Update of DarkSide with Underground Argon

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on behalf of the DarkSide Collaboration
19 May. 2015

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)

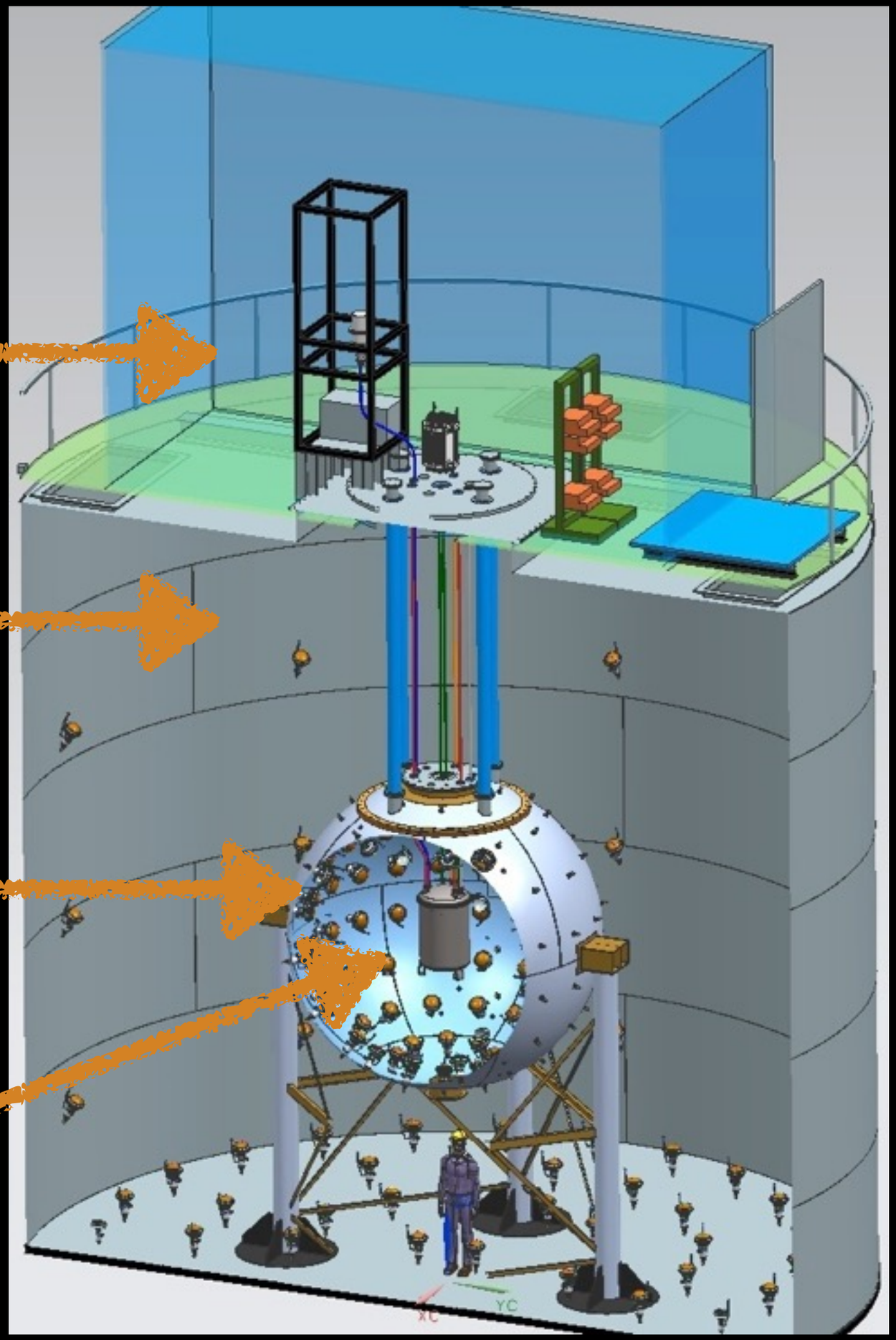
DarkSide 50

Radon-free Assembly
Clean Room

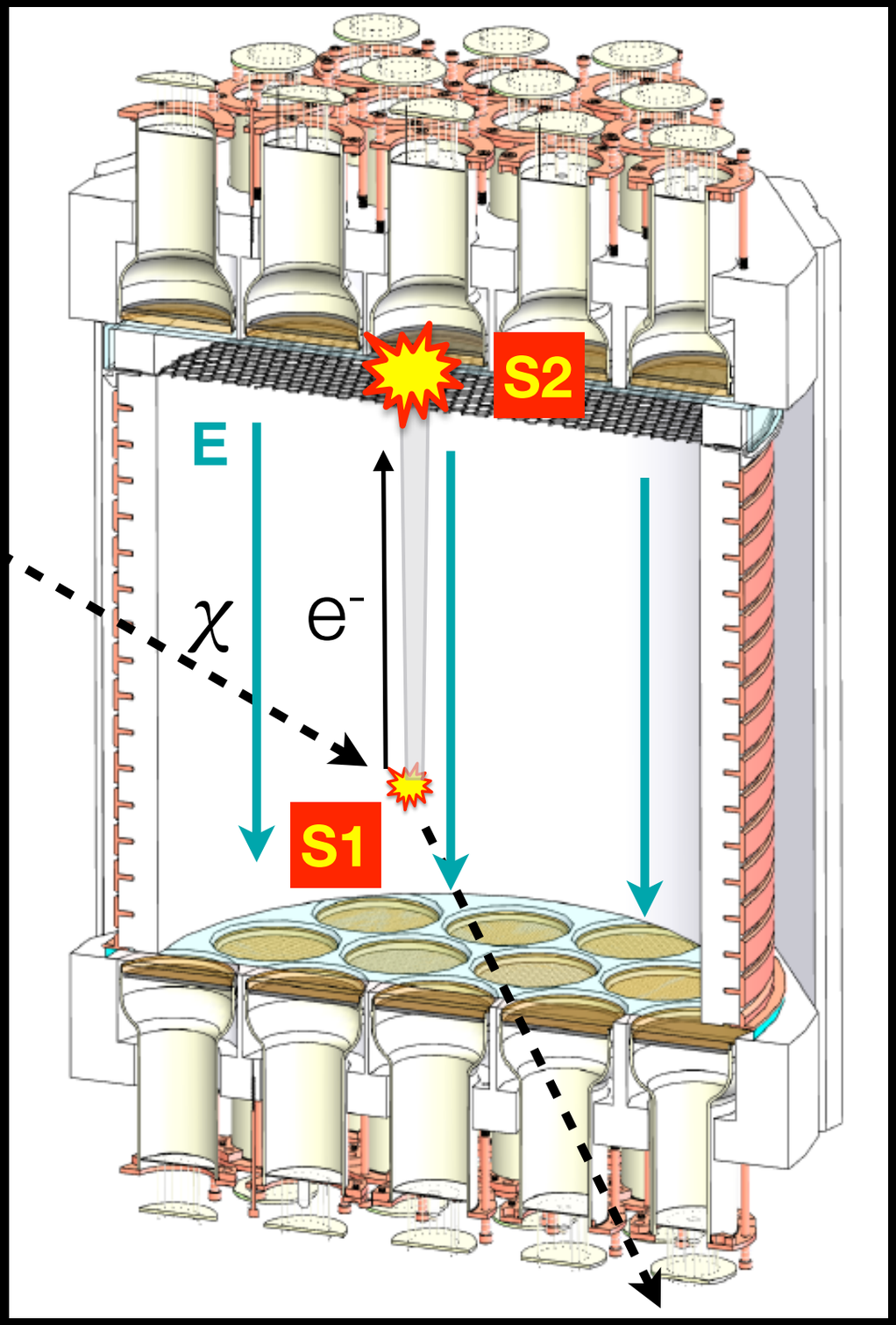
1,000-tonne Water-based
Cherenkov **Cosmic Ray Veto**

30-tonne Liquid Scintillator
Neutron and γ's Veto

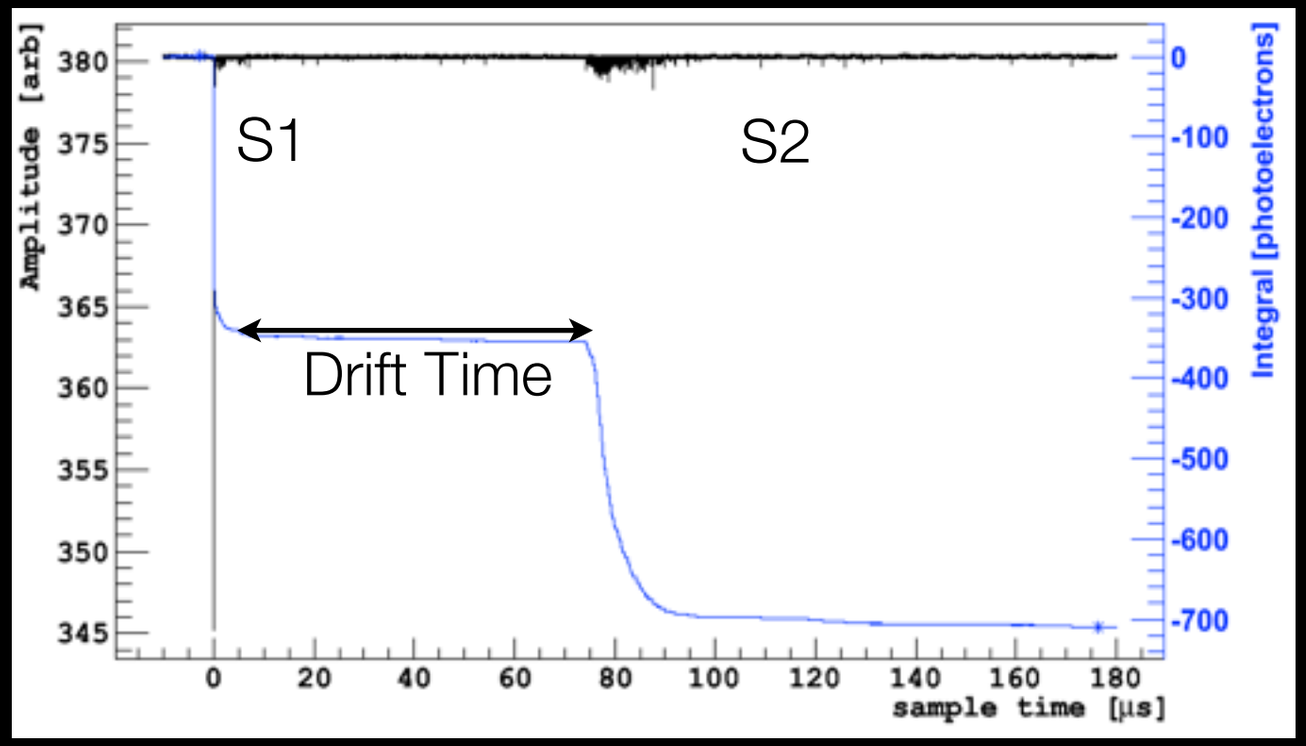
Inner detector **TPC**



Two Phase Argon TPC



S1: primary scintillation light
S2: scintillation light proportional to free electrons from primary ionization



