DUNE ND Workshop
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R&D for HPTPC with optical readout in the UK

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Outline

HPTPC prototype project between Imperial College London, University of Lancaster, Royal Holloway University of London, University of Warwick

- Introduction
- Description of HPTPC prototype
- Physics goals for beam test
- Flux measurements at CERN test beam
- Software status

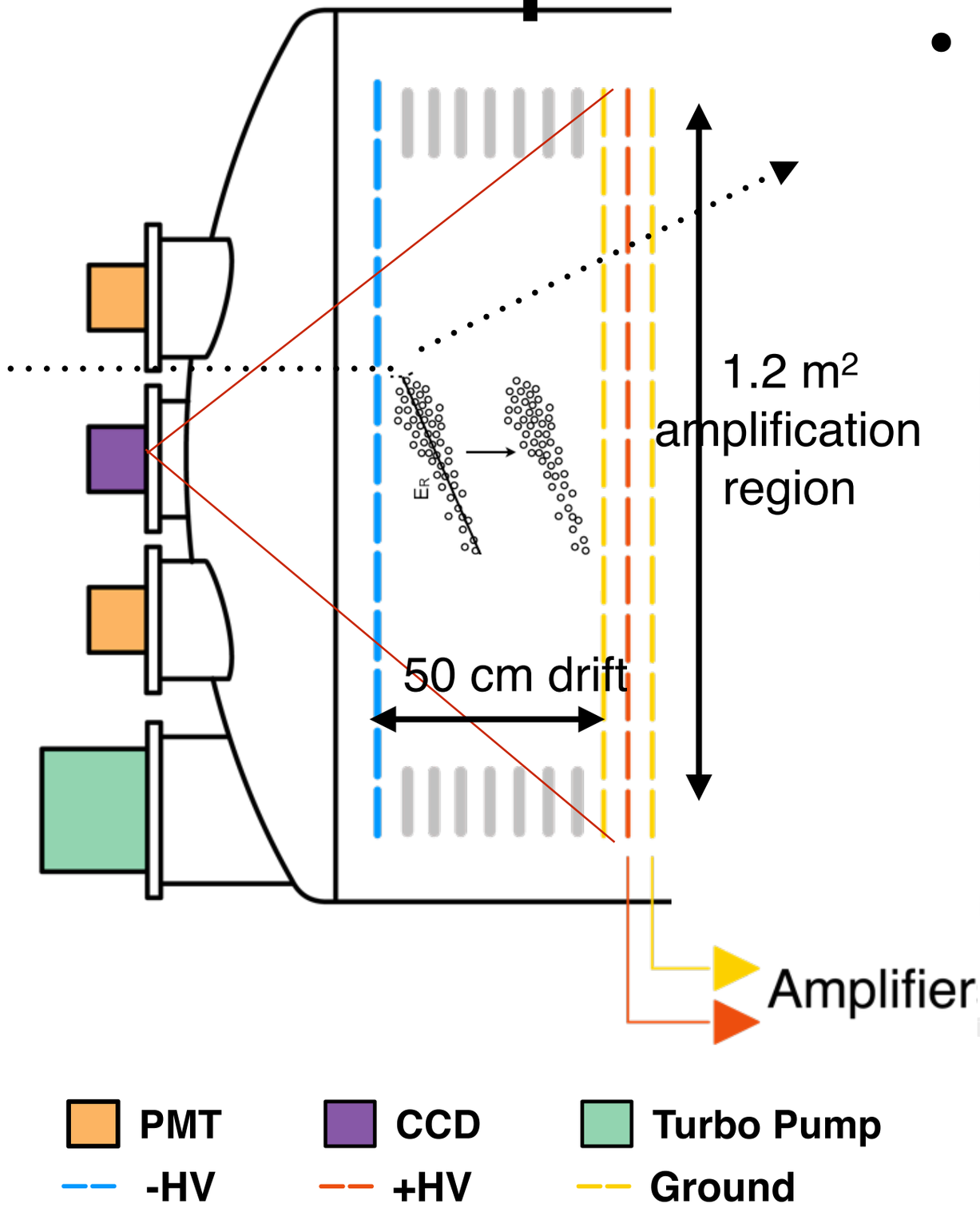
Advertisement: HPTPC-WG

- ~biweekly WG meeting established
  - currently alternate Mondays
- Connect and focus several HPTPC efforts
  - Focus on developing physics studies
  - report on software tools
  - report on hardware R&D
- Coordinate UK efforts with European and North American work, hope to expand to Japan as well
- Slides etc posted on RHUL Indico server
  - contact <jocelyn.monroe@rhul.ac.uk> for access
- Have an email list
  - contact <m.wascko@imperial.ac.uk> to join

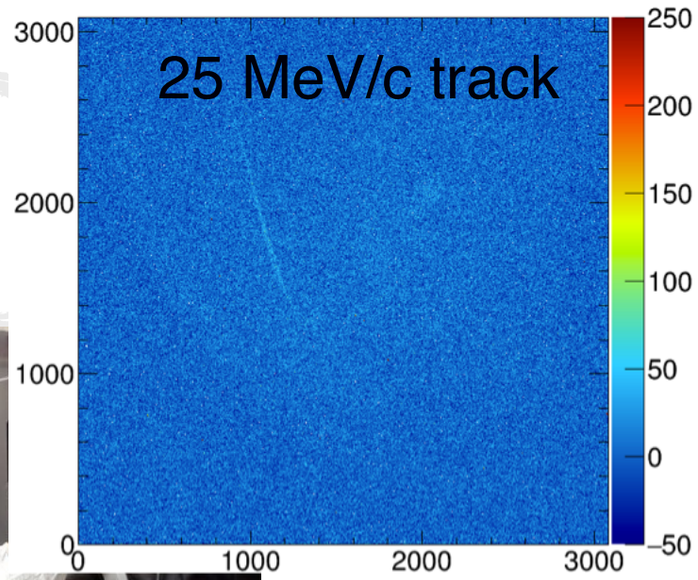
Project overview

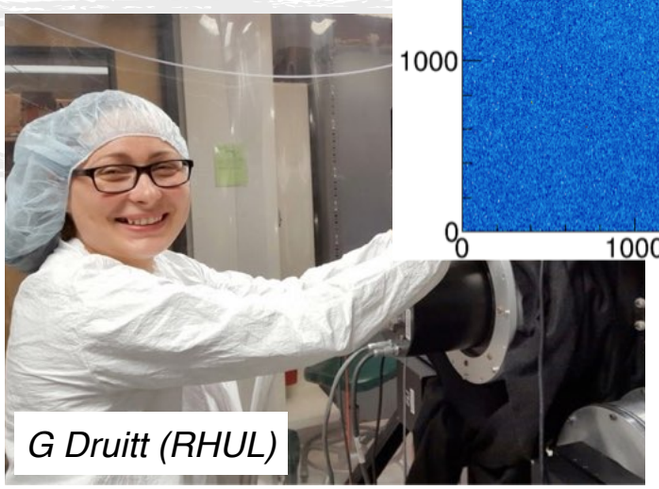
- Building ~1 m^3 HPTPC prototype with charge and optical readout
  - designed for 5 bar CF_4 and Ar gas targets,
    - also perform R&D on mixtures with N-CO_2 and Ne
  - 50 cm drift length, adjustable
- segmented amplification plane gives 4 direct charge readouts
  - test platform for micromegas or other amplification structures
  - aim for <100 MeV/c threshold for protons -> mm readout pitch
- Prototype goal: CERN beam test to measure proton/pion response, optimise readout pitch, **make hadron scattering measurements**
- Optical readout R&D to reduce cost of mm pitch readout
  - Combine optical pixel readout with charge strip readout to mitigate reconstruction ambiguity, and instrumental backgrounds
  - Building on expertise from DMTPC and T2K

Optical Readout



- CCD images scintillation produced in the amplification region
  - 16 MPix CCD + lens outside pressure vessel
  - 90 cm object distance
  - results in 1 mm readout pitch with 4x4 readout binning
  - CCD readout time implies 2D image

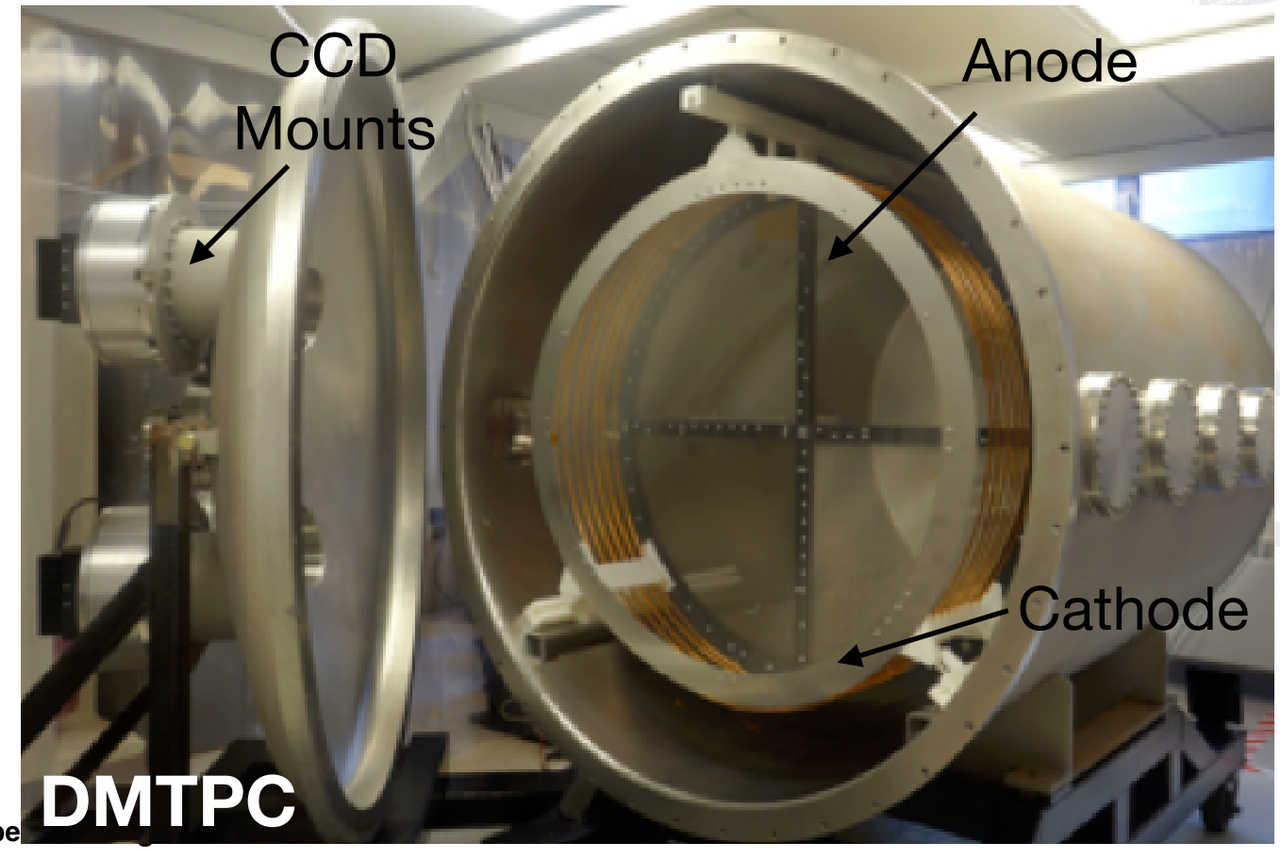


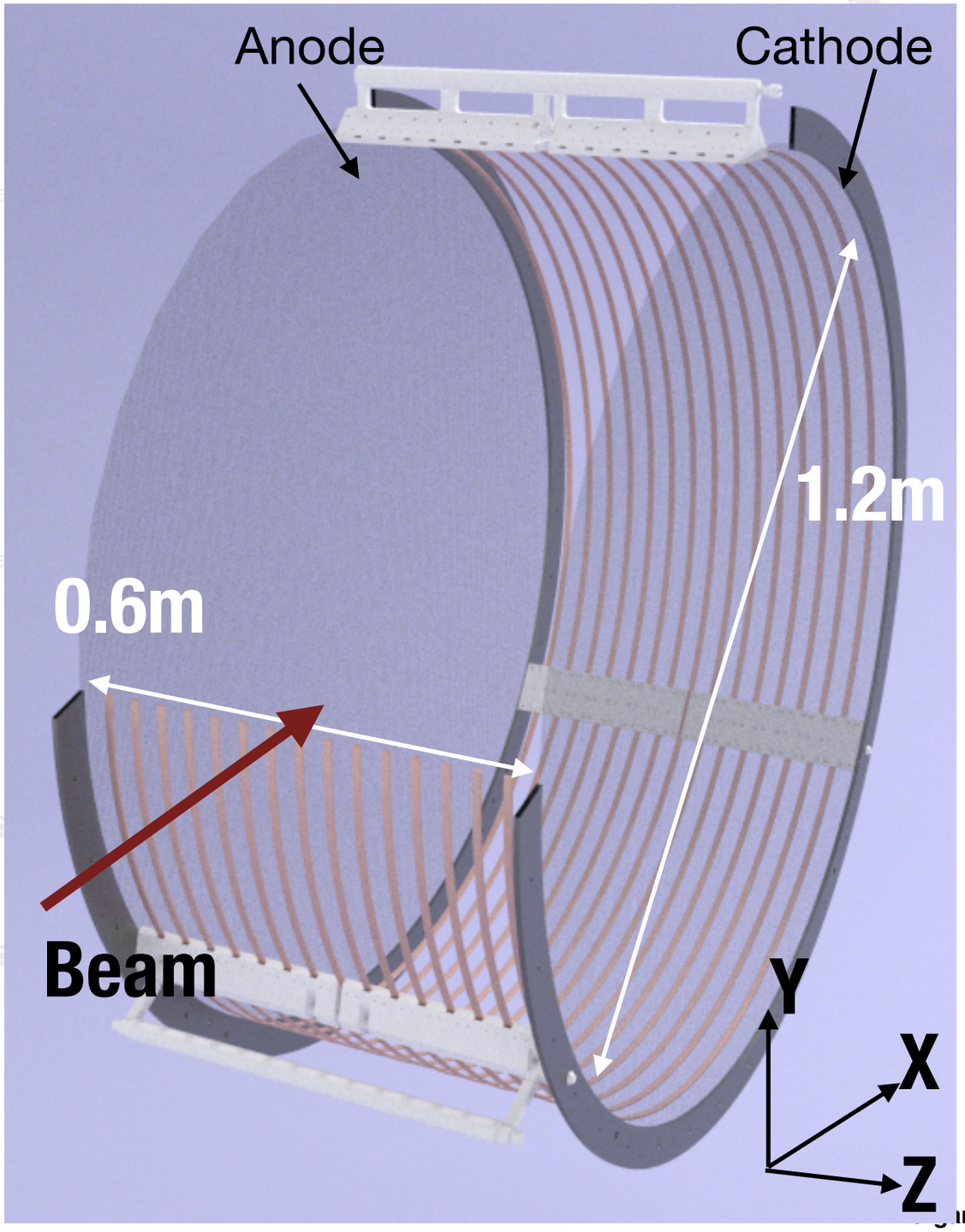


G Druitt (RHUL)

