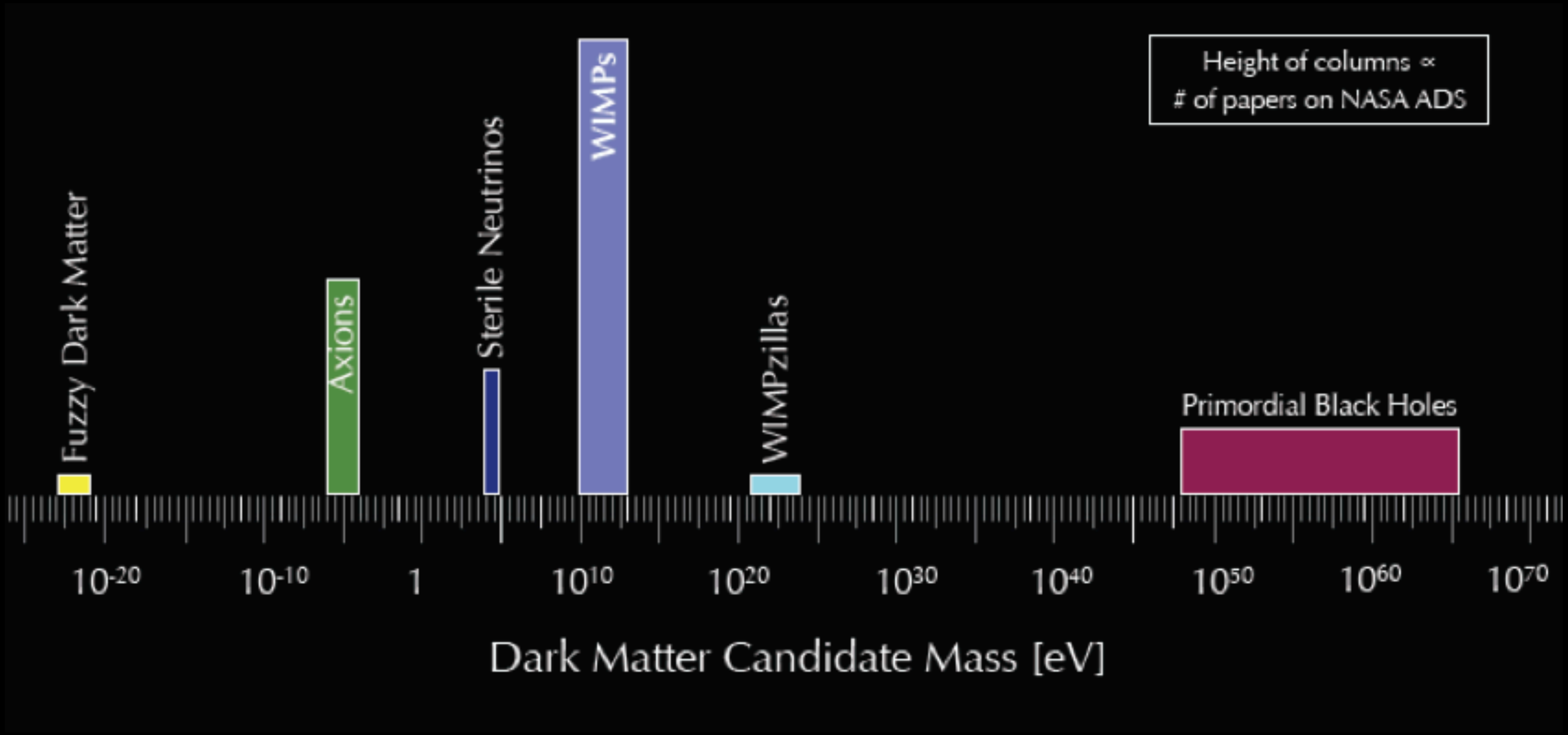
DARK MATTER DIRECT DETECTION WITH NOBLE LIQUIDS

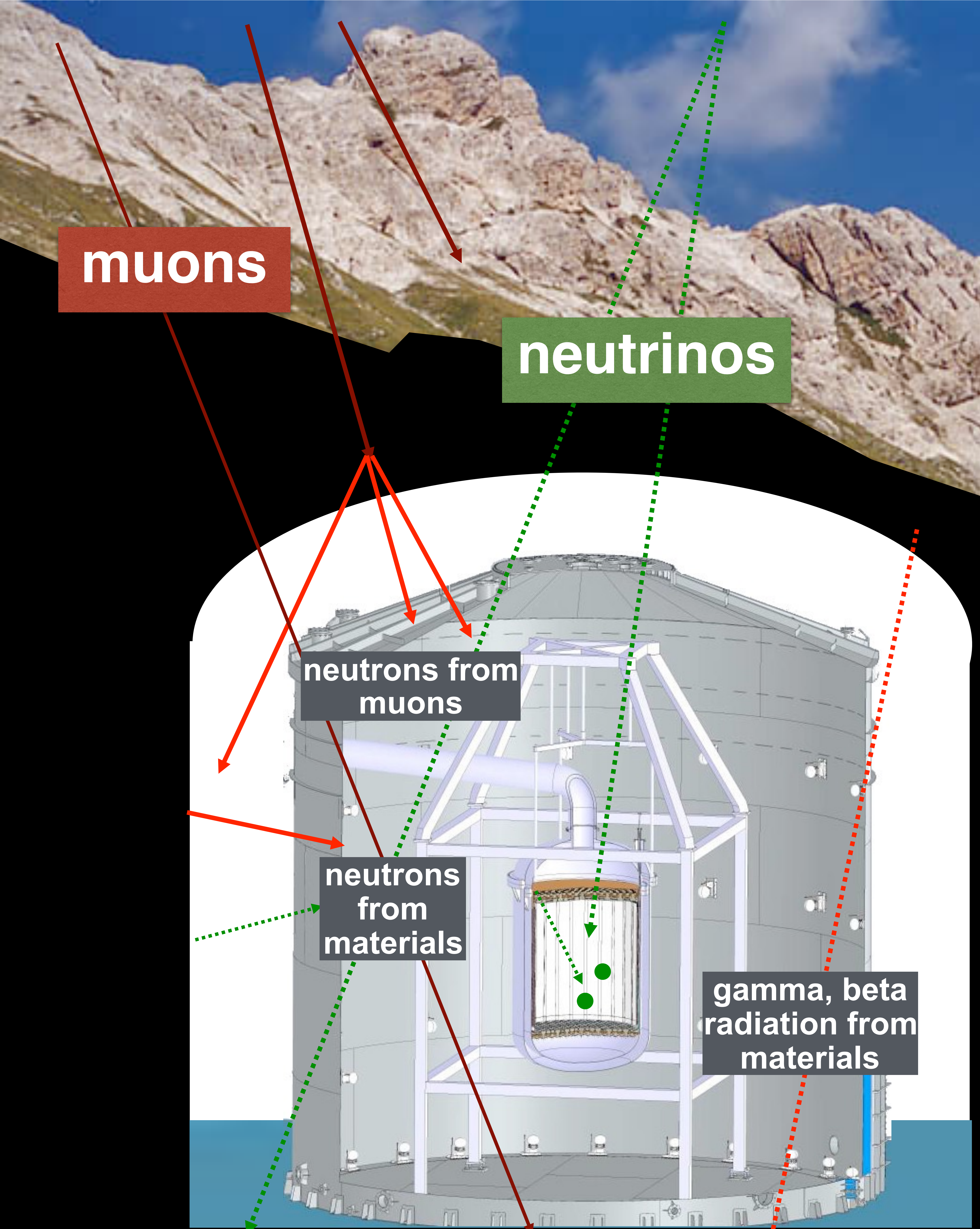
ELENA APRILE
COLUMBIA UNIVERSITY

CONFERENCE ON NEUTRINO AND NUCLEAR PHYSICS (CNNP2020)
SOUTH AFRICA, FEBRUARY 25, 2020

Dark Matter Particle Candidates

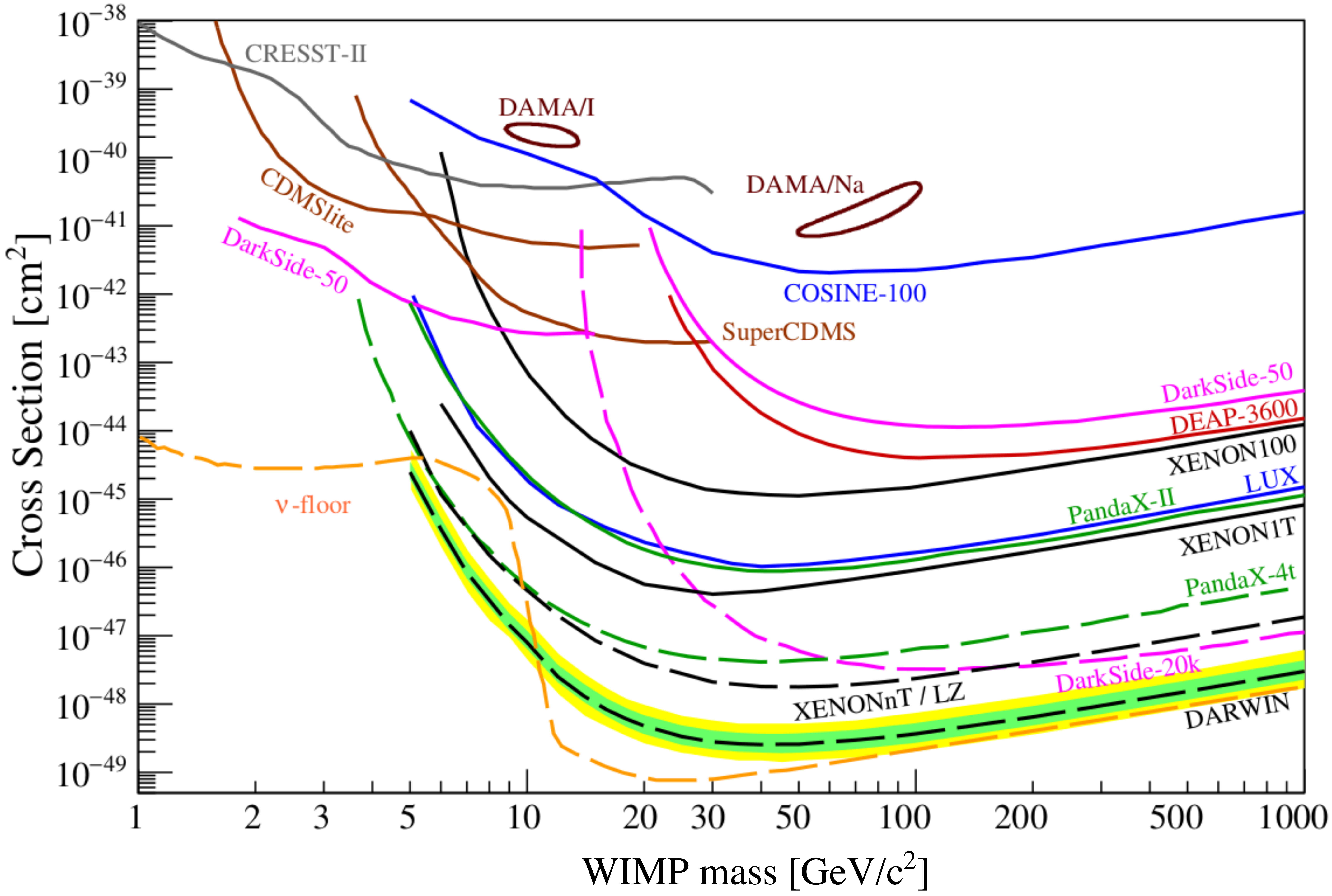


Key Requirements



Detectors must be massive, with low energy threshold and effective discrimination of background produced by:
(1) Cosmic rays
(2) Intrinsic radioactivity (U,Th,K,Co)
(3) ultimately solar, atmospheric and SN neutrinos

Where do we stand?

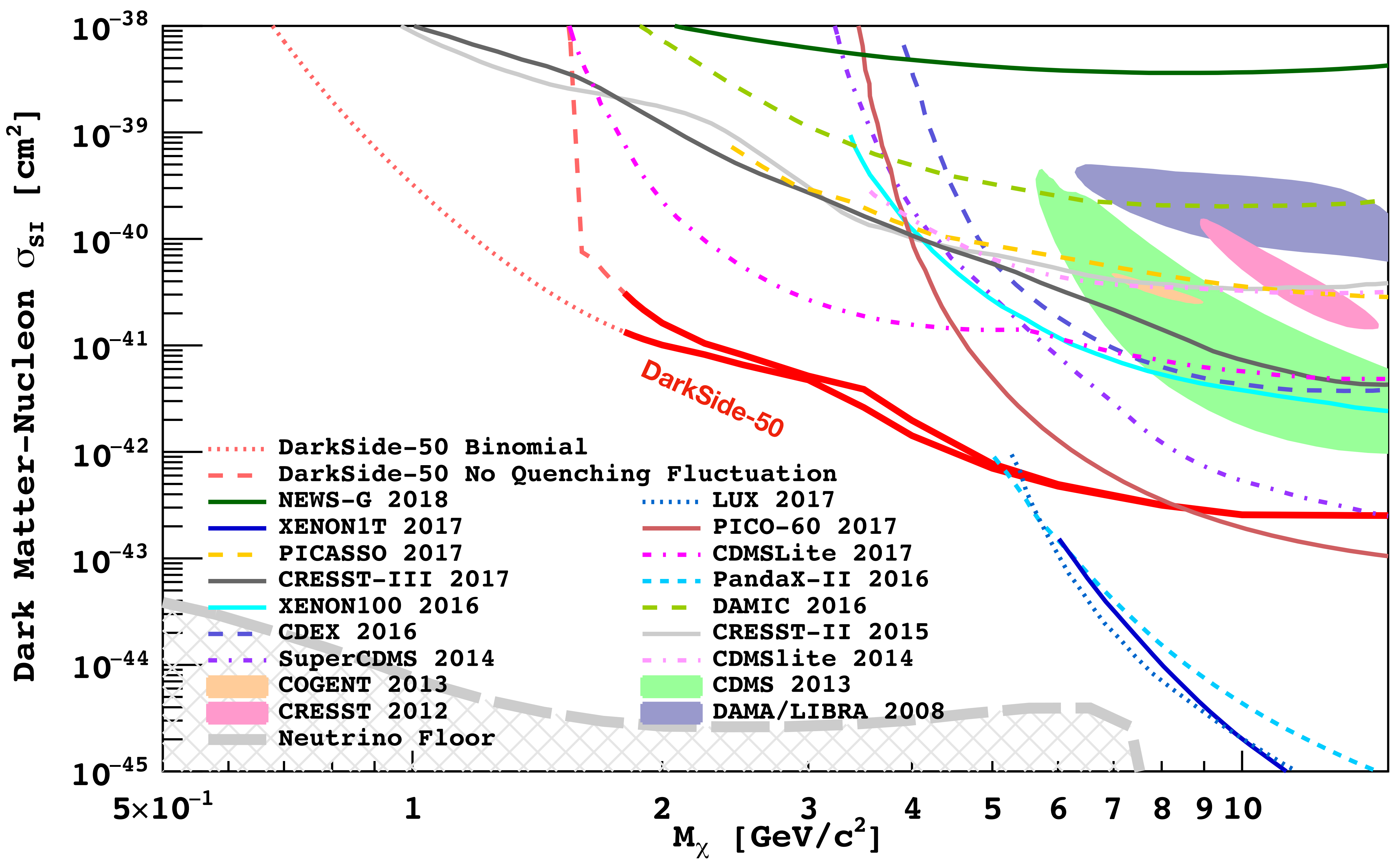


~ 1 event/ kg-day

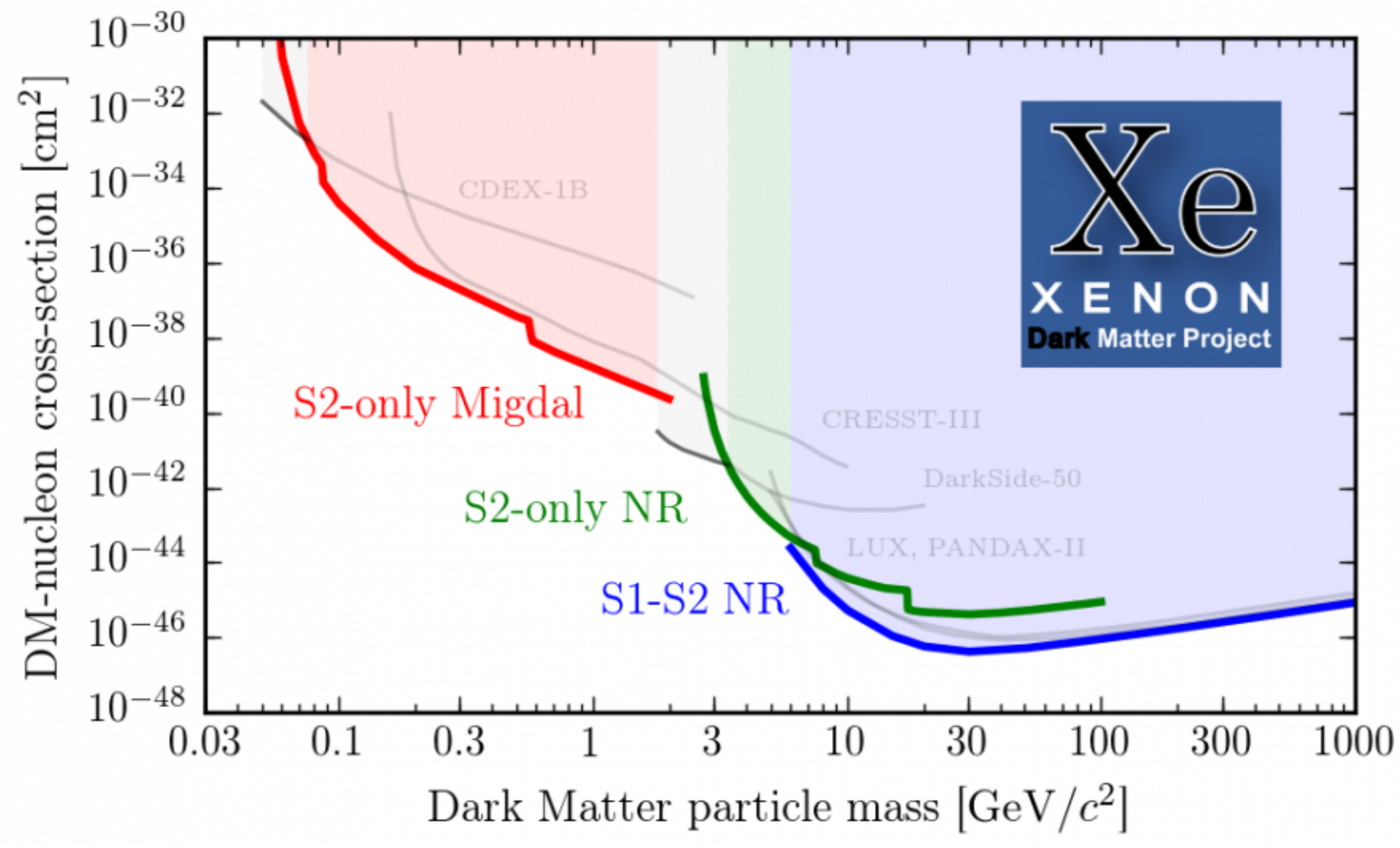
→ Current limits

~ 1 event/ tonne-year

Noble Liquid targets: superior performance also for light(< 10 GeV) WIMPs Search



Phys. Rev. Lett. ***121*** *081307 (2018)*



https://arxiv.org/abs/1907.11485

What makes Noble Liquids ideal WIMP Targets?

