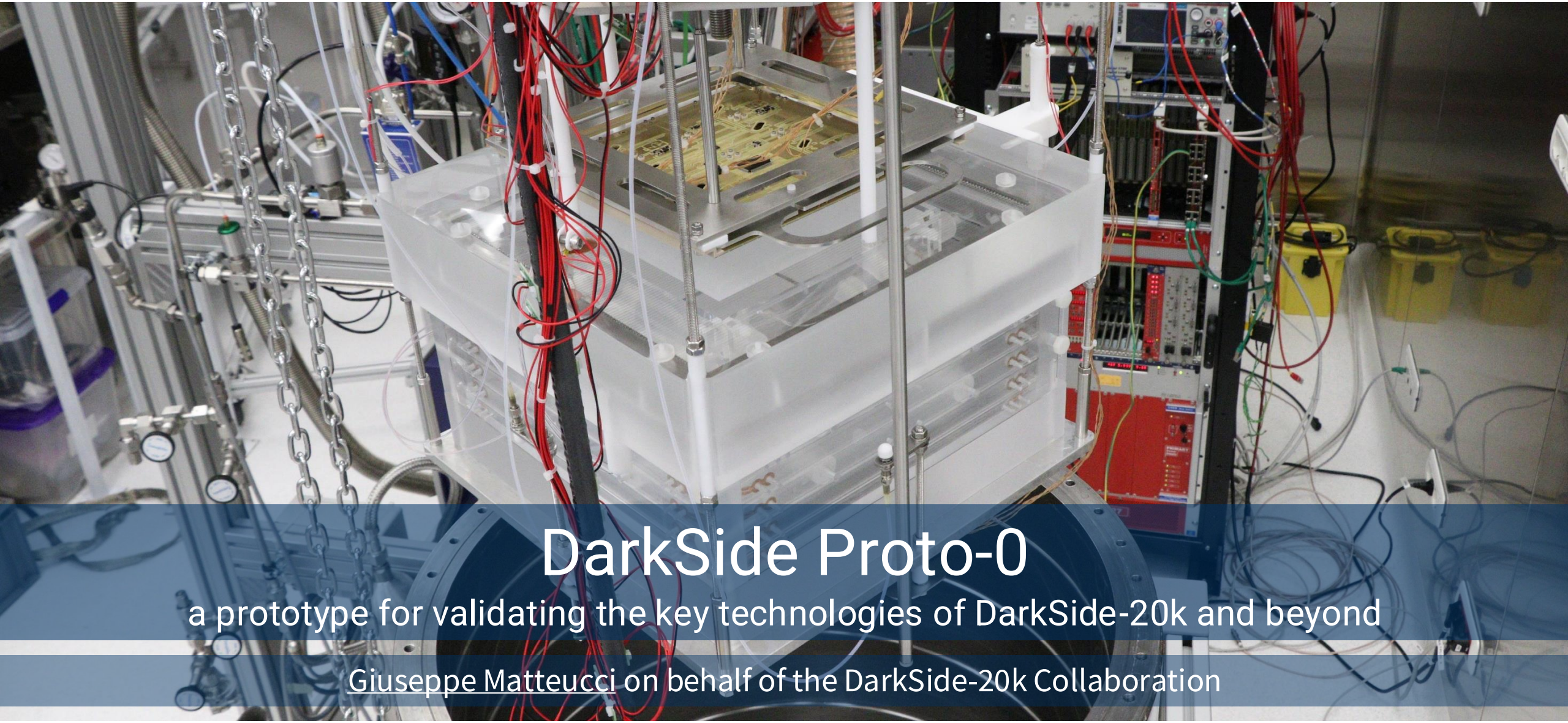


DarkSide Proto-0

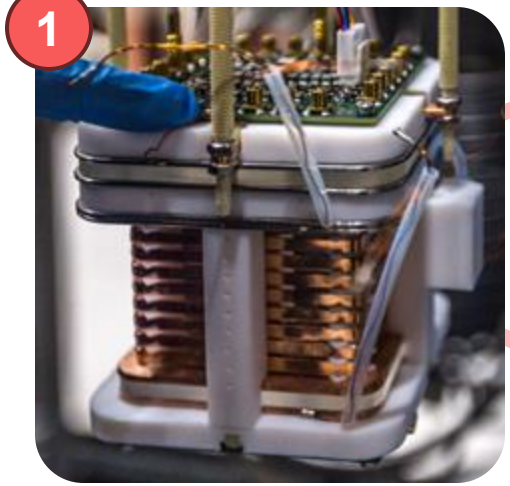
a prototype for validating the key technologies of DarkSide-20k and beyond

Giuseppe Matteucci on behalf of the DarkSide-20k Collaboration

Prototyping DarkSide-20k

ReD
~200 g LAr TPC
24+4 Ch SiPM Readout
@ INFN Naples, INFN Catania, LNS

1

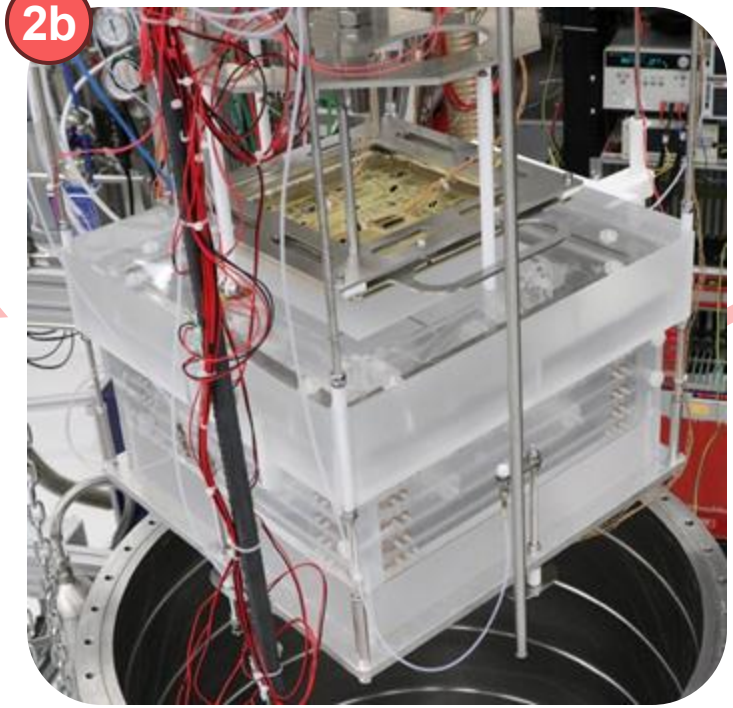


2a

Next talk by Paolo Salomone

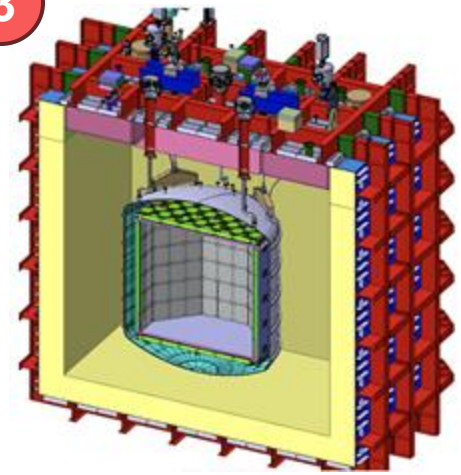
Mockup
800 kg LAr TPC
No optical readout
Test assembly, fields, cryogenics
@ LNGS

2b



Proto-0
7 kg LAr TPC
2 PDU (8 ch) optical readout
Test signal production, materials
cryogenics, PDU stability, DAQ
@ INFN Naples

3



DarkSide-20k
50 ton LAr TPC
524 PDU optical readout
@ LNGS

Previous talks by Ako Jamil and Marek Walczak

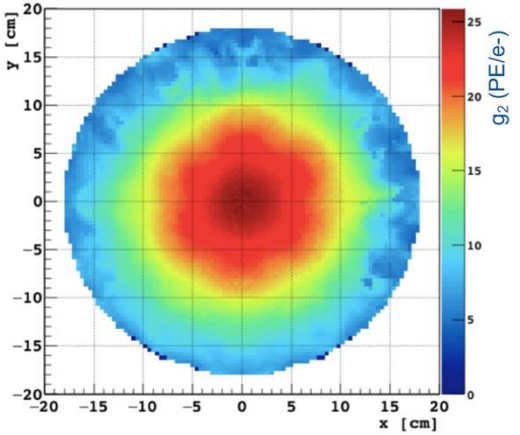
General Overview

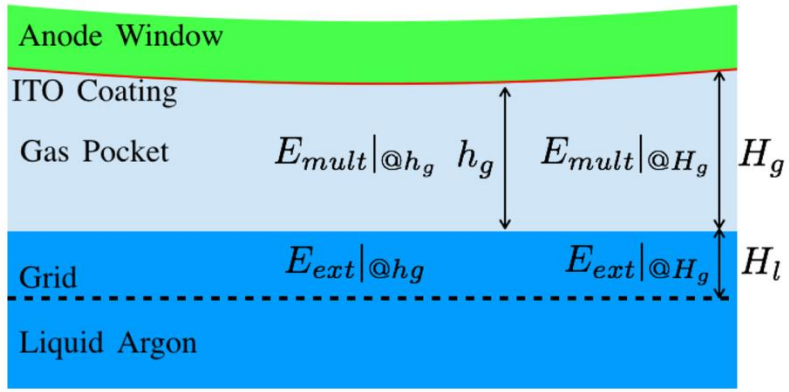
- Electroluminescence versus geometry, pressure and fields
- Shed light on S2 non-uniformity
- Test new technologies: materials, coatings, PDUs
- Test triggerless DAQ

