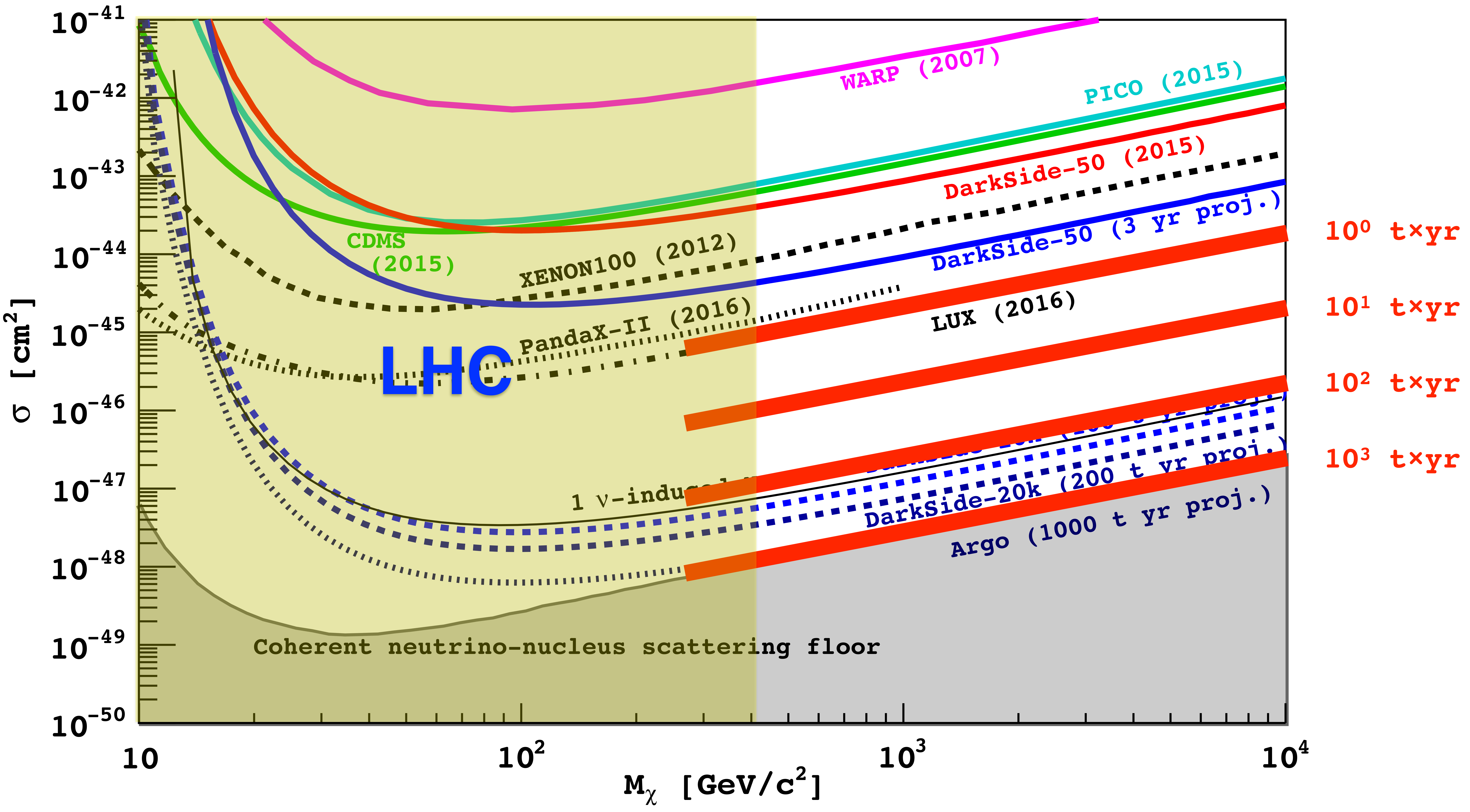
DarkSide
Dark Matter with Ar

Cristiano Galbiati
Princeton University
Buenos Aires
June 30, 2017

Yann Guardincerri (1983-2017)



WARP (2007)
PICO (2015)
DarkSide-50 (2015)
CDMS (2015)
XENON100 (2012)
DarkSide-50 (3 yr proj.)
LUX (2016)
PandaX-II (2016)
LHC
1 ν-induced
DarkSide-20k (200 t yr proj.)
Argo (1000 t yr proj.)
Coherent neutrino-nucleus scattering floor
10⁰ t×yr
10¹ t×yr
10² t×yr
10³ t×yr
σ [cm²]
M_χ [GeV/c²]

(New) Argon Collaboration

Researchers from

- DarkSide
- DEAP
- ArDM
- MiniCLEAN

DS-20K $\longrightarrow$ multi-100-T

planning to collaborate on future program:

- Completion of current science and R&D programs by each collaboration (DS-50, DEAP-3600, MiniCLEAN, ArDM)

- Joint collaboration on DS-20K at LNGS, including Low Radioactivity Argon (operation starting 2021) and SiPM photodetectors

- Joint collaboration on future multi-hundred-tonne LAr detector, site TBD (mid-2020's)

Towards global argon collaboration:

DarkSide, DEAP, miniCLEAN, ArDM > 350 researchers

Collaboration

- 68 institutes
- 350 researchers
- 12 nations:

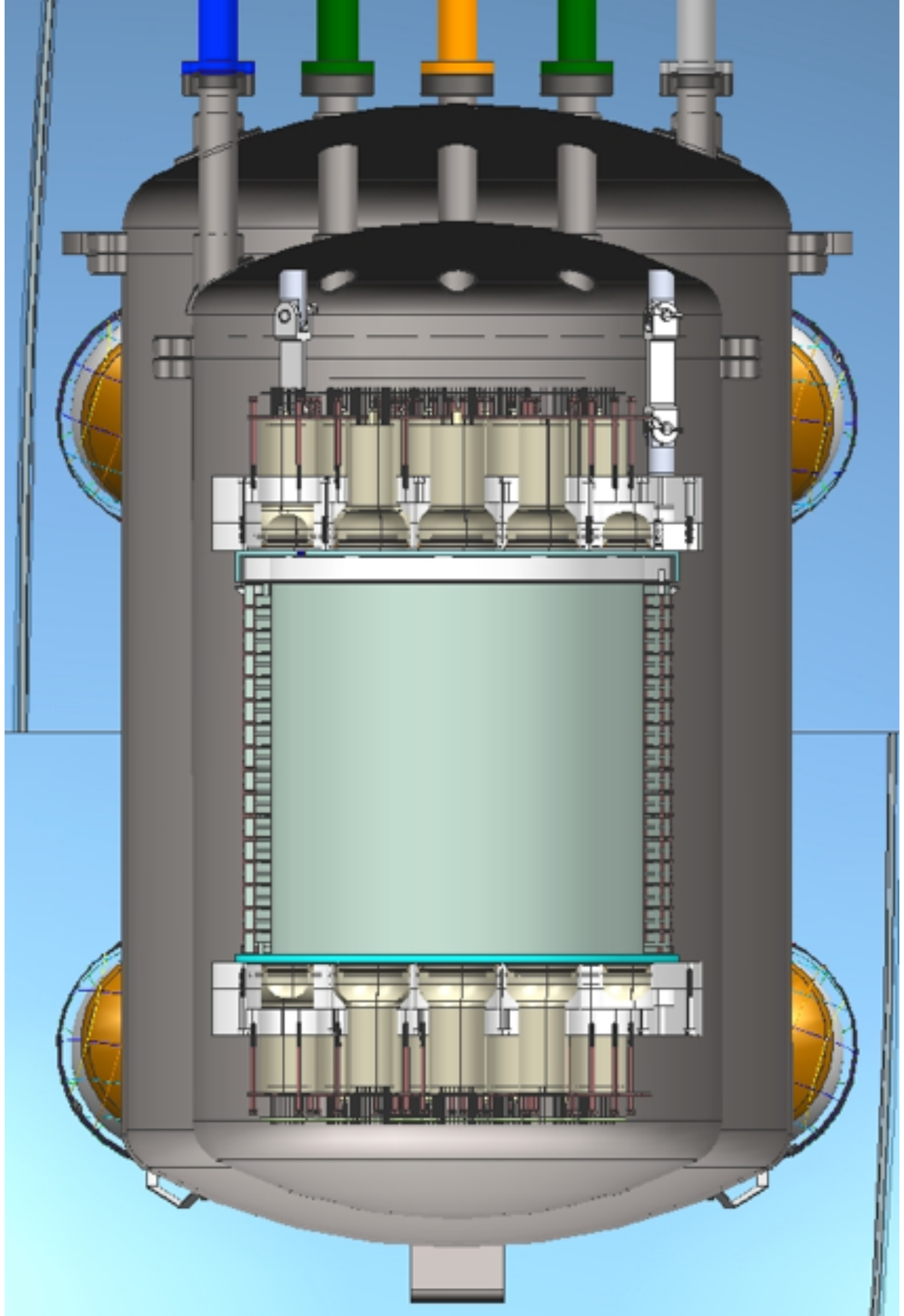
  Brasil, Canada, China, France, Greece, Italy, Poland, Romania, Spain, Switzerland, UK, USA

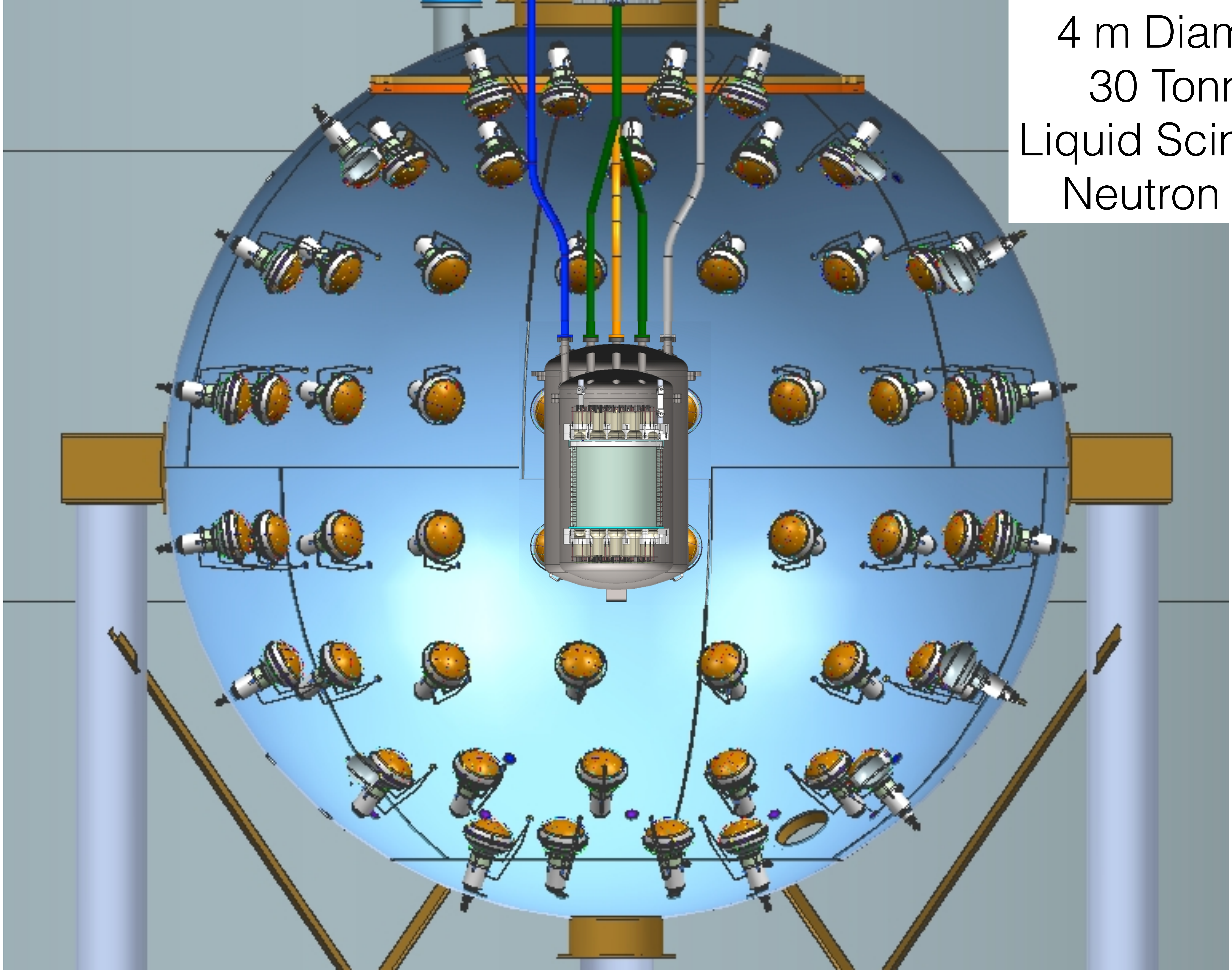
Mark Boulay

An Ambitious Discovery Program

- Complementary to LHC
- Raising the bar: from 1 tonne × yr → 1,000 tonne × yr
- “Zero Background” necessary for a discovery program
- Two crucial technologies
    - Liquid argon target depleted in the radioactive ^{39}Ar
    - SiPMs replacing cryogenic PMTs

