Beyond DarkSide-50

Very Large Argon TPCs for Heavy WIMP Searches

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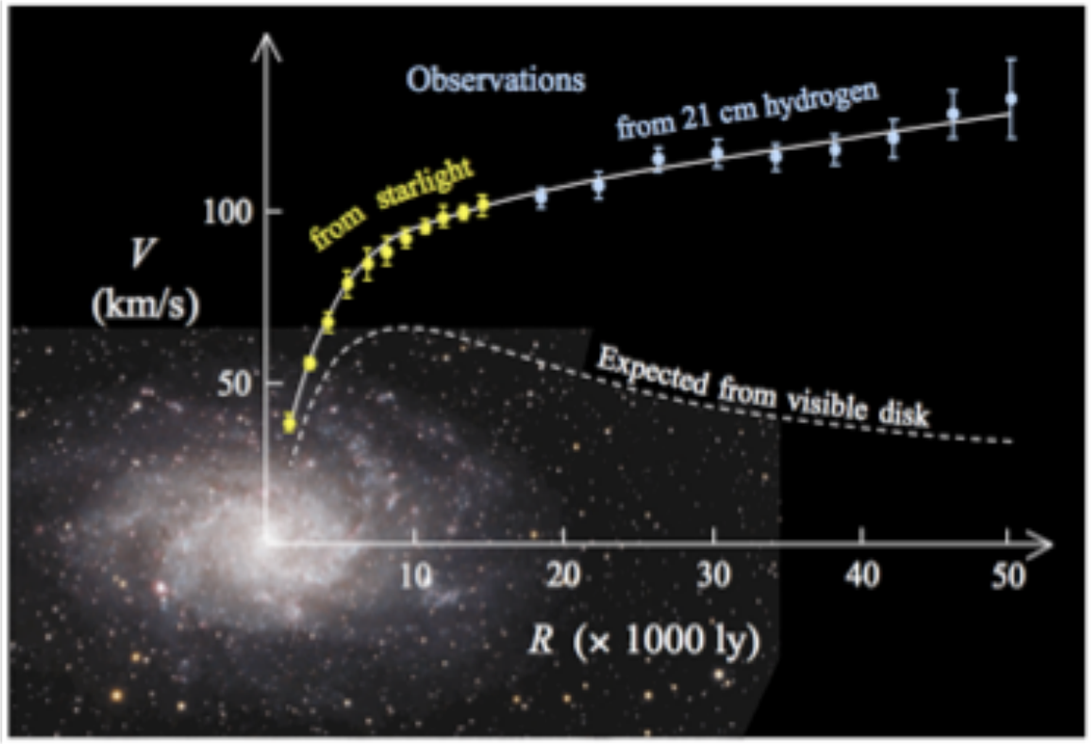
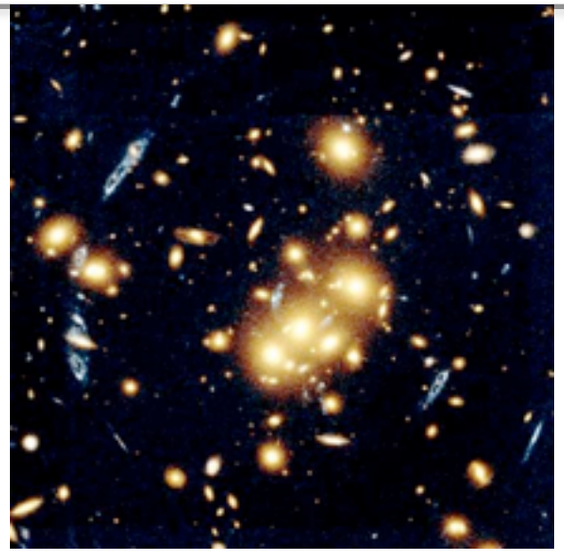
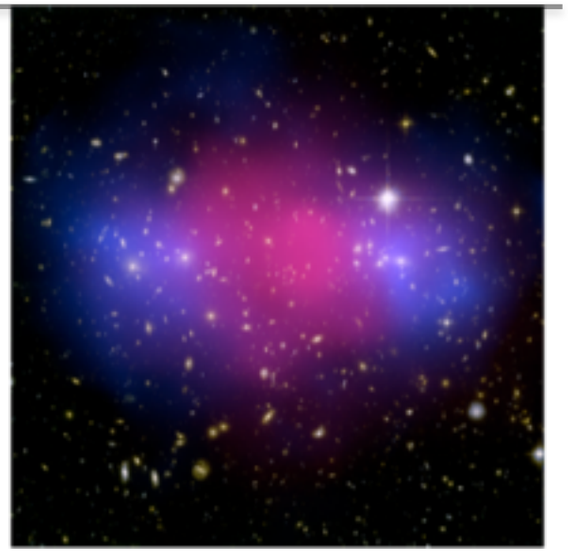
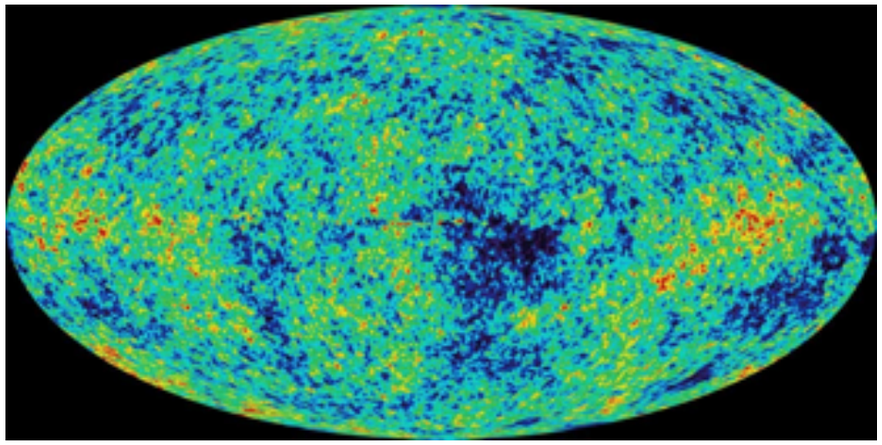
(for the DarkSide collaboration)

Outline

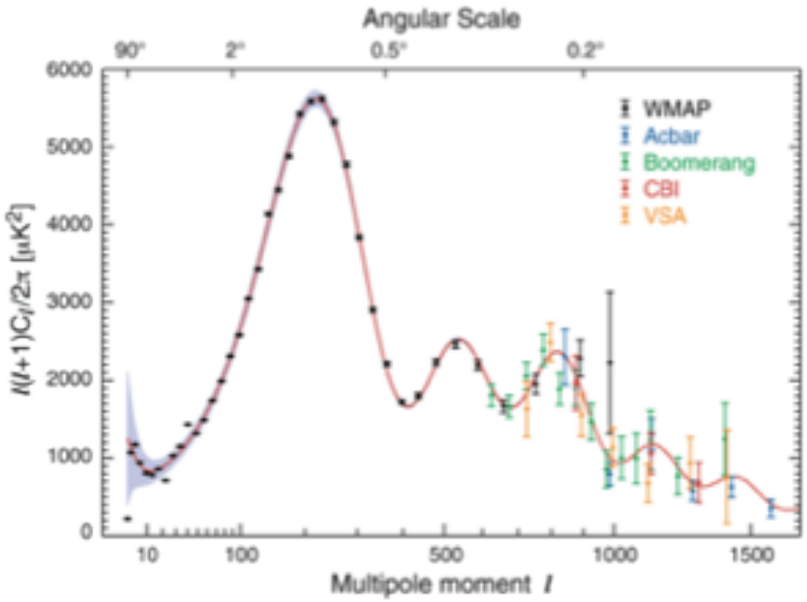








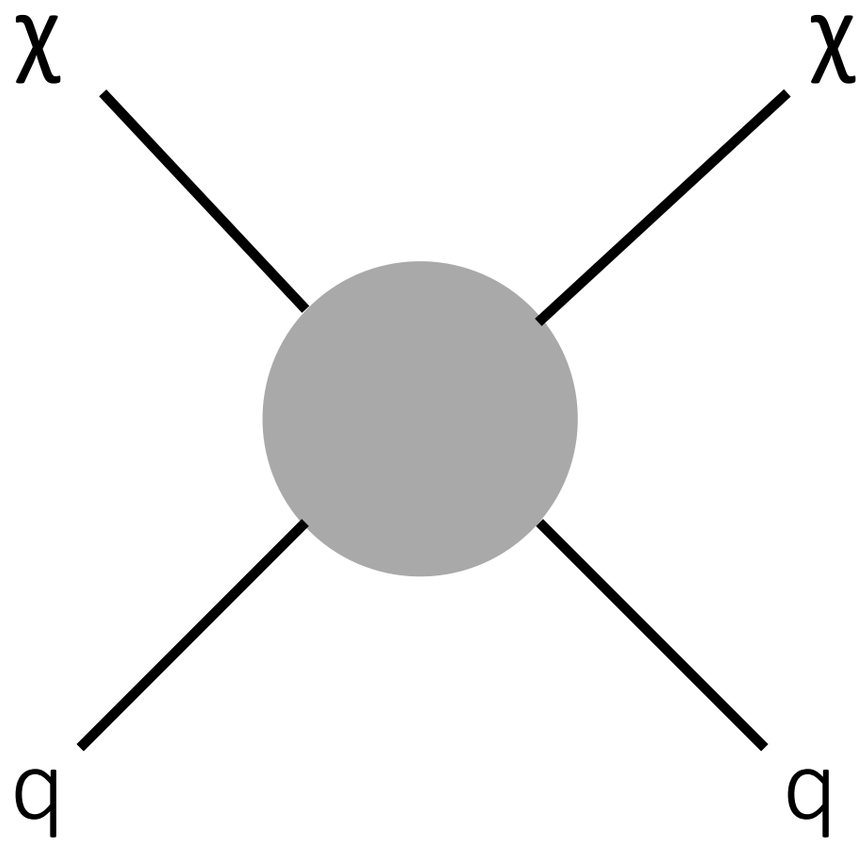
- DarkSide
- DS-50: results, status, future
- Beyond DS-50
  - DS-20k, Argo
- Outlook



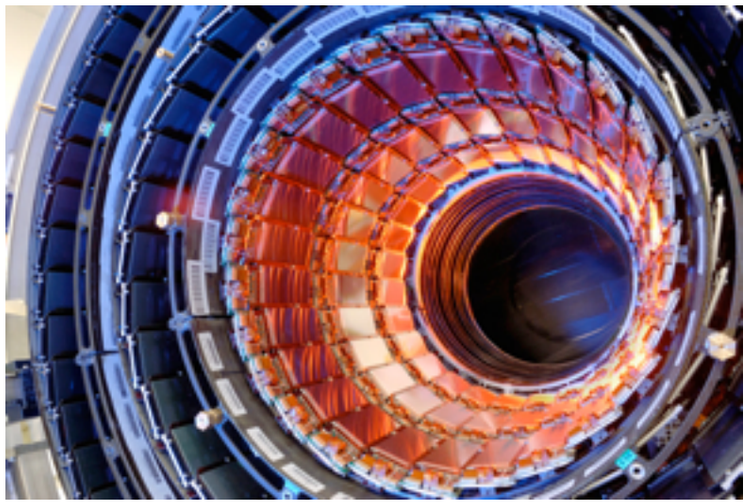
Dark matter detection

Annihilation

Indirect Detection

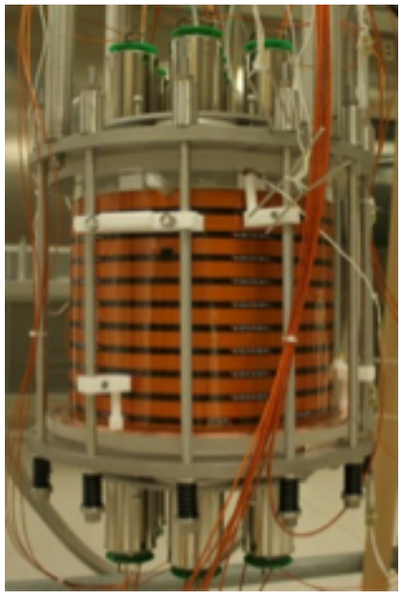


Production



Colliders

Scattering



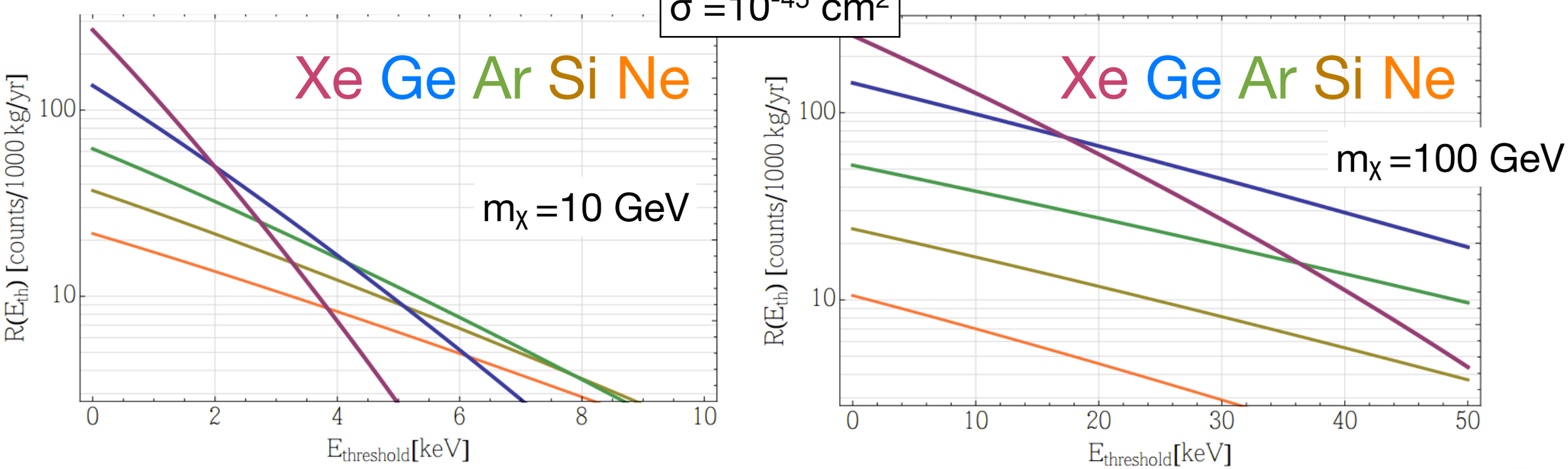
Direct Detection

DarkSide program at Gran Sasso

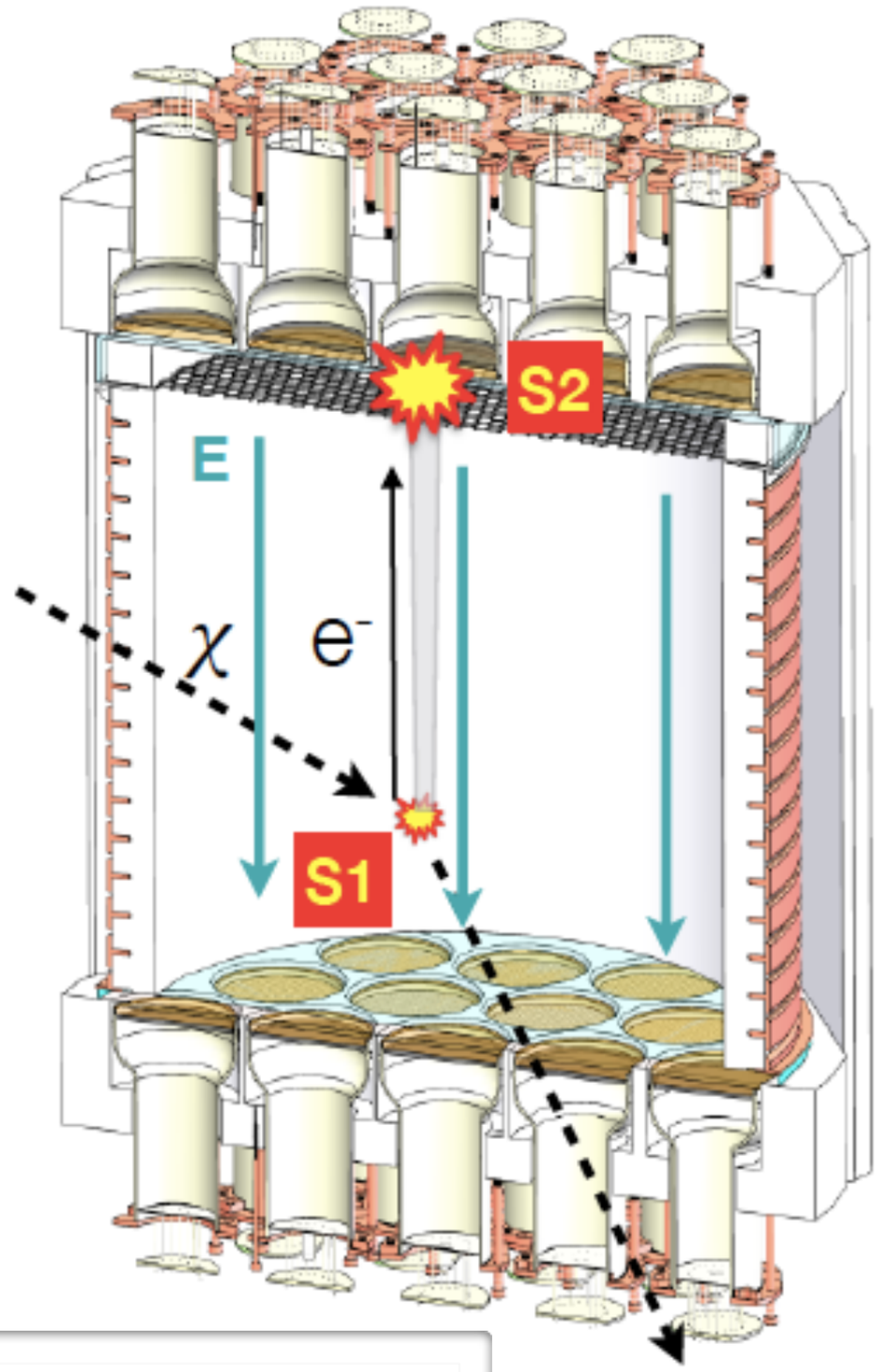
- Direct detection of WIMP dark matter
- Dual-phase Time Projection Chambers (TPCs) with argon target (Ar-40, entirely 0^+ nuclei)
- Ultra low background design, with active suppression of non-WIMP signals
- Scalable technology → very large target mass

arXiv:1310.8327v2 [hep-ex]