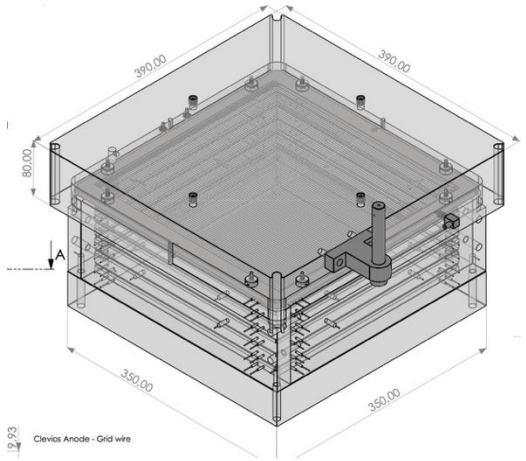
The TPC of Proto-0

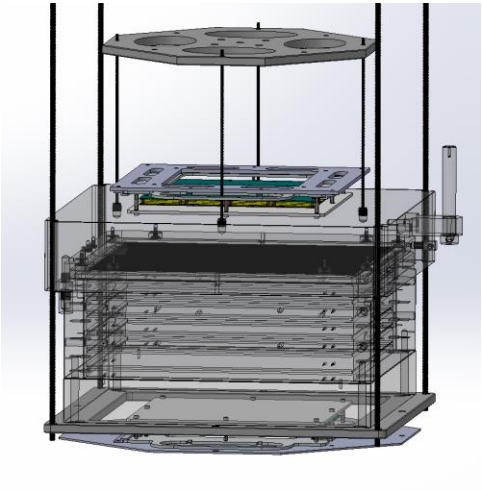
~7 kg active mass TPC
12 cm drift
Square geometry
Acrylic parts with Clevios coatings
Movable diving bell / bubbler
DS-20k style grid (*)
Two PDUs for optical readout

S2 disuniformity in DS50. Possibly explained by anode sagging.





