

THE DARKSIDE EXPERIMENT – PRESENT STATUS AND FUTURE

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for the DARKSIDE Collaboration

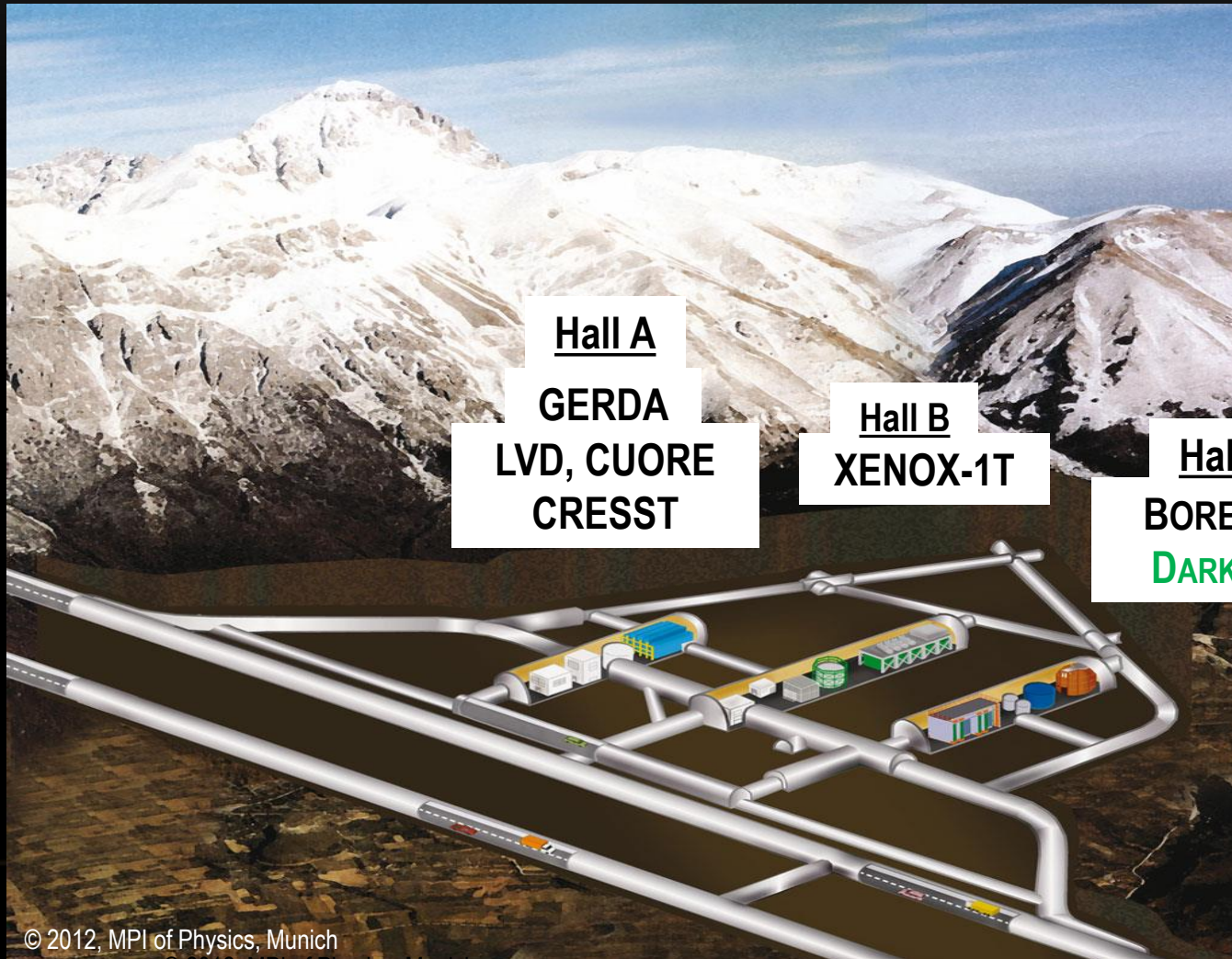
OUTLINE

- The DARKSIDE program
- DARKSIDE-50 detector
- Physics results from DARKSIDE-50
- Future DARKSIDE detectors
- Summary

THE DARKSIDE PROGRAM

- Multi-stage program for searches of dark matter direct interactions in low-background detectors deployed at the Gran Sasso underground laboratory.
- Based on a two-phase low-radioactivity argon time projection chamber (TPC)
- Ultra-low background design
- Active suppression of residual backgrounds for true **background-free** operation

THE DARKSIDE PROGRAM

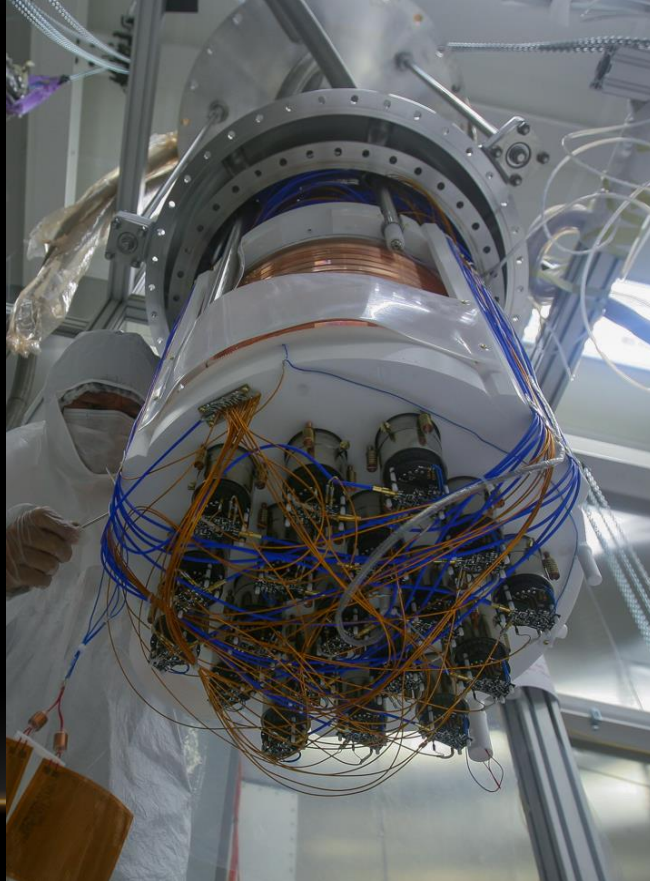


THE DARKSIDE PROGRAM

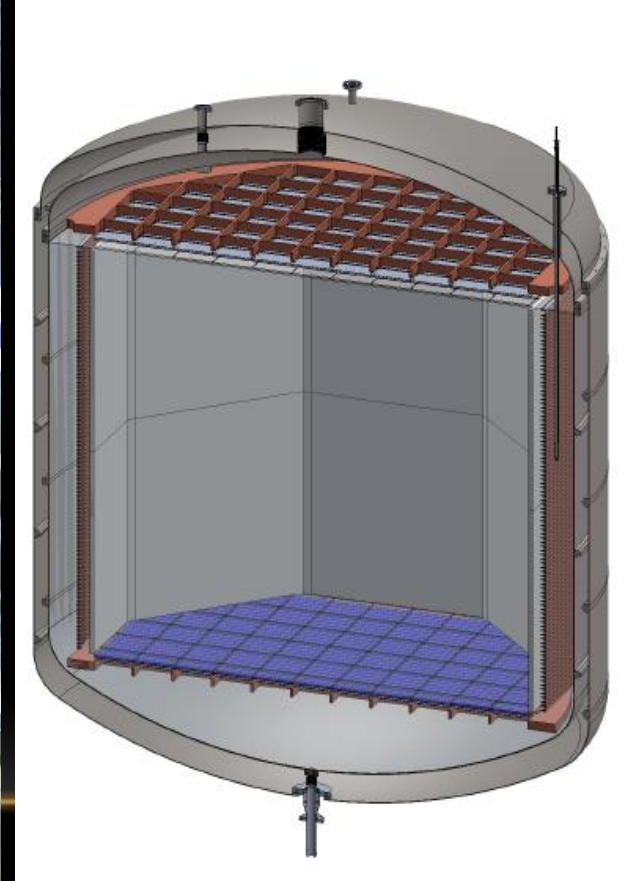
DS-10 prototype
(2011 - 2013)



DS-50 detector
(Since Oct. 2013)



DS-20k
(2020 -)



