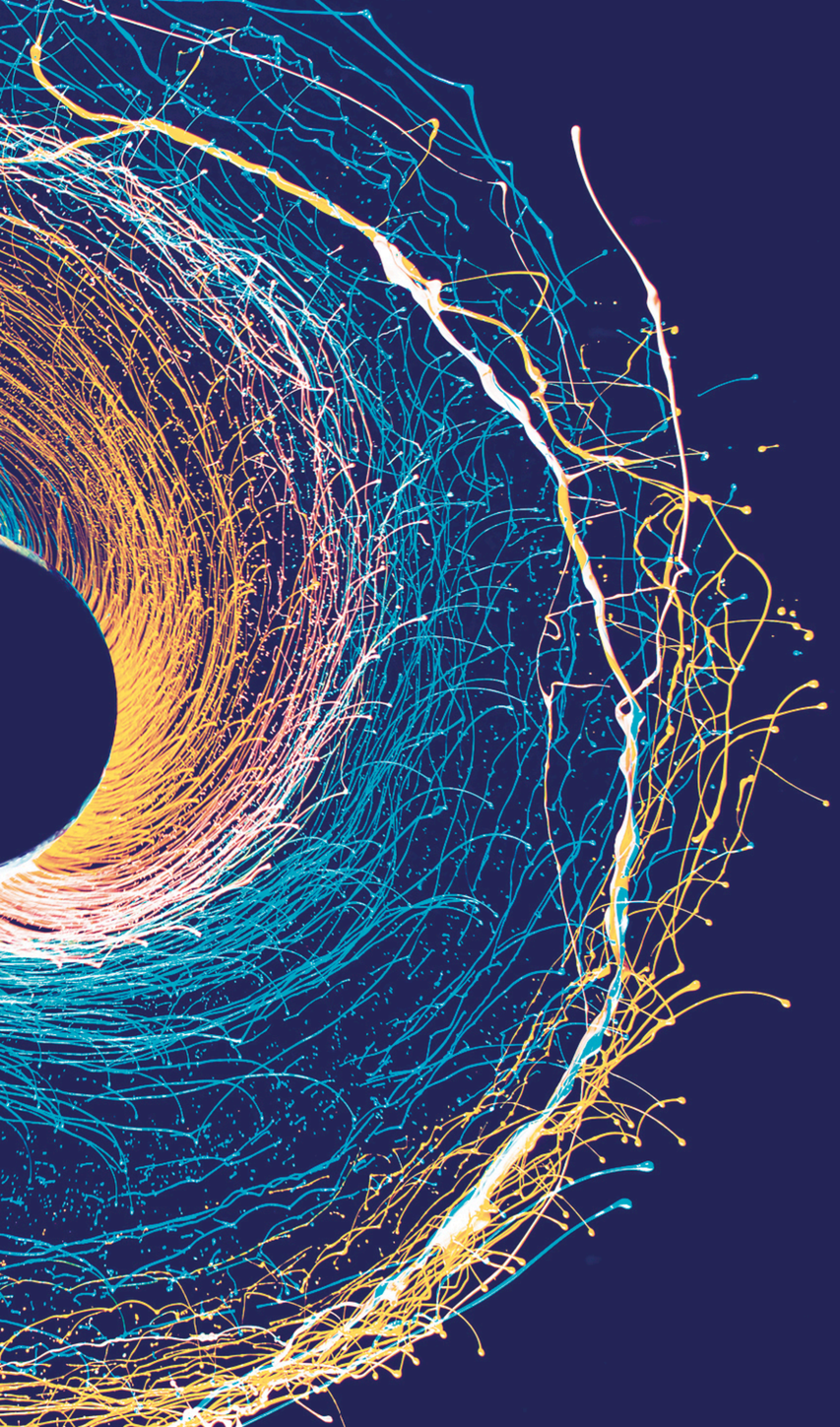
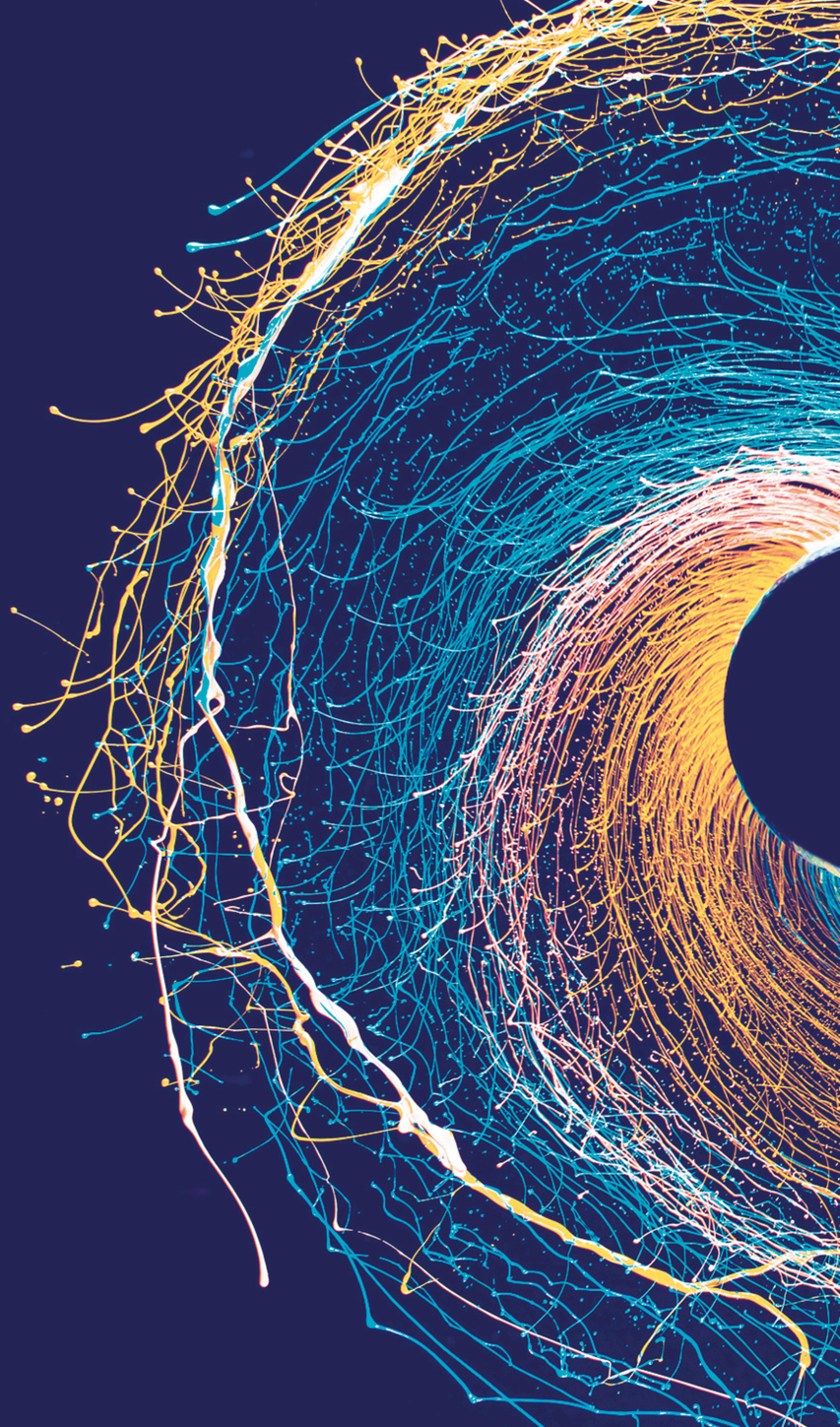


Cryogenic Materials for Particle Detectors

Cristiano Galbiati
Princeton University
Gran Sasso Science Institute

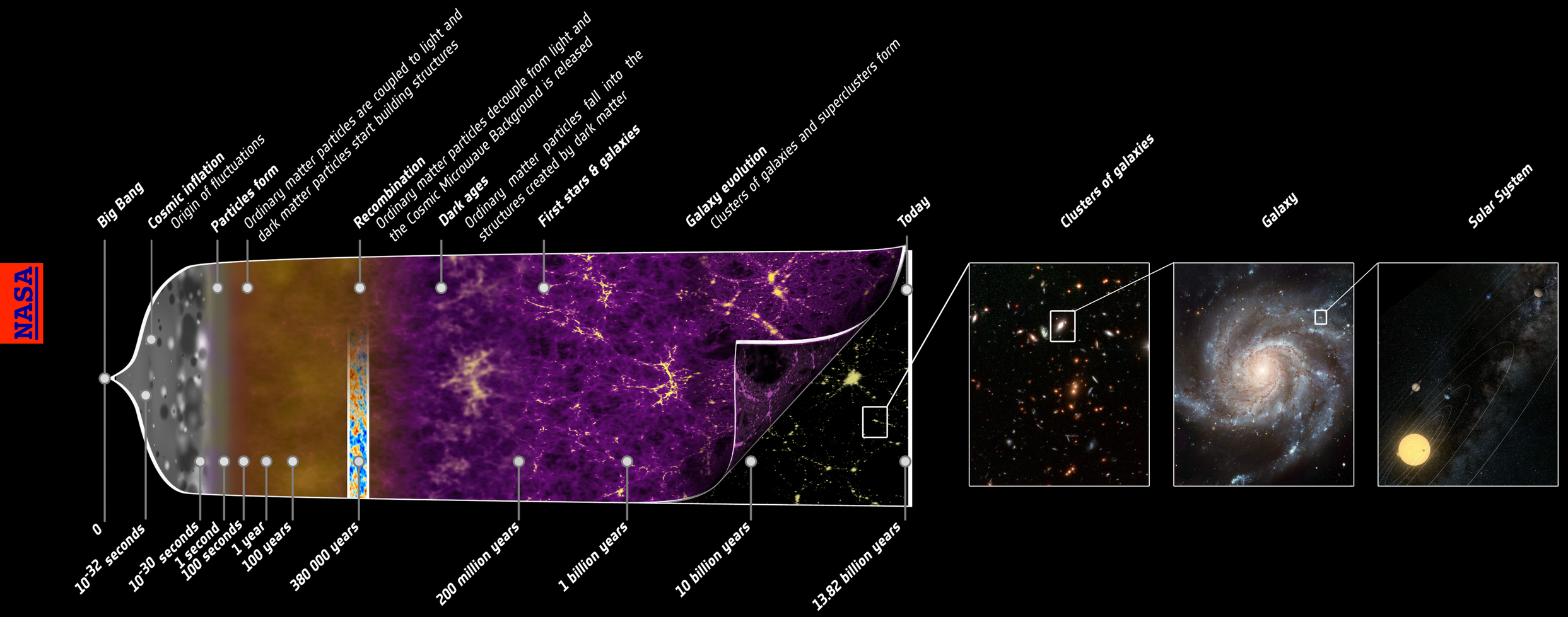
~

Società Italiana di Fisica
Passion for Science 2019
Accademia delle Scienze
dell'Istituto di Bologna
Bologna, November 7, 2019

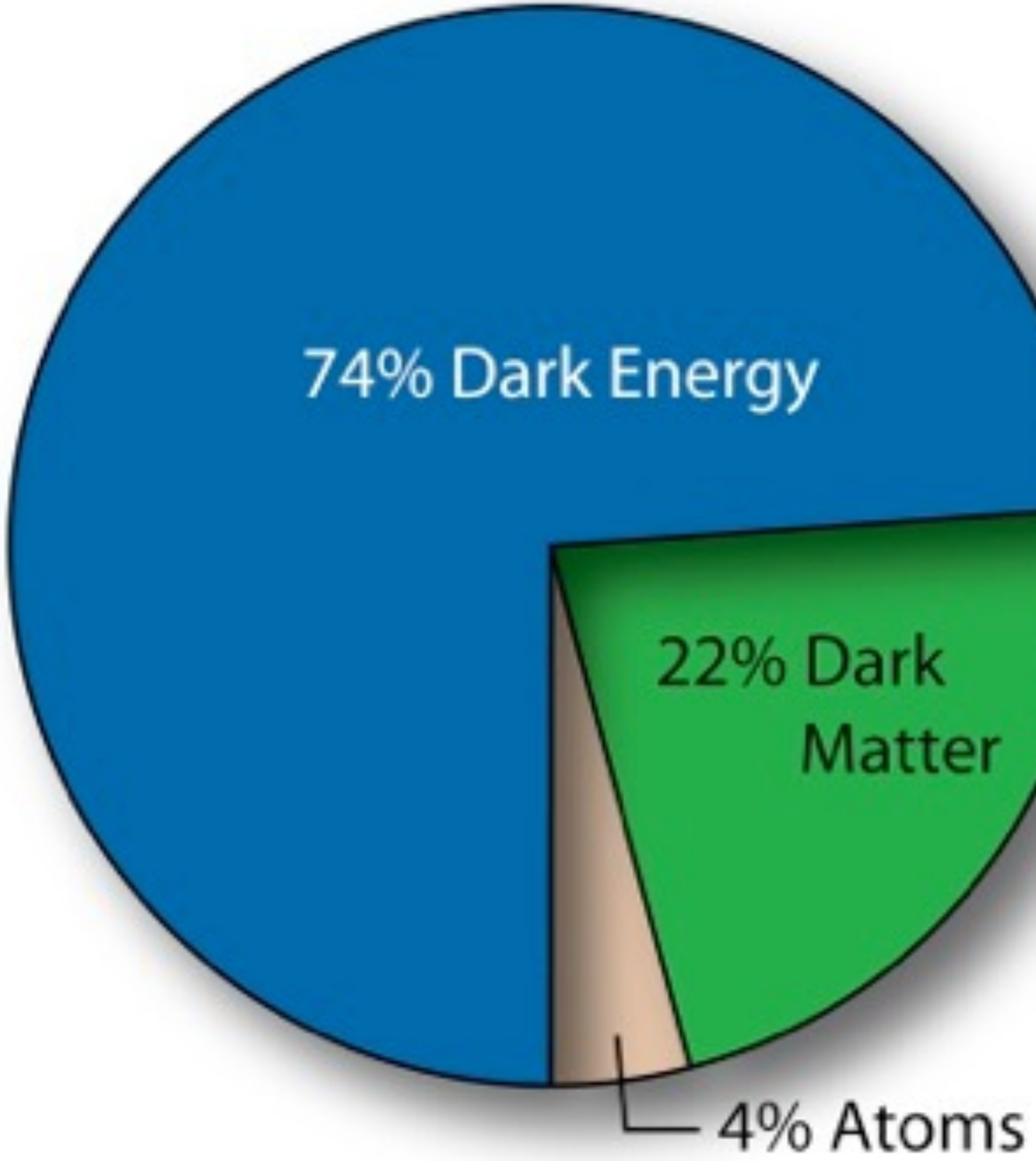


THE SCIENCE PERSPECTIVE

- Discovery of scalar boson completes Standard Model of particle physics
- Discovery of gravitational waves further validates General Relativity
- The two dark entities dominating the Universe, dark matter and dark energy, do not fit in the Standard Model
- Two big open questions at the intersection of particle physics and cosmology

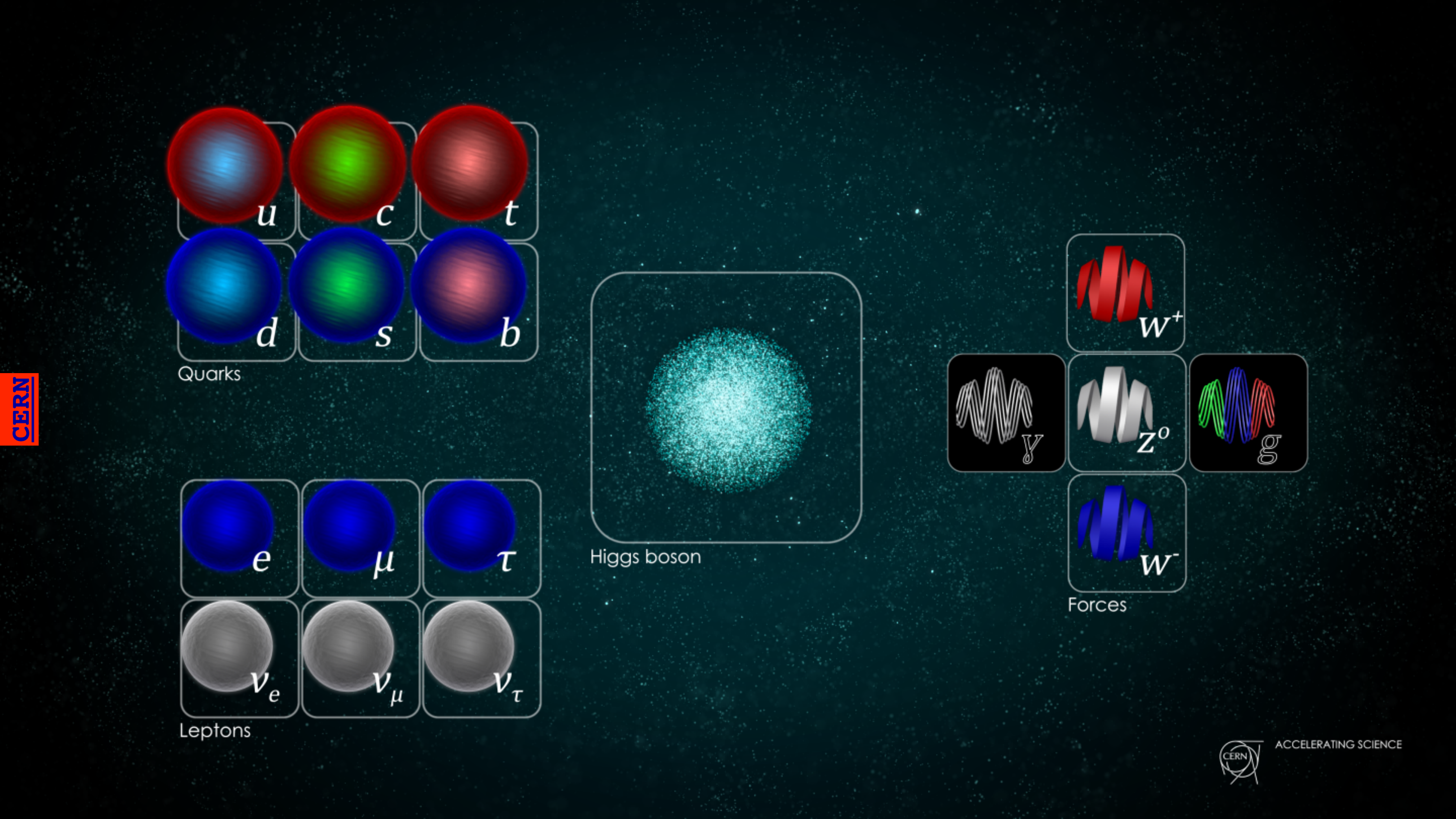

NASA
Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
Clusters of galaxies
Galaxy
Solar System
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

