Review of Experimental WIMPs Searches with liquid Xenon and Argon: Present Status and Future Prospects

Cristiano Galbiati
Princeton University

Renata-DM Workshop
Laboratorio Subterráneo de Canfranc
Spain
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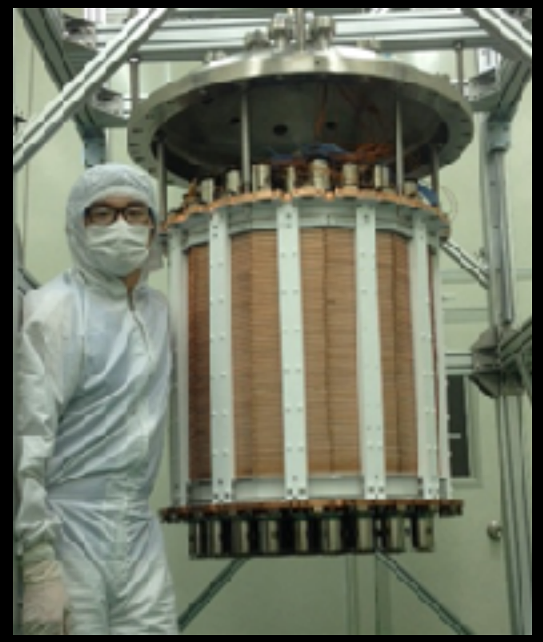
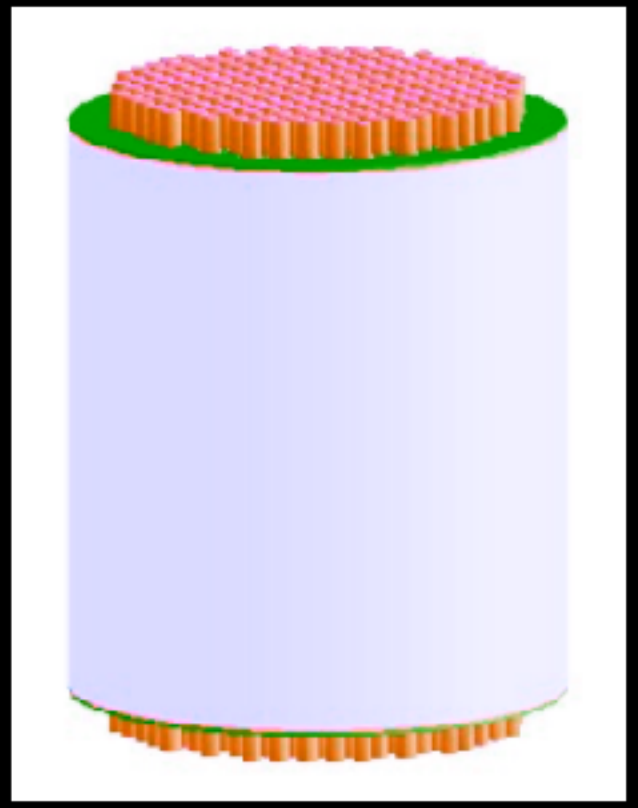
PandaX @ CJPL

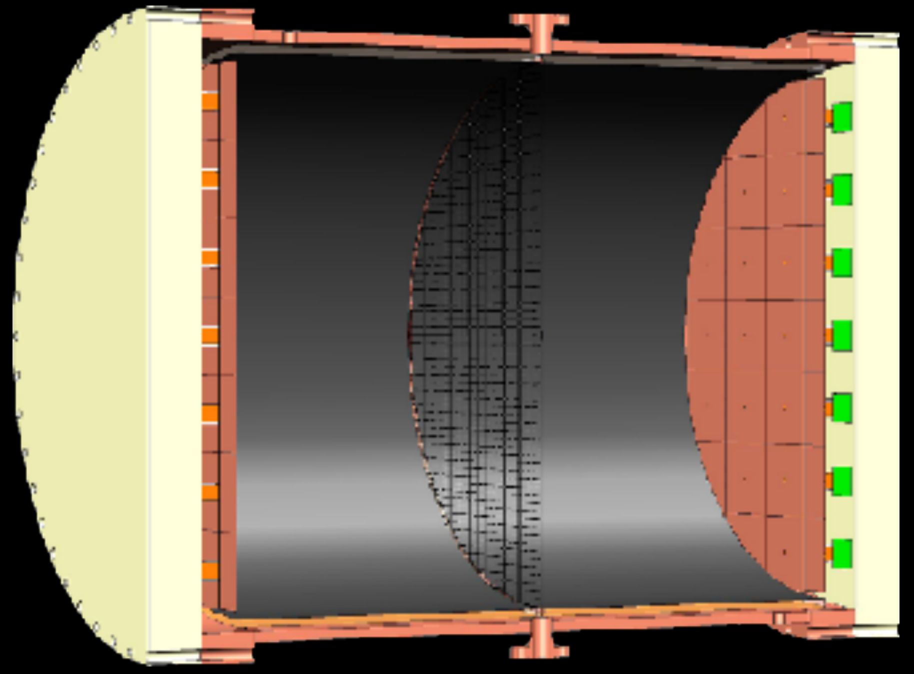
PandaX-I: 120 kg DM experiment
2009-2014



PandaX-II: 500 kg DM experiment
2014-2018



PandaX-xT: multi-ton DM experiment
Future



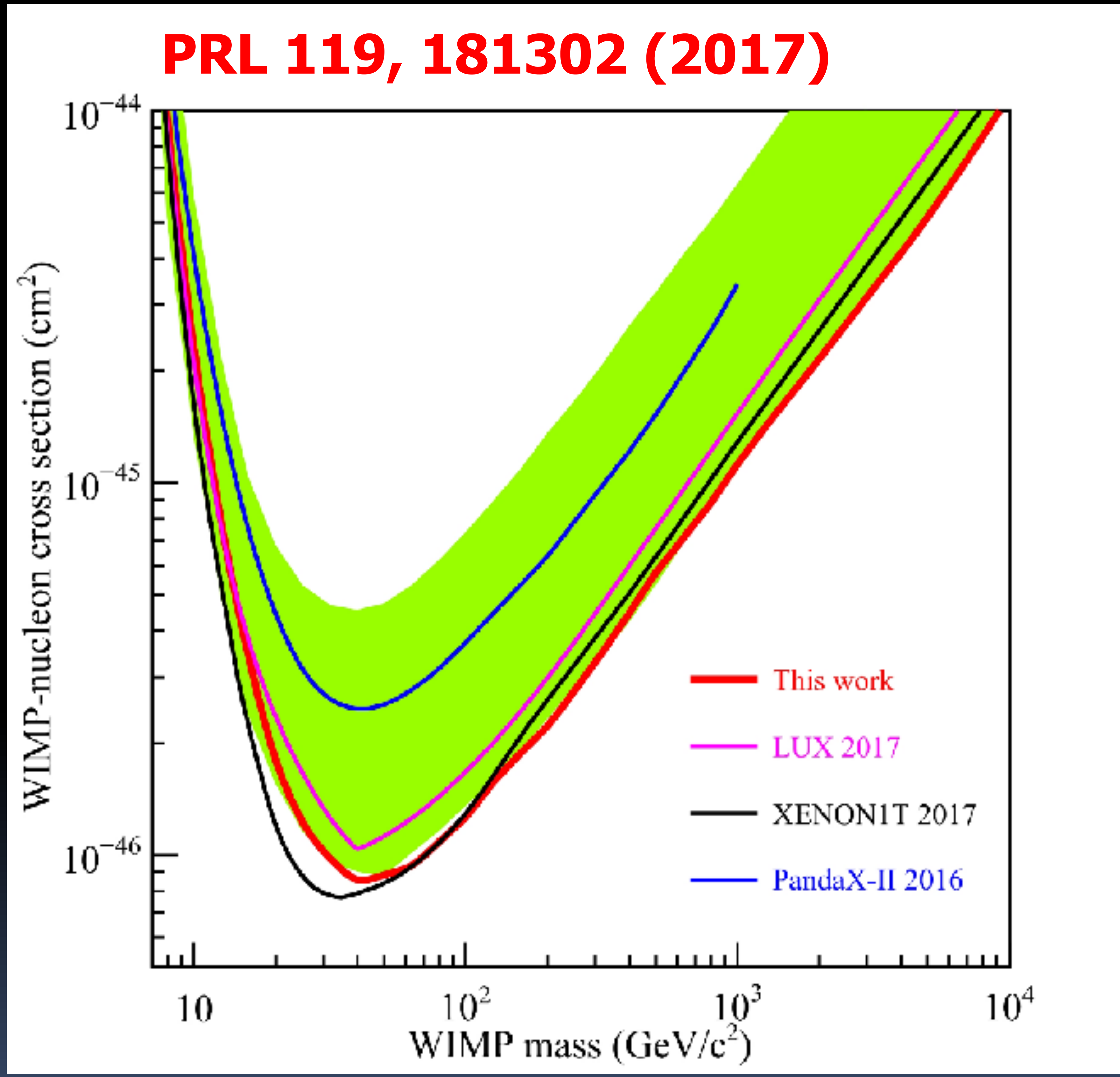
PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment
Future

CJPL-I

CJPL-II

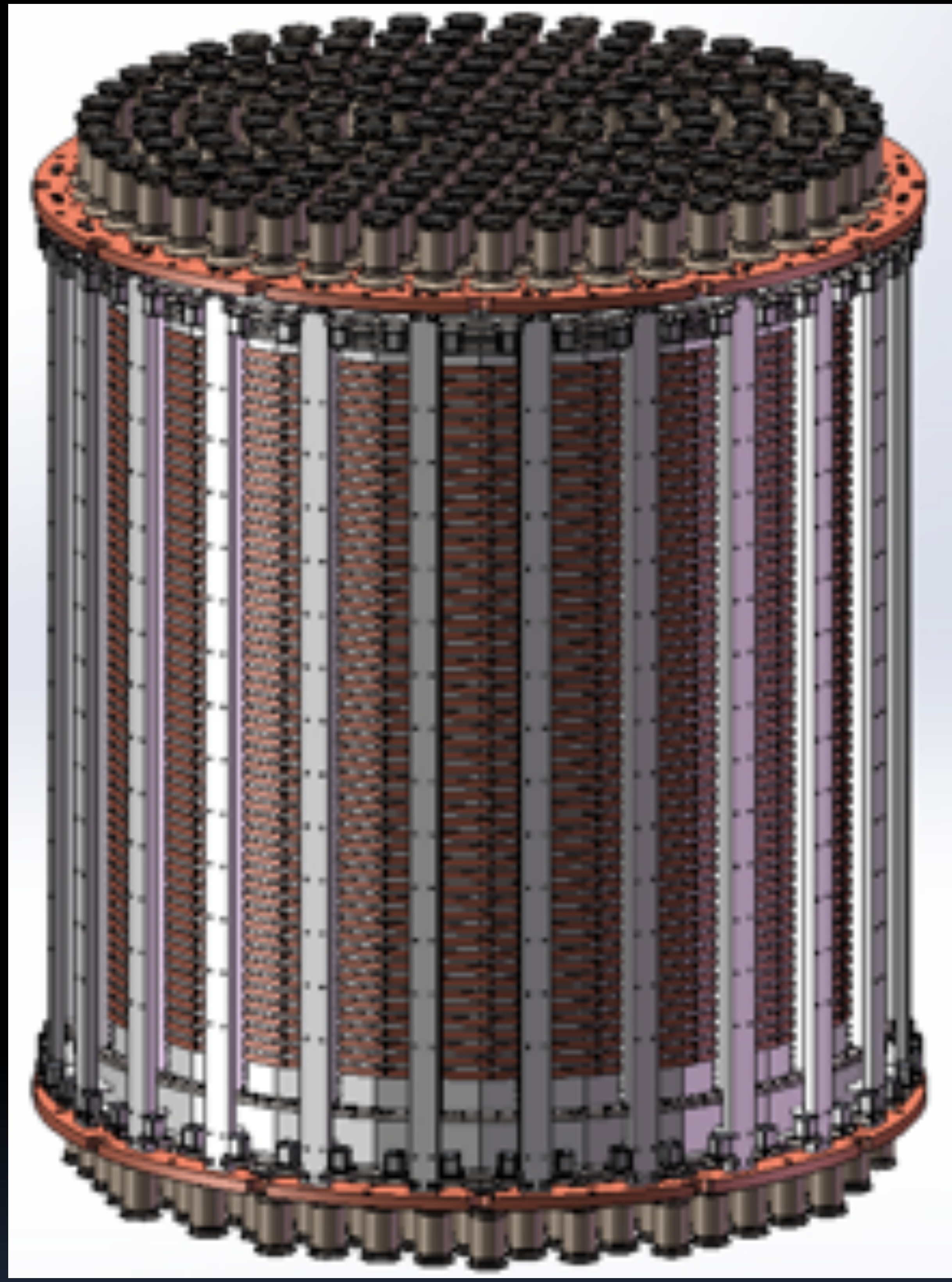
PANDA X = Particle and Astrophysical Xenon Experiments

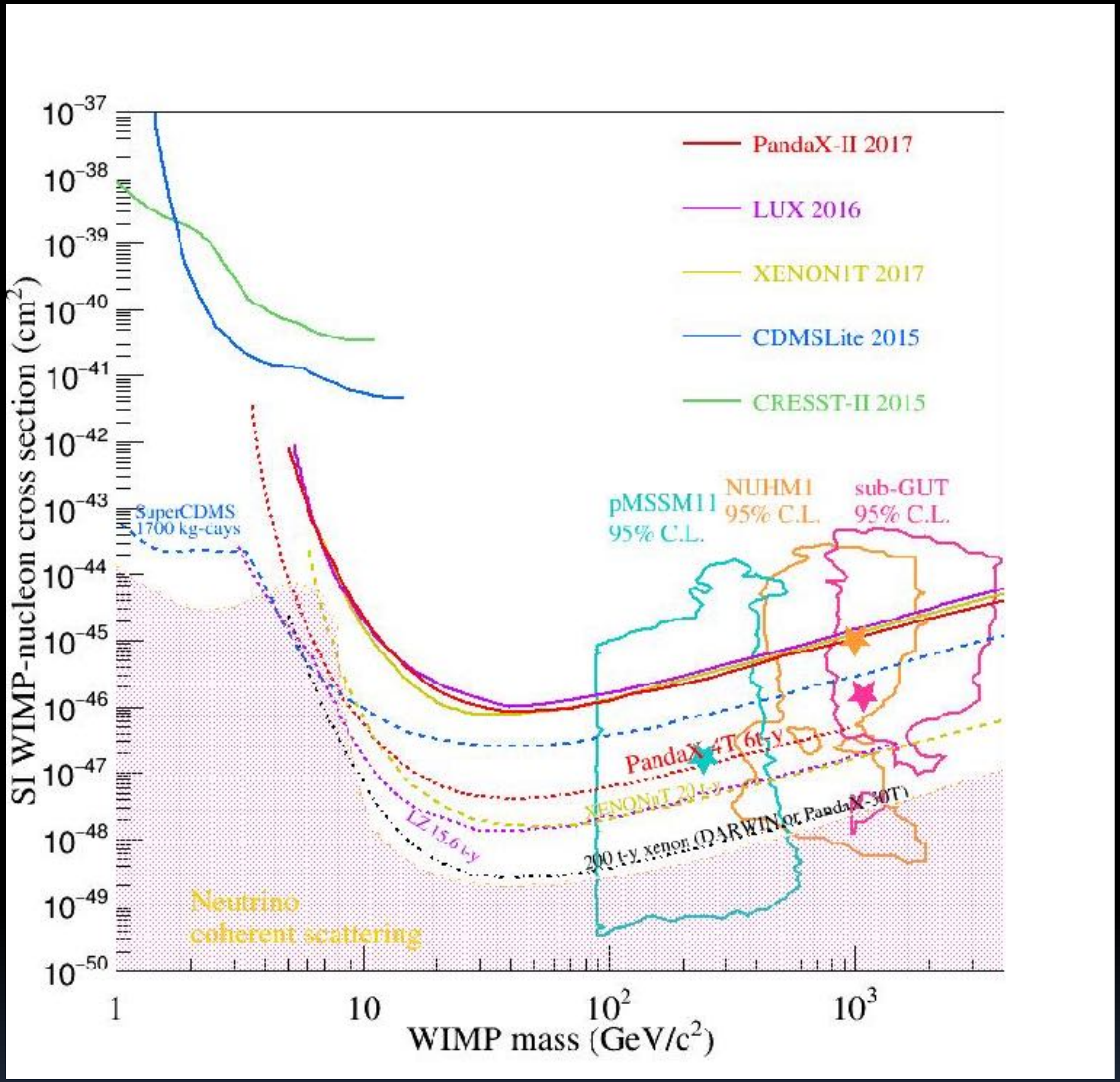
PandaX-II 54 ton-day results (SI limit)



- Improved from PandaX-II 2016 limit about 2.5 time for mass>30 GeV
- Lowest exclusion at $8.6\times10^{-47}cm^2$ at 40GeV/c^2
- Most stringent limit for WIMP-nucleon cross section for mass >100GeV