DS-50 DETECTOR

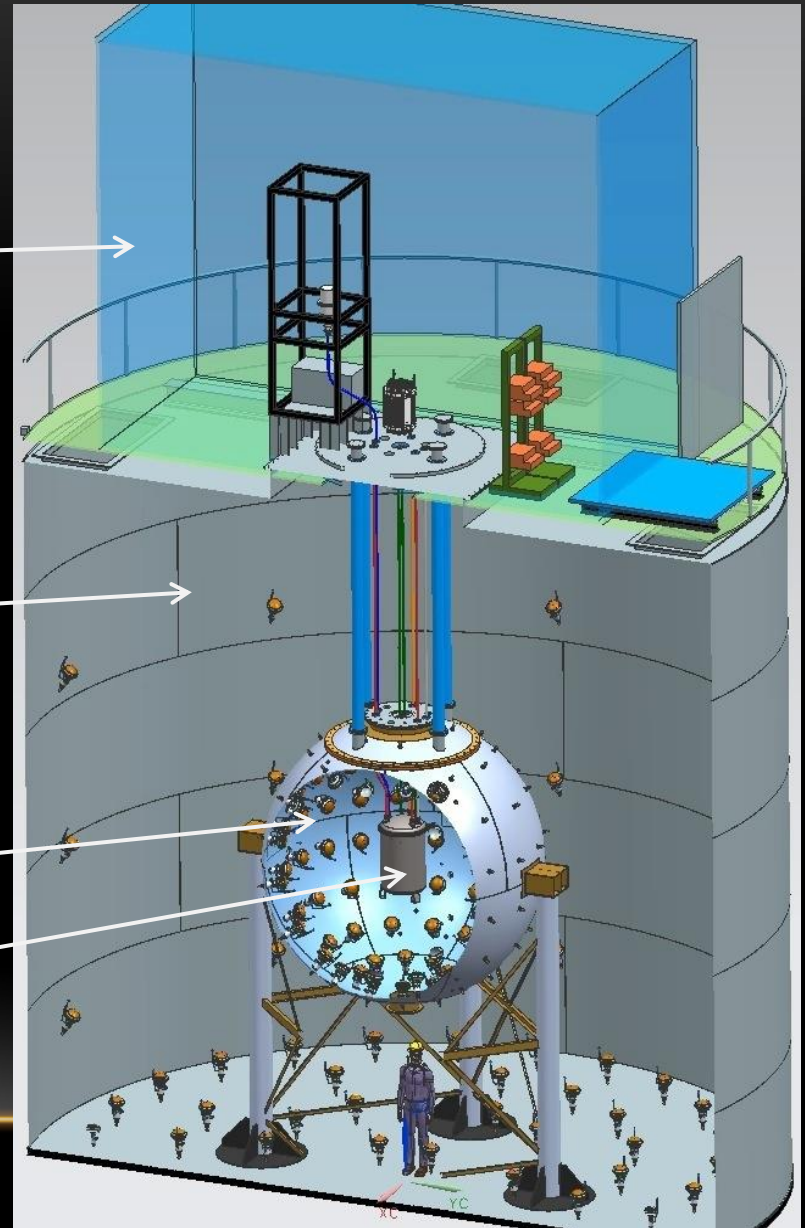
Clean room

Instrumented water tank (1 kton)

- 80 8" PMTs
- 11 m dia. x 10 m high
- Muon and cosmogenic veto (~ 99.5% efficiency)
- Passive γ/n shielding

Liquid scintillator detector

Inner detector: TPC



DS-50 TPC

Anode (15 nm film ITO on silica fused window)

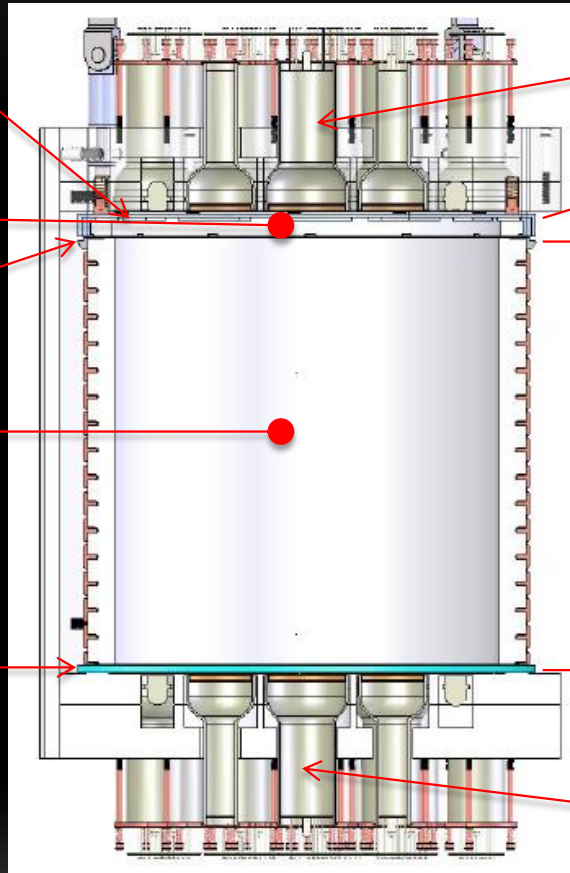
Gaseous Argon

Extraction grid

Liquid Argon

Cathode

TPC: 36 cm φ \times 36 cm high



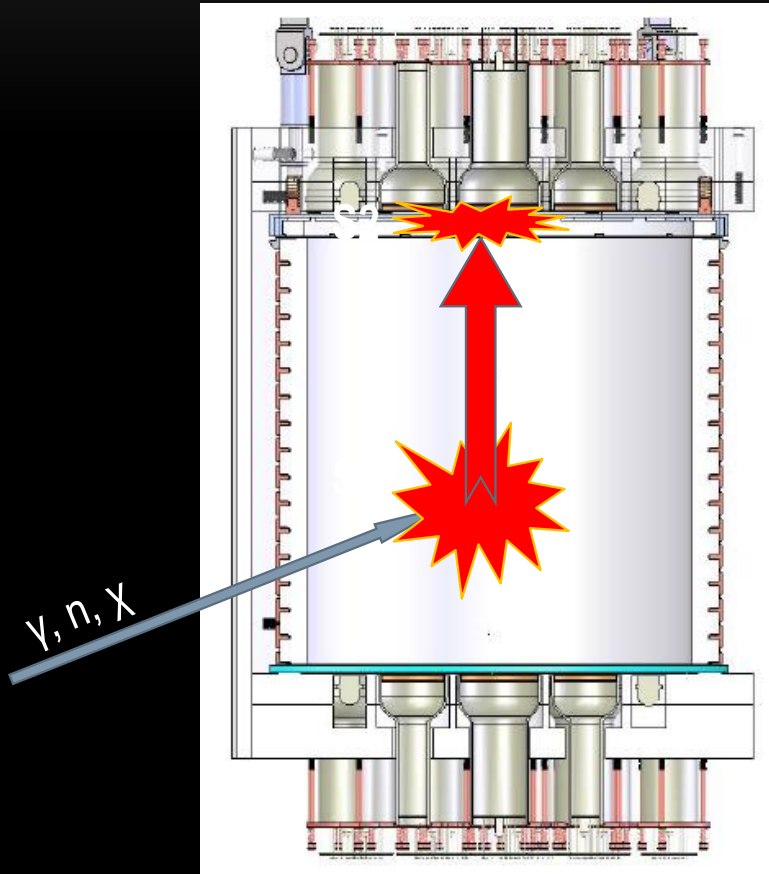
PMTs (19 x 3" R11065)

$\vec{E}_{\text{extr.}}$ (2.8 kV/cm)

\vec{E}_{drift} (200 V/cm)

PMTs (19 x 3" R11065)

DS-50 TPC

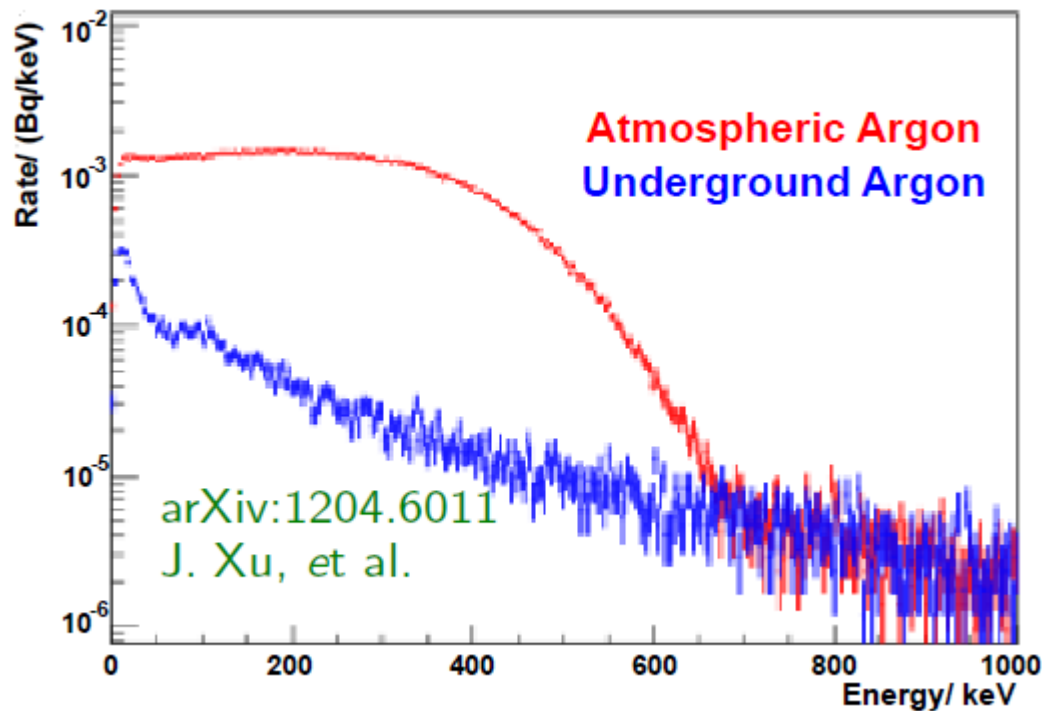


- Nuclear recoil produces primary scintillation light: S1
- Electrons that survive recombination are drifted towards the liquid-gas interface by the electric field
- The electrons are extracted into the gas region, where they induce electroluminescence: S2
- Time difference between S1 and S2 gives Z position, PMT hit pattern gives X-Y position
- Tools for backgrounds rejection:
 - PSD based on S1
 - S2/S1 ratio
 - Position reconstruction