WMAP



THE SCIENCE OPPORTUNITY

- Searches of dark matter in underground laboratories at the forefront of discovery: the cosmic frontier becomes the new energy frontier
- Neutrino sector deeply intertwined with dark matter if neutrinos are Majorana particles

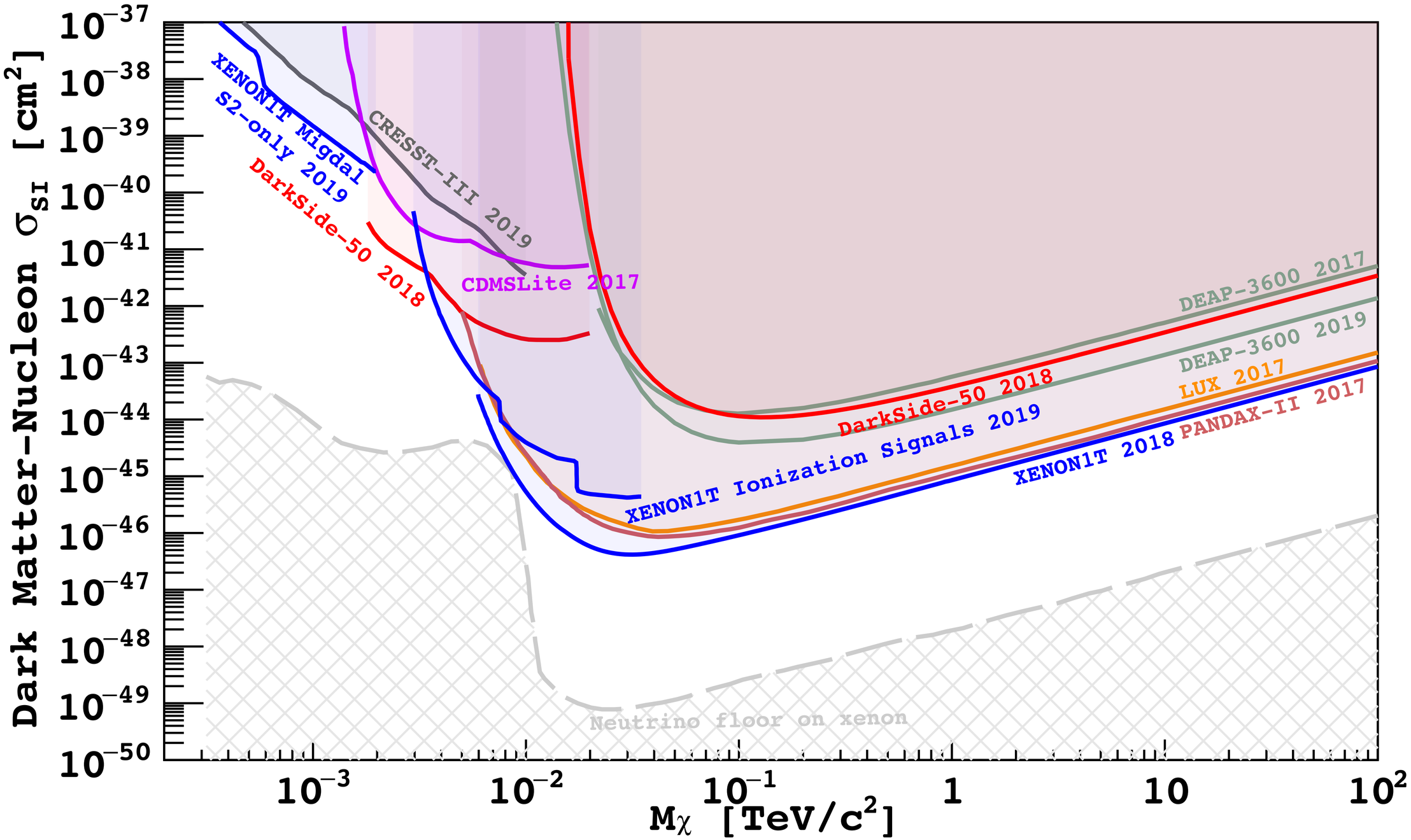

u
c
t
d
s
b
Quarks
e
μ
τ
ν_e
ν_μ
ν_τ
Leptons
Higgs boson
W^+
γ
Z^o
g
W^-
Forces
CERN
ACCELERATING SCIENCE

TEORIA SIMMETRICA DELL'ELETTRONE E DEL POSITRONE

Nota di Ettore Majorana

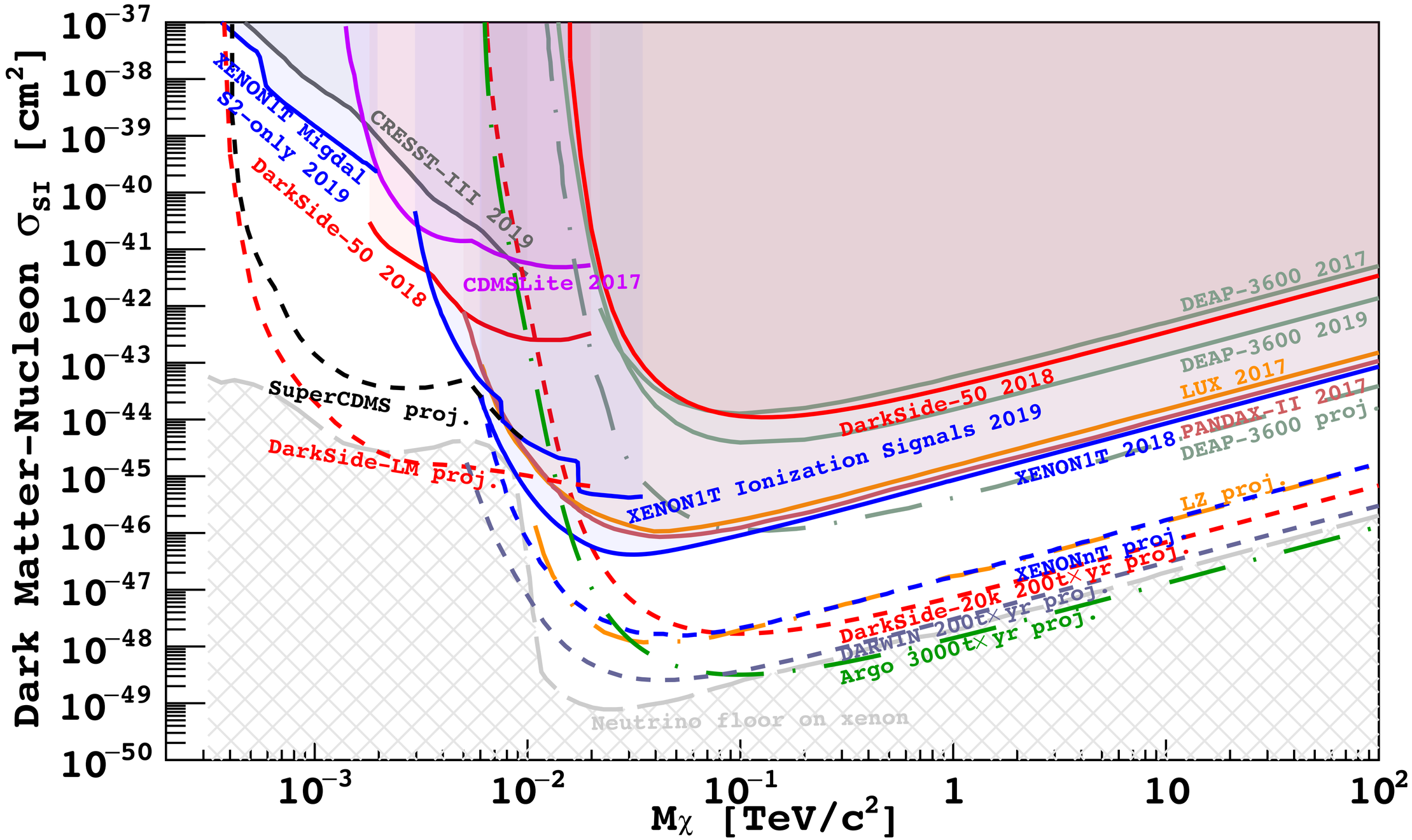
THE SCIENCE GOALS

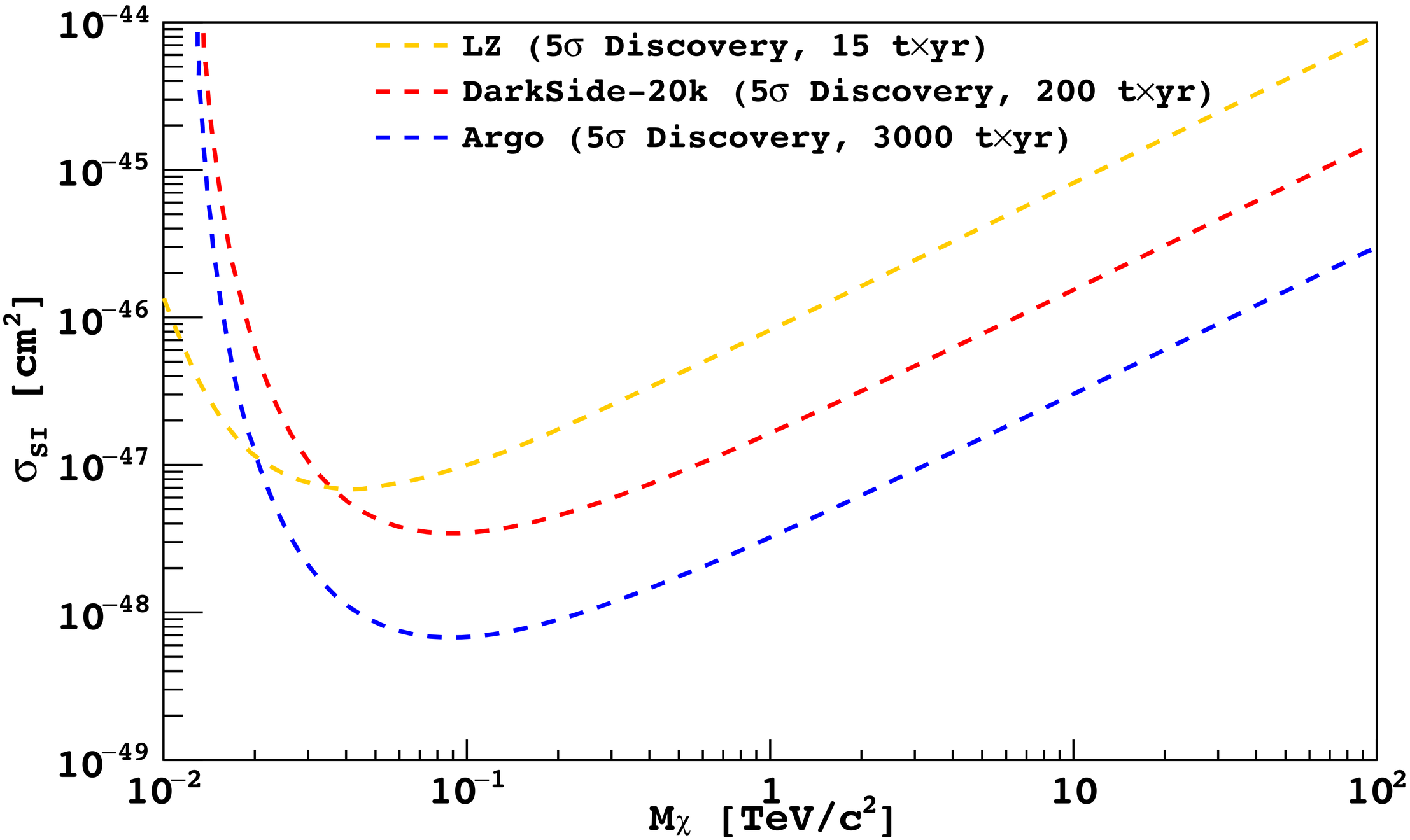
- Find the bottom of the dark matter well
- Yes/no search for Majorana neutrinos


Dark Matter-Nucleon σ_{SI} [cm^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
M_χ [TeV/c^2]
XENON1T Migdal
S2-only 2019
DarkSide-50 2018
CRESST-III 2019
CDMSLite 2017
DEAP-3600 2017
DEAP-3600 2019
LUX 2017
DarkSide-50 2018
PANDAX-II 2017
XENON1T Ionization Signals 2019
XENON1T 2018
Neutrino floor on xenon

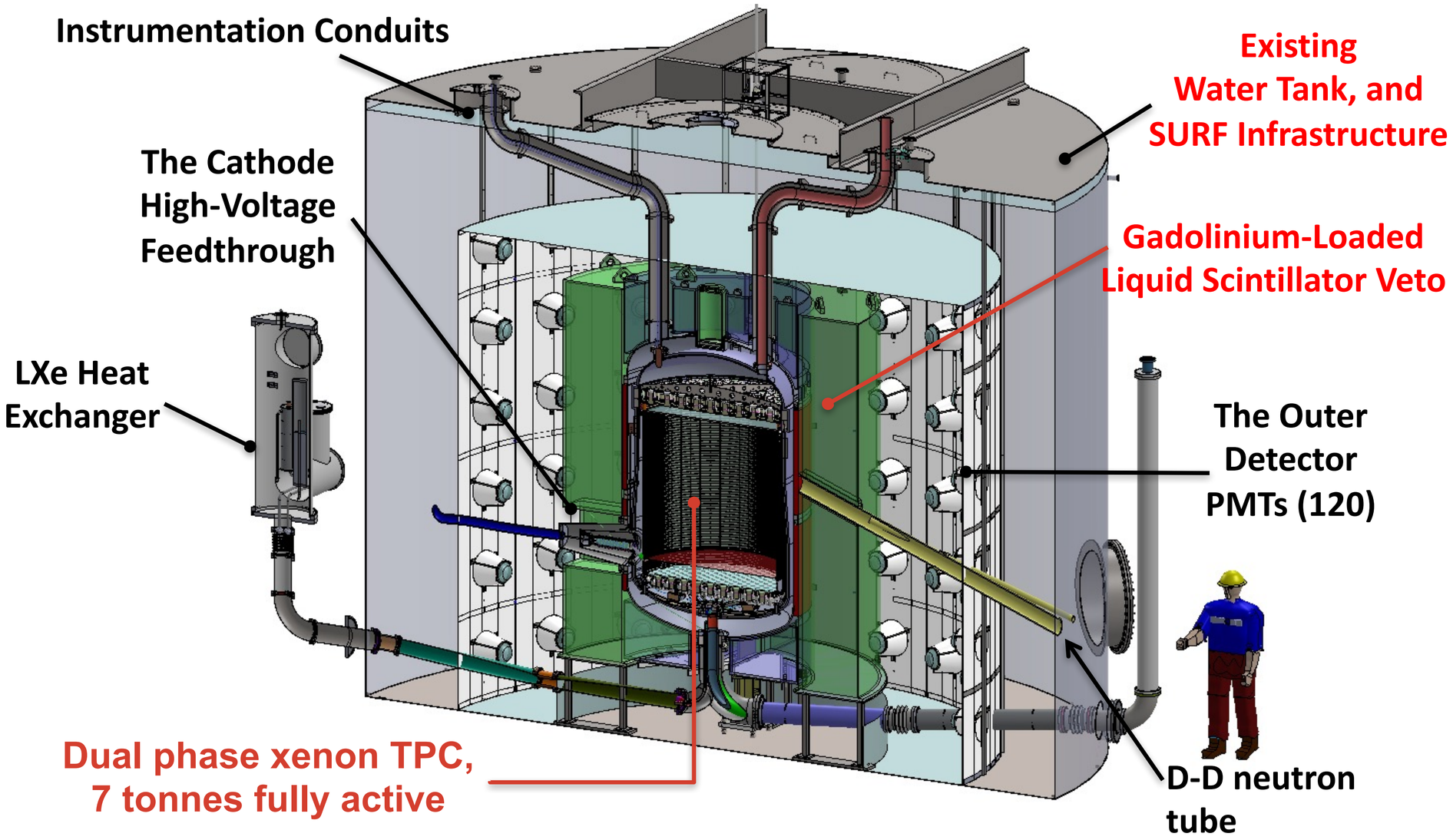
HIGH MASS SEARCH REQUIREMENTS

- Exposure of O(1000 tonne × year)
- Background free operation
  - Solar neutrinos become background: rejection of minimum ionizing background must reach at least one part in 10^5

