The High Pressure gas Time Projection Chamber:

A Future Neutrino Detector

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Aims and Objectives

- A High Pressure Time Projection Chamber is a novel possibility for a neutrino detector
  - For example, the official DUNE Near Detector design includes a high pressure gas TPC
- Capable of measuring low momentum outgoing hadrons (typically a few hundred MeV) required for neutrino-nucleus interaction modelling
- To test the HPTPC: Beam test was performed at the T10 Beamline in CERN in August/September 2018
- Innovative off-axis beam technique and moderator used to reduce signal to background fraction and reduce proton momentum measured

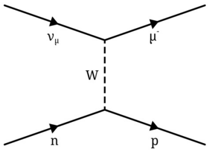
Motivation for HPTPC as a Neutrino Detector

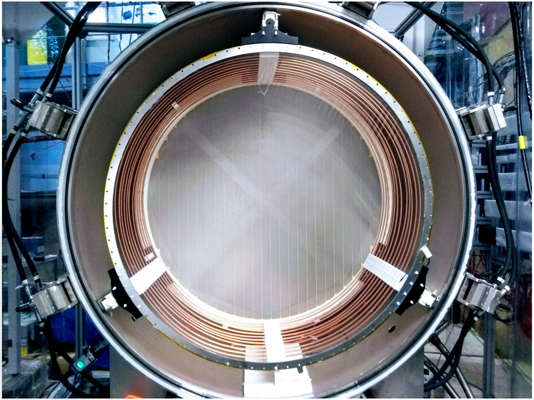
Gaseous detectors:

- Low momentum threshold for final state particles
- Fewer readout channels required to resolve a track
- Ability to change target gas

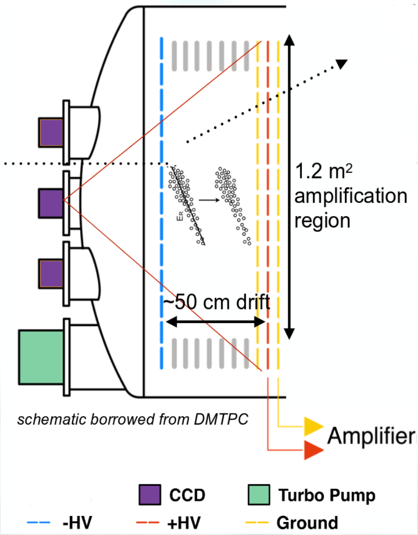
High pressure:

- Increases target mass $\rightarrow$ sufficient events when combined with neutrino beams from MegaWatt facilities

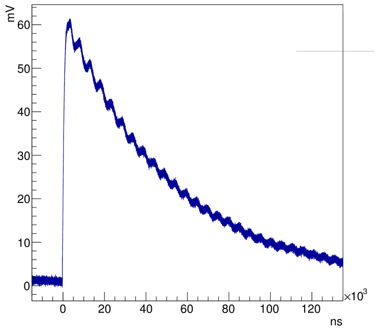




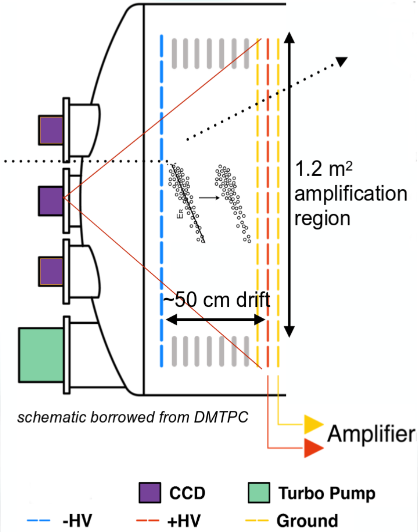
TPC Design: Charge Readout



- Charged particles ionise gas
- Electrons drift to amplification region
- Electron avalanche in the amplification region

