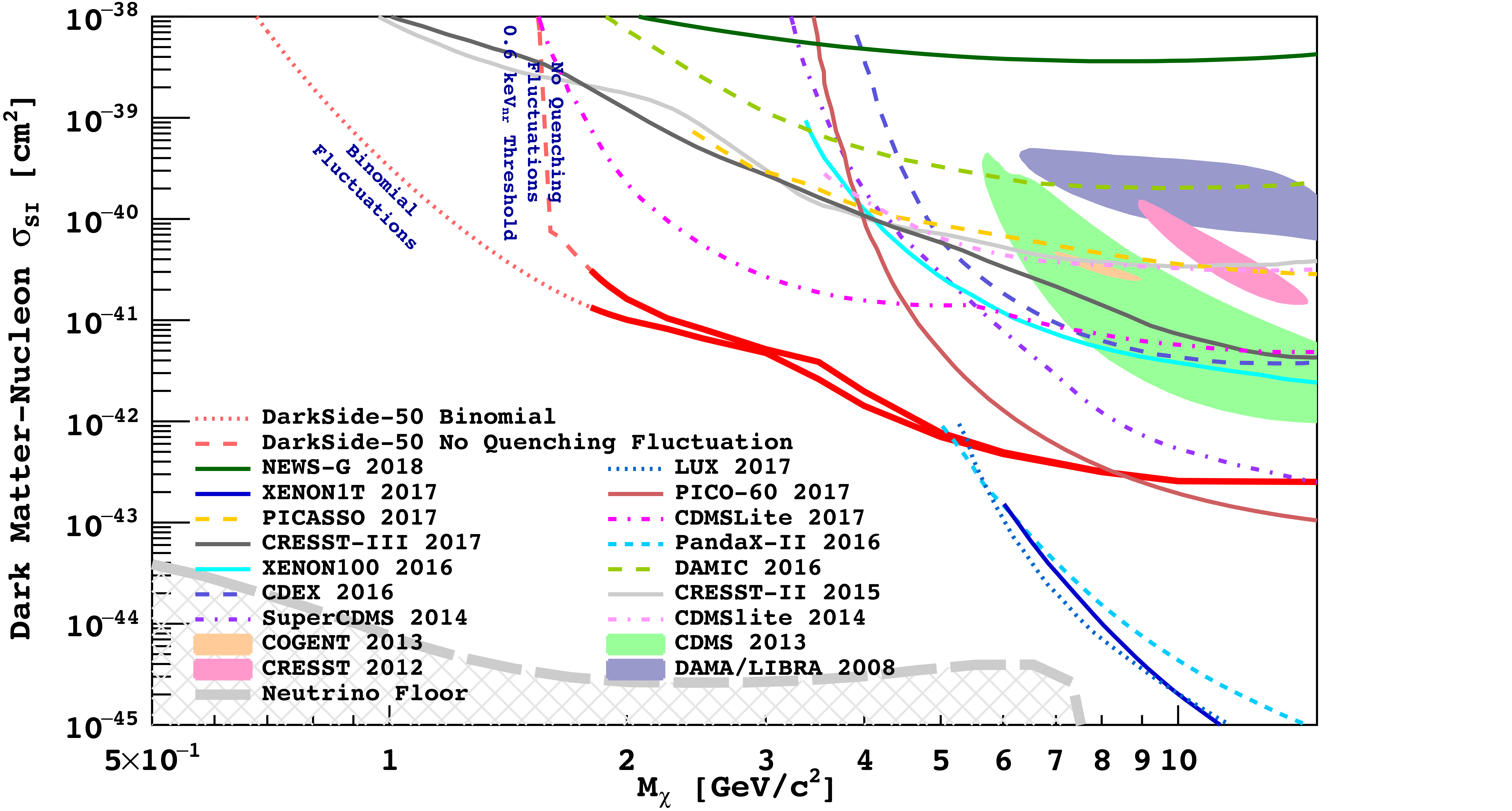
Direct Dark Matter Detection with Noble Gases

Cristiano Galbiati
Princeton University

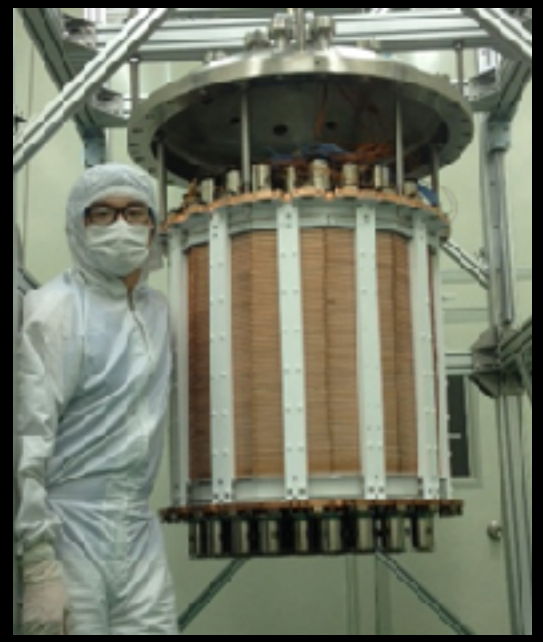
UCLA DM 2018
Los Angeles, CA
February 21, 2018



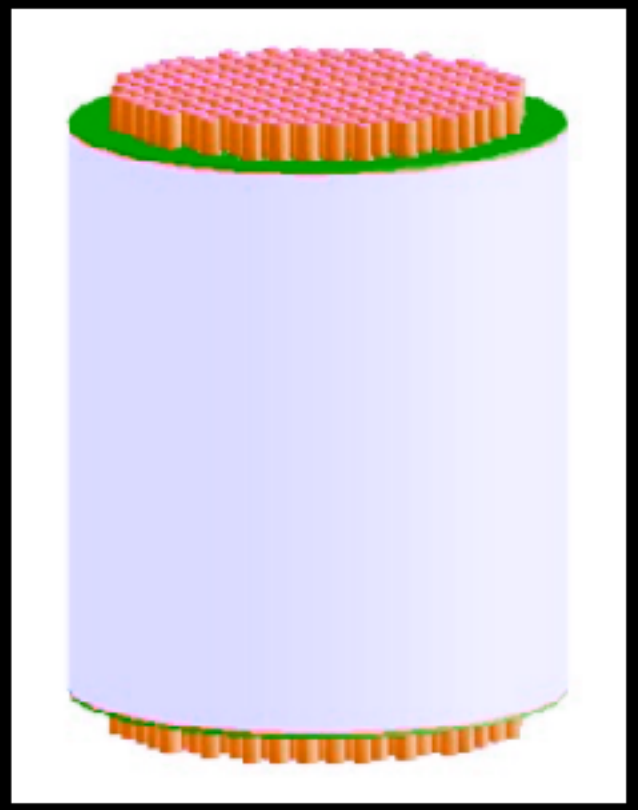
Dark Matter-Nucleon σ_{SI} [cm^2]
M_χ [GeV/c^2]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
5×10^{-1}
1
2
3
4
5
6
7
8
9
10
Binomial Fluctuations
0.6 keV_{nr} Threshold
No Quenching Fluctuations
DarkSide-50 Binomial
DarkSide-50 No Quenching Fluctuation
NEWS-G 2018
XENON1T 2017
PICASSO 2017
CRESST-III 2017
XENON100 2016
CDEX 2016
SuperCDMS 2014
COGENT 2013
CRESST 2012
Neutrino Floor
LUX 2017
PICO-60 2017
CDMSLite 2017
PandaX-II 2016
DAMIC 2016
CRESST-II 2015
CDMSlite 2014
CDMS 2013
DAMA/LIBRA 2008

PandaX @ CJPL

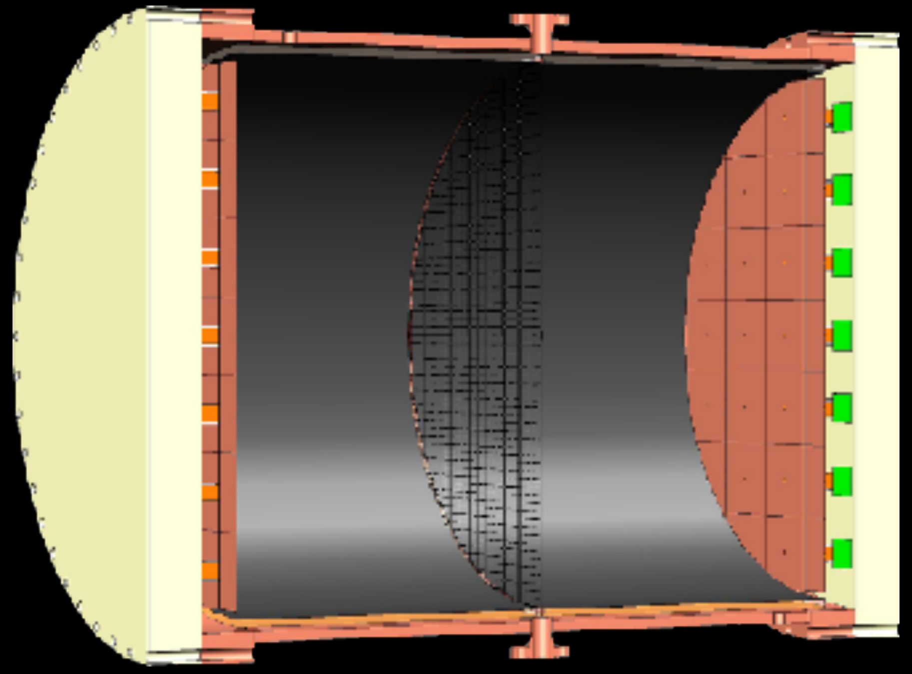
PandaX-I: 120 kg
DM experiment
2009-2014



PandaX-II: 500 kg
DM experiment
2014-2018



PandaX-xT:
multi-ton DM
experiment
Future



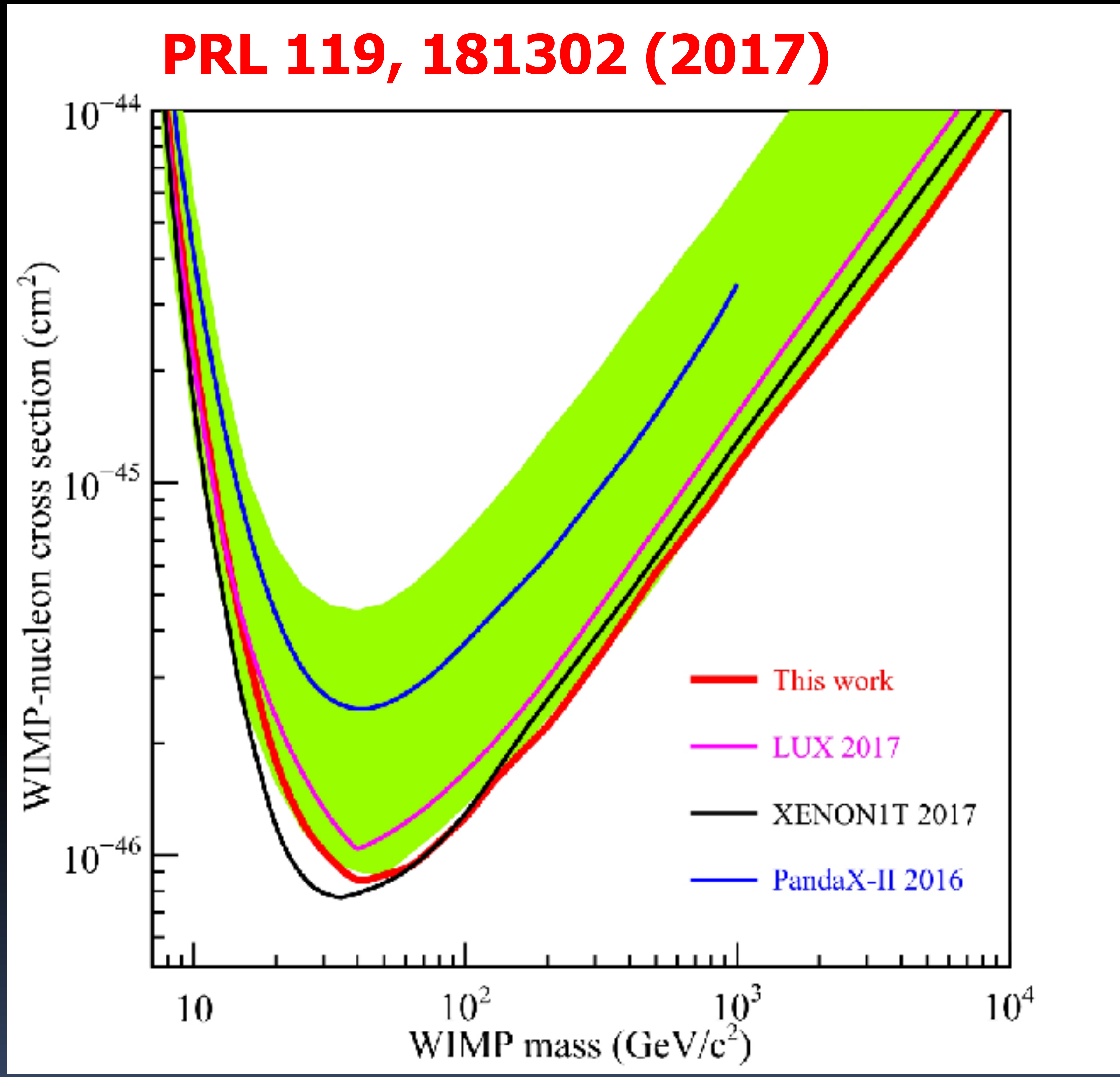
PandaX-III: 200 kg to
1 ton HP gas ^{136}Xe
0vDBD experiment
Future

CJPL-I

CJPL-II

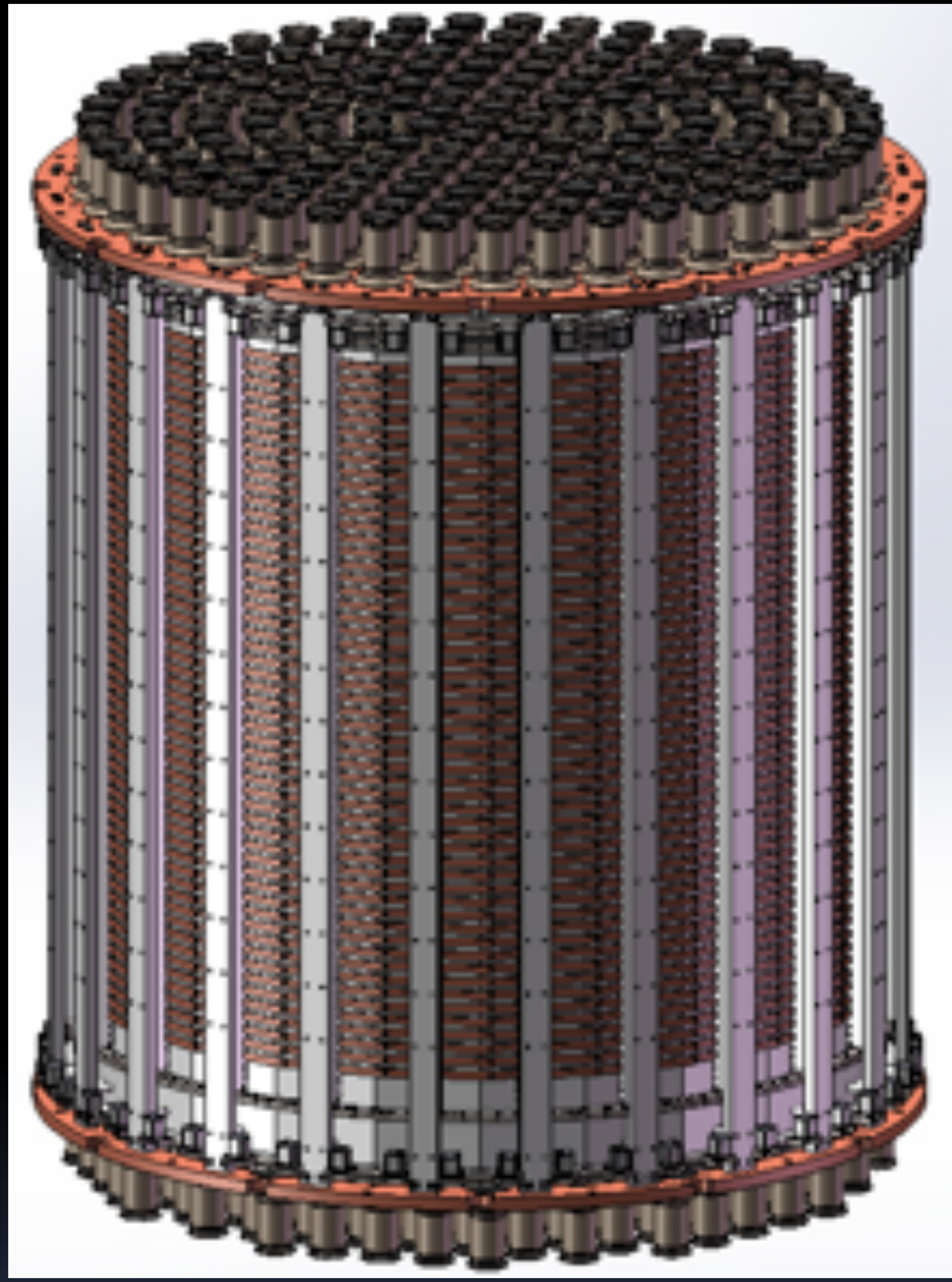
PANDA X = Particle and Astrophysical Xenon Experiments

