The DarkSide physics program and its recent results

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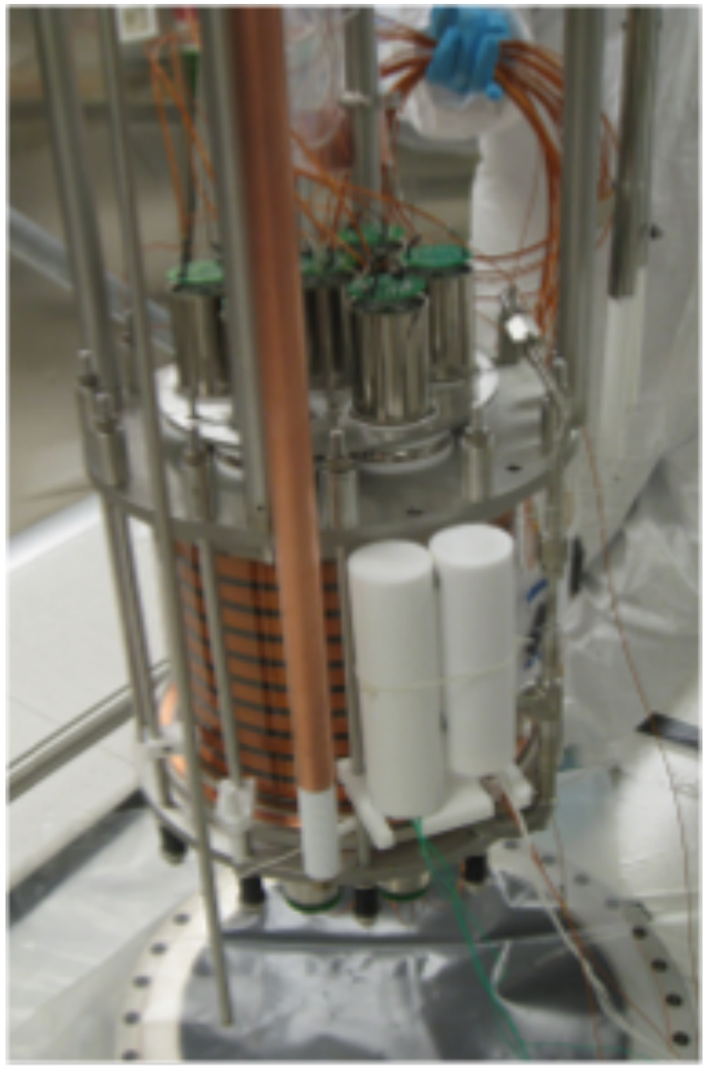
DarkSide Keywords

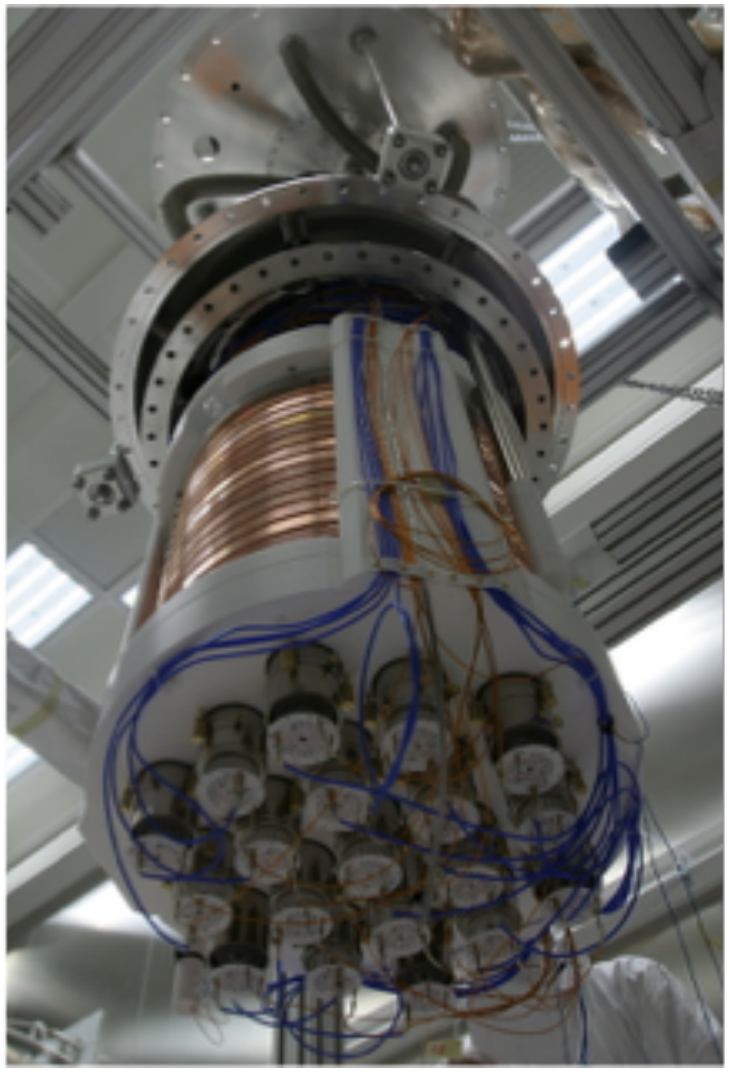
- ➡ Direct detection of dark matter
- ➡ Wimp-nucleus scattering in **liquid Argon**
- ➡ Dual-phase Time Projection Chambers (TPC)
- ➡ Multi-stage approach
- ➡ At Laboratori Nazionali del Gran Sasso (LNGS) in central Italy

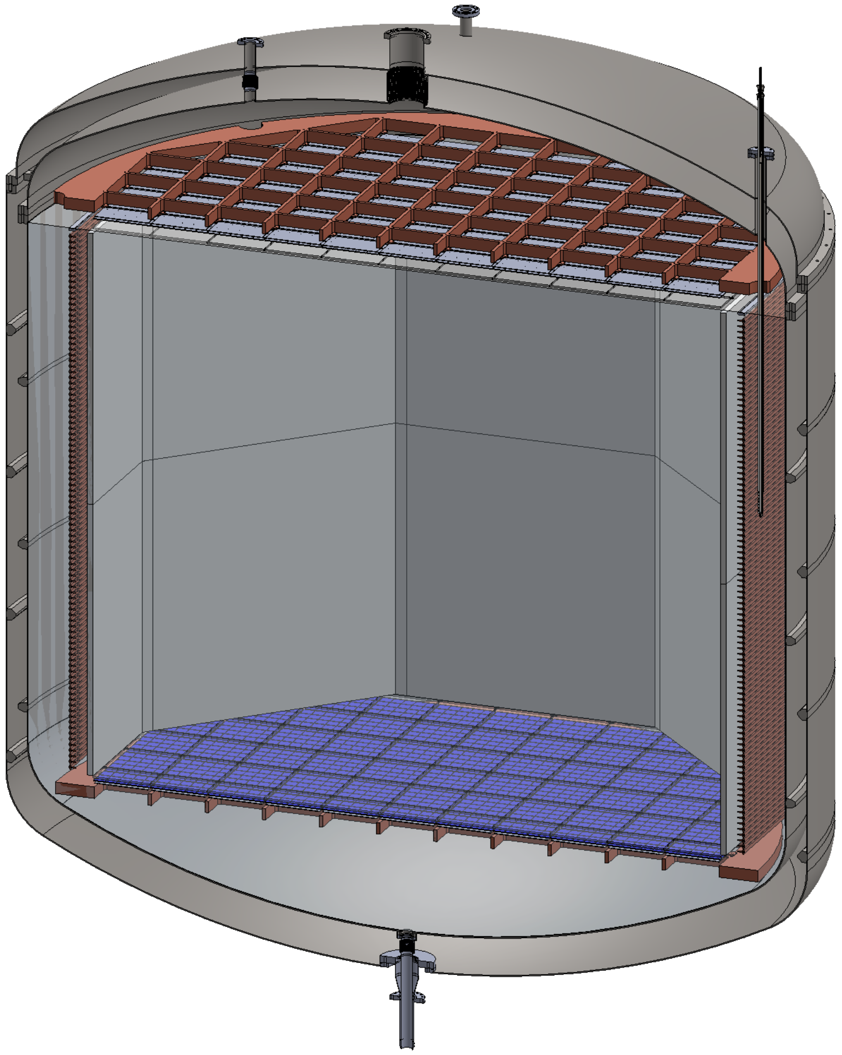
  rock coverage: ~3800m w.e.
- ➡ Very low intrinsic background levels
- ➡ Electron recoil discrimination
- ➡ Neutron active suppression

Background-free operation

DarkSide Multi-stage Program







DarkSide-10
Prototype detector

DarkSide-50
First physics detector
$\sim 10^{-45}$cm^2 @100GeV

DarkSide-20k
Future multi-ton detector
$\sim 10^{-47}$cm^2 @100GeV

Deep underground location at LNGS, Italy.

DarkSide-50

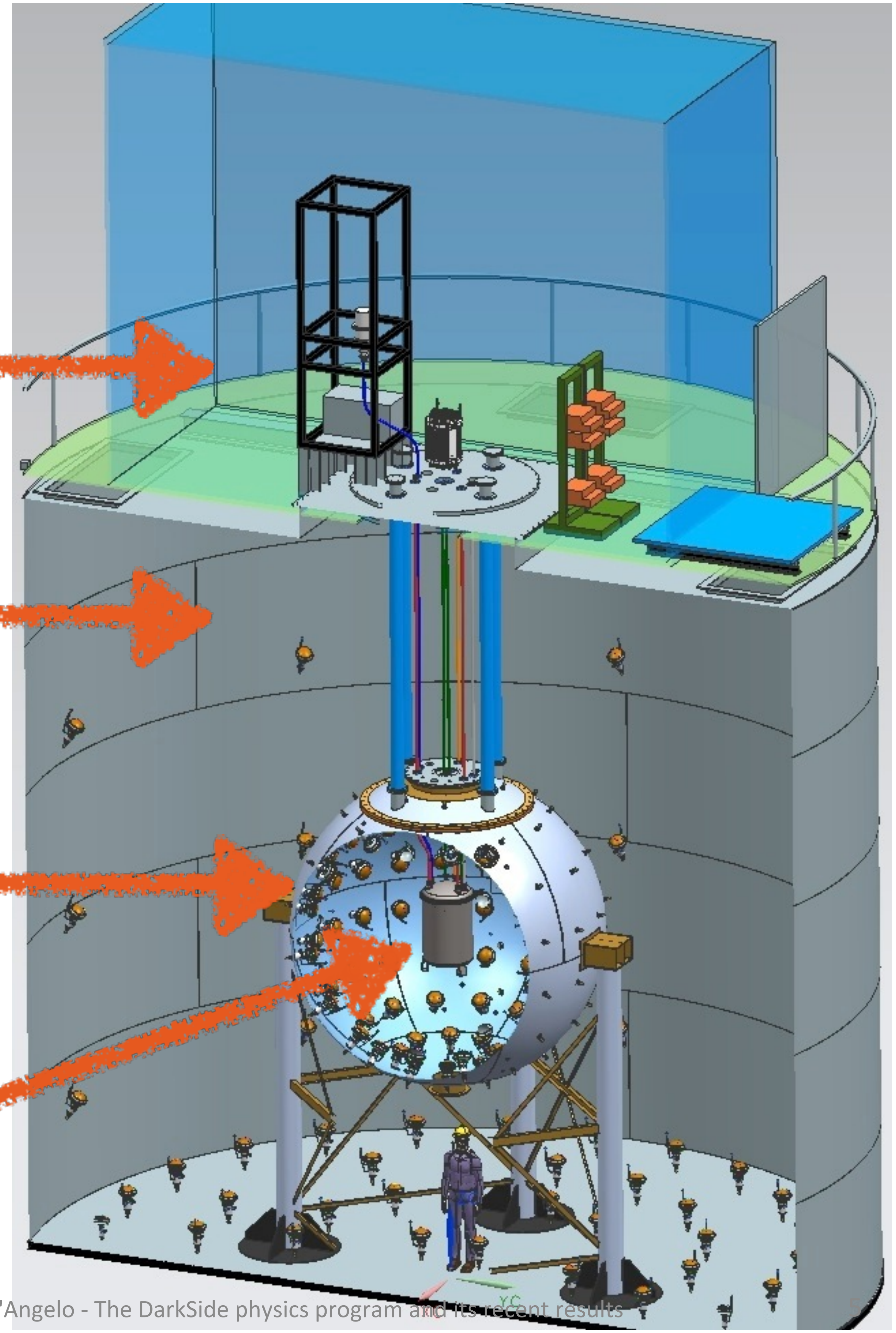
Housed in CTF
Borexino Counting Test Facility

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

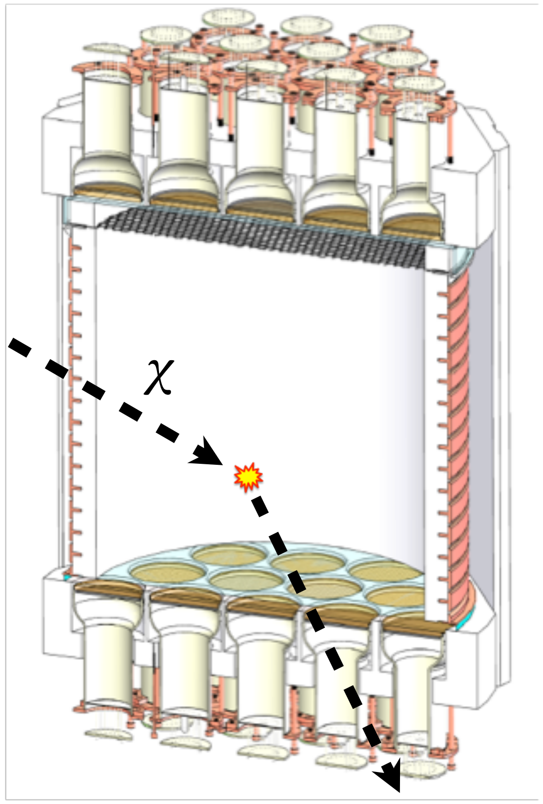
1,000-tonne Water-based
Cherenkov **Cosmic Ray Veto**

