The 18th International Workshop on Next generation Nucleon Decay and Neutrino Detectors

NNN17

平成29年 10月 26日

R&D Towards an HPTPC Neutrino Detector

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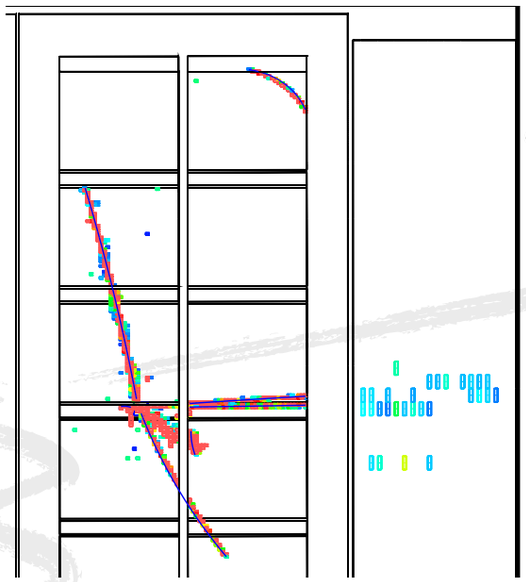
Outline

- Introduction to HPTPC
  - Physics motivation and initial studies
- 1m3 HPTPC prototype work
  - Hardware overview & status
  - Preparation for CERN beam tests
- Fermilab HPTPC R&D using ALICE TPC modules
- Conclusion

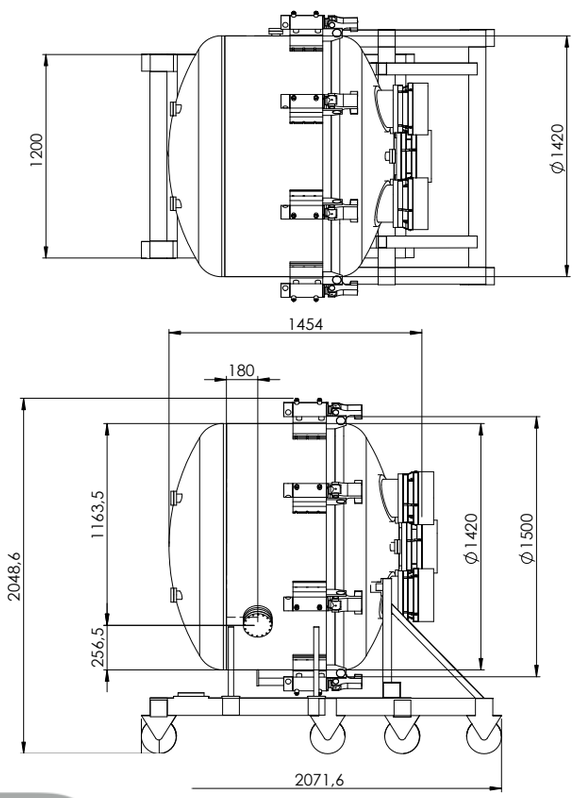
HPTPC overview

- Neutrino detector wish list:
  - ☑ ~4π coverage
  - ☑ Magnetisation
  - ☑ 3D reconstruction
  - ☑ Excellent PID
  - ☑ Nuclear target flexibility
  - ☑ Low momentum particle detection threshold
  - ☑ Technology synergy with other areas/fields

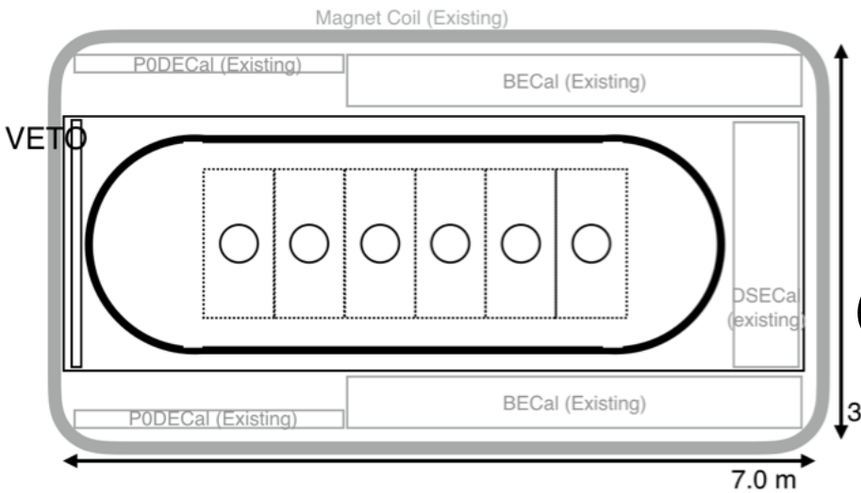
➡HPTPC has it all!



Pip Hamilton's thesis: analysis of gas interactions in existing T2K TPCs



Schematic of 5 bar pressure vessel



Cartoon of HPTPC in ND280

(0th order design: simplest pressure vessel possible)

HPTPC Event rates

CC-inclusive interactions per 10^{21} POT

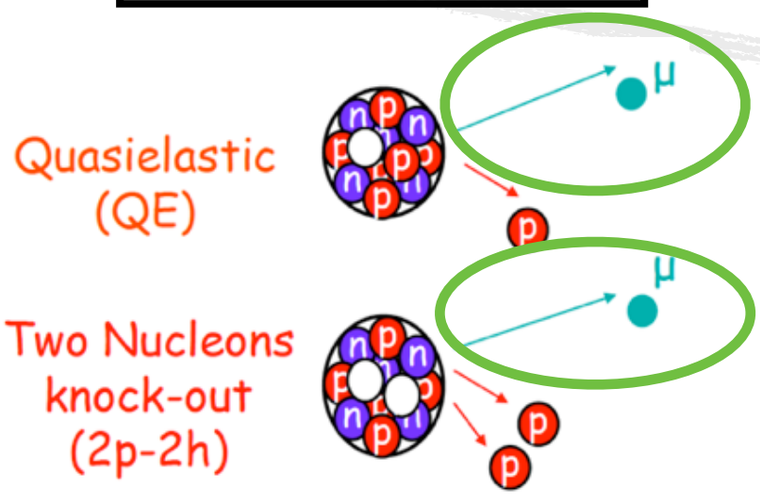
Gas	mass, 10 m^3 at 10 bar	J-PARC (0.6 GeV)	FNAL (2-3 GeV)
He	16.4 kg	1.10E+03	3.76E+04
CH_4	65.6 kg	4.39E+03	1.50E+05
Ne	82.8 kg	5.50E+04	1.88E+05
Ar	163.8 kg	1.09E+04	3.76E+05
CF_4	362. kg	2.42E+04	8.28E+05
CO_2:N_2	174. kg	1.17E+04	3.99E+05

(These J-PARC and FNAL numbers were calculated in a consistent manner.)

Complementary approaches

~belt & braces~

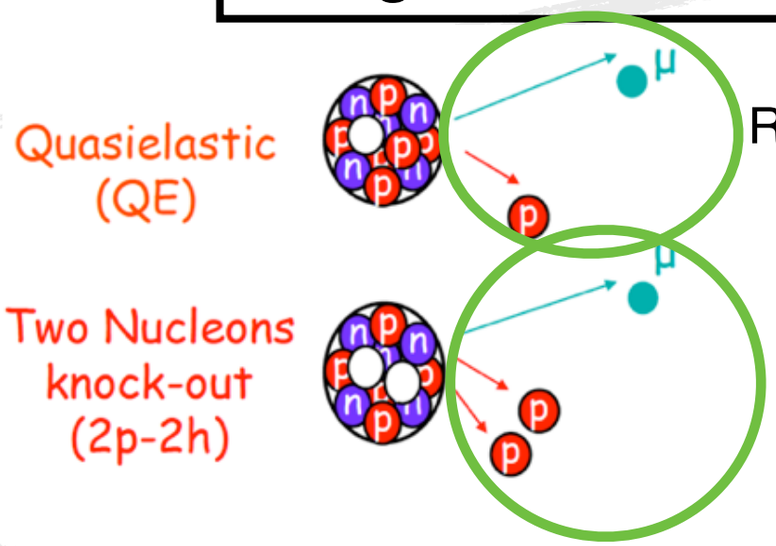
Water Cherenkov



Resolve charged lepton partners. Filter out recoil hadrons.

- Same observable as far detector
  - Same target nuclei
- Relies on model
- Gd allows neutron tagging
- E61 approach: integrate out the model dependence
  - use off-axis effect to study FD observables as function of true neutrino energy

Fine grained detectors



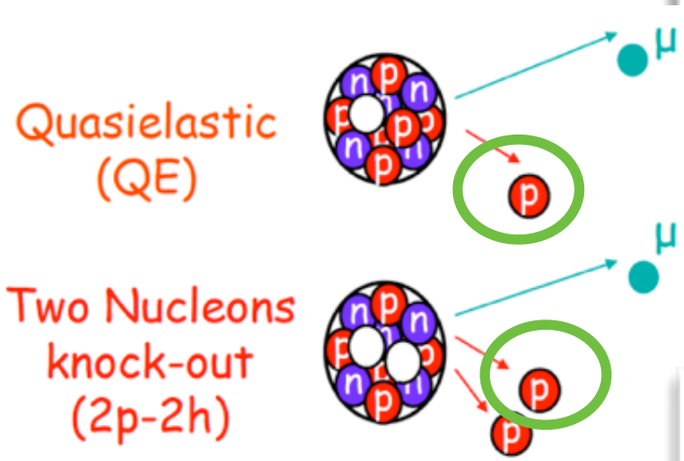
Resolve as much as possible. Compare detailed information to models.

- More info than far detector
  - Can use multiple target nuclei
- Additional info allows more model testing
  - allows/requires close coordination with theory community
- HPTPC approach: reduce detection thresholds as far as possible
  - Maximise usable information

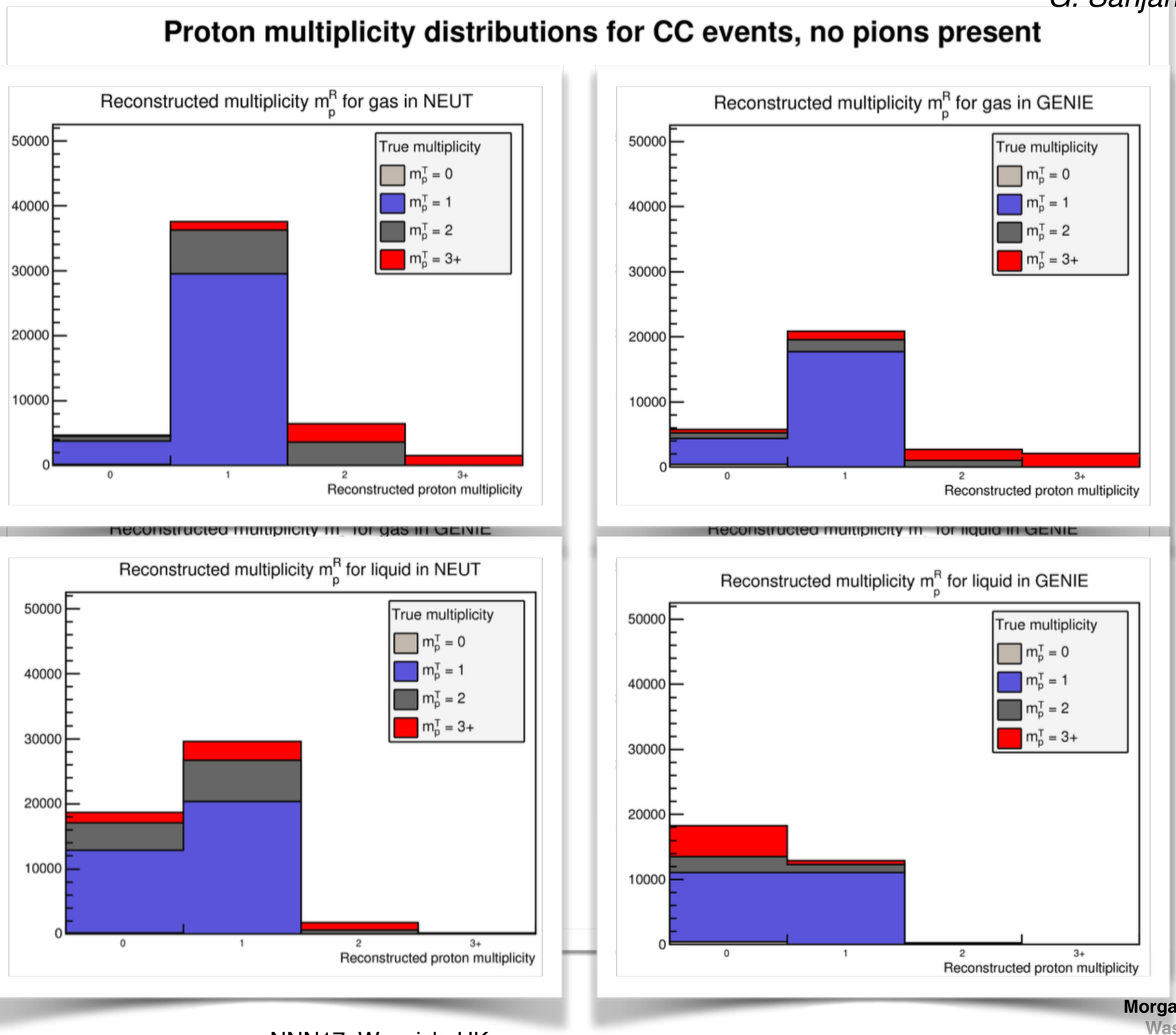
Proton multiplicity studies

G. Sanjana

True proton multiplicity
m^T_p

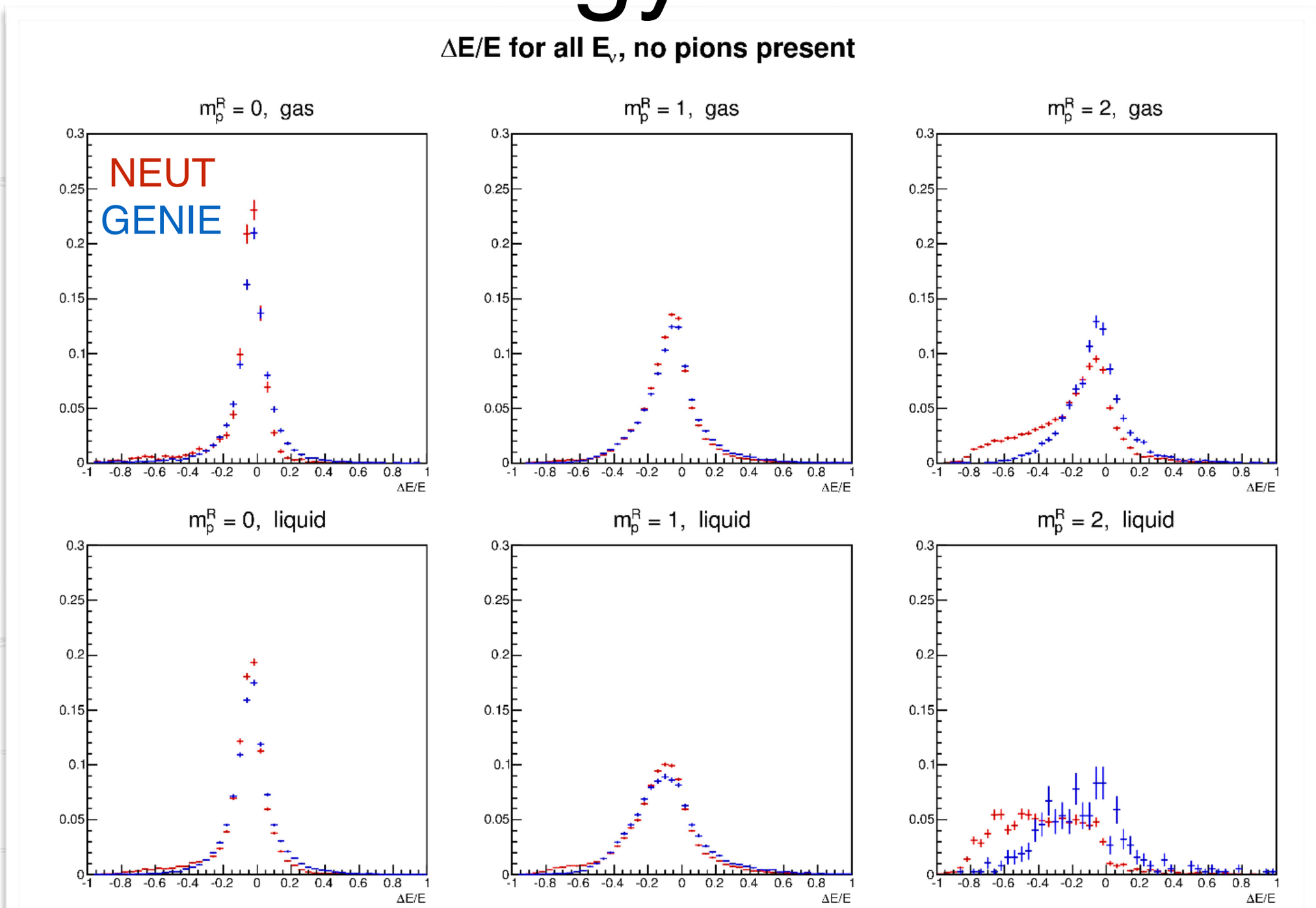


reconstructed proton multiplicity m^R_p



Neutrino Energy Reconstruction

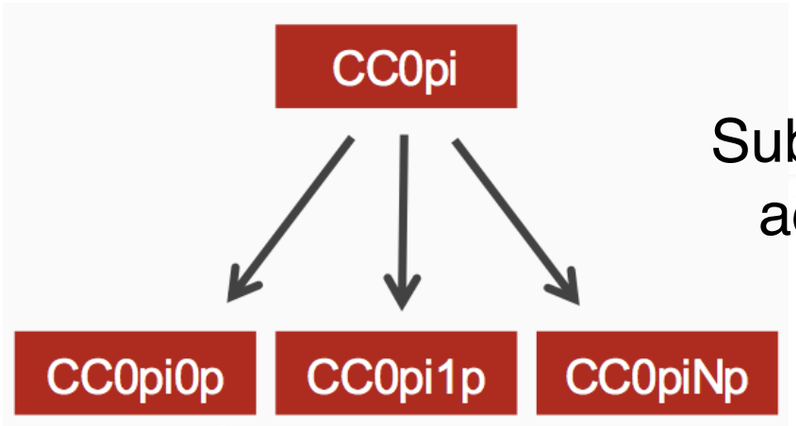
G. Sanjana



Generator-level studies of neutrino energy bias (kinematic recon)