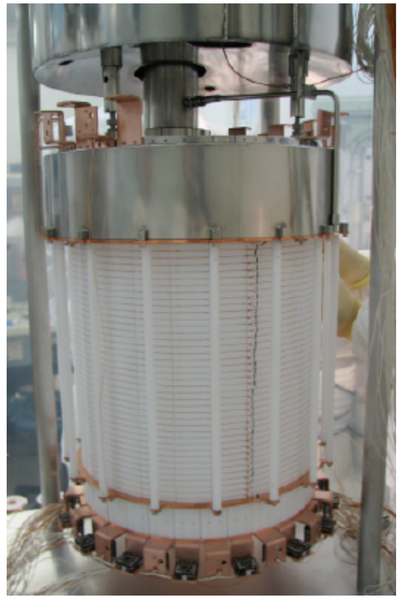
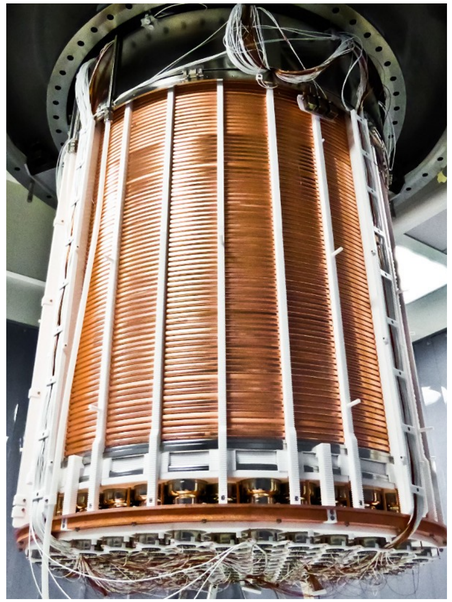
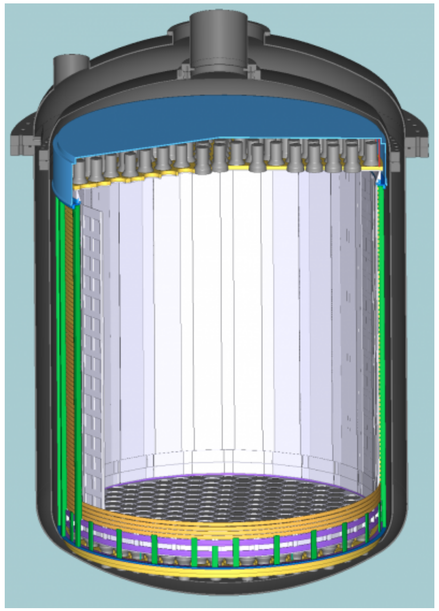

Dark Matter-Nucleon σ_{SI} [cm^2]
M_χ [TeV/c^2]
XENON1T Migdal
S2-only 2019
DarkSide-50 2018
CRESST-III 2019
CDMSLite 2017
SuperCDMS proj.
DarkSide-LM proj.
DEAP-3600 2017
DEAP-3600 2019
LUX 2017
PANDAX-II 2017
DEAP-3600 proj.
DarkSide-50 2018
XENON1T Ionization Signals 2019
XENON1T 2018
LZ proj.
XENONnT proj.
DarkSide-20k 200t×yr proj.
DARWIN 200t×yr proj.
Argo 3000t×yr proj.
Neutrino floor on xenon


LZ (5σ Discovery, 15 t×yr)
DarkSide-20k (5σ Discovery, 200 t×yr)
Argo (5σ Discovery, 3000 t×yr)
σ_{SI} [cm^2]
M_χ [TeV/c^2]
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-2}
10^{-1}
1
10
10^{2}

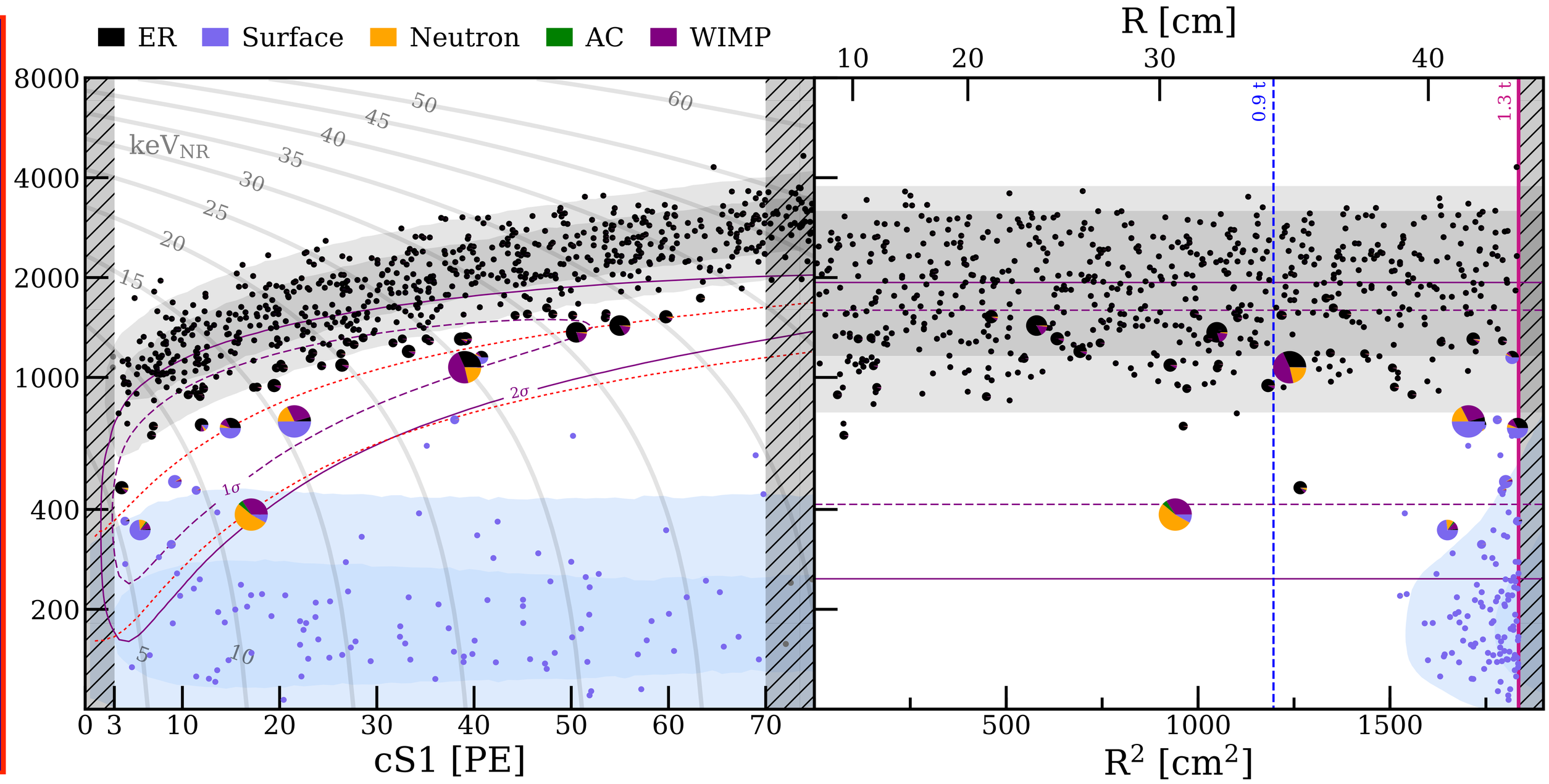
The LUX-ZEPLIN detector



The phases of the XENON Program

XENON10	XENON100	XENON1T	XENONnT
			
2005-2007	2008-2016	2012-2018	2019-2023
25 kg- 15cm drift	161 kg- 30 cm drift	3200 kg- 100 cm drift	8000 kg-150 cm drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

Physical Review Letters 121, 111302 (2018)



LZ backgrounds summary

5.6 tonnes, 1000 days

Intrinsic Contamination Backgrounds	ER (cts)	NR (cts) (w/ SF rej.)
Subtotal (Detector Components)	**9**	**0.072**
222Rn (1.81 μBq/kg)	681	-
220Rn (0.09 μBq/kg)	111	-
natKr (0.015 ppt g/g)	25	-
natAr (0.45 ppb g/g)	2	-
210Bi (0.1 μBq/kg)	40	-
Laboratory and Cosmogenics	5	0.06
Fixed Surface Contamination	0	0.39
Subtotal (Non-ν counts)	**873**	**0.52**
Physics Backgrounds		
136Xe 2νββ	67	0
Astrophysical ν counts (pp+7Be+13N)	255	0
Astrophysical ν counts (8B)	0	0**
Astrophysical ν counts (Hep)	0	0.21
Astrophysical ν counts (diffuse	0	0.05
Astrophysical ν counts (atmospheric)	0	0.46
Subtotal (Physics backgrounds)	322	0.72
Total	1,190	1.24
Total (with 99.5% ER discrimination,	5.97	0.62
	6.59	

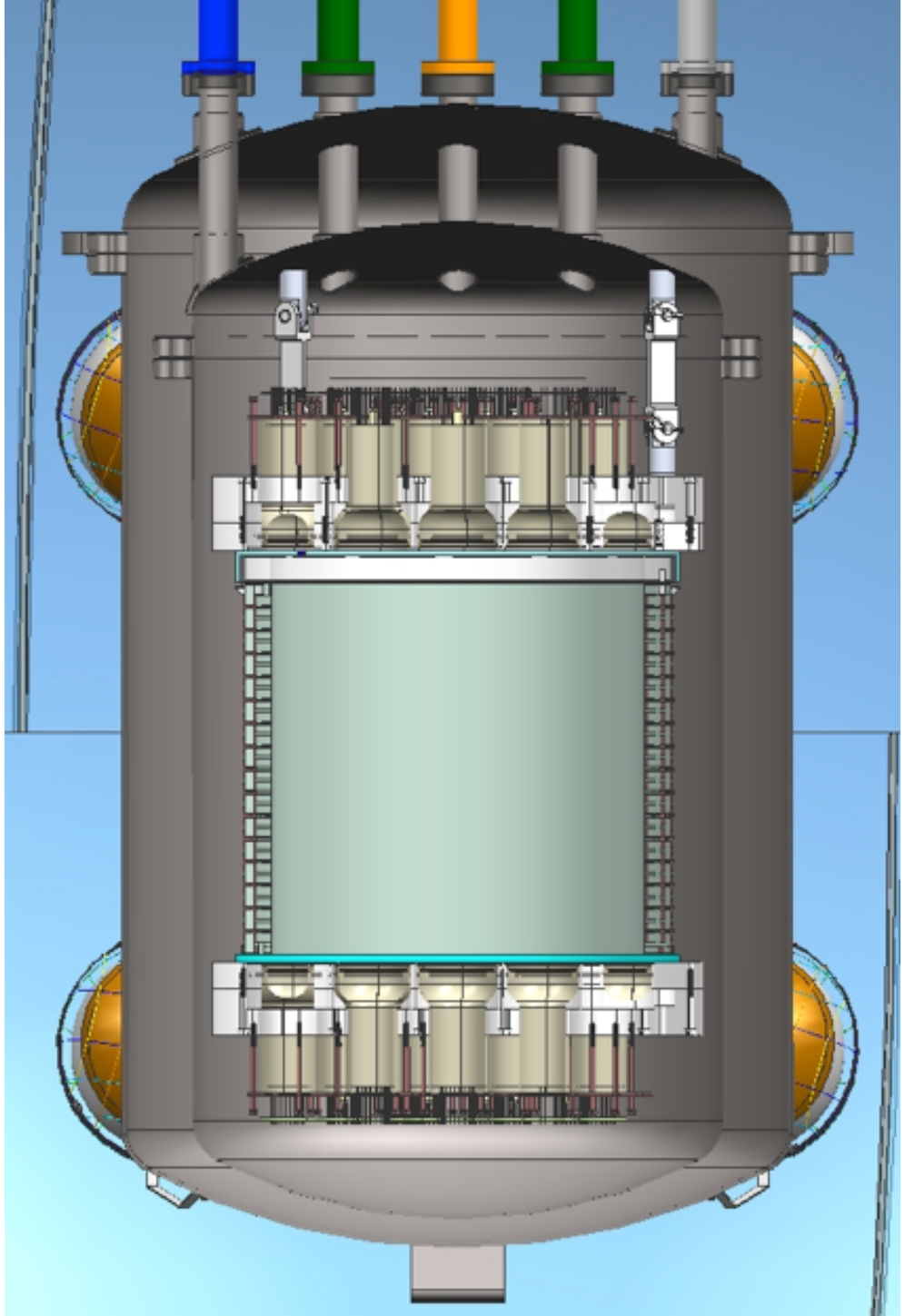
Radon dominates ER backgrounds

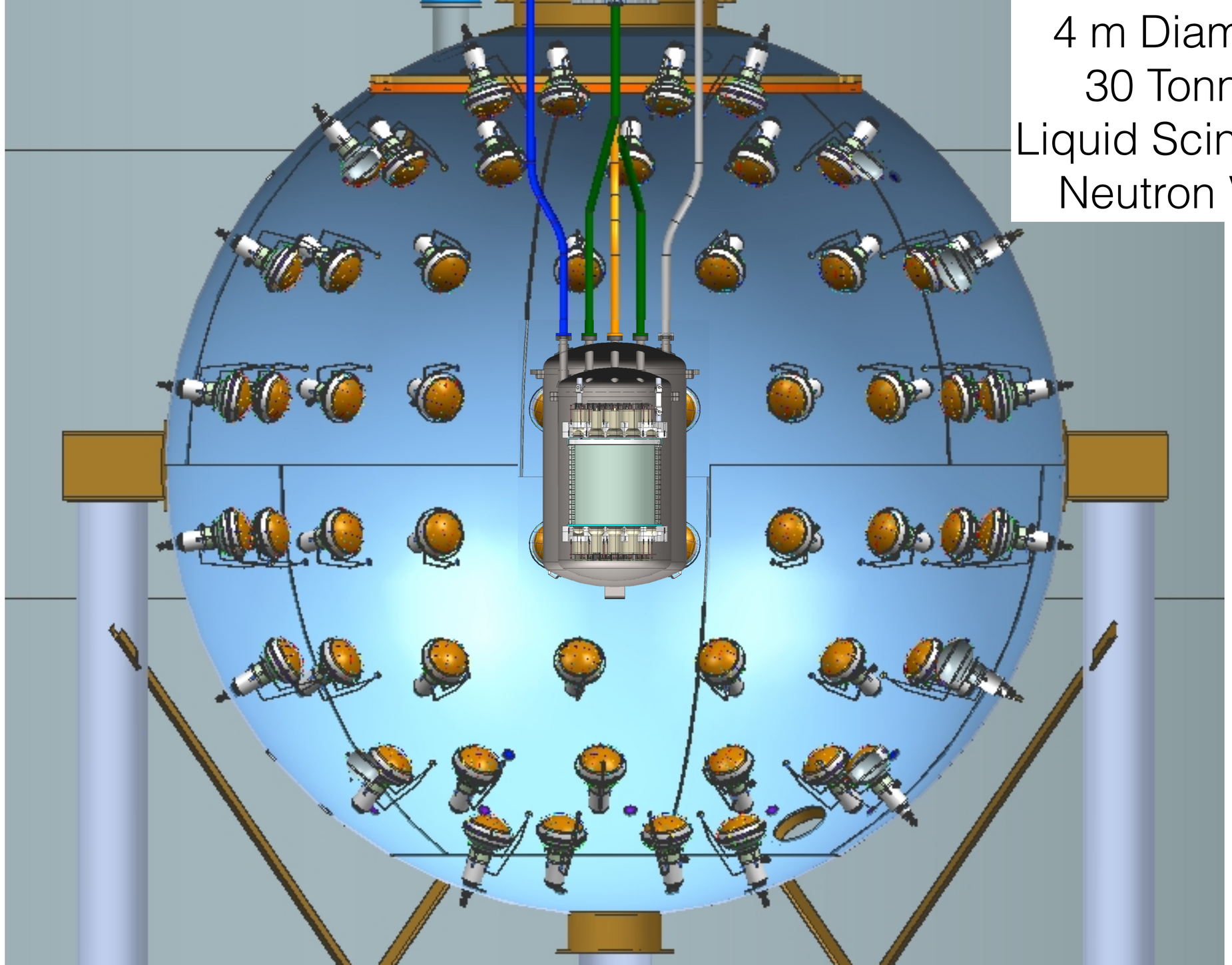
Gamma backgrounds (PMTs, cryostat) are negligible.

pp solar neutrinos, elastic scattering on atomic electrons

Coherent neutrino scattering on xenon nuclei

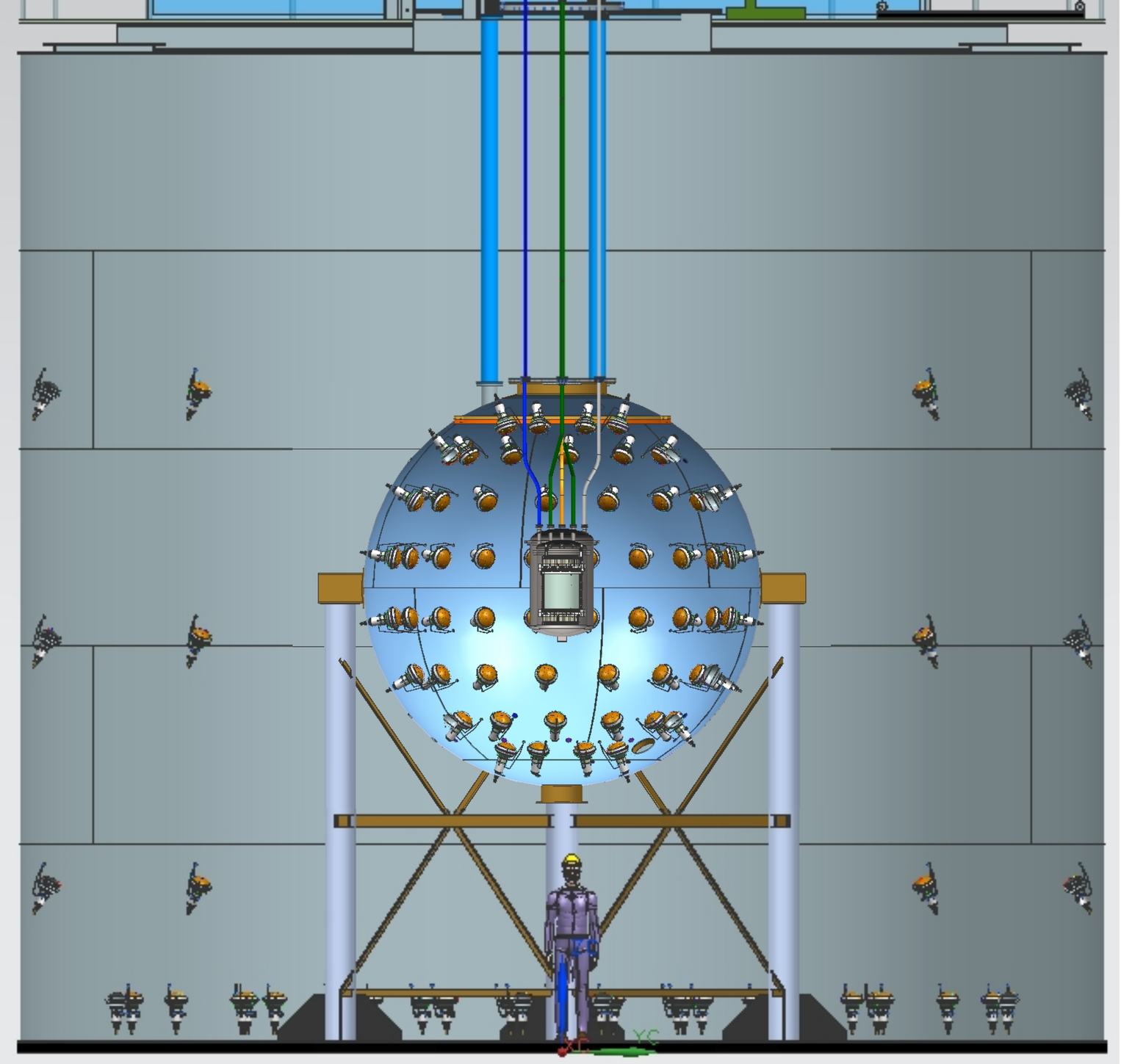
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target





