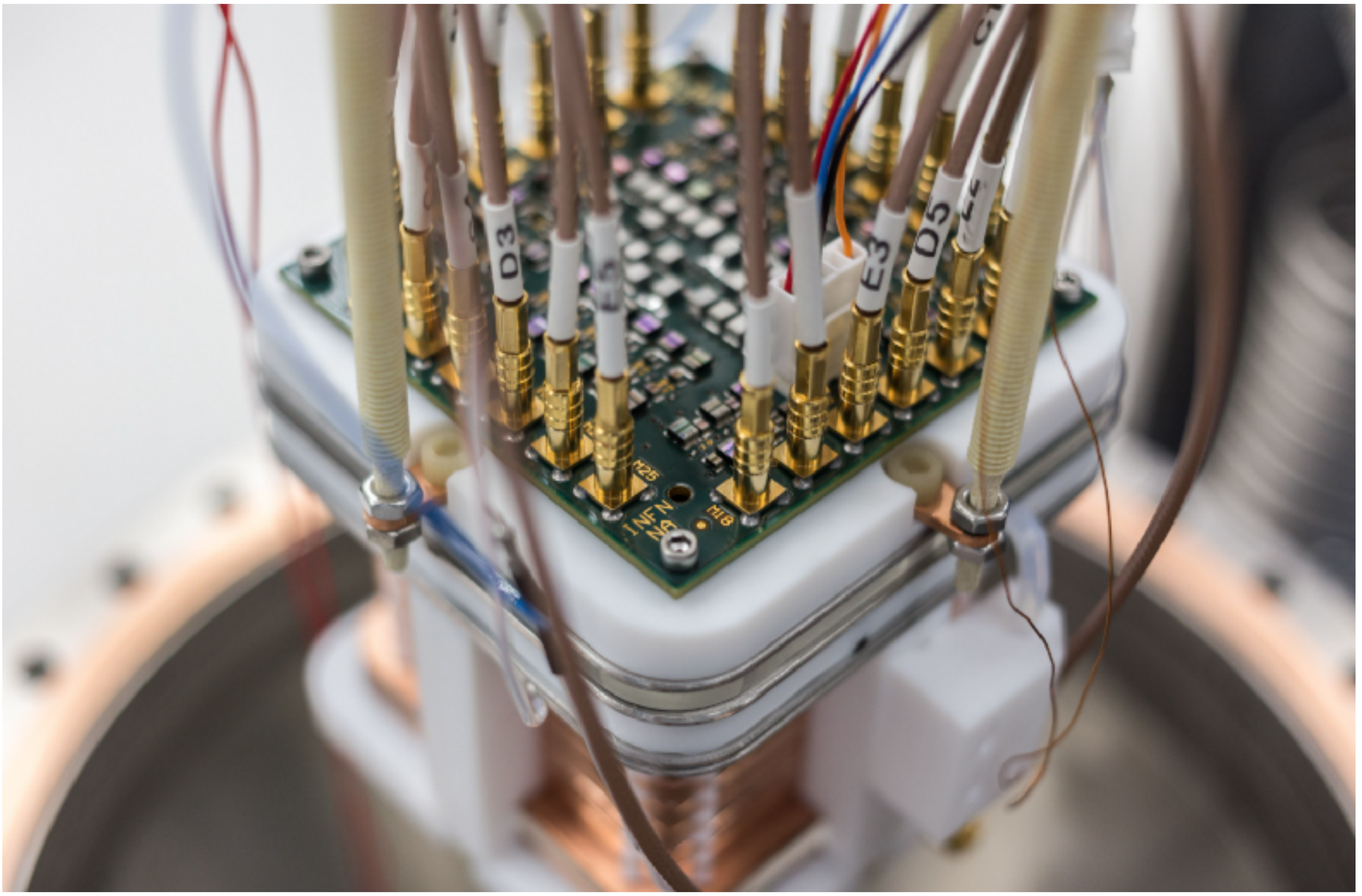
ReD: characterisation of a SiPM based Liquid Argon TPC for directional dark matter detection studies

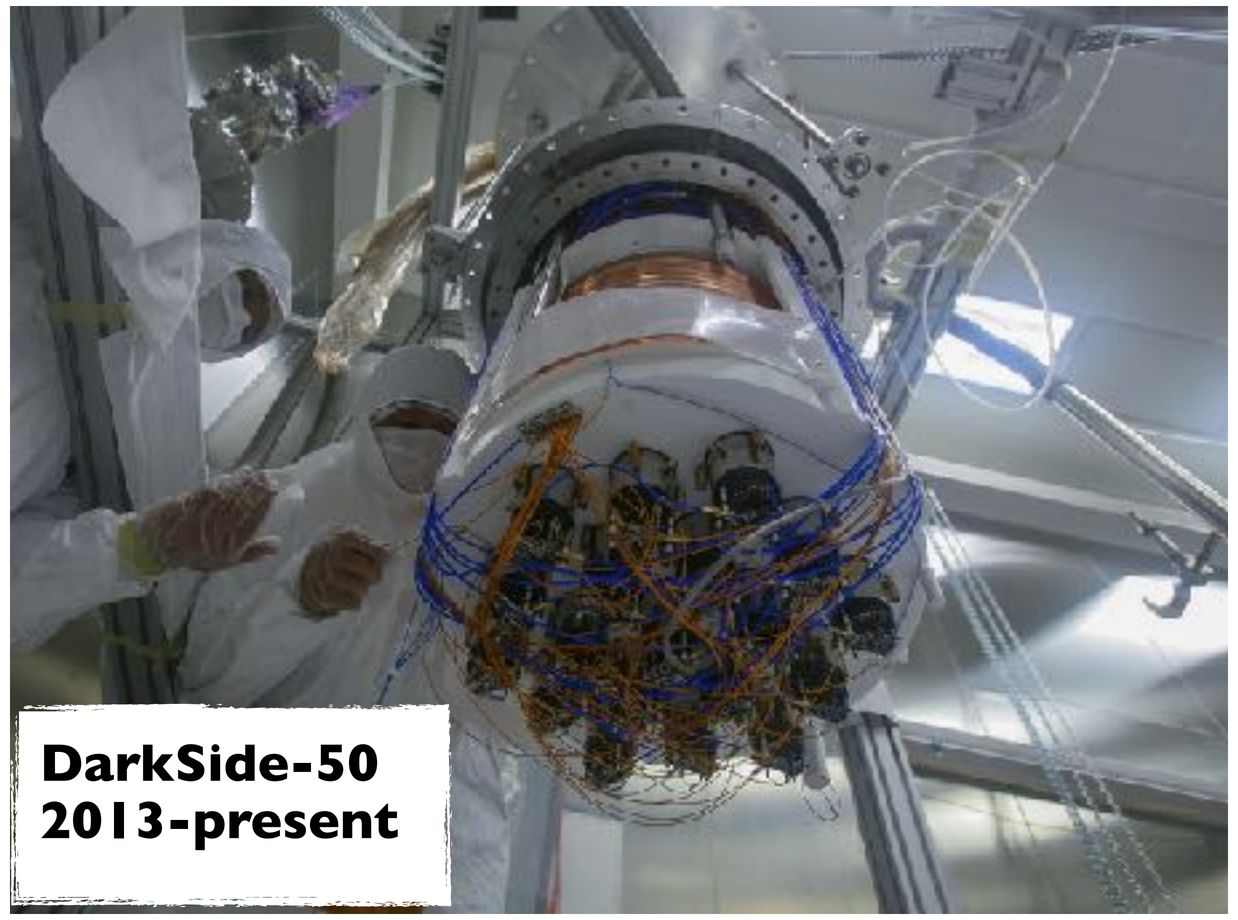


Yury Suvorov - Naples University Federico II. On behalf of DarkSide collaboration

EPS-HEP on-line Conference, 26th July, 2021

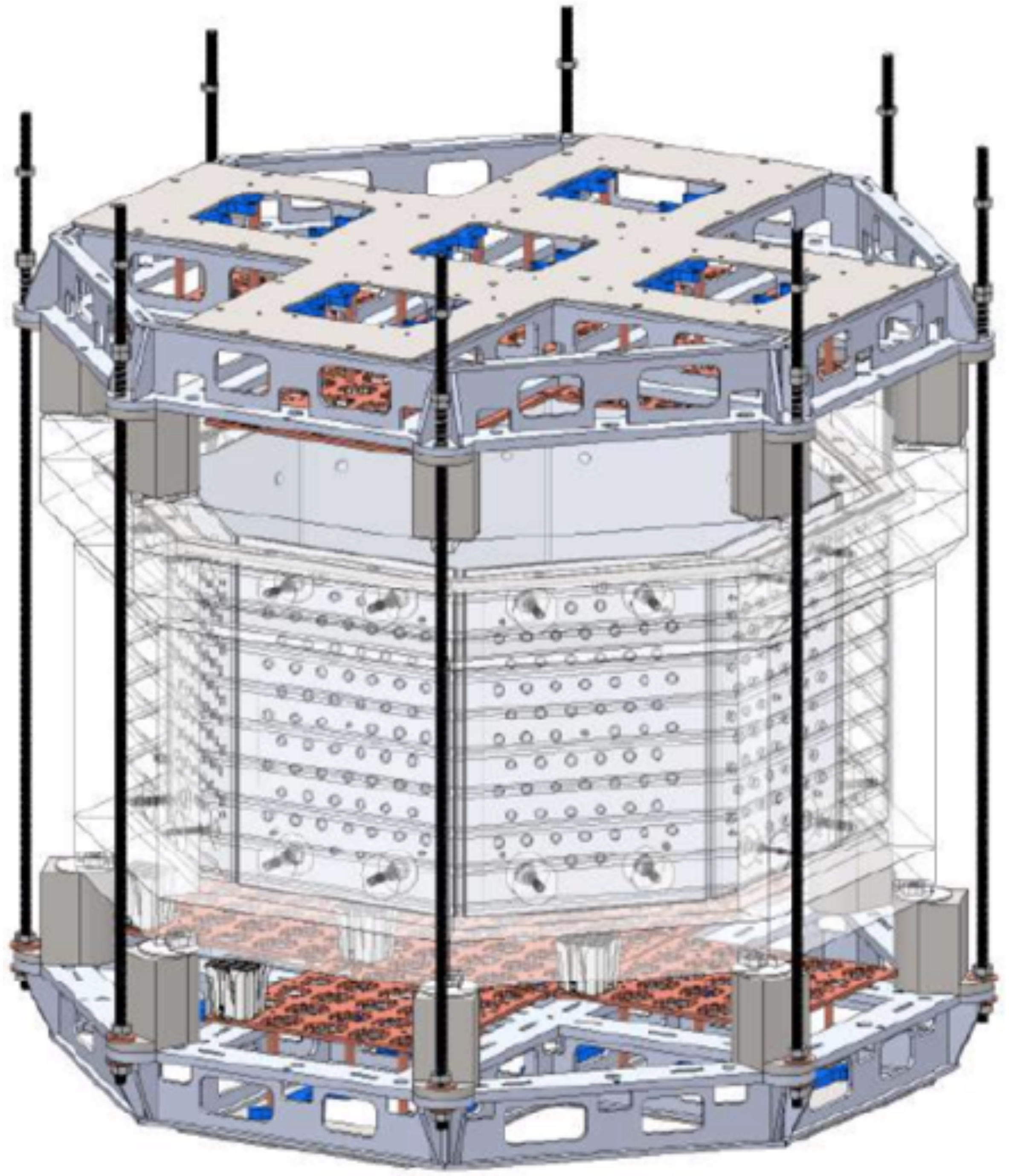
DarkSide

The DarkSide project exploit the LAr TPC technology with UAr for the direct DarkMatter search. Starts with 10 kg detector (LNGS run in 2012), final goal is 300 t detector (ARGO, SNO Lab).

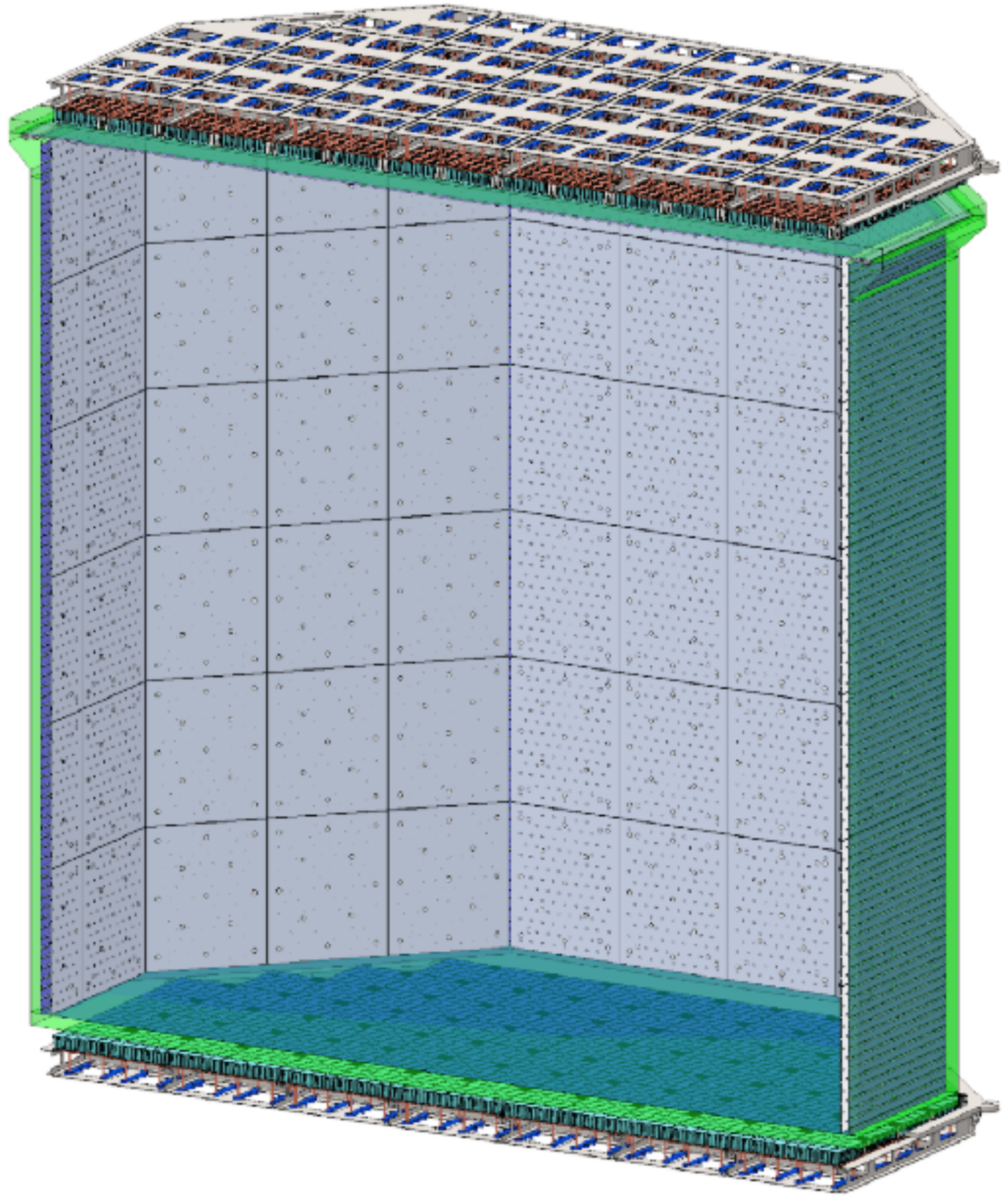


P. Agnes et al., Phys. Rev. D 98 (2018) 102006

Proto-1t. The 175 kg LAr.
2021-2022



DarkSide-20k. 2024-??



