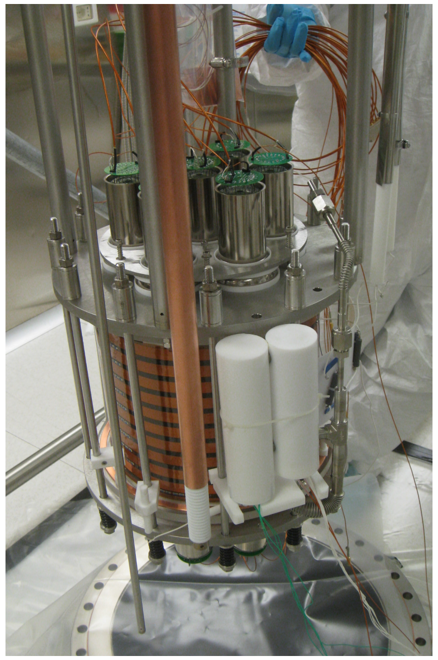
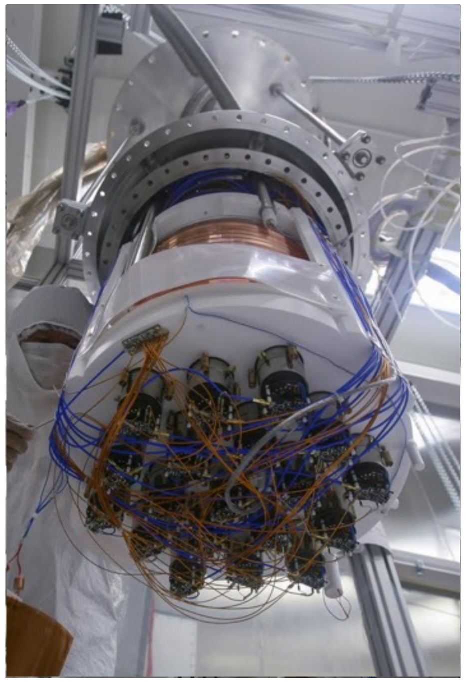
Dark Matter search from DarkSide

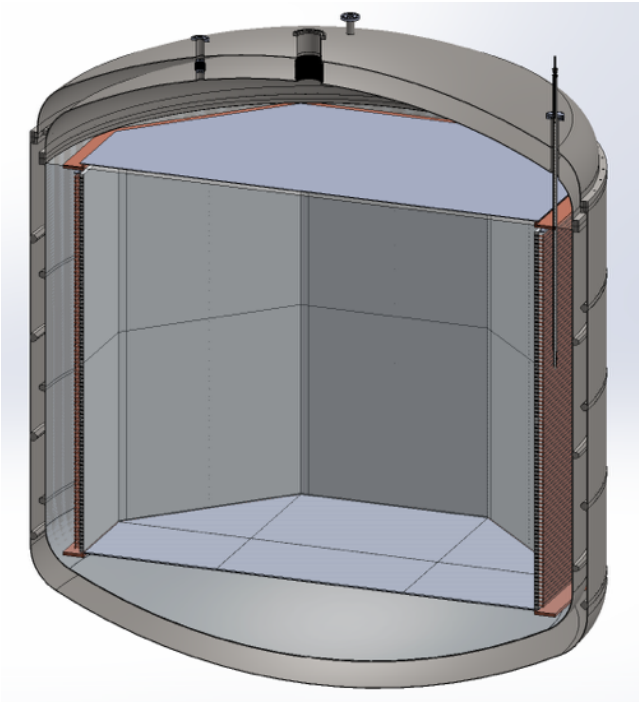
Masayuki Wada
Princeton University
on behalf of the DarkSide Collaboration
29 Oct. 2015

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)








Gran Sasso
3800 m w. e.
Deep underground location at LNGS, Italy.

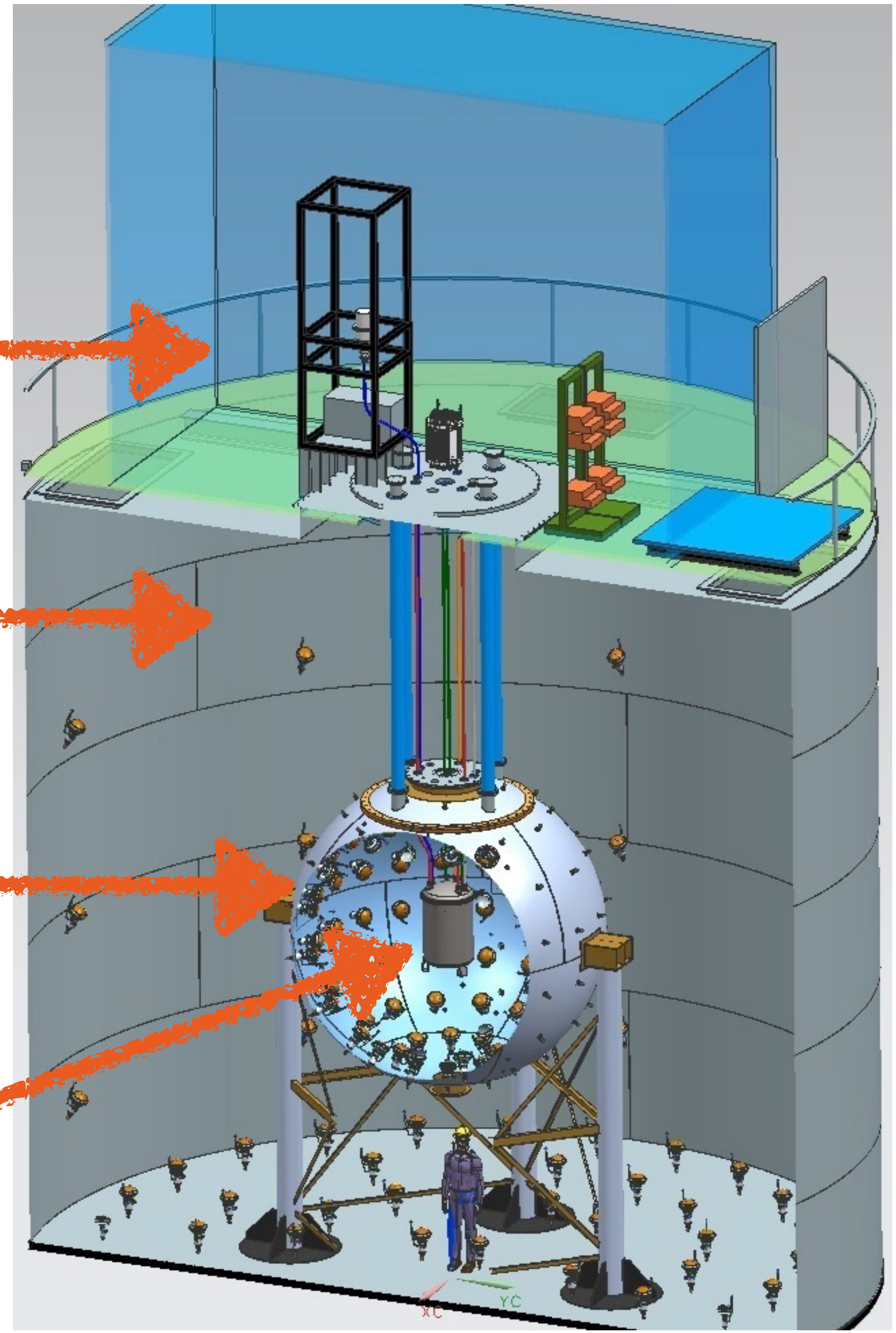
DarkSide 50

Radon-free (Rn levels < 5 mBq/m^3)
Clean Room

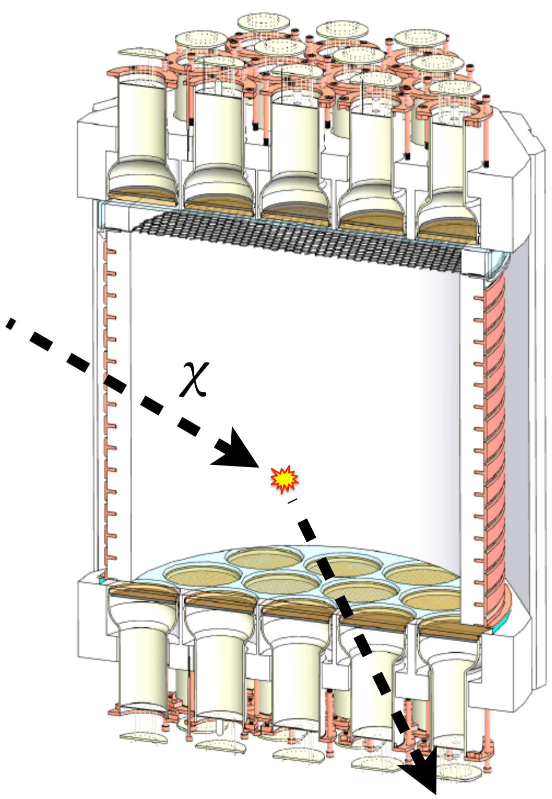
1,000-tonne Water-based
Cherenkov **Cosmic Ray Veto**

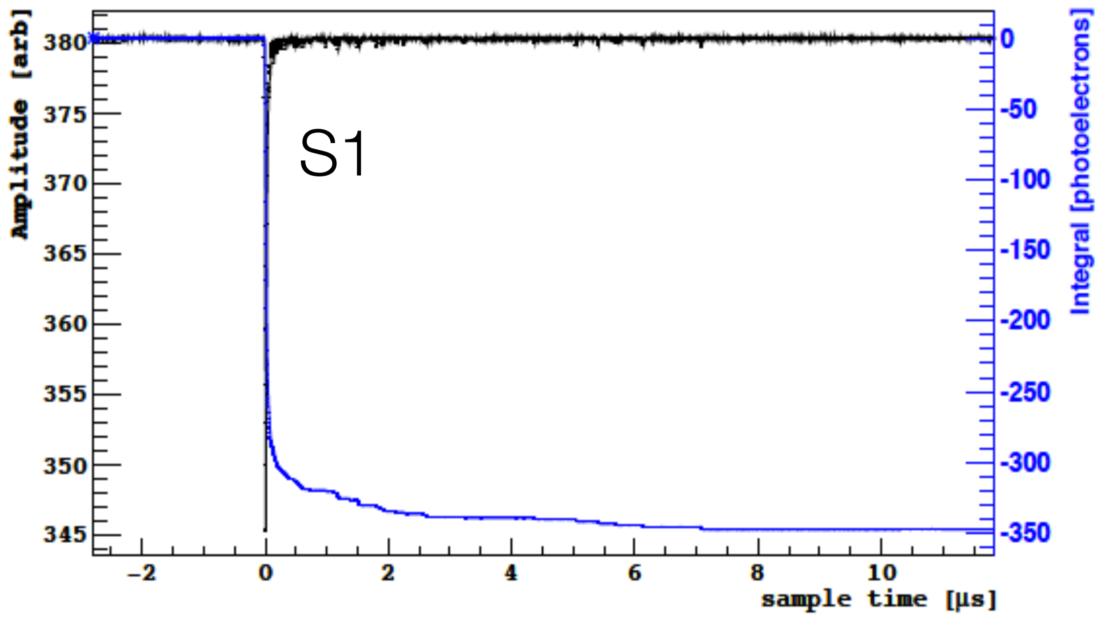
30-tonne Liquid Scintillator
Neutron and γ's Veto