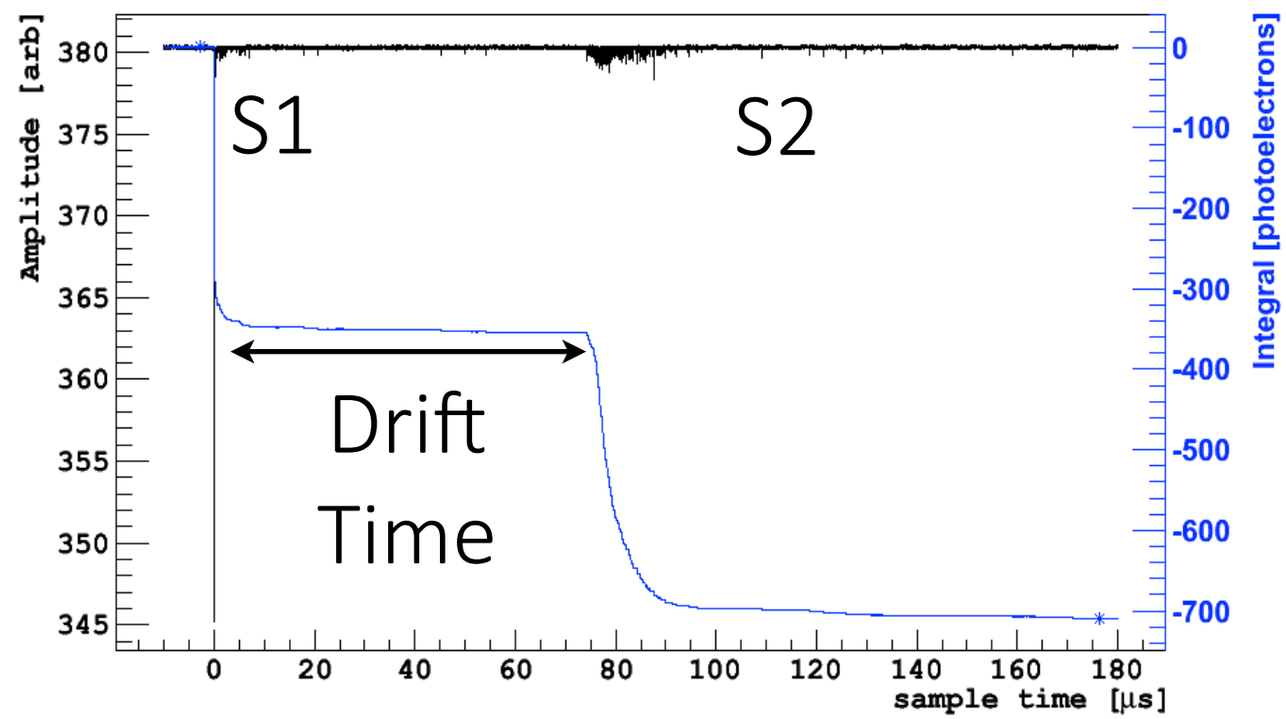
$\sigma = 10^{-45}$ cm^2



The DarkSide-50 dual-phase argon TPC



S1: prompt scintillation
S2: delayed electroluminescence of drifted ionization extracted into the gas



Electron drift lifetime > 5 ms
(max. drift time of ~ 375 μs)

Electron drift speed = 0.93 ± 0.01 mm/μs

E_{drift} ~ 0.2 kV/cm

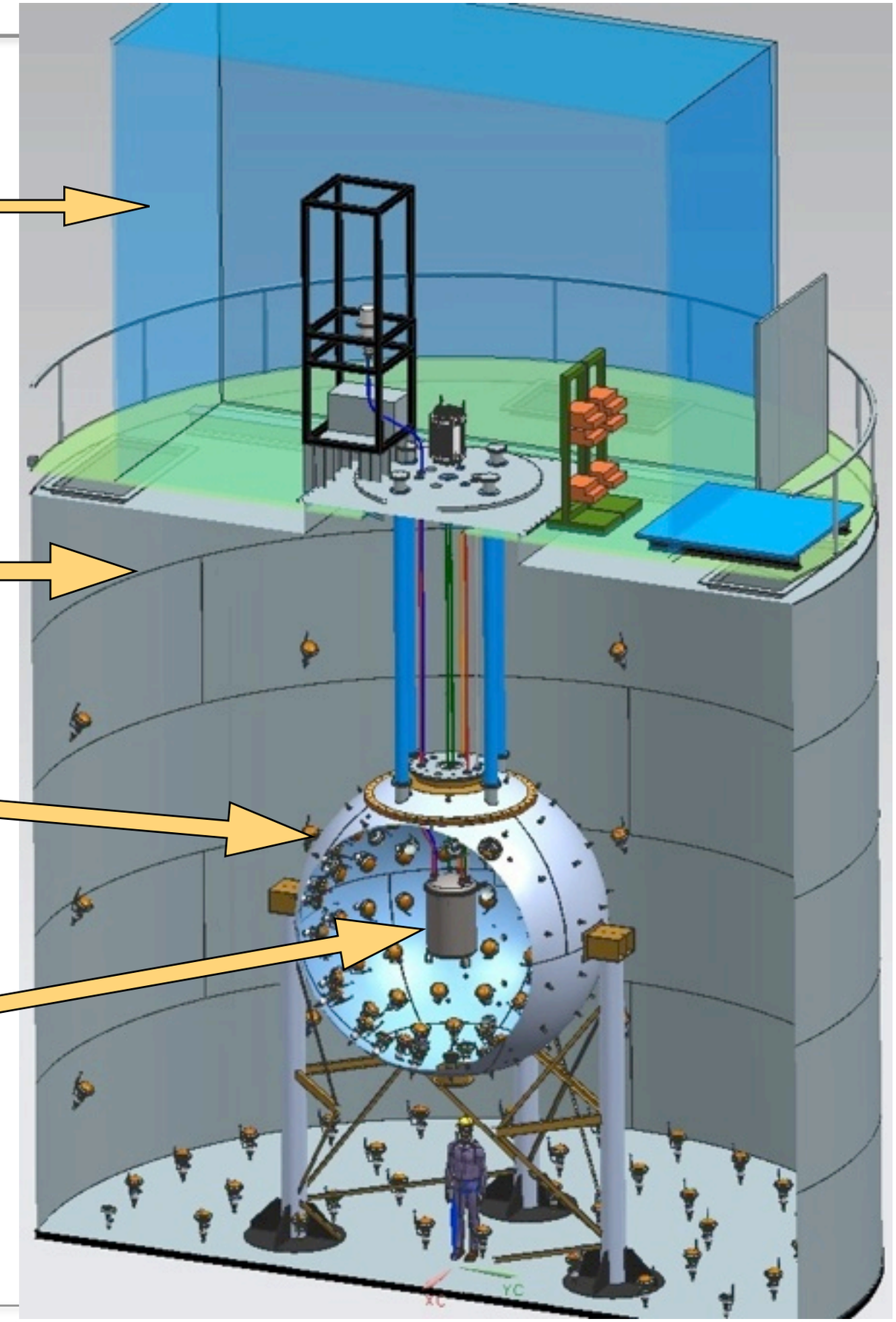
The DarkSide-50 detector

Radon-free clean room

Water tank (muon veto)

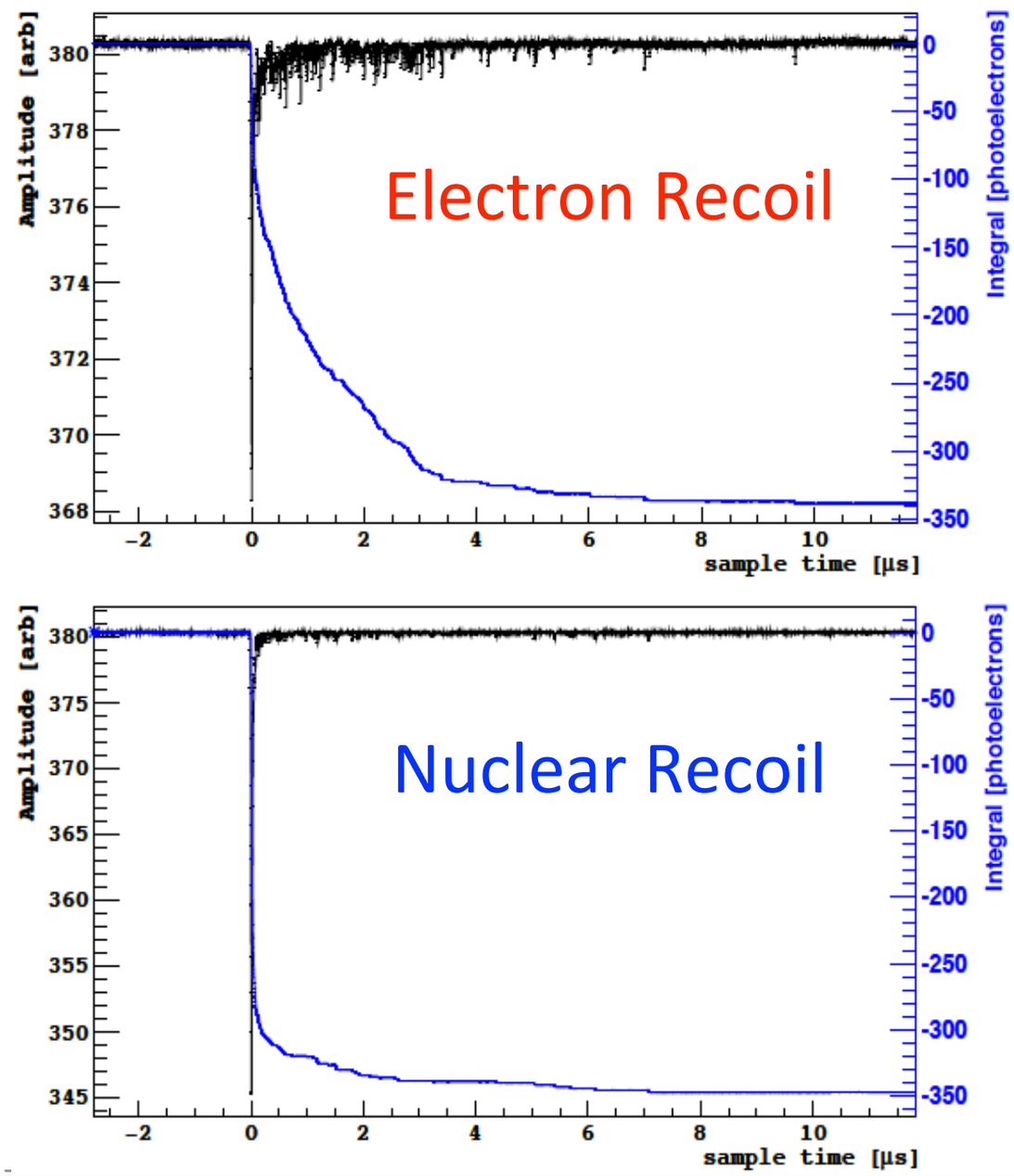
Borated liquid scintillator
(Tri Methyl Borate)

Inner detector TPC
(2-phase LAr)



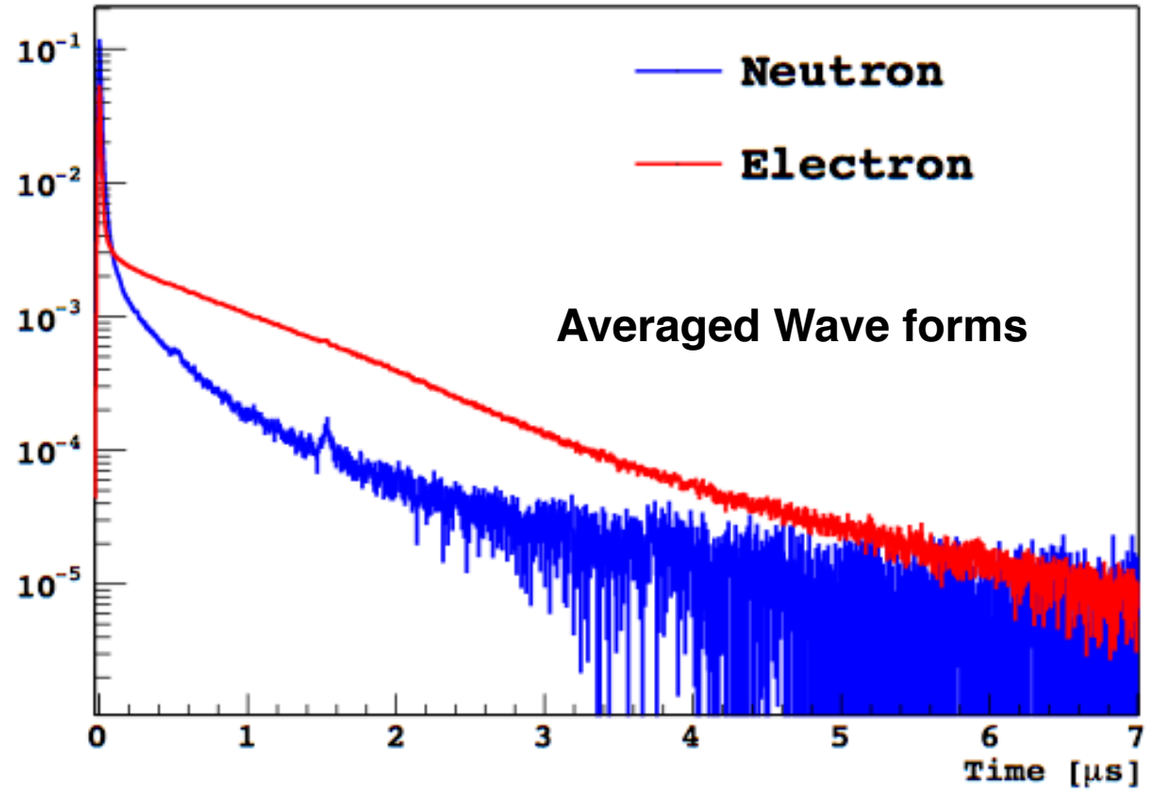
Pulse shape background discrimination (S1)

Electron and nuclear recoils produce different excitation/ionization densities in the argon, leading to different ratios of singlet and triplet Ar_2^* dimer states



