106th SIF National Congress Italian Physical Society

16th September 2020

# The DarkSide project

## present status and future prospects

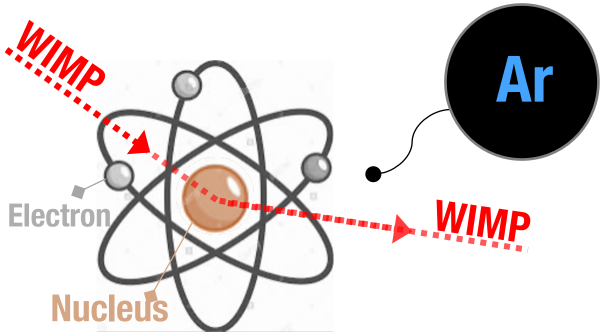
**Francesca Carnesecchi**

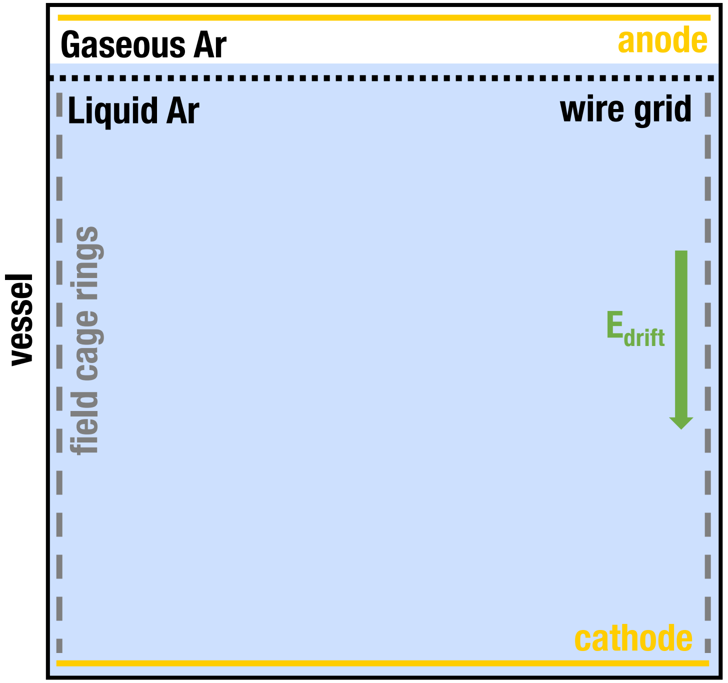
on behalf of the **DarkSide** collaboration

University and INFN of Bologna

# Two-Phase Argon TPC for Dark Matter direct detection

**WIMP** direct detection → **nuclear recoils** from elastic scattering



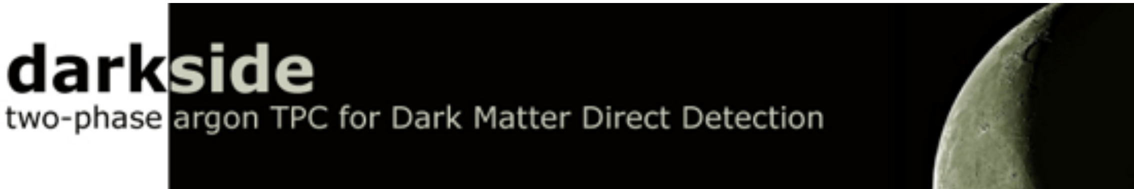




## Why noble elements?

- High **light yield**, transparent to their own scintillation
- Easy to **purify** and **scalable** to very high masses
- (At least) two available detection channels: **ionization** (charge) and **scintillation** (light)

## Why Argon?

- Superior Electron Recoil rejection (powerful **PSD**)

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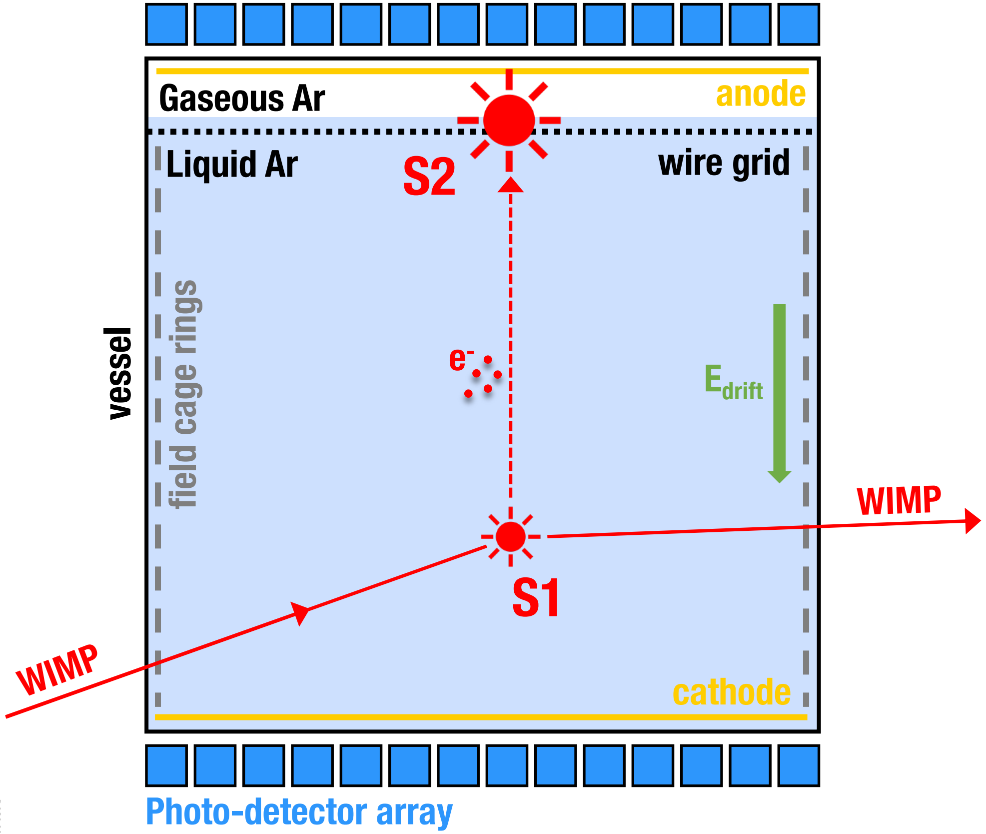
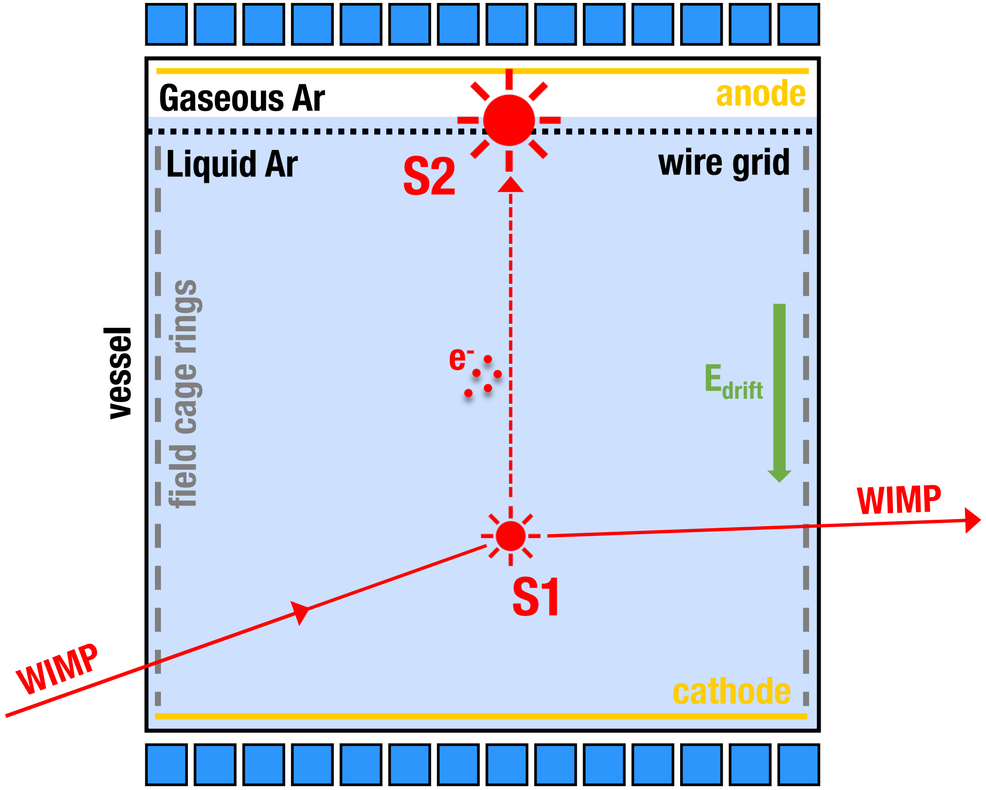
# Two-Phase Argon TPC

