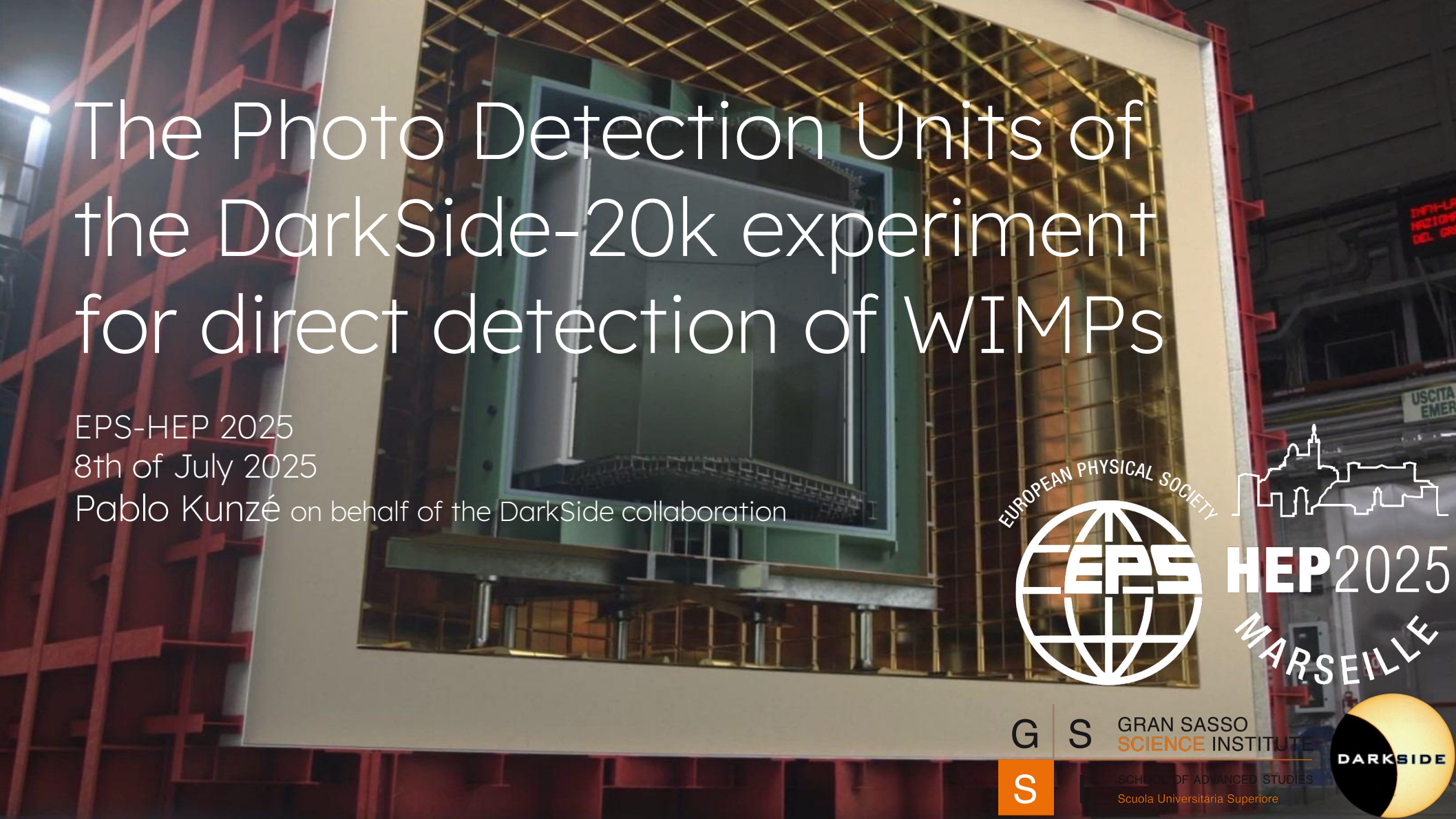
The Photo Detection Units of the DarkSide-20k experiment for direct detection of WIMPs



EPS-HEP 2025
8th of July 2025
Pablo Kunzé on behalf of the DarkSide collaboration

EUROPEAN PHYSICAL SOCIETY
EPS
HEP2025
MARSEILLE

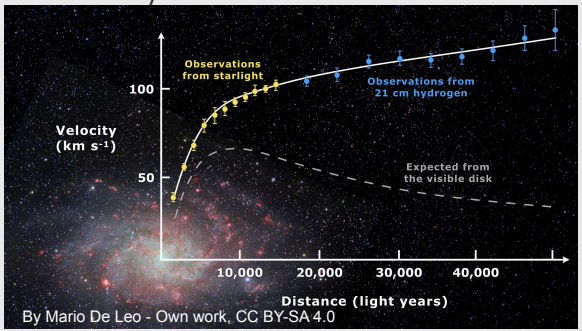
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

DARKSIDE

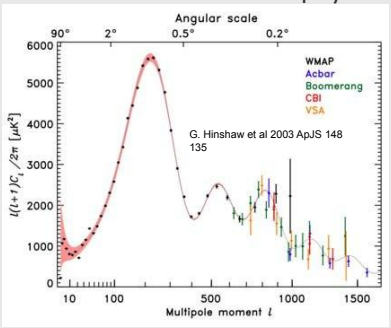
Dark matter summary

Evidence

- Galaxy rotation curve



- CMB anisotropy



- Bullet cluster
- Etc

Properties

- About 27% of the energy content of the Universe
- Interacts gravitationally
- Most likely “cold” (non relativistic)

- → One possible candidate: WIMPs (Weakly Interacting Massive Particles)

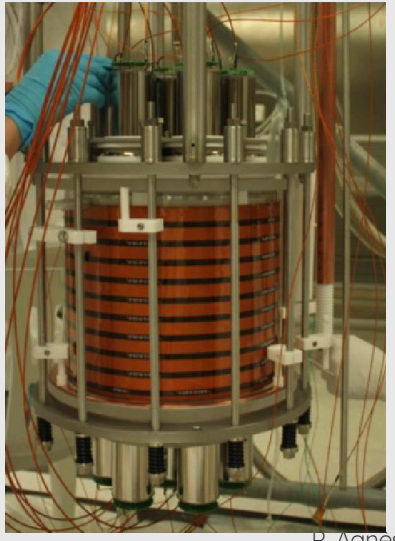
- DarkSide goal: probe WIMP-nucleus cross section and other phenomena (WIMP-e^- interaction, boosted Dark Matter, Supernovae neutrino)

DarkSide experiments

Program

- Liquid Argon Time Projection Chamber (LArTPC)
- Dual Phase (amplification through electroluminescence in the gas phase)
- Discriminate electron and nuclear recoil with pulse shape discrimination
- Underground Argon

Experiments



▸Prototype DarkSide-10

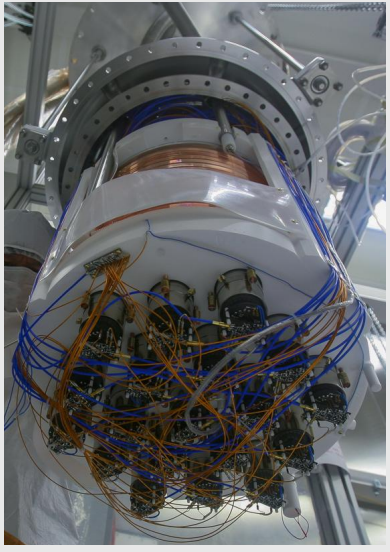
Light Yield in DarkSide-10

T. Alexander et al.

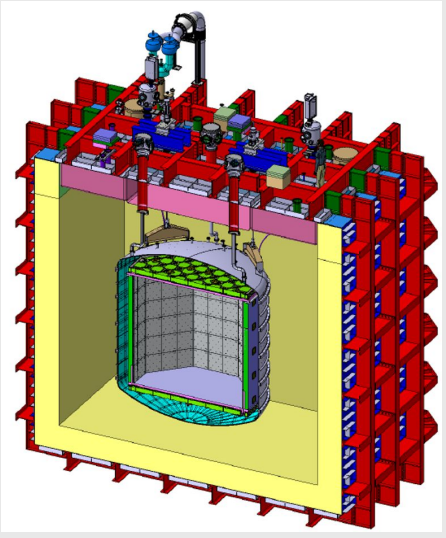
DarkSide-50 ◂
2013-2020

Search for low-mass dark matter WIMPs with 12 ton-day exposure of DarkSide-50

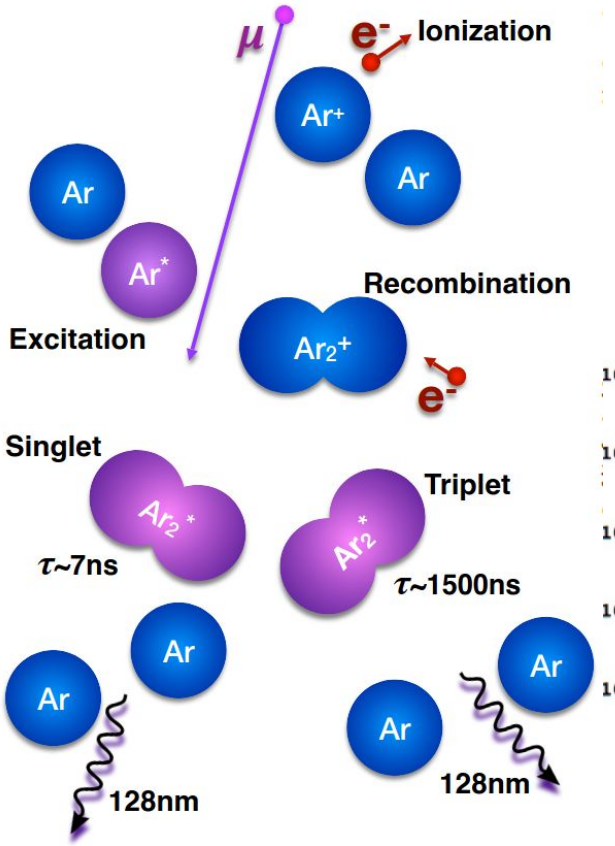
P. Agnes et al. (DarkSide-50 Collaboration)



