Current and Future of DarkSide Dark Matter Experiment

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on behalf of the DarkSide Collaboration
25 Aug. 2015

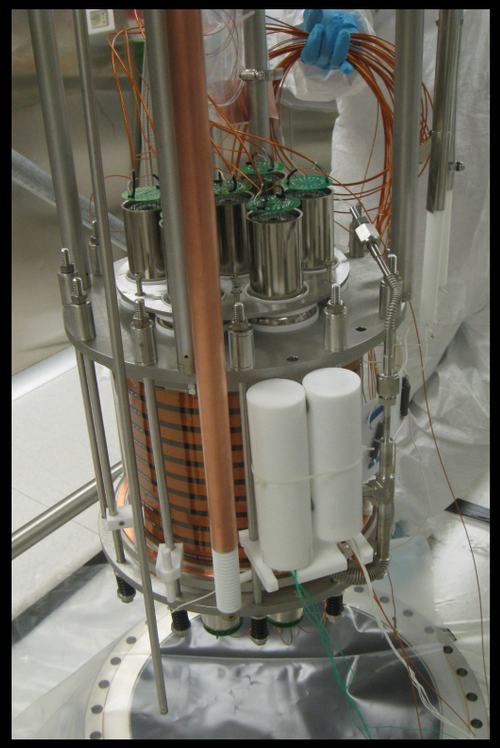
SNOLAB Future Planning Workshop

DarkSide Program

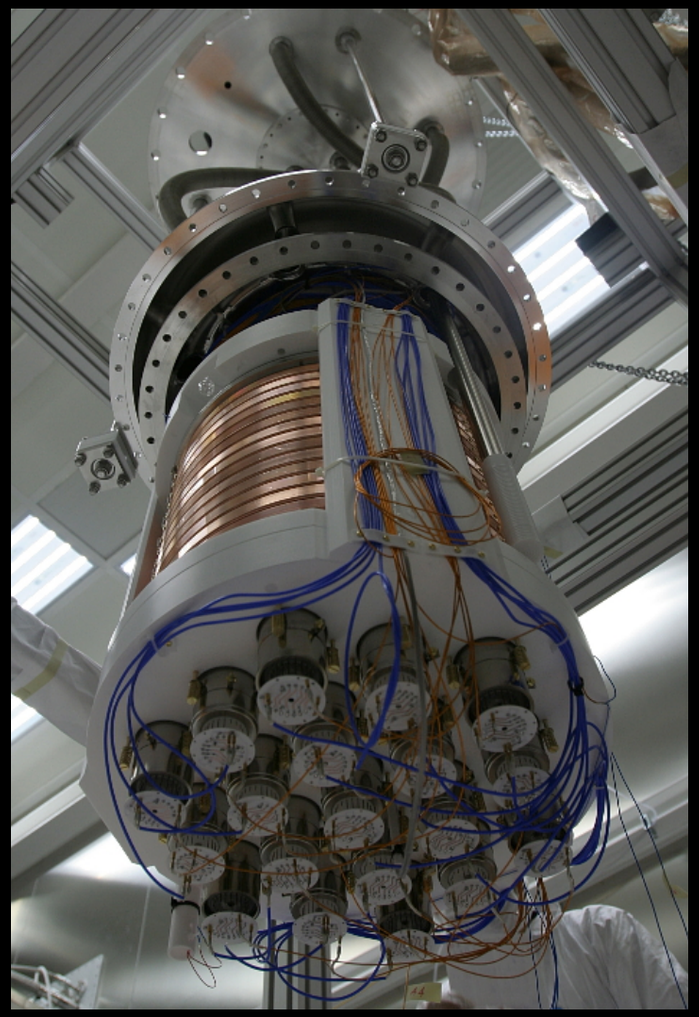
- **Direct detection** search for WIMP dark matter
- Based on a **two-phase argon** time projection chamber (**TPC**)
- Design philosophy based on having very low background levels that can be further reduced through **active suppression**, for **background-free** operation from backgrounds (both from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

DarkSide Program

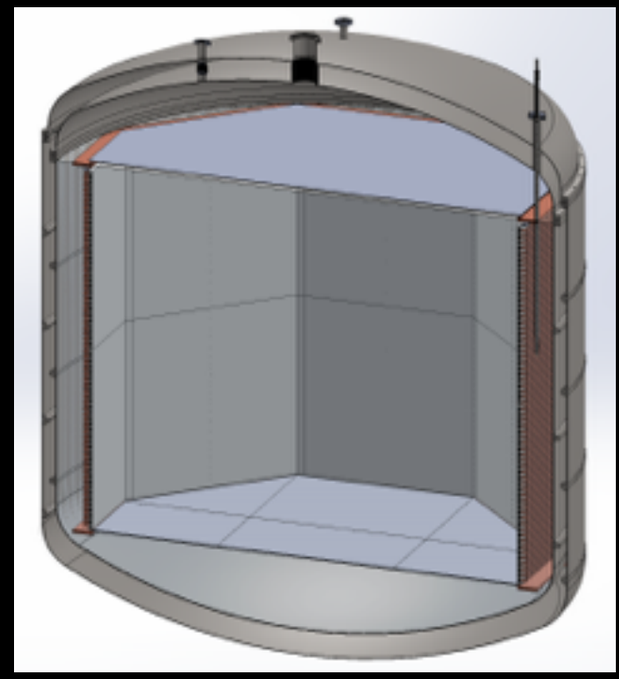
Multi-stage program at Gran Sasso National Laboratory in Italy



DarkSide 10
Prototype detector



DarkSide 50
First physics detector
Commissioned Oct.2013



DarkSide-20k

30 tonne (20 tonne fiducial depleted argon detector proposed to LNGS for operations within **2020**)

+ multiple smaller test setups and prototypes

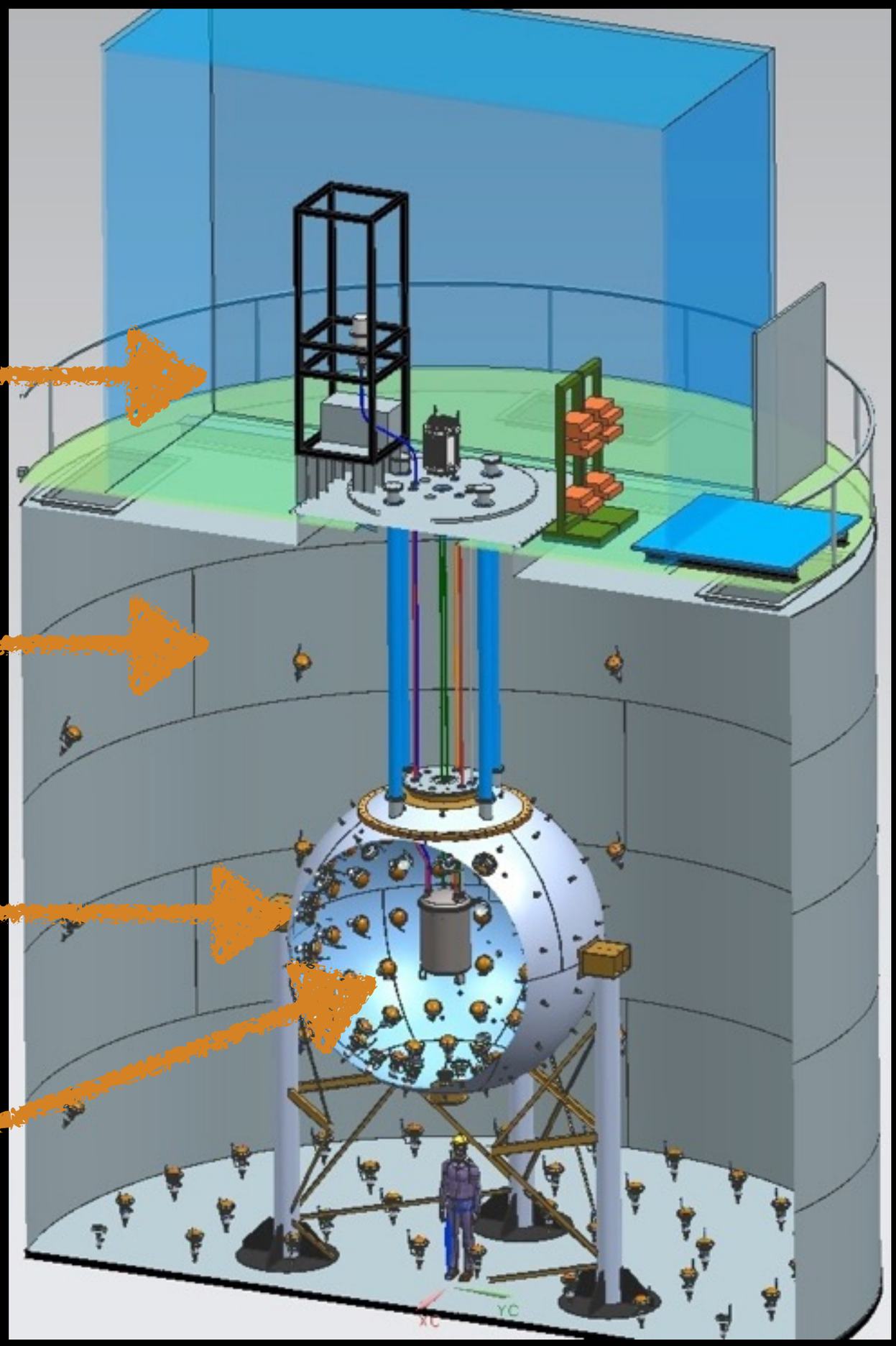
DarkSide 50

Radon-free Assembly
Clean Room

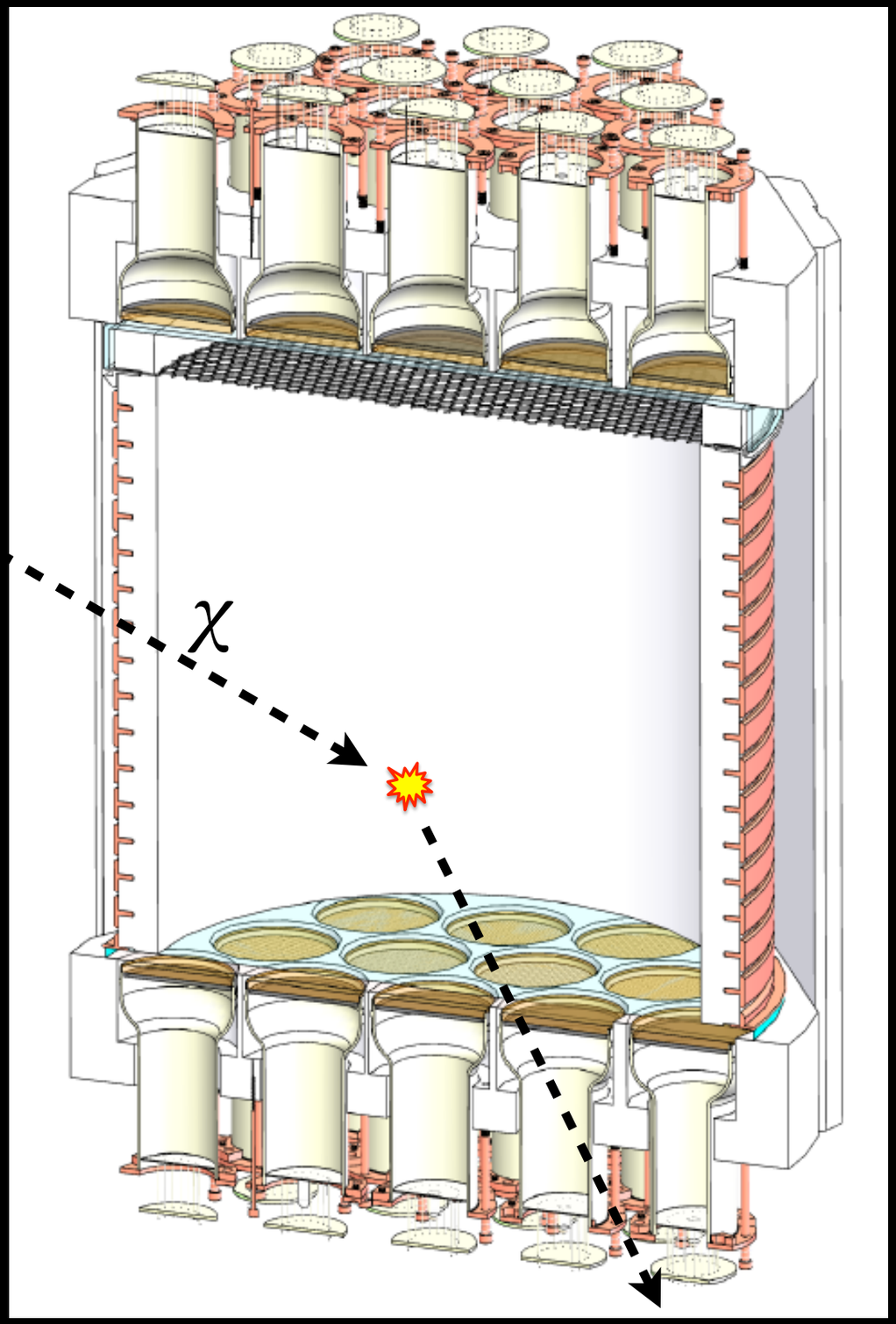
1,000-tonne Water-based
Cherenkov **Cosmic Ray Veto**