Inner detector **TPC**

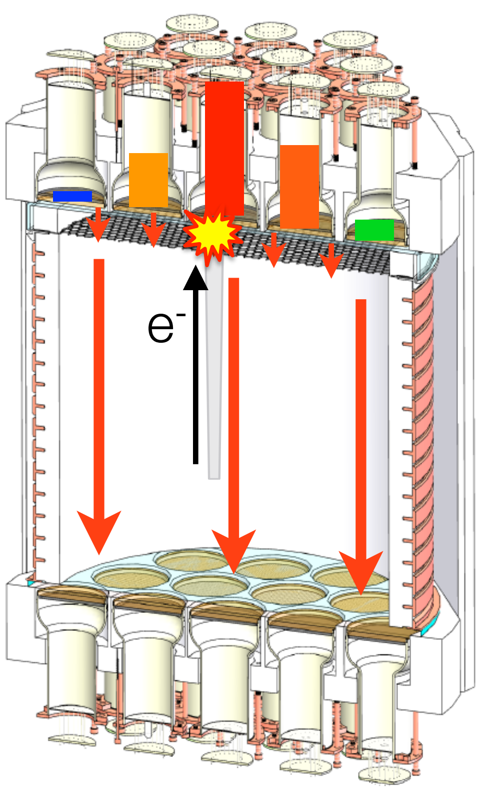


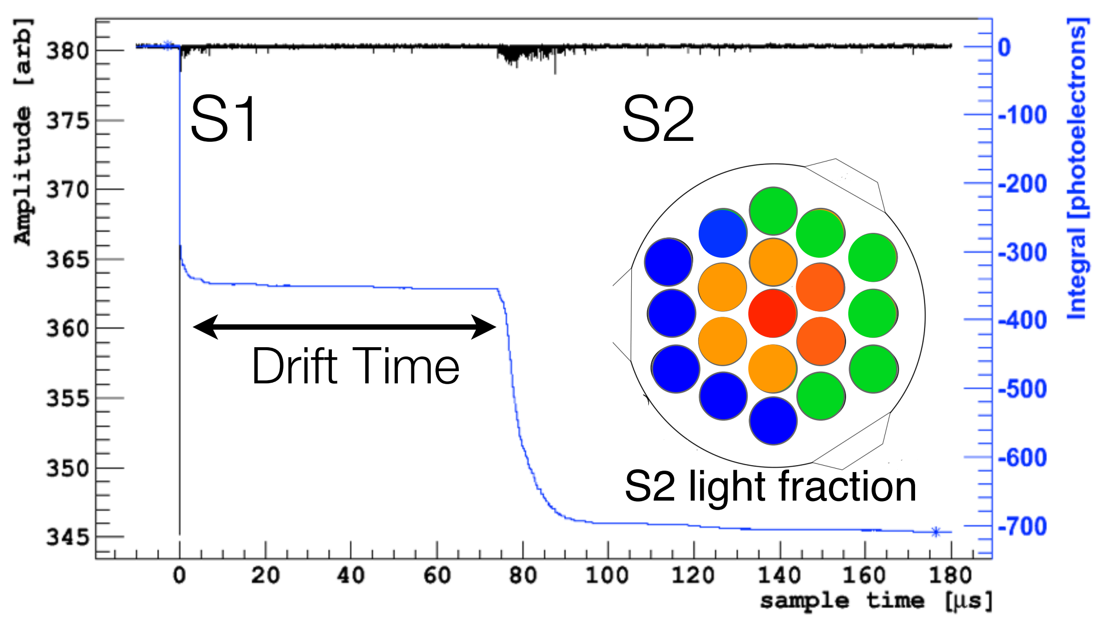
Two Phase Argon TPC





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





- 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.
- x-y position of events are reconstructed from fraction of S2 in each PMT.

Electron drift lifetime > 5 ms, compared to max. drift time of ~ 375 µs.
Electron drift speed = 0.93 mm/µs

