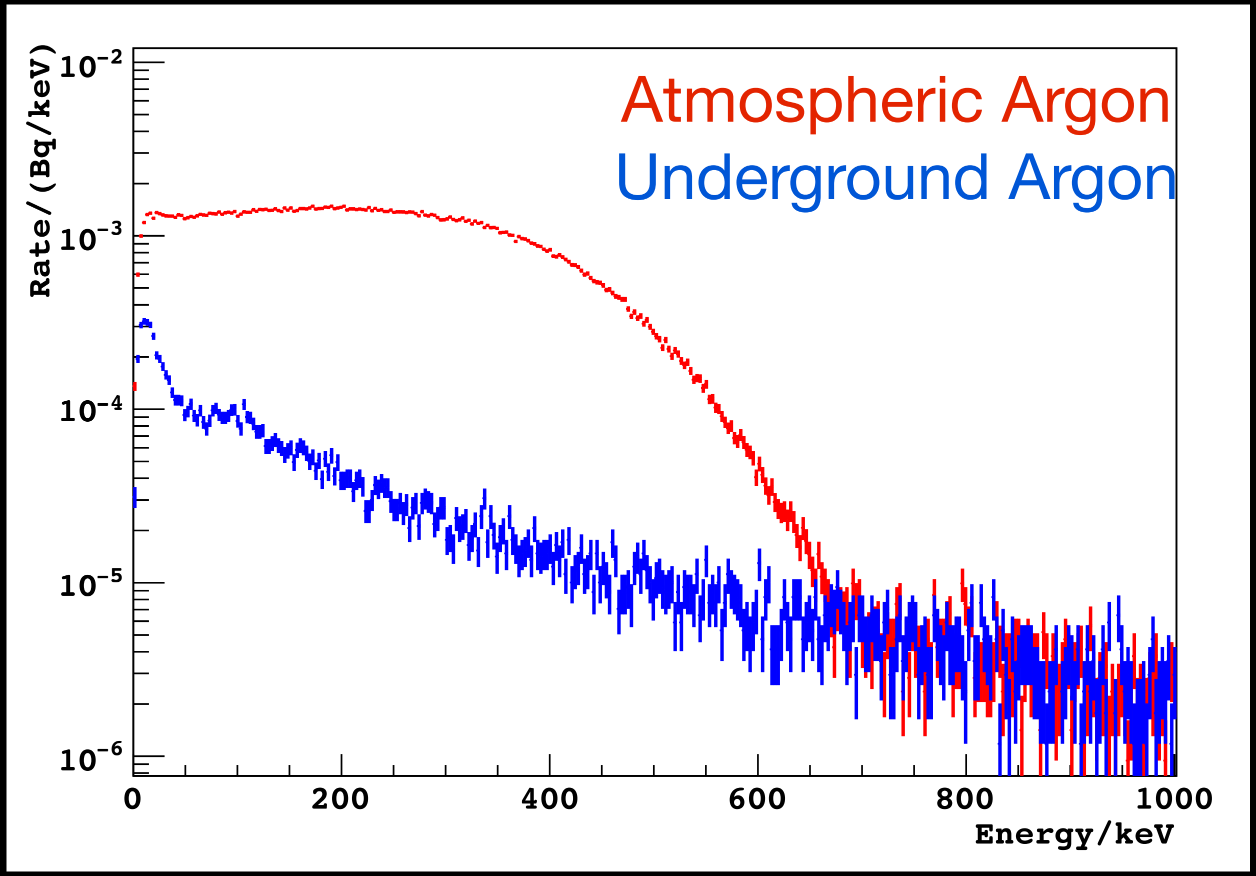
Organic liquid scintillator

Inner detector TPC



^{39}Ar

- Intrinsic ^{39}Ar radioactivity in **atmospheric** argon (1 Bq/kg) is the primary background for argon-based detectors
- ^{39}Ar is a cosmogenic isotope, and the activity in argon from **underground** sources can be significantly reduced compared to **atmospheric** argon



Source of underground argon measured to have **> 150 times lower rate of ^{39}Ar**, compared to atmospheric argon

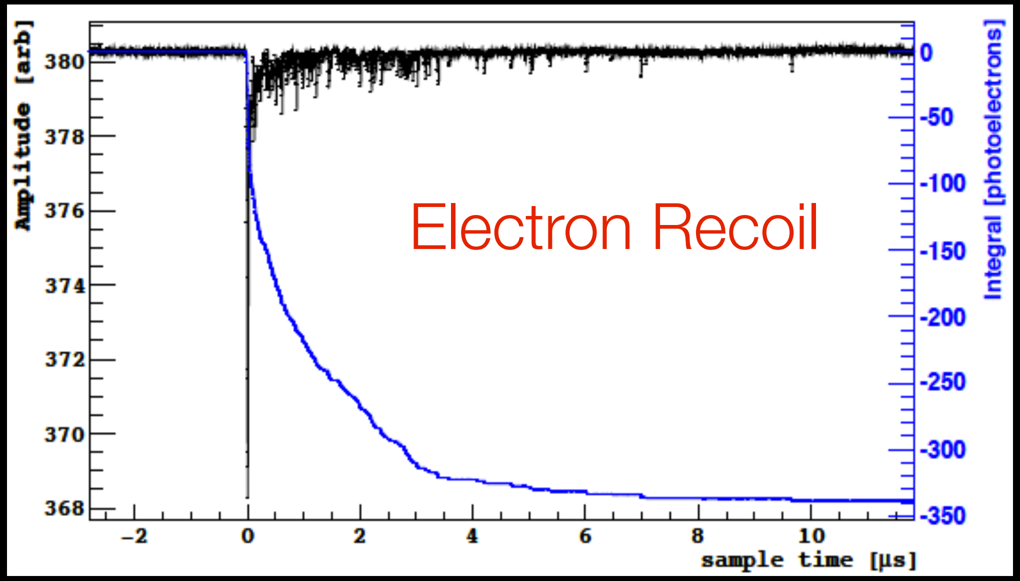
Pulse Shape Discrimination

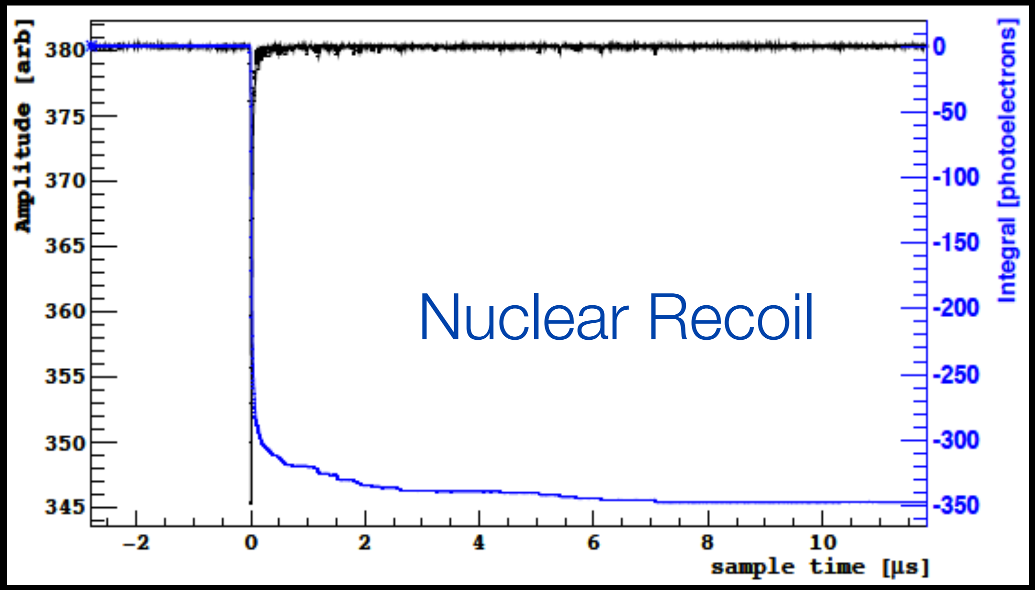
Electron Recoil Discrimination

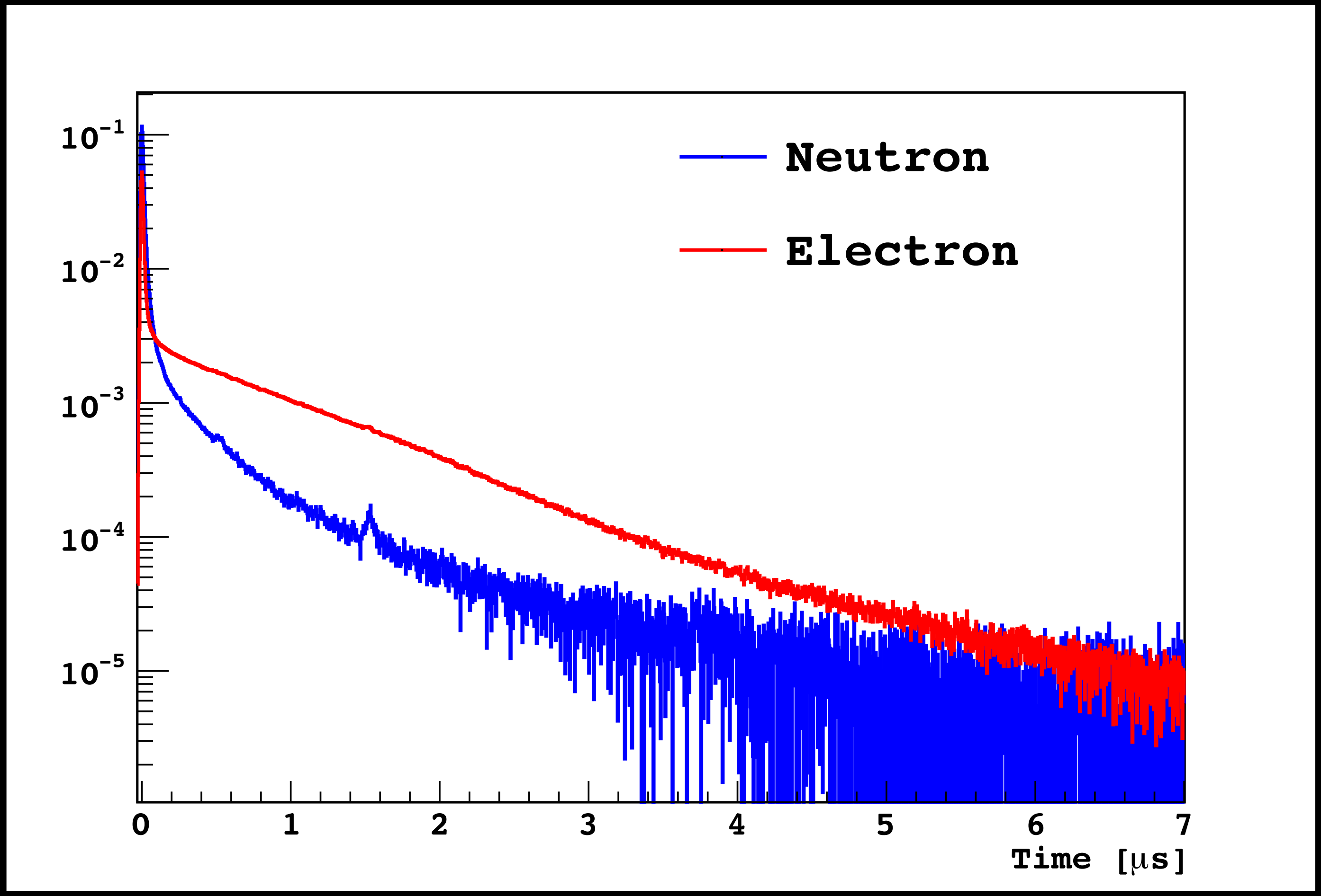
Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

