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A Prototype High Pressure Gas Time Projection Chamber for Future Long Baseline Neutrino Experiments

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On behalf of the HPTPC Collaboration

DPG Spring Conference
[T 44.1]

III. Physikalisches Institut B
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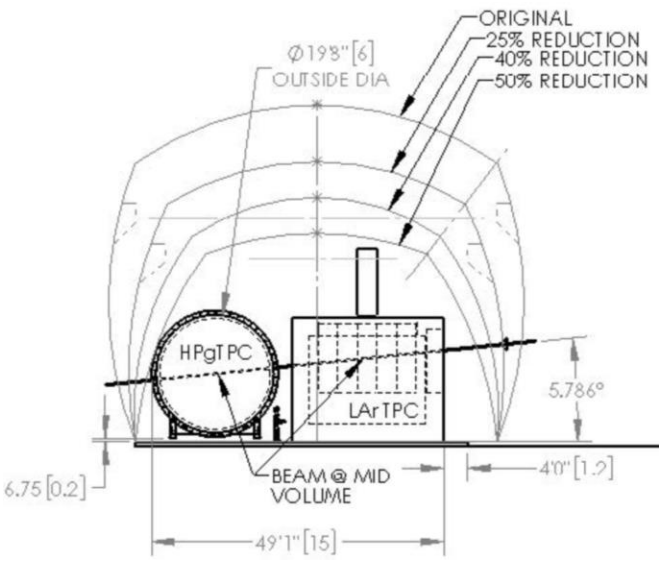
Outline

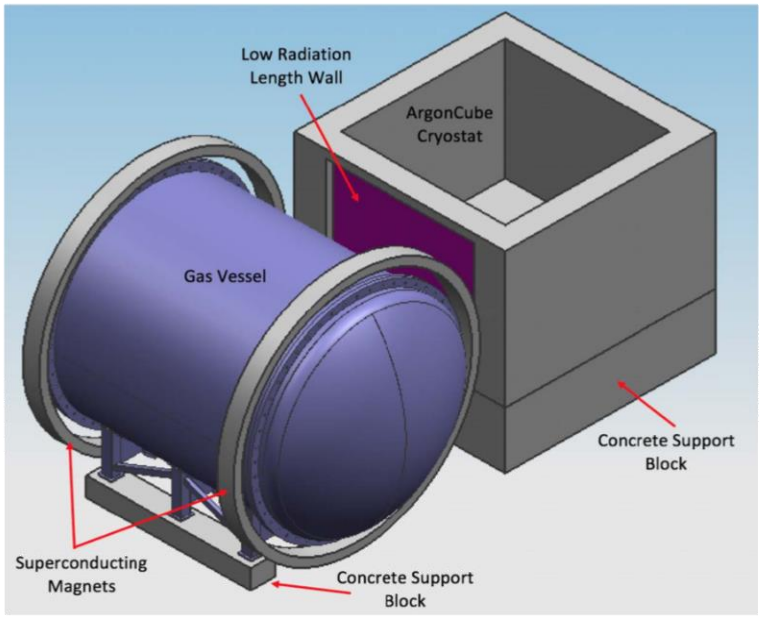
1. Long Baseline Neutrino Exp.
2. High Pressure TPC
3. Calibration
4. Testbeam @ T10 / CERN
5. Outlook

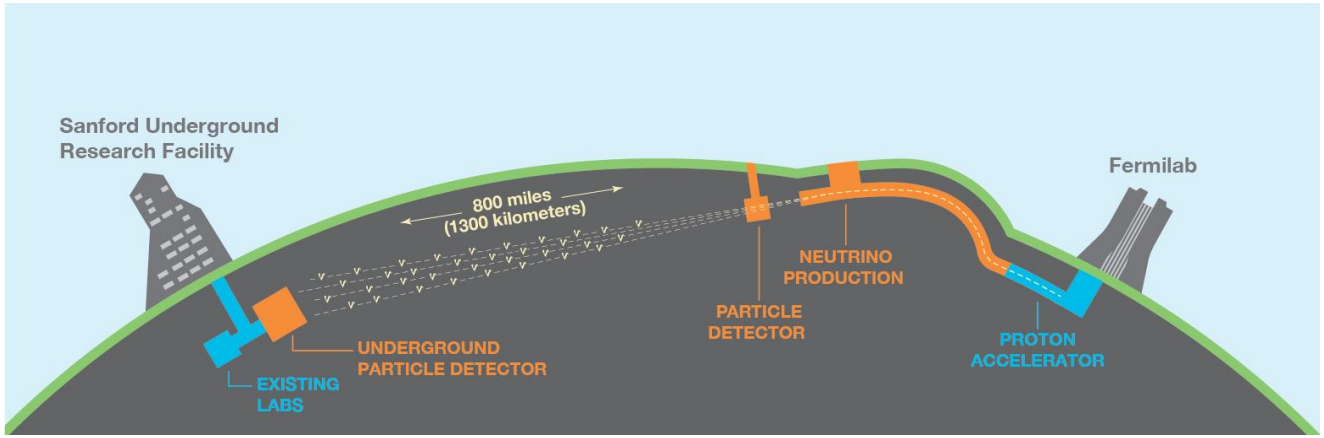
Collaborators:

- RWTH Aachen University
- Université de Genève
- Imperial College London
- Lancaster University
- Royal Holloway University London
- University College London
- University of Warwick

Future Neutrino Beamline Experiment: DUNE







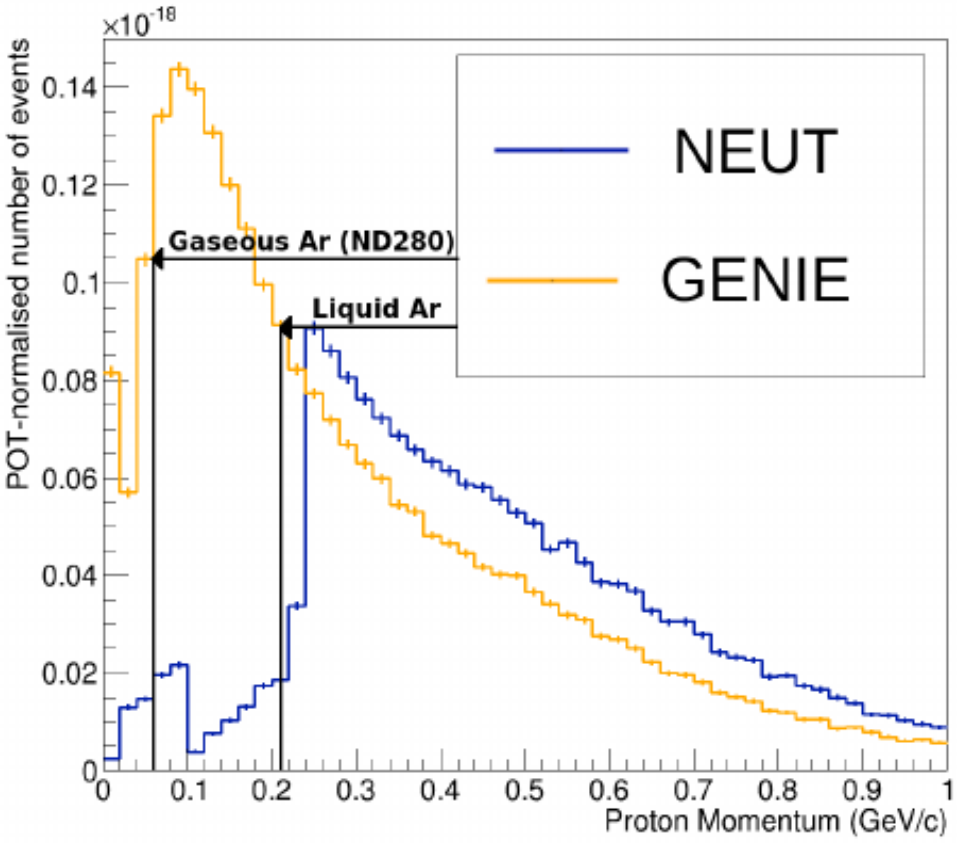
Modeling Neutrino Interactions in Pure Argon

Mainly using NEUT and GENIE generators

Models disagree at low momenta

- Number of protons produced
- Final state momentum distribution
- Systematic uncertainty for oscillation and CP measurements

- Gaseous detectors:
  - Low thresholds
  - But also low target mass
- Liquid detectors have a too high threshold
- Compromise: **Pressurized Gas**