Improved Analysis Techniques

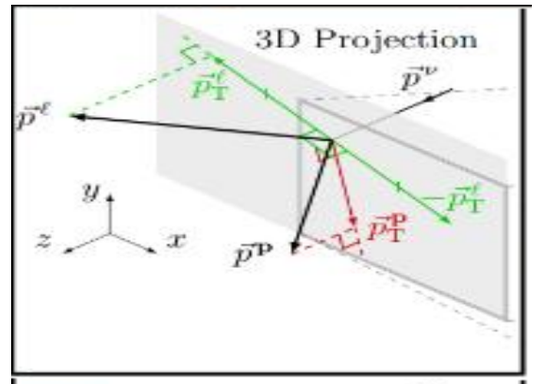
W. Parker



Subdivide neutrino event samples according to proton multiplicity

Single Transverse Variables

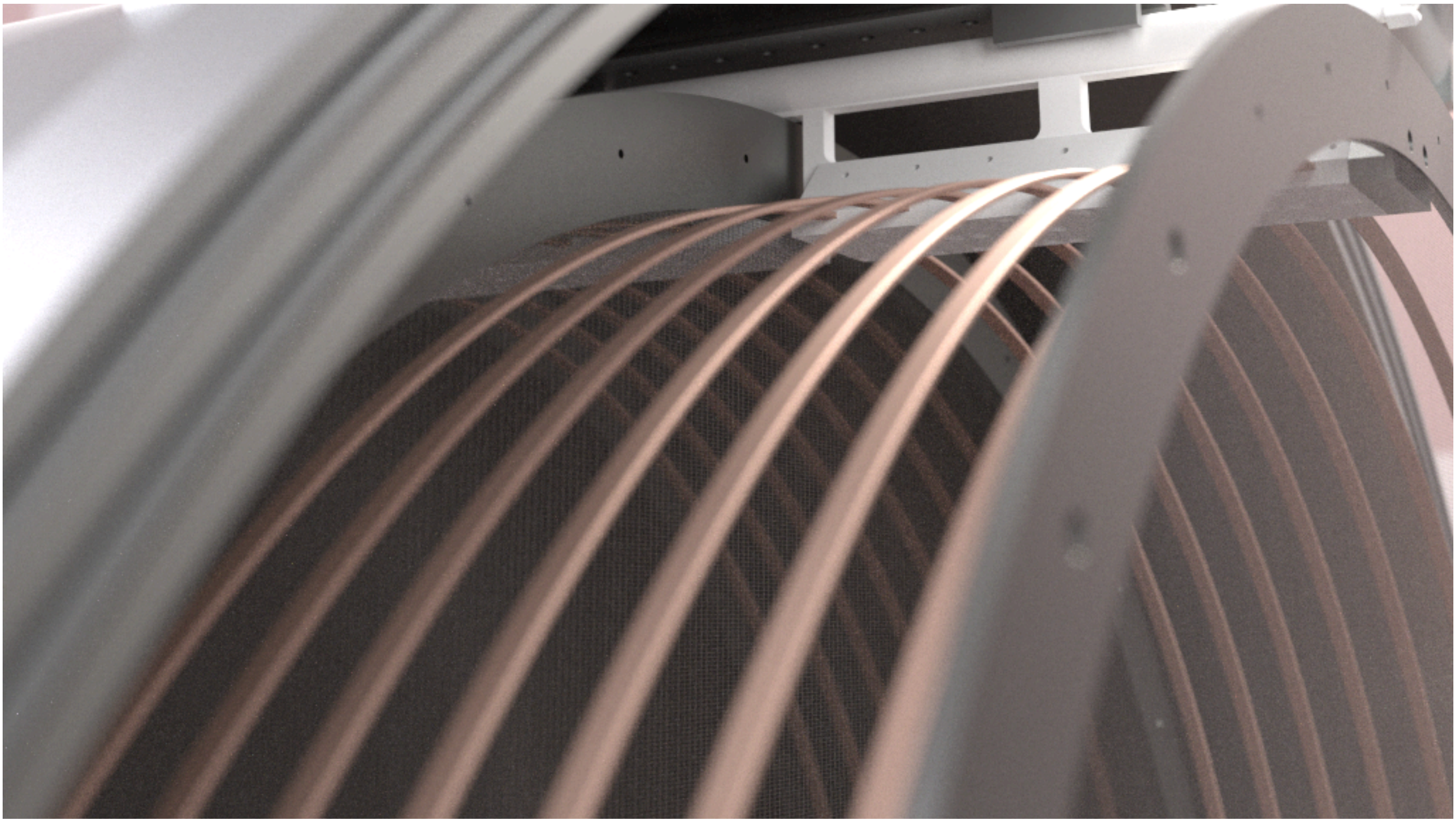
- New kinematic variables implemented in MaCh3
- Fits have been run in Pion and Proton momentum, as well as transverse variables $\delta\alpha$, $\delta\phi$, and δp
- Missing mass in transverse plane tells us about nuclear effects



Lu, et al., Phys. Rev. C 94, 015503

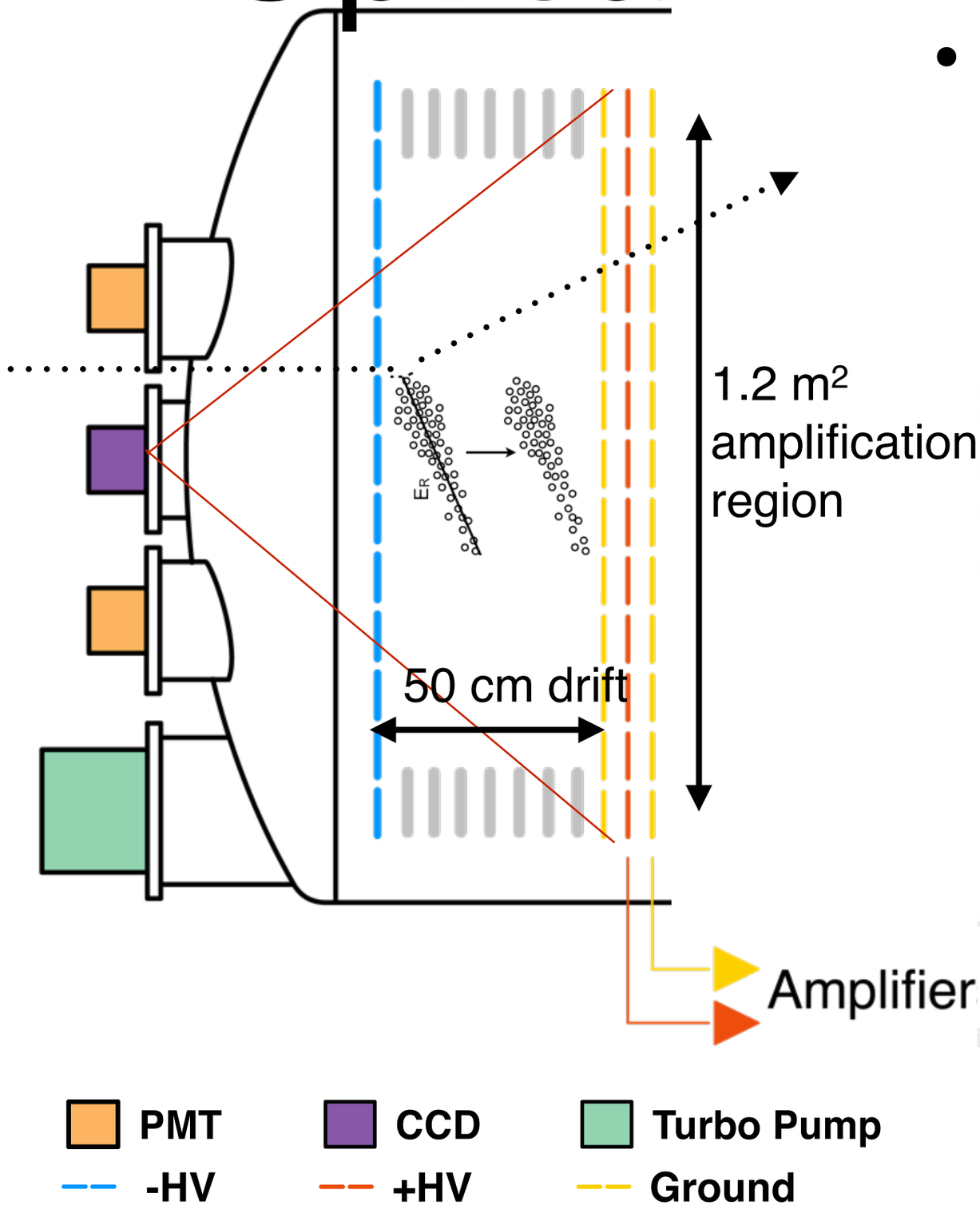
08/10/17 Sensitivity Studies for HPTPC as a Near Detector, Will Parker, RHUL 5

Studies of transverse variables ongoing…

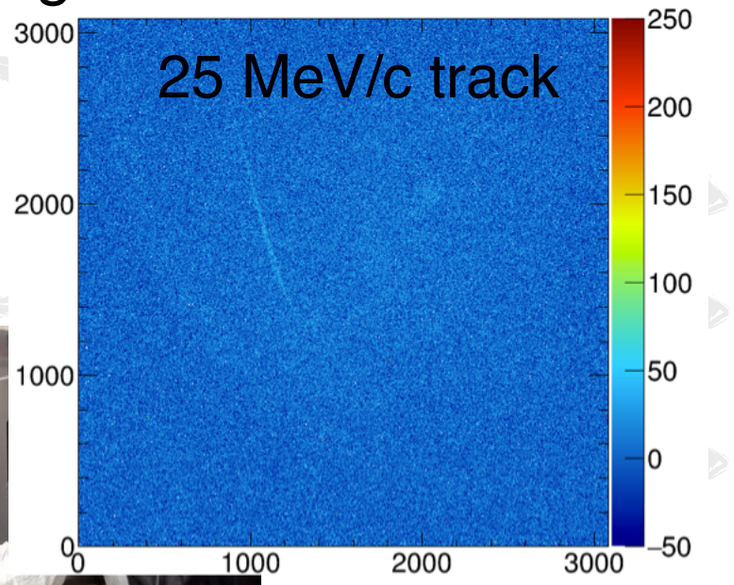


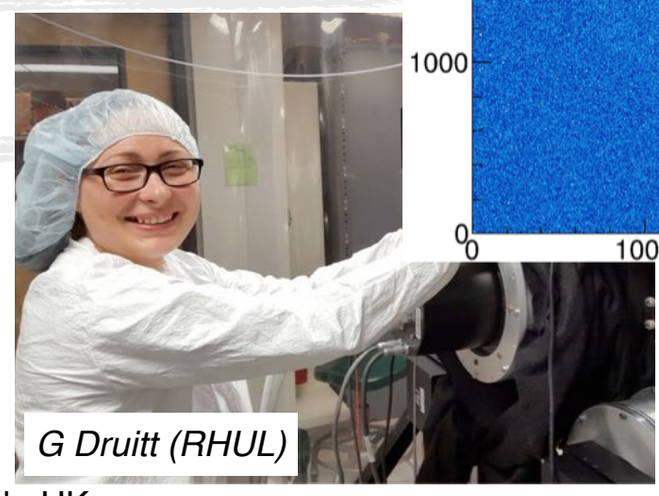
1m3 HPTPC R&D

Optical TPC Readout



- Image electroluminescent scintillation produced in amplification region
  - Digital camera + lens outside vessel
    - Currently using CCDs
  - Commission: CF_4, physics: Ar-CF_4
  - ~1 m object distance
  - results in 1 mm readout pitch with 4x4 readout binning



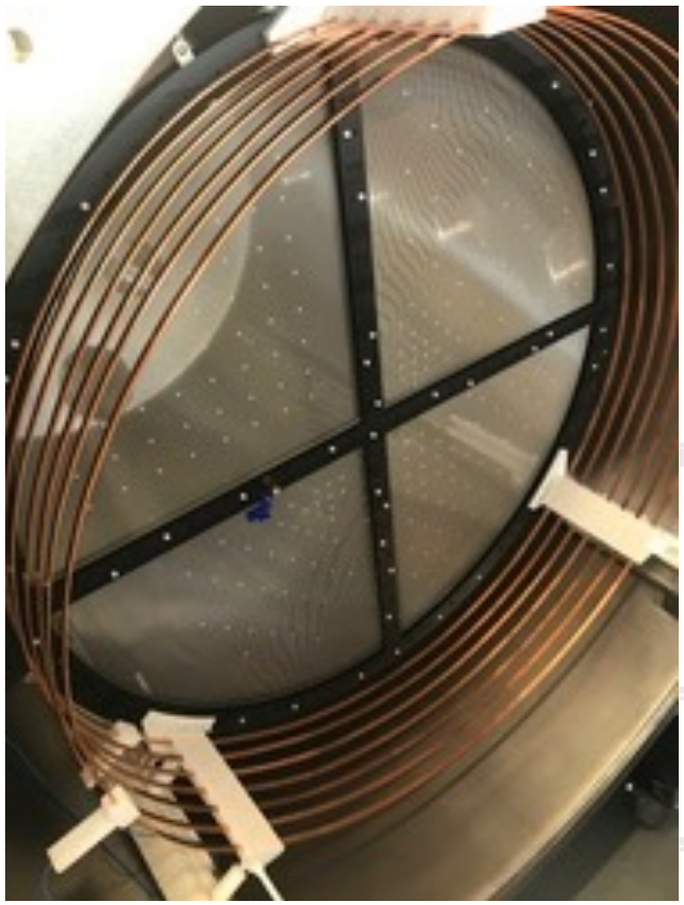


G Druitt (RHUL)

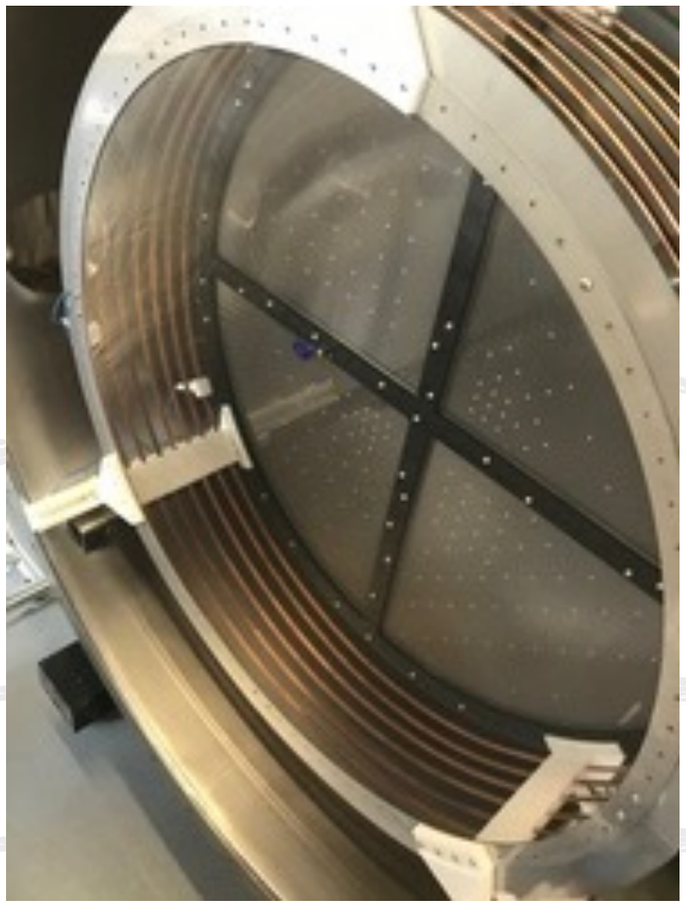
TPC with “short stack” Field Cage

Z. Chen-Wishart

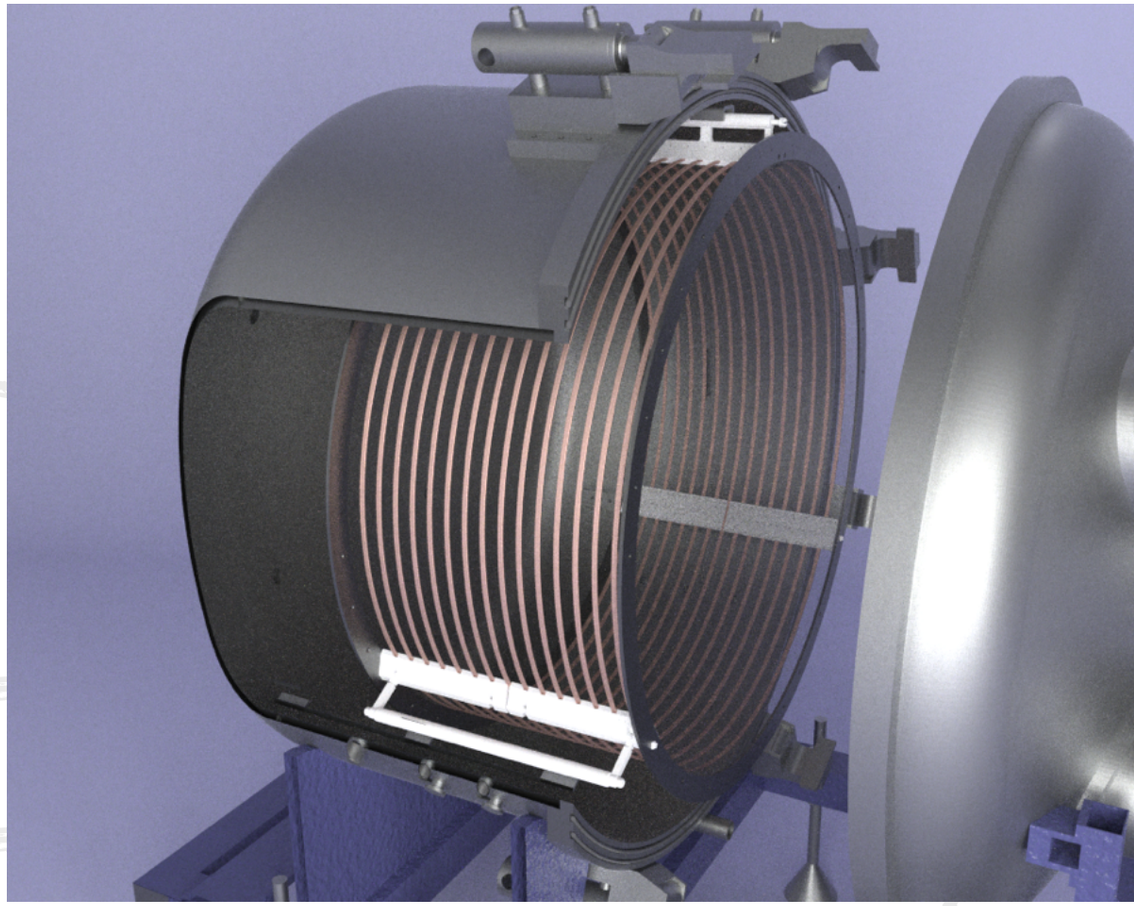
- Commissioning TPC & readout in low pressure vessel
  - 1.2m diameter, 30–60 cm length
- charge and optical readout of anode and ground segments



amplification plane + short stack field cage



cathode plane with delrin support structure.