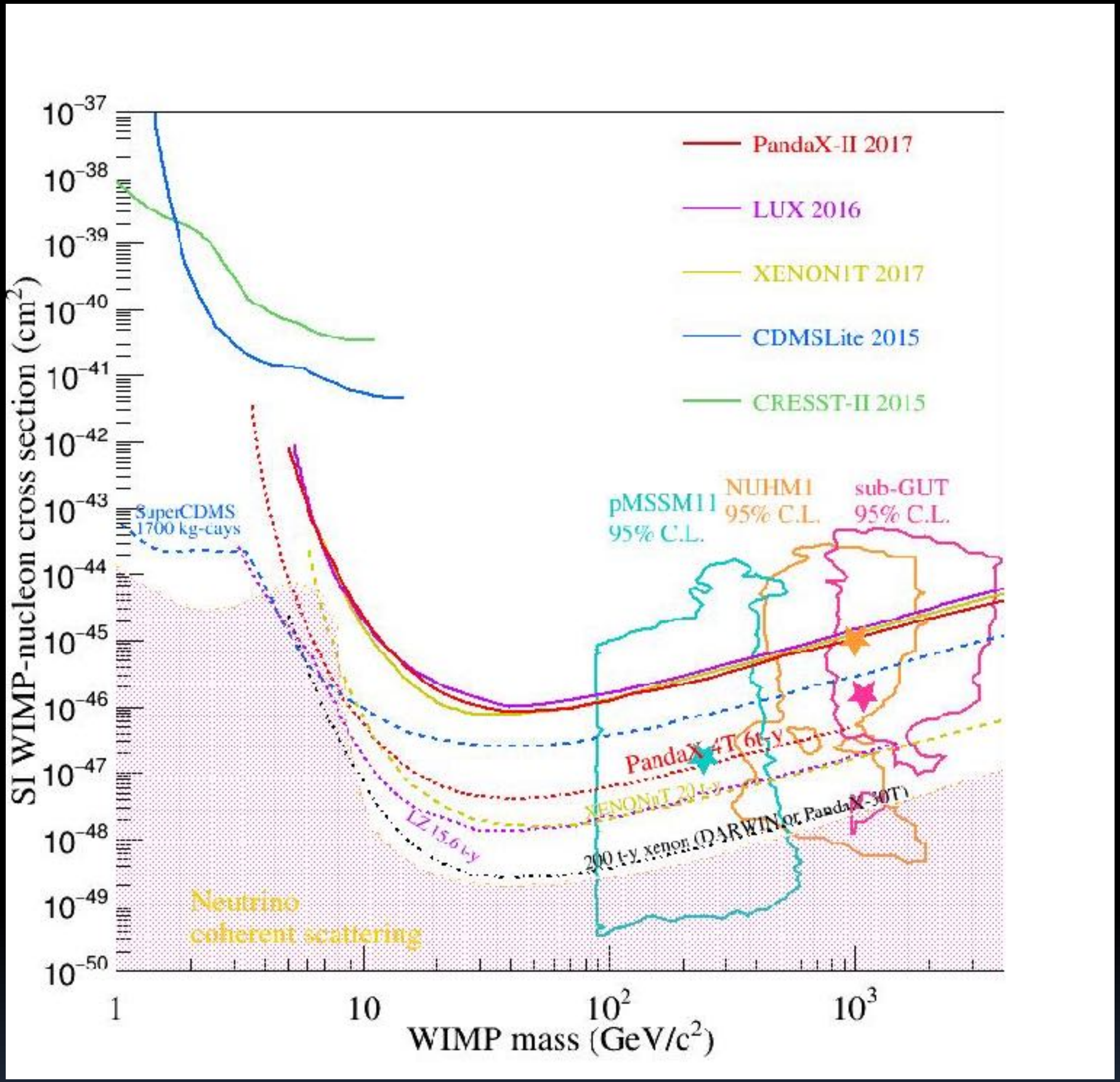
PandaX-II 54 ton-day results (SI limit)



- Improved from PandaX-II 2016 limit about 2.5 time for mass>30 GeV
- Lowest exclusion at 8.6×10^{-47}cm^2 at 40GeV/c^2
- Most stringent limit for WIMP-nucleon cross section for mass >100GeV

PandaX-xT

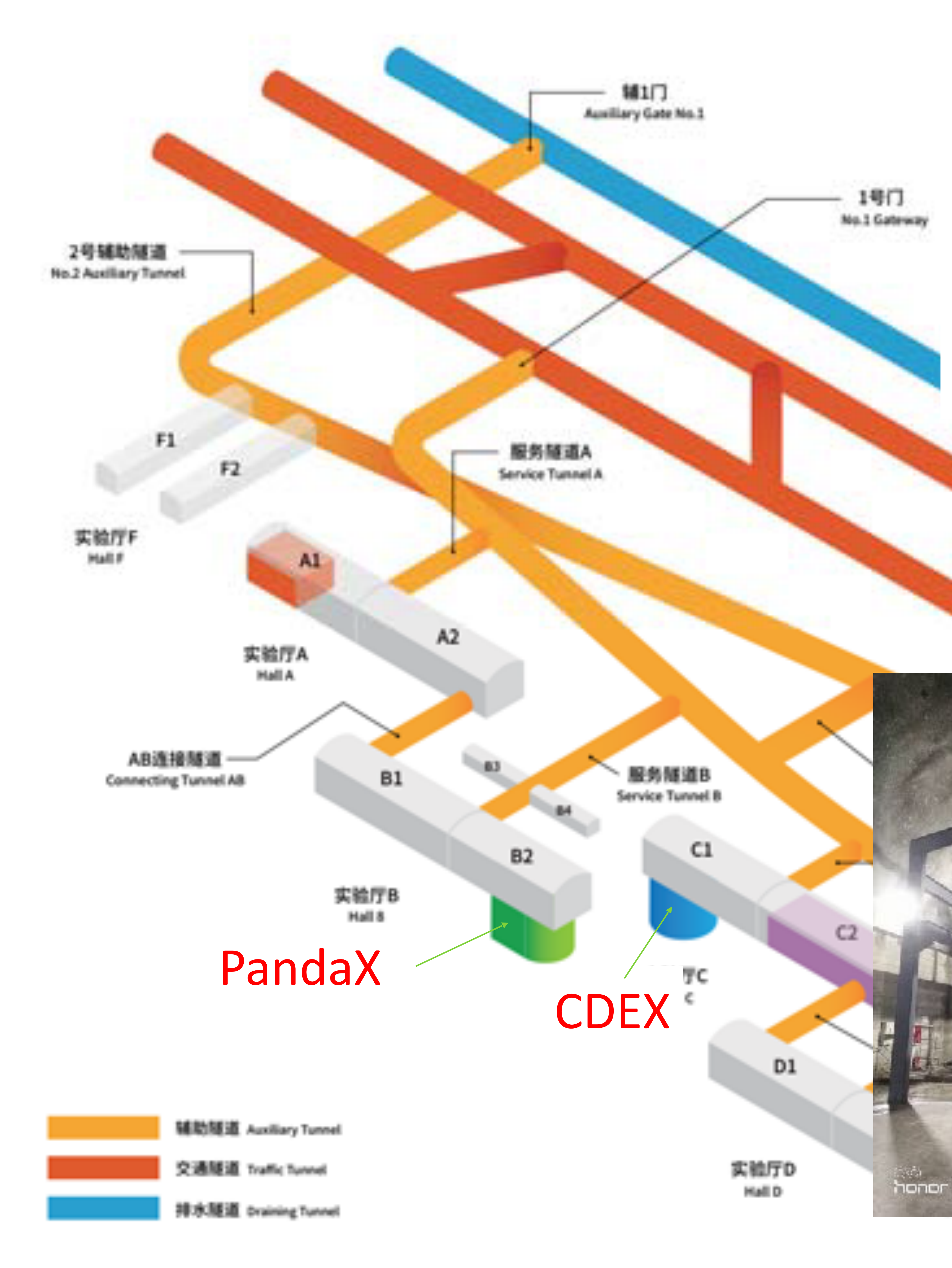


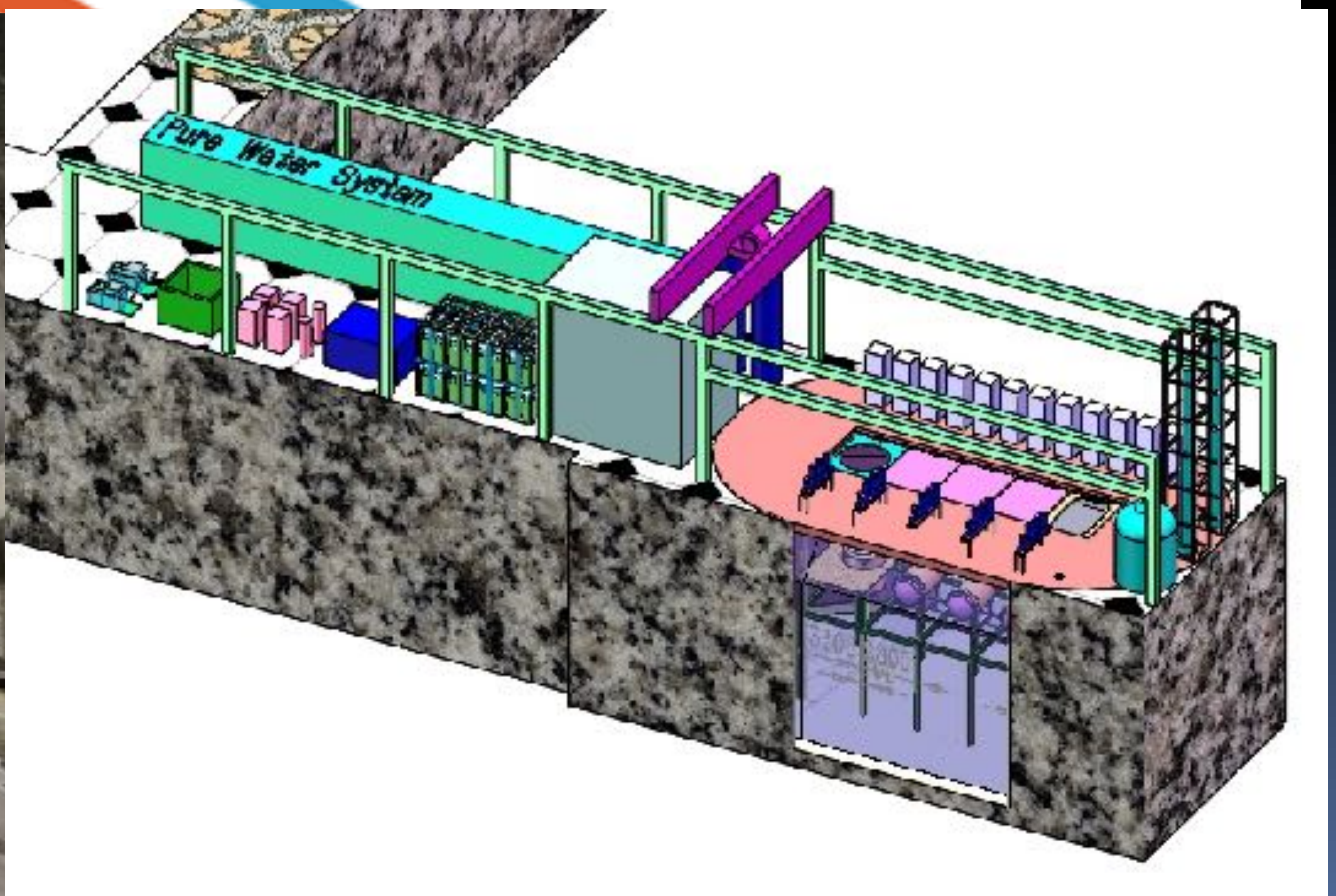


- Intermediate stage:
  - **PandaX-4T** (4-ton target) with SI sensitivity ~10^{-47} cm^2
  - On-site assembly and commissioning: 2019-2020