Generators using different FSI models

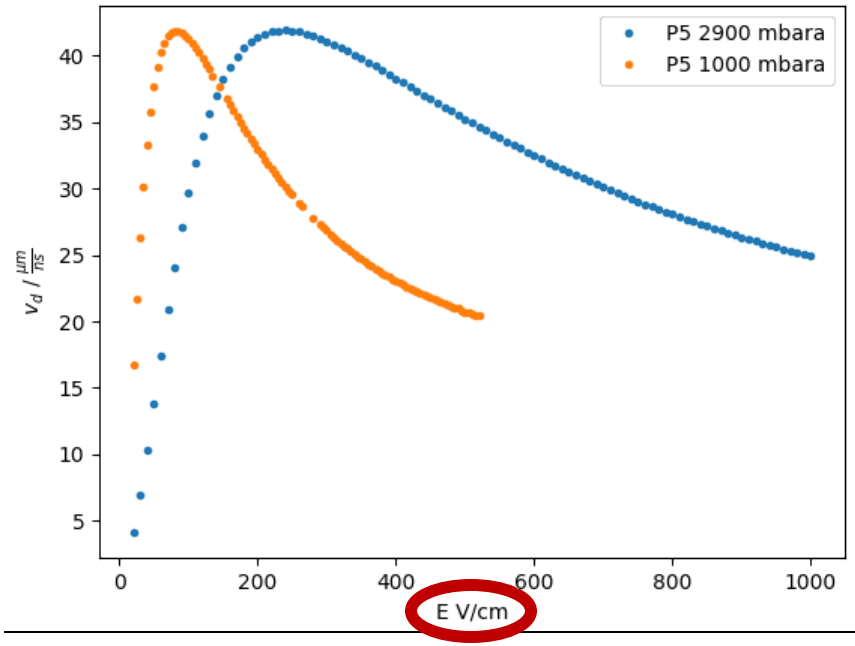
Operation at Above Atmospheric Pressure

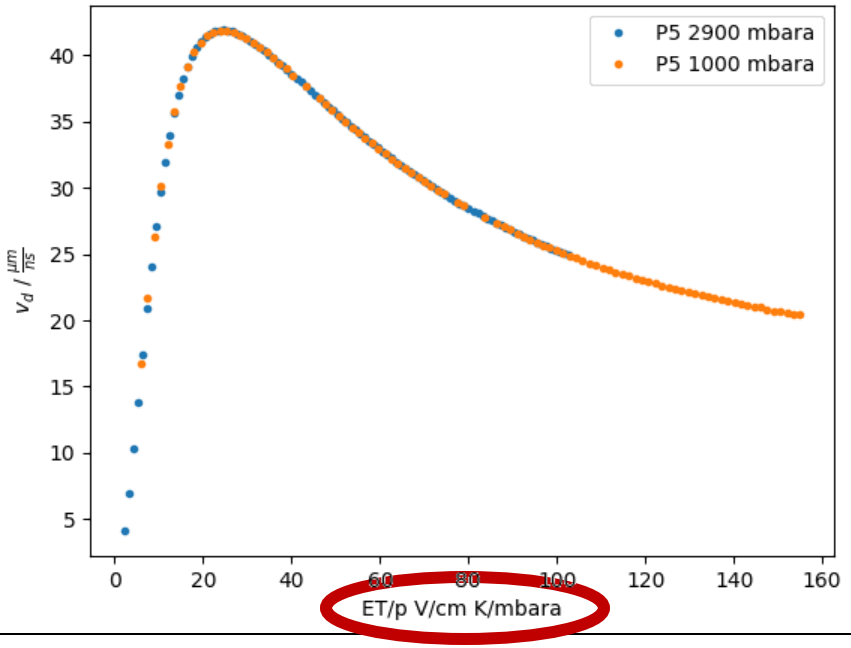
- Many gases behave nearly ideal at <10 bar
  - e.g. Ar, N_2, CH_4, CF_4, CO_2, …
- Increased density affects electron propagation

Transformations for simulation

$$d_{t,l} = d'_{t,l} \cdot \sqrt{\frac{T_{\mathrm{lab}}/p_{\mathrm{lab}}}{T_{\mathrm{sim}}/p_{\mathrm{sim}}}}$$

$$v_{\mathrm{d}} = v'_{\mathrm{d}} \left(\frac{ET}{p} \right)$$





A High Pressure Time Projection Chamber

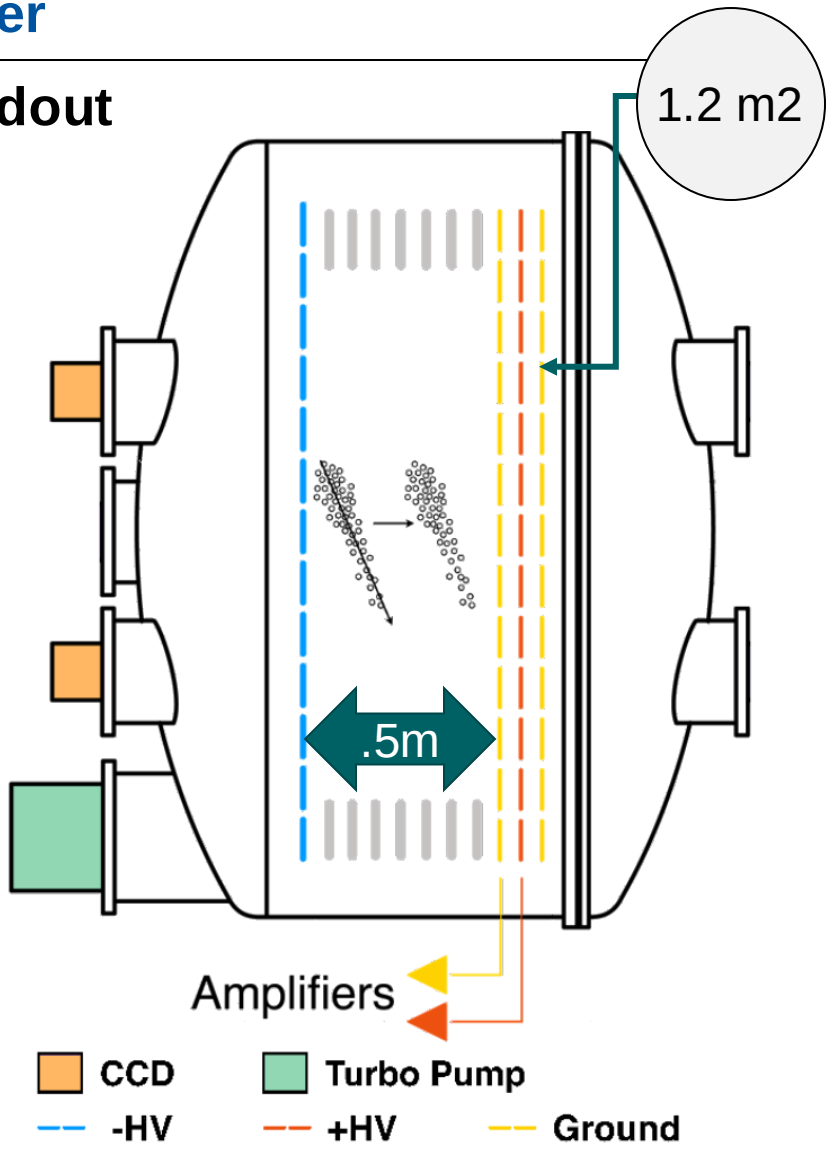
Single-pixel anode stack with optical readout

- Active target ~ 1m3
- Easily interchangeable target material
- Pressure rated up to 5 bar

- Maximum drift field 450 V/cm

- Reconstruction:
  - Arrival of charge at anode meshes
  - Anode waveforms
  - Secondary scintillation
  - Cameras image secondary scintillation

