The DarkSide Project

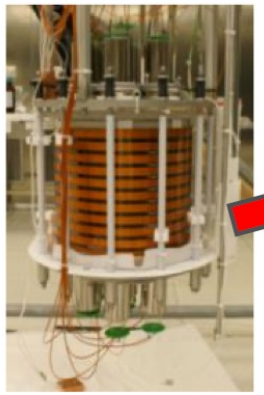
a direct dark matter search project using liquid argon

王毅
中国科学院高能物理研究所
for the DarkSide collaboration and the GADMC

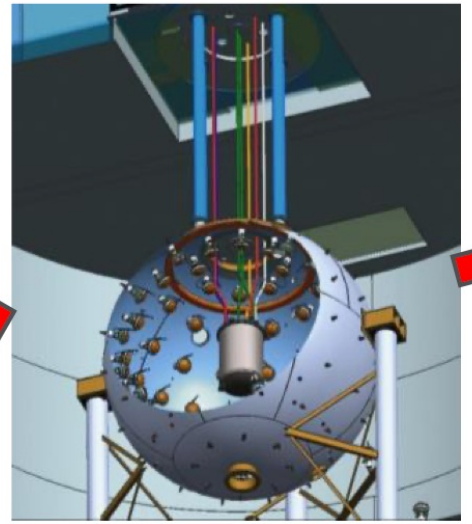
第二届地下和空间粒子物理与宇宙物理前沿问题研讨会
杭州 千岛湖 2023/05/10

The Roadmap of DarkSide

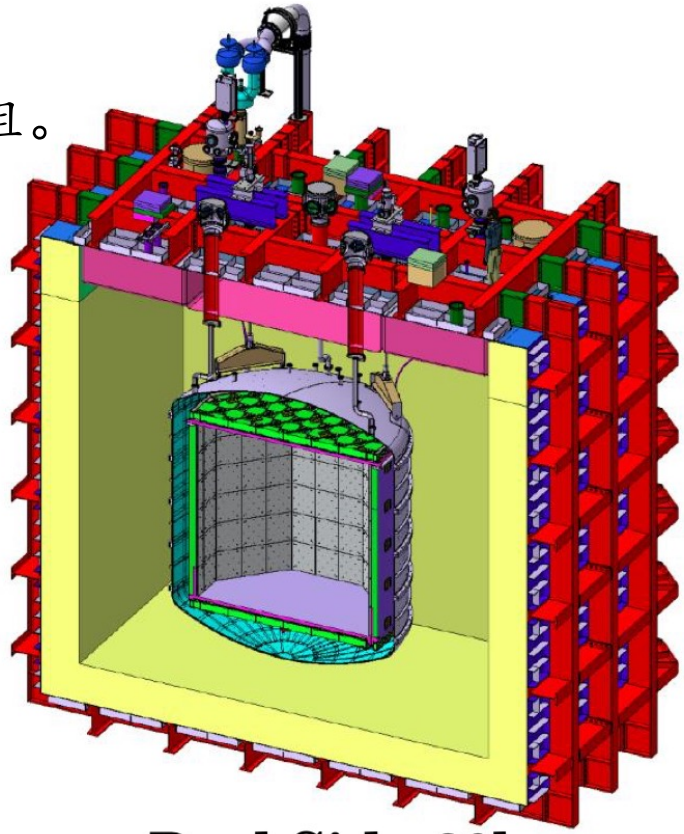
- Direct WIMP dark matter search;
- Dual phase argon time projection chamber (TPC);
- Deep underground at LNGS, Italy.
- 高能所于2011年正式加入DarkSide合作组。



DarkSide-10
2012



DarkSide-50
0.03 tyr exposure
2013-2018



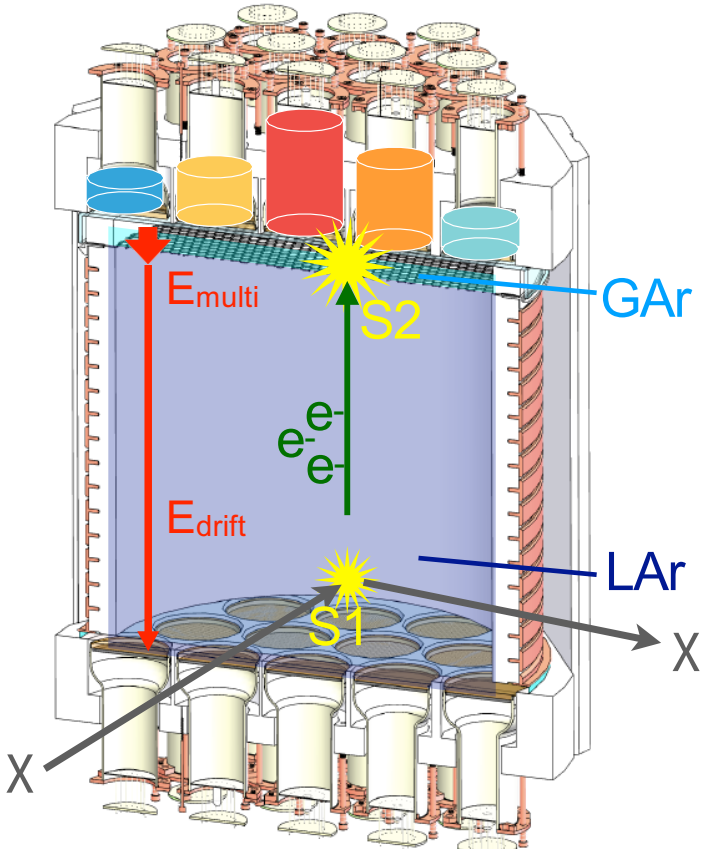
DarkSide-20k
200 tyr exposure
2026 +

ARGO
3000 tyr exposure
2030s +
High mass focus

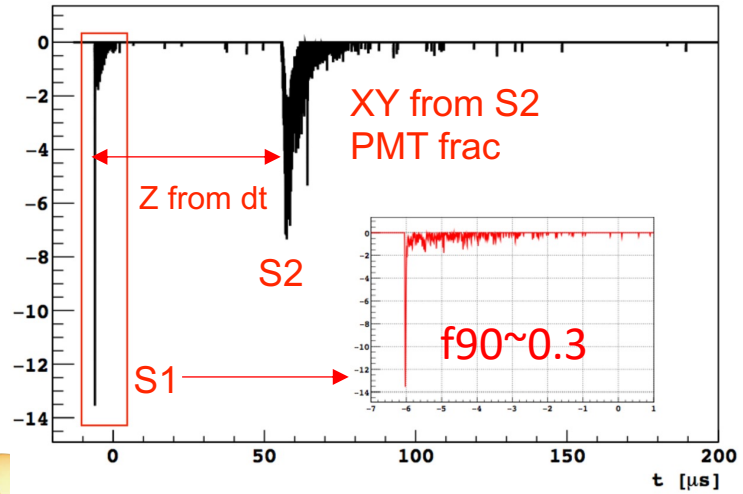
DarkSide-LowMass
Proposed 1 tyr
exposure
Low mass (sub GeV)

Dual-phase Argon TPC

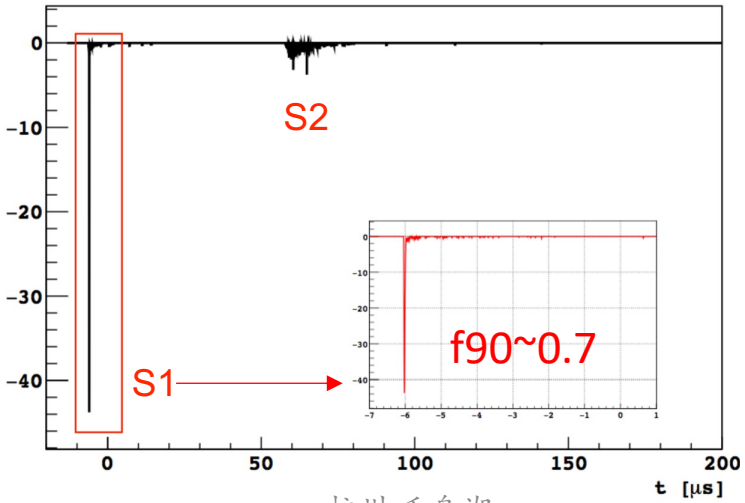
- Scintillation (S1) + Ionization (S2);
- 3D positioning using T_{drift} and S2 distributions;
- 128 nm -> wavelength shifter -> 420 nm;
- Pulse shape discrimination (PSD):
  - De-excitation time: singlet 6 ns, triplet 1.5 us;
  - ER background rejection > 1×10^8;
  - f90: ratio of light in the first 90 ns (S1).

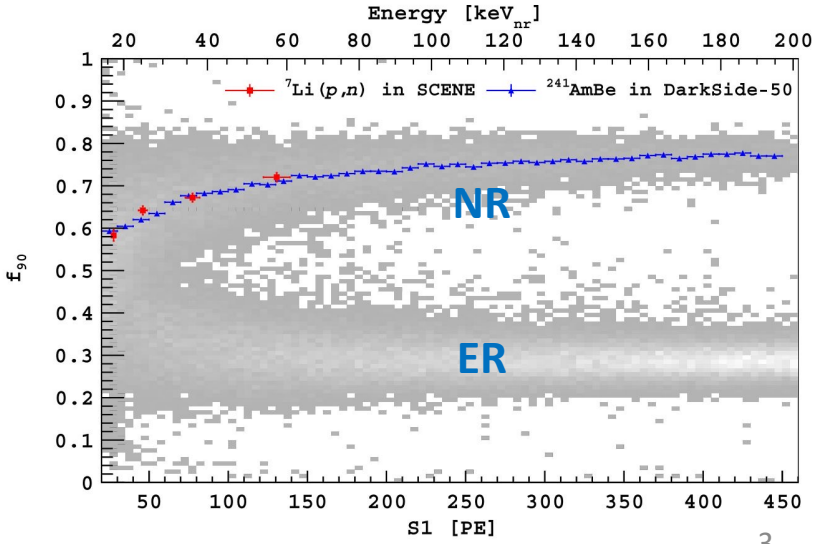


Electron Recoil



Nuclear Recoil

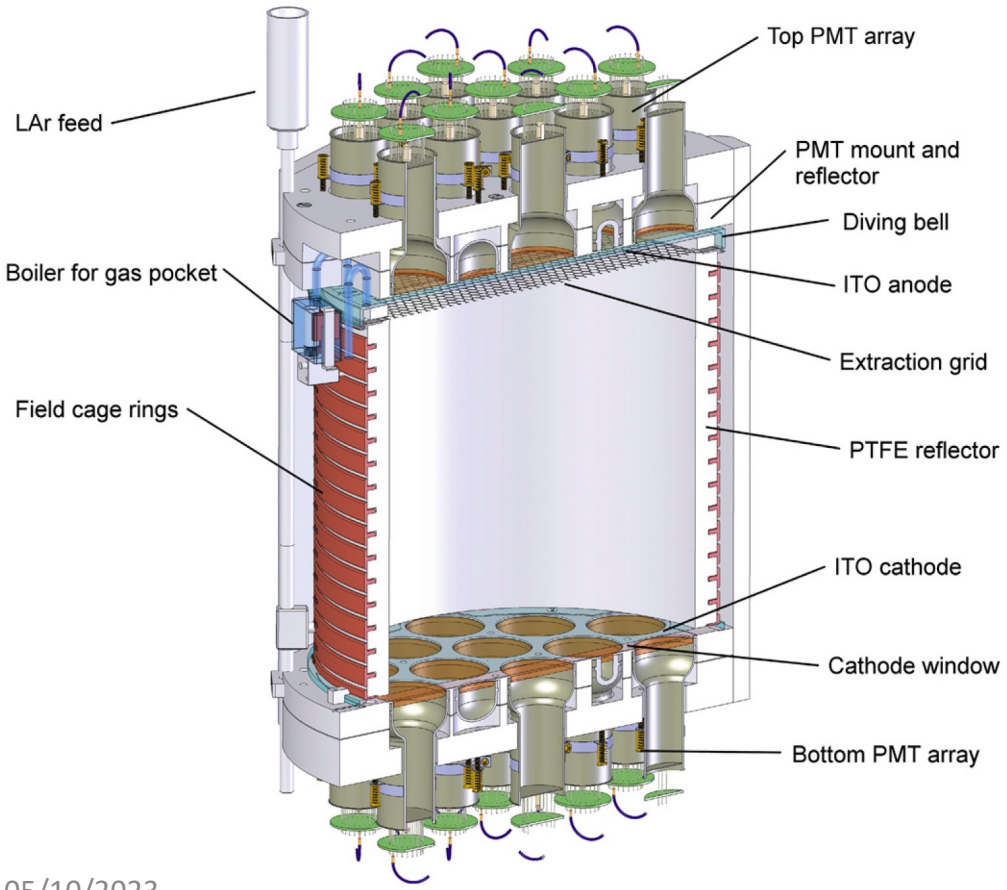


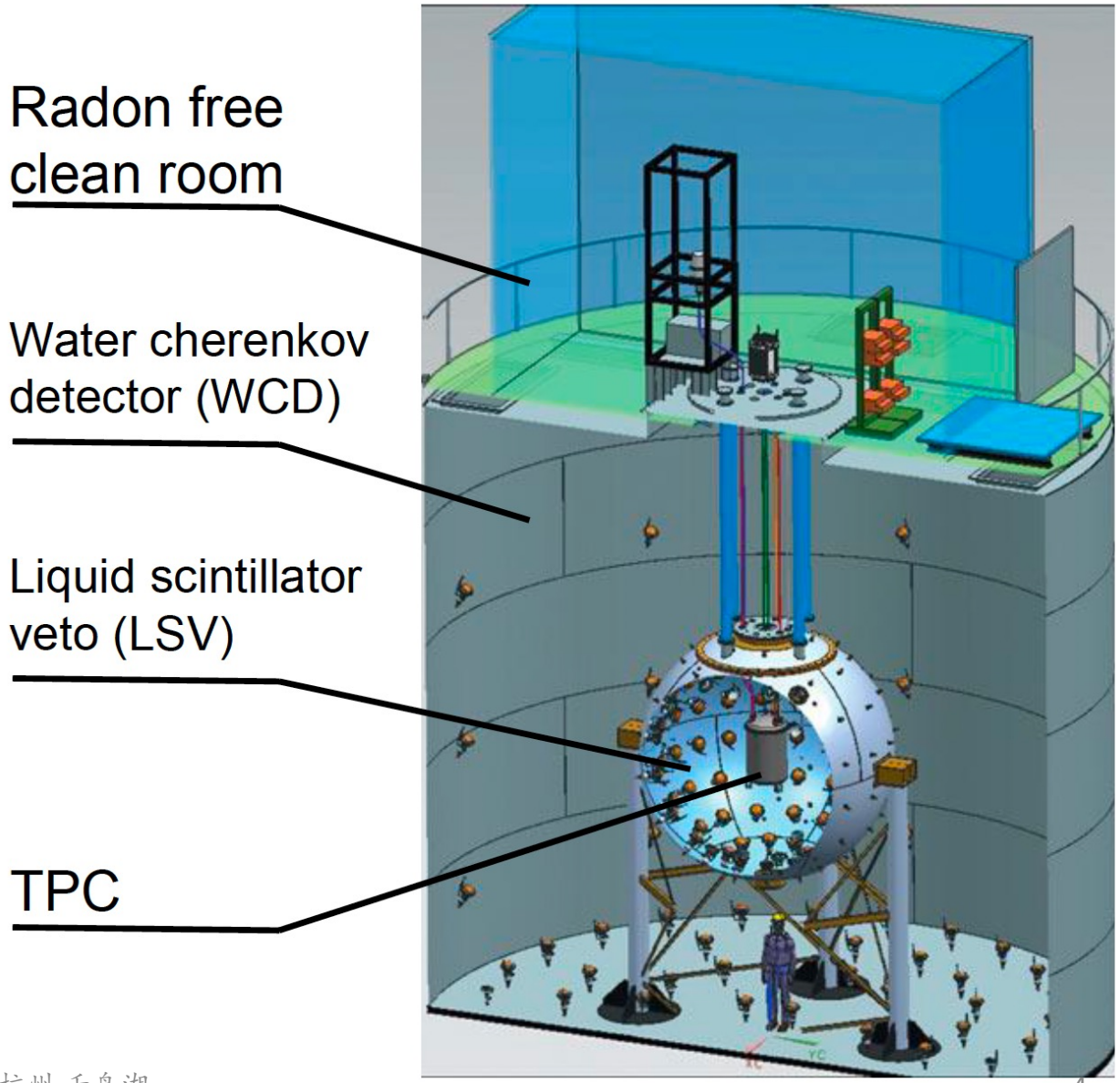


The DarkSide-50 Detector

高能所在TPC、制冷系统、veto反射结构做出重要贡献。

- Dual phase argon TPC;
- 46.4 kg active mass;
- Light yield (@null field) ~ 8 p.e./keVee.