	Z(A)	Boiling Point at 1 atm [K]	Density [g/cm^3]	Ionization[e^-/keV]	scintillation [photon/keV]
Ar	18(40)	87.3	1.40	42	40
Xe	54(131)	165	3.06	64	46

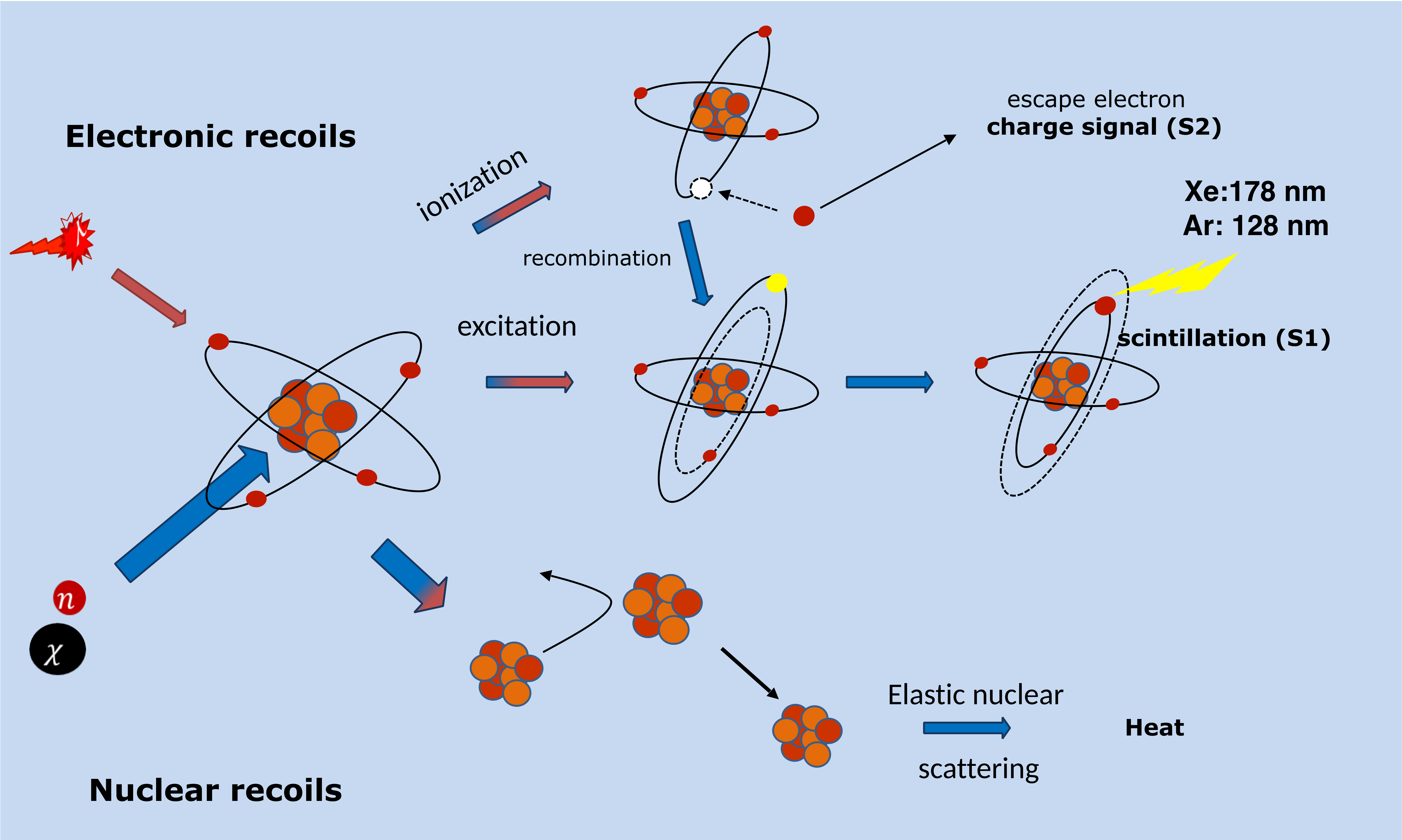
Dense liquids: for massive and homogeneous targets at modest cost (~2k$/kg of LXe)

Easy to purify and keep cold: mature cryogenic and purification technologies

Radiopure liquids: no intrinsic radioactivity (other than Kr85 /Ar39 which can be removed to required levels). Long-lived isotopes ^{136}Xe (double beta decay) and^{124}Xe (double electron capture) are an added asset for LXe detectors.

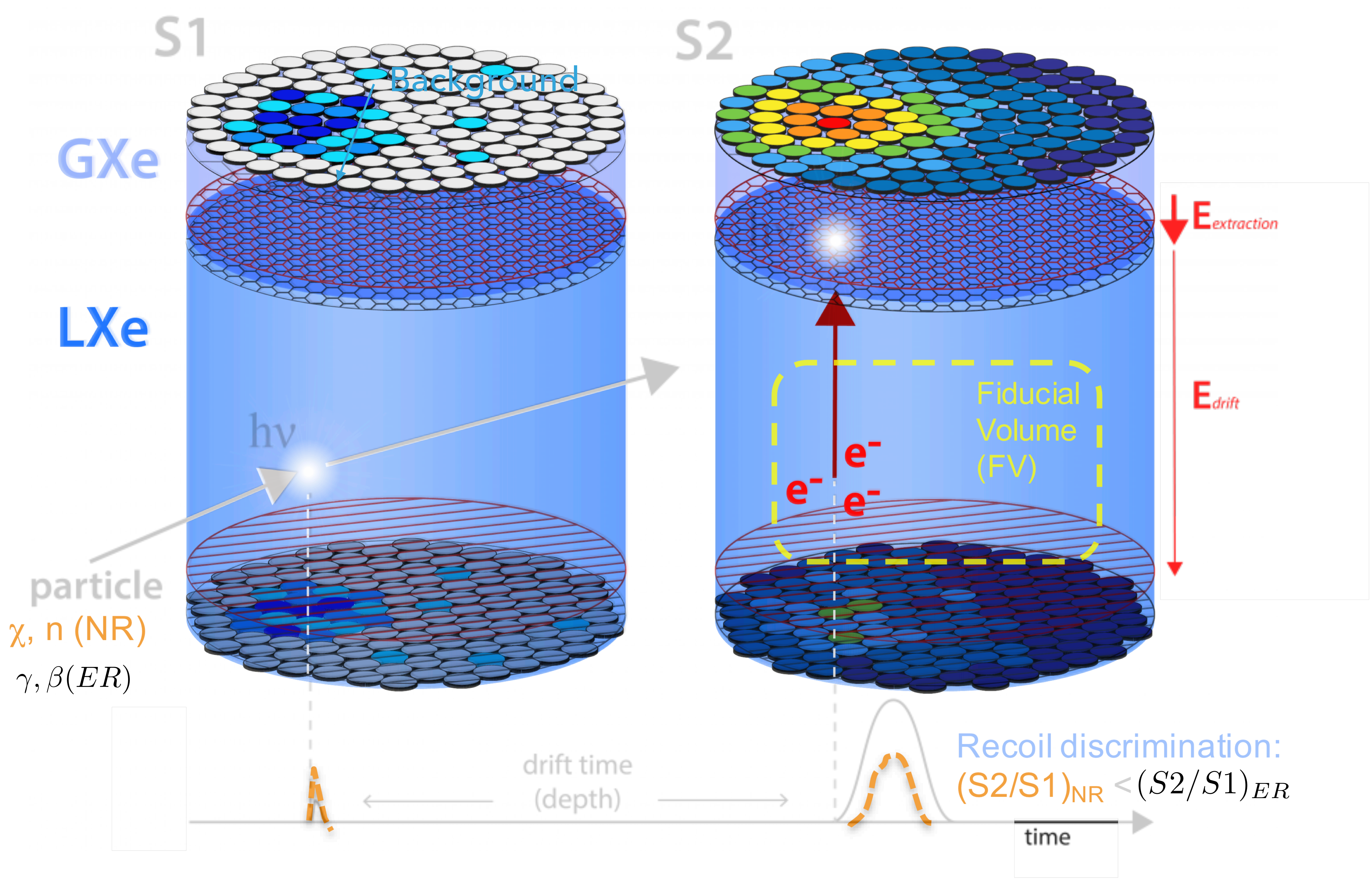
Two signals: excellent ionizers and scintillators

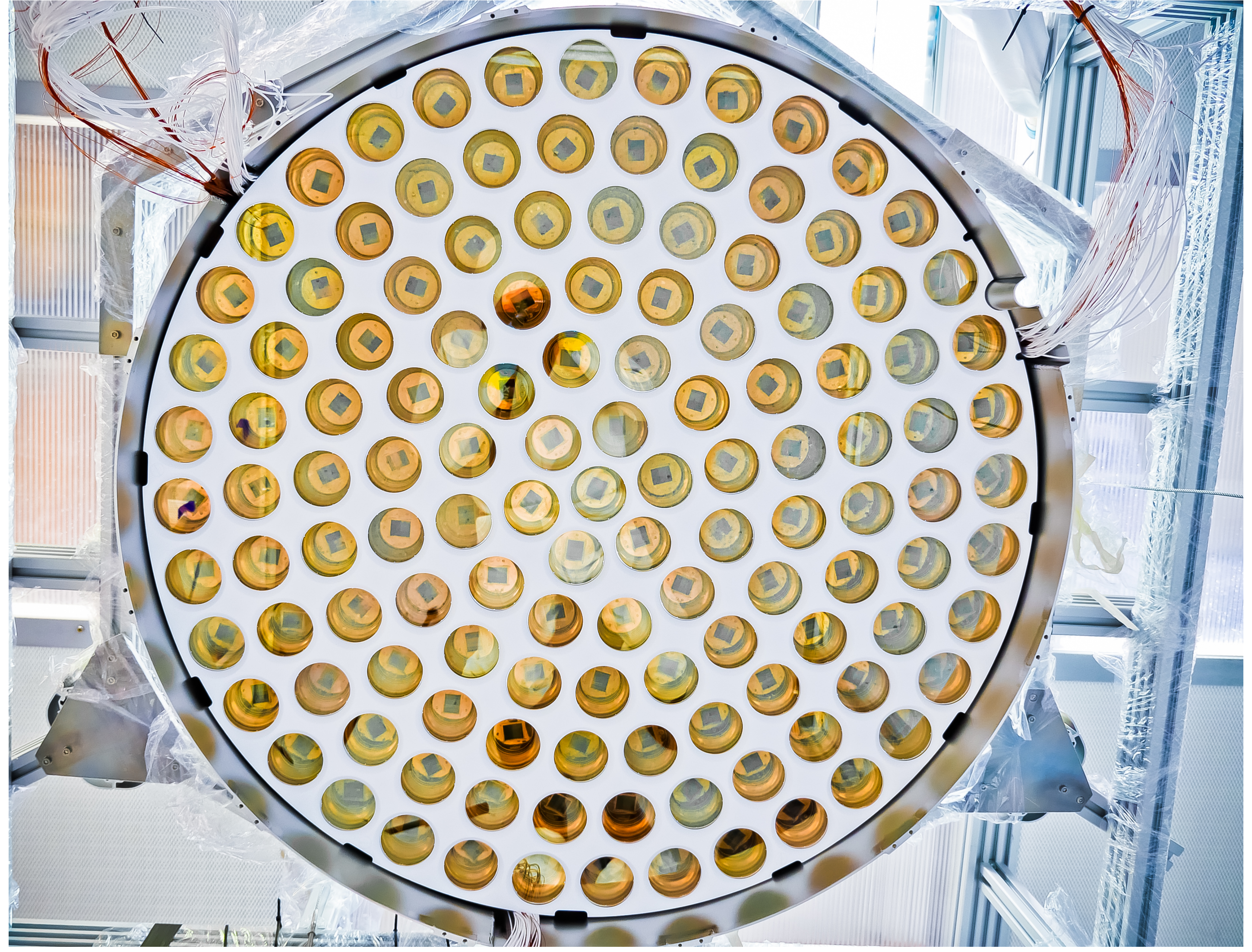
Light and Charge Signals in Noble Liquids



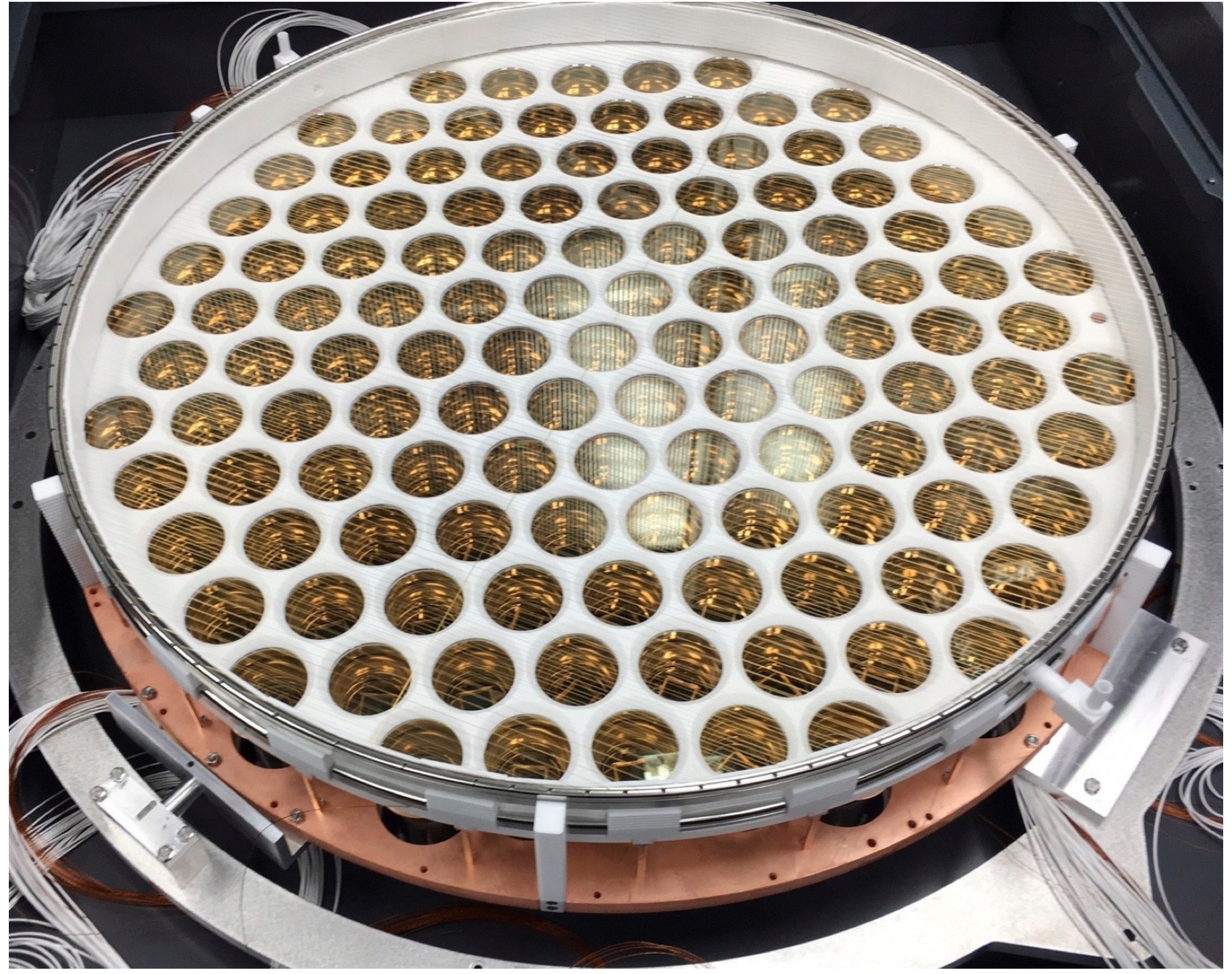
Two-phase Noble Liquid Time Projection Chamber:

a 3D imaging detector with keV energy threshold

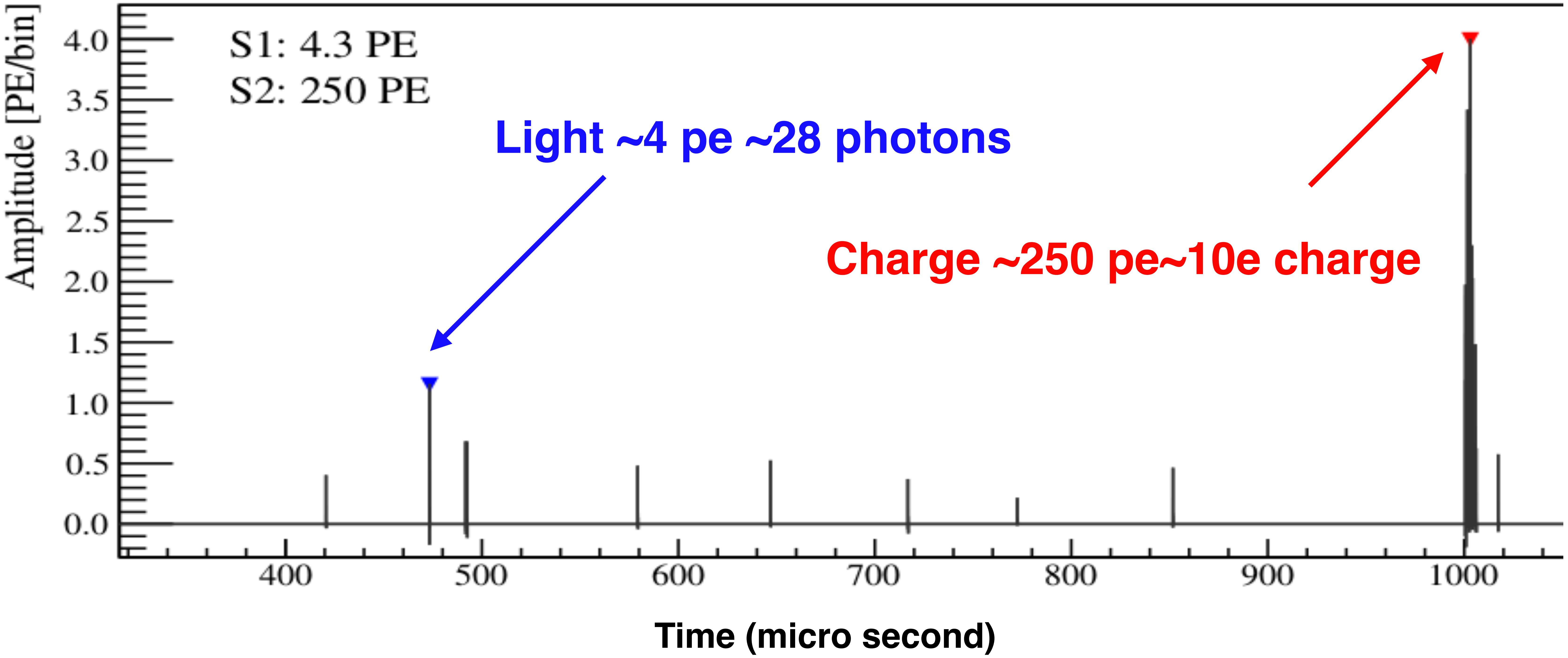




127 PMTs in the top array



121 PMTs in the bottom array

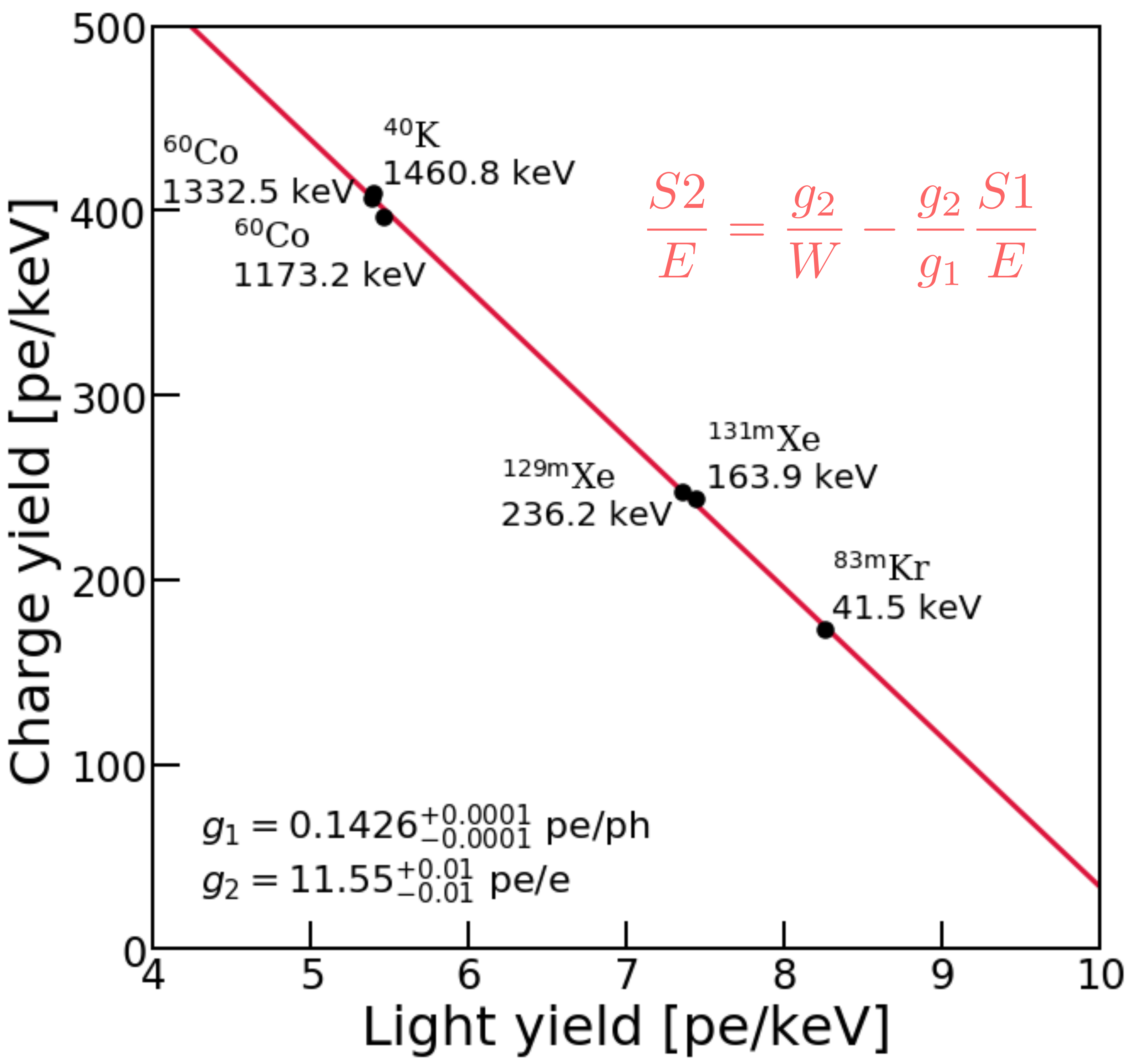


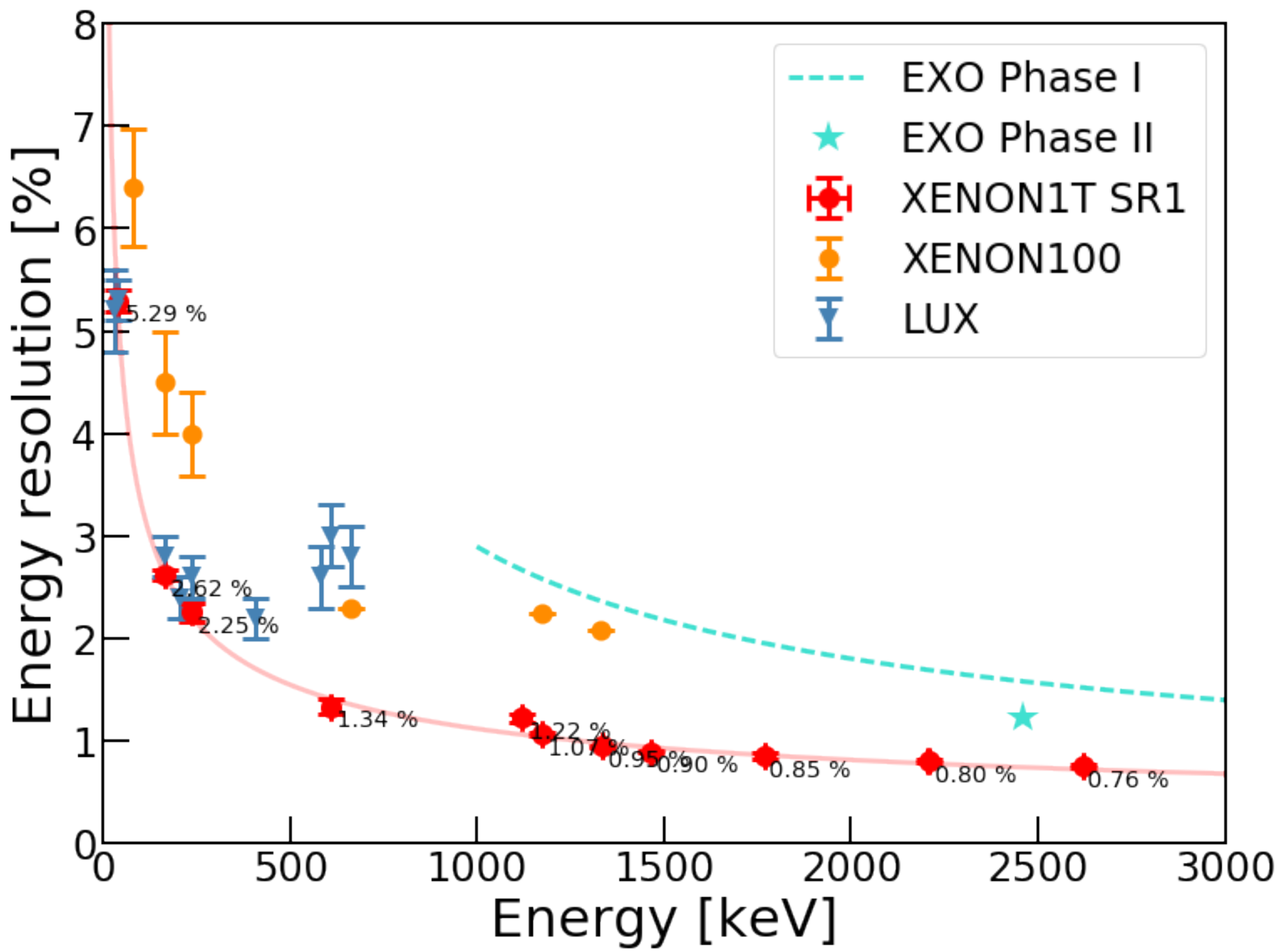
The power of combining two signals for precise Energy measurement

$$E = (n_{ph} + n_e) \cdot W = \left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right) \cdot W$$

Example for XENON1T: excellent linearity and resolution from ~ keV (DM) to ~ MeV (0vbb)

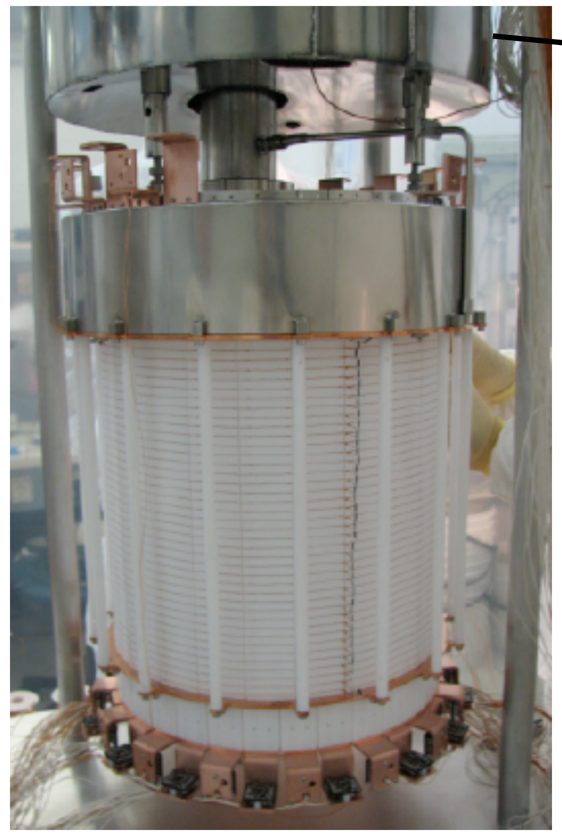
world-record 0.8% relative energy resolution (σ/E) around 2.5 MeV (^{136}Xe 0νββ energy)





Noble Liquid TPCs (20-2000 kg active target)

