DarkSide-20k and the Direct Dark Matter Search with Liquid Argon

Tom Thorpe for the DarkSide collaboration

Overview

- Dual phase Argon TPCs
- DarkSide-50
- DarkSide-20k technologies
- Prototypes
- Summary

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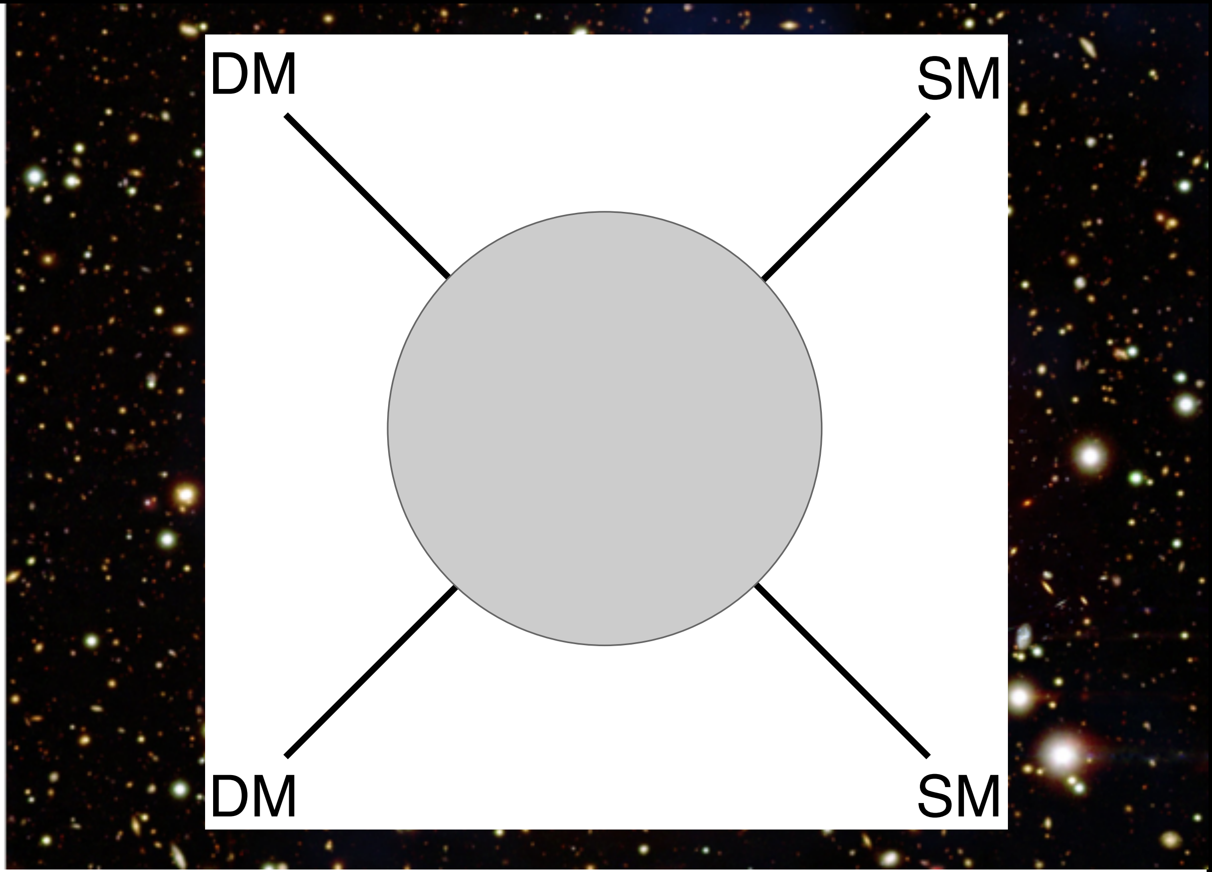

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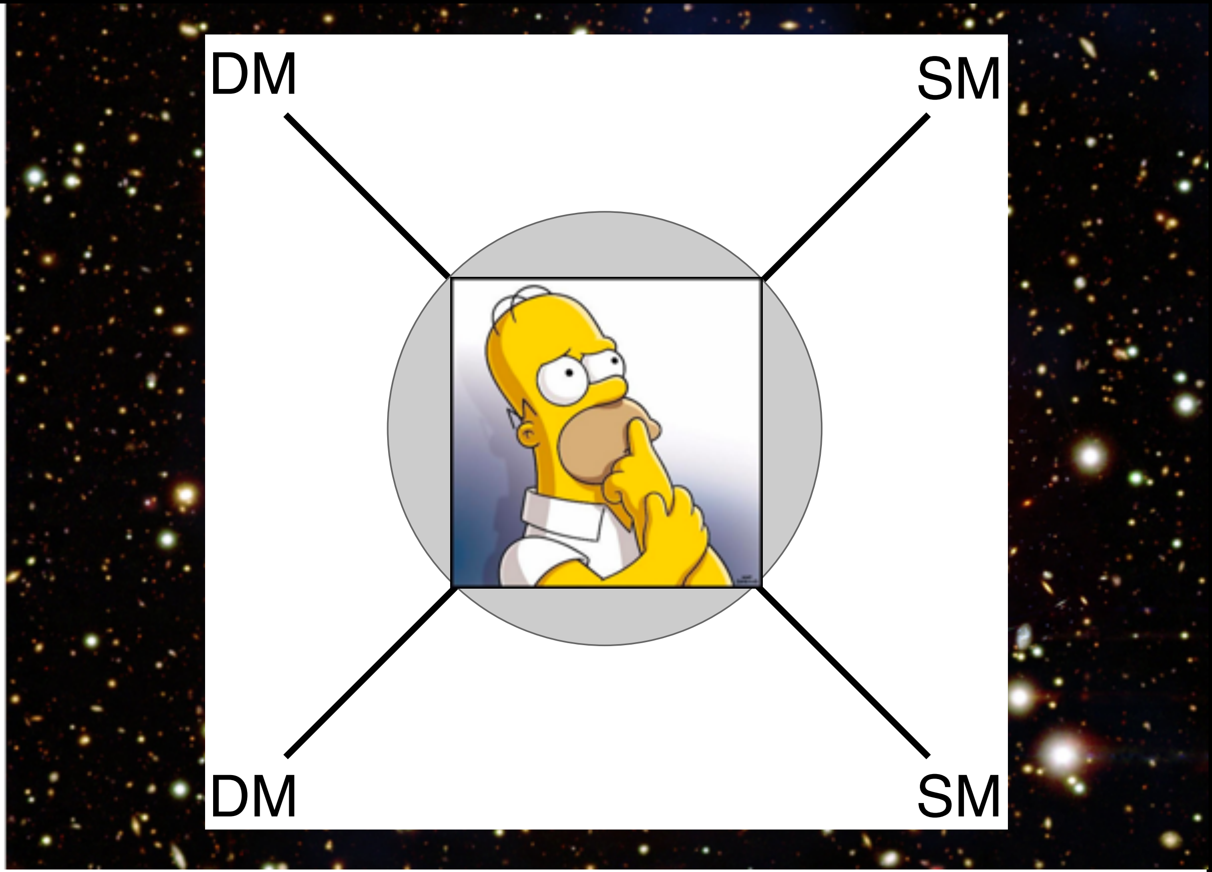
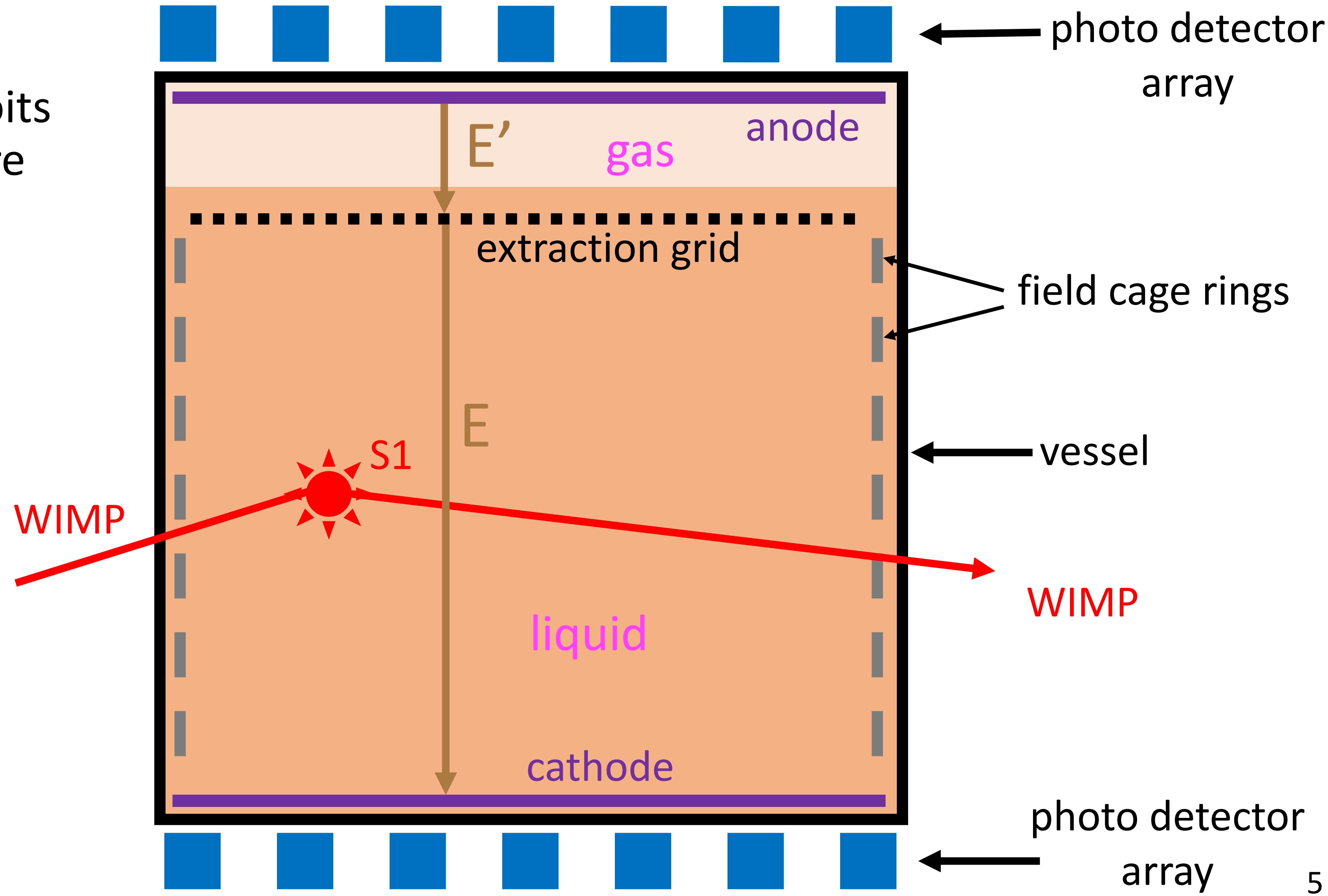


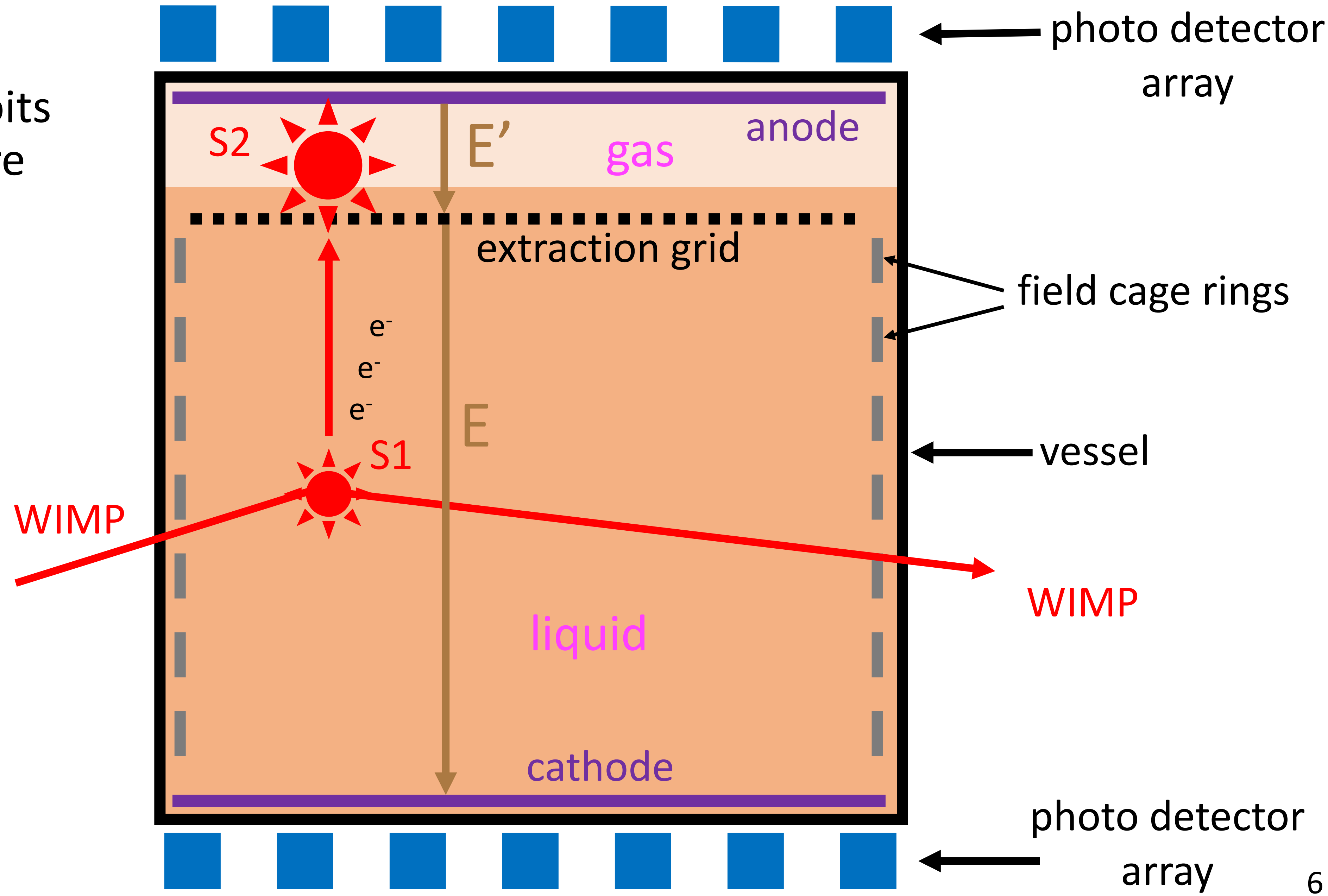
Dual Phase TPC Cartoon

- Primary event discrimination exploits the S1 time signature



Dual Phase TPC Cartoon

- Primary event discrimination exploits the S1 time signature
- X and Y are reconstructed by localizing the S2 signal
- Z is reconstructed via the drift time (time difference between S2 and S1)
- Further event discrimination can be done with S2



Why Liquid Argon?

- Excited states relax by emitting 128 nm photons
- Very different decay times of singlet (~ 7 ns) vs. triplet (~ 1500 ns) state
- Electron recoils cause a higher fraction of triplet states than nuclear recoils
- Results in superior electron rejection
- DS-50 rejected 1.5 x 10^7, all, ER events in AAr run from 8.6 - 65.6 keV
  - Statistics limited

arxiv:1410.0653

- DEAP-3600 has just shown an ER leakage factor of 4.1 x 10^{-9} from 15.6 - 32.9 keV w/ 90% NR acceptance

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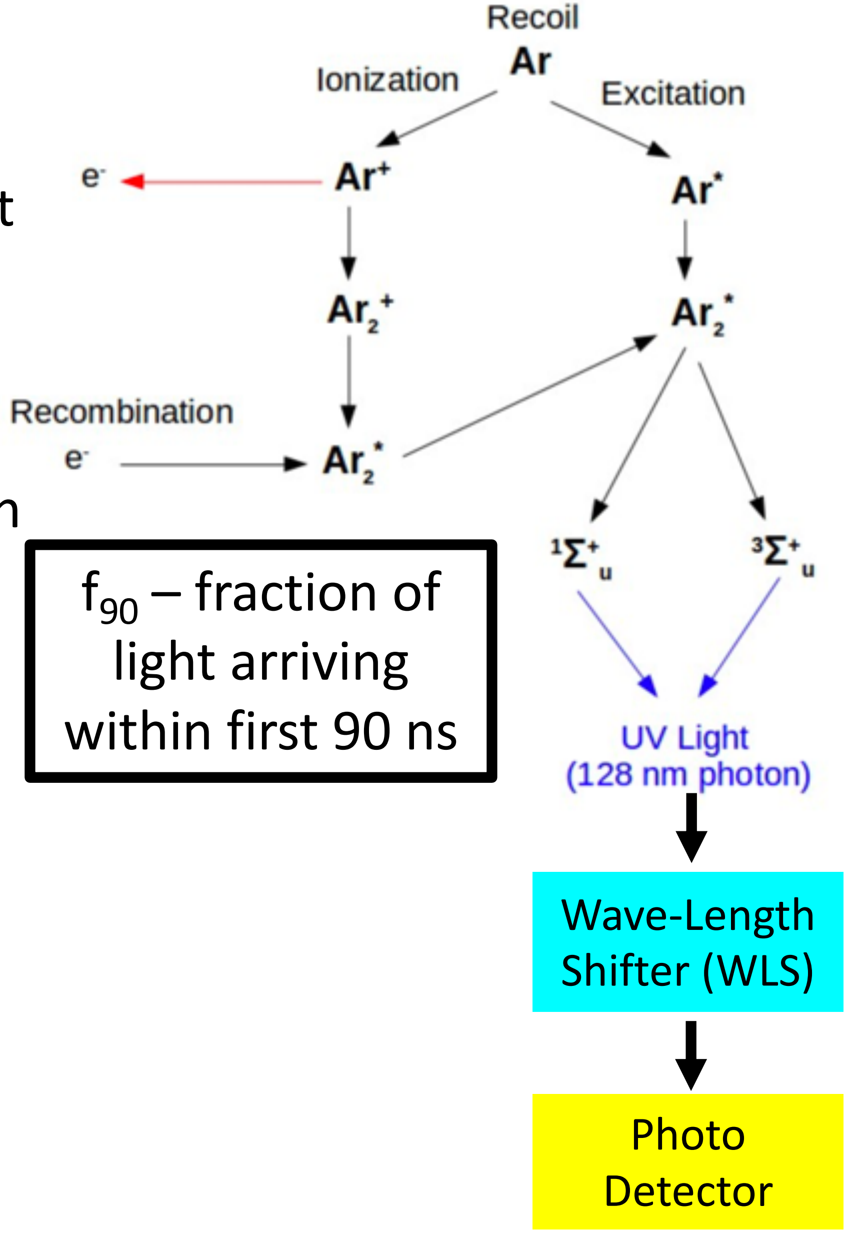
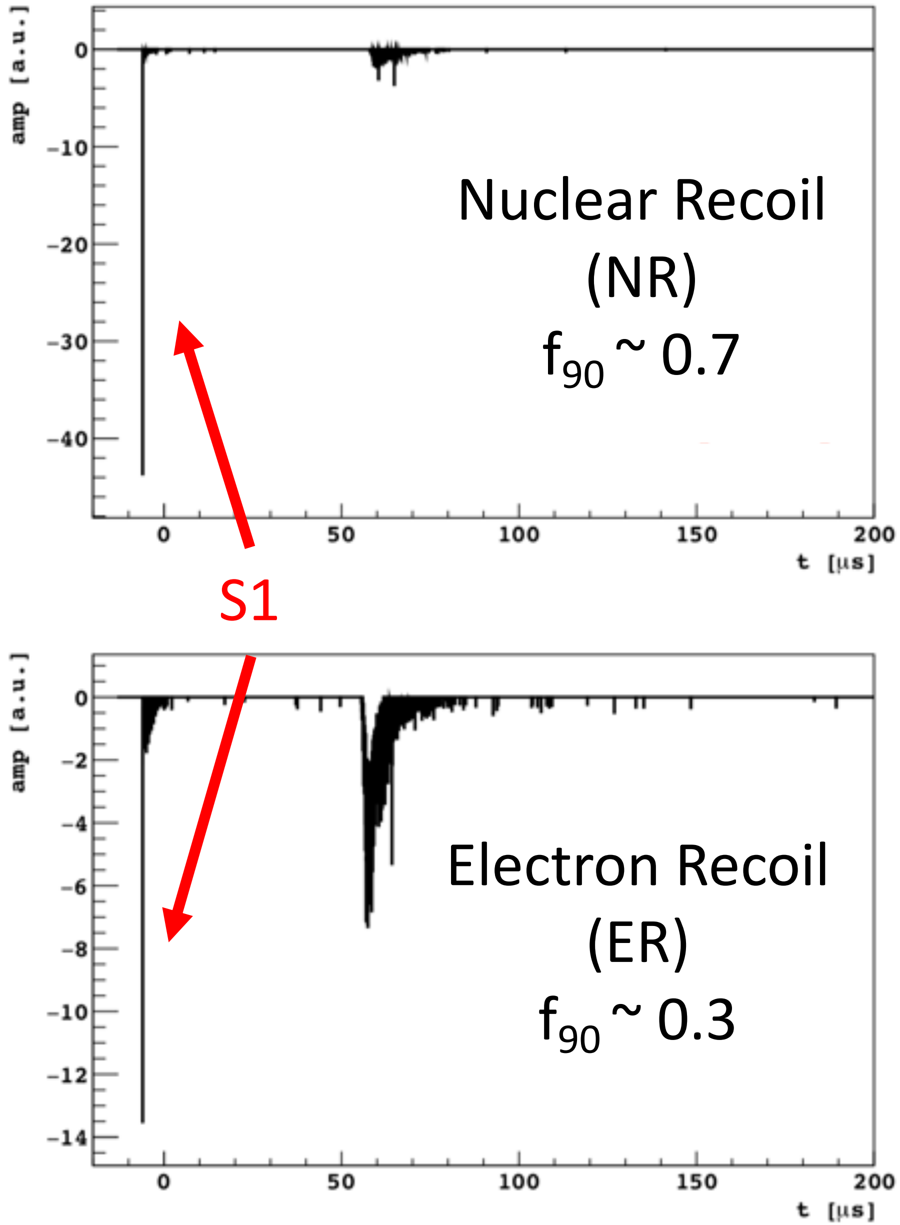


