



darkside

two-phase argon TPC for Dark Matter Direct Detection



Development of Photosensor and Inner Detector in DarkSide-20k

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On behalf of the DarkSide Collaboration

TeVPA 2019, Sydney, Australia

December 5, 2019

From DarkSide-50 to DarkSide-20k

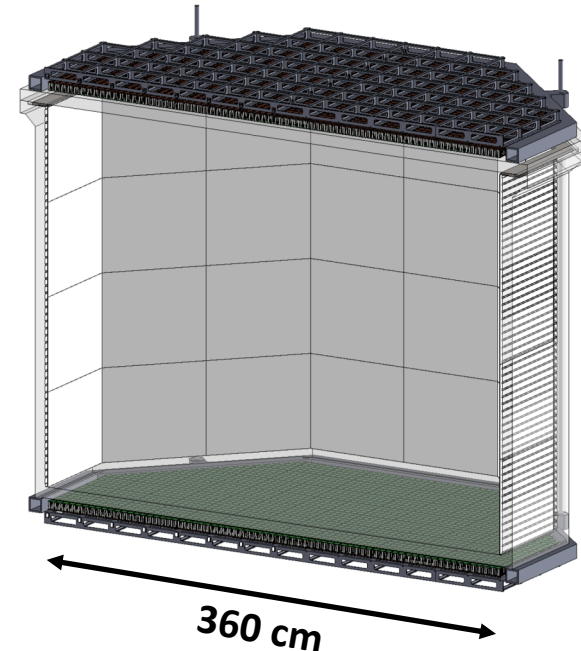
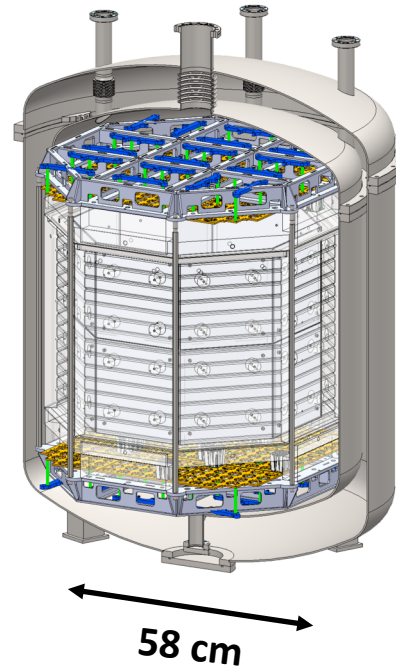
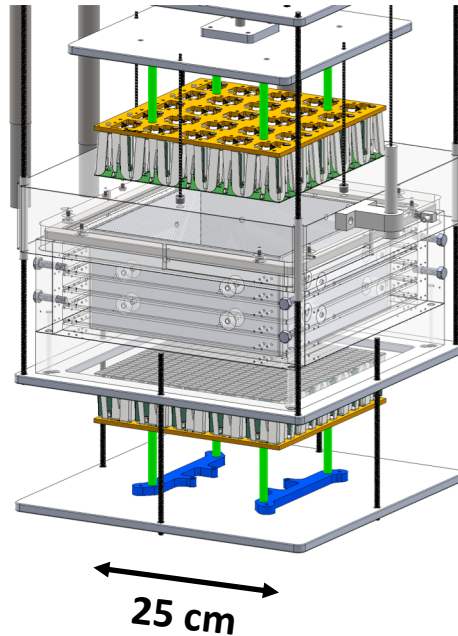
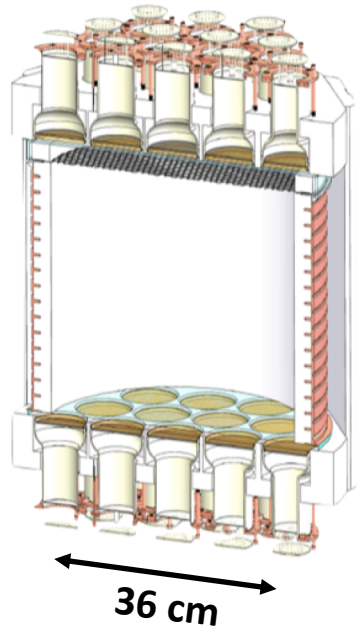
(PDM = Photodetector module)

38 PMTs

50 PDMs

370 PDMs

8280 PDMs



DS-50
(2014–present)
46 kg active
Conventional TPC

DS-Proto-0
(2019–2020)
10 kg active
Test bench

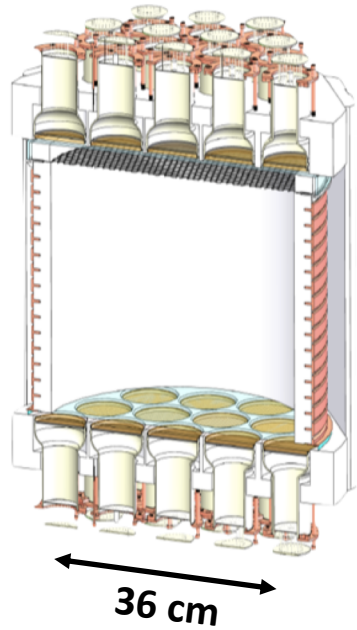
DS-Proto-1
(2020–2021)
175 kg active
Scaled-down of
DS-20k TPC

DS-20k
(2022–)
48 ton active
Novel sealed TPC

From DarkSide-50 to DarkSide-20k

From PMTs to SiPM-based PDMs

38 PMTs



DS-50
(2014–present)
46 kg active
Conventional TPC

Pros:

- Lower background
- Higher light yield
 - Higher photon detection efficiency
 - Compact -> higher active area
- Lower bias voltage
- Lower cost
- Naturally suitable for LAr temperature

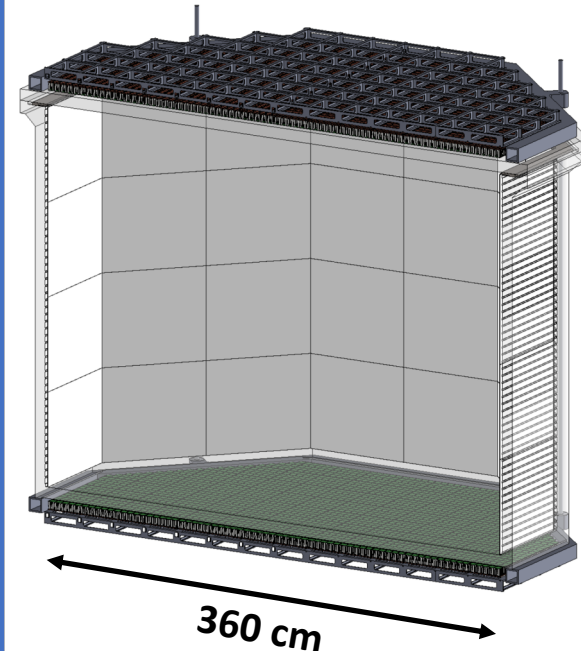
Cons:

- Smaller size -> more channels
- Higher rate of dark count and correlated noises (after-pulse, cross talk)
- High output capacitance -> high electronic noise, low bandwidth

R&D programs:

- Tiling and packaging
- SiPM optimization (PDE, DCR and CN)
- Cryogenic electronics (SNR, timing)