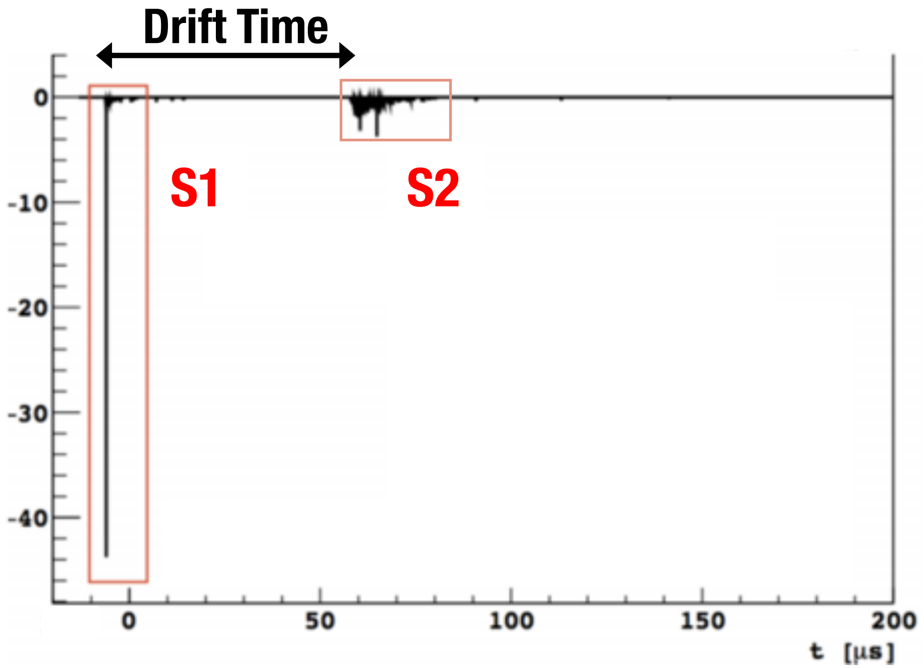



**S1**: from Scintillation (light)

**S2**: from Ionization (charge) + electroluminescence (light)

# Two-Phase Argon TPC



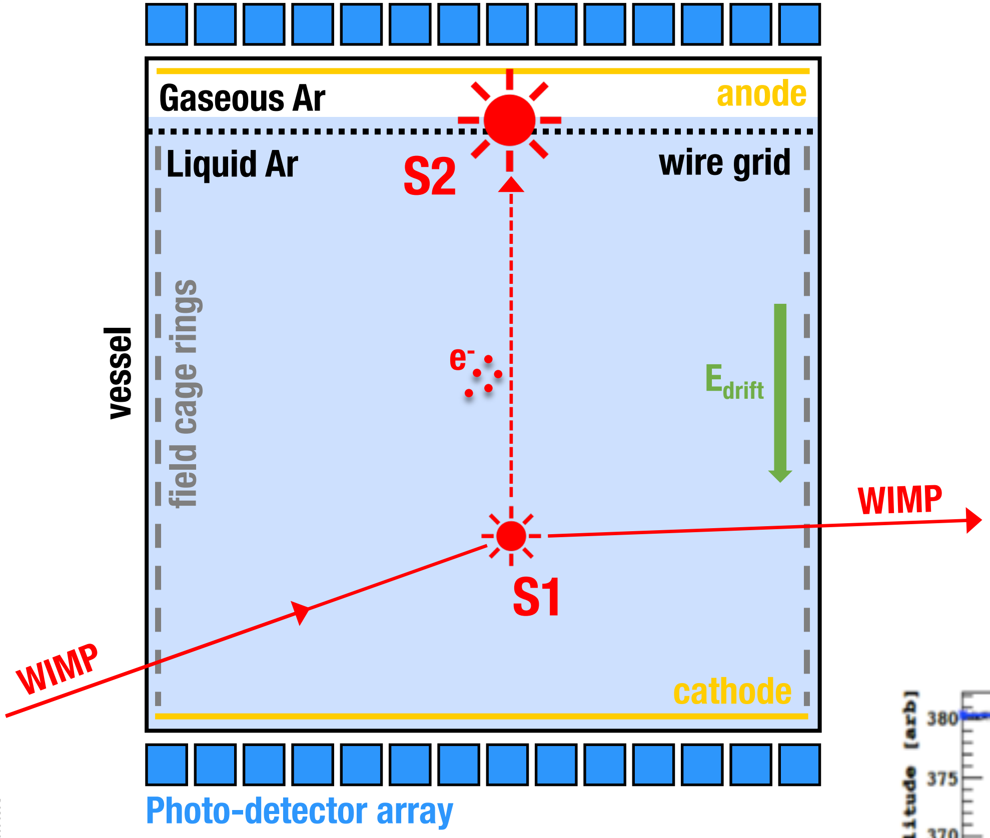



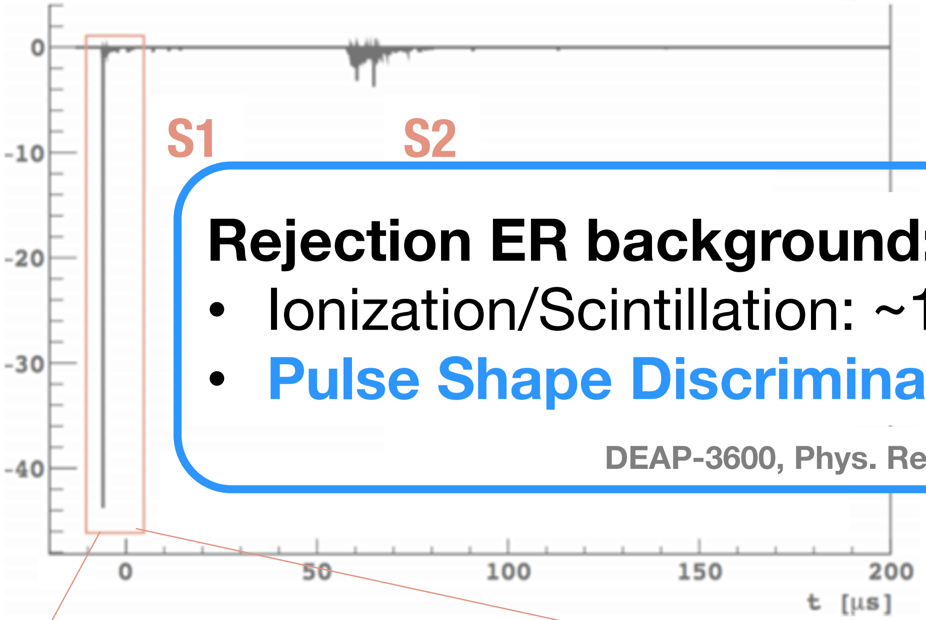

**3D vertex reconstruction**

- X –Y by S2 pattern on photodetectors
- Z by Drift Time ($t_{S2}$-$t_{S1}$)

→ Precise fiducialization

# Two-Phase Argon TPC

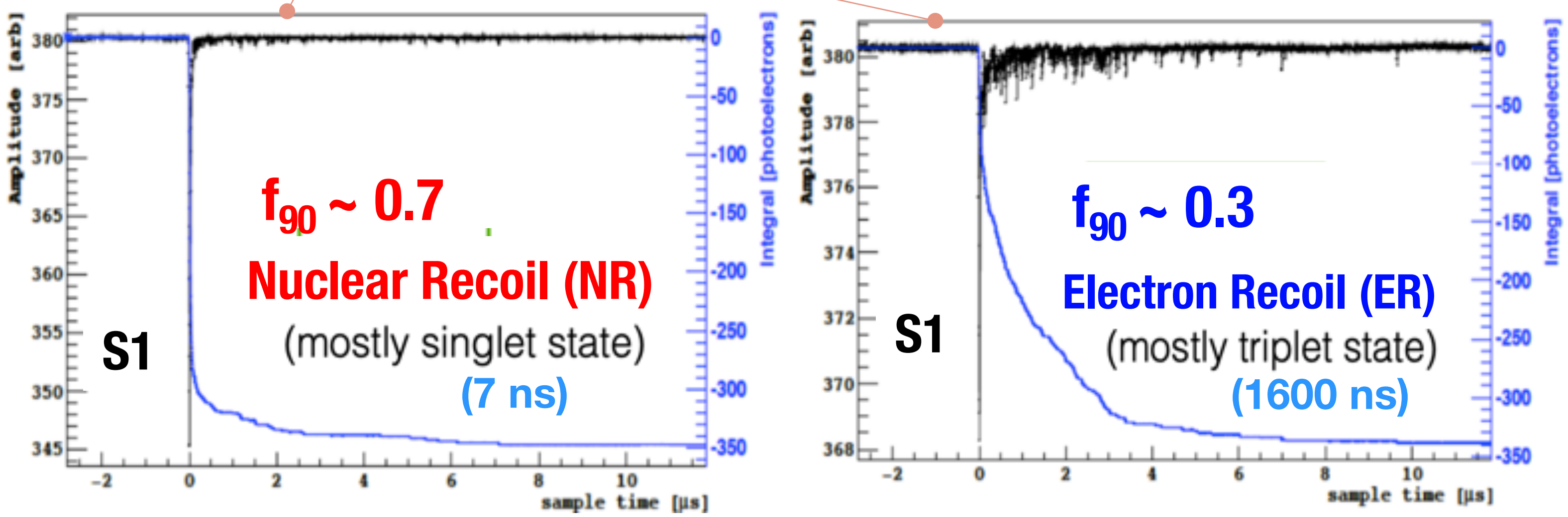



**Rejection ER background:**

- Ionization/Scintillation: ~$10^3$
- **Pulse Shape Discrimination** ($f_{90}$): **~$10^9$**

DEAP-3600, Phys. Rev. D 100, 022004




$f_{90}$ = fraction of S1 light arriving within first 90 ns



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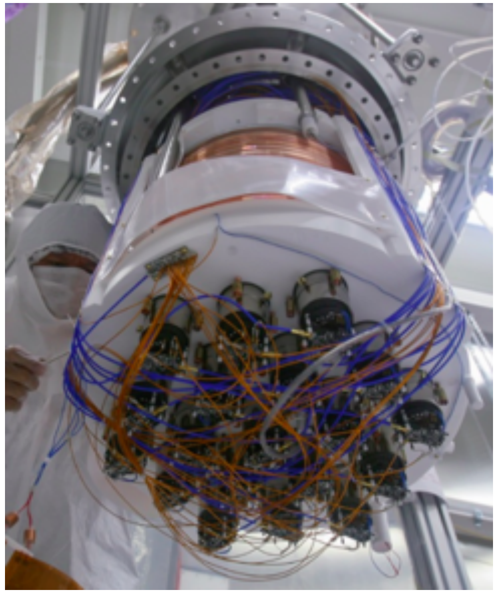
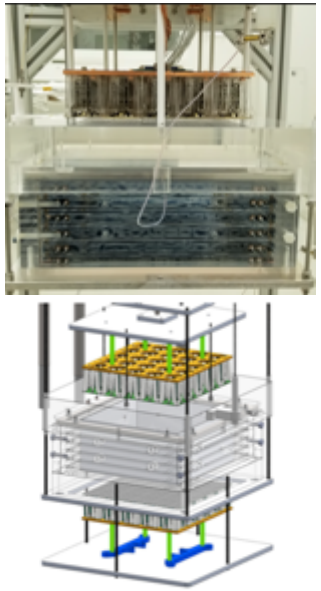
# The DarkSide program

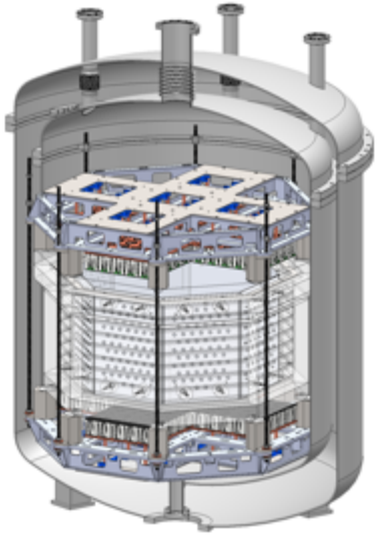
**Global Argon Dark Matter Collaboration**
**(DarkSide-50+DEAP-3600+miniCLEAN+ArDM)**



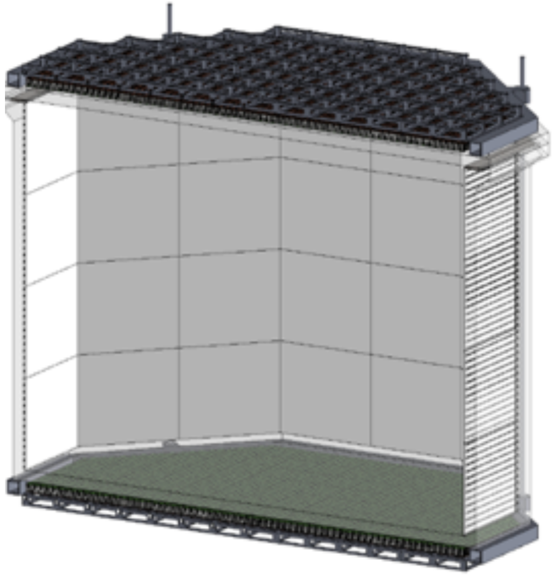
**DarkSide-50**



**DS-Proto0**



**DS-Proto1**



**DarkSide-20k**

**ARGO**

2013-present → 2019-present → 2021 → 2024 → ~2029

**LAr**

50 kg → 10 kg → 175 kg → 20 t → 300 t

$\sigma(\chi N) \sim 10^{-44}$ cm$^2$ ($M_\chi$ =100 GeV/c$^2$) ← Prototypes → $\sigma(\chi N) \sim 10^{-48}$ cm$^2$ ($M_\chi$ =100 GeV/c$^2$) → $\sigma(\chi N) \sim 10^{-49}$ cm$^2$ ($M_\chi$ =100 GeV/c$^2$) neutrino floor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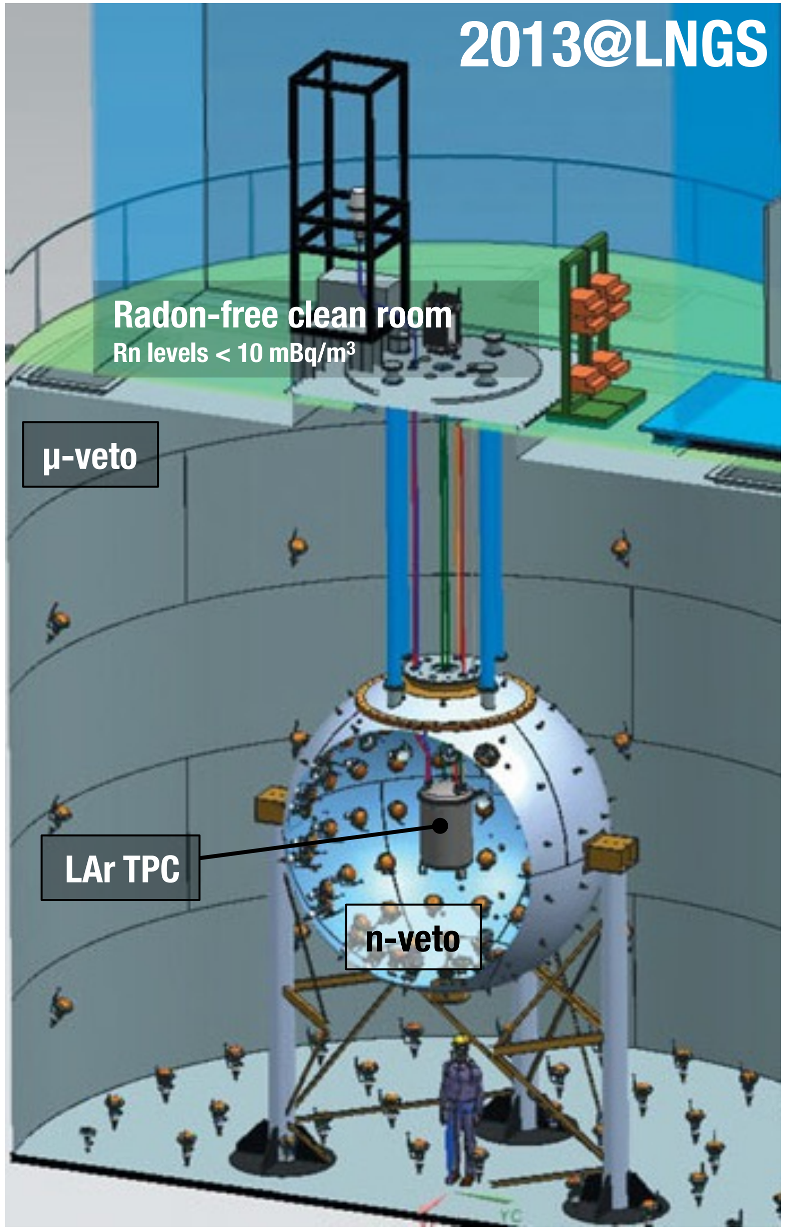
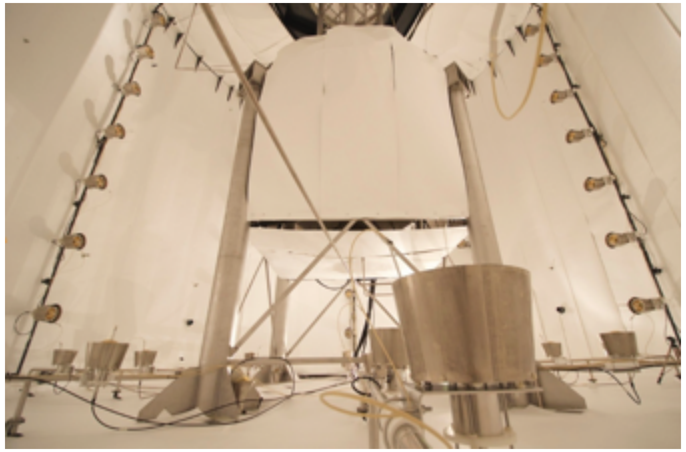
# DarkSide-50