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

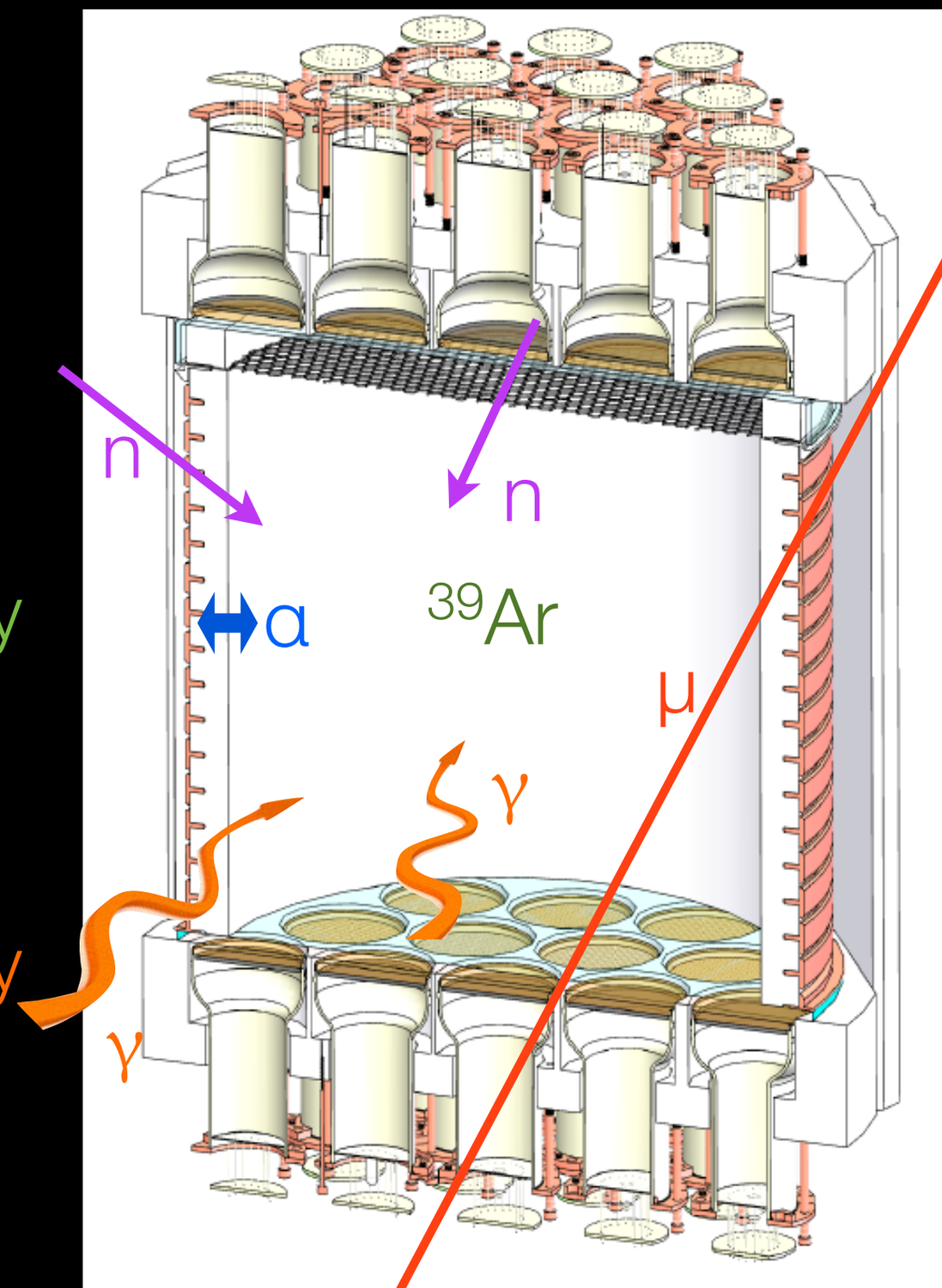
Backgrounds

[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

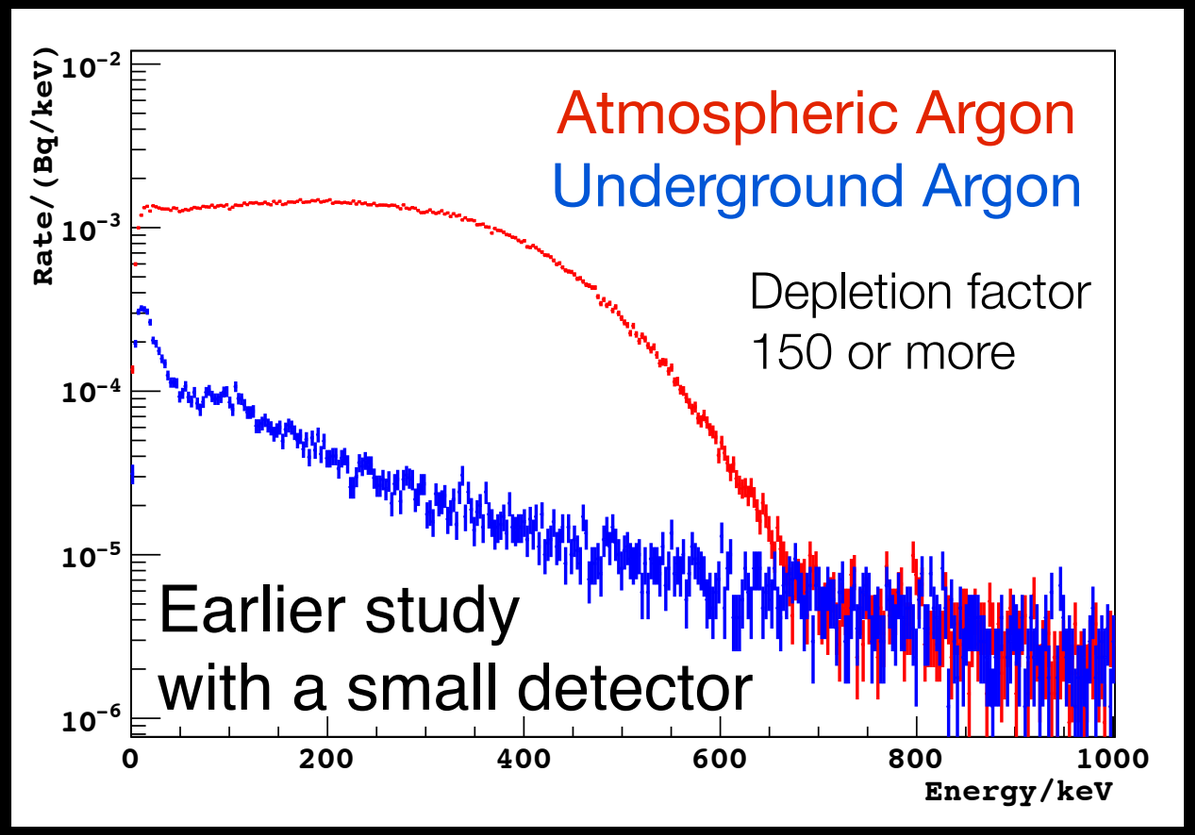
Radiogenic n
~$6x10^{-4}$ evt/kg/day

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



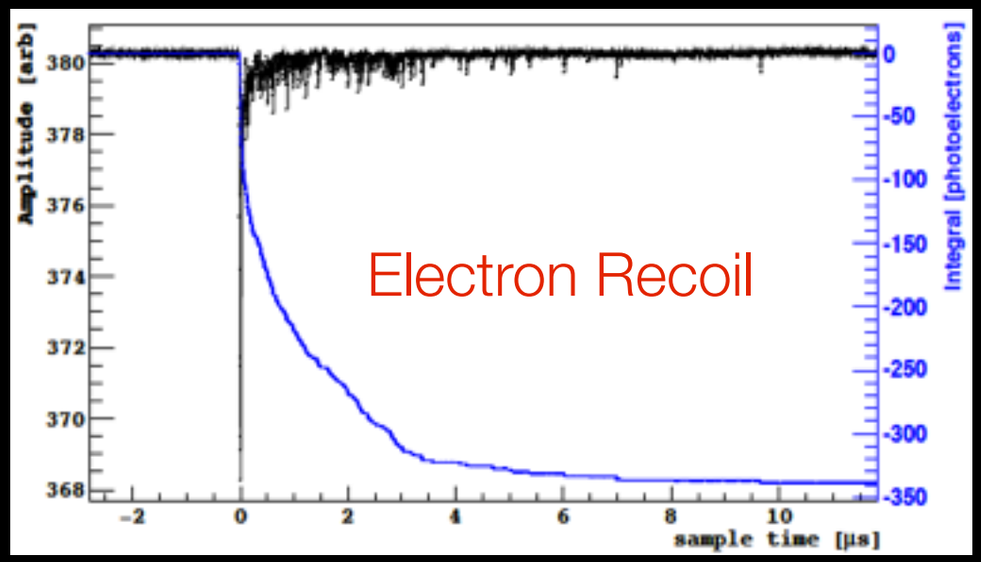
arXiv:1204.60111 [physics.ins-det]

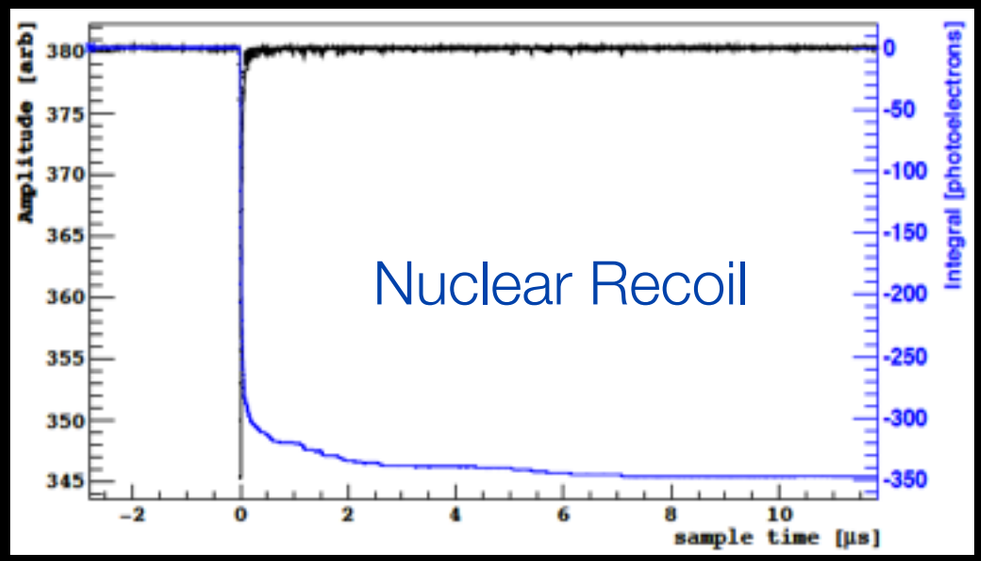
Pulse Shape Discrimination

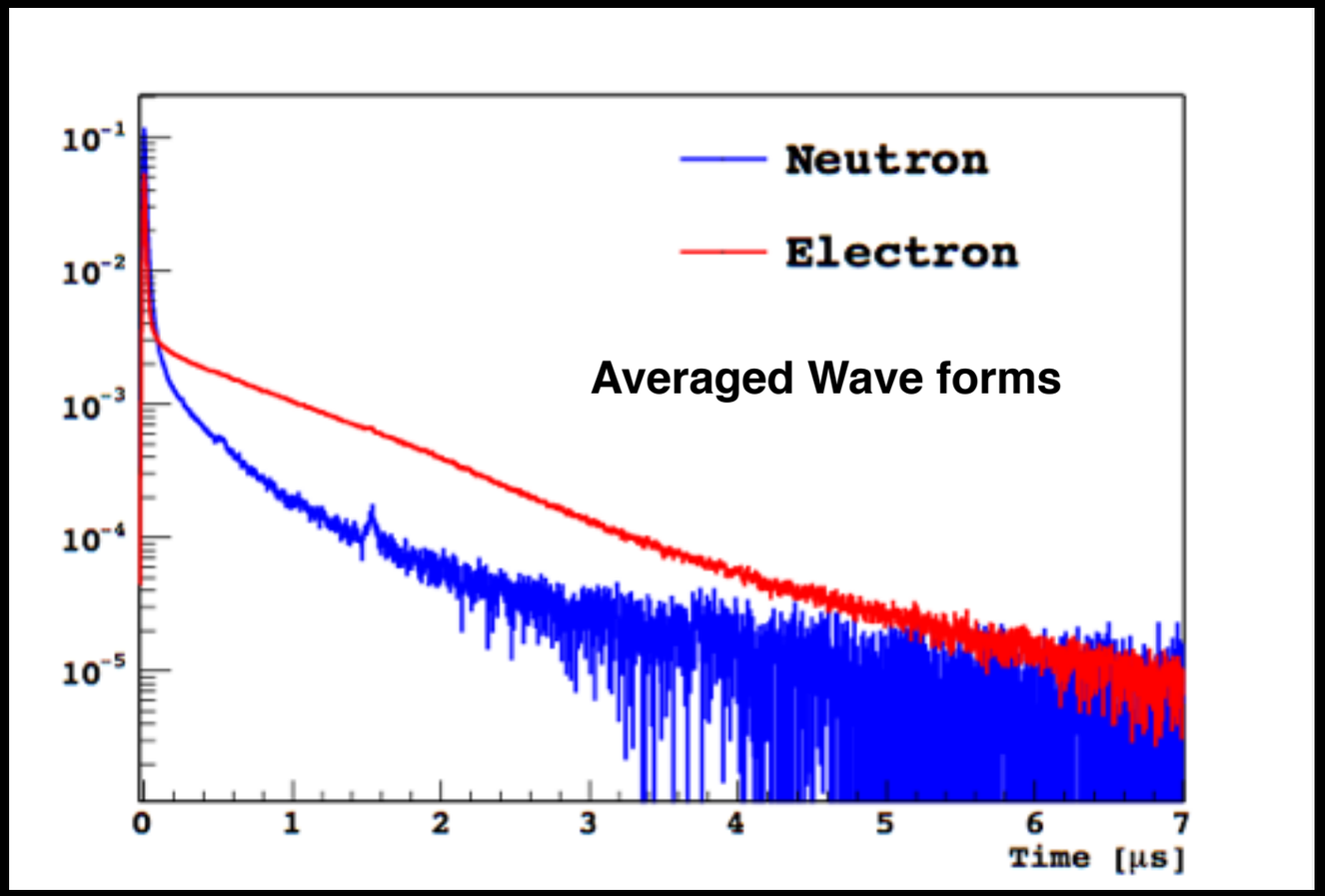
Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states