8280 PDMs

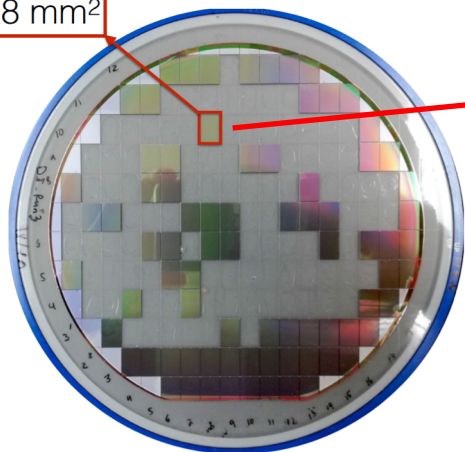


DS-20k
(2022–)
48 ton active
Novel sealed TPC

Tiling and packaging

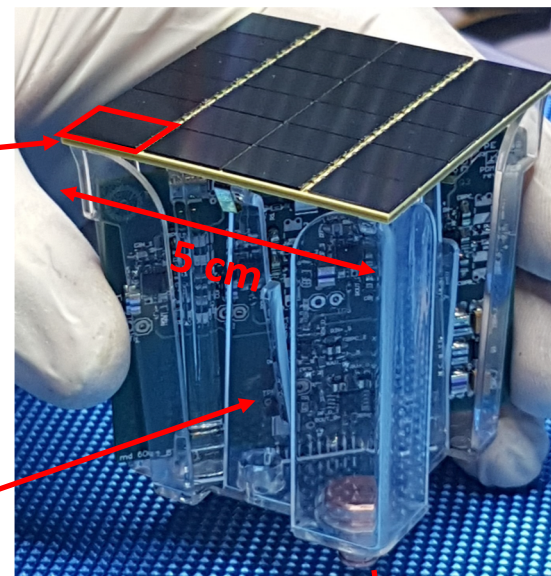
SiPM tile

12x8 mm²



PDM, 24 SiPM tiles

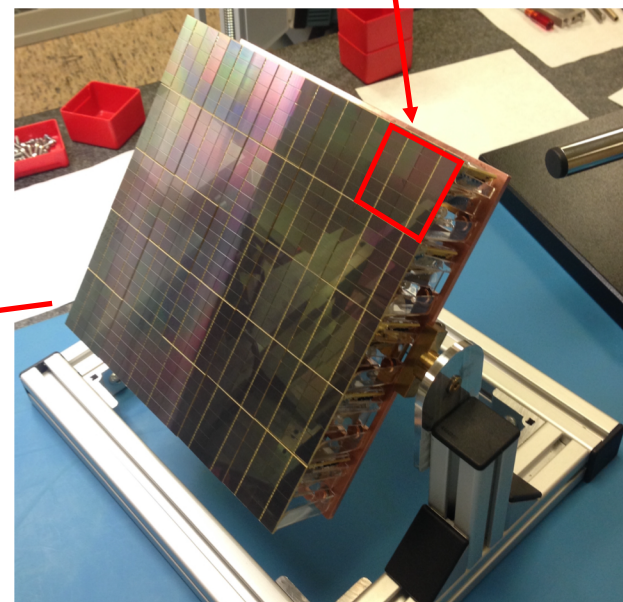
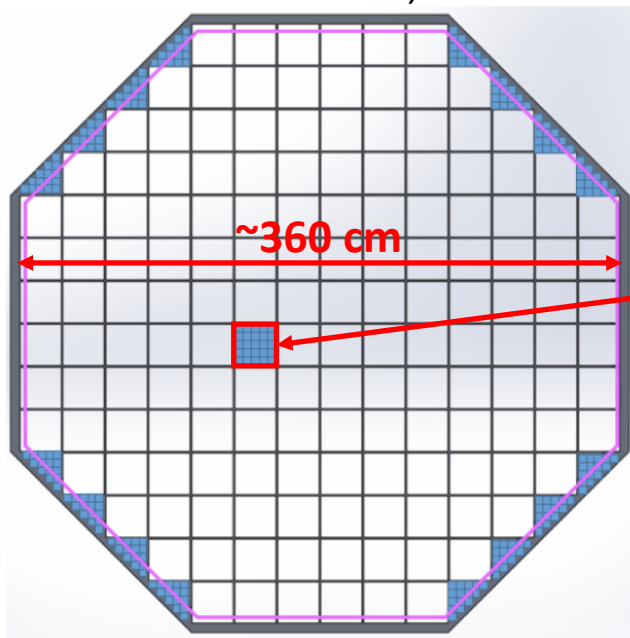
5 cm x 5 cm x 5 cm



Front-end board
(FEB)

Top/Bottom photosensor array

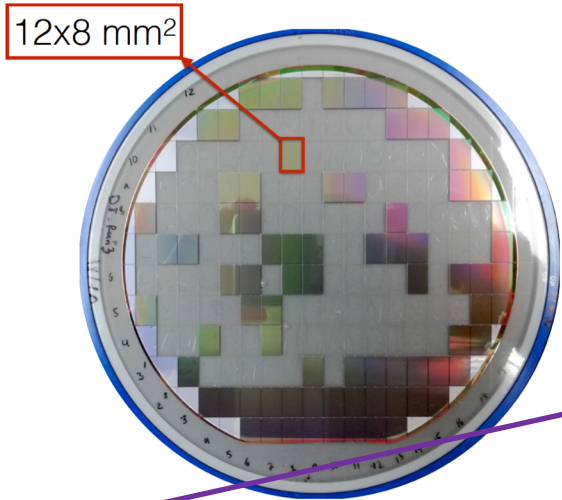
In total 8280 PDMs, ~20 m²



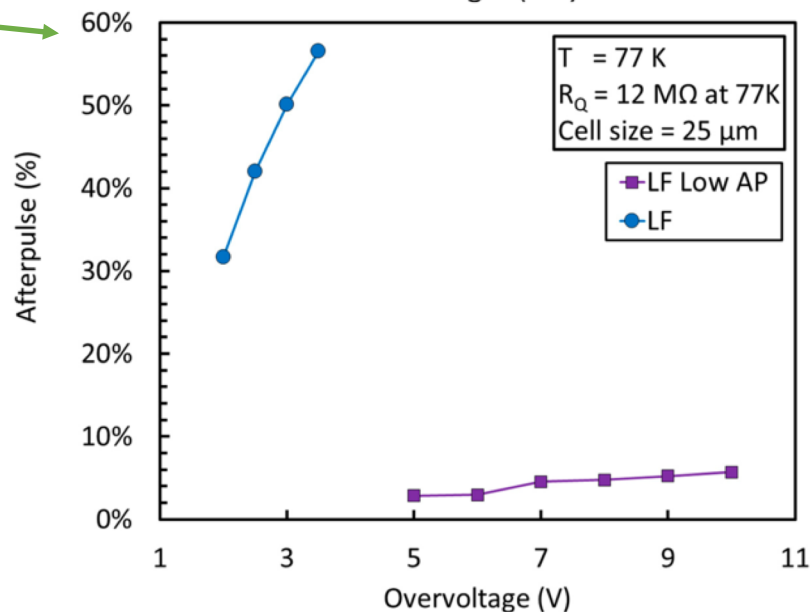
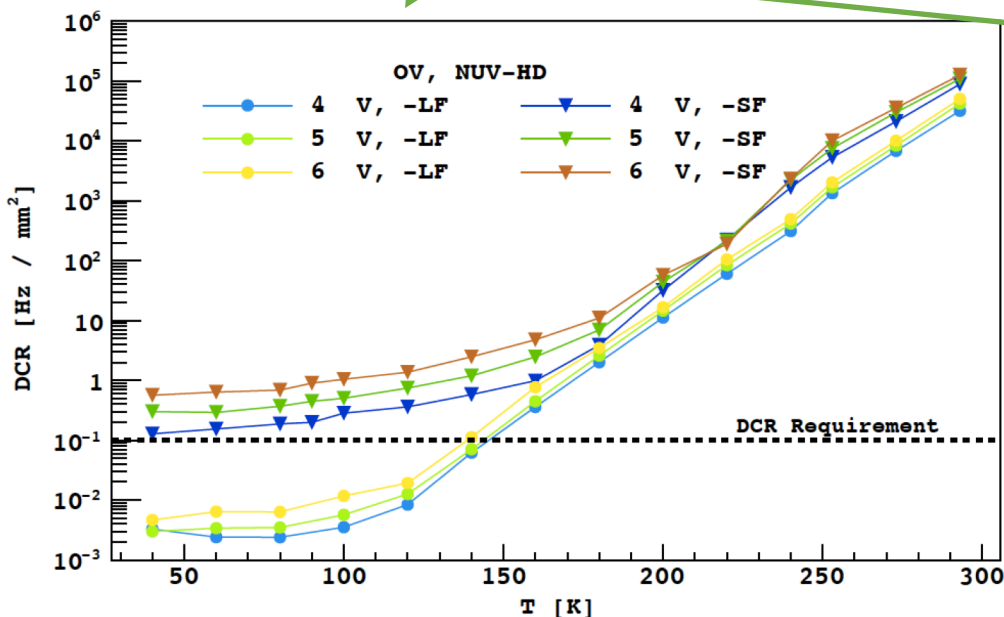
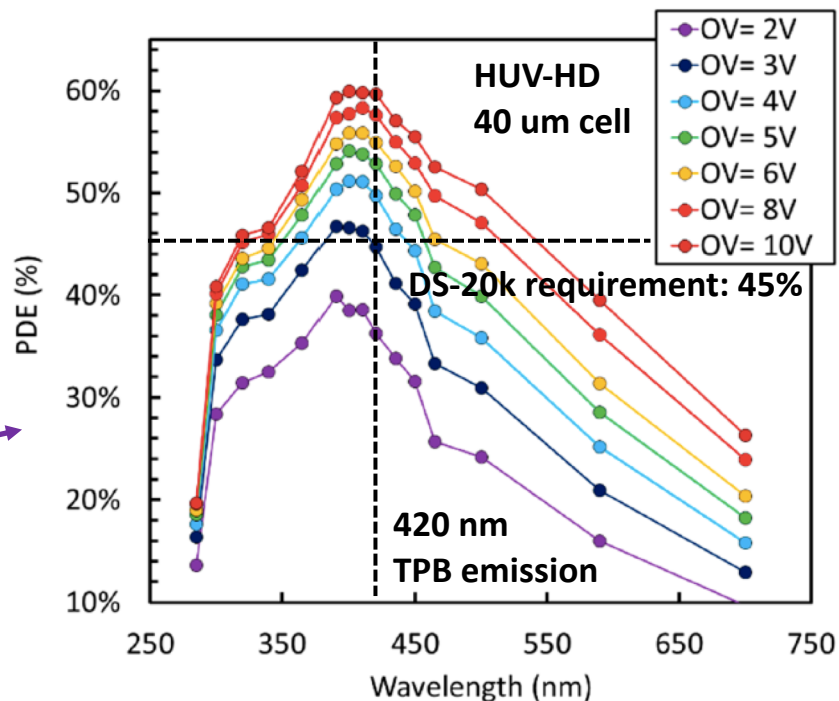
25 PDMs