$\tau_{singlet} \sim 7$ ns

$\tau_{triplet} \sim 1600$ ns







Pulse Shape Discrimination

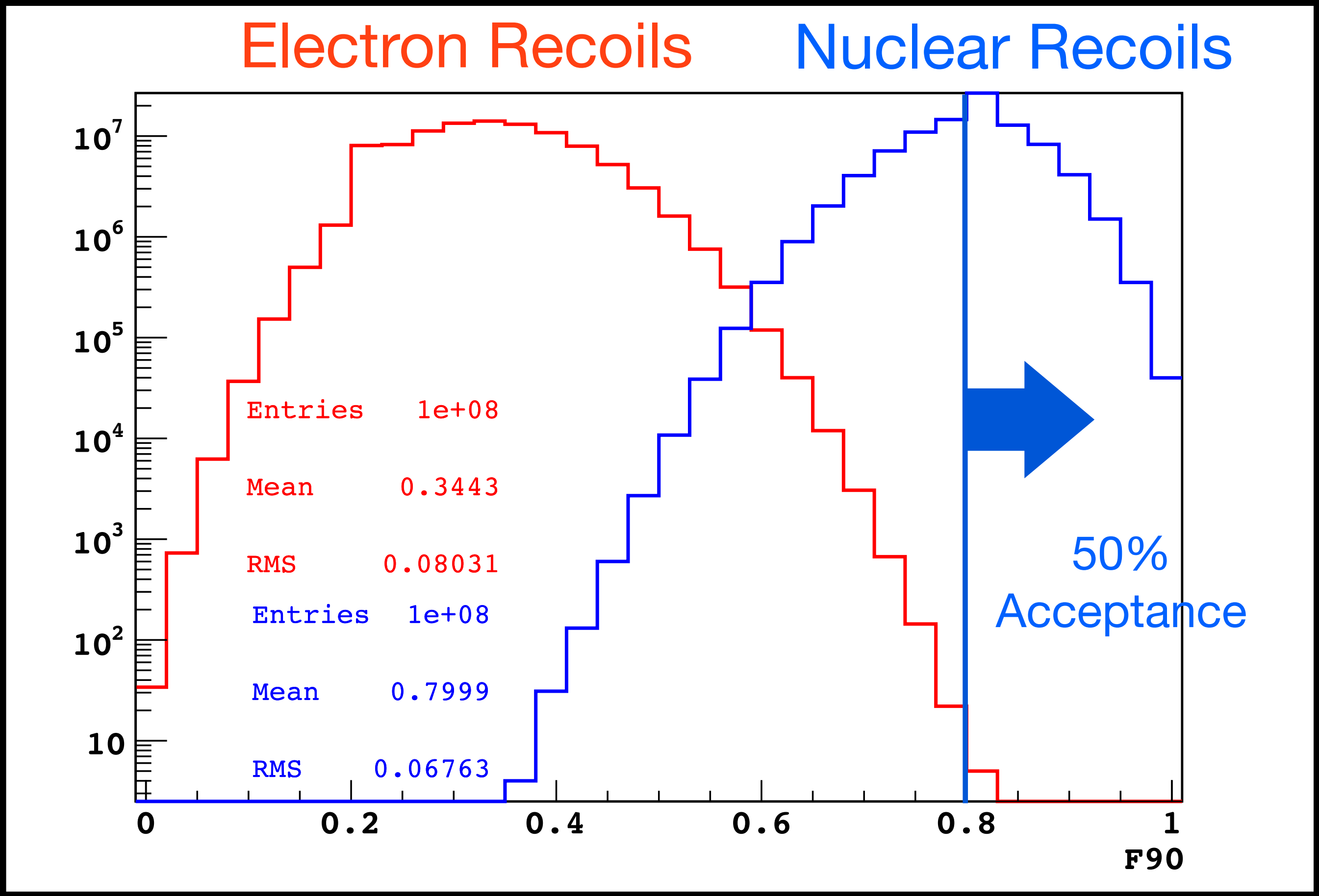
Electron Recoil Discrimination

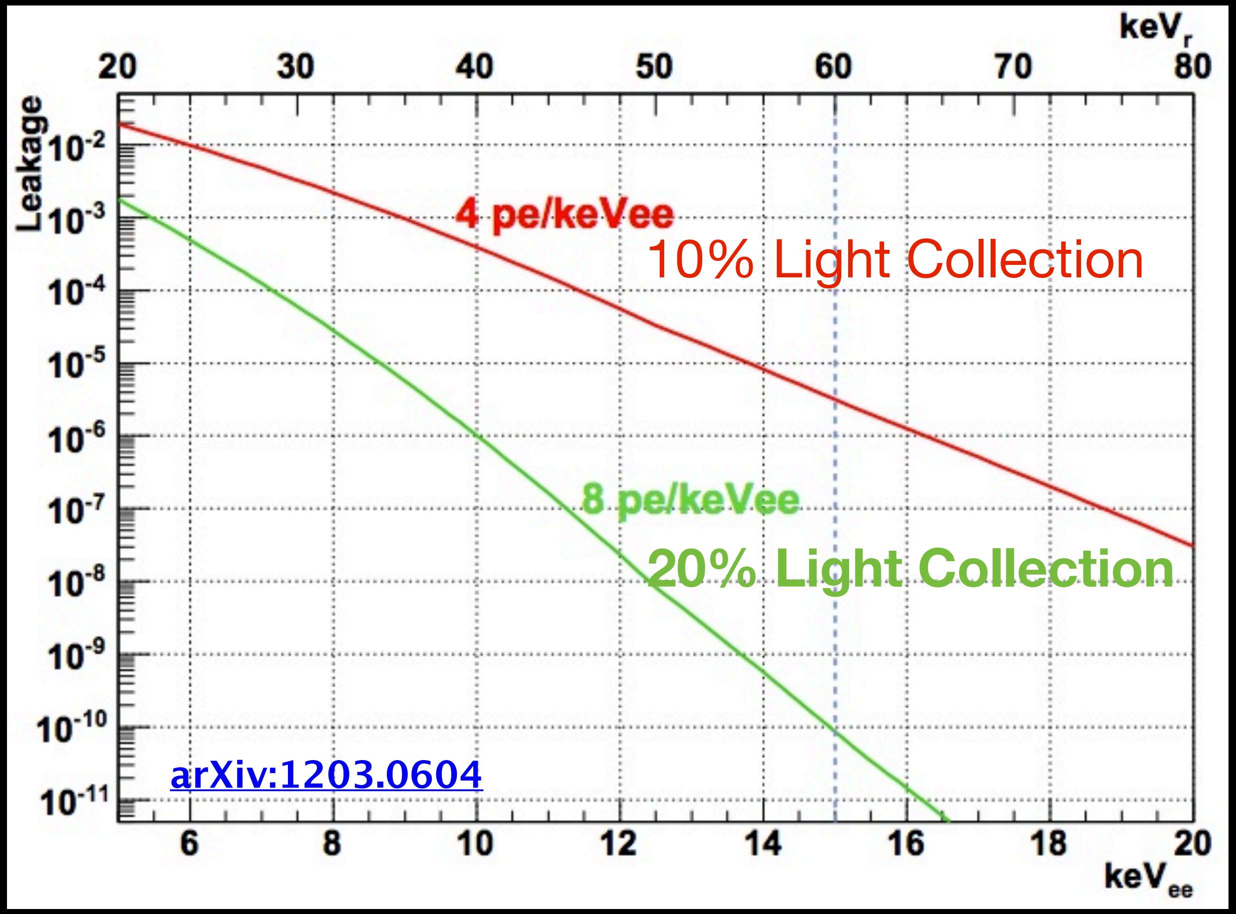
F90: Ratio of detected light in the first 90 ns, compared to the total signal

$\tau_{singlet} \sim 7$ ns

$\tau_{triplet} \sim 1600$ ns

F90 ~ Fraction of singlet states



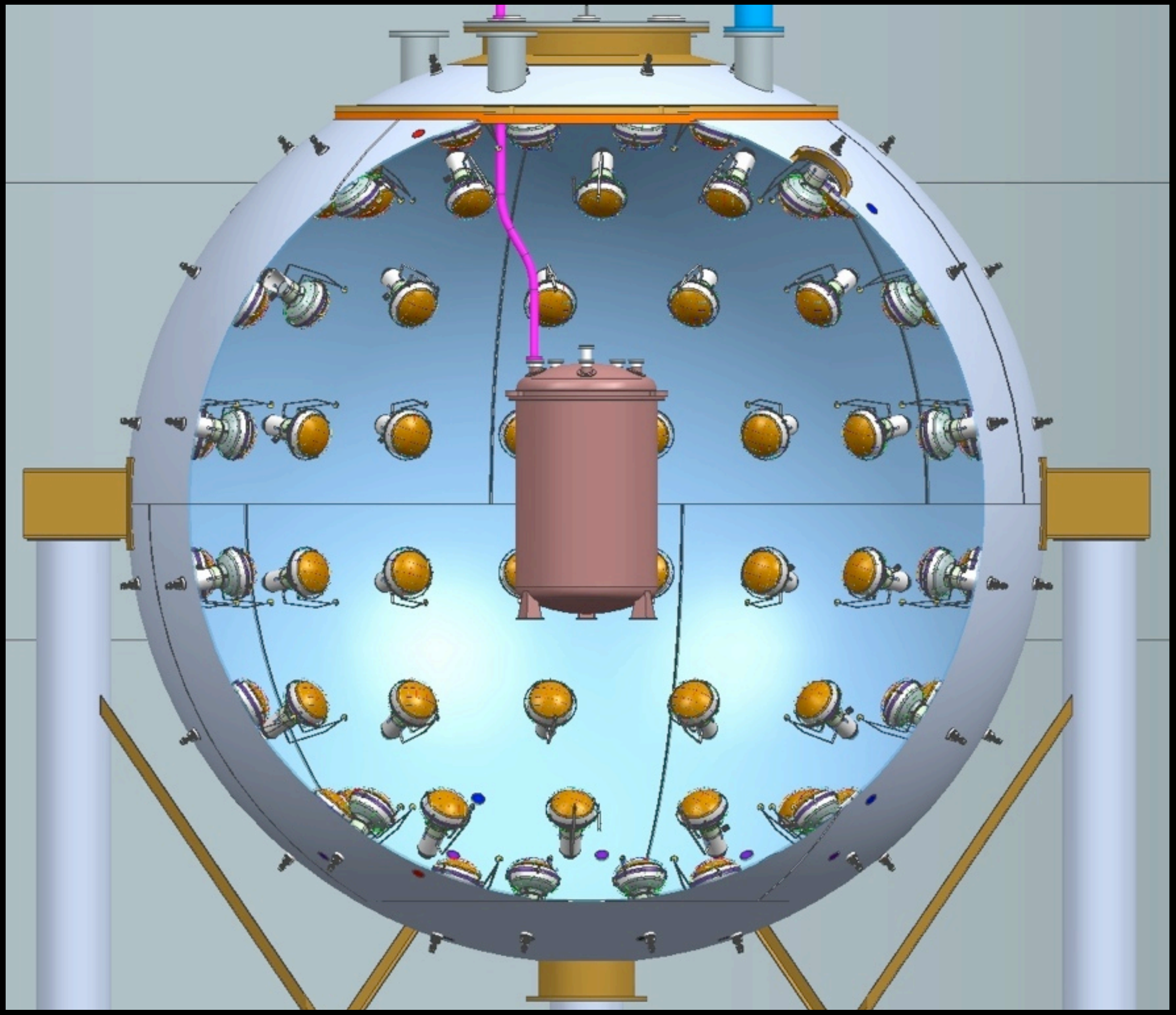


Discrimination power strongly dependent on light collection

Liquid Scintillator Veto

Neutron Rejection

Liquid scintillator allows coincident veto of neutrons in the TPC and provides *in situ* measurement of the neutron background rate

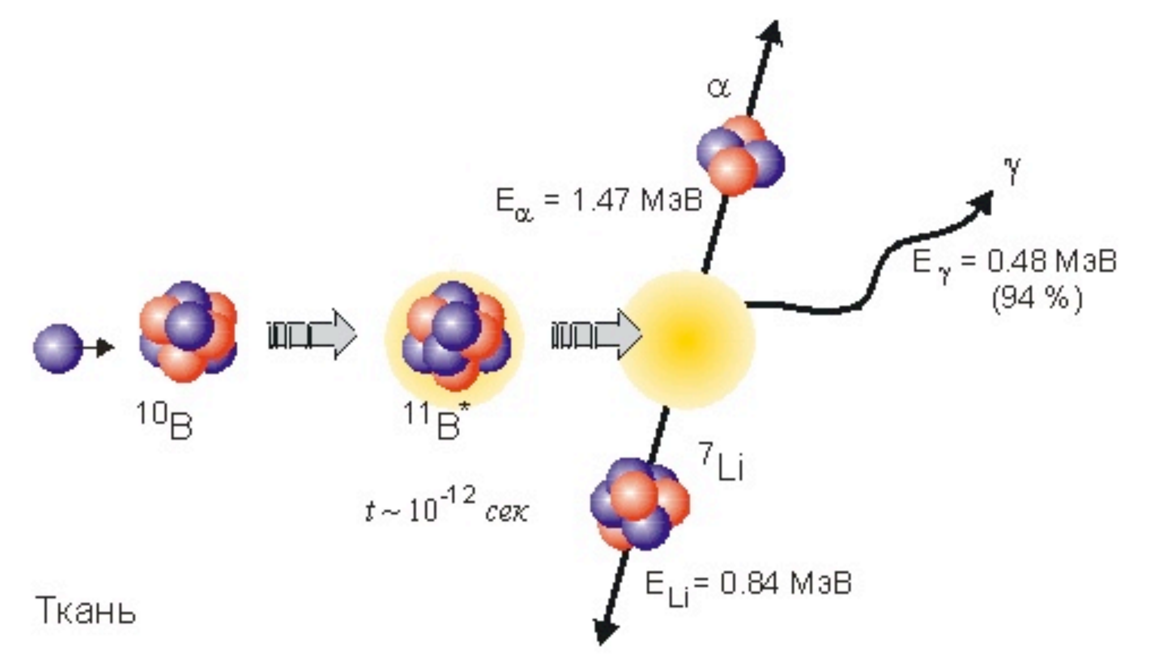


- 4 m diameter sphere containing 1:1 PC + TMB scintillator
- Instrumented with 110 8” PMTs

Neutron Rejection

Borated Liquid Scintillator

- High neutron capture cross section on boron allows for compact veto size
- Capture results in 1.47 MeV **α** particle - detected with high efficiency
- Short capture time (2.3 **μ**s) reduces dead time loss



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

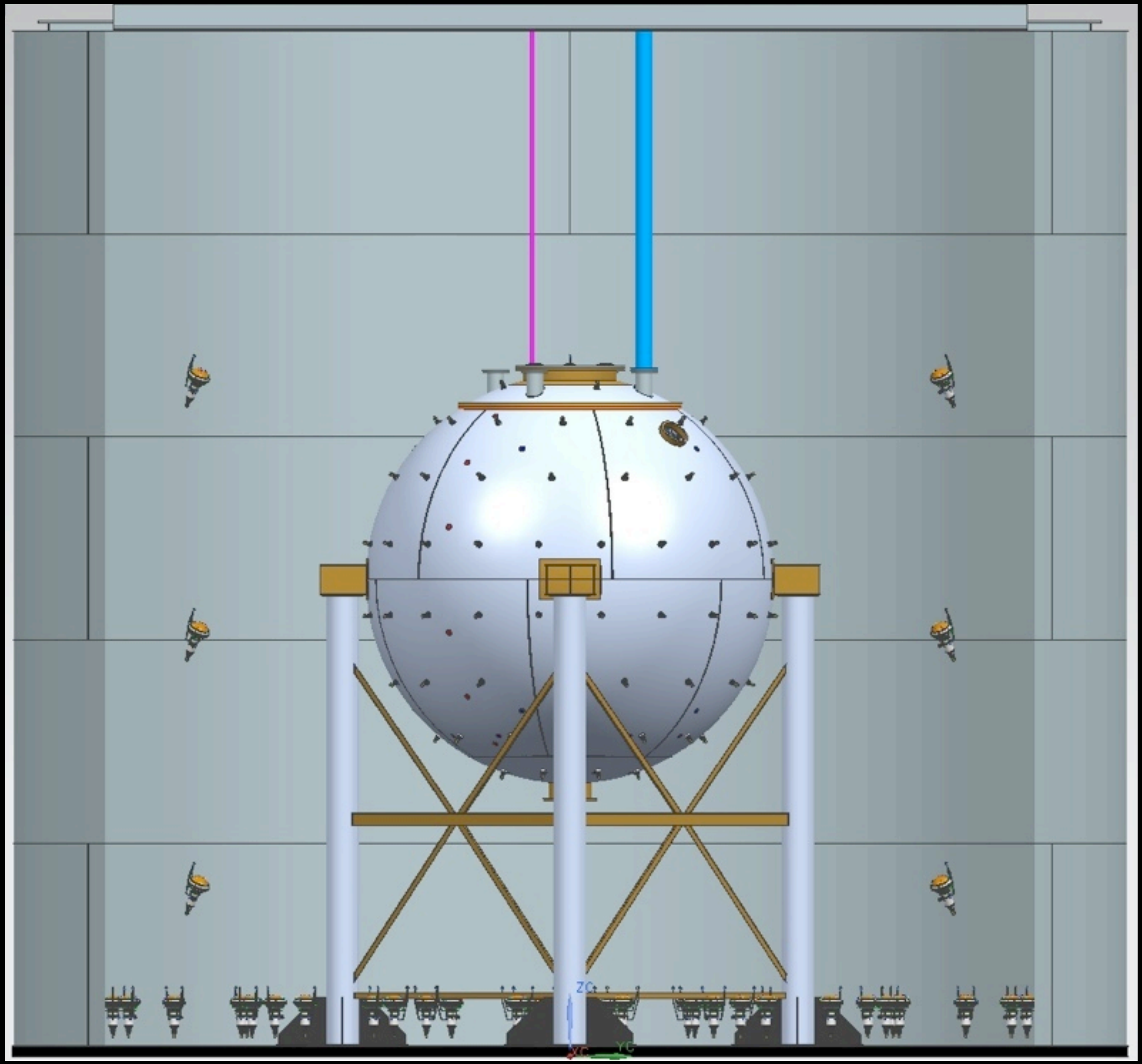
Nuclear Instruments and Methods A 644, 18 (2011)

