DarkSide-20k and the Darkside Program for Dark Matter Searches

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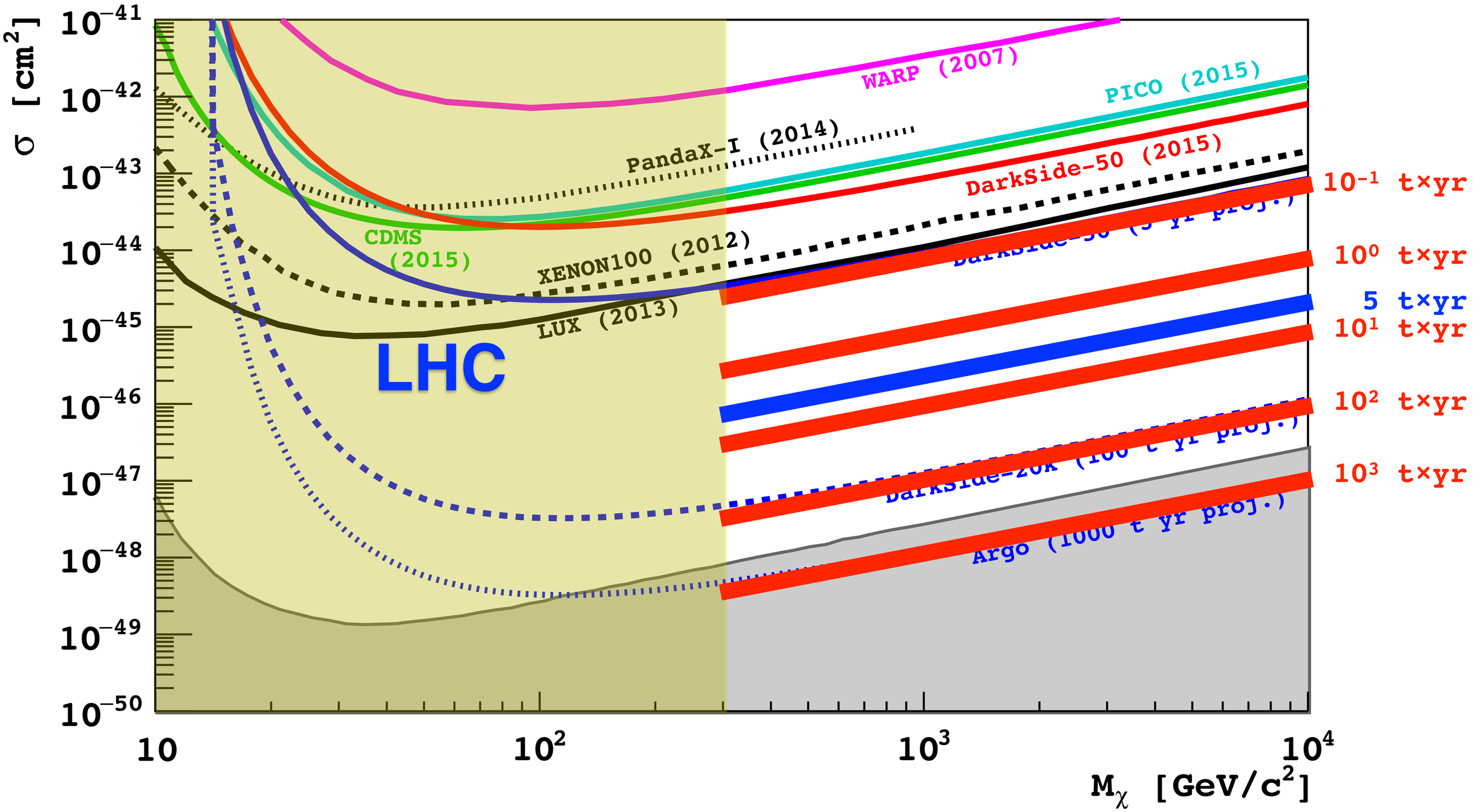
Princeton University
Laboratoire de l'Accélérateur Lineaire
Orsay
April 22, 2016

DarkSide-20k Institutions


σ [cm²]
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10⁻⁴⁶
10⁻⁴⁷
10⁻⁴⁸
10⁻⁴⁹
10⁻⁵⁰
10
10²
10³
10⁴
M_χ [GeV/c²]
WARP (2007)
PICO (2015)
DarkSide-50 (2015)
PandaX-I (2014)
CDMS (2015)
XENON100 (2012)
LUX (2013)
LHC
10⁻¹ t×yr
10⁰ t×yr
5 t×yr
10¹ t×yr
10² t×yr
10³ t×yr
Argo (1000 t yr proj.)

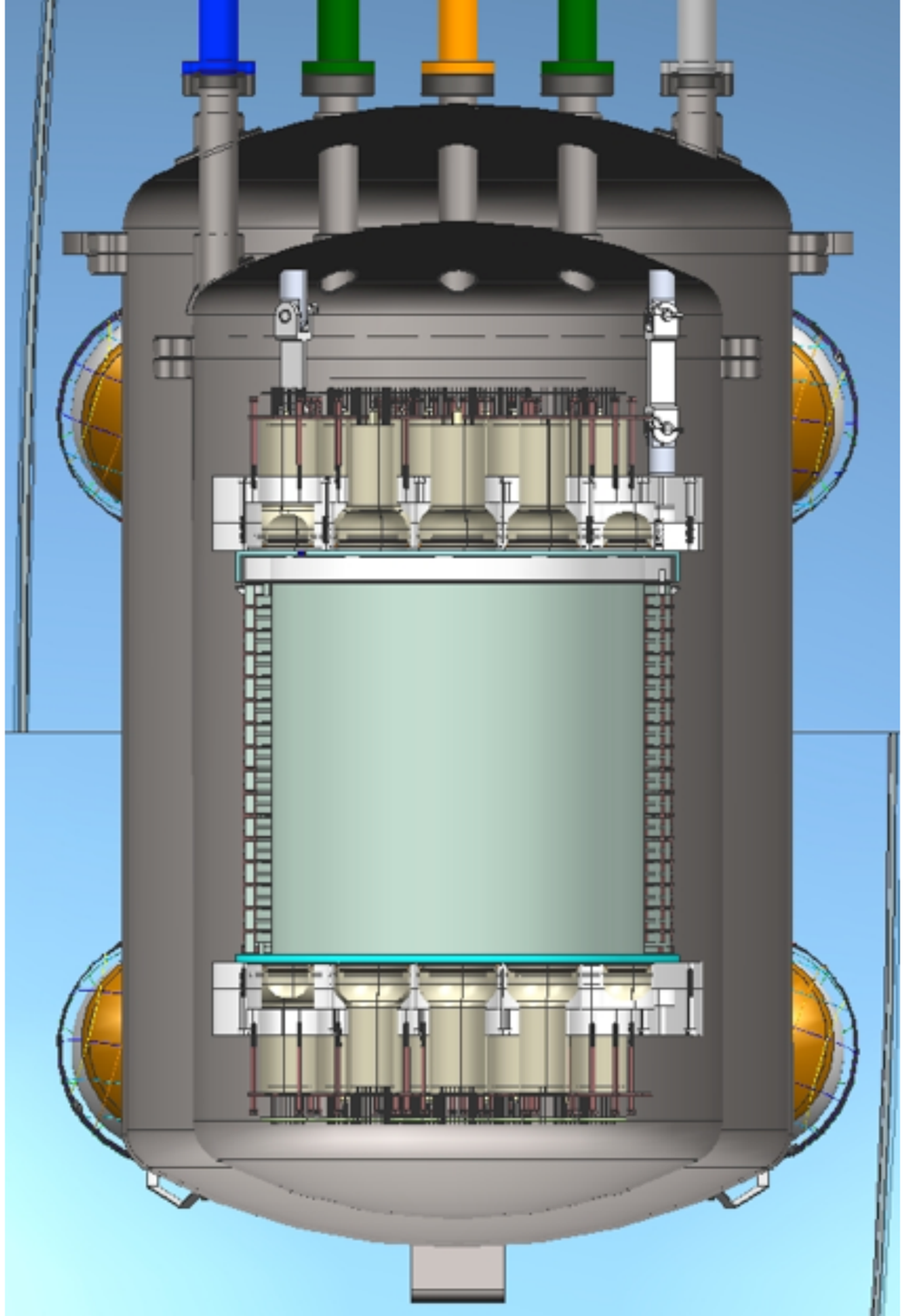
An Ambitious Discovery Program

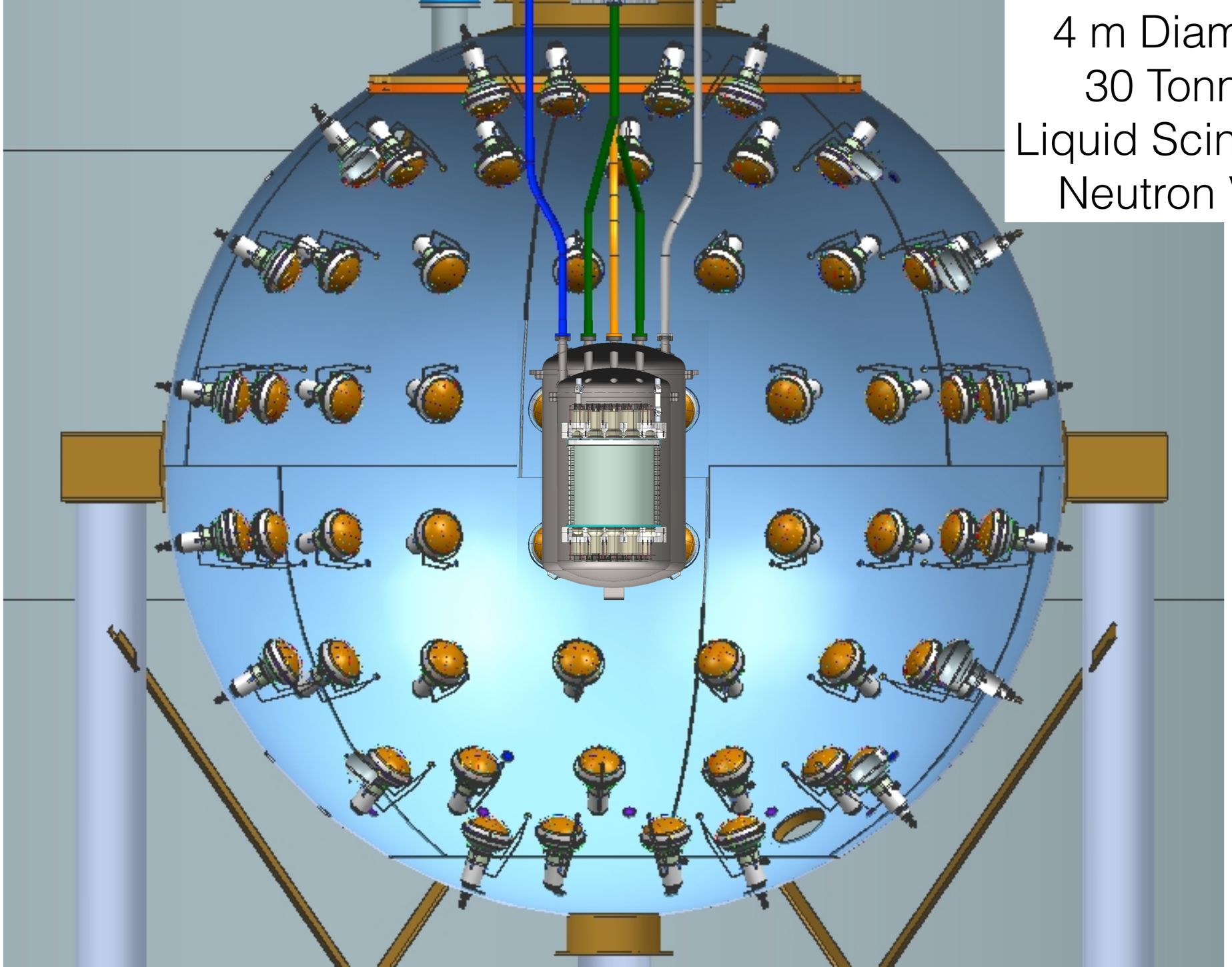
- Raising the bar: 0.1 ton×yr ⇒ 1000 ton×yr
- Complementary to LHC and raising its energy scale:
  - 500 GeV ⇒ 1 TeV ⇒ 10 TeV ⇒ …
- “Zero Background” absolutely necessary for a discovery program
- Strong investment in ^{40}Ar by INFN, NSF, and Fermilab
- Ambitious program for discovery of heavy dark matter, potential flagship program for LNGS