30-tonne Liquid Scintillator
Neutron and γ's Veto

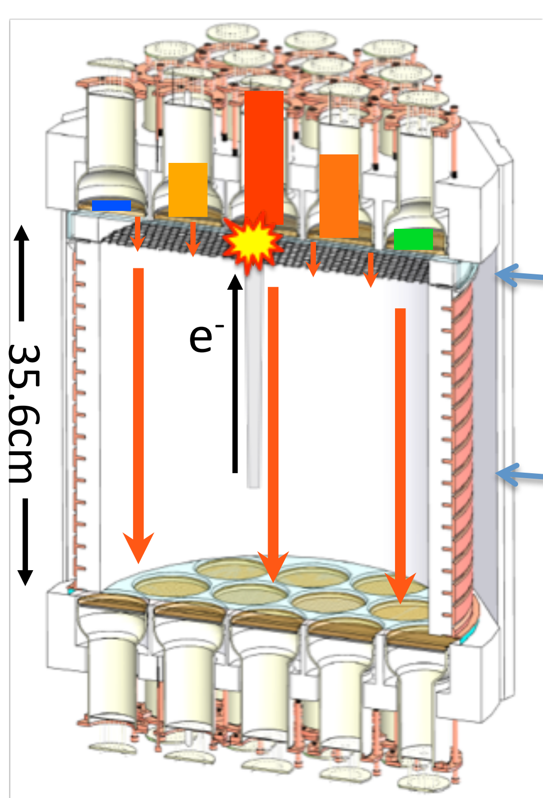
Inner detector **TPC**



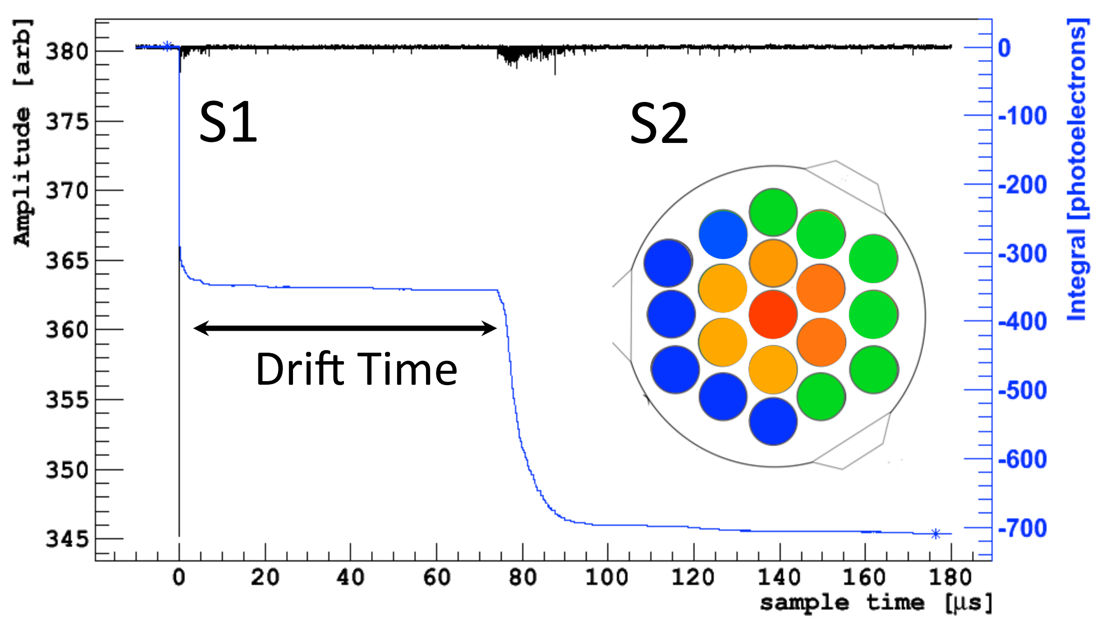
Two Phase Argon TPC



19x2 3" PMTs
~20% photocathode coverage
~60% of end plate surface



Total Ar mass: 145kg
Active mass: 49.4kg
Fiducial mass: 44.9kg



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

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

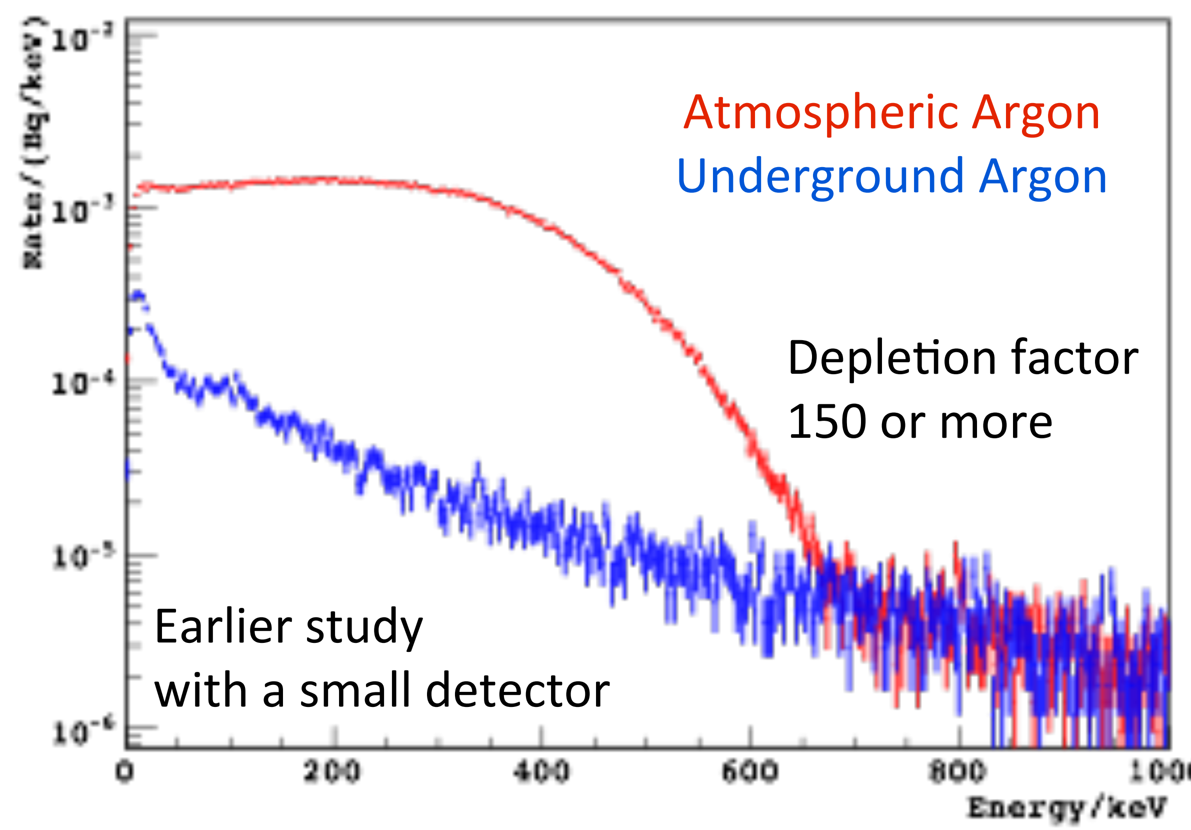
- Nuclear Recoil **excites** and **ionizes** the liquid argon, producing **scintillation** light (S1) that is detected by the photomultipliers
- The electrons are extracted into the gas region, where they induce **electroluminescence** (S2)
- The time between the S1 and S2 signals gives the vertical 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

Underground Ar

- Intrinsic ^{39}Ar radioactivity in atmospheric **argon** (~1 Bq/kg) 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, produced via ^{40}Ar(n,2n)^{39}Ar.
  It is a β emitter with Q=565 keV and $T_{1/2}$=269 years

- The activity in argon from **underground sources** can be significantly lower
- Identified source in Colorado, measured to have <6.5mBq/kg, i.e. > 150 times lower rate compared to atmospheric argon.
- Plant (including cryogenic distillation at FNAL) produces ~0.5 kg/d
- First results with UAr in this talk



arXiv:1204.60111 [physics.ins-det]

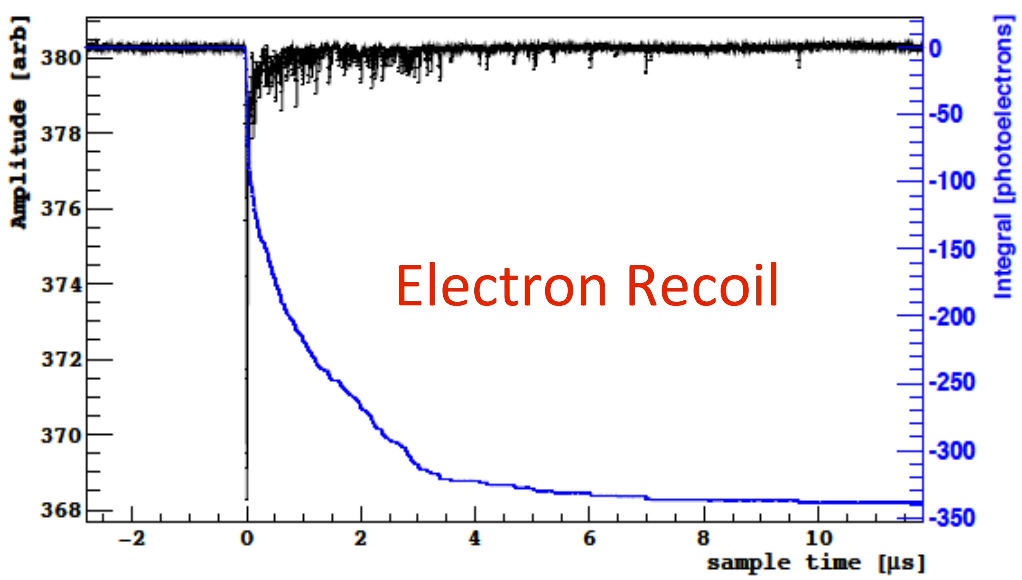
Pulse Shape Discrimination

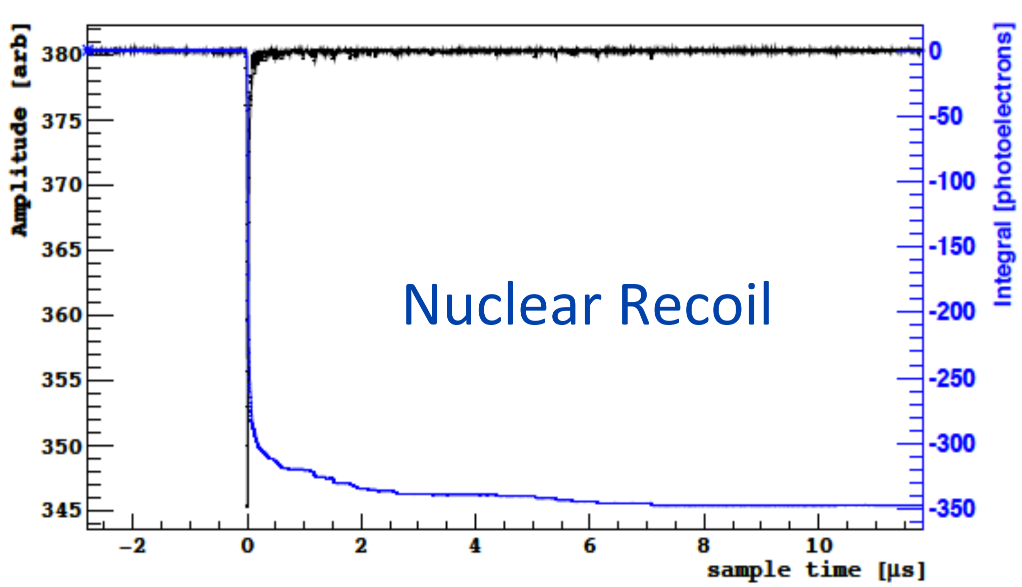
Electron and nuclear recoils produce different excitation densities in the argon, leading to different **ratios of singlet and triplet excitation states**