25 cm x 25 cm x 5 cm

SiPM optimization



NUV-HD-Cryo SiPM tile from FBK



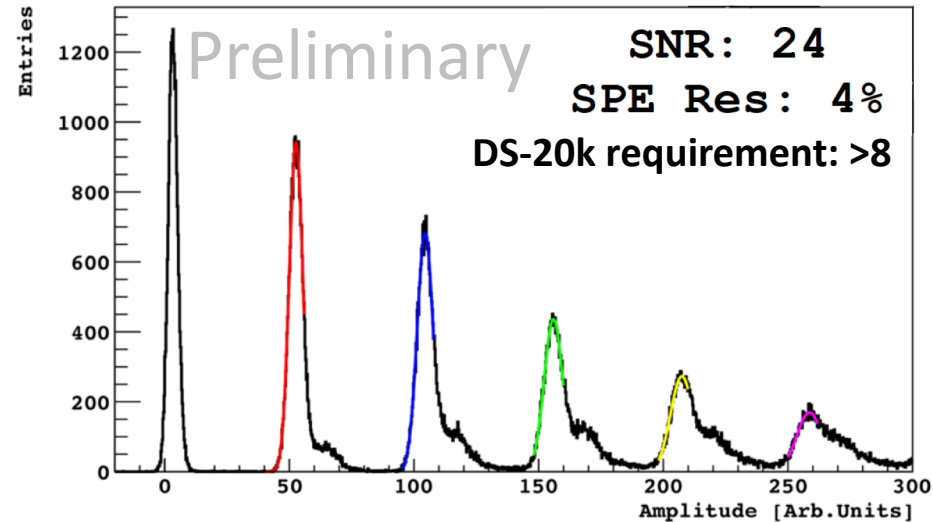
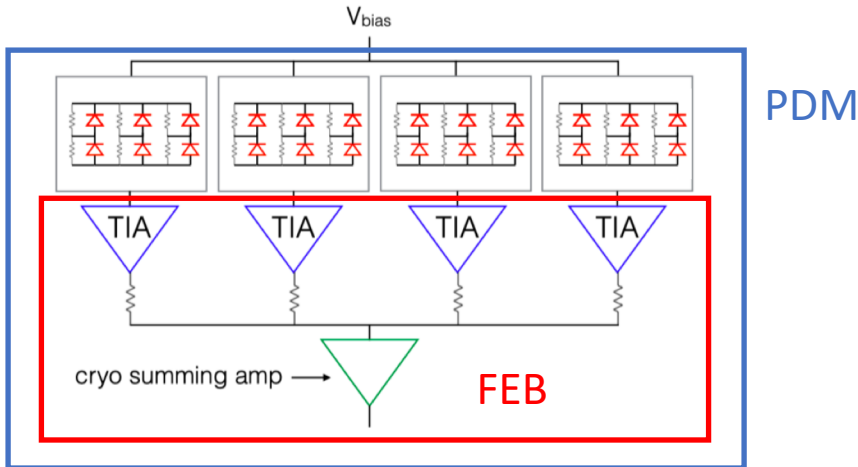
Cryogenic electronics

Challenges:

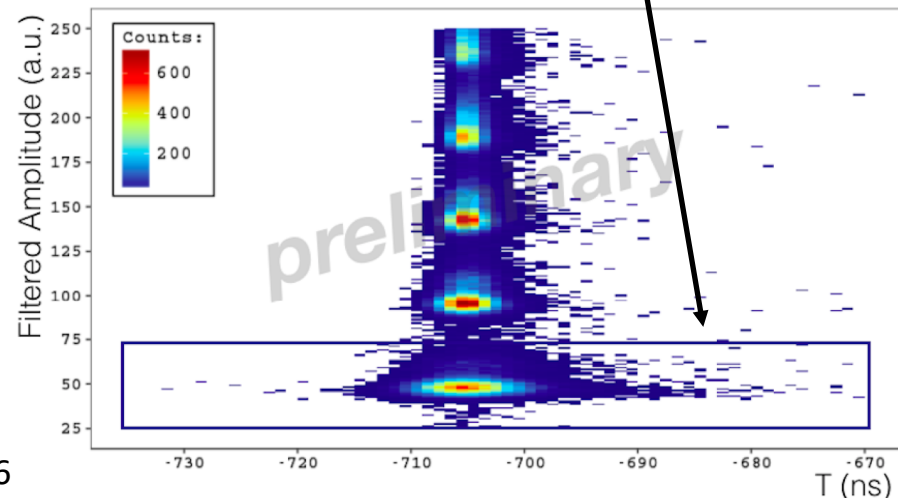
- High $C_{SiPM} \sim 50 \text{ pF/mm}^2$
- Limited power consumption $< 250 \text{ mW per PDM}$

Solutions:

- Transimpedance amplifier (TIA) with high bandwidth and low noise, optimized for LAr temperature
- Mixed series/parallel SiPM configuration to reduce $C_{in@TIA}$
- Number of TIA limited to 4, compromise between SNR and power consumption



Time resolution $< 10 \text{ ns @ 1 PE}$
DS-20k requirement: $O(10\text{ns})$



M. D'Incecco et al., IEEE Trans. Nucl. Sci., 65, 1, (2017), 591-596

M. D'Incecco et al., IEEE Trans. Nucl. Sci., 65, 4, (2018), 1005 - 1011

DS-20k PDM requirements for Inner Detector

- ✓ $5 \times 5 \text{ cm}^2$ per channel
- ✓ $\text{PDE}_{\text{PDM}} > 40\%$
- ✓ $\text{DCR} + \text{electronic noise} < 0.1 \text{ Hz/mm}^2$
- ✓ $\text{SNR} > 8$
- ✓ Time resolution $O(10\text{ns})$
- ✓ Power dissipation $< 250 \text{ mW}$ per PDM
- ✓ Dynamic Range $> 50 \text{ PE}$