The Root: DarkSide-50

- The DarkSide-50 direct dark matter search:
  - A liquid argon TPC in stable operation having matched or surpassed all basic requirements
  - Thanks to Fermilab, first dark matter detector operating with isotopically enhanced target
  - Dark matter search operating in background-free mode

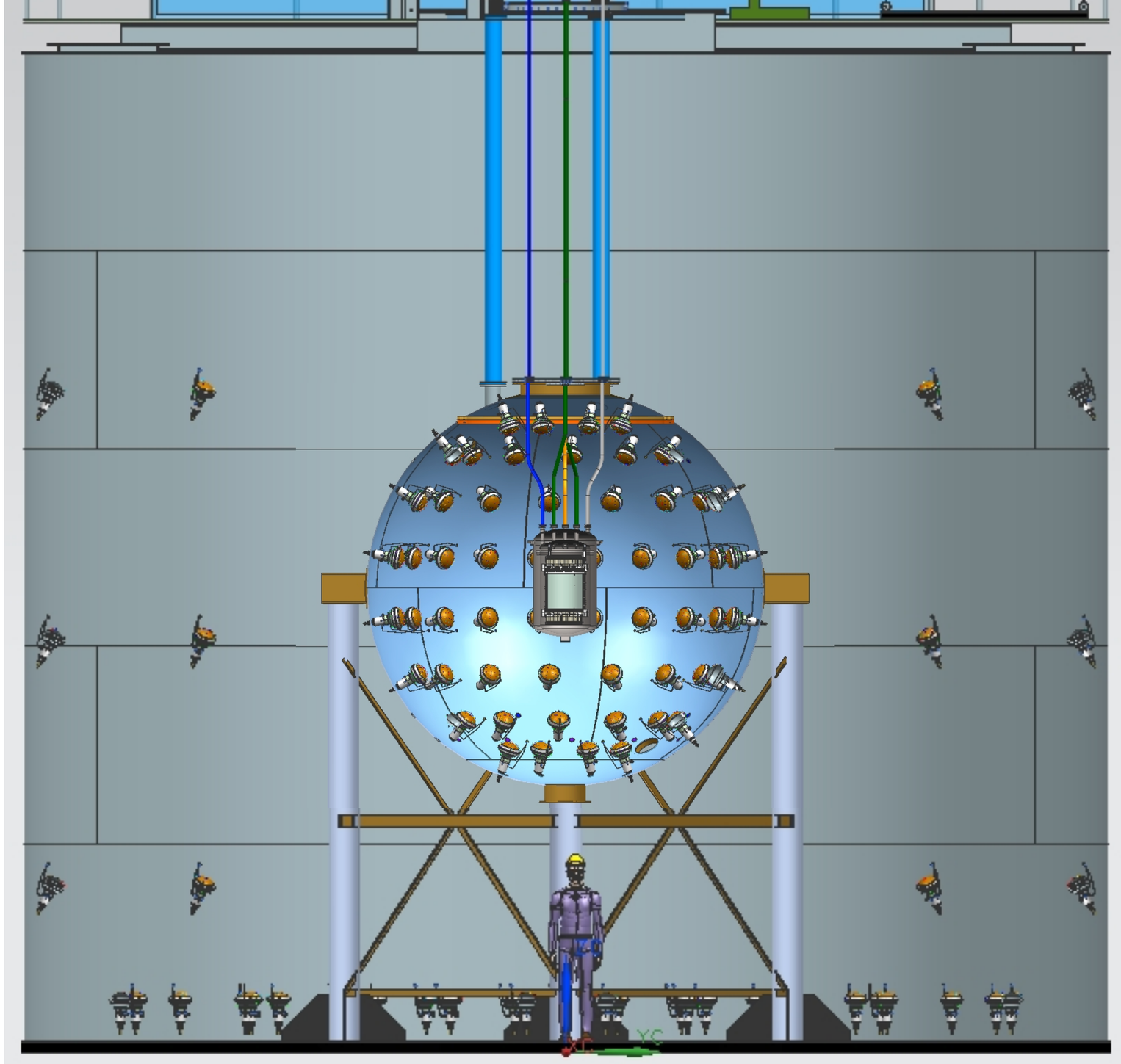
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target