4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

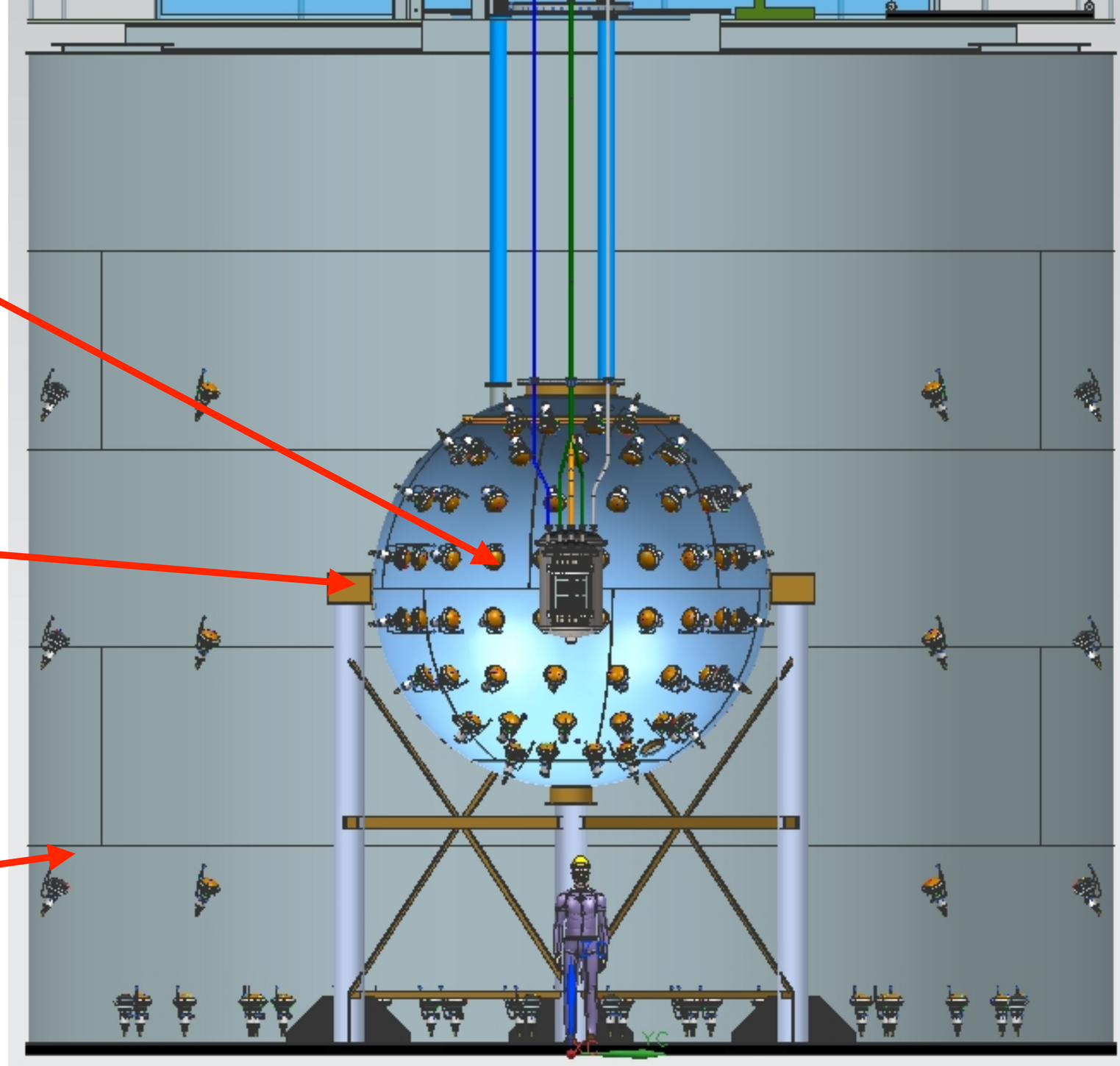
10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



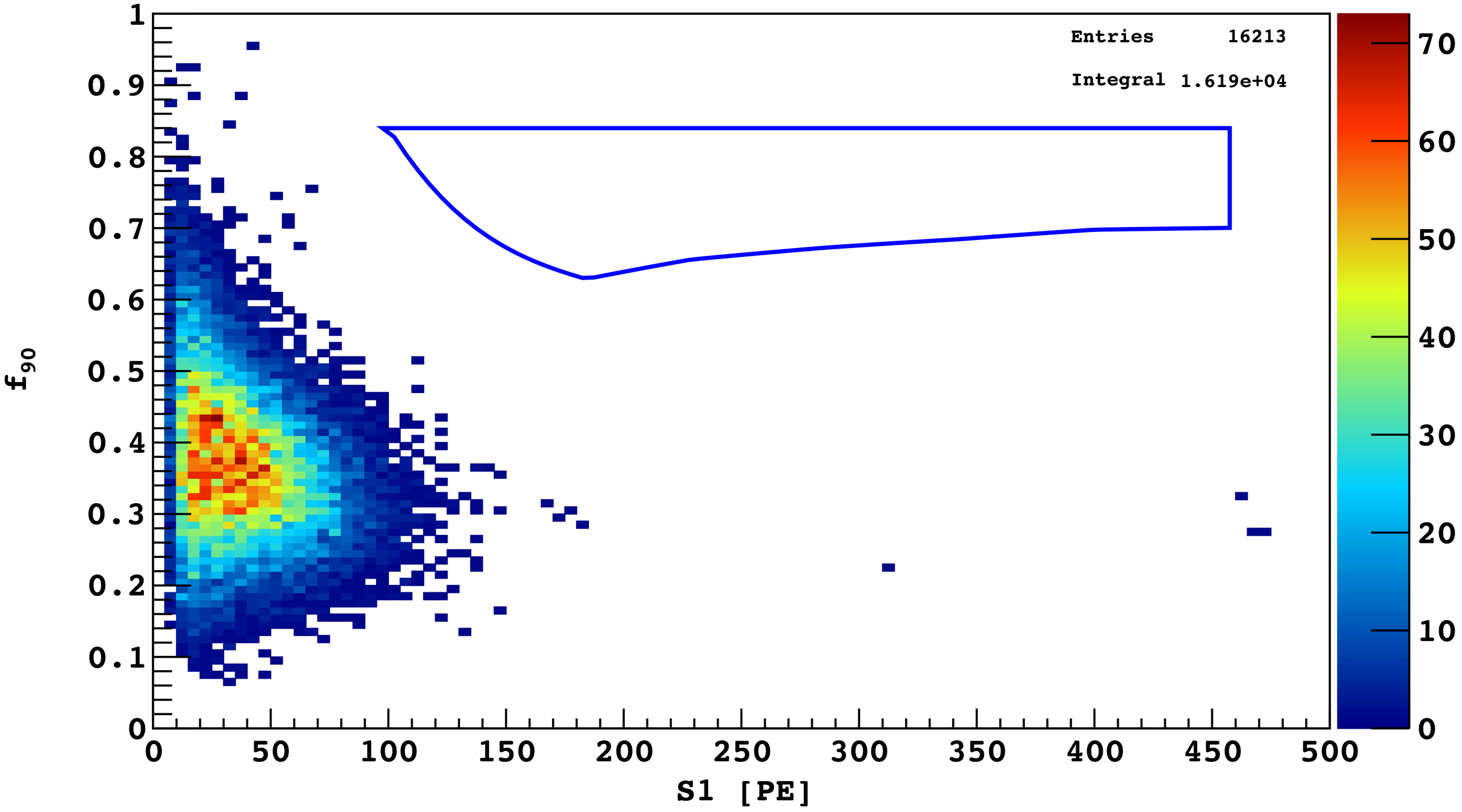
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

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



+r<10 cm && 50% loss S2/S1 cut (70d)

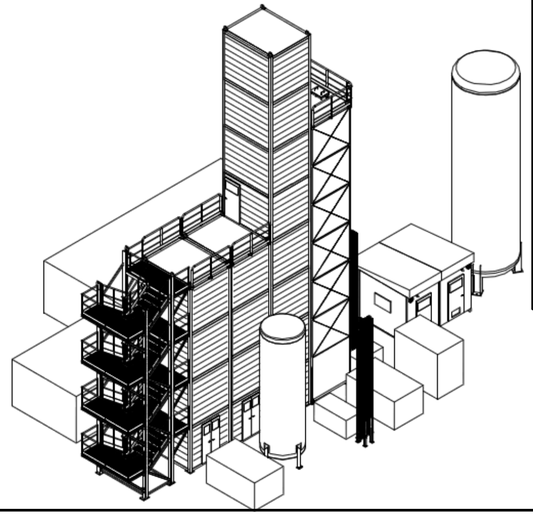


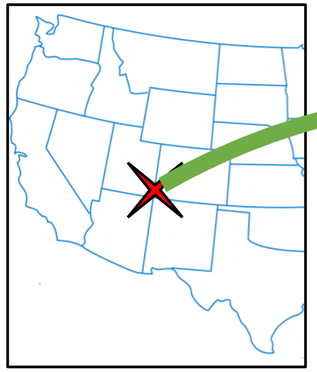
Physical Review D 98, 102006 (2018)

THE DARKSIDE-20K PROJECT

- €90M capital funding
- Agencies: IT INFN, US NSF, US DOE, CAN CFI, UK STFC
- Seed funding by Regione Abruzzo and Regione Autonoma della Sardegna

Production and Purification





UAr transported via boat for final purification at Aria

Production: Urania

- Commercial-scale plant to extract UAr
- Located in Southwestern Colorado
- UAr extracted from CO_2 well gas at the tonne scale

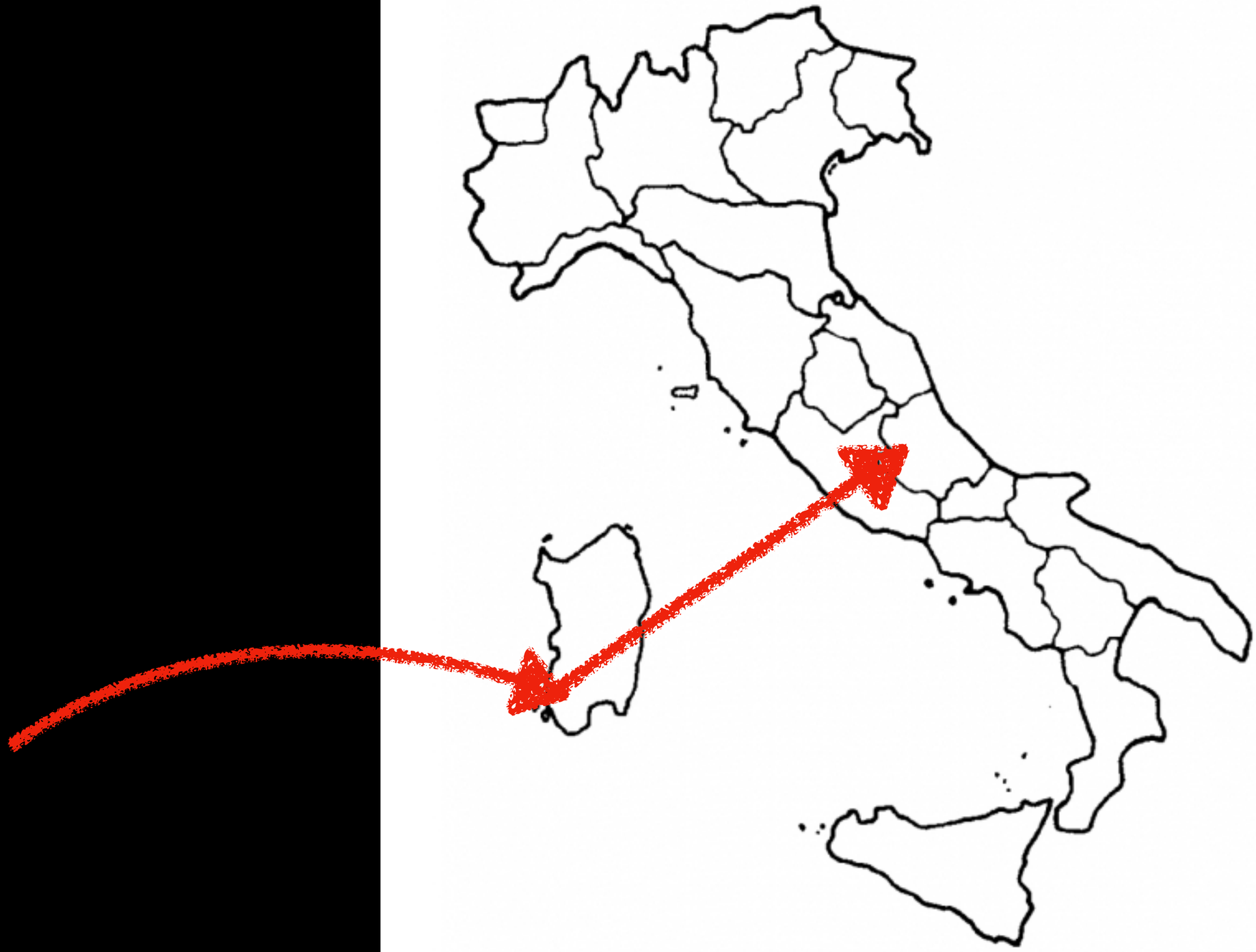
Focus of this talk

Purification: Aria

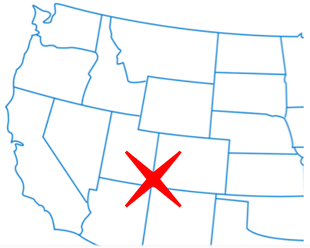
(see M. Simeone's talk for details)

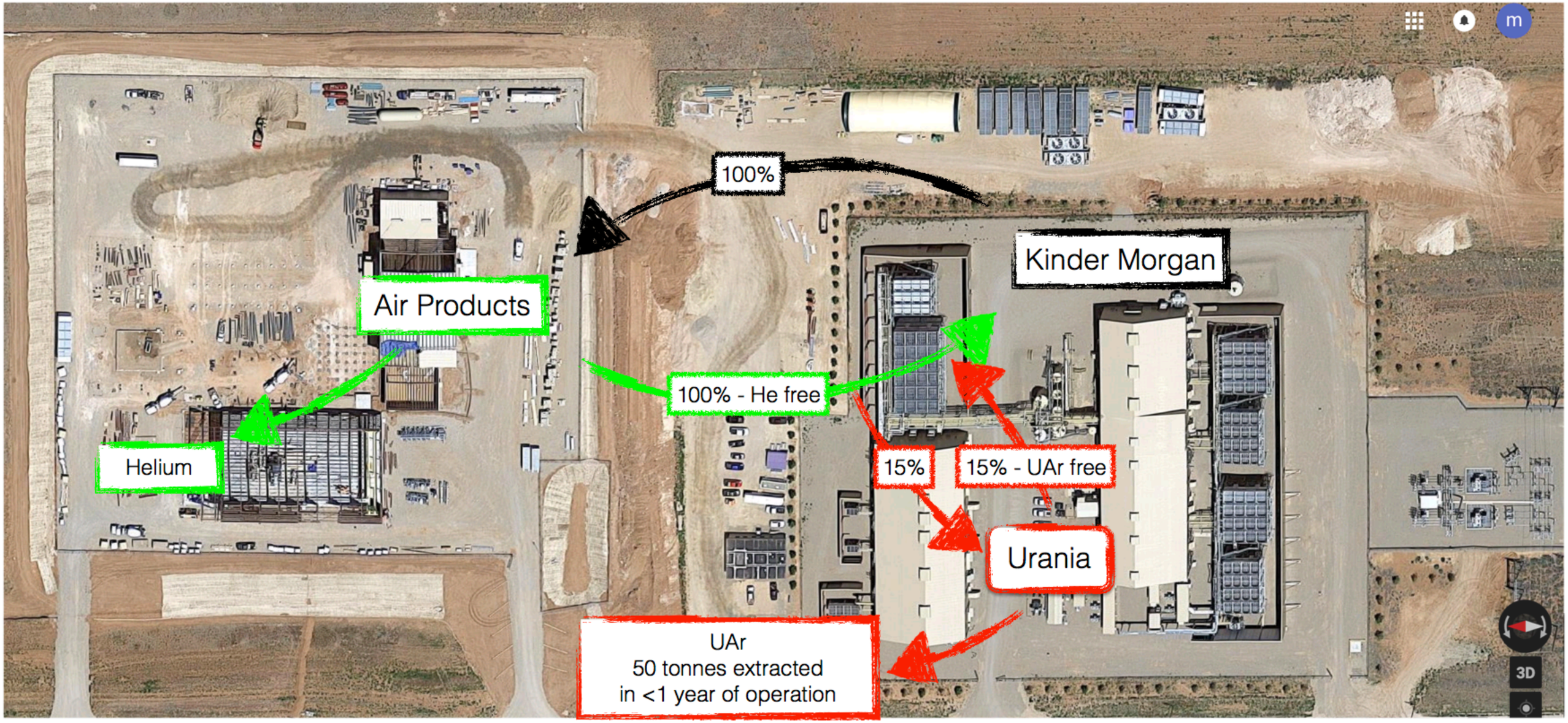
- 350 m tall cryogenic distillation column to purify UAr and isotopically separate argon and other elements
- Located in refurbished carbon mine shaft in Sardinia, Italy
- Will chemically purify the UAr for DS-20k to detector grade