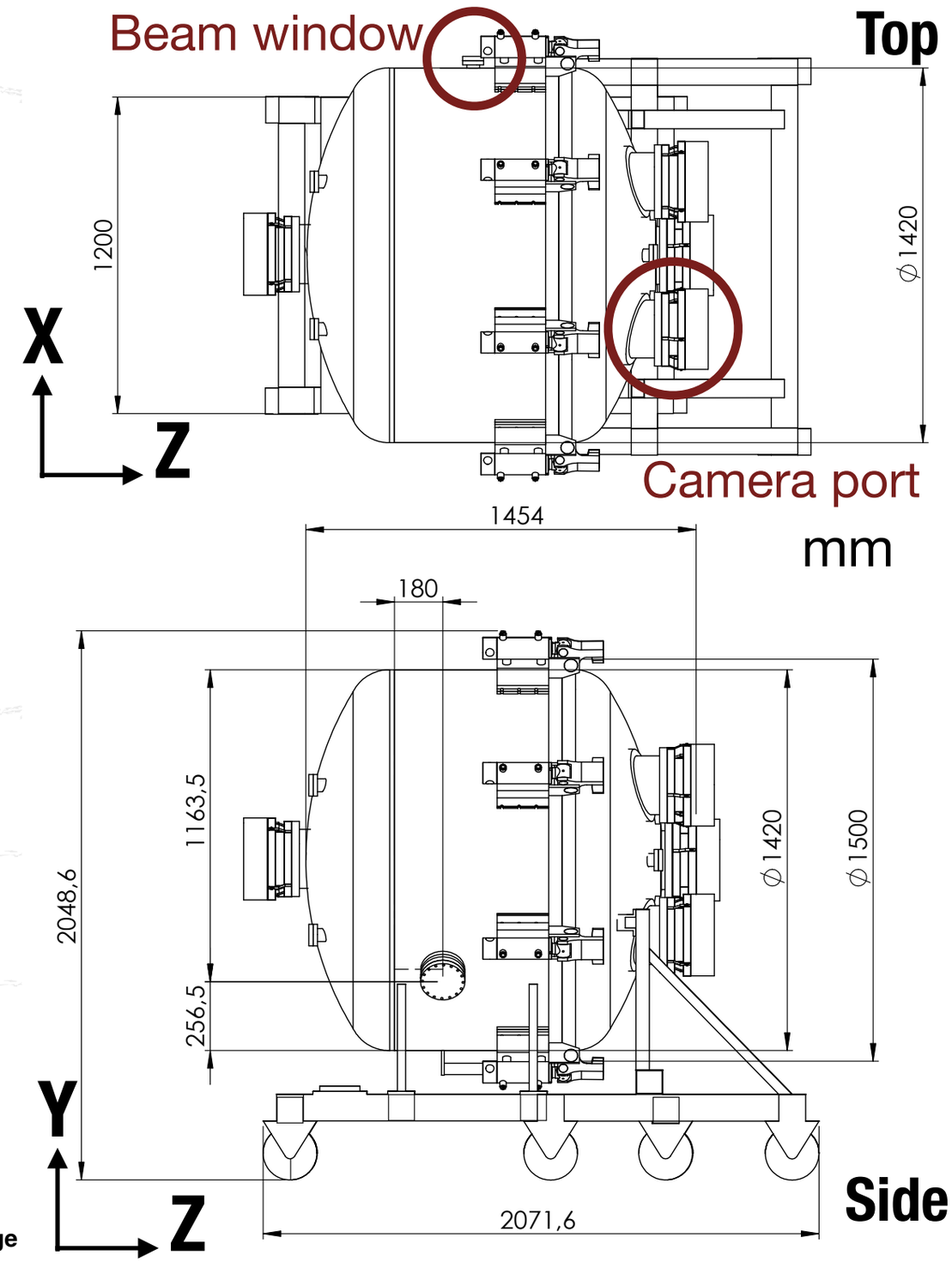
TPC Design

- Build upon DMTPC Design
- Central Anode
- Copper ring field cage
- Cylindrical Volume of 0.65m^3





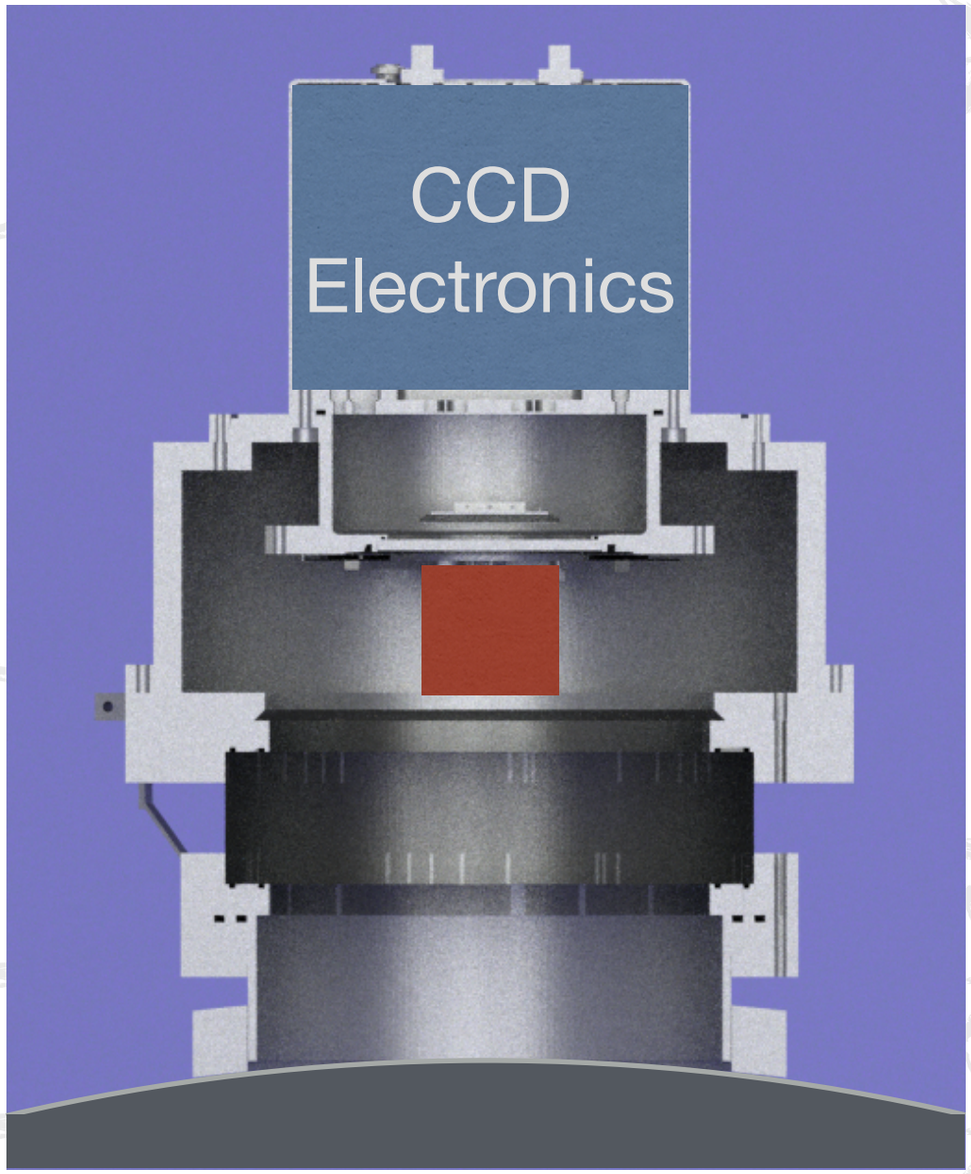
Vessel Design



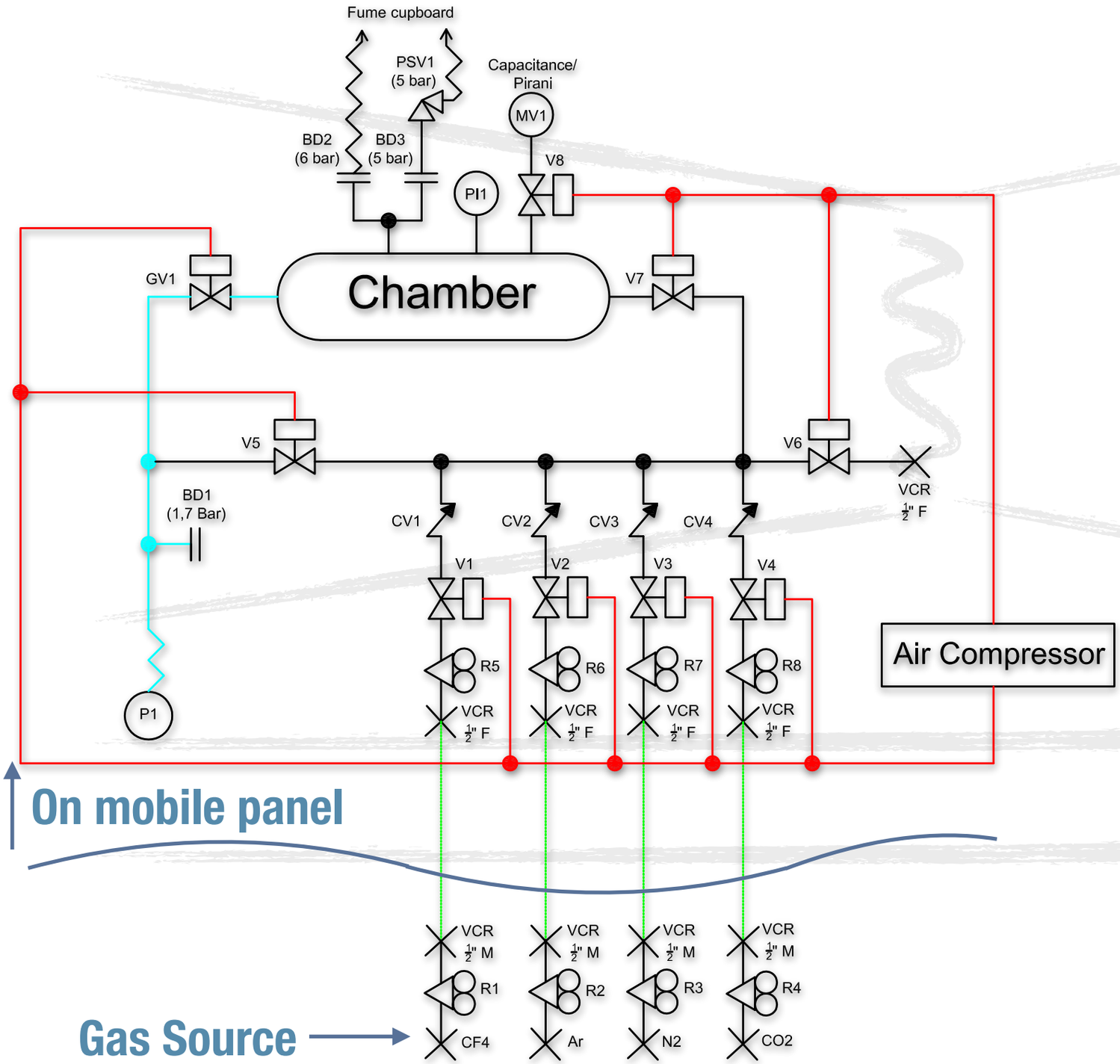
- 1cm thick stainless steel chamber
- Internal volume ~2m^3
- 4+2 Optical readout ports
  - CCD readout - XY readout
- Designed operating pressure 0–4.75Bar
- Internal 3 rail supports for mounting TPC
- Delivery at RHUL <2 Months

CCD Details

- Optics and CCD mounted to end flange
- Fairchild CCD486
  4096x4097 pixels
  0.01–0.05 e/pix/sec dark count
  Low readout noise
  Vacuum Cooled
  <300µm / pixel mapped to Anode
- Commercial optics 50mm f/ 0.95–f/1.2 lens (As fast as possible!)
- Quartz window separates internal volume from CCD
- Allows readout to be serviced without opening the vessel



Gas System Design



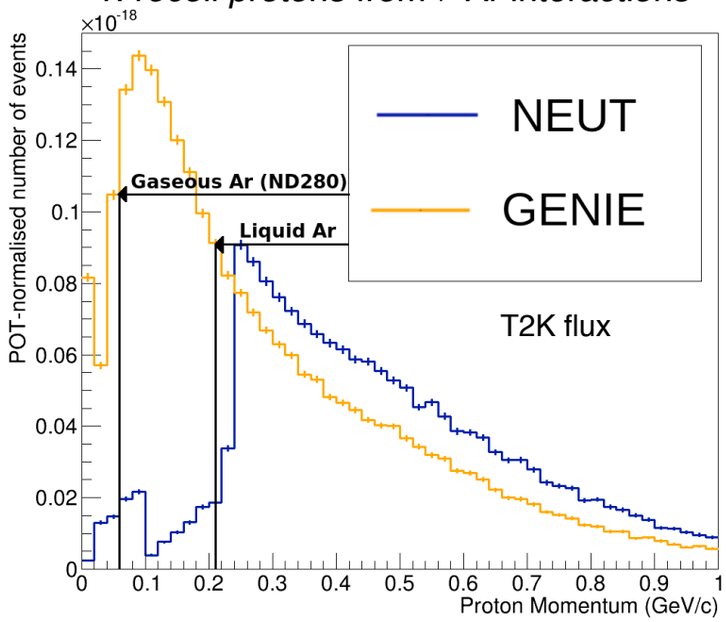
- Panel-mounted mobile system.
- Gas-actuated valves for remote operation.
- Bellows-sealed valves used throughout
  - Minimal trapped spaces, good purity
- Option to add flow control
- Rough pump via scroll pump

Hadron measurements

- **Goals:**
  1. **Make new proton-nucleus (and pion-nucleus) scattering measurements**
  2. **Tune neutrino interaction generators, demonstrate feasibility of <2% systematics**
- Neutrino generators disagree in recoil particle multiplicity & kinematics (Fig 1)
- Low energy final state protons are created at higher energy, lose energy exiting nucleus (Fig 2)
- Need new data for tuning generator MC hadron scattering models (Fig 3)

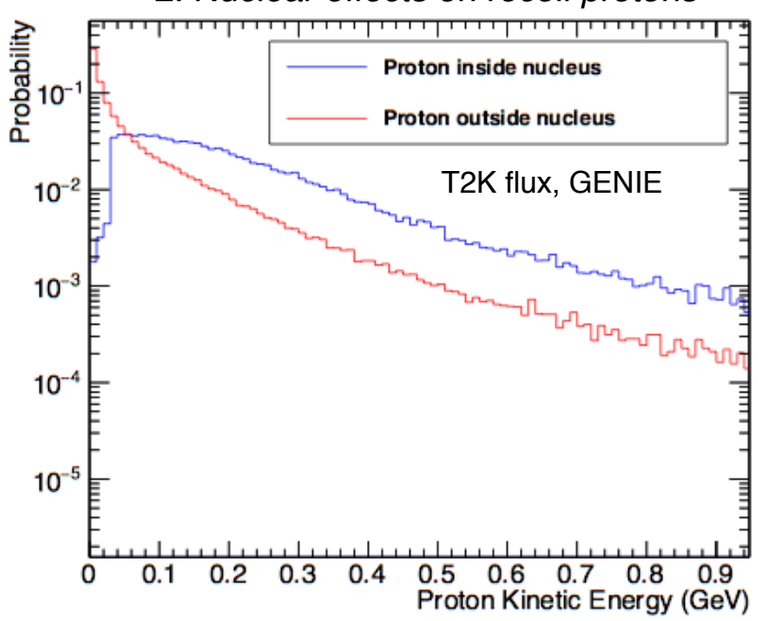
P Hamilton (Syracuse)

1. recoil protons from ν-Ar interactions



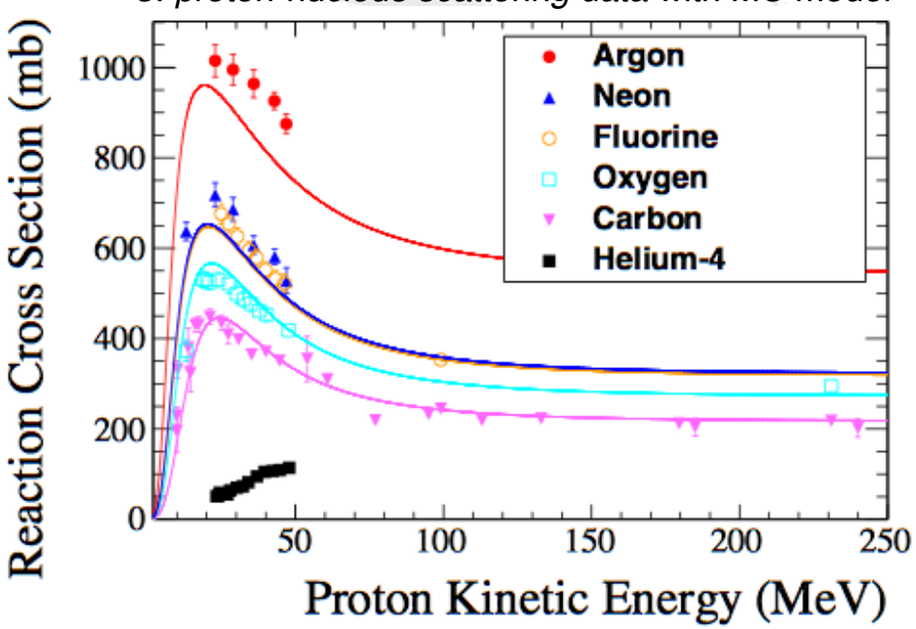
A Kaboth (RHUL)