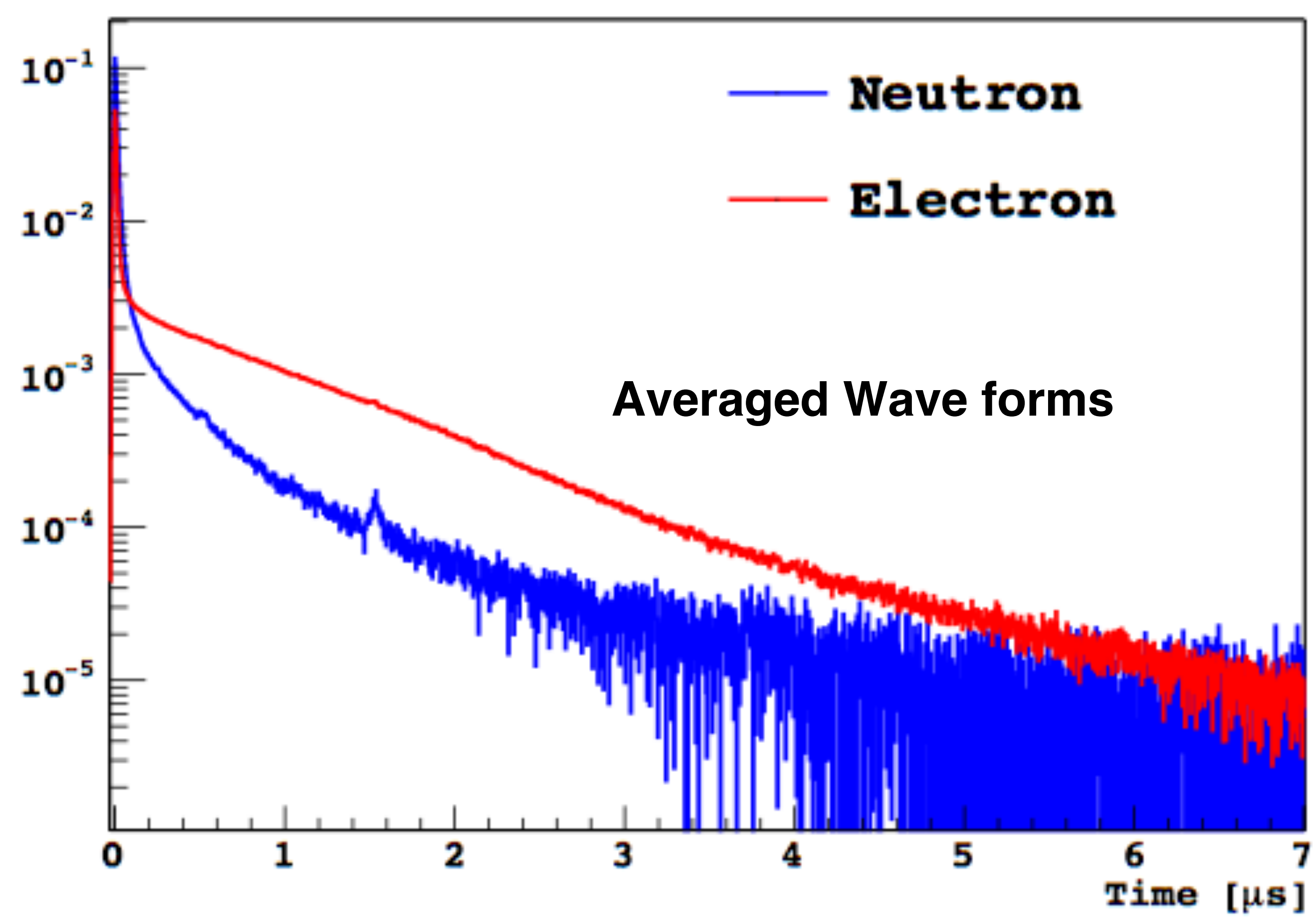
$T_{singlet} \sim 7$ ns

$T_{triplet} \sim 1500$ ns

$$F_{90} = \frac{\int_0^{90ns} dt\, f(t)}{\int_0^{\infty} dt\, f(t)} = \begin{cases} 0.3 \text{ ER} \\ 0.7 \text{ NR} \end{cases}$$



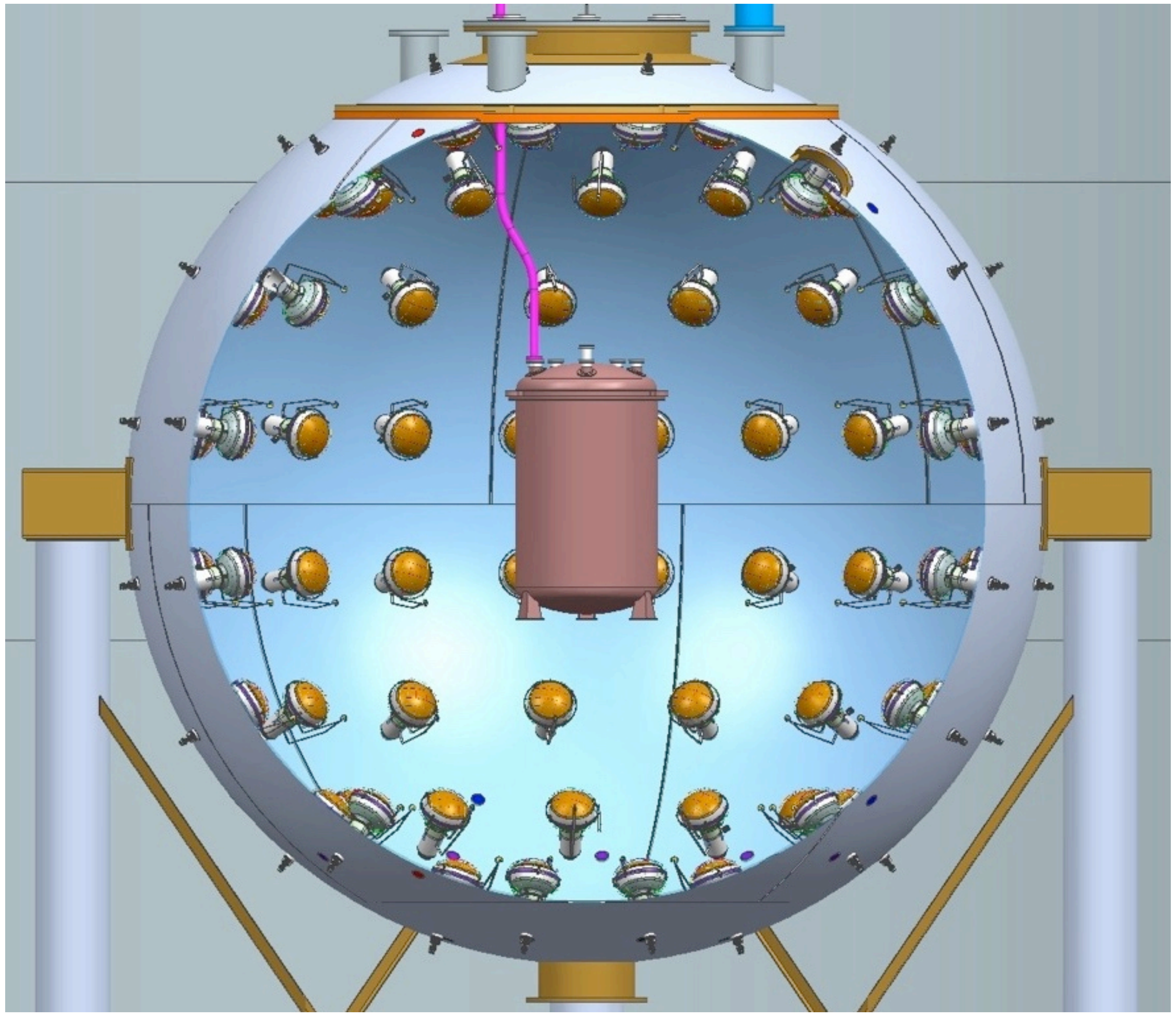




Liquid Scintillator Veto

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



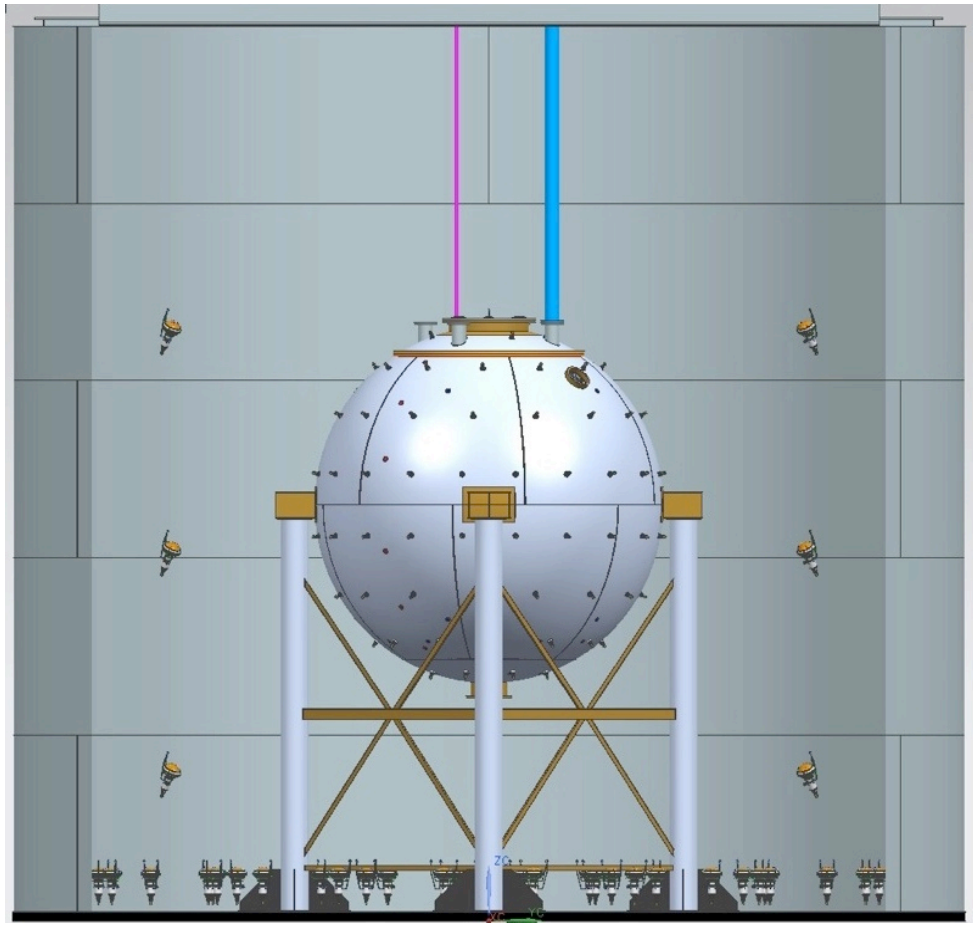
- 4 m diameter sphere containing PC + TMB scintillator
- Instrumented with 110 8" PMTs

^{14}C content was 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**.

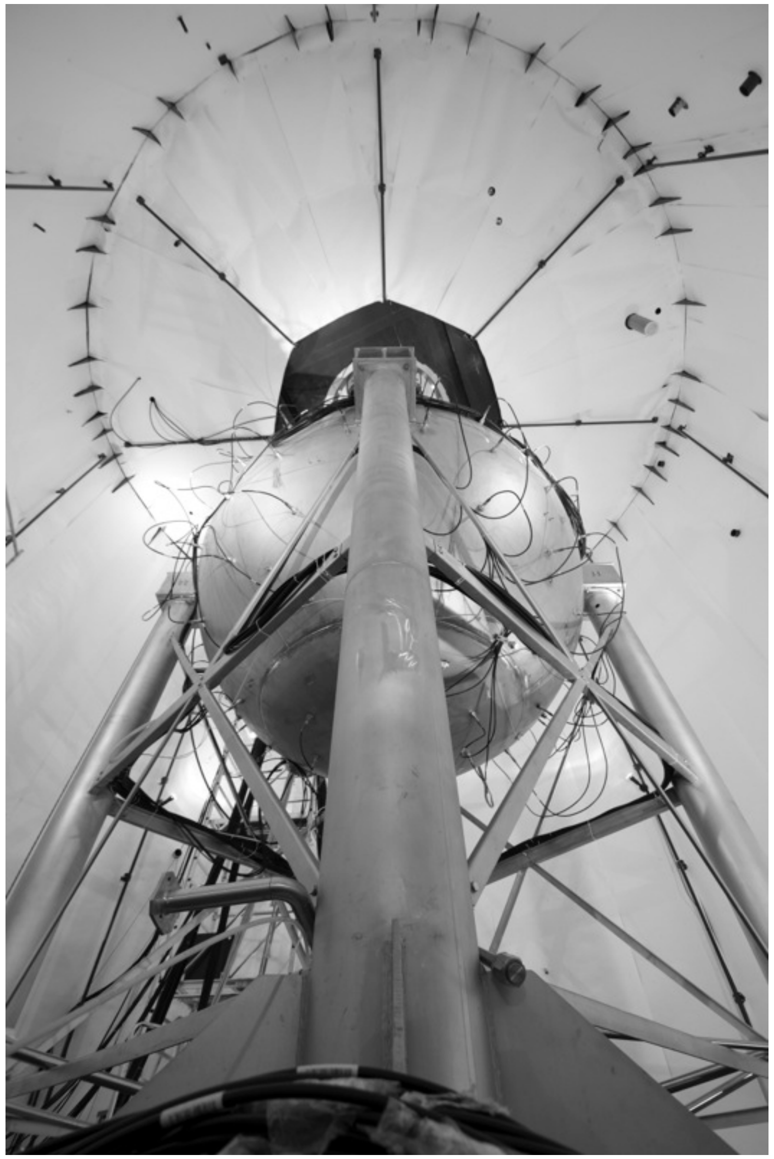
External Water tank

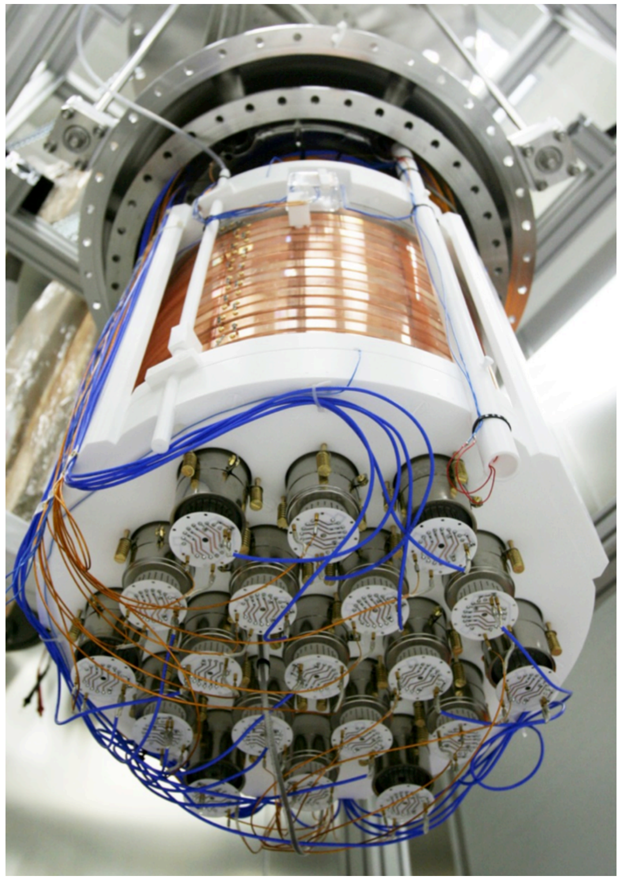
- 80 PMTs within water tank (11 m diameter x 10 m height)
- Acts as a **muon and cosmogenic veto** (~ 99% efficiency)
- Provides **passive γ's and neutron shielding**

