DarkSide: recent results with underground argon and outlook

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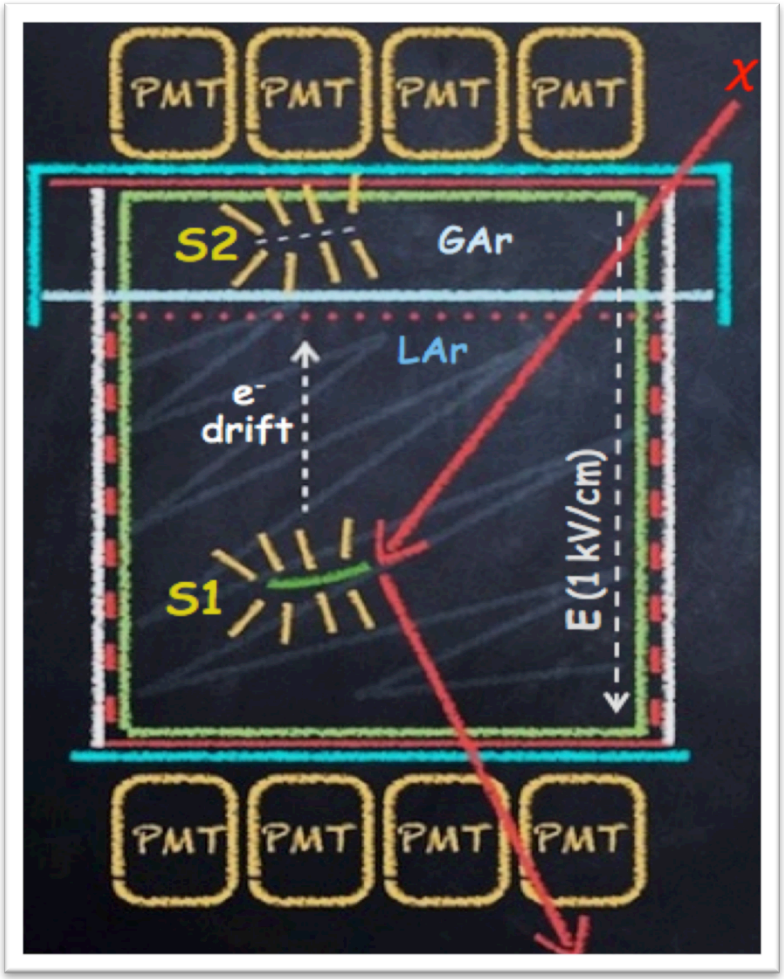
APC
on behalf of the
DarkSide Collaboration

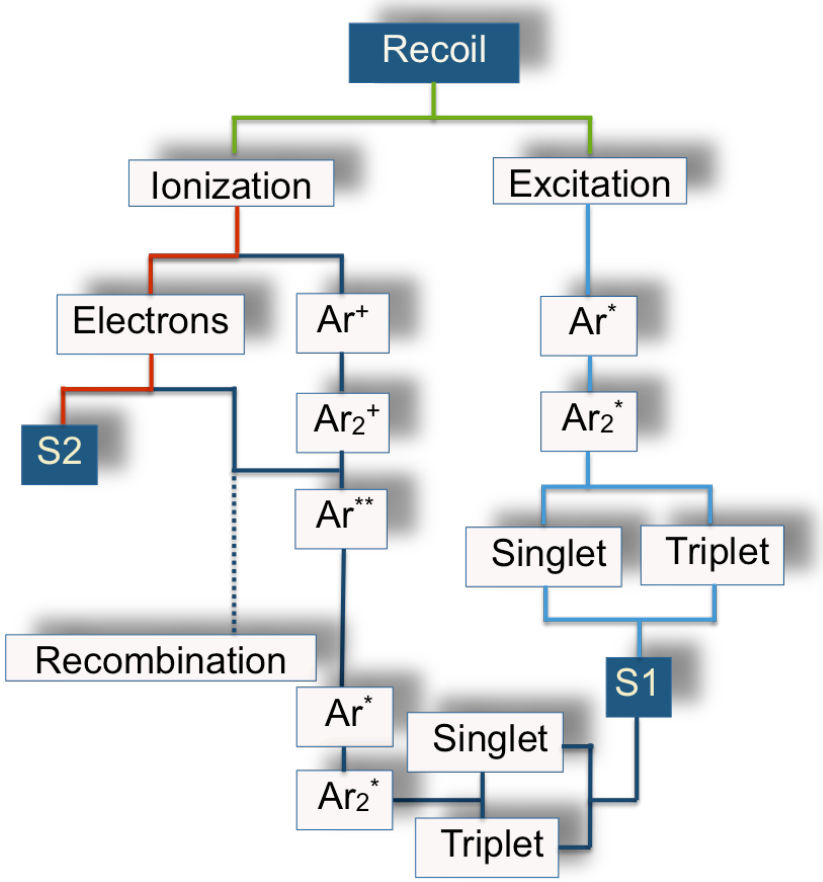
Prospects in Low Mass Dark Matter
30th November and 1st December 2015
MPI-P Munich

DarkSide

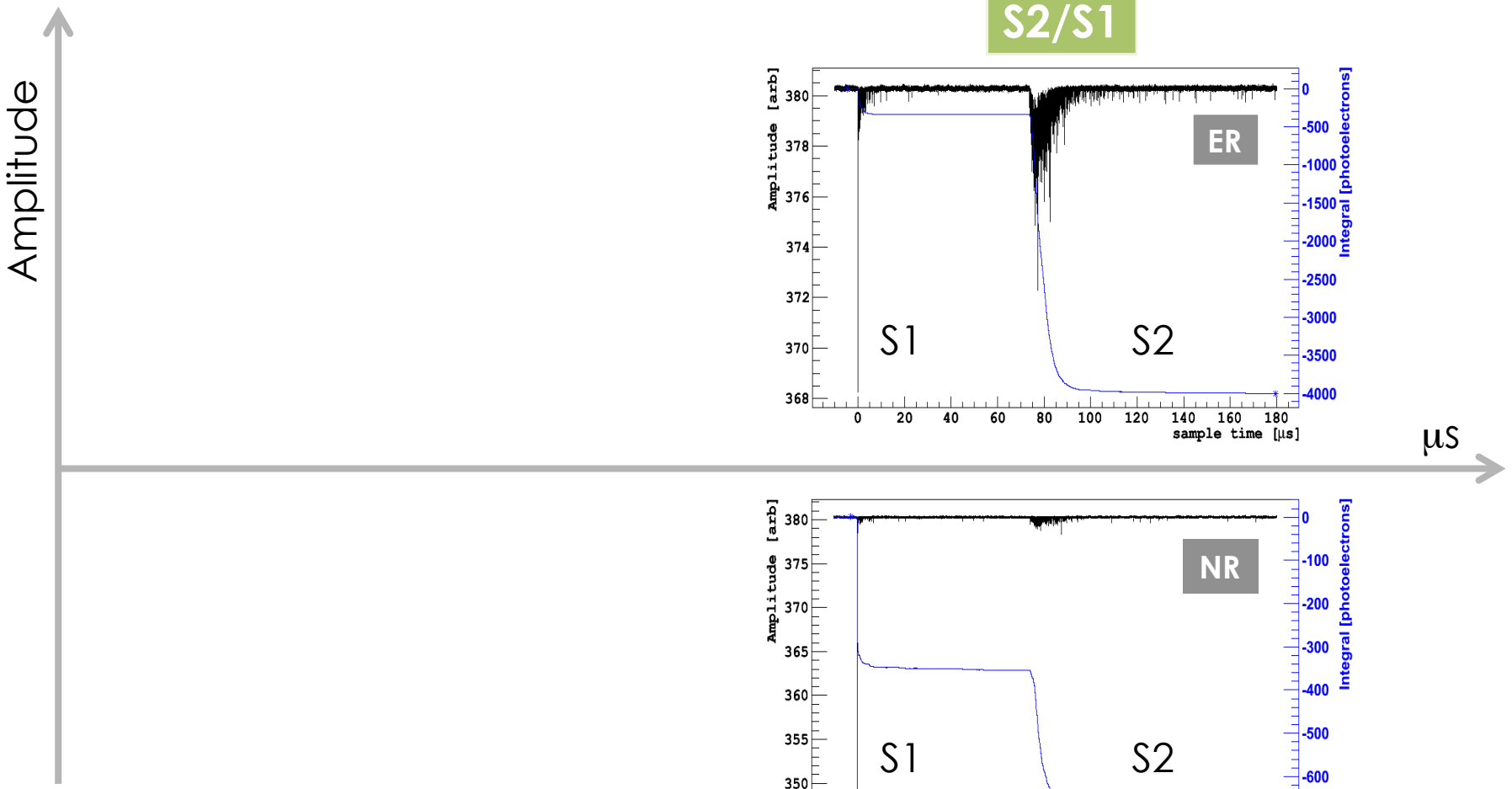
- WIMP dark matter search using **direct detection**
- **Dual-phase Liquid Argon** Time Projection Chamber (LAr TPC)
- Ultra low **background**
  - Deep underground (LNGS)
  - Low-background materials, including **Ar target**
- **Active neutron** and muon **vetoes**
  - in situ background measurement
- Powerful **background rejection**
  - **Pulse shape discrimination** (PSD)
  - Ionization to scintillation ratio (S2/S1)
  - Surface rejection using 3D position reconstruction
  - Multiple scatter event rejection

