3rd Workshop on Neutrino Near Detectors based on gas TPCs
平成29年 05月 21日

Overview of HPTPC Work (WP9)

M O Wascko
<m.wascko@imperial.ac.uk>
Imperial College London

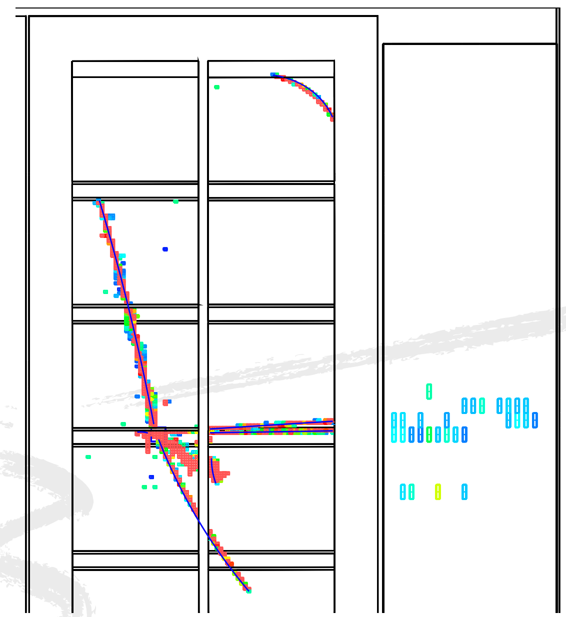
Outline

- Introduction to HPTPC
  - Complementarity of ND concepts
- Cartoon of HPTPC neutrino detector
  - HPTPC neutrino interaction rates
- HPTPC R&D work threads
- 1m3 prototype outlook
- RHUL lab development (Shitov)
- Conclusion

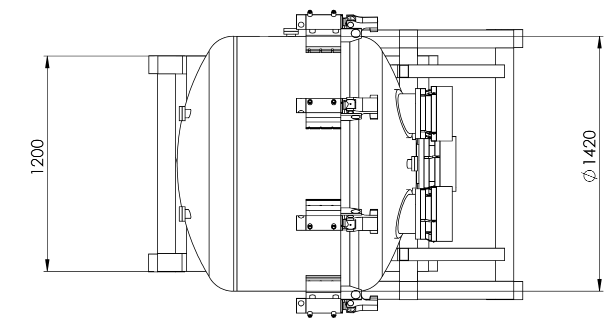
HPTPC overview

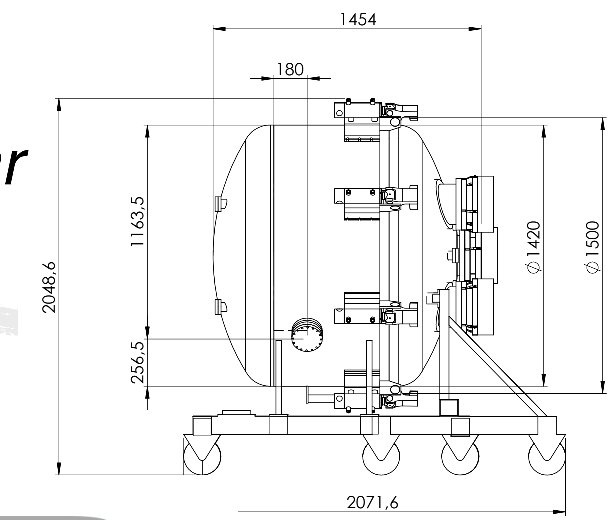
- Neutrino detector wish list:
  - ☑ ~4π coverage
  - ☑ Magnetisation
  - ☑ 3D reconstruction
  - ☑ Excellent PID
  - ☑ Nuclear target flexibility
  - ☑ Low momentum particle detection threshold
  - ☑ Technology synergy with other areas/fields

➡HPTPC has it all!