XENON100 at LNGS
Active Target: 62kg

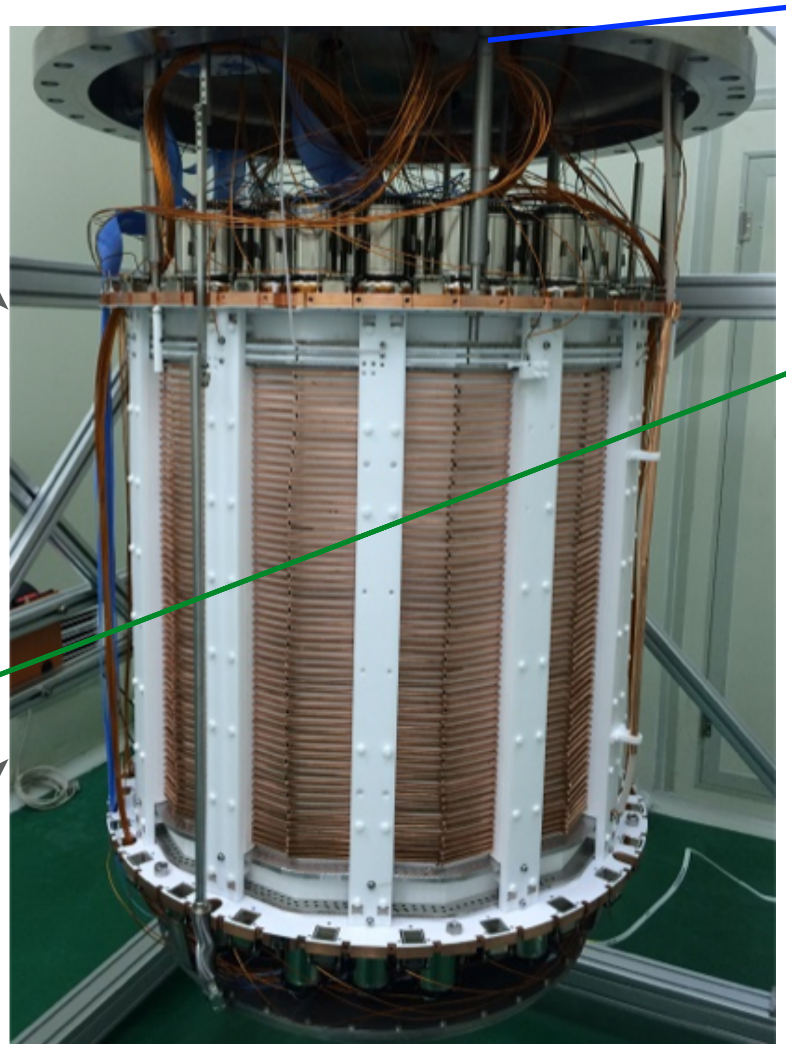


30cm

LUX at SURF
Active Target: ~250 kg

48 cm

PandaX-II at CJPL-I
Active Target: ~580 kg

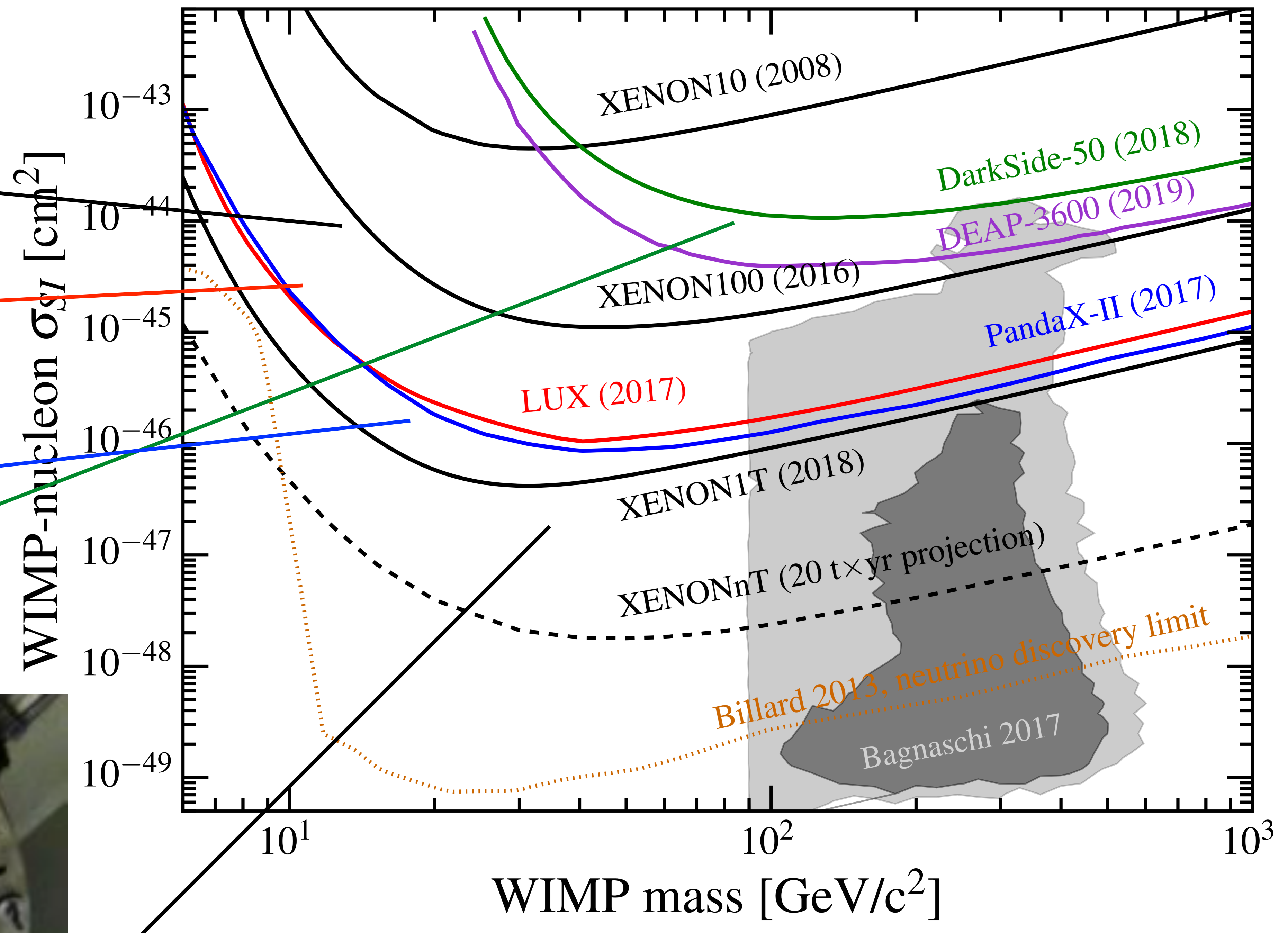


60 cm

DarkSide-50 at LNGS
Active Target: 50kg

XENON1T at LNGS
Active Target: 2000 kg

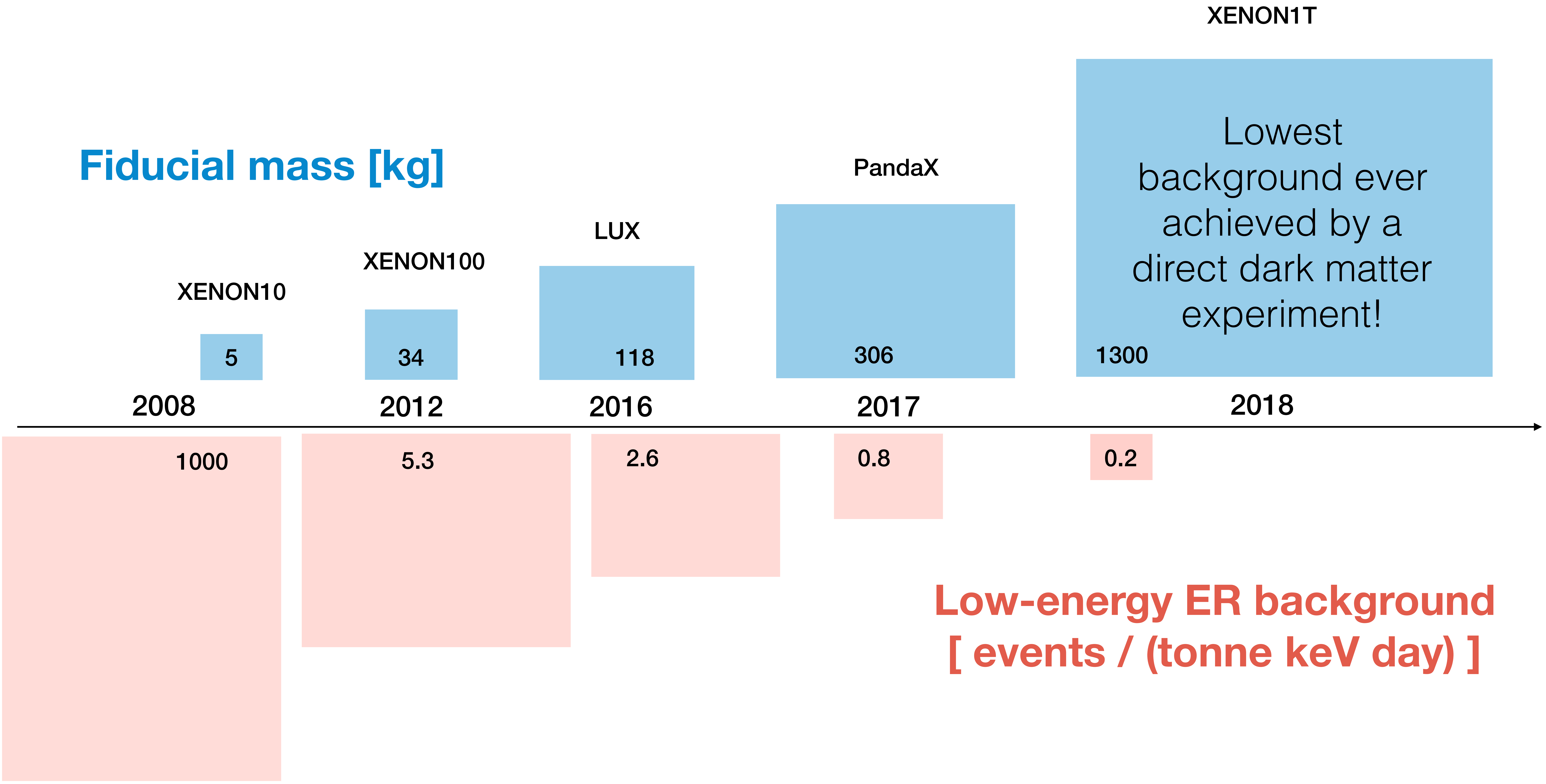
100 cm



~2008 - 2018

from ~10^{-43} cm^2 to ~10^{-47} cm^2

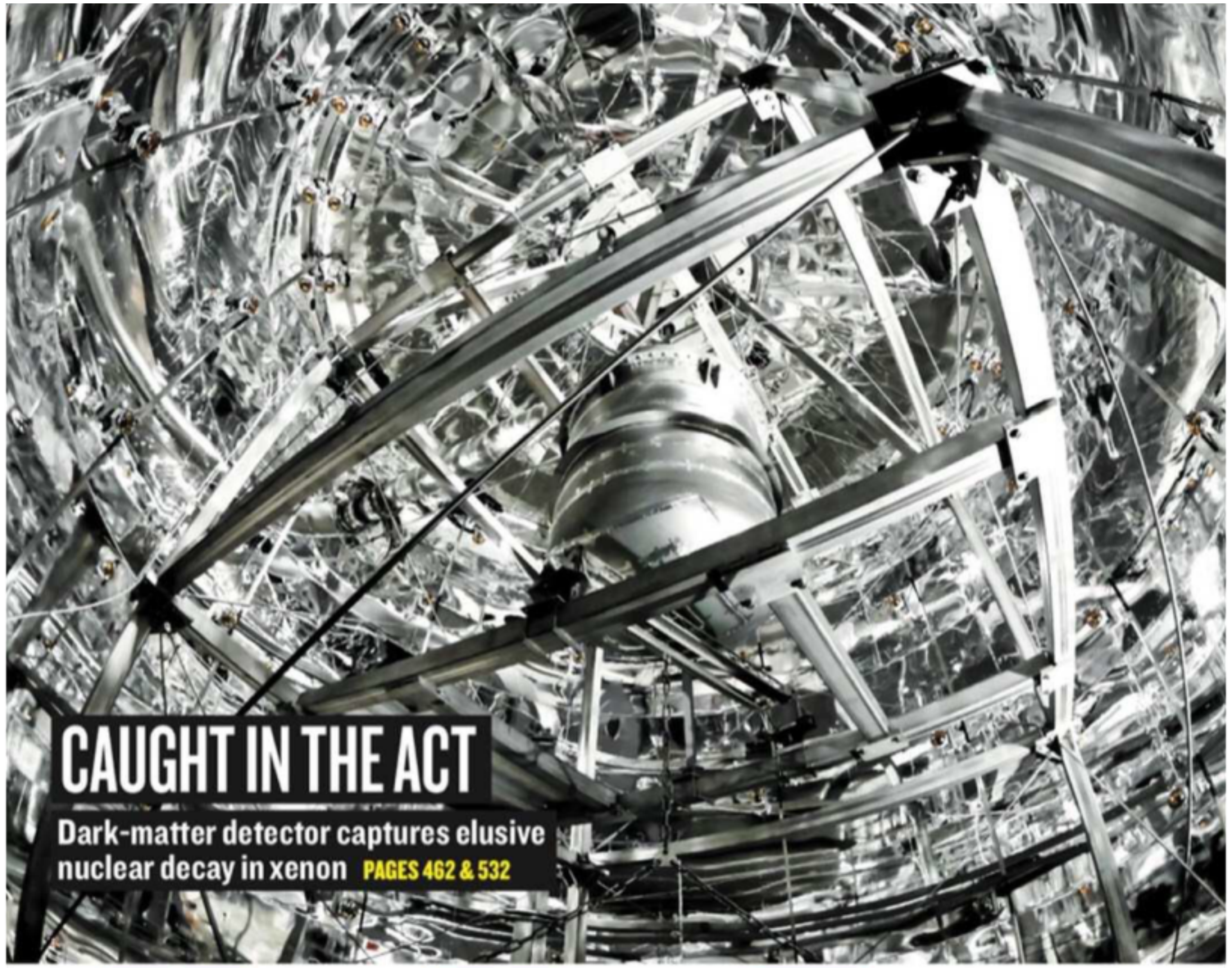
Evolution of LXeTPCs as WIMP detectors

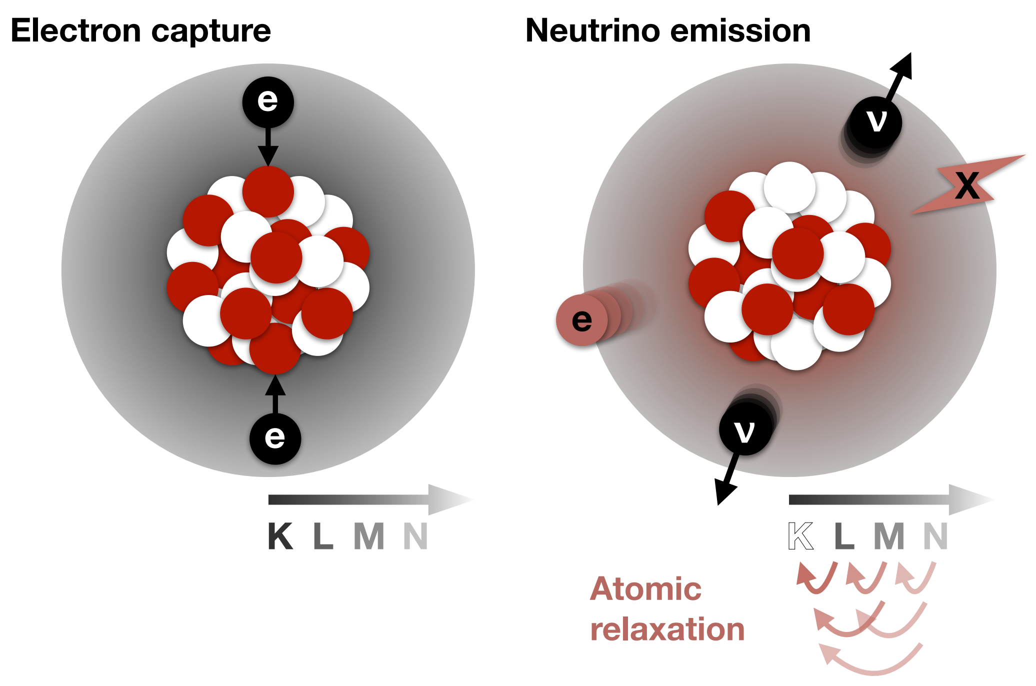


Observation of two-neutrino double electron capture in ^{124}Xe with XENON1T

nature

Half-life $T_{1/2}^{2\nu ECEC} = (1.8\pm0.5_{stat}\pm0.1_{sys})\times10^{22}$ y

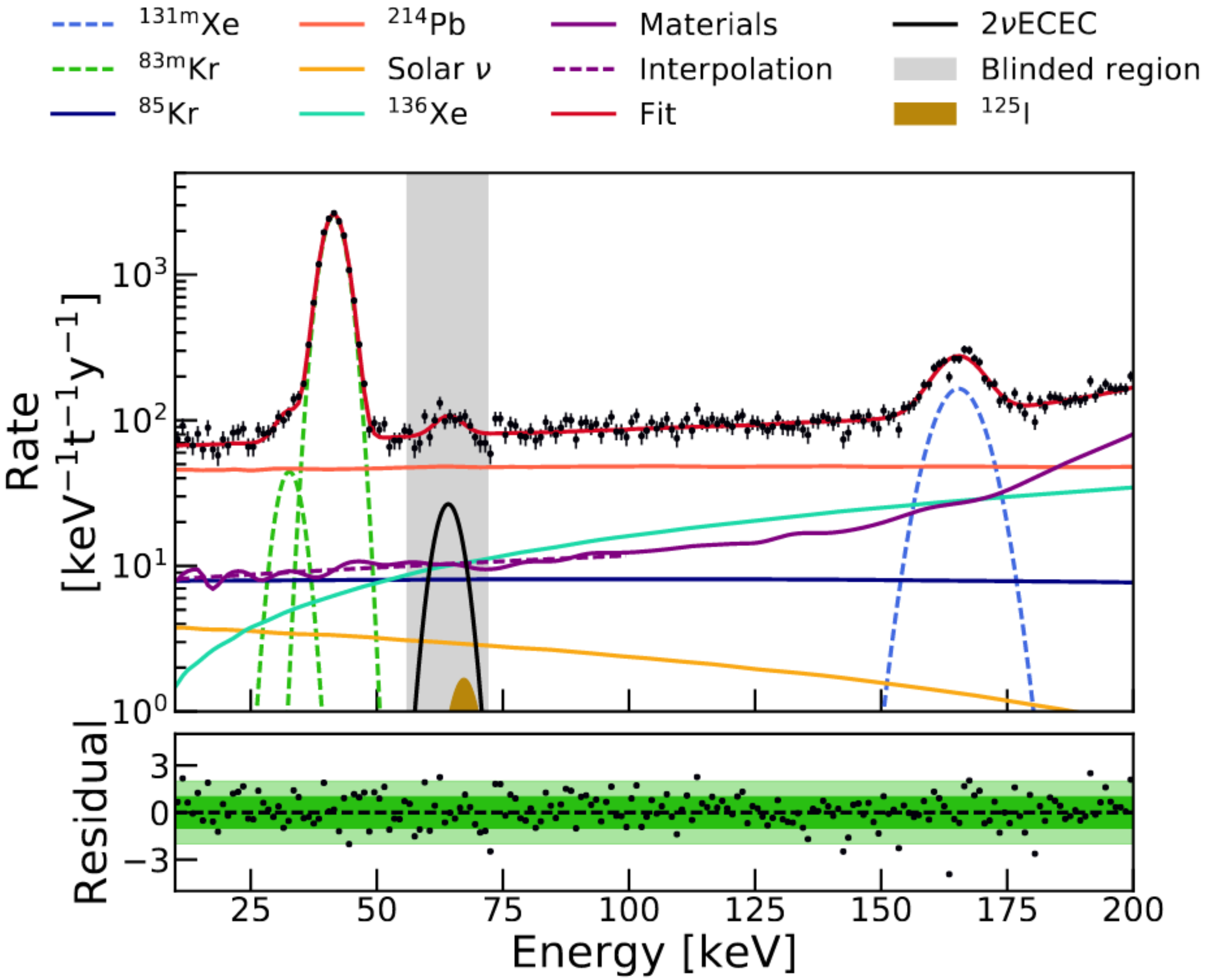




$Q_{2\nu ECEC}$ = 2857 keV

$E_{2\nu KK}$ = 64.3 keV

$^{124}Xe + 2e^- \rightarrow {}^{124}Te + 2\nu_e$

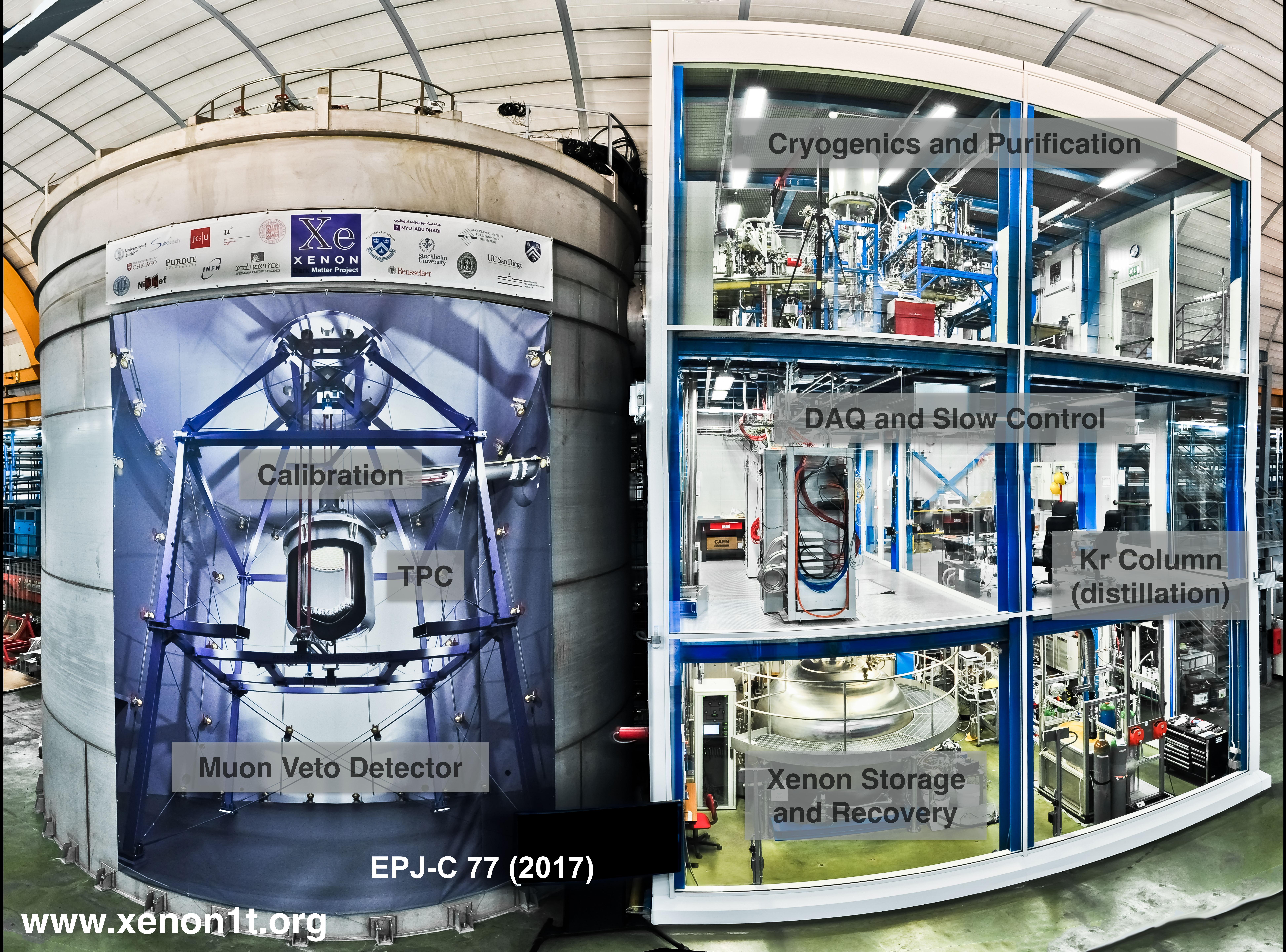


Next Step: G2 LXe and LAr DM Experiments

Which are the major technical challenges?

- Radon concentration in the bulk liquid xenon
  - Lowest achieved in XENON1T: 5 μBq/kg
  - G2 goal: 1~2 μBq/kg (still the dominant ER background in XENONnT & LZ)
  - Rn control, online distillation, charcoal adsorption
- Neutron background
  - Neutron veto (LZ: liquid scintillator, XENONnT: Gd-doped water)
- Long electron drift length (over a meter)
  - Require >1 ms electron lifetime: fast/efficient purification
  - Need faster drift velocity to avoid too much diffusion: 30~100 kV on cathode
- Large diameter TPC
  - Electron emission rate from gate/cathode electrodes needs to be controlled
  - Signal uniformity

From XENON1T to XENONnT



A more massive and lower background LXeTPC

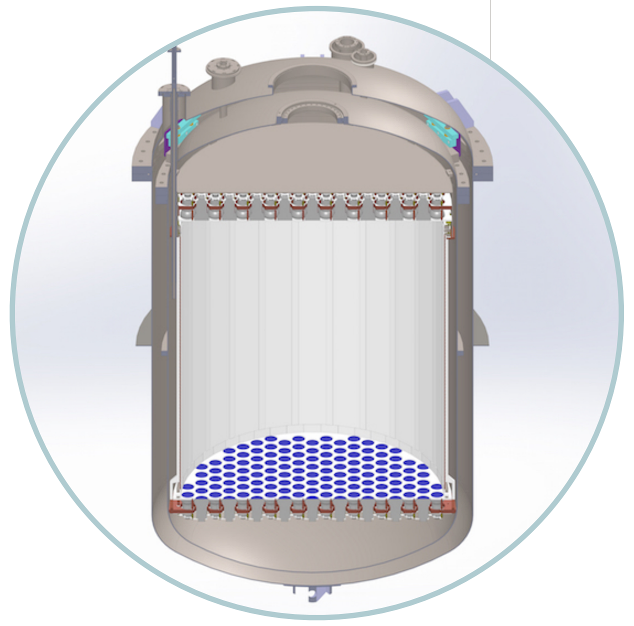
XENON1T Infrastructure and sub-systems already operative

Aprile et al., Eur. Phys. J. C (2017) 77

1/10 reduction of background and x10 sensitivity improvement

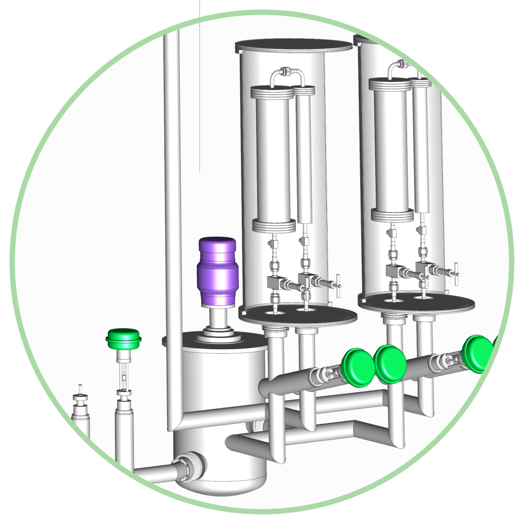
Some upgrades aimed at reducing Rn220 already implemented and working

Fast turnaround: ongoing commissioning. Start data taking Summer 2020



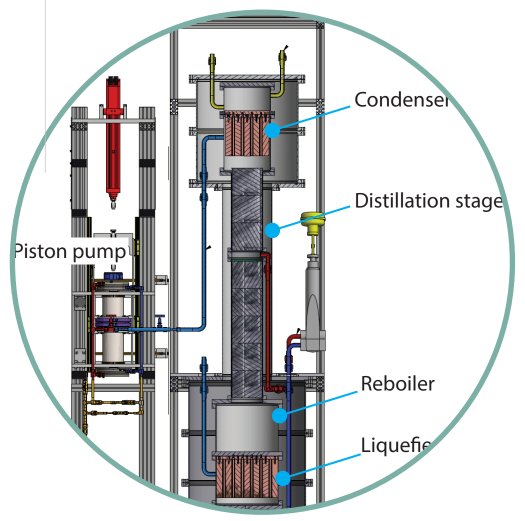
New TPC

8.4 ton (5.9 active) Time Projection Chamber



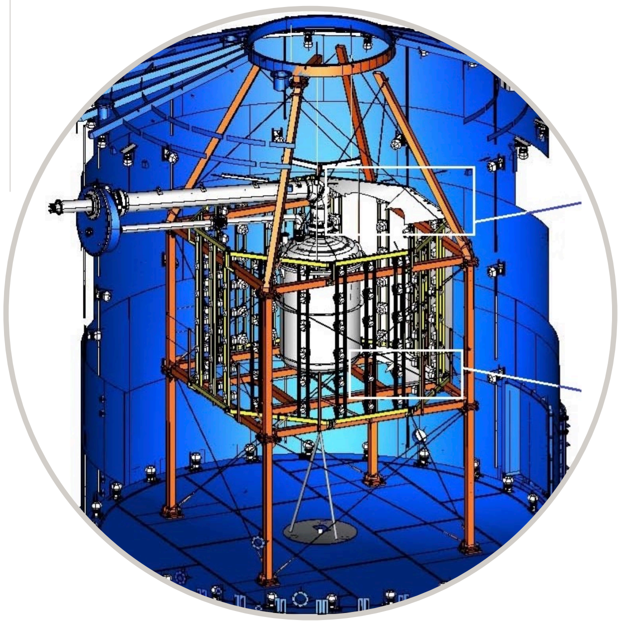
LXe Purification

To achieve fast cleaning of the large LXe volume (5000 SLPM)



Radon Distillation

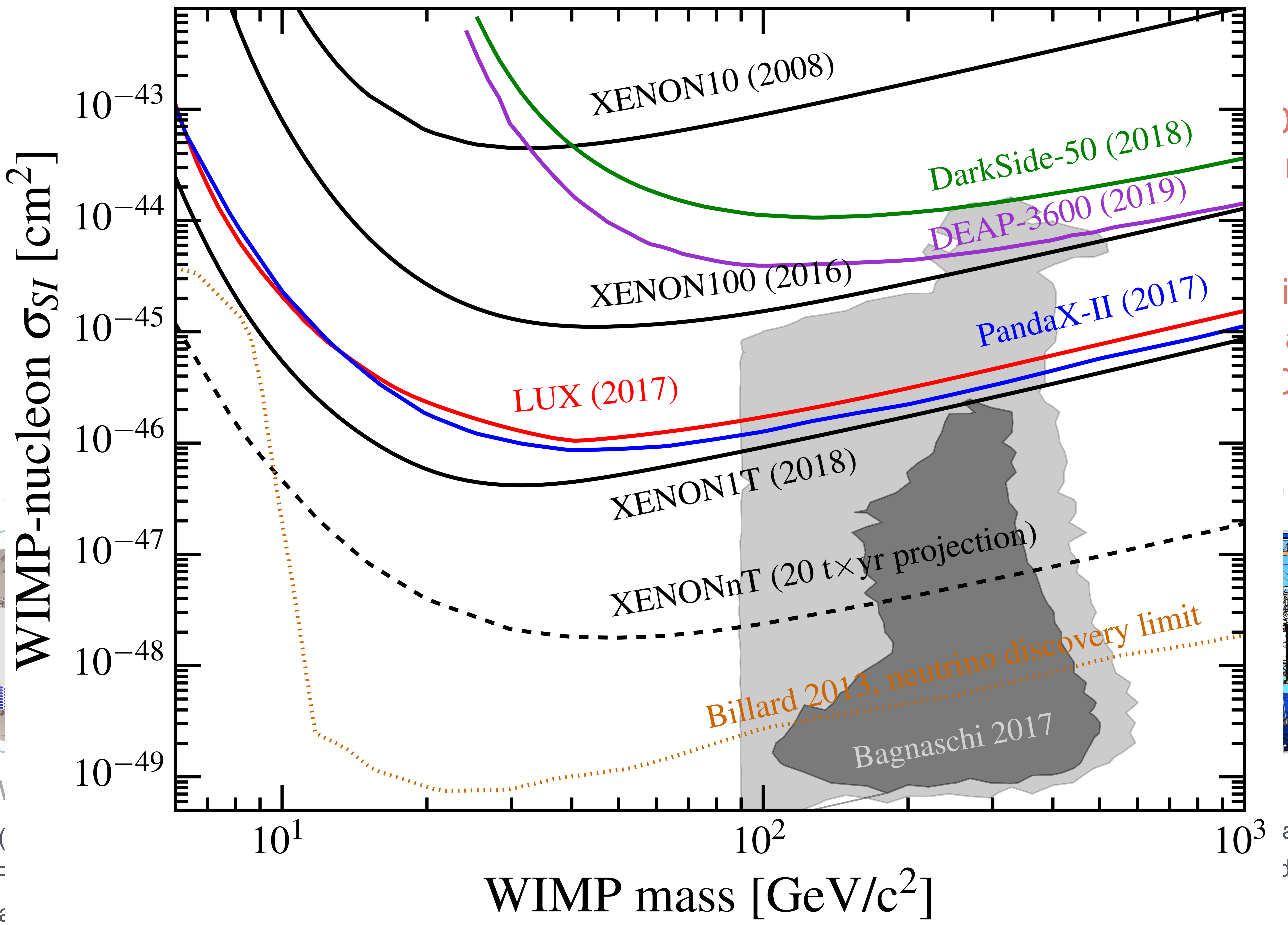
To remove the ^{222}Rn emanated inside the detector