UNIQUE FEATURES OF DARKSIDE

- Argon depleted in ^{39}Ar : underground argon (UAr)
- Liquid scintillator veto for neutrons
- Pulse shape discrimination for background rejection
- ^{222}Rn -free clean rooms

UNDERGROUND ARGON (UAr)



- ^{39}Ar radioactivity in atmospheric Ar (~ 1 Bq/kg) limits its usability as a WIMP target
- ^{39}Ar is of cosmogenic origin
- Source of underground argon (CO_2 well near Cortez, Colorado) measured to have > 150 times lower rate of ^{39}Ar (< 7 mBq/kg), compared to atmospheric argon
- Large-scale production possible (multi-ton Ar detectors)

UNDERGROUND ARGON (UAr)



Extraction of UAr at Colorado.
Crude argon gas mixture (Ar, N₂ and He)

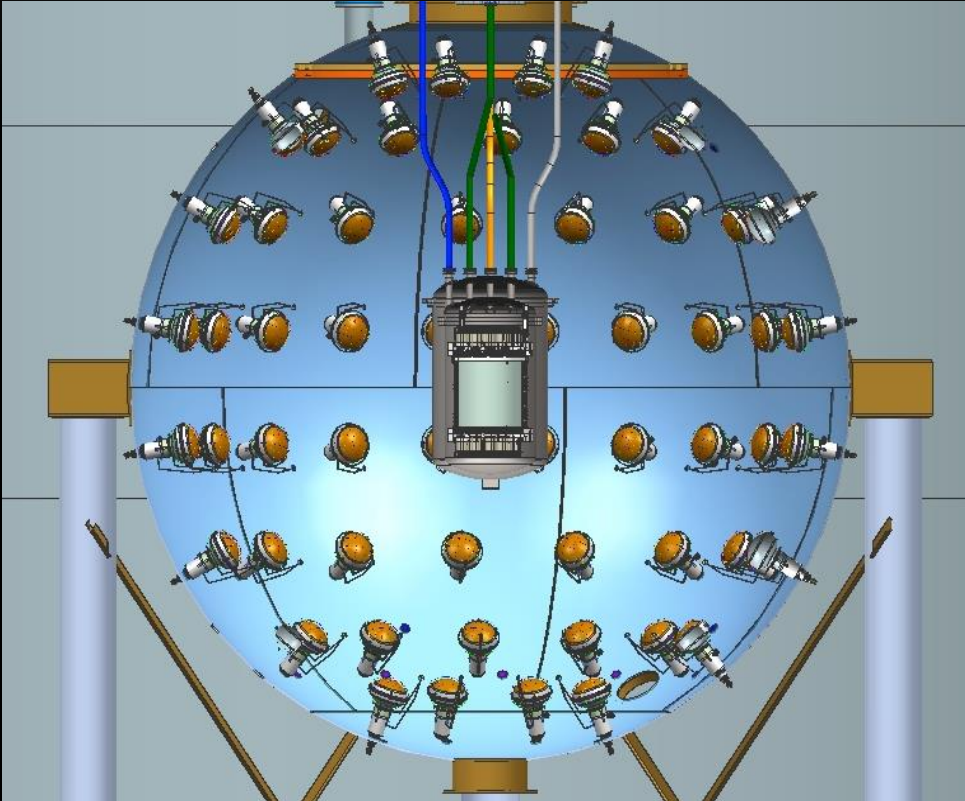


Distillation at Fermilab
Separate Ar from N₂ / He



UAr bottles (156 kg) at LNGS
Final purification with getters

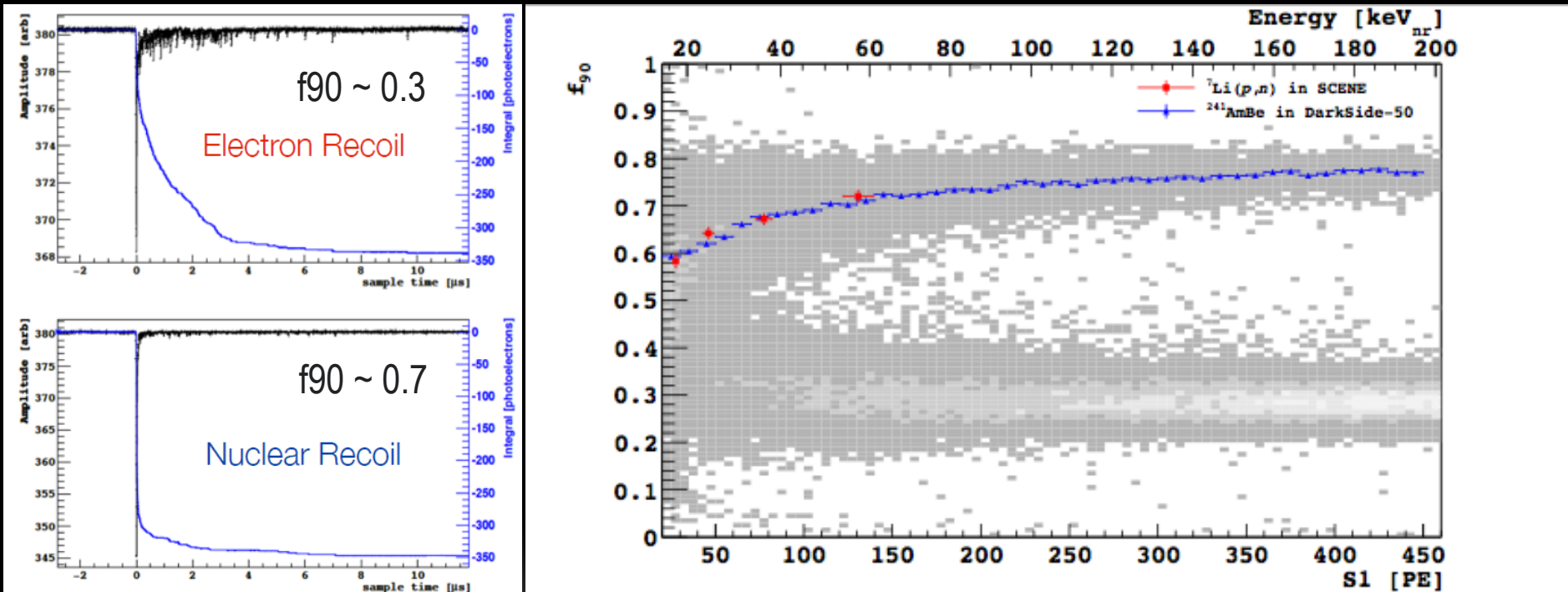
LIQUID SCINTILLATOR VETO



- 4 m diameter sphere containing PC + 5% trimethyl borate (TMB) scintillator (30 ton)
- Instrumented with 110 8" PMTs
- Veto of neutrons coincident in the TPC and provides in situ measurement of the neutron background rate
- Neutron capture results in 1.47 MeV α , capture time 23 μ s
- Veto efficiency: >99.1% for neutrons detected via delayed capture on ^{10}B and ^1H

PULSE SHAPE DISCRIMINATION

Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states \rightarrow f_{90} : Ratio of detected light in the first 90 ns, compared to the total signal (\sim single states fraction)