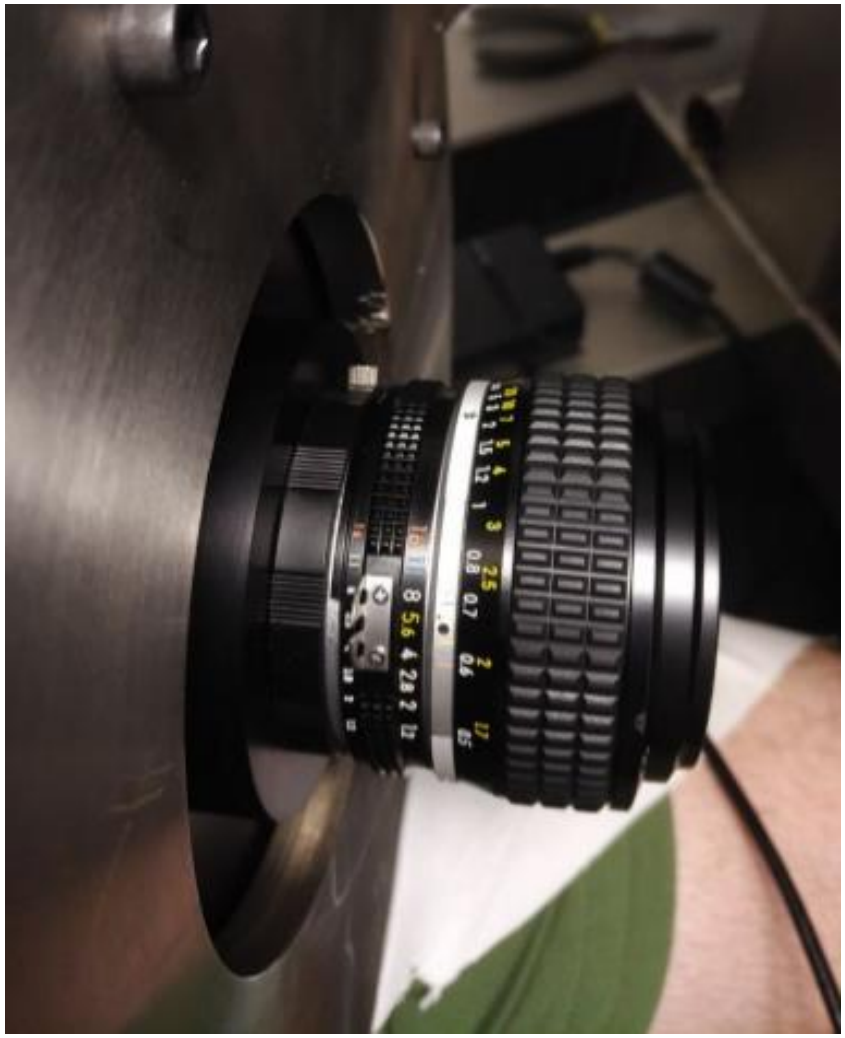
- Free add-on flange
  - PMT for UV range scintillation
  - Another camera



Optical readout: Camera Specs

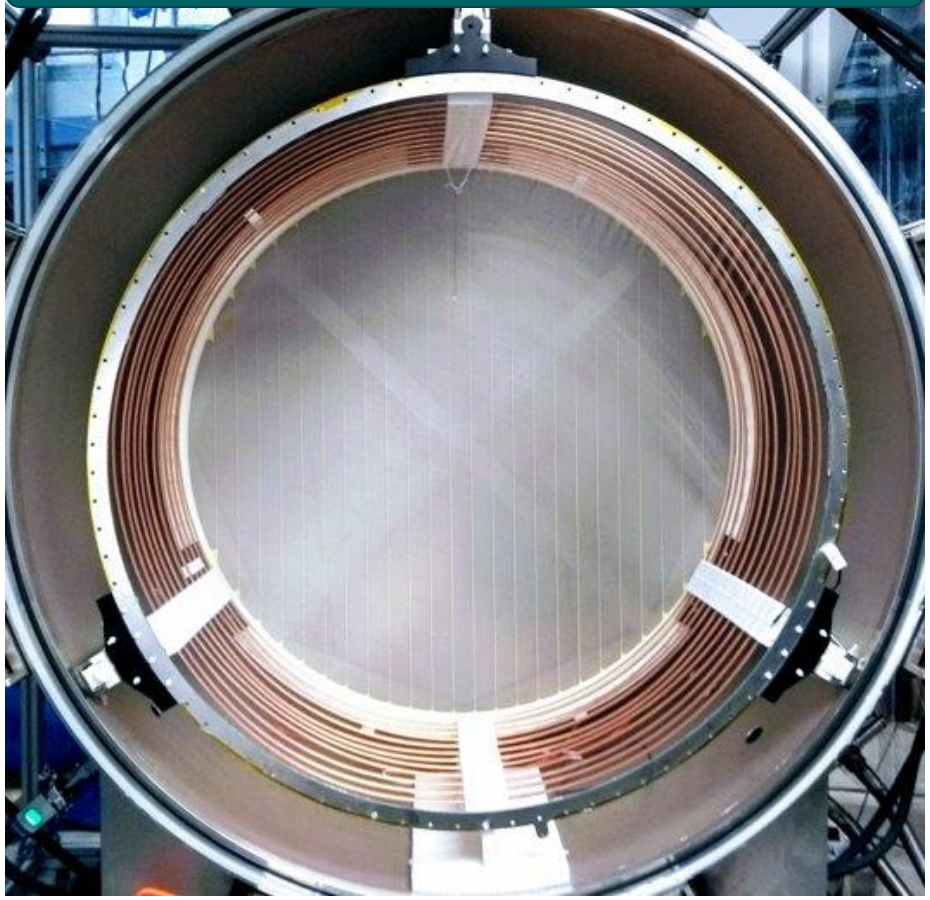
- 4x FLI Proline PL09000 CCD
  - Cameras are operated at an internal temperature of –30 °C
  - Adjustable shutter times
- Granularity at anode is 230 x 230 µm

- Tracking data is generated **outside** of vessel.
- No need for pressure tight feedthroughs.
- Cost per channel ~0.005 €/channel



Pictures of HPTPC

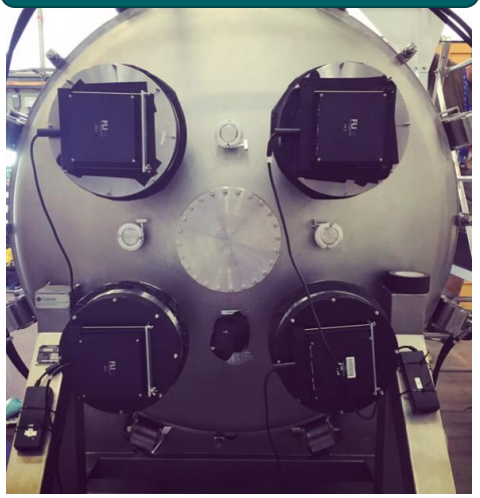
View on anode through cathode mesh



Anode is a series of stacked meshes

Optical ports ...

… with cameras



5 bar rated window

Gas System and Mode of Operation

- Partial pressure mixing
- Up to 4 gases

- Old gas is vented
- Vaccuum cycle before refilling

- Refilling ca. once per week

- Hydraulic pistons seal door
  - Full diameter of vessel
  - Field cage independent of vessel

Setup in T10 beam area

Calibration

Charge, *Light yield*, optical coverage and camera alignment

- Inserted Am241 sources into TPC
  - Monoenergetic alpha's 5.5 MeV
  - Some x-rays ~ 60 keV
- Very low activity sources

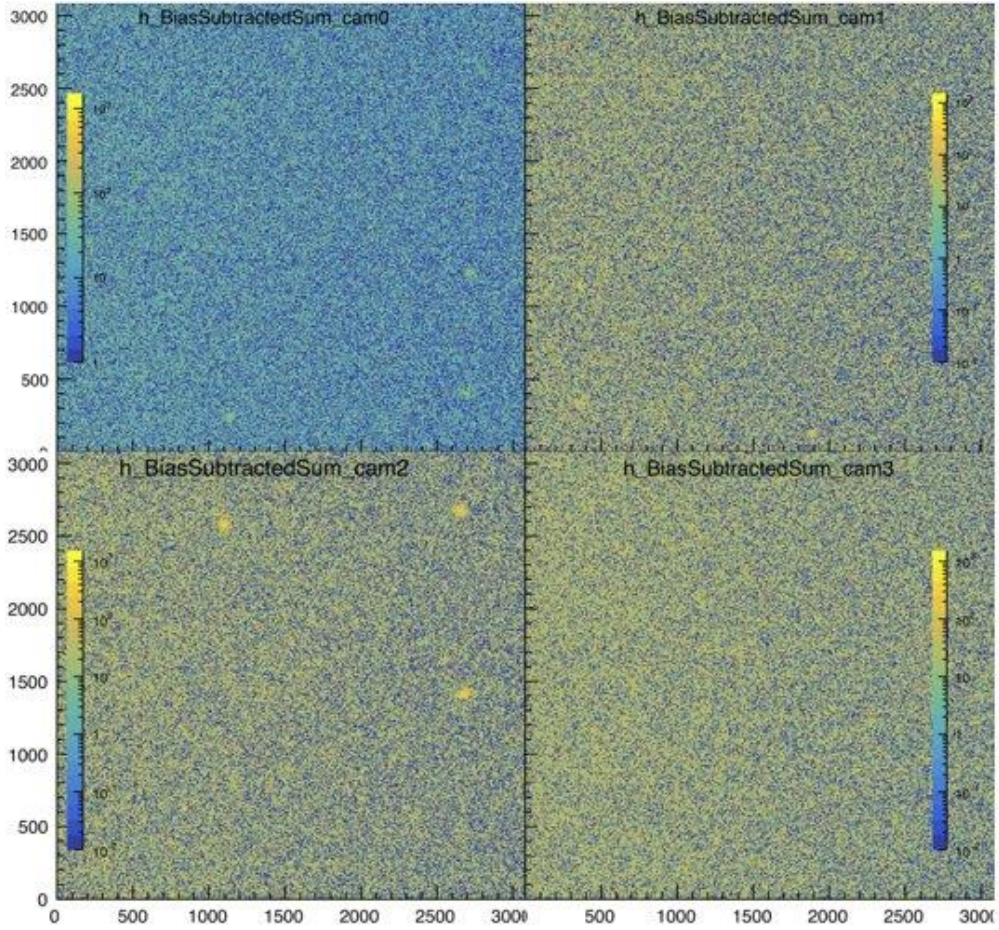
One example for positions, multiple were tested.

