Characterization of DarkSide-20k Photo Detector Units

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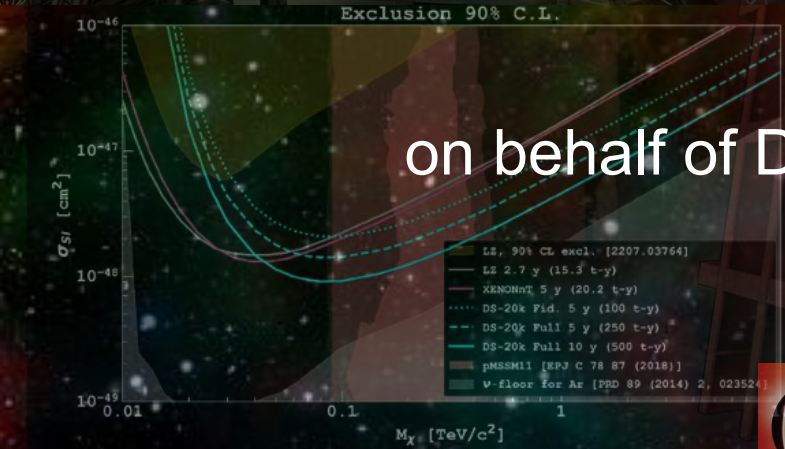
on behalf of DarkSide-20k collaboration

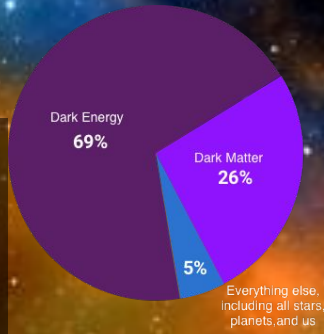
Hong Kong,
LIDINE 2025



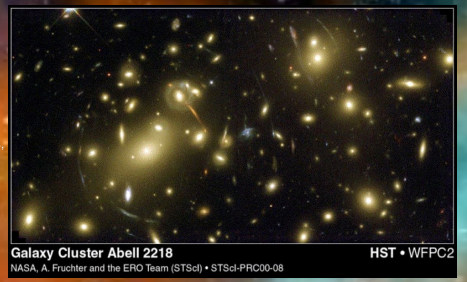
Outline

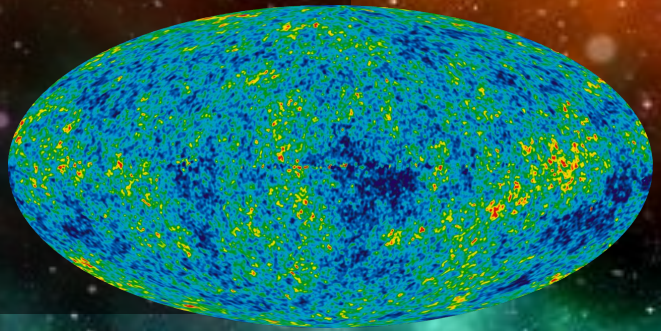
- DarkSide-20k and its optical readout
- Production of the Photo Detector Units (PDU)
- PDU testing facilities
- Tests of PDUs
- QA/QC strategy
- Conclusion