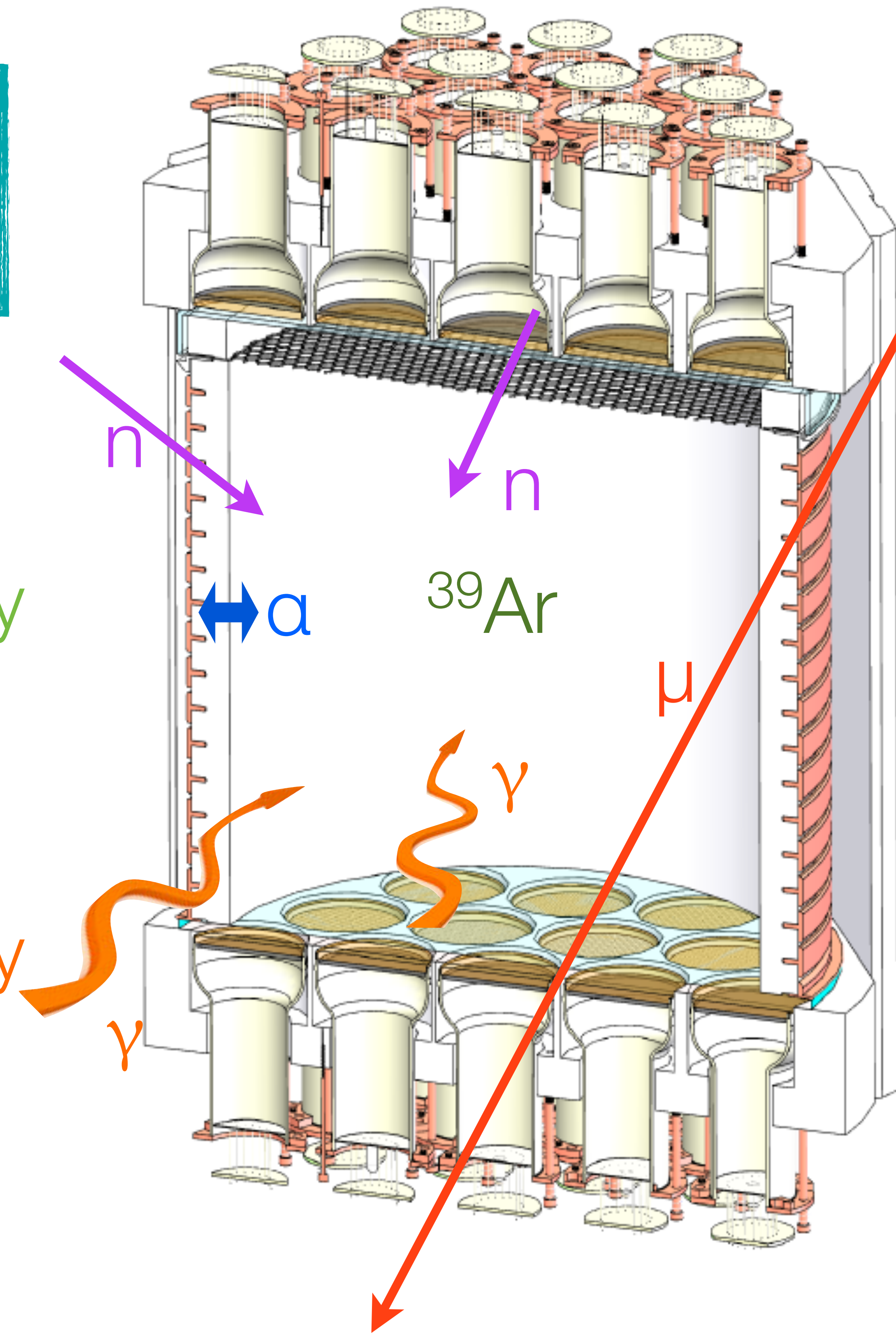
Backgrounds

[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

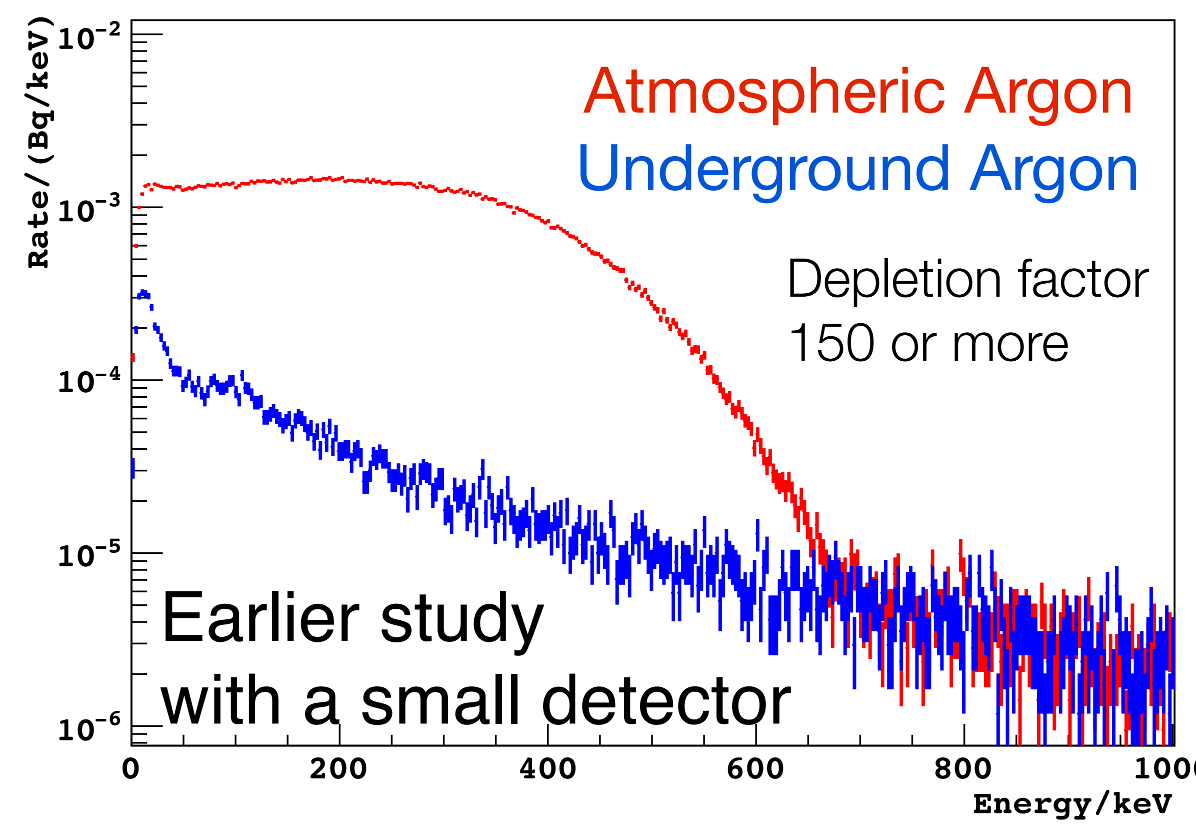
Underground Ar

^{39}Ar Reduction

- 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 Recoil Discrimination

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

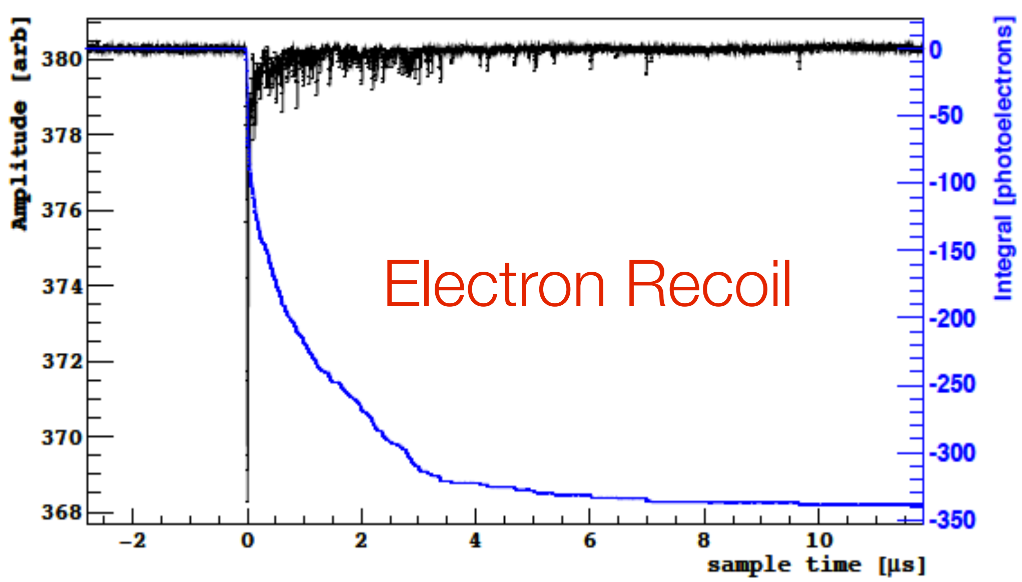
τ singlet ~ 7 ns

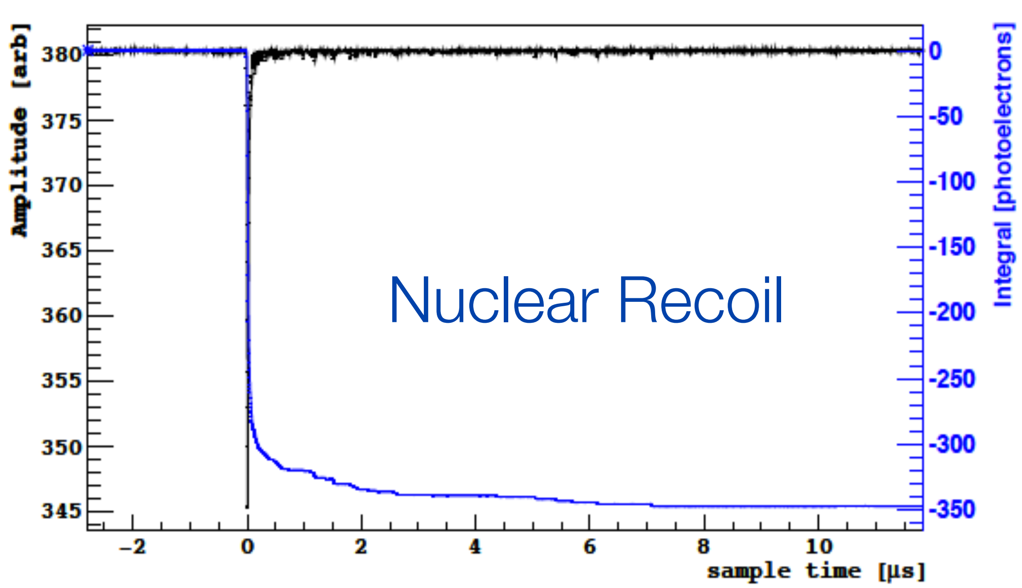
τ triplet ~ 1500 ns

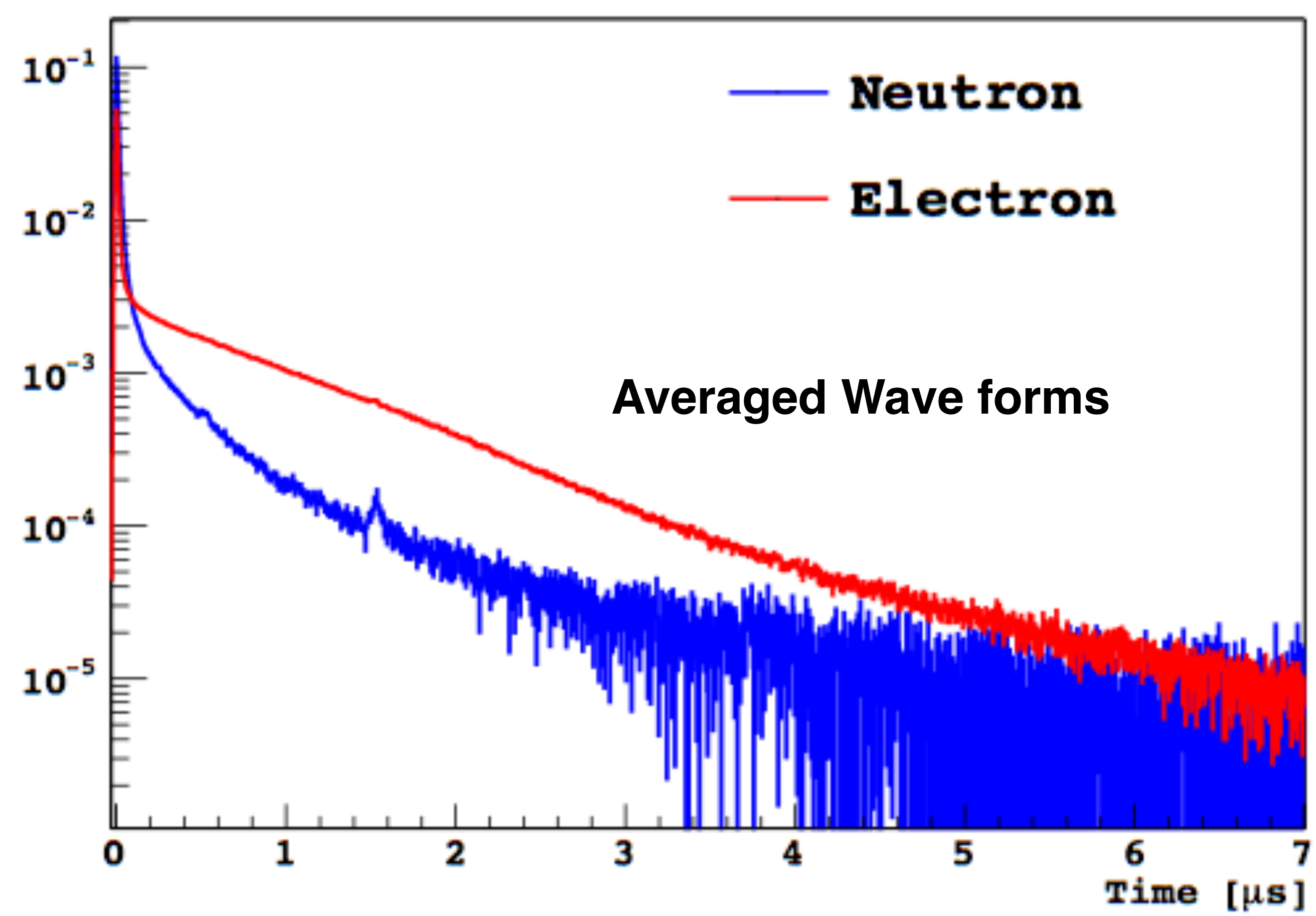
PSD parameter

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

~ Fraction of singlet states





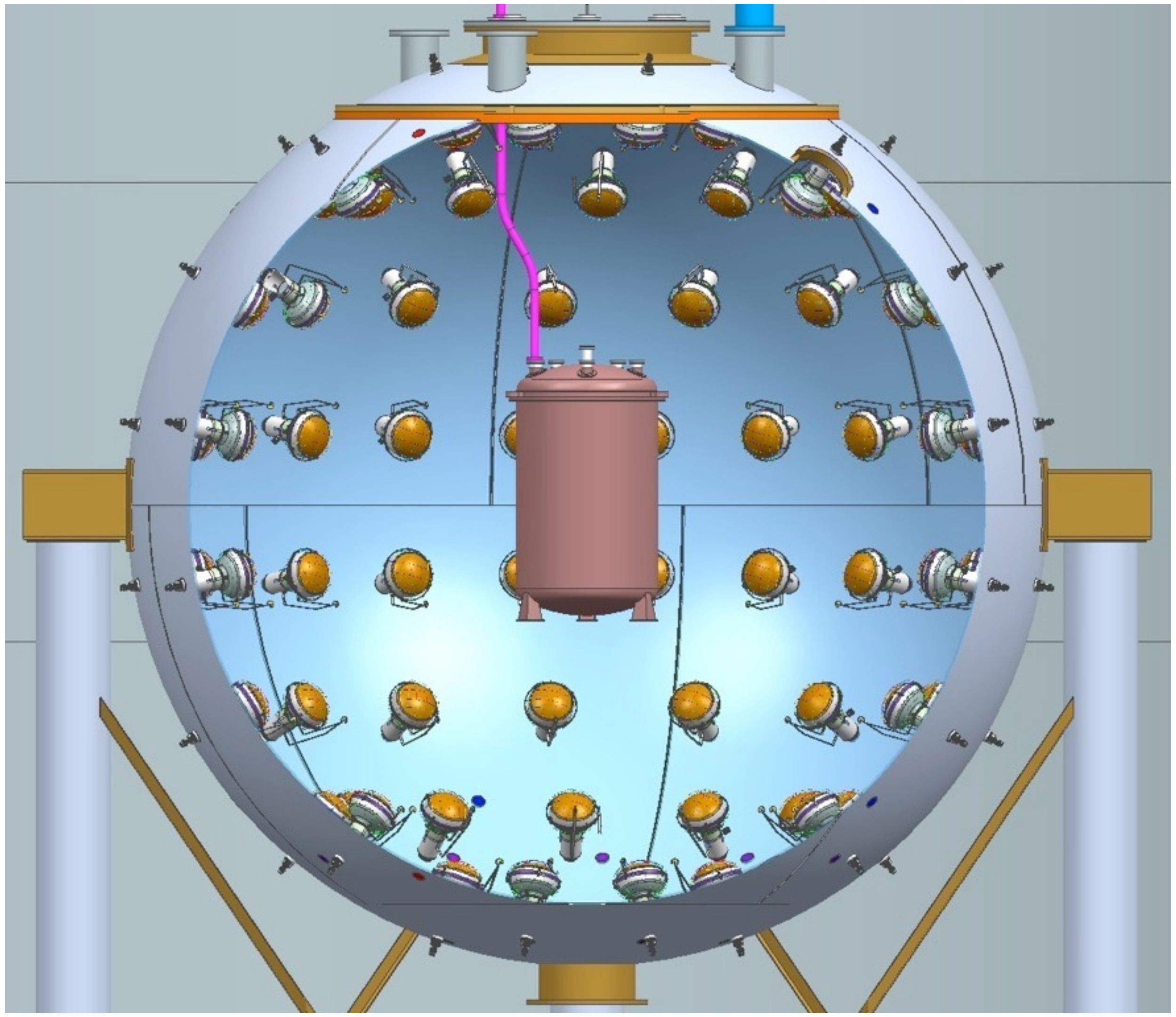


Liquid Scintillator Veto

Neutron Rejection

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



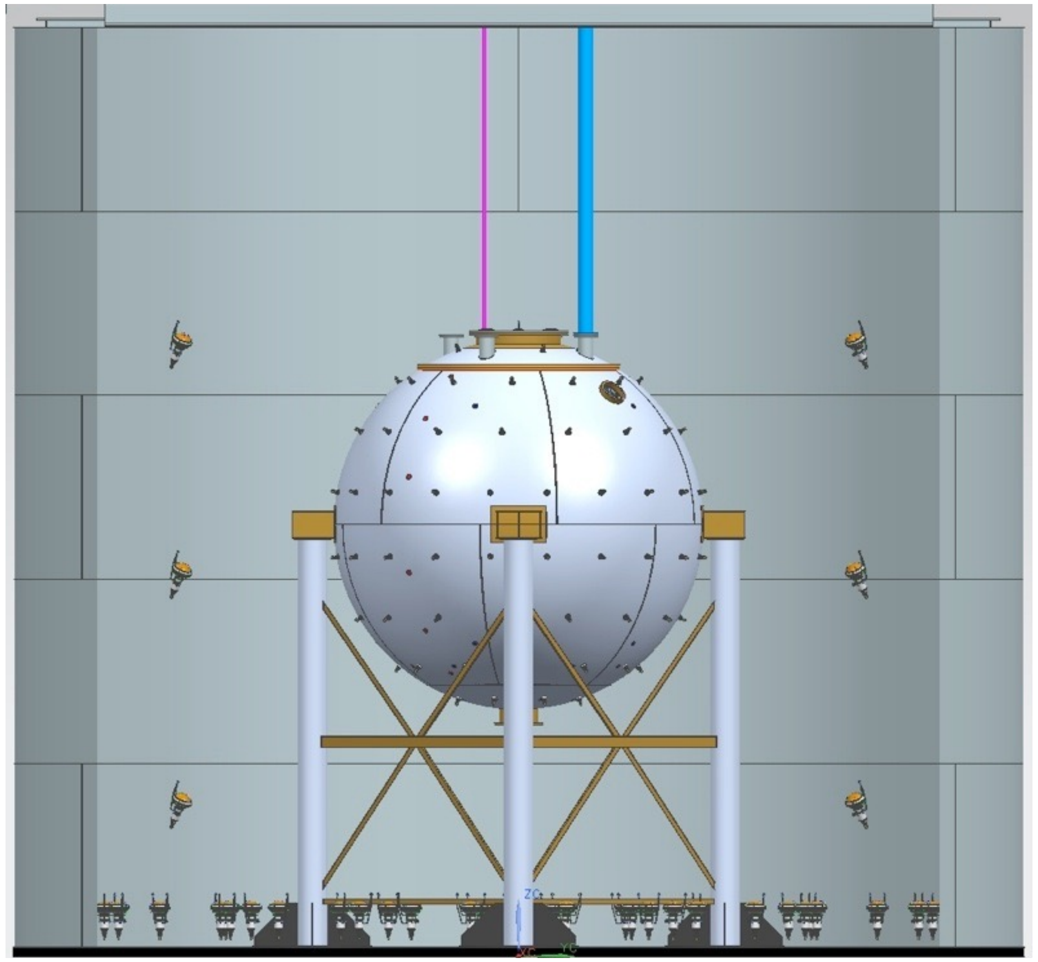
Odd time structure: ^{14}C content is too high (~98% efficiency) to achieve design efficiency (~99.5%) after the first fill.