The 50 t of UAr, acrylic TPC (3.5 m drift). Surrounded by the active Neutron Veto (Gd laded acrylic panels). About 28 m^2 of SiPM top+bottom. ProtoDune-like membrane cryostat.

See Izabela Kochanek presentation (26th) & Bianca Bottino talk (27th).

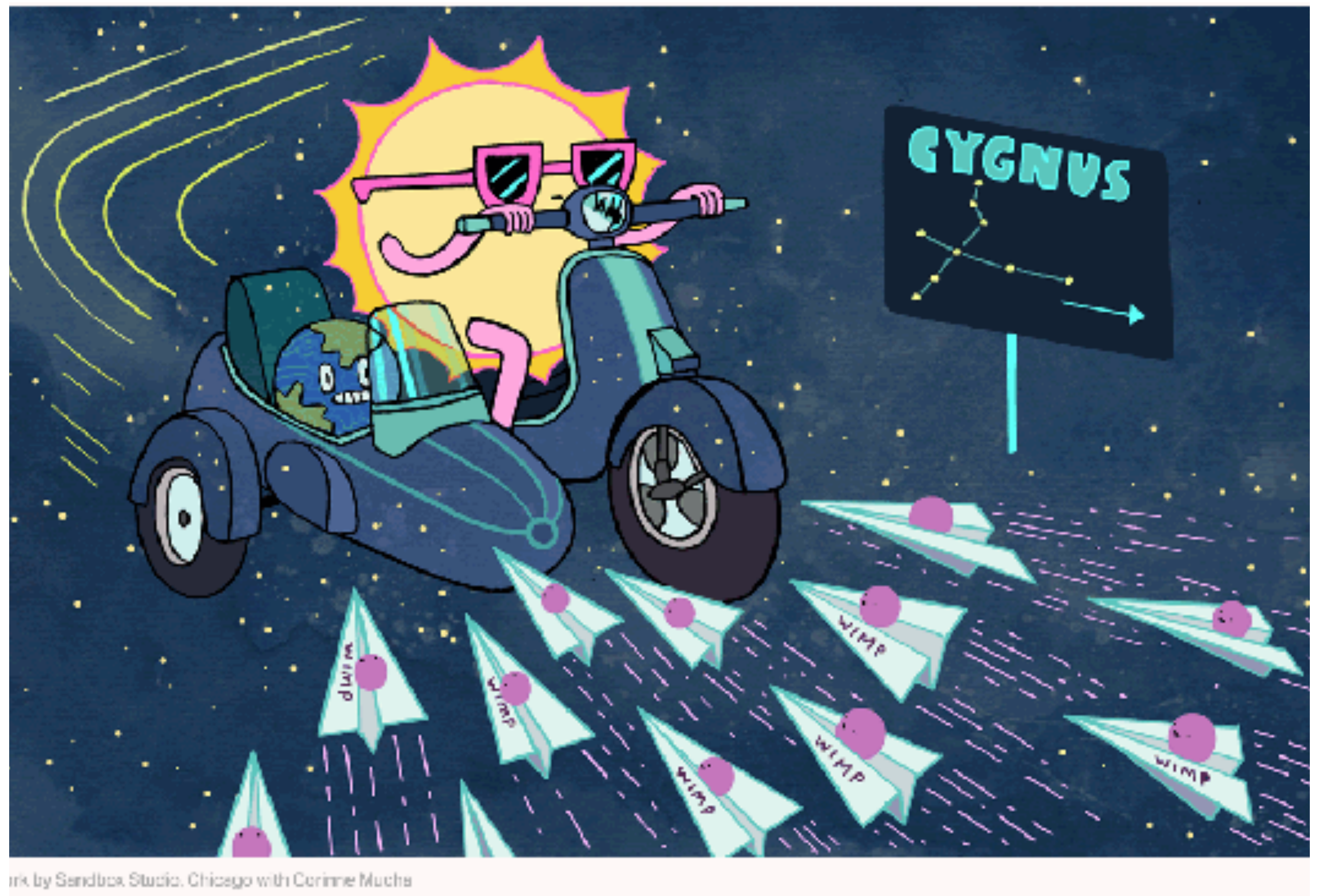
Directionality in LAr TPC

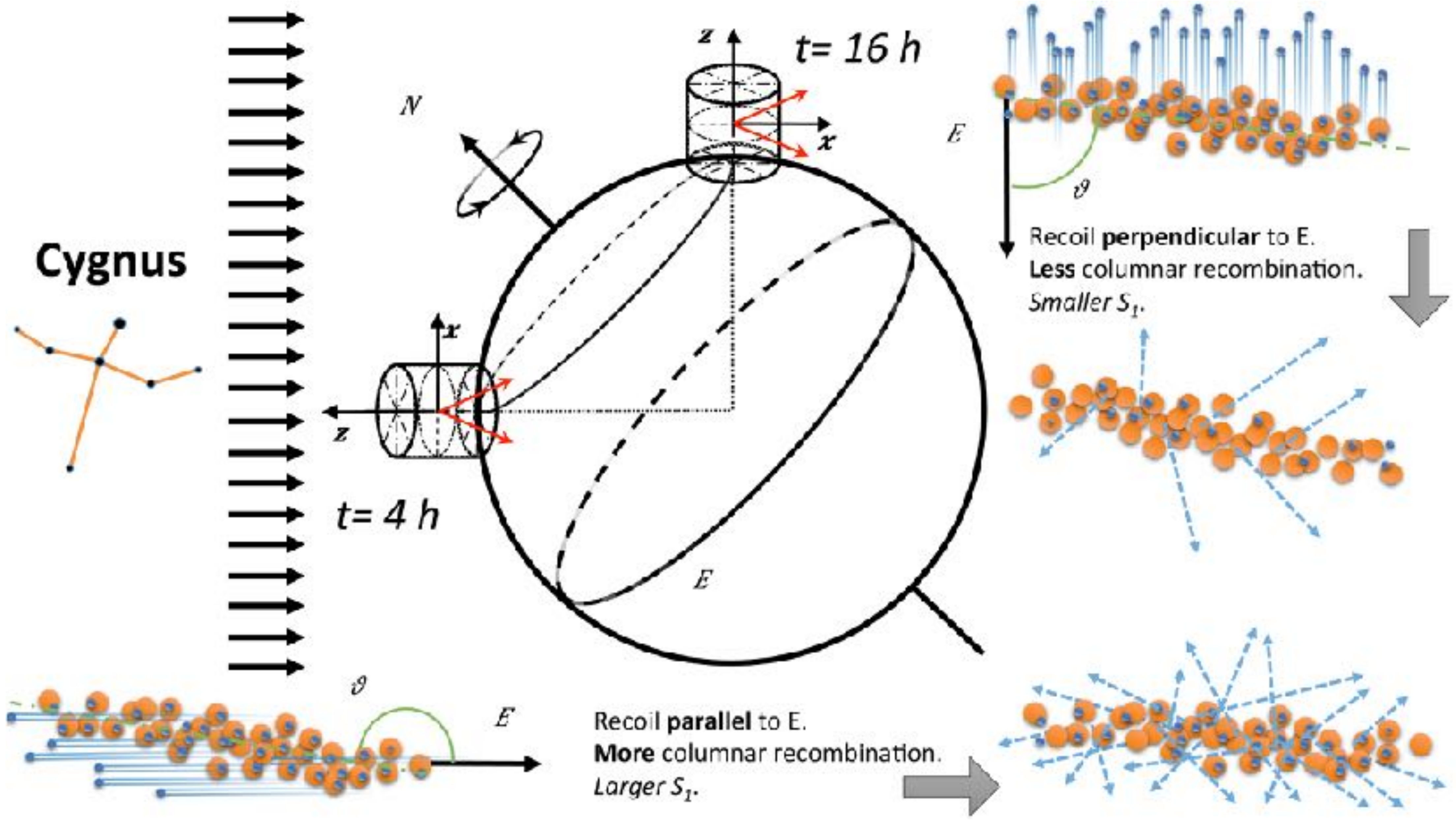
Sidereal variation of WIMP wind from Cygnus, results in a substantial anisotropy in nuclear recoils. Ratio of horizontal WIMP induced Ar recoils to vertical ones, varies of a factor 10 over the day. Hard to mimic (for the background).

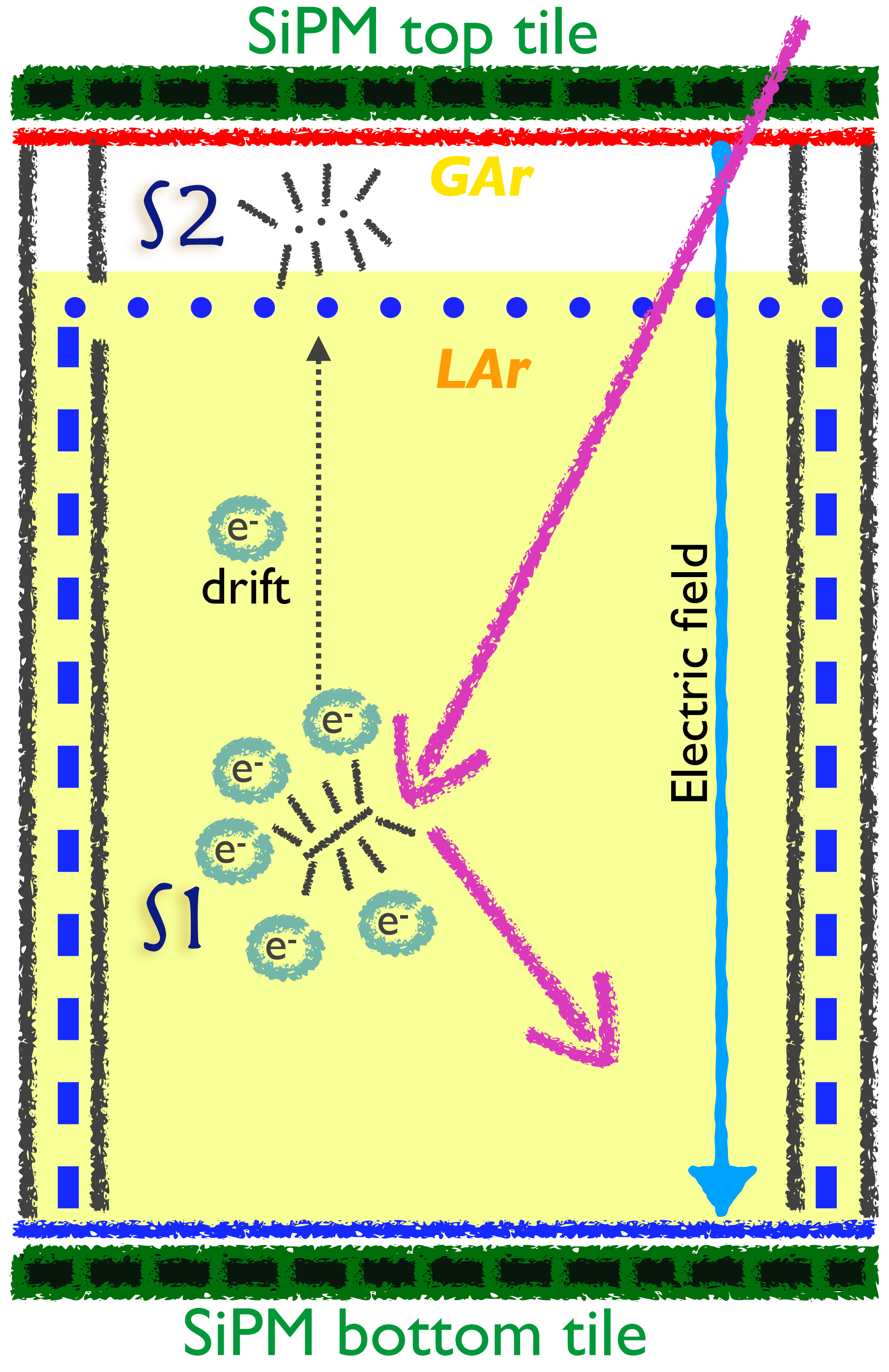
Recombination: capture by ions of freed electrons (released by the ionizing particle).

Columnar recombination: dependency on how the column of ionization is formed with respect to the electric field of the TPC. Sensitive to the angle that forms between the drift field and the direction of the Nuclear Recoil. Both S1 (scintillation) and S2 (ionisation) are expected to be dependent on the this angle.

First attempt to investigate this dependancy in liquid Argon - SCENE experiment (2013), *H. Cao et al., Phys. Rev. D 91 (2015) 092007.*

