The DarkSide experimental program

Walter Bonivento, INFN Cagliari, Italy

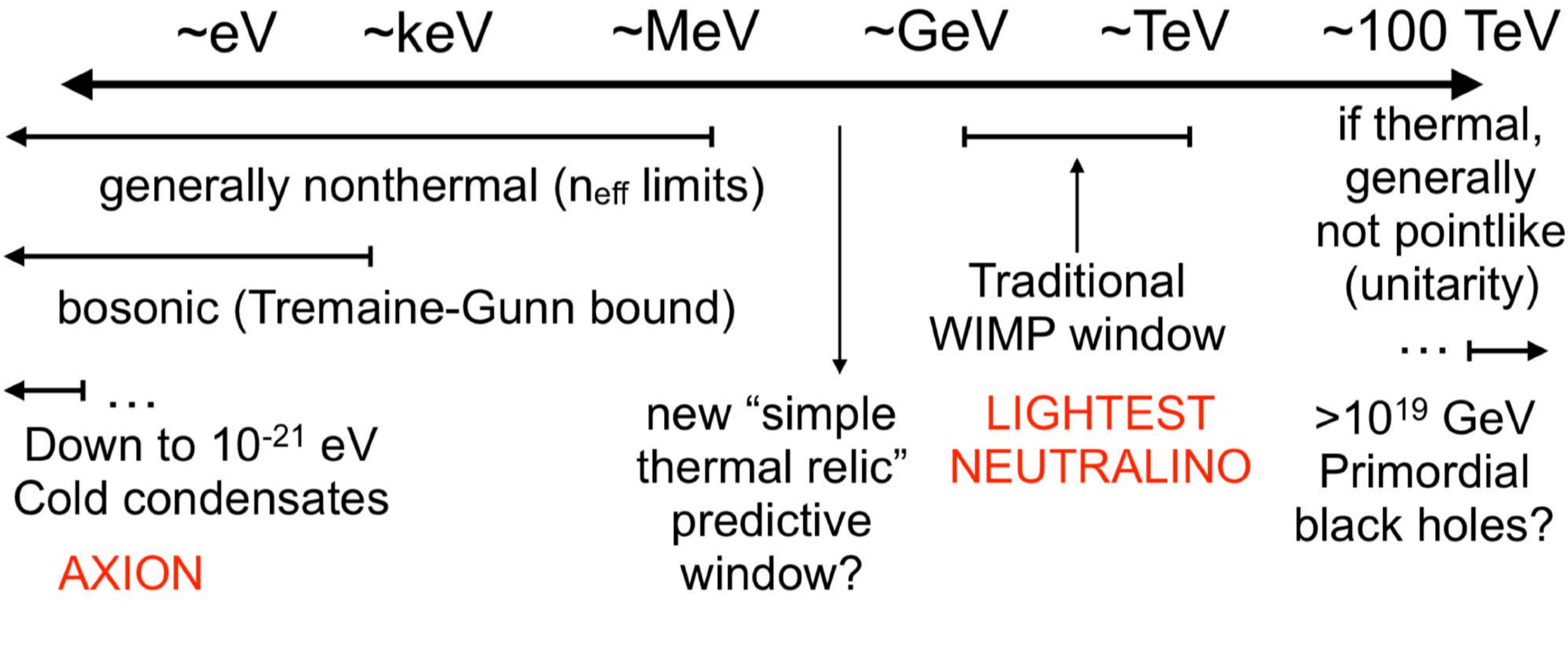
Korea-Italy Bi-lateral Symposium

Current developments in underground physics

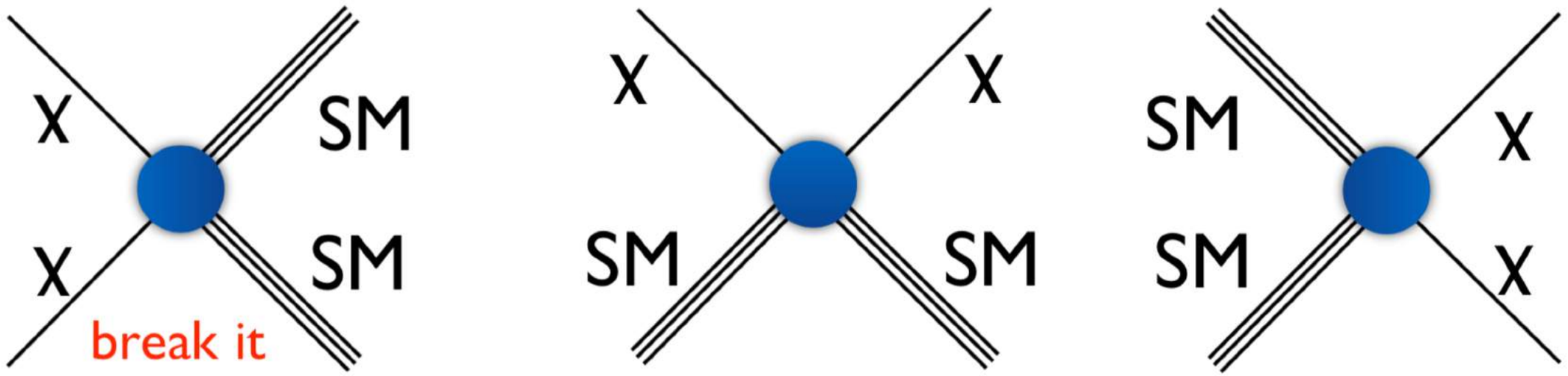
- Time: October 1, 2018 (9:00 - 17:00)
- Location: Theory bulid. B109, Institue for Basic Science, Korea

DarkSide:
Not only science
Also a big technology driver!

Dark matter mass scales

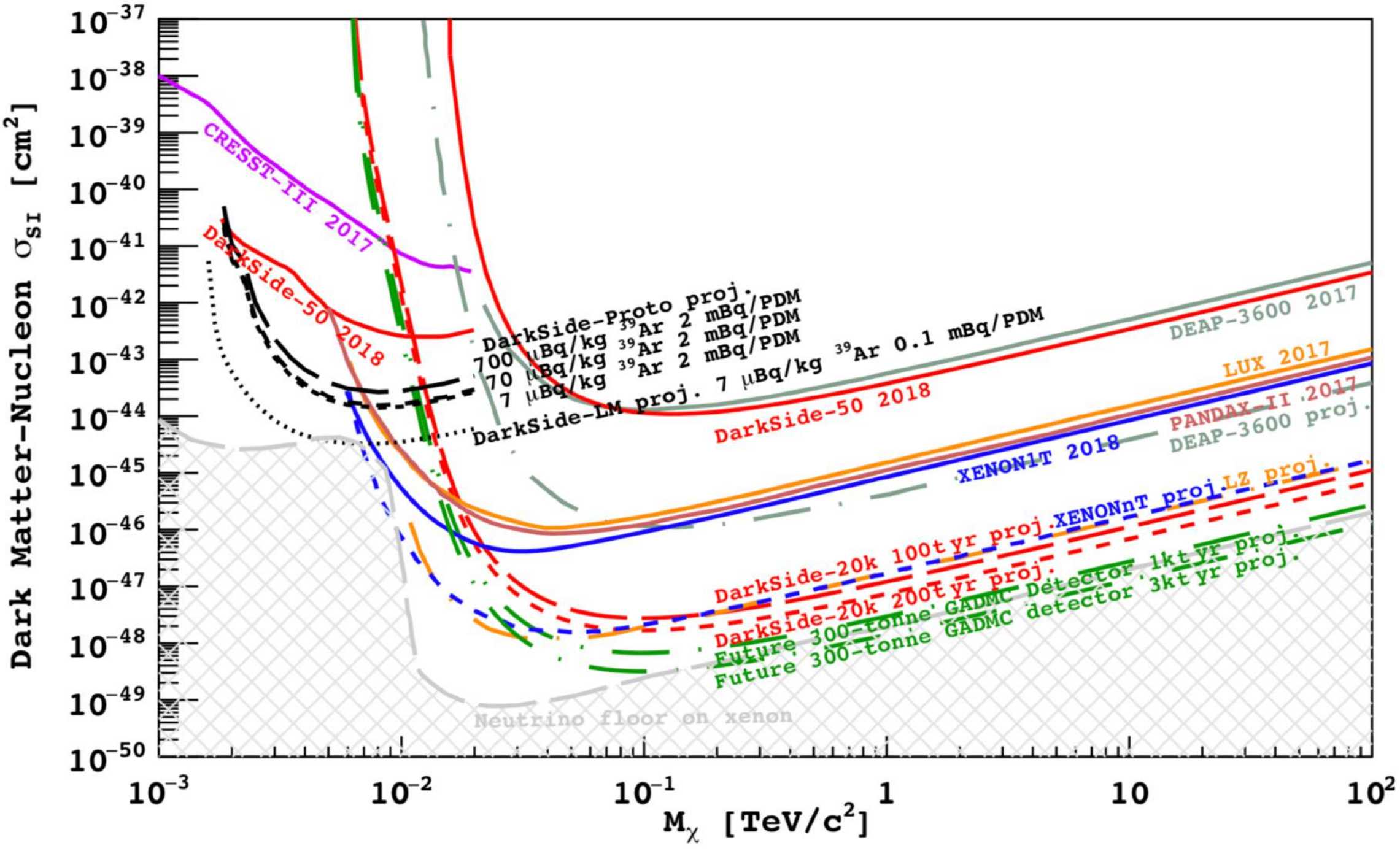


WIMP searches



Indirect detection Direct detection Collider

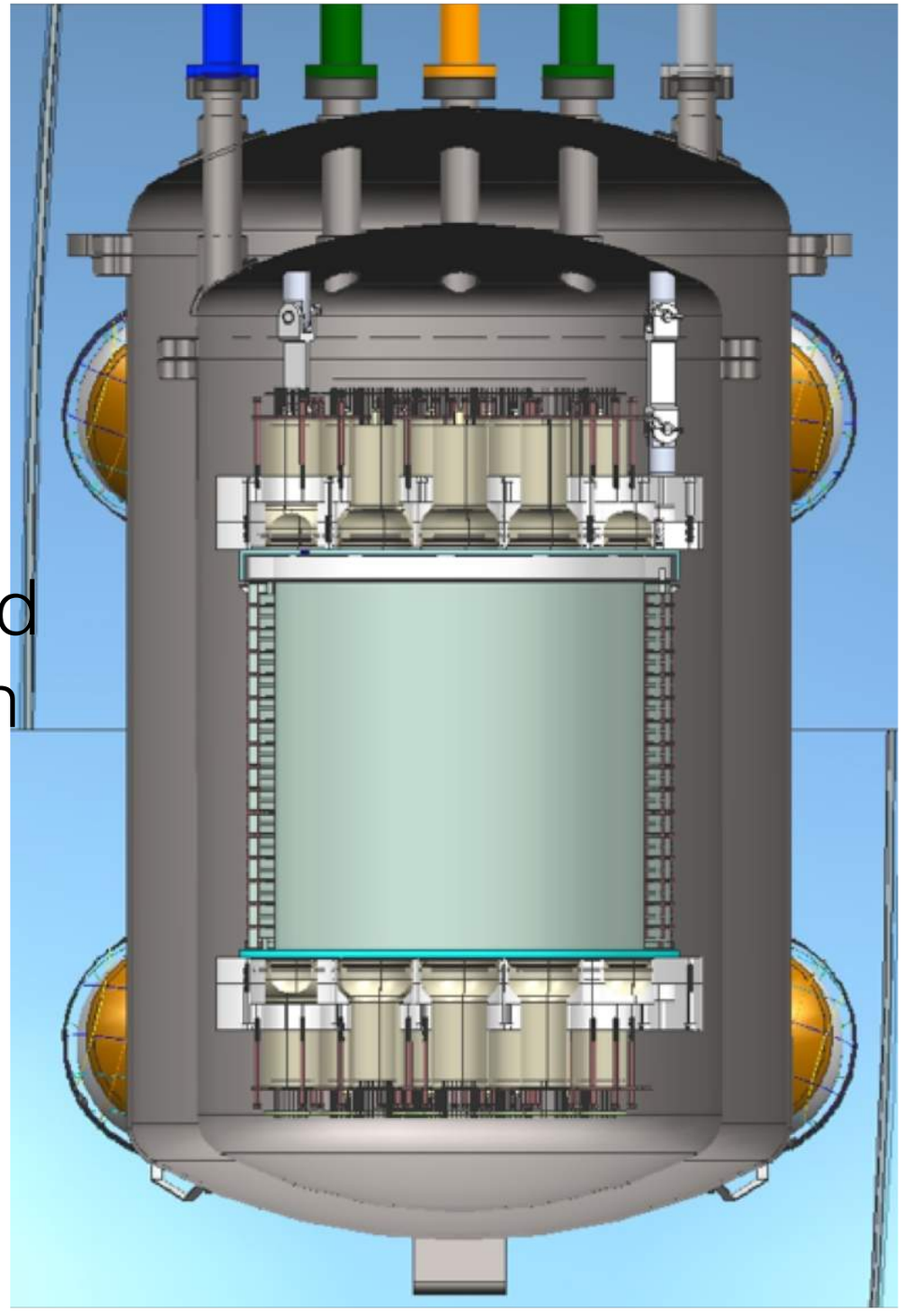
Time

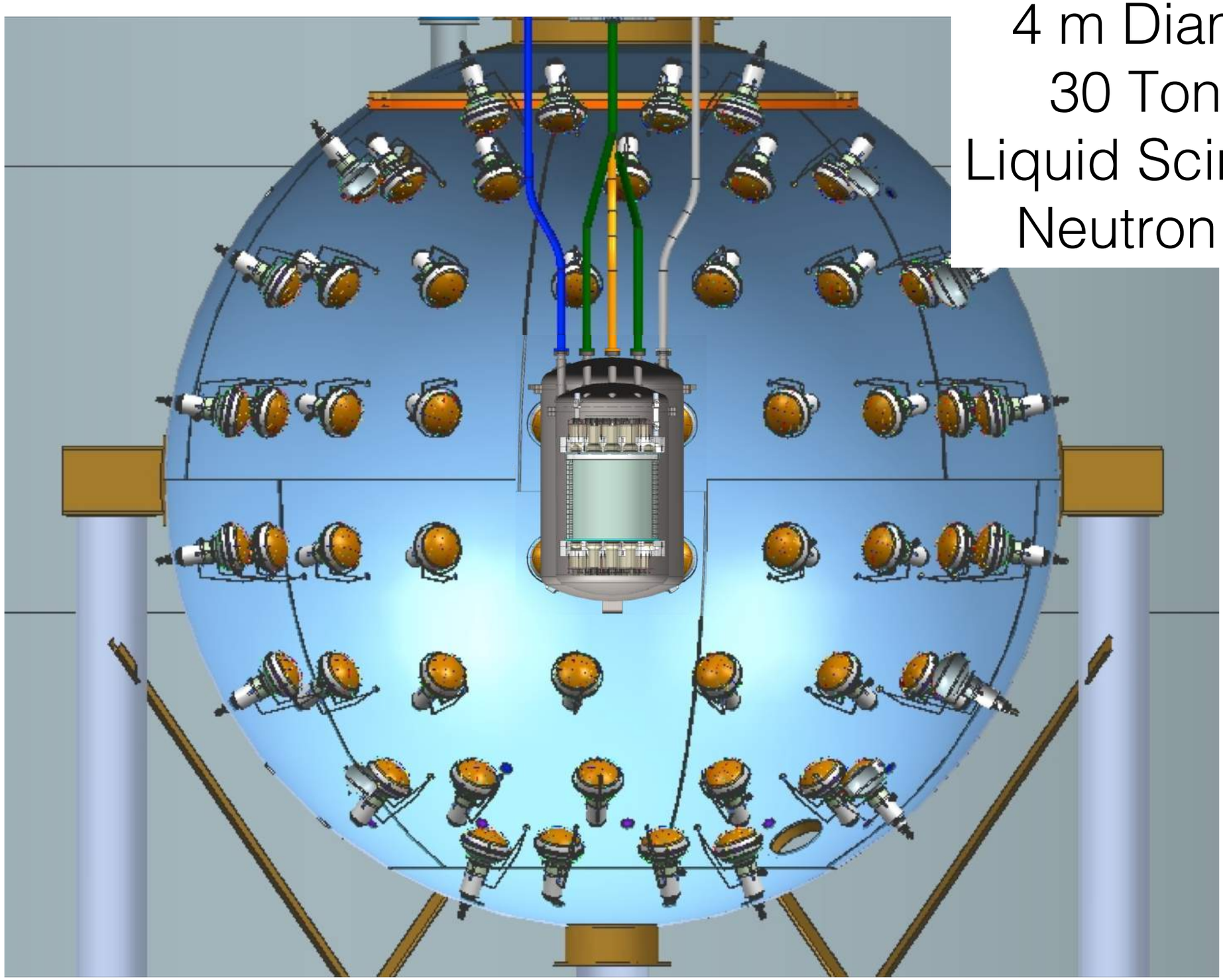

Dark Matter-Nucleon σ_{SI} [cm^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
M_χ [TeV/c^2]
CRESST-III 2017
DarkSide-50 2018
DarkSide-Proto proj.
700 μBq/kg ^{39}Ar 2 mBq/PDM
70 μBq/kg ^{39}Ar 2 mBq/PDM
7 μBq/kg ^{39}Ar 2 mBq/PDM
DarkSide-LM proj. 7 μBq/kg ^{39}Ar 0.1 mBq/PDM
DarkSide-50 2018
DEAP-3600 2017
LUX 2017
PANDAX-II 2017
XENON1T 2018
DEAP-3600 proj.
DarkSide-20k 100t yr proj.
XENONnT proj.
LZ proj.
DarkSide-20k 200t yr proj.
Future 300-tonne GADMC Detector 1kt yr proj.
Future 300-tonne GADMC detector 3kt yr proj.
Neutrino floor on xenon

Setting the stage:

DarkSide-50 results

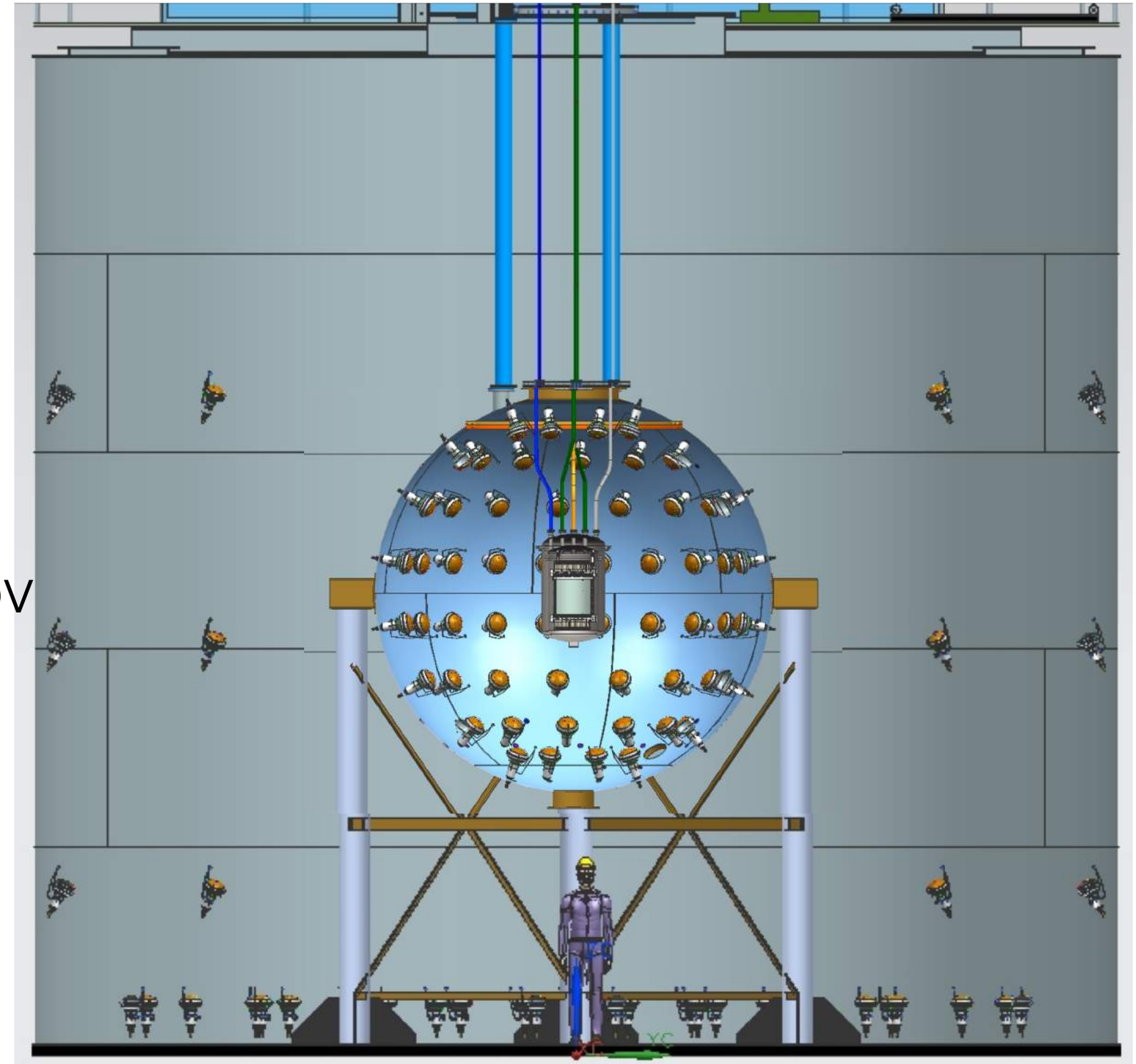
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target





4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

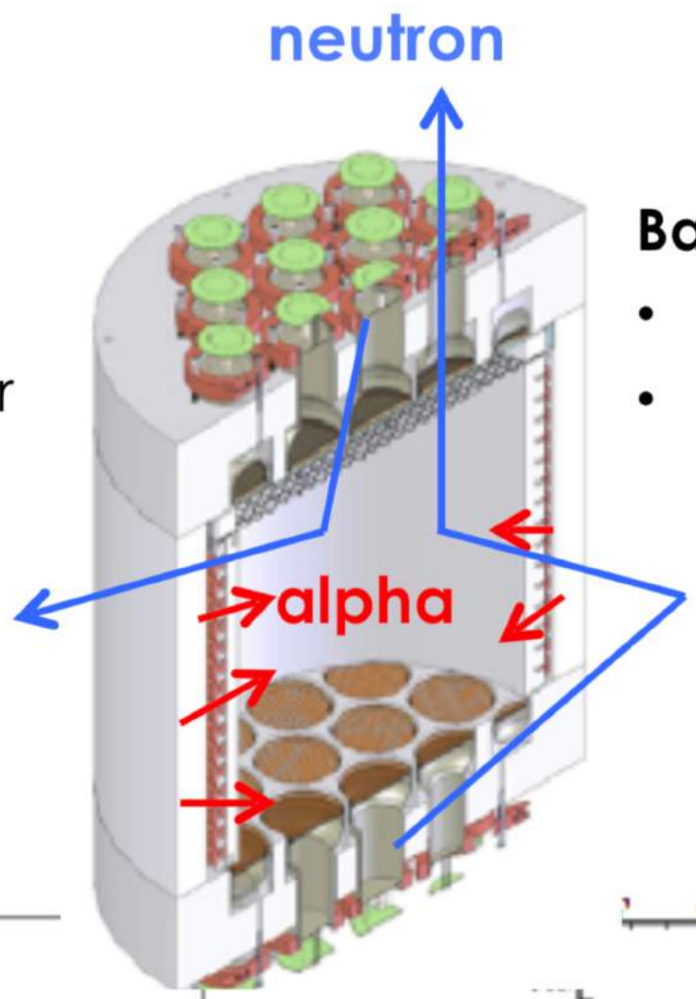
10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



Neutrons

Background rejection:

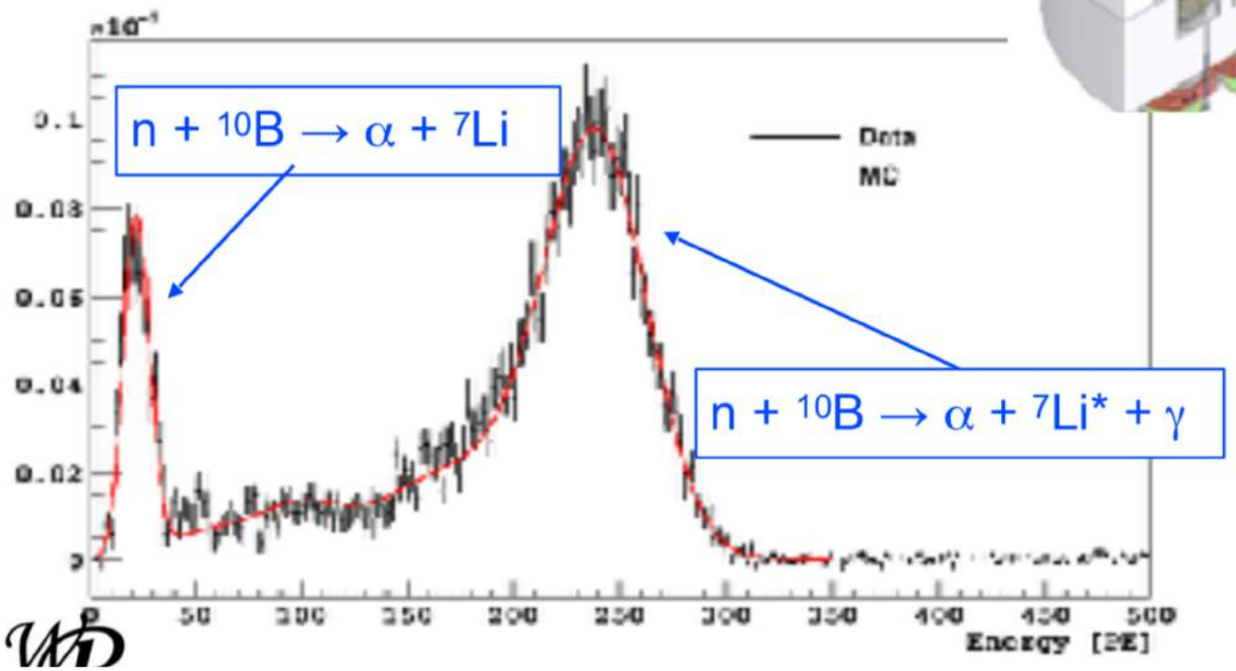
- TPC: multi-scatter
- LS Veto: efficiency from Am-C for TPC single-NR: **0.9964±0.0004**
- Water Cherenkov Veto
- Neutrons in data counted