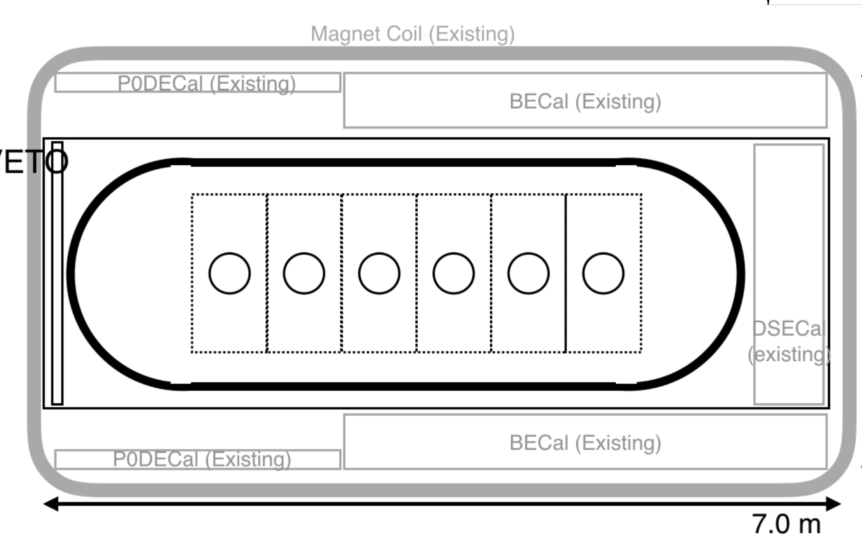


Pip Hamilton's thesis: analysis of gas interactions in existing T2K TPCs





Schematic of 5 bar pressure vessel



Cartoon of HPTPC in ND280

(0th order design: simplest pressure vessel possible)

What do we get with a near detector?

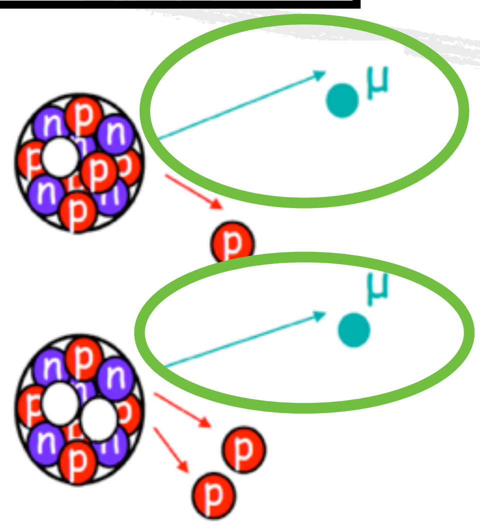
Two complementary approaches to near detectors

~belt & braces~

Water Cherenkov

Quasielastic (QE)

Two Nucleons knock-out (2p-2h)



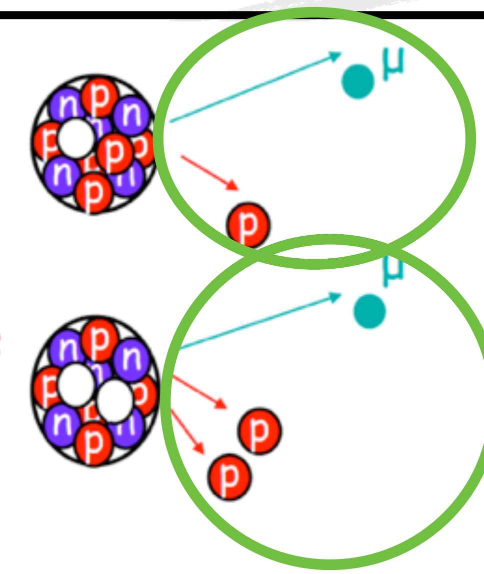
Resolve charged lepton partners. Filter out recoil hadrons.