Let's start with the Dark Matter



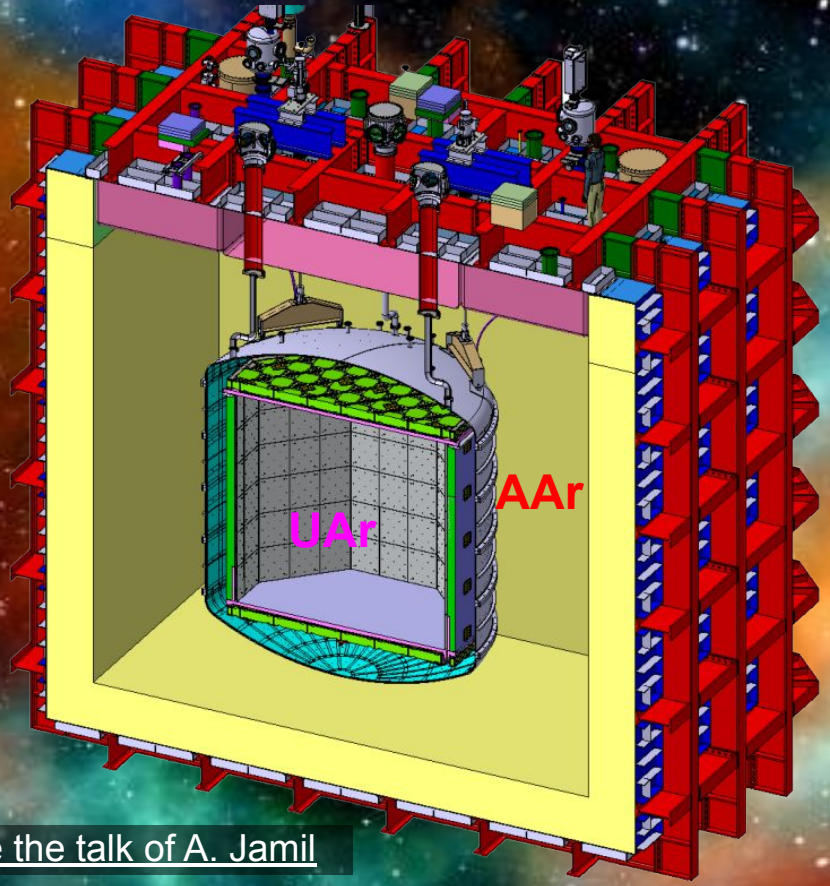
Some Dark Matter evidences





The DarkSide-20k experiment

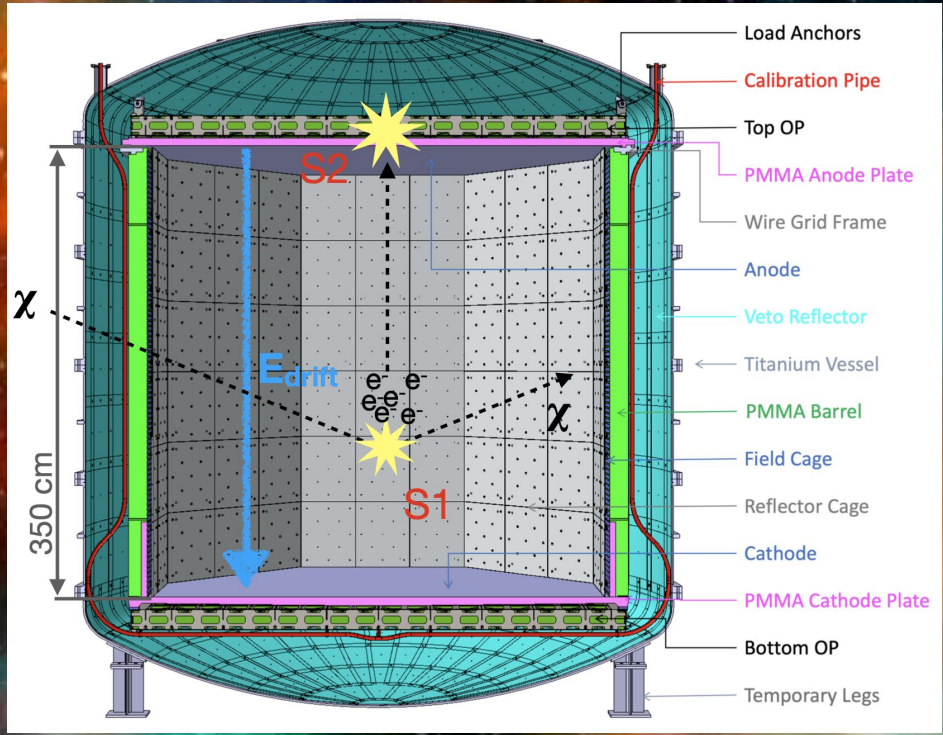
- Double-phase LAr detector for the Dark Matter search in the form of WIMPs
- Under construction @ LNGS hall C (3800 m w.e.)
- Outer veto: DUNE-like membrane cryostat (8×8×8 m3) ~650 t of liquid atmospheric argon (AAr)
- Stainless steel inner detector
  ~100 t of ultra pure underground liquid argon (UAr)
  ~50 t of UAr in the active volume (~ 20 t in fiducial volume)
- Gas pocket: “diving bell” technology
- Fields:
  - clevios coated acrylic (PMMA) walls, cathode and anode
  - wire grid
- Readout:
  - Wavelength shifter: TPB in TPC; PEN foils in vetos
  - 528 (detector) + 152 (two vetoes) SiPM-based Photo Detector Units (PDU and veto vPDU)
  - Enhanced Specular Reflector film (ESR)



See the talk of A. Jamil

Two-phase TPC technology

- Liquid noble gas (Ar)
- Two signals
  - Scintillation (S1)
  - Electroluminescence (S2)
  - λ = 128 nm → wavelength shifter is needed
- Electric field to extract ionization electrons
- Sensitive to the single ionization electron (SE)
- Arrays of photodetectors from top and bottom
- 3D position reconstruction
- Self-shielding or "wall-less" detector



Optical readout in DarkSide-20k

TPC:

- Two optical planes
- ~21 m^2 in total
- ~100% coverage of cryogenic SiPMs
- 2112 channels

Vetoes:

- Same SiPM technology
- 480 (inner veto) + 128 (outer veto) channels

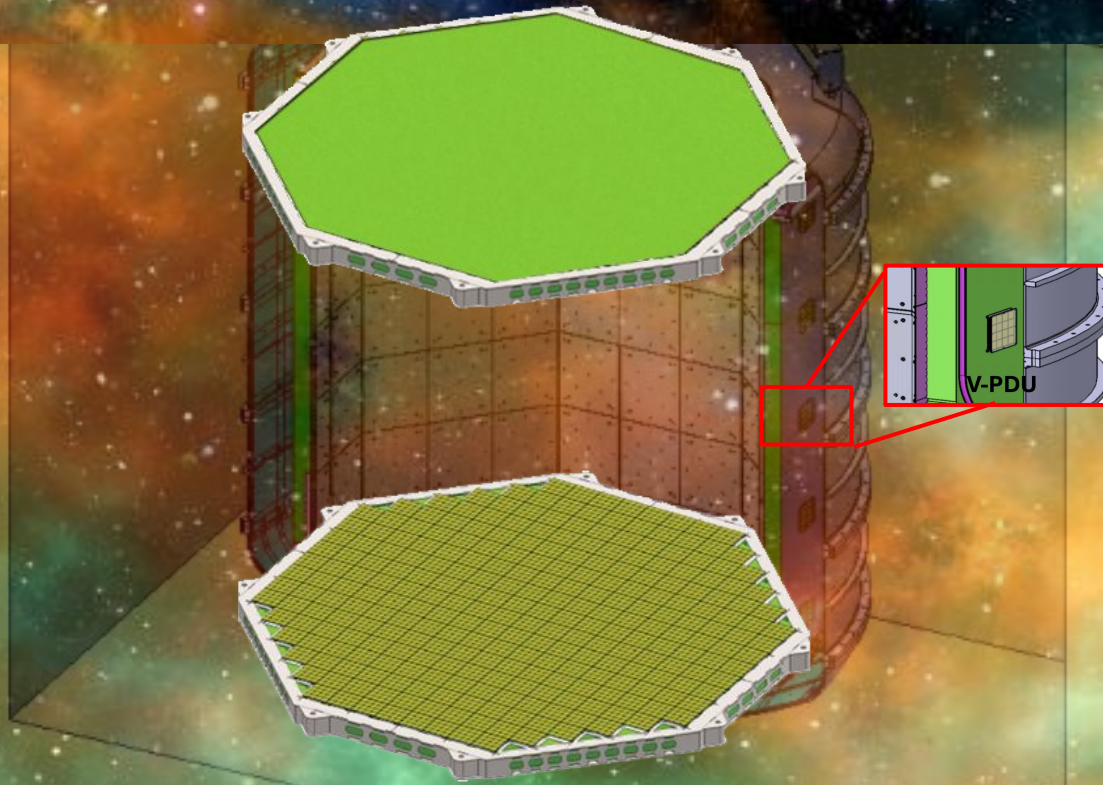


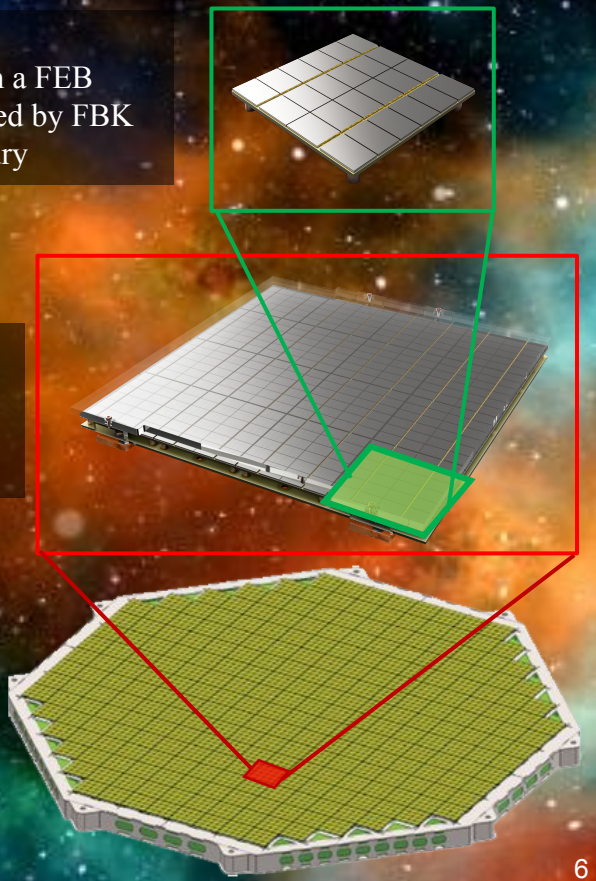
Photo Detector Units

- PDU
- 16 tiles hosted on a motherboard
- 4 readout channels (sum of 4 tiles each → quadrants of 10x10 cm^2)
- Power controller allows to switch on/off each tile independently