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

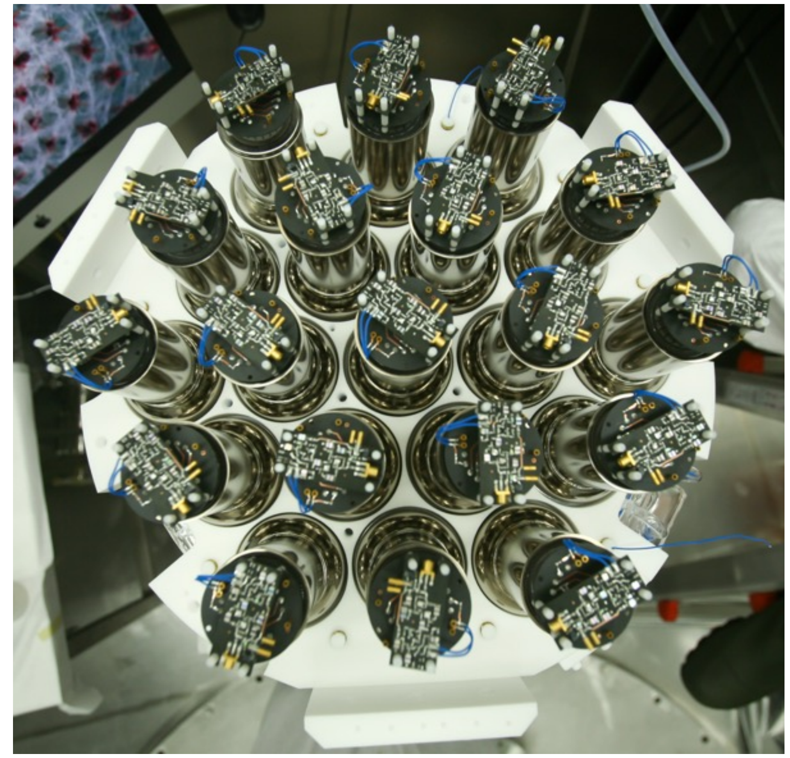
External Water tank

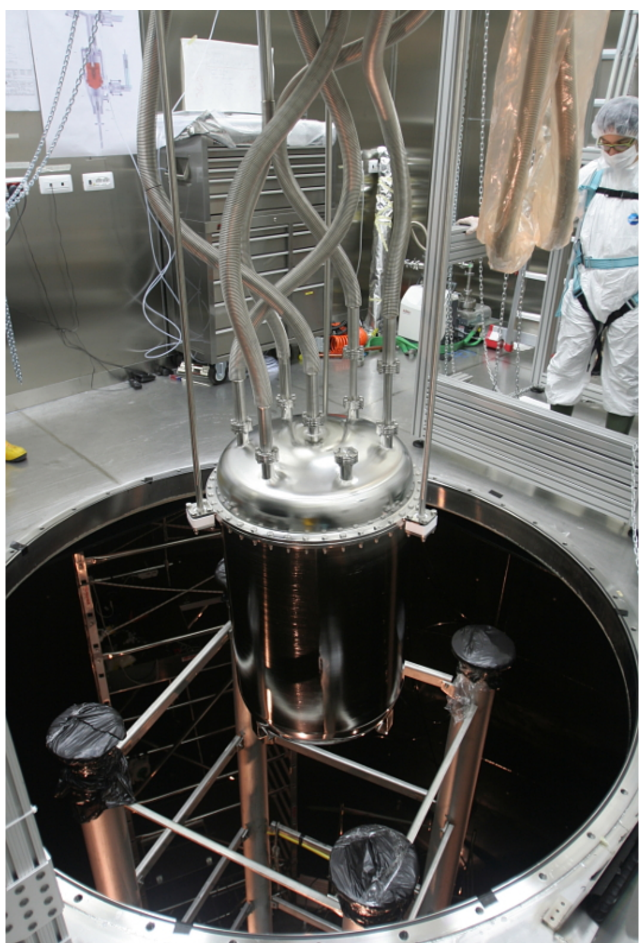
Cosmogenics Rejection

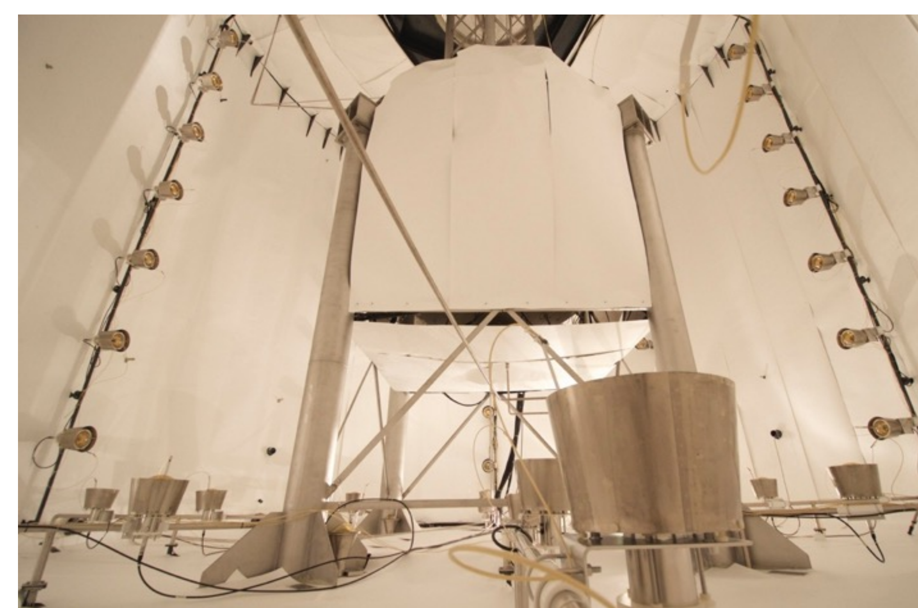
- 80 PMTs within water tank (11 m diameter x 10 m height)
- Acts as a **muon and cosmogenic veto** (~ 99% efficiency)
- Provides **passive γ's and neutron shielding**



DS50 Commissioning (Oct. 2013)

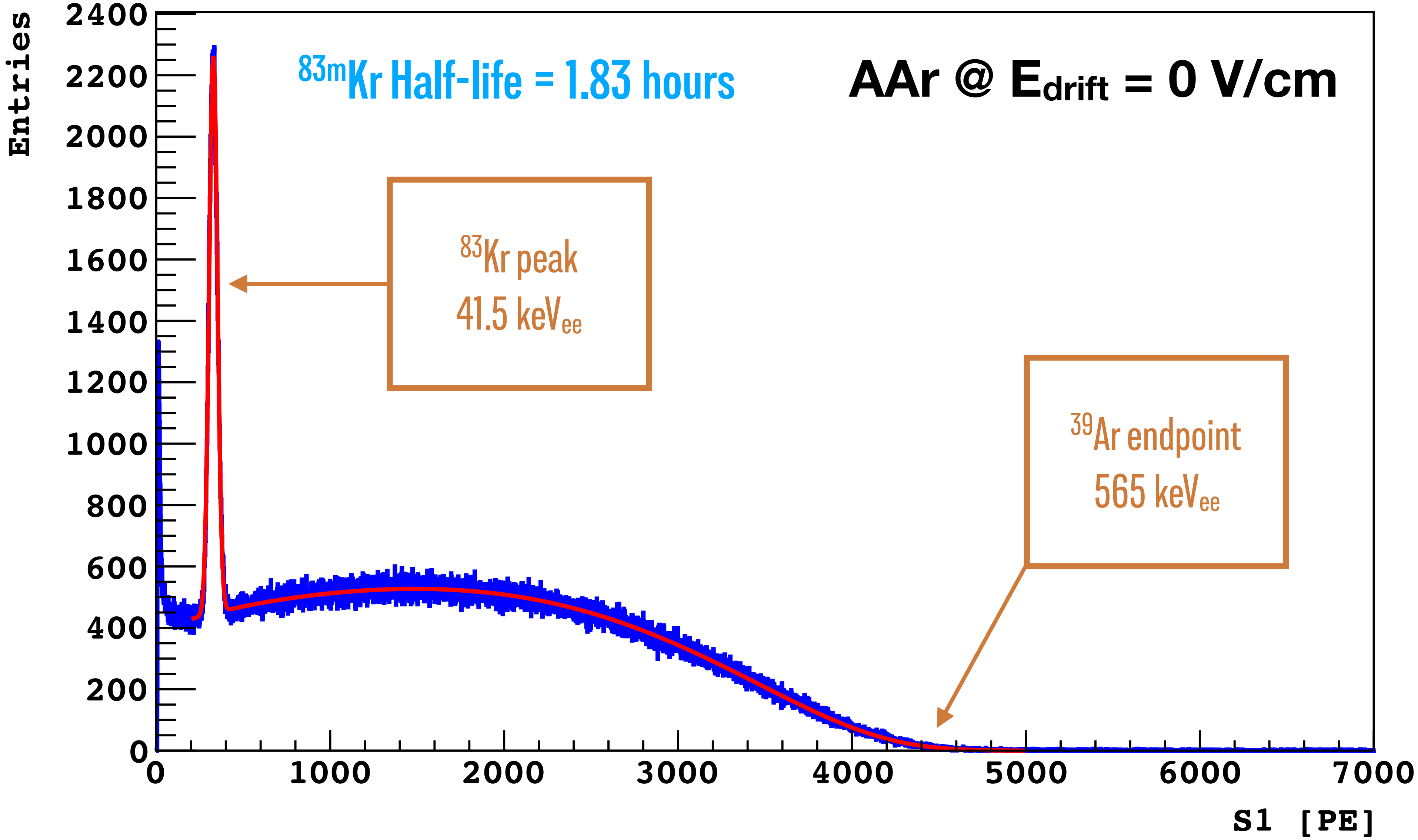






TPC: Electric Recoils calibration

- ^{39}Ar (565 keV$_{ee}$ endpoint) present in AAr
- ^{83m}Kr gas deployed into detector (41.5 keV$_{ee}$)

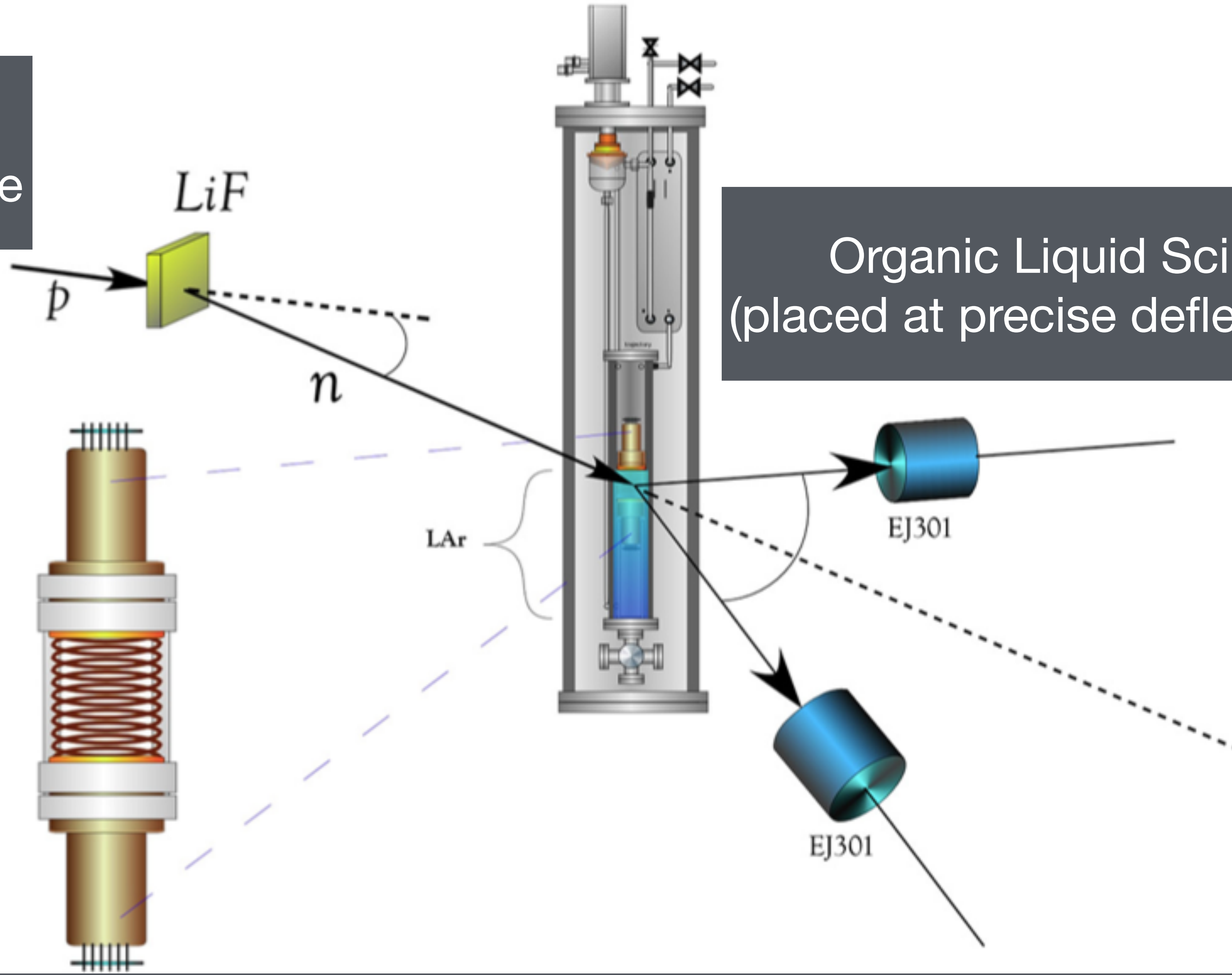


Fits to ^{39}Ar and ^{83m}Kr spectrum indicate
LIGHT YIELD: **7.9 ± 0.4** PE/keV$_{ee}$ at zero field and **7.0 ± 0.3** PE/keV$_{ee}$ at 200 V/cm

For Nuclear Recoils

SCENE
(Scintillation Efficiency of Nuclear Recoils in Noble Elements)

Proton Beam at University of Notre Dame



Organic Liquid Scintillators (placed at precise deflection angles)