*Based on 60 **μ**s veto window

Cosmogenics Rejection

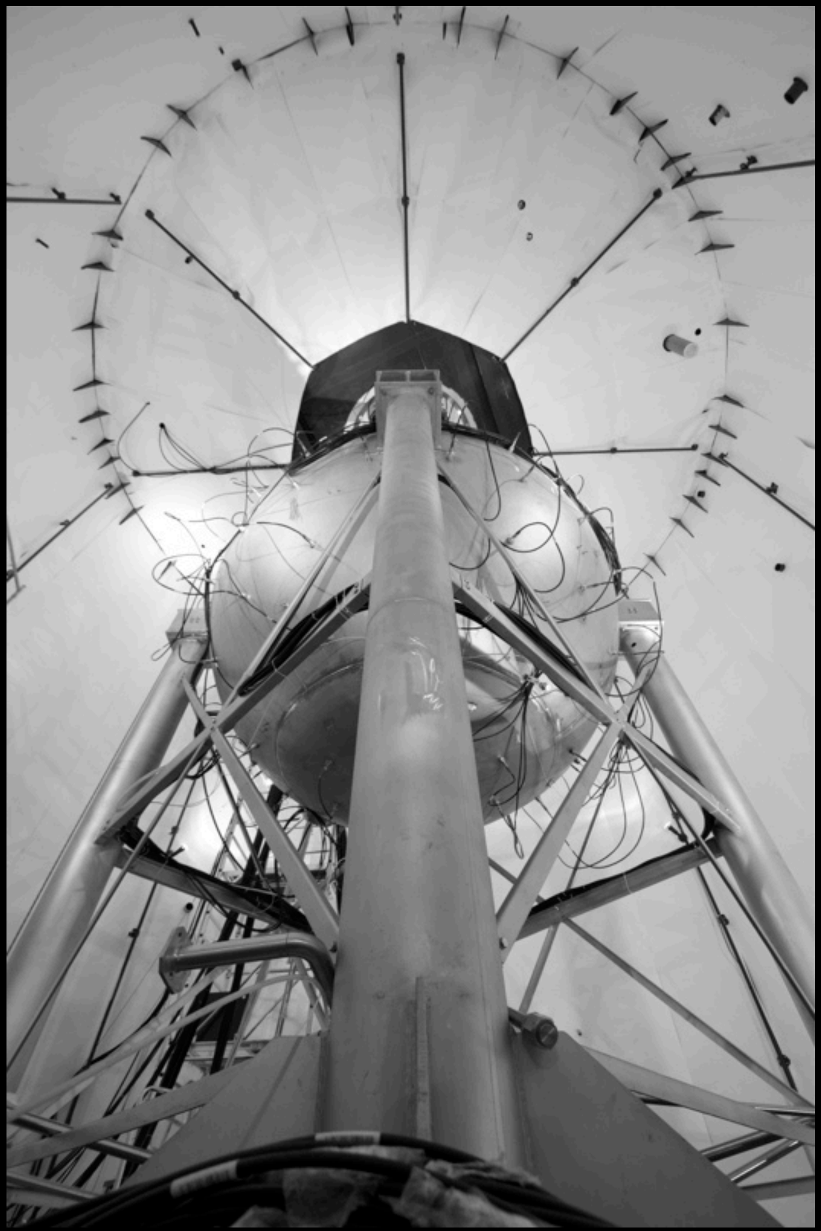
External Water tank

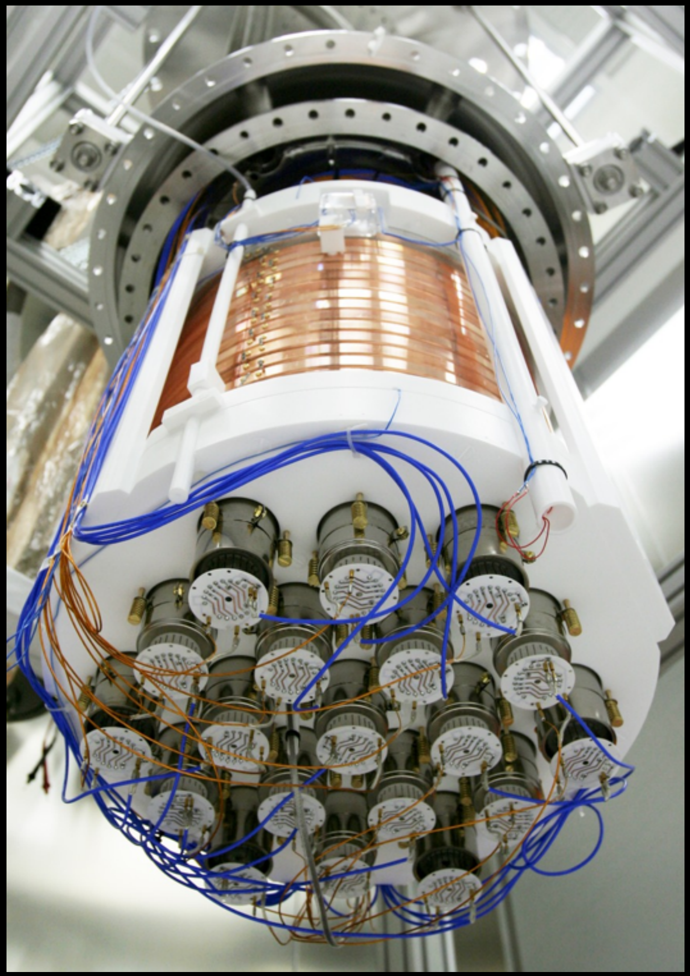
- 80 PMTs within Borexino CTF
(11m dia. x 10 m high)
- Acts as a muon and cosmogenic veto
(~ 99% efficiency)
- Provides passive gamma and neutron shielding



DS-50 Assembly

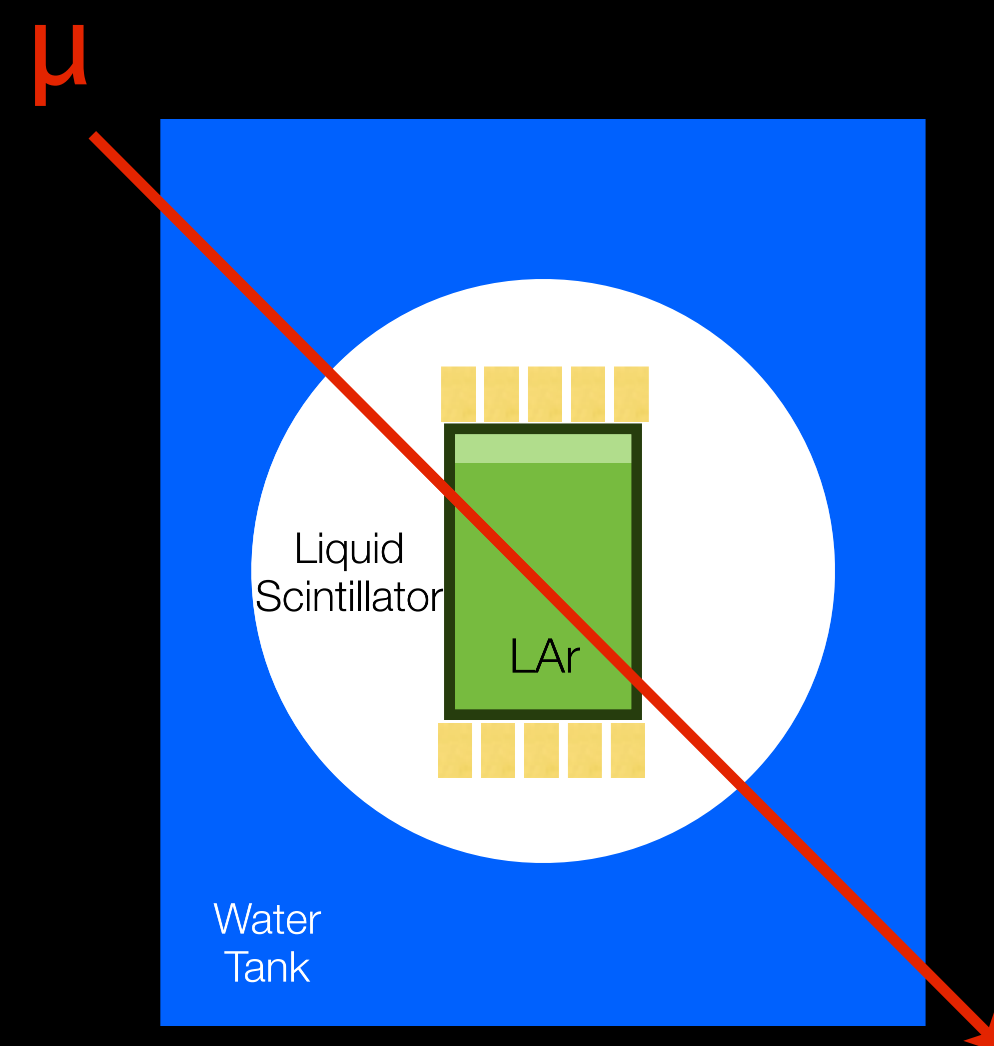
Sept - Oct 2013





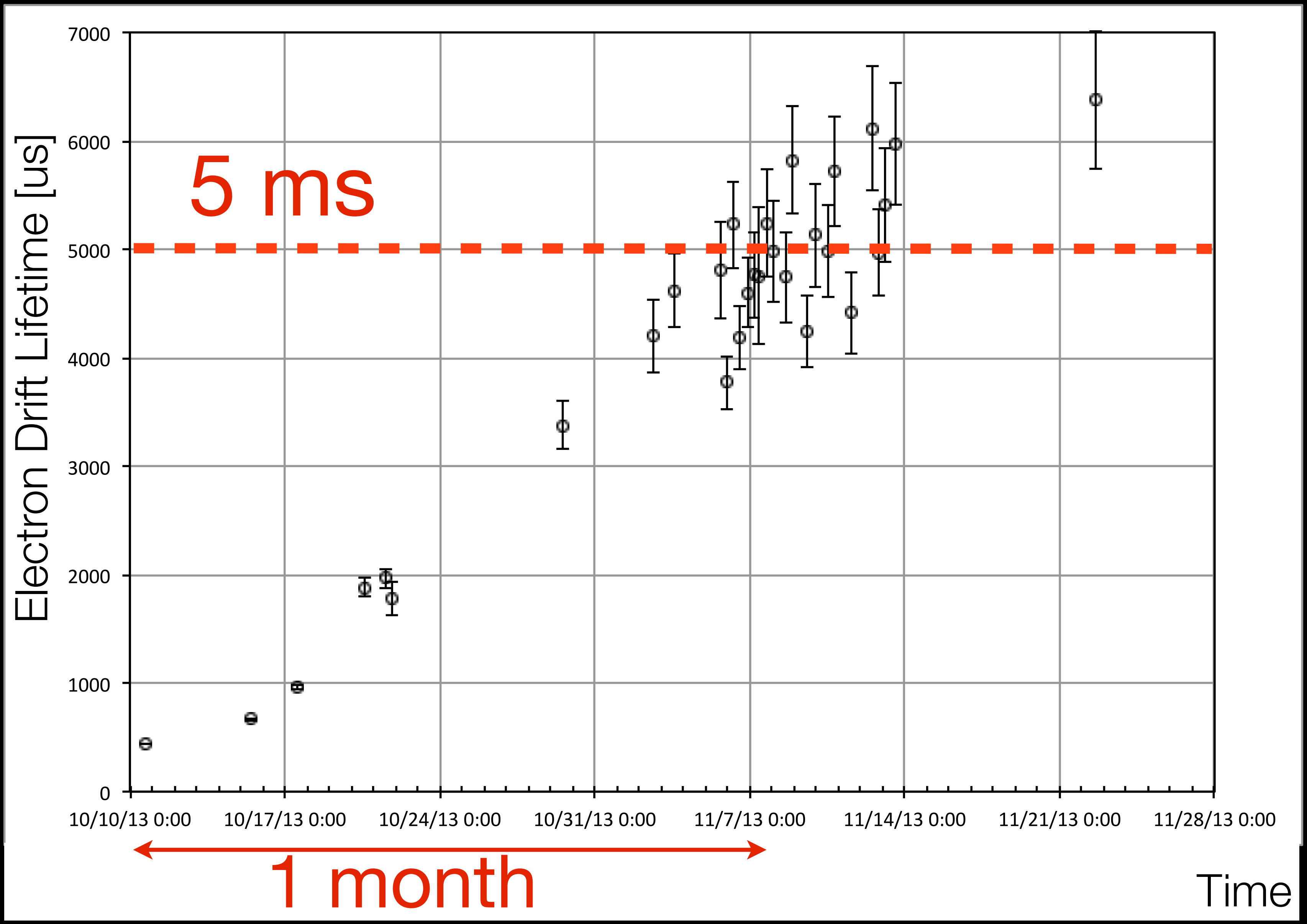
DS-50

All 3 detectors are filled and currently operating



TPC Commissioning

Closed loop Ar recirculation (~30 slpm)
Gaseous phase purification using commercial getter
Cryogenic charcoal trap to remove Rn contamination