4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



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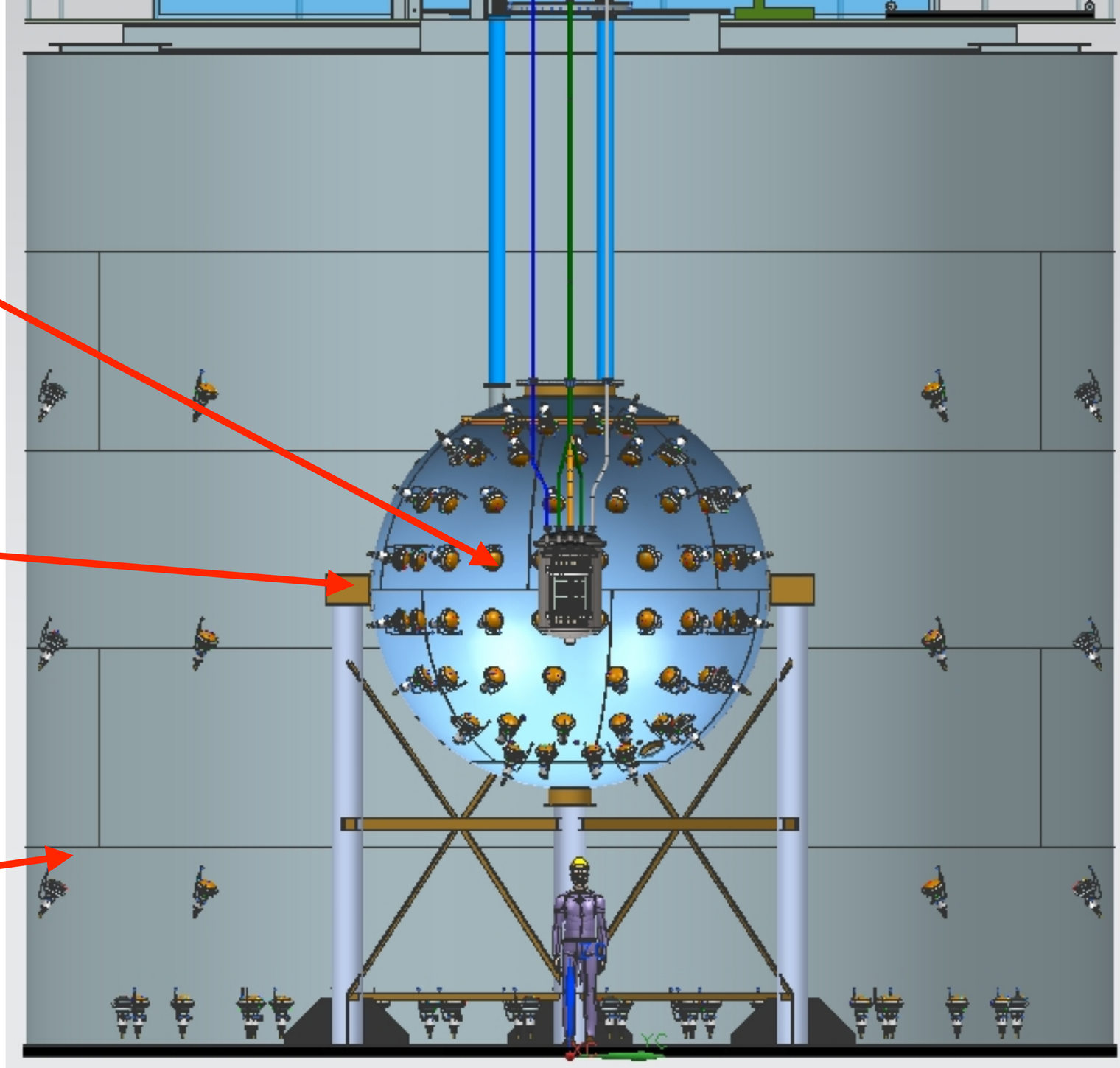
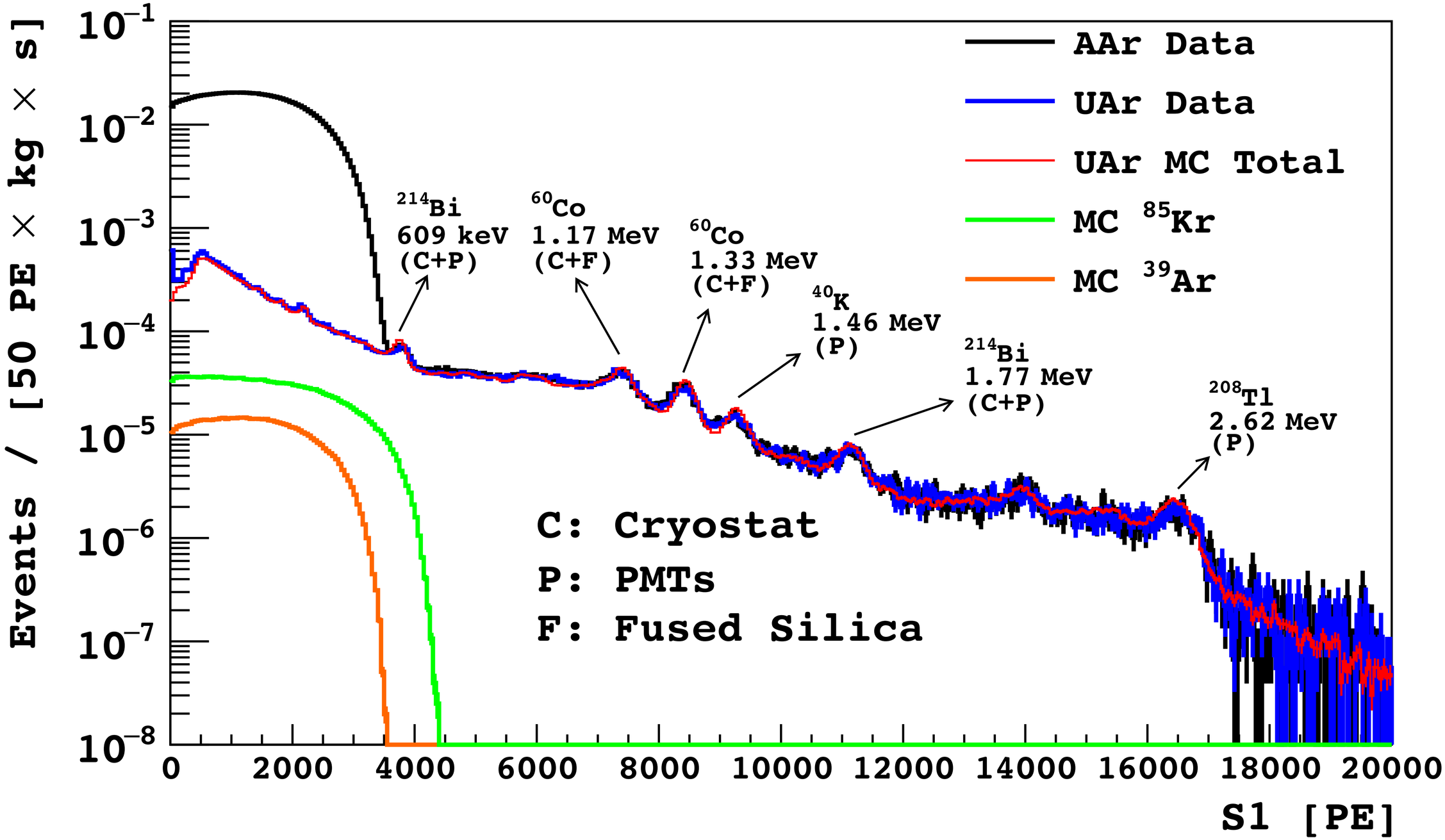
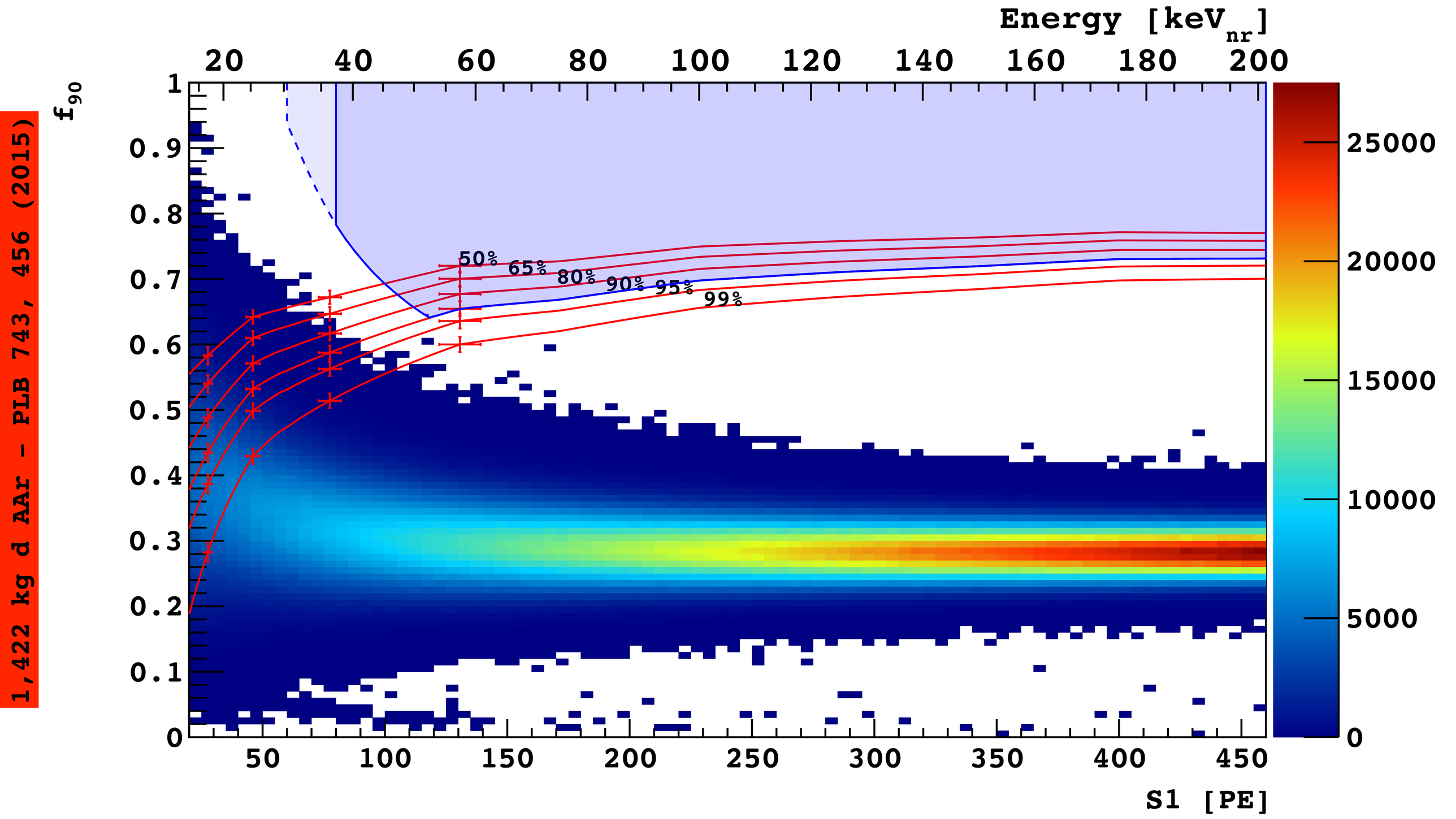
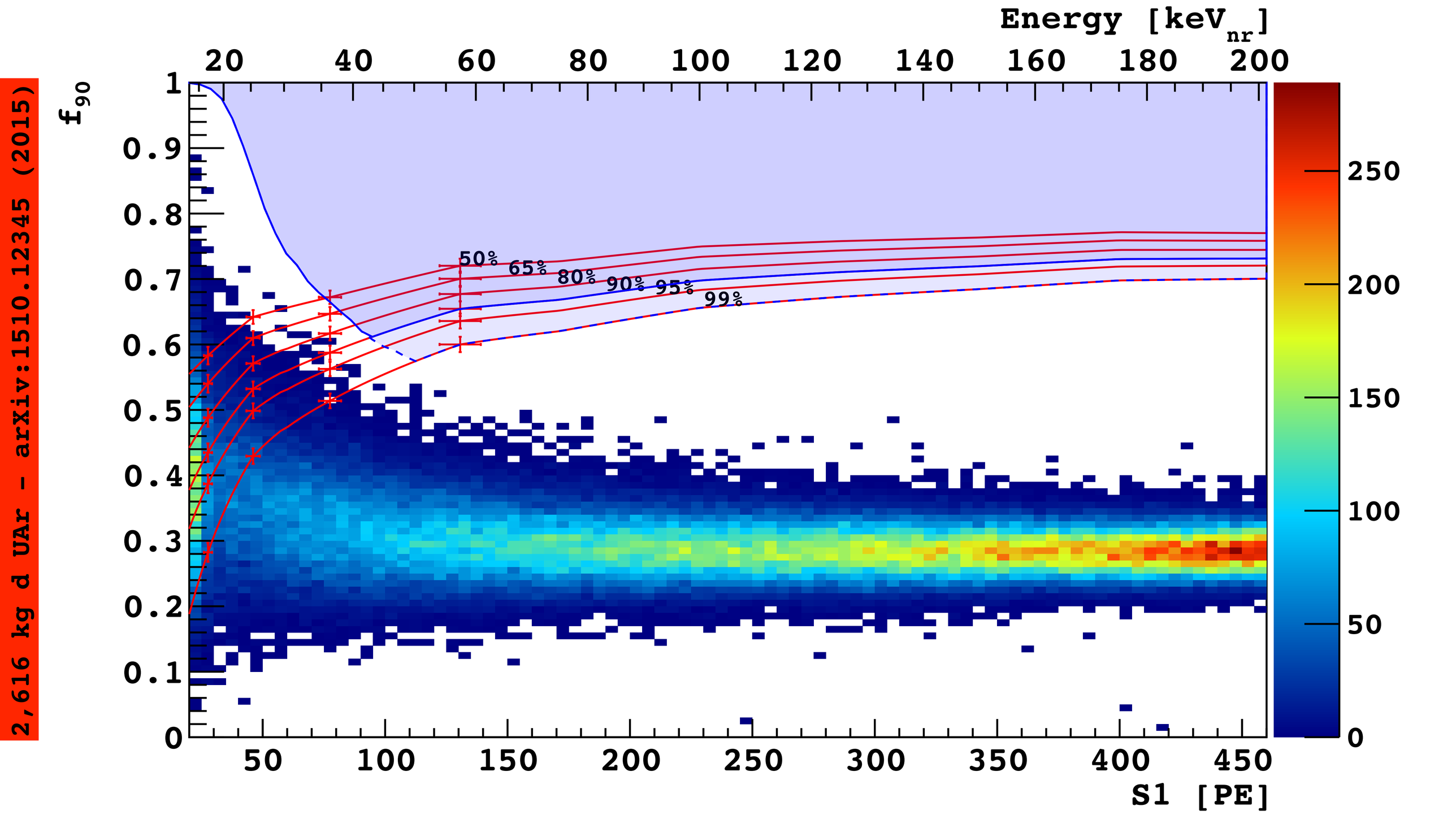