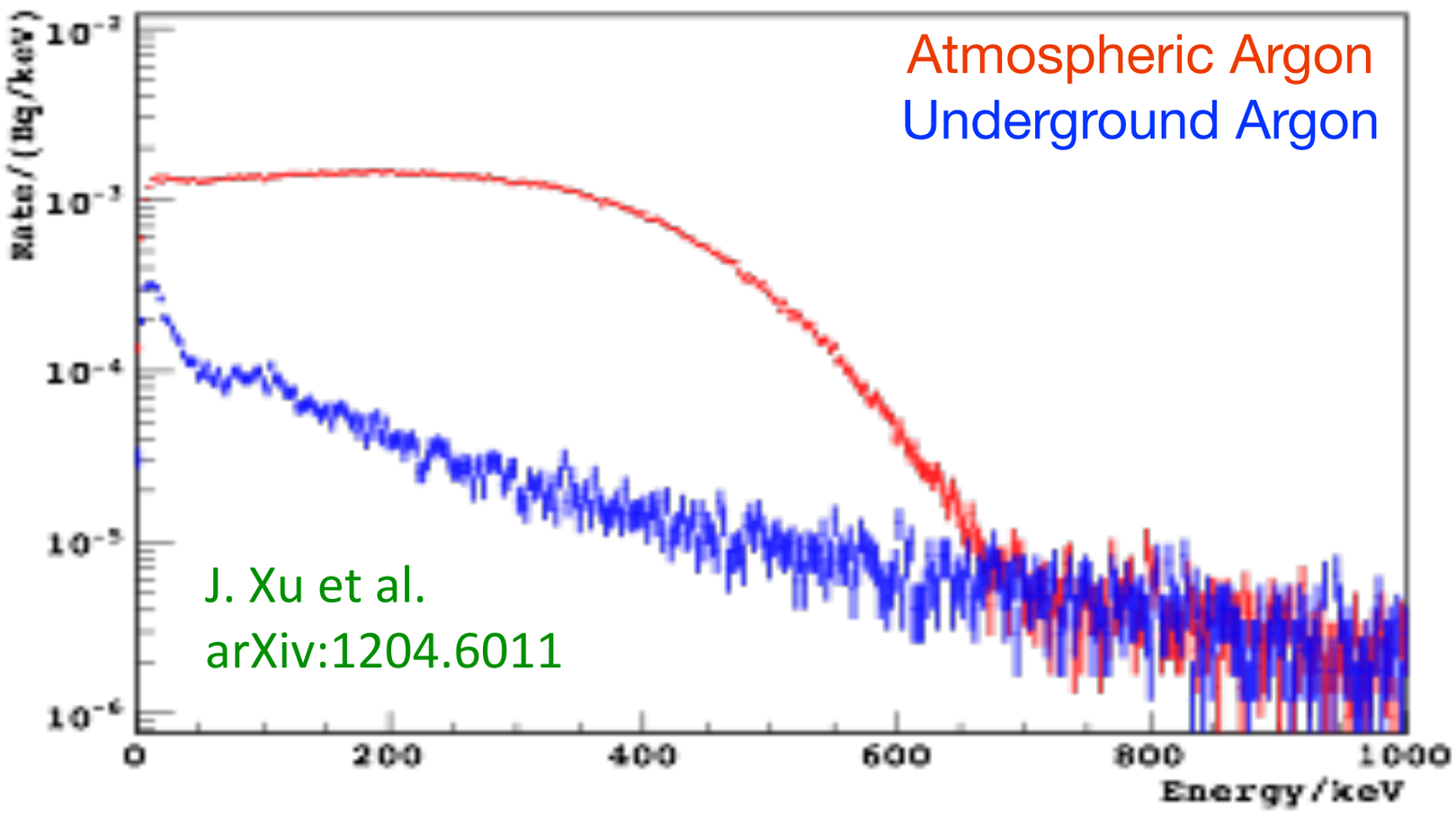
$\tau_{singlet} \sim 7$ ns

$\tau_{triplet} \sim 1500$ ns

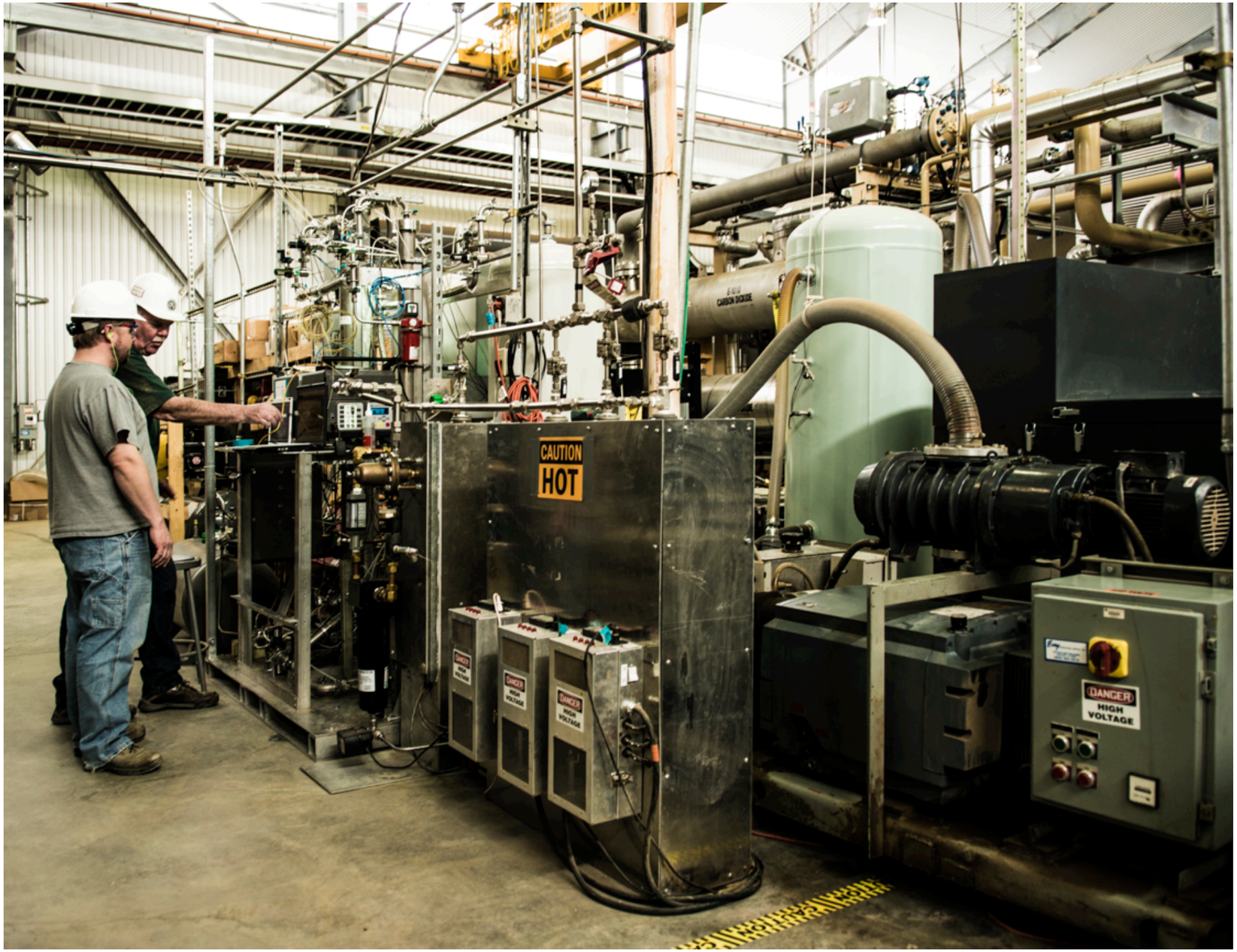


Argon-39 background

- Background in atmospheric argon: ^{39}Ar (cosmogenic, 1 Bq/kg)
- Source of underground argon measured to have > 150 times less ^{39}Ar than atmospheric argon
- Key for tonne-scale dual-phase experiment



UAr VPSA extraction facility, Cortez CO



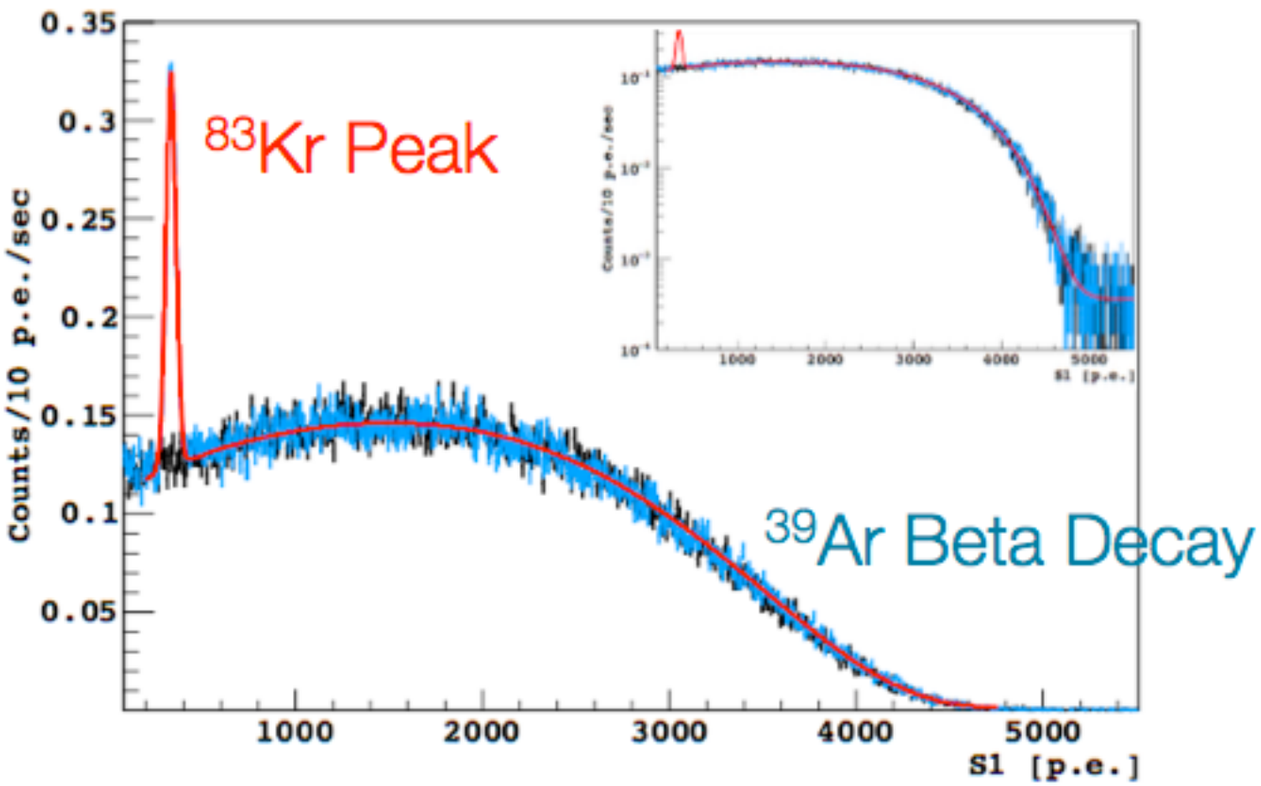
0.1-7 bar

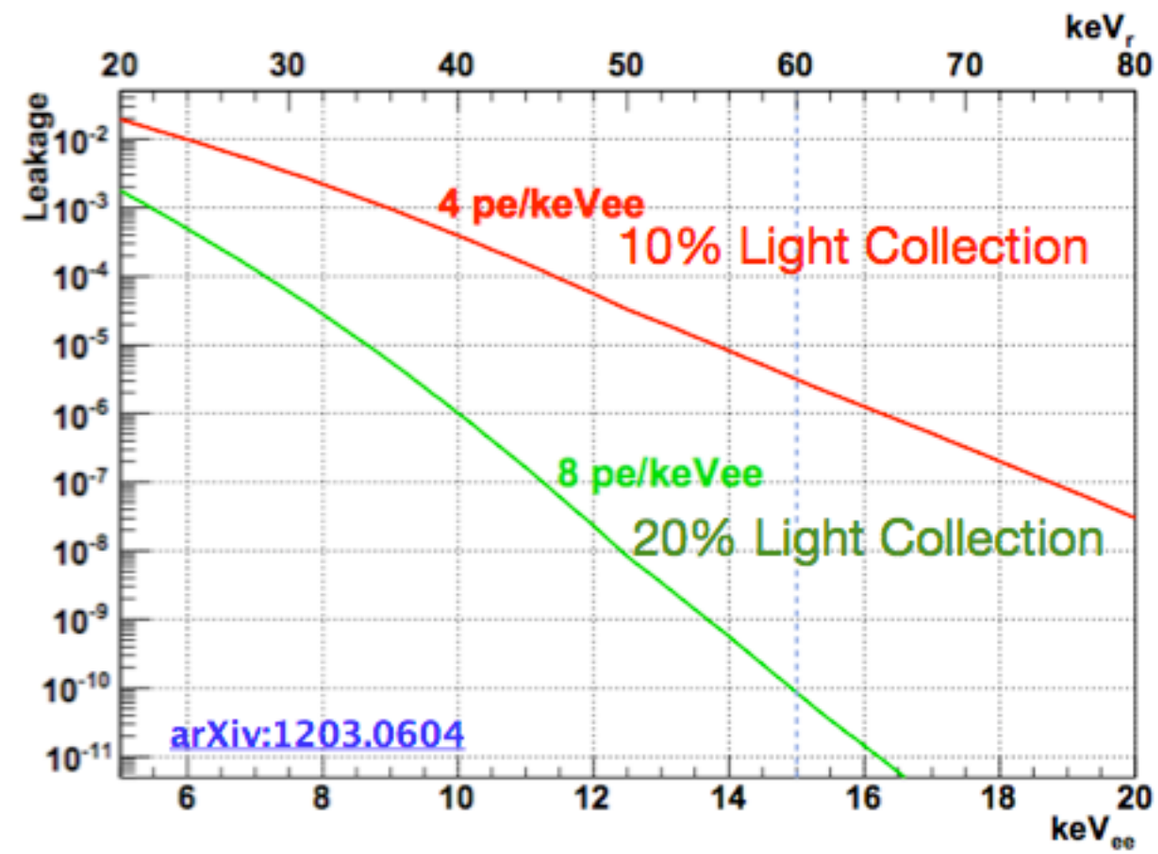
adsorption of CO_2 on zeolite 4A

Operated locally by technician Gary Forster – Managed by H. Back

DS-50 light yield

- TPC filled with atmospheric argon (1 Bq/kg)
- ^{83m}Kr gas deployed into detector (41.5 keVee)



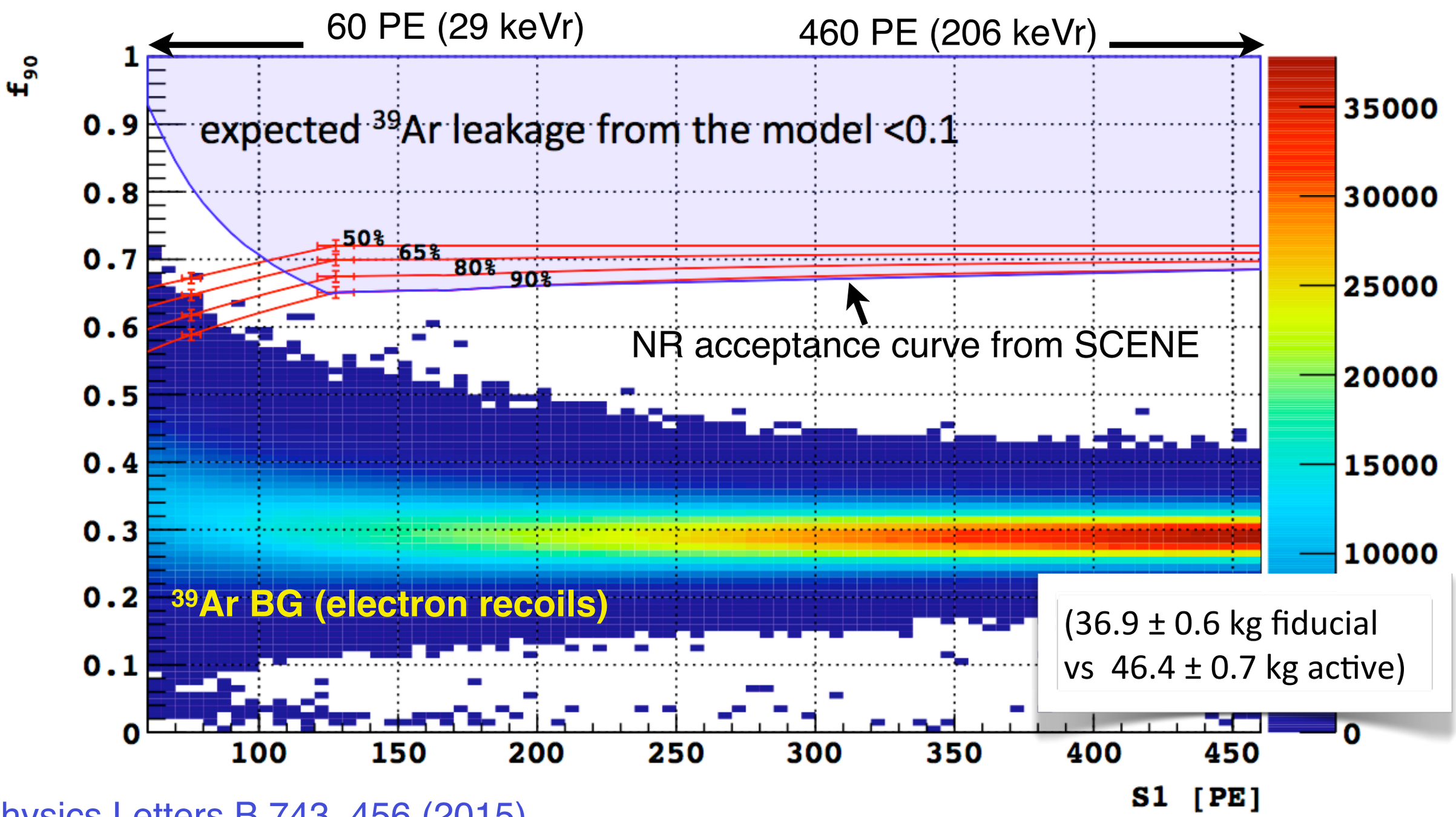


- Light yield at zero field: (7.9 ± 0.4) PE/keV
- Light yield at 200 V/cm: (7.0 ± 0.3) PE/keV
- Exceeding design requirements of 6.0 PE/keV

DS-50 results

AAr: 1422 ± 67 kg·days

WIMP search plot. All analysis cuts applied



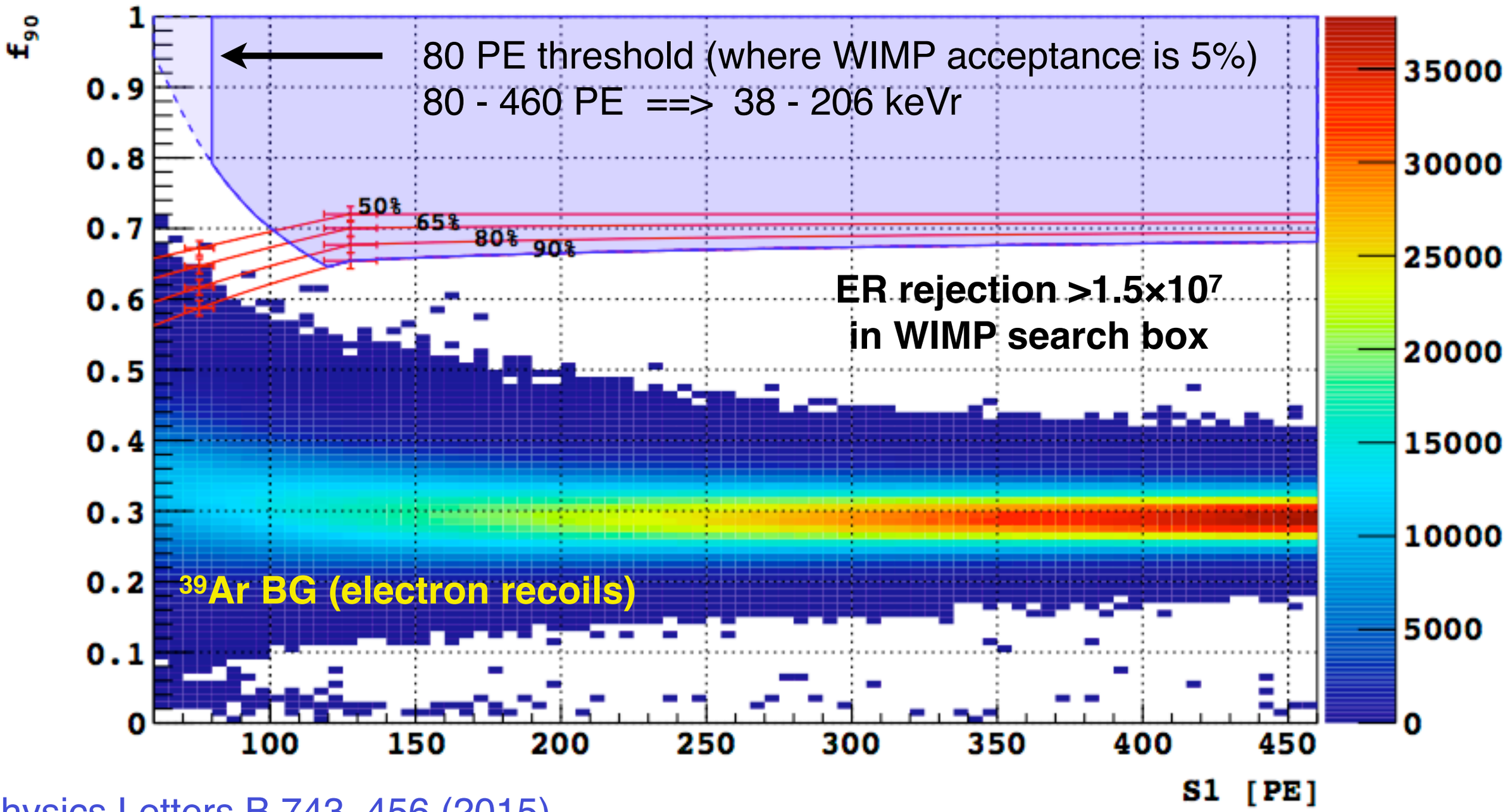
(36.9 ± 0.6 kg fiducial
vs 46.4 ± 0.7 kg active)