f_{90} – fraction of light arriving within first 90 ns



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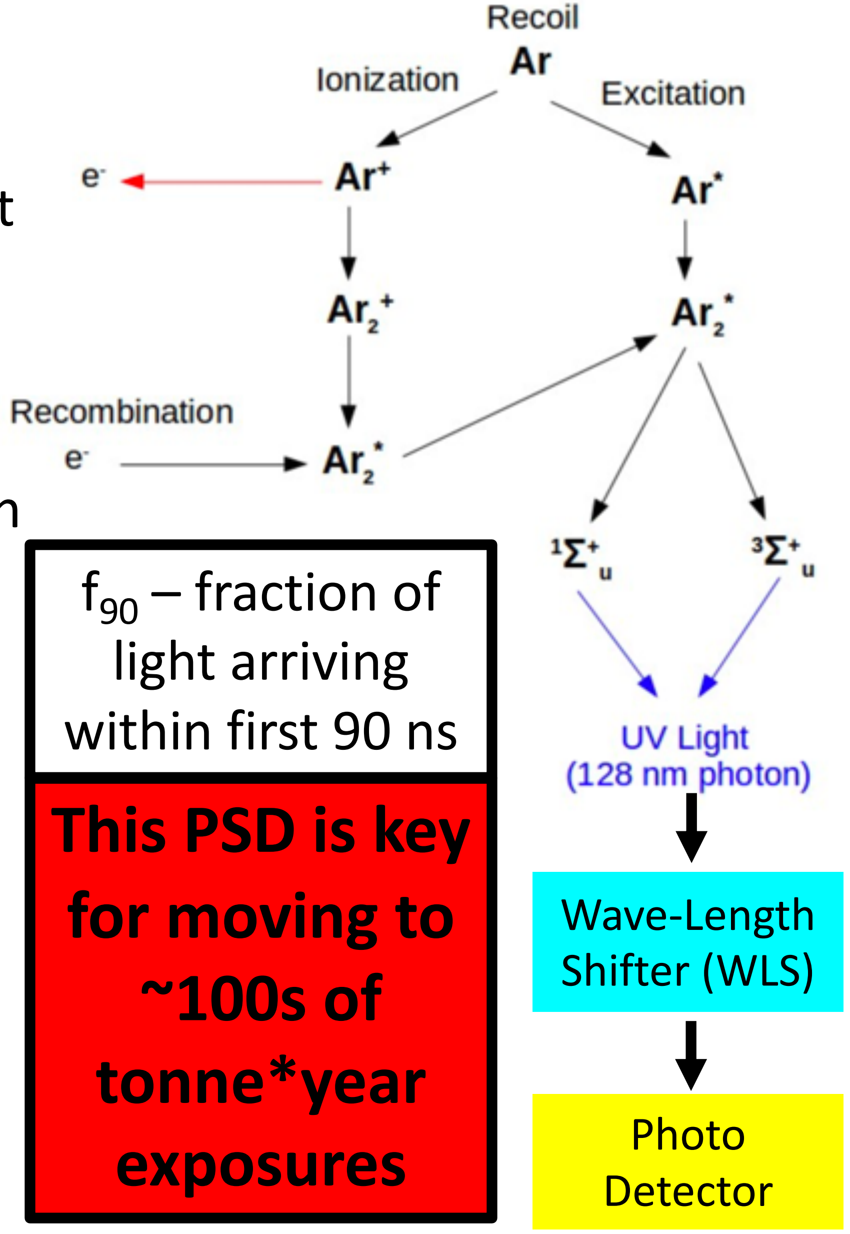

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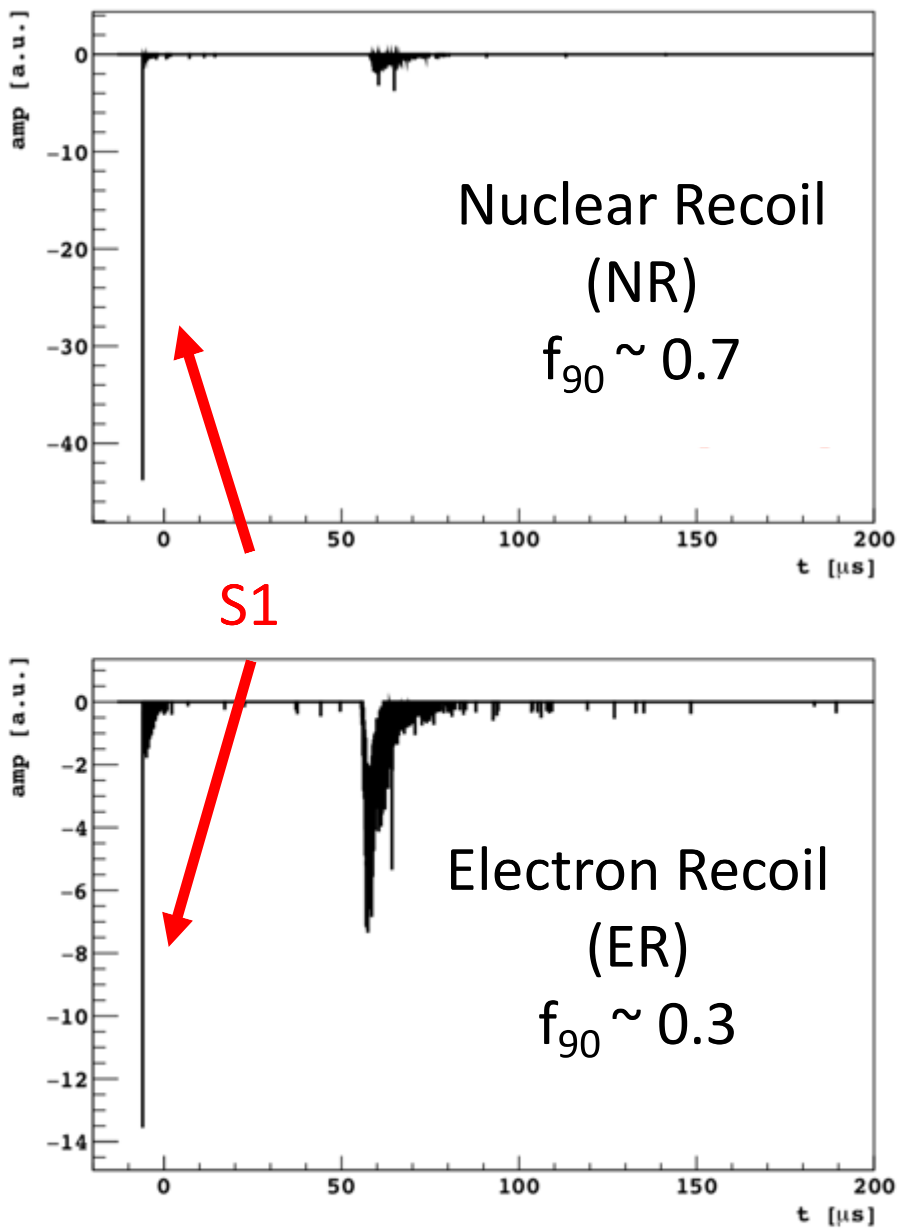
This PSD is key for moving to ~100s of tonne*year exposures



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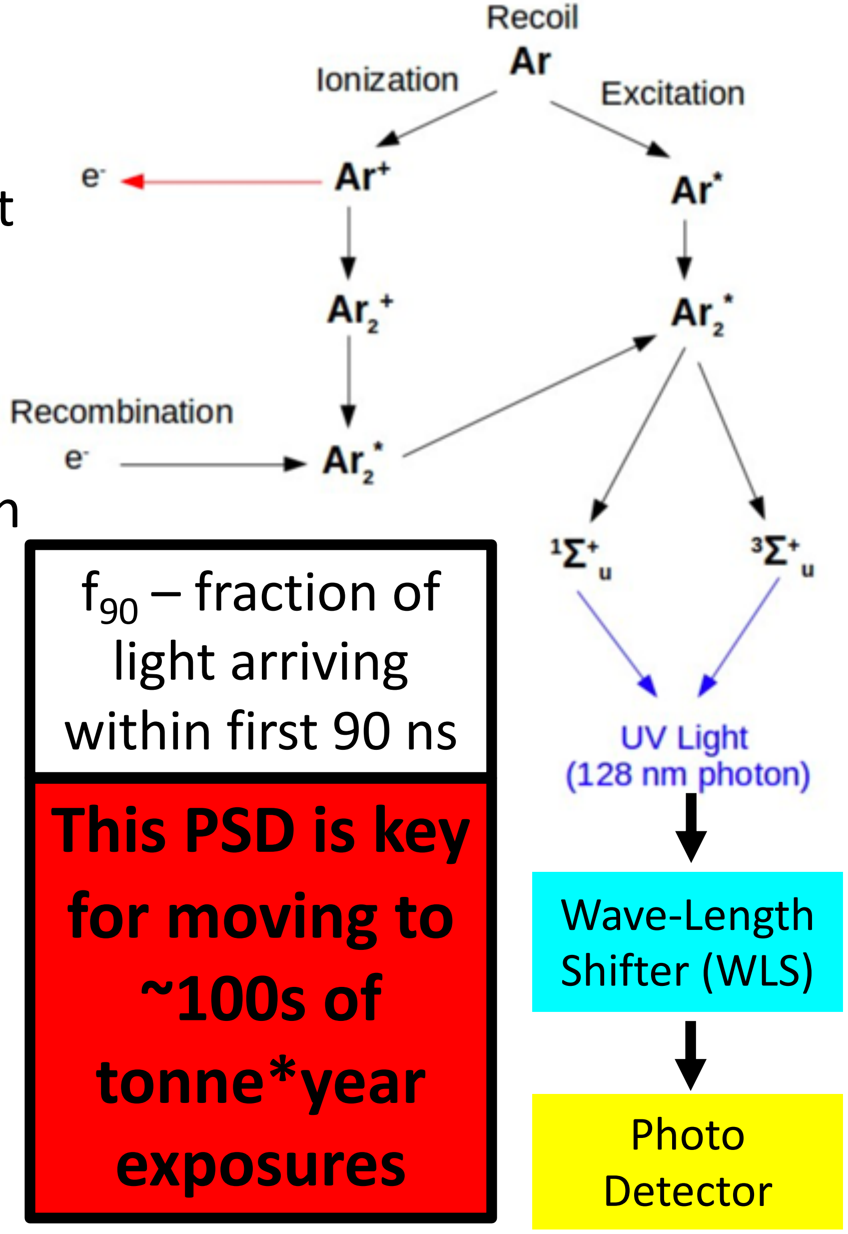

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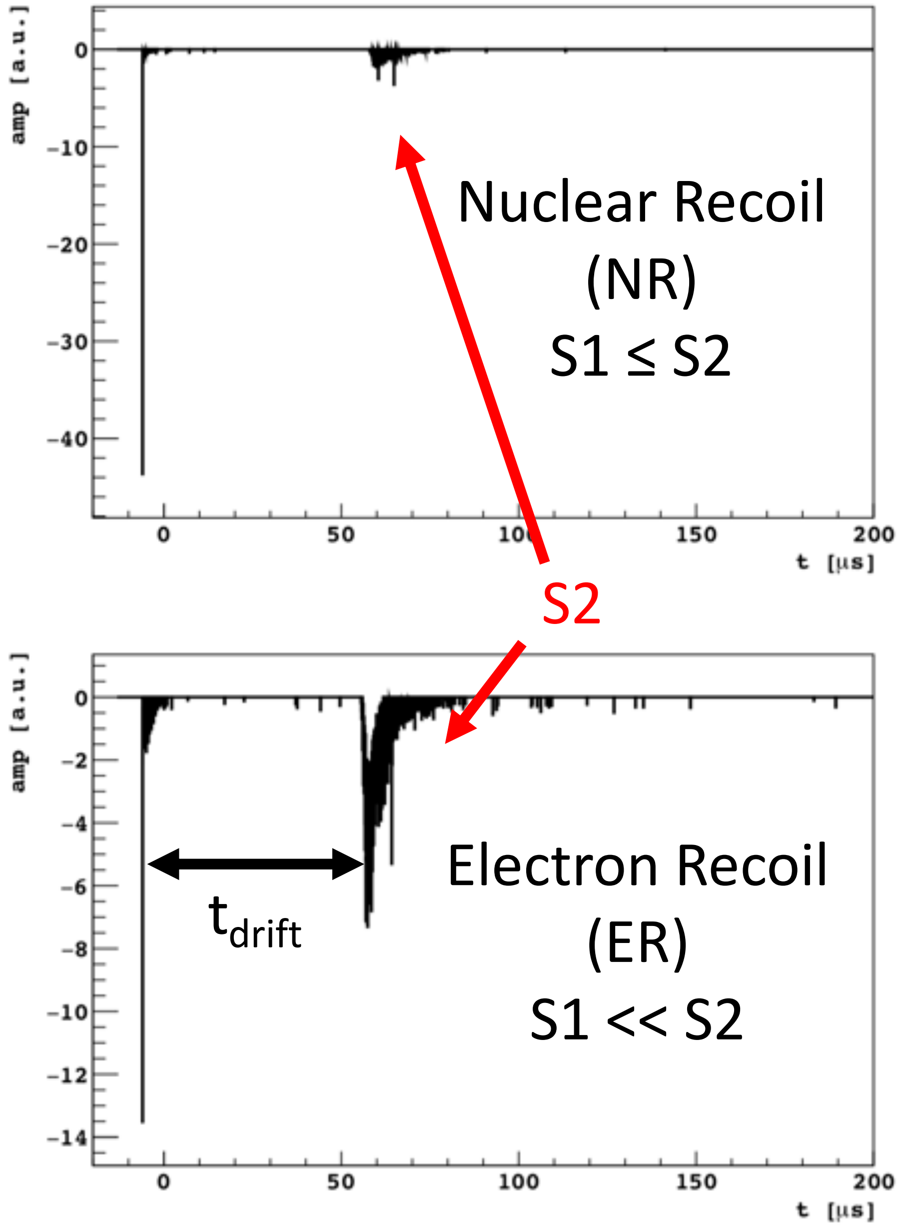
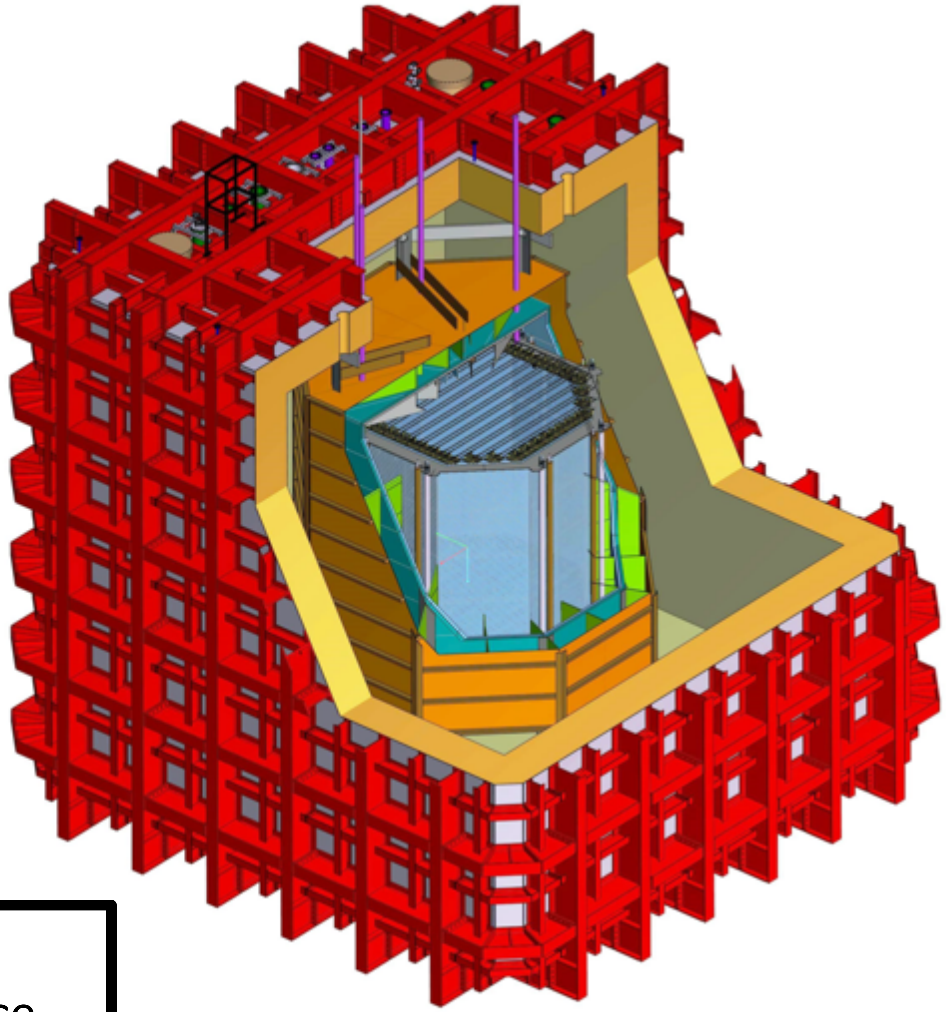


Global Argon Dark Matter Collaboration (GADMC)

Past, current experiments joining forces

- DEAP-3600
- DarkSide-50
- MiniCLEAN
- ArDM



DarkSide-20k: 2022 - (LNGS)