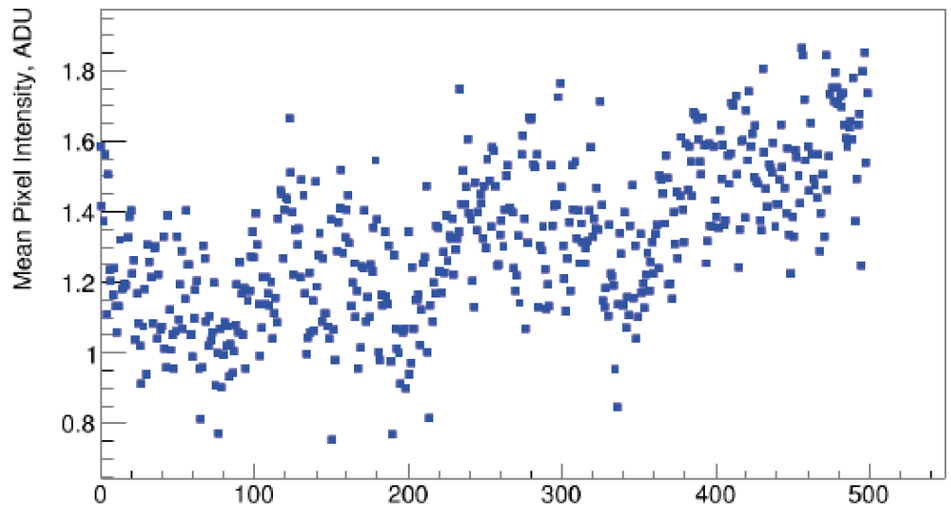


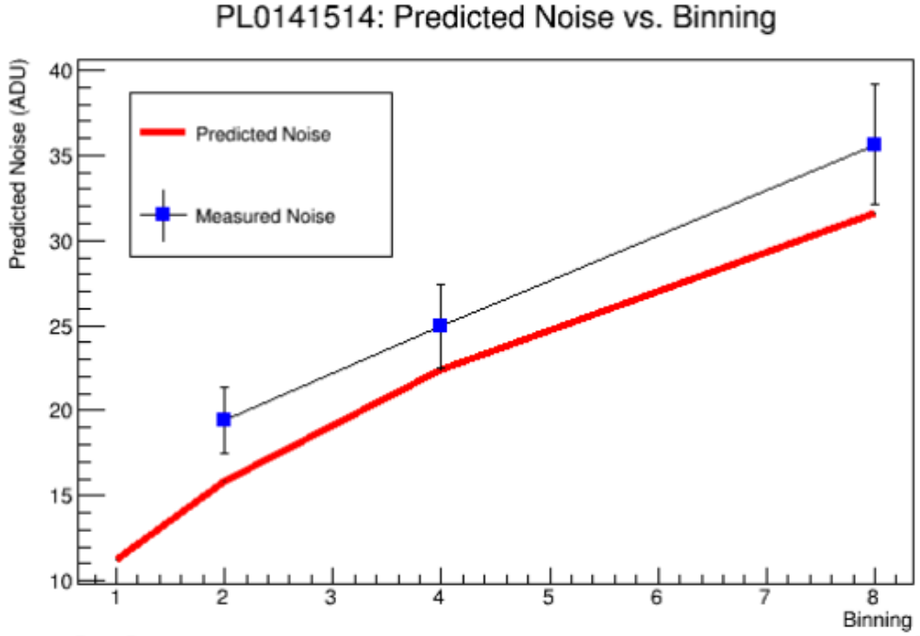
supports slide on rails welded to vessel, as in HPTPC vessel

Readout commissioning

M. Ward

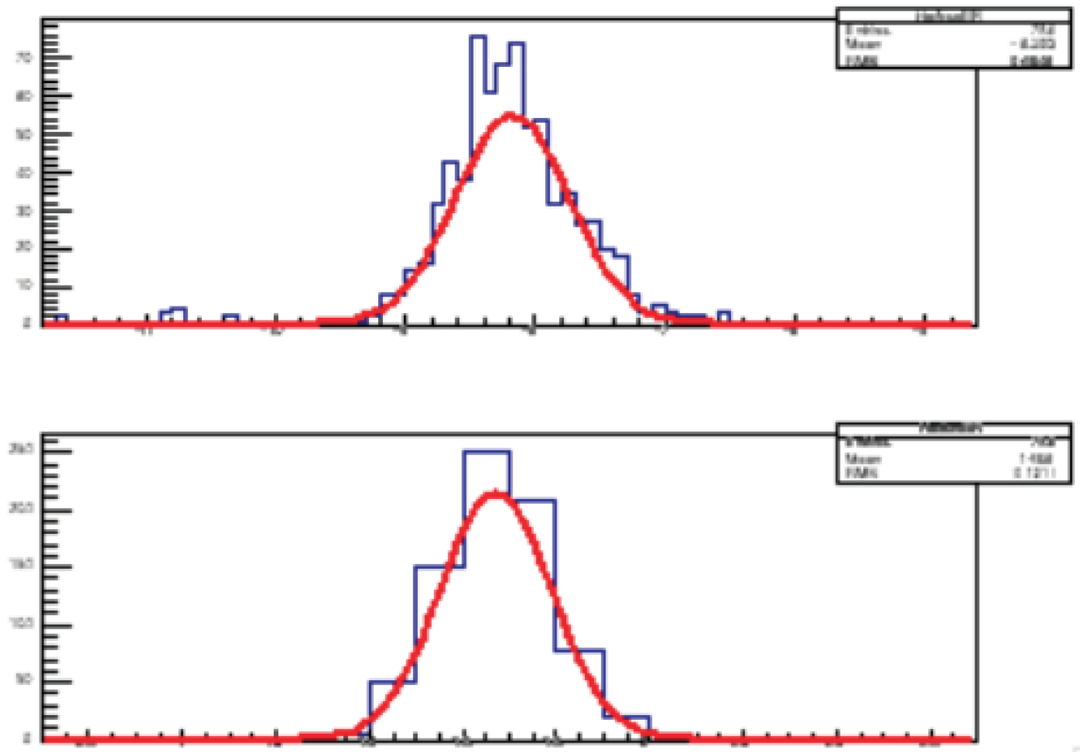
CCD





- CCD noise stable to ~1 ADC across device, and rms in line with manufacturer specs

Wire Mesh

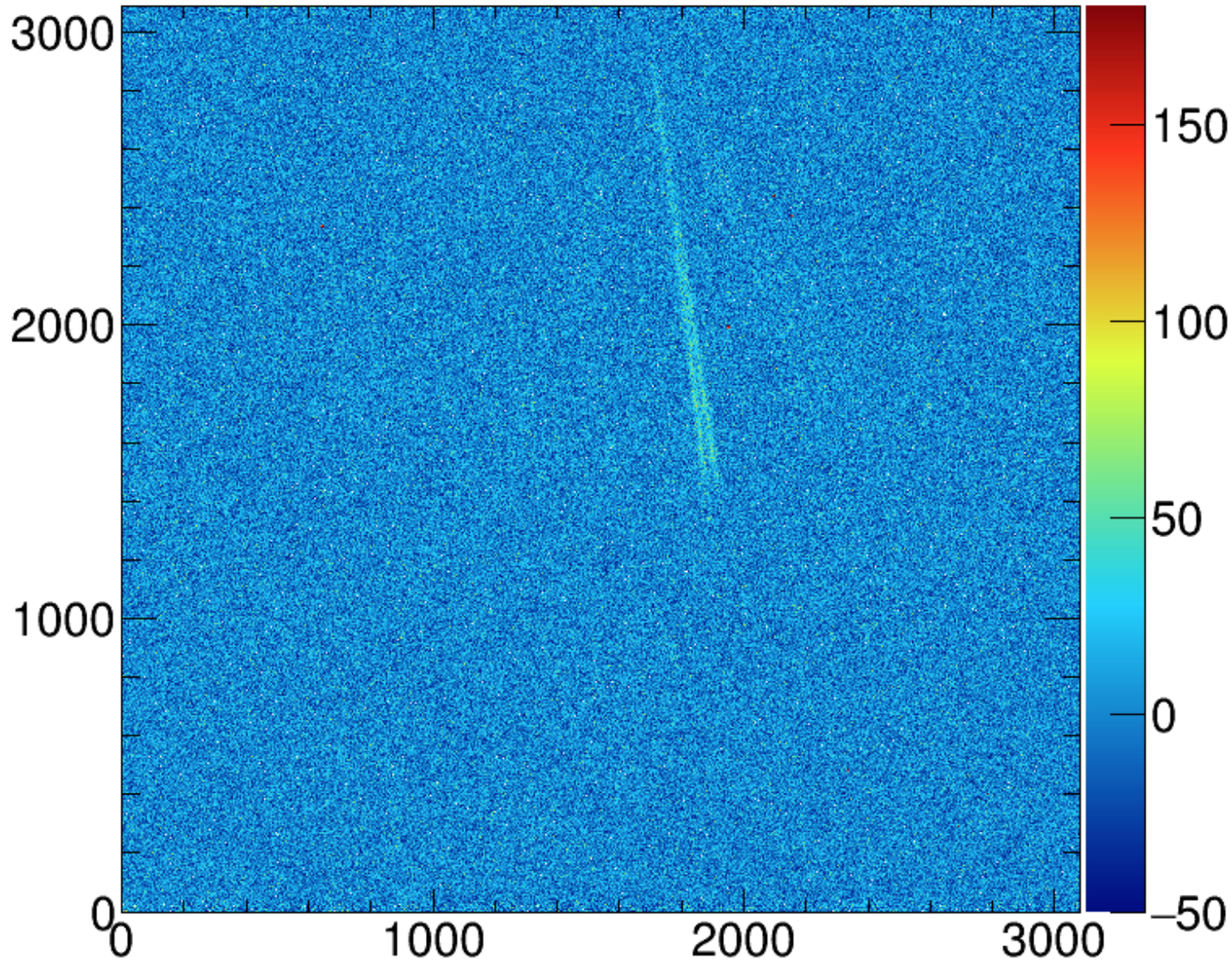


- good baseline stability, with RMS of whole readout chain consistent with digitizer-only noise rms of <1 ADC (=0.5 mV).
  - top: anode preamplifiers, bottom: ground mesh fast amplifiers
- Initial measured gas gain ~3.2×10^4

Tracking Calibration

M. Ward

- example 25 MeV/c alpha tracks in CCD readout
- Currently testing TREx reconstruction on HPTPC simulation; preparing for calibration data



High Pressure Vessel

- Rated to 7.5 atm,
- 1 beam window (2 mm Al), 6 optical ports + 12 flanges for gas, HV, controls, calibration, etc.

Pressure vessel arrived at RHUL yesterday!

3D design rendering

Vessel on crane at RHUL

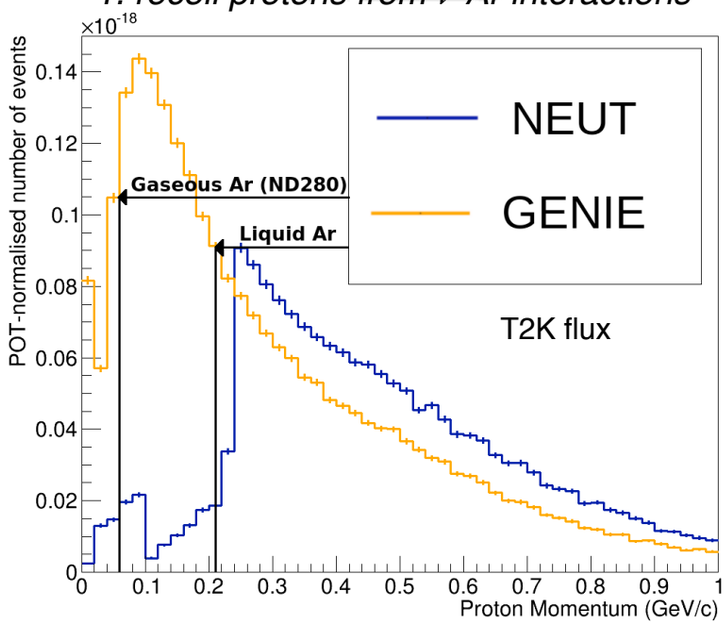
Vessel in clean tent at RHUL

CERN beamtest

- **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)
- Preparing proposal to SPSC for beam time before long shutdown

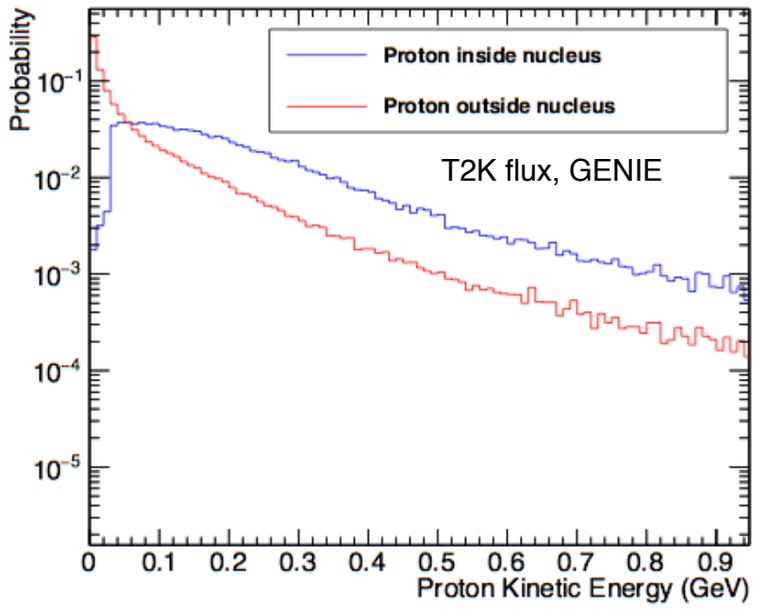
P Hamilton (Syracuse)

1. recoil protons from ν-Ar interactions



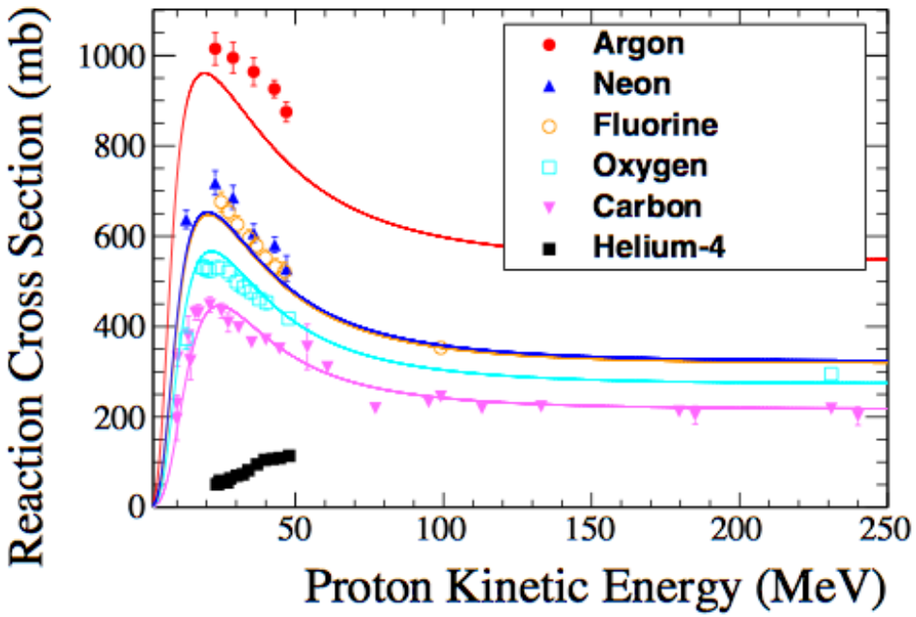
A Kaboth (RHUL)

2. Nuclear effects on recoil protons



A Kaboth (RHUL)

3. proton-nucleus scattering data with MC model



Beam Time Proposal to CERN SPSC

- CERN-SPSC-2017-030 ; SPSC-P-355
- Interest from Upgrade EOI groups + more (55+ authors, 34 groups, 11 countries)
- **Request: 4 weeks beam time + 2 weeks parasitic running**
- Feedback from SPSC referees expected Nov. 2017