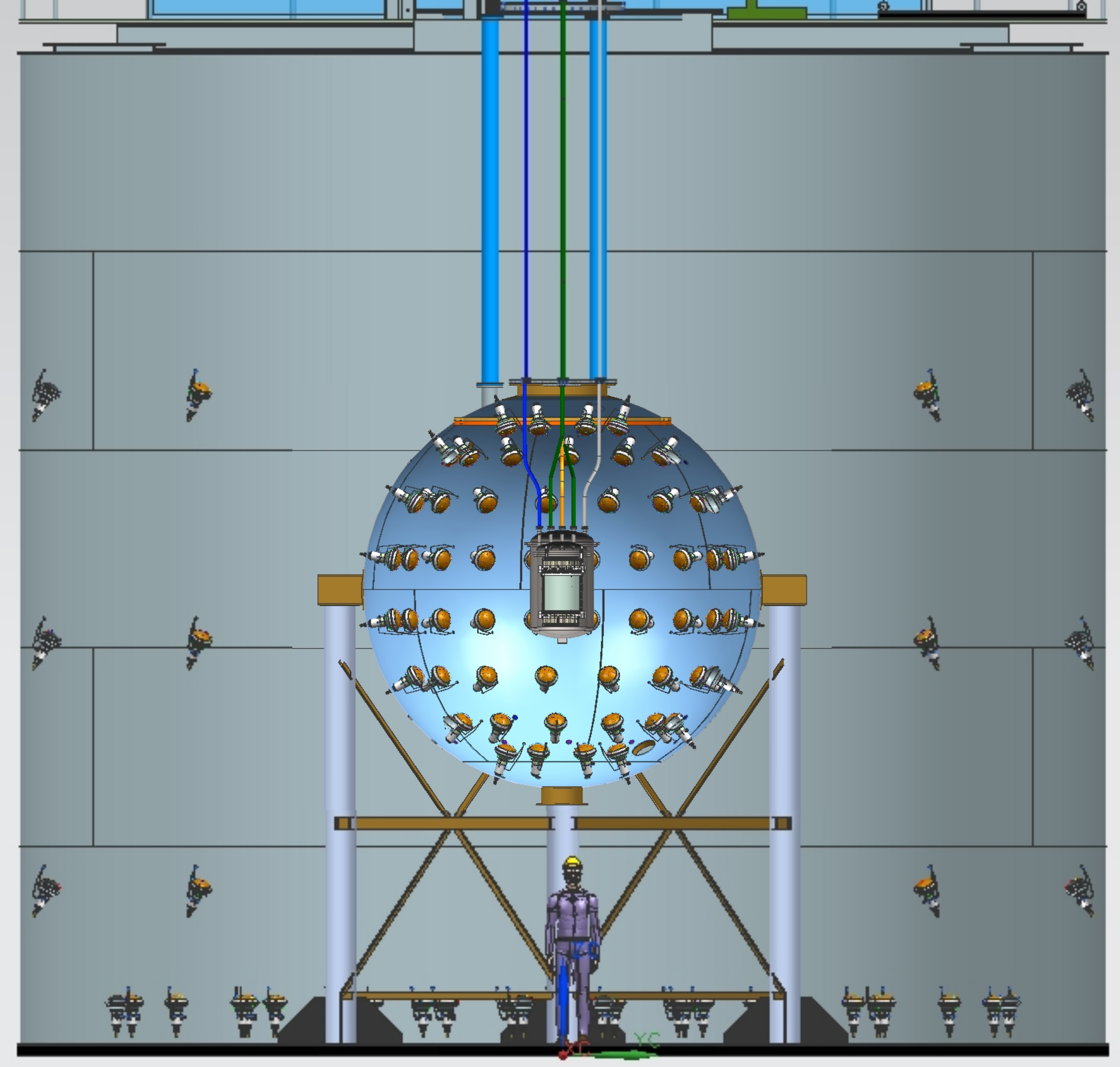
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target





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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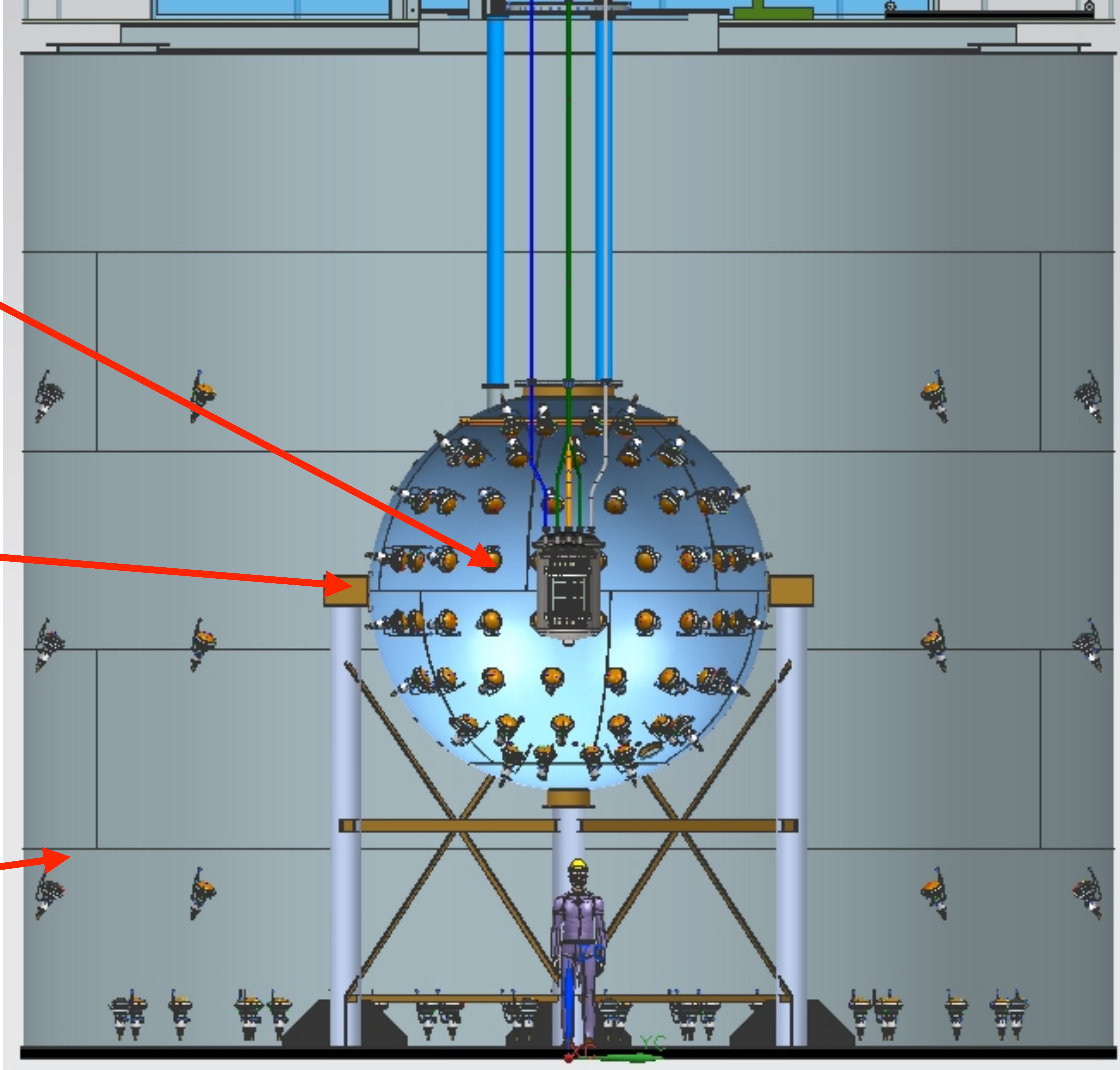
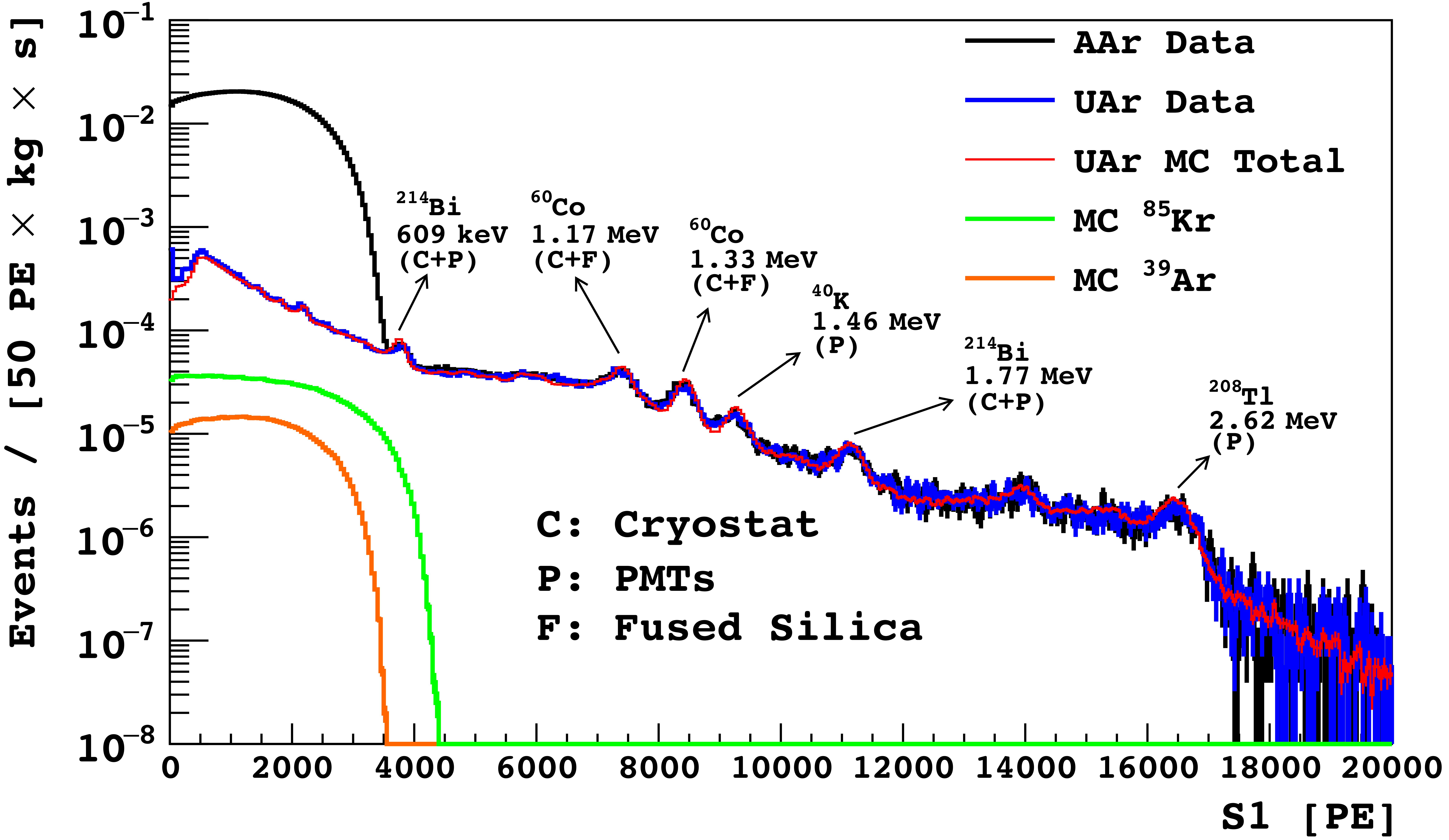