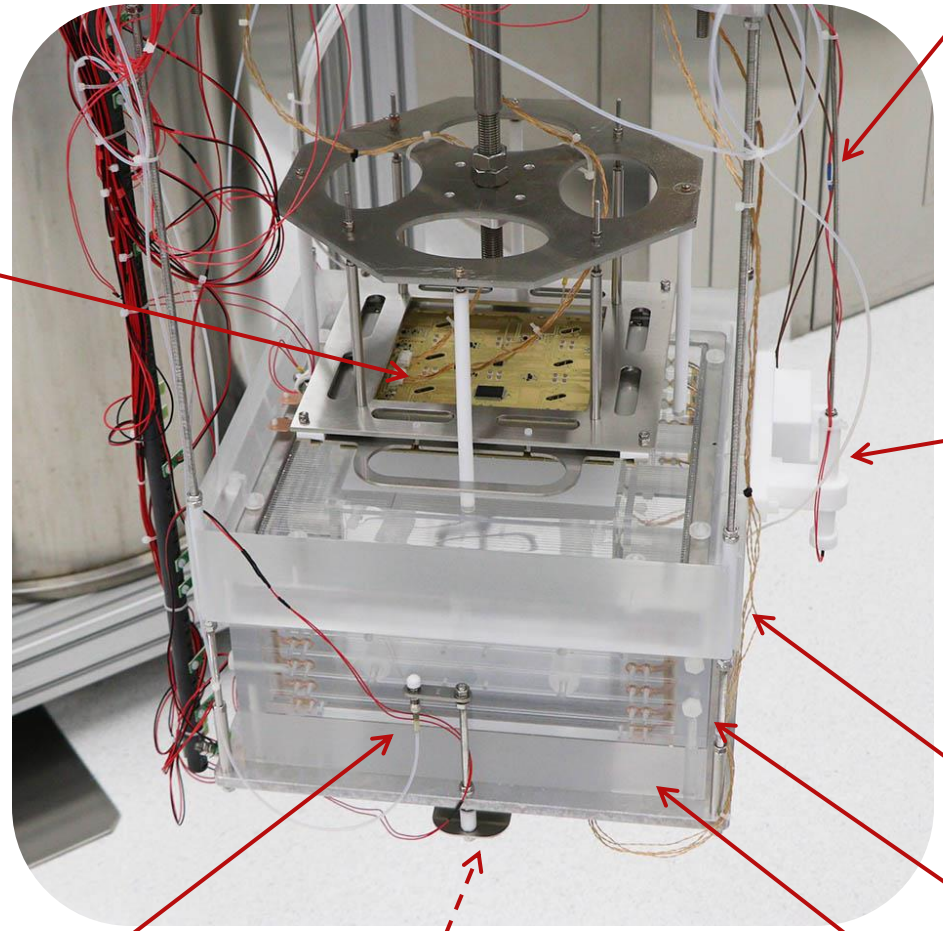




2024			
Q1	Q2	Q3	Q4
Parts procurement	Cryogenic system commissioning	TPC Assembly warm tests	Cold Campaign Commissioning

2025			
Q1	Q2	Q3	Q4
System upgrades	Cold Campaign	Data Analysis, System upgrades	

The TPC of Proto-0: Adjustable Geometry



Motion Control **A**node

Motion Control **B**ubbler

TOP PDU

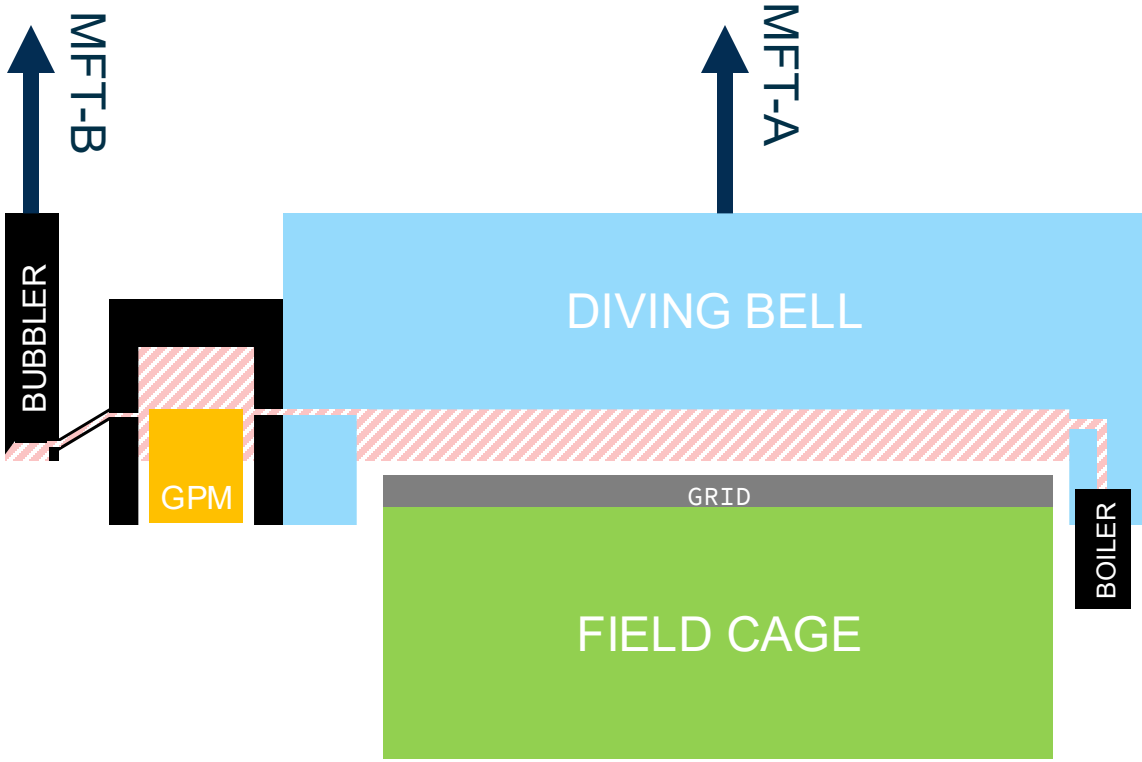
Illumination system

BOTTOM PDU

Diving bell

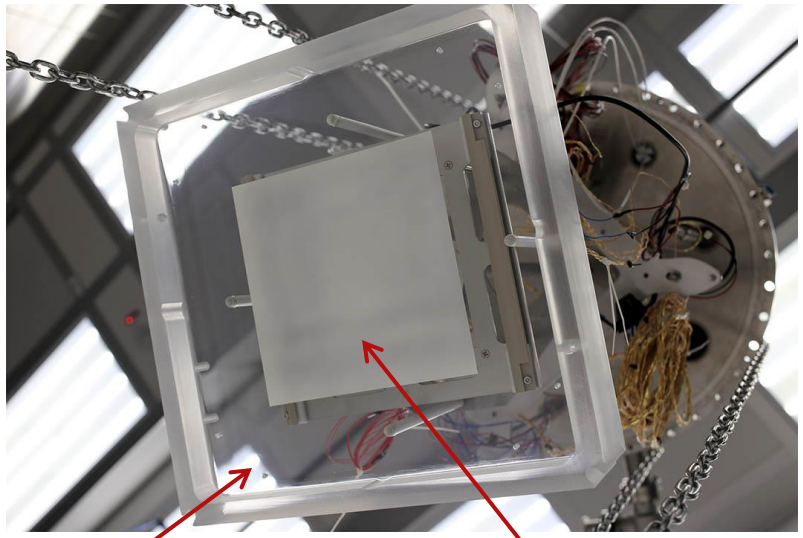
Field Cage

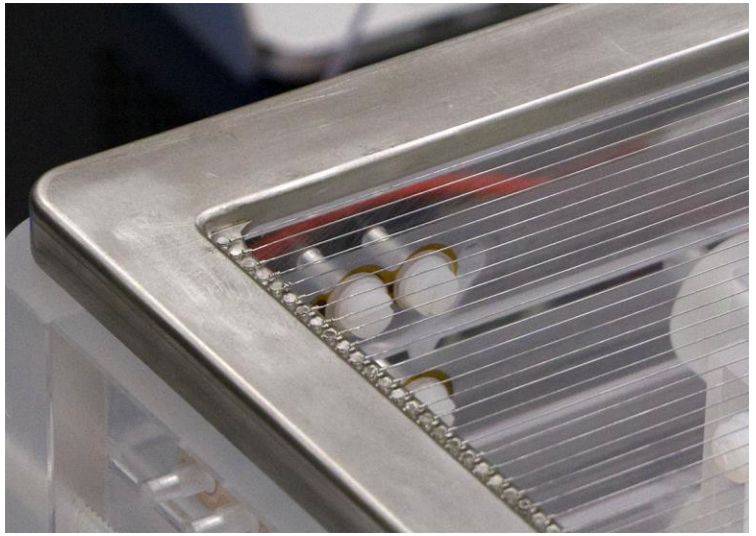
PMMA Cathode Block

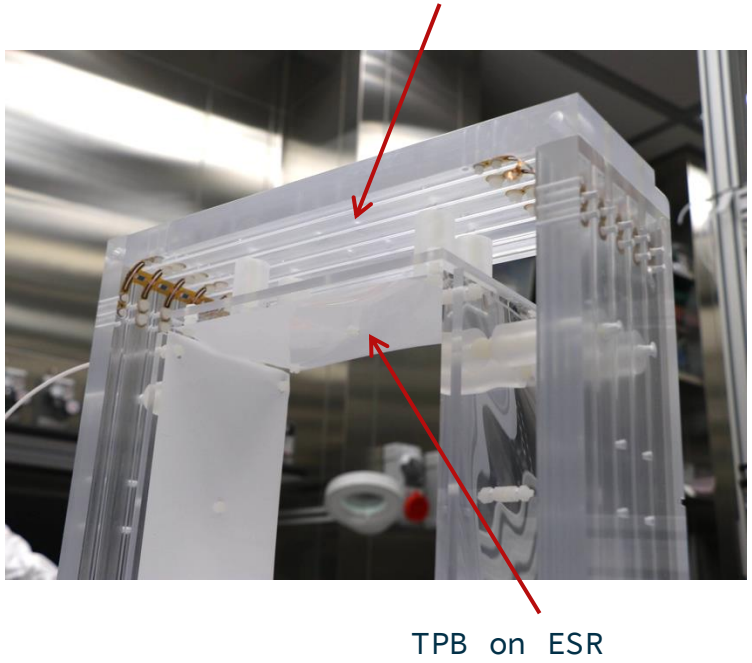


* not in scale

The TPC of Proto-0: Construction materials and details







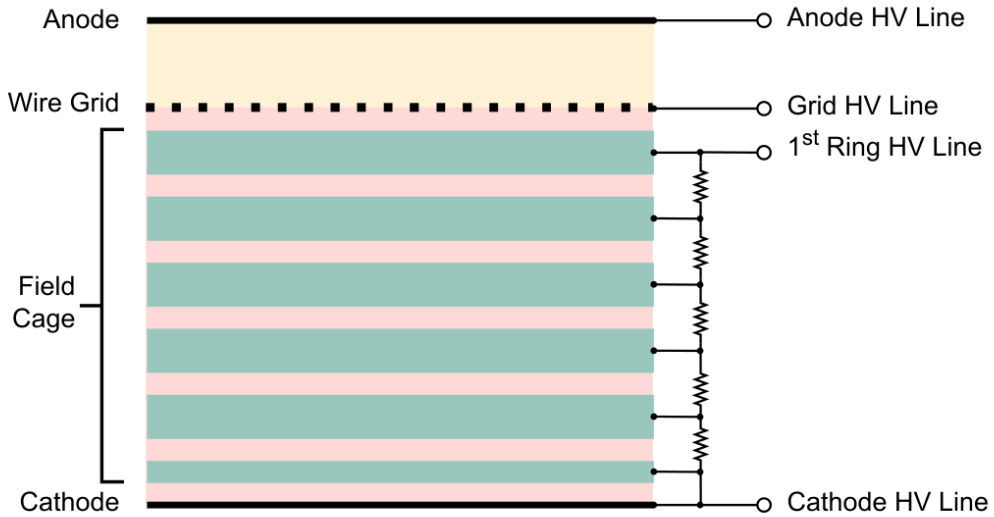
- PMMA (Acrylic) components
- 10 nm Clevios coating (Anode and Cathode)
- TPB WLS (3 um) evaporated on Clevios

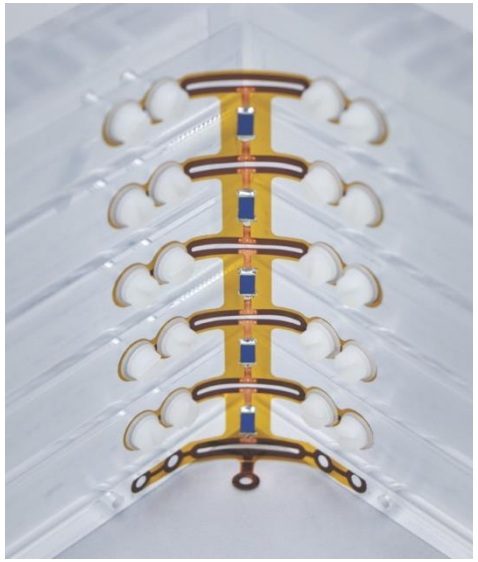
- Wire grid for drift/extraction field decoupling
- 200 um diameter wires
- 3 mm pitch

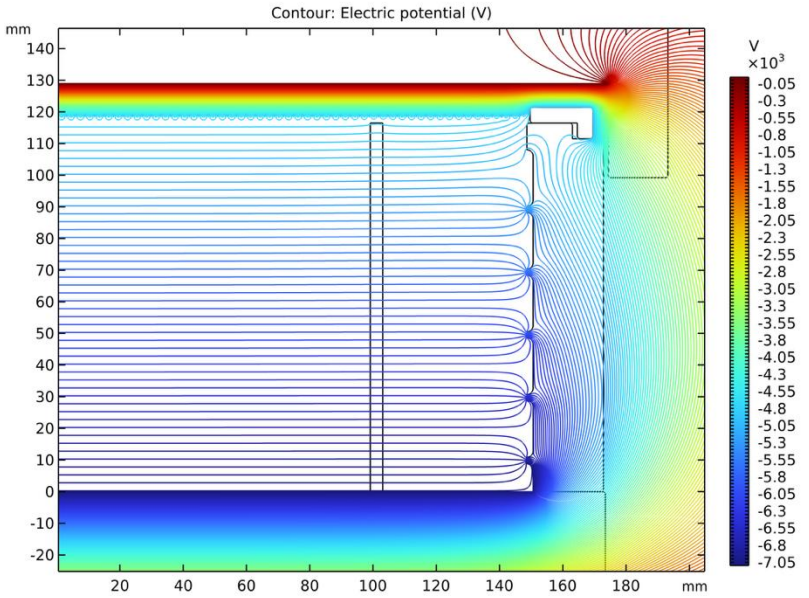
- 20x20x12 cm^3 active volume
- Enclosed by ESR reflector foils evaporated with 3 um TPB
- within field shaping rings made of Clevios on PMMA panels