DarkSide-20k ◂
under construction

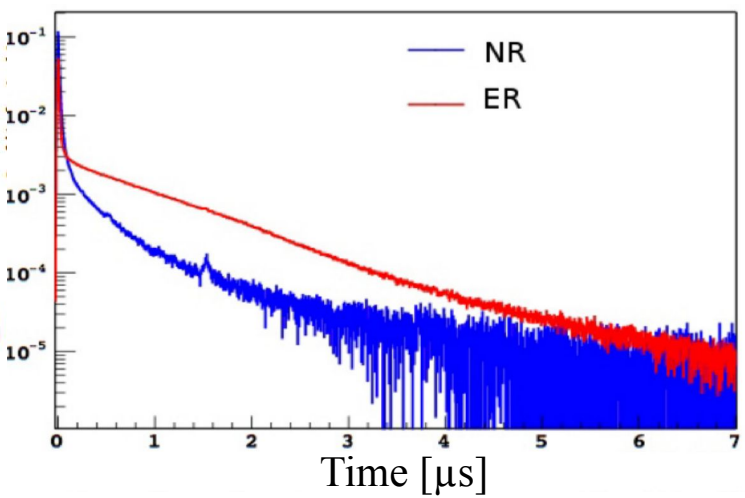


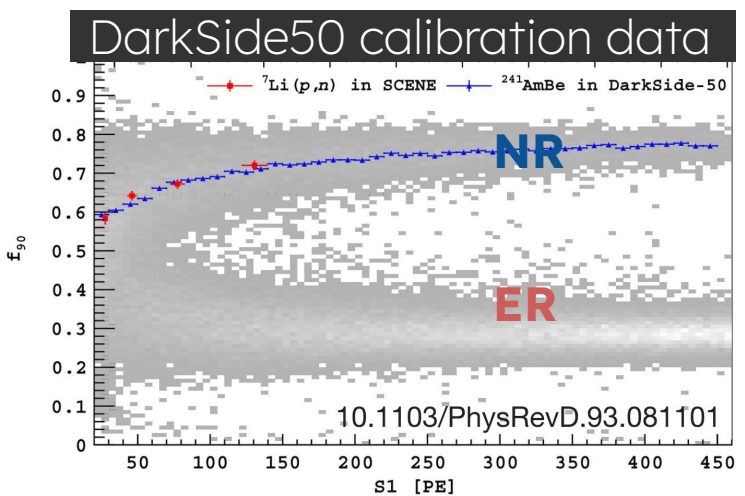
Dark matter direct detection with DarkSide-20k: Pulse shape discrimination in Liquid Argon



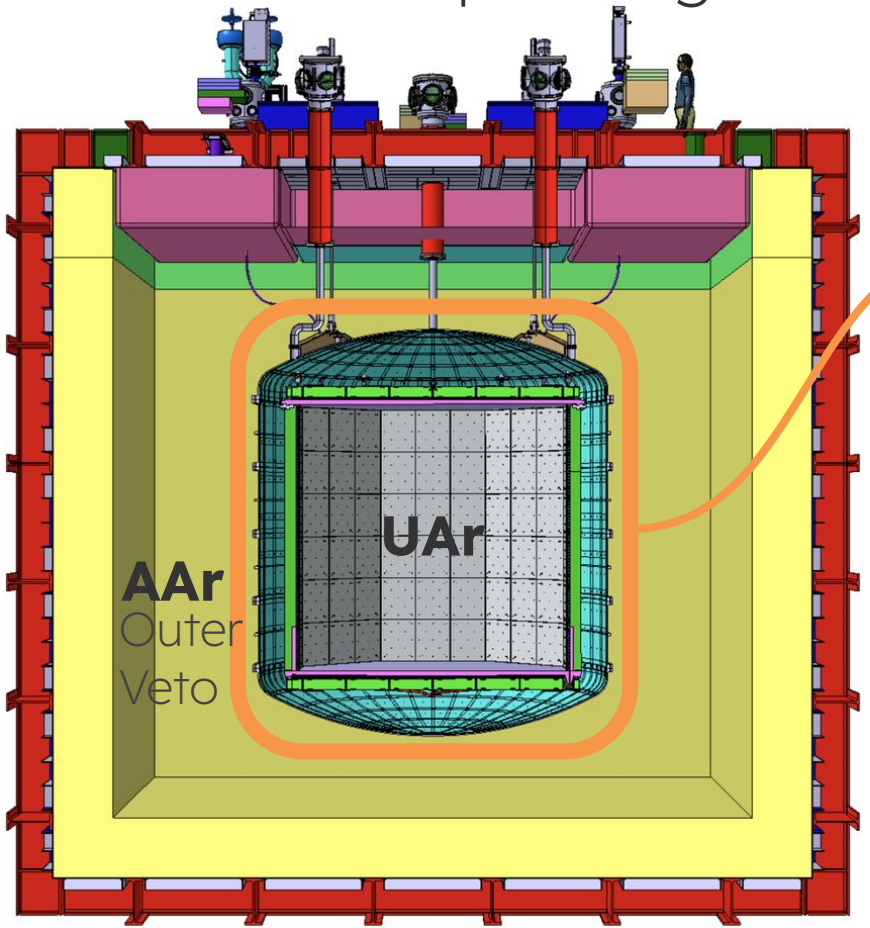
Electron recoils (**ER**) produce more triplet state than Nuclear recoils (**NR**)
Shape of S1 pulse is different -> Excellent discrimination (**1E9**) for ER and NR using **Pulse Shape Discrimination**

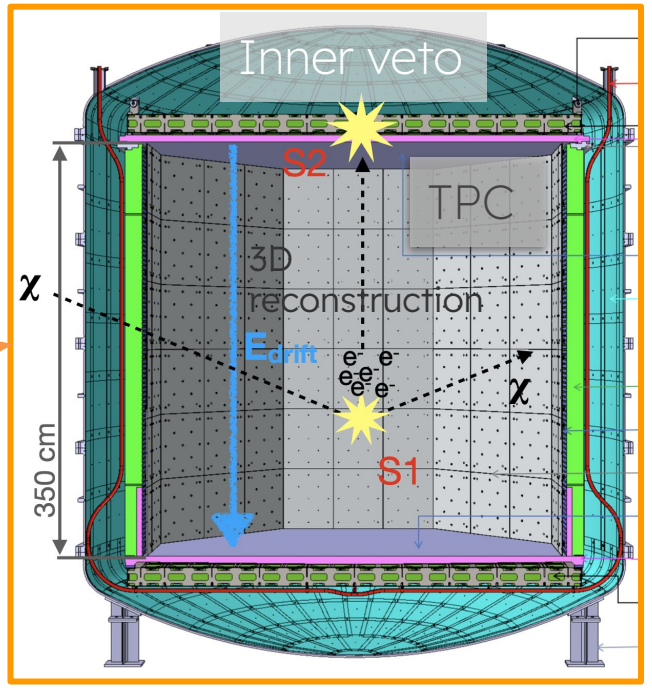
Pulse-shape discrimination against low-energy Ar-39 beta decays in liquid argon with 4.5 tonne-years of DEAP-3600 data
DEAP Collaboration