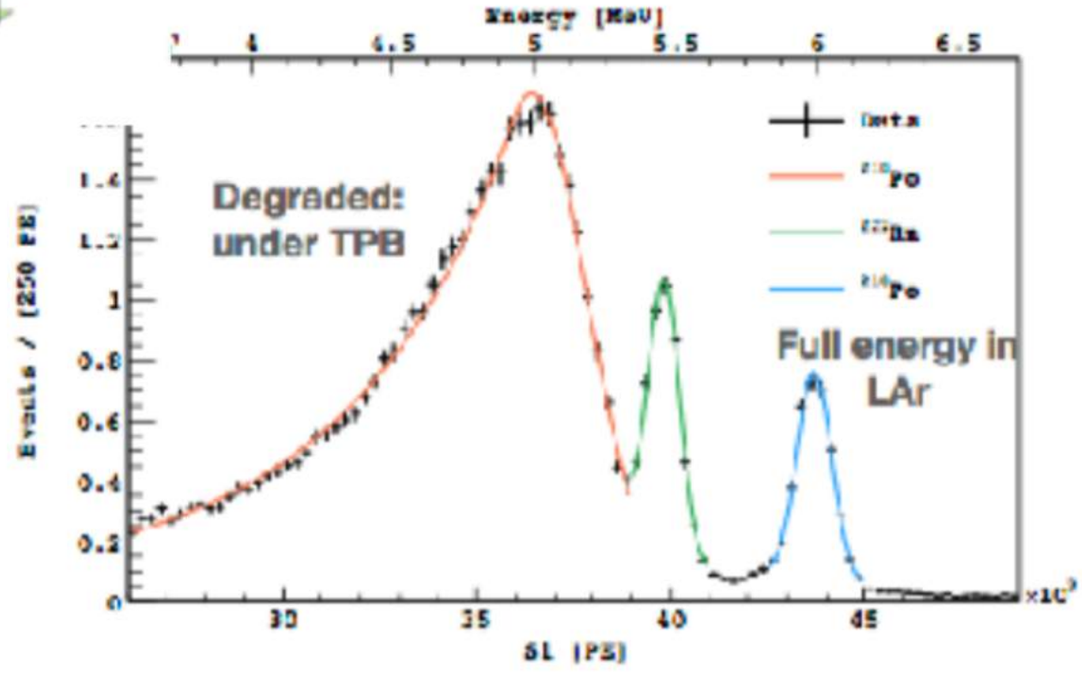


Alpha's

Background rejection:

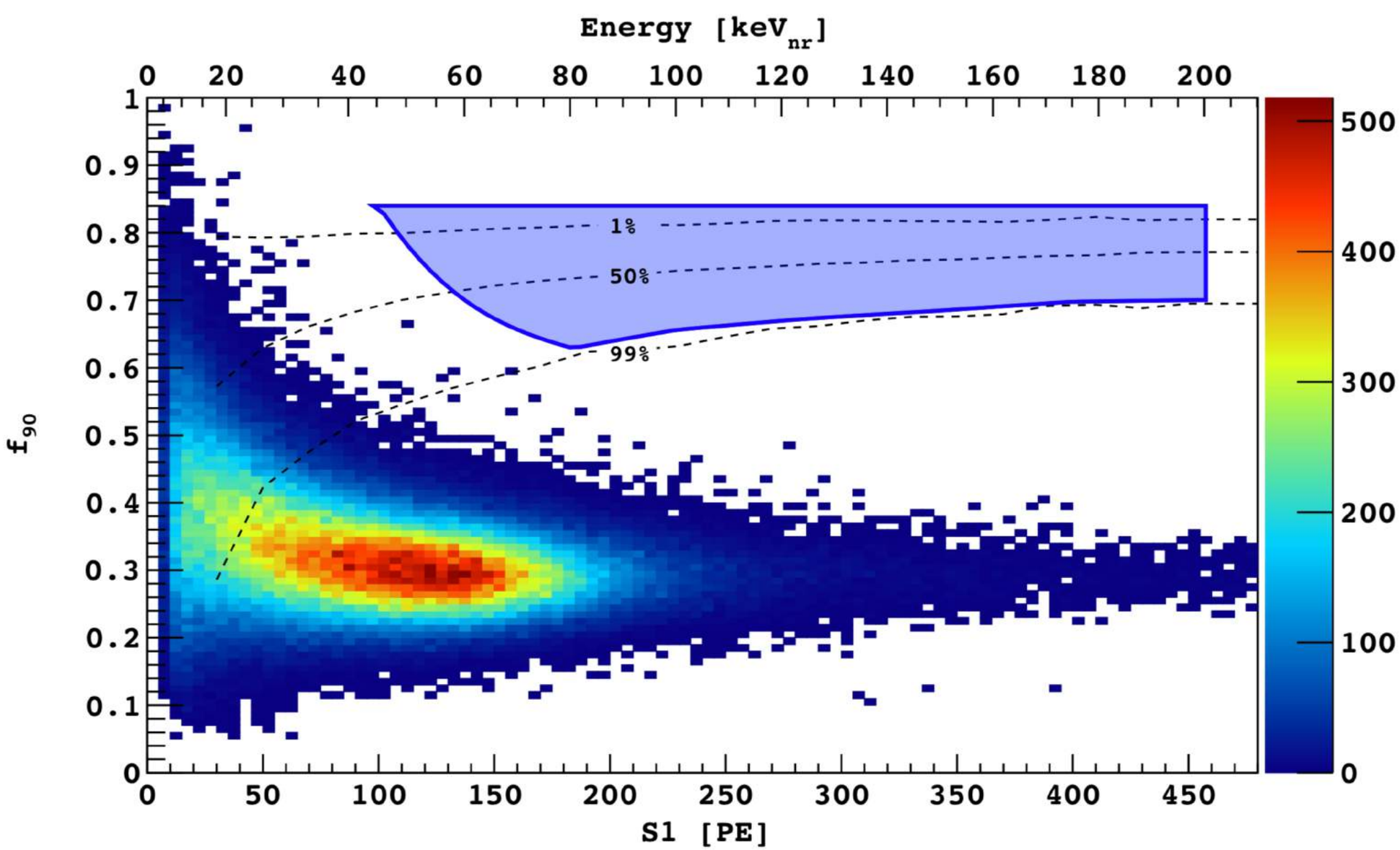
- Small fraction at low energies
- Self-vetoing in DS-50!
  - Small or no S2
  - Long S2 tail from TPB fluorescence





DM-nucleon

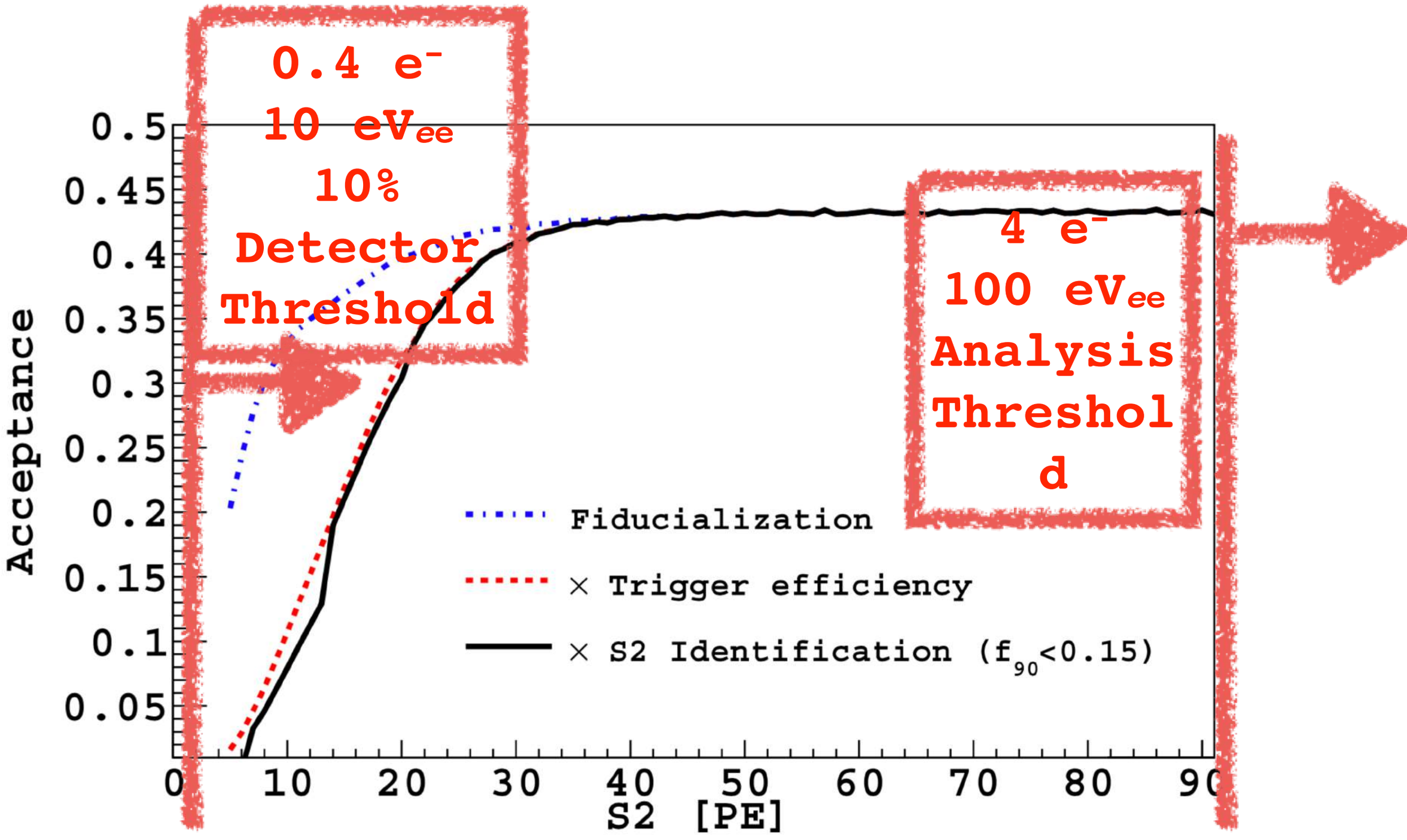
High-mass

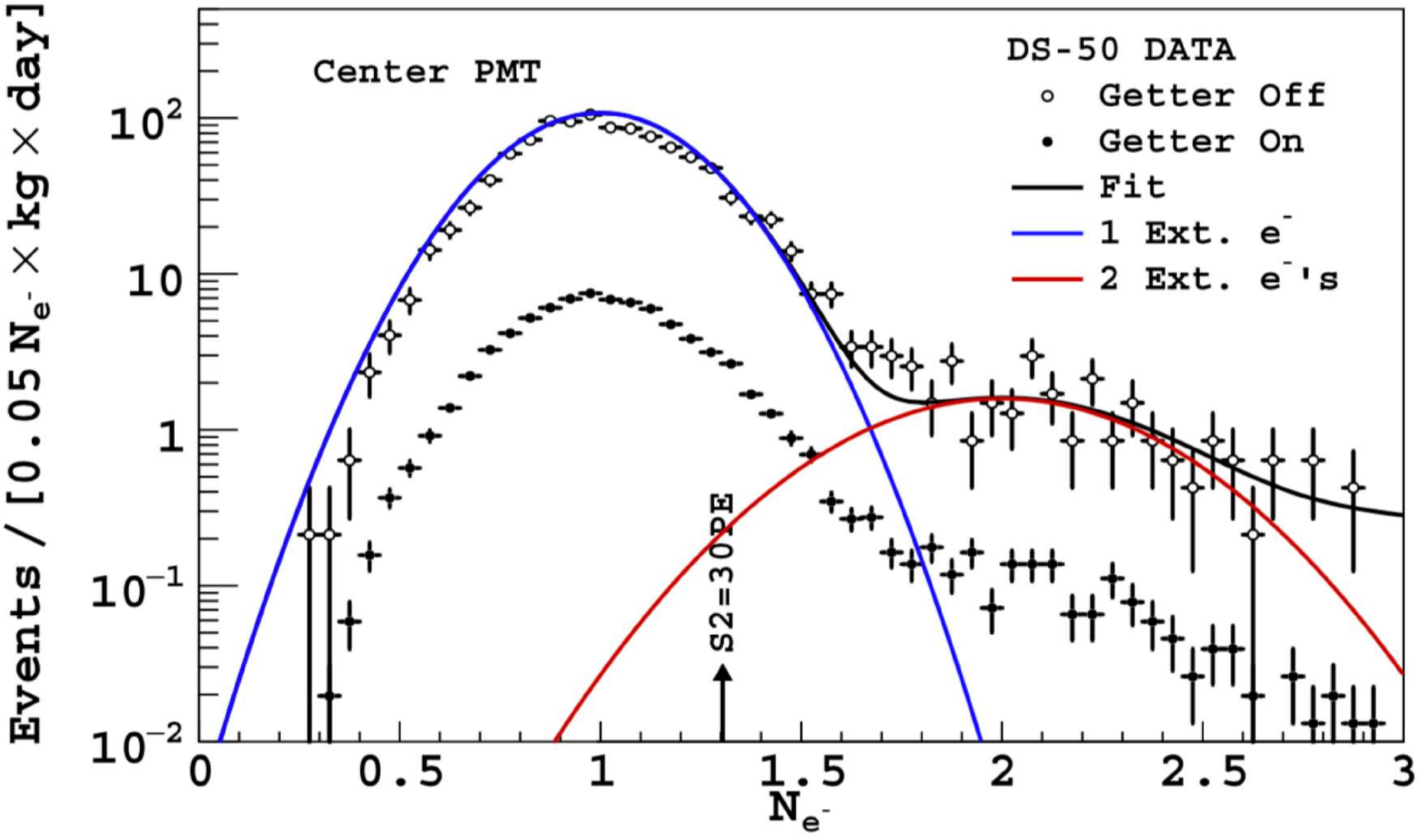


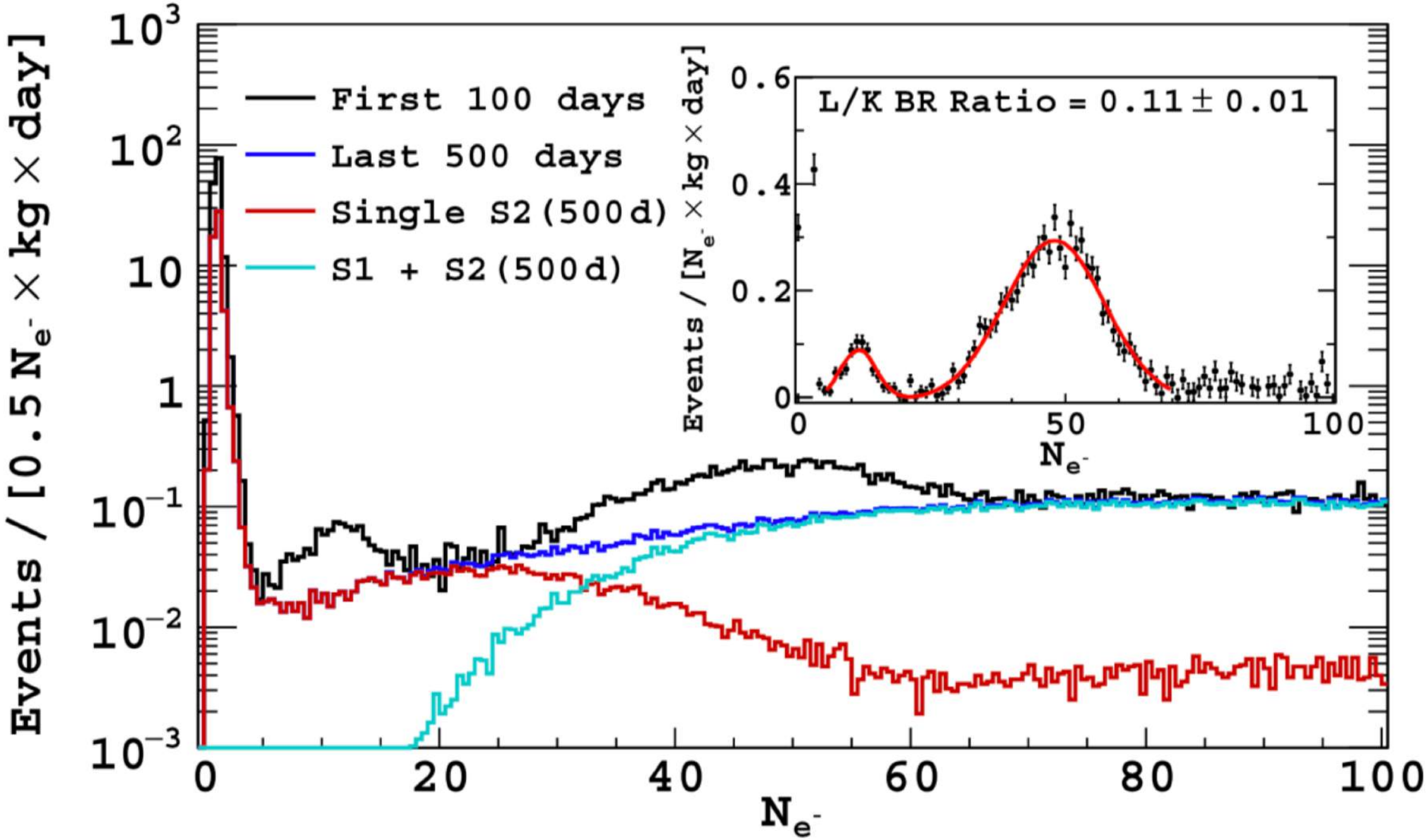
High Mass WIMPs: > 20 GeV/c²

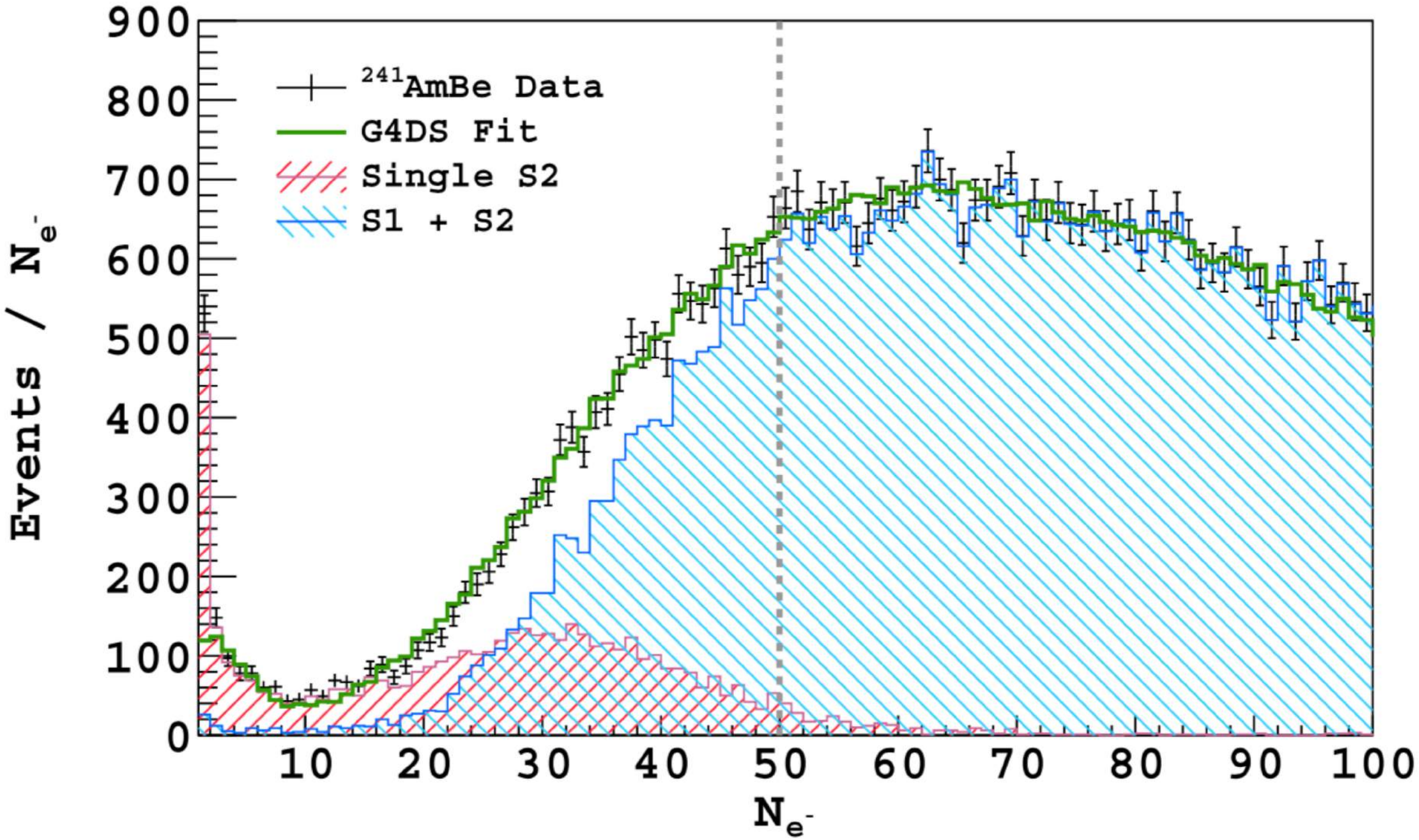
- Range: **45-200 keV$_{nr}$**
- S1 and S2 signals
- Excellent Pulse Shape Discrimination
- **Background free (<0.1 events) analysis**

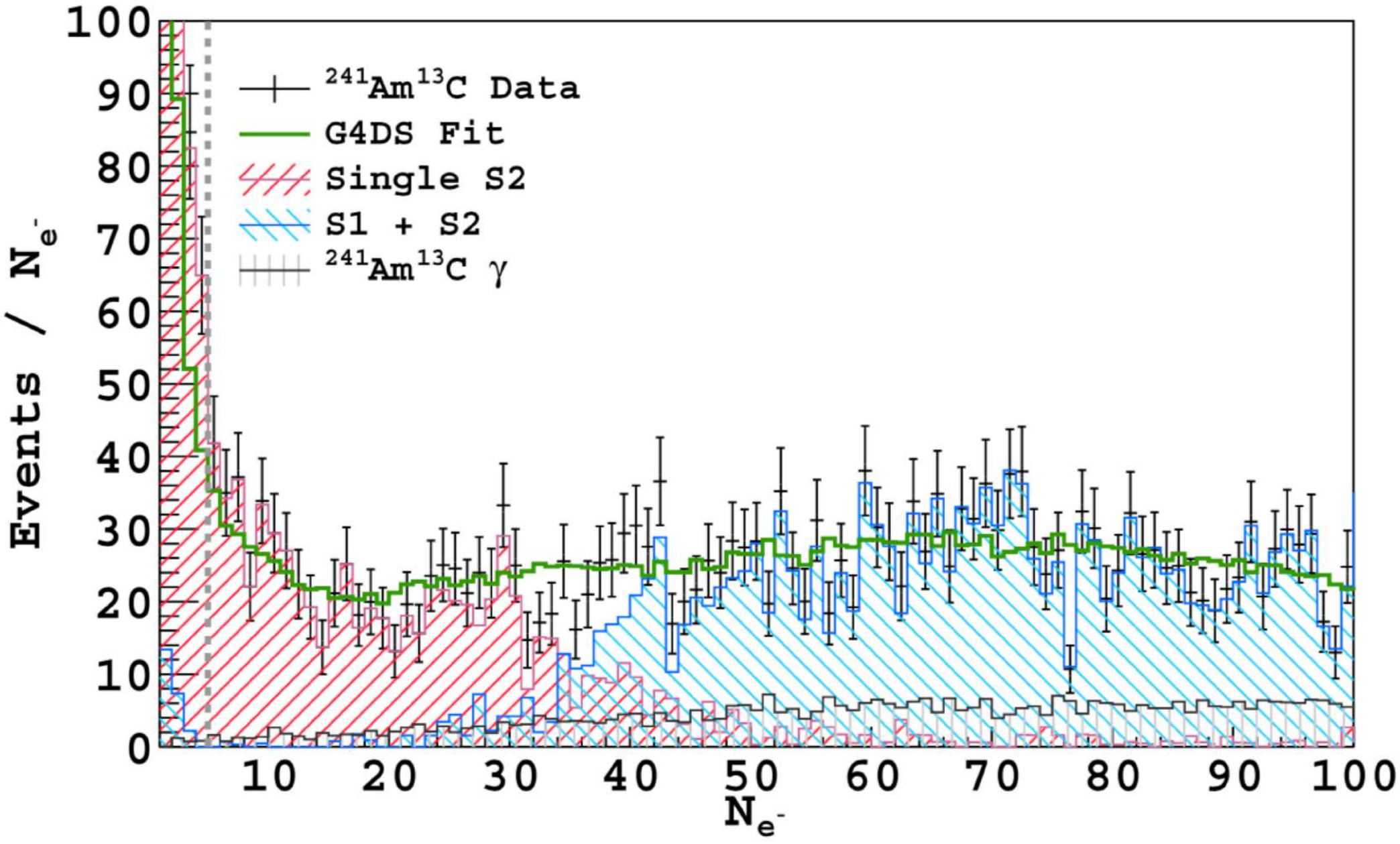
DM-nucleon low-mass

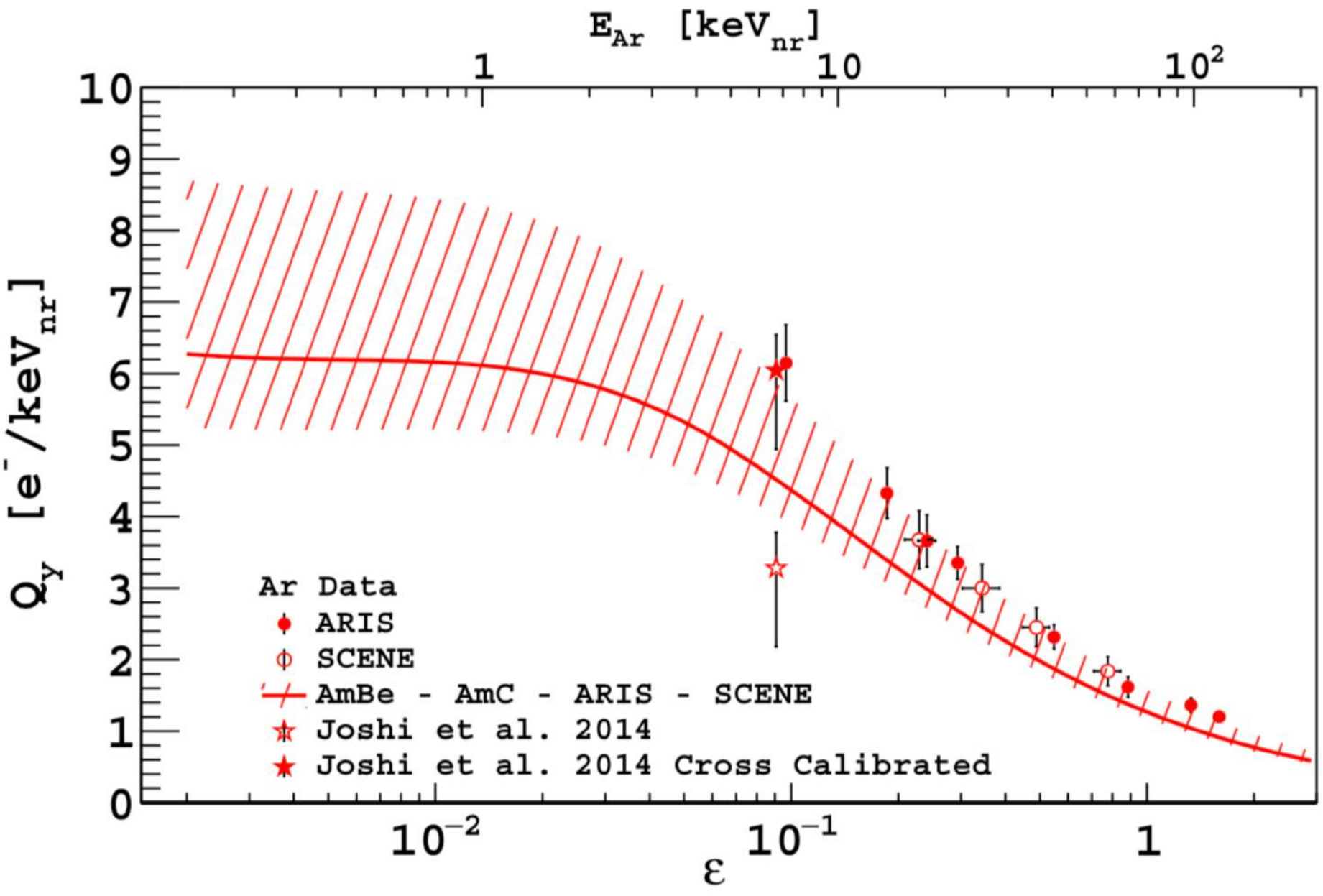

0.4 e⁻
10 eVee
10%
Detector
Threshold
4 e⁻
100 eVee
Analysis
Threshol
d
Acceptance
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
20
30
40
50
60
70
80
90
S2 [PE]
Fiducialization
× Trigger efficiency
× S2 Identification (f90<0.15)