Calibration

Charge, *Light yield*, optical coverage and camera alignment

- Inserted Am241 sources into TPC
  - Monoenergetic alpha's 5.5 MeV
  - Some x-rays ~ 60 keV
- Very low activity sources

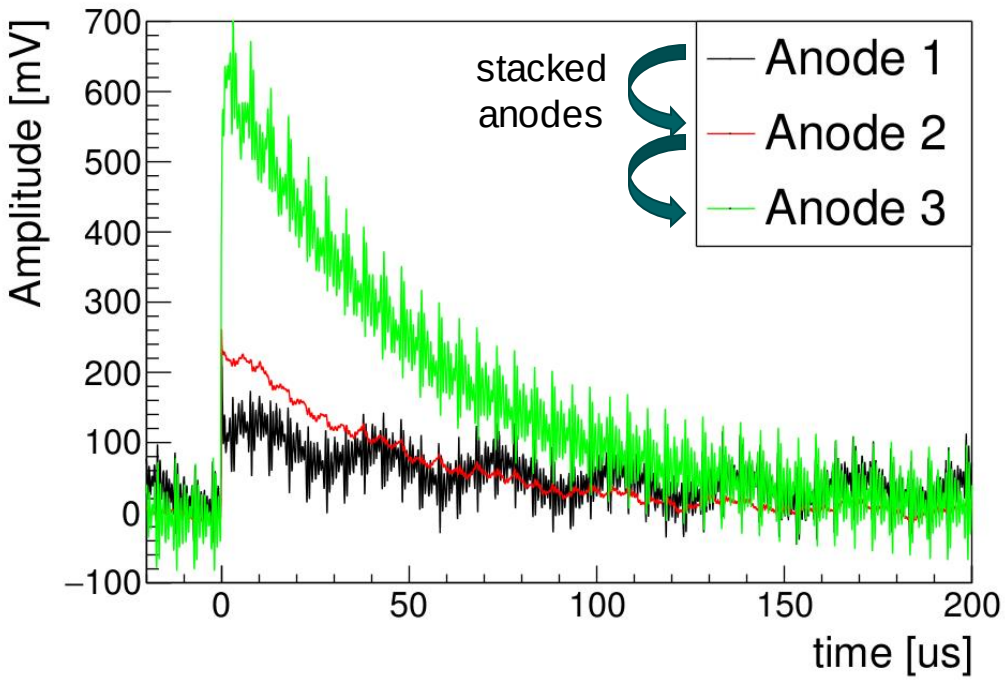
- Summing 100 x 2s exposures reveals source positions
  - Sources become visible even with low gas gain



Calibration

Charge, Light yield, optical coverage and camera alignment

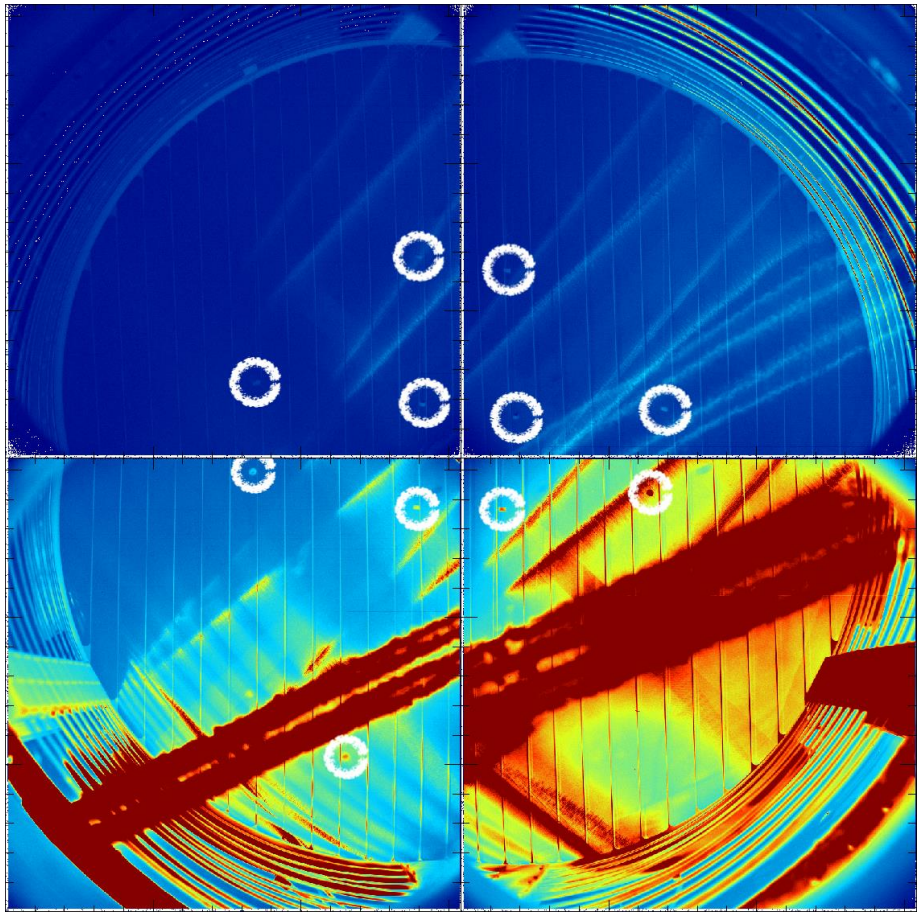
- During exposures, anode signals are recorded
- Offline matching of anode pulses to light clusters
  - Measure charge in anode signals
  - Charge proportional to light yield
- Decoupling and amplification circuits calibrated ex-situ
  - Charge sensitive CREMAT CR113 (1.2mV / pC)



Calibration

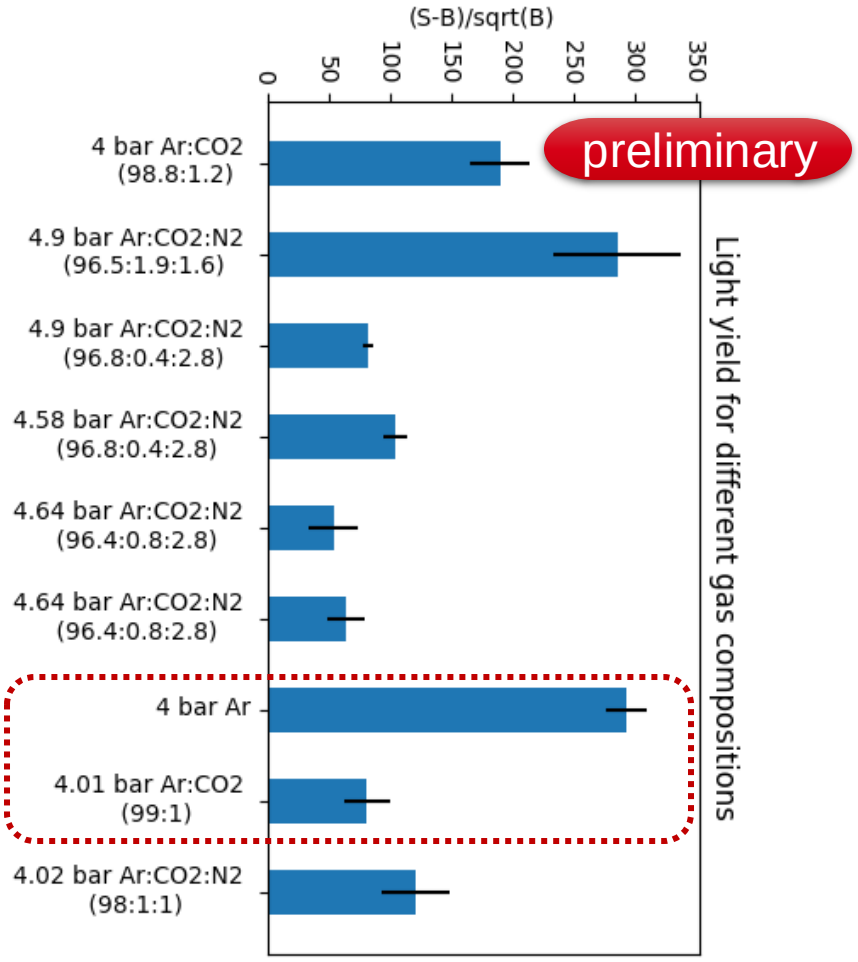
Charge, Light yield, *Optical Coverage and Camera Alignment*