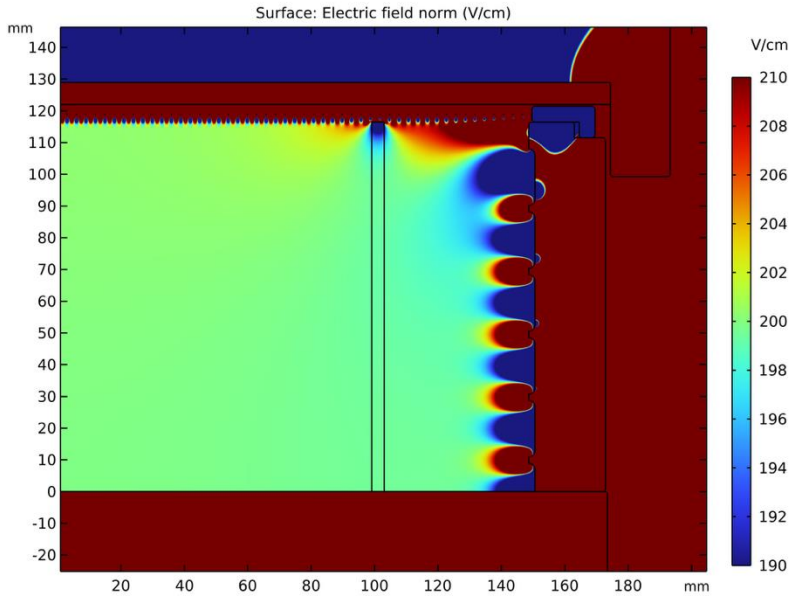
Field Generation

- Anode: Clevios (10 nm)
  - Positive, up to 4kV
- Cathode: Clevios (10 nm)
  - Negative, up to -12kV
- Grid: SS Wire Grid
- Field shaping rings:
  - 100 nm Clevios
  - Precision voltage divider, 1.25GOhm total
- Tested drift fields up to 1000 V/cm
- Electroluminescence field up to 6.7 kV/cm
- COMSOL predicted uniformity of ~1% in the active volume



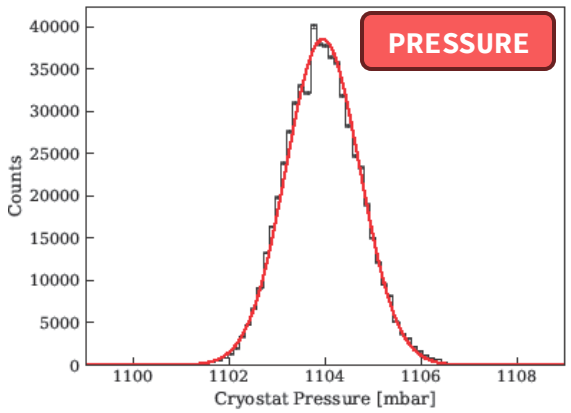




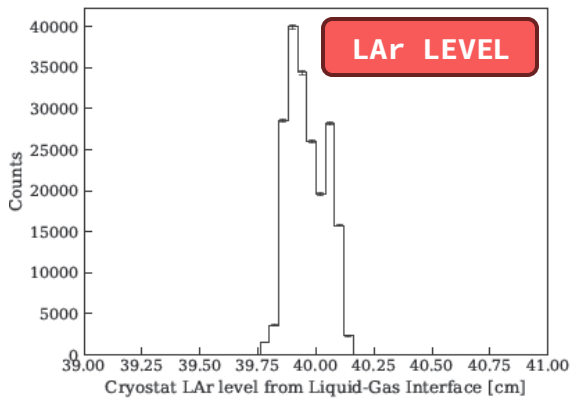


The Cryogenic System

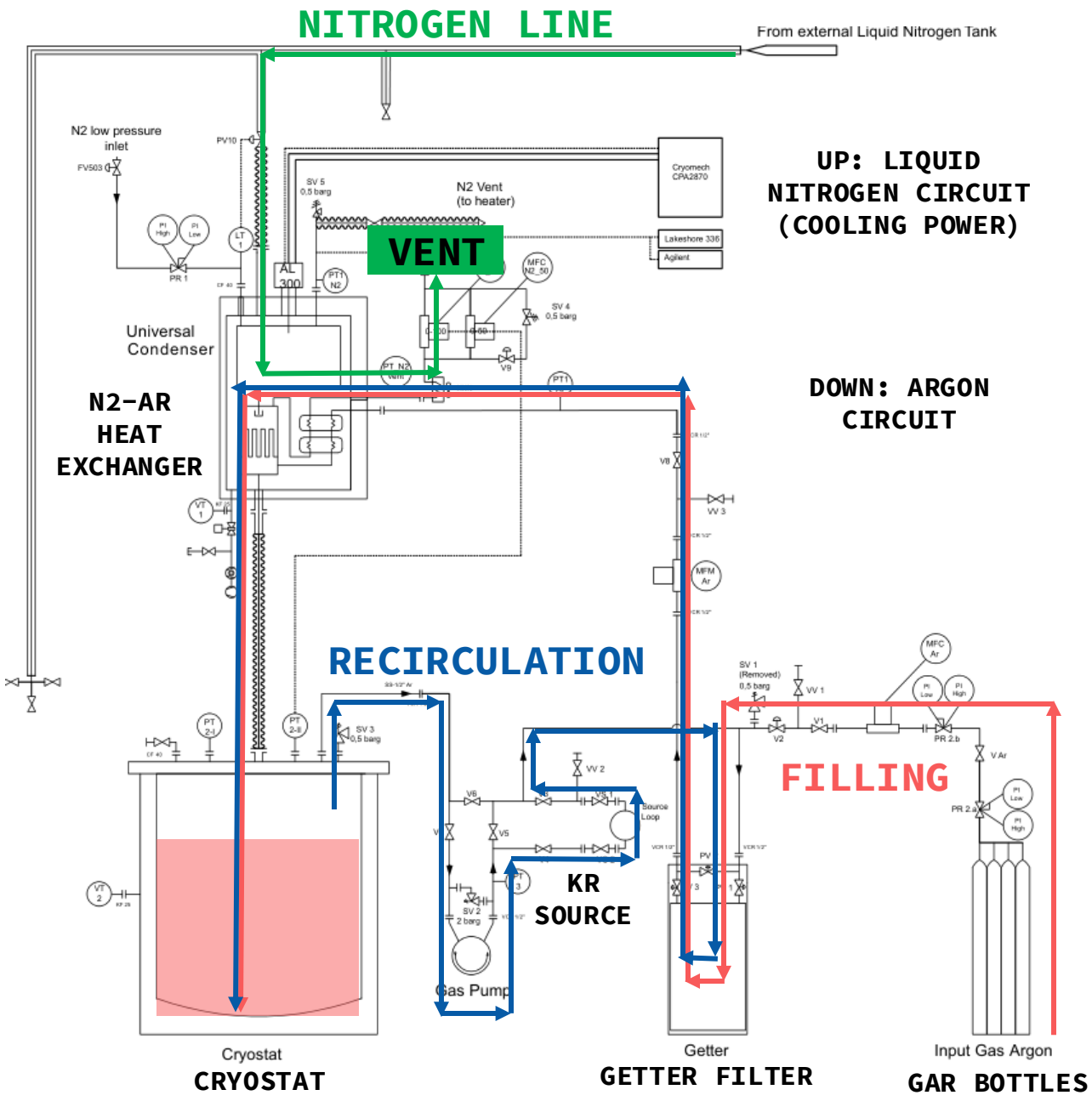
- Condensation tower:
  - 200 L Cryostat in ISO6 cleanroom
  - LN-heat exchanger for noble-gas liquefaction running either on LN or GN condensed with a cold-head
  - SAES Getter Molecular filter for purification
  - Sub-mbar cryostat pressure stability
  - LabView + Midas slow control systems
  - Gaseous source injection system
  - Filling speed 65 slpm (5 L/h of LAr)