2. Nuclear effects on recoil protons



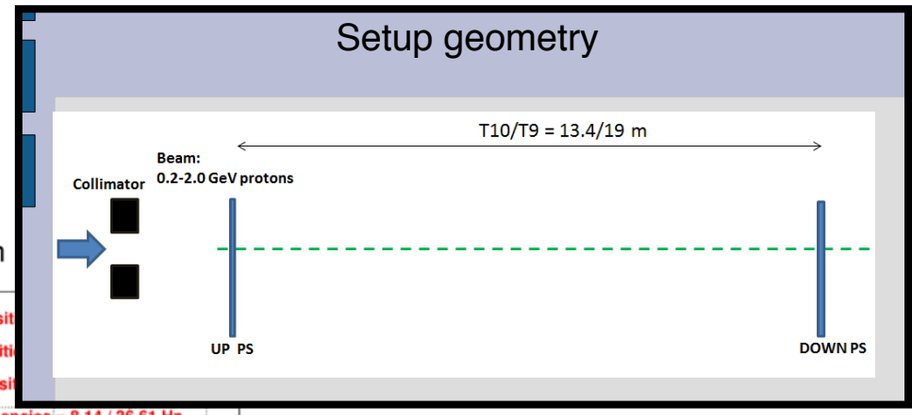
A Kaboth (RHUL)

3. proton-nucleus scattering data with MC model

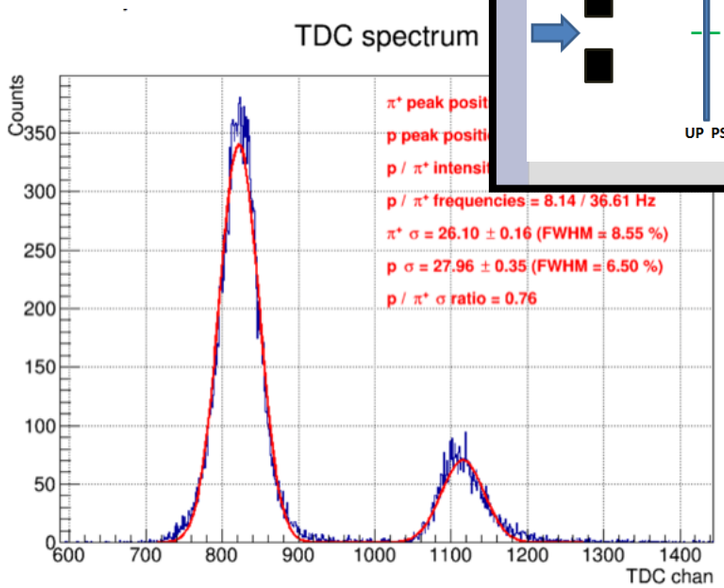


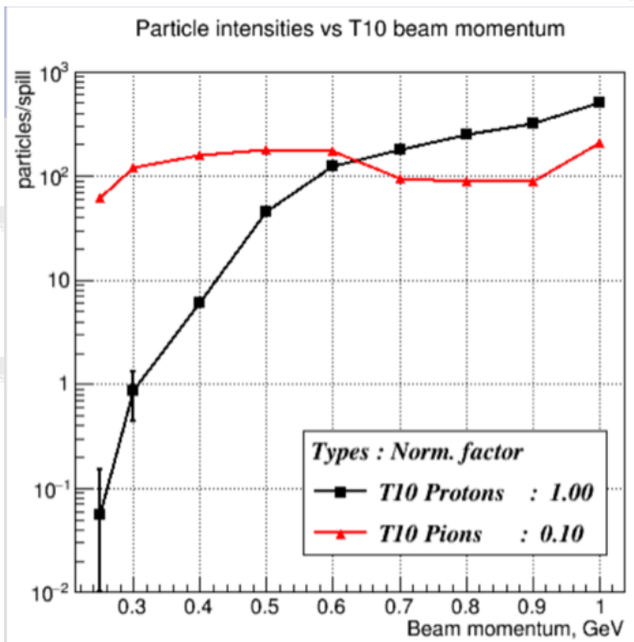
Testbeam fluxes

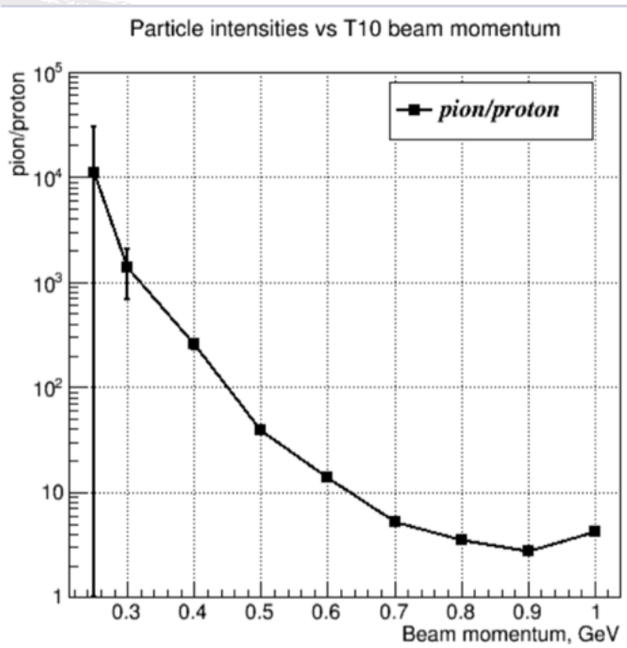
- Took data in T9 & T10 test beams at CERN
  - Z Chen-Wishart, W Parker, Yu. Shitov,(RHUL)
  - S Boyd, J Haigh (Warwick)
- Push proton measurements as low as possible in momentum
  - fluxes dominated by pions
- Exploring use of beam absorbers to get higher proton ratios



Yu Shitov (RHUL)

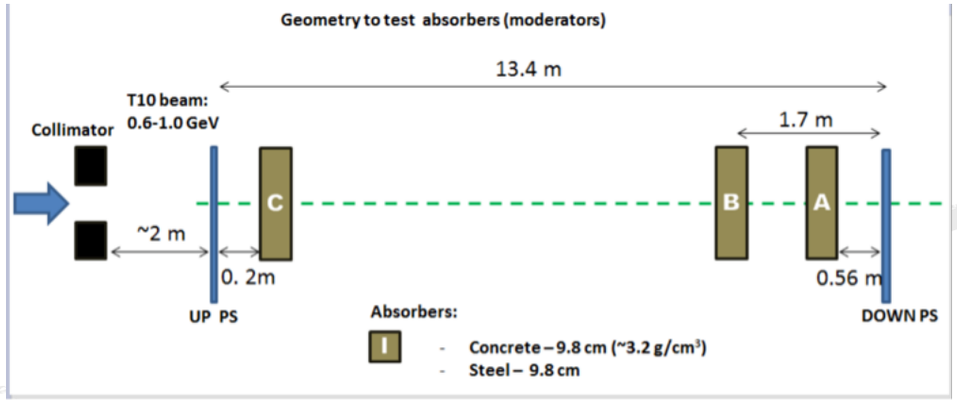


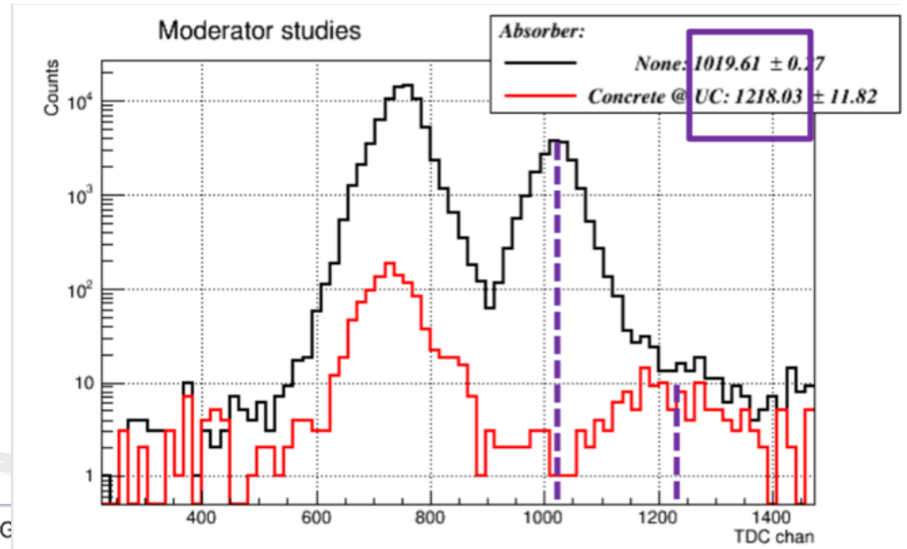


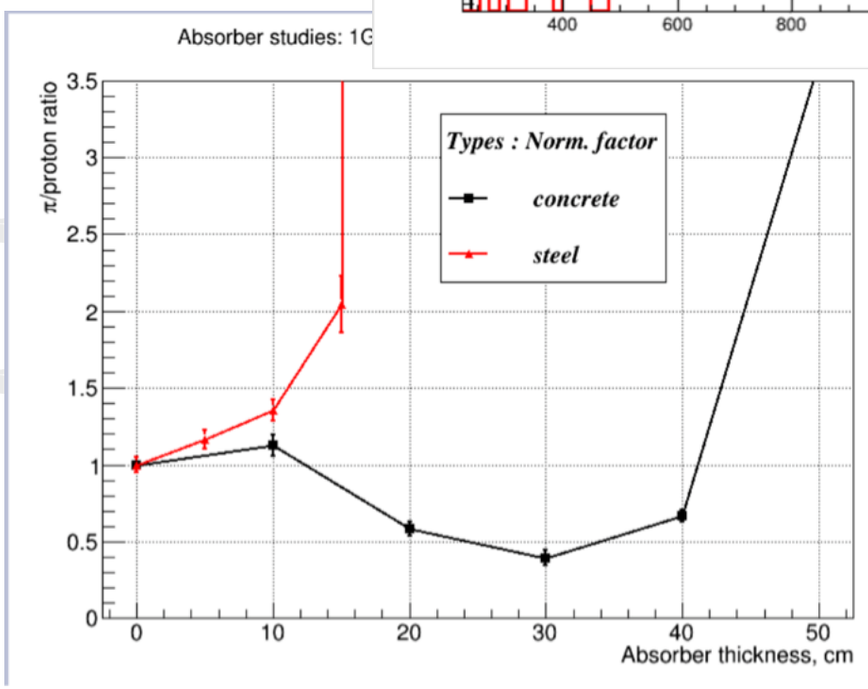


Absorber studies

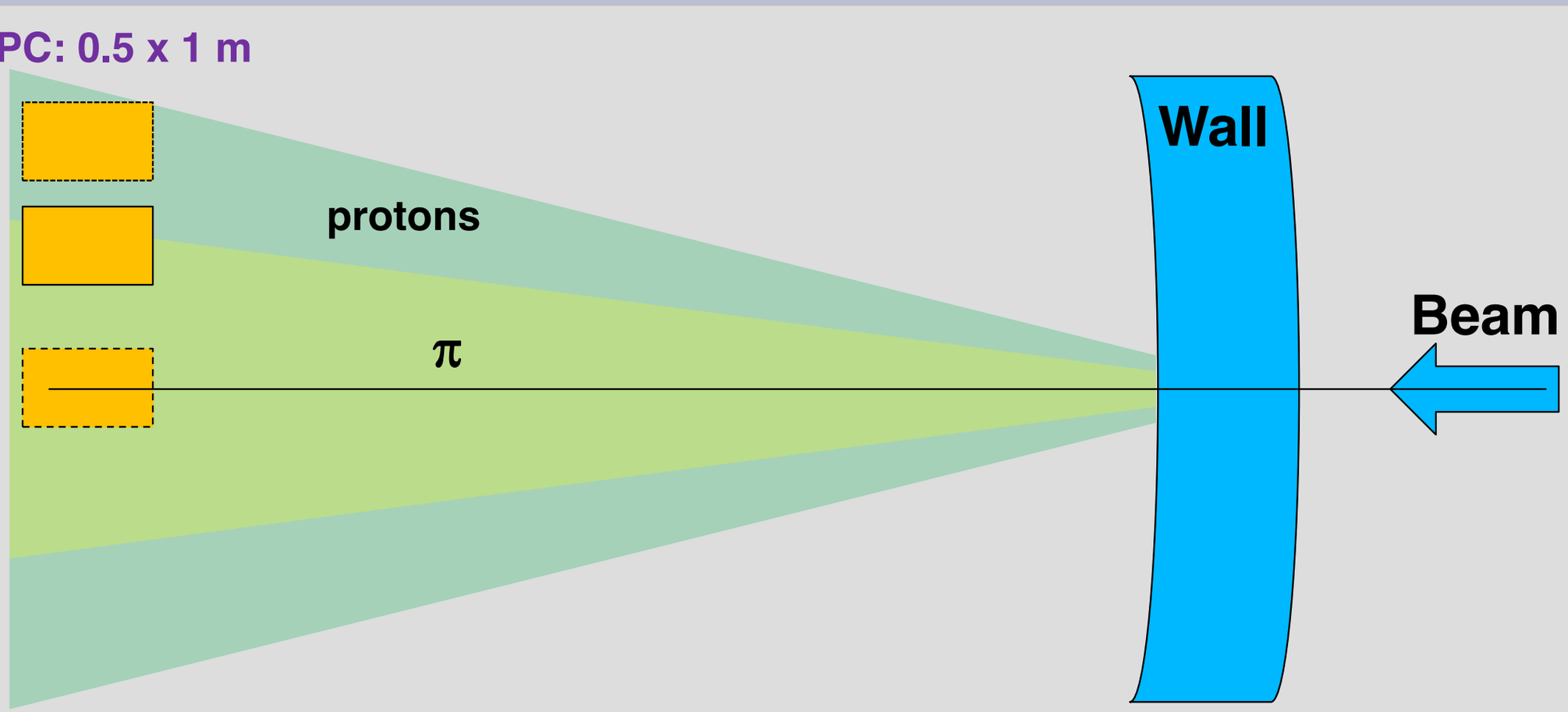
- Also took data with ~10 cm absorbers in beam path
  - steel, concrete
- Studying effects on particle fluxes and energies
  - particle momentum is reduced
  - relative proton yield increased
- Found that pi/p yield changes as a function of off-axis angle
  - Nuclear electric fields act as spectrometer?