AAr Data
UAr Data
UAr MC Total
MC ^{85}Kr
MC ^{39}Ar
^{214}Bi 609 keV (C+P)
^{60}Co 1.17 MeV (C+F)
^{60}Co 1.33 MeV (C+F)
^{40}K 1.46 MeV (P)
^{214}Bi 1.77 MeV (C+P)
^{208}Tl 2.62 MeV (P)
C: Cryostat
P: PMTs
F: Fused Silica
Events / [50 PE × kg × s]
S1 [PE]


1,422 kg d AAr - PLB 743, 456 (2015)
Energy [keV$_{nr}$]
S1 [PE]
f_{90}
50%
65%
80%
90%
95%
99%

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
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]
50
40
30
20
10
0
2,616 kg d UAr - arXiv:1510.12345 (2015)

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

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

Minimum Ionizing Events:

- Scatters of *pp* solar neutrinos on electrons
- Radioactive noble gases (^{39}Ar)

Nuclear Recoils:

- ν-induced coherent scattering of atm neutrinos [~1/(100 tonne ×yr)]

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 $1 \div 1.6\times10^{7}$

16M ^{39}Ar events
1,422 kg×day (@AAr)

÷1400 39Ar depletion
AAr/UAr

16M ^{39}Ar events
5.5 tonne×yr (UAr)

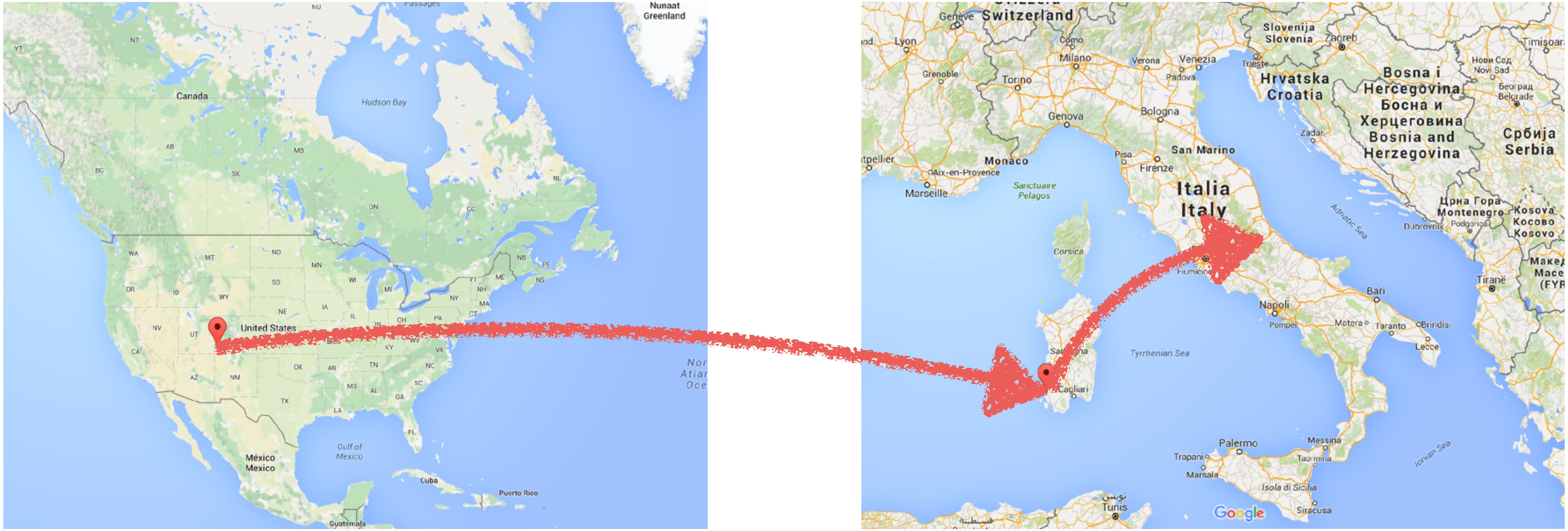
additional active
isotopic depletion
higher light yield

1,000 tonne×yr (DAr)

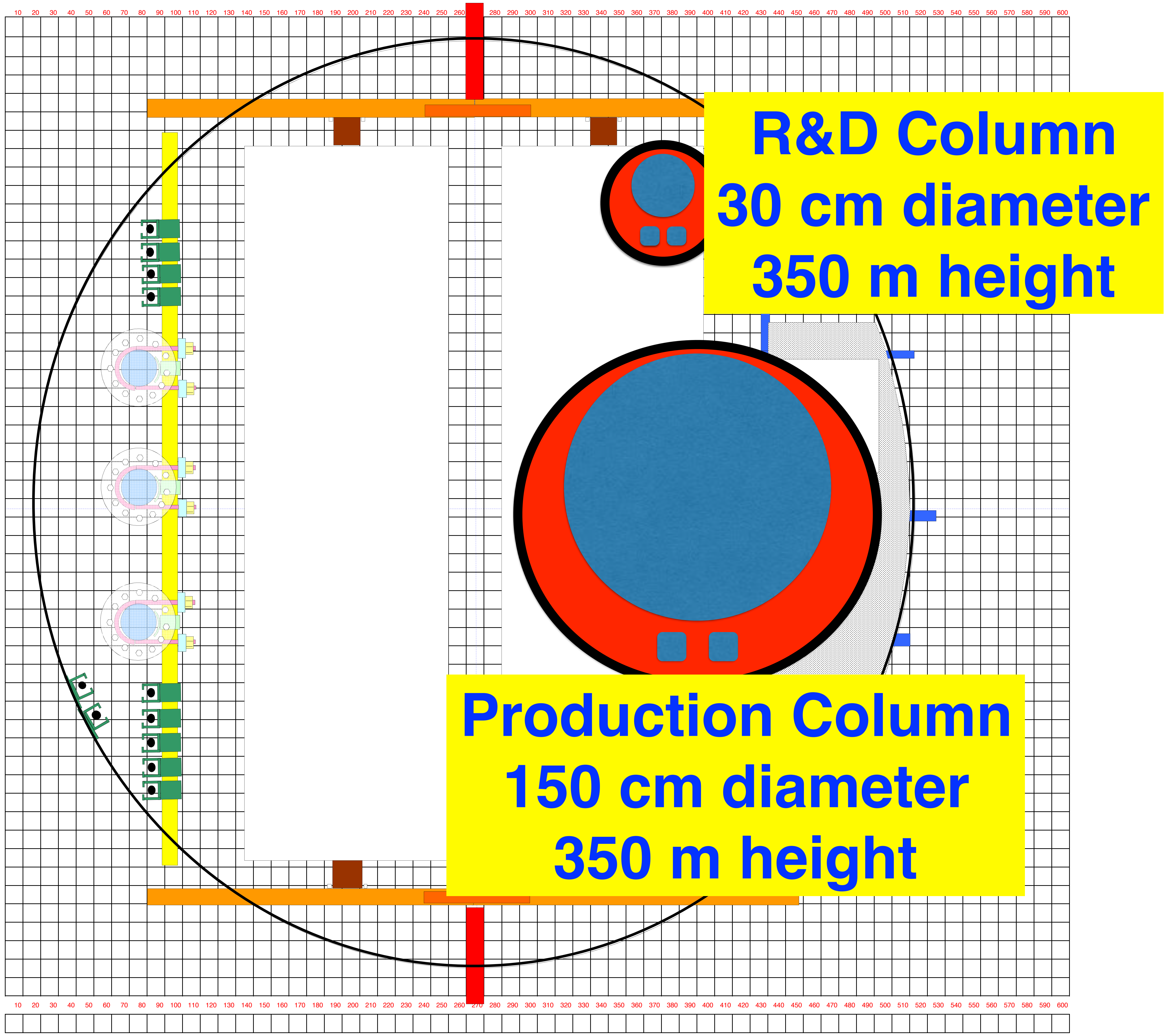
Based on what we know today, can a depleted argon experiment be free of any instrumental (other than ν-induced recoils) background at the scale of 1000 tonnes×yr?

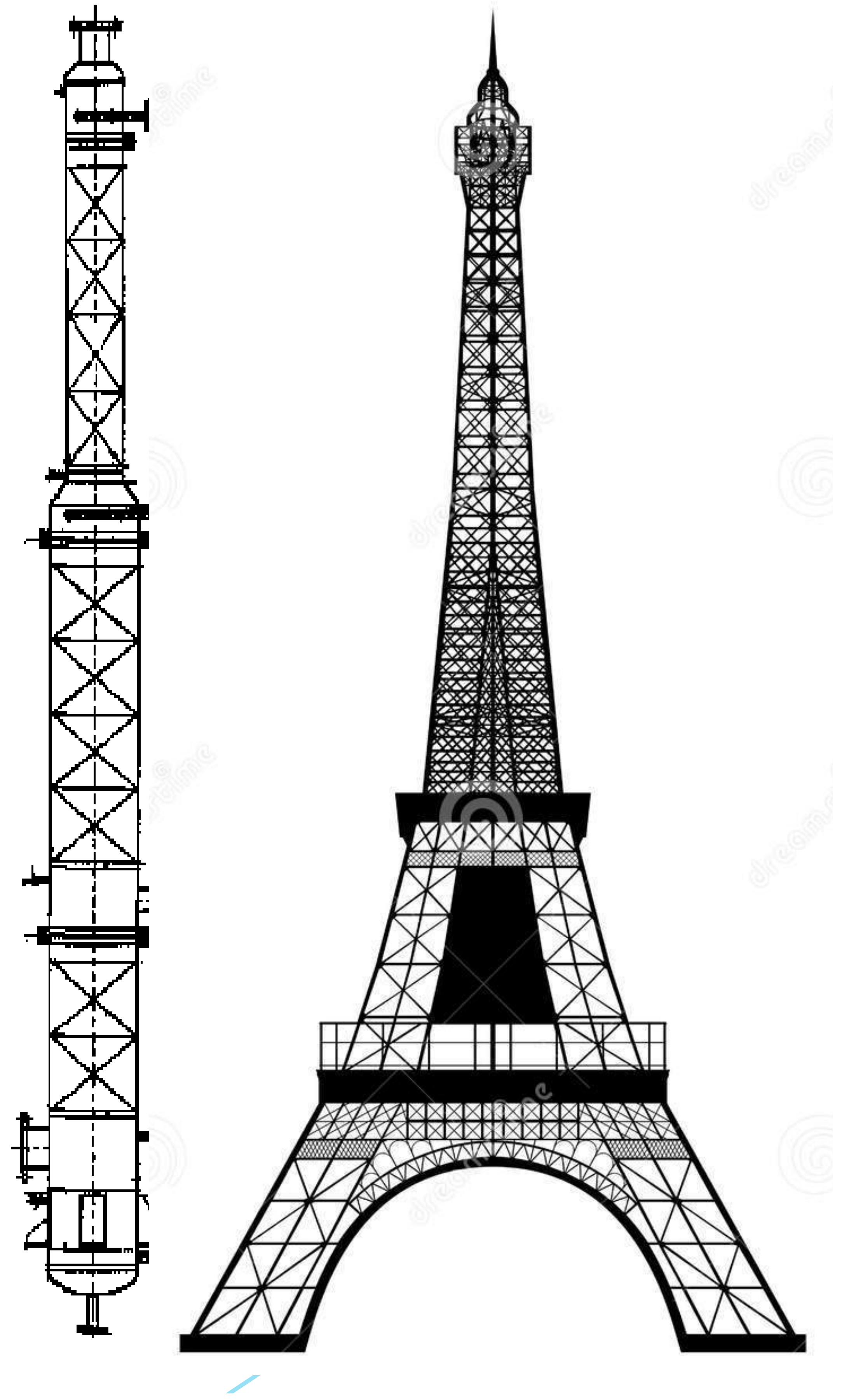
Yes.