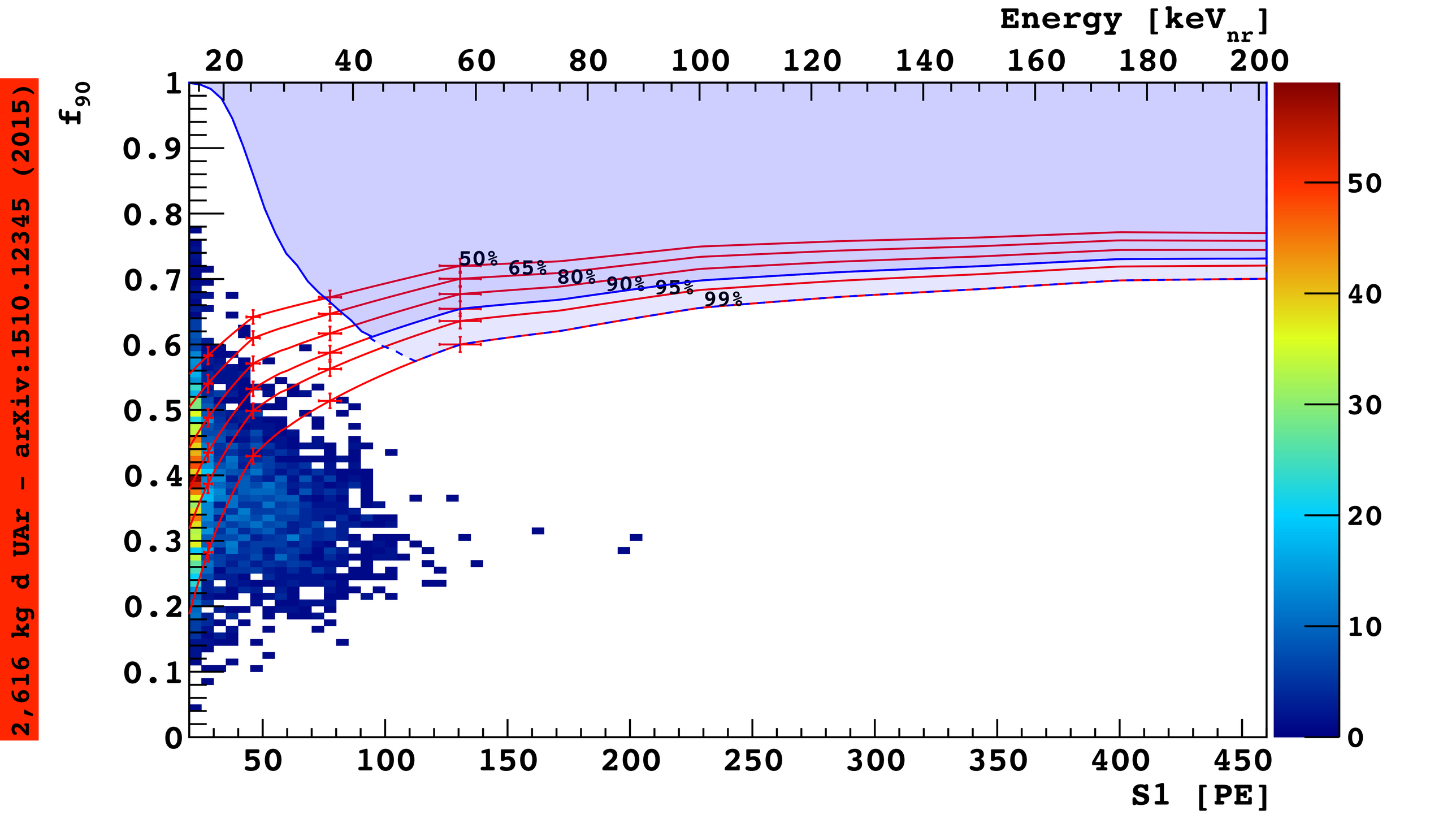
DarkSide-50 Milestones

- Oct 2013: three detectors commissioned, cryostat filled with AAr
- Oct 2014: WIMP search results with 1422 kg d AAr exposure
- Fall 2014: Calibration campaign
- Winter 2014: Refurbishment of LSV, ^{14}C rate from 150 kHz to 0.3 kHz
- Apr 2015: cryostat drained and filled with 153 kg of UAr
- Oct 2015: WIMP search results with 2616 kg d UAr exposure


AAr Data
UAr Data
UAr MC Total
MC ^{85}Kr
MC ^{39}Ar
^{214}Bi
609 keV
(C+P)
^{60}Co
1.17 MeV
(C+F)
^{60}Co
1.33 MeV
(C+F)
^{40}K
1.46 MeV
(P)
^{214}Bi
1.77 MeV
(C+P)
^{208}Tl
2.62 MeV
(P)
C: Cryostat
P: PMTs
F: Fused Silica
Events / [50 PE × kg × s]
S1 [PE]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000


1,422 kg d AAr - PLB 743, 456 (2015)
Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f$_{90}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
25000
20000
15000
10000
5000
0


2,616 kg d UAr - arXiv:1510.12345 (2015)
Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f$_{90}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
250
200
150
100
50
0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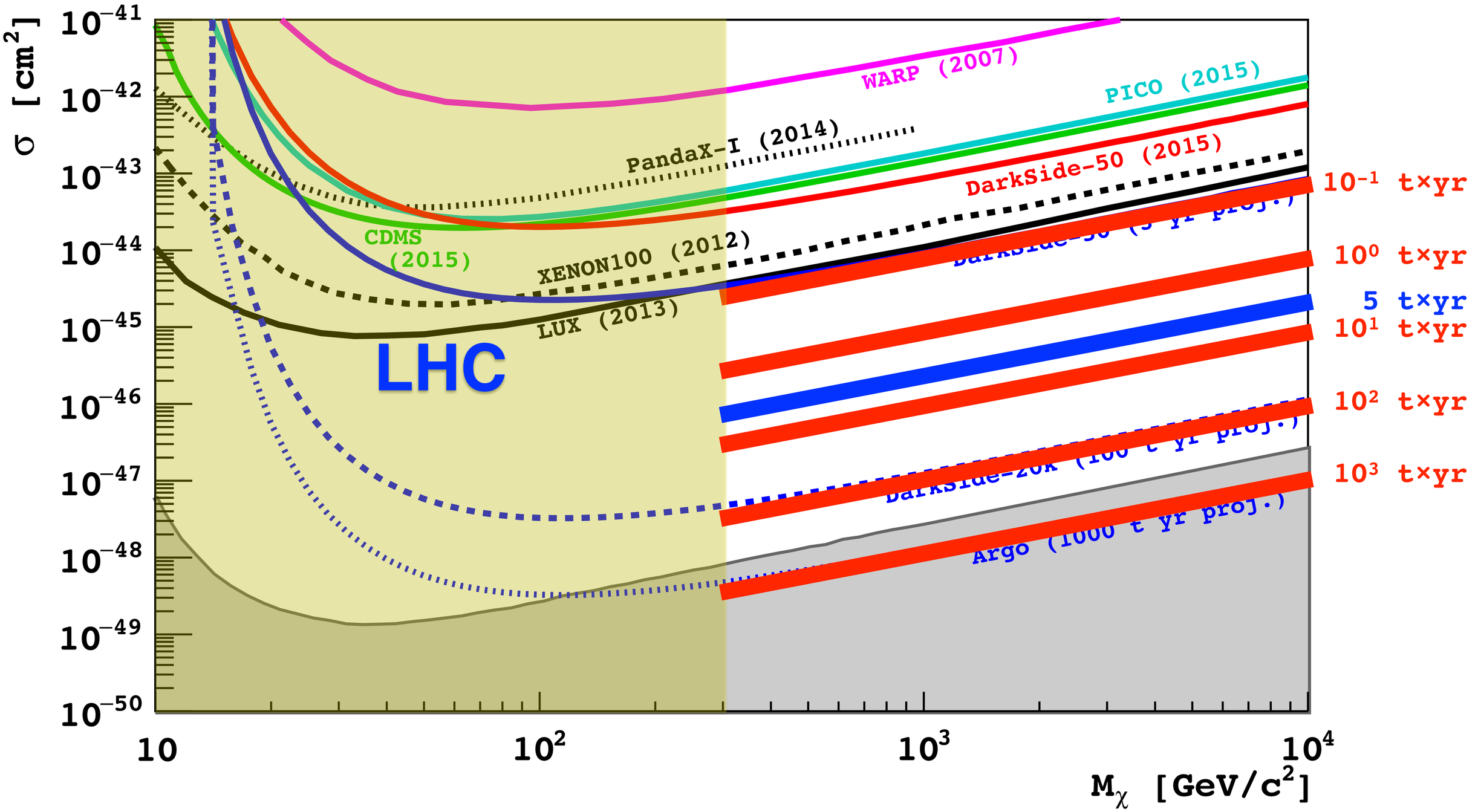
40
60
80
100
120
140
160
180
200
f$_{90}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
50
40
30
20
10
0
2,616 kg d UAr - arXiv:1510.12345 (2015)

Meeting Basic Requirements Pays Off

- Light Yield: > 8 p.e./keV
- Electron meanlife: >>>5 ms
- ^{39}Ar contamination: 0.7 mBq/kg, factor 1,400 reduction res to atmosphere
- ^{222}Rn contamination: <2 μBq/kg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LHC
10⁻¹ t×yr
10⁰ t×yr
5 t×yr
10¹ t×yr
10² t×yr
10³ t×yr
Argo (1000 t yr proj.)

“Zero Background” condition (<0.1 background events) necessary to conduct discovery program

What are the backgrounds for large scale, high mass dark matter searches?