Tile: 5x5 cm^2
24 SiPMs directly mounted on a FEB
SiPM: NUV-HD-CRYO developed by FBK and produced by LFoundry

PDU: 20x20 cm^2
16 Tiles Assembled on a Motherboard
4 readout channels

Optical planes: ~2x10 m^2
Total PDUs used (TPC): 528
Readout channels: 2112



PDU production

- TPC PDUs Produced in Nuova Officina Assergi (NOA), Italy
- Including cryoprobing and dicing of SiPMs for the vPDUs

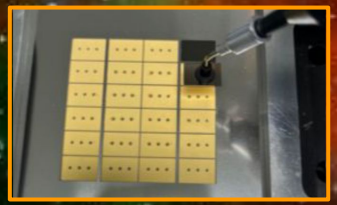
- Tiles test bench in NOA
- Tiles production and QA/QC: https://doi.org/10.48550/arXiv.2507.07226
- Recently accepted by EPJC

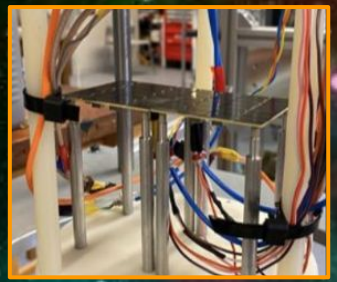
See the talk of D. Gahan

vPDU production

PCB population in Birmingham for Veto PDUs.

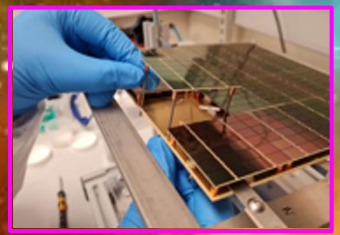
SiPM Die Attach & Wire Bonding in Liverpool and in STFC Interconnect (UK)

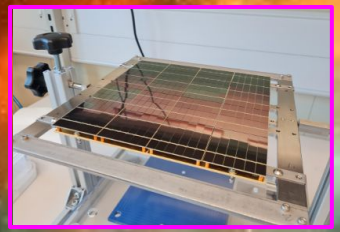




Tile testing in Oxford and STFC Interconnect

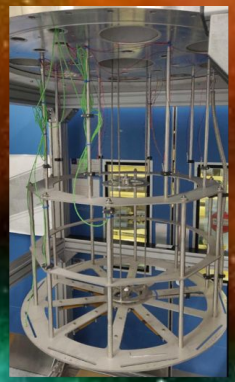
PDU assembly in Manchester and Warwick





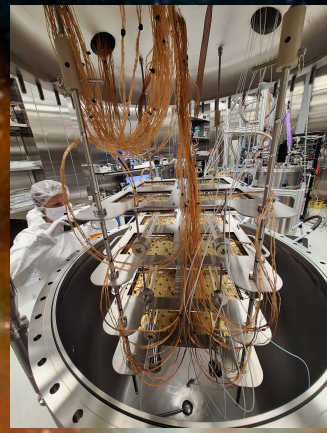
(v)PDU cryogenic testing facilities

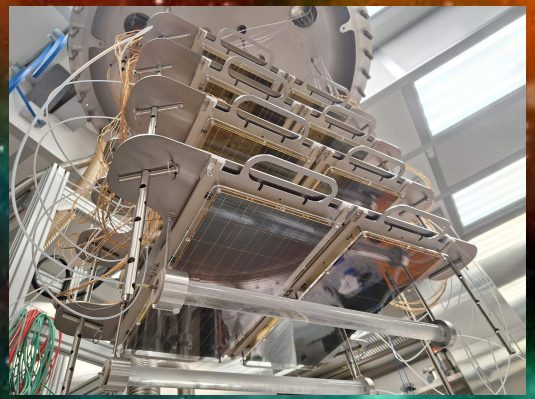
- Cryogenic tests are performed in LN and in LAr
- Several facilities for vPDU testing: Edinburgh, AstroCeNT, Liverpool
  - Capacity: 4, 10 and 16 PDUs
- TPC PDU test facility in Naples
  - Capacity: 16 PDUs



PDU testing facility (PTF) in Naples

- ISO-6 clean room environment
- ~800 L cryostat
- Two external tanks 3000L each
- Fully automated filling system
  - Automatically keep the LN level above PDUs
- ~100 ps Hamamatsu laser (λ = 403 nm)
  - Laser splitter + 8 acrylic rods as diffusers
- 16 PDUs at 4 levels
- CAEN power boards: two A2552 (LV) and one A1619 (HV)
- CAEN VX2740 digitizer