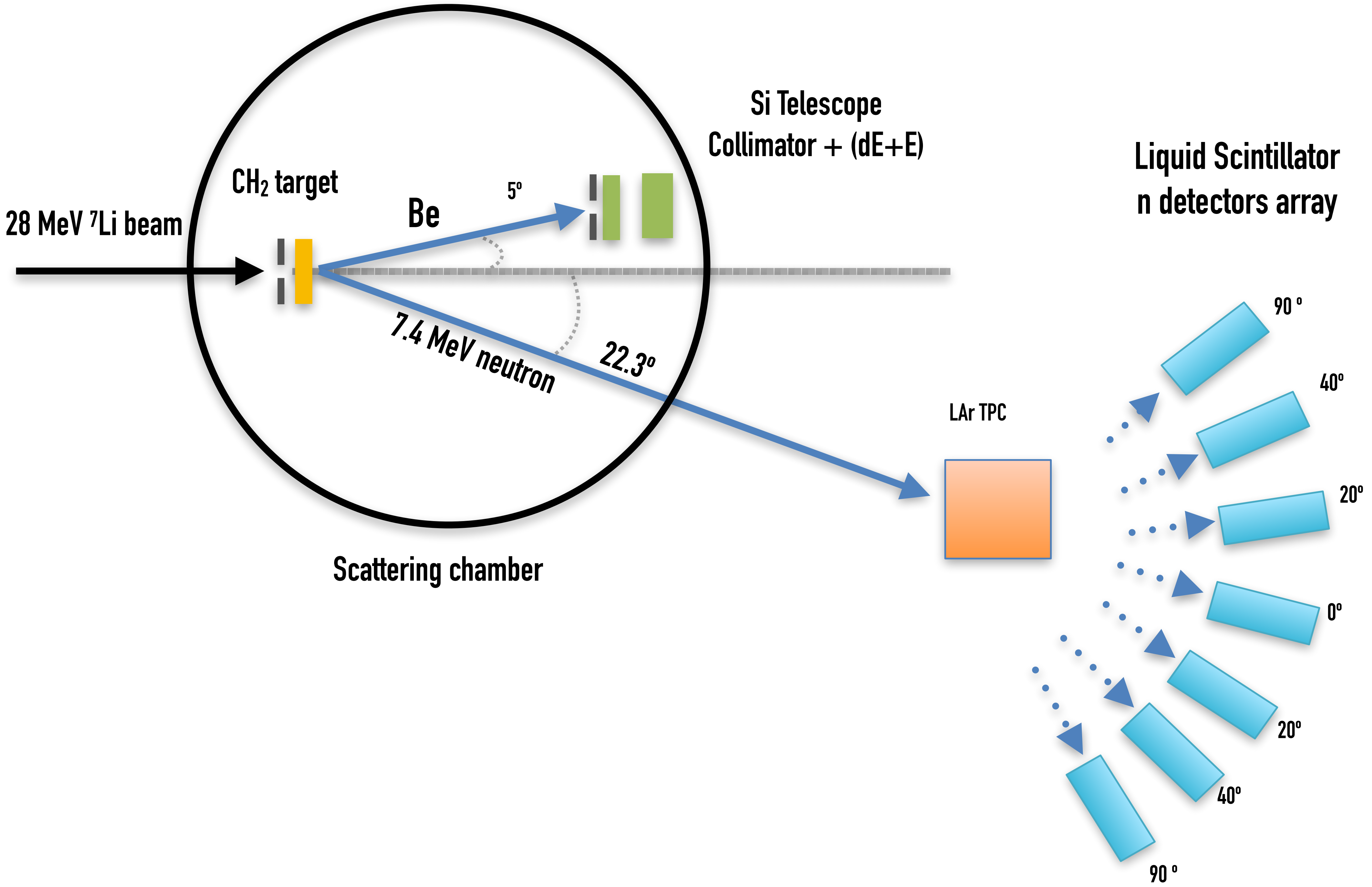


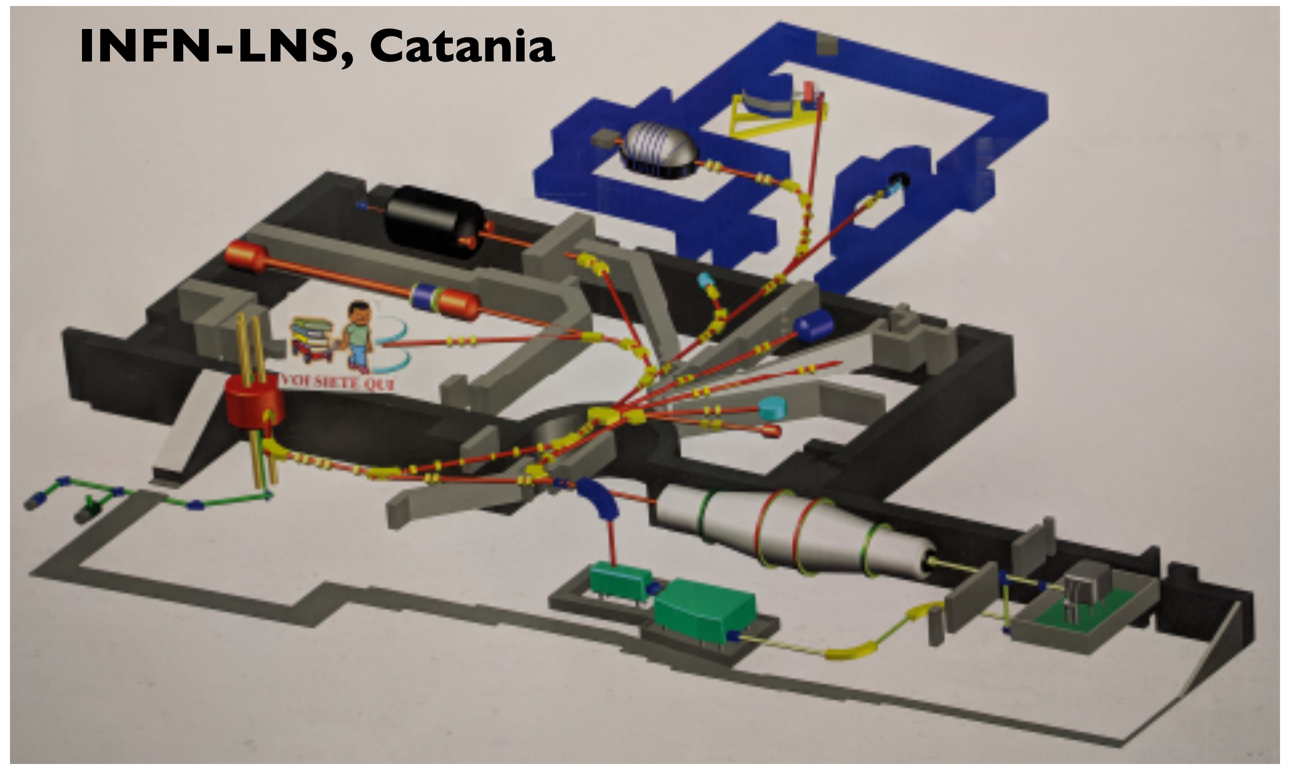


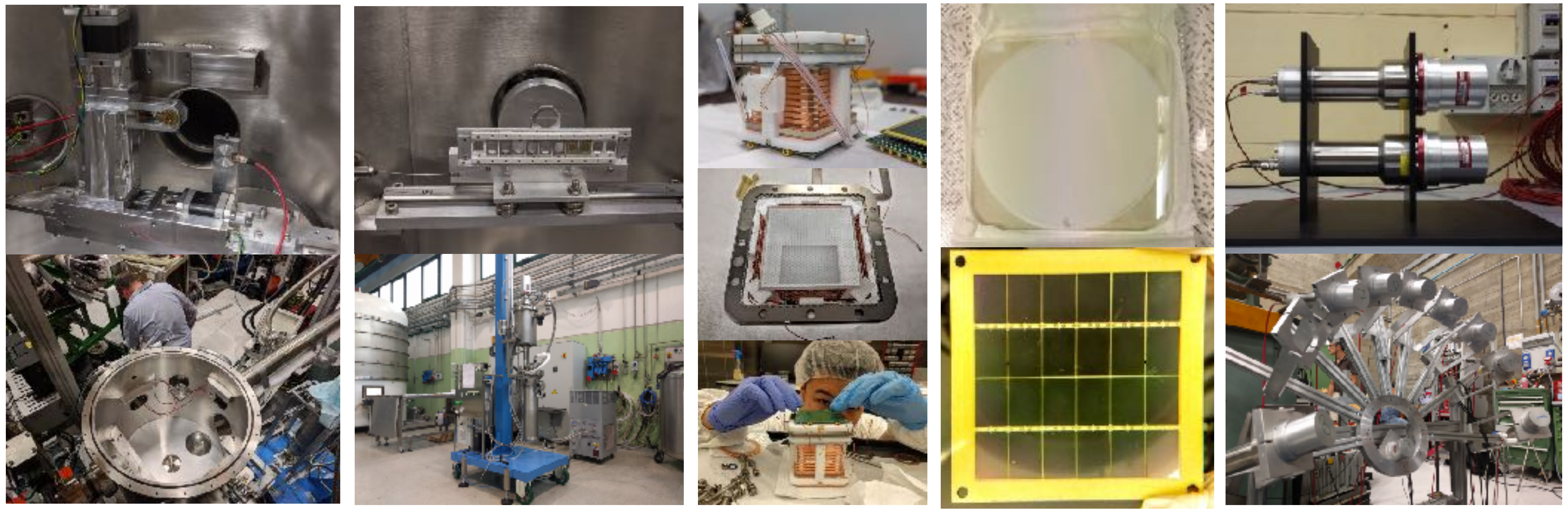


ReD Experiment

- TANDEM accelerator at INFN LNS in Catania. 28 MeV ^{7}Li ions. Neutrons from $p(^7Li,^7Be)n$ reaction;
- The Scattering Chamber, polyethylene target (CH2), dE-E telescope (5°) to tag Be7 produced in the reaction and the associated neutron (70 KeV_{nr} of recoil energy);
- The TPC with SiPM light sensors and customised cryogenic system, all controlled by the PXI & Labview based slow control;
- LScint detectors array (9 of 3" neutron detectors).





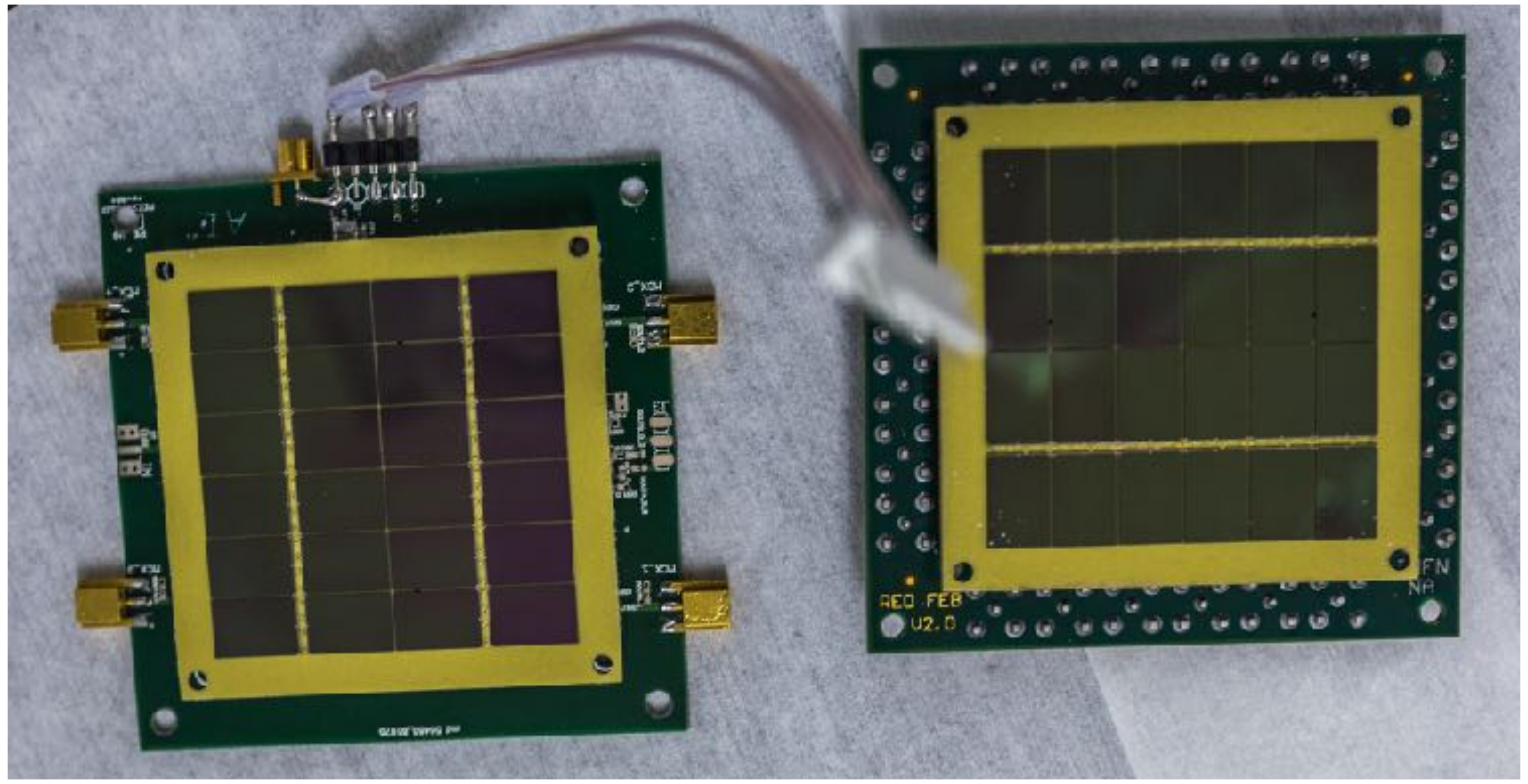


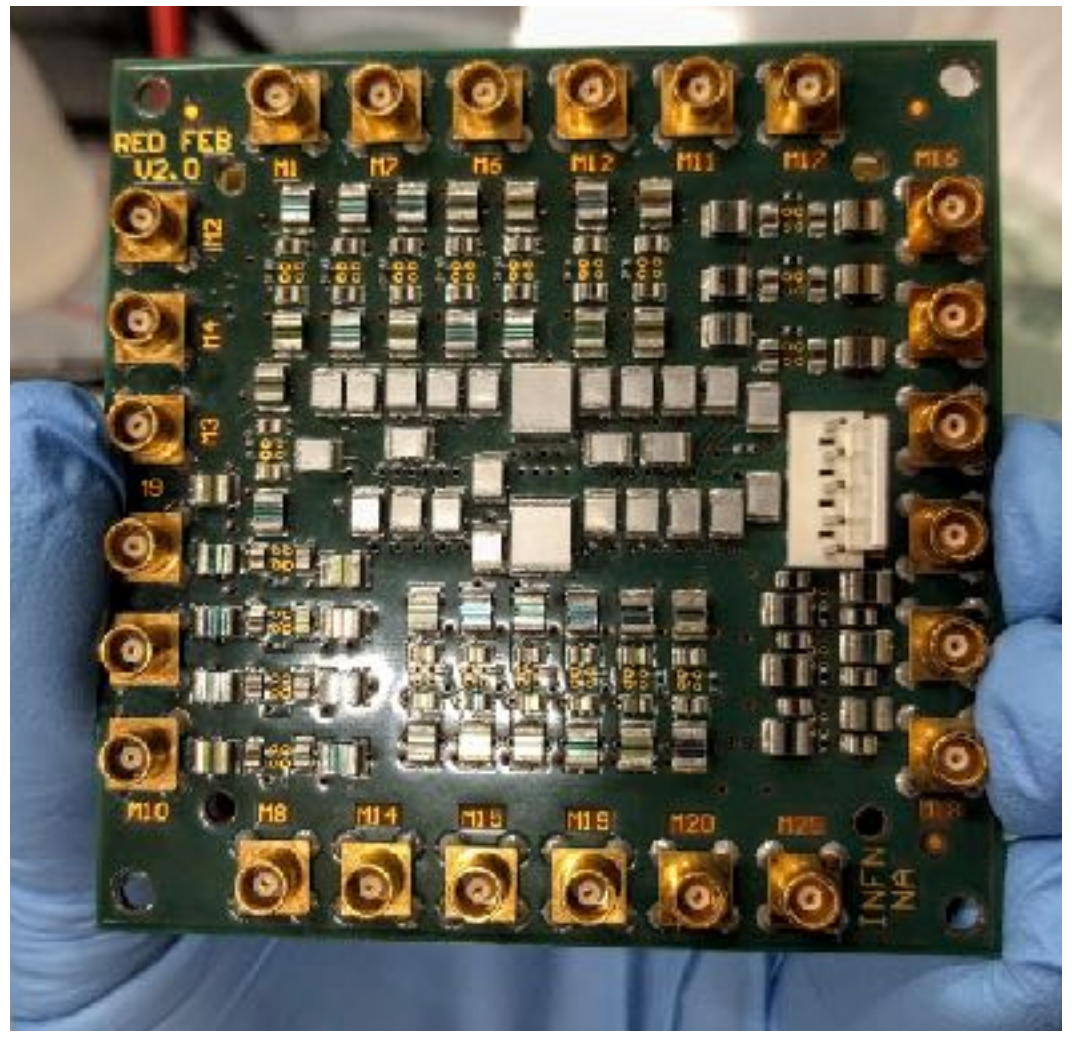
ReD SiPMs and readout

Light readout
The customised NUV-HD-Cryo SPMs developed for DarkSide in collaboration with Fondazione Bruno Kessler (FBK),
Two 5x5 cm^2 tiles with 24 individual rectangular SiPMs of ~12x8 mm^2. The 10 MΩ quenching resistance, 25x25 µm^2 cell. Max PDE at ~420 nm. Dark count rate ~5 cps /1 cm^2. Each SiPM works at fixed bbias voltage of 34V (7 VoV).

Front-End Board electronics designed by INFN-Napoli + INFN-Bologna + LNGS.
Top tile coupled with 24 channel readout FEB (to improve x-y).
Bottom tile coupled with 4 channel readout FEB (24 devised are summed in 4 group of 6).

Electronic readout
CAEN FADC boards V1730B, 500 MHz sampling rate (data rate of 40MB/s, limited by writing on disk). A total of 32 acquired channels, 28 are used for the TPC readout.