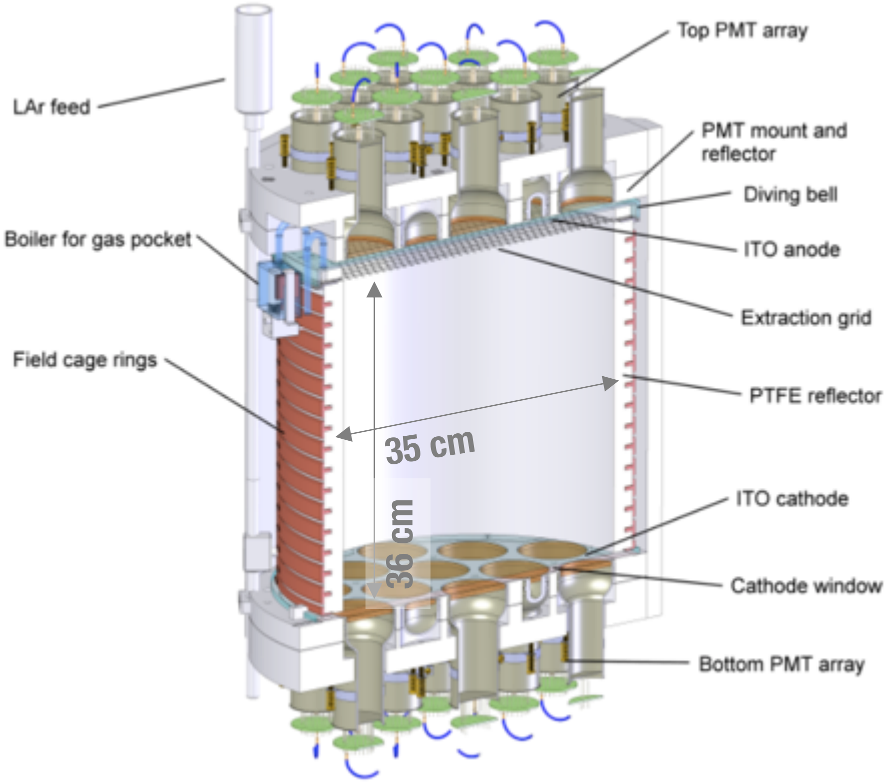



**Muon veto** (& passive shield)
1 kton ultra pure Water Cherenkov



**Neutron veto**
30 ton Borated Liquid Scintillator

**Two-phase LAr TPC**
46.4 kg Liquid Argon from **underground** source depleted in $^{39}$Ar ~ 0.7 mBq/Kg (since 2015)



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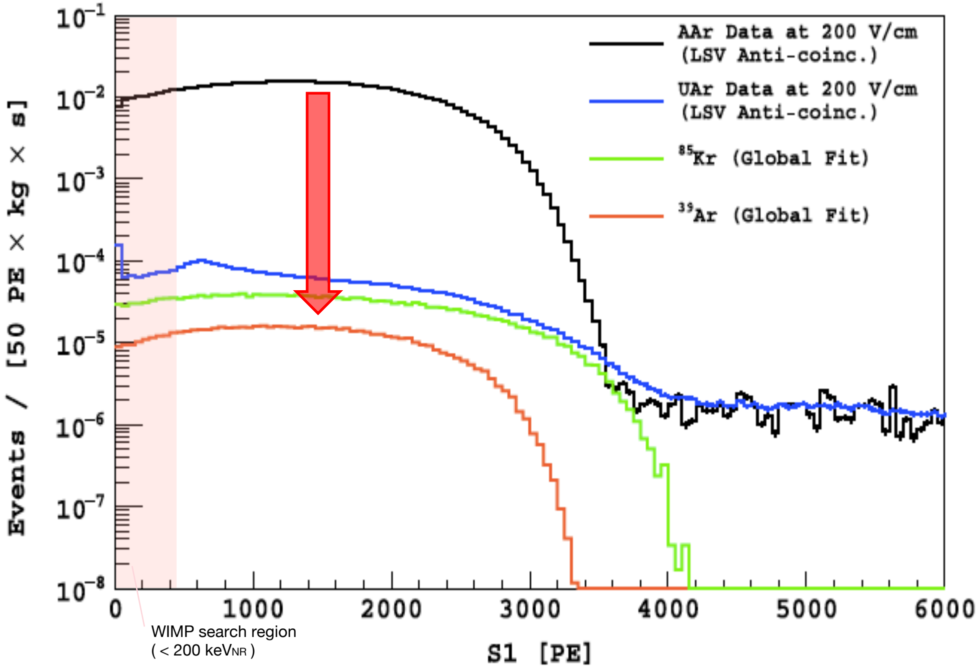
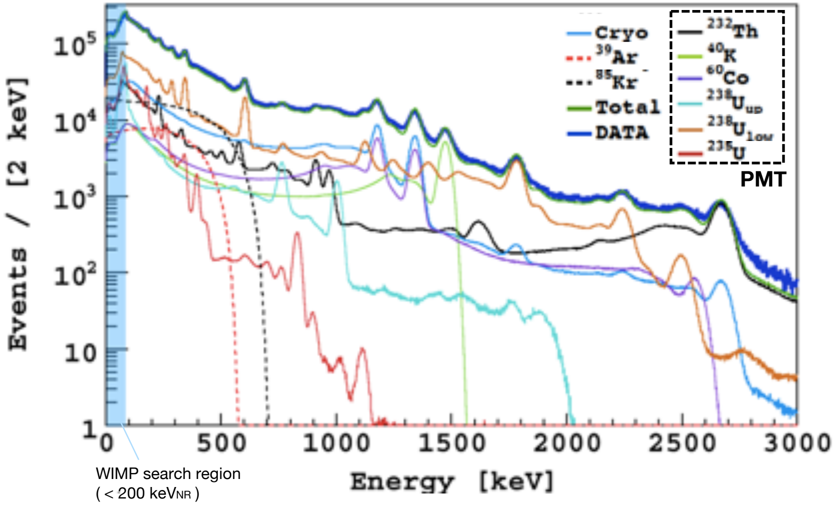
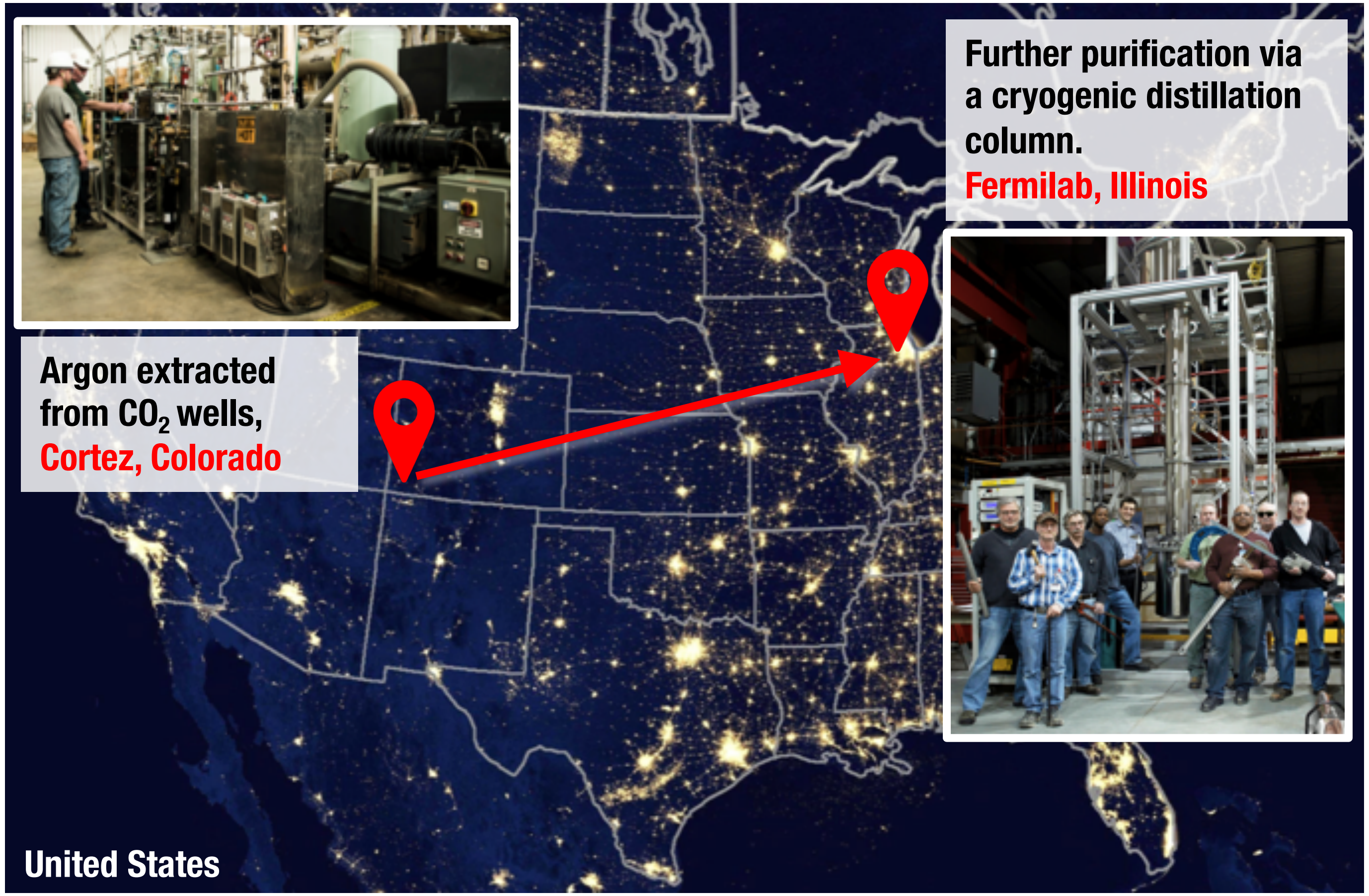
# DS-50 Underground Argon




**UAr ~ 1400 fewer $^{39}$Ar events than AAr**




**Main Background source in DS-50:**

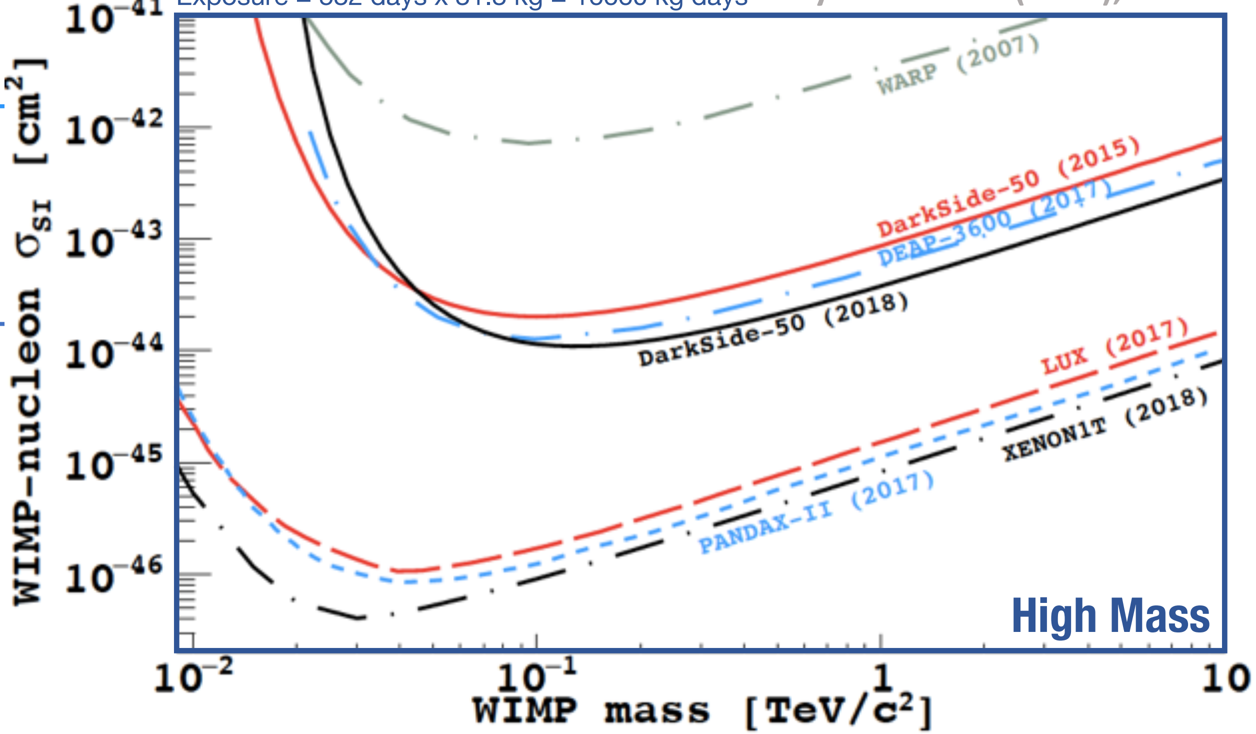
- $^{85}$Kr and $^{39}$Ar
- Cryostat
- PMTs