- Occasional sparking observed
- Sparks illuminate full detector
- Field of view overlap of cameras
  - Easy to stitch single exposures together
  - Can see what happens inside



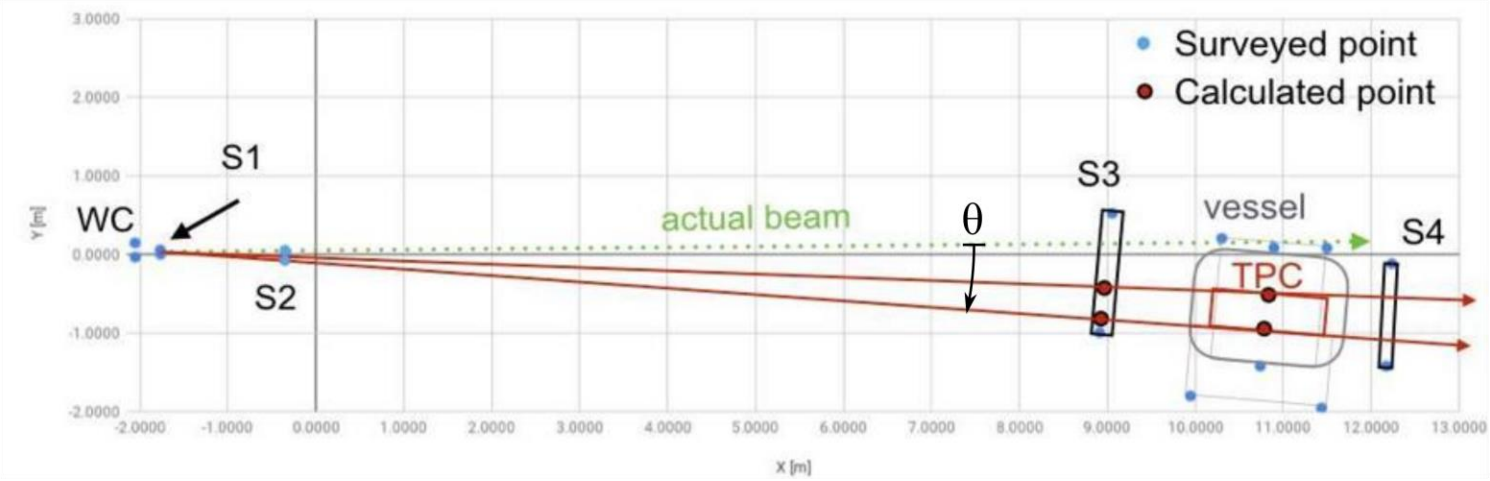
Light Yield: Preliminary results

- A study of low quencher, high Argon content gas with different pressures was performed
- Choice of quencher can enhance or reduce light seen by cameras
  - Increased stability with quencher addition
  - Possible reduction of light output
  - Issues with gas transparency
- CO2 good for HV stability
- ... but bad for light yield
- Data shown for highest achieved anode voltages

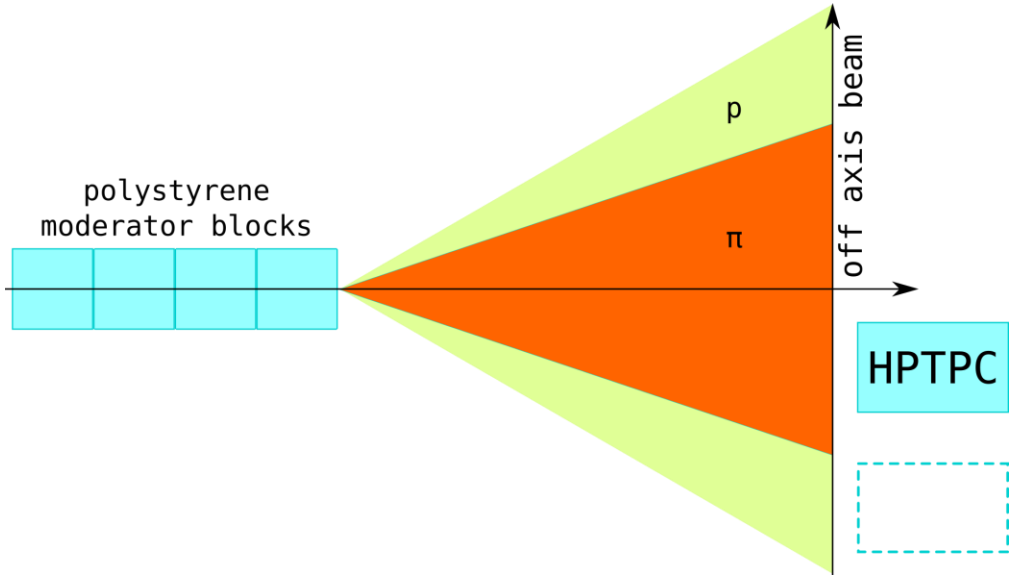


M. Mironova M.Sc. thesis

Beam Test, T10 @ CERN: Beam Characteristics



- Placing the active volume on an **off-axis** angle of a few degrees reduces proton to pion ratio.
- Moderator blocks further widen and decelerate the beam bunches.

