The DarkSide Rises

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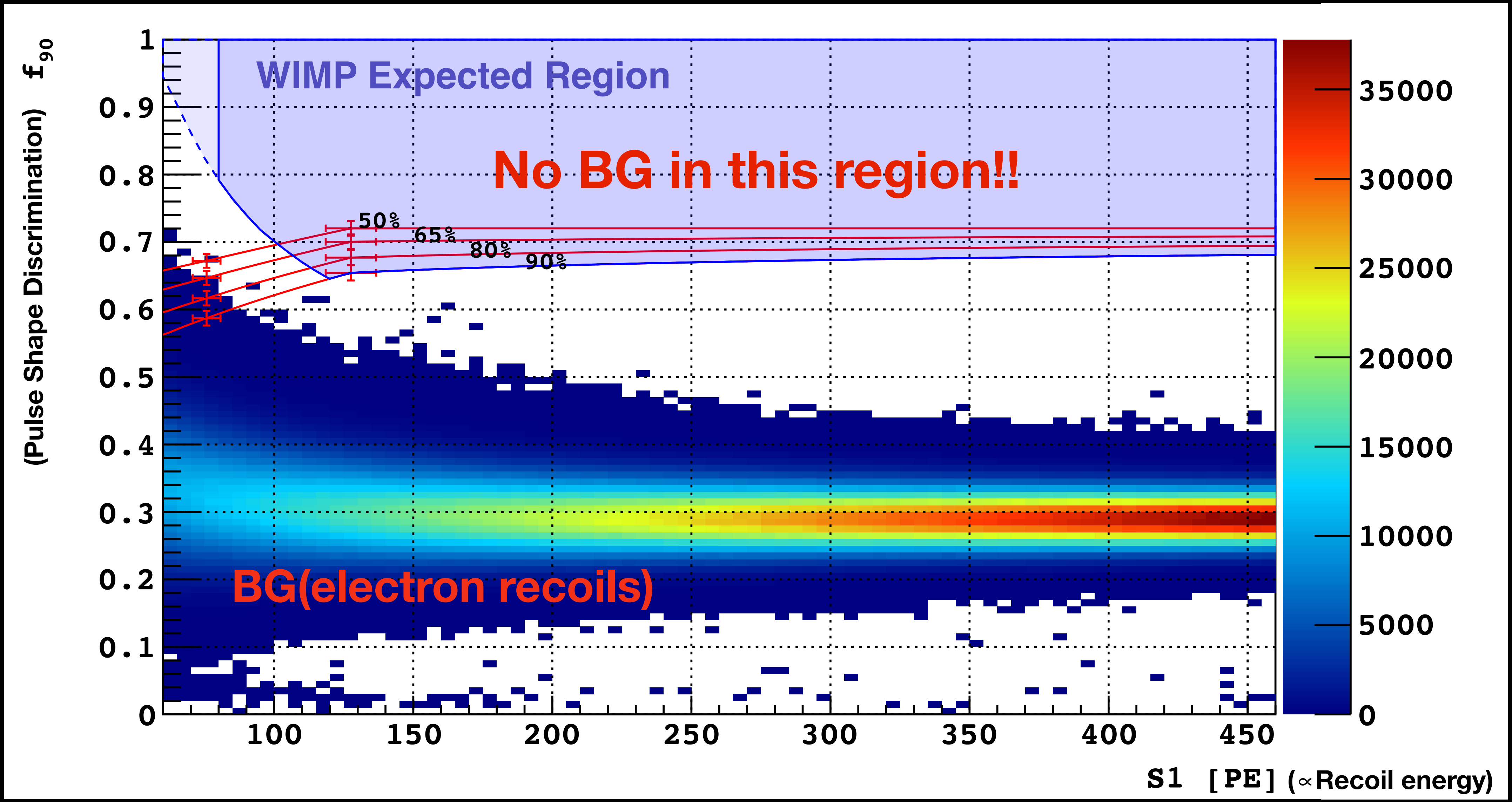
on behalf of the DarkSide Collaboration
06 Oct. 2014

Double Beta Decay and
Underground Science Workshop

*This title is not related to actual movie. Any resemblance to real movie title is purely coincidental.

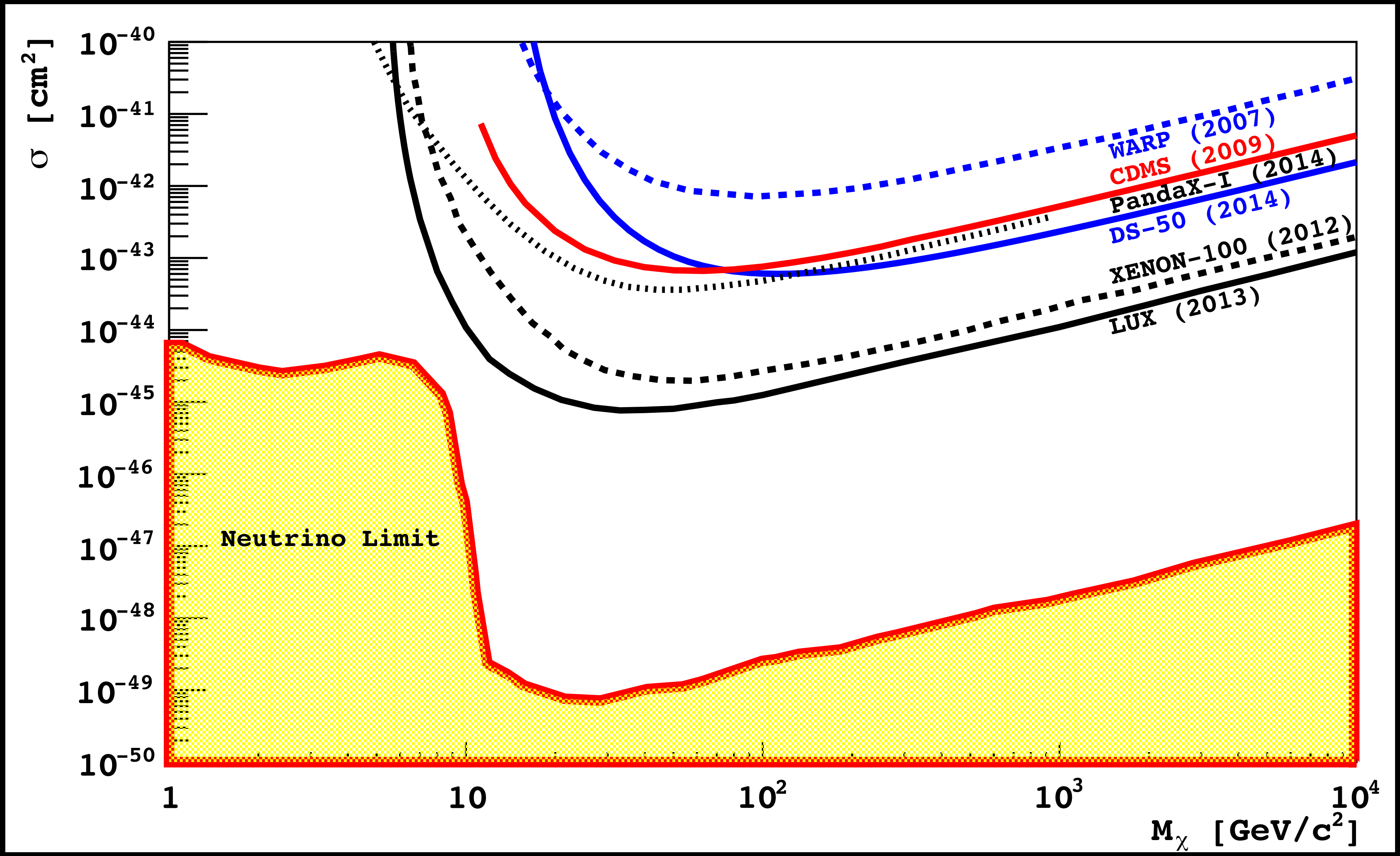
Background Free Operation

We recently (2 days ago) published physics (**null**) results arXiv:1410.0653 with 1422 kg×days exposure (47days).



Dark Matter exclusion plot

This is the most sensitive dark matter search performed with an **argon** target.

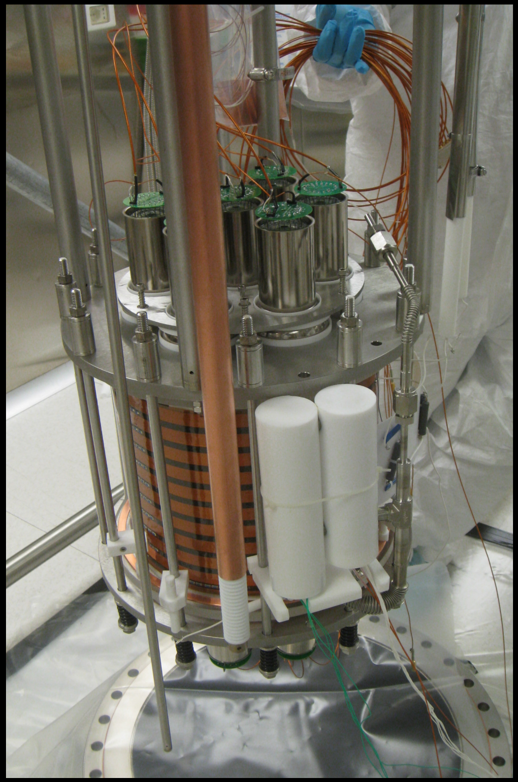


DarkSide Program

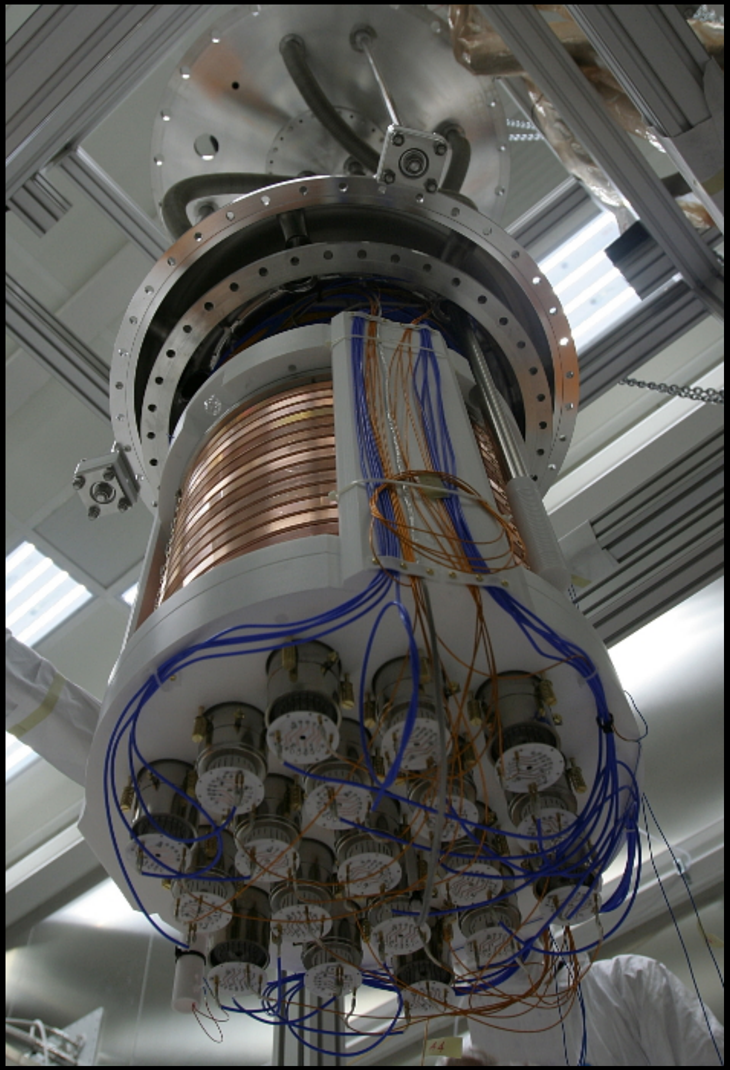
- Direct detection search for WIMP dark matter
- Based on a two-phase argon time projection chamber (TPC)
- Design philosophy based on having very low background levels that can be further reduced through active suppression, for **background-free** operation

DarkSide Program

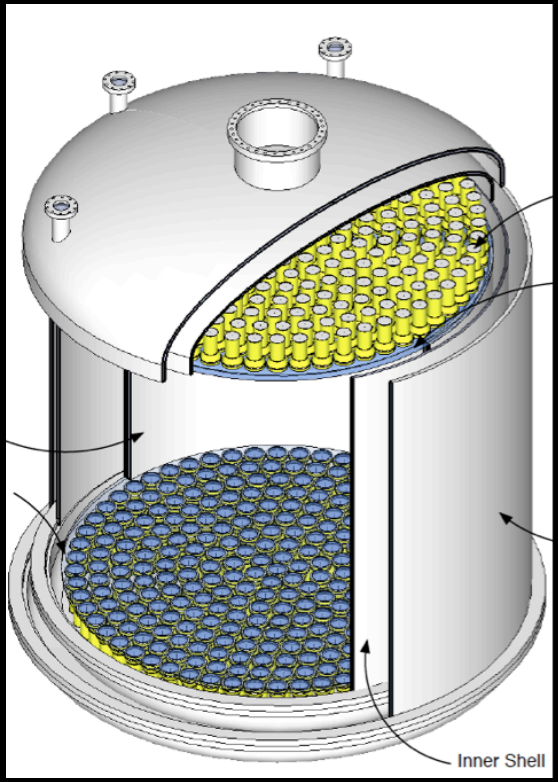
Multi-stage program at Gran Sasso National Laboratory in Italy