# DS-50 results

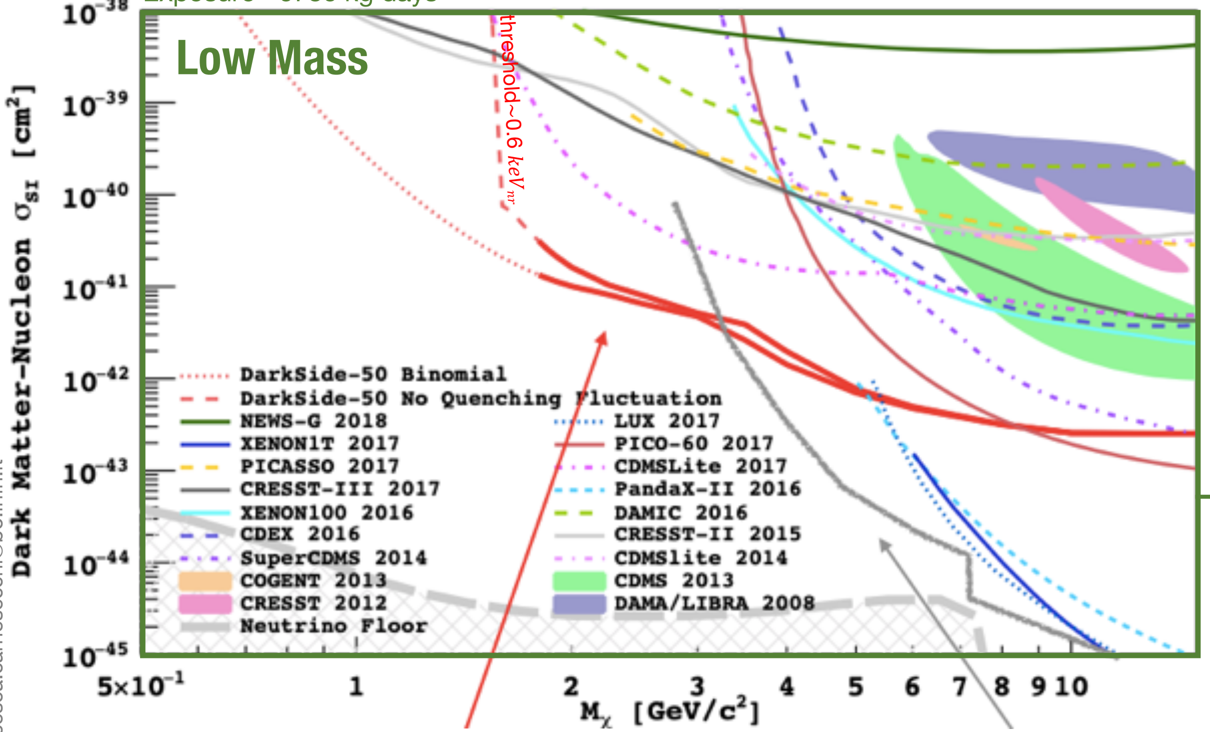
**High Mass:**
1.14 × $10^{-44}$ $cm^2$ @100GeV

Exposure = 532 days x 31.3 kg = 16660 kg days

Phys. Rev. D 98 (2018), 102006




Exposure= 6786 kg days




**50 kg of Ar**

**1 ton of Xe**

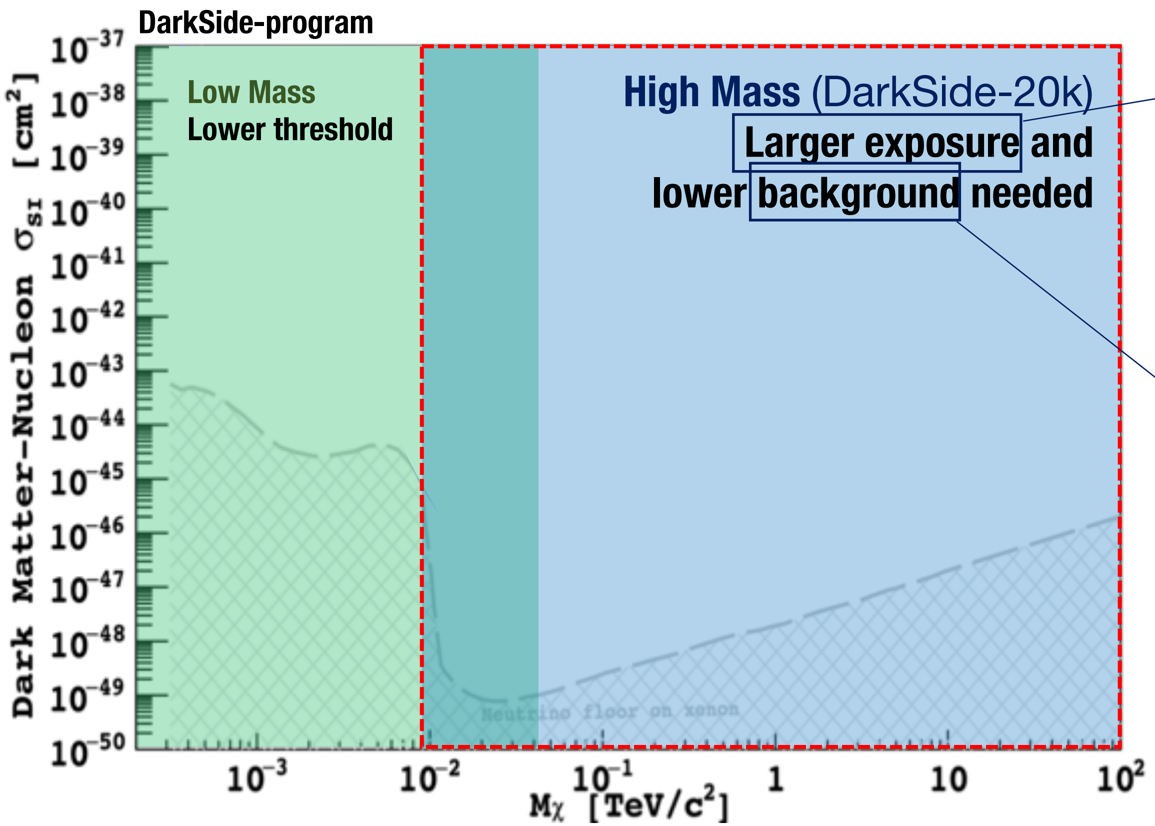
Phys.Rev.Lett. 121 (2018) 8, 081307

Phys.Rev.Lett. 123 (2019) 25, 251801

**Low Mass: S2-only analysis**
~$10^{-41}$ $cm^2$ @2GeV
1.8-3.5 GeV

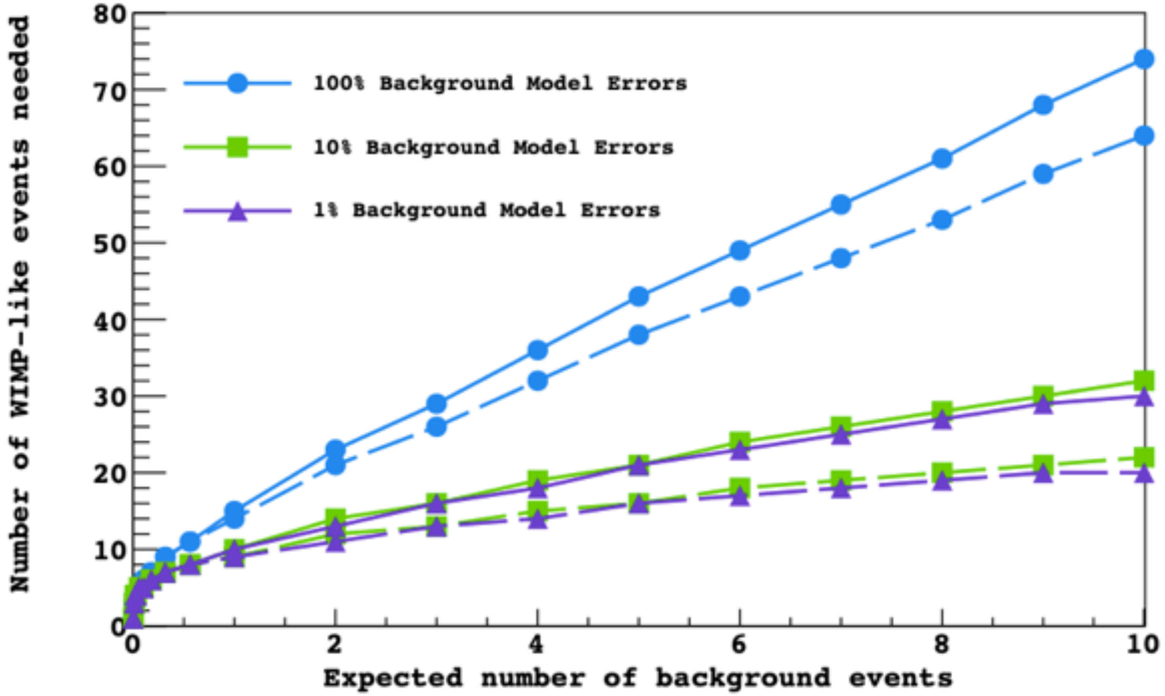
Sub-GeV: S2-only analysis, DM-Electron
Phys.Rev.Lett. 121 (2018) 8, 111303