Dual-Phase Liquid Argon TPC





Discrimination Power



Rejection Factors

10^2-10^3

Benetti et al. (WARP) 2006

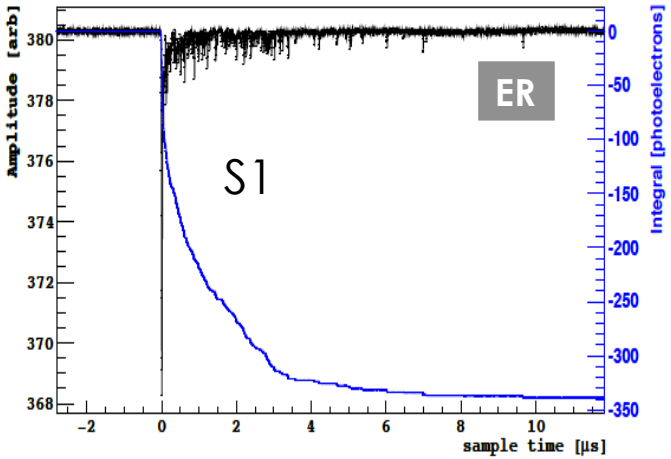
Discrimination Power

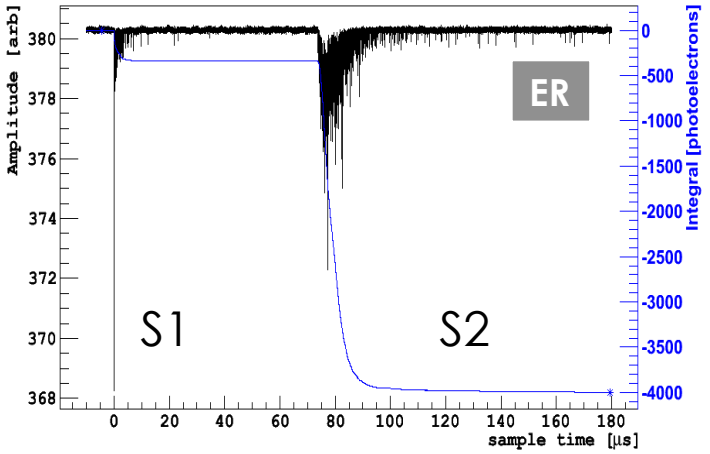
Pulse Shape Discrimination

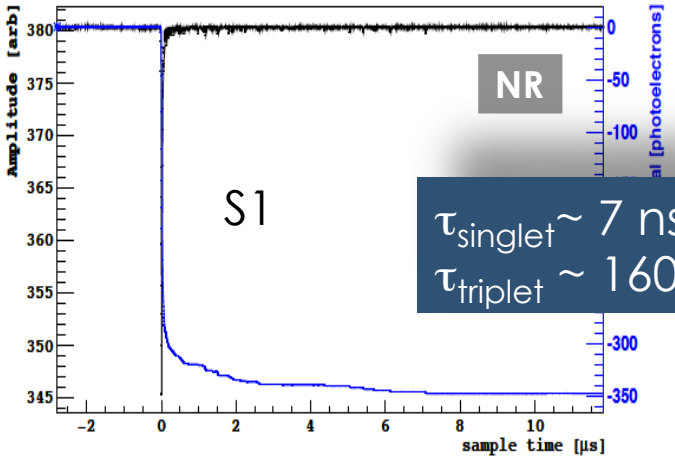
S2/S1

Amplitude

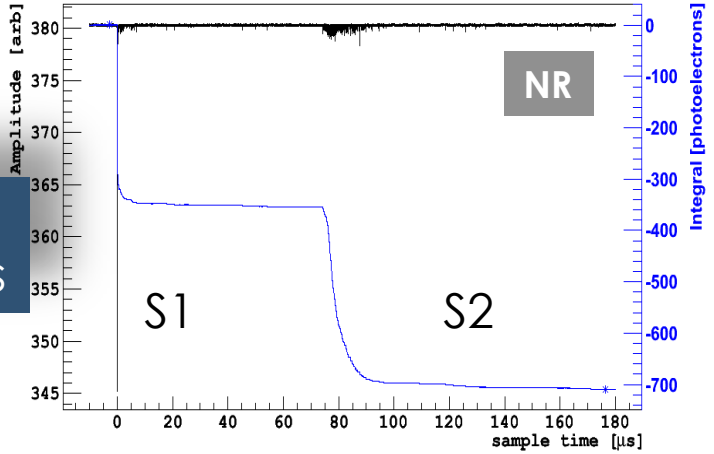
μs







$\tau_{singlet}$ ~ 7 ns
$\tau_{triplet}$ ~ 1600 ns



Rejection Factors

10^7-10^8

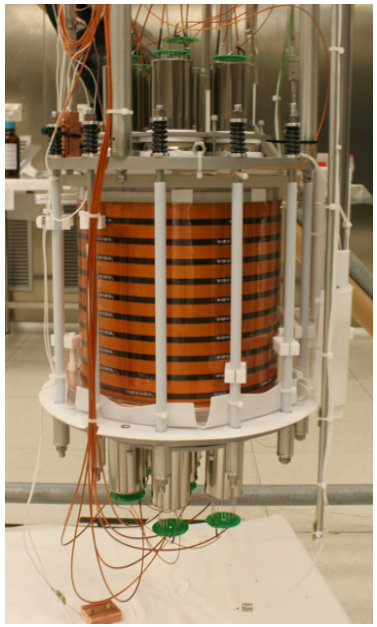
10^2-10^3

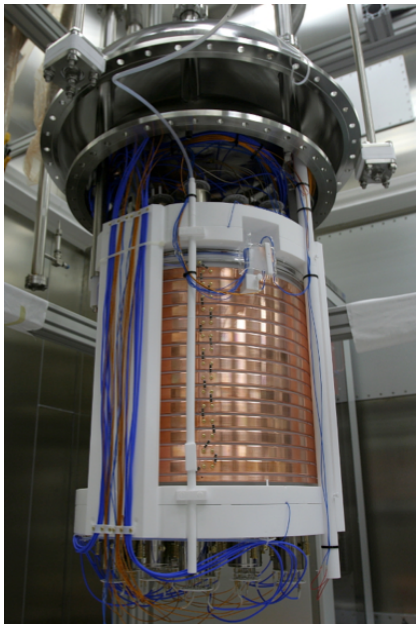
DarkSide Phys. Lett. B 743 (2015)

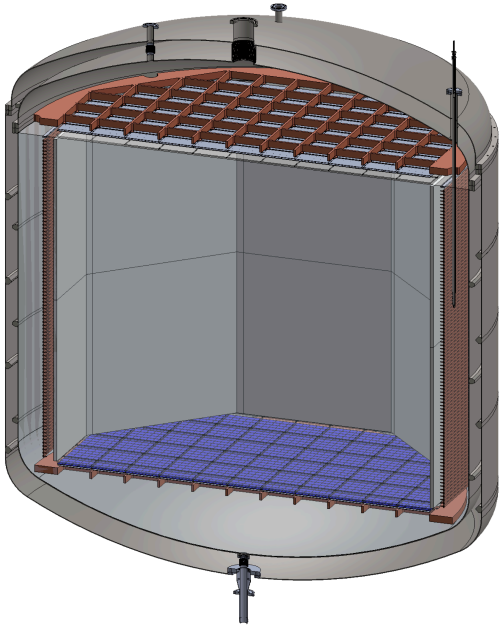
Benetti et al. (WARP) 2006

The DarkSide Program

DarkSide-10	DarkSide-50	DarkSide-20k	ARGO
2011-2013	2013-2016	2020-2025	2025-2030
10 kg	150 kg 50 kg FM	30 ton 20 ton FM	150 ton 100 ton FM







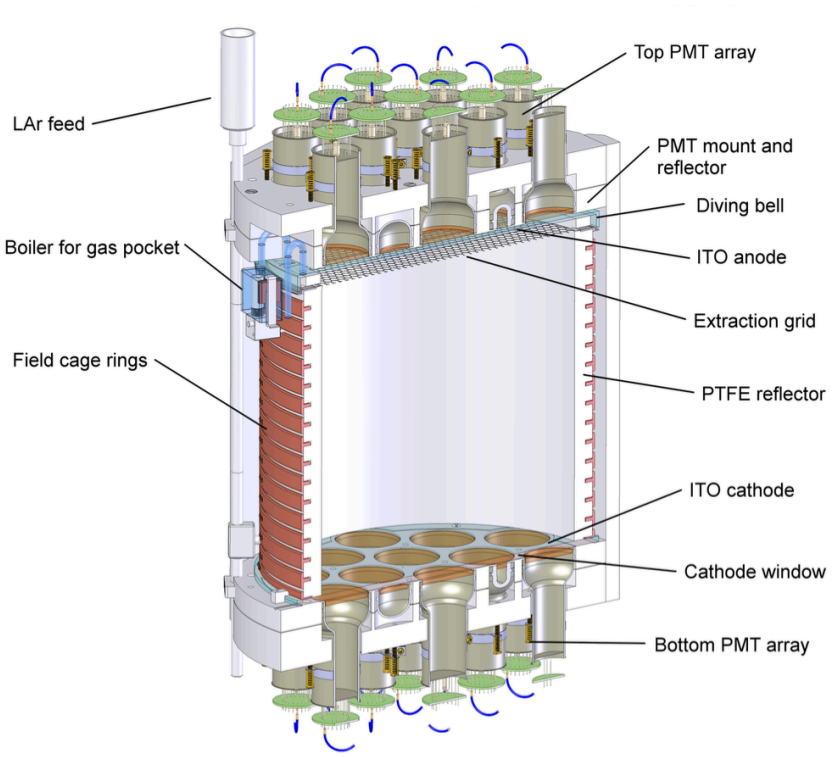
~10^{-45} cm^2

~10^{-47} cm^2

"neutrino floor"
~10^{-48} cm^2

The TPC

- 50 kg active mass of **UAr**
- 19 top + 19 bottom R11065 HQE 3'' PMTs
- 36 cm height, 36 cm diameter
- Low field of **0.2 kV/cm drift**
- Lateral walls covered by high reflectivity PTFE
- Cold pre-amps
- 2.8 kV extraction field



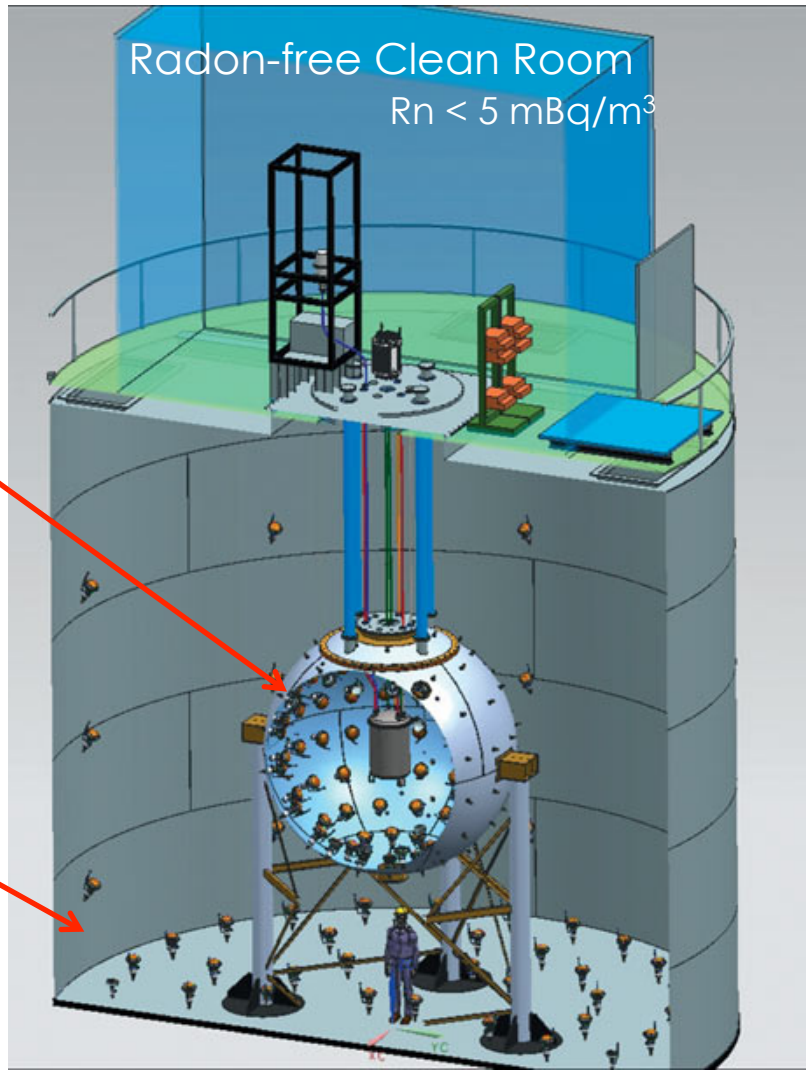
DarkSide-50

Liquid Scintillator Veto (against neutrons)