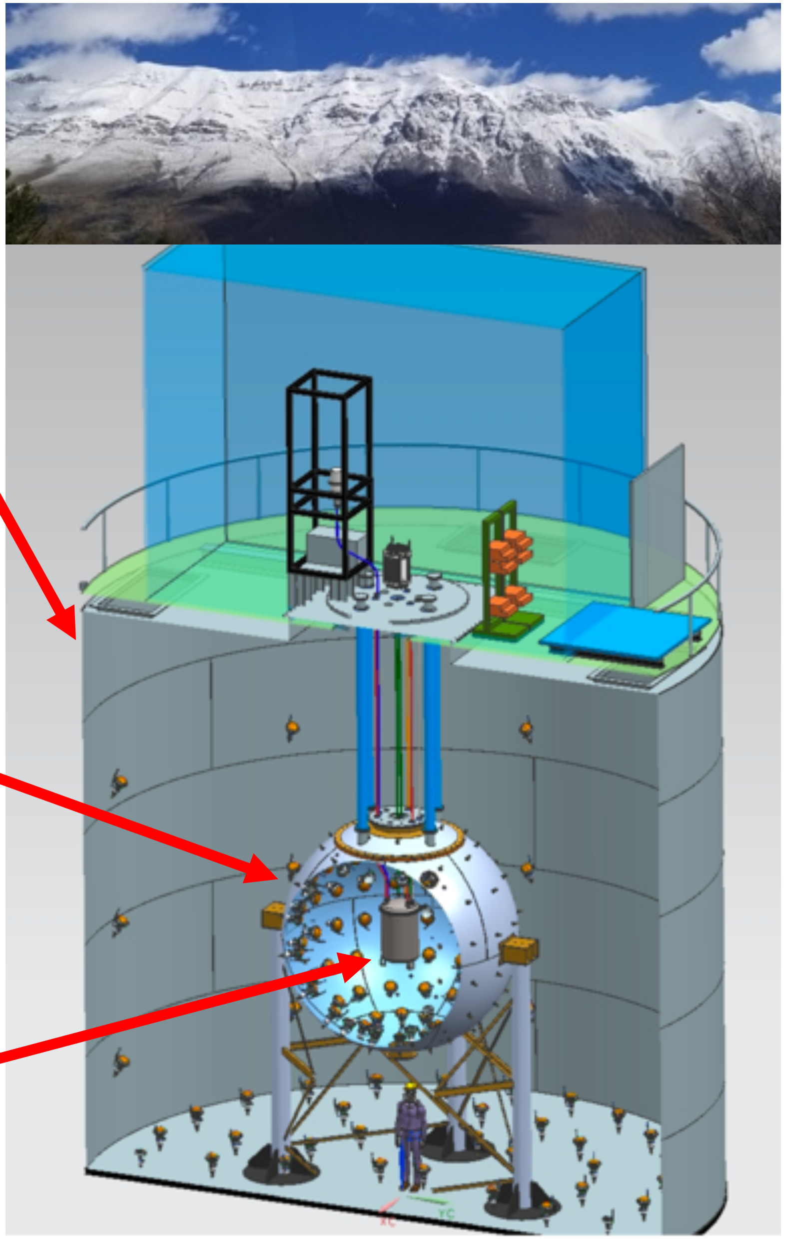
~ 300 tonnes

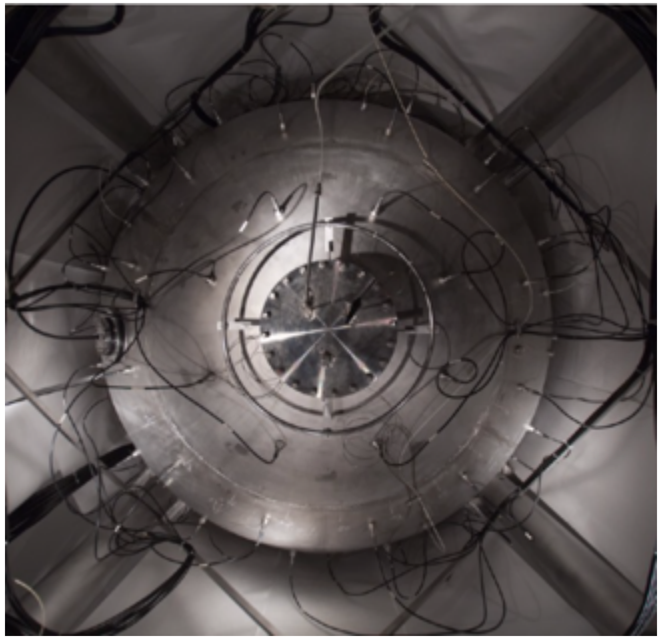
Argo: ~ 2029 - (SNOLAB)

59 institutions, > 400 researchers, 14 countries: Brazil, Canada, China, France, Greece, Russia, Italy, Mexico, Poland, Romania, Spain, Switzerland, UK, USA.

DarkSide-50 Structural Overview

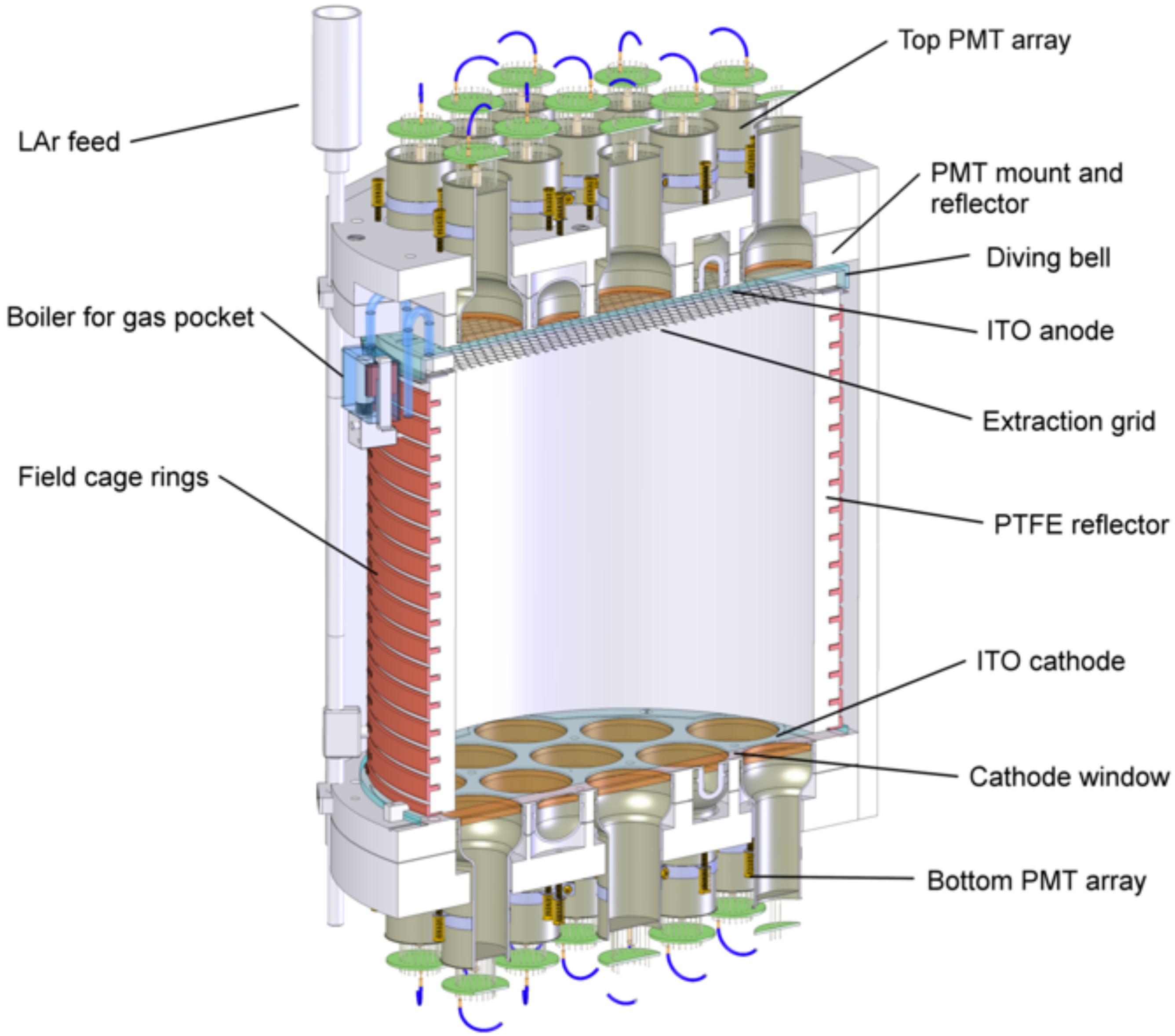
- Water Cherenkov detector
  - Stainless steel cylinder d=11 m; h=10 m
  - 1,000 tonnes of ultra pure water
  - Active veto for muons and passive shield for external radiation
  - 80 8” PMTs
- Liquid scintillator detector
  - 4 m stainless steel sphere
  - 30 tonnes of Boron loaded scintillator
  - Active gamma and neutron veto thanks to ^{10}B loading
  - 110 8” PMTs
- Inner LAr TPC…





DarkSide-50 Inner TPC

- PTFE cylinder containing 46 kg (37 kg fiducial) LAr
- Inner surfaces coated with wavelength shifter - Tetraphenyl Butadiene (TPB)
- Cathode and anode have Indium Tin Oxide (ITO) transparent layers on the fused silica windows and TPB coating
- 38 3” Hamamatsu PMTs R11065; 19 each on top and bottom
- Fused silica diving bell to contain the 1 cm gas pocket



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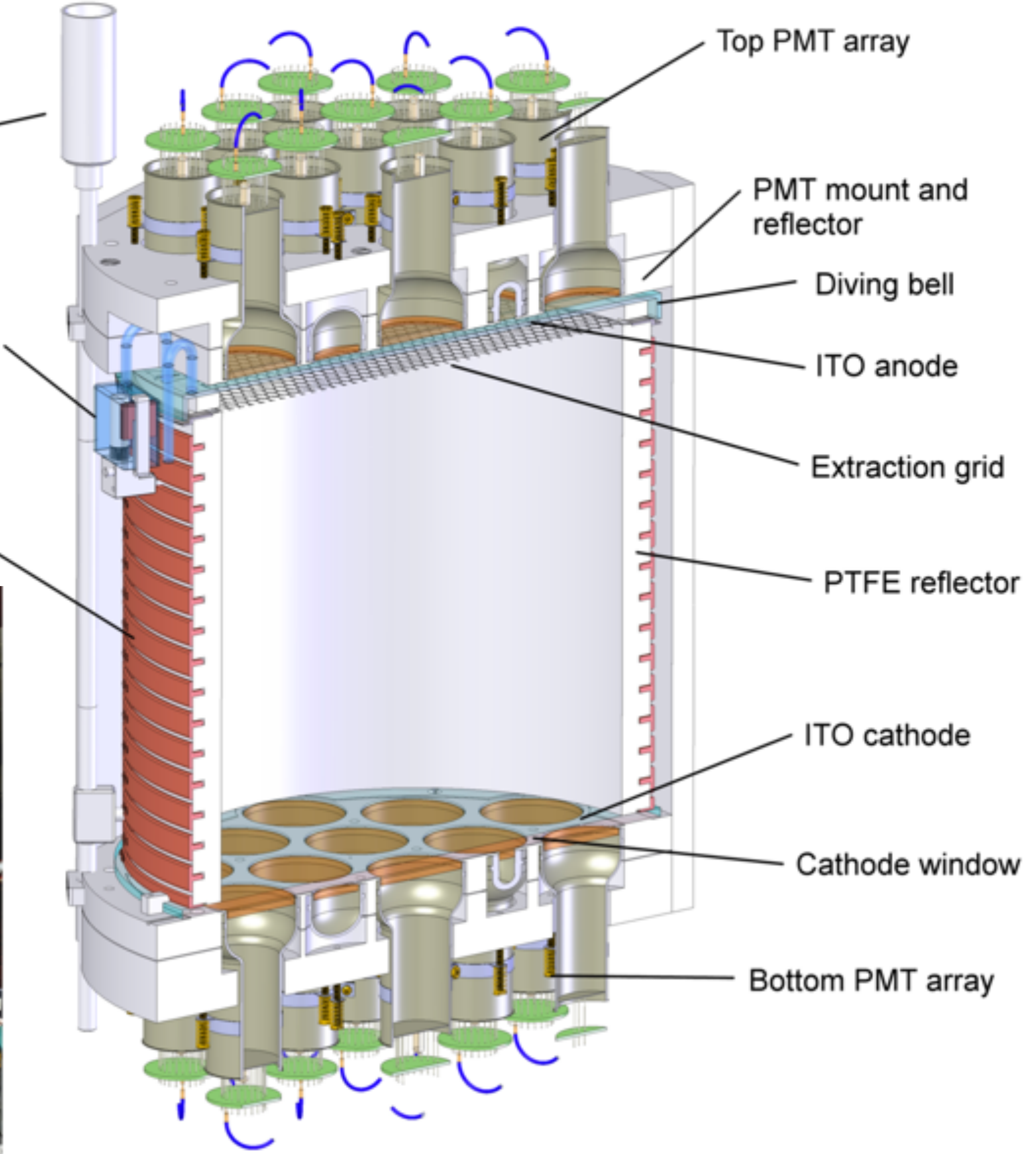
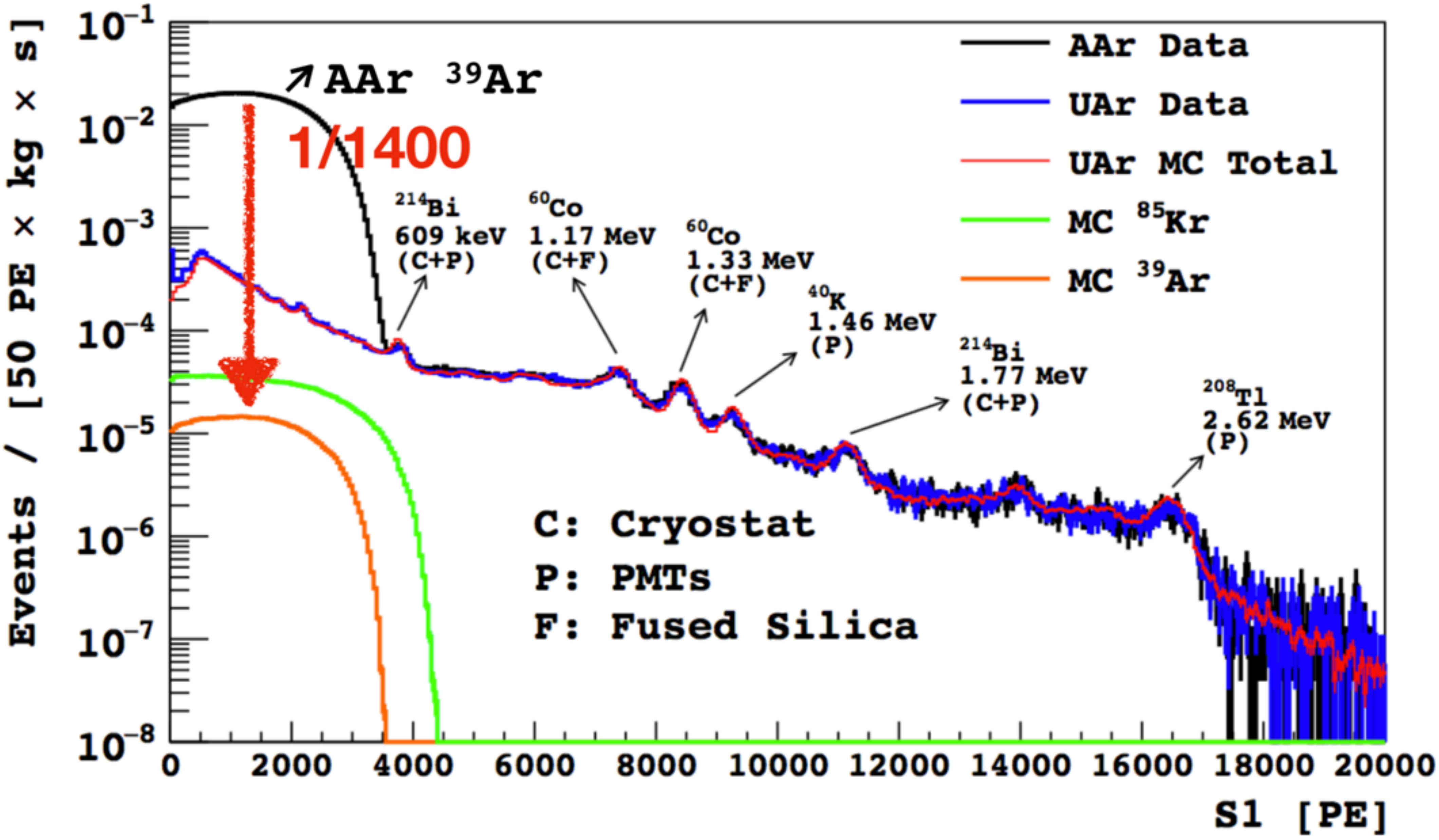
- Underground Argon (UAr)
    - Argon extracted from CO_2 wells in Colorado
    - Further purification via a cryogenic distillation column at Fermilab
    - Result is (1.4±0.2) x 10^3 fewer ^{39}Ar events than atmospheric Argon



DarkSide-50 Underground Argon

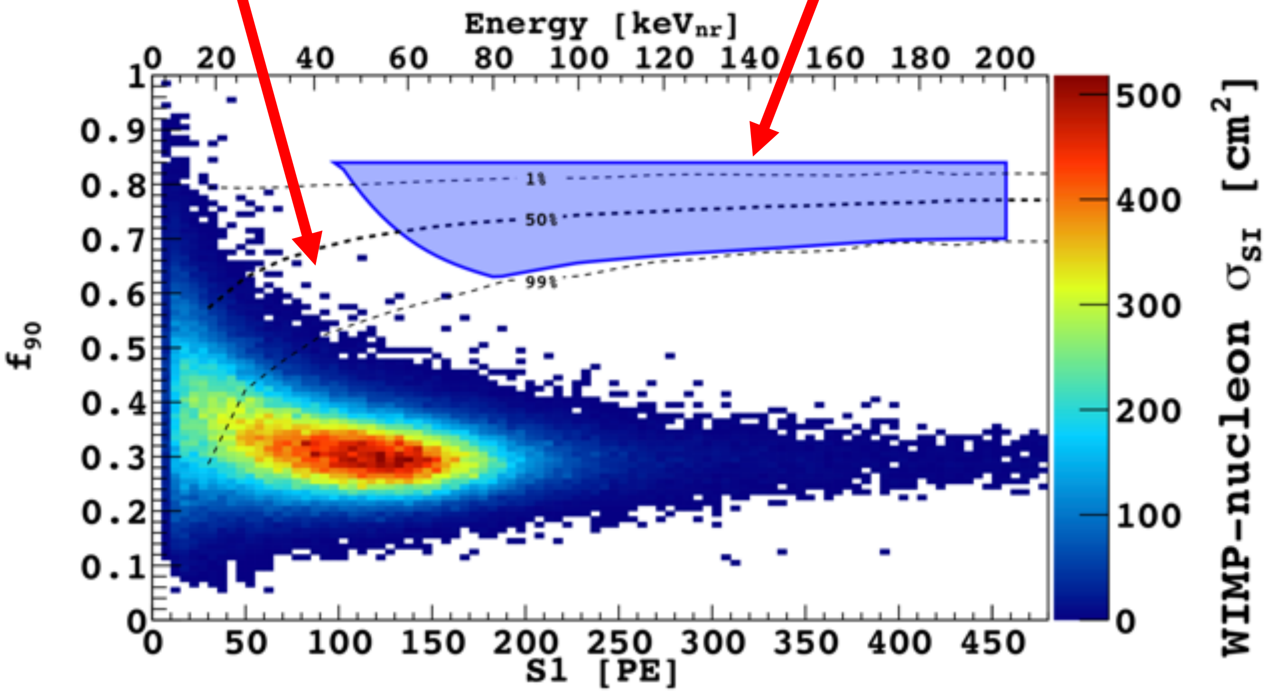


PRD, 93 (2016): 081101(R)

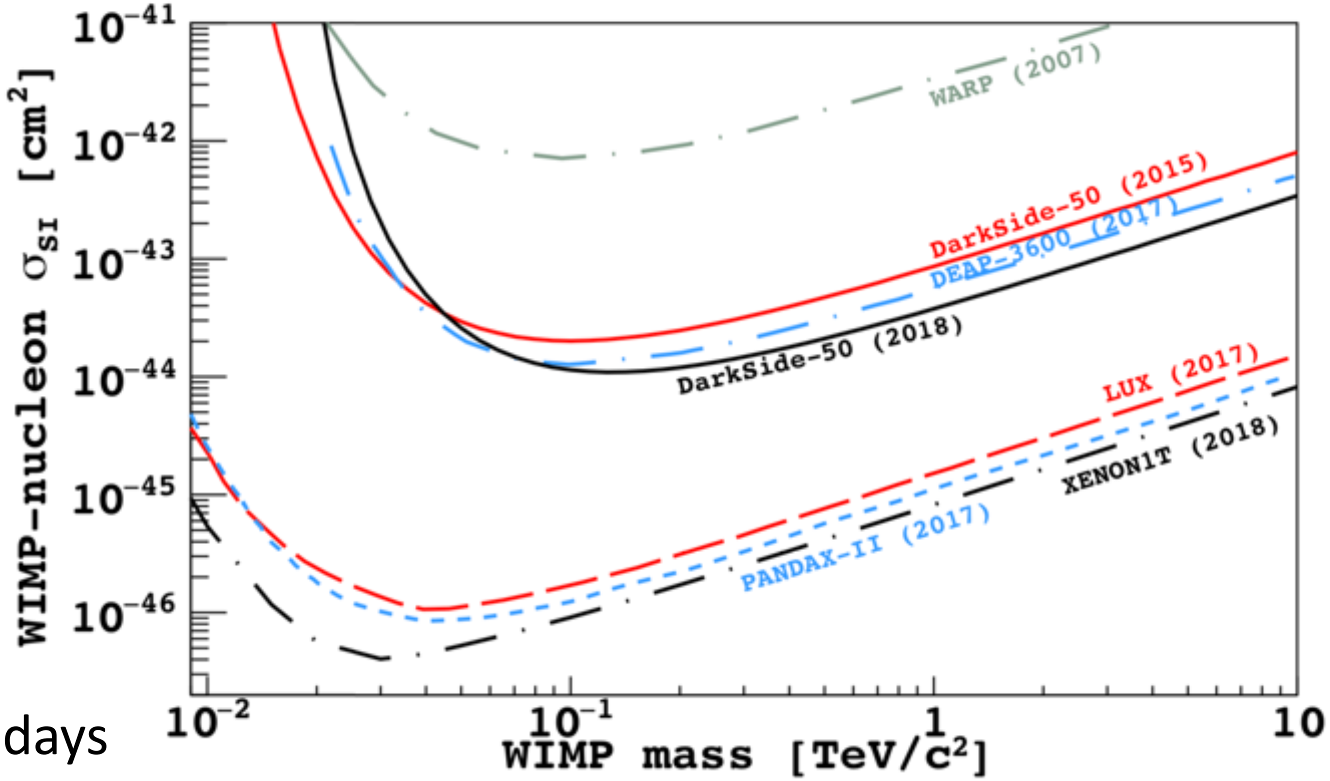
DarkSide-50 Results (High Mass)

Electron recoil band

WIMP search box with < 0.1 background events



WIMP-nucleon Spin Independent (SI) scattering limit (90% C.L.)