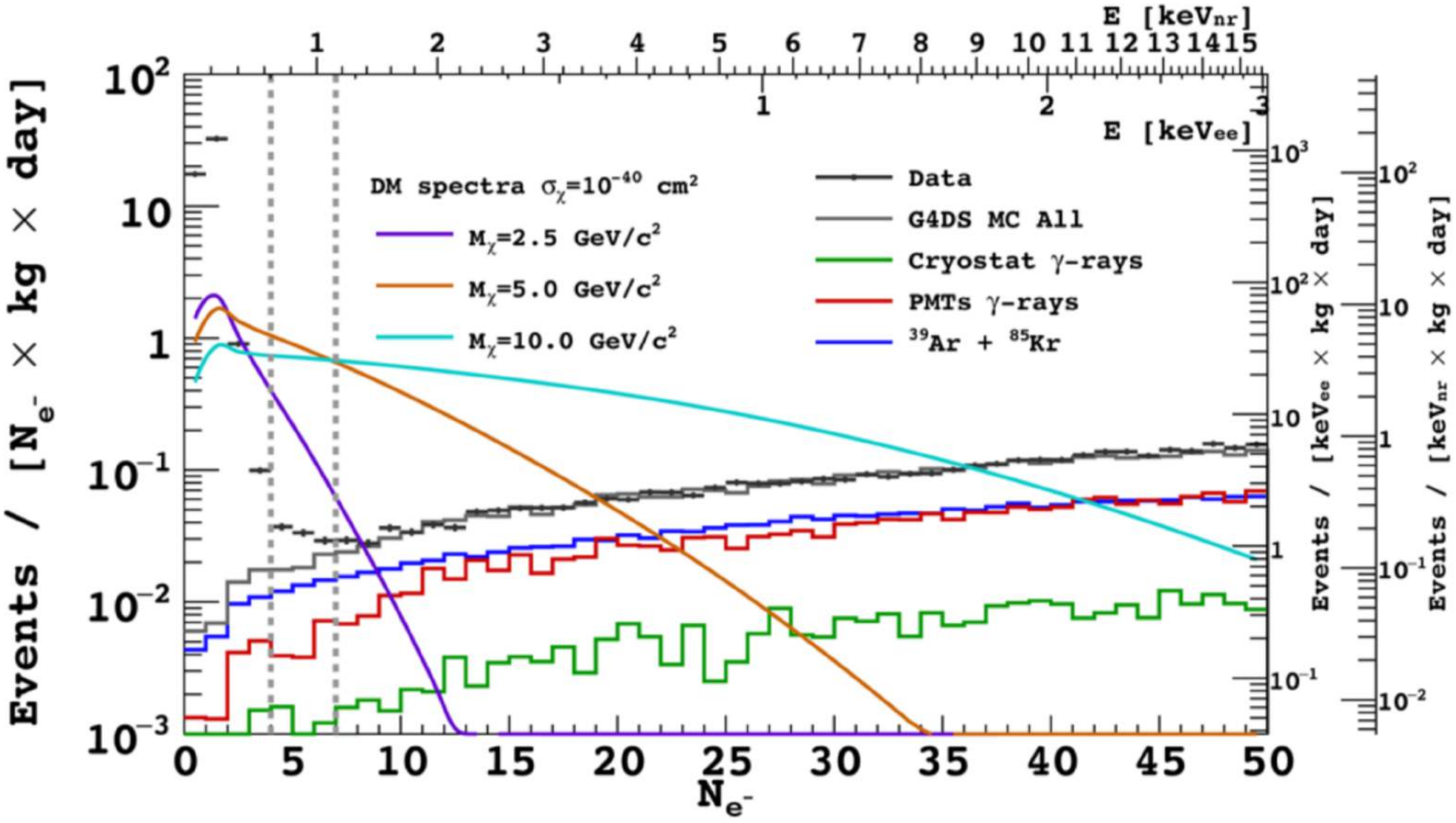

Center PMT
DS-50 DATA
Getter Off
Getter On
Fit
1 Ext. e⁻
2 Ext. e⁻'s
S2=30PE
Events / [0.05 N_e⁻ × kg × day]
N_e⁻
10²
10
1
10⁻¹
10⁻²
0
0.5
1
1.5
2
2.5
3

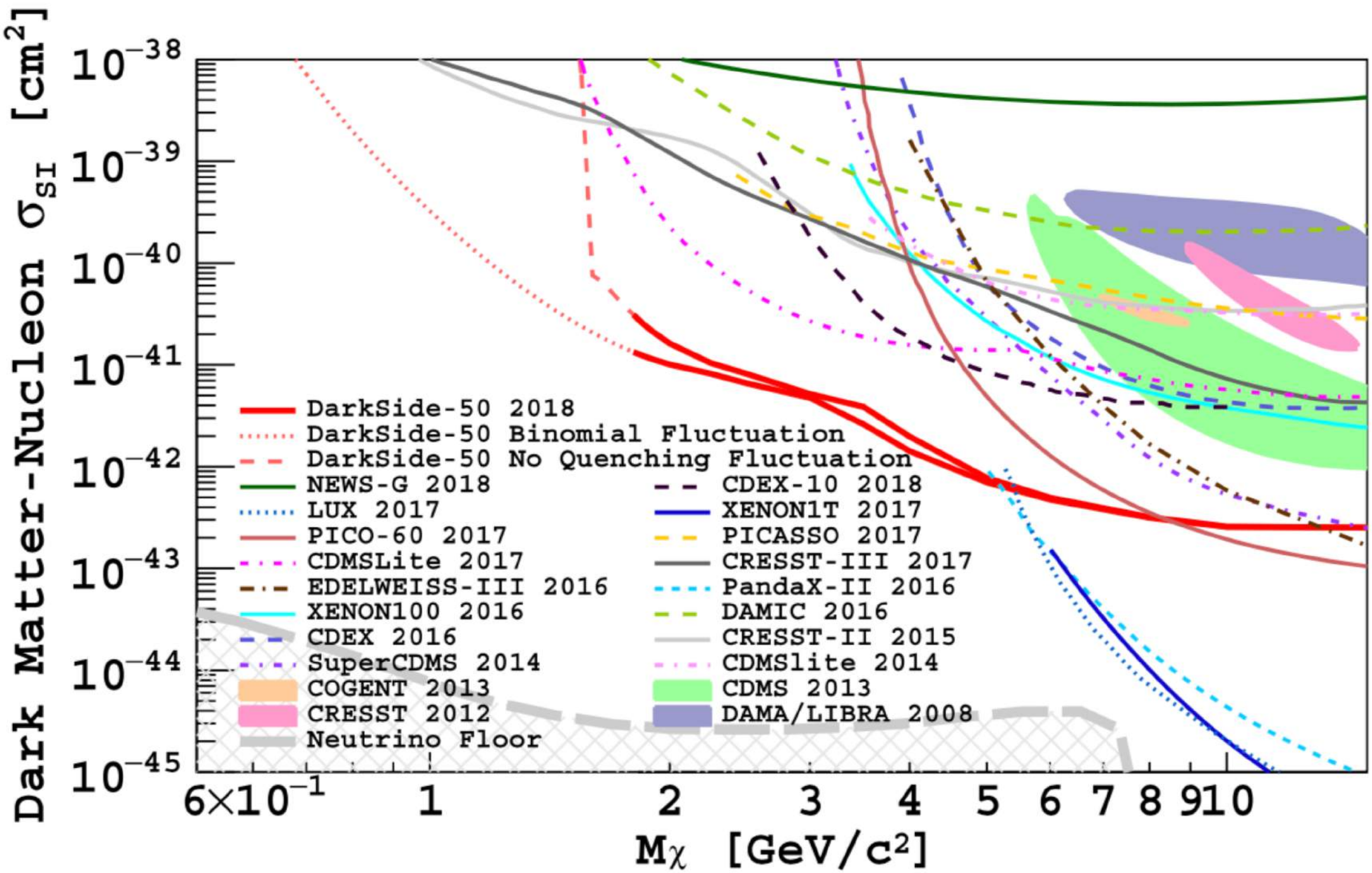

First 100 days
Last 500 days
Single S2(500d)
S1 + S2(500d)
Events / [0.5 N_{e^-} × kg × day]
N_{e^-}
L/K BR Ratio = 0.11 ± 0.01
Events / [N_{e^-} × kg × day]
N_{e^-}


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

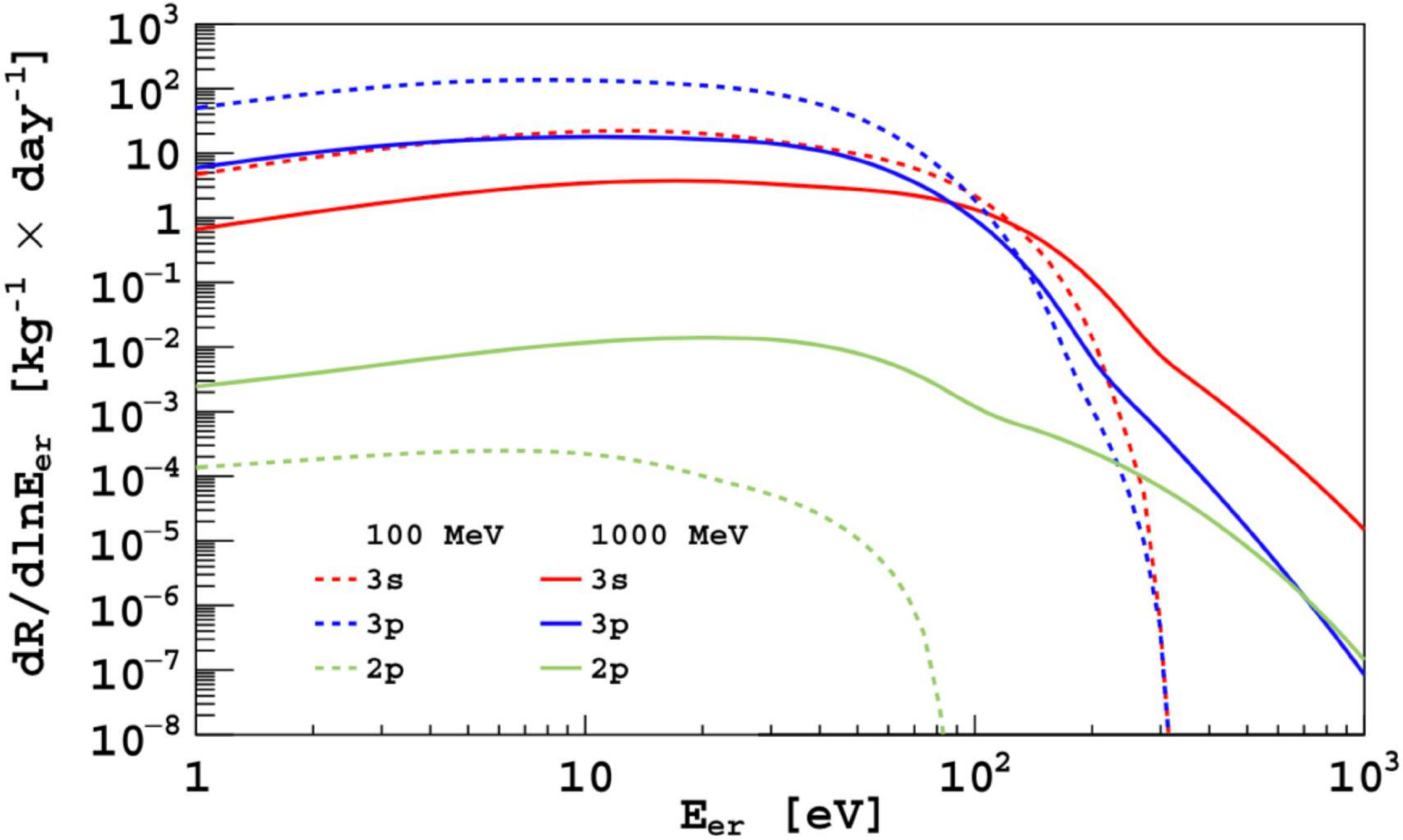

$^{241}Am^{13}C$ Data
G4DS Fit
Single S2
S1 + S2
$^{241}Am^{13}C$ γ
Events / N_{e^-}
N_{e^-}
0
10
20
30
40
50
60
70
80
90
100

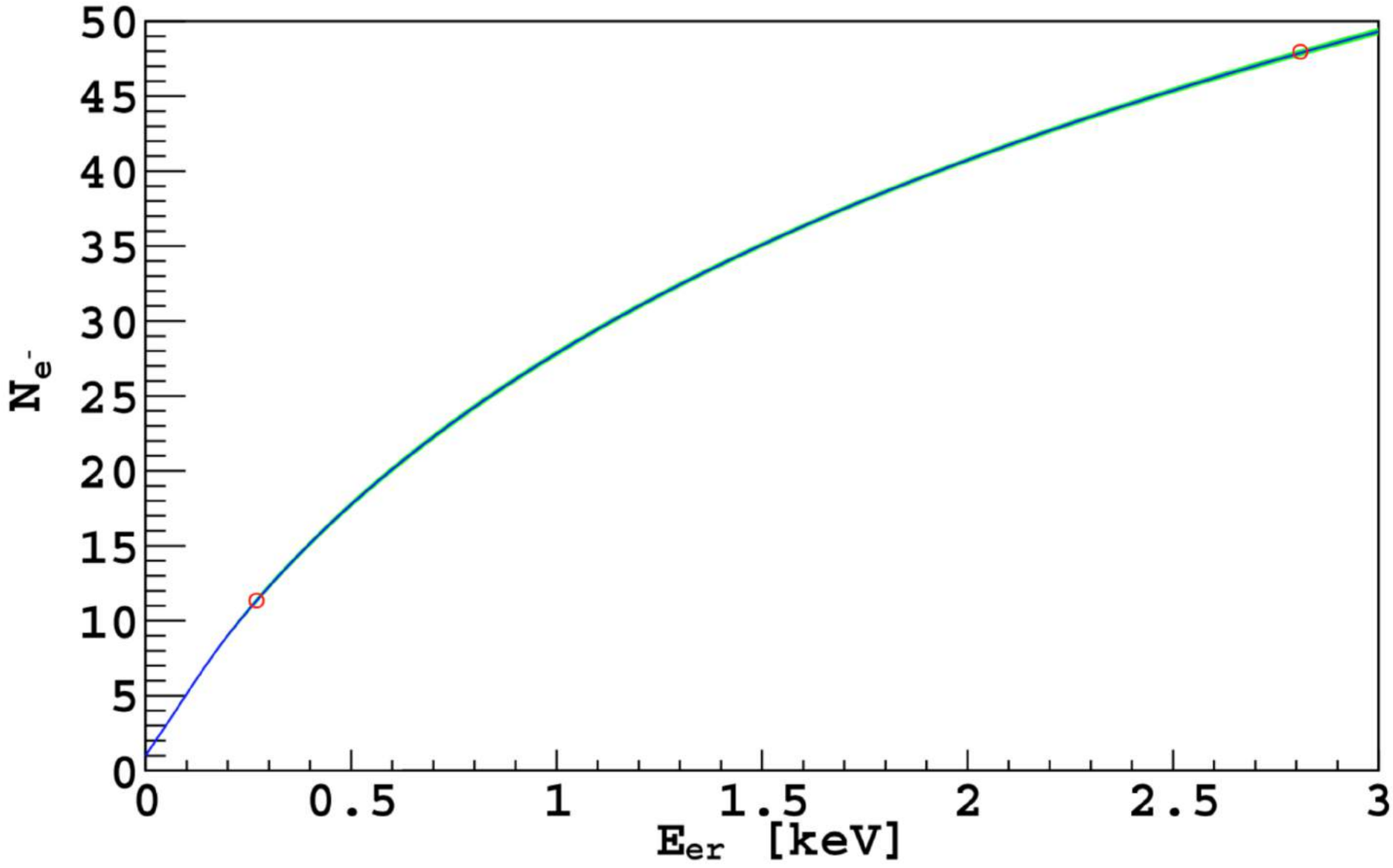

E_Ar [keV_nr]
1
10
10^2
Q_y [e^-/keV_nr]
0
1
2
3
4
5
6
7
8
9
10
Ar Data
ARIS
SCENE
AmBe - AmC - ARIS - SCENE
Joshi et al. 2014
Joshi et al. 2014 Cross Calibrated
10^-2
10^-1
1
ε

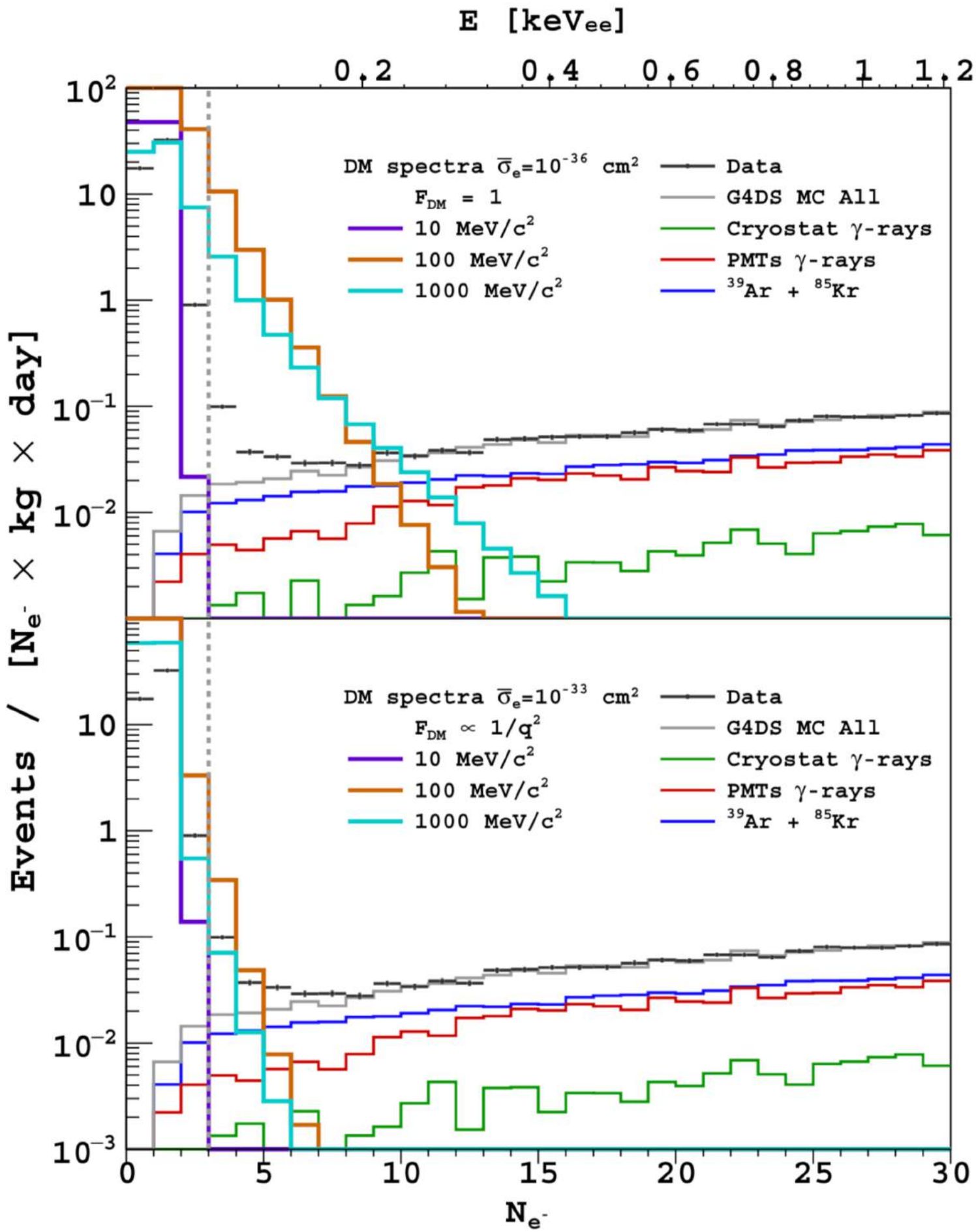

E [keVnr]
E [keVee]
DM spectra σχ=10-40 cm²
Mχ=2.5 GeV/c²
Mχ=5.0 GeV/c²
Mχ=10.0 GeV/c²
Data
G4DS MC All
Cryostat γ-rays
PMTs γ-rays
39Ar + 85Kr
Events / [Ne- × kg × day]
Events / [keVee × kg × day]
Events / [keVnr × kg × day]
Ne-

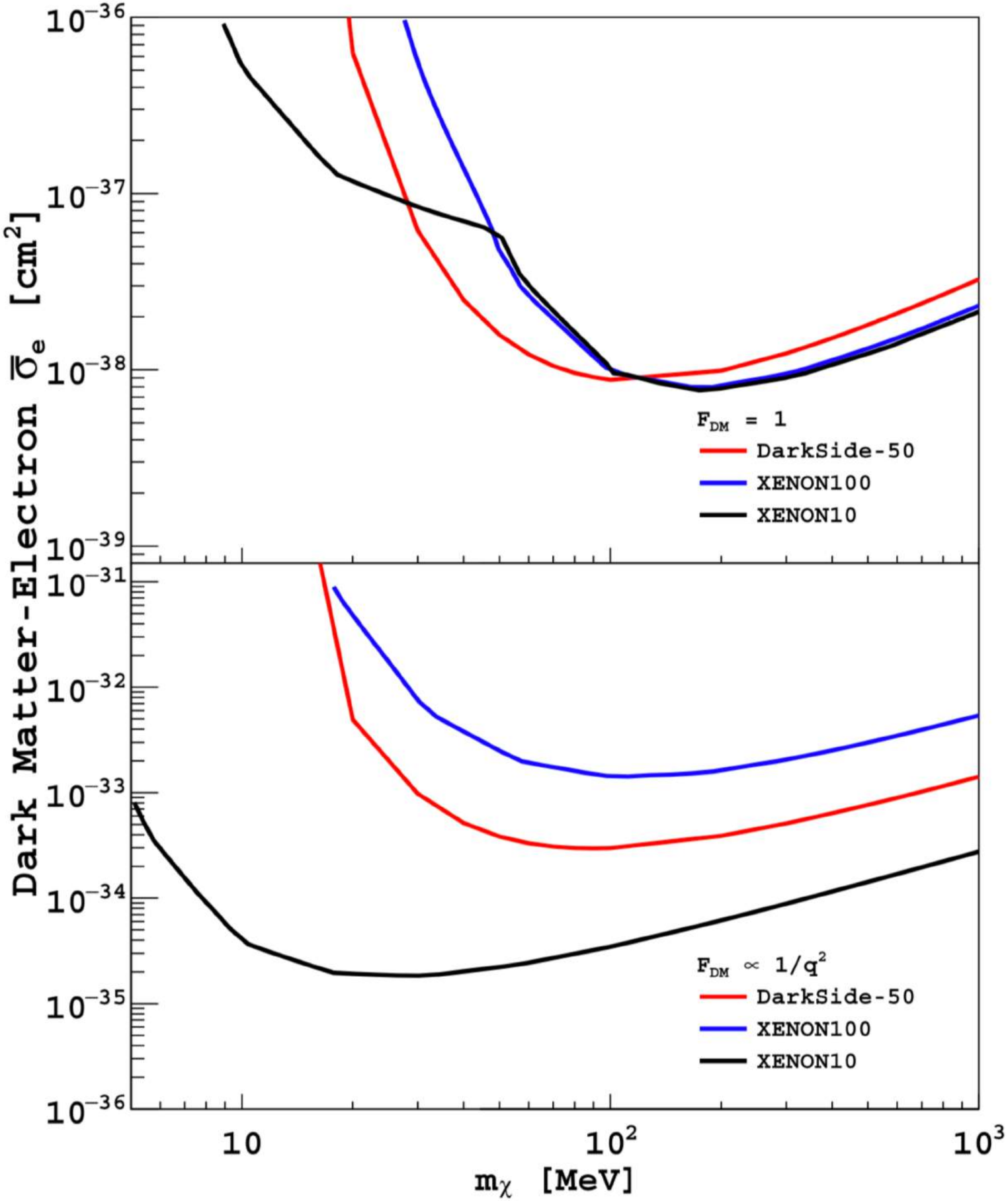

Dark Matter-Nucleon σ_{SI} [cm^2]
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
6×10^{-1}
1
2
3
4
5
6
7
8
9
10
M_χ [GeV/c^2]
DarkSide-50 2018
DarkSide-50 Binomial Fluctuation
DarkSide-50 No Quenching Fluctuation
NEWS-G 2018
LUX 2017
PICO-60 2017
CDMSLite 2017
EDELWEISS-III 2016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

DM-electron low-mass


dR/dlnE$_{er}$ [kg^{-1} × day^{-1}]
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1
10
10^{2}
10^{3}
E$_{er}$ [eV]
100 MeV
3s
3p
2p
1000 MeV
3s
3p
2p