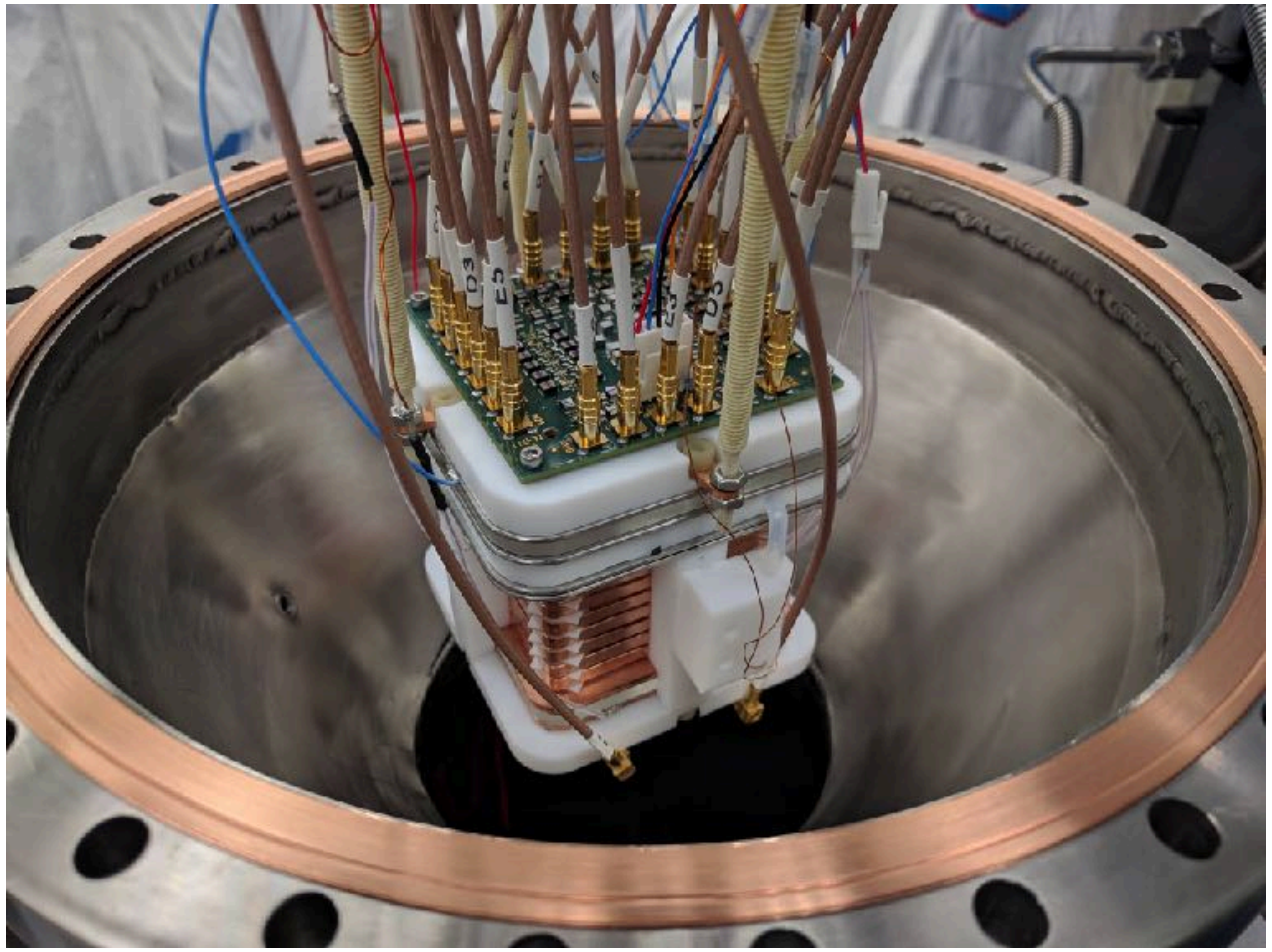


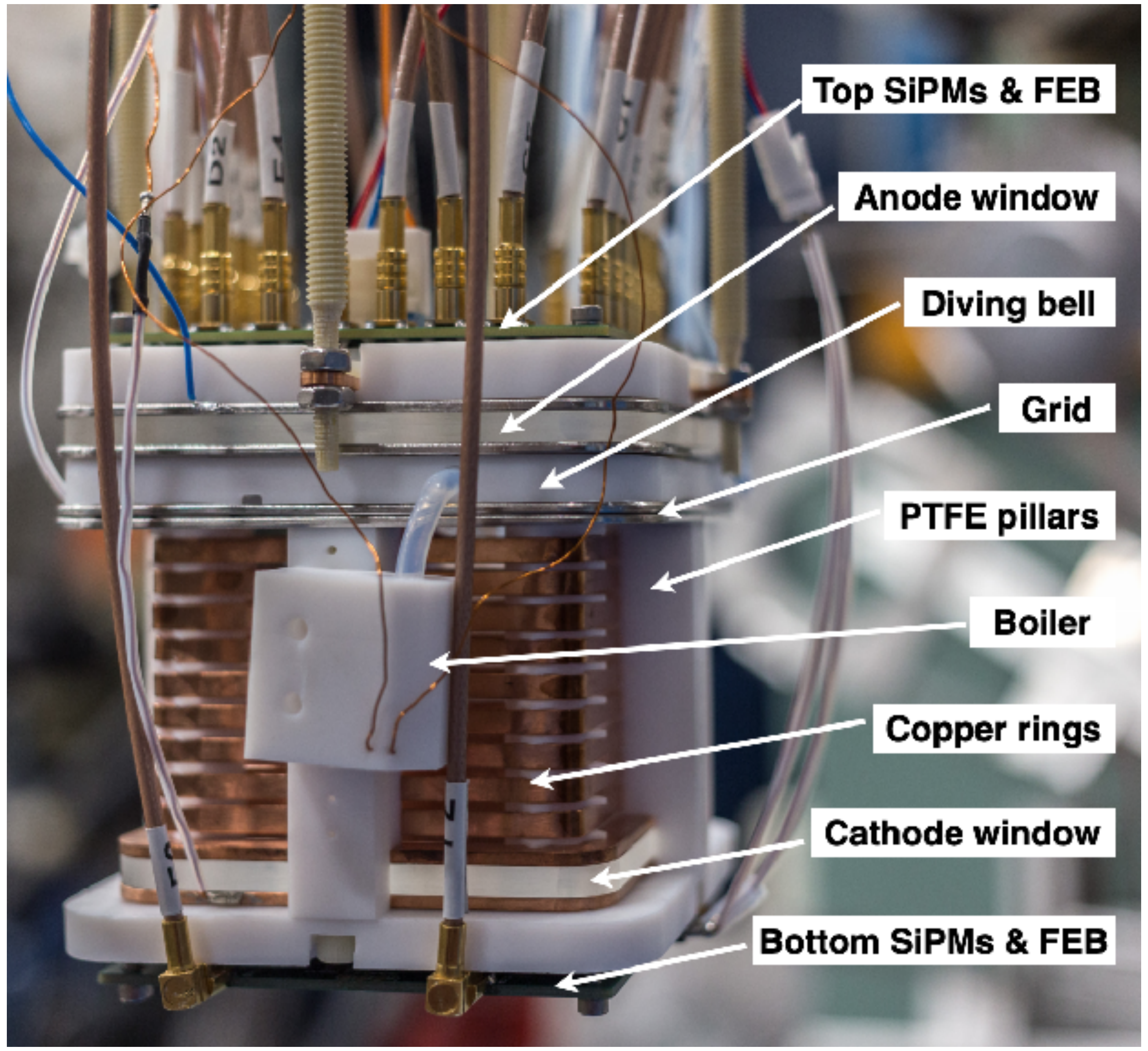
ReD Time Projection Chamber

The cuboid of 5 cm x 5 cm x 6 cm (L x W x H) designed and builded by UCLA group.
Active mass of LAr is 185 g.

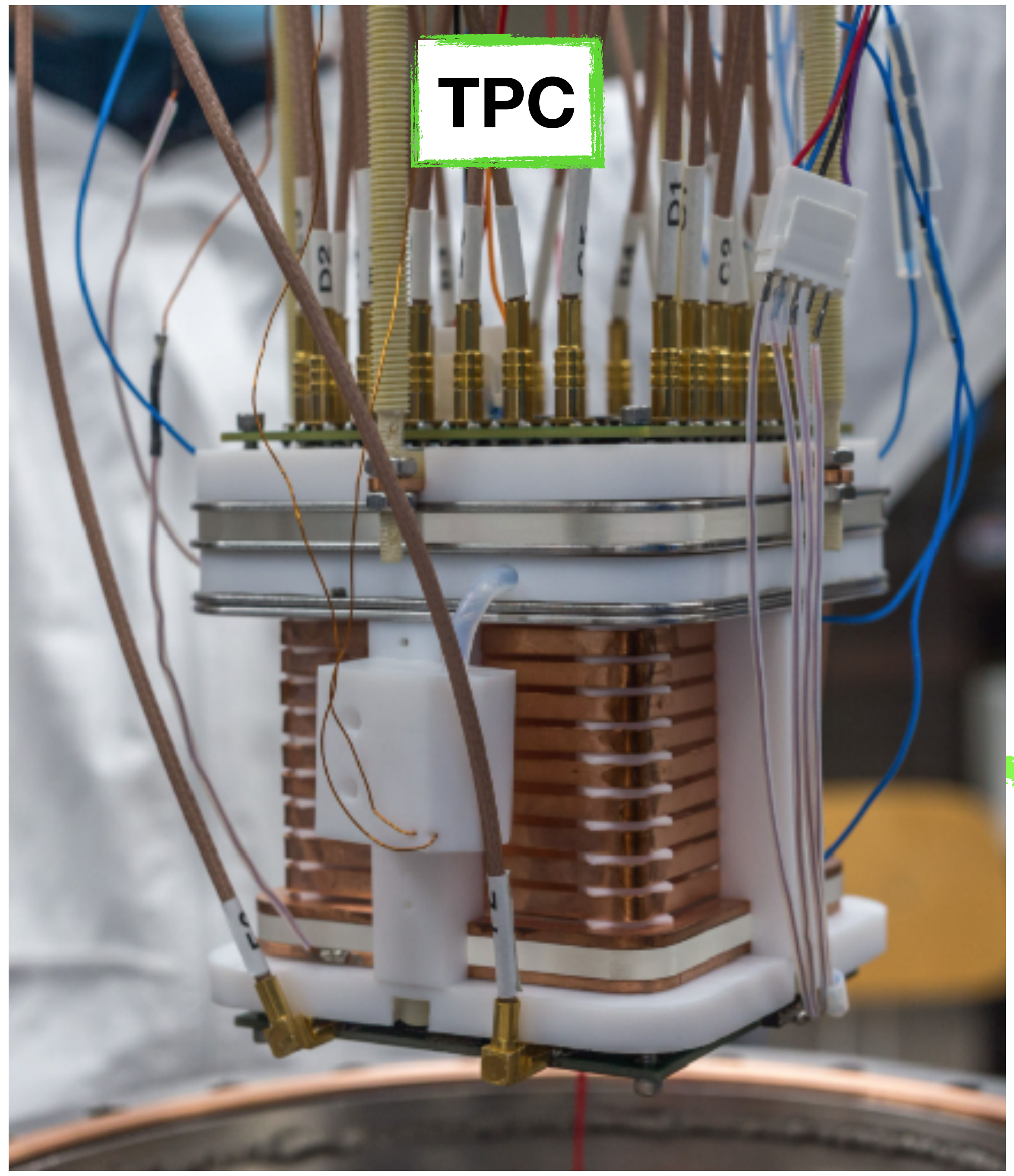
Teflon structure and acrylic top and bottom 4.5mm thick windows (ITO coating → Cathode & Anode.)
Inner side of the TPC (acrylic + 3M reflective foil) all covered with a wls TPB (128 nm → 420 nm).

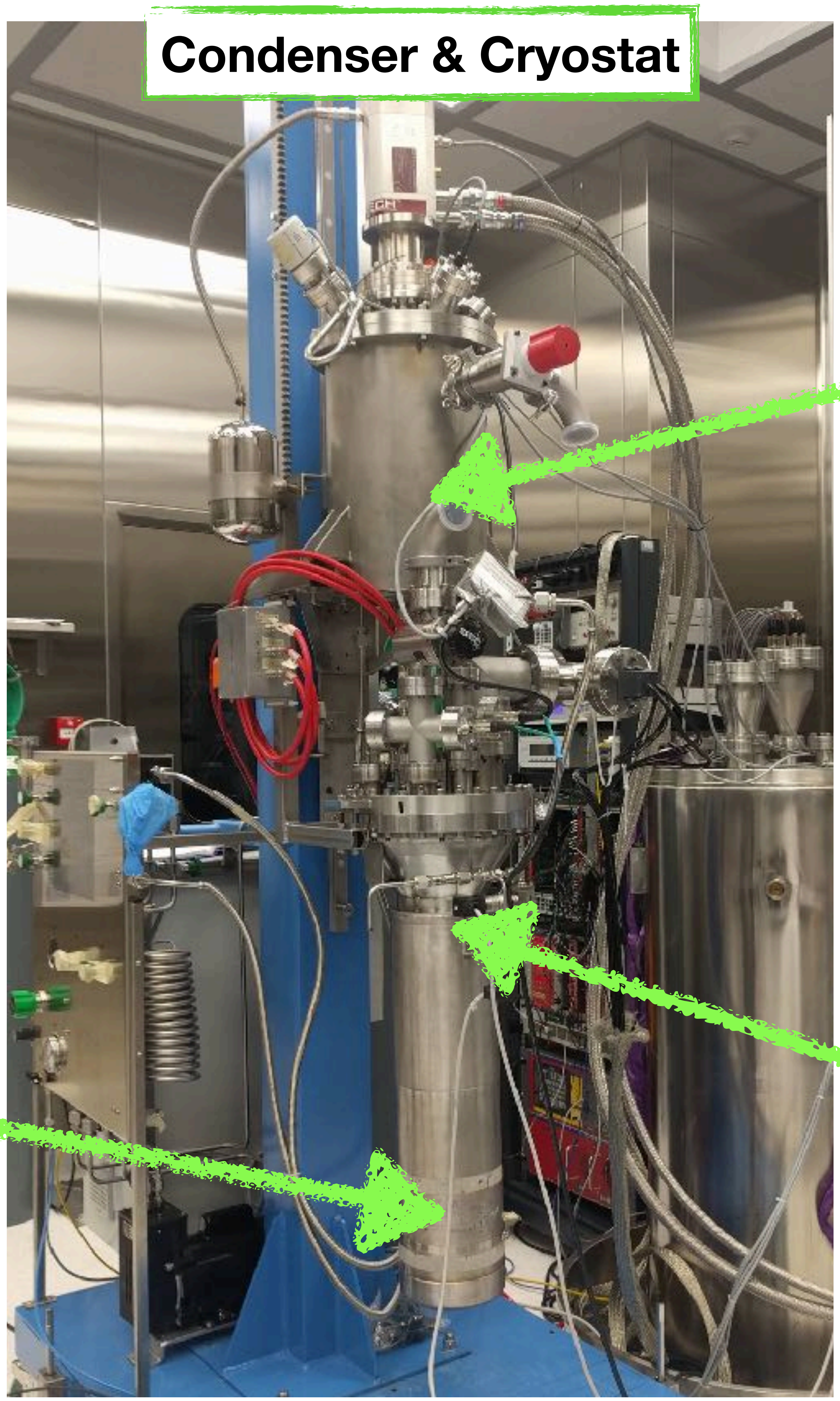
Customised cryostat and condenser.