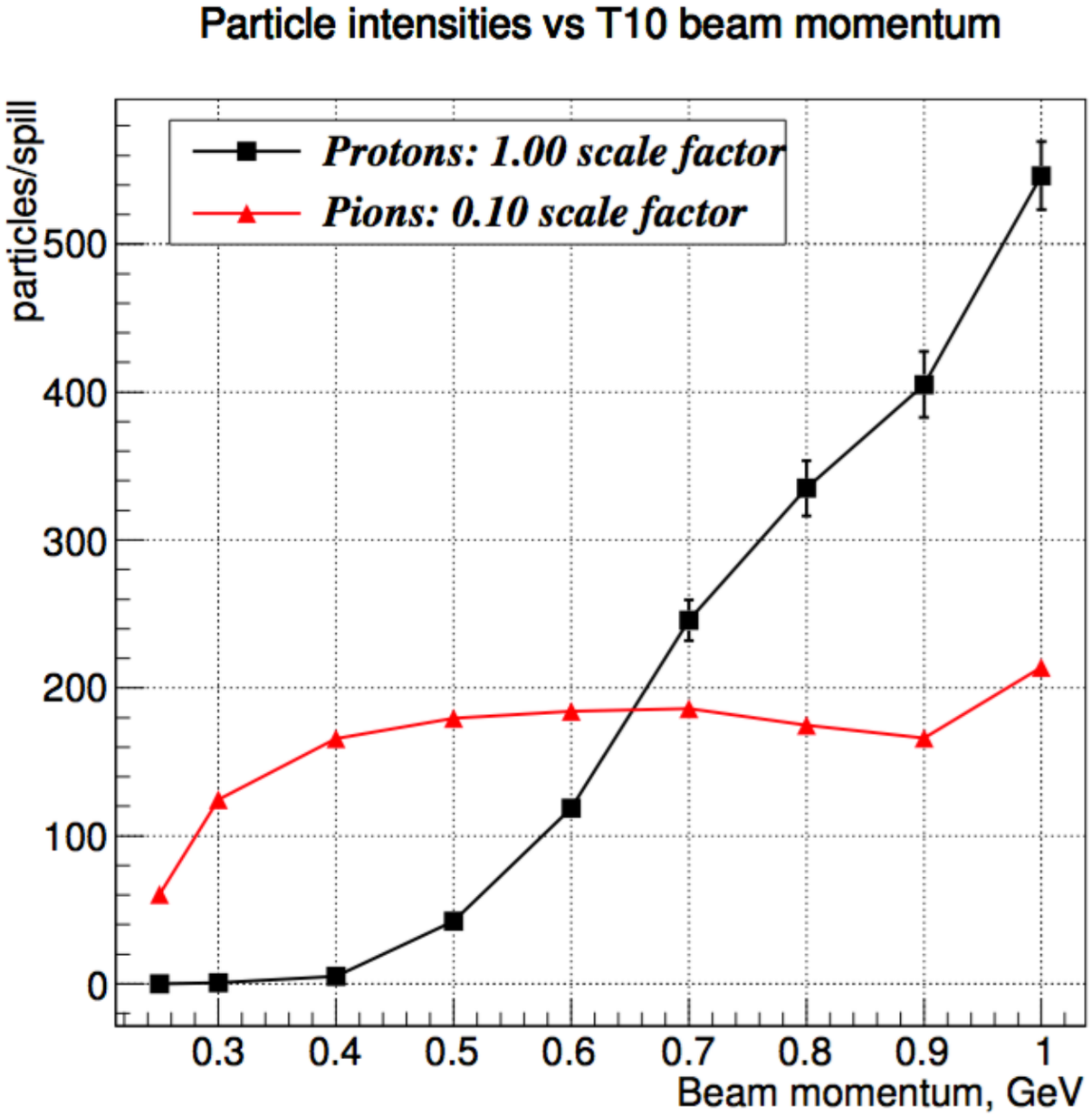
http://cds.cern.ch/record/2284748

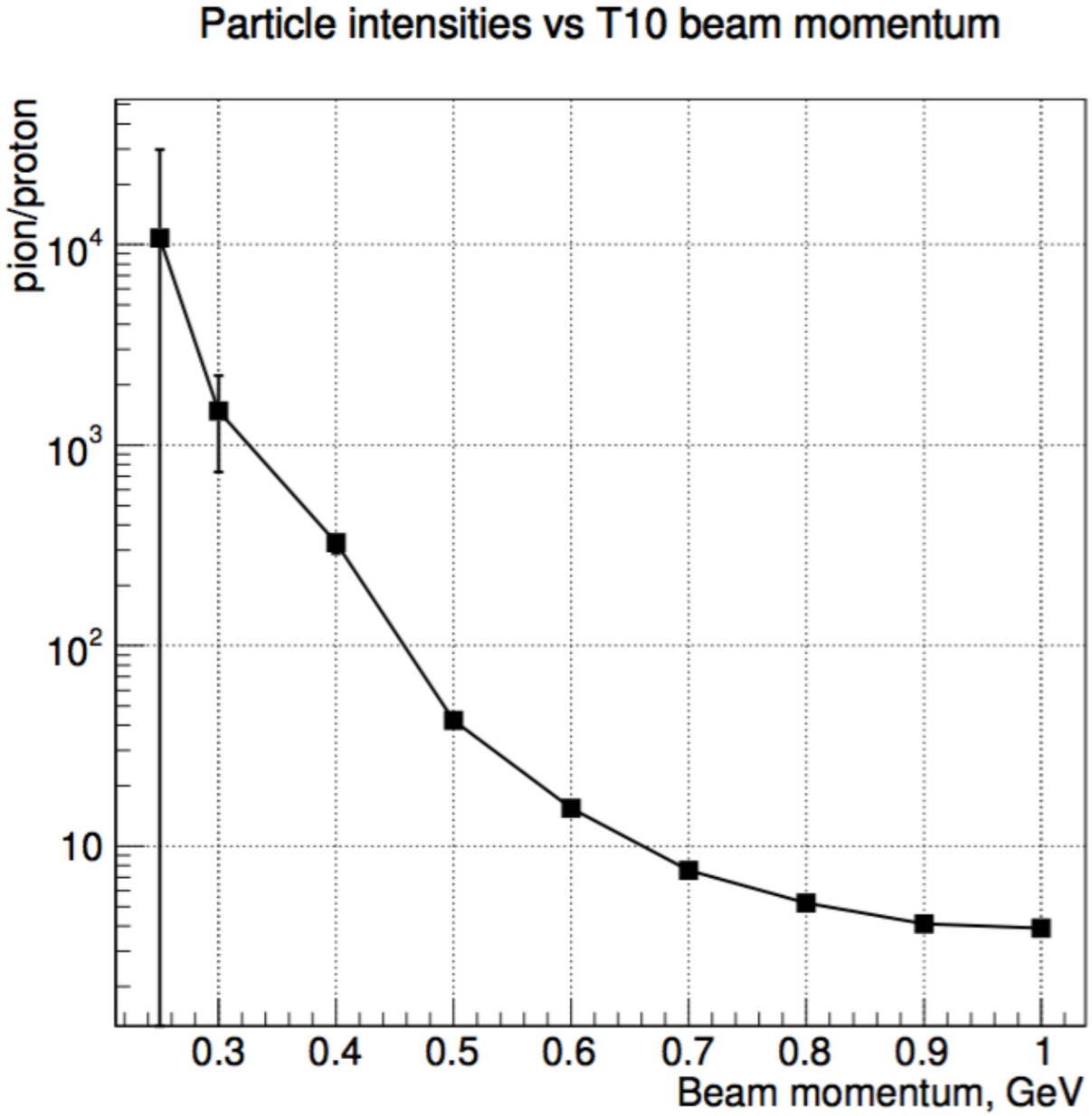
Proposal to Measure Hadron Scattering with a Gaseous High Pressure TPC for Neutrino Oscillation Measurements

C. Andreopoulos[25], G. Barker[30], S. Bolognesi[10], S. Bordoni[1], S. Boyd[30], D. Brailsford[13], S. Brice[3], G. Catanesi[8], Z. Chen-Wishart[16], P. Denner[30], P. Dunne[4], C. Giganti[12], D. Gonzalez Diaz[6], J. Haigh[30], P. Hamacher-Baumann[17], S.-P. Hallsjö[24], Y. Hayato[28], A. Ichikawa[11], I. Irastorza[33], B. Jamieson[31], P. Jonsson[4], A. Kaboth[16], A. Korzenev[22], Yu. Kudenko[9], M. Leyton[18], R.P. Litchfield[4], K.-B. Luk[20], W. Ma[4], K.B.M. Mahn[14], M. Martini[2], N. McCauley[25], P. Mermod[22], J. Monroe (P.I.)[16], U. Mosel[23], R. Nichol[21], J. Nieves[5], T. Nonnenmacher[4], J. Nowak[13], W. Parker[16], J.L. Raaf[3], J. Rademacker[19], T. Radermacher[17], E. Radicioni[8], E. Rondio[15], S. Roth[17], R. Saakyan[21], F. Sanchez[18], D. Sgalaberna[22], Y. Shitov[4], J. Sobczyk[32], F.J.P. Soler[24], A. Sztuc[4], C. Touramanis[25], Y. Uchida[4], S. Valder[30], J. Walding[16], M. Ward[16], M.O. Wascko[4], A. Weber[26], C.V.C. Wret[4], M. Yokoyama[27], A. Zalewska[7], M. Ziembicki[34], and M. Zito[10]

T9/T10 flux measurements

Yu. Shitov





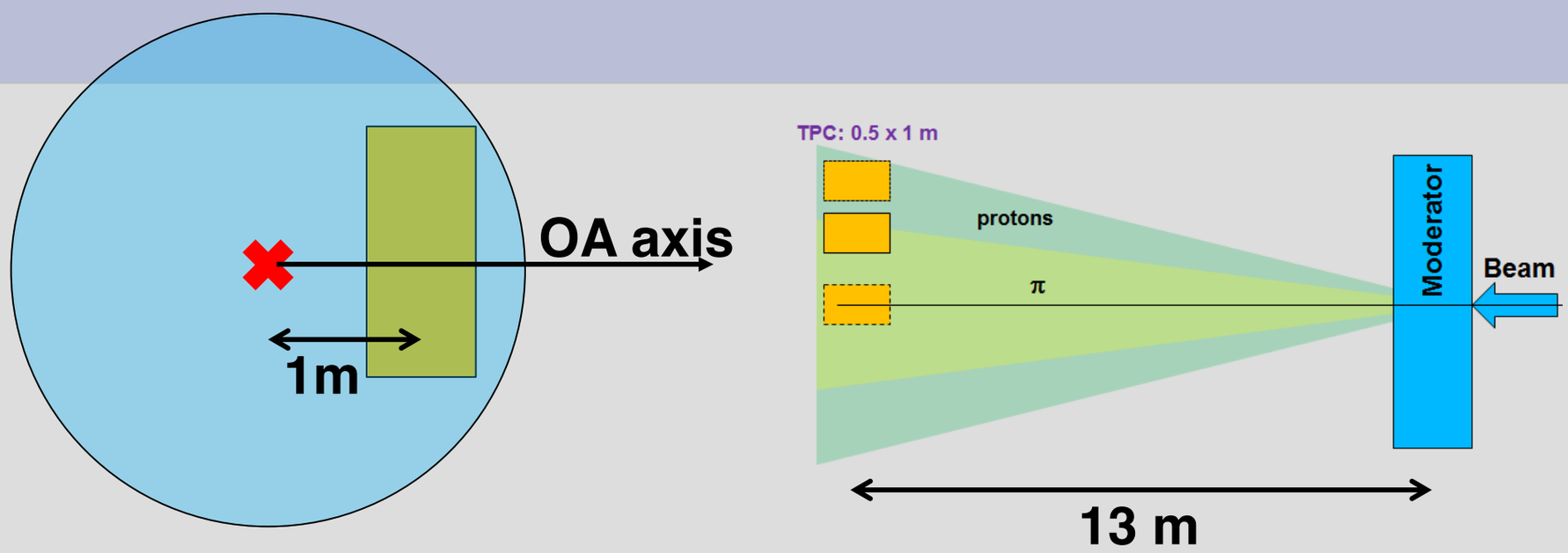
Proposal Fig. 7

http://cds.cern.ch/record/2284748

Test beam studies

Yu. Shitov

Proposed OFF-AXIS (OA) measurement



1) **TPC entrance surface 0.5 x 1 m2, optimal beam 0.8 GeV & 30 cm of Plastic (PS) absorber (+ 1cm of steel from vessel). We don't have simulation of PS + Steel, so use simulation of pure 35 cm of PS, which should be close to 30 cm PS + 1 cm of Steel.**
2) **Optimal location is 1 m at 13 m from absorber .**

Aim of this study

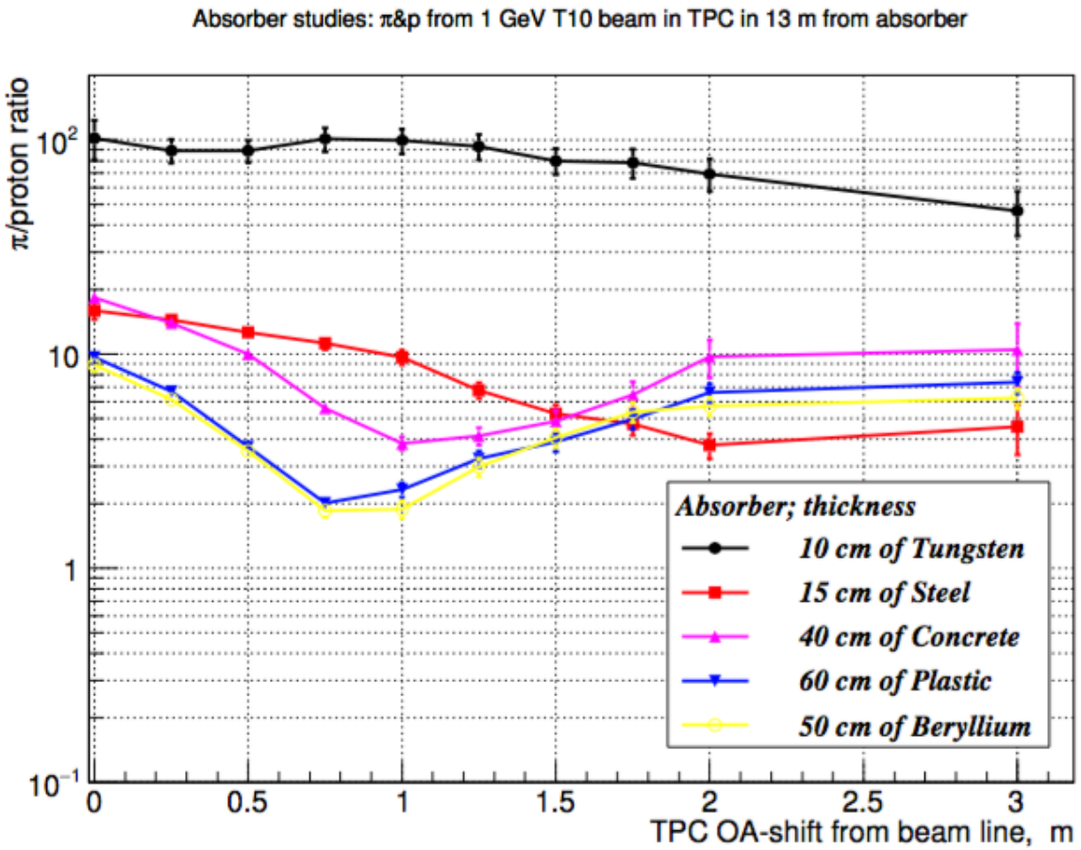
Looking for: 1) spatial, 2) momentum, 3) 1 + 1 2D distros vs. different particles normalized: a) per single incoming beam particle, b) per spill – spill data info has been taken from test measurements.

2

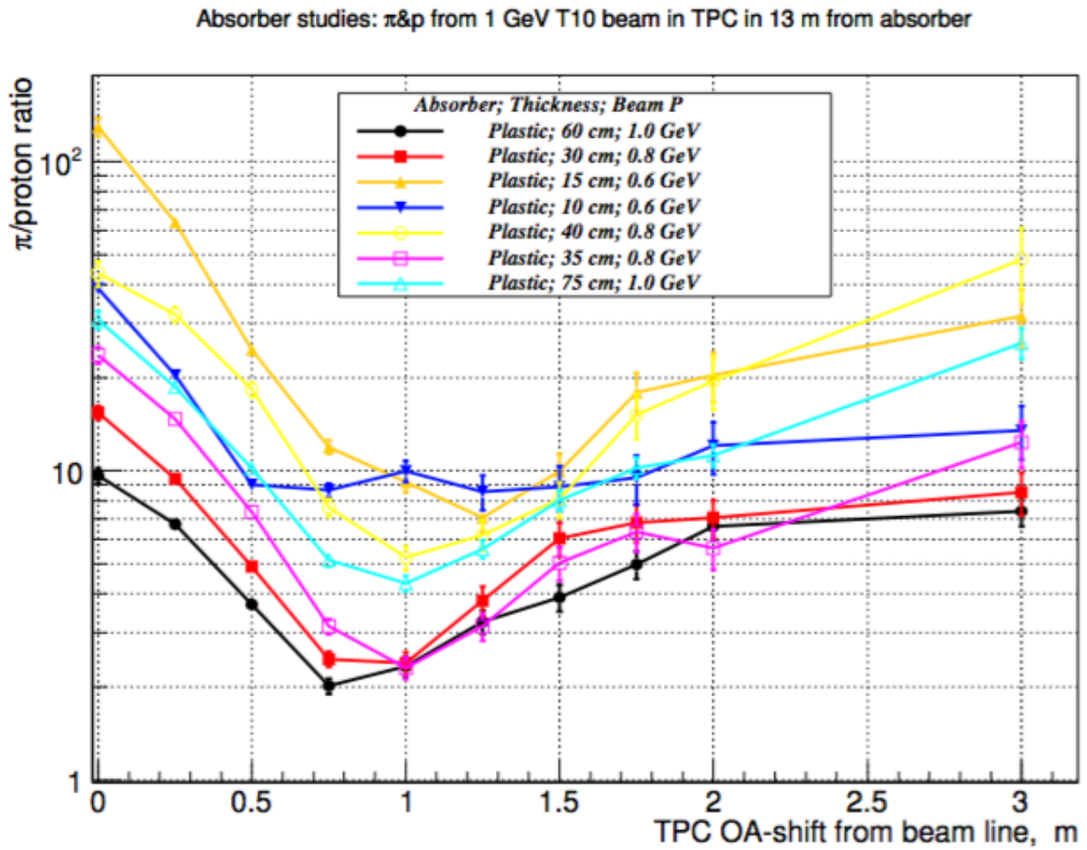
Try moving detector off-axis to enhance proton fraction

T9/T10 flux measurements

Yu. Shitov



(a) Effect of using different moderator materials.