PDU testing pipeline

day 1 | day 2 | days 3 till n | day n+1 | day n+3

Time

Test batch arrival

PDUs unpacking, visual inspection

PDUs installation, warm tests

Cryostat closing

LN fill

Laser calibration

Cold tests

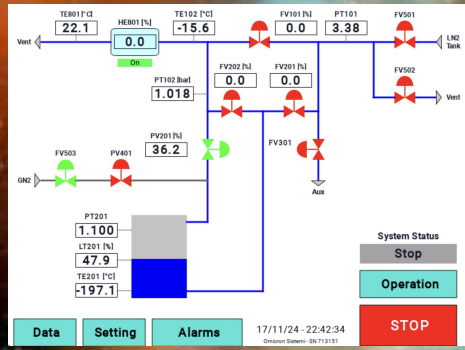
Stability test

LN drain

Warming up

Warm tests Cryostat opening, PDUs packing

- Production mode
  - Currently: 2 weeks per batch (~ 9 days in LN)
- Long tests (~months) are possible thanks to the automated refilling system

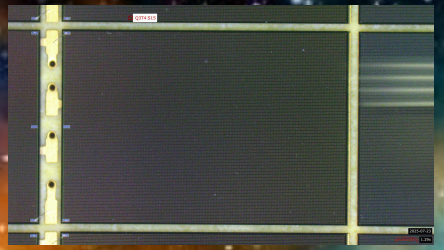


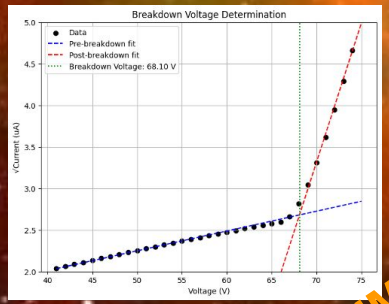
Visual inspection and warm/cold tests

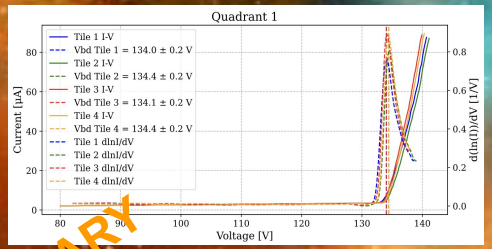
- Before the cold tests
- Visual inspection
  - Contamination and mechanical damages control
- IV curves
  - Double or late breakdown
- FFT
  - Noise condition
  - Spectral shape