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

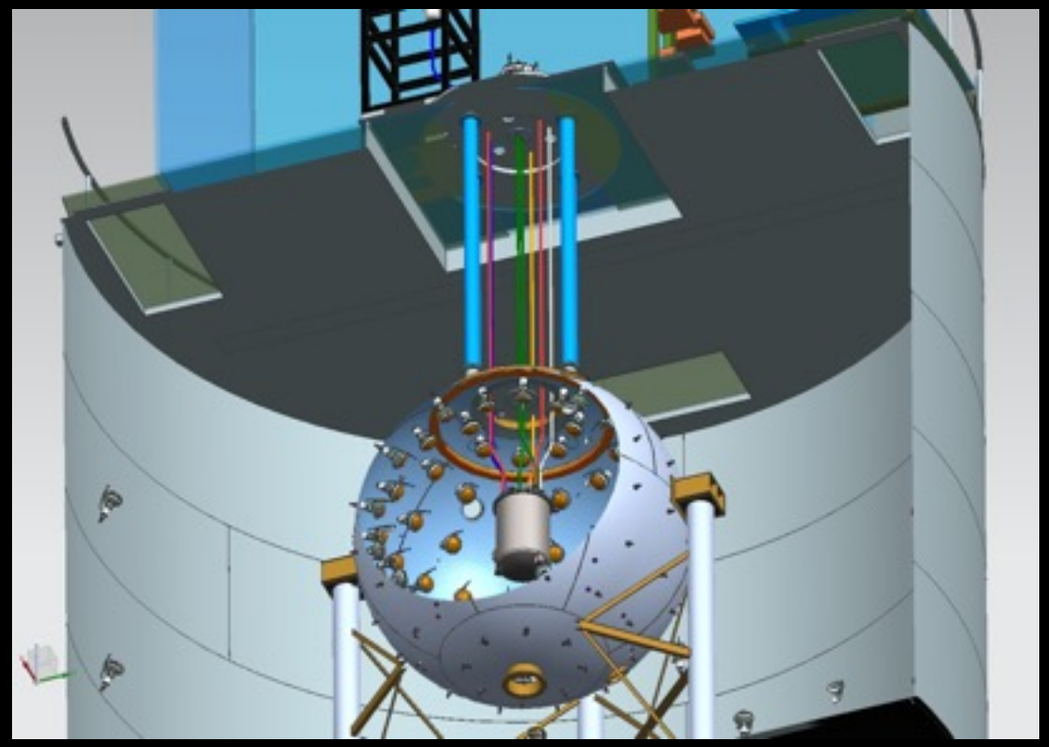
$\tau_{\text{triplet}} \sim 1500$ ns







Veto System



Liquid Scintillator Veto (Neutron Rejection)

- 4 m diameter sphere containing PC + TMB scintillator with 110 8” PMTs
- Coincident veto of **neutrons (and γ’s)** in the TPC

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**.

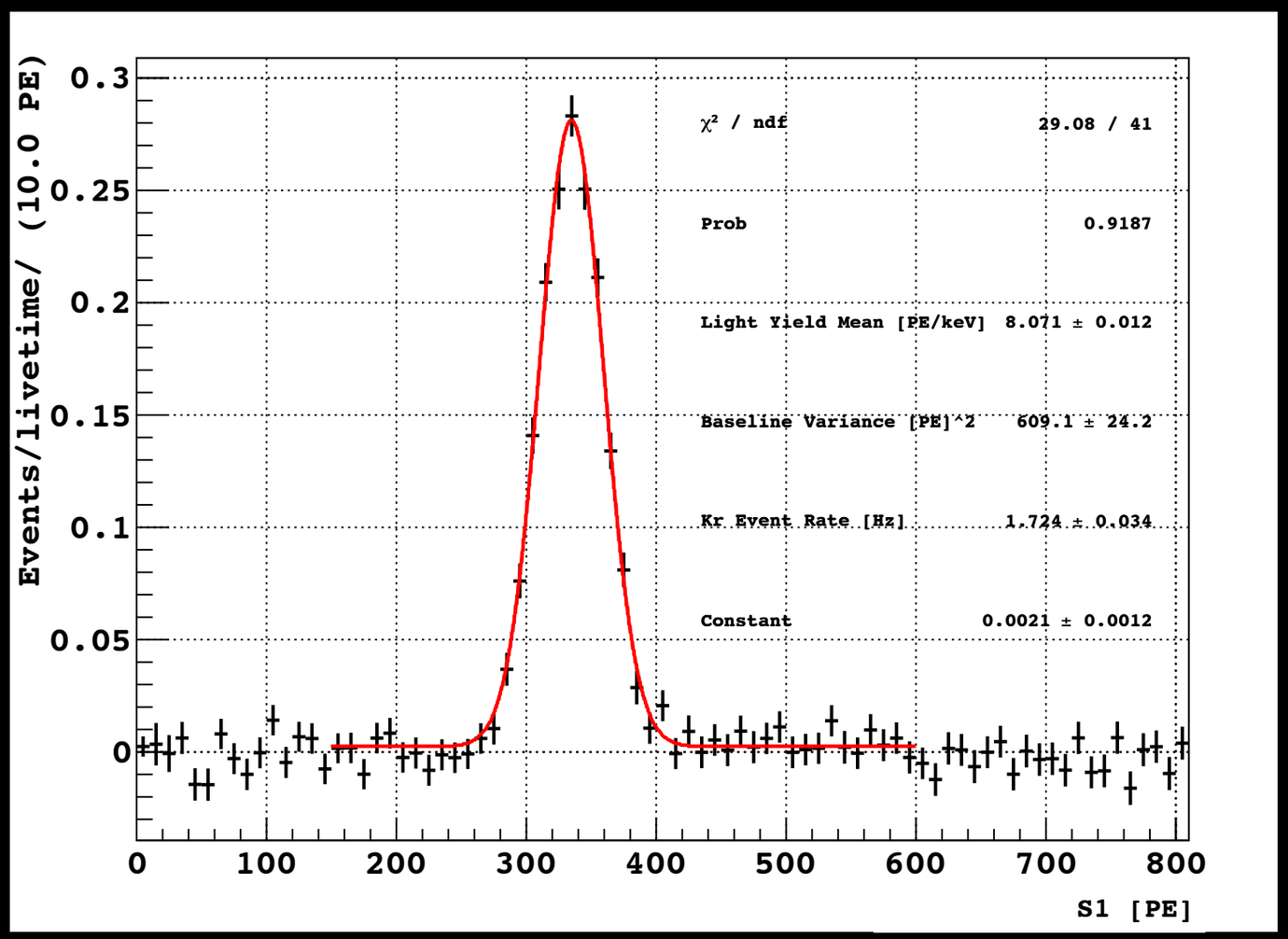
Water Cherenkov Veto (Cosmogenics Rejection)

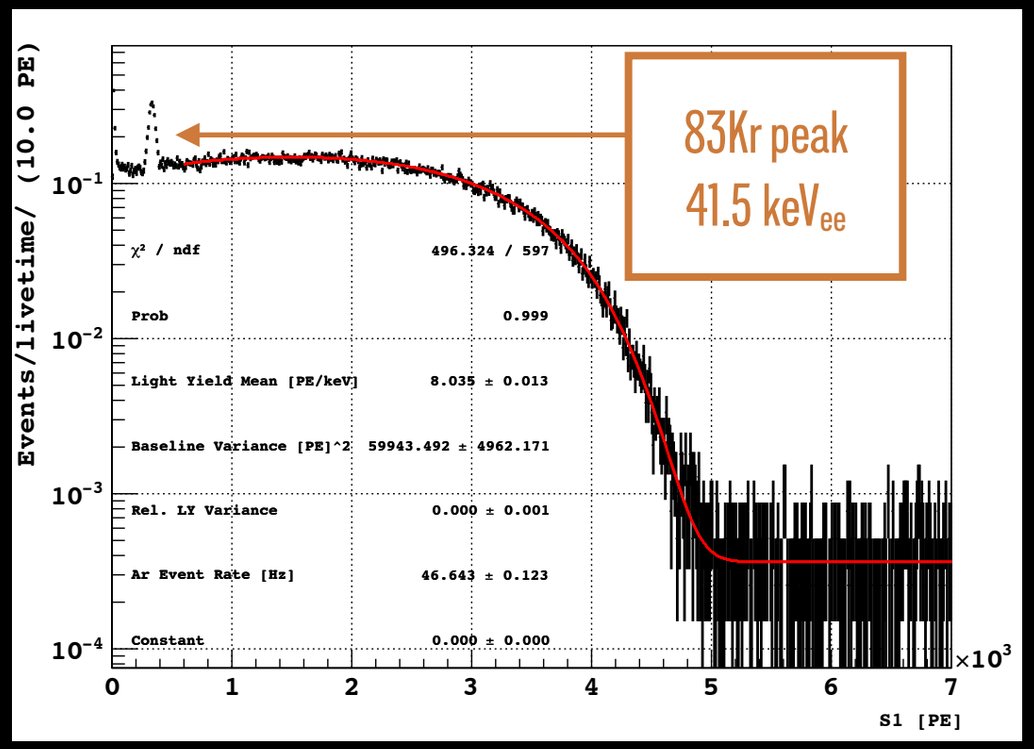
- 80 PMTs within water tank (11 m diameter x 10 m height)
- Acts as **a muon and cosmogenic veto** (~ 99% efficiency)
- Provides **passive γ’s and neutron shielding**

TPC Calibration

Recoil energy calibration @ null field

For Electron Recoils





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$_{ee}$

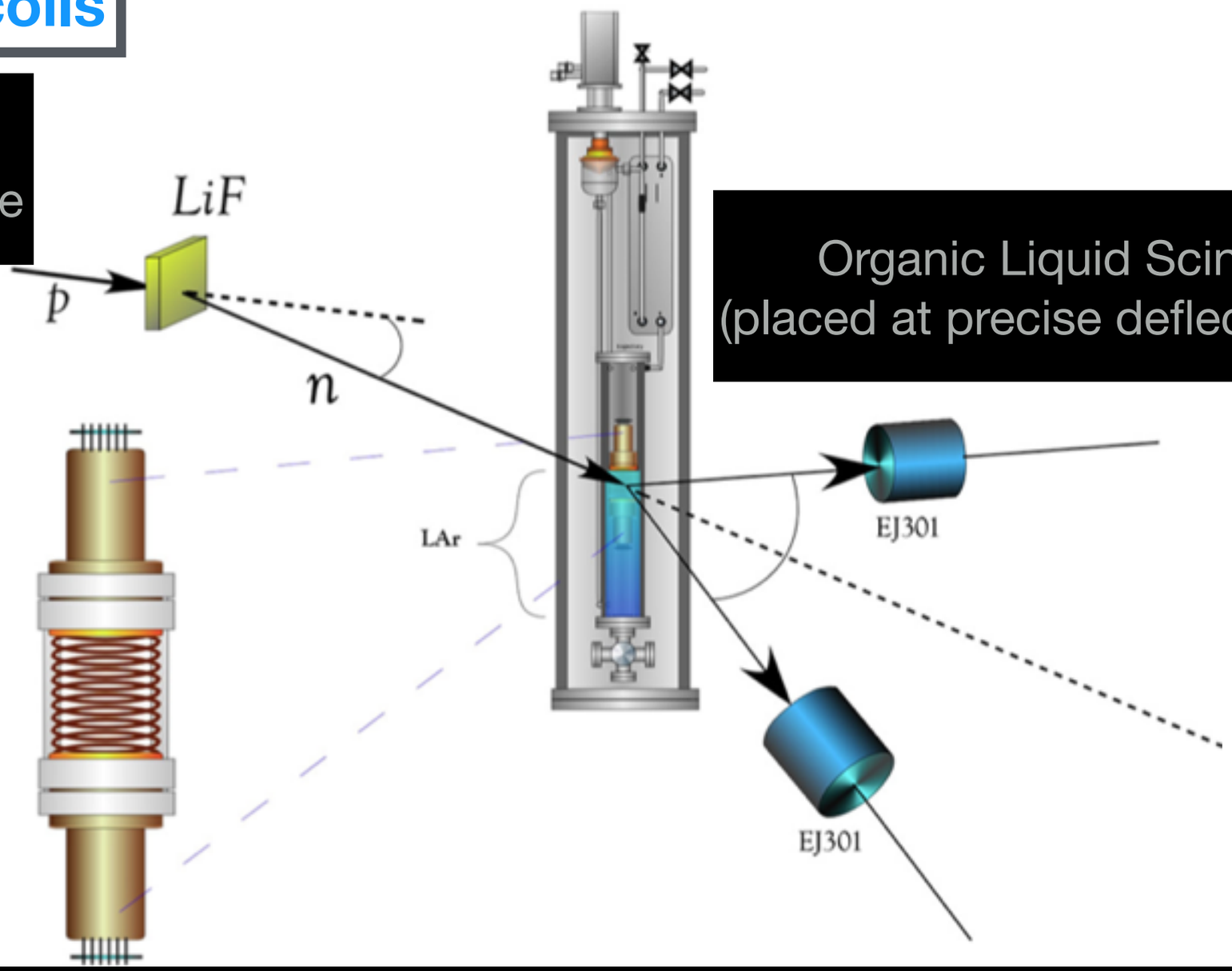
SCENE
(Scintillation Efficiency of Nuclear Recoils in Noble Elements)