Dark matter direct detection with DarkSide-20k:
Dual Phase Liquid Argon TPC





Vetos
Reduce neutrons and μ backgrounds

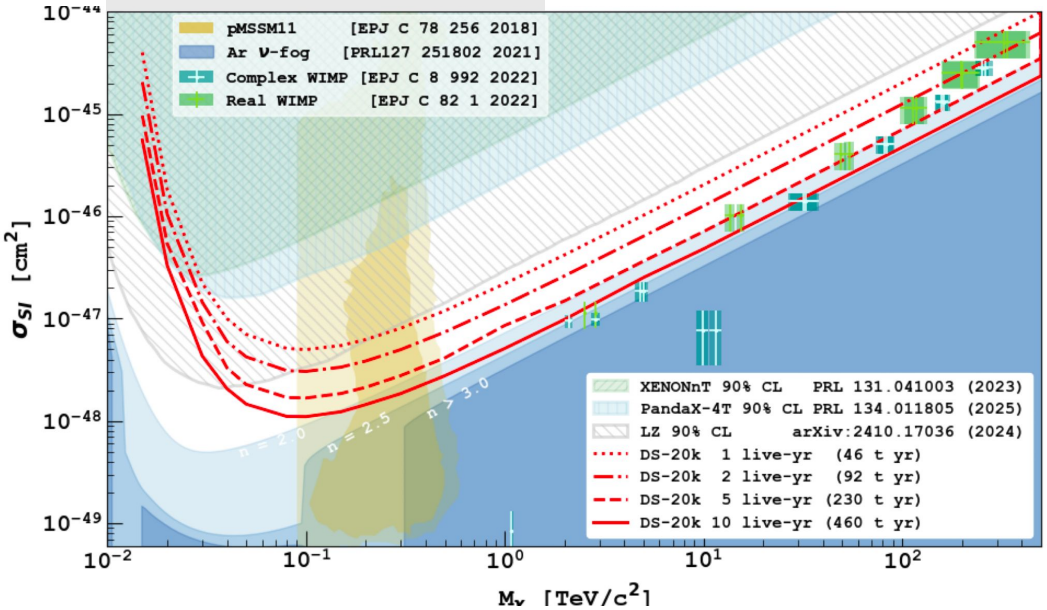
Underground Ar
Argon depleted in radioactive 39Ar
Avoid too much pile up due to scaling up detector

Signal from WIMP
Nuclear recoil in liquid Argon
- S1: Liquid Argon scintillation (128nm) - prompt signal
- S2: Ionization electrons drifting to the top reaching gas phase -> second light signal

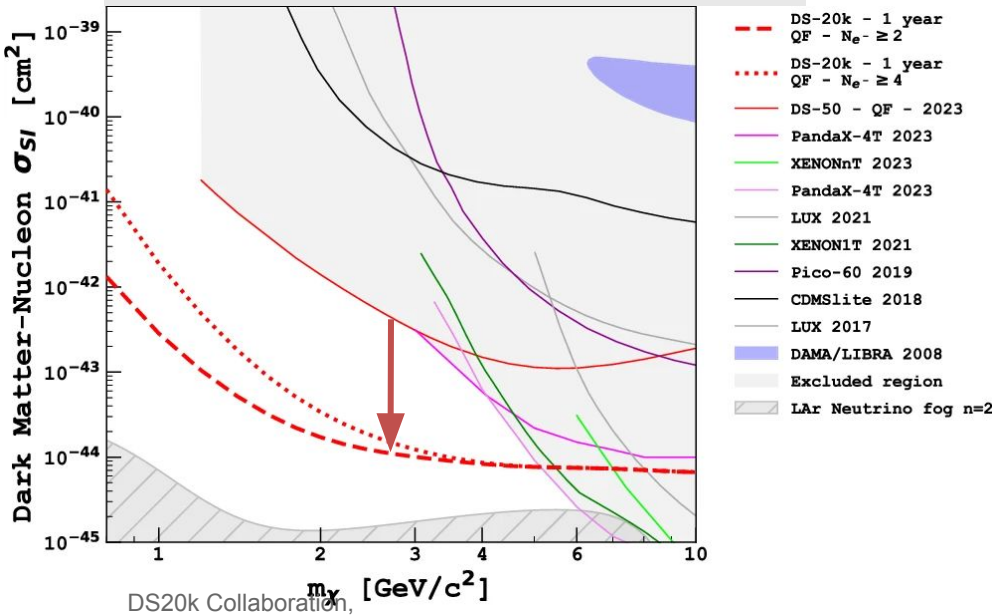
Need background free condition for discovery program

WIMPs Sensitivity with DarkSide-20k

Projected exclusion



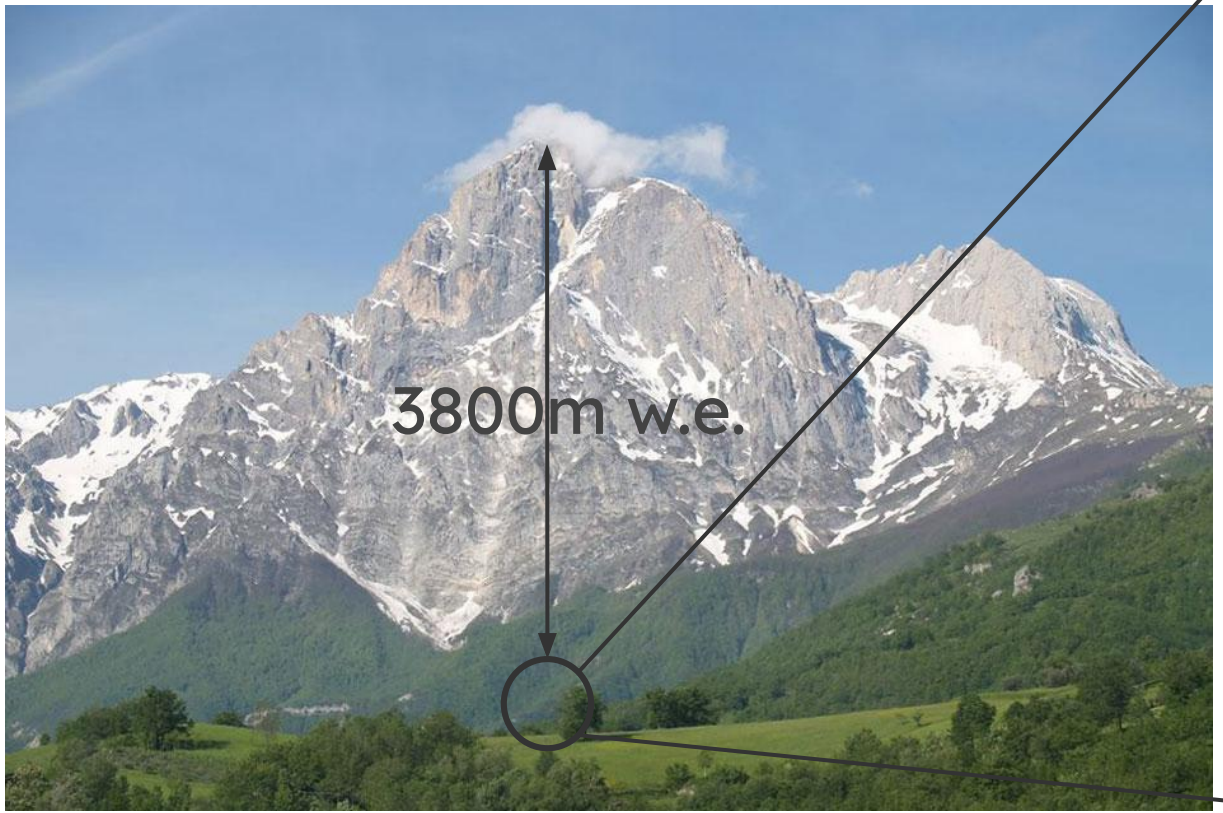
Ionization signal only study:
~x100 improved sensitivity



DS20k Collaboration,
Commun Phys 7, 422 (2024)

See more details on this in Zoe Balmforth's talk

DarkSide-20k location



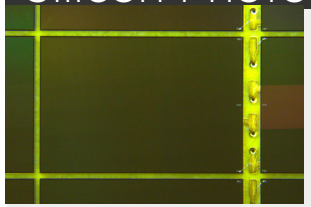
DarkSide-20k under construction at Gran Sasso's underground laboratory (Italy).

DarkSide photodetection from PMTs to SiPMs

PMTs

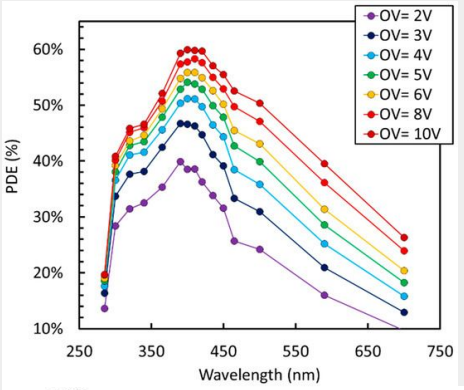
Source of background in DarkSide50

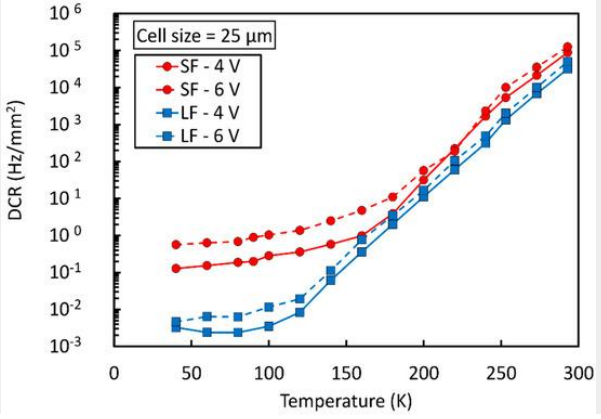
Silicon PhotoMultiplier (SiPM)



Arrays of reverse-biased pn-junction diode operated in Geiger mode.
Absorption of photons triggers an avalanche of electrons.