Neutron Veto

To tag and measure in situ neutron-induced background

A more massive and lower background LXeTPC

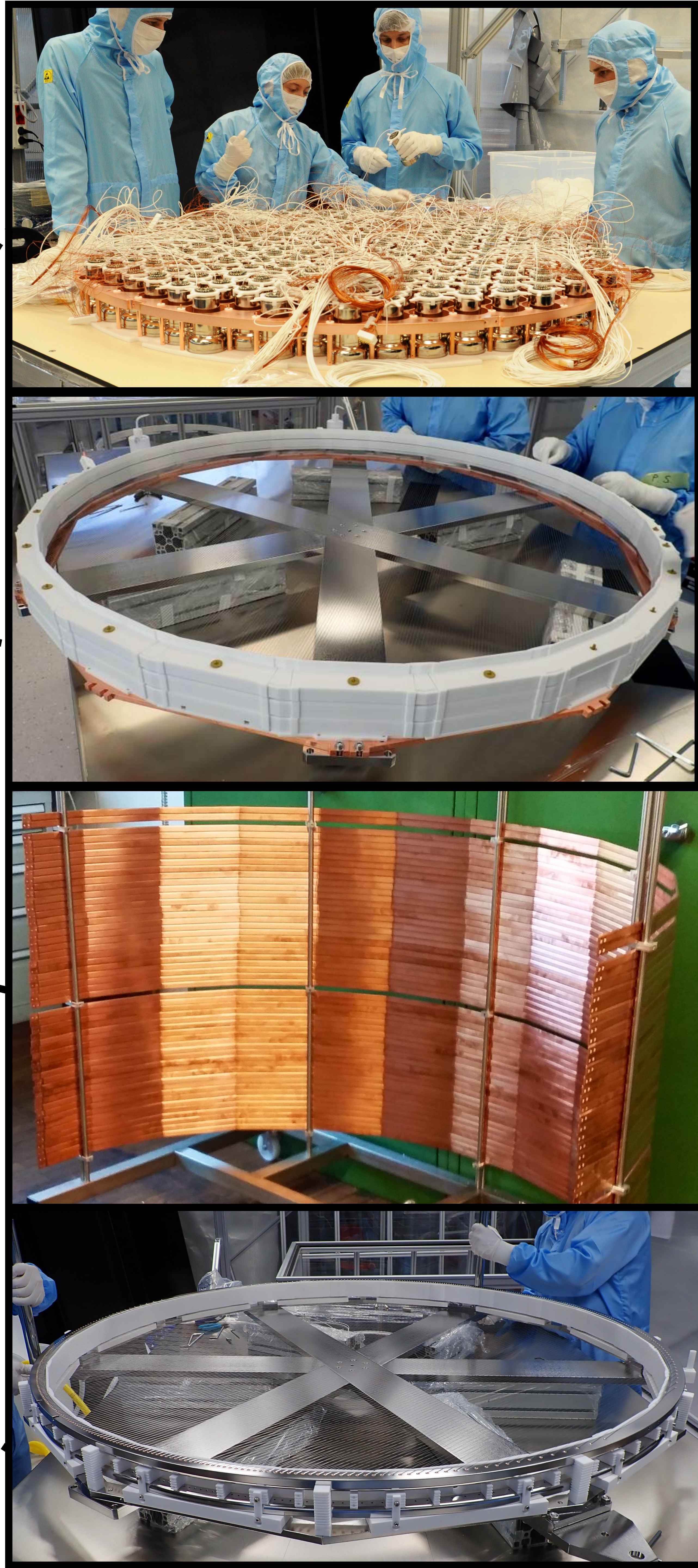


New
8.4 ton (
Time F
Cha

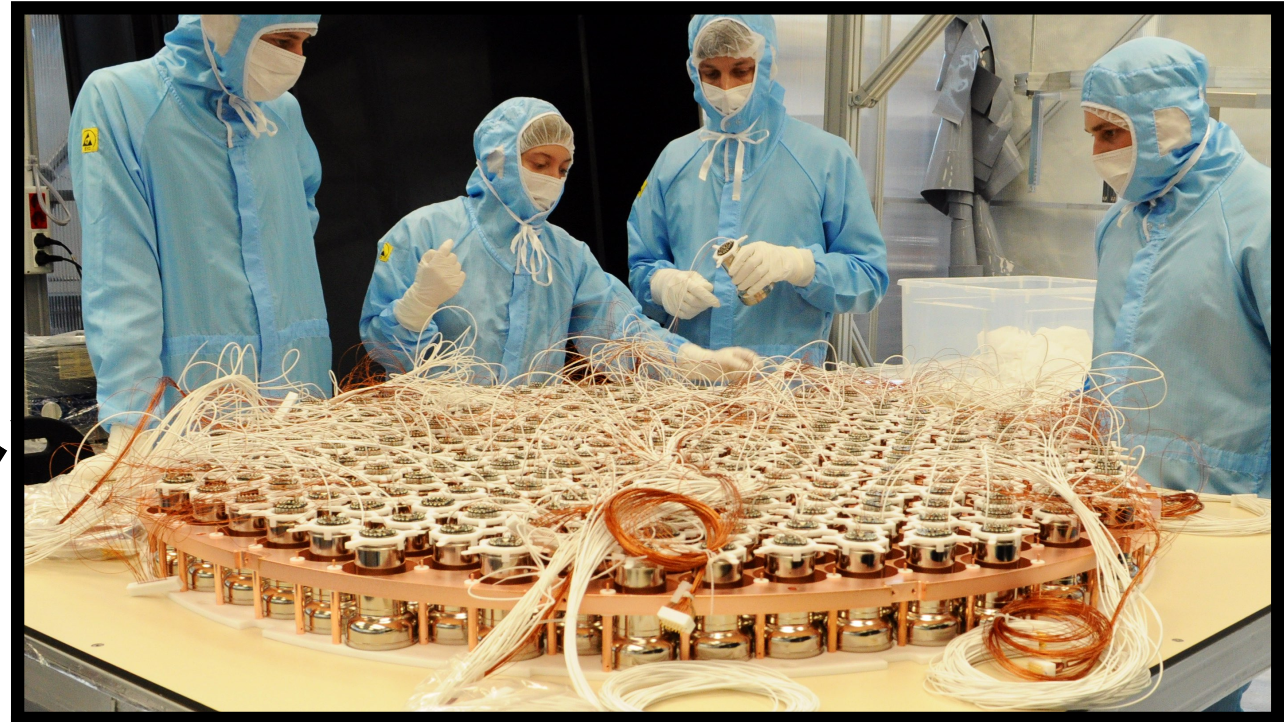
)
nt
ing
ata
)
Veto
asure in situ
d background

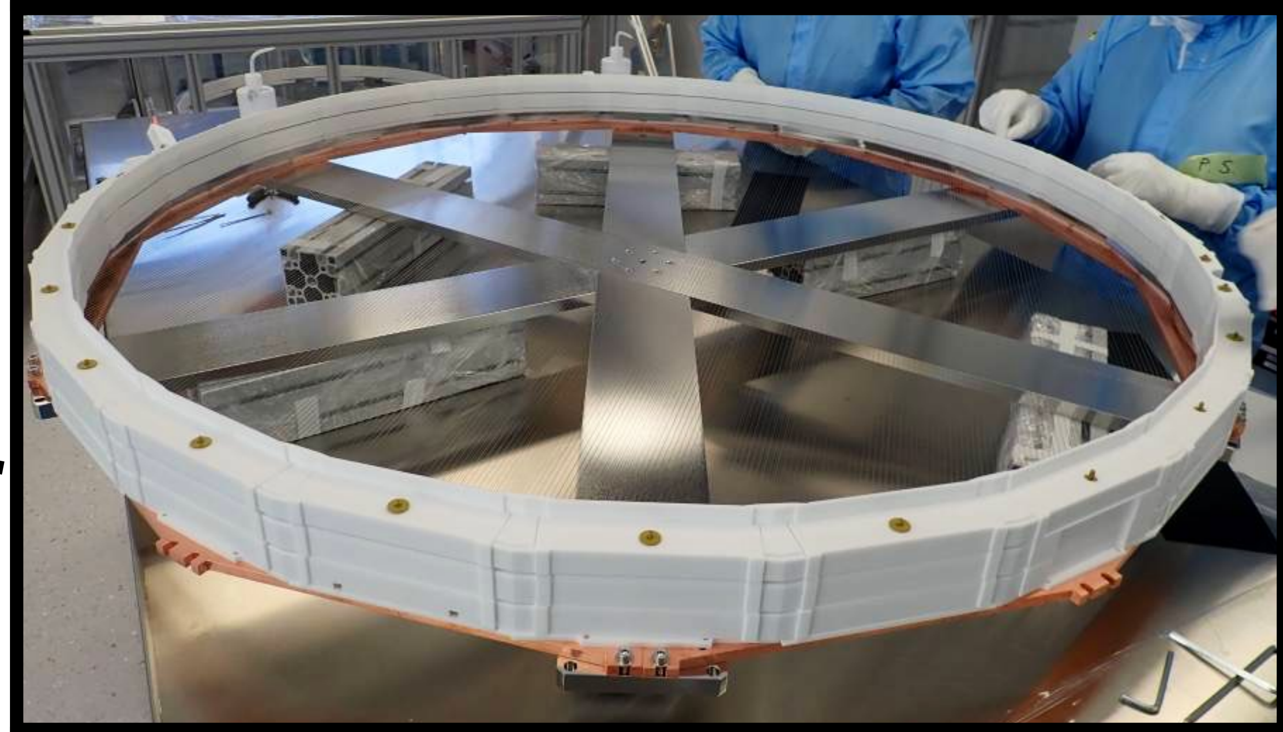
Time Projection Chamber

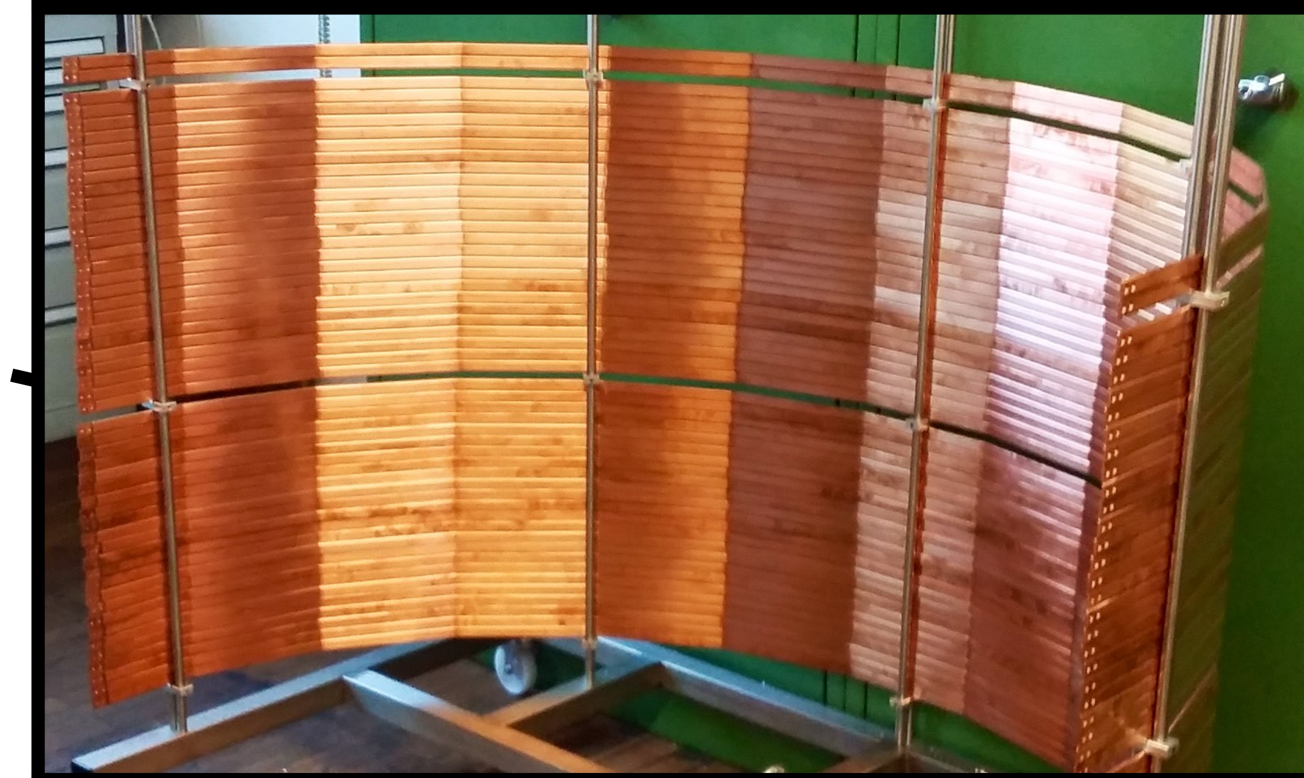
- 1.3 m diameter, 1.6 m high
- 253 PMTs (3”) in top array
- 241 PMTs (3”) in bottom array
- 6 tons target mass of LXe
- being assembled now at LNGS
- start of LXe filling (8.4 tons) planned in April 2020

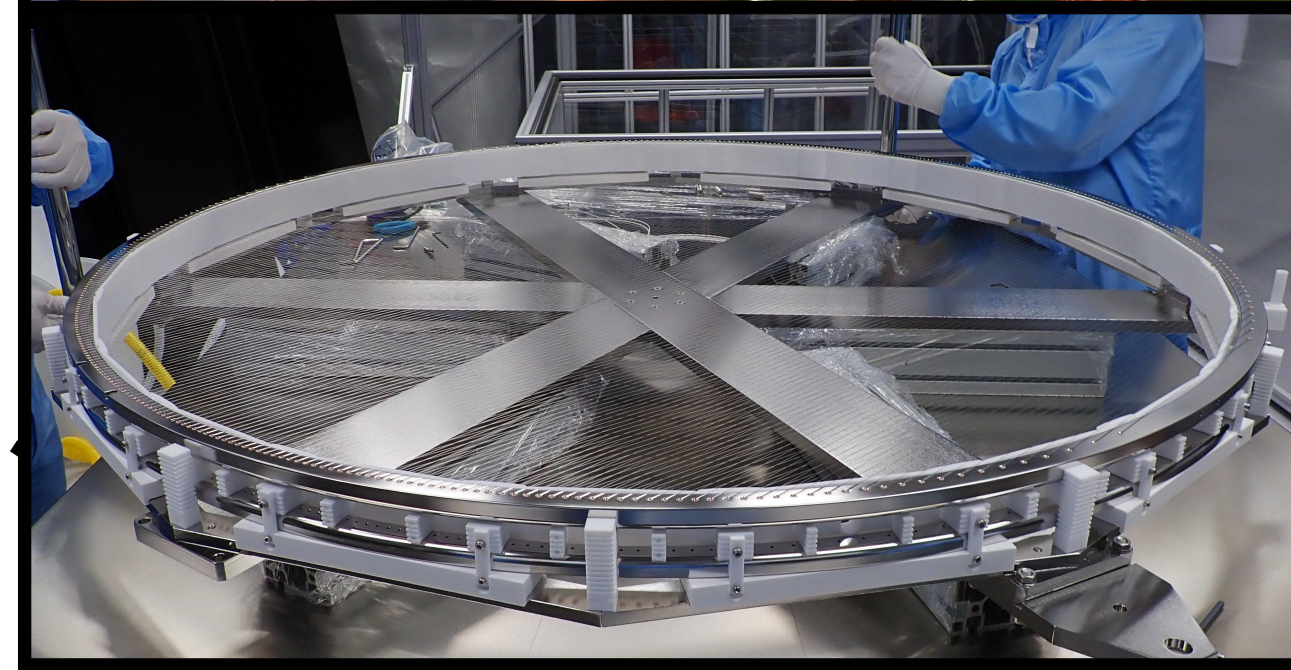


Time Projection Chamber





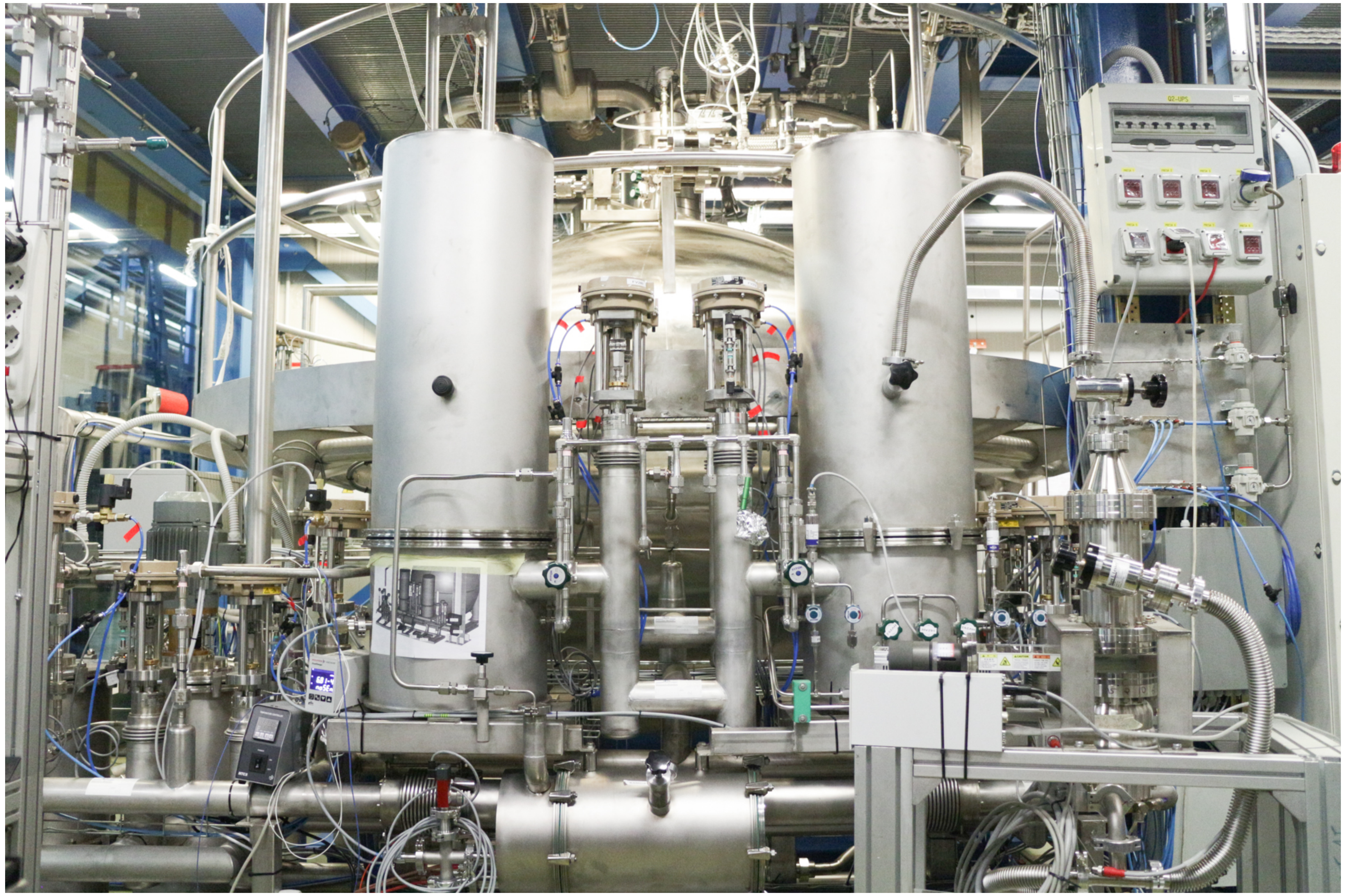




Cryogenic LXe Purification System

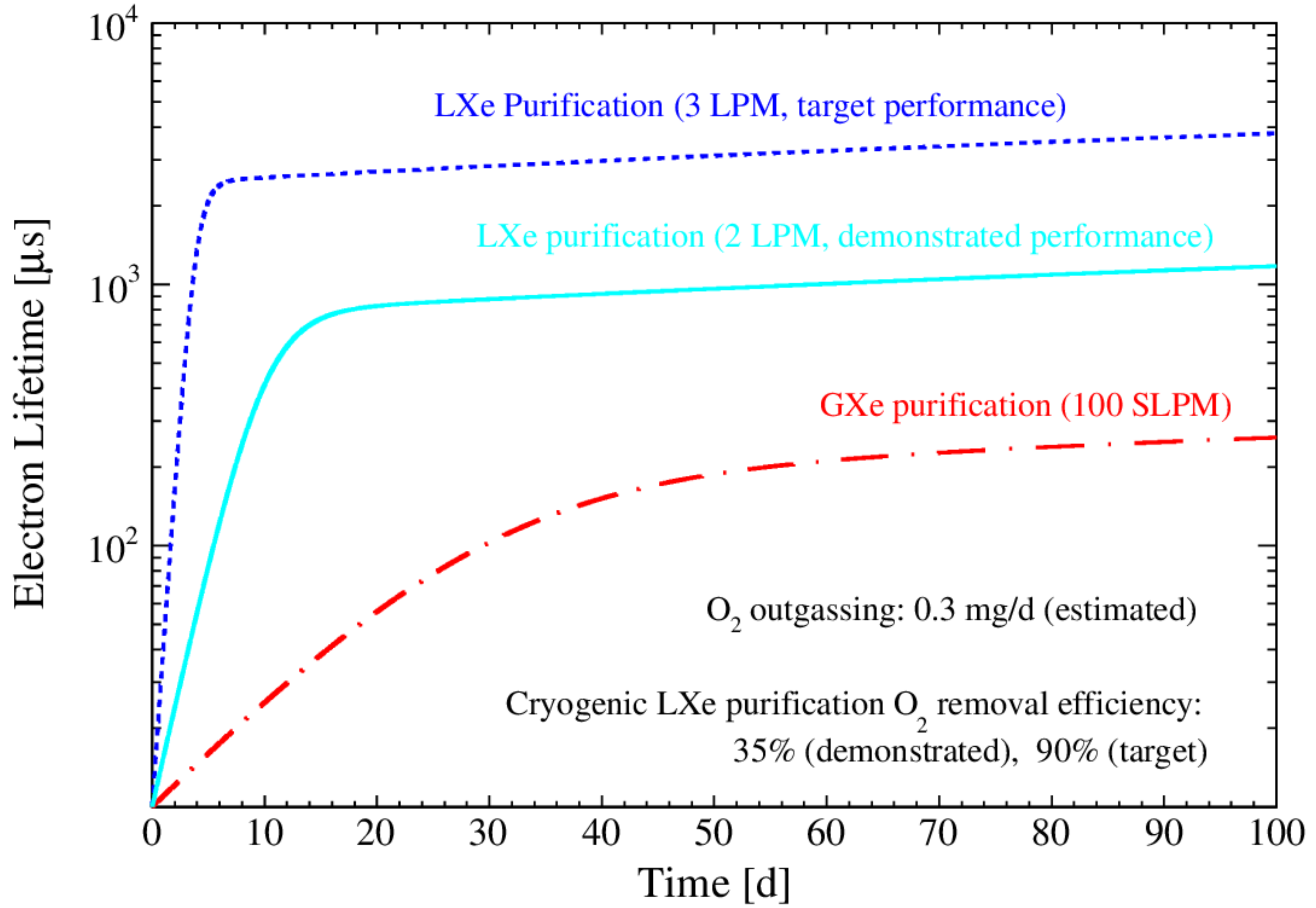
Design

- Reduce O_2 concentration to << 1 ppb
- Range of LXe flows possible, from 1 LPM to 5 LPM
- Continuous operation (backup LXe pump, backup O_2 filter)
- Fast electron lifetime measurement with purity monitor