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)

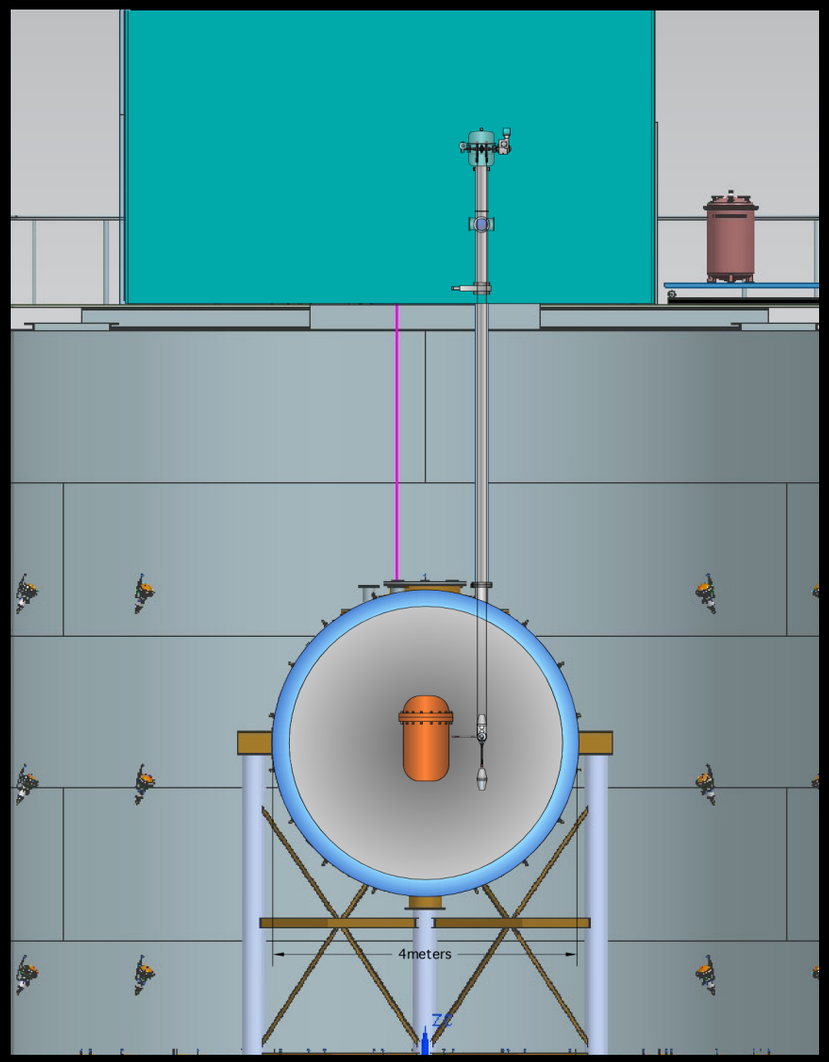


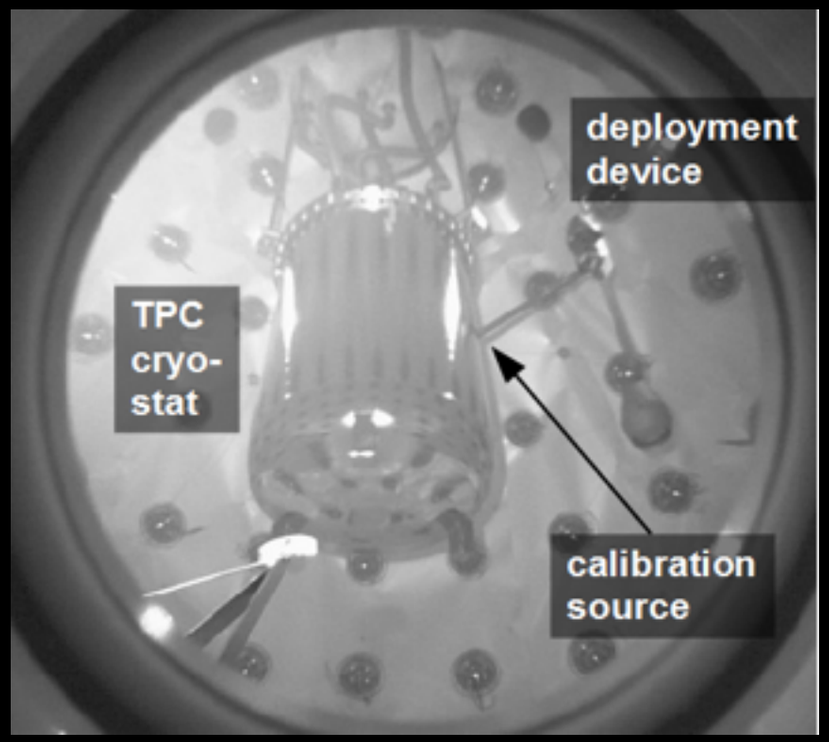
^{7}Li(p, n)^{7}Be reaction produces low energy monoenergetic neutrons
TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy

CALIS - CALibration Insertion System

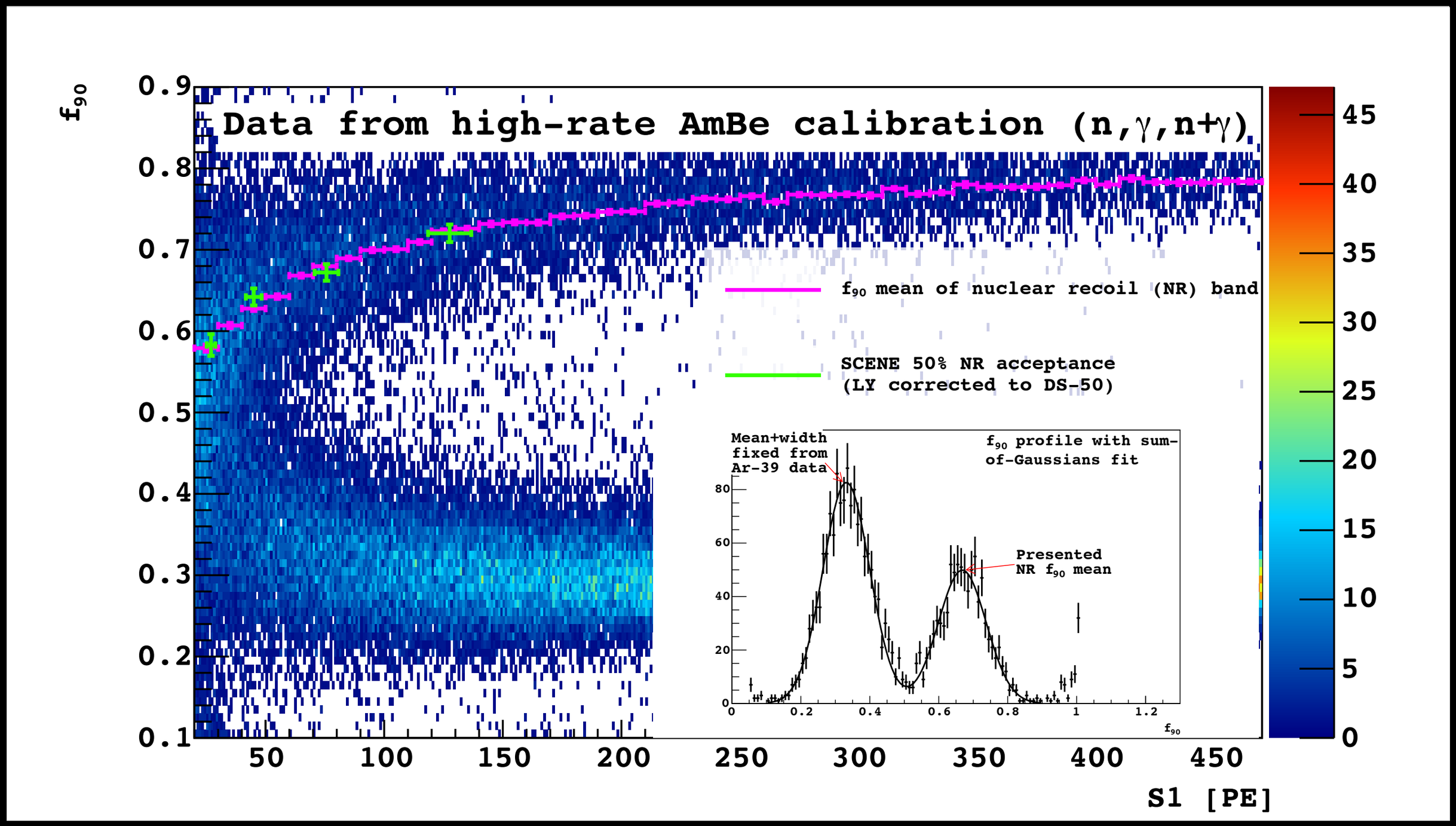
Calibrate both **TPC** and **Neutron veto**

