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

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Princeton University
APC Paris Diderot
GDR Neutrinos
LPSC Grenoble
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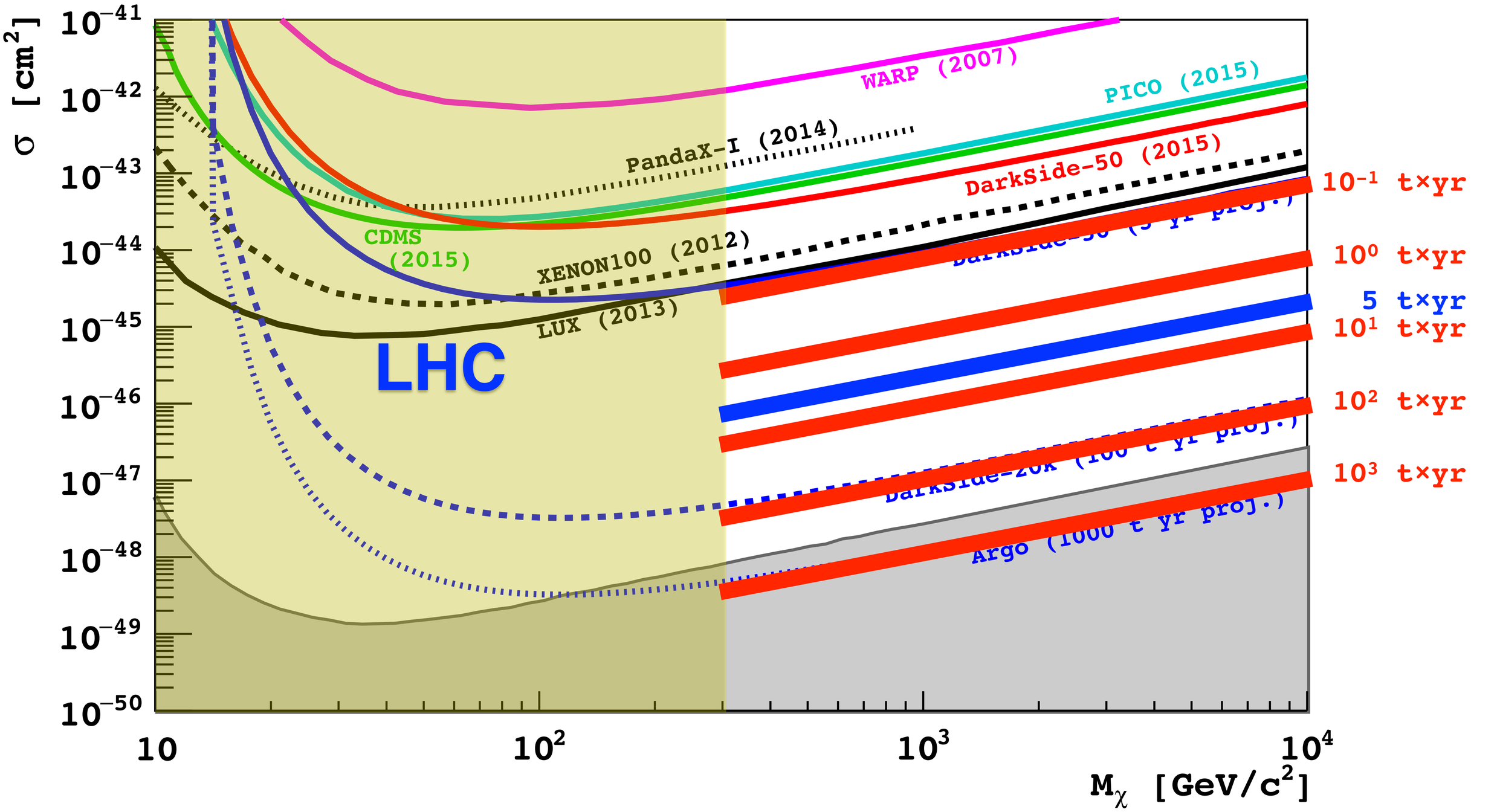
DarkSide-20k Institutions


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)
PandaX-I (2014)
DarkSide-50 (2015)
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.)