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

Fine grained detectors

Quasielastic (QE)

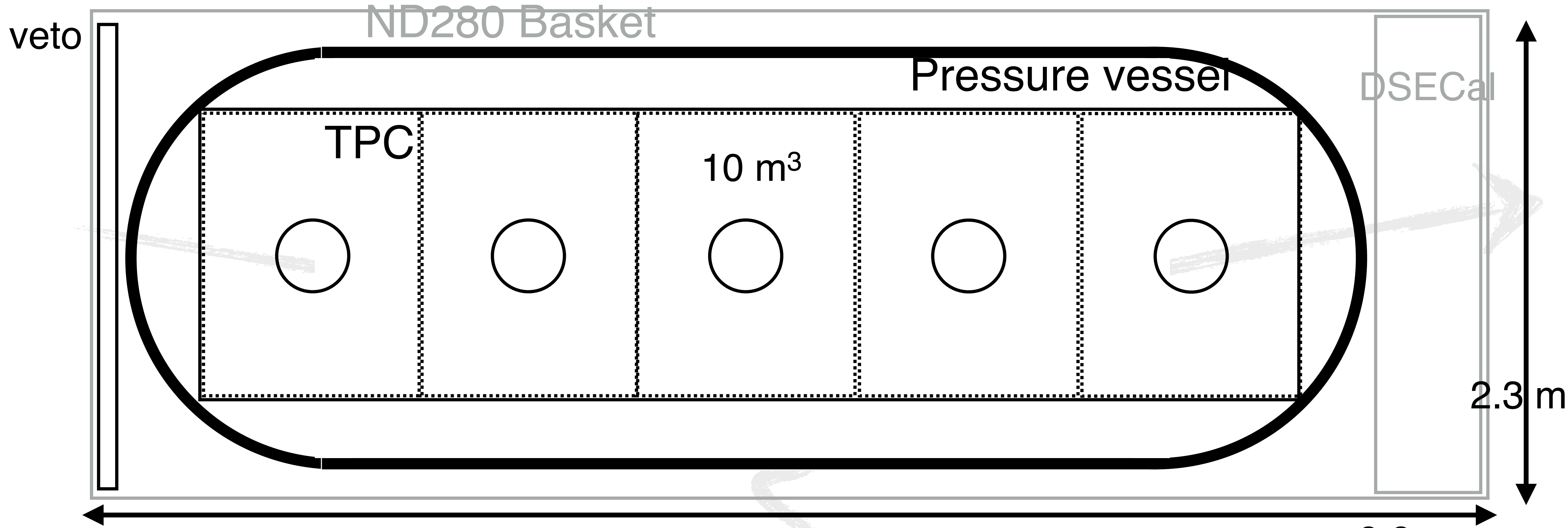
Two Nucleons knock-out (2p-2h)