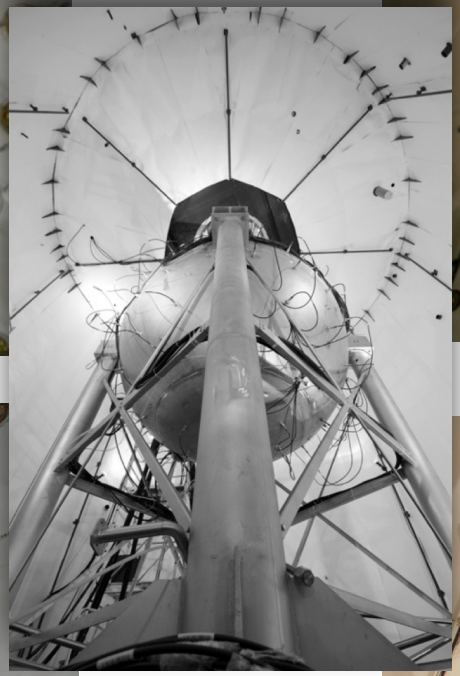
- 4 m diameter sphere
- **30 tonne** of boron-loaded scintillator (PC+PPO+TMB)
- 110 8" PMTs
- LY ~ 500 pe/MeV

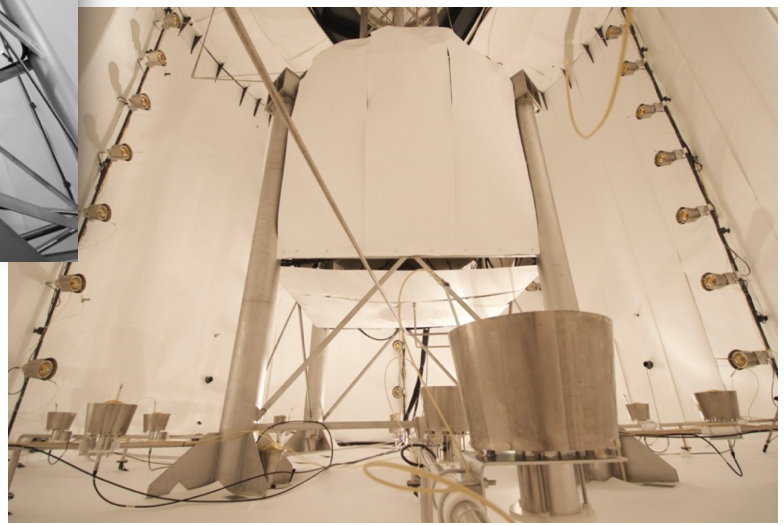
Cherenkov Water Detector

- 11 m diam. x 10 m
- 1000 tonne water Cherenkov detector
- 80 PMTs



The Detectors





The ^{39}Ar Issue Before DS50

Atmospheric Ar:

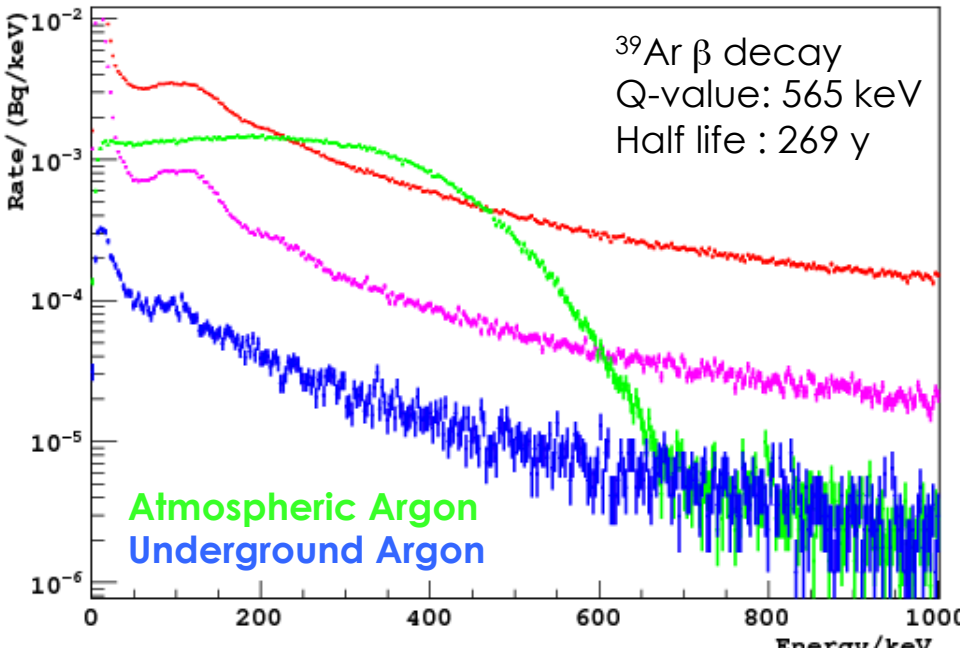
$^{39}Ar/^{40}Ar = 8 \times 10^{-16}$

Rate ~ **1 Bq/kg**

Underground Ar:

$^{39}Ar <$ **6.5 mBq/kg**

(arXiv:1204.6011)



	Total Rate [mBq /100 keV]	Estimated BG Rate [mBq/100keV]	BG Subtracted Rate [mBq/100keV]
Atmospheric Argon	108.8 ± 0.4	1.5 ± 0.2	107.2 ± 1.9
Underground Argon	1.87 ± 0.06	1.5 ± 0.2	0.32 ± 0.23
^{39}Ar Suppression Factor	58.2 ± 1.9		**> 153 (95%)**

arXiv:1204.60111

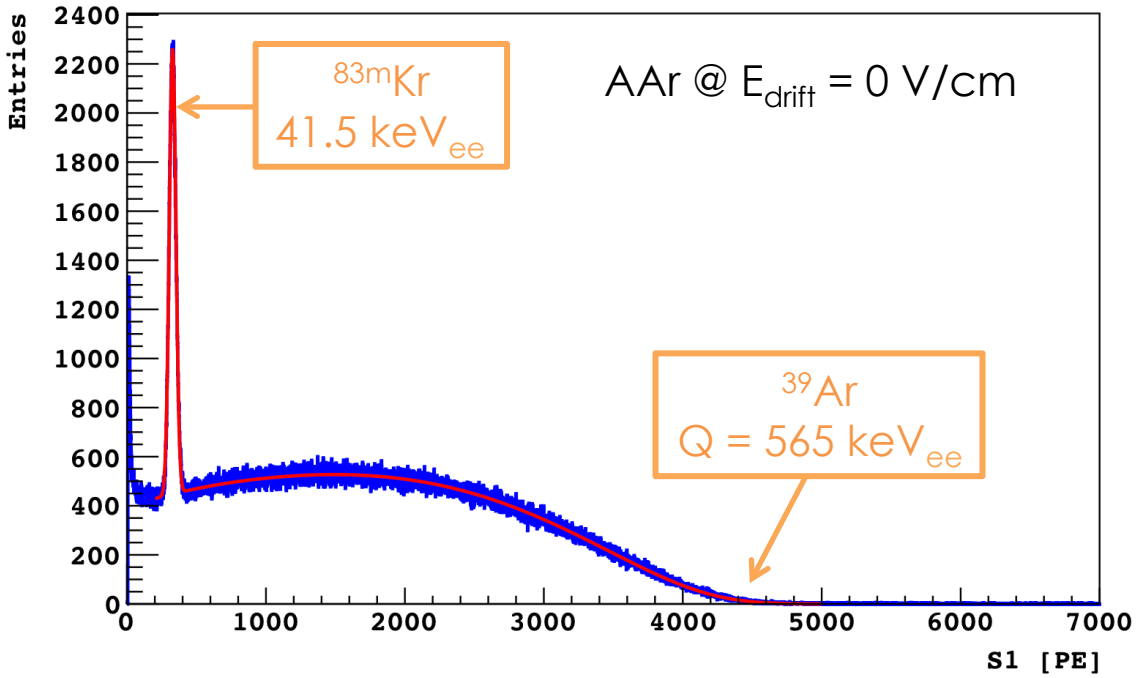
Depletion Factor > 150

Internal Calibrations

Atmospheric argon:
~1 Bq / kg of **^{39}Ar**
1.5 x 10^7 events in 47.1 days
Q-value = 565 keV

Injected gaseous **^{83m}Kr**
E = 41.5 keV

Average **Light Yield**:
~7.9 pe/keV at null field
~**7.0 pe/keV at 200 V/cm**

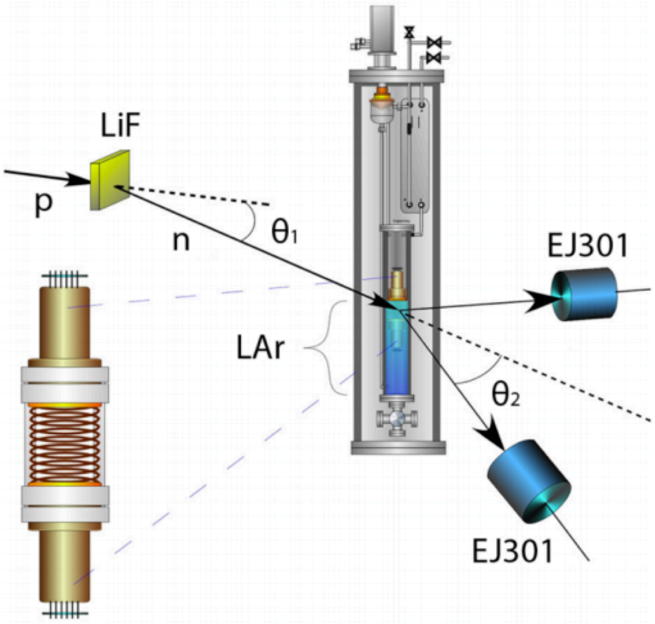


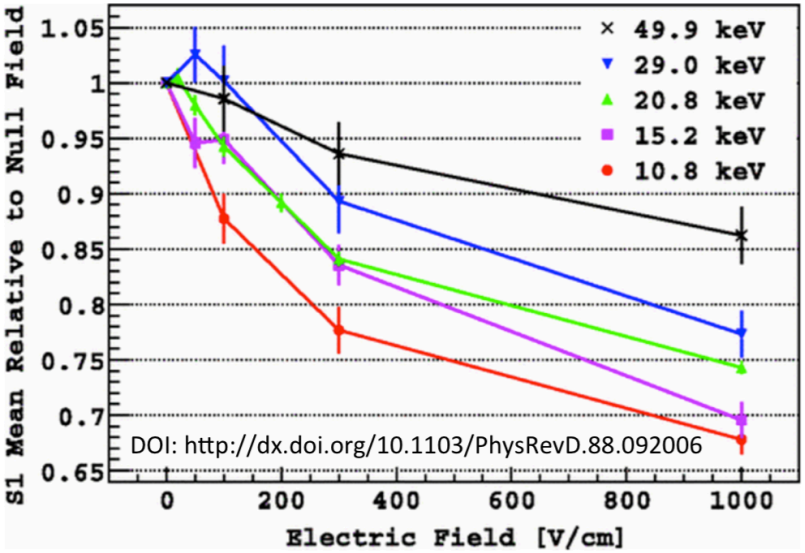
Electron lifetime: ~10 ms
Maximum drift time in the TPC: **375 μs** at 200 V/cm
Drift velocity **0.93 mm/μs**