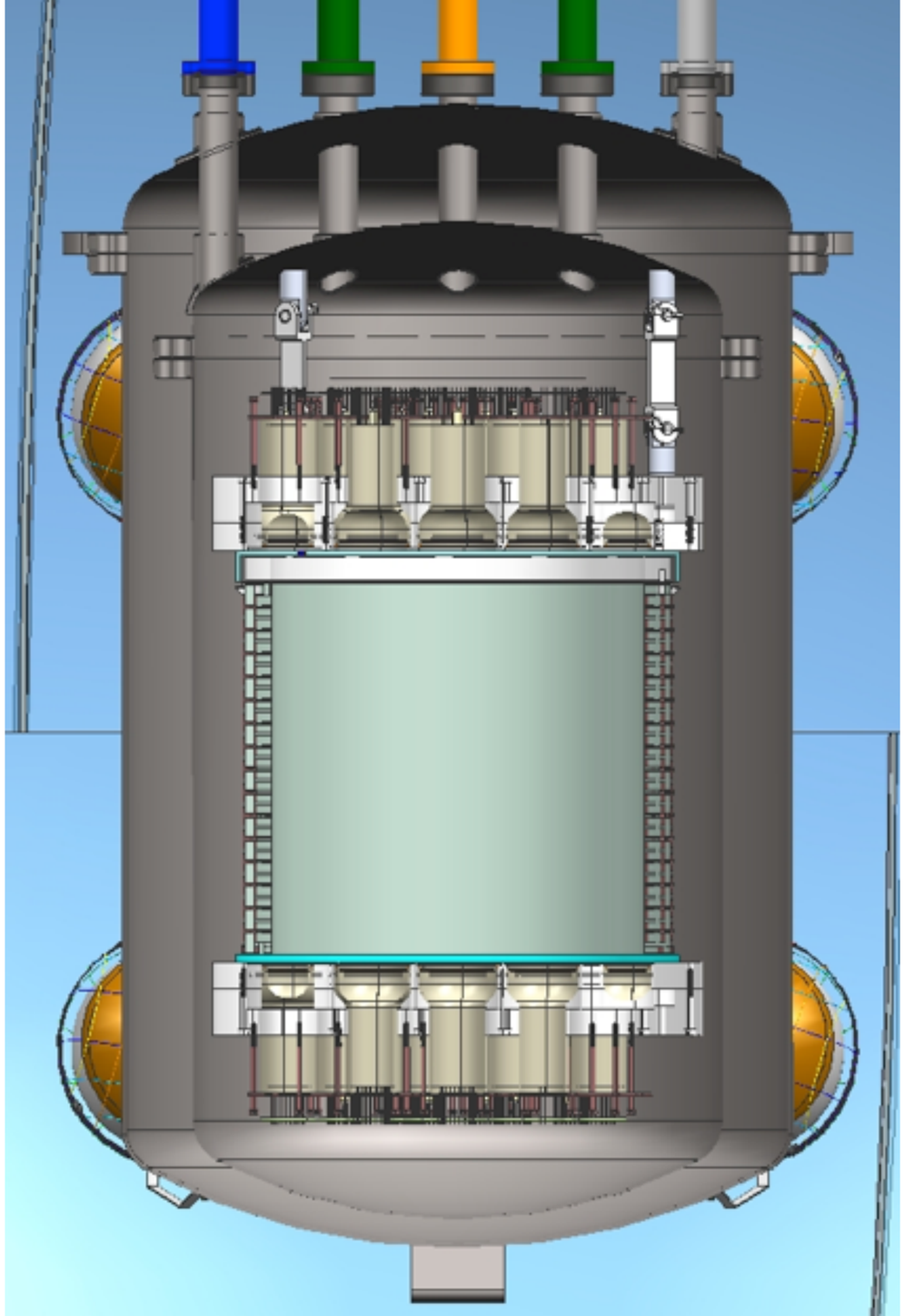
An Ambitious Discovery Program

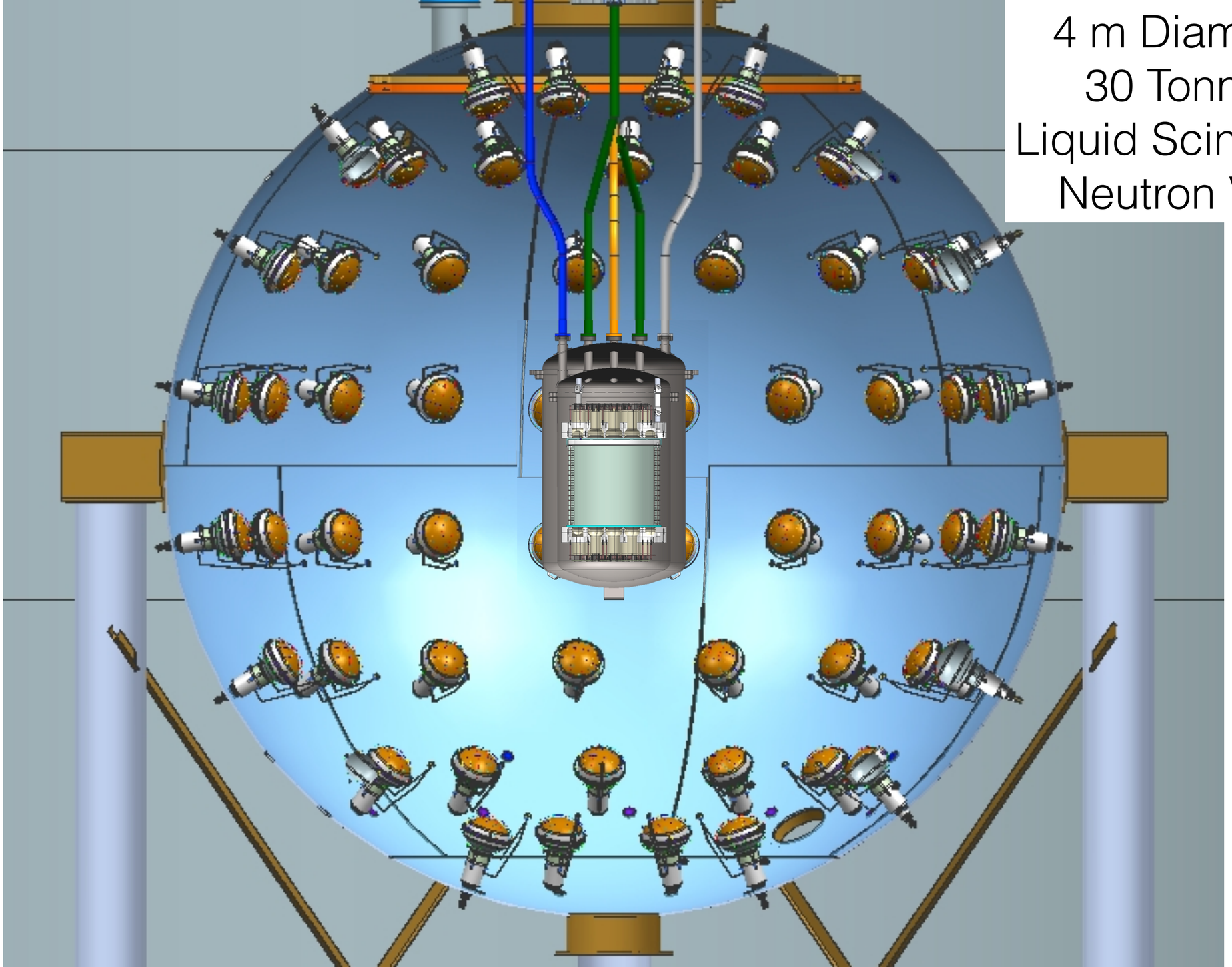
- Raising the bar: 0.1 ton×yr ⇒ 1000 ton×yr
- Complementary to LHC and raising its energy scale:
  - 500 GeV ⇒ 1 TeV ⇒ 10 TeV ⇒ …
- “Zero Background” absolutely necessary for a discovery program
- Strong investment in ^{40}Ar by INFN, NSF, and Fermilab
- Ambitious program for discovery of heavy dark 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
  - The first dark matter detector operating with isotopically enhanced target
  - Dark matter search operating in background-free mode

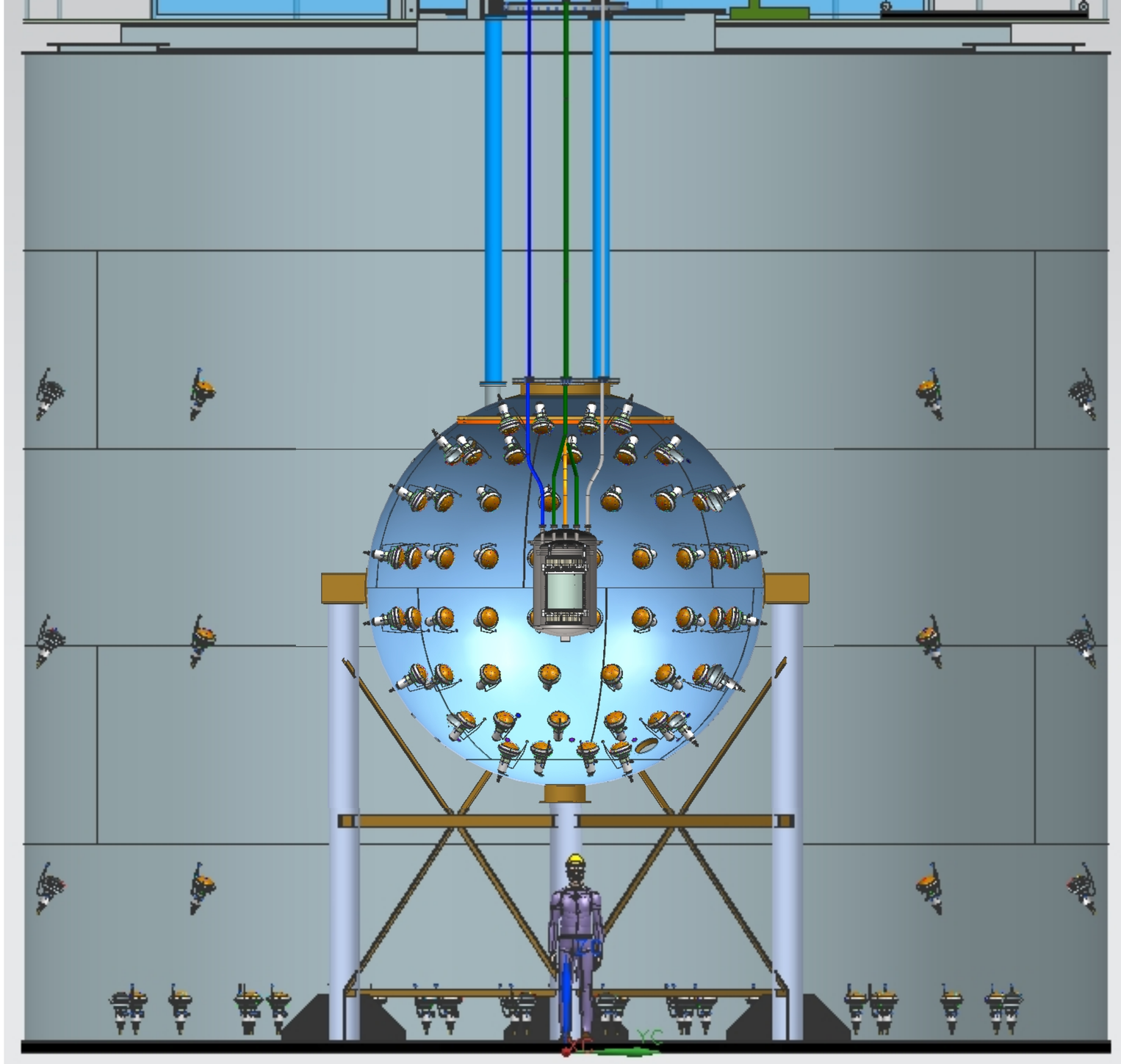
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target