DarkSide 10
Prototype detector



DarkSide 50
First physics detector
Commissioned Oct.2013



Future multi-ton detector

+ multiple smaller test setups and prototypes

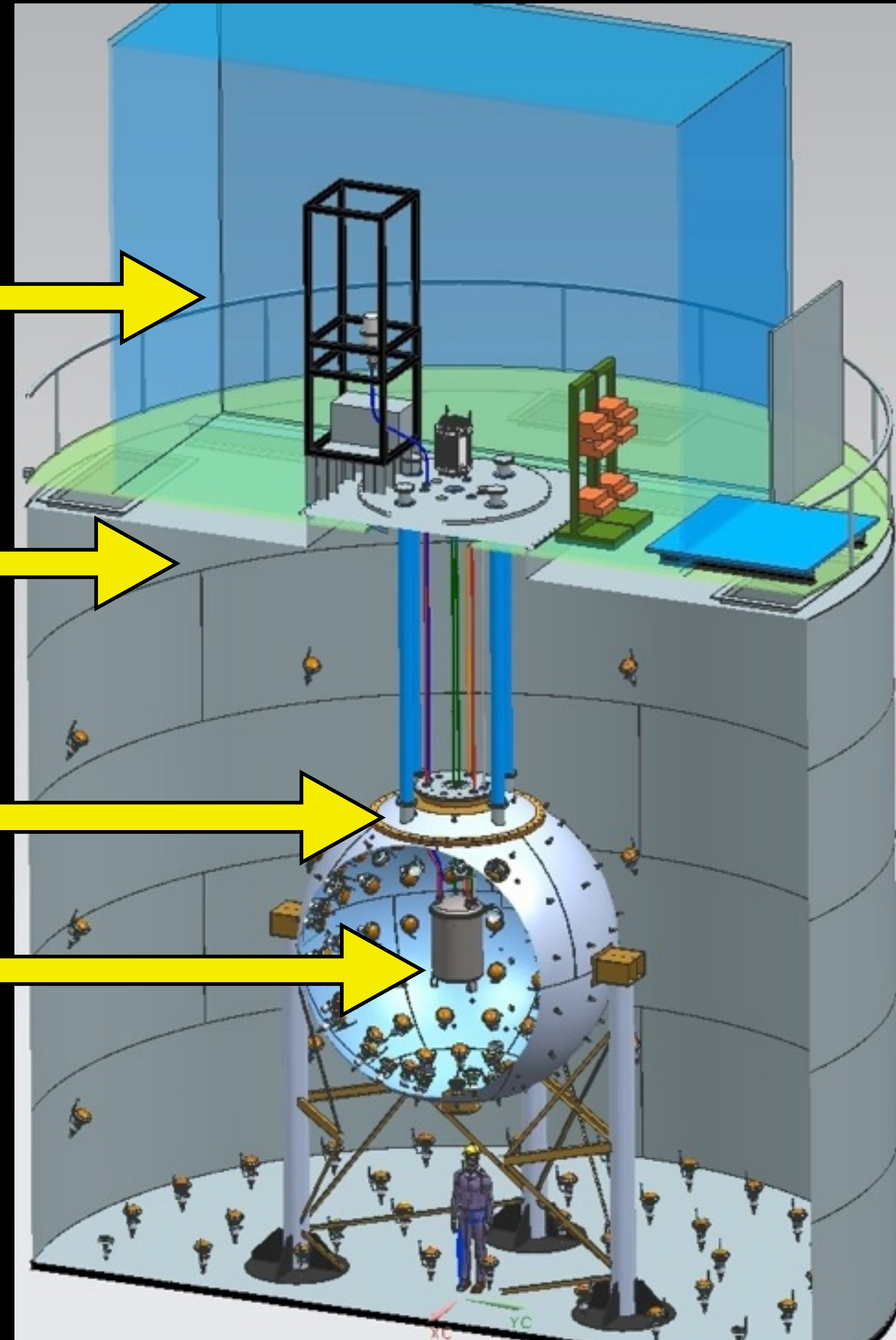
DarkSide 50

Radon-free clean room

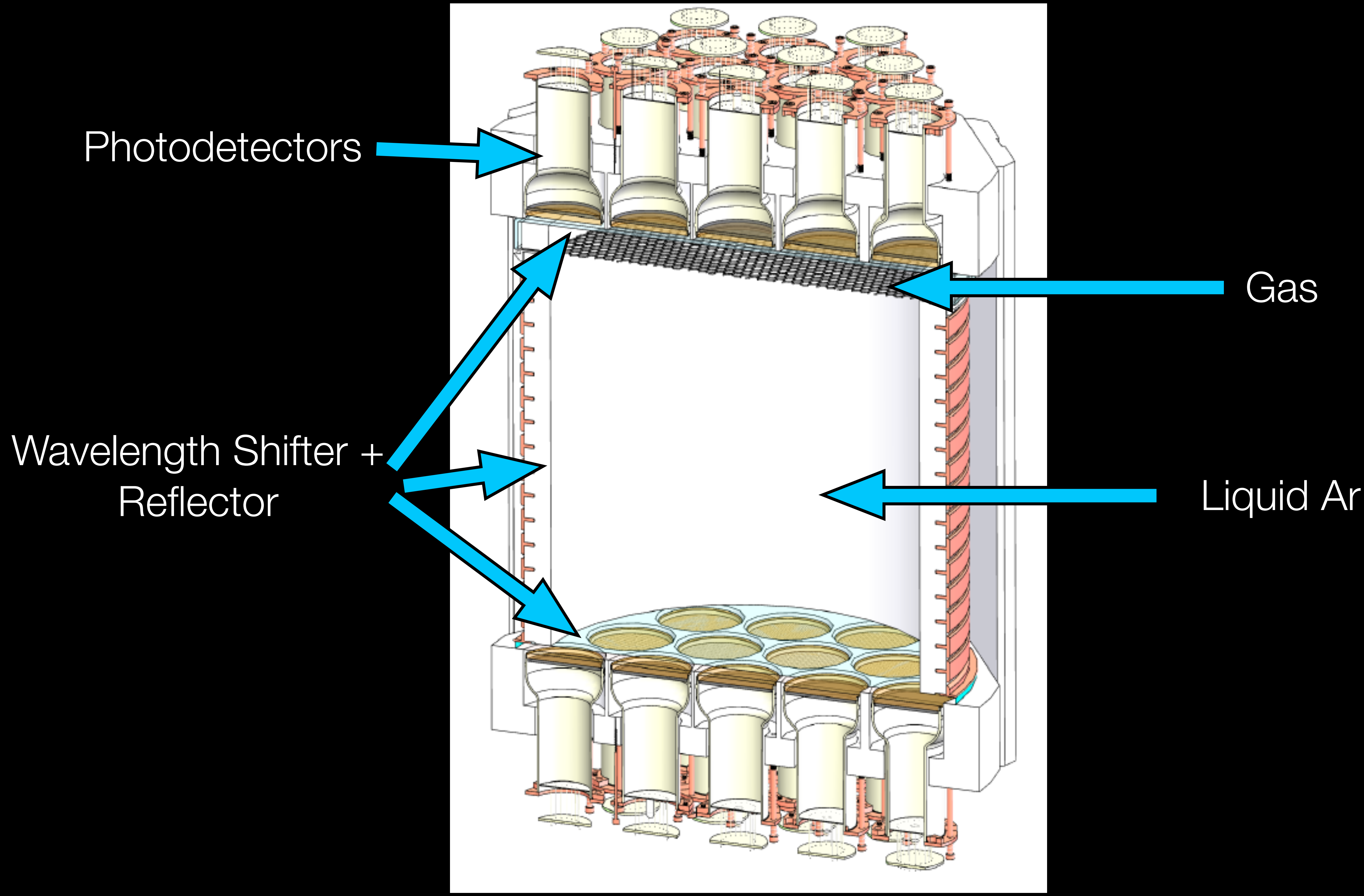
Instrumented water tank

Liquid scintillator

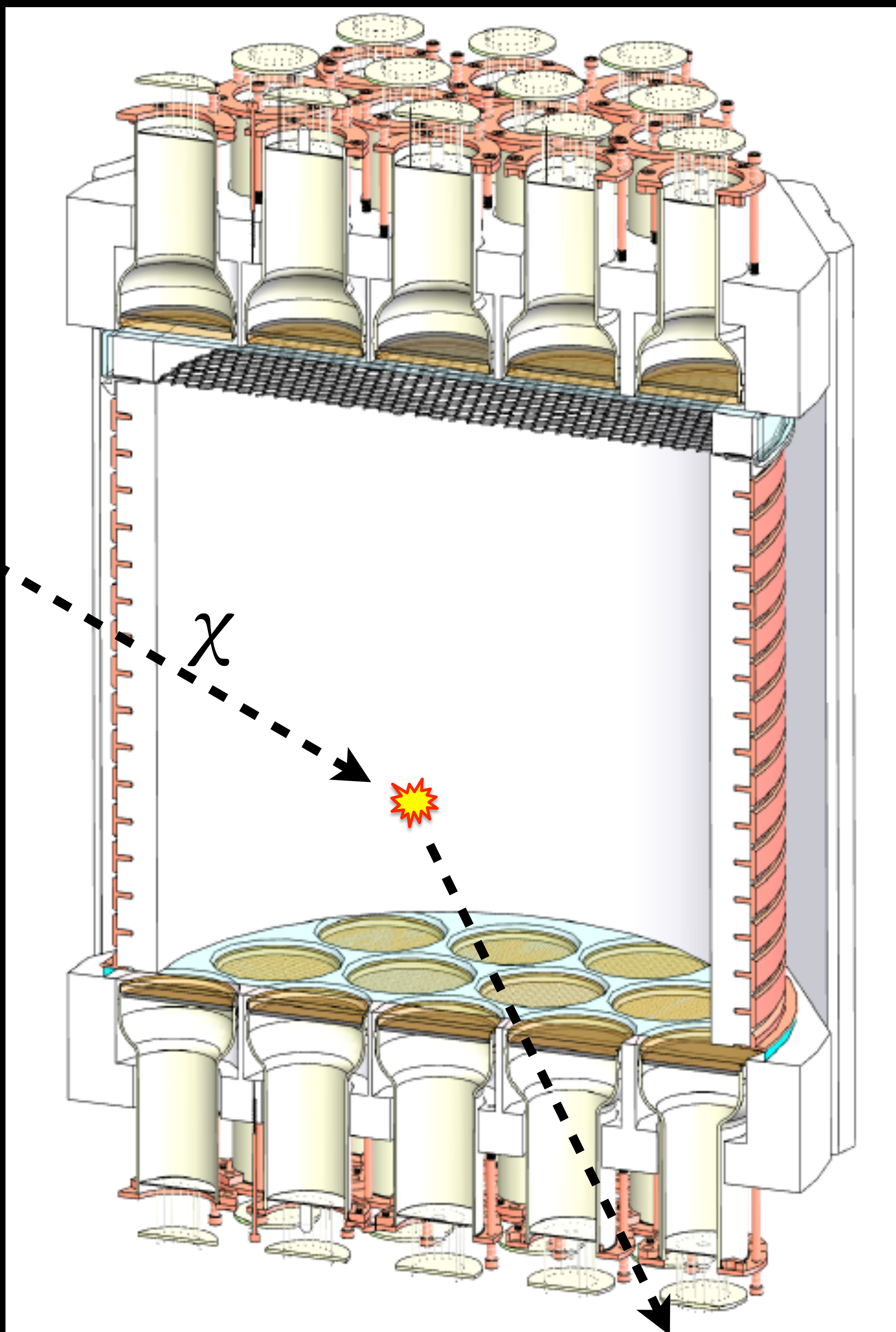
Inner detector TPC



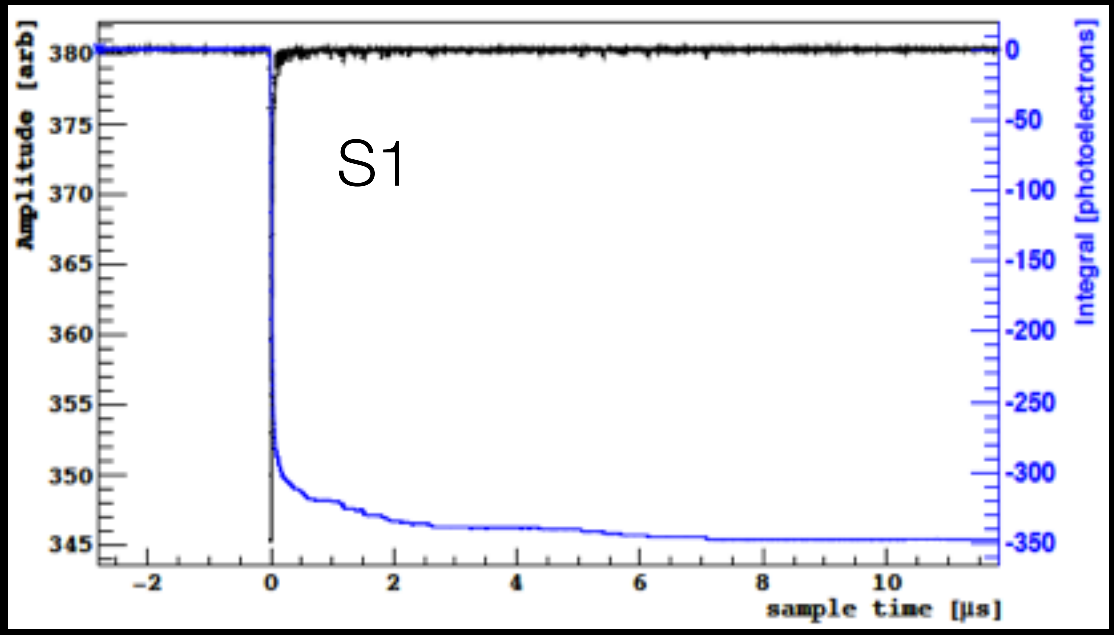
Two Phase Argon TPC



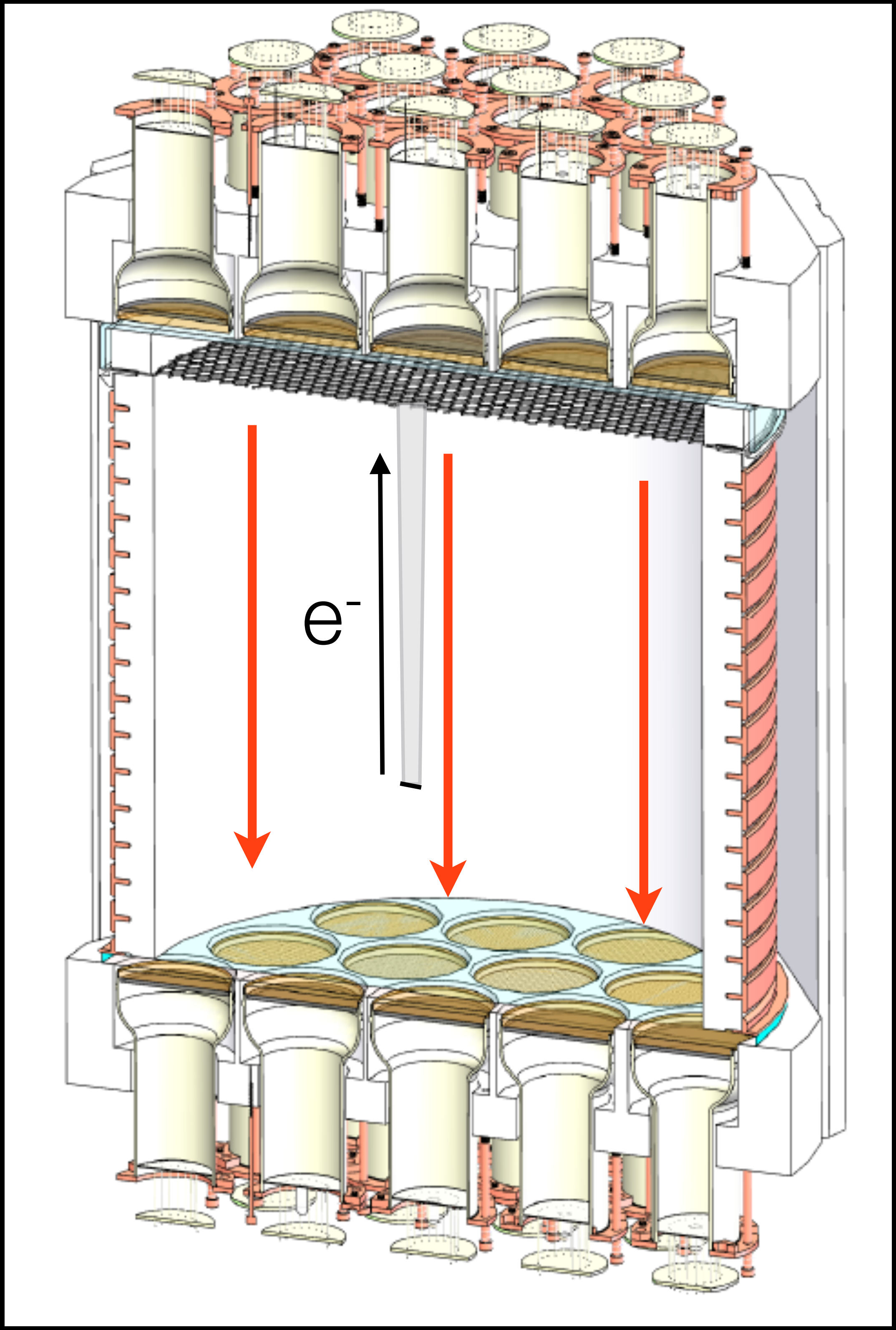
Detecting WIMPs



Nuclear Recoil excites and ionizes the liquid argon, producing scintillation light (S1)that is detected by the photomultipliers



Detecting WIMPs

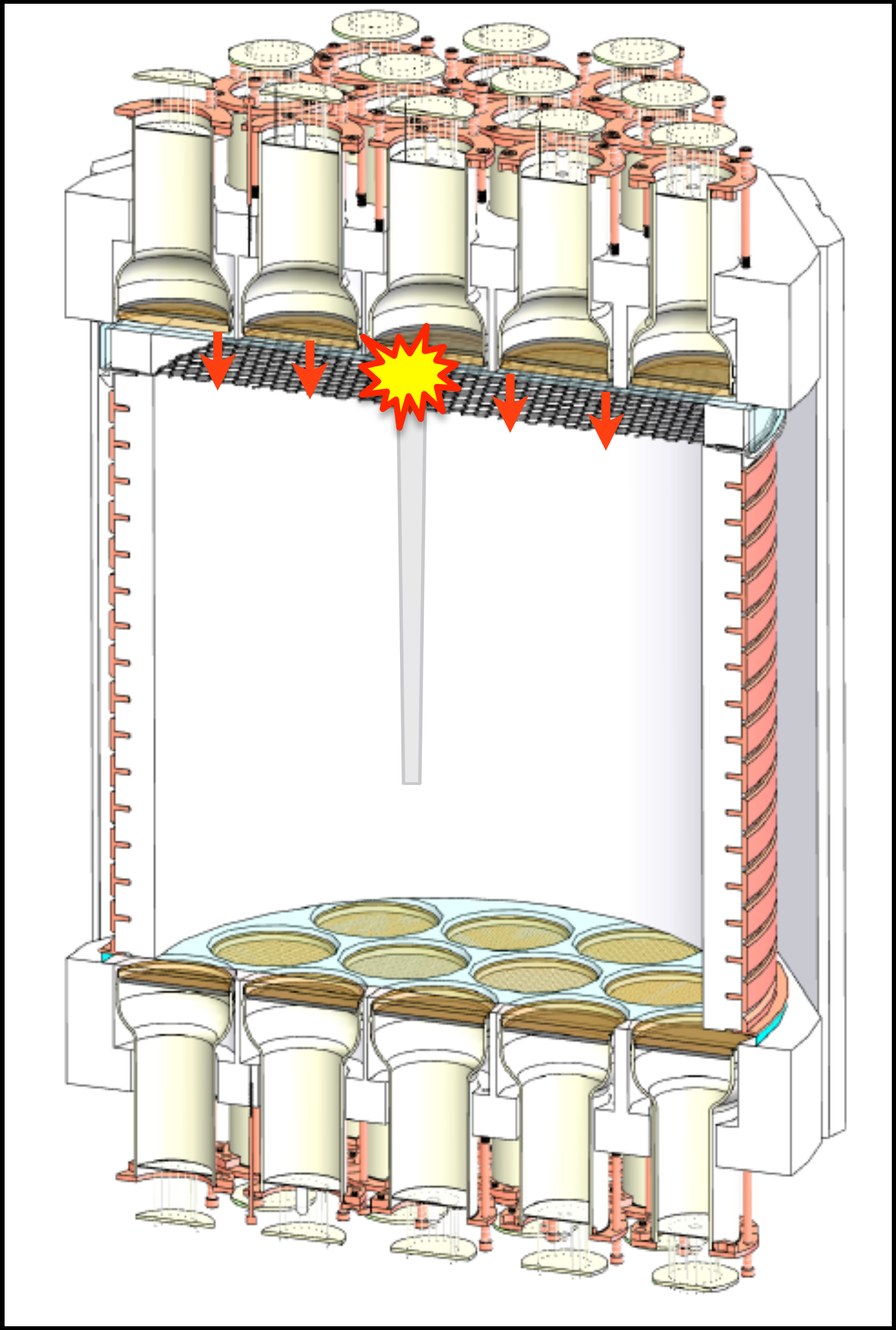


The ionized electrons that survive recombination are drifted towards the liquid-gas interface by the electric field

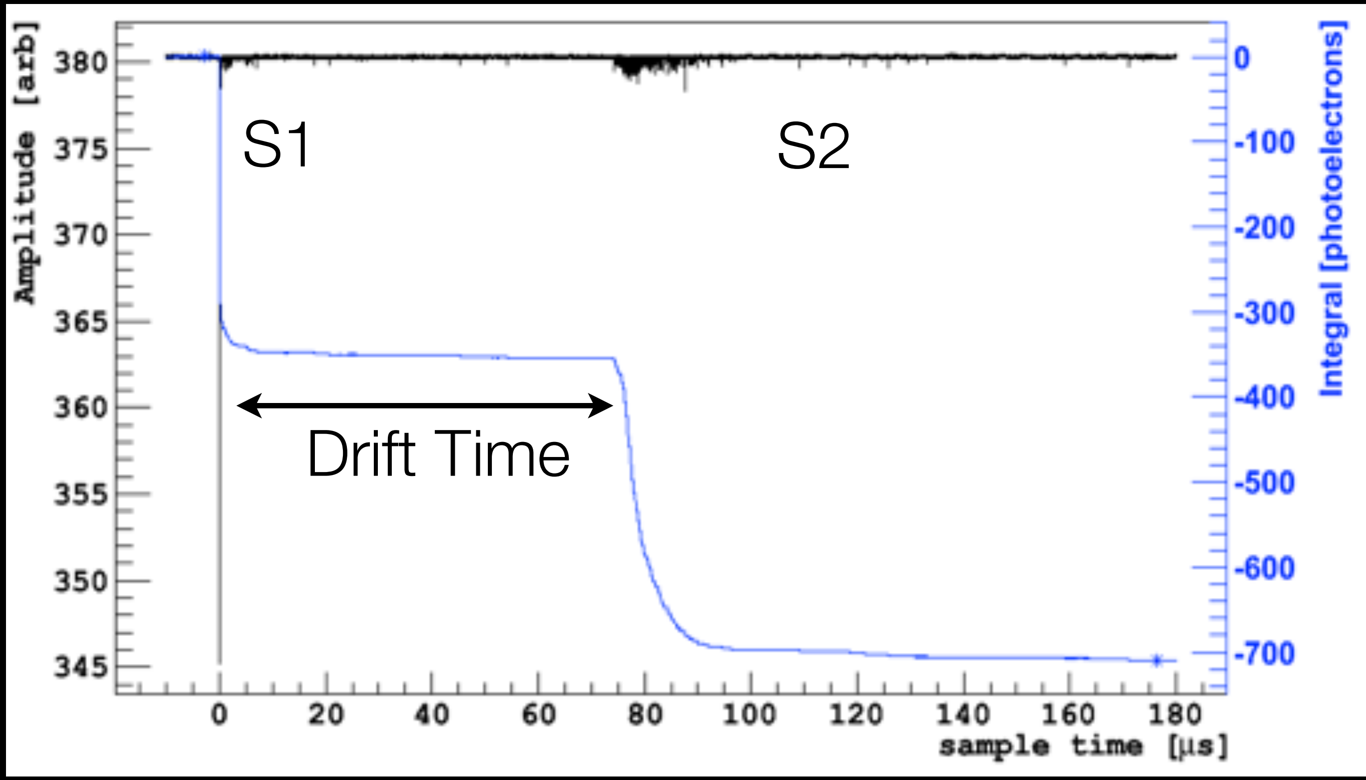
Electron drift lifetime > 5 ms,
compared to max. drift time of ~ 375 μs

Electron drift speed = 0.93 ± 0.01 mm/μs

Detecting WIMPs



The electrons are extracted into the gas region, where they induce electroluminescence (S2)