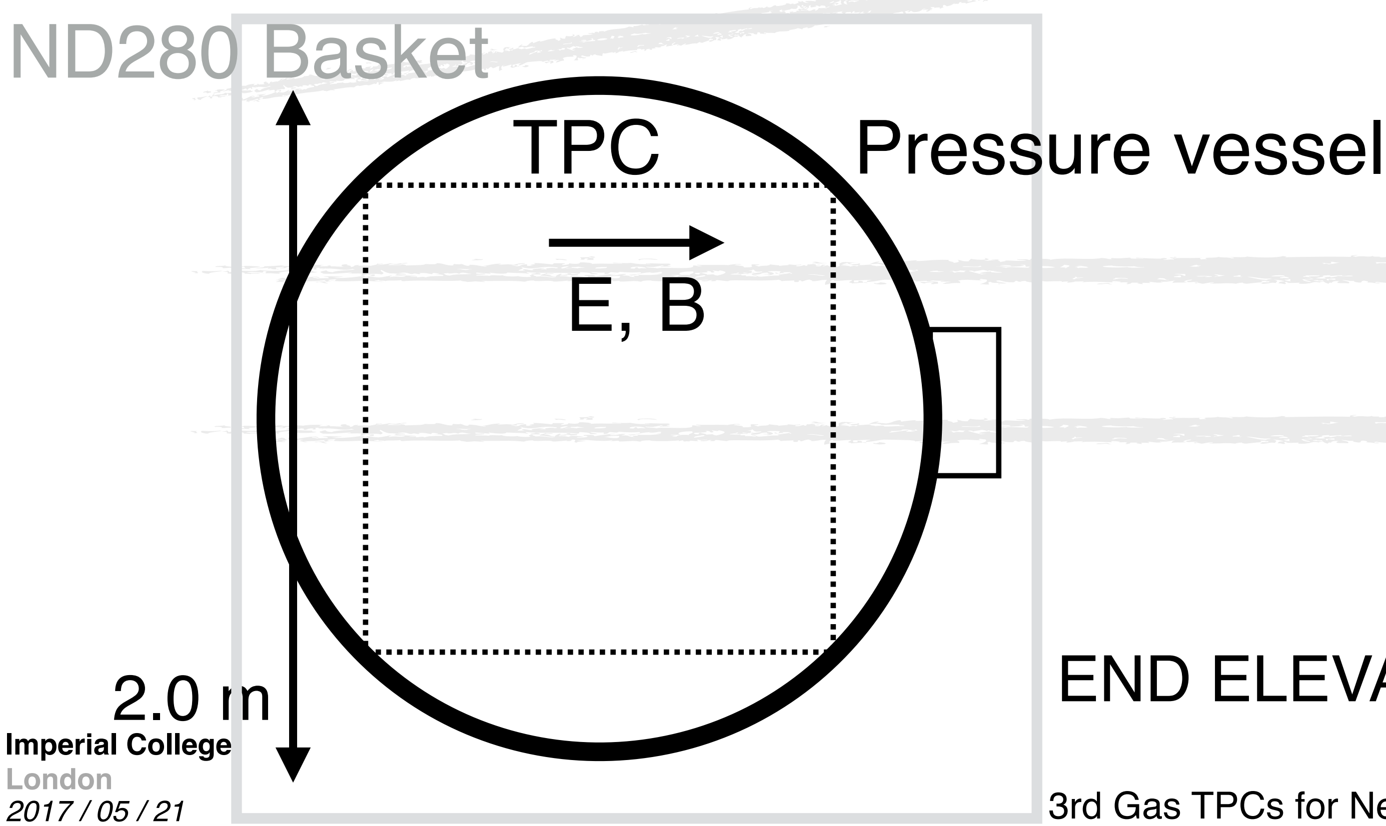


Resolve as much as possible. Compare detailed information to models.

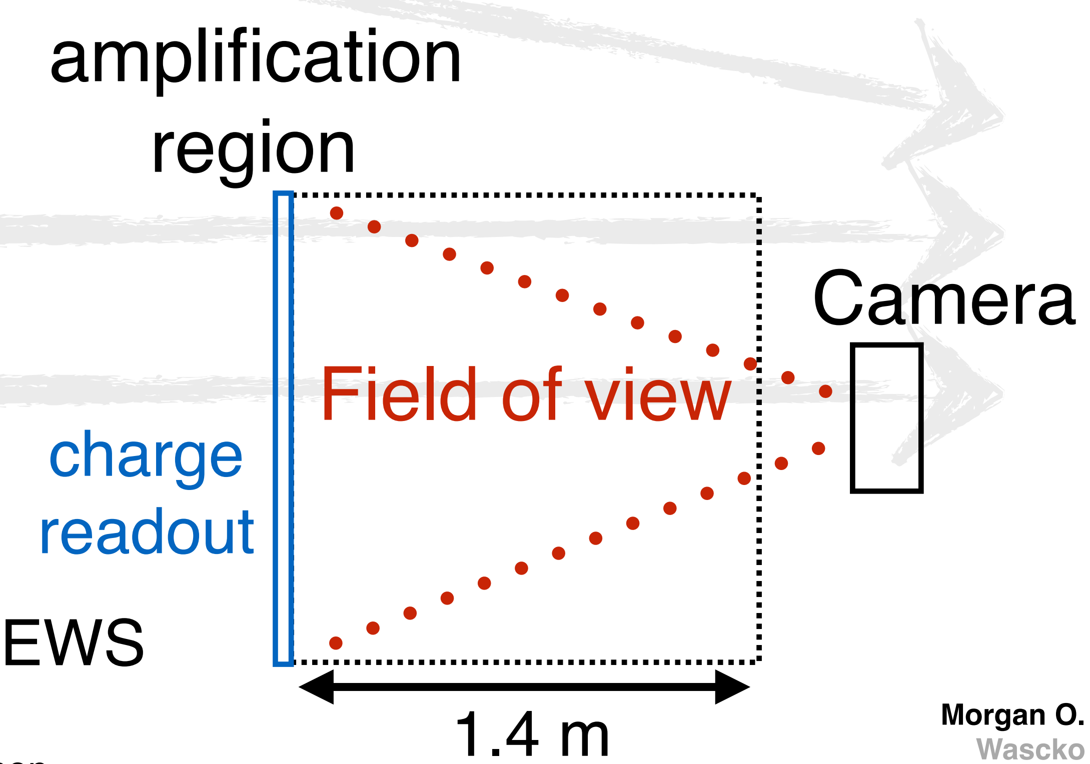
- More info than far detector
  - Can use multiple target nuclei
- Additional info allows more model testing
  - allows/requires close coordination with theory community
- HPTPC approach: reduce detection thresholds as far as possible
  - Maximise usable information