Urania to Aria to LNGS

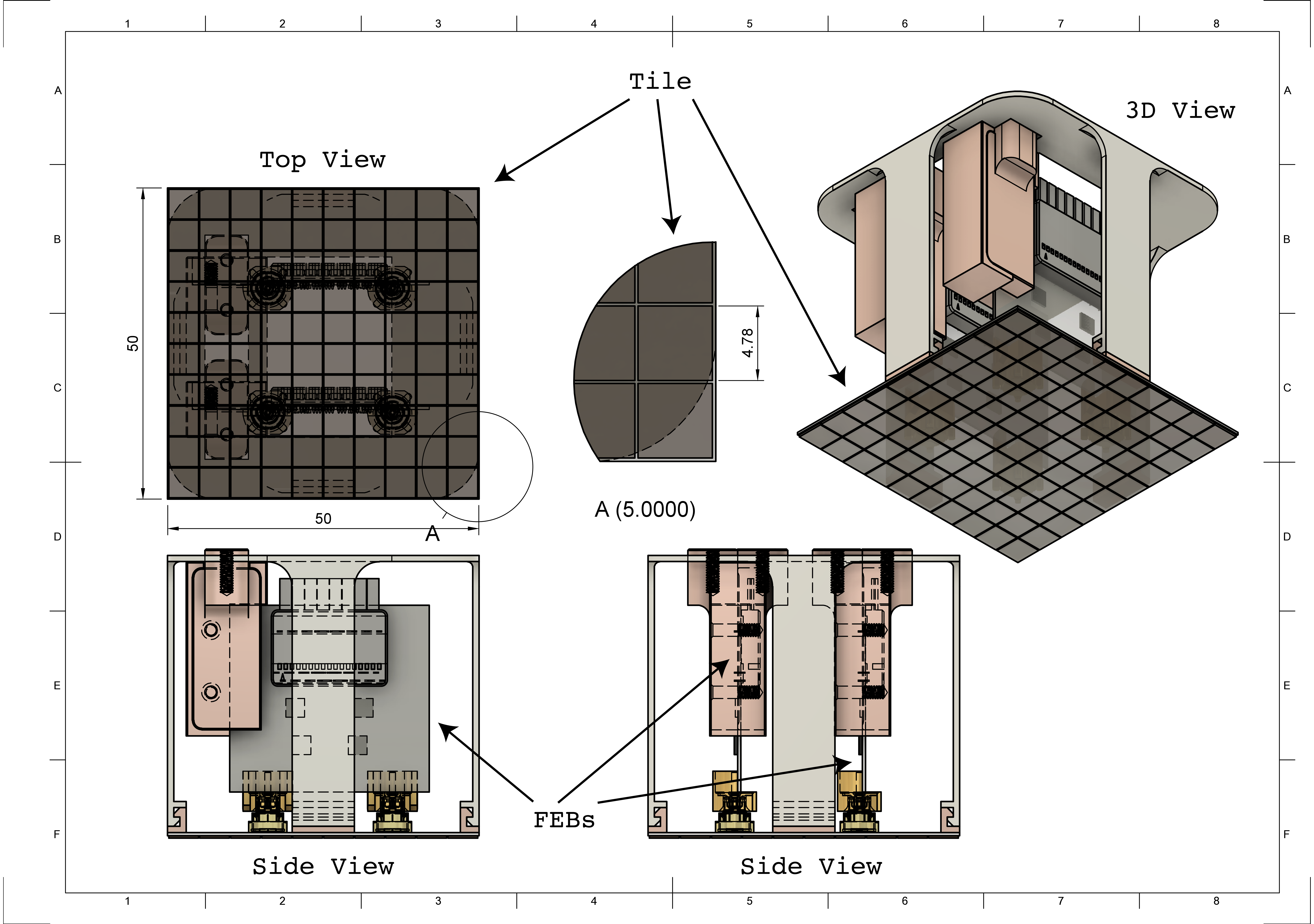


Aria


R&D Column
30 cm diameter
350 m height
Production Column
150 cm diameter
350 m height



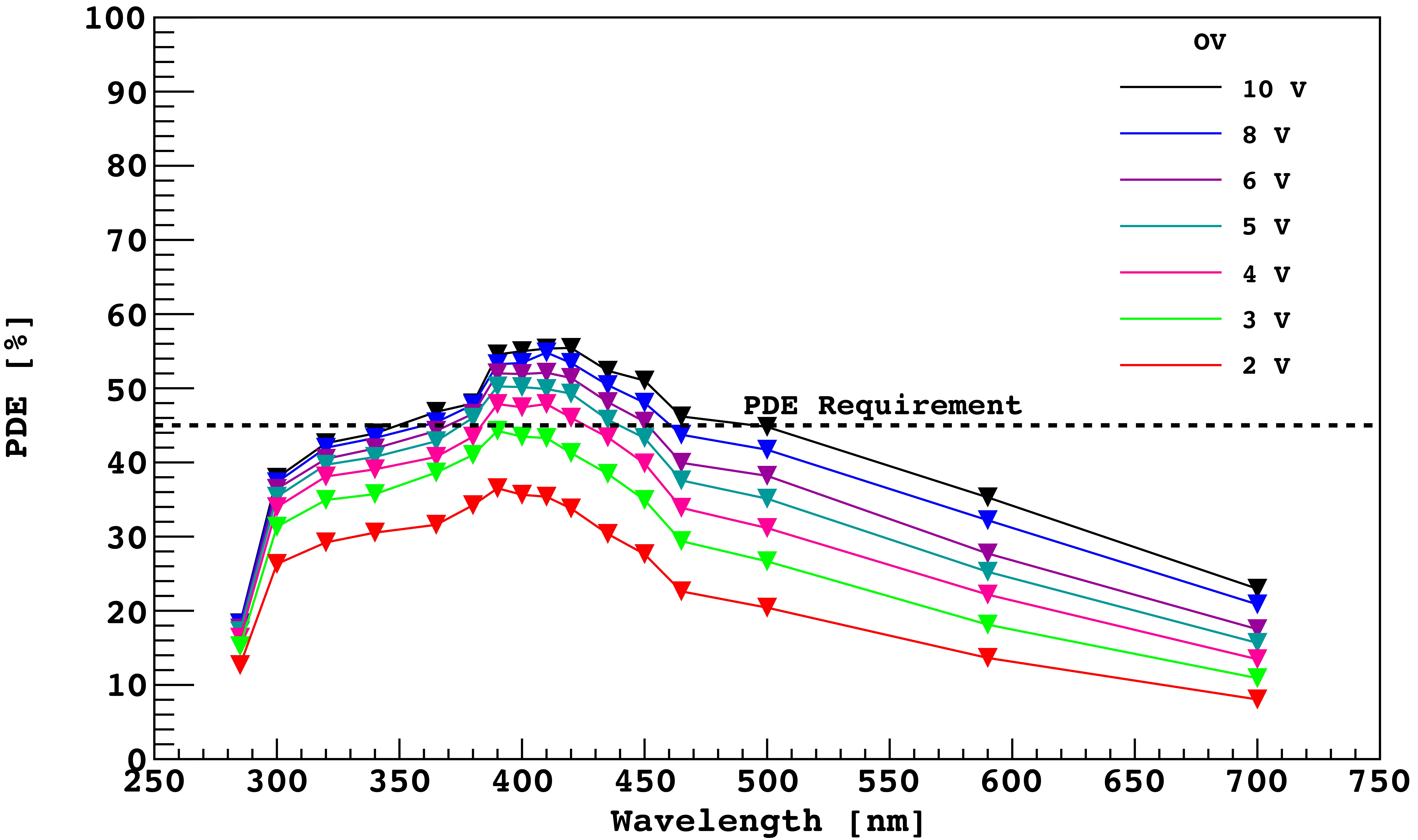
Nostra Signora di Bonaria, Cagliari

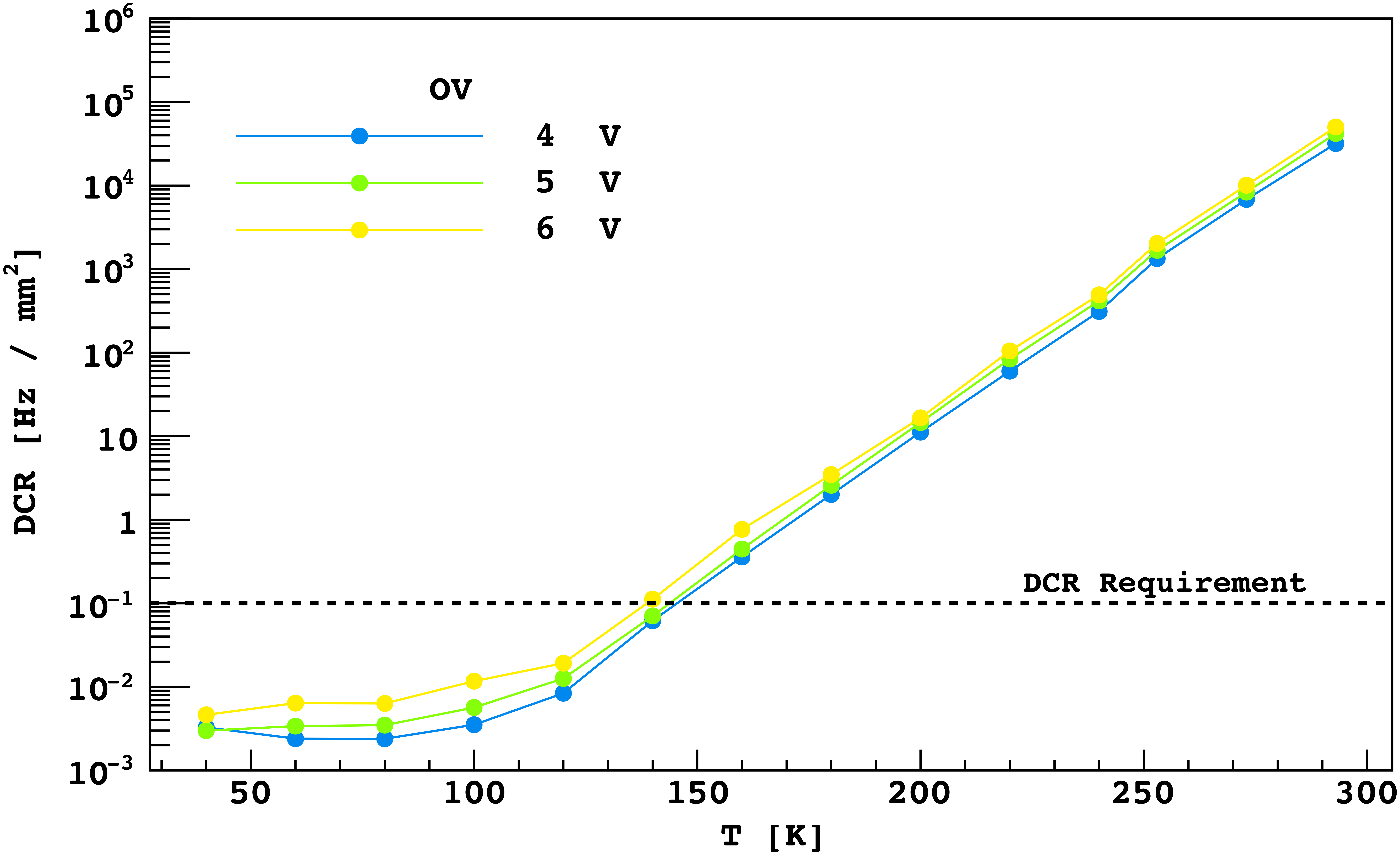


Tile
Top View
3D View
50
50
4.78
A
A (5.0000)
FEBs
Side View
Side View
1
2
3
4
5
6
7
8
A
B
C
D
E
F