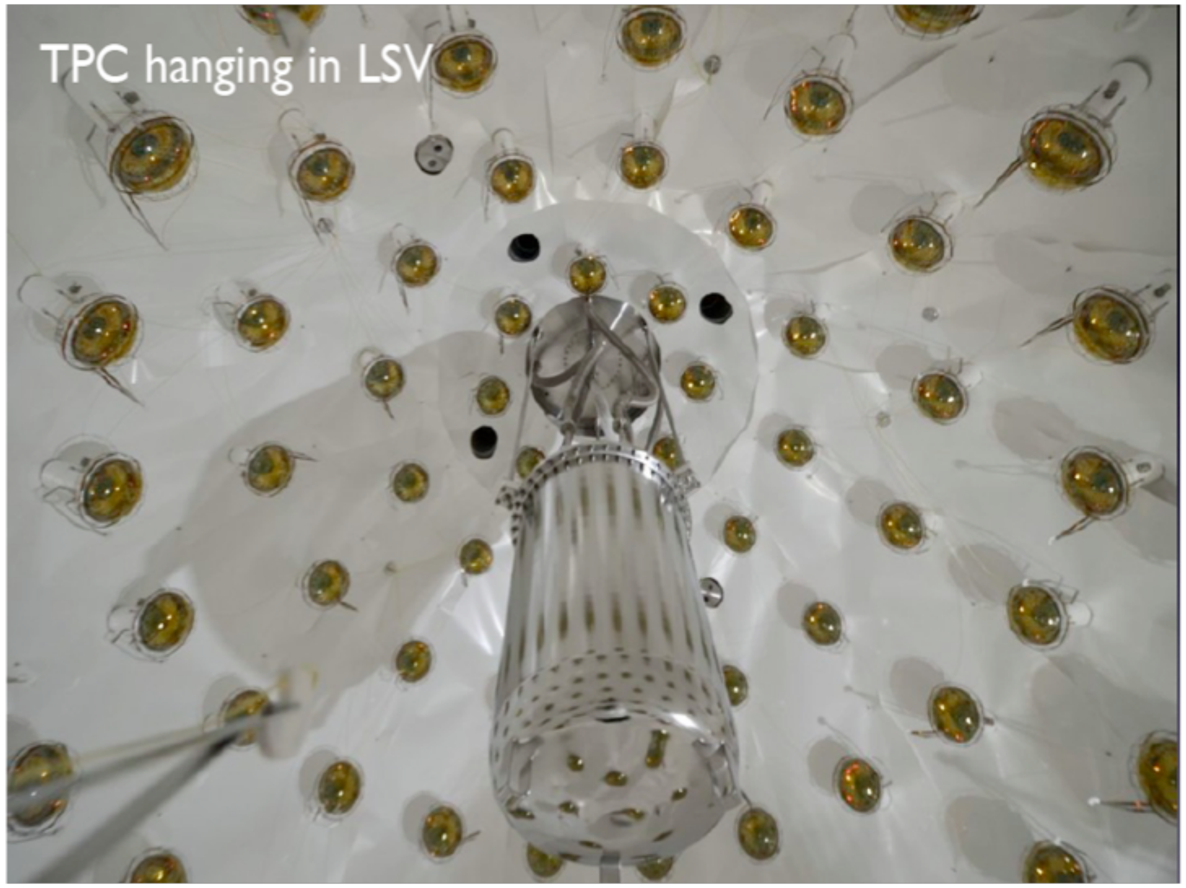


DS-50 Assembly

Sept - Oct 2013

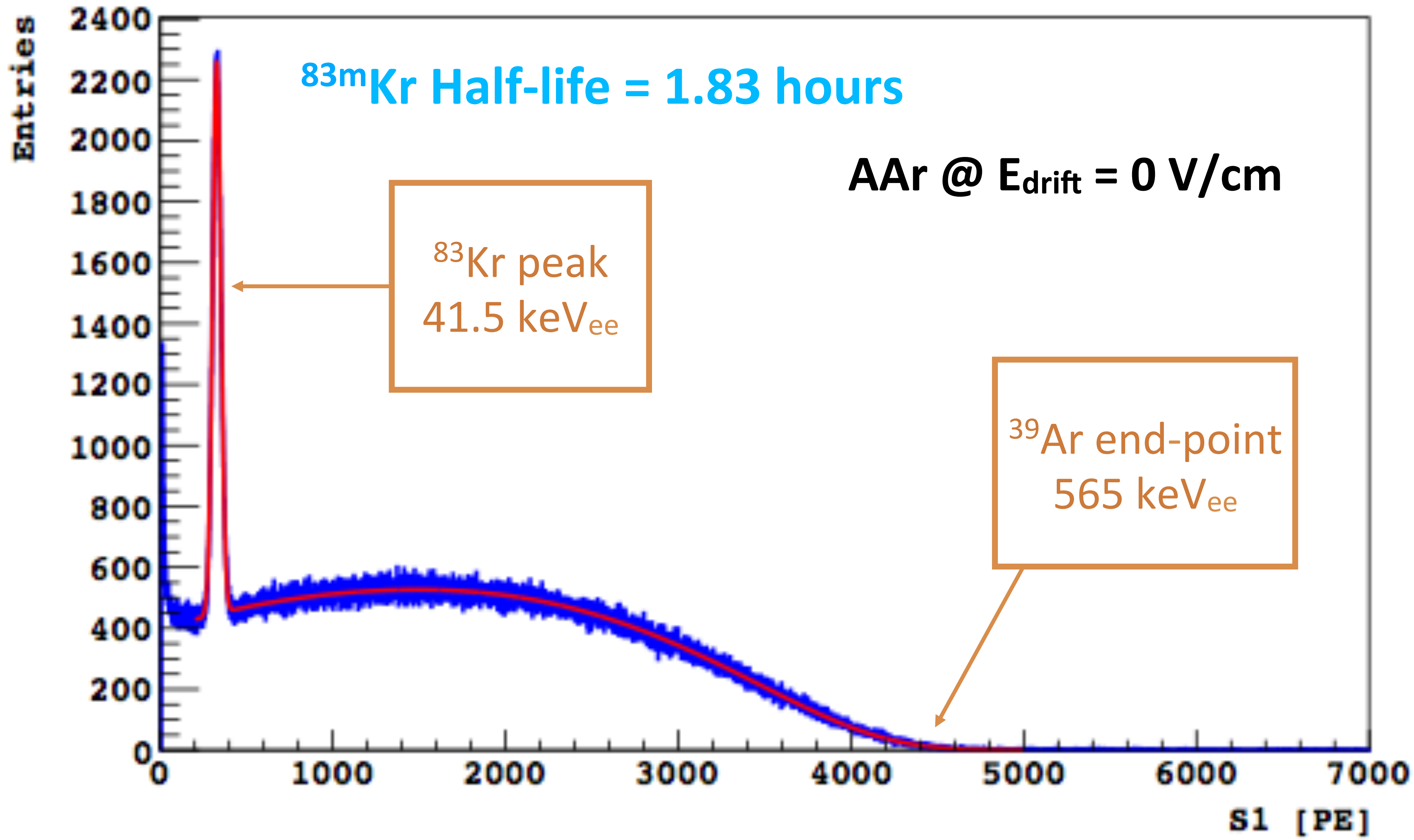






TPC: Electron Recoils calibration

- ^{39}Ar (565 keV_{ee} end-point) present in AAr
- ^{83m}Kr gas deployed into detector (41.5 keV_{ee})



LIGHT YIELD: **8.1 ± 0.2** PE/keV_{ee} at zero field and **7.0 ± 0.3** PE/keV_{ee} at 200 V/cm

For Nuclear Recoils

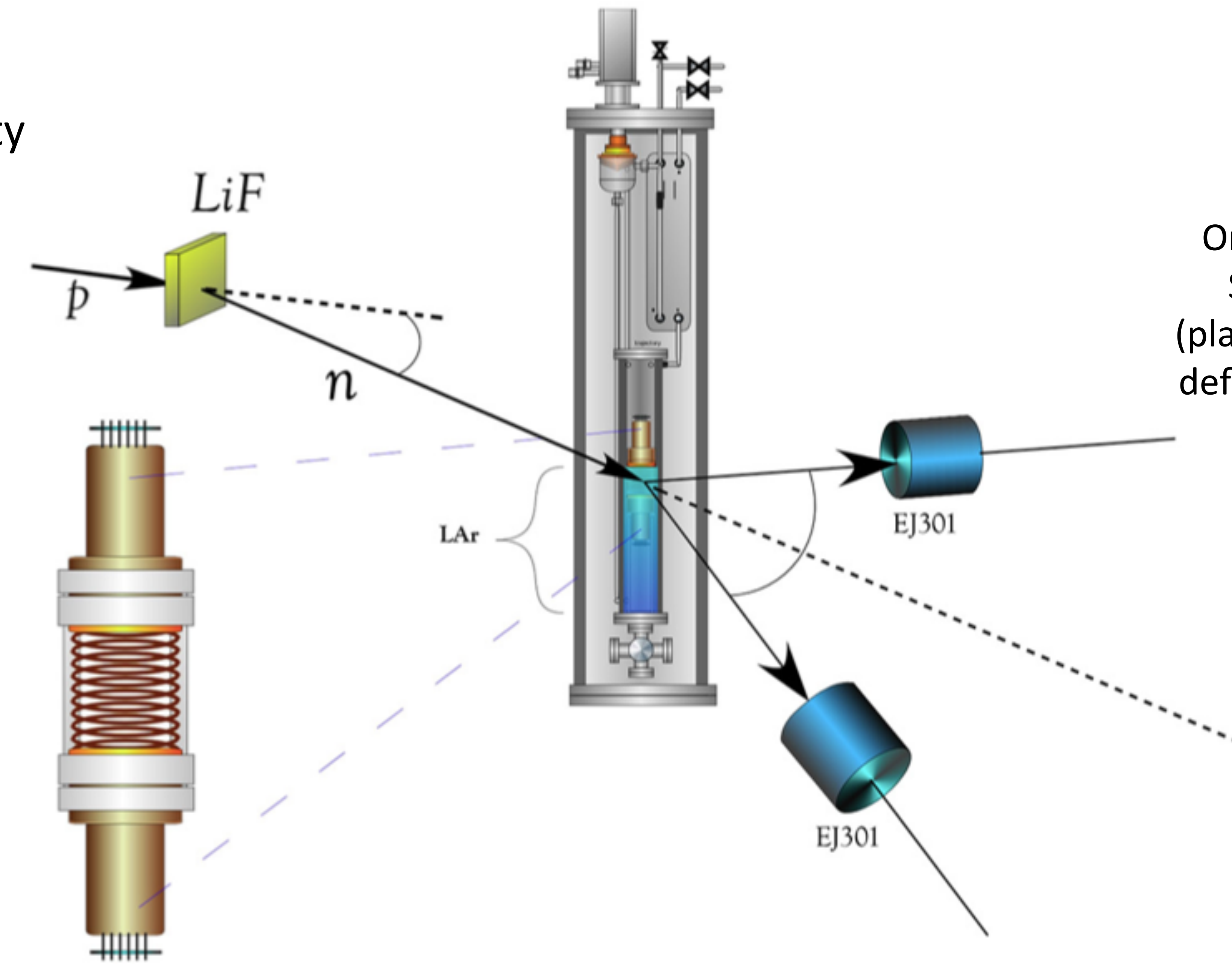
SCENE

(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 mono-energetic neutrons TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy

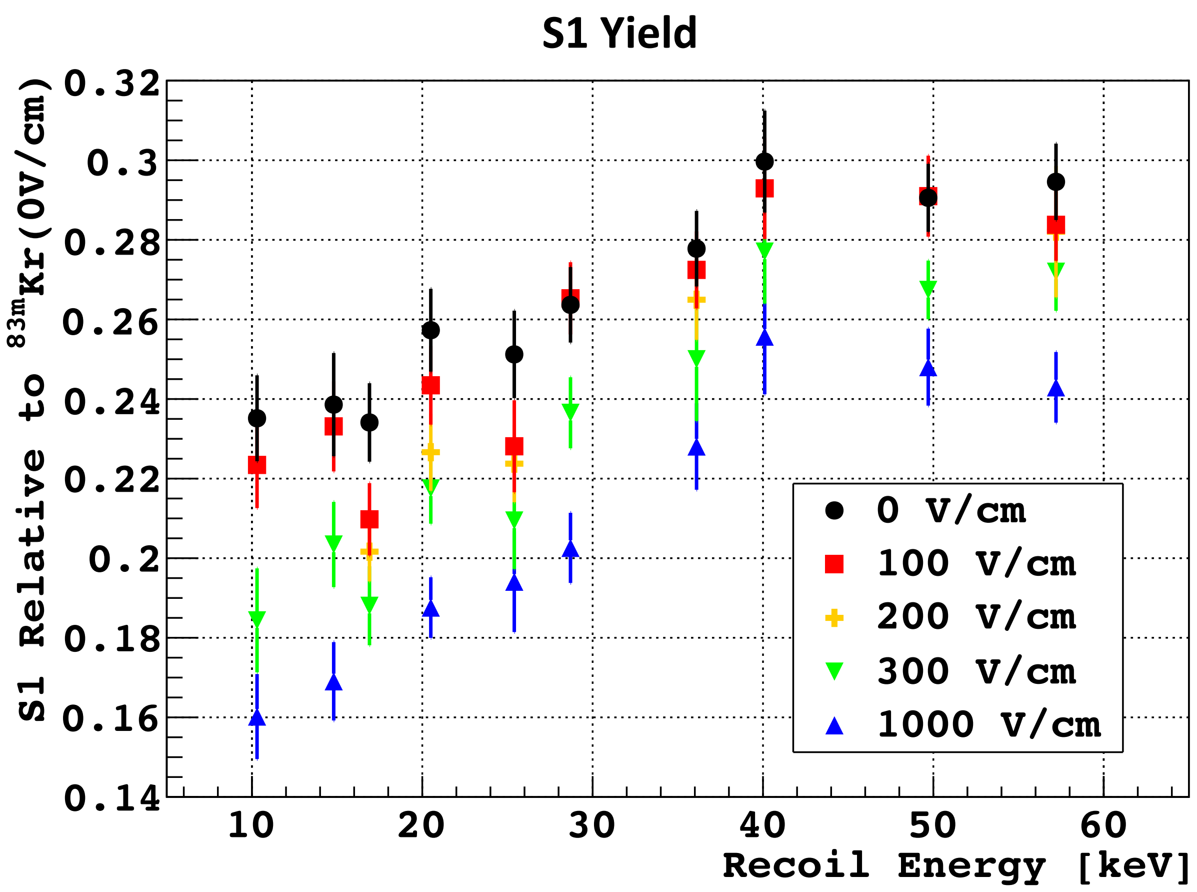
Nuclear Recoil

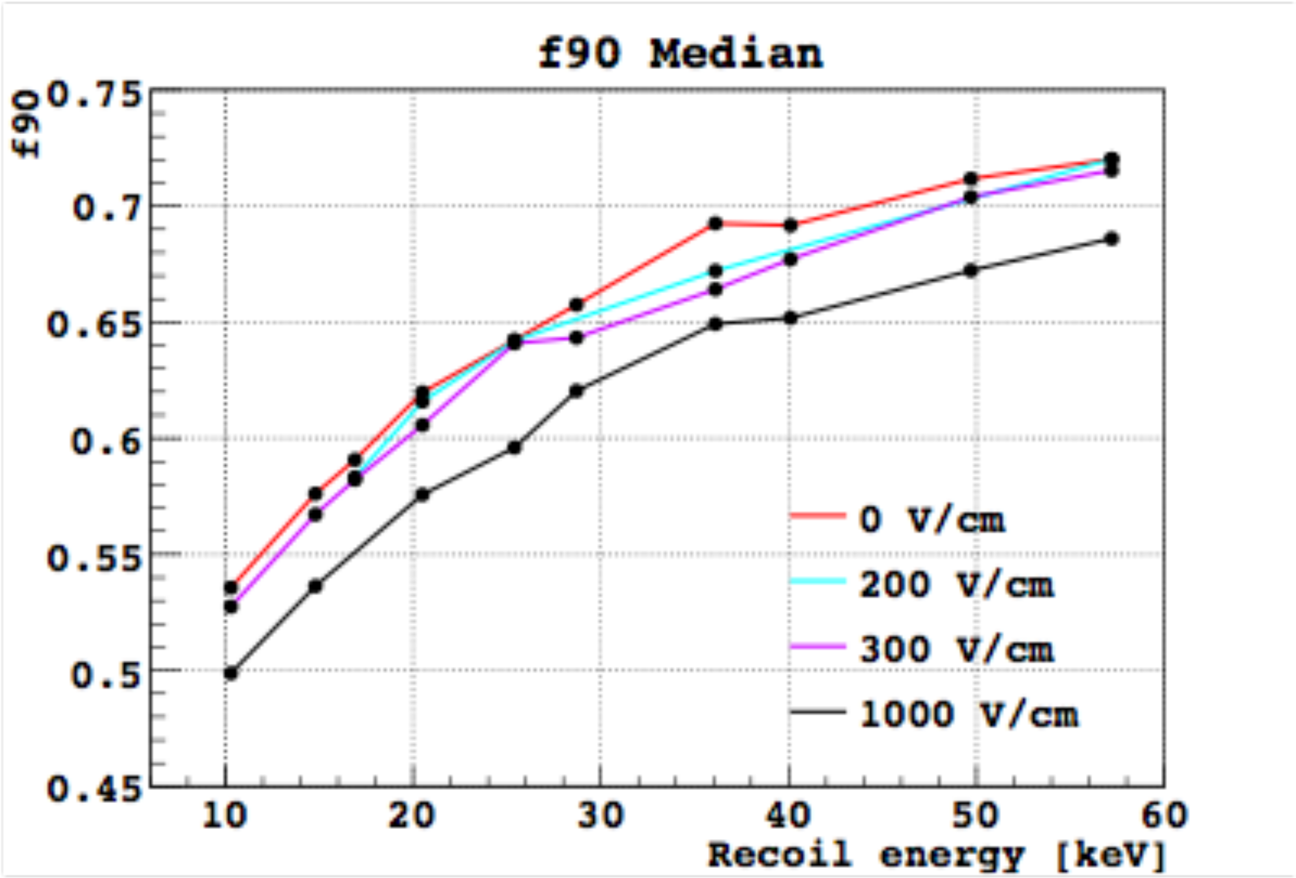
From **SCENE**:

1. nuclear recoil quenching
2. the F90 distribution

by processing SCENE data with DS-50 code and extrapolated to DS-50 detector along with the systematics.

Phys. Rev. D 91, 092007



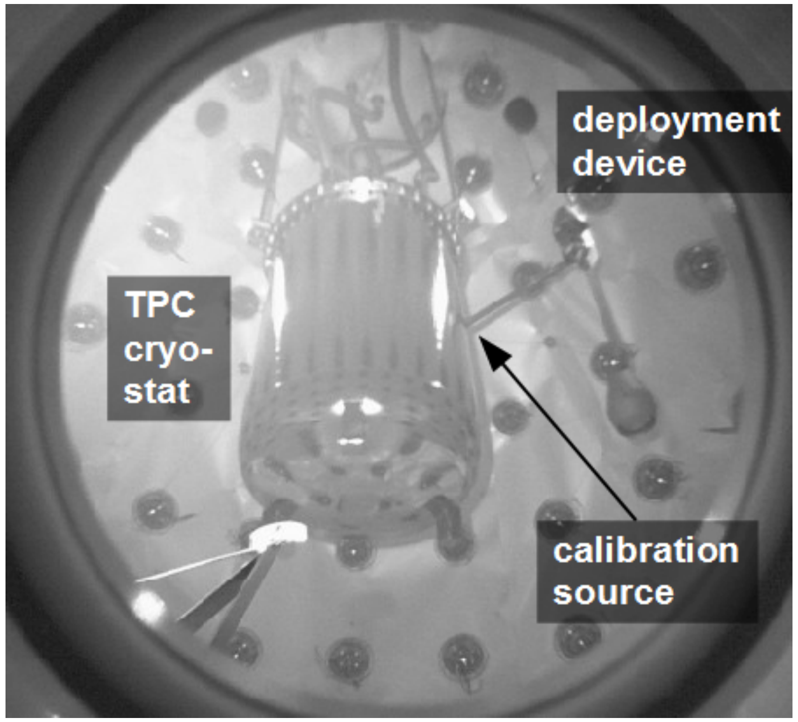


CALIS

CALibration Insertion System

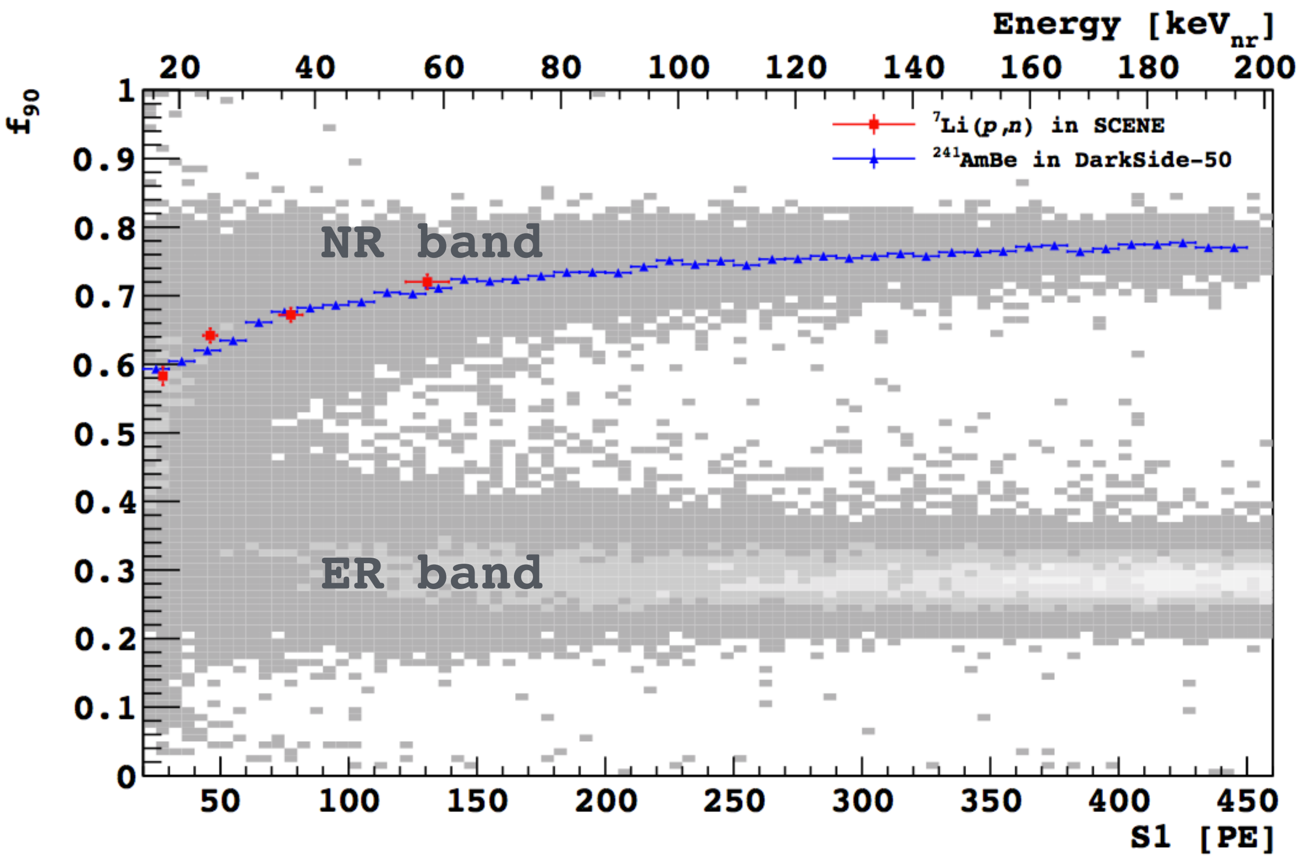
Calibrate both **TPC** and **Neutron veto**

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

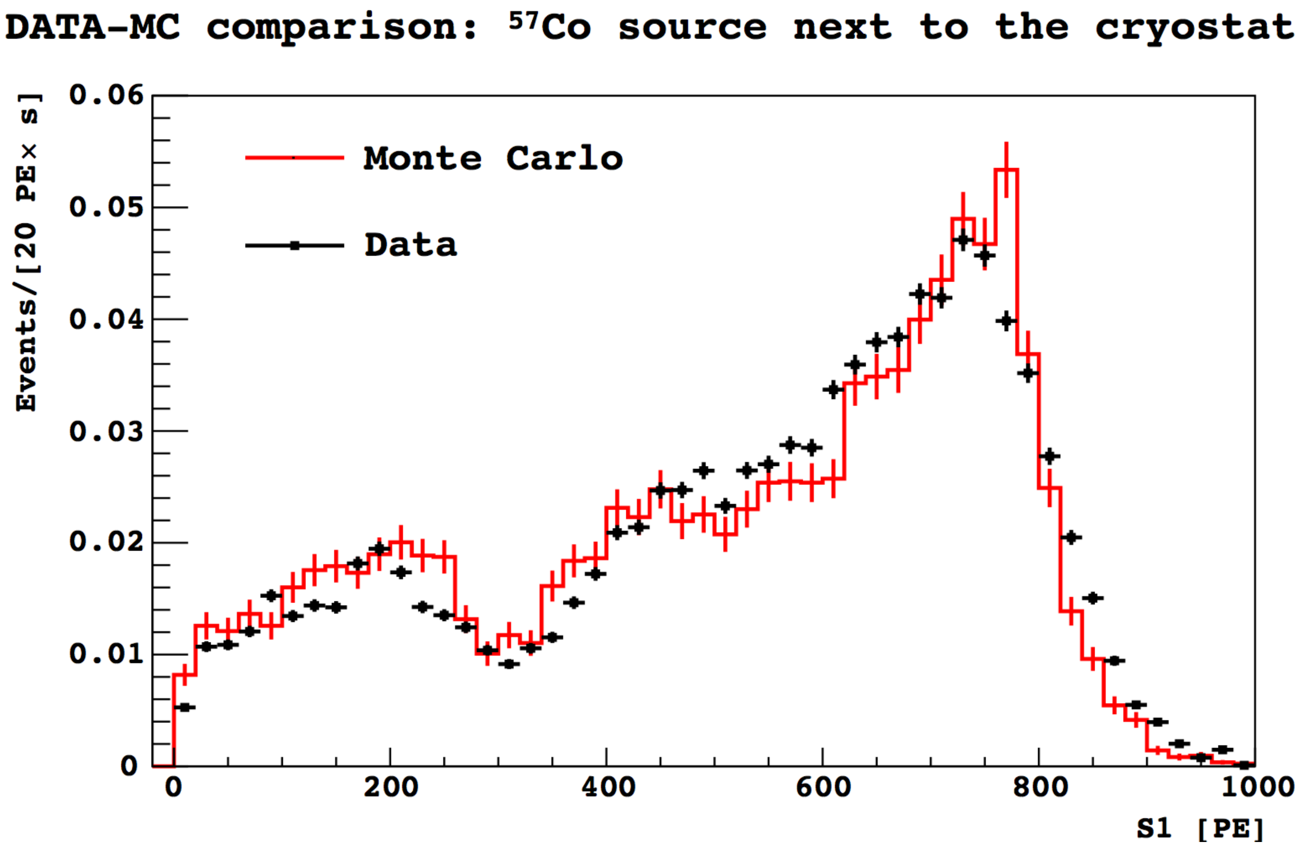


NR band matches with the points extrapolated from SCENE.