30-tonne Liquid Scintillator
Neutron and γ's Veto

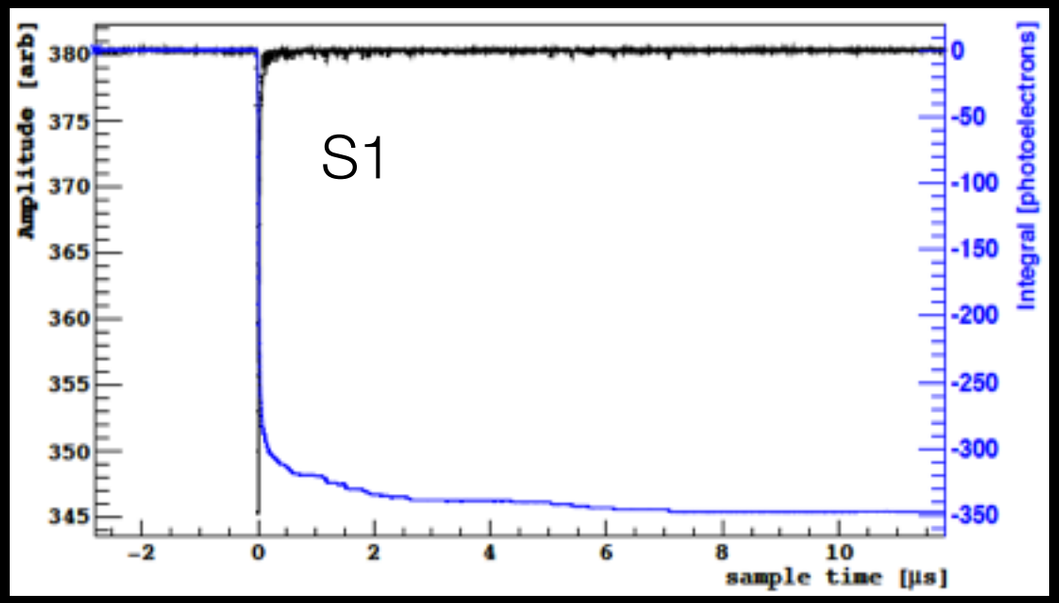
Inner detector **TPC**



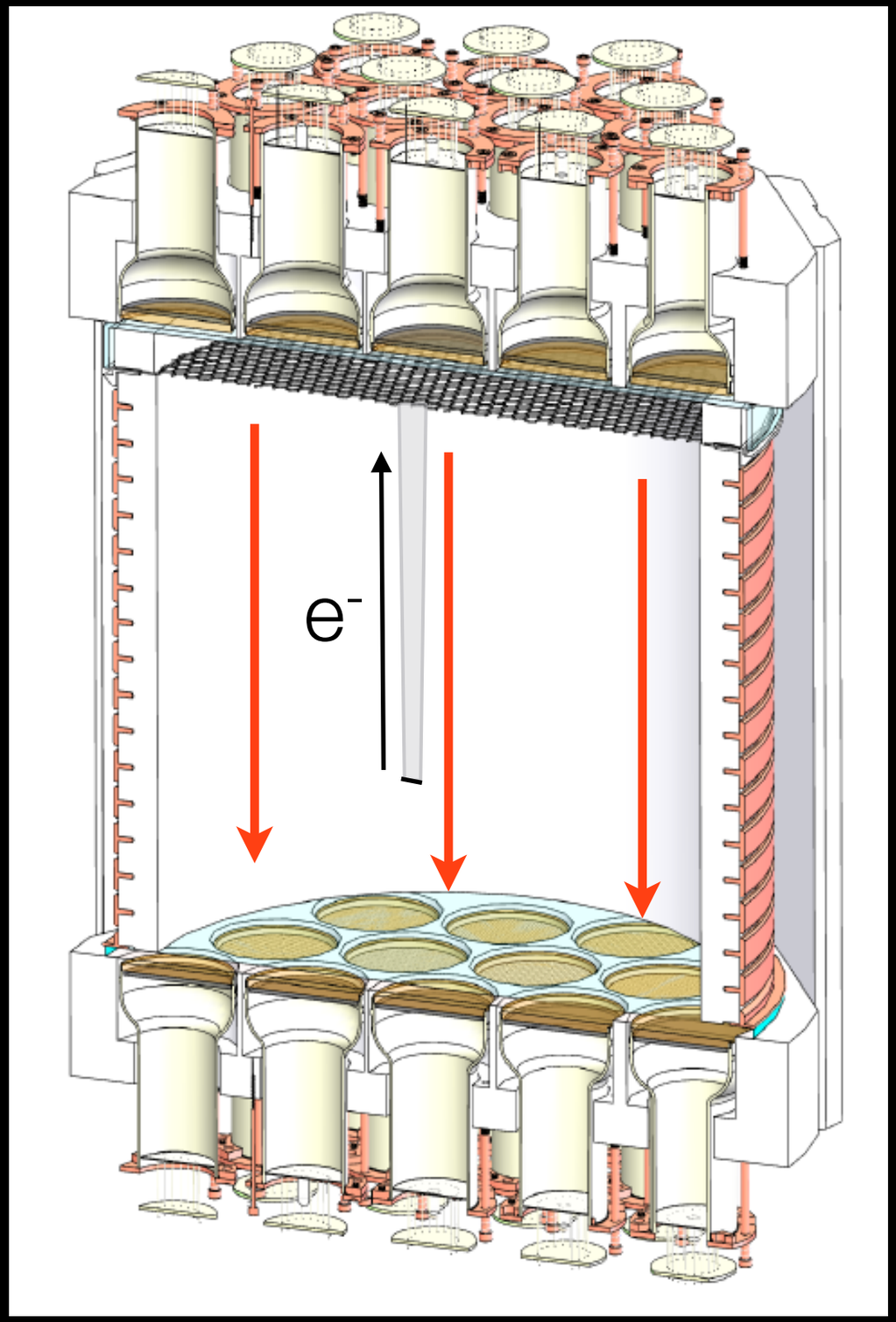
Two Phase Argon TPC



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



Detecting WIMPs

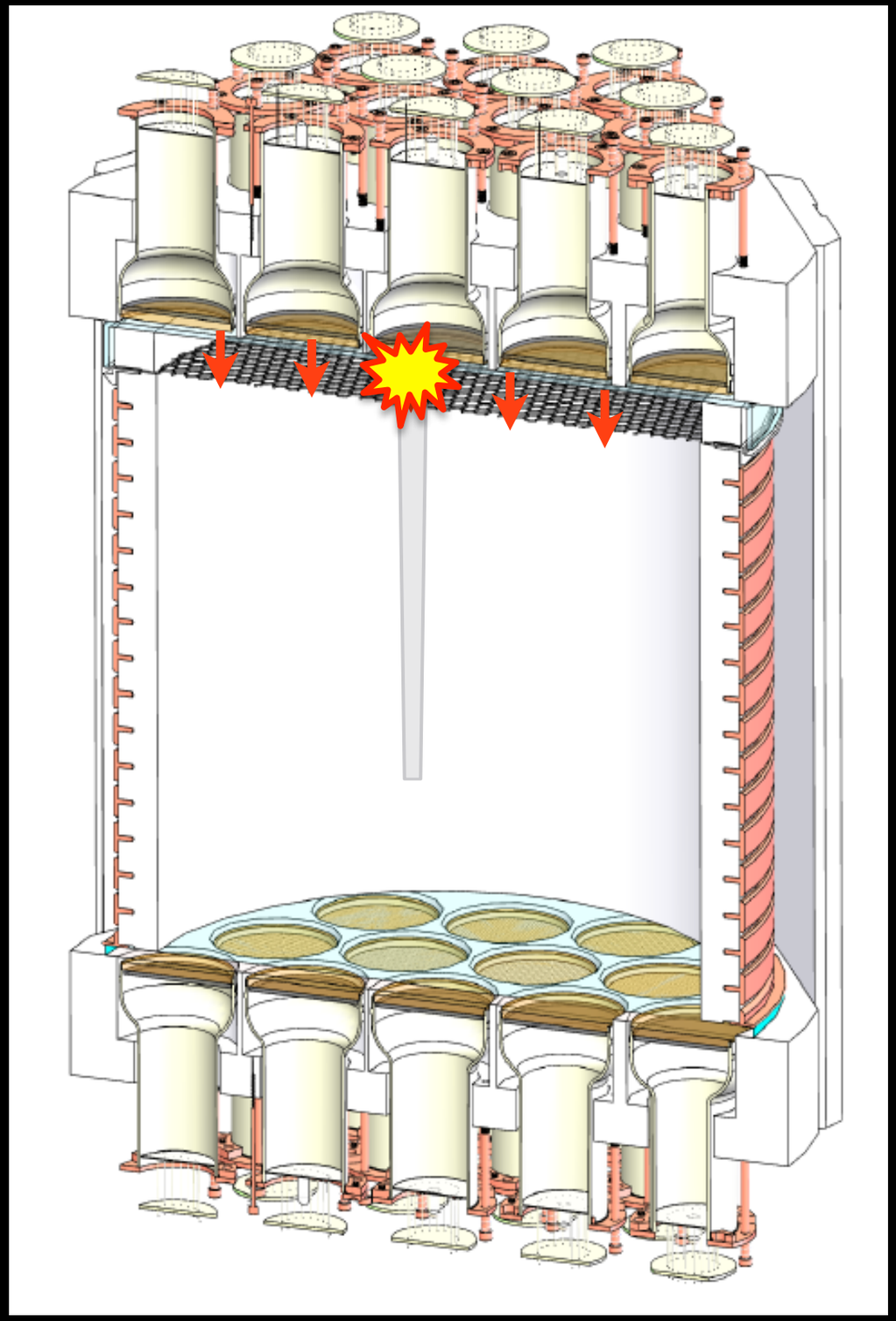


The ionized electrons that survive recombination are drifted towards the liquid-gas interface by the electric field.

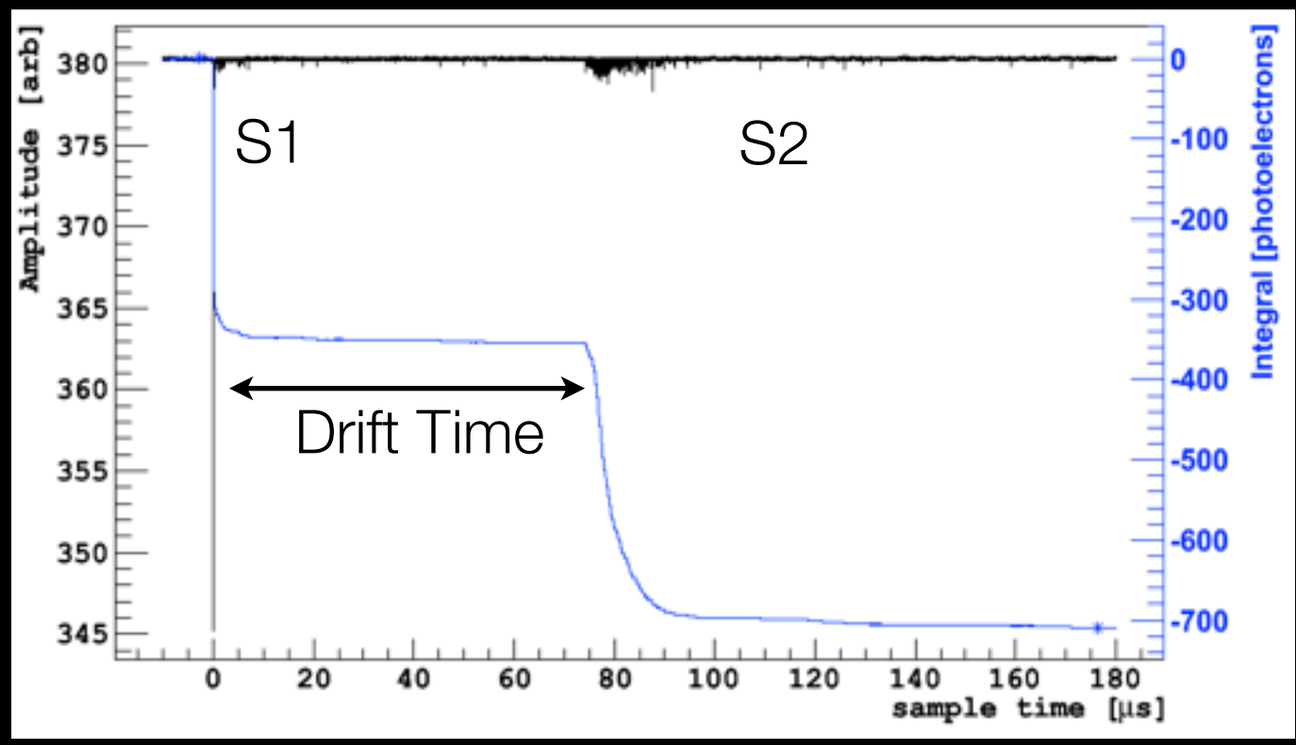
Electron drift lifetime > 5 ms,
compared to max. drift time of ~ 375 μs

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

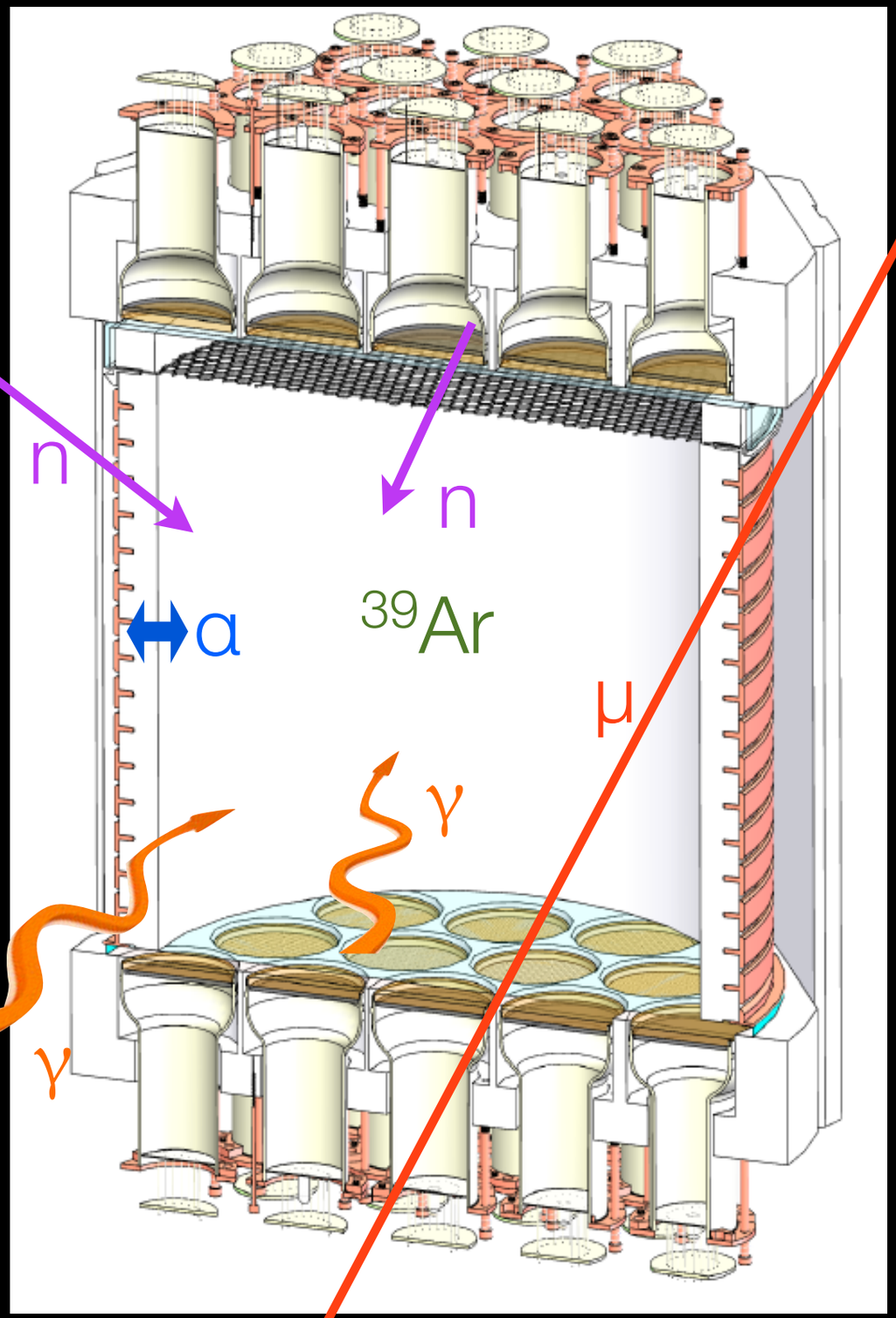
Backgrounds

[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

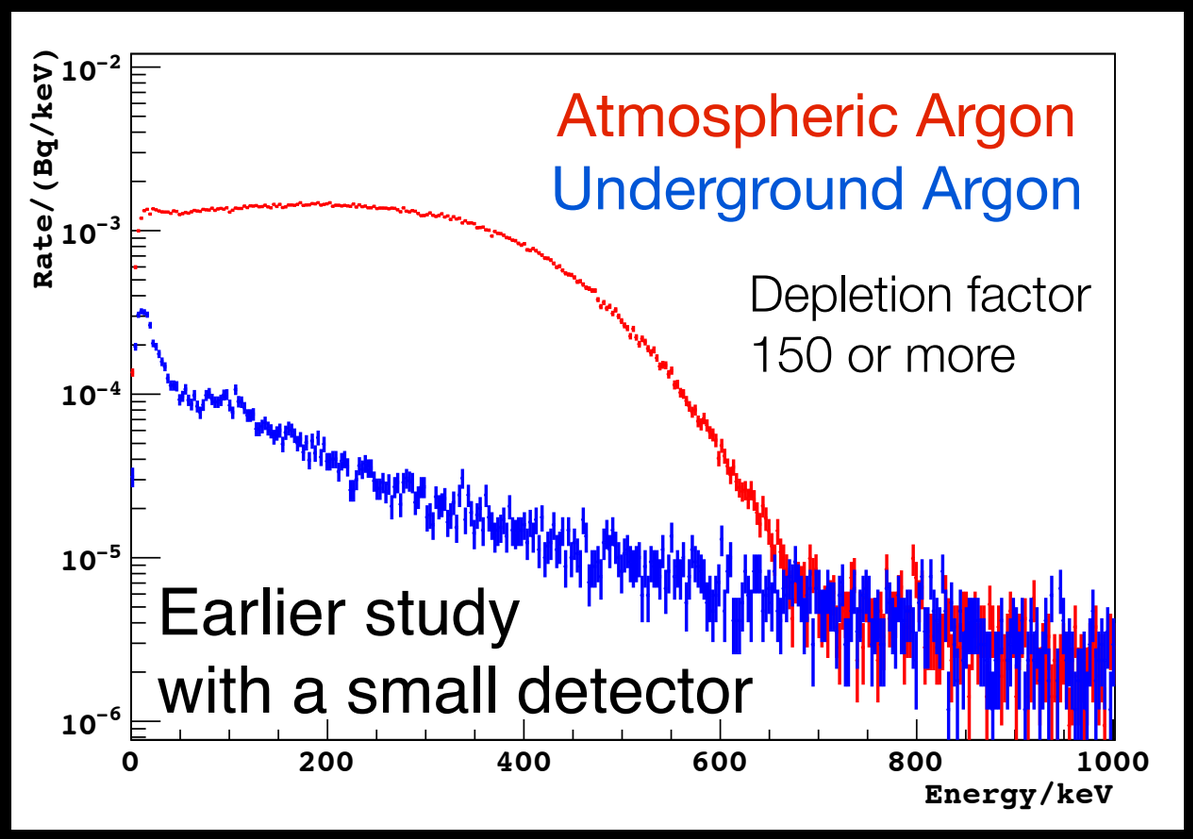
Radiogenic n
~$6x10^{-4}$ evt/kg/day

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 lower compared to **atmospheric argon**
- Recently DarkSide deployed underground argon. **Update will be at the end of this talk.**