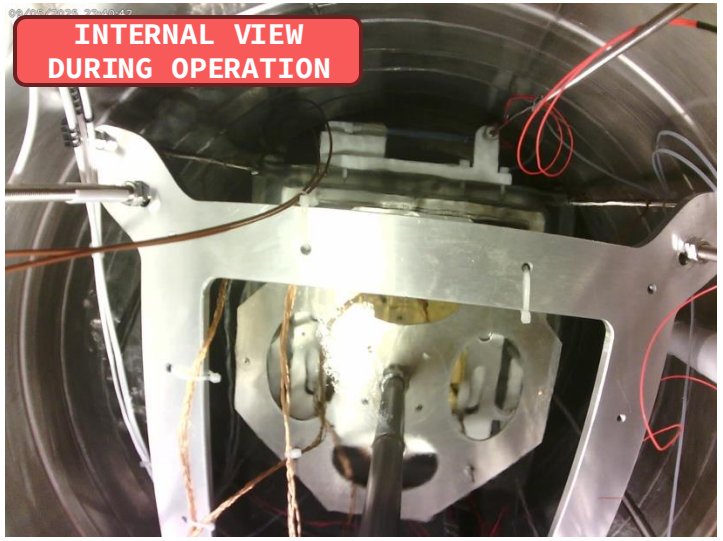


Stability 0.7 mbar



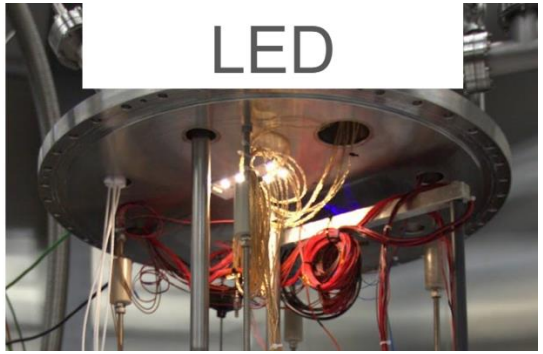
Stability 0.3 mm




INTERNAL VIEW
DURING OPERATION


CONDENSER


Camera

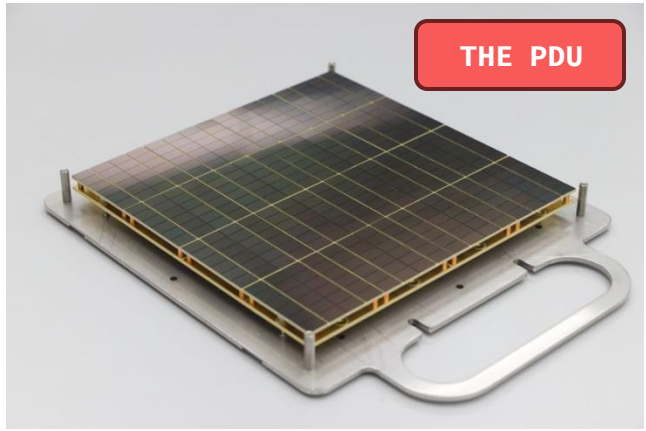

LED

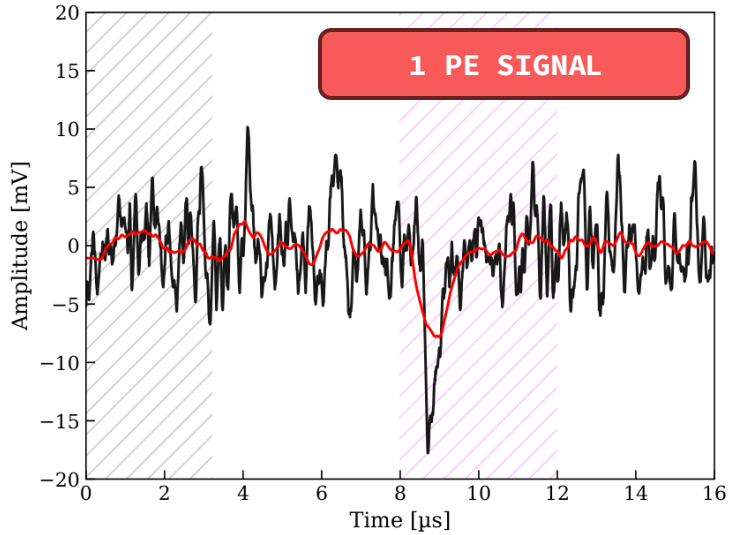

CRYOSTAT WITH
LEAD SHIELDING

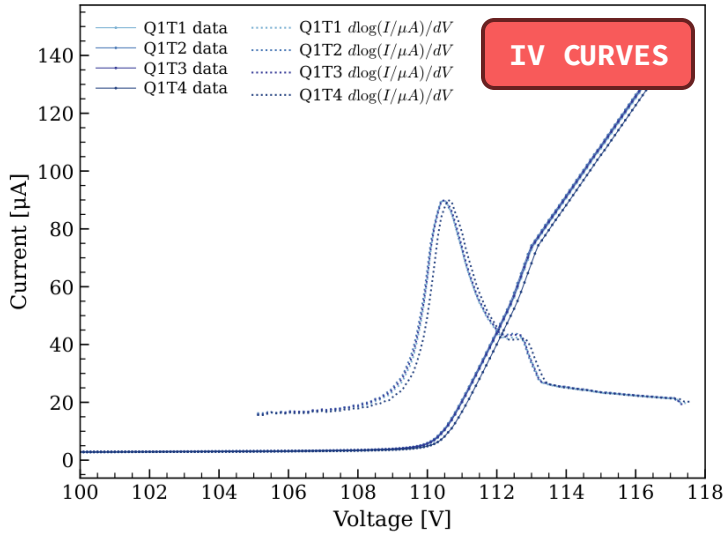

PROTO-0 INSTALLATION

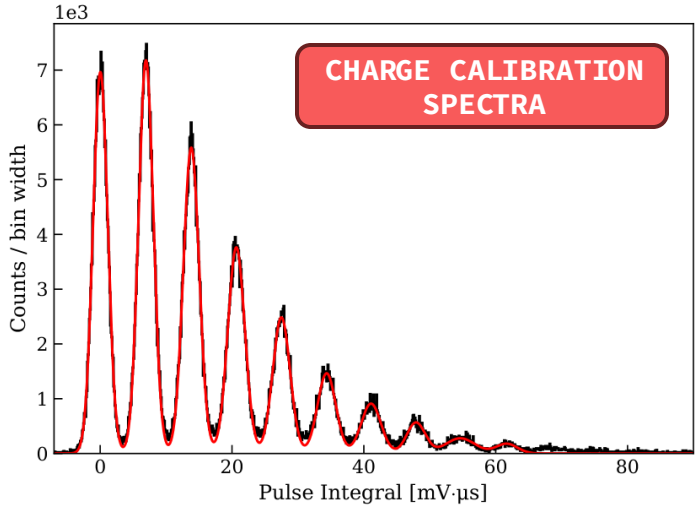
Photo-Electronics in Proto-0

- 2 pre-production PDUs for optical readout in Proto-0
- Qualified in LN at the PDU Test Facility *See talk by D. Rudik*
- Operated at 7V overvoltage
- PDU Specifics
  - 20x20 cm² active surface
  - 384 NUV-HD-Cryo SiPMs
  - 4 total differential channels (100 cm² per ch.)
  - 7 V o.v. ↔ ~140V PDU bias (partitioned across 4 SiPMs)
- 1PE Ampl. ~14 mV (7V o.v.)
- SNR~6 ($\frac{Amp\ 1_{PE}}{baseline\ rms}$ @ 7V o.v.)