# DarkSide 20k - a ~~Bigger~~ Better Detector




**Larger detector:**

- From 50 kg to 20 tons of LAr




**For a discovery :** we need 5 events **if** background<0.1

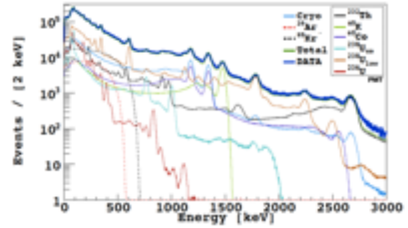
# DS-20k URANIA and ARIA

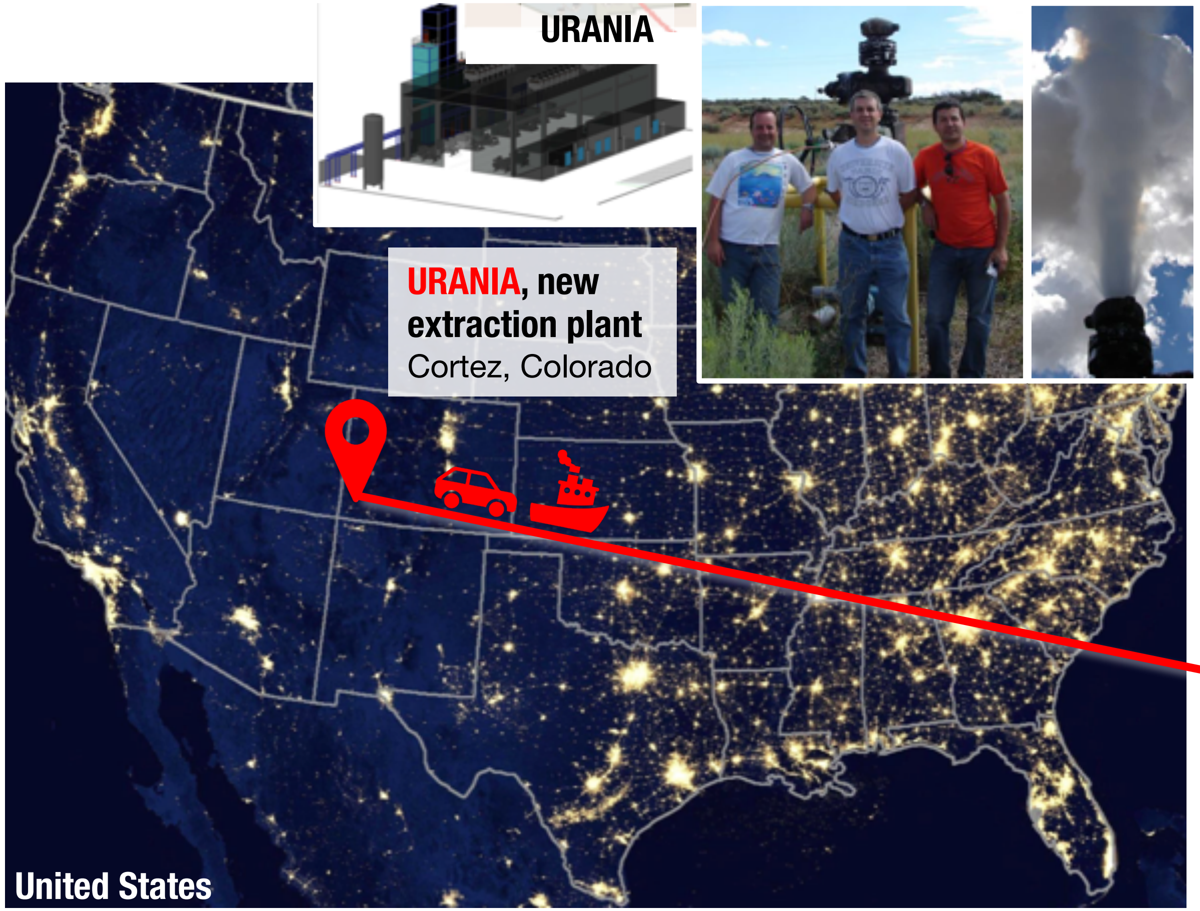
GADMC

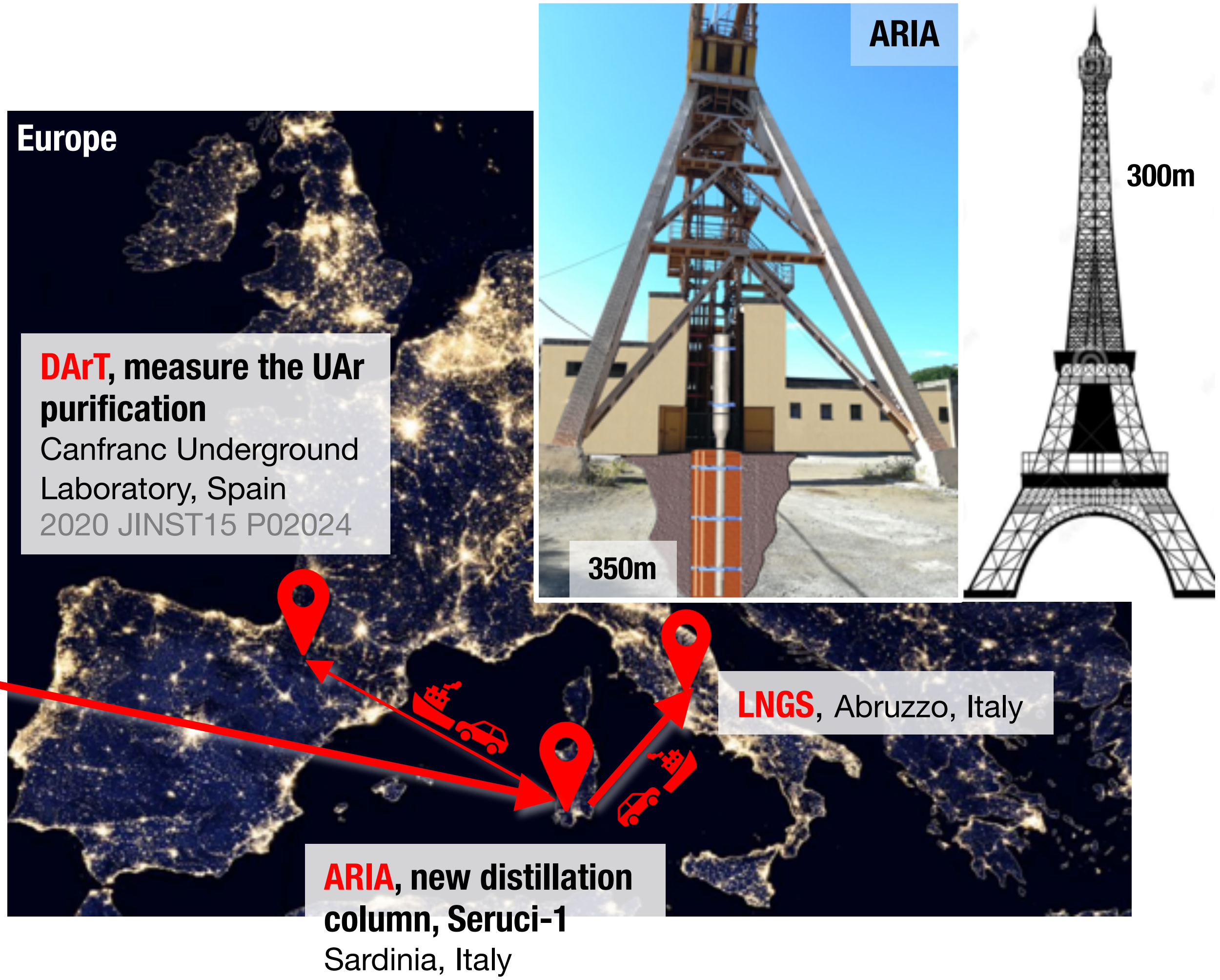
## UAr and Purification

**Main Background in DS-50:**

- $^{85}$Kr and $^{39}$Ar
- Cryostat
- PMTs




Extraction rate 330 kg/day with 99.99% purity

Purify 1 ton/day UAr (x100 reduction of all chemical impurities) and isotopically separate $^{39}$Ar form $^{40}$Ar (x10 reduction) at 10 kg/day.

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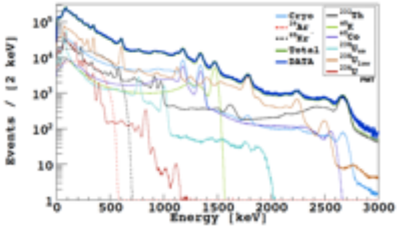
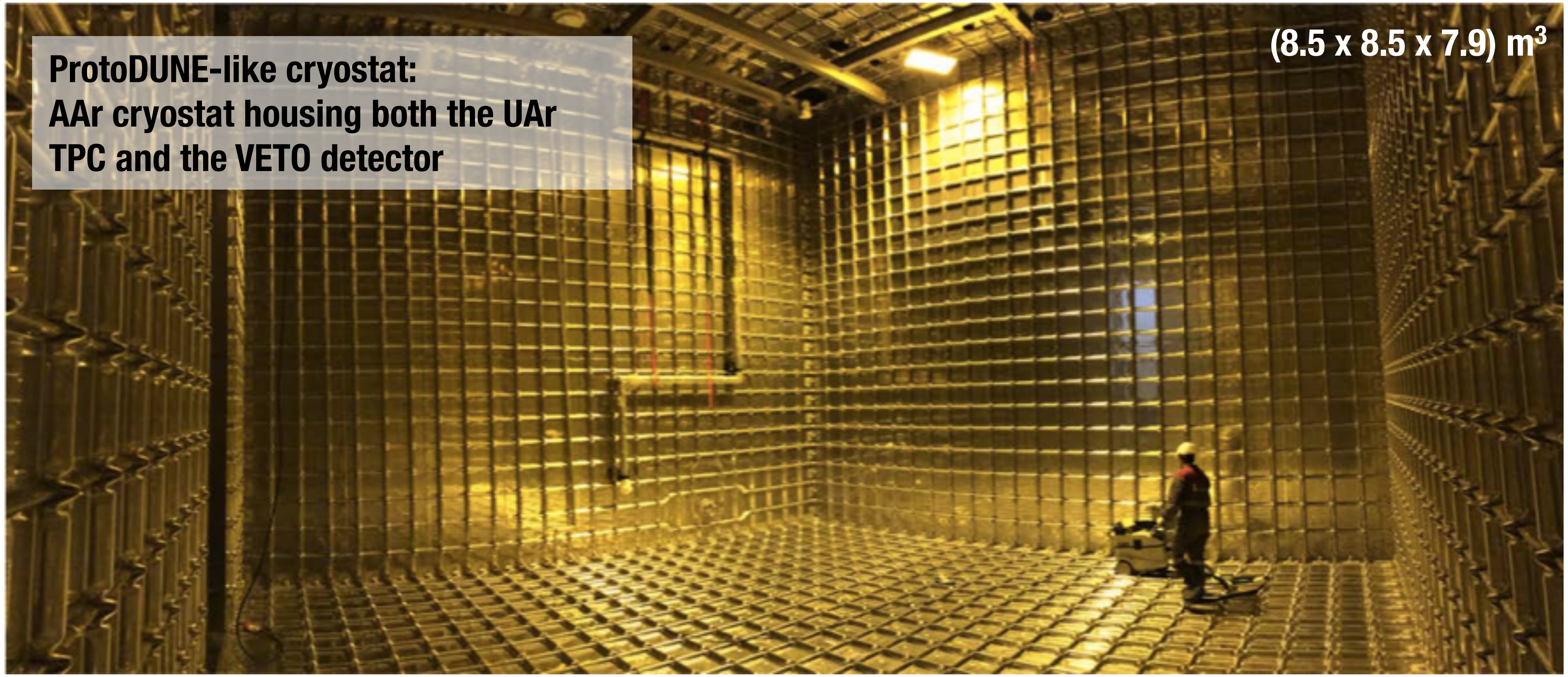
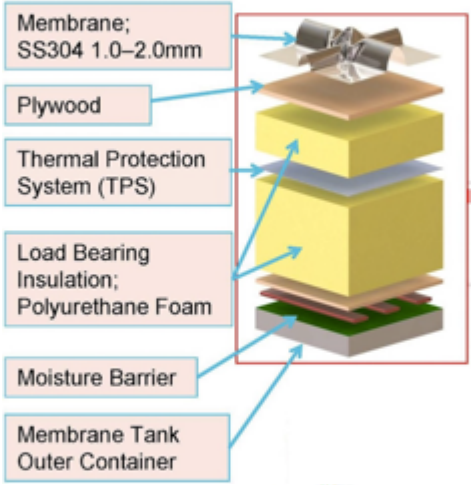
# DS-20k ProtoDUNE cryostat

GADMC

**Main Background in DS-50:**
- $^{85}$Kr and $^{39}$Ar
- Cryostat
- PMTs



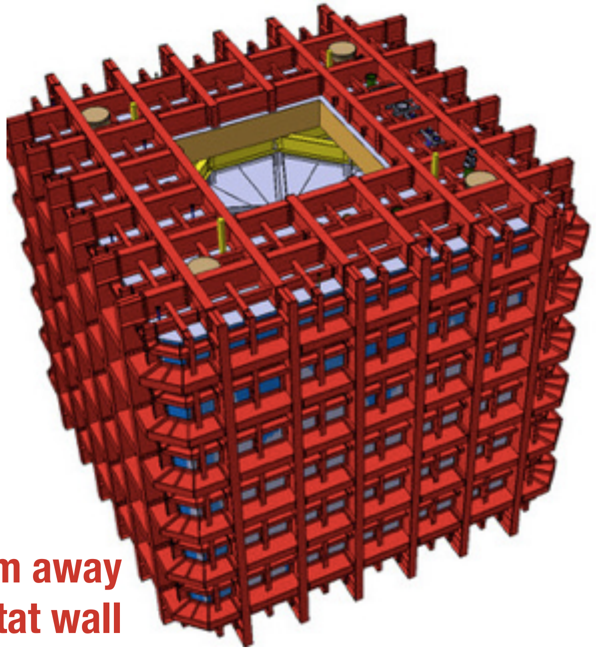




**UAr TPC immersed in a liquefied AAr** (same temperature and pressure)

→ **No more** (stainless steel vacuum vessel) **cryostat** (necessary for DS-50**)**
**in the immediate proximity of TPC**

**Vessel** → replaced by a **sealed radio-pure acryilic vessel**



**TPC outer walls ~2m away from inner cryostat wall**

# DS-20k Photoelectronics

## From 38 PMTs to ~200’000 SiPMs

GADMC

**Main Background in DS-50:**
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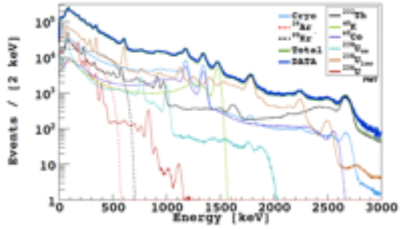
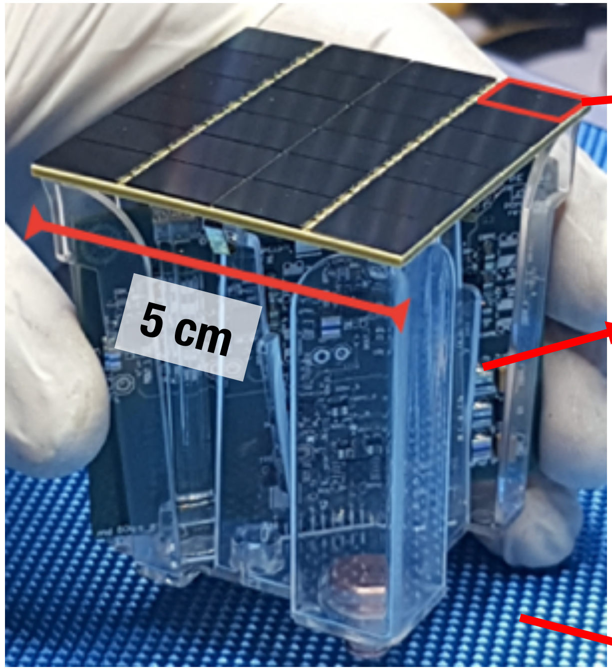
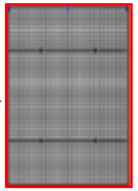
- Cryostat
- PMTs

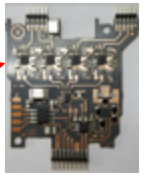


- **Compact** Size → High coverage efficiency
- Low Radioactivity



**11.7 x 7.9 mm$^2$ NUV-HD-CRYO SiPM** designed by **FBK. LFoundry** is in charge for the mass production



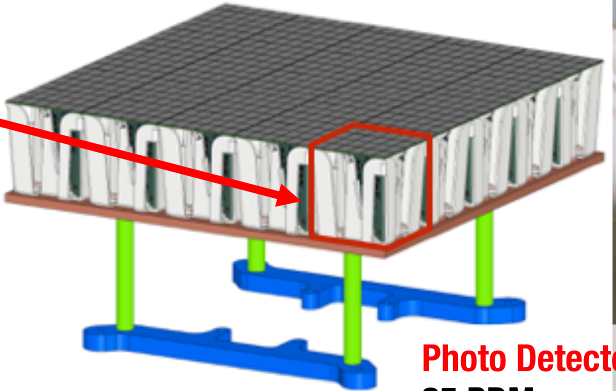
**4xTransImpedence Amplifier (TIA)** developed and optimized for cryo operations

IEEE Trans. Nucl. Sci., **65**, 1, (2017)