Physics Letters B 743, 456 (2015)

DS-50 results

AAr: 1422 ± 67 kg·days

No WIMP candidates after all analysis cuts applied

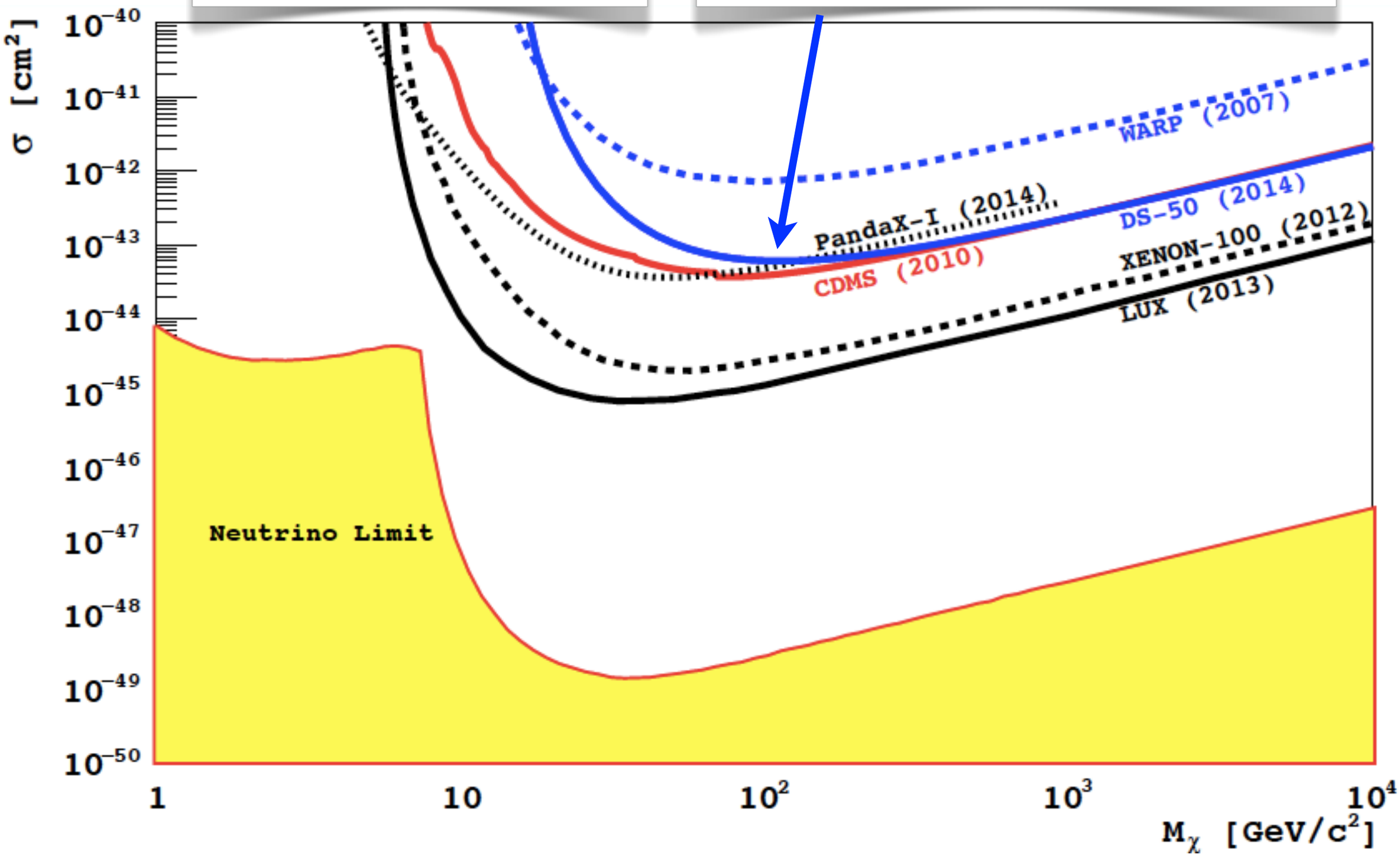


Physics Letters B 743, 456 (2015)

DS-50: third best WIMP dark matter limit at high masses

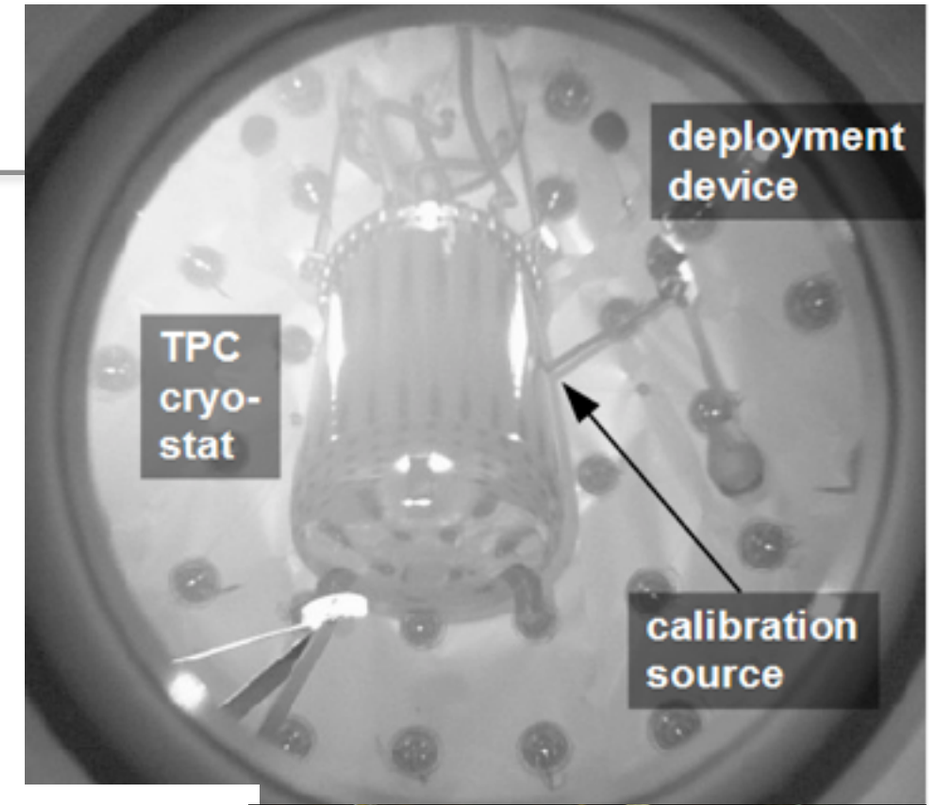
DS-50: 1422 ± 67 kg•days

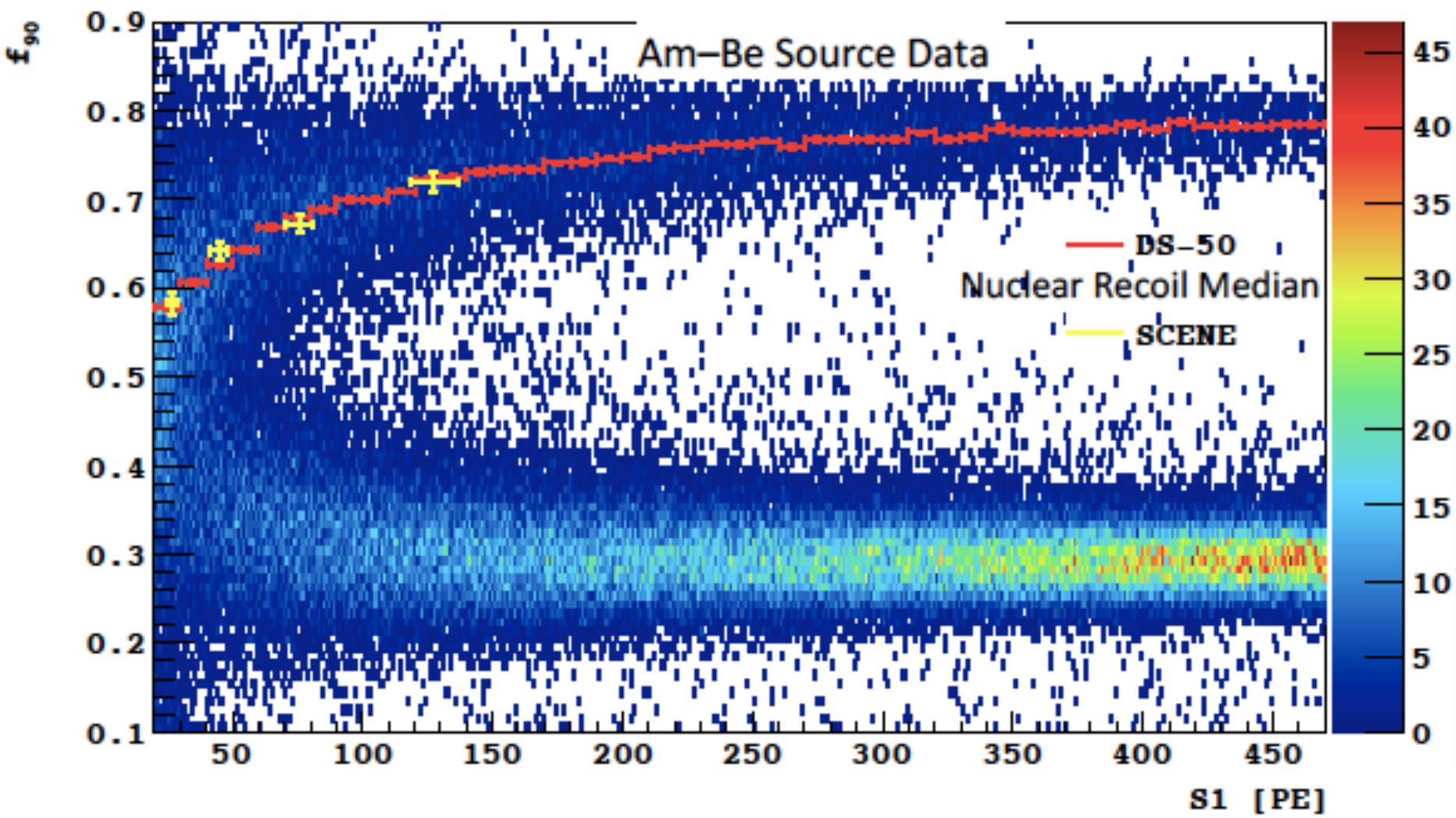
$\sigma = 6.1\times10^{-44}$ cm^2 for 100 GeV/c^2 WIMPs

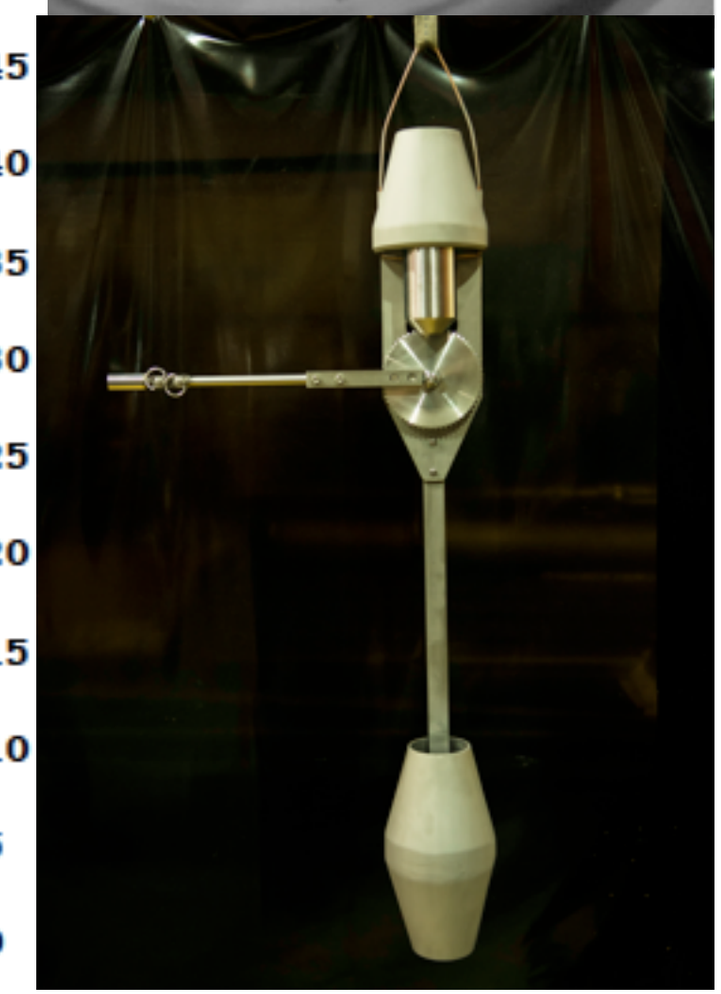


DS-50 neutron calibration

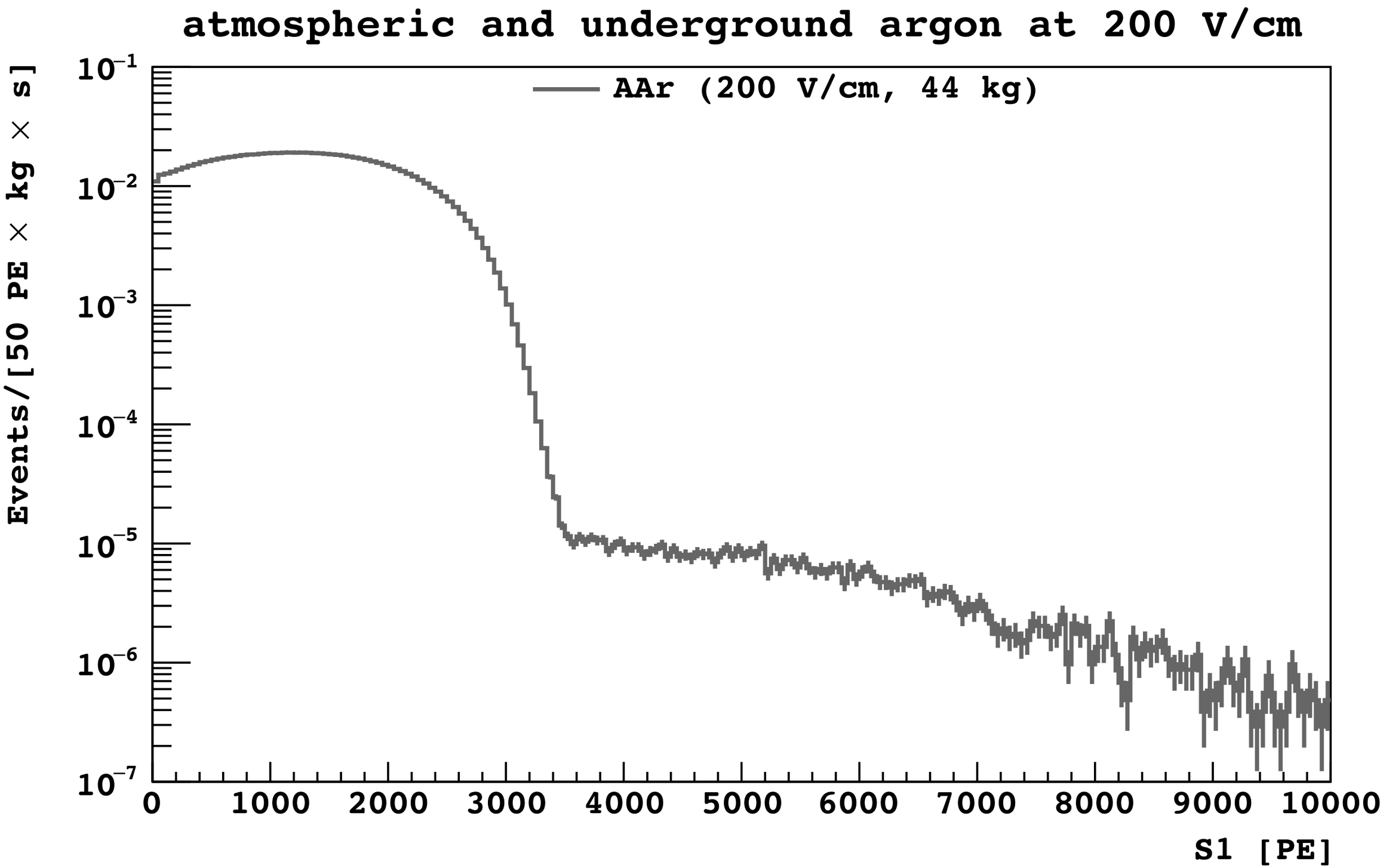
- Calibration performed in Oct — Dec 2014
- Completed after 1st paper was submitted, still valid for AAr data
- Full analysis and simulations in progress
- NR band from Am-Be source data matches the points extrapolated from SCENE