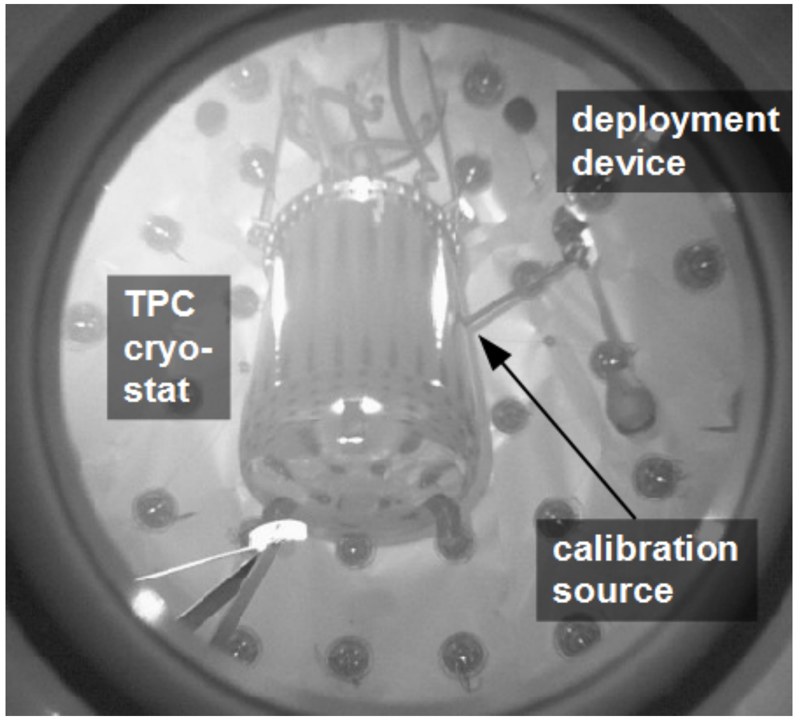
Liquid Argon TPC (based on DarkSide design)

$^{7}Li(p, n)^{7}Be$ 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

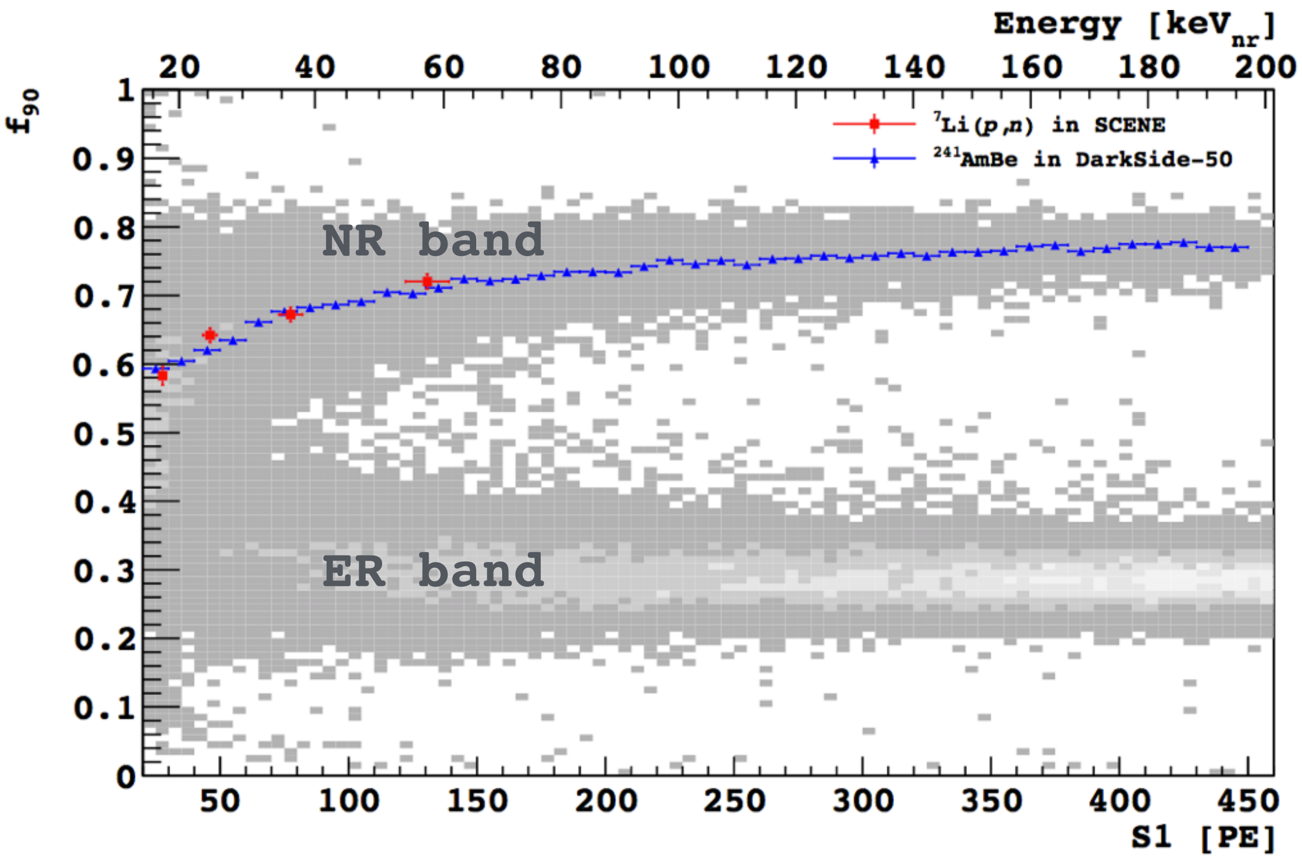
Calibrate both **TPC** and **Neutron veto**

- **Gamma sources:** ^{57}Co (122 keV), ^{133}Ba (356 keV), ^{137}Cs (663 keV)
- **Neutron source:** AmBe w/ and w/o collimator

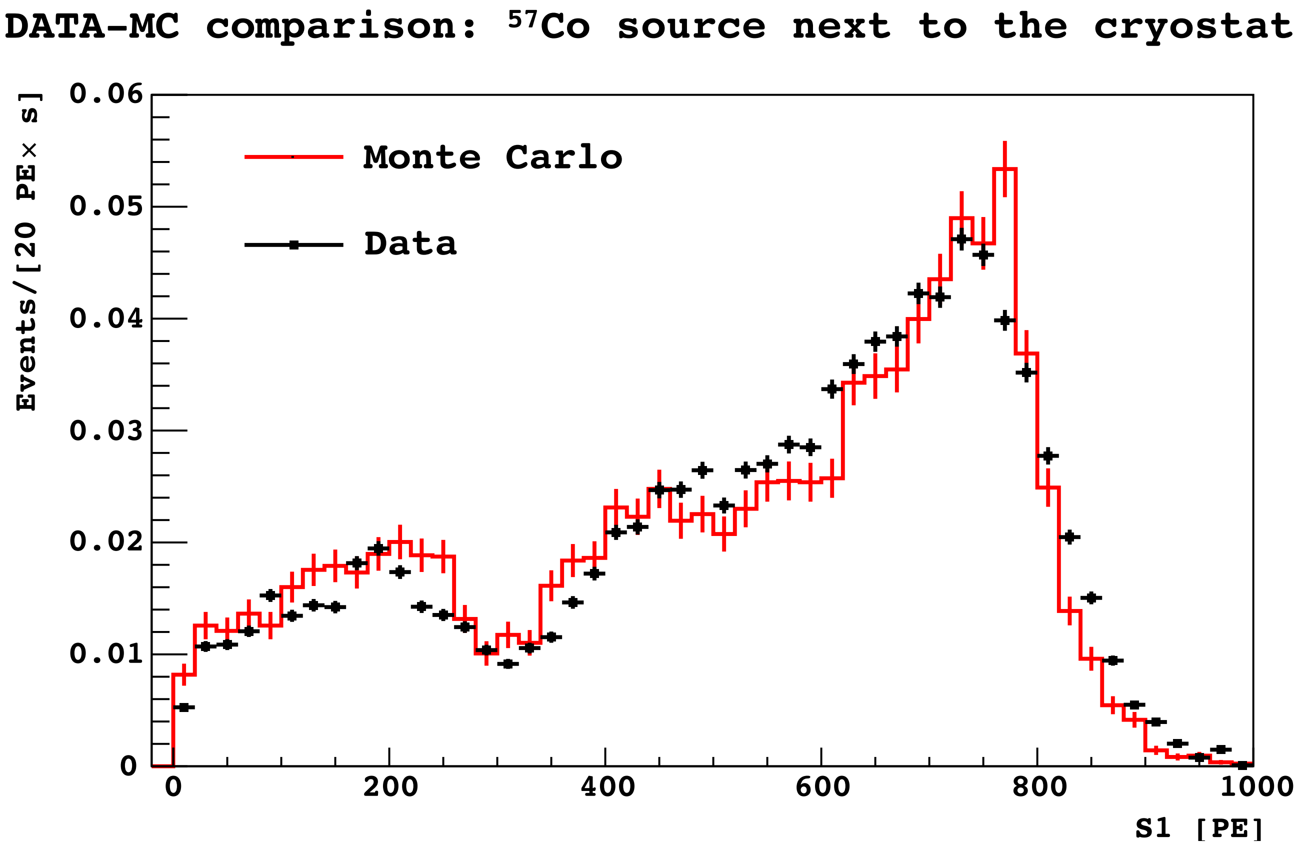


NR band matches with the points extrapolated from SCENE.

NR study (crosscheck of **SCENE** data)



Test of the MC code



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.

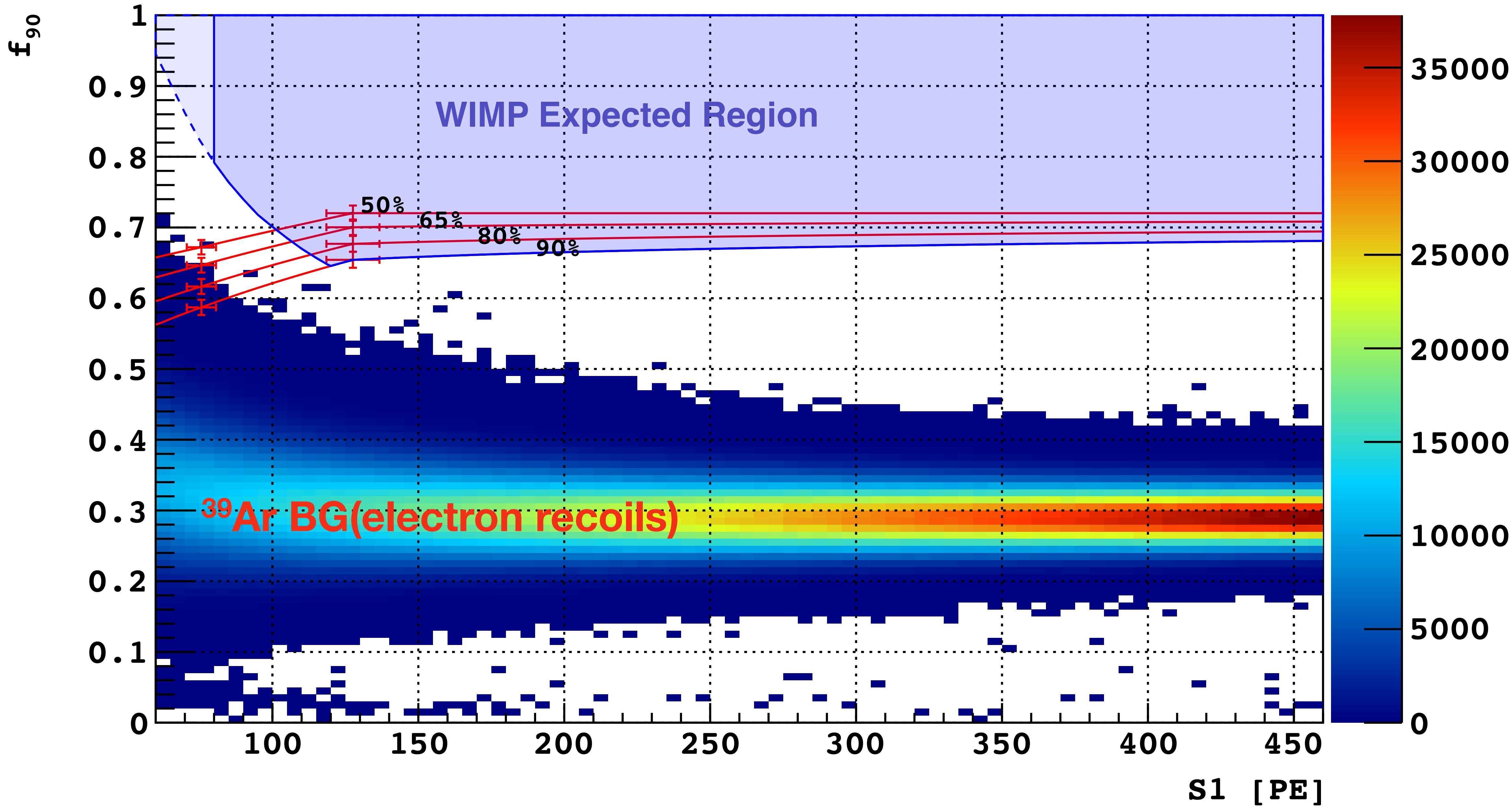
  Mar. to Apr. 2015: Fill with **UAr** and re-commissioning the detector.