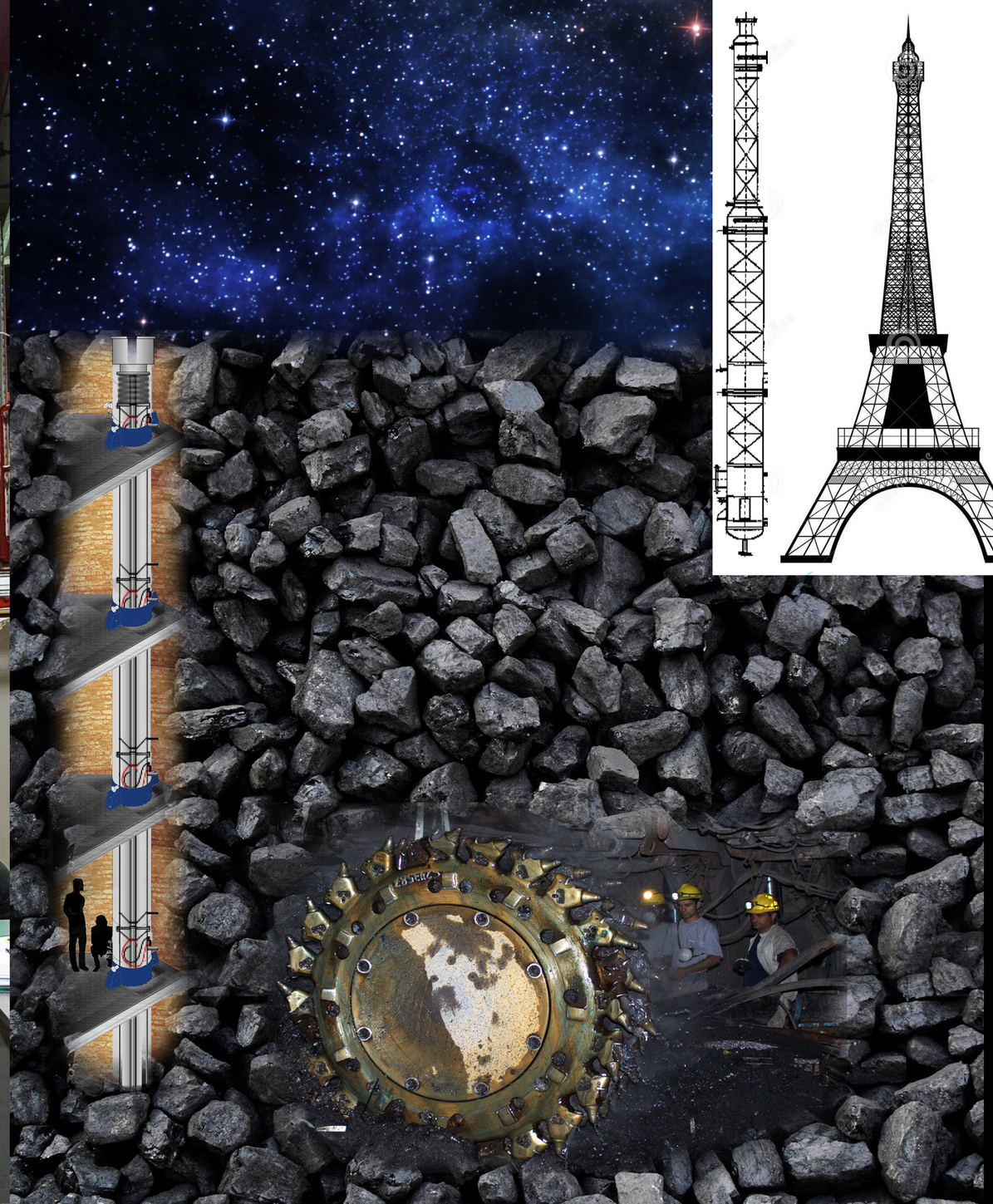
Renshaw, PNNL LRUA Workshop 2018

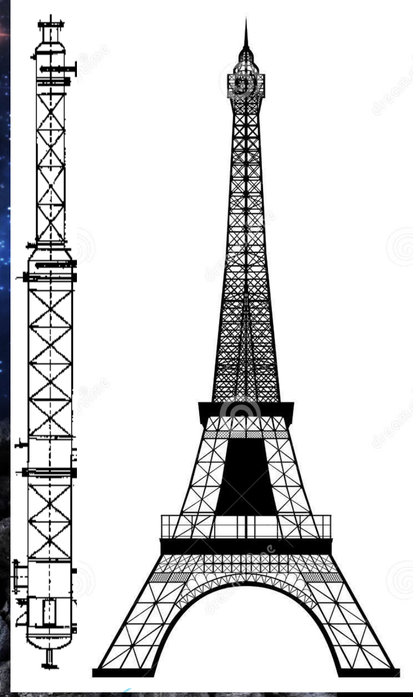


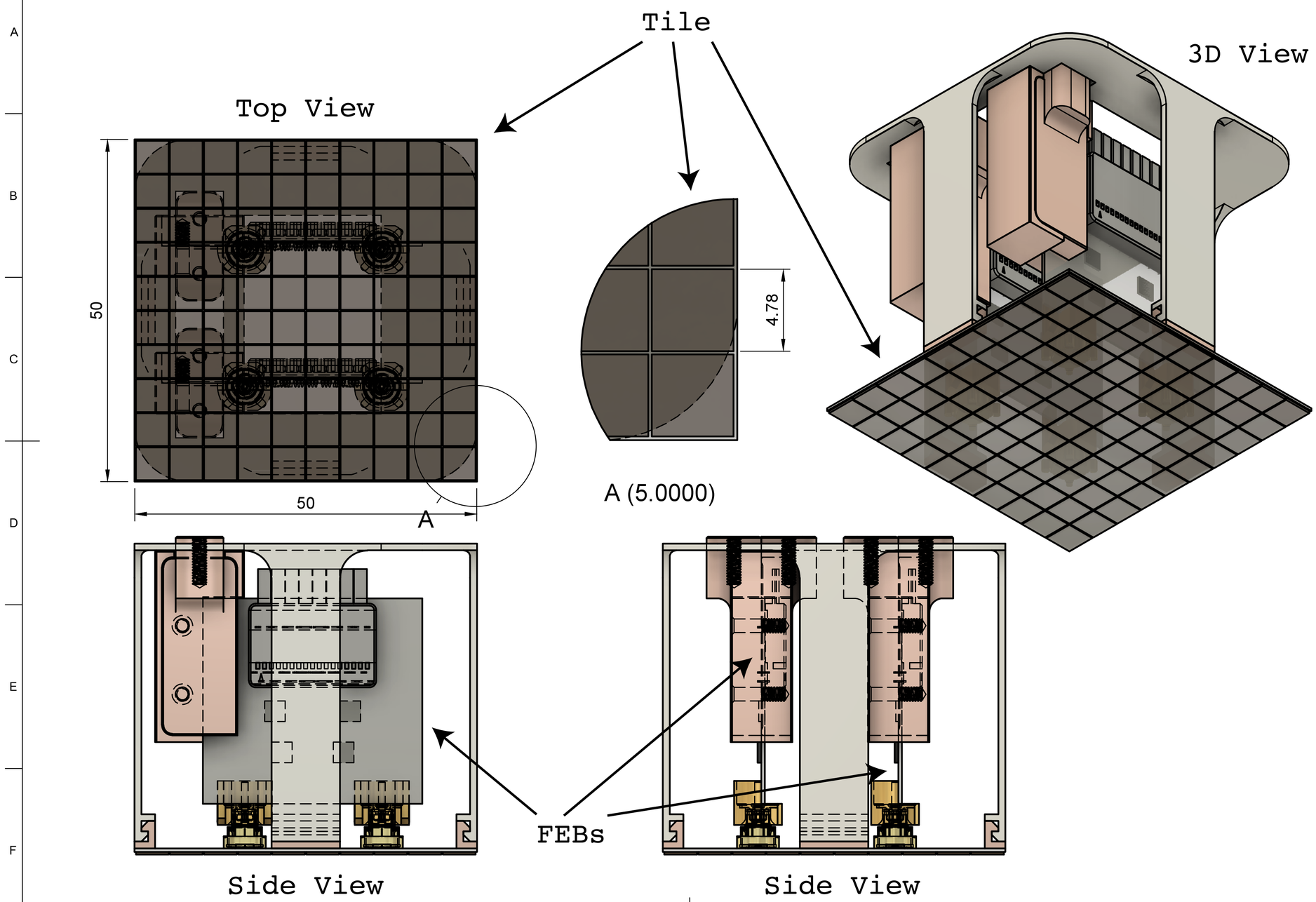
Enter the Age of Urania

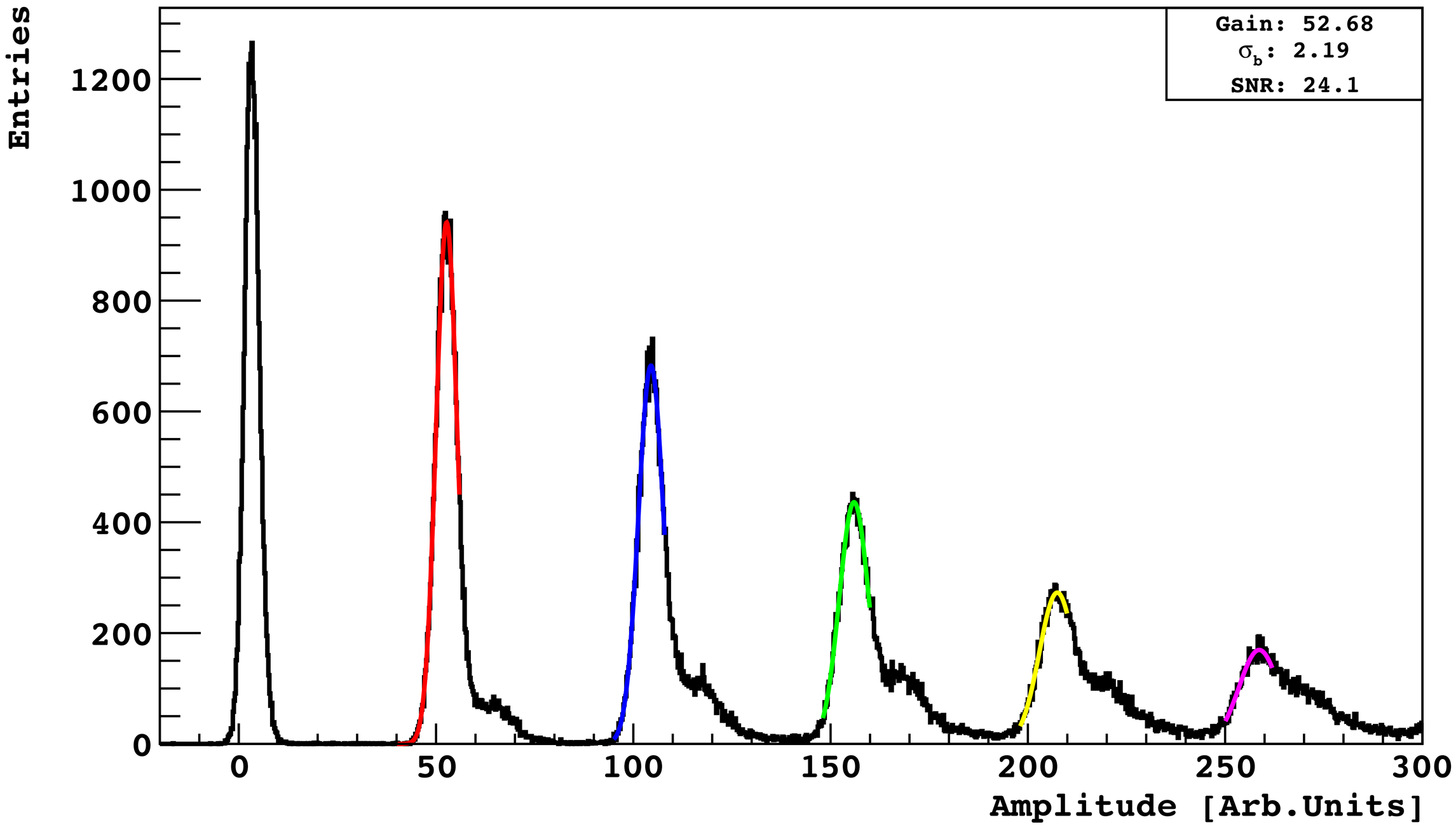


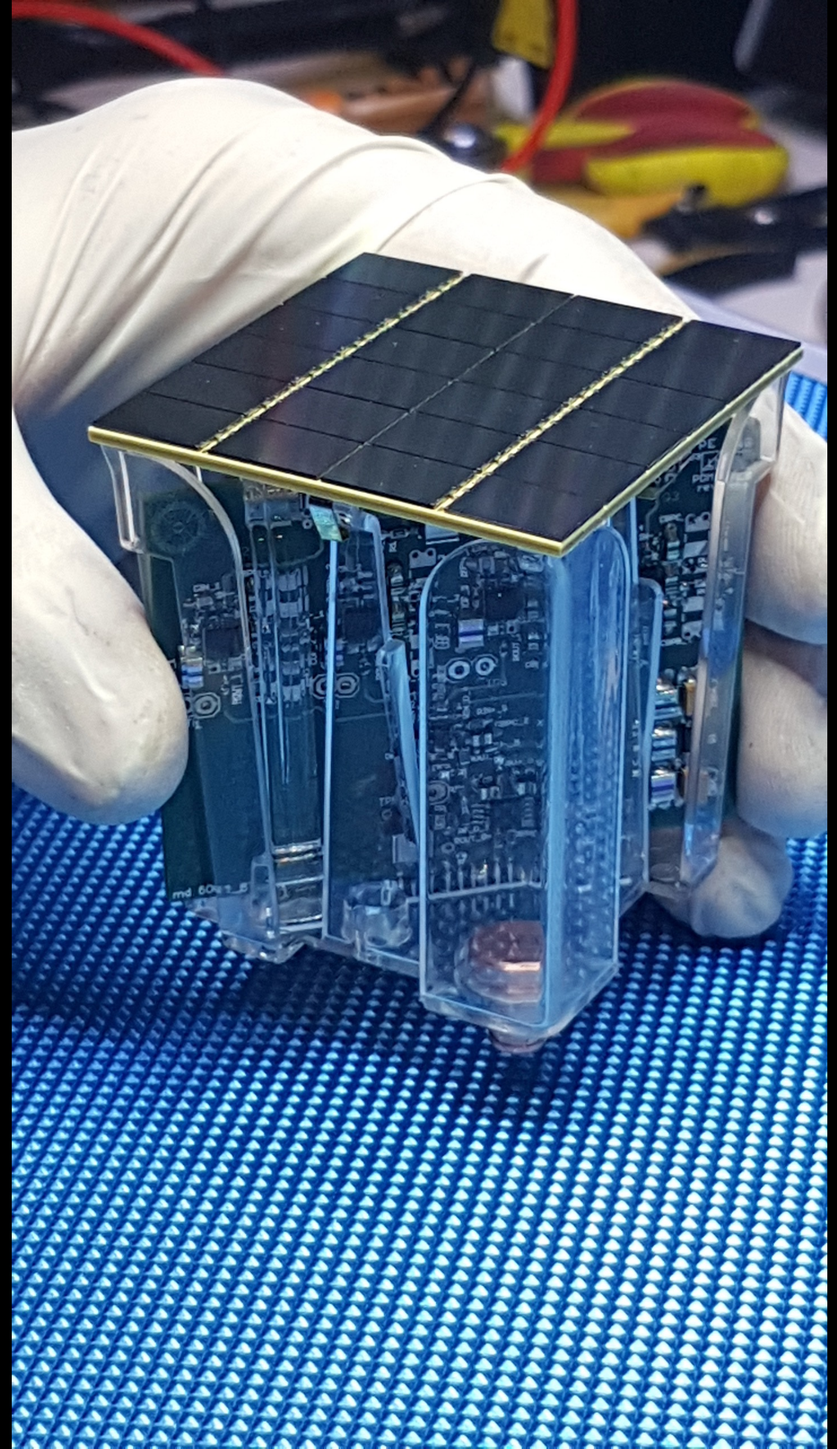


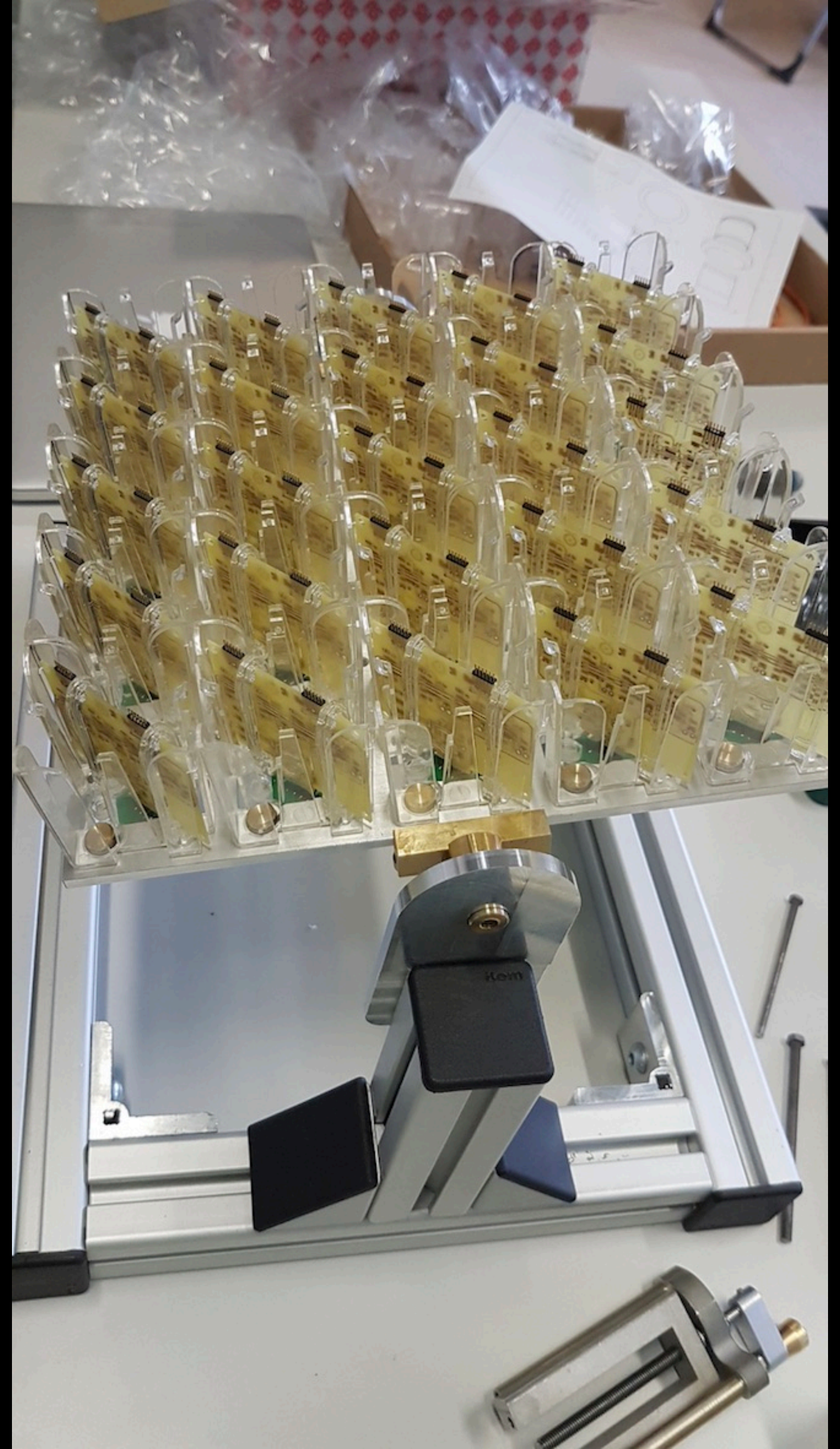