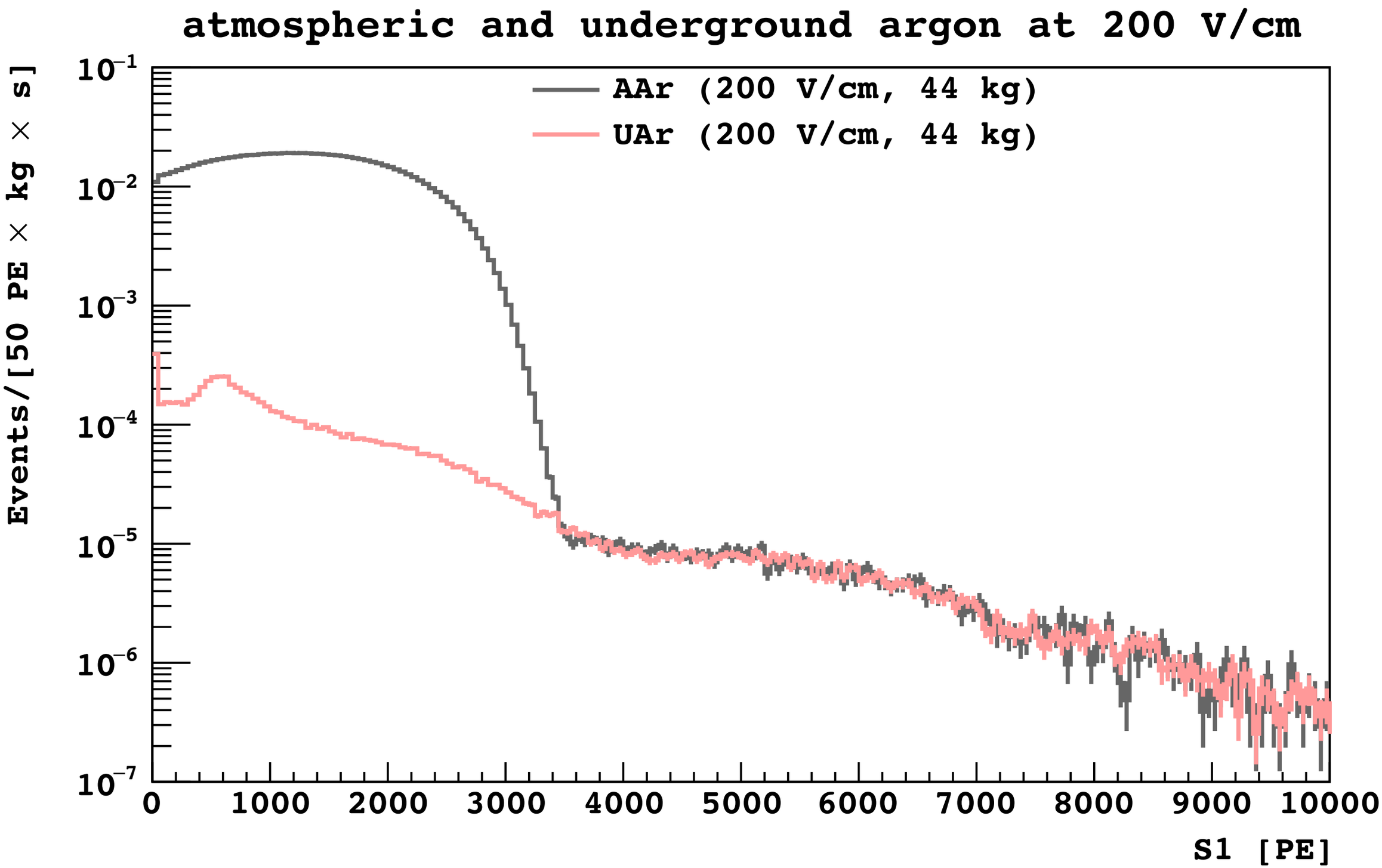




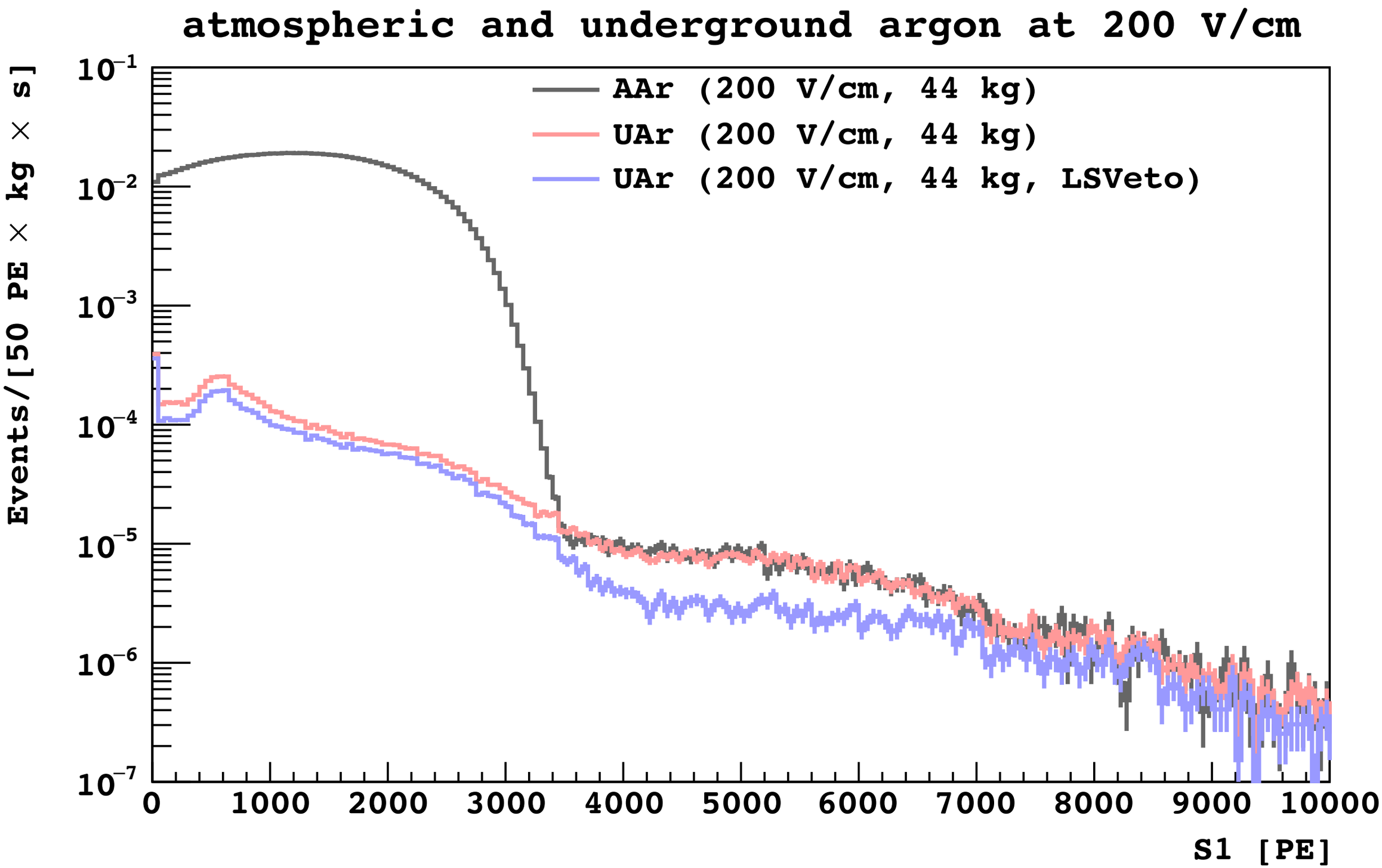
Atmospheric argon (AAr) in DS-50



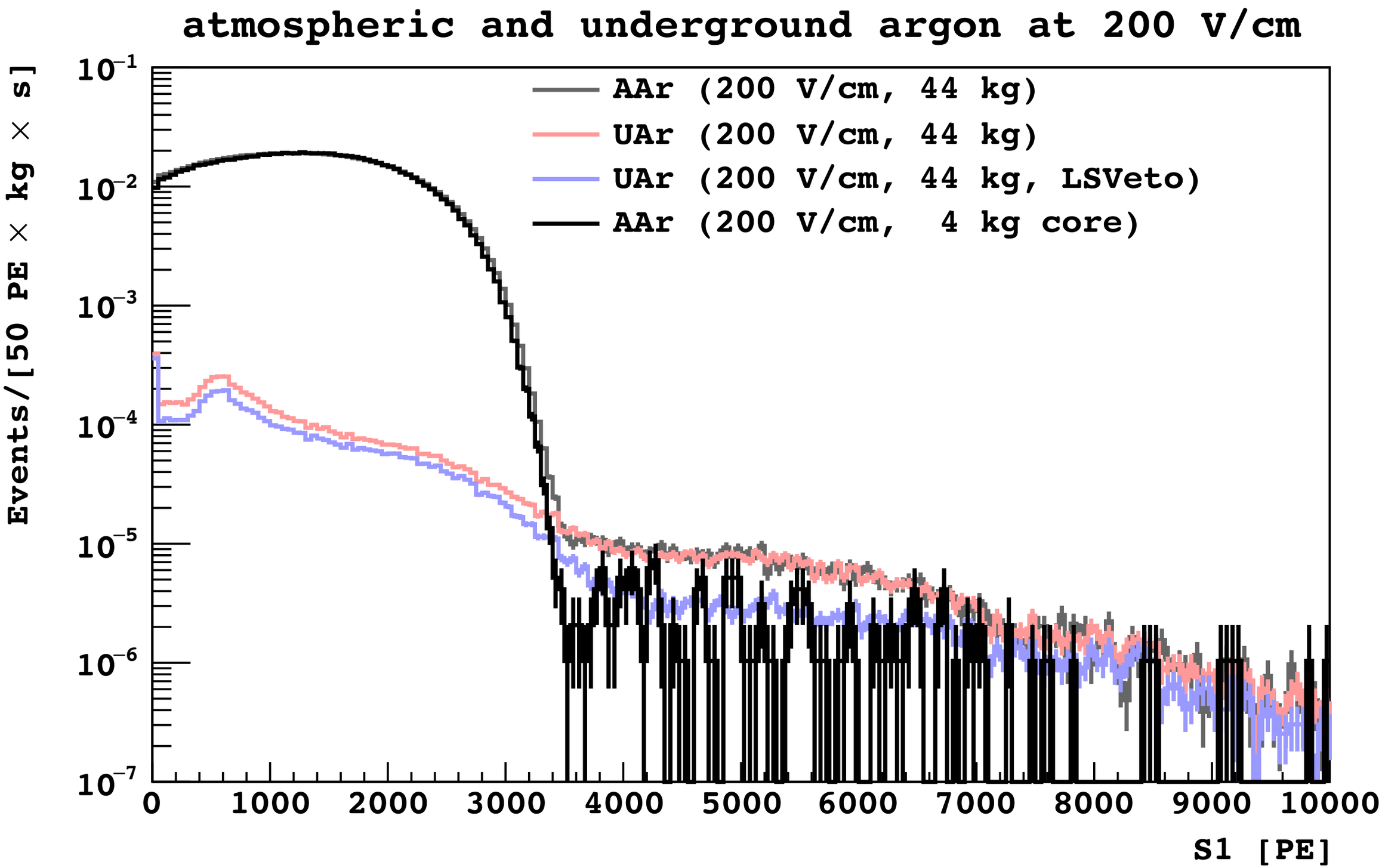
Underground argon (UAr) in DS-50



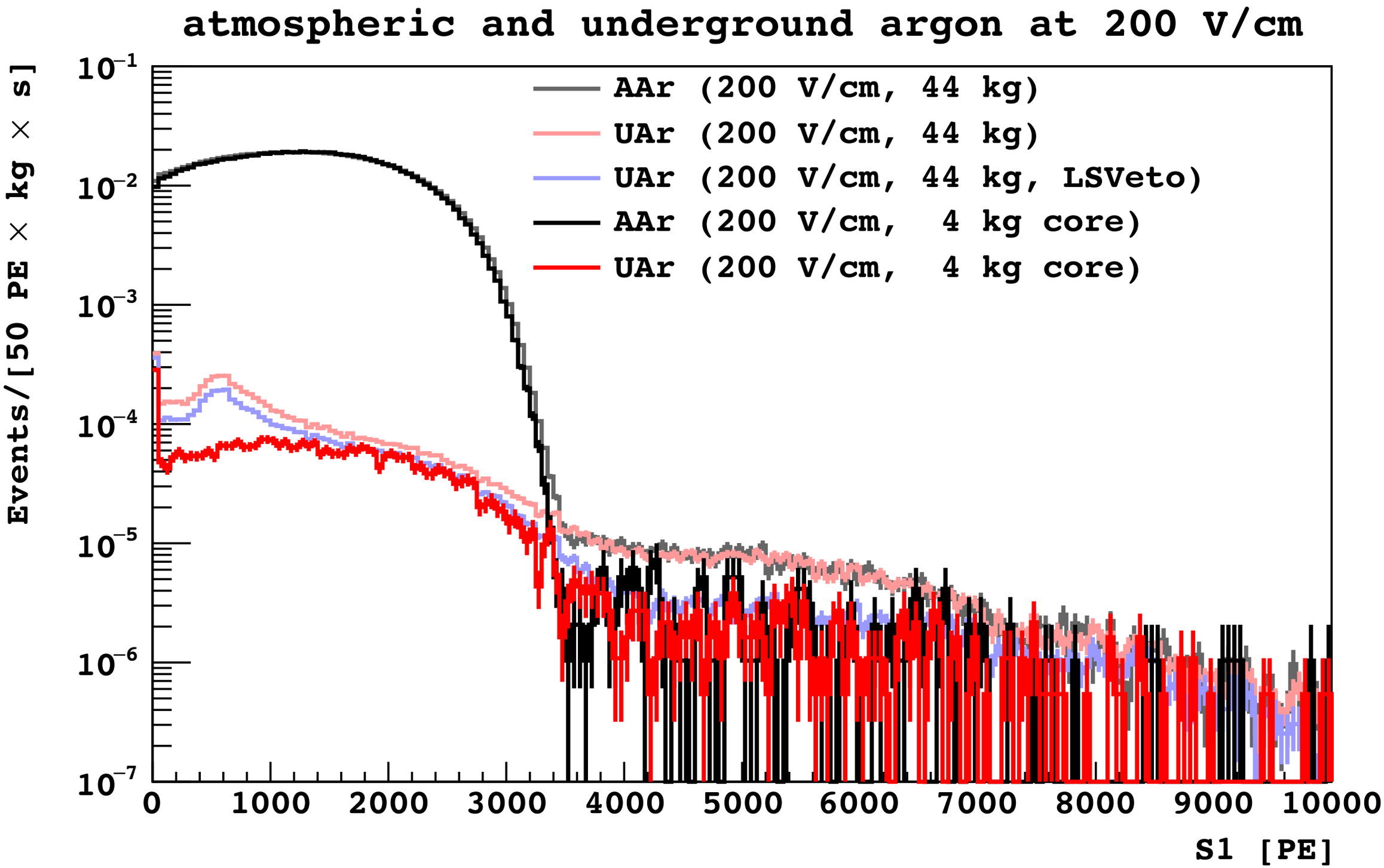
DS-50 with UAr



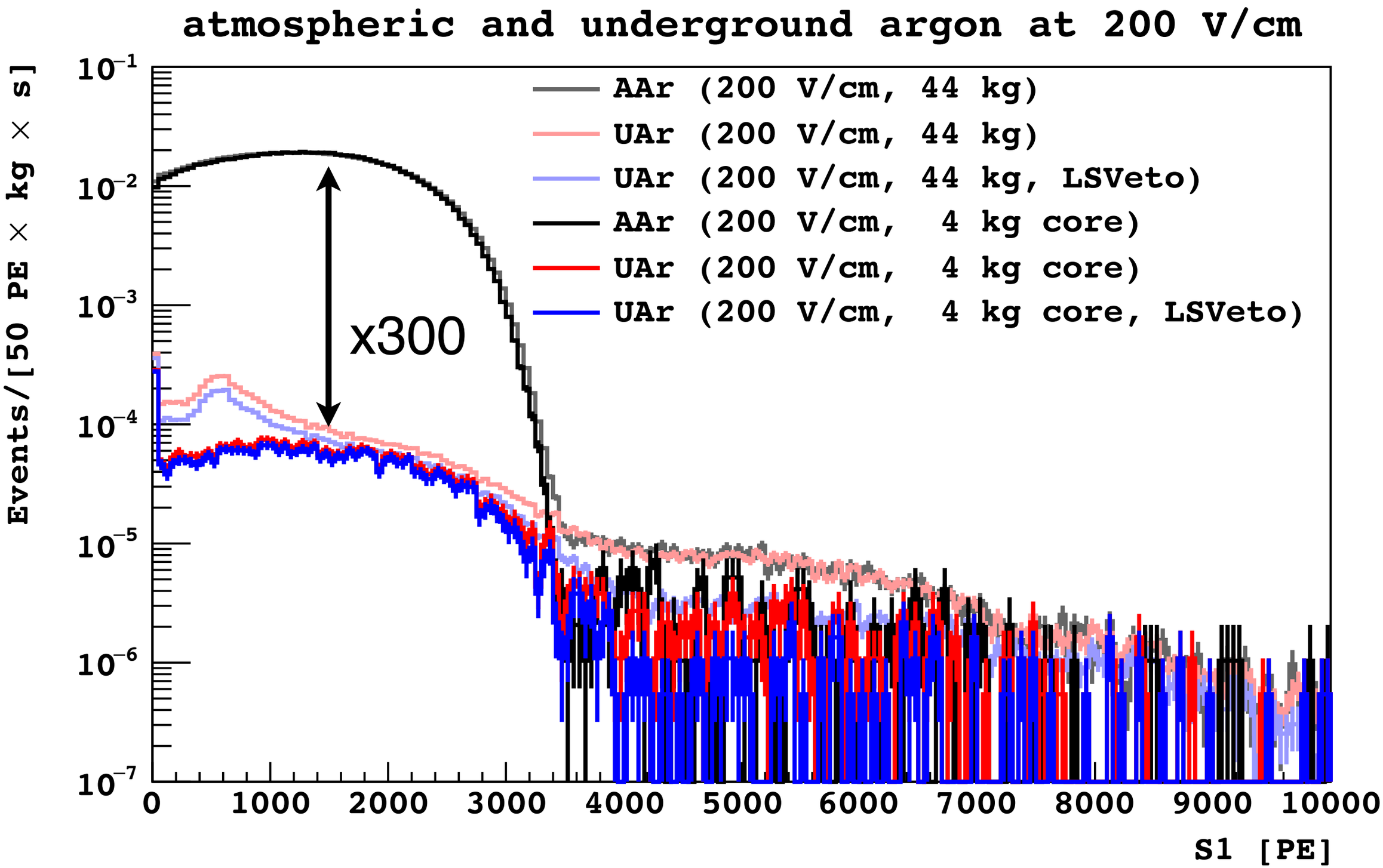
DS-50 with UAr



DS-50 with UAr



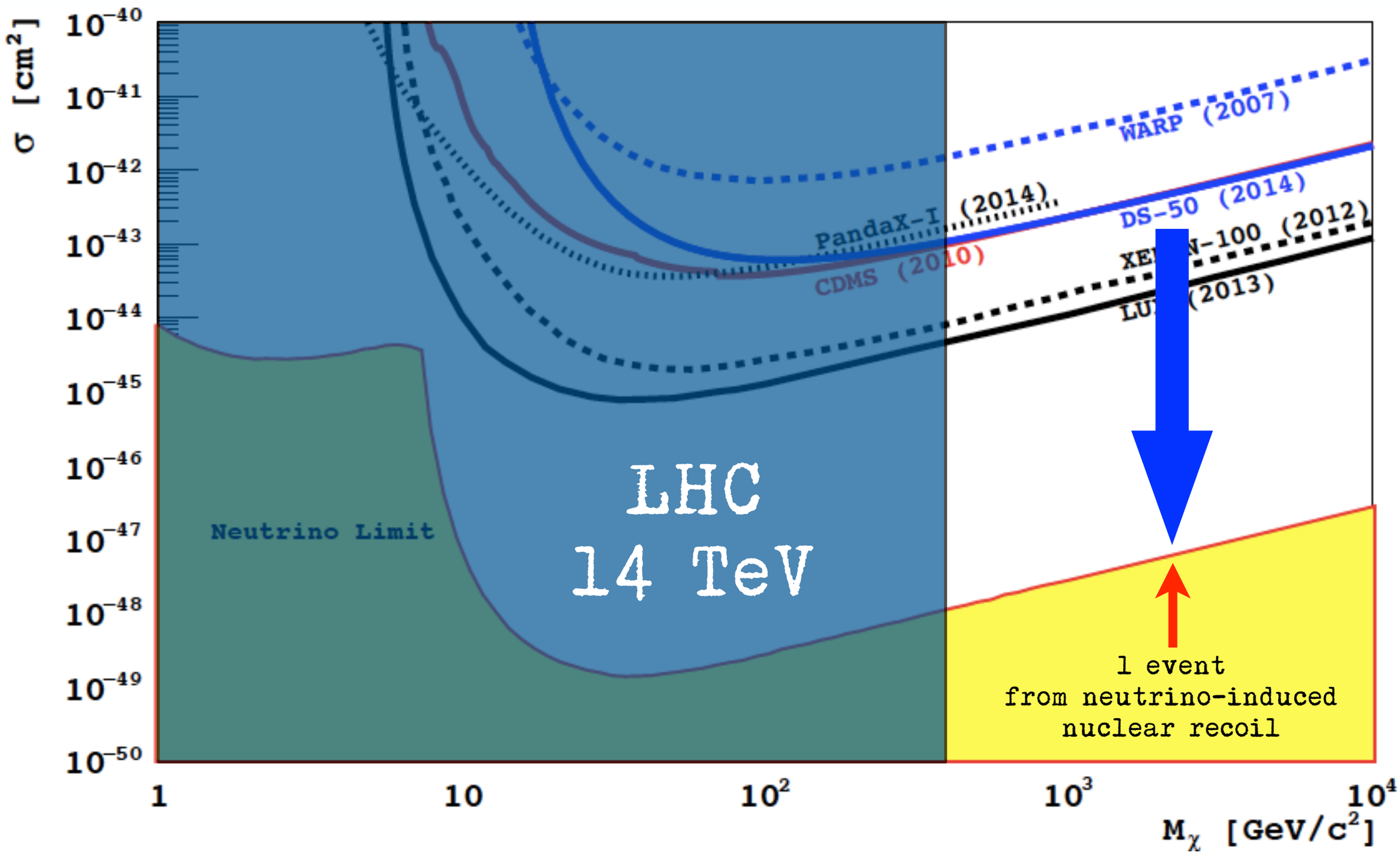
DS-50 with UAr



DS-50 status

- Third best high mass dark matter limit (with AAr, ~20 years of ^{39}Ar in UAr)
- Background-free exposure of 1,422 kg×days (~ 1 tonne×yr with UAr)
- Rejection factor better than 1.6×10^{7}
- Detector in final configuration
  - UAr science run started (April, 2015)
  - Additional exposure of ~1,000 kg×day already collected
  - Underground argon isotopic depletion factor: 300±7
  - Calibration system
  - TMB problem fixed (500× less ^{14}C)
  - Veto at design 99.5% neutron rejection
- Expected 3-year sensitivity: 10^{-45} cm^{2}

DS-50: third best WIMP dark matter limit at high masses

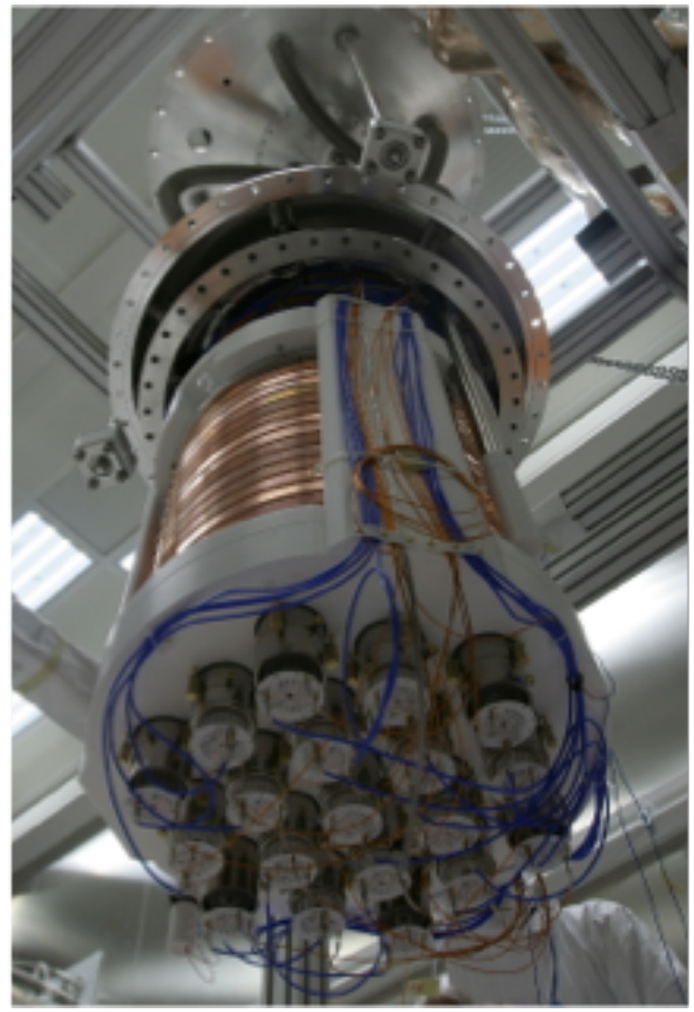


DarkSide timeline (old plans)

DS-10

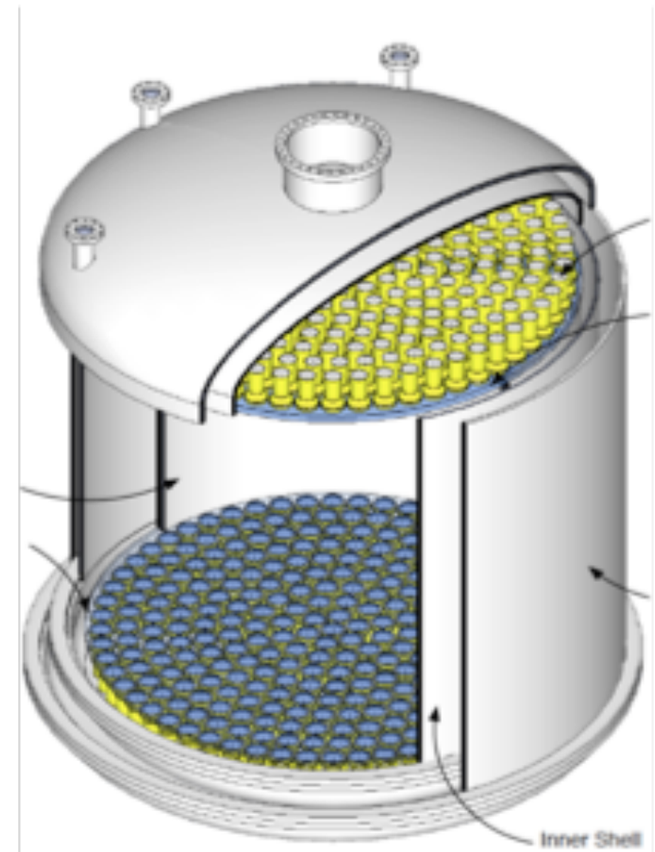
Prototype
(2011)

DS-50



commissioned
October 2013

Multi-tonne DS
(G2)



DarkSide timeline (new plans)

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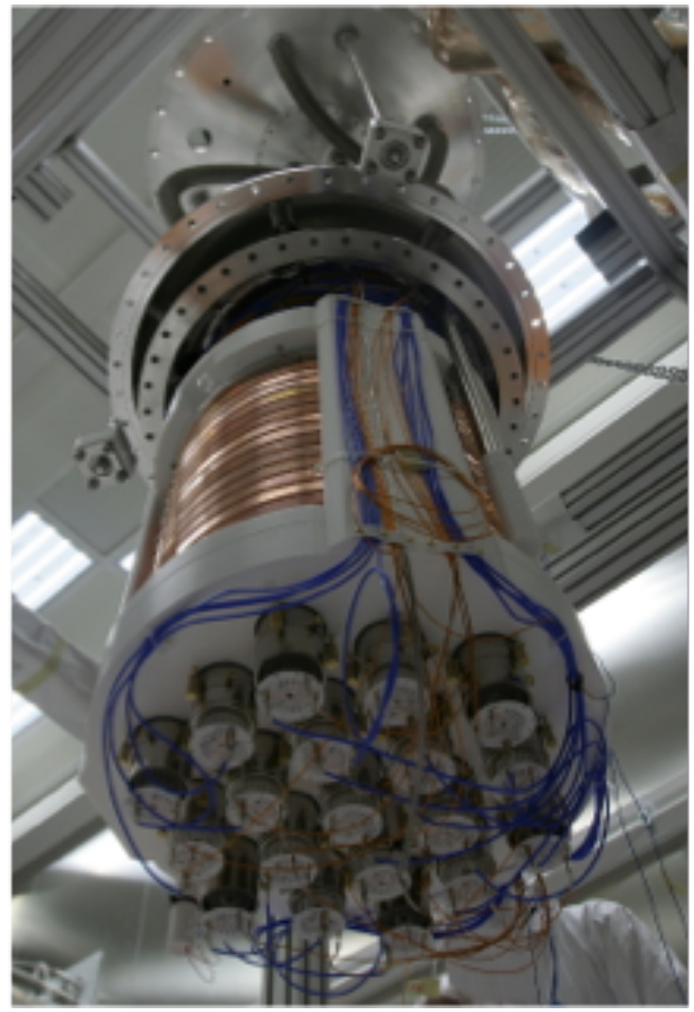
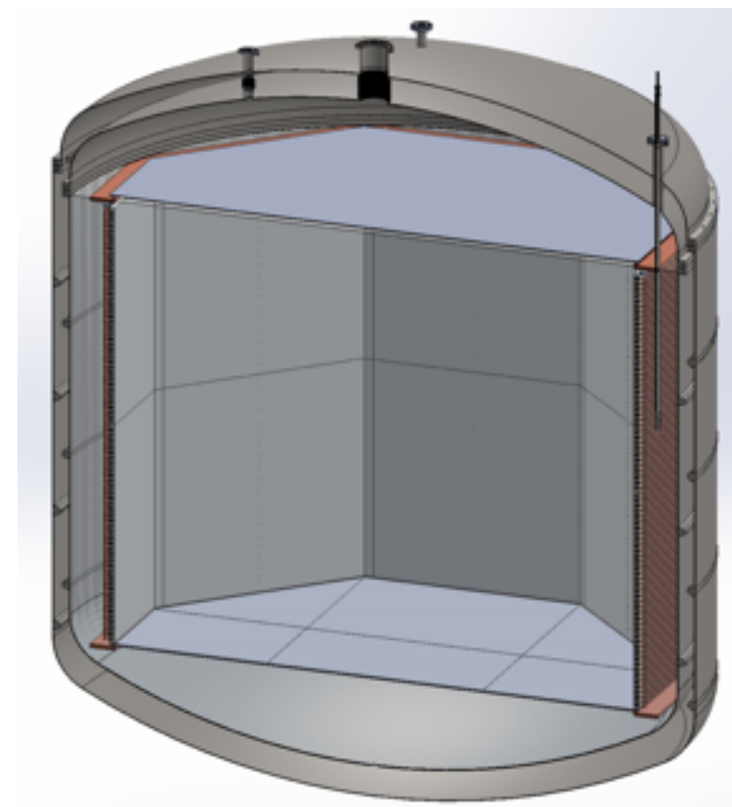
Prototype
(2011)

DS-50



commissioned
October 2013

DS-20k



Argo

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]	7×10^{-45}	7×10^{-44}
DEAP-3600 [3.0 tonne×yr Ar]	5×10^{-46}	5×10^{-45}
XENON-1ton [2] [2.7 tonne×yr Xe]	3×10^{-46}	3×10^{-45}
LZ [1] [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}

Probing the neutrino floor

What are the main backgrounds?

1) Neutrino elastic scattering

2) Radioactive noble gases