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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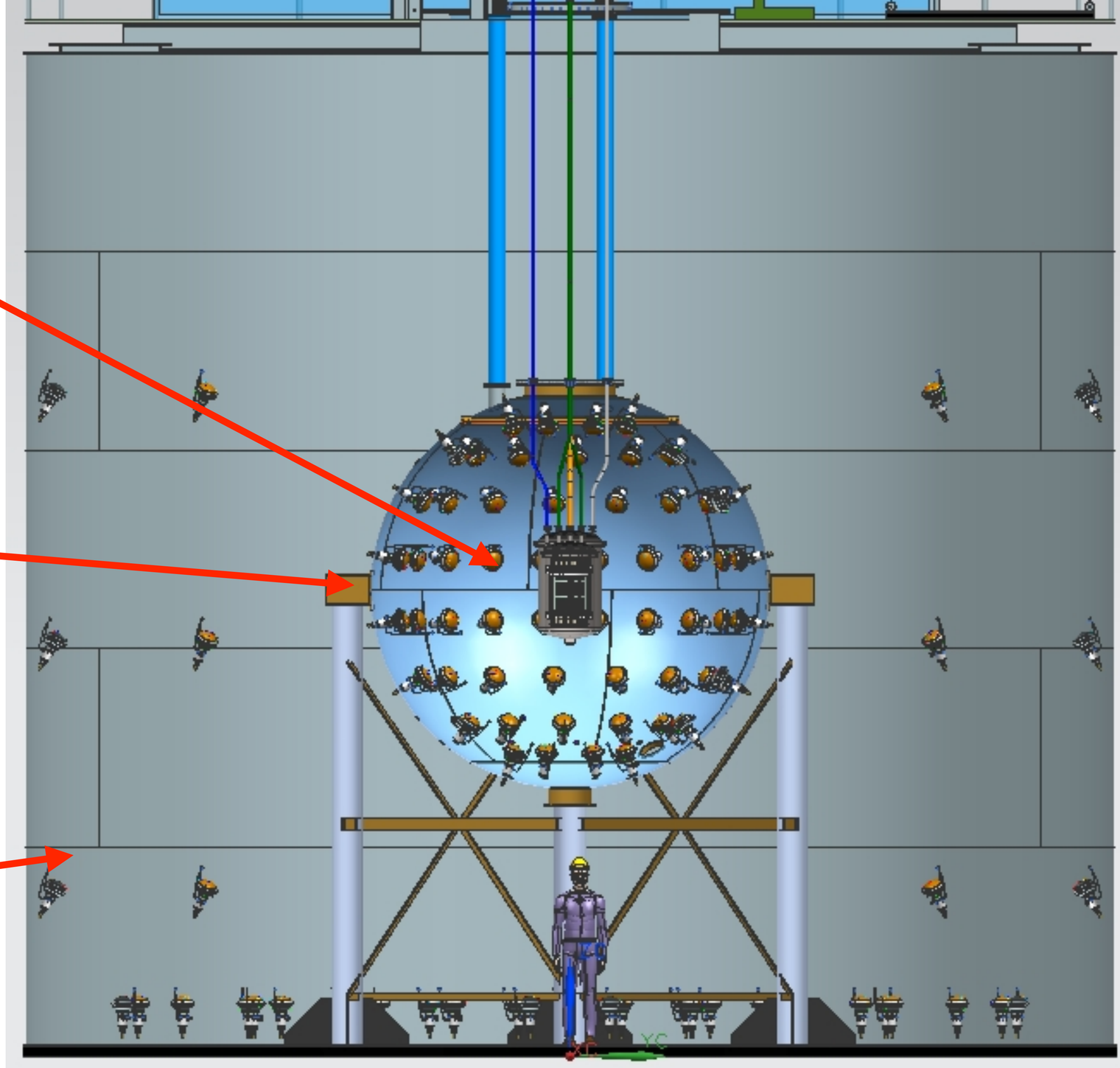
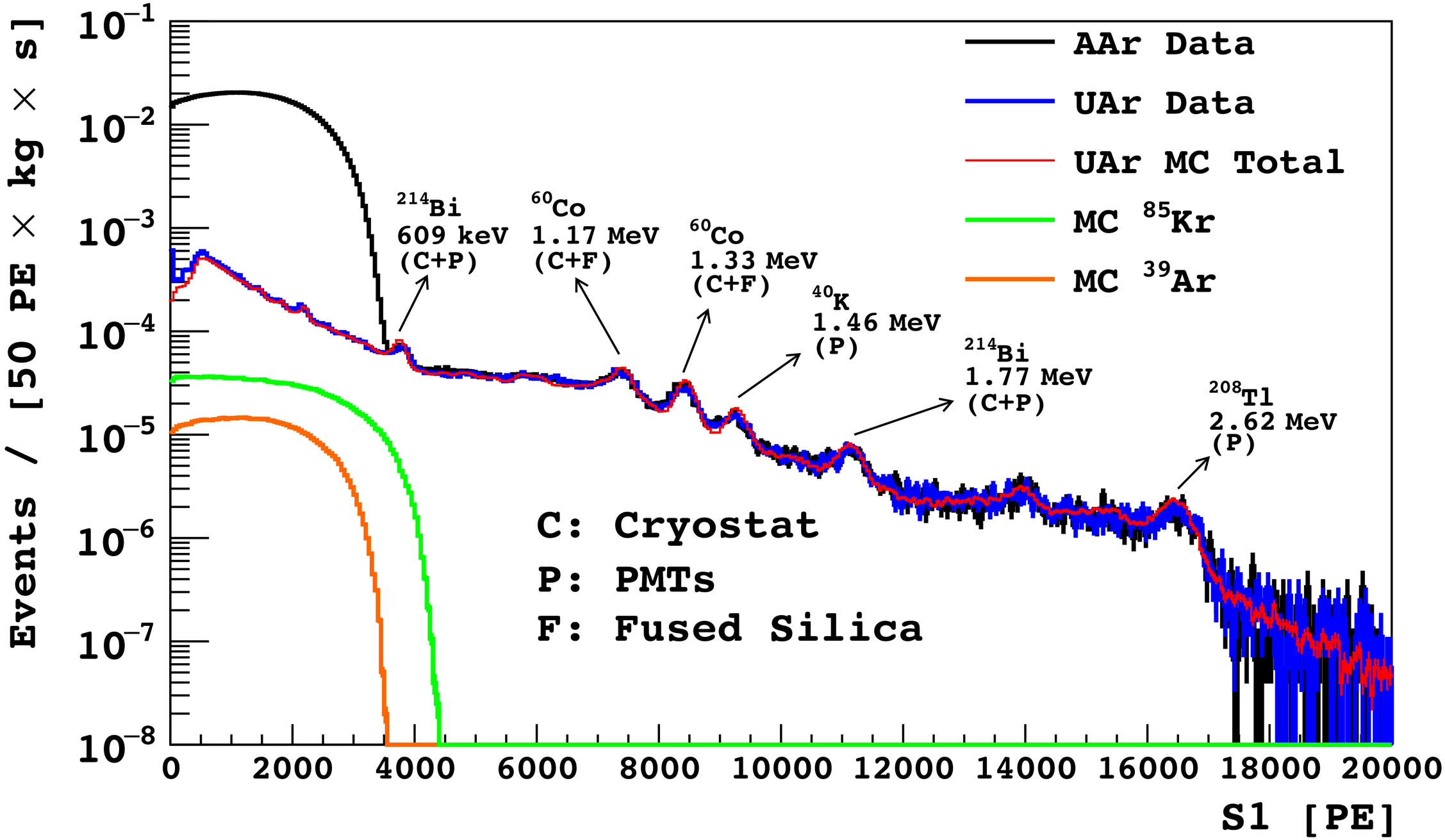
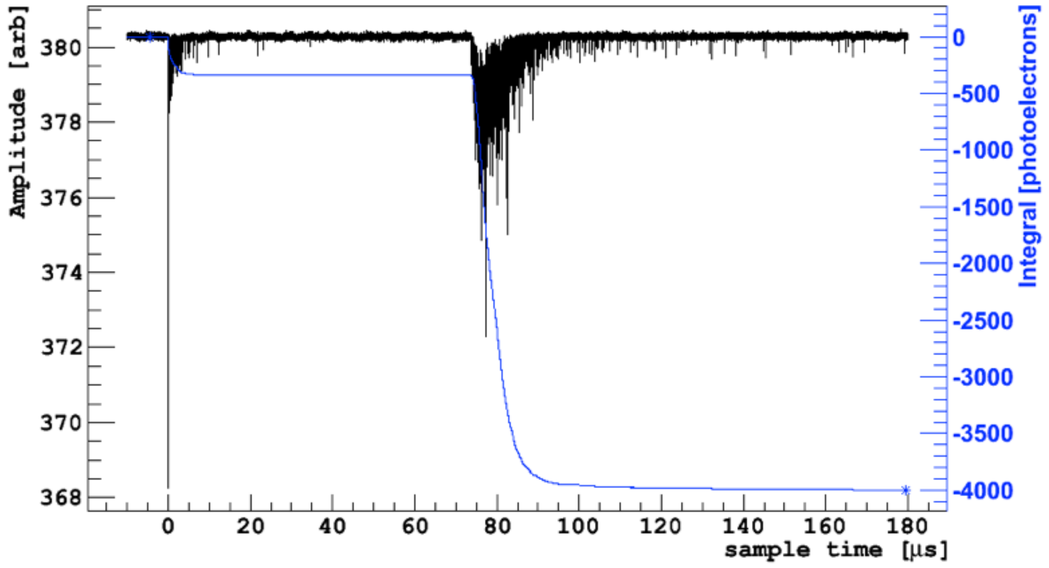