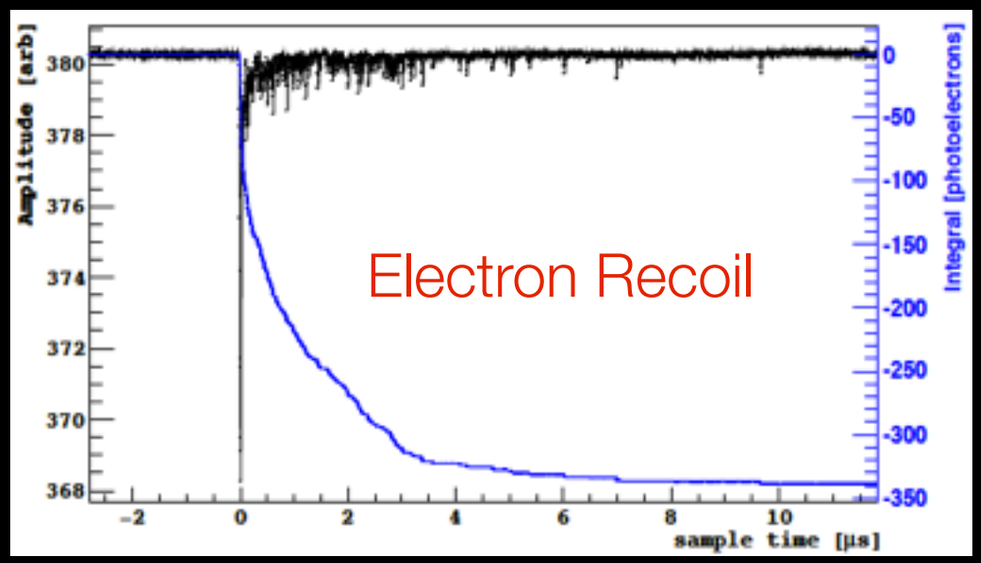
arXiv:1204.60111 [physics.ins-det]

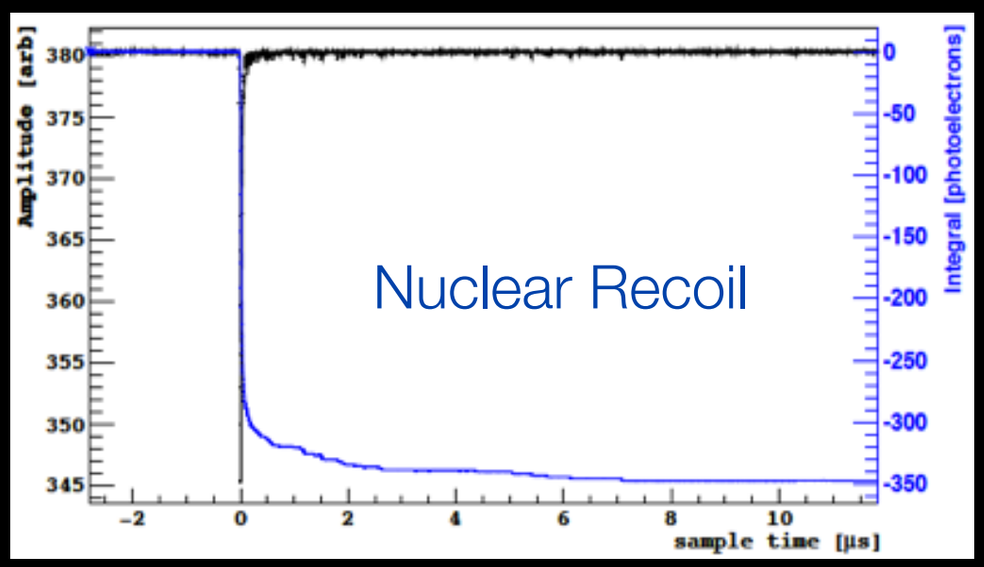
Pulse Shape Discrimination

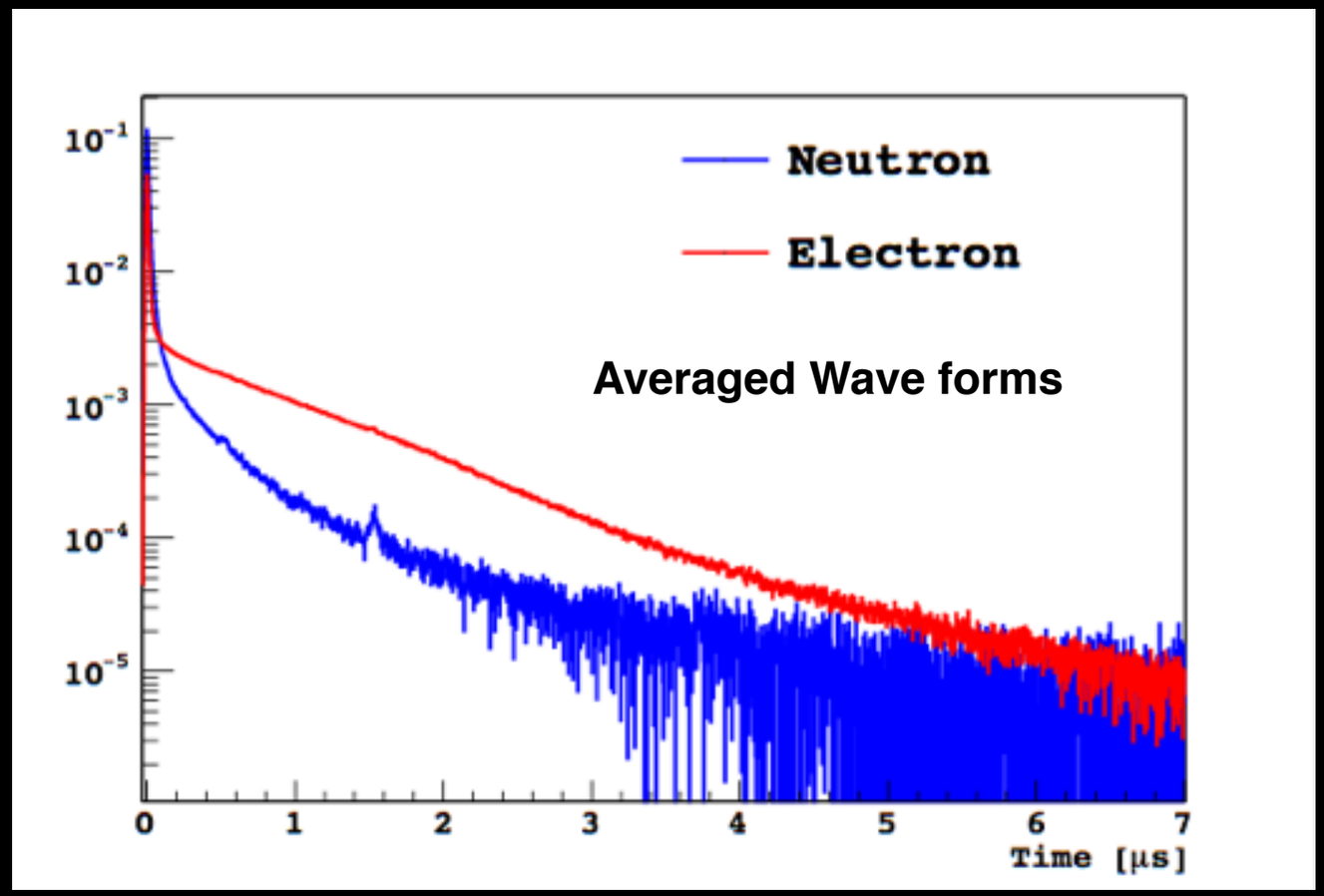
Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

τ singlet ~ 7 ns

τ triplet ~ 1500 ns

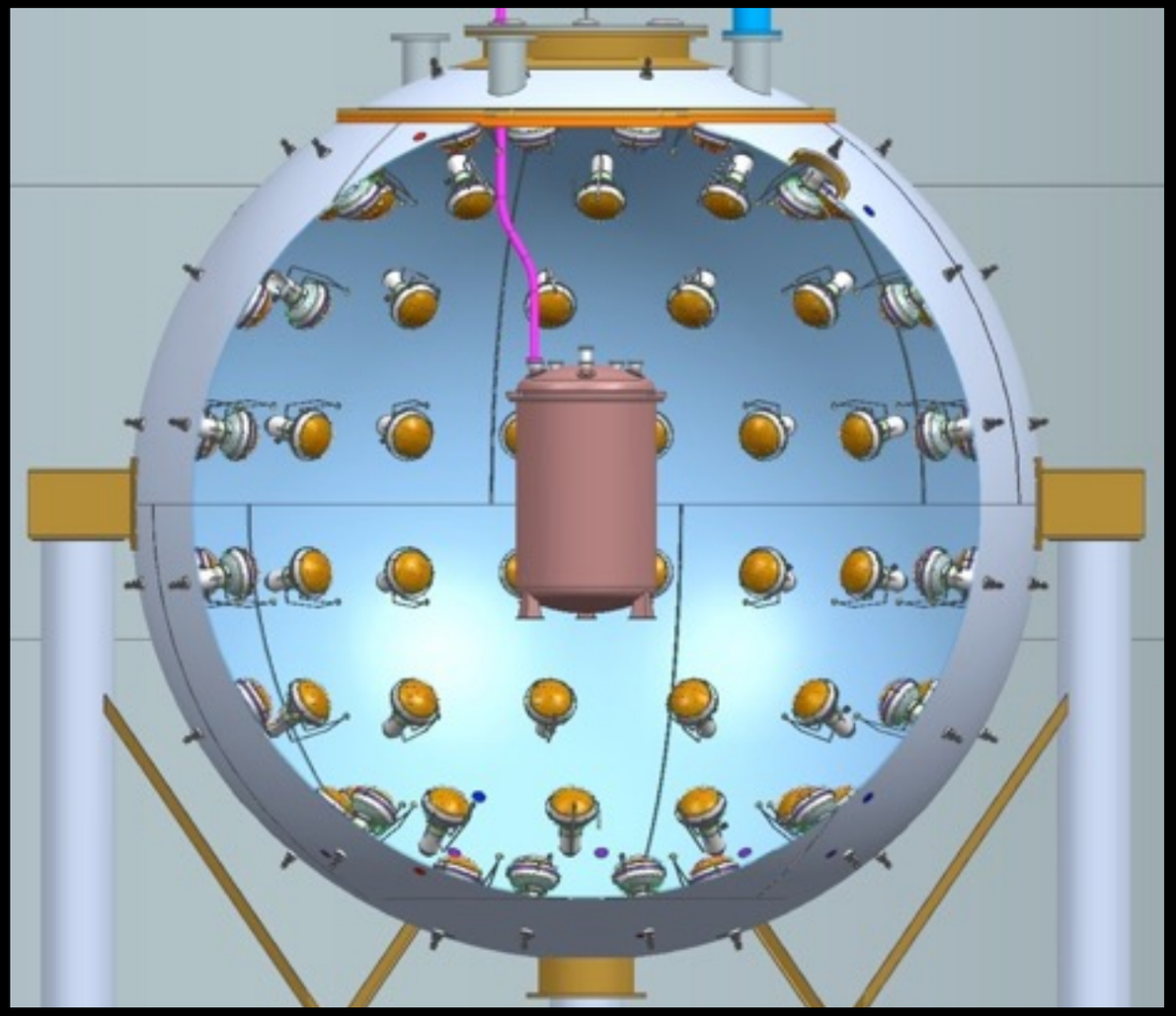






Liquid Scintillator Veto

Liquid scintillator allows coincident veto of **neutrons (and γ's)** in the TPC and provides *in situ* measurement of the neutron background rate



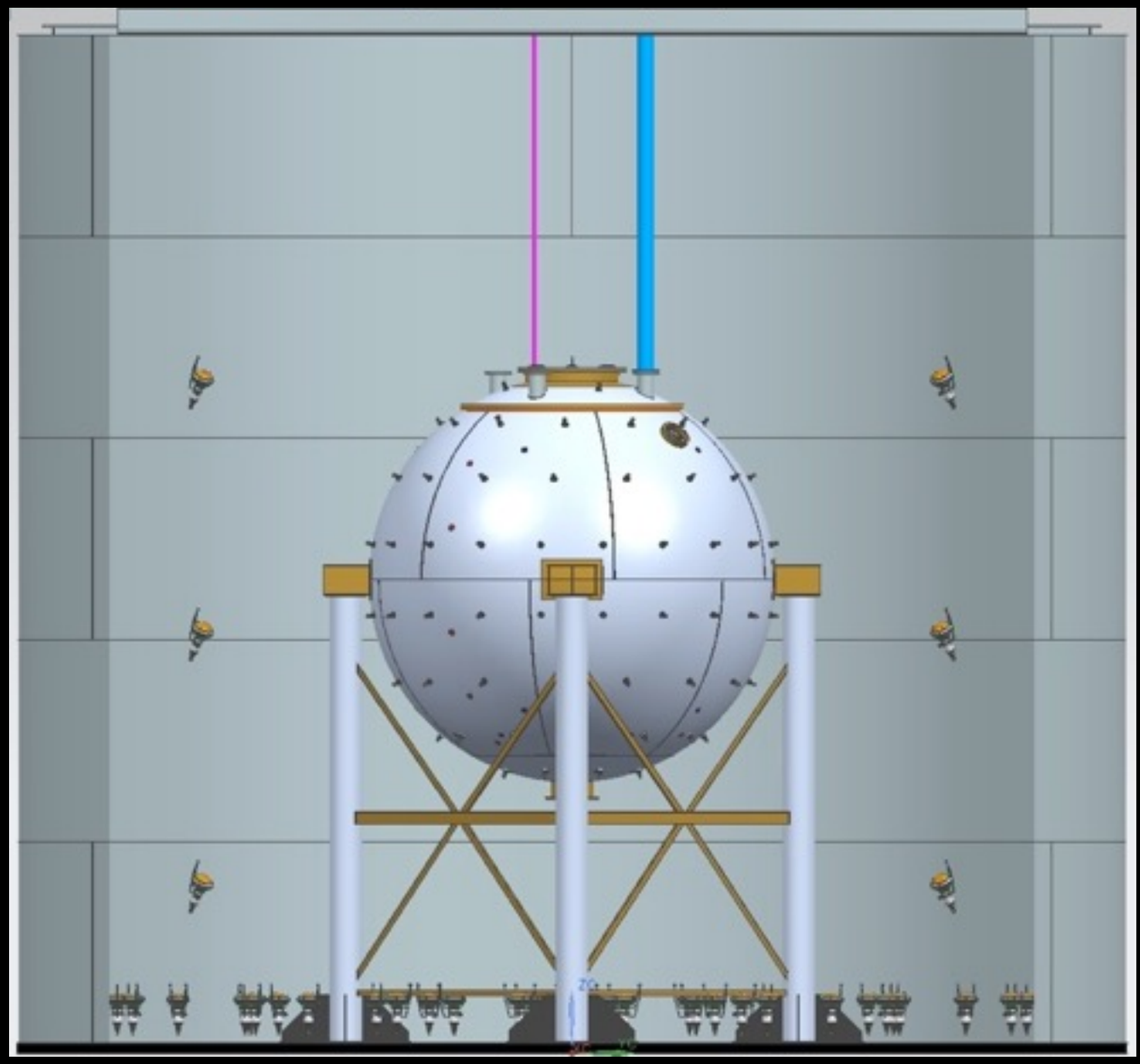
- 4 m diameter sphere containing PC + TMB scintillator
- Instrumented with 110 8" PMTs

Odd time structure: ^{14}C content is too high (~98% efficiency) to achieve design efficiency (~99.5%) after the first fill.

The TMB was replaced with new low ^{14}C TMB (Jan. 2015). ^{14}C activity decreased from **150 kBq** to **0.3 kBq**.