- Better radiopurity per unit of sensitive area wrt pmts
- Better photo-detection efficiency (>40%)
  - Critical for light yield and thus for PSD
- Better single photon resolution
- Ideal at cryogenic temperature





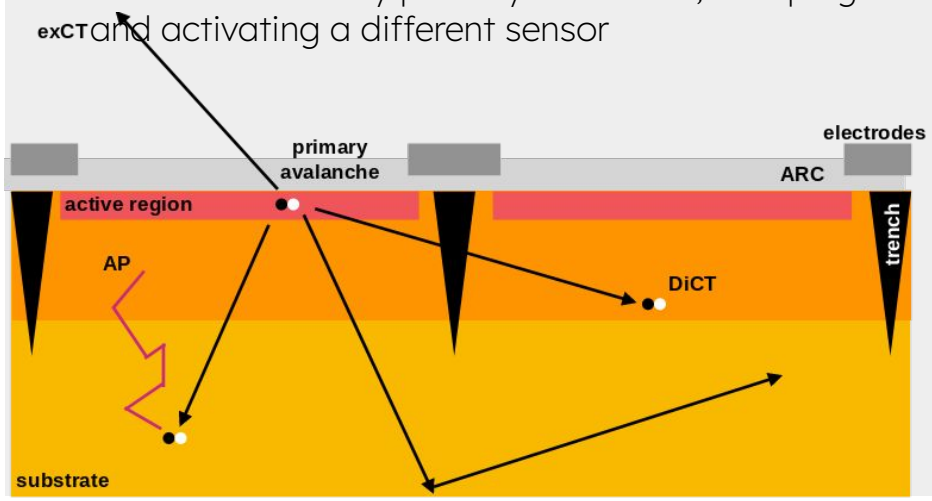
DarkSide SiPMs based on FBK NUV-HD Cryo, developed during several years of R&D
e.g. reduction of Dark Count Rate by 1E3!

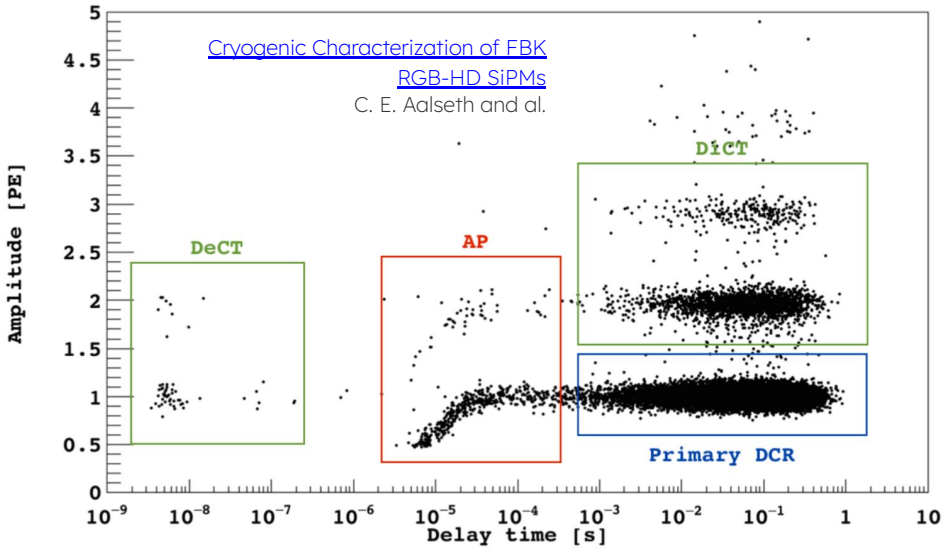
NUV-Sensitive Silicon Photomultiplier Technologies Developed at Fondazione Bruno Kessler
Alberto Gola and al.

Operating SiPMs

Additional sources of correlated noise

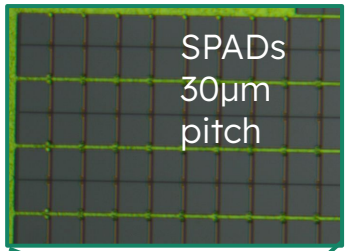
- After pulses (AP)
  - Late avalanche correlated with a previous event (τ ~ 0.1-1 us)
- Direct cross talk (DiCT)
  - Avalanche triggered in neighbour cell in a short time by secondary photon by primary avalanche (10-40% depending on Vbias)
- External cross talk (exCT)
  - Photon created by primary avalanche, escaping the cell and activating a different sensor

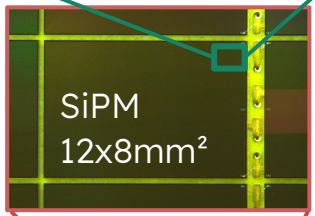


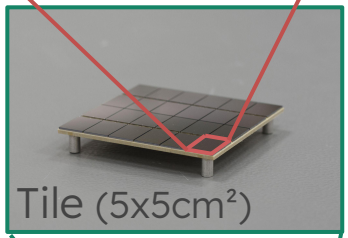


→ Noise can have a **direct impact on the physics** results, needs to be understood, monitored and suppress

DarkSide-20k photodetectors construction







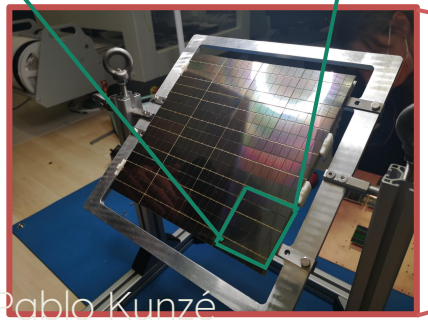
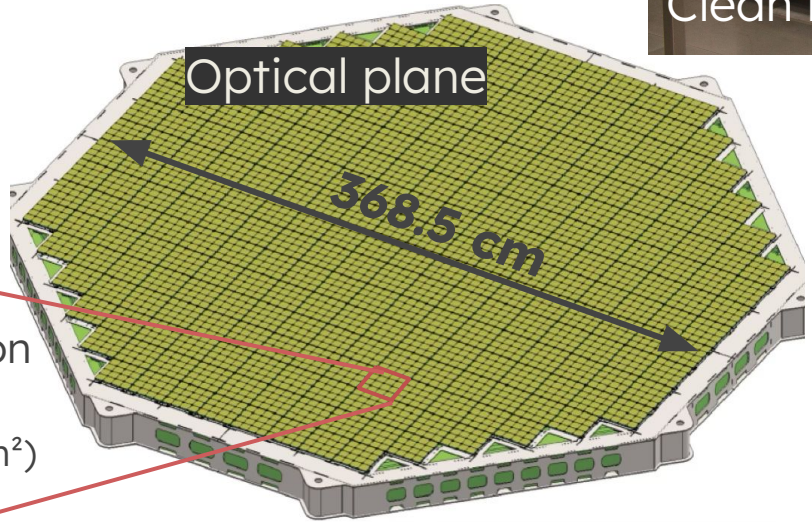


Photo-Detection Unit (20x20cm²)

Production goals

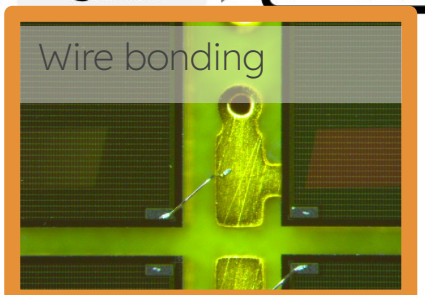
- 528 TPC PDUs (NOA)
- 120 Veto PDUs (UK group)
- Requirements to enable the experiment **physics reach** :
  - Signal-to-noise-ratio single PE > 7
  - Timing resolution < 10 ns (TPC)
  - DCR < 1E-2 Hz / mm^2
  - PDE > 40% (high fill factor)

