



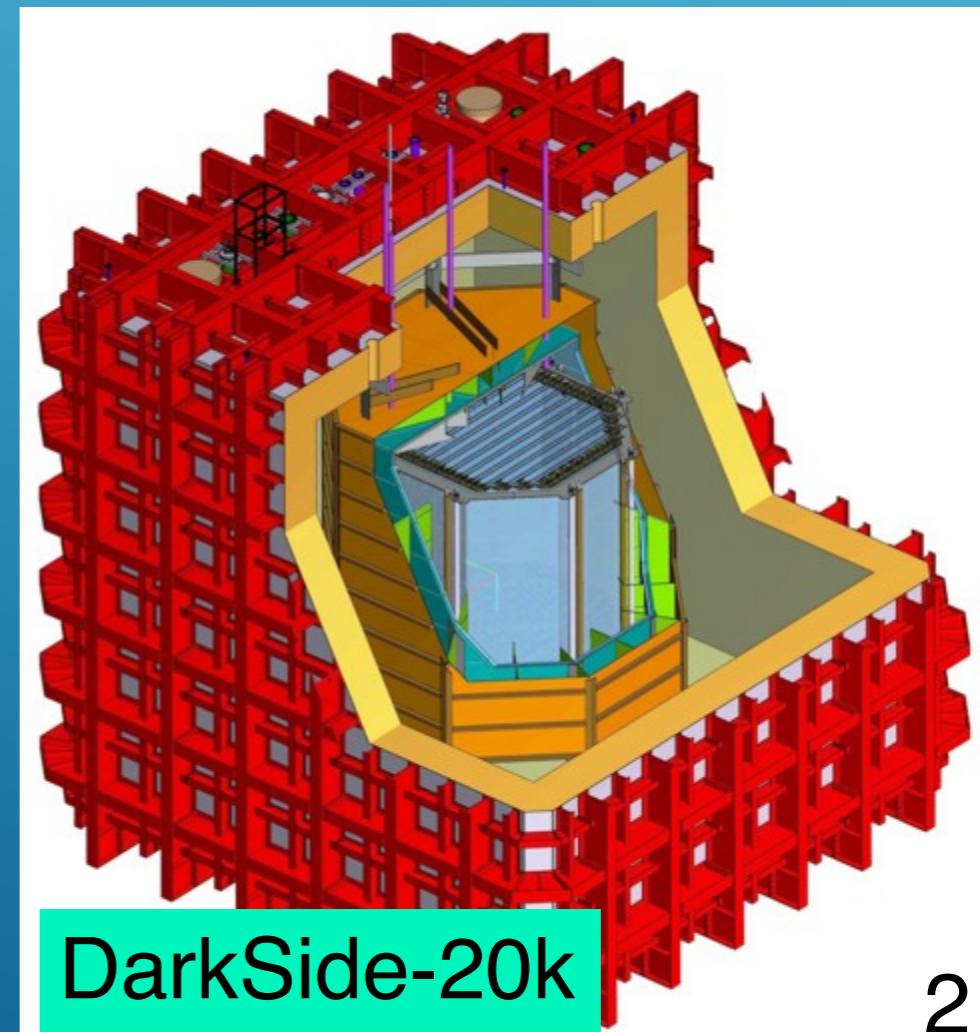
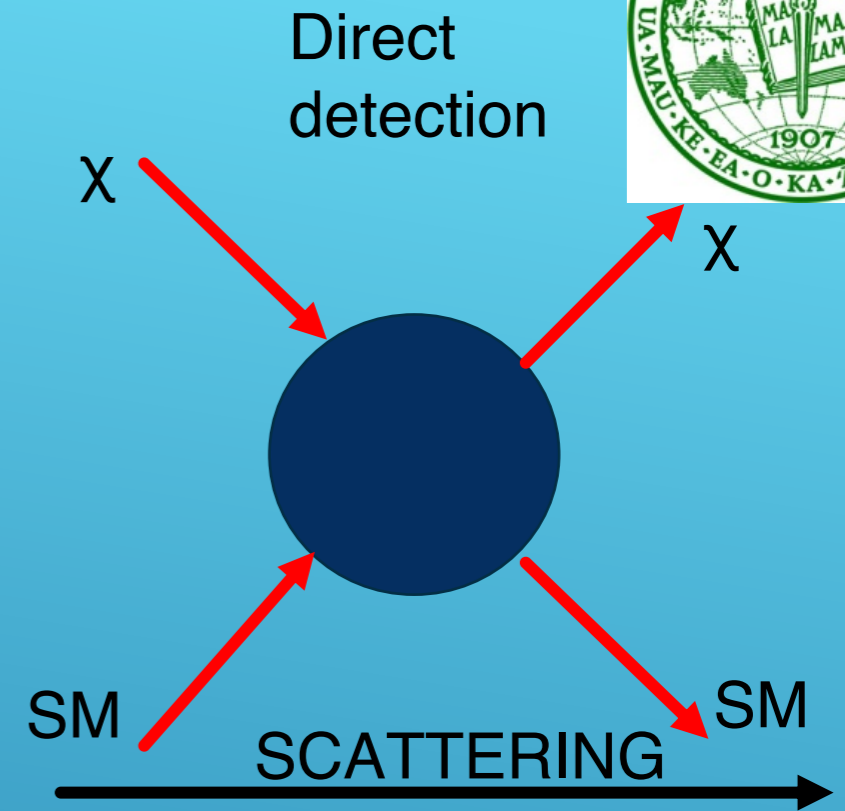
GLOBAL LIQUID ARGON DARK MATTER PROGRAM

Jelena Maricic,
University of Hawaii
For Global Argon
Dark Matter Collaboration
December 8, 2019



OUTLINE

- Introduction to Global Liquid Argon Dark Matter Collaboration
- Dual Phase Argon Time Projection Chamber (TPC) detectors for direct DM particle detection with zero instrumental background
- DarkSide-50 design and results
- Developments toward DarkSide-20k and ARGO
- Summary and Outlook





GLOBAL LIQUID ARGON DARK MATTER COLLABORATION



GLOBAL ARGON DARK MATTER COLLABORATION (GADMC)



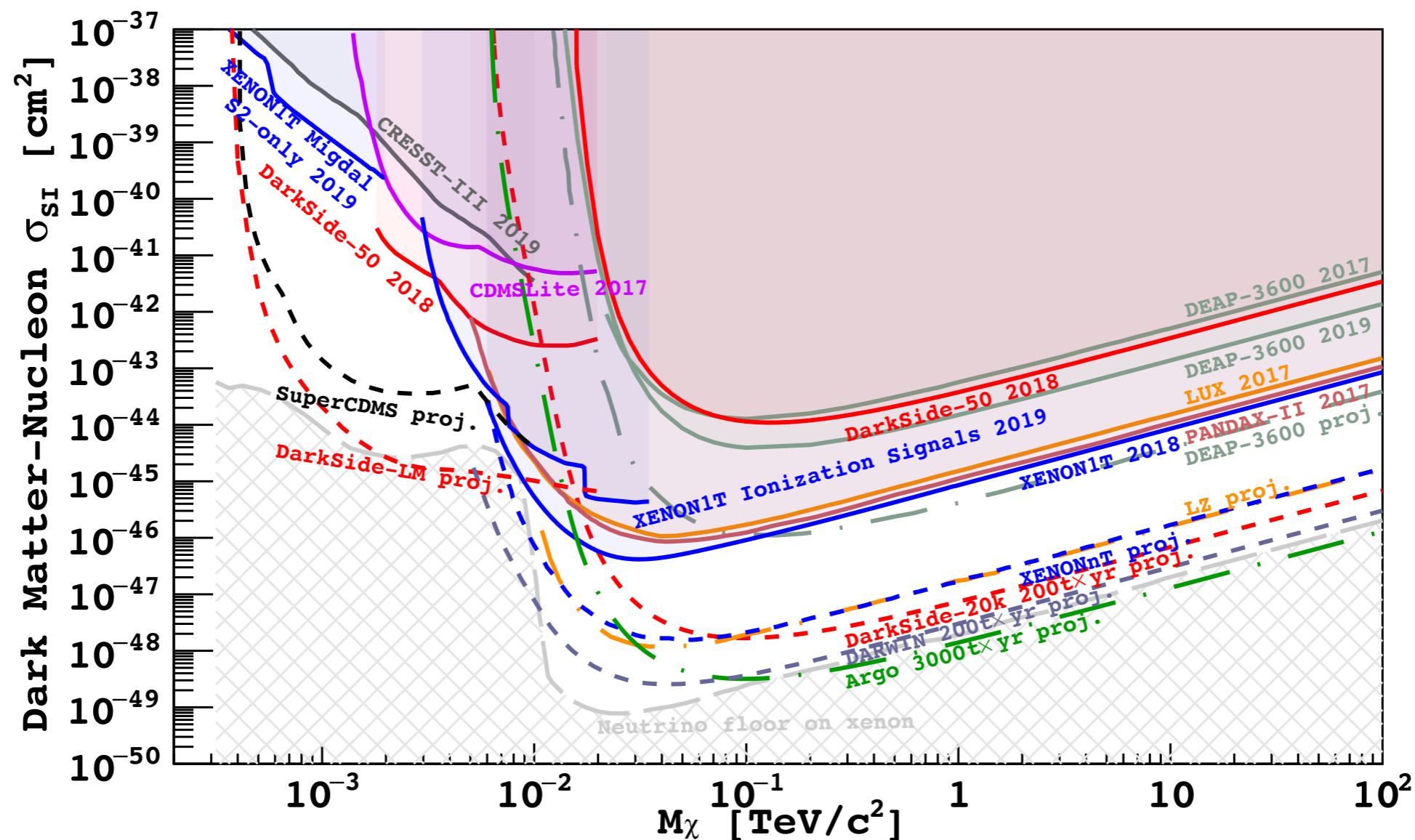
- DarkSide-50
- DEAP3600
- ArDM
- MiniCLEAN



Unified Global Argon Dark Matter Program for DM Search beyond neutrino floor with zero inst. bkg.



DarkSide-20k @ LNGS ~2022 (30 t fiducial)
ARGO @ SNOLAB ~2029 (300 t fiducial)





GADMC

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

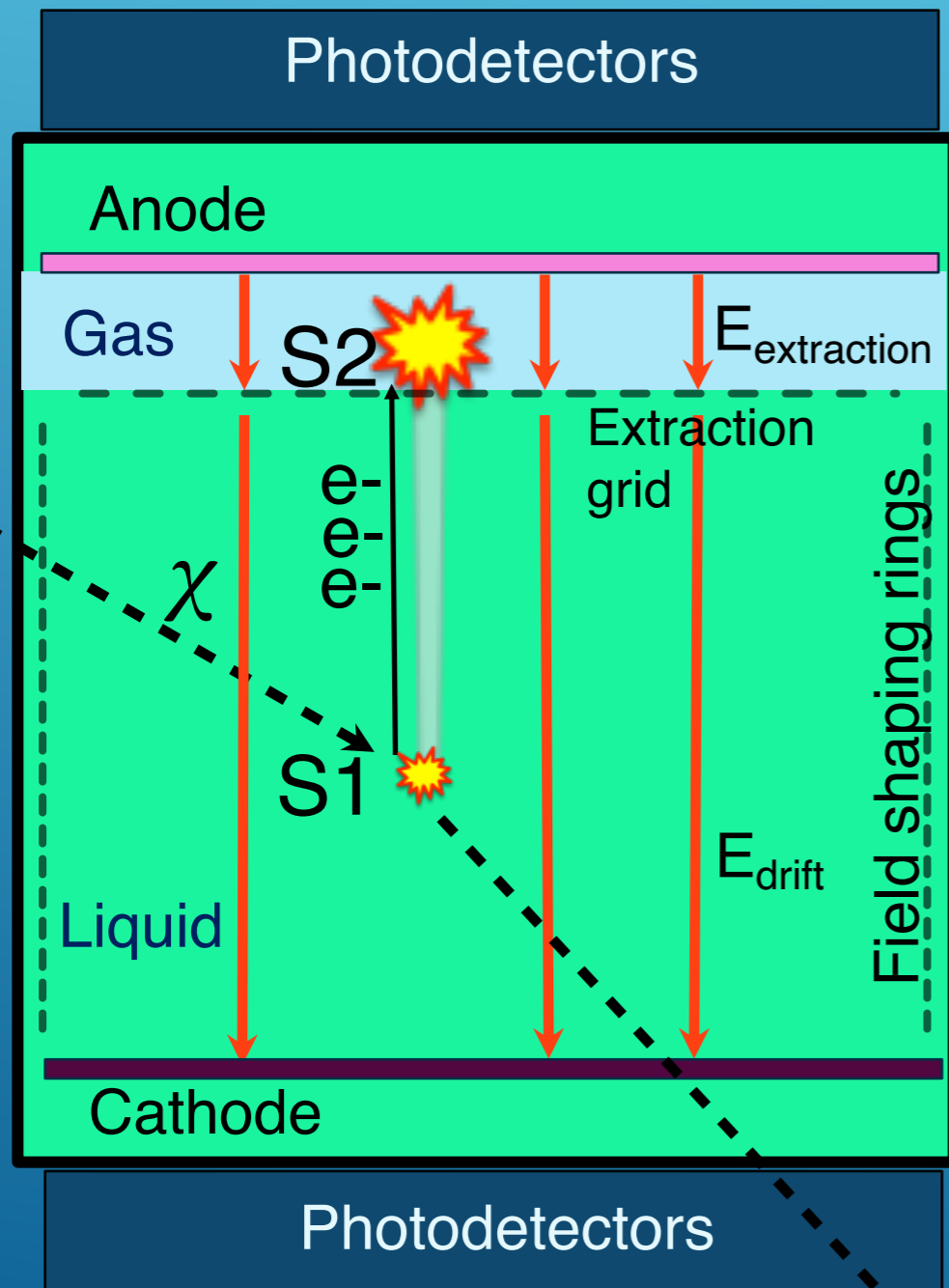




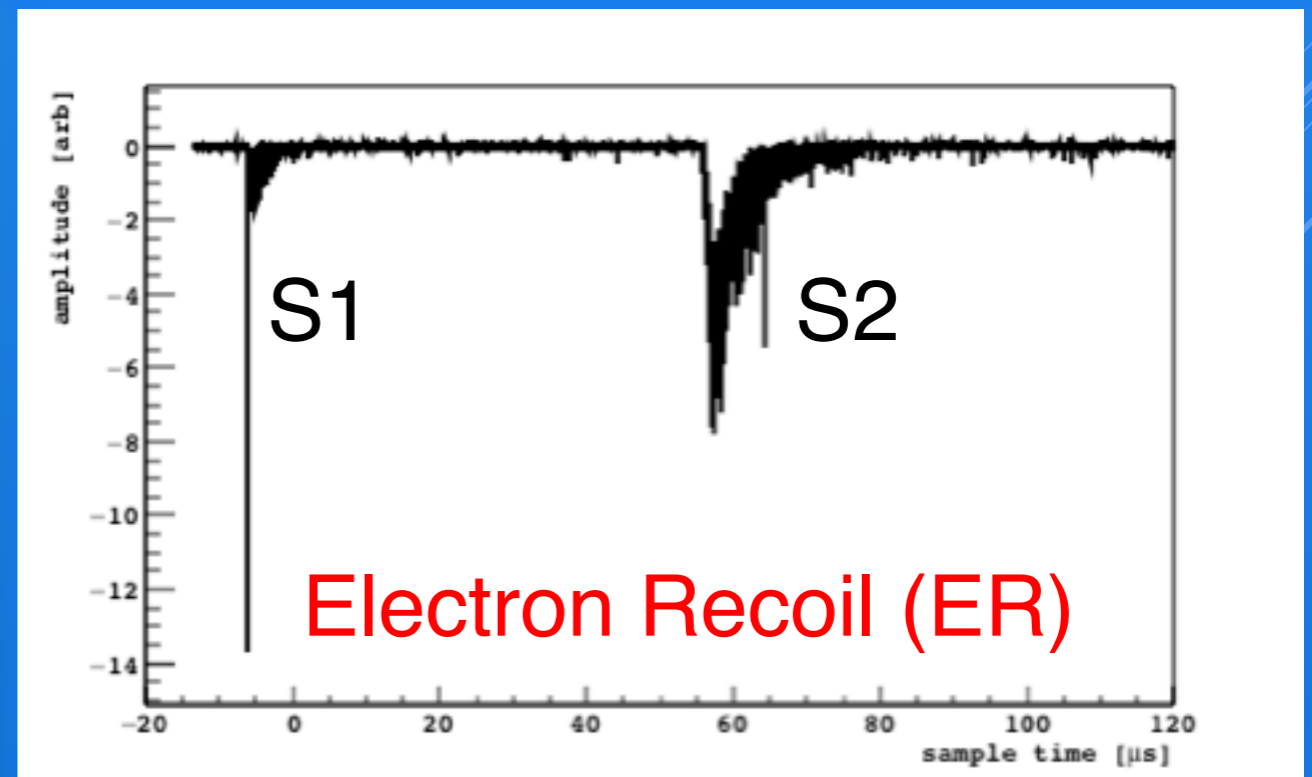
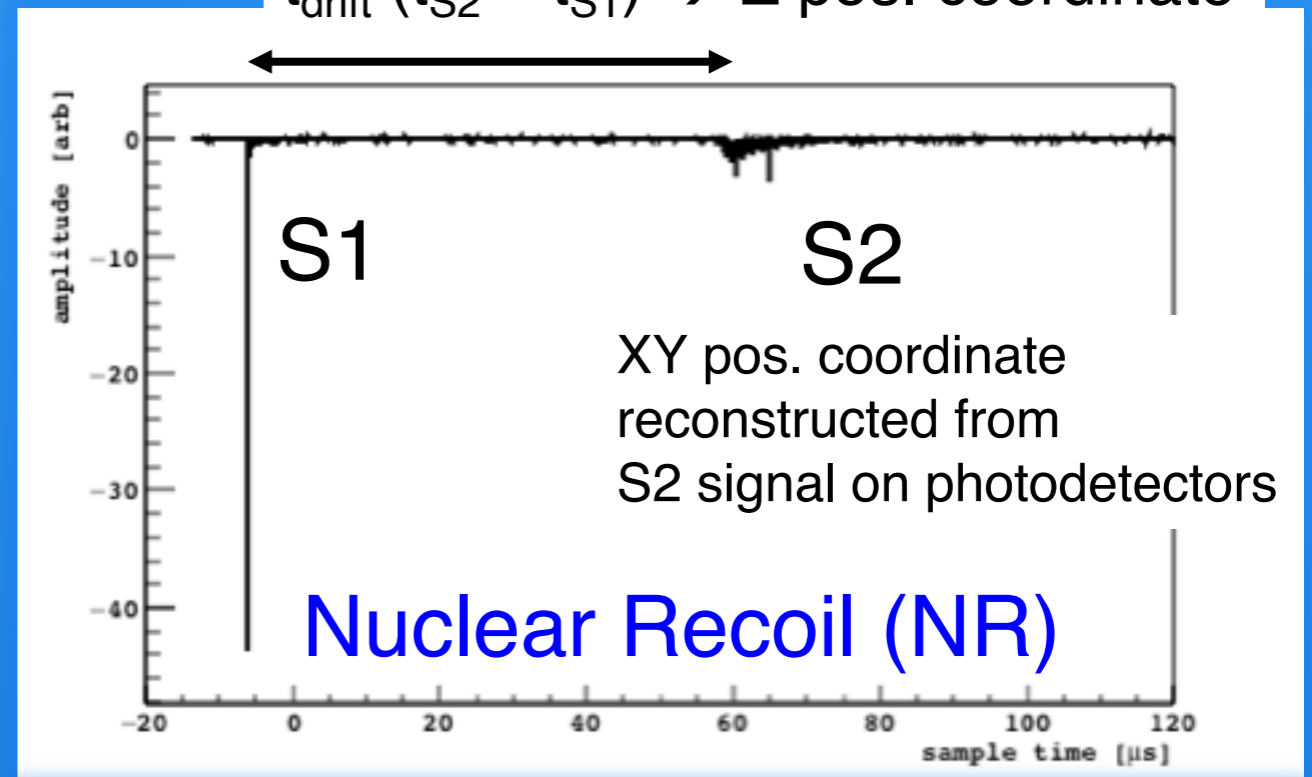
DUAL PHASE ARGON TIME PROJECTION CHAMBER (TPC) DETECTORS FOR DIRECT DM PARTICLE DETECTION WITH ZERO INSTRUMENTAL BACKGROUND



DUAL PHASE ARGON TIME PROJECTION CHAMBER CONCEPT



$t_{\text{drift}} (t_{S2} - t_{S1}) \rightarrow Z \text{ pos. coordinate}$



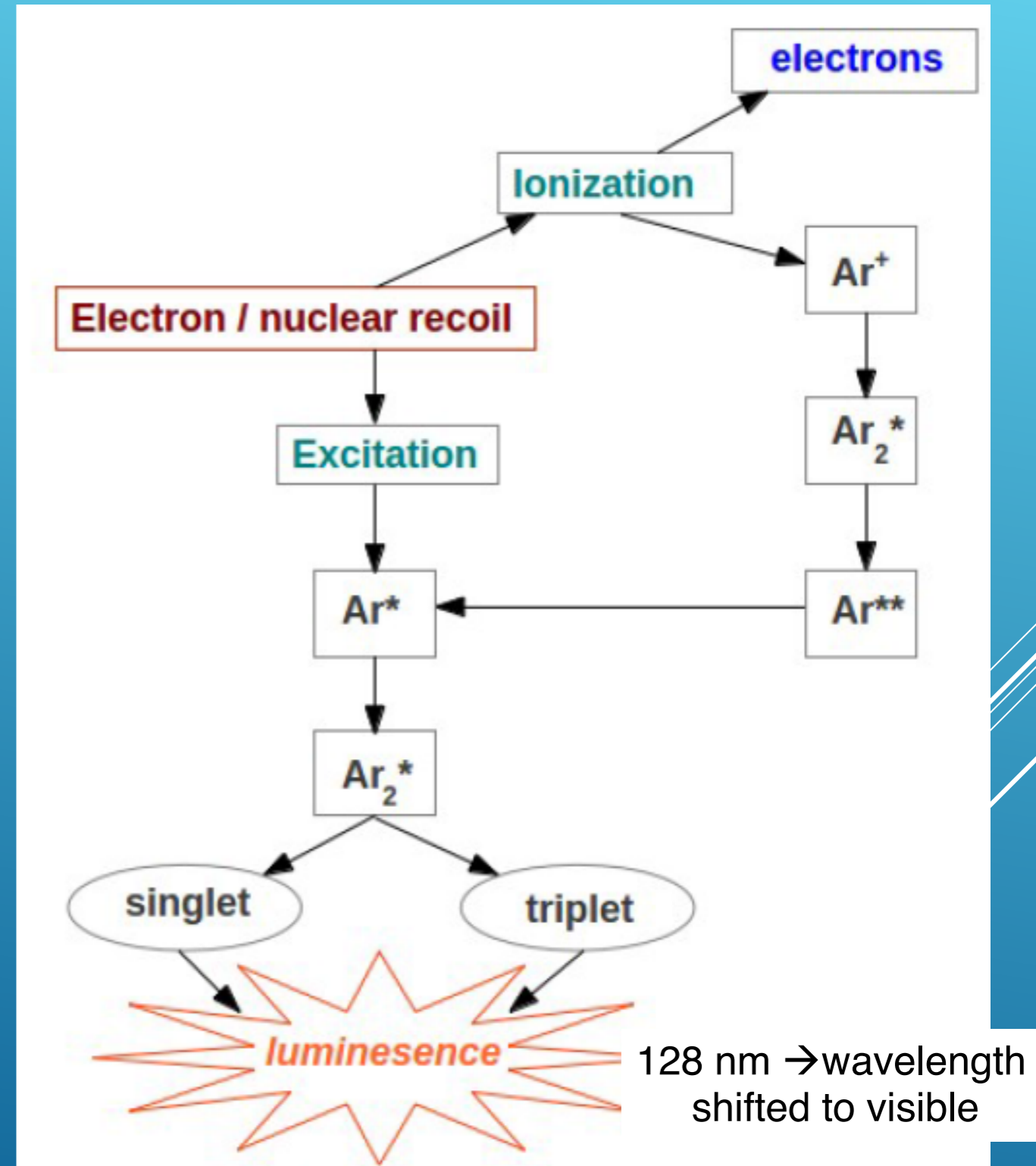
Both NR and ER produce S1 and S2 signal, albeit with different time profile and signal strength.



BASIS OF PULSE SHAPE DISCRIMINATION (PSD) IN LIQUID ARGON



- ▶ Both ER and NR form triplet and singlet Ar_2^* states
- ▶ *Triplet and singlet states have very different time constants:*
- ▶ Singlet: $\tau = 7 \text{ ns}$
- ▶ Triplet: $\tau = 1500 \text{ ns}$
- ▶ NRs are characterized by much larger dE/dx than ERs
- ▶ \rightarrow Scintillation light from the triplet states is severely suppressed in case of NRs compared to ERs
- ▶ \rightarrow Scintillation light time profile for NR and ER very different \rightarrow basis of PSD



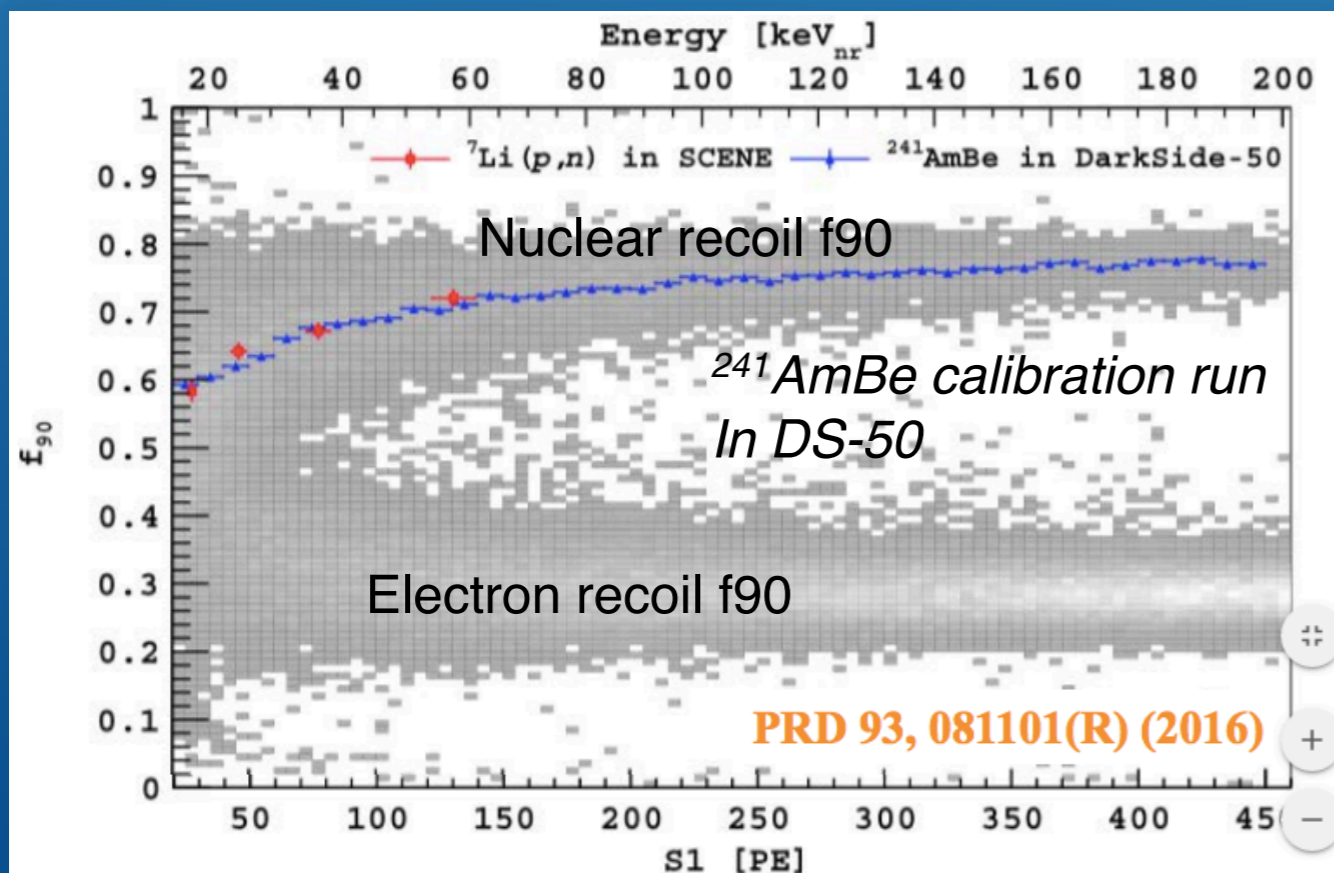
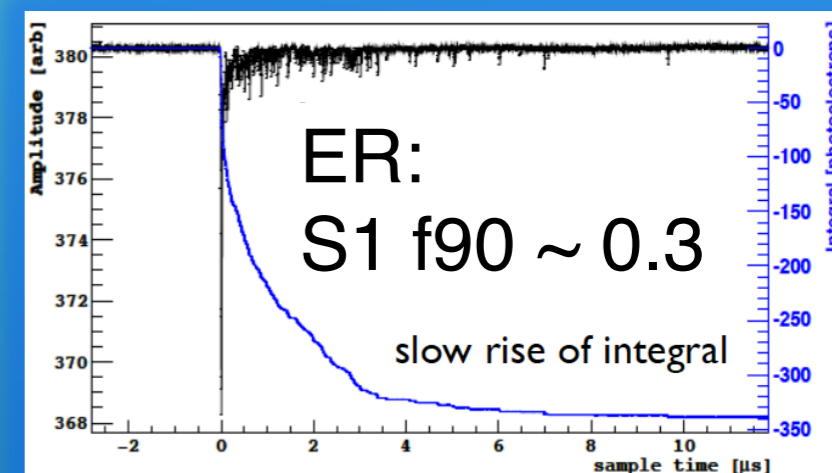
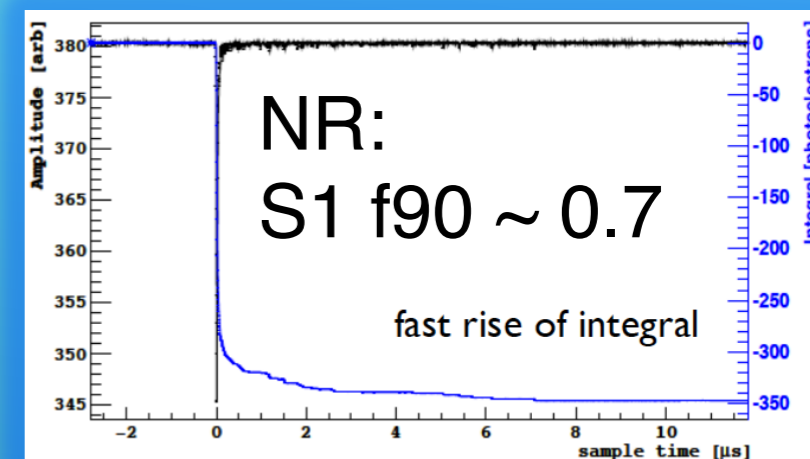


POWER OF S1 PULSE SHAPE DISCRIMINATION (PSD) IN LIQUID ARGON



PSD parameter: $f_{90} = \frac{\text{S1 light integral in the first 90 ns}}{\text{Total S1 light integral}}$

> 10^7 bkg rejection of electron recoils based on S1 PSD in DS-50 AAr run (statistics limited) - [arxiv:1410.0653](https://arxiv.org/abs/1410.0653).

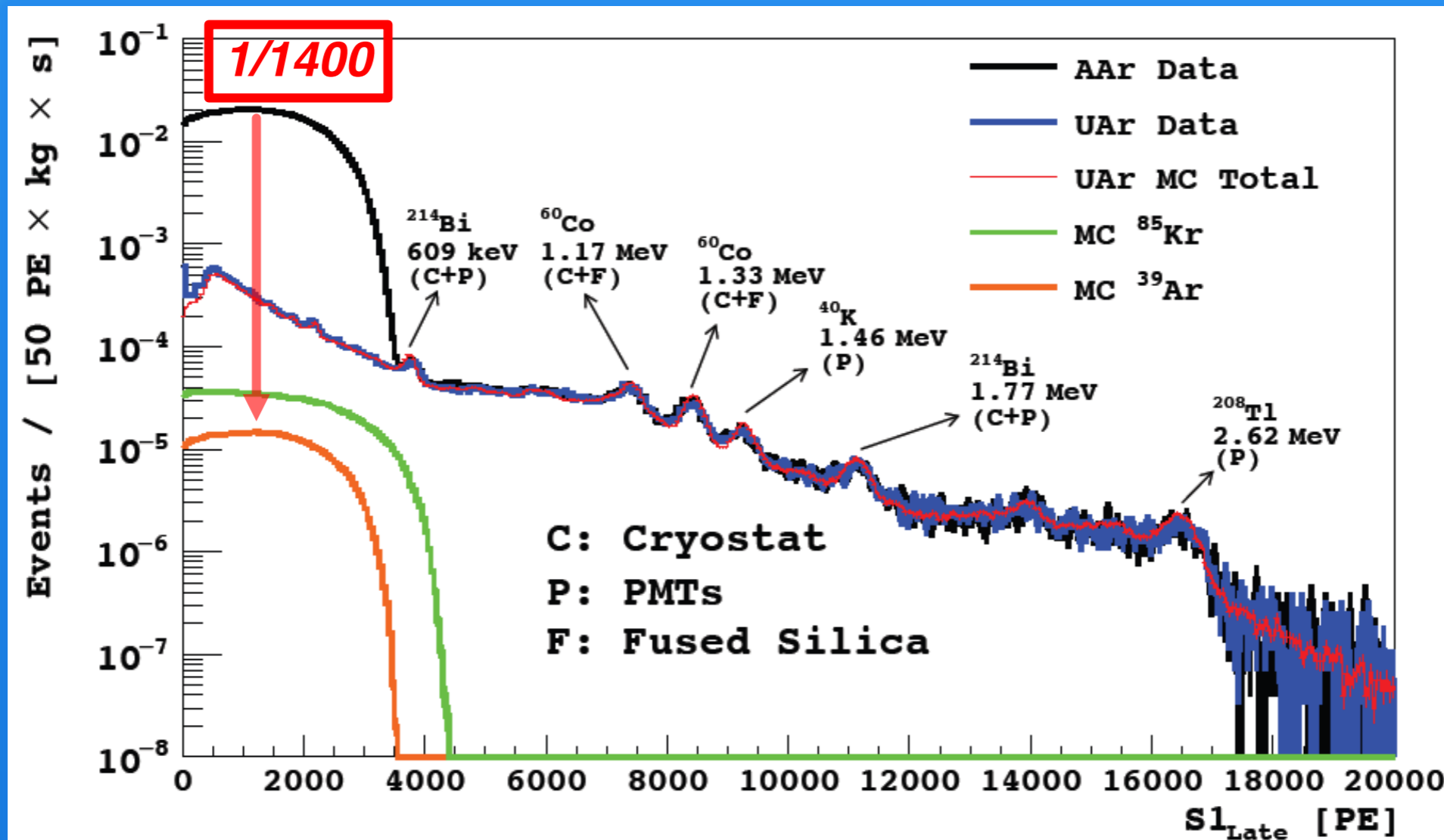


Enables WIMP search @ 100s of tonne-years exposure with zero inst. bkg.

> 10^9 bkg rejection of electron recoils based on S1 PSD in DEAP3600 - [arxiv:1902.04048](https://arxiv.org/abs/1902.04048).



INTRINSIC BACKGROUND ^{39}Ar MITIGATED IN UNDERGROUND ARGON



Phys. Rev. D 93, 081101 (2016)

In March 2015, DS50 was filled with underground argon UAr. Major undertaking – extracted from Colorado mine and purified at FNAL.

Exhibits 1400 times smaller content of ^{39}Ar in UAr than AAr!

Low level of ^{39}Ar in UAr allows extension of DS to ten and hundred ton-scale detector.



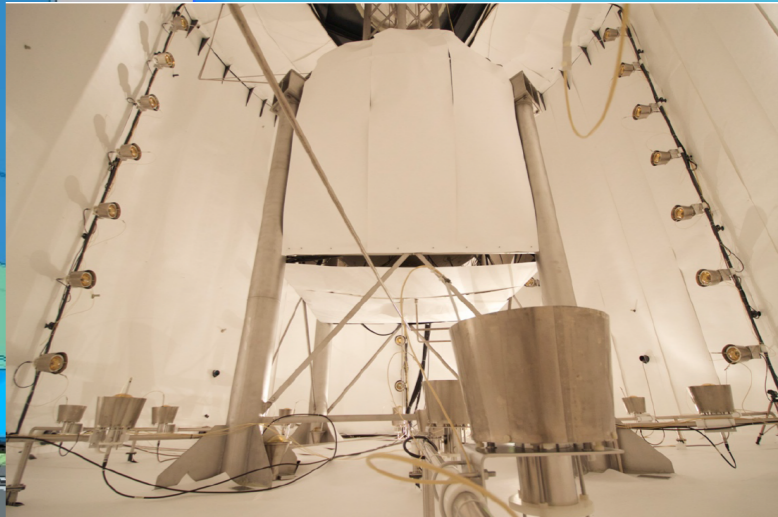
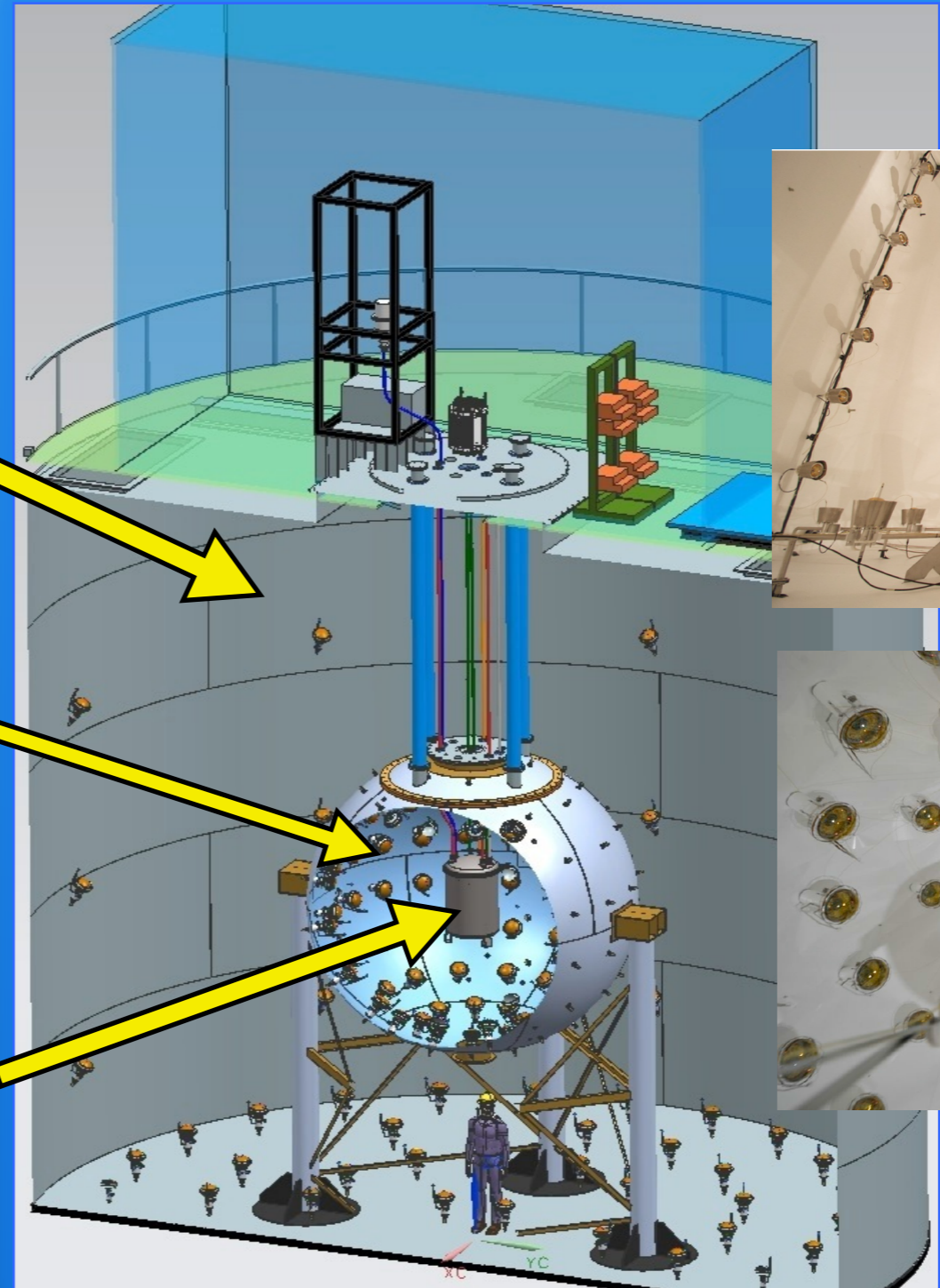
DARKSIDE-50 DESIGN AND RESULTS



@ Gran Sasso Underground Lab

DARKSIDE-50

Active muon veto –
water Cherenkov detector
(99% efficiency)
(1000 tonnes, 11 m high)



Active liquid scintillator veto for
neutrons and gammas
(30 tons, 4 m diameter)
Boron-loaded: PC + TMB

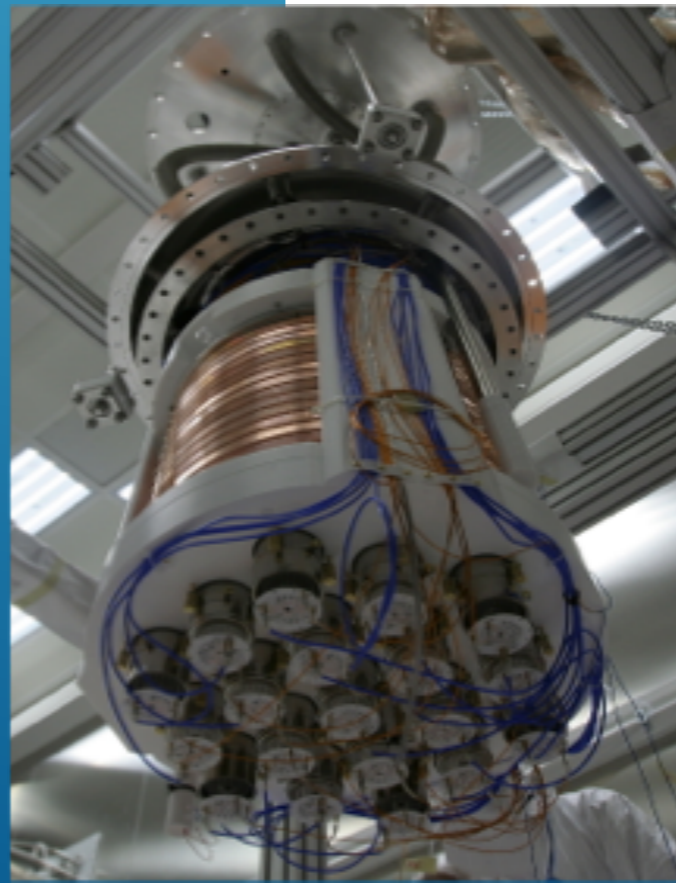
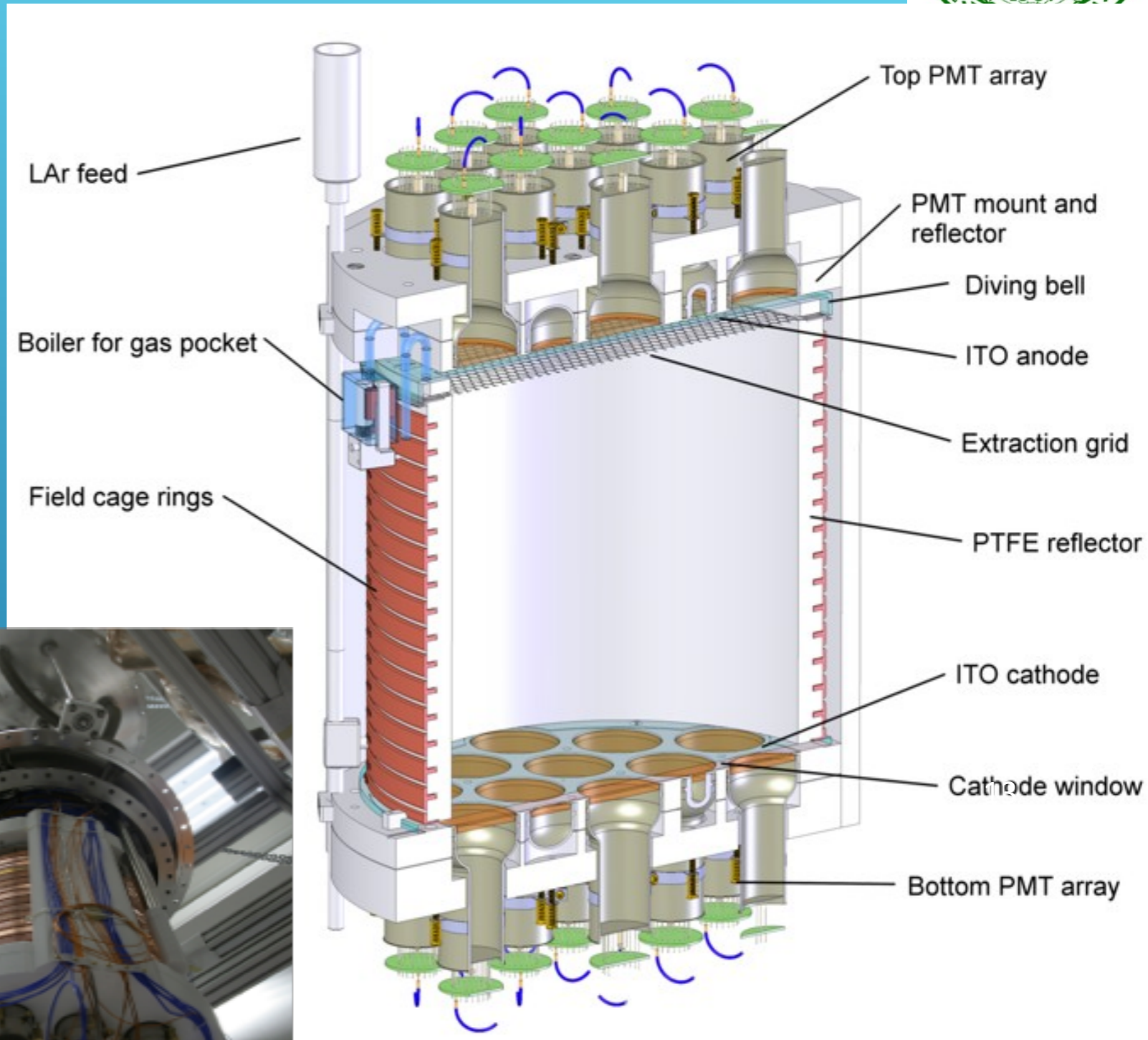
Inner detector TPC
(sensitive DM target volume,
Filled with underground ^{39}Ar)



DARKSIDE-50 TPC



- 46.4 kg LAr in active volume
- 38 Hamamatsu R11065 3" PMTs
- PTFE as reflector
- TPB as wavelength shifter
- Copper field cage
- ITO layers as anode and cathode
- Drift Field: 200 V/cm
- Extraction Field: 2.8 kV/cm

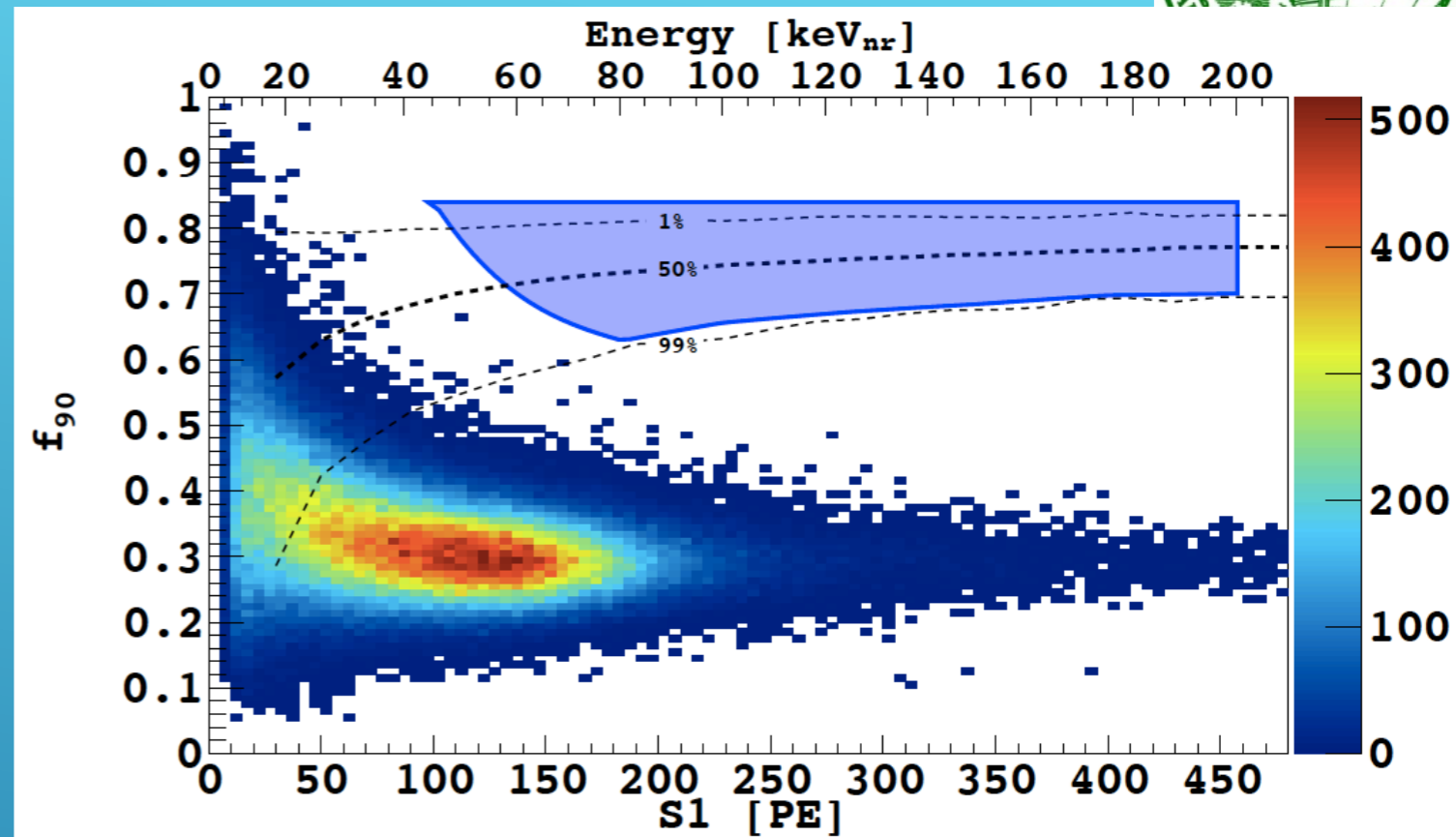




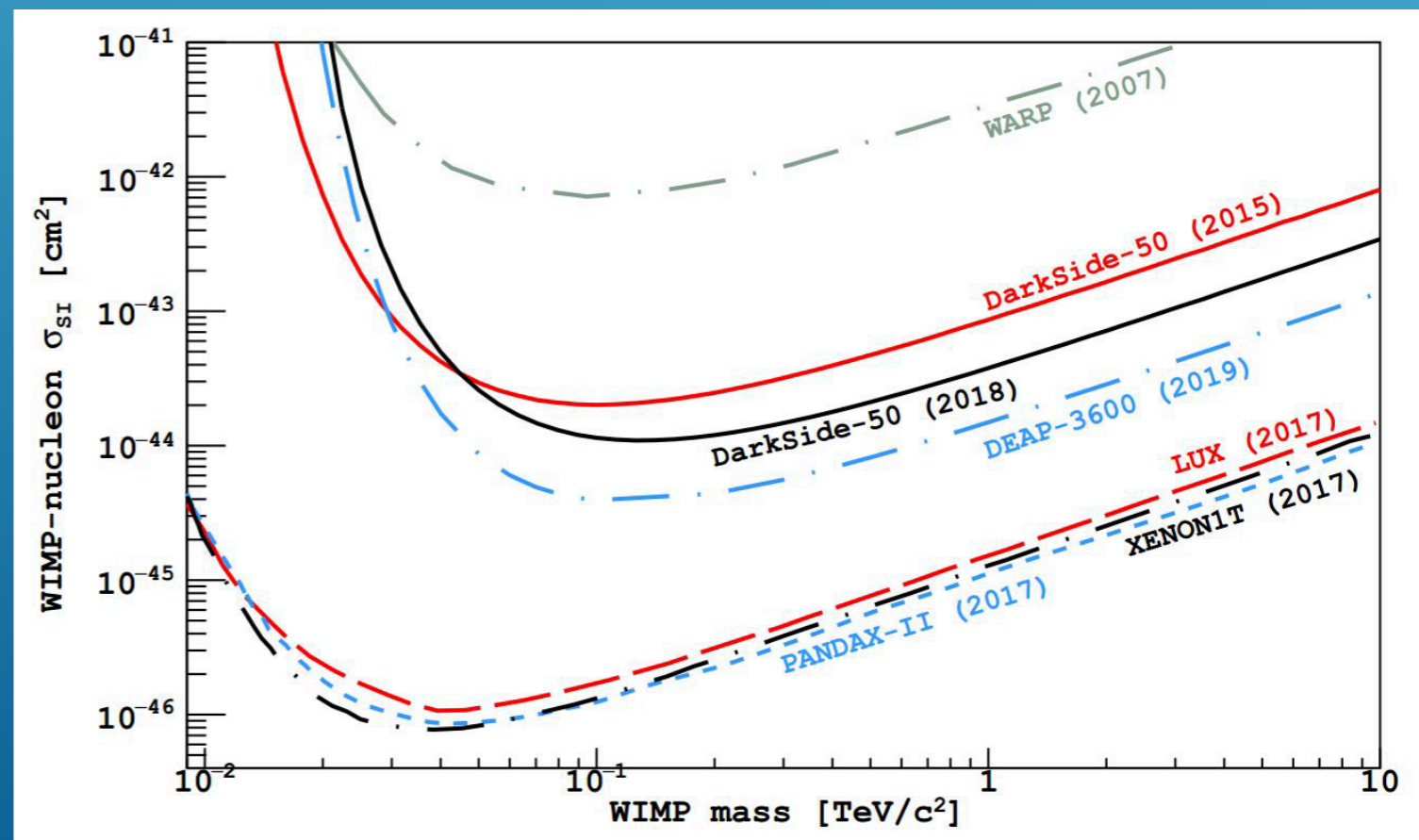
HIGH MASS WIMP SEARCH (> 10 GeV)



- ▶ 532 days data set search
- ▶ Blind analysis applied (blinded region defined on previous 70 day run)
- ▶ LY ~ 8 pe/keV
- ▶ UAr activity 0.7 mBq/kg
- ▶ **Background free (< 0.1 events in WIMP box over entire exposure)**



- ▶ 90% C.L. exclusion
- ▶ Excellent sensitivity to high mass WIMPs



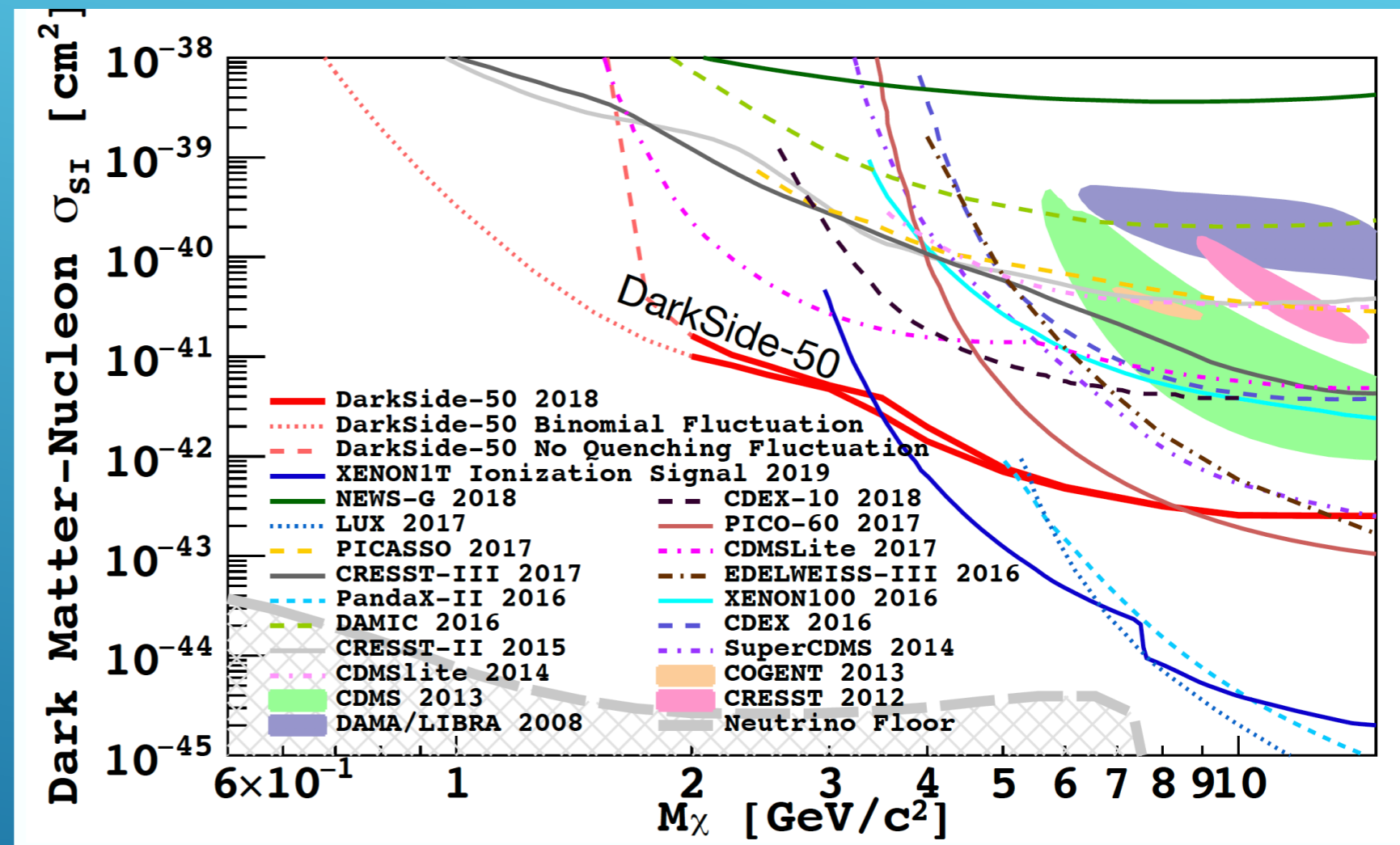
PRD 98 (10), 102006 (2018)



S2-ONLY SPIN-INDEPENDENT DM-NUCLEAR INTERACTION – 90% C.L.



- ▶ S1 scintillation signal threshold at 2 keVee = 10 keVnr
- ▶ S2 ionization signal threshold at < 0.1 keVee = 0.4 keVnr
- ▶ → give up S1 → trigger on S2 → lower energy threshold, BUT no PSD and position in Z
- ▶ Requires very low background level → achieved in DS-50
- ▶ Resulted in leading sensitivity below 3.5 GeV
- ▶ PRL 121 (8), 081307 (2018)
- Sub-GeV DM-Electron Scattering, PRL 121 (11), 111303 (2018)



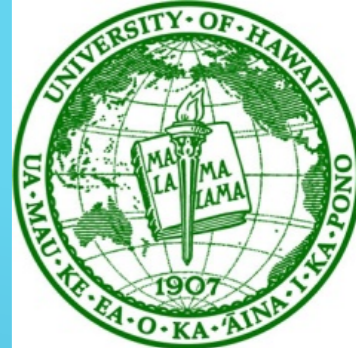
- ▶ *Two cases: no quenching fluctuations and binomially distributed fluctuations*



DEVELOPMENTS TOWARD DARKSIDE-20K AND ARGO



ACTIVITIES TOWARD DS-20K AND ARGO



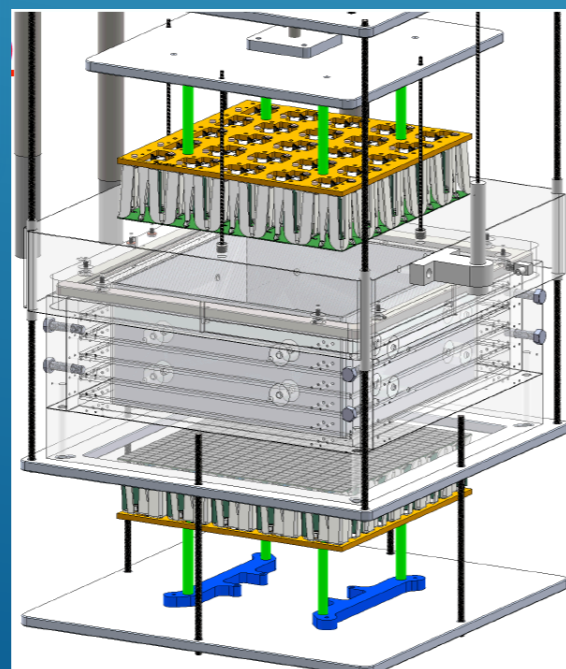
Multistage and multiprong program toward **inst. bkg. free** DM search. Very low bkg. levels from all components + reduction through active suppression.

DarkSide-50 at LNGS

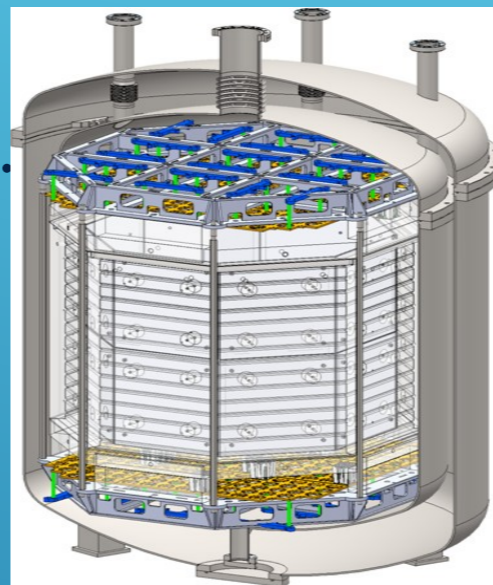


Running, 50 kg fiducial: WIMP search + Low DM search With S2

Proto-0(2019): PDM, S2, reflector...



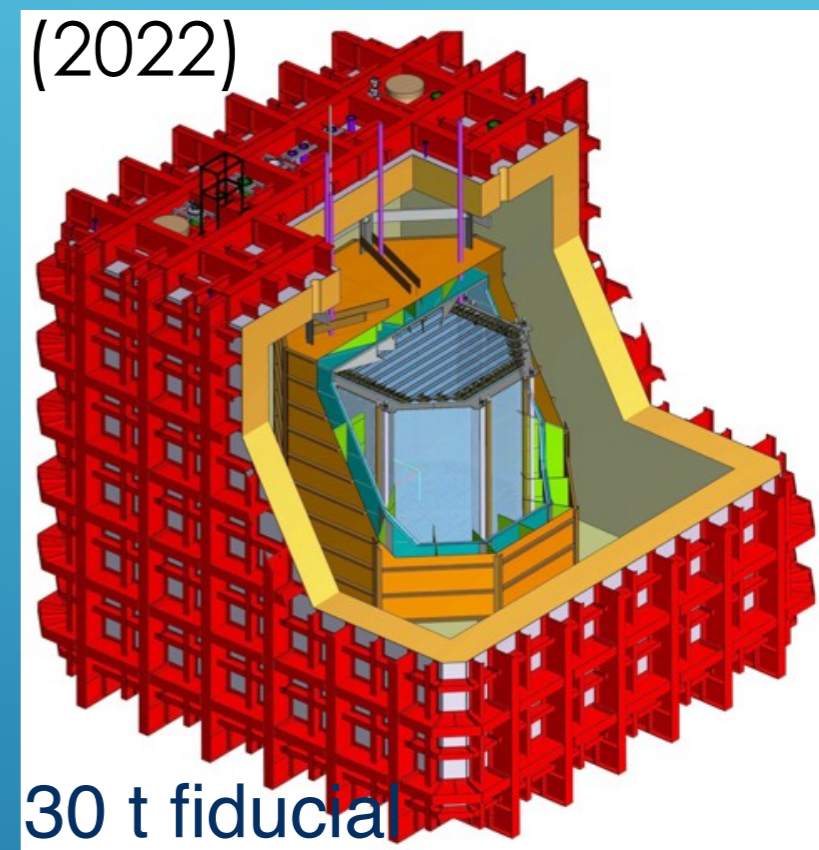
ReD at LNS (2018): NR, directionality



Proto-1t (2020): PDMs, acrylic, cryogenics



DarkSide-20k at LNGS (2022)



30 t fiducial



ARGO at SNOLAB (2029)

300 t fiducial

1 ton fiducial

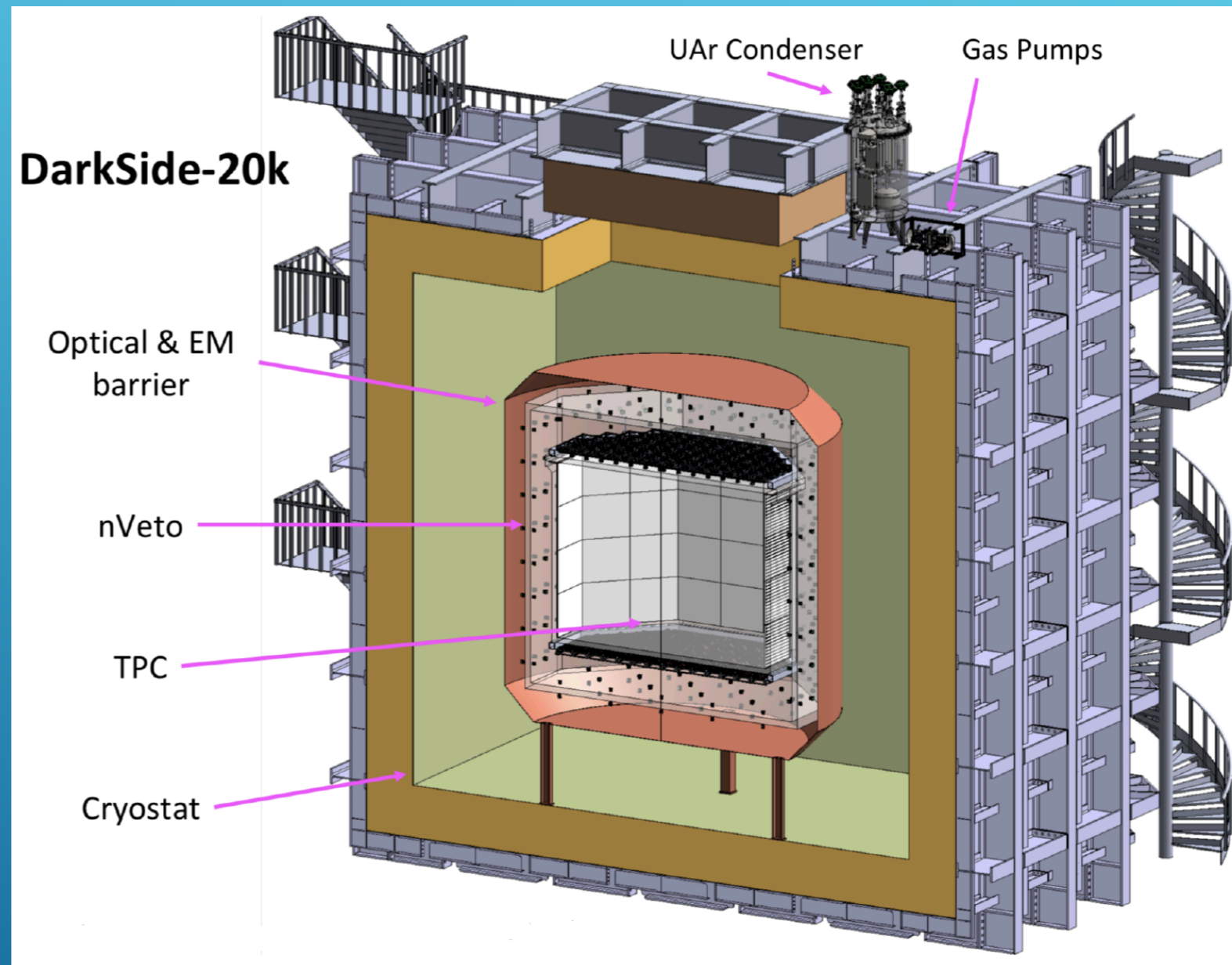


DS-20K DESIGN



DarkSide-20k at Gran Sasso:

- 50 t Depleted Ar in a sealed acrylic dual phase Ar TPC detector
- Builds upon experience from DEAP3600 acrylic vessel production
- 30-t LAr fiducial volume
- Neutron veto: Gd loaded acrylic panels and AAr
- Separate cryogenic systems for DAr and AAr.
- Light detection by Silicon Photomultipliers in TPC and Veto
- nVeto enclosed in optical and EM barrier
- Placed inside ProtoDUNE-like cryostat.



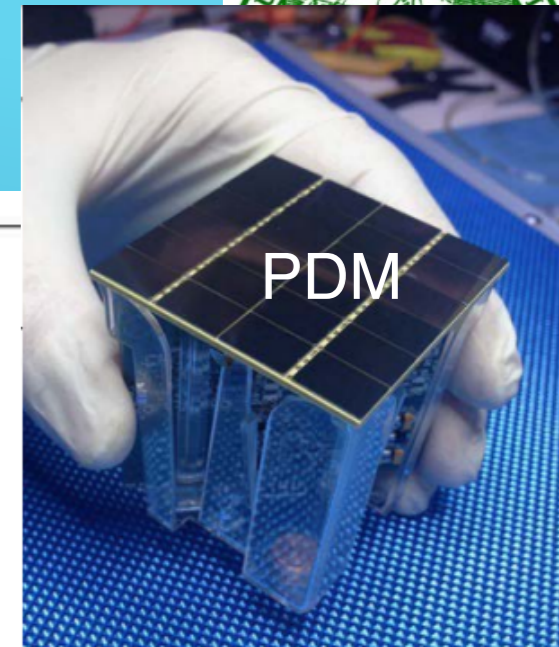
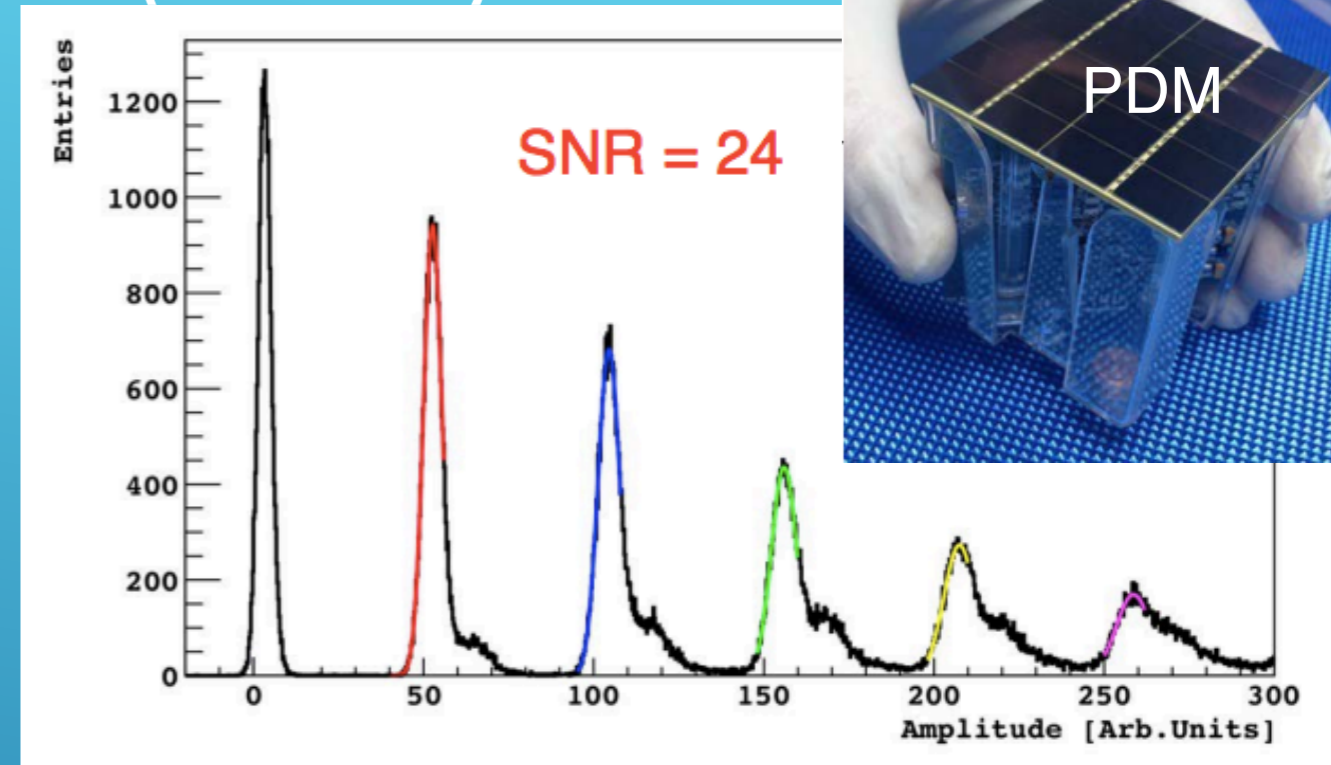
Background-free:
< 0.1 instrumental background event
in 200 tonne-year exposure



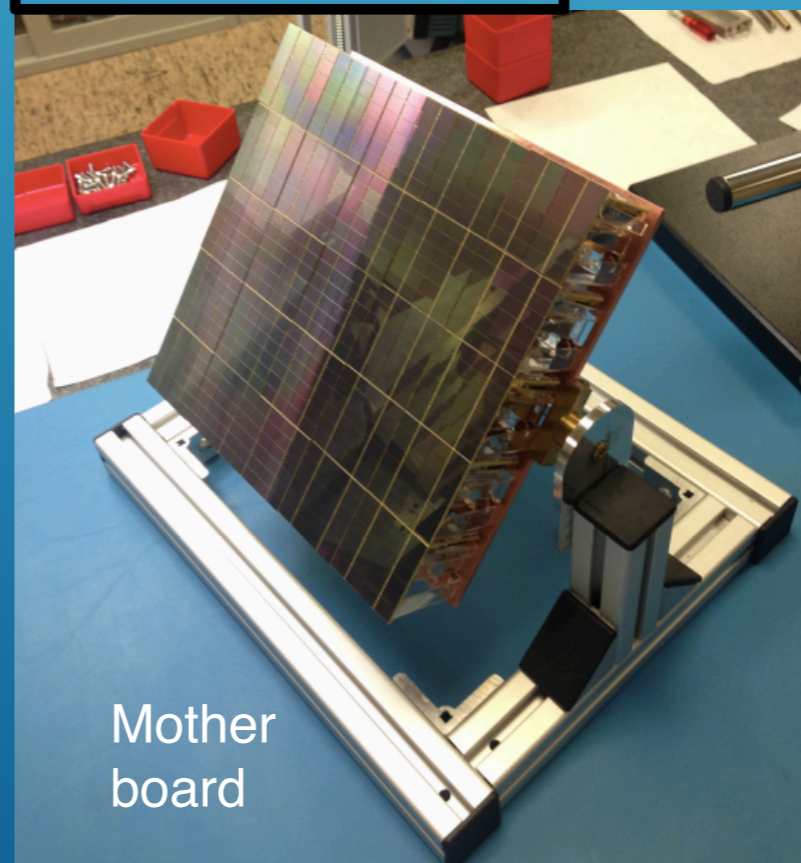
NEW PHOTODIODES – SILICON PHOTOMULTIPLIERS (SiPMs)



- 5×5 cm² single-channel modules (array of 24 SiPMs) – Photon detection modules (PDMs)
- ~ 5 ns timing resolution
- Photon Det. Efficiency 50%
- Gain > 10⁶
- 0.1 Hz/mm² dark count rate (cryogenic electronics)
- Single PE resolution
- Signal/Noise ~ 24
- Power consumption < 100 μW/mm²
- Compact and radio-clean



~ 25 cm x 25 cm x 5 cm



Mother board:

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

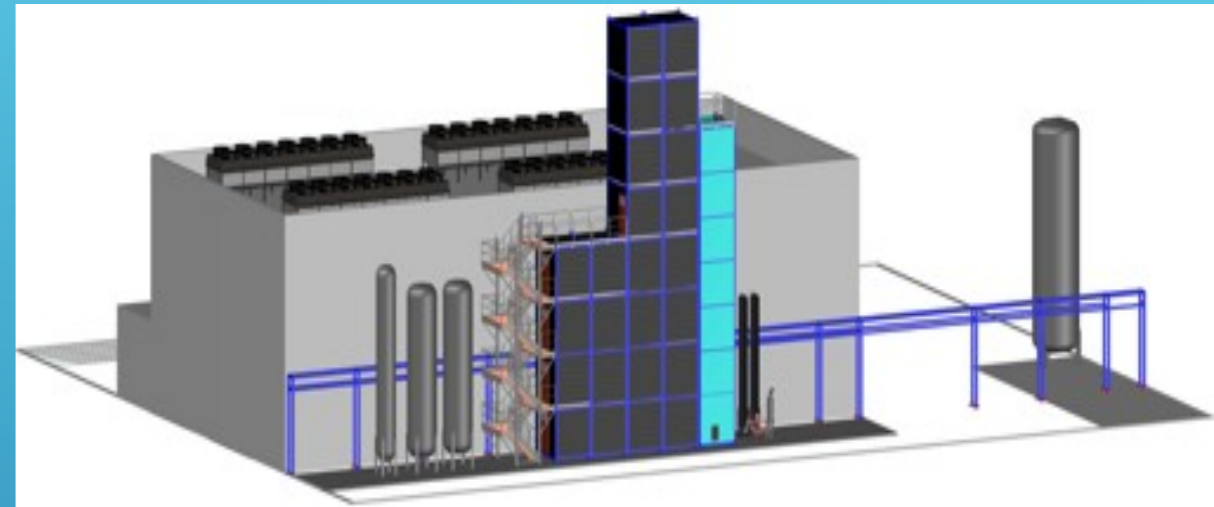


LOW RADIOACTIVITY ARGON – PROCUREMENT WITH URANIA AND PURIFICATION WITH ARIA



Urania plant (extraction of UAr)

- extraction plant at Cortez mine, Colorado
- 330 kg/day UAr production (compare to 153 kg/6 years for DS-50)
- 99.99% purity
- 55 tonnes for DS-20k
- Will provide UAr for ARGO

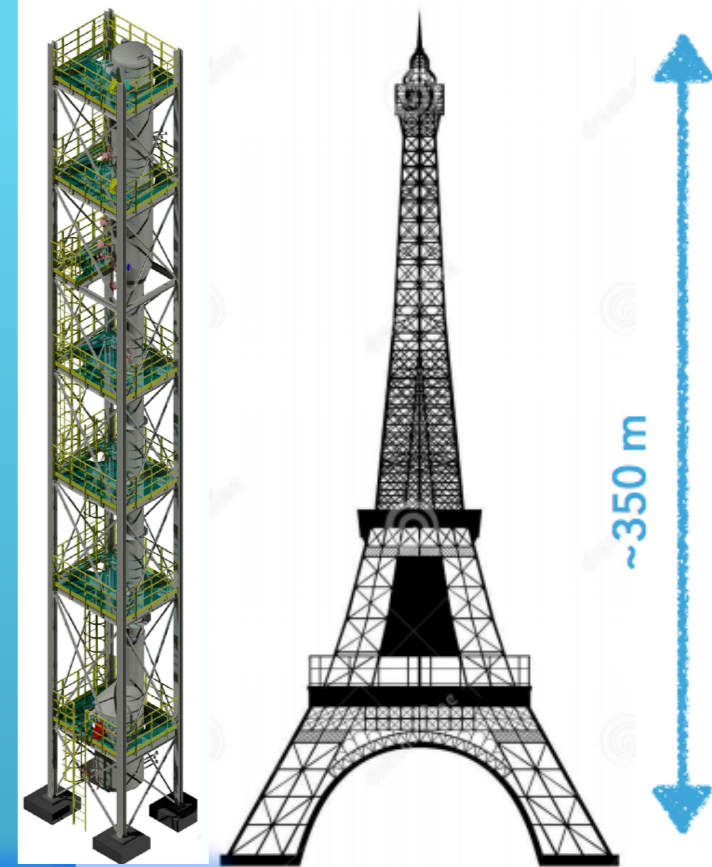




LOW RADIOACTIVITY ARGON – PURIFICATION AT ARIA PLANT

Aria plant

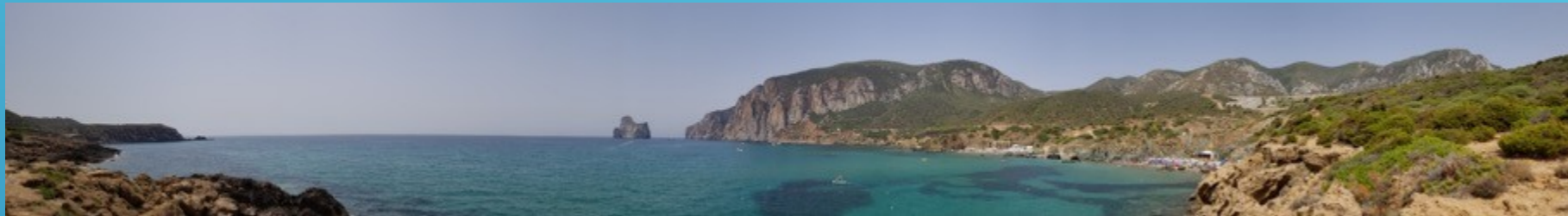
- Distillation plant in Seruci, Sardinia
- production of depleted argon DAr with 0.01 content of ^{39}Ar compared to UAr \rightarrow required for tonne-like light DM experiment
- removal of impurities such as Kr
- isotopic cryogenic distillation of ^{39}Ar and ^{40}Ar
- 350 m tall distillation column under construction in Sardinia: Seruci I (30 cm diameter column) with depletion factor of 10
- Chemical purification rate: 1 tonne/day



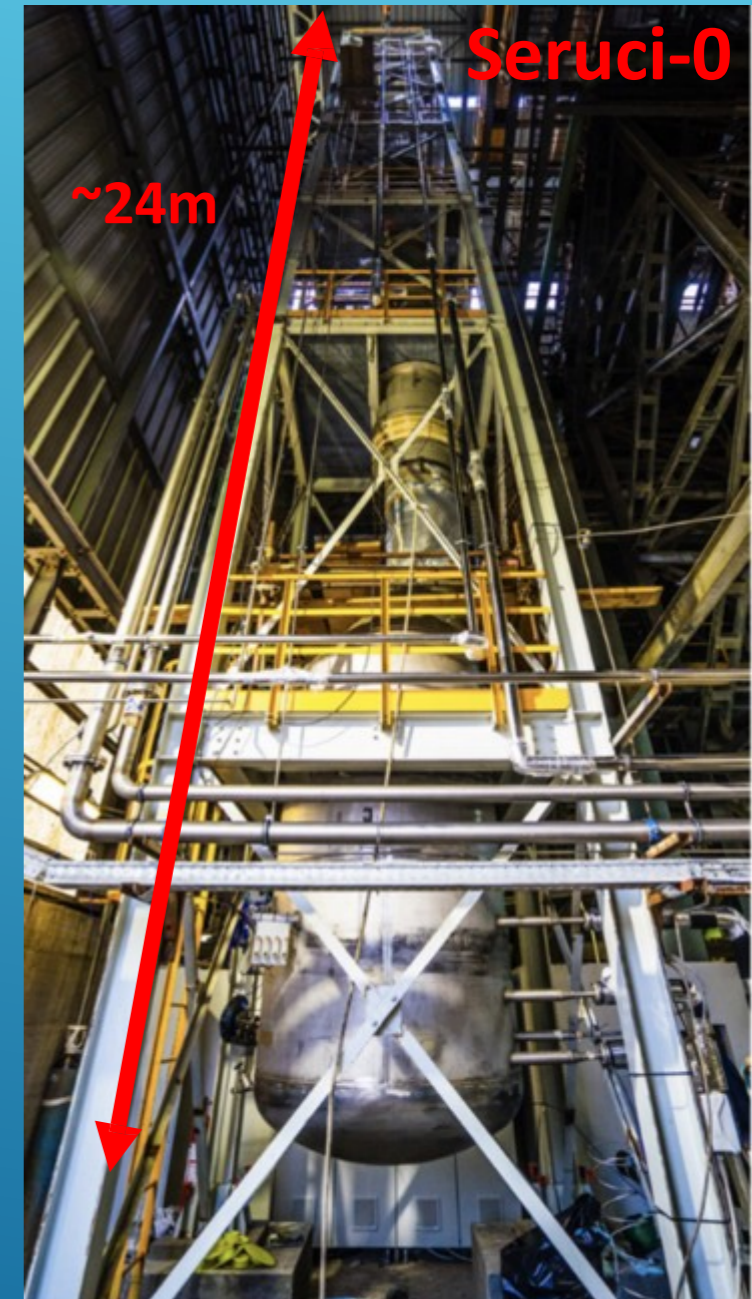
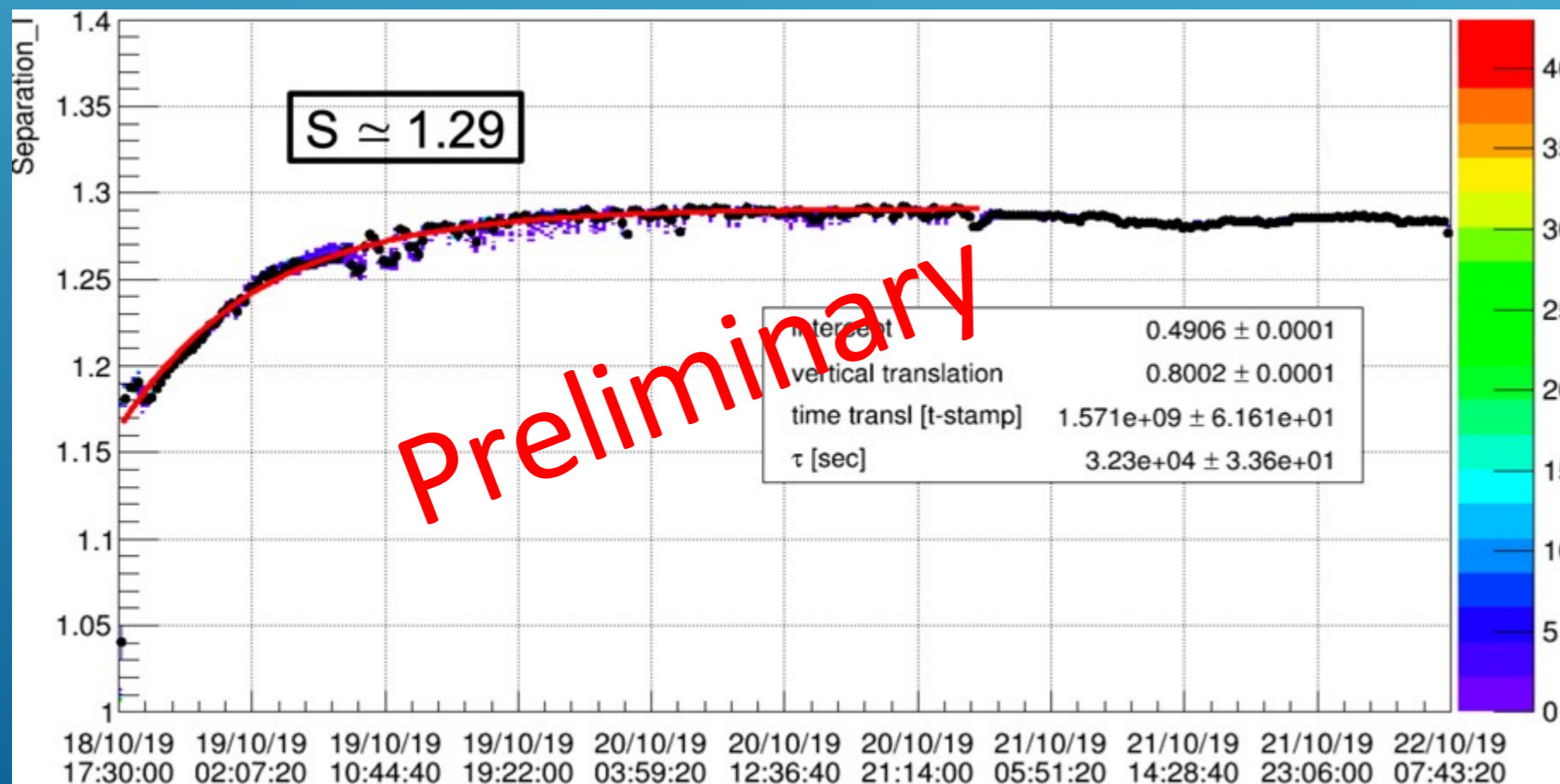
Seruci 0
- prototype
column



ARIA – FIRST RESULTS WITH NITROGEN

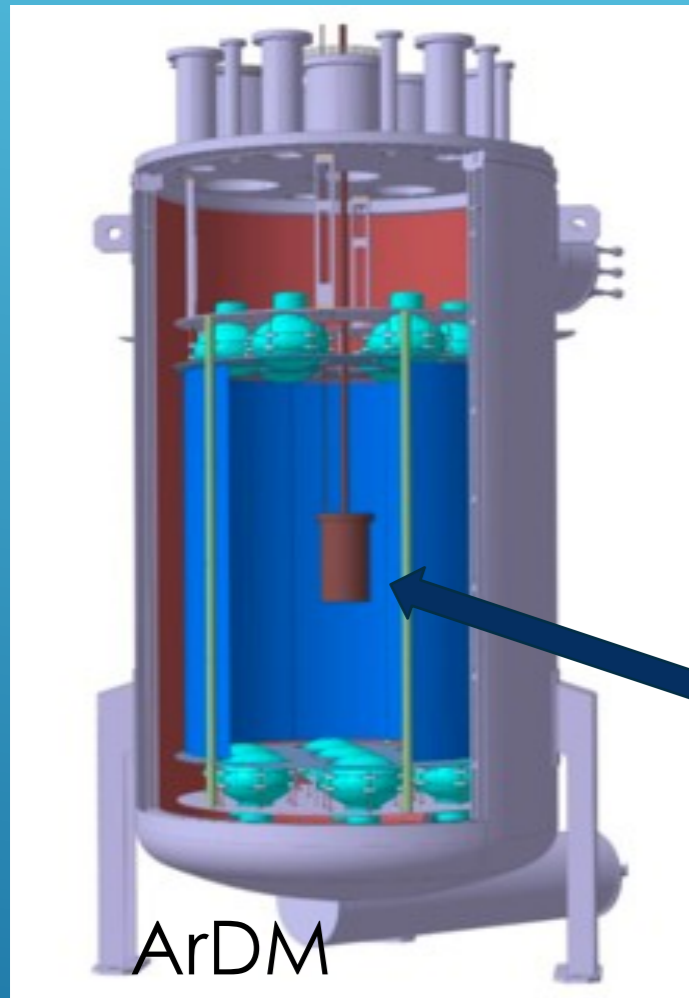


First commissioning results look promising.





DART – DEPLETED Ar TEST IN ArDM AT CANFRANC

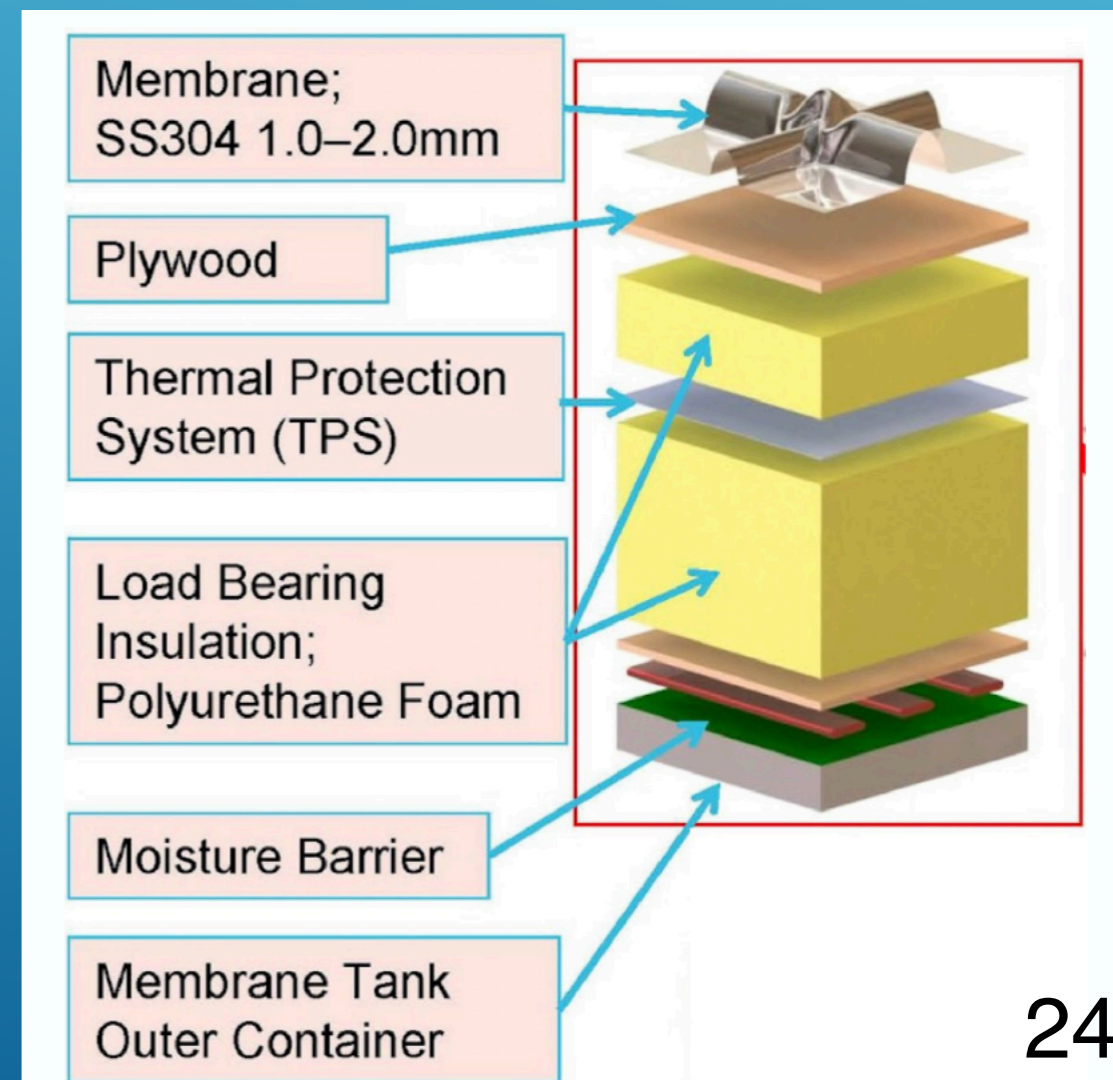


- ▶ DArT – measure depletion factor of UAr produced by Urania and Aria
- ▶ 1 liter active volume detector made of ultra pure Cu
- ▶ Housed in 1 tonne AAr ArDM detector at Canfranc



PROTODUNE CRYOSTAT

ProtoDUNE style membrane cryostat
filled with atmospheric argon.

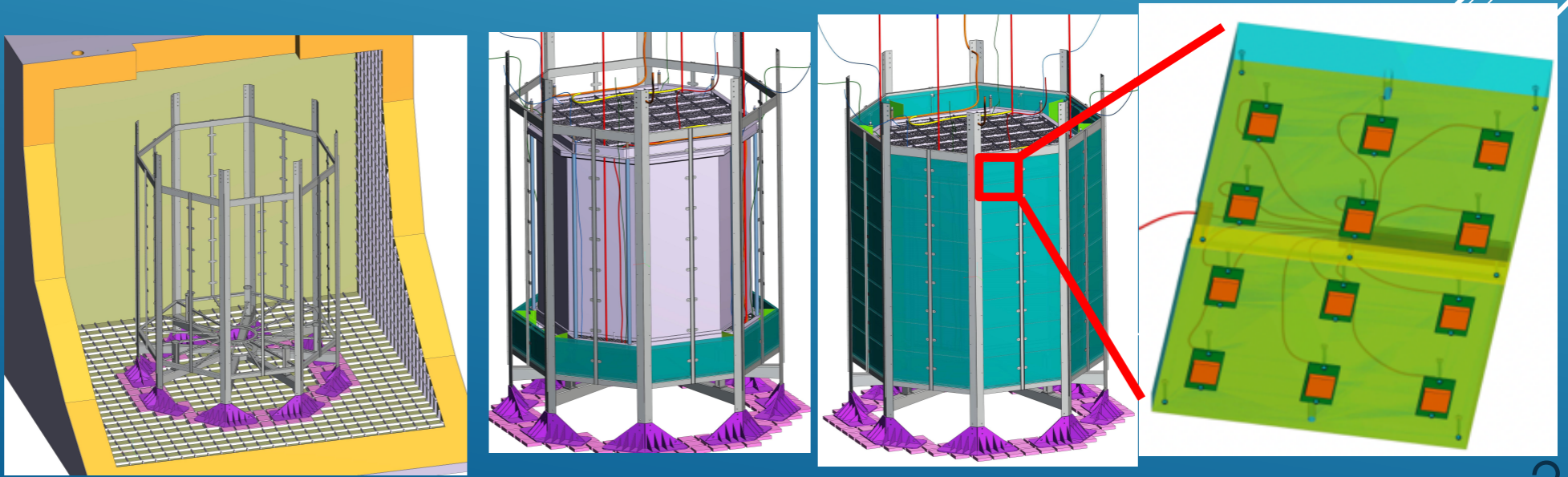
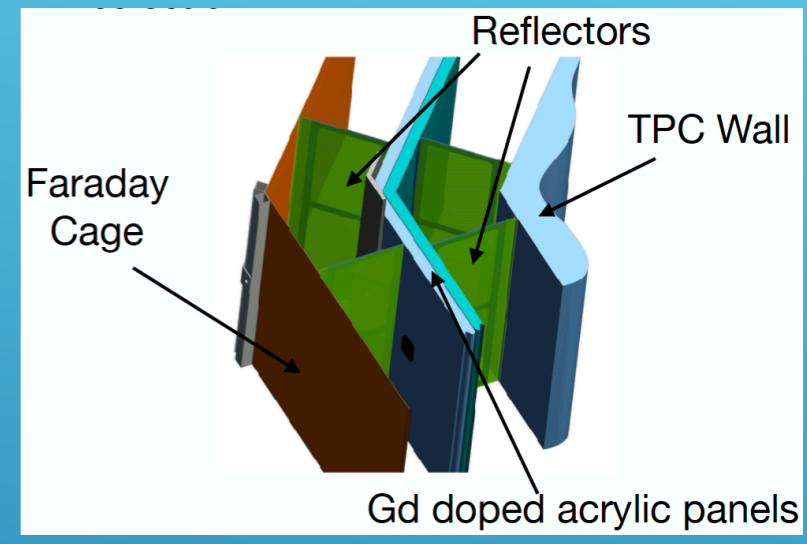
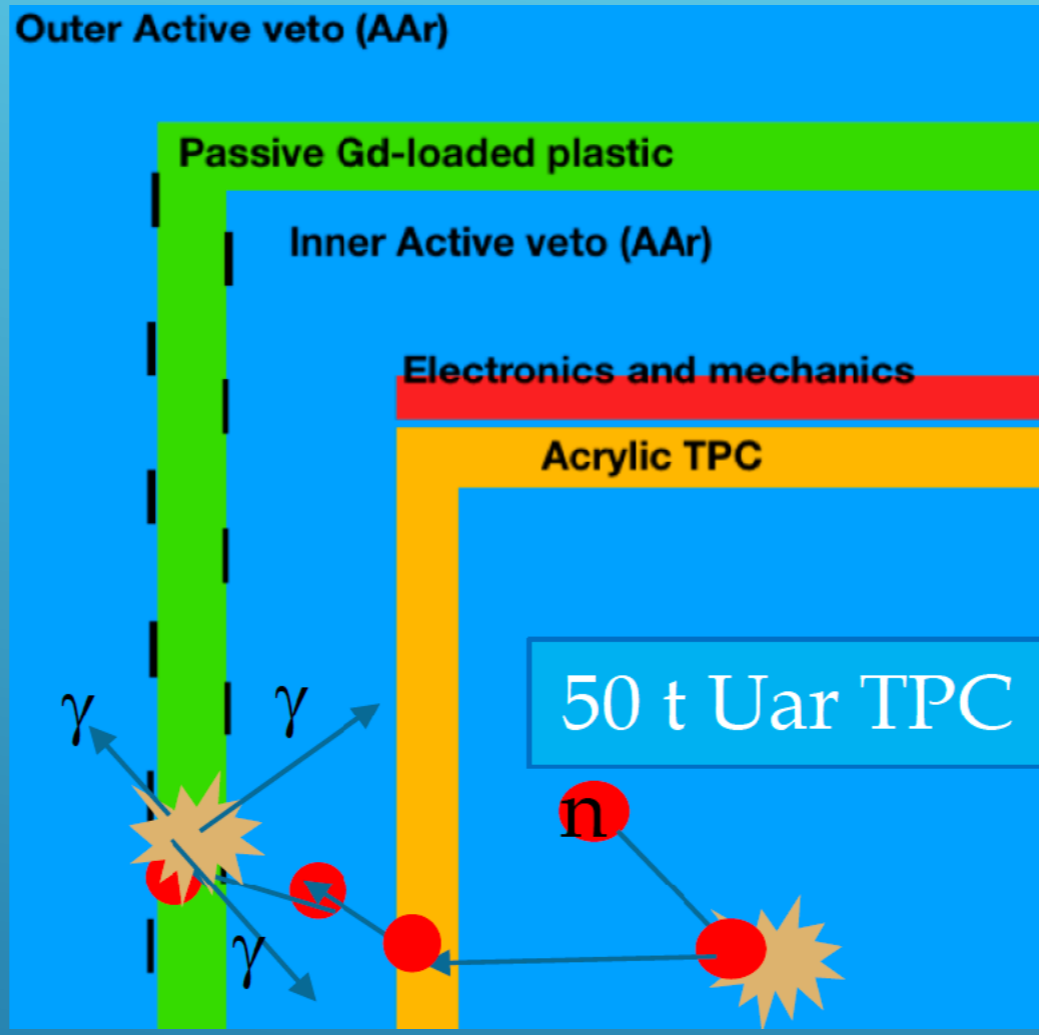




ACTIVE NEUTRON VETO



- Gd loaded acrylic panels + LAr - 10 cm thick vessel surrounding TPC
- Moderate and capture neutrons
- 120 tonnes AAr
- ~3000 modified PDMs
- ESR reflectors
- WLS (TPB or PEN)
- Requirement:
 $< 0.1 \text{ n}/(200 \text{ t } \gamma)$ after veto and TPC cuts



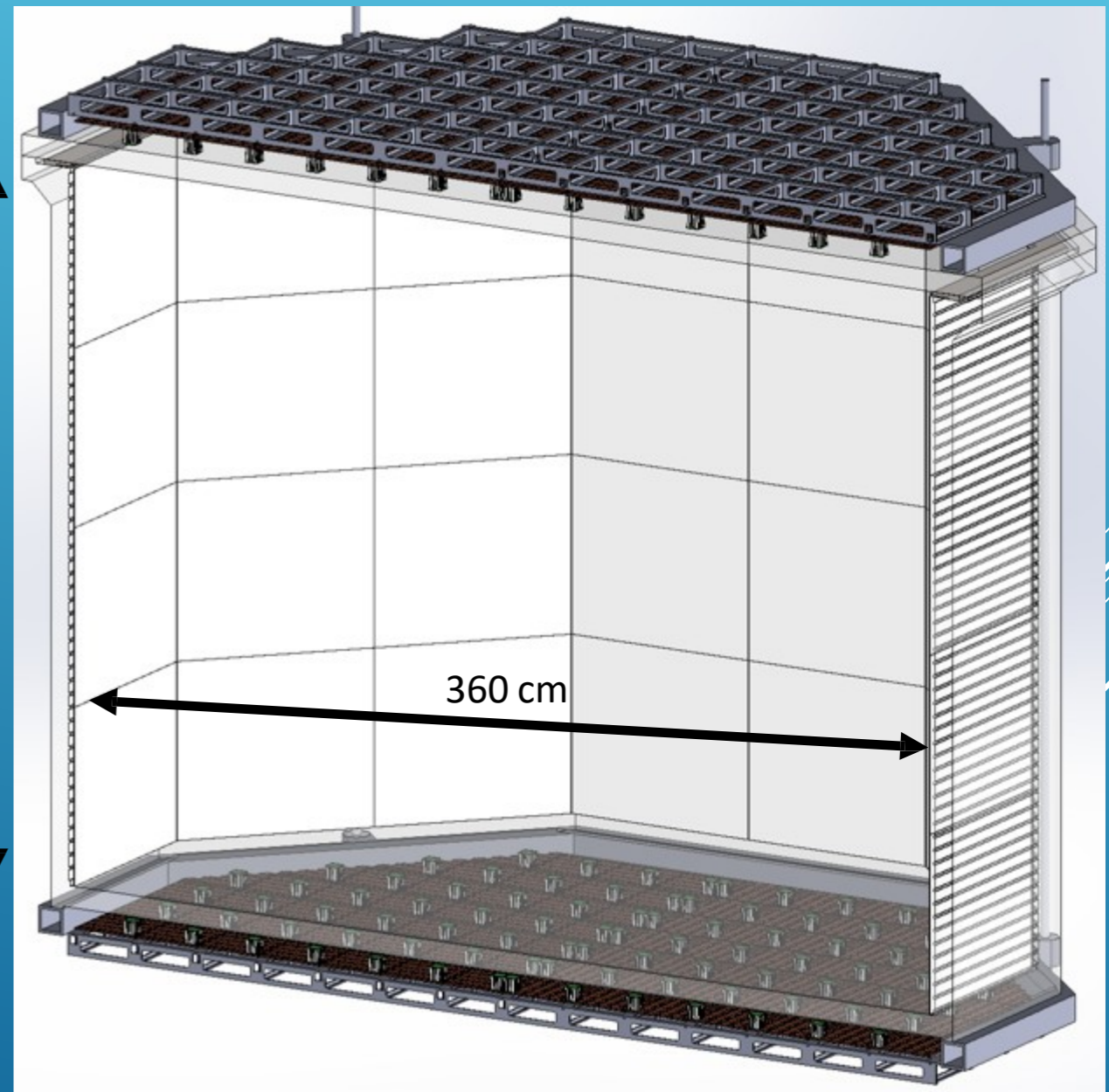


INNER TPC DETECTOR



- Sealed octagonal acrylic vessel
- 50 tonnes Depleted underground Ar
- 30 tonnes fiducial
- 8280 PDMs total – half on top and half on bottom
- Clevios conductive polymer coating for field shaping rings
- Anode and cathode from clevios coated with TPB for WLS
- Wire grid made of SS
- Reflector in front of field cage – ESR + TPB

350 cm drift





DARKSIDE-PROTO 1 TONNE



Scaled down version of DS-20k.

175 kg fiducial volume in sealed acrylic vessel.

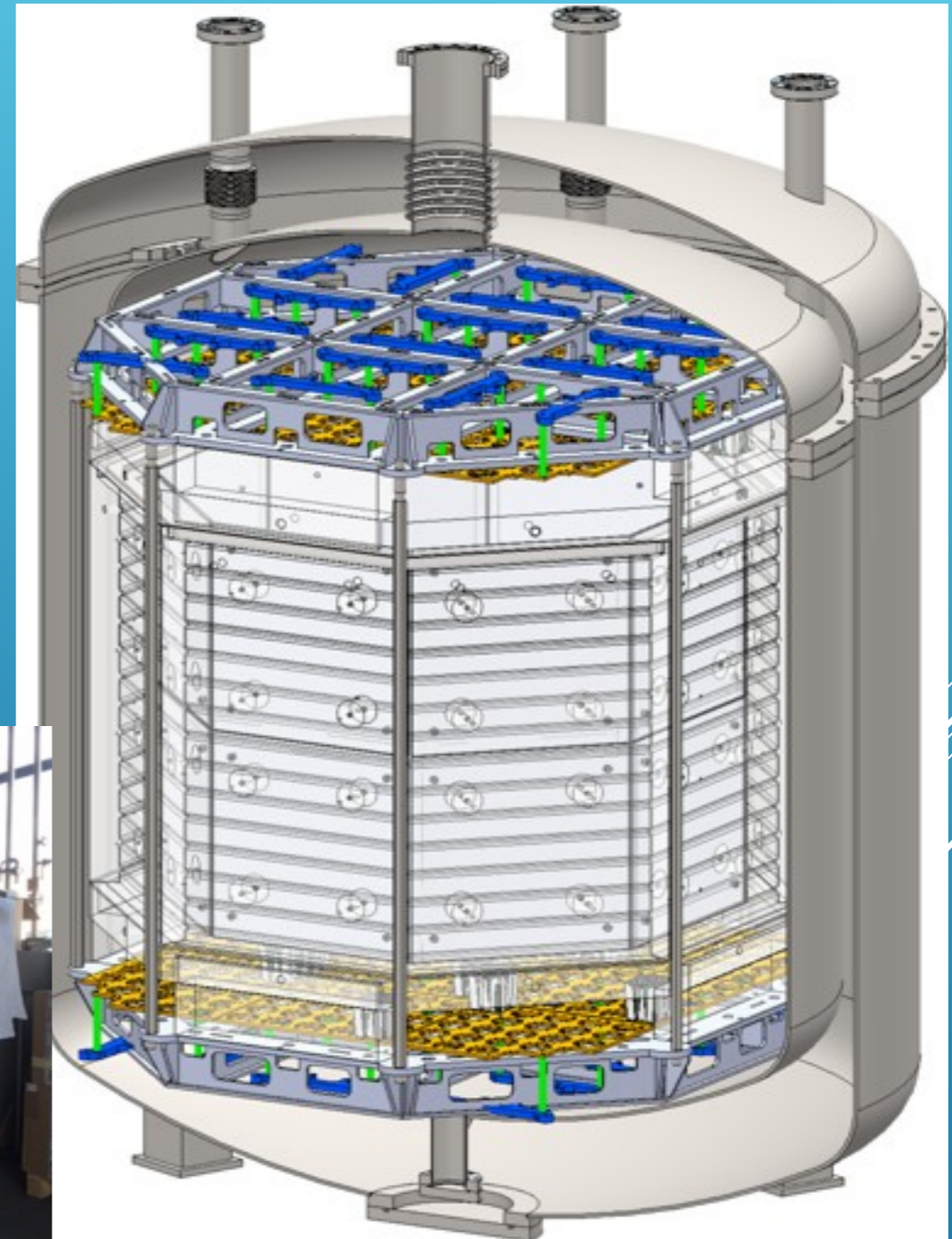
370 PDM channels.

PDMs and electronics production in Italy.

Full DS-20k cryogenic system test.

Acrylic vessel work by DEAP collaborators in Canada.

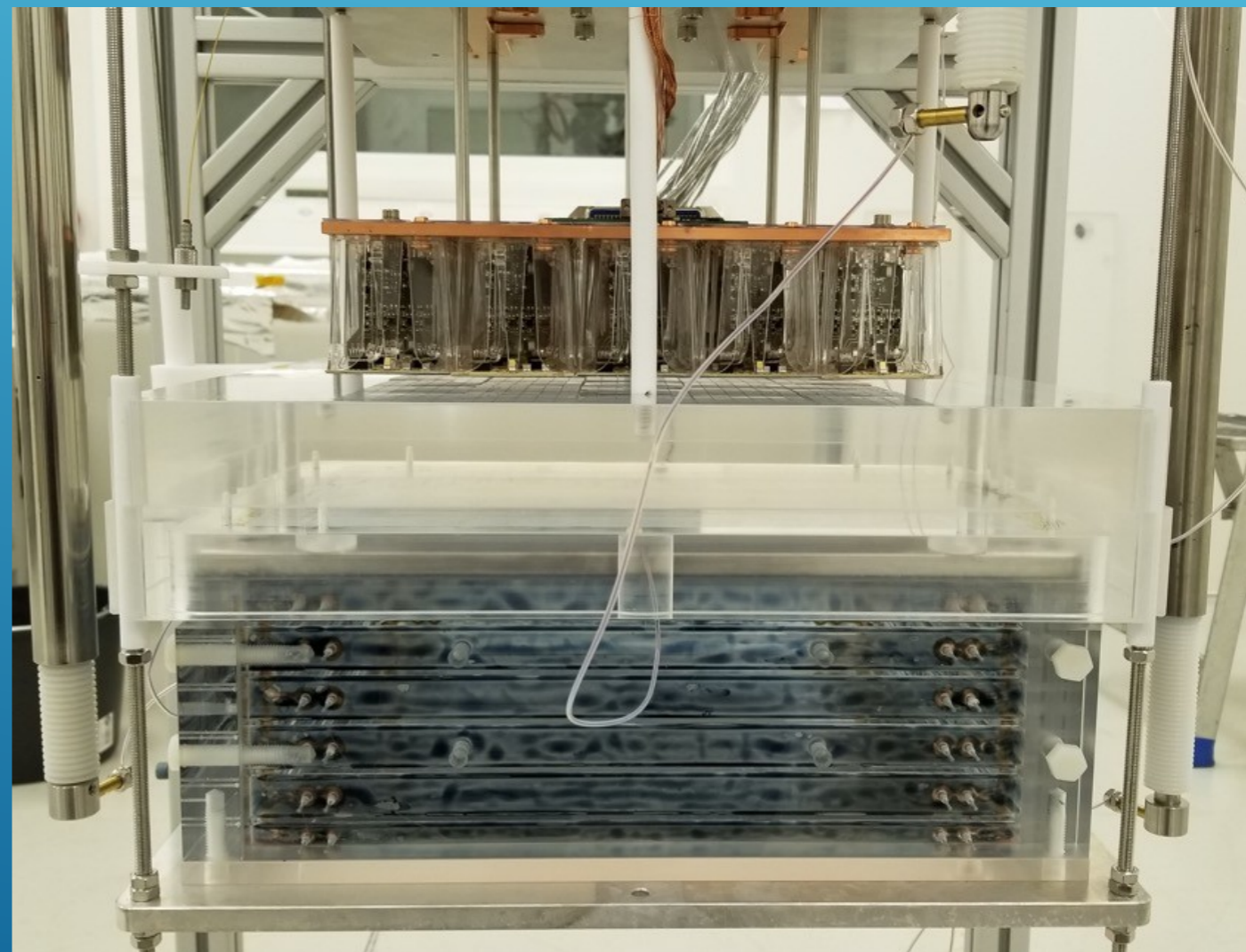
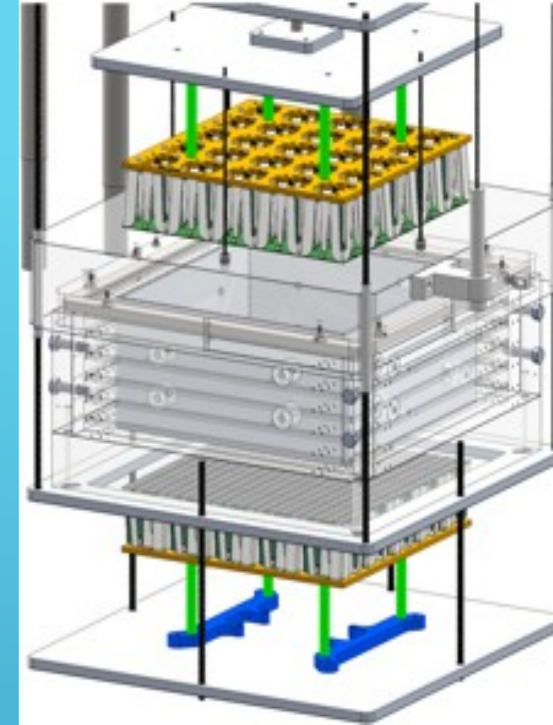
Assembly – summer 2020.





DARKSIDE-PROTO-0

- 10 kg LAr active volume
- Test – mother board with PDMs, clevises, ESR, wire grid, S2 studies...
- Integrated with DS-20k technologies
- First LAr run with TPC and source just finished
- Observed first LAr scintillation light with full photo detector
- Next run in early 2020.

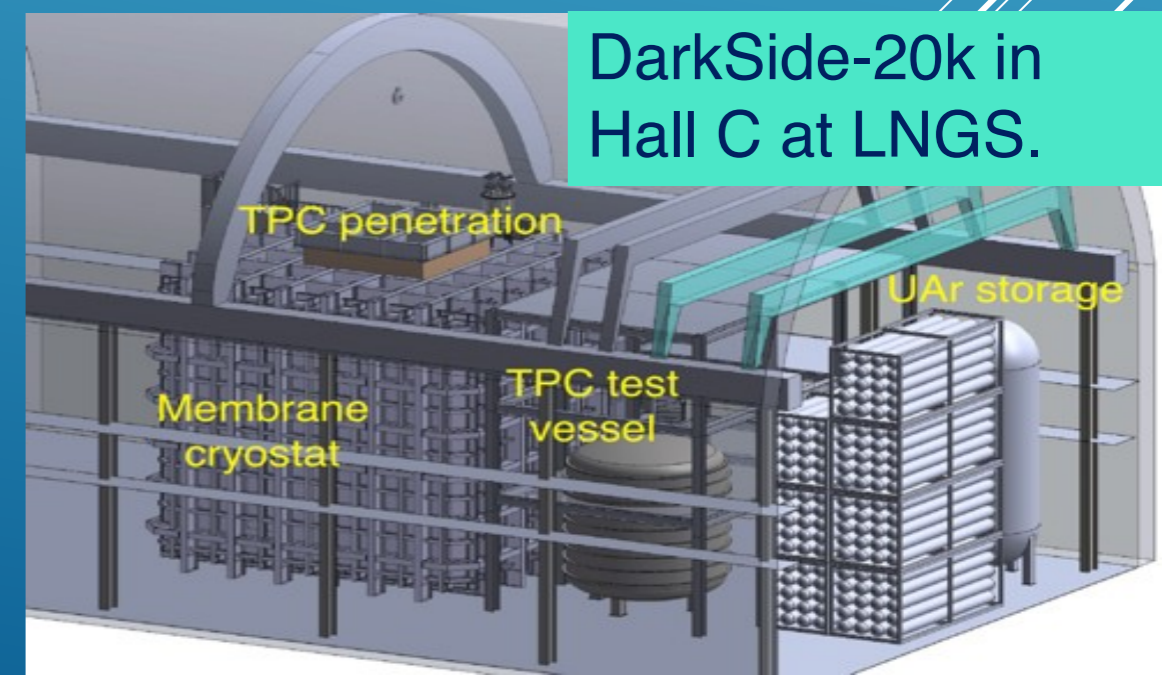
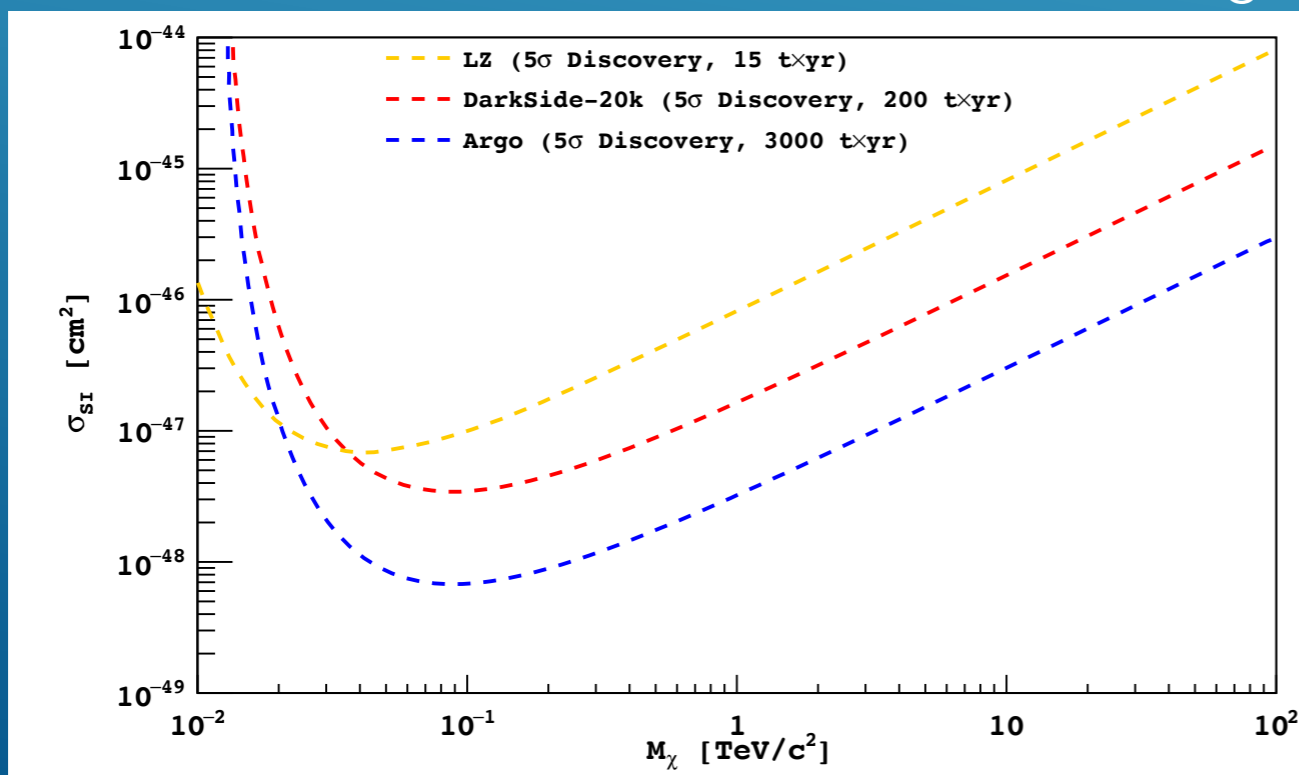




SUMMARY AND OUTLOOK



- DS-50 demonstrated excellent performance and proven technology of dual phase argon TPCs for wide range of WIMP masses:
 - best sensitivity below 3.5 GeV
 - background-free for > 10 GeV
- Ambitious dark matter search program with the Global Argon DM Collaboration builds upon:
 - production of DAr, novel SiPM based photodetectors, innovative TPC design, acrylic knowledge and experience from DEAP3600 and DS-50.
- DarkSide-20k at LNGS (inst. bg-free 200 tonne-year exposure)
- Future detector ARGO \sim ktonne-year exposure, reaching *beyond neutrino floor* and opening *potential for neutrino physics*.
- DarkSide-LM – low mass DM search with ionization signal S2 enabled by isotopic separation of $^{39}\text{Ar}/^{40}\text{Ar}$.



THANK YOU