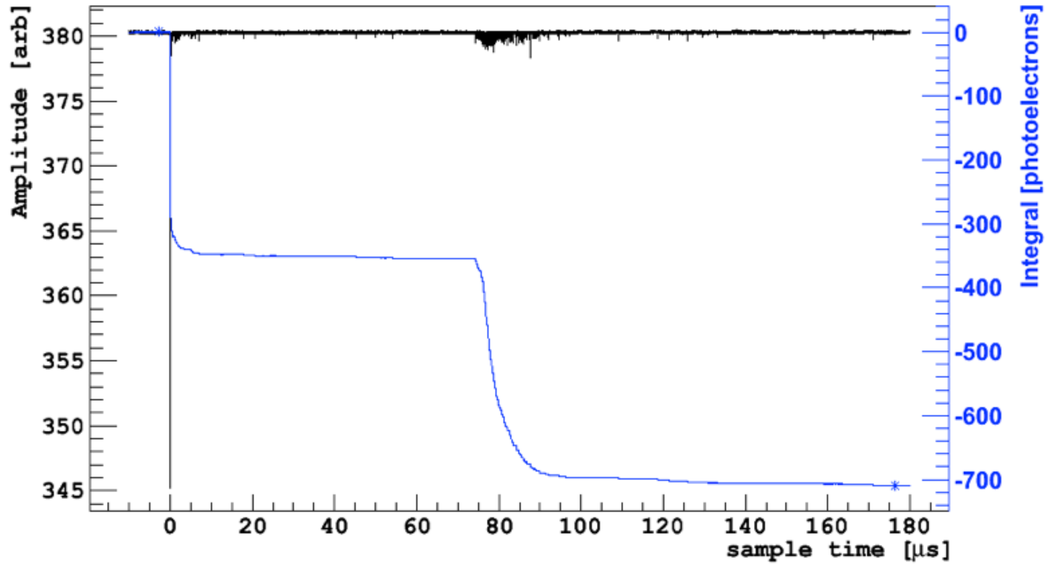
DarkSide-50 Milestones

- 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

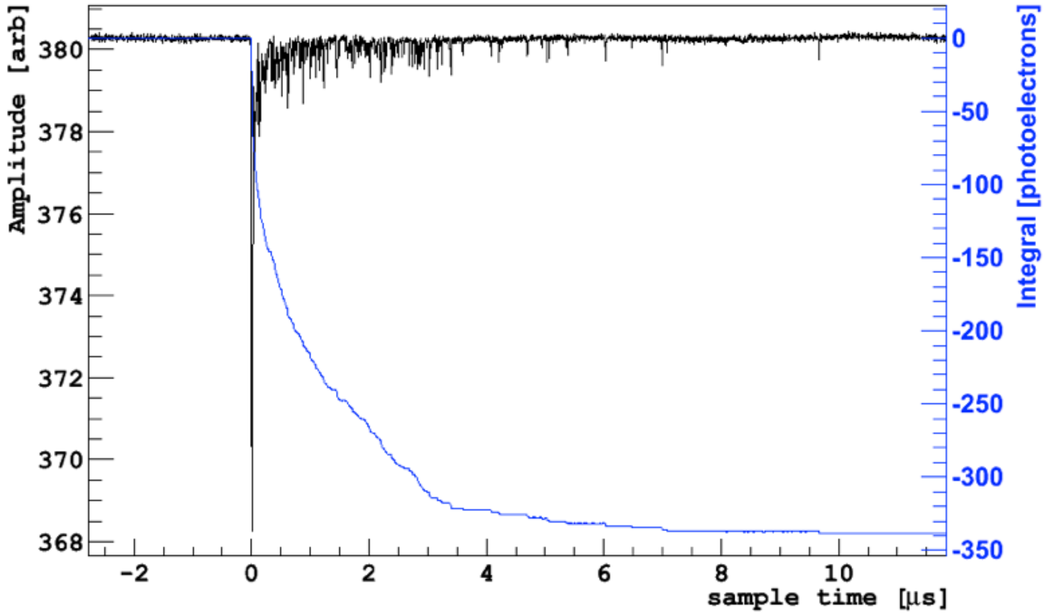

AAr Data
UAr Data
UAr MC Total
MC ^{85}Kr
MC ^{39}Ar
^{214}Bi
609 keV
(C+P)
^{60}Co
1.17 MeV
(C+F)
^{60}Co
1.33 MeV
(C+F)
^{40}K
1.46 MeV
(P)
^{214}Bi
1.77 MeV
(C+P)
^{208}Tl
2.62 MeV
(P)
C: Cryostat
P: PMTs
F: Fused Silica
Events / [50 PE × kg × s]
S1 [PE]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}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