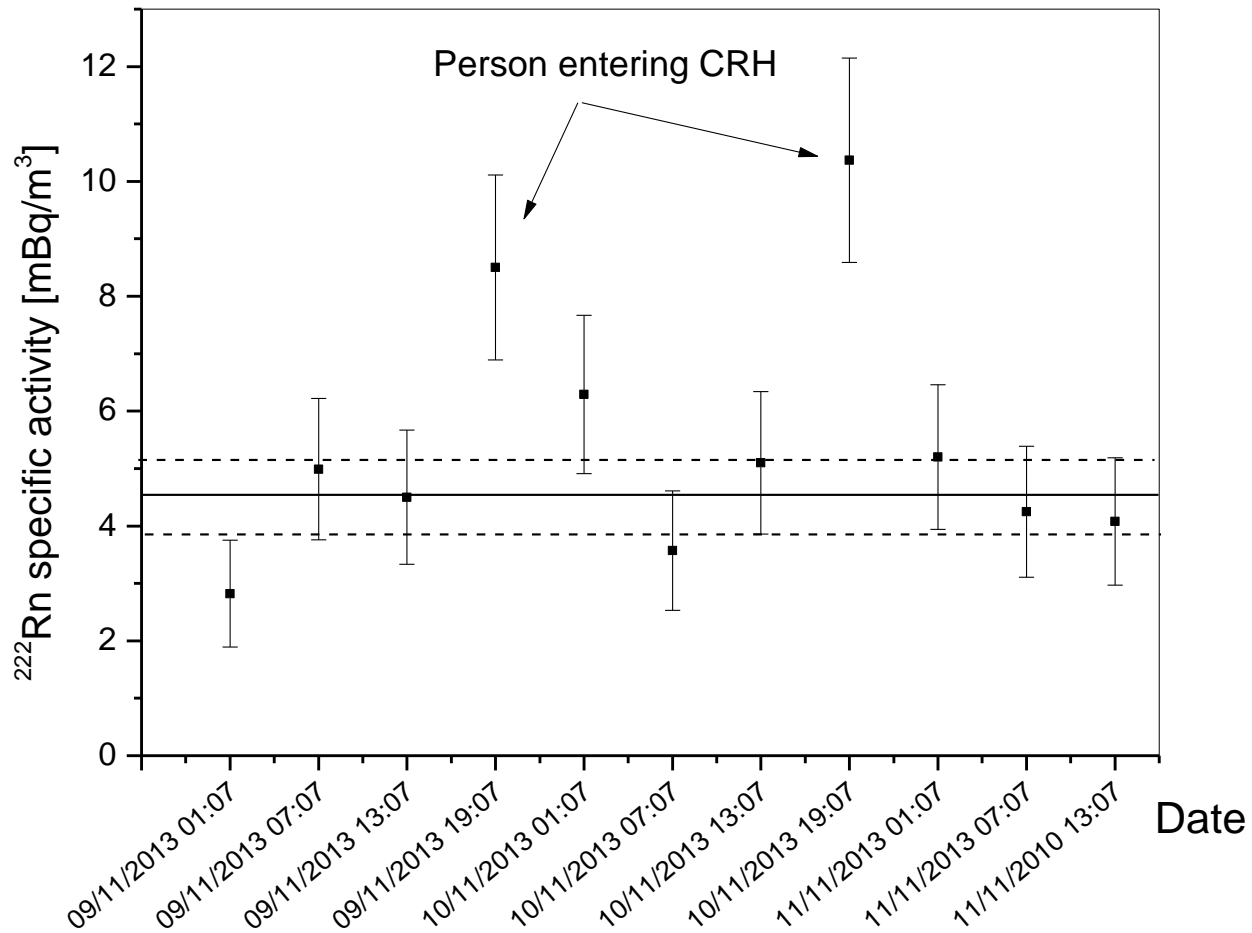
^{222}Rn -FREE CLEAN ROOMS



- Class 10 - 100
- Radon daughters plating out on surfaces of the detector may cause dangerous alpha-induced nuclear recoils
- Dedicated scrubbing system reducing ^{222}Rn concentration in the air down to $\sim 1 \text{ mBq/m}^3$ has been implemented
- DARKSIDE clean rooms are supplied with the ^{222}Rn -free air
- ^{222}Rn content in the clean rooms is monitored online by a dedicated detector

Typical radon in hall C air $\sim 30 \text{ Bq/m}^3$
Cleanroom radon levels $5 - 50 \text{ mBq/m}^3$

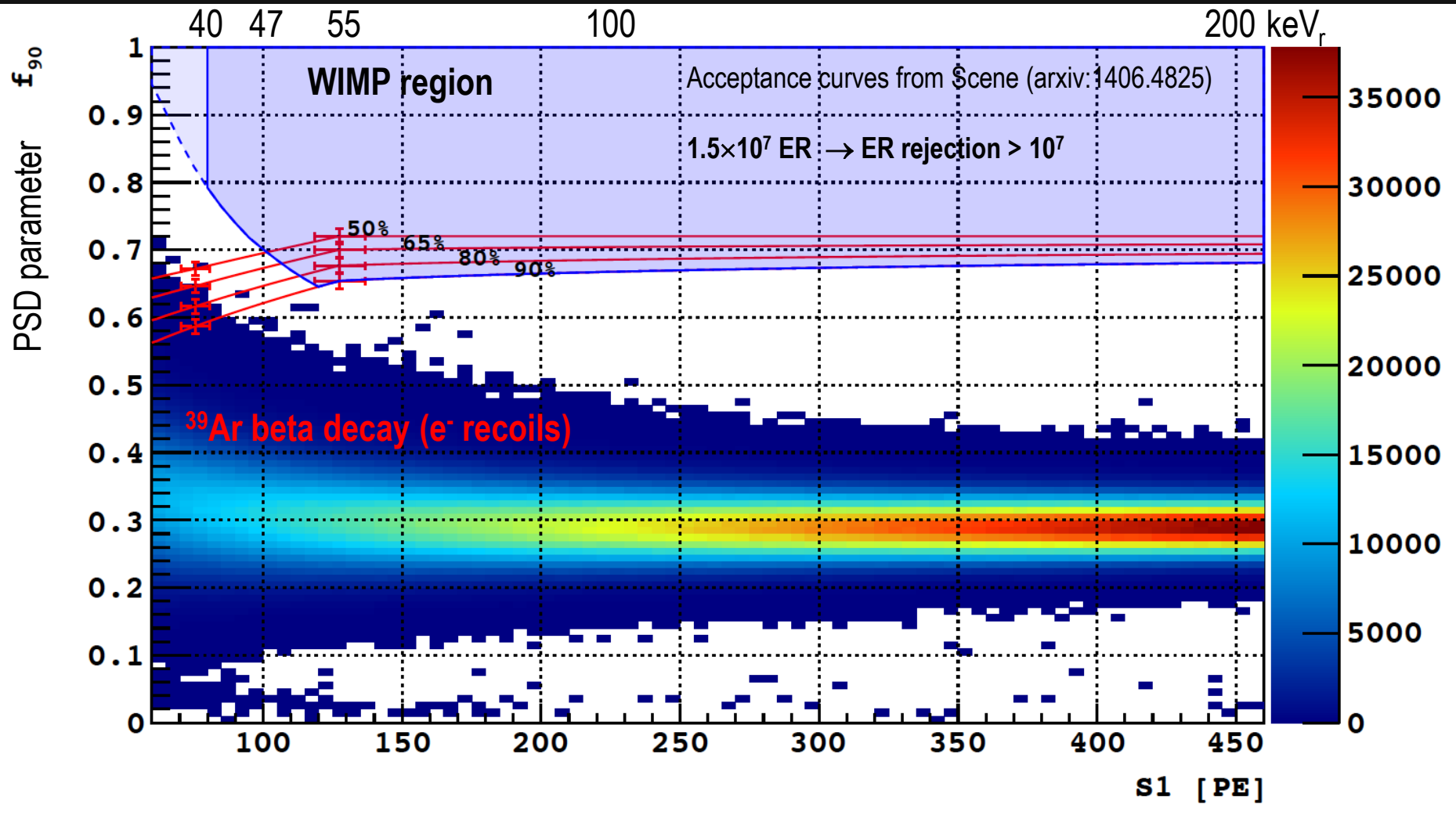
^{222}Rn -FREE CLEAN ROOMS



DS-50 RESULTS (AAr)

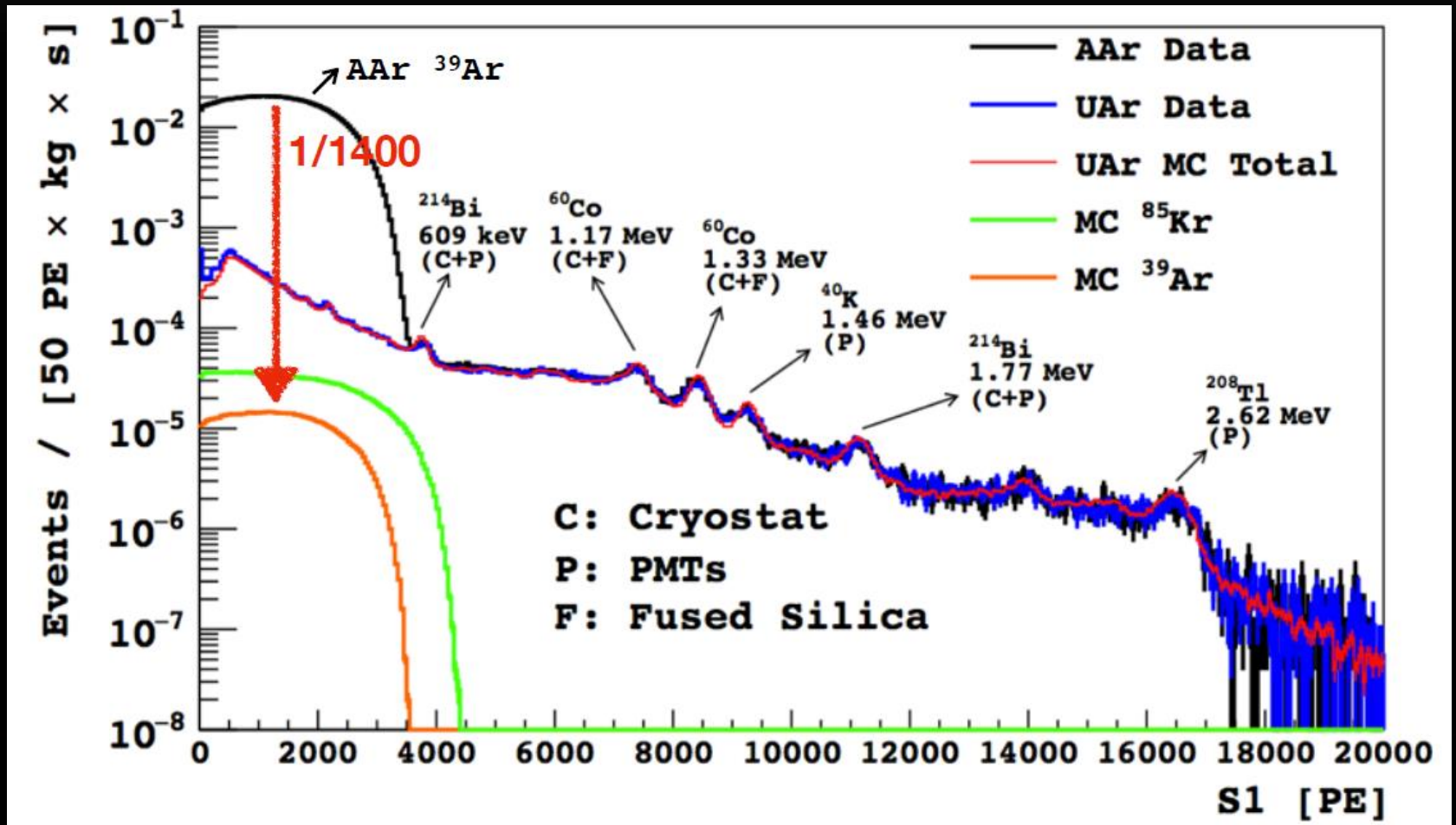
47.1 live-days after all cuts, (1422±67) kg day exposure.