The time between the S1 and S2 signals gives the vertical position

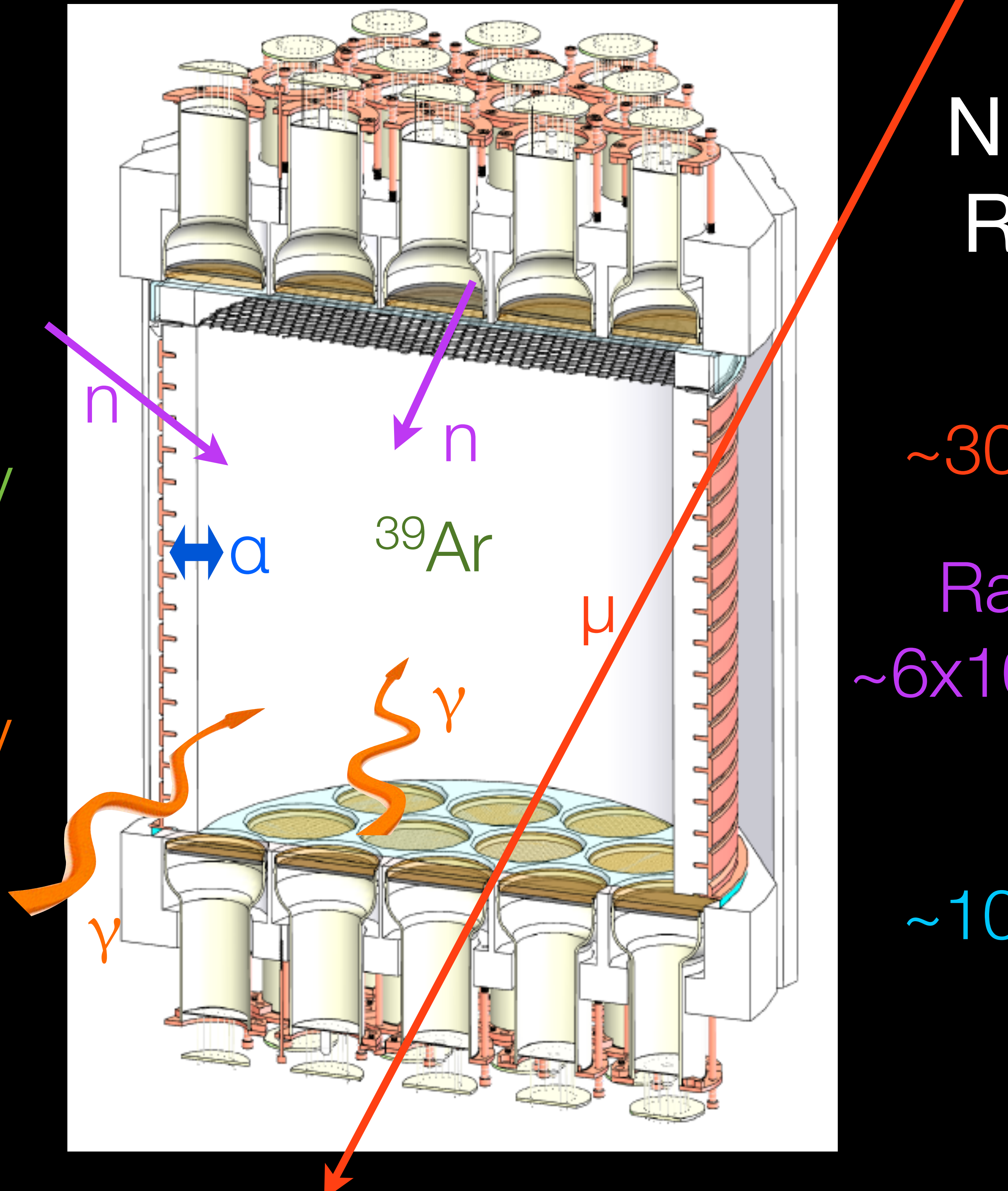
Backgrounds

[30-200]keVr

ELECTRON RECOILS

^{39}Ar
~9x10^{4} evt/kg/day

γ
~1x10^{2} evt/kg/day



NUCLEAR RECOILS

μ
~30 evt/m^{2}/day

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

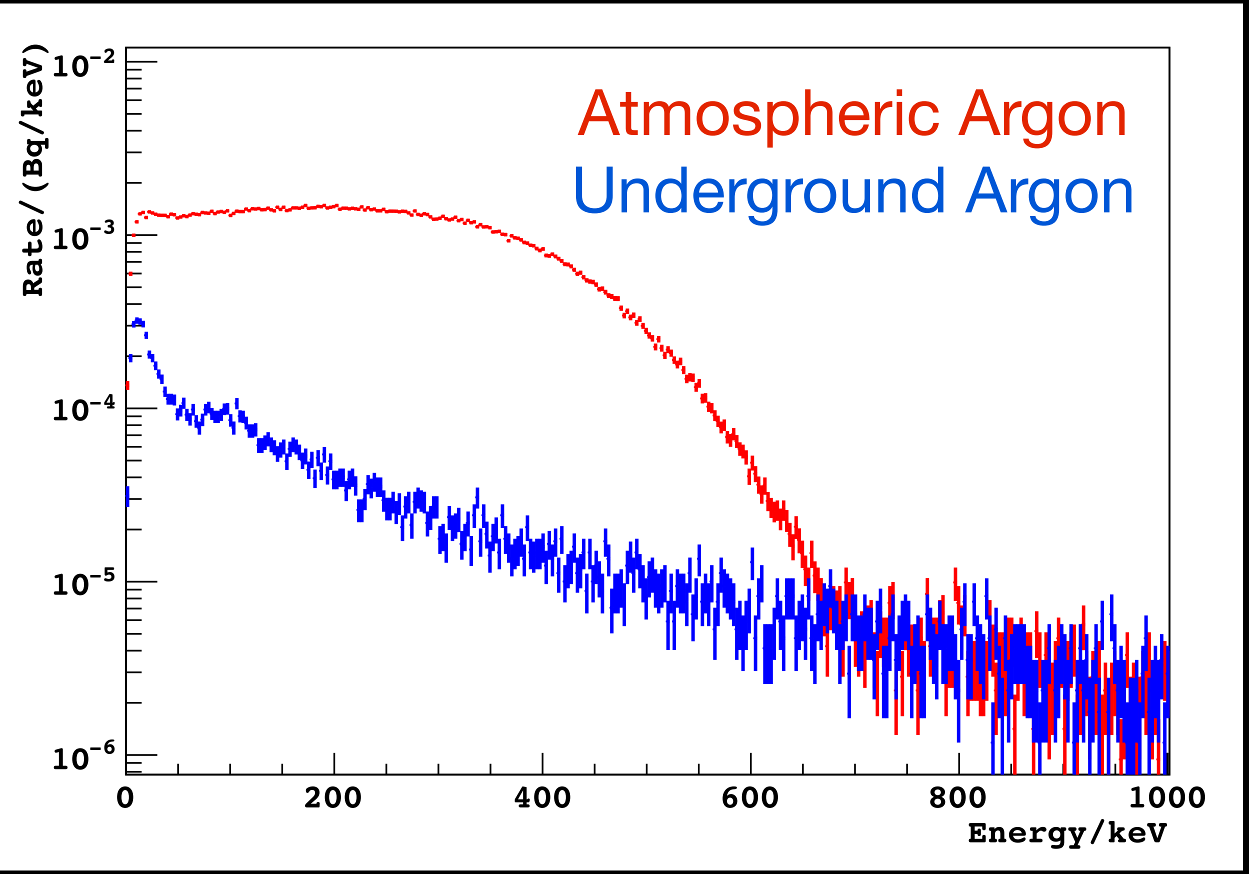
α

~10 evt/m^{2}/day

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

^{39}Ar

- Intrinsic ^{39}Ar radioactivity in atmospheric argon is the primary background for argon-based detectors
- ^{39}Ar activity sets the dark matter detection threshold at low energies (where pulse shape discrimination is ineffective)
- ^{39}Ar is a cosmogenic isotope, and the activity in argon from underground sources can be significantly reduced compared to atmospheric argon



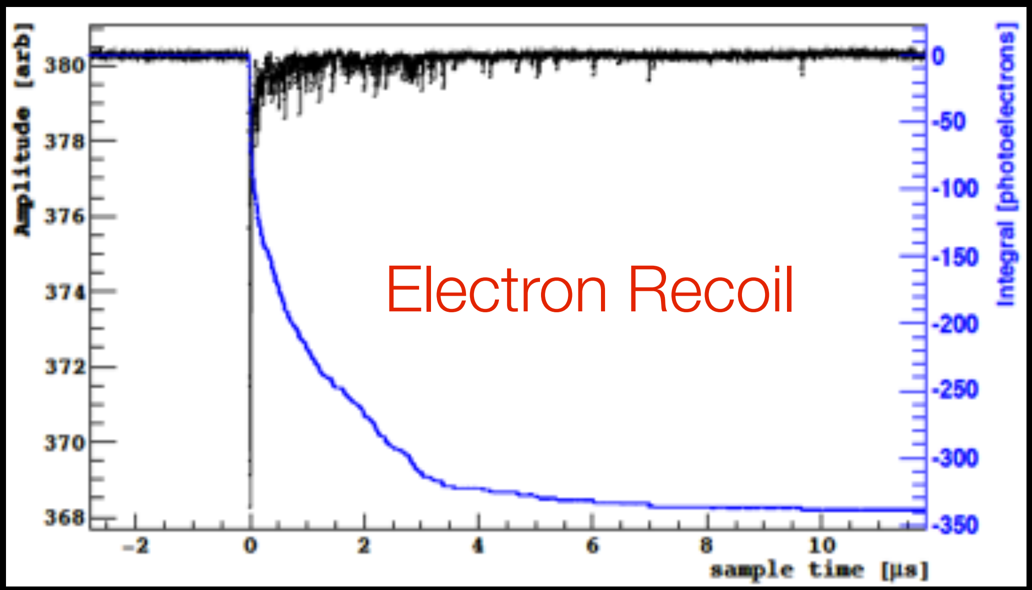
arXiv:1204.60111 [physics.ins-det]

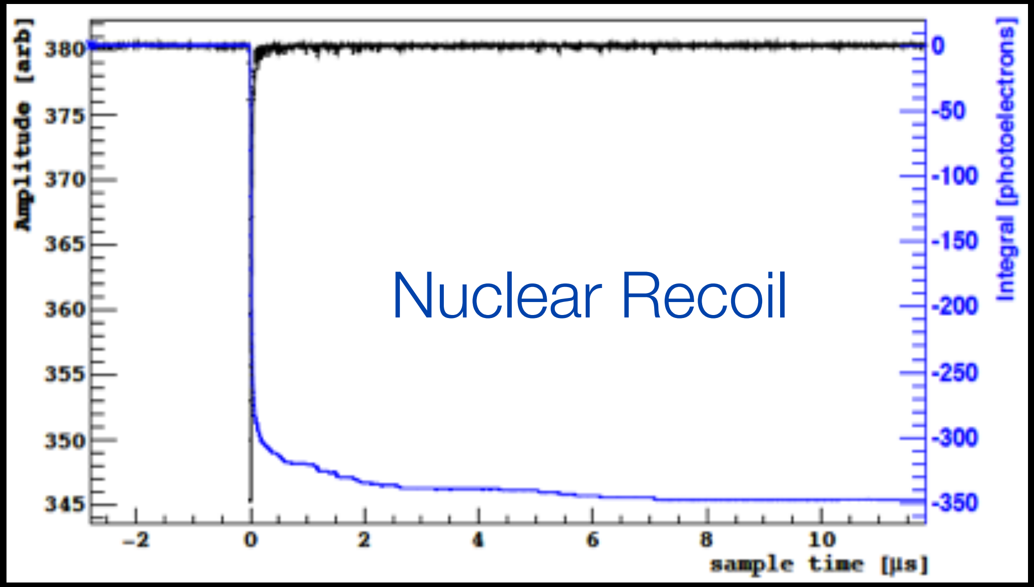
Pulse Shape Discrimination

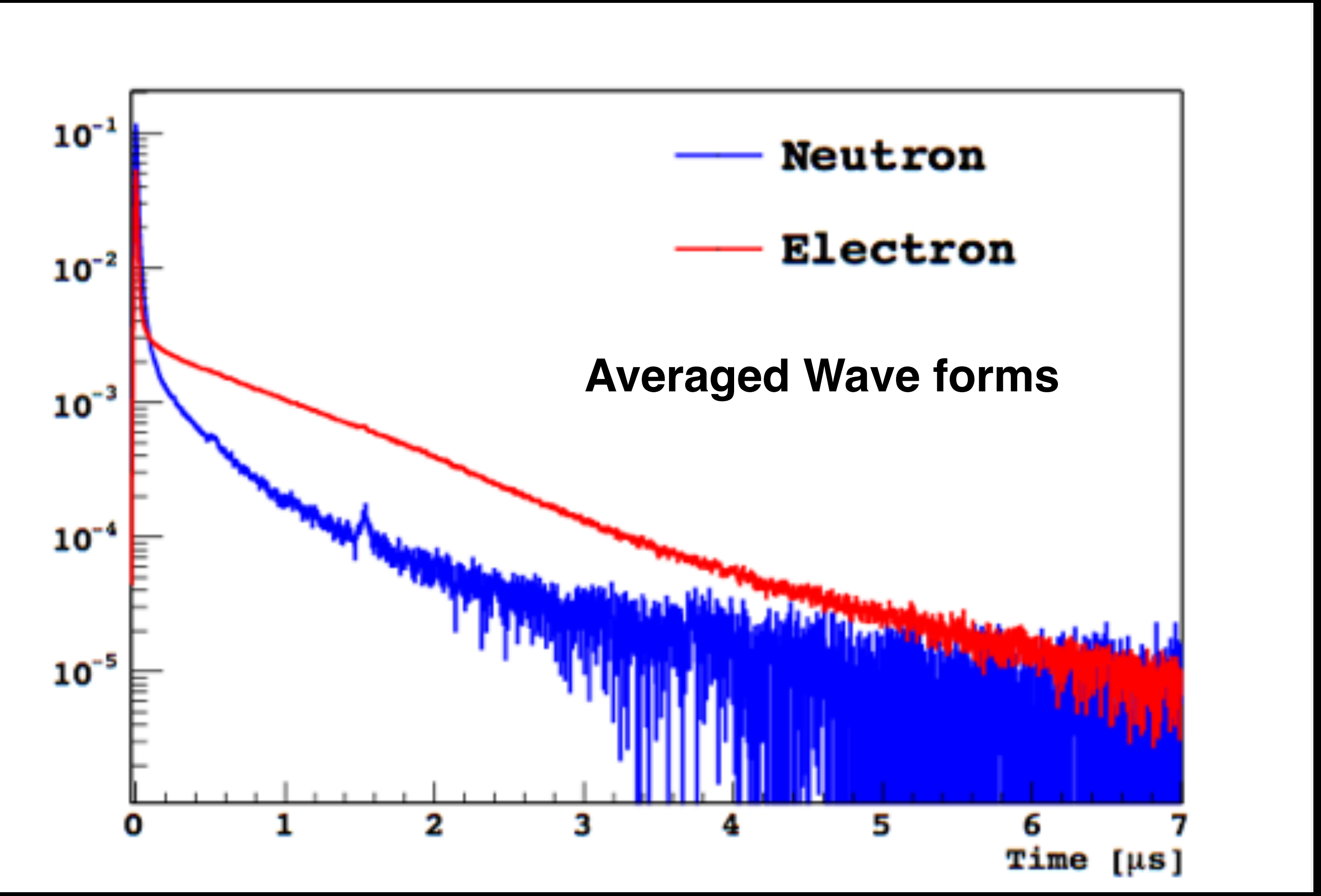
Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