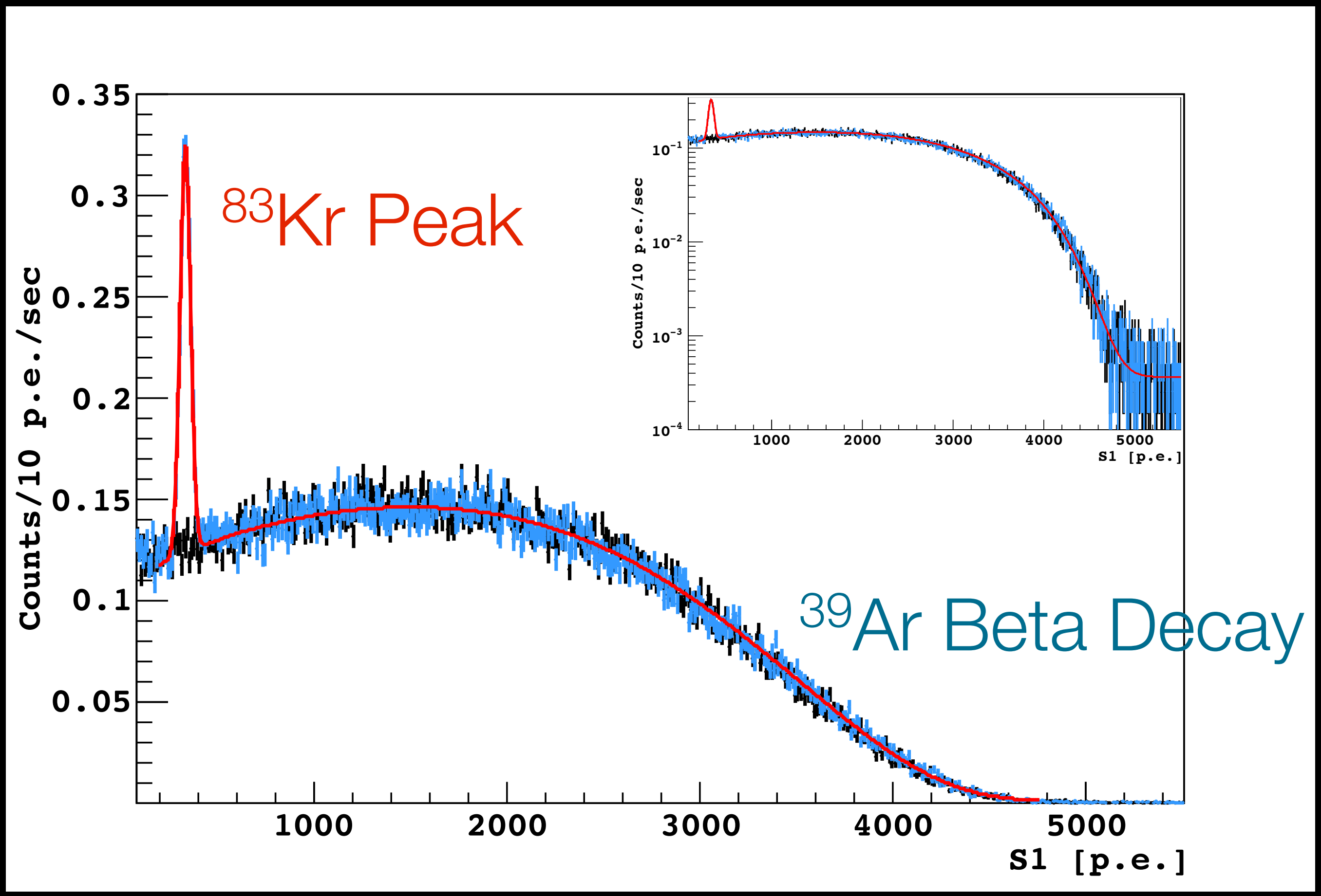


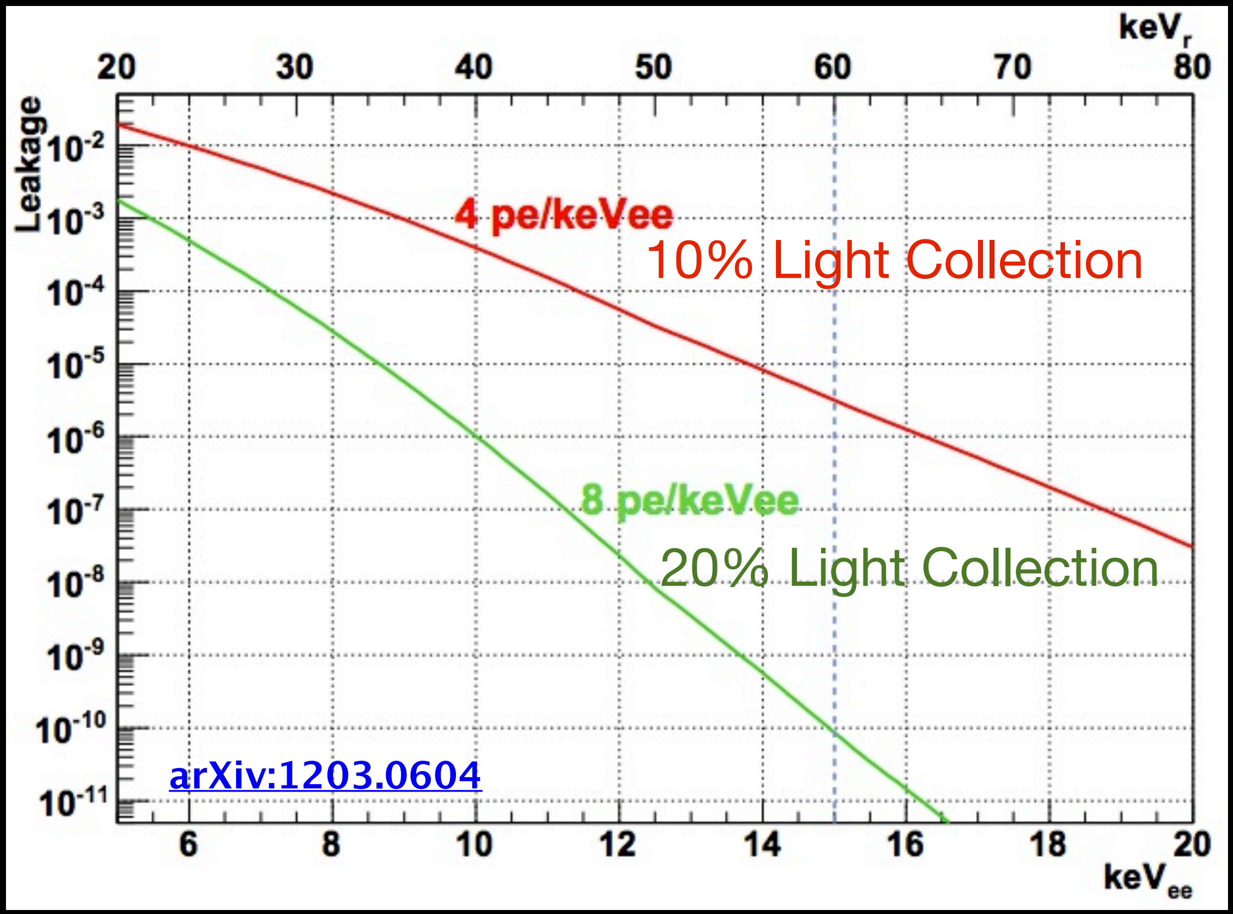
Electron drift lifetime > 5 ms, compared to max. drift time of ~ 375 us

TPC Commissioning

TPC currently filled with **atmospheric** argon (1 Bq/kg)

^{83m}Kr gas deployed into detector (41.5 keV_{ee})





Light Yield
8 PE/keV_{ee}

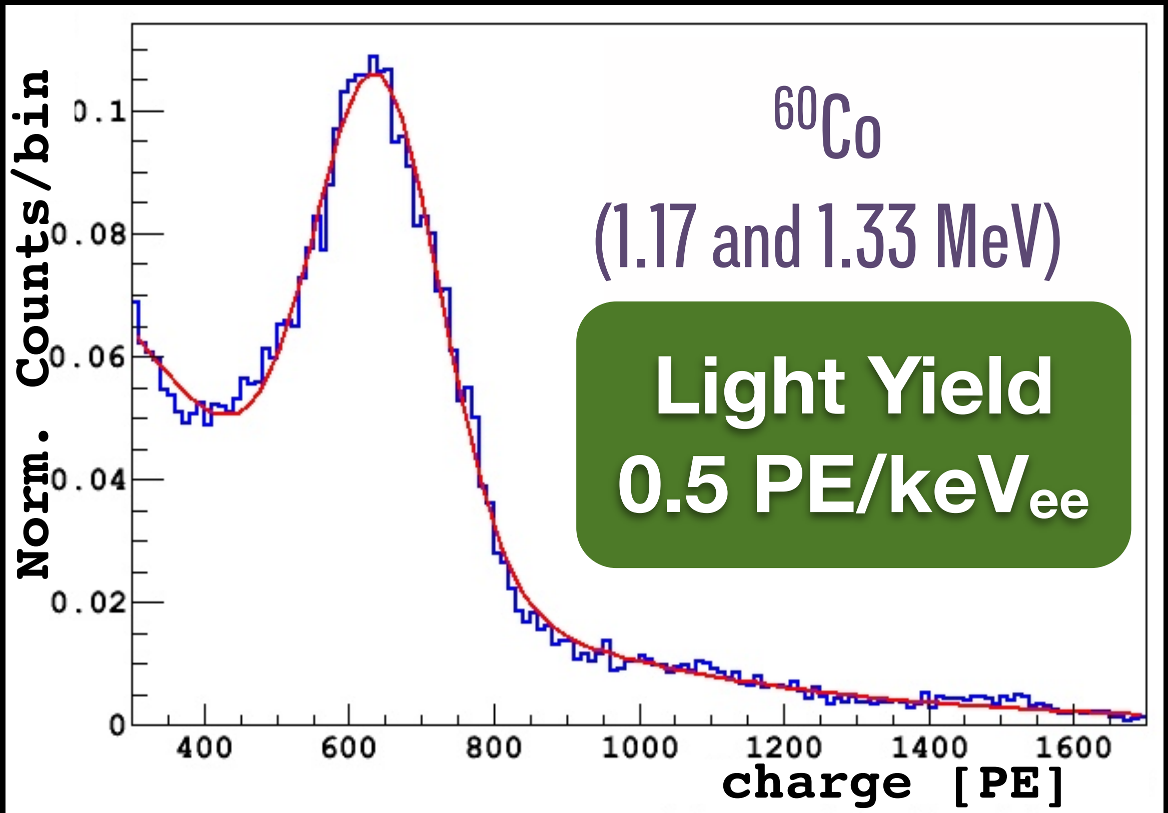
Measured light yield **exceeds** previous projections of 6 PE/keV_{ee}

Neutron Veto Commissioning

Neutron veto setup to trigger on events in the liquid Ar TPC

Use high energy coincident ^{60}Co events from cryostat stainless steel to evaluate lightyield in scintillator

Lightyield ~ 0.5 PE/keV_{ee} sufficient to detect ~ 50 keV_{ee} α from neutron capture



Found high rate at low energies due to intrinsic ^{14}C in (biogenic) TMB

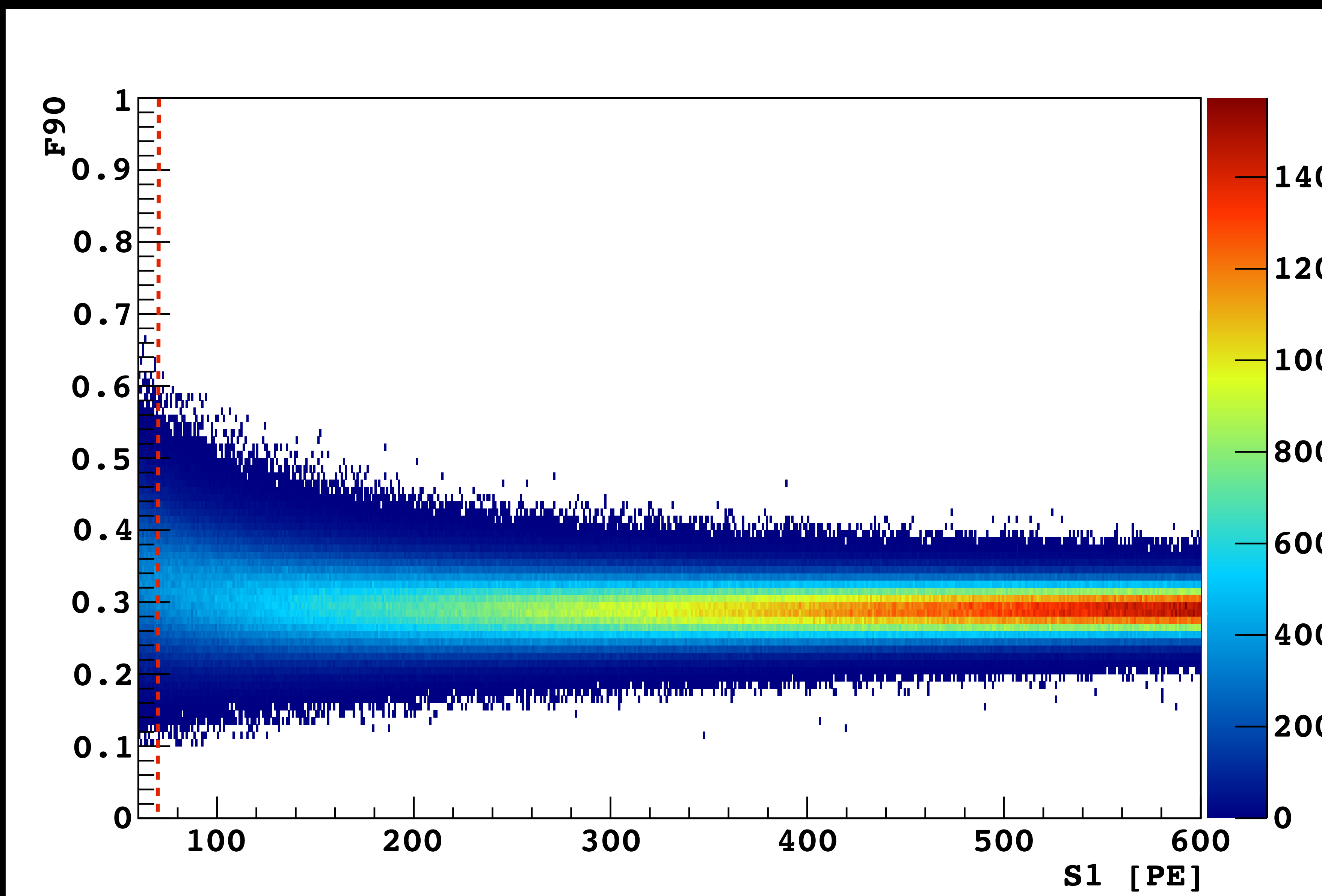
Scintillator currently being distilled to remove TMB (expected 1000x reduction)