PandaX-xT

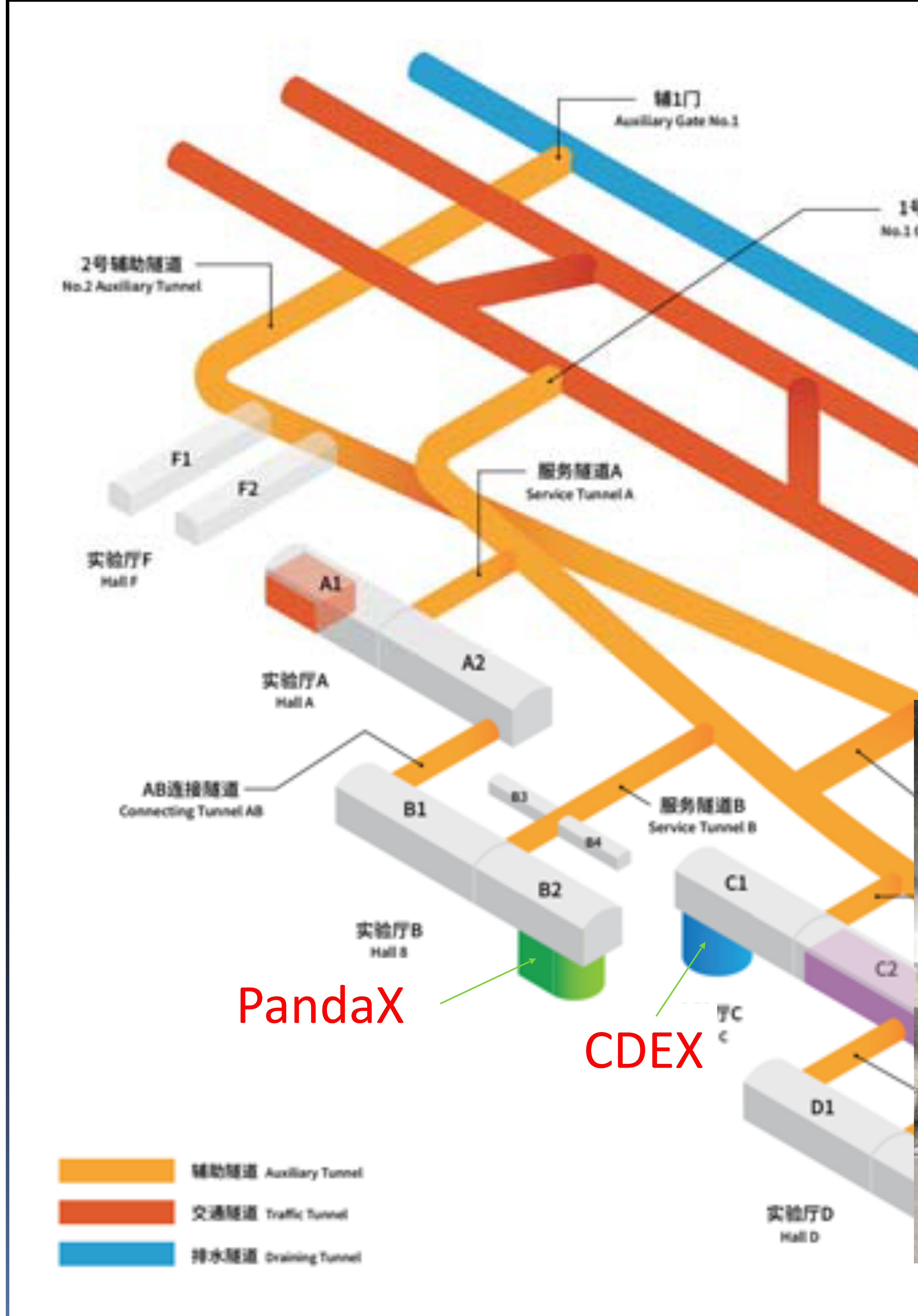


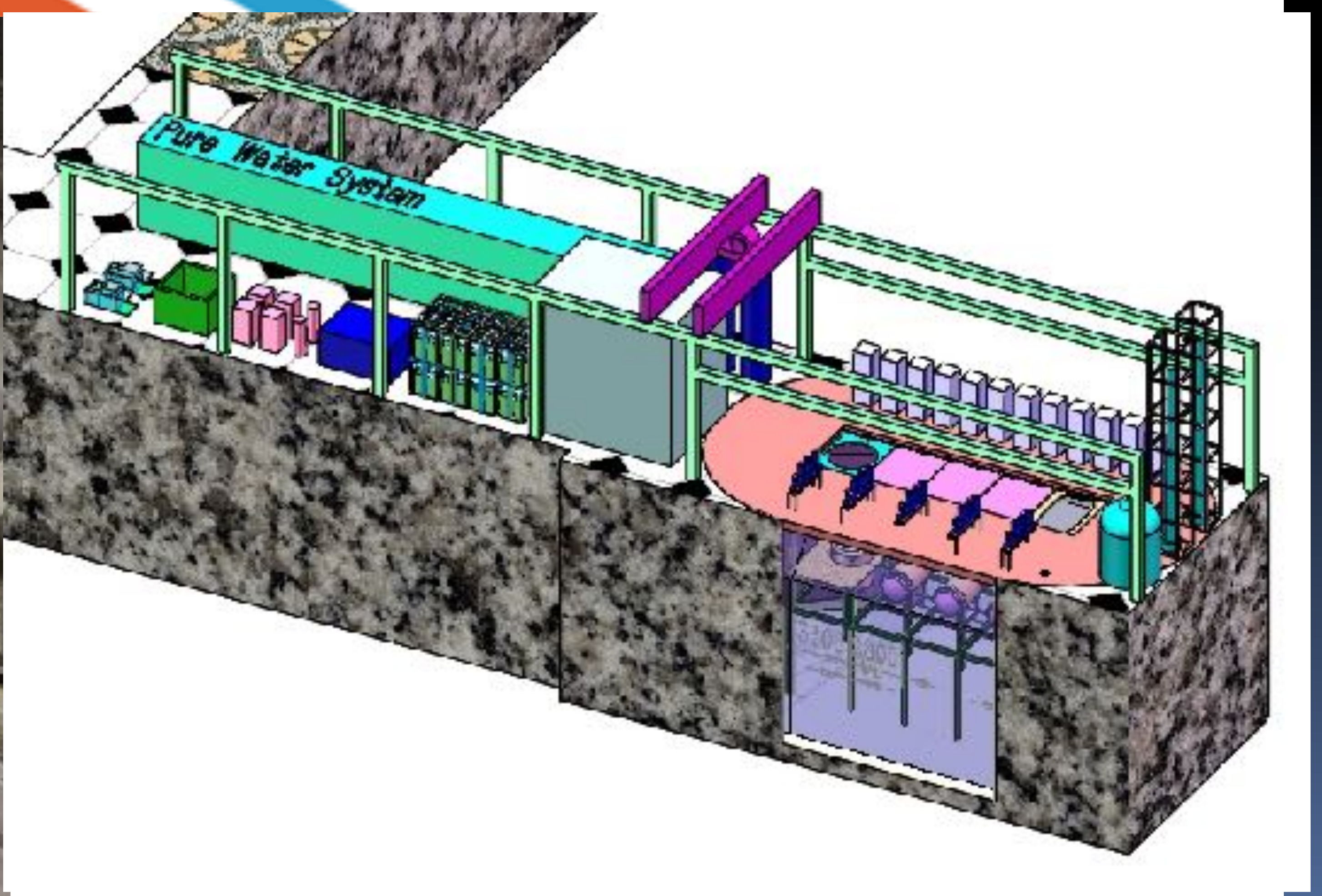


- Intermediate stage:
  - **PandaX-4T** (4-ton target) with SI sensitivity ~10^{-47} cm^2
  - On-site assembly and commissioning: 2019-2020

PandaX @ CJPL-II

- Experimental hall B2 secured
- Single ultrapure water pool which hosts PandaX-xT and PandaX-III (modules of high pressure ^{136}Xe TPCs)



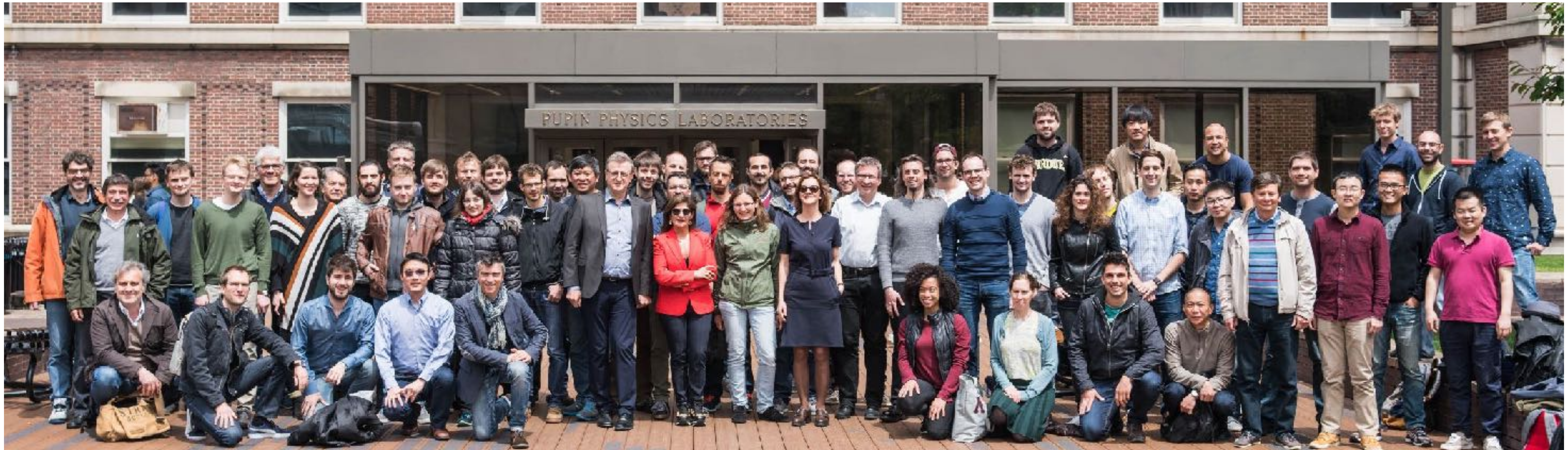


The XENON collaboration

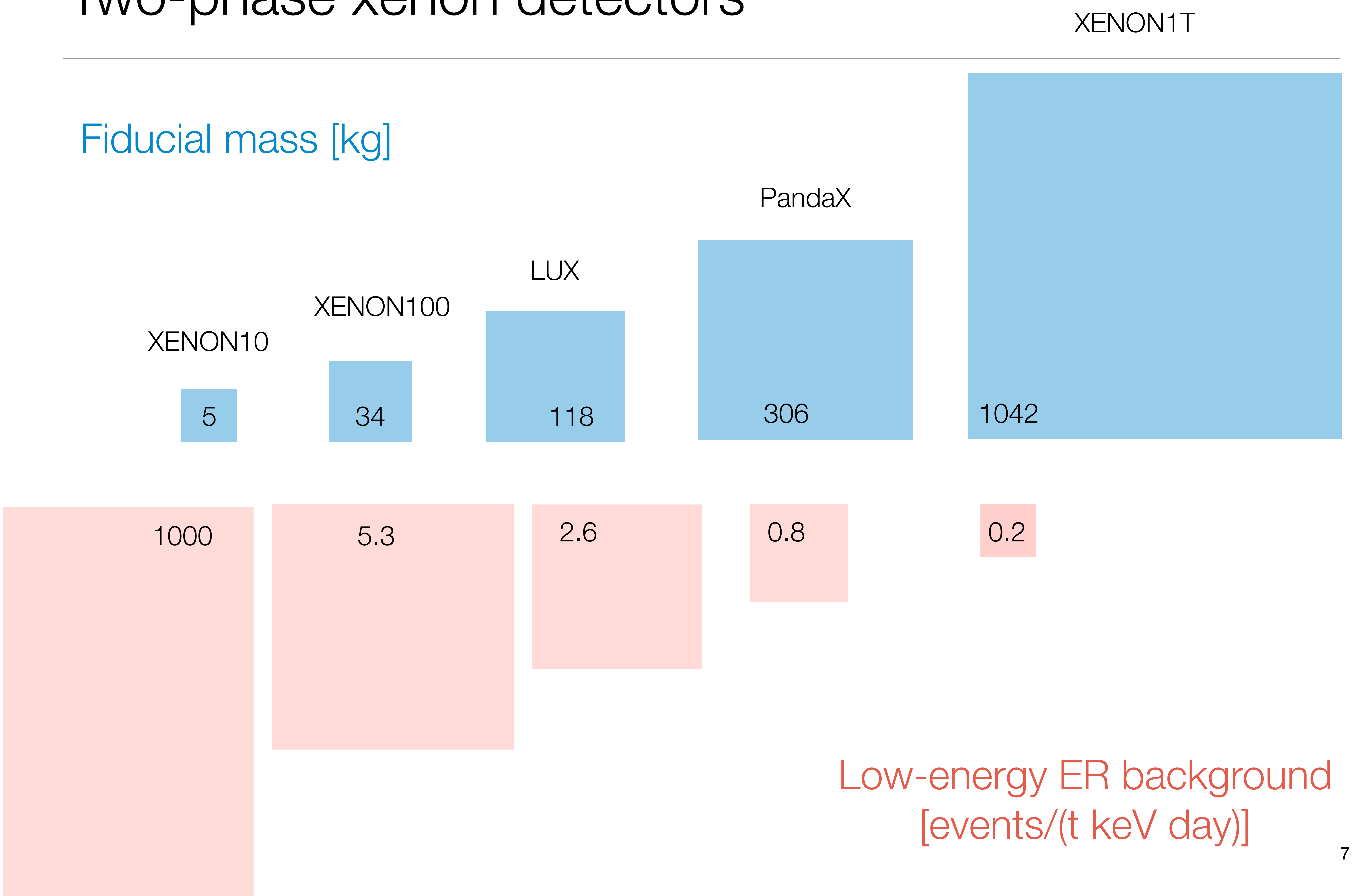
160 scientists

29 institutions

11 countries



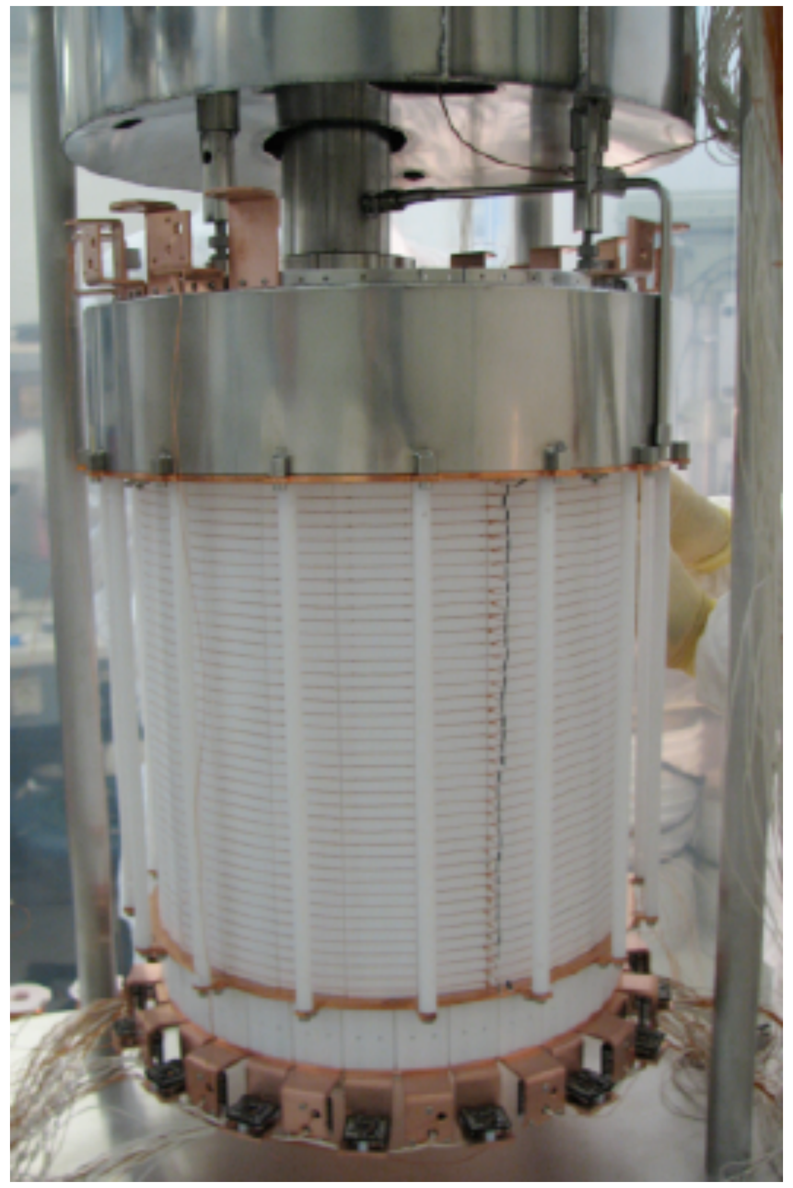
Two-phase xenon detectors



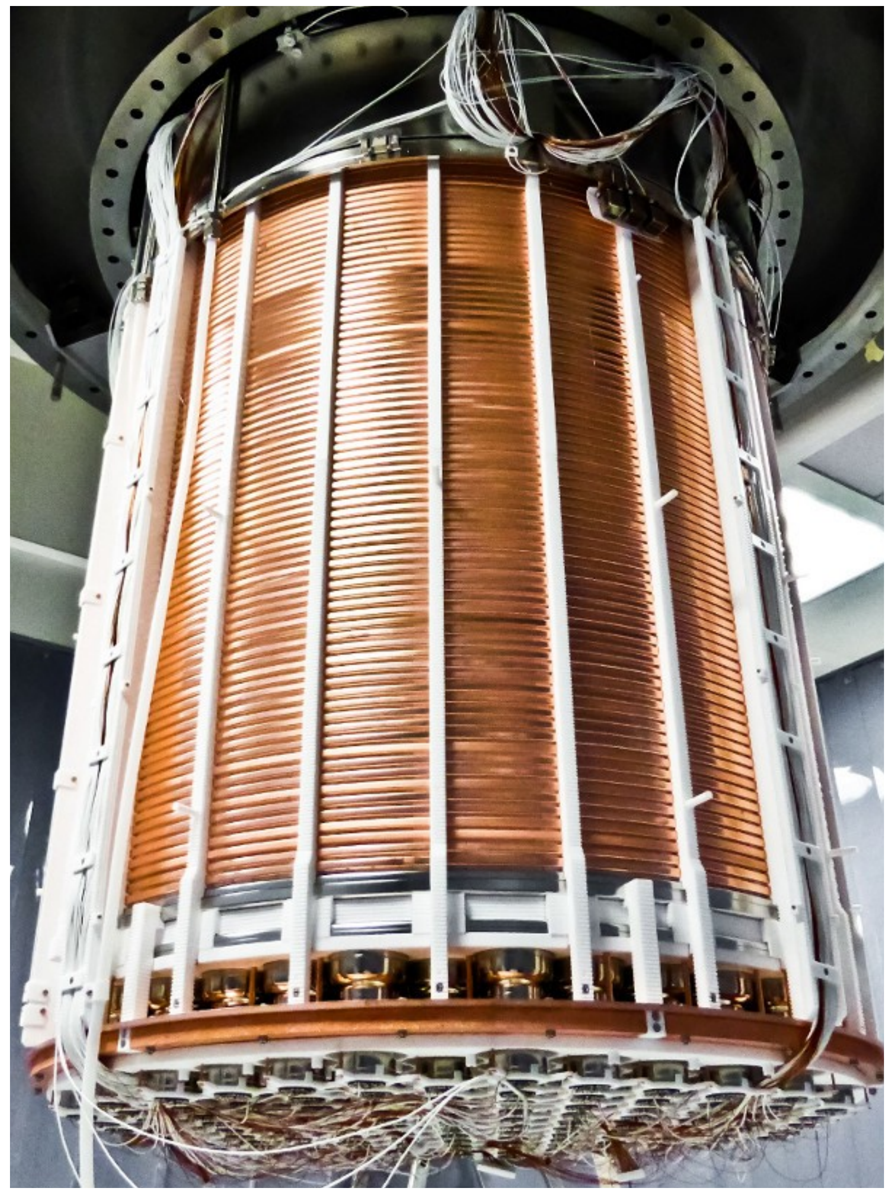
The phases of the XENON Program

XENON10

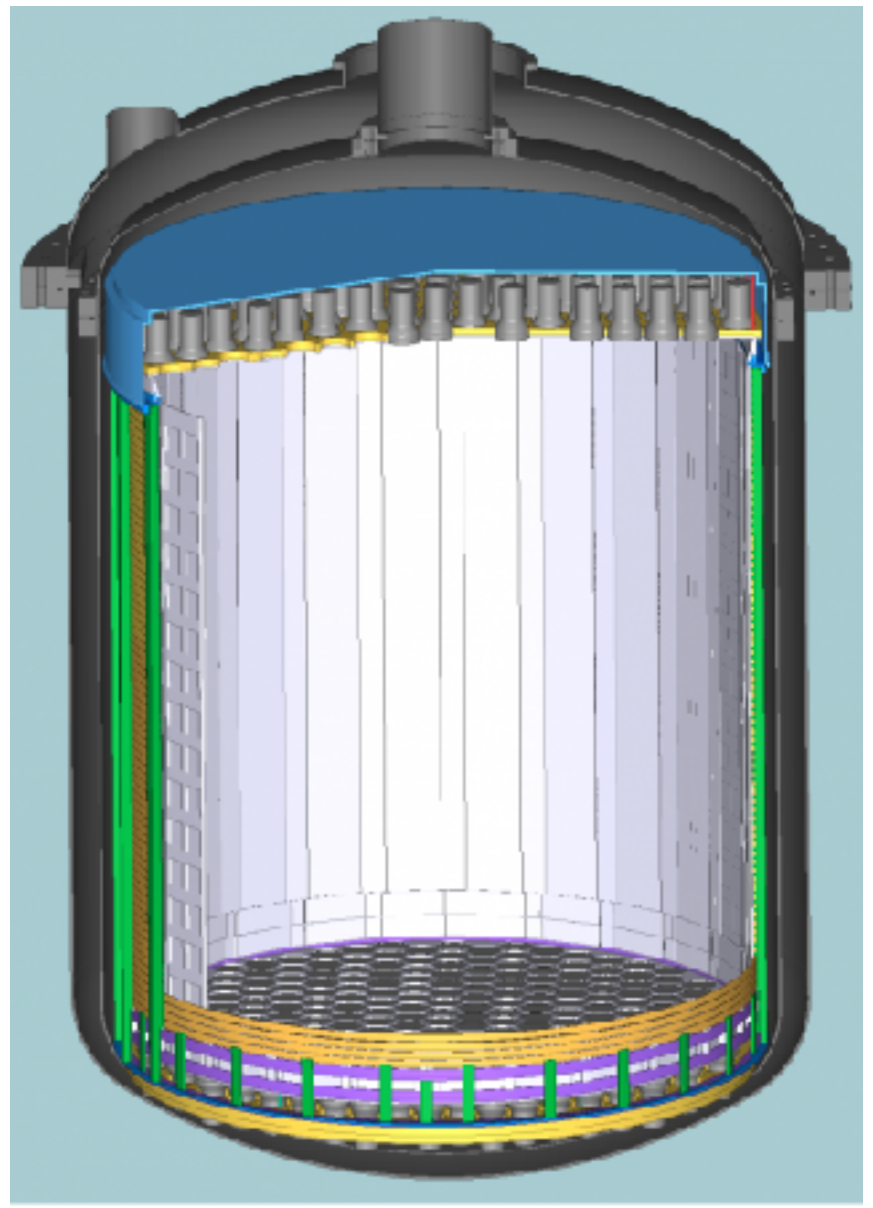
XENON100



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

XENON1T Overview

Water tank and Cherenkov muon veto

Cryostat and support structure for TPC

Time projection chamber

Umbilical pipe (cables, xenon)