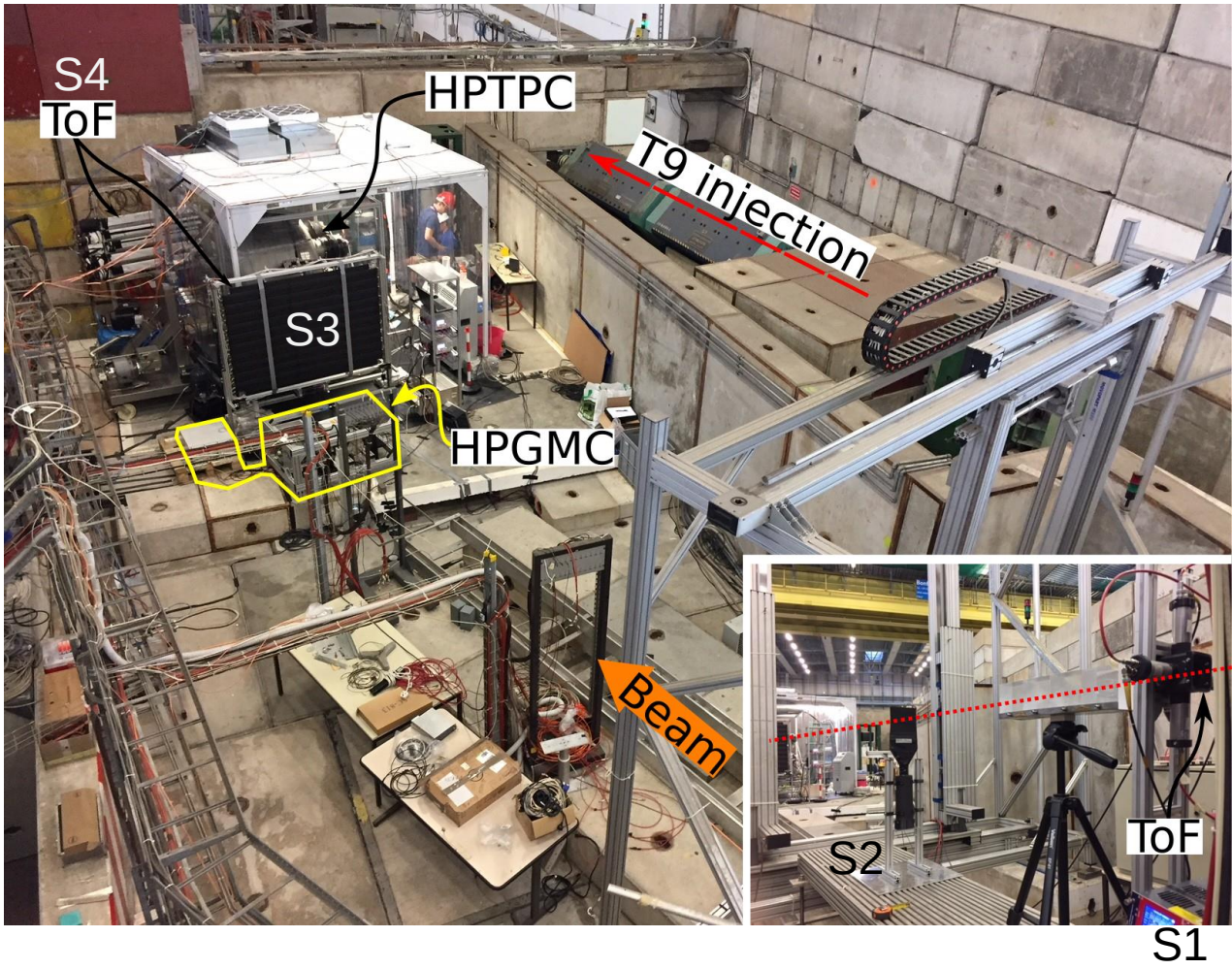


Setup in the Beamarea

T10 Beamline at CERN's PS

- During Aug/Sep 2018
- Low momentum beam
  - < 800 MeV/c momentum

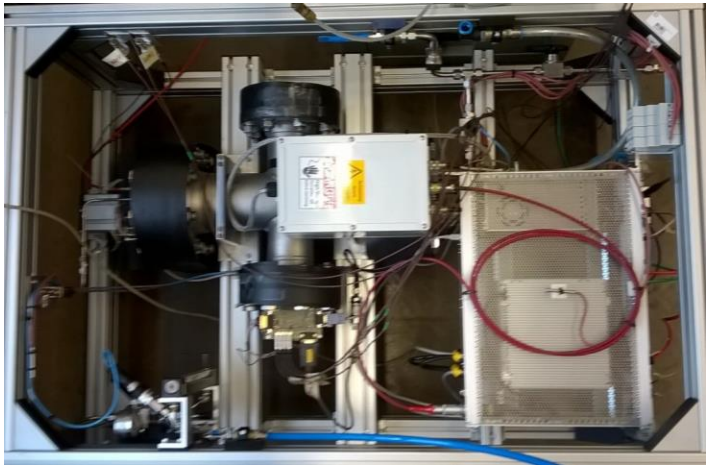
- Objectives:
  - Measuring p-Ar scattering
  - Test of optical TPC in beam

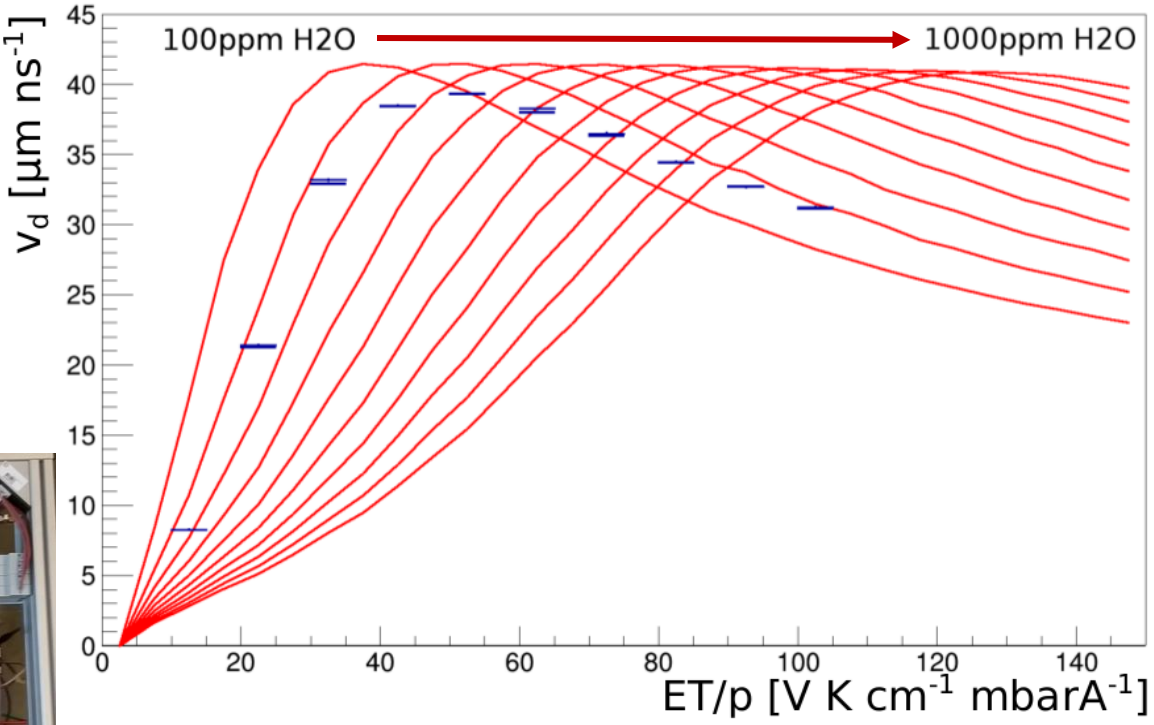


High Pressure Gas Monitoring Chamber

Mini-TPC to reconstruct drift properties from known track positions

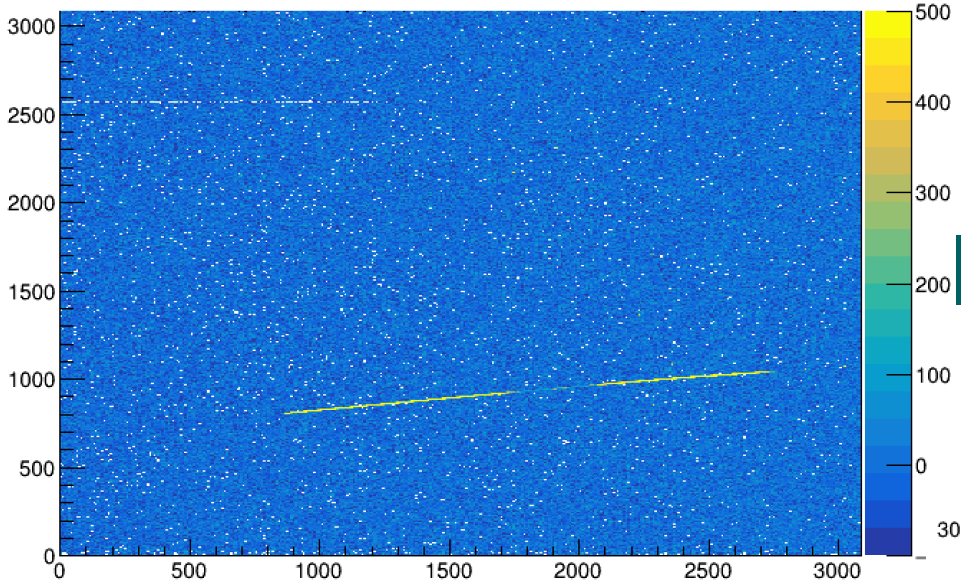
- Scans through different drift voltages
- Compare measurement to expectation / simulation



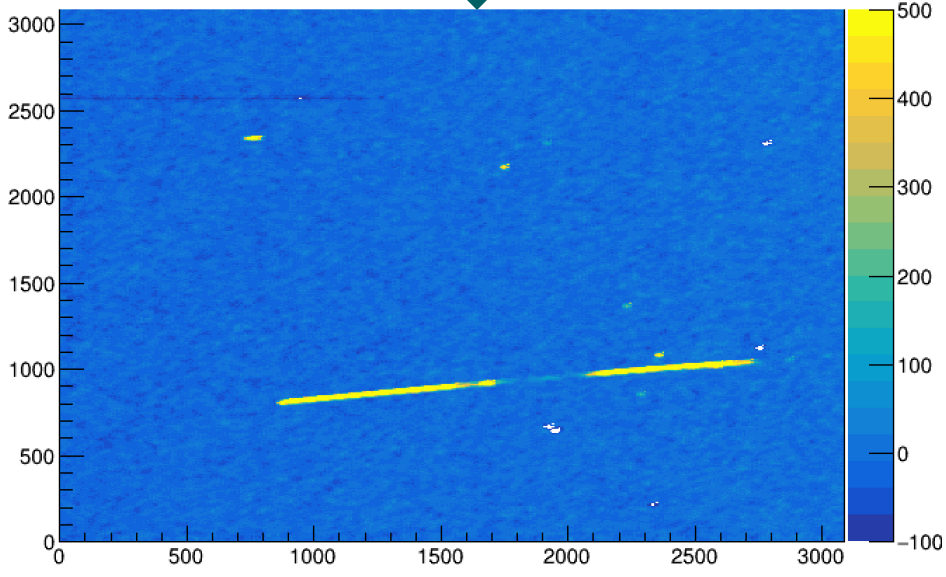


P5 calibration measurement with simulations with varying H2O contaminations

Track Finding in Acquired Data: A Work in Progress



Gaussian blurring can make diffuse signals more visible.



Some tracks visible without reco

- Only thin, concentrated tracks
- Length mm to cm
- Typically expect a few mm diffusion
- Thin tracks likely close to anode

Outlook

Optical charge readout in high pressure gas works!