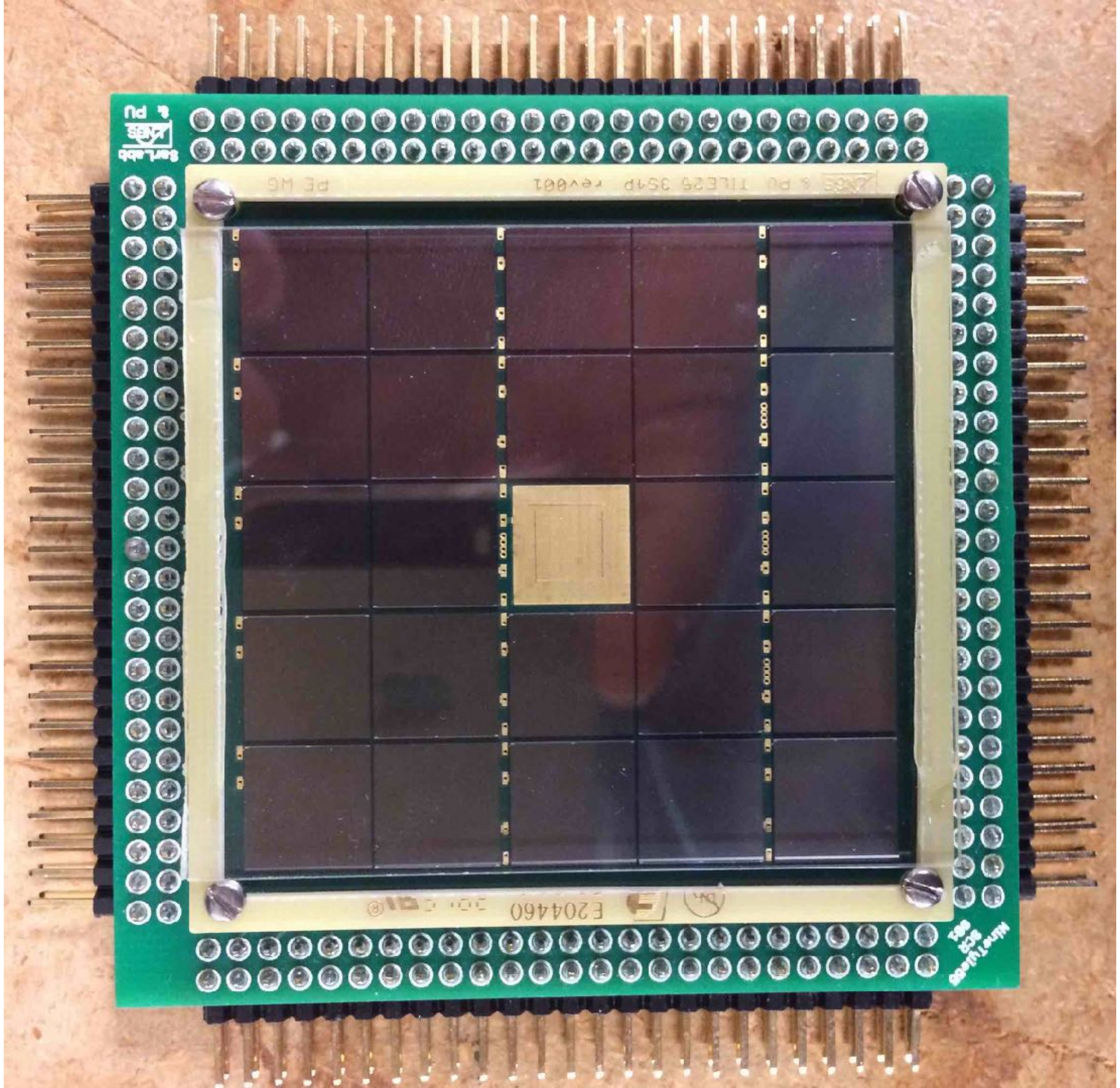
SiPM Status

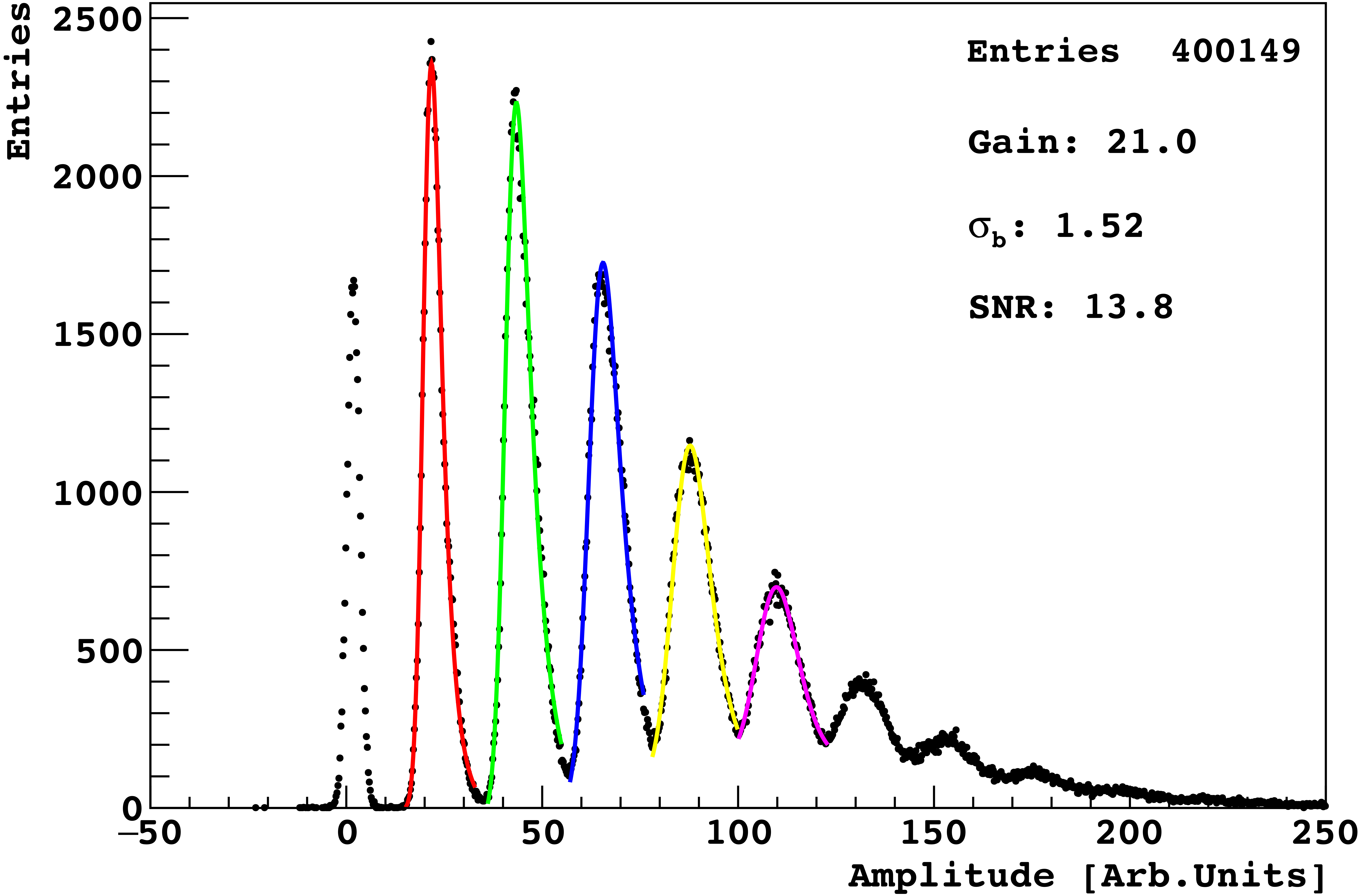
- Photon Detection Efficiency (PDE): 45% requirement met and surpassed
- Dark Count Rate (DCR): 0.1 Hz/mm^2 requirement met and surpassed
- Challenge in tiling due to 50 pf/mm^2 capacity. Signal-to-Noise Ratio (SNR) rapidly decreases with increasing surface. The steps:
  - 2×2 cm^2 tile: fully demonstrated
  - 3.5×3.5 cm^2 tile: on the way, success projected on the basis of available data
  - 5×5 cm^2 tile: in 2017, some R&D necessary to improve SNR due to the increase in capacity