Cryogenics and purification

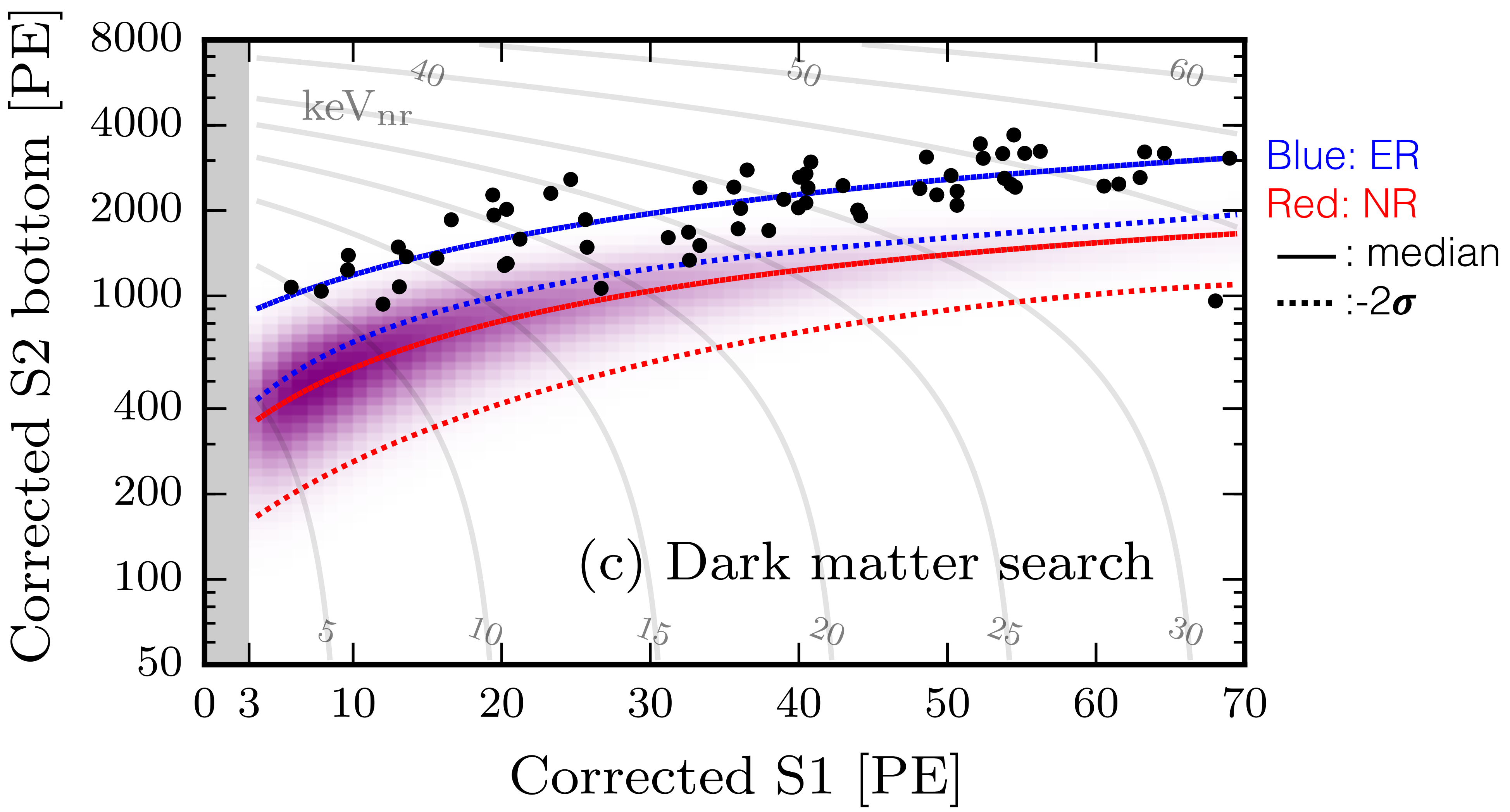
Data acquisition and slow control

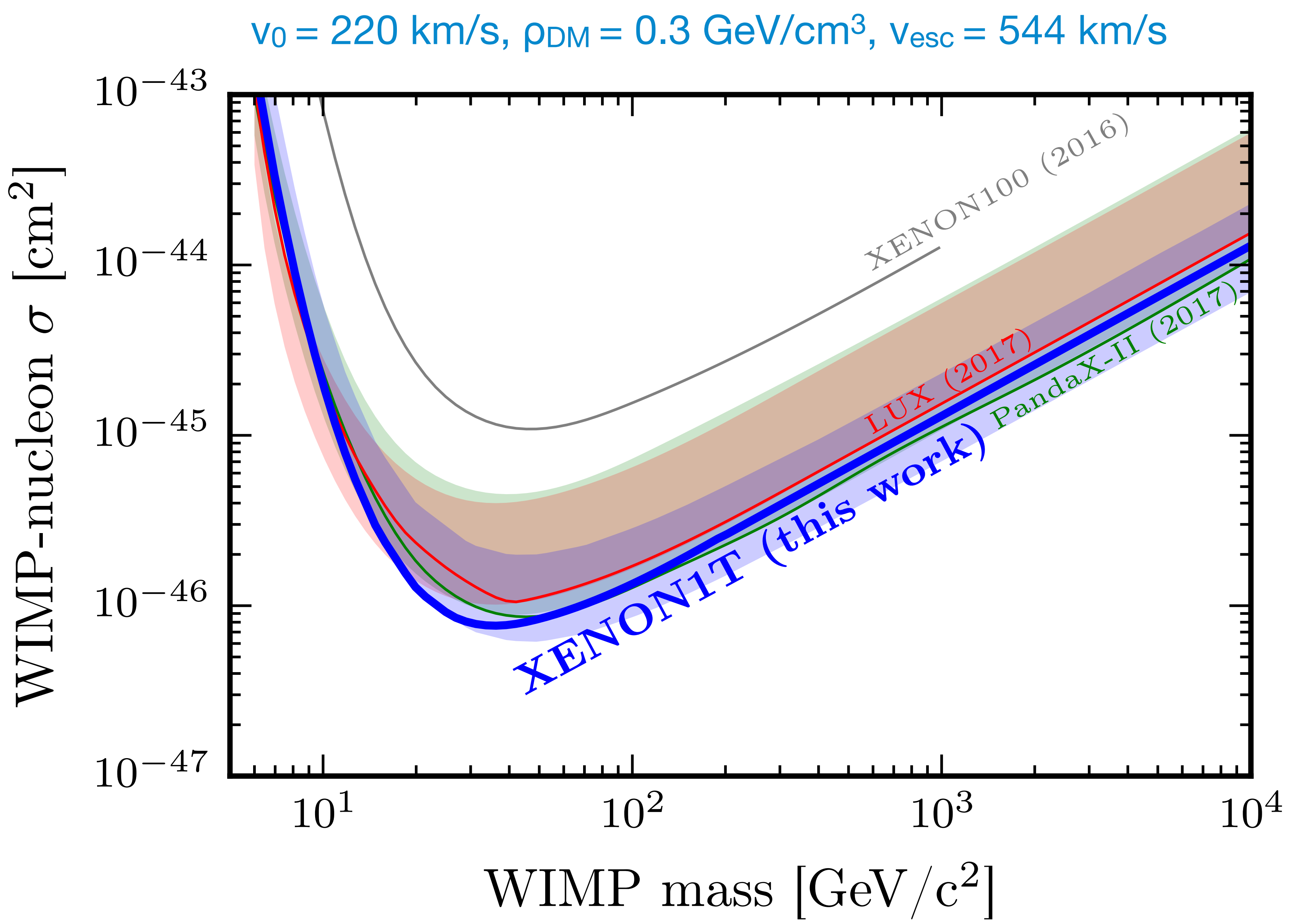
Xenon storage, handling and distillation column

The XENON1T Time Projection Chamber

Dark matter search

- 2017: analysis of data from short exposure gives best SI limit worldwide
- 2018: analysis of data from ~1 full year almost completed. New result to be released soon!

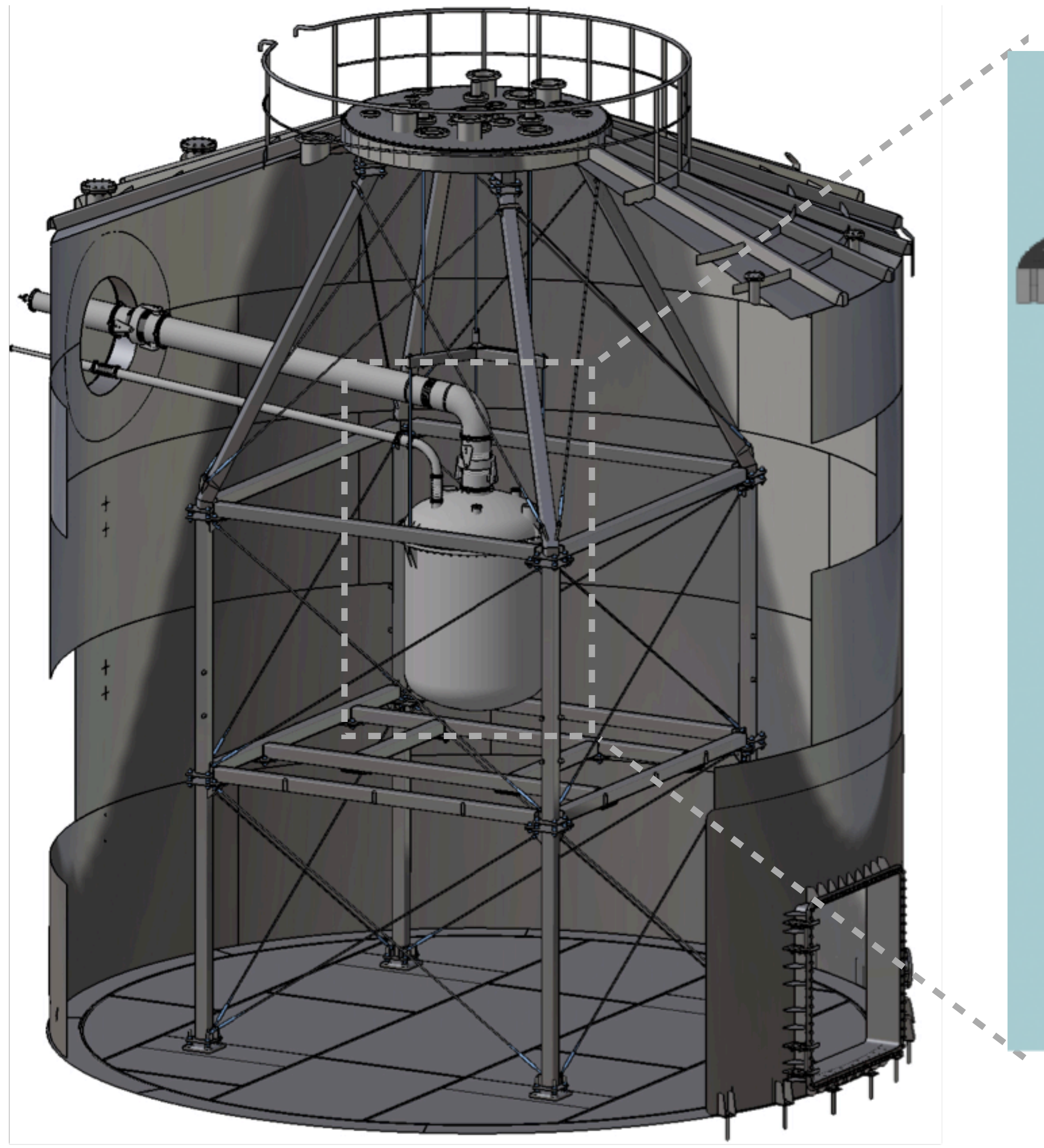


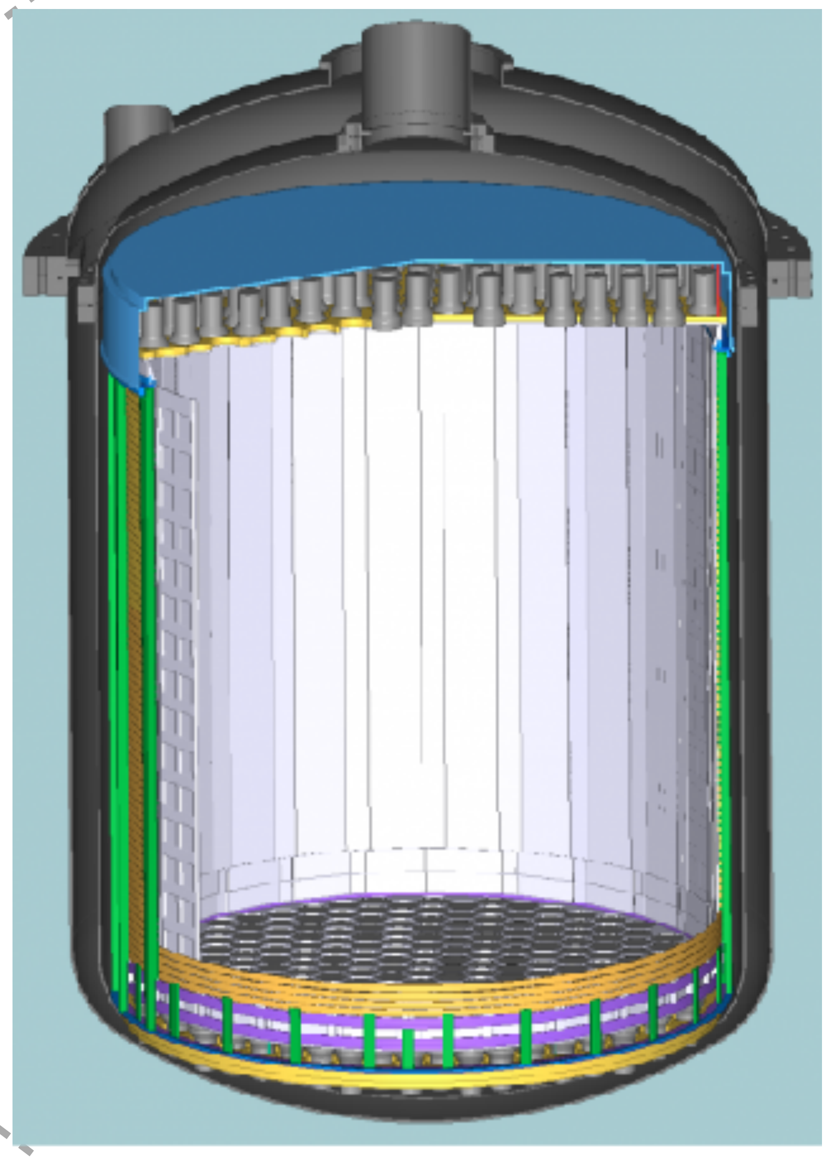


$$\sigma_{\min} = 7.7 \times 10^{-47}\,\mathrm{cm}^2 \text{ at } 35\,\mathrm{GeV/c}^2$$

Next step: XENONnT to start in 2019

- A rapid upgrade to XENON1T, with: 8 t total LXe mass, 6 t active (x3 compared to 1T)
- Most sub-systems can handle a larger detector with up to 10 t of LXe:



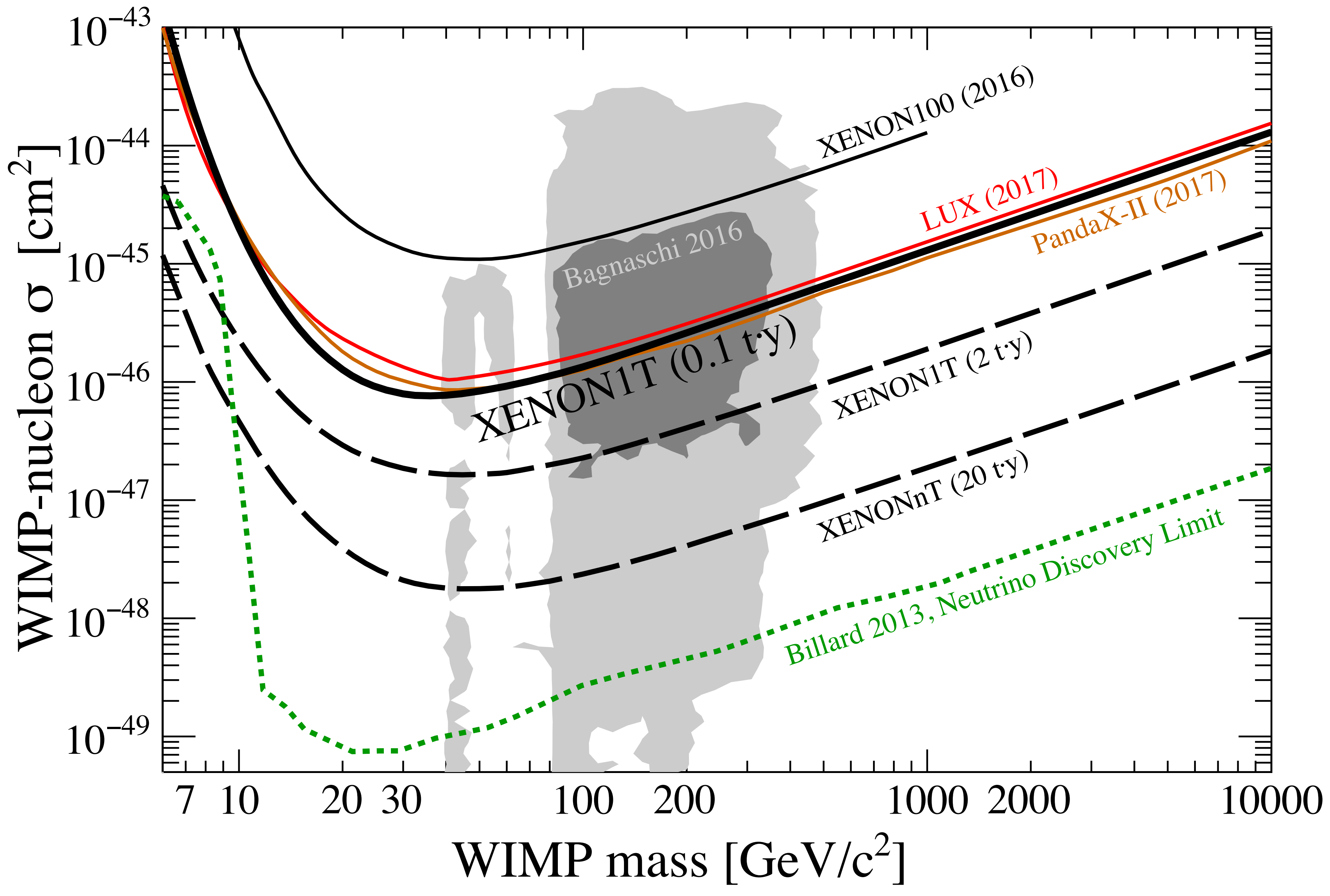


- Water tank + muon veto
- Outer cryostat and support structure
- Cryogenics and purification system
- LXe storage system
- Cables installed for XENONnT as well
- New inner cryostat, new TPC, 476 PMTs
- Neutron veto, Rn removal tower, additional LXe purification and storage system
- Work on new systems progressing

XENON1T and XENONnT science reach

- XENON1T: 1.6 x 10^{-47} cm^2 with an exposure of 2 tonnes x year
- XENONnT: to start in mid 2019, aiming for 20 tonnes x year exposure