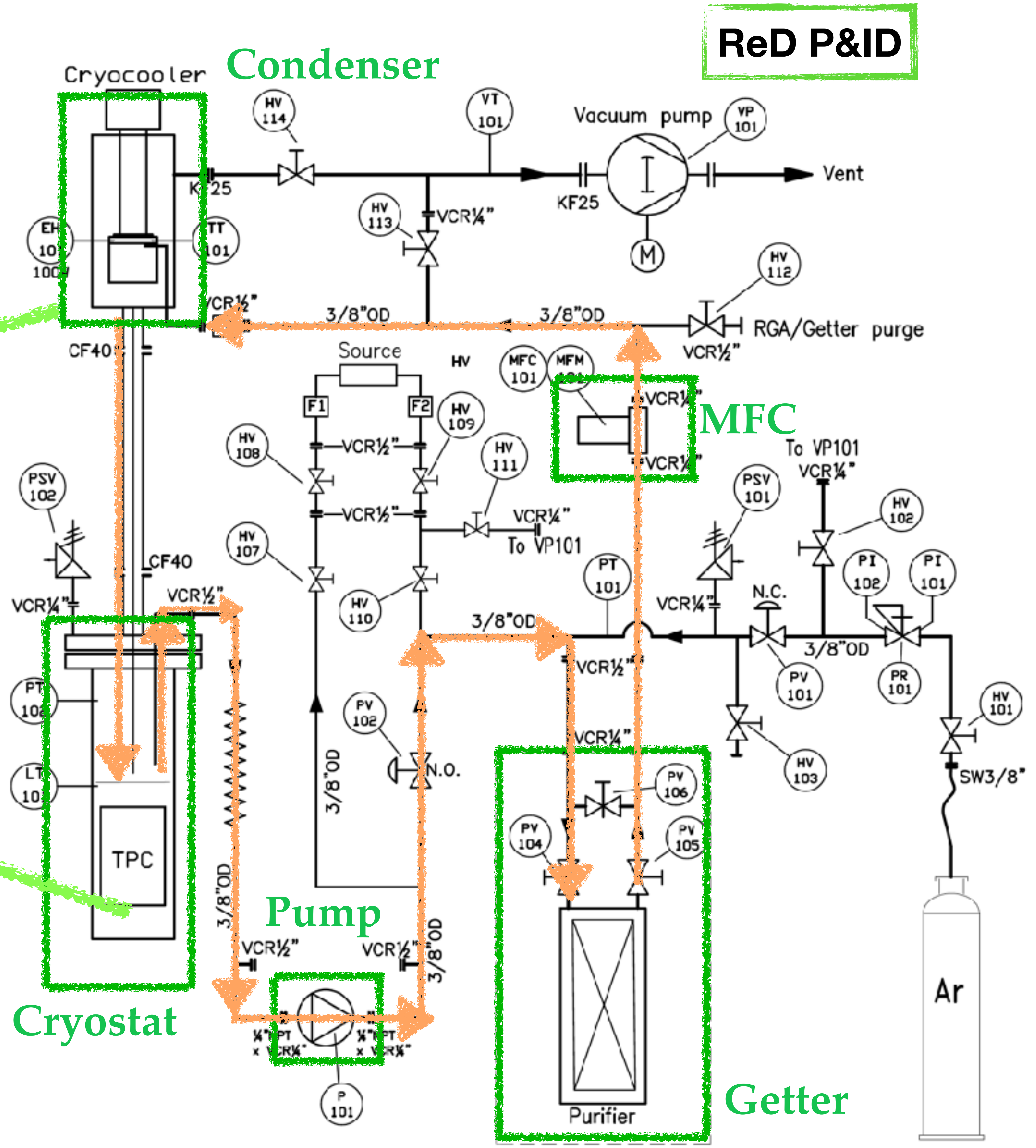




ReD Cryogenics



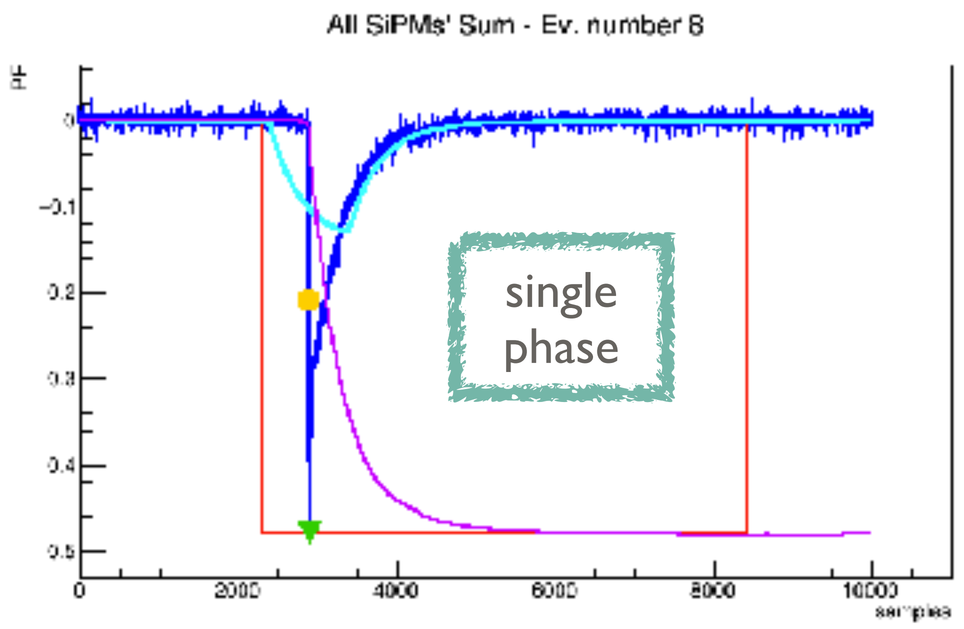




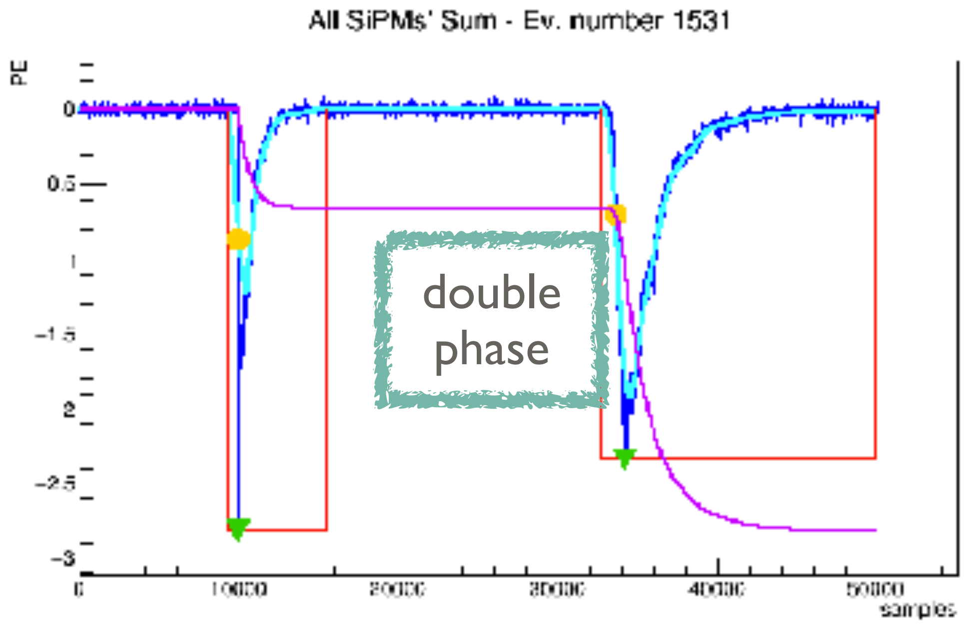
Five months in LAr

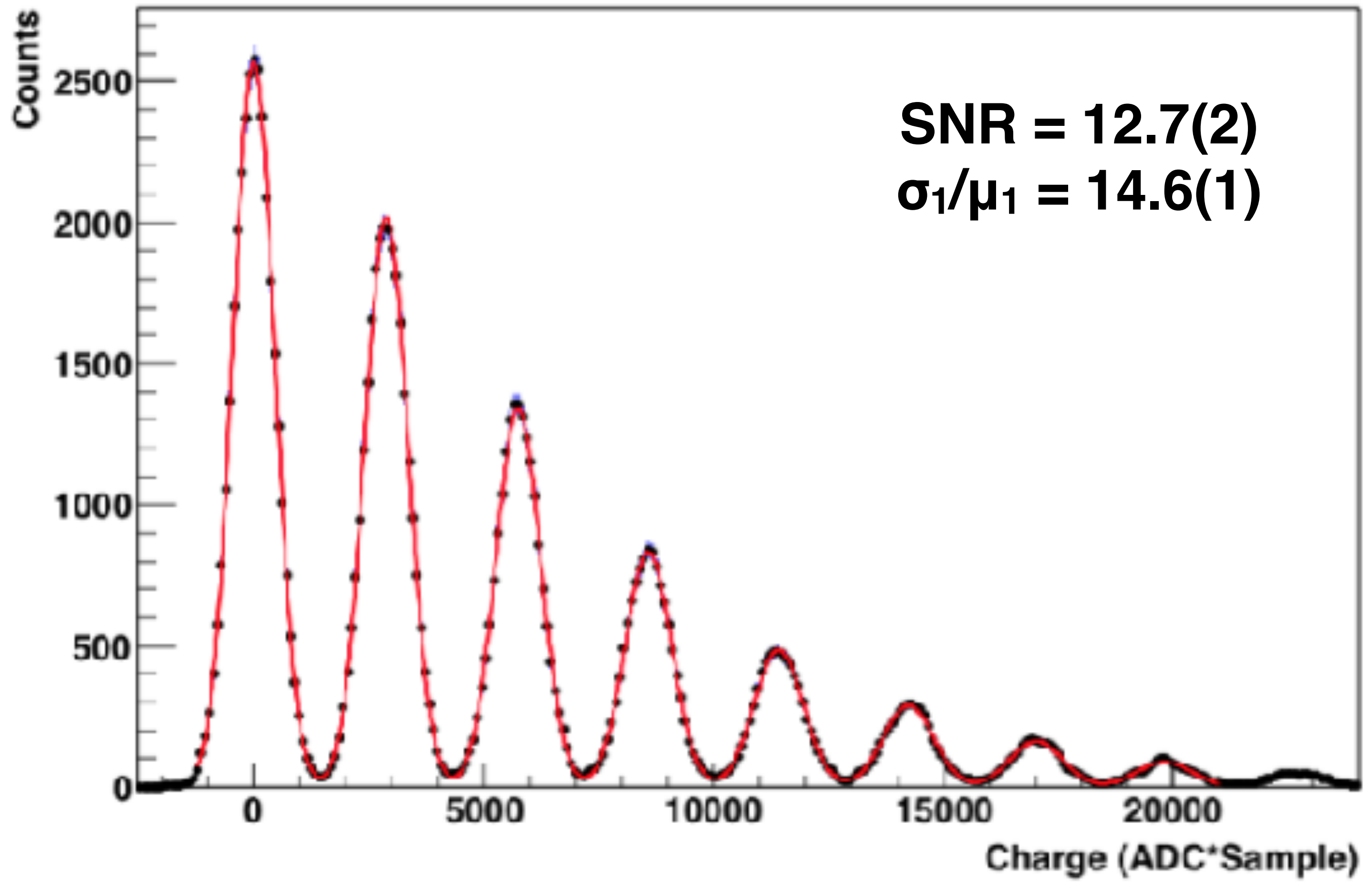
Jun-Nov of 2019. The 165 days run in LAr.
System was assembled, leak tested & filled in the Naples Cryogenic Laboratory for the Dark Matter search.
Over 5 months of continuous data run in order to fully characterise the TPC before the beam run in Catania.
First events in LAr in *single (S1)* & *double (S1+S2)* phase. Multiple calibration runs with radioactive sources (laser, gamma, neutron).
Operational conditions: drift field varying from 100 V/cm up to 1000 V/cm. Nominal values: ε_d =182 V/cm; ε_{ex} = 3.8 kV/cm and ε_{el} = 5.7 kV/cm, grid is at ground. Gas pocket of 7 mm maintained by 20V on the pt1000.

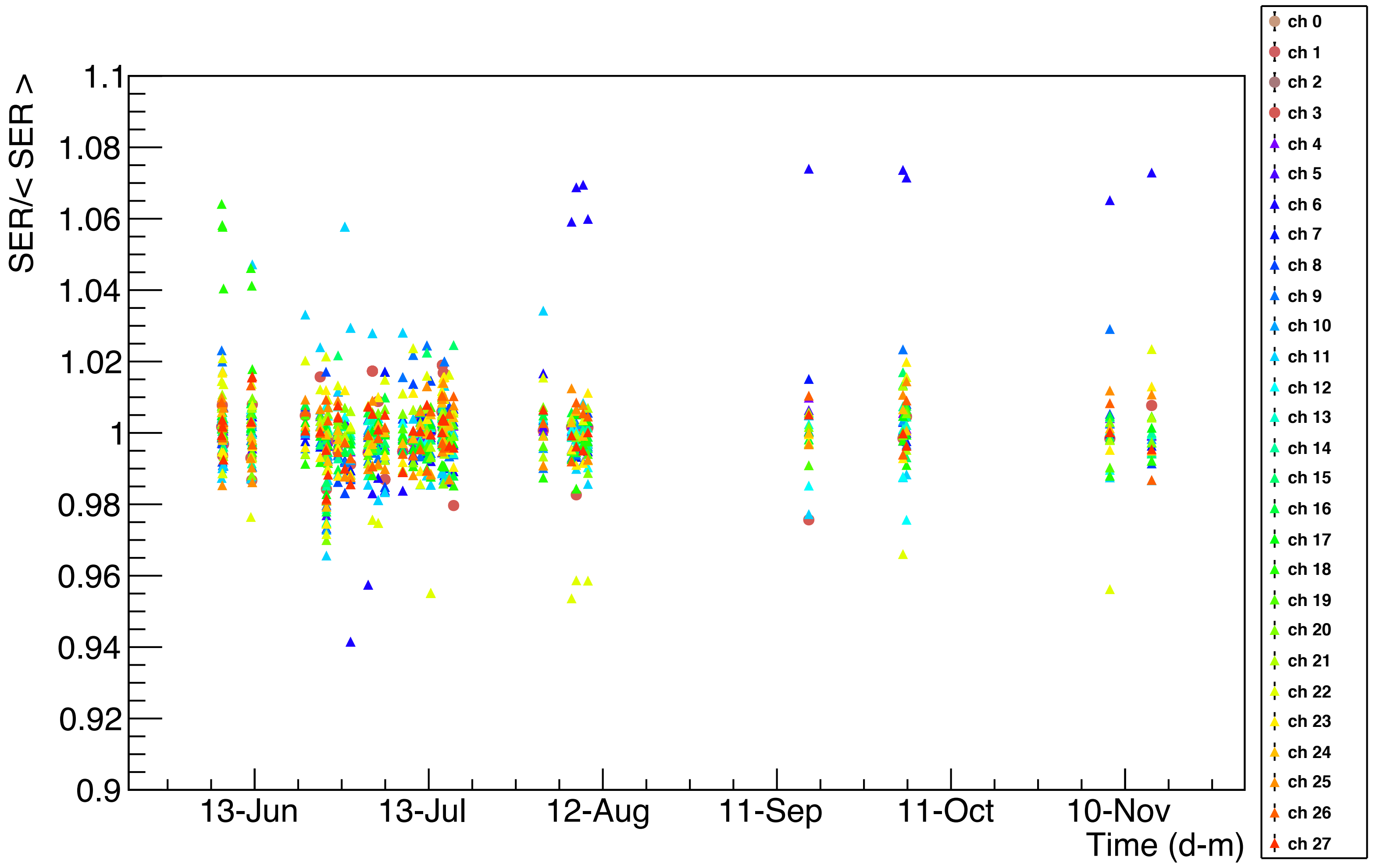
Performance of the ReD TPC, a novel double-phase LAr detector with Silicon Photomultiplier Readout
https://arxiv.org/pdf/2106.13168.pdf



Single photoElectron Response (SER) studied with laser calibration (50 ps pulses generated by Hamamatsu PLP-10 403 nm pulsed diode laser) triggered by wave generated at 100 Hz.
Well defined and separated Single Photons. Very stable SER (0.7 % rms) over 5 months run.