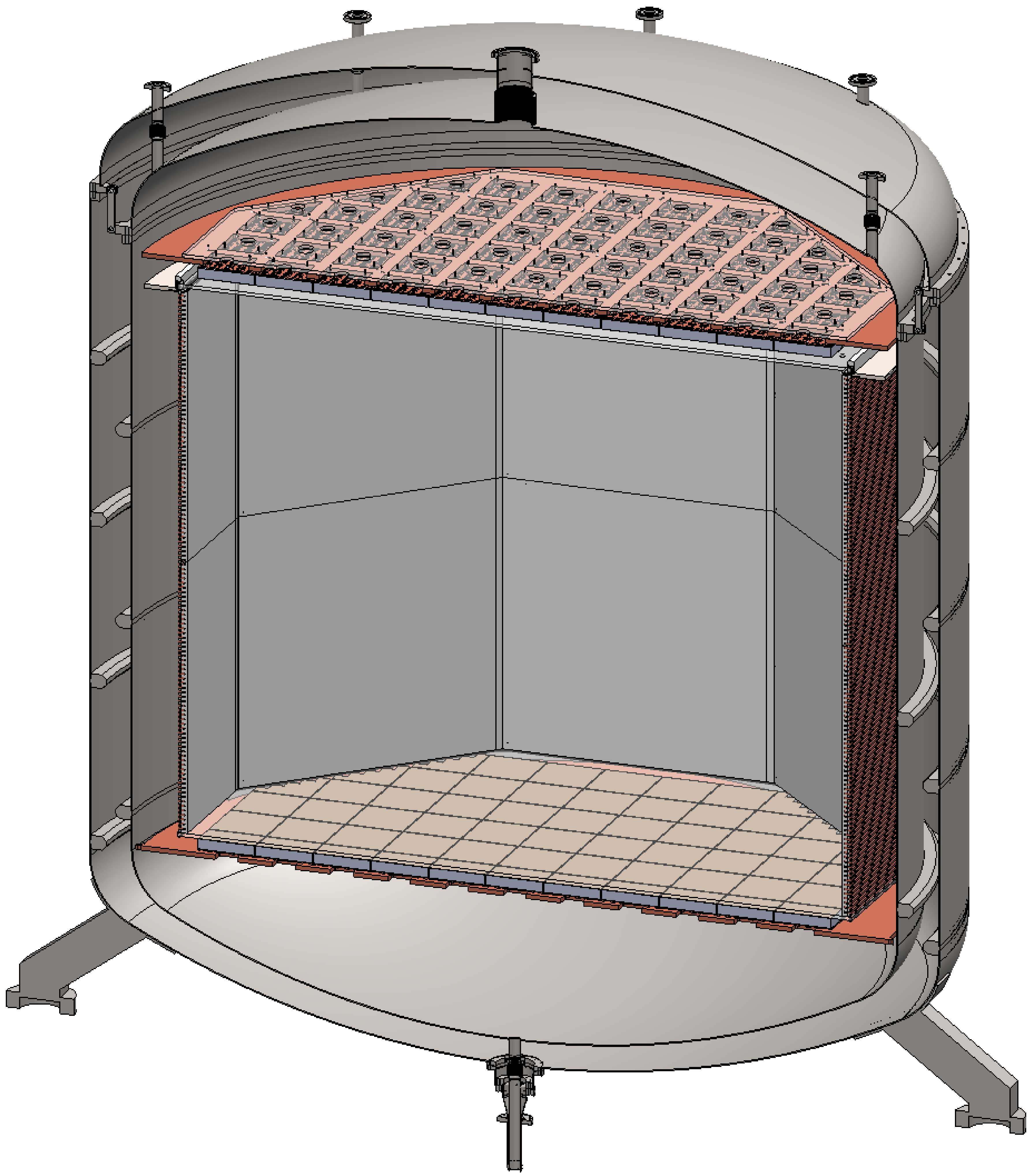
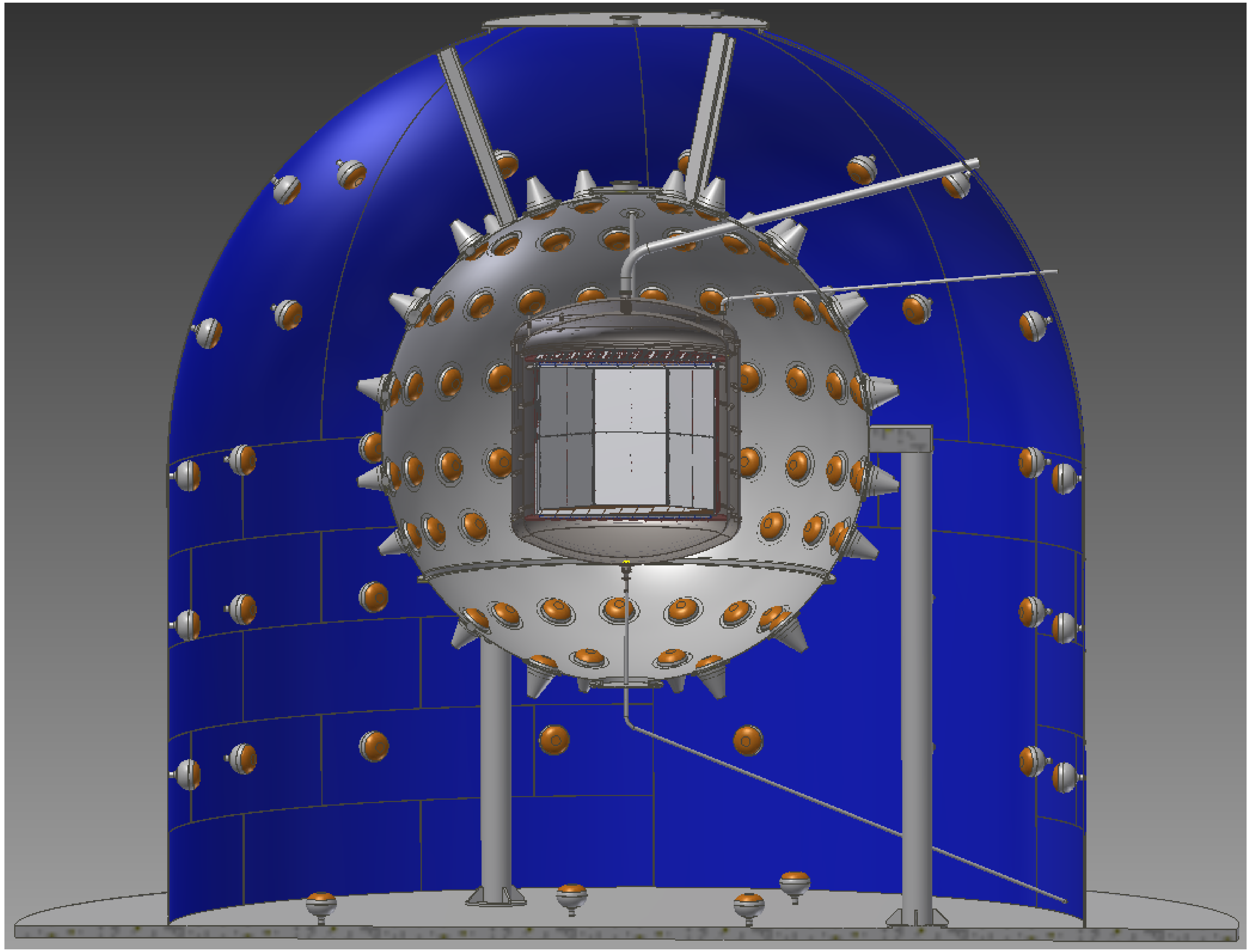

PDE [%]
Wavelength [nm]
OV
10 V
8 V
6 V
5 V
4 V
3 V
2 V
PDE Requirement
0
10
20
30
40
50
60
70
80
90
100
250
300
350
400
450
500
550
600
650
700
750



OV
4 V
5 V
6 V
DCR Requirement
DCR [Hz / mm^2]
T [K]
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
50
100
150
200
250
300




Entries 400149
Gain: 21.0
σ_b: 1.52
SNR: 13.8
Entries
Amplitude [Arb.Units]
2500
2000
1500
1000
500
0
−50
0
50
100
150
200
250

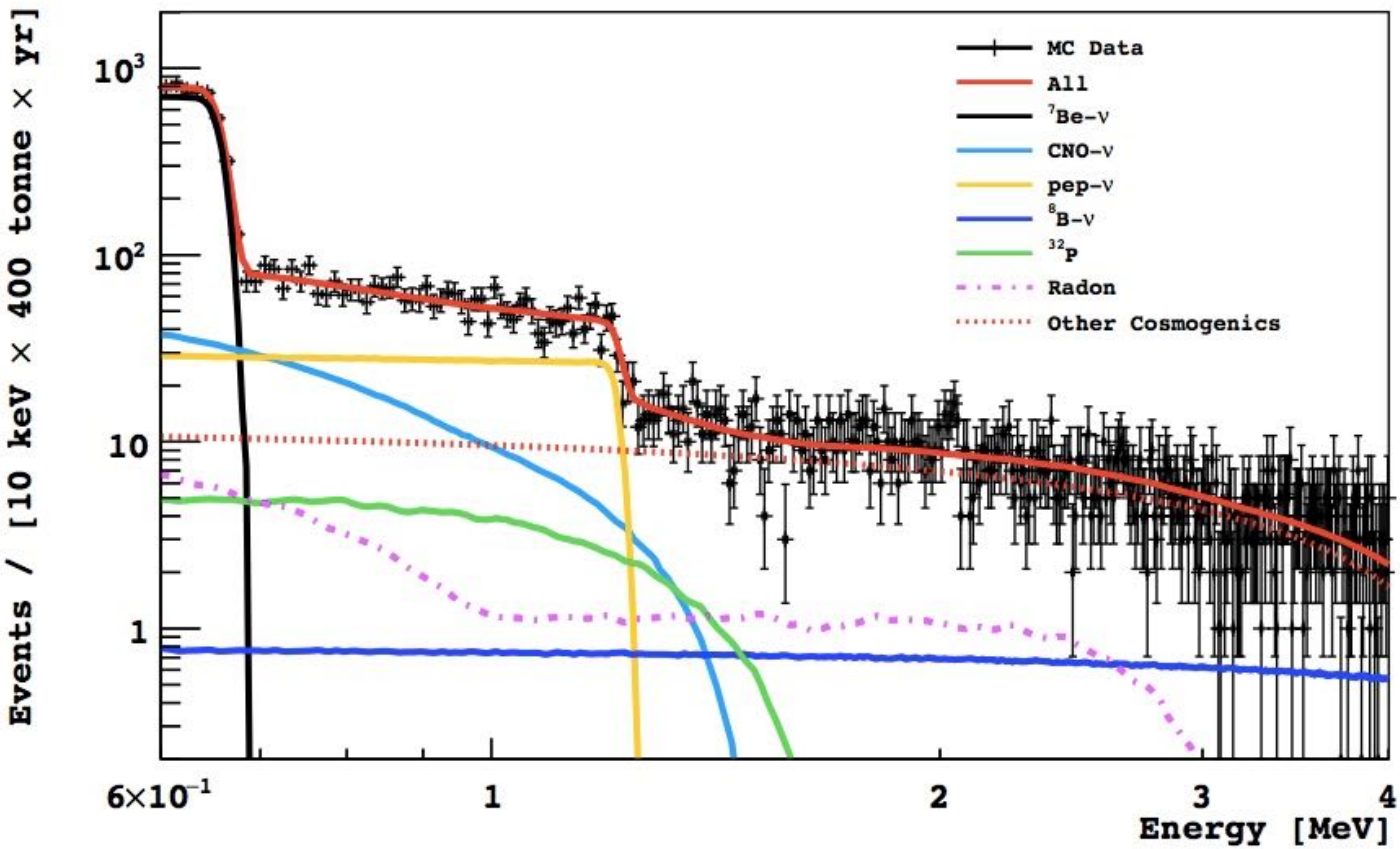



DarkSide-20k

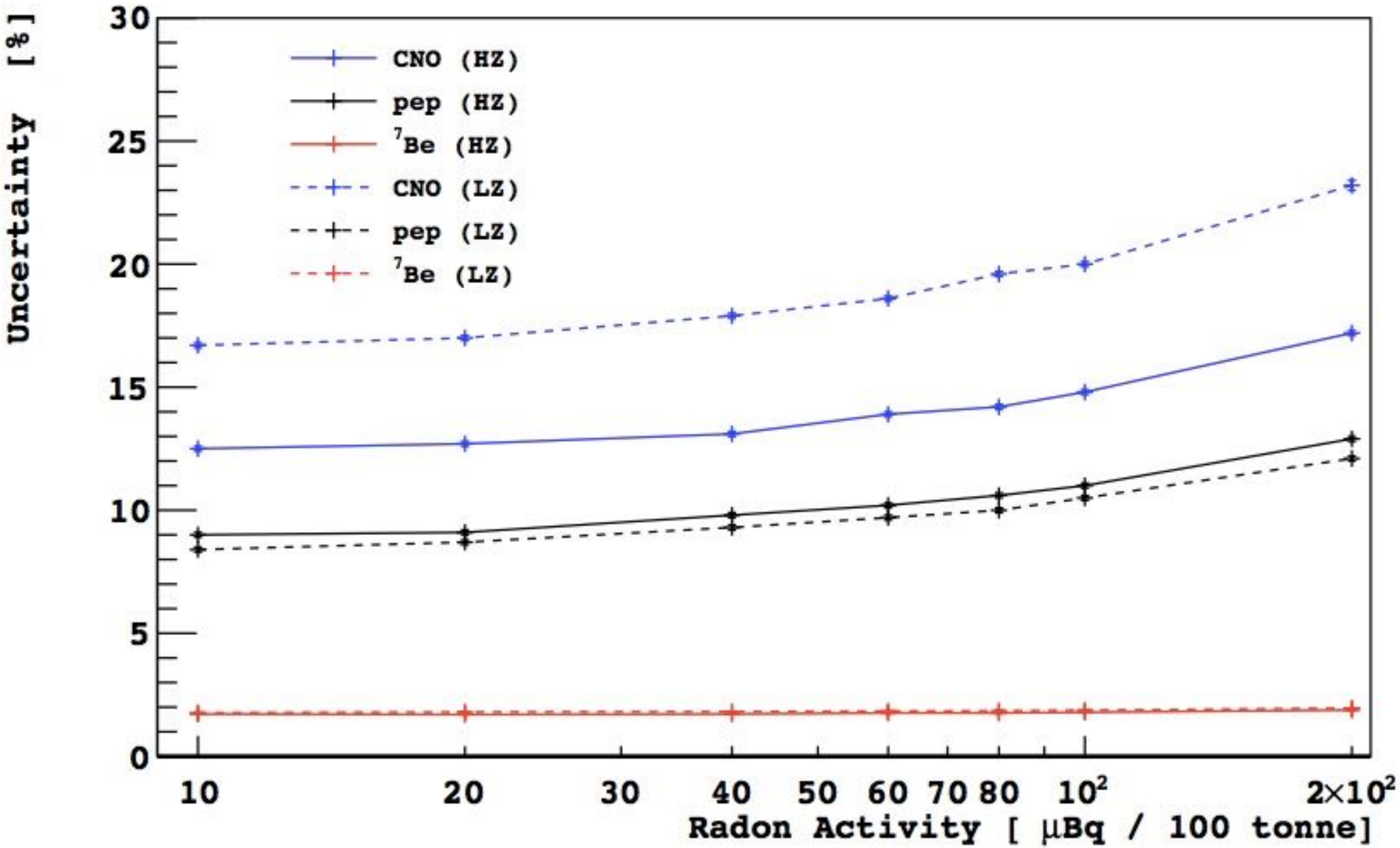
20-tonnes fiducial dark matter detector
start of operations at LNGS within 2021
100 tonne×year search for dark matter free of instrumental background
INFN-NSF science review: ✓
Yellow Book to LNGS: ✓
INFN-NSF budget and schedule review: ongoing