UK

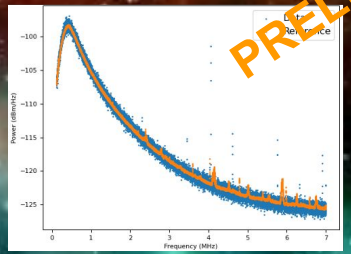
Naples

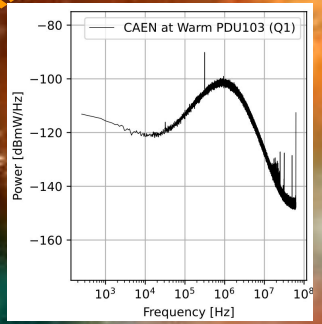






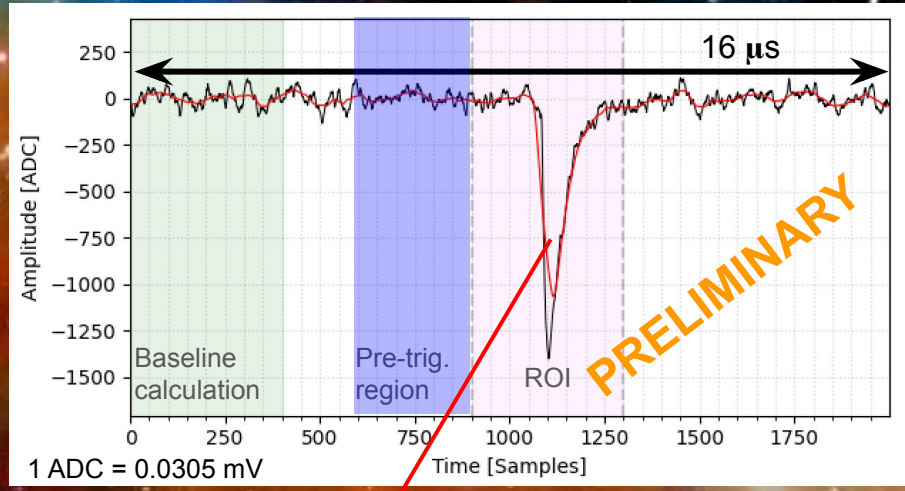
PRELIMINARY

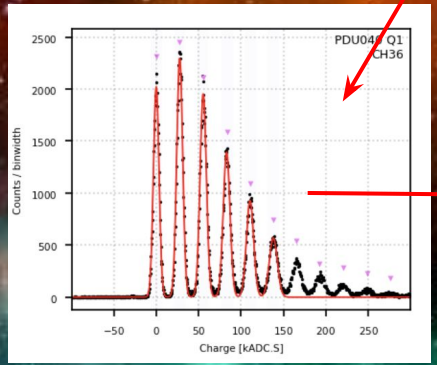


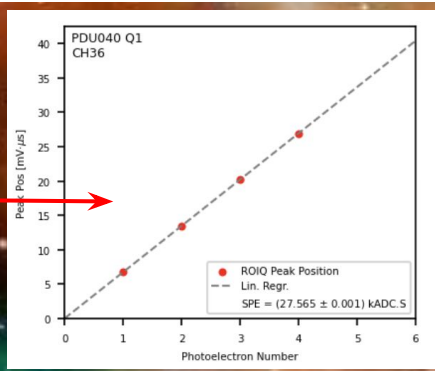


Laser calibration in cold

- After PDU immersed in LN
  - IV curves, FFT
- Laser calibration each 2-4 hours
  - Trigger synchronized with the laser pulse
- Reconstruction
  - Baseline calculation in a first 400 samples (3.2 μs)
  - Integration in the trigger region (ROI)
  - Pulse finder
- Output
  - baseline, baseline std, (+ filtered) auxiliary info
  - ROI: area, amplitude (+ filtered)
  - Pulses + pulses info (time, area, amplitude etc)
- Followed by the high-level automated analysis to get key-parameters
  - Single photoelectron charge (SPE), amplitude, signal to noise ratio (SNR), duplication factor (Kdup), resolution, pulse count rate (PCR) in the pre-trigger region

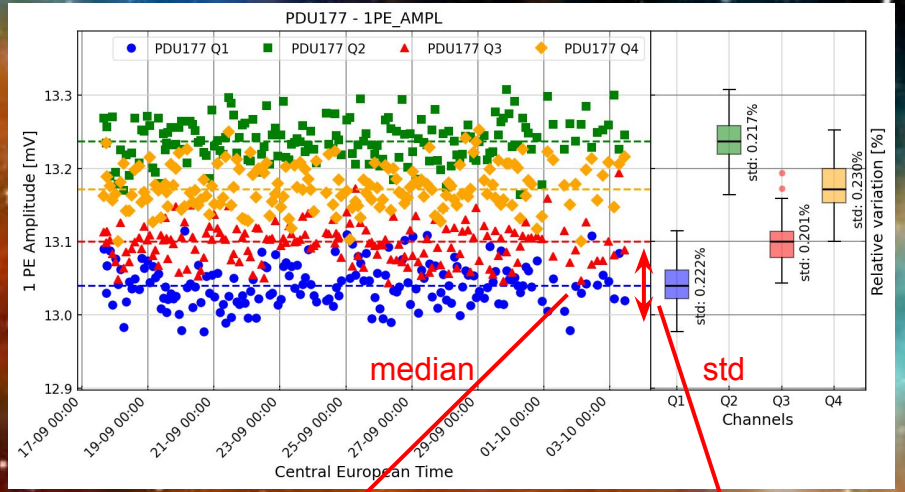


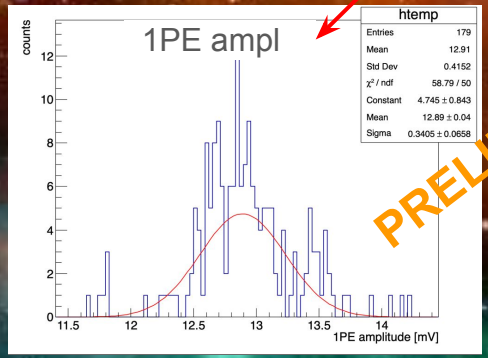


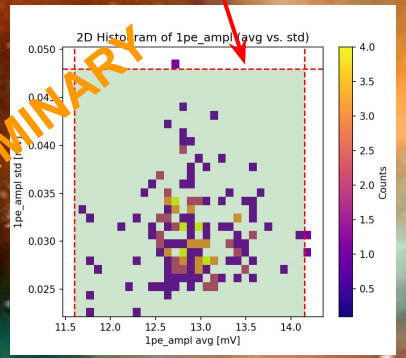


Stability test

- Stability of all observables in time during the test in LN
- 2D parameter space
  - Median
  - STD
  - For each metric
- All deviations are inspected in a single tile mode
  - Turn on only one tile per quadrant
  - Problematic tiles are substituted in NOA