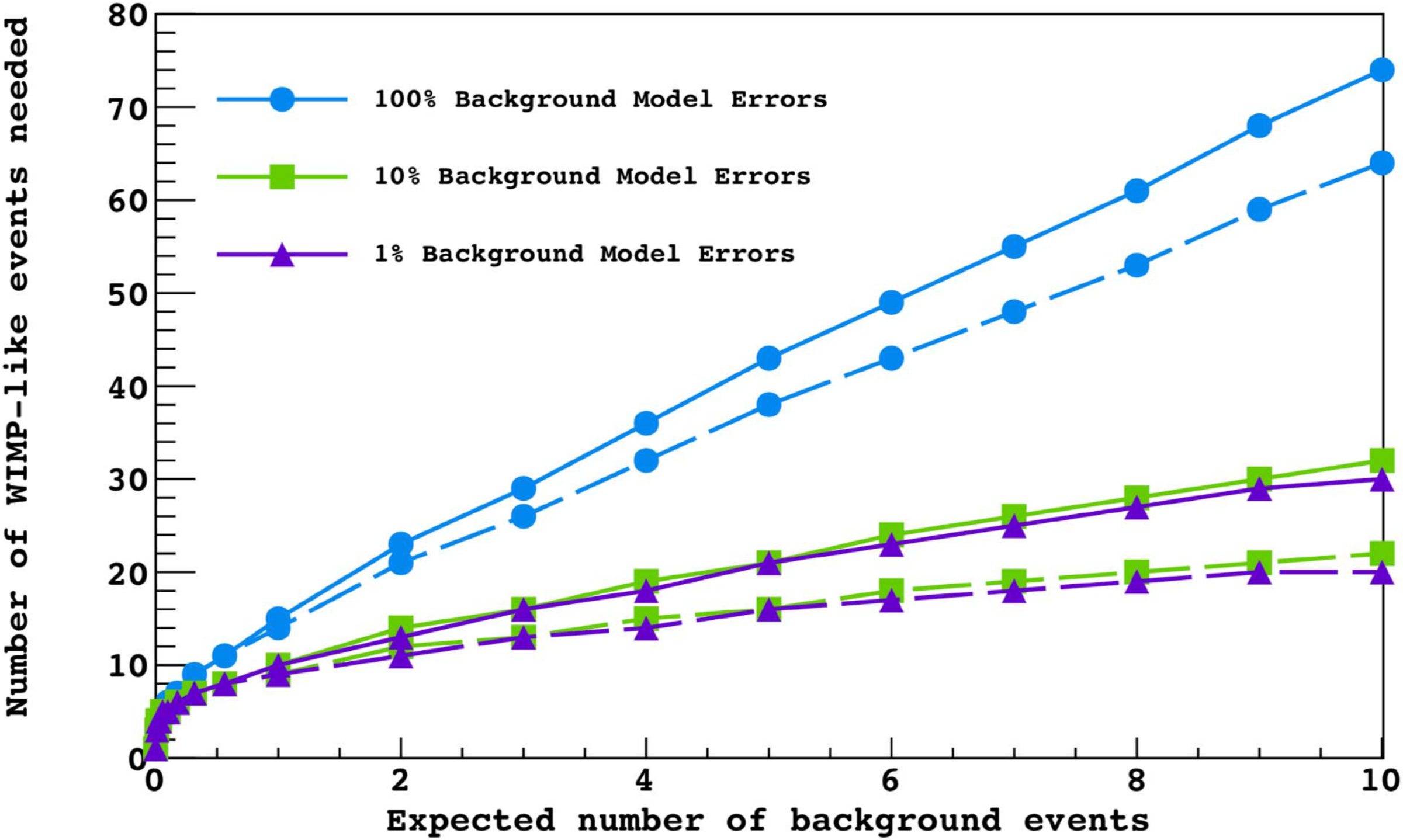

50
45
40
35
30
25
20
15
10
5
0
N_{e^-}
0
0.5
1
1.5
2
2.5
3
E_{er} [keV]


E [keVee]
0.2
0.4
0.6
0.8
1
1.2
DM spectra $\bar{\sigma}_e=10^{-36}$ cm²
F_{DM} = 1
10 MeV/c²
100 MeV/c²
1000 MeV/c²
Data
G4DS MC All
Cryostat γ-rays
PMTs γ-rays
^{39}Ar + ^{85}Kr
DM spectra $\bar{\sigma}_e=10^{-33}$ cm²
$F_{DM} \propto 1/q^2$
10 MeV/c²
100 MeV/c²
1000 MeV/c²
Data
G4DS MC All
Cryostat γ-rays
PMTs γ-rays
^{39}Ar + ^{85}Kr
Events / [Ne- × kg × day]
Ne-


Dark Matter-Electron $\bar{\sigma}_e$ [cm^2]
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
F_{DM} = 1
DarkSide-50
XENON100
XENON10
$F_{DM} \propto 1/q^2$
DarkSide-50
XENON100
XENON10
10
10^2
10^3
m_χ [MeV]

Search for high-mass DM: DarkSide-20k and beyond

The GADMC Collaboration

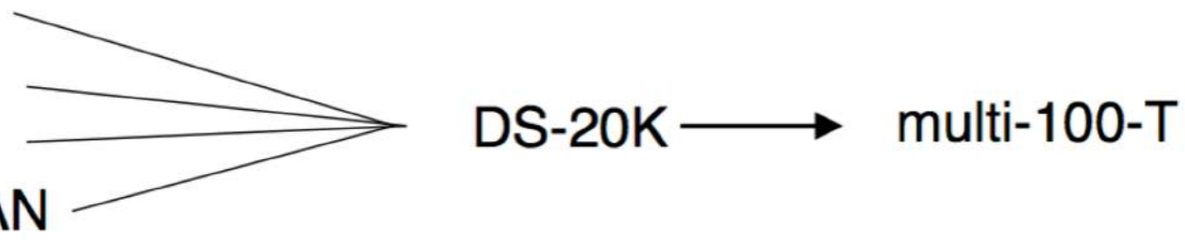

Number of WIMP-like events needed
80
70
60
50
40
30
20
10
0
100% Background Model Errors
10% Background Model Errors
1% Background Model Errors
0
2
4
6
8
10
Expected number of background events

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

(New) Argon Collaboration

Researchers from

- DarkSide
- DEAP
- ArDM
- MiniCLEAN



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)

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 extended operation). This detector will be competitive with next generation liquid xenon dark matter searches at high WIMPs masses and will be built in time to start data taking by 2021.

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

To whom it may concern;

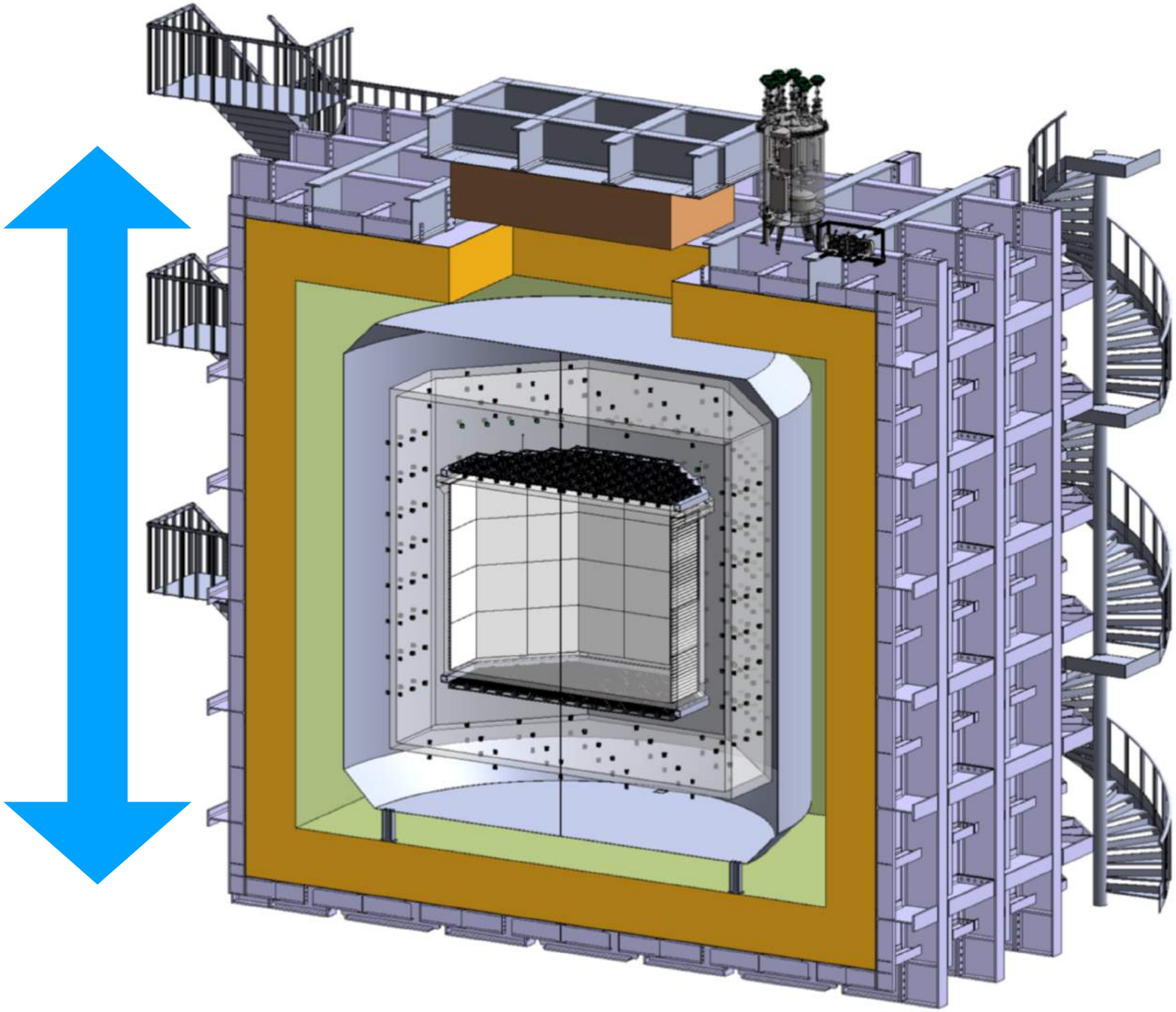
As hosts of the existing operational liquid argon direct dark matter detectors, and as proponents and supporters of the Underground-GRI initiative, the LNGS, SNOLAB and LSC deep underground research facilities are pleased to recognize the collaborative developments within the global liquid argon dark 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, the three deep underground research facilities will support the activities and development of the various generations of liquid argon detectors.

No liquid scintillator allowed anymore in LNGS:

how to do the experiment?

How to reach <0.1n/100ty?

NEW CONCEPTUAL DESIGN

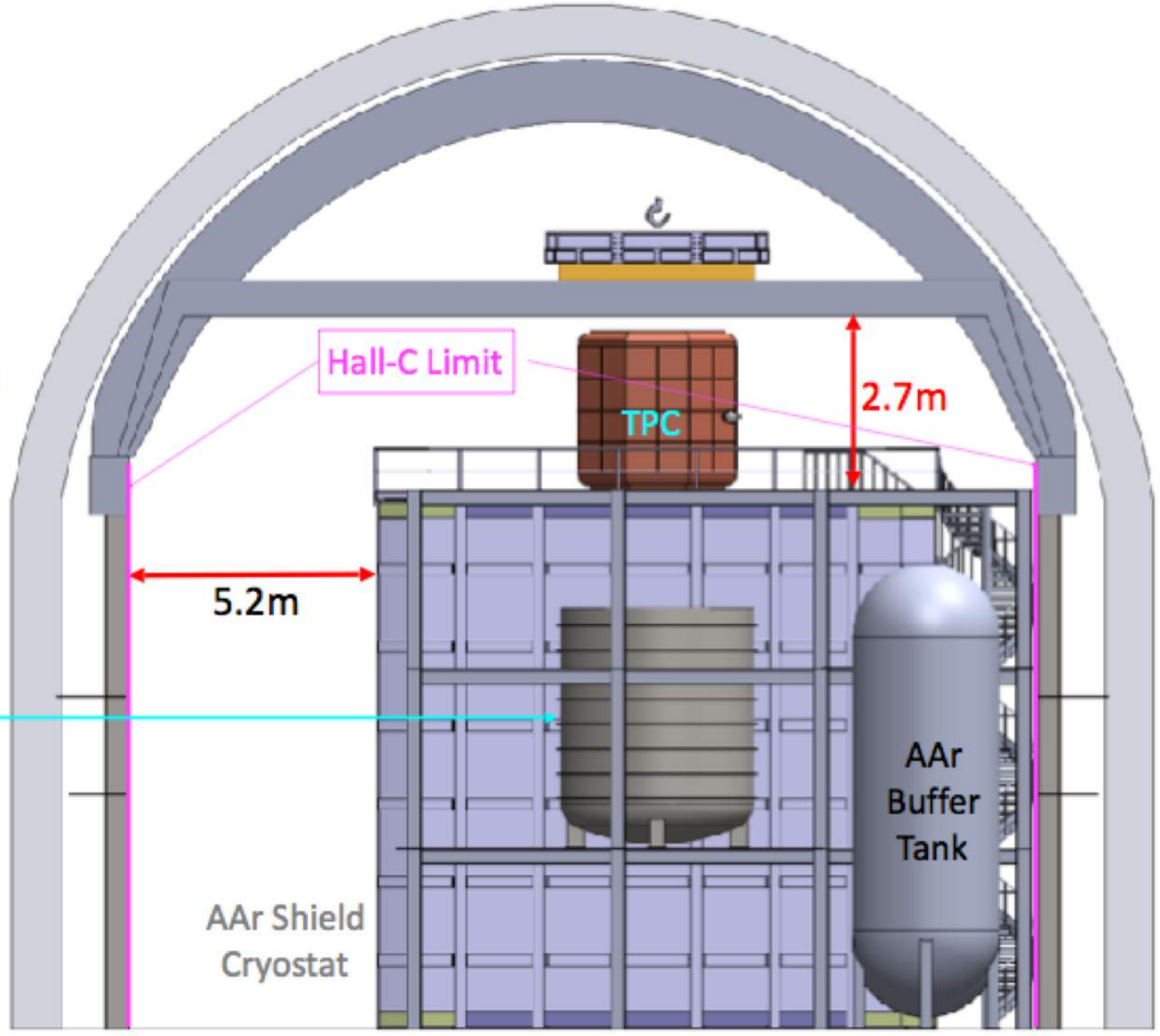


Allows a straightforward scale-up to the 300t detector

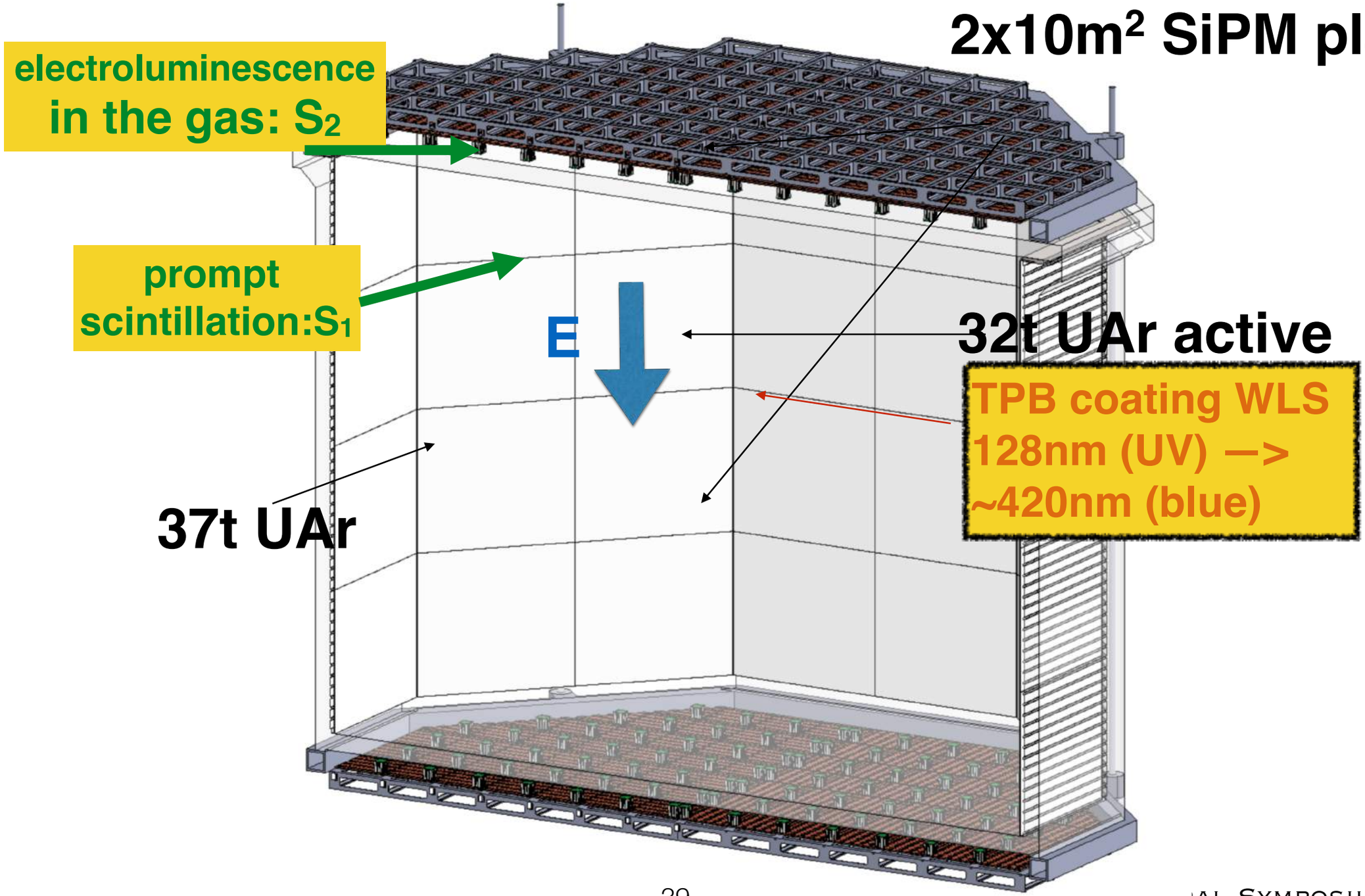
DarkSide-20k Inner Detector include TPC and UAr Cryogenics System

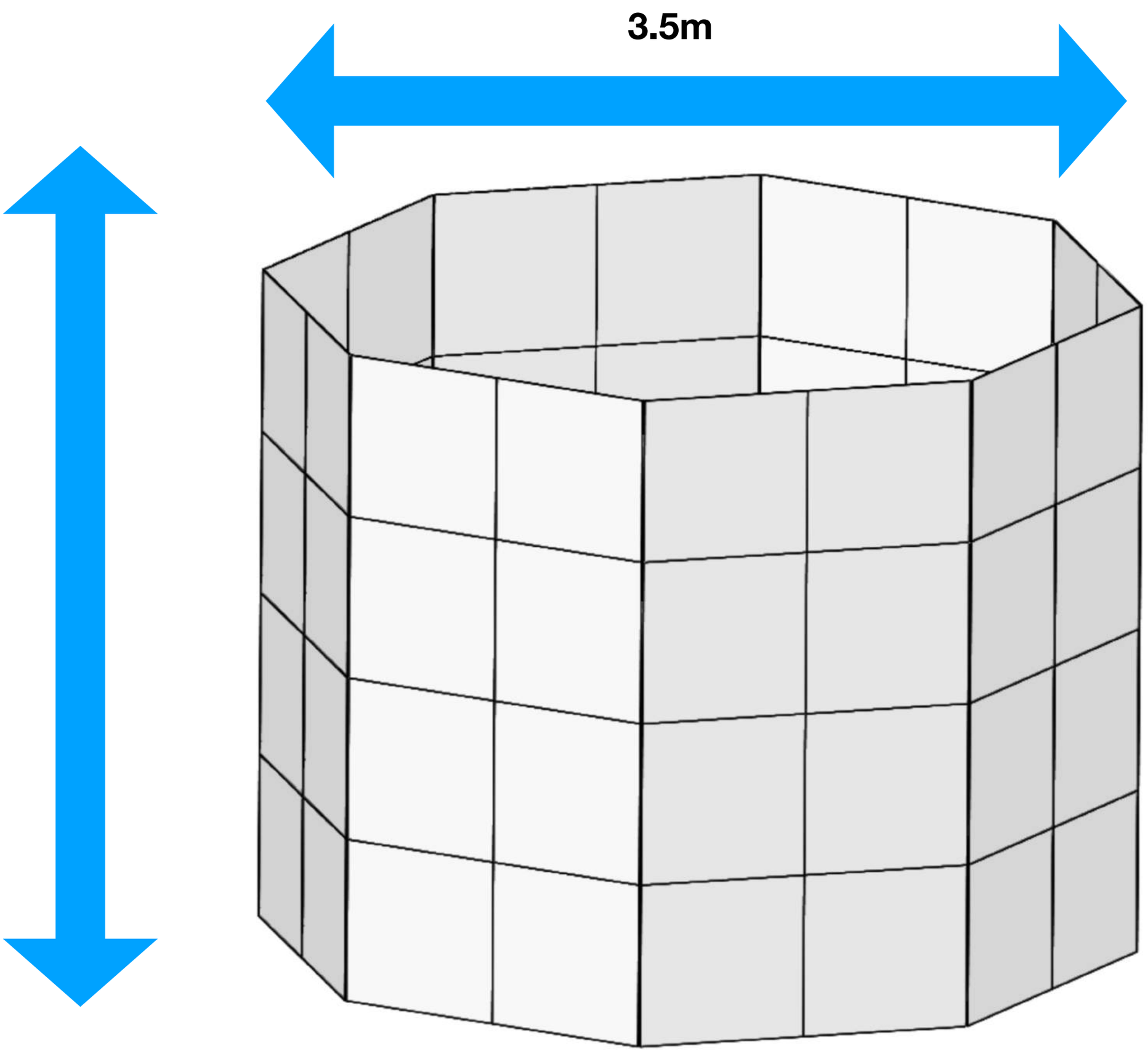
Relative sizing of the DarkSide-20k system in Hall-C