Argo

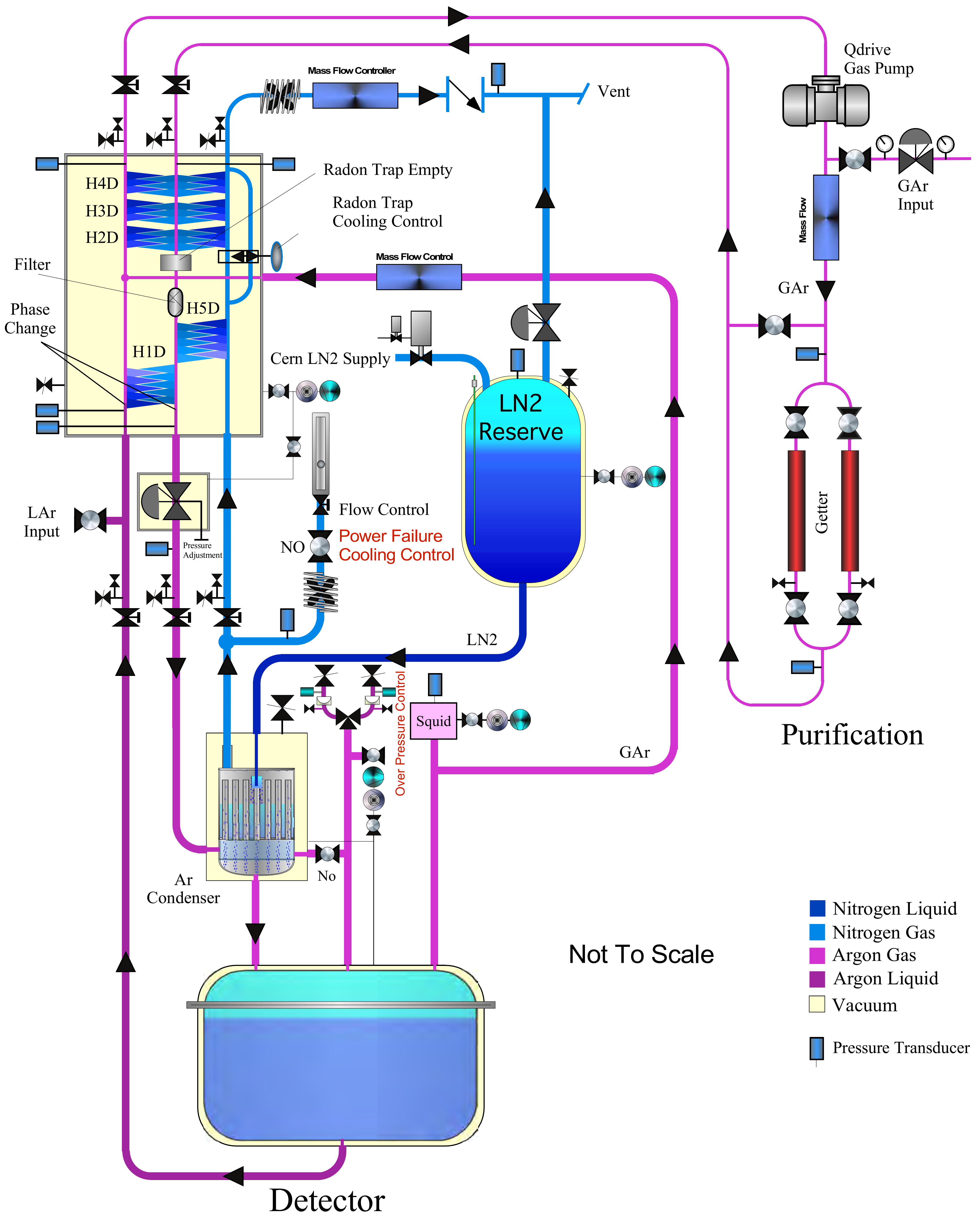
300-tonnes depleted argon detector
start of operations at LNGS within 2027
100 tonne×year search for dark matter free of instrumental background
precision measurement of solar neutrinos

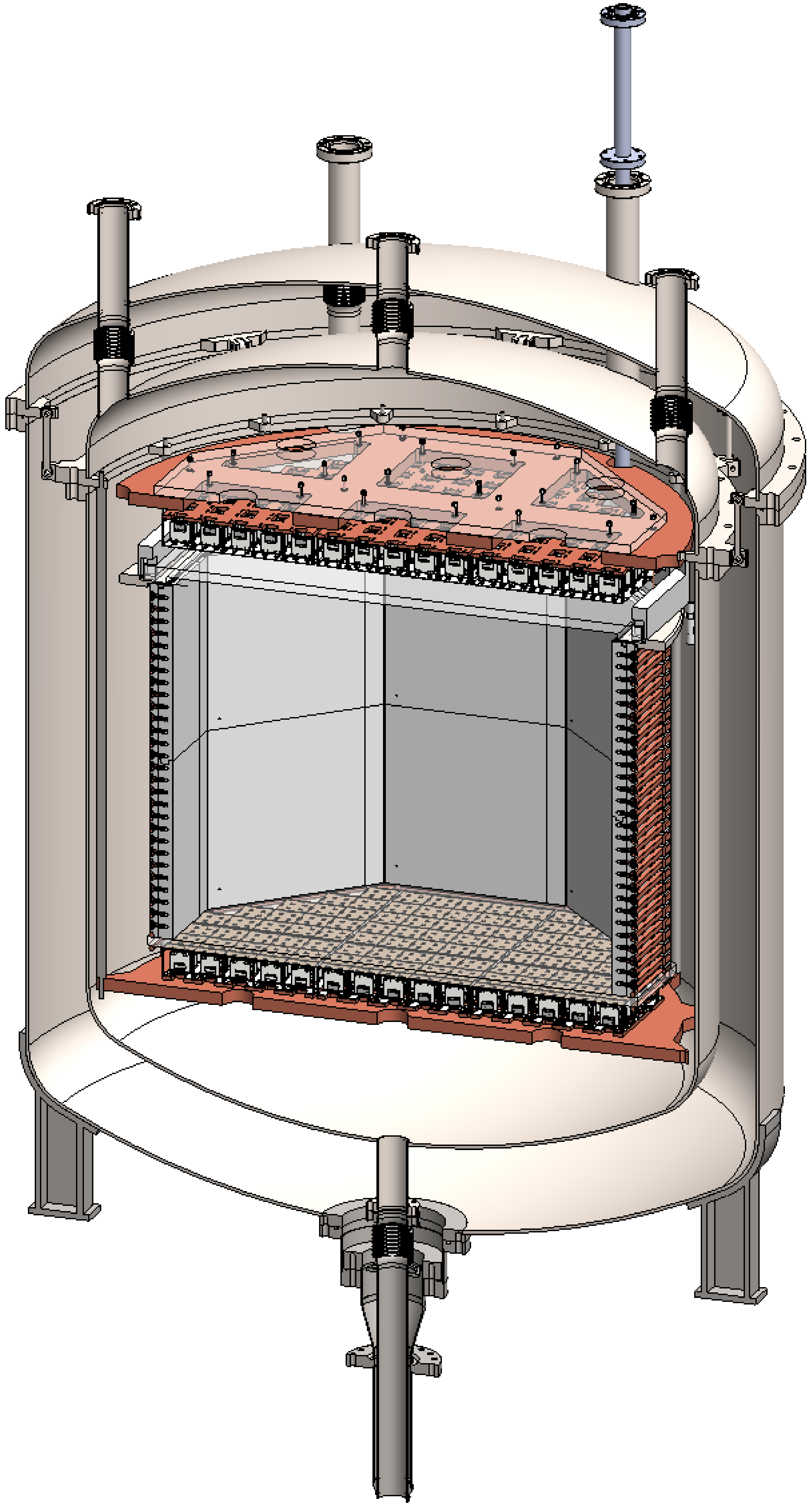


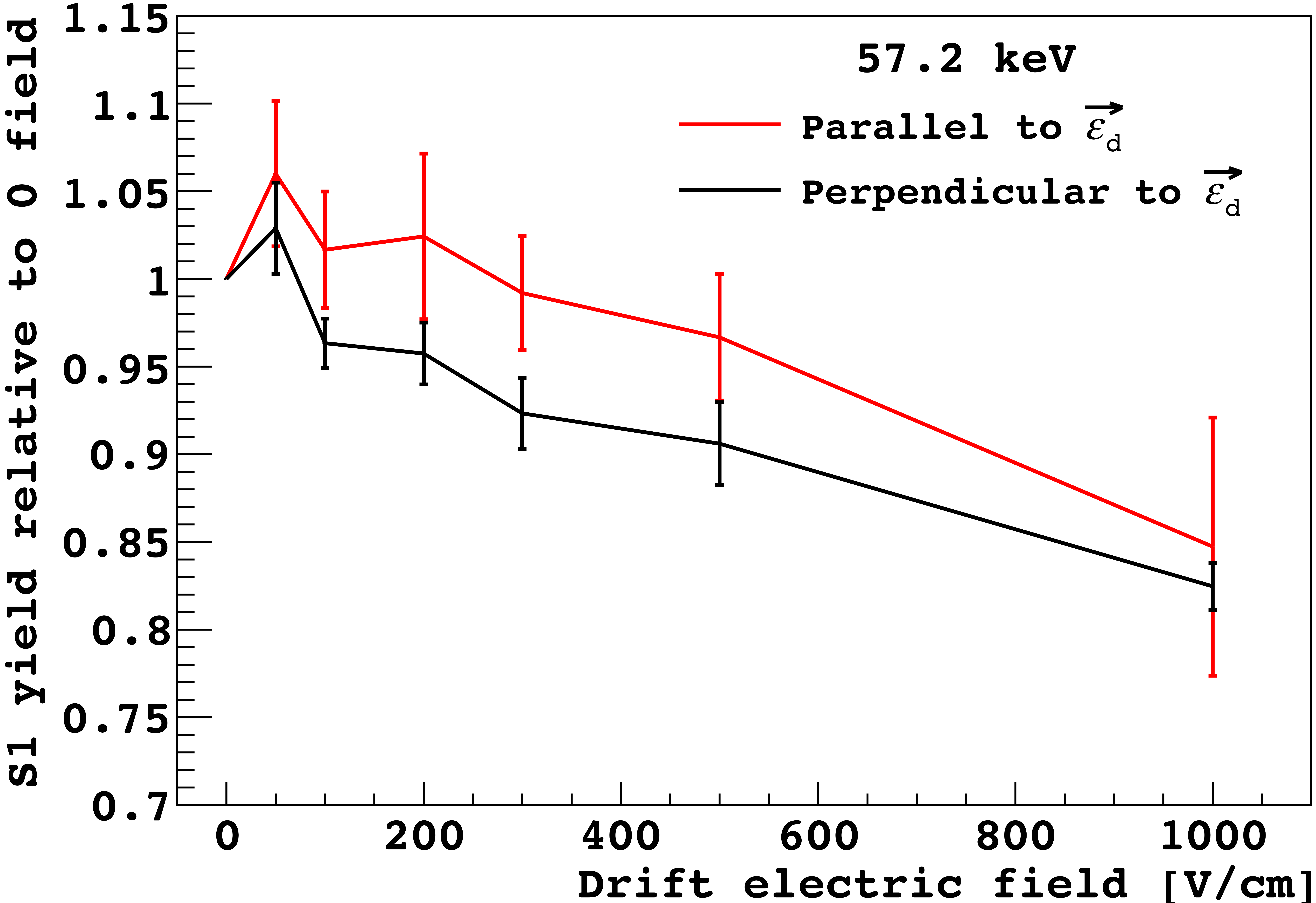
MC Data
All
7Be-ν
CNO-ν
pep-ν
8B-ν
32P
Radon
Other Cosmogenics
Events / [10 keV × 400 tonne × yr]
Energy [MeV]
10^3
10^2
10
1
6×10^-1
1
2
3
4