Nuclear Recoil Energy Scale

SCENE

Scintillation Efficiency of Nuclear Recoils in Noble Elements



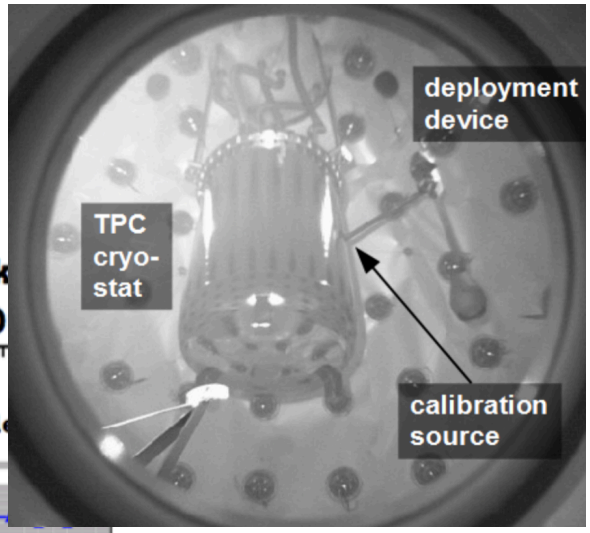


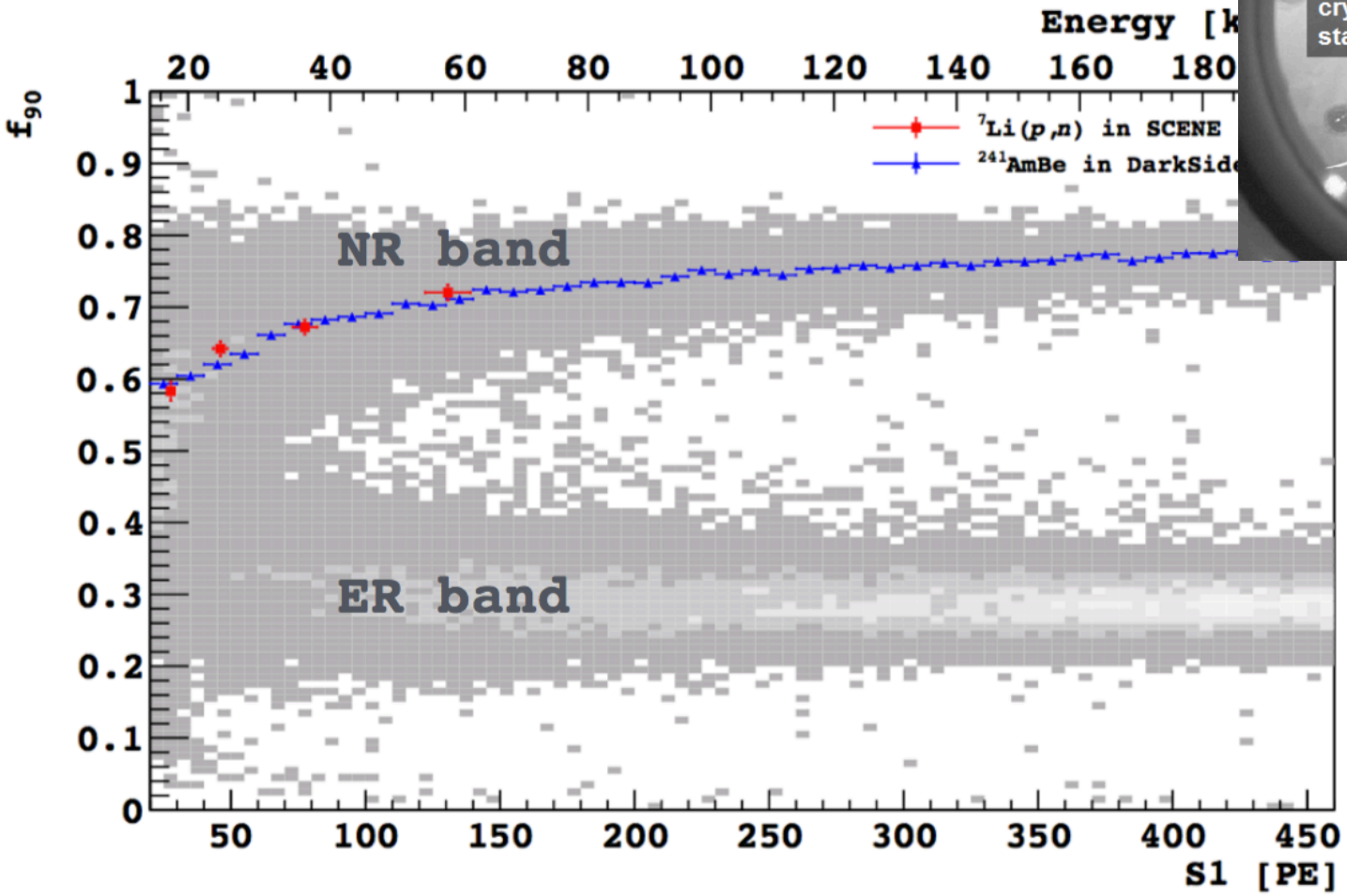
Neutron calibration in large detectors affected by neutron **multiple scatterings**

SCENE has collected extremely **pure samples of single nuclear recoils** in a small scale TPC

External Calibrations

Neutron source: AmBe w/ and w/o collimator



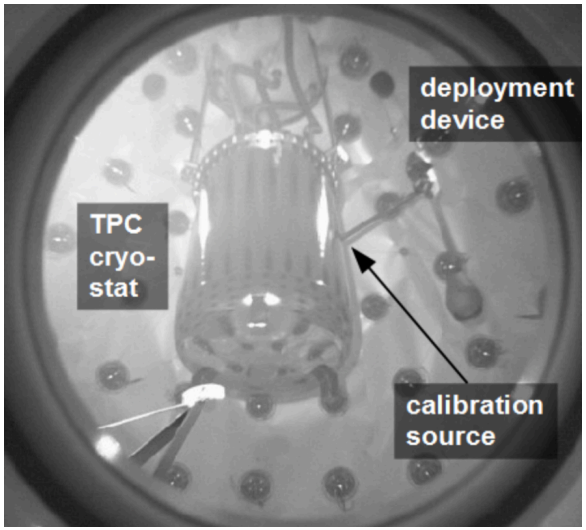


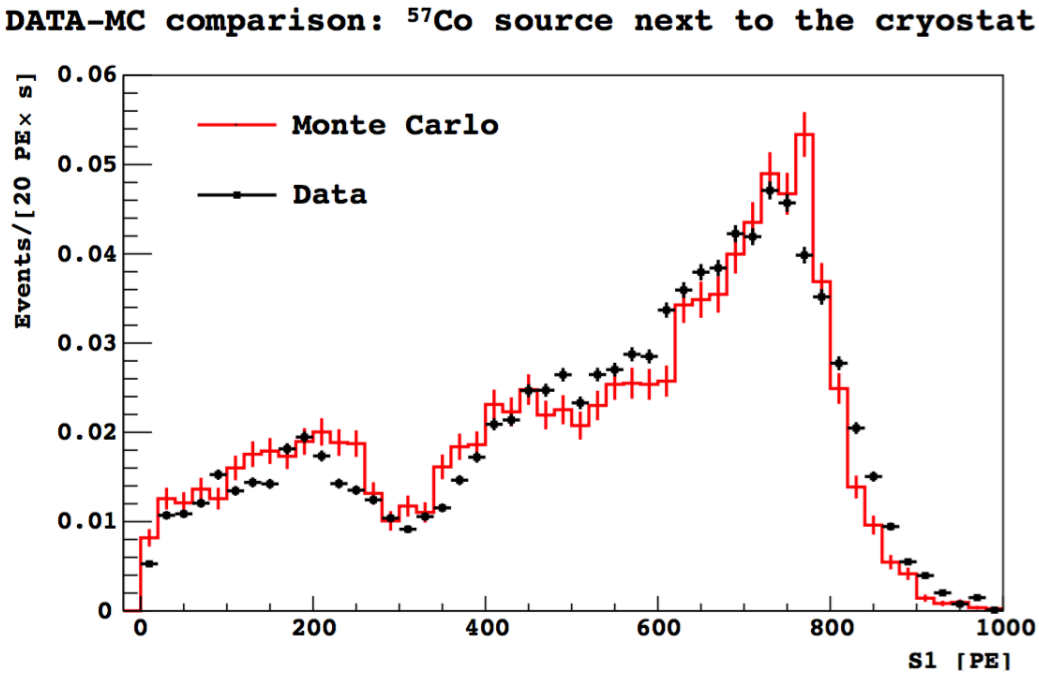
External Calibrations

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

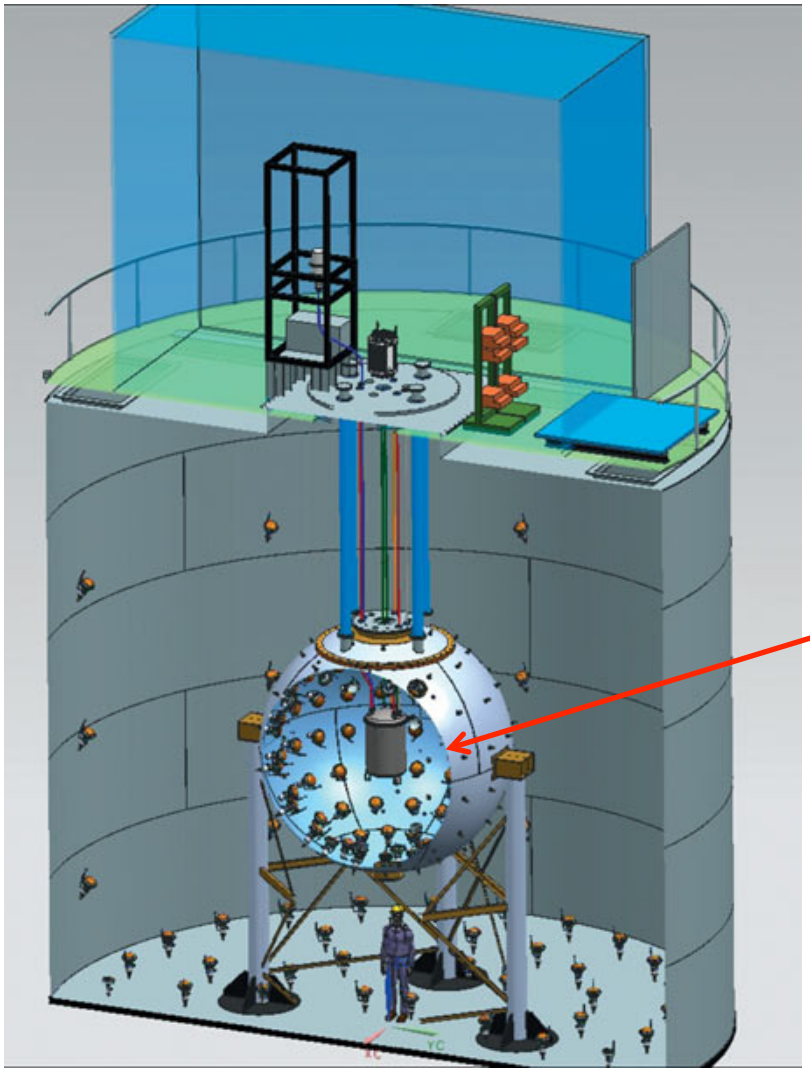
Full **MC** description of all the DS detectors, including:

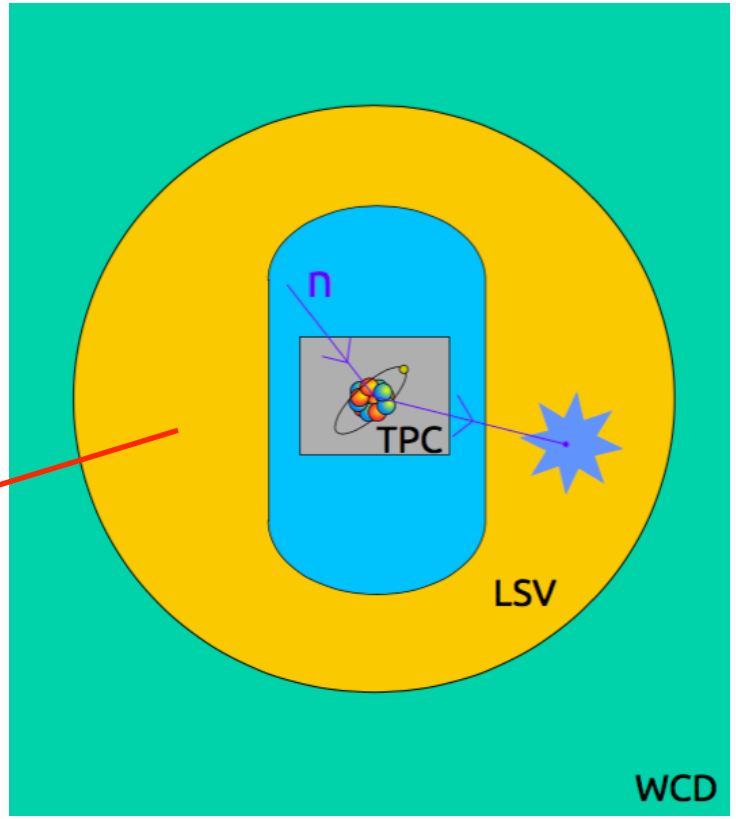
- Custom-made ionization, excitation, and recombination model
- Full photon generation and tracking
- Optical tuning of the TPC: accuracy at a few percent level
- Nuclear quenching model



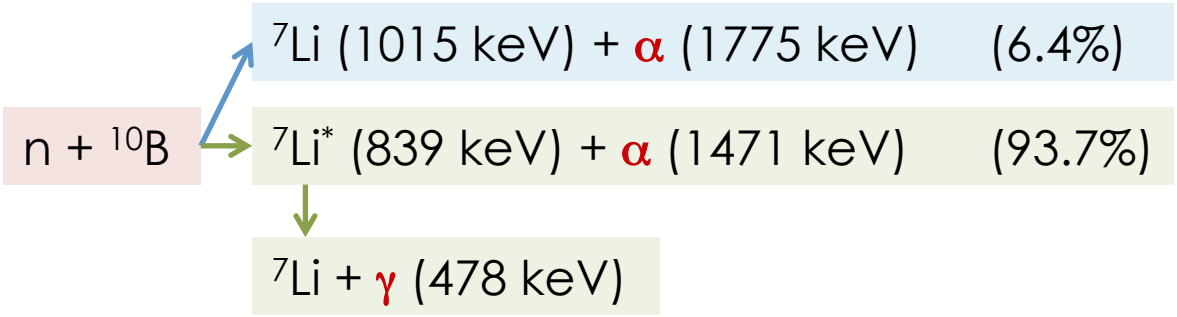


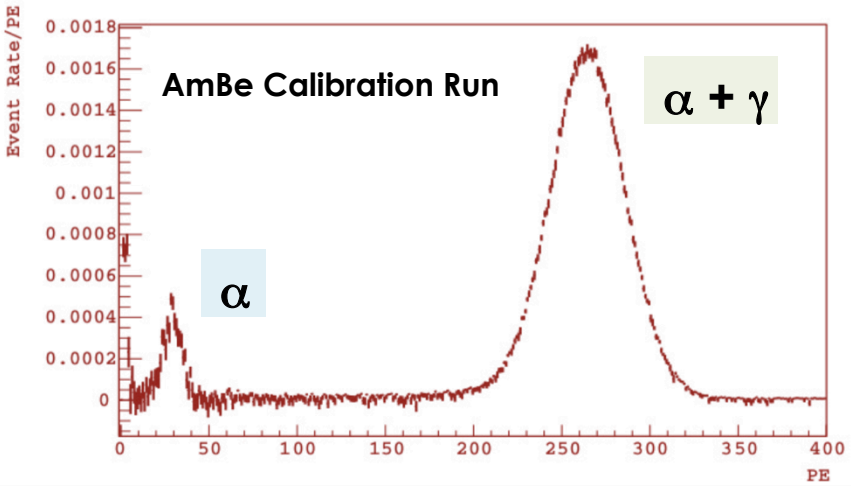
The Neutron Veto





The Neutron Veto





Neutron Veto Efficiency

Efficiency from capture signal alone at > 99%
(from calibrations and simulations)

- ~0.6% of lost neutrons because of escaping proton capture gamma
- ~0.05% of neutrons leave no signal in LSV at all

Larger total efficiency due to thermalization signal

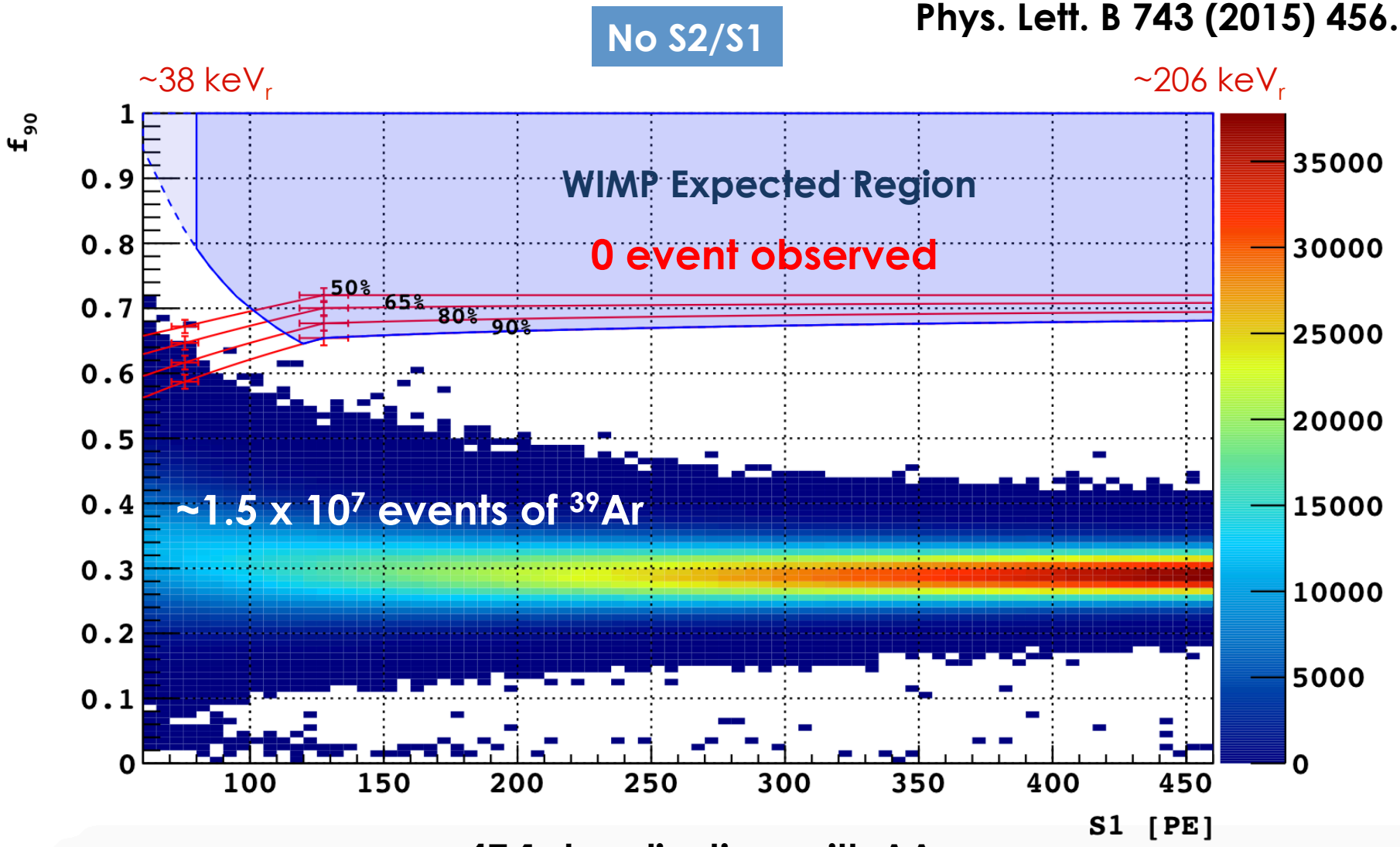
Cut at 1 PE threshold: ~0.9% acceptance loss

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 with radioactive sources
- **Jan 2015**: Add **radiopure TMB** at 5% concentration
- **Mar to Apr 2015**: filling with **underground argon** (UAr) and re-commissioning the detector
- **Apr to Aug 2015**: Accumulate data with UAr for **dark matter search**

Atmospheric Argon Run: the PSD

Phys. Lett. B 743 (2015) 456.