What might an HPTPC neutrino detector look like?





END ELEVATION VIEWS



HPTPC Event rates

CC-inclusive interactions per 10^{21} POT

Gas	mass, 10 m3 at 5 bar	NuMu Interactions	NuE interactions
He	1.59	524	9
CH4	6.35	2,097	38
Ne	7.94	2,621	47
Ar	15.9	5,243	94
CF4	34.9	11,530	207
CO2:N2	16.8	5,558	100

HPTPC work threads

- MC development (Zack)
- Software work
  - TREx reconstruction (Sammy/Paula/Jen)
  - Analysis development (Will, Patrick)
- hardware work
  - gas measurements for tuning MC
  - Build 1m^3 HPTPC and use in CERN testbeam to measure p-nucleus cross section
    - **start with CF_4**, then try for Ar, Ne, CH4
    - Use optical readout design based on DMTPC
- Future R&D direction:
  - Install charge readout electronics into 1m3 HPTPC prototype
  - Develop hybrid detector readout
    - Saves money, and helps eliminate instrumental effects

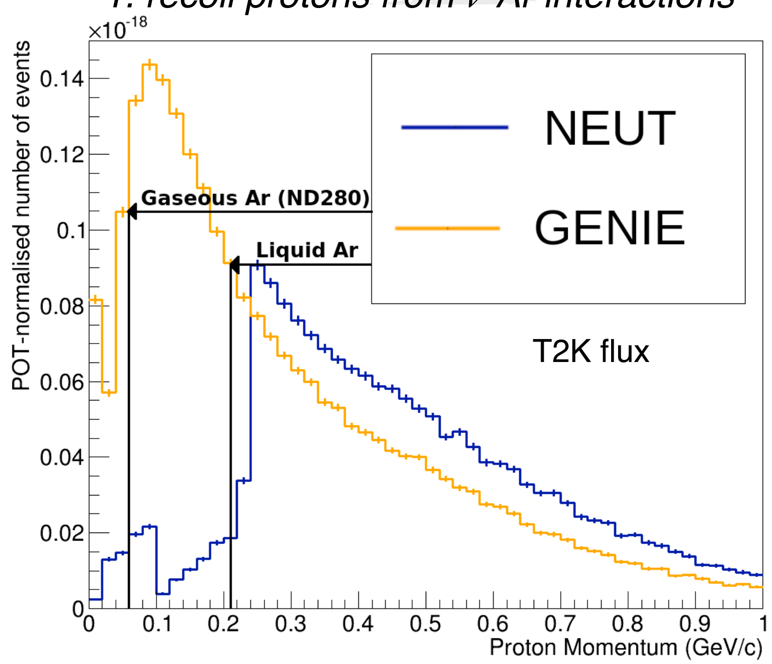
CERN beamtest

Imperial, Lancs, RHUL, Warwick

- **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)