- **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

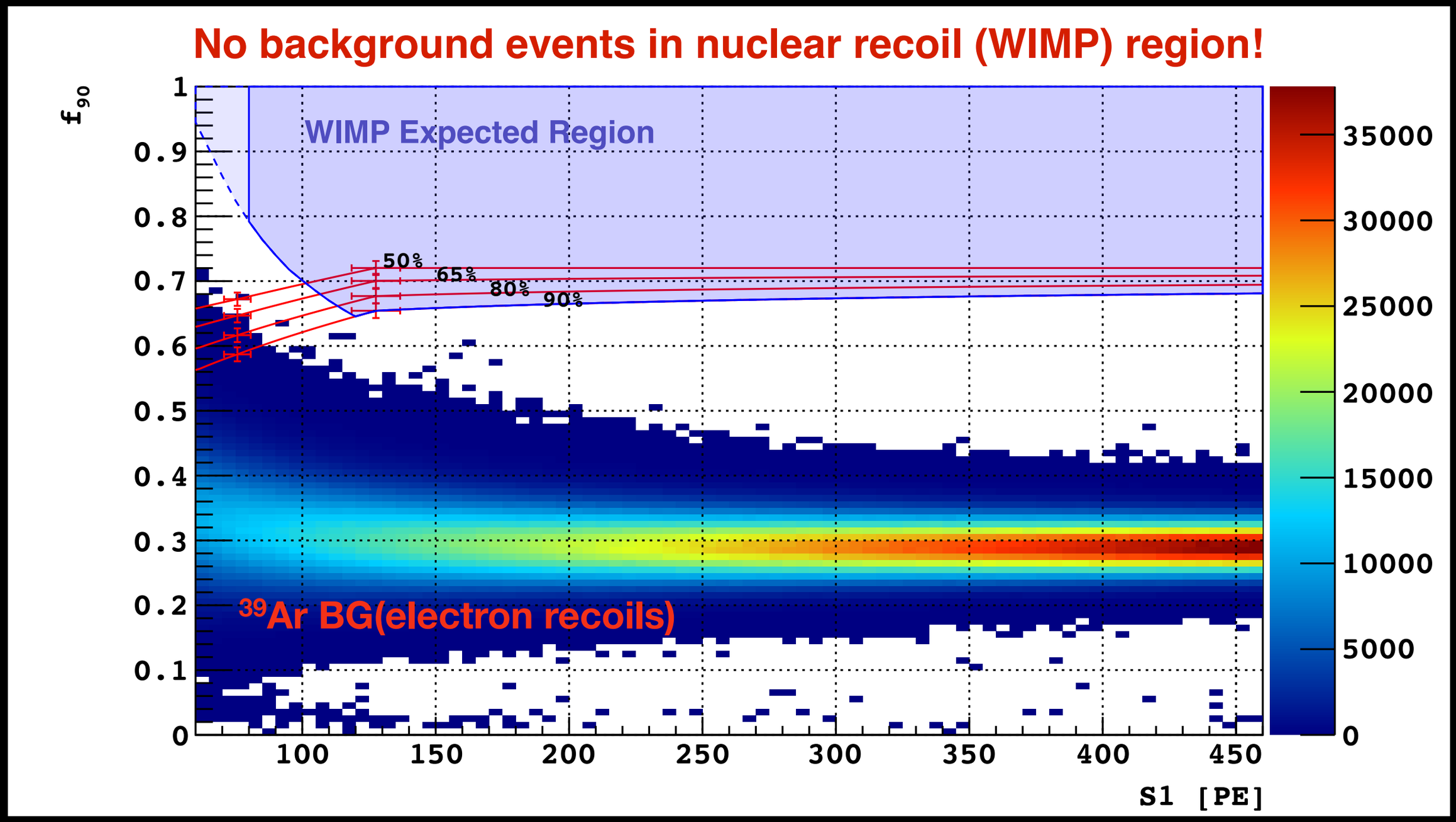


NR band matches with the points extrapolated from SCENE.

The First Physics Result from DS-50

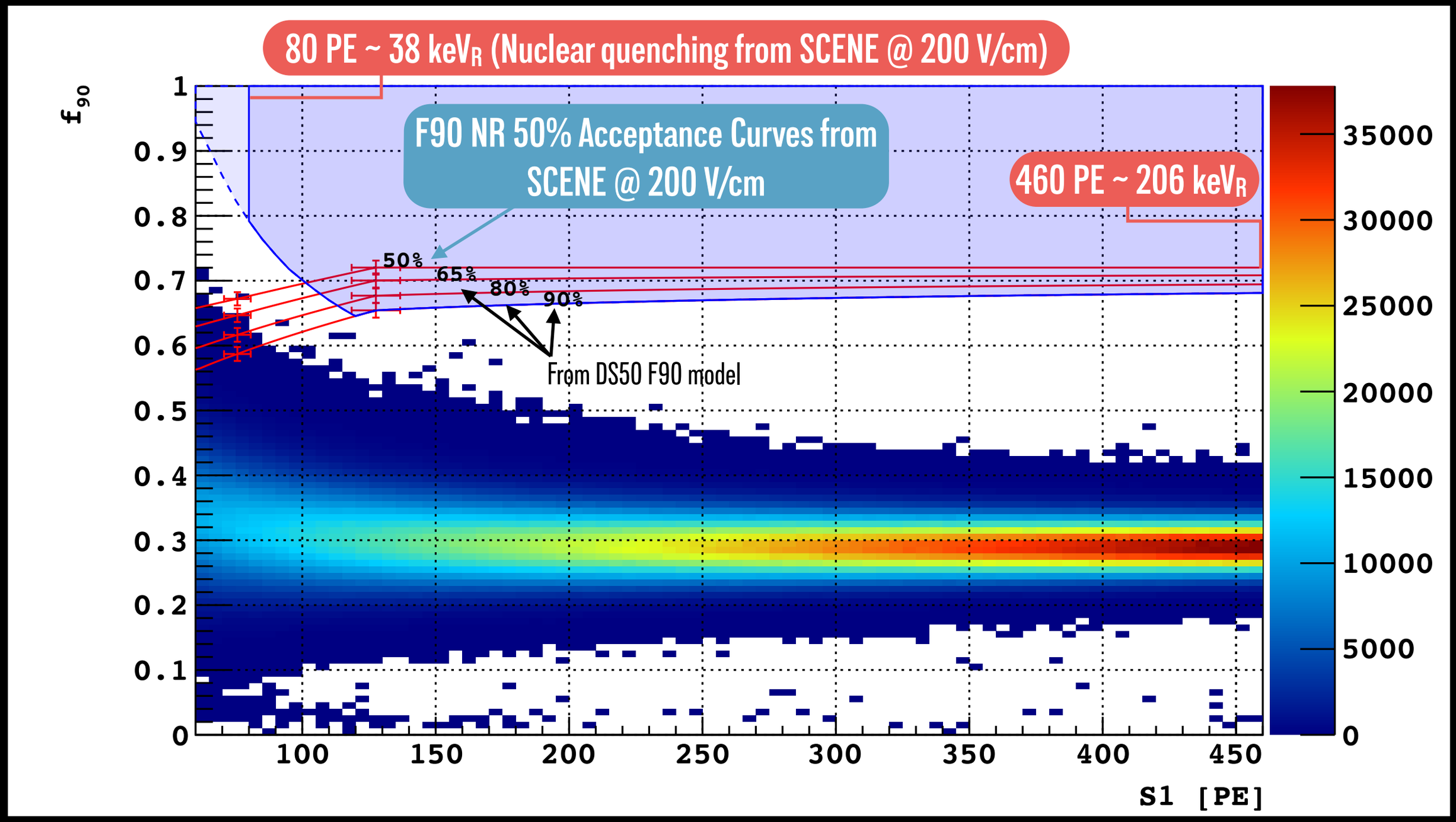
Background-free exposure of 1422 ± 67 kg·day

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

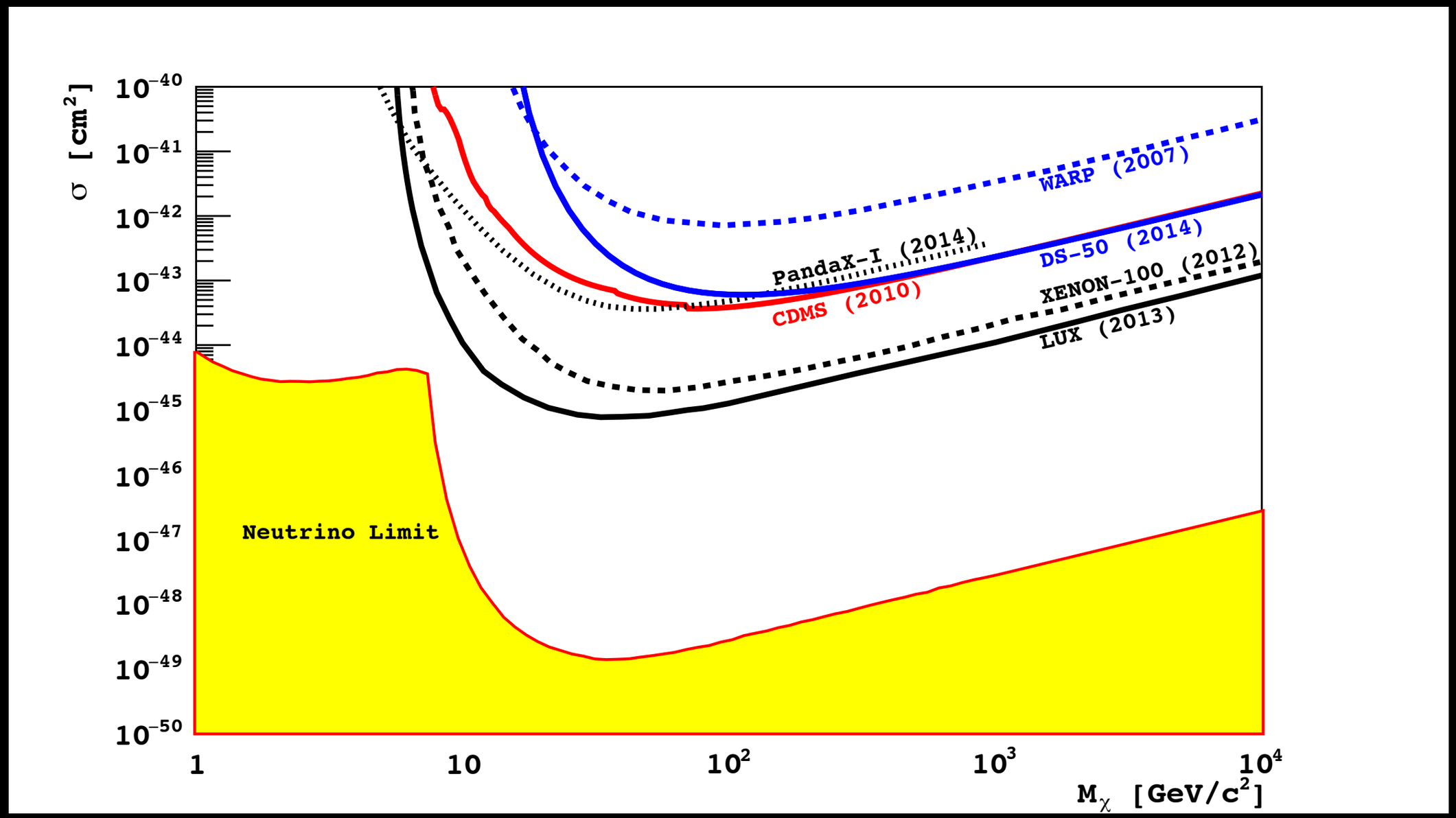


Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

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 TPV w/ radioactive sources.
- **Jan. 2015:** Add radiopure TMB at 5% concentration.
- **Mar. to Apr. 2015:** Fill with **UAr** and re-commissioning the detector.