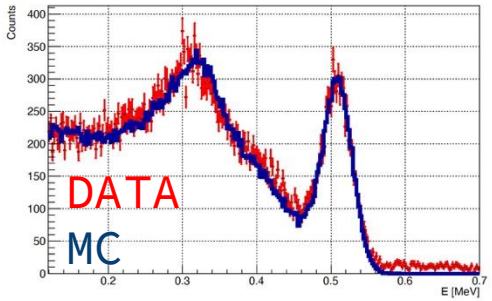




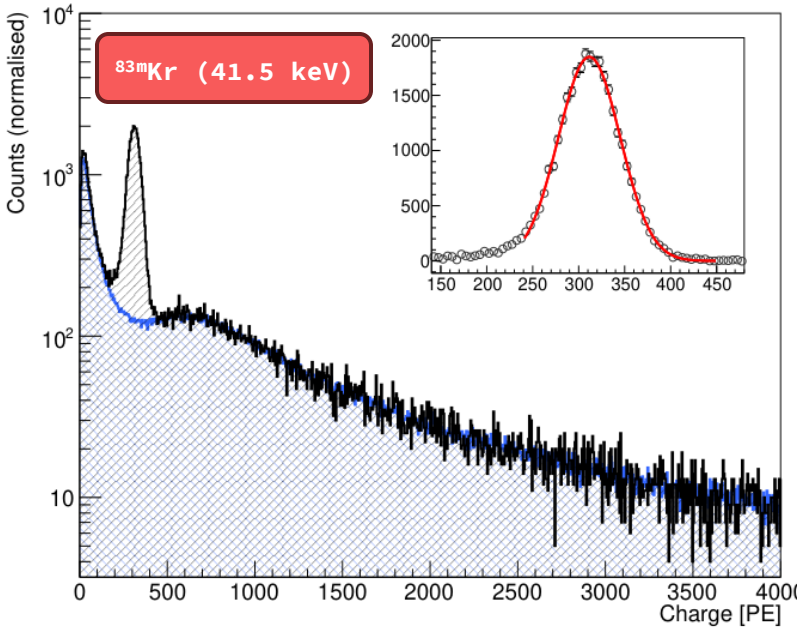


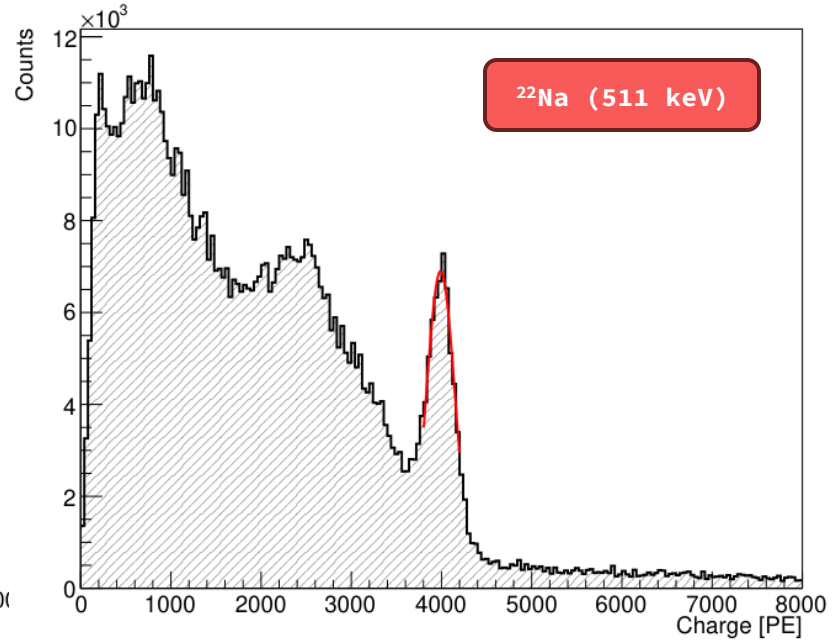
Single phase characterization

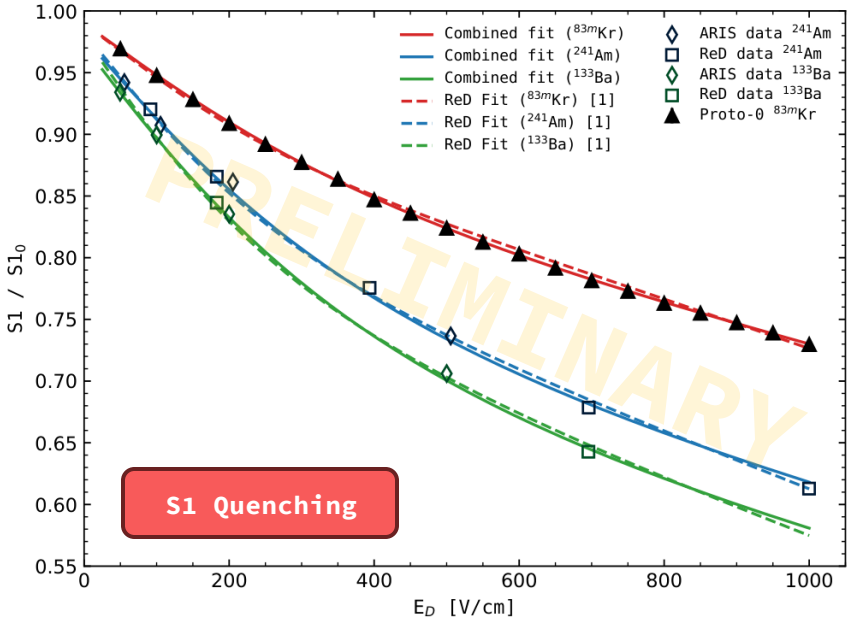
Light Yield at null field
LY(7V o.v.) = 5.2 PE/keV



[1] 10.1140/epjc/s10052-021-09801-6





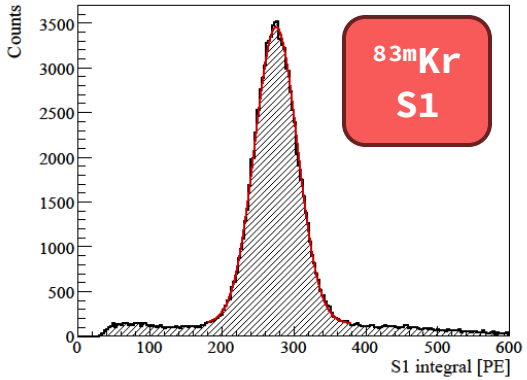


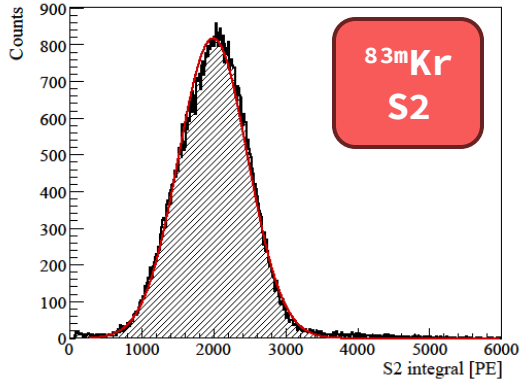
^{83}Rb (solid) $t_{½}$=90d
→ ^{83m}Kr (gas) $t_{½}$=2h
→ (diffusion in LAr)
→ 41.5 keV emission

^{22}Na $t_{½}$=2600yr
→ β+ emitter
→ 2 back-to-back γs
→ 511 keV emission

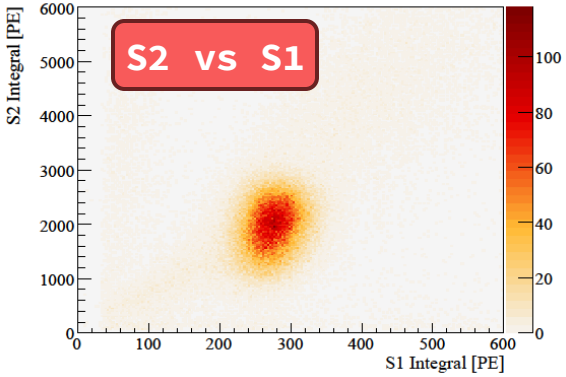
Two-phase characterization

Fields: Gas 5200 kV/cm / Drift: 200 V/cm
Gas Pocket size: 7.0(2) mm (3.0(2) mm LAr above grid)
Gas Pocket pressure: 1160(11) mbar