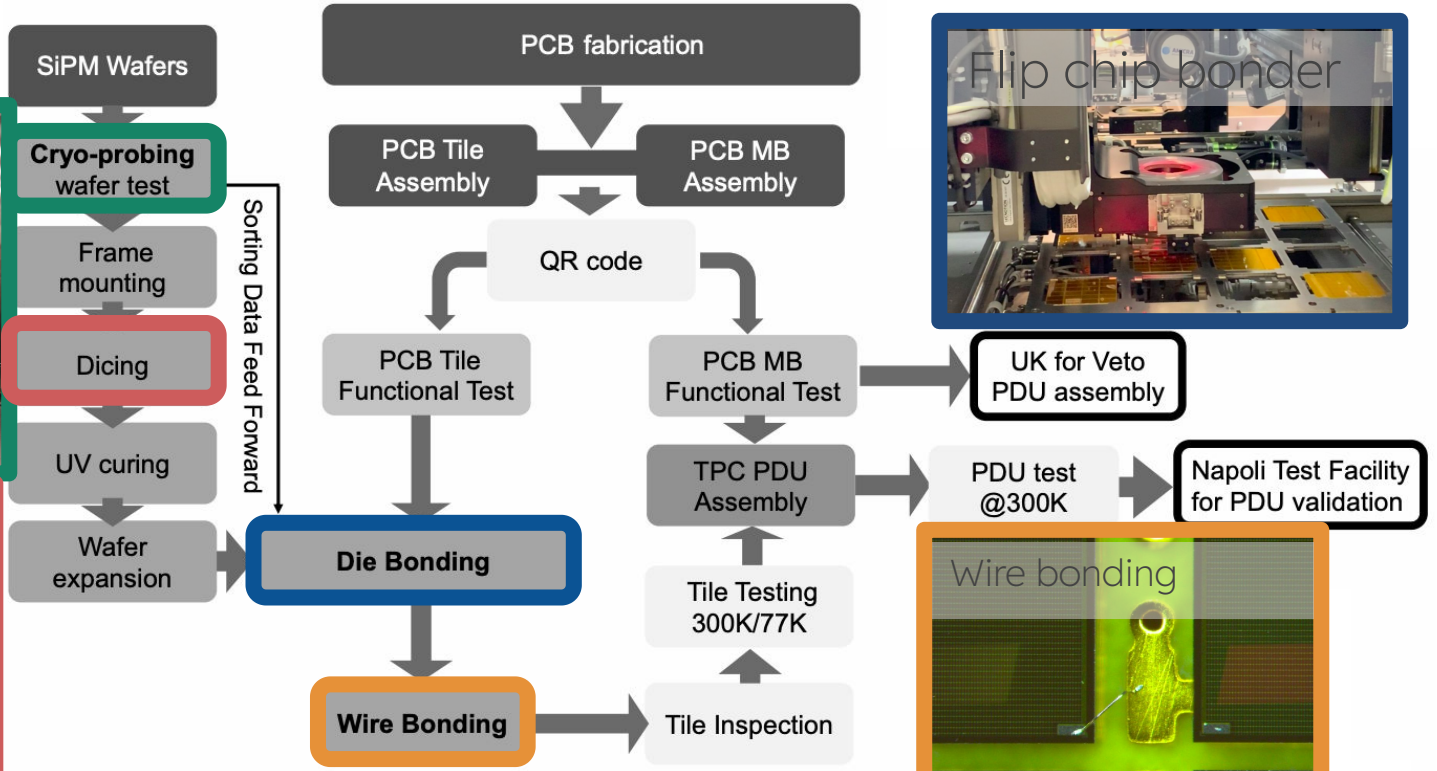


Nuova Officina Assergi (NOA)

NOA

- ISO6 Clean room at LNGS completed in 2023 - 400m²
- Made for large-area silicon based PhotoDetection Unit (PDU) for the TPC and optical plane assembly

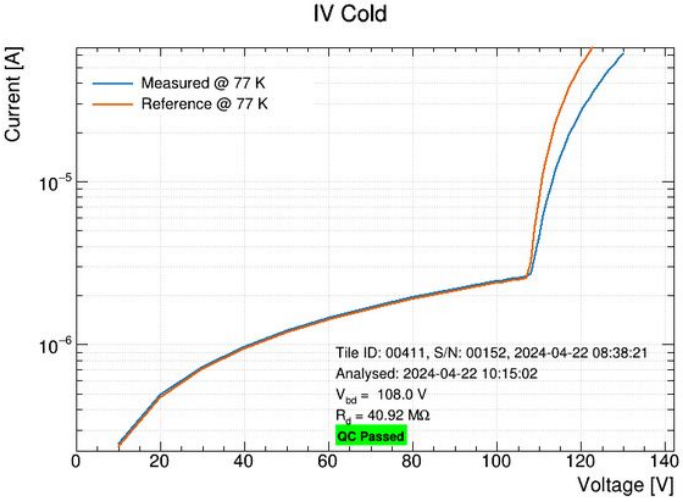


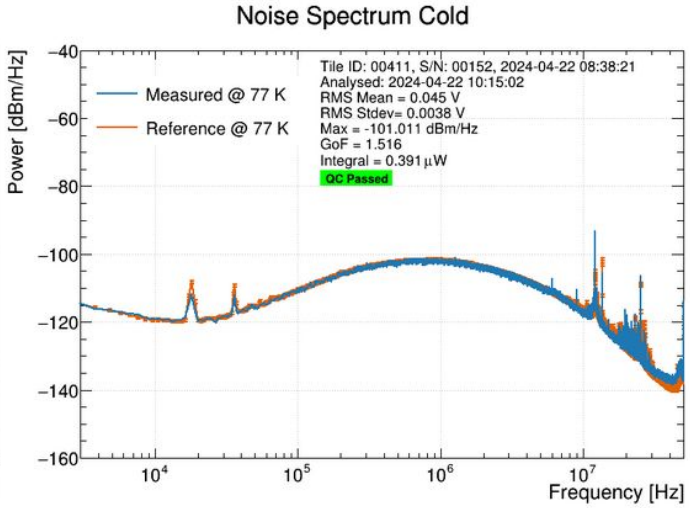


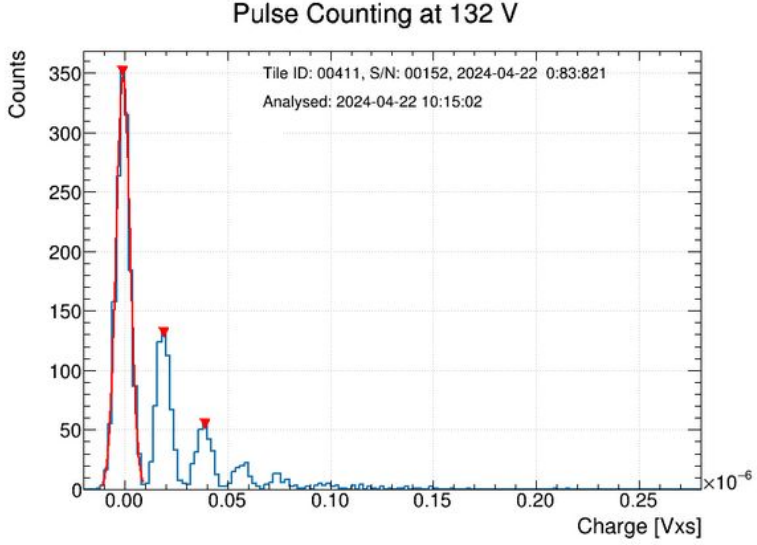
Tile testing

Testing setup in NOA

Example of cold test result







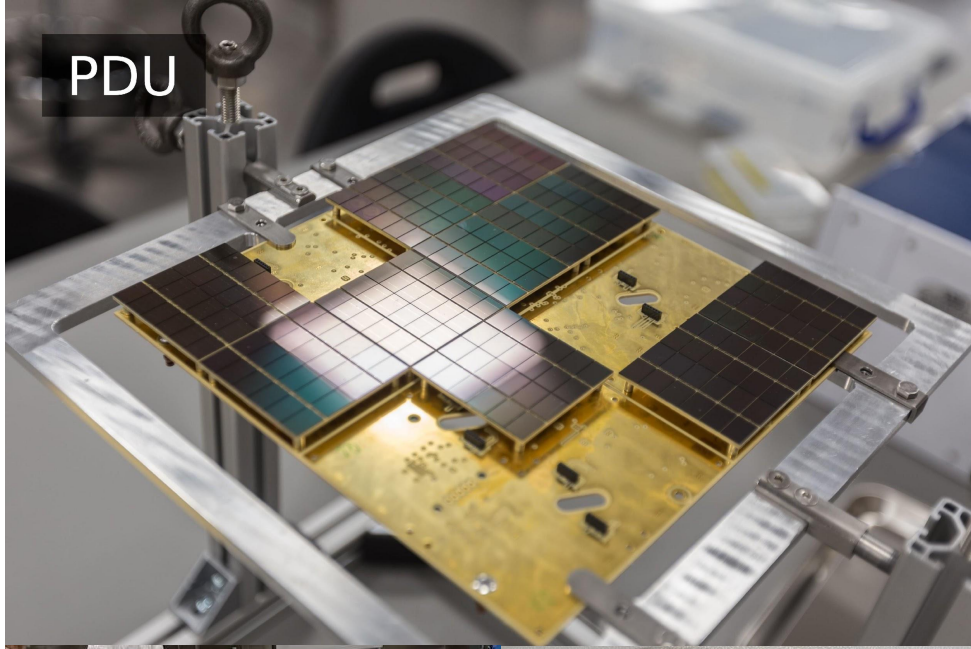
- Test at warm and cold temperature (liquid nitrogen)
- Automated with LabView software and linked to database
- IV curve, noise power spectrum, pulse study for single photon resolution, DCR analysis
- QA/QC criteria on the measured parameters