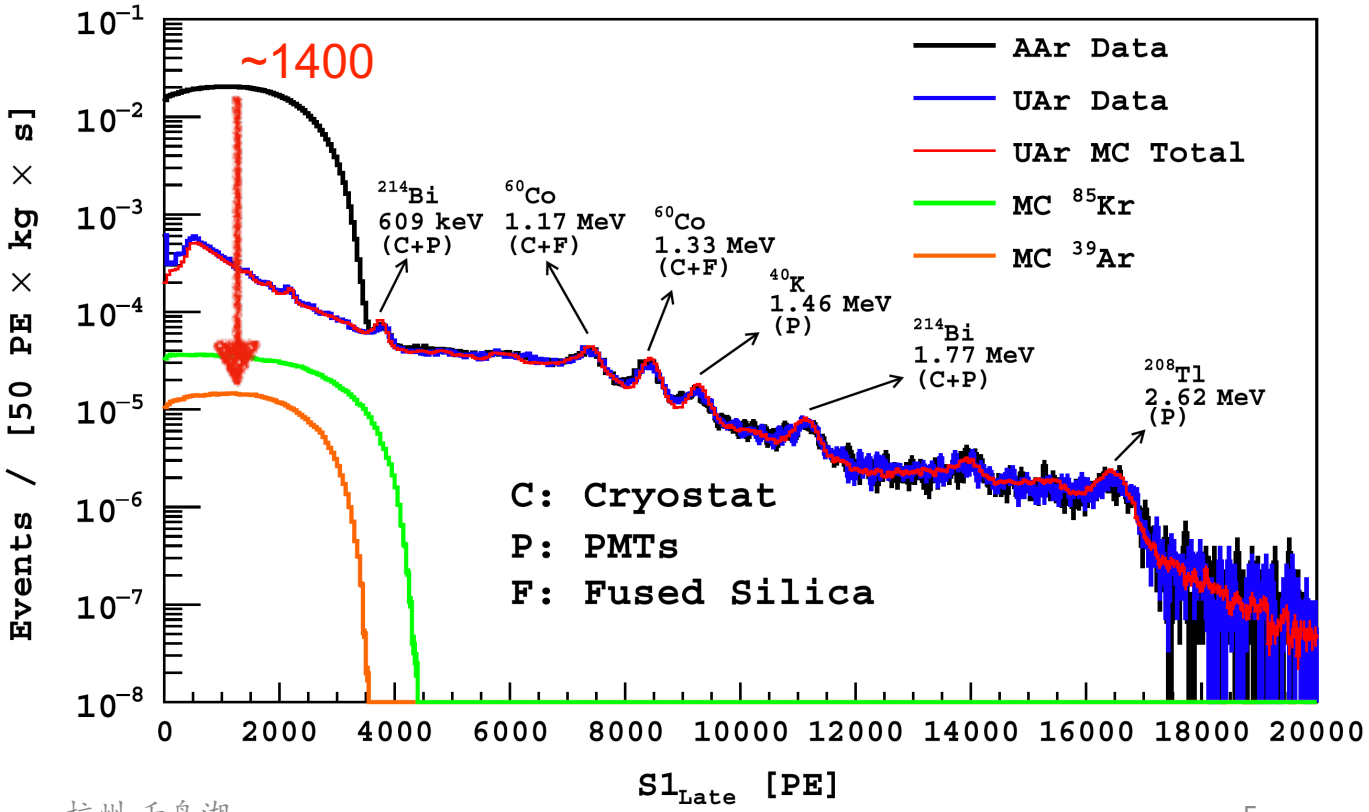


Underground Argon (UAr)

- Atmospheric argon (AAr) has intrinsic ^{39}Ar radioactivity ~1 Bq/kg;
- β decay with 565 keV endpoint, 269 years half-life;
- ^{39}Ar activities set the threshold at low energies.

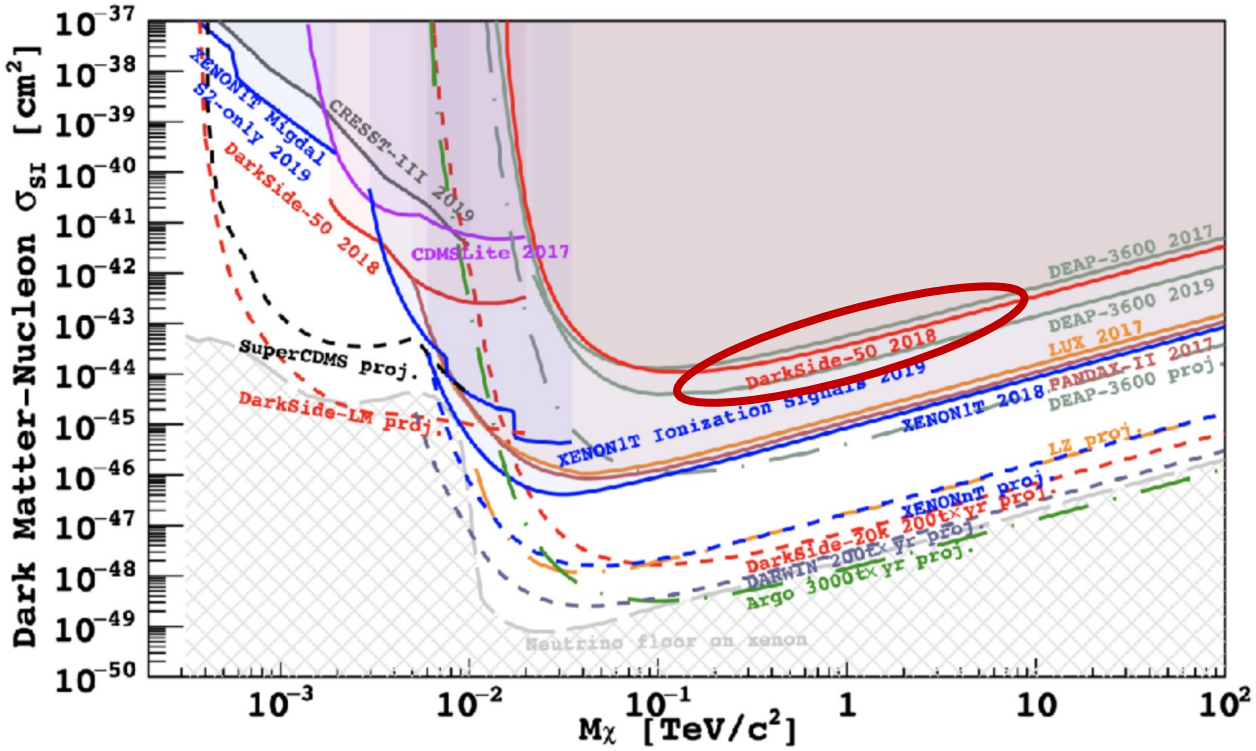
- ^{39}Ar is a cosmogenic isotope;
- Argon from underground sources has significantly lower ^{39}Ar concentration than AAr;
- CO_2 well in Corolado, USA
- 160 kg UAr extracted for DarkSide-50:
  - ➢ ^{39}Ar reduction factor ~1400.

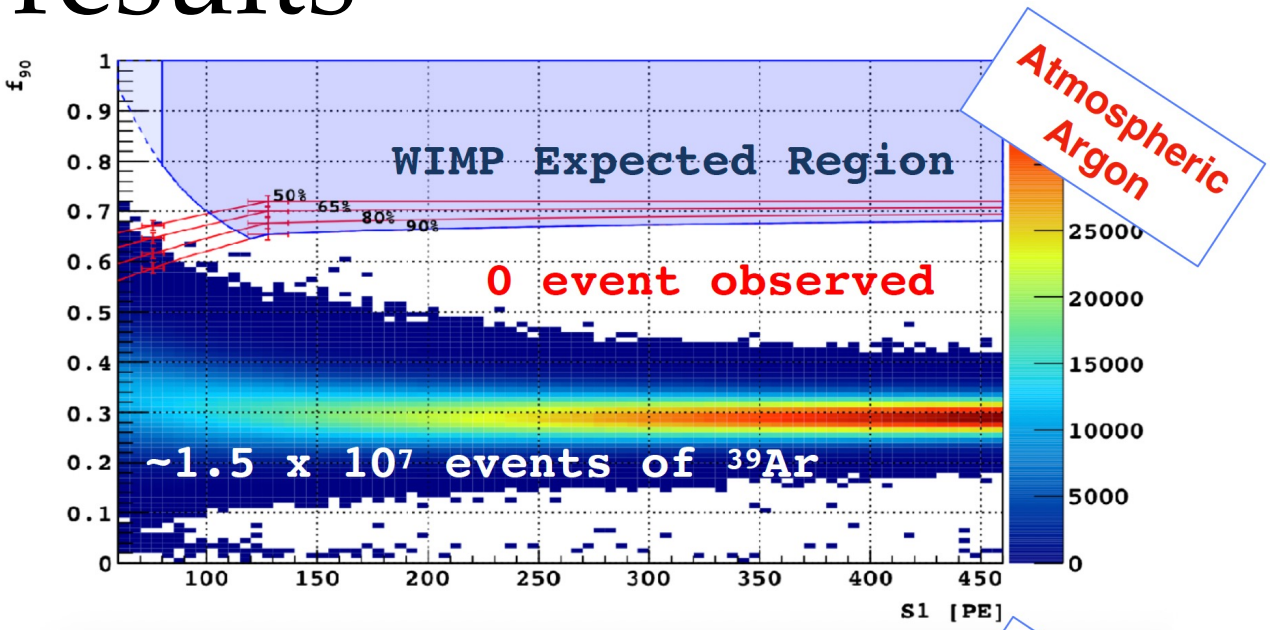
Phys. Rev. D 93, 081101 (2016)

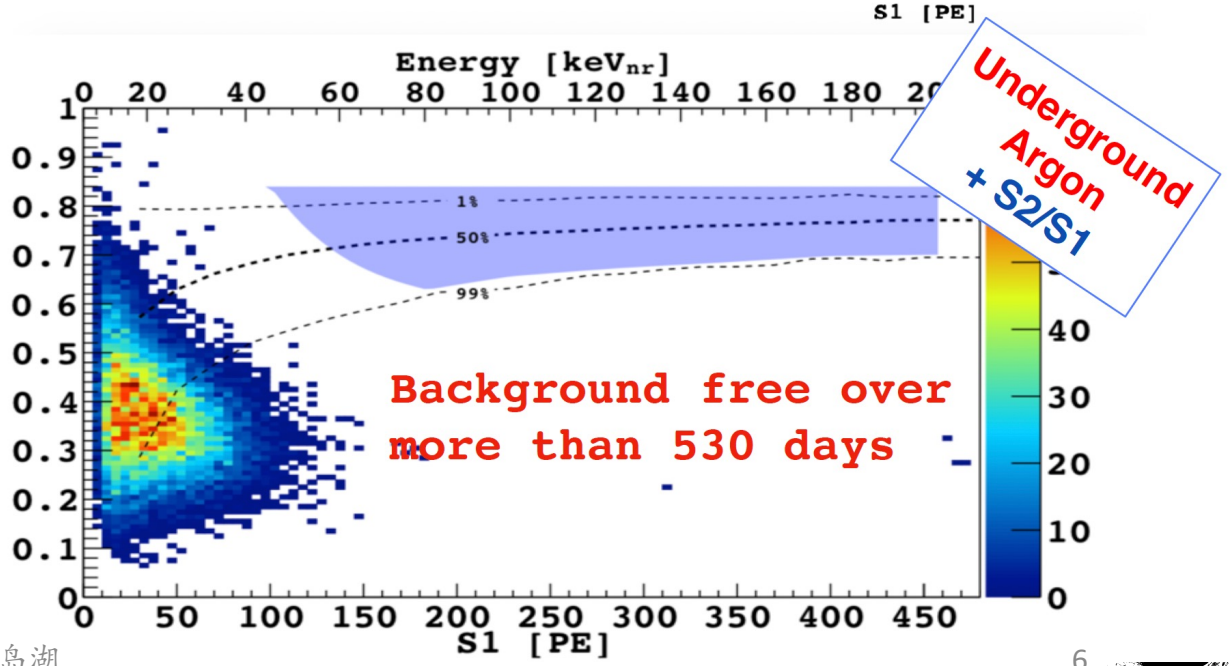


DarkSide-50 high-mass results

Phys. Rev. D 98, 102006 (2018)



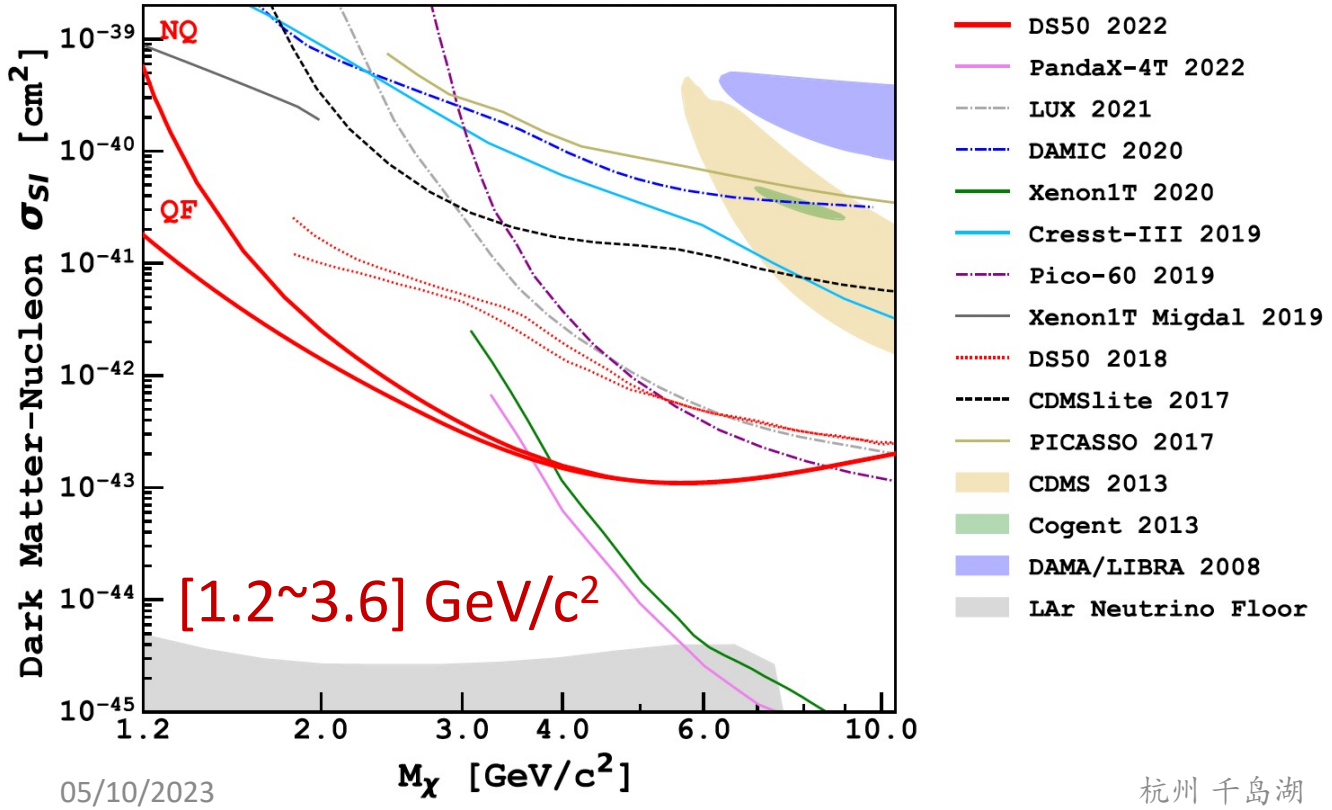


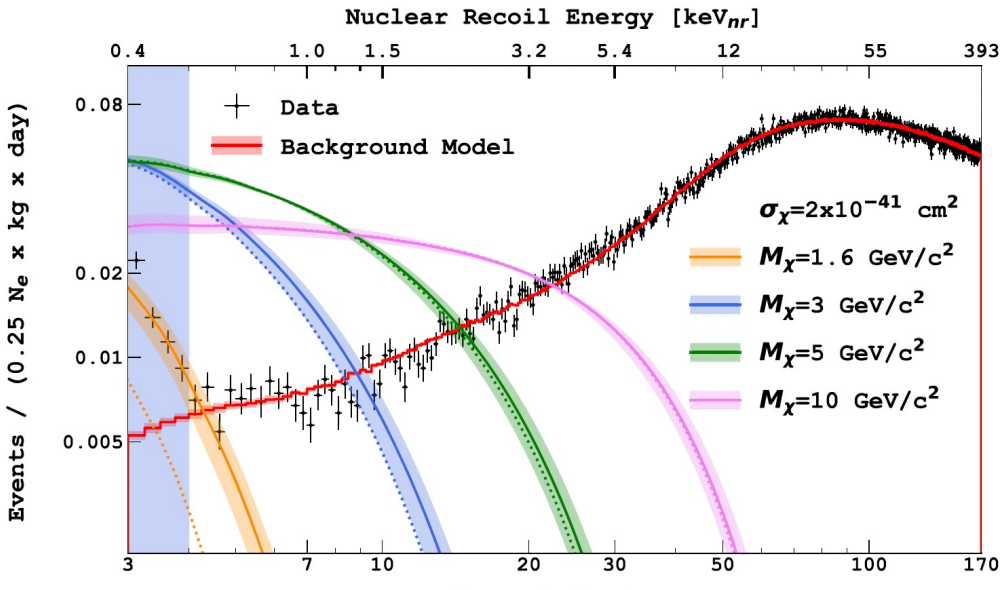


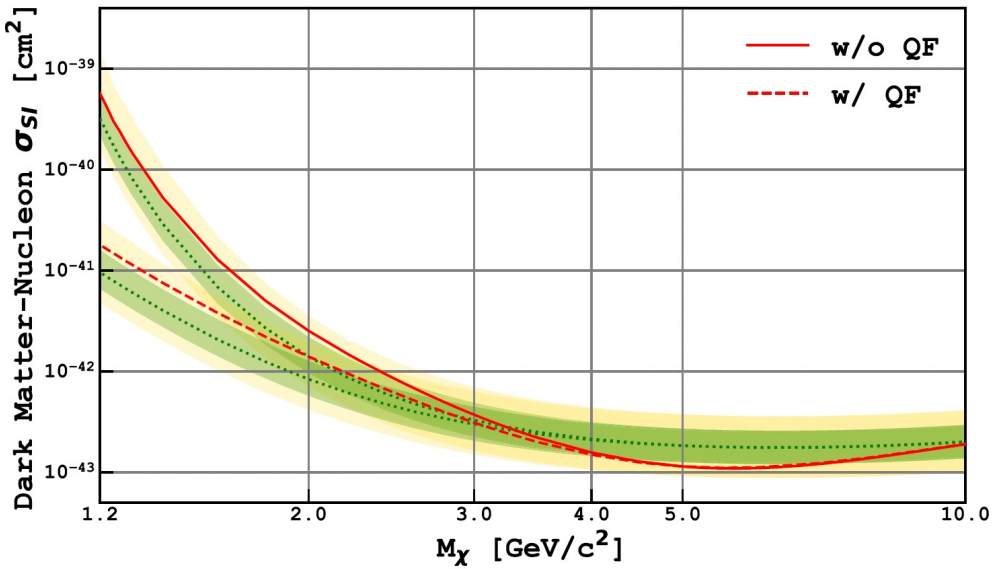
DarkSide-50 low-mass results

Phys. Rev. Lett. 121, 081307 (2018)
Phys. Rev. D 107, 063001 (2023)

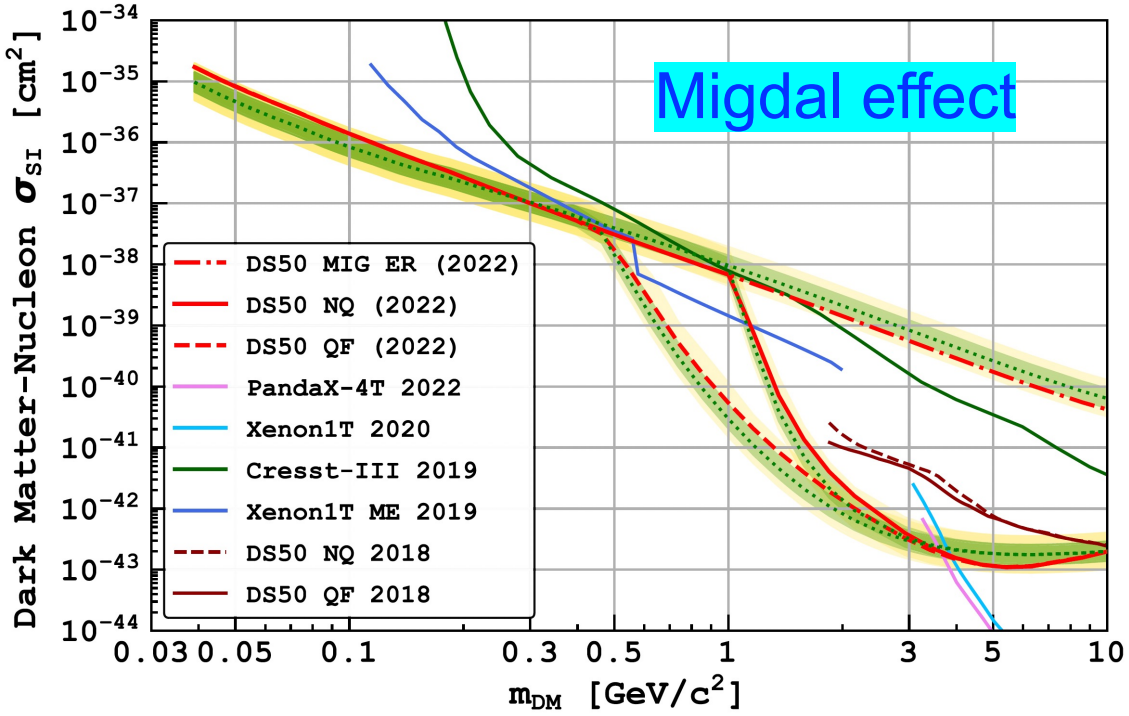
- Scintillation (S1): detection eff. ~16%;
- Ionization (S2): 100% eff. to extract e- in gas pocket, amplification factor 23 p.e./e-;
- 12 t-days (2023) vs 6.78 t-days (2018).



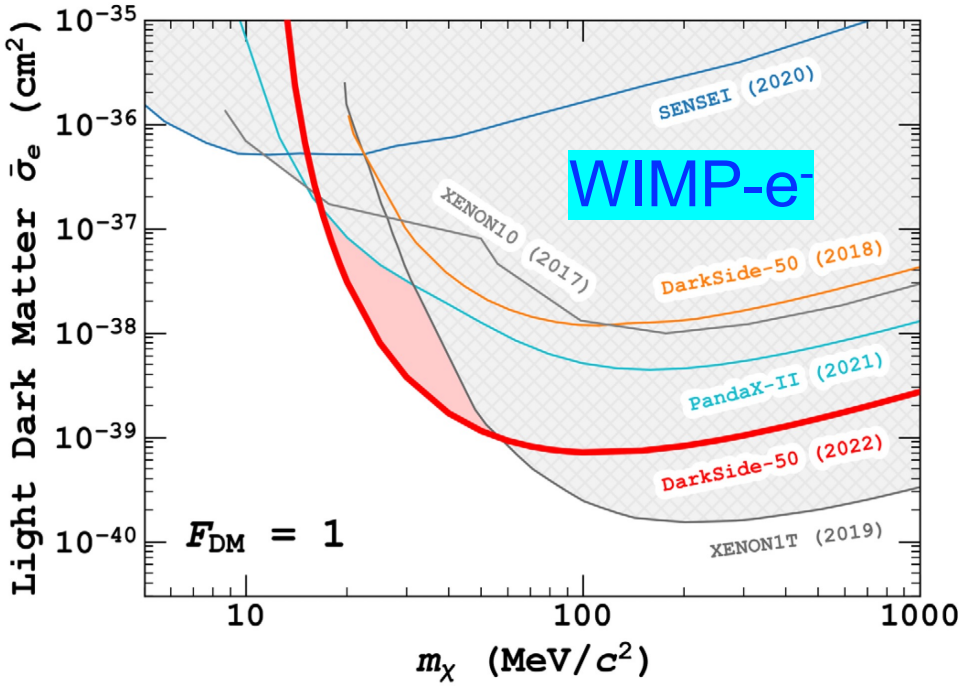


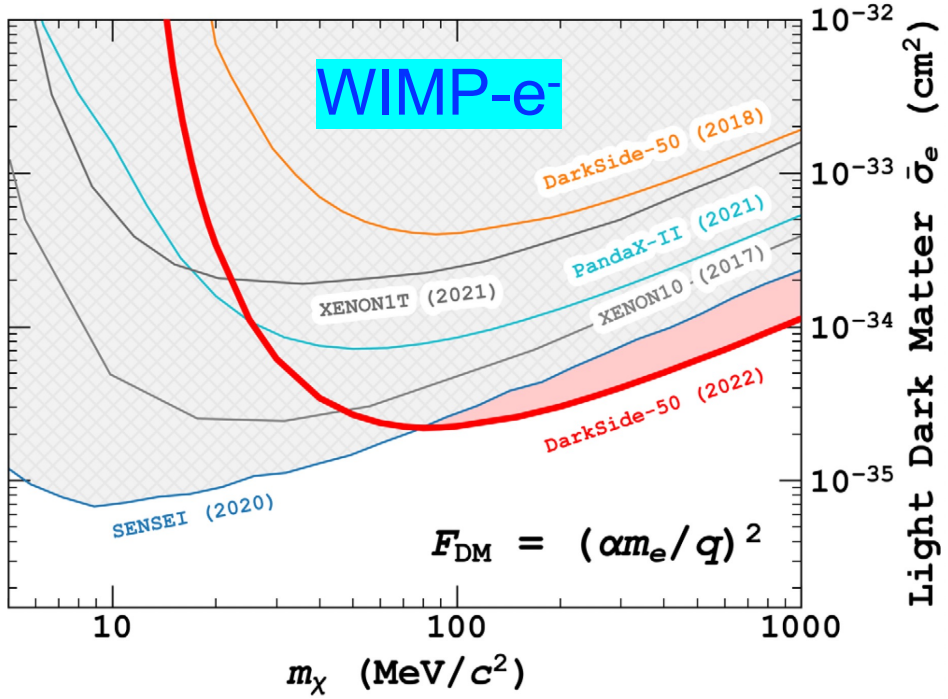


DarkSide-50: light DM



Phys. Rev. Lett. 130, 101001 (2023)

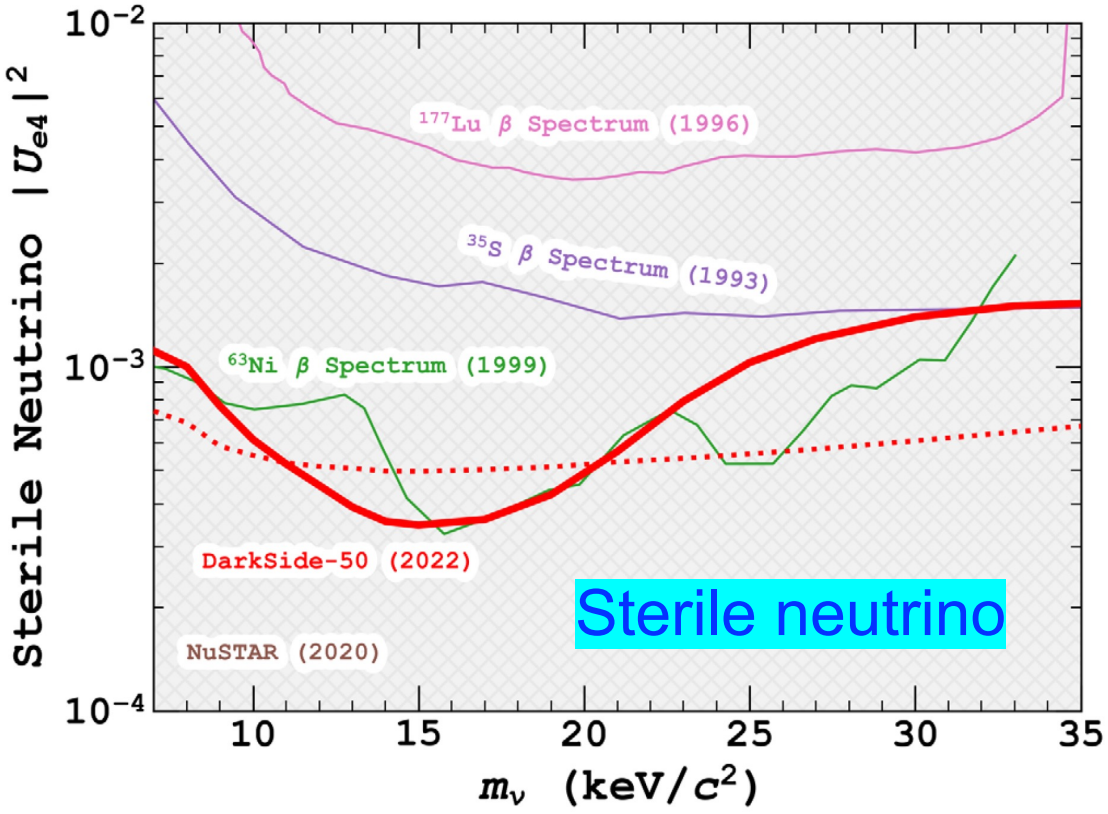


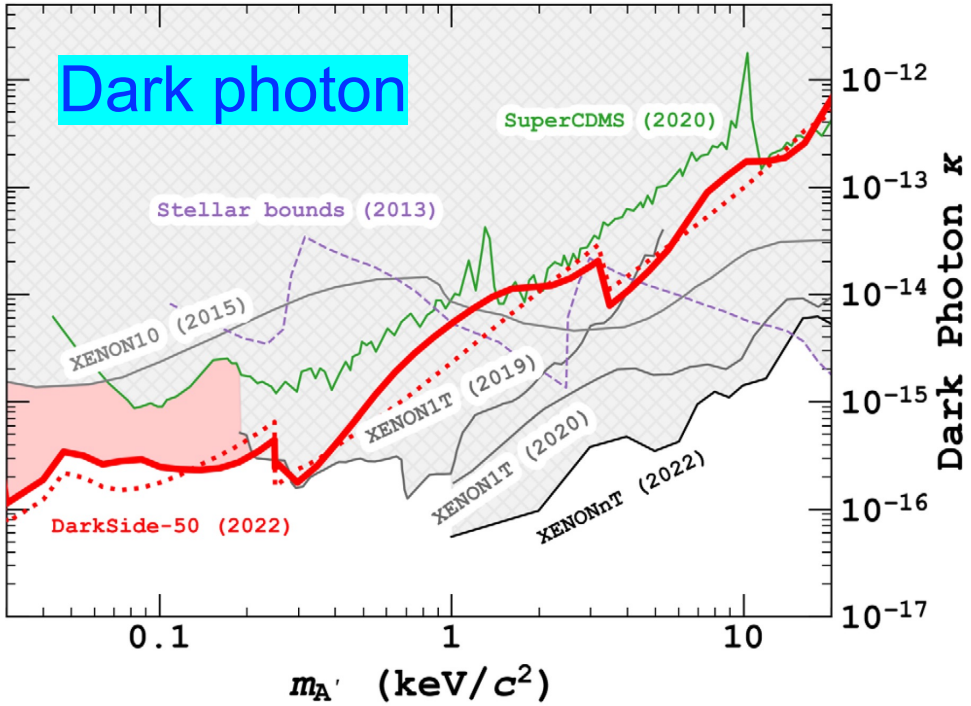


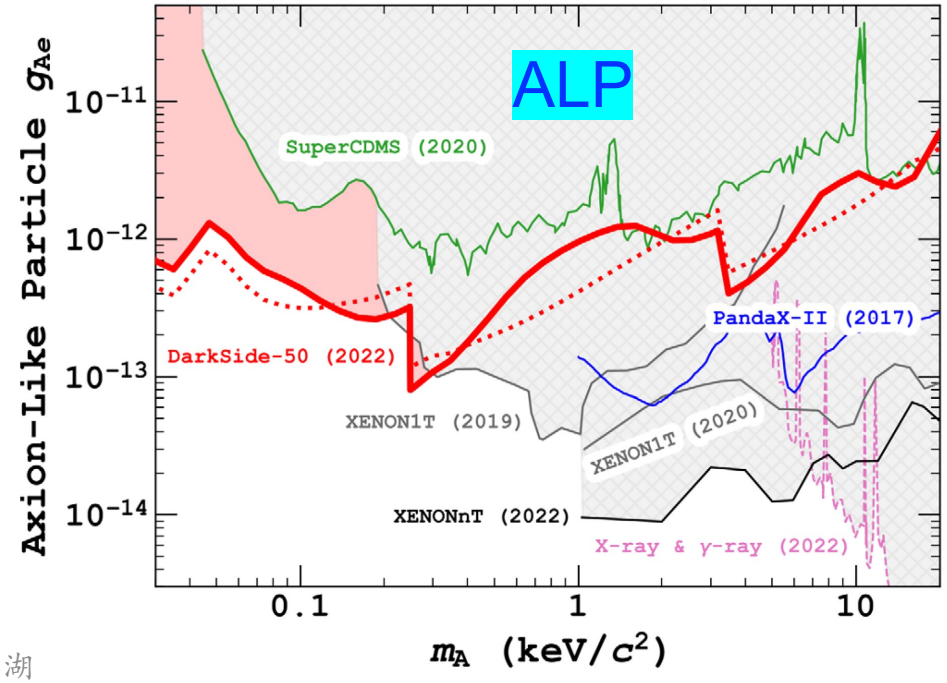
Phys. Rev. Lett. 121, 111303 (2018)
Phys. Rev. Lett. 130, 101002 (2023)

DarkSide-50: light DM

Phys. Rev. Lett. 130, 101002 (2023)

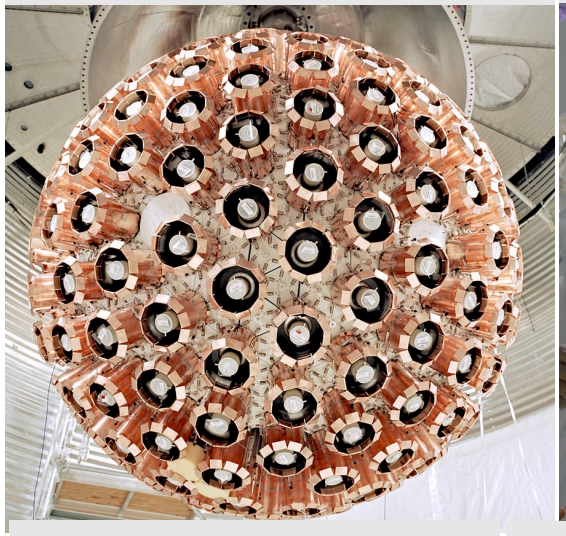




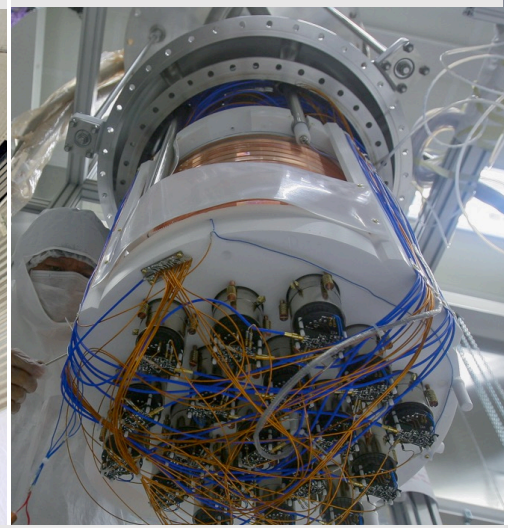


The GADMC

DEAP-3600 @SNOLAB

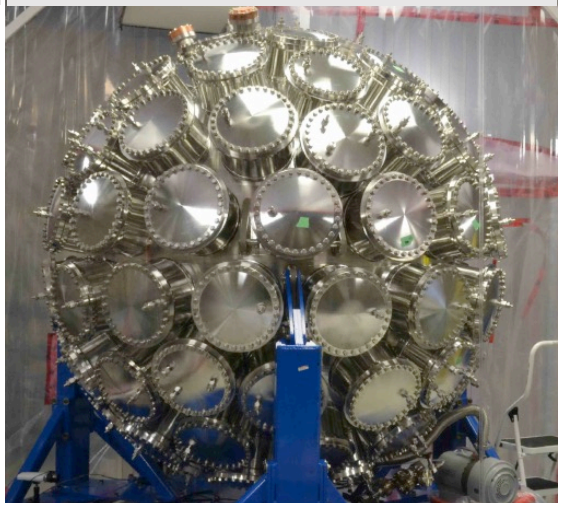


DarkSide-50 @LNGS



ArDM @LSC

miniCLEAN @SNOLAB



- Global Argon Dark Matter Collaboration;
- Established in 2017;
- >500 collaborators, >100 institutes, 14 countries.

DarkSide-20k (high-mass 200 ty)

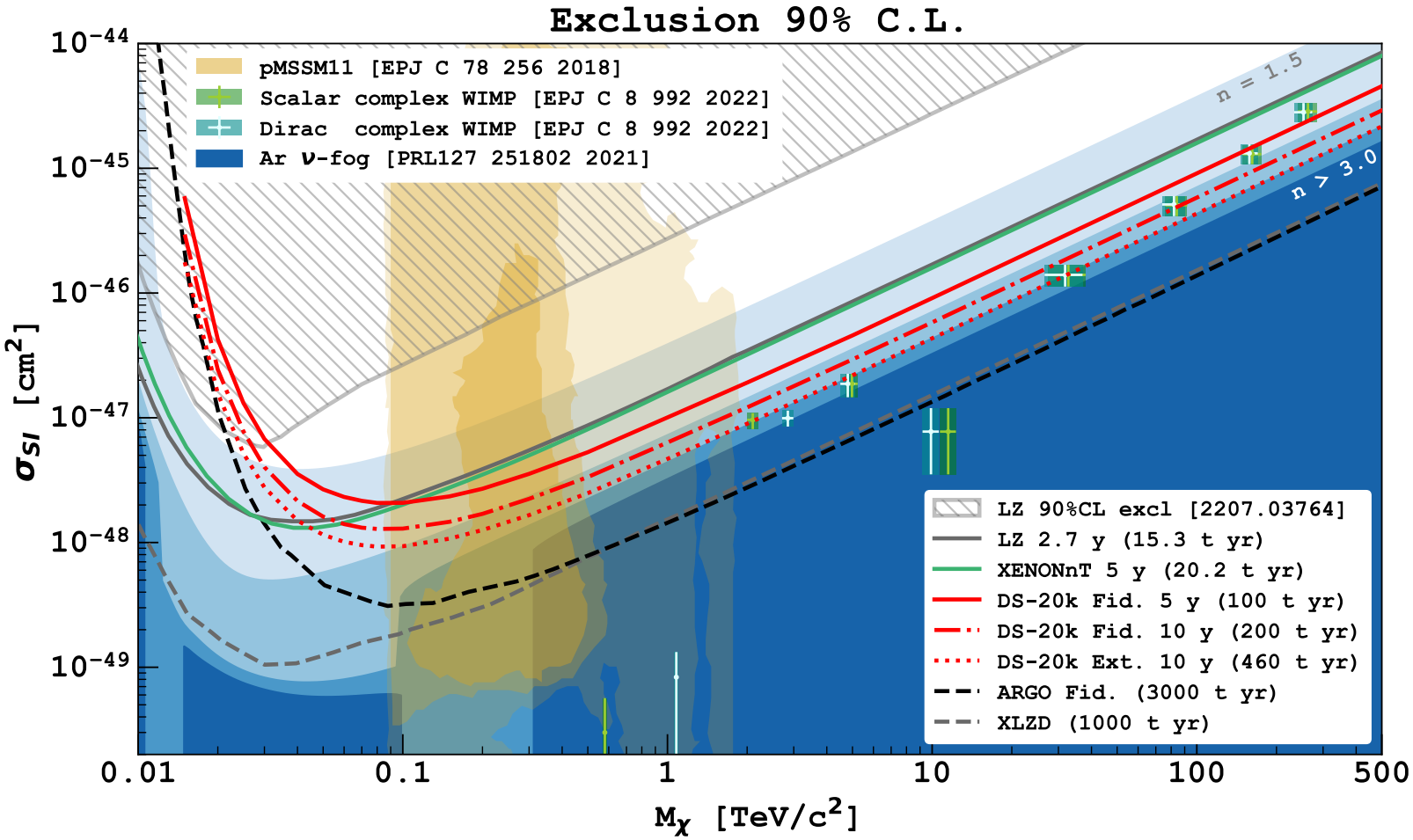
DarkSide-LM (low-mass)

ARGO (high-mass 3000 ty)

DarkSide-20k Projections

- Sensitivity to SI WIMPs;
- With nominal exposure 200 t-y (20 t x 10 years):
  - 90% C.L. exclusion: 6.3×10^{-48} cm^2 @1 TeV/c^2 ;
  - 5 σ discovery: 2.1×10^{-47} cm^2 @1 TeV/c^2 ;
  - 3.2 CEvNS events expected.

- Instrumental background: < 0.1 neutron in RoI (30~200 keVnr) with 200 t-y exposure.

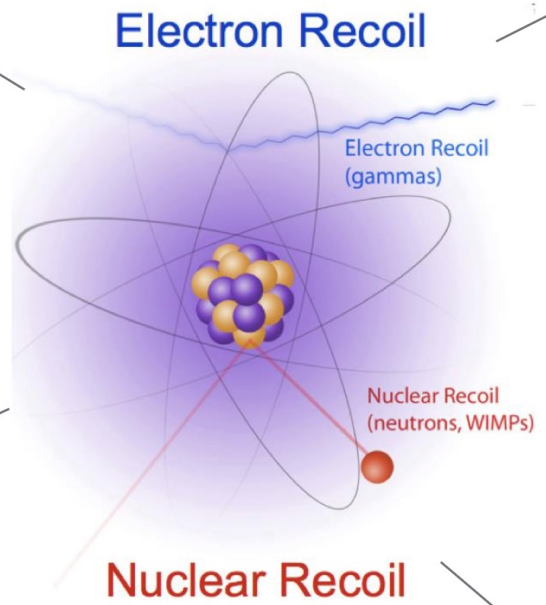


Backgrounds for DarkSide-20k

^{85}Kr β-decay

Cosmogentic activation of LAr - ^{39}Ar undergoes β-decay

Gammas from radioactive contamination of detector components



Coherent elastic neutrino interactions

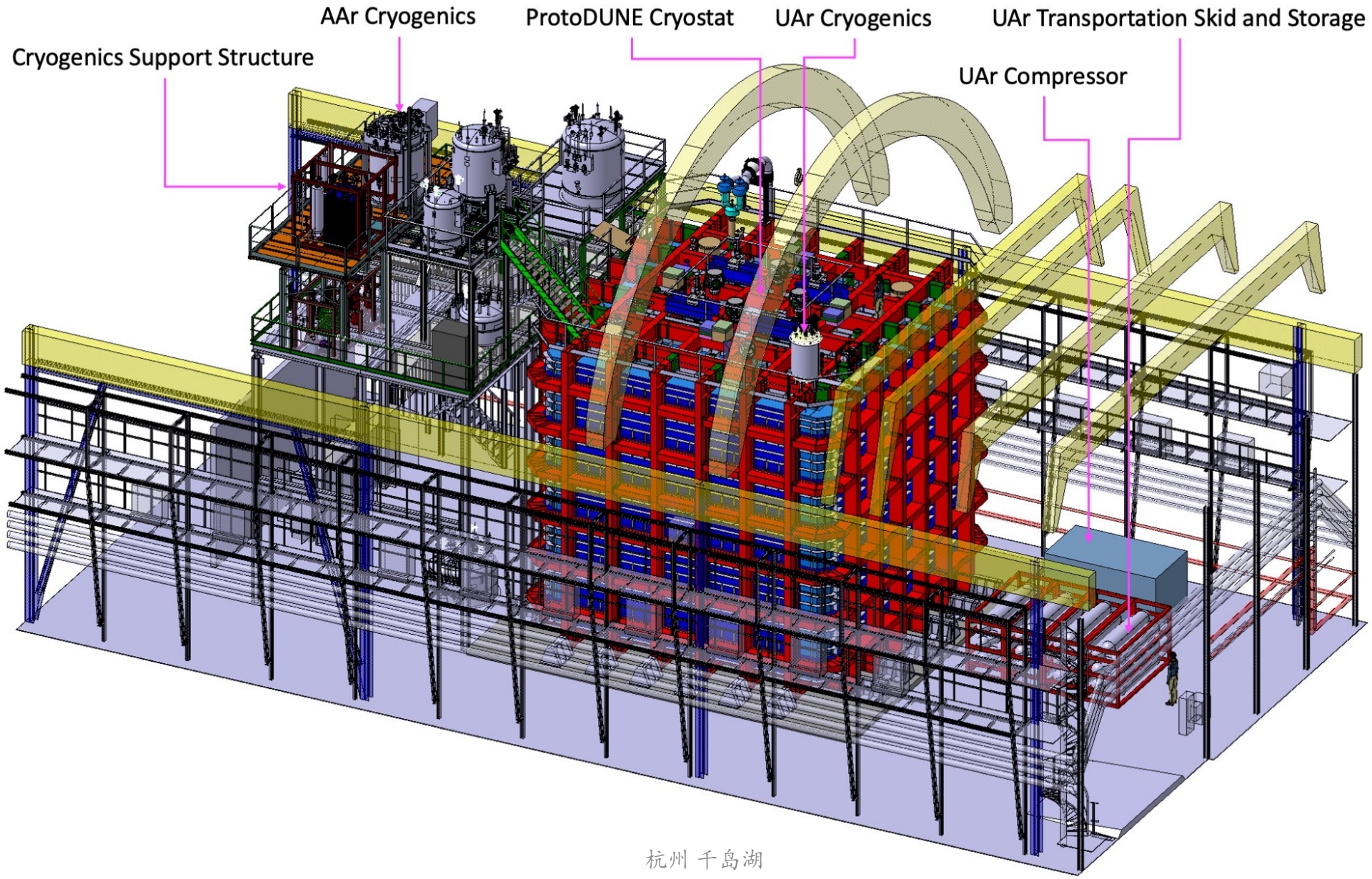
Cosmogenic muon induced neutrons

U-238 and Th-232 contamination of detector materials

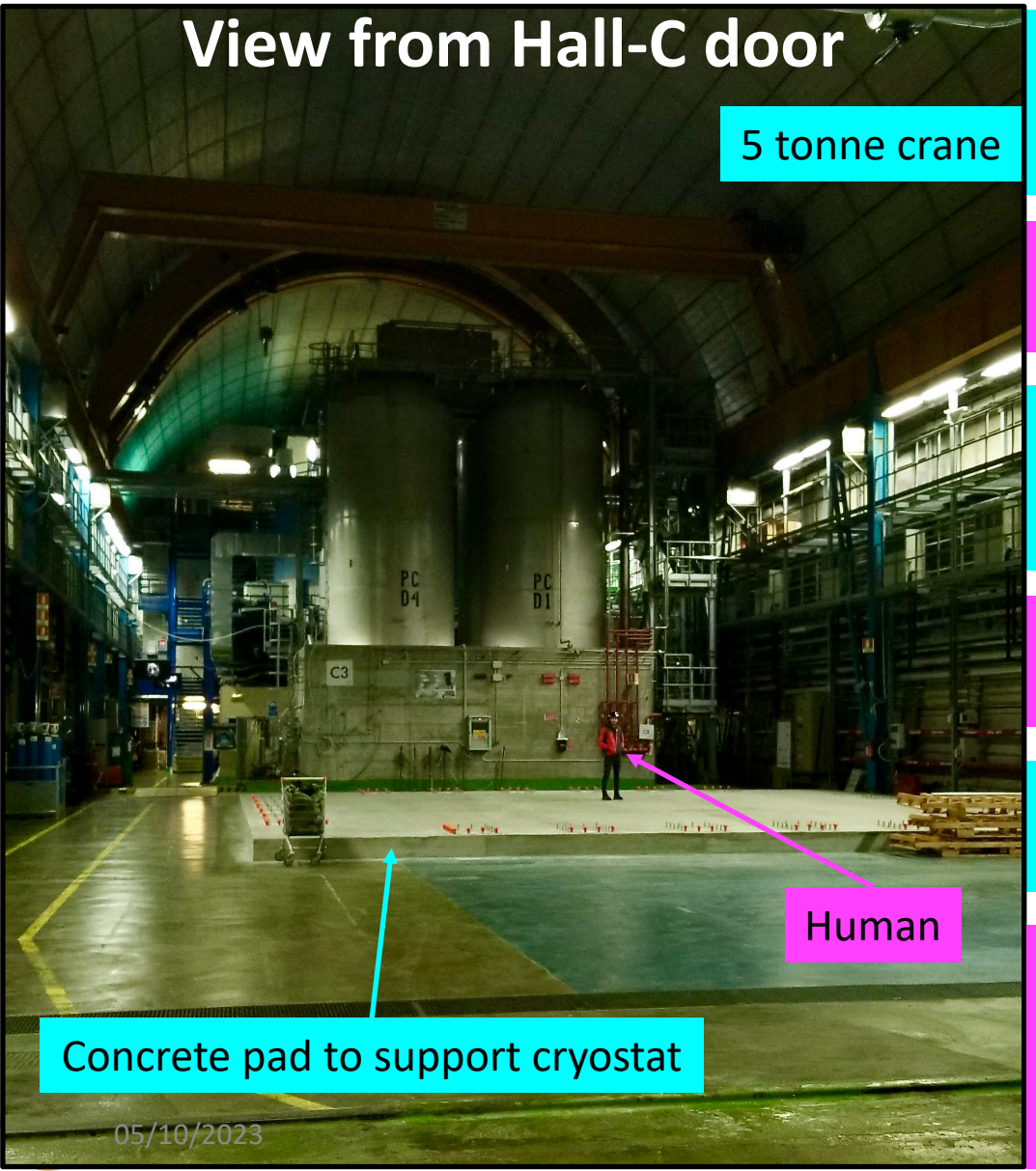
(α,n) reaction in the detector material

Goal: <0.1 neutron in RoI (30~200 keVnr) with 200 t-y exposure.

DarkSide-20k in LNGS Hall C



DarkSide-20k Overview



Membrane "ProtoDUNE-like" cryostat

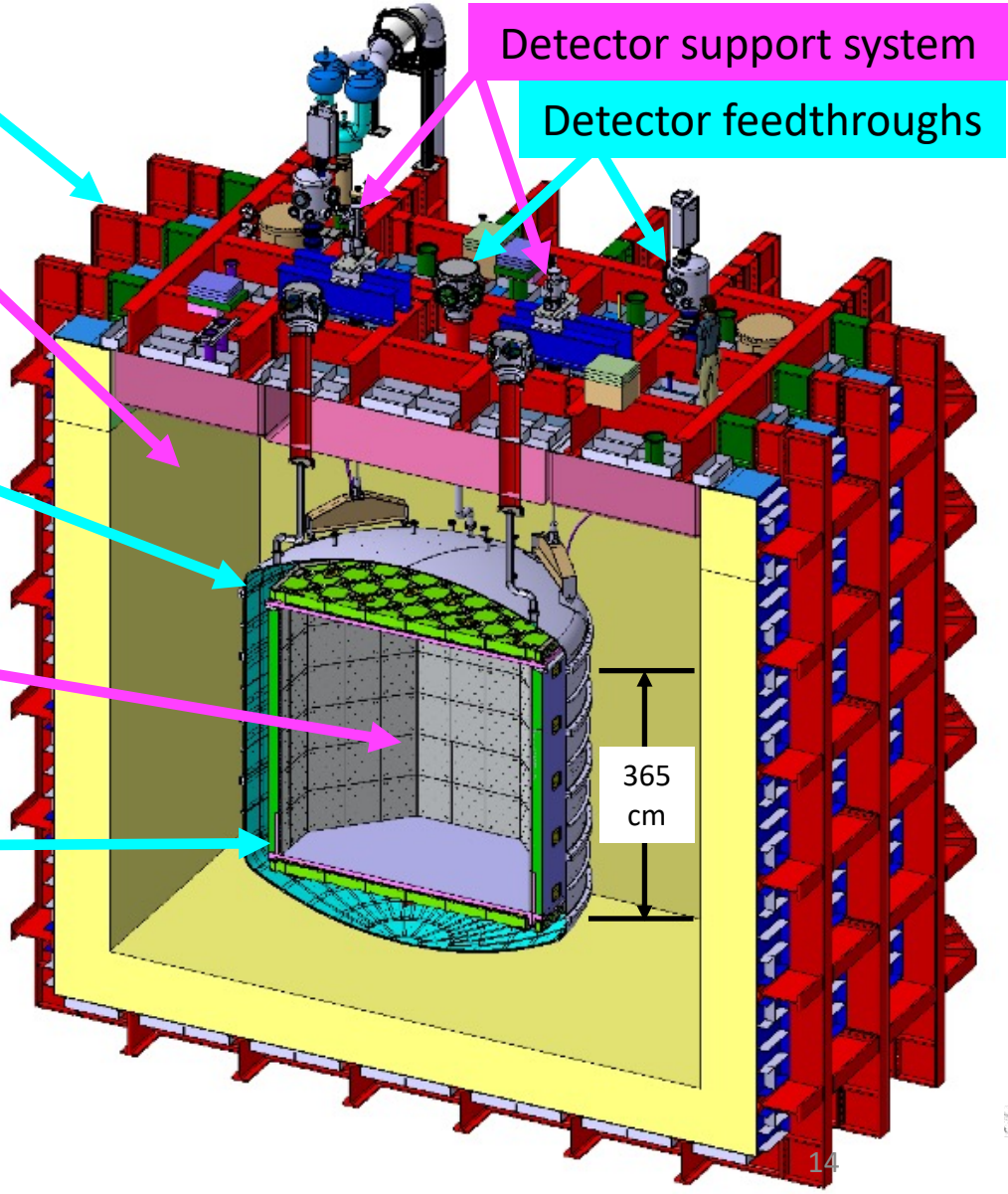
Atmospheric argon (AAr) volume (≈700 t)

Vacuum vessel containing UAr and TPC/veto

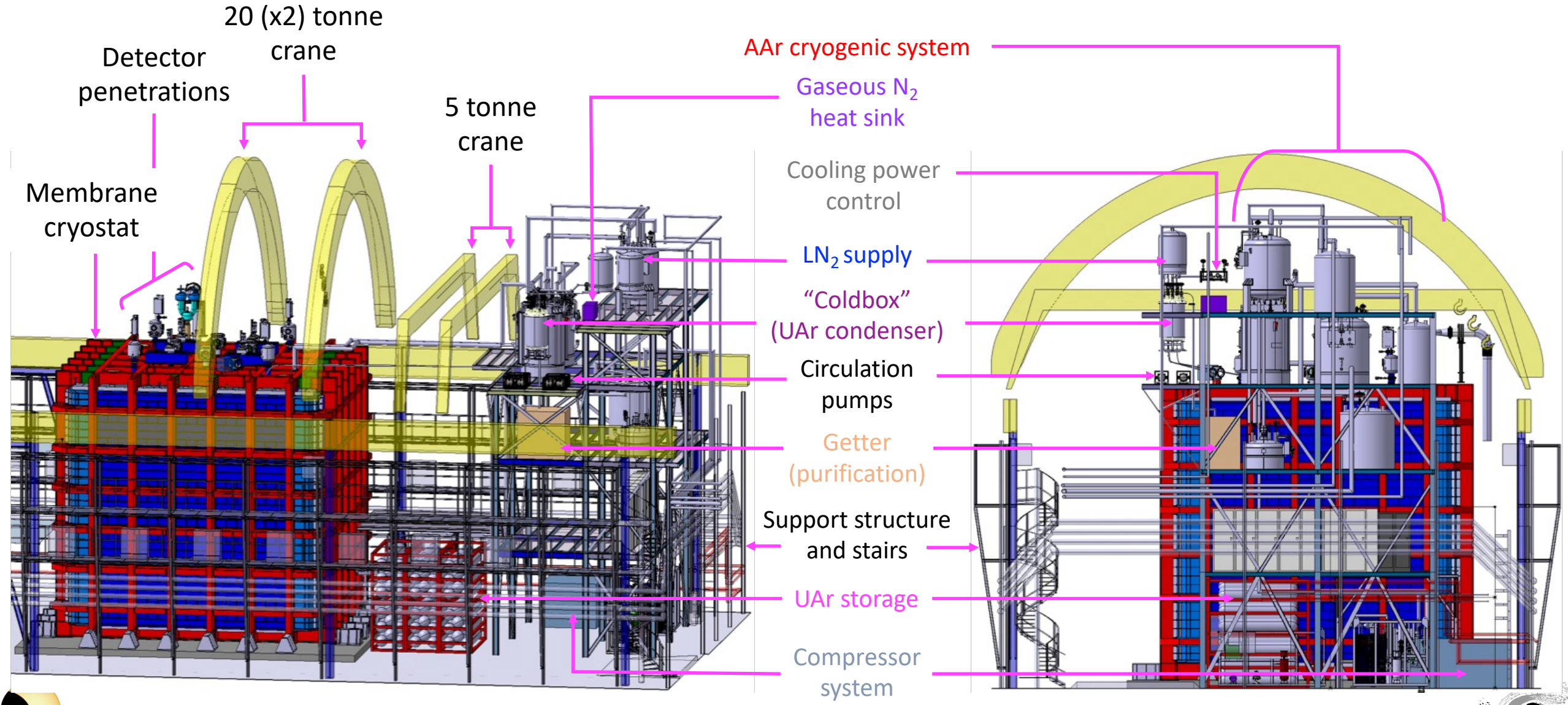
Underground argon (UAr) volume (≈100 t)

"Inner detectors", TPC and neutron veto

Outer veto will consist of SiPM arrays near the cryostat walls looking inward

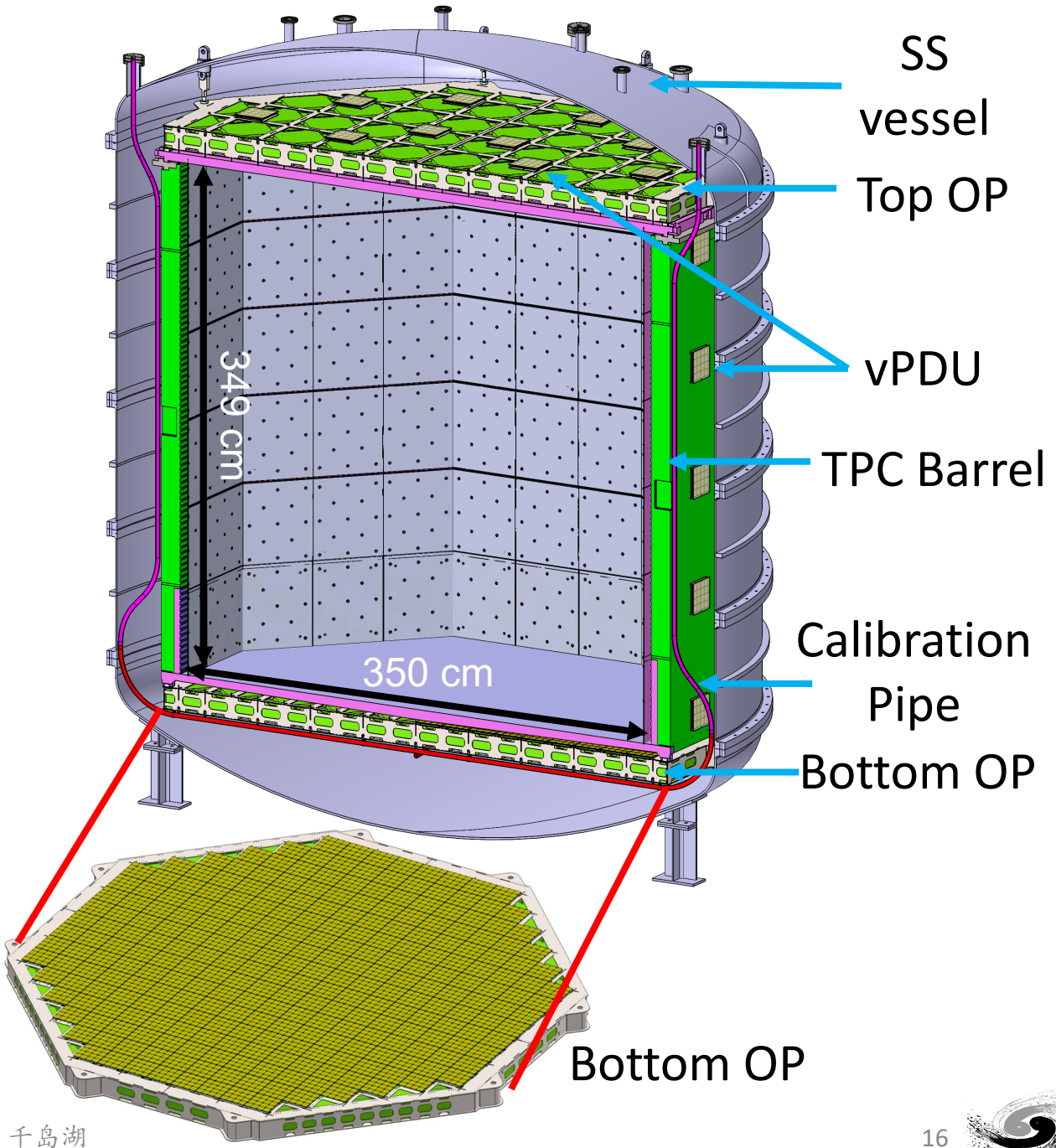


DarkSide-20k Overview



The Inner Detector

- TPC + neutron veto;
- Octagonal shape dual phase argon TPC:
  - Active UAr mass: 49.7 tonnes;
  - Fiducial UAr mass: 20.2 tonnes;
- Neutron veto:
  - Active UAr mass: 32 tonnes.
- SiPM as the photosensor;
- Single readout channel size: 10 cm x 10 cm;
- TPC: 2112 channels:
  - Top and bottom optical plane (OP);
- Veto: 480 channels;
- Pipe to deliver calibration sources.



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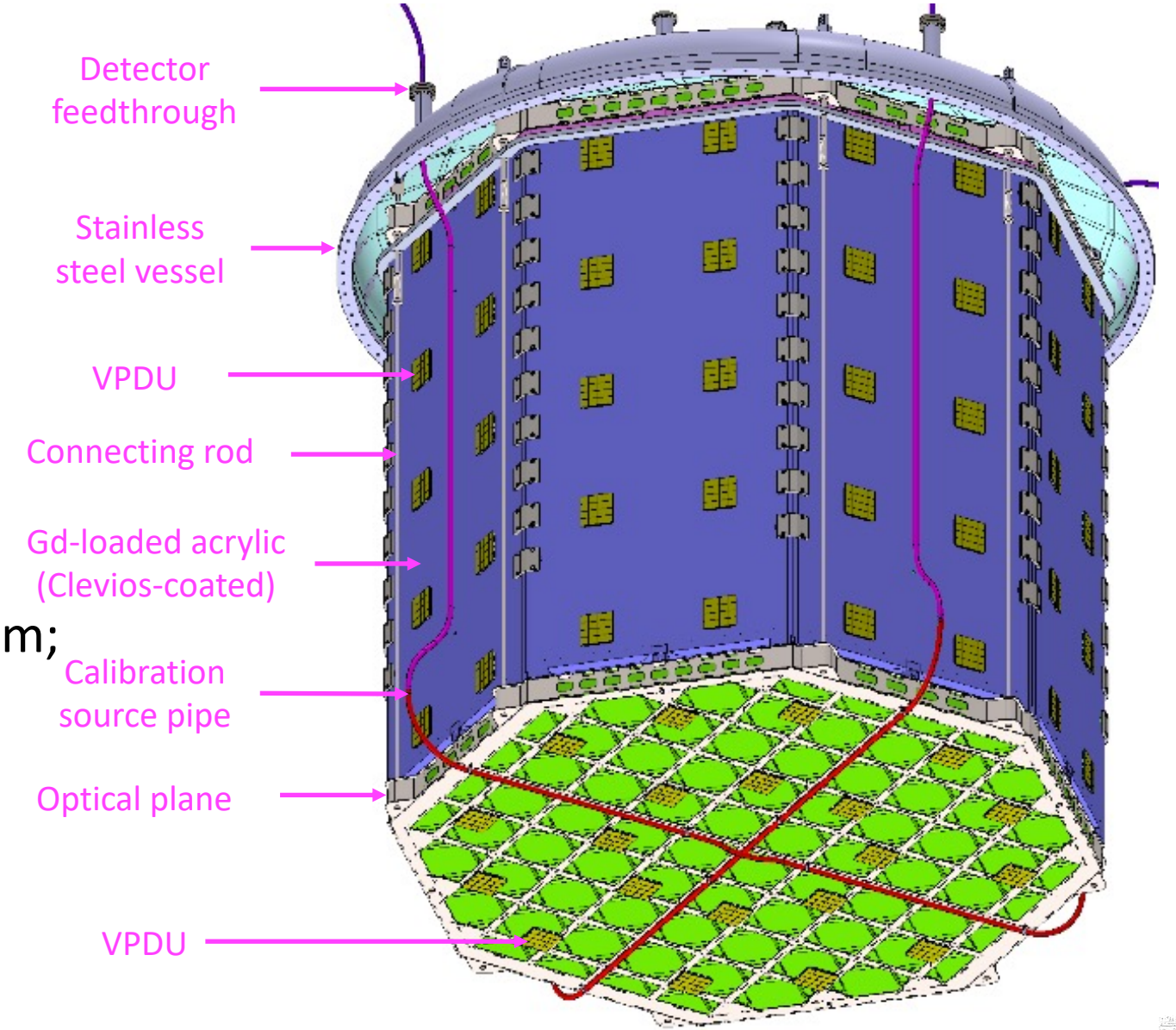


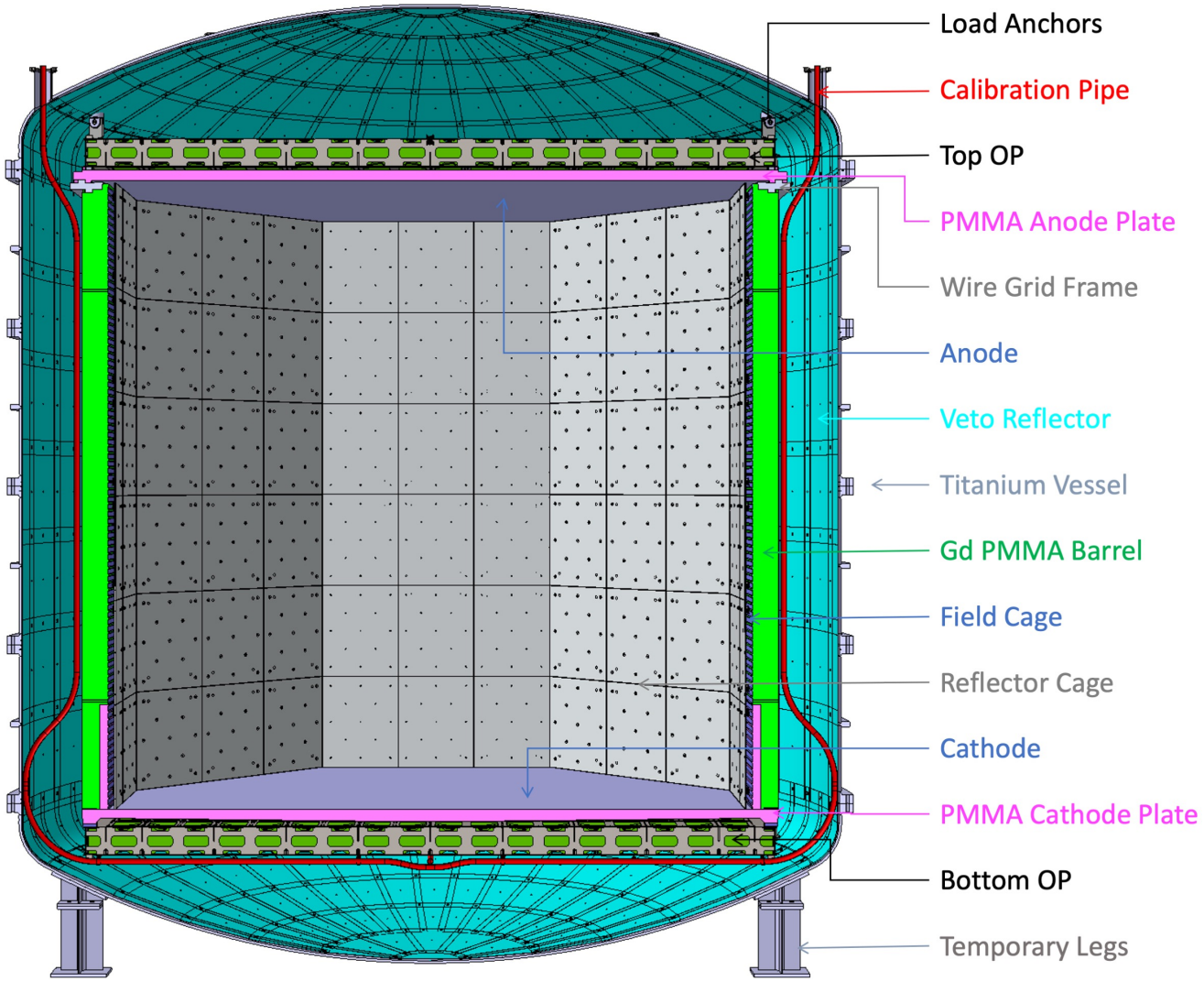
The Inner Detector - TPC

- Drift field: 200 V/cm;
- Extraction field: 2.8 kV/cm;
- Cathode voltage: -73.38 kV.

- Gas pocket thickness: 7.0±0.5 mm.

- LY (@null field) ~10 p.e./keVee;
- S2 yield > 20 p.e./e^-.

- Acrylic as the main structure (pure and Gd-doped);
- E-field:
  - Conductive polymer (Clevios™) coating as anode, cathode and field cage rings;
  - SS wire grid;
- ESR as reflector and TPB as wavelength shifter.



The Inner Detector - TPC

- New designed TPC with a batch of new technologies.

- From DS-50 to DS-20k

➢Main structure: PTFE -> Acrylic

➢Reflectors: PTFE -> ESR

➢Wavelength shifter: TPB -> TPB

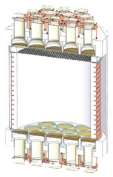
➢Grid: Hexagonal mesh -> Wires

➢Field cage rings: Copper -> Clevios™

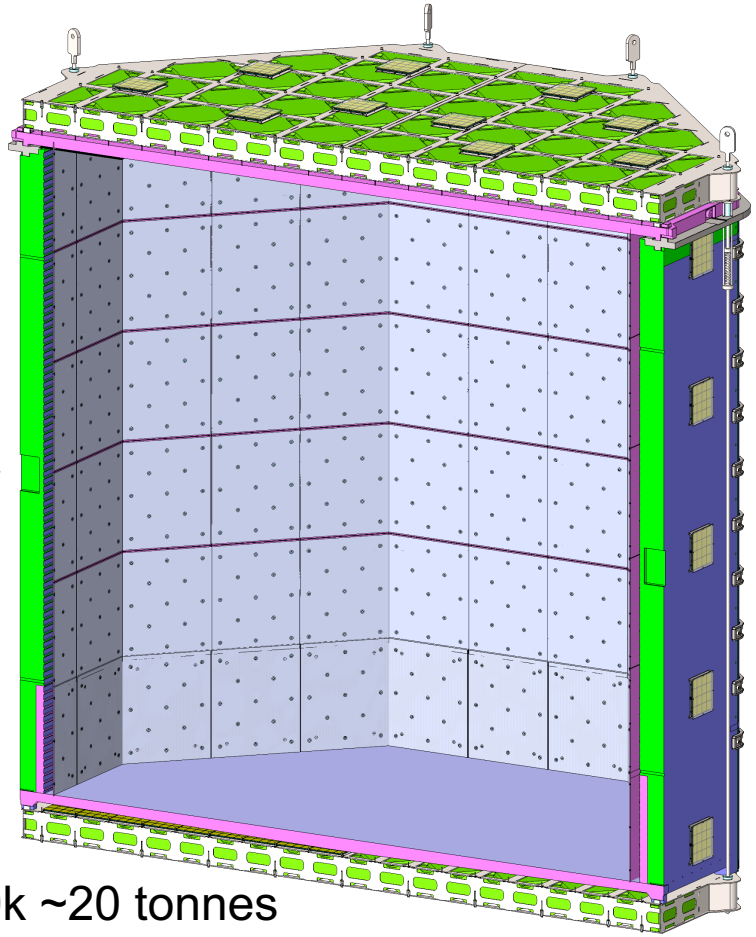
➢Windows: Fused silica -> Acrylic

➢Anode & cathode: ITO -> Clevios™

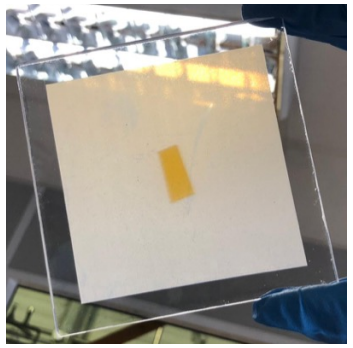
➢Photosensors: PMT -> SiPM



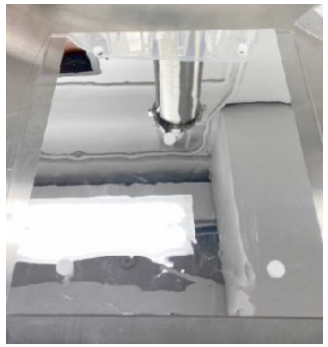
DS-50 ~20 kg



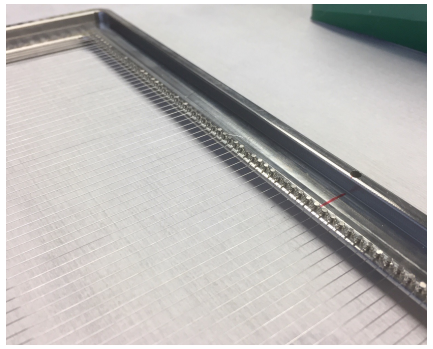
DS-20k ~20 tonnes



TPB on Clevios™



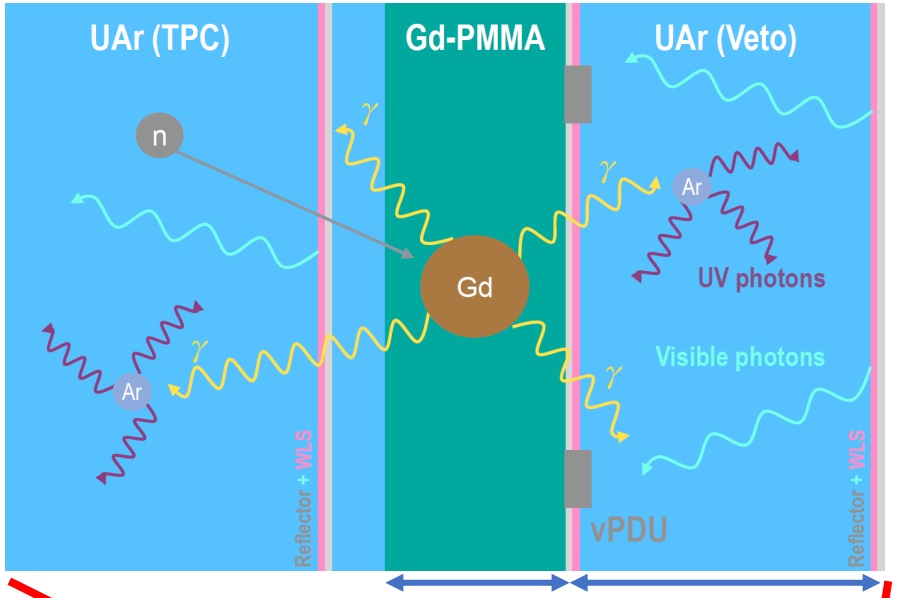
ESR mounting



Wire grid demonstrator

The Inner Detector - n veto

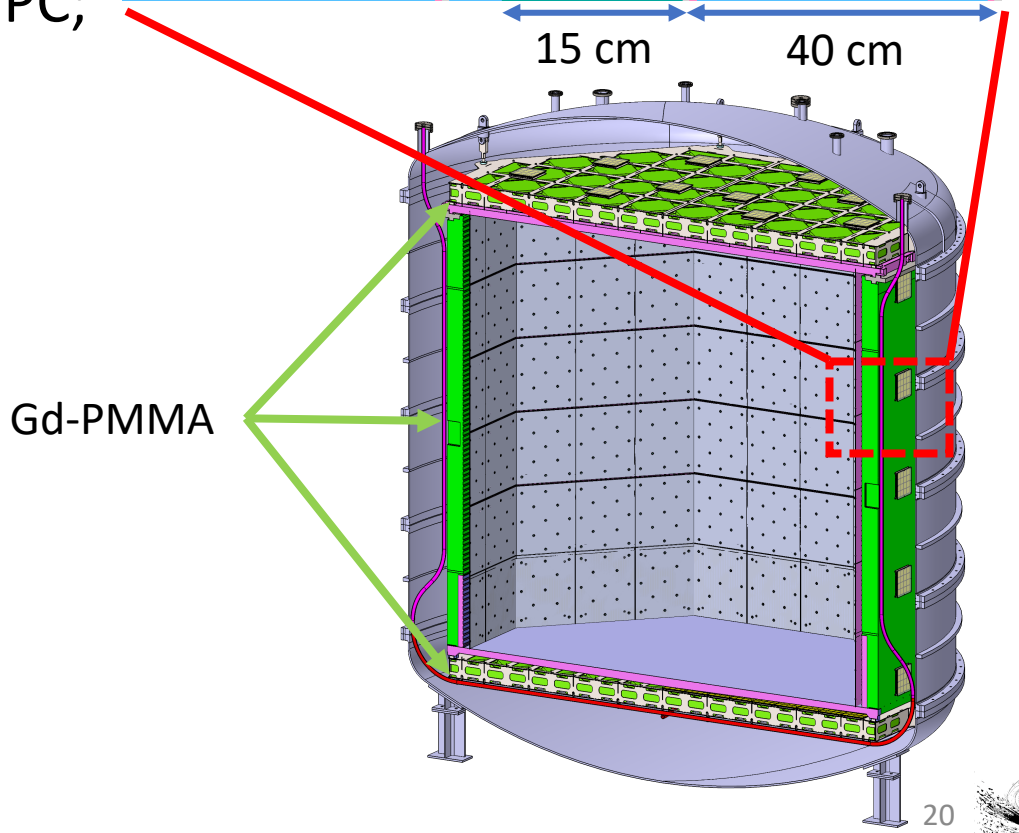
- Acrylic (Hydrogen) + Gadolinium + Argon
  - ➢Gd-PMMA (1 wt%), 15 cm thick;
  - →4π coverage: TPC walls, top & bottom endcaps;
  - ➢40 cm thick UAr buffer + UAr in TPC;
- Produced γ rays interact in UAr in both buffer and TPC;
- ESR as reflector and PEN as wavelength shifter;
- Scintillation lights detected by SiPMs in both buffer and TPC.



Gd(MAA)3-doped acrylic with 1 wt% Gd concentration.

由高能所、扬州大学、泰兴汤臣亚克力公司联合完成技术研发和工业化转移。

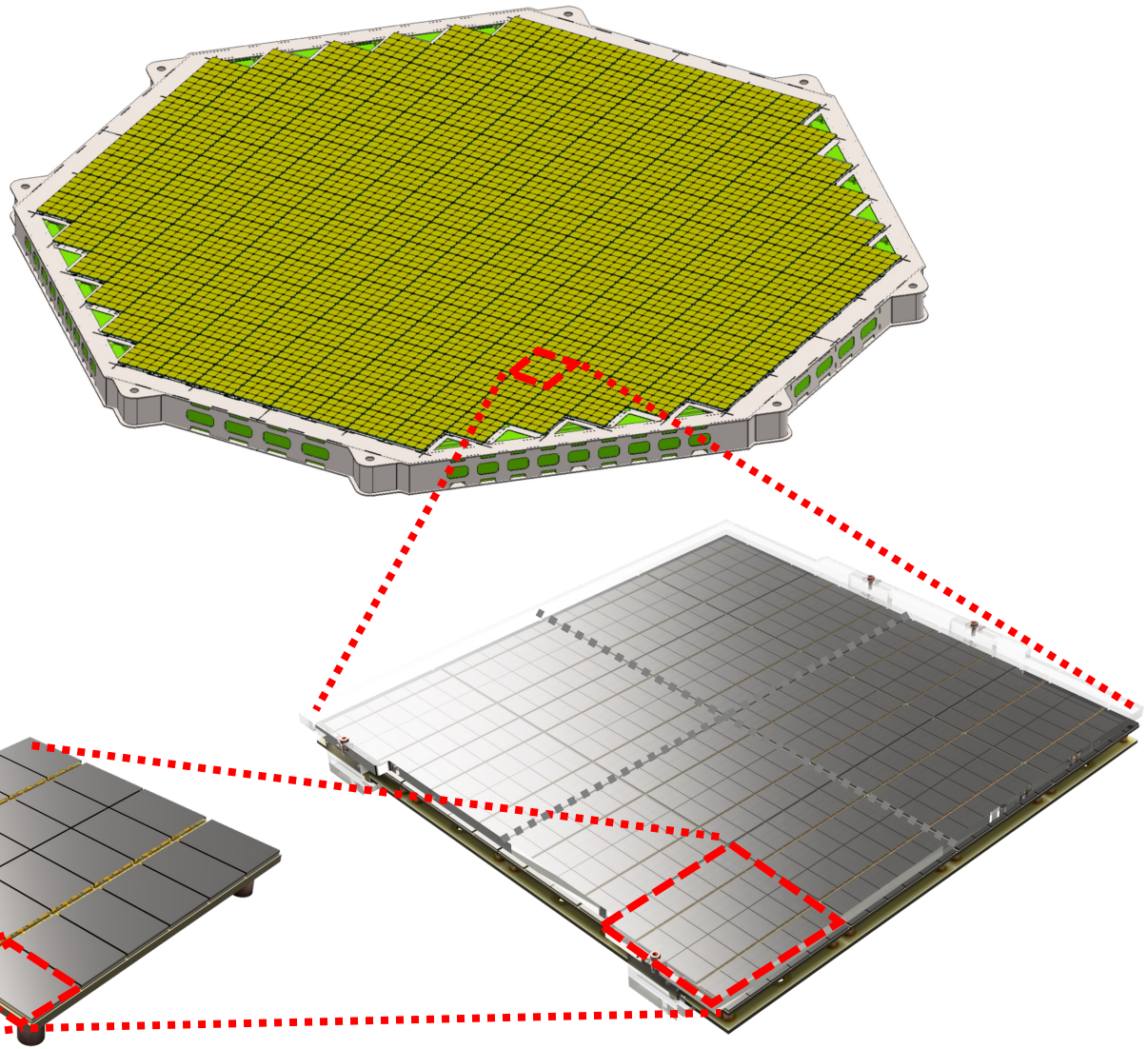
DS-20k中子反符合探测器获得基金委国际合作重点支持。

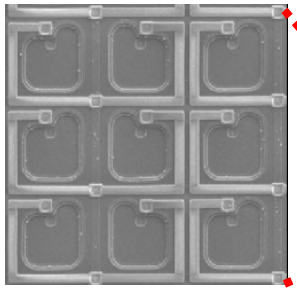


Photodetectors

- Cryogenic SiPMs developed with Fondazione Bruno Kessler (FBK):
  - PDE > 42% @ 77K;
  - DCR < 0.01 Hz/mm^2 @ 77K (7 VoV);
  - SNR > 15 (TPC requirement: 8);
- Need 27 m^2 for both TPC and veto.

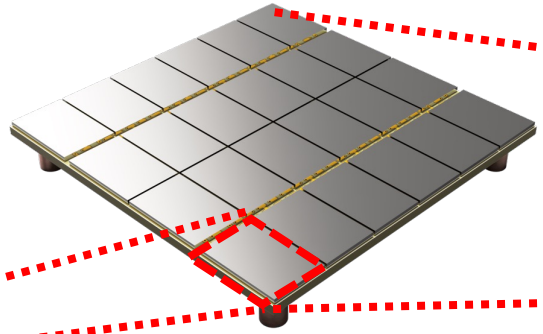
Optical Plane with 1056 channels





Pixels

SiPMs
Each chip: 8 x 12 mm^2



Tile (24 SiPMs)
5 x 5 cm^2

Photo Detection Unit (PDU)
(16 tiles) 20 x 20 cm^2
with 4 readout channels

PDU Production

- SiPM production at LFoundry, Italy. Wafers delivery to LNGS starting in 2022;
- PDU packaging and assembly in Nuova Officina Assergi (NOA) cleanroom at LNGS;
  - LNGS surface lab ～350 m^2, Rn abatement cleanroom.
- Assembly will be tested in a cryogenic test facility in Naples.

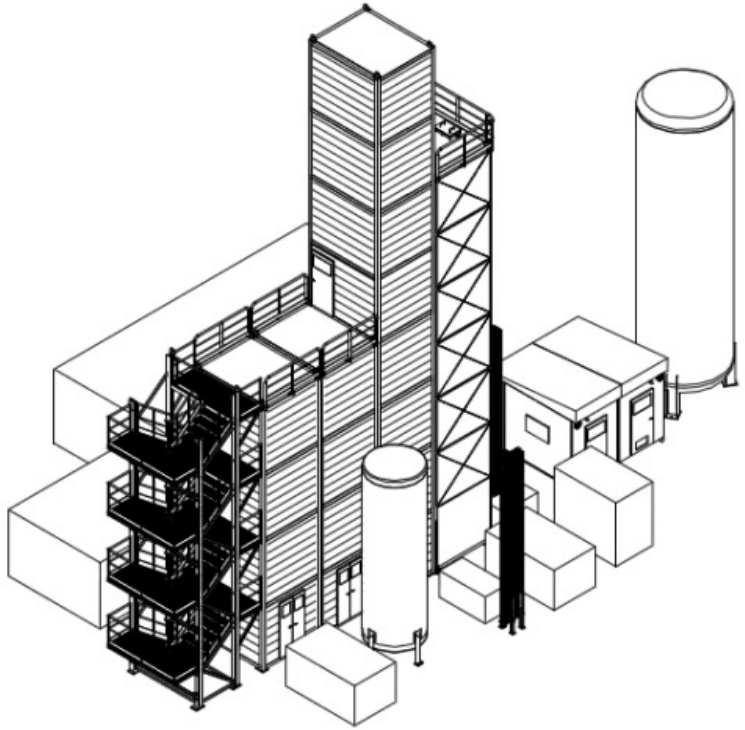
Working area

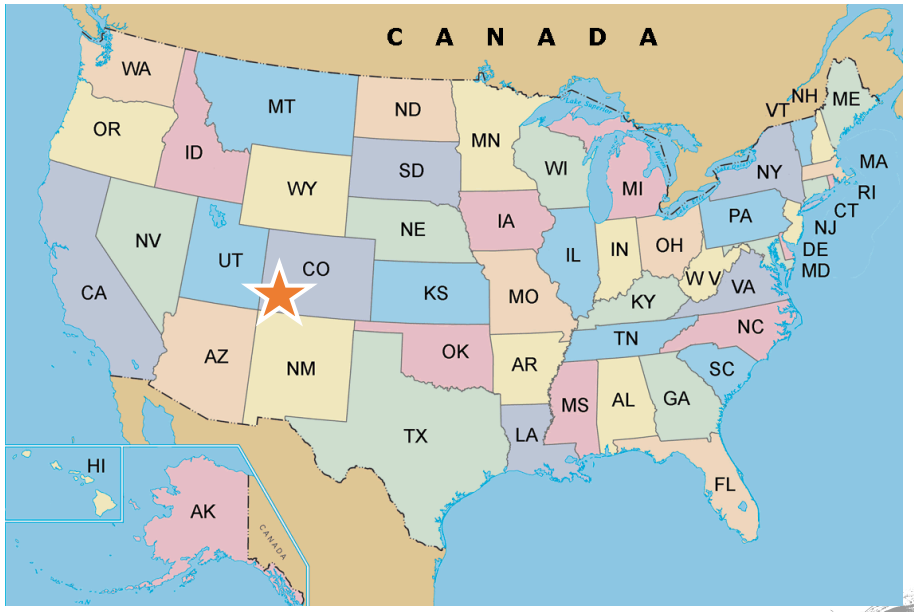
Wafer storage

Flip-chip bonder

UAr Production: Extraction

- URANIA, an industrial scale extraction plant;
- CO_2 well in Cortez, CO, USA;
- Extraction rate: 250~330 kg/day; UAr purity: 99.99%;
- Capable to extract 120 tonnes UAr in 2 years;
- Plant assembly in progress.





UAr Production: Purification

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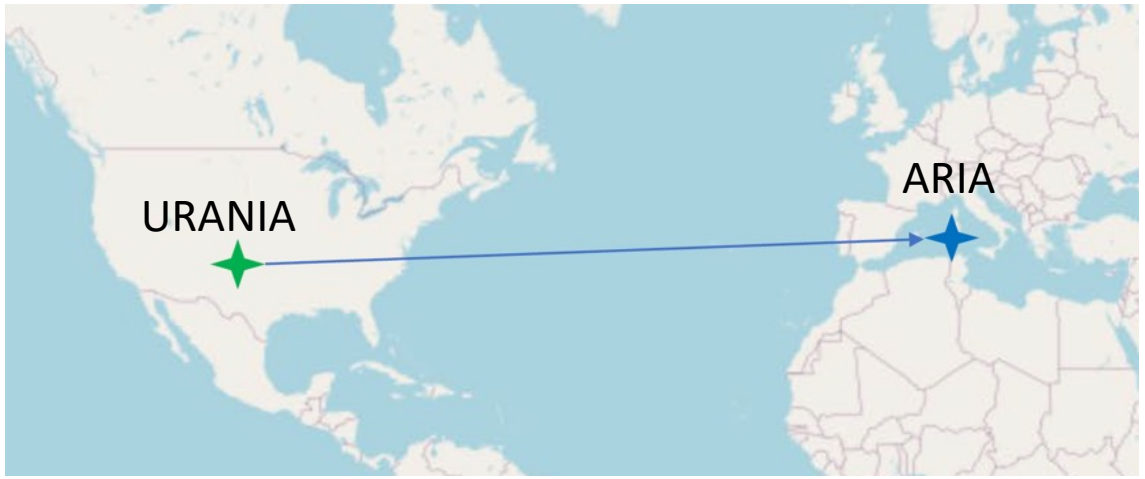
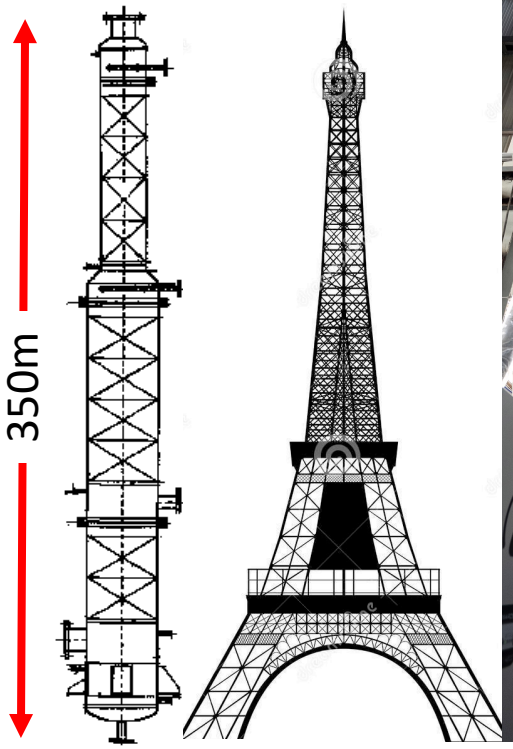
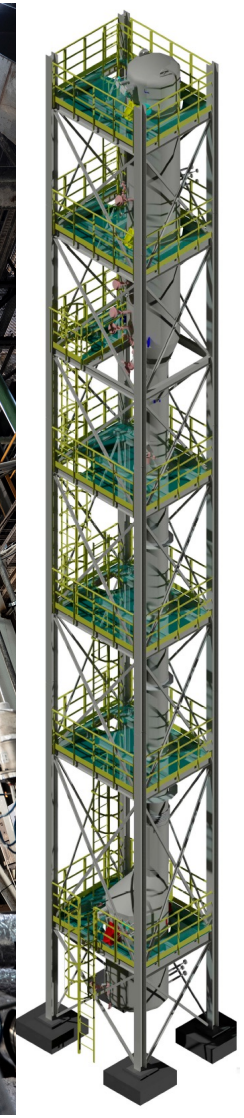
- ARIA, 350 m tall cryogenic distillation column;
- In a coal mine in Sardinia, Italy;
- Chemical purification rate O (1 tonne/day);
- UAr purity after ARIA: 99.999%
- Seruci-0 tested, Seruci-1 under construction;
- Capable to separate ^{39}Ar from ^{40}Ar (low-mass).





Seruci-I & II

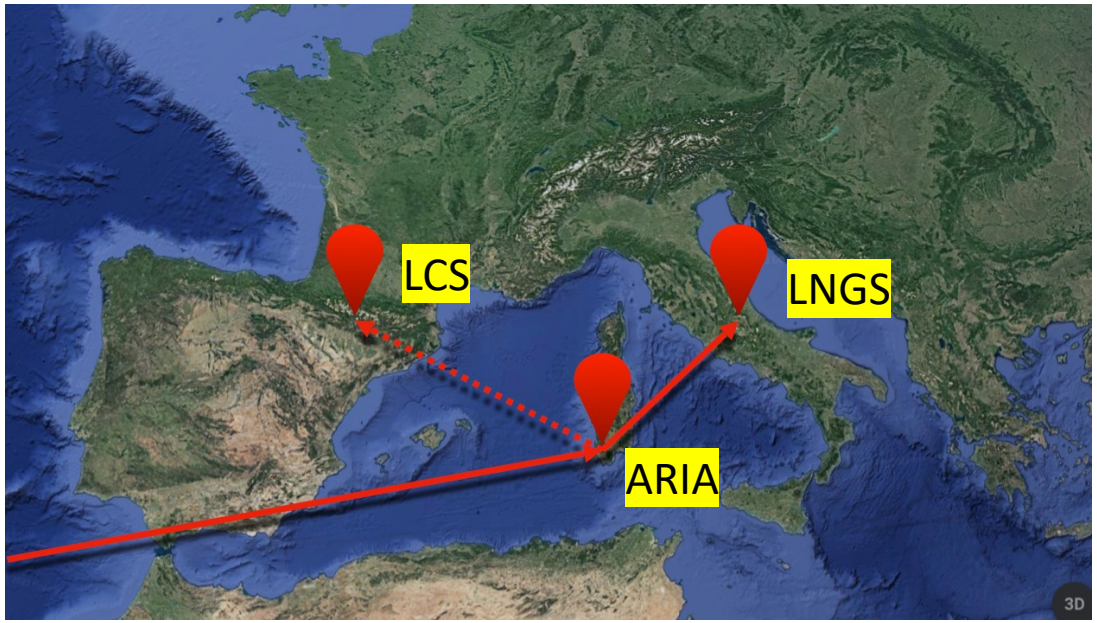


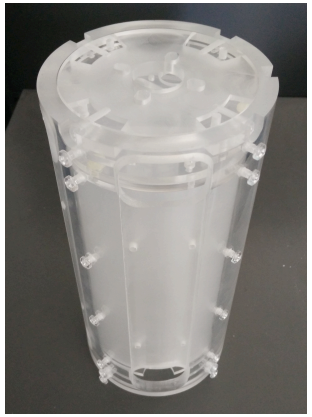
Seruci-0

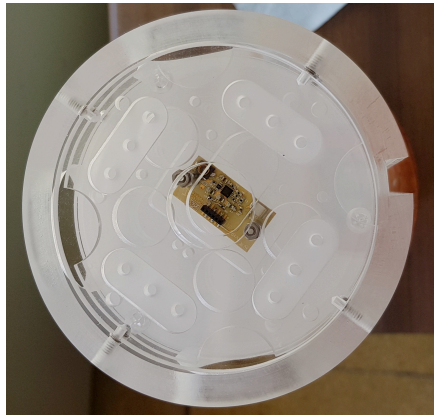
UAr Production: Assaying

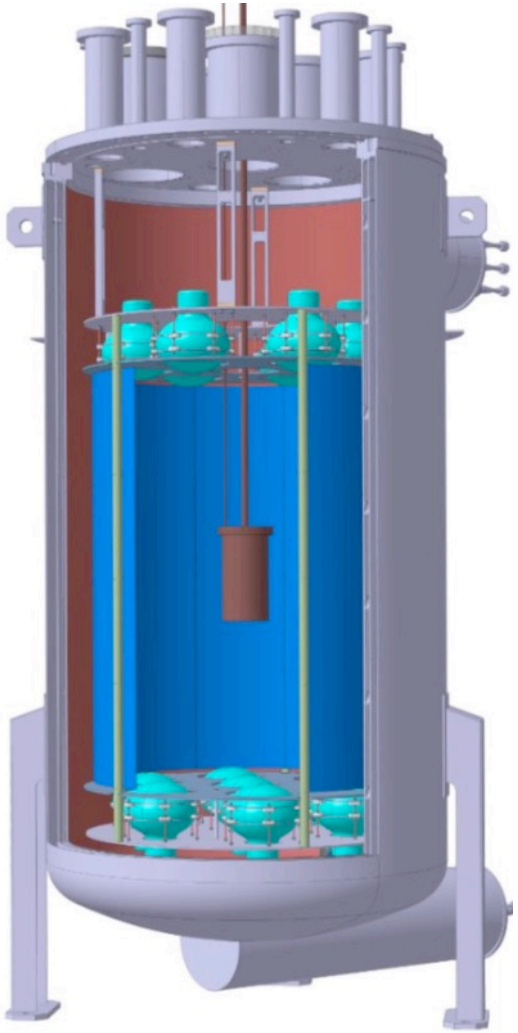
2020 JINST 15 P02024

- DArT at Canfranc Lab, Spain (LCS);
- A single-phase detector to measure ^{39}Ar depletion factor;
- Use ArDM apparatus as an active veto (850 kg AAr).
- Sensitive to measure UAr depletion factors in excess of 1000 with statistical accuracy better than 10% in one week of counting time.





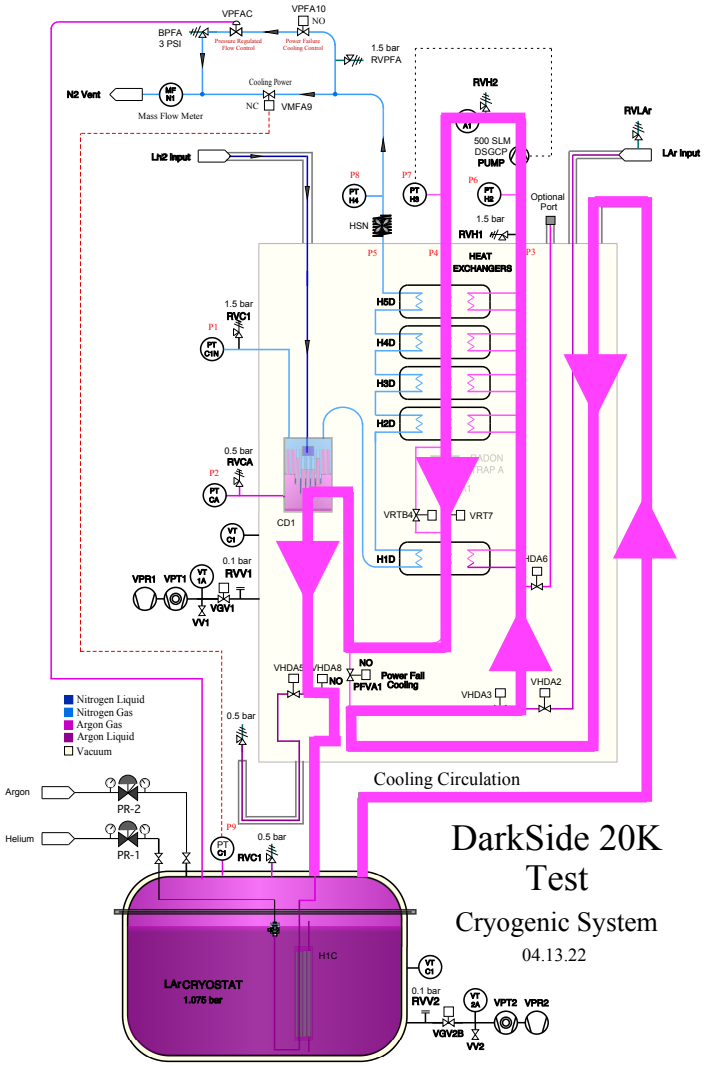


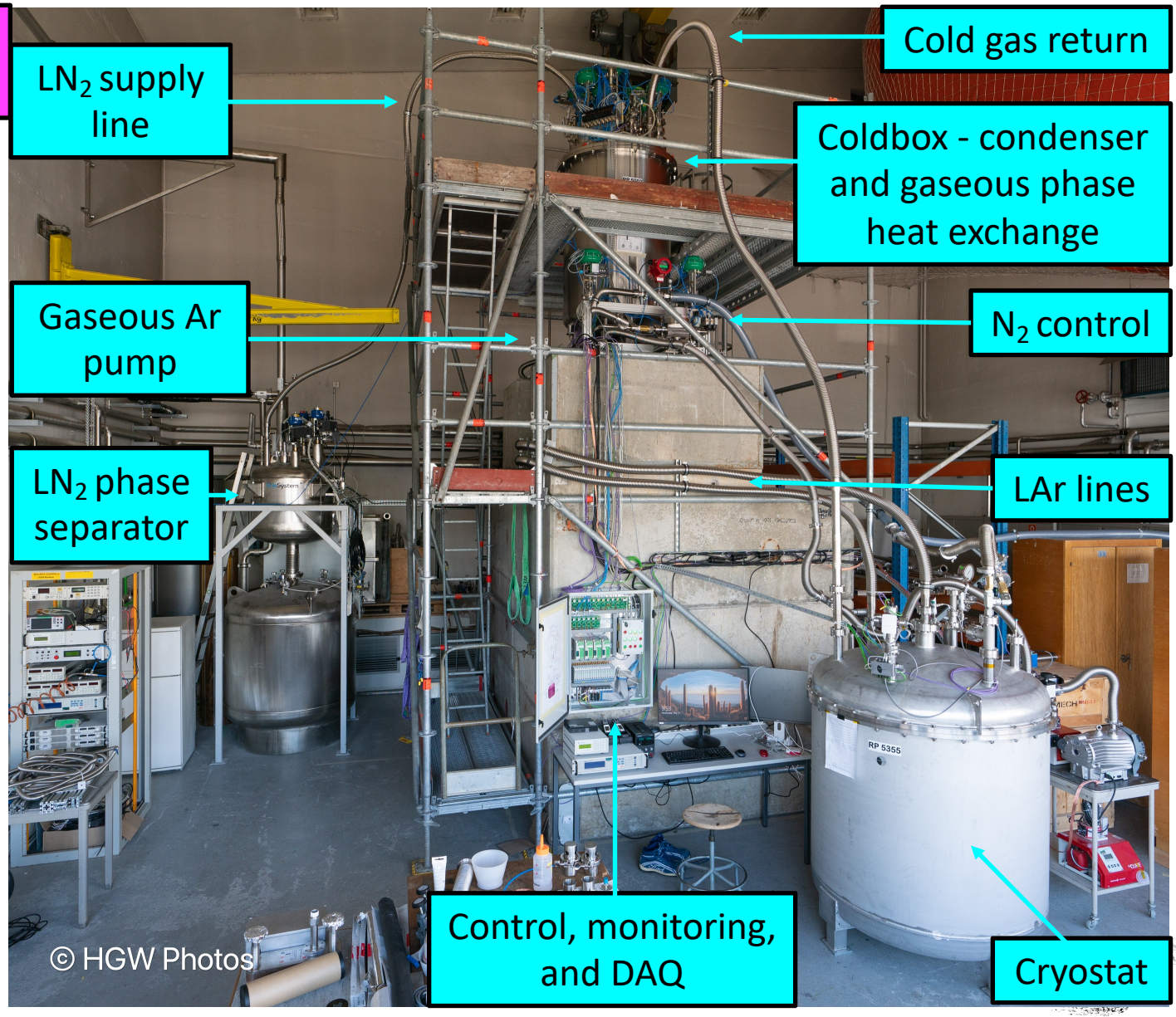


UAr cryogenics (tested at CERN)

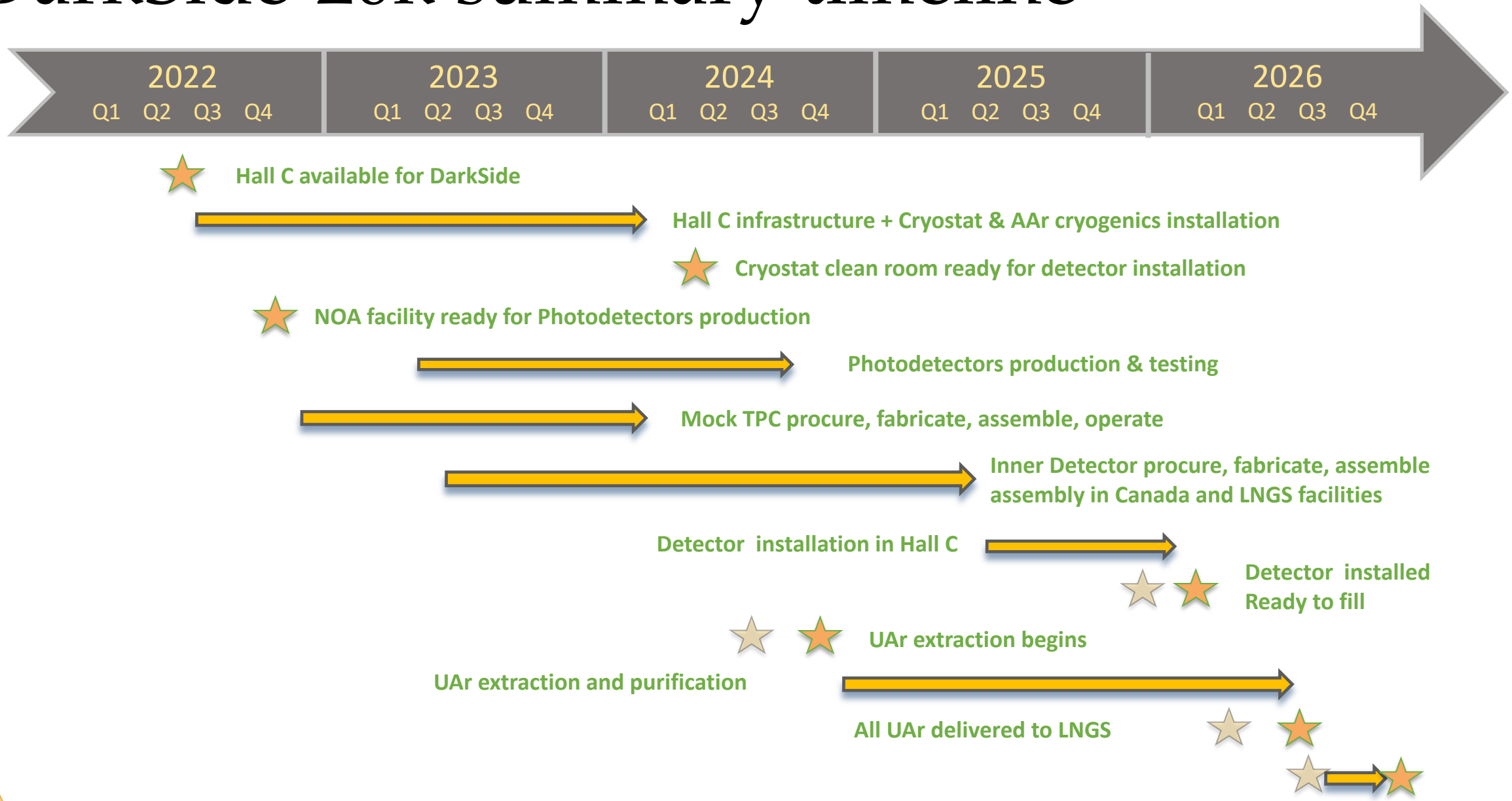
- Core of DS-20k UAr cryogenic system tested
- Performance tests conducted in 2022
- Measured **cooling power recovery efficiency** of >99%
- Verified **detector circulation** in gaseous phase
- Gas pump is developed and fabricated by IHEP.

Closed argon loop with gaseous argon pump highlighted





DarkSide-20k summary timeline

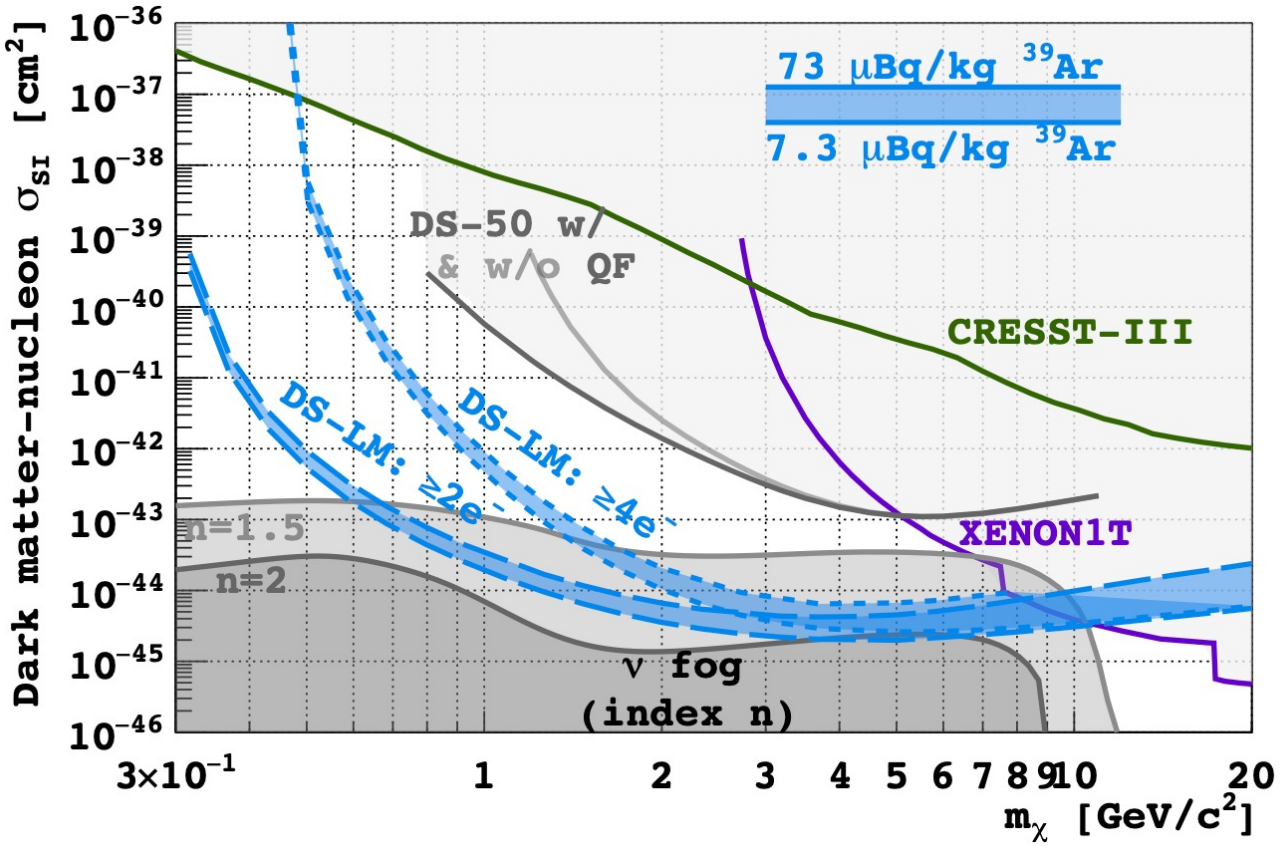


DarkSide-LM

- GADMC旗下独立项目；
- Dual phase Ar TPC optimized for low-mass dark matter searches through ionization channel;
- Dedicate to low energy ER background: ^{85}Kr, ^{39}Ar;
- Sensitivity projection for 1 tonne-year exposure.

- Technical design in progress;
- Host lab candidate: CJPL-II.

arXiv: 2209.01177



Summary

- DarkSide uses dual-phase argon TPC to search for WIMPs;
- Argon from underground sources with reduced ^{39}Ar contamination;
- DarkSide-50 has reached instrumental background-free high-mass results and leading low-mass results
- GADMC established in 2017 (DS-20k, DS-LM, ARGO);
- DarkSide-20k is currently in the construction phase;
- We will start filling the detector with UAr in 2026.