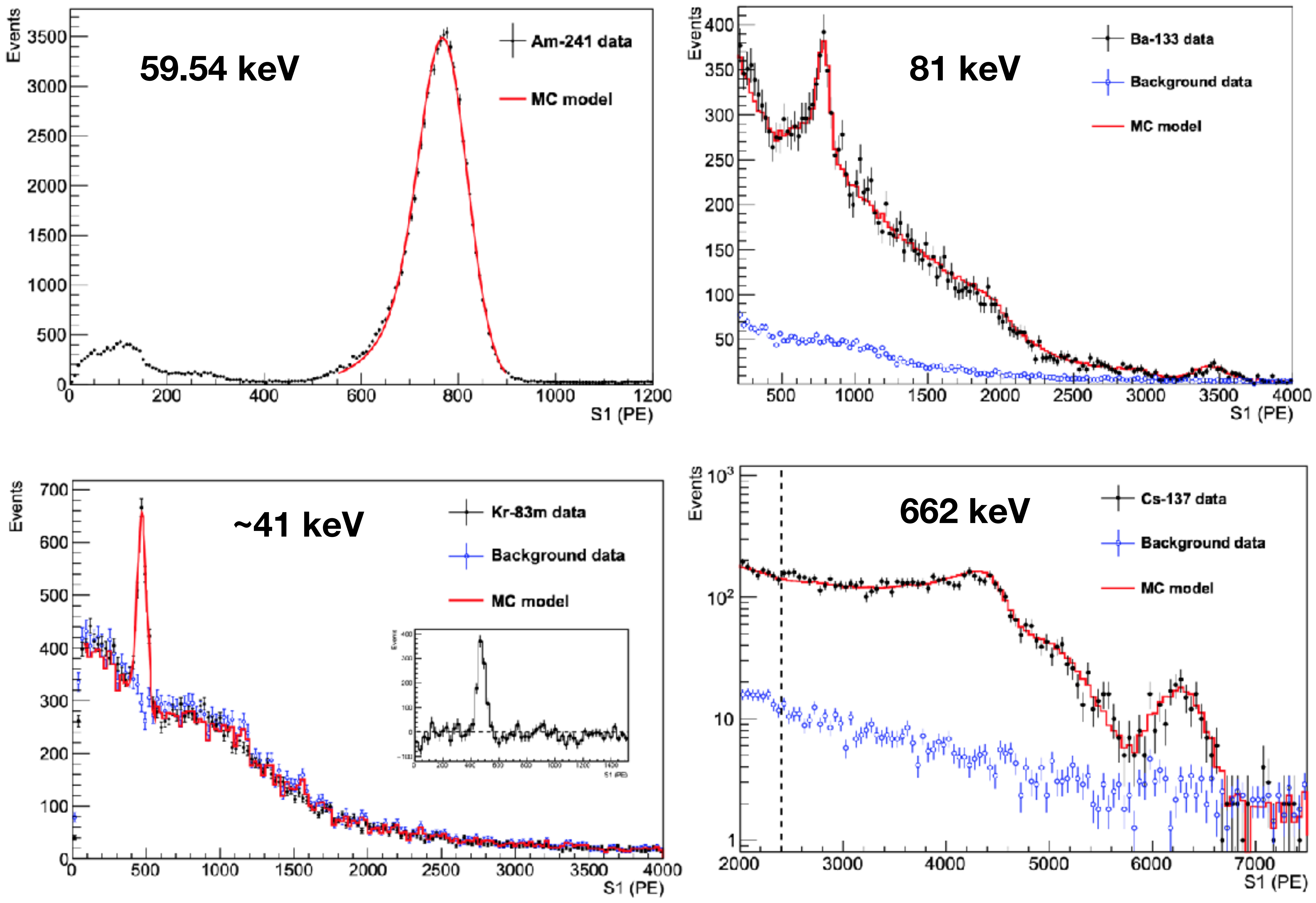
TPC characterization in Naples

The ReD TPC energy responds and stability were studied with laser and the number of radioactive gamma sources (Kr-83, Am-241, Ba-133, Cs-137) and neutron sources (AmBe and DD-gun).

The corrected Light Yield obtained, single phase data at null field ($\varepsilon_d = \varepsilon_{ex} = \varepsilon_{el} = 0$), CT and AP are considered:

$$\boxed{Y_{1,corr} = (9.80 \pm 0.13)\ \text{PE/keV.}}$$

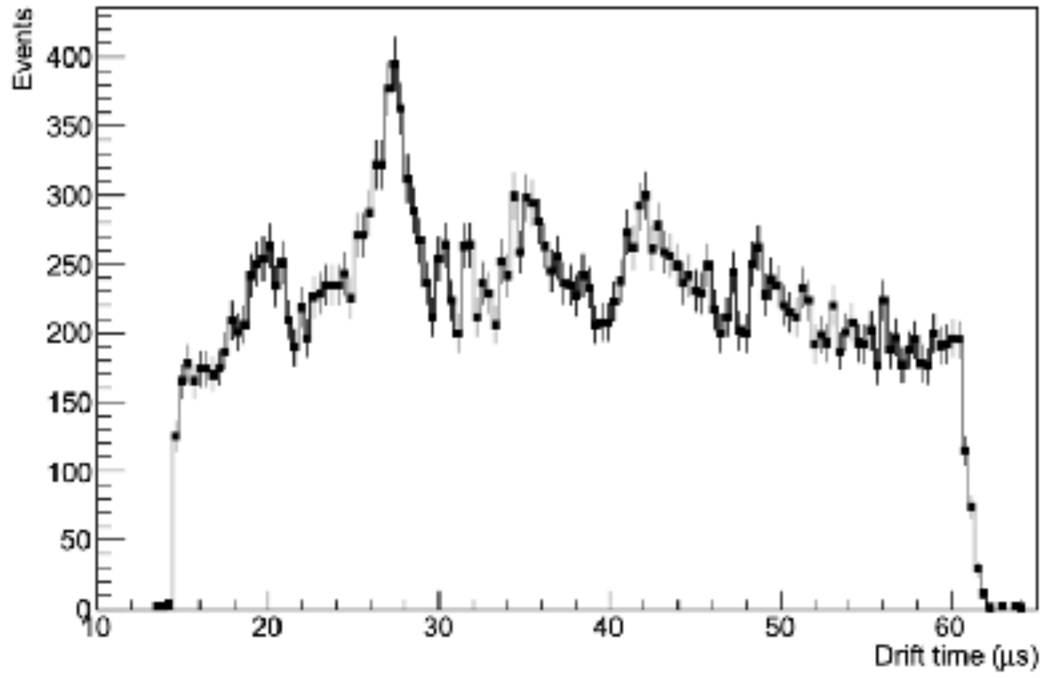
Stable result within 2% over 165 days.



https://arxiv.org/pdf/2106.13168.pdf

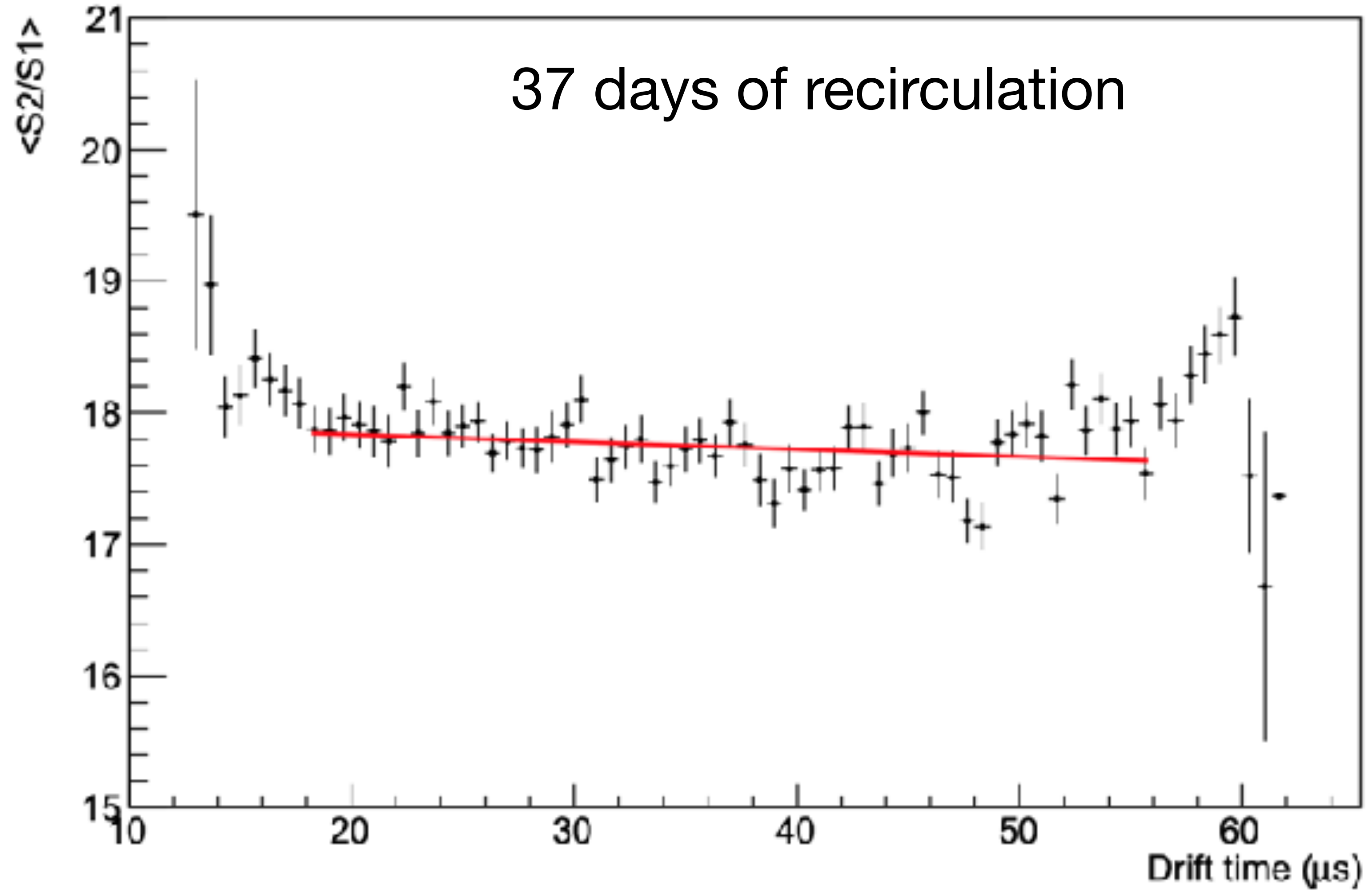
TPC characterization in Naples

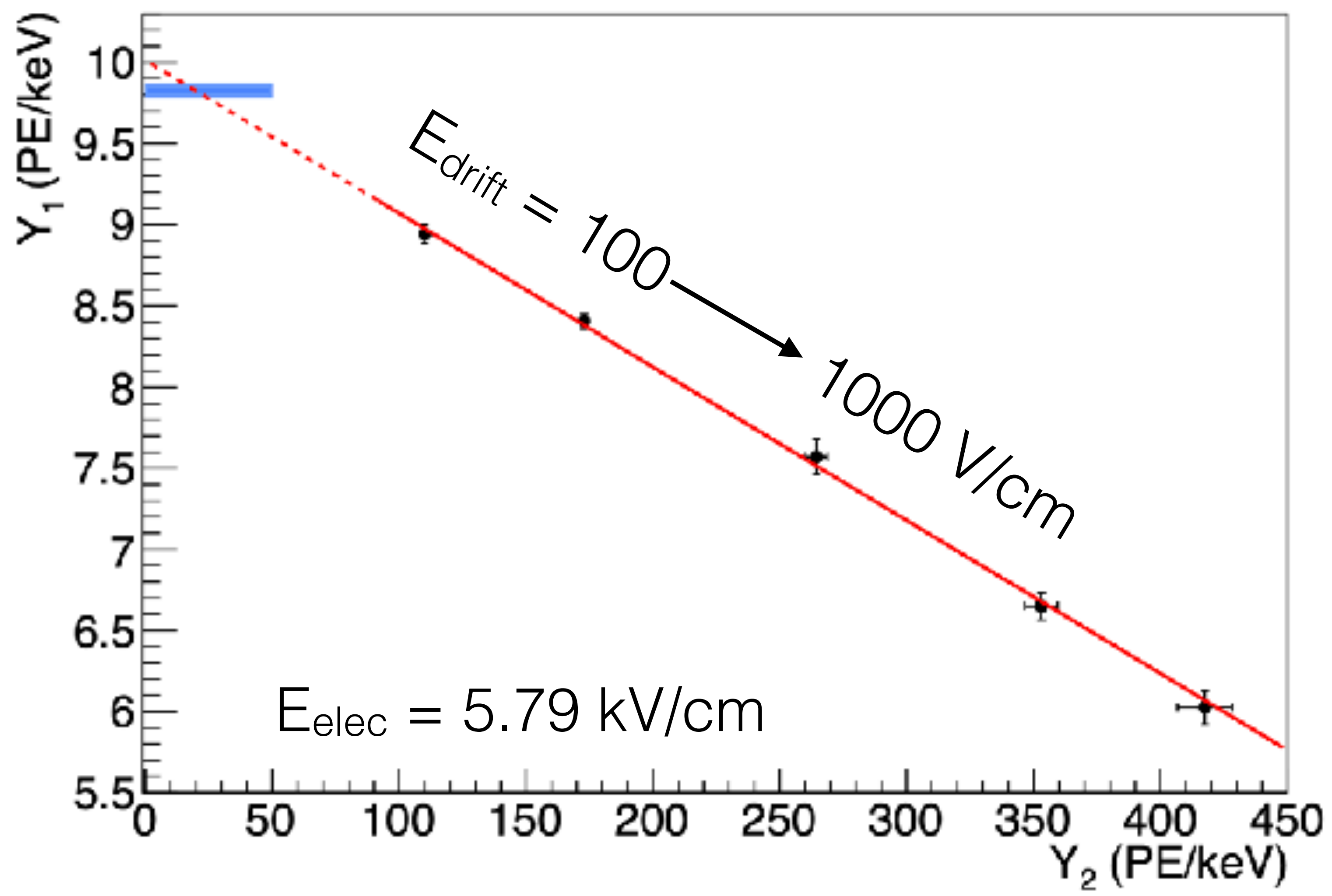
Max drift time T_{max} is ~62 μs for $\varepsilon_d = 183$ V/cm (~ 125 μs at $\varepsilon_d = 75$ V/cm and ~ 25 μs at $\varepsilon_d = 1000$ V/cm).