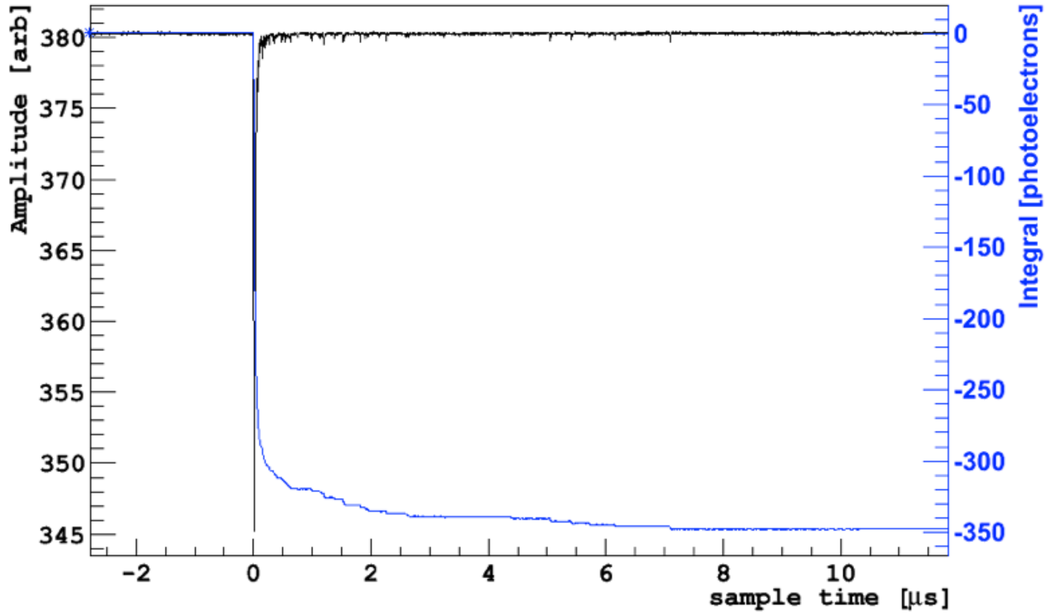


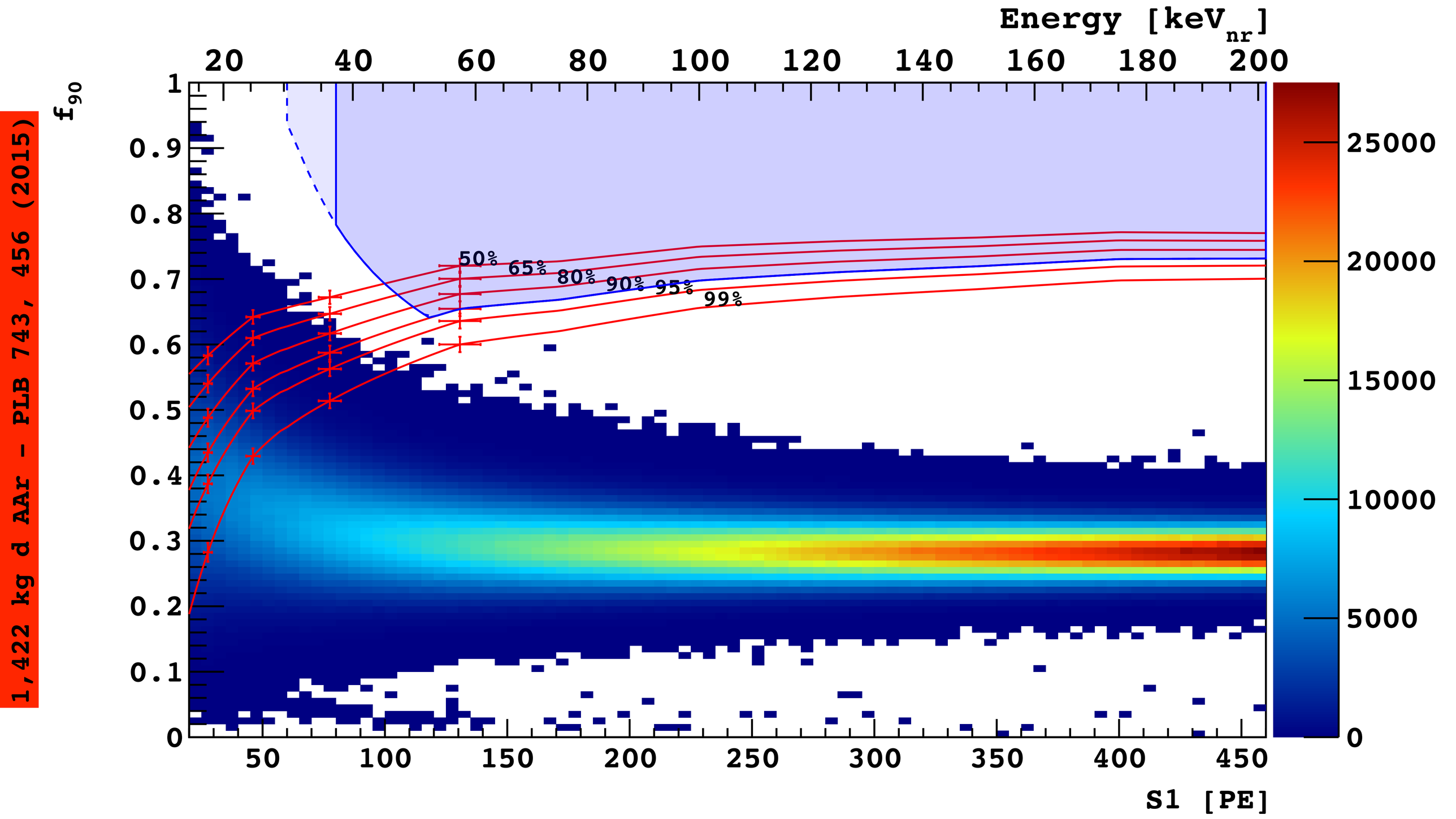
β/γ

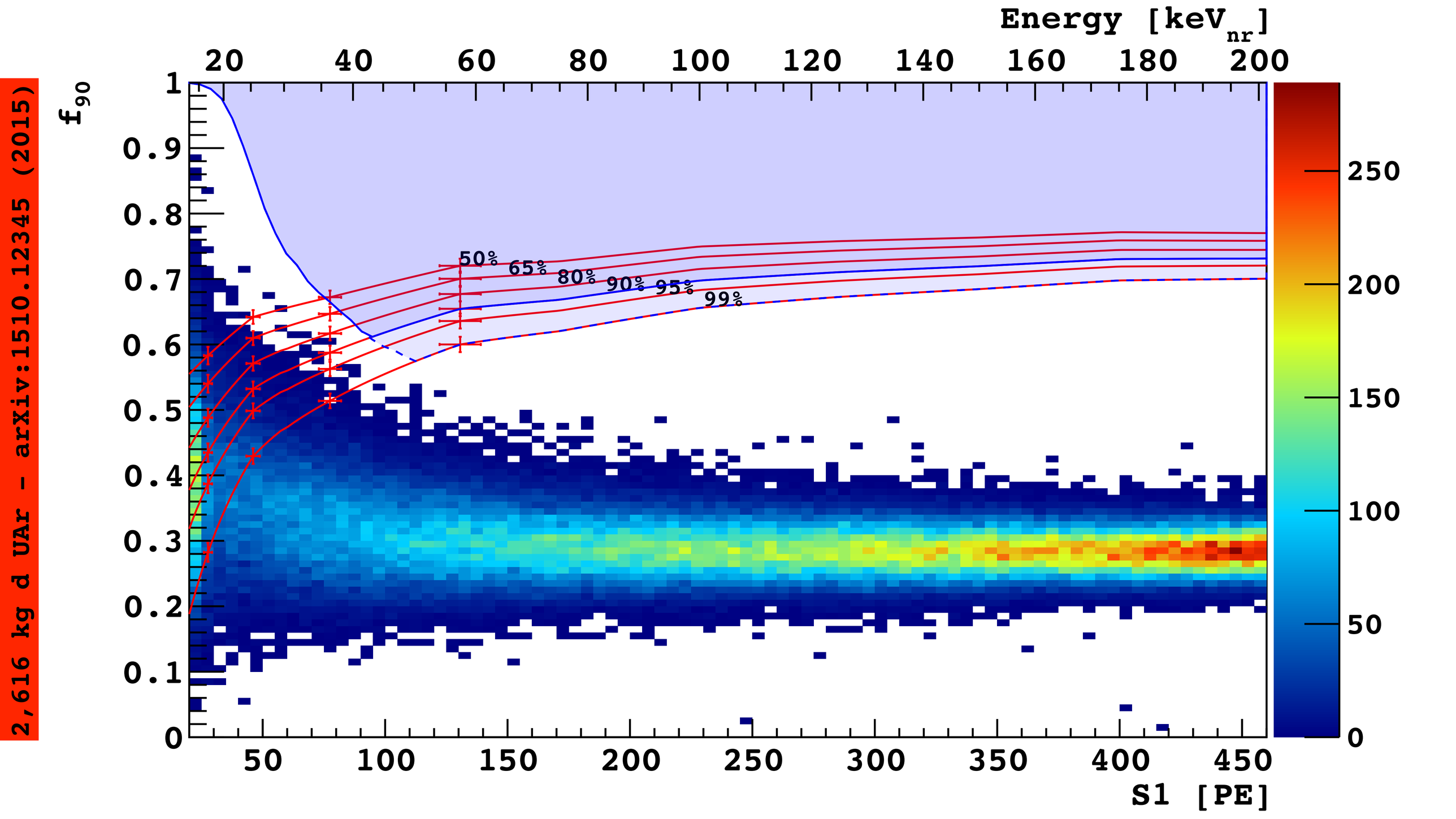


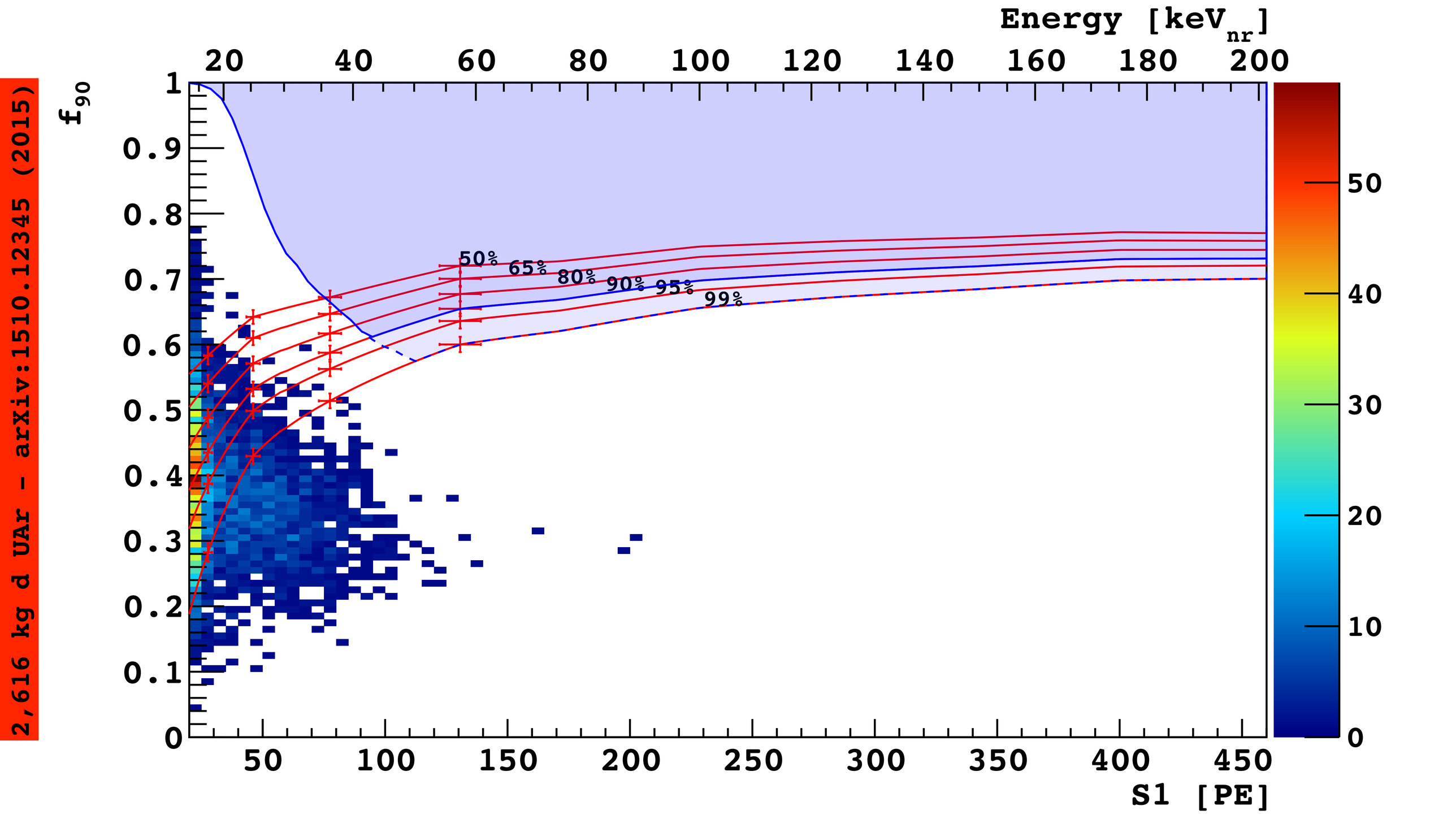
nuclear recoils






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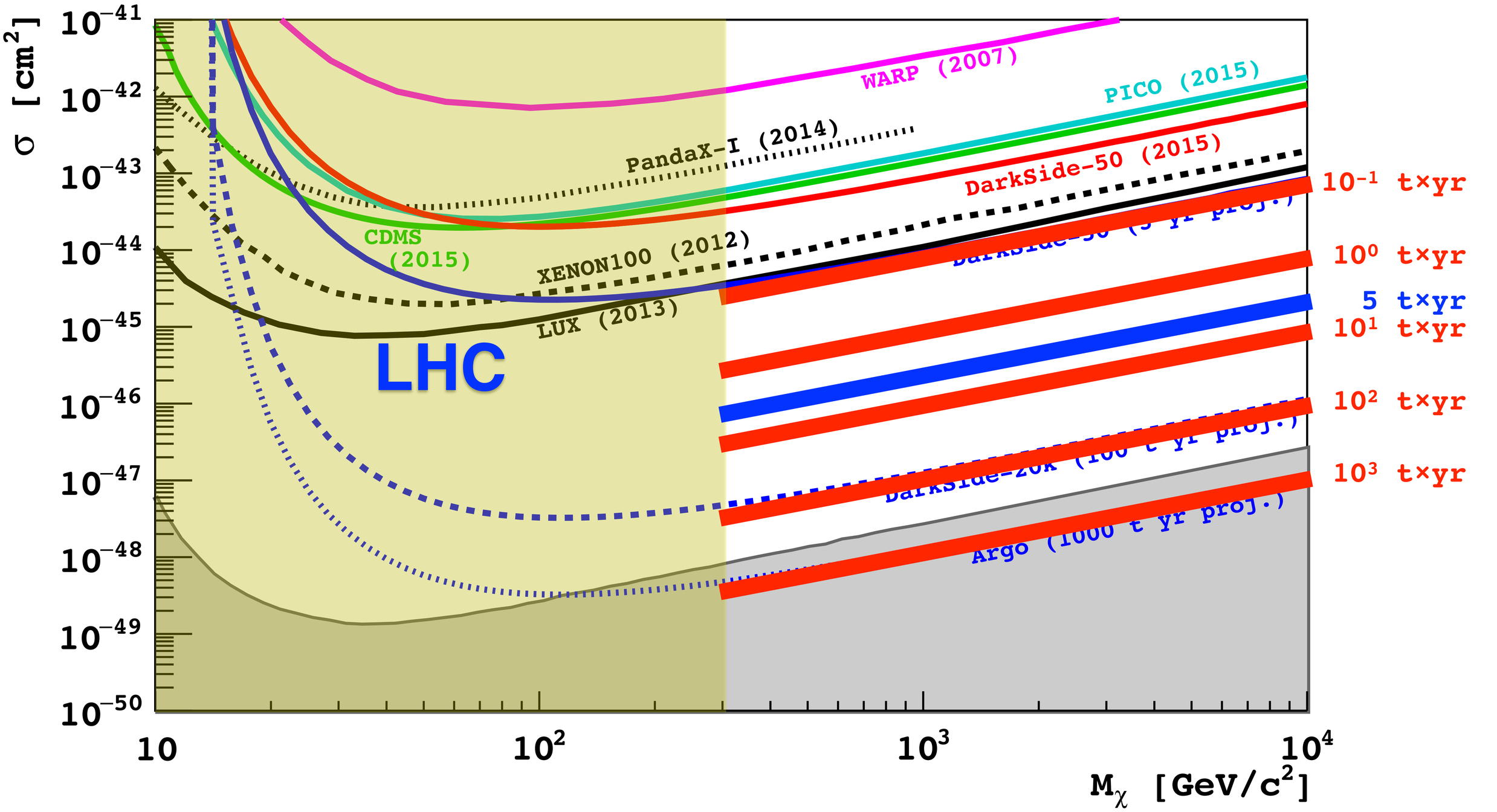
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
50
100
150
200
250
300
350
400
450
S1 [PE]
50
40
30
20
10
0
2,616 kg d UAr - arXiv:1510.12345 (2015)

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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10⁻⁵⁰
10
10²
10³
10⁴
M_χ [GeV/c²]
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LHC
10⁻¹ t×yr
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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?