47.1 days livetime with AAr

1422 ± 67 kg day

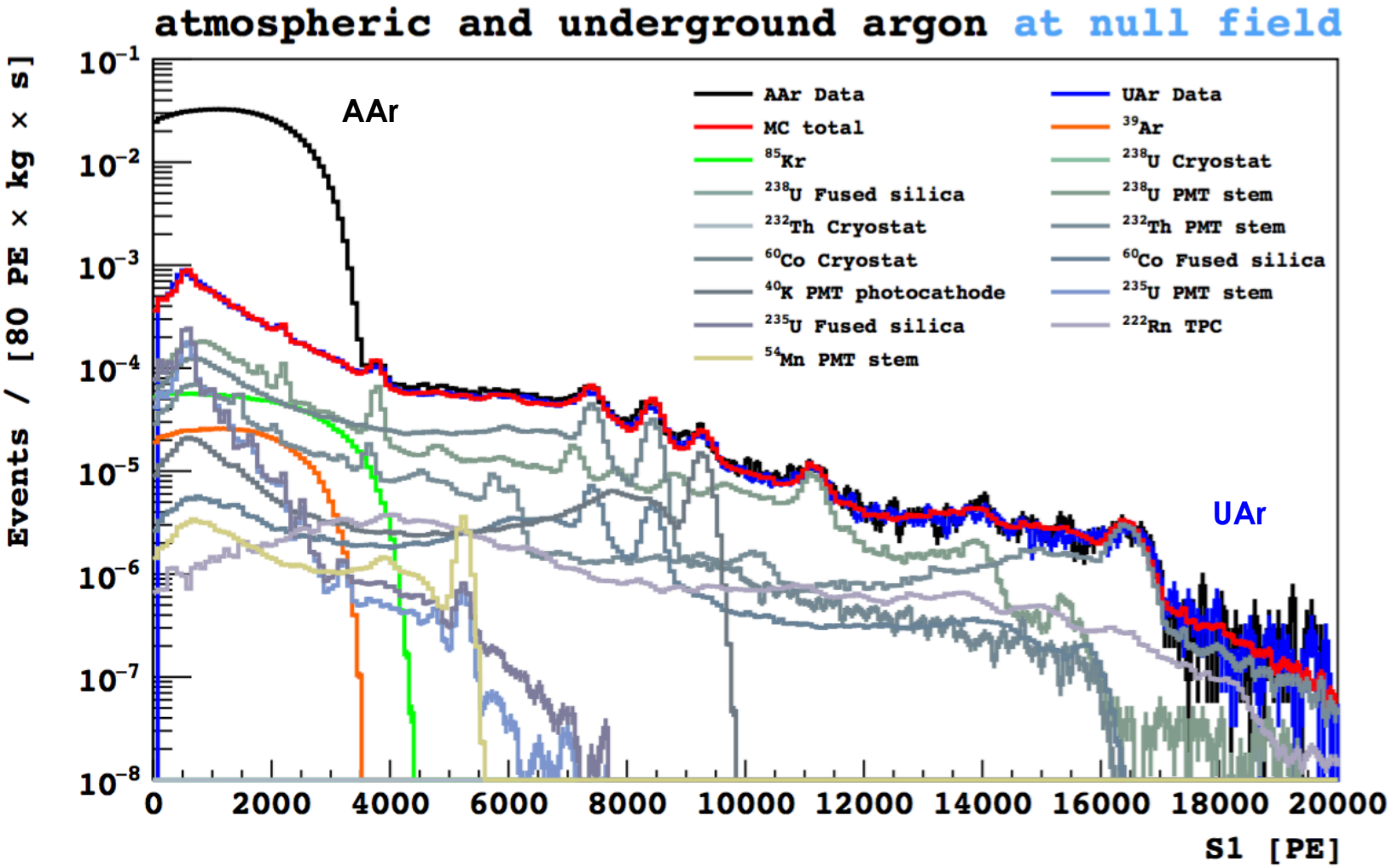
Underground Argon

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

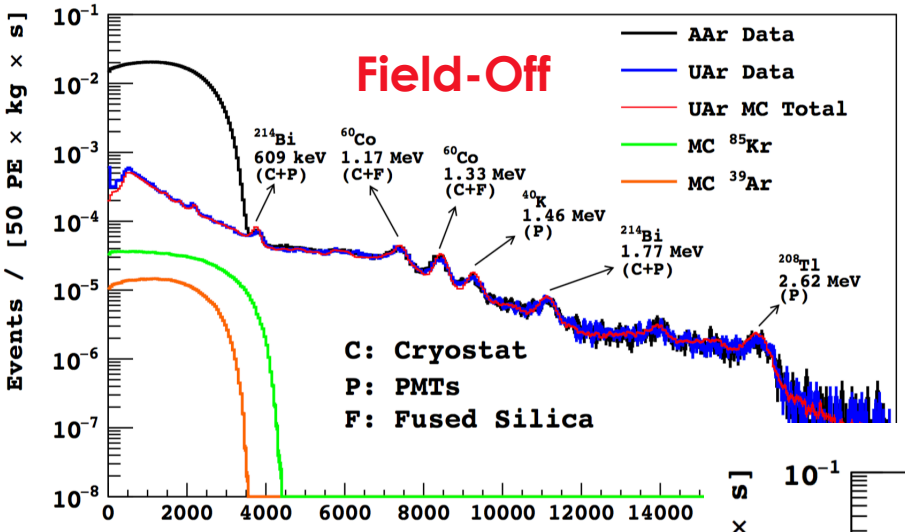
2. Purification at Fermilab
Separate Ar from He and N_2

3. Ship to LNGS
Ready to fill into DS-50

The Underground Argon Run



The Underground Argon Run



Three-dimensional likelihood fit based on MC pdf's using:

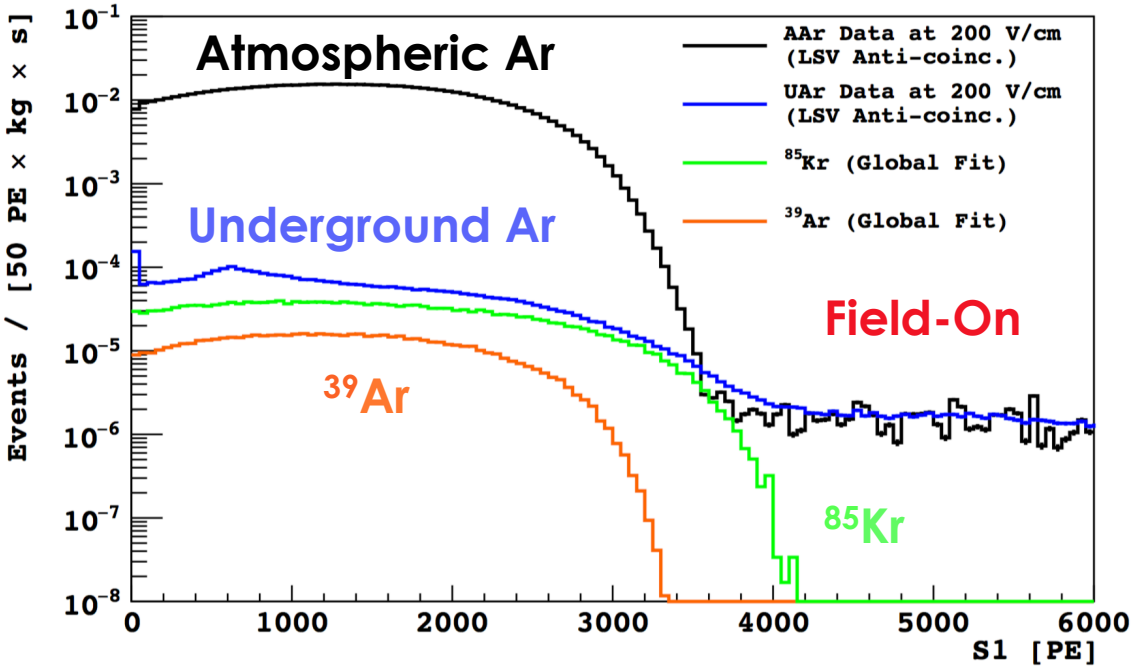
- **S1 field-off**
- **S1 field-on**
- **Drift time**

Underground Ar:

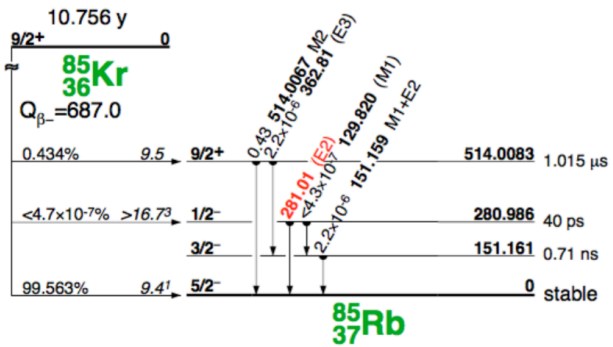
Naturally shielded against cosmic rays

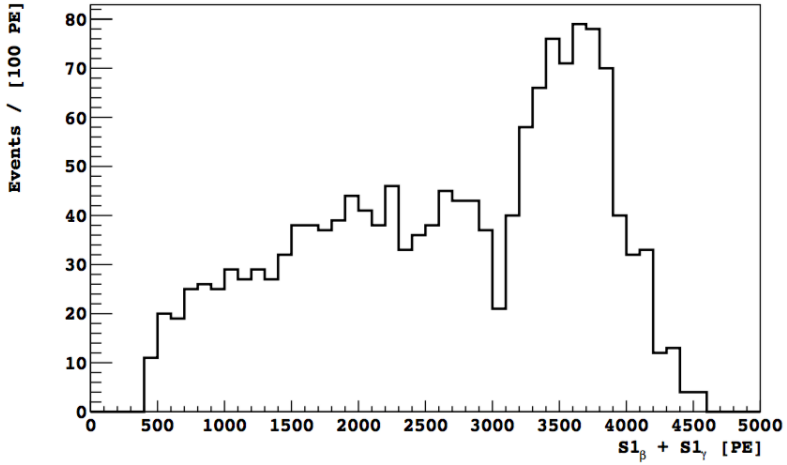
Rate ~ **0.7 mBq/kg**

Depletion factor ~ 1400



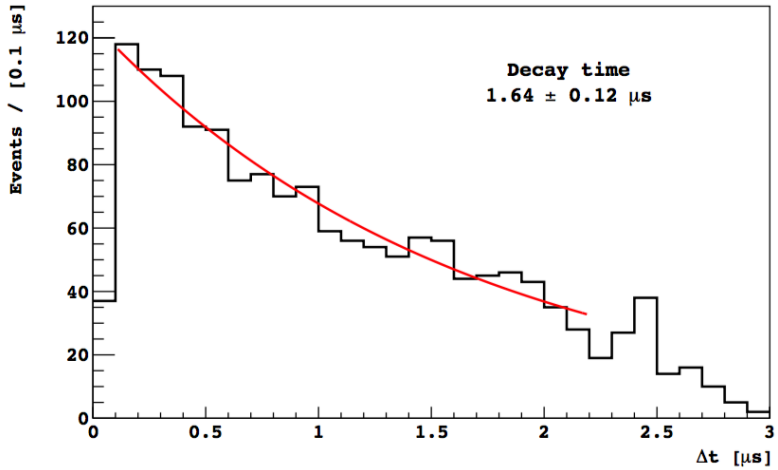
The ^{85}Kr Contamination





99.57% BR via β (687 keV)