IEEE Trans. Nucl. Sci., 65, 4, (2018)

**Single channel Photo Detector Module (PDM)**

**24 SiPMs + front-end board**



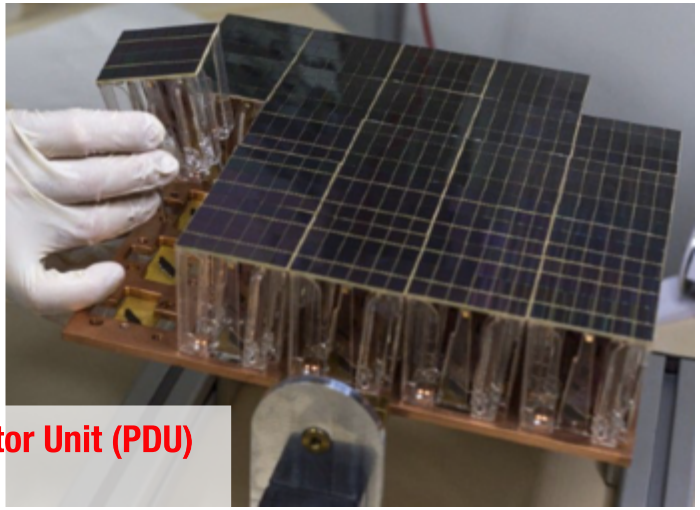


**Photo Detector Unit (PDU)**

**25 PDMs**

**First PDU assembled**
082018@LNGS
**Tested at cryo temp**
112018@LNGS 082019@CERN

**Second PDU assembled**
082019@LNGS
**Tested at cryo temp**
092019@LNGS 102019@CERN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# DS-20k Photoelectronics

## From 38 PMTs to ~200'000 SiPMs

GADMC

**Main Background in DS-50:**
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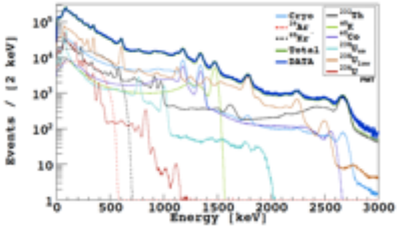
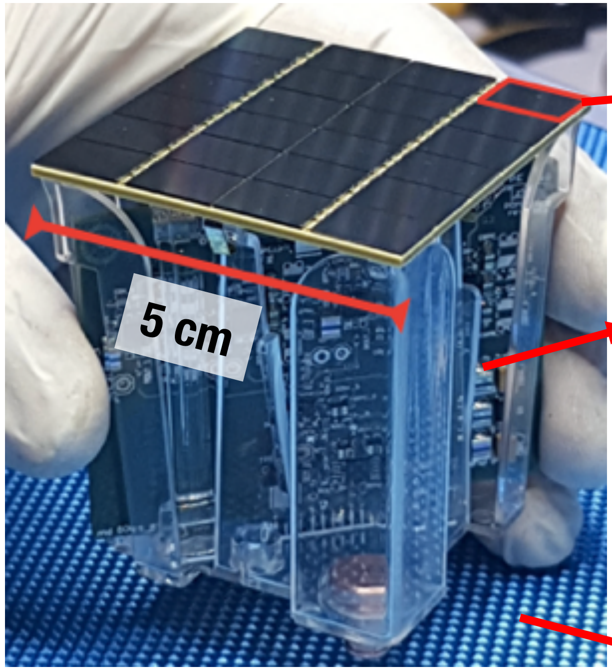
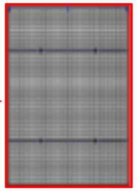
- Cryostat
- PMTs




- **Compact** Size → High coverage efficiency
- Low Radioactivity

- **TPB** coating inner TPC as WaveLength Shifter to shift the 128nm to 420 nm
- PDUs mounted **outside** the **TPC vessel** (thanks to the new acrylic vessel): less background, simpler assembly strategy



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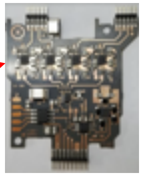

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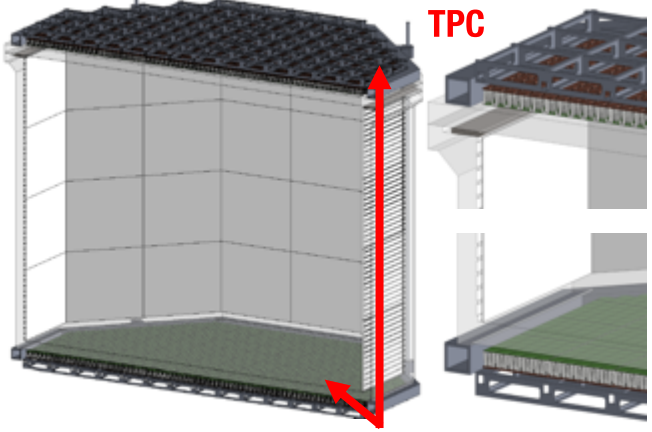
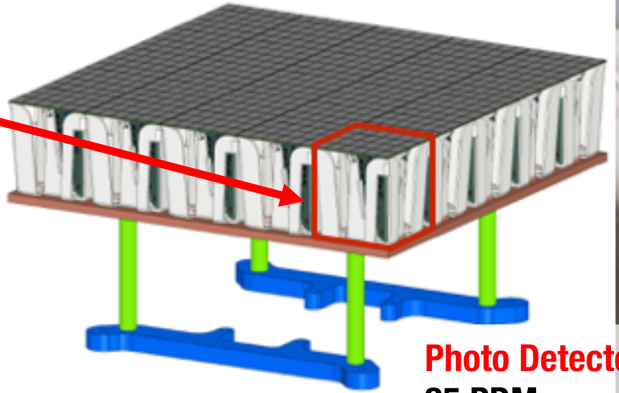



**Single channel Photo Detector Module (PDM)**

**24 SiPMs + front-end board**



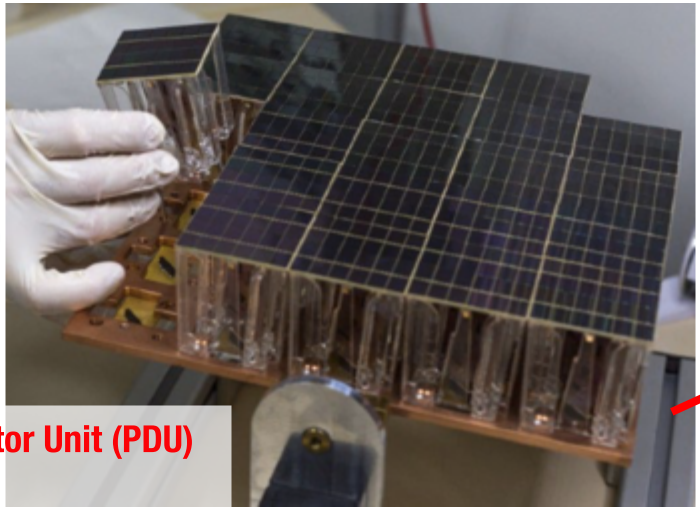
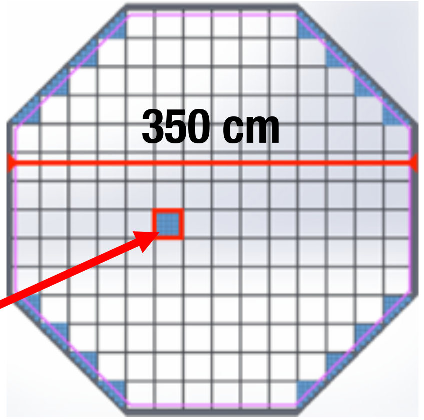


**Photo Detector Unit (PDU)**

**25 PDMs**

**TPC top & bottom:**

344 PDUs, ~8280 PDM







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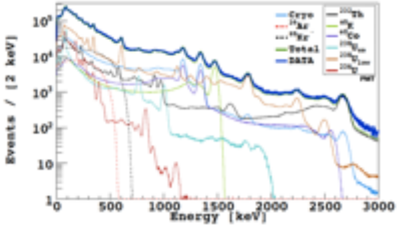
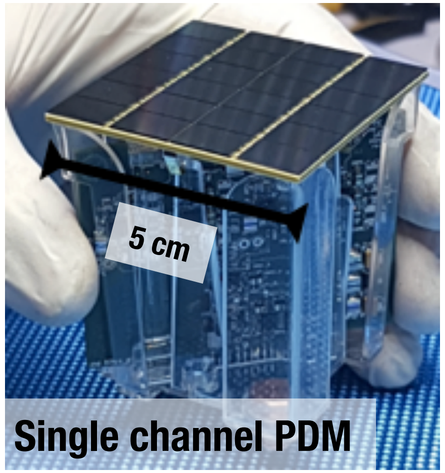
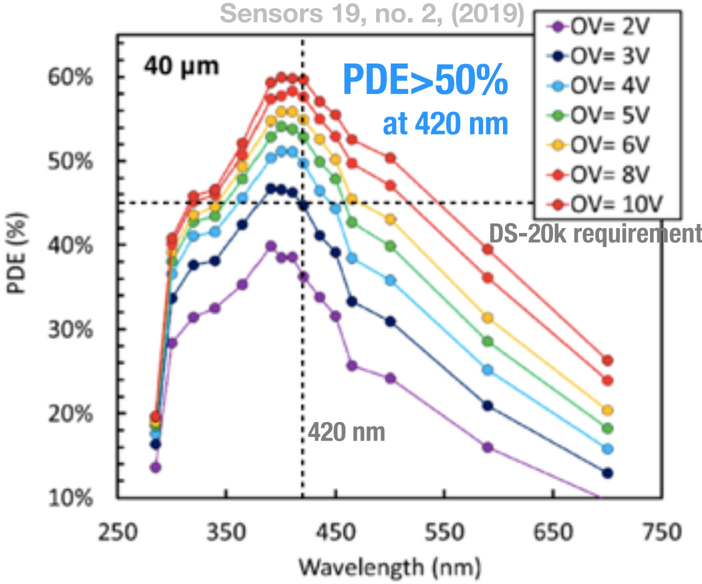
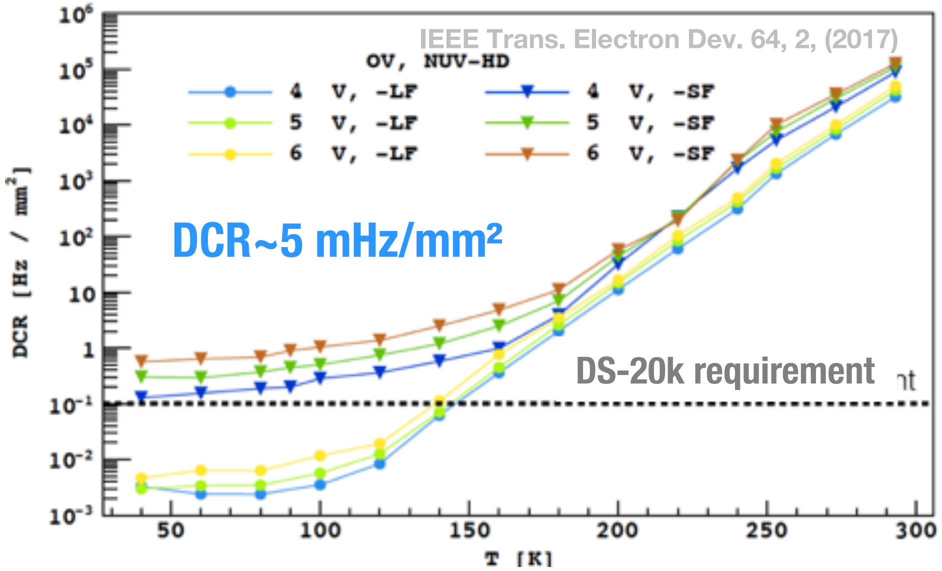


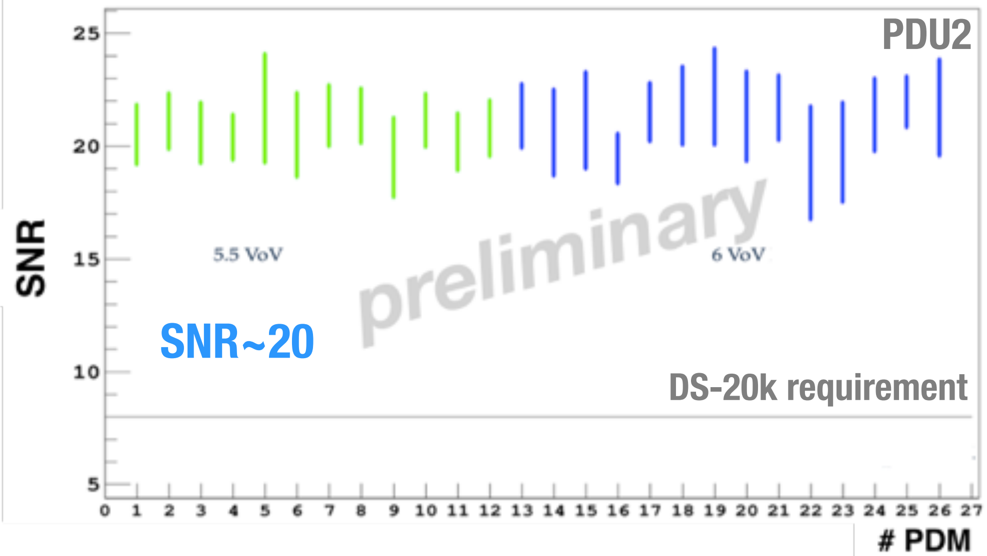




### DS-20k Requirements ⟶ fulfilled:

- **5 x 5 cm² area per channel** ⟶ to optimize the number of channels
- **Power dissipation < 100 μW/mm²** ⟶ avoid bubbling and excessive thermal load on the cryogenic system
- **$PDE_{PDM}$ at 420 nm > 40% ($PDE_{SiPM}$ >45%)** ⟶ higher light yield and then PSD power
- **Noise rate**< 0.1 Hz/mm² and **SNR>8**⟶ PSD power
- **Time resolution O(10ns)** ⟶ PSD power