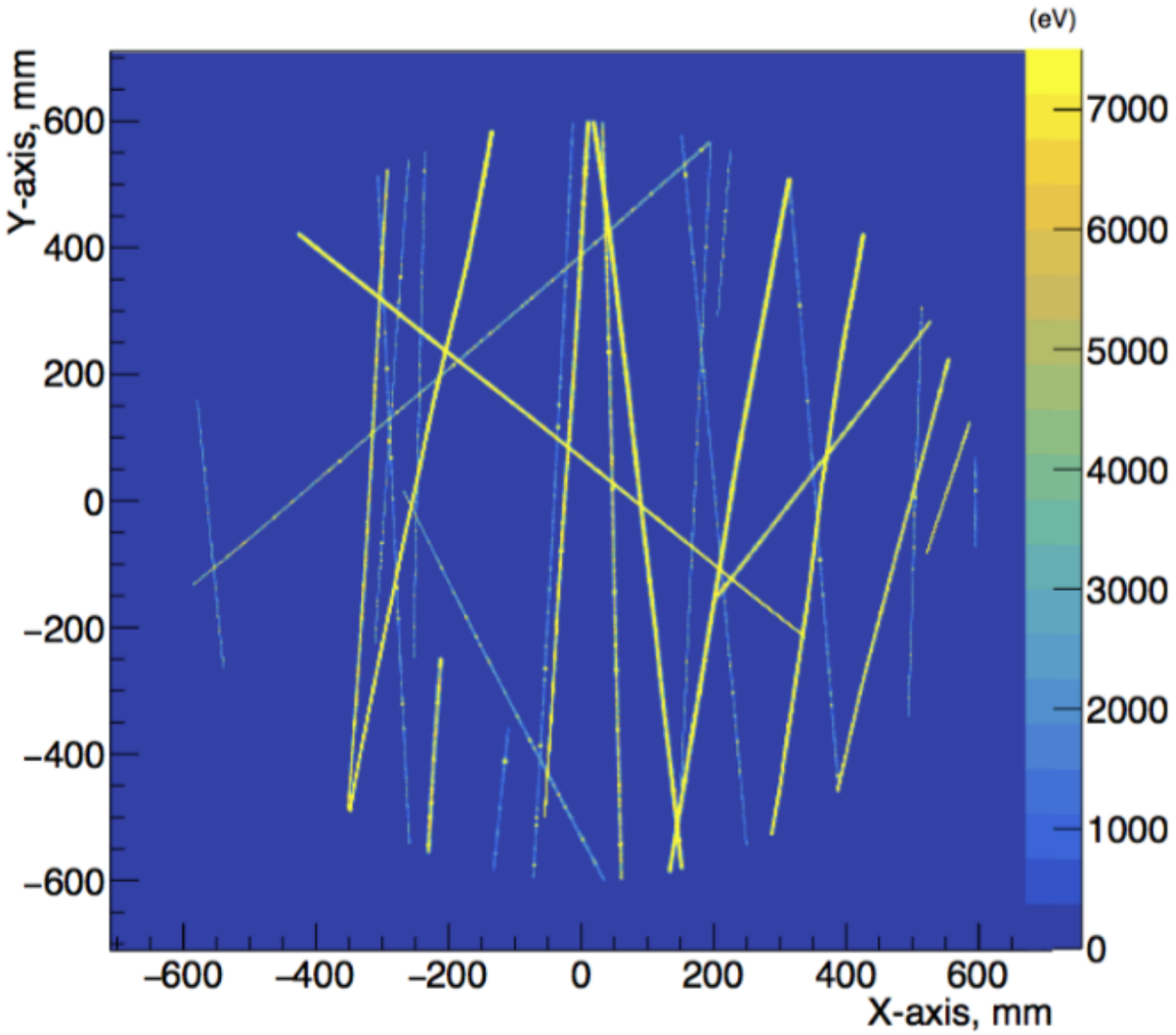
(b) Effect of beam momentum and moderator thickness.

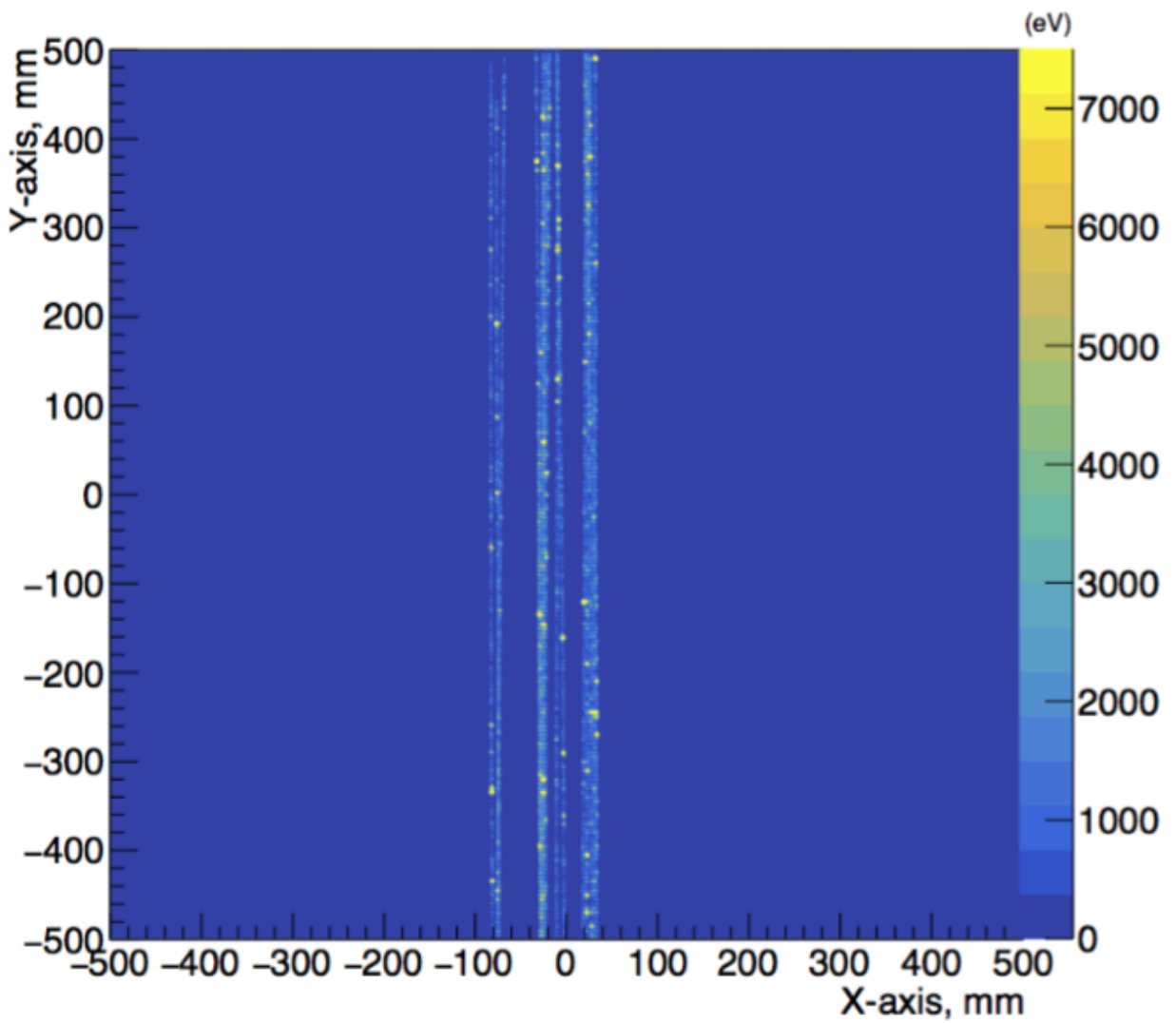
Proposal Fig. 9

http://cds.cern.ch/record/2284748

Particle tracks in HPTPC (MC)

Z. Chen-Wishart





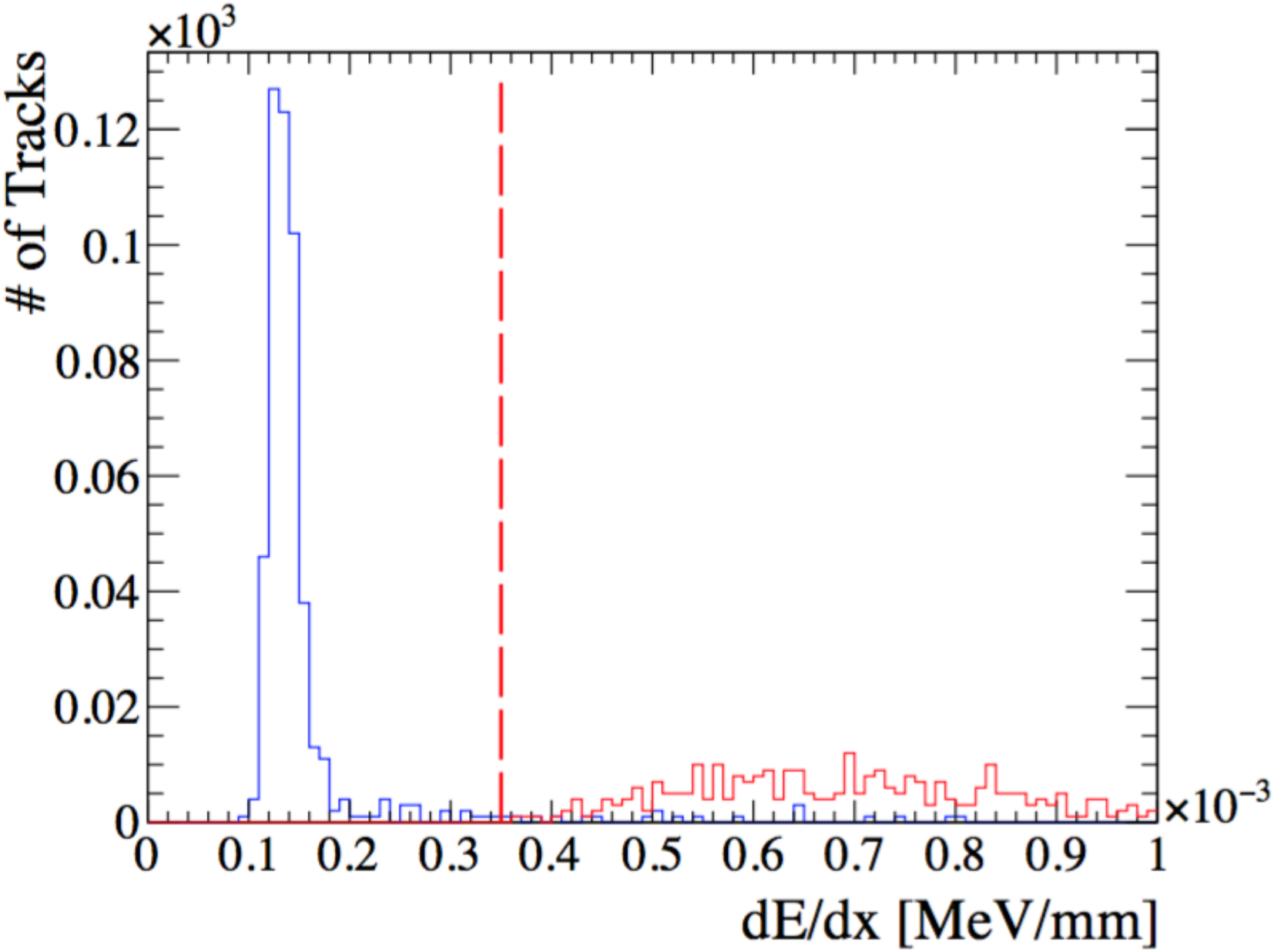
off-axis → on-axis

Proposal Fig. 14

http://cds.cern.ch/record/2284748

Proton/pion separation in HPTPC (MC)

P. Denner

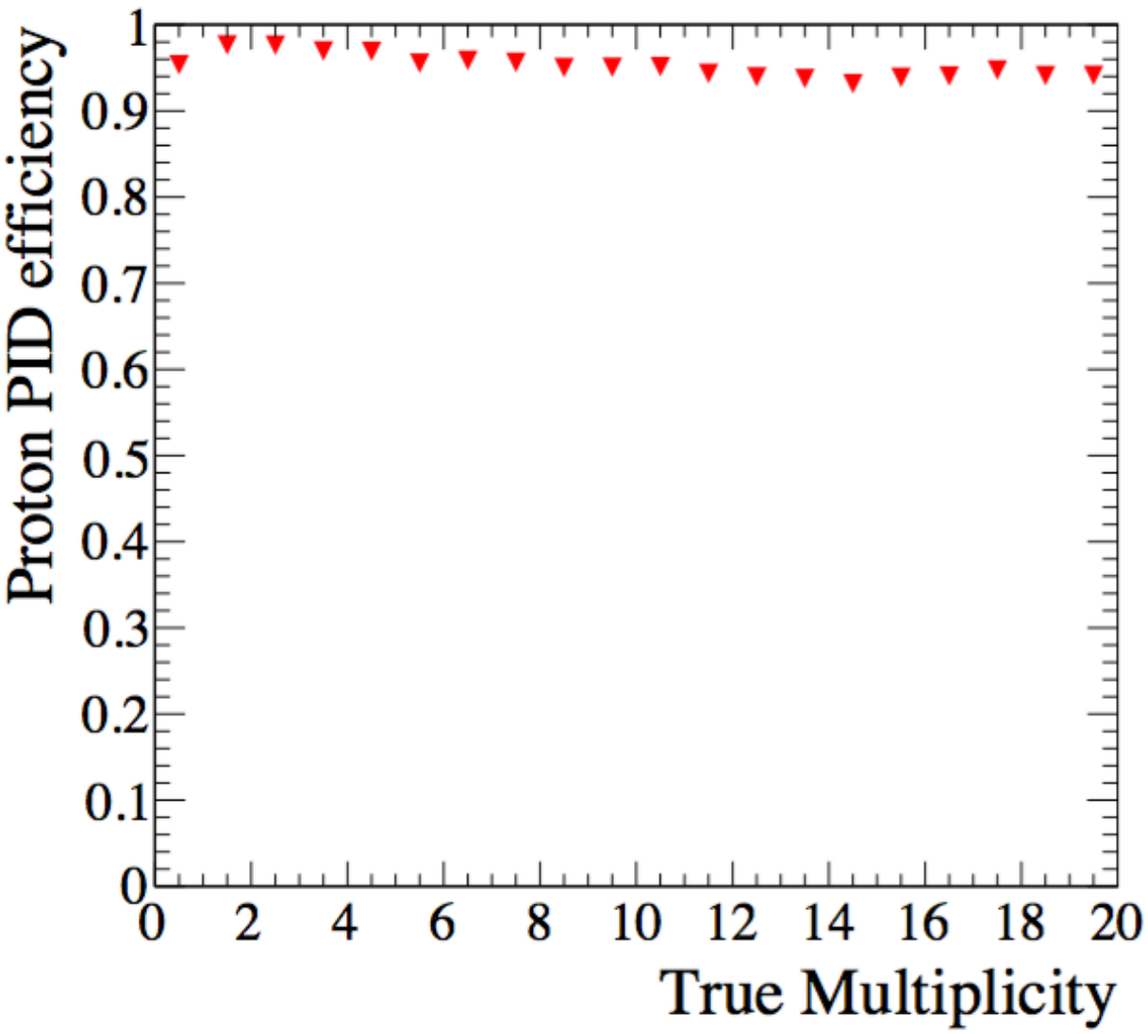


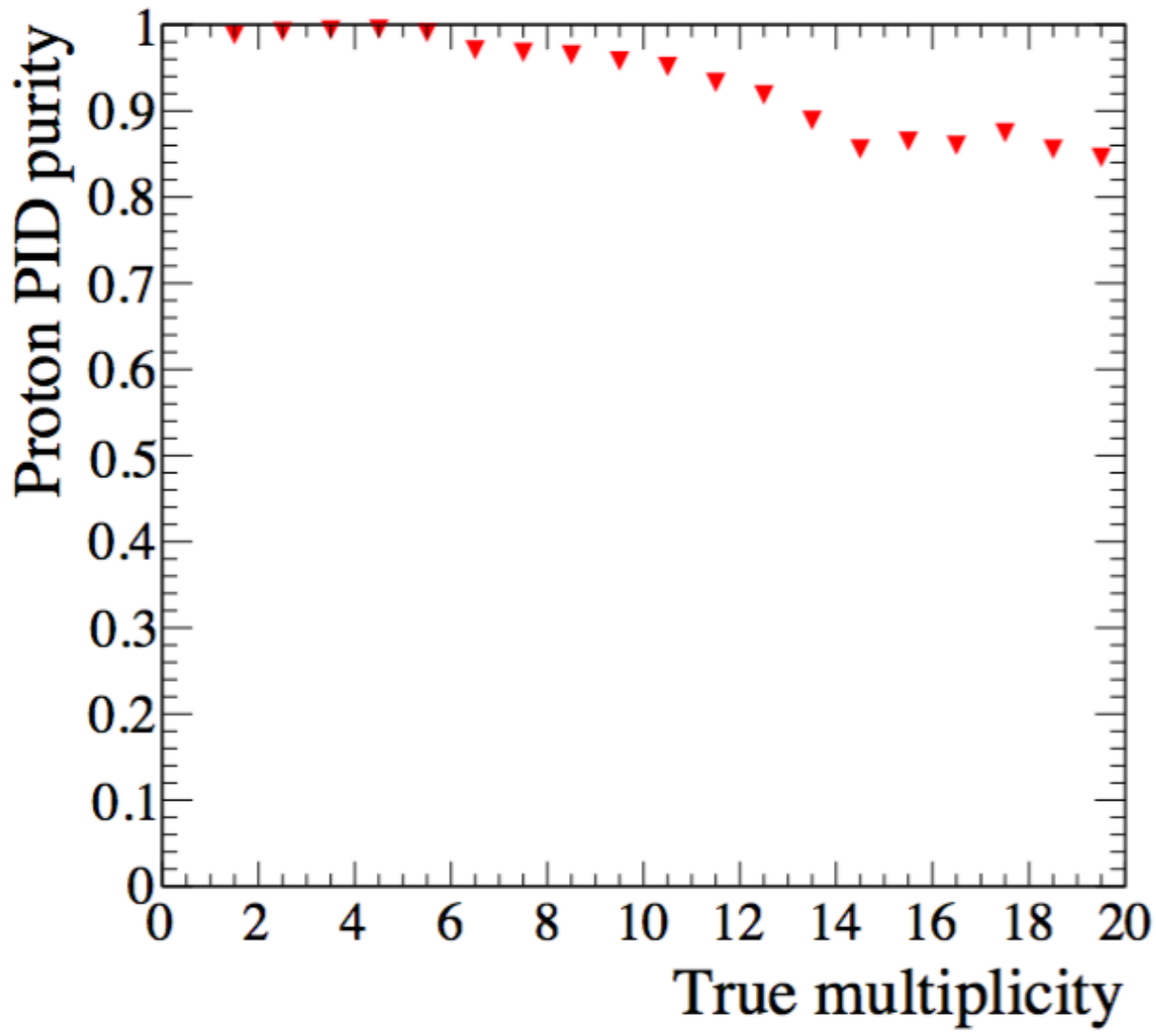
Proposal Fig. 15

http://cds.cern.ch/record/2284748

Proton reconstruction in HPTPC (MC)