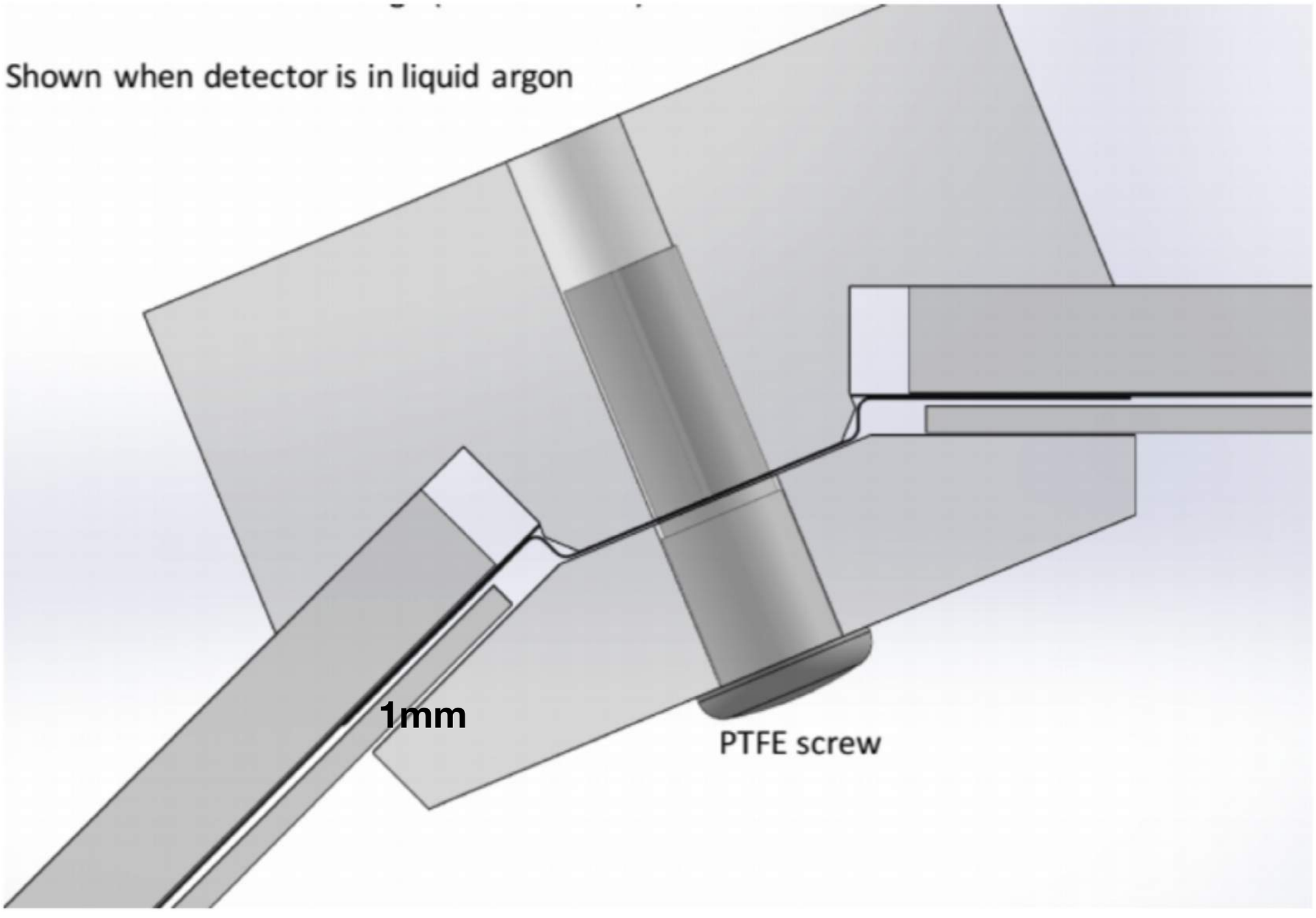
Temporary TPC Test Dewar



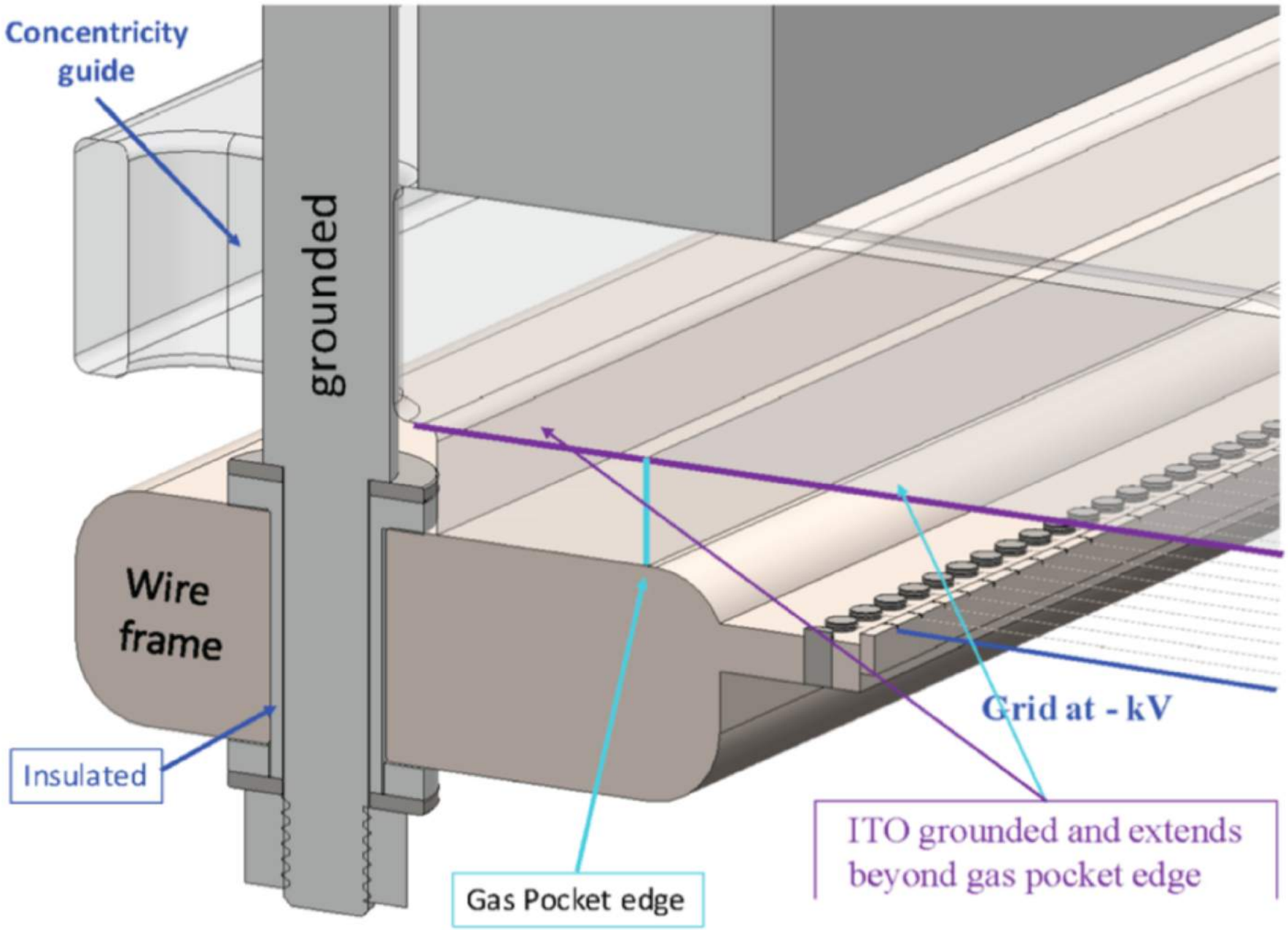
The DarkSide-20k TPC



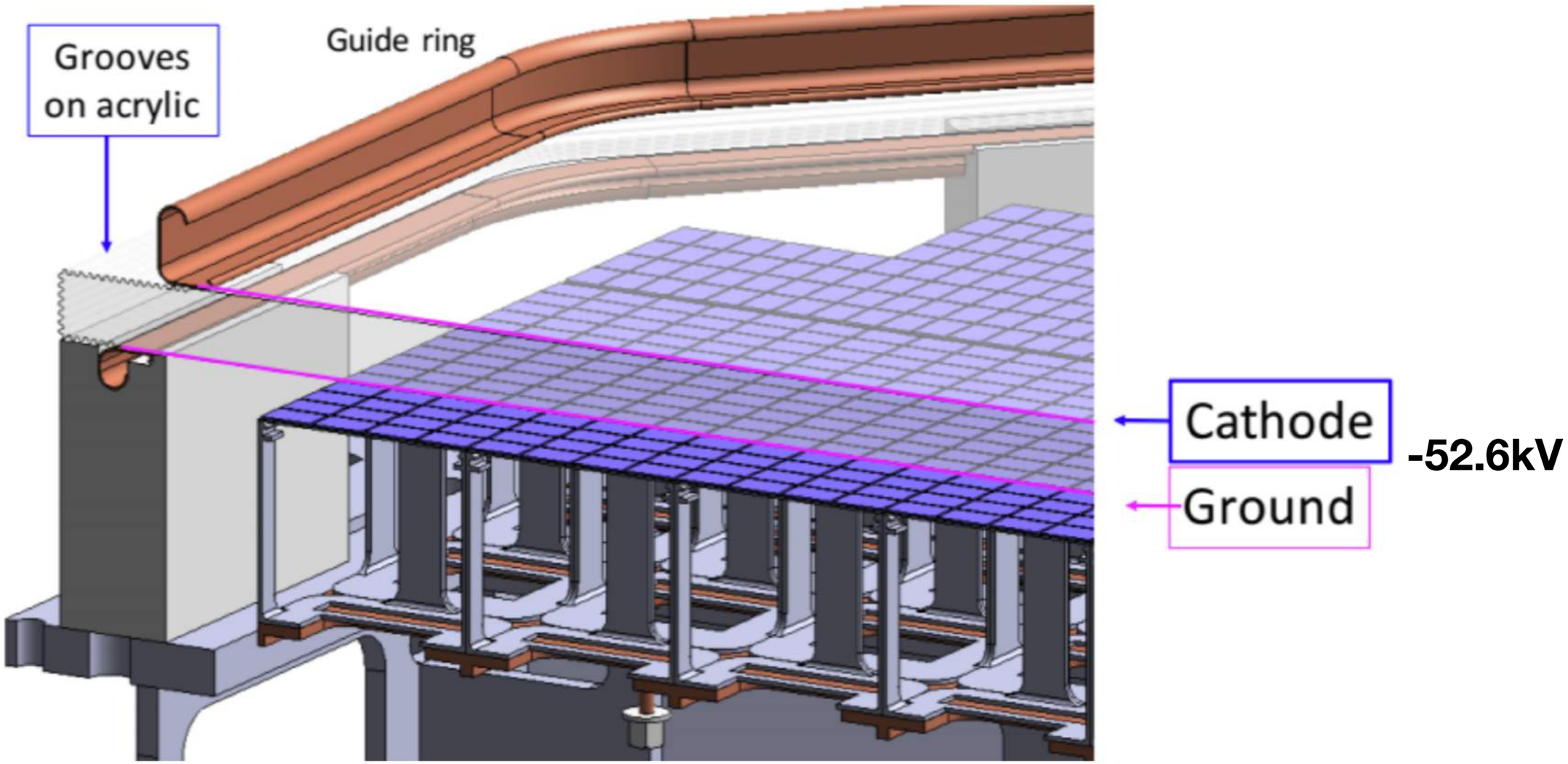

3.5m
2.6m

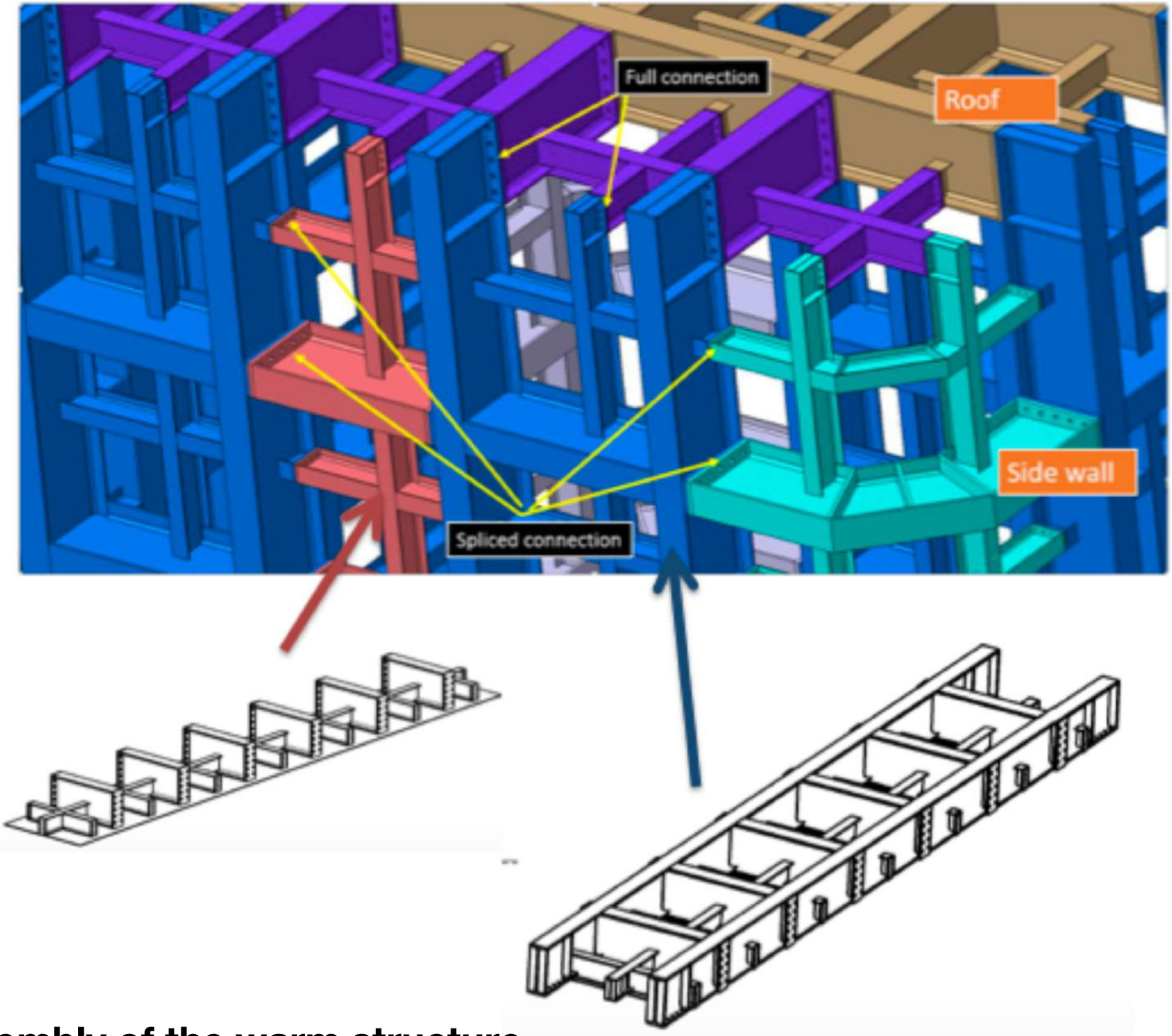


ESR 65um

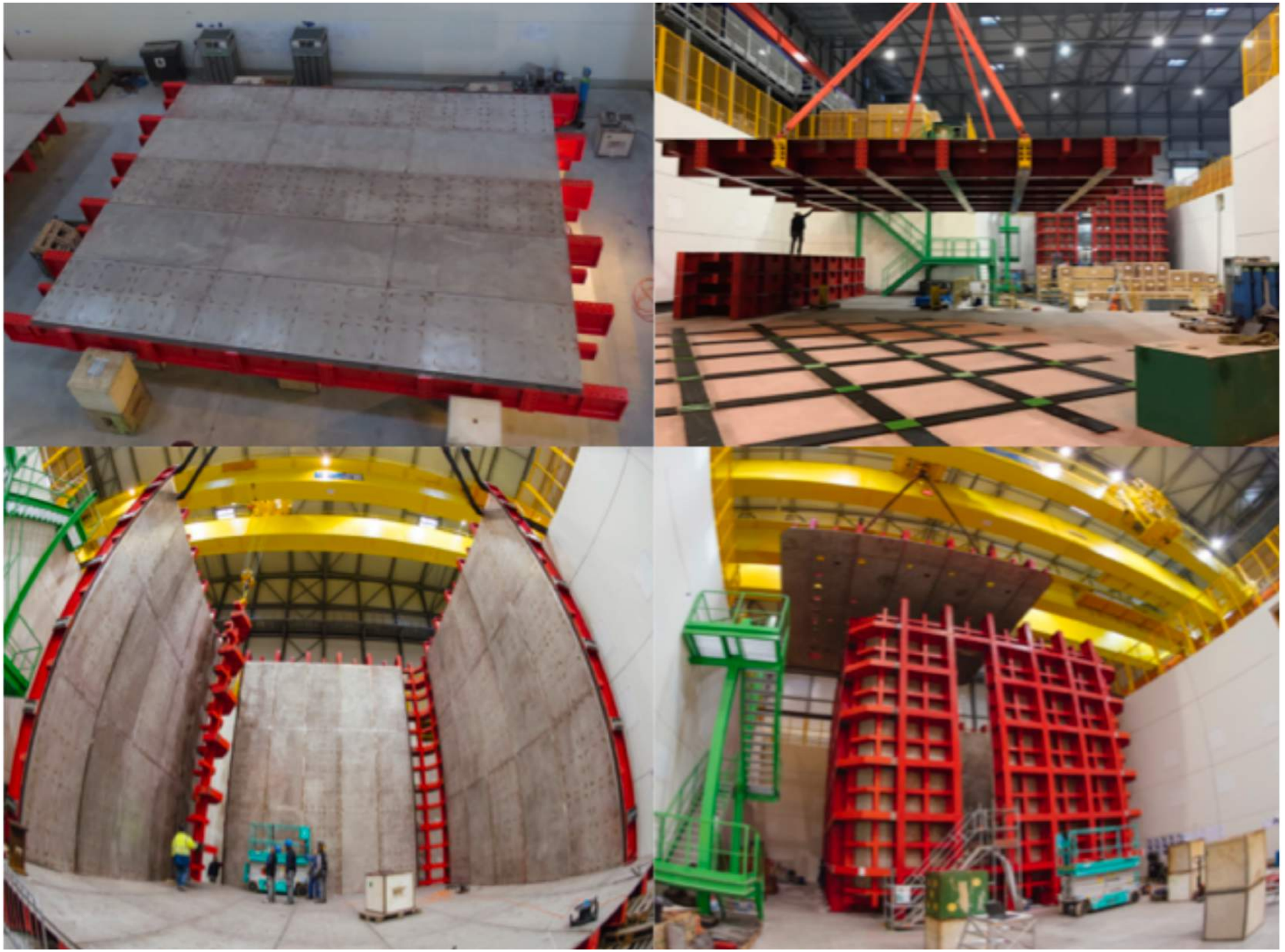

Concentricity guide
grounded
Wire frame
Insulated
Gas Pocket edge
Grid at - kV
ITO grounded and extends beyond gas pocket edge

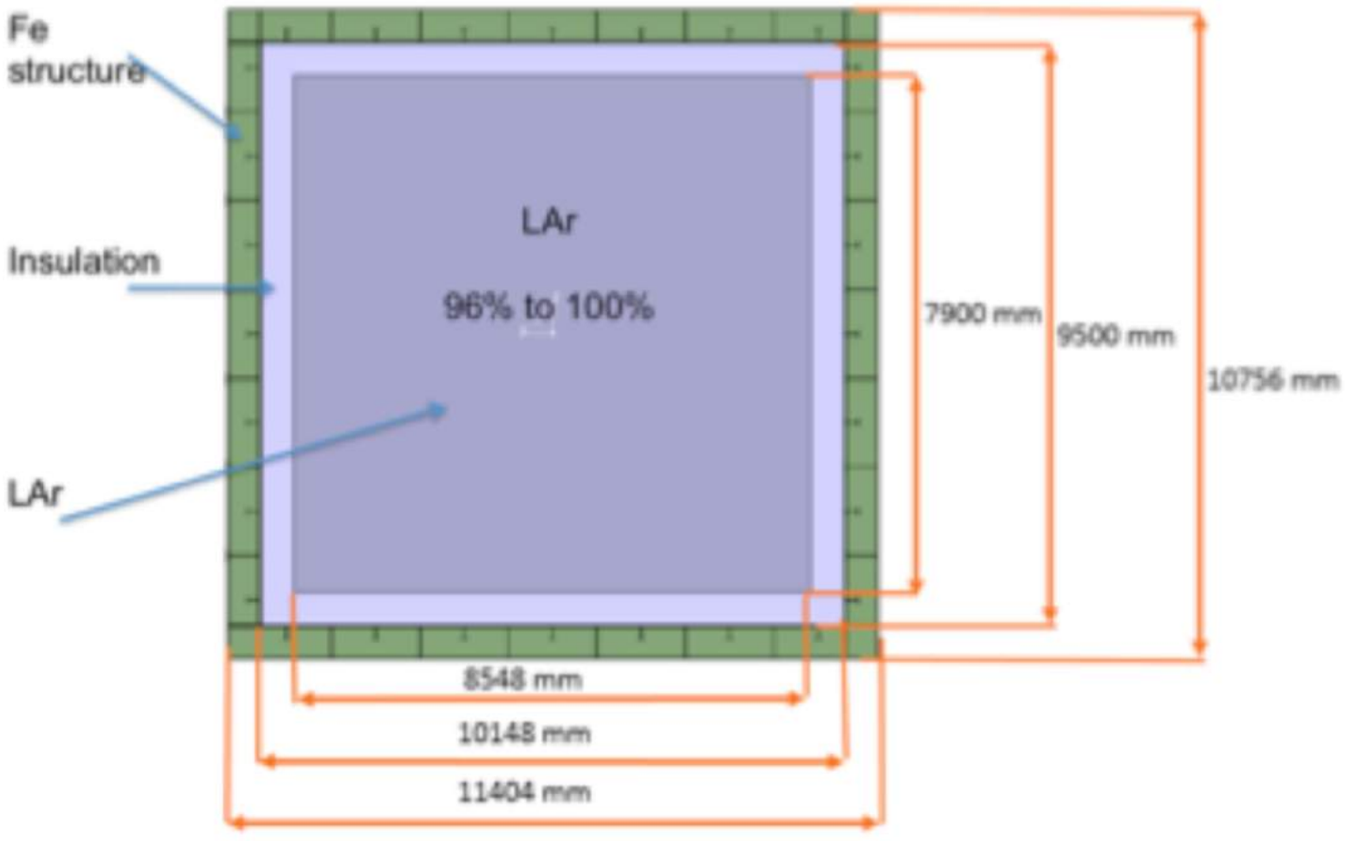
ITO + TPB

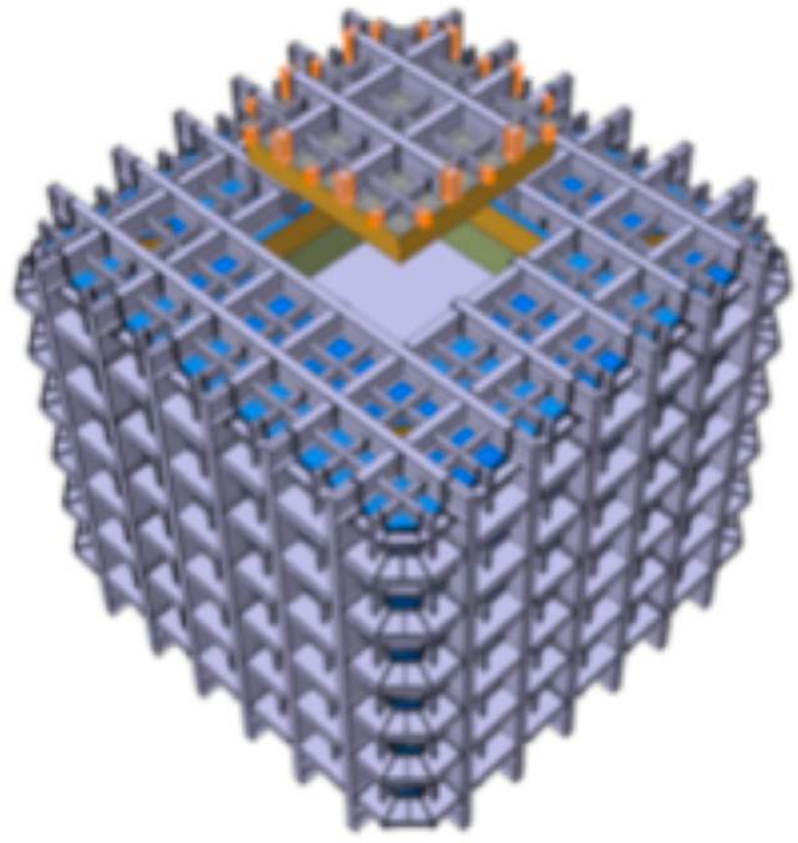

Grooves
on acrylic
Guide ring
Cathode
-52.6kV
Ground



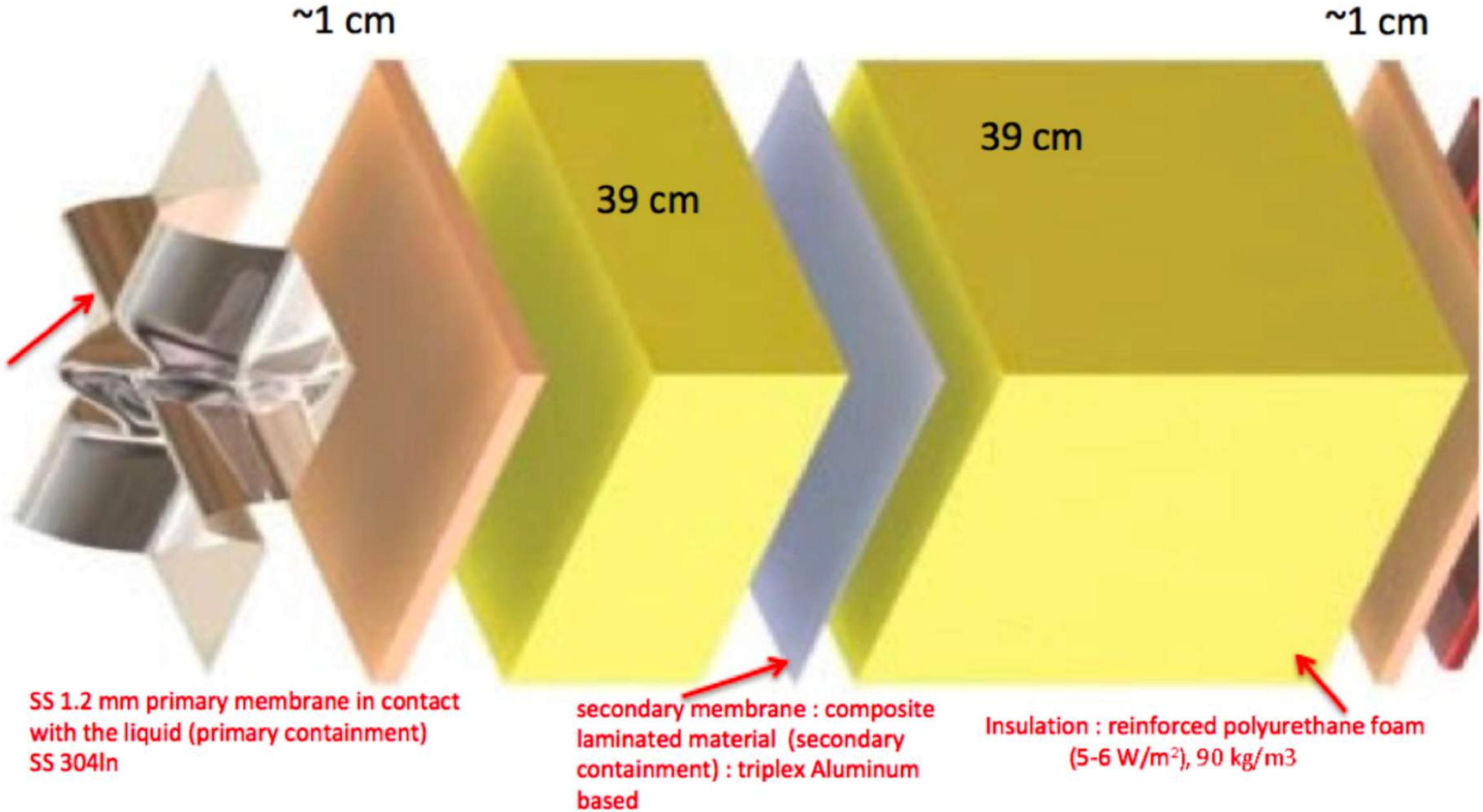
Assembly of the warm structure




Fe
structure
Insulation
LAr
LAr
96% to 100%
7900 mm
9500 mm
10756 mm
8548 mm
10148 mm
11404 mm