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



Test of the MC code



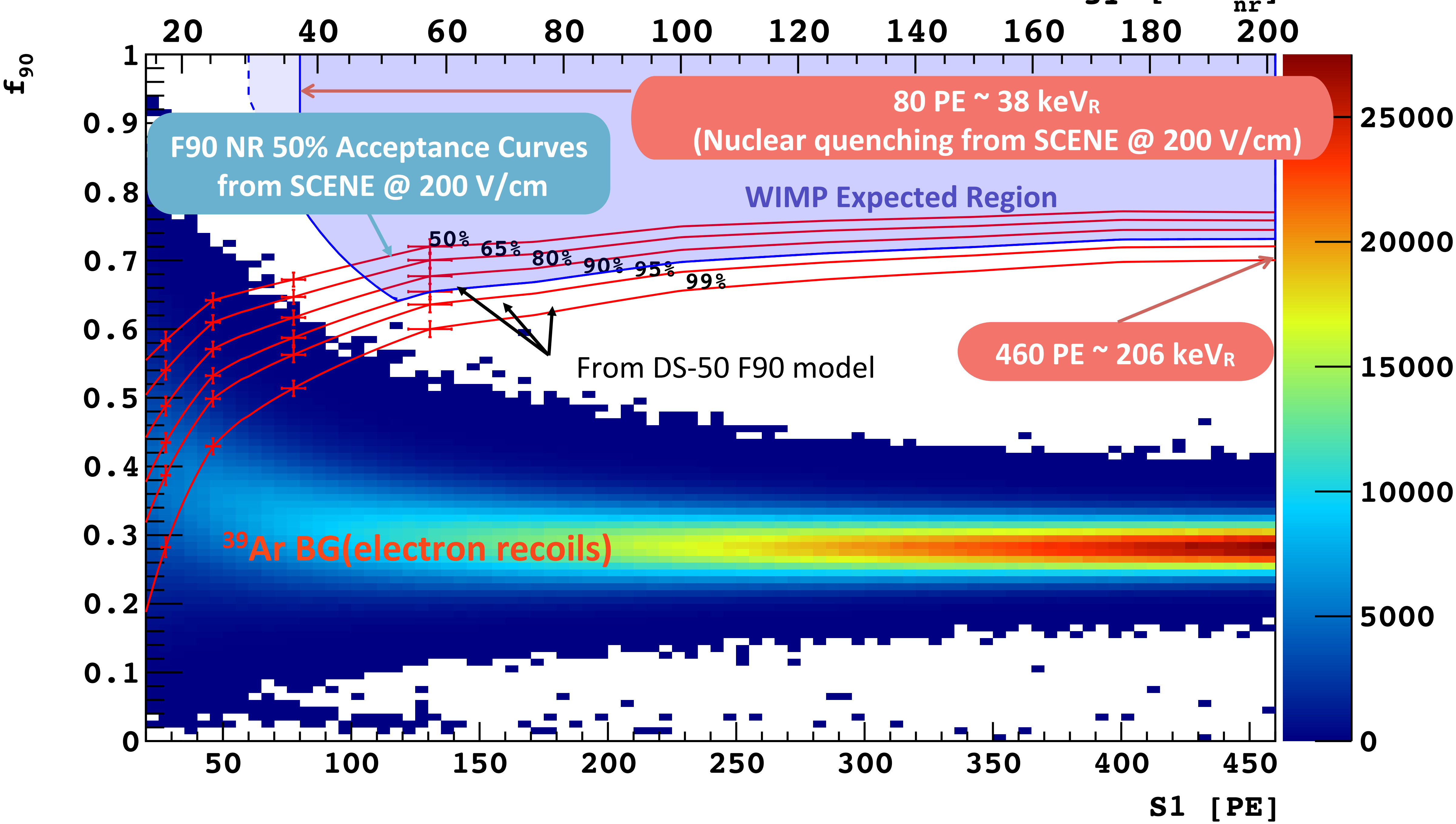
DarkSide-50 Timeline

- **Oct. 2013:** LArTPC, Neutron Veto and Muon Veto commissioned.
  - TPC filled with **atmospheric argon** (AAr).
- **Up to Jun. 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 with 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 first data with **UAr** for **dark matter search**.
- Data taking is foreseen to last until approximately the end of 2017

Atmospheric Argon run (2014)

Exposure of 1422 ± 67 kg·day

No background events in nuclear recoil (WIMP) region!



Phys. Lett. B 743 (2015) 456

three cuts only: single-hit (1) interactions in the Fiducial Volume (2) and no energy deposition in the veto (3).

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

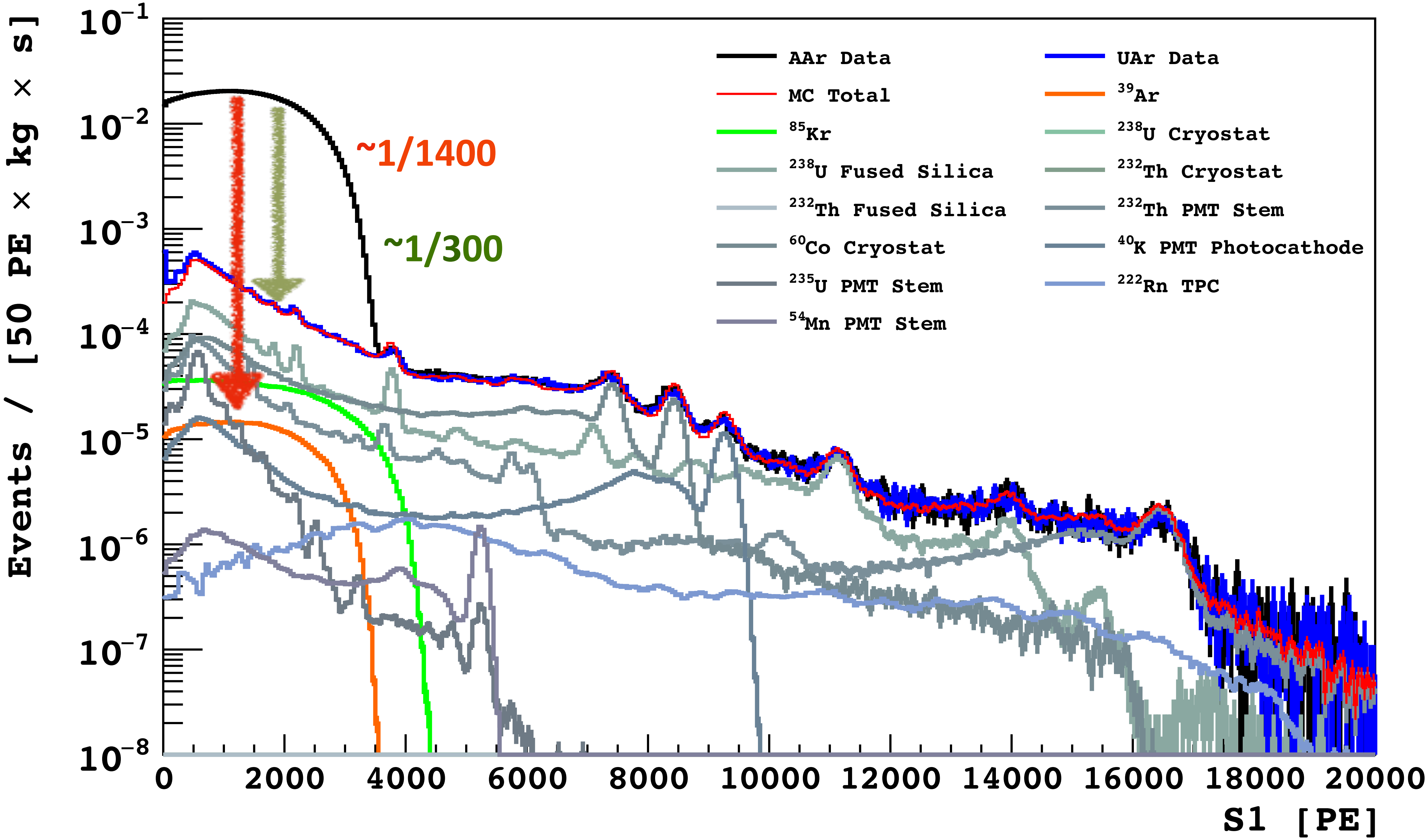
2. **Purification at Fermilab**
   Separate Ar from He and N_2


UAr bottles at LNGS

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

UAr First Results

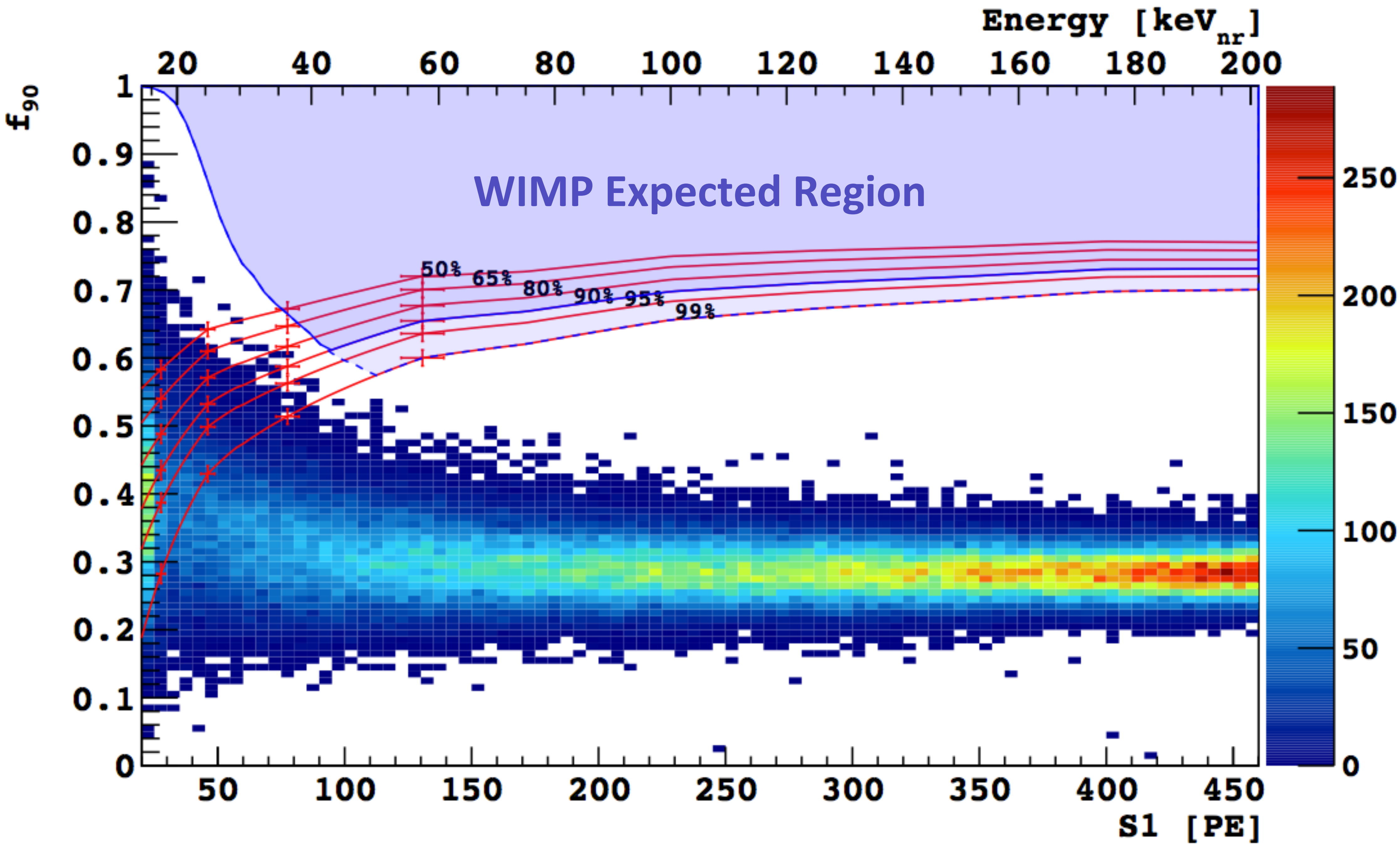
AAr vs UAr. Live-time-normalized S1 pulse integral spectra at Zero field.