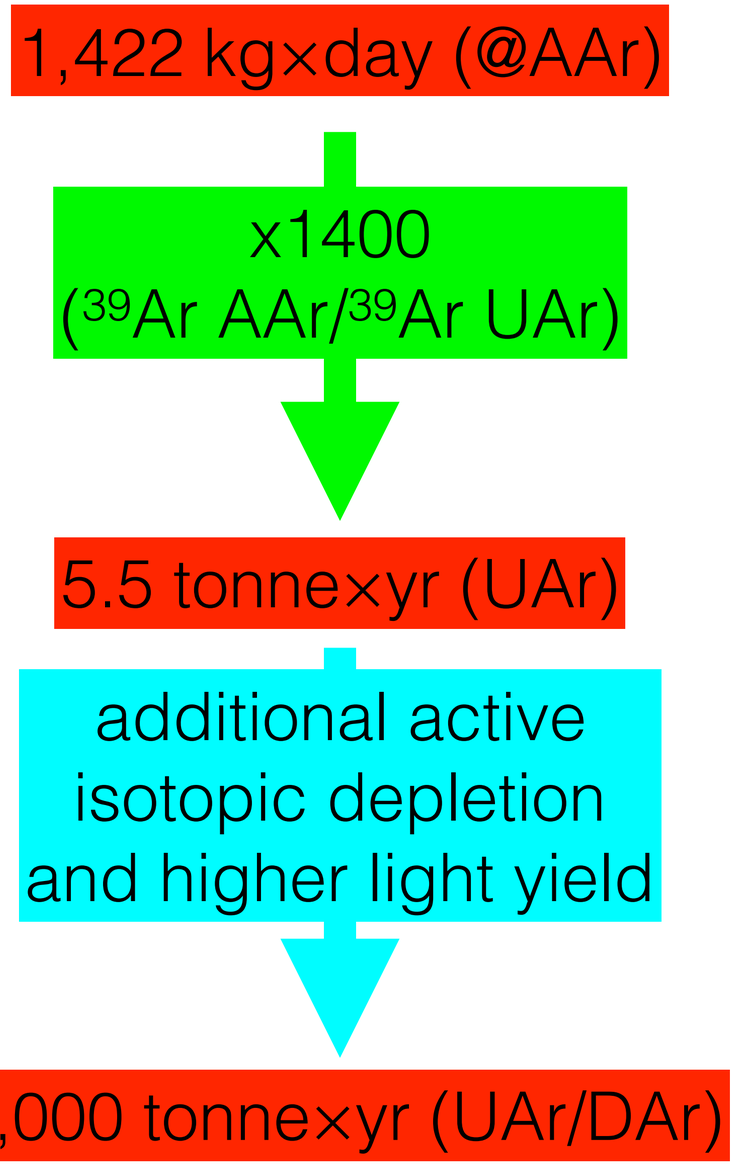
Scatters of *pp* solar neutrinos on electrons

Radioactive noble gases (^{39}Ar)

Elastic Scatters of *pp* Solar Neutrinos on Electrons

- 200 events/tonne×yr in ROI
- 200,000 background events @neutrino floor
- Defeated in argon thanks to β/γ rejection better than $1 \div 1.6 \times 10^{7}$

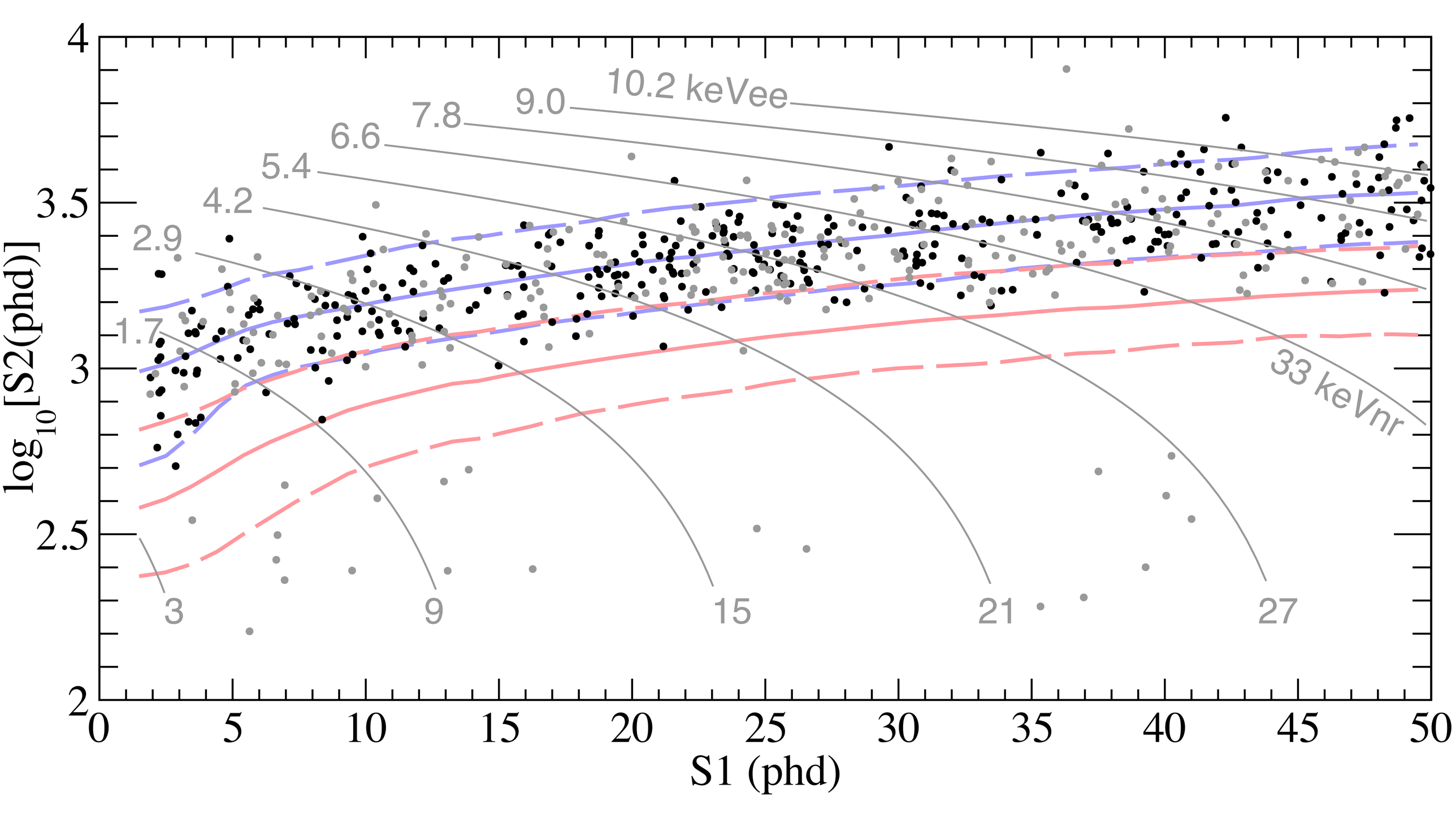
^{39}Ar Rejection

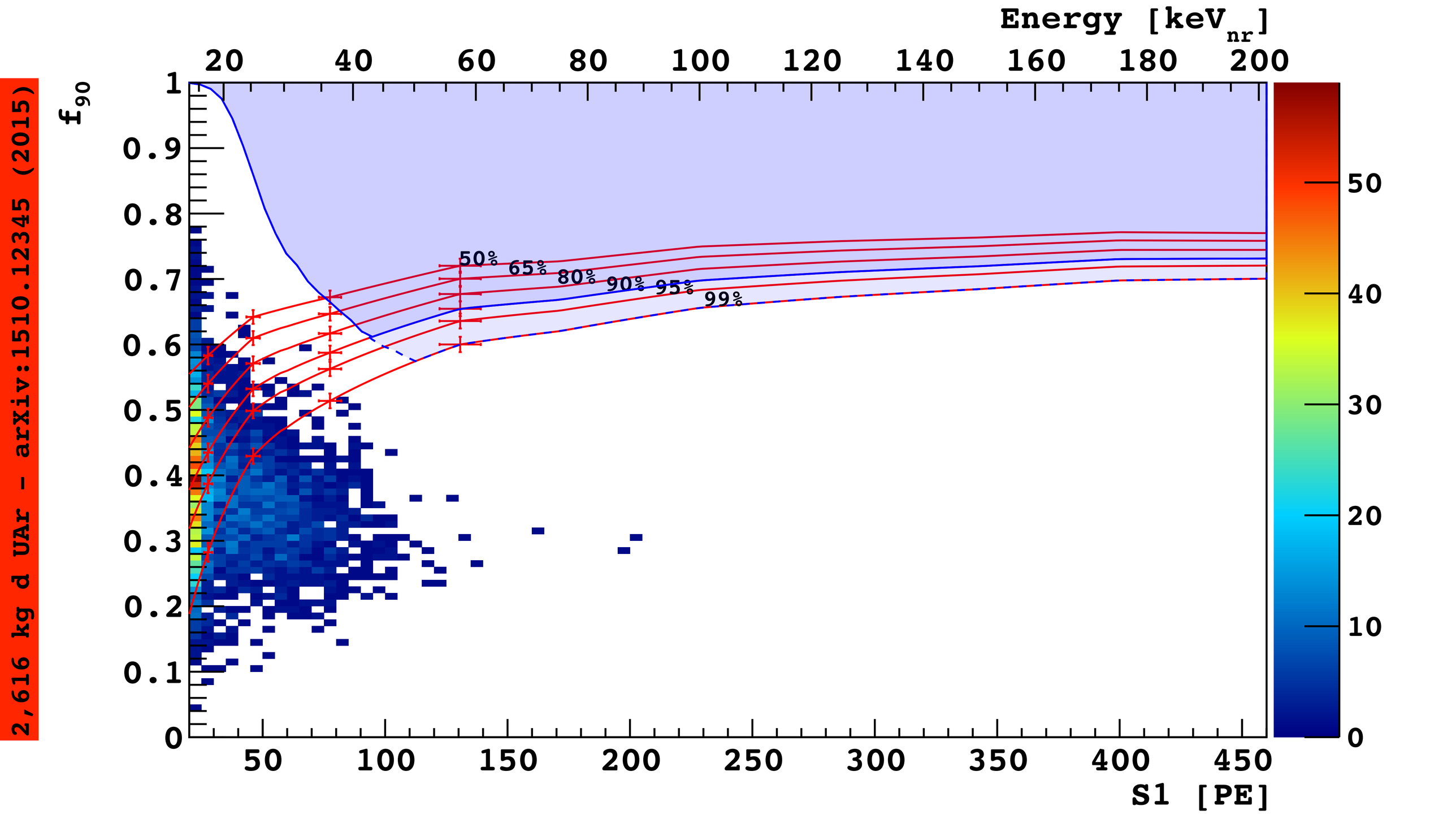


Based on what we know today, can a depleted argon experiment be background free at the scale of 1000 tonnes×yr?

Yes

Based on what we know today, can a xenon experiment be background free at the scale of 1000 tonnes×yr?