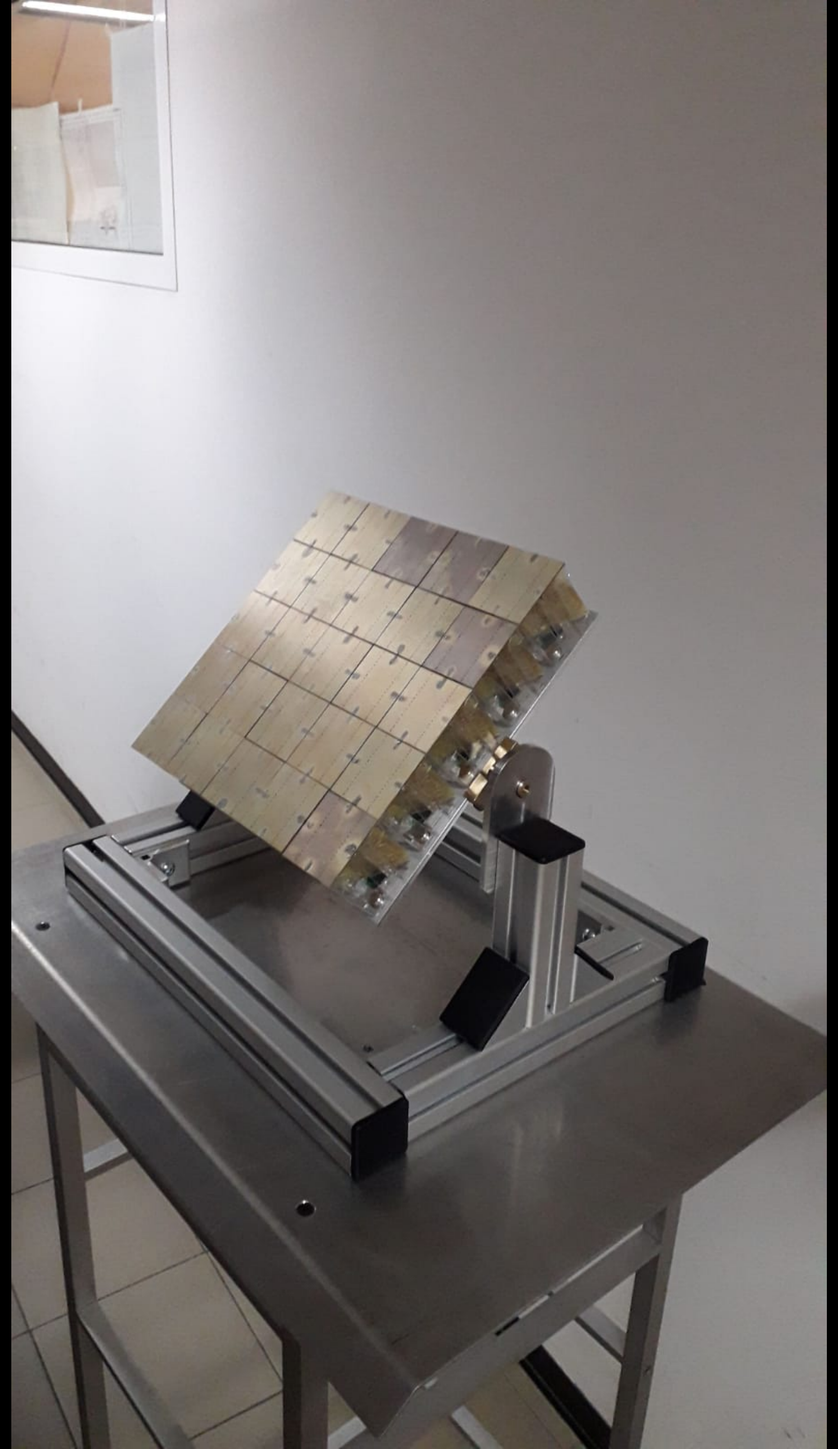


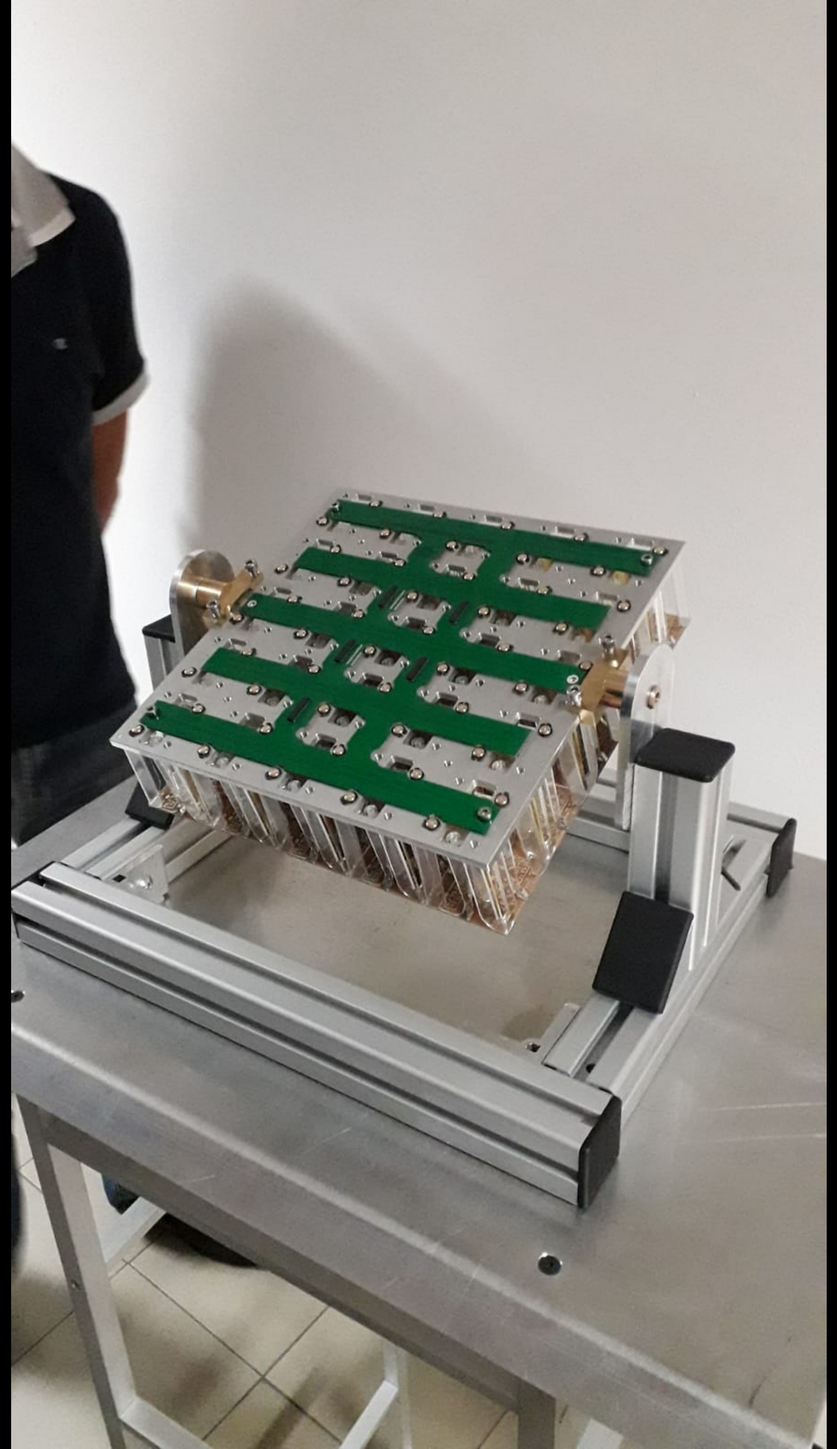

Tile
Top View
3D View
50
50
A
4.78
A (5.0000)
FEBs
Side View
Side View

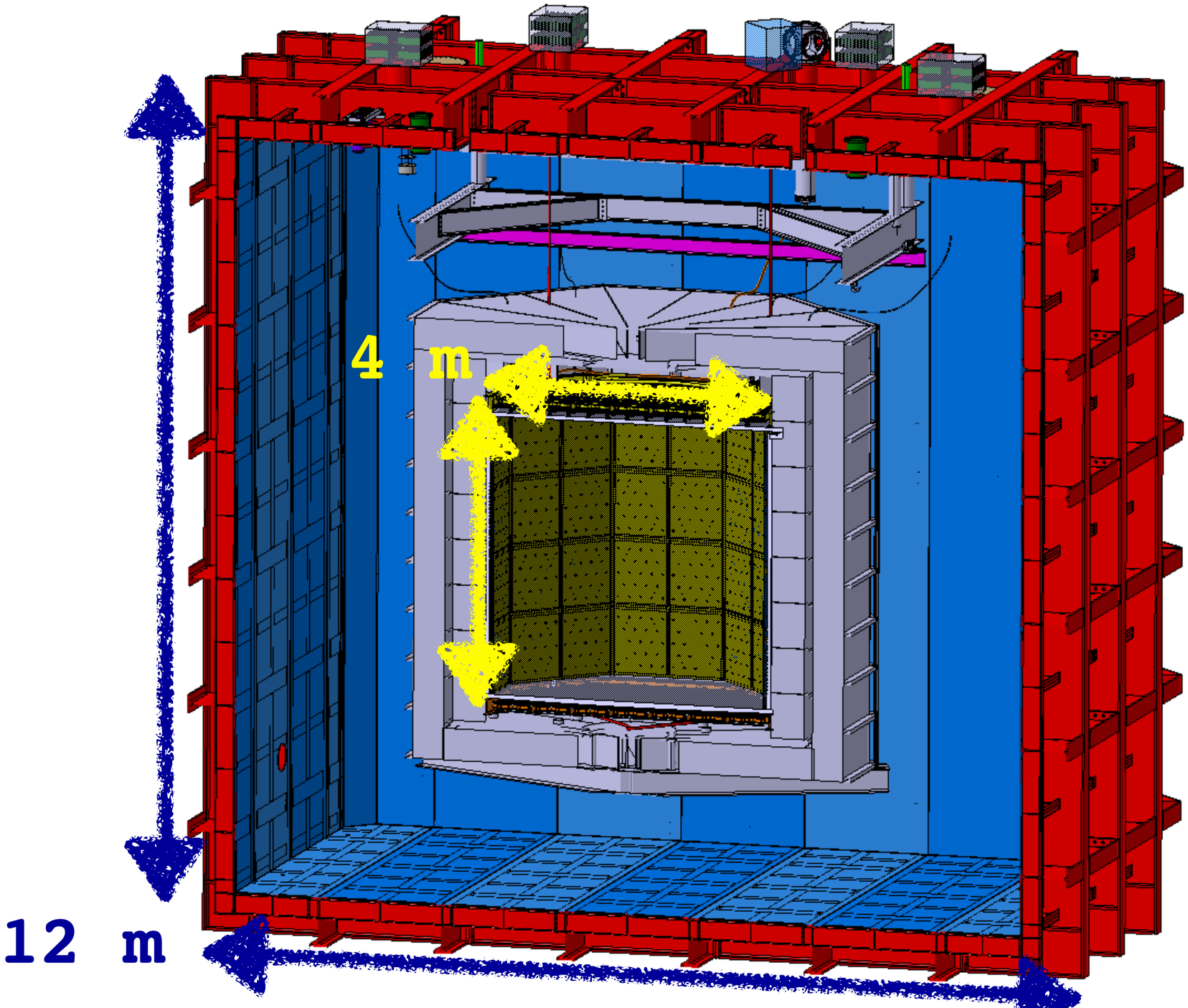

Gain: 52.68
σ_b: 2.19
SNR: 24.1
Entries
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
Amplitude [Arb.Units]