Elastic scattering of *pp* solar neutrinos on electrons

- 200 events/tonne×yr in 30-200 keV_{nr} ROI for argon means 80,000 background events @neutrino floor (400 tonne×yr)
    - Reducible background: $1 \div 1.6 \times 10^7$ rejection
- 20 events/tonne×yr in 0-10 keV_{ee} ROI for xenon means 6,000 background events @neutrino floor (300 tonne×yr)
    - Ir-reducible background: $1 \div 200$ rejection

^{39}Ar rejection roadmap

1,422 kg×day (AAr)

×300 (AAr/UAr)

already achieved

1 tonne×yr (UAr)

additional active isotopic depletion

stronger discrimination
presently stat limited
x10 gain with 15% LY increase

1,000 tonne×yr (UAr/DAr)

A very large argon detector?

Based on what we know today,
can a depleted argon
experiment run background-free
at the 400 tonne×yr scale?

400 tonne×yr depleted argon experiment

- *pp* neutrino-electron scattering
  --> Not a concern thanks to pulse shape discrimination
- ^{214}Pb (from ^{222}Rn) and ^{85}Kr
  --> Not a concern thanks to pulse shape discrimination
- ^{39}Ar
  --> Discrimination proven so far on exposure of 1 tonne×yr UAr
  --> No deviations from statistical behavior of discrimination
  --> Current $1 \div 1.6 \times 10^{7}$ rejection limited by statistics
  --> SiPM should allow to increase light yield by 50%, which projects to more than 3 additional orders of magnitude in discrimination at the same threshold
  --> Further isotopic depletion of ^{39}Ar possible if required

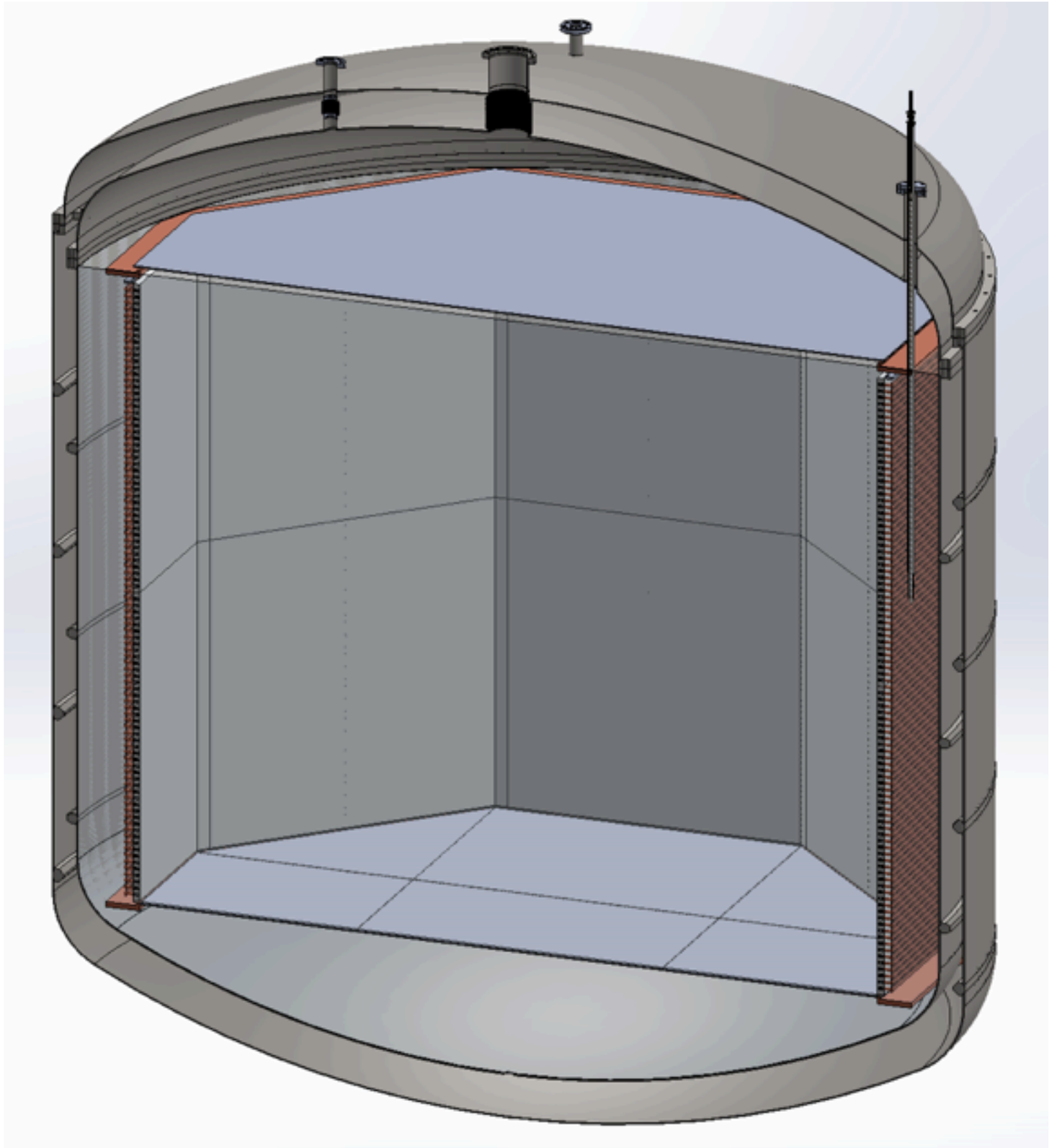
DarkSide-20k

- 100 tonne×yr background-free exposure
- 30 tonne detector (20 tonnes fiducial)
- Projected sensitivity of 9×10^{-48} cm2 @1 TeV/c^2 (5× better than LZ)
- LS veto not required (MC indicates that UAr active shield is sufficient)
- Gd-loaded water Cherenkov veto for enhanced *in-situ* neutron measurement