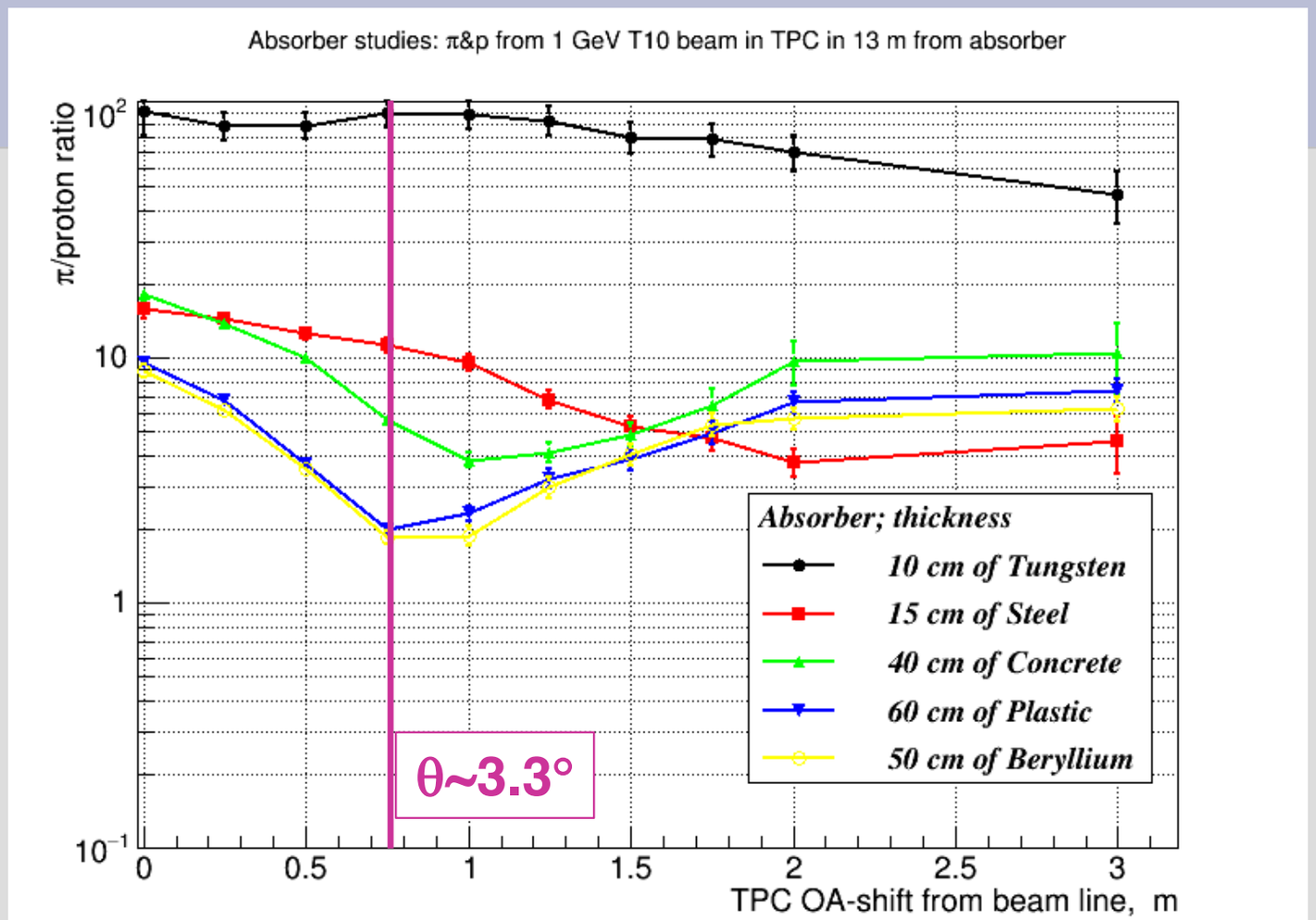


OA measurement



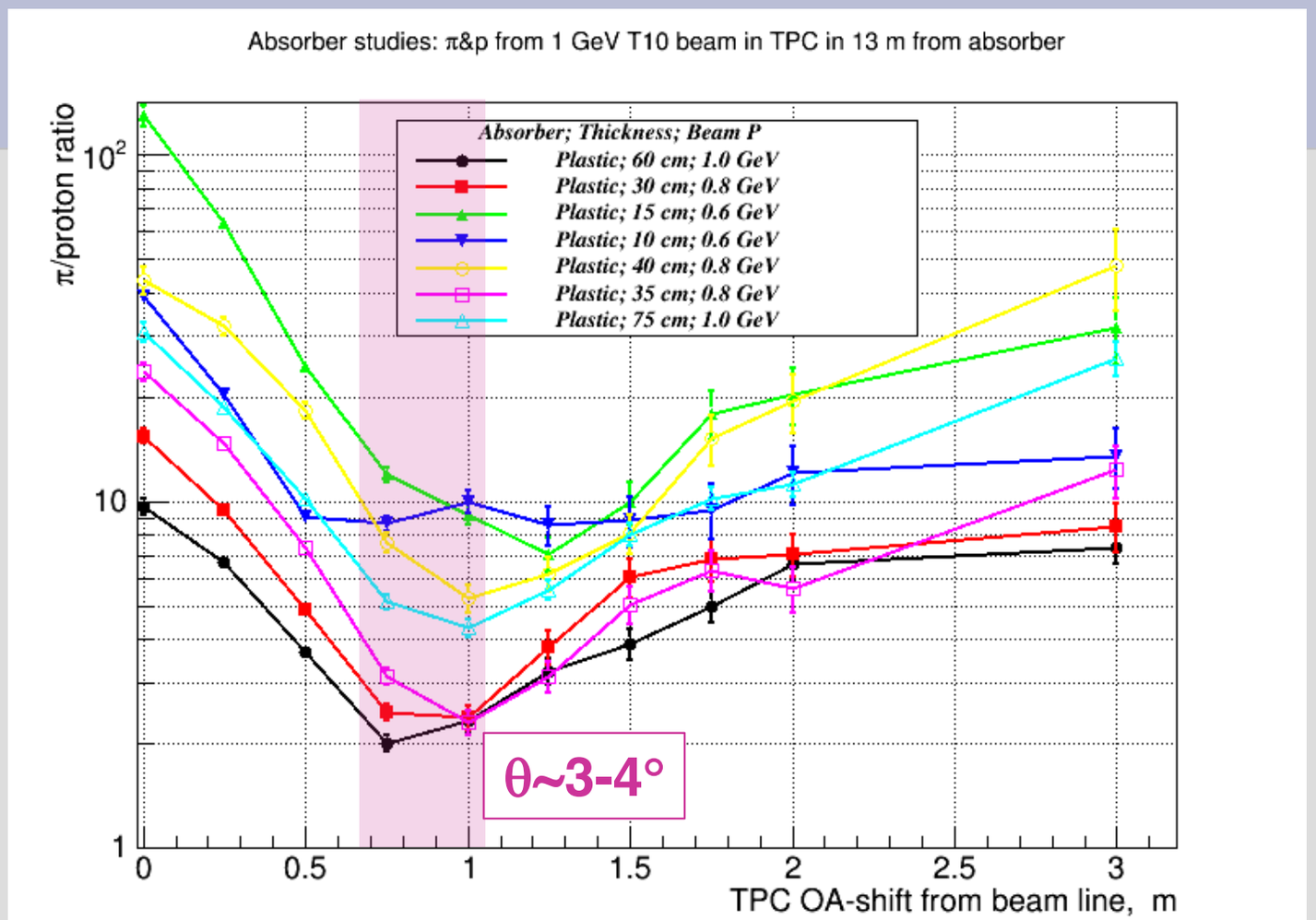
Moving TPC off axis we can probably benefit in pi/p ratio especially taking into account the fact that we don't need high intensity proton flux in the TPC

Pions/protons ratios vs absorbers



Bingo! We really have optimal position at OA ~ 3.3% (arctan(0.75/13))!

Pions/protons ratios in PS vs beam P

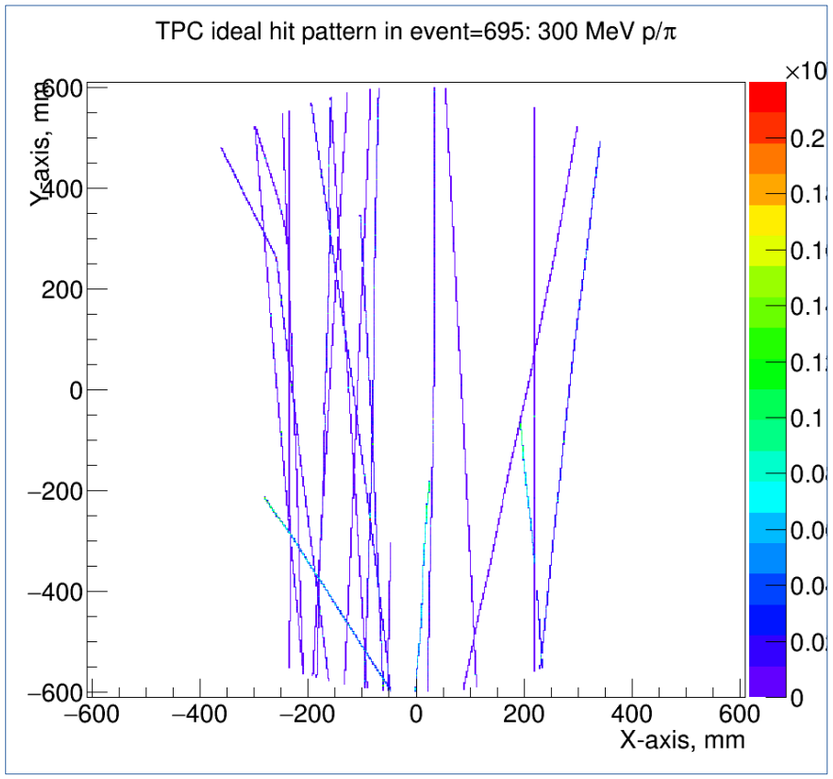


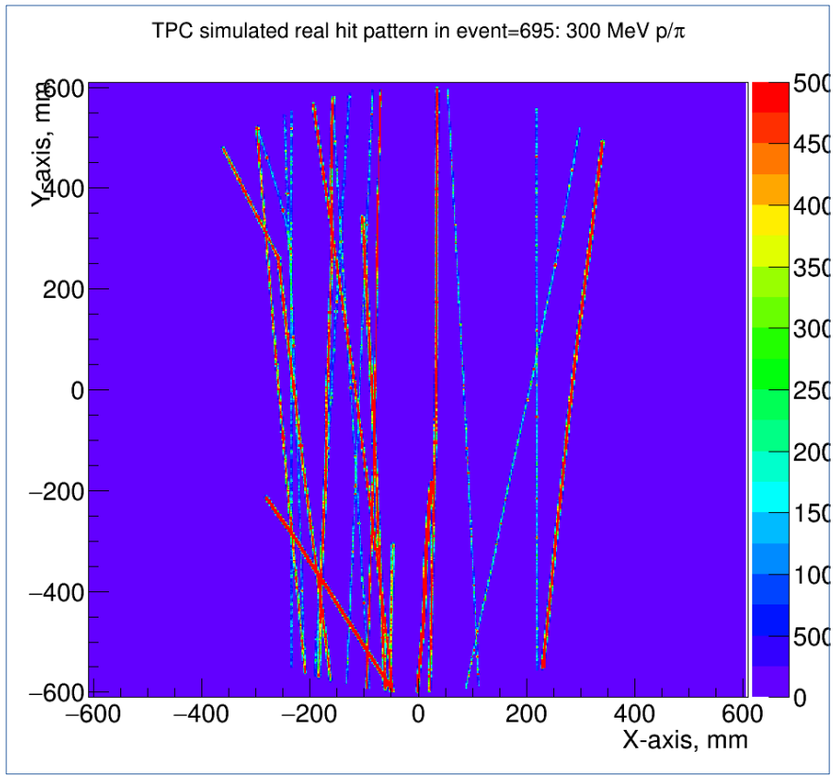
We really have optimal band at OA ~ 3-4°, depending of particular beam & absorber thickness

Progress in prototype simulation

MC Update

- On/Off axis ideal images running well.
- Some single particle multi track images created and sent to Warwick - More being generated.
- Simple single track truth completed – currently testing





What's the right reconstruction for νs in gas?

The Origins of TREx

The Natural Habitat

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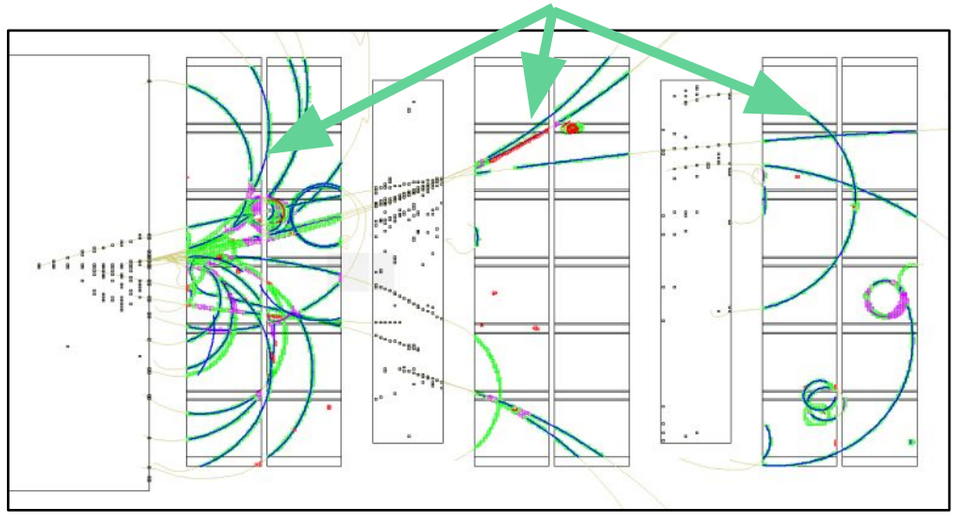
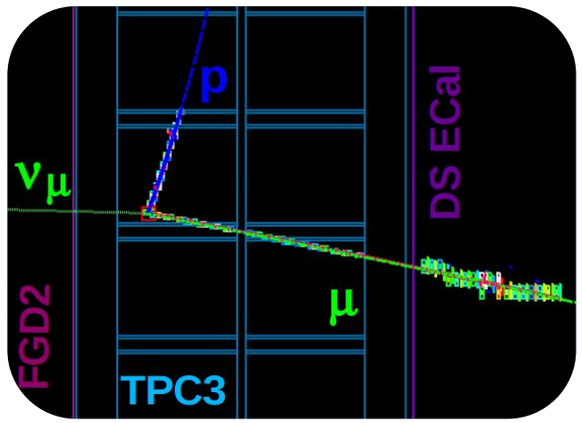
TREx was developed to cope with reconstructing vertices in the 3 large Argon-Gas TPCs in ND280

- Needed to be fully 3D i.e. no assumptions about forward going tracks or vertex position
  ⇒**Homogeneity & Isotropy**
- **As physics-agnostic as possible:** Lets analysers decide whether something is a vertex or a secondary interaction.
- Good reconstruction of delta-rays (distinguishing tightly curled/curved track from sharp kinks (potential nu-interaction)

T2K TPCs





Gas Interaction in ND280.
T2K Argonuts Group

How does TREx work with our CCD readout?

TREx for CCD Test Beam Images

Coming soon to an Accelerator near you!

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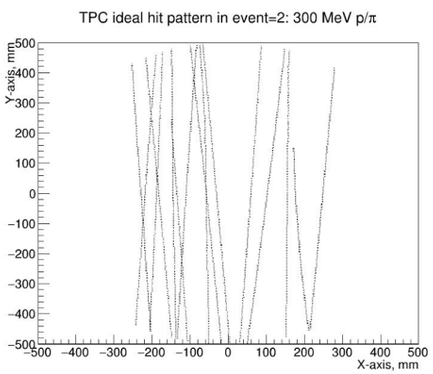
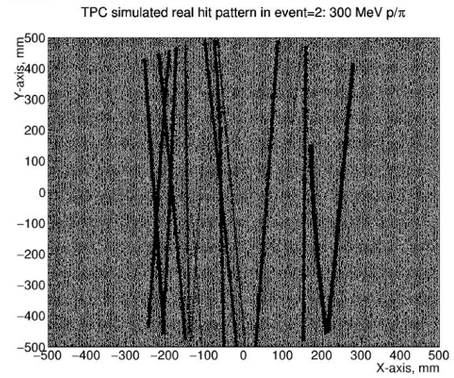
- For the upcoming Beam Test of the Prototype at CERN we have tried out TREx on 2D CCD images from the simulation:



ideal



realistic

- 2D means there lots of ambiguities for the reconstruction that we are attempting to solve by improving the tracking algorithms and the track-matching & merging.
- Beam density and high multiplicity are also a challenge but we are making steady progress to get us into a position where we can reconstruct real test beam data.