External Water tank

- 80 PMTs within water tank (11 m diameter x 10 m height)
- Acts as a **muon and cosmogenic veto** (~ 99% efficiency)
- Provides **passive γ's and neutron shielding**



Surface contamination

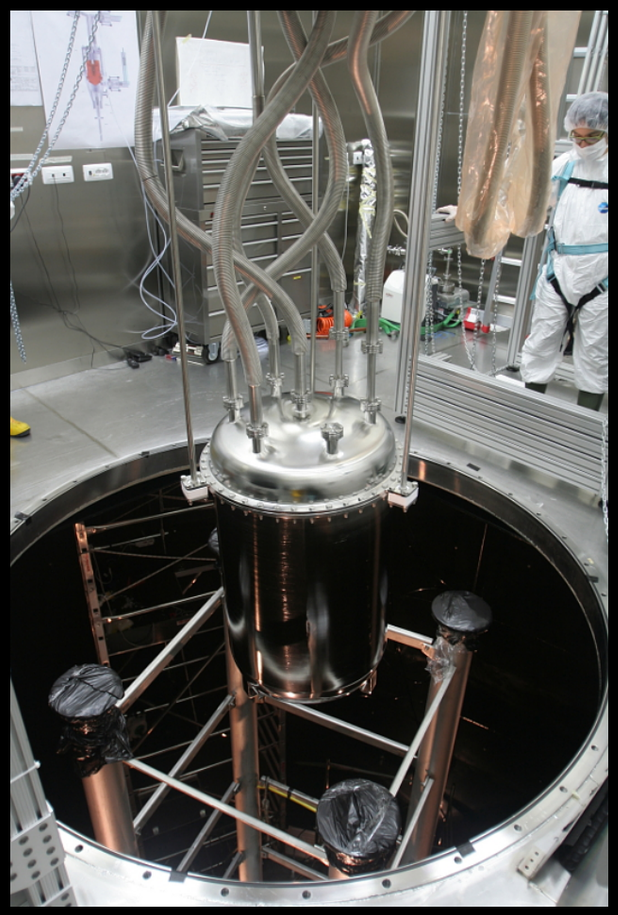
Radon-Free Clean Rooms

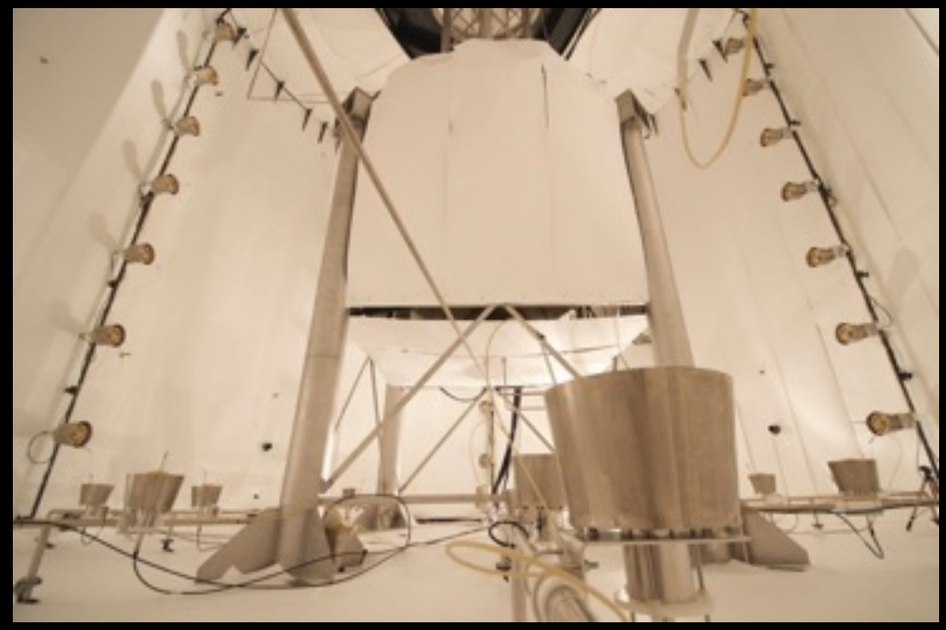
Radon daughters plate out on surfaces of the detector causing dangerous alpha-induced nuclear recoils.

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 < 5 mBq/m^3

DS50 Commissioning

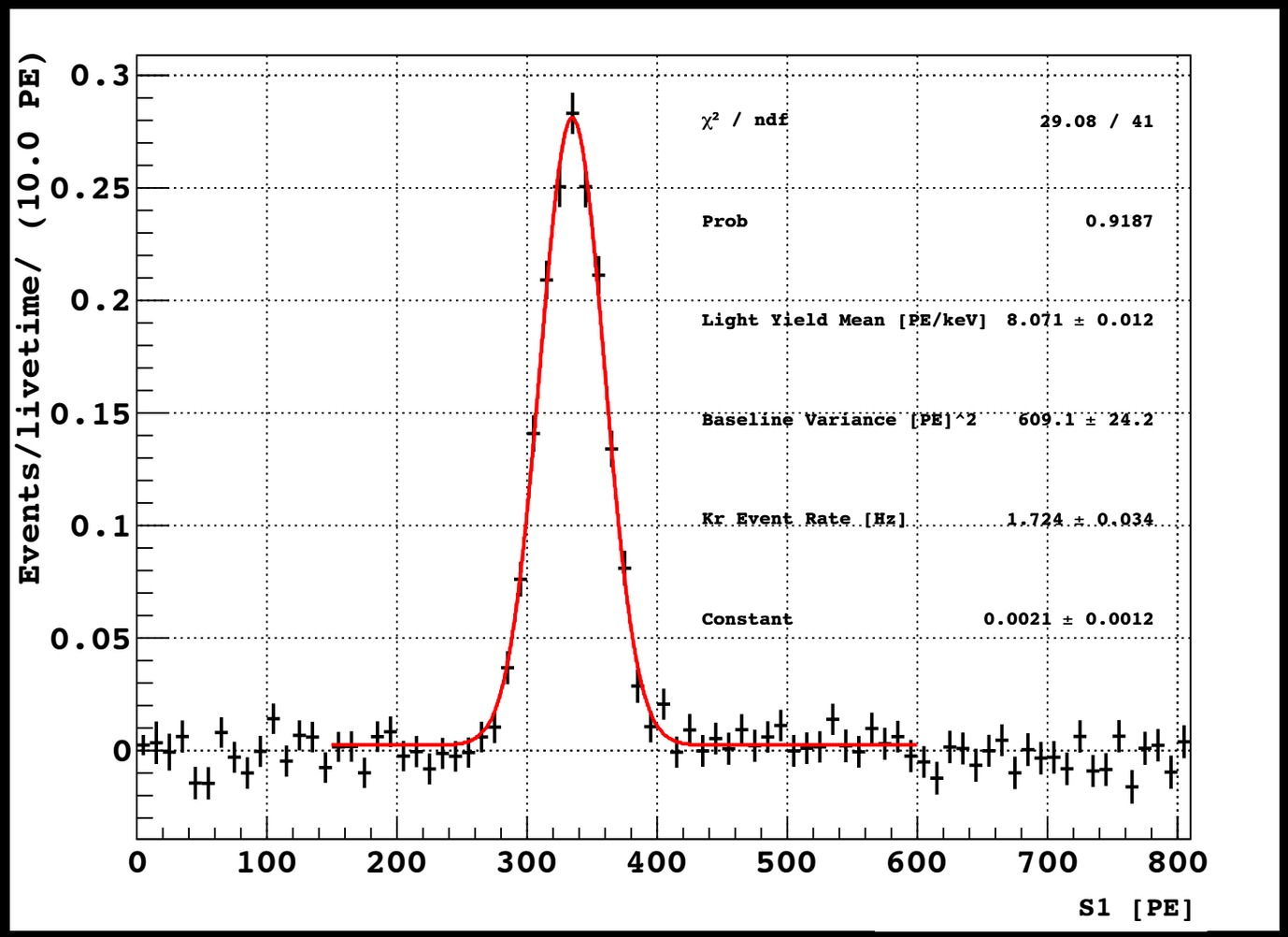


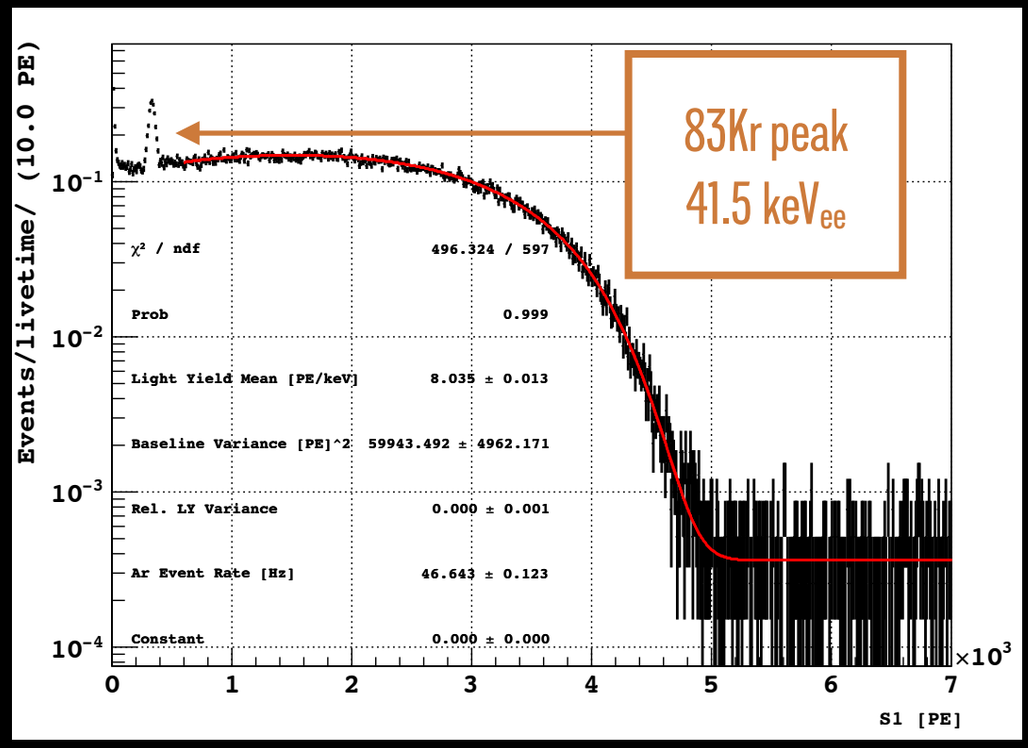


TPC Calibration

TPC: ER calibration @ null field

Subtracted BG





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

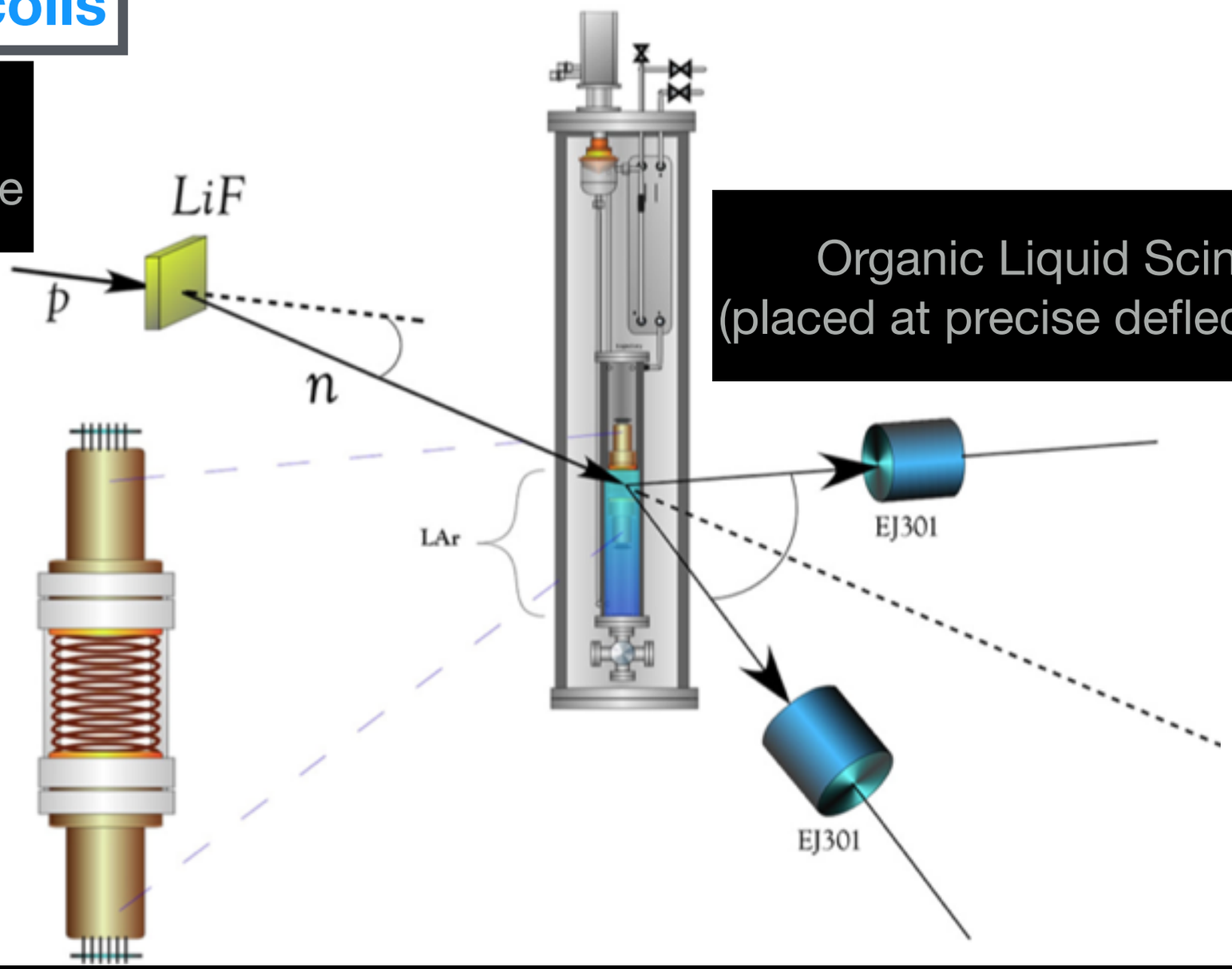
^{83m}Kr gas deployed into detector (41.5 keV$_{ee}$)

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)

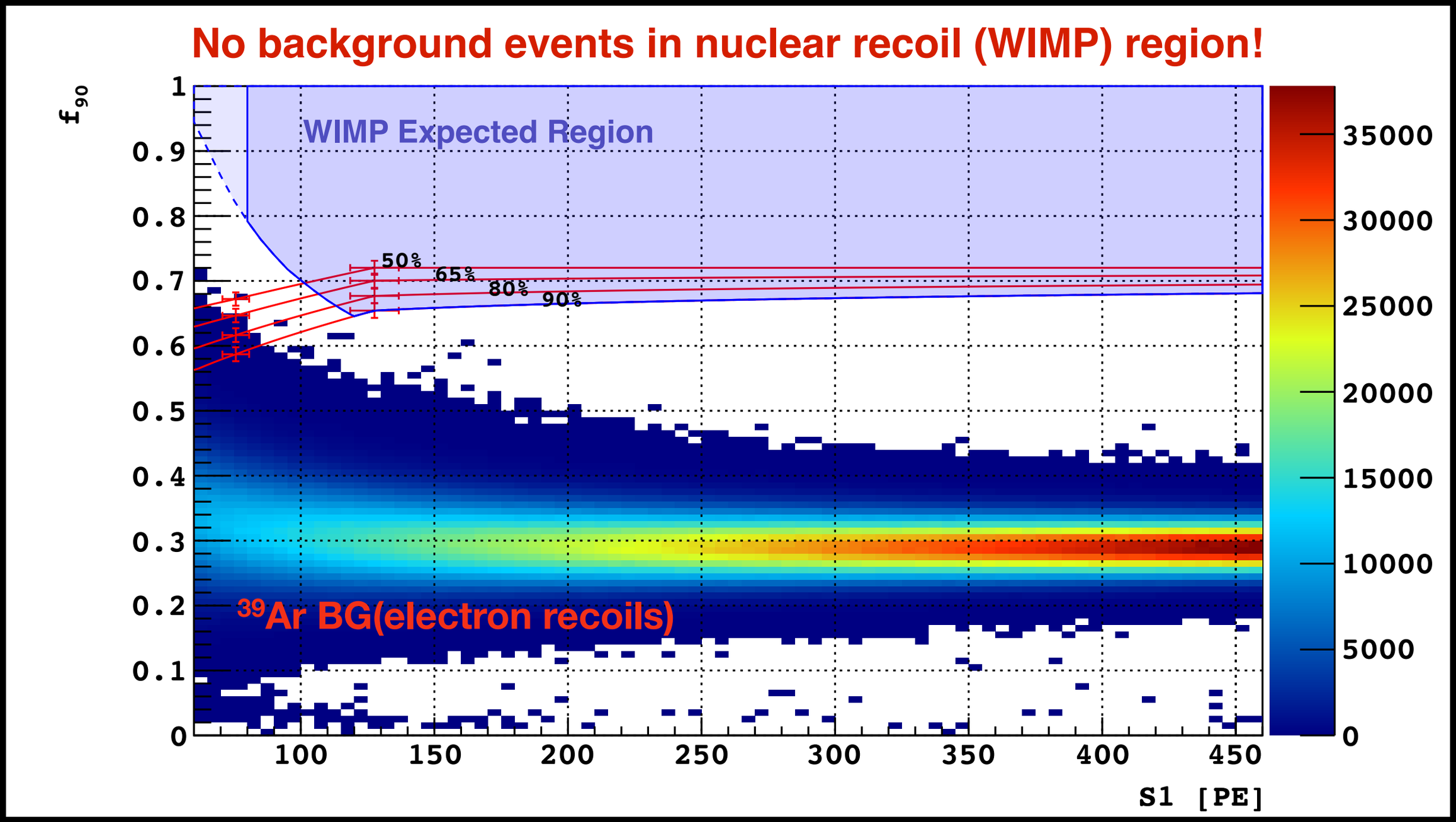
Liquid Argon TPC (based on DarkSide design)