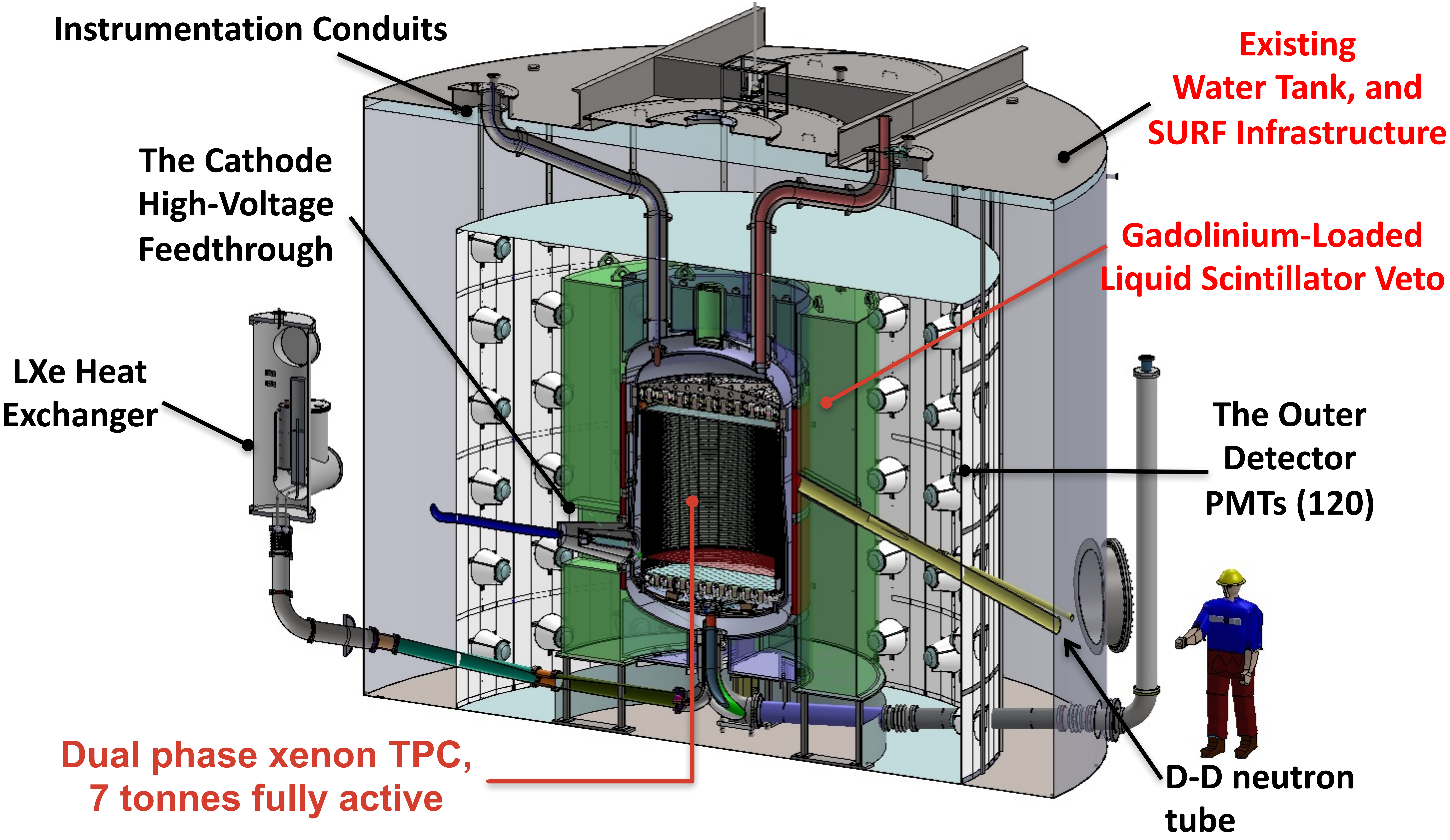
	XENON1T	XENONnT	LZ
Fiducial Volume [tons]	1	4	5.6
Livetime Fraction	80%	80%	80%
WIMP Energy Range [keV_{nr}]	4-50	4-50	6-30
NR Acceptance	40%	40%	50%
ER Rejection	99.75%	99.75%	99.5%
Bkg rate [evt/year]	2.08	1.15	2.35



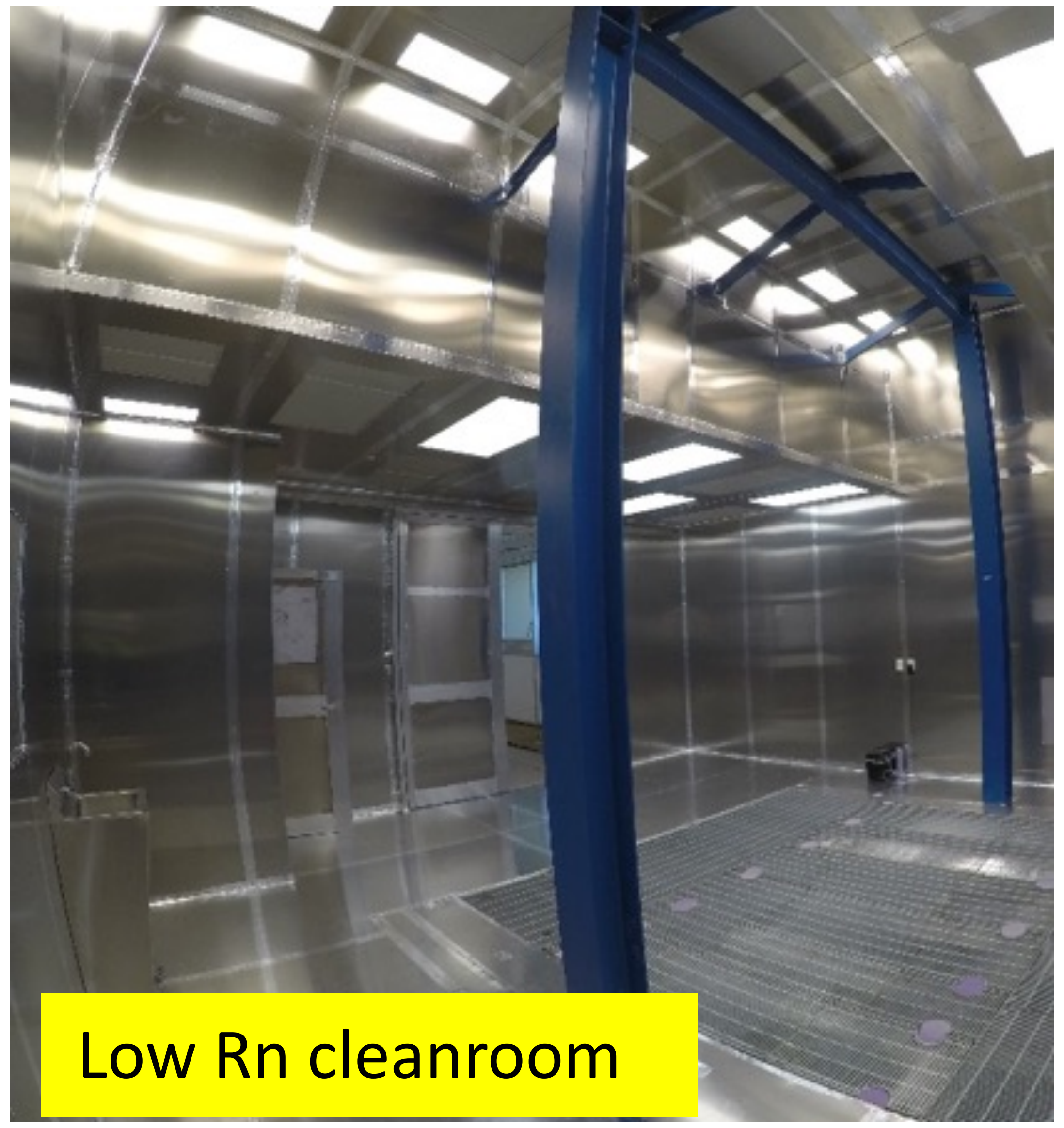
Summary

- The XENON1T experiment operates the largest LXeTPC (ton-scale)
- First physics results published in PRL, from 34.2 live days of data
- Lowest background in a dark matter detector (~0.2 events/(t d keV))
- Data-taking continues in stable conditions and with very good performance
- New result from ~a full year of data will be released in a few weeks.
- Work for the XENONnT phase on schedule for a 2019 start.