Using the TREx tracks

pi/p separation for MULTI TRACK sample

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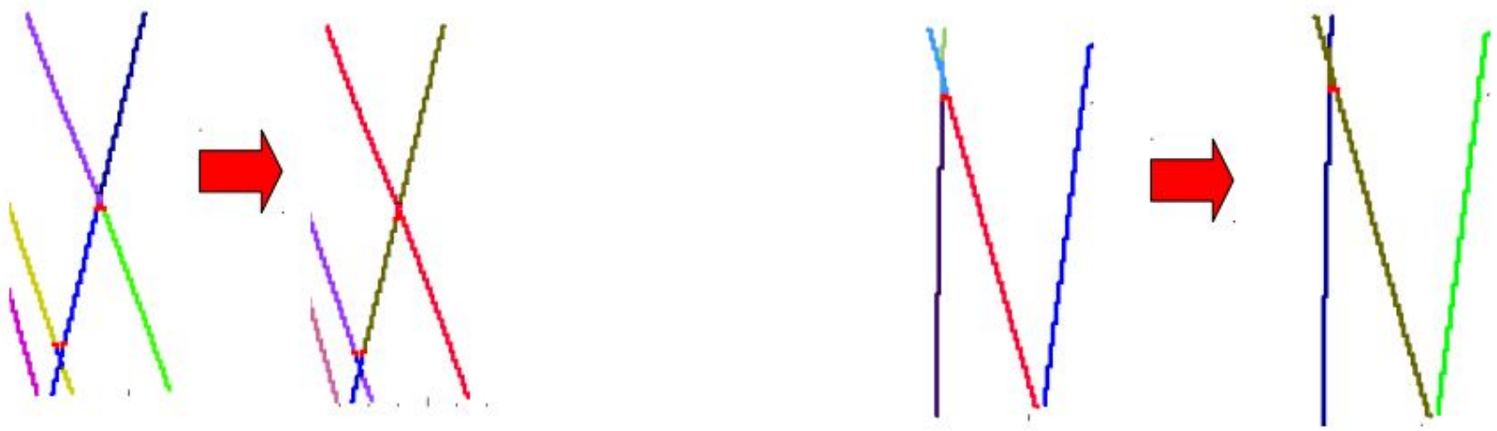
- For the MULTI TRACK sample and realistic multiplicities things get much more complicated since the dE/dx is affected by clustering mistakes and we have many co-linear tracks, that are hard to separate, competing for hits.
- Have been fine-tuning the pattern recognition to improve these pathologies and have introduced **new tracking and matching routines especially for the PRD data**:



Example of TREx successfully merging tracks in 2D

(this is in constant development as we are fixing more and more pathologies)

First pass of simple PID

pi/p separation for MULTI TRACK sample

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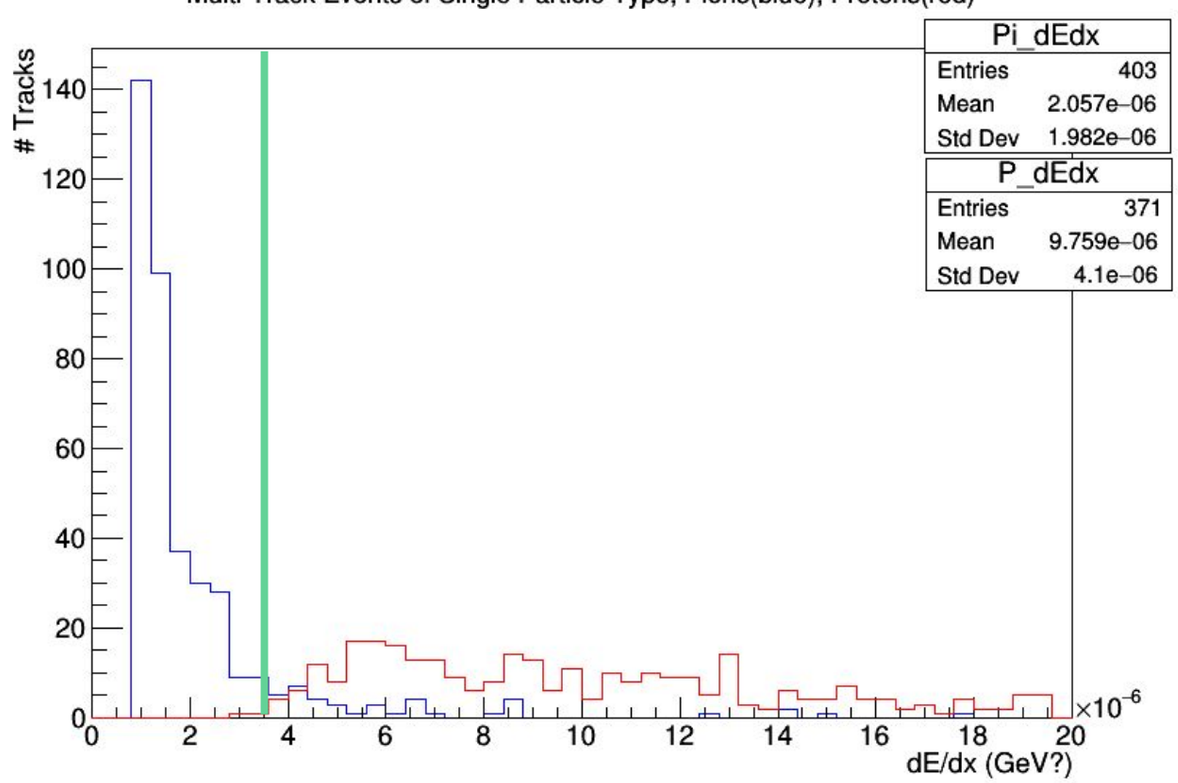
- Despite numerous pattern recognition challenges, it looks like we are still getting good separation and we can try to use a **pion veto with a cut around ~3.5 GeV** (units from ideal simulation):
- We are currently validating this in order to produce **PID Efficiency & Purity** predictions.



Looking forward

- Building HPTPC prototype with CCD optical readout
- Will perform hadron scattering in test beam
- Hardware for prototype is progressing well
- Software is working, for ideal cases
  - TREx adapted for use with optical (CCD) readout
  - Will tune with hardware once it is working
  - Next step is to estimate signal efficiency with automated analysis
- Have measured test beam fluxes for use in hadron scattering measurements

Thank you for your attention!

ご清聴ありがとうございました

水戸の梅の花

Thanks to Z Chen-Wishart, P Denner, J Haigh, J Monroe, Yu Shitov, S Valder, M Ward

MEN WANTED

for hazardous journey, small wages, bitter cold, long months of complete darkness, constant danger, safe return doubtful, honor and recognition in case of success.

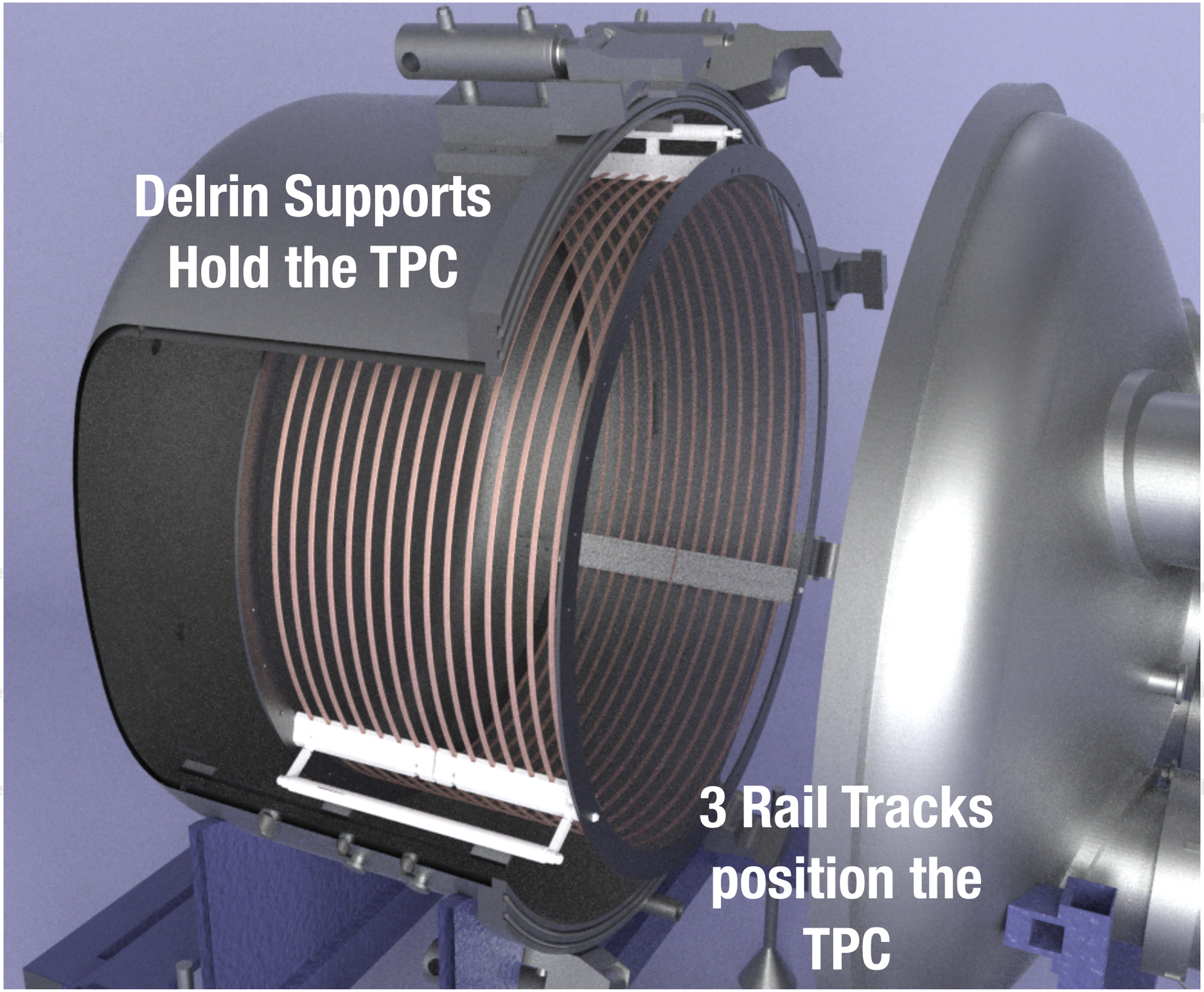
Ernest Shackleton 4 Burlington st.

MEN—Neat-appearing young men of pleasing personality,

HPTPC wish list

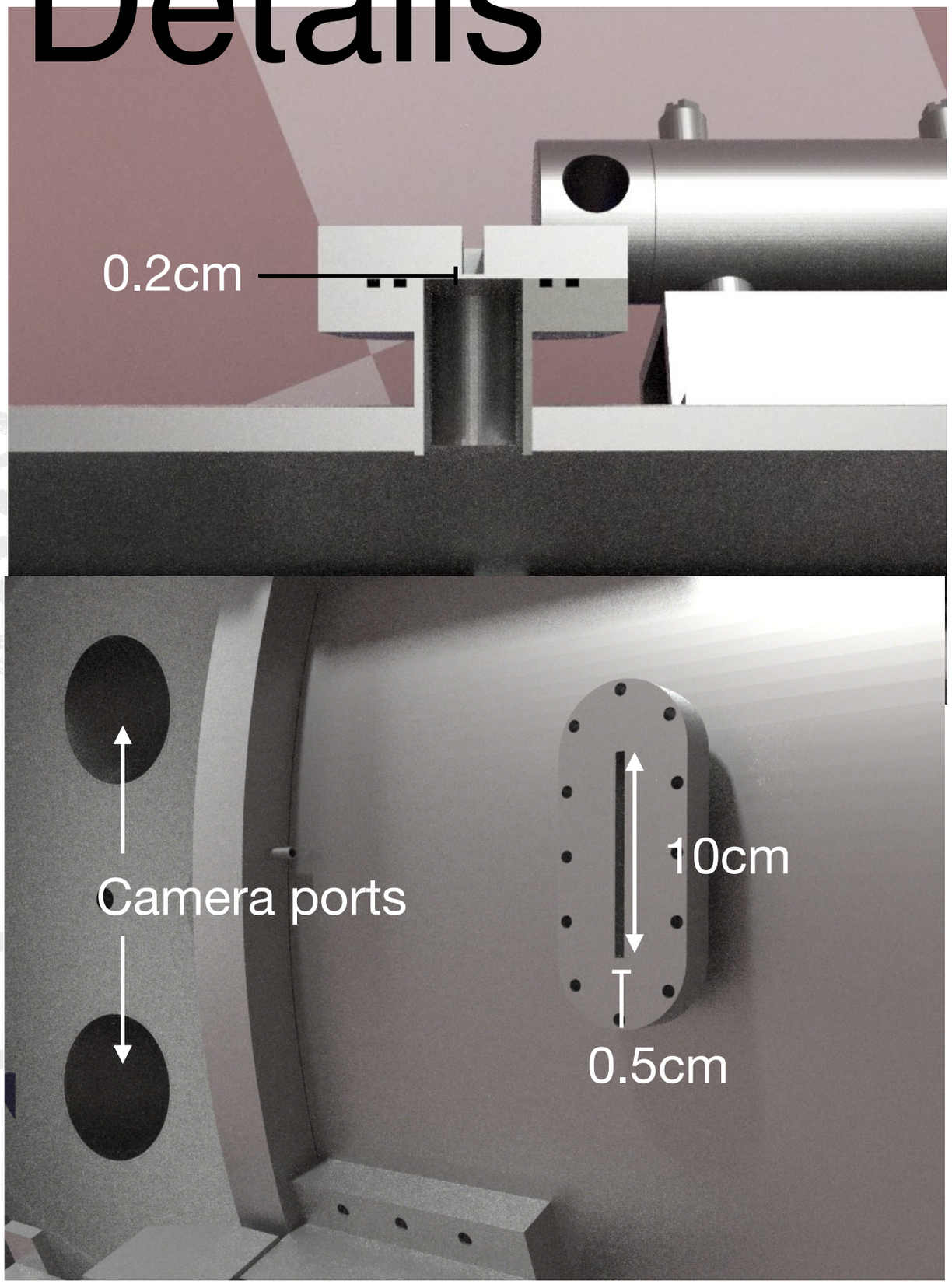
- ~4π coverage
- Magnetisation
- 3D reconstruction
- Excellent PID
  - high purity nu_e sample is possible
- Nuclear target flexibility
- Low momentum particle detection threshold
  - Good for model discrimination, generator tuning
- Technology synergy with other areas/fields