^{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

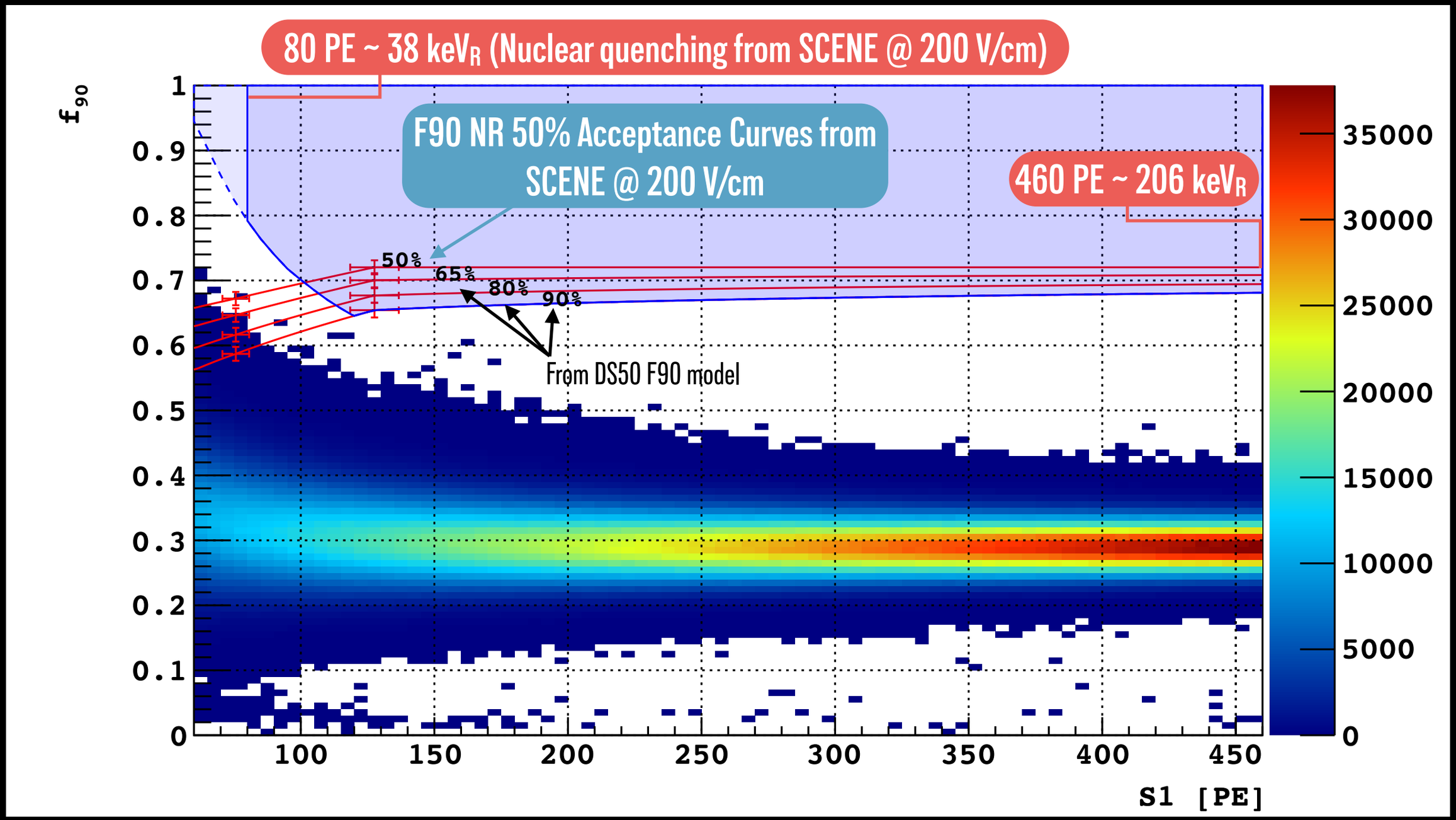
Background-free exposure of 1422 ± 67 kg·day

Phys. Lett. B 743 (2015) 456



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

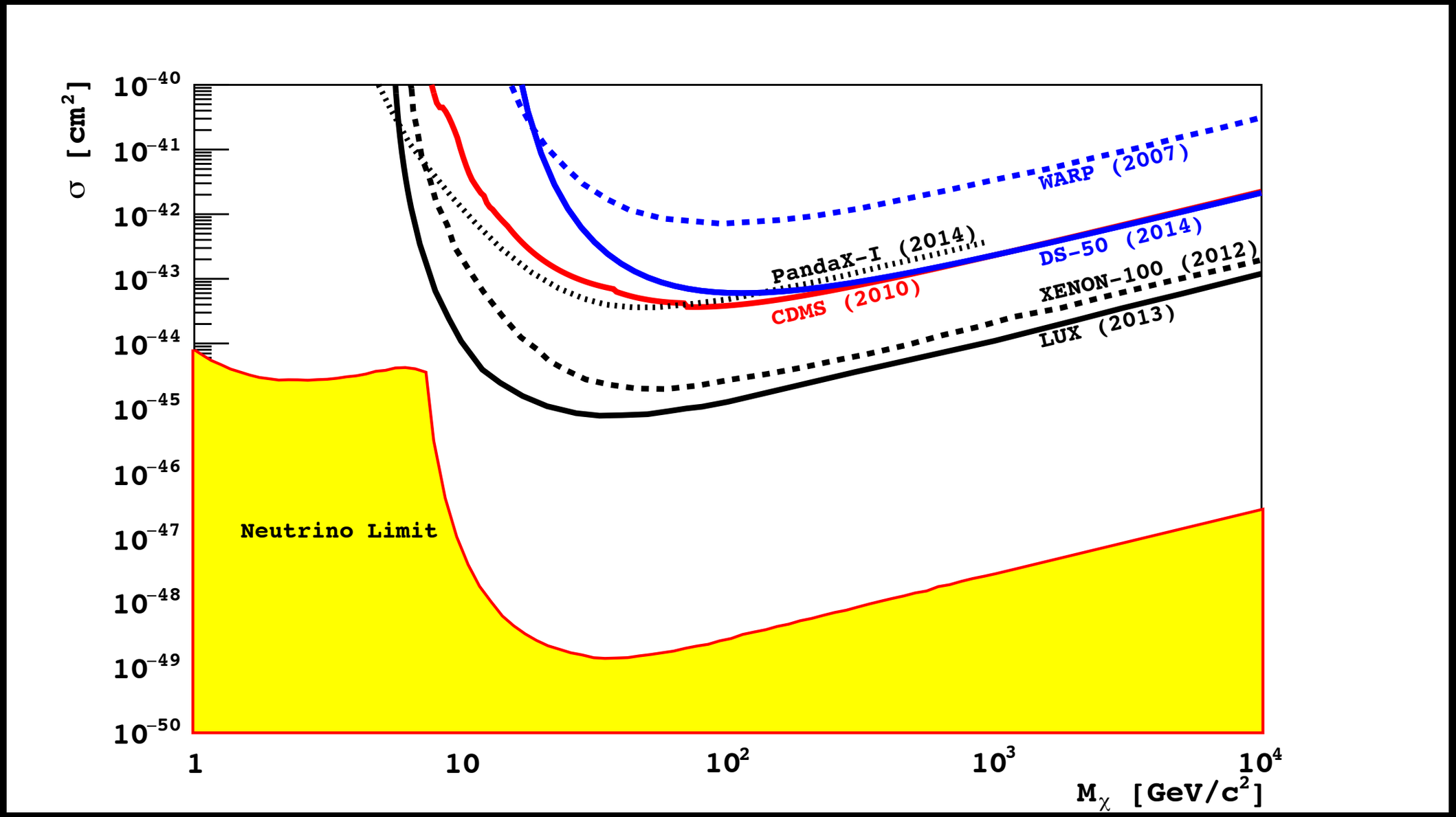


Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

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.

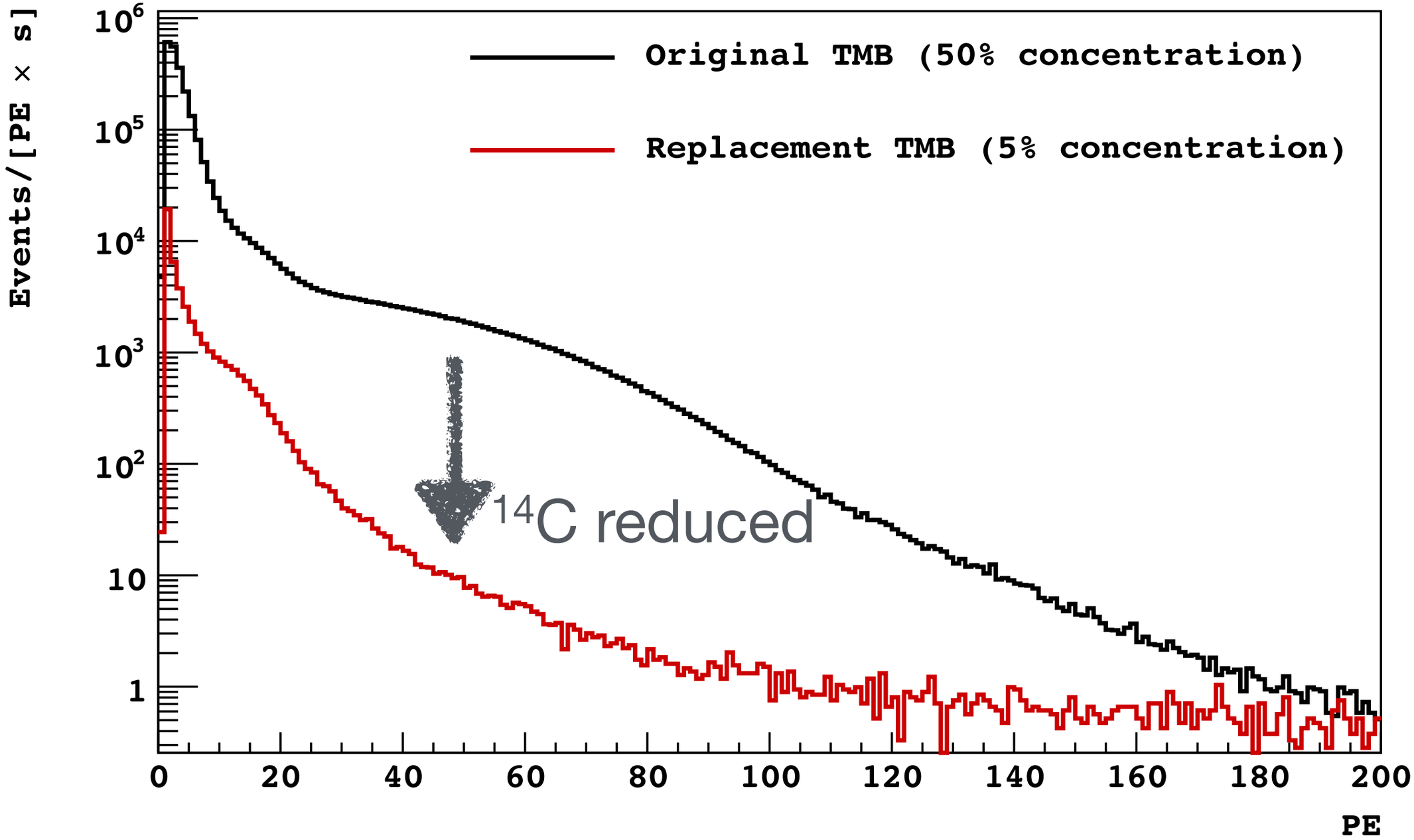


DS50 Timeline

- **Oct. 2013:** LArTPC, Neutron Veto and Muon Veto commissioned.
  - TPC filled with **atmospheric argon** (AAr).
- **Up to June 2014:** data taken with high ^{14}C content in LSV.
  - **47.1 live days** (1422 kg · day fiducial) for the first physics result.
  - TMB (^{14}C) was removed to reduce the ^{14}C rate.
- **Oct. to Dec. 2014:** Calibration of TPC w/ radioactive sources.
- **Jan. 2015:** Add radiopure TMB at 5% concentration.
- **Mar. to Apr. 2015:** Fill with **UAr** and re-commissioning the detector.
- **Apr. to Aug. 2015:** Accumulate data with **UAr** for **dark matter search**.

DS-50 Current Status

Status of Liquid Scintillator Veto

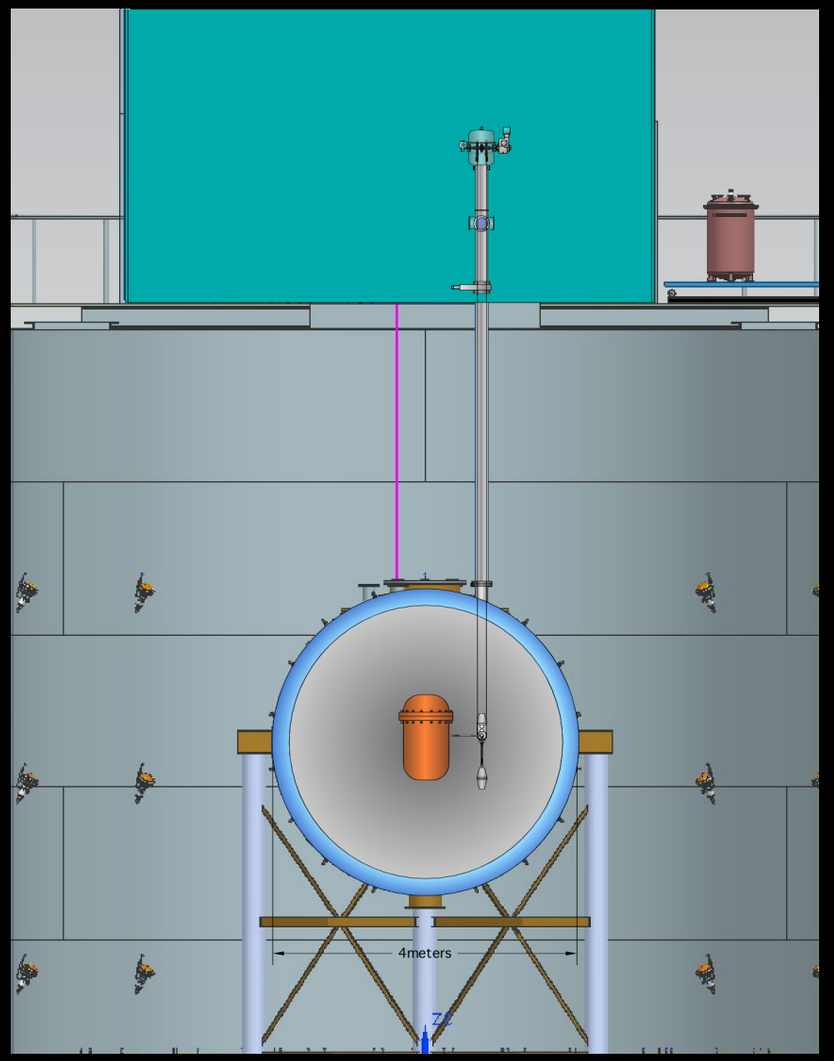


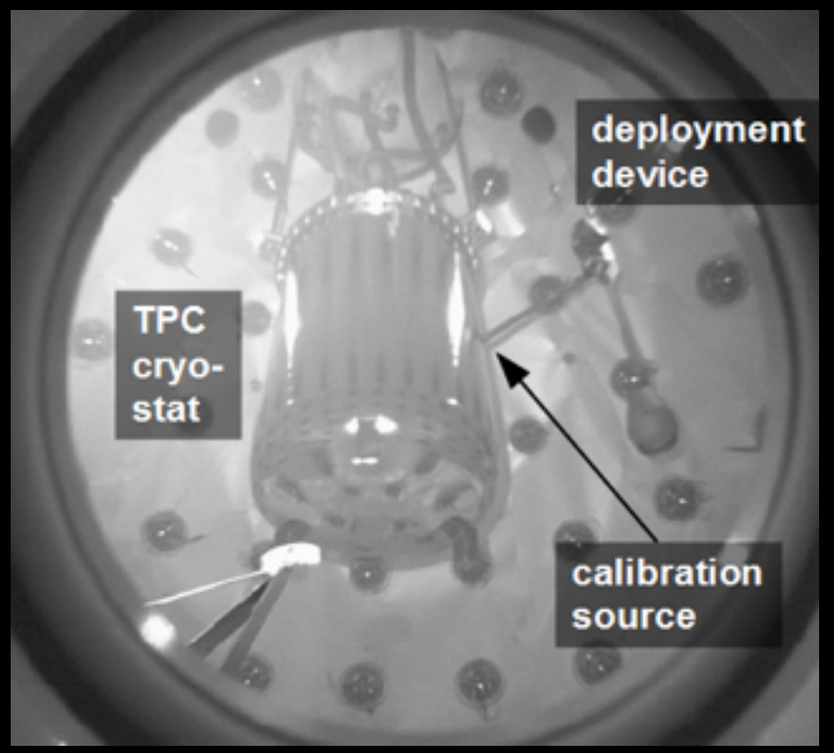
^{14}C activity decreased from 150 kBq to 0.3 kBq.