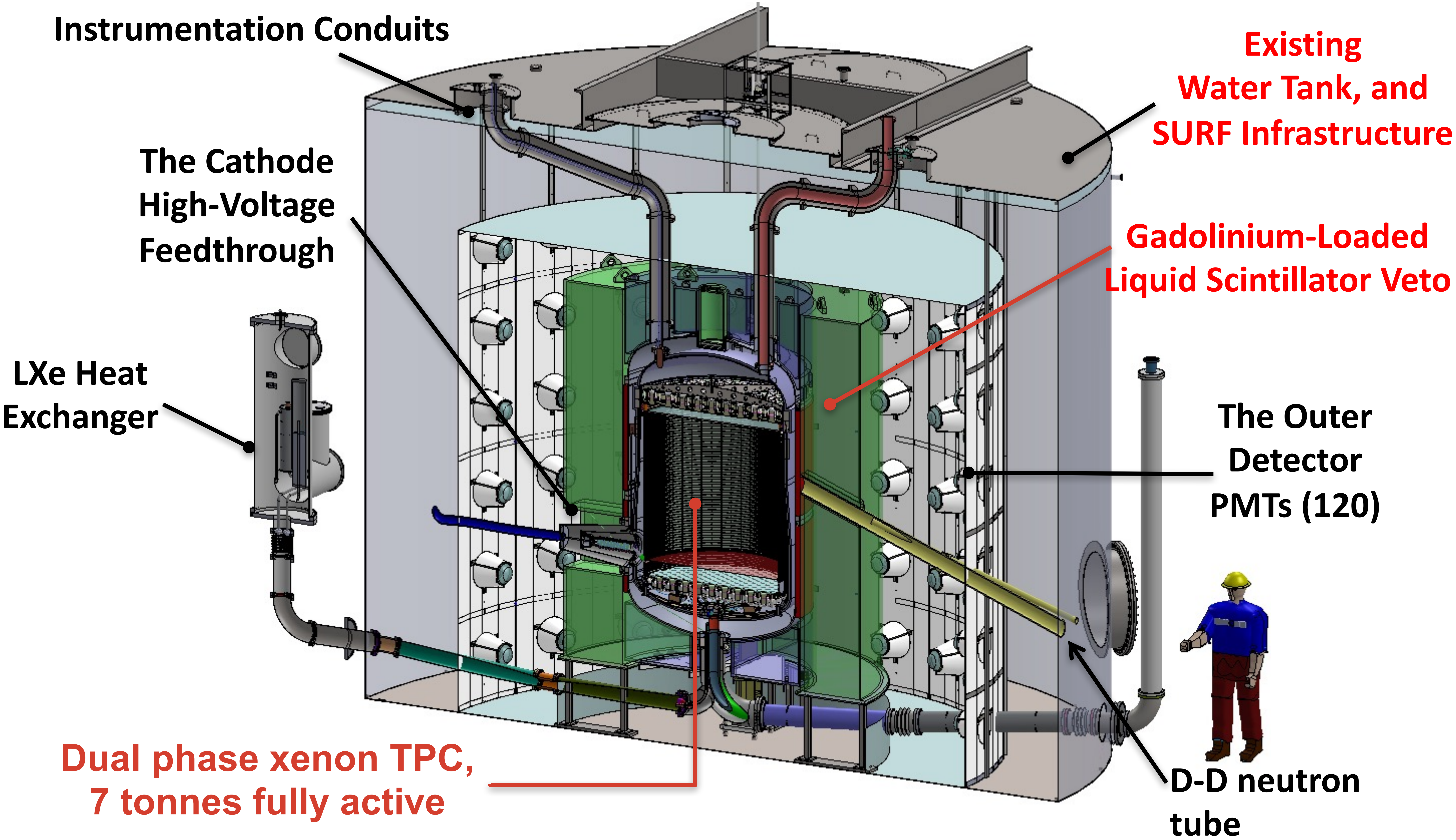
PandaX @ CJPL-II

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

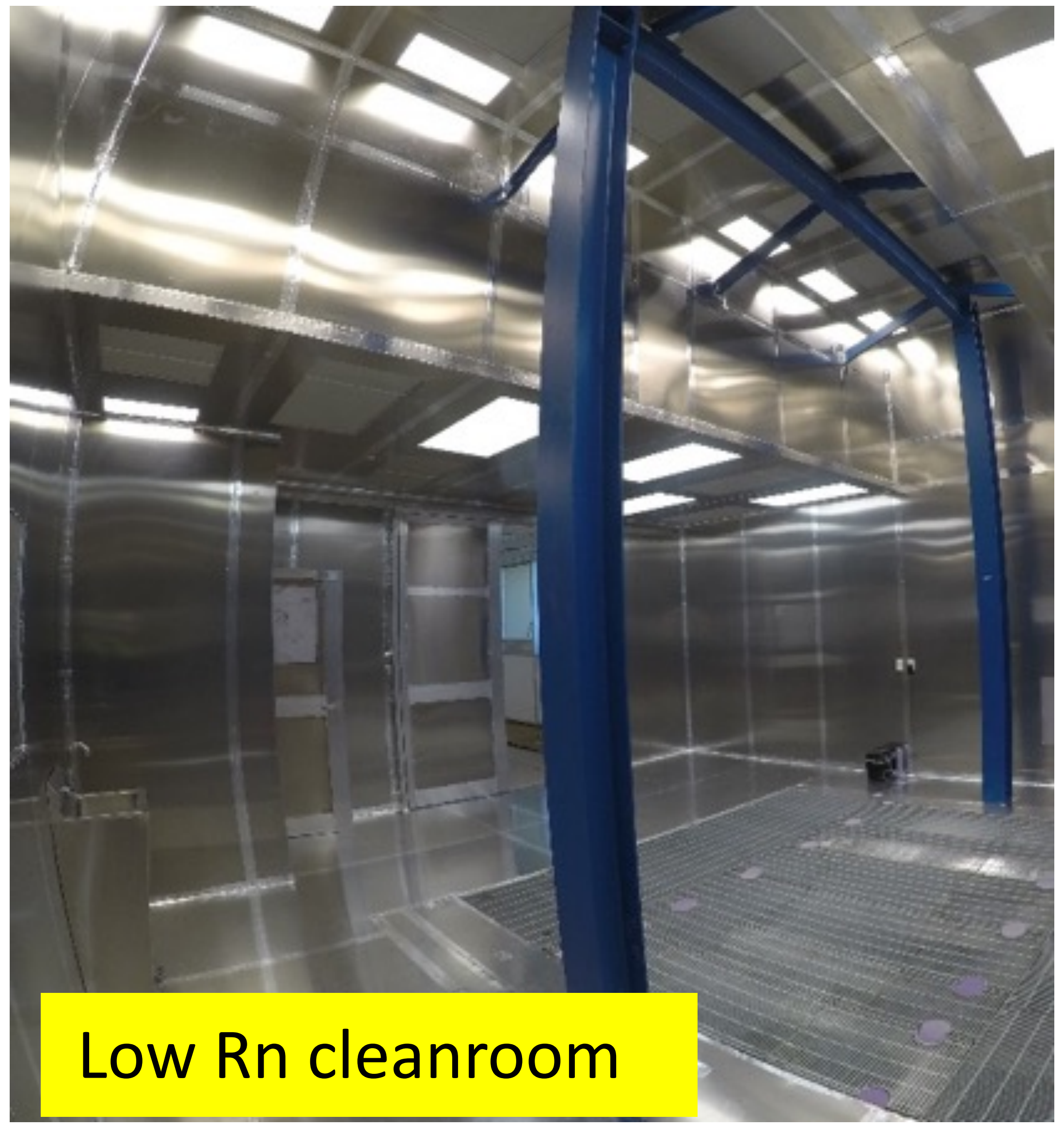


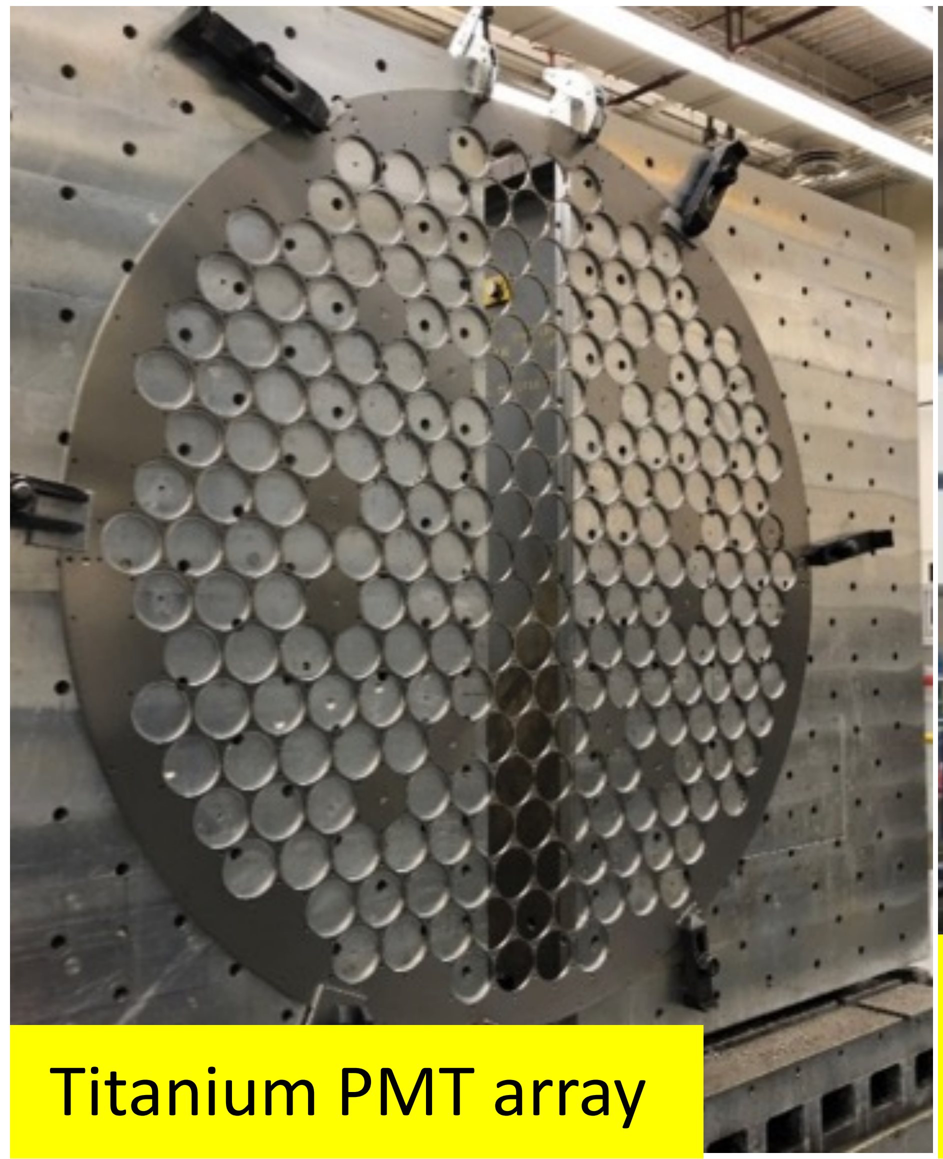


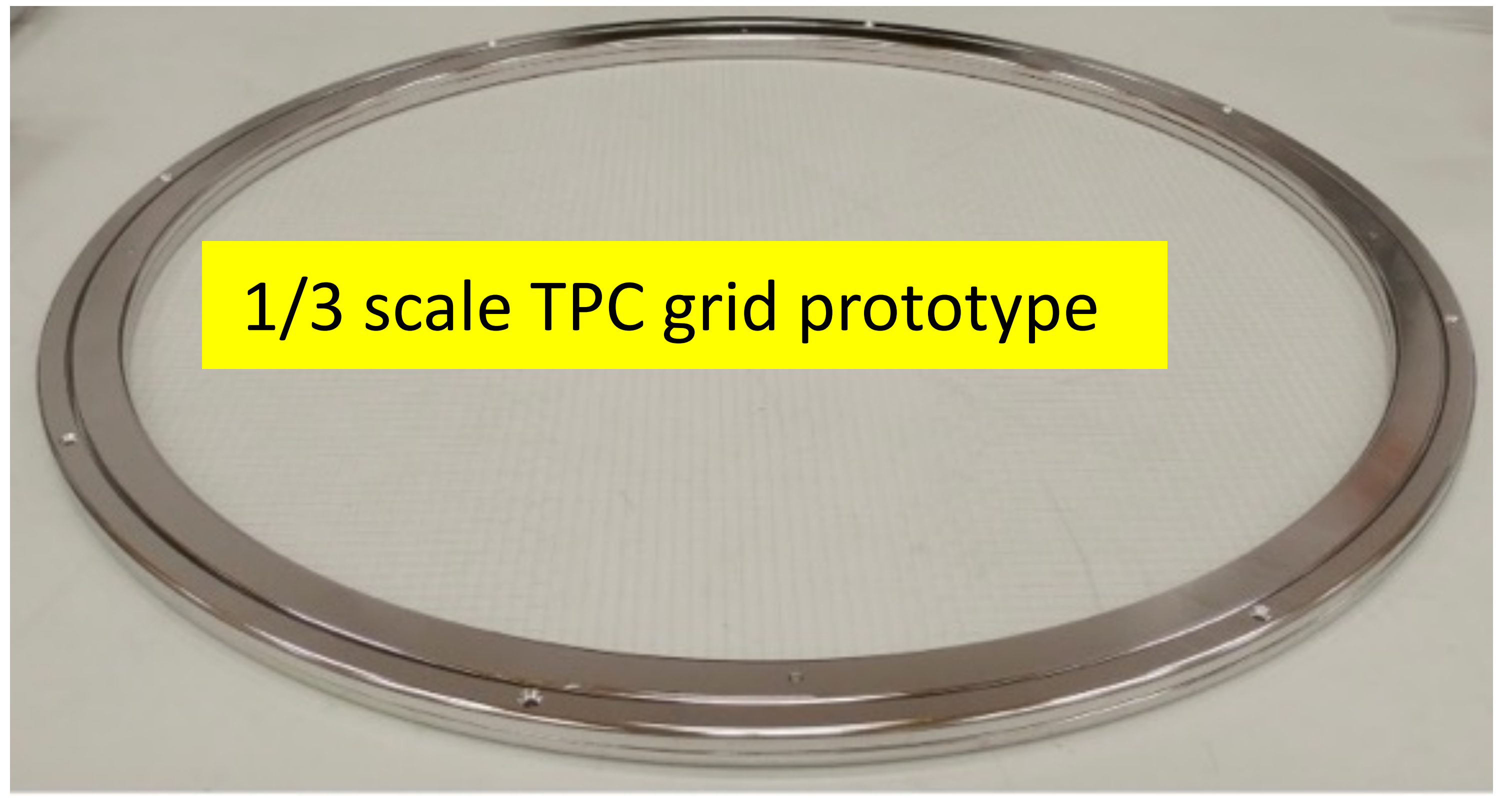
The LUX-ZEPLIN detector

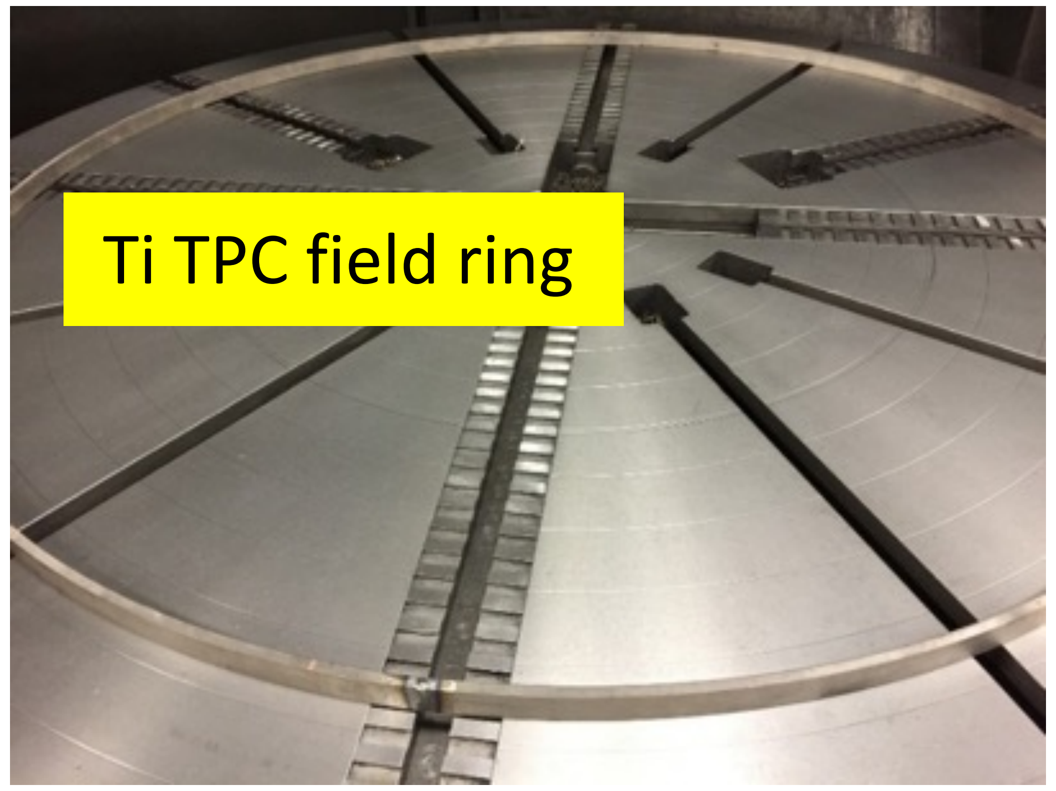


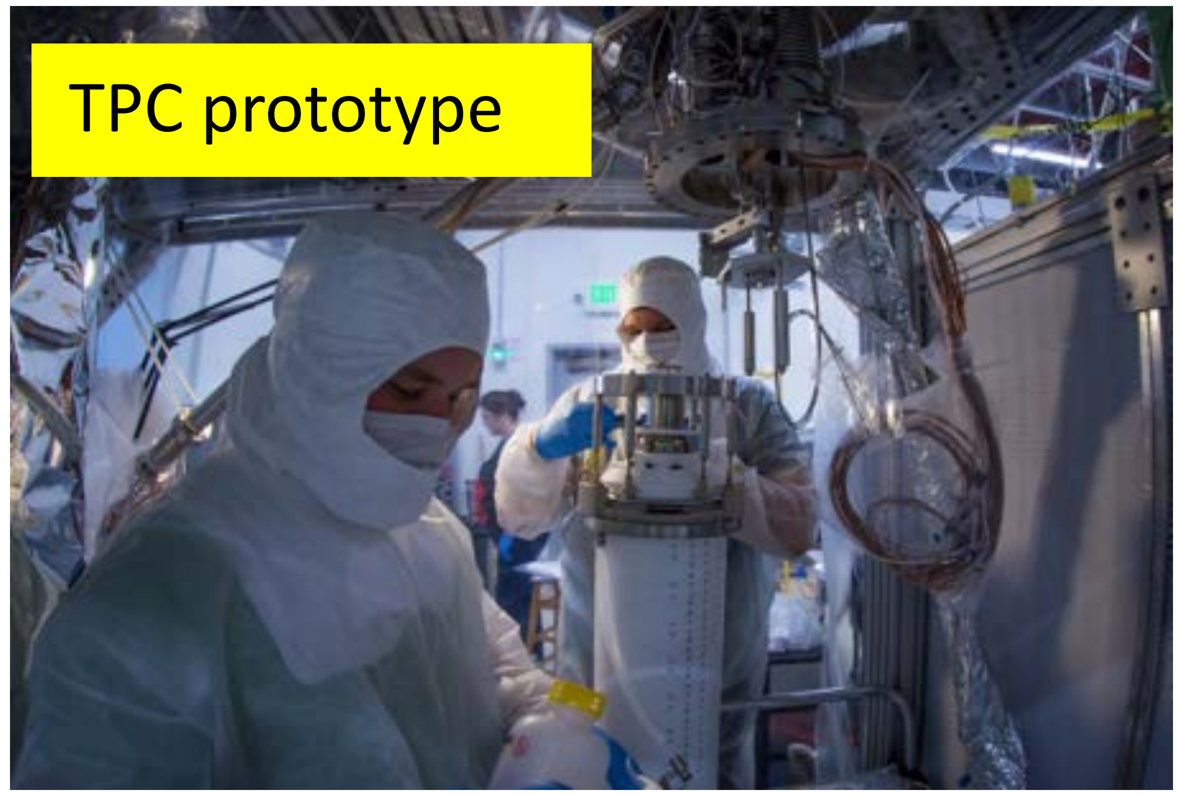
TPC fabrication is underway









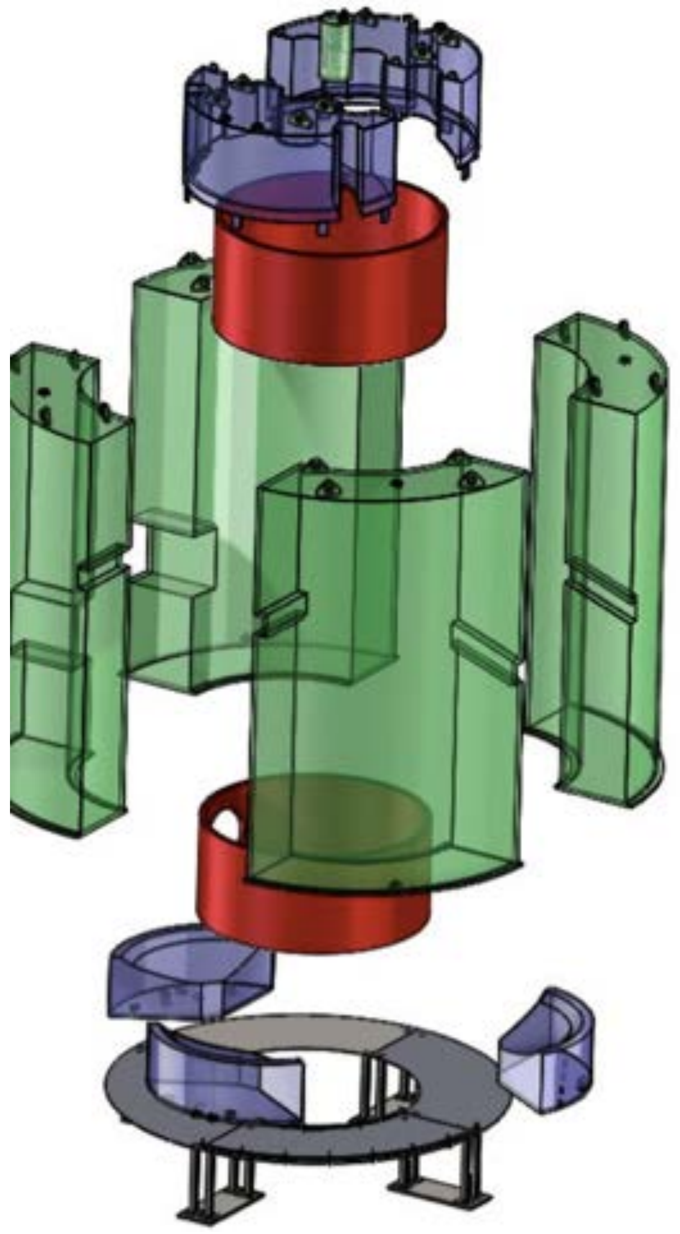


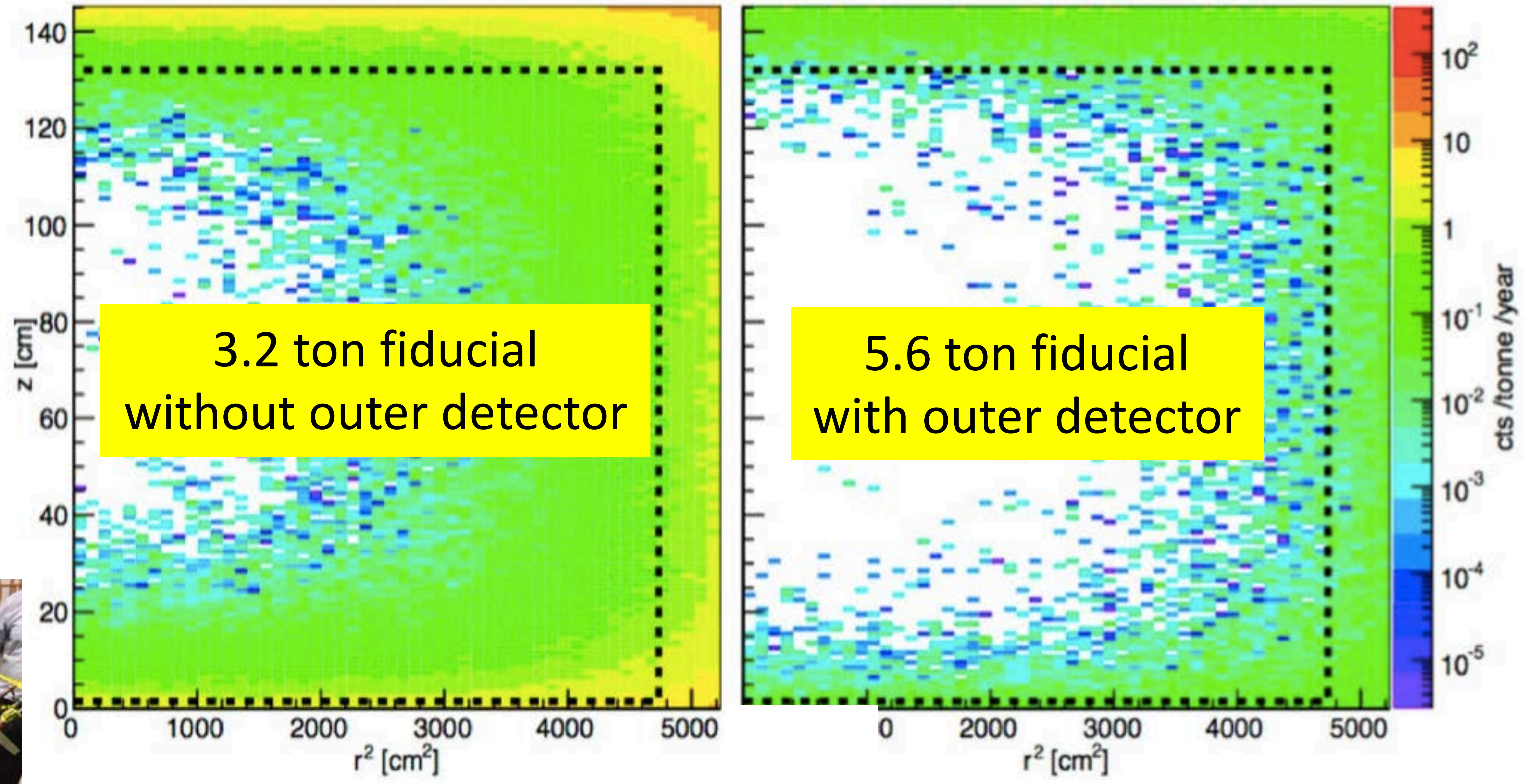
Begin on-site assembly spring 2018, install underground 2019, first data spring 2020.