  Apr. to Aug. 2015: Accumulate data with **UAr** for **dark matter search**.

The First Physics Result from DS-50

Background-free exposure of 1422 ± 67 kg•day

No background events in nuclear recoil (WIMP) region!

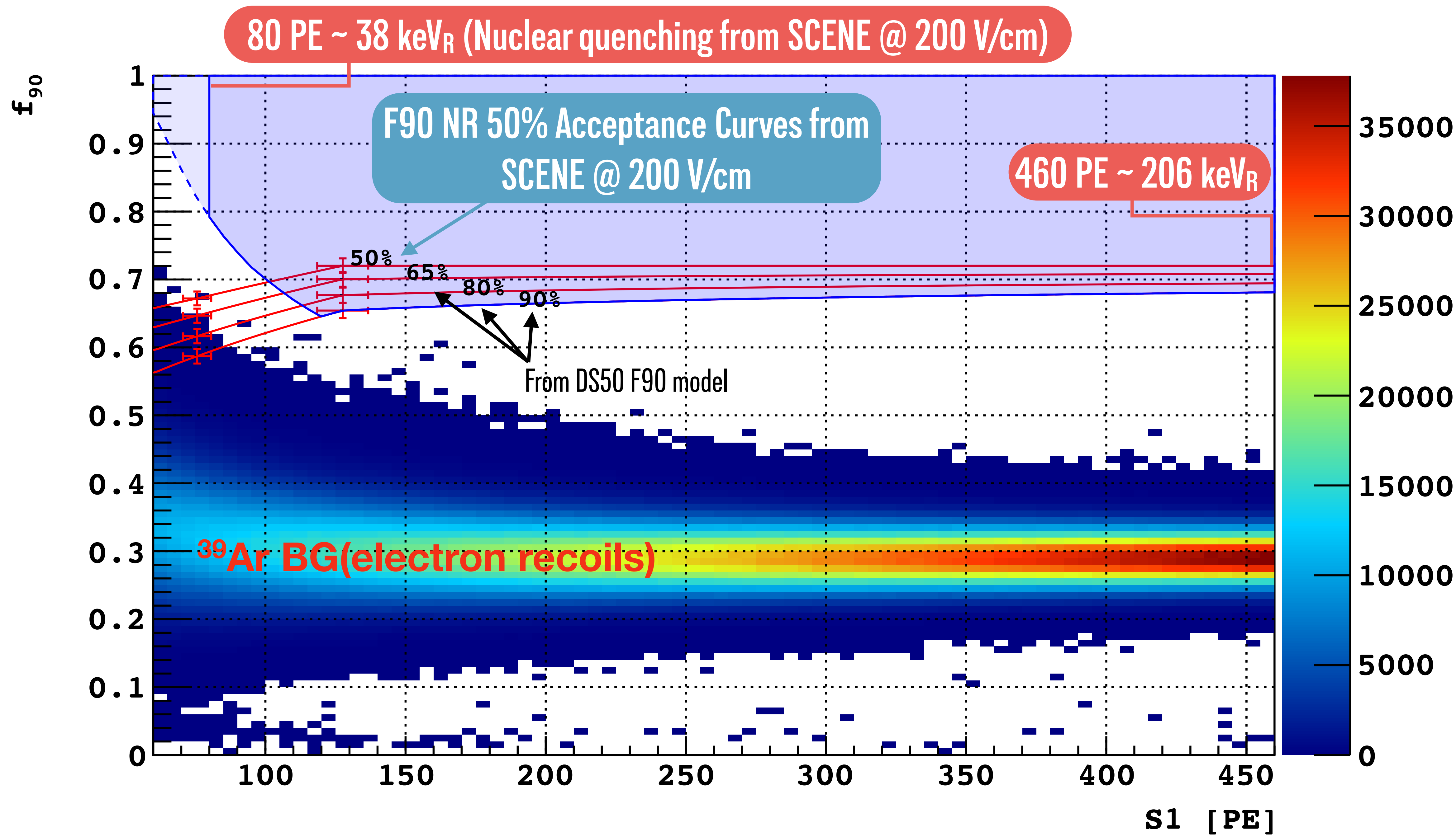


Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

Phys. Lett. B 743 (2015) 456

The First Physics Result from DS-50

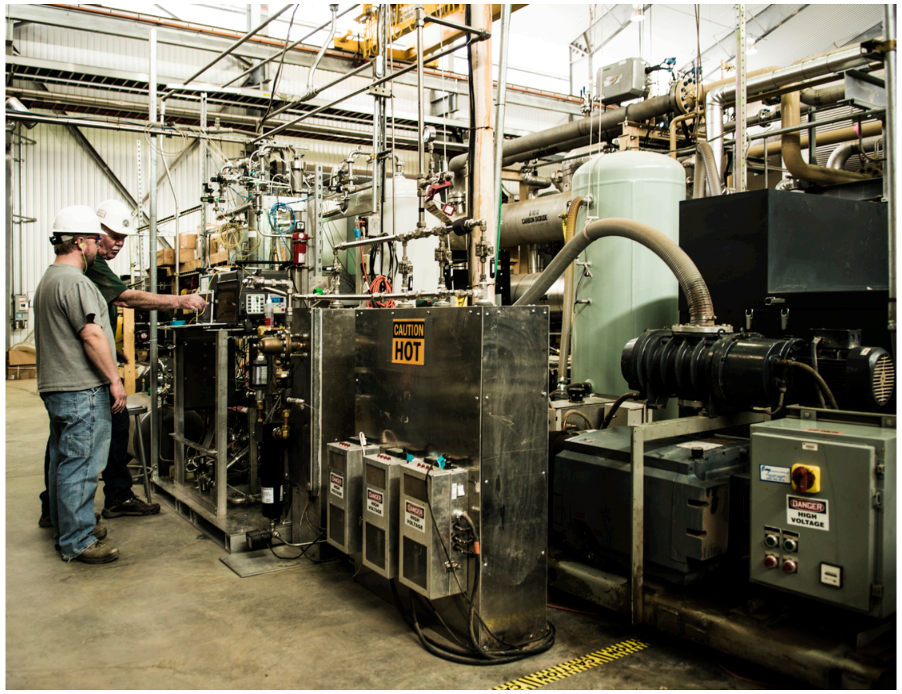
Background-free exposure of 1422 ± 67 kg•day



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

Phys. Lett. B 743 (2015) 456

Underground Ar



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

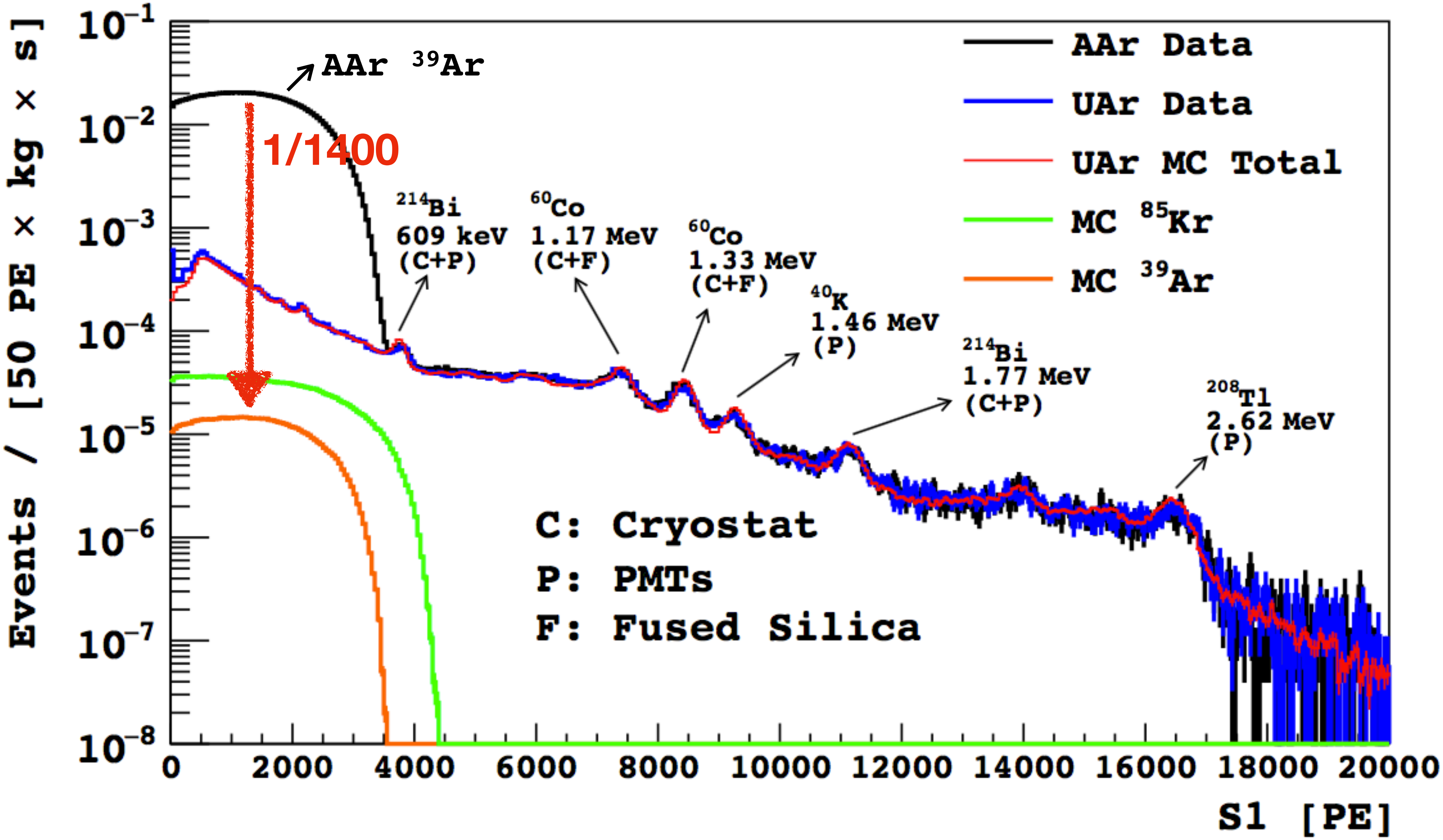
2. Purification at Fermilab
Separate Ar from He and N_2

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

UAr First Results

AAr vs UAr. Live-time-normalized S1 pulse integral spectra at **Zero** field.

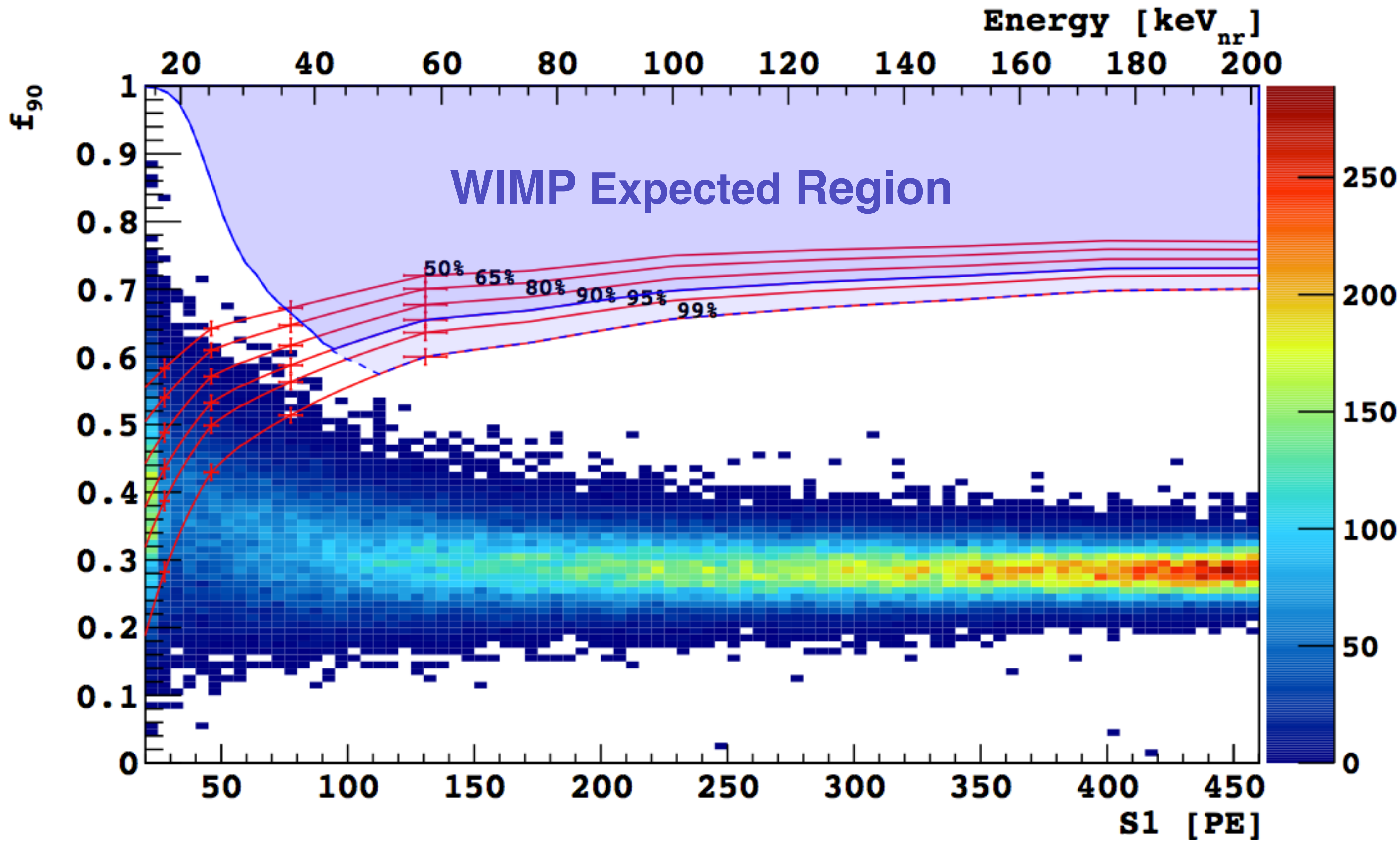
^{39}Ar reduction factor of ~1400!