From DarkSide-50 to DarkSide-20k

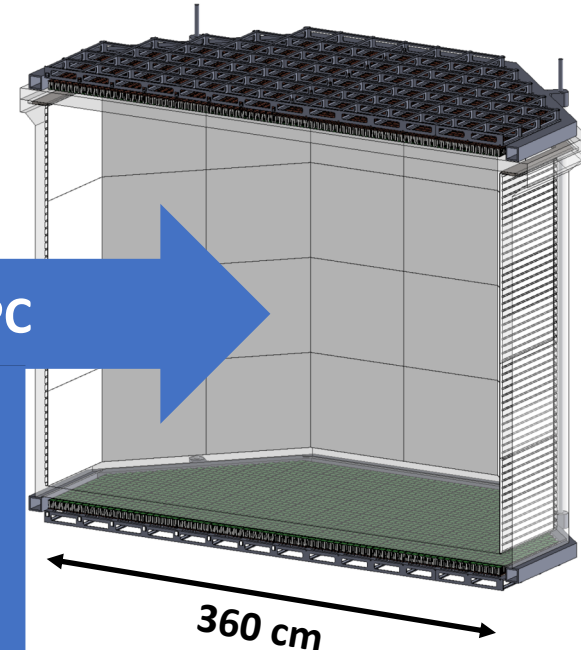
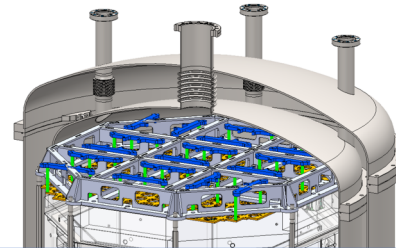
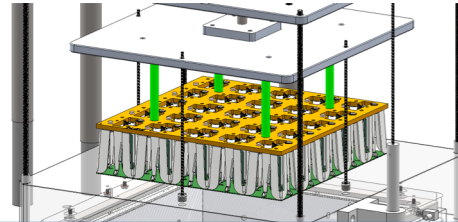
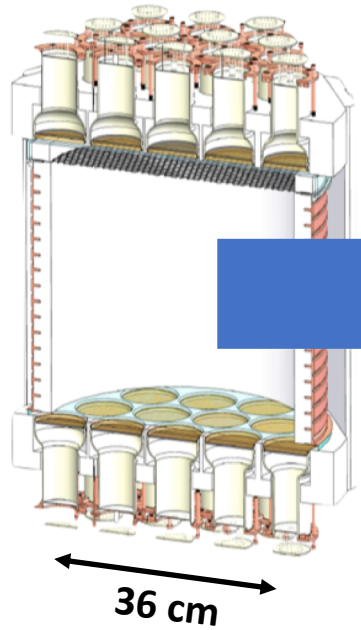
(PDM = Photon Detection Module)

38 PMTs

50 PDMs

370 PDMs

8280 PDMs



From conventional TPC to novel sealed TPC

- Open volume TPC -> Sealed acrylic TPC
- LAr cryostat -> removed
- PTFE reflector -> Enhanced Specular Reflector (ESR)
- ITO -> Clevios
- Cu field cage -> Clevios field cage

DS-50
(2014–present)

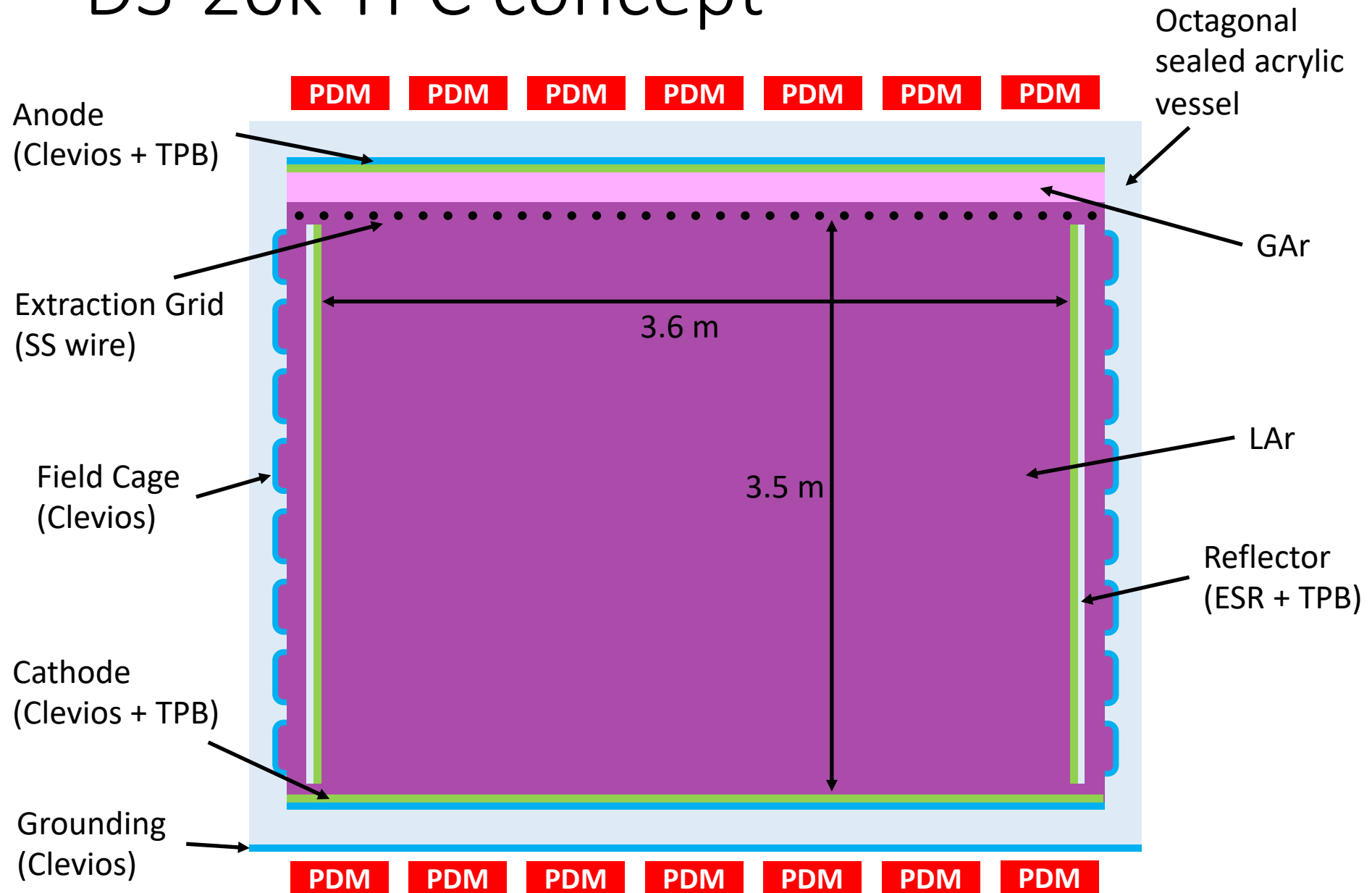
46 kg active
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Test bench