Physics Letters. B, 2015 vol. 743, p. 456-466



DS-50 RESULTS (UAr)

AAr vs UAr: ^{39}Ar depletion factor ~ 1400 ($C_{\text{Ar-39}} = 0.7 \text{ mBq/kg}$), $C_{\text{Kr-85}} = 2.1 \text{ mBq/kg}$
Low level of ^{39}Ar allows extension of DARKSIDE program to a ton-scale detector

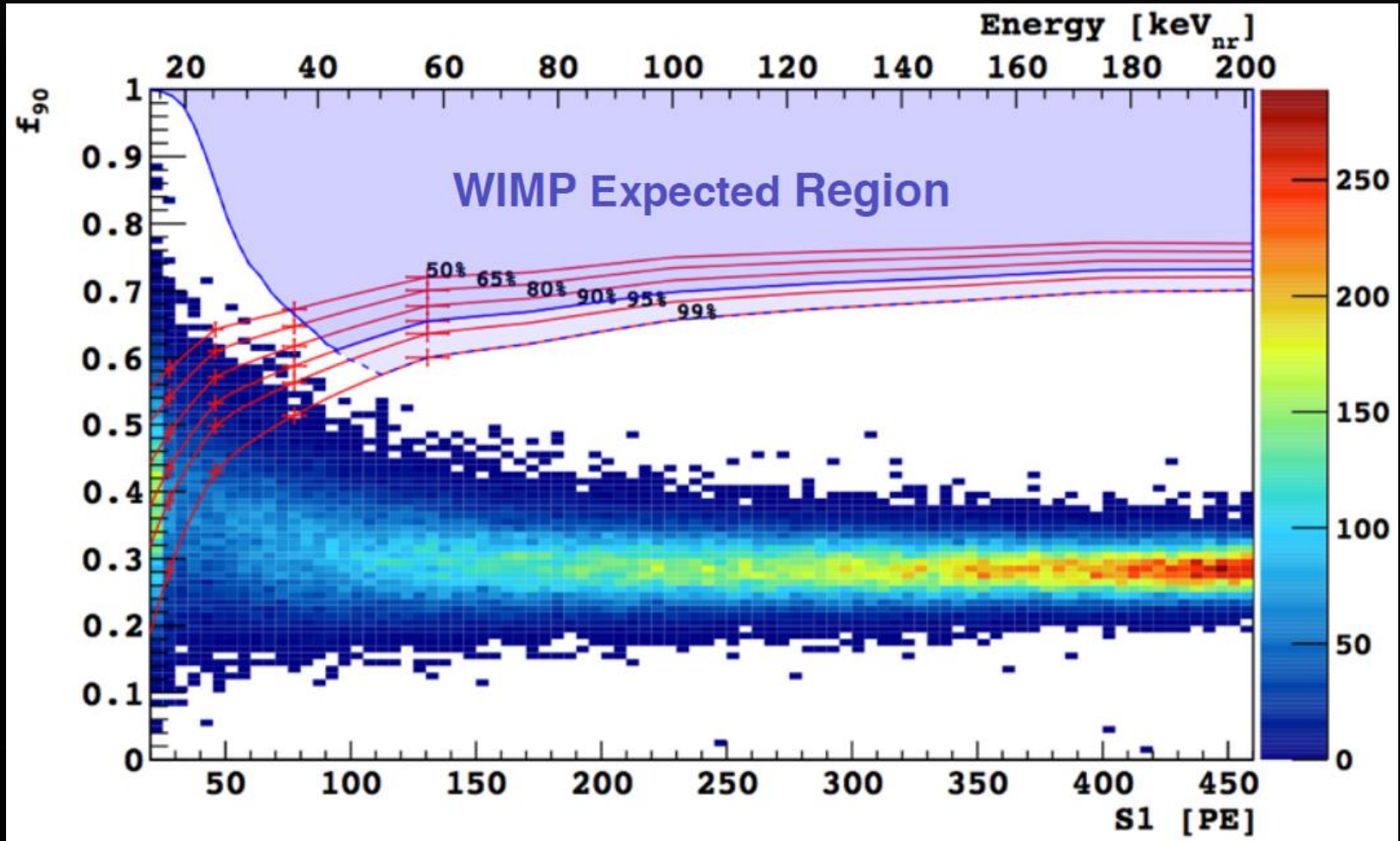


DS-50 RESULTS (UAr)

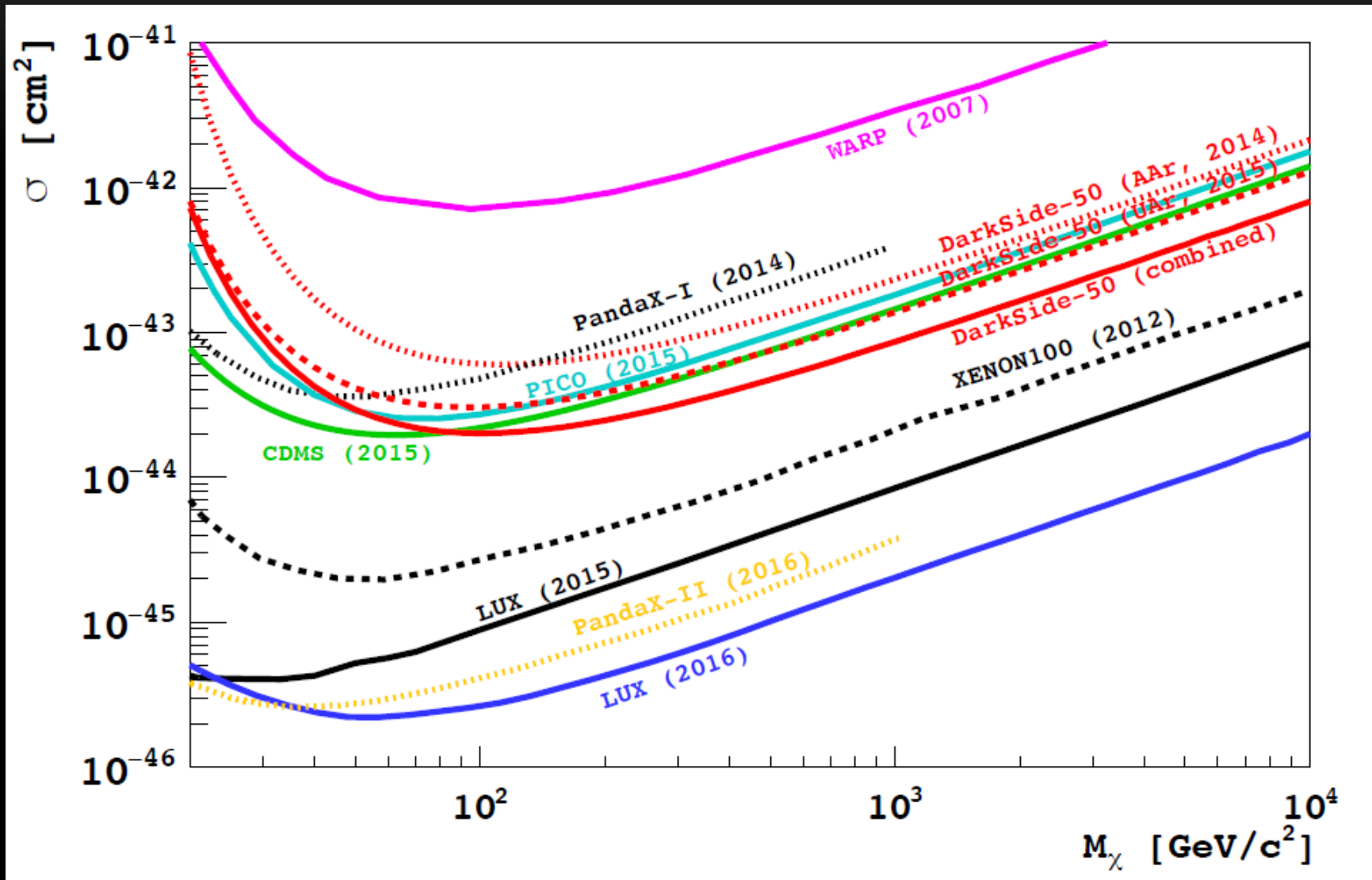
Phys. Rev. D 93 (2016) 081101

70.9 live-days after all cuts, (2616±43) kg day exposure.