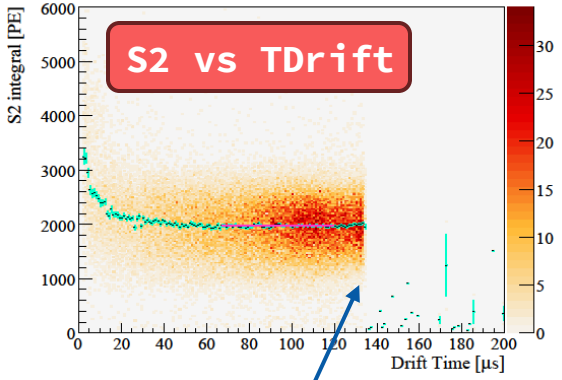




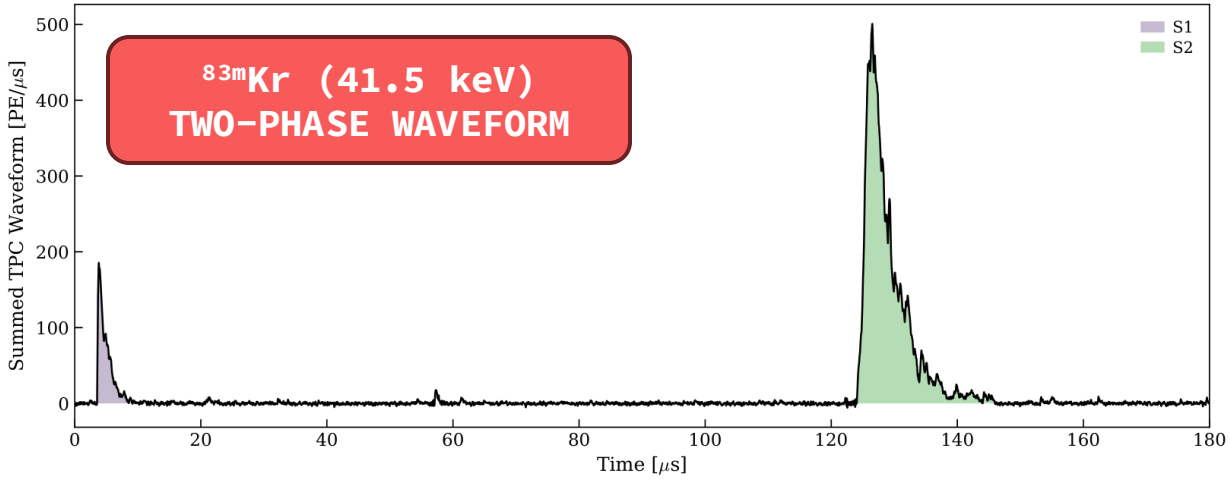
S2/S1 ~ 7.4



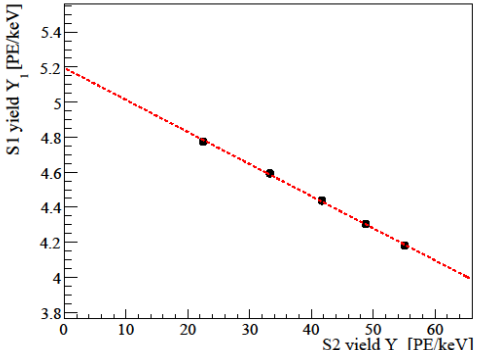
Electron lifetime > 1 ms



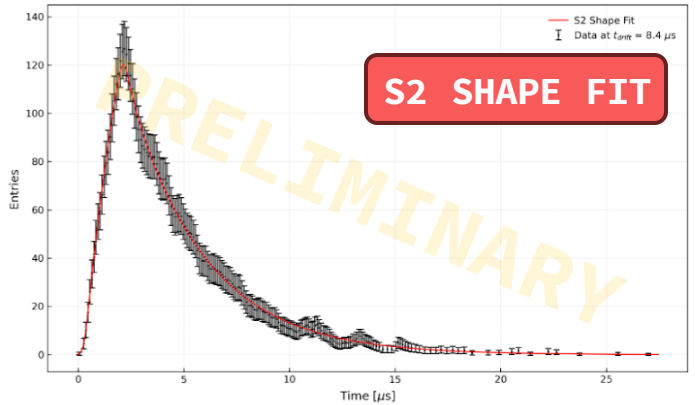
Sharp drift time max. ~133.5(1) us → **v_e = 0.899 mm/us**
(theoretical at 88.5K, 200V/cm: v_e = 0.899 mm/us [lar.bnl.gov]



Doke Plot Analysis
g1 ~ 0.10 PE/ph
g2 ~ 6 PE/e^-
(W_{ph} = 19.5(10) eV)

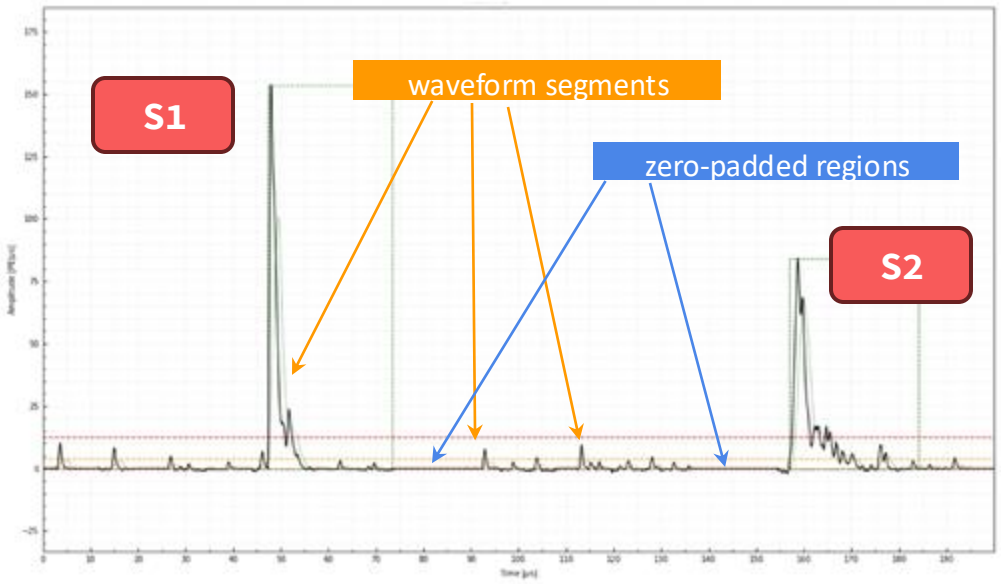


* Not directly compatible with DS20K due to different optical efficiency

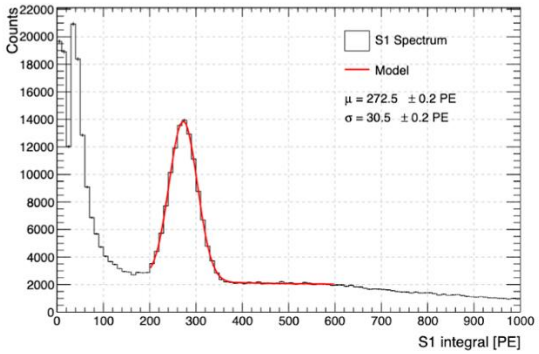


Triggerless DAQ Tests

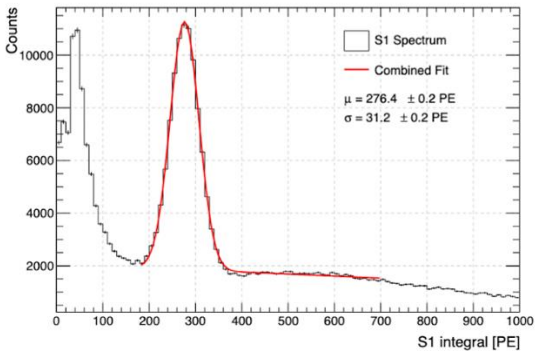
- PDU signals digitized with CAEN VX2745 (as DS20k): 16 bit, 125 MS/s, 64 channels, IDR 4 V
- Custom firmware via OpenFPGA inspired to DS-20k DAQ system
- Trigger based on individual channel Time over Threshold
- Test bench for the triggerless acquisition foreseen for DS-20k