TPC Mounting

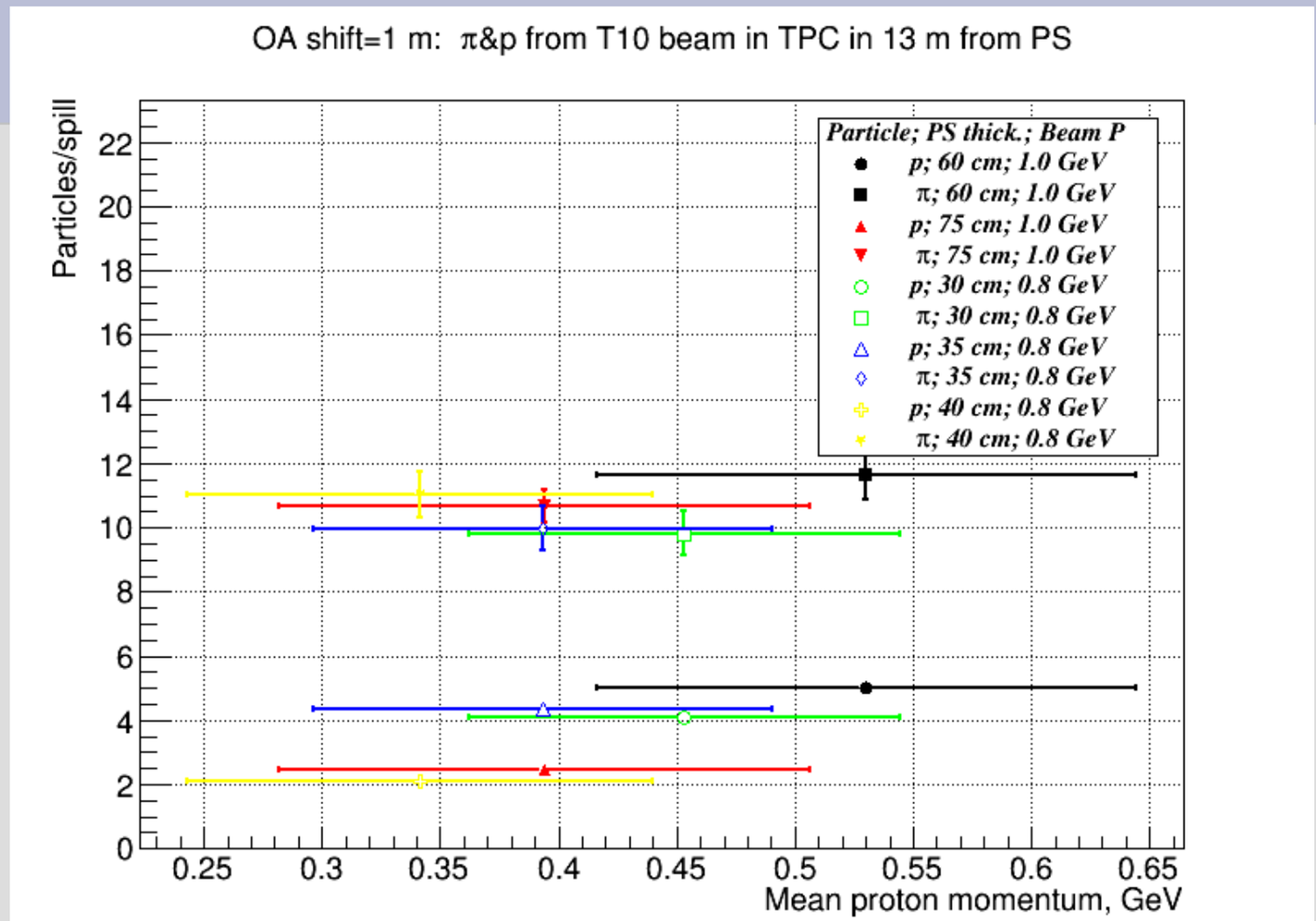


Vessel Details

- Beam window
  - Custom Aluminium flange
  - 10.0 x 0.5 cm cross section
  - 0.2 cm thickness
  - Have option to use opposite side of the detector for off axis configuration
- Camera ports
  - 6 x 22cm ID ports
    - 4 ports in quadrants
    - 2 ports on central axis face to face
  - Allows single camera readout of whole TPC, or multi-camera readout



P&pi spectra reduced by PS



In best cases we have ~ 10 pions vs 5 protons for proton in [0.3-0.5] range. Any further attempt to go to lower energy gives sharp fall of protons
Horizontal bars – RMS of proton momentum spectra

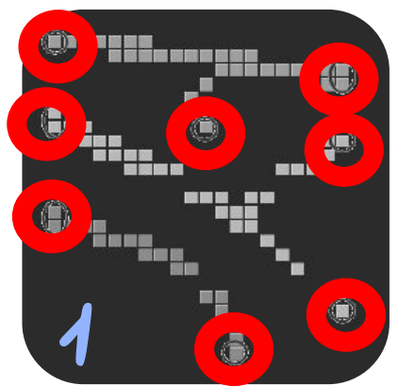
How does TREx work?

The Pattern Recognition

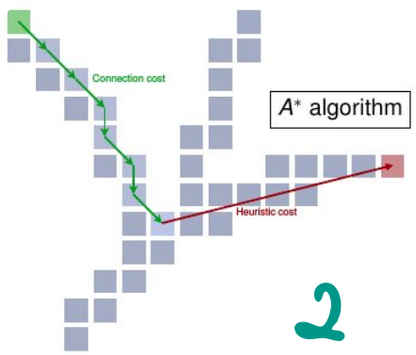
The Guts of TREx

TREx uses the A* Algorithm for pathfinding

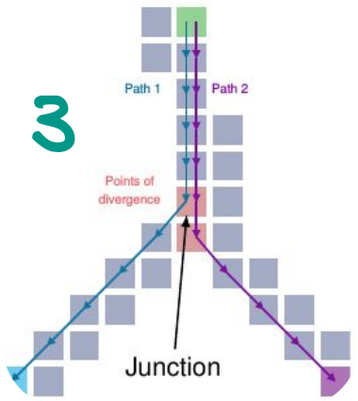
- Paths are formed according to connection cost factors between pattern edges.
- Diverging paths are used to identify junctions.
- Kink-finding can distinguish hard scatters from curved tracks



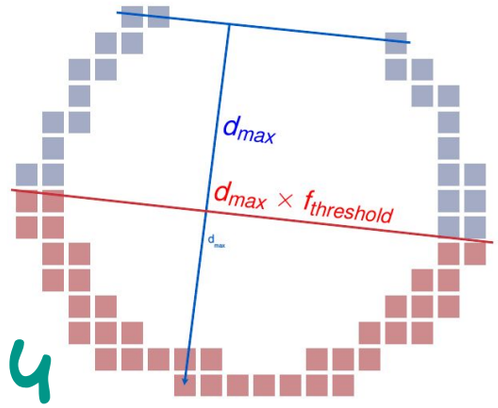
Edge detection



Path finding



Junction finding



Kink finding

Learn more: TREx tutorial

http://www.t2k.org/nd280/physics/xsec/subgroup/TPCInteractions/meetings/gas-interactions-2016-06-17/eddy-patrec-tutorial-2016-17-06/view

Why does the name TREx sound familiar?

TREx unleashed

Into the Wild

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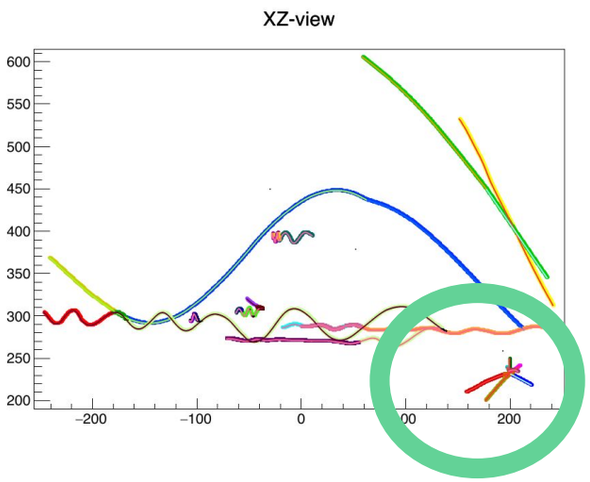
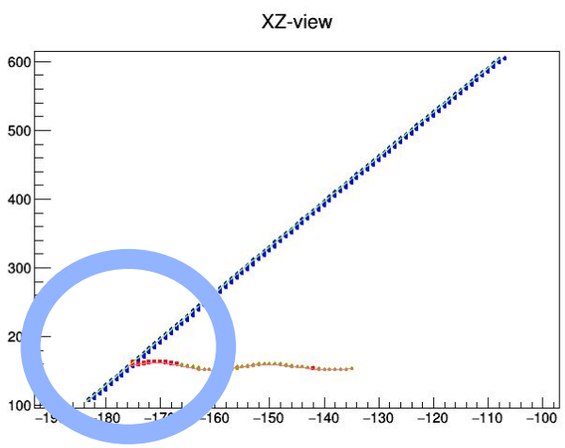
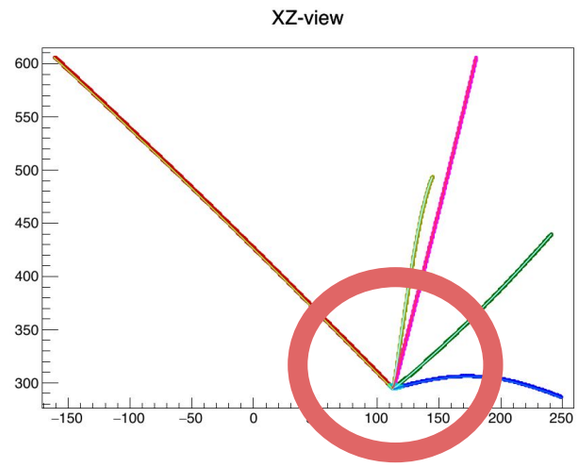
- The package is **now standalone** and independent of T2K software.
- **DUNE** is considering using HPTPC technology (or a hybrid) as its **Near Detector** option so Warwick has been working on reconstructing the near detector simulation with TREx.
- An often mentioned concern with HPTPCs are the large backgrounds from heavy materials surrounding the detector, so **good reconstruction is key.**



Reconstructing genuine gas interaction vertices in the presence of such backgrounds is paramount!



Recovery of through going Tracks from paths that got ‘broken’ by delta ray emission, using likelihood Matching & Merging



The pattern recognition produces Junctions that can be used to identify true Vertices in the gas.

How does it work with our CCD readout?

dE/dx Calculation

= Total Charge / Track Length

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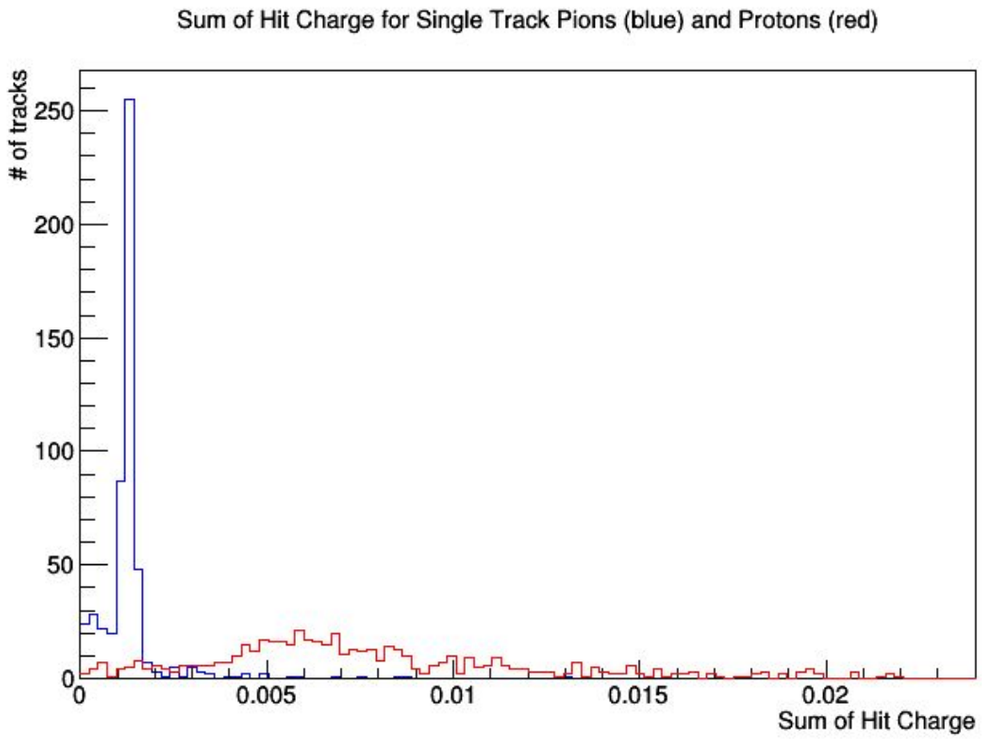
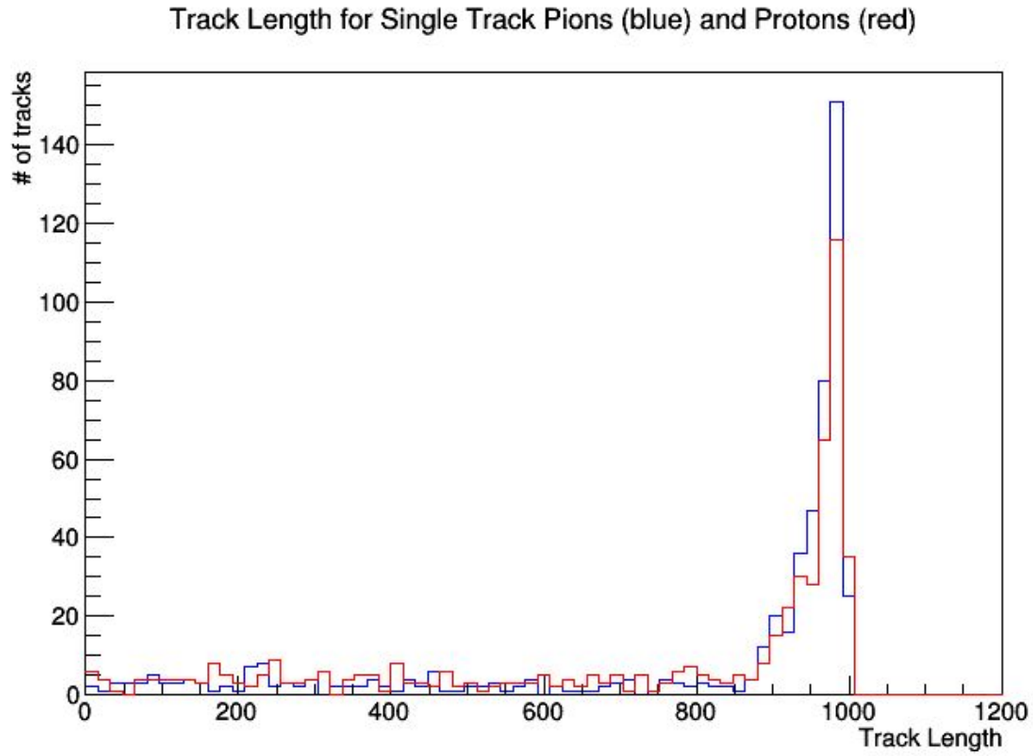
- We are averaging the total charge over the length of the track in order to do proton and pion PID.