Powerful background rejection: outer detector & xenon skin

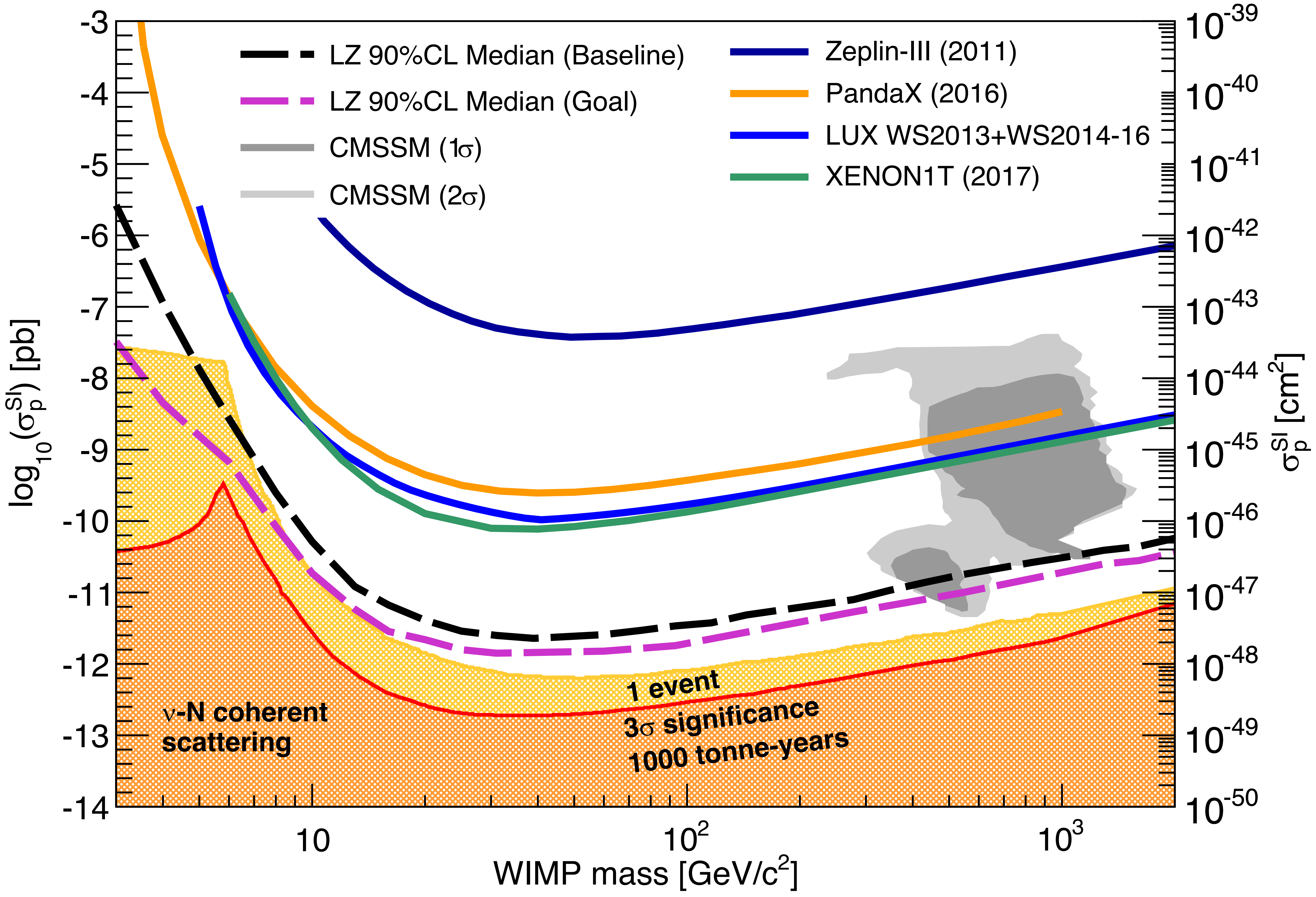
- 61-cm thick Gd-loaded liquid scintillator
  - 97% effective for neutron rejection
- Xenon skin layer for gamma rejection

in-situ monitoring of residual backgrounds





LZ Spin-Independent WIMP Sensitivity



- Baseline WIMP sensitivity is 2.3 x 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

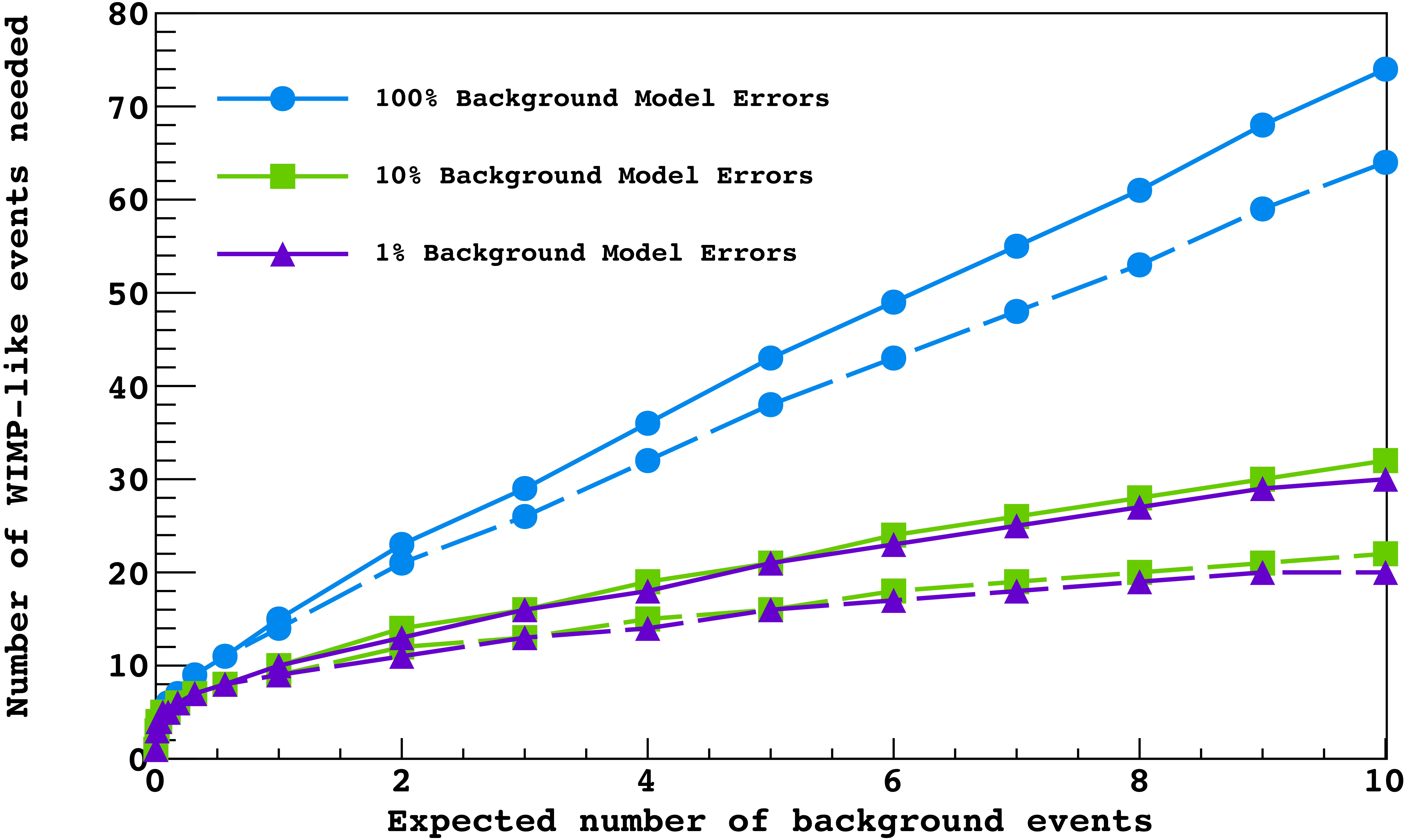
Intrinsic Contamination Backgrounds	ER (cts)	NR (cts) (w/ SF rej.)
Subtotal (Detector Components)	**9**	**0.072**
222Rn (1.81 μBq/kg)	681	-
220Rn (0.09 μBq/kg)	111	-
natKr (0.015 ppt g/g)	25	-
natAr (0.45 ppb g/g)	2	-
210Bi (0.1 μBq/kg)	40	-
Laboratory and Cosmogenics	5	0.06
Fixed Surface Contamination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

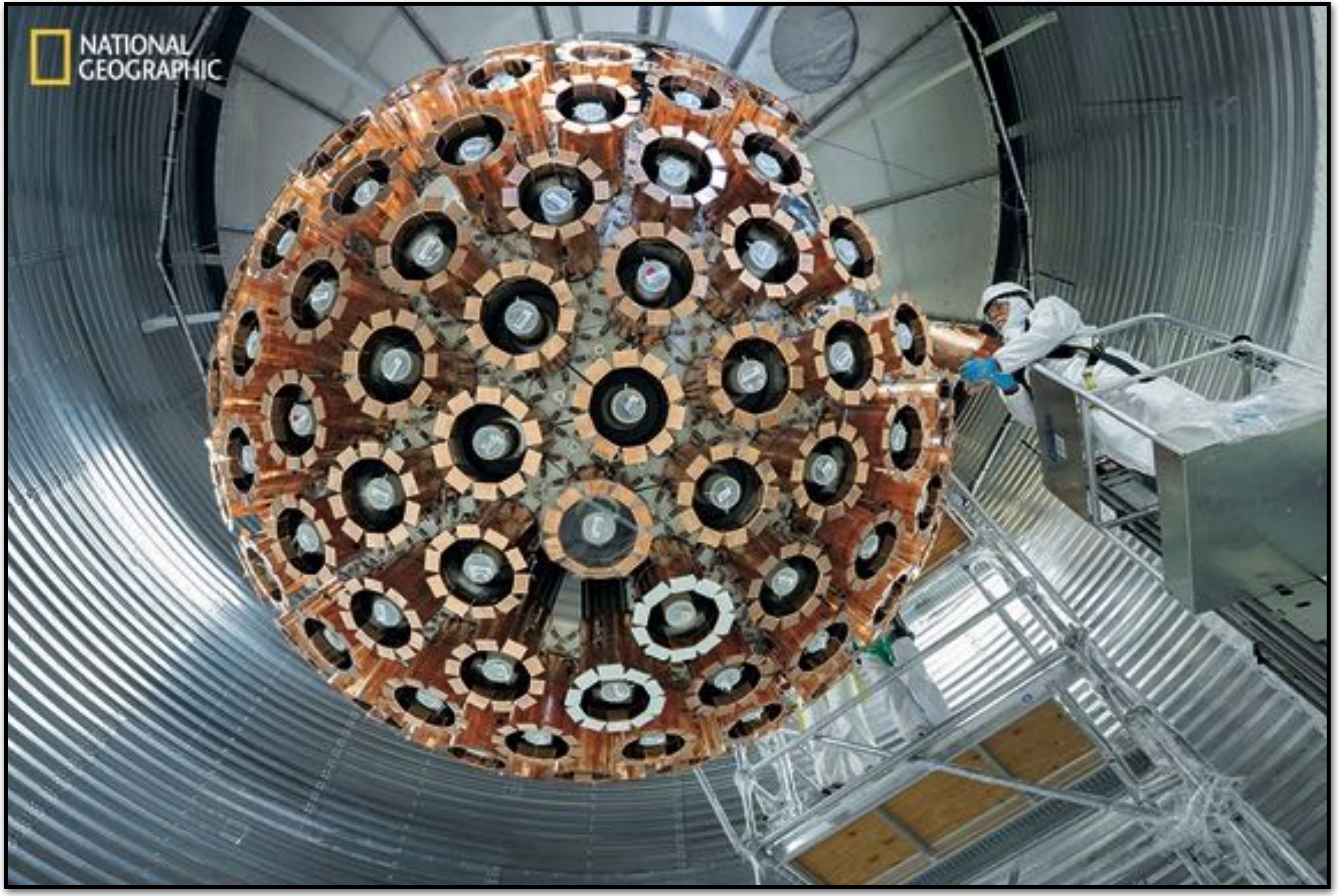
Coherent neutrino scattering on xenon nuclei



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 3600

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

University of Alberta

Carleton University

Laurentian University Université Laurentienne

Queen's University

Royal Holloway University of London

Particle Physics Rutherford Appleton Laboratory

SNOLAB Mining for Knowledge Creuser pour trouver... l'excellence

US University of Sussex

TRIUMF

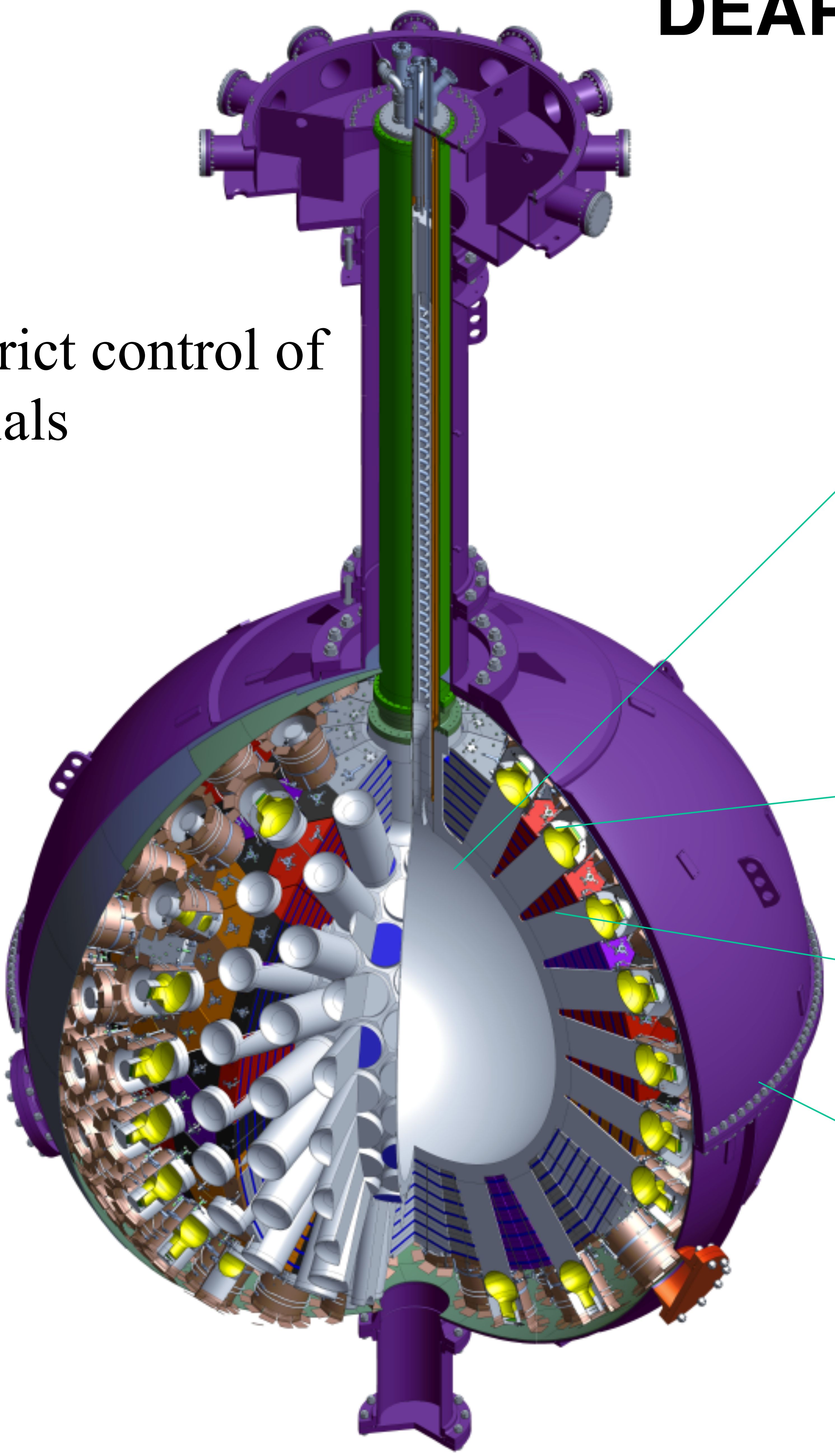
IF Instituto de Física

Technical University of Munich TUM

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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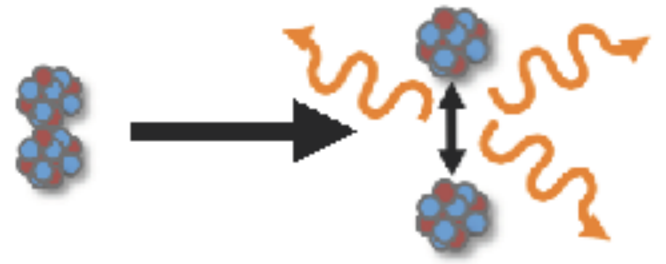
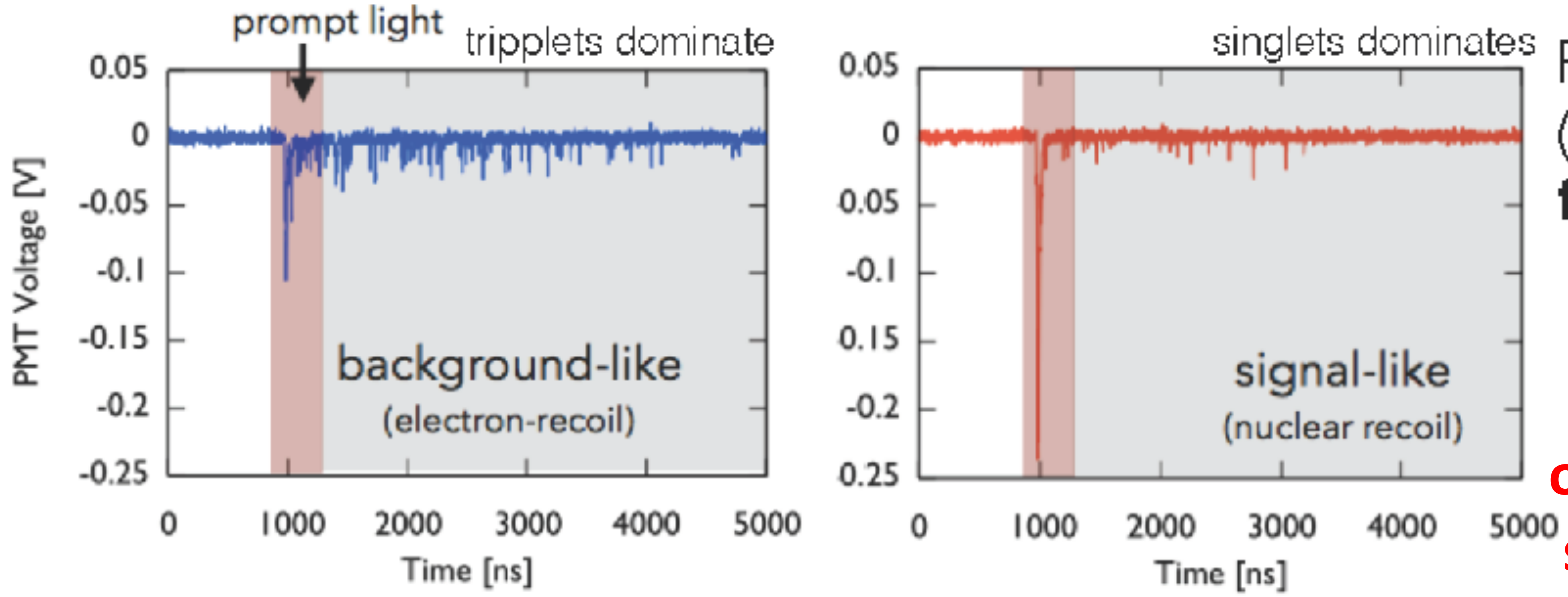
Experimental Signatures