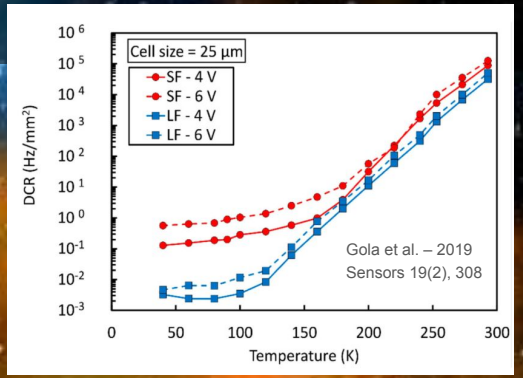


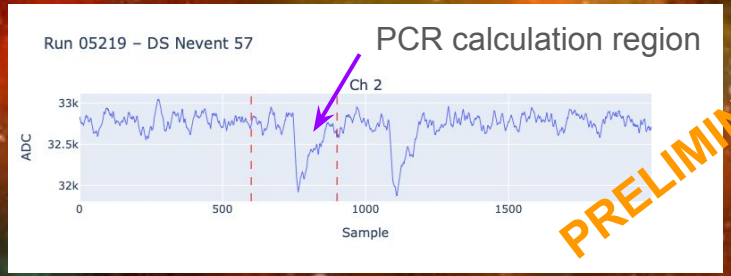


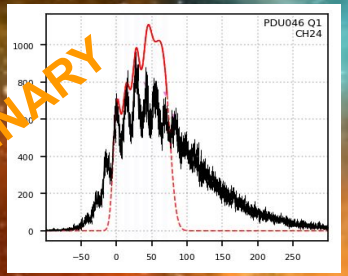
PRELIMINARY

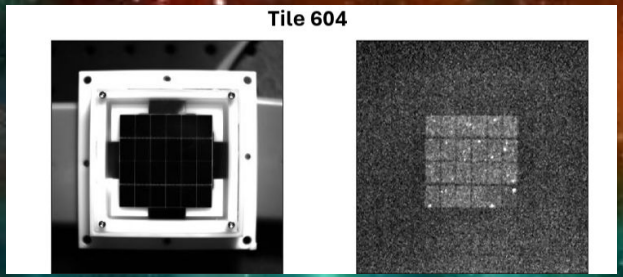
Dark count rate (DCR)

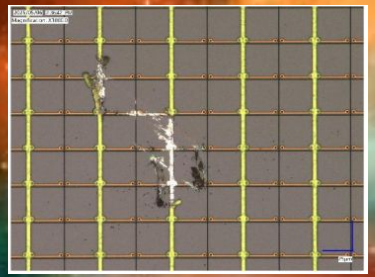
- High DCR is a potential problem
  - Can mimic low energy events
  - Influence on DAQ
  - Worsening resolution
- FBK SiPMs (NUV-HD-CRYO) developed to have low DCR
- A few SiPM can have high DCR
  - Microscopic defects
  - Hot spots
- Can be spotted by calculating the number of pulses in the pre-trigger region (only ~ 2% of tiles, passed other criteria have this problem)
- Implementing CMOS imaging at NOA to catch the problem of high DCR in advance