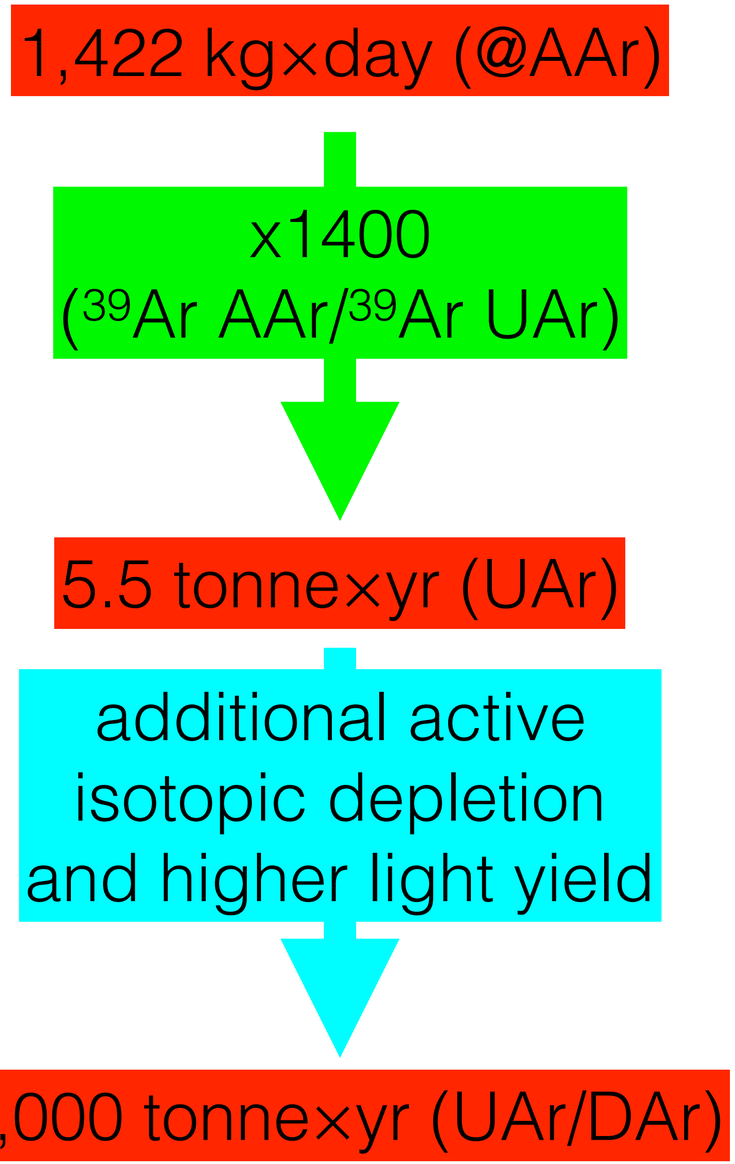
Scatters of *pp* solar neutrinos on electrons

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

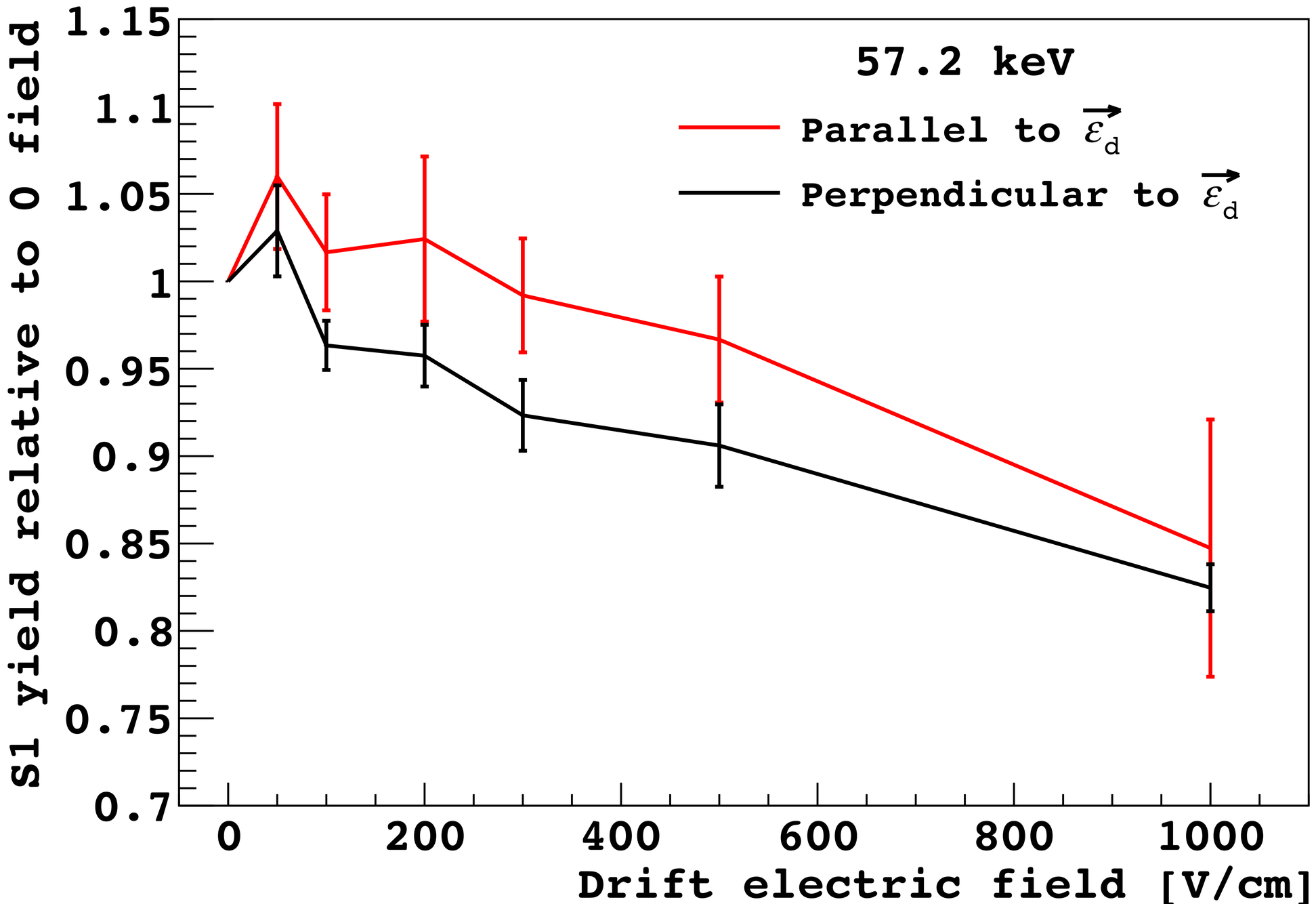


Based on what we know today, can a depleted argon experiment be background free at the scale of 1000 tonnes×yr?

Yes

Strategic Issues

- Strong cooperation with Sardegna and Abruzzo on key associated programs
  - Aria, Urania, SiPM, EBW
- 1-ton technical prototype proposed @CERN
- Exploring a possible directional effect