Identified new batch of low-^{14}C (underground) TMB

Initial Exposure (280 kg-days)

High rate of ^{39}Ar in atmospheric argon allows us to calibrate our S1 pulse shape discrimination with an exposure that is equivalent to 2.6 yrs with underground argon

Pulse Shape Parameter

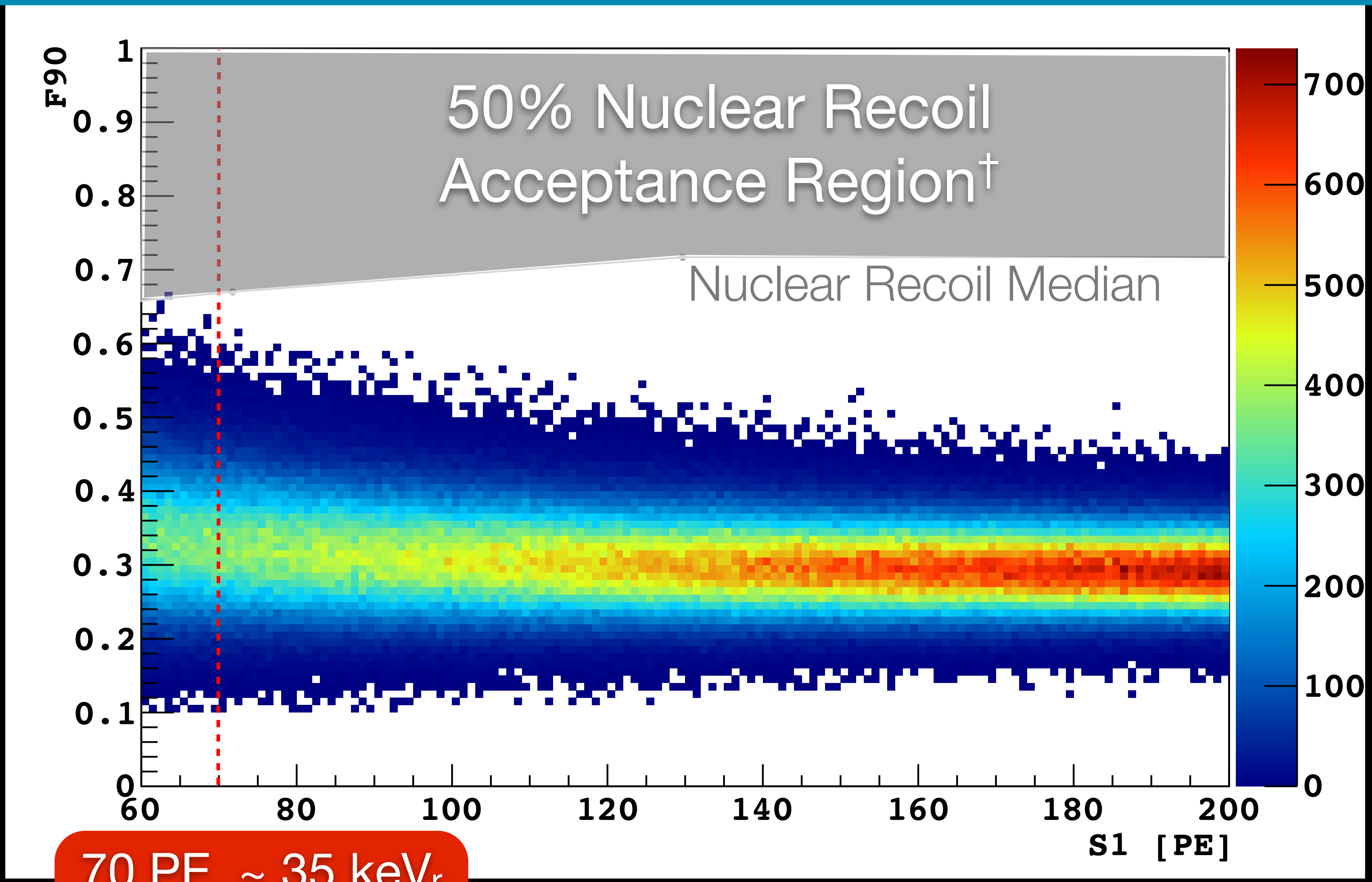


70 PE ~ 35 keV_r

- 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

Initial Exposure (280 kg-days)

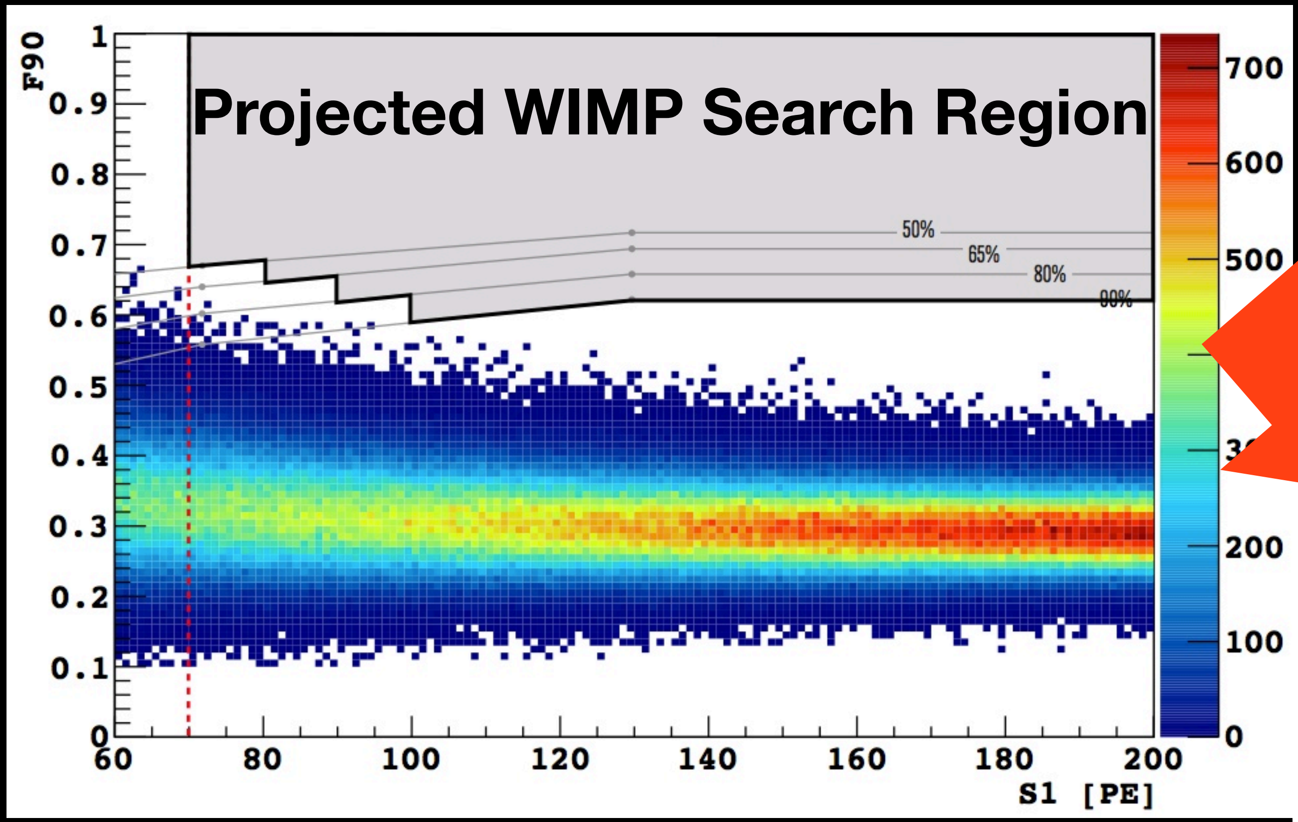
We have **PROVEN** that PSD @ 200 V/cm (+ z fiducialization from S2) can efficiently suppress the dominant ER background that we expect in 2.6 years of DS-50 UAr run, while maintaining high acceptance for WIMPs.

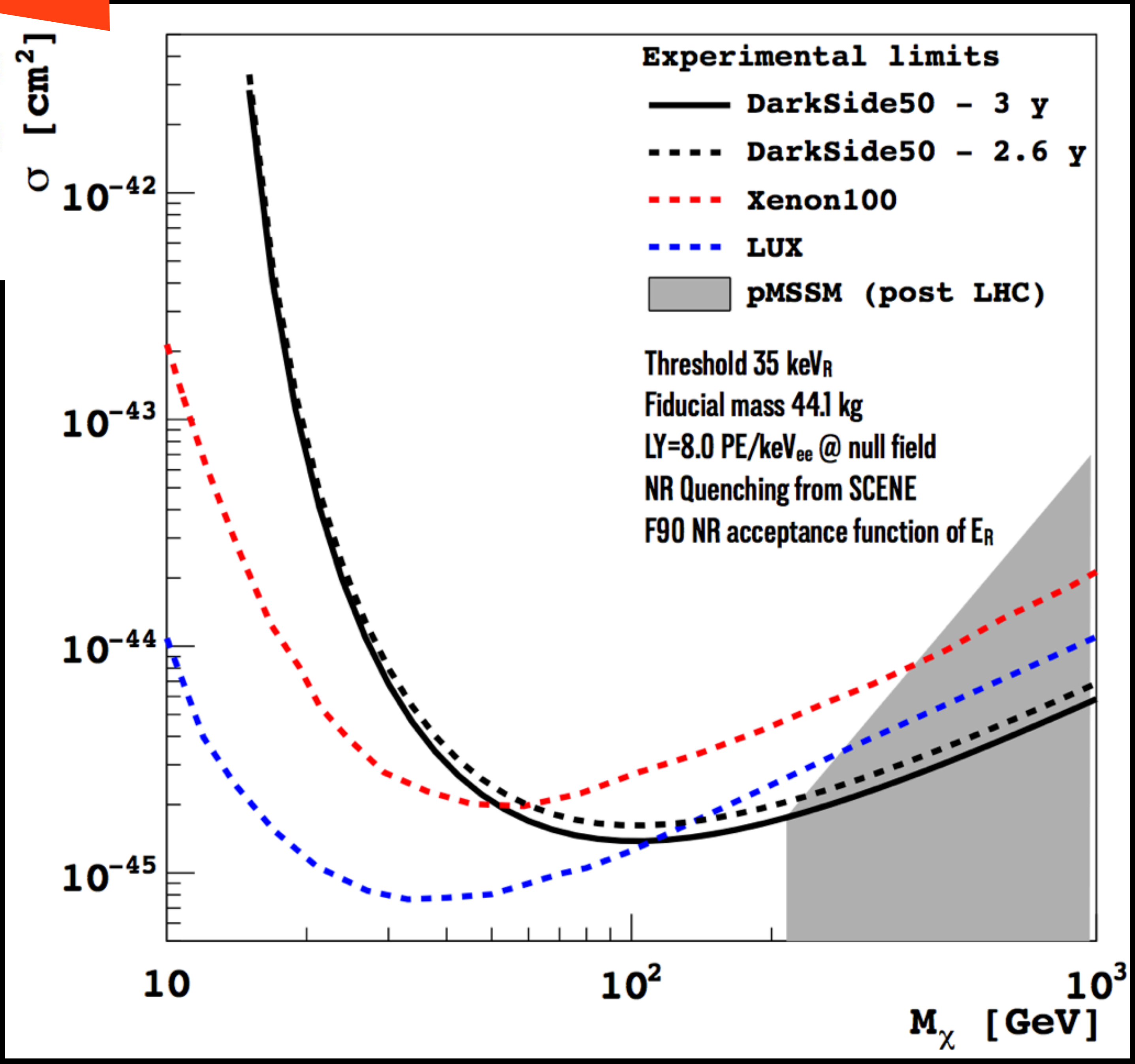


70 PE ~ 35 keV_r

†SCENE Experiment: arXiv:1406.4825

DS-50 Projected Sensitivity





Assumptions

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

Systematics

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

DS-50 Current Status

- **Have currently acquired ~ 5000 kg · days of atmospheric argon data with TPC (TPC+Veto: ~2500 kg · days)**
  Data being used to improve understanding of backgrounds, S2 signal, x-y position reconstruction, S1-S2 correlations

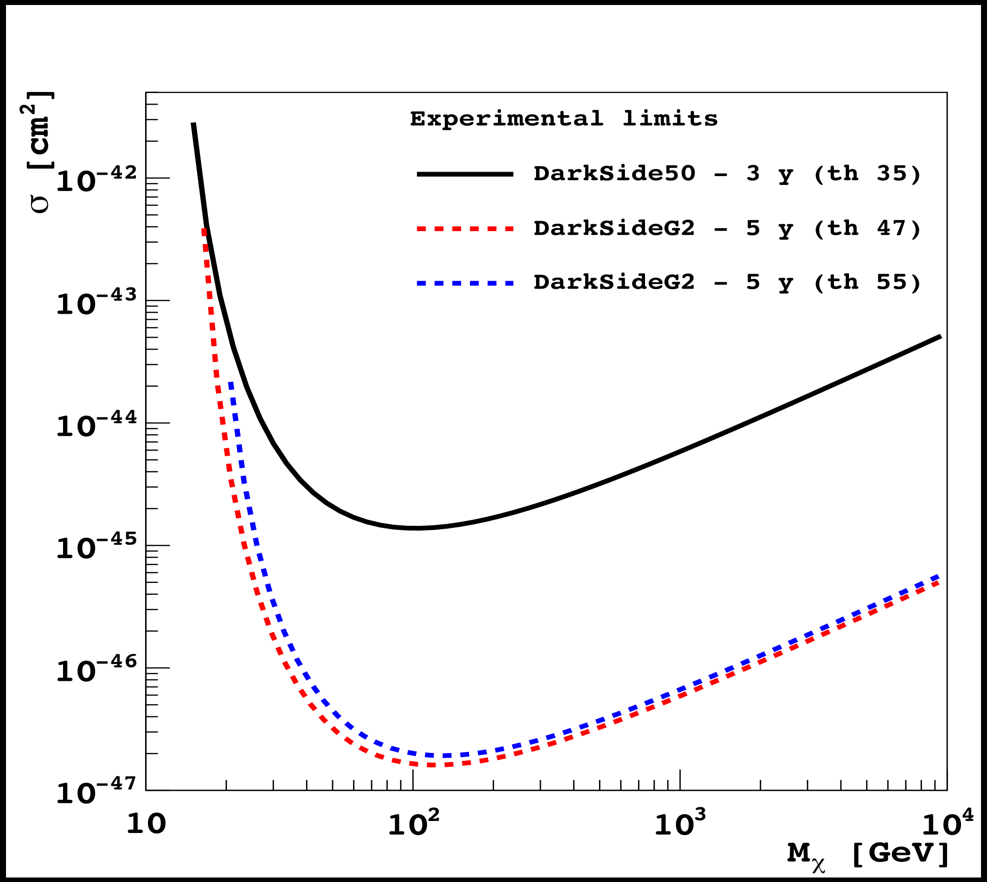
- **High rate of ^{14}C found in TMB used for neutron veto**
  Operations currently underway to remove TMB - achieved 100x reduction, aiming for 1000x. Will replace with low-^{14}C TMB