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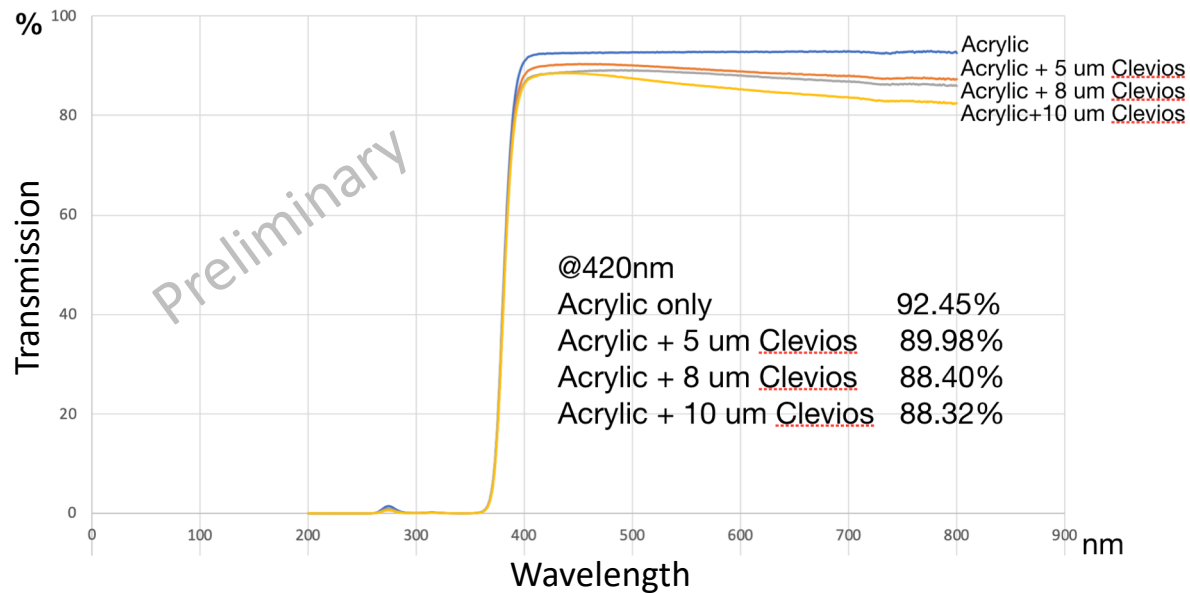
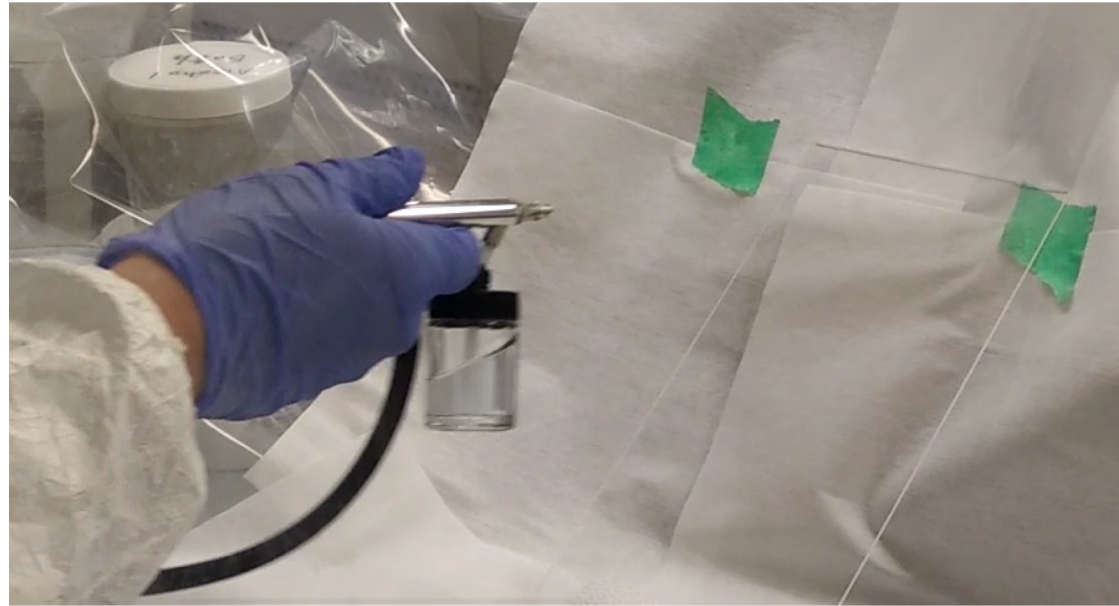
DS-20k
(2022–)
48 ton active
Novel sealed TPC

DS-20k TPC concept

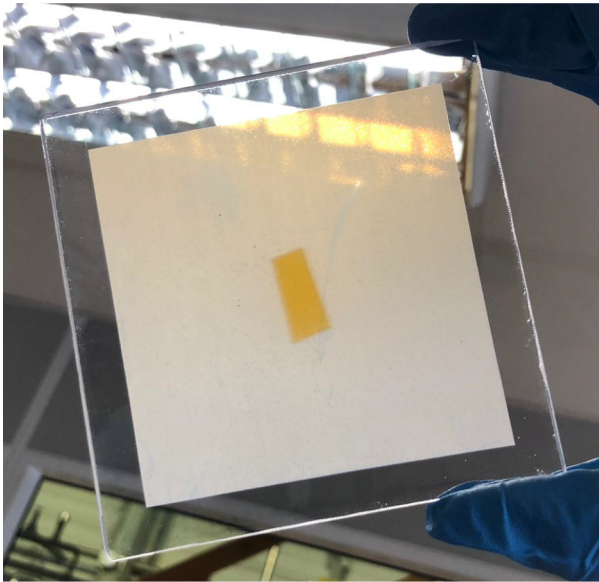


Clevios coating

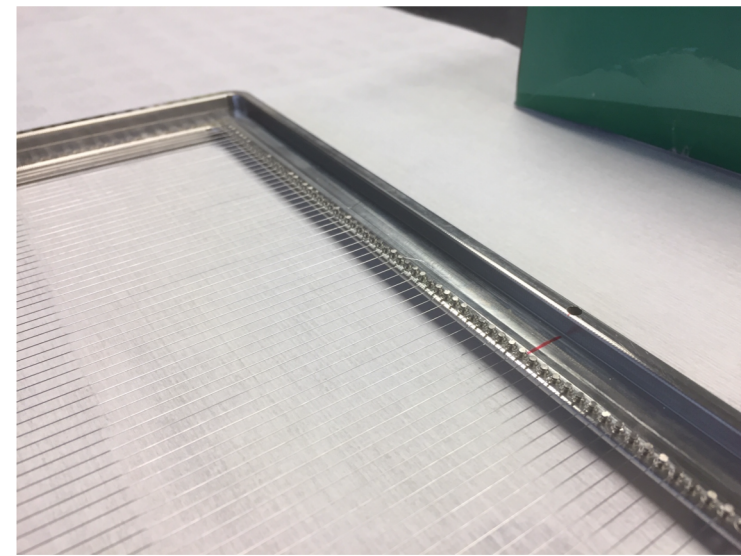
- Clevios: transparent, conductive polymer
- Blue aqueous dispersion
- Radio-pure in bulk
- Rn emanation measured after coating: no ^{222}Rn trace
- Coating methods:
 - Wire Wound Rod (small, flat substrate)
 - Painting (large substrate) with brush or spray gun
- High transparency for 420 nm light