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

UAr First Results

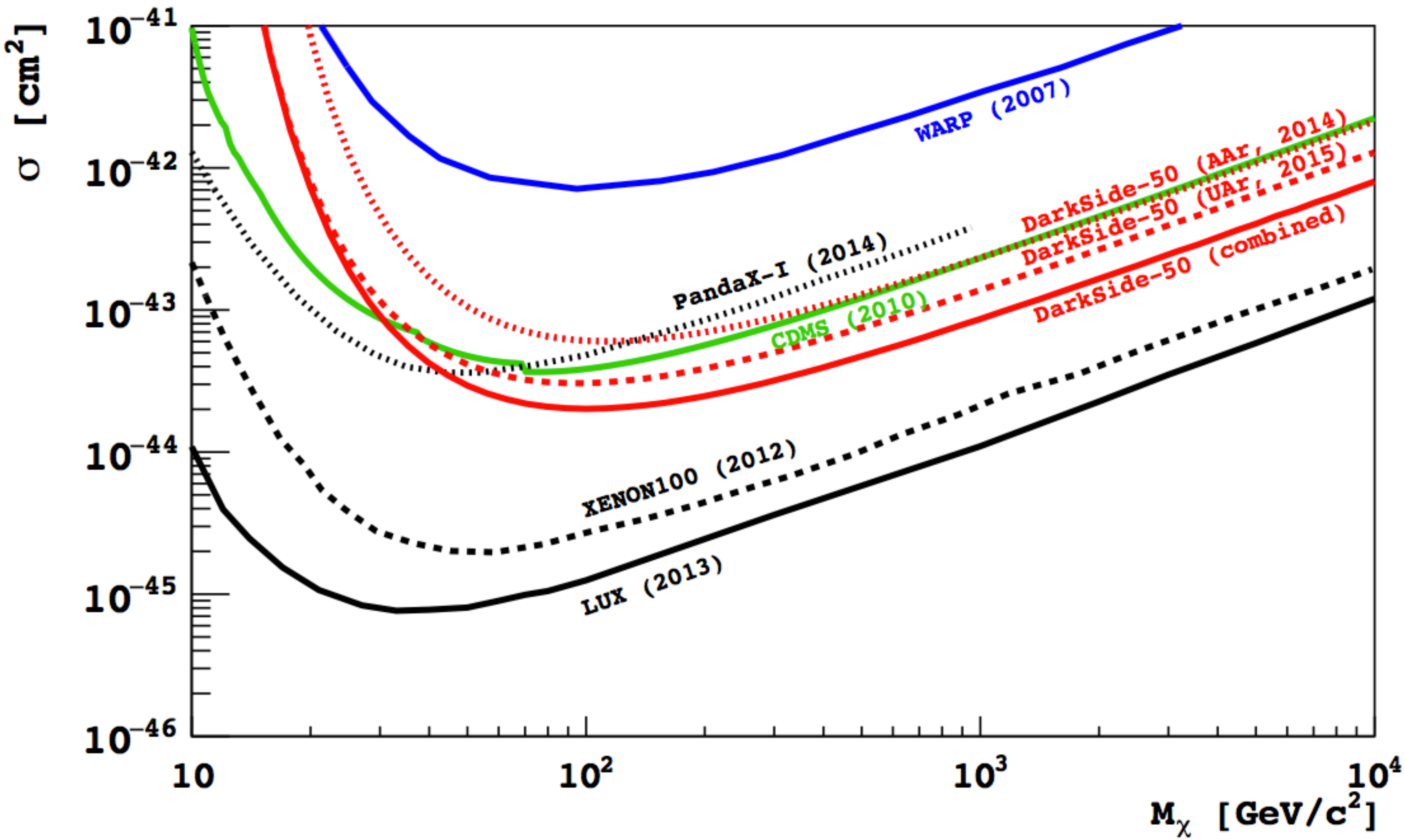
No background events in nuclear recoil (WIMP) region!



71 live-days after all cuts. (2616±43) kg day exposure.
Single-hit interactions in the TPC, no energy deposition in the veto.

arXiv:1510.00702

UAr First Results



Best limit to date, with argon target, third best limit behind LUX & Xenon100.

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).

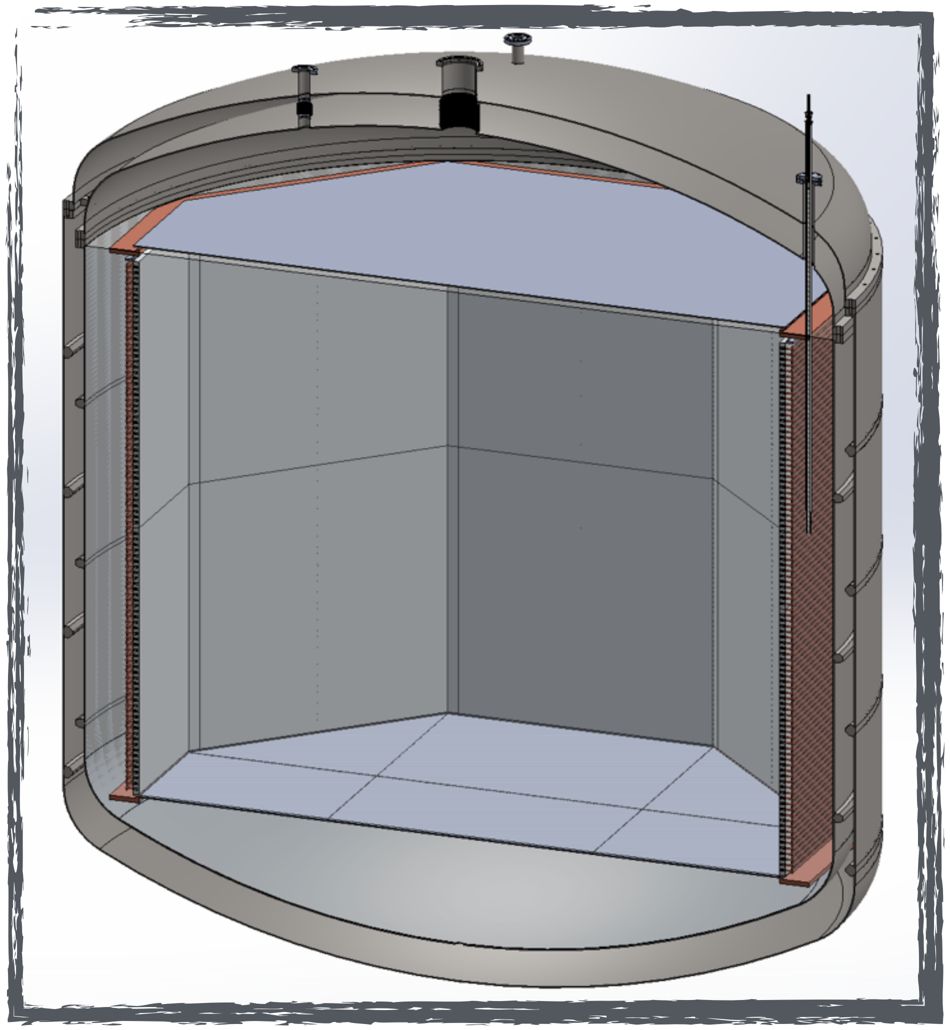
Concentration of ^{39}Ar in **UAr** is **1400** times lower than in **AAr**.

With the BG-free exposure of 1422 kg · day fiducial and depletion factor of 1400, DarkSide demonstrates **^{39}Ar BG** rejection at level of **5.5 tonne·year** with UAr.

Future detectors are planned and Letter of Intent was submitted to LNGS April 27 2015.

THE END

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 [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}

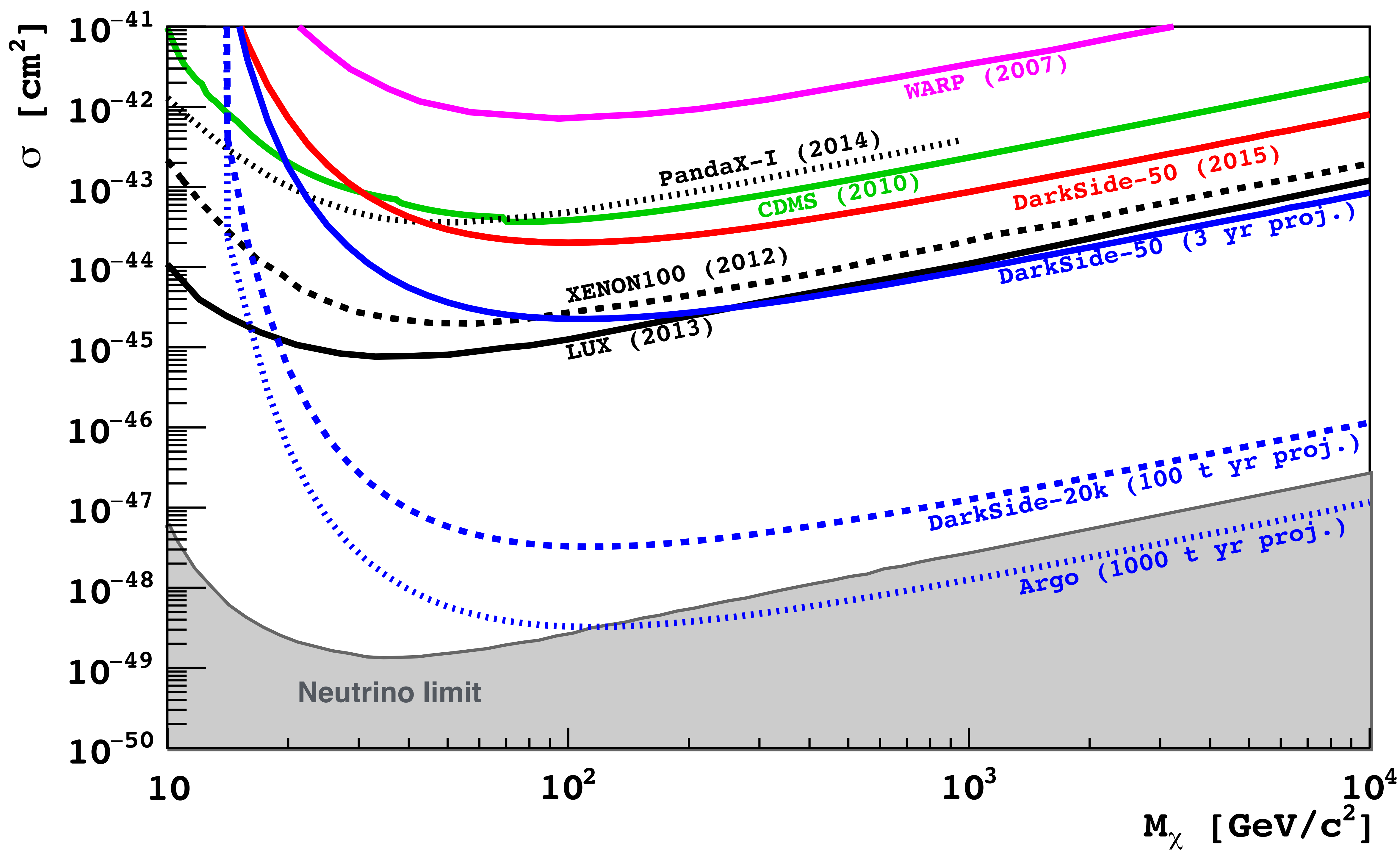
Experiment	σ [cm^2] @1 TeV/c^2	σ [cm^2] @10 TeV/c^2
LUX [10k kg×day Xe]	1.1×10^{-44}	1.2×10^{-43}
XENON [7.6k kg×day Xe]	1.9×10^{-44}	1.9×10^{-43}
DS-50 [1.4k kg×day Ar]	2.3×10^{-43}	2.1×10^{-42}
ArDM [1.5 tonne×yr Ar]	8×10^{-45}	7×10^{-44}
DEAP-3600 [3.0 tonne×yr Ar]	5×10^{-46}	5×10^{-45}
XENON-1ton [2.7 tonne×yr Xe]	3×10^{-46}	3×10^{-45}
LZ [15 tonne×yr Xe]	5×10^{-47}	5×10^{-46}