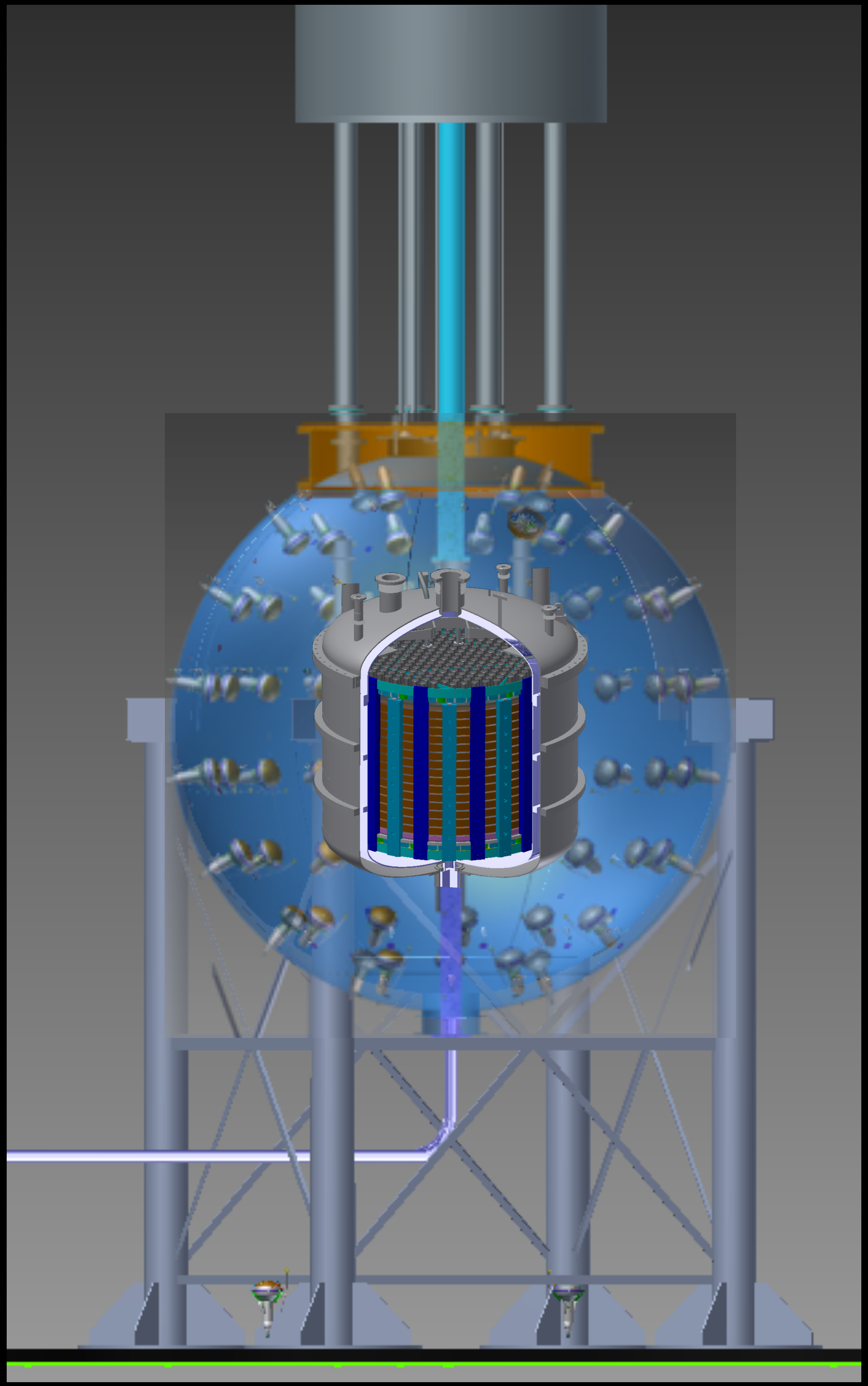
- **Source calibration**
  Hope to have gamma and neutron data by end of summer 2014

- **Underground argon**
  Switch to using underground argon foreseen at the end of 2014

DarkSide G2

- Next generation experiment designed to have 3.8 ton active mass
- Neutron veto and water tank were sized to hold the G2 detector - already built and running.
- Modest upgrade of cryogenic and gas handling system required





THE END

DarkSide 50
Inner Detector Parameters

Dimensions

- Active volume diameter 35.6 cm
- Active volume height 35.6 cm
- Gas pocket height 1.0 cm
- LAr above grid 0.5 cm
- TPC full height 69.0 cm

Masses

- Active LAr 49.4 kg
- Total LAr ~145 kg
- Main PTFE reflector 22.8 kg
- Total PTFE 59.2 kg
- Total fused silica 3.5 kg
- Copper field cage rings 23.5 kg
- 38 R11065 PMTs 7.9 kg

Other parameters

- Recirculation rate (min)* 15 slpm
  (max)* 40 slpm
  =4.1 kg/h
- Photocathode coverage ~20%
  of top and bottom ~60%

* Estimate

Underground Argon

- ^{40}Ar is mostly produced underground (through decay of ^{40}K)
- ^{39}Ar is cosmogenic, produced by ^{40}Ar(n,2n) interactions in the atmosphere
- Argon that has remained underground can therefore have extremely low levels of ^{39}Ar
- However, ^{39}Ar can also be produced underground through ^{39}K(n, p) interactions, where the neutron originates from (α, n) reactions.

^{39}Ar/^{40}Ar depends on the local concentration of ^{238}U and ^{232}Th

Surface contamination

Radon-Free Clean Rooms

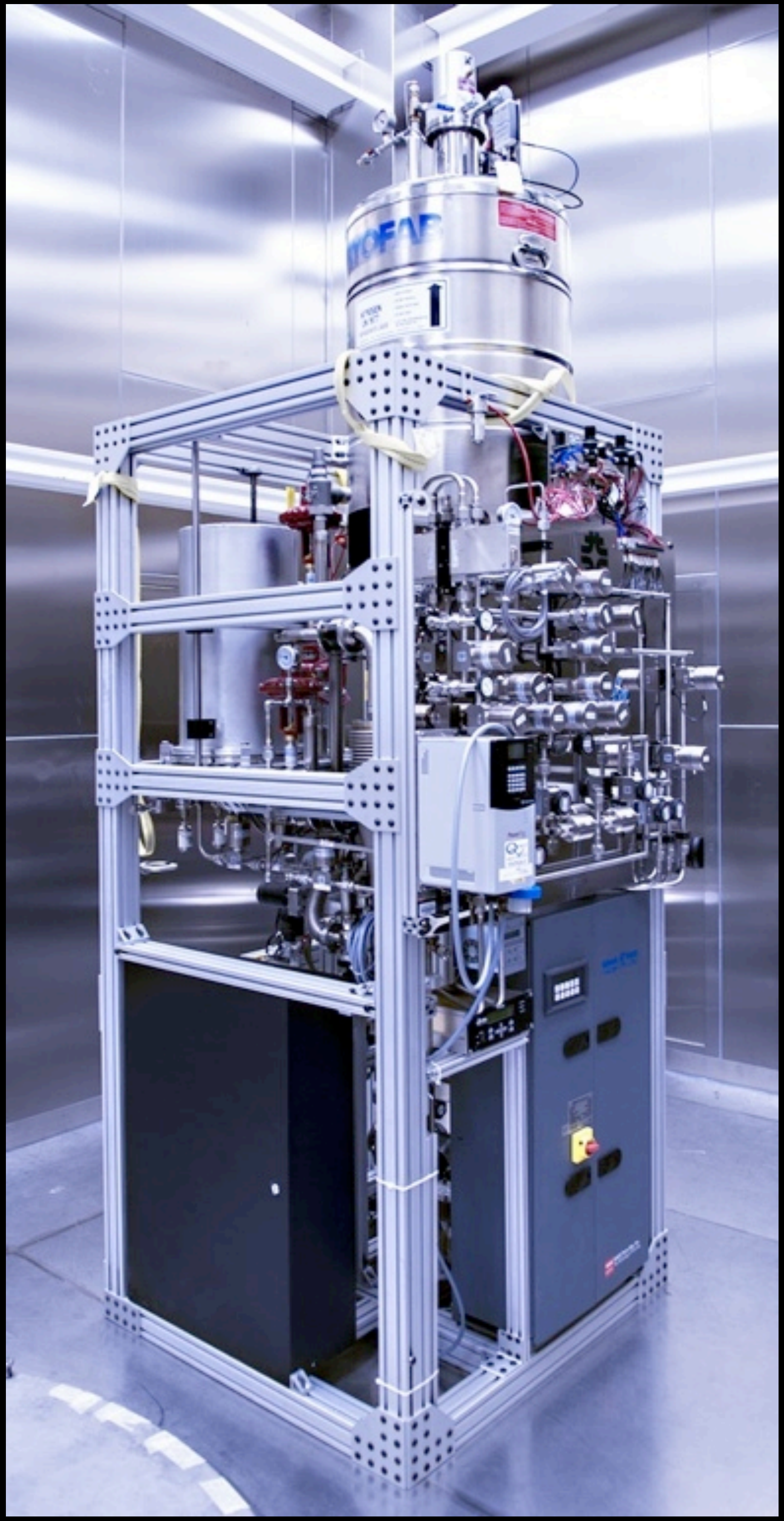
Radon daughters plate out on surfaces of the detector causing dangerous alpha-induced nuclear recoils

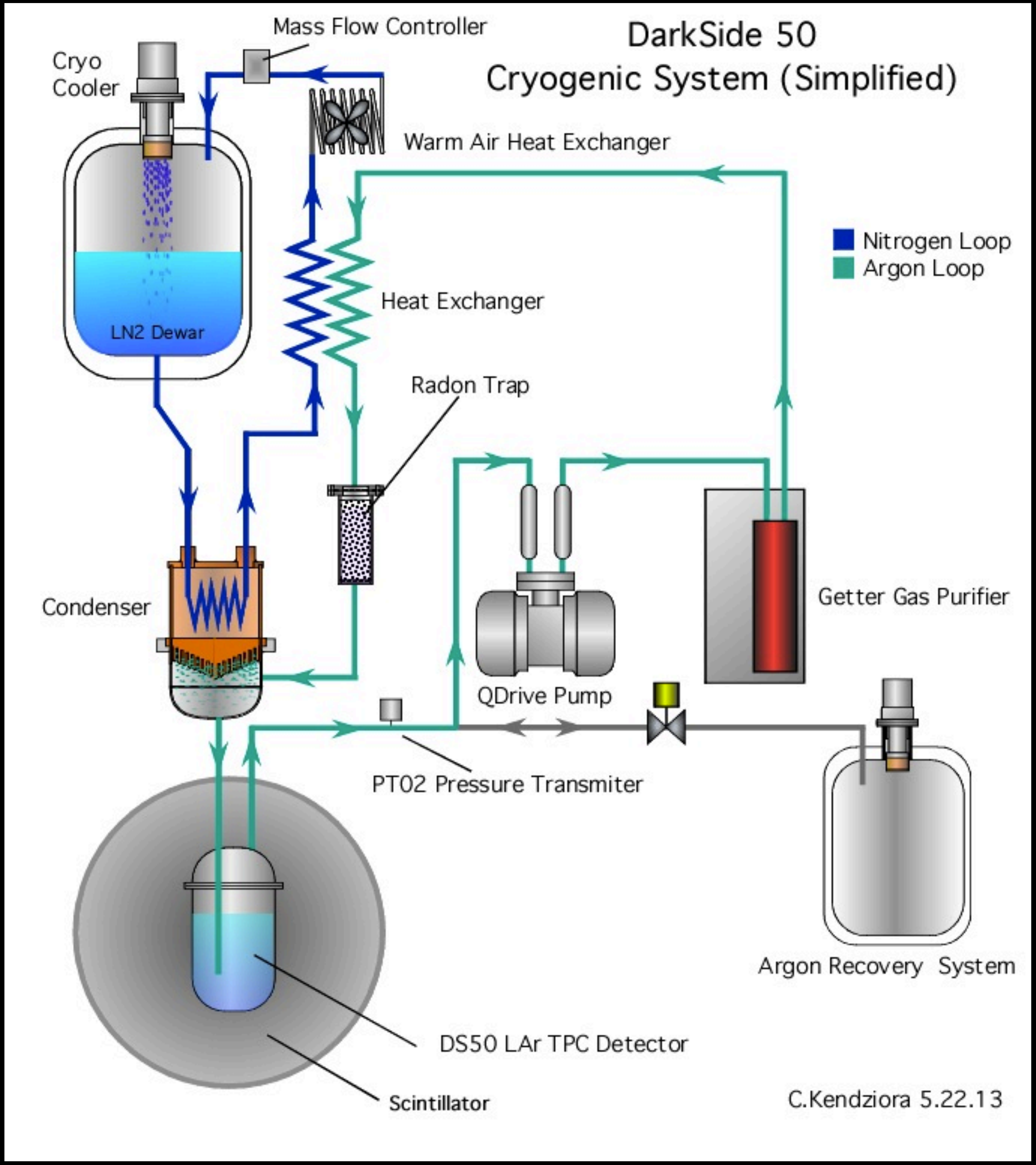
Final preparation, cleaning, evaporation and assembly of all inner detector parts was carried out in radon-free clean rooms