- Exposure = 532 live days x 31.3 kg = 16660 kg*days
- 1.14 × 10–44 cm^2 @ 100 GeV
- Underground Ar (UAr) activity ~ 0.7 mBq/kg
- LY ~ 8 photoelectrons/keV

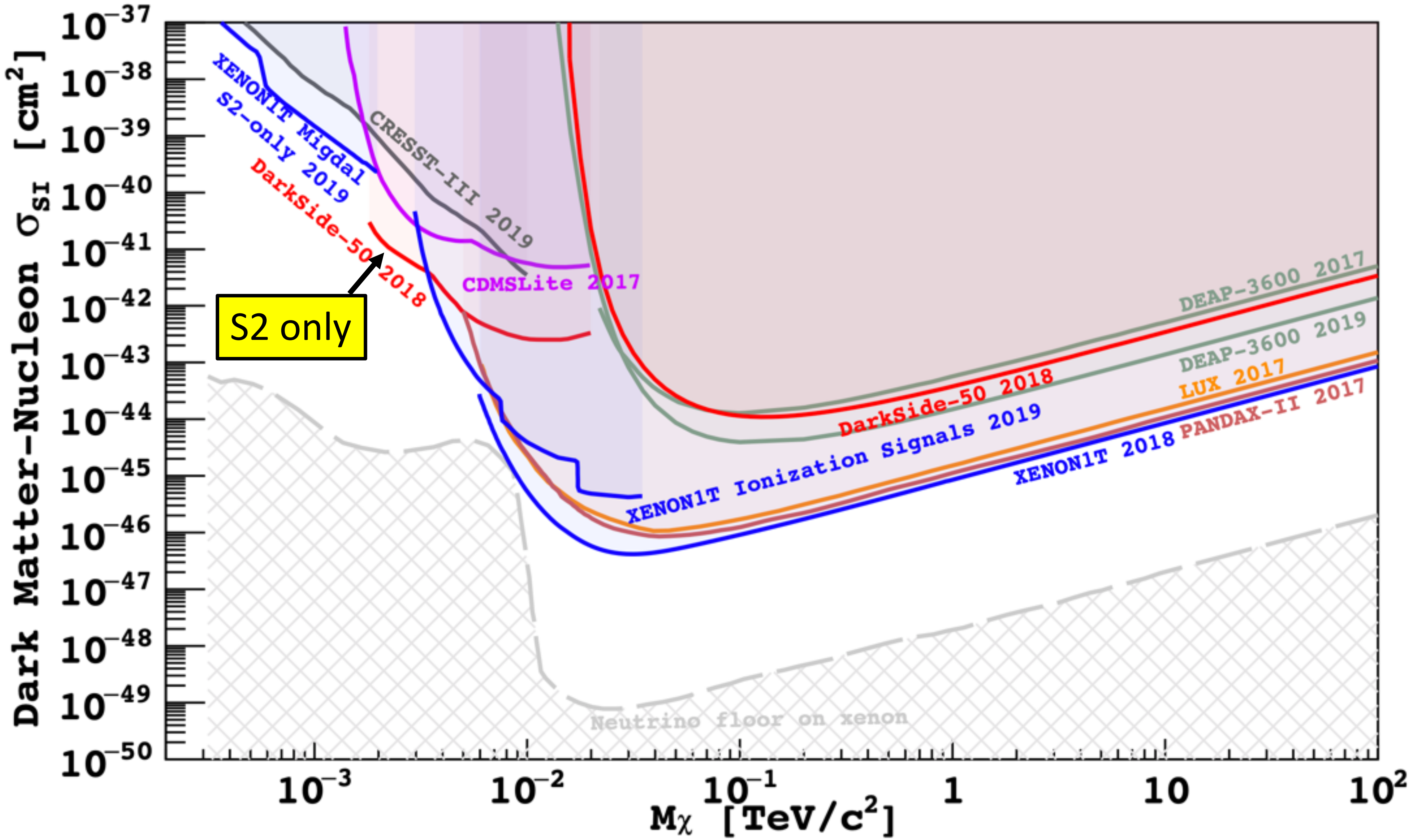
Physical Review D 98 (10), 102006 (2018)

arxiv:1802.07198

DarkSide-50 Results (Low Mass)

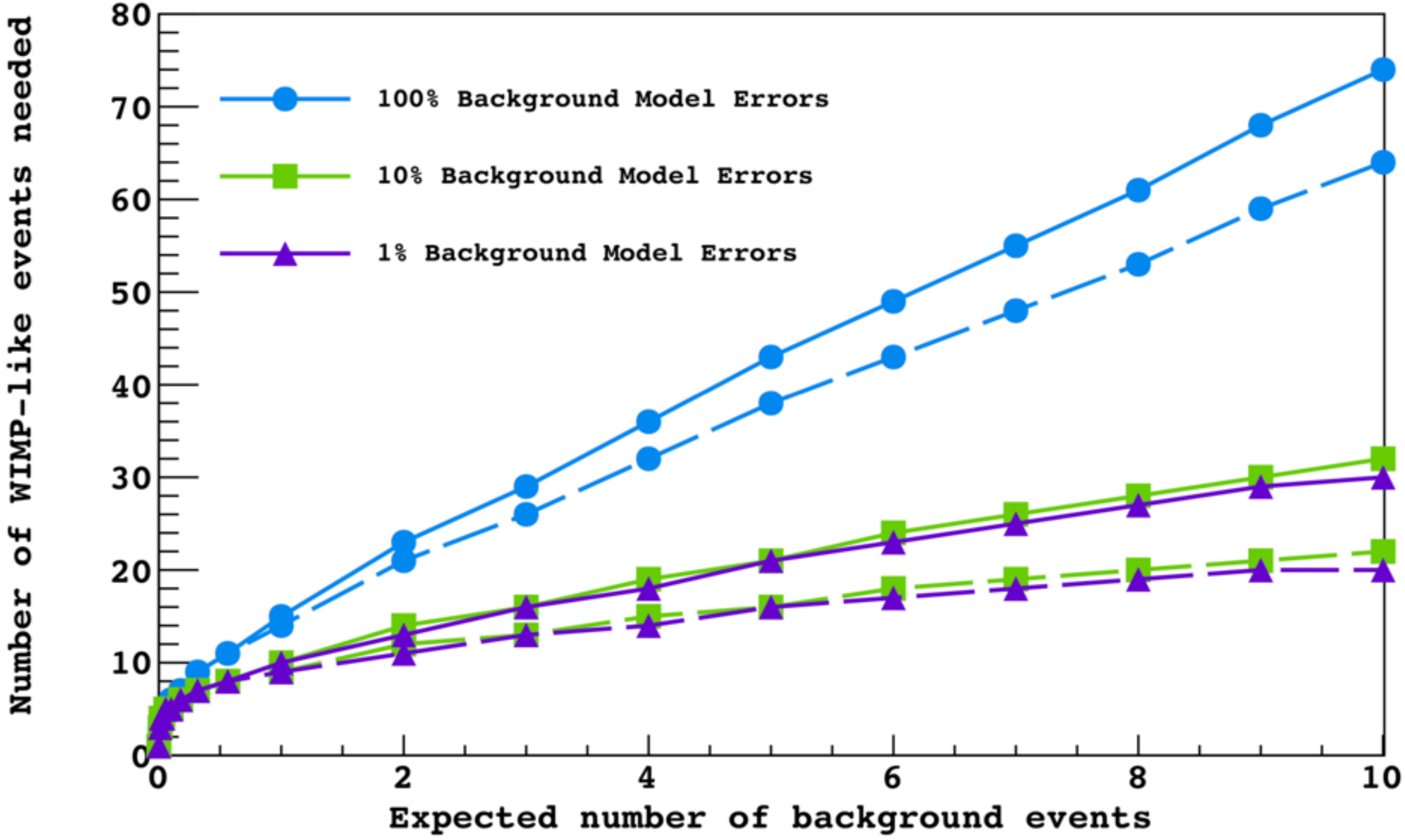
- Low-Mass: S2-only analysis
  - Physical Review Letters 121 (8), 081307 (2018)
  - arxiv:1802.06994
- Sub-GeV: S2-only analysis; DM-Electron
  - Physical Review Letters 121 (11), 111303 (2018)
  - arxiv:1802.06998

Current Sensitivity

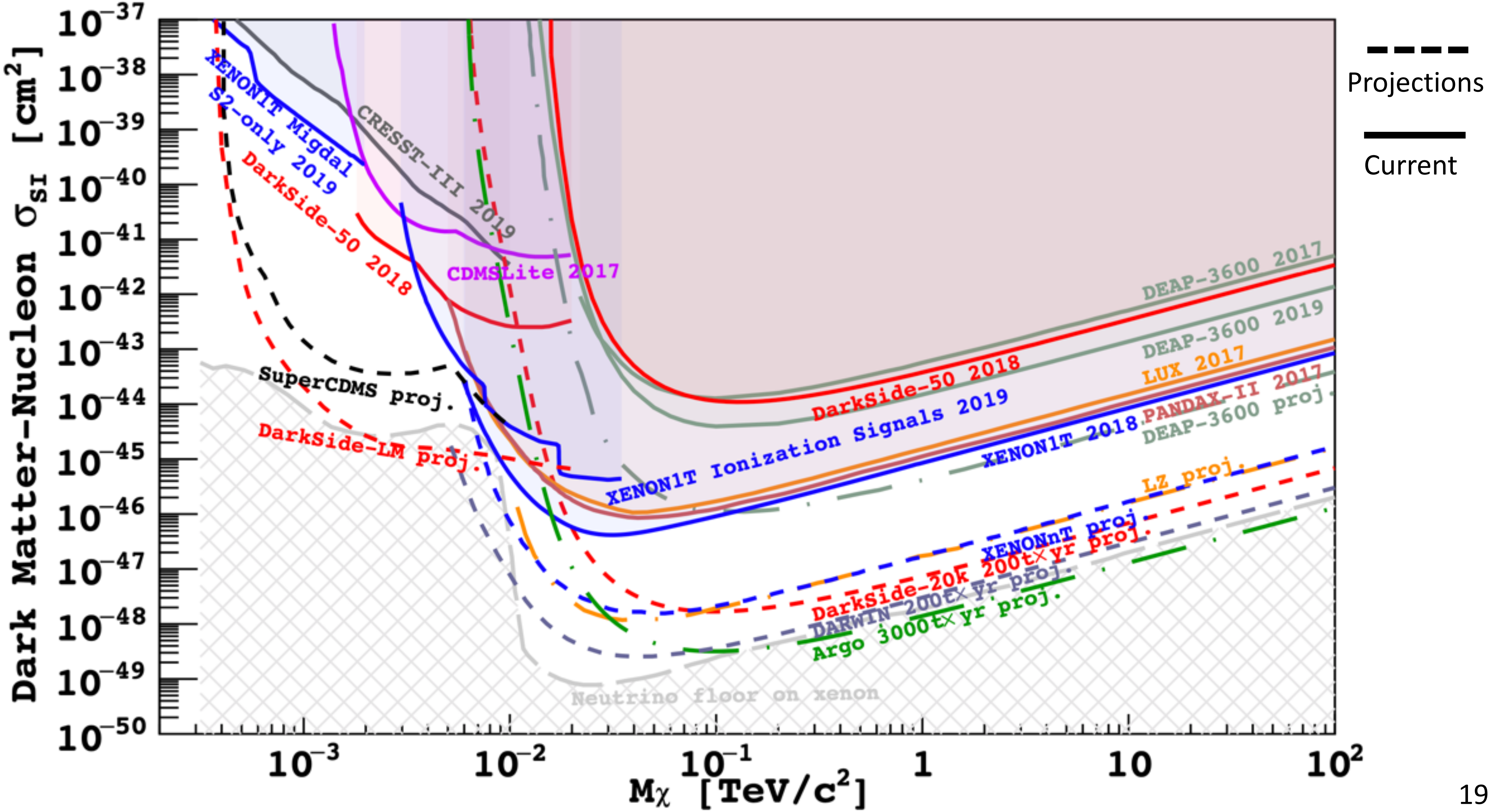


The Case for DarkSide-20k

If the number of background events is < 0.1, assuming the correct model, then as few as five events would claim discovery



Projected Sensitivity



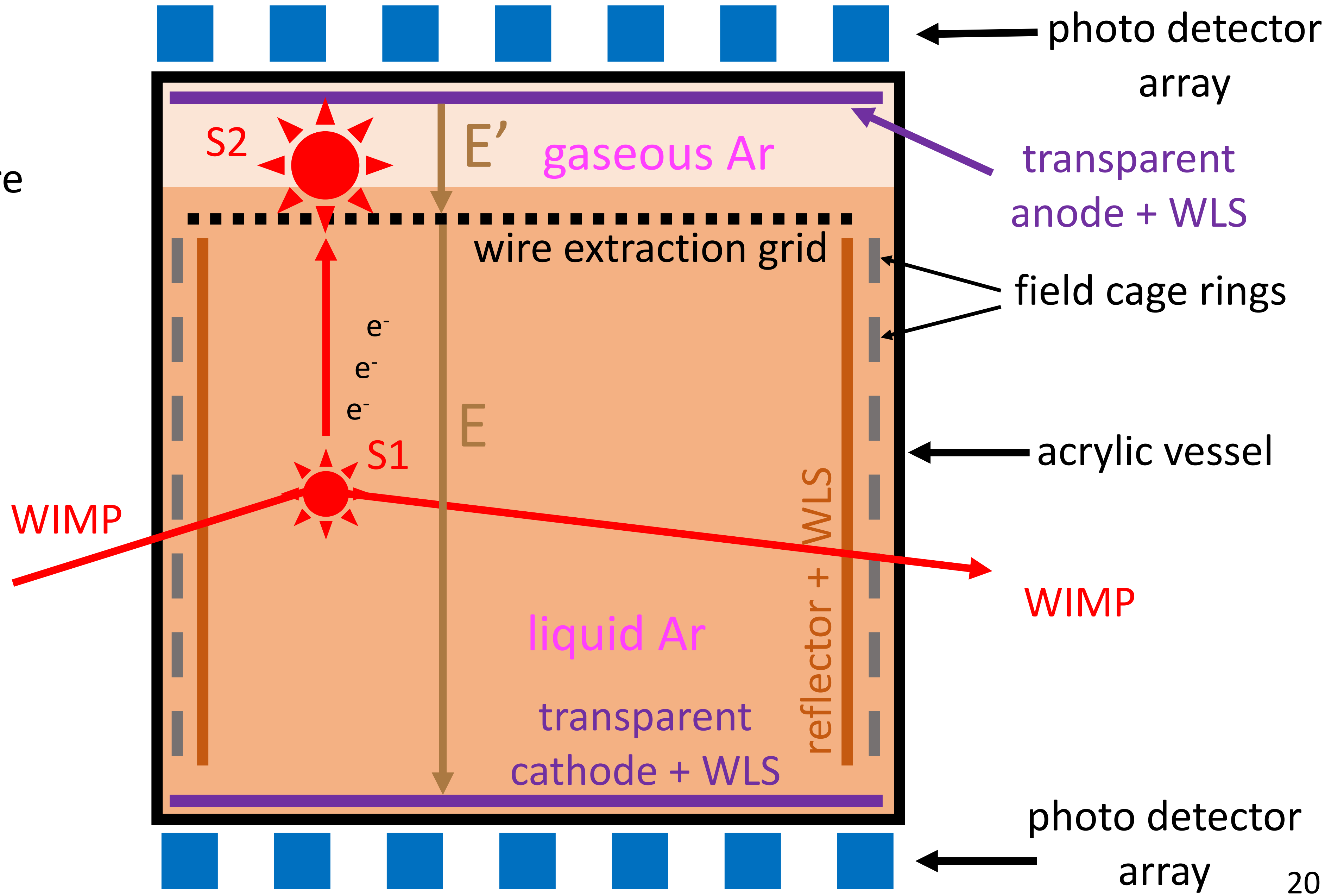
DS-20k Cartoon

We want:

- To increase exposure by ~ 10^3 or 10^4
- Same total number of background events: < 0.1

We need:

- Less radioactivity
- Photo detectors optimized for 87K



DarkSide-20k Structural Overview

- ProtoDUNE like cryostat
- Optical and EM barrier
- Neutron veto will use Gd doped acrylic panels and Atmospheric Argon (AAr)
- Inner TPC will be a sealed acrylic vessel containing UAr
- Separate cryogenic systems for UAr and AAr volumes
- Acrylic knowledge from DEAP-3600 is being implemented
- Silicon Photo Multipliers (SiPMs) will replace PMTs in TPC and veto (not shown)