CALIS - CALibration Insertion System

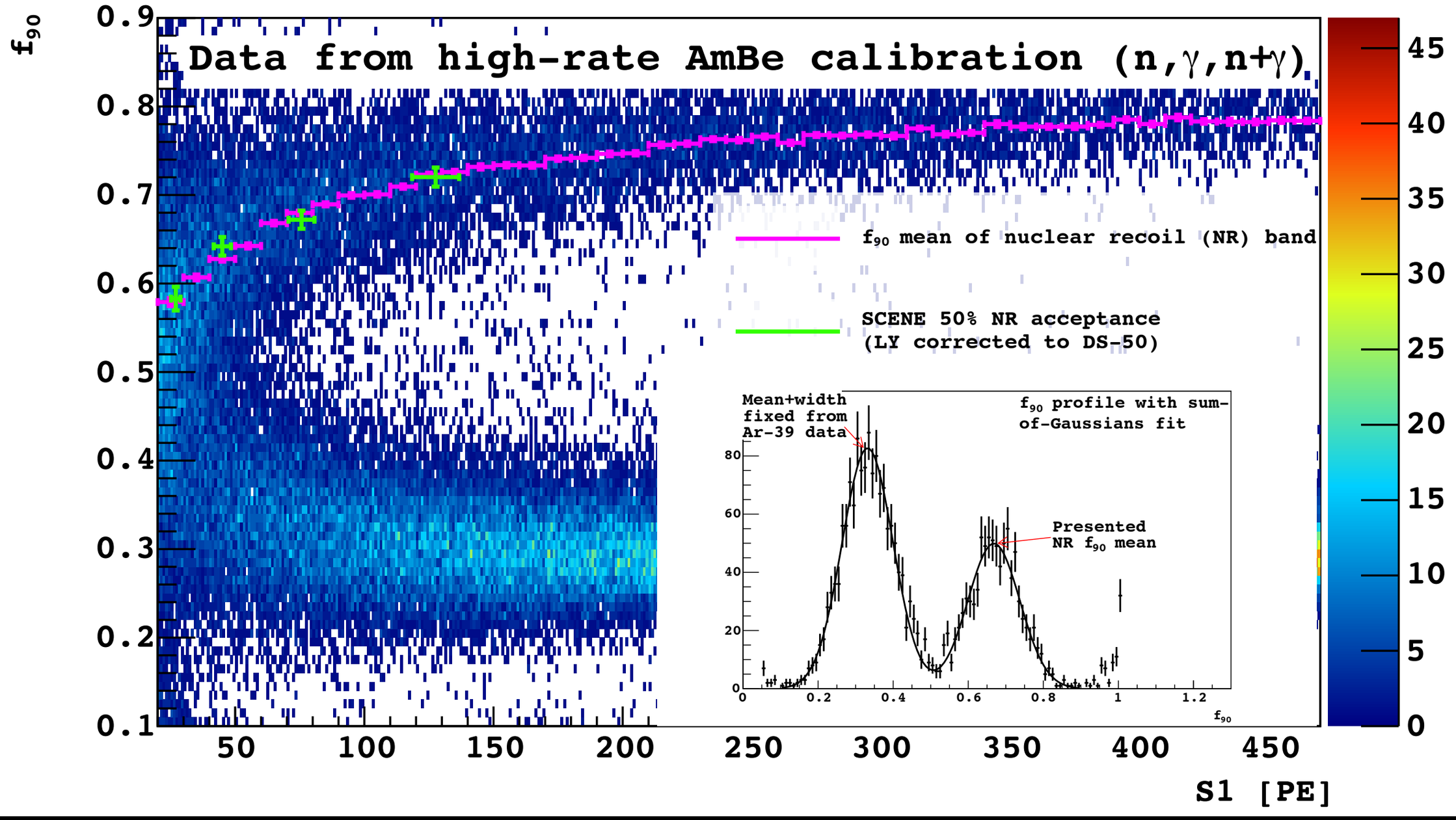
Calibrate both **TPC** and **Neutron veto**

- **Gamma sources:** ^{57}Co (122 keV), ^{133}Ba (356 keV), ^{137}Cs (663 keV)
- **Neutron source:** AmBe w/ and w/o collimator
- **Different drift fields:** null, 100 V/cm, 150 V/cm, 200 V/cm





NR from AmBe source



NR band matches with the points extrapolated from SCENE.

Underground Ar

Plant at Colorado

1. Extraction at Colorado (CO_2 Well)
Extract a crude argon gas mixture (Ar, N_2, and He)

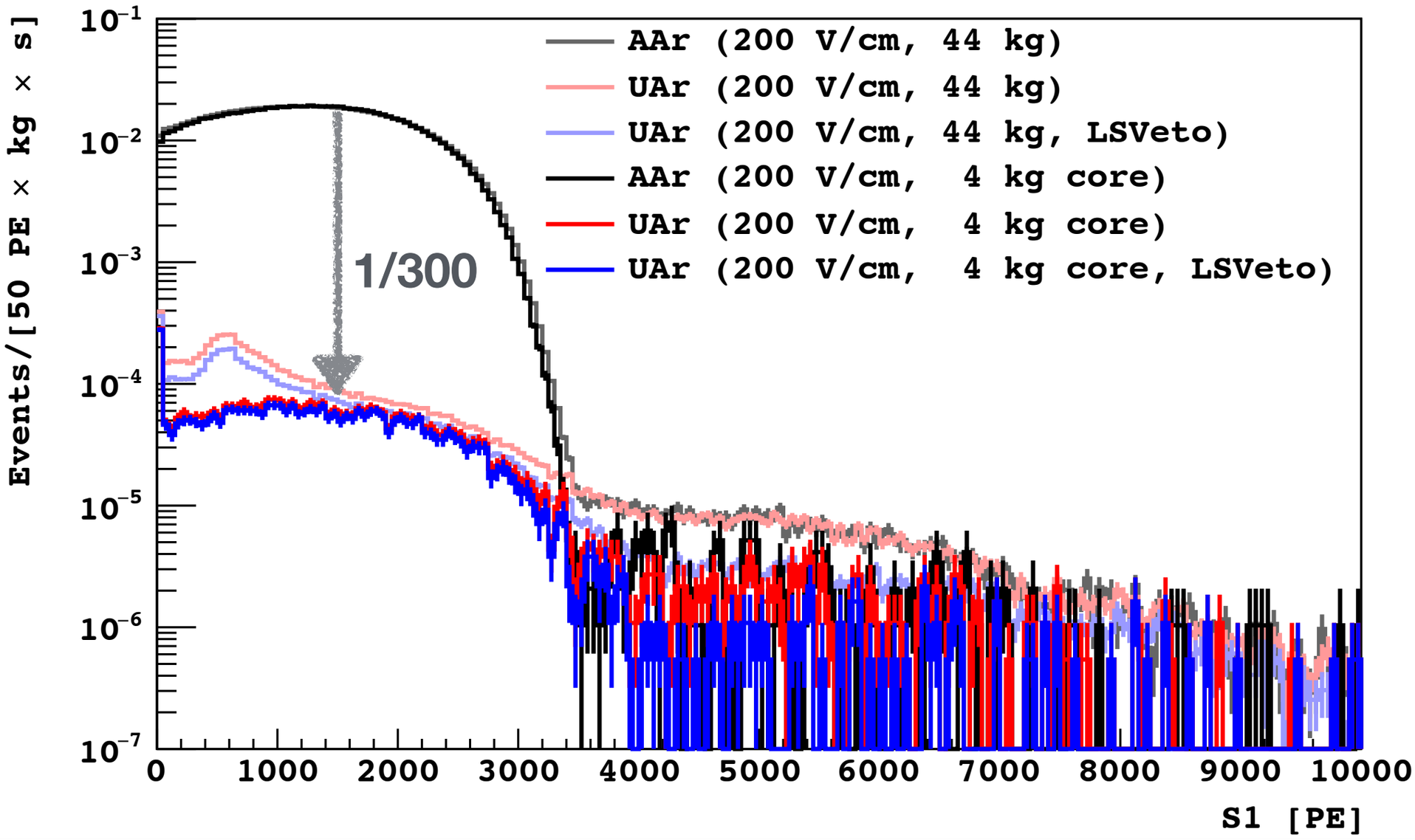
2. Purification at Fermilab
Separate Ar from He and N_2

Distillation Column at Fermilab

UAr bottles at LNGS

3. Arrived at LNGS
Ready to fill into DS-50

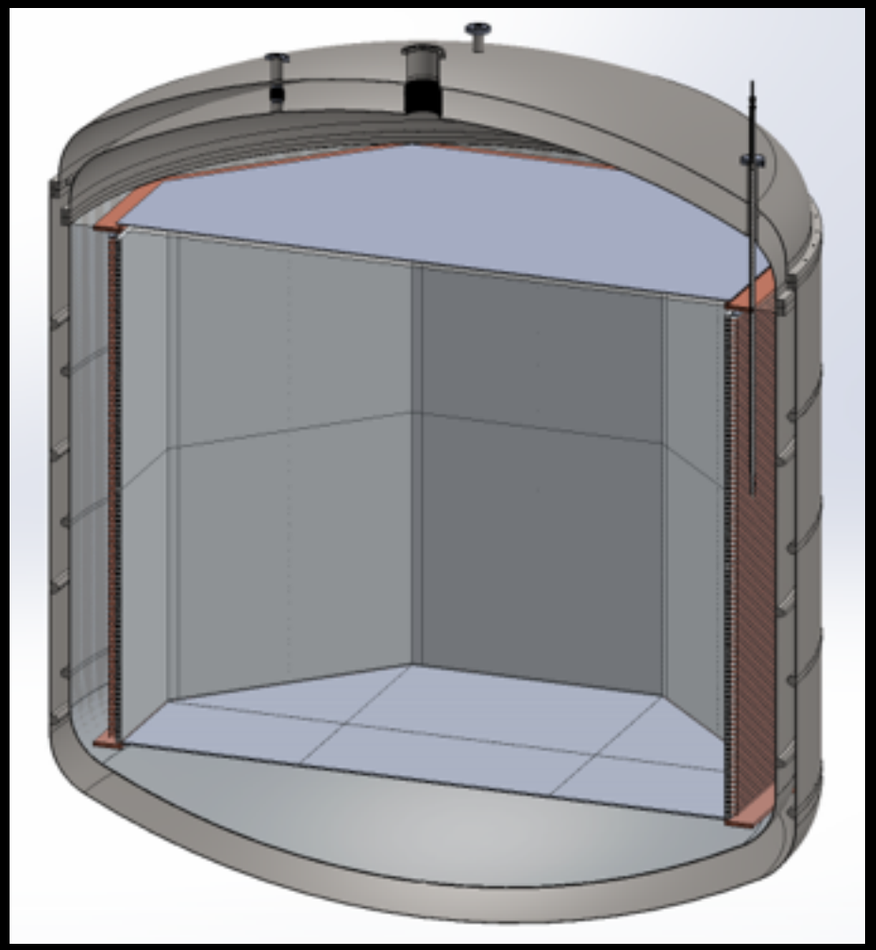
Underground Ar



Concentration of ^{39}Ar in **UAr** is at least **300** times lower than in **AAr**.

Low level of ^{39}Ar allows extension of DarkSide program to ton-scale detector.

Future Detectors



DS-20k

30 tonne (20 tonne fiducial) detector

?

ARGO

300 tonne (200 tonne fiducial) detector

Requirements for DS-20k

Neutron Background:

- Cosmogenic: Veto system
- Radiogenic: radiopure SiPM & ultra-clean Titanium (TPC cryostat)

β/γ background:

- ^{39}Ar: Underground Argon (Urania Project) & Depleted Argon (Aria Project)
- γ: SiPM & ultra-clean Titanium

Further Depletion of Ar

Urania (Underground Argon):

- Expansion of the argon extraction plant in Cortez, CO, to reach capacity of **100 kg/day** of Underground Argon

Aria (UAr Purification):

- Very tall column in the Seruci mine in Sardinia, Italy, for high-volume chemical and isotopic purification of Underground Argon

Experiment	σ [cm²] @1 TeV/c²	σ [cm²] @10 TeV/c²
LUX [10k kg×day Xe]	1.1×10^{-44}	1.2×10^{-43}
XENON [7.6k kg×day Xe]	1.9×10^{-44}	1.9×10^{-43}
DS-50 [1.4k kg×day Ar]	2.3×10^{-43}	2.1×10^{-42}
ArDM [1.5 tonne×yr Ar]	8×10^{-45}	7×10^{-44}
DEAP-3600 [3.0 tonne×yr Ar]	5×10^{-46}	5×10^{-45}
XENON-1ton [2.7 tonne×yr Xe]	3×10^{-46}	3×10^{-45}
LZ [15 tonne×yr Xe]	5×10^{-47}	5×10^{-46}
DS-20k [100 tonne×yr]	9×10^{-48}	9×10^{-47}
1 Neutrino Event [400 tonne×yr Ar or 300 tonne×yr Xe]	2×10^{-48}	2×10^{-47}
ARGO [1,000 tonne×yr]	9×10^{-49}	9×10^{-48}