10.2 keVee
9.0
7.8
6.6
5.4
4.2
2.9
1.7
33 keVnr
3
9
15
21
27
log10[S2(phd)]
S1 (phd)
4
3.5
3
2.5
2
0
5
10
15
20
25
30
35
40
45
50

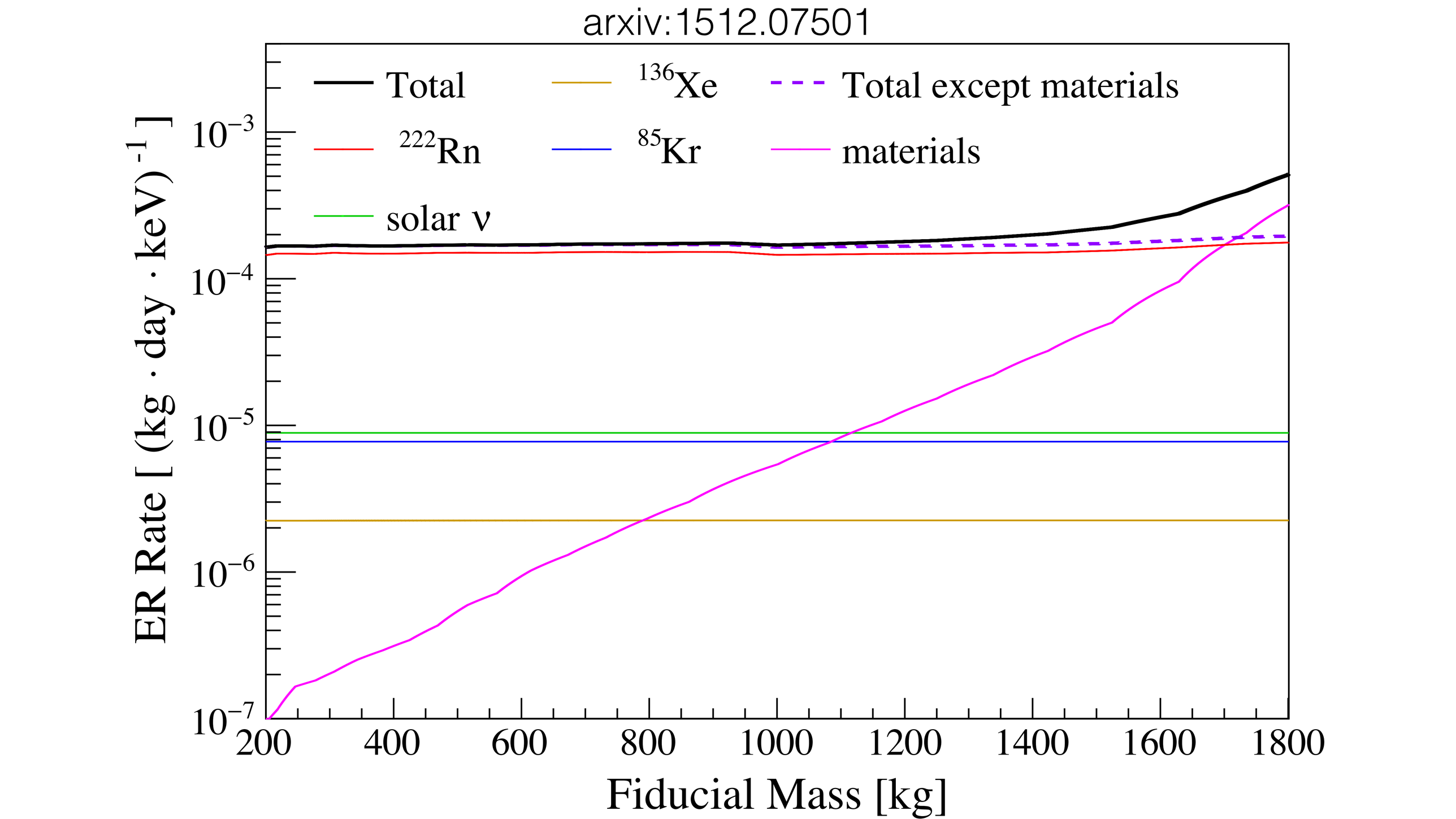

Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f$_{90}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
50
40
30
20
10
0
2,616 kg d UAr - arXiv:1510.12345 (2015)

arxiv:1512.07501

Abstract. The XENON1T experiment is currently in the commissioning phase at the Laboratori Nazionali del Gran Sasso, Italy. In this article we study the experiment's expected sensitivity to the spin-independent WIMP-nucleon interaction cross section, based on Monte Carlo predictions of the electronic and nuclear recoil backgrounds.

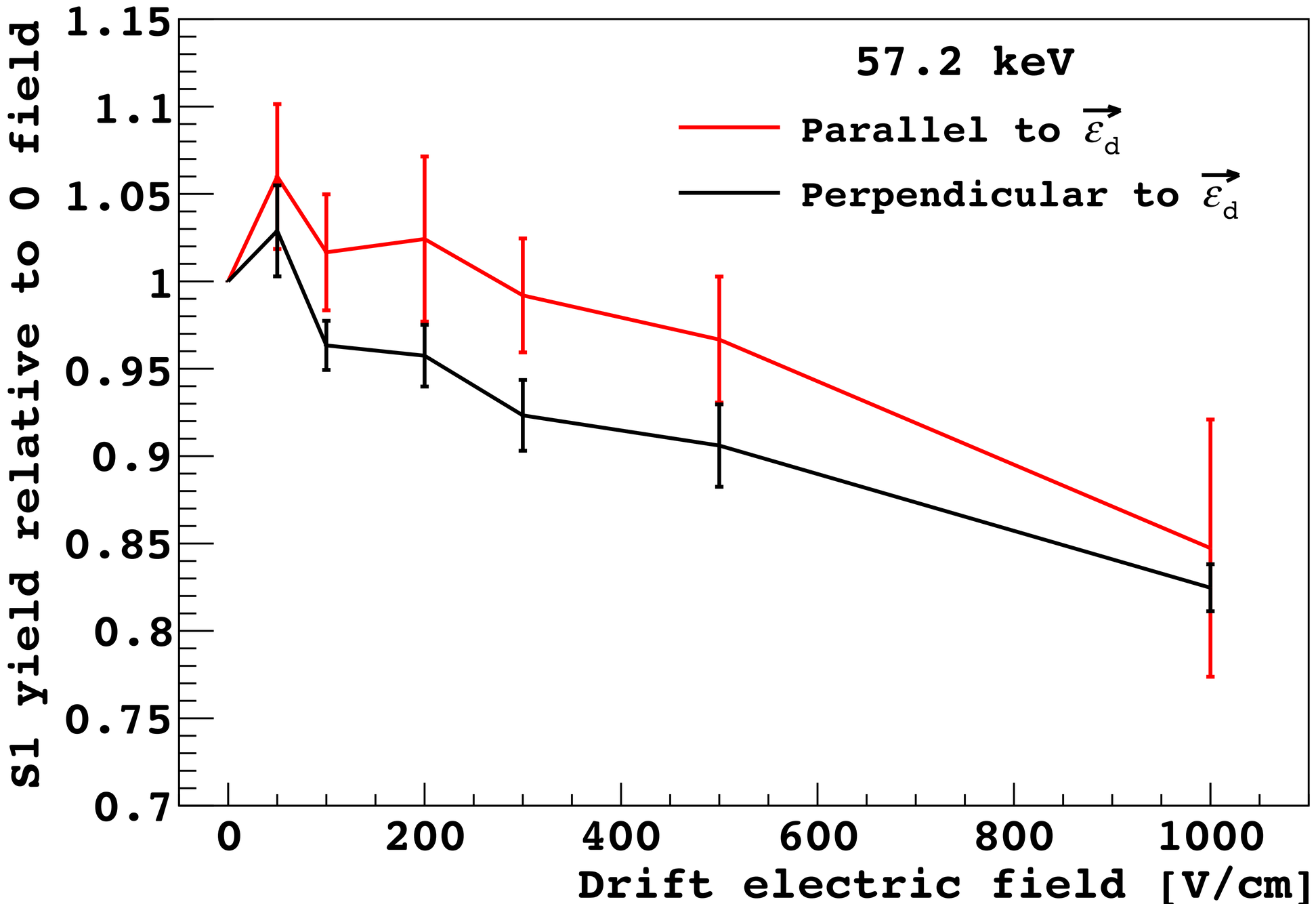
The total electronic recoil background in 1 tonne fiducial volume and (1, 12) keV electronic recoil equivalent energy region, before applying any selection to discriminate between electronic and nuclear recoils, is $(1.80 \pm 0.15) \cdot 10^{-4}$ $(\mathrm{kg \cdot day \cdot keV})^{-1}$ mainly due to the decay of ^{222}Rn daughters inside the xenon target. The nuclear recoil background in the corresponding nuclear recoil equivalent energy region (4, 50) keV, is composed of (0.6 ± 0.1) $(\mathrm{t \cdot y})^{-1}$ from radiogenic neutrons, $(1.8 \pm 0.3) \cdot 10^{-2}$ $(\mathrm{t \cdot y})^{-1}$ from coherent scattering of neutrinos, and less than 0.01 $(\mathrm{t \cdot y})^{-1}$ from muon-induced neutrons.

The sensitivity of XENON1T is calculated with the Profile Likelihood Ratio method, after converting the deposited energy of electronic and nuclear recoils into the scintillation and ionization signals seen in the detector. We take into account the systematic uncertainties on the photon and electron emission model, and on the estimation of the backgrounds, treated as nuisance parameters. The main contribution comes from the relative scintillation efficiency $\mathcal{L}_{\mathrm{eff}}$, which affects both the signal from WIMPs and the nuclear recoil backgrounds. After a 2 y measurement in 1 t fiducial volume, the sensitivity reaches a minimum cross section of $1.6 \cdot 10^{-47}$ cm^2 at m_χ=50 GeV/c^2.


arxiv:1512.07501
Total
^{136}Xe
Total except materials
^{222}Rn
^{85}Kr
materials
solar ν
ER Rate [(kg · day · keV)$^{-1}$]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
200
400
600
800
1000
1200
1400
1600
1800
Fiducial Mass [kg]

Strategic Issues

- INFN leadership on a flagship program at LNGS participated by over forty institutions
- Strong cooperation with Sardegna and Abruzzo on key associated programs
  - Aria, Urania, SiPM, EBW
- PNNL strategic partnership with LNGS on low background
- 1-ton technical prototype @CERN


57.2 keV
Parallel to $\vec{\varepsilon}_d$
Perpendicular to $\vec{\varepsilon}_d$
S1 yield relative to 0 field
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0
200
400
600
800
1000
Drift electric field [V/cm]

Impact of Basic Research on Industry

Air Products and Helium: A Success Story

- Based on research for underground argon funded by US NSF, the discovery of a sustained fraction of helium in the Kinder Morgan CO_2 stream
- An investment by Air Products resulted in the most modern helium extraction plant
- Production started in June 2015 accounts for 15% of the total production by the US govt at the National Helium Reservoir