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

$\tau_{\text{triplet}} \sim 1500$ ns



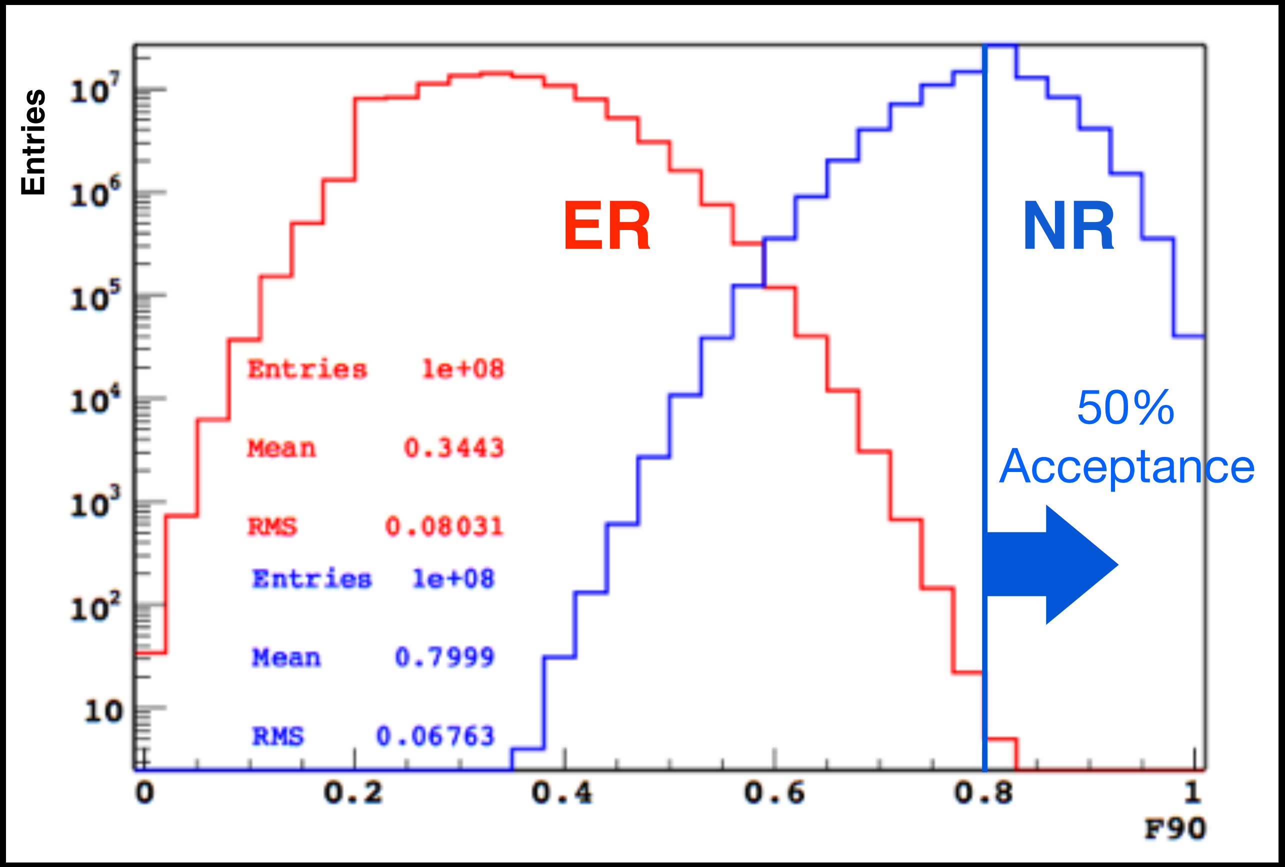


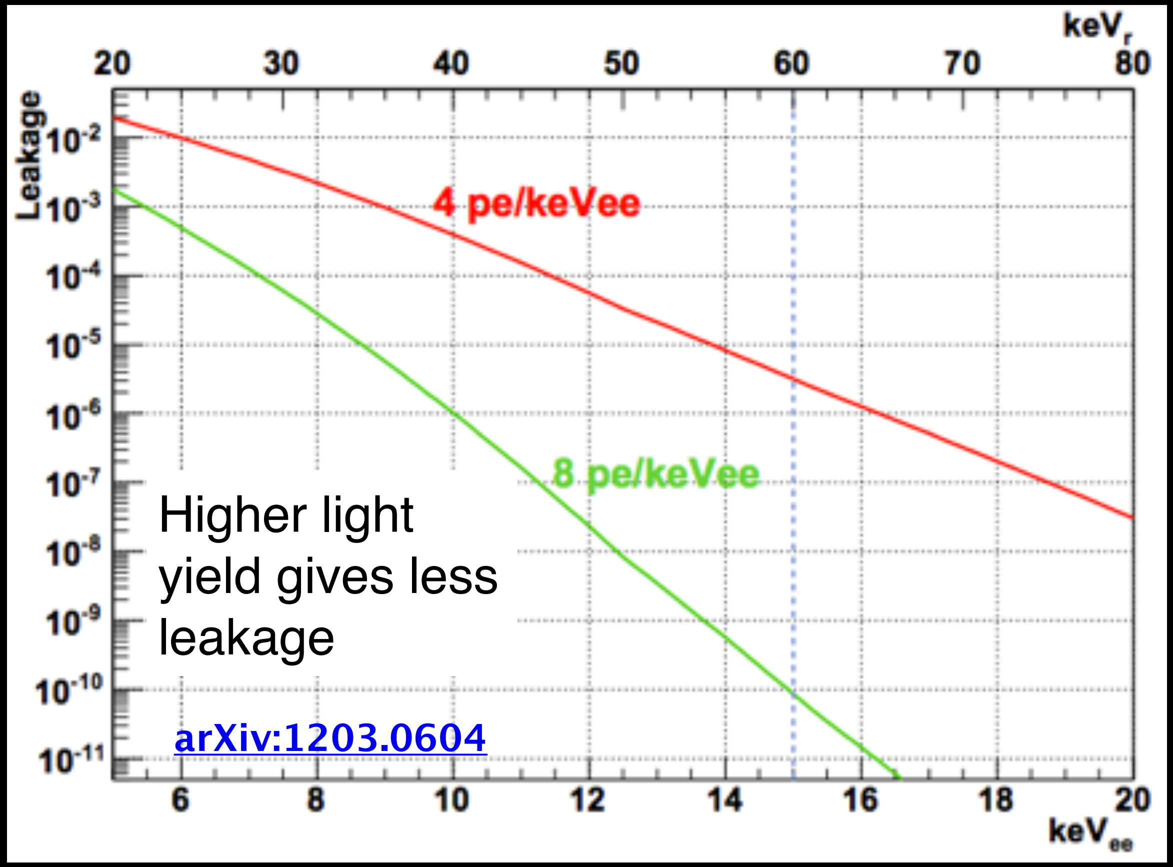


Pulse Shape Discrimination

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

τ singlet ~ 7 ns
τ triplet ~ 1500 ns

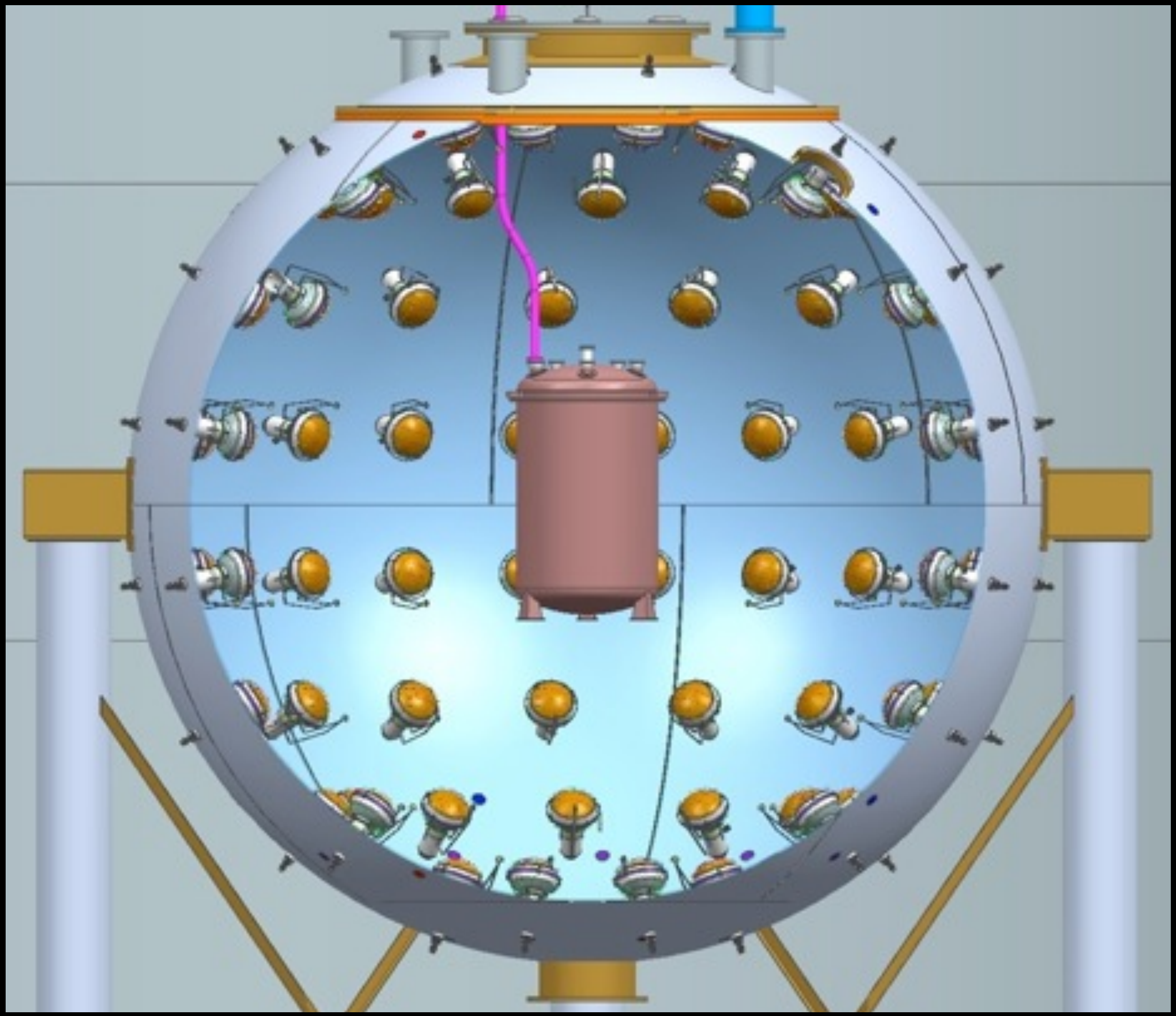




Discrimination power strongly dependent on light collection

Liquid Scintillator Veto

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



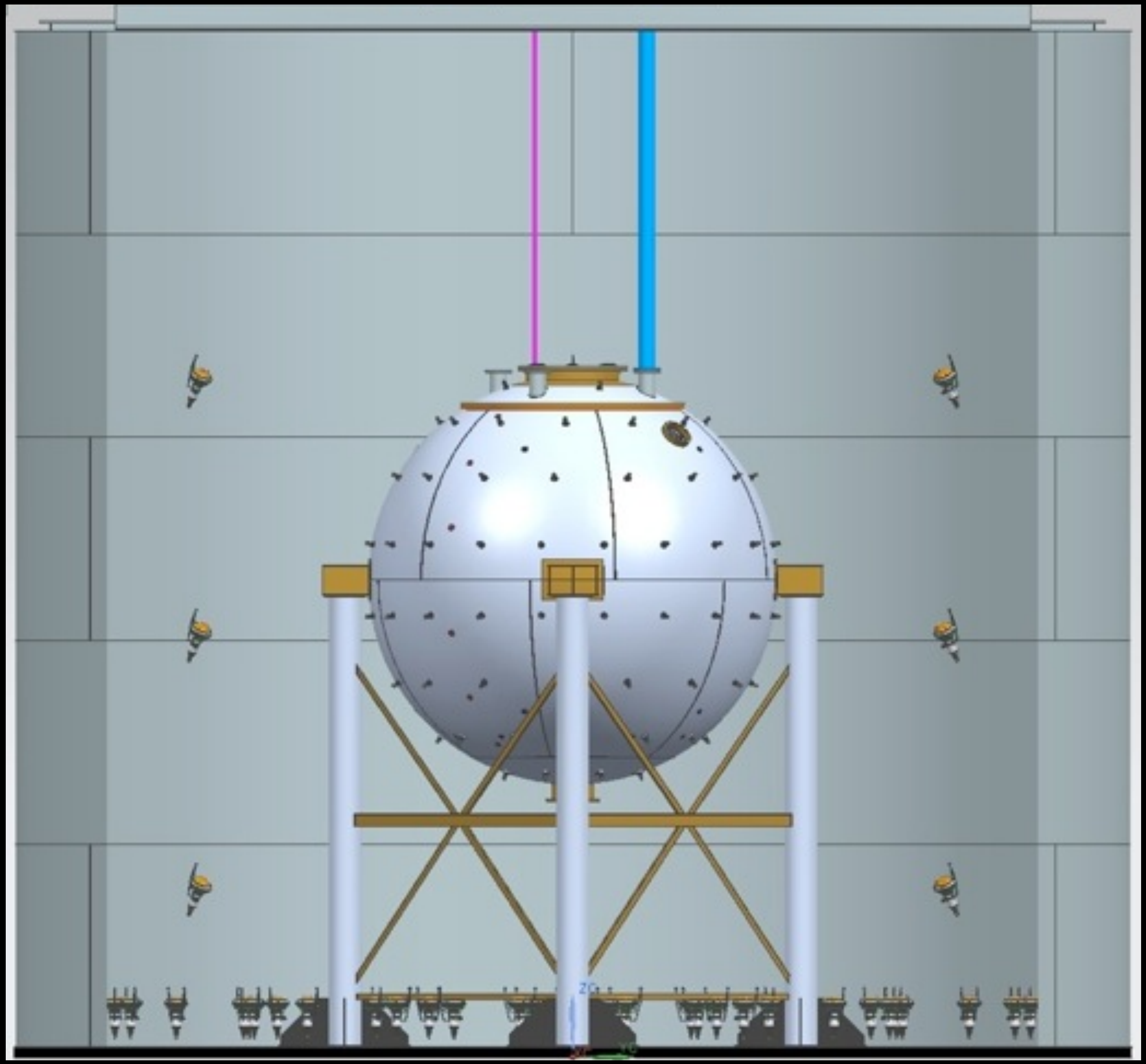
- 4 m diameter sphere containing 1:1 PC + TMB scintillator
- Instrumented with 110 8” PMTs

^{14}C content (~10^{-13} $^{14}C/^{12}C$, ~120kHz) is too high (~98% efficiency) to achieve design efficiency (~99.5%).

The current TMB will be replaced with new low ^{14}C TMB.

External Water tank

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



Radon-Free Clean Rooms

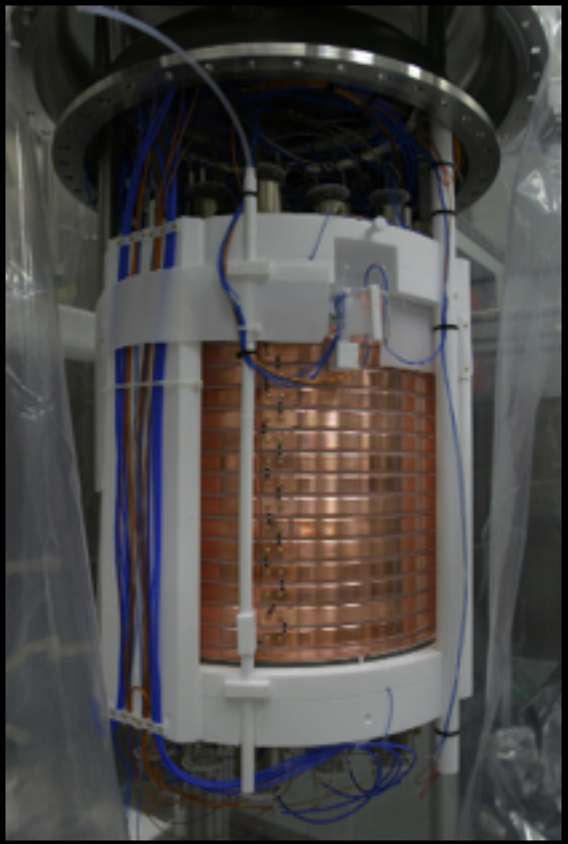
Radon daughters plate out on surfaces of the detector causing dangerous alpha-induced nuclear recoils

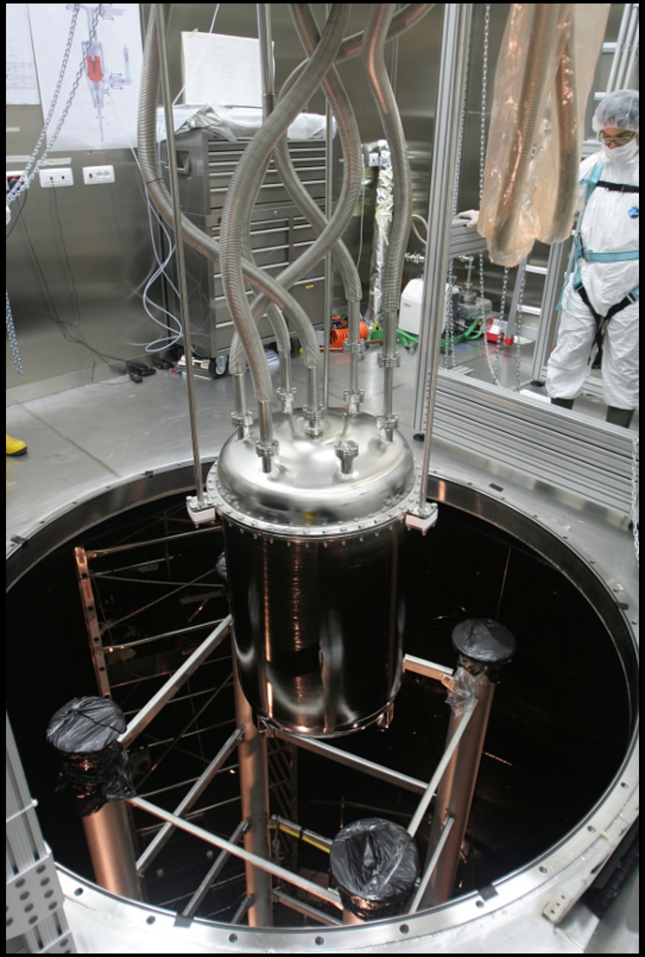
Final preparation, cleaning, evaporation and assembly of all inner detector parts was carried out in radon-free clean rooms

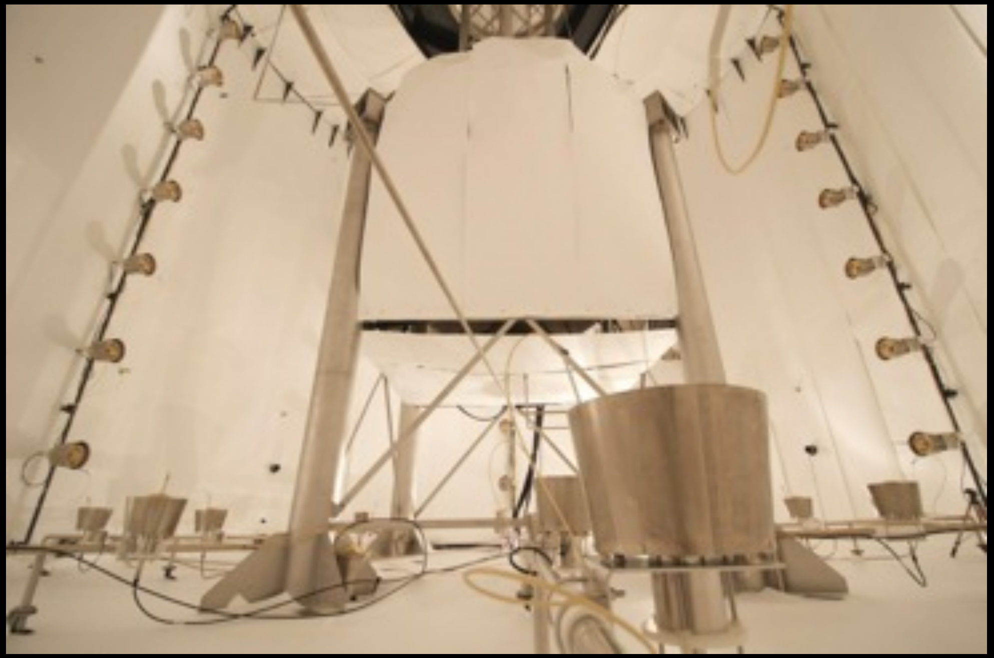
Typical radon in air ~ 30 Bq/m^3

Cleanroom radon levels < 5 mBq/m^3

DS50 Commissioning







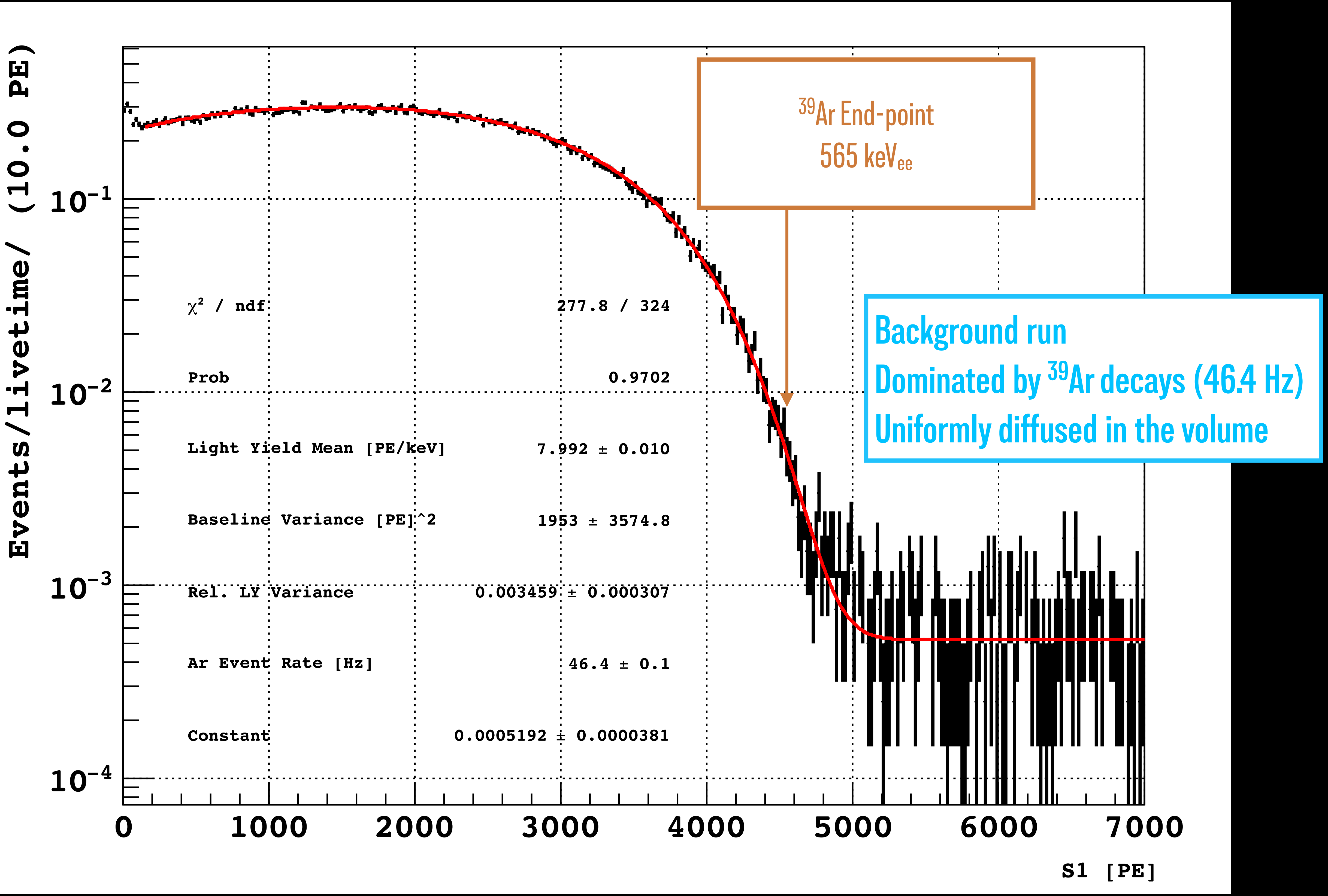
DS50 Timeline

- **Oct. 2013:** LArTPC, Neutron Veto and Muon Veto commissioned.
  - TPC filled with atmospheric argon (AAr).
- **Nov. - Jan. 2014:** large majority dedicated to improve DAQ, DATA HANDLING and PROCESSING.
- **Up to June 2014:** data taken with high ^{14}C content in LSV.
  - ^{39}Ar BG from **47.1 live days** (1422 kg · day fiducial) of AAr corresponds to that expected in **19.4 year** of **UAr** DS-50 run.
  - TMB (^{14}C) was removed to reduce the ^{14}C rate.