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

UAr First Results

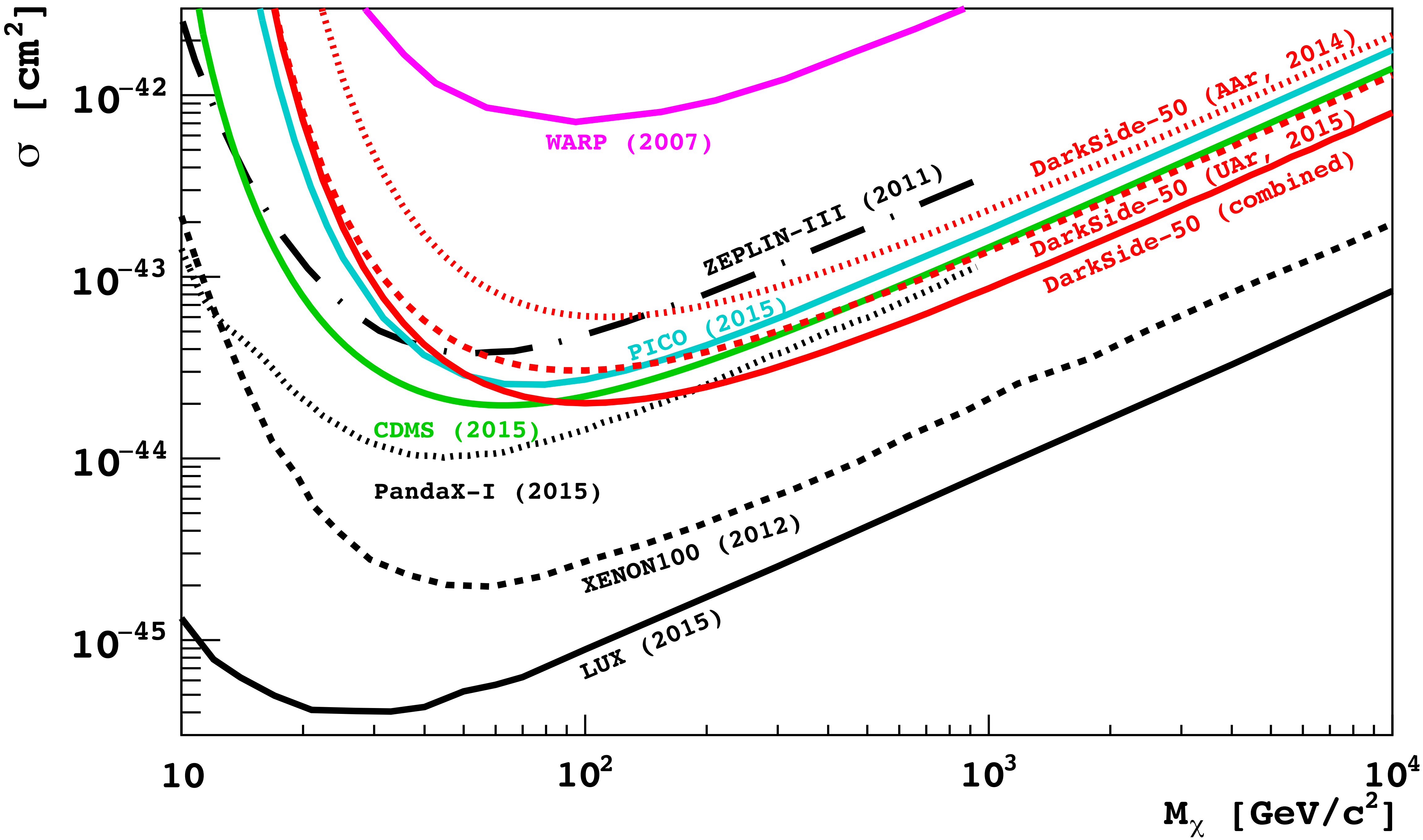
No background events in nuclear recoil (WIMP) region!



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

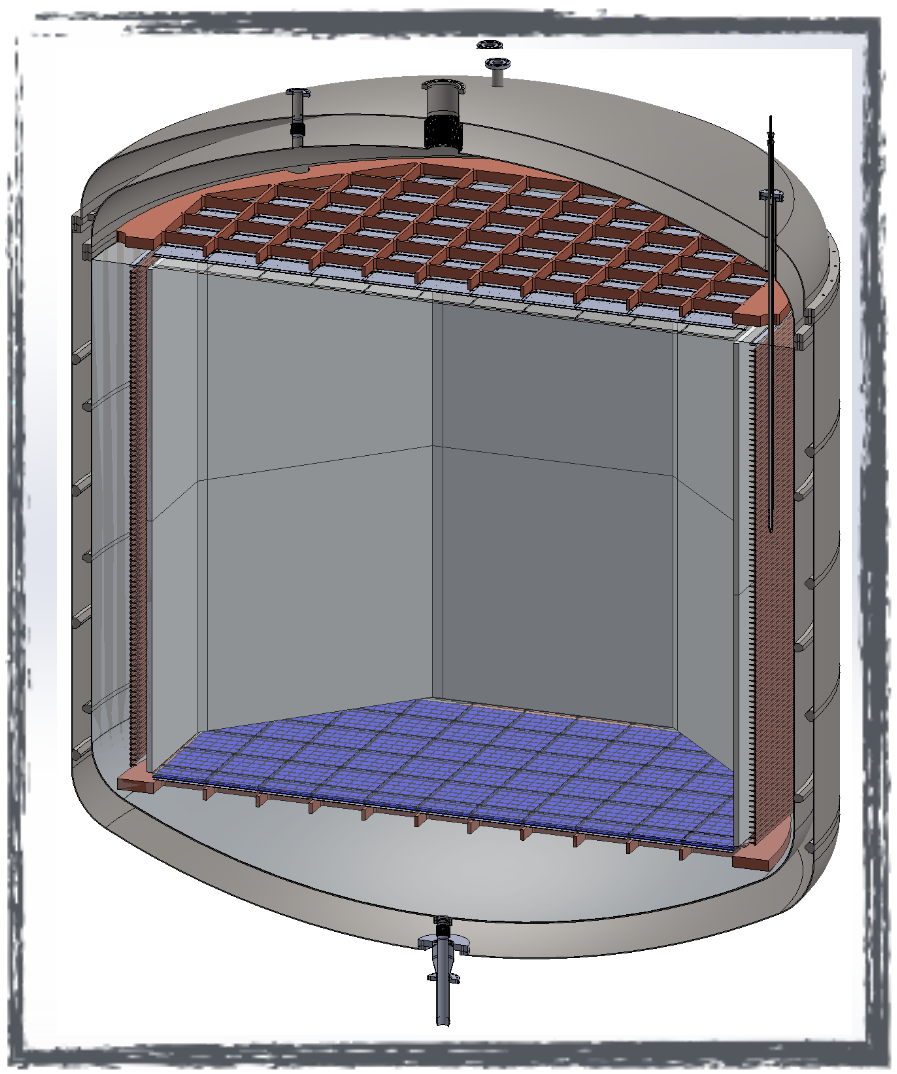
arXiv:1510.00702

UAr First Results



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

Future Detectors



DS-20k

30 tonne (20 tonne fiducial) detector

?

ARGO

300 tonne (200 tonne fiducial) detector

Further Depletion of Ar

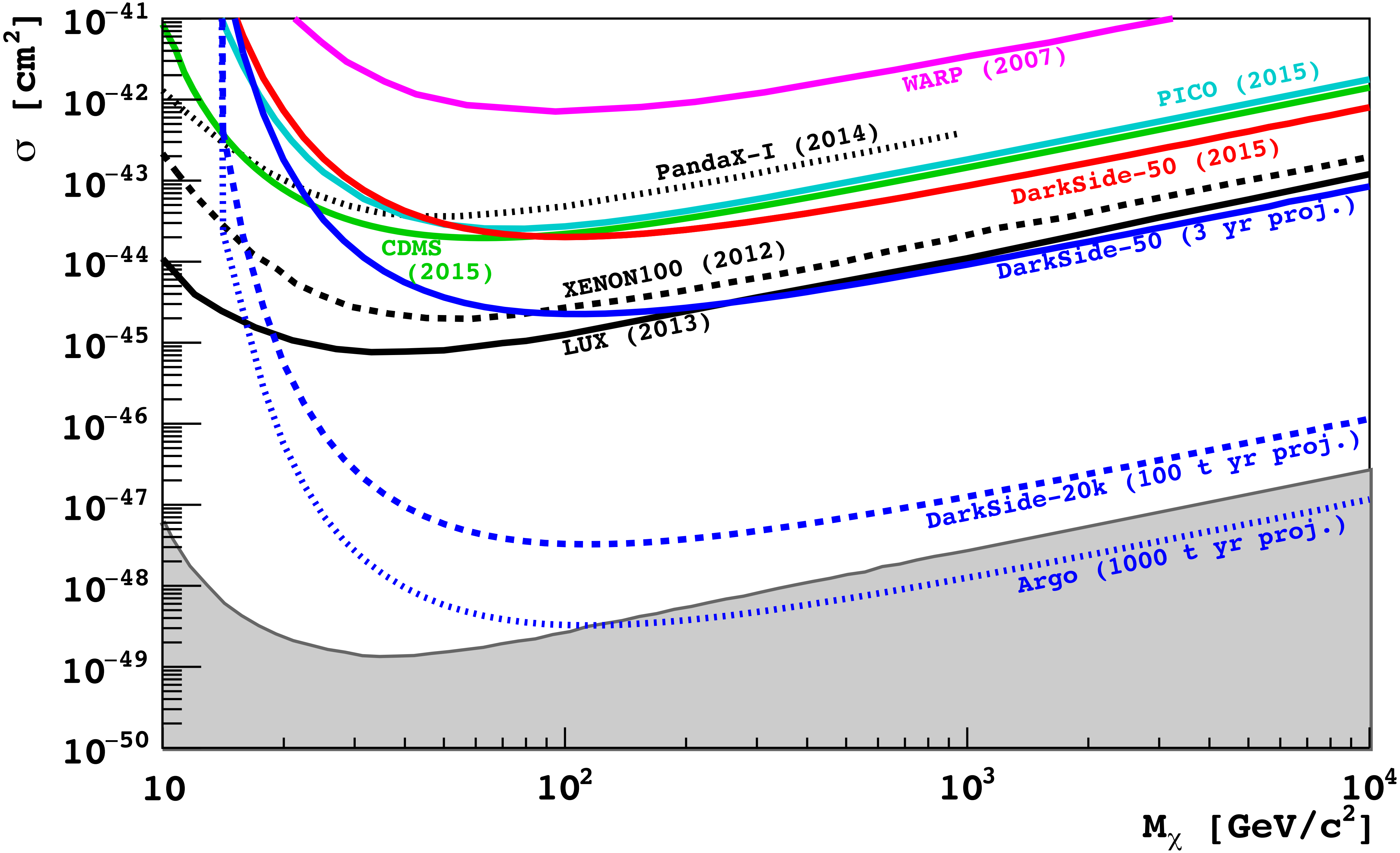
Urania (Underground Argon):

– 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

Expected sensitivity



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 ($\gg$ planning physics run time, 3 years).
  - Concentration of ^{39}Ar in **UAr** is **1400** times lower than in **AAr**.
  - DarkSide demonstrates **^{39}Ar BG** rejection at level of **5.5 tonne·year** with UAr.
- Elastic spin-independent WIMP-nucleon interaction: the non observation of events in the ROI in DarkSide-50 excludes cross-sections larger then 2 10^{-44} cm^2 for 100 GeV WIMPs.
  - Best limit obtained with Argon target
  - Third best limit after Xenon detectors
- Future detectors are planned with sensitivities of 10^{-47} and 10^{-48} cm^2 (@100GeV)
  - Letter of Intent was submitted to LNGS April 27 2015.