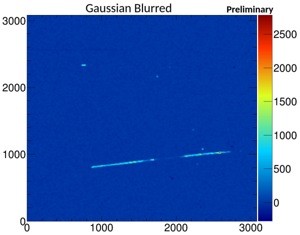


TPC Design: Optical Readout



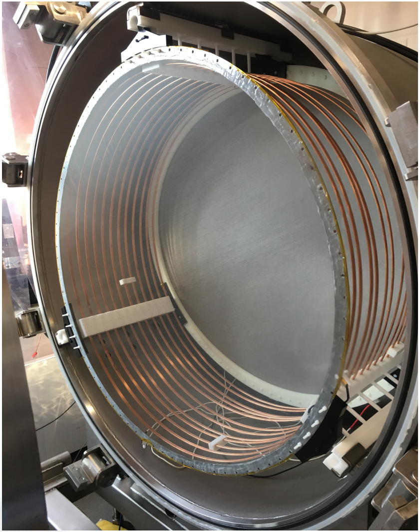
schematic borrowed from DMTPC

- Avalanche excites gas → emits scintillation light
- Optical signal is read by CCD cameras
- CCD cameras sensitive in the 300-800nm range
- Necessary to choose gas such as to optimise both charge gain and optical yield



Prototype HPTPC

- Vessel rated to 5 barG of pressure
- Steel mesh cathode and anodes create drift field and amplification region respectively
- Field cage: 12 copper rings maintain uniformity of the drift field
- 4 CCD cameras image a quadrant of amplification region



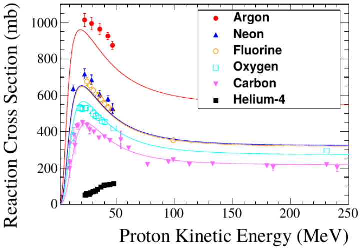
Beam Test Overview

- Beam Test took place at the T10 beamline, East Area at the PS in CERN
- 1 Month of beam from 15 August to 18 September
- Primary beam configuration used 0.8 GeV/c beam
- R&D goal: Test HPTPC prototype to provide proof of concept
- Physics goal: Making measurements of hadronic scattering

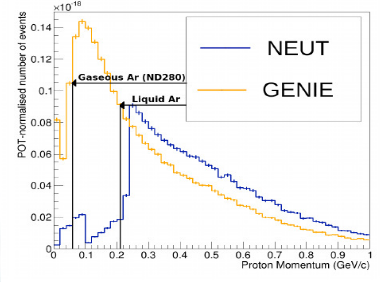
Motivation for beam test

- Lack of hadron scattering data in the low proton energy region
- More data can be used to tune nuclear models
- Ability to change target gas helps constrain nuclear models further

- Neutrino generators disagree in predictions at low momentum
- Leads to higher systematic uncertainties in nuclear models for neutrino experiments



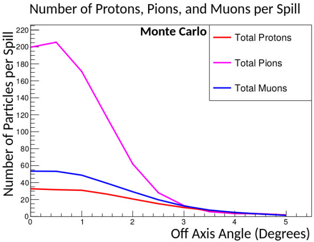
H. Wellisch and D. Axen, Physical Review C 54, 1329

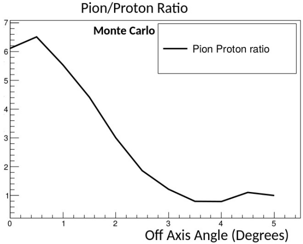


Plot courtesy of Pip Hamilton Neut/Genie models differ

Off-axis angle technique

- Seek to increase the proton ratio while decreasing the proton energy of the beam
- Use of acrylic moderator blocks in front of beamline
- Causes protons to scatter at wider angles than pions
- Moving off axis increases proton:pion ratio
- Trade off between improved Proton:Pion ratio and raw number of particles
- Range of 3-4 degrees chosen for beam test





Beam Test Layout

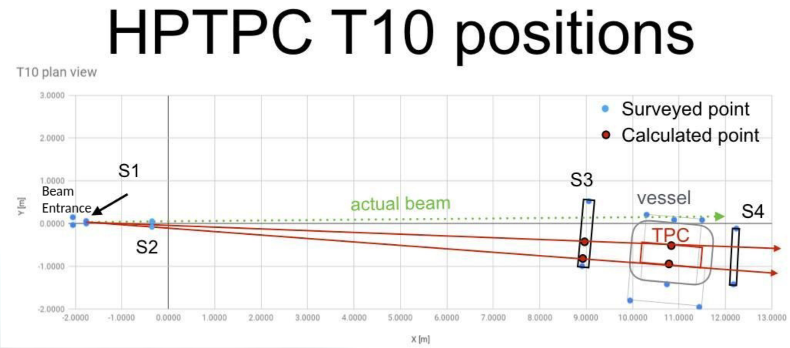
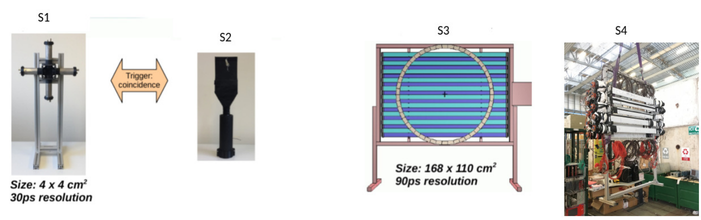