DarkSide-20k and Argo LoI Signatories

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A. Rubbia - ETH Zürich
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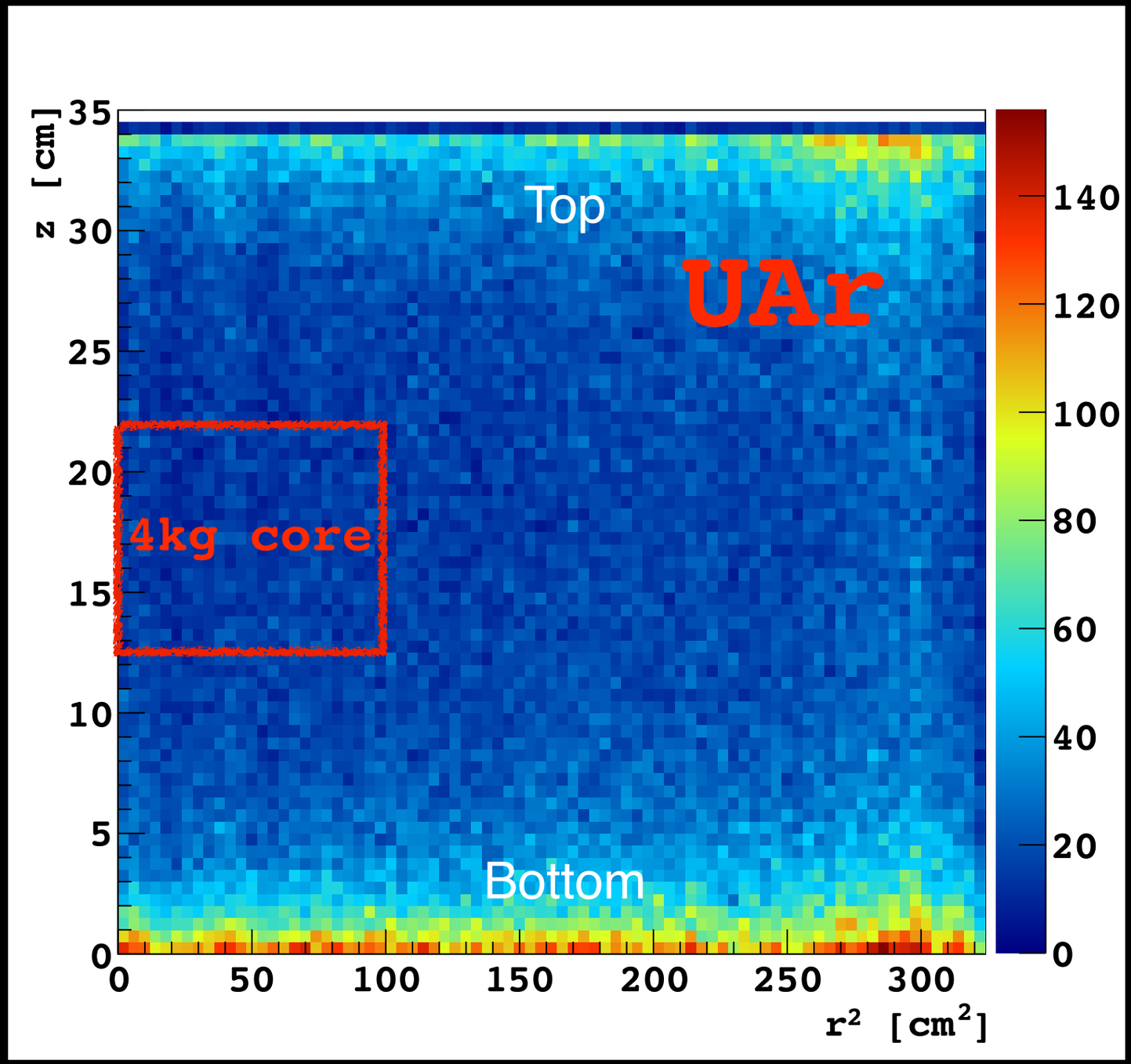
P. Cavalcante - Virginia Tech

Summary

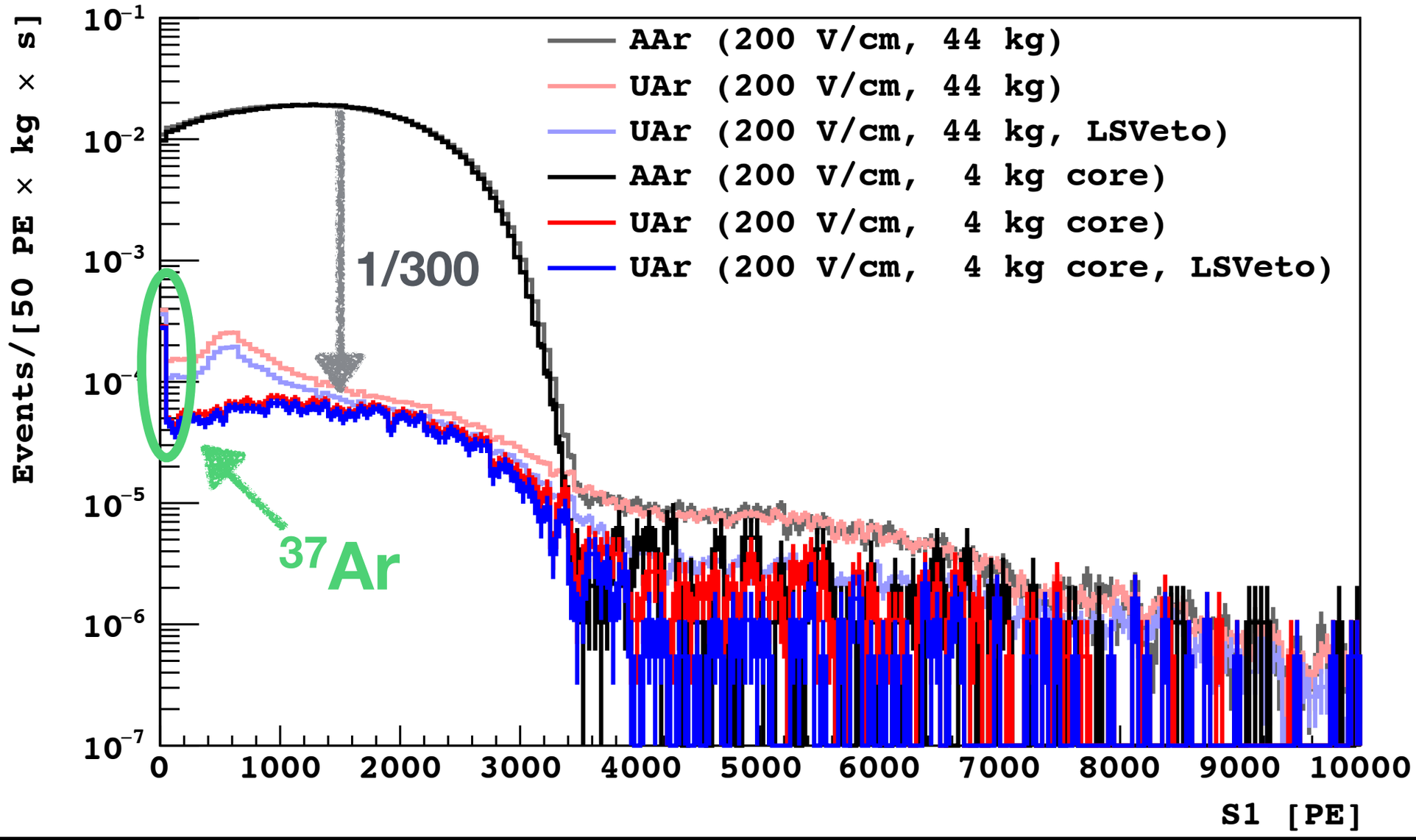
- **Background free**
  ^{39}Ar BG from **47.1 live days** (1422 kg · day fiducial) of AAr corresponds to that expected in **38.7 years** of **UAr** DS-50 run (≫planning physics run time, 3 years).
- Concentration of ^{39}Ar in **UAr** is at least **300** times lower than in **AAr**.
- With the BG-free exposure of 1422 kg · day fiducial, DarkSide demonstrates ^{39}Ar BG rejection at level of **1 tonne·year** with UAr.
- Future detectors are planned and Letter of Intent was submitted to LNGS April 27 2015.

THE END

Event Position in TPC

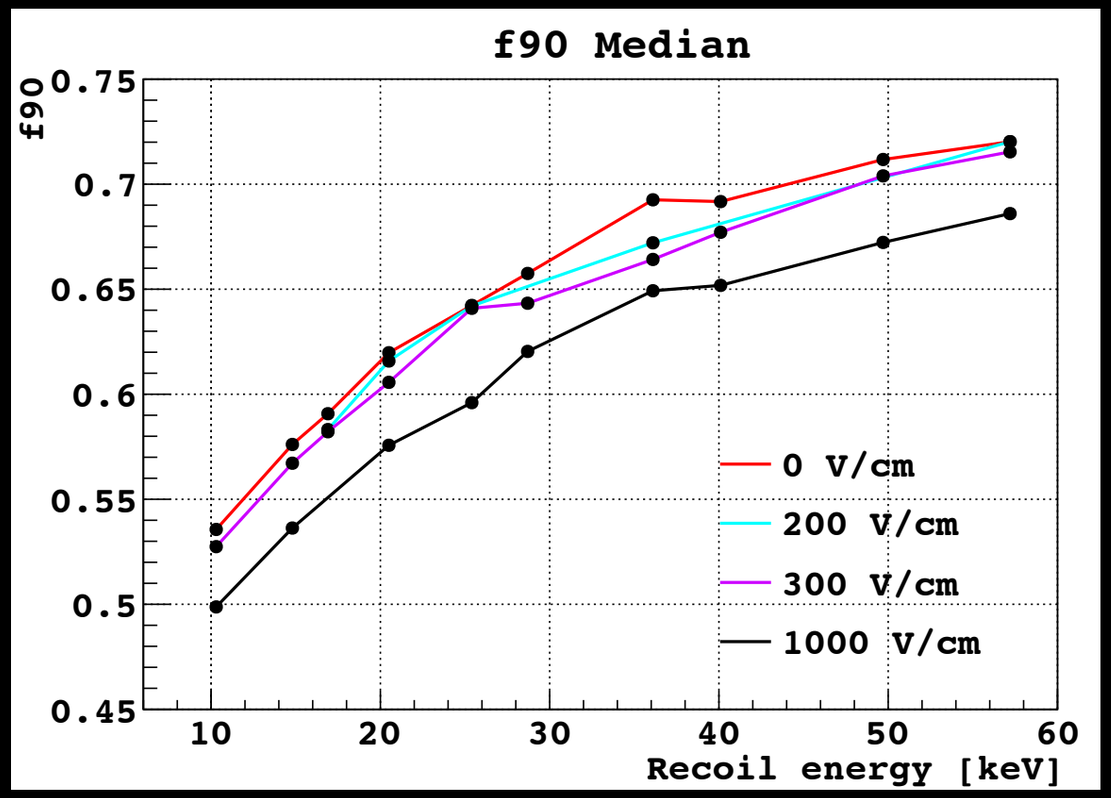


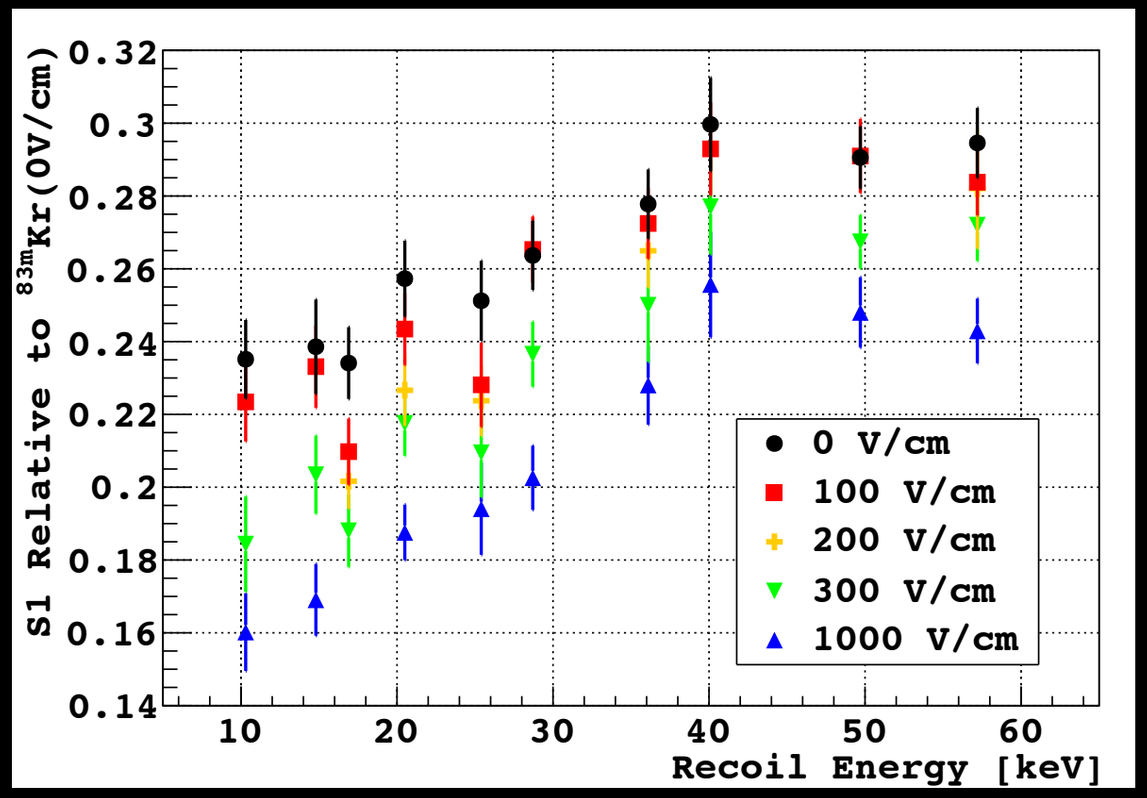
^{37}Ar



^{37}Ar is activated by cosmic rays.
Only 35 day half life
Provide **low energy (~2-3 keV) calibration point**.

Data from SCENE and the plots





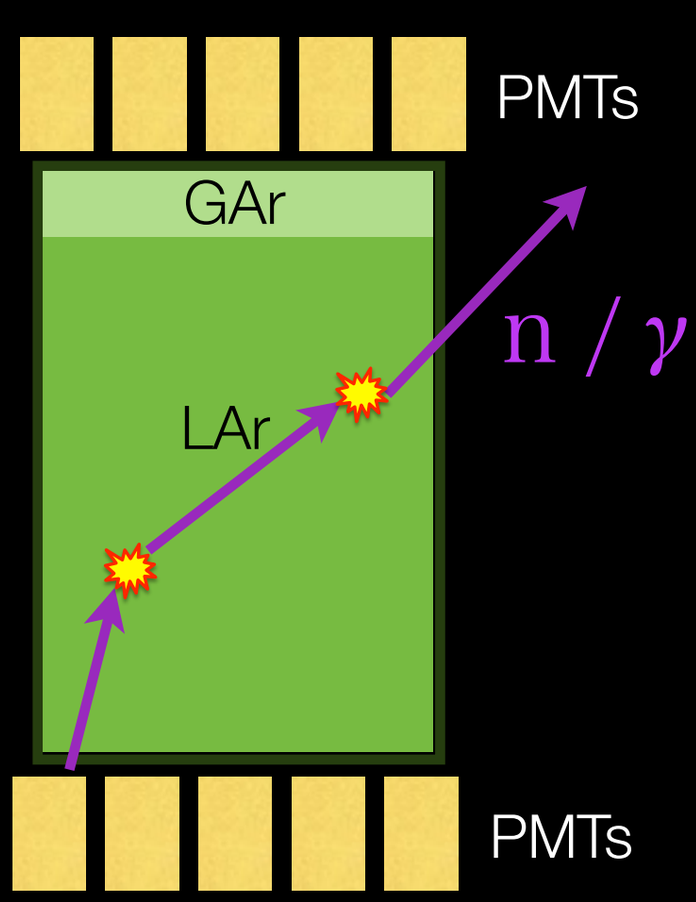
- Left : the median of the f90 distribution for nuclear recoils as a function of energy as measured in the SCENE experiment
- Right: the quenching factor for nuclear recoils as measured by the SCENE experiment

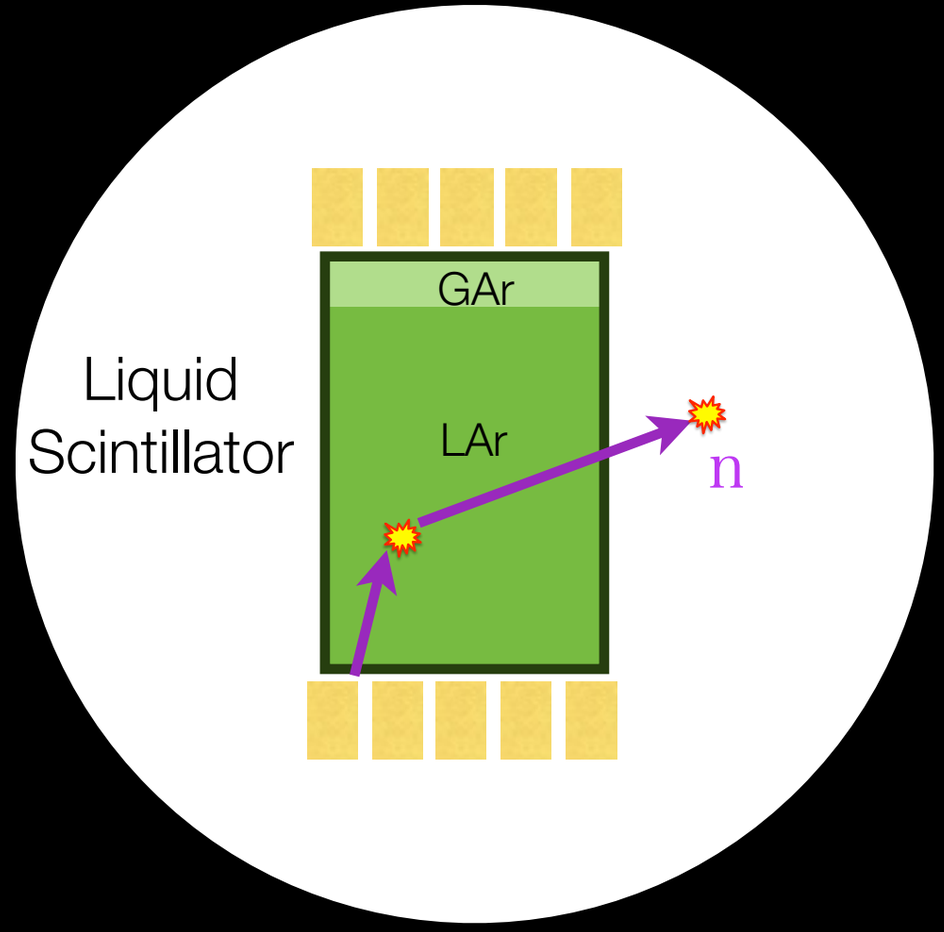
Kr calibration data is used for cross calibration of light yield between DS50 and SCENE.