THE END

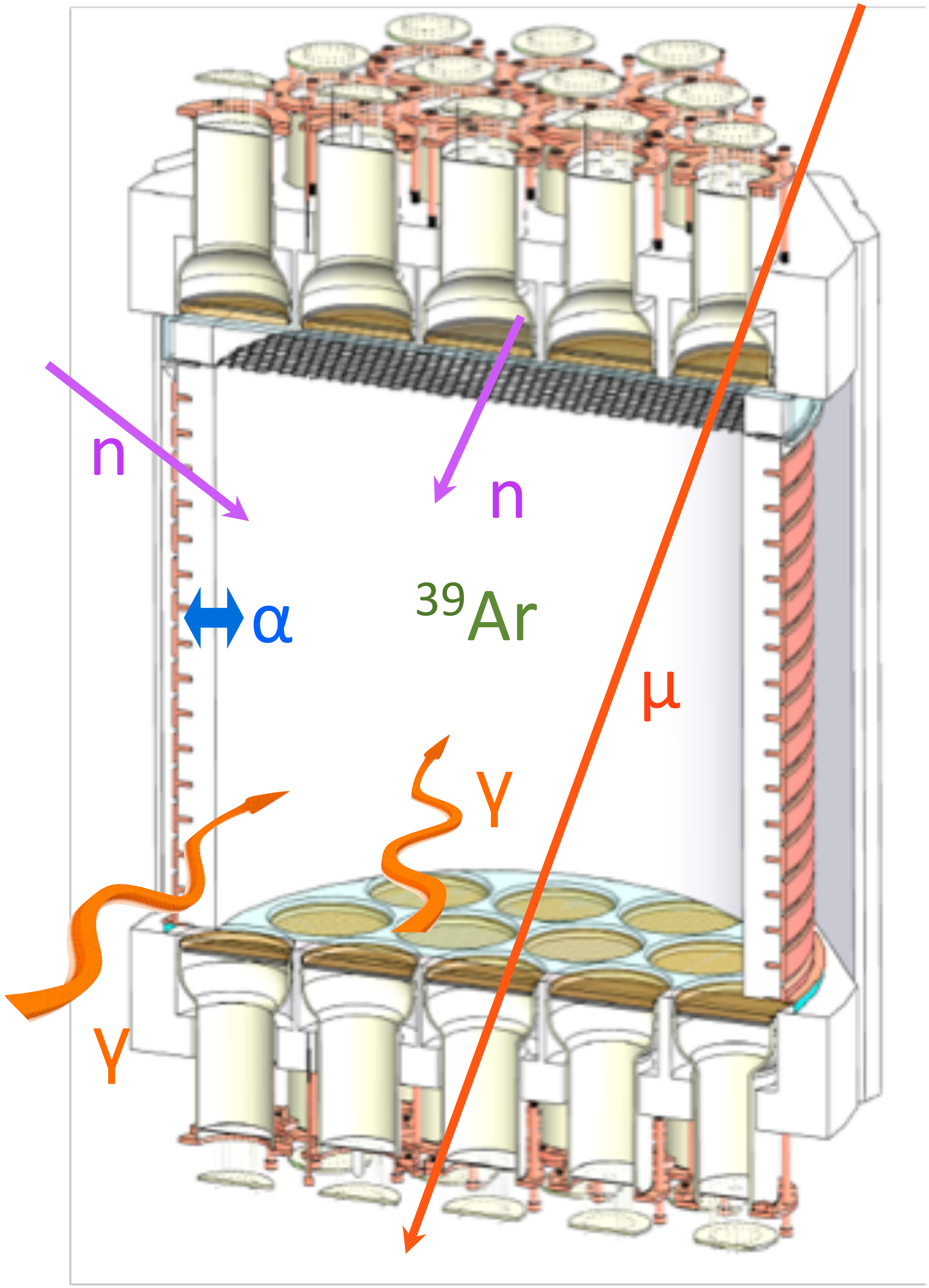
Backgrounds

[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

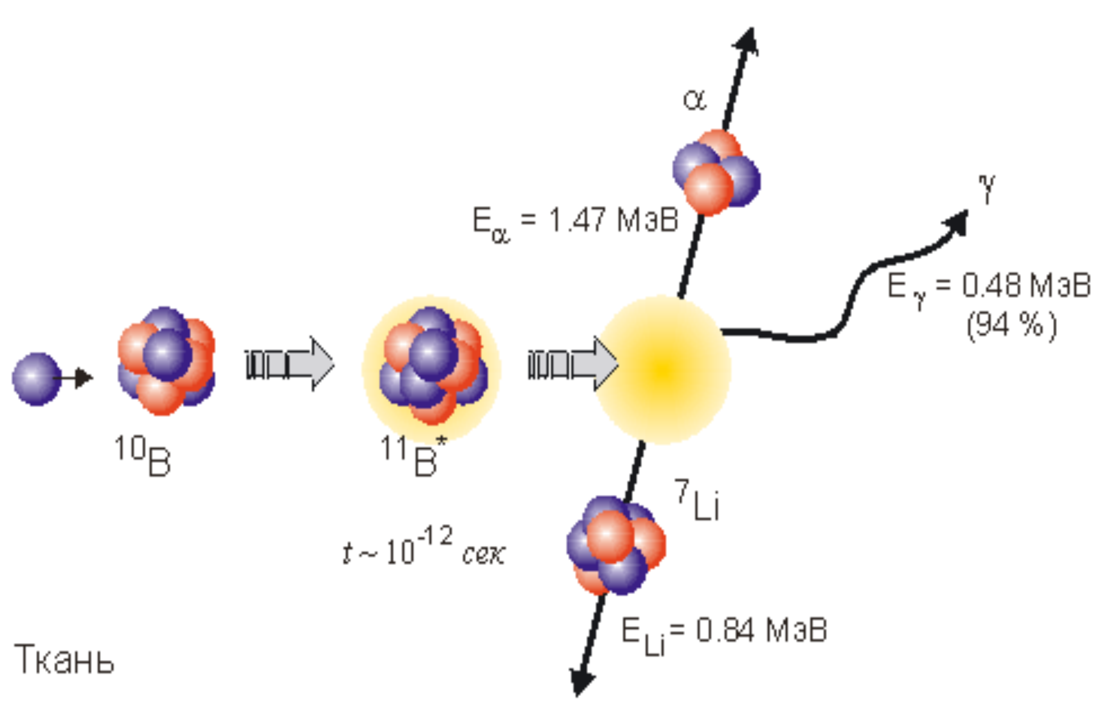
100 GeV, 10^{-45}cm^2 WIMP Rate ~ 10^{-4} evt/kg/day

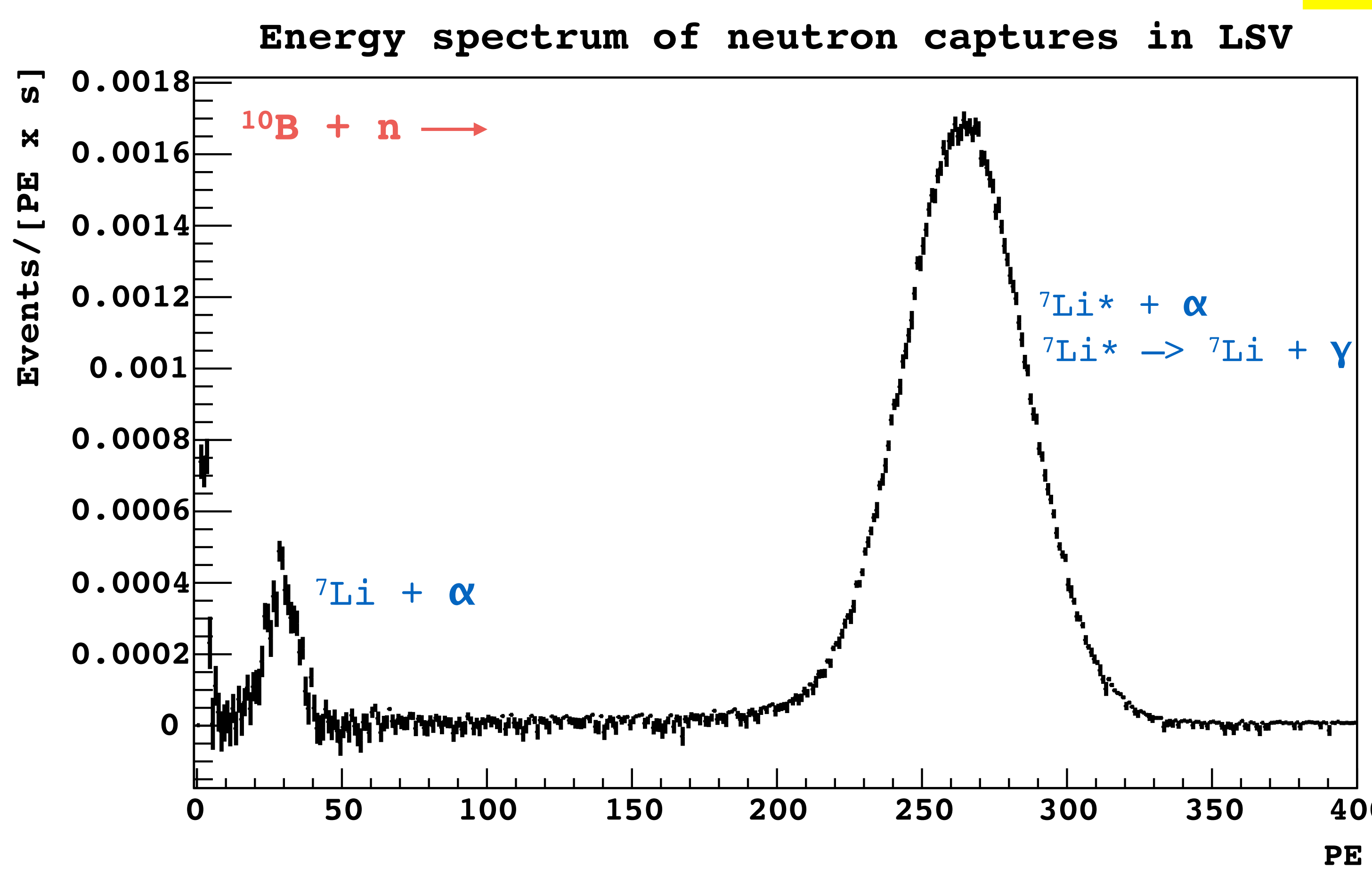
Borated Liquid Scintillator

Nucl. Instr. and Meth. A 644, 18 (2011)

- High neutron capture cross section on Boron allows for compact veto size
- Short capture time 2.3 μs reduces dead time loss. Cmp. ~260μs in pure scintillator
- Capture results in 1.47 MeV α particle, quenched to ~50 keV:
  it must be detected with high efficiency!

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





PMTs with cold-amplifiers

- 3” PMTs
- Hamamatsu R11065 series
- The “-20” have **good background levels** but show problems at nominal gain at LAr temperature
- Require low PMT Gain ~ 4×10^5
- Custom cold amplifiers:

Noise ~3 μV on 200 MHz

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

Sensitivity Comparison

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

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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
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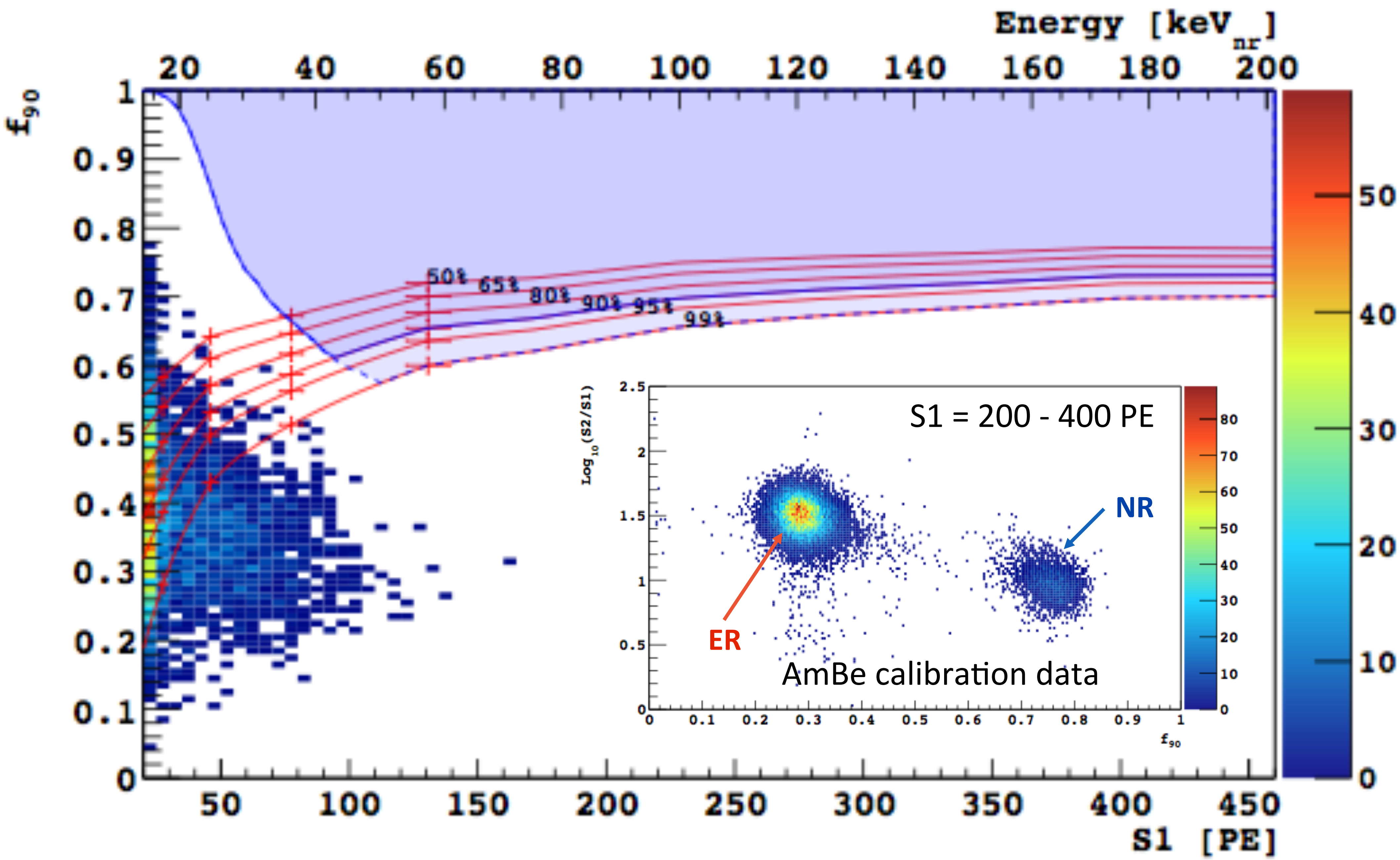
C. Dionisi, S. Giagu, M. Rescigno - Università La Sapienza & INFN Roma
S. Bussino, S. Mari - Università & INFN Roma 3
J. Maricic, R. Milincic, B. Reinhold - University of Hawaii
P. Cavalcante - Virginia Tech

UAr First Results with S2/S1 cut

Electron Recoil Discrimination

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



Sample F90 models

- Use analytic model for F90 distributions
- Fit to high statistics AAr data
- Scale to UAr data
- Derive 0.01 ER leakage events / S1 bin