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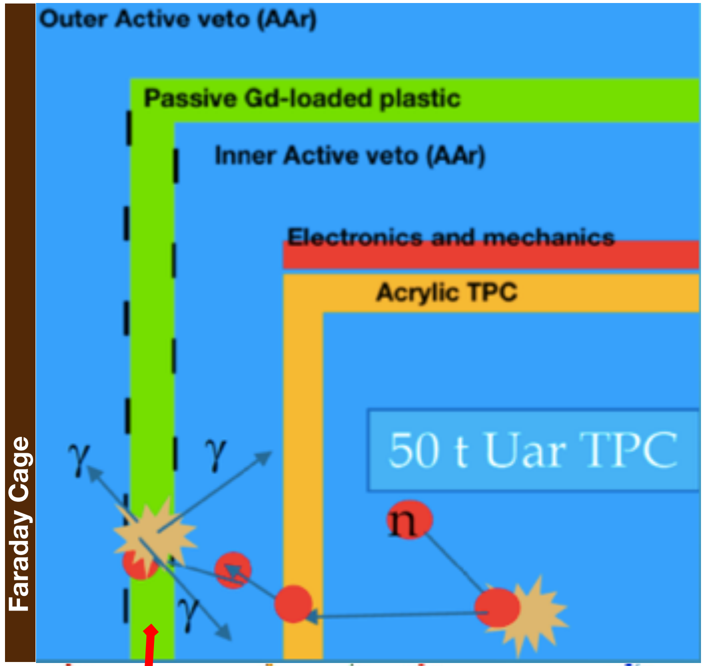
# DS-20k neutron VETO

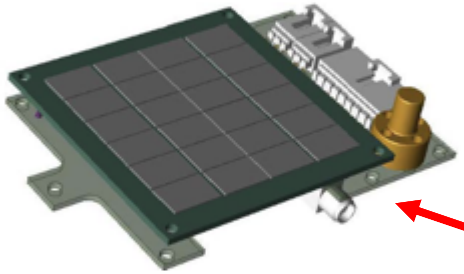
GADMC

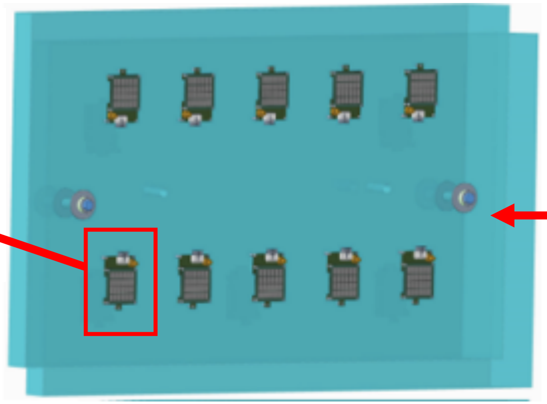
- **Moderate and capture neutrons: 10 cm thick Gd doped acrylic vessel** (~2% of Gd oxide in mass)
- **Detect gammas** (due to neutron capture on Gd): **40 cm thick inner** (towards the TPC) and **outer** (towards the Faraday Cage) active liquid **AAr** volumes
- **Faraday cage** to optically and electrically isolate veto and TPC detectors
- **Vertical segmentation:** reduce pile-up rate of $^{39}Ar$ (from Aar).
- ESR foil (same as TPC) as **reflector** to maximize light collection
- TPB or PEN (**wavelength shifter**) coated on all internal surface

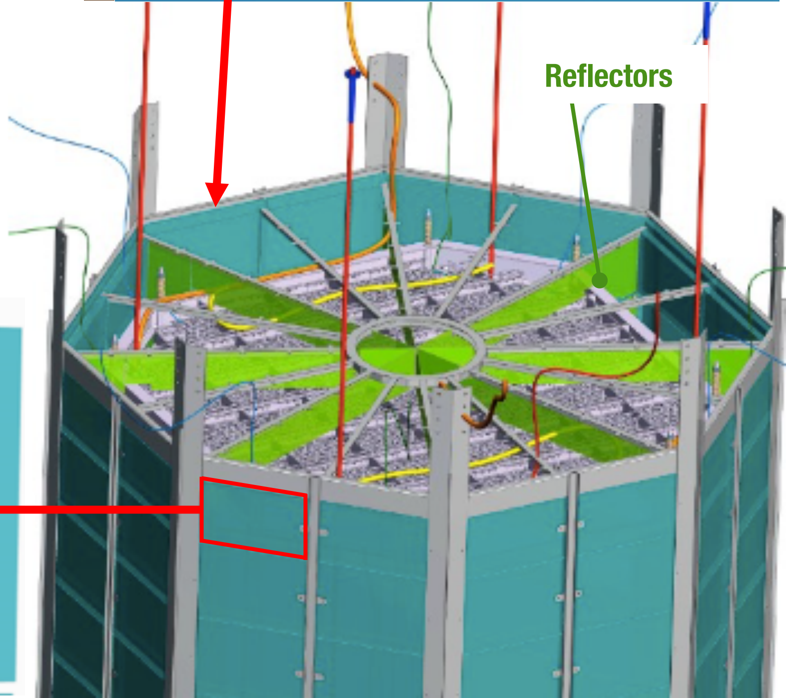



Design goal: < 0.1 n/(200 t year) after VETO&TPC event selection

**atticon12765**, *The Darkside-20k veto detector*, Rossi M.








3000 channels (Veto-PDMs)
4 π coverage

# DarkSide-20k

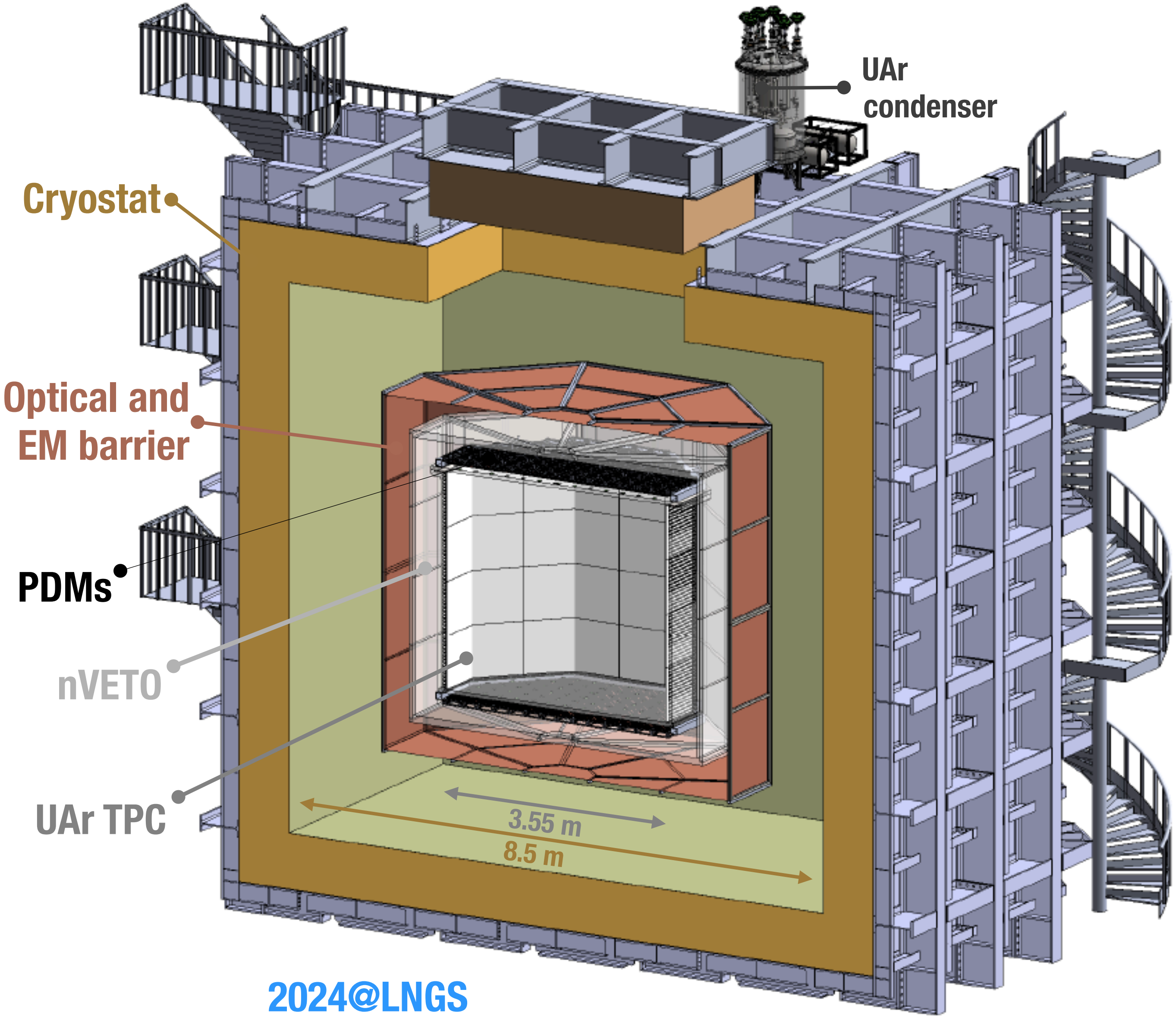
## a “background-free” detector

- **TPC**
  - Underground Ar (UAr)
  - Acrylic vessel
  - ~8000 PDMs
- **nVETO**
  - Gd doped acrylic panels
  - Atmospheric Argon (AAr)
  - ~3000 Veto-PDMs
- **Cryostat**
  - AAr
  - ProtoDUNE like

Separate cryogenic systems for UAr and AAr volumes

**AAr ~ 700t (cryo) + 120t (veto)**
**UAr ~ 51t.1 (20.2t fiducial)**

GADMC

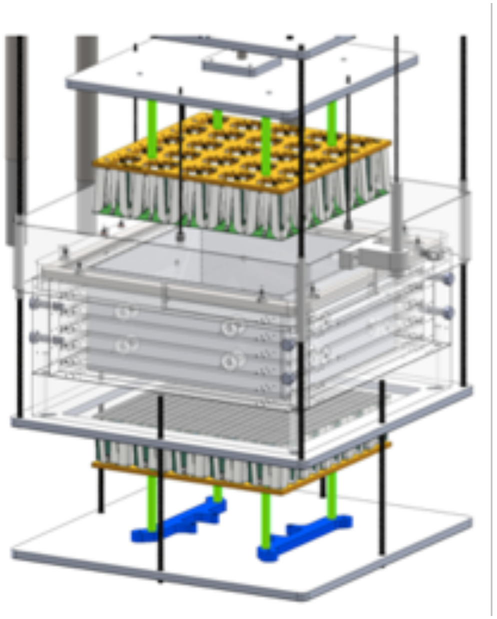



2024@LNGS


francesca.carnesecchi@bo.infn.it

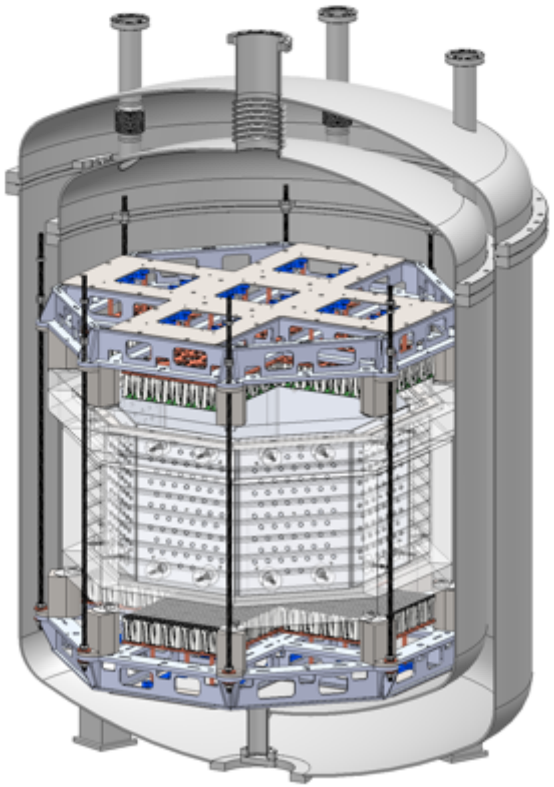
# DS-20k Prototypes

GADMC



2 PDUs
**50 PDMs**
1200 SiPMs

**10kg Active LAr**



10 PDUs
**250 PDMs**
6000 SiPMs

**350kg Active LAr**
(175kg fiducial )

**DS-Proto0**

**DS-Proto1**

- **S2 study with PDMs**
- **test of new techniques** (conductive polymer (Clevios), ESR, wire grid…)