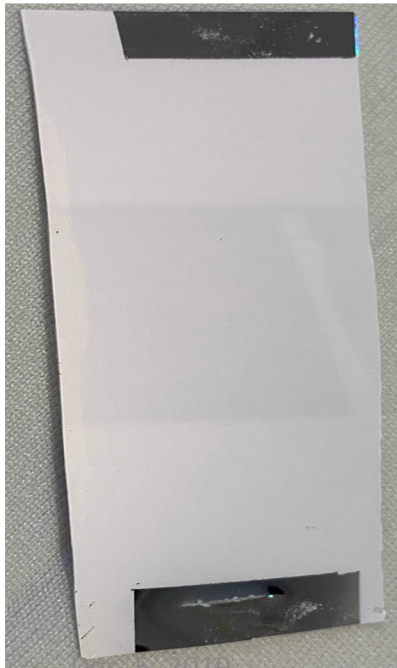
TPC component R&D



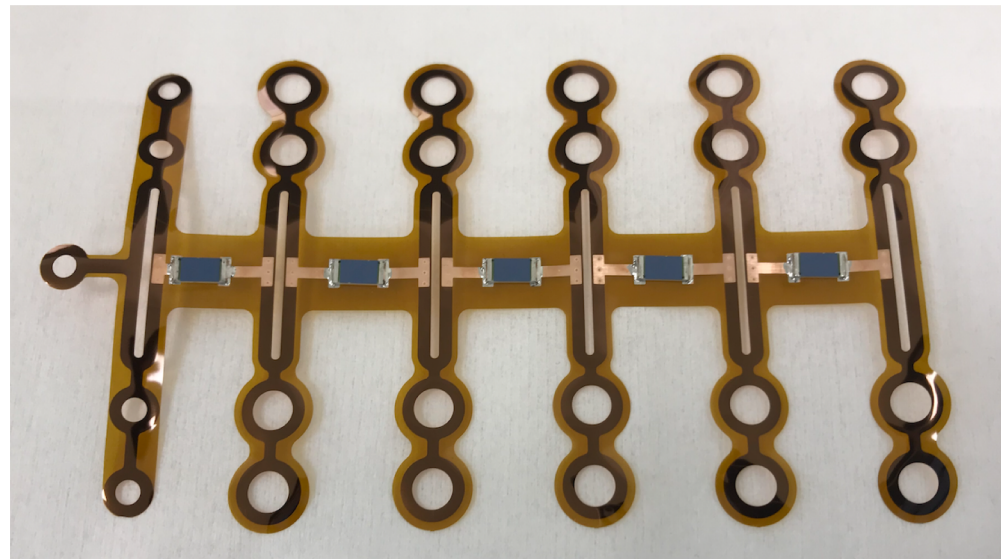
Acrylic plate coated with 5 μm Clevios by wire wound rod, then coated with TPB. Passed LAr dumping test



Stainless steel wire grid for Proto-0, 100 μm wire, 3 mm pitch



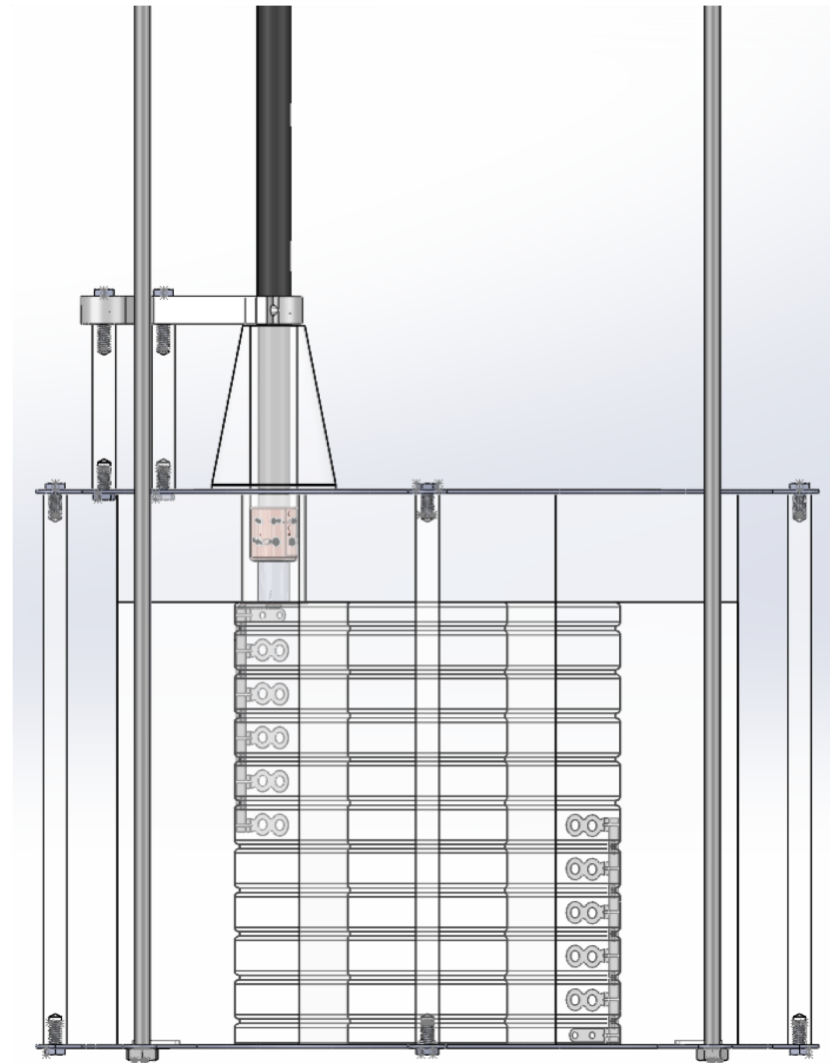
Enhanced Specular Reflector (ESR) coated with TPB. Passed LAr dumping test.