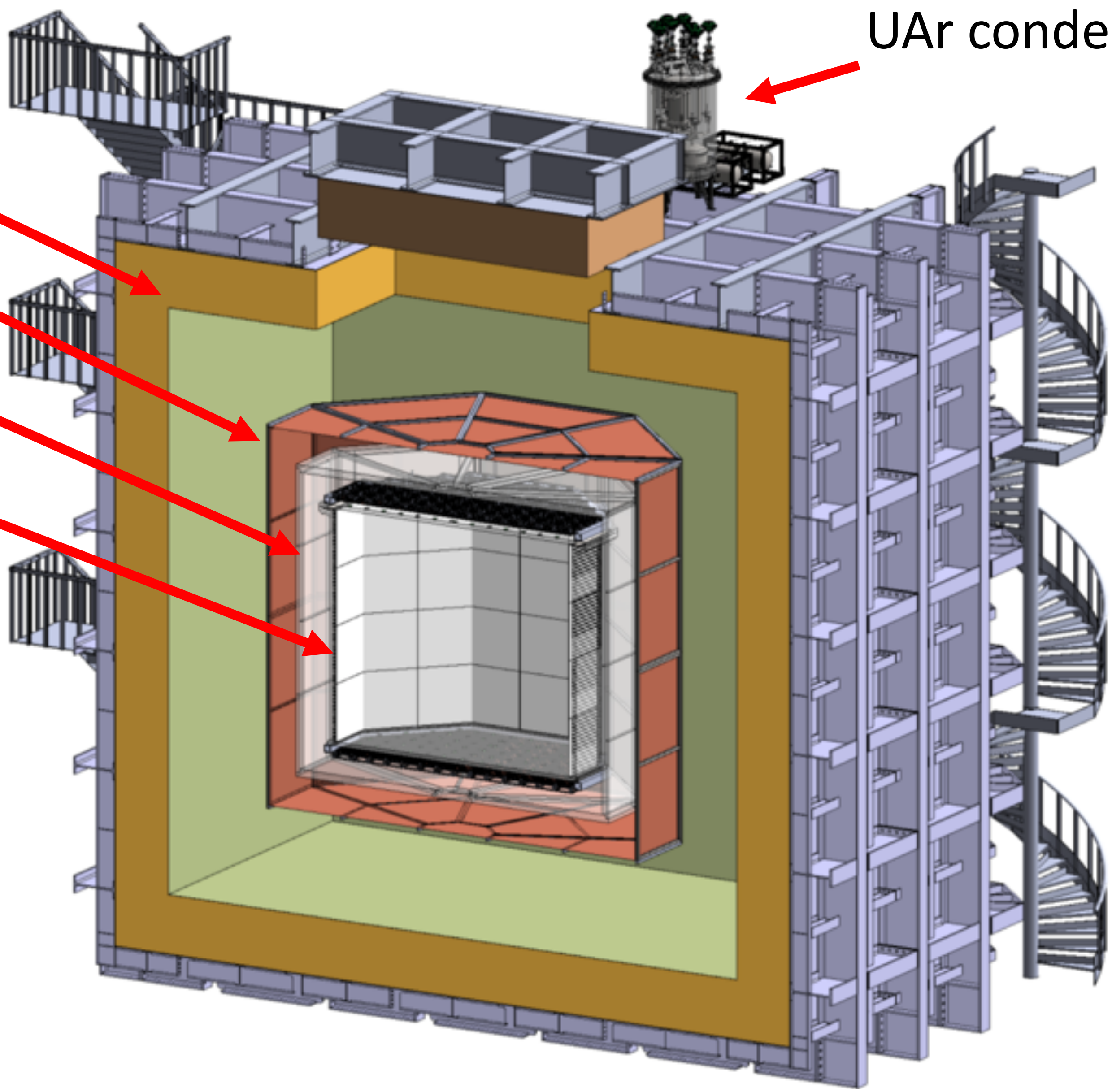
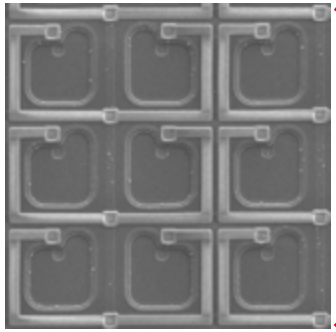
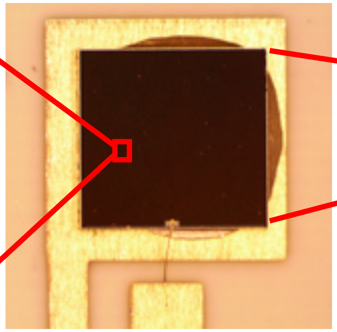


Photo Electronics for DS-20k

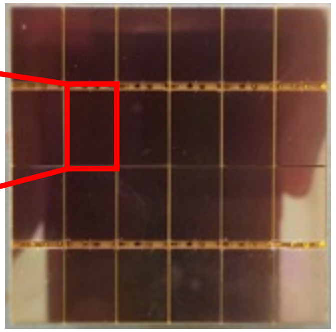
87K also allows for electronic advantages!



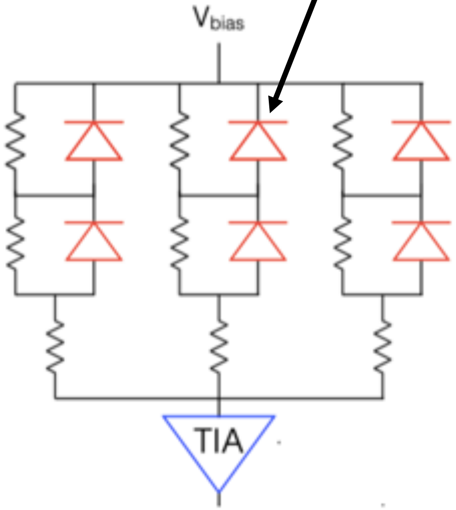
Individual SPADs
25-30 um^2



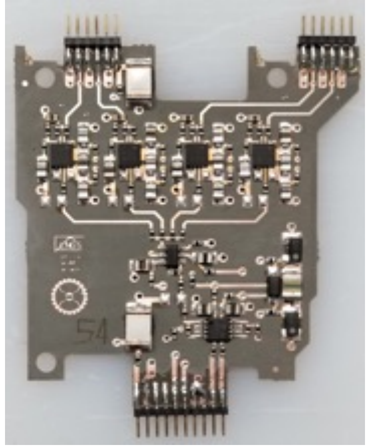
Single SiPM
~ 1cm^2



Single tile
(24 SiPMs;
(2|3_)x4;
~ 5 cm x 5 cm)

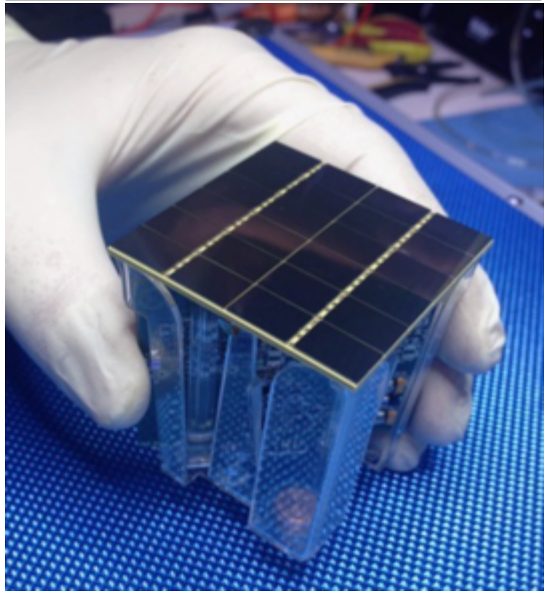


x4 then summed



Front End Board

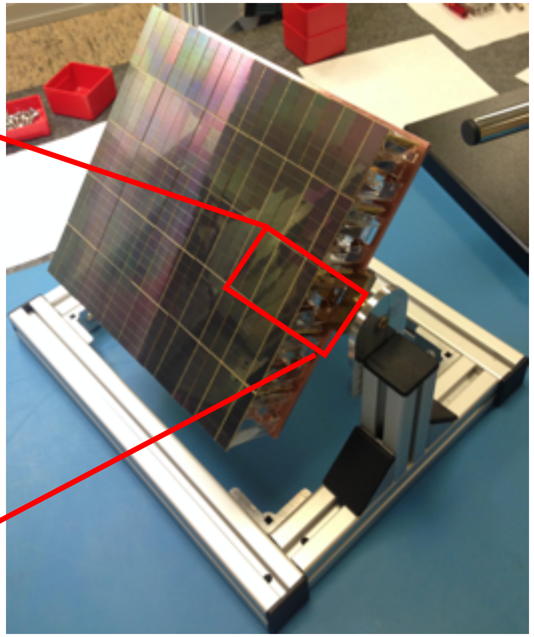
~ 5 cm x 5 cm x 5 cm



PDM

Photo Detection Module
(Tile + FEB in acrylic cage;
base detection unit; one
summed readout channel)

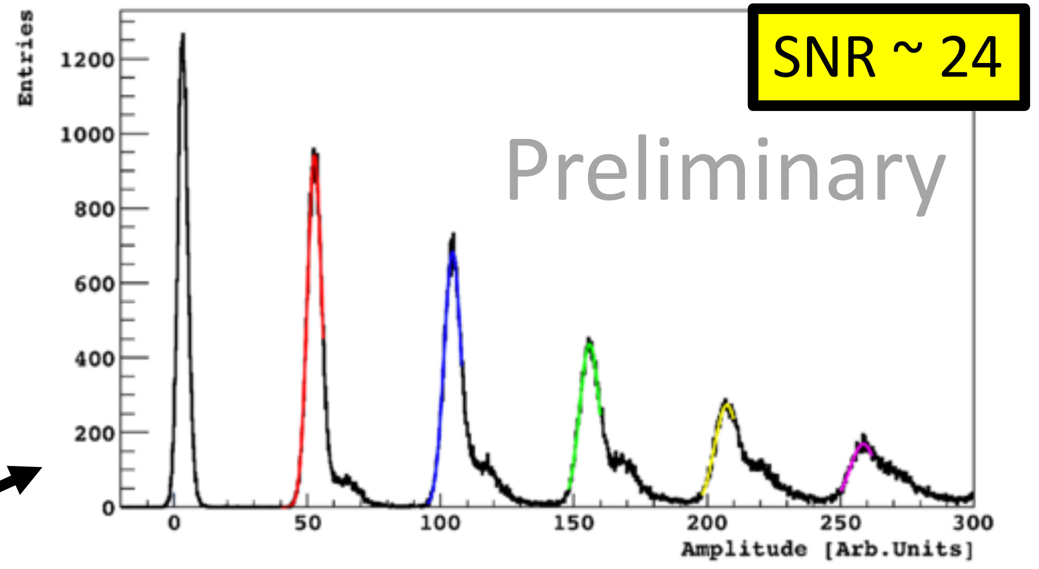
~ 25 cm x 25 cm x 5 cm

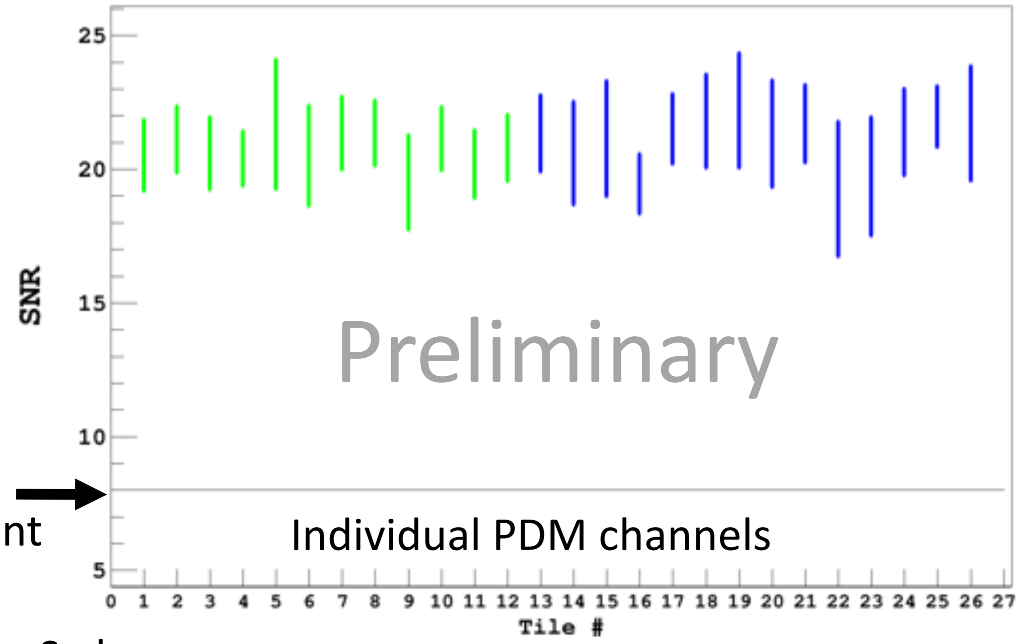


25 PDMs with mechanical support structure; base mechanical unit for DS-20k; routing structure for power and signal readout contained

PDM Performance

- Photo Detection Efficiency (PDE) ~50%
- FBK, Trento IT, NUV-HD-LF tech
  - Optimized for LAr temperatures
  - > 90% fill factor
- Power consumption required to be < 100 $\mu W/mm^2$
- 0.1 Hz/mm^2 dark count rate
- < 10 ns timing resolution
- Single Photo Electron (SPE) resolution
- High SNR



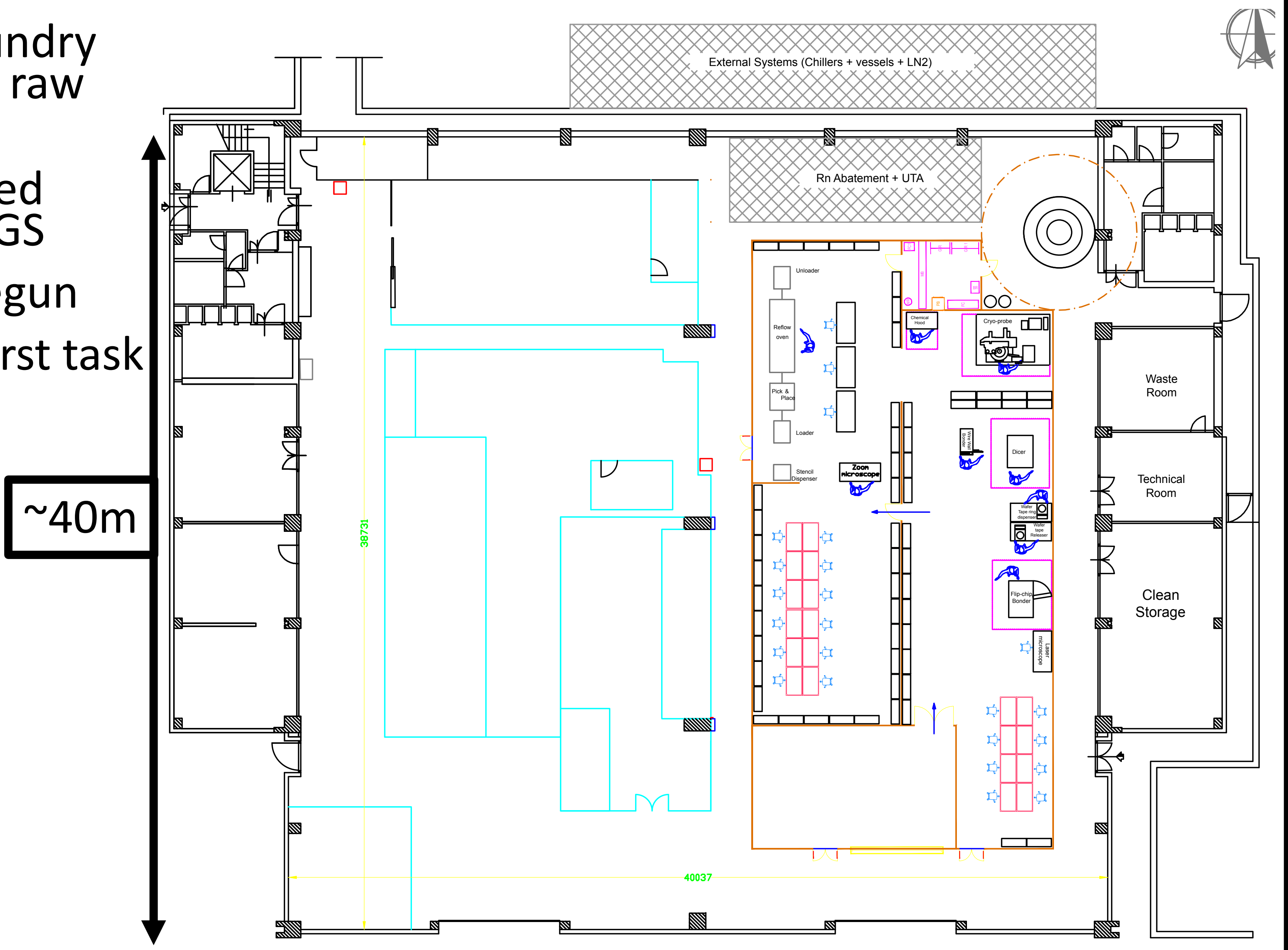


DS-20k requirement

Details:		
arxiv:1706.04213	arxiv:1706.04220	arxiv:1610.01915

Photo Electronics Production - NOA

- FBK technology transfer to LFoundry (Avezzano, IT) for production of raw SiPM wafers
- Production facility for SiPM based photo electronics located at LNGS
- Equipment procurement has begun
- DS-20k production will be the first task



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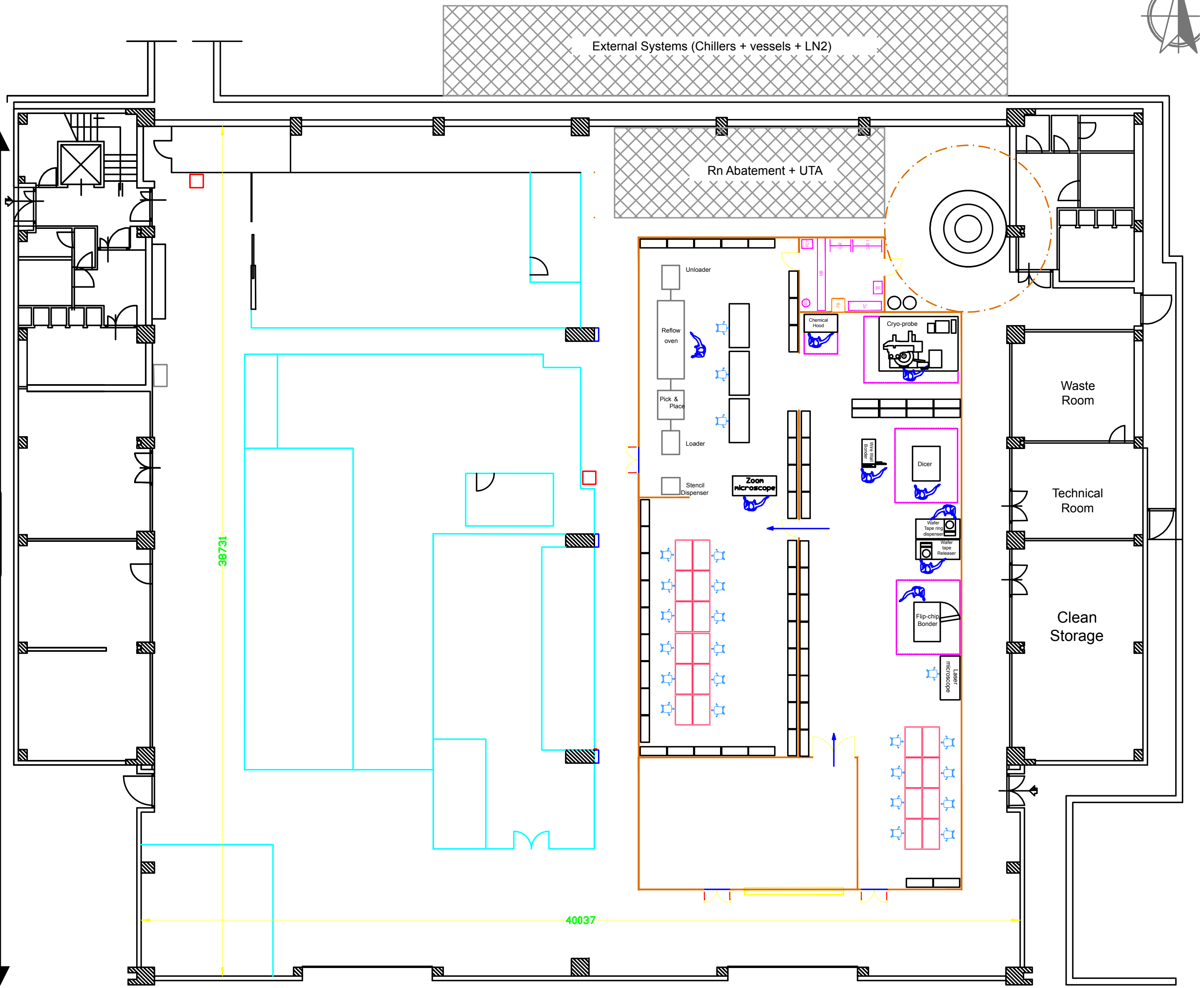
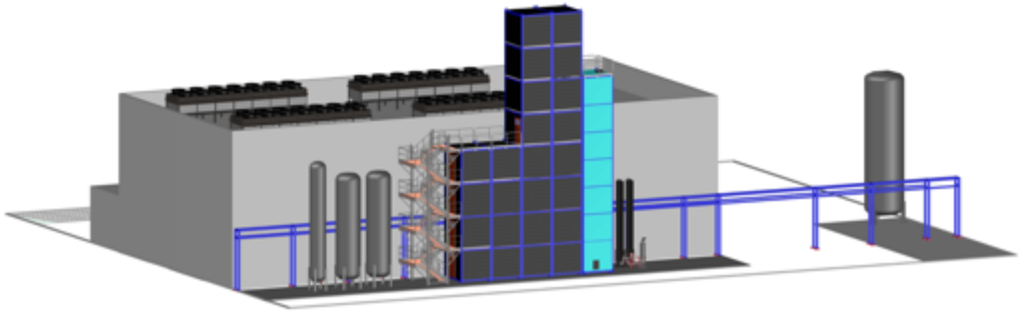
- Final testing facility for 25cm^2 photo detectors is being constructed in Naples