P. Denner



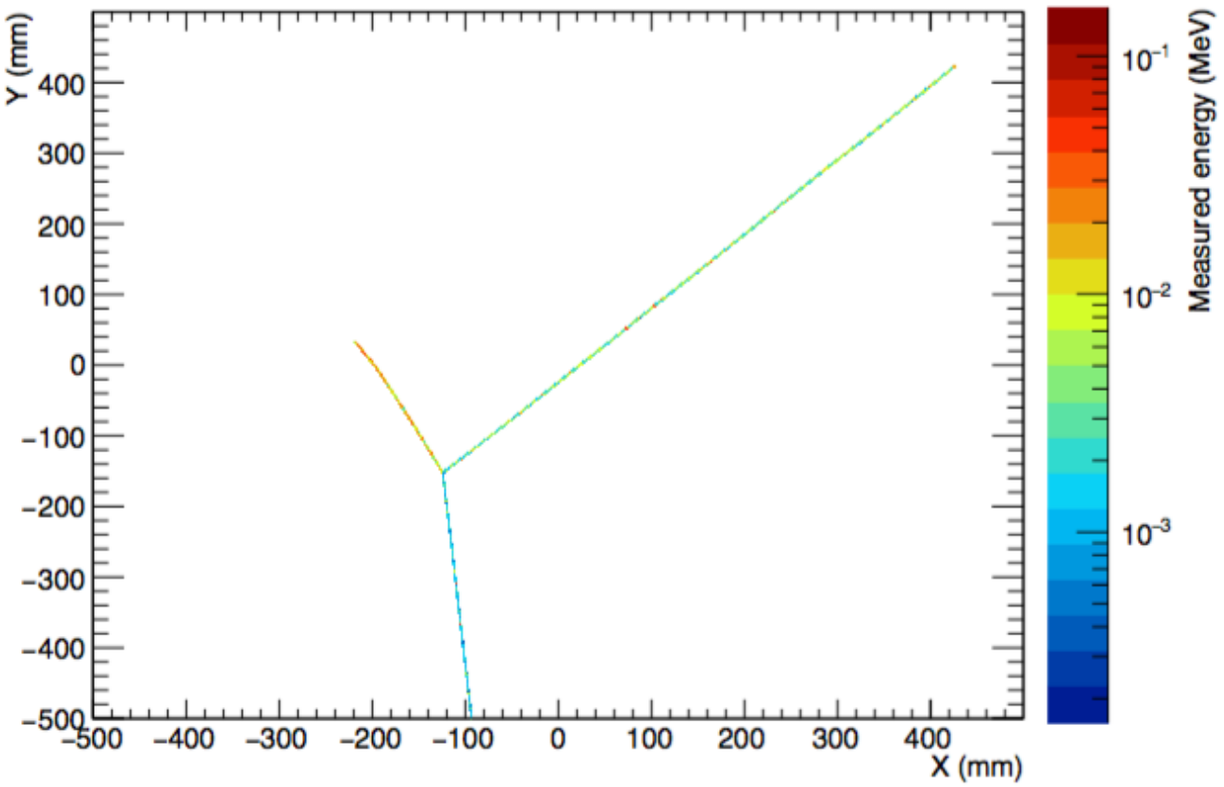


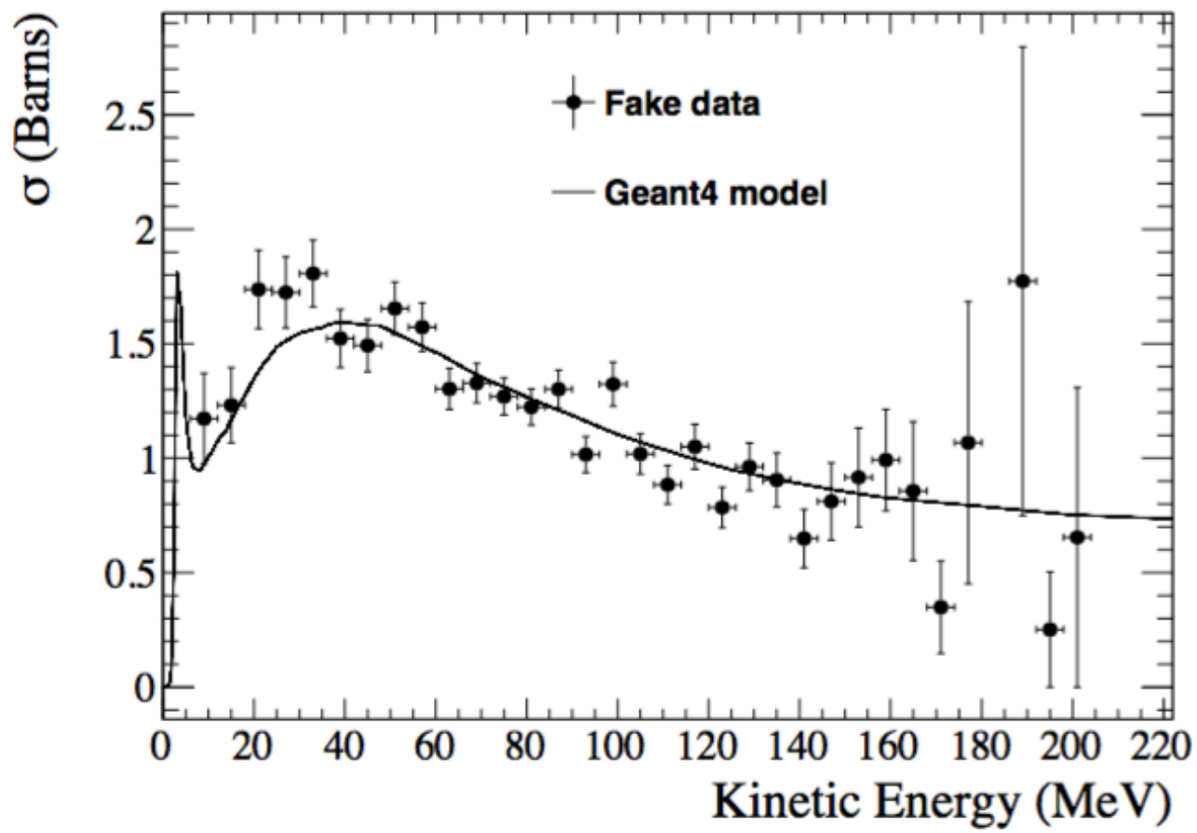
Proposal Fig. 17

http://cds.cern.ch/record/2284748

HPTPC mock data analysis

D. Brailsford





Proposal Fig. 18

http://cds.cern.ch/record/2284748

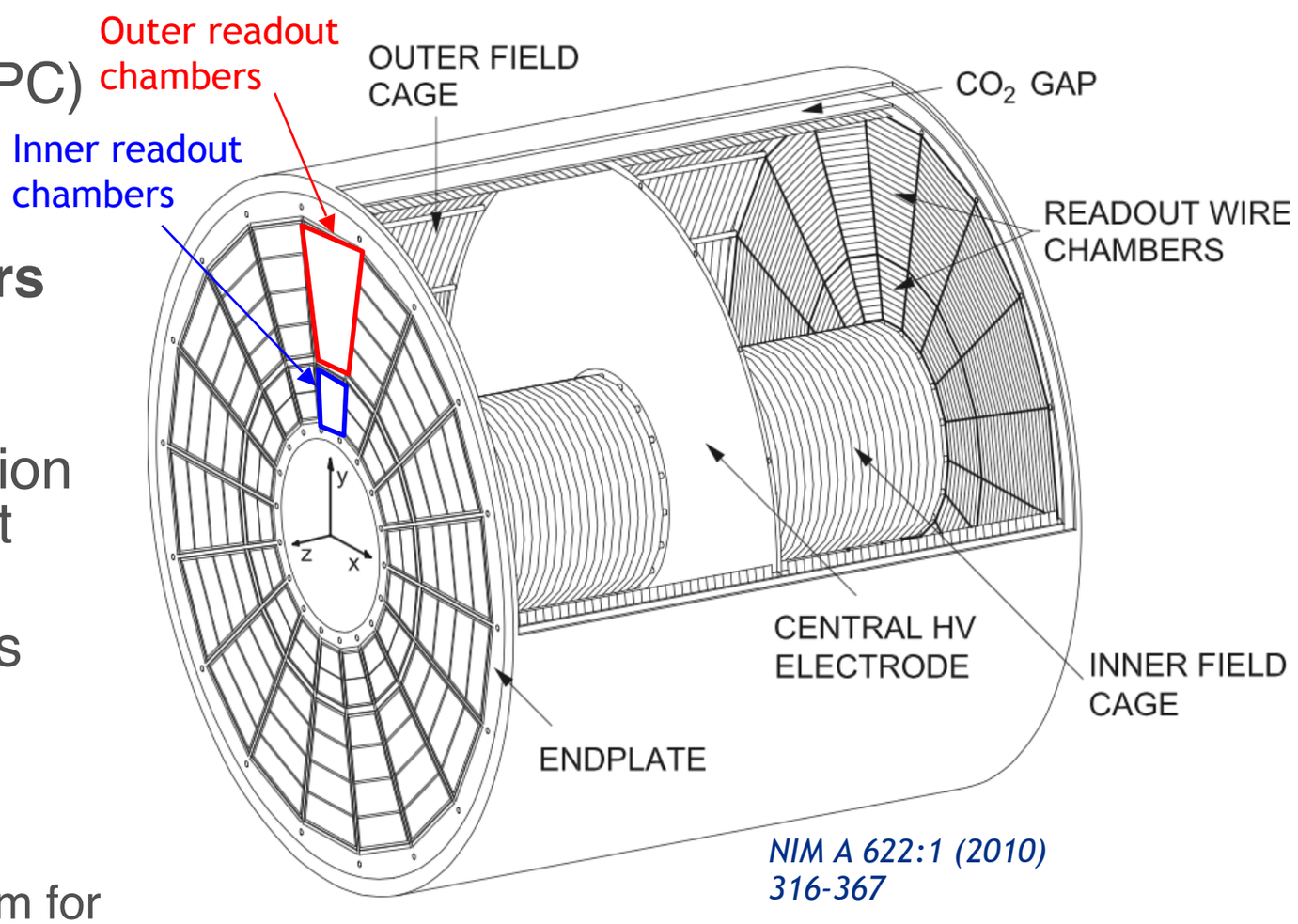
Fermilab HPTPC R&D

High Pressure GArTPC R&D at Fermilab

- DUNE Near Detector design options are under study now
  - LArTPC + downstream magnetized fine-grained tracker (e.g., HP-GArTPC)

- Attractive possibility for HP-GArTPC: **recycle ALICE TPC readout chambers**
  - ALICE chambers will be replaced during upcoming upgrade
  - Demonstrated excellent reconstruction capabilities in high-rate environment
  - Will provide excellent vertex visualization for neutrino interactions
  - Raw 3D data (pad plane readout)
    - Readout area ~32 m^2, ~557k channels
  - ALICE operation was at 1 atm
    - Need to demonstrate capability at 10 atm for use in DUNE ND complex