Typical radon in air ~ 30 Bq/m^3

Cleanroom radon levels 10-15 mBq/m^3

Cooling, Recirculation and Purification





Expected Backgrounds

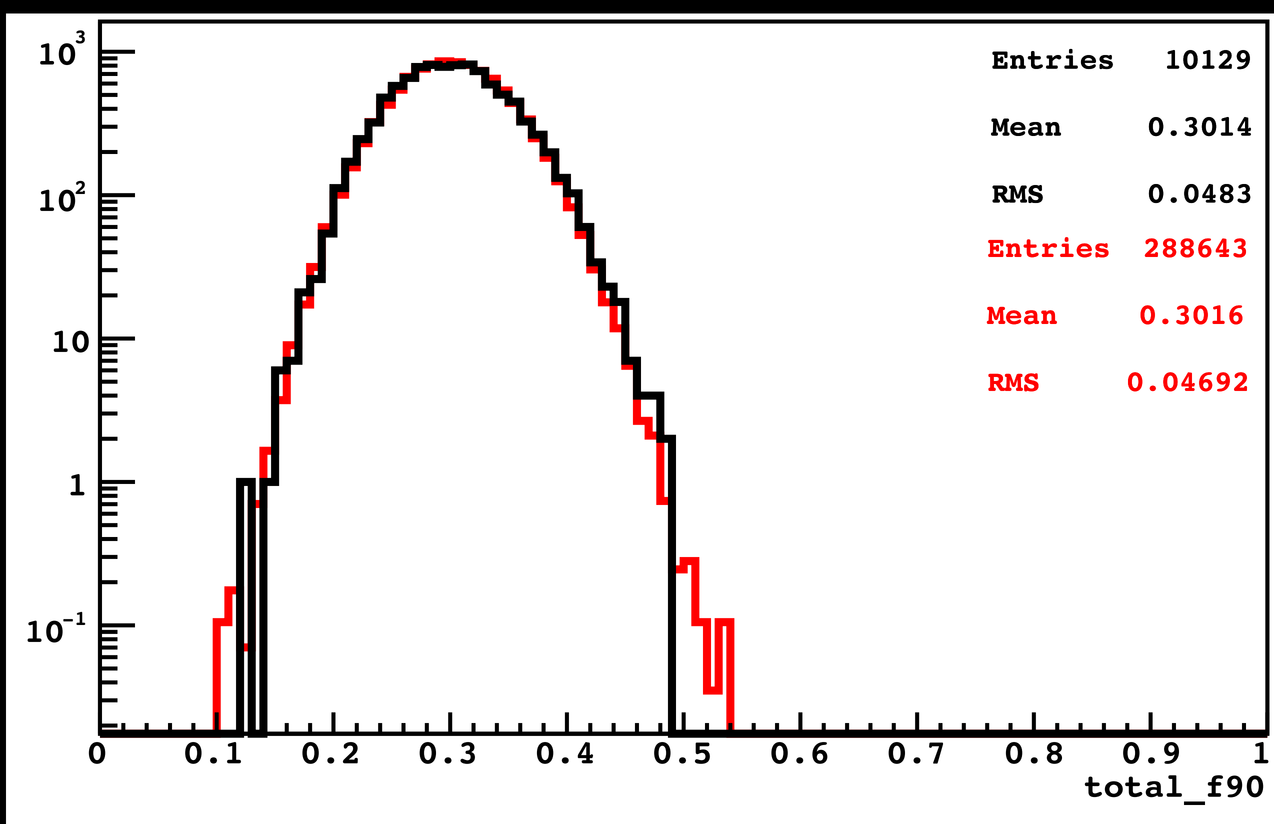
TO BE UPDATED

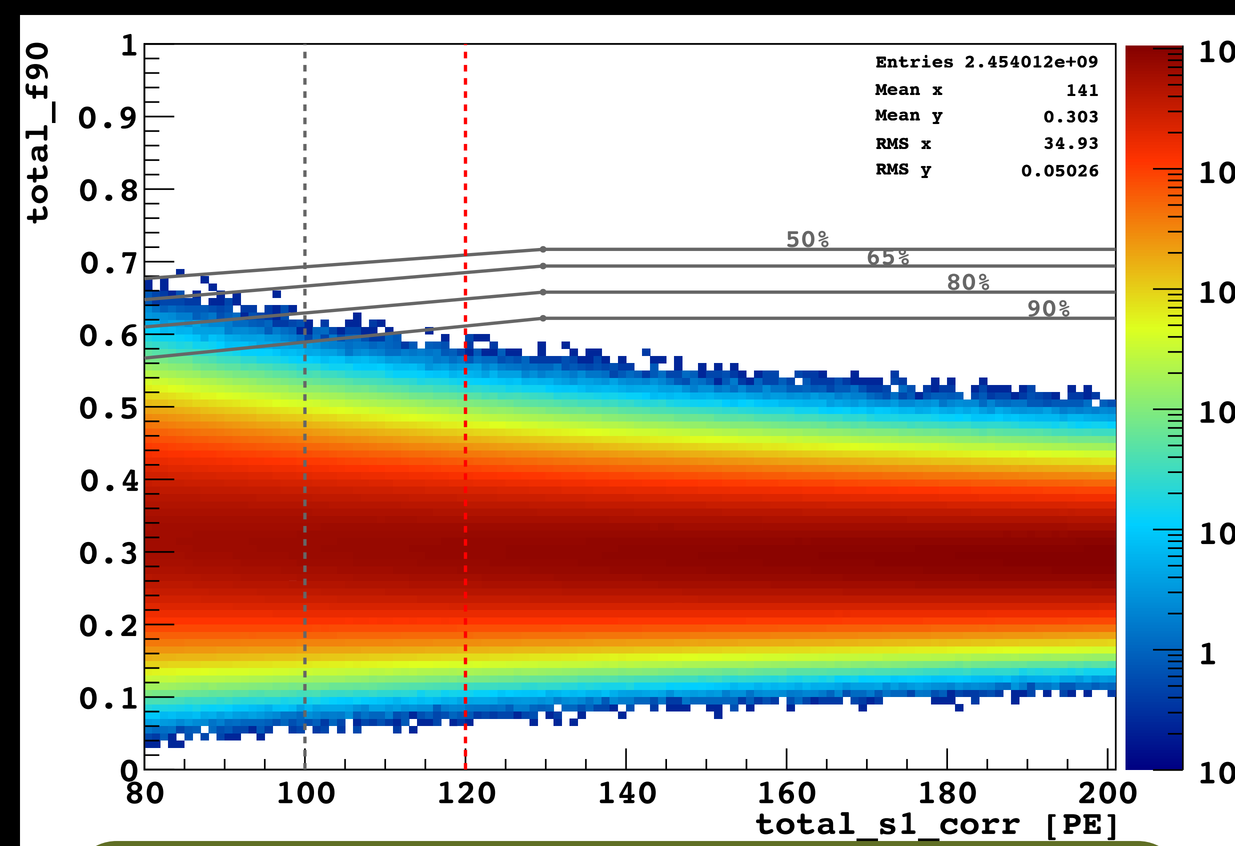
Detector Element	Electron Recoil Backgrounds		Radiogenic Neutron Recoil Backgrounds		Cosmogenic Neutron Recoil Backgrounds	
	Raw	After Cuts	Raw	After Cuts	Raw	After Cuts
^{39}Ar (<0.01 Bq/kg)	$<6.3\times10^6$		–	–	–	–
Fused Silica	3.3×10^4		0.17	4.3×10^{-4}	0.21	1.3×10^{-5}
PTFE	4,800		0.39	9.8×10^{-4}	2.7	1.6×10^{-4}
Copper	4,500		5.0×10^{-3}	1.3×10^{-5}	1.5	9.0×10^{-5}
R11065 PMTs	2.6×10^6		19.4	4.8×10^{-2}	0.34	2.0×10^{-5}
Stainless Steel	5.5×10^4		2.5	6.3×10^{-3}	30	0.0018
Veto Scintillator	70		0.030	7.5×10^{-5}	26	0.0016
Veto PMTs	2.5×10^6		0.023	5.8×10^{-5}	–	–
Veto tank	1.7×10^5		6.7×10^{-5}	1.7×10^{-7}	19	0.0071
Water	6,100		6.7×10^{-4}	1.7×10^{-6}	19	0.0071
CTF tank	8,300		3.5×10^{-3}	8.7×10^{-6}	0.068	2.6×10^{-5}
LNGS Rock	920		0.061	1.5×10^{-4}	0.31	0.012
Total	–	< 0.1	–	0.055	–	0.030

0.1 ton x year exposure, 30 - 200 keV_r window,

PSD Model for DarkSide-G2 extrapolation

Model the **statistical** properties of the F90 discrimination parameter 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 and reconstruction and noise effects.

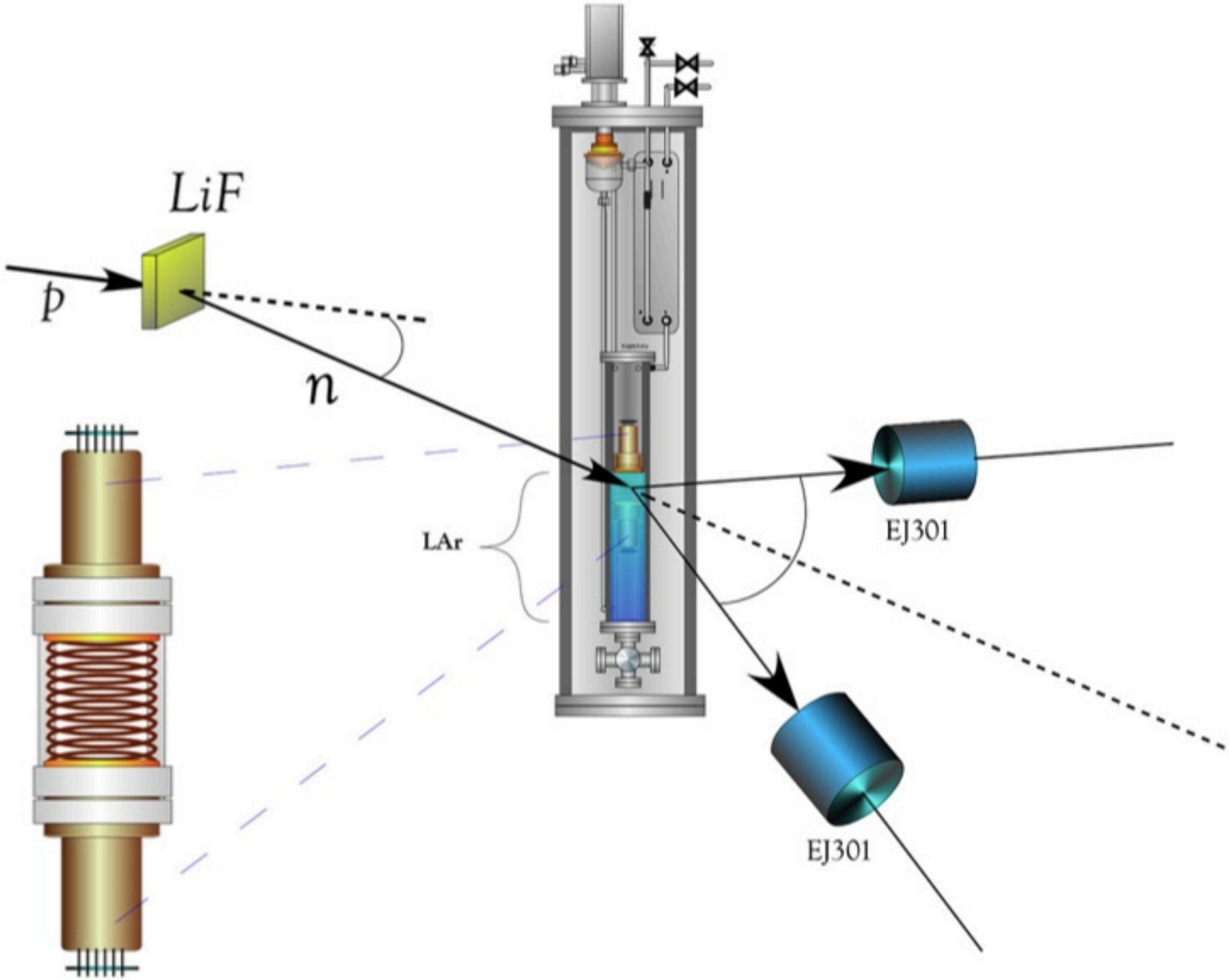




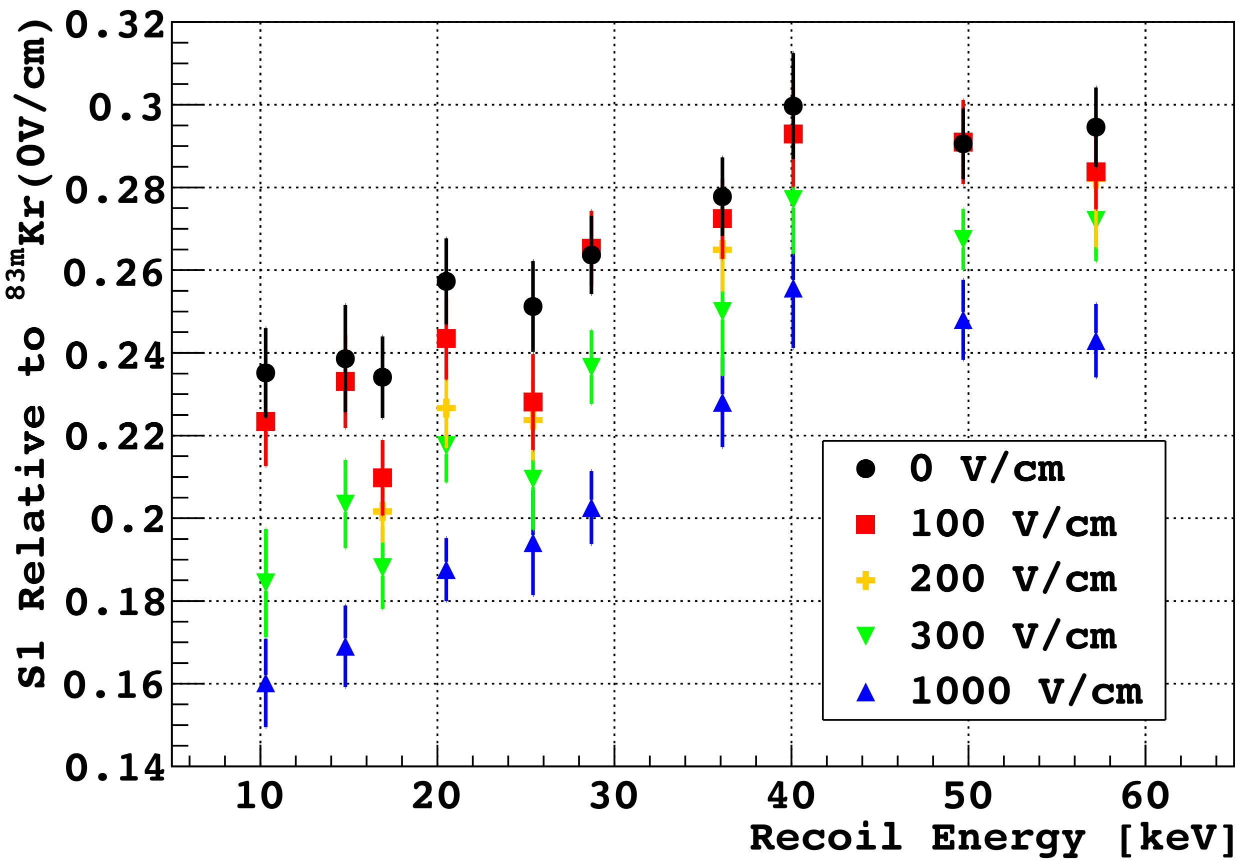
Excellent agreement between data and model through several orders of magnitude