All 3 detectors are filled and currently operating in the same mode of dark matter search

TPC Calibration

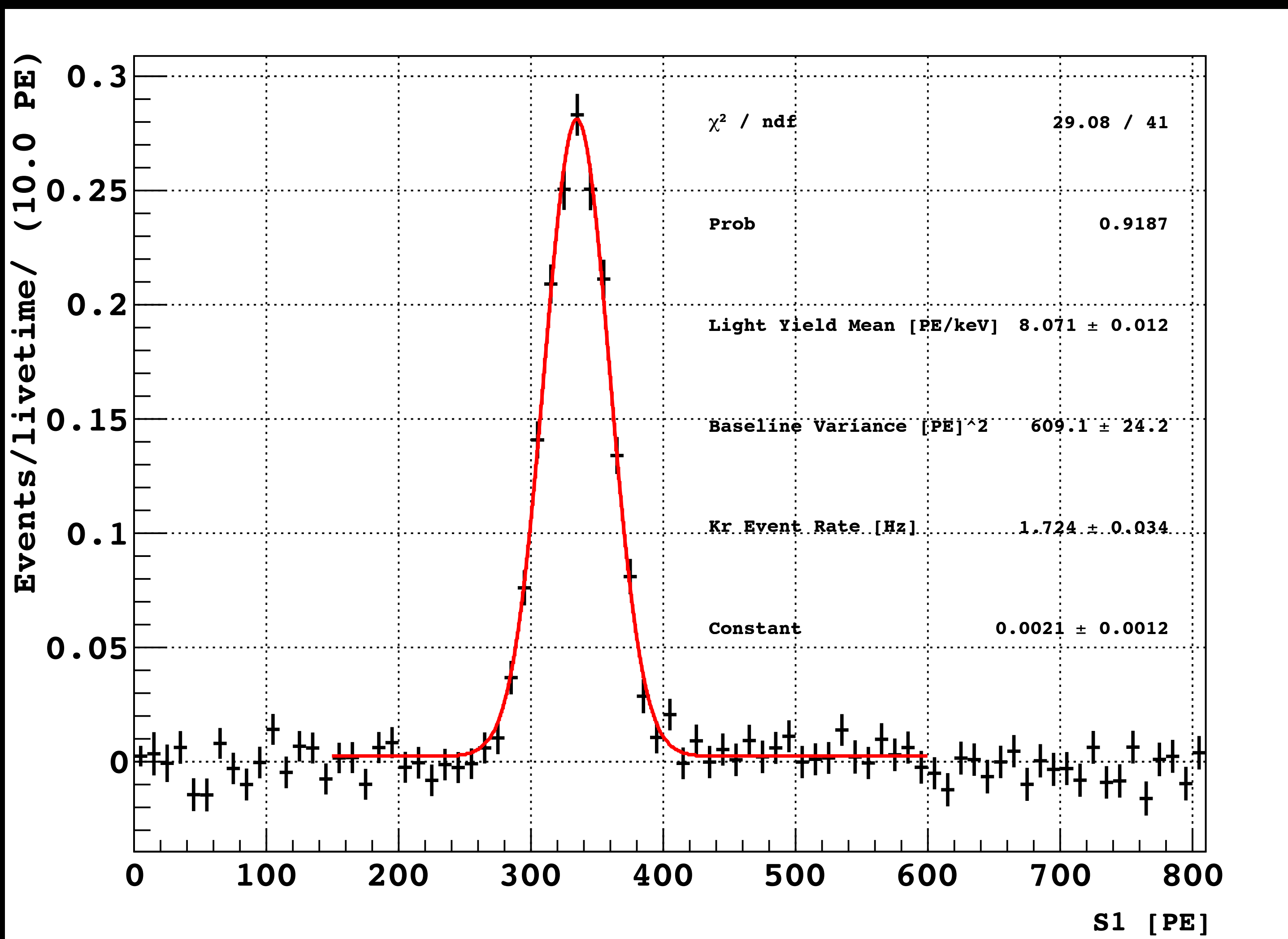
TPC: ER calibration @ null field

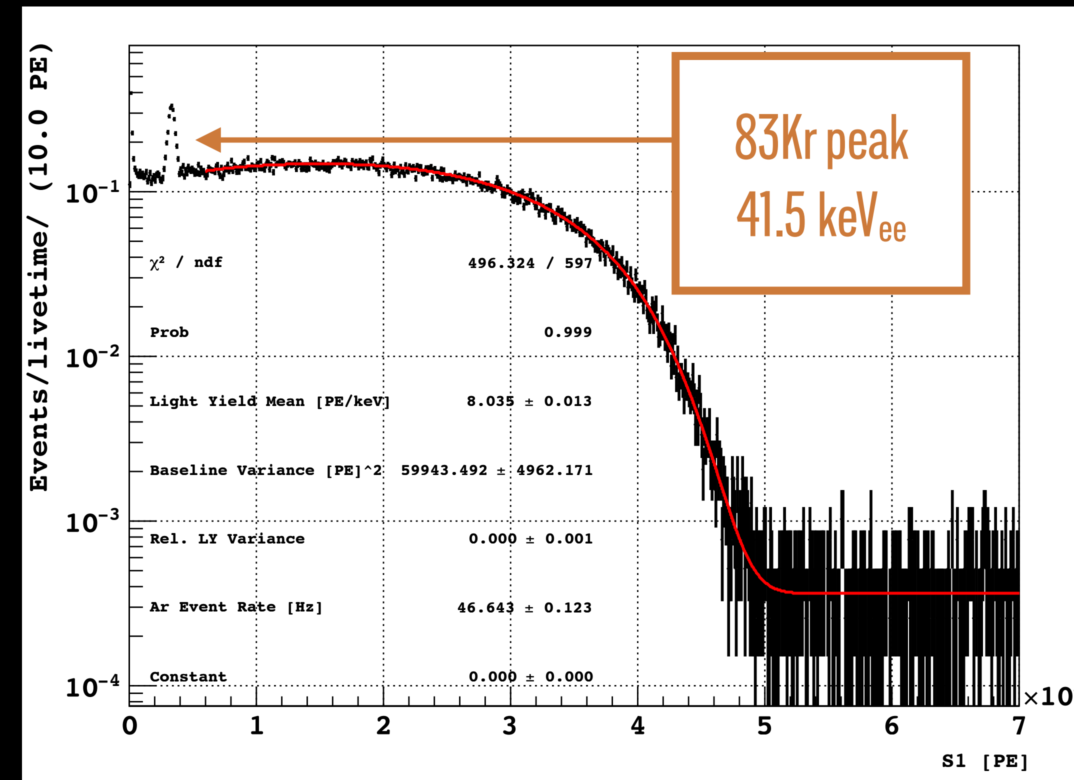


AVERAGE LIGHT YIELD: 8.040 ± 0.006 (stat. only) PE/keV$_{ee}$

TPC: ER calibration @ null field

Subtracted BG





^{83m}Kr Half-life = 1.83 hours

^{83m}Kr gas deployed into detector (41.5 keV$_{ee}$)

Fits to ^{39}Ar and ^{83m}Kr spectrum indicate
AVERAGE LIGHT YIELD: 7.9 ± 0.4 PE/keV$_{ee}$

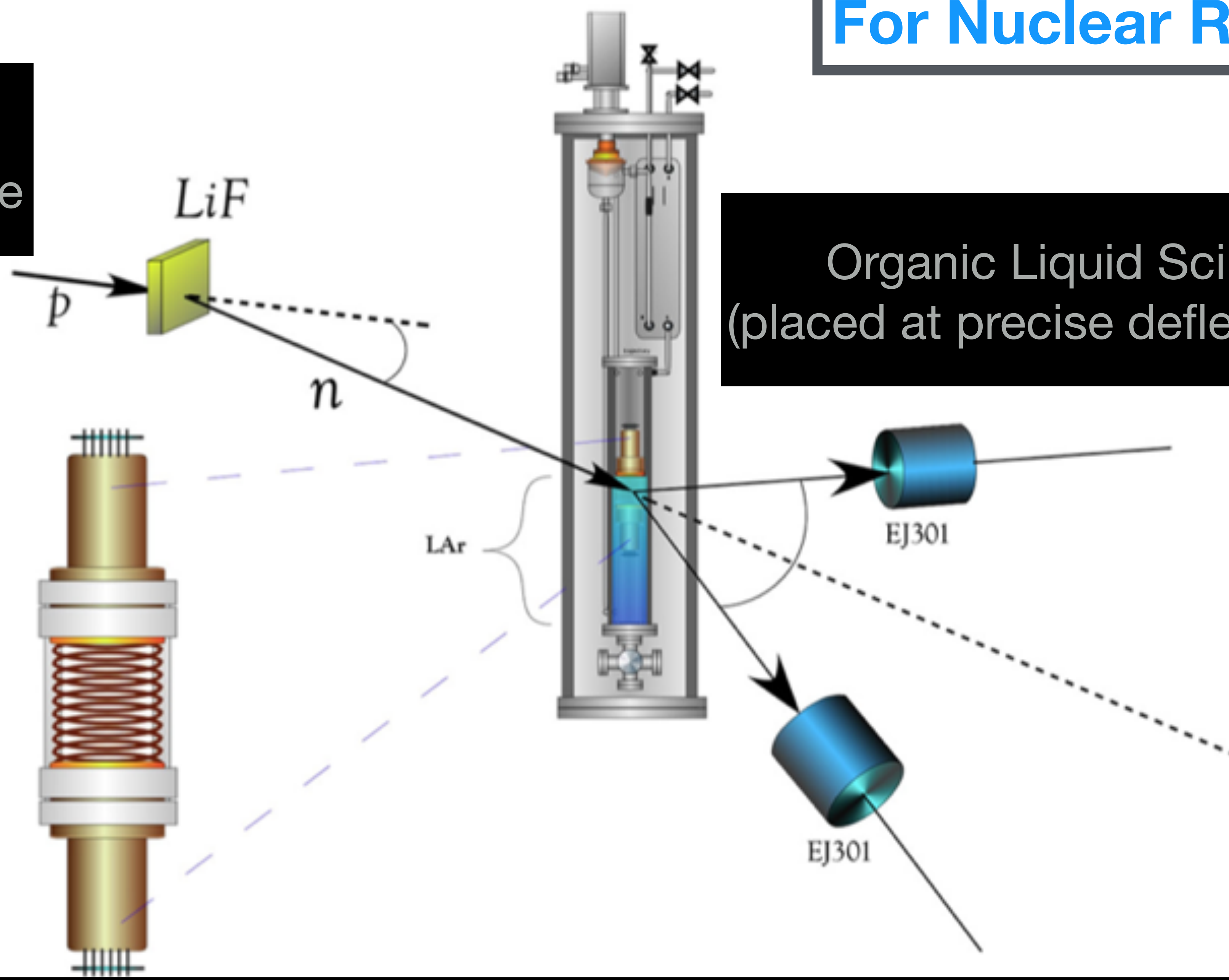
SCENE
(Scintillation Efficiency of Nuclear Recoils in Noble Elements)

For Nuclear Recoils

Proton Beam at University of Notre Dame

Organic Liquid Scintillators (placed at precise deflection angles)

Liquid Argon TPC (based on DarkSide design)

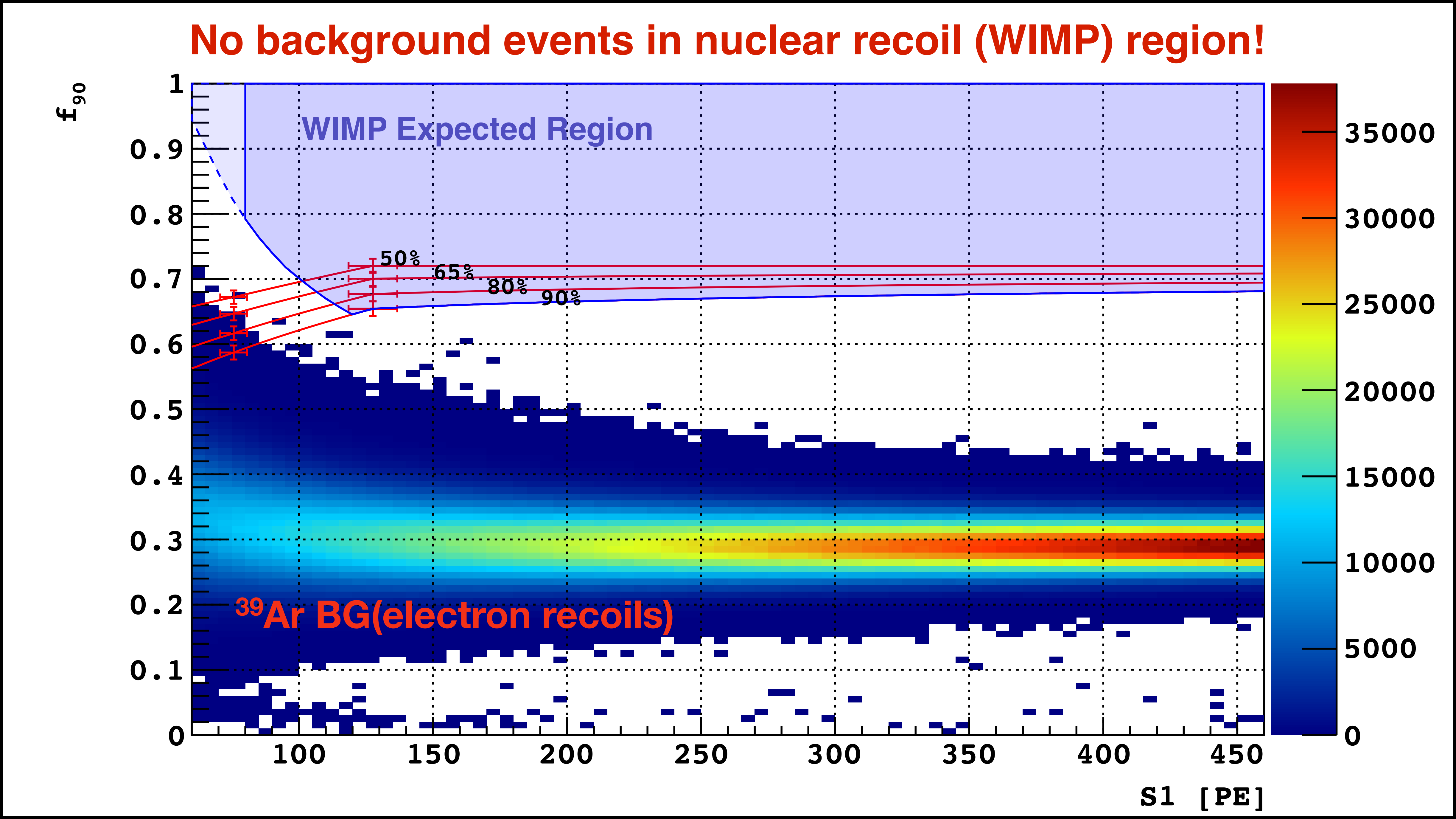


^{7}Li(p, n)^{7}Be reaction produces low energy monoenergetic neutrons
TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy

The First Physics Result from DS-50

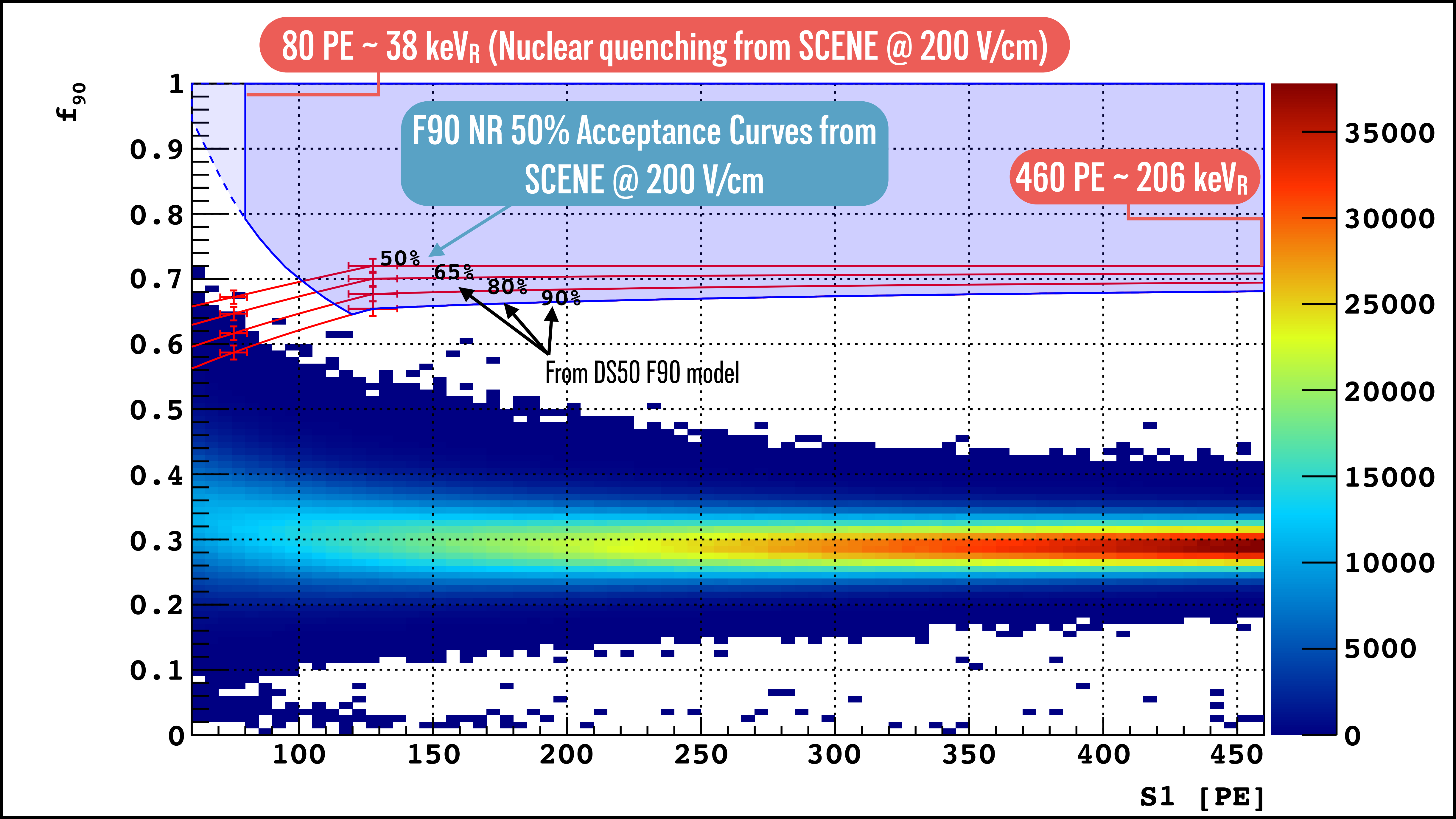
^{39}Ar BG from **47.1 live days** (1422 kg · day fiducial) of AAr corresponds to that expected in **19.4 years** of **UAr** DS-50 run (≫planning physics run time, 3 years).