~40m

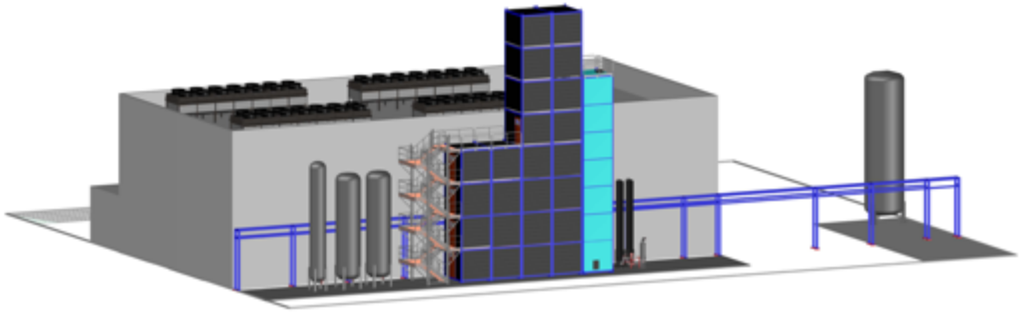


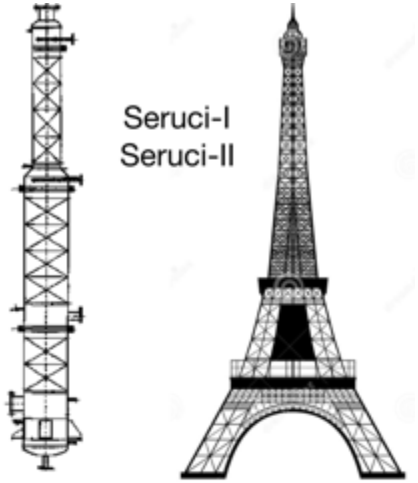
Production - Urania - CO, US



Underground Argon (UAr)

Production - Urania - CO, US

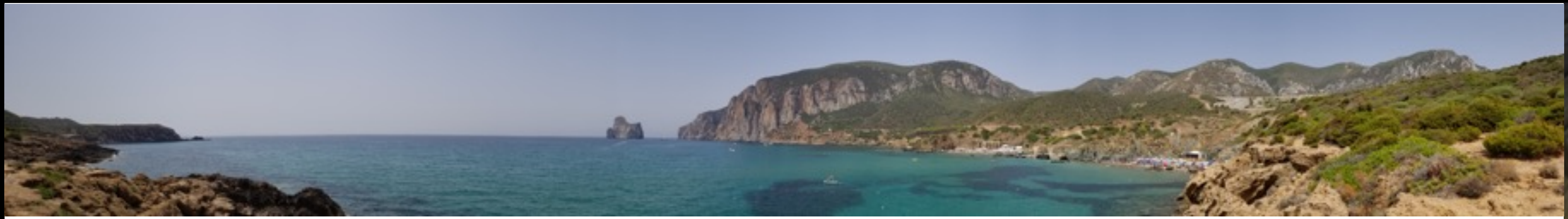


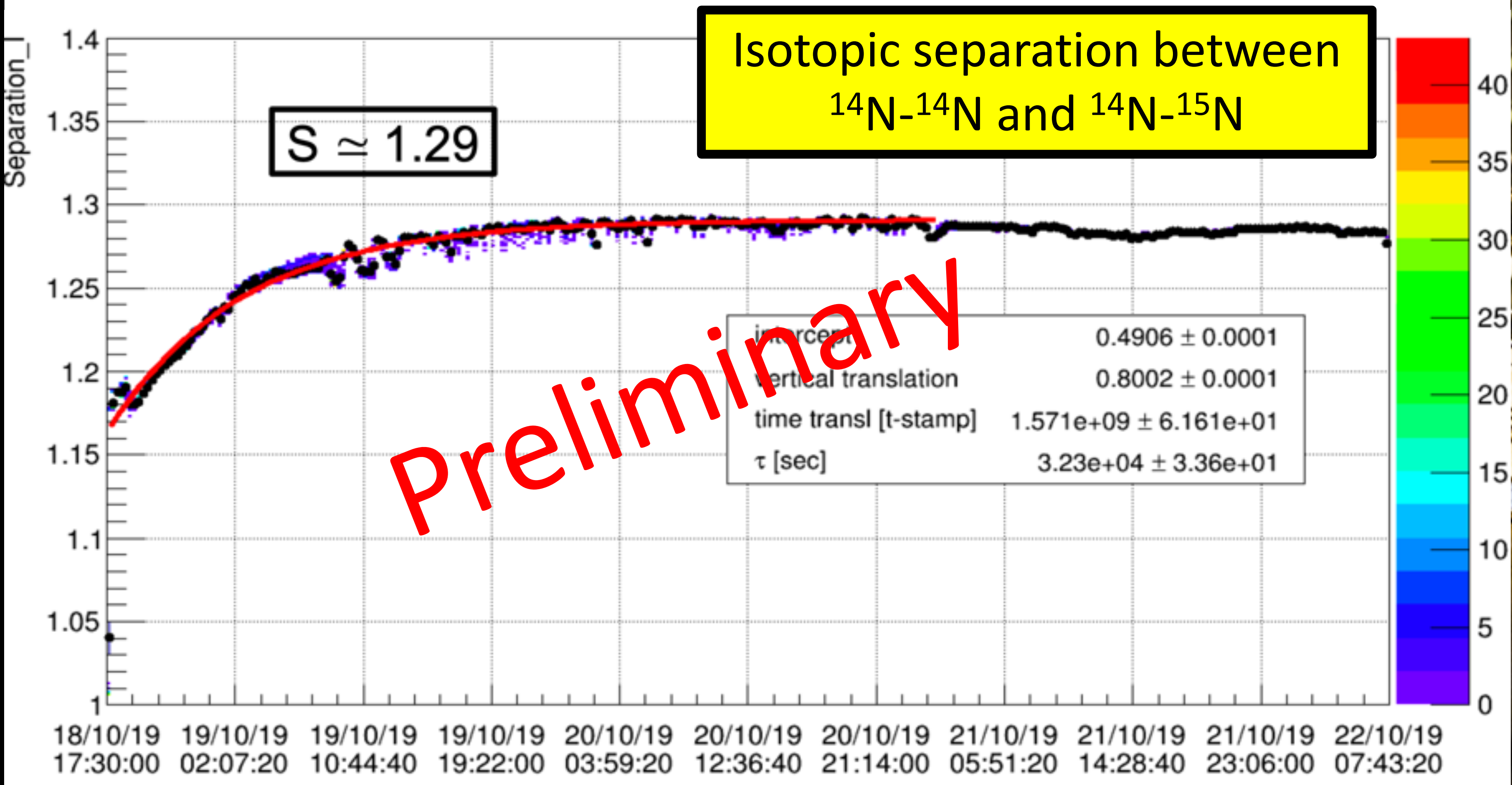


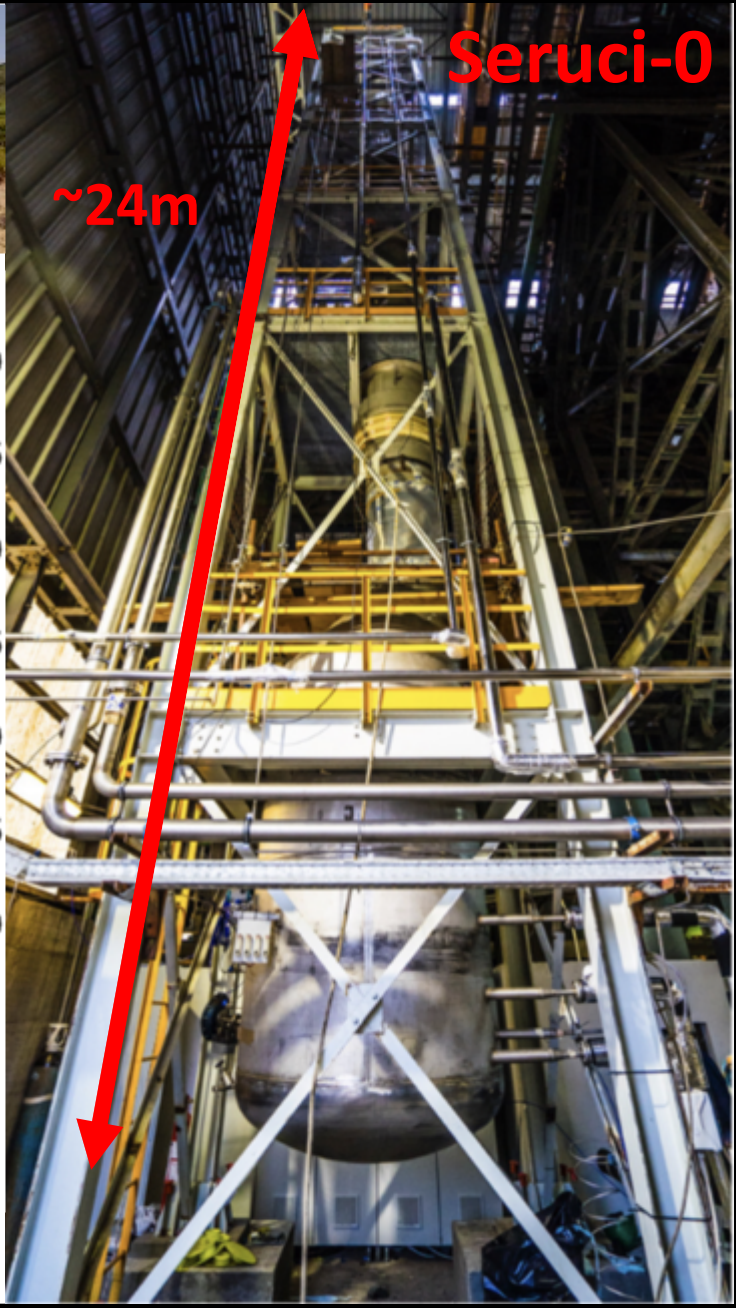
Purification - Aria - Sardinia, IT

- Ground/sea transport
- Final product will allow for multi-tonne scale experiments

Aria - First Results w/ Nitrogen



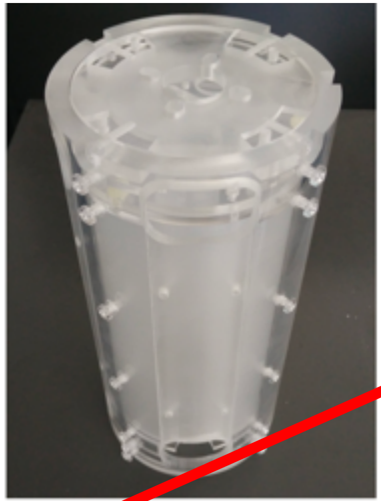


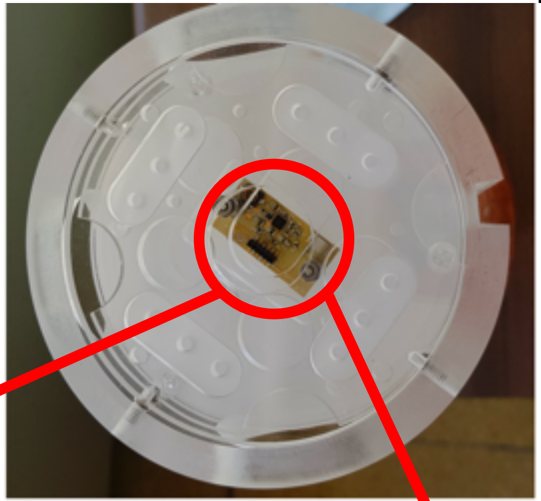


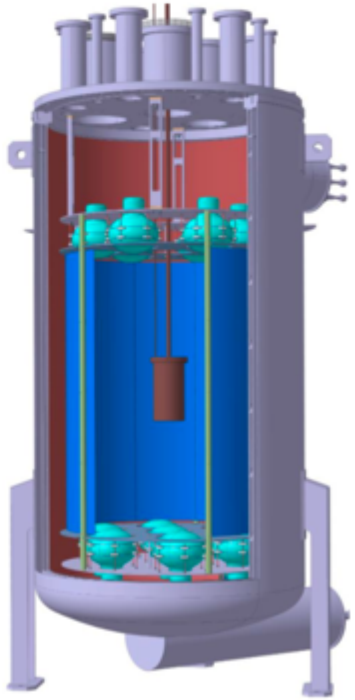
DArT - Measuring Argon Purification

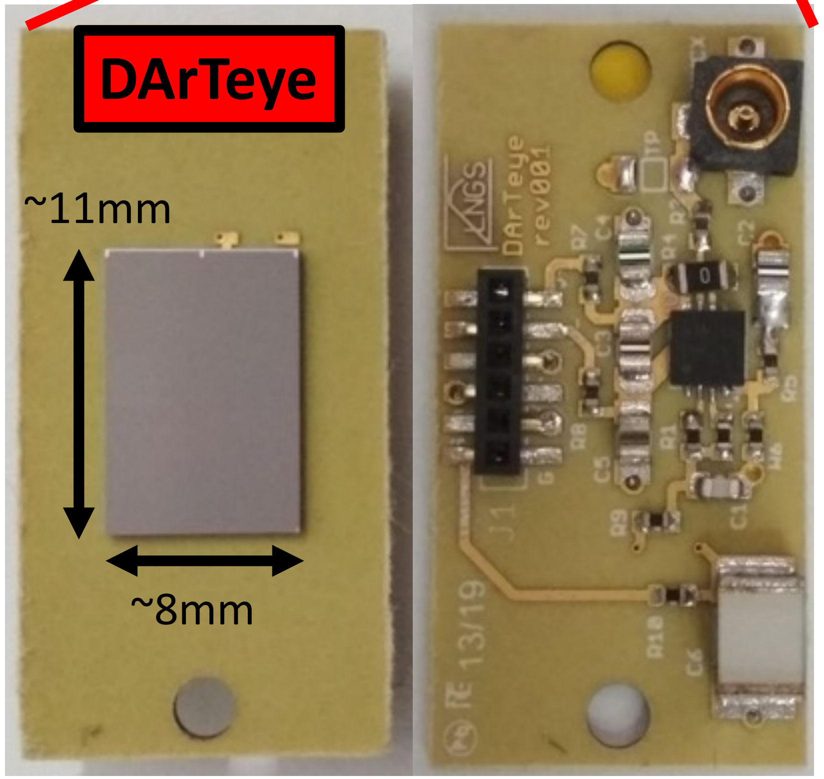
- Measure the depletion factors of the UAr produced by Urania and Aria
- Depletion factor of 10^4 should give ~85 events per week
- 99.99% OFHC Cu; Acrylic coated w/ TPB
- ~1L active volume
- 2 x $1cm^2$ SiPMs as photo sensors (DArTeye)
- To be housed in center of ~1 tonne AAr in the ArDM detector, CanFranc, acting as veto

***Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon.* DarkSide collaboration; In preparation for JNIST.**



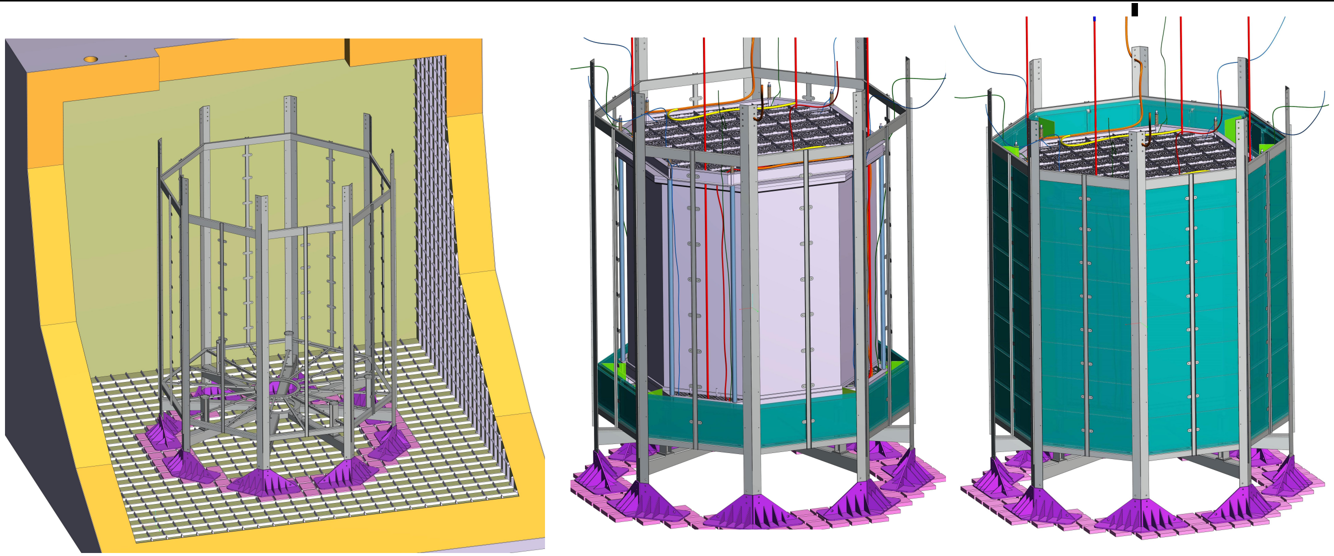






Active Neutron Veto

- Primary work in Genoa and Torino
- No more organic liquid scintillators at LNGS…
- Will utilize LAr and Gd doped acrylic panels
- 10 cm thick vessel surrounding TPC
- 300 tonnes AAr; ~3000 “PDMs”
- Requires higher dynamic range than the inner TPC
- Integrated front end electronics
- R&D for reflector and WLS is ongoing



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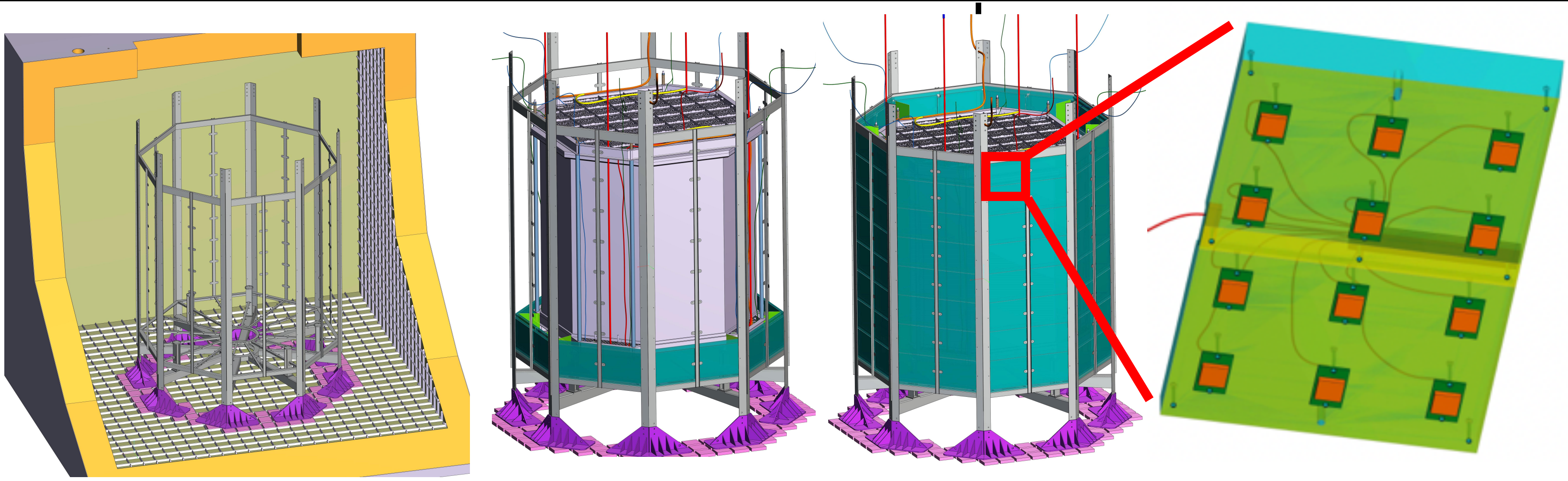

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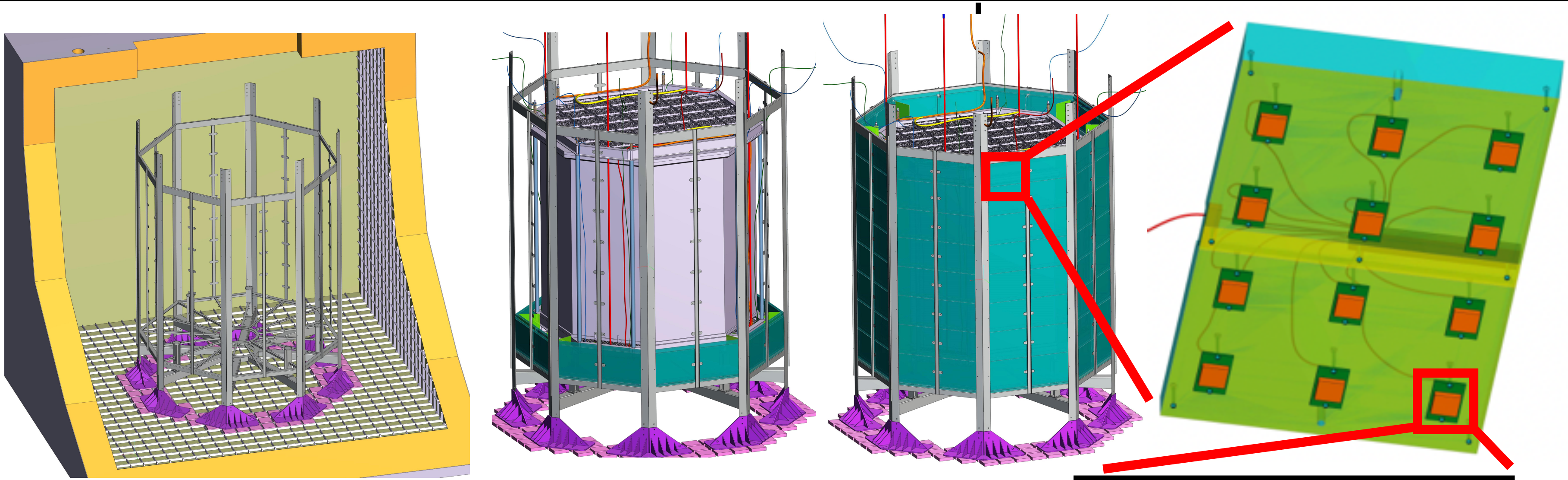
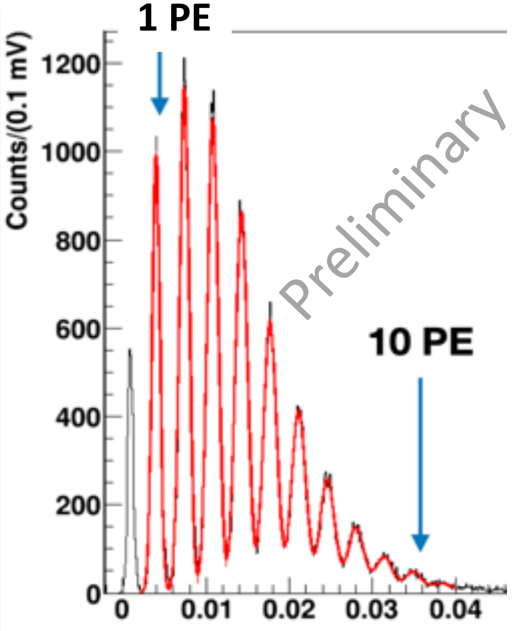
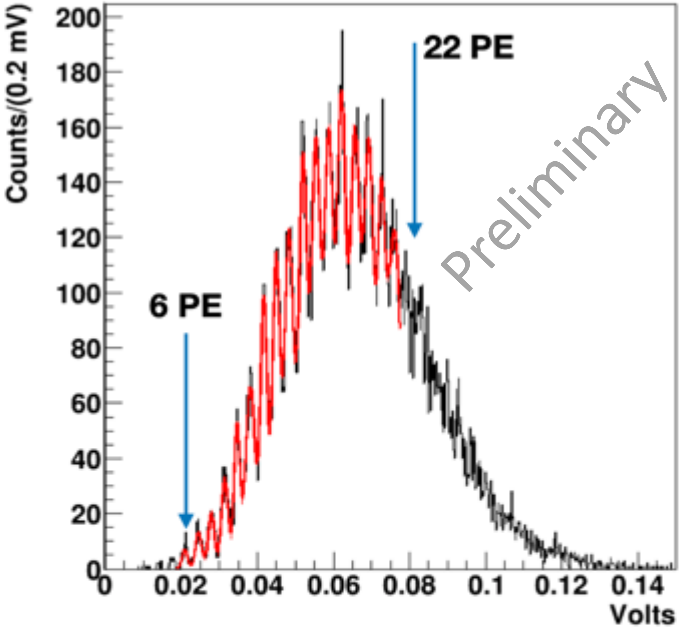
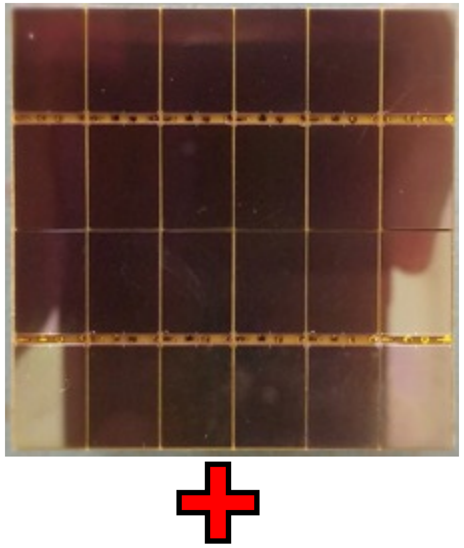




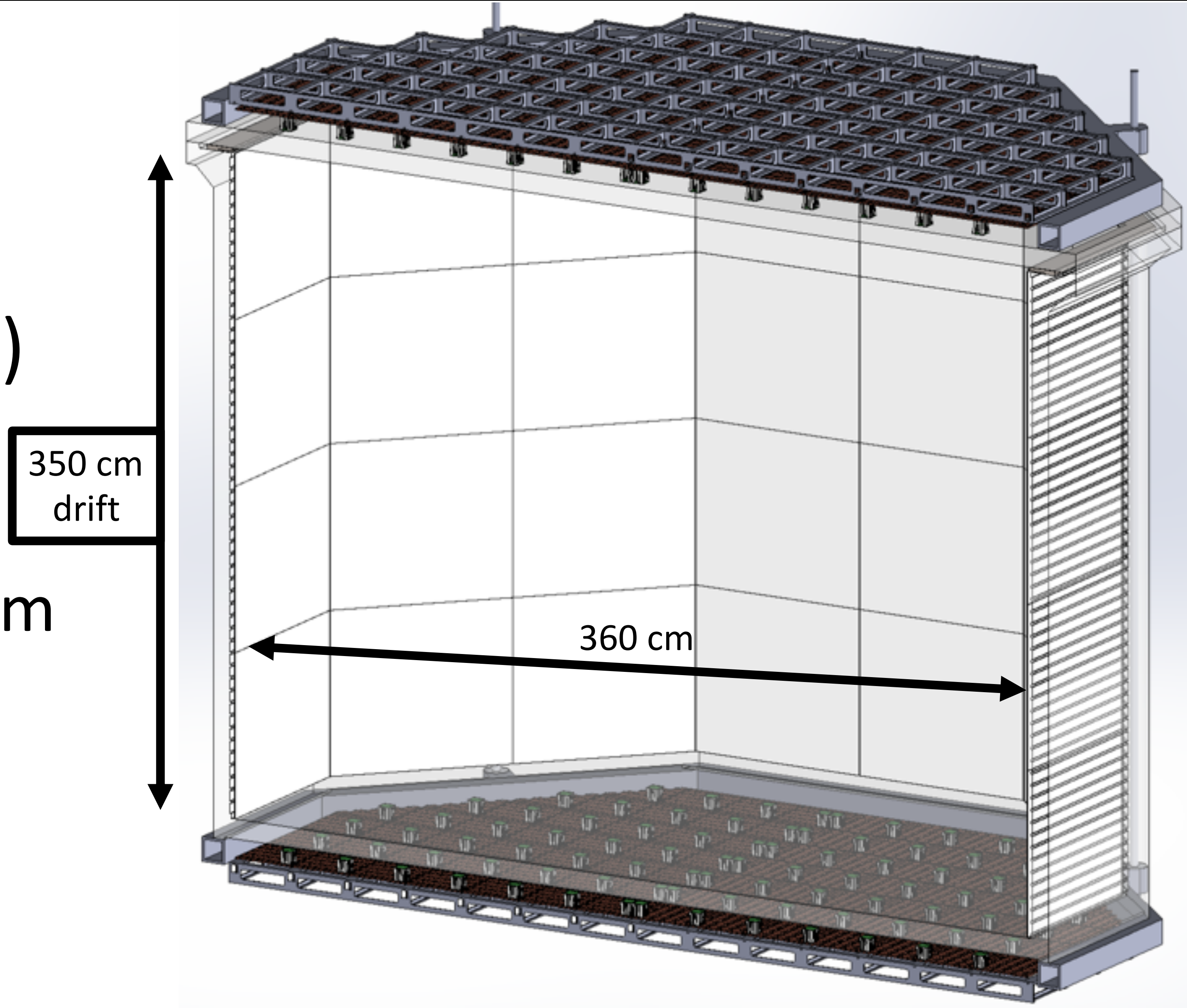




Analog CMOS integrated readout

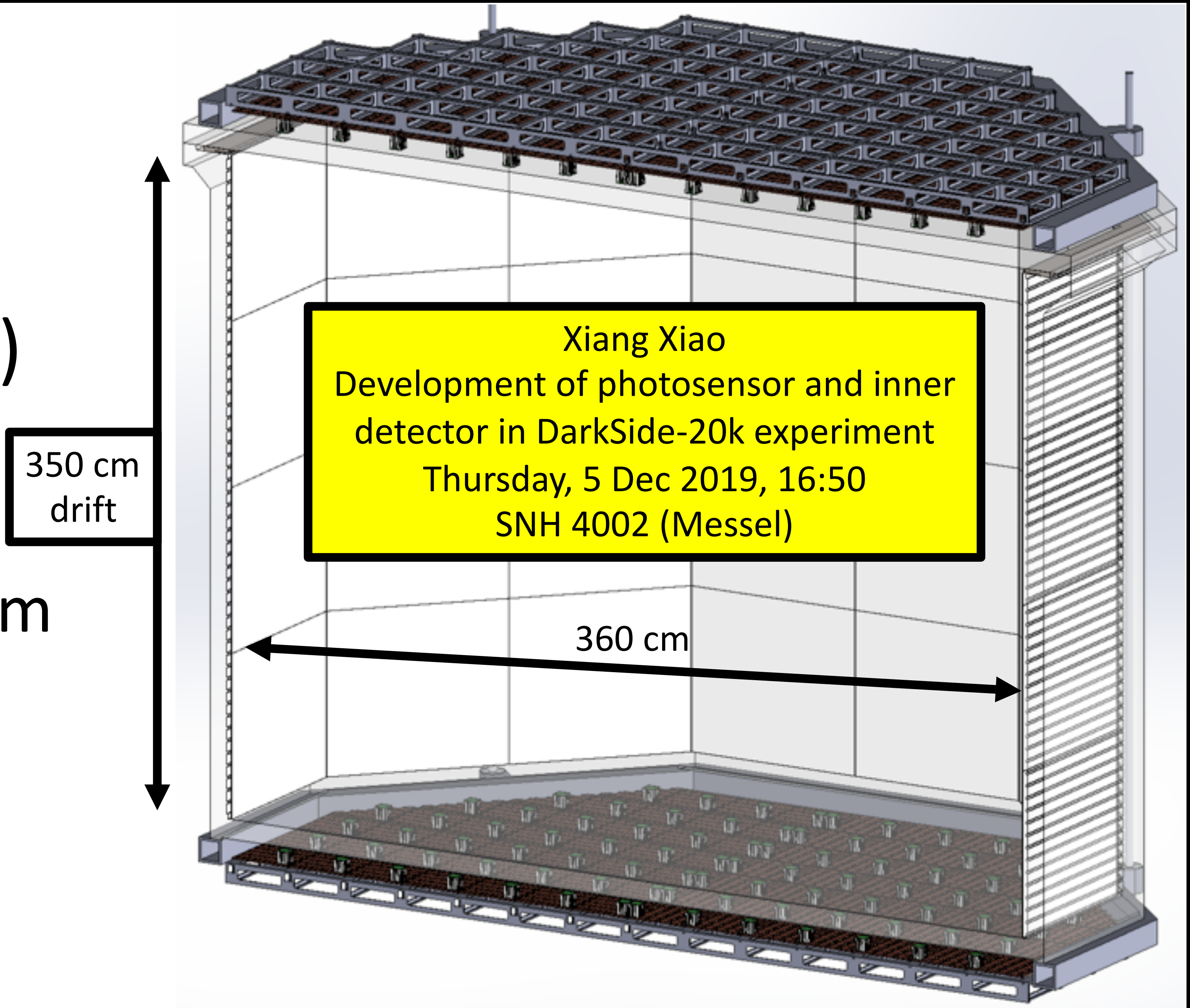
Inner TPC

- Sealed octagonal acrylic vessel
- ~50 tonnes Depleted underground Argon (DAr)
  - 20 tonnes fiducial
- 8280 PDMs
  - Split evenly on top/bottom
- Clevios conductive polymer coating
- TPB coating for WLS



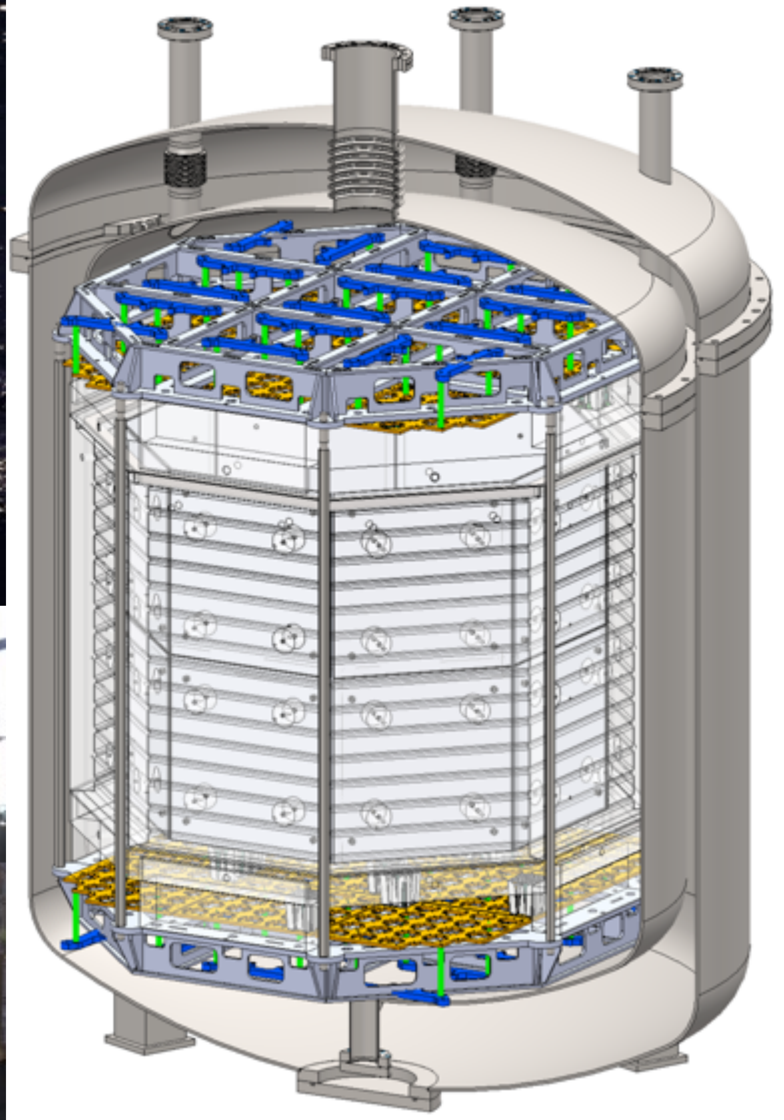
Inner TPC

- Sealed octagonal acrylic vessel
- ~50 tonnes Depleted underground Argon (DAr)
  - 20 tonnes fiducial
- 8280 PDMs
  - Split evenly on top/bottom
- Clevios conductive polymer coating
- TPB coating for WLS



Proto-1T

- Scaled down version of DS-20k inner TPC
- ~ 350 kg active volume
- 250 PDM channels, possibly 370
- Assembly starting Summer 2020
- Photo electronics are being produced and tested in Italy
- Cryogenics work is being done at CERN
- Acrylic vessel work is being done in Canada (DEAP)



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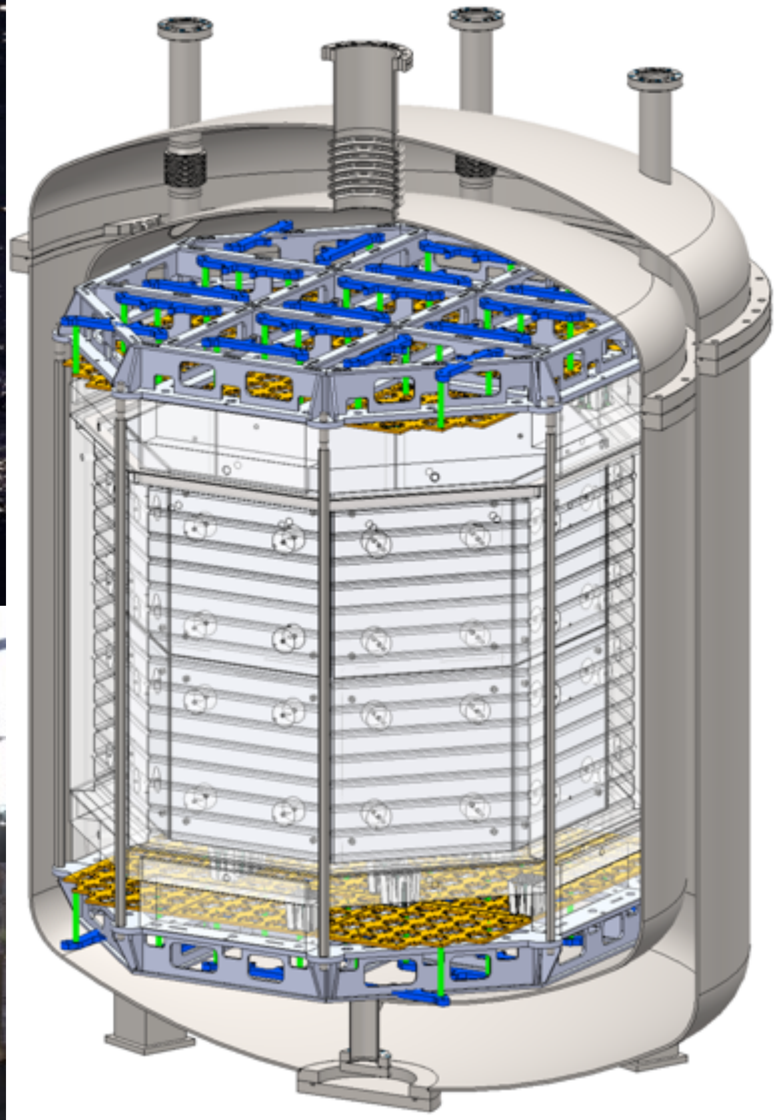
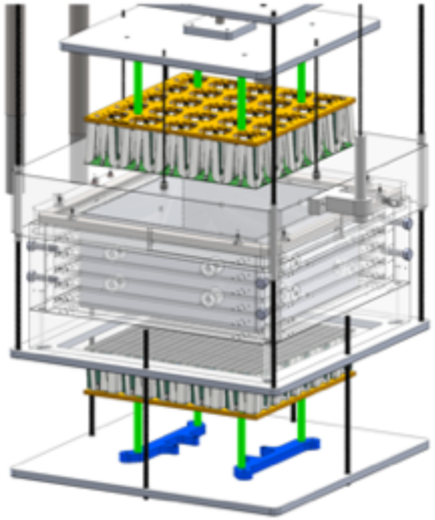
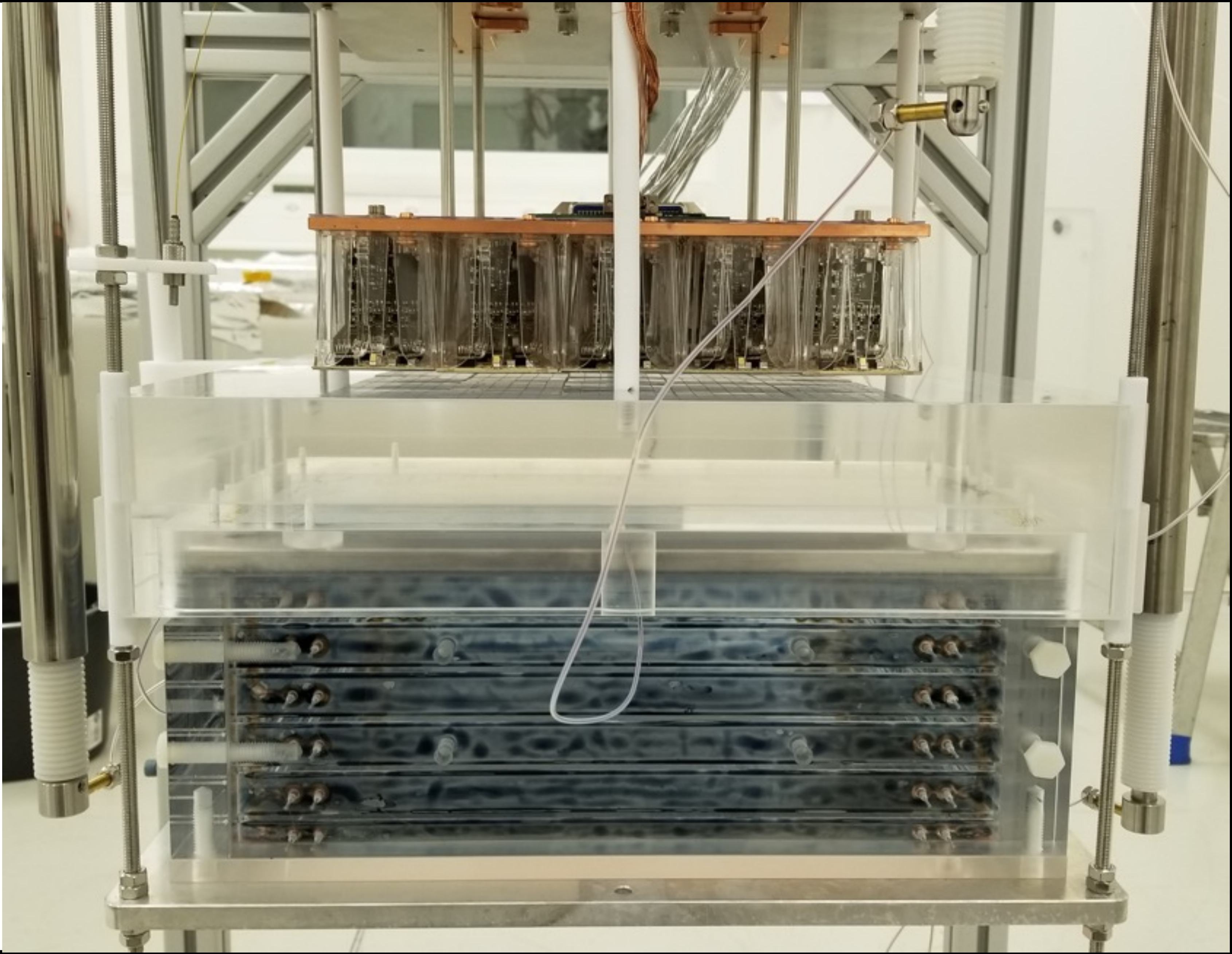


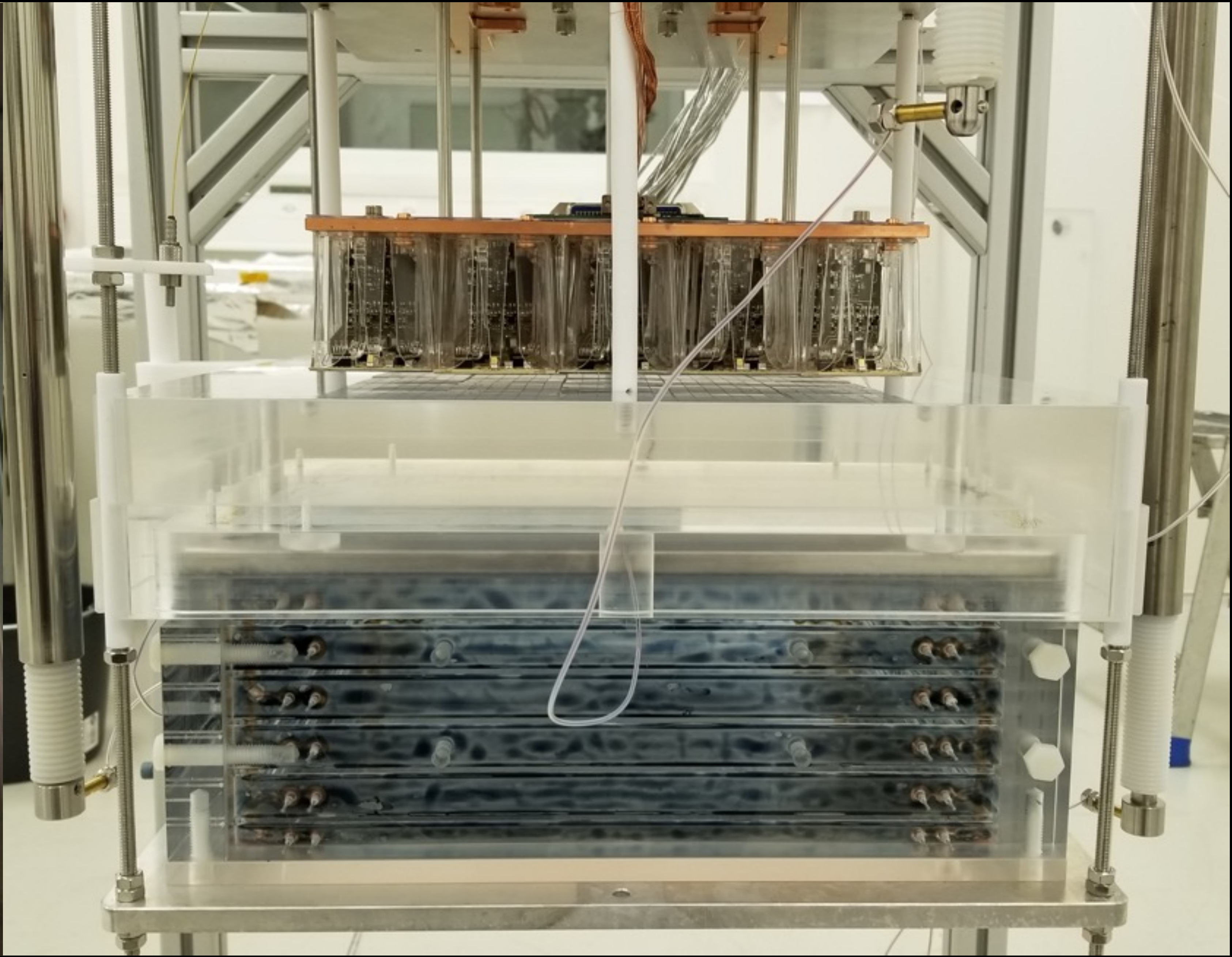
Proto-0

- Deployed at CERN
- Integrated with DS-20k technologies
- First LAr run with TPC and source just finished
- First experience of DAQ and analysis with 25 channel photo detectors in a LAr TPC
- New TPC design proven successful; fully functional
- Observed first S2 signals
- Run after the new year will study details of S2; X-Y





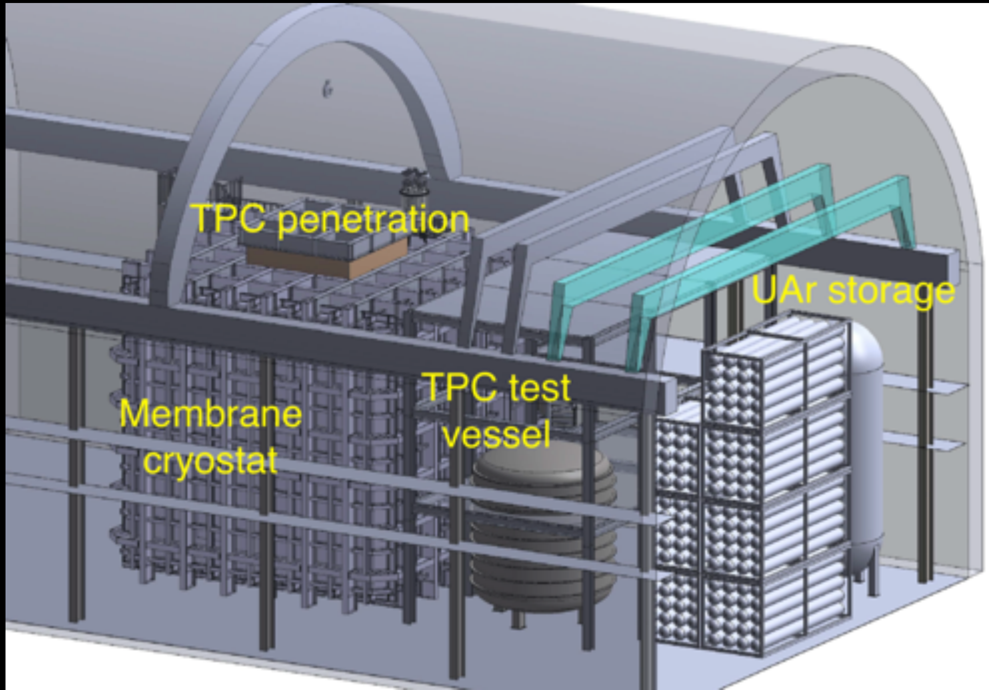
Proto-0



Summary

- Dual phase Argon TPCs are a proven technology for background-free dark matter searches
  - Zero background > 10 GeV
- The GADMC is now pooling resources with DarkSide-20k as the next step
- DarkSide-20k could reach the neutrino floor using key technologies:
  - Large scale production of novel SiPM based cryogenic photo detectors
  - Extraction and purification of large quantities of low radioactivity underground Argon
  - TPC technologies – Clevios, reflectors, SS wire grid, gas pocket formation…
  - Active neutron veto utilizing atmospheric Argon, Gd doped acrylic, SiPMs
  - Acrylic structural R&D
  - Acrylic knowledge and experience from DEAP-3600
- DarkSide-20k technology could also decrease the low mass WIMP cross section by orders of magnitude
- The future of this technology (Argo) aims to reach well into the neutrino floor

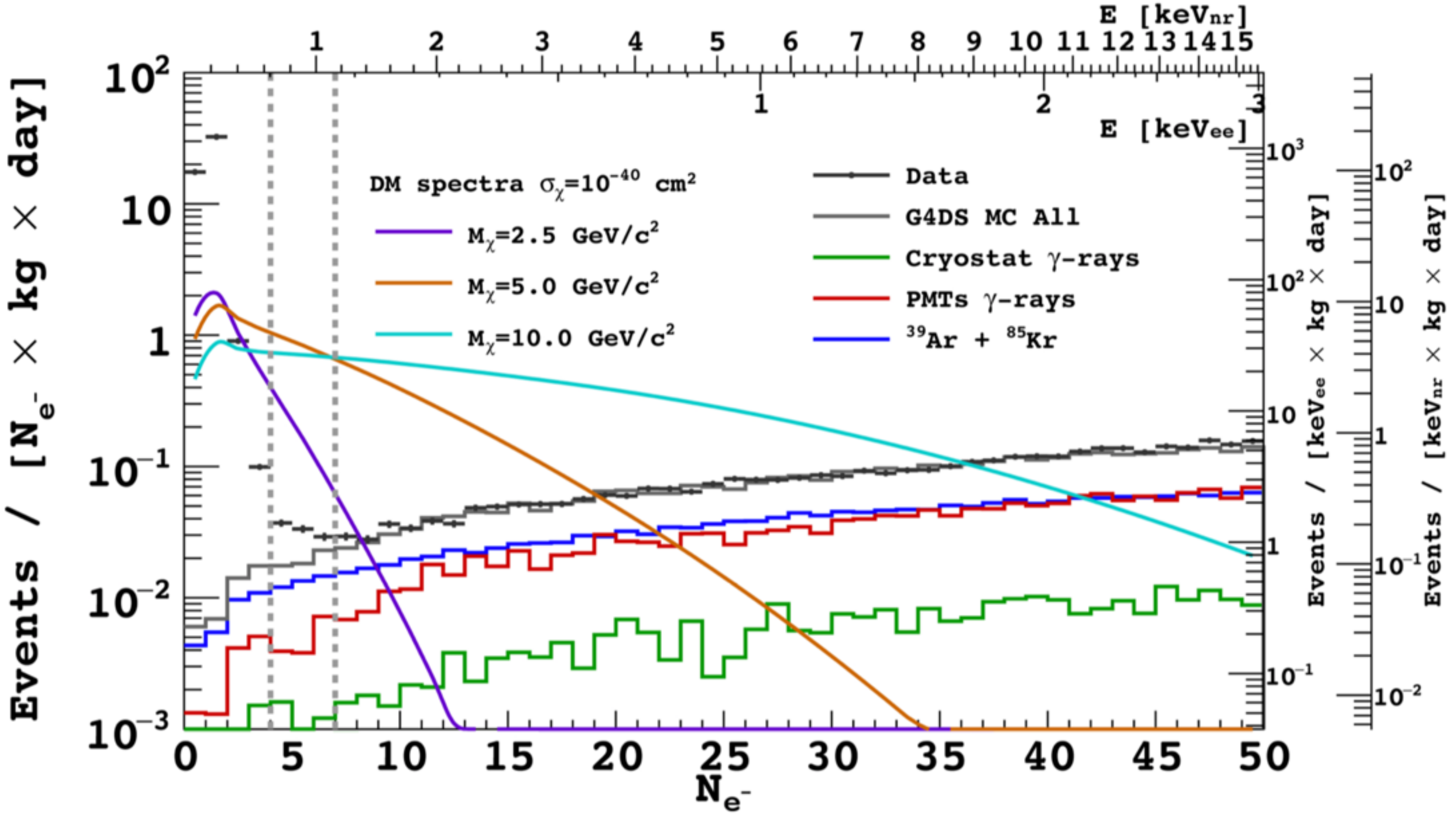
Thank You


TPC penetration
UAr storage
TPC test vessel
Membrane cryostat

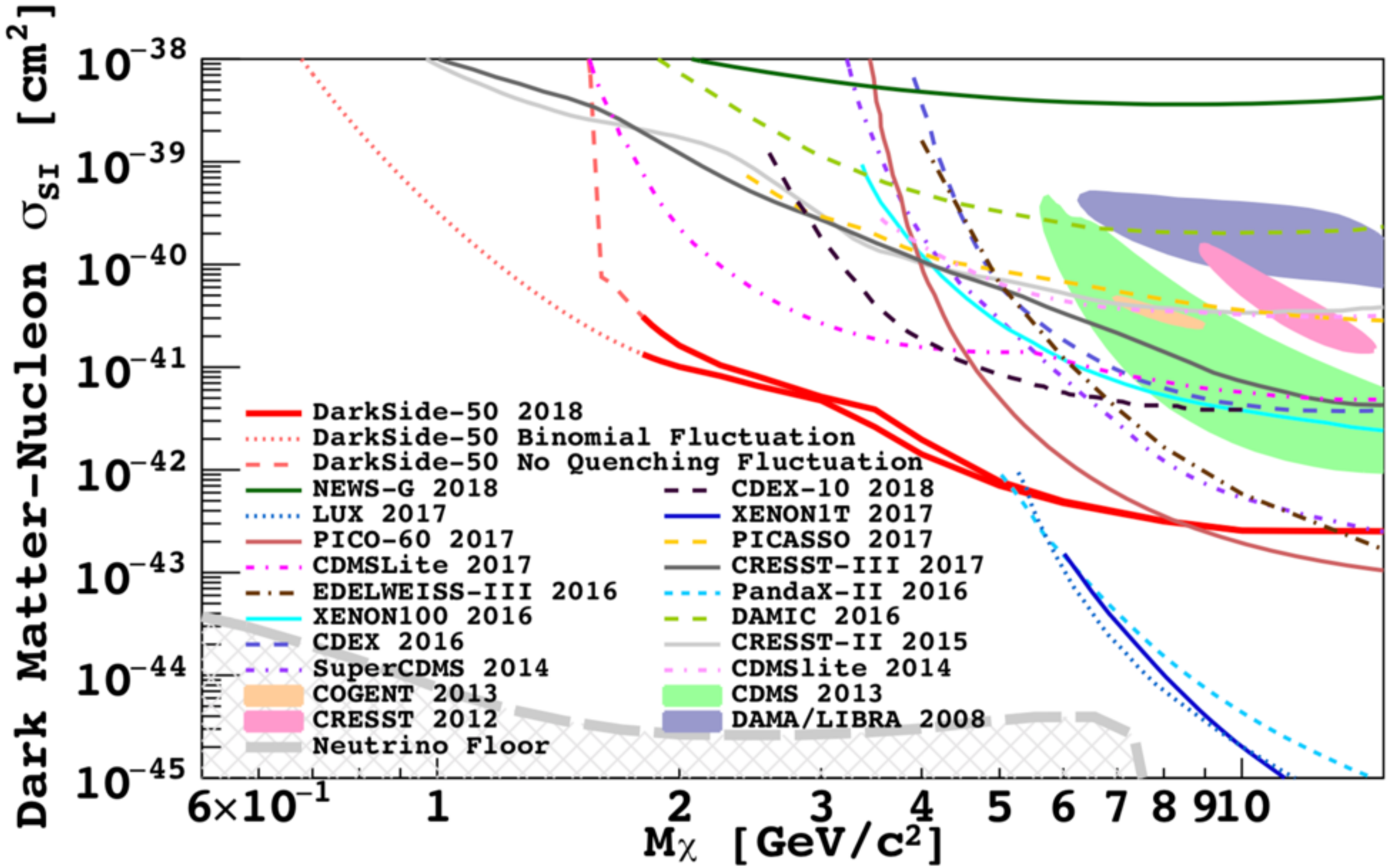
Backup

Backup

DarkSide-50 Background Spectra (Low-Mass)



DarkSide-50 Limit (Low-Mass)



DarkSide-50 Results (Sub-GeV; DM-Electron)