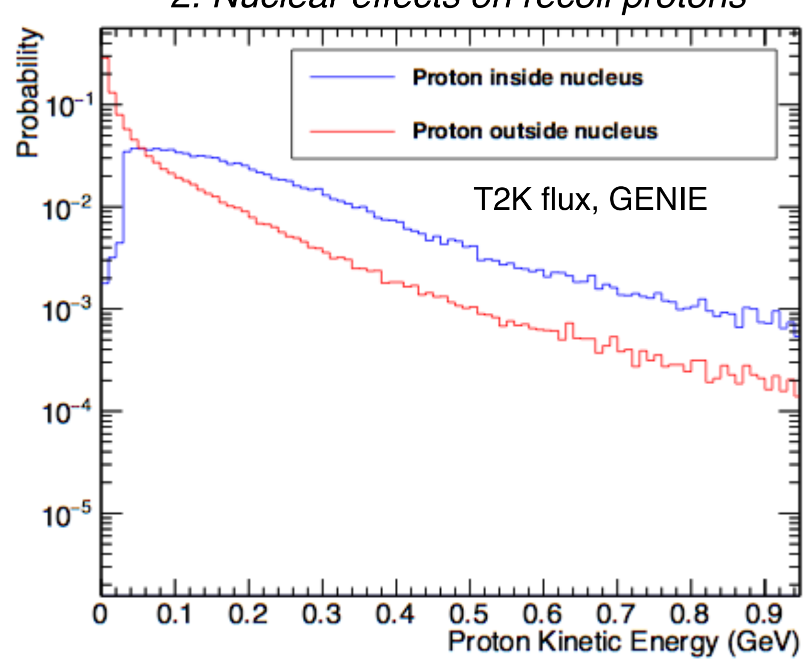
P Hamilton (Syracuse)

1. recoil protons from ν-Ar interactions



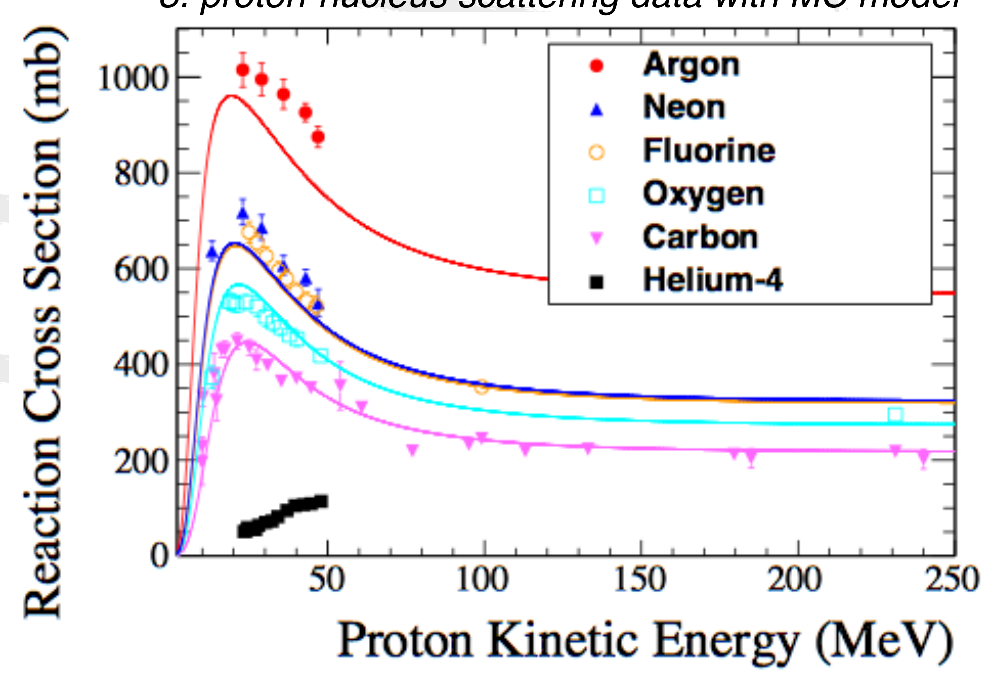
A Kaboth (RHUL)

2. Nuclear effects on recoil protons



A Kaboth (RHUL)

3. proton-nucleus scattering data with MC model



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

Update of RHUL lab development