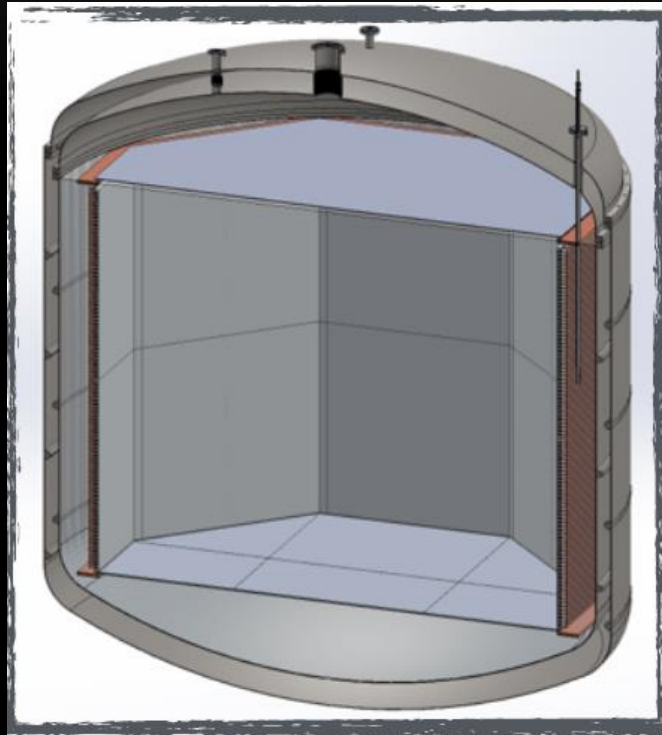
Single-hit interactions in the TPC → **No background events in the WIMP region**



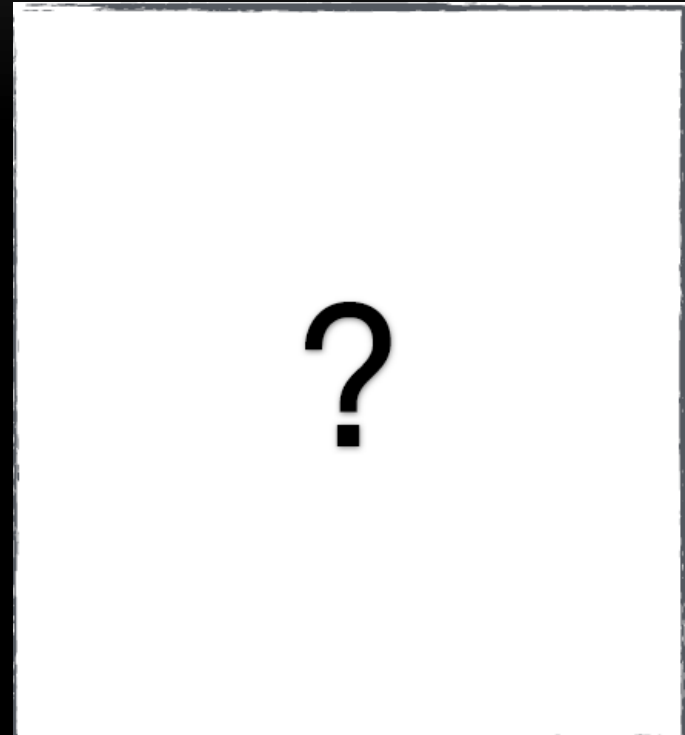
DS-50 RESULTS (UAr)



FUTURE DETECTORS

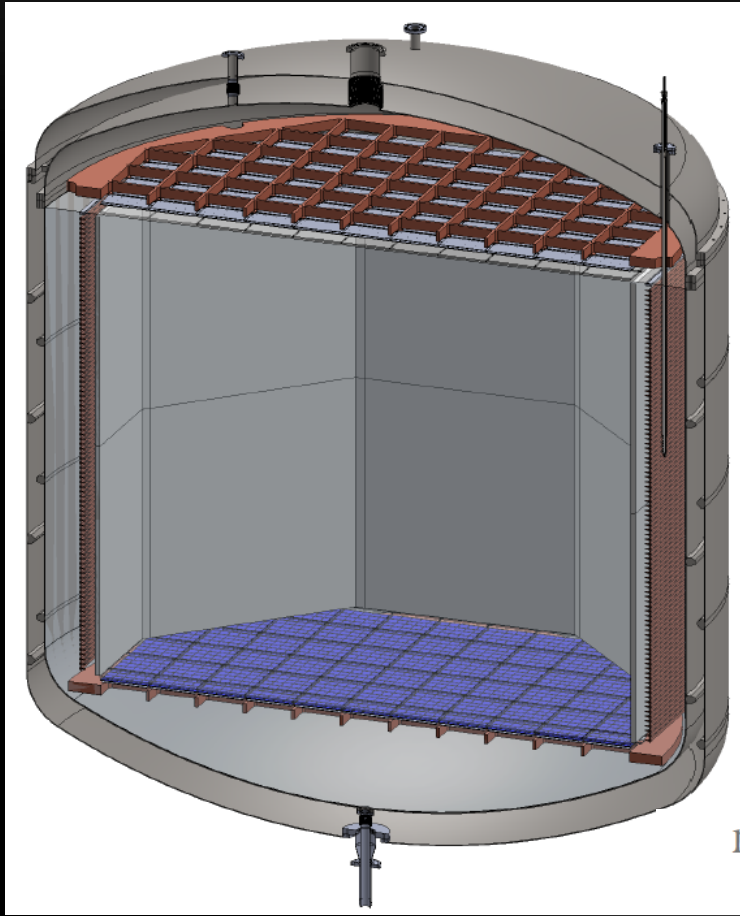


DS-20k
30 t (20 t fiducial) of UAr



ARGO
300 t (200 t fiducial) of UAr

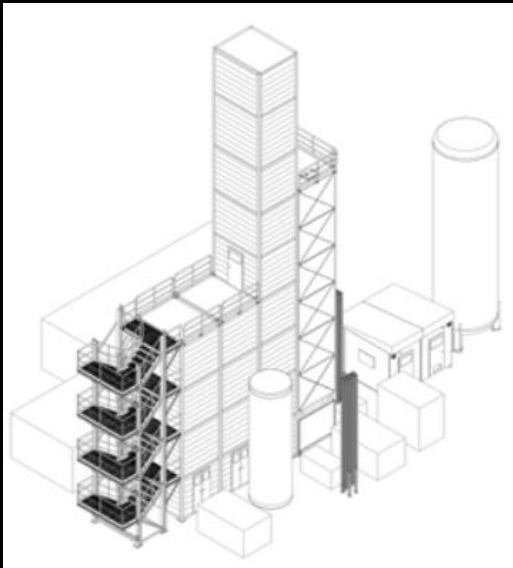
DS-20k



- Octagonal TPC filled with UAr
- 20 t Fiducial Volume (100 t yr)
- Radio-pure construction materials (ULR Ti)
- 15 m² of SiPMs (5210 modules 5×5 cm, lower radioactivity compared to PMTs, custom development by FBK, production in Abruzzo)
- DS-50-like veto design
- Time-line: 2020 – 202x