Underground Ar

Plant at Colorado

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

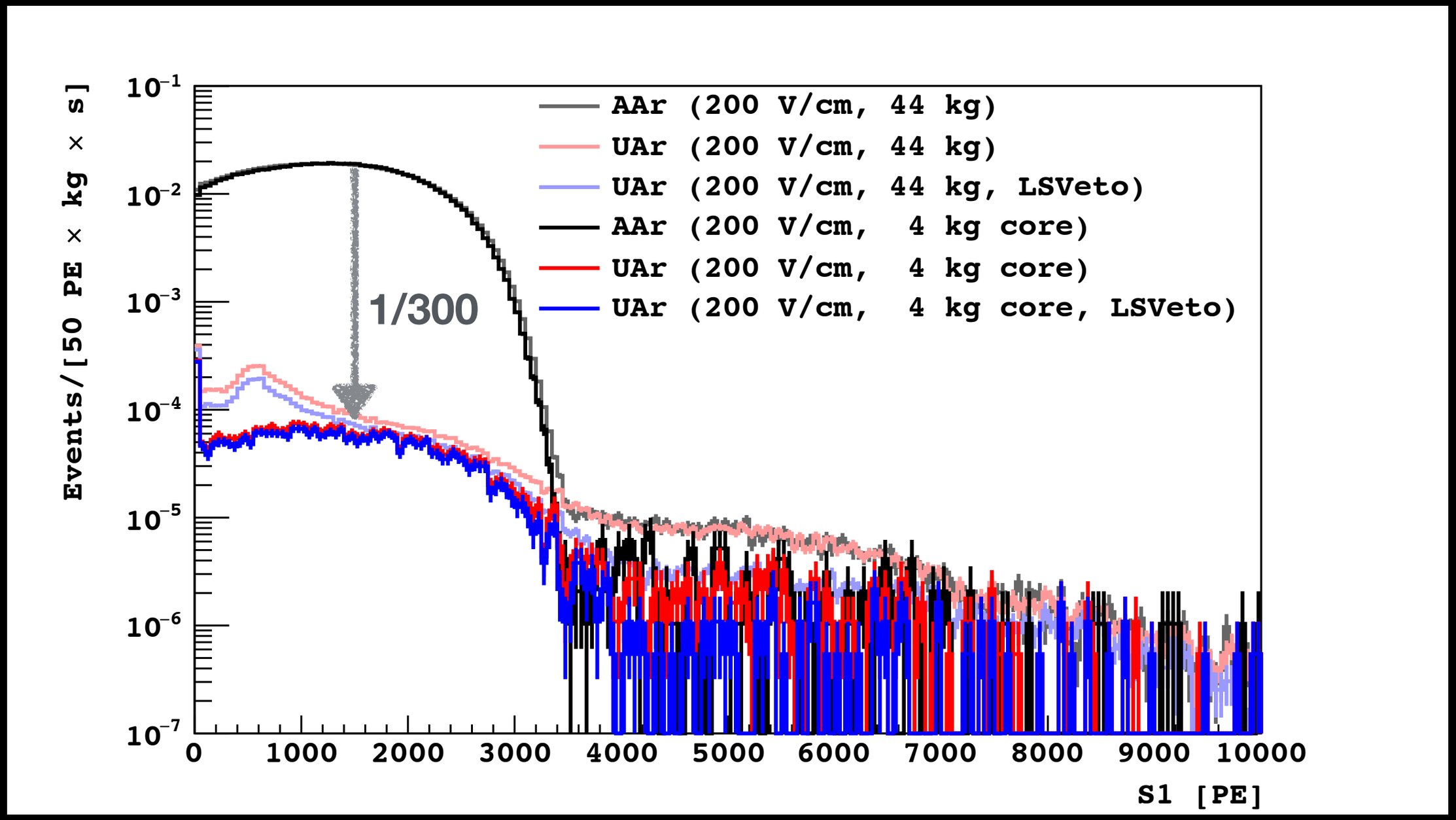
Distillation Column at Fermilab

2. Purification at Fermilab
Separate Ar from He and N_2

UAr bottles at LNGS

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

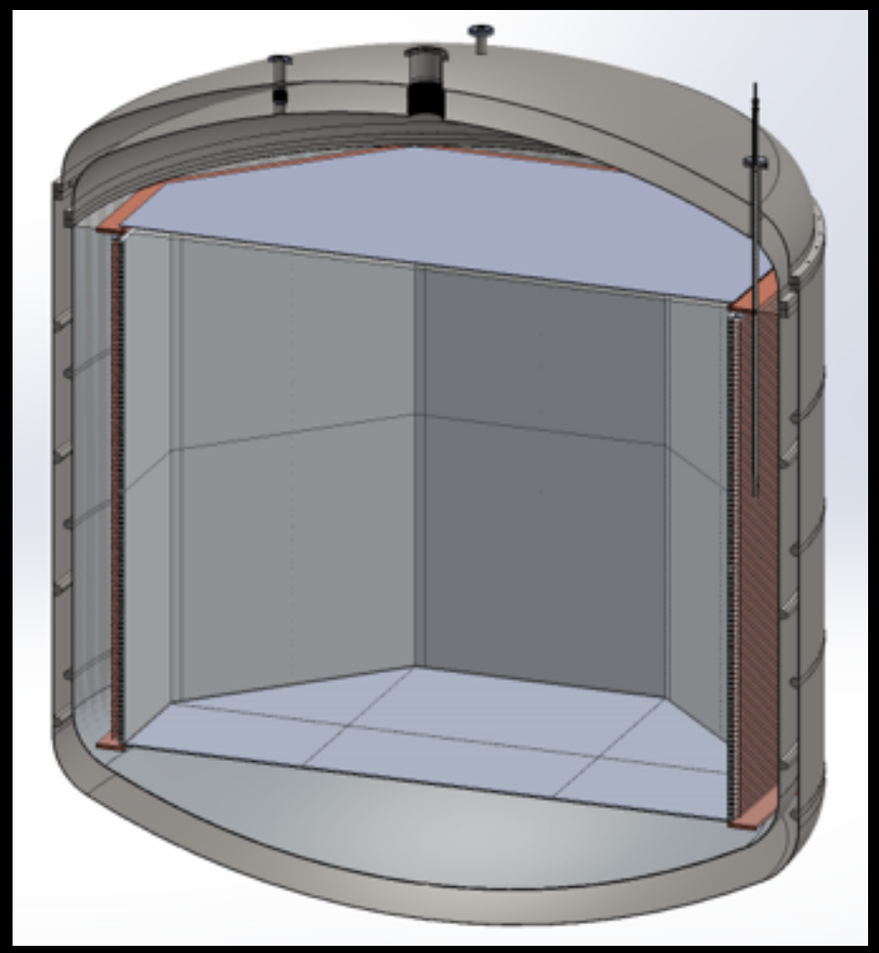
Underground Ar



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

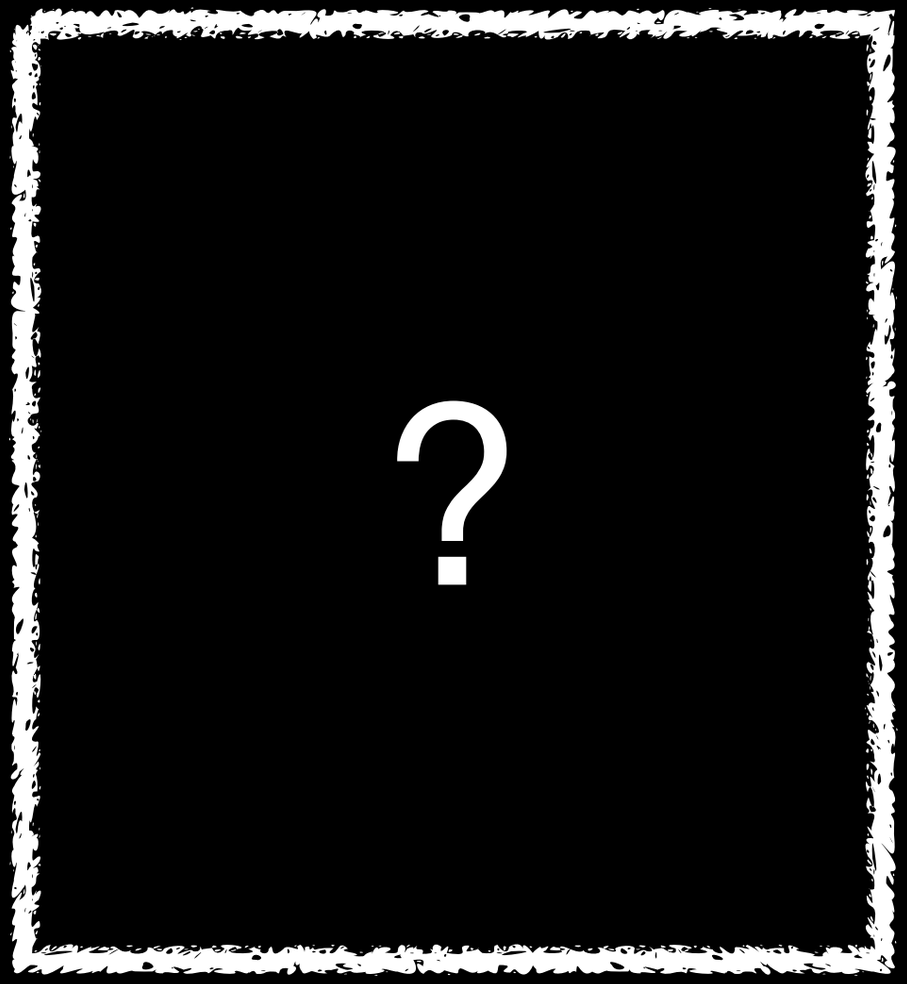
Low level of ^{39}Ar allows extension of DarkSide program to ton-scale detector.

Future Detectors



DS-20k

30 tonne (20 tonne fiducial) detector



ARGO

300 tonne (200 tonne fiducial) detector

Experiment	σ [cm^2] @1 TeV/c^2	σ [cm^2] @10 TeV/c^2
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

D. Franco, A Tonazzo - APC Paris
D. Alton - Augustana College
A. Kubankin - Belgorod National Research University
K. Keeter, B. Mount - Black Hills State University
L. Romero, R. Santorelli - CIEMAT
S. Horikawa, K. Nikolics, C. Regenfus,
A. Rubbia - ETH Zürich
S. Pordes - Fermilab
A. Gola, C. Piemonte - FBK & TIFPA
S. Davini - GSSI
E. Hungerford, A. Renshaw - University of Houston
M. Guan, J. Liu, Y. Ma, C. Yang, W. Zhong - IHEP Beijing
N. Canci, F. Gabriele, G. Bonfini, A. Razeto, N. Rossi,
F. Villante - LNGS
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M. Misziazek, M. Woicik, G. Zuzel - Jagiellonian University
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F. Zappa - Politecnico di Milano
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M. Wada - Princeton University
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Y. Suvorov, H. Wang - UCLA
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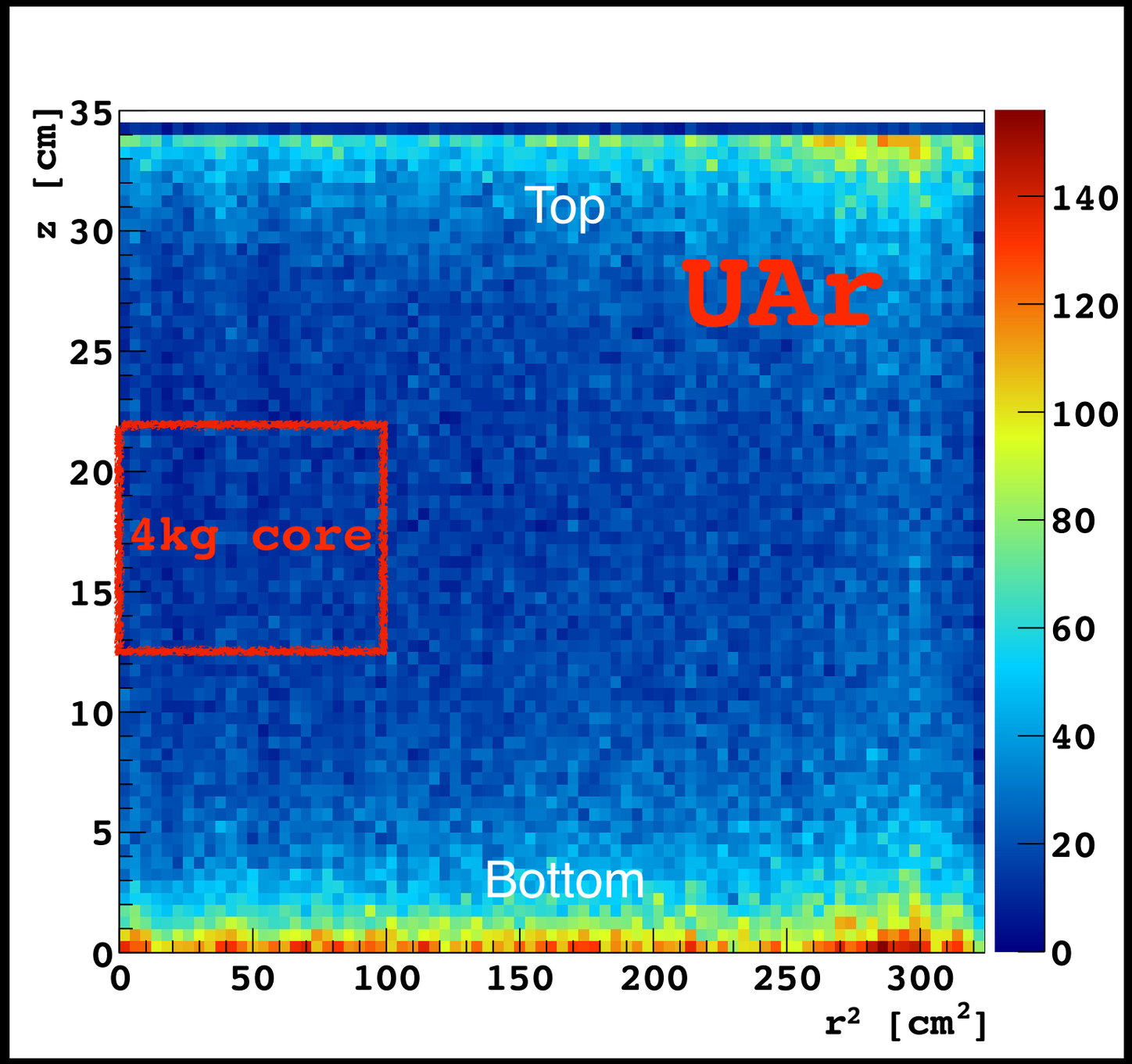
S. Zavatarelli - Università & INFN Genova
D. D'Angelo, G. Ranucci - Università & INFN Milano
F. Ortica, A. Romani - Università & INFN Perugia
S. Catalanotti, A. Cocco, G. Covone, G. Fiorillo,
B. Rossi - Università Federico II & INFN Napoli
C. Dionisi, S. Giagu, M. Rescigno - Università La Sapienza & INFN Roma
S. Bussino, S. Mari - Università & INFN Roma 3
J. Maricic, R. Milincic, B. Reinhold - University of Hawaii
P. Cavalcante - Virginia Tech