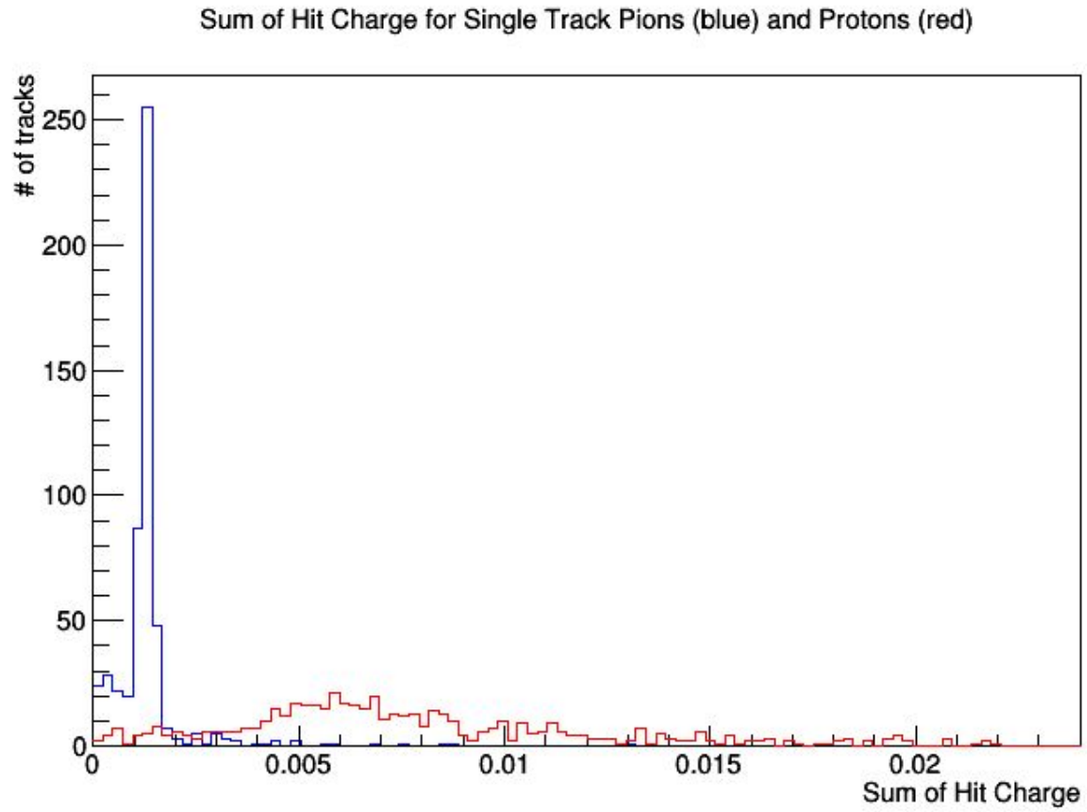


Using the TREx output for data analysis

pi/p separation for SINGLE TRACK sample

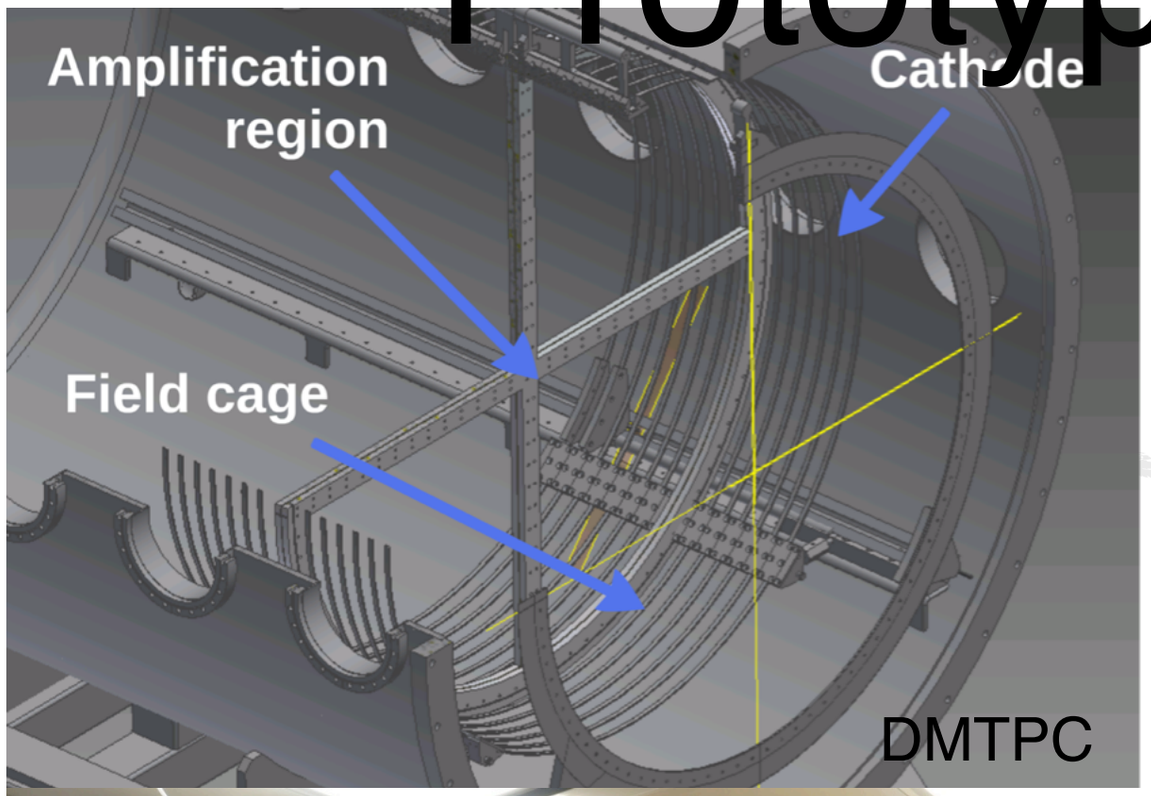
WARWICK
THE UNIVERSITY OF WARWICK

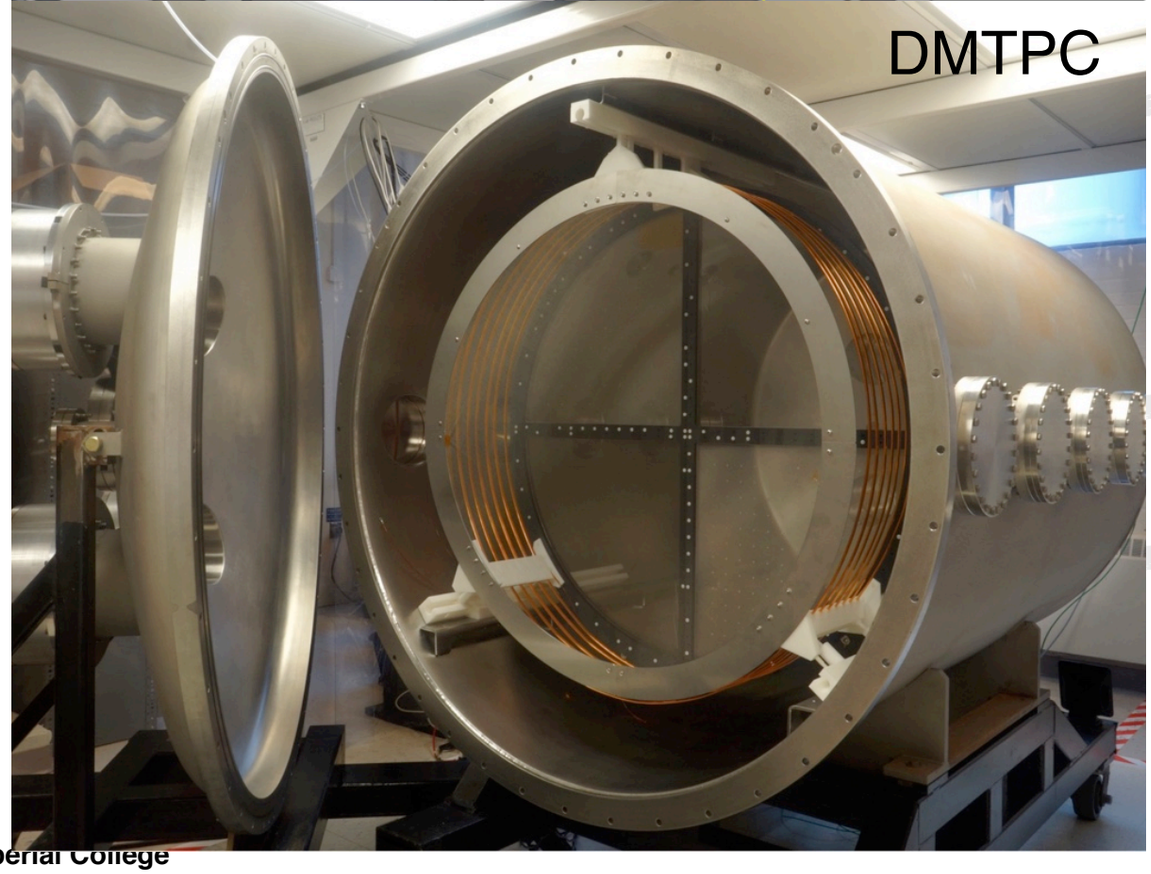
- For SINGLE TRACKS where TREx always performs perfectly **(unrealistic case!)** we can achieve a very good separation:



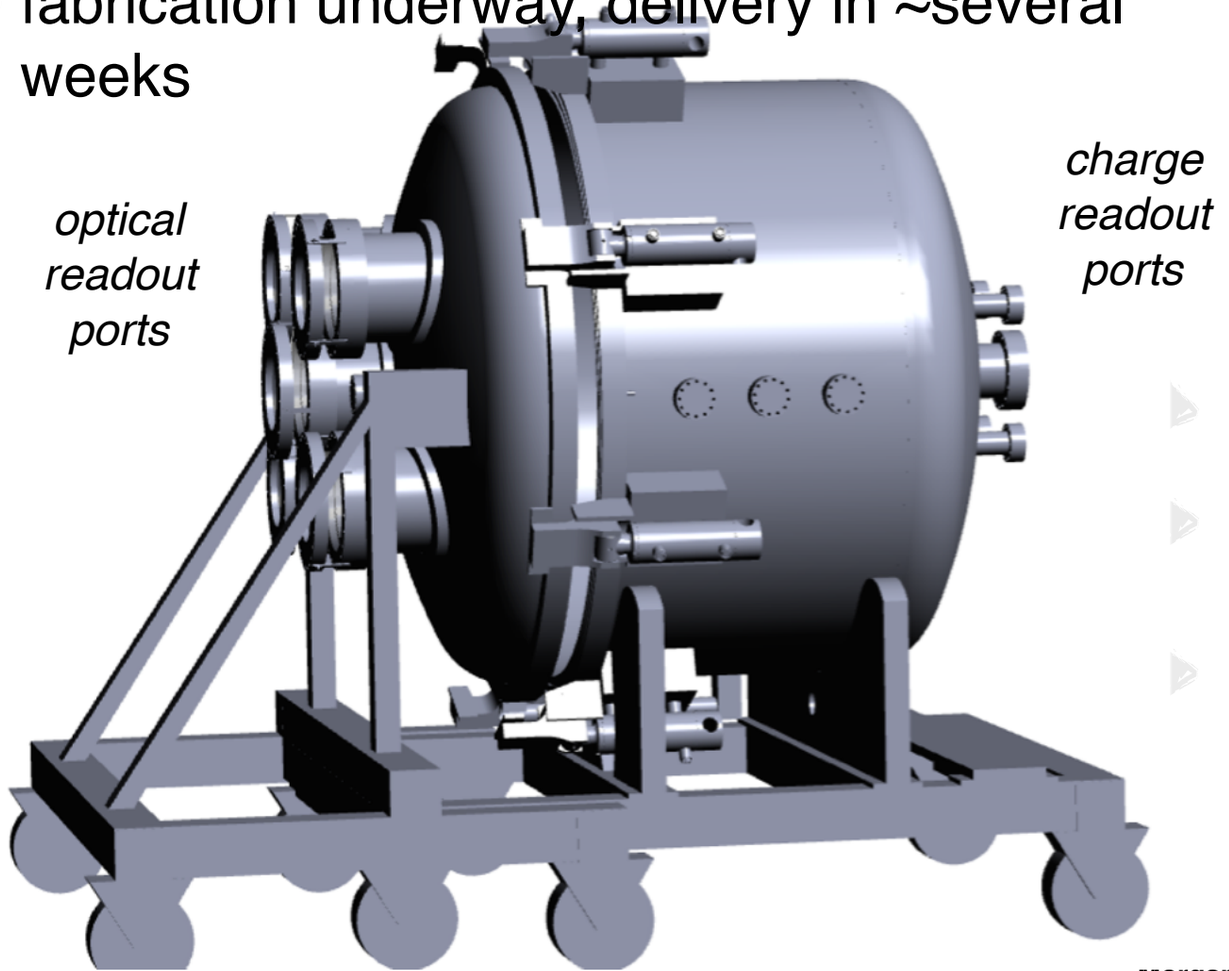
Prototype HPTPC

Imperial
Lancaster
RHUL
Warwick





- UK HPTPC prototype design based on DMTPC 1m3 detector
  - current design is mesh amplification region, plan to also use MPGD (e.g. micromegas)
- HPTPC vessel and gas system under construction by Cryovac (ES)
  - fabrication underway, delivery in ~several weeks