Commissioning

- System commissioning almost completed
- Demonstrated reliable LXe operation over weeks
- High efficiency and low specific radon emanation rate
- Higher efficiency of O_2 filter with better controlled activation
- New LXe purification system will allow electron lifetime
- goal to be achieved early in detector commissioning phase



Cryogenic Radon Distillation Column

New MagPump Design
-
Compressor
based on prototype
Eur. Phys. J. C (2018) 78: 604

Flow: 200 slpm (72 kg/h)

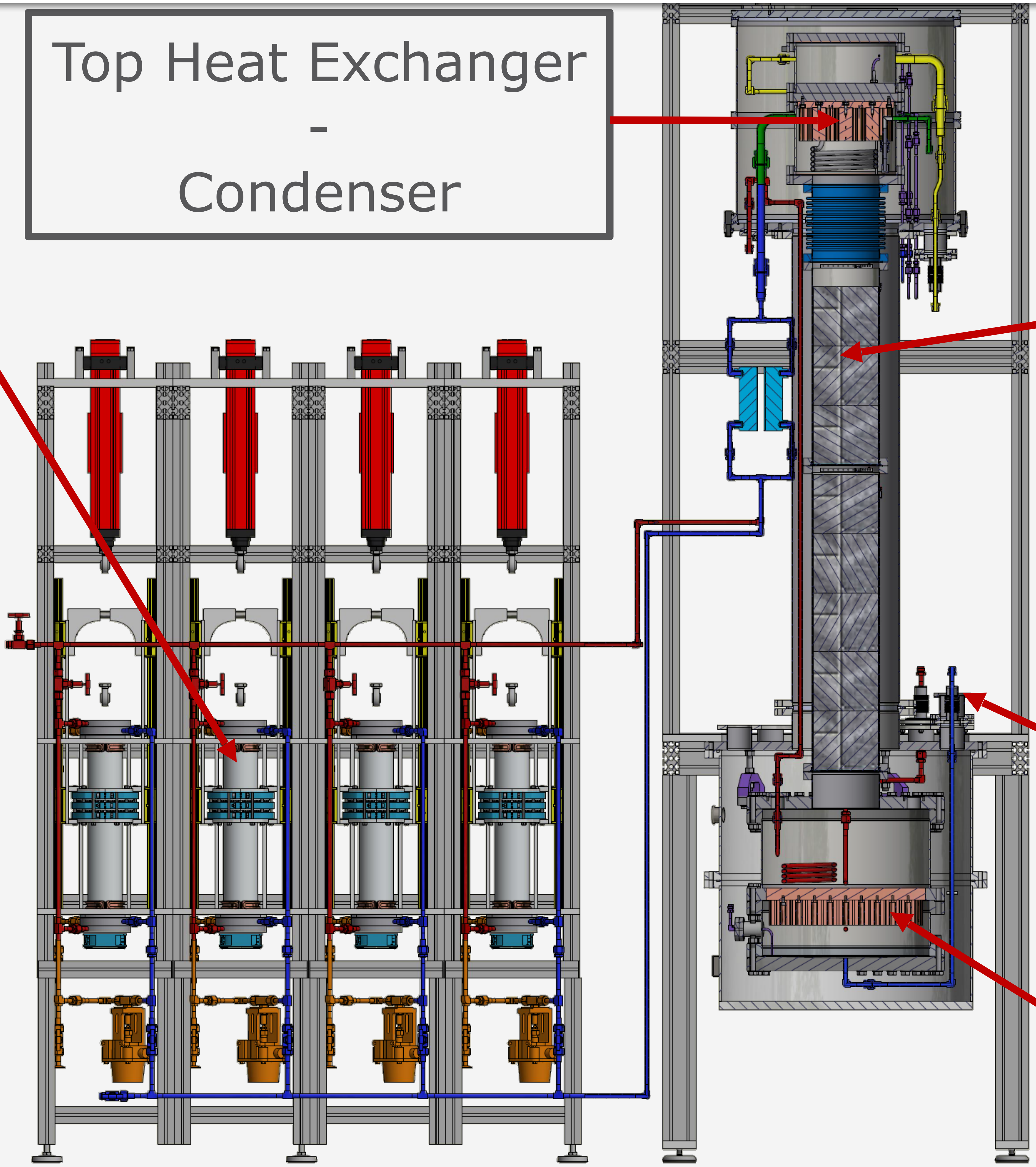
Reflux ratio: 0.5
→ > 1 kW cooling power required

Depletion factor 100 at top

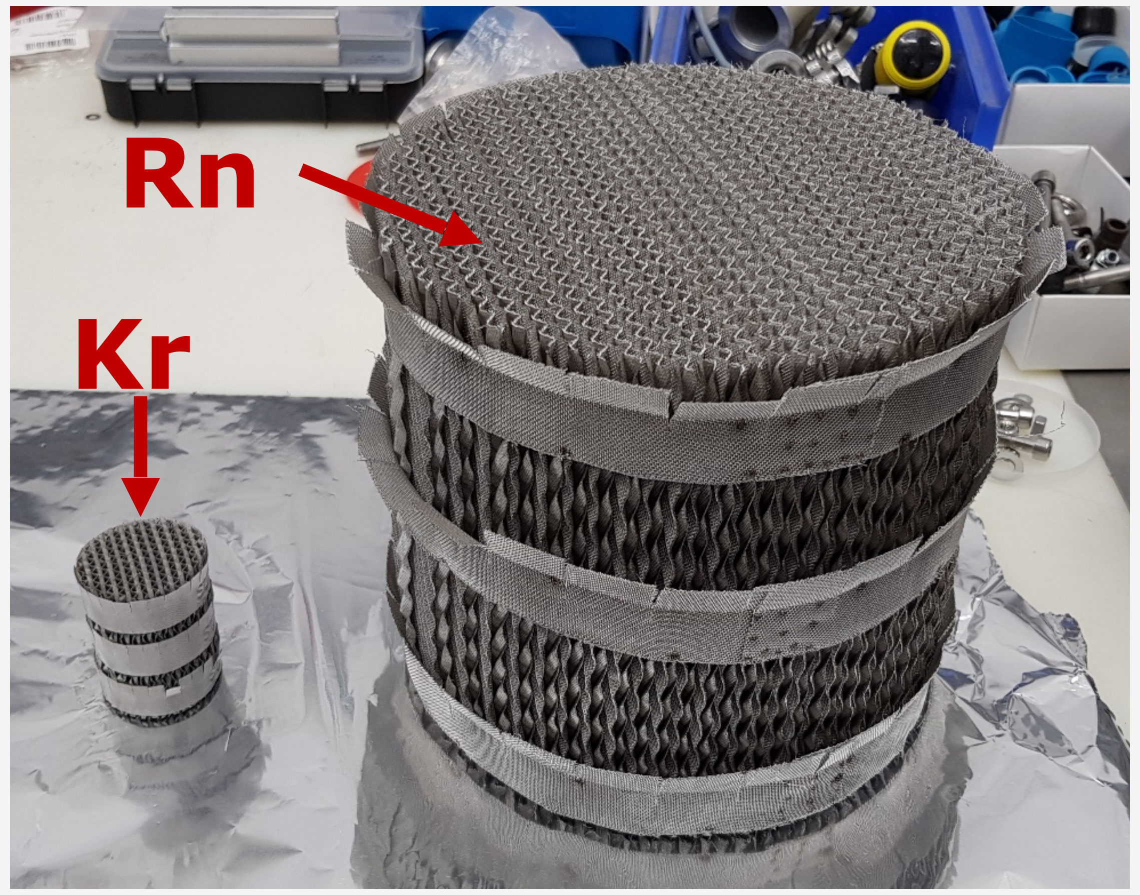
Enrichment factor 1000 at bottom

No additional cooling power required due to radon-free compressor

Top Heat Exchanger
-
Condenser



Larger package material



LXe inlet and outlet
-
Connection to LXe PUR
by Costruzioni Generali

Bottom Heat Exchanger
-
Reboiler

XENON

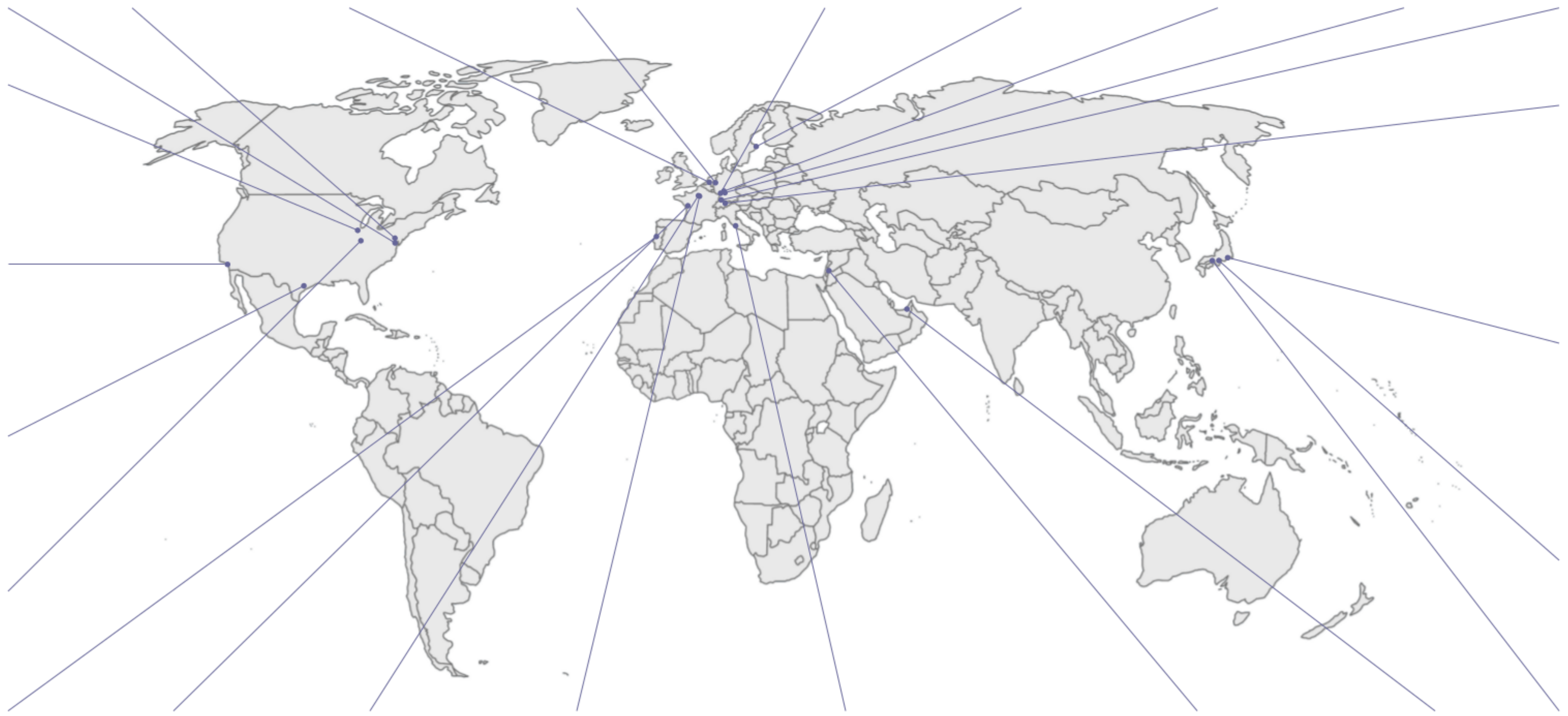
175 scientists from 27 institutions

Columbia · RPI · Nikhef · Muenster · KIT · Stockholm · Mainz · MPIK, Heidelberg · Freiburg