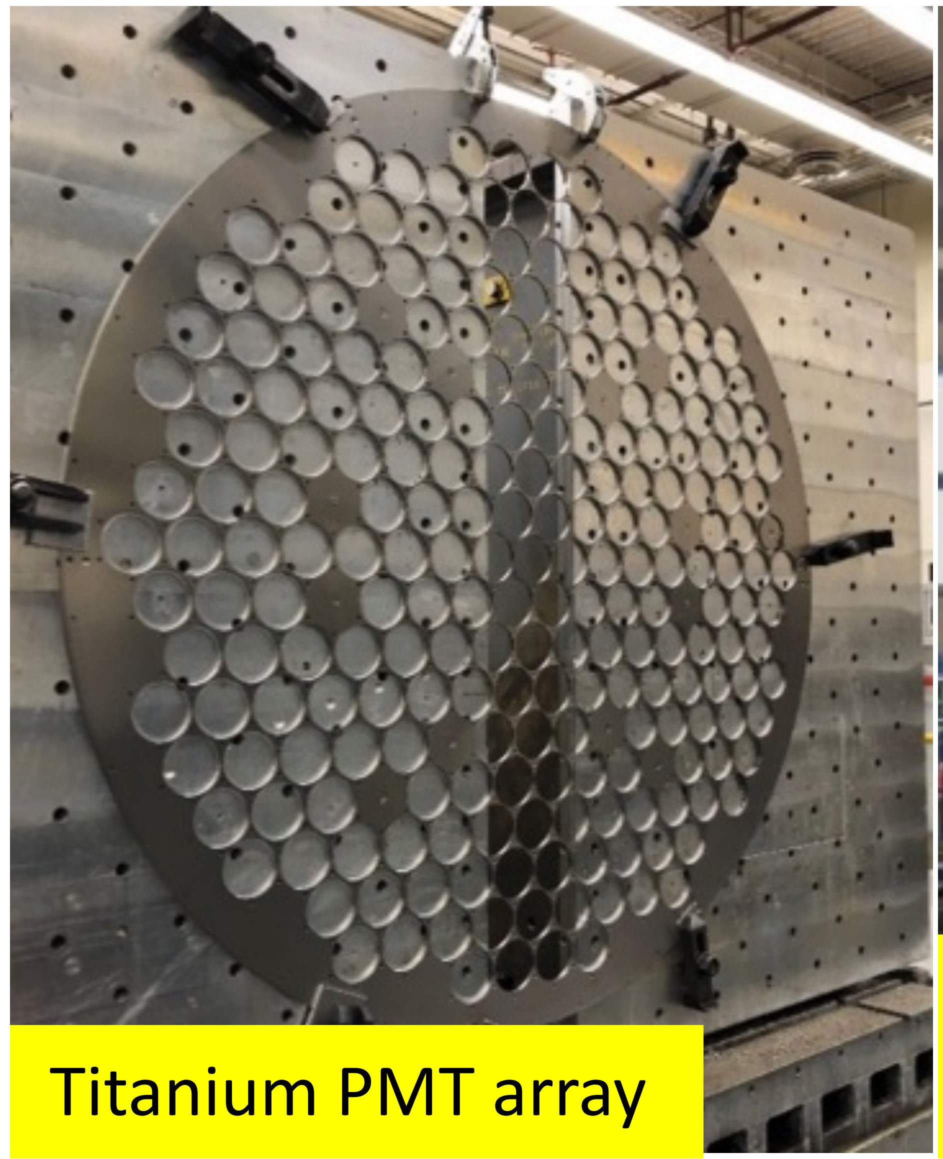
The LUX-ZEPLIN detector



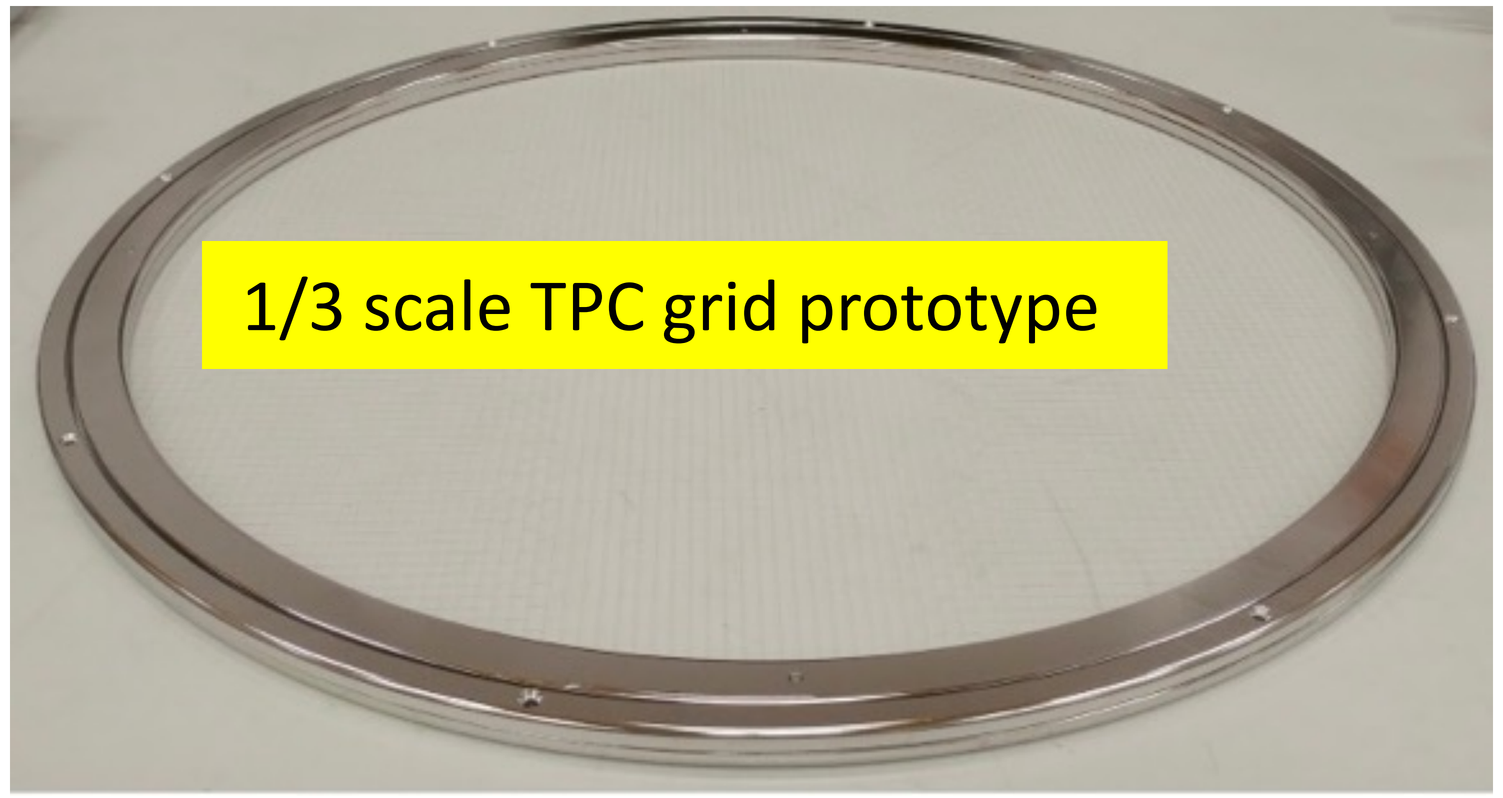
TPC fabrication is underway

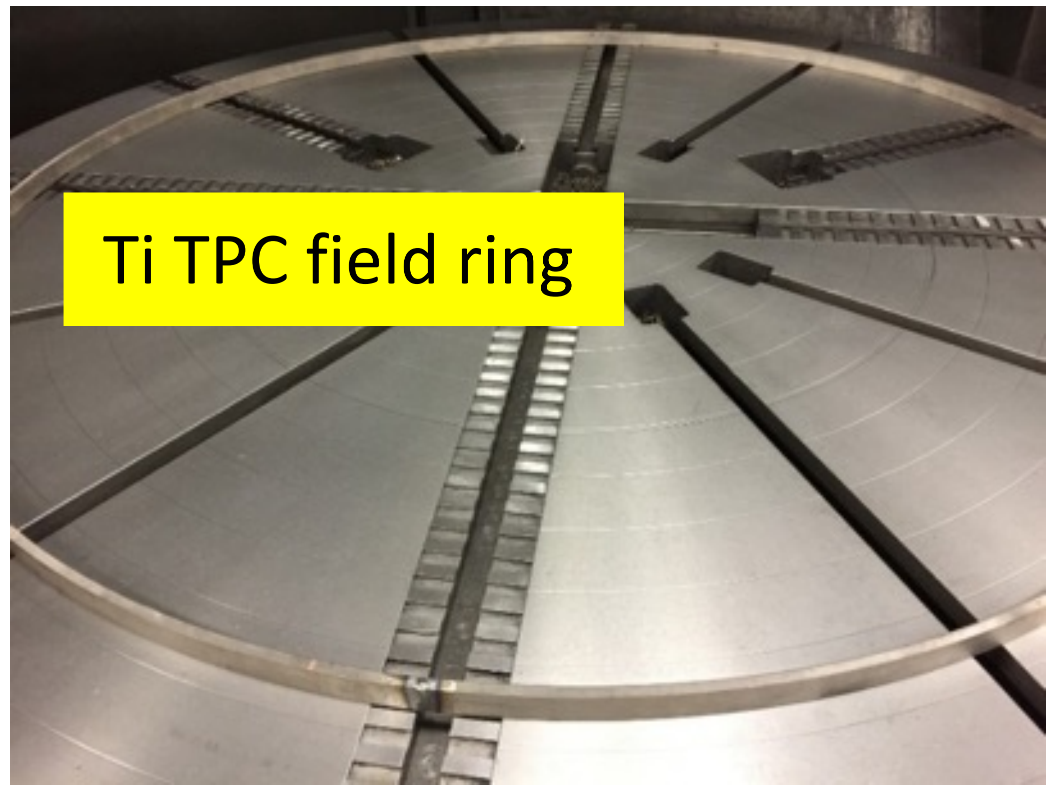

Low Rn cleanroom

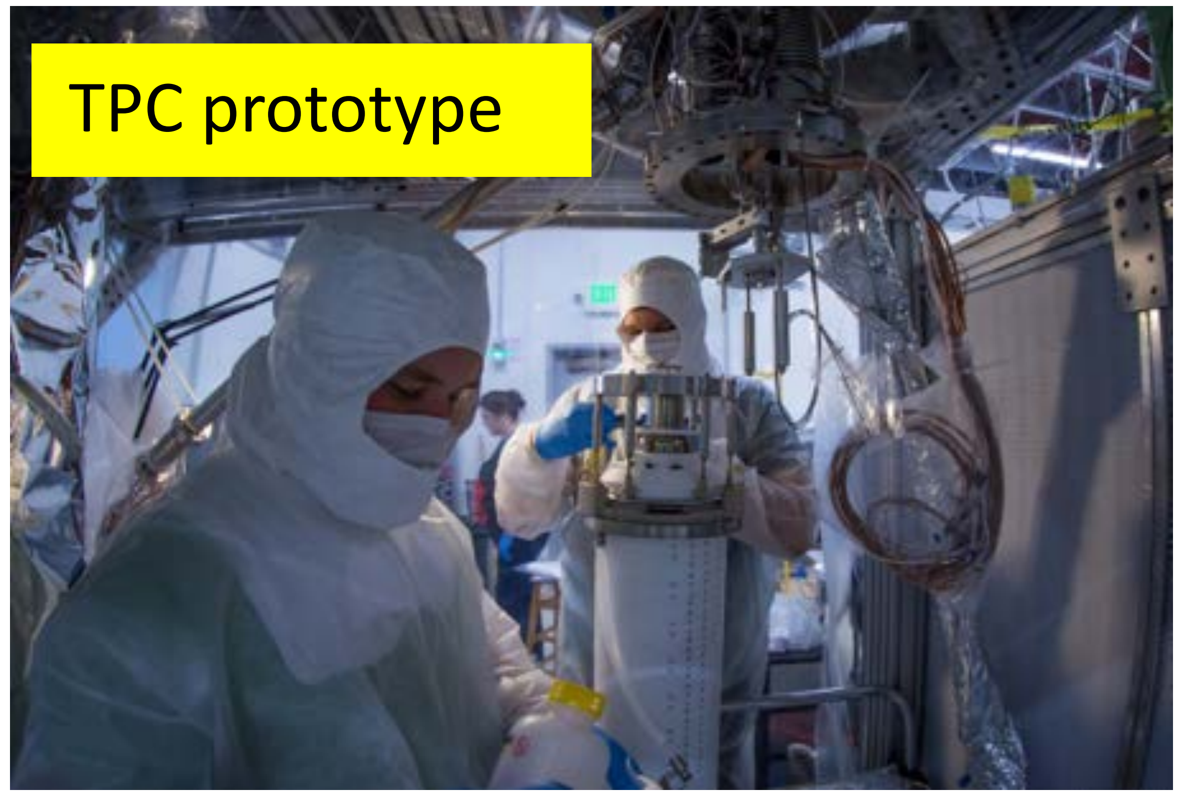

Cold PMT testing


Titanium PMT array


Ultraclean Ti cryostat
arXiv:1702.02646


1/3 scale TPC grid prototype


Ti TPC field ring

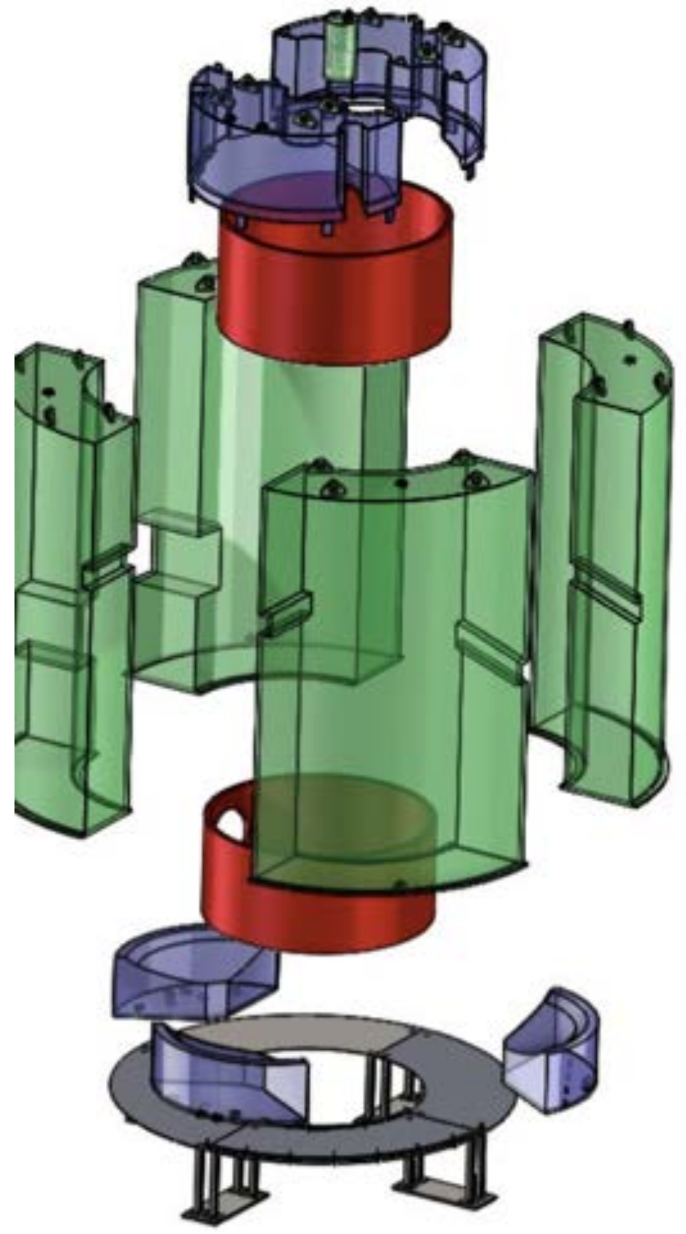

TPC prototype

Begin on-site assembly spring 2018, install underground 2019, first data spring 2020.

Powerful background rejection: outer detector & xenon skin

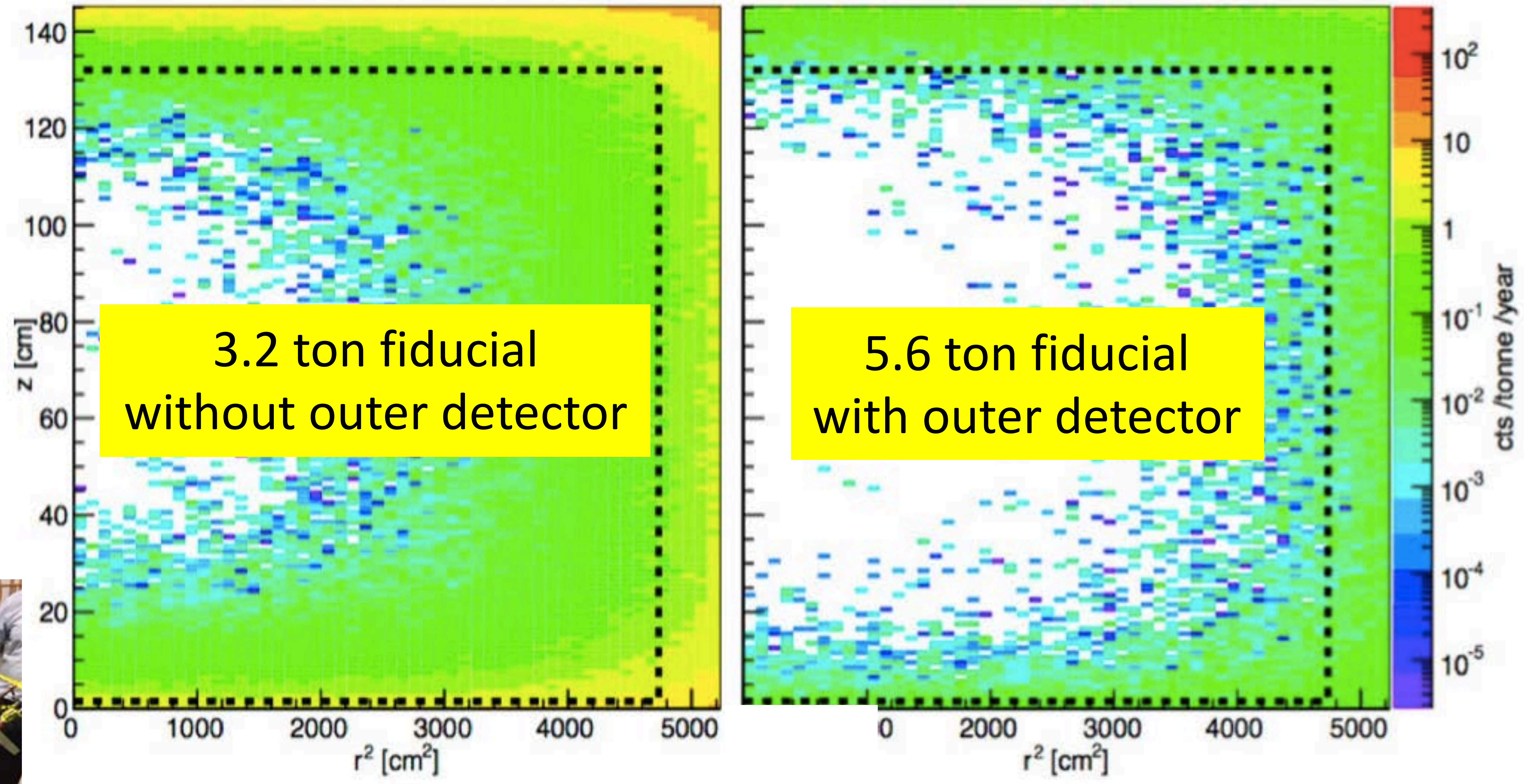
- 61-cm thick Gd-loaded liquid scintillator
  - 97% effective for neutron rejection
- Xenon skin layer for gamma rejection

in-situ monitoring of residual backgrounds

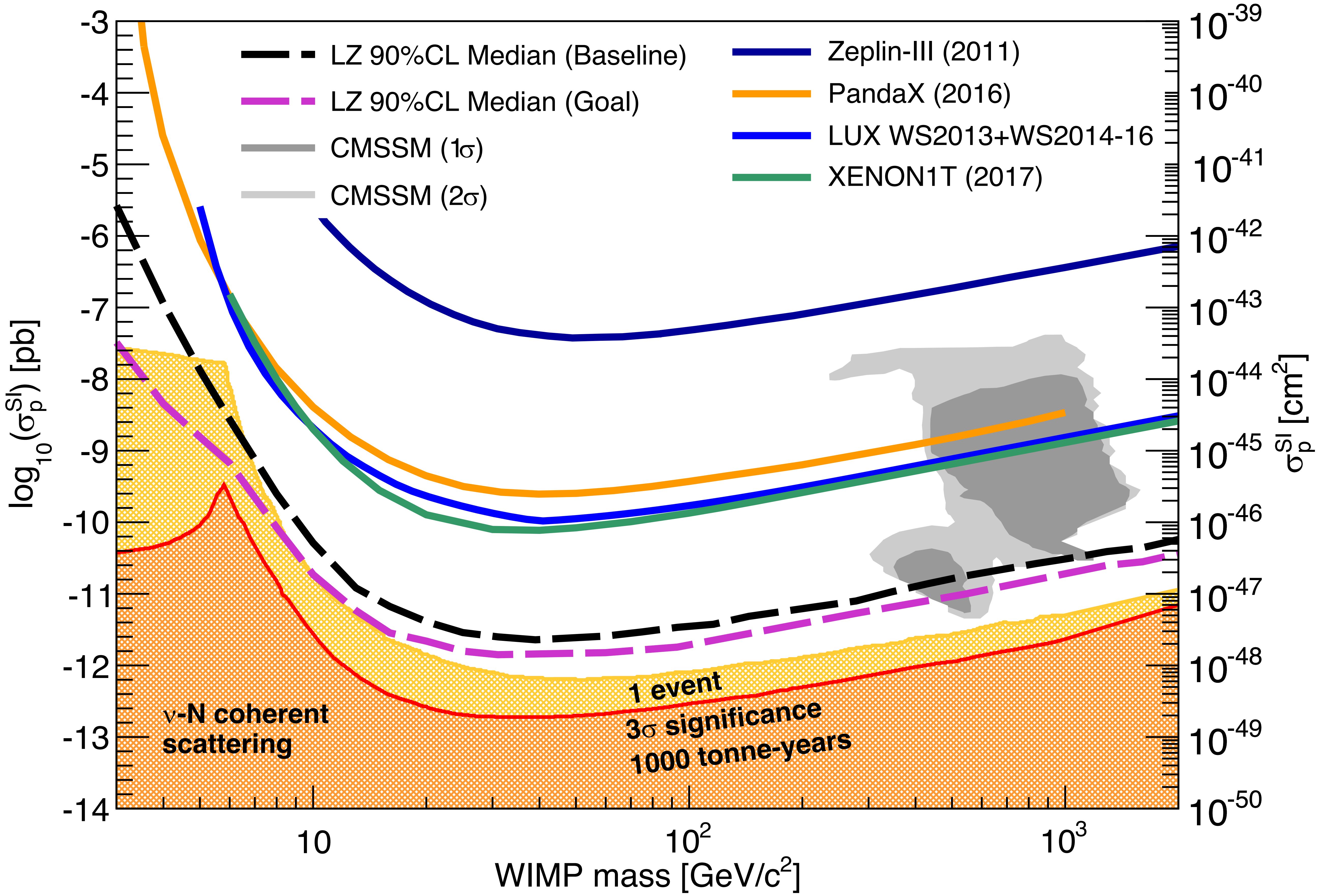


Energy RoI + Single Scatter

RoI + SS Cut + All Vetoes



LZ Spin-Independent WIMP Sensitivity



- Baseline WIMP sensitivity is 2.3×10^{-48} cm^2 @ 40 GeV/c^2 (arXiv:1703.0914).
- 1000 days, 5.6 tonne fiducial mass.
- Begin on-site assembly spring 2018, install underground 2019, first data spring 2020.

LZ backgrounds summary

5.6 tonnes, 1000 days

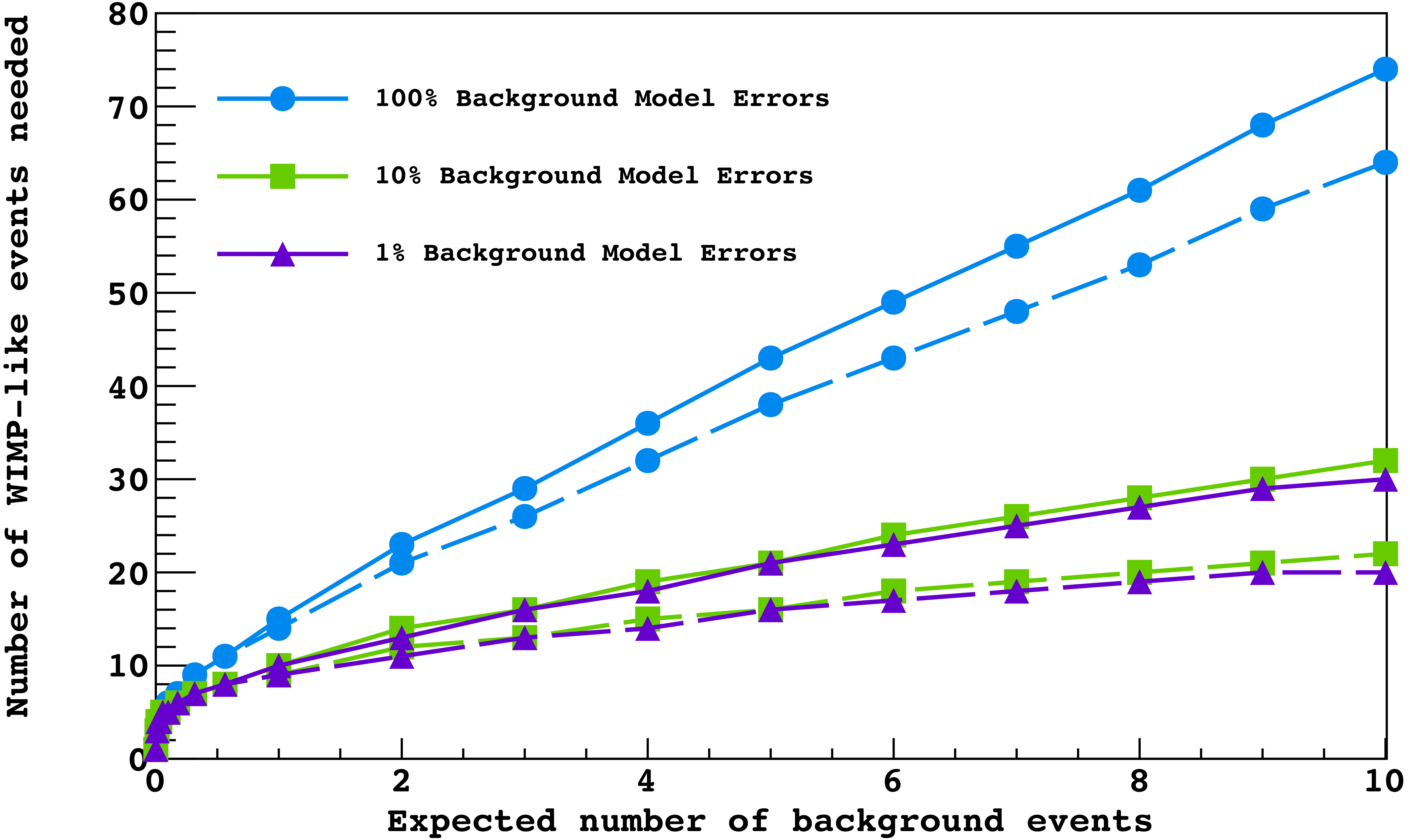
Intrinsic Contamination Backgrounds	ER (cts)	NR (cts) (w/ SF rej.)
Subtotal (Detector Components)	**9**	**0.072**
222Rn (1.81 μBq/kg)	681	-
220Rn (0.09 μBq/kg)	111	-
natKr (0.015 ppt g/g)	25	-
natAr (0.45 ppb g/g)	2	-
210Bi (0.1 μBq/kg)	40	-
Laboratory and Cosmogenics	5	0.06
Fixed Surface Contamination	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

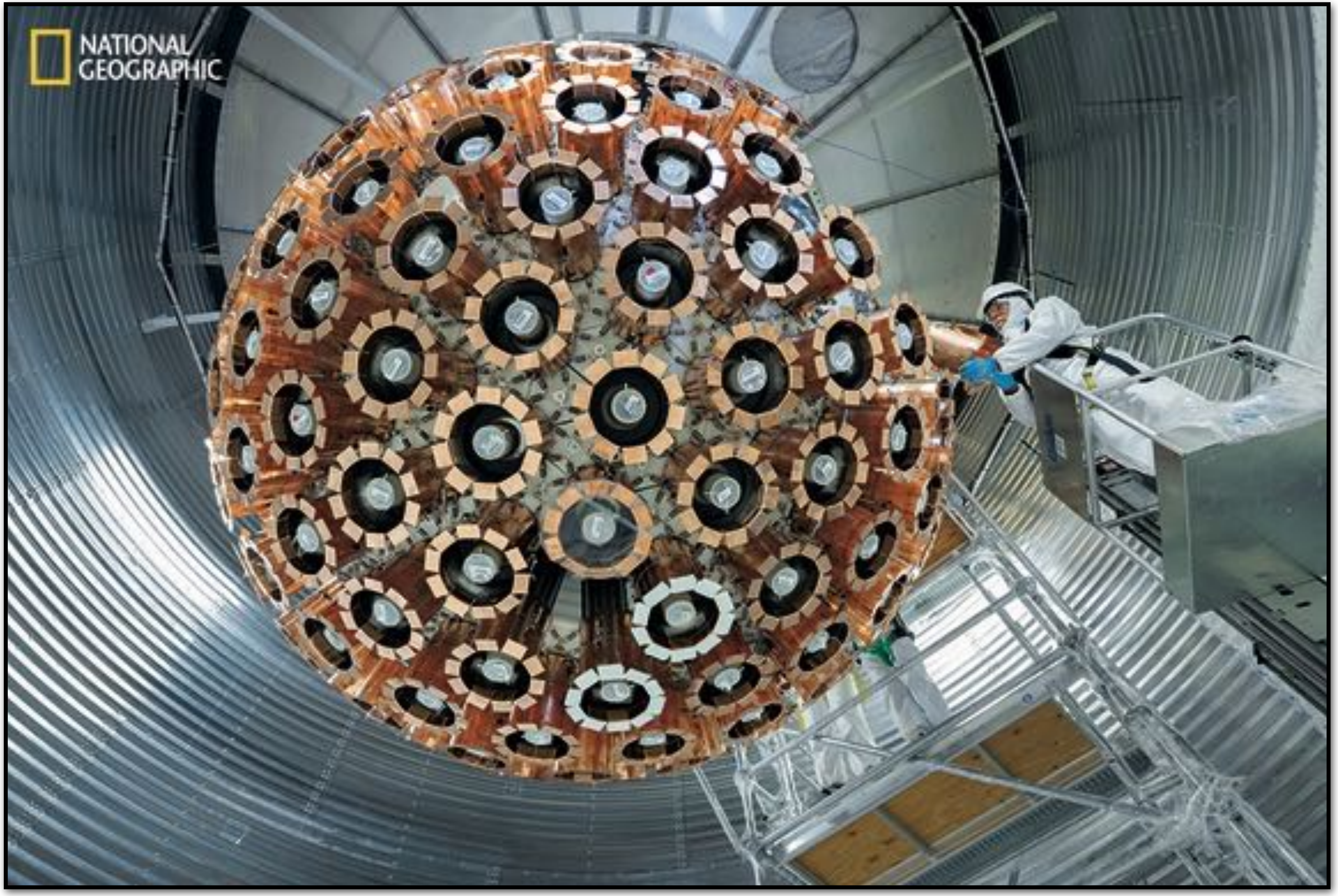
Coherent neutrino scattering on xenon nuclei



100% Background Model Errors
10% Background Model Errors
1% Background Model Errors
Number of WIMP-like events needed
Expected number of background events
0
10
20
30
40
50
60
70
80
0
2
4
6
8
10