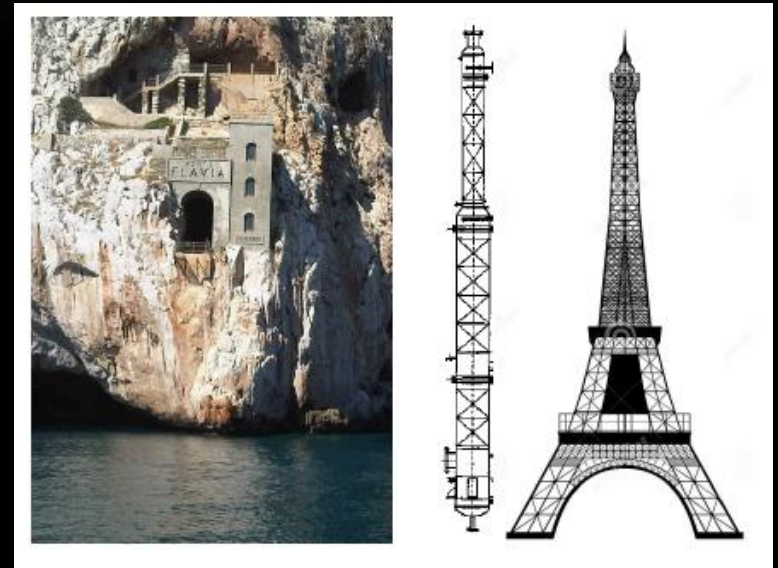
PRODUCTION / DEPLETION OF UAr

URANIA



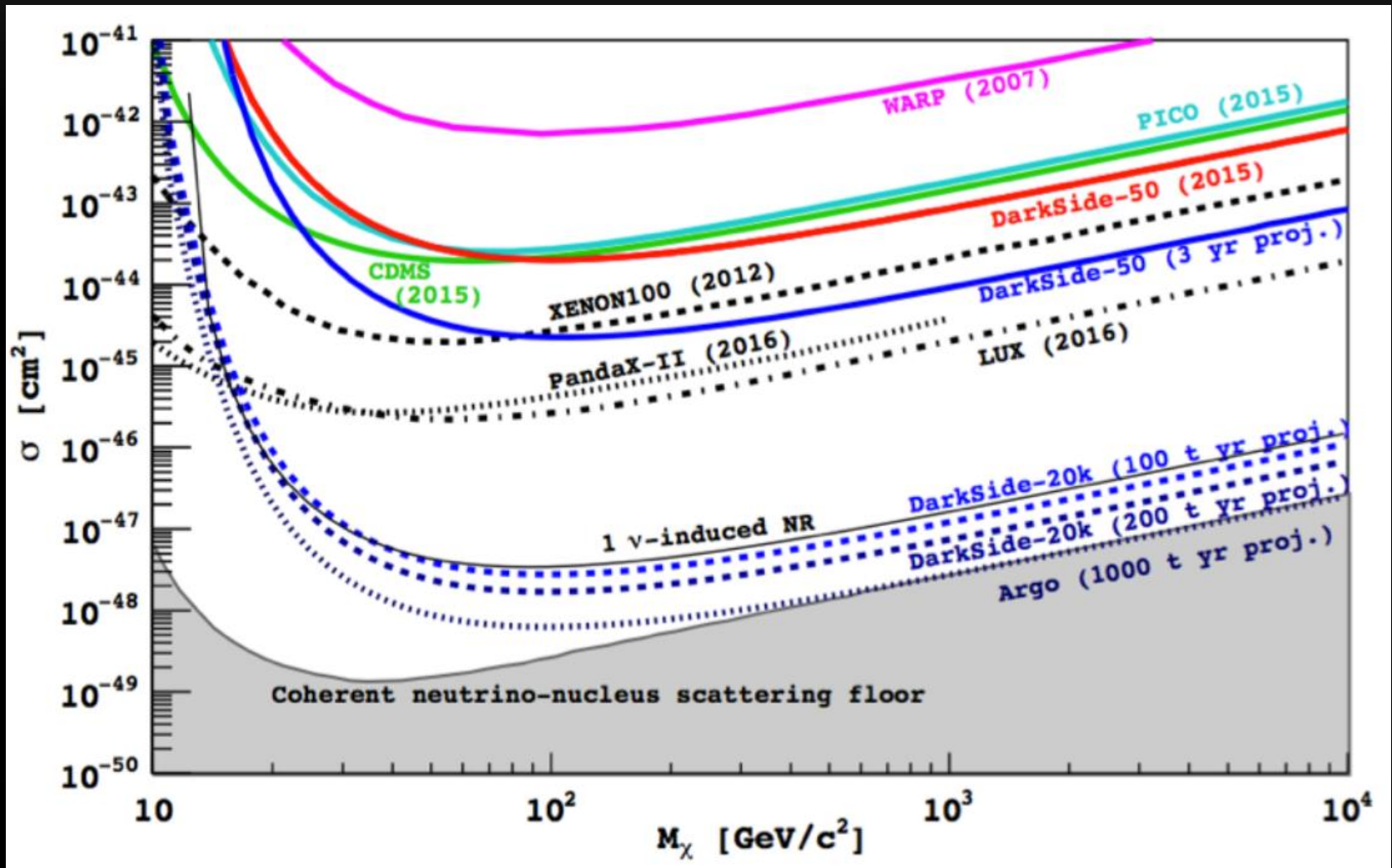
Expansion of the argon extraction plant in Cortez to reach capacity of **100 kg/day** of Underground Argon

ARIA



Additional purification and depletion of UAr at 150 kg/day: 350 m distillation column in the Seruci mine in Sardinia.

PROJECTED SENSITIVITY



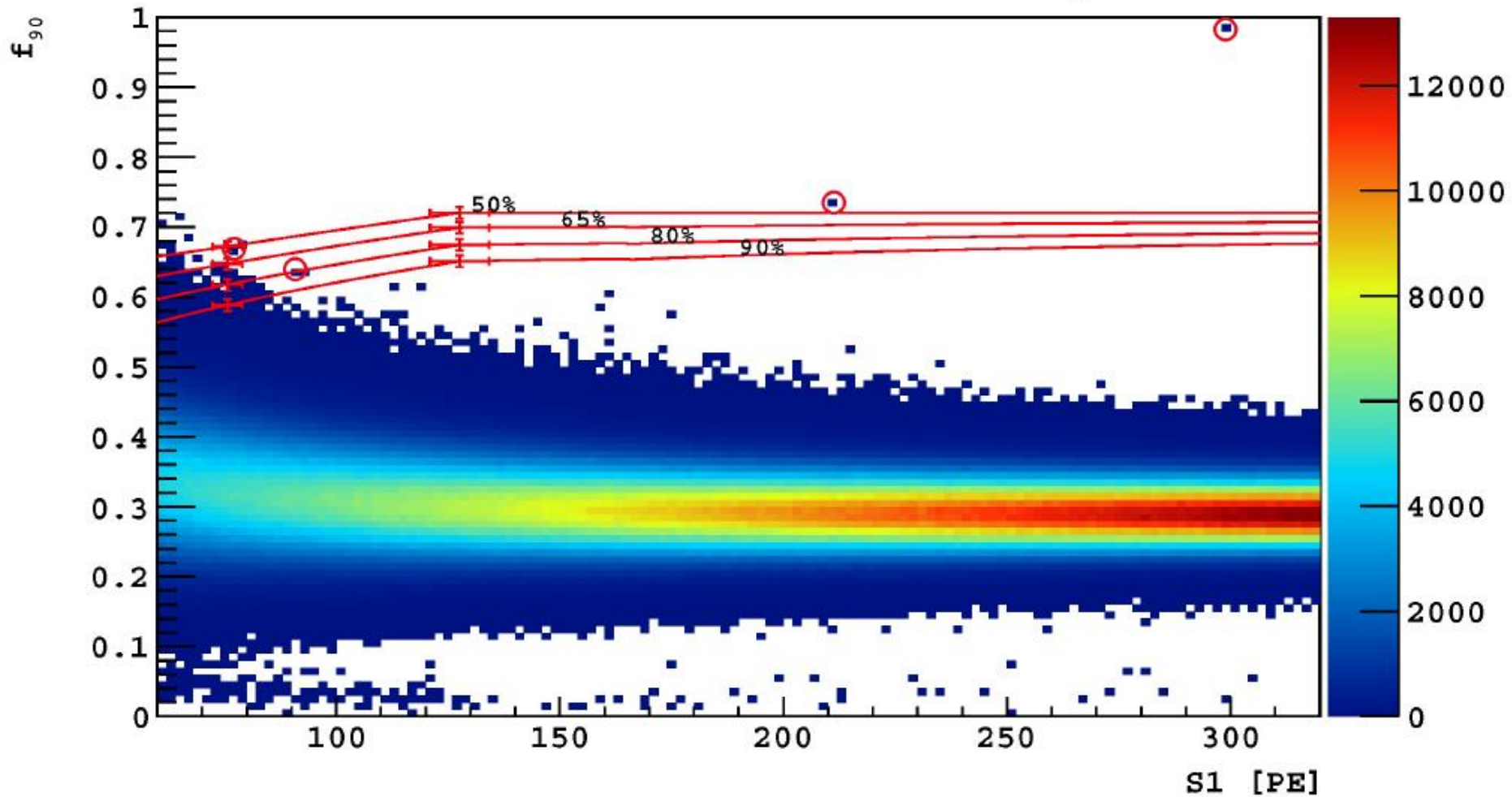
SUMMARY

- 1422 kg×day of truly background-free exposure has been demonstrated with AAr (> 20 yr of ^{39}Ar -free operation of DS-50 with UAr)
- So far 2616 kg×day of truly background-free exposure has been demonstrated with UAr, data taking continues
- Concentration of ^{39}Ar in DS-50 UAr is 1400 times lower than in AAr
- Within DS-50 the strongest WIMP limit among Ar target experiments has been obtained
- DS-20k detector (along with URANIA / ARIA) is under development
- Background-free exploration of DM signal down to the neutrino floor for $M_\chi > 100 \text{ GeV}/c^2$ feasible