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

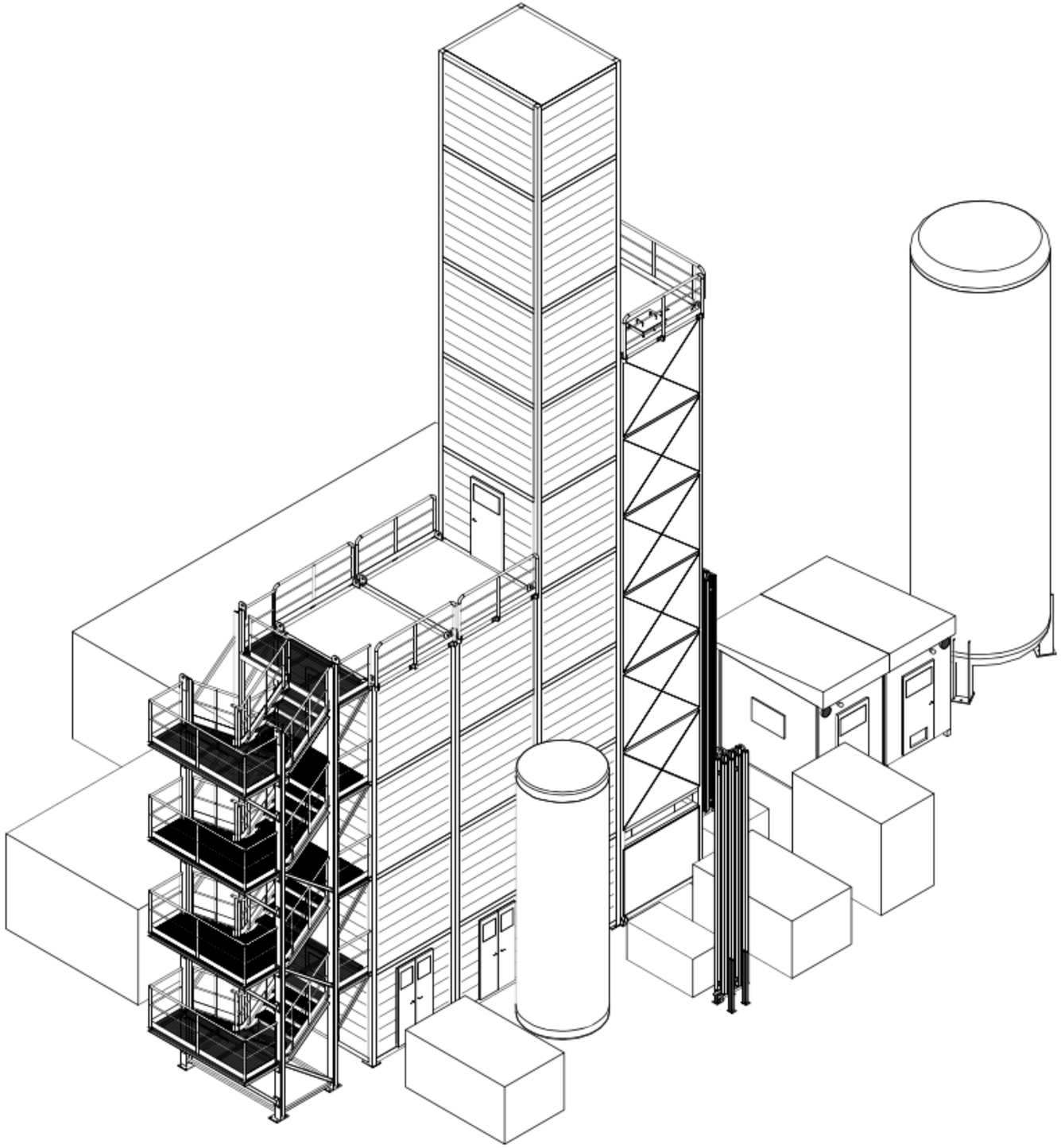
Cryogenic Distillation Column at Fermilab

Goals of Future Program

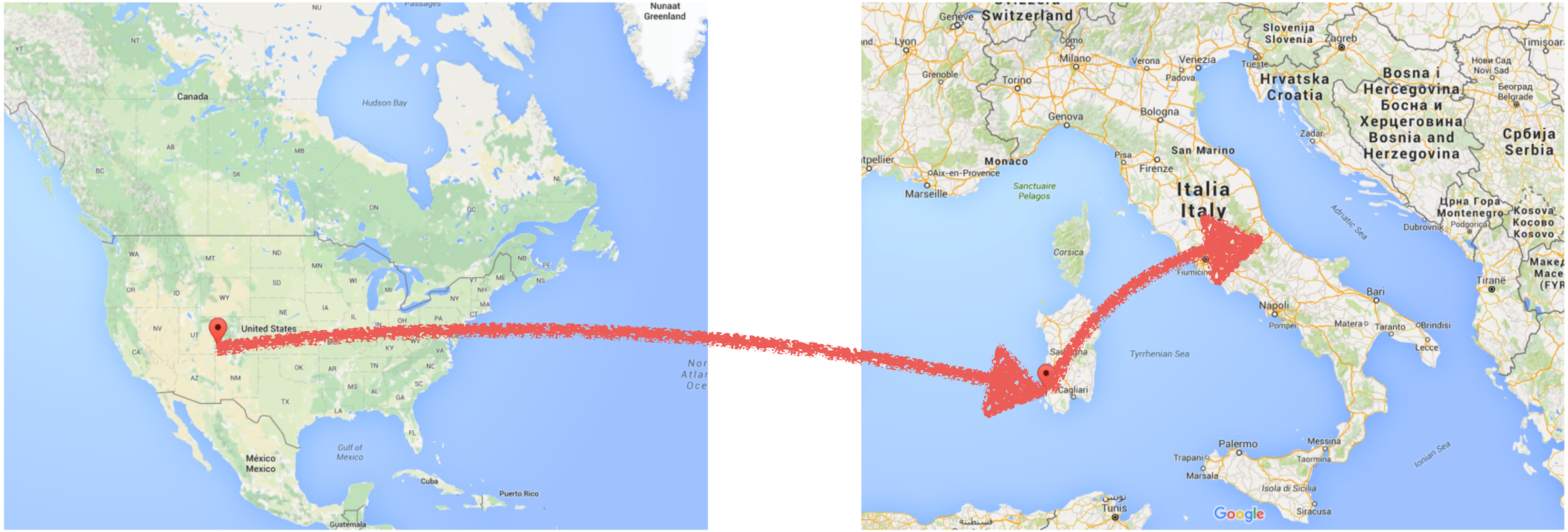
- Procurement of 30 tonnes by 2020 in support of DarkSide-20k
  - 100 tonne×yr background free exposure for dark matter
- Procurement of 300 tonnes by 2030 in support of Argo
  - 1000 tonne×yr background free exposure for dark matter
  - Precision solar neutrino measurements
- Possible procurement of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