Summary

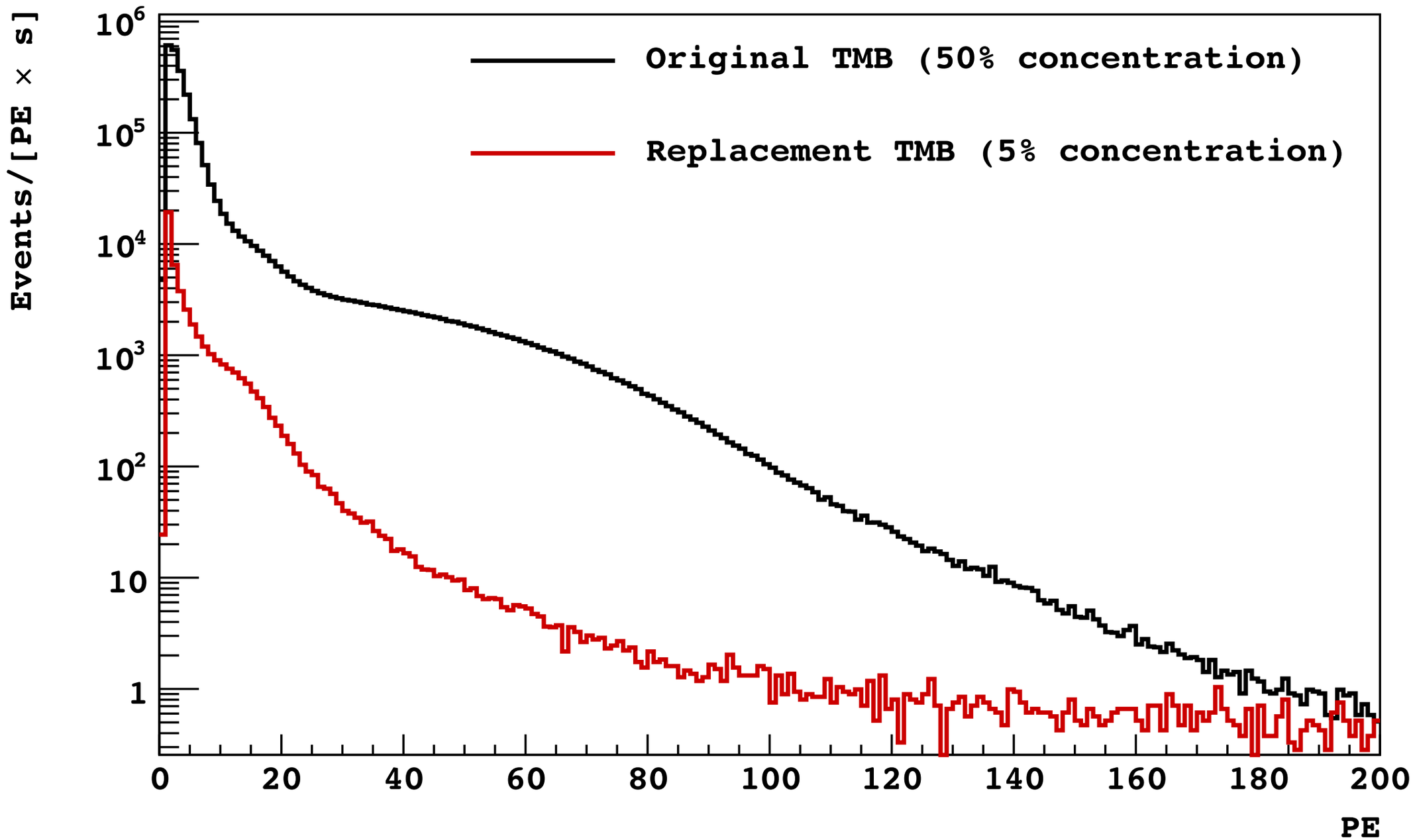
- **Background free**
  ^{39}Ar BG from **47.1 live days** (1422 kg · day fiducial) of AAr corresponds to that expected in **38.7 years** of **UAr** DS-50 run (≫planning physics run time, 3 years).
- TMB problem (high ^{14}C content in LSV) was fixed.
- Concentration of ^{39}Ar in **UAr** is at least **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

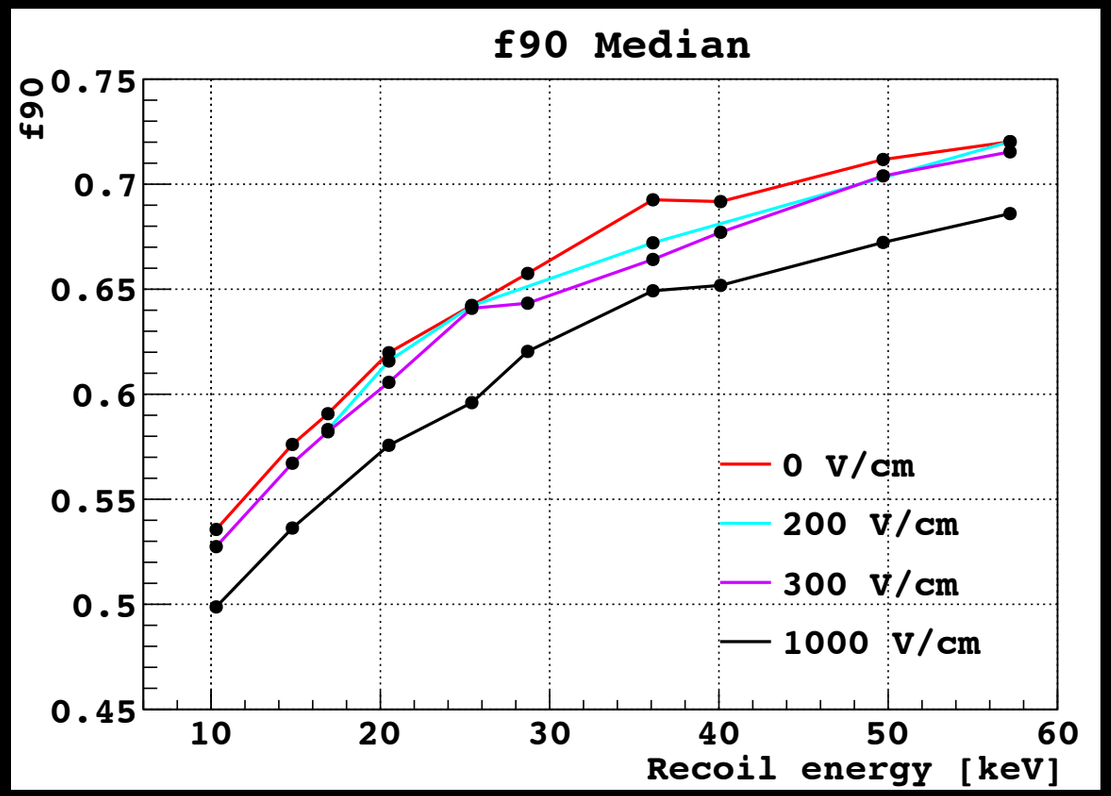


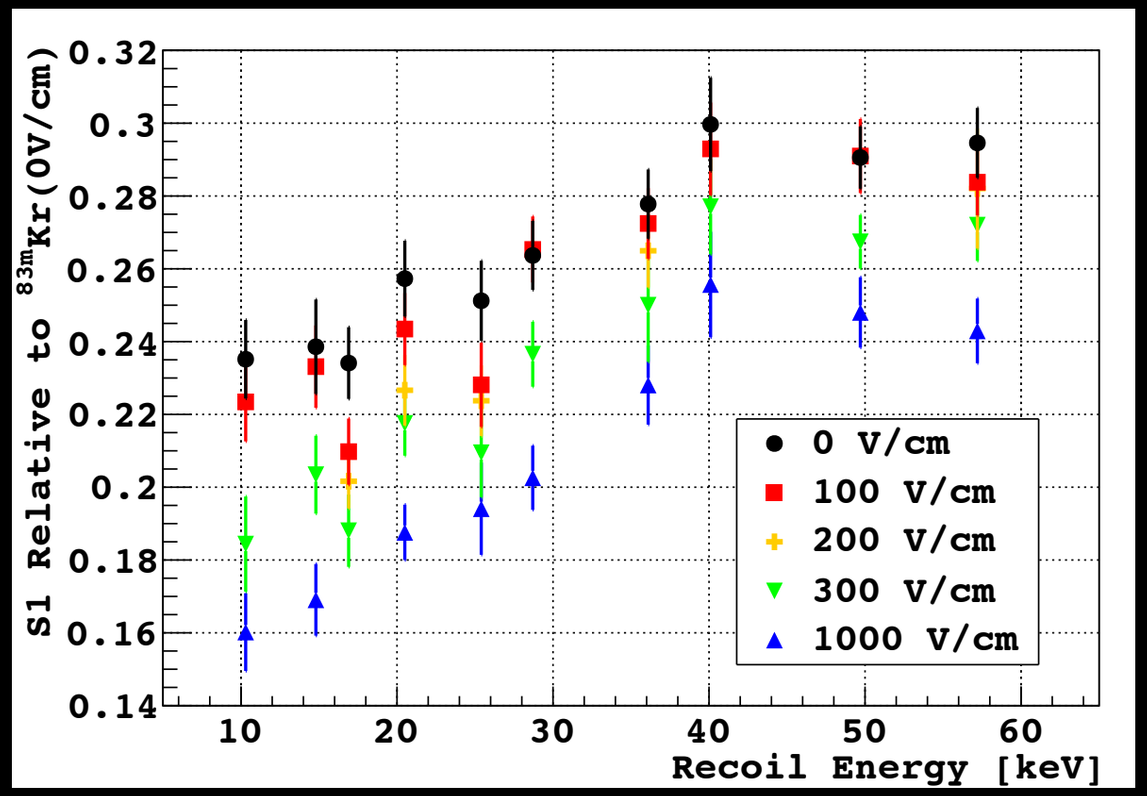
Status of Liquid Scintillator Veto



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

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)

Surface contamination

Radon-Free Clean Rooms

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

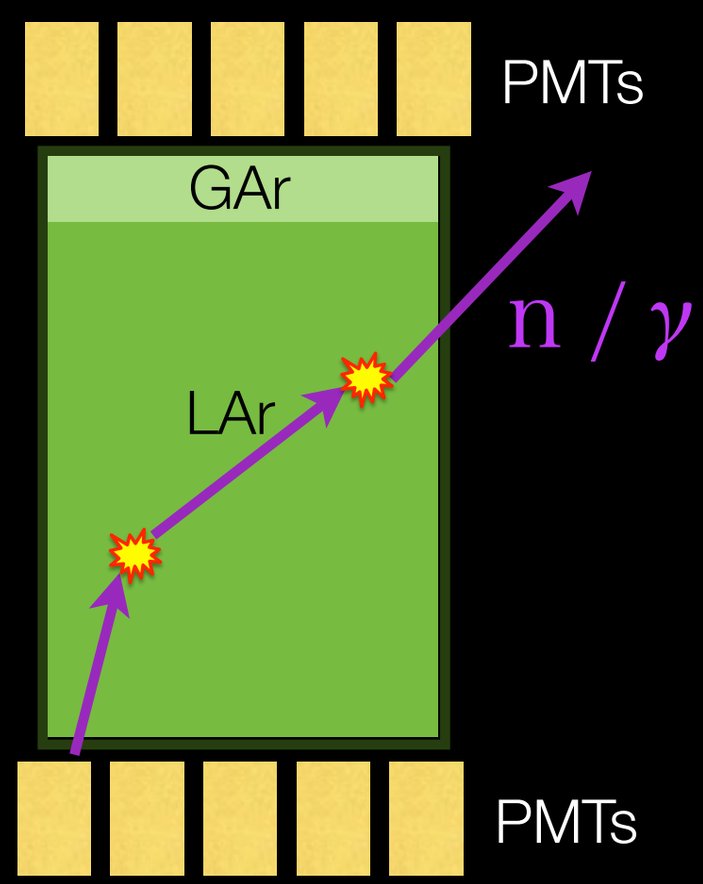
Final preparation, **cleaning**, **evaporation** and **assembly** of all inner detector parts was carried out in radon-free clean rooms.