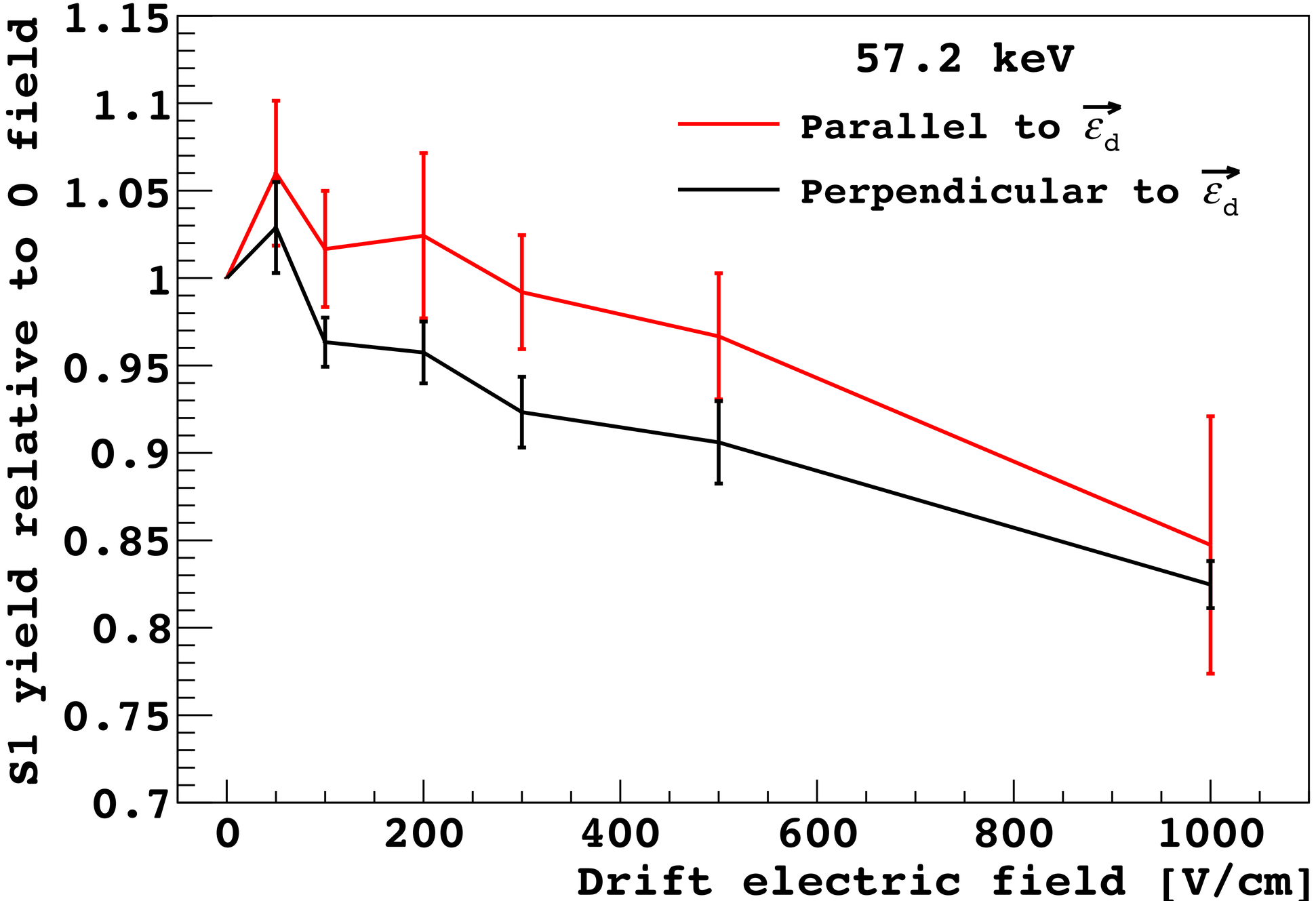


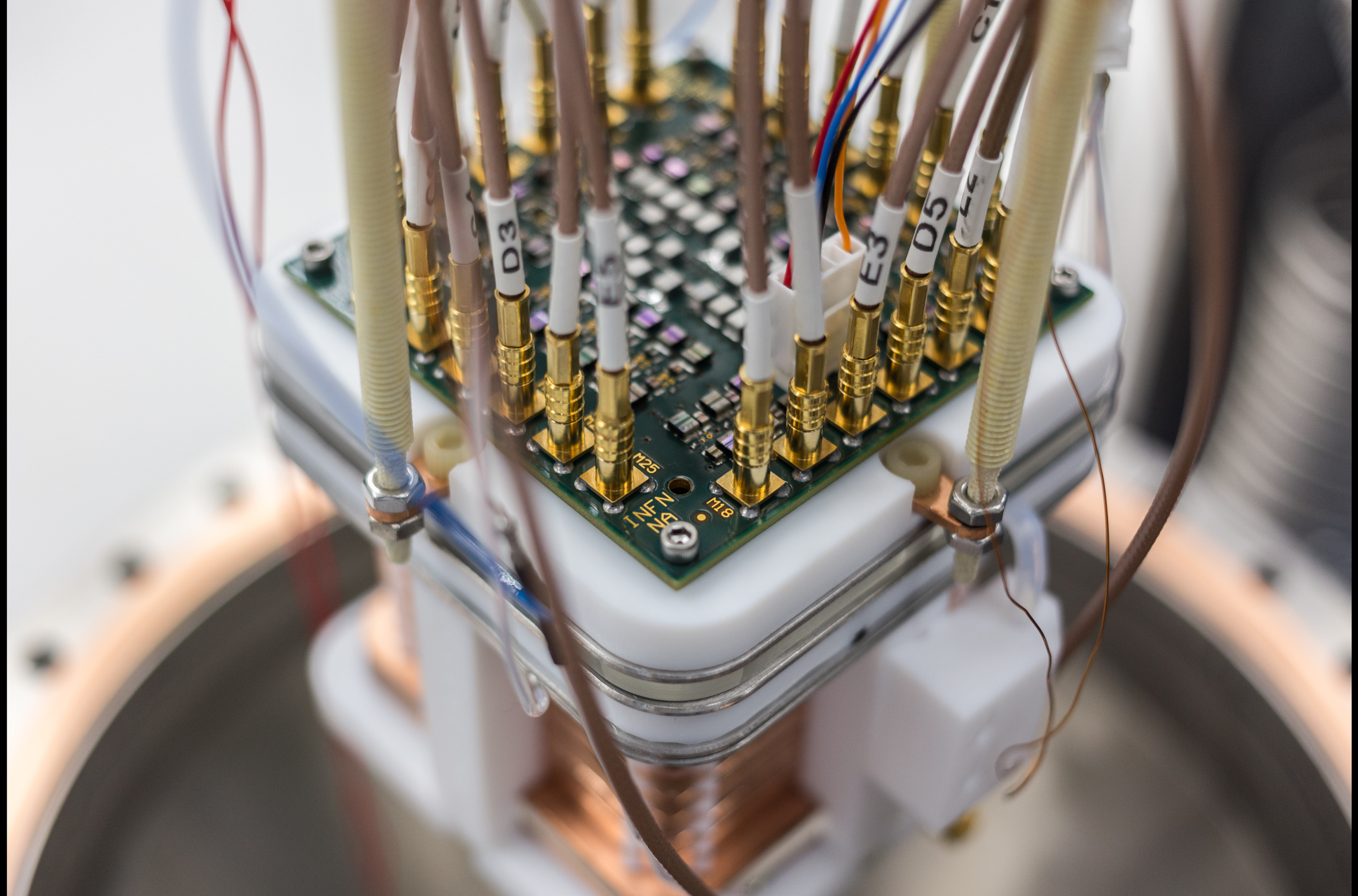

4 m
12 m

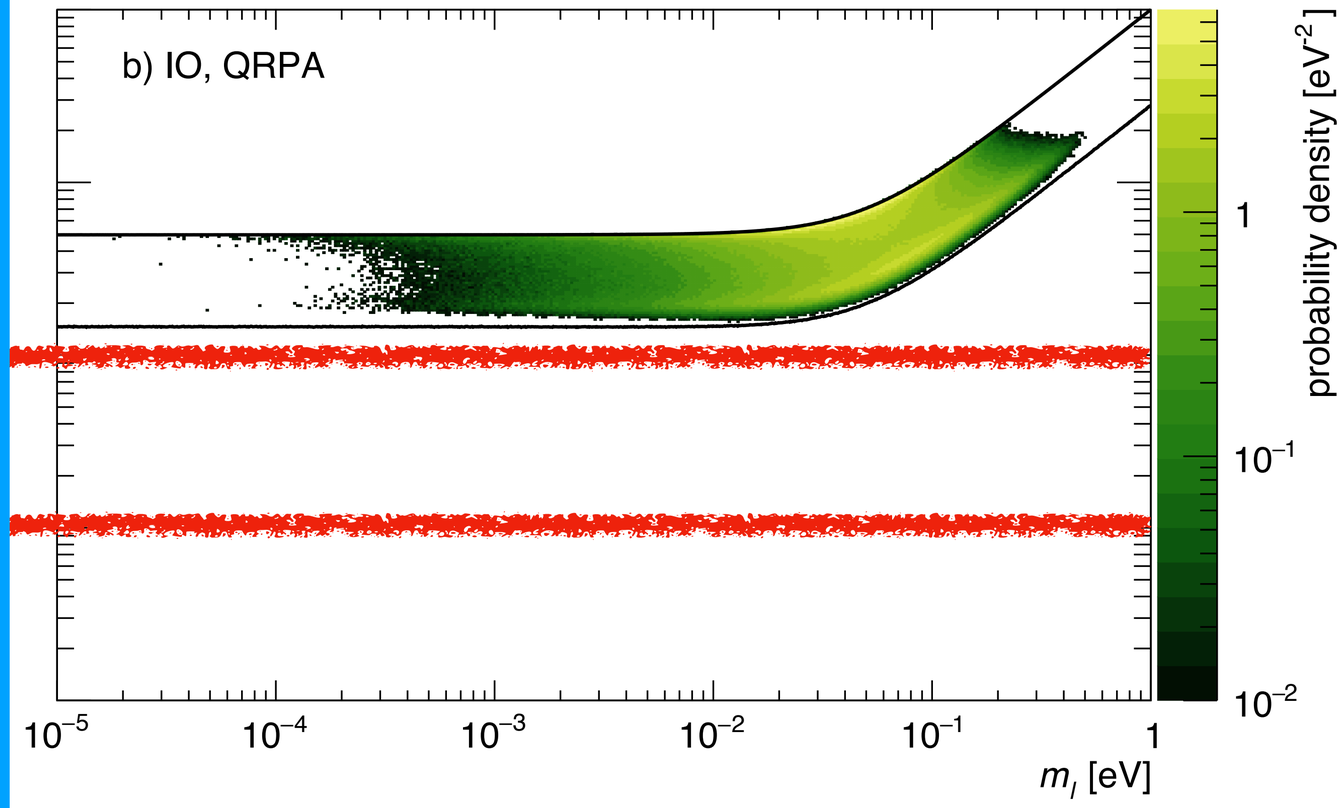
DIRECTIONALITY REQUIREMENTS

- Directional sensitivity to be deployed on the top of technology already independently able to provide background free operation for O(1000 tonne × year) exposure

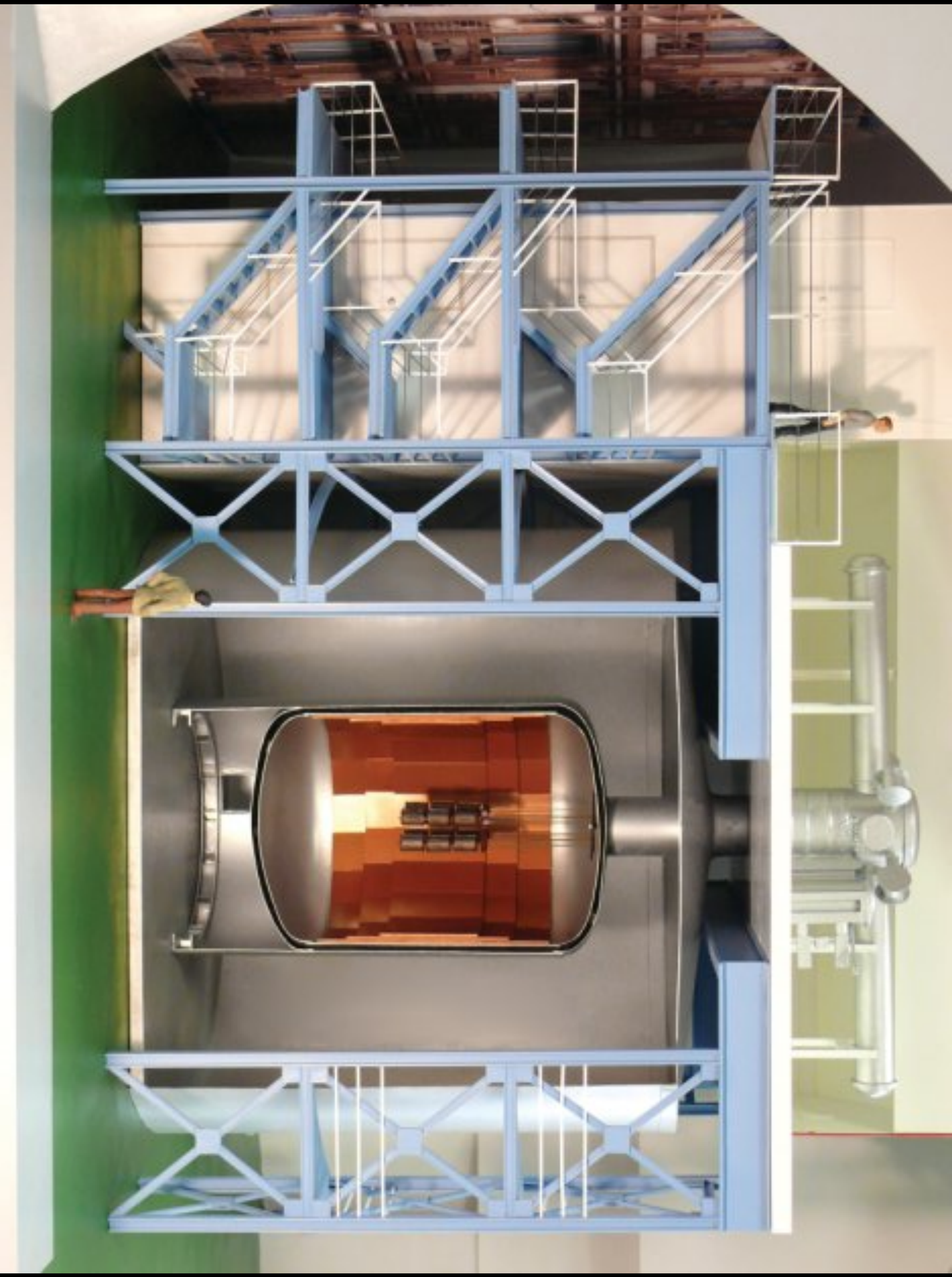
Physical Review D 91, 092007 (2014)




D3
E3
D5
M25
M18
INFN


b) IO, QRPA
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
m_l [eV]
1
10^{-1}
10^{-2}
probability density [eV^{-2}]

GERDA/LEGEND @LNGS



CUORE/CUPID @LNGS

NEUTRINOLESS DOUBLE BETA DECAY REQUIREMENTS

- 10^{30} years
- Exposure O(1000 tonne × year)
- Nearly background free operation
- <1% (σ) resolution

ArDM
DarkSide
DEAP
MiniCLEAN

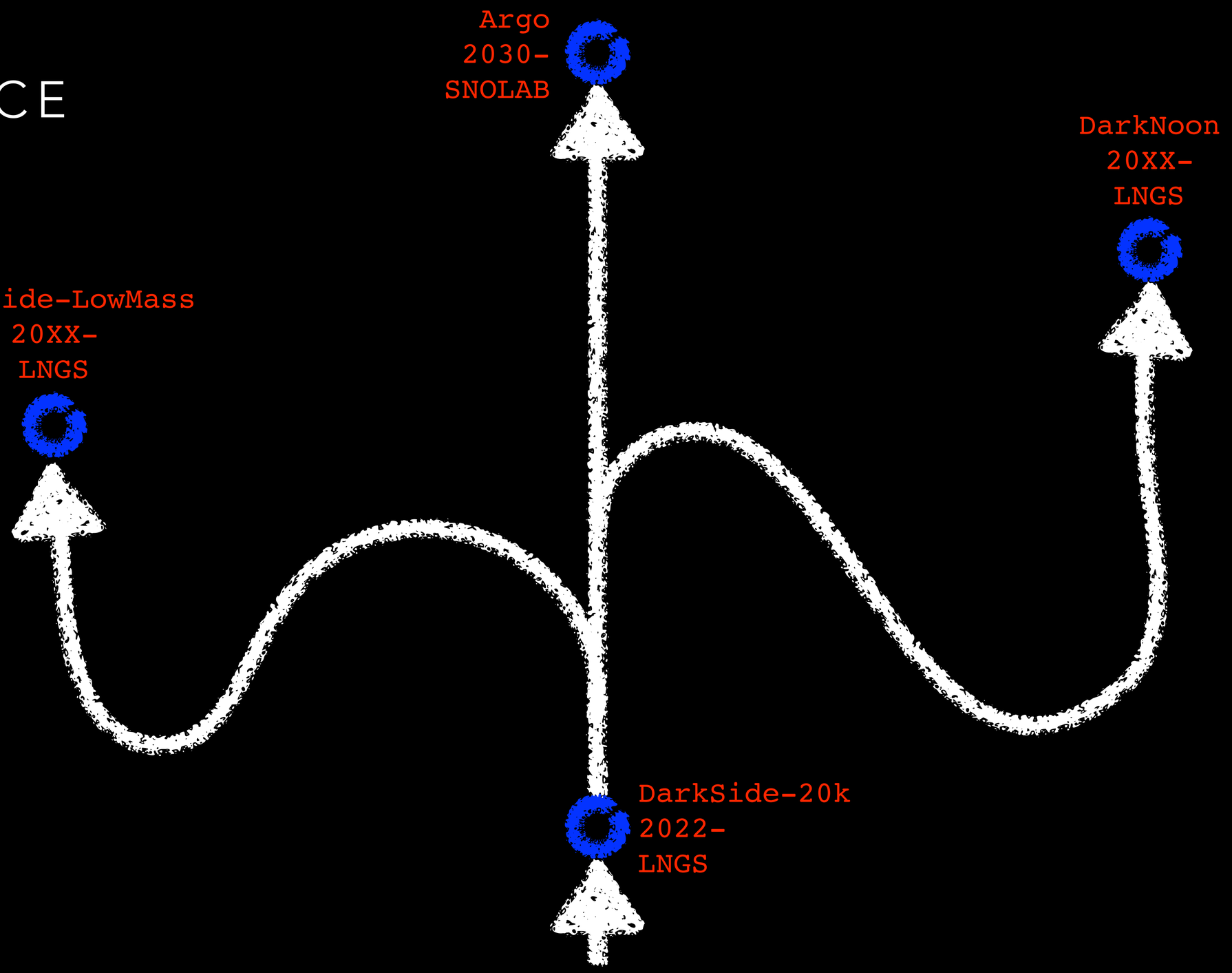
The Global Argon Dark Matter Collaboration

DS-20k
DS-LM
Argo
DarkNoon

350 COLLABORATORS

ITALY, US, CANADA, BRAZIL, CHINA, FRANCE, GERMANY, POLAND, RUSSIA, SPAIN, UNITED KINGDOM

SCIENCE PLAN



amastuola
amastuola
ORGANIC WINE
calaprice
PRODUCT OF ITALY

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Italia

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cristian.galbiati@gssi.it
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Stanza P1-I

Progetto Satyria

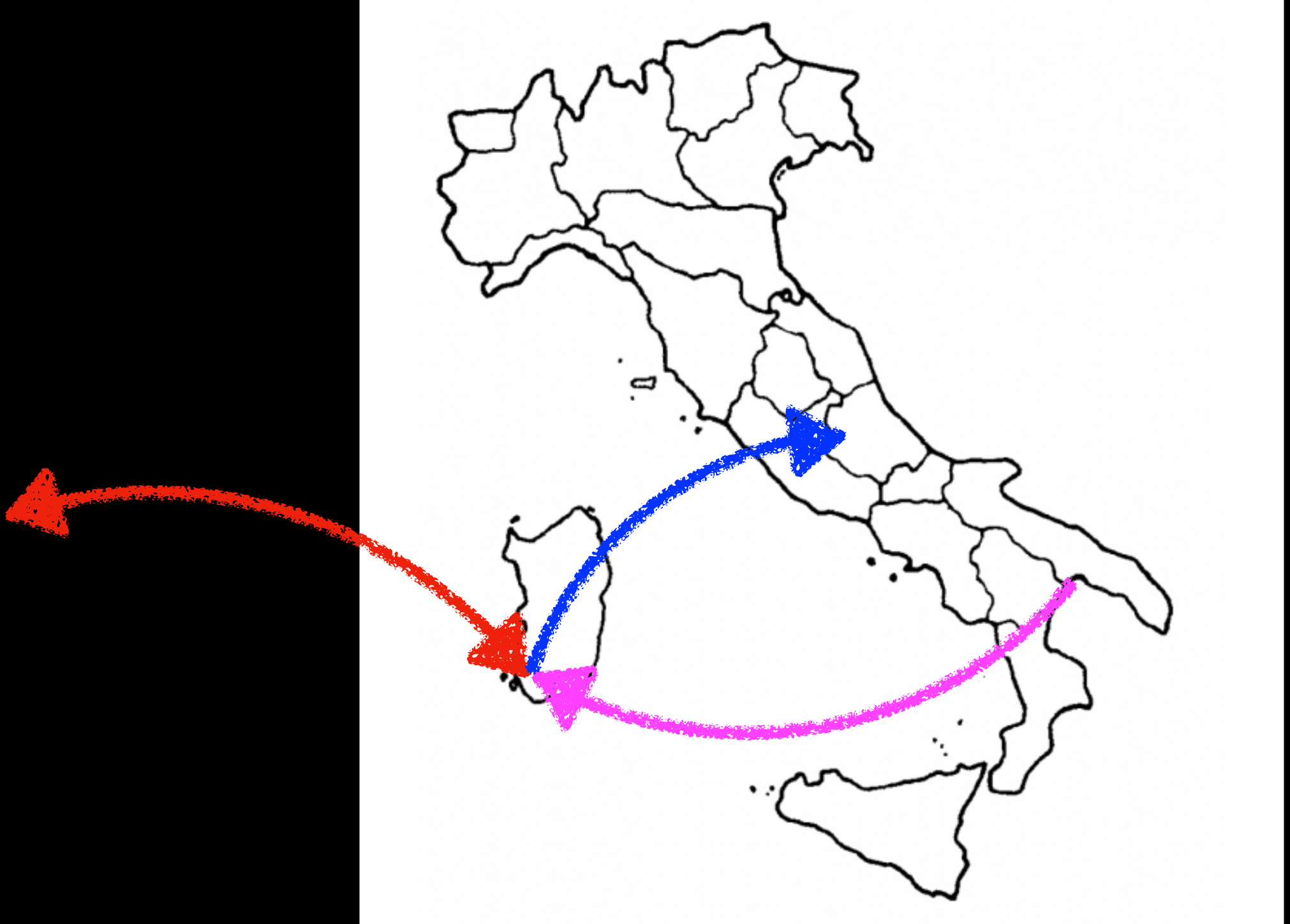
Letter of Introduction

Saturday, March 16, 2019

To: Lakshmi Mittal, Chairman and CEO, ArcelorMittal
Carlo Messina, CEO, Banca Intesa
Giuseppe Guzzetti, President, Fondazione Cariplo
Aditya Mittal, CEO, ArcelorMittal Europe