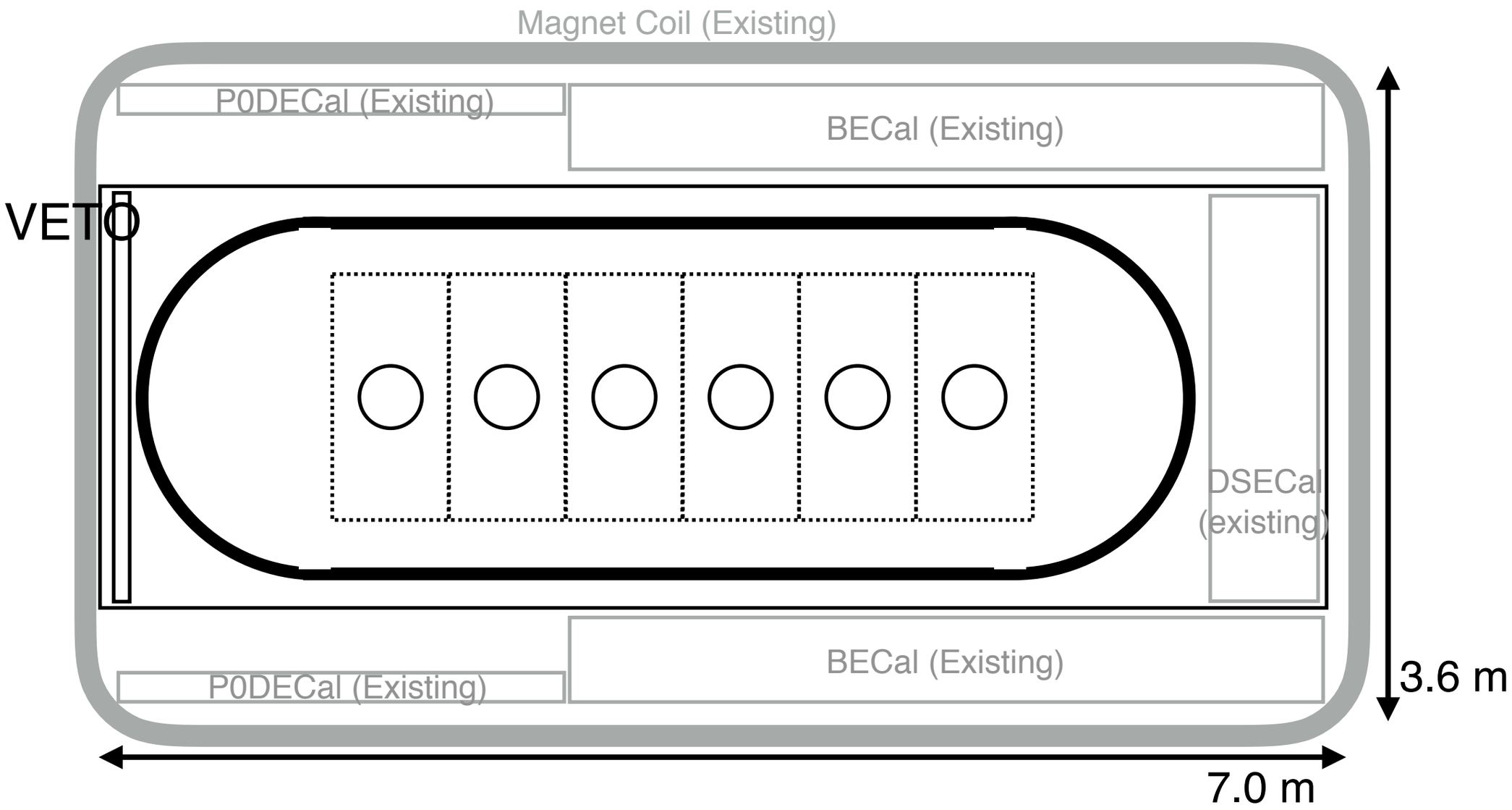


Looking toward a neutrino detector

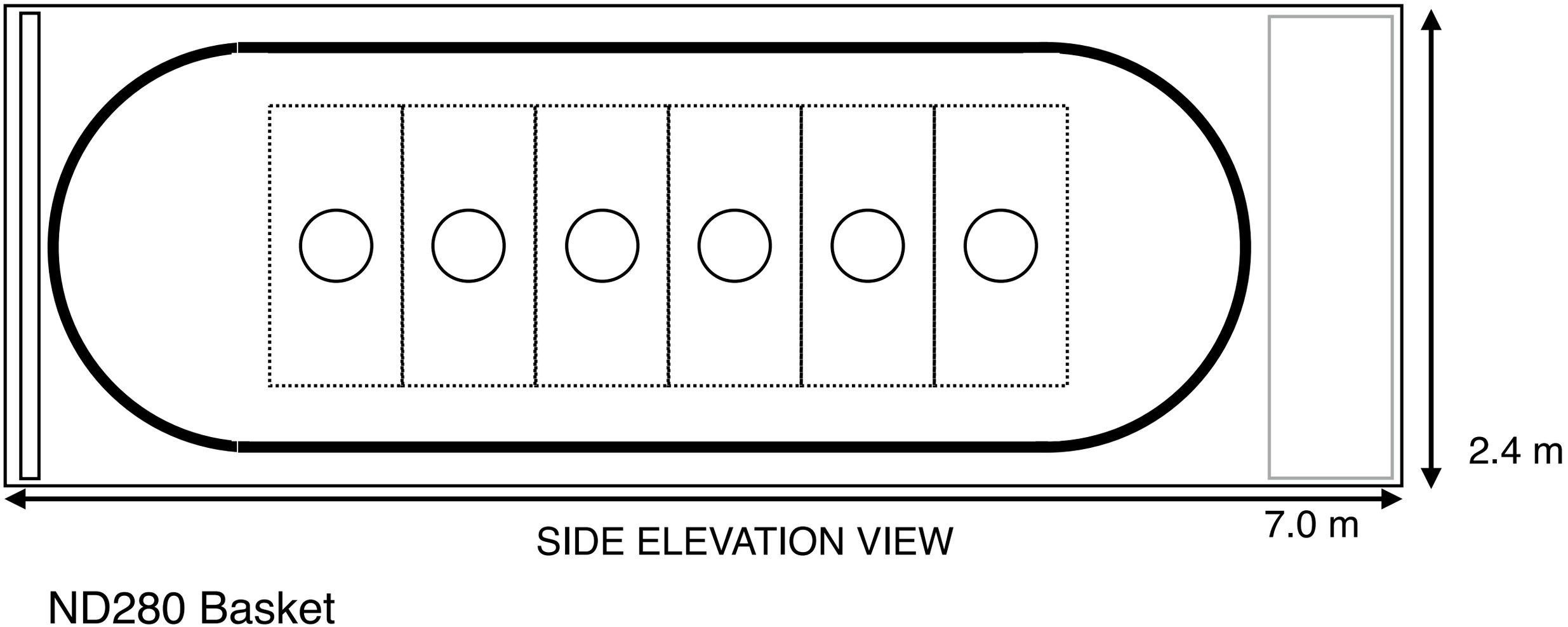
- Many possibilities for detector systems that surround HPTPC
  - Is just ECal the right choice?
  - Detector elements need to be tried out, optimised

- Next slides: cartoons of what optical HPTPC in ND280 detector hall could look like.

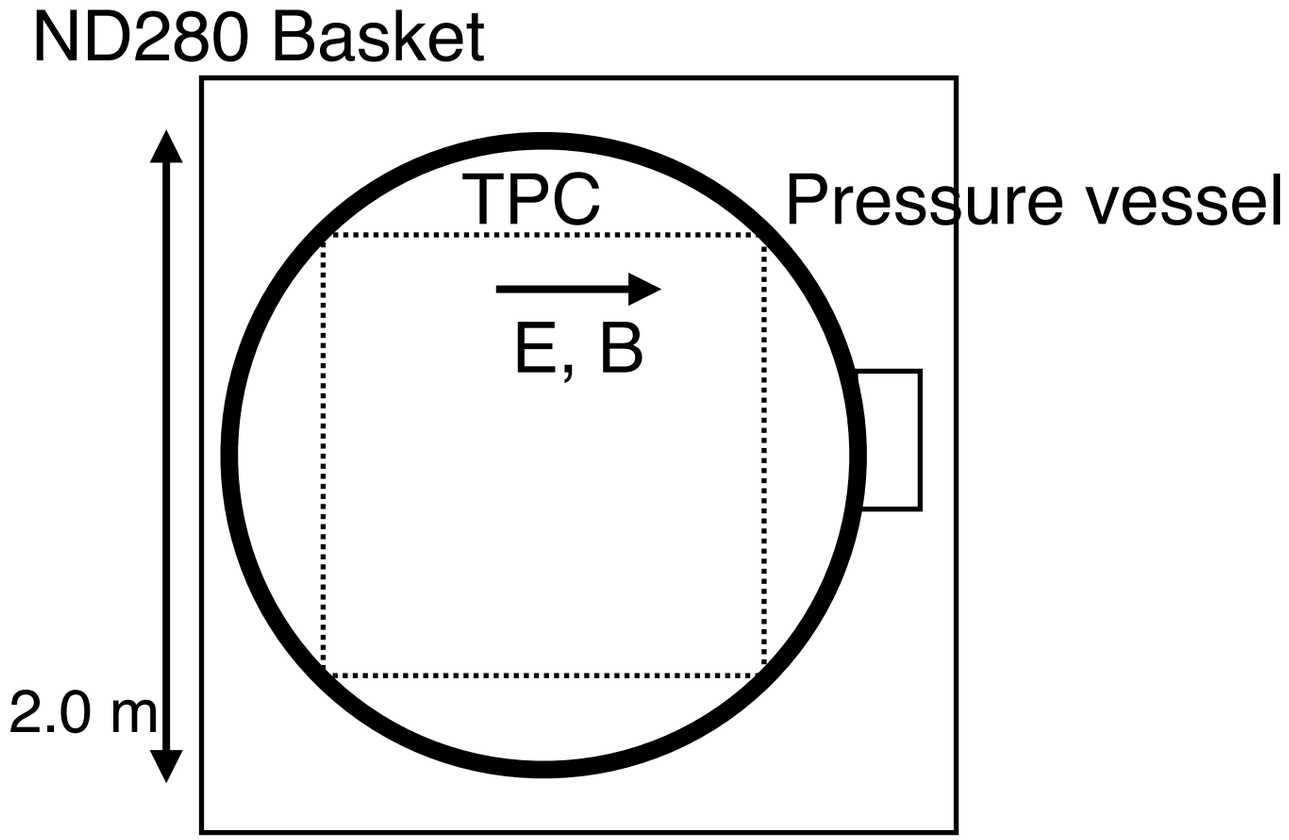
ND280 HPTPC



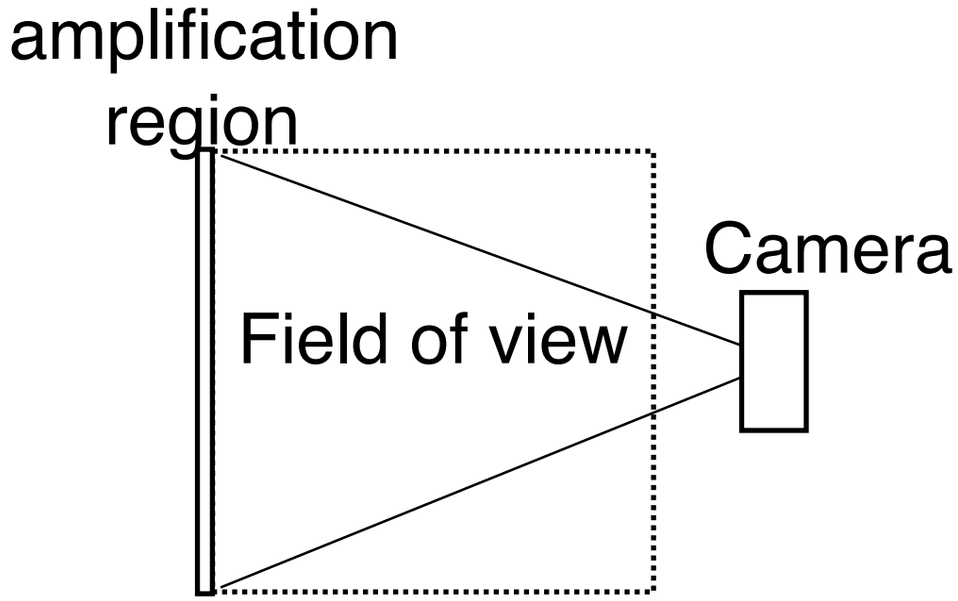
SIDE ELEVATION VIEW



SIDE ELEVATION VIEW



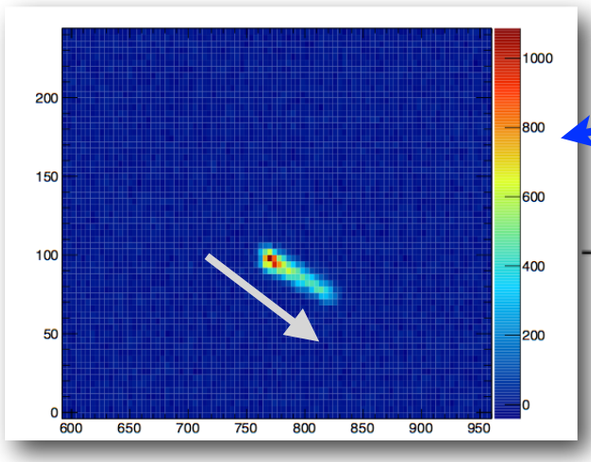
END ELEVATION VIEW



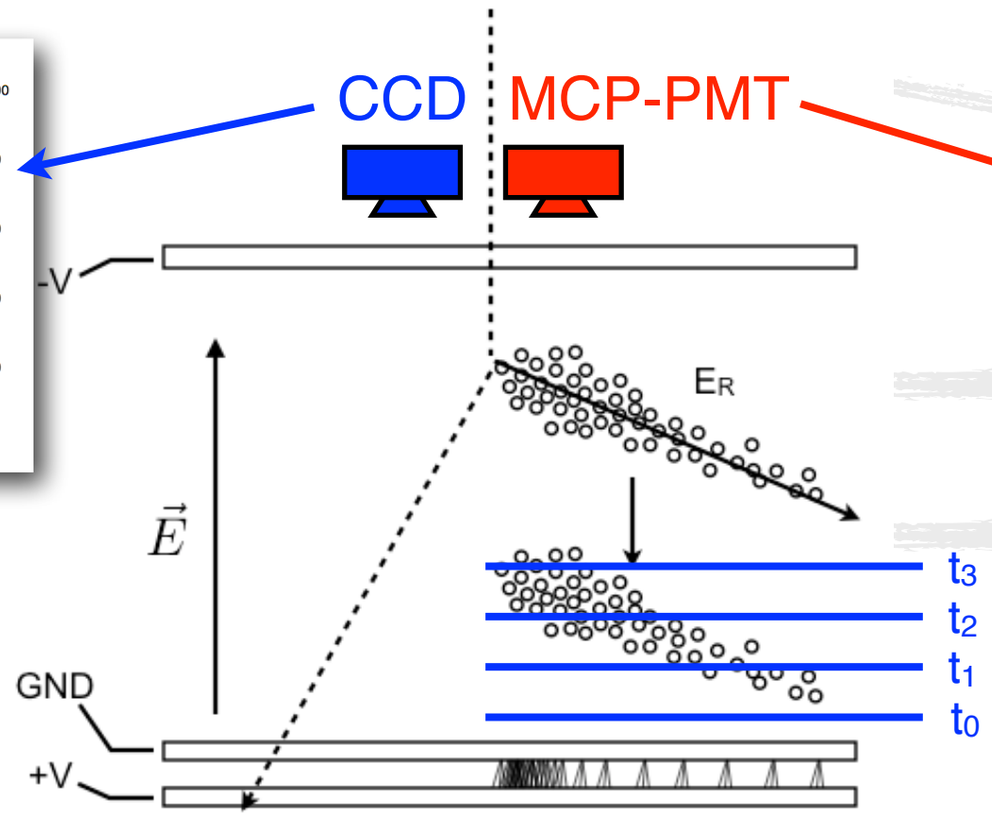
END ELEVATION VIEW

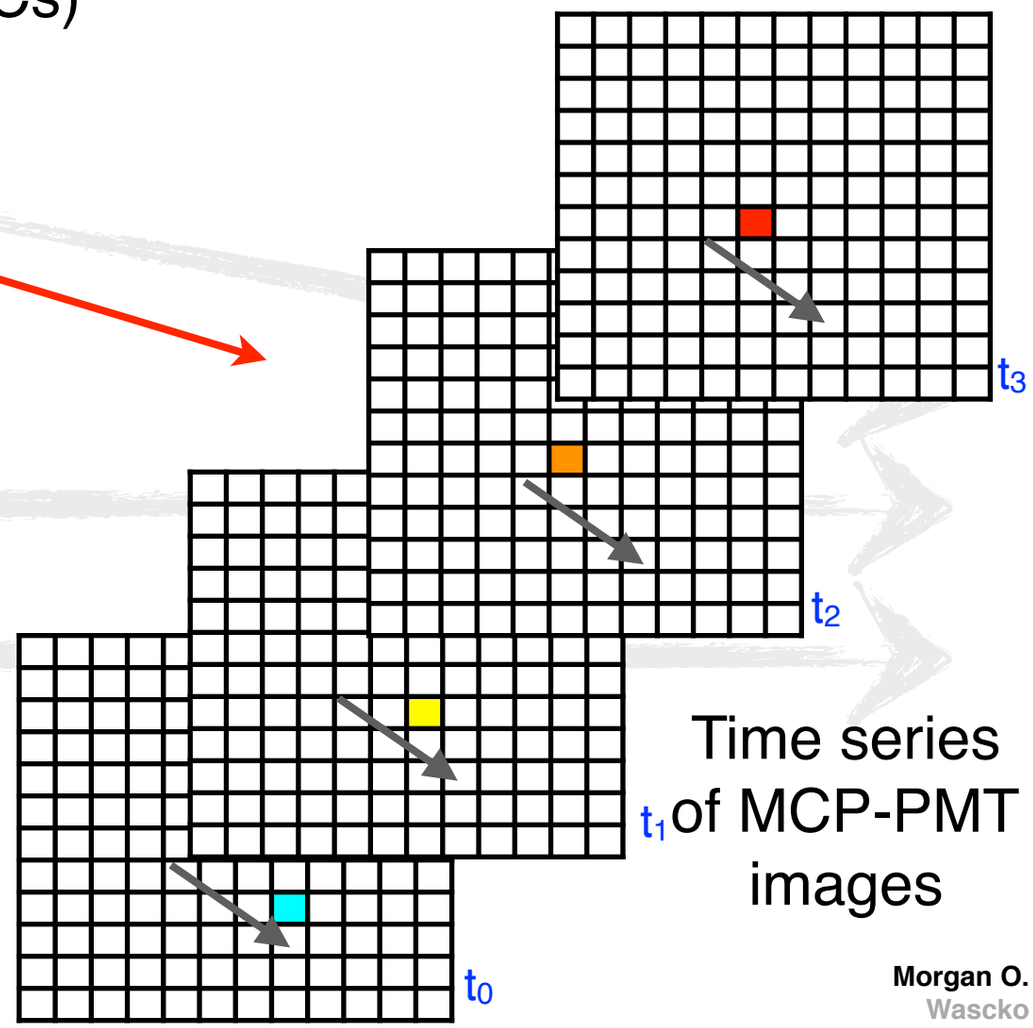
Hybrid optical readout

- **Can we establish 3D tracking with only optical HPTPC readout?**
- Build hybrid system of high spatial resolution CCD with fast timing optical system (e.g. MCP-PMT) to reconstruct tracks in the third (drift) dimension
  - High-res, slow CCD readout as described previously
  - Combine with low-res, FAST MCP-PMT (or MPPCs)



High resolution CCD image





Time series of MCP-PMT images