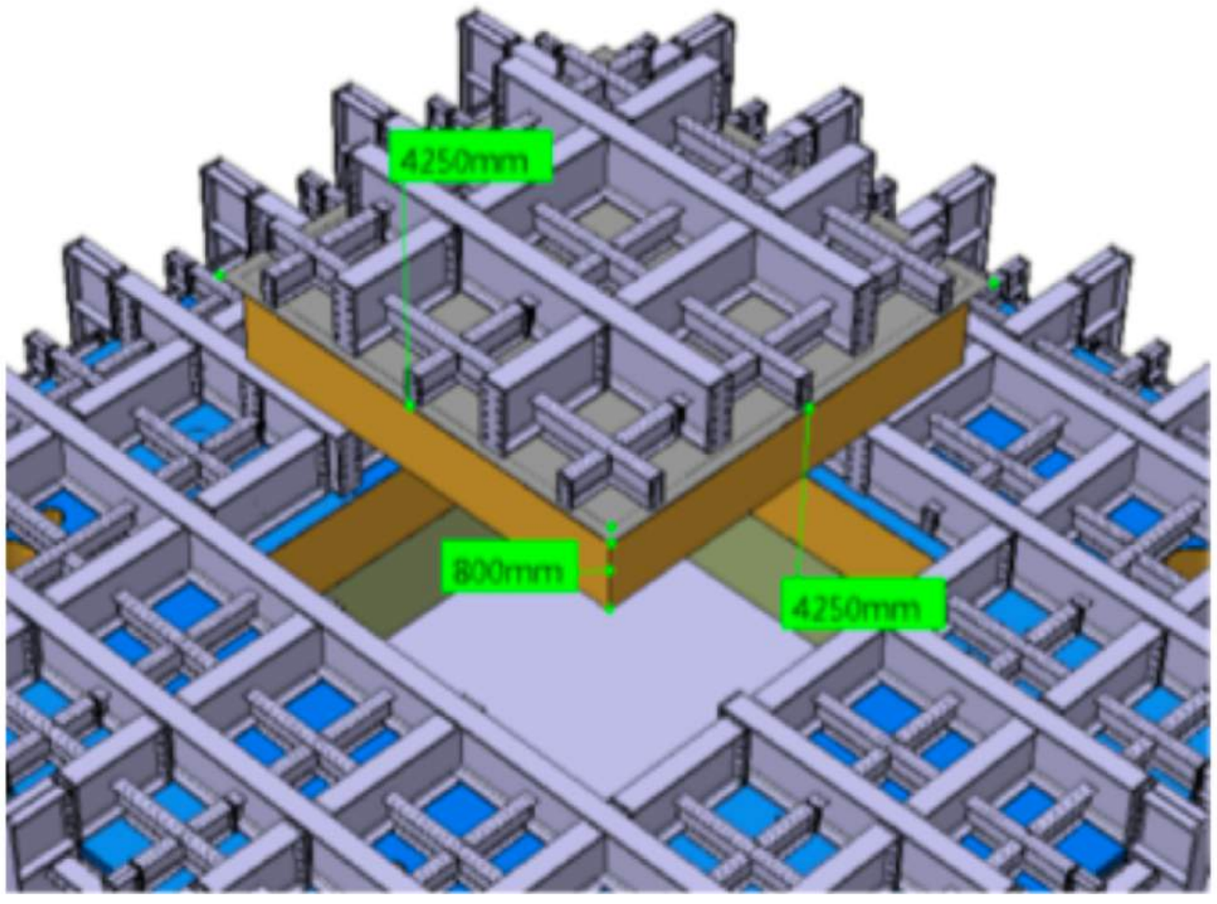


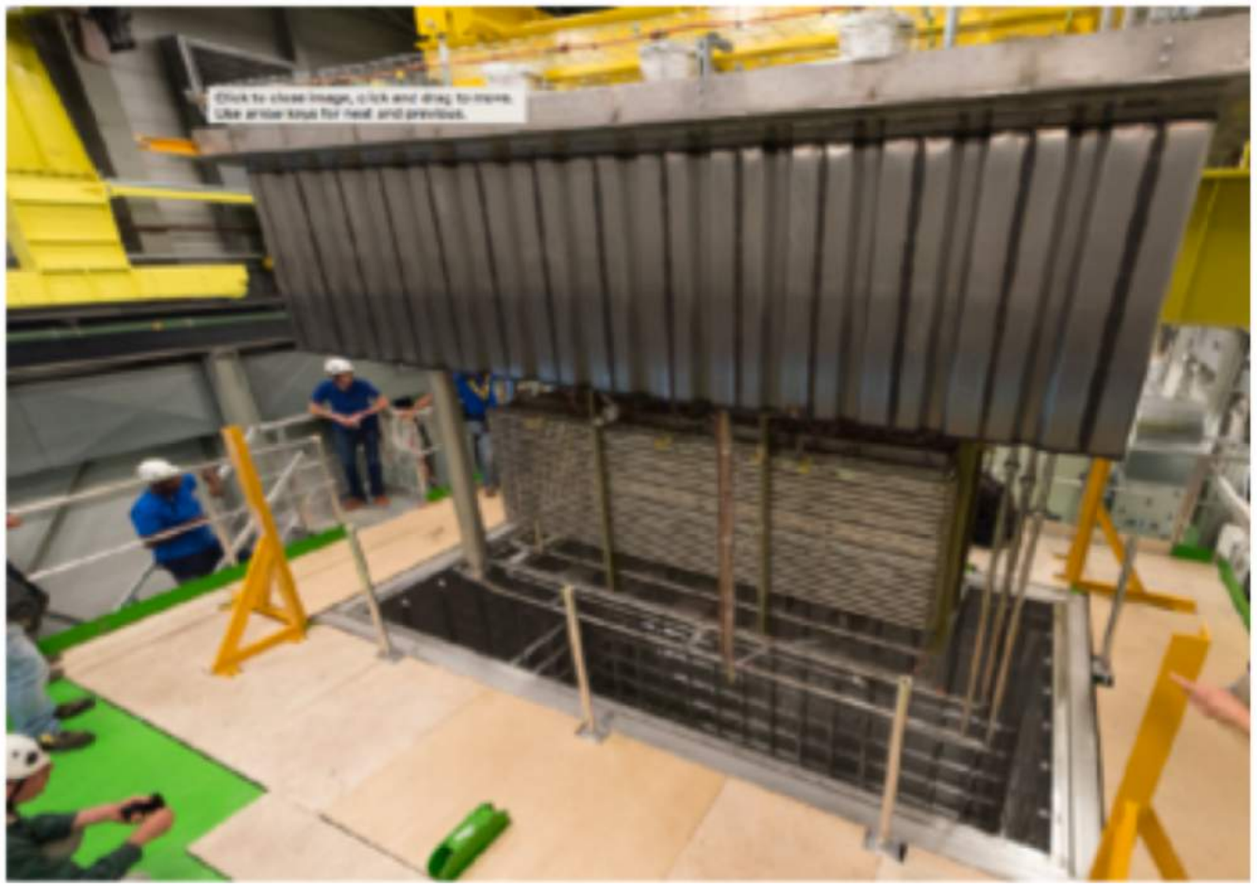
GTT technology – Collaboration agreement with CERN

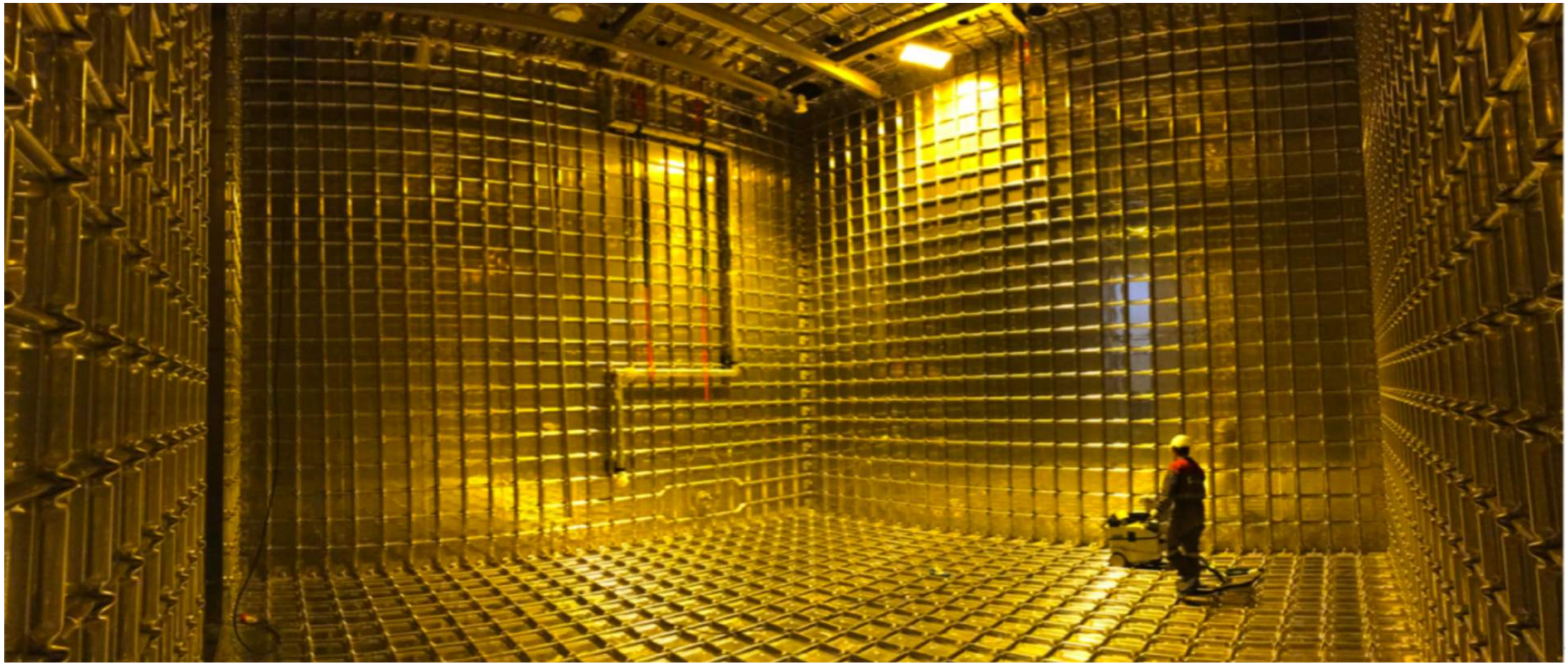


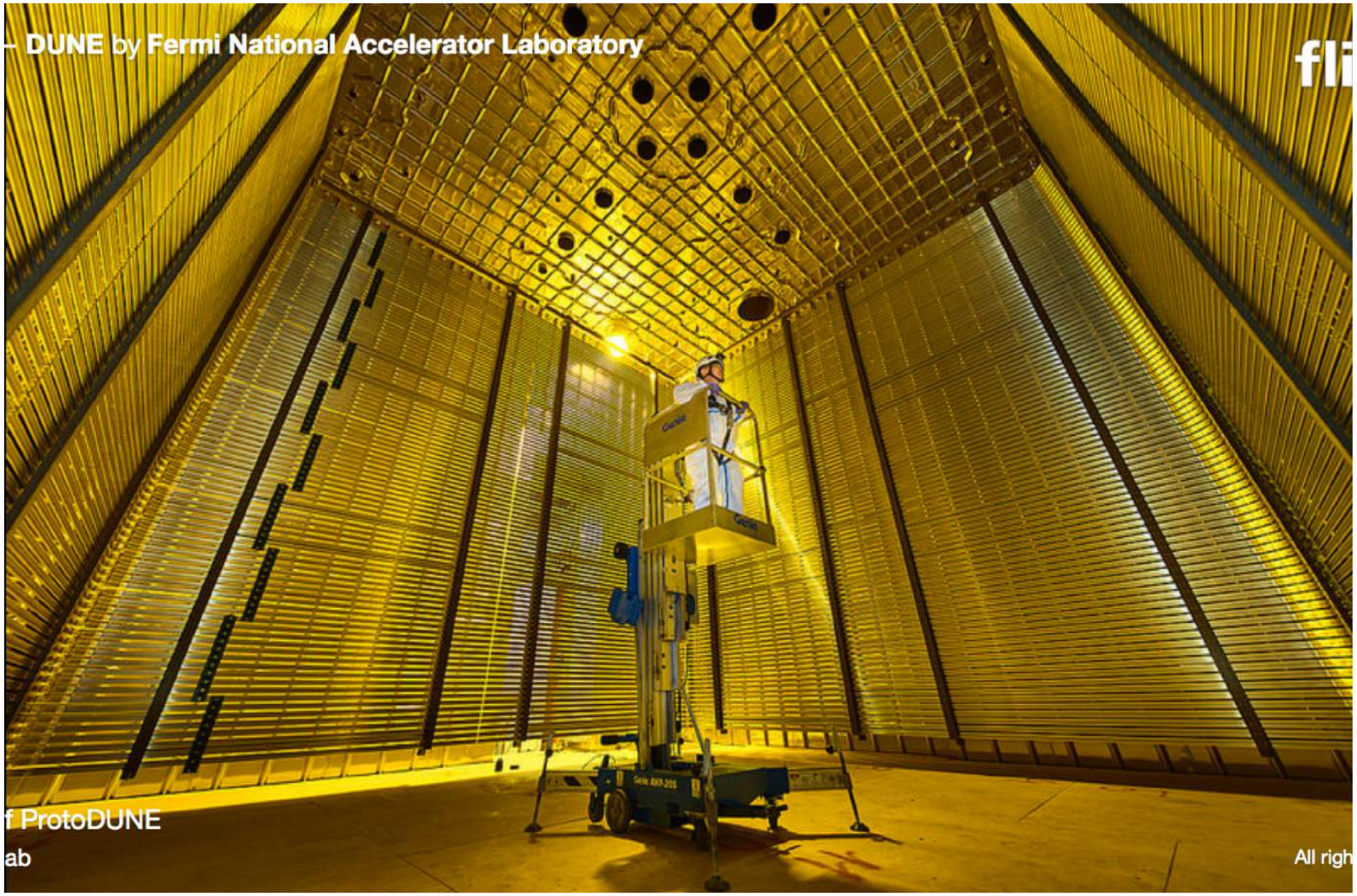
Foam and corrugated membrane produced in South Korea

<6.3W/m2


4250mm
800mm
4250mm






DUNE by Fermi National Accelerator Laboratory
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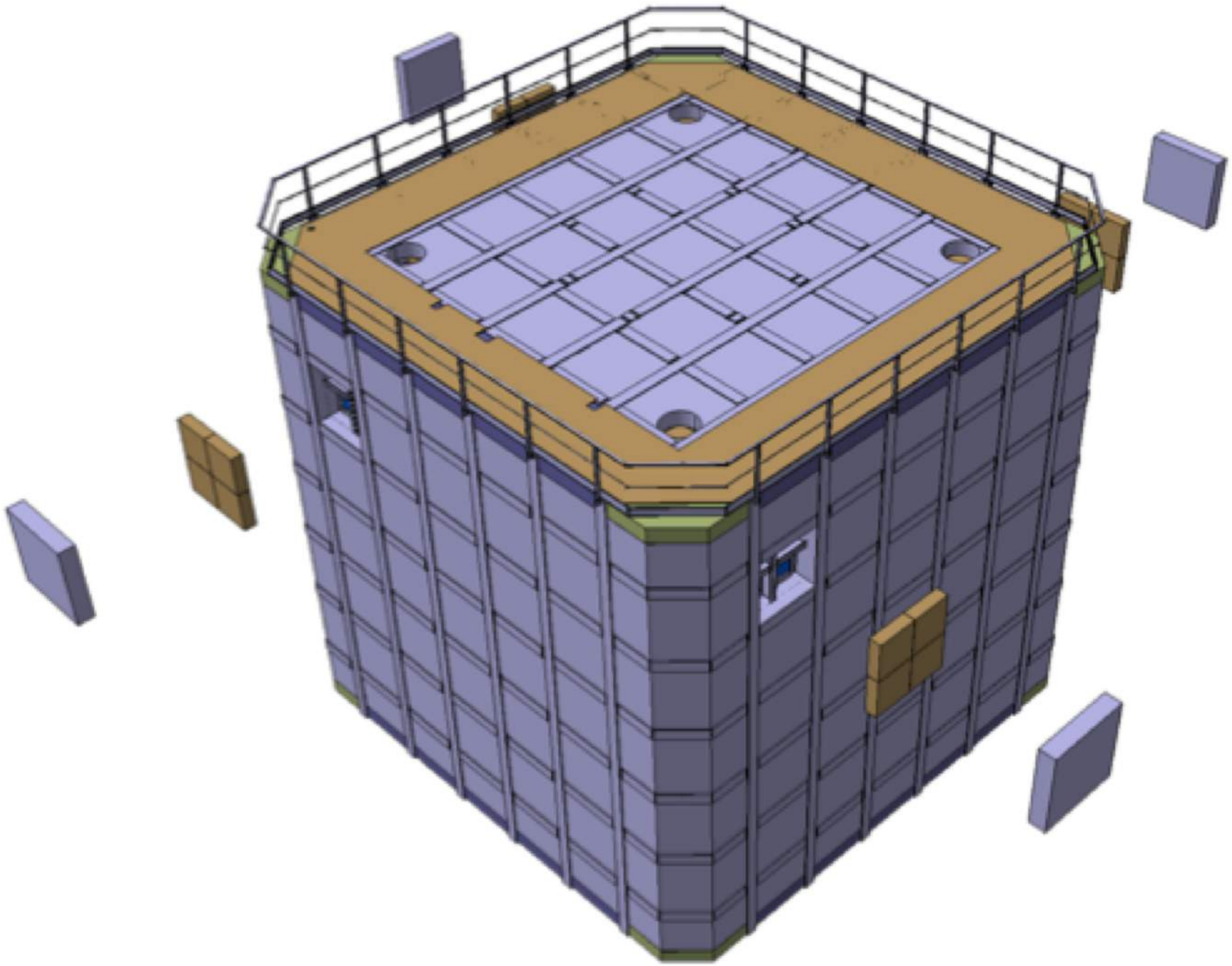


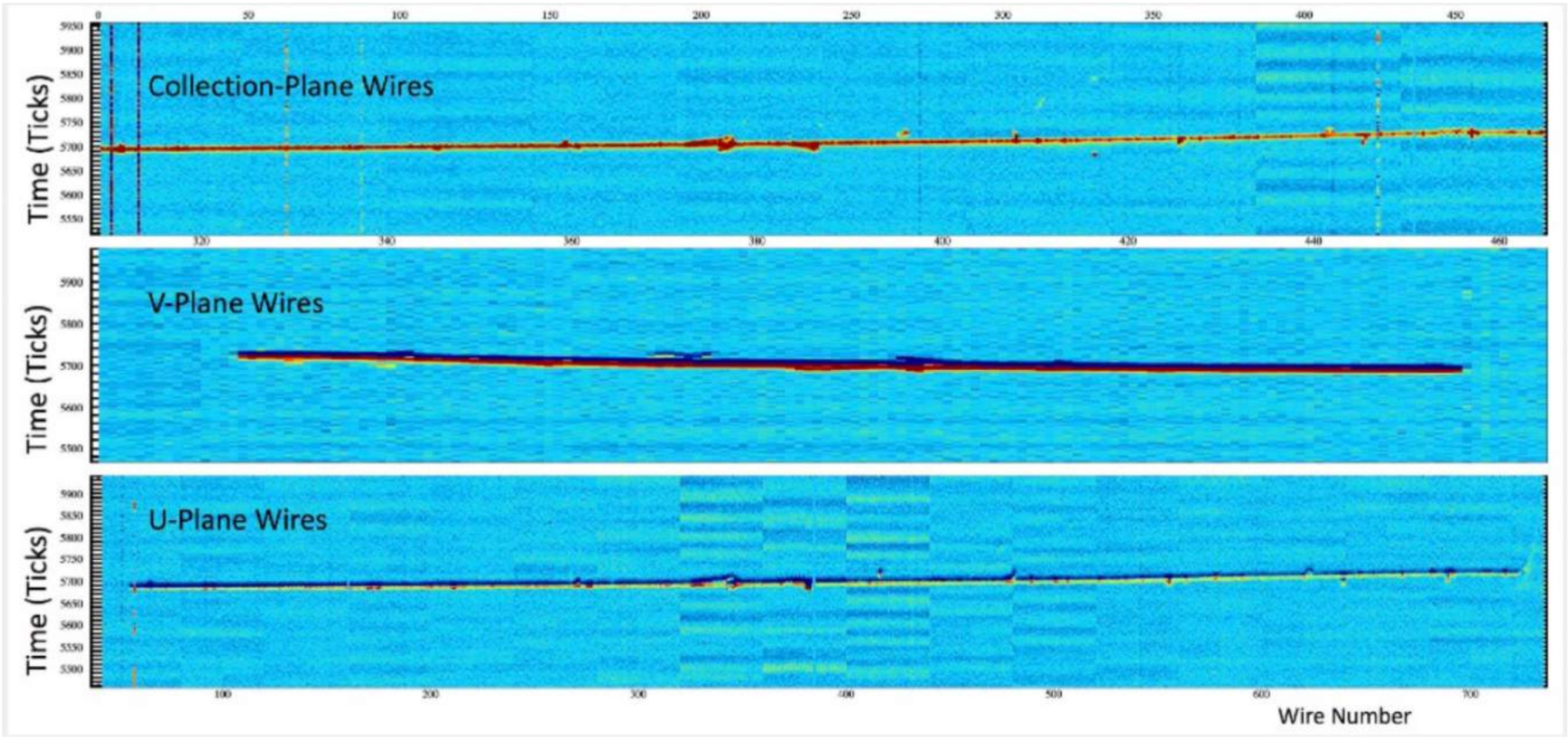
INTERACTIONS.ORG
PARTICLE PHYSICS NEWS AND RESOURCES

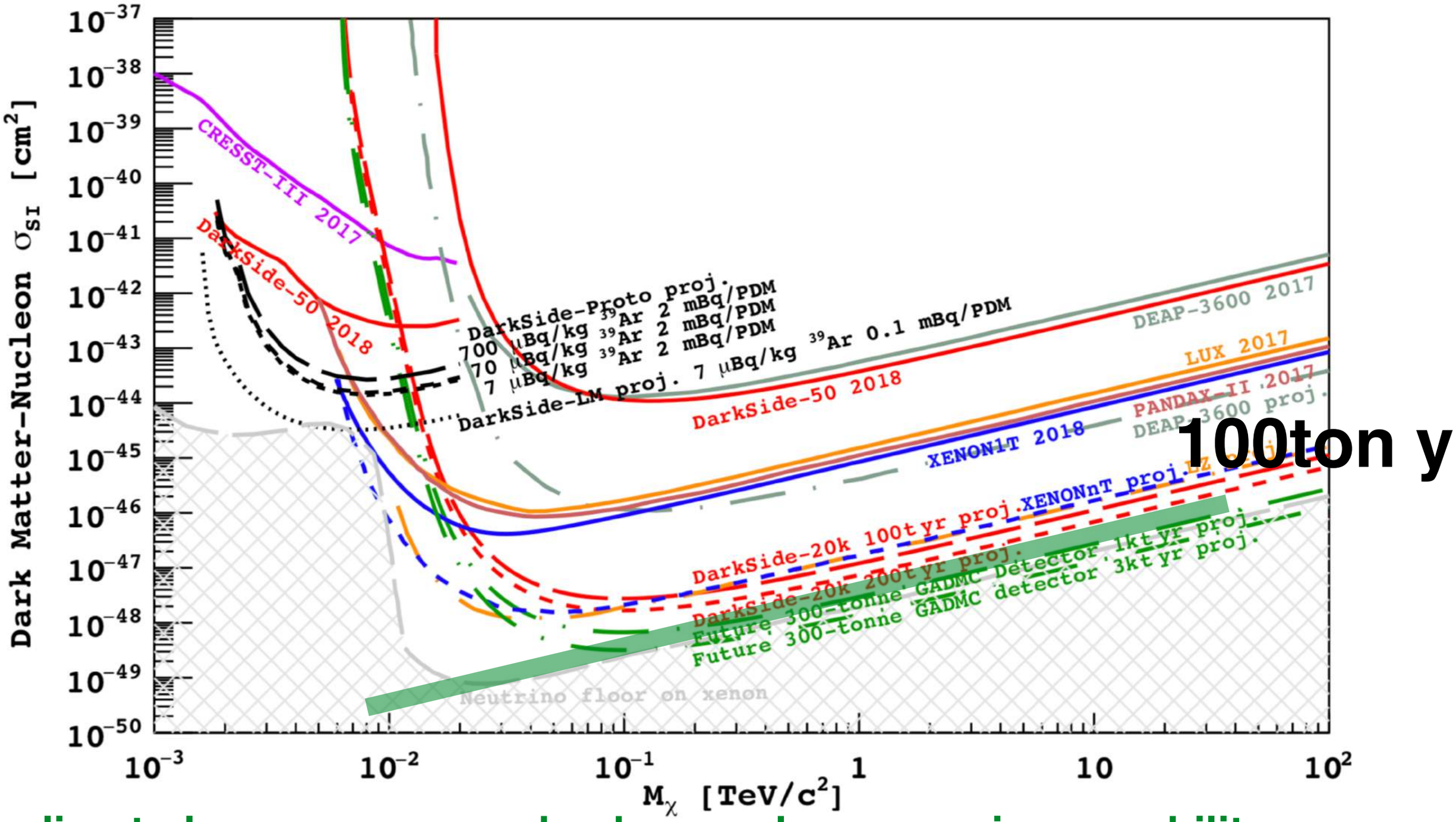
First particle tracks seen in prototype for international neutrino experiment

DATE ISSUED
September 18th, 2018

SOURCE
CERN

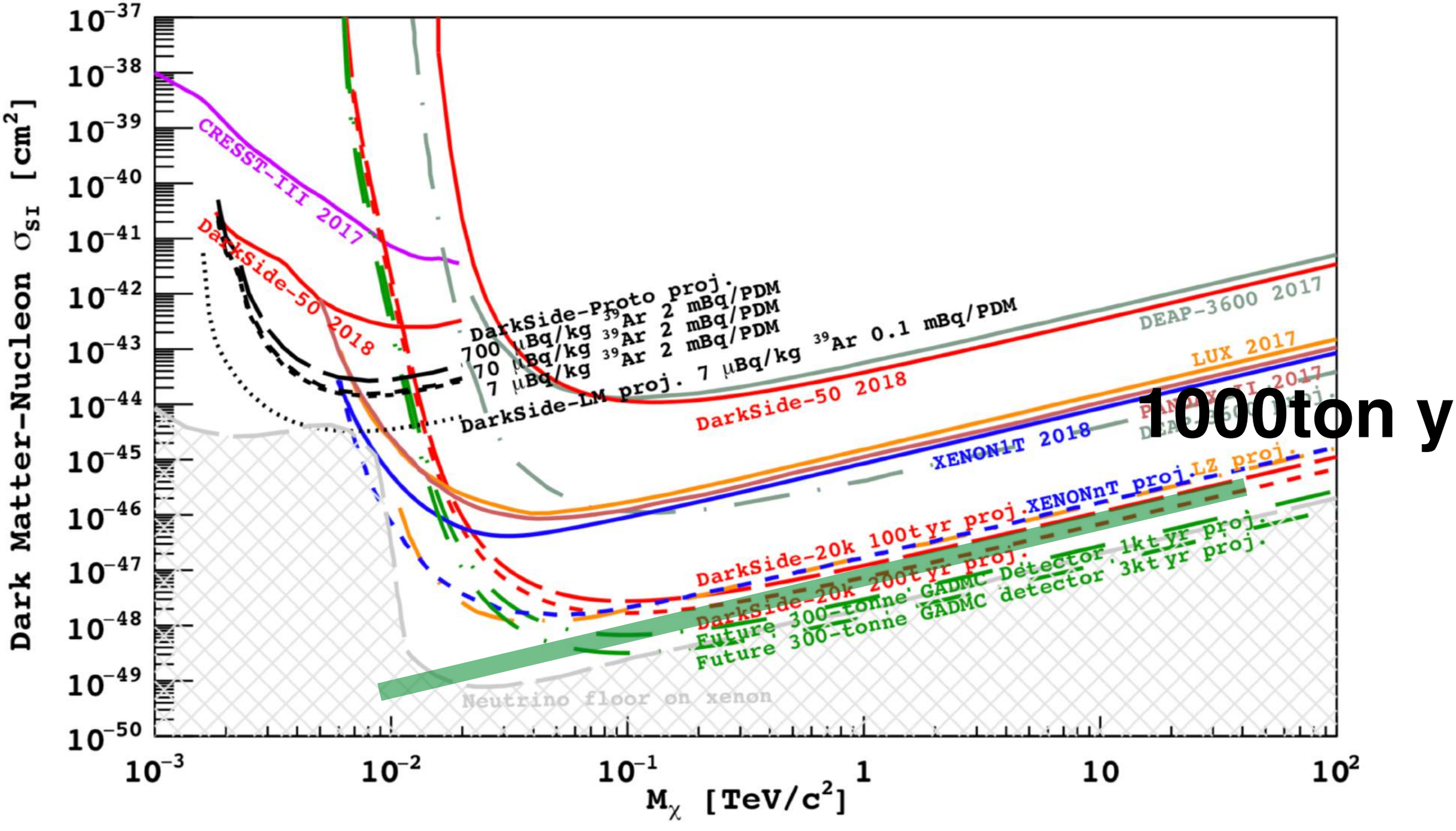
CERN and Fermilab announce big step in Deep Underground Neutrino Experiment