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

DEAP-3600 Status



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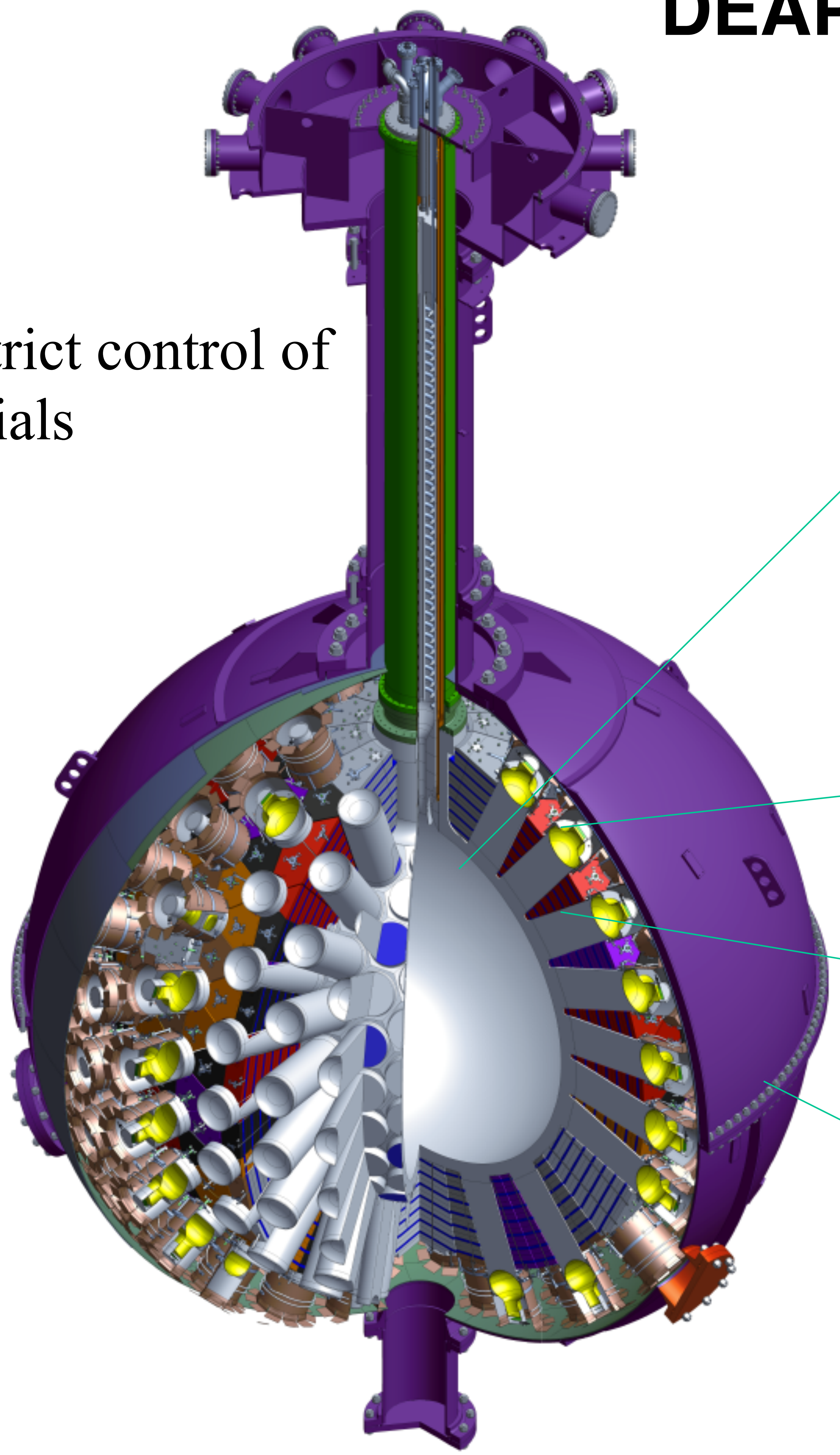
DEAP Collaboration: 75 researchers in Canada, UK, Germany and Mexico + new groups joining from DarkSide

DEAP-3600 Detector (single-phase)

very strict control of materials



3.5 meters

3600 kg argon
in sealed ultraclean
Acrylic Vessel (1.7 m ID)

Vessel is “resurfaced”
in-situ to remove
deposited Rn daughters
after construction

255 Hamamatsu
R5912 HQE PMTs 8-inch
(Light Sensors)

50 cm light guides +
PE shielding provide neutron
moderation

Steel Shell immersed in 8 m
water shield at SNOLAB

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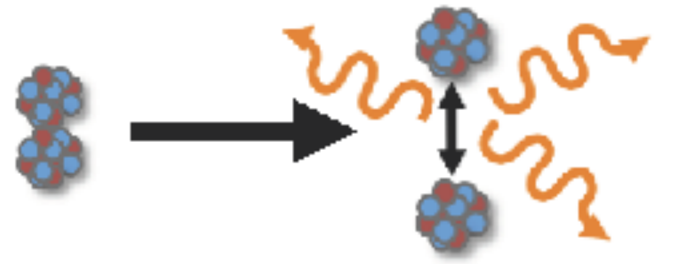
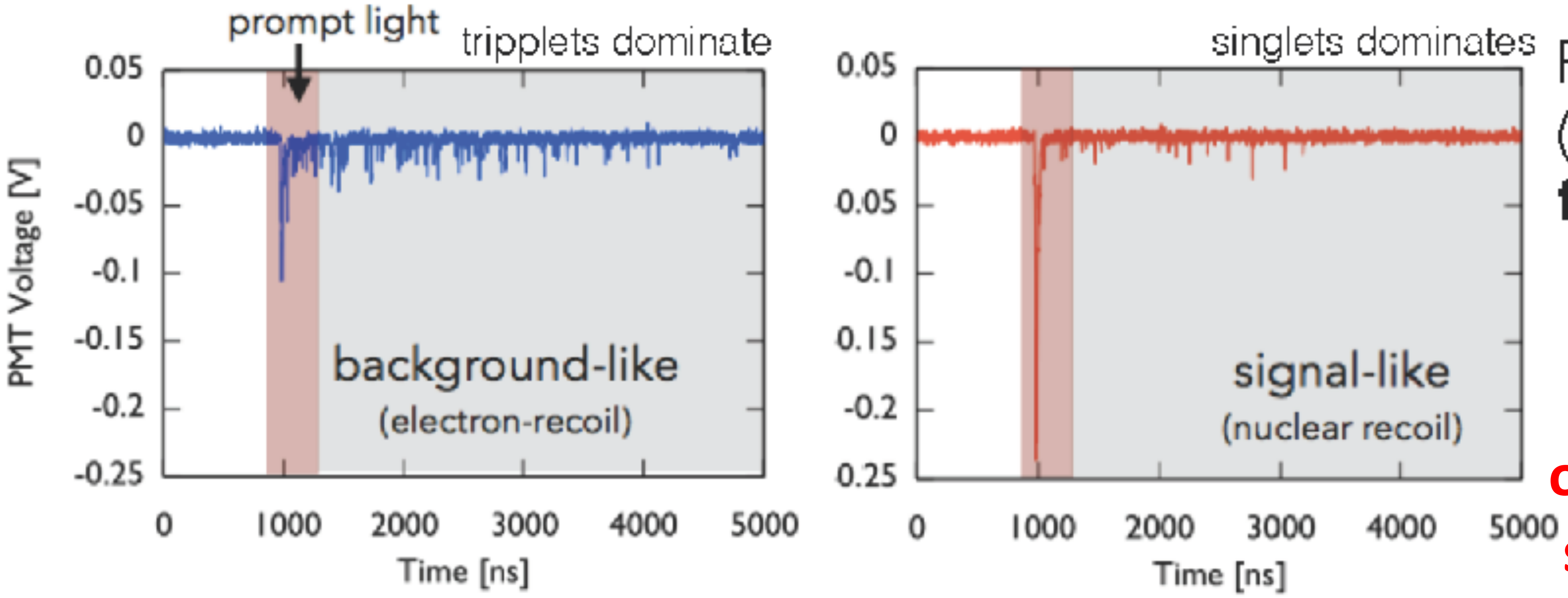
Experimental Signatures

Ar scintillation:
- excimers are create



- singlet: 6 ns
- tripplet: 1500 ns
- wavelength: 128 r

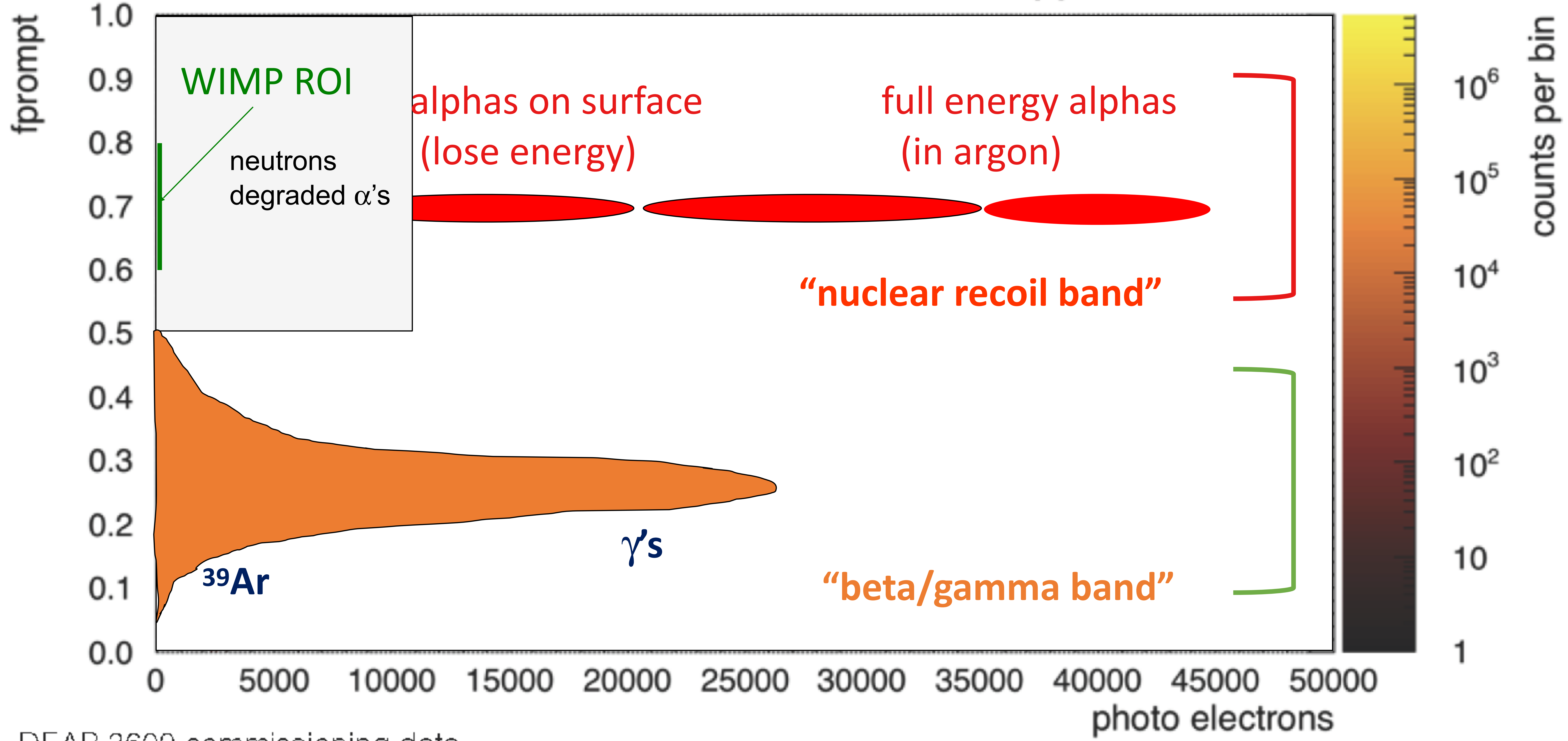


Pulse shape discrimination (PSD) parameter:

fprompt =

$$\frac{\textbf{prompt light (150 ns)}}{\textbf{total light (10000 ns)}}$$

overview of backgrounds:
see Bjoern Lehnert R1-5



DEAP 3600 commissioning data

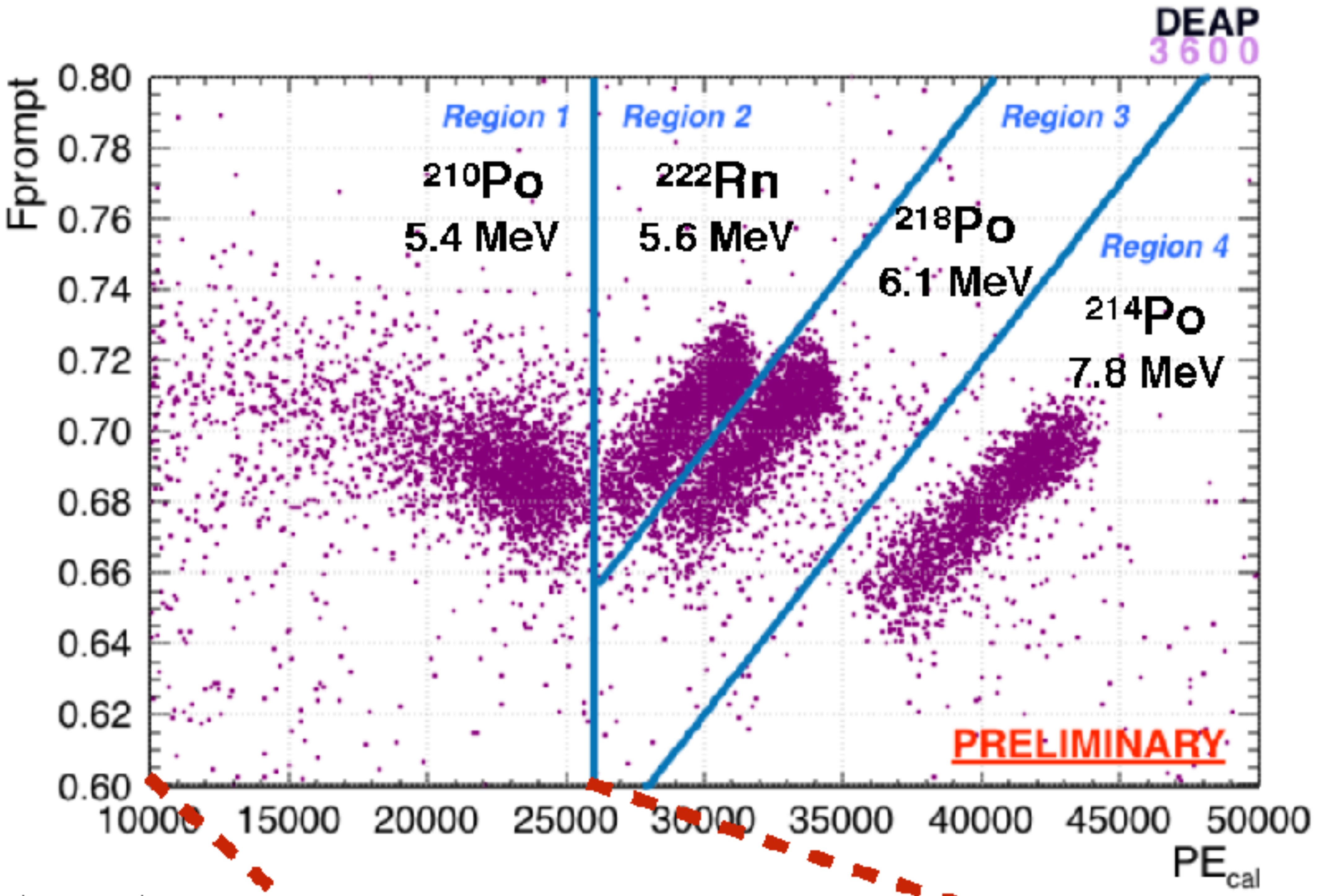
Slide from MG Boulay – TAUP 2017, Sudbury

Alpha Background

- Measuring the ^{222}Rn content in the bulk LAr shows the well very competitive results
- **Preliminary** ^{222}Rn activity

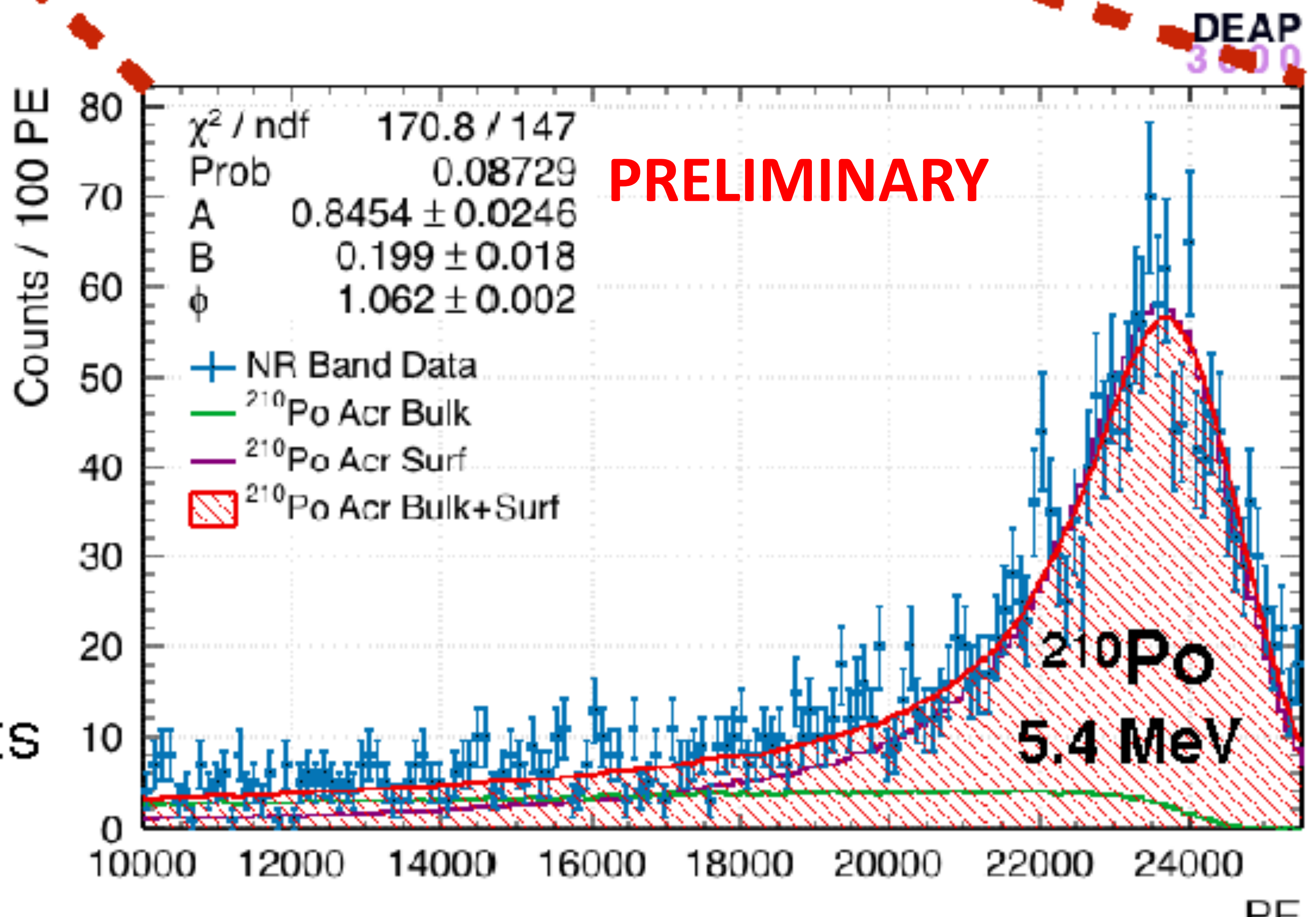
^{222}Rn in Dark Matter experiments:

Target	Experiment	Activity [mBq]
LAr	DEAP-3600	≈0.5
LXe	Xenon1T	5.7
LXe	PandaX	3.9
LXe	LUX	17.9