Background-free exposure of 1422 ± 67 kg·day



Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

Background-free exposure of 1422 ± 67 kg·day

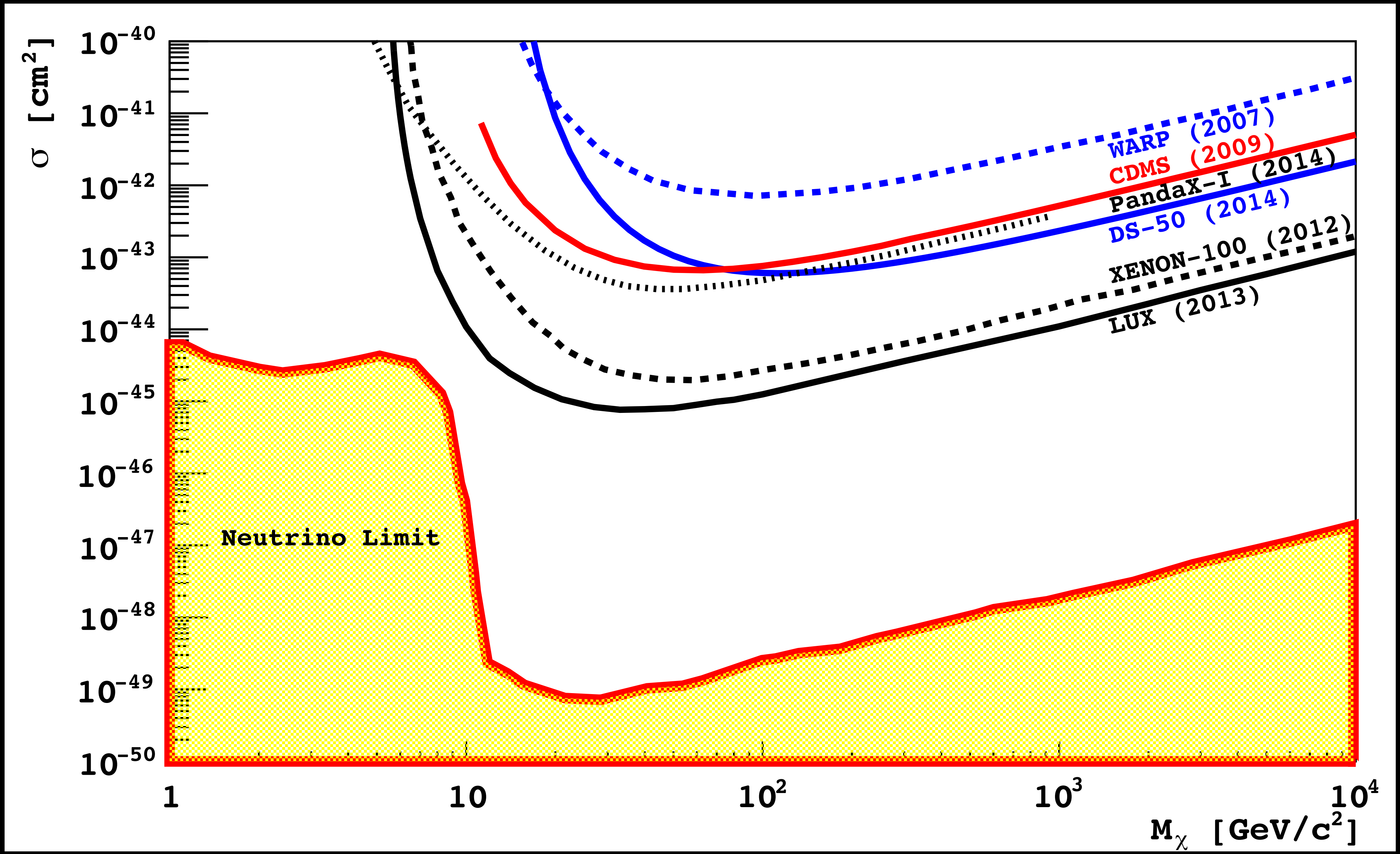


Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

SCENE (arXiv:1406.4825)

Dark Matter exclusion plot

This is the most sensitive dark matter search performed with an **argon** target. The WIMP-nucleon spin-independent cross section is **6.1×10^{-44}** cm^2 for a WIMP mass of 100 GeV/c^2.



Summary

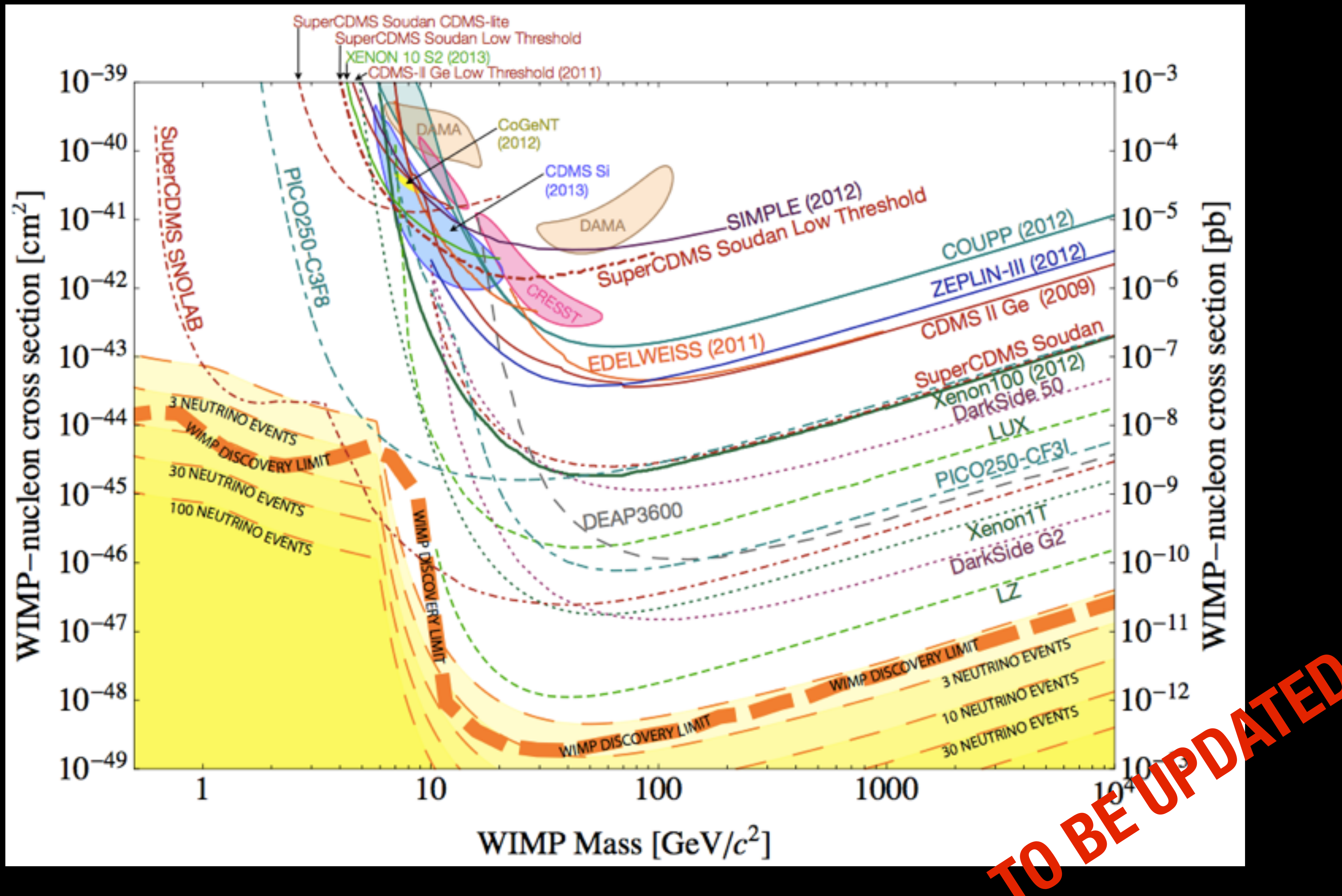
- Background free
  From this result, the ^{39}Ar BG in the full DS-50 run w/ UAr can be suppressed, and future ton-scale LAr TPCs can be free of ^{39}Ar BG.

Future Plans

- Increase ER statistics by injecting ^{39}Ar (possible plan)
  Improve ER pulse shape discrimination
- Deploy calibration sources
  Calibrate both neutron veto and TPC using gamma and neutron sources
- Refill with underground argon
  Fill TPC with underground argon at early 2015
- **Begin dark matter search with underground argon**

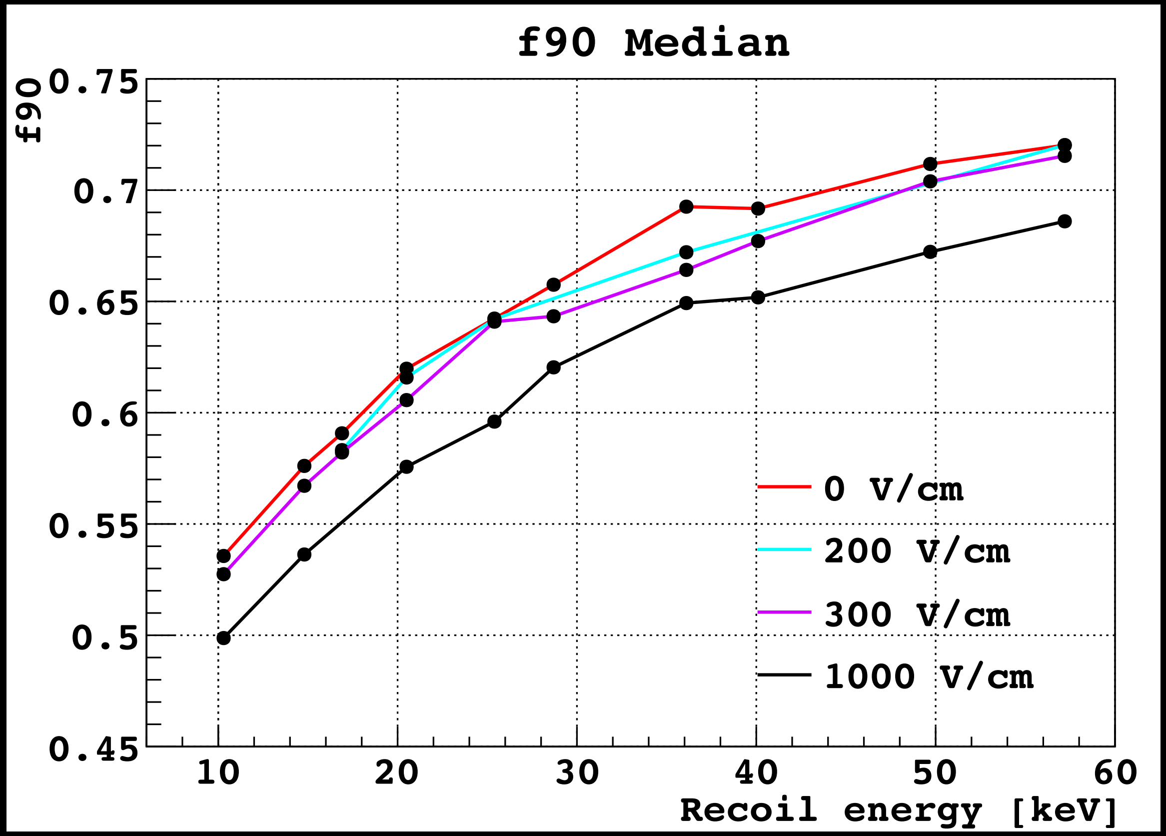
THE END

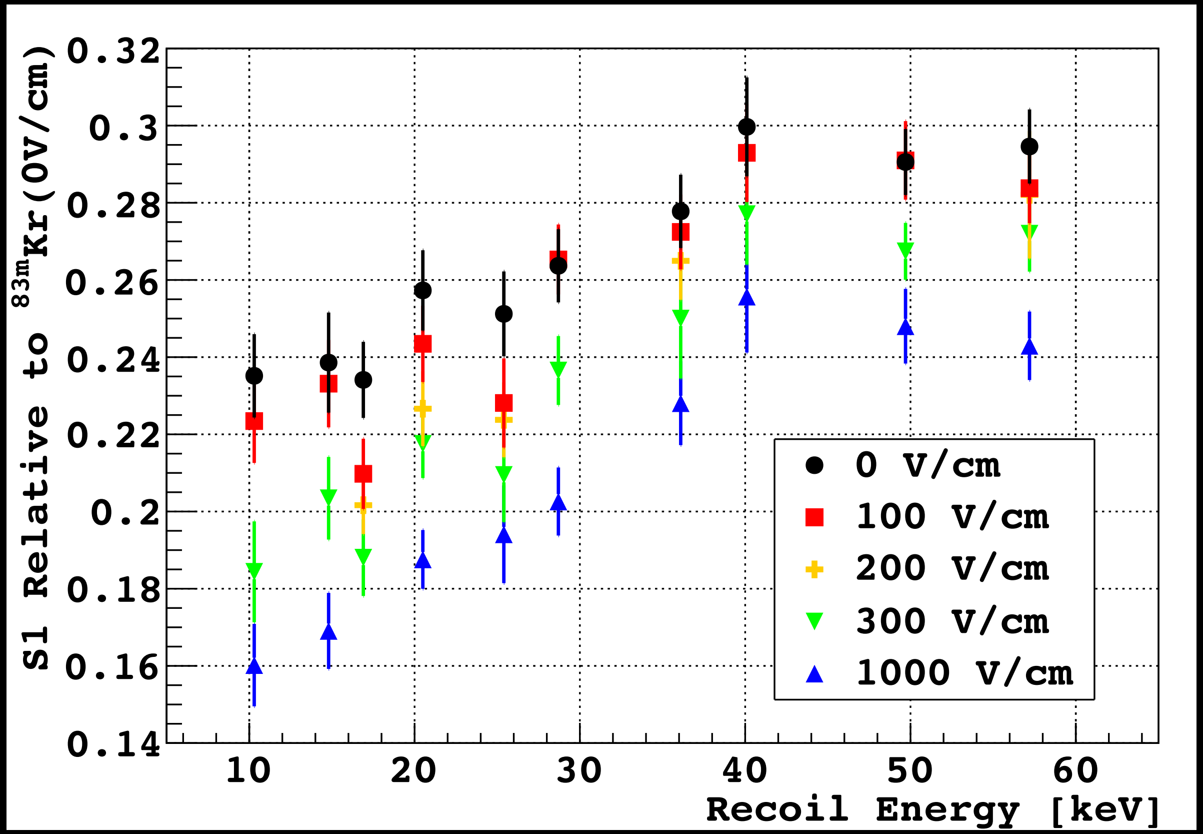
DS-50 & G2 Sensitivity



Sensitivity projection made on Nov. 2013.

Data from SCENE and the plots



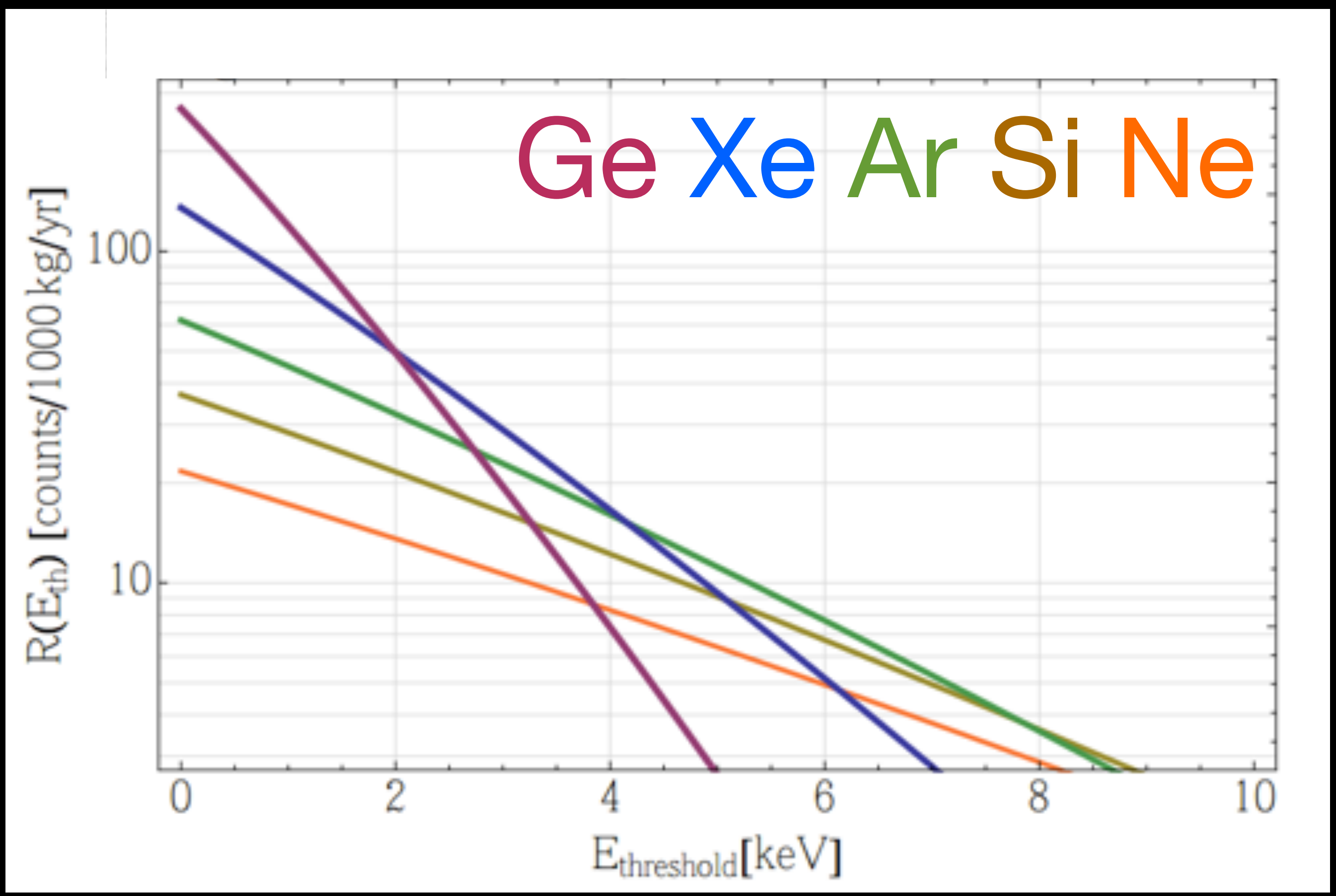


- Left : the median of the f90 distribution for nuclear recoils as a function of energy as measured in the SCENE experiment
- Right: the quenching factor for nuclear recoils as measured by the SCENE experiment

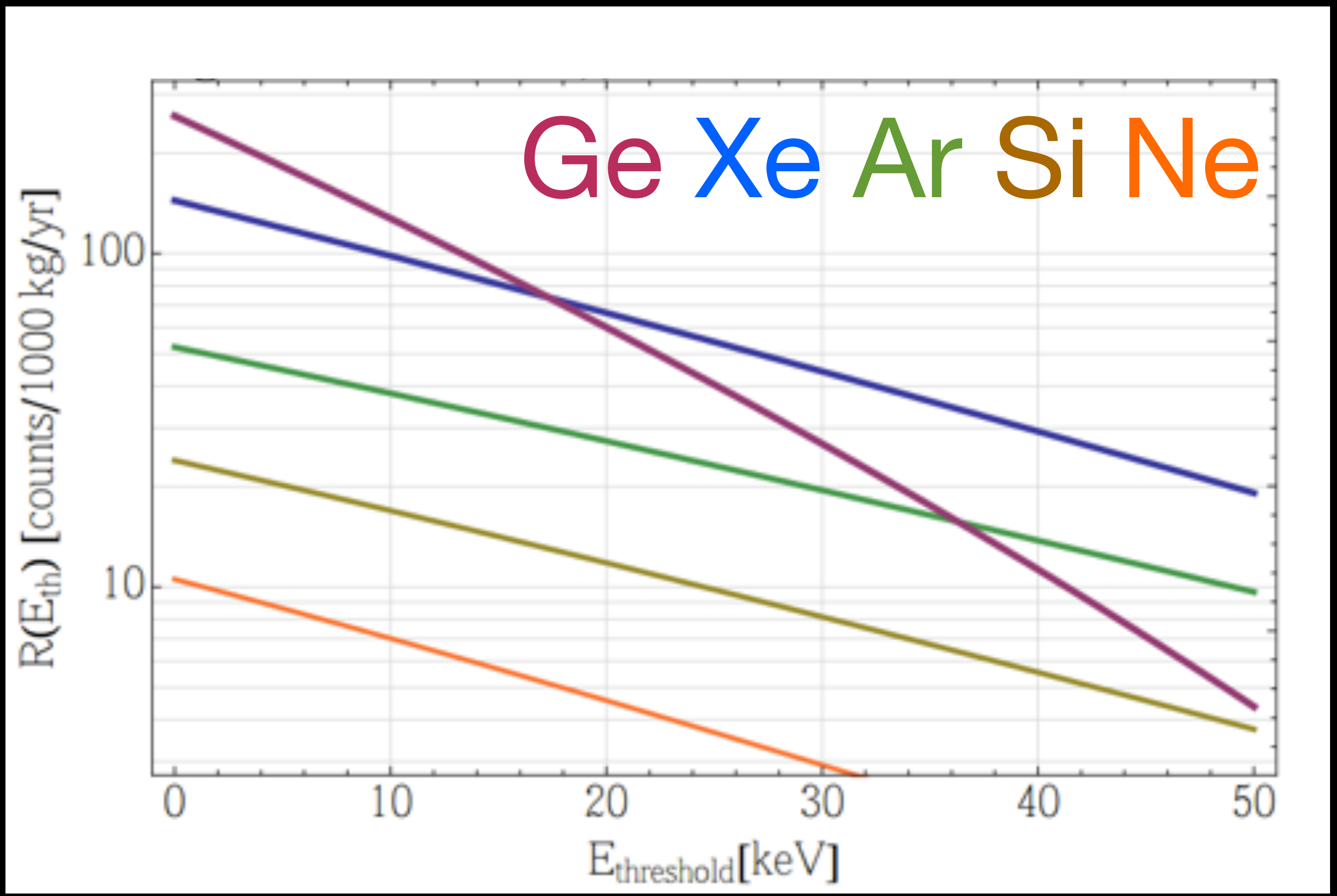
SCENE (Phys. Rev. D 88, 092006 (2013), arXiv:1406.4825)