Ar scintillation:
- excimers are create



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

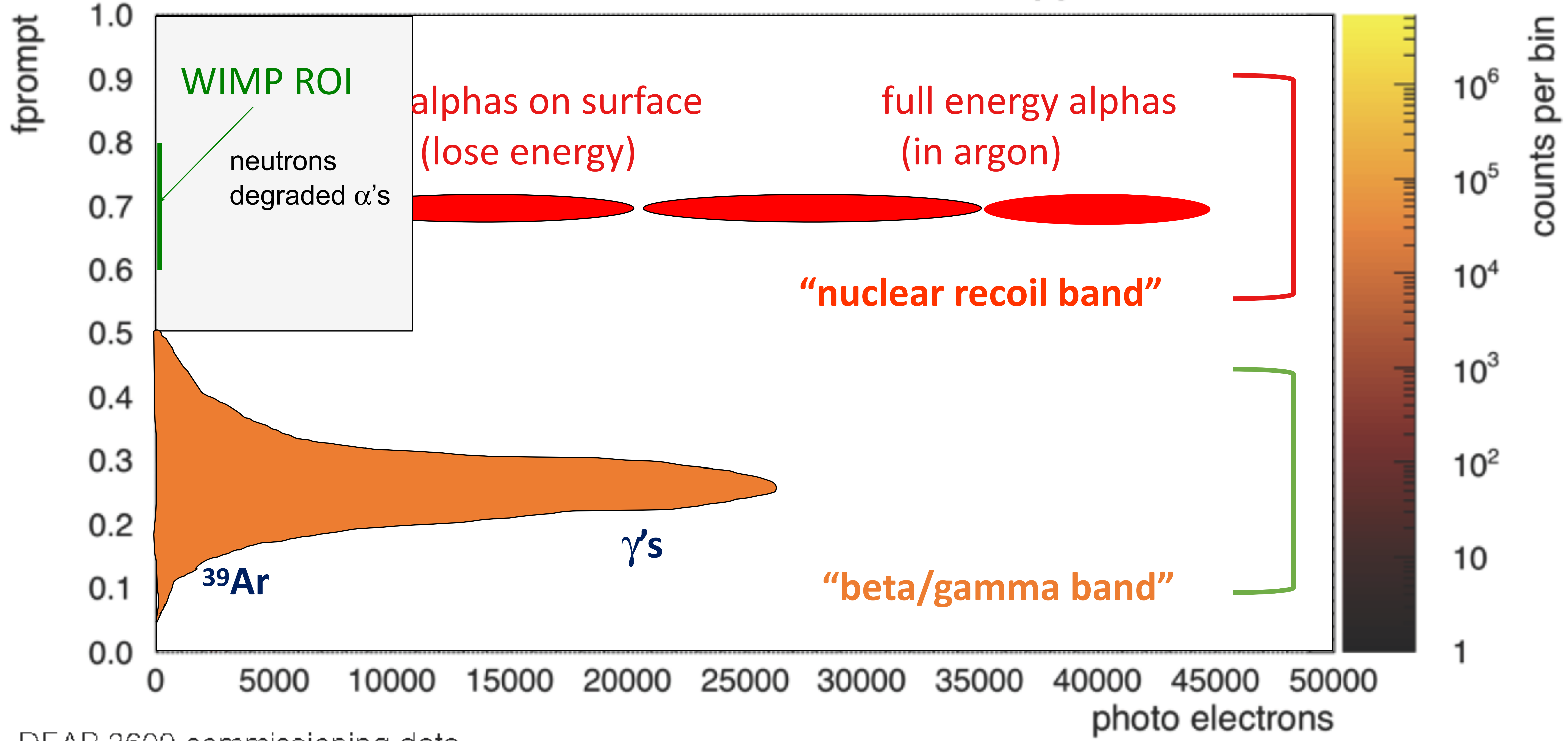


Pulse shape discrimination (PSD) parameter:

fprompt =

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

overview of backgrounds: see Bjoern Lehnert R1-5



DEAP 3600 commissioning data

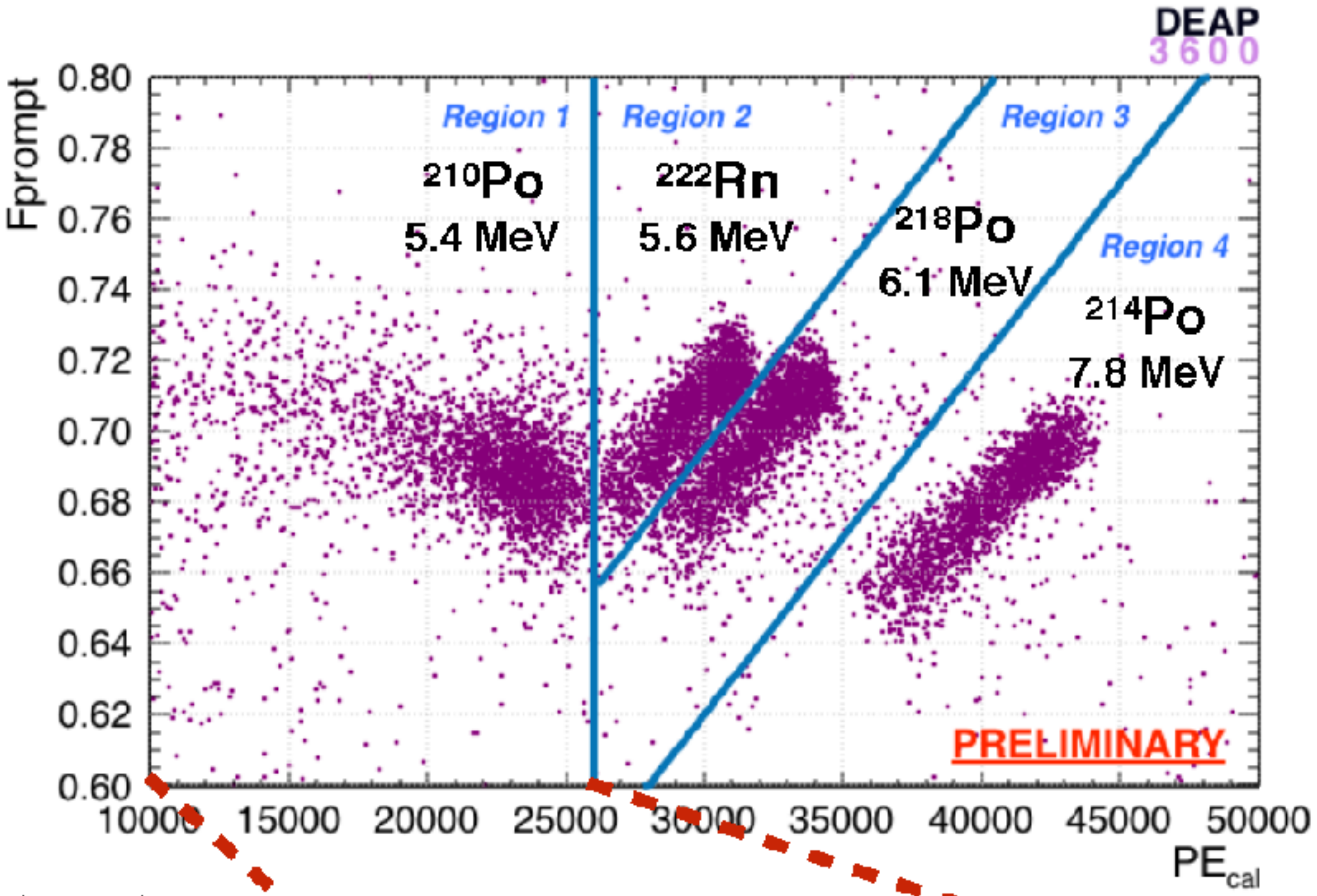
Slide from MG Boulay – TAUP 2017, Sudbury

Alpha Background

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

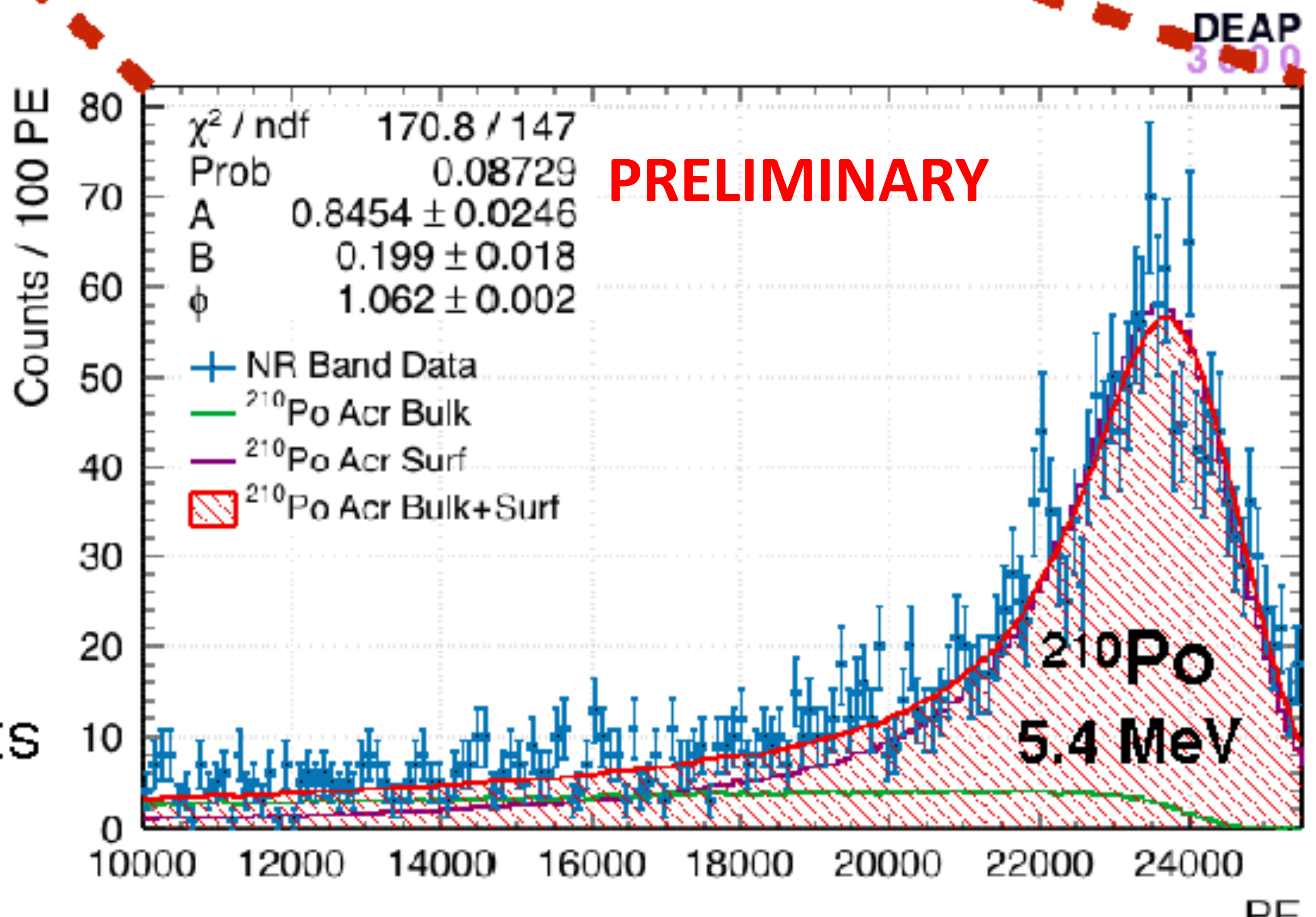
^{222}Rn in Dark Matter experiments:

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

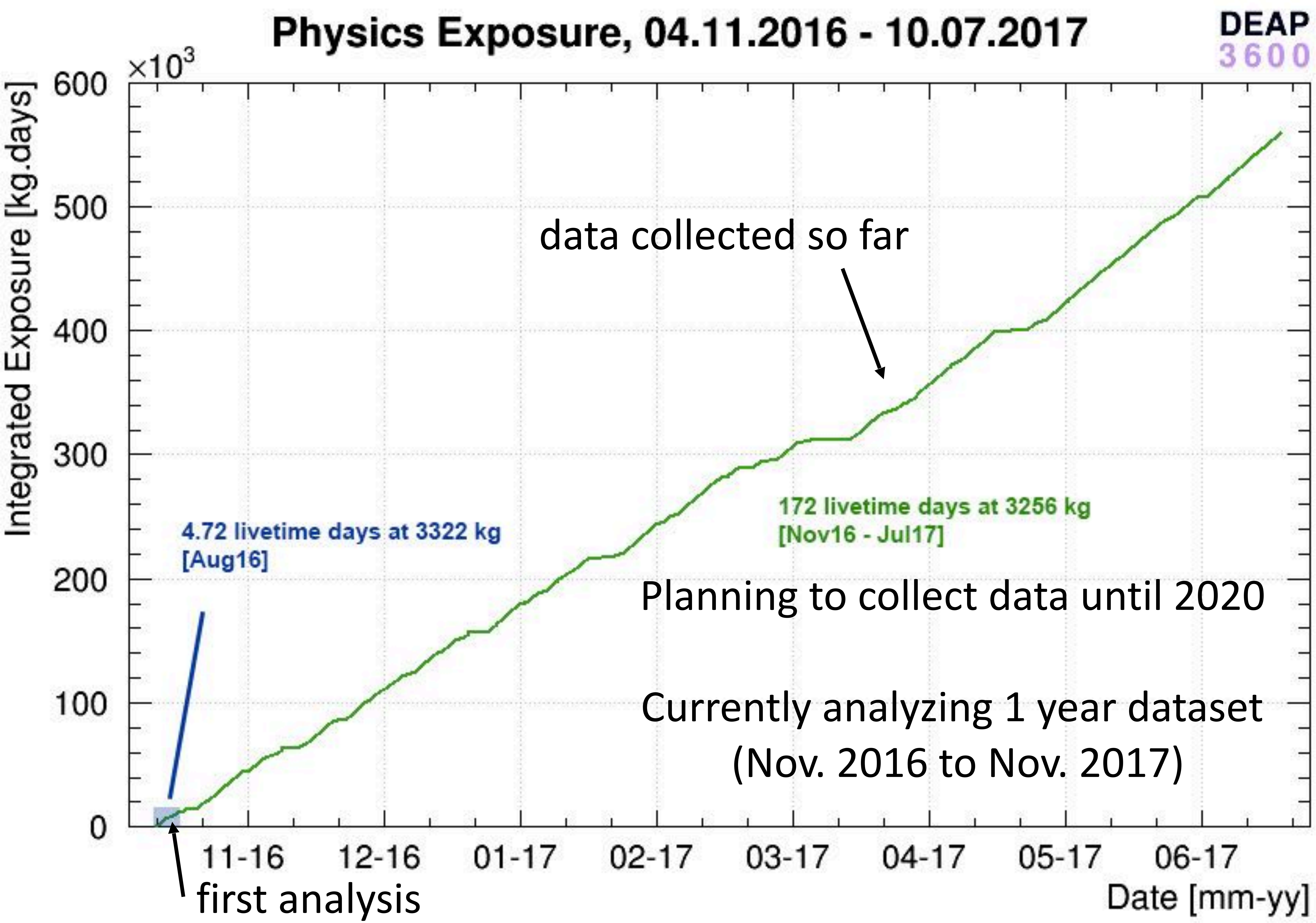


- https://indico.cern.ch/event/432527/contributions/1071738/attachments/1321292/1981557/ICHEP2016_EthanBrown_v1.pdf
- "Krypton and radon background in the PandaX-I dark matter experiment," JINST 12, 2017.
- "Radon-related backgrounds in the LUX dark matter search," Phys. Procedia. vol. 658, 2015.