Chicago · UCSD · Rice · Purdue · Coimbra

Zurich · Tokyo · Nagoya · Kobe

Subatech · LPNHE · LAL · Bologna · LNGS · Torino · Napoli · Weizmann · NYUAD



LUX-ZEPLIN (LZ) detector *at SURF (~2020)*

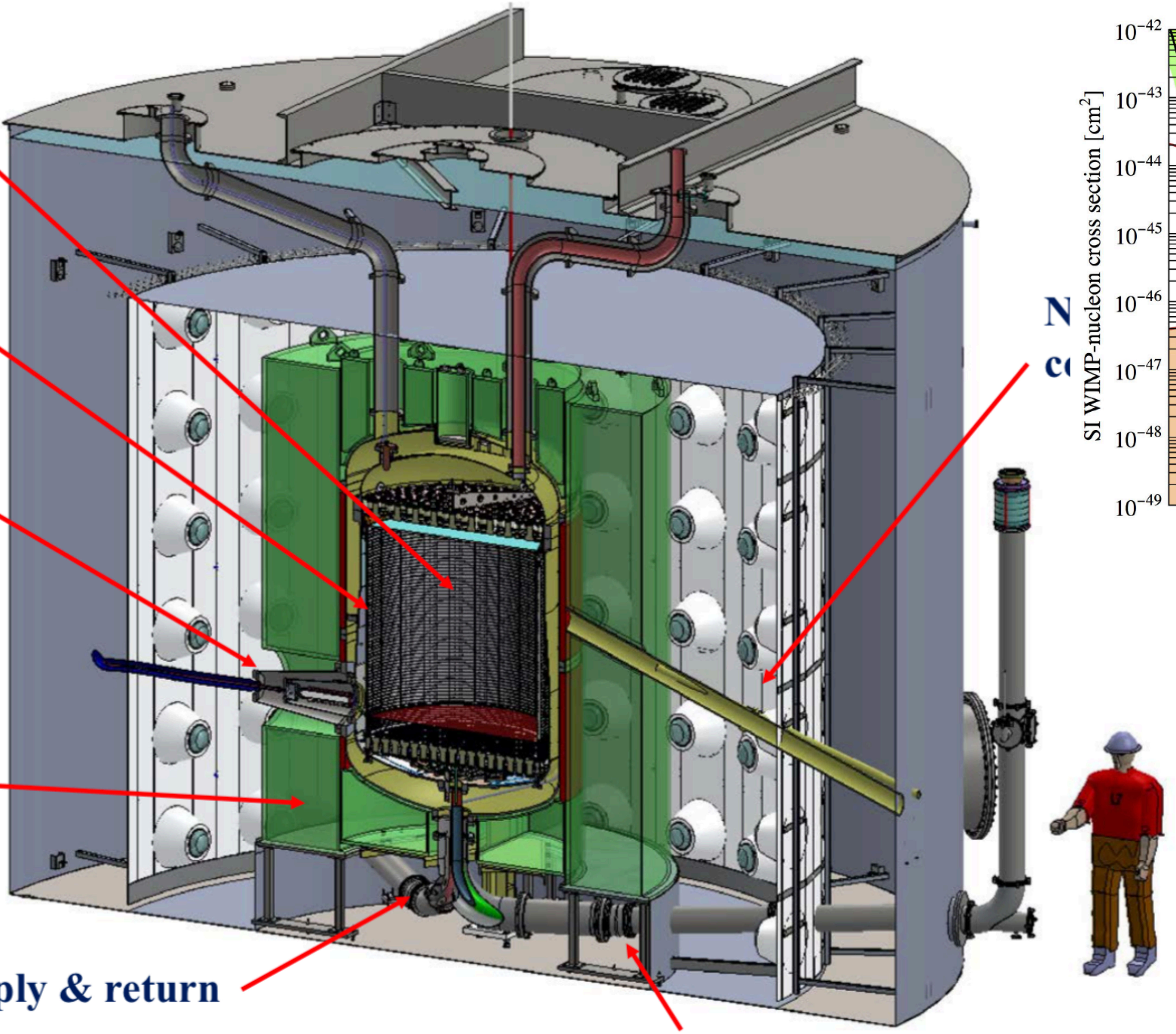
7.0 T active LXe
5.6T fiducial

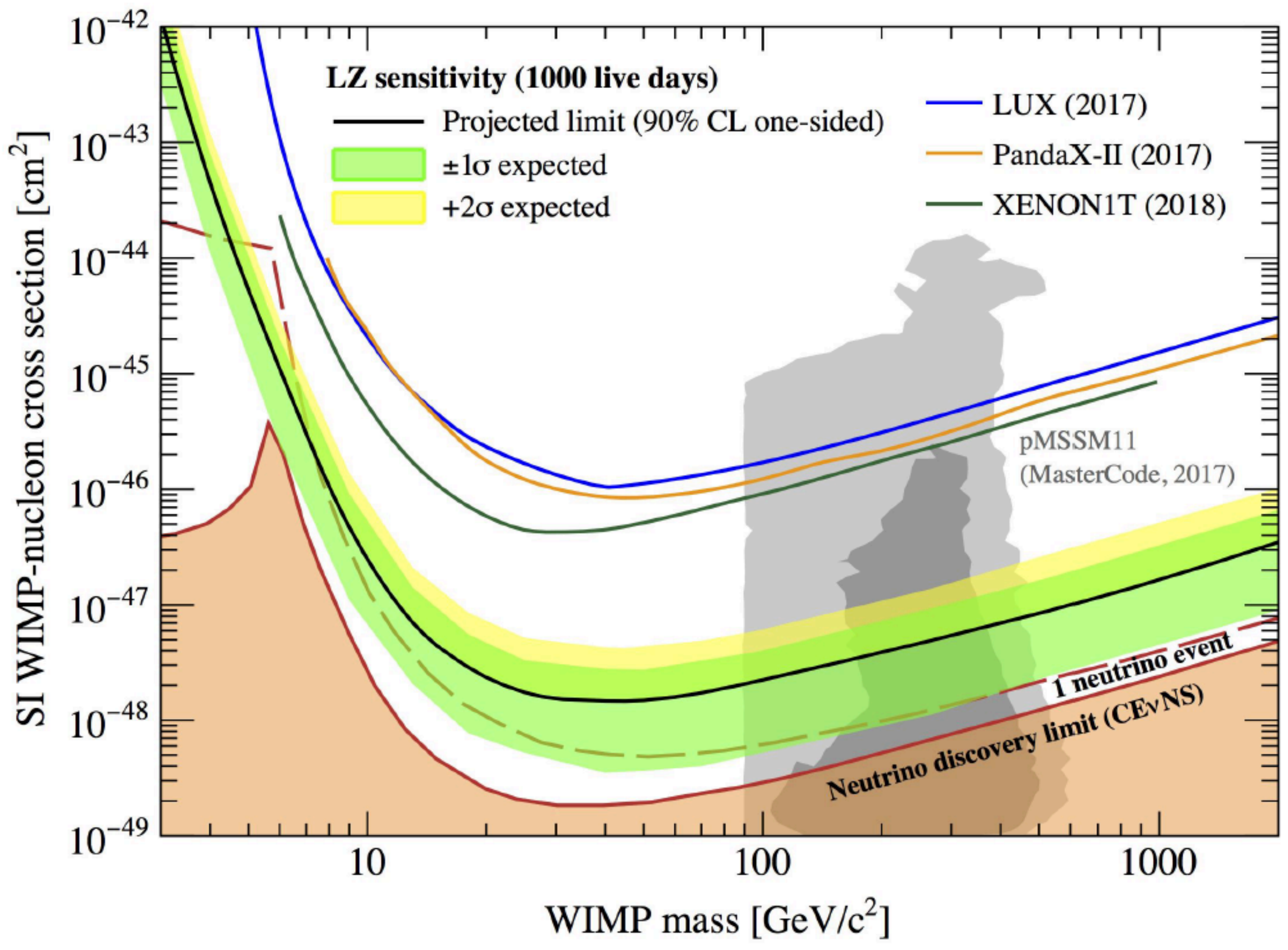
Instrumented
Xe skin detector

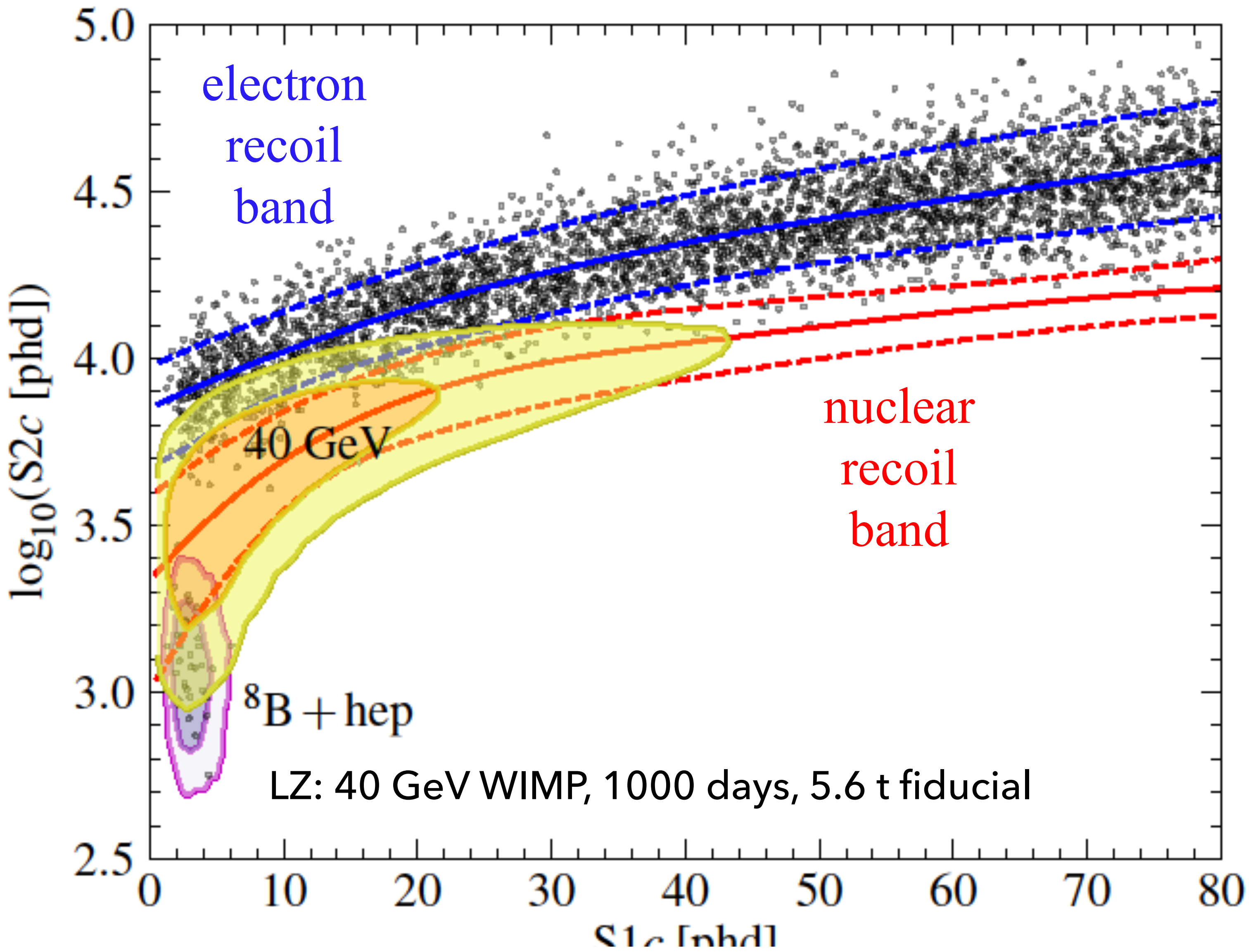
50 kV cathode
high voltage

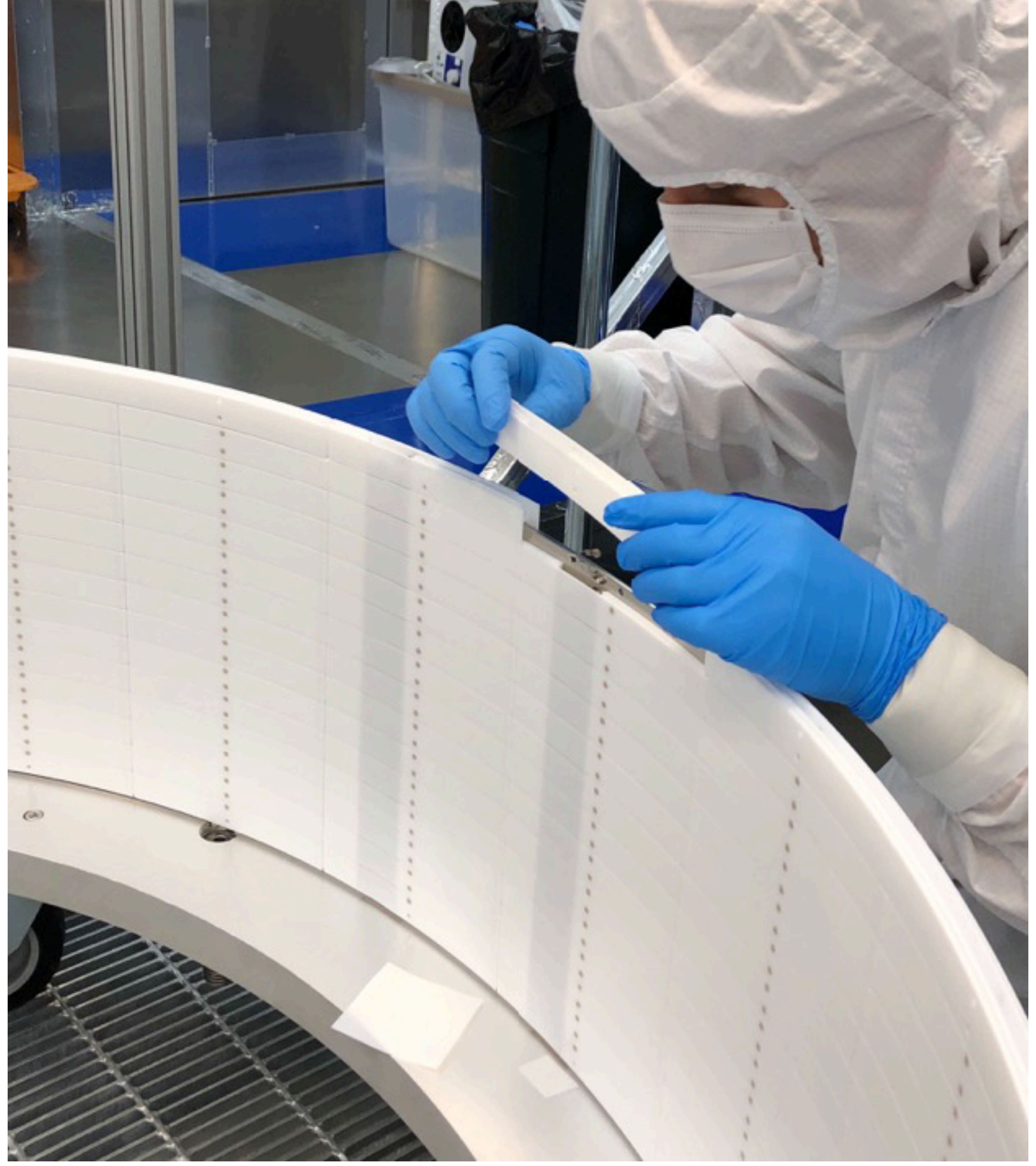
17 tonnes
Gd-LS
Outer
Detector

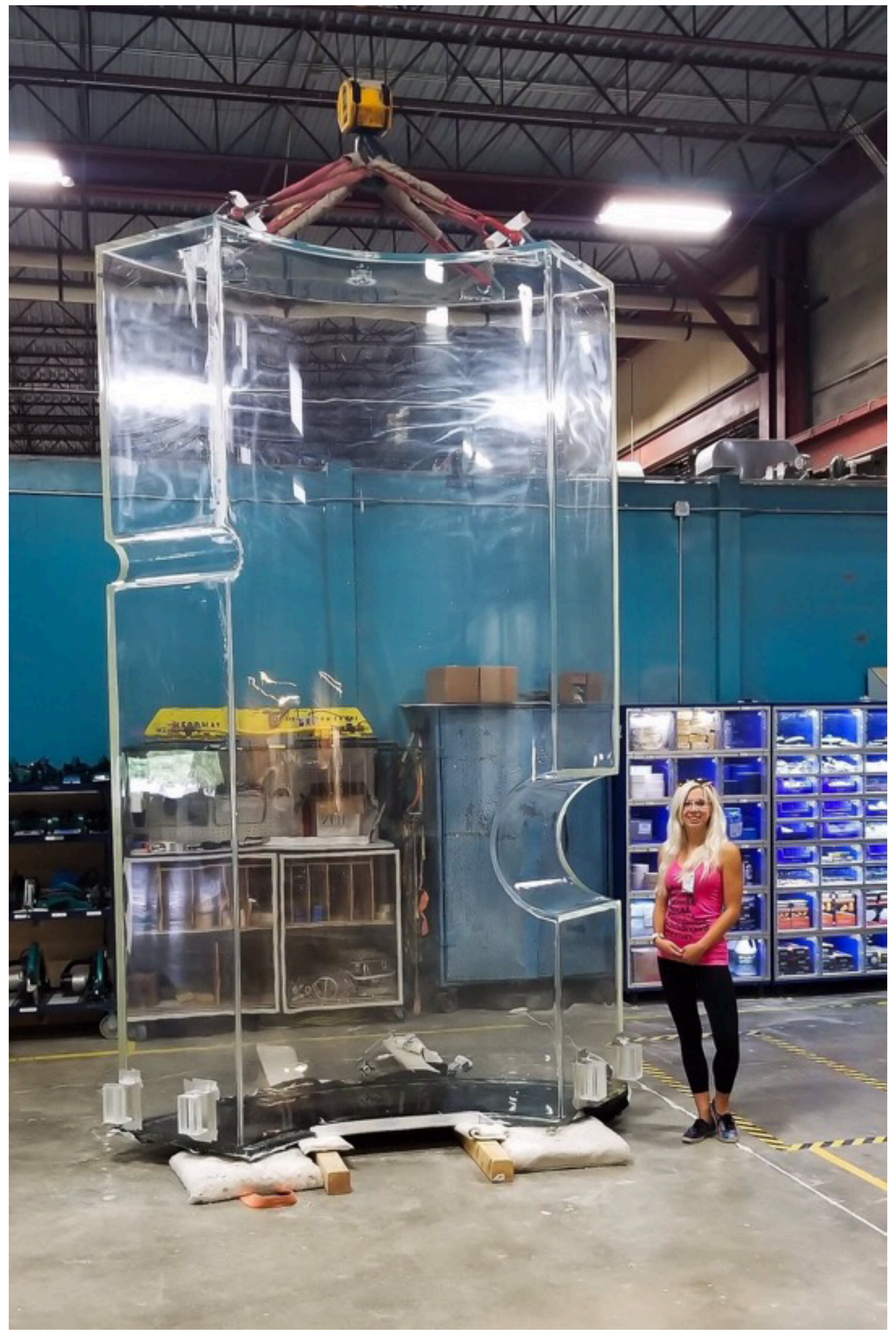
LXe supply & return

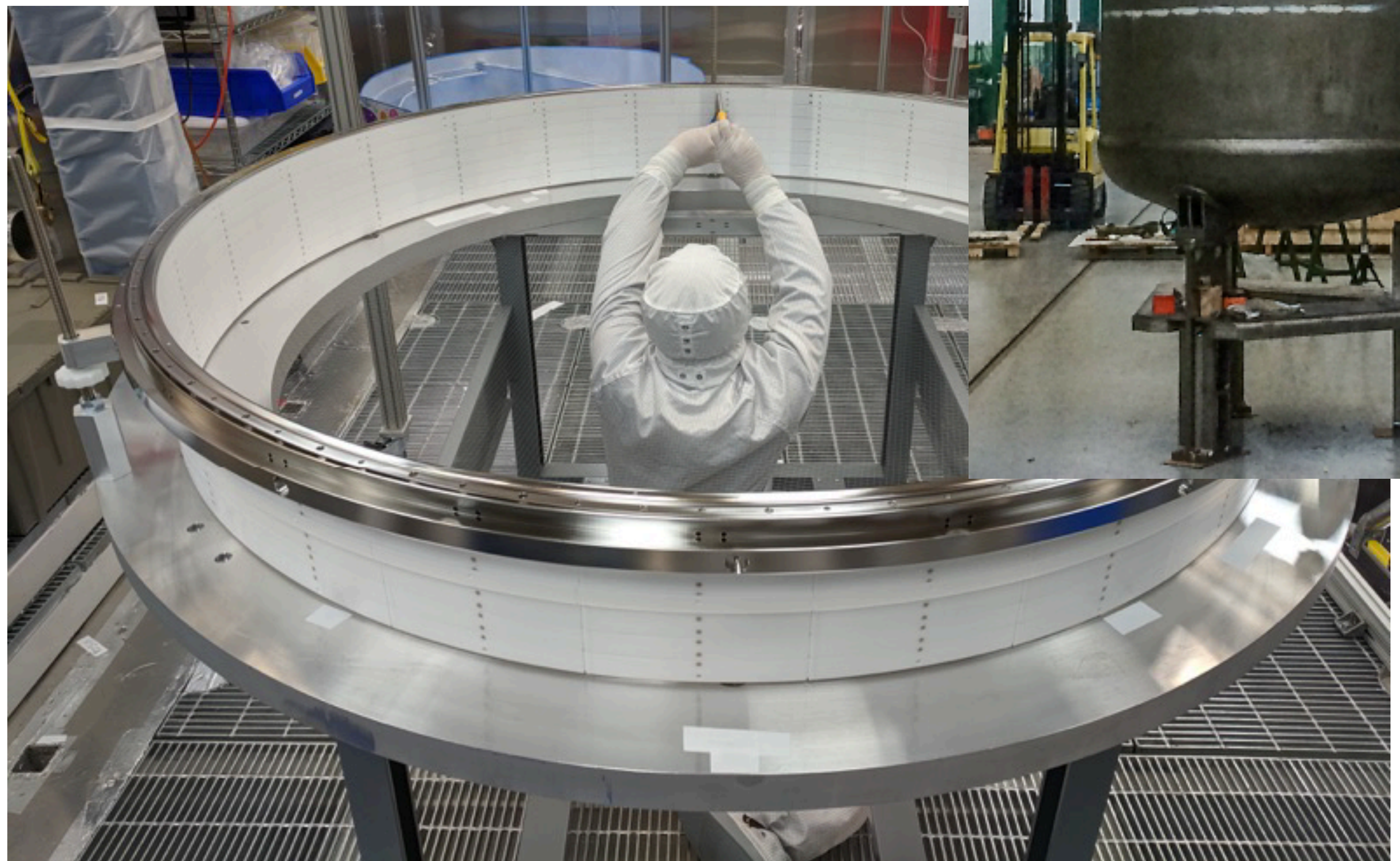











DarkSide-20K at Gran Sasso (~2022)

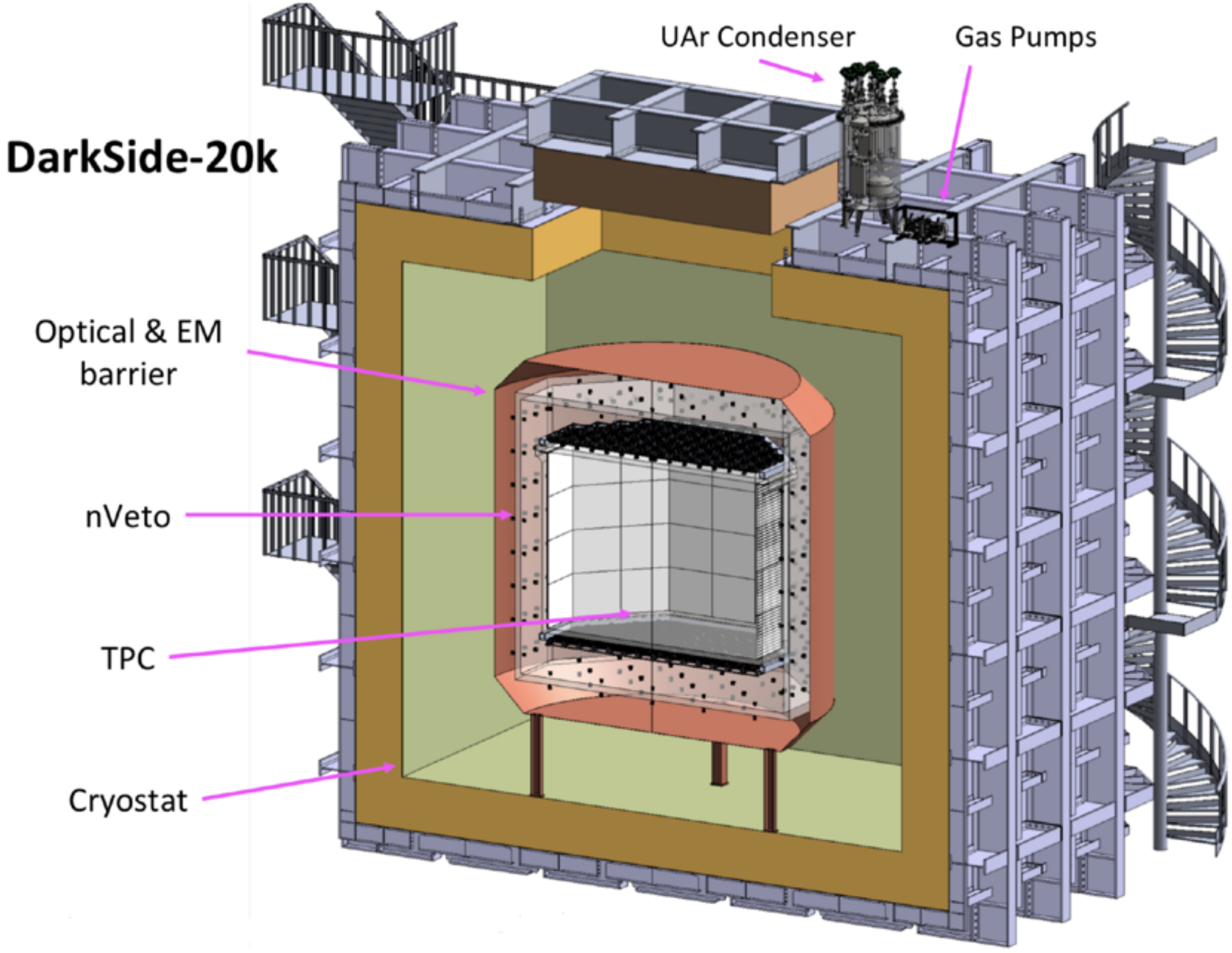
two-phase TPC with 50 ton (30 ton iducial) underground Ar with <1 μBq/kg)

Facilities (URANIA and ARIA) to produce UAr depleted in Ar39 by multi-path cryogenics distillation

TPC acrylic vessel surrounded by atmospheric Ar (in ProtoDUNE like cryostat) + acrylic shell (Gd loaded) as neutron veto