Uncertainty [%]
30
25
20
15
10
5
0
CNO (HZ)
pep (HZ)
7Be (HZ)
CNO (LZ)
pep (LZ)
7Be (LZ)
10
20
30
40
50
60
70
80
10^2
2×10^2
Radon Activity [μBq / 100 tonne]


Mass Flow Controller
Vent
Qdrive
Gas Pump
Radon Trap Empty
Radon Trap
Cooling Control
H4D
H3D
H2D
Filter
Mass Flow Control
Mass Flow
GAr
Input
GAr
H5D
Phase
Change
H1D
Cern LN2 Supply
LN2
Reserve
Getter
LAr
Input
Pressure
Adjustment
Flow Control
NO
Power Failure
Cooling Control
LN2
Over Pressure Control
Squid
GAr
Purification
Ar
Condenser
No
Not To Scale
Nitrogen Liquid
Nitrogen Gas
Argon Gas
Argon Liquid
Vacuum
Pressure Transducer
Detector





57.2 keV
Parallel to $\vec{\mathcal{E}}_d$
Perpendicular to $\vec{\mathcal{E}}_d$
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]

Why we need more Latin American Astroparticle Physicists?

Pablo Javier Mosteiro y Romero

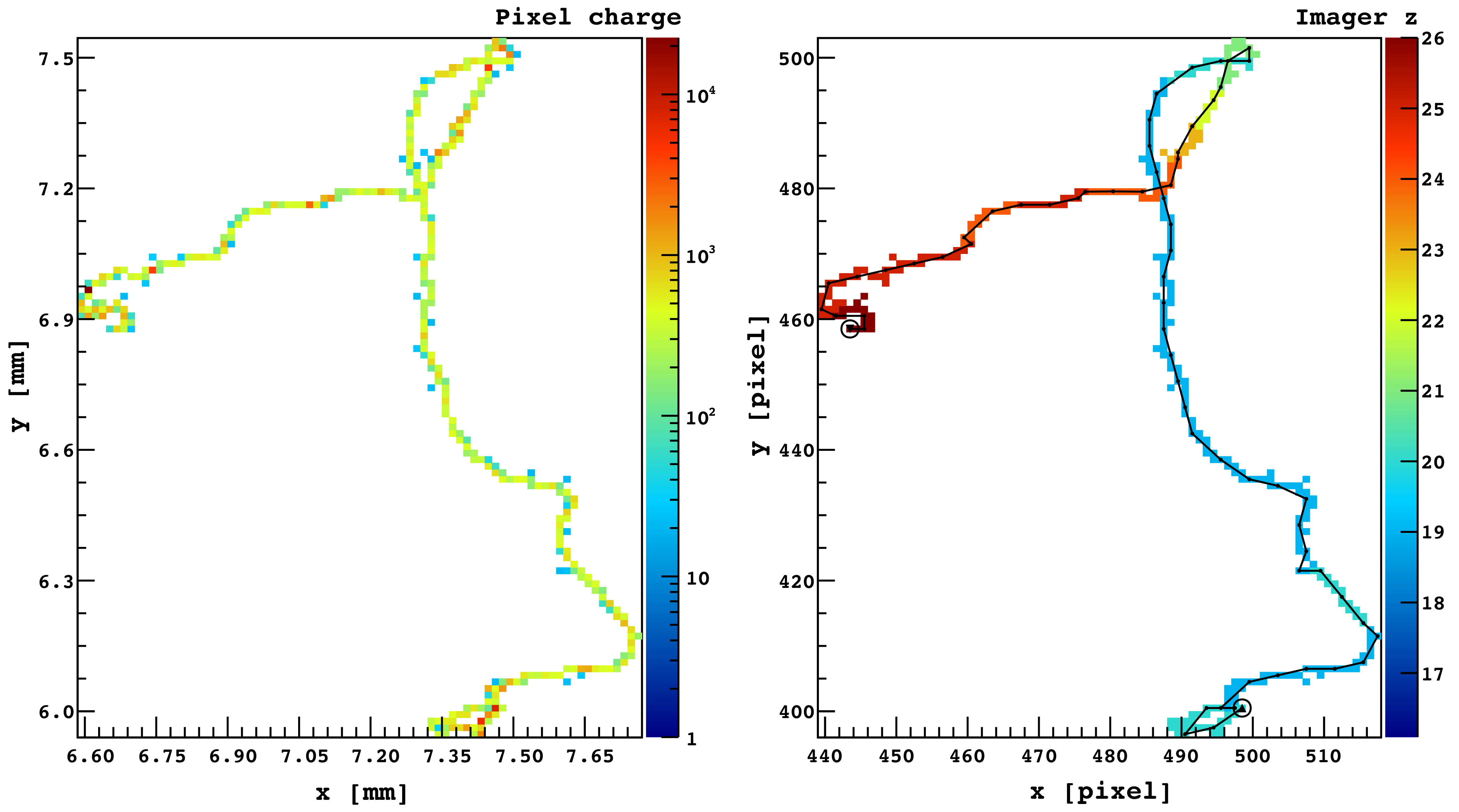
Alvaro Eugenio Chavarria

Single/double electron

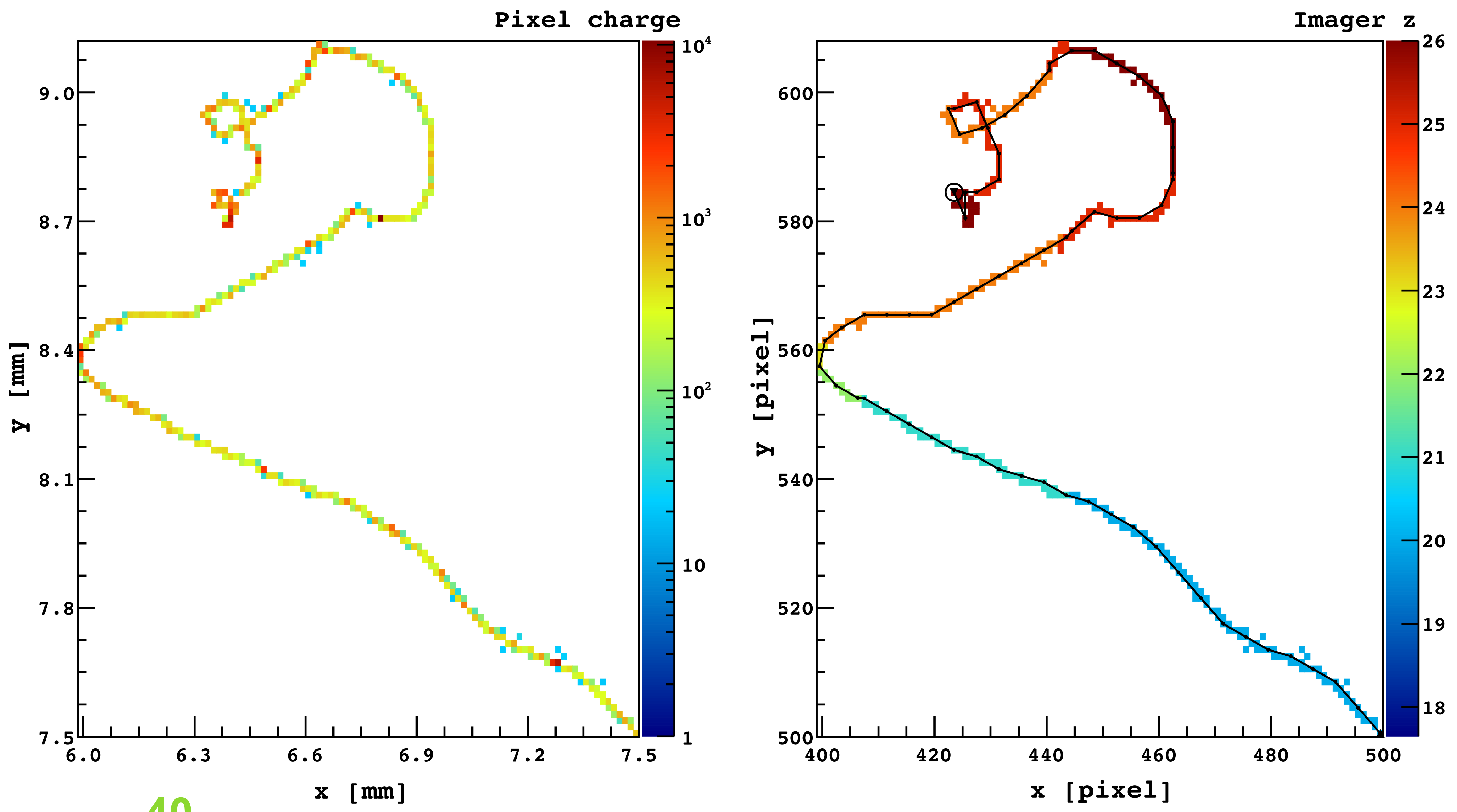
From simulation:
By identification of Bragg peak have achieved 10^{-3} suppression of single electron background, with 50% signal acceptance.

Strongly suppresses γ-ray and single β backgrounds

Double electron



Single electron



Radioactive backgrounds

In ROI Source	Raw background rate / $kg^{-1}y^{-1}$	After discrimination / $kg^{-1}y^{-1}$
β-decay (bulk)	$< 3.3 \times 10^{-1}$	$< 3.7 \times 10^{-9}$
β-decay (surface)	$< 4.1 \times 10^{-1}$	$< 1.2 \times 10^{-8}$
β-decay (cosmo.)	$< 9.9 \times 10^{-5}$	$< 1.5 \times 10^{-7}$
γ-ray (photo-elec.)	$< 7.2 \times 10^{-4}$	$< 7.2 \times 10^{-7}$
γ-ray (Compton)	$< 1.6 \times 10^{-3}$	$< 4.1 \times 10^{-7}$
γ-ray (pair prod.)	$< 1.9 \times 10^{-6}$	$< 1.9 \times 10^{-7}$
Total	$\mathbf{< 7.4 \times 10^{-1}}$	$\mathbf{< 1.5 \times 10^{-6}}$

Bulk backgrounds suppressed by α/β particle ID and spatial coincidences.

Also applied multiple scattering cut, limited to 10^{-1} suppression of nearby scatters.

Why we need more Latin American Astroparticle Physicists?

Ivone Albuquerque

Maximo Ave Pernas

Why we need more Latin American Astroparticle Physicists?

Ana Amélia Machado

Ettore Segreto

Ana Amélia Machado, que coordena o projeto na Unicamp ao lado de Segreto: “Tem de ter uma eficiência de visualização muito grande para poder detectar alguma coisa”

O pesquisador Ettore Segreto, um dos coordenadores do projeto: “O estudo do neutrino poderia explicar essa assimetria entre matéria e antimatéria. Essas são questões muito fundamentais”

The End