The DS-20k detector

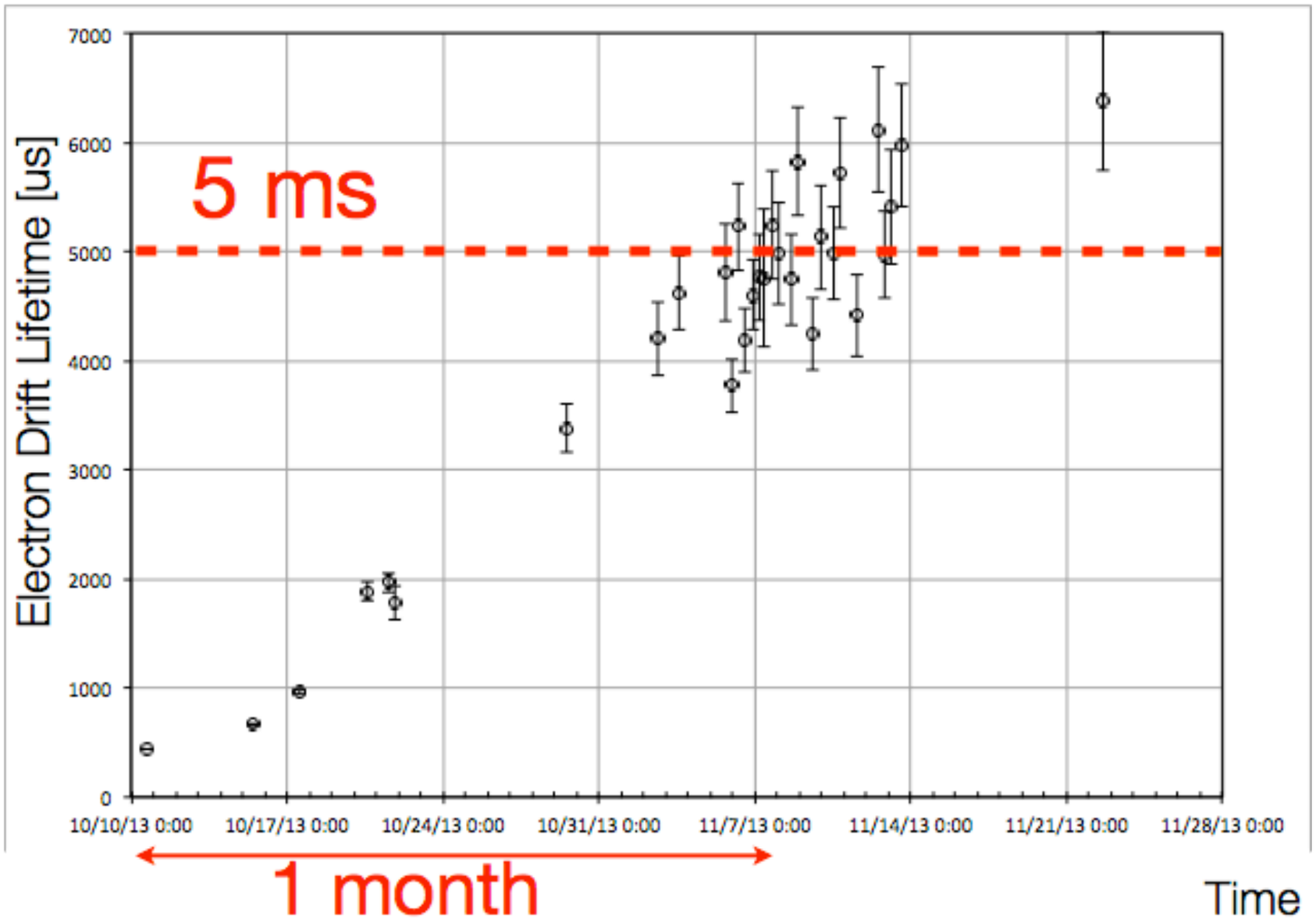
Large TPC

no PMTs



Argon purity - very promising results from DS-50

- Closed loop argon recirculation (~30 slpm)
- Gaseous phase purification using commercial getter
- Cryogenic charcoal trap to remove Rn contamination



Measured electron drift lifetime > 5 ms

to be compared to max. drift time of ~ 375 μs

DS-20k characteristics and challenges

- 15 m^2 of SiPMs

  --> shown 15-50% LY/unit area increase over PMTs

  --> dark count under control on prototype

  --> demonstrated noise control and good performance for 10 cm^2 SiPM tile t 87 K

  --> Tile size required for DS-20k is 25 cm^2 (another ~2x)

  --> custom design by FBK: first custom production soon

  --> mass production possibly at L-foundry

- Low background titanium from Russia for the cryostat

- Requires 50 kV

  --> already demonstrated by DS-10 and DS-50

DarkSide depleted argon sources and testing

- Urania

  --> expansion of Colorado UAr extraction facility to reach 100 kg/day

- Aria

  --> giant cryogenic distillation column in Seruci, Sardinia

  --> gas purification and active isotopic depletion exploiting finite $^{39}Ar/^{40}Ar$ vapor pressure difference

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  --> expansion of Colorado UAr extraction facility to reach 100 kg/day

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  --> giant cryogenic distillation column in Seruci, Sardinia

  --> gas purification and active isotopic depletion exploiting finite $^{39}Ar/^{40}Ar$ vapor pressure difference

  - initial assessment with 1 kg detector in shallow underground site at Seruci

    --> ^{39}Ar sensitivity: 1 mBq/kg

    (probe 10^3 depletion factor, 2-3 times better than in DS-50)

  - ArDM for high sensitivity tests of tonne-scale batches

    --> ^{39}Ar sensitivity: 10 μBq/kg

    (probe 10^5 depletion factor)

Argo concept (300 tonnes)

- Background-free exposure of 1,000 tonne×yr
- Sensitivity 9×10^{-49} cm^2 @1 TeV/cm^2
  Covers space throughout neutrino floor

- Precision measurements of solar neutrinos
  --> TPC affords very sharp definition of fiducial volume
  --> Argon ten times brighter than organic liquid scintillator
  --> Statistical precision 2% for 7Be, 10% for pep, and 15% for CNO neutrinos
  --> Systematics under study
  --> Cosmogenics under control

- 300 tonne detector
  Requires Borexino-style shield for solar neutrinos study

Gaseous Argon detector being considered

Gaseous argon detectors have reached thresholds below 100 eV

I. Giomataris et al., “A novel large-volume spherical detector with proportional amplification read-out”, Journal of Instrumentation 3, P09007 (2008).

Availability of depleted argon made available by the Urania and Aria programs may enable construction of ultra-low background gaseous argon detectors

--> Suitable to explore dark matter interactions on electrons
--> Suitable to monitor supernovae explosions via the detection of neutrino induced coherent scattering of argon nuclides

DS-20k 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
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Y. Suvorov, H. Wang - UCLA
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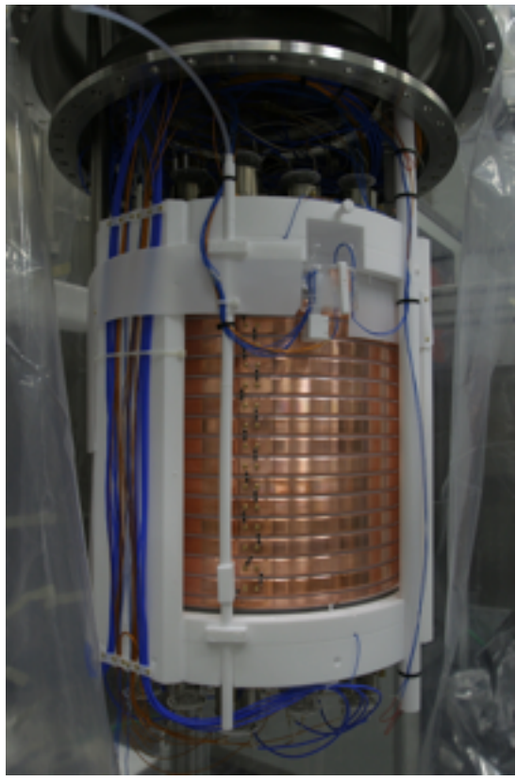
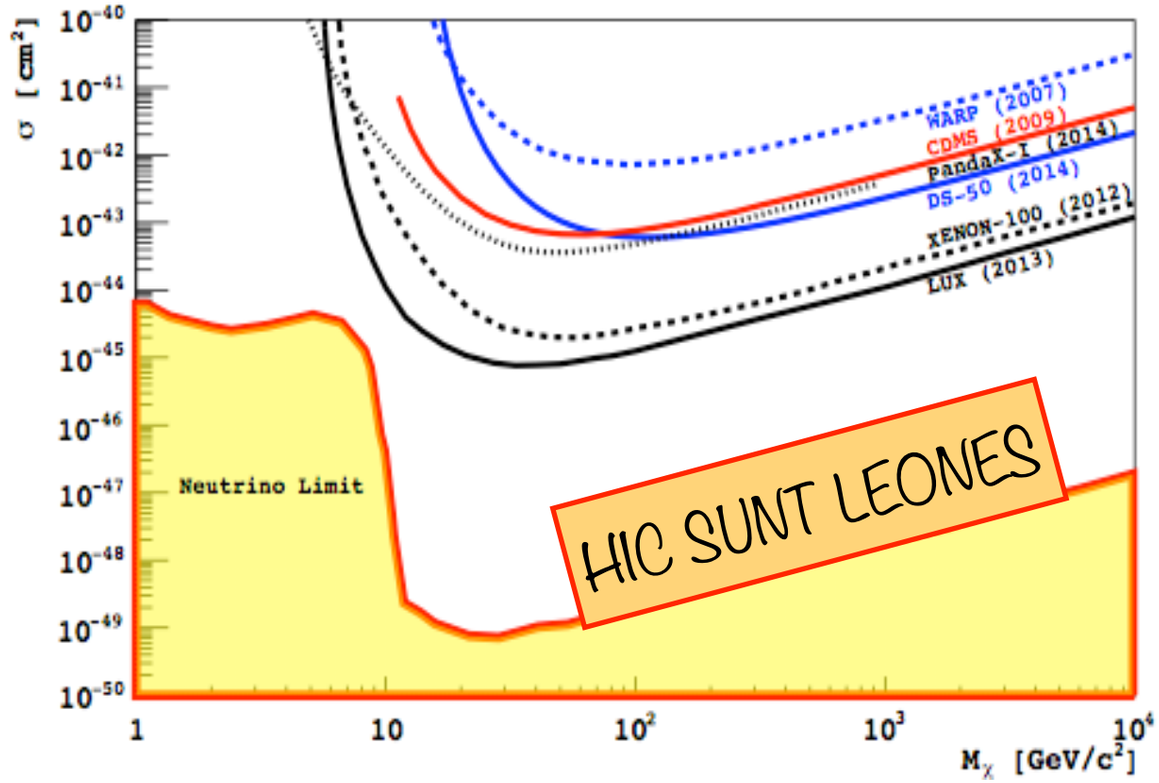
S. Bussino, S. Mari - Università & INFN Roma 3
J. Maricic, R. Milincic, B. Reinhold - University of Hawaii
P. Cavalcante - Virginia Tech

Conclusions

stay hungry, my friend

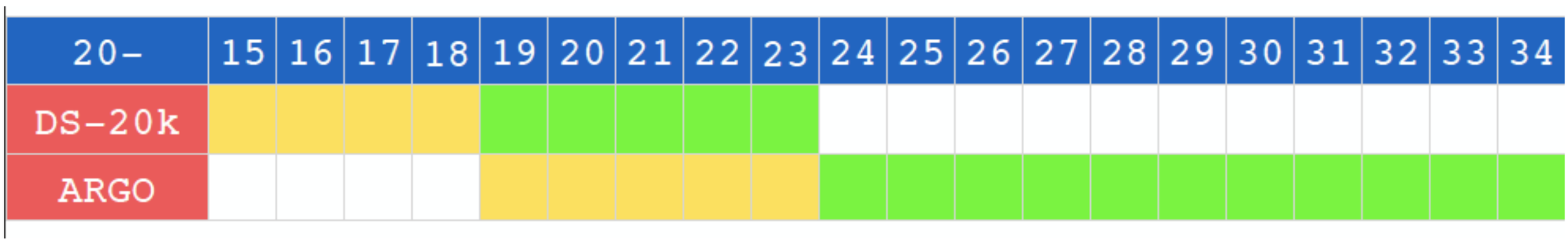
- DS-50 is running with UAr at LNGS
- first UAr physics results coming soon
- DS-50 has provided the tested basis for very large 2-phase LAr TPCs to reach the neutrino floor
- future: DS-20k (April 27 LOI to LNGS)
  Argo





extra slides

Timeline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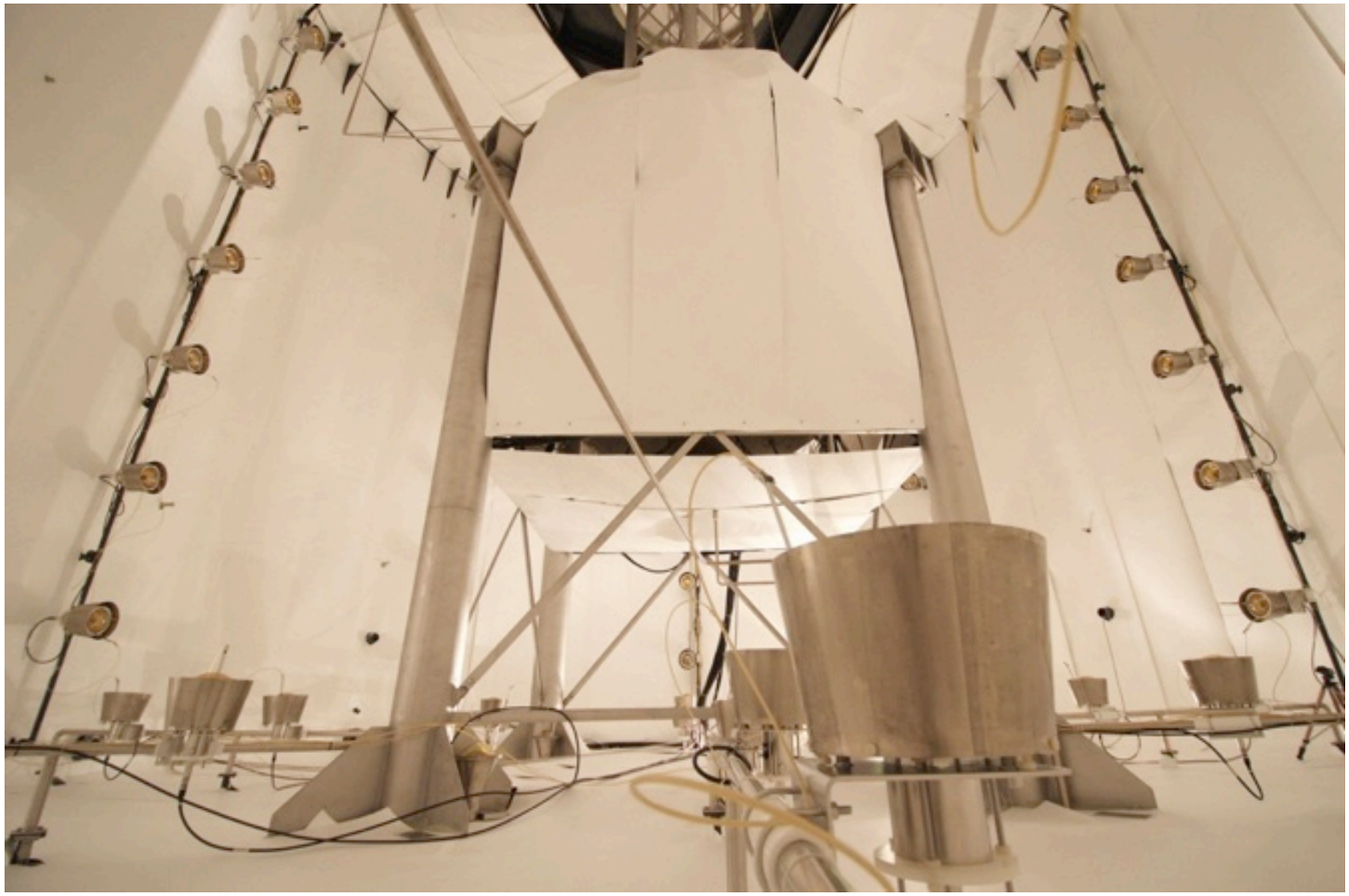
DS-20k
ARGO