Separate cryogenic systems for DAr and AAr

Cryogenic SiPMs as photosensors: 8280 in TPC, ~3000 in Veto



DarkSide-20K at Gran Sasso (~2022)

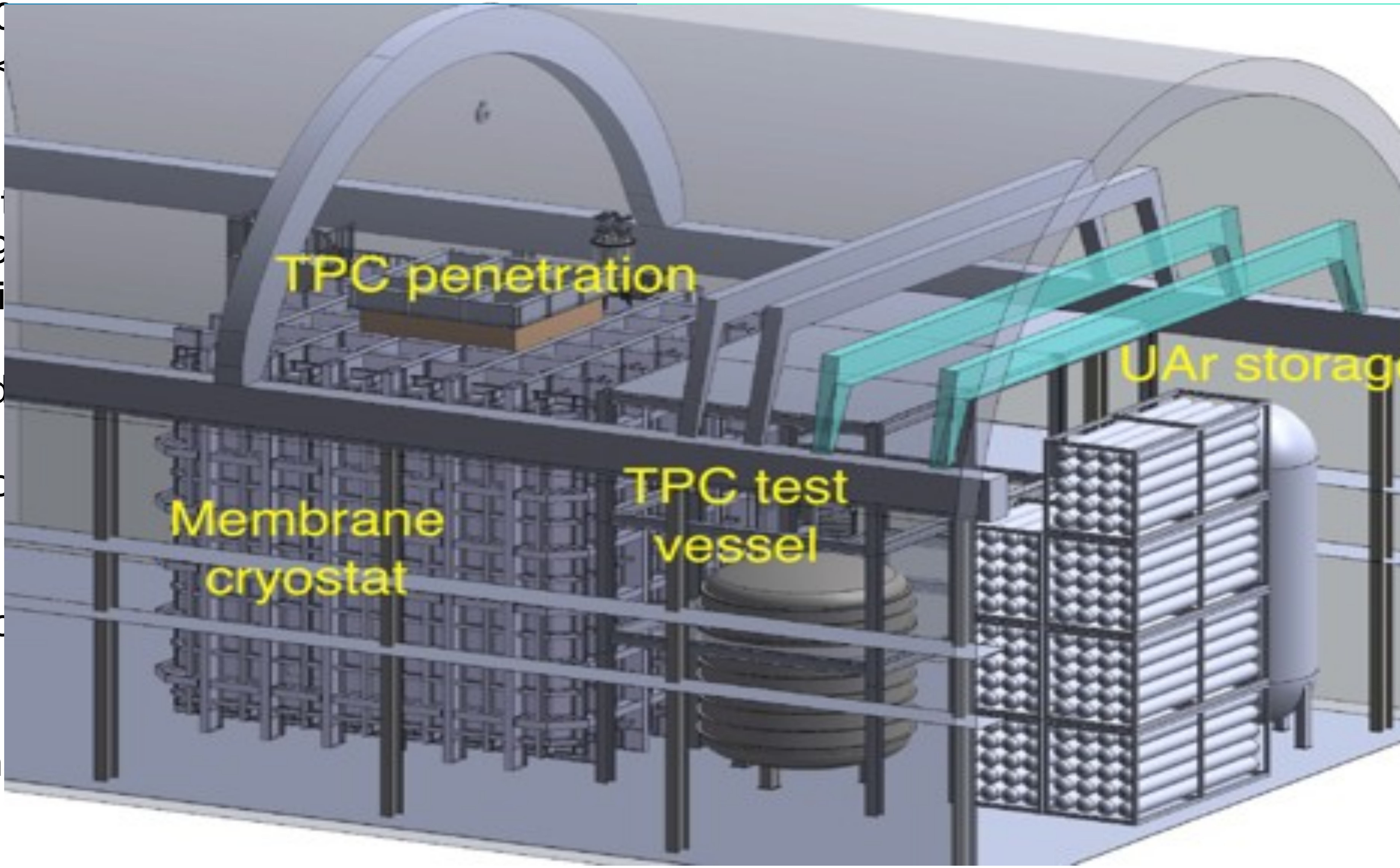
two-phase TPC with 50 ton (30
iducial) underground Ar with <
kg)

Facilities (URANIA and ARIA) t
produce UAr depleted in Ar39
multi-path cryogenics distillati

TPC acrylic vessel surrounded
atmospheric Ar (in ProtoDUN
cryostat) + acrylic shell (Gd lo
as neutron veto

Separate cryogenic systems fo
and AAr

Cryogenic SiPMs as photosen
8280 in TPC, ~3000 in Veto



DarkSide-20K at Gran Sasso (~2022)

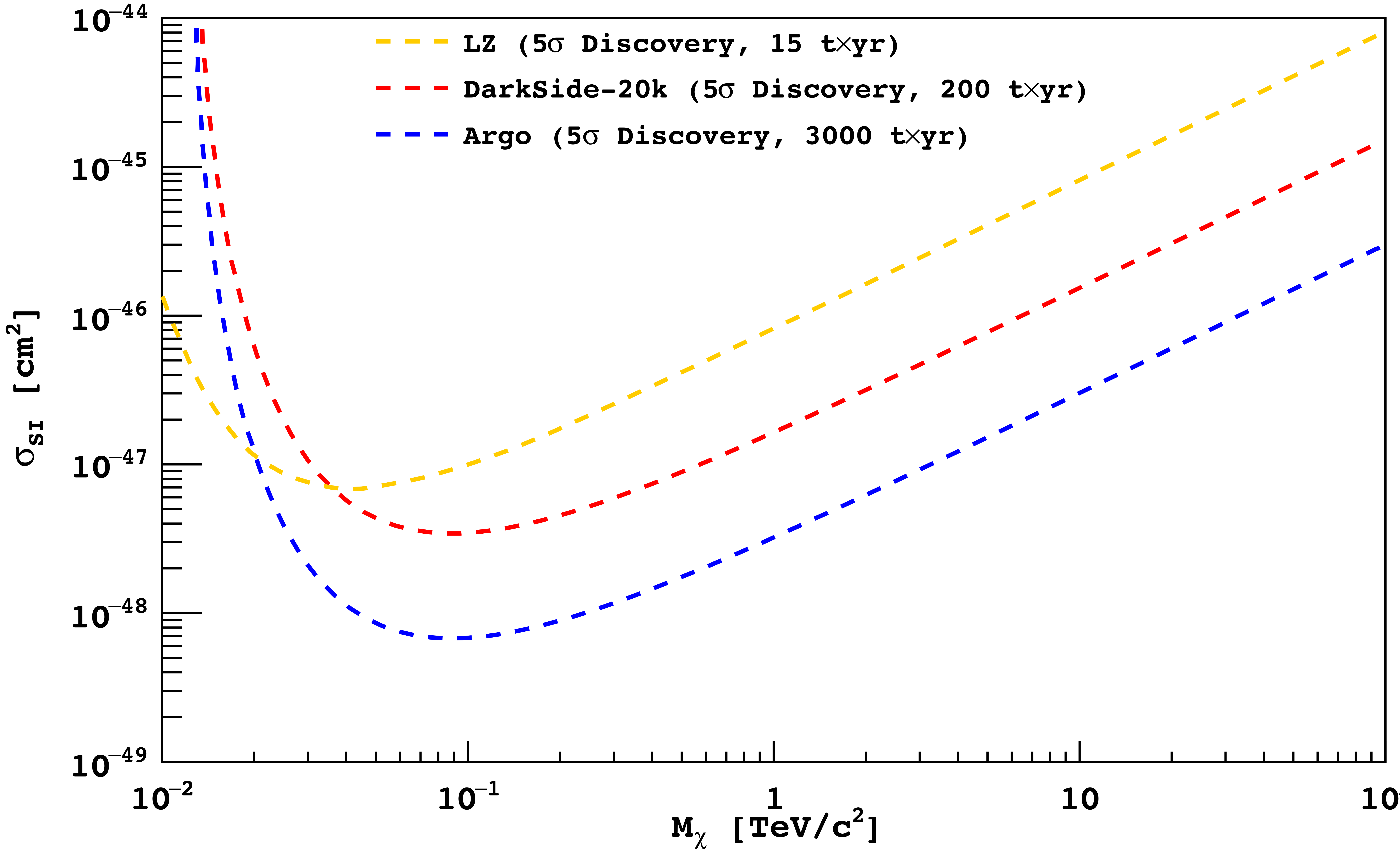
two-phase TPC with 5
 iducial) underground
 kg)

Facilities (URANIA and
 produce UAr depleted
 multi-path cryogenics

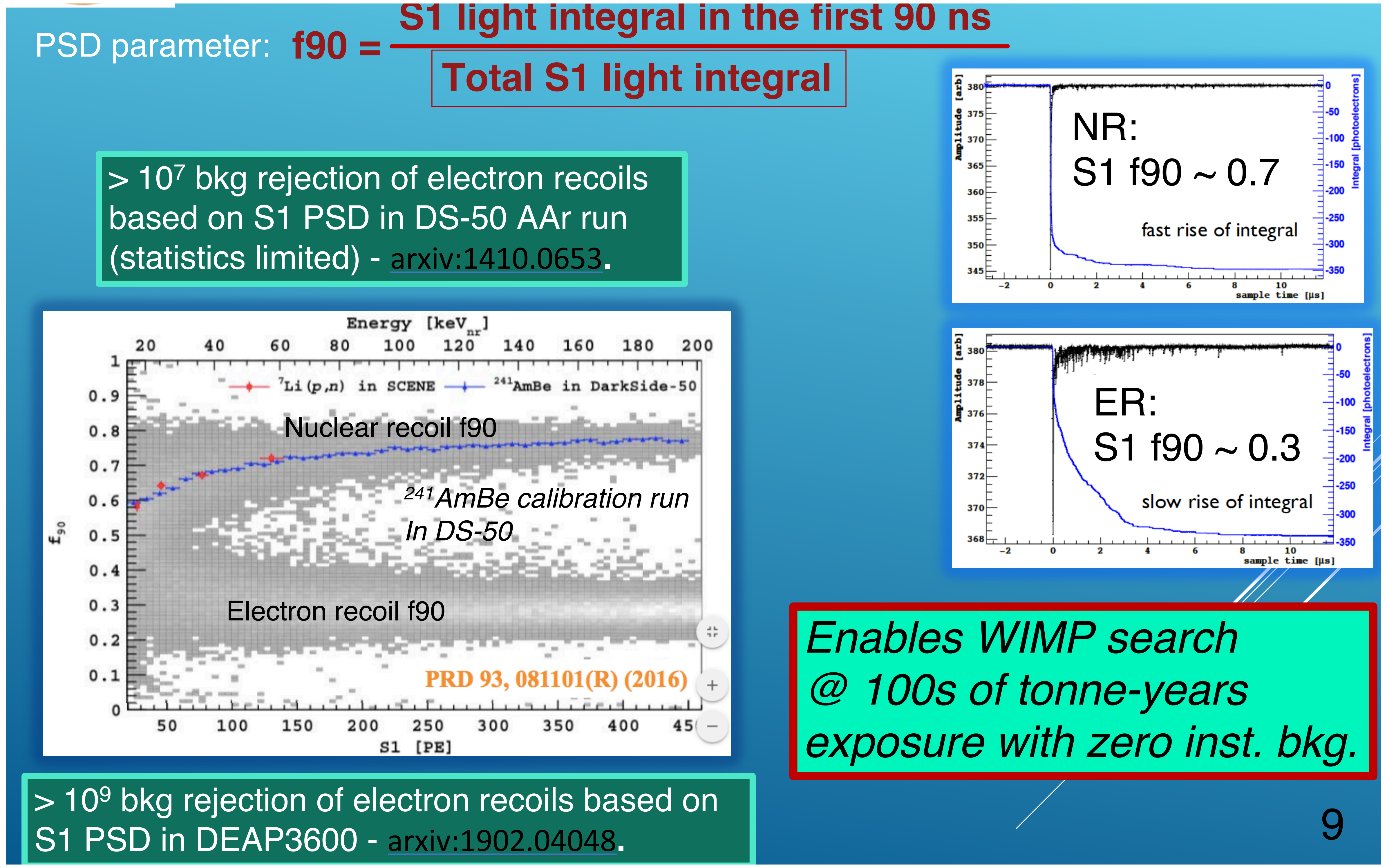
TPC acrylic vessel sur
 atmospheric Ar (in Pr
 cryostat) + acrylic she
 as neutron veto

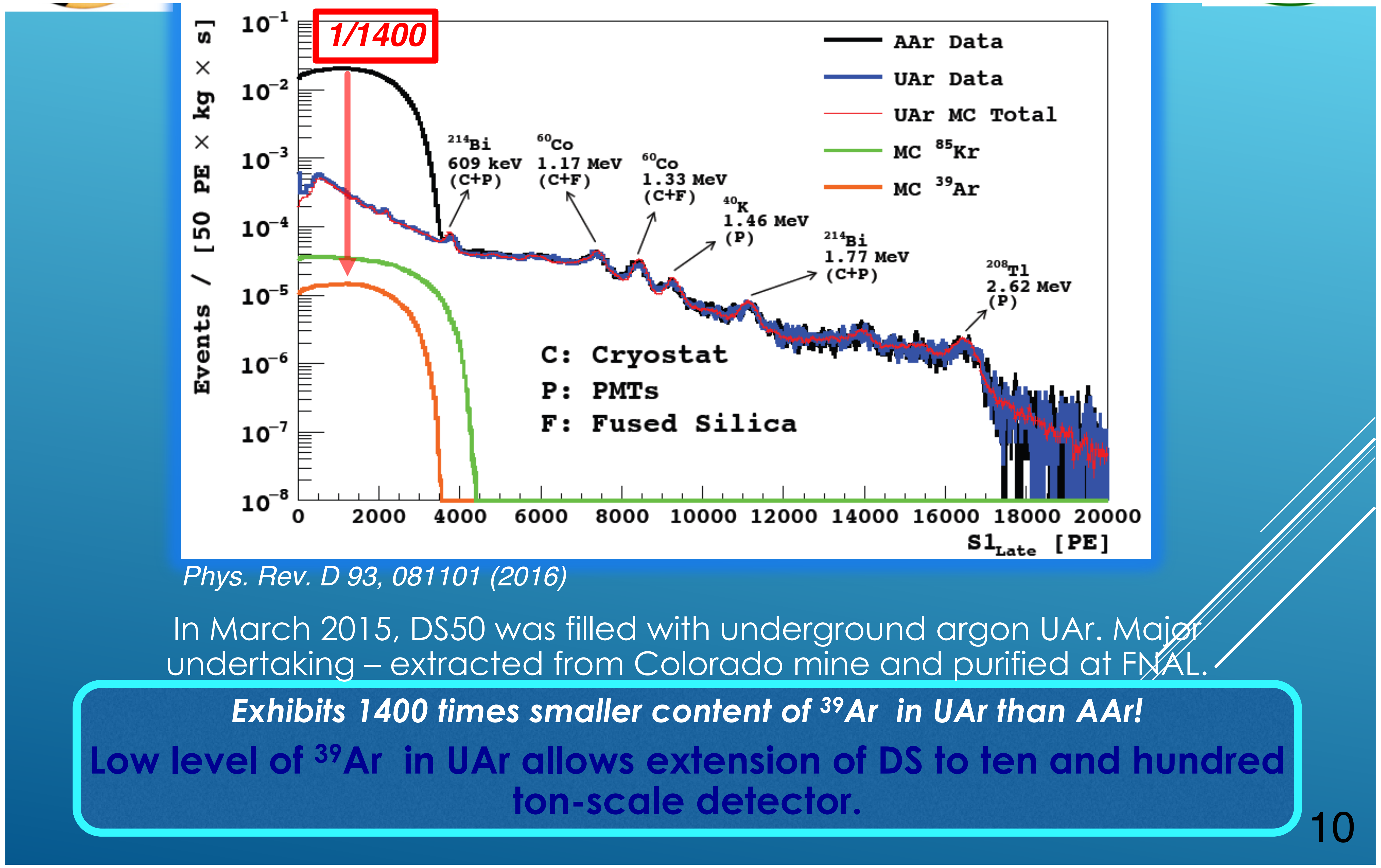
Separate cryogenic sy
 and AAr

Cryogenic SiPMs as p
 8280 in TPC, ~3000 i



Two key requirements demonstrated with DS-50 and DEAP-3600: PSD and Depleted Ar

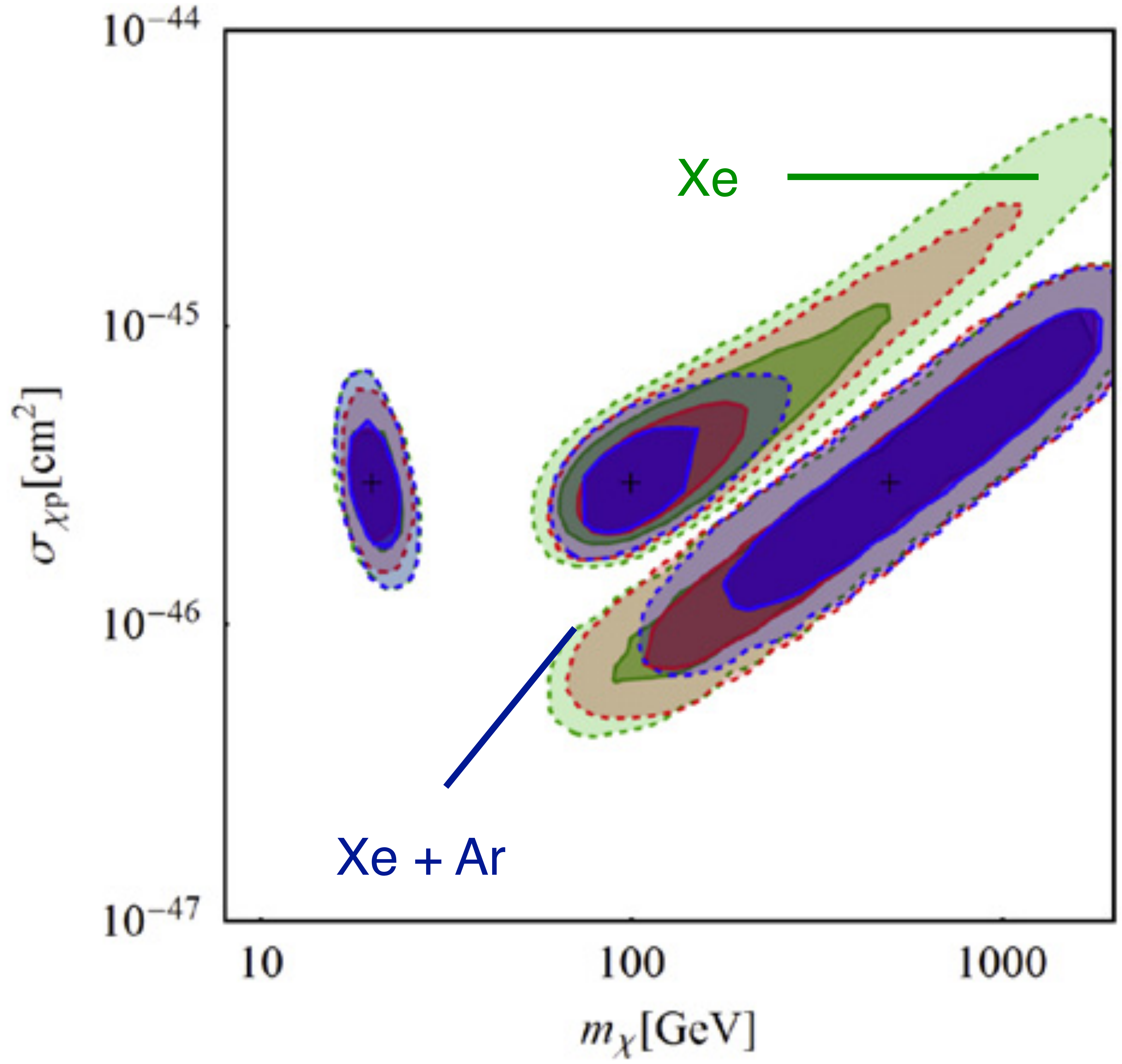




from Jelena Maricic

Complementarity of Targets

essential to better constrain WIMP mass and x-section once we have signals!



J. Newstead et al , PRD 88, 076011 (2013)

Summary

- Scalability and low-background demonstrated by noble liquid targets make them most promising to search for WIMPs in a large mass range.
- In this decade LXe and LAr experiments will reach unprecedented sensitivities to nail down the WIMP as an explanation for DM.

Summary

- Scalability and low-background demonstrated by noble liquid targets make them most promising to search for WIMPs in a large mass range.
- In this decade LXe and LAr experiments will reach unprecedented sensitivities to nail down the WIMP as an explanation for DM.