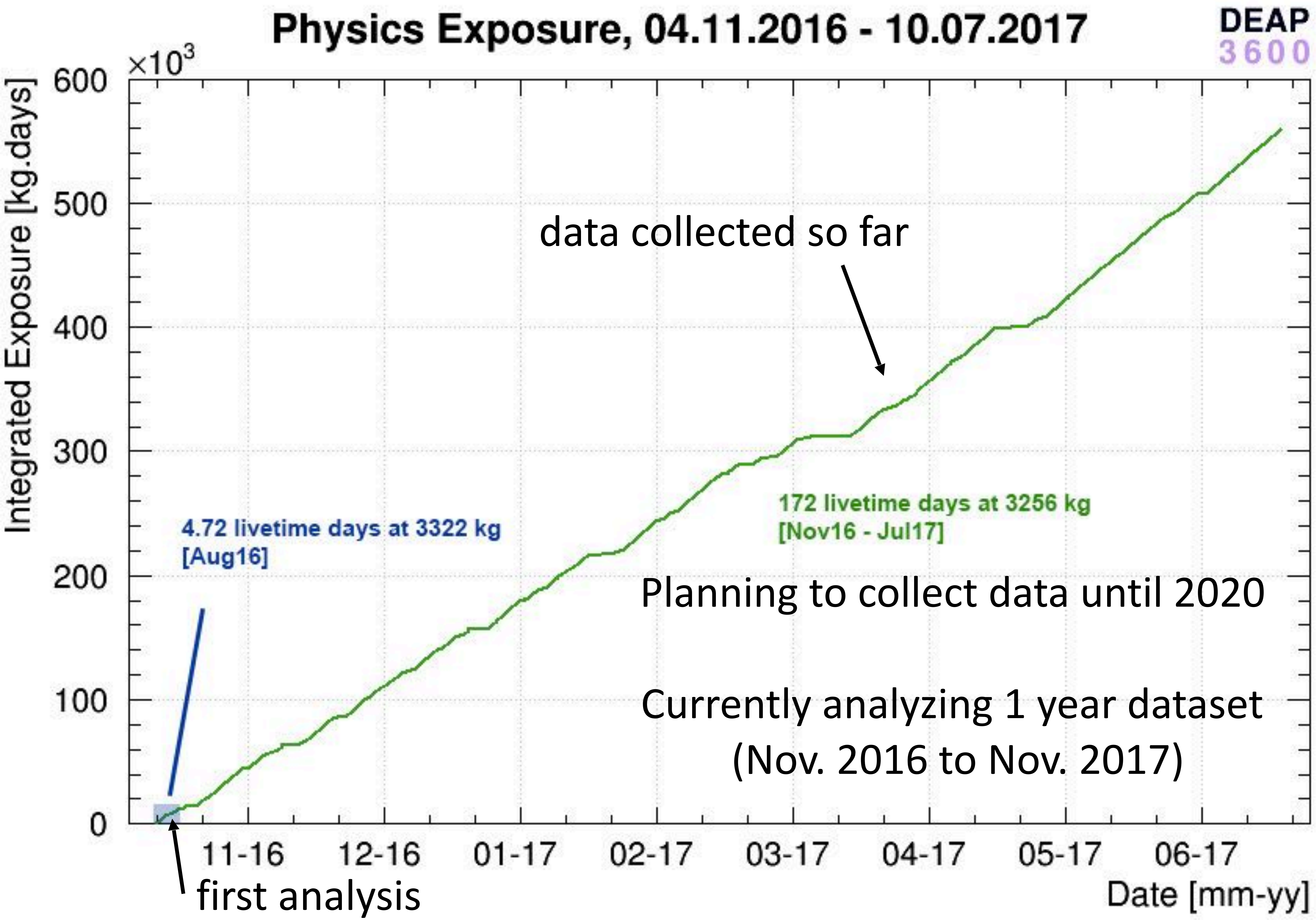


- https://indico.cern.ch/event/432527/contributions/1071738/attachments/1321292/1981557/ICHEP2016_EthanBrown_v1.pdf
- "Krypton and radon background in the PandaX-I dark matter experiment," JINST 12, 2017.
- "Radon-related backgrounds in the LUX dark matter search," Phys. Procedia. vol. 658, 2015.

Majority of ^{210}Po events on the acrylic surface

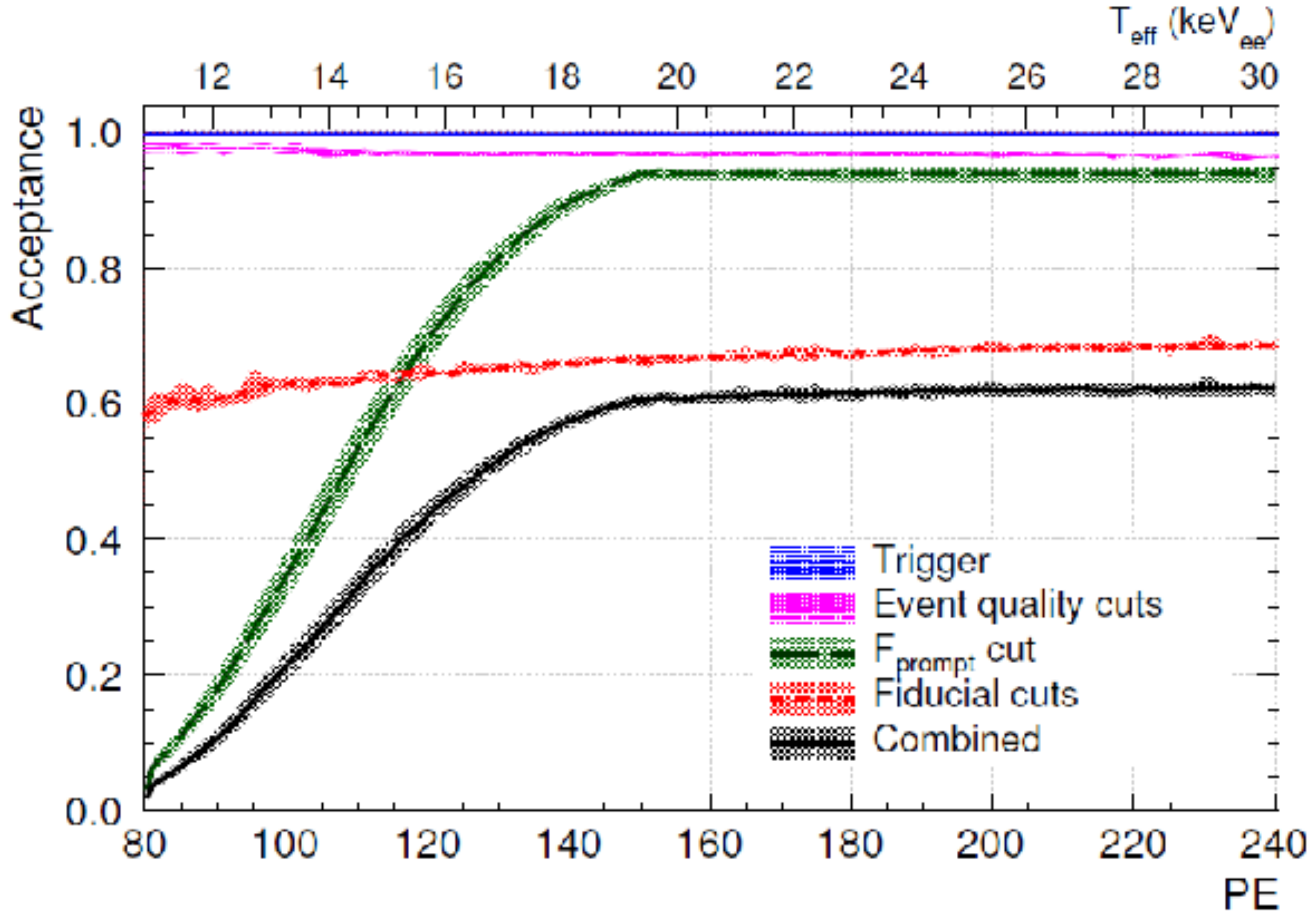


Slide from MG Boulay – TAUP 2017, Sudbury

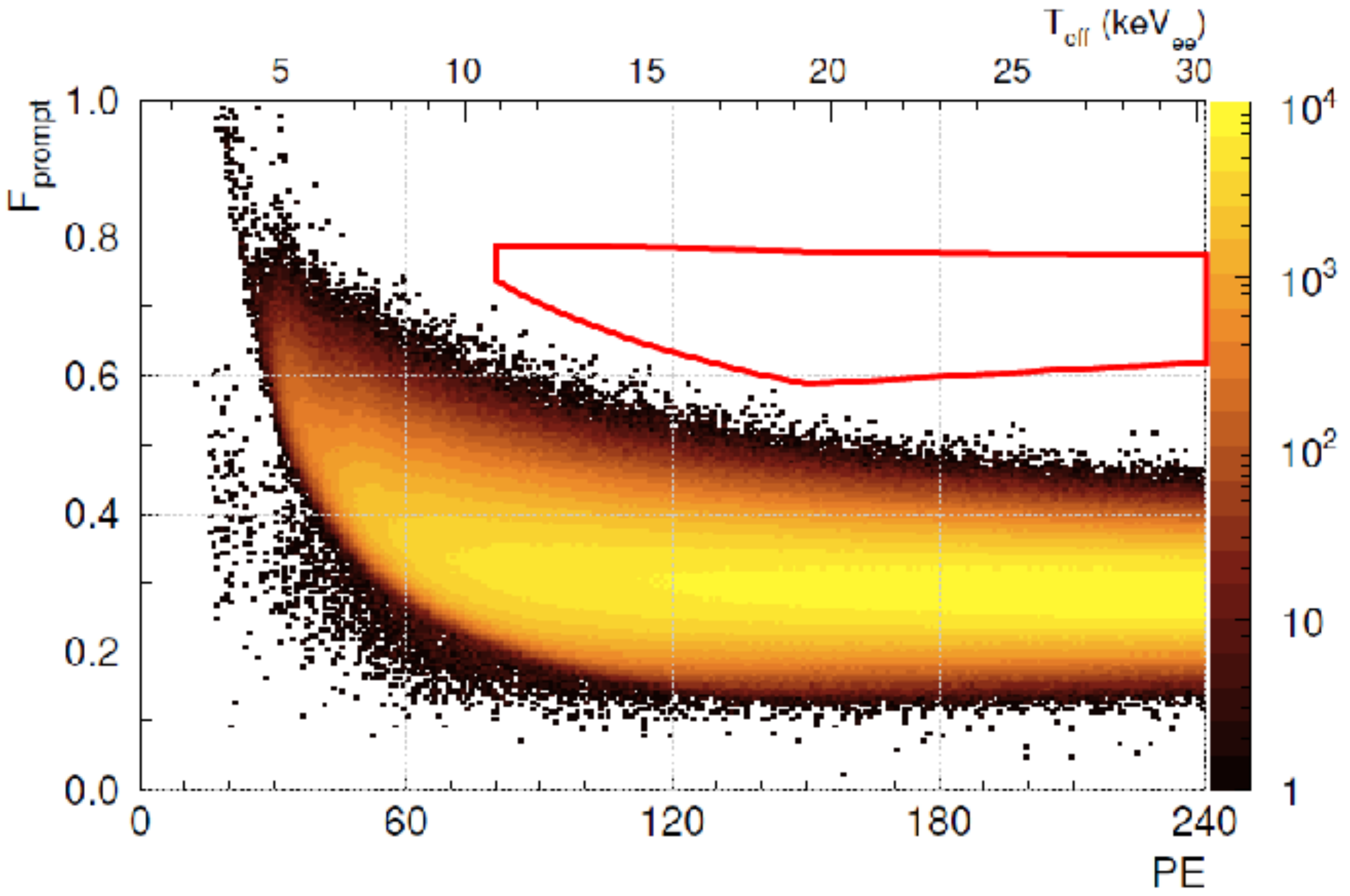


Physics Exposure, 04.11.2016 - 10.07.2017
DEAP
3600
×10^3
Integrated Exposure [kg.days]
600
500
400
300
200
100
0
11-16
12-16
01-17
02-17
03-17
04-17
05-17
06-17
Date [mm-yy]
data collected so far
4.72 livetime days at 3322 kg
[Aug16]
172 livetime days at 3256 kg
[Nov16 - Jul17]
Planning to collect data until 2020
Currently analyzing 1 year dataset
(Nov. 2016 to Nov. 2017)
first analysis

First Dark Matter Search with DEAP-3600 – 9,870 kg-days   July 2017 arXiv:1707.08042



	Cut	Livetime	Acceptance %		$\#^{ROI}_{evt.}$
run	Physics runs	8.55 d			
run	Stable cryocooler	5.63 d			
run	Stable PMT	4.72 d			
run	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
low level	Pile-up				100700
low level	Event asymmetry				787
quality	Max charge fraction per PMT		99.58±0.01		654
quality	Event time		99.85±0.01		652
quality	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
fiducial	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	0
	Total	4.44 d	96.94±0.03	$66.91^{+0.20}_{-0.15}$	0



4.4 live days

Selected ROI for < 0.2 leakage from β's

9,870 kg-day exposure

No events observed in ROI

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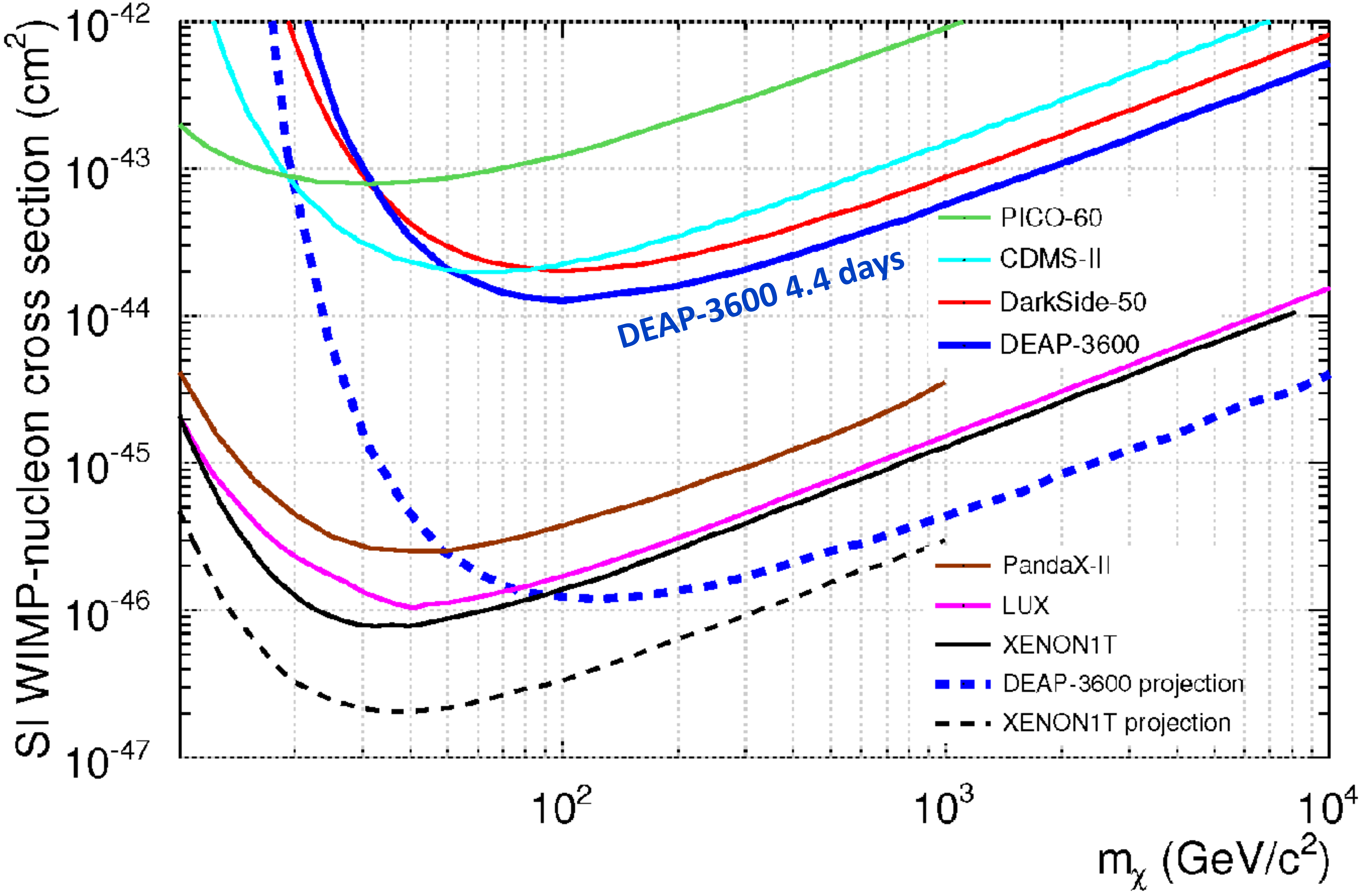
WIMP exclusion with DEAP-3600 First Result

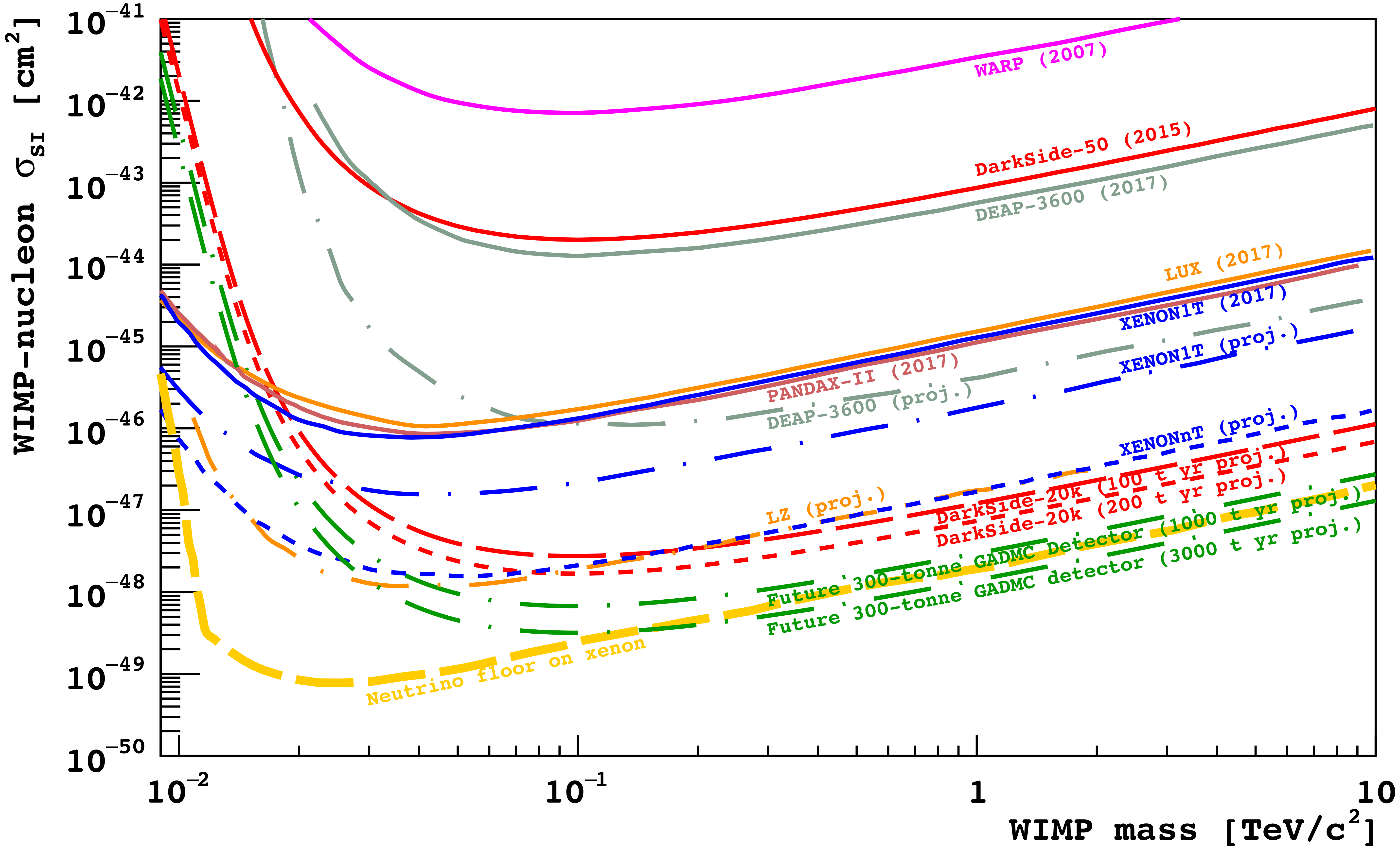


Slide from MG Boulay – TAUP 2017, Sudbury

The Global Argon Dark Matter Collaboration

ArDM
DarkSide
DEAP
MiniCLEAN

A Single Global Program for Direct Dark Matter Searches
Currently taking data: ArDM, DarkSide-50, **DEAP-3600**
Next step: DarkSide-20k at LNGS (2021-)
Last Step: **300 tonnes detector**, location t.b.d **(2027-)**