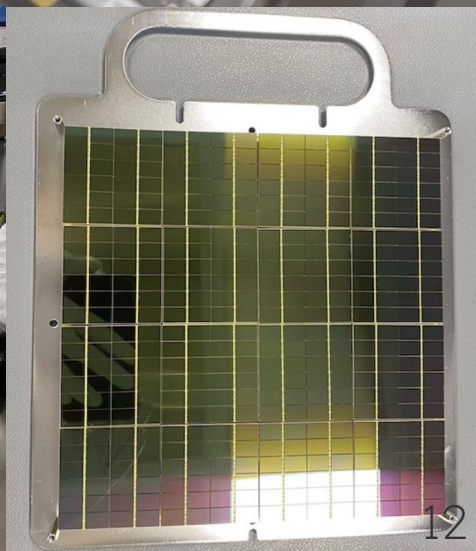
PDU assembly

PDU assembly in NOA

- Tiles passing the tests go to PDU assembly
- 16 tiles mounted on a motherboard to create a PDU
- Specific handler and safe transport box designed by the collaboration

After assembly, PDU are sent for PDU testing





PDU testing

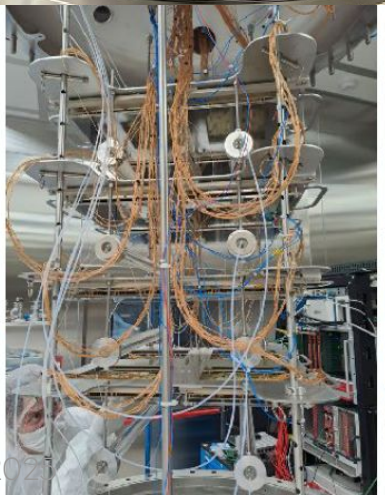
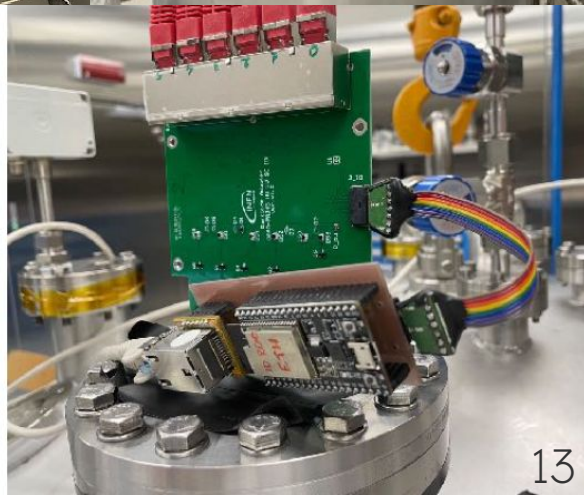
Cryogenic test facility in Naples

- ISO6 clean room
- Setup to test 16 PDUs at once

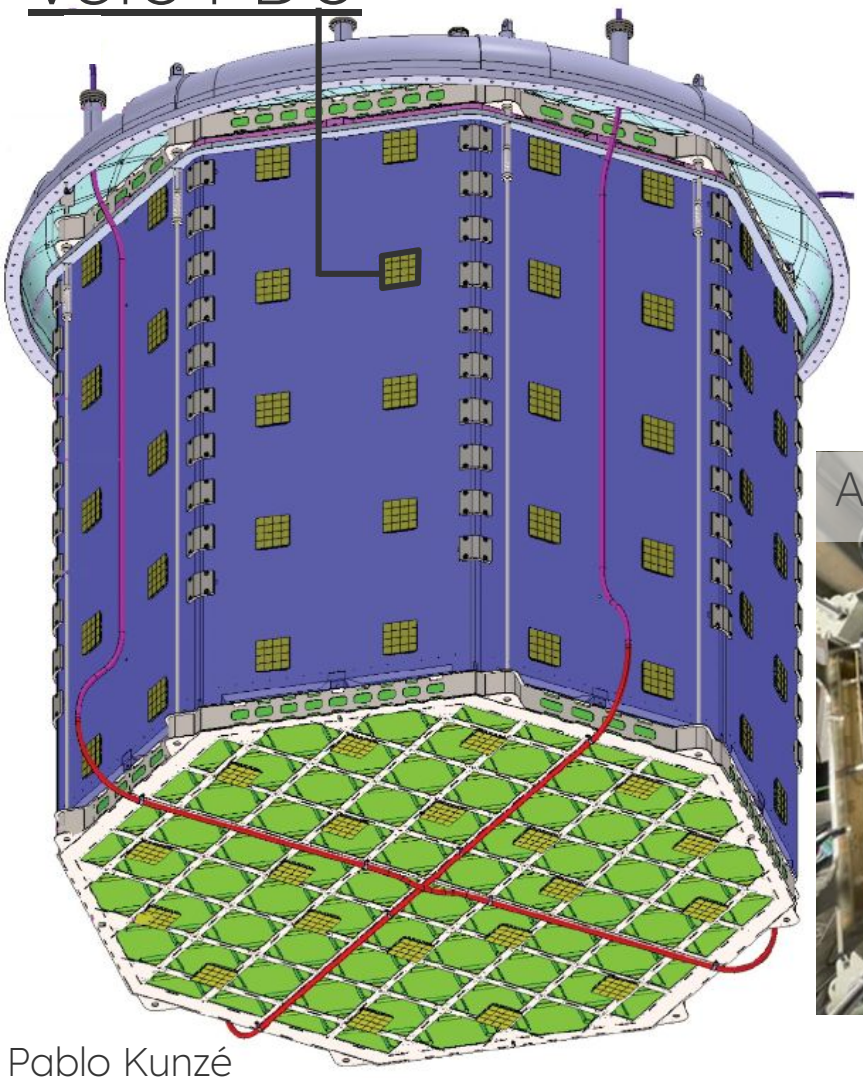
Once cold tested, PDU are sent back to NOA for a last warm test.
Sealed and stored until mounting in the optical plane.



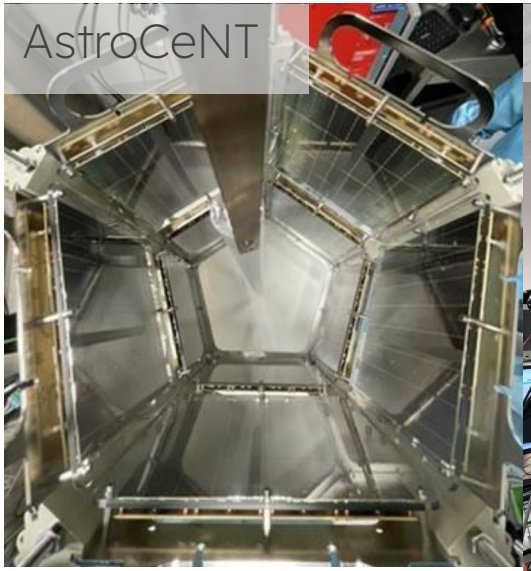


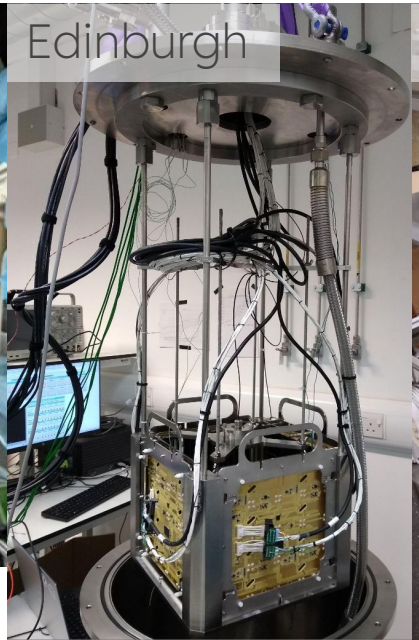




Veto PDU



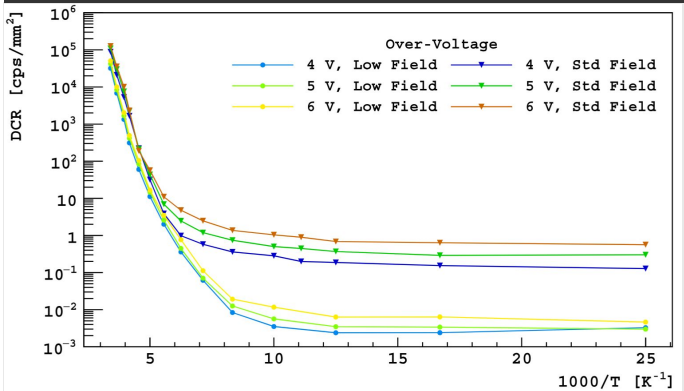
- 120 Veto PDUs
- Same SiPM tested in NOA
- Tiles and PDUs produced in the UK (STFC Interconnect,Liverpool, Manchester and Warwick)
- Tested at: AstroCeNT, Edinburgh, Liverpool and Oxford





Production yields and publications

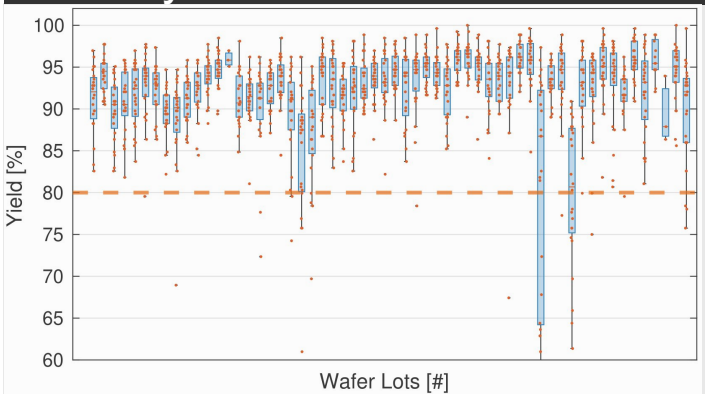
NUV-LF SiPM characterisation



[Cryogenic Characterization of FBK HD Near-UV Sensitive SiPMs]

Acerbi, F. et al. (DarkSide-20k Collaboration)
1e3 reduction of DCR at low temperature
Characterisation of DS20k SiPM paper in preparation

Wafer yield - QA/QC SiPM



[QA QC of the SiPM production for the DarkSide-20k dark matter experiment.]