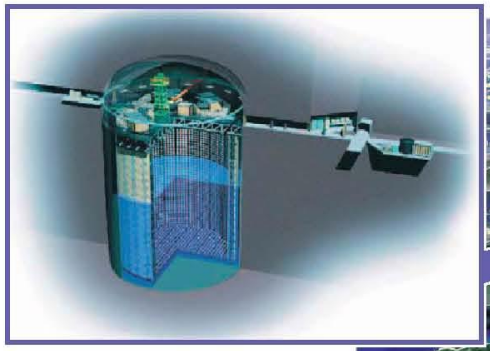
- High level tracking algorithm to find tracks in TPC (TREx)
  - Algorithm proven to work in T2K
  - Can also handle 2D tracks
- Currently two paper under preparation:
  - Instrumentation paper on the HPTPC operation principle and calibration characterization measurements.
  - Beam flux paper characterizing the off-axis technique using the installed ToF systems
- HPTPC might move to Fermilab for another beam time in the future

Thank you!

T2K: 295km Baseline Neutrino Experiment

Muon neutrino beam from Tokai to Kamioka

- Neutrinos are created at J-PARCs proton accellerator in Tokai
- **ND280**: Neardetector 280m downstream of conversion target
  - Measurements constrain flux, beam contaminations, cross-sections
- Far detector 295km baseline in SK underground neutrino observatory

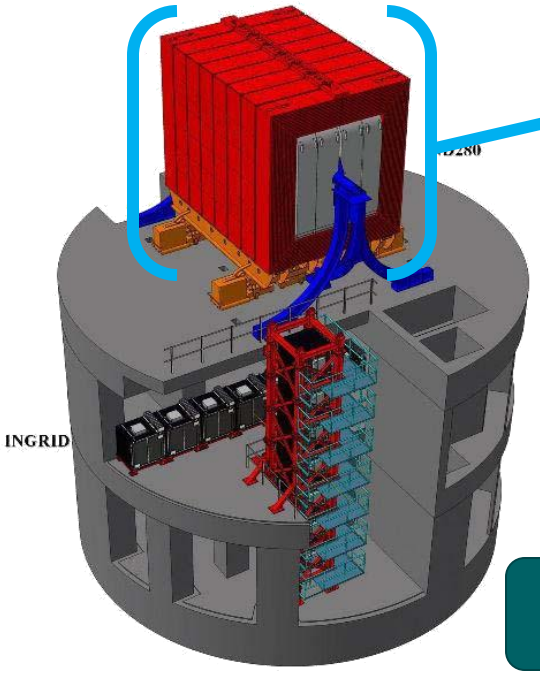


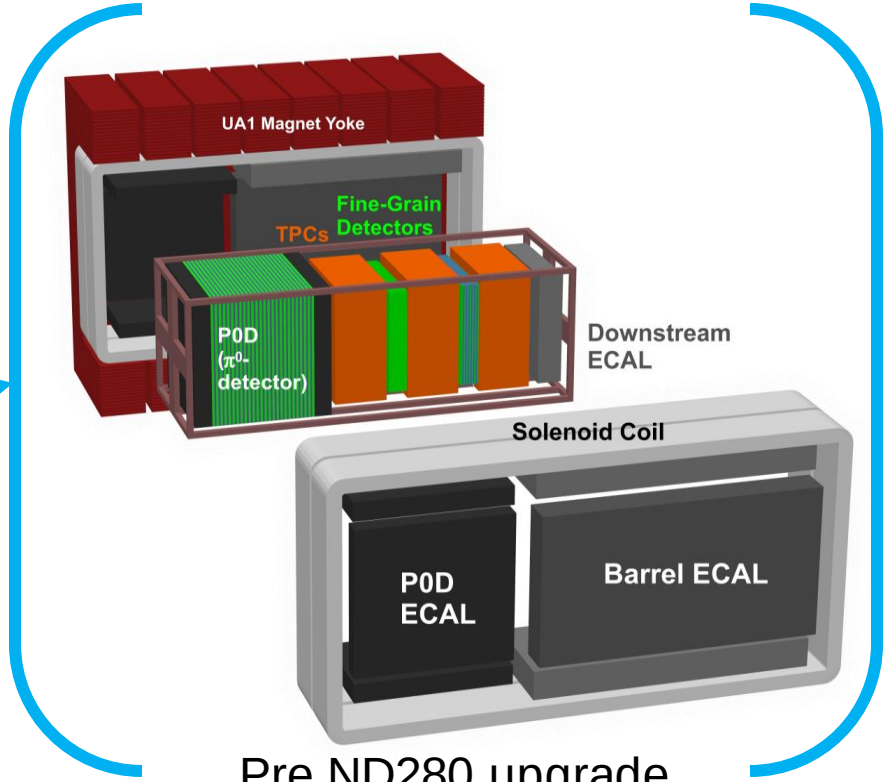
Super-Kamiokande
(ICRR, Univ. Tokyo)

J-PARC Main Ring
(KEK-JAEA, Tokai)

Near Detector of T2K

Heavy tracking detectors sandwiched by TPCs, fully magnetized.





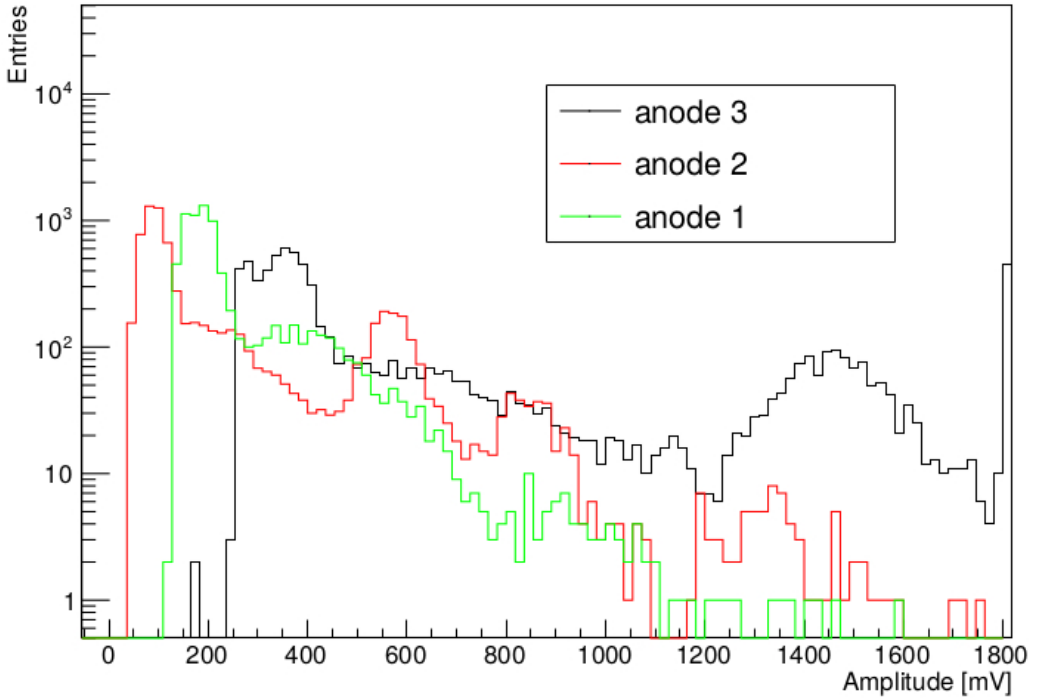
Pre ND280 upgrade

T2K II without high pressure TPCs, but possible for HK era.

Calibration

Charge, Light yield, optical coverage and camera alignment

- During exposures, anode signals are recorded
- Offline matching of anode pulses to light clusters
  - Measure charge in anode signals
  - Charge proportional to light yield
- Decoupling and amplification circuits calibrated ex-situ
  - Charge sensitive CREMAT CR113 (1.2mV / pC)



Sum of 1000 x 2s exposures

CCD & Optical Path Efficiency

Argon (mixtures with Argon predominance) emit light in the ultra-violet and near infra-red region (λ from 600 nm to 1000 nm)

- The cameras are sensitive in the latter wavelength range
- Considering the full optical path including quartz window and lens, we expect up to 1×10^{-4} acceptance
- This factor has to be compensated for with a higher light gain in the gas amplification stage