Interaction Rates

mχ: 10 GeV, $\sigma_{\chi\text{-n}}$: 10^{-45} cm^2



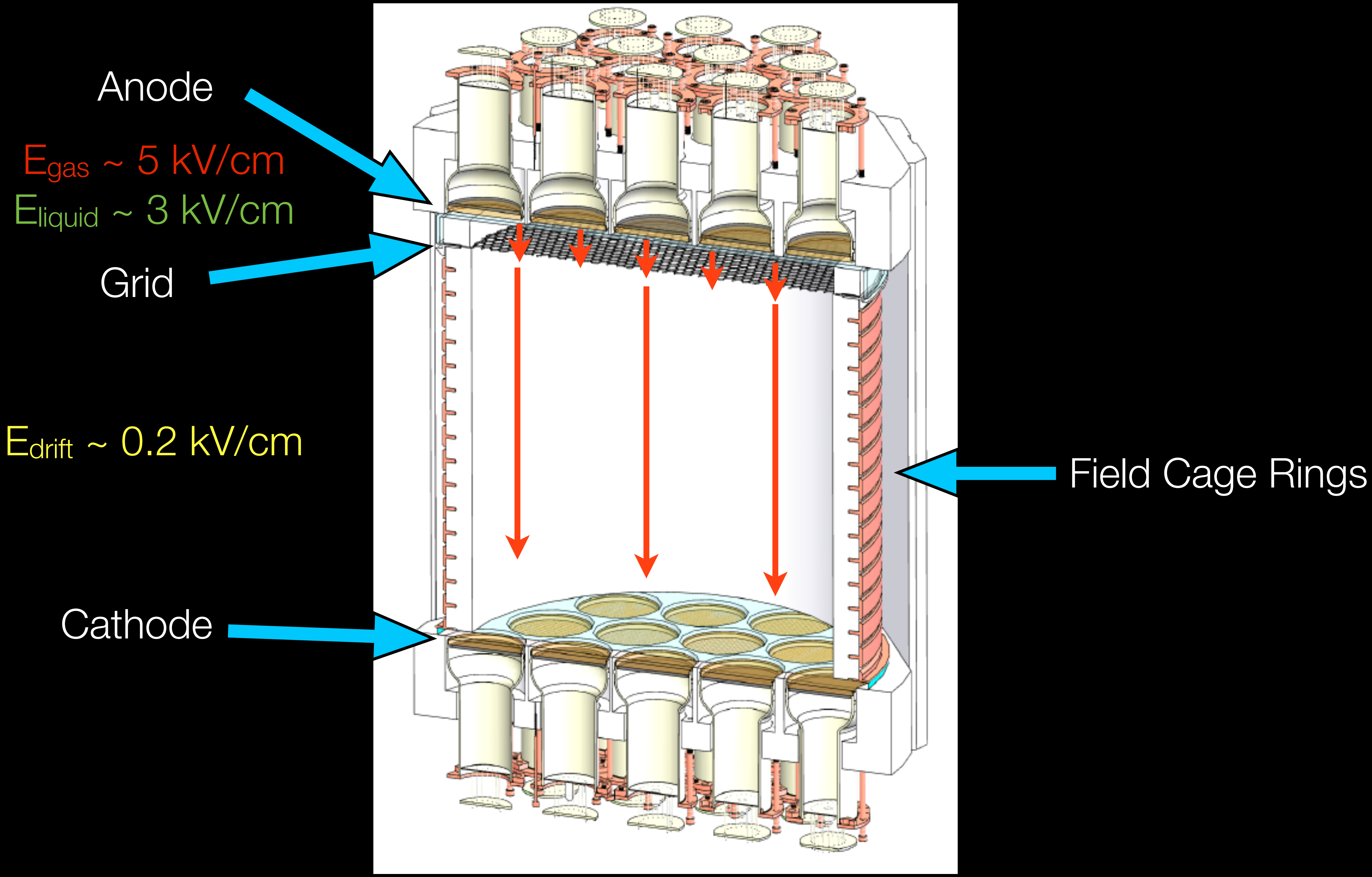
mχ: 100 GeV, $\sigma_{\chi\text{-n}}$: 10^{-45} cm^2



arXiv:1310.8327v2 [hep-ex]

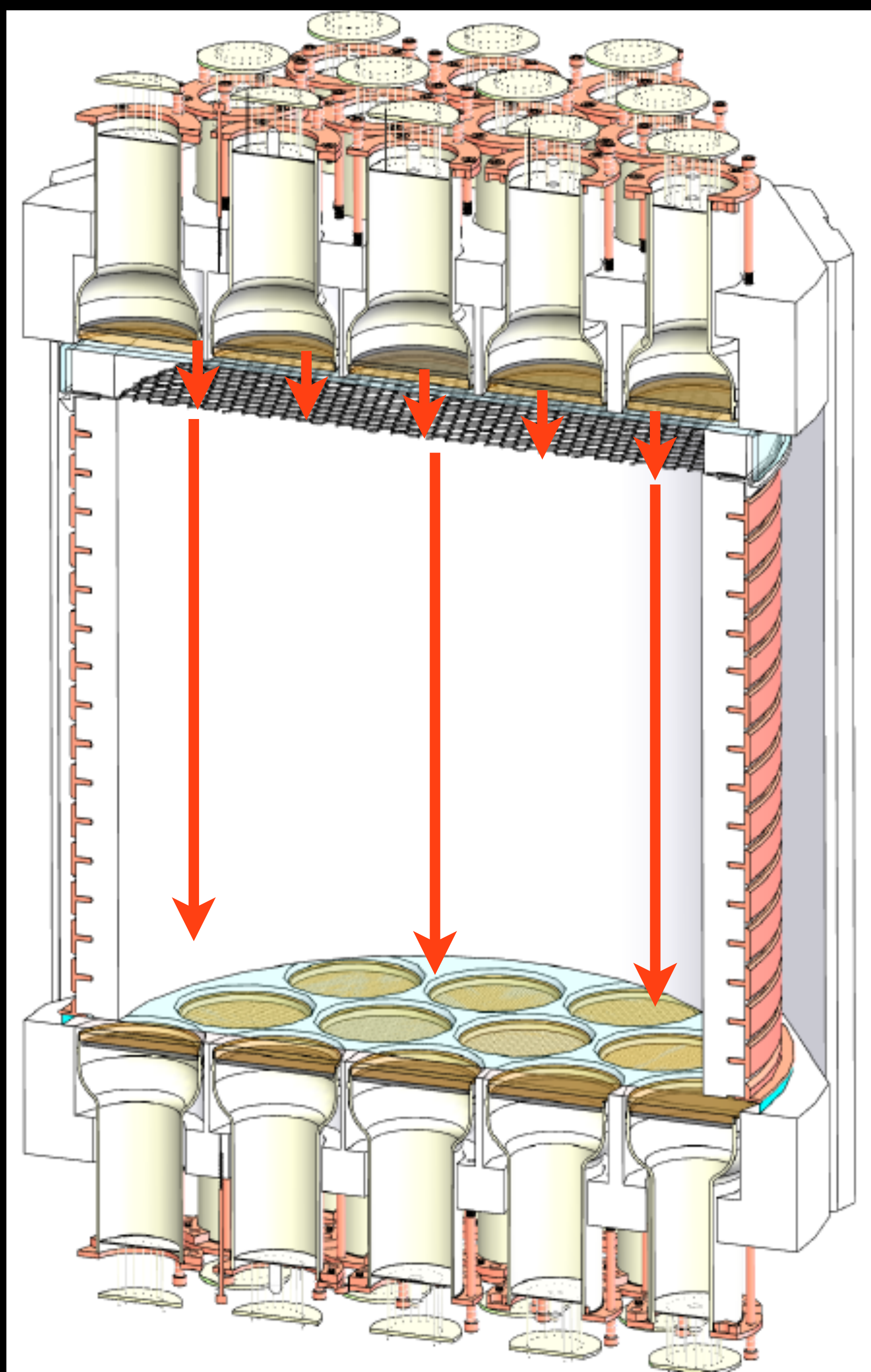
Total Interaction Rate for Ar ~ 10^{-4} evt/kg/day
Rock Natural Radioactivity ~ 10^{7} evt/kg/day

Two Phase Argon TPC



Drift Field

DS50 has been operating at a drift field of 200 V/cm and an extraction field of 2.8 kV/cm



Anode: 0 V

E_{gas} : 4200 V/cm

E_{ext} : 2800 V/cm

Grid: -5600 kV

E_{drift} : 200 V/cm

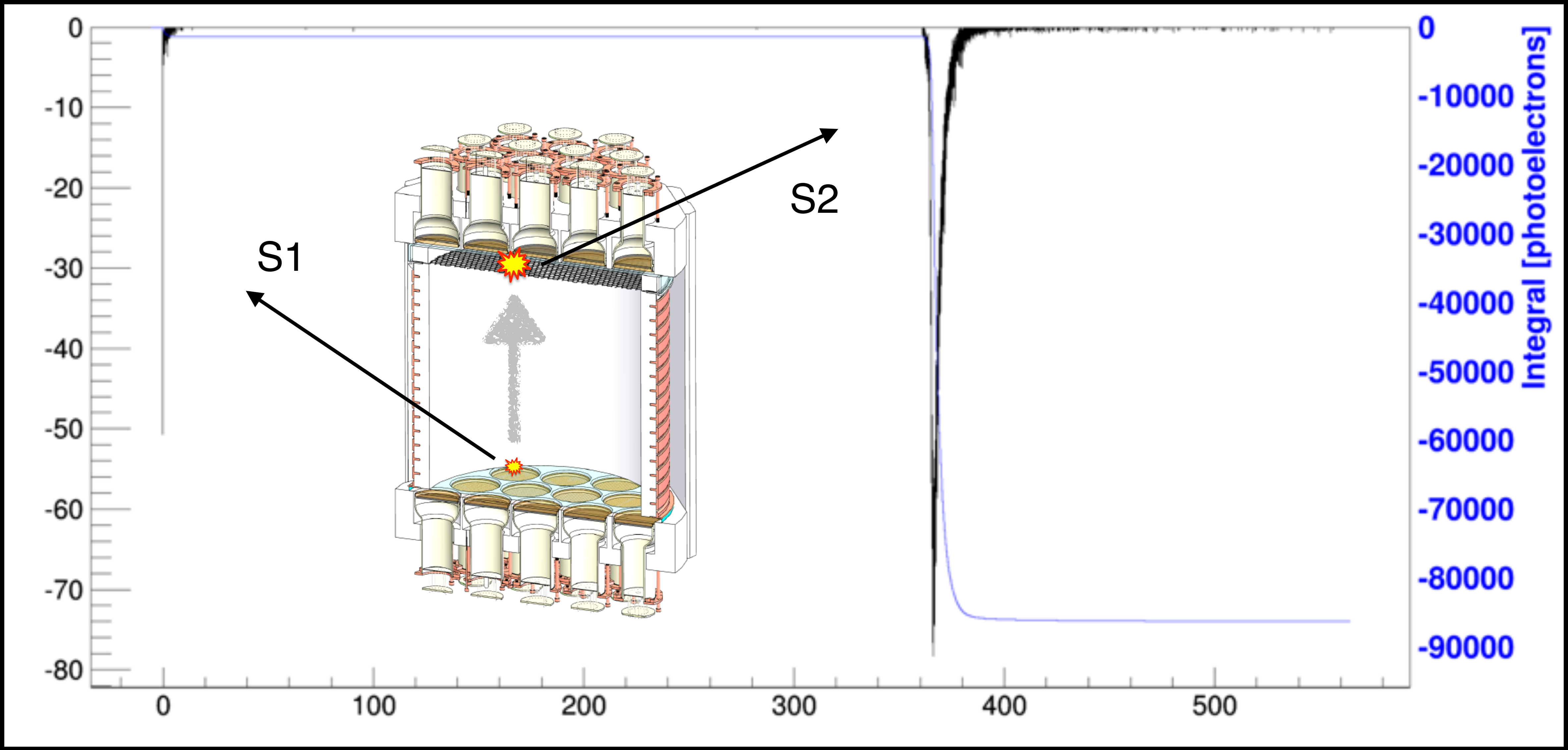
Cathode: -12700 V

Stable operation for several months at -12700 V

Max Drift Time ~ 370 us

Electron Drift Lifetime > 5ms

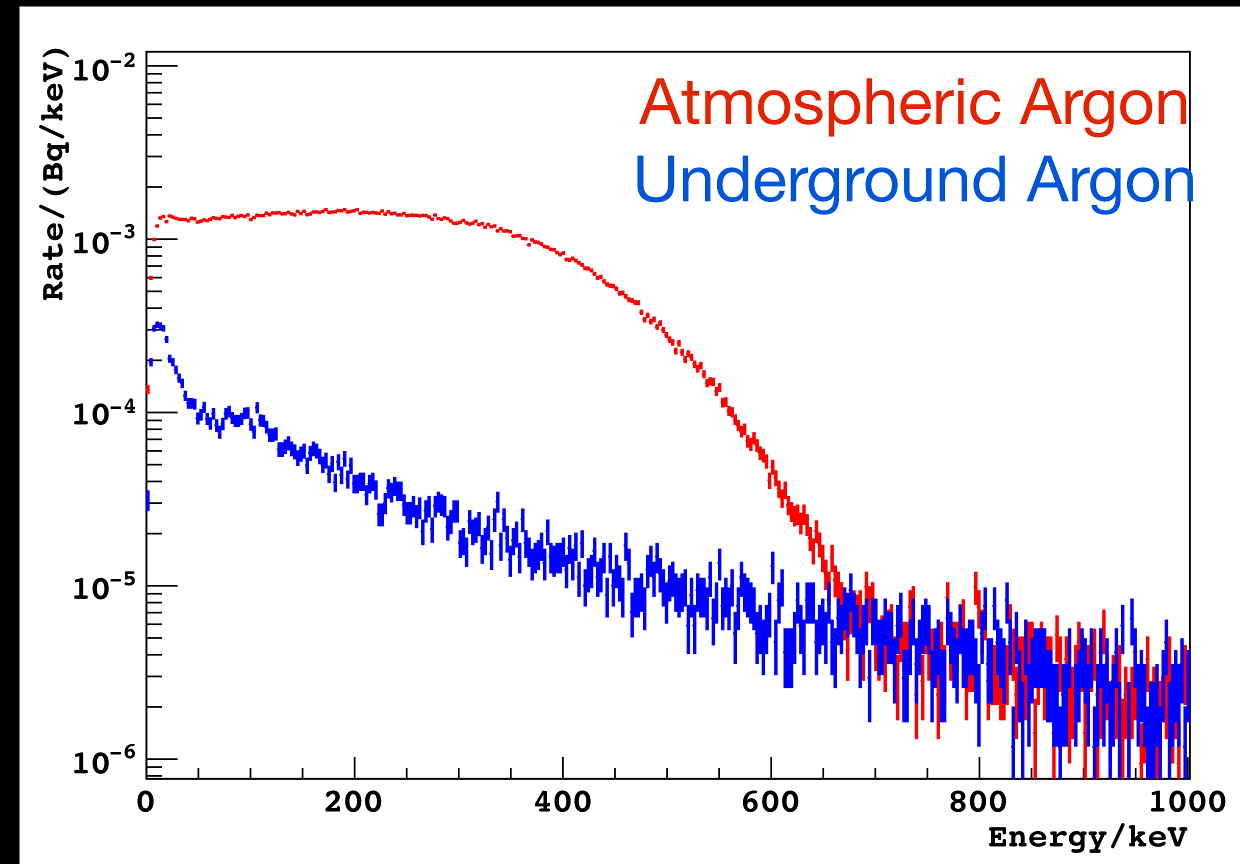
S1 + S2 waveform



Underground Argon Measurement

Low background LAr detector was operated underground at KURF with both atmospheric and underground argon

arXiv:1204.60111 [physics.ins-det]