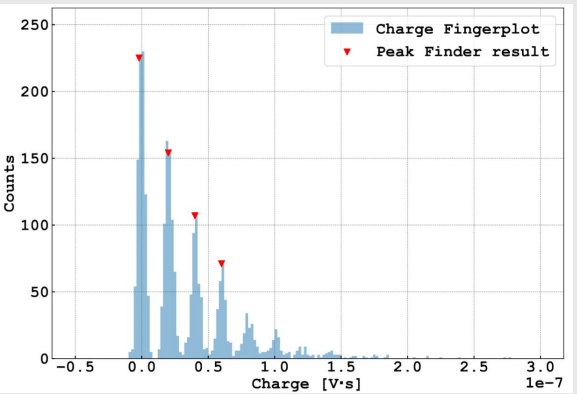
Acerbi, F., Adhikari, P., Agnes, P. et al. (DarkSide-20k Collaboration)

Req > 80% accomplished

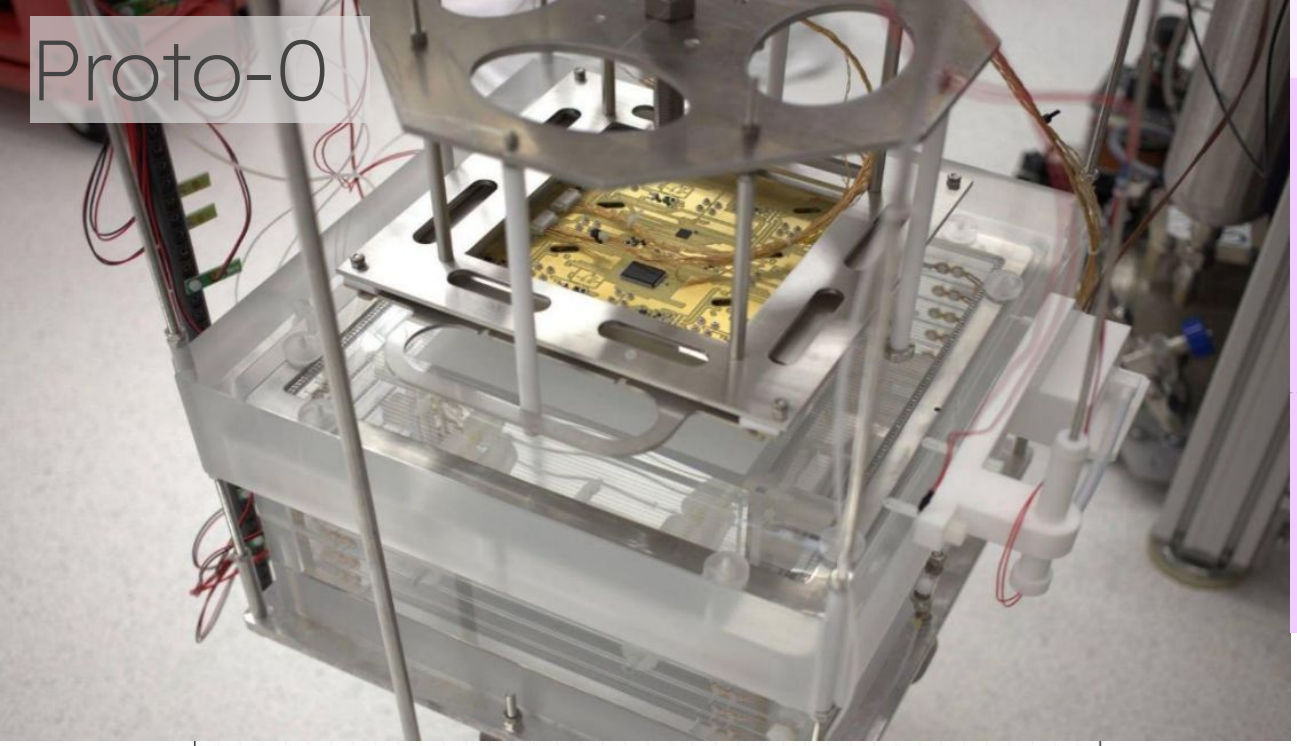
TPC Tile QA/QC

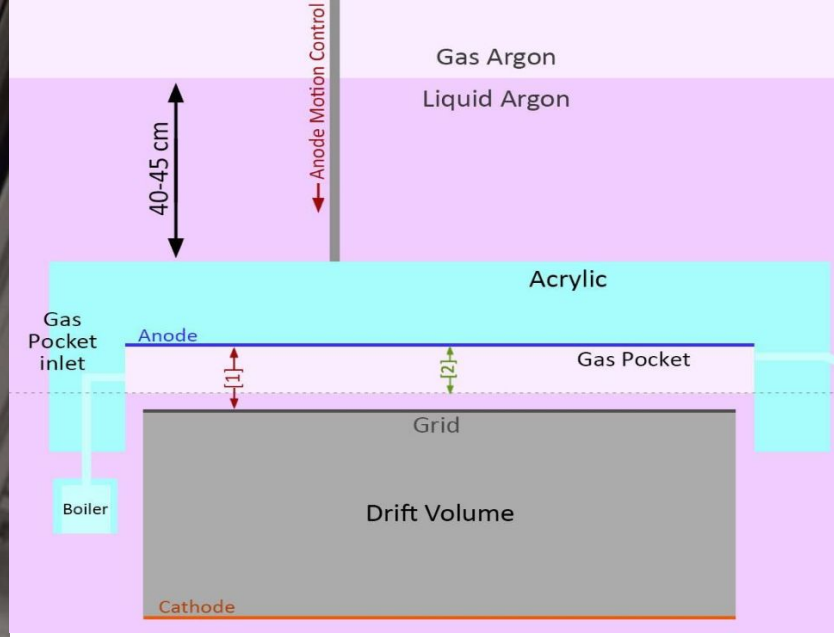
Production, Quality Assurance and Quality Control of the SiPM Tiles
for the DarkSide-20k Time Projection Chamber

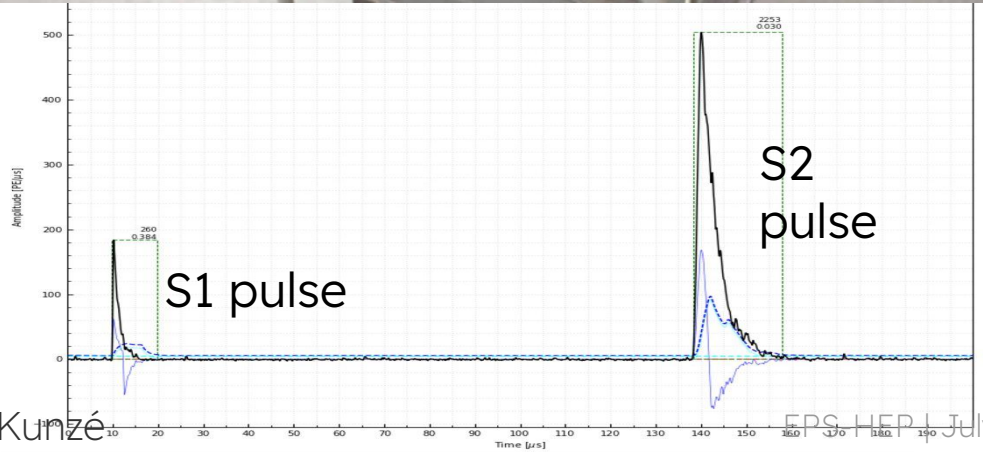
Paper in preparation.