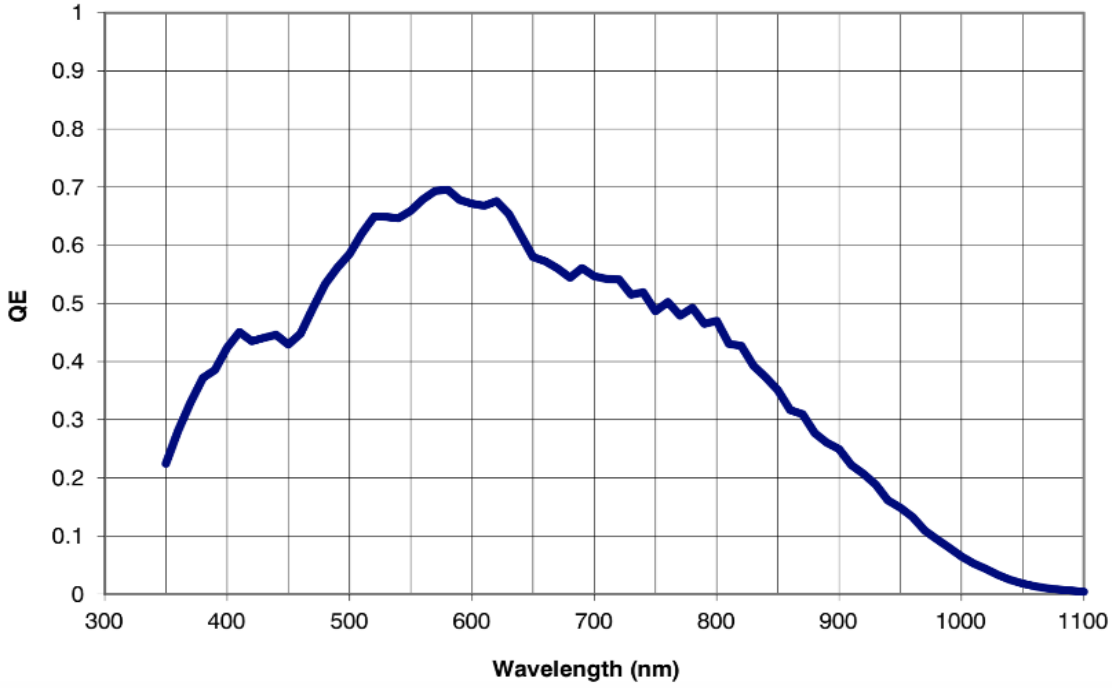


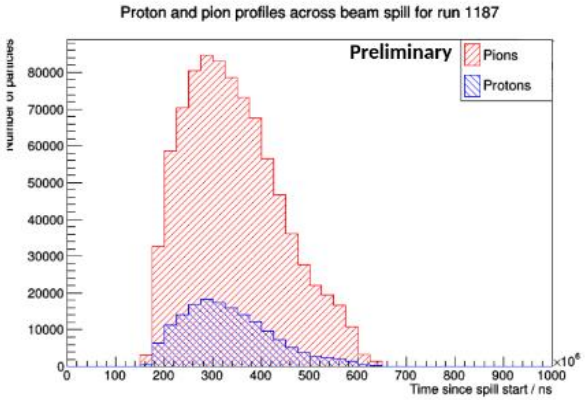
Table of camera specs

CCD	Read noise (e^-)	Read noise (ADU)	Dark current (e^-)	Dark current (ADU)	Dark current (e^-)	CCD gain (e^-/ADU)
PL0141514	11.2	7.22	1.74 (-25C)	2.7 (-25C)	1.70 (-30C)	1.55
PL0251514	10.2	7.71	0.39 (-25C)	0.6 (-25C)	0.38 (-30C)	1.52
PL0261514	9.6	6.27	0.45 (-25C)	0.7 (-25C)	0.44 (-30C)	1.52
PL0544710	11.3	7.38	26.27(-25C)	40.2 (-25C)	25.74 (-30C)	1.53
Fairchild	7	4.66	0.006 (-60C)	0.01 (-60C)	N/A	1.5

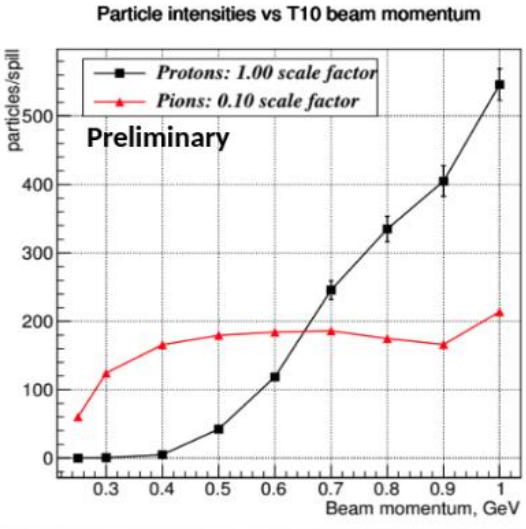
Table 1.7: Manufacturer noise specifications for the CCD's used on the cubic metre detector

Beam Conditions

- Beam spill on the order of 500ms
- Approximately 5-10s between spills



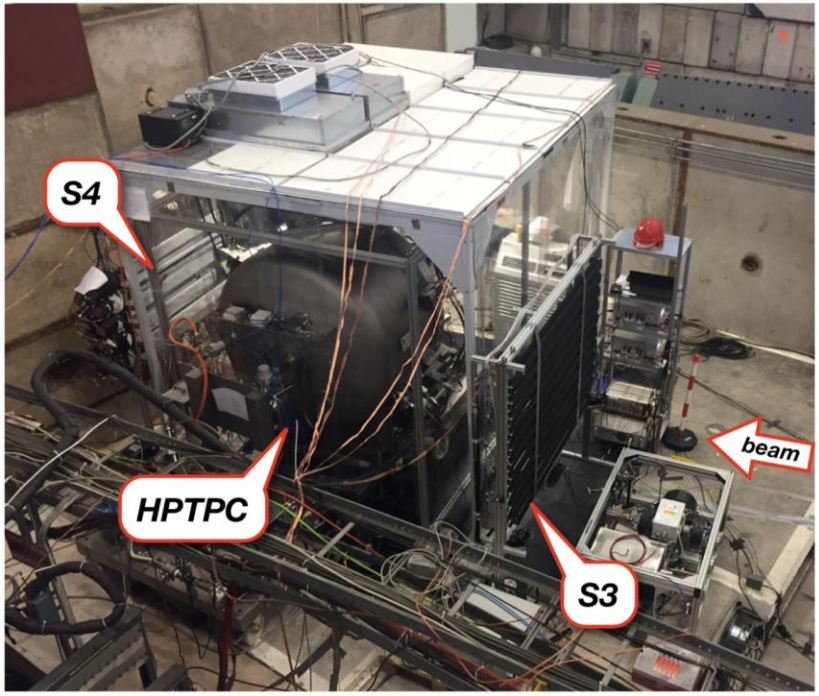
Plot courtesy of Seb Jones

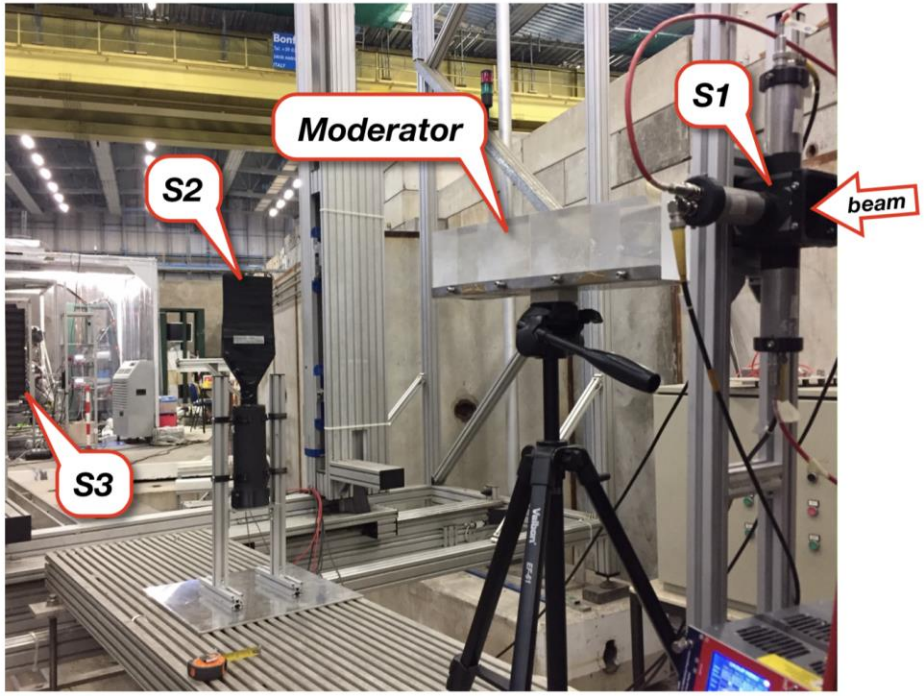


From HPTPC Beam test proposal to CERN

- Beam has high pion component at low momentum settings
- Pions are a background for $p - Ar$ cross-section measurement

Particle Identification and Beam Characterization





- Deployed two ToF systems
  - S3: based on SiPMs
  - S4: based on PMTs
- S3 ToF development for SHiP and T2KII
  - See arXiv:1901.07785

- Characterization of low momentum hadron beam
- Measure proton and pion content
- Vary number of moderator blocks and beam momentum