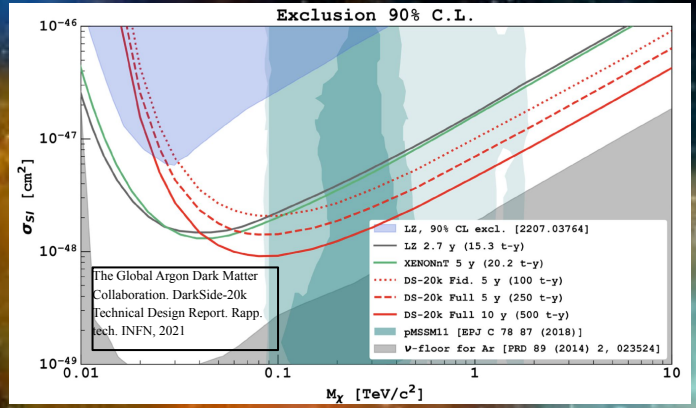


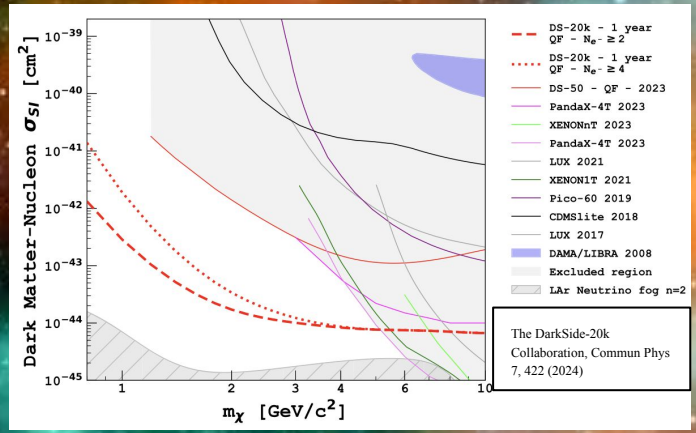




QA/QC strategy

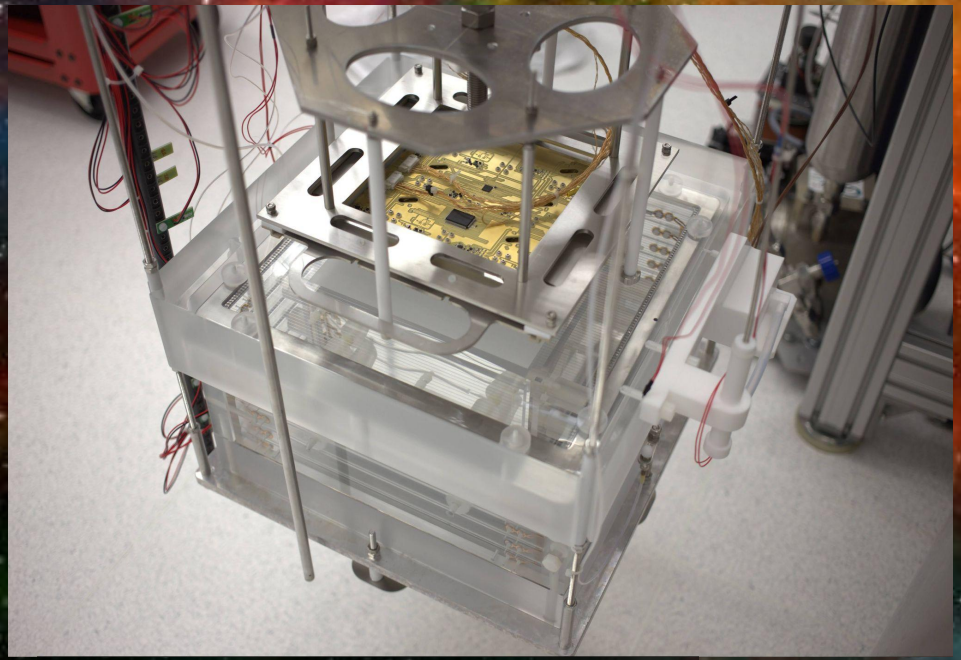
- Tested ~ 15% PDUs (out of 528) and ~50% vPDUs (out of 120)
- Preliminary constraints defined based on the observed distributions of good PDUs
- External constraints based on physics needs and DAQ
  - More stringent for the TPC PDUs
  - Detector response uniformity
  - Influence on the sensitivity
  - DAQ limitations
  - Work is in progress
- Most of the problems are of single tile (reworkable)

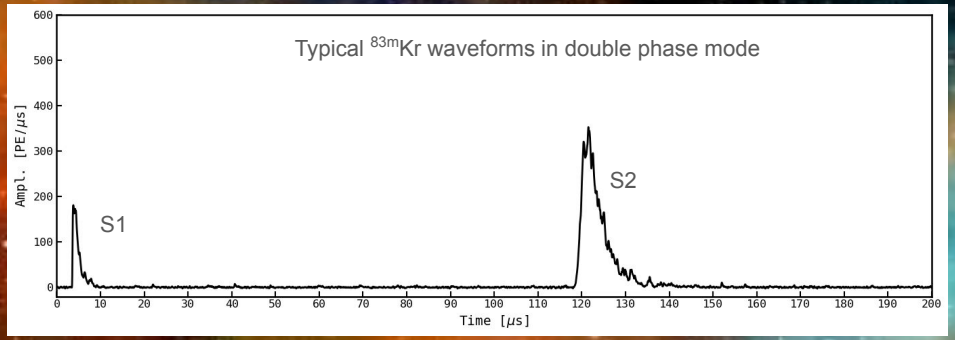




See the talks of M. Walczak and D. Franco

First long PDU operation in LAr TPC





- Proto-0: First fully operational test of DS20k PDUs in LAr TPC
- Stable operation during several months
- Good performance during the test

See the talk of G. Matteucci

Conclusion

- Production and characterization of the PDUs for DarkSide-20k is ongoing
- ~ 15% TPC PDU and ~50% vPDU are tested in LN
- Most of the problems are on the level of single tiles (reworkable)
- First fully operational test of DS20k PDUs in LAr TPC (Proto-0) was done