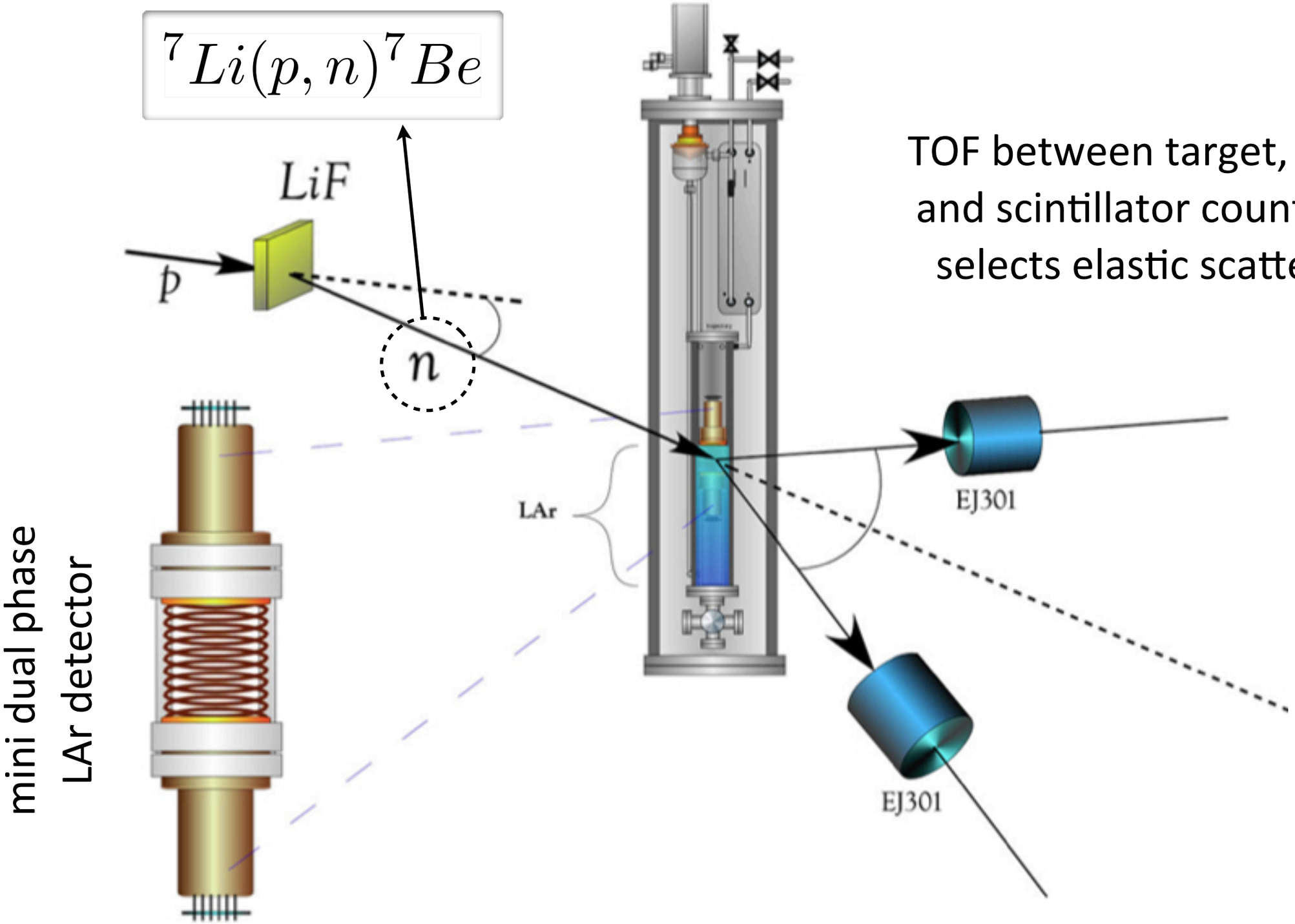
Čerenkov muon detector



- 80 PMTs
- 11 m x 10 m tank
- 99% efficient
- neutron, γ shield

SCENE @ Notre Dame

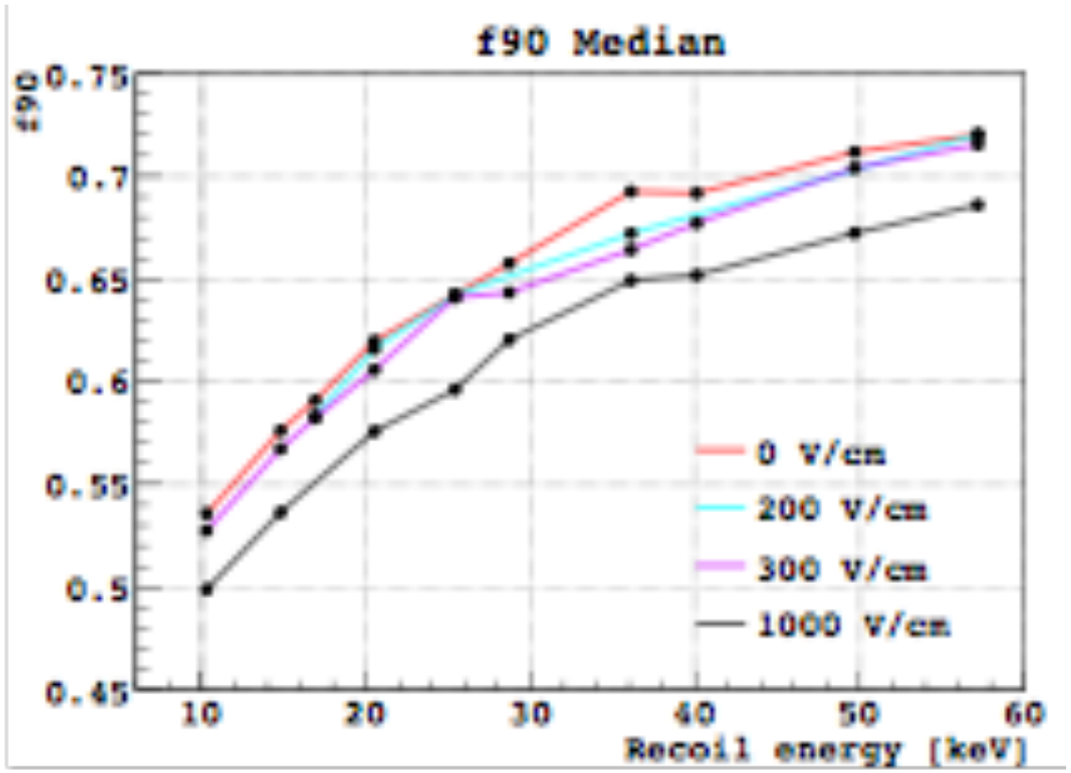
mono-energetic neutrons:

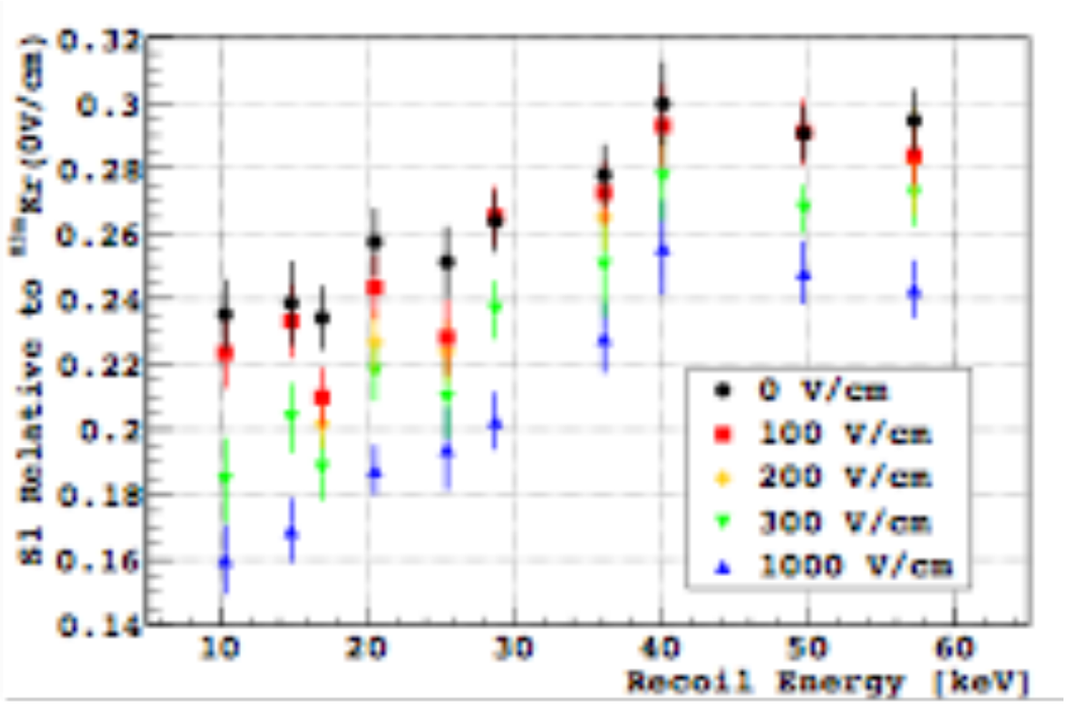


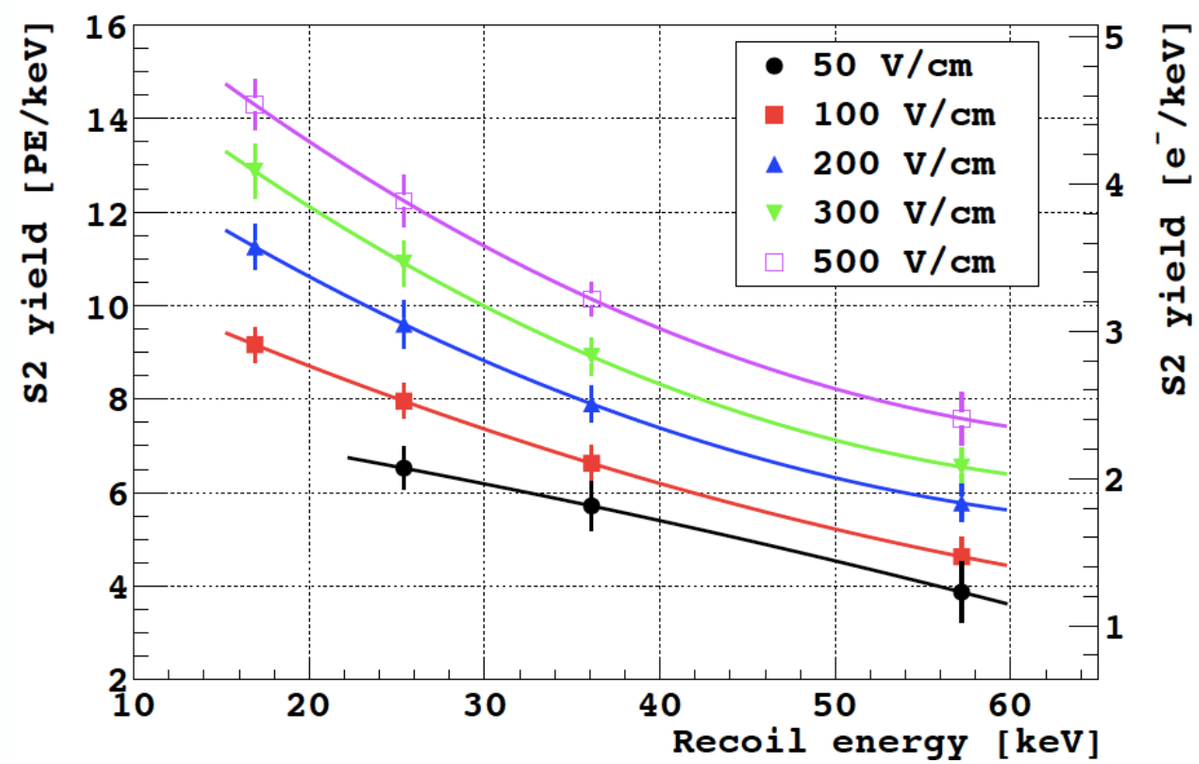
TOF between target, LAr, and scintillator counters selects elastic scatters

SCENE data

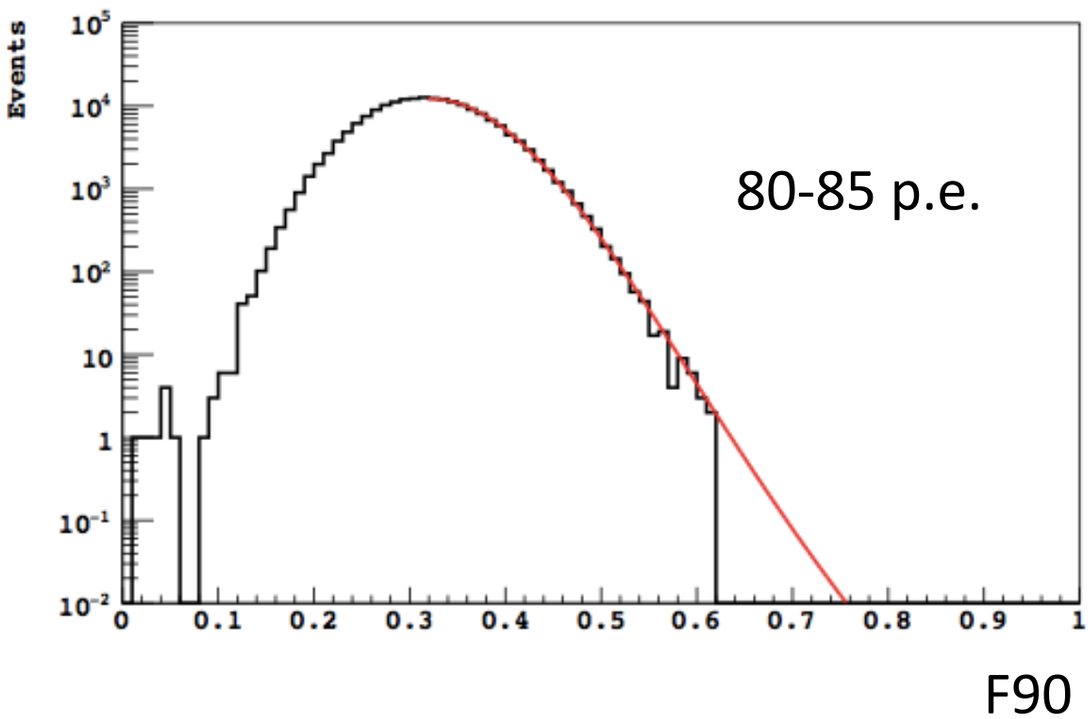
Phys. Rev. D 88, 092006 (2013), arXiv:1406.4825)

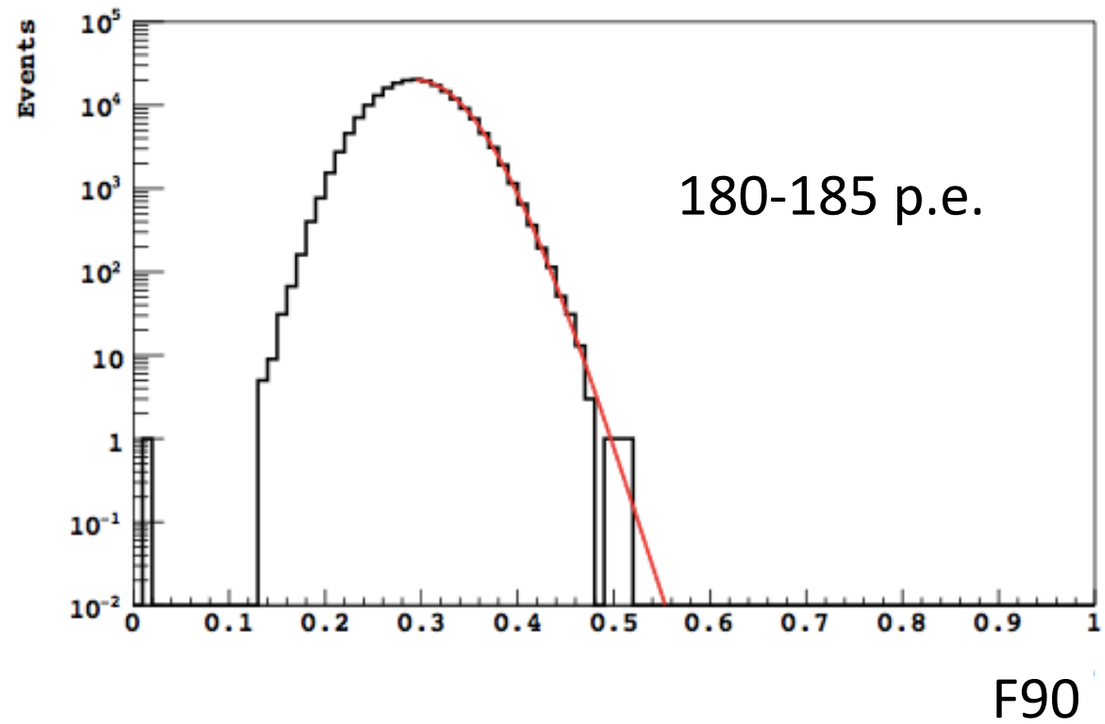






F90 contours





Model:

W. H. Lippincott, K. J. Coakley, D. Gastler, A. Hime,
E. Kearns, D. N. McKinsey, J. A. Nikkel, and L. C. Stone- hill,
Phys. Rev. C 78, 035801 (2008).
(Note that there is a misprint in the relevant equation 11)

M. G. Boulay et al. (DEAP Collaboration), arxiv:0904.2930.

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

The Rn abatement system

Cryogenic adsorption on activated charcoal
(Sicarbon K48, two 1.5 m^3 tanks in series)

200 m^3/h
T = -60 C
P = 10 bar

1 mBq/m^3
delivered to
clean rooms

CRH ~ 5 mBq/m^3
CRH ~ 50 mBq/m^3

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[1] E. Aprile et al. (XENON Collaboration), Physical Review D 83, 082001 (2011)

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[5] D. S. Akerib et al. (LUX Collaboration), Physical Review Letters 112, 091303 (2014)