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

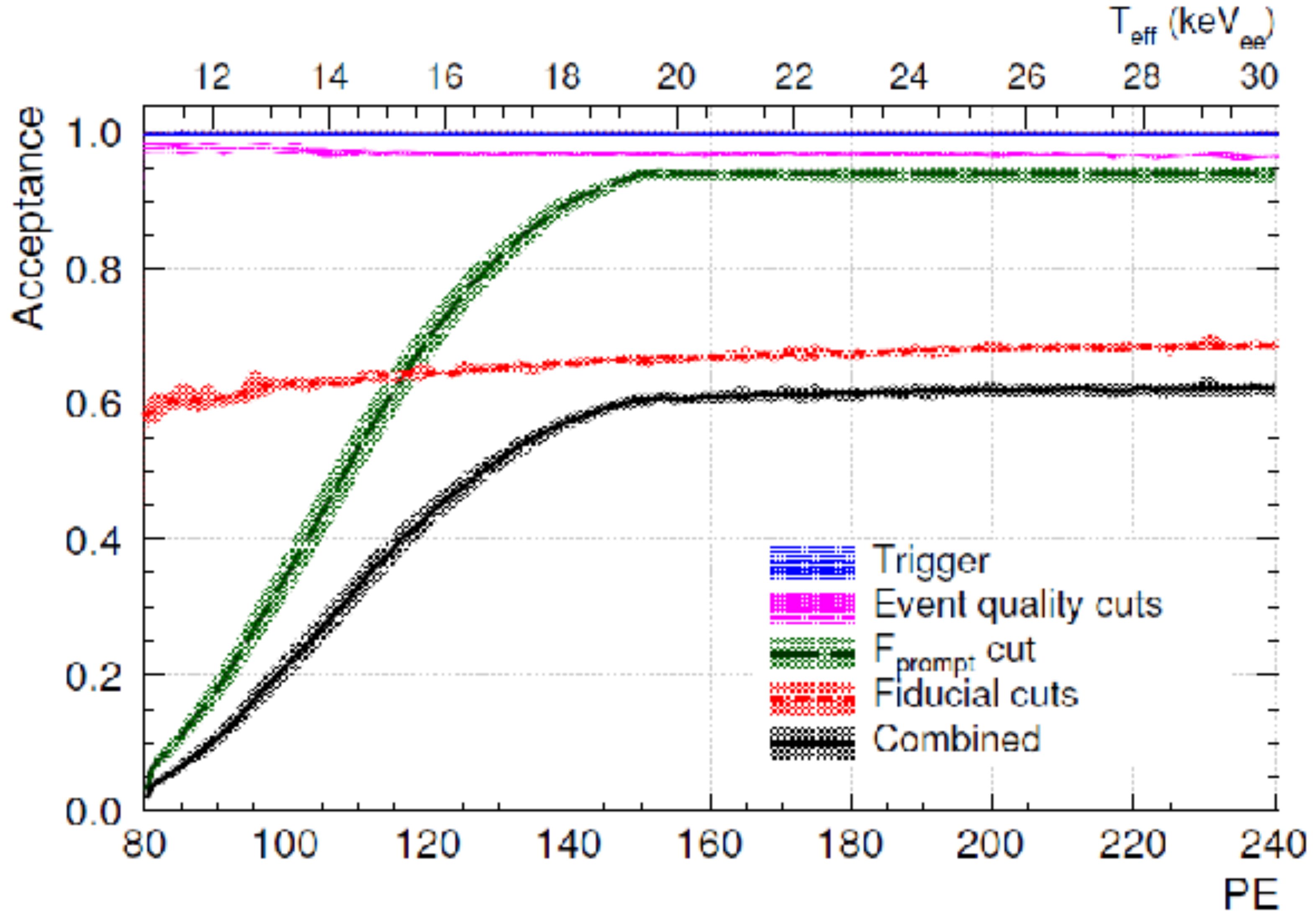


Slide from MG Boulay – TAUP 2017, Sudbury

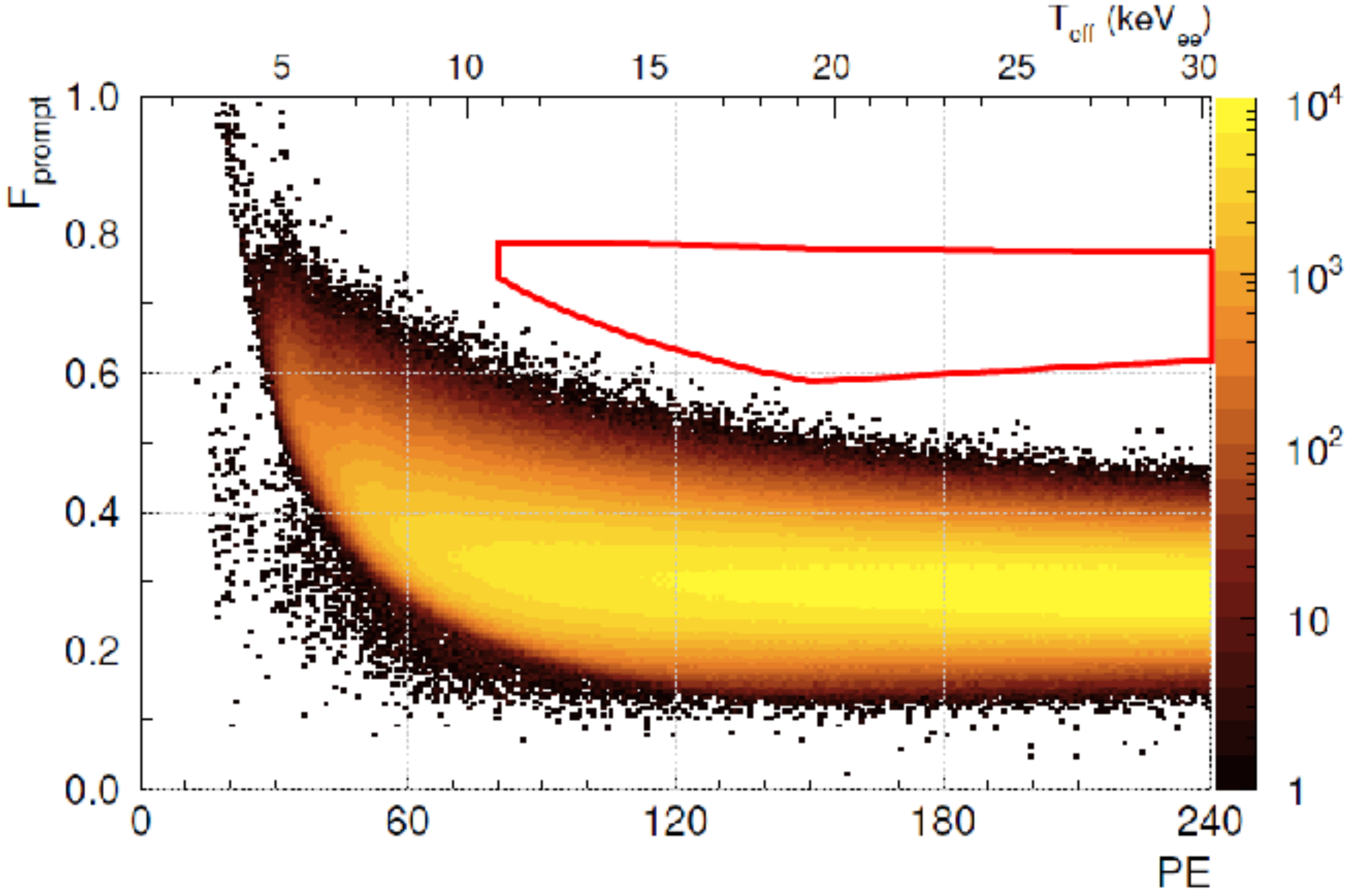


Physics Exposure, 04.11.2016 - 10.07.2017
DEAP
3600
Integrated Exposure [kg.days]
×10^3
600
500
400
300
200
100
0
11-16
12-16
01-17
02-17
03-17
04-17
05-17
06-17
Date [mm-yy]
4.72 livetime days at 3322 kg
[Aug16]
172 livetime days at 3256 kg
[Nov16 - Jul17]
data collected so far
first analysis
Planning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

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			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58±0.01		654
	Event time		99.85±0.01		652
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	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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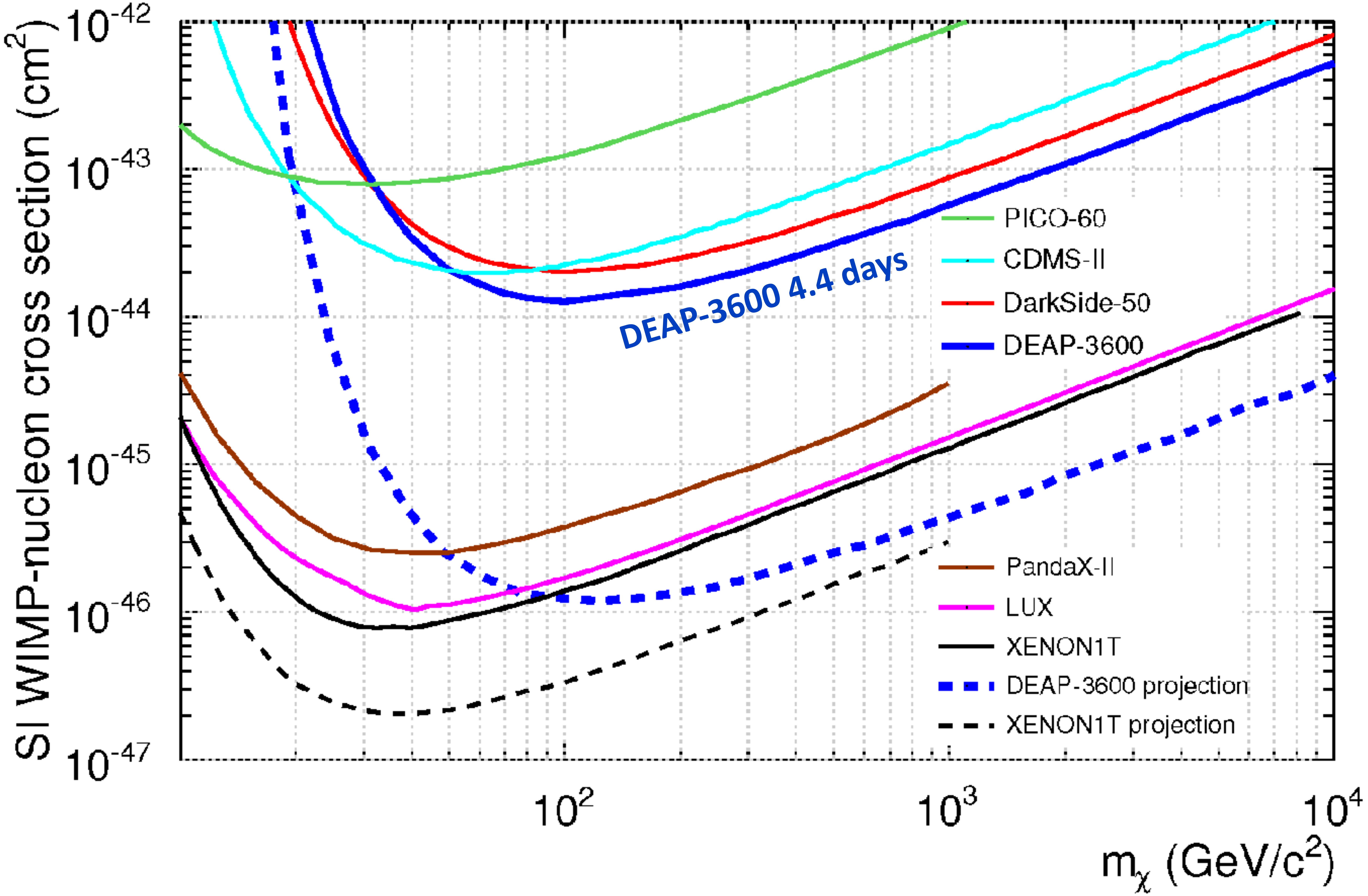
WIMP exclusion with DEAP-3600 First Result

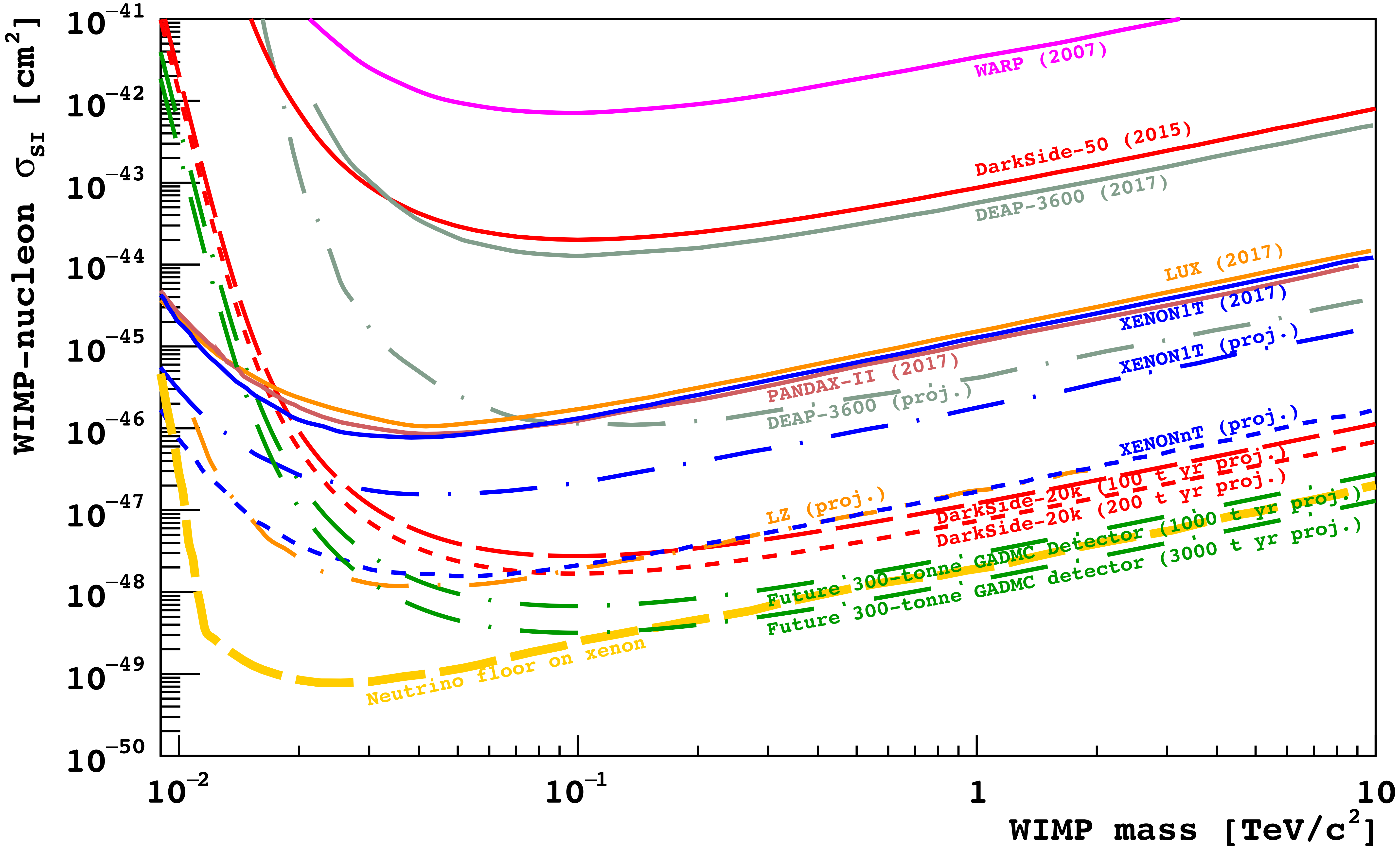


Slide from MG Boulay – TAUP 2017, Sudbury

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

University of Alberta
APC
LNGS
GSSI
Augustana University
БелГУ
Black Hills State University
Alma Mater Studiorum
Carleton University
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
ETH Zürich
Fort Lewis College
University of Hawaii
University of Houston
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
Politecnico Milano
Universitas Studiorum Mediolanensis
НГУ
Studium Generale Civitatis Perusii
Pacific Northwest National Laboratory
Proudly Operated by Battelle Since 1965
Queen's University
Roma Tre Università degli Studi
Studium Salerni
SNOLAB
University of Sussex
Temple University
Fondazione Bruno Kessler
TIFPA Trento Institute for Fundamental Physics and Applications
Politecnico di Torino
TRIUMF
Technische Universität München
The University of California Davis
The University of California UCLA
University of Massachusetts Amherst
Universidade de São Paulo
Virginia Polytechnic Institute and State University

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.

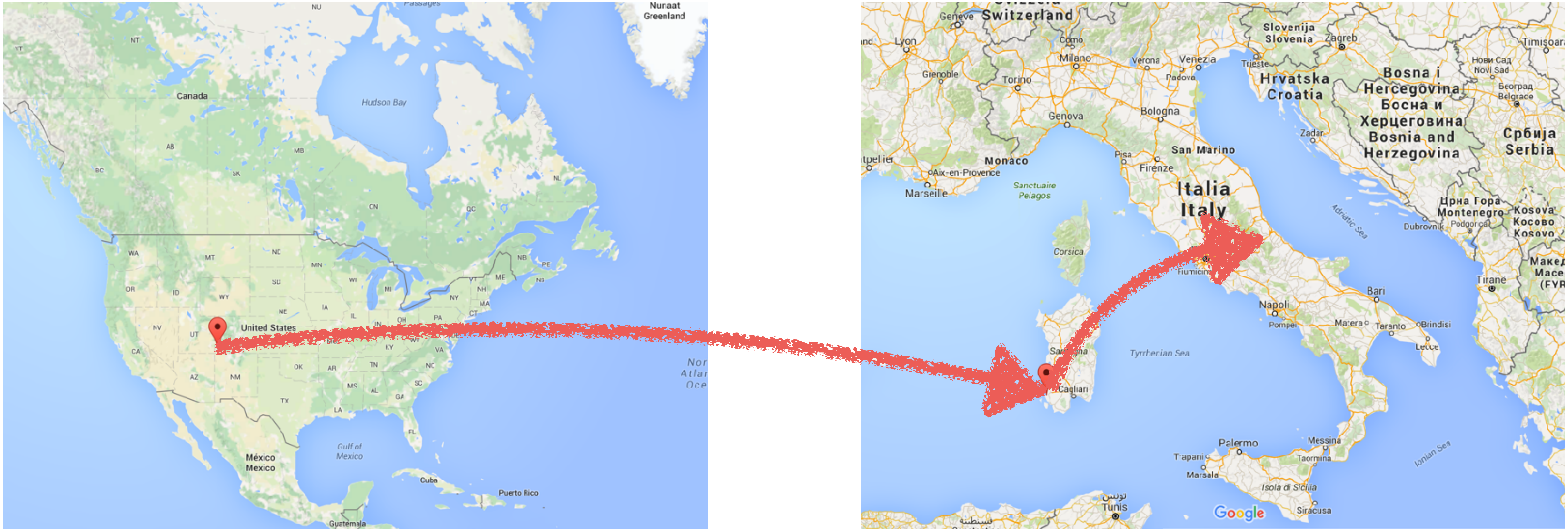
The first element of the program is the DarkSide-20k experiment at LNGS, whose science goal is to perform a dark matter search with an exposure of 100 tonne·yr of low-radioactivity underground argon (the low intrinsic background, free from any background other than that induced by atmospheric neutrinos,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

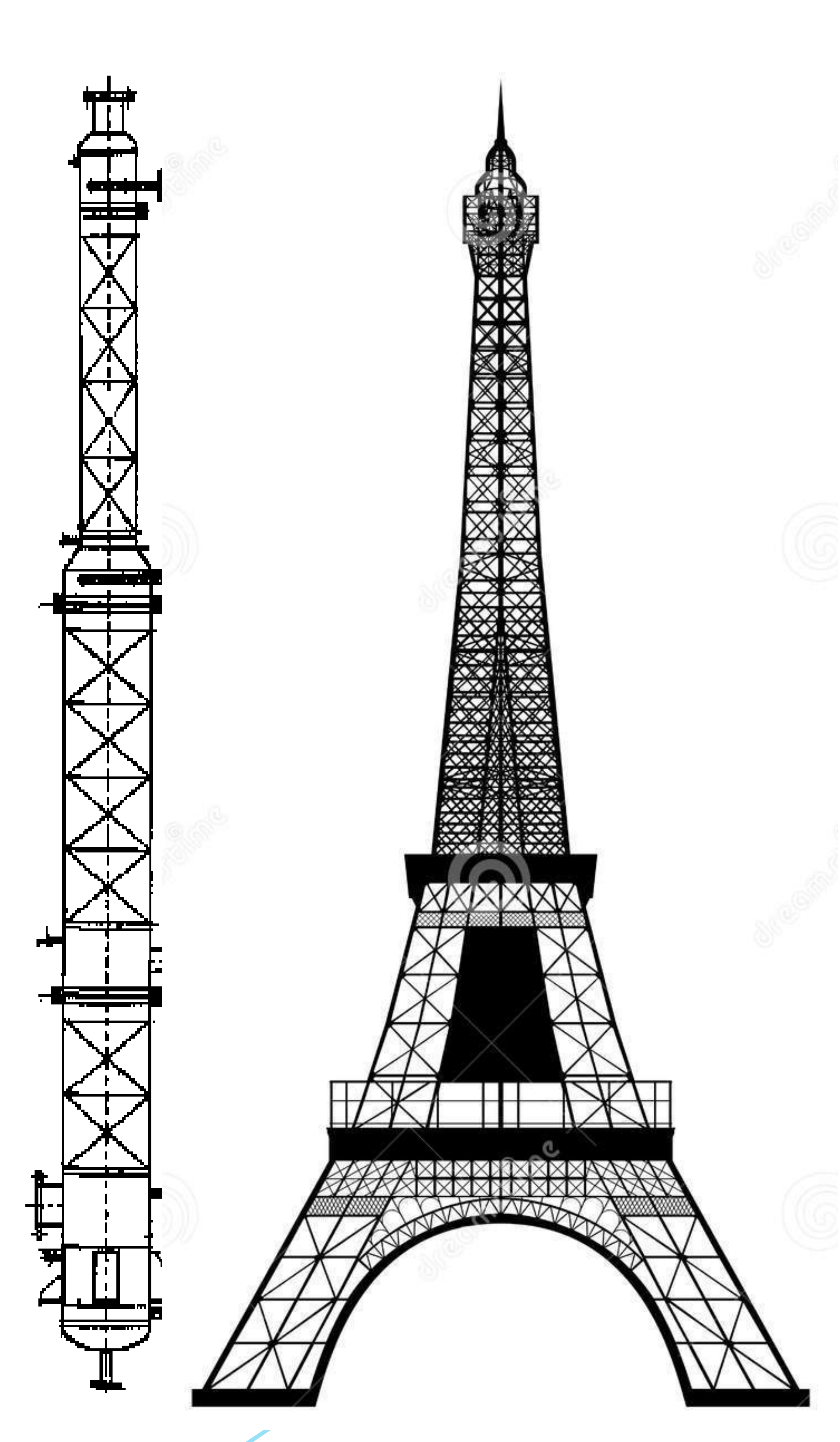
To whom it may concern;

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,

Urania to Aria to LNGS








DarkSide-50

- P. Agnes et al. (The DarkSide Collaboration), “DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon”, arxiv:1802.07198.
- P. Agnes et al. (The DarkSide Collaboration), “Constraints on Sub-GeV Dark Matter-Electron Scattering from the DarkSide-50 Experiment”, arxiv:1802.06998.
- P. Agnes et al. (The DarkSide Collaboration), “Low-mass Dark Matter Search with the DarkSide-50 Experiment”, arxiv:1802.06994.