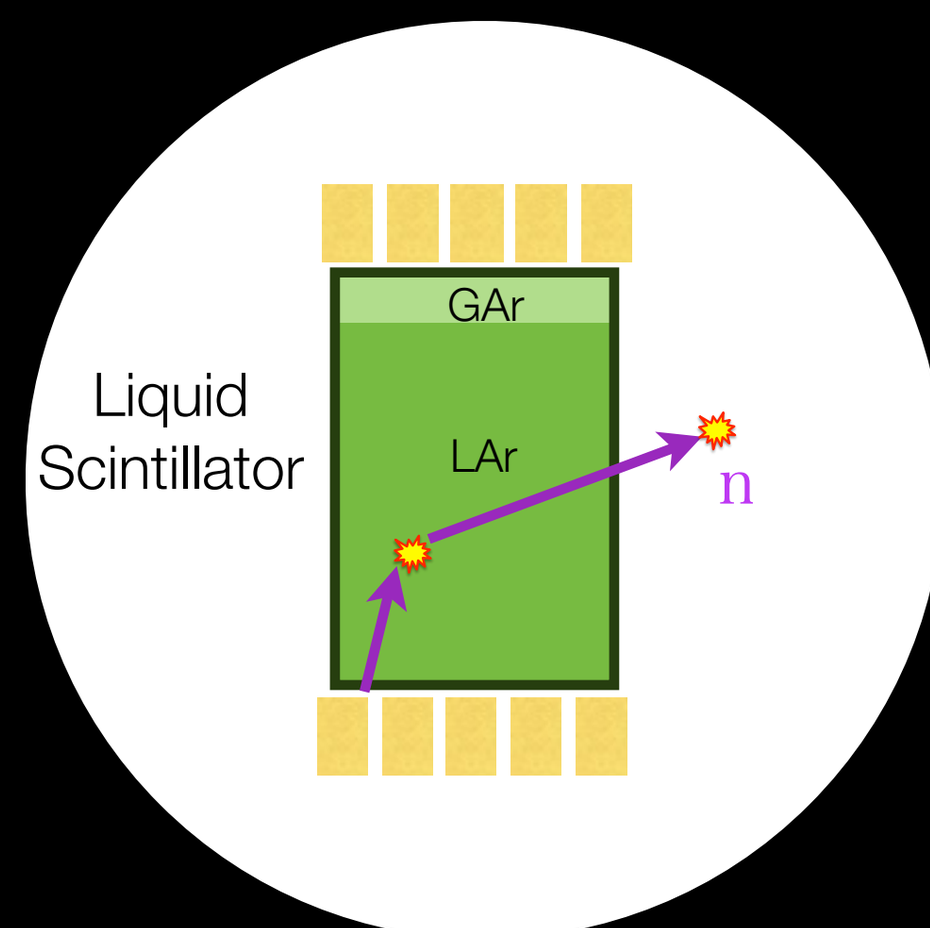
Typical radon in air ~ 30 Bq/m^3
Cleanroom radon levels < 5 mBq/m^3

Neutron Rejection

Multiple Interactions

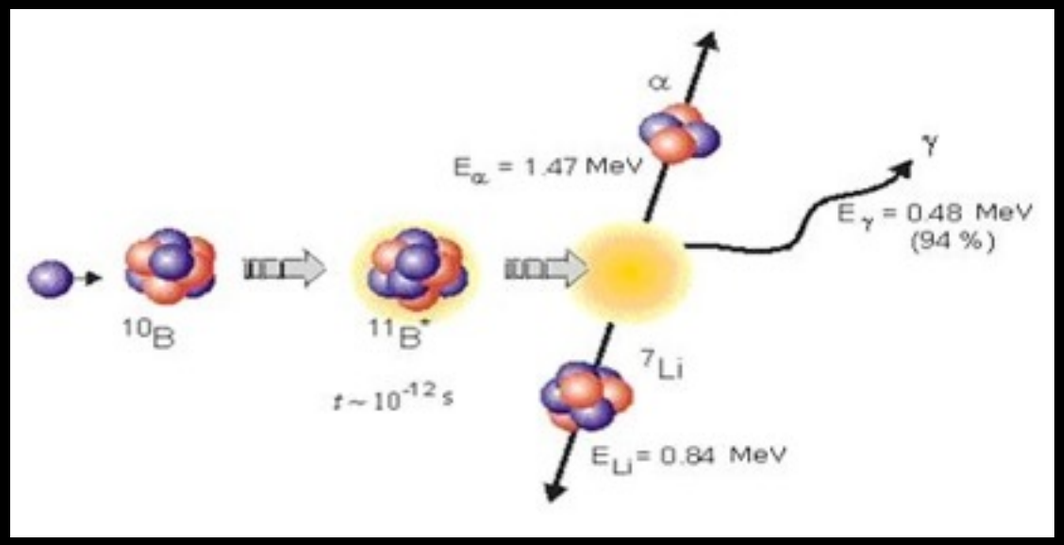
Expected WIMP signal	Background Rejection Technique	Backgrounds Removed
Single Interaction	Multiple S2 Cut in TPC Liquid Scintillator Veto	Neutrons, Gamma rays





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



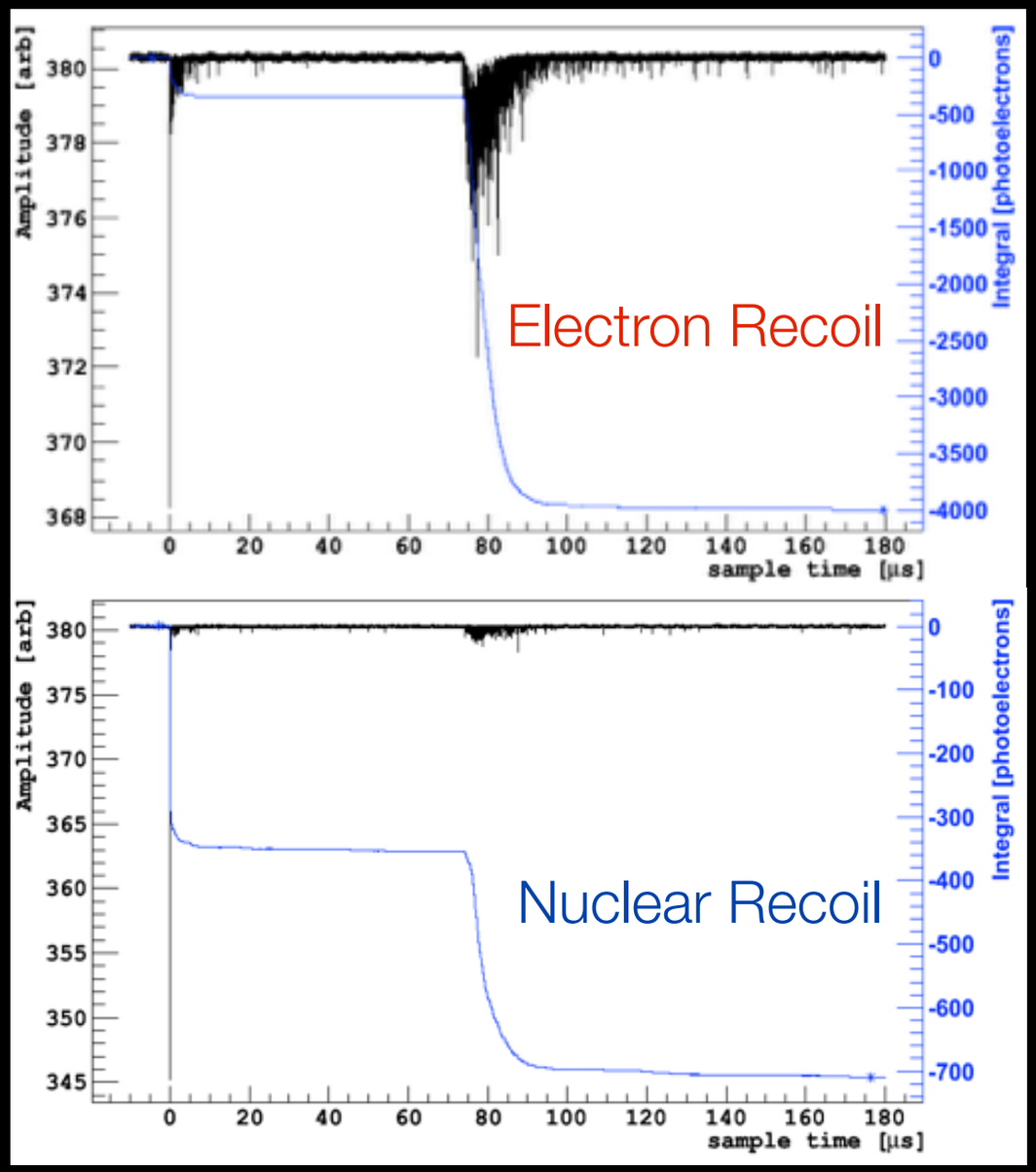
	Veto Efficiency (MC)
Radiogenic Neutrons	> 99%*
Cosmogenic Neutrons	> 95%

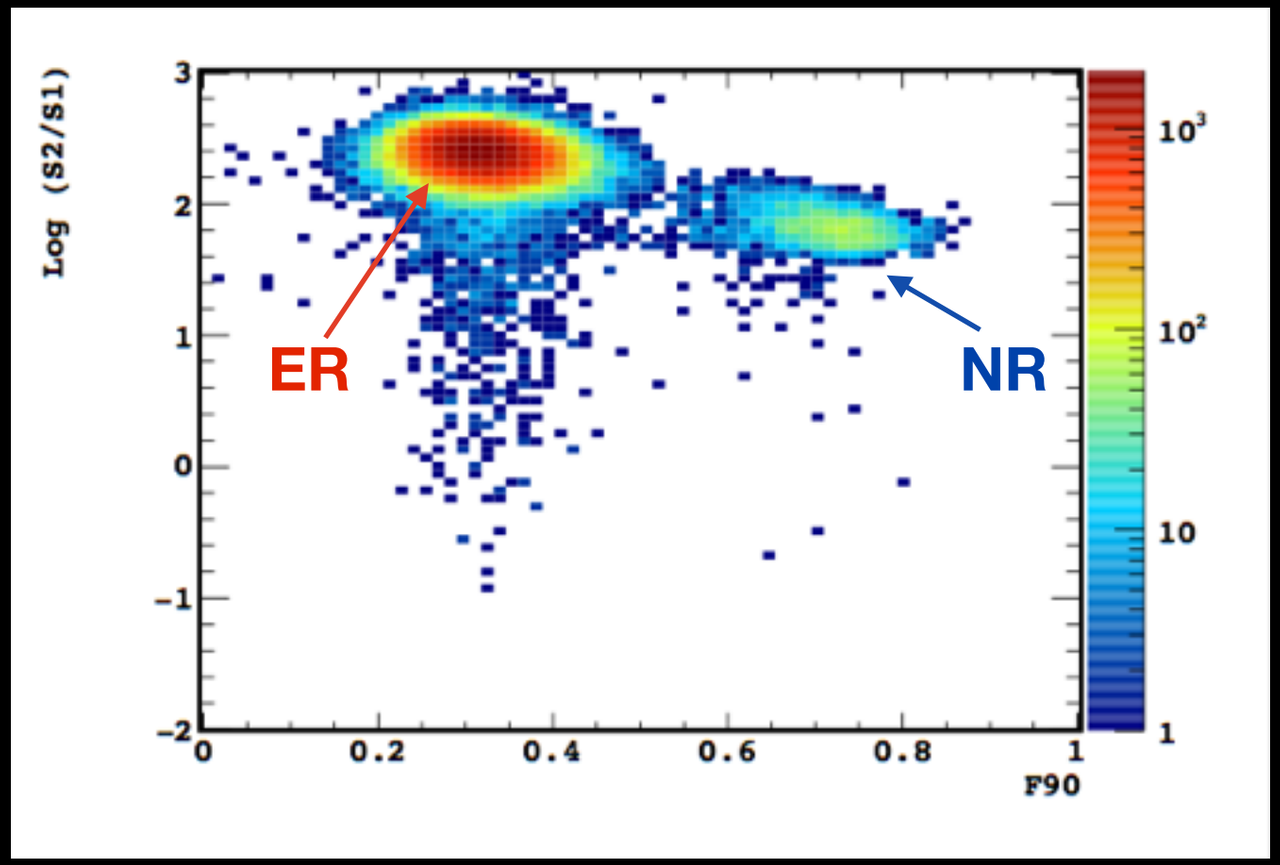
Nuclear Instruments and Methods A 644, 18 (2011)

*Based on 60 μs veto window

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