ALICE TPC

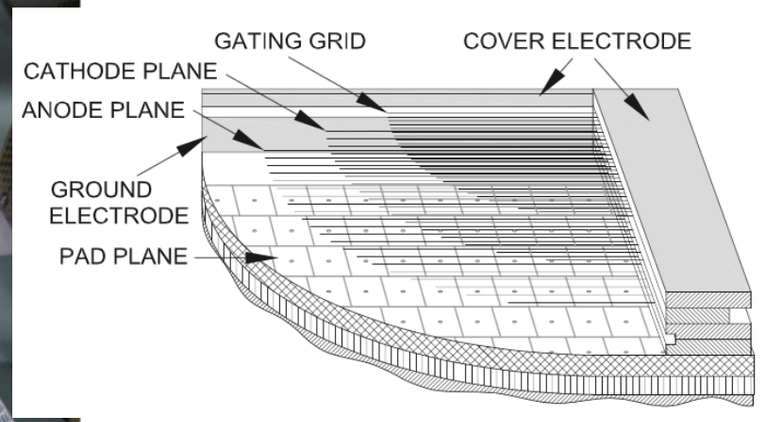


NIM A 622:1 (2010) 316-367

ALICE Inner Readout Chamber (IROC) @ Fermilab

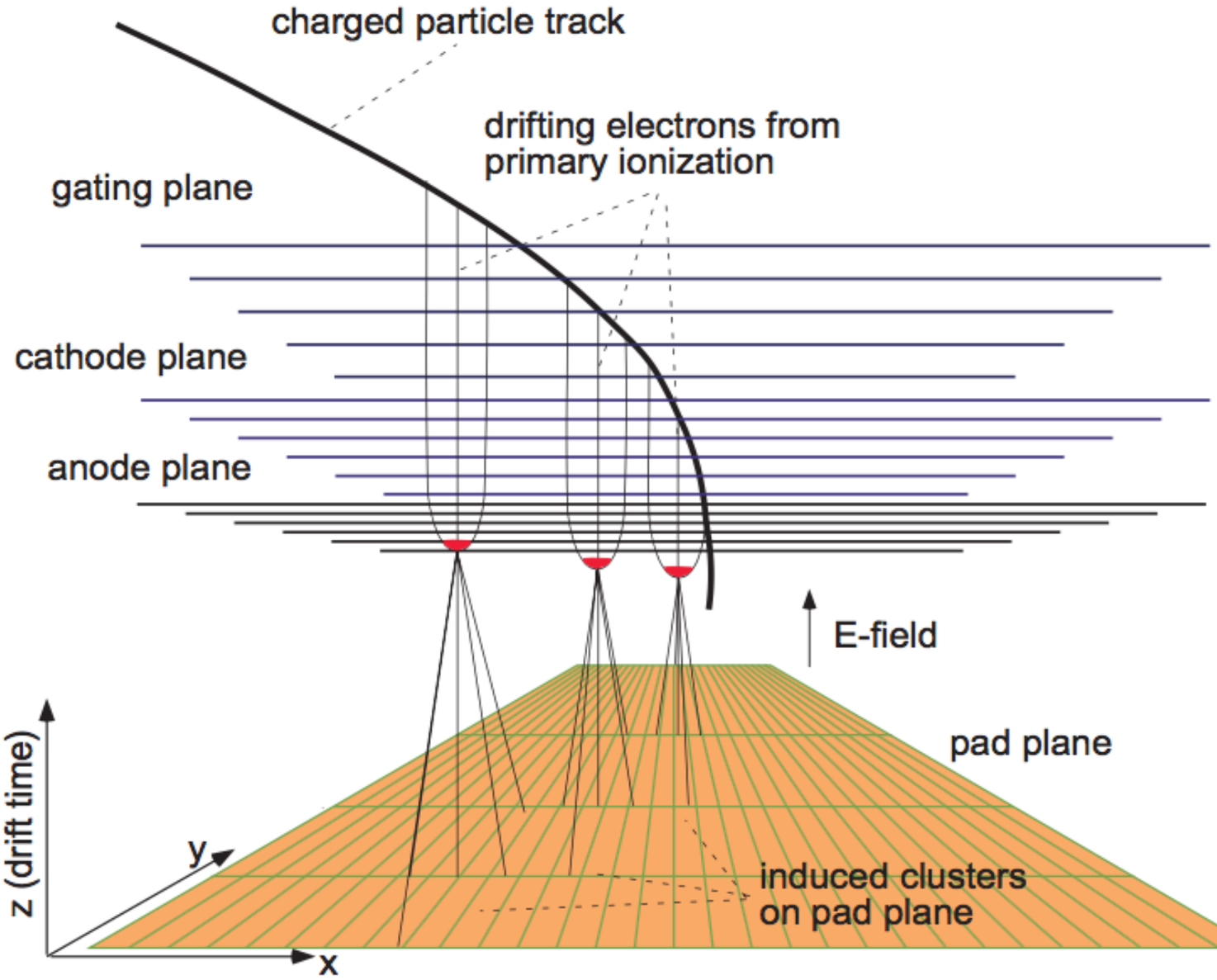
IROC @ FNAL

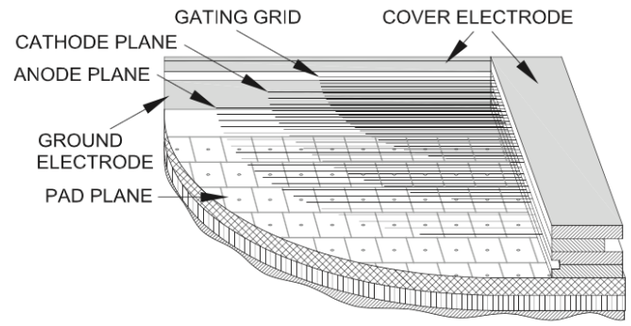
~5500 channels,
pad size 4x7mm



IROC: connector side

Operating Principle



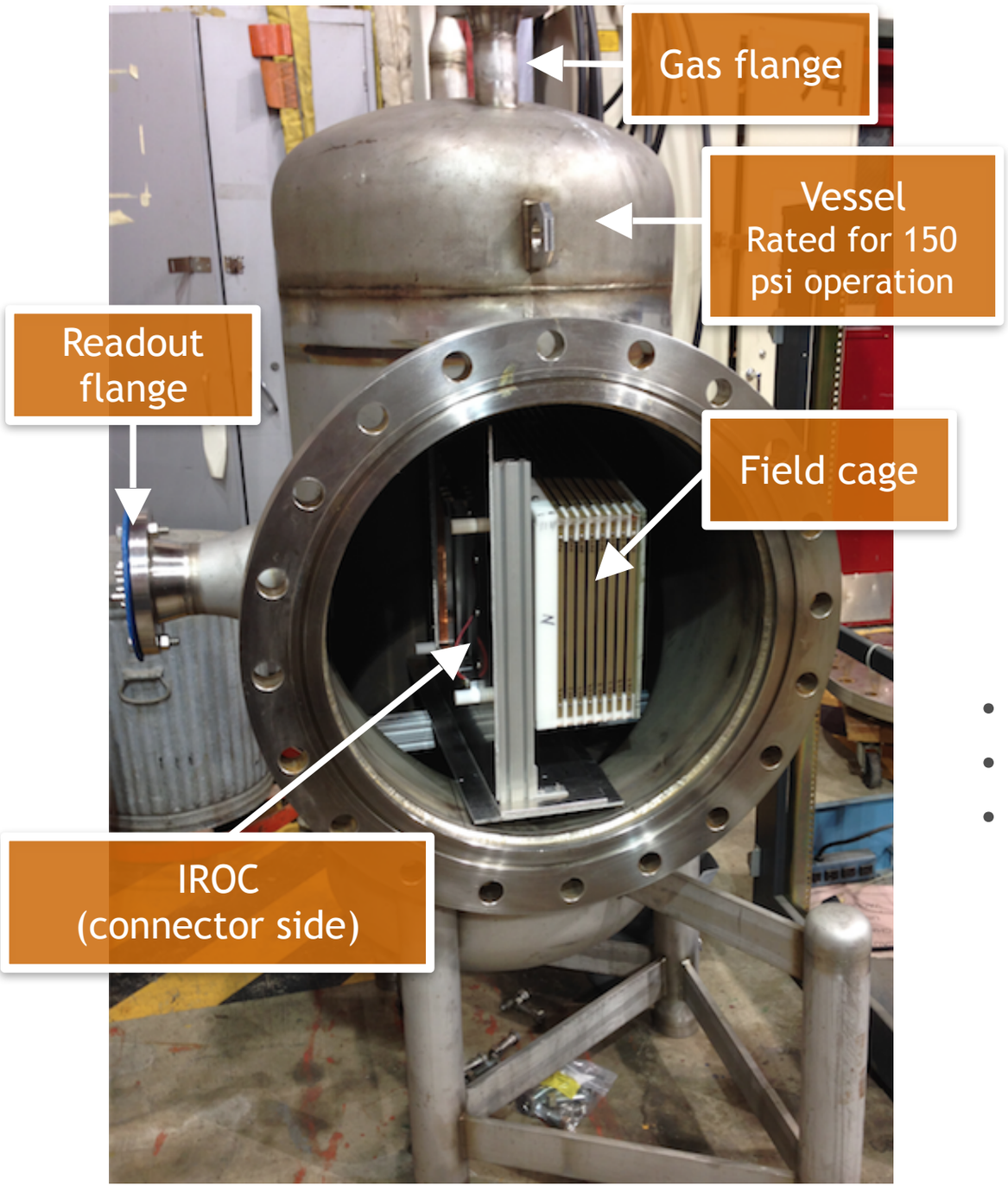


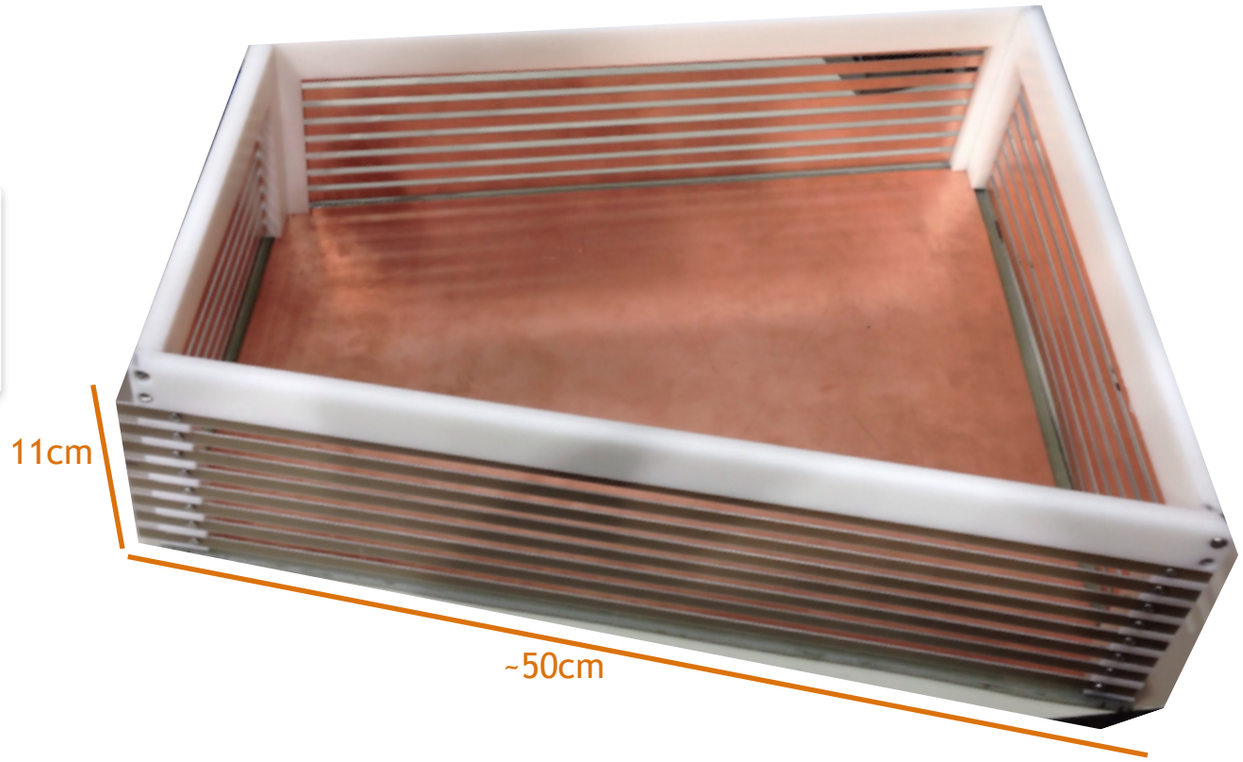
gain = ~2 x 10^4

Readout pad plane

Characterization of a fully equipped ALICE TPC Readout Chamber, M.L. Knichel

Fermilab High Pressure GArTPC Test Bench





- Active volume ~0.025 m^3 (25L)
- System designed for both 1 atm and 10 atm tests
- Will use LArIAT DAQ for pad readout
  - Verify TPC performance: gain, stability, uniformity
  - Operation in Fermilab charged particle test beam
    - Particle ID & reconstruction
    - Pile-up studies

Status and Future Plans

- Readout chamber and field cage constructed
- Preparing interface from IROC to LArIAT DAQ
- Gas system under construction
  - Test at 1 atm by the end of the year
    - 90:10 Ar:CO_2 and/or Ar:CH_4 to start
    - Test other gas mixtures, e.g. Xe-doped Ar
  - Tests at higher pressure after successful completion of 1 atm
- Future
  - Operation in charged particle test beam
  - Larger vessel and readout chambers (~1 m^3) in NuMI neutrino beam

Summary

- An HPTPC neutrino detector will open a new window into dynamics of neutrino-nucleus scattering
  - Complementary to Ar-only measurements of LArTPCs & off-axis techniques of E61
- Building 1m3 prototype for HPTPC R&D in UK
  - Measure hadronic scattering on Ar (at least)
    - ✓ TPC & readout working, pressure vessel delivered
    - ✓ Baseline reconstruction & analysis working
  - Will become a test bench for further collaborative R&D efforts
- Separate FNAL HPTPC R&D programme ongoing
- Proposal for beam test run submitted to CERN SPSC

➡ Working toward international collaboration to develop (and build) HPTPC *neutrino* detector

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

Motivation: xsec systematics

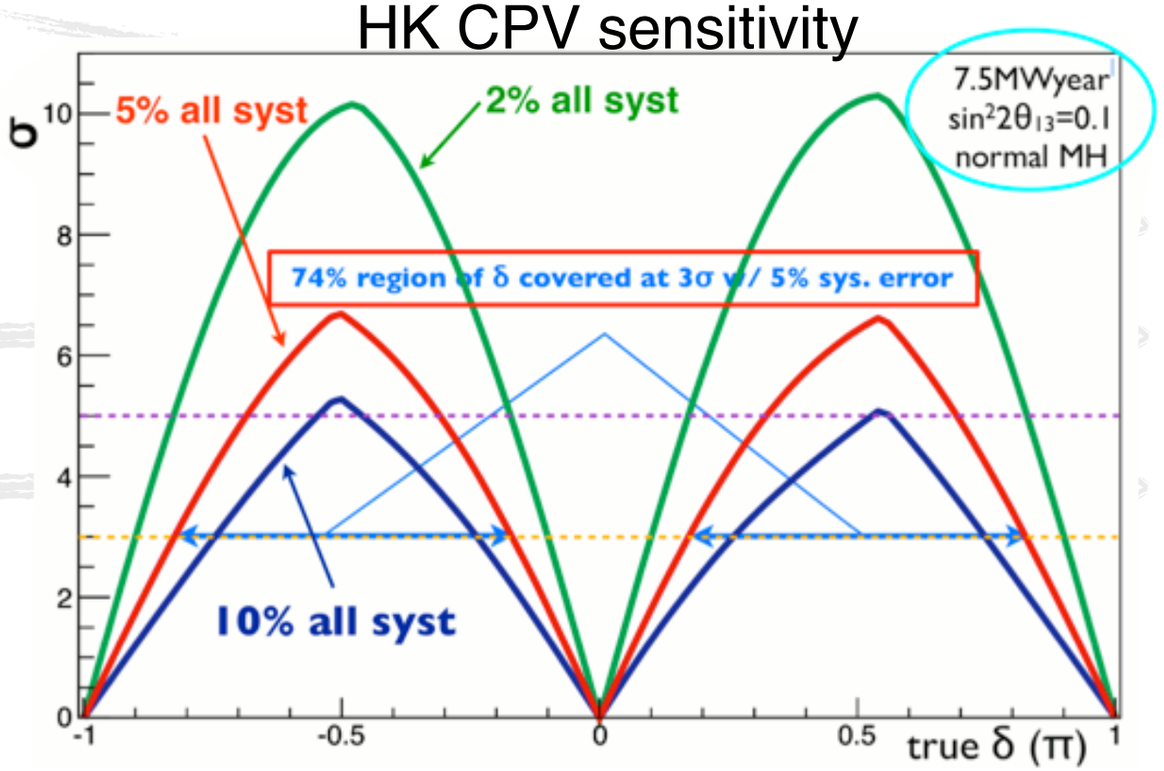
- 2016 T2K OA xsec systematics at 6-7% level
  - **this table does not include biases from 2p2h effects**
- CPV sensitivity improved dramatically with ~2% overall systematics
- Systematics driven by discrepancies between interaction models and data
  - What will we find with newer/ better data??

➡To get better models in generators, need better data for tuning models

T2K 2016 systematic error table

	$\delta_{N_{SK}}/N_{SK}$ (%)				
	1-Ring μ		1-Ring e		
Error Type	ν mode	$\bar{\nu}$ mode	ν mode	$\bar{\nu}$ mode	$\nu/\bar{\nu}$
SK Detector	3.9	3.3	2.5	3.1	1.6
SK Final State & Secondary Interactions	1.5	2.1	2.5	2.5	3.5
ND280 Constrained Flux & Cross-section	2.8	3.3	3.0	3.3	2.2
$\sigma_{\nu_e}/\sigma_{\nu_\mu}$, $\sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.0	0.0	2.6	1.5	3.1
NC 1γ Cross-section	0.0	0.0	1.5	3.0	1.5
NC Other Cross-section	0.8	0.8	0.2	0.3	0.2
Total Systematic Error	5.1	5.2	5.5	6.8	5.9
External Constraint on θ_{12}, θ_{13}, Δm^2_{21}	0.0	0.0	4.1	4.0	0.8

HK CPV sensitivity

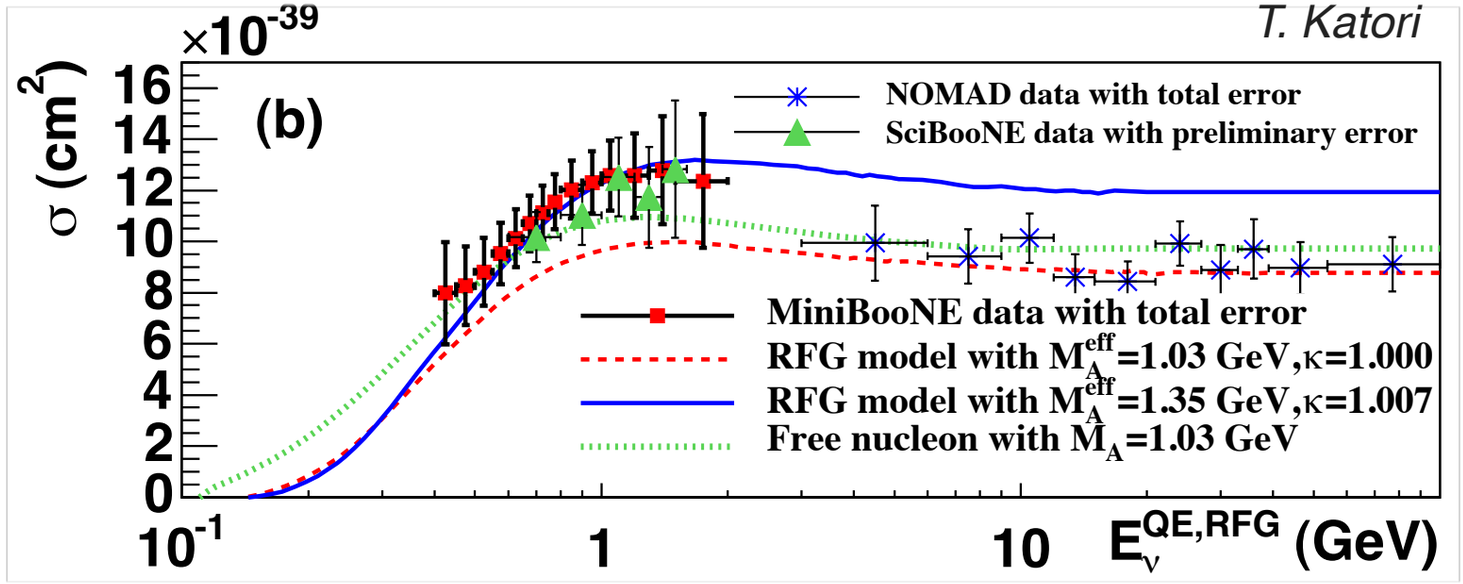


Cross-section systematics

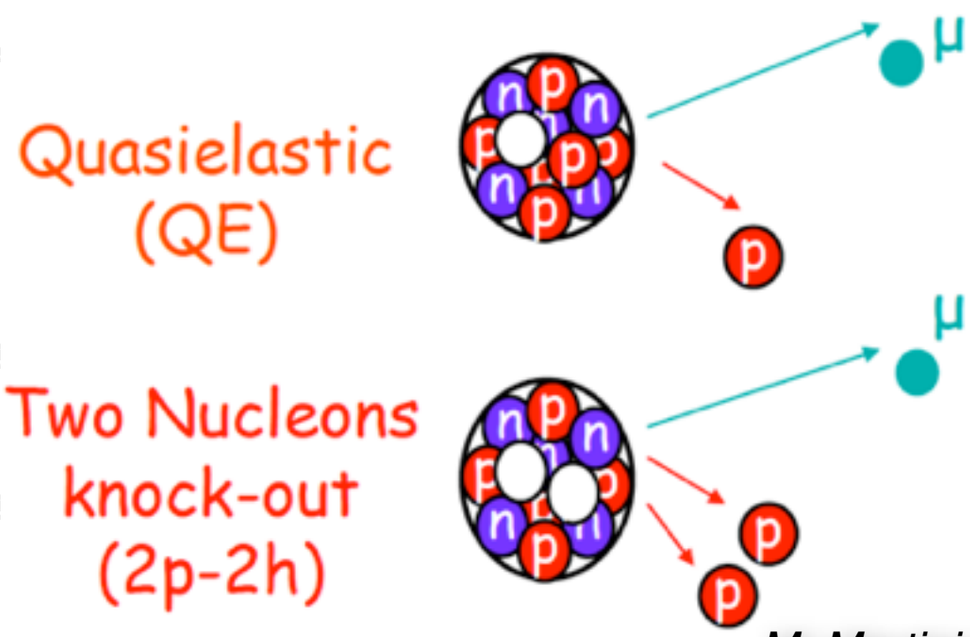
- ν_μ CCQE data show low/high E_ν discrepancies
  - MiniBooNE/SciBooNE & NOMAD
- Explanation: multinucleon scattering—not simulated by neutrino interaction generator MCs

➡Not included in MINOS, MiniBooNE, early T2K, early NOvA publications

- Misidentified events are not reconstructed correctly—results in biased E
- Even very small effects can become important when you are driving toward 2% total errors!



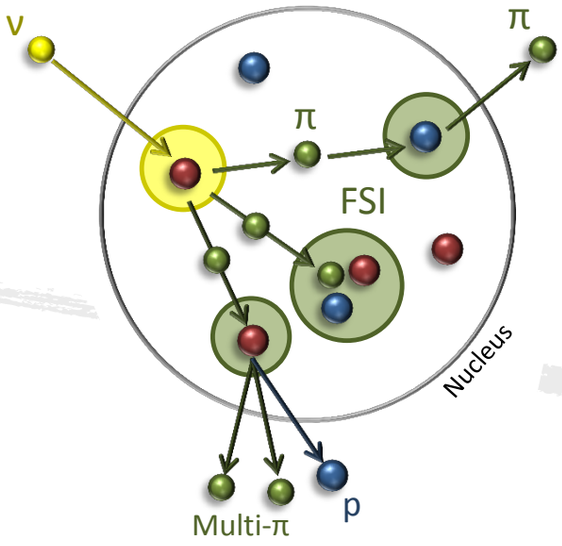
arXiv:1002.2680 [hep-ex]



M. Martini

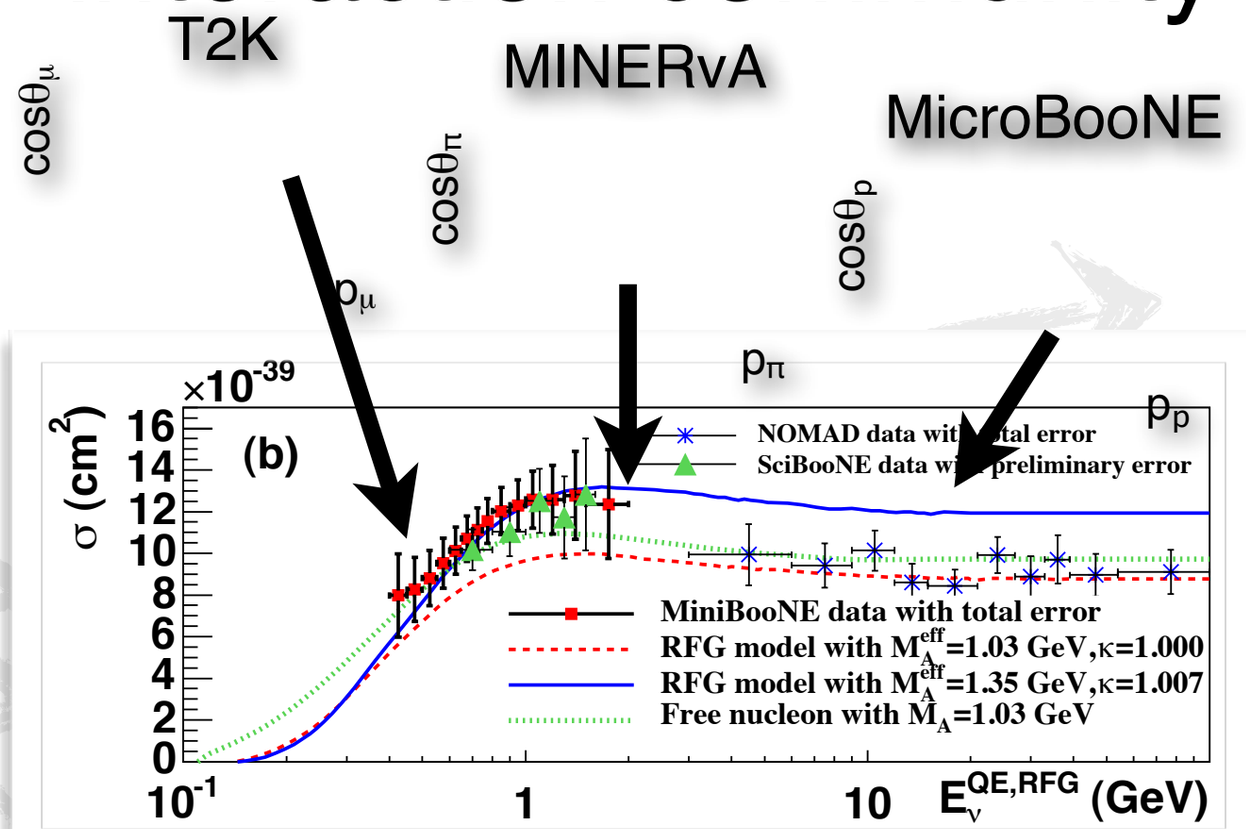
arXiv:0910.2622[hep-ex]