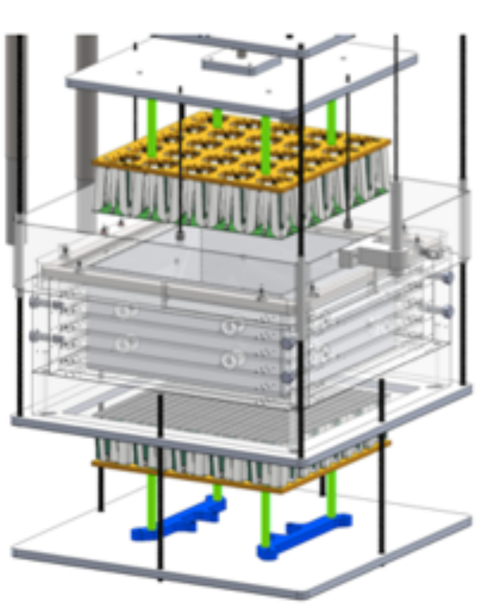
- Sealed acryilic TPC
- to **validate DS-20k in mechanical and functional aspect** (scaled-down version)

~~Assembly in summer 2020~~ (delayed due to COVID-19)

# DS-20k Prototypes

GADMC

**atticon12747**, *Characterisation of SiPM light detectors in the Darkside prototype liquid-argon TPC,* Luzzi L.



2 PDUs
**50 PDMs**
1200 SiPMs

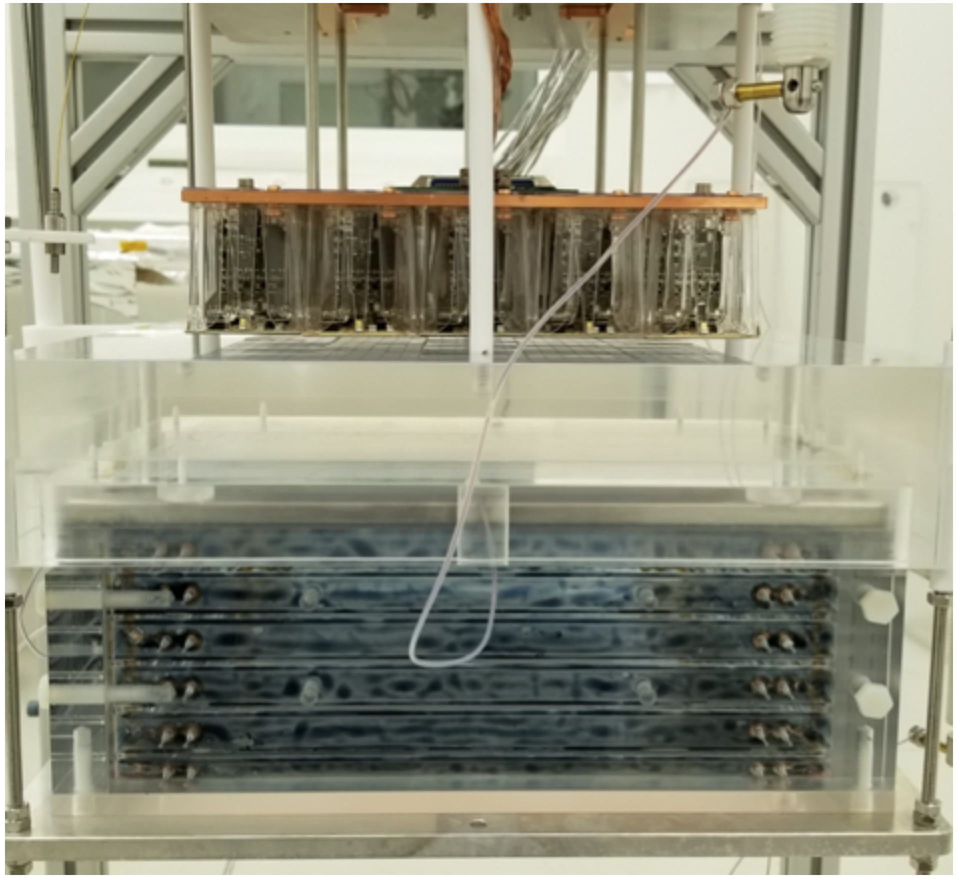
**10kg Active LAr**

**DS-Proto0**

- S2 study with PDMs
- **test of new techniques** (conductive polymer (Clevios), ESR, wire grid…)

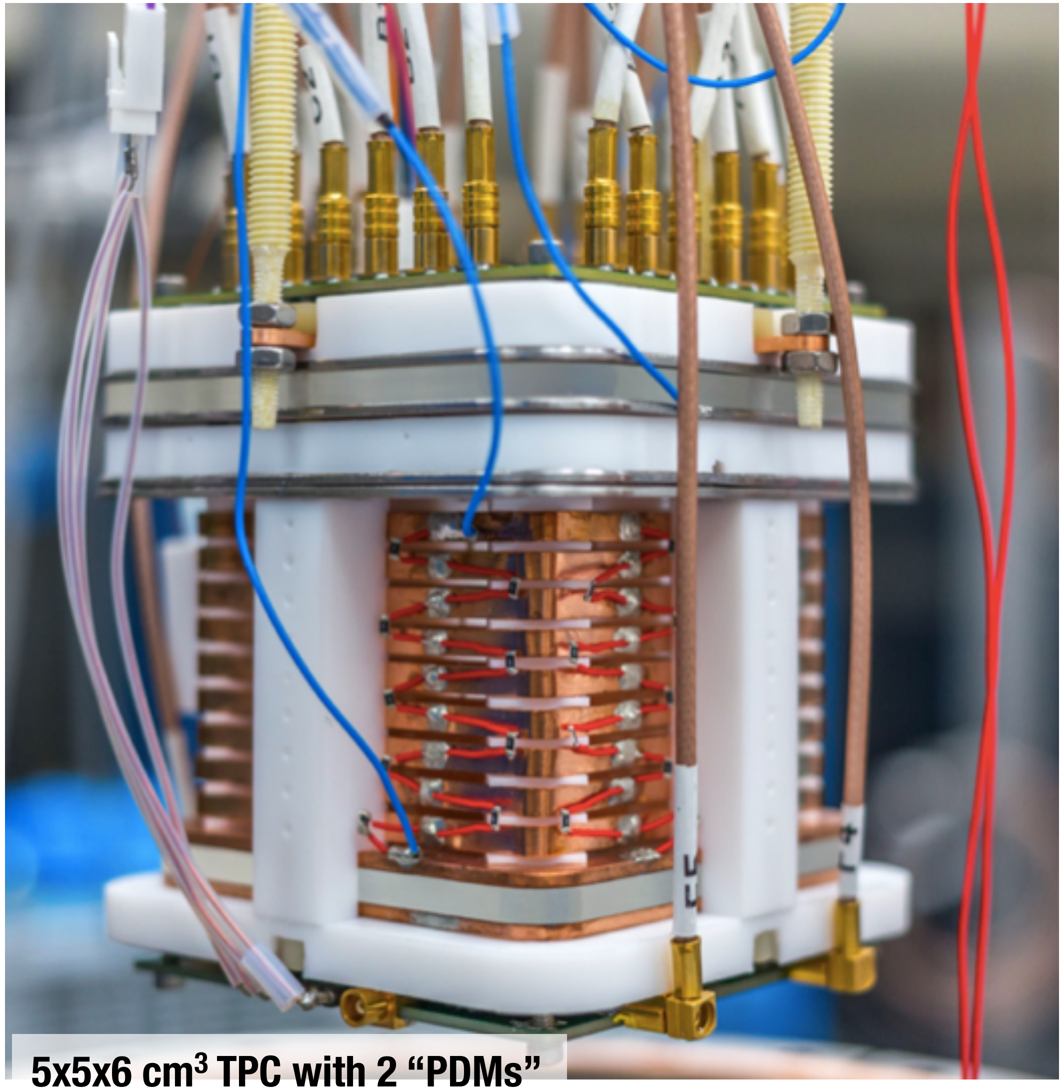
**summer2019@CERN**
JINST 15 C03038, 2020

•**First LAr run** with TPC done
•First experience of DAQ and analysis with 25 PDMs (channels) in a LAr TPC
•New TPC design proven successful; **fully functional**
•~~Next run in early 2020~~ (suspended due to COVID-19)



# ReD

directionality



5x5x6 cm$^3$ TPC with 2 “PDMs”

Acrylic inner chamber and reflective foil ERS. Acrylic windows for Anode and Cathode both coated with 15nm ITO and TPB.

- **Study the LAr TPC response to the neutron induced Ar recoils using the key features of the future detector:** recoils **parallel** or **orthogonal** wrt $E_{field}$ to probe **directionality** in LAr
- Long characterisation campaign in **Naples**. Detailed study of the S1&S2. Multiple calibrations with radioactive sources, laser. System continuously operated for 5 months with stable and reproducible performance. Paper in preparation.
- **Two weeks beam run in Catania (LNS).** Data analysis in progress. **022020@INFN-LNS**
- Next goal**: direct measurement of low-energy nuclear recoils (important for low-mass searches), 2021**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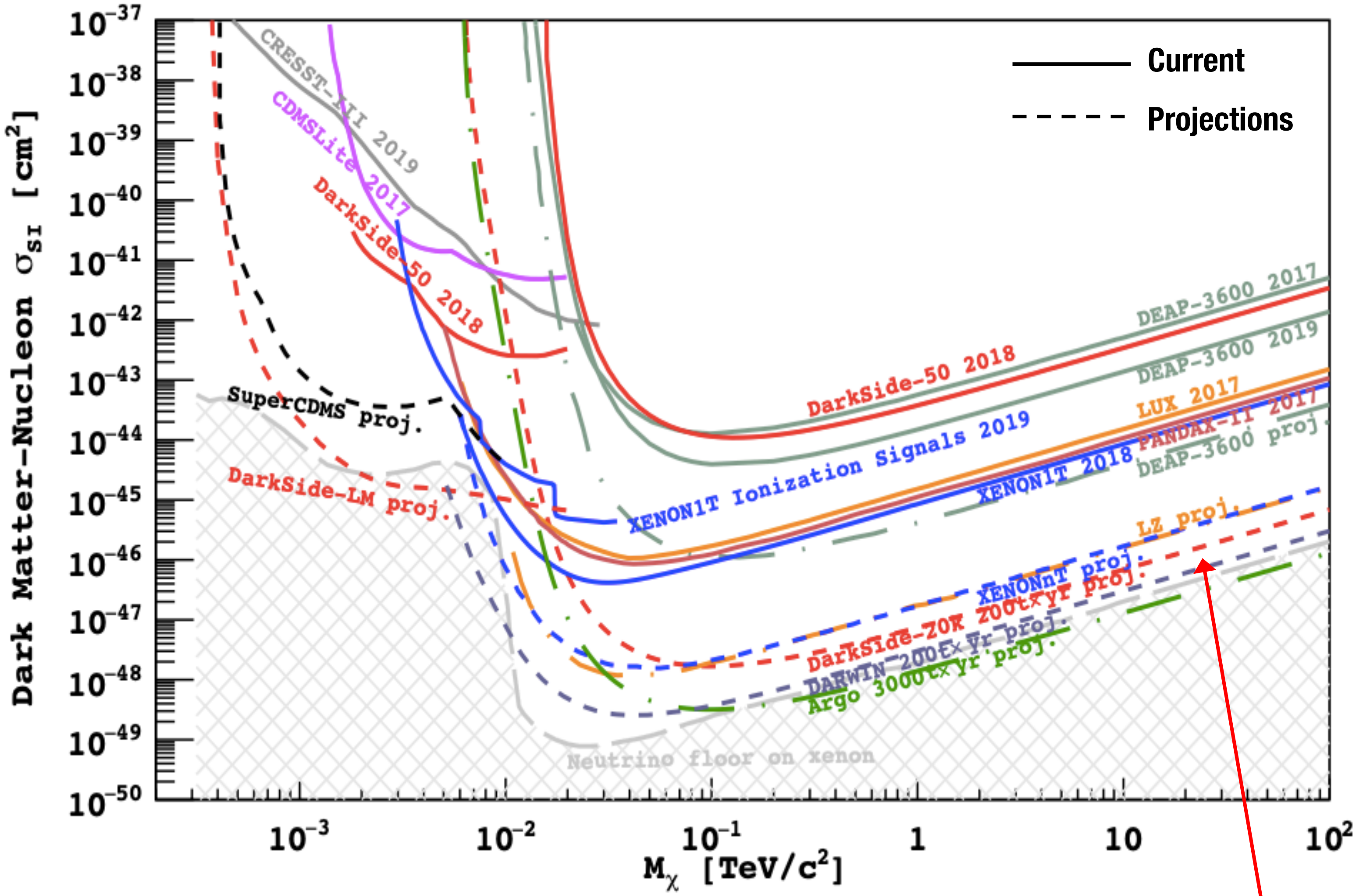
# Conclusions

**DarkSide leads the WIMP search at low mass**
DS-50 2015@LNGS with depleted Ar, for $m_{WIMP} < 3.5$ GeV

**Unique discovery potential at high mass**
DS-20k 2024@LNGS, a ”free-background" search, with PSD, purified Ar, new cryostat design, SiPM

**Could reach neutrino floor using DS-20k technologies**
ARGO 2029, 300t

**Construction and test phases started with prototypes**
DS-Proto0 2019@CERN, first working demonstrated test performed




$7.4{\times}10^{-48}$cm$^2$
@1TeV/c$^2$, in ten years run