Cryogenic Distillation Column at Fermilab

Goals of Future Program

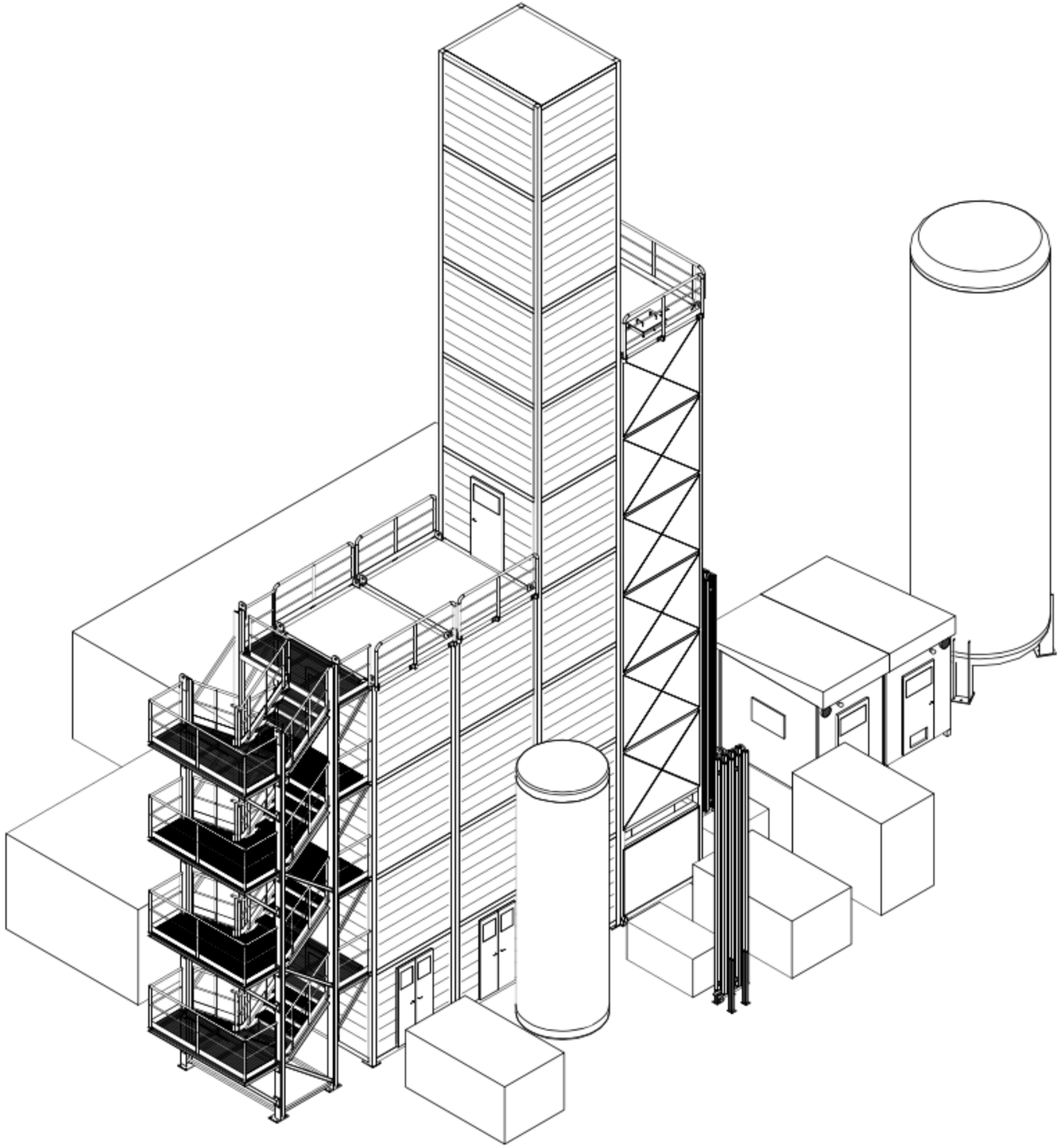
- Procurement of 30 tonnes by 2020 in support of DarkSide-20k
  - 100 tonne×yr background free exposure for dark matter
- Procurement of 300 tonnes by 2030 in support of Argo
  - 1000 tonne×yr background free exposure for dark matter
  - Precision solar neutrino measurements
- Possible procurement of larger quantities … maybe to enable solar and supernova relic neutrino physics in DUNE?

Urania

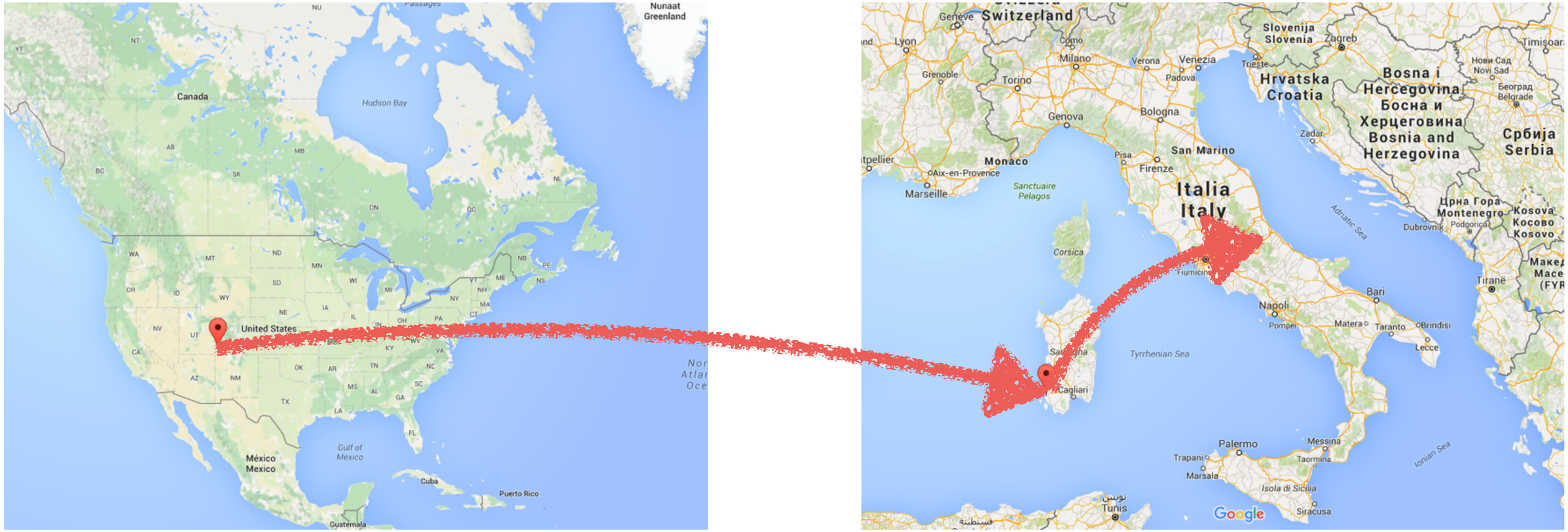
- The goal is to build a plant capable of extracting UAr at a rate of about 100 kg/d from the Cortez, CO source
- Cooperation with Air Products and utilization of a premium stream from their He extraction plant may result in a significant boost of production with the same plant

Argon Purification Unit

- A set of elemental process units:
  - The first cryogenic column removes the bulk of CO2 and CH_4
  - The Pressure Swing Adsorption columns removes the traces of CO2 and CH_4
  - The second cryogenic column removes N_2 and He
  - The third cryogenic column refines the argon-rich stream detector-grade argon



Urania to Aria to LNGS



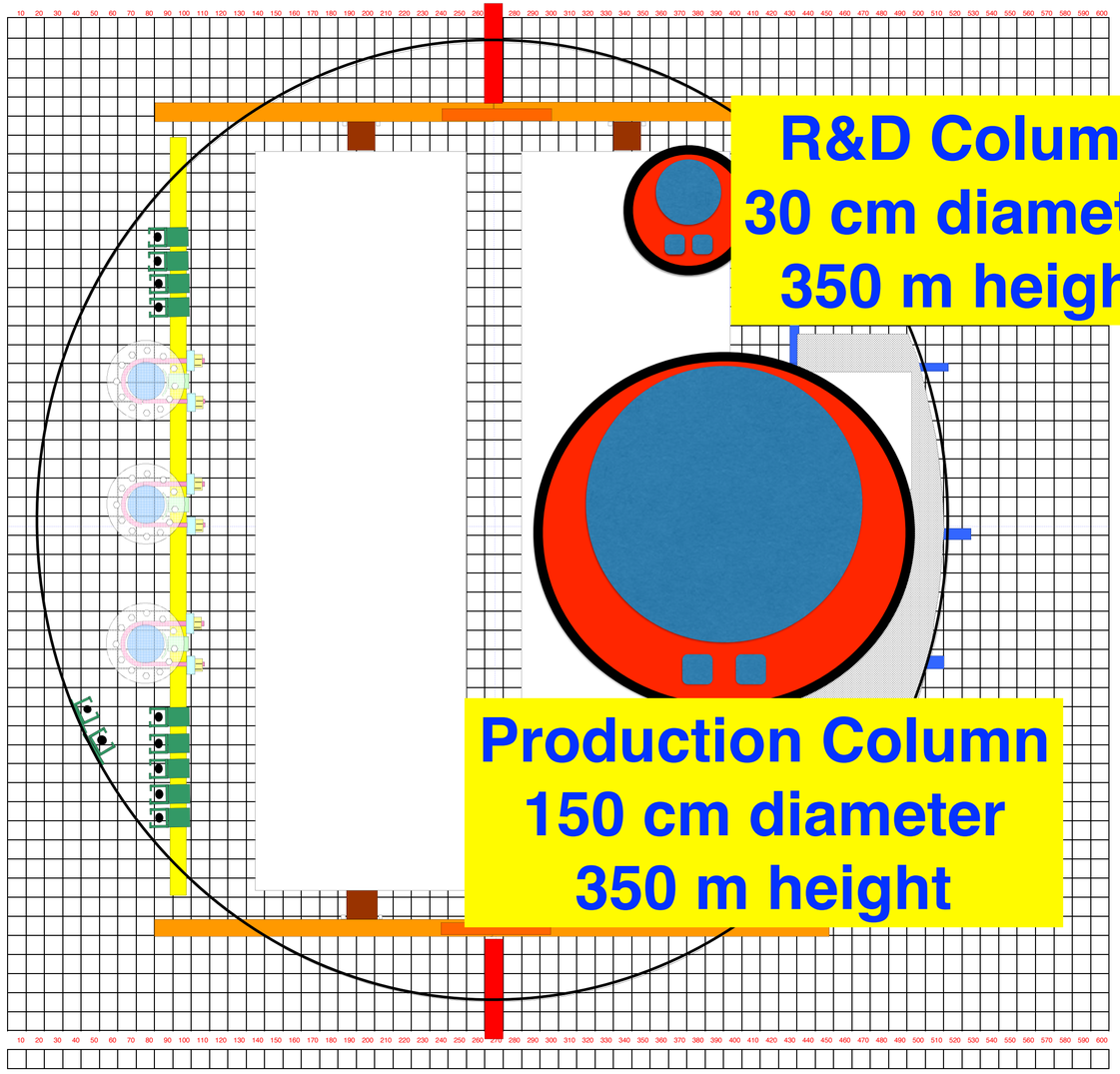
Aria

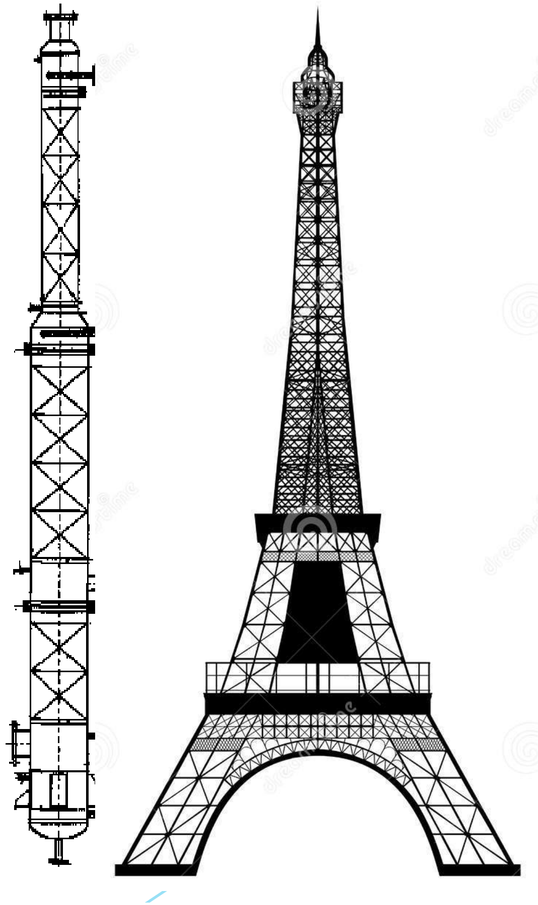
- The purpose of Aria is the reduction of ^{39}Ar in the target of the DarkSide detectors
- The method of isotopic separation is cryogenic distillation
- The project is supported by INFN, US NSF, and Regione Autonoma della Sardegna