Collection-Plane Wires
V-Plane Wires
U-Plane Wires
Time (Ticks)
Wire Number



100ton y

Scaling to large masses—> background suppression capability: argon is very well suited to this due to PulseShapeDiscrimination (PSD) capability


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]
CRESST-III 2017
DarkSide-50 2018
DarkSide-Proto proj.
700 μBq/kg ^{39}Ar 2 mBq/PDM
70 μBq/kg ^{39}Ar 2 mBq/PDM
7 μBq/kg ^{39}Ar 2 mBq/PDM
DarkSide-LM proj. 7 μBq/kg ^{39}Ar 0.1 mBq/PDM
DEAP-3600 2017
LUX 2017
PANDAX-II 2017
XENON1T 2018
DarkSide-20k 100t yr proj.
XENONnT proj.
LZ proj.
DarkSide-20k 200t yr proj.
Future 300-tonne GADMC Detector 1kt yr proj.
Future 300-tonne GADMC detector 3kt yr proj.
Neutrino floor on xenon

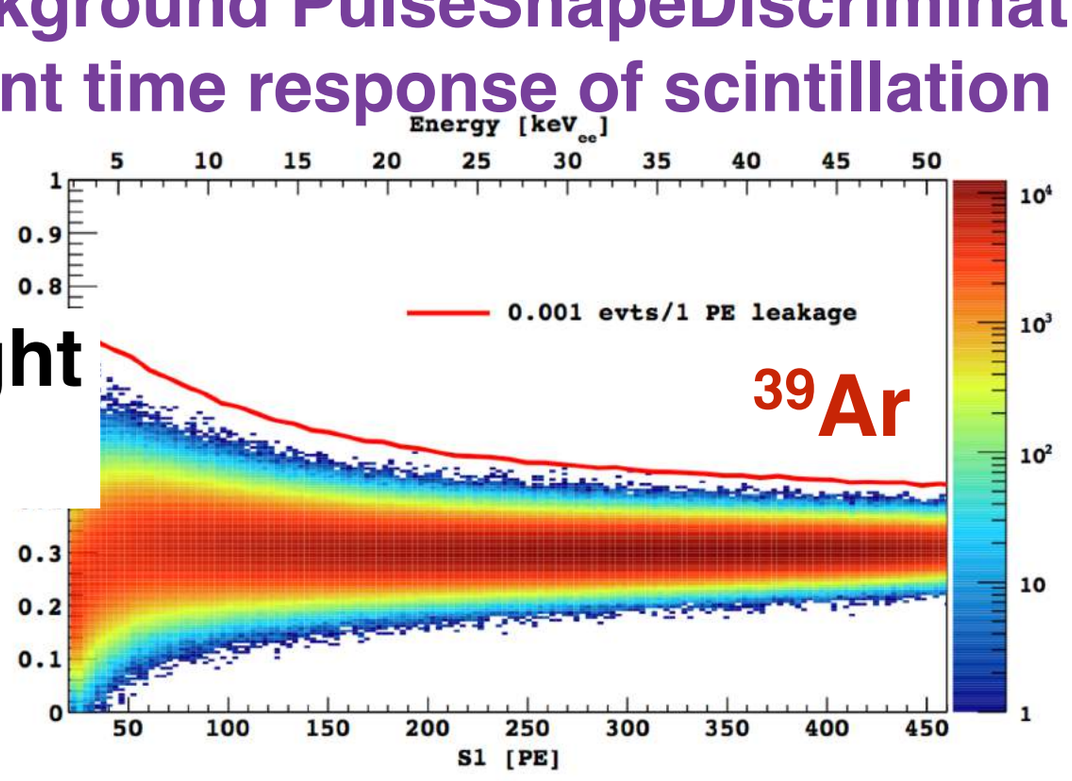
1000ton y

Backgrounds to DM search: e- recoils and nuclear recoils

For Ar detectors the dominant e- recoil background is due to the cosmogenic ^{39}Ar, with atmospheric or natural Ar having a radioactivity of 1Bq/Kg

To reject e- background PulseShapeDiscrimination (PSD) is used based on different time response of scintillation to e- and nuclear recoils

fraction of S1 light in 200ns



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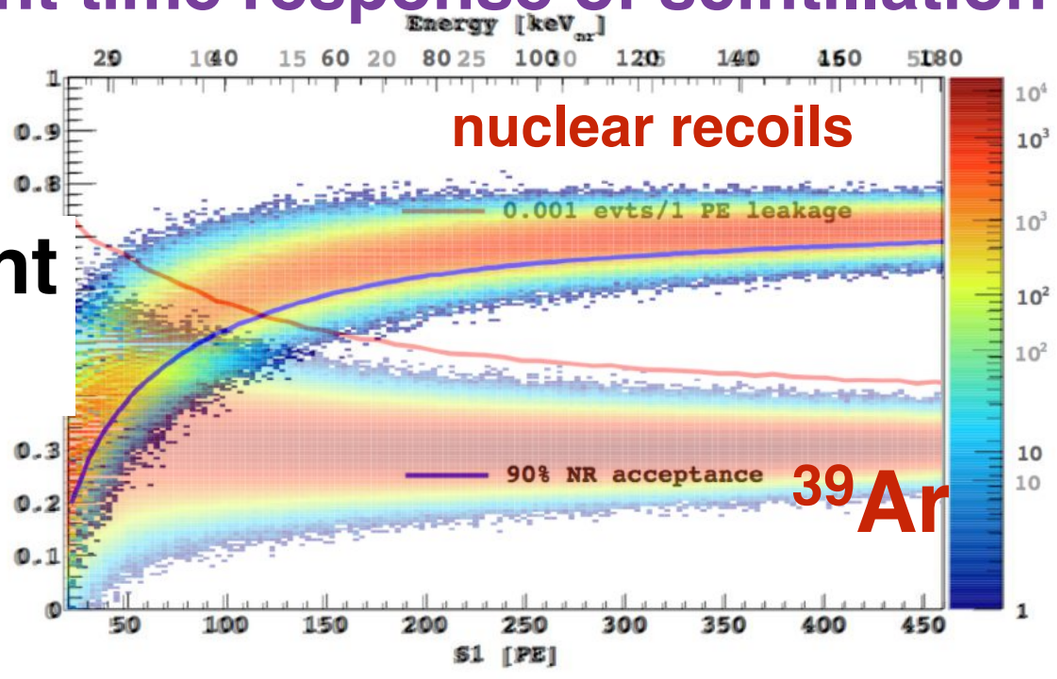


DarkSide-20k 10p.e./KeV

Two crucial technologies

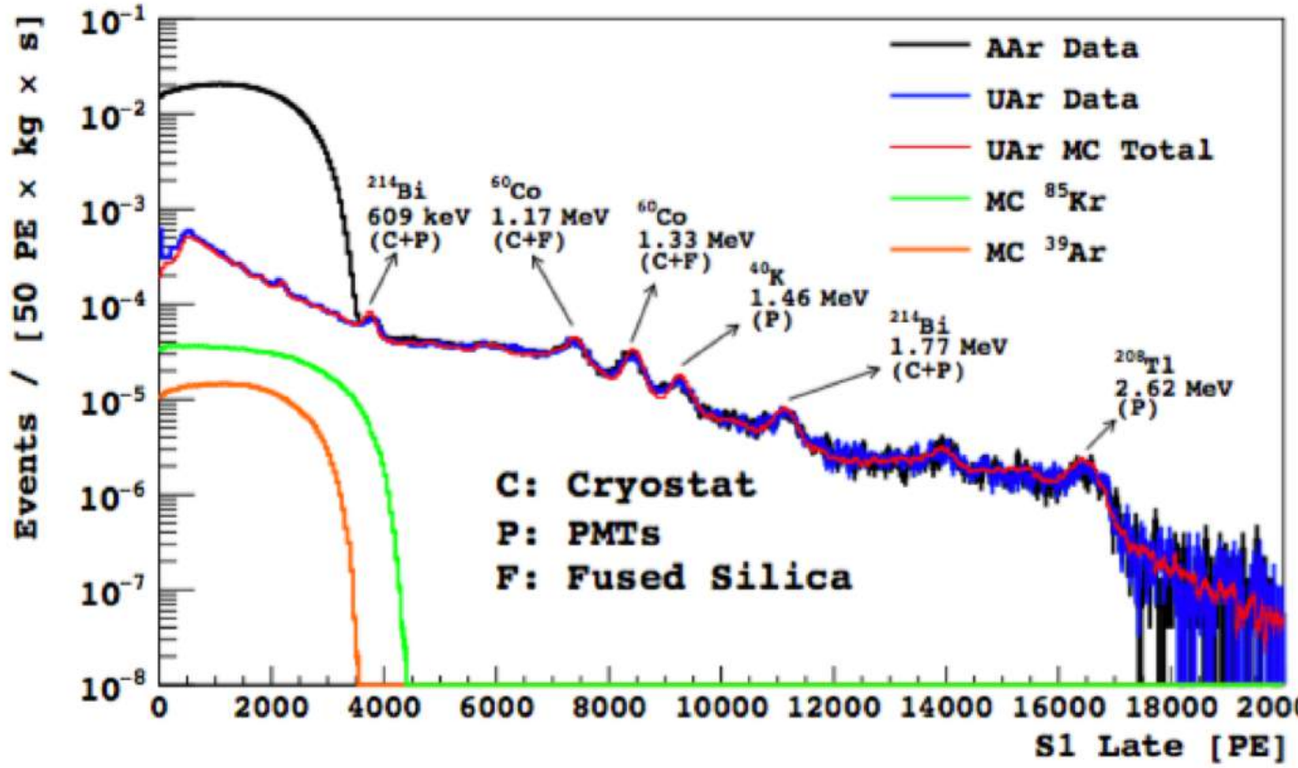
Liquid argon target depleted in the radioactive ^{39}Ar , with respect to the 1Bq/Kg of the atmospheric argon (AAr)

—> allows to keep PSD thresholds low

—> mandatory to <u>reduce pile-up</u> for dual phase argon detectors above the few 100Kg,

Cryogenic SiPMs replacing PMTs

—> higher light yield (#PE/KeV), essential to keep PSD threshold low, low cost for large areas, very low dark noise, very low radioactivity background (with radio-pure substrates), long term stability



For DarkSide-50, about 70Kg of underground argon (UAr) were extracted with a pilot plant

UAr vs AAr in DS-50: (0.73±0.11)x10^{-3}Bq/Kg vs 1Bq/Kg

The argon path

The Urania project@Kinder Morgan Doe Canyon Facility, CORTEZ,CO (USA)

extraction of 50t of UAr from CO_2 deep wells where cosmic rays hardly make any ^{39}Ar

Starting from 95% CO2 and 440ppm of UAr!

New plant, funded, under tendering

The Aria project: includes regional funds from Sardinia, Italy

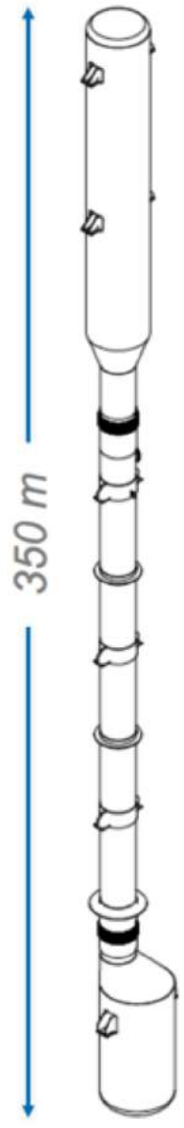
^{39}Ar isotopic separation with cryogenic distillation —> factor 10 suppression per pass (from UAr to DAr)

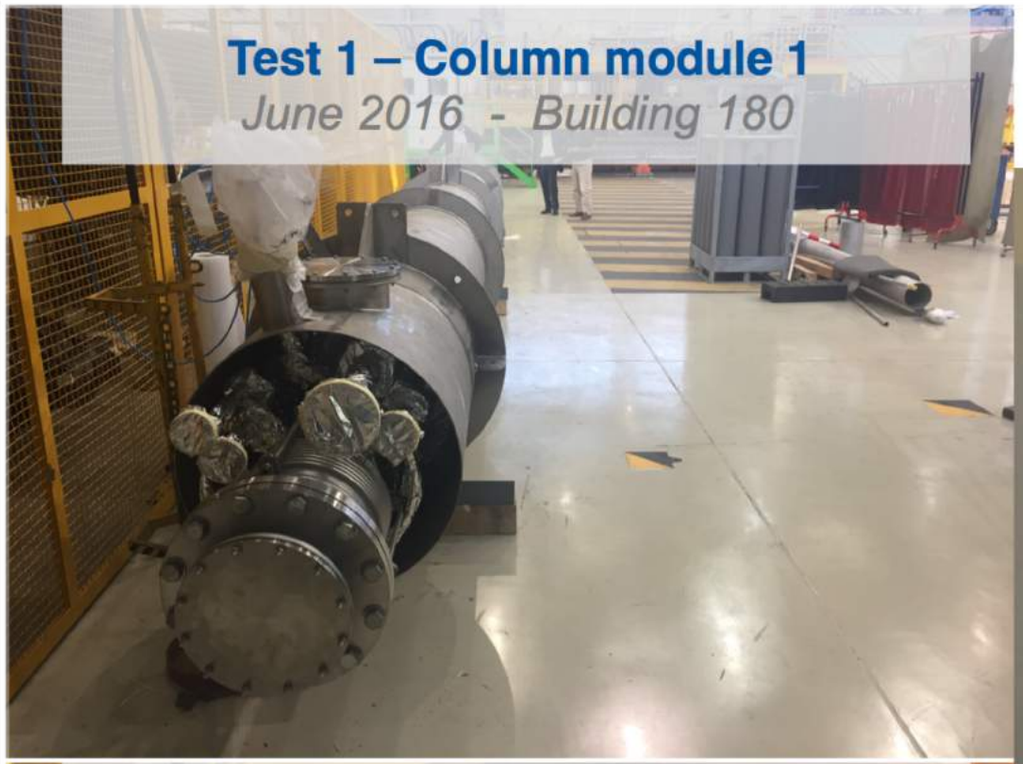
CarboSulcis mine in

Nuraxi-Figus

The Seruci-I column:

350m height, 30cm diameter





CERN : leak tests

first step : installation and test of a 28m tall test column Seruci-0 in a surface building at the mine


Genie ZX-135/70
TECNOALT
Genie
CTE

For DarkSide-20k:

Seruci I —>removal of chemical impurities to make the UAr detector grade with 2 passes at 1t/day with 85% recovery—> inlet purity required by DS20k getters of order 0.25-1ppm

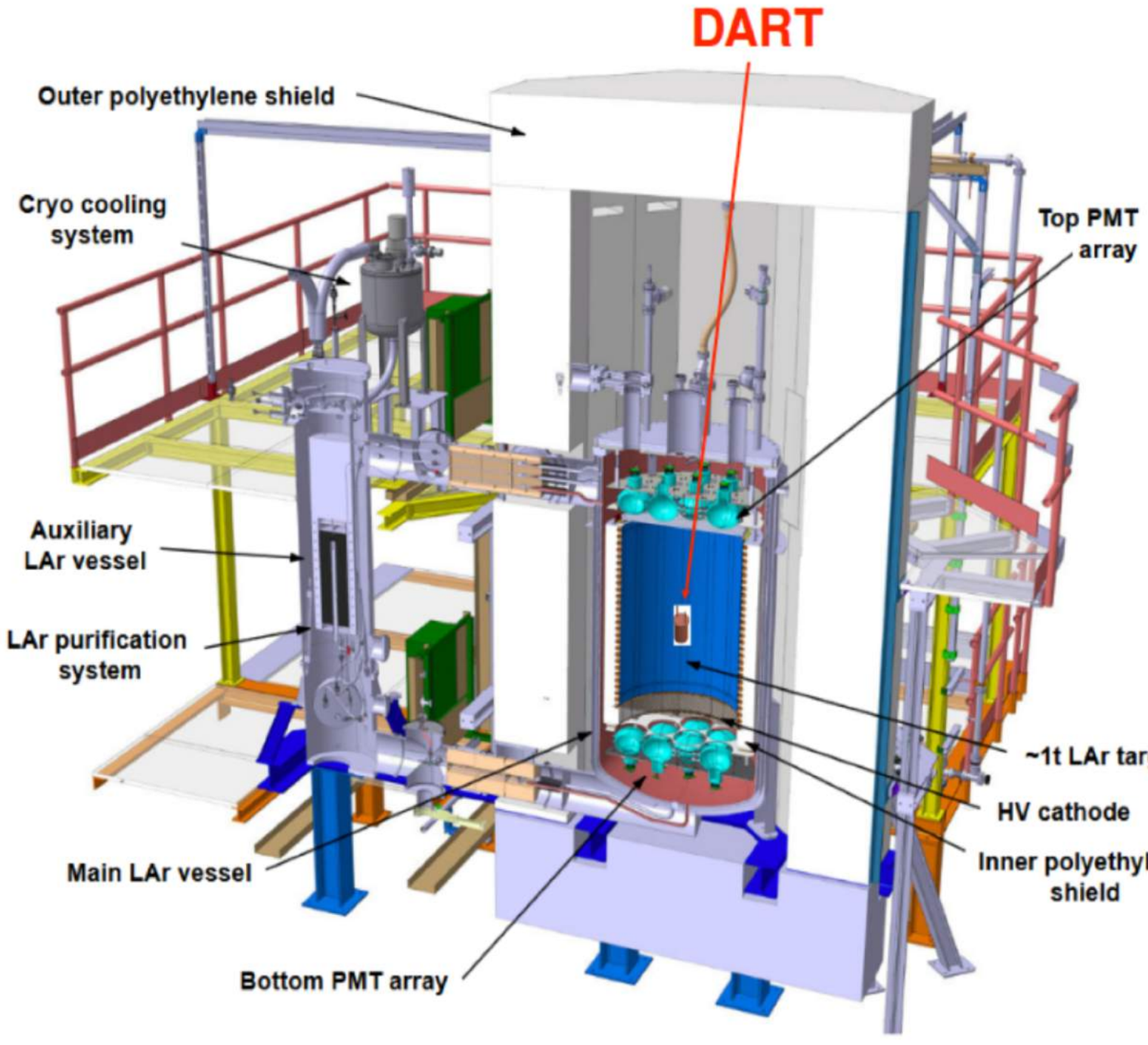
For DarkSide low-mass:

10Kg/day isotopic distillation of ^{39}Ar and chemical purification

A measuring device:

The measurement of ^{39}Ar content in the argon coming from Urania and Aria is planned with a specific innovative device named DART based on LAr active vetoing approach

Experimental set-up using the ArDM facility



Insertion of active small chamber in ArDM. Use ArDM as veto(single phase).

Dissipated power and condensation heat to be absorbed by ArDM cryogenic system.

At LSC Spain

3

A new SiPM production chain

NUV-HD-LF working at cryogenic temperatures

Low field SPADs, near UV (410nm) peak efficiency, 25μm cell size

Regional funds from Abruzzo, Italy—>

— SiPM large scale production at LFoundry, Avezzano (AQ) after successful R&D and design by FBK, Trento (TN)

— NuovaOfficinaAssergi at LNGS for packaging and module assembly

Summary of SiPM technologies produced by FBK used in DS 20k project

NUV-HD

(PDE peak at 410nm)

RGB-HD

(PDE peak at 560nm)

Other runs 2016/17

NUV-HD Triple Dose

(Low AP at cryo-T, high operating over-voltage)

DS NUV Run 2015/16

NUV-HD LF

(Low DCR, high Rq ~10MΩ at 77 K)

DS RGB Run 2015/16

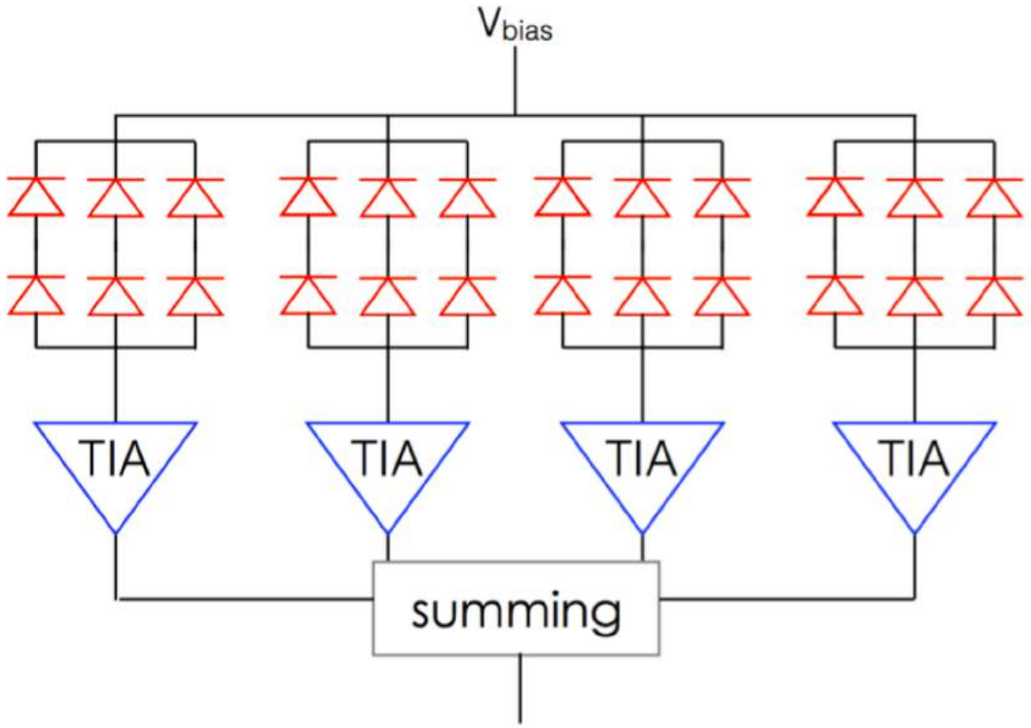
RGB-HD LF

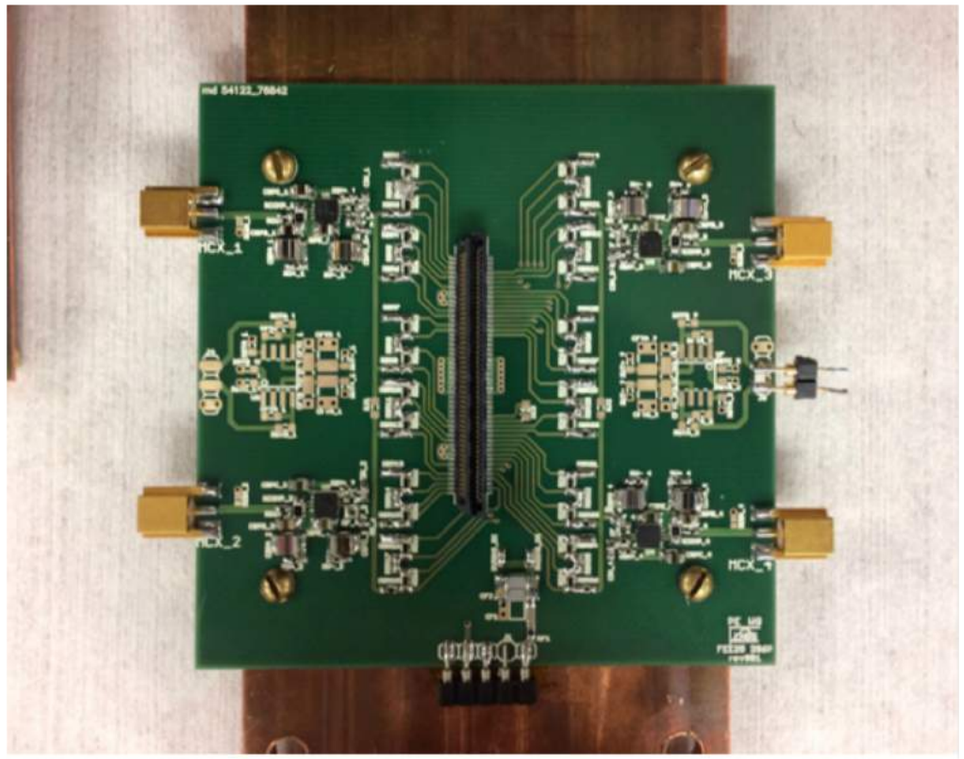
NEW !