Proto-0







Detector

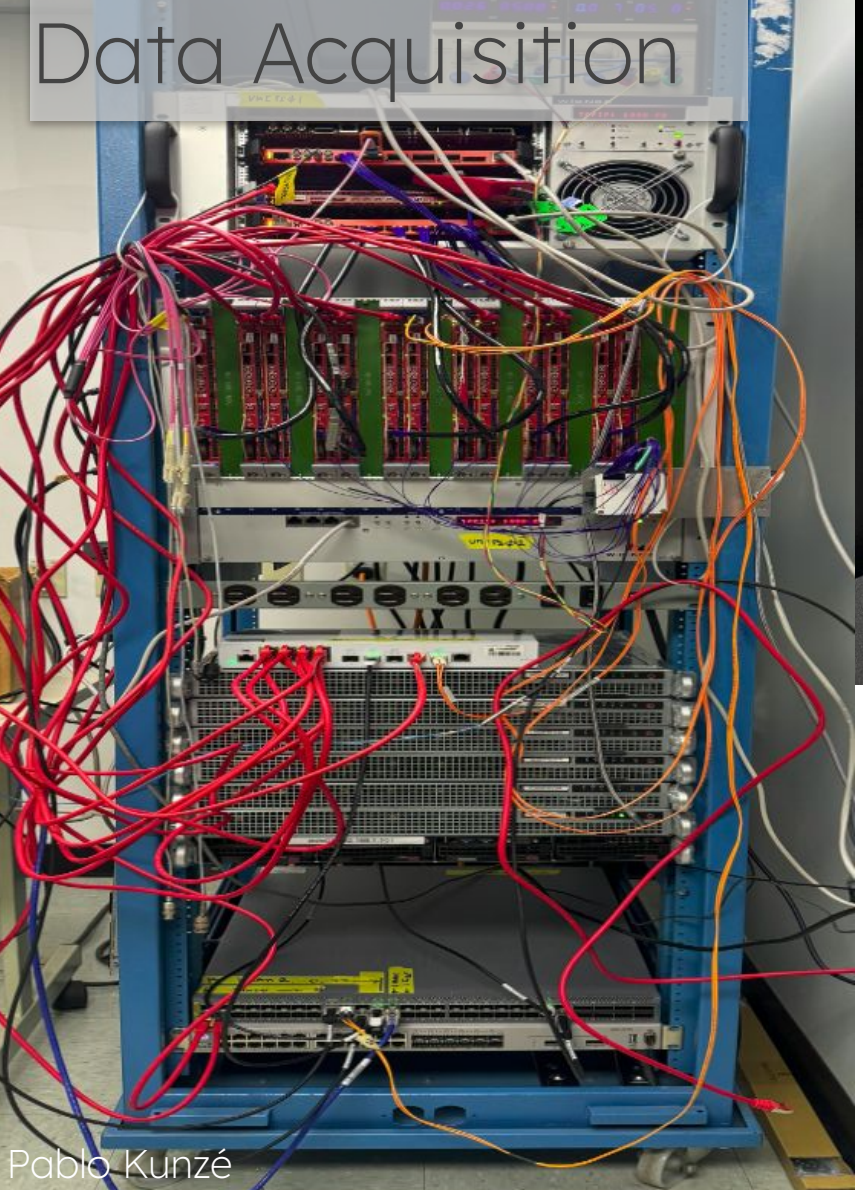
Dual Phase LAr TPC (12cm drift, 20x20 cm^2)
Operated in Napoli
Analysis ongoing
First working TPC with DarkSide PDUs !

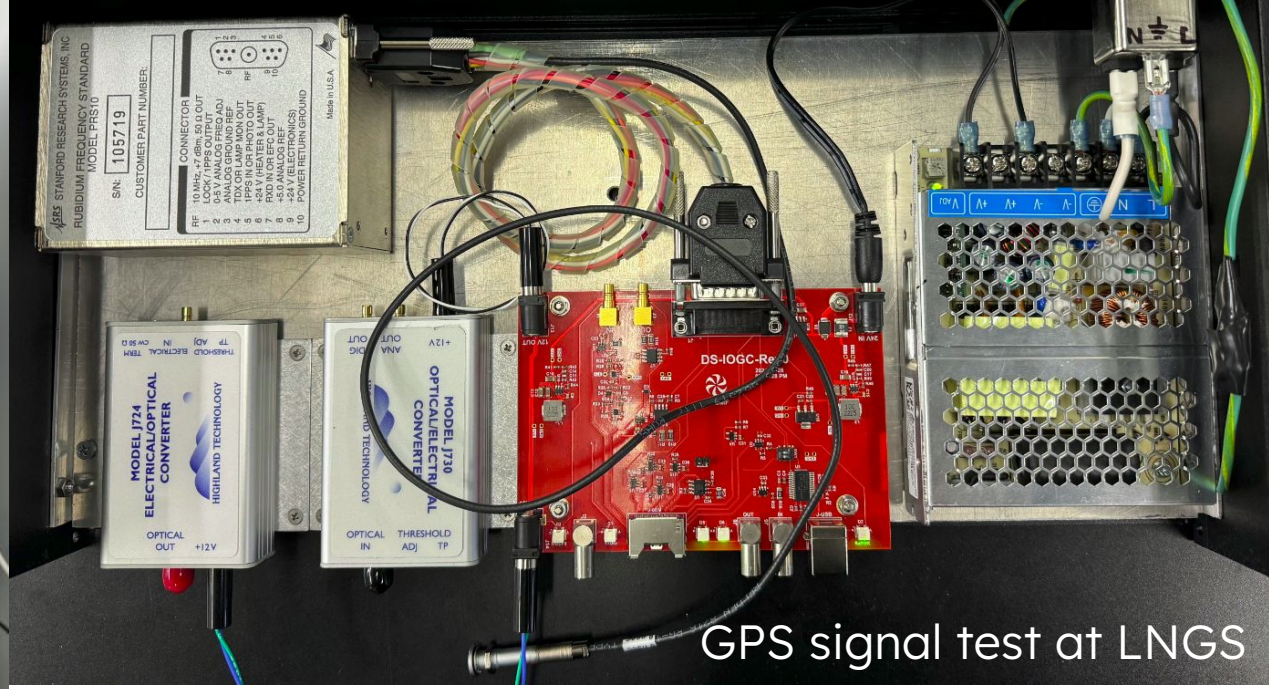
Conclusions

- ➔ DarkSide-20k photosensors represent a real technical advance and are a key point for **the search of WIMPs** and for the **future of astroparticle experiments**.
- ➔ A joint effort from all the collaboration.
- ➔ TPC PDU are produced at NOA, test setup in Napoli
- ➔ Veto PDU are produced in the UK. Test setups in AstroCeNT, Edinburgh and Oxford.
- ➔ Procedures for full production and test of PDUs are in place.
  - Recently hit 10% of TPC PDU and 75% of Veto PDU production
- ➔ DarkSide PDU **successfully used** for the first time in a TPC: **Proto-0**

Thanks for your attention !

Data Acquisition





GPS signal test at LNGS

DAQ challenges

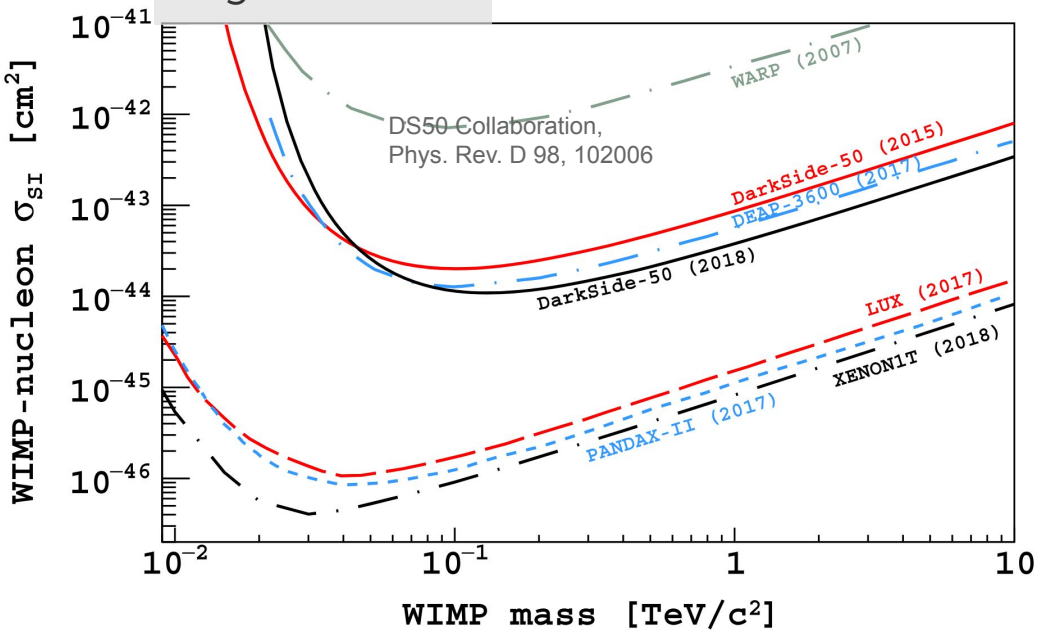
More than 2720 channels (TPC + Veto)
Triggerless operation, aiming at extracting single PEs from each channel (hit time and charge)
Expected event data rate ~100 Hz (1 S1 lasting 10 us, several S2s lasting 20-50 us each)
Filtering and hit/charge data reduction online
Digitize with CAEN VX2745 ADCs
Ensure high efficiency and precise timing (10 ns for PSD)
2 PB/yr of data written to disk

WIMPs Sensitivity with the DarkSide program

DarkSide 50 (final results)

46kg Ar target mass

Bkg-free result



Ionization signal only study:
World leading lowmass WIMPs limit