Ionization-Only (S2-Only) Signals

1. The PMTs have zero dark rate at 88 K so a signal is always real

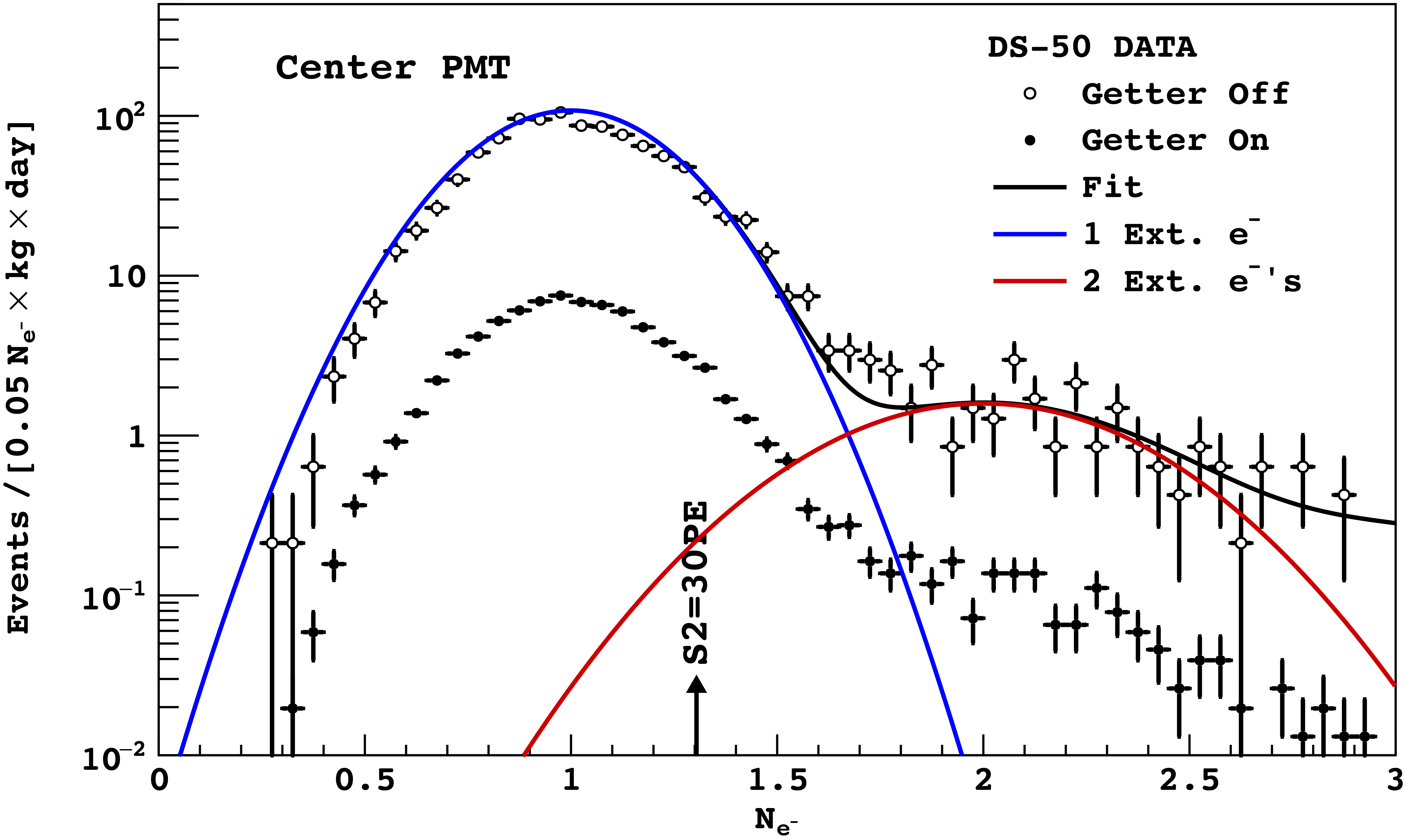
2. The gain in the gas region (~70 PE/e^-, reduced to 23 PE/e^- when accounting for the 30% QE of the PMTs) means that we are sensitive to a single extracted electron

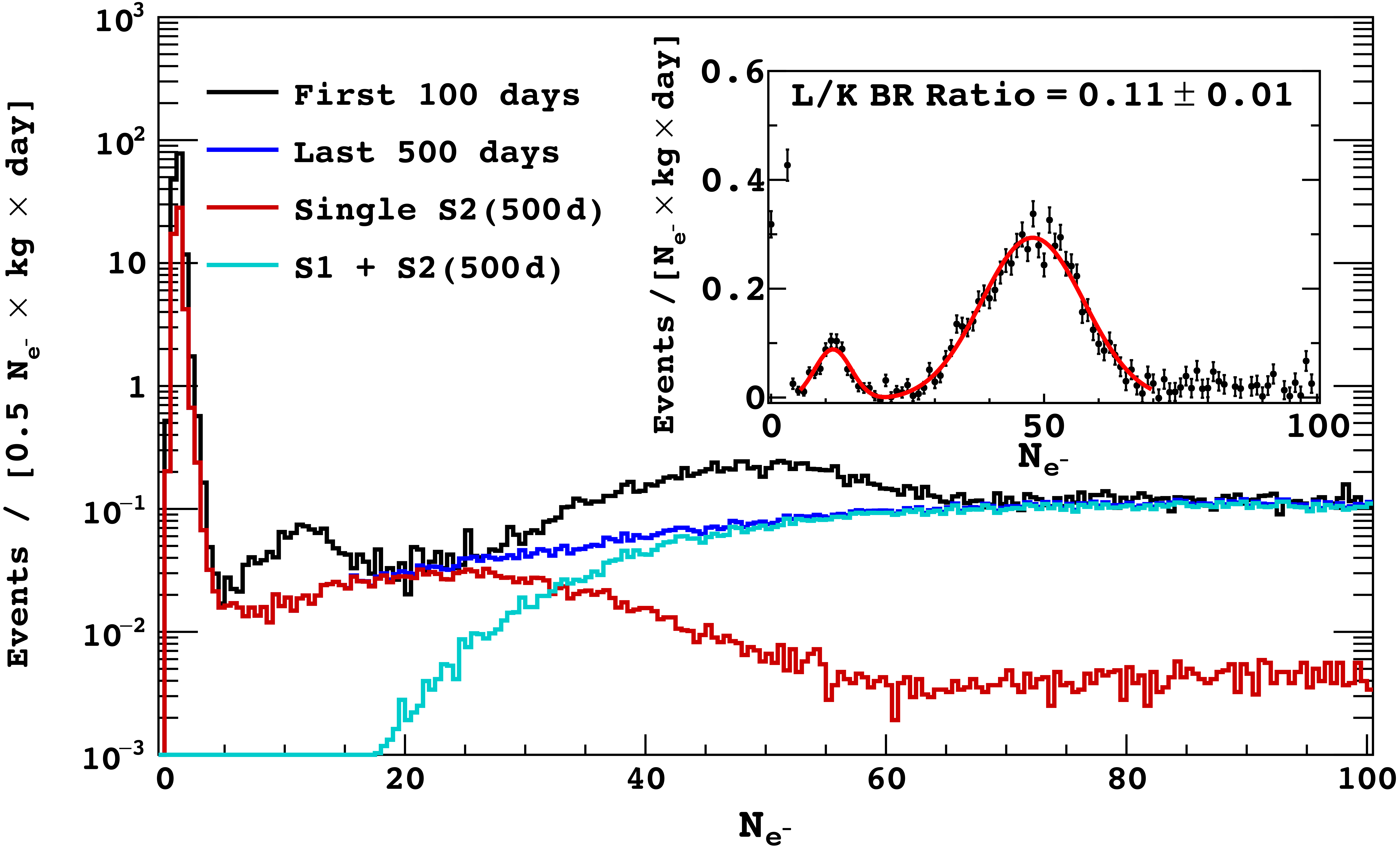
3. The radioactivity rate in the detector is remarkably low, so …

4. We don't need PSD

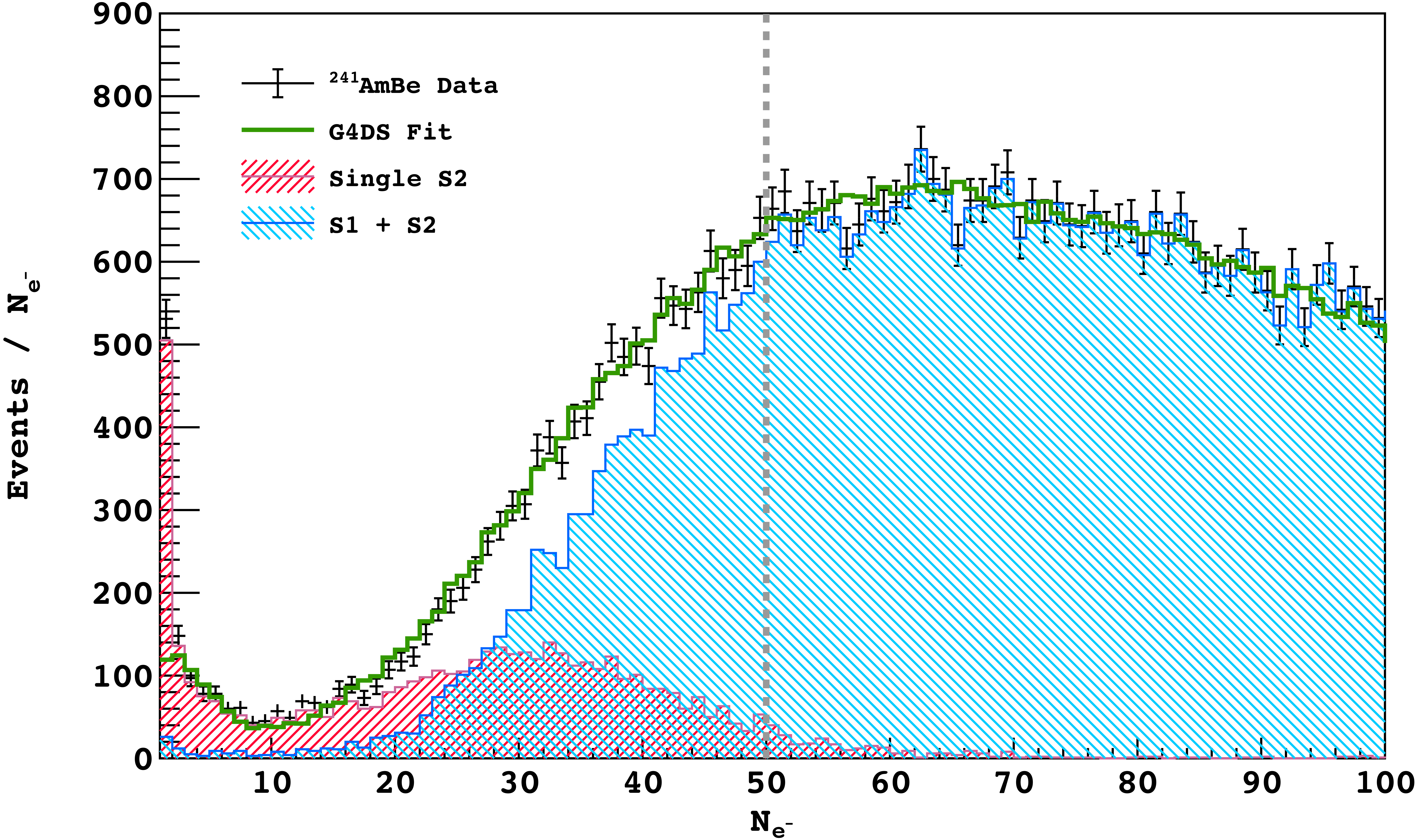
5. The electron yield for nuclear recoils rises at low energy

0.4 e-
10 eV$_{ee}$
10% Detector Threshold
4 e-
100 eV$_{ee}$
Analysis Threshold
arxiv:1802.06994
Acceptance
S2 [PE]
Fiducialization
× Trigger efficiency
× S2 Identification (f_{90}<0.15)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
20
30
40
50
60
70
80
90

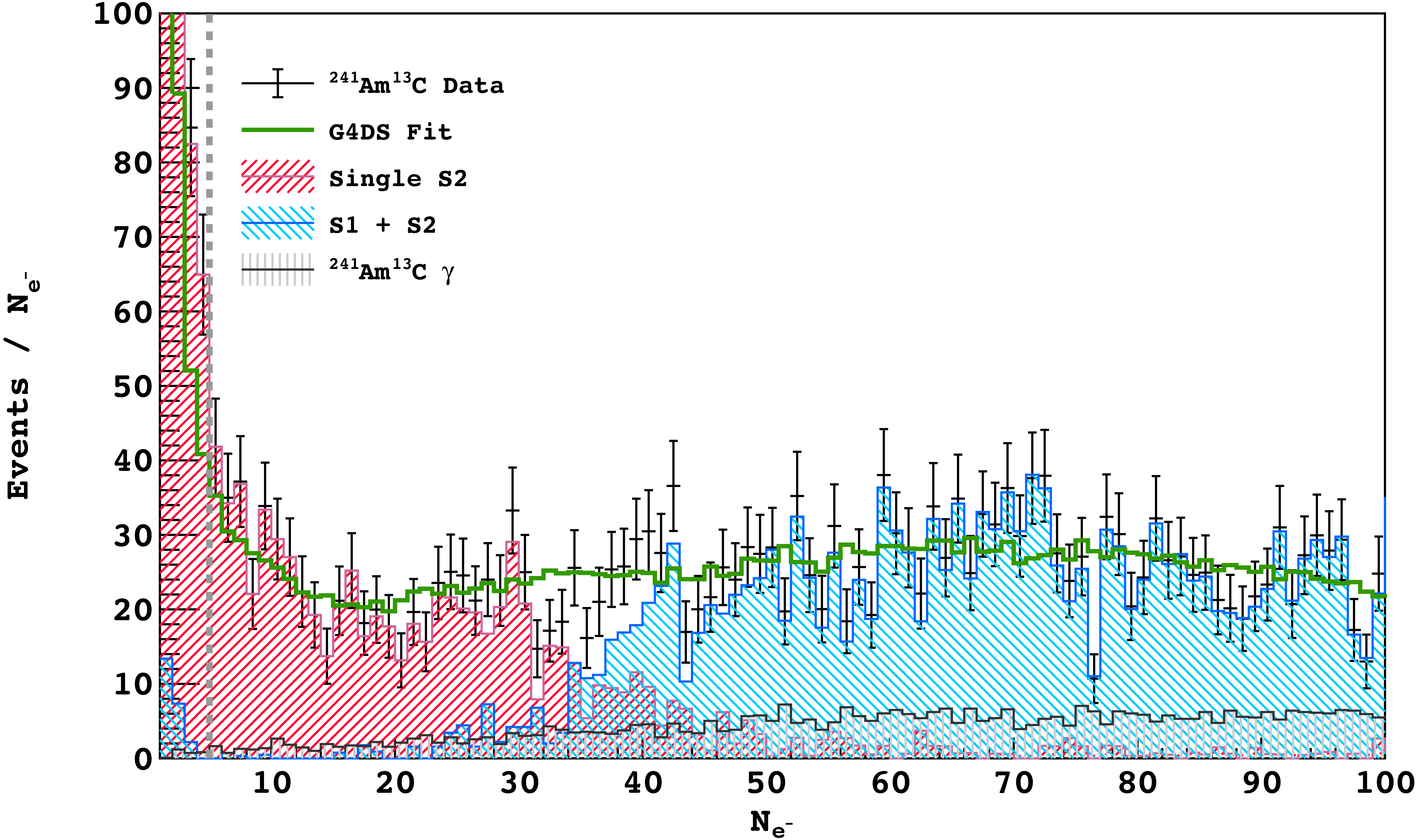

Center PMT
DS-50 DATA
Getter Off
Getter On
Fit
1 Ext. e⁻
2 Ext. e⁻'s
S2=30PE
Events / [0.05 N_e⁻ × kg × day]
N_e⁻
10²
10
1
10⁻¹
10⁻²
0
0.5
1
1.5
2
2.5
3



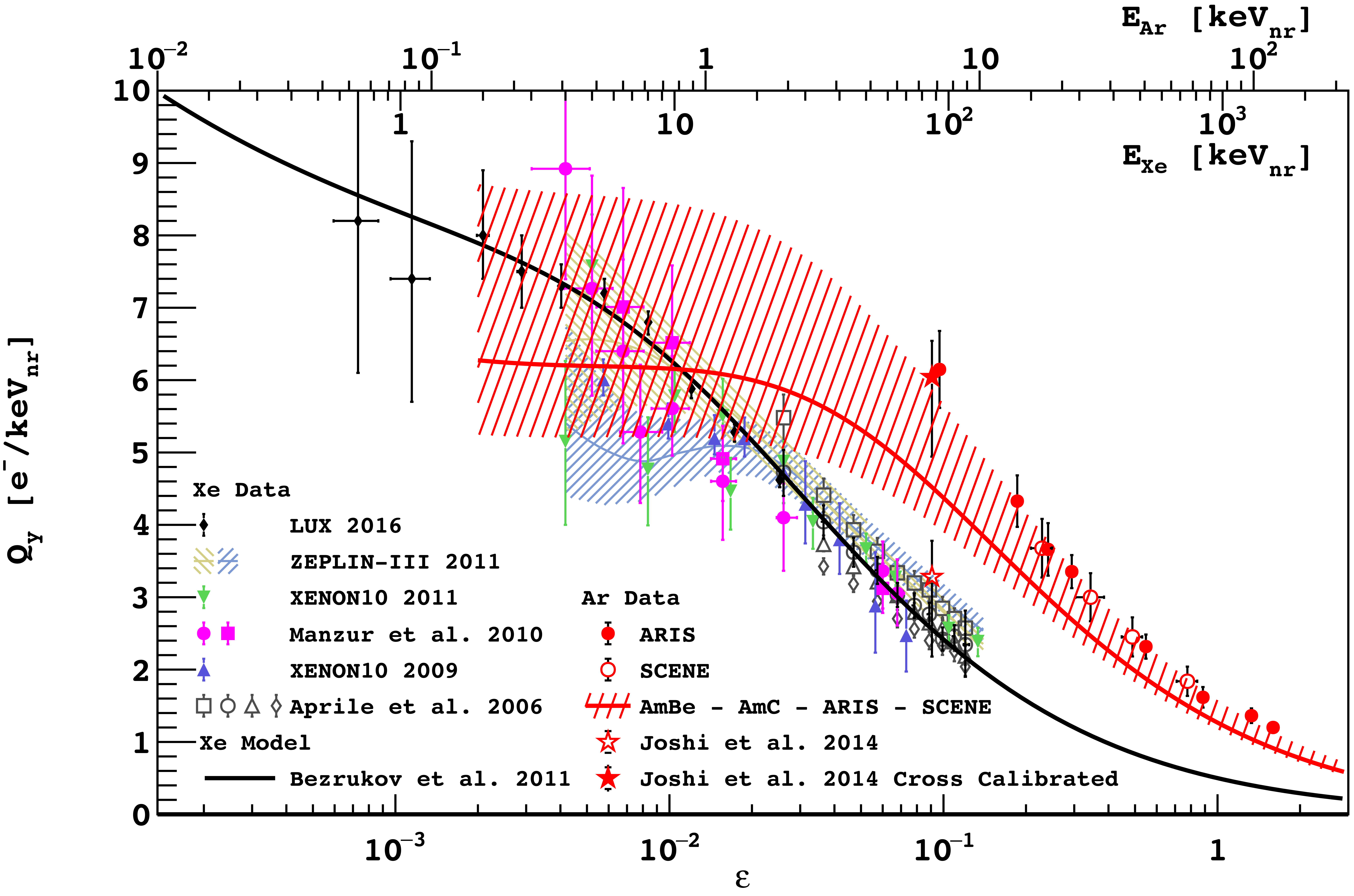
First 100 days
Last 500 days
Single S2(500d)
S1 + S2(500d)
L/K BR Ratio = 0.11 ± 0.01
Events / [0.5 N_{e^-} × kg × day]
Events / [N_{e^-} × kg × day]
N_{e^-}