Seruci Wells

Seruci in Sardinia an excellent location

A Very Tall Column



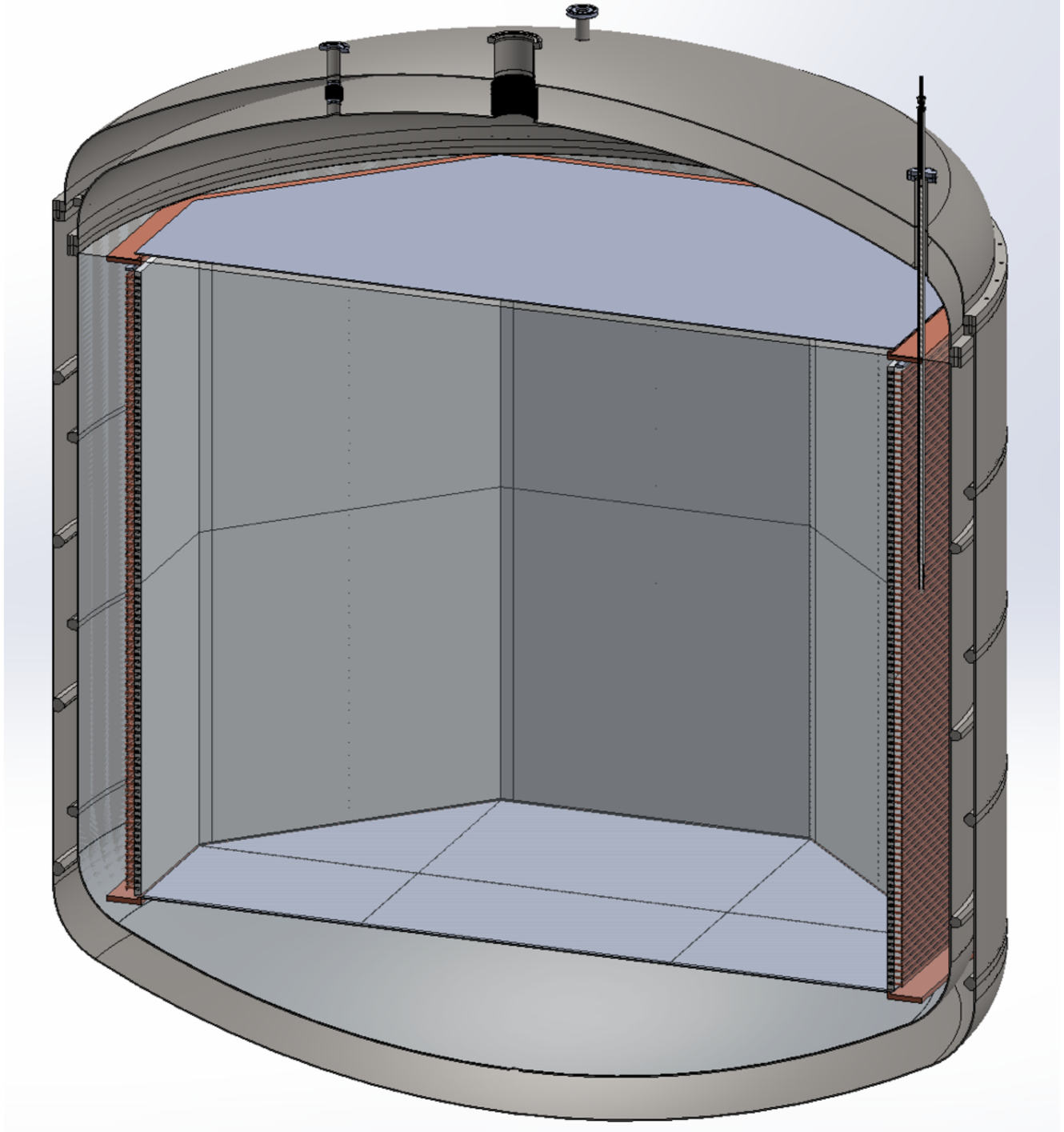


DarkSide-20k

20-tonnes fiducial dark matter detector
start of operations at LNGS within 2020
100 tonne×year background-free search for dark matter

Argo

300-tonnes depleted argon detector
start of operations at LNGS within 2025
1,000 tonne×year background-free search for dark matter
precision measurement of solar neutrinos



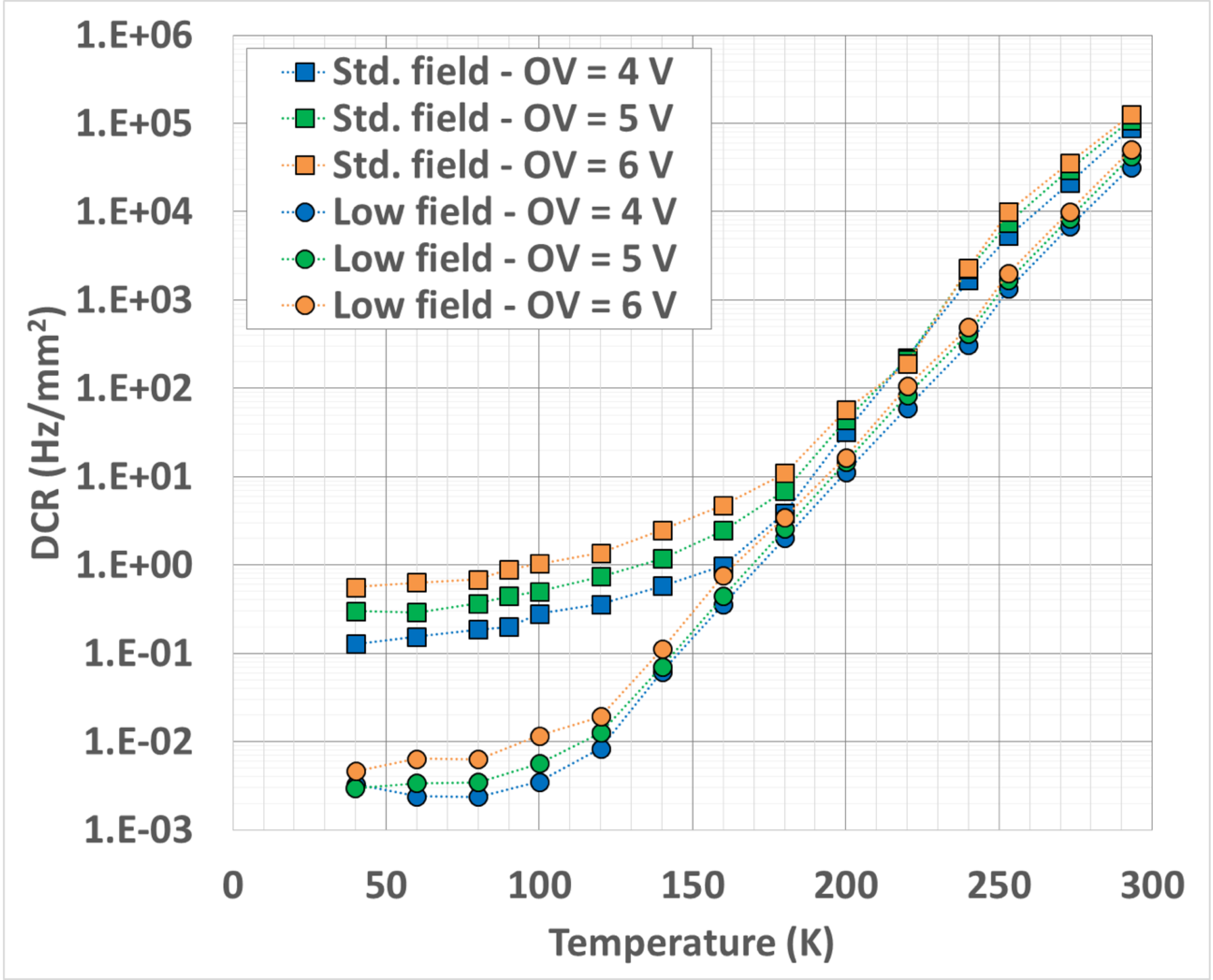
Photosensors for LAr Detectors

Trento Institute for
Fundamental Physics
and Applications

- A new program of FBK/TIFPA and LFoundry under the guidance of INFN and Princeton: complete replacement of Hamamatsu cryogenic PMTs
  - Much lower radioactivity
  - Light yield increase by 50%
  - Greater stability
  - Ten-fold reduction of costs per unit area vs. R11065-xx
  - Capability of large-scale production at LFoundry

SiPM Requirements

- PDE larger than 40% at 420 nm, signicant improvement over the 34% QE of the photocathode of the Hamamatsu R11065 PMTs used in DarkSide-50
- Dark count rate (DCR) lower than 1 Hz/mm^2, as higher rates would impact both the trigger efficiency and the pulse shape discrimination power
- Total correlated noise probability (TCNP) (crosstalk + afterpulsing) lower than 40%
- Inactive gap between devices smaller than 200 μm to maximize the tiling efficiency
- Photo-electron gain larger than 1M and a signal duration of less than 300 ns
- Overall surface 14 m^2


Std. field - OV = 4 V
Std. field - OV = 5 V
Std. field - OV = 6 V
Low field - OV = 4 V
Low field - OV = 5 V
Low field - OV = 6 V
DCR (Hz/mm²)
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
0
50
100
150
200
250
300
Temperature (K)

The End