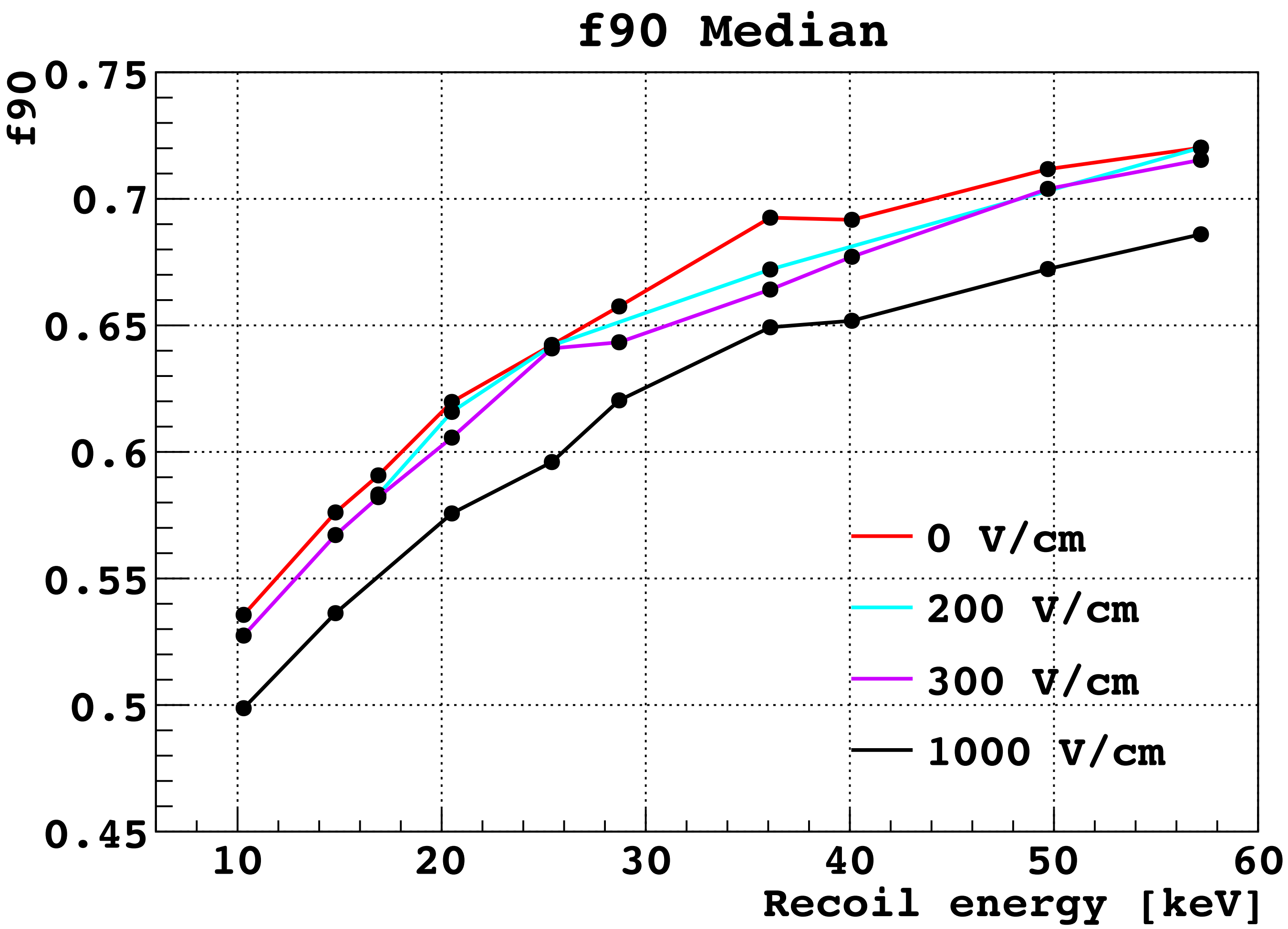
Simulated F90 distribution for DS-G2
5 years run, assuming the ER bkgd in the fiducial volume will be dominated by ^{39}Ar at its present upper limit.

SCENE Experimental Scheme
(Scintillation and Ionization Efficiency of Noble Elements)



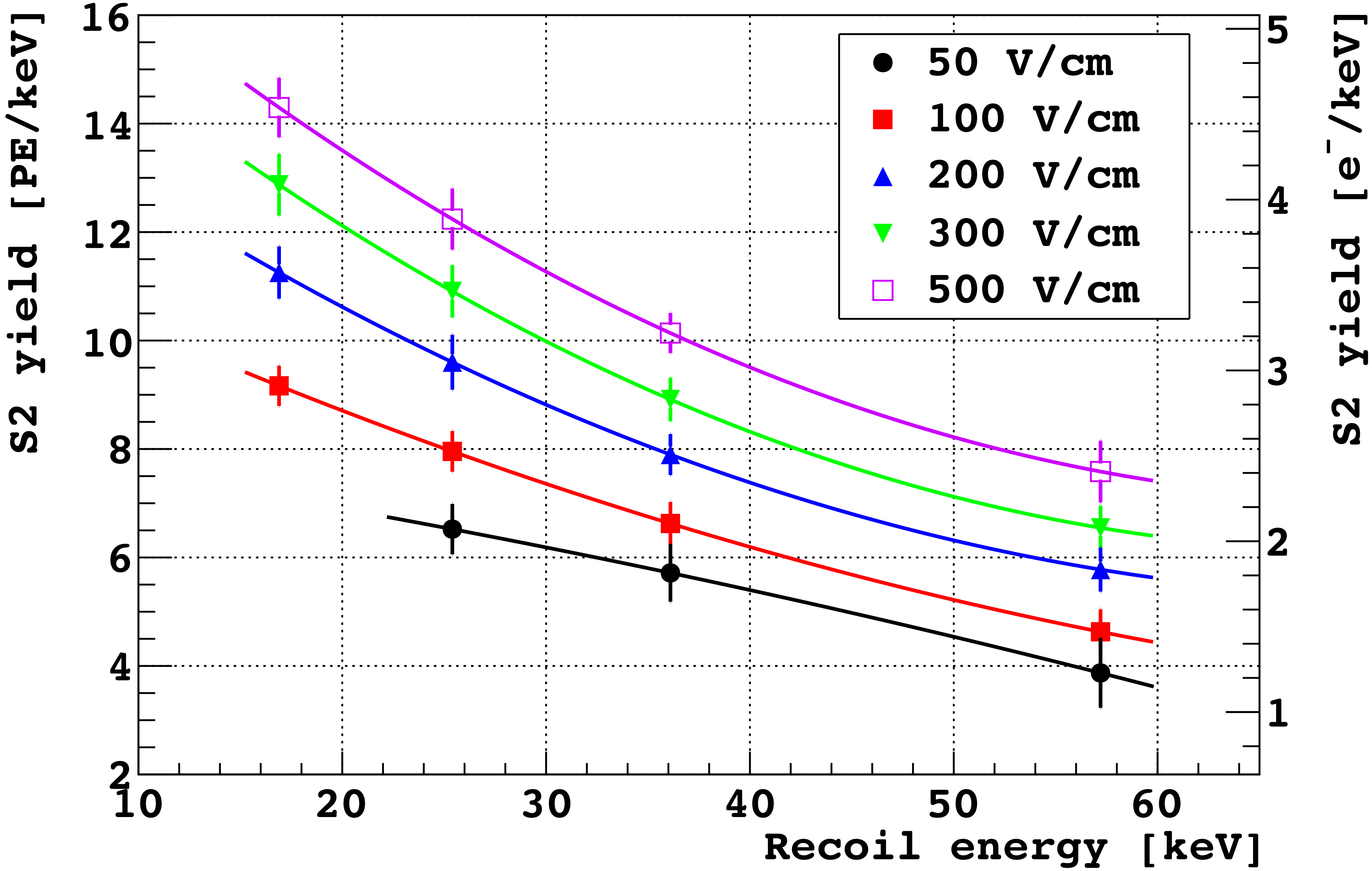
Nuclear Recoil Scintillation Yield and Pulse Shape vs Drift Field





Paper on most recent results:
H. Cao et. al.
arXiv:1406.4825

Nuclear Recoil
Ionization Yield vs Drift Field

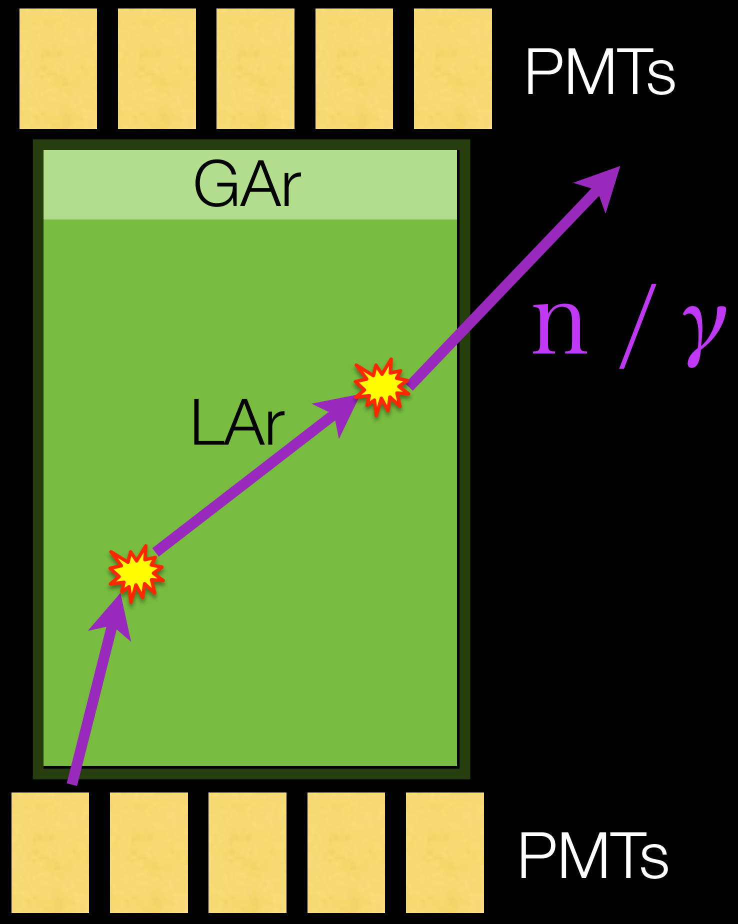


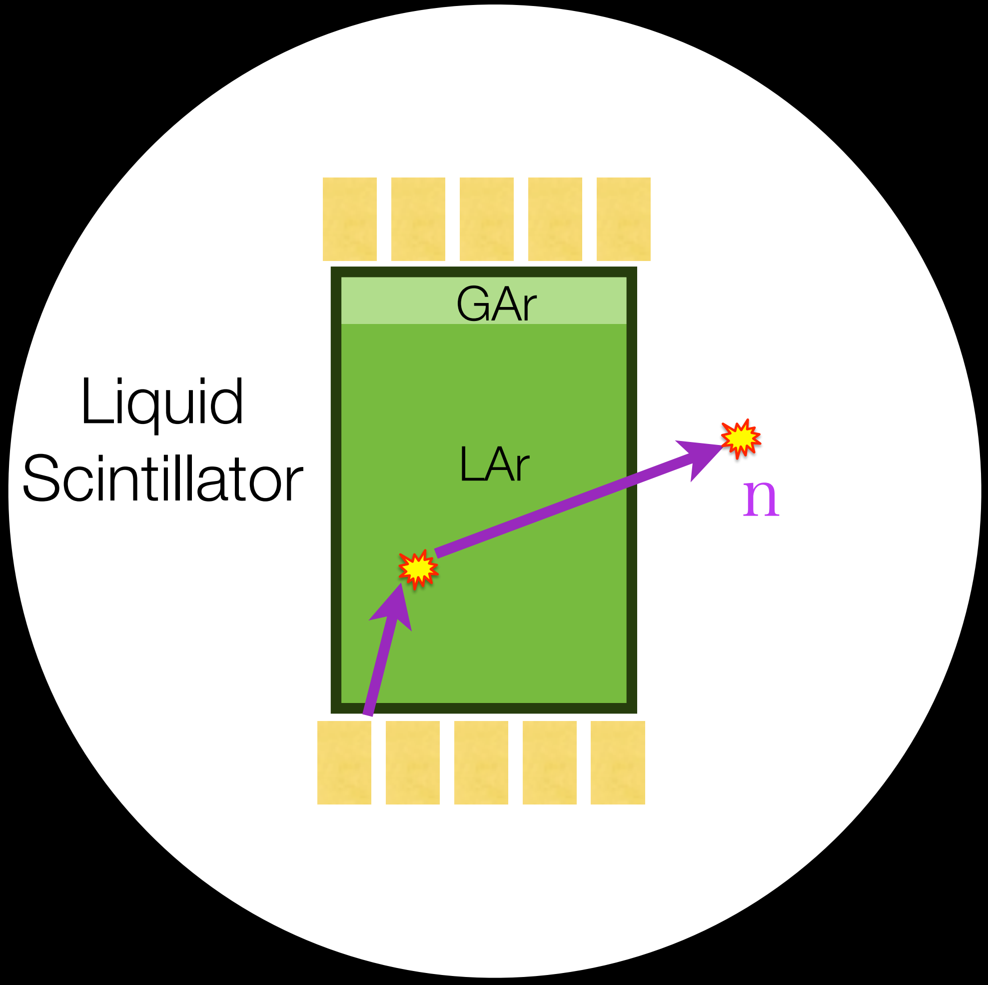
Paper on most recent results:
H. Cao et. al.
arXiv:1406.4825

Multiple Interactions

Neutron Rejection

Expected WIMP signal	Background Rejection Technique	Backgrounds Removed
Single Interaction	Multiple S2 Cut in TPC or Liquid Scintillator Veto	Neutrons, Gamma rays





Calibration Source System