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



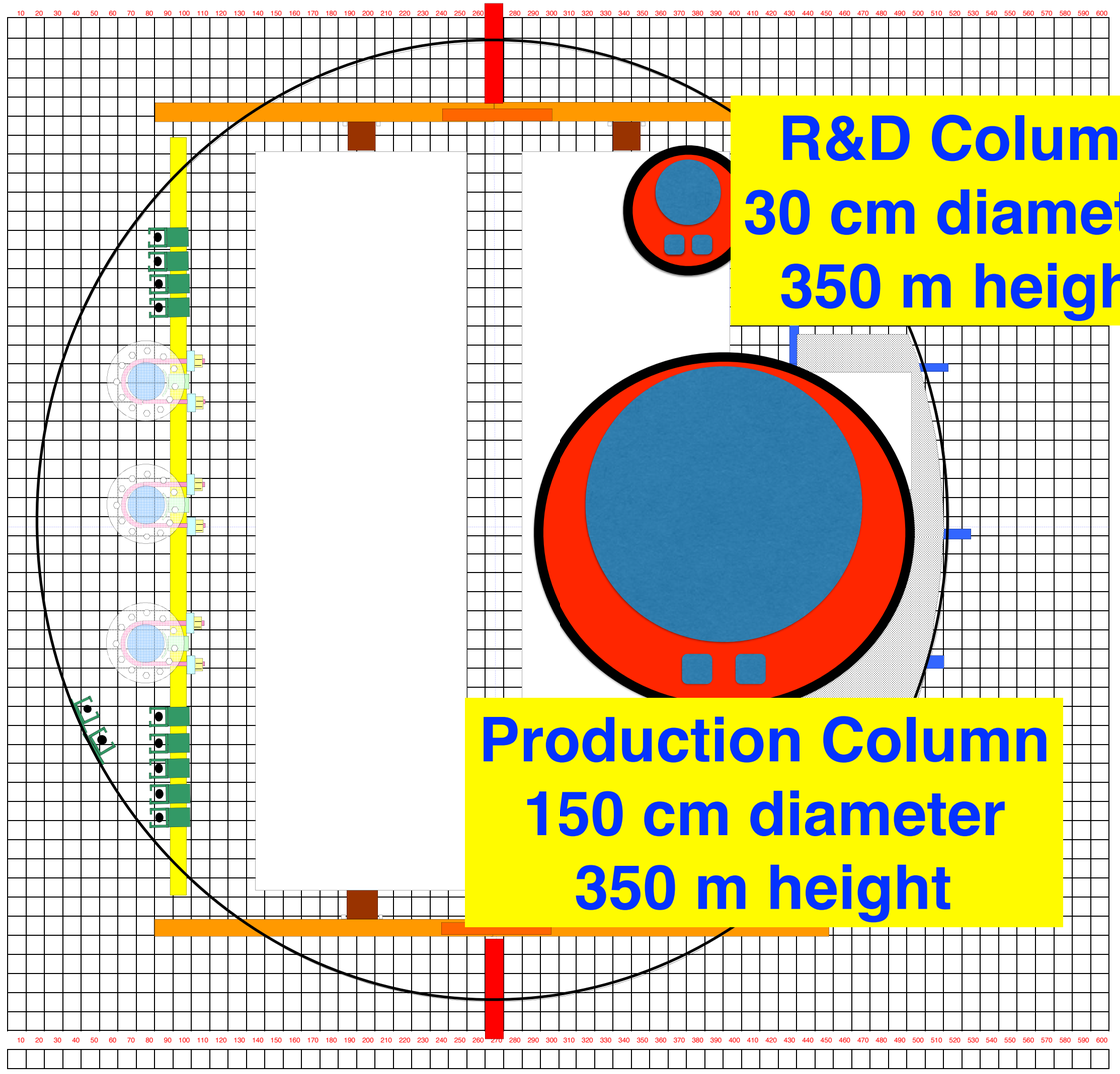
Aria

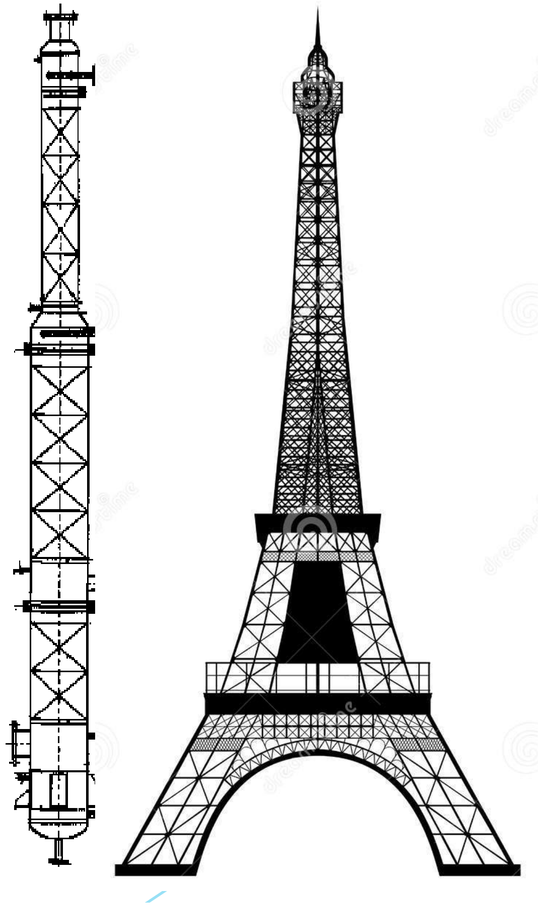
- The purpose of Aria is the reduction of ^{39}Ar in the target of the DarkSide detectors
- The method of isotopic separation is cryogenic distillation
- The project is supported by INFN, US NSF, and Regione Autonoma della Sardegna

Seruci Wells

Seruci in Sardinia an excellent location

A Very Tall Column



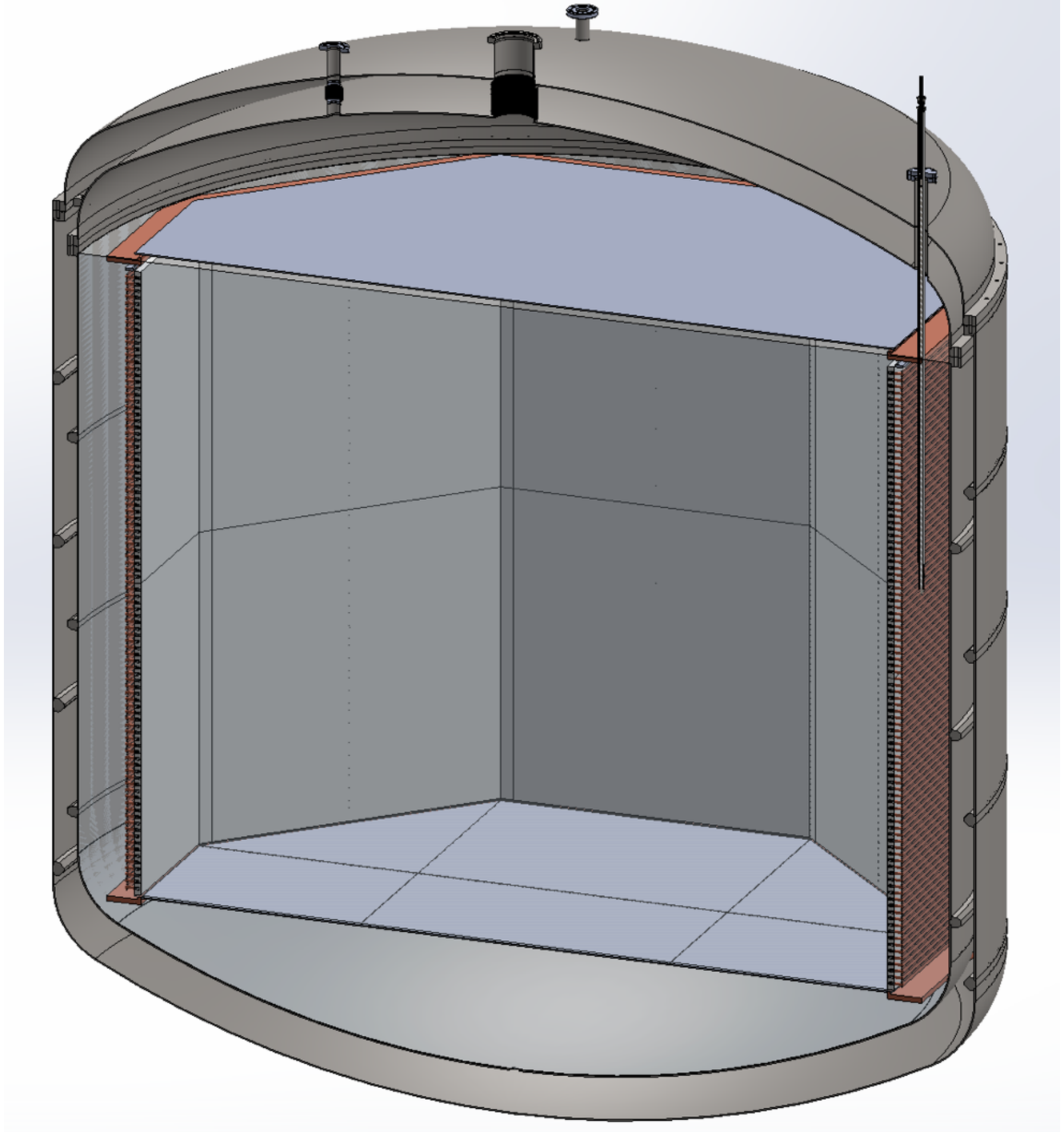


DarkSide-20k

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



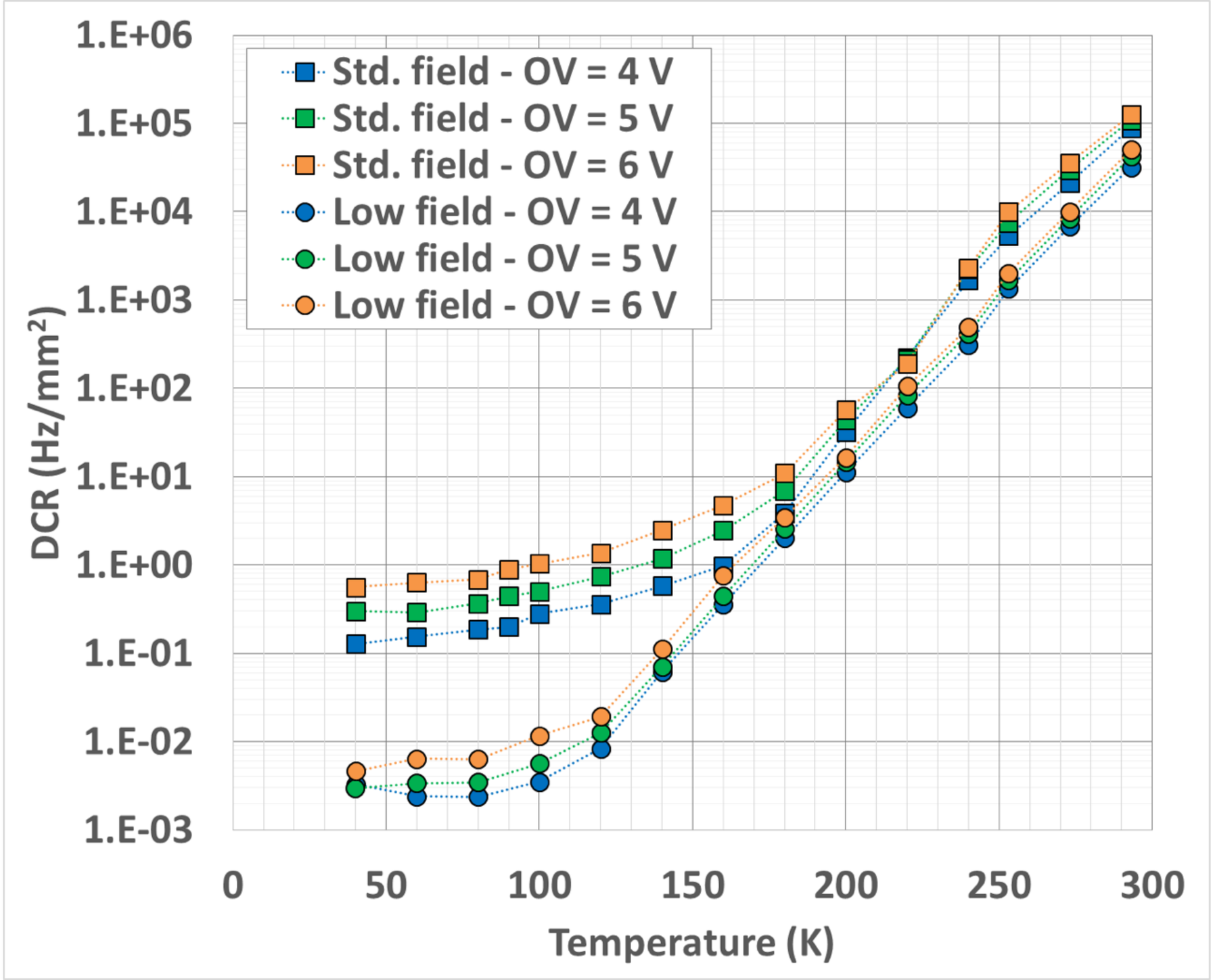
Photosensors for LAr Detectors

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