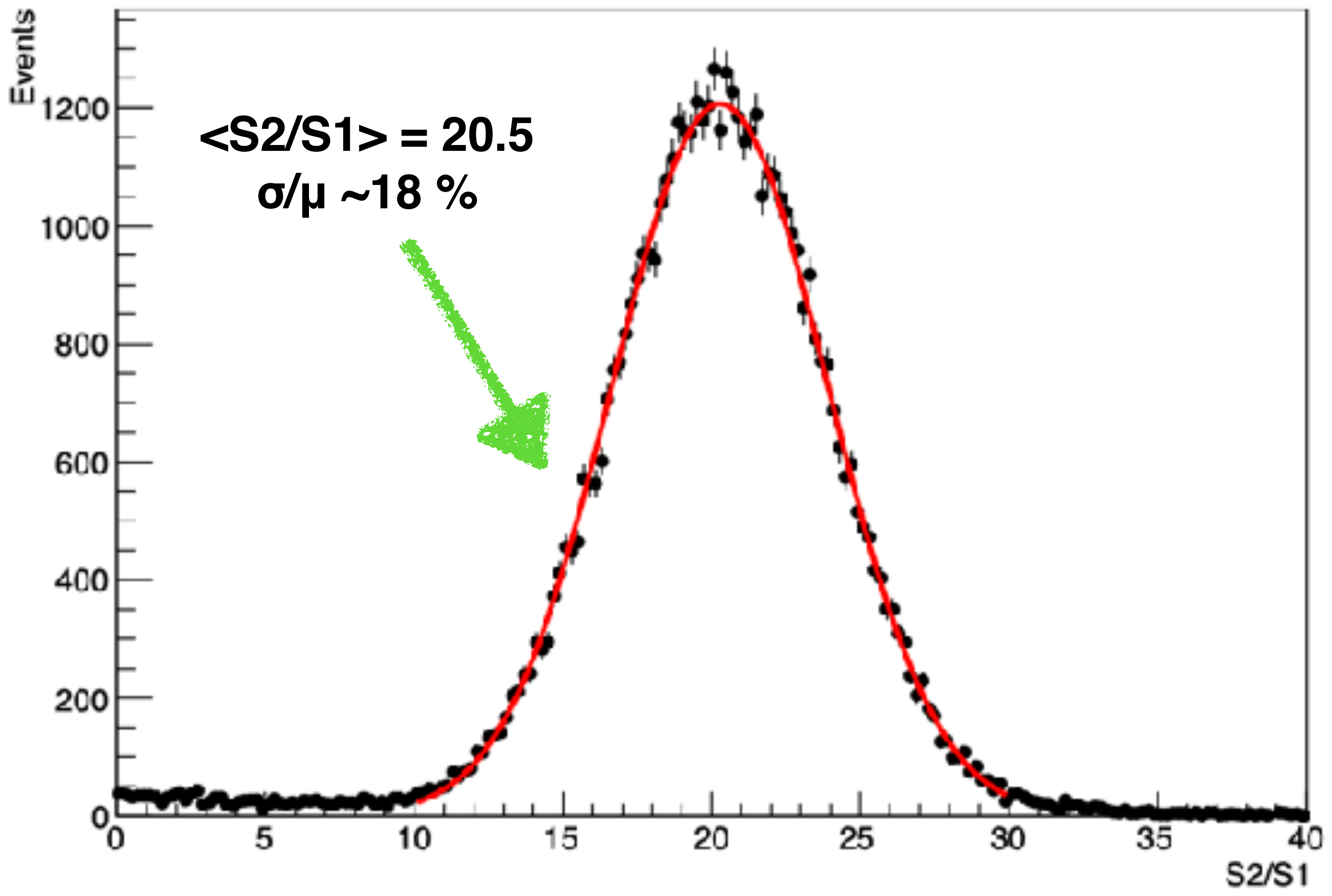


The electron lifetime is (1.8 ± 0.6) ms (> 1ms after 1 week of recirculation), much larger than T_{max}. Usage of SEAS hot getter for rear gases, continuous argon gas recirculation, level of system tightness of 10^{-9} mbar l/s of helium.

Anti-correlation of S1 and S2. The S2/S1 = 20.5 @ $\varepsilon_d = 183$ V/cm & ε_{el} = 5.7 kV/cm.







Scintillation gain **g1 ~ 0.19 PE/ph** (0.16 PE/ph in DarkSide-50 and 0.11 PE/ph in SCENE).
Ionisation gain **g2 ~ 20 PE/el** (23 PE/el in DarkSide-50 and 3.1 PE/el in SCENE)

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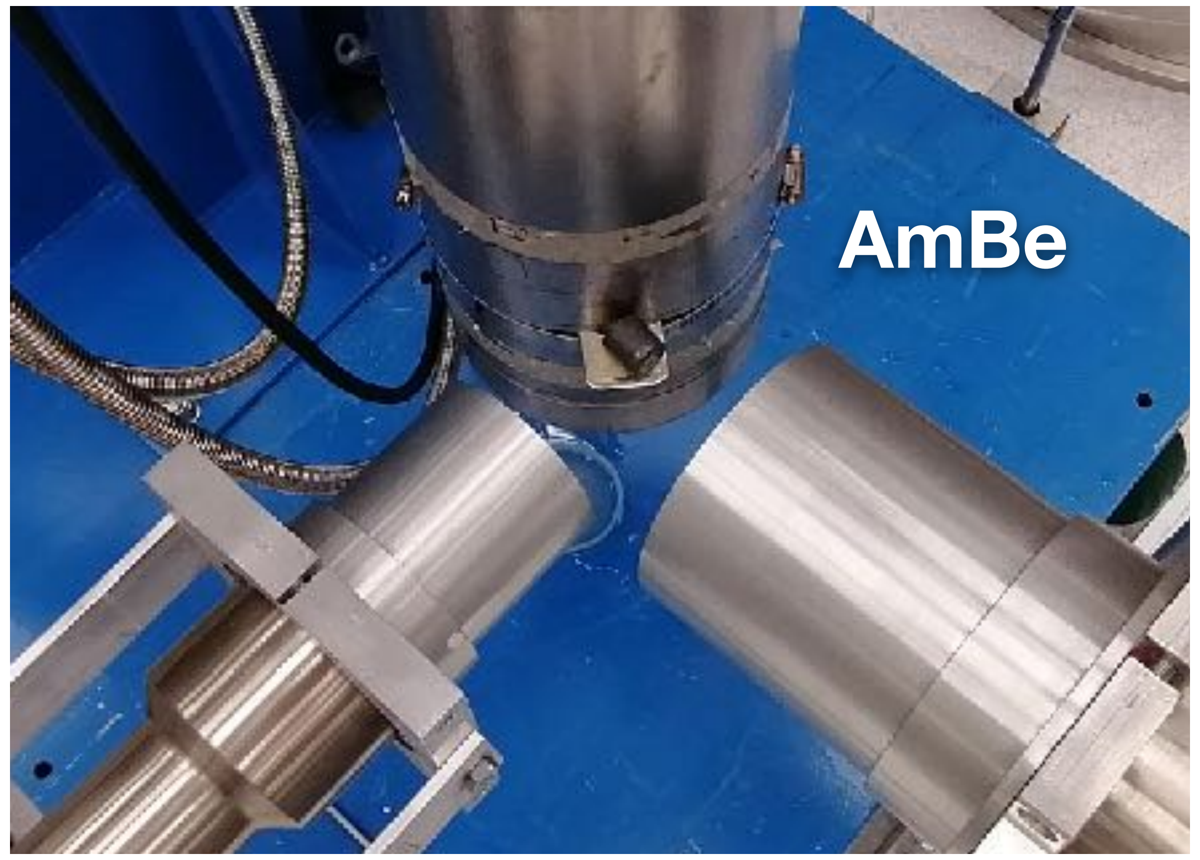
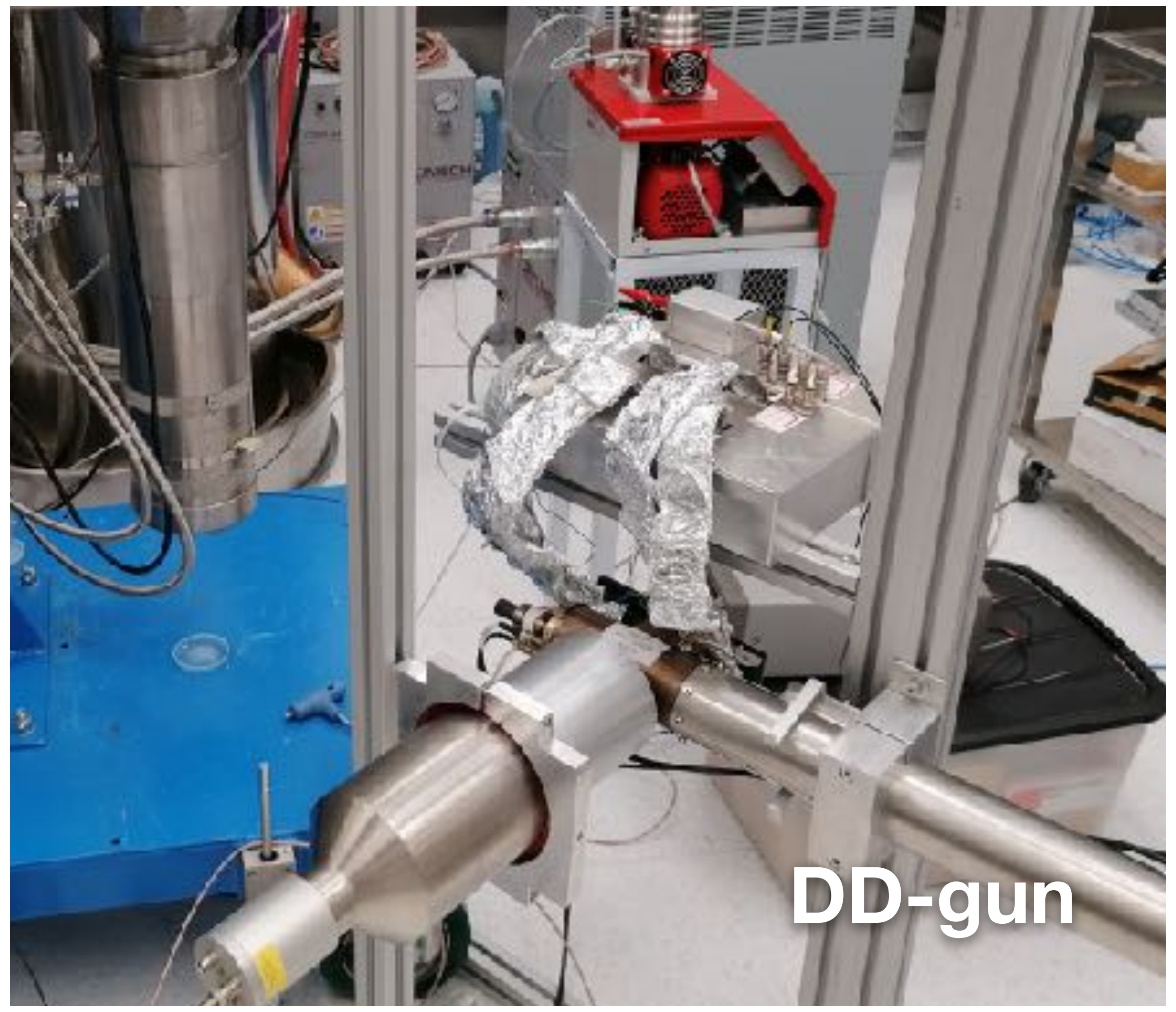
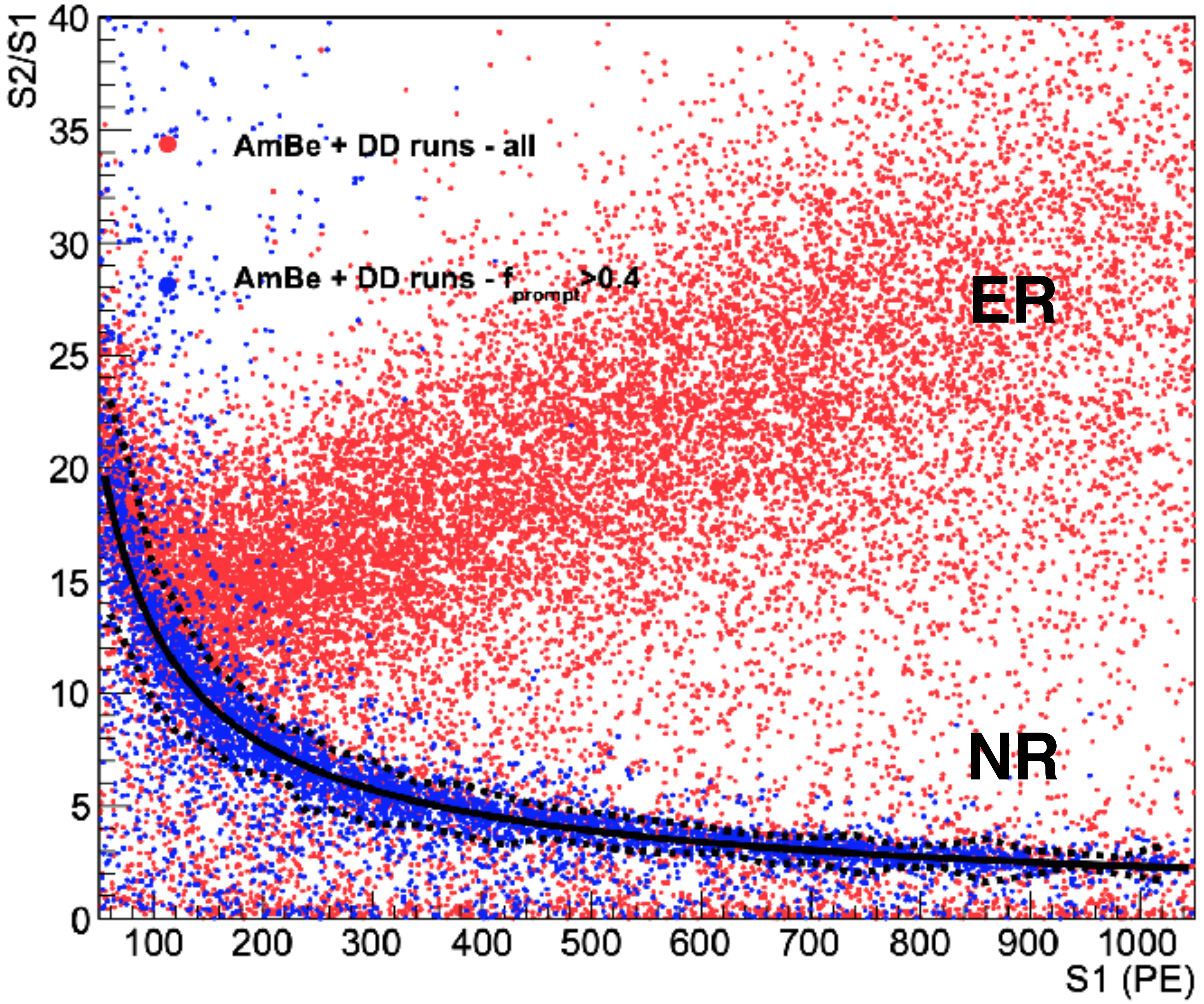
TPC characterization in Naples