PCB resistor chain for Proto-0, 1 G Ω SM resistor

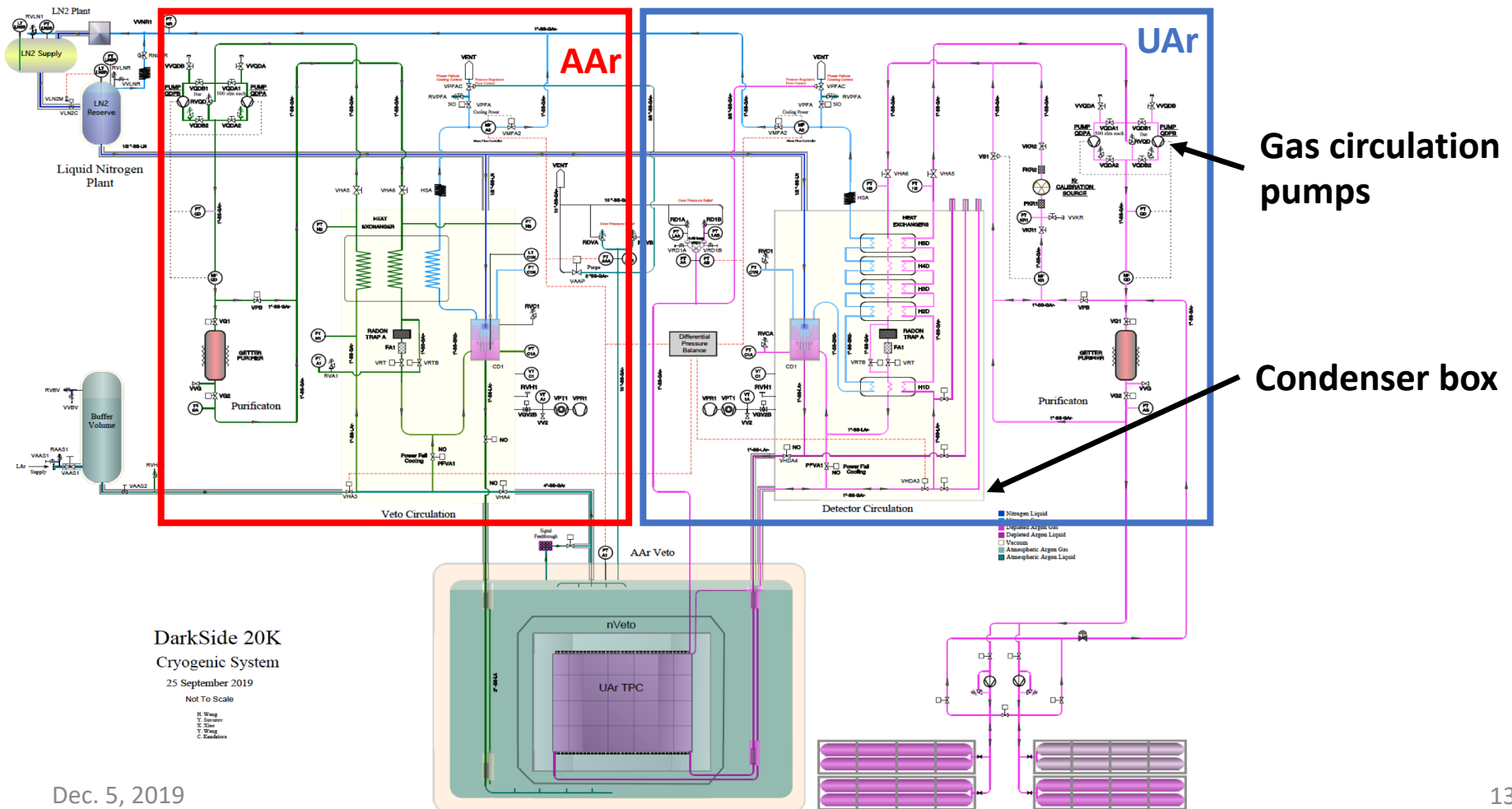
HV delivery mockup test

- Abandon conventional HV feedthrough for new concept:
 - Acrylic/metal plug bonded with the TPC cathode
 - Full polyethylene HV cable from HV plug to AAr cryostat roof
 - Conventional HV feedthrough on AAr cryostat roof
- It will feature:
 - 5 cm thick acrylic walls
 - Clevis field cage and PCB resistor chain
 - Nominal -70kV foreseen for DS20k
 - Camera to monitor sparks and/or bubble formation
 - Upside-down configuration



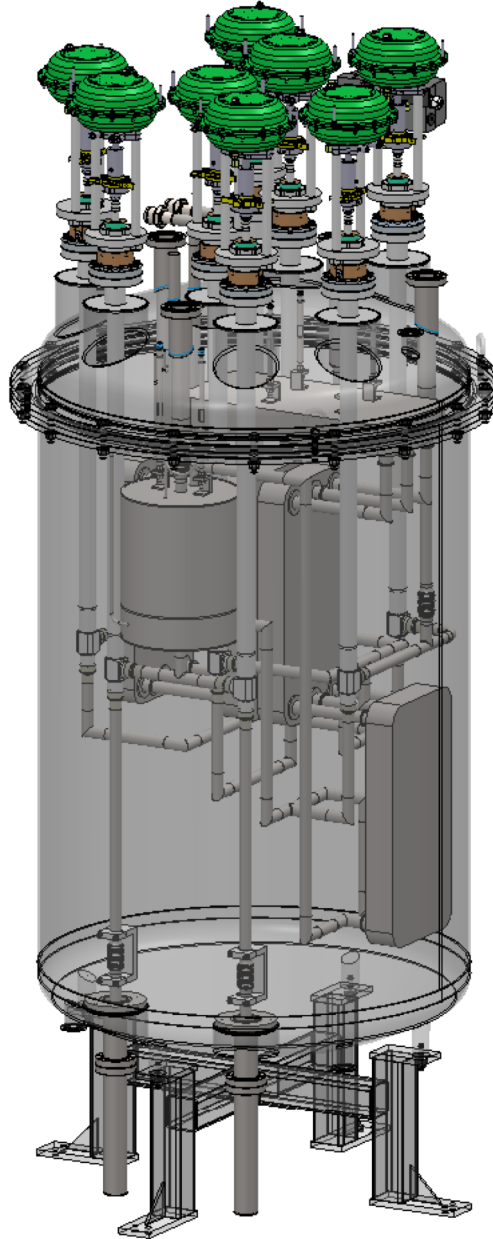
Cryogenics system

- Separate Atmospheric Argon (AAR) and Underground Argon (UAr) cryogenics systems, with integrated slow control system
- UAr cryogenics system derived from the success of DS-50: electron lifetime >5ms, TPC pressure stability ± 0.0023 psi
- Gas phase purification and circulation at speed up to 1000 slpm (full cycle per 20 days)



UAr condenser box

- **LAr condenser, heat exchangers, (radon trap), valves, sensors, bayonet ports and piping, integrated into a single, stand-alone vacuum chamber**
- **LN2 cooling, continuous adjustable cooling power up to 8 kW**
- **Auto-adjusting cooling power**, with UAr pressure in TPC as feedback parameter
- **Immunity of power failure**
- Fabrication finished, leak check and pressure test passed



UAr gas circulation pump

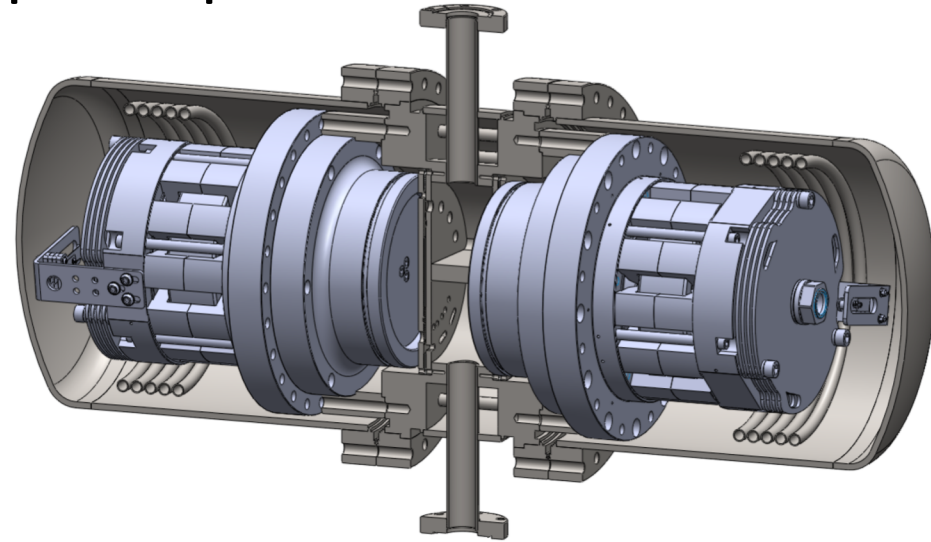
No existing commercial product to meet requirements:

- Ultra-high purity application
- Risk- and maintenance-free
- High speed

So we built it by ourselves...

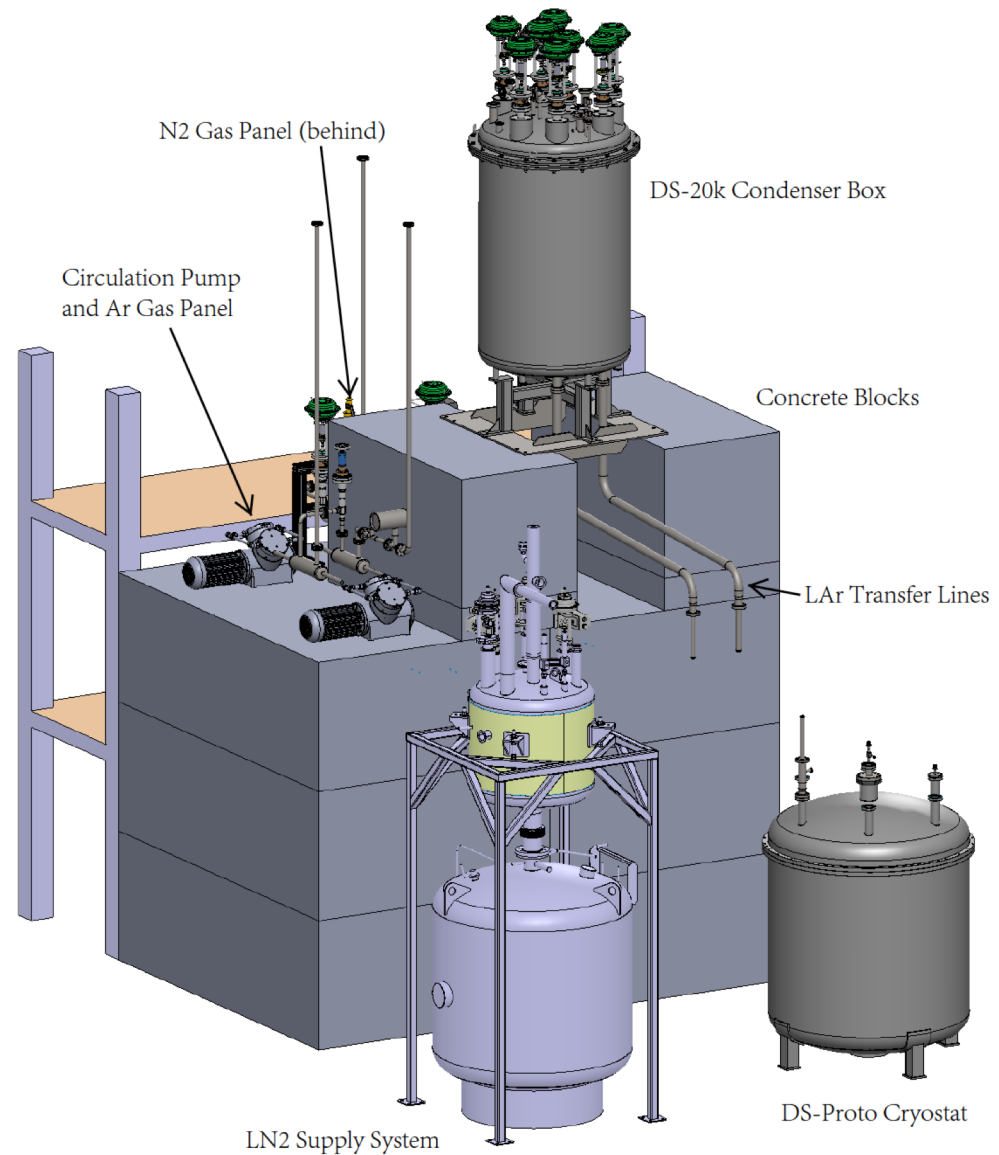
- Two commercial electromagnetic motors (customized a bit) placed face to face and operating in opposite phase
- Minimized vibration, friction-free
- Integrated water cooling
- Integrated automatic protection features
- Designed pumping speed: 500 slmp