THE GOALS OF THE SATYRIA PROJECT

- Provision of ^{136}Xe-enriched xenon for a neutrinoless double beta decay searches with a fiducial target of 50 tonnes of ^{136}Xe
- Provision of 700 tonnes of argon for DarkSide-20k
- Provision of 5,000 tonnes of argon for Argo
- Provision of 100,000 tonnes of argon for DUNE
- Provision of special steel I-beams for DUNE



Detector Configuration

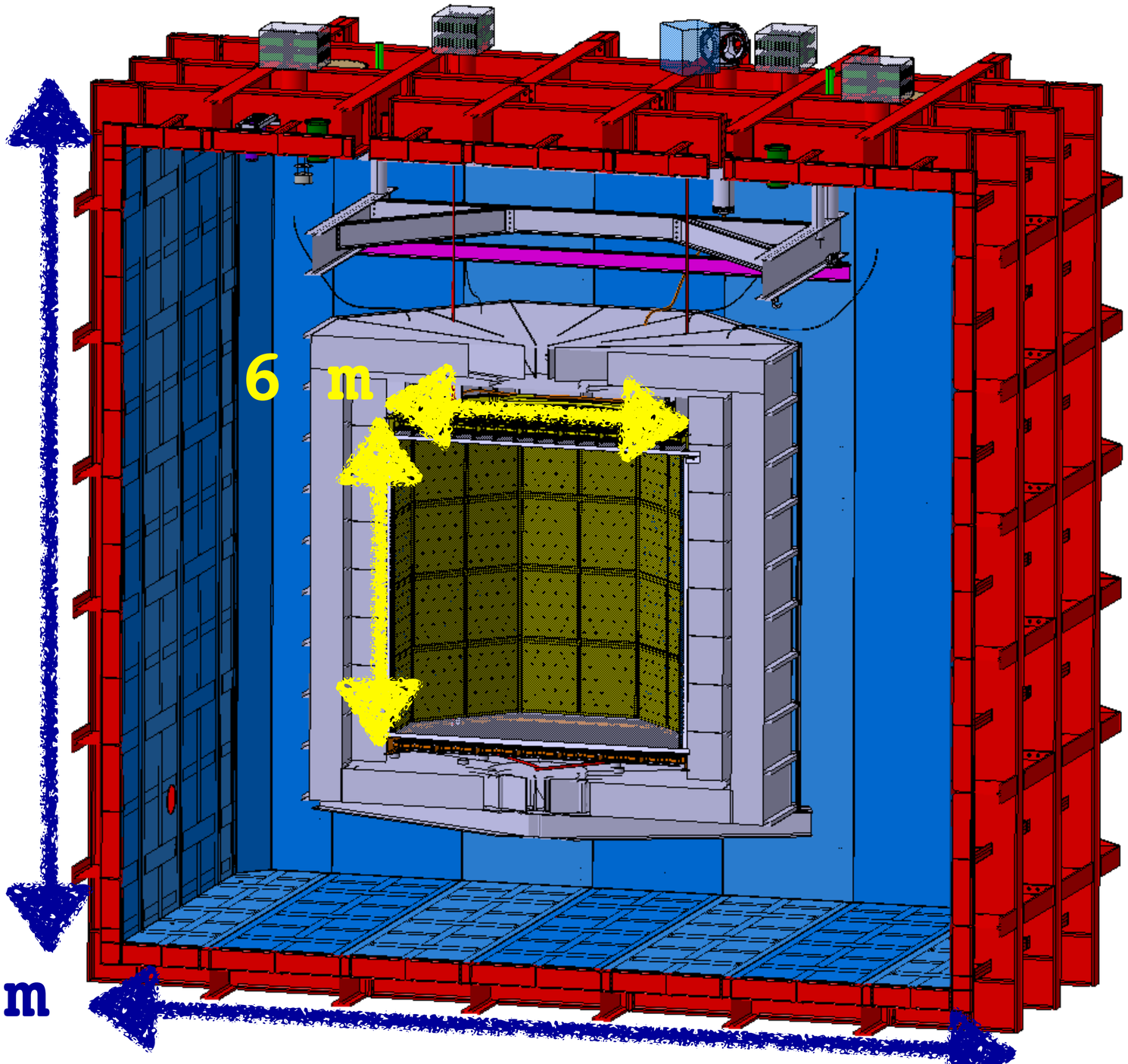
- TPC as of DarkSide-20k,
  Veto as DUNE cryostat

- AAr in veto, UAr+Xe in TPC

- Fiducial mass of 50 t of ^{136}Xe,
  Xe 20% molar fraction,
  ^{136}Xe enriched to 90% via Aria technology

- 4π SiPM coverage,
  0.1ns timing resolution,
  0.8% σ resolution

- ^{222}Rn reduction and SiPMs' single photon counting by operation at 87 K,
  Cherenkov-based discrimination of single and multiple electrons



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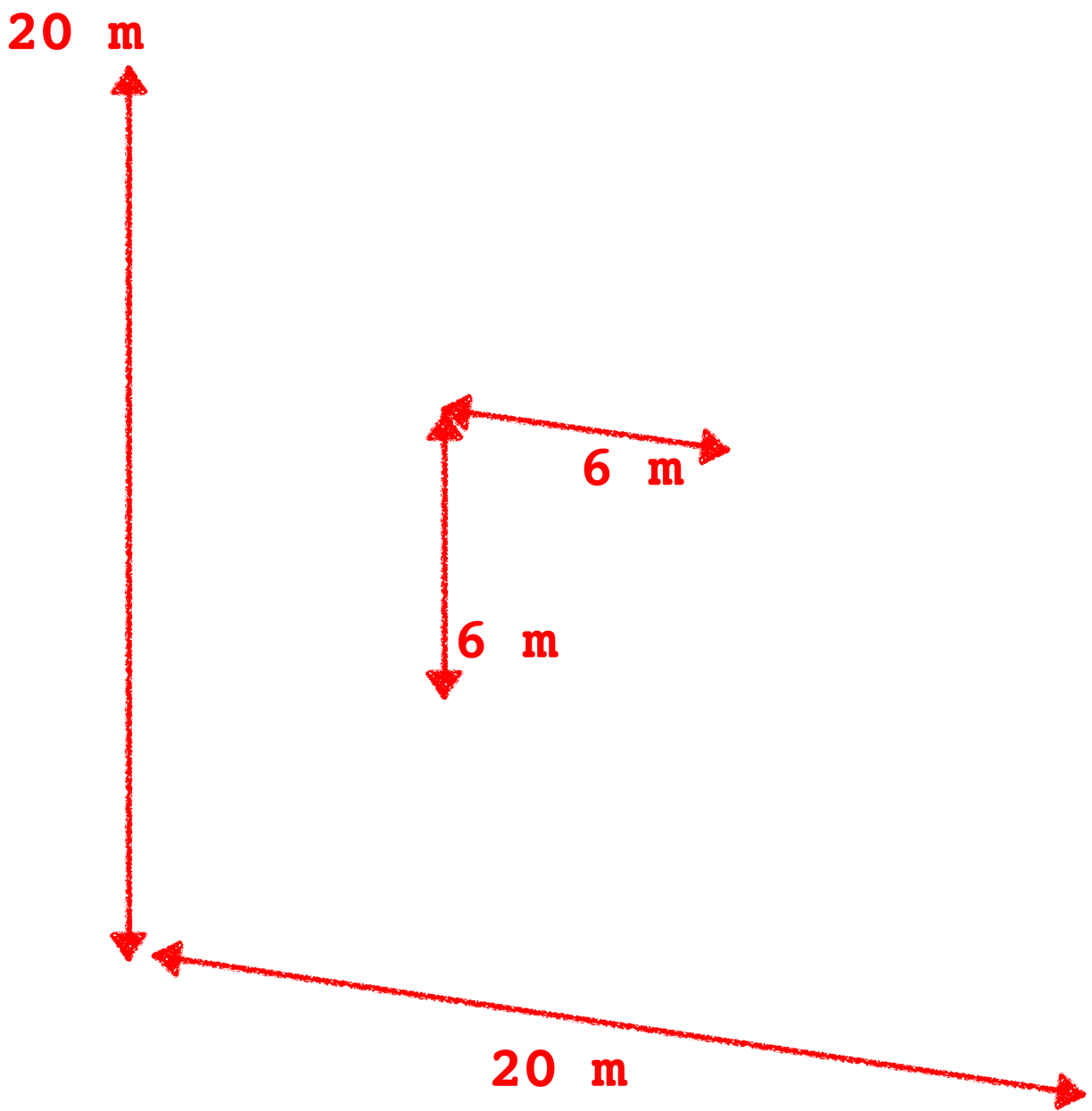
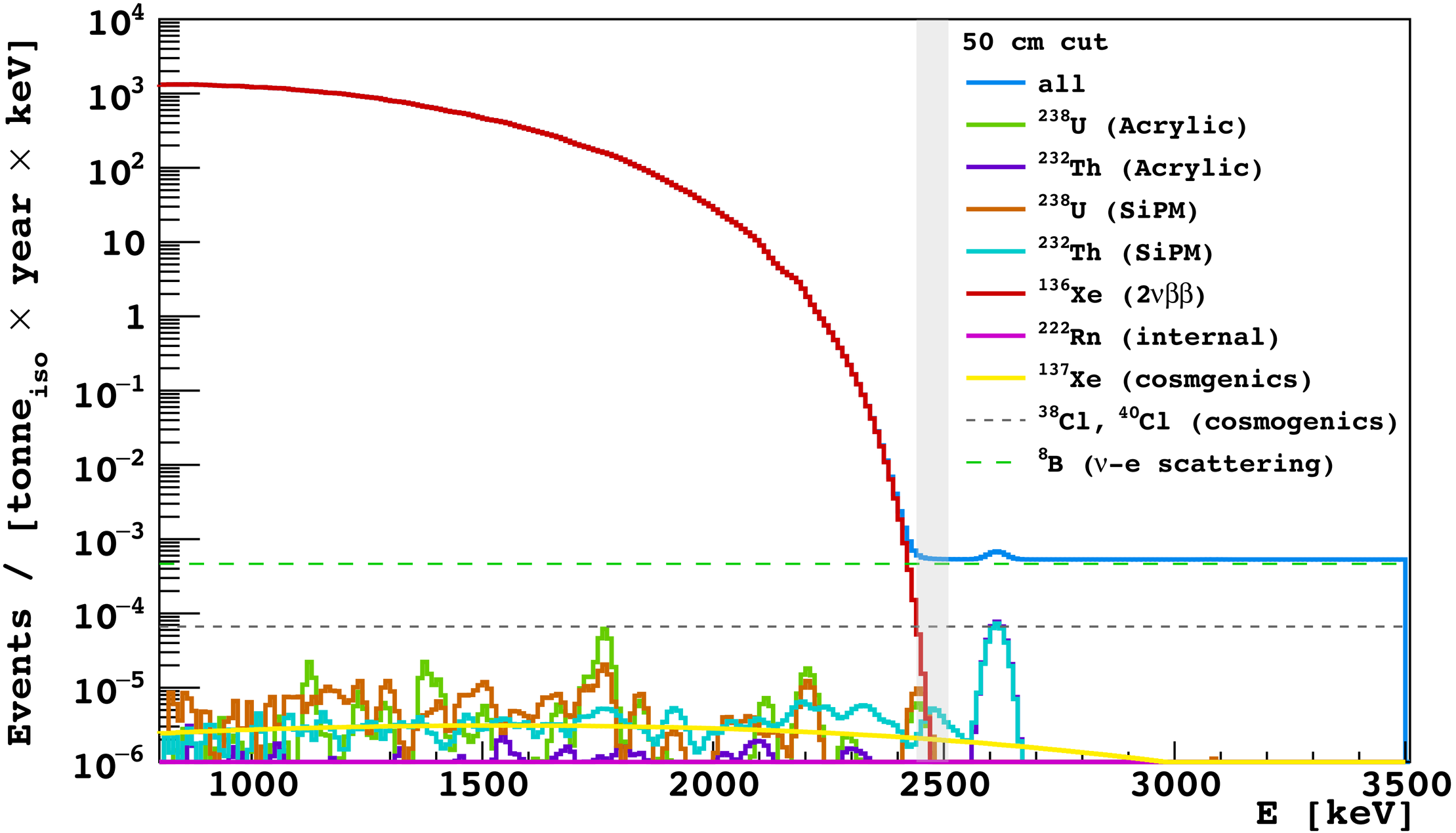
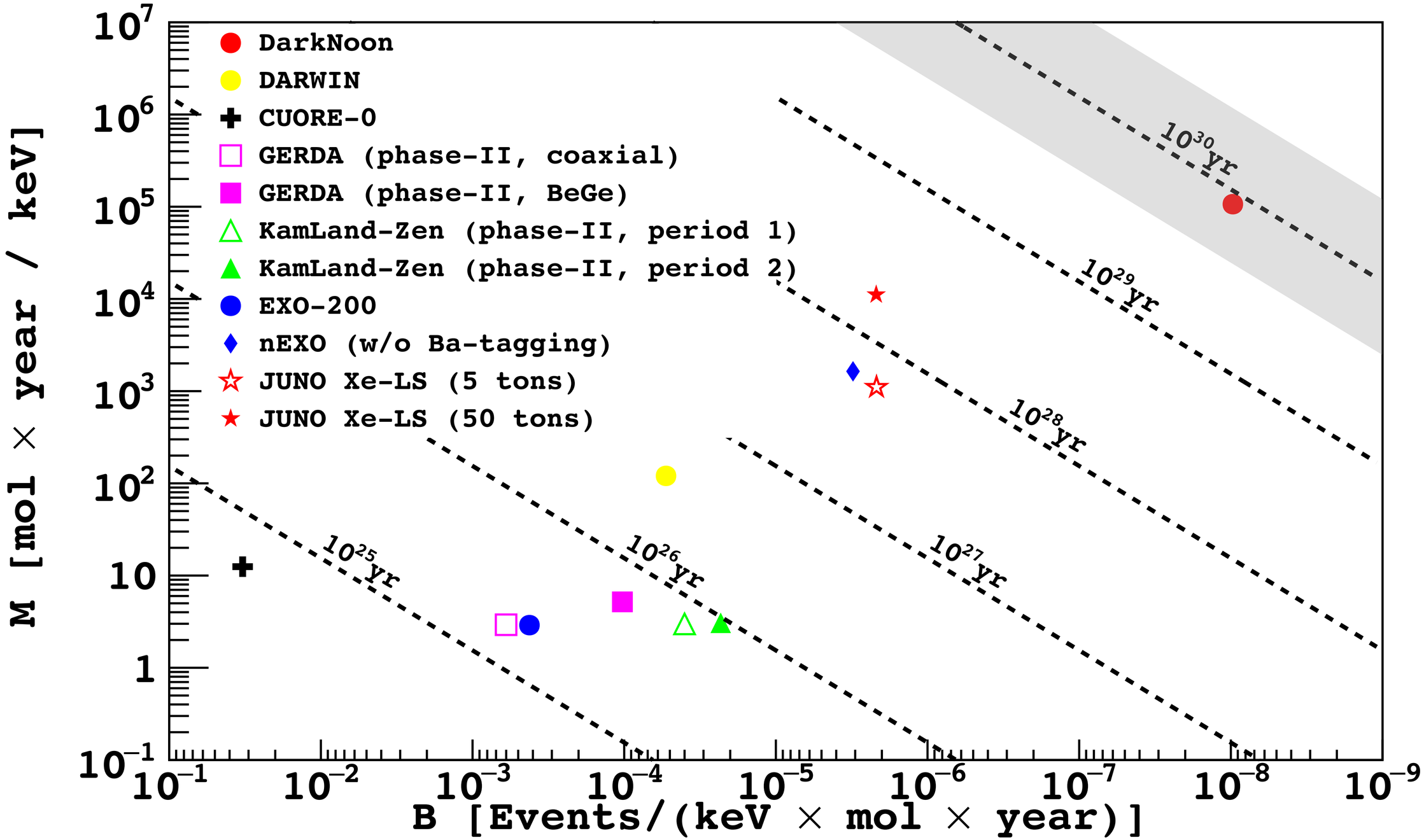



50 cm cut
all
238U (Acrylic)
232Th (Acrylic)
238U (SiPM)
232Th (SiPM)
136Xe (2νββ)
222Rn (internal)
137Xe (cosmgenics)
38Cl, 40Cl (cosmogenics)
8B (ν-e scattering)
Events / [tonne_iso × year × keV]
E [keV]
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
1000
1500
2000
2500
3000
3500


DarkNoon
DARWIN
CUORE-0
GERDA (phase-II, coaxial)
GERDA (phase-II, BeGe)
KamLand-Zen (phase-II, period 1)
KamLand-Zen (phase-II, period 2)
EXO-200
nEXO (w/o Ba-tagging)
JUNO Xe-LS (5 tons)
JUNO Xe-LS (50 tons)
10^{25} yr
10^{26} yr
10^{27} yr
10^{28} yr
10^{29} yr
10^{30} yr
M [mol × year / keV]
B [Events/(keV × mol × year)]

THE END