DS Runs 1 to 3 2017/18

NUV-HD LF Triple Dose

- **Higher overvoltage**
- **Larger cells**
- **Lower value of quenching resistors**

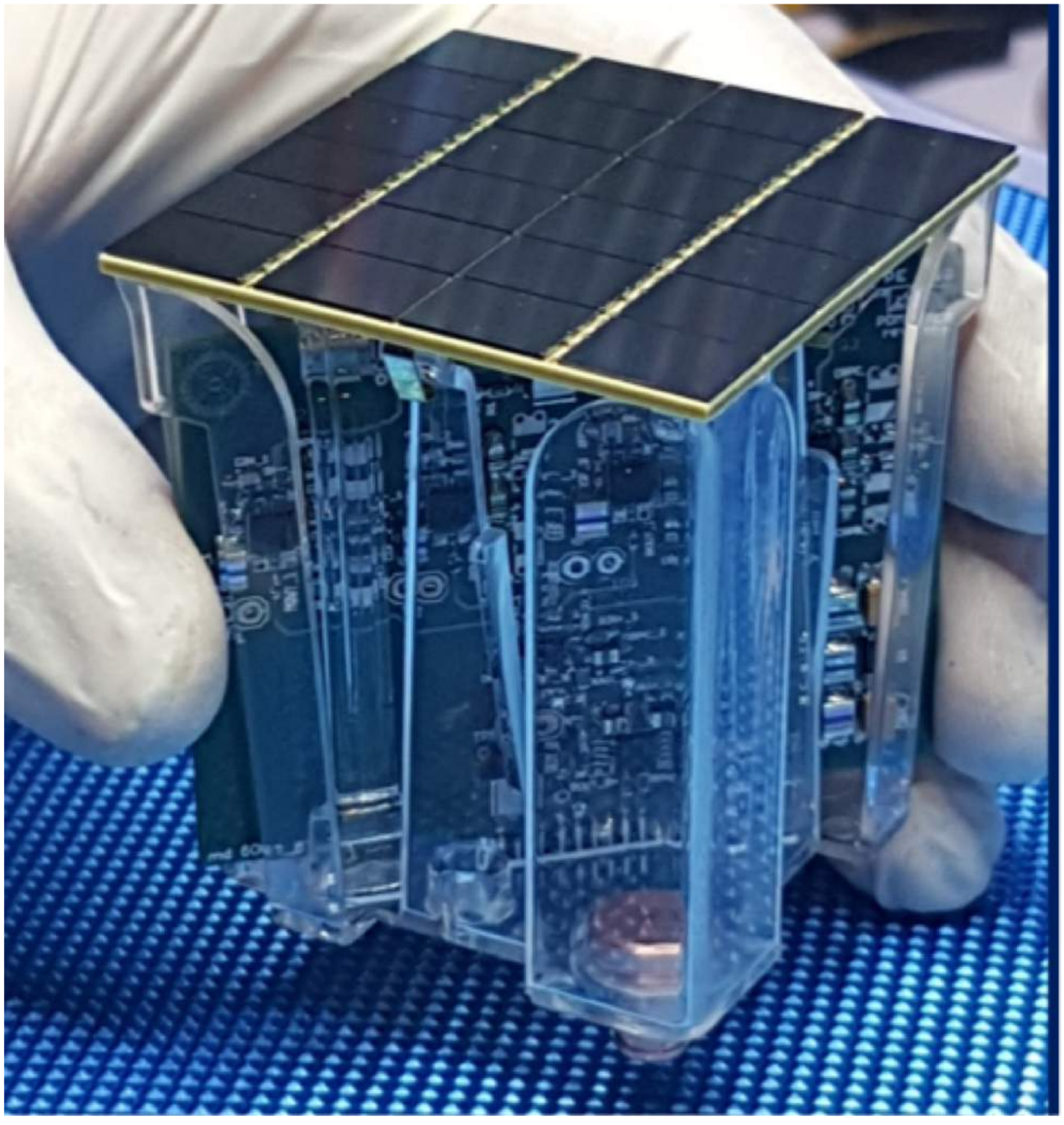




The tile is readout by 4 TransImpedanceAmplifiers (large detector C of 50 pF/mm^2) with discrete components

mounted on radio-pure substrates

24 cm² tiles equipped with 1x1cm² SiPMs fully working



Need 8280

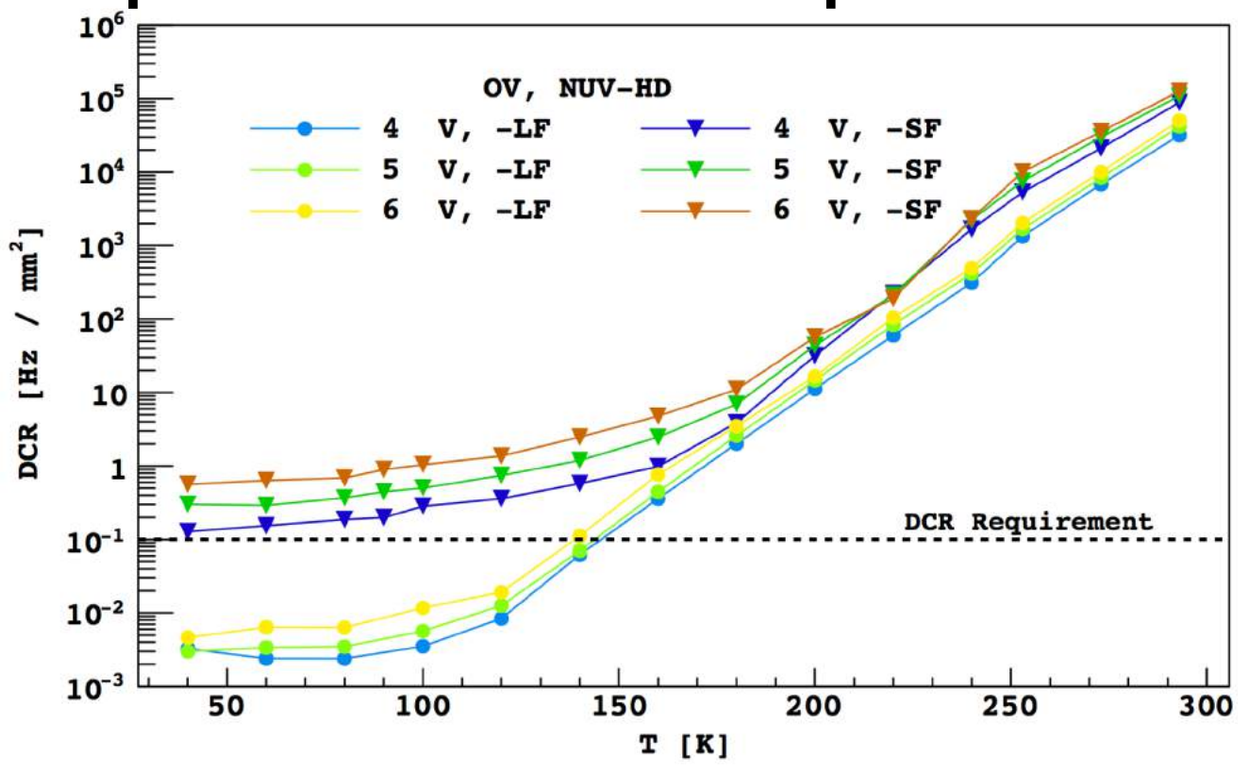
… assembled as self-consistent one-channel units PhotonD

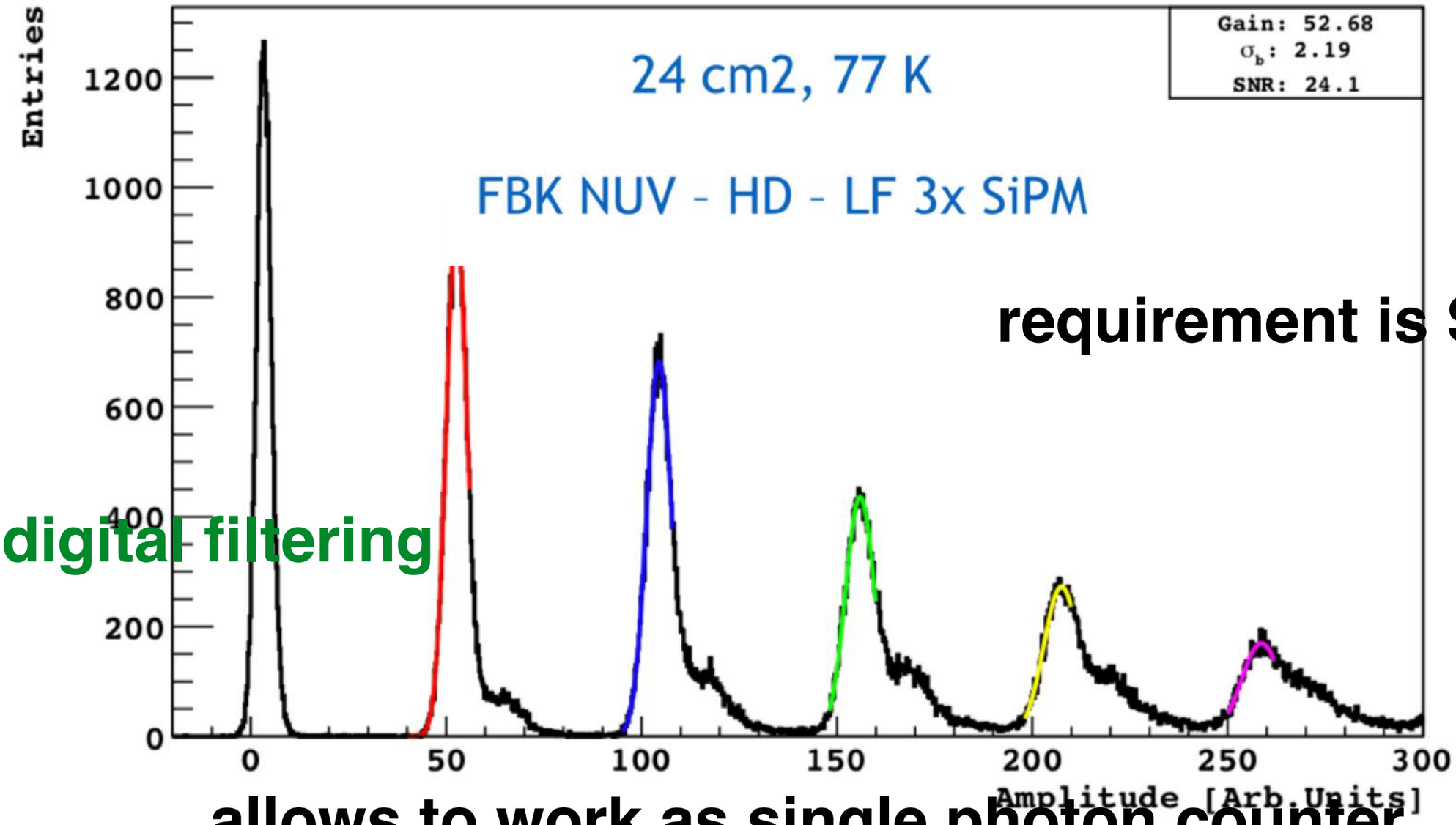
Photon Detection Efficiency (PDE): 45% requirement met and surpassed

Dark Count Rate (DCR): 0.1 Hz/mm^2 requirement met and surpassed

250mW power/consumption/PDM

20ns time resolution

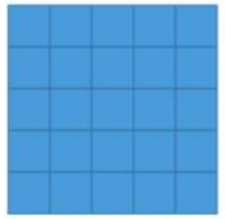




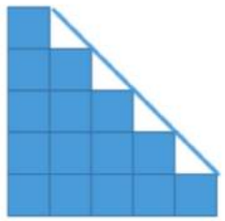
requirement is SNR>8

after digital filtering

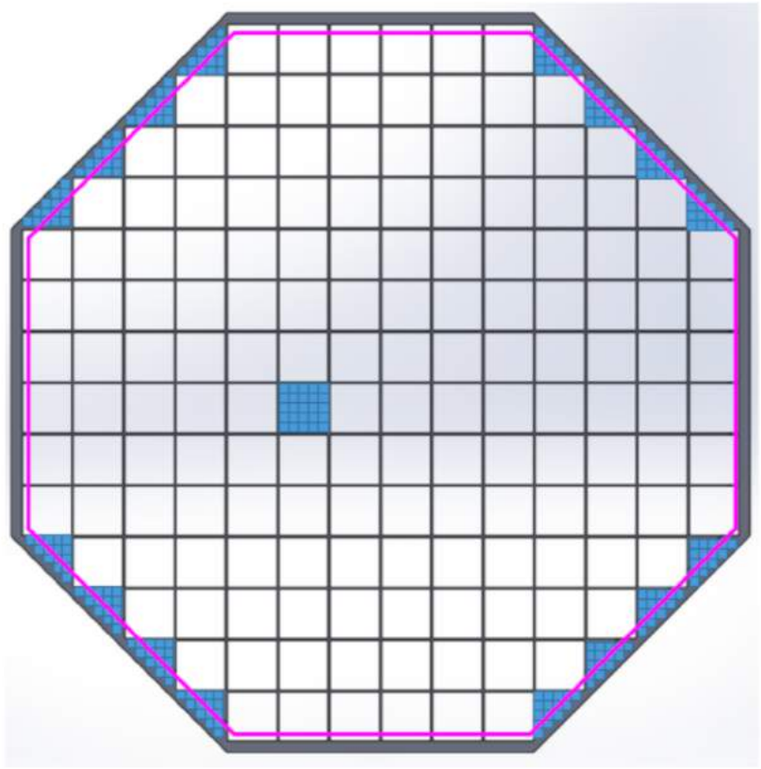
allows to work as single photon counter

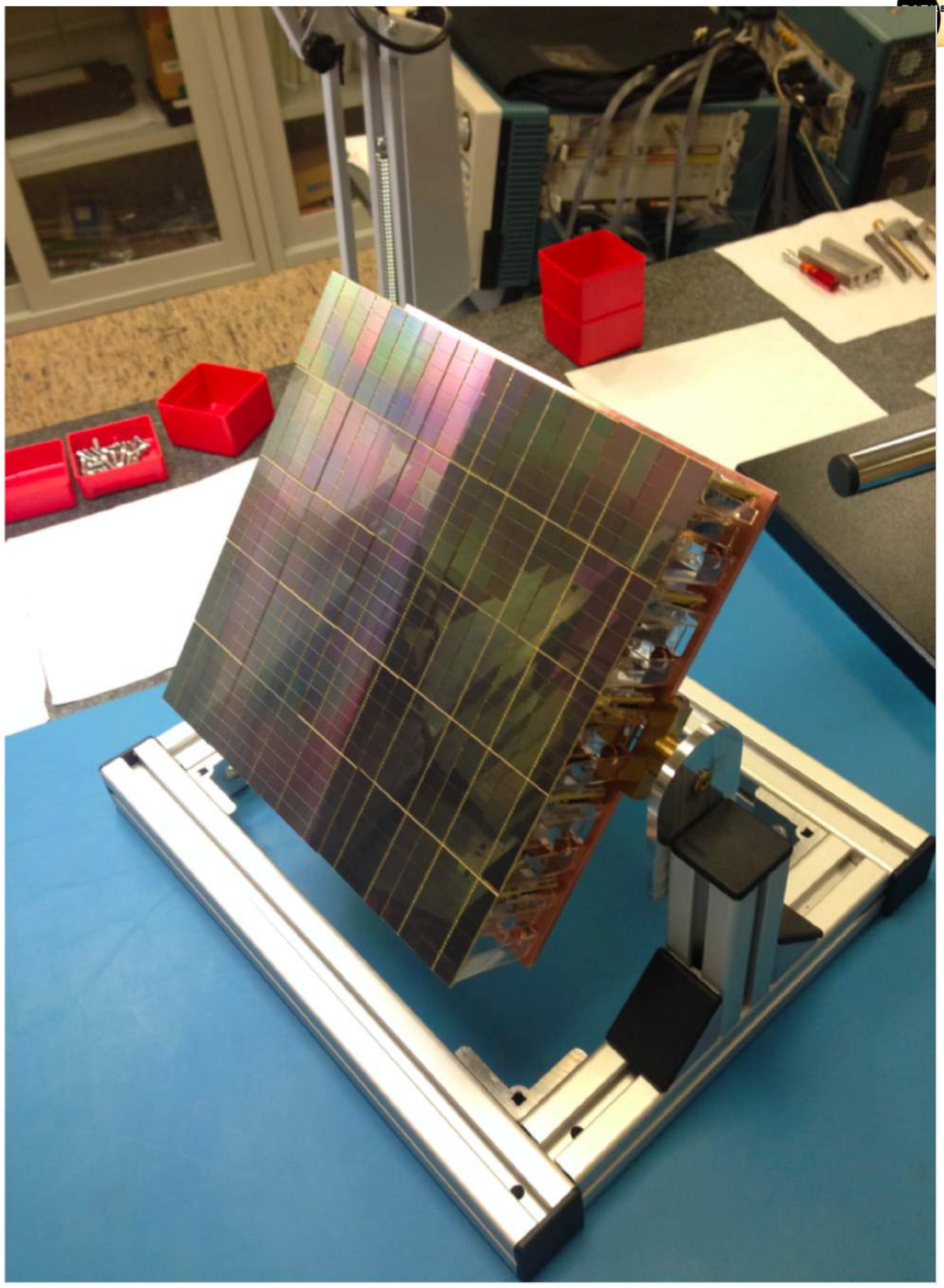


SQB



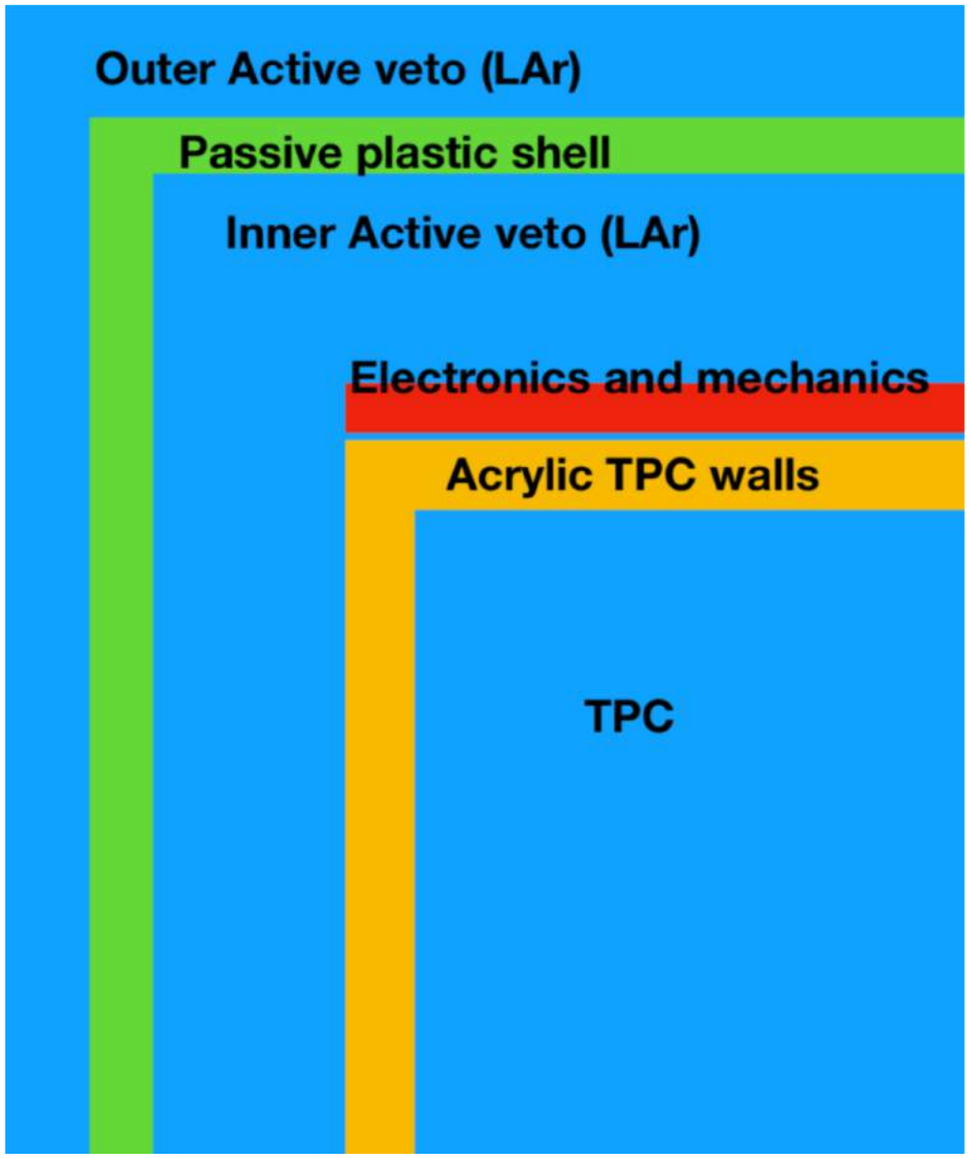
TRB





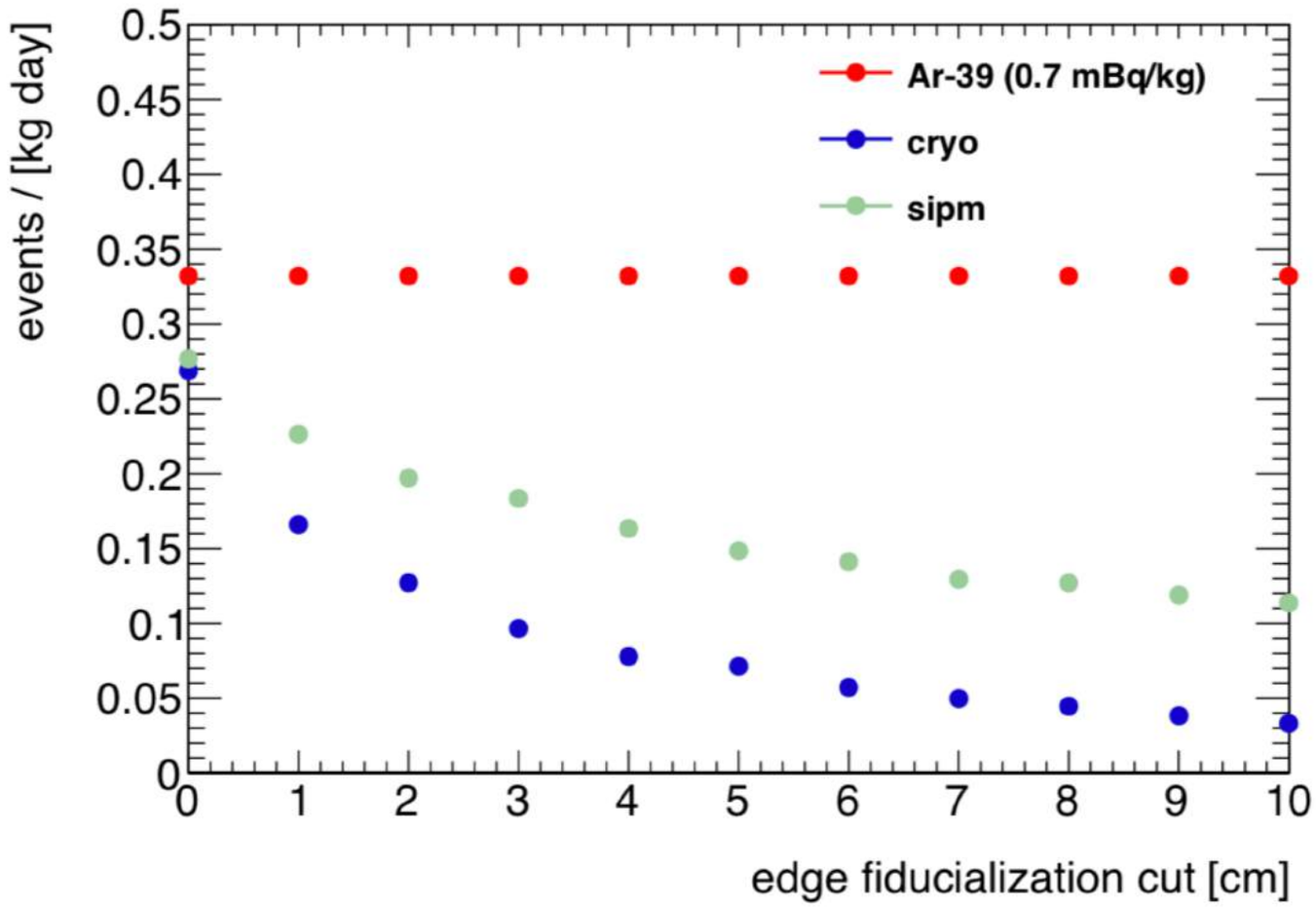
The neutron veto

PRELIMINARY NUMBERS



Neutron source position	LAr TPC cuts ineff.	Veto cuts ineff.	Sourced n's $[100\,\mathrm{t\,yr}]^{-1}$	Residual background $[100\,\mathrm{t\,yr}]^{-1}$
PDMs	2.4×10^{-4}	0.08	2000	0.04
LAr TPC PMMA vessel	3.3×10^{-4}	0.10	5	$<10^{-3}$
GdsAS	2.3×10^{-5}	0.10	750	0.002
Total				<0.05

Search for low-mass DM: DarkSide-LM

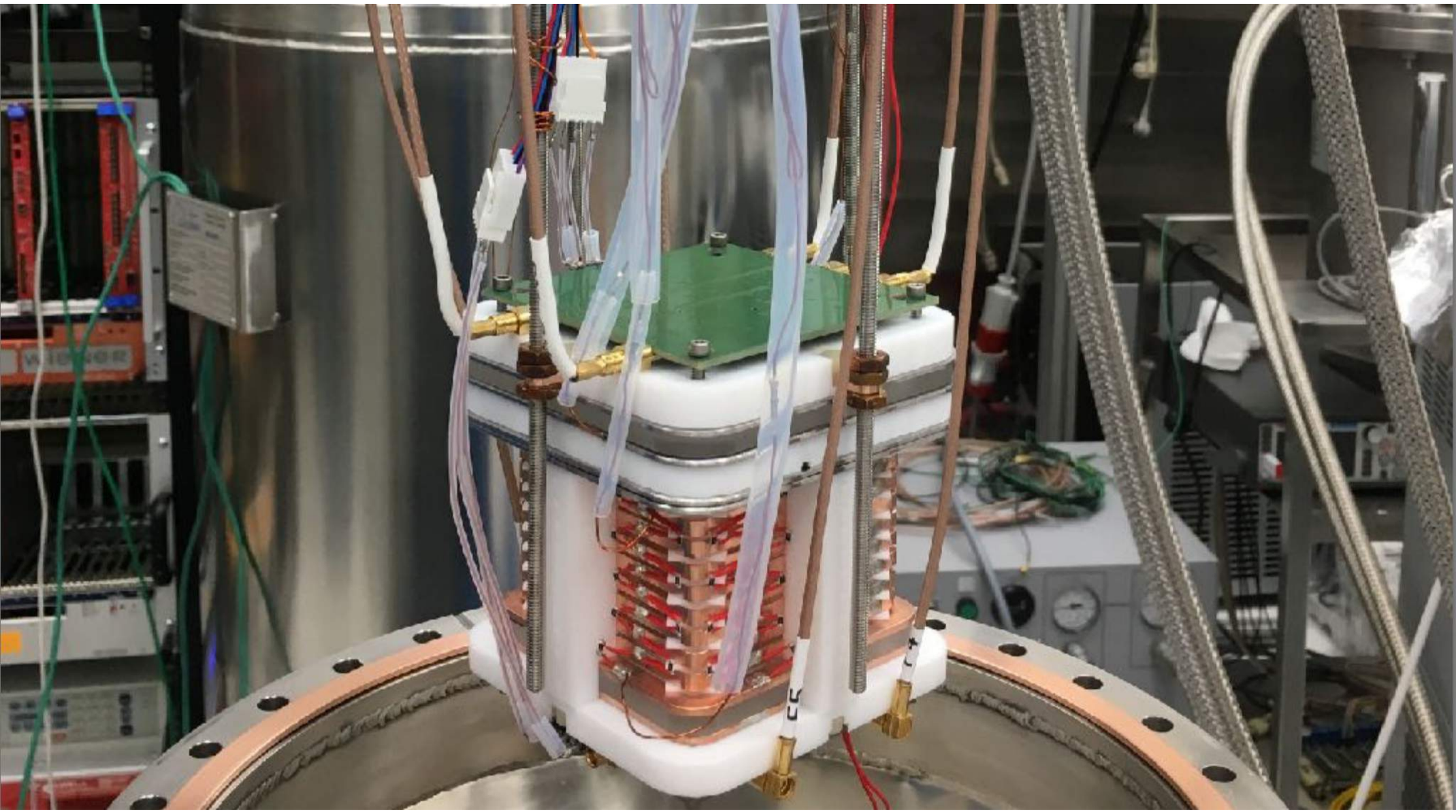


To be compared to DS50

$^{39}Ar+^{85}Kr$: 1.75 ev/kg/day

cryo: 0.27 ev/kg/day

PMT: 1.57 ev/kg/day



Reaching and going beyond the neutrino floor for discovering WIMPS demands for a ultra-low background technology

This is in our opinion best done with LAr thanks to its PSD capability and the GADMC is pursuing this road with the UAr and more with the 1ton DS-proto and DS-LowMass for low mass, the DS-20k and the ultimate 300t detector for the high mass WIMPs