Fabrication finished, to be tested individually



UAr cryogenics test

- Simplified version of DS-20k UAr cryogenics (e.g., radon trap and getter purifier not included)
- To validate design and check performance
- Major components to be used in the final DS-20k UAr cryogenics system, directly or after minor modifications
- System integration on-going
- Test scheduled in Q1, 2020

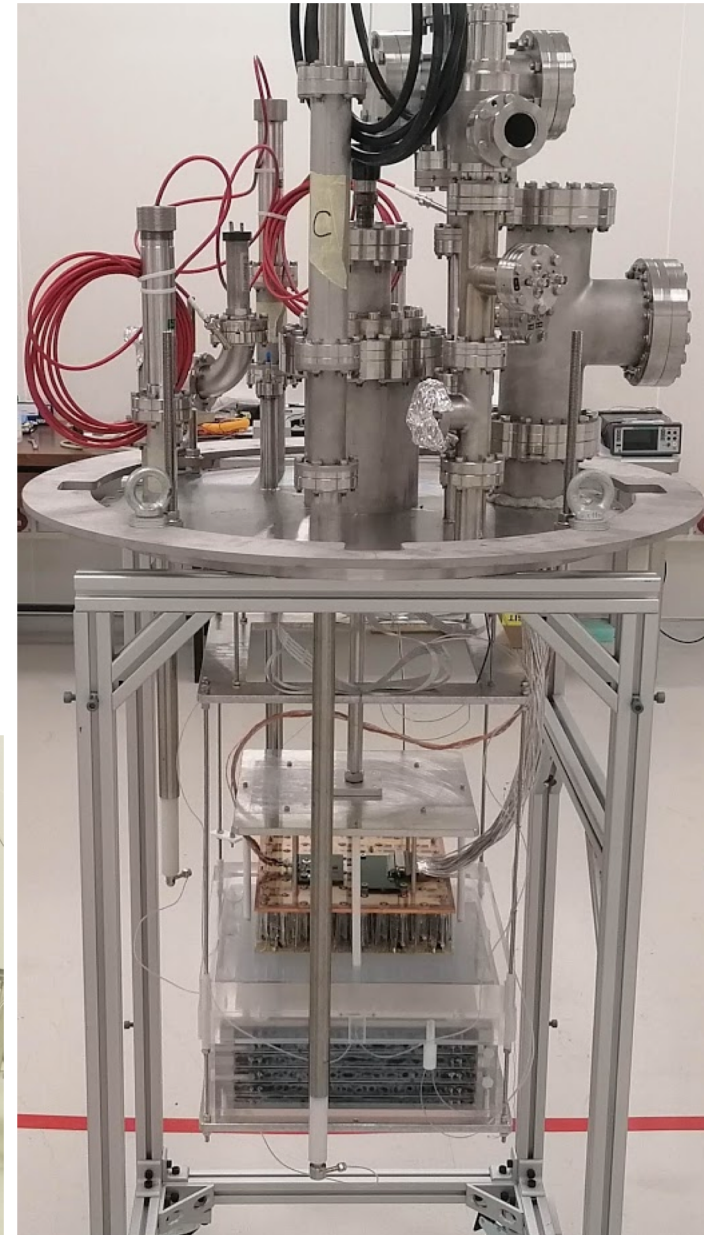
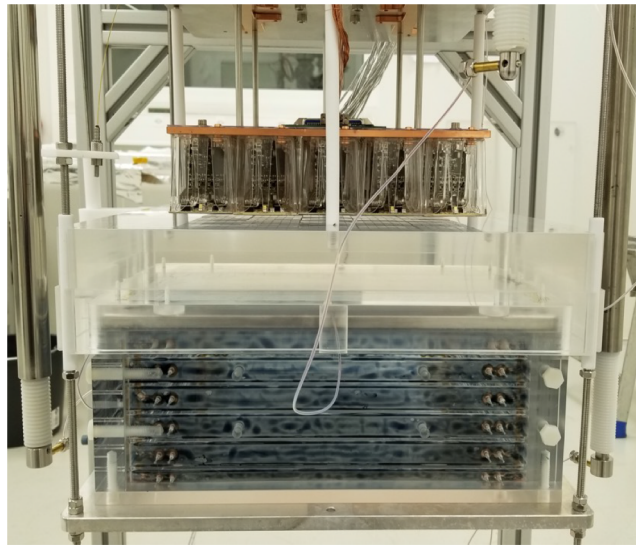
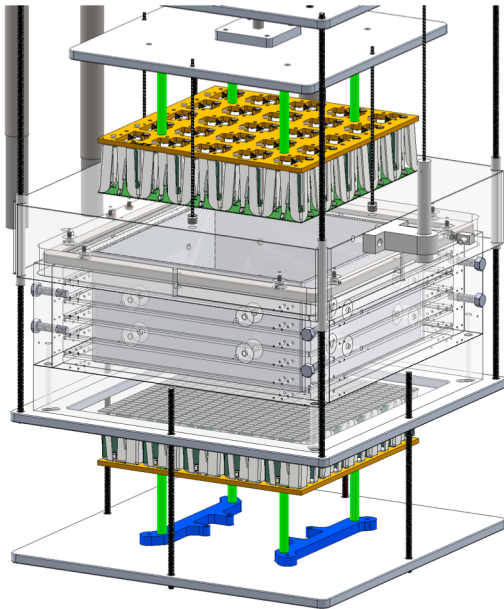


DarkSide Proto-0

25 cm x 25 cm x 12 cm TPC, as test bench for:

- DS-20k TPC design: Clevios, ESR, wire grid, resistor chain...
- S2 study: S2 pulse shape, X-Y position reconstruction...
- Online adjustable gas pocket to optimize configuration
- Motherboard full-chain readout
- Full DAQ scheme

First phase with one motherboard on top has been successfully commissioned, more tests are scheduled in 2020.



Summary

- From DarkSide-50 to DarkSide-20k, we put big effort of photosensor and inner detector R&D
- SiPM-based photosensor development is very successful
- Key features of novel LAr TPC design have been or are being validated
- Key components of customized UAr cryogenics system have been fabricated and are ready for test
- Prototype programs are in good shape