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

Multiple Interactions

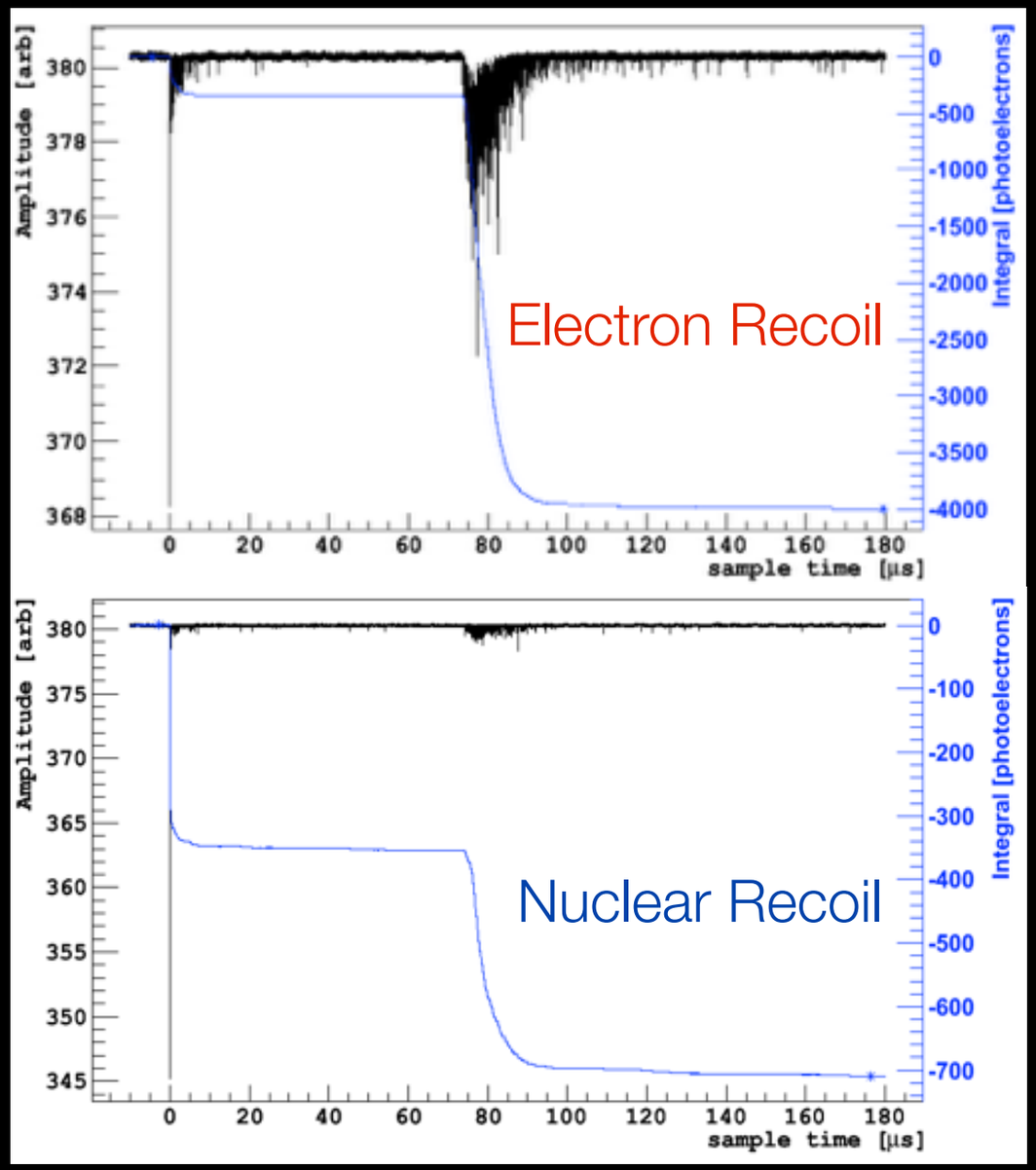
Expected WIMP signal	Background Rejection Technique	Backgrounds Removed
Single Interaction	Multiple S2 Cut in TPC Liquid Scintillator Veto	Neutrons, Gamma rays

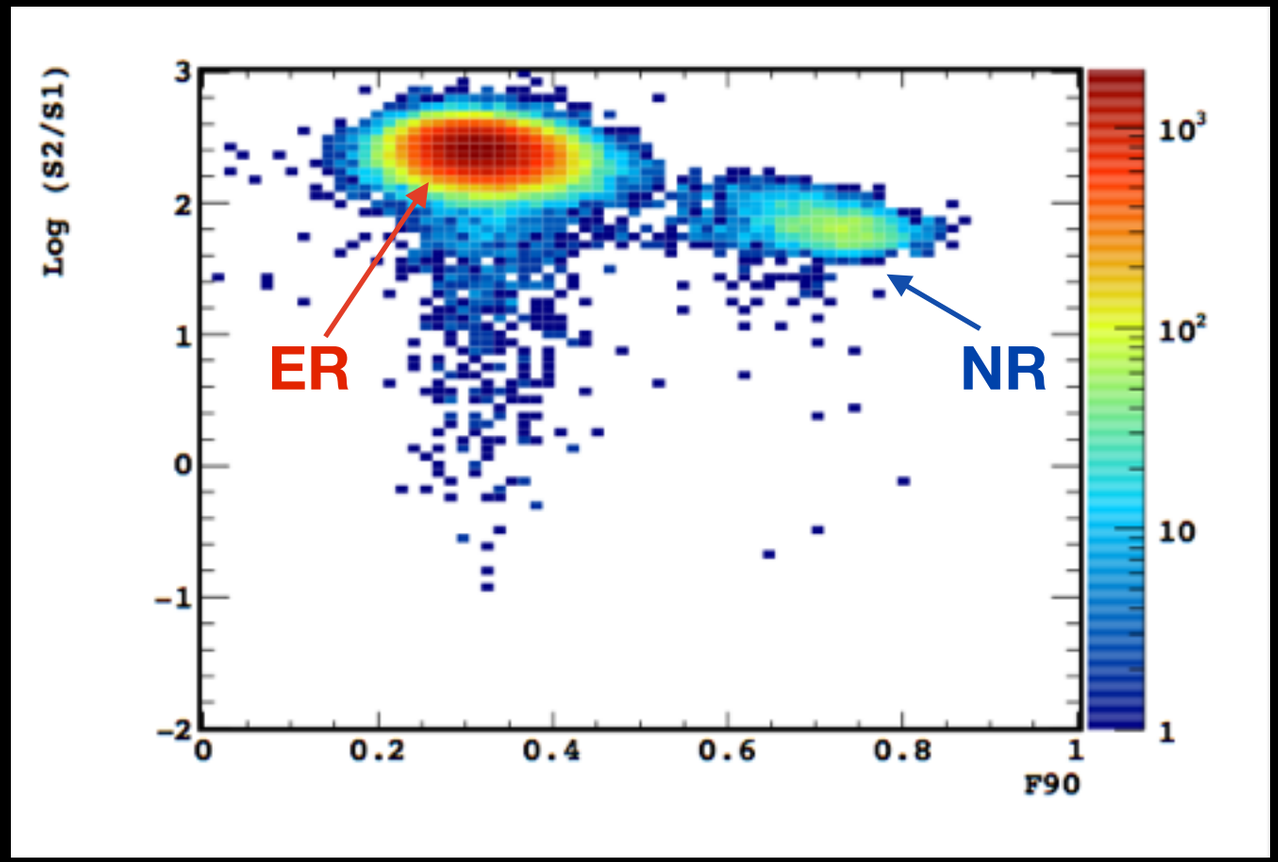




S2/S1

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



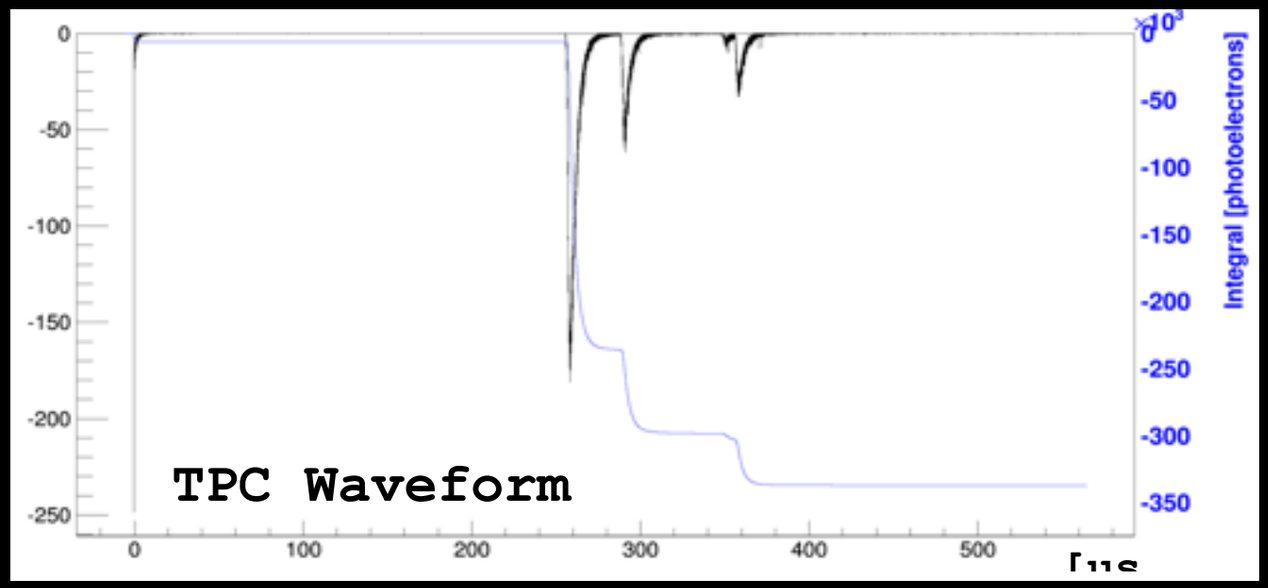


Am-Be Source

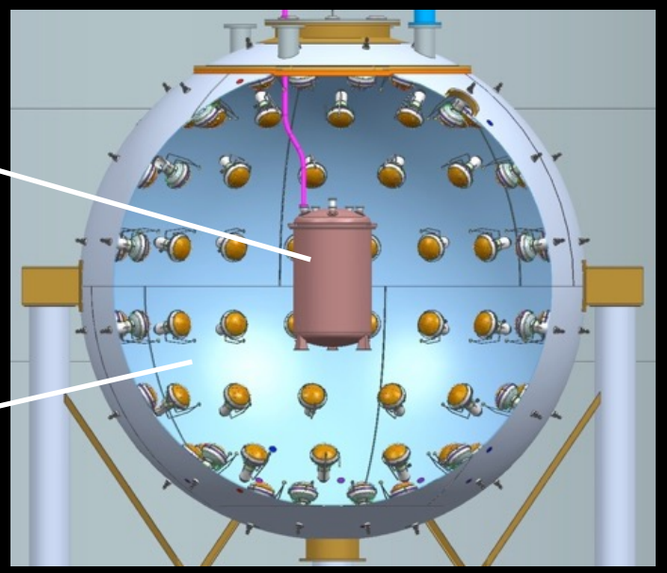
Ratio of ionization and scintillation signal (S2/S1) can be used to distinguish between the two populations

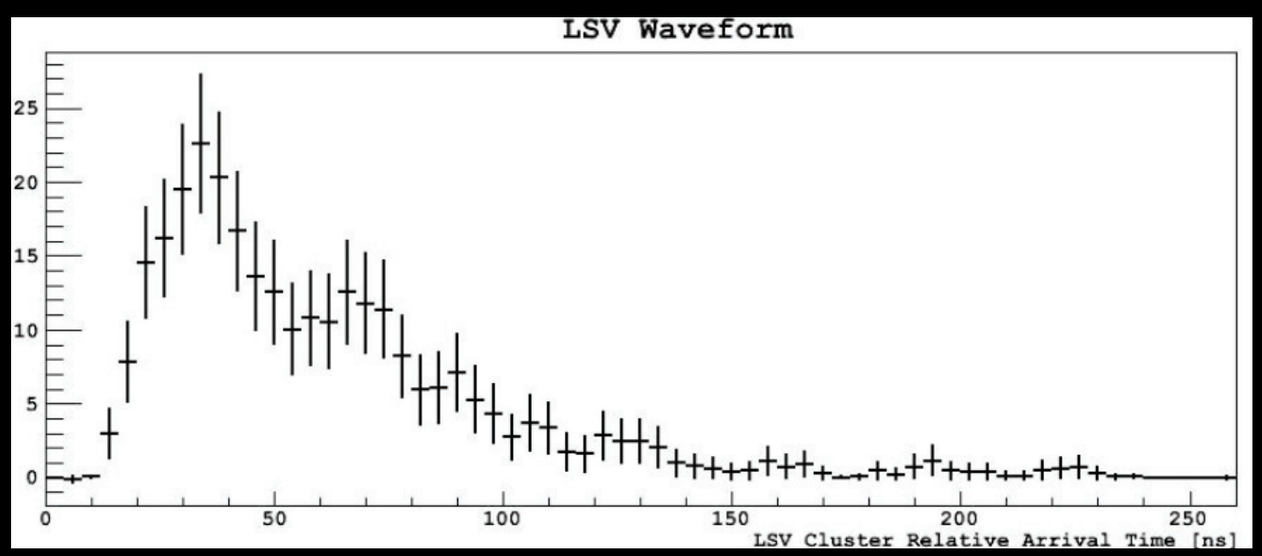
Neutron Veto Commissioning

Coincident event in TPC and Neutron Veto



Electron recoil event with multiple S2 signals in TPC



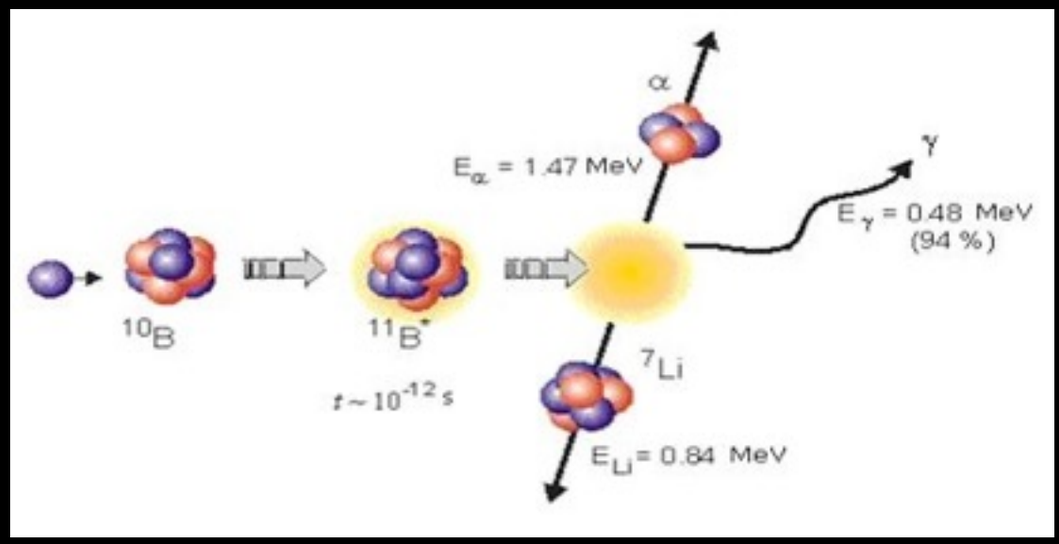


Coincident signal in liquid scintillator veto

Light Yield: 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%

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*Based on 60 μs veto window