Diagram courtesy of Morgan Wascko

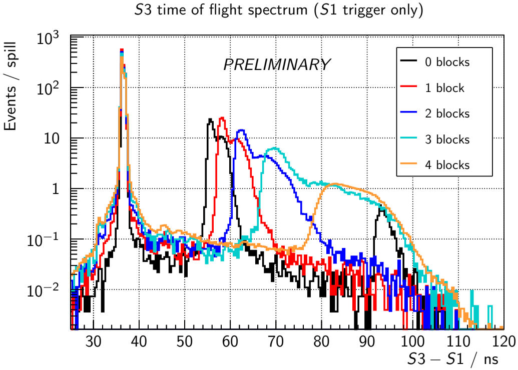
Time of Flight Systems

- 3 constituents upstream of TPC (S1-3):
  - Plastic scintillator upstream counter (S1) of 4cm x 4cm with trigger counter (S2)
  - Further downstream timing detector (S3) with 20 bars of plastic scintillator with 90ps timing resolution - a SHiP prototype from the Université de Genève
- 1 constituent directly behind the TPC vessel
  - Bars are 1cm x 10cm x 140cm plastic scintillator with Timing resolution of ∼1ns, built by UCL



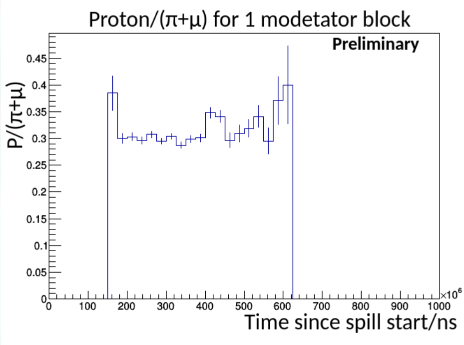
Images courtesy of Alexander Korzenev and Seb Jones

Time of Flight Results: S1 to S3



- Proton and Pion peak spread further apart with increased number of moderator blocks
- Protons experience momentum spread
- Effect observed over entire S3 wall

Particle Ratio Results

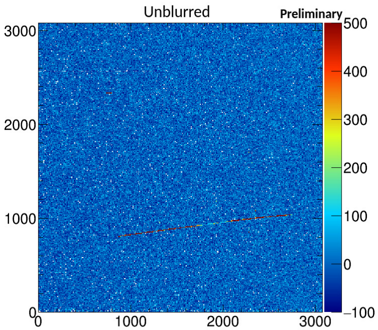


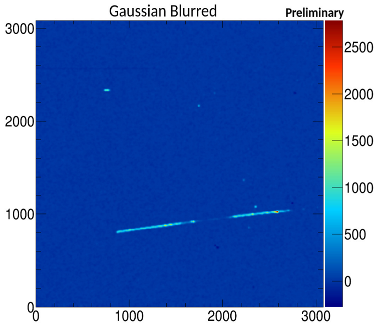
Plot courtesy of Seb Jones

Proton/$(\pi + \mu)$ ratio within a single spill

- Nearly constant, with low statistics near the end of the spill
- For one block: significant increase in Proton/MIP ratio compared with previous on-axis measurements

CCD Image Data Analysis

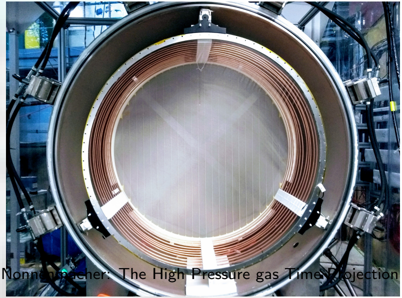




- Gaussian blurring one method being pursued for image processing
- Reduces effects of charge diffusion in the gas
- This will allow us to pick out local features on top of background noise