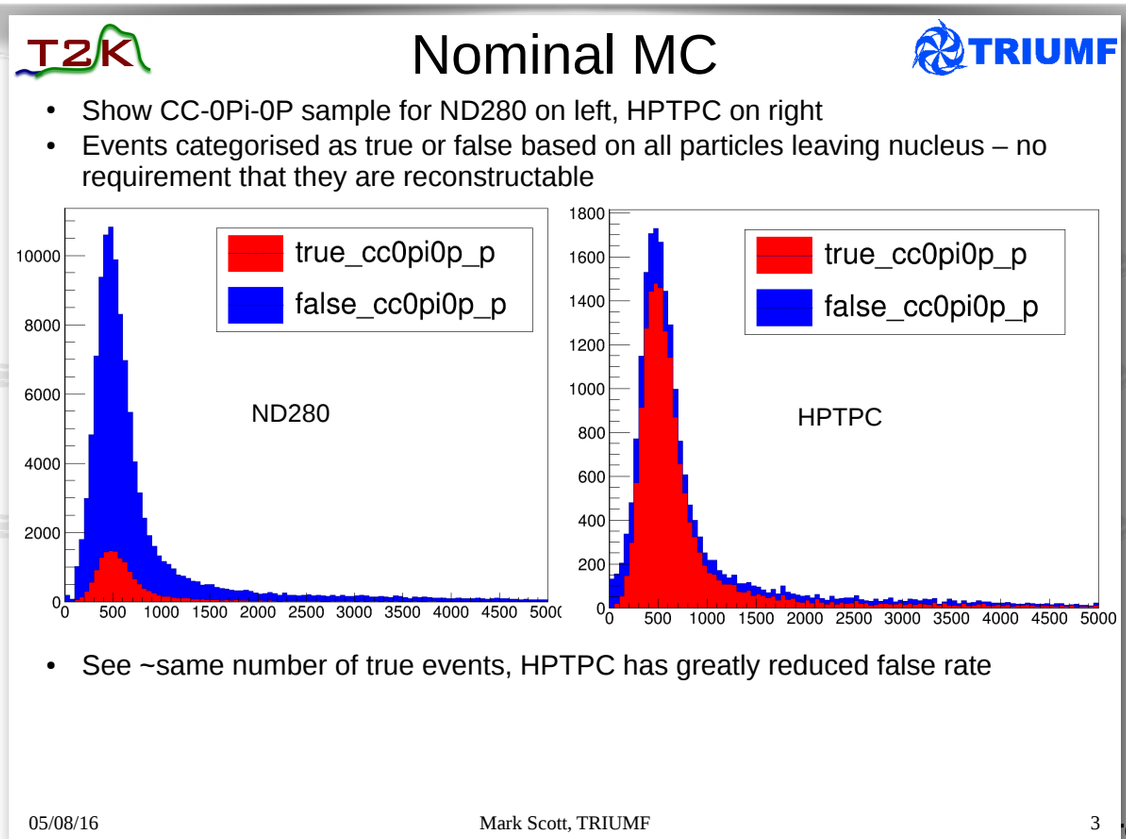
Growing Consensus in ν-interaction community



- We need broad coverage
  - Model independent measurements spanning full phase space (4π) **and many nuclei**
- Need sufficiently low energy thresholds for recoil nucleons to separate 1p1h from 2p2h events

➡ Gas TPC provides unique opportunities to address issues





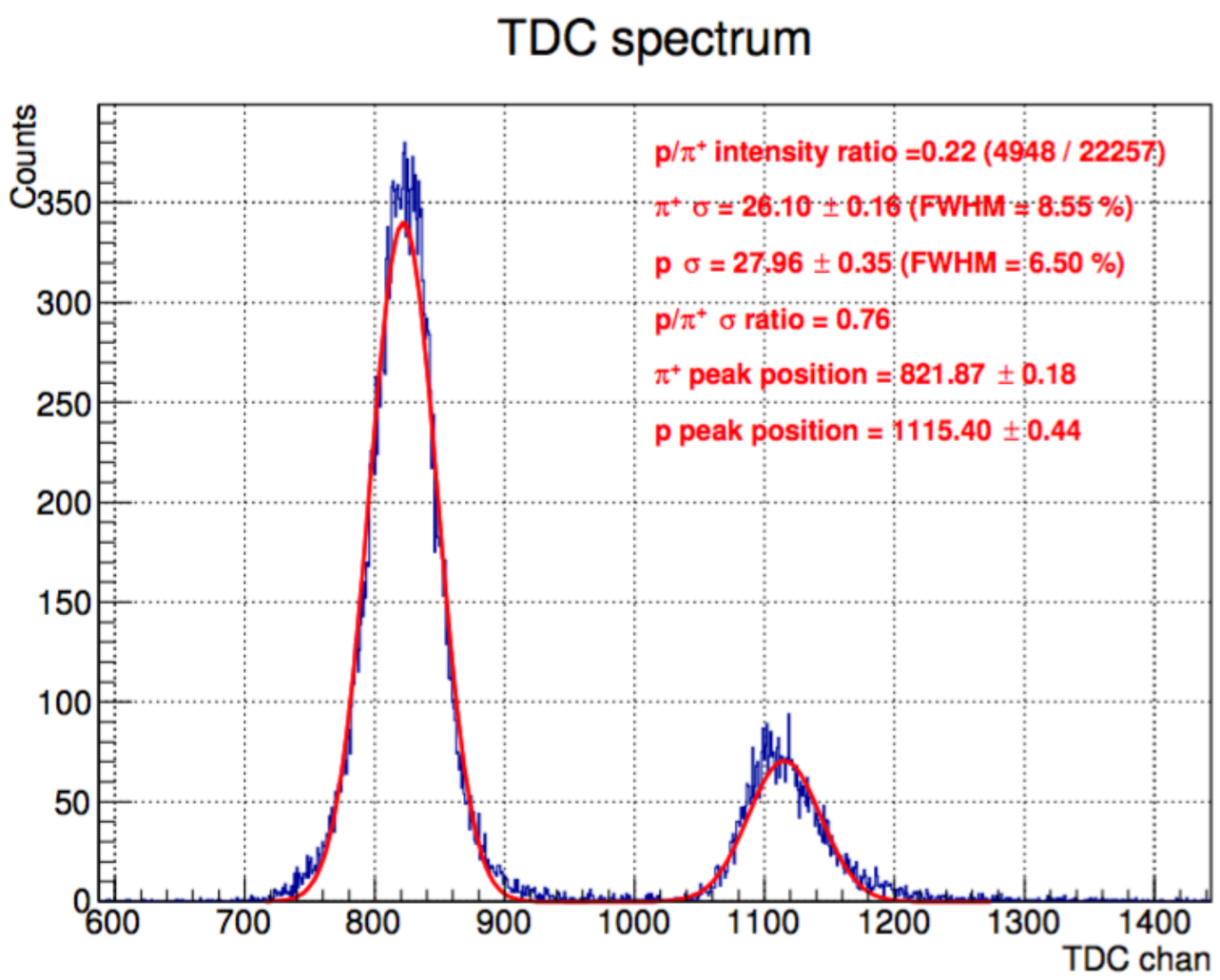
1m3 prototype overview

- Will use 1m3 prototype for future collaborative work work
- 1m3 is appropriate size for construction of full neutrino detector
  - 1m2 readout area
  - 1m drift length
  - baseline: CCD readout
    - UK area of expertise
    - very cost effective
  - extendable—we can add:
    - other optical readouts
    - different amplification devices
    - direct charge readout

T9/T10 flux measurements

Yu. Shitov

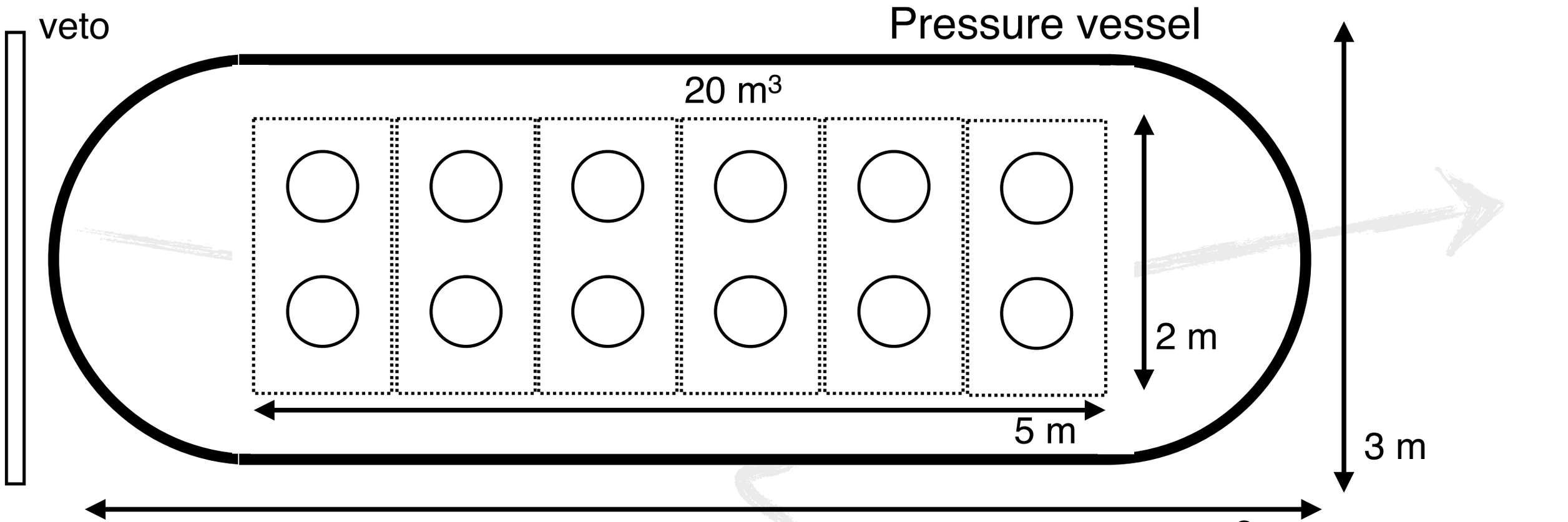
(a) Upstream TOF station in T9.



(b) Example of TOF spectra accumulated during a single run.

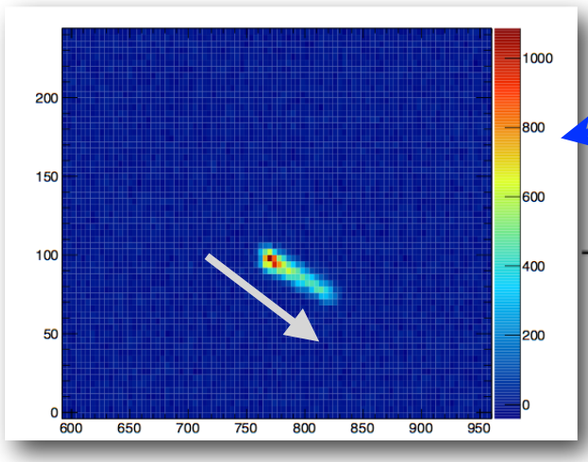
Proposal Fig. 4

What might an HPTPC neutrino detector look like?

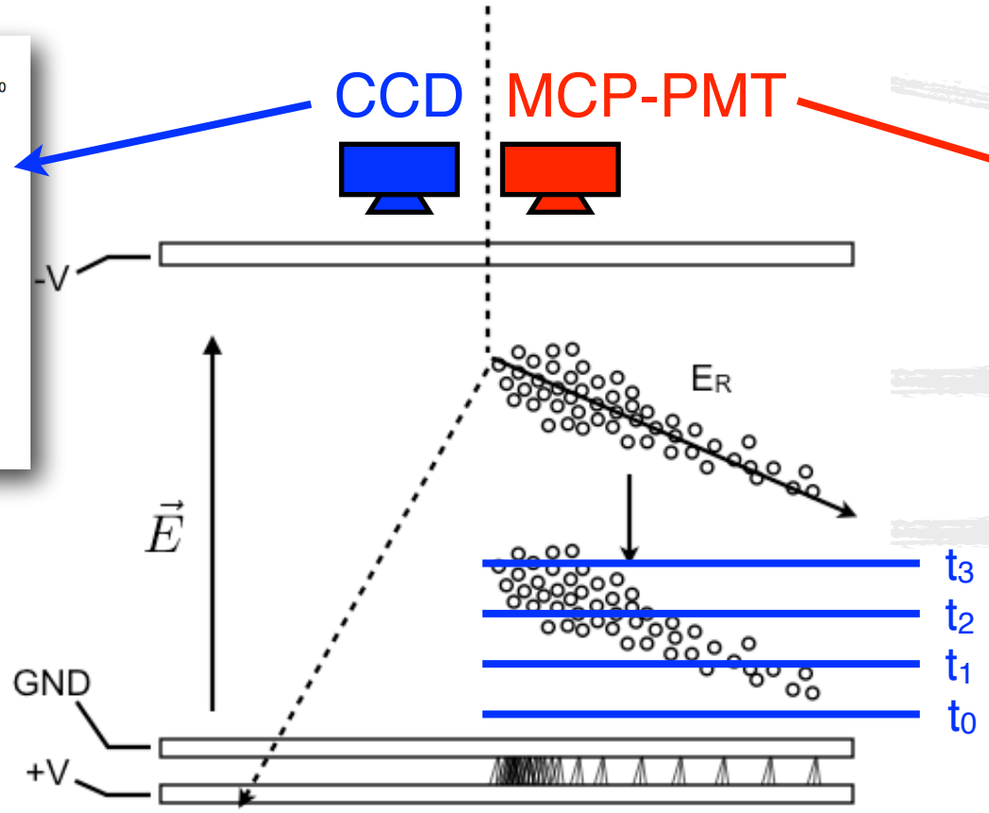


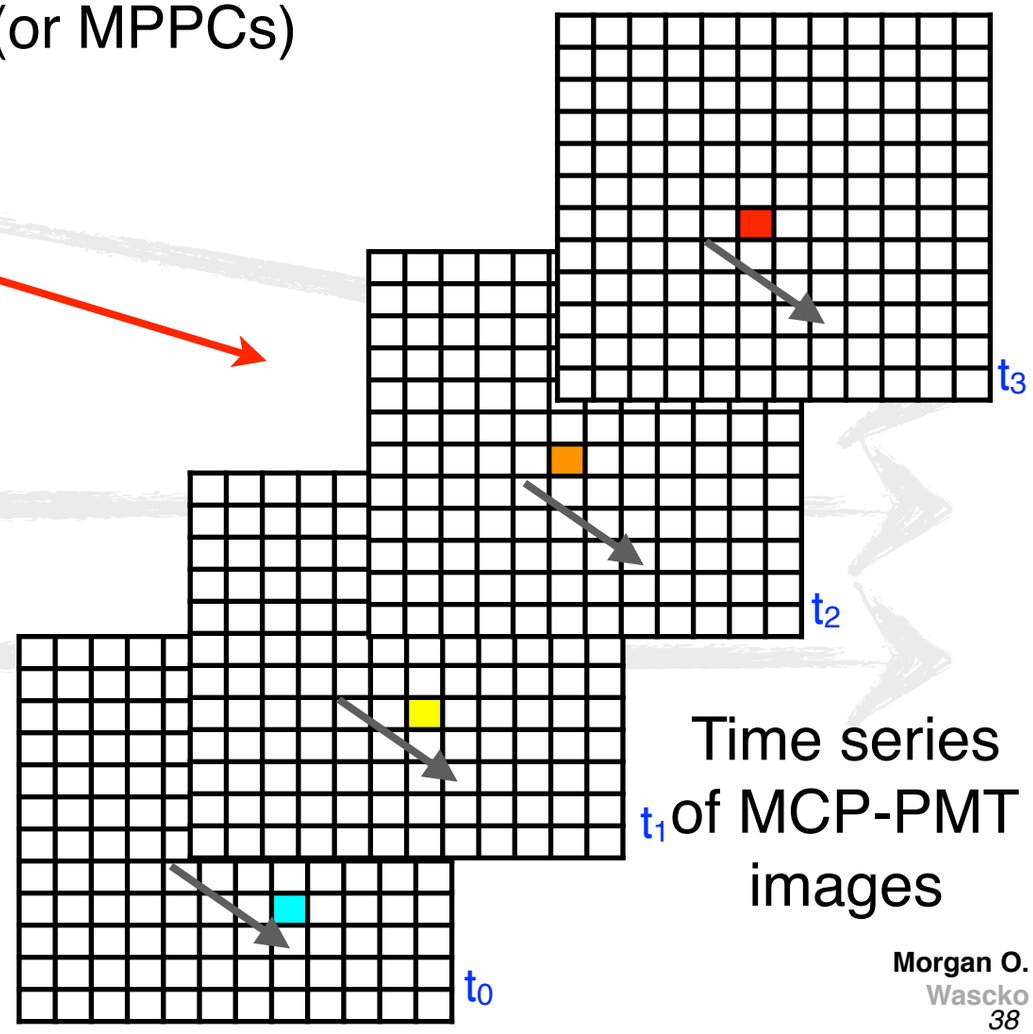
Hybrid optical readout

- **Can tracking be established with only optical 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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