DarkSide-20k approved by INFN and LNGS in April 2017 and by NSF in Oct 2017
Officially supported by LNGS, LSC, and SNOLab
30 tonnes (20 tonnes fiducial) of low-radioactivity underground argon
14 m^2 of SiPM coverage

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
40
30
20
10
0
50
100
150
200
250
300
350
400
450
S1 [PE]

University of Alberta · Quaecumque Vera
APC
LNGS
GSSI
AU Augustana University
БелГУ 1876
Black Hills State University
Alma Mater Studiorum A.D. 1088
Carleton University

Studiorum Universitas Caralitana
UNICAMP Universidade Estadual de Campinas
Centro Fermi Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
INFN LNS
Universitas Hennae Studiorum · Libera Università Kore Enna

ETH Zürich
Fort Lewis College · Artes Liberales · Established 1911
University of Hawaii · Mānoa 1907
University of Houston · Founded 1927
Institute of High Energy Physics Chinese Academy of Sciences
INFN

IPN Institut de Physique Nucléaire Orsay
INSTM
IPHC Institut Pluridisciplinaire Hubert Curien Strasbourg
Joint Institute for Nuclear Research JINR
Laurentian University Université Laurentienne
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati
LPNHE Paris

MEPhI National Research Nuclear University Moscow Engineering Physics Institute
Politecnico Milano
Universitas Studiorum Mediolanensis
Semper Augustus Fridericus Imperator Romanorum
НГУ
Studium Generale Civitatis Perusii A.D. MCCCVIII
In Supremae Dignitatis 1343
Pacific Northwest National Laboratory · Proudly Operated by Battelle Since 1965
Vet Nov Tes Tam En Tvm

Queen's University
Roma Tre Università degli Studi
Hippocratica Civitas Studium Salerni
SNOLAB
University of Sussex
Sacerensis Universitas Turritana
Temple University
FBK Fondazione Bruno Kessler

TIFPA Trento Institute for Fundamental Physics and Applications
Universitas Athesina Studiorum
Politecnico di Torino 1859 · 1906
Politecnico di Torino
Taurinorum Sigillum Universitatis Augustae
TRIUMF
TUM Technische Universität München
Universidad Nacional Autónoma de México

The University of California Davis · Let There Be Light
The University of California UCLA · Let There Be Light
University of Massachusetts Amherst 1863
ΕΥΡΩΠΗ
Universidade de São Paulo · Scientia Vinces
Virginia Polytechnic Institute and State University · Ut Prosim

Letter of Intent

September 8, 2017

Rev B

Scientists at LNGS, LSC, and SNOLAB are joining in an international effort to mount a phased argon dark matter program with the goal of being sensitive to the neutrino floor. This effort will include a broad collaboration of scientists and will represent the global community for dark matter searches with argon. This letter is an update of a previous communication dating June 2017, which detailed the first conception of the program; this letter was expanded to capture the intent of all institutions and scientists participating in the program.

In this document, the undersigned representatives of groups working on argon dark matter searches, including Brazilian, Canadian, Chinese, French, German, Greek, Italian, Mexican, Polish, Romanian, Russian, Spanish, Swiss, US, and UK groups among others, memorialize their intent to form a Global Argon Dark Matter Collaboration to carry out a program for direct dark matter searches, consisting of two main elements.

The first element of the program is the DarkSide-20k experiment at LNGS, whose science goal is to perform a dark matter search with an exposure of 100 tonne·yr of low-radioactivity underground argon (the low intrinsic background, free from any background other than that induced by atmospheric neutrinos, may also permit a 200 tonne·yr exposure for

Deep underground laboratory support for global collaboration towards discovery of dark matter utilising liquid argon detectors.

To whom it may concern;

As hosts of the existing operational liquid argon direct dark matter detectors, and as proponents and supporters of the Underground-GRI initiative, the LNGS, SNOLAB and LSC deep underground research facilities are pleased to recognize the collaborative developments within the global liquid argon dark matter community. The DarkSide project at LNGS, the DEAP project at SNOLAB and the ArDM project at LSC are all developing new technologies and capabilities to search for WIMP dark matter, and are beginning to coalesce into one collaboration to develop future, larger generations of liquid argon direct dark matter detectors. We encourage and support the development of this global community, with a focus on the development of DarkSide-20k at LNGS in the first instance, and a larger detector at a location to be determined from scientific requirements, in the future. Using available assay and research infrastructure,

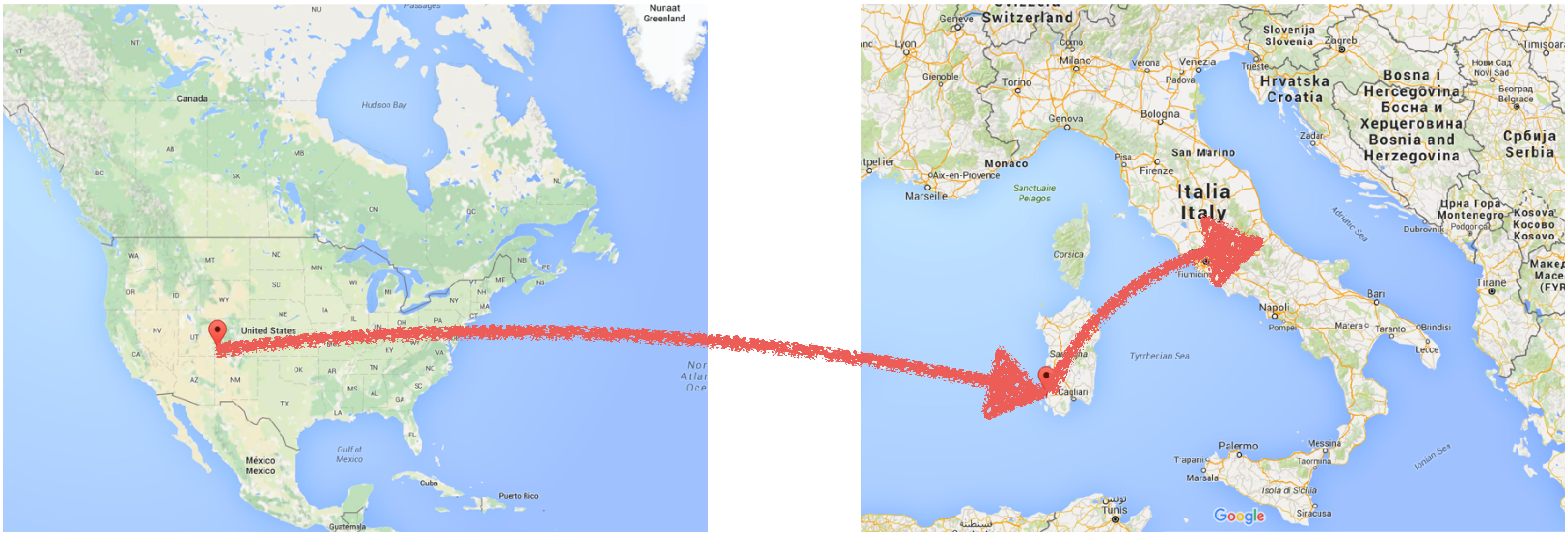
DarkSide-20k

20-tonnes fiducial dark matter detector
start of operations at LNGS within 2021
100 tonne×year background-free search for dark matter

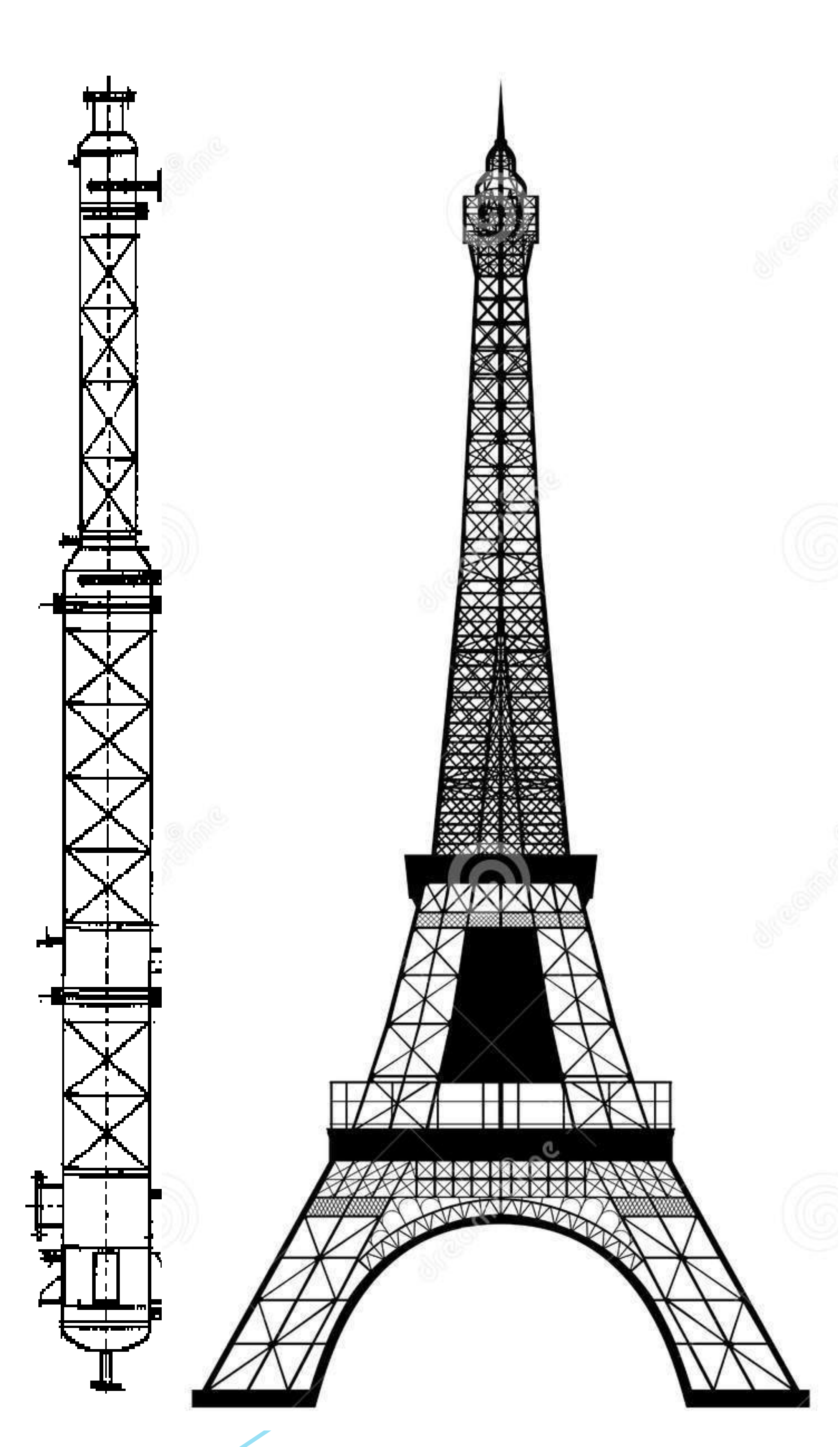
Future 300-tonne Detector

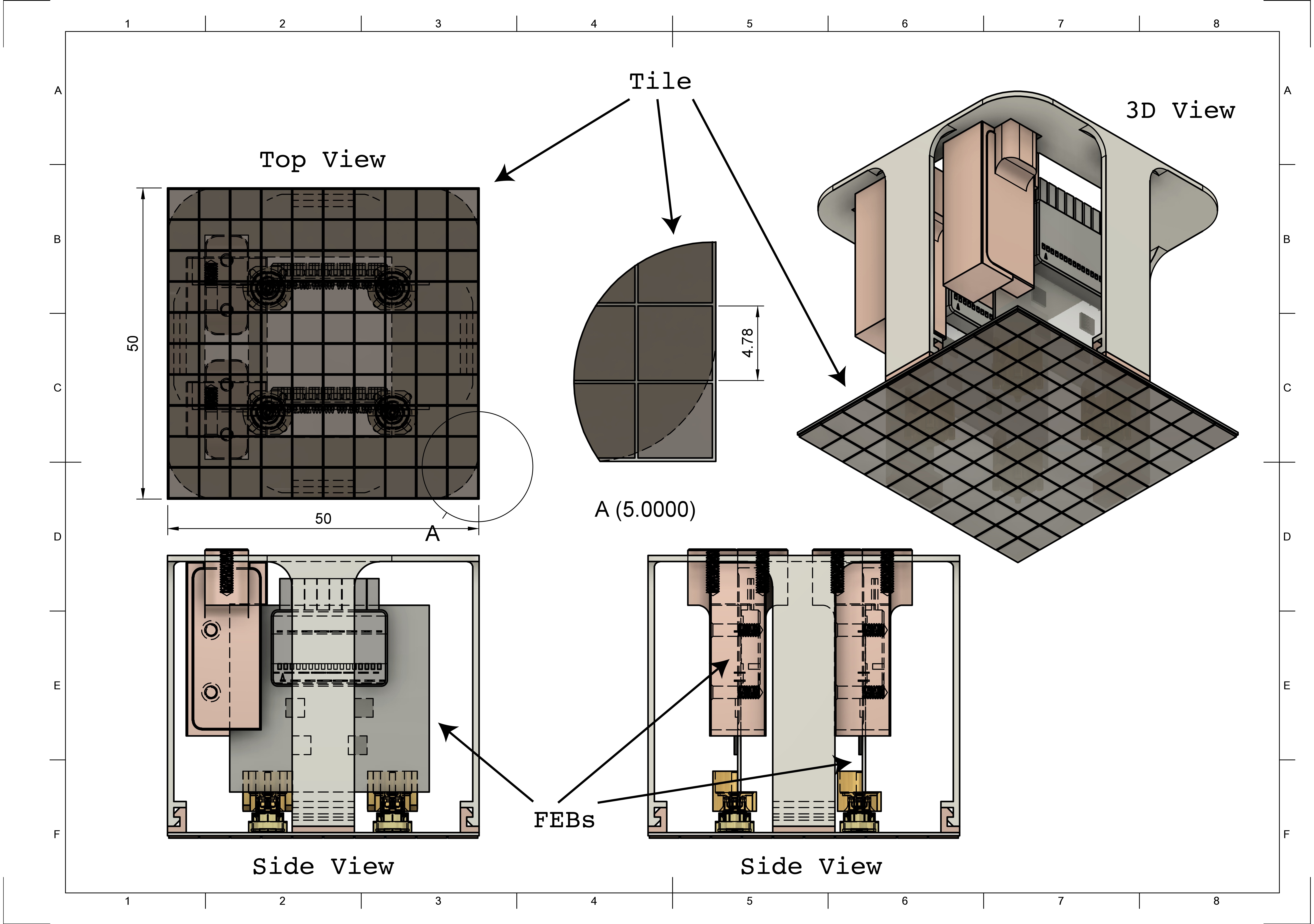
300-tonnes depleted argon detector
start of operations within 2026
1,000 tonne×year background-free search for dark matter
precision measurement of solar neutrinos

Urania to Aria to LNGS









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

STATUS OF DART

Achievements

Mechanical DART design and simulations
Integration studies of DART into ArDM
Background simulations
DART chamber material procurement
3 cylinders of 99.99% OHFC to machine the chamber

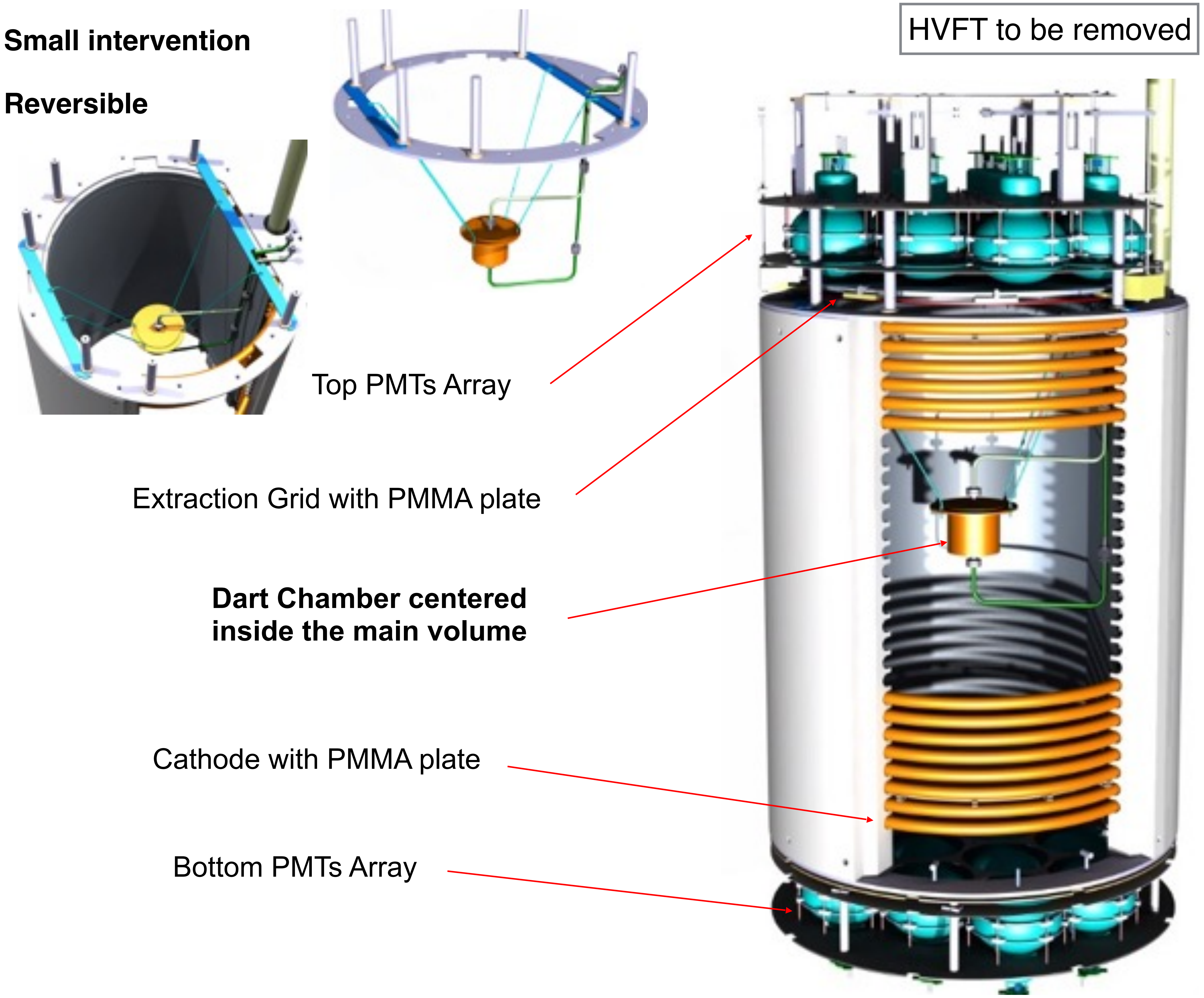
Next points to be reached

light response simulation → Jan-Feb2018
procurement of 1kg of UAr → OPEN ISSUE
Availability of non-radiopure photo-electronics and FEBs → Feb 2018
Work on circuit for adjustment of dynamic range → March 2018
Design of cryogenics of DArT for ArDM → Feb 2018
Decision on further shielding of ArDM → Feb 2018
DART chamber construction (CIEMAT) → Feb 2018
DART assembly (CIEMAT) → March 2018
test in a clone ArDM cryostat at CERN → March/April 2018
Availability of new SiPMs → April 2018 **OPEN ISSUE**
Radio-pure FEBs → May 2018 **OPEN ISSUE**
DART assembly with radio pure photo-electronics → will follow
final installation in Canfranc and test with the spare UAr → will follow

Integration into ArDM fully engineered

Small intervention

Reversible



The End