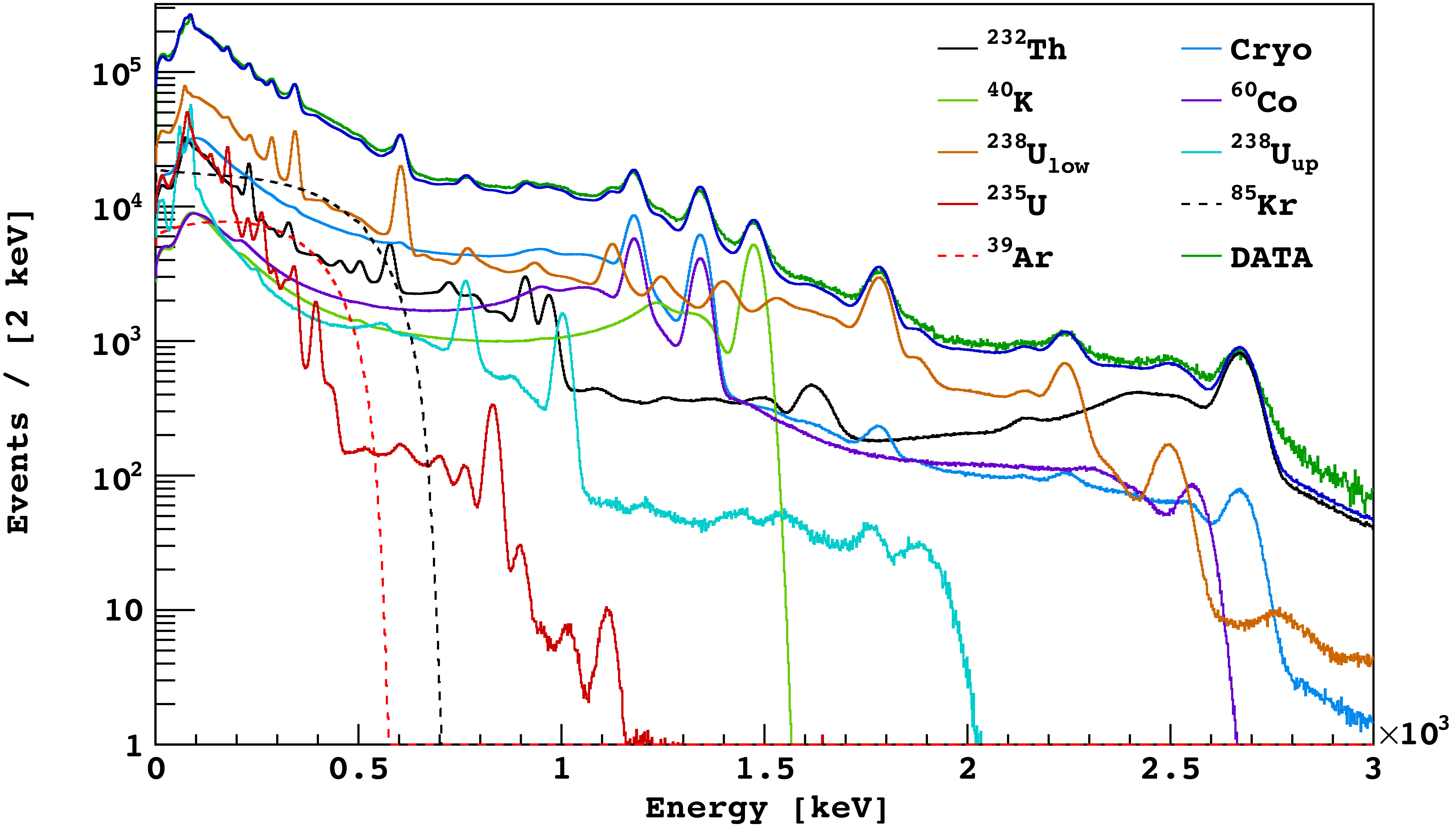
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100
^{241}AmBe Data
G4DS Fit
Single S2
S1 + S2
Events / N_{e^-}
N_{e^-}



241Am13C Data
G4DS Fit
Single S2
S1 + S2
241Am13C γ
Events / Ne-
Ne-

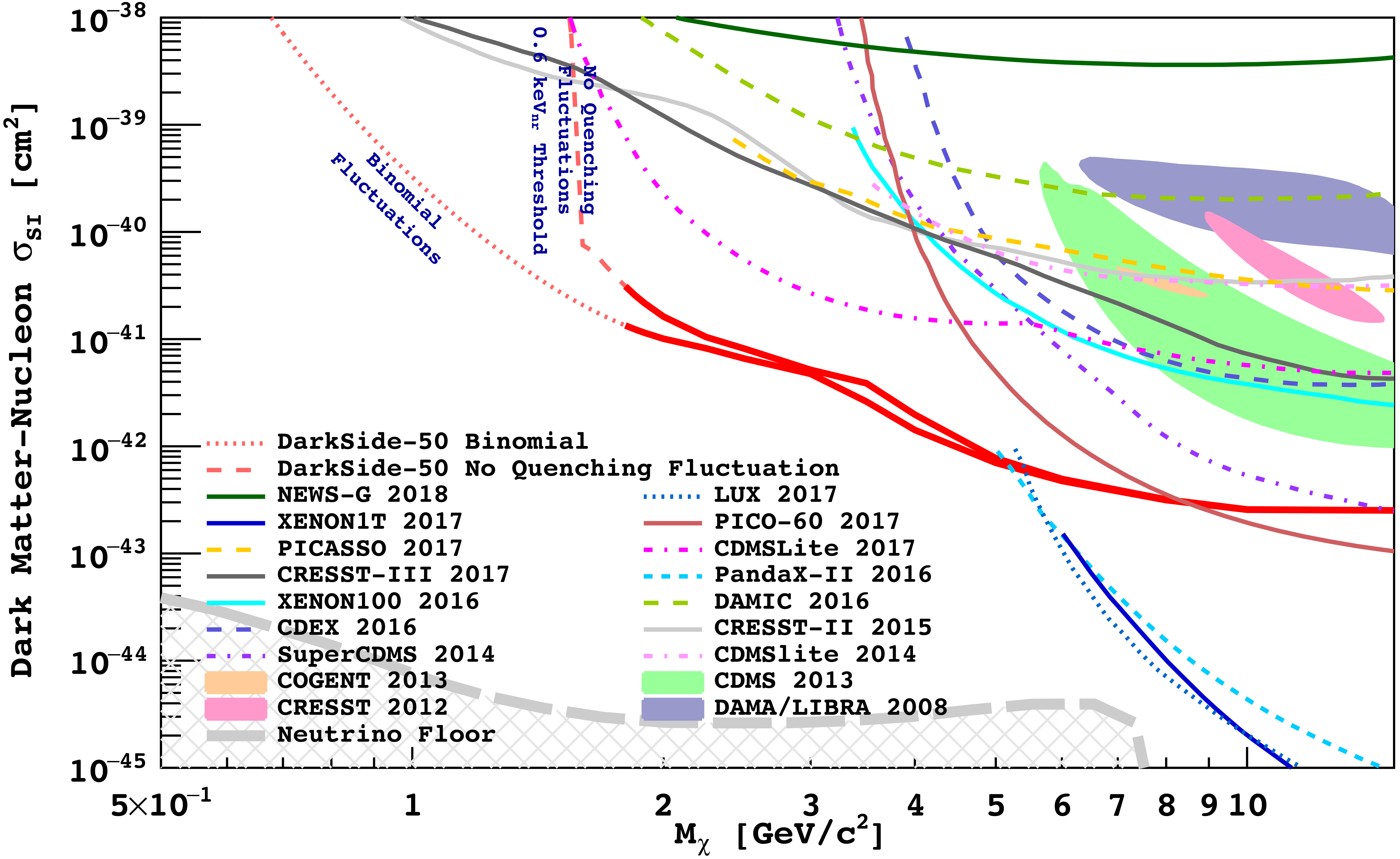


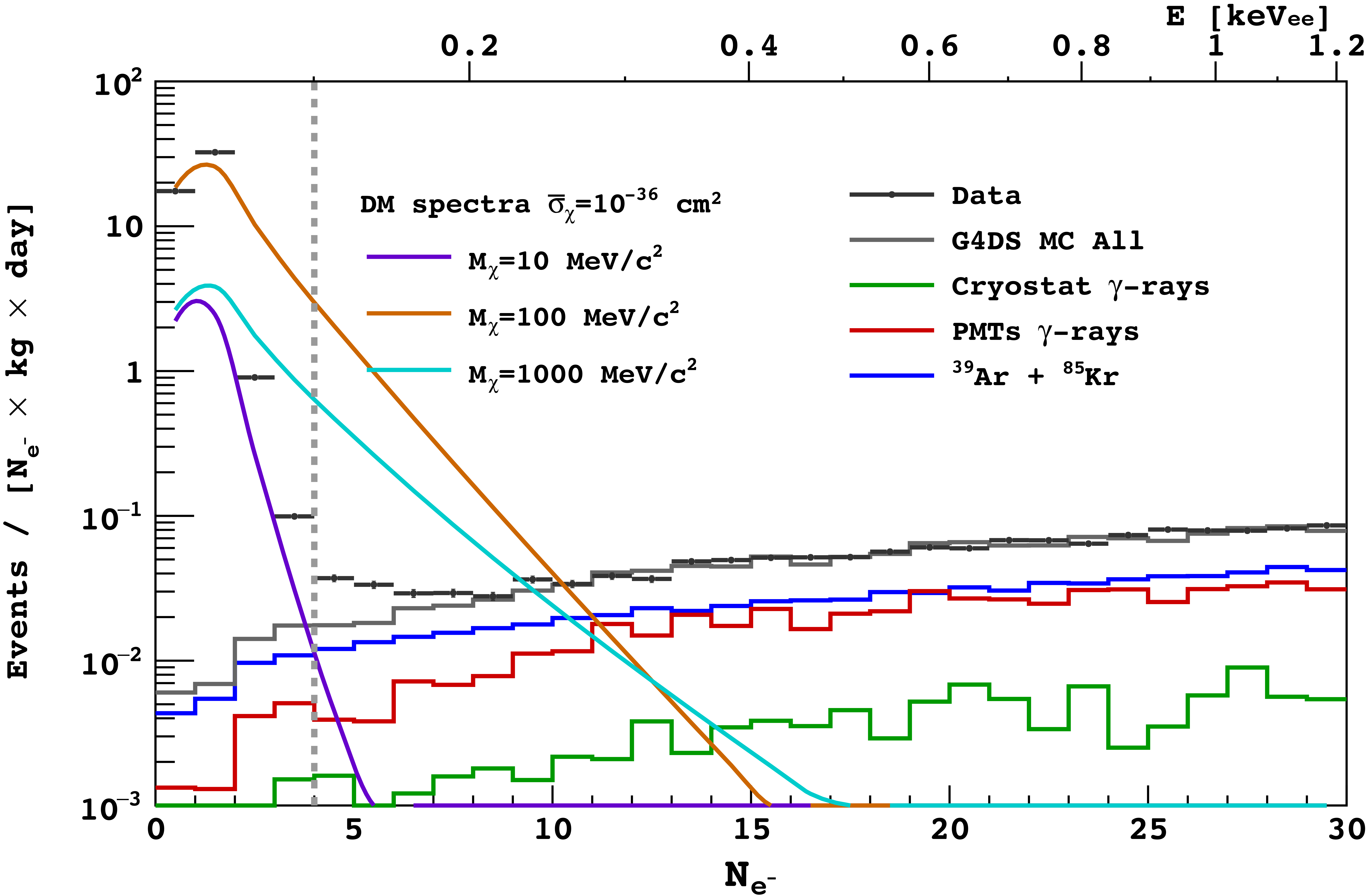
E_{Ar} [keV_{nr}]
E_{Xe} [keV_{nr}]
Q_y [e^-/keV_{nr}]
ε
Xe Data
LUX 2016
ZEPLIN-III 2011
XENON10 2011
Manzur et al. 2010
XENON10 2009
Aprile et al. 2006
Xe Model
Bezrukov et al. 2011
Ar Data
ARIS
SCENE
AmBe - AmC - ARIS - SCENE
Joshi et al. 2014
Joshi et al. 2014 Cross Calibrated

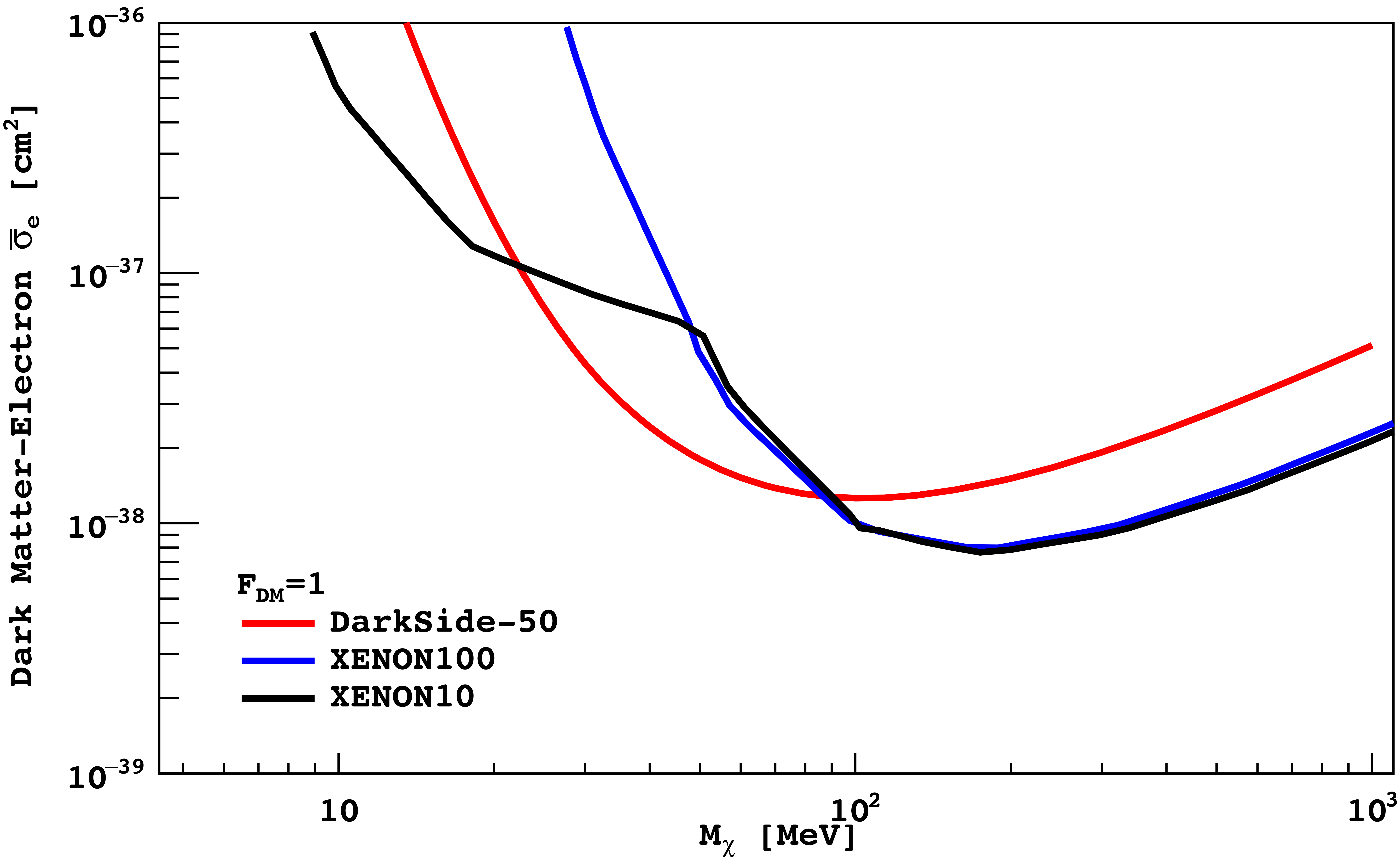


Events / [2 keV]
Energy [keV]
$\times 10^3$
^{232}Th
^{40}K
^{238}U$_{low}$
^{235}U
^{39}Ar
Cryo
^{60}Co
^{238}U$_{up}$
^{85}Kr
DATA

arxiv:1802.06994
E [keVnr]
E [keVee]
DM spectra σχ=10⁻⁴⁰ cm²
Mχ=2.5 GeV/c²
Mχ=5.0 GeV/c²
Mχ=10.0 GeV/c²
Data
G4DS MC All
Cryostat γ-rays
PMTs γ-rays
³⁹Ar + ⁸⁵Kr
Events / [Ne- × kg × day]
Events / [keVee × kg × day]
Events / [keVnr × kg × day]
Ne-


Dark Matter-Nucleon σ_SI [cm²]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
5×10⁻¹
1
2
3
4
5
6
7
8
9
10
M_χ [GeV/c²]
Binomial Fluctuations
0.6 keV_nr Threshold
No Quenching Fluctuations
DarkSide-50 Binomial
DarkSide-50 No Quenching Fluctuation
NEWS-G 2018
XENON1T 2017
PICASSO 2017
CRESST-III 2017
XENON100 2016
CDEX 2016
SuperCDMS 2014
COGENT 2013
CRESST 2012
Neutrino Floor
LUX 2017
PICO-60 2017
CDMSLite 2017
PandaX-II 2016
DAMIC 2016
CRESST-II 2015
CDMSlite 2014
CDMS 2013
DAMA/LIBRA 2008


E [keVee]
0.2
0.4
0.6
0.8
1
1.2
Events / [Ne- × kg × day]
10²
10
1
10⁻¹
10⁻²
10⁻³
DM spectra σ̄χ=10⁻³⁶ cm²
Mχ=10 MeV/c²
Mχ=100 MeV/c²
Mχ=1000 MeV/c²
Data
G4DS MC All
Cryostat γ-rays
PMTs γ-rays
³⁹Ar + ⁸⁵Kr
0
5
10
15
20
25
30
Ne-



10^{-36}
10^{-37}
10^{-38}
10^{-39}
Dark Matter-Electron $\overline{\sigma}_e$ [cm^2]
10
10^2
10^3
M_χ [MeV]
F_{DM}=1
DarkSide-50
XENON100
XENON10

The End