0.43% BR via β (173 keV) + delayed γ (514 keV)
Coincidence mean time: ~**1.46 µs**

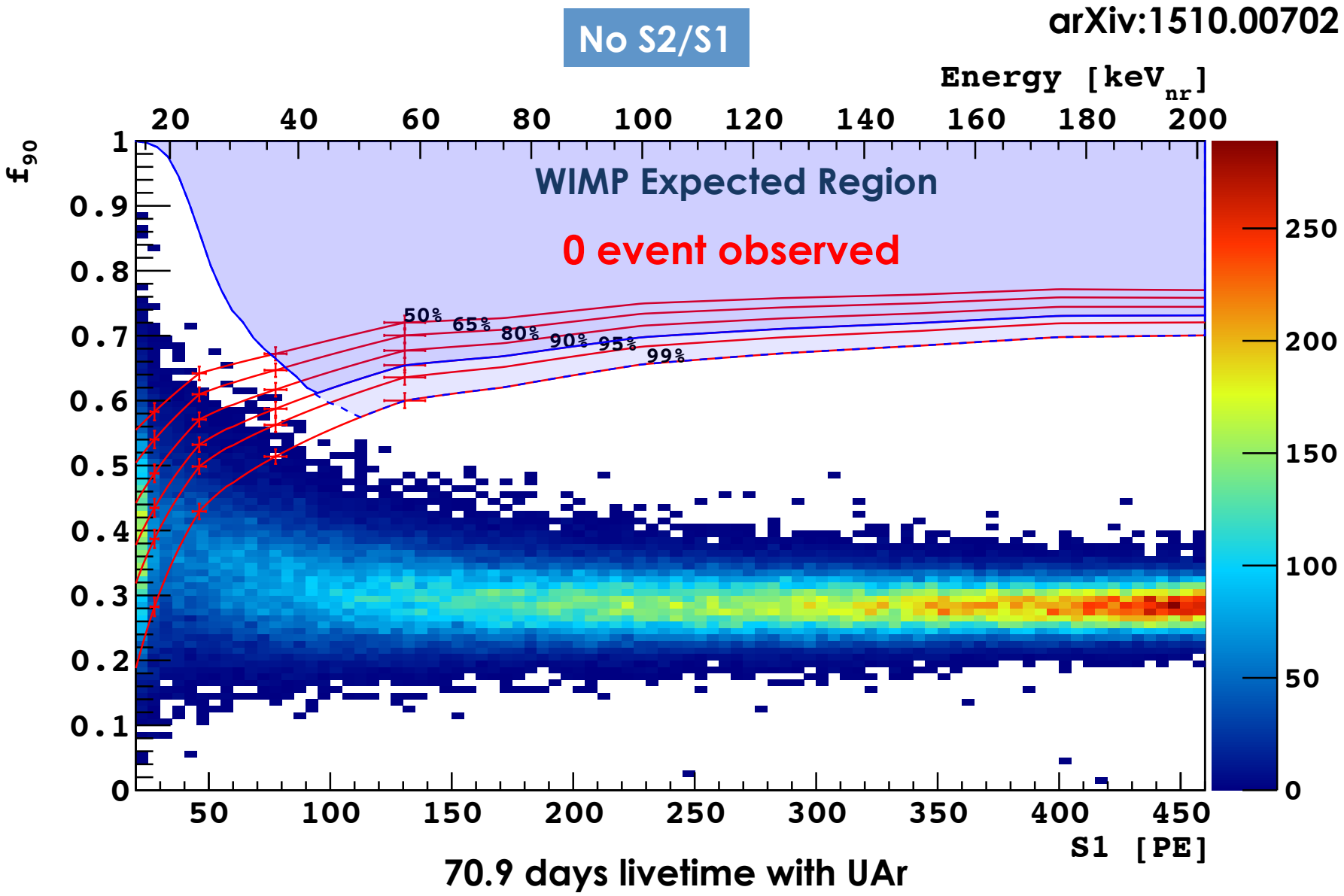


Deriving the small BR rate from the main branch:

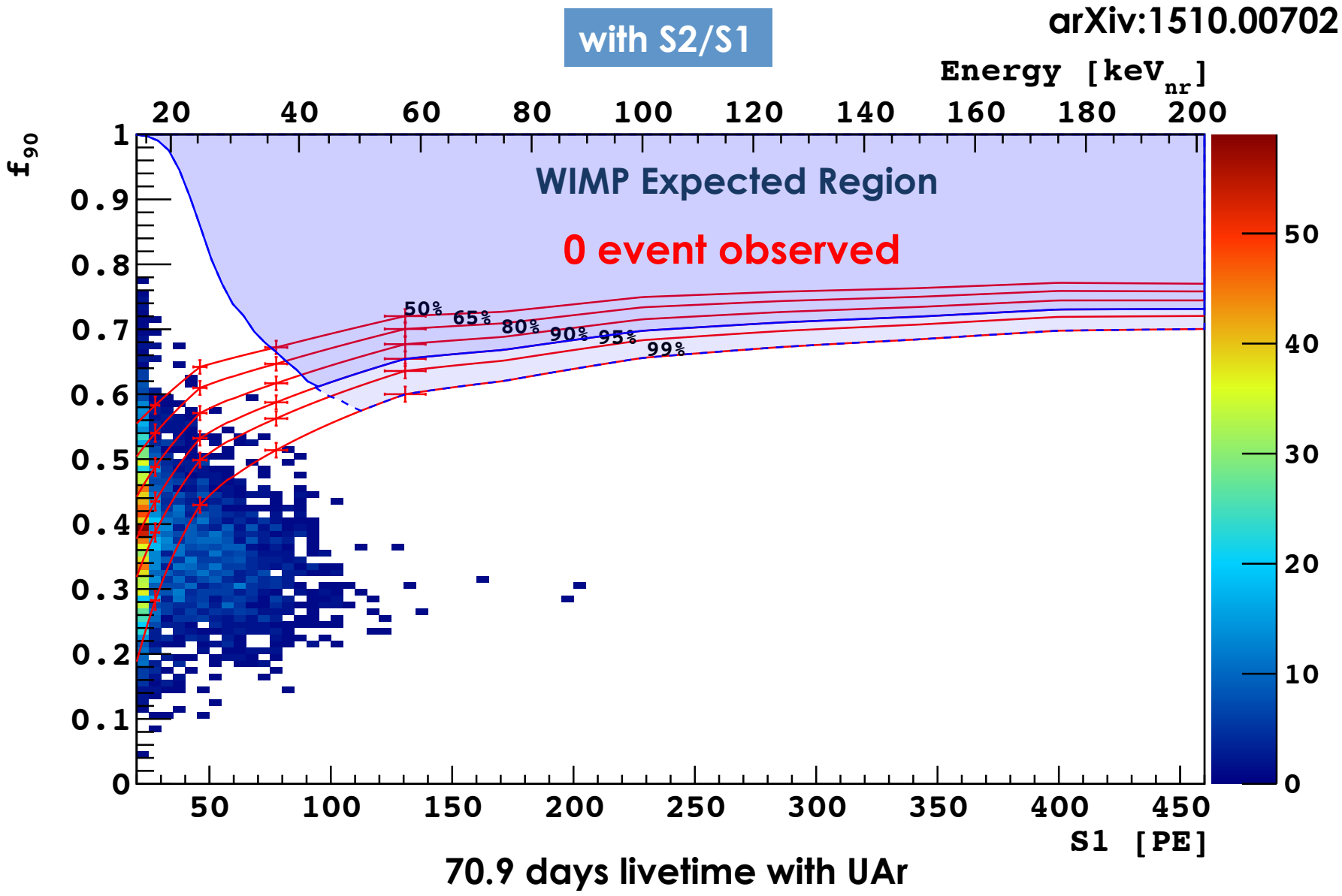
35.3 ± 2.2 cpd

33.1 ± 0.9 cpd

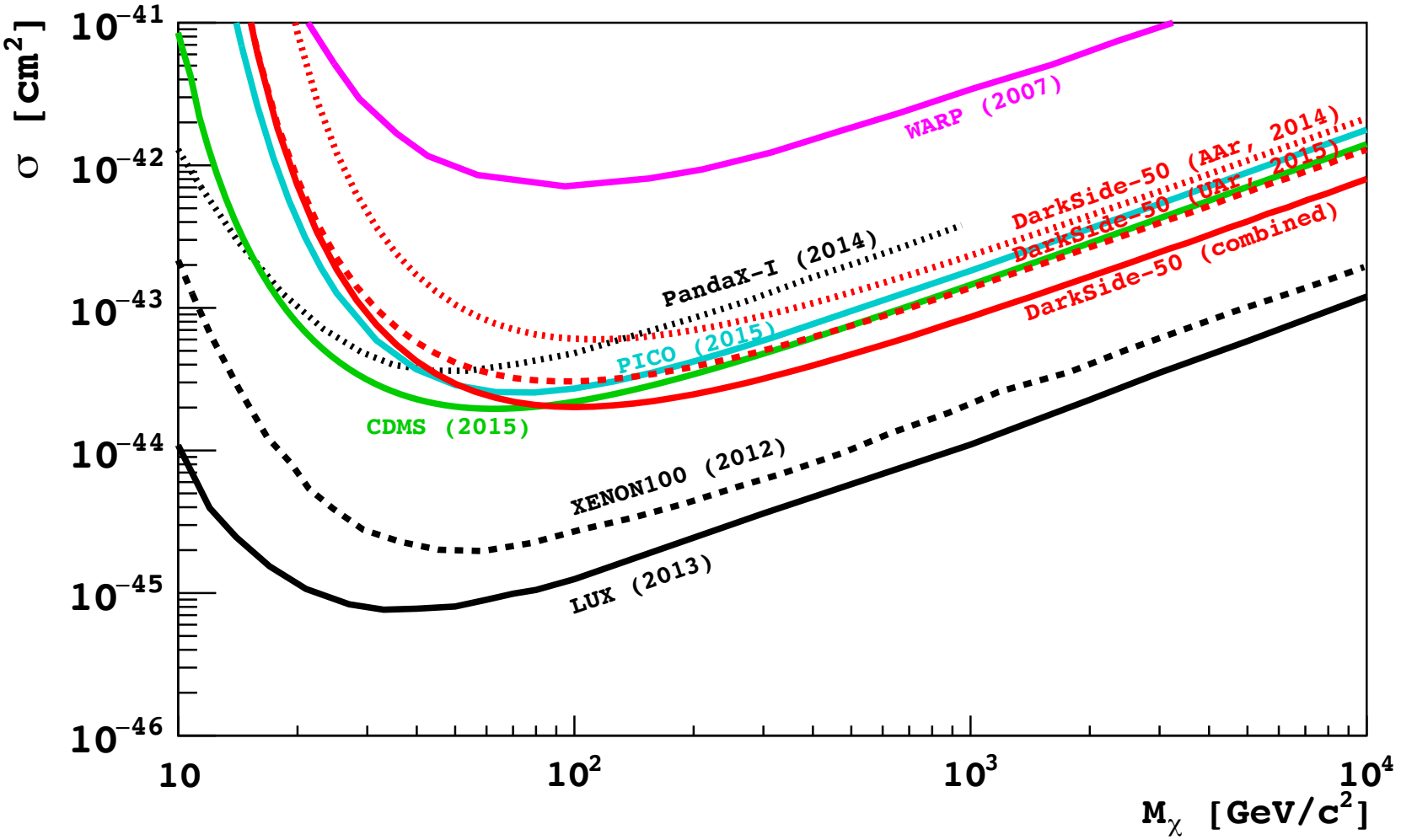
Underground Argon Run: the PSD



Underground Argon Run: the PSD + S2/S1



WIMP Limits



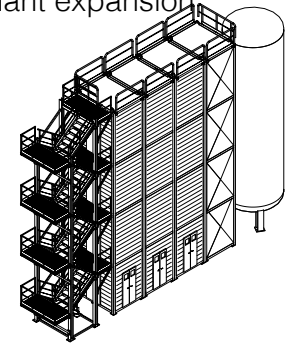
DarkSide arXiv:1510.00702

Depleted Ar: the **URANIA** and **ARIA** projects

URANIA

Replacement of the Ar extraction plant in Colorado to reach capacity of **100 kg/day** of UAr

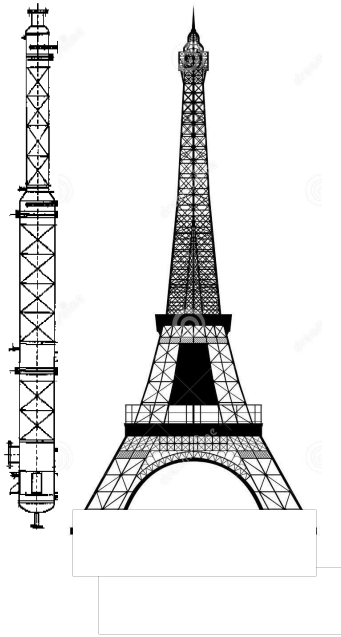
Plant expansion



ARIA

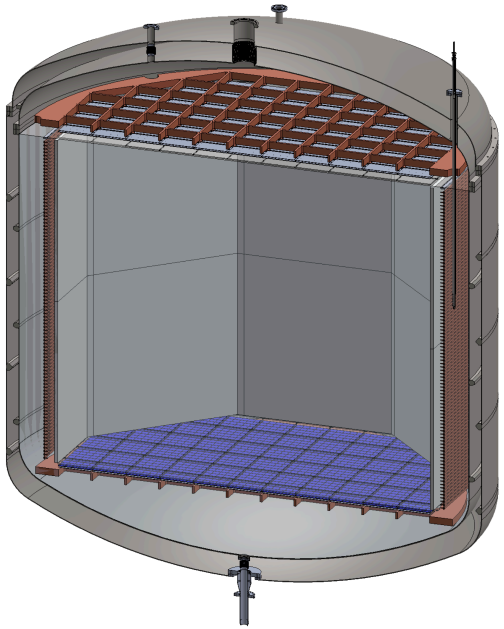
Very tall distillation column in Seruci mine (Sardinia) for chemical and isotopic purification of UAr

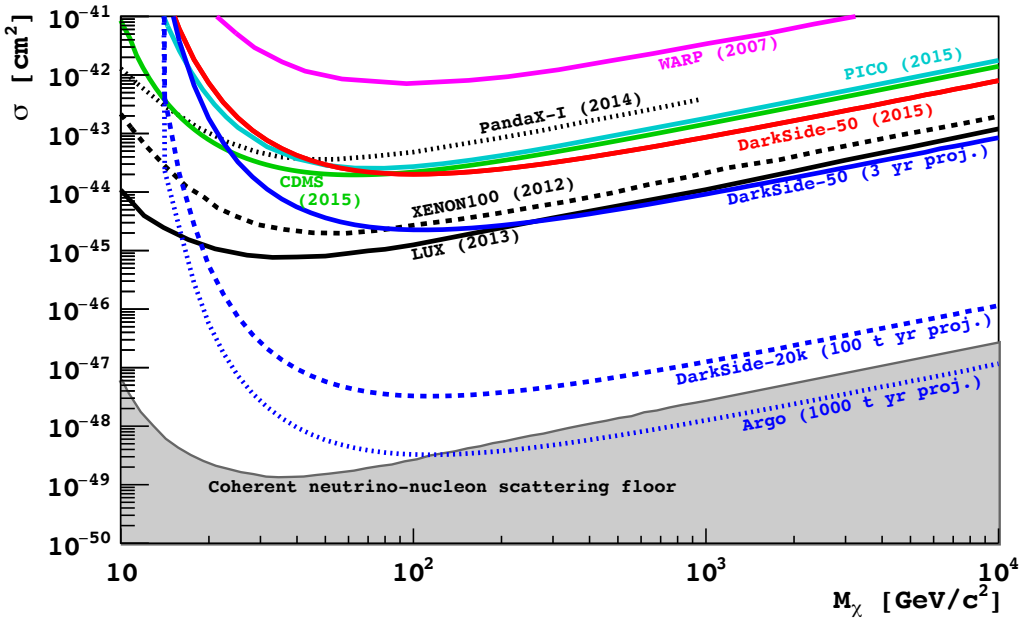
Exploits finite vapor pressure difference between ^{39}Ar/^{40}Ar: ^{39}Ar reduction factor of 10 per pass at the rate of **100 kg/day**



DarkSide-20k

- Octagonal TPC (~3 m diamater – ~3 m height)
- Target mass: **23 ton UAr**
- Equipped with 15 m^2 of **SiPM:** more radio-pure, smaller total mass, higher efficiency
- **Veto** similar to the DS50 one
- LoI submitted in April
- Technical proposal under submission





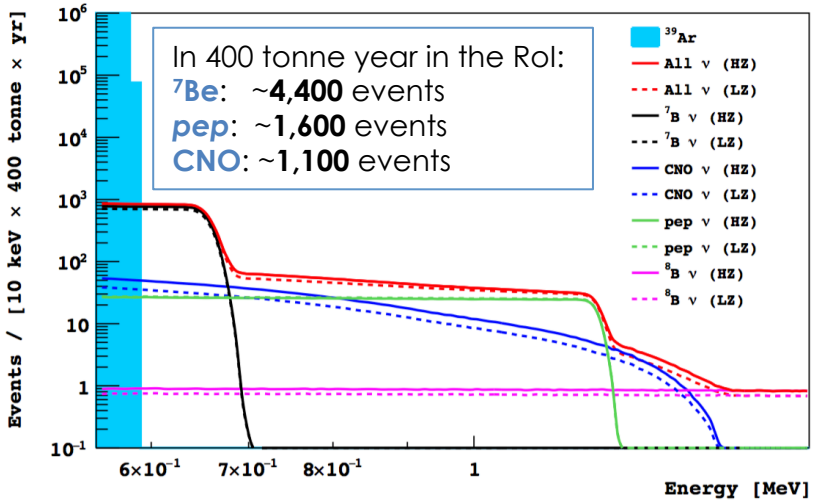
all projected sensitivities are evaluated by assuming 0 bg

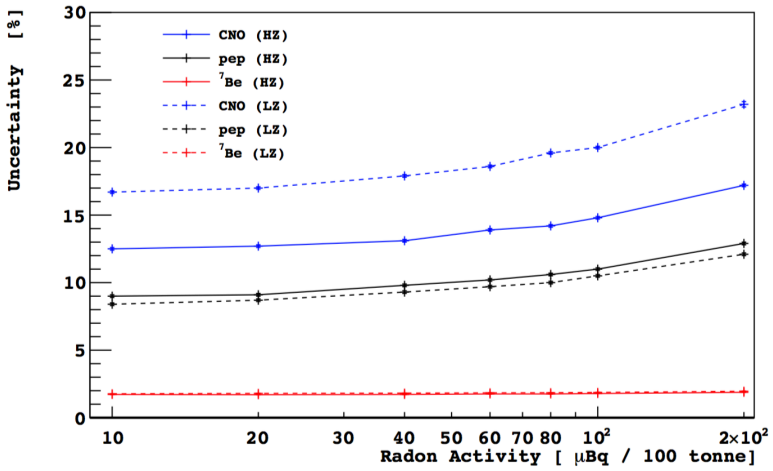
ARGO: the Solar Neutrino Channel

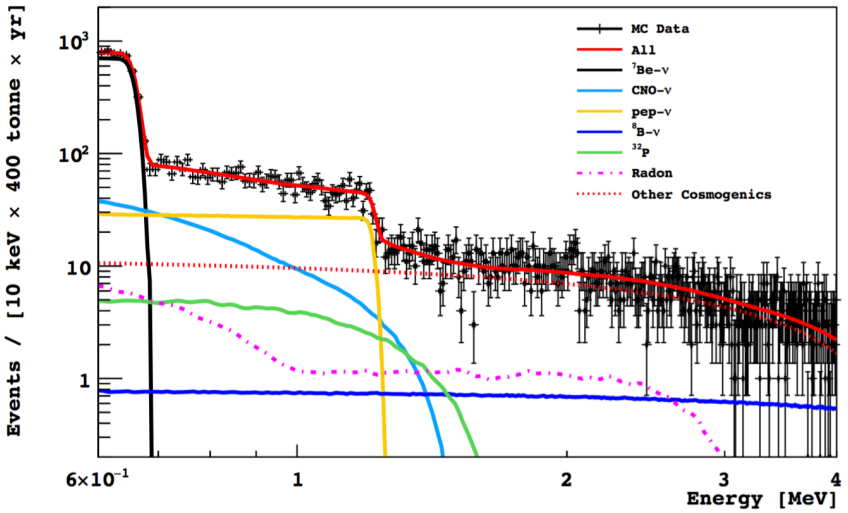
Goals:

- **Observation of CNO** neutrinos in 400 tonne year exposure (accuracy at ~15%)
- **Metallicity** solar models discrimination
- **^{7}Be** accuracy at 2%
- ***Pep*** accuracy at ~10%

Elastic Scattering







arXiv:1510.04196

Conclusions

^{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

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

Pulse shape discrimination **rejects ER with a factor larger than 1.5×10^7**

Future detectors are planned:
Letter of Intent submitted to LNGS April 27 2015
Technical Proposal under submission to INFN and NSF

DarkSide is demonstrating that
a background free large volume LAr TPC is possible