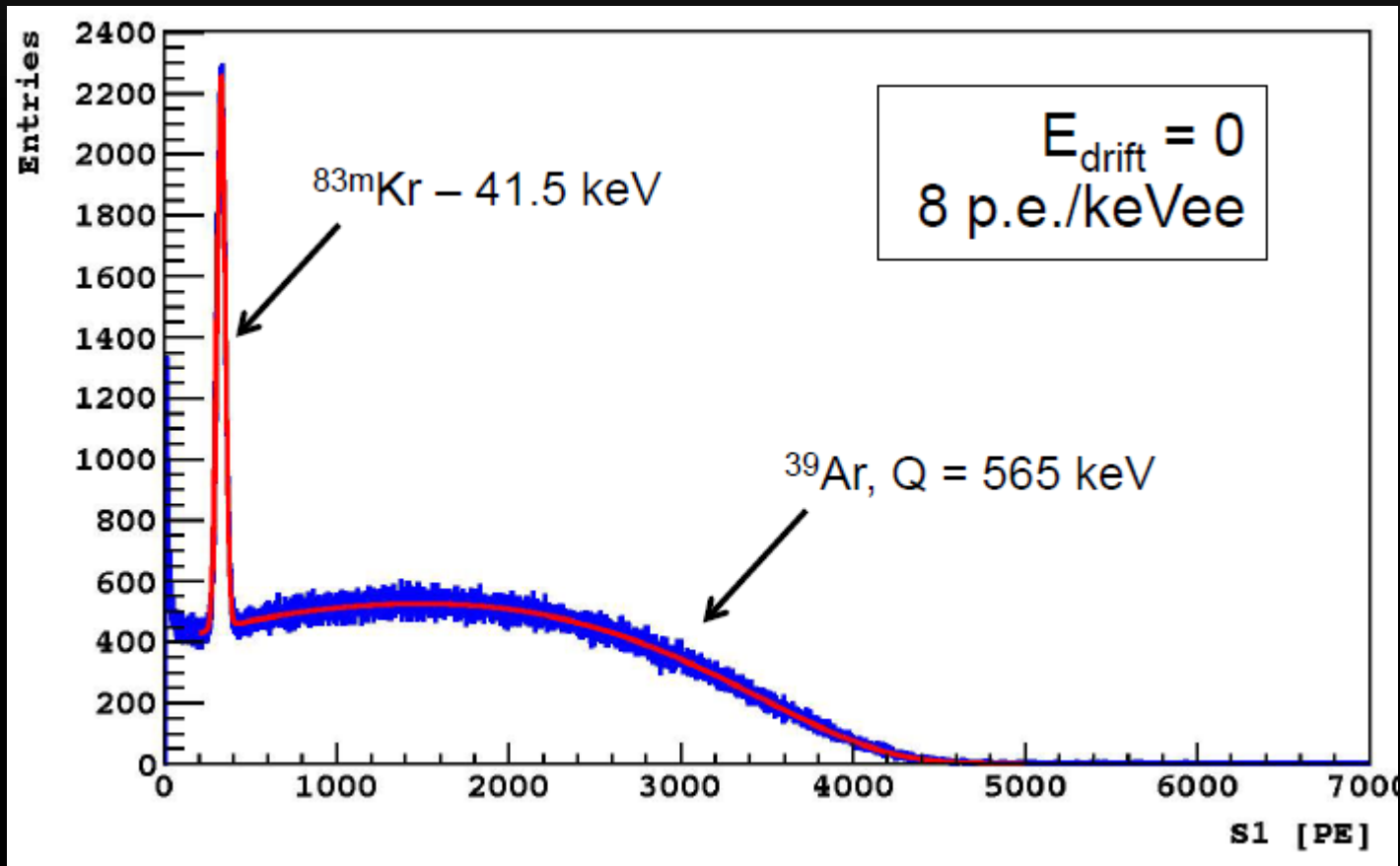
BACKUP SLIDES

DS-50 RESULTS

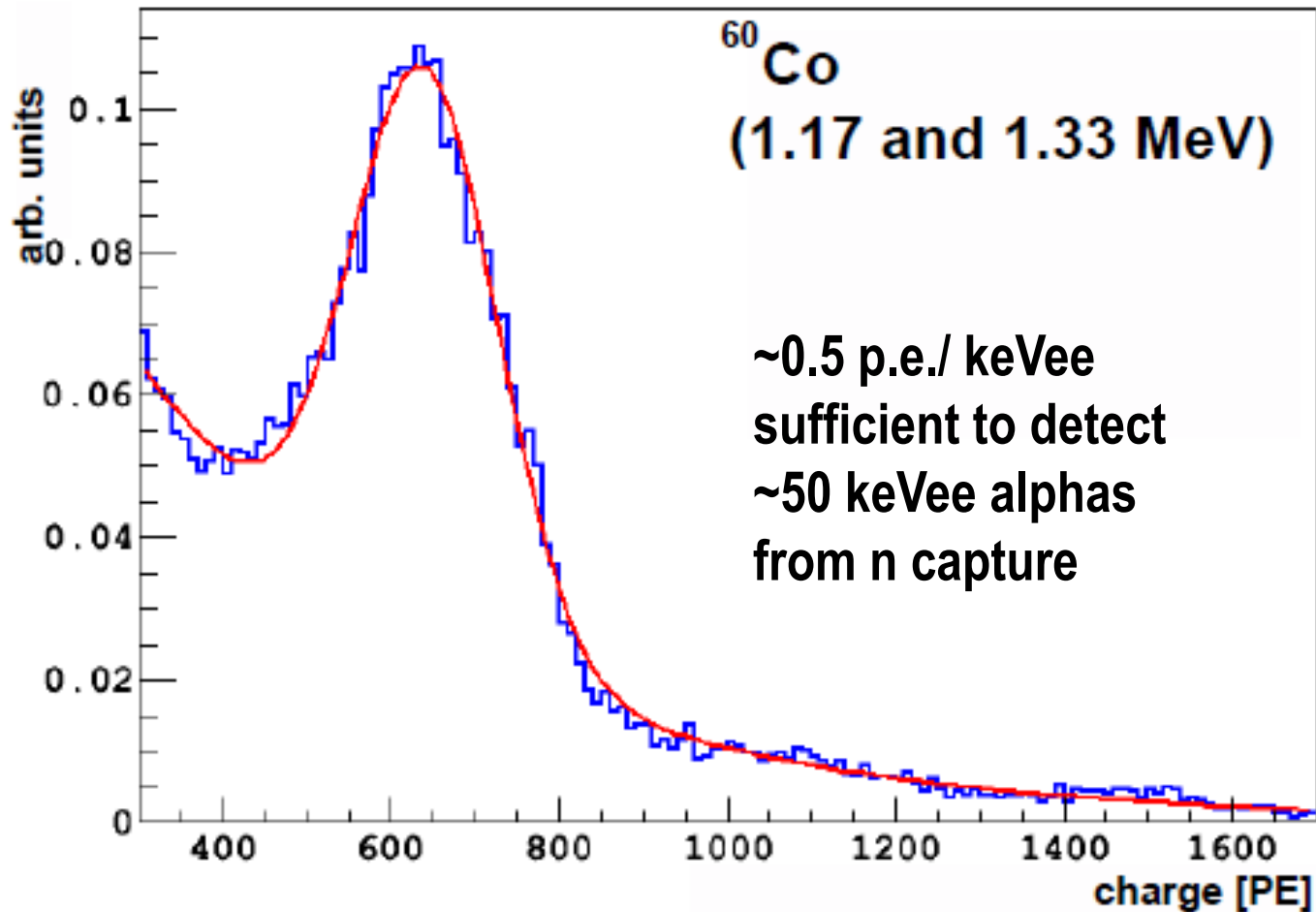
Dark Matter Search without Veto: f_{90} vs. S1



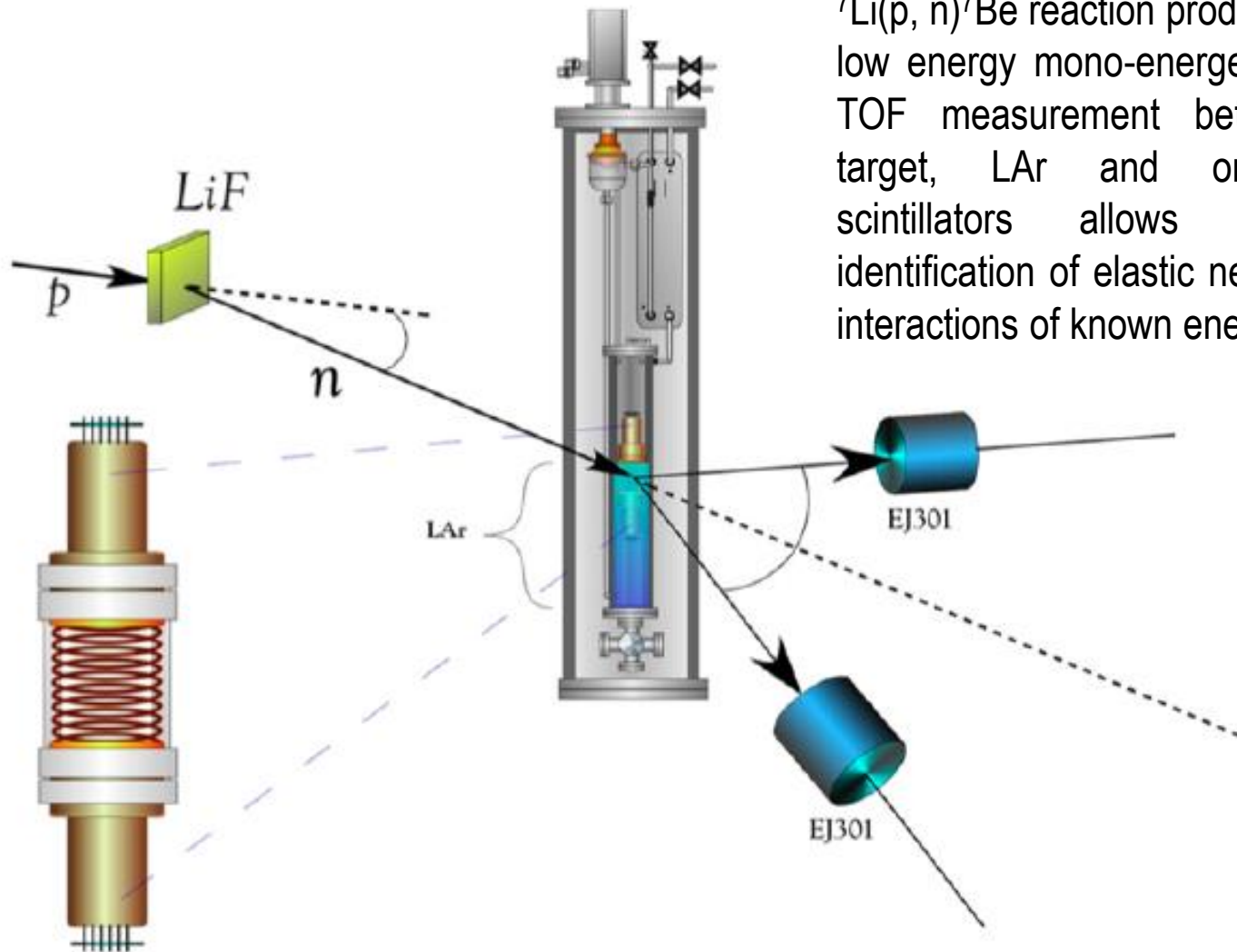
TPC CALIBRATION



LSV CALIBRATION



SCENE



${}^7\text{Li}(p, n){}^7\text{Be}$ reaction produces low energy mono-energetic n . TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy