DarkSide-20k and the future Liquid Argon Dark Matter program

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The case for DarkSide-20k

- WIMPs are still excellent candidates for particle dark matter
- WIMP masses: 0.01 - 10 TeV and cross sections: 10^{-40} - 10^{-50} cm^2
- Several 100 ton yr exposures needed for a discovery program

➡ staged program to reach fully scalable detector design and operation at the multi-ton scale

The DarkSide program at LNGS

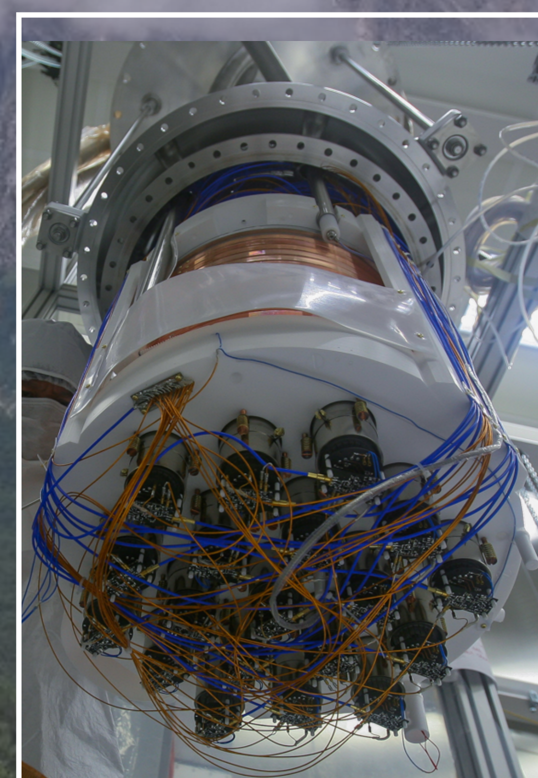
A scalable technology for direct WIMP search:

2-phase low background Argon TPC

DarkSide-10

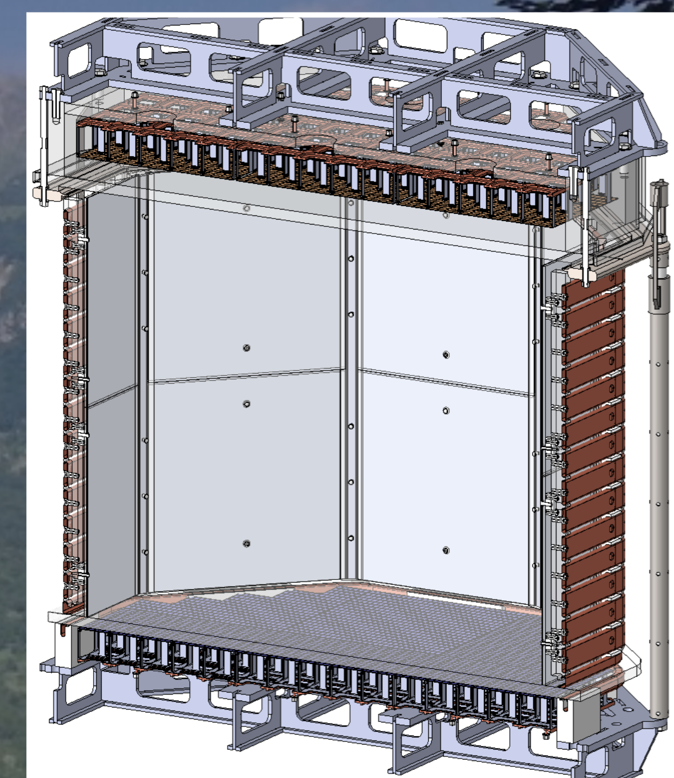
technical prototype
no DM goal

DarkSide-50



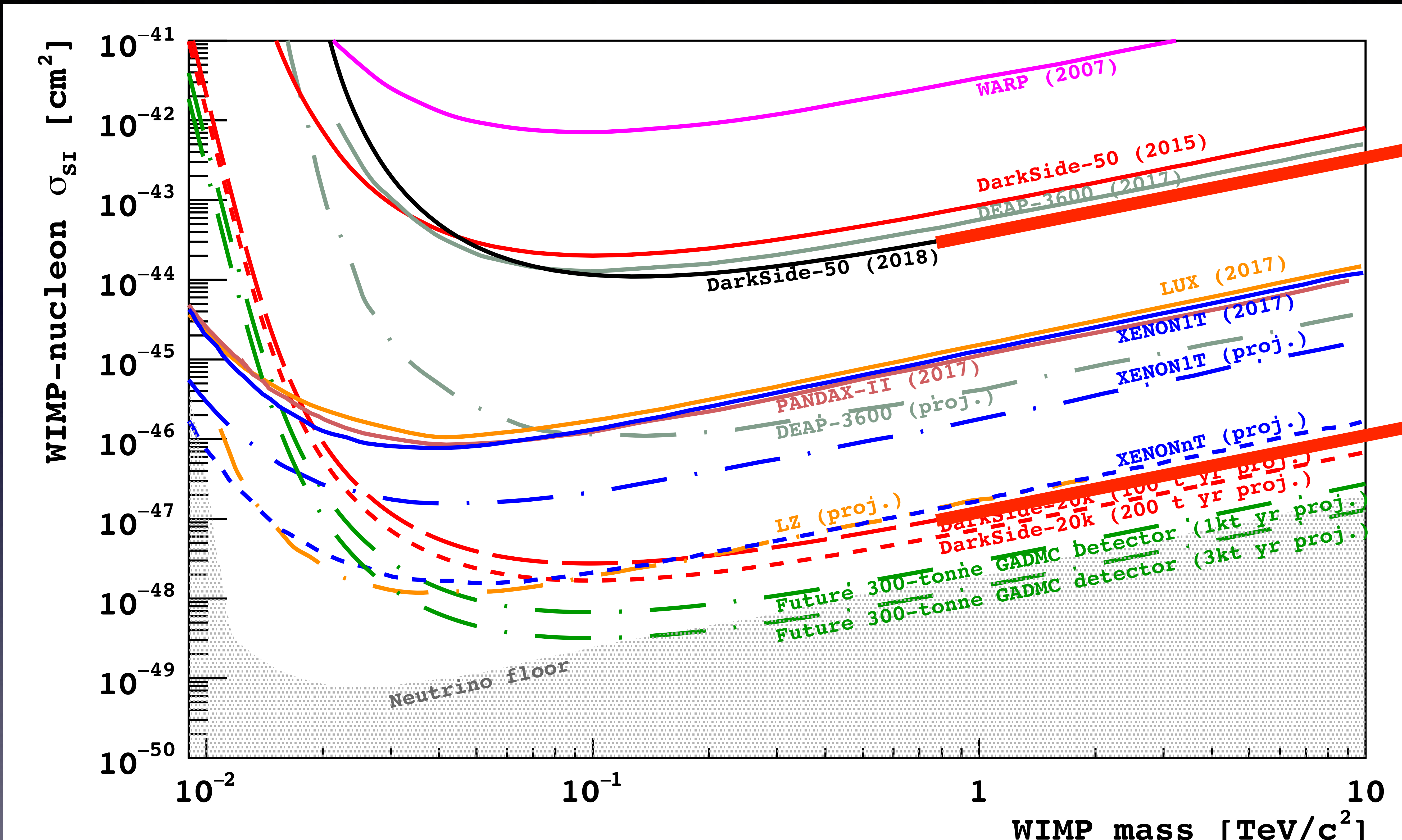
sensitivity
10^{-44} cm^2

DarkSide-20k



sensitivity
10^{-47} cm^2

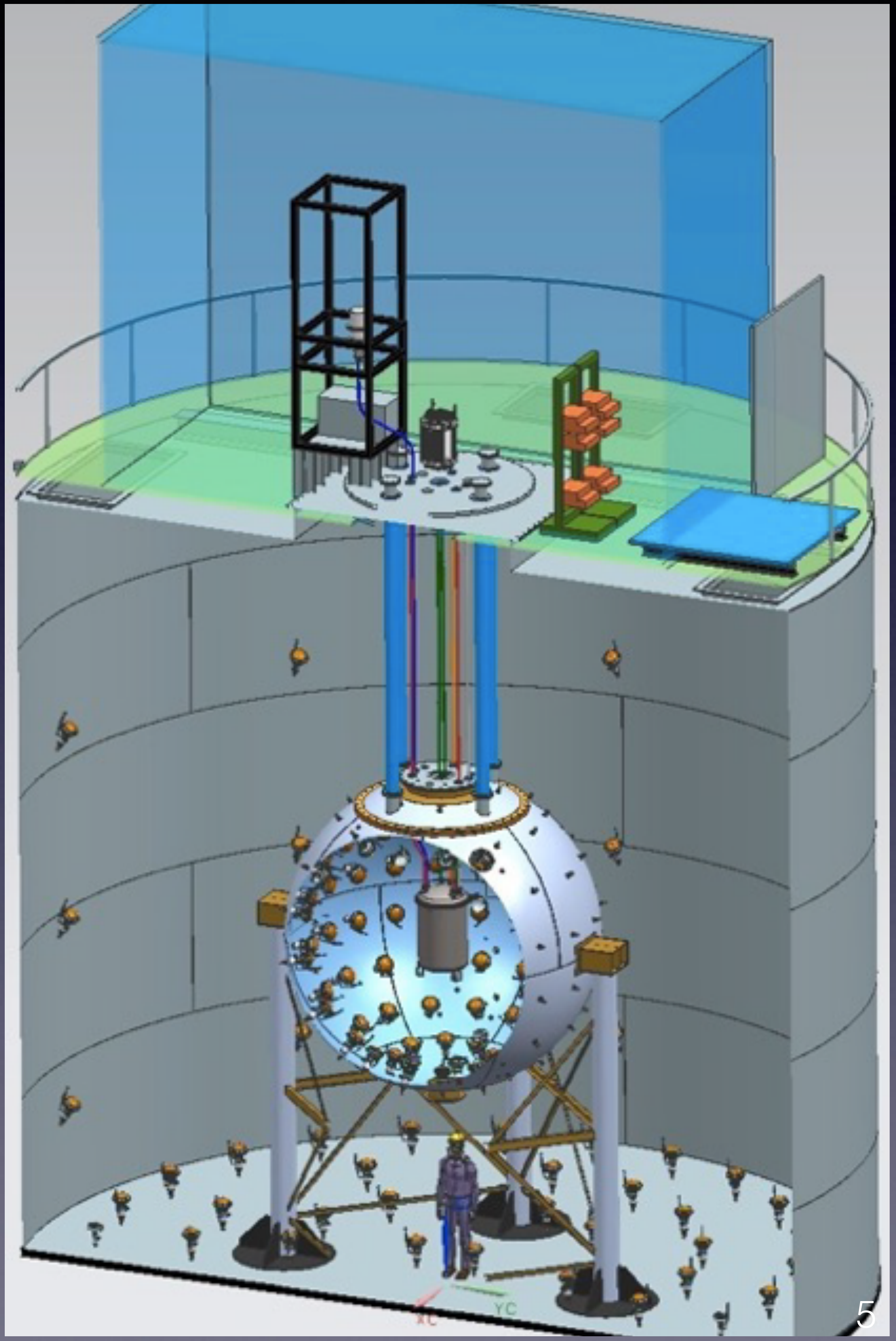
2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022



WARP (2007)
DarkSide-50 (2015)
DEAP-3600 (2017)
DarkSide-50 (2018)
LUX (2017)
XENON1T (2017)
XENON1T (proj.)
PANDAX-II (2017)
DEAP-3600 (proj.)
XENONnT (proj.)
LZ (proj.)
DarkSide-20k (200 t yr proj.)
Future 300-tonne GADMC detector (1kt yr proj.)
Future 300-tonne GADMC detector (3kt yr proj.)
Neutrino floor
WIMP-nucleon σ_{SI} [cm^2]
WIMP mass [TeV/c^2]
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10^{-2}
10^{-1}
1
10

DarkSide design: how to defeat background

- **Identification:**
  - ER/NR discrimination using PSD
  - ER/NR discrimination via S2/S1
  - 3D reconstruction of interactions (rejects γ and surface bkgs)
- **Passive suppression:**
  - Isotopically depleted Argon
  - Low radioactive materials
  - Low radioactive light-detectors
- **Active shielding:**
  - Neutron Veto (Liquid Scintillator)
  - Muon Veto (Water Cherenkov Detector)



DarkSide-50

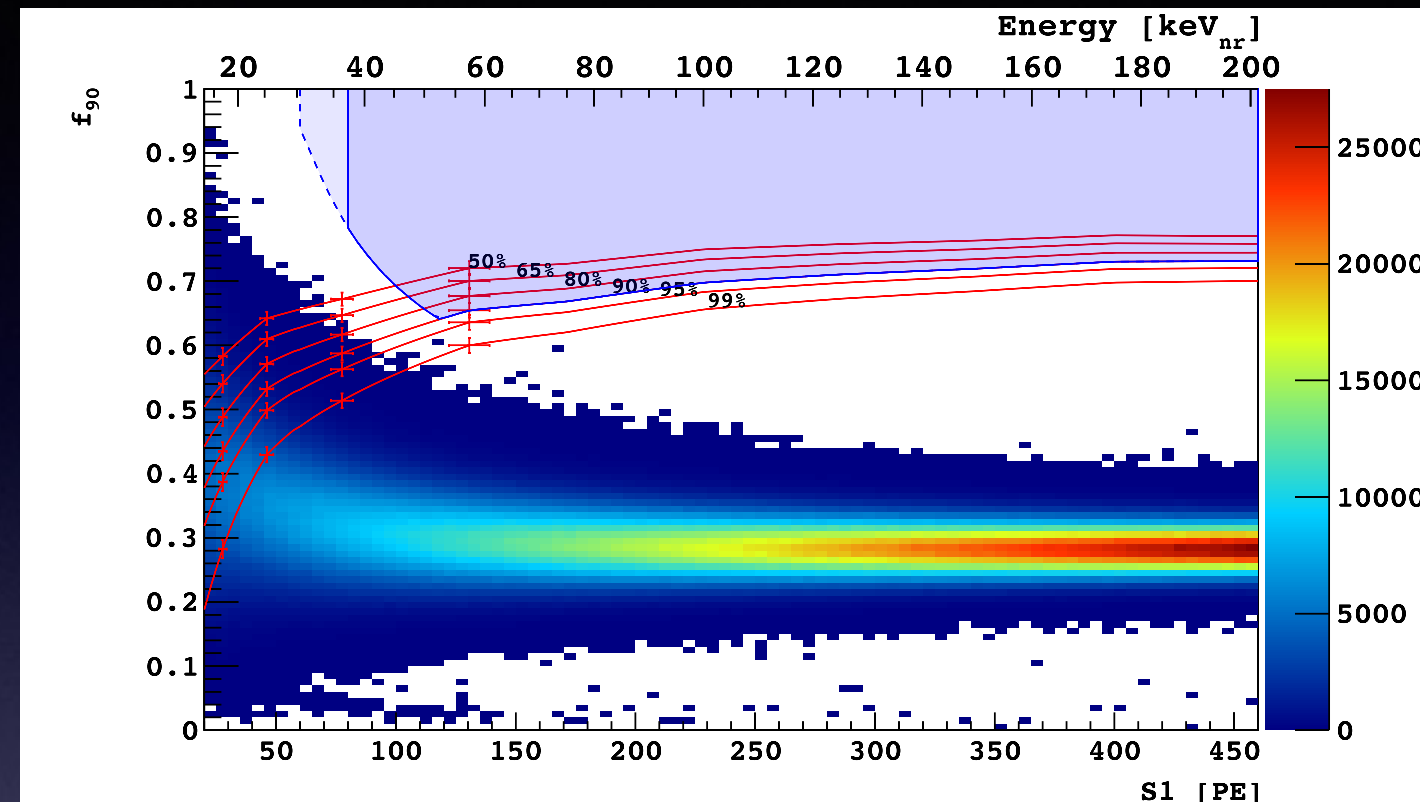
✓ ER/NR Discrimination

- PSD vs S1 for 1422 kg d atmospheric argon (AAr) exposure
- 1.5×10^7 ER events from ^{39}Ar activity in AAr and Zero NR events

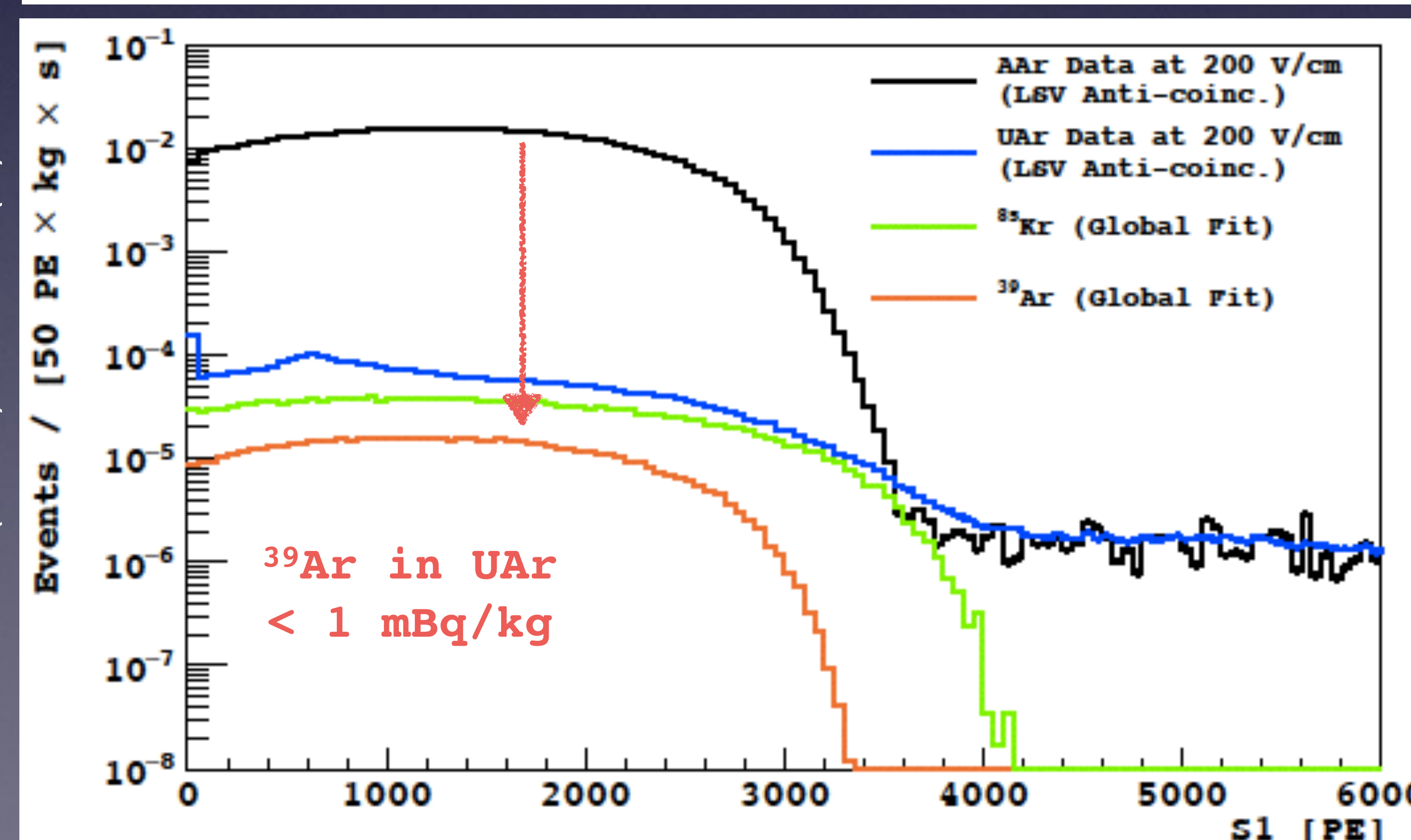
✓ Suppression: AAr Vs UAr

- Underground argon (UAr): 150 kg successfully extracted from a CO_2 well in Colorado
- ^{39}Ar depletion factor >1400

PLB 743, 456 (2015)



PRD, 93 (2016): 081101(R)



see talk by P. Meyers

Scaling up towards the neutrino floor: next stage world Argon program

LAr high discrimination power + depleted argon allow for the several hundreds ton yr background-free exposures needed to reach the neutrino floor

DS50-1: discrimination 1.5 10^7 at LY=7 PE/keV at 200 V/cm [PLB 743, 456 (2015)]
DEAP-1: predict discrimination 10^{10} at LY=8 PE/keV [Astropart. Phys. 85, 1 (2016)]

see talk by S. Westerdale

- DarkSide
- DEAP-3600
- miniCLEAN
- ArDM

} DarkSide-20k ⇢ multi 100 ton

> 350 researchers from ~ 80 Institutes

➠ Global Argon Dark Matter Collaboration (GADMC)

DarkSide future program

DarkSide-20k
a 20-tonnes fiducial argon detector
100 tonne×year background-free search for dark matter

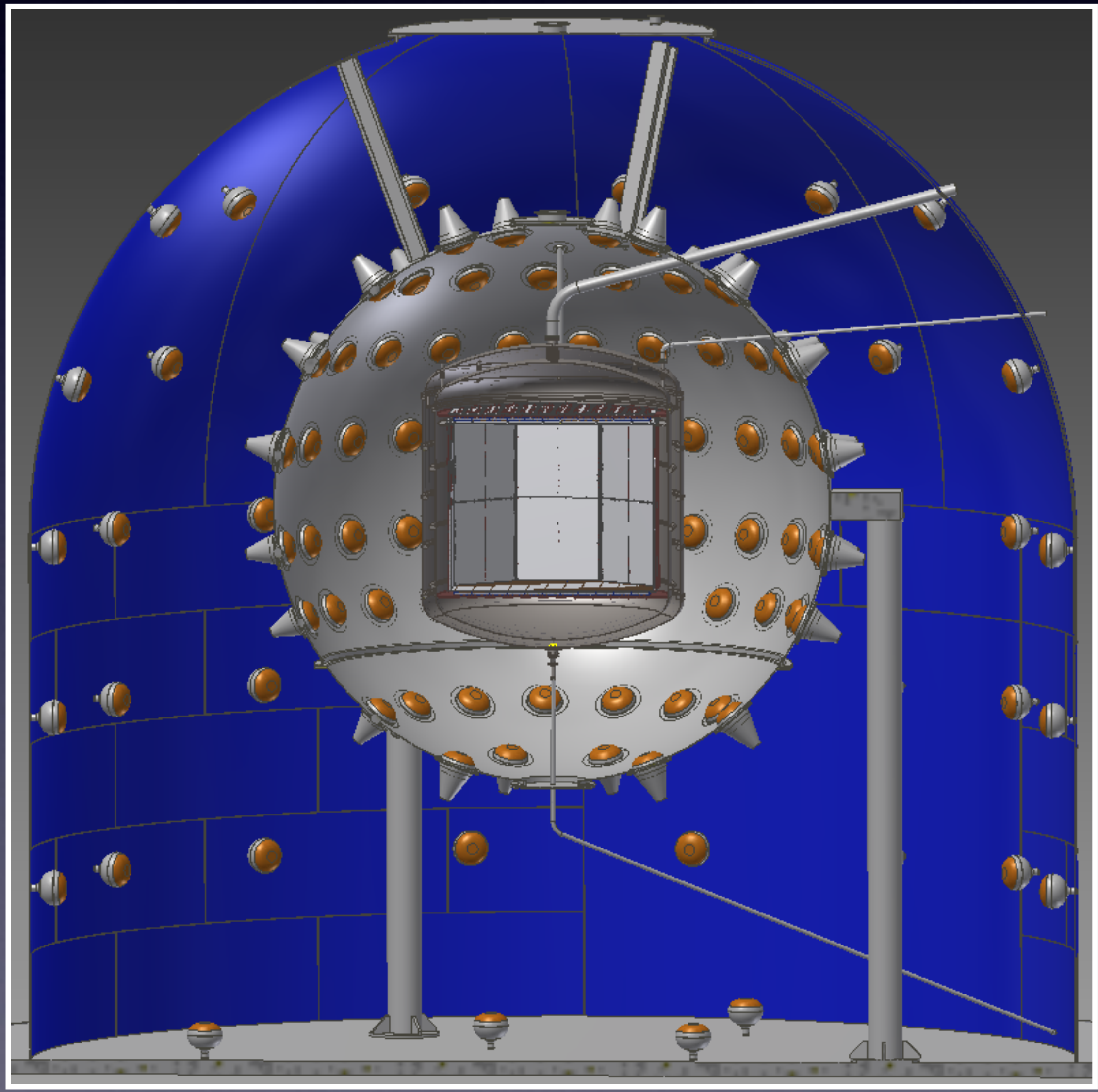
GADMC detector
a 300-tonnes depleted argon detector
1,000 tonne×year background-free search for dark matter

DarkSide-20k

Conceptual approach: ultra-low background levels and the ability to measure backgrounds in situ

Baseline design:

- 30 ton total, 20 ton fiducial, underground argon
- 14m^2 SiPM sensors (low radioactivity, increased LY)
- inside high efficiency neutron shield/veto



arXiv:1707.08145

100 ton yr background-free exposure

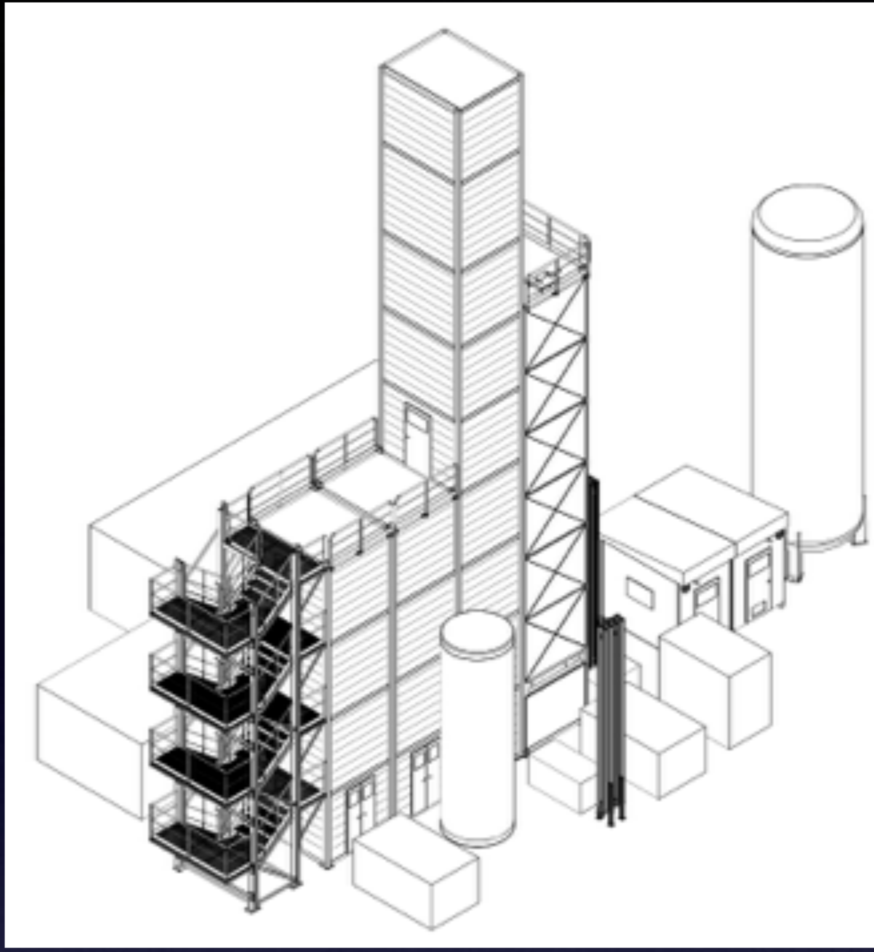
Two key technologies

enabling DarkSide-20k and future LAr program

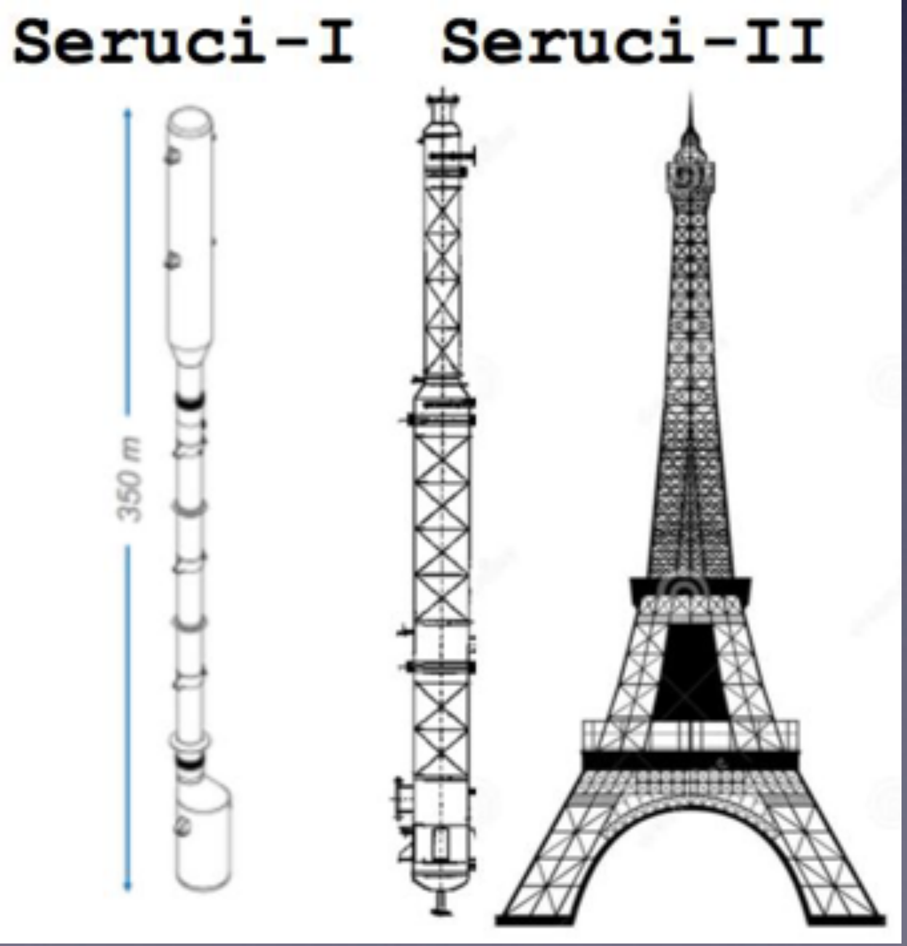
- Cryogenic SiPMs
    - **DarkSide-20k @ Abruzzo** large area, cryogenic silicon photomultiplier optical modules assembly and test facility (**Nuova Officina Assergi - NOA**)
- Liquid argon target depleted in the radioactive ^{39}Ar
    - **URANIA** extraction of large quantities of underground argon
    - **ARIA** Isotopic separation via cryogenic distillation

URANIA

- Procurement of 50 tonnes of UAr from same Colorado source as for DS-50
- Extraction of 100 kg/day, with 99.9% purity
- UAr transported to Sardinia for final chemical purification at Aria



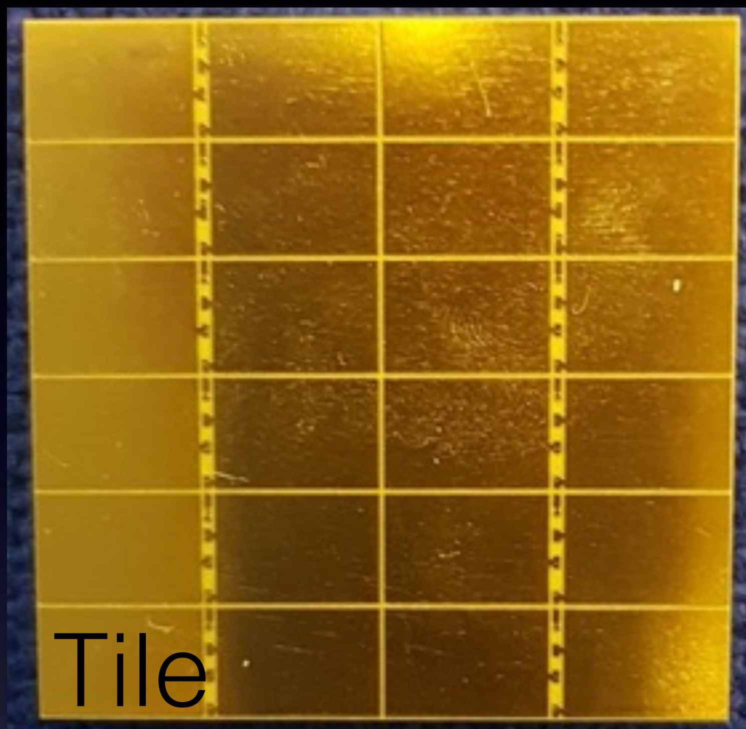
ARIA

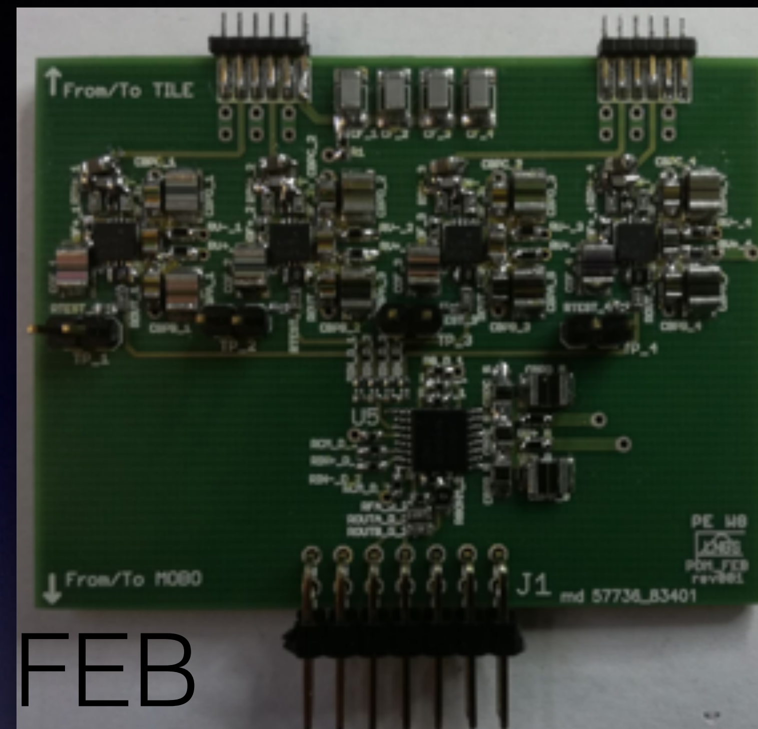


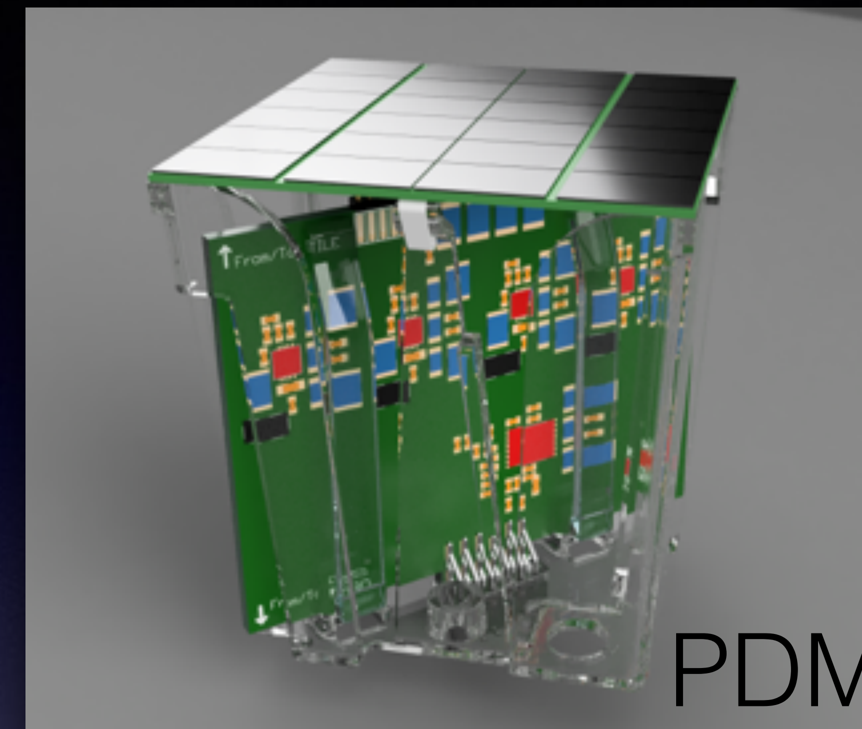
- Big cryogenic distillation column in Seruci, Sardinia
- Final chemical purification of the UAr
- Can process O(1 tonne/day) with 10^3 reduction of all chemical impurities
- Ultimate goal is to isotopically separate ^{39}Ar from ^{40}Ar

see talk by A. Renshaw

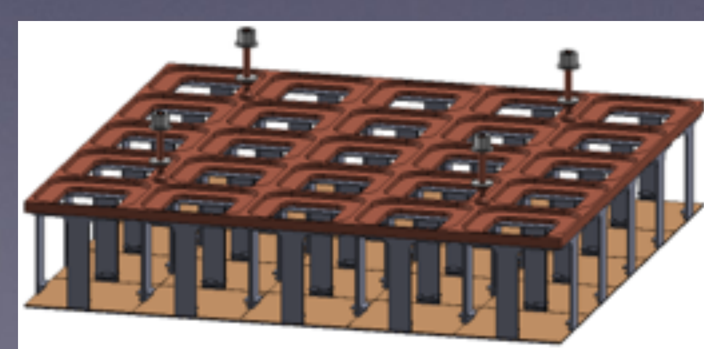
Nuova Officina Assergi







- SiPM cryotest
- Tile & FEB packaging
- Photon Detector Modules and Motherboards (25 PDM) assembly



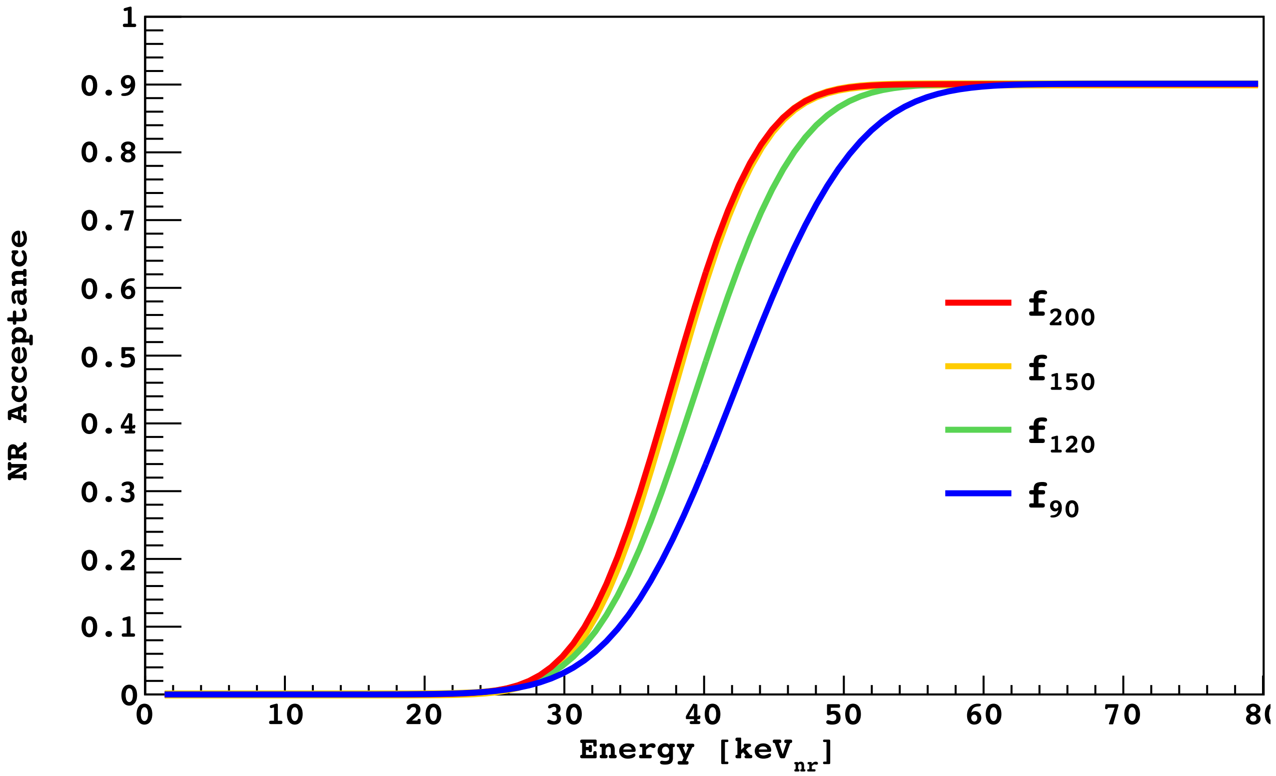
see talk by A. Razeto

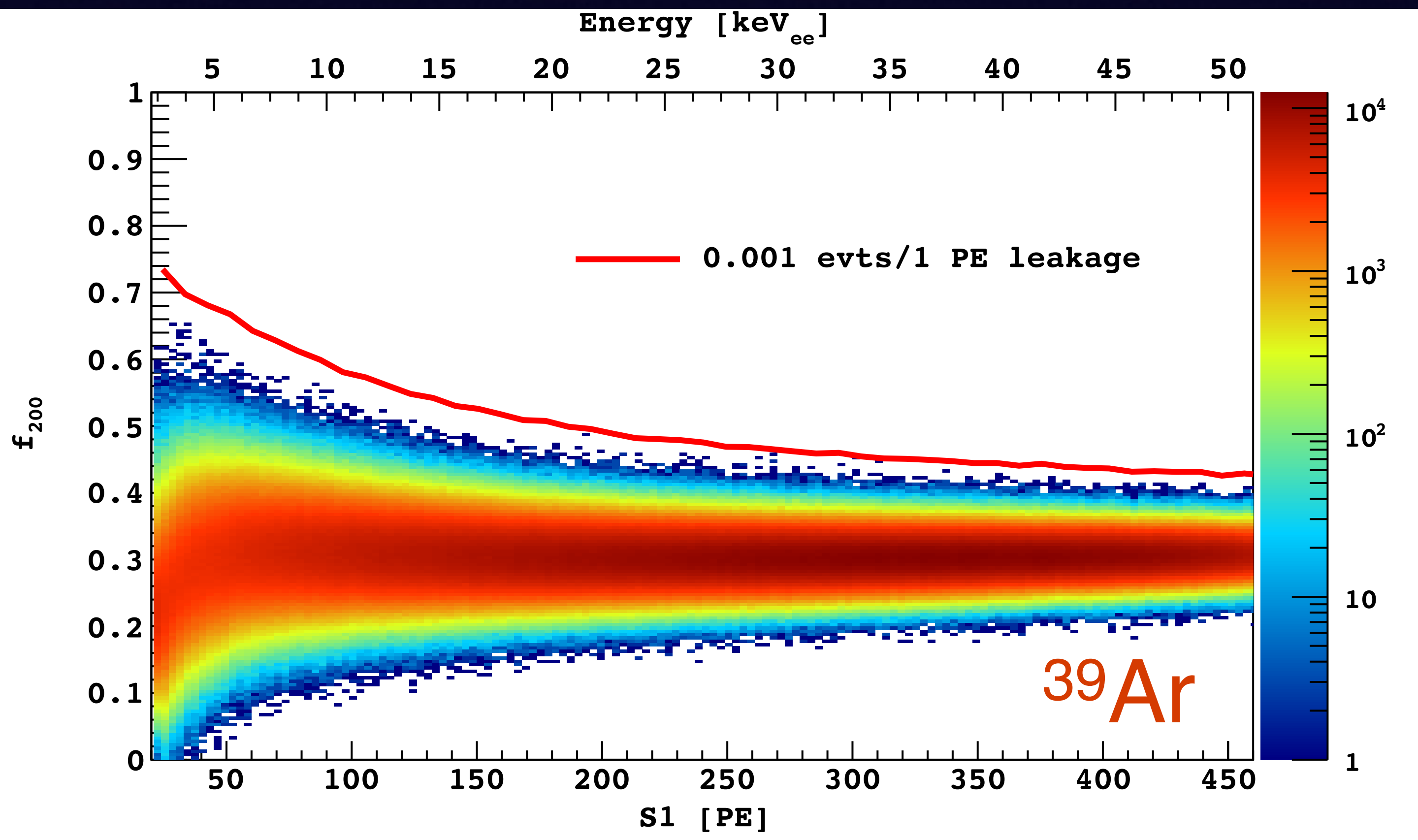
DarkSide-20k PSD

projected LY: 10PE/keV

f_{200}: fraction of S1 light in 200ns

arXiv:1707.08145





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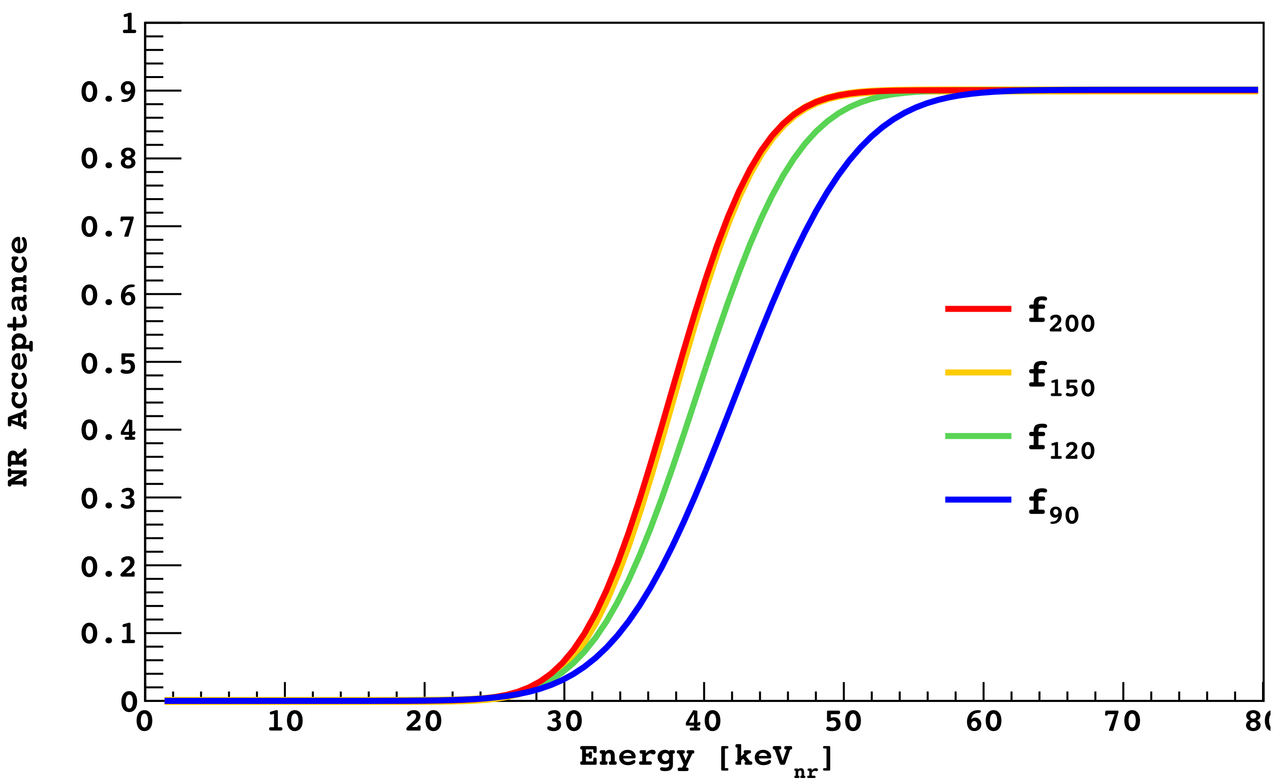
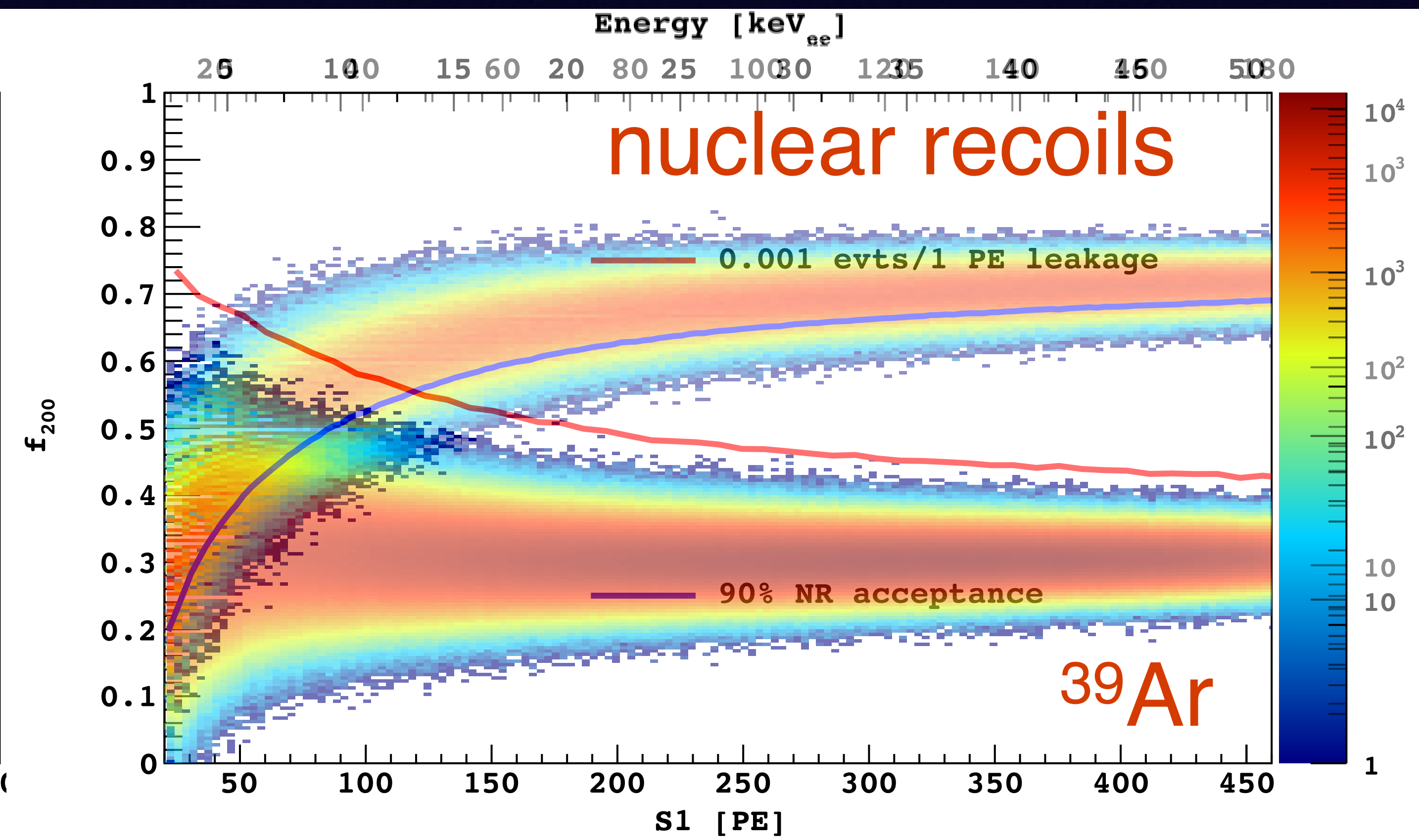




- NR acceptance region defined by requiring < 0.005 ER events/(5-PE bin) (< 0.1 events in the WIMP search region),
- The resulting equivalent ER reduction factor is > 3 $\times 10^9$, more than sufficient to maintain background-free operation for more than 200 t yr.

DarkSide-20k backgrounds

arXiv:1707.08145

Background	Events in ROI $[100\,\mathrm{t\,yr}]^{-1}$	Background $[100\,\mathrm{t\,yr}]^{-1}$
Internal β/γ's	1.8×10^8	0.06
Internal NRs	negligible	negligible
e^--ν_{pp} scatters	2.0×10^4	negligible
External β/γ's	10^7	<0.05
External NRs	<81	<0.15
Cosmogenic β/γ's	3×10^5	$\ll$0.01
Cosmogenic NRs	–	<0.1
ν-Induced NR	1.6	–

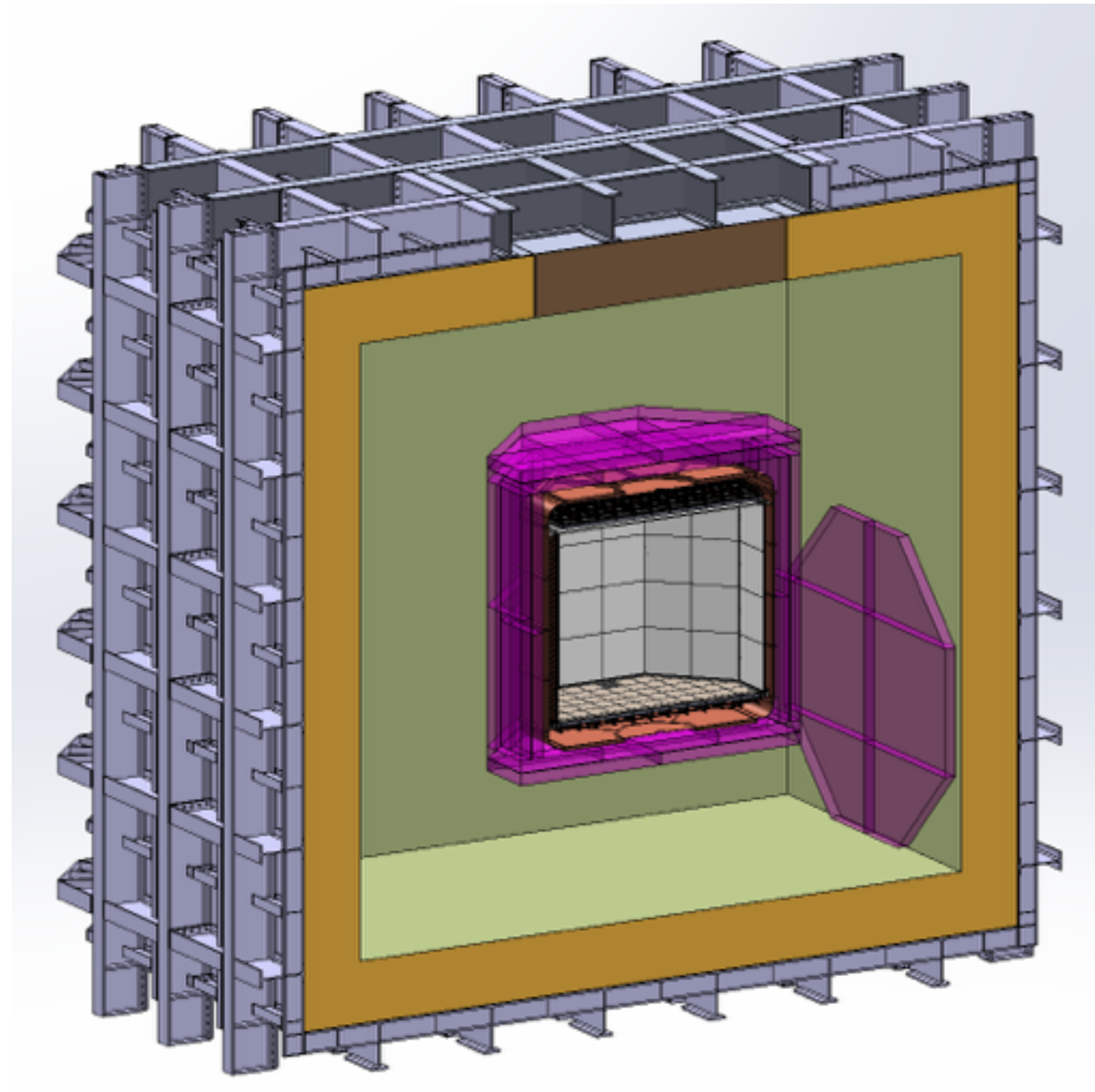
- TPC inside a SS cryostat, inside a liquid scintillator active neutron veto, inside a 15m diameter 16m tall water tank, as active muon veto
  - ➡ assuming the same level of radioactivity as in DS50, ER background dominated by ^{39}Ar
  - ➡ (α ,n) reactions in PTFE reflector and cryostat largest sources of neutrons

A LAr shield for DarkSide-20k

- AAr in ProtoDune style large cryostat to provide shielding and active VETO
- allows to eliminate Liquid Scintillator Veto and Water tank

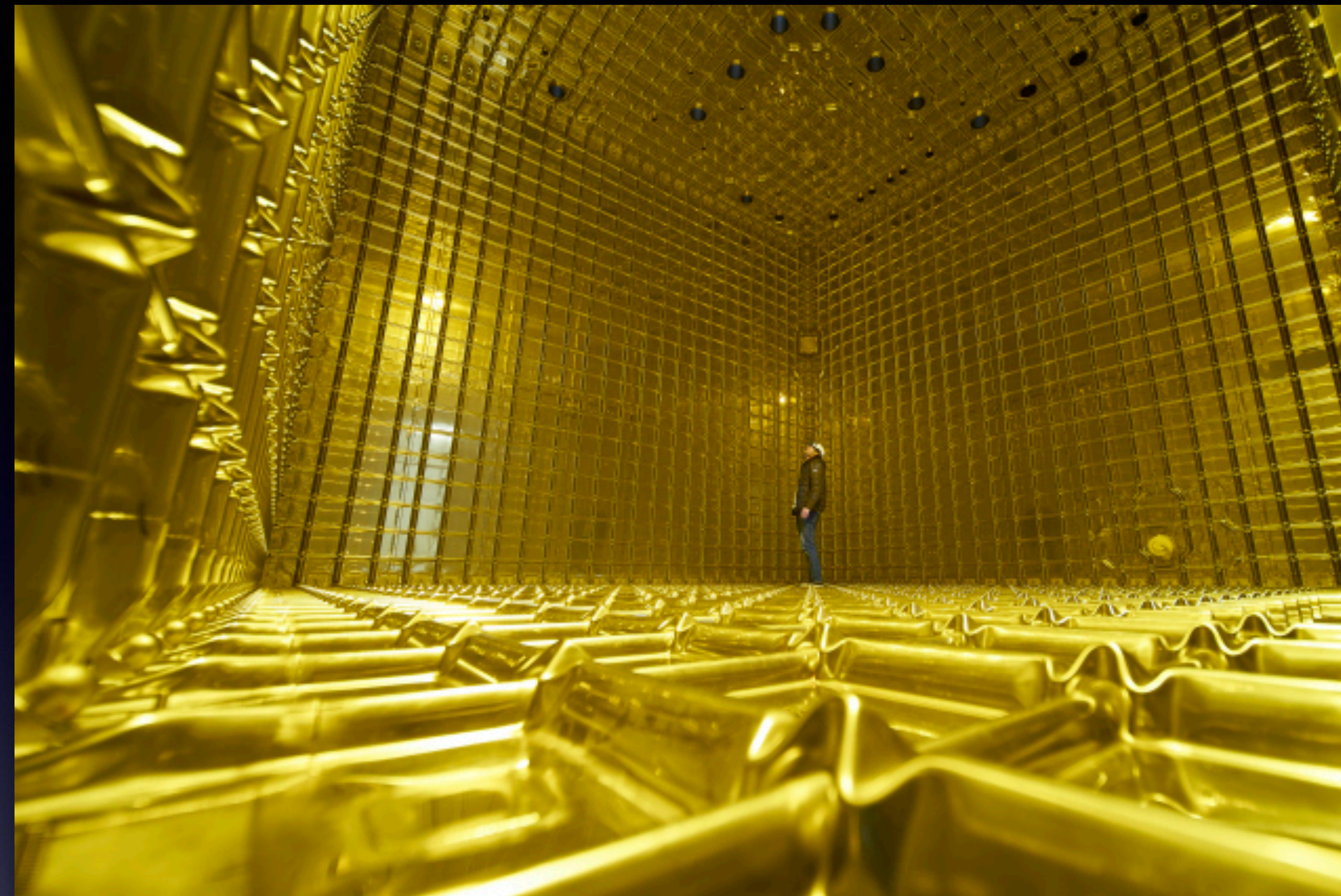
➡ Significantly simplify the overall system complexity and operation

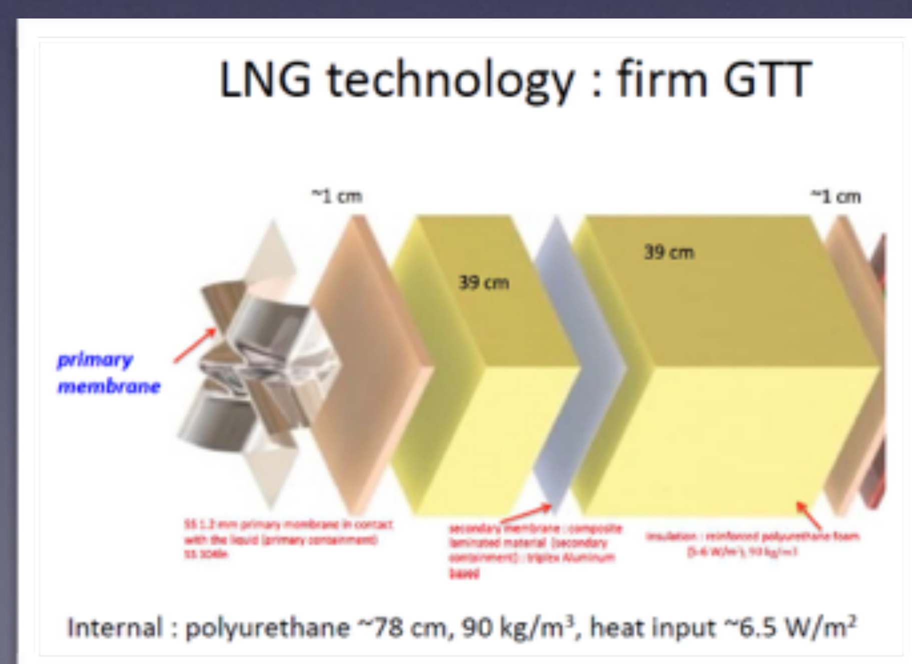
➡ Fully scalable design for future larger size detector (300 ton)

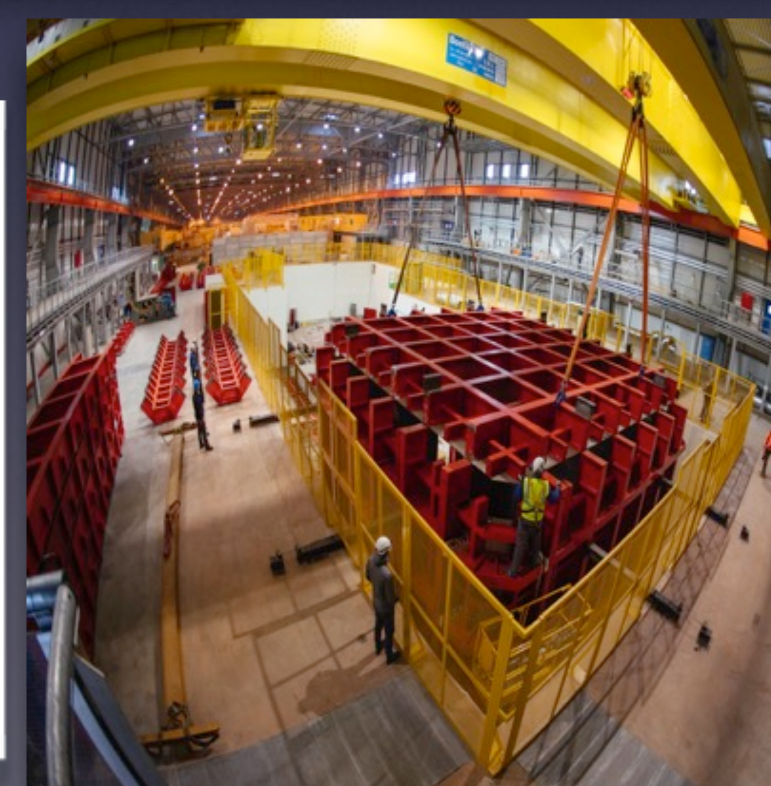


CERN Neutrino Platform:

- Two almost identical cryostats built for NP02 and NP04 experiments
- About 8x8x8 m^3 inner volume, 750 t of LAr in each one
- Cryostat technology and expertise taken from LNG industry
- Construction time: 55 weeks (NP04), 37 weeks (NP02)
- Thought since the beginning to be installable underground



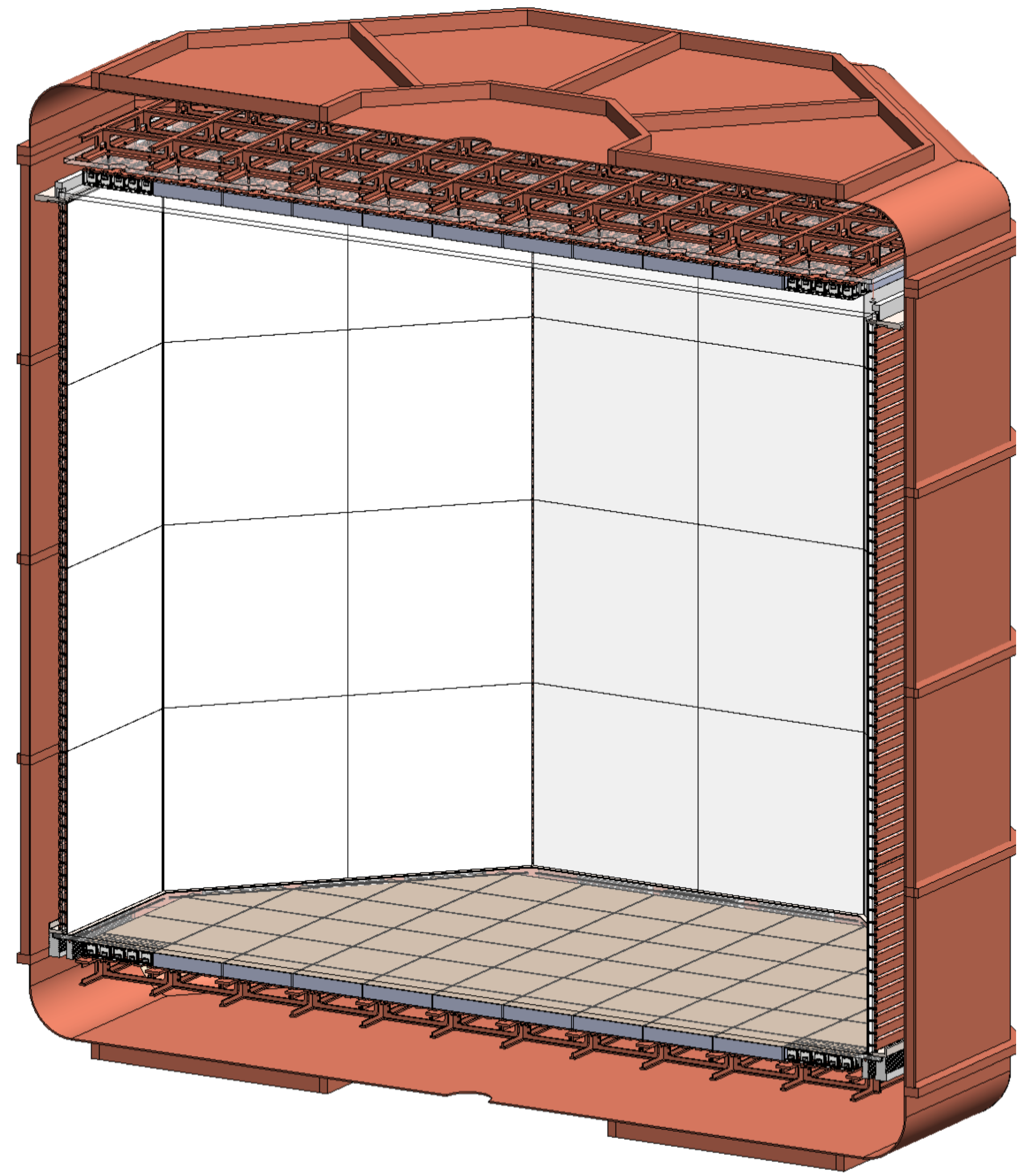




DarkSide-20k inner detector

- AAr shield provides the opportunity to remove the largest contribution to neutron background, the SS cryostat:
  - CU vessel with the shape of the TPC (octagonal prism) providing also a possible path to increase the active Argon size
- TPC reflector realised from a sandwich of acrylic+3M foil removes the second big contributor to neutron background (PTFE)

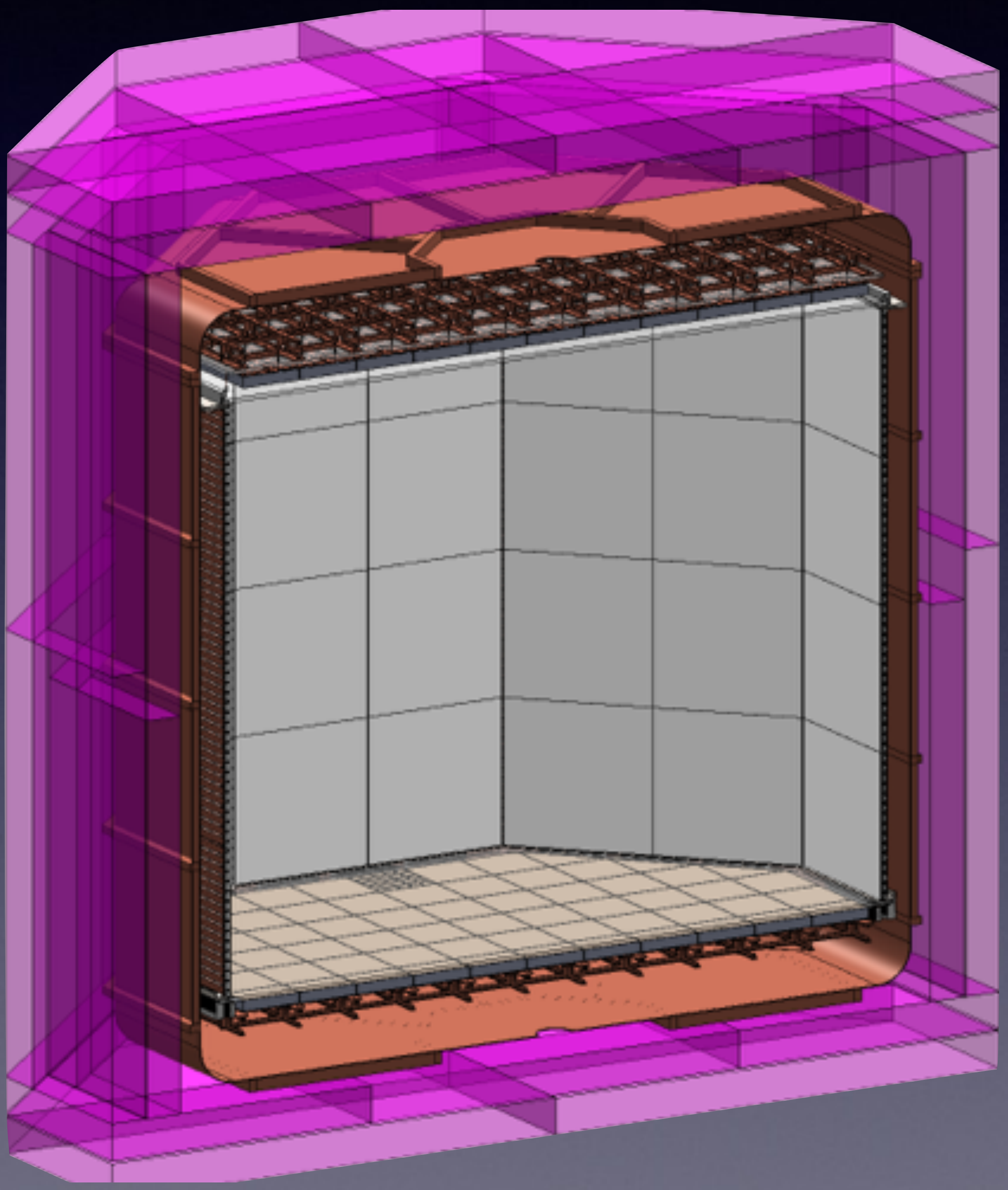
➡ Residual neutron background from sub-leading contribution from substrates, electronic components, optical fibers, copper parts and acrylic



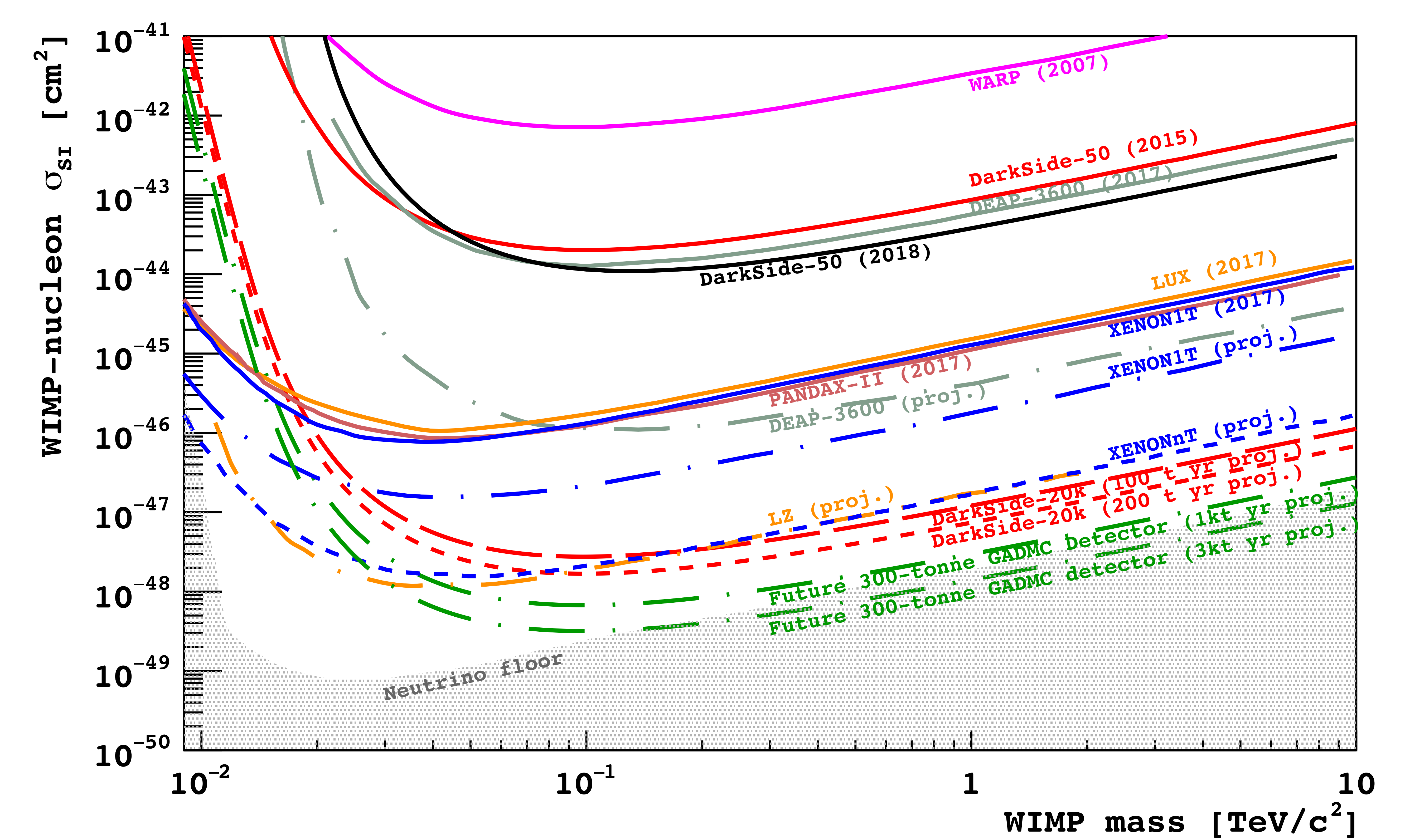
DarkSide-20k nVeto conceptual design

- Several options are being considered for a cryogenic veto inside the LAr shield:
  - hydrogenated materials for efficient thermalisation
  - possible addition of further material with high capture cross section

➡ no showstoppers for meeting the goal of 0.1 neturon/100 t yr identified so far, considering also the reduced neutron background of the new design



DarkSide-20k sensitivity

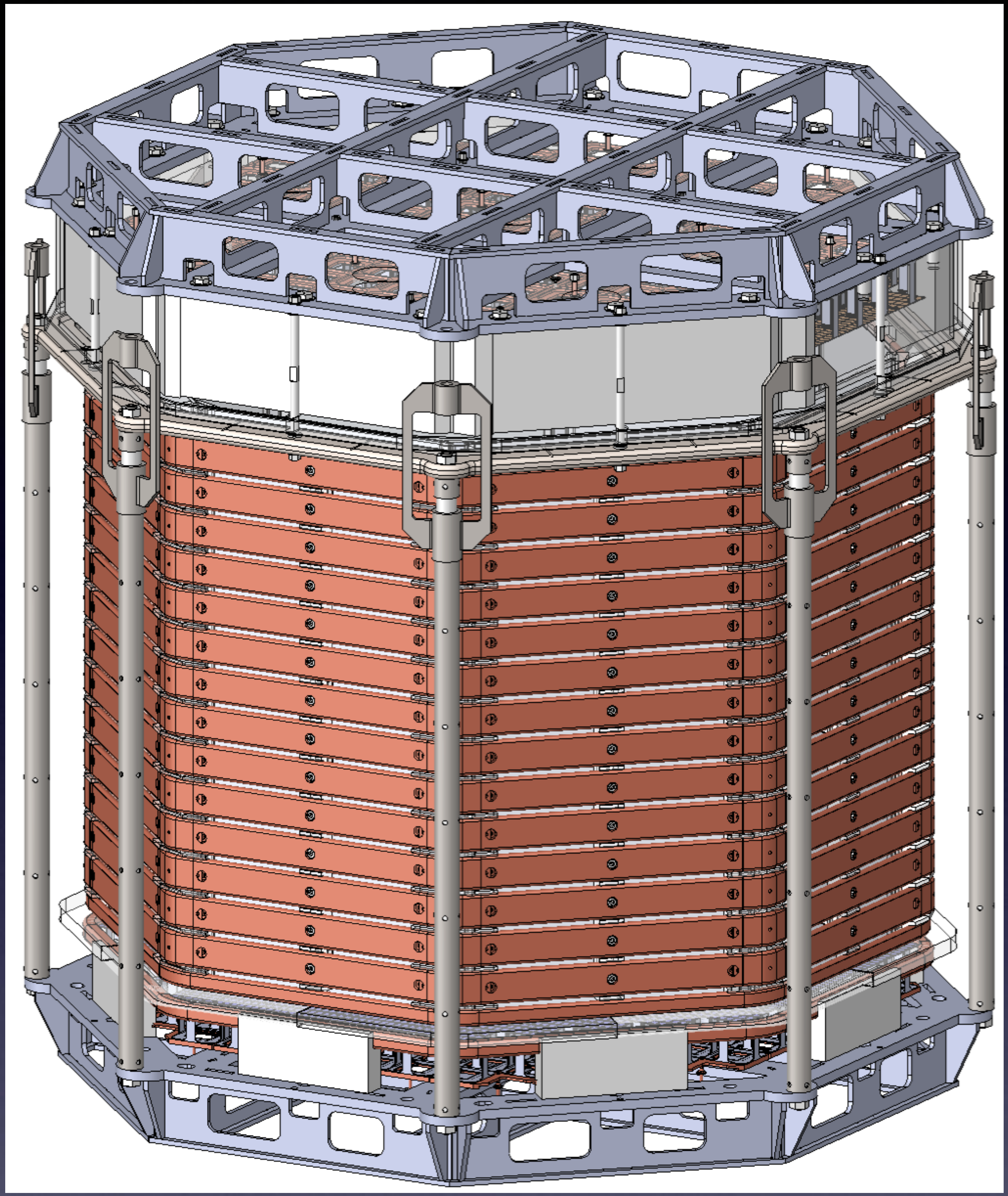


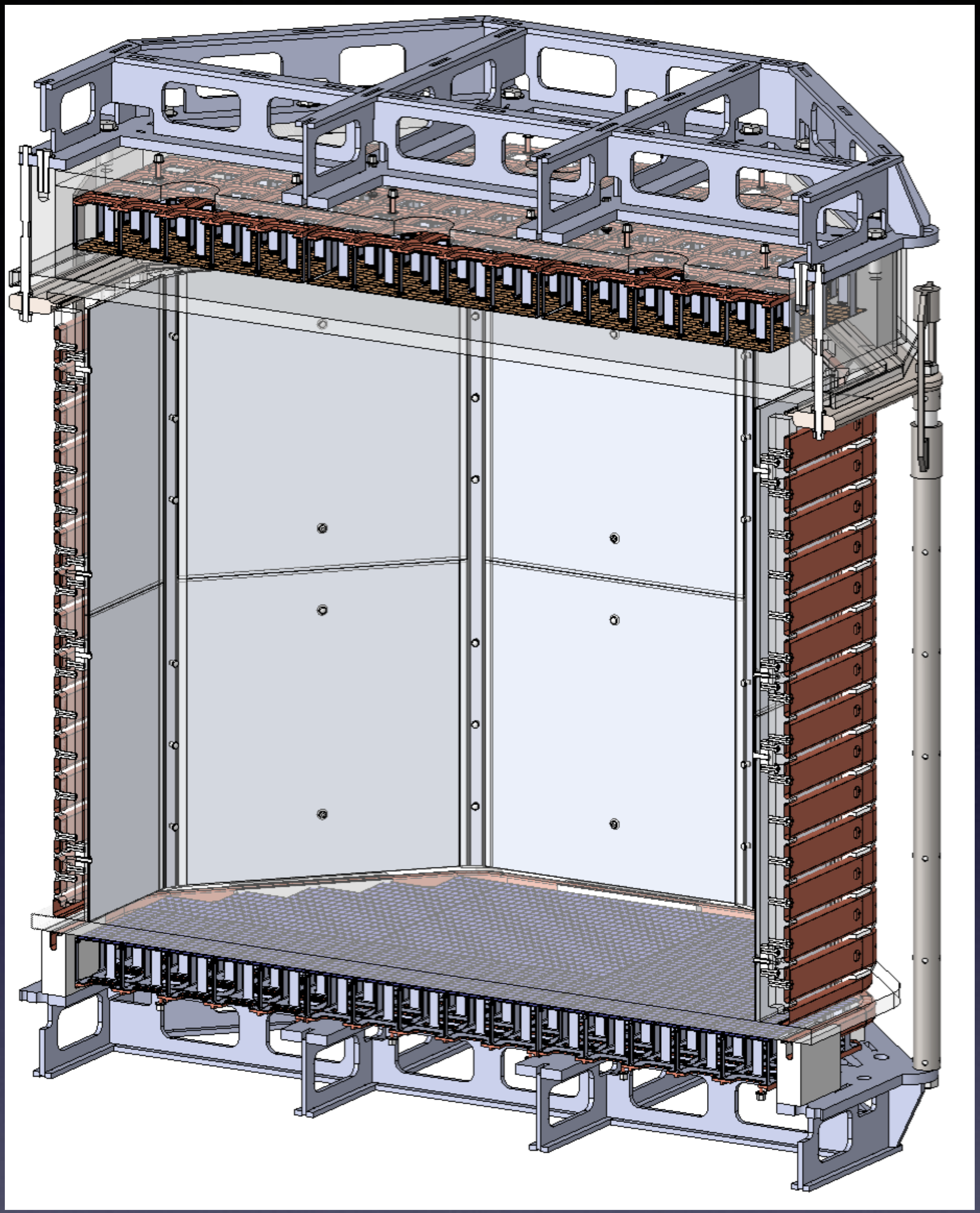
Conclusions

- DarkSide-20k set to start in 2021, with a projected sensitivity of 1×10^{-47} cm^2 for a 1 TeV/c^2 dark matter particle mass and an exposure of 100 tonne×yr
- Global Argon Dark Matter Collaboration aiming at 1,000 tonne×year search for dark matter
- Two key enabling technologies:
  - Upgrade of production of depleted argon to many tonnes (URANIA & ARIA)
  - Cryogenic photosensors based on SiPM arrays with area of 15 m^2 (NOA)

DarkSide-20k @ LNGS Hall C

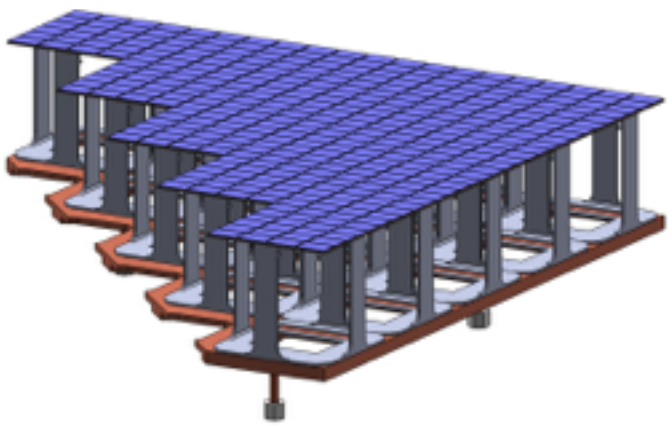
THANK YOU



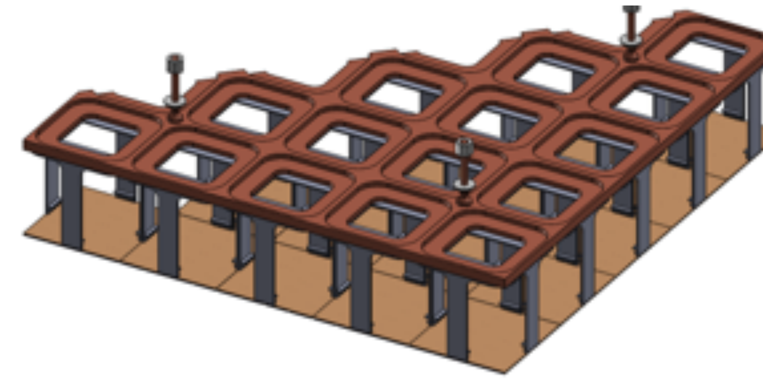


1ton prototype TPC

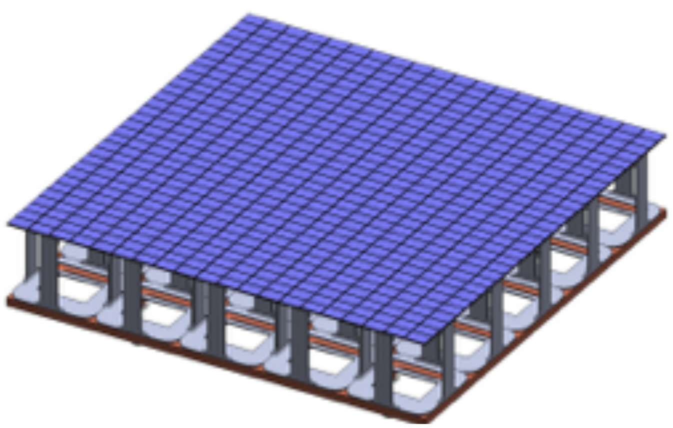
Triangular Mother Board (TRB)



15 PDMs each



Square Mother Board (SQB)



25 PDMs each