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}

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}

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}

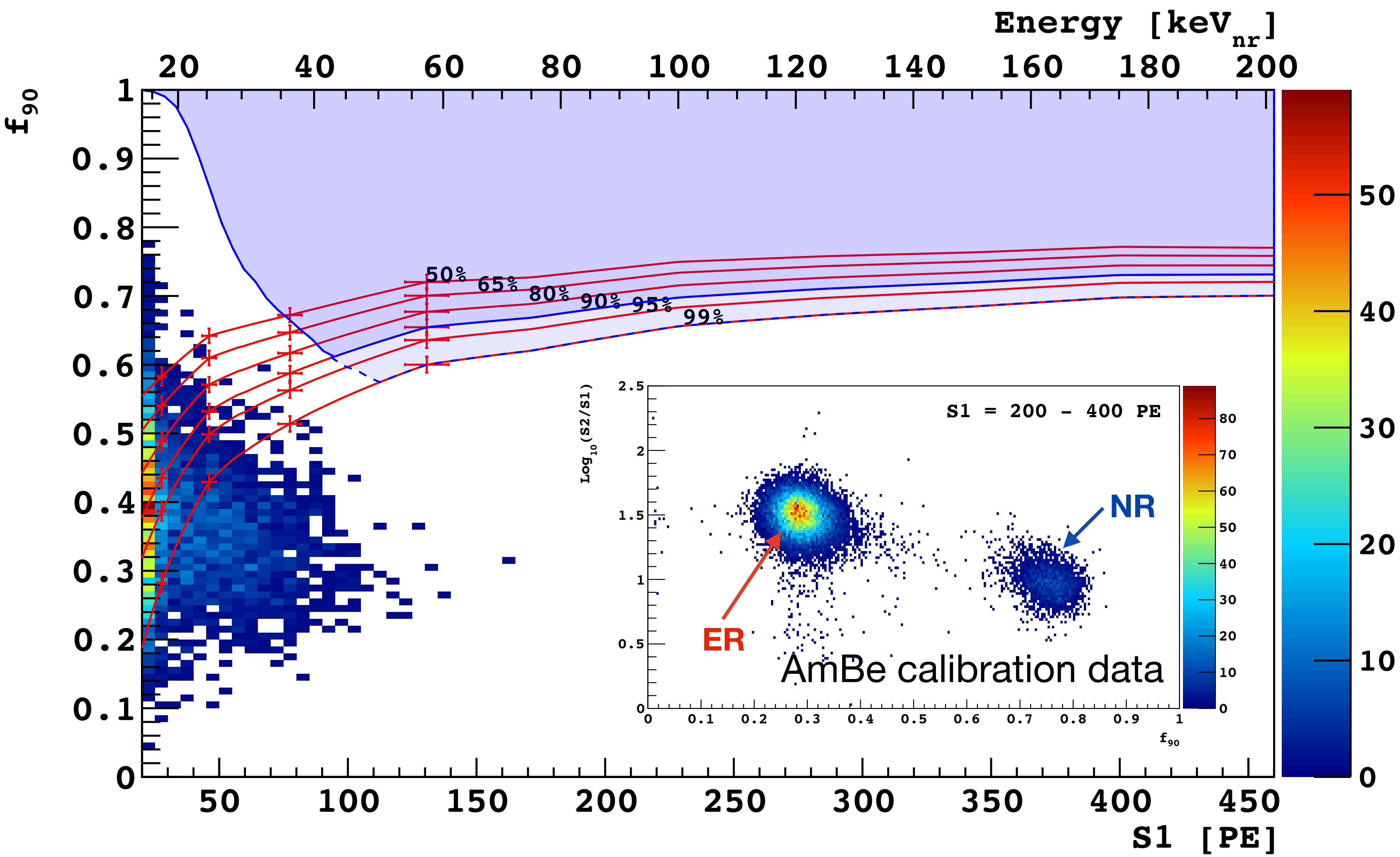
Expected sensitivity



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
C. Jollet, A. Meregaglia - IPHC Strasbourg
M. Misziazek, M. Woicik, G. Zuzel - Jagiellonian University
K. Fomenko, A. Sotnikov, O. Smirnov - JINR
M. Skorokhvatov - Kurchatov Institute Moscow
A. Derbin, V. Muratova, D. Semenov, E. Unzhakov - PNPI Saint Peterburg
S. De Cecco, C. Giganti - LPNHE Paris
H. O. Back - PNNL
M. Ghioni, A. Gulinatti, L. Pellegrini, I. Rech, A. Tosi, F. Zappa - Politecnico di Milano
C. Galbiati, A. Goretti, A. Ianni, P. Meyers, M. Wada - Princeton University
A. Chepurnov, G. Girenok, I. Gribov, M. Gromov, I. Zilcov - SINP MSU Moscow
C.J. Martoff, J. Napolitano, J. Wilhelmi - Temple University
E. Pantic - UCDavis
Y. Suvorov, H. Wang - UCLA
A. Pocar - UMass Amherst
A. Machado, E. Segreto - Campinas
A. Devoto, M. Lissia, M. Mascia, S. Palmas - Università & INFN Cagliari
M. Pallavicini, G. Testera, 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

UAr First Results w/ S2/S1 cut

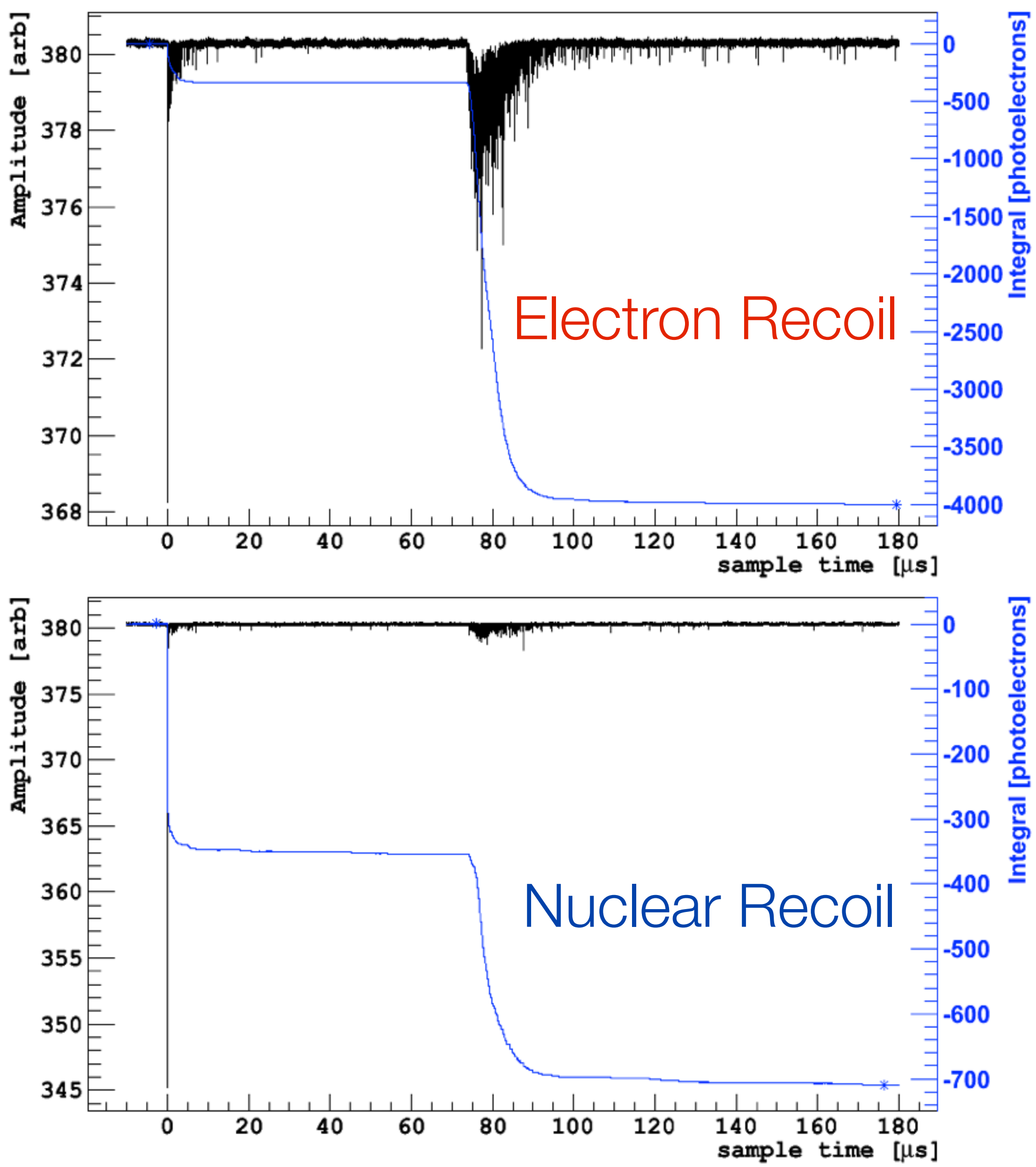


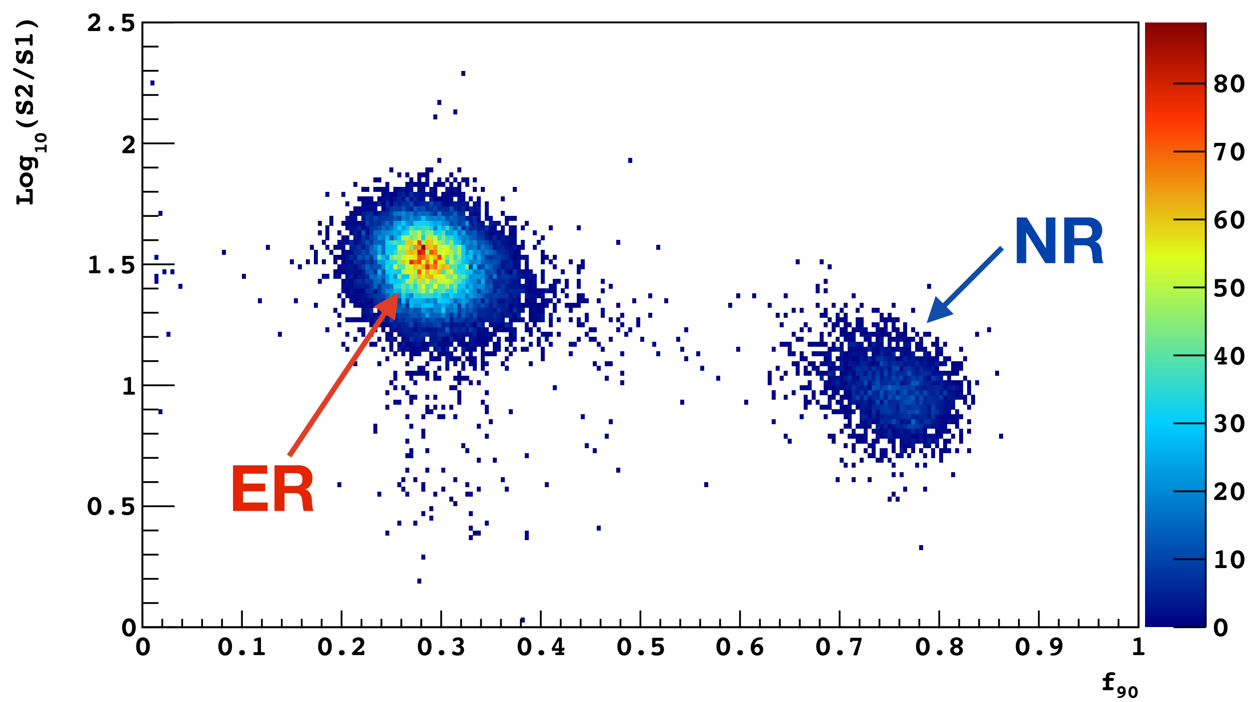
We have another discrimination power to suppress ERs (S2/S1 cut w/ 50% acceptance of NRs).

S2/S1

Electron Recoil Discrimination

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

Radon-Free Clean Rooms

Surface contamination

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