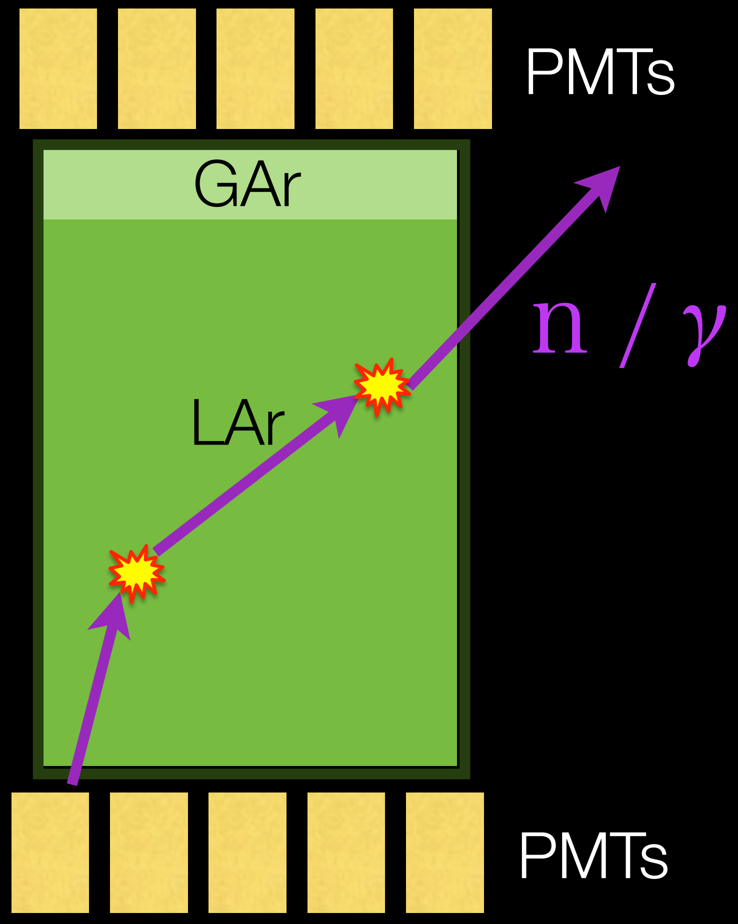


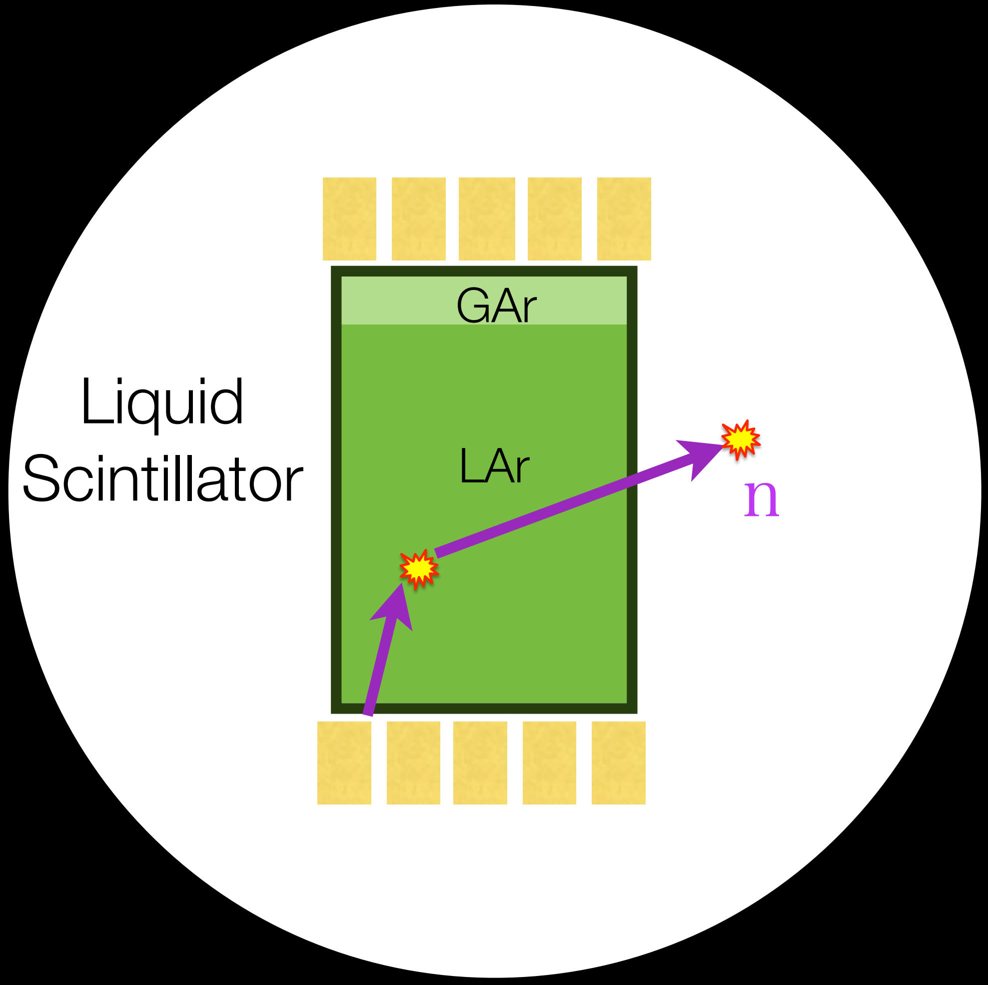
	Total Rate [mBq/100 keV]	Estimated Background Rate [mBq/100 keV]	Background Subtracted Rate [mBq/100 keV]
Underground Argon (UAr)	1.87 +/- 0.06	1.5 +/- 0.2	0.32 +/- 0.23
Atmospheric Argon (AAr)	108.8 +/- 0.4		107.2 +/- 1.9*
^{39} Factor	1.71 +/- 0.05 %		< 0.65 % (95 CL)

* Includes ^{85}Kr upper limit

Multiple Interactions

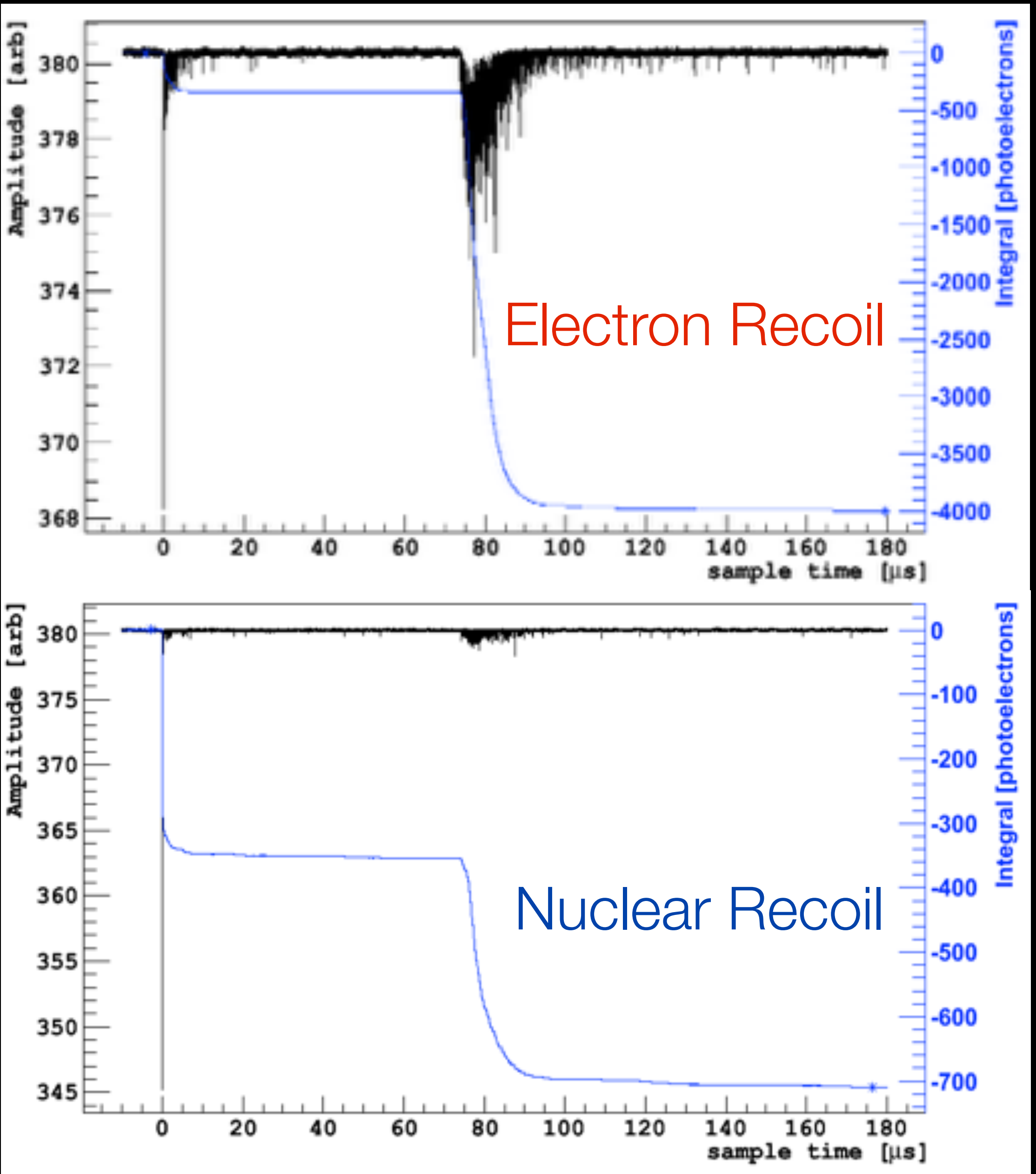
Expected WIMP signal	Background Rejection Technique	Backgrounds Removed
Single Interaction	Multiple S2 Cut in TPC Liquid Scintillator Veto	Neutrons, Gamma rays

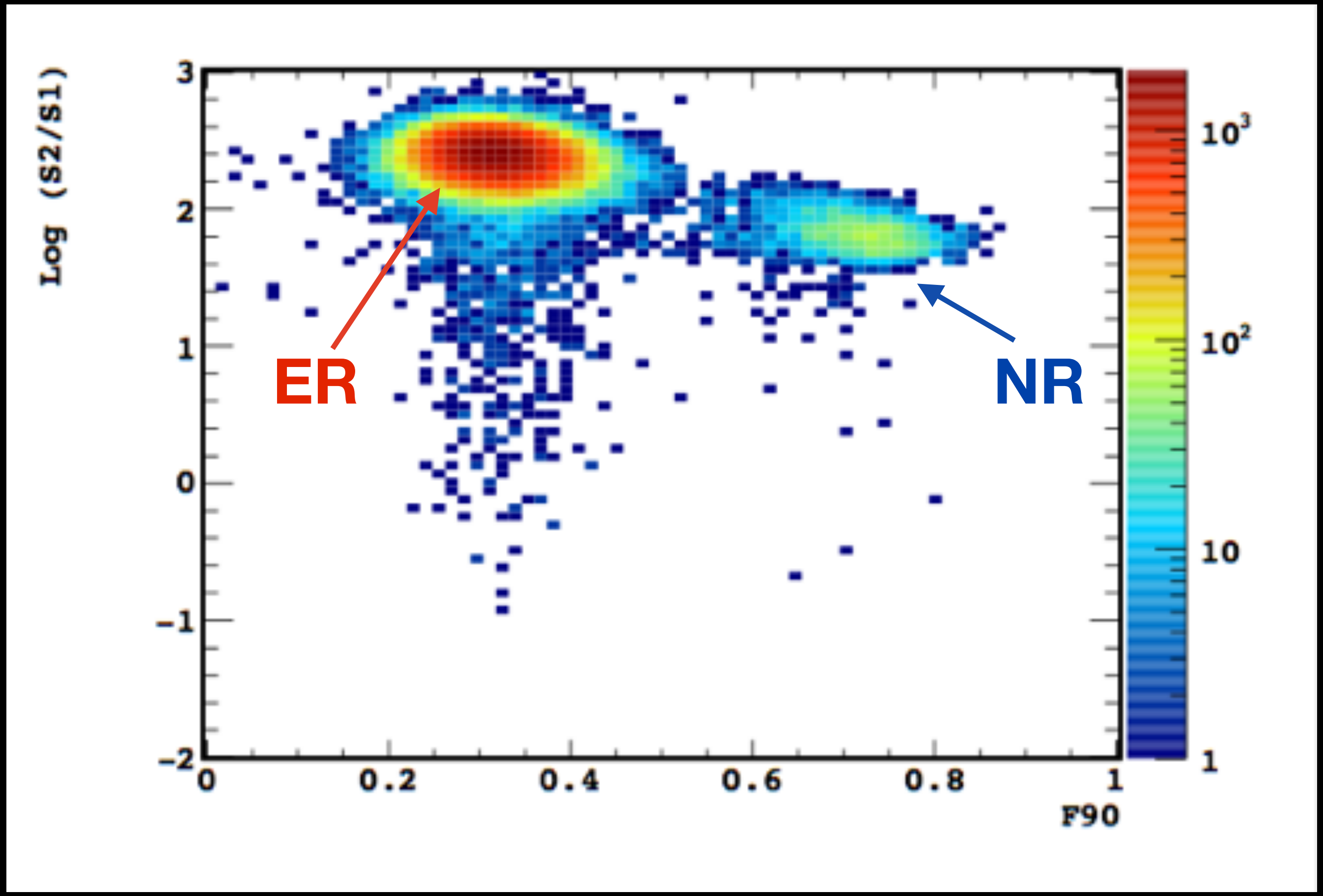




S2/S1

Electron and nuclear recoils produce different ionization densities that lead to different fractions of electrons that survive recombination



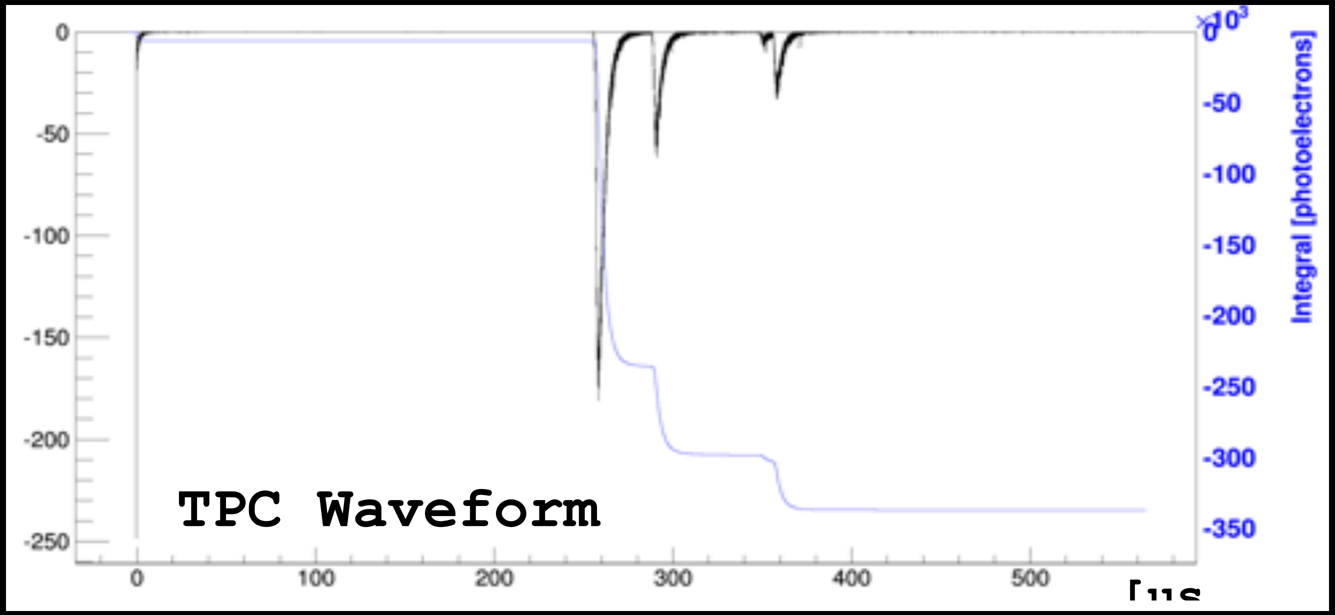


Am-Be Source

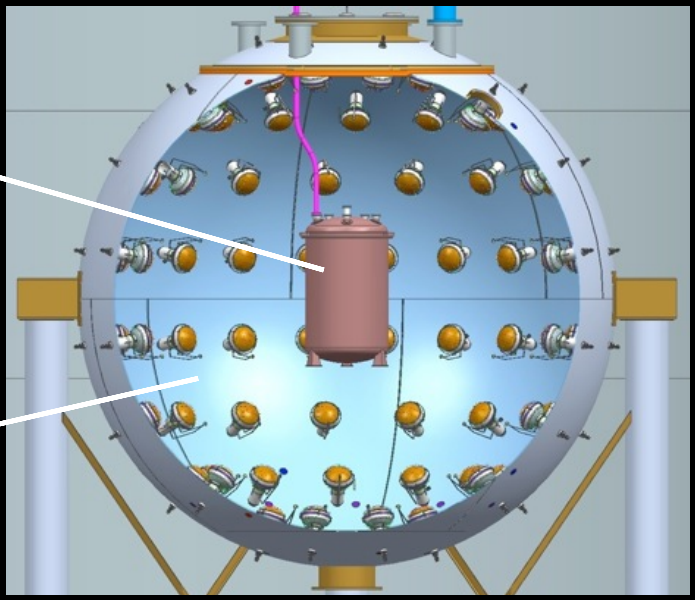
Ratio of ionization and scintillation signal (S2/S1) can be used to distinguish between the two populations

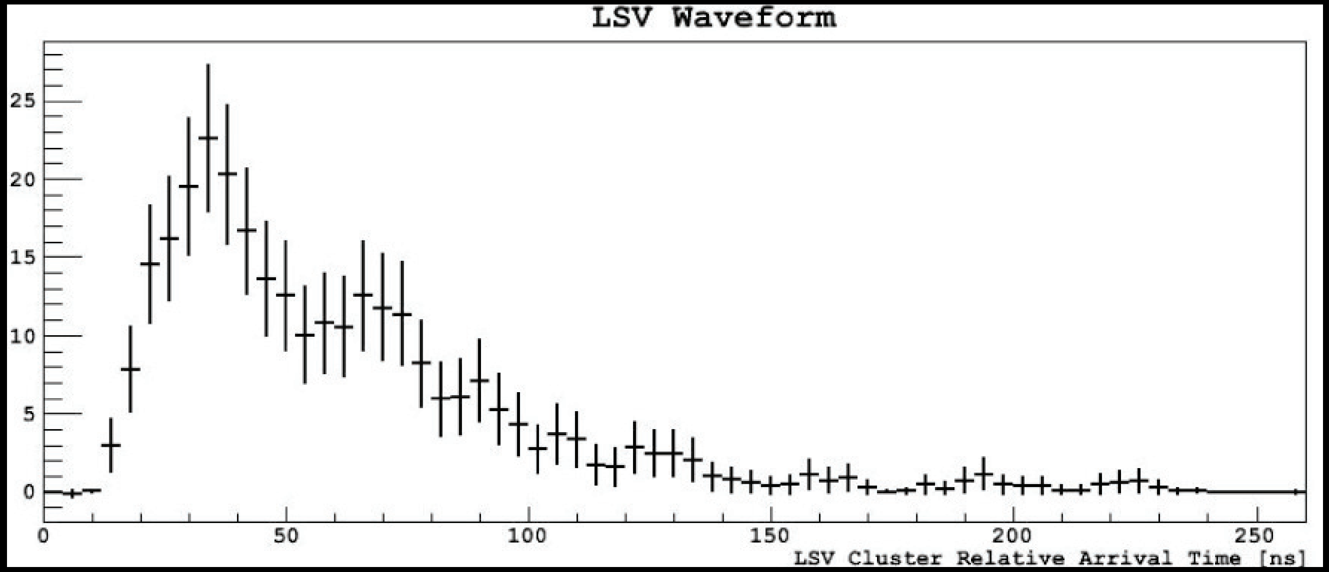
Neutron Veto Commissioning

Coincident event in TPC and Neutron Veto



Electron recoil event with multiple S2 signals in TPC



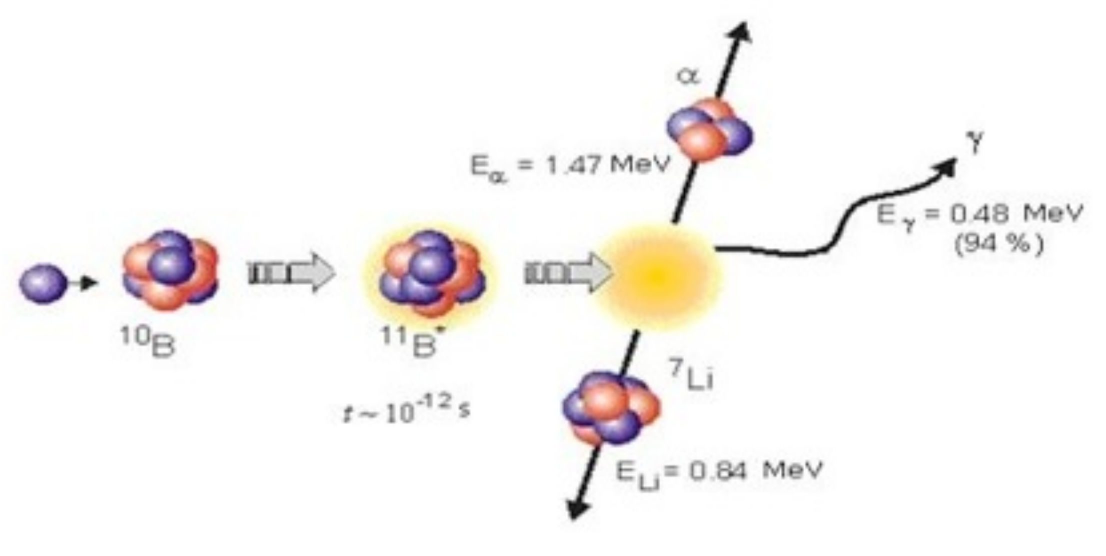


Coincident signal in liquid scintillator veto

<u>Light Yield:</u> liquid scintillator VETO LY of about 0.5 PE/keV_{ee}, satisfactory for VETO requirements.

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 μs) reduces dead time loss



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

Nuclear Instruments and Methods A 644, 18 (2011)

*Based on 60 μs veto window