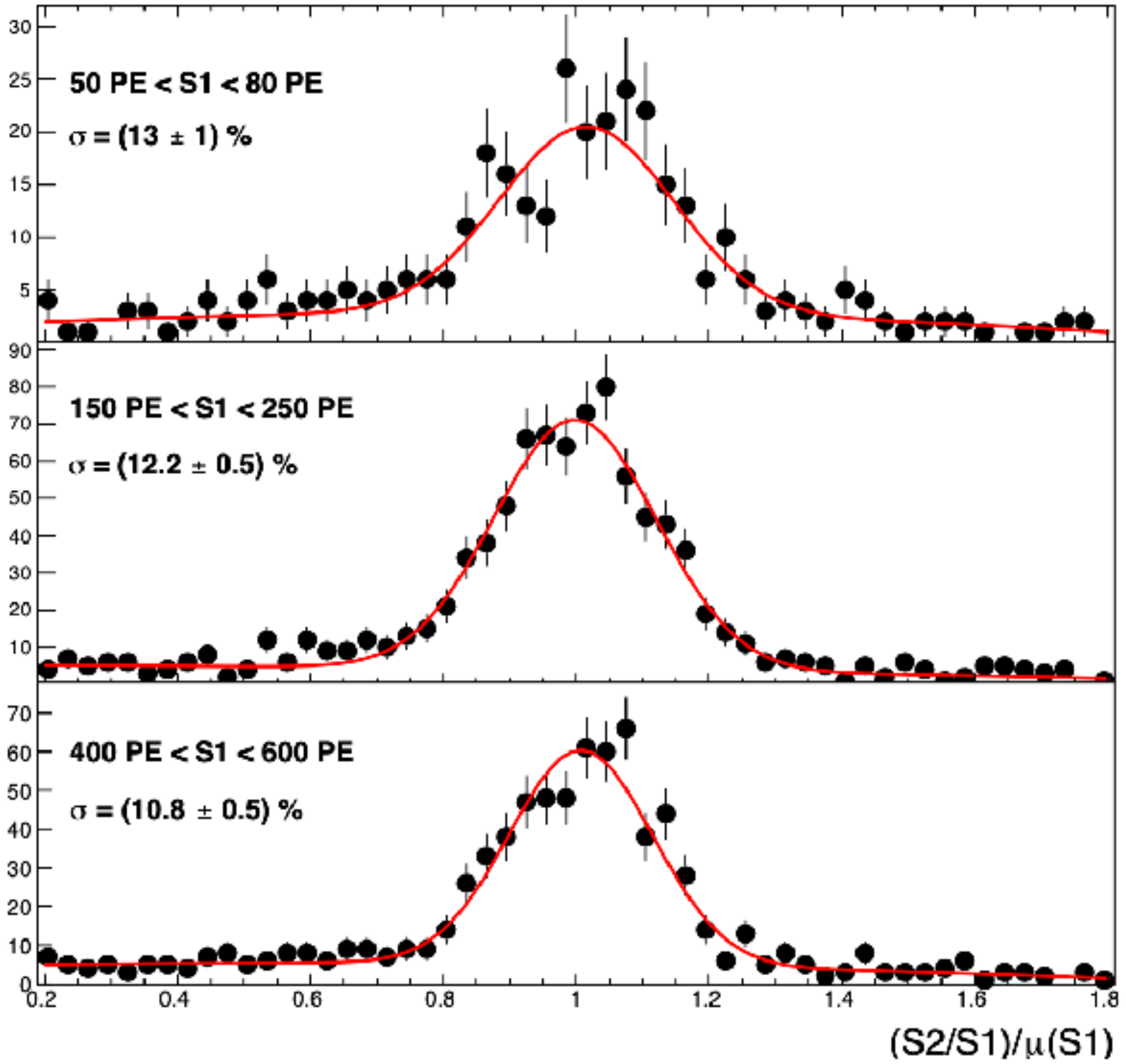




Nuclear Recoil signal was studied with AmBe source (*neutrons up to 8 MeV*) and DD neutron generator (*monochromatic ~2.5 MeV neutron*).

NR band is clearly separated from ER band above ~200 PE. The set of most probable values for S2/S1 as a function of S1, μ(S1) = a(S1 + b)^c , determine the black curve for the NR. The ratio of $(S2/S1)/\mu$ in case of three different energy intervals.





https://arxiv.org/pdf/2106.13168.pdf

Conclusions

The ReD experiment primary focus is to probe the directional sensitivity of argon-base TPC of nuclear recoils.

The 5cm x 5 cm x 6 cm TPC with 185 g of active mass was characterised in LAr with gamma and neutron sources during the 165 days run in Naples cryogenic laboratory. The result of this activity is available on arxiv.org:

"Performance of the ReD TPC, a novel double-phase LAr detector with Silicon Photomultiplier Readout"
(*https://arxiv.org/pdf/2106.13168.pdf*)

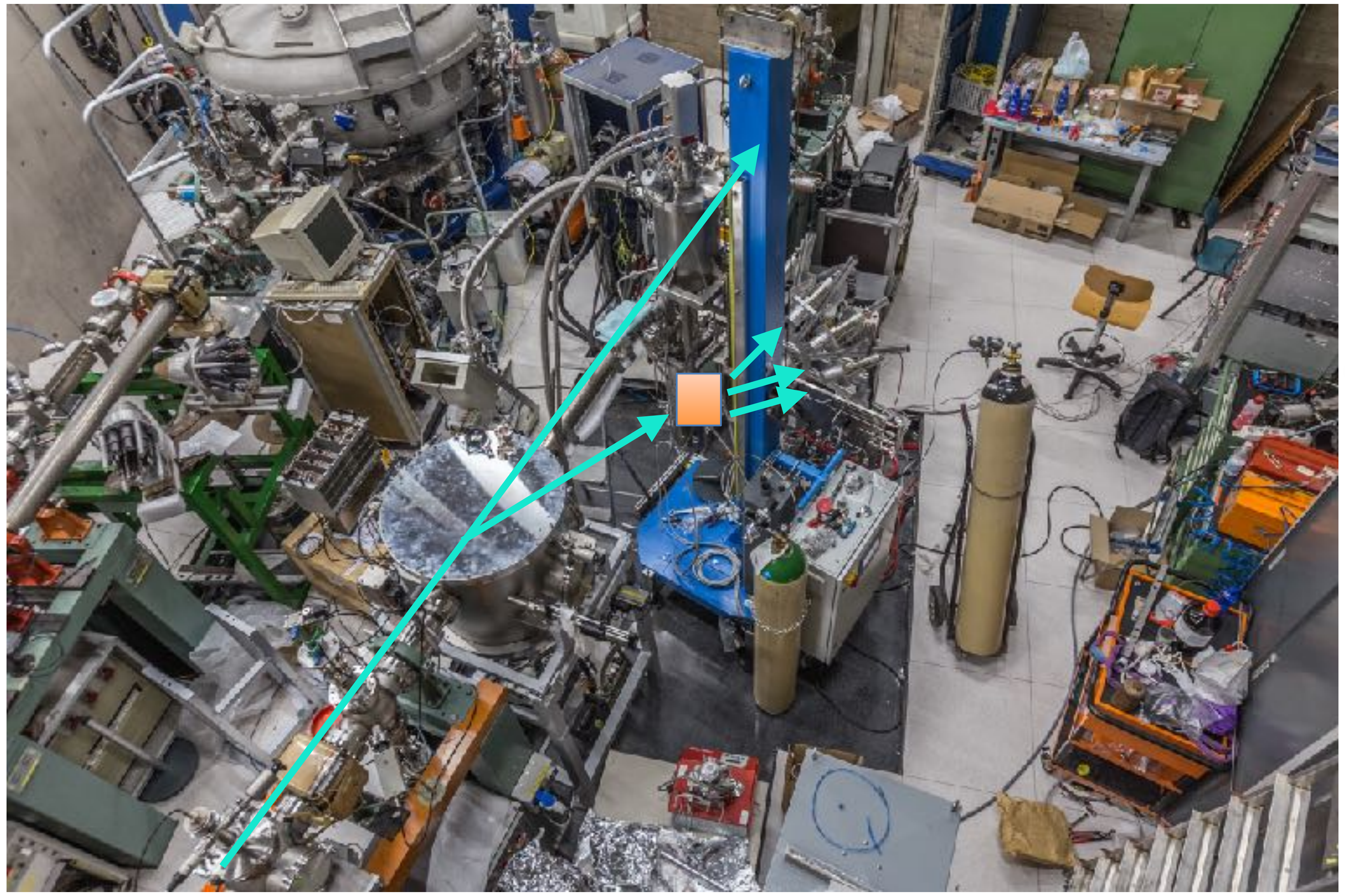
and was submitted for publication.

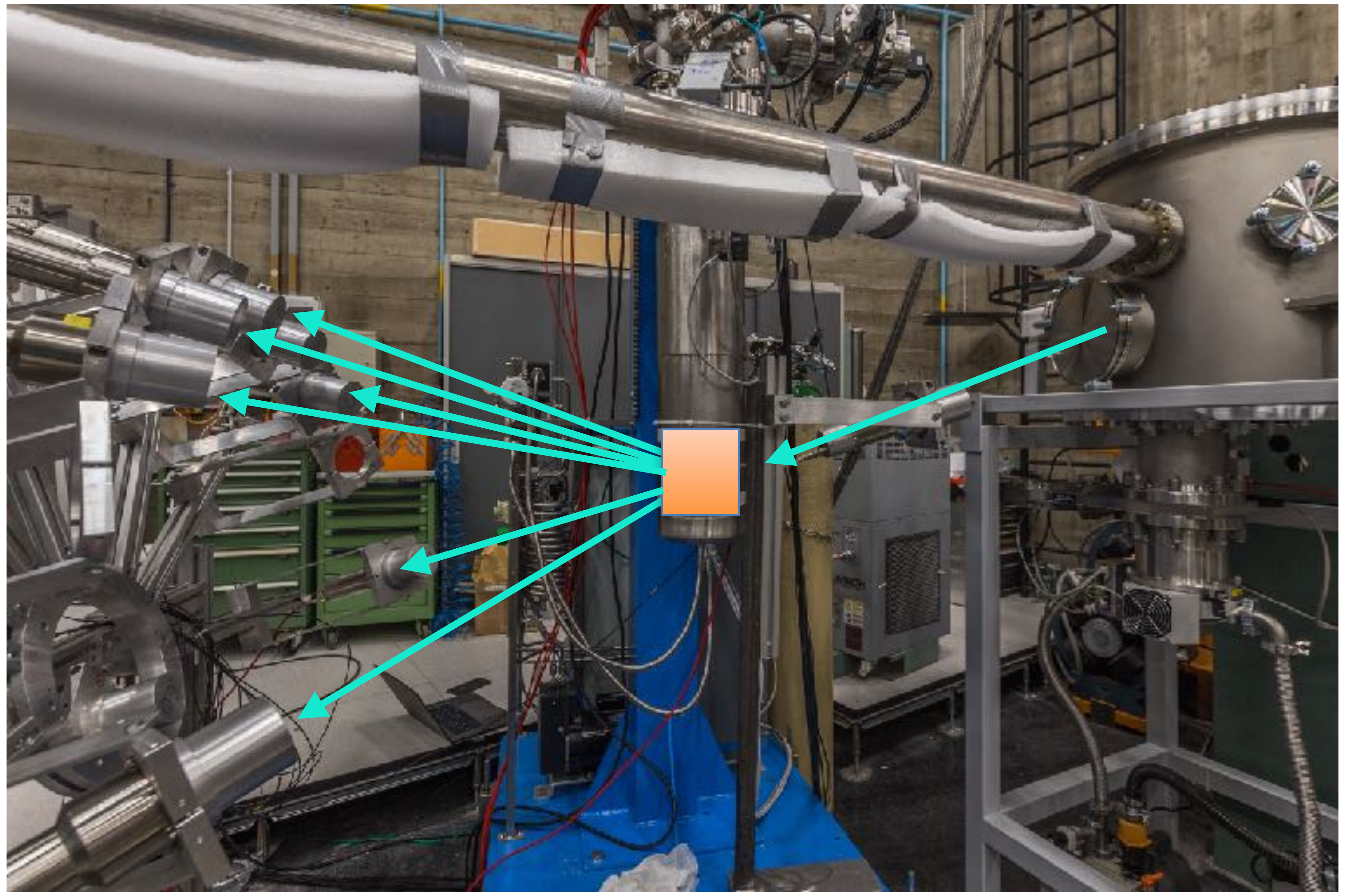
The TPC performance criteria necessary for the reaching the scientific goal were defined and evaluated. Found values satisfies the requirements in order to fully the scientific goal of ReD experiment.

Beam run in LNS (Catania) was acquired in Feb 2020, analysis are on going, stay tuned!

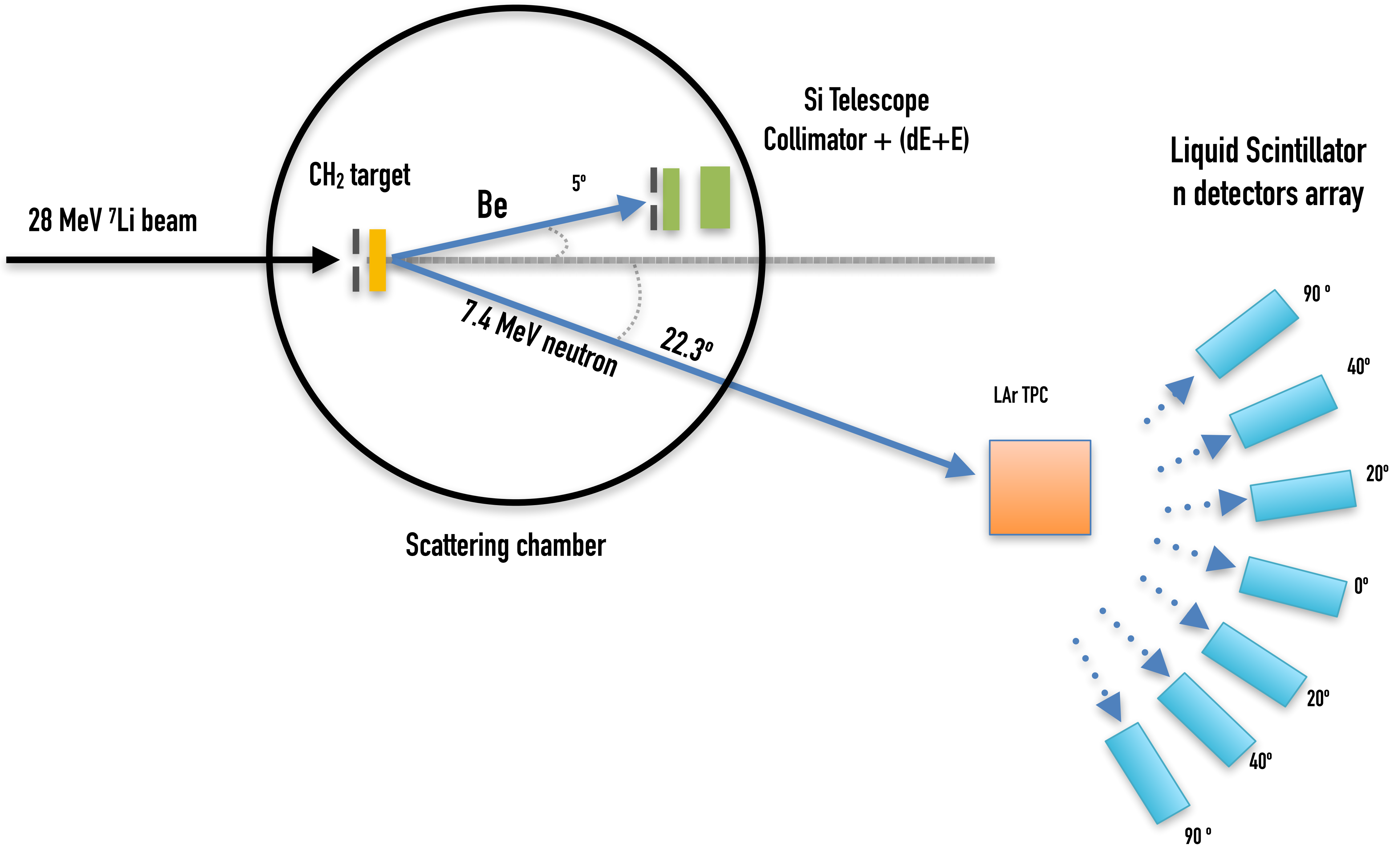
Backup Slide

Experimental setup in Catania (INFN-LNS)





Top View



Side View