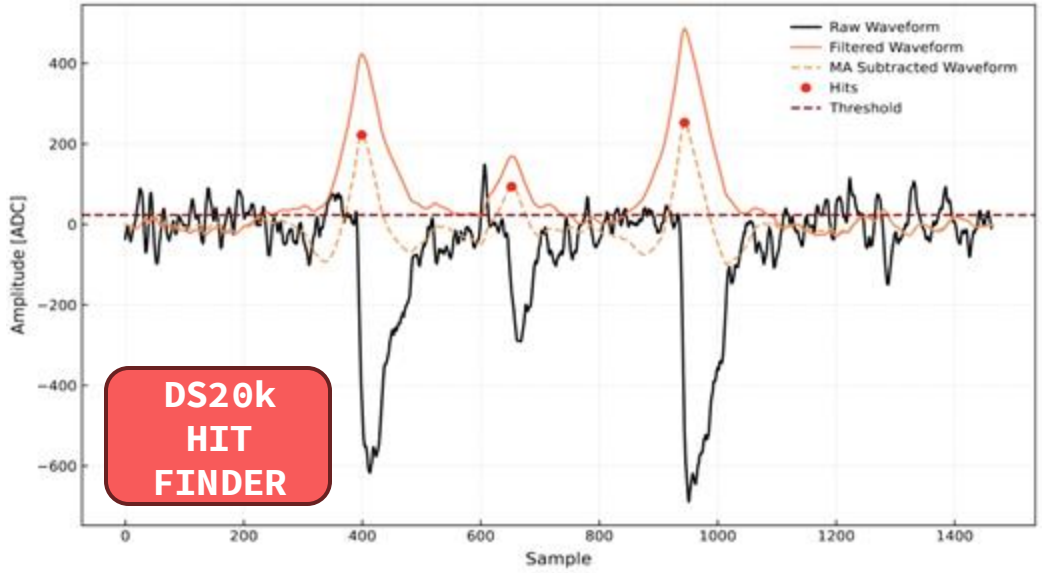


TRIGGERLESS



TRIGGERED



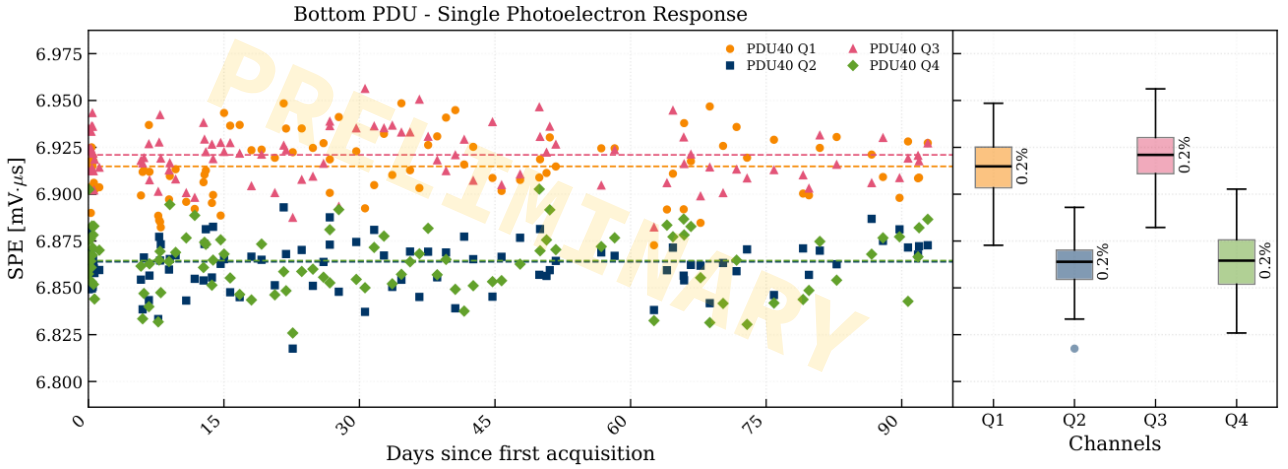


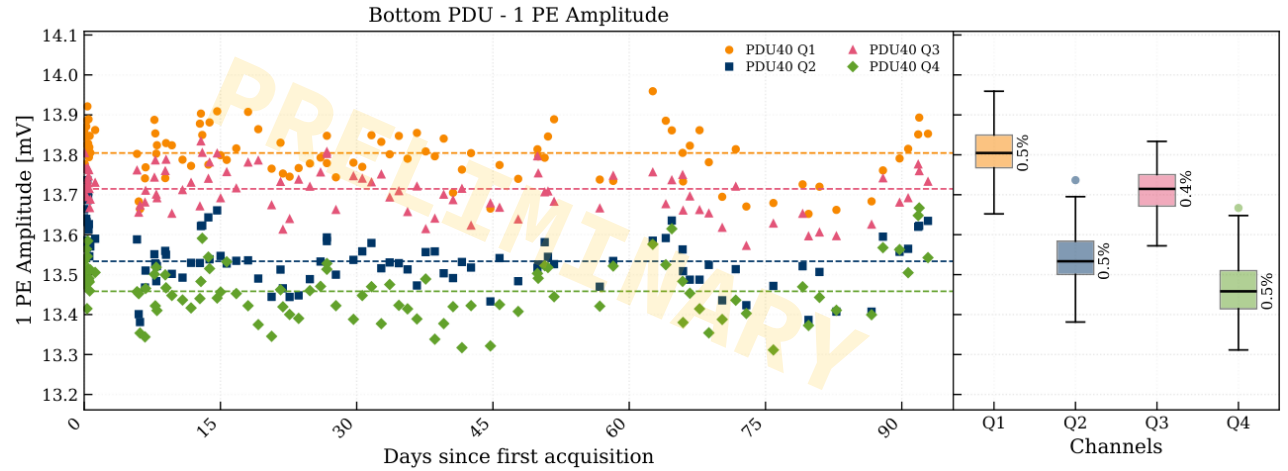
Long term PDU stability analysis

- Key parameters stable over 3 months
- No ageing effect or drift

Highest relative variations reported for:

- 1 PE Charge: 0.4%
- 1 PE Amplitude: 0.8%
- Signal-to-Noise Ratio: < 1%
- Baseline fluctuations: 0.08%





Electroluminescence study

- Study EL Photon Yield (Y) vs pressure, geometry and fields

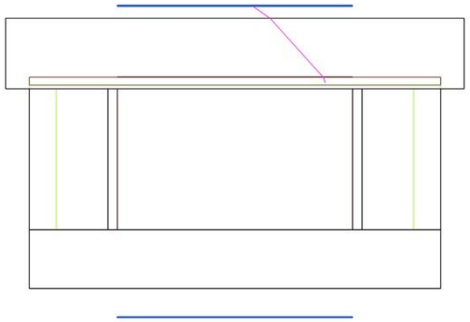
Gain definition: $< S2 > = g_2 N_e$
Signal formation: $< S2 > = h_{GP} Y \varepsilon^{S2} N_e$

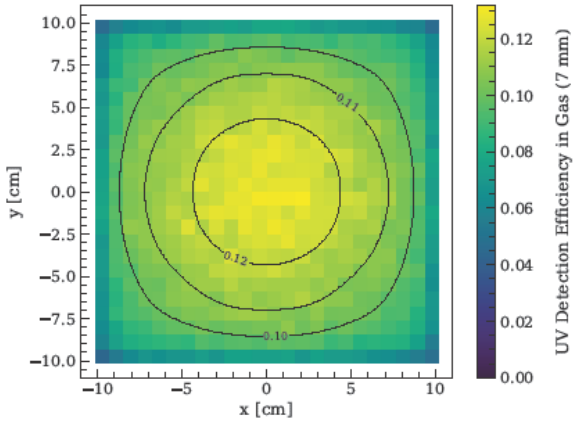
$$\rightarrow Y = \frac{1}{h_{GP}} \frac{g_2}{\varepsilon^{S2}}$$

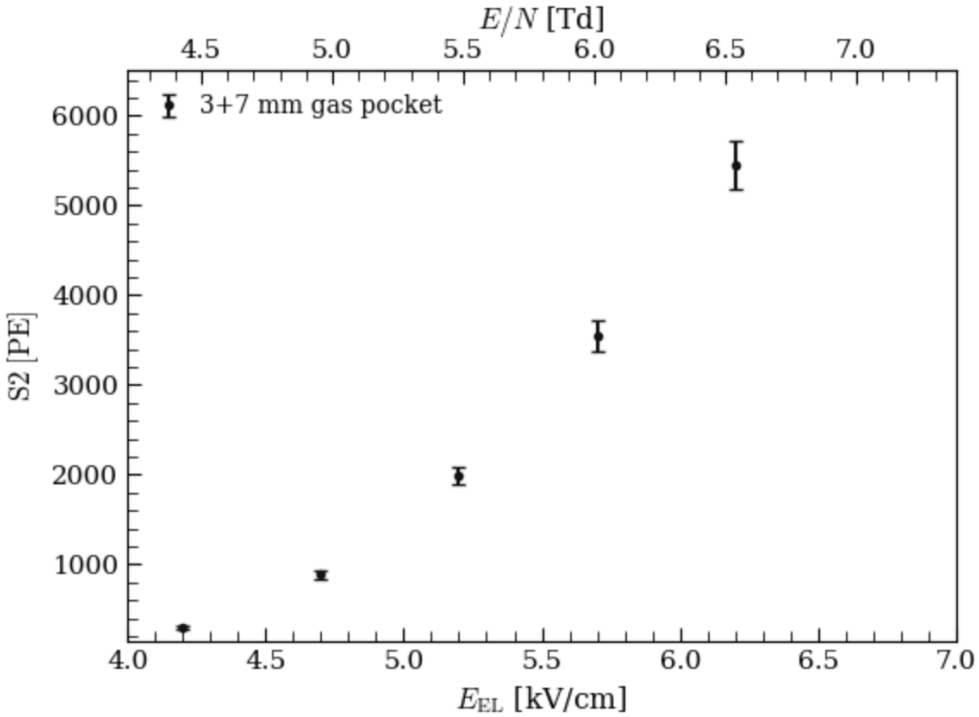
From Doke plot or single electron signals

h_{GP} from capacitive level meter (0.2 mm resolution)

Detection efficiency from Monte Carlo







- Analysis still ongoing to extract Y in all tested configurations
- Future run: investigate EL with two internal sources (^{83m}Kr 41.5 keV and ^{241}Am 59.5 keV)
- Improve several aspects to reduce systematics

Conclusions

- Proto-0 is a key asset for the DarkSide-20k
  - Provides feedback on materials, photosensors, cryogenics, daq, offline analysis
  - Small scale demonstrator of final design choice of DS-20k
  - Complementarity with Mockup program
- Electroluminescence data acquired, analysis ongoing
- Objective of the next runs:
  - Shed light on systematics
  - Study EL with lower energy emission
  - Integrate and test DarkSide-20k DCS system


THANK YOU