Summary

- An HPTPC is an excellent candidate for future detectors
- A prototype HPTPC has been built and operated in a test beam at CERN
- A moderator and off-axis beam technique were successfully used to increase proton ratio
- Analysis of the data taken at beam test is ongoing
- Now preparing to replace the amplification region with ALICE TPC wire chamber in preparation for DUNE
- Hope to conduct further beam tests in the future

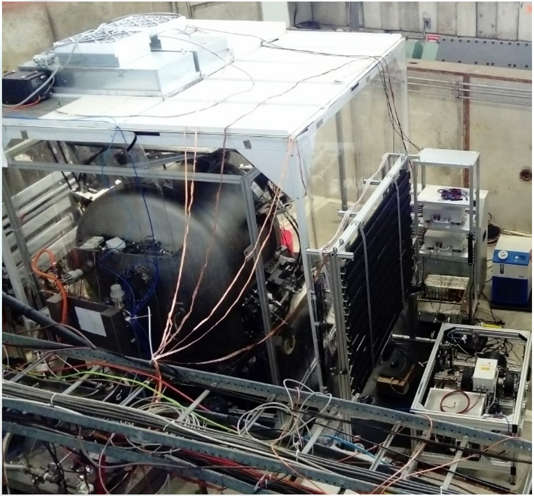


Thanks for listening!

- CERN
- Imperial College
- Lancaster University
- Royal Holloway University
- RWTH Aachen University
- University College London
- University of Geneva
- University of Warwick

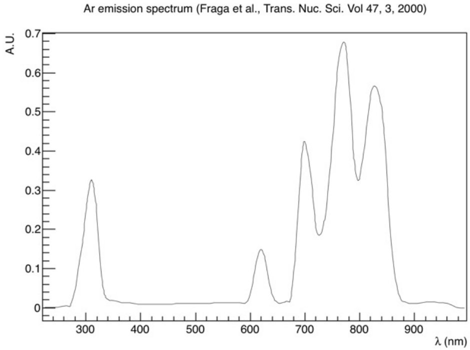
BACKUPS

HPTPC in Beamline



Optical Readout

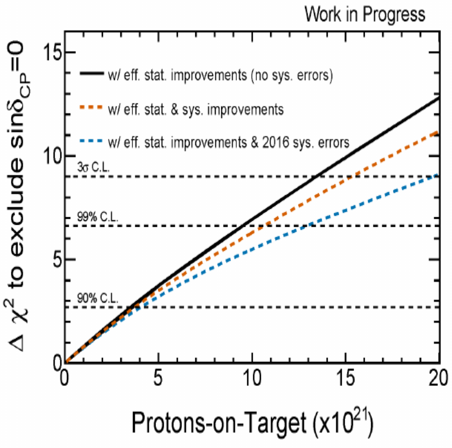
- Electron avalanche excites gas $\rightarrow$ emits γ's
- Optical signal is read out by CCD cameras
- CCD cameras sensitive in the 300-800nm range
- Light yield can be enchanced with quencher



From Fraga, M. M., et al. "Study of scintillation..." Nuclear Science Symposium, 1999. Conference Record. 1999 IEEE. Vol. 2. IEEE, 1999

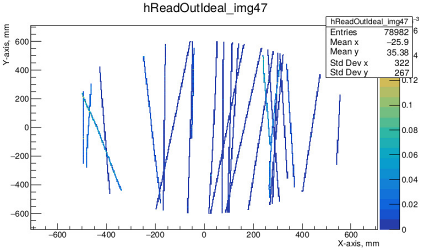
Motivation

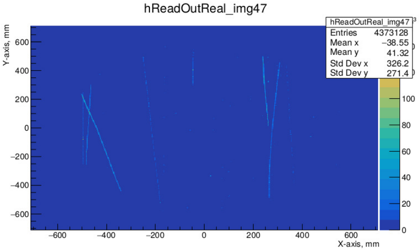
- Sensitivity to oscillation parameters dependent on systematic uncertainties



TREx

- One method of reconstruction available using the a* algorithm
- Example Monte Carlo to be anlysed by TREx:





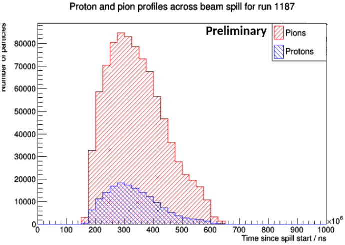
Camera specs

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

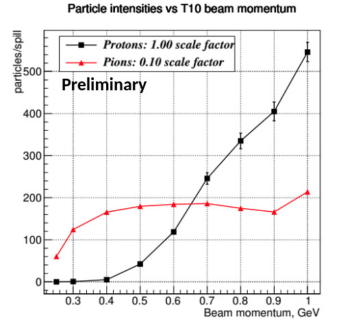
Table 1.7: Manufacturer noise specifications for the CCD's used on the cubic metre detector

Beam Test: 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

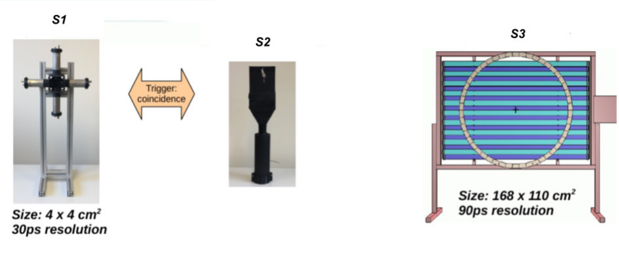
- Beam has high pion component at low momentum settings
- Pions are a background for $p - Ar$ cross-section measurement

Downstream Time of Flight

- S4: 1 constituent directly behind TPC vessel, integrated with S1-S3
- Timing resolution of 1ns
- Corresponds to approximately 9cm horizontally
- Bars are 1cm x 10cm x 140cm plastic scintillator

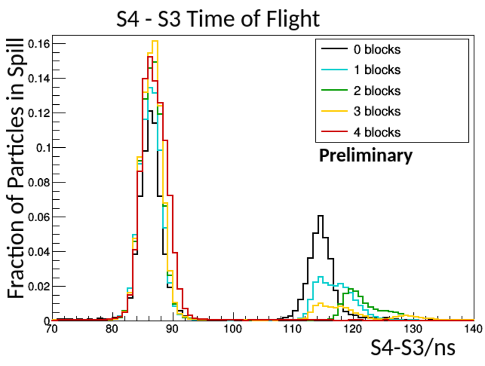
Upstream Time of Flight

- 3 constituents upstream of TPC (S1-3)
- Plastic scintillator upstream counter (S1) of 4cm x 4cm with trigger counter (S2)
- Further downstream timing detector (S3) with 20 bars of plastic scintillator with 90ps timing resolution
- S3 is a SHiP prototype from the Université de Genève: larger version of that used for the ND280 beam test



Images courtesy of Alexander Korzenev

Time of Flight Results: S3 to S4

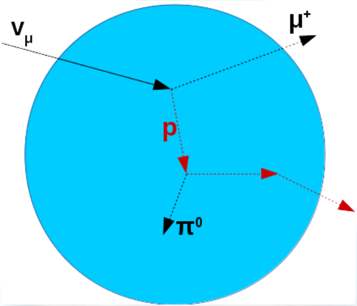


Plot courtesy of Seb Jones

Time of Flight between S3 and S4:

- Left peak corresponding to MIPs
- Right peak corresponding to Protons

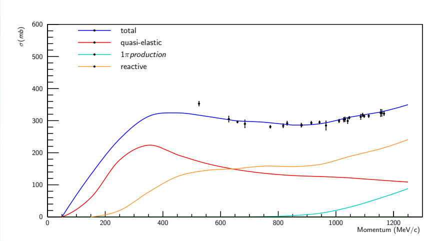
Nucleon FSI



- Nucleons produced in neutrino interactions undergo various interactions in the target nucleus (affecting their kinematics)
- The lack of full understanding of nuclear interactions in the nucleus is a source of systematic uncertainty

Data Comparison

Also interested in comparing variation of the dials to data (done very roughly below)



- Comparison to proton-Carbon data in the low momentum region
- Data taken from RF Carlson: Proton-Nucleus Total Reaction Cross Sections and Total Cross Sections Up to 1 GeV (1996)
  - dials adjusted to give overlap
  - overall scaling = 1.0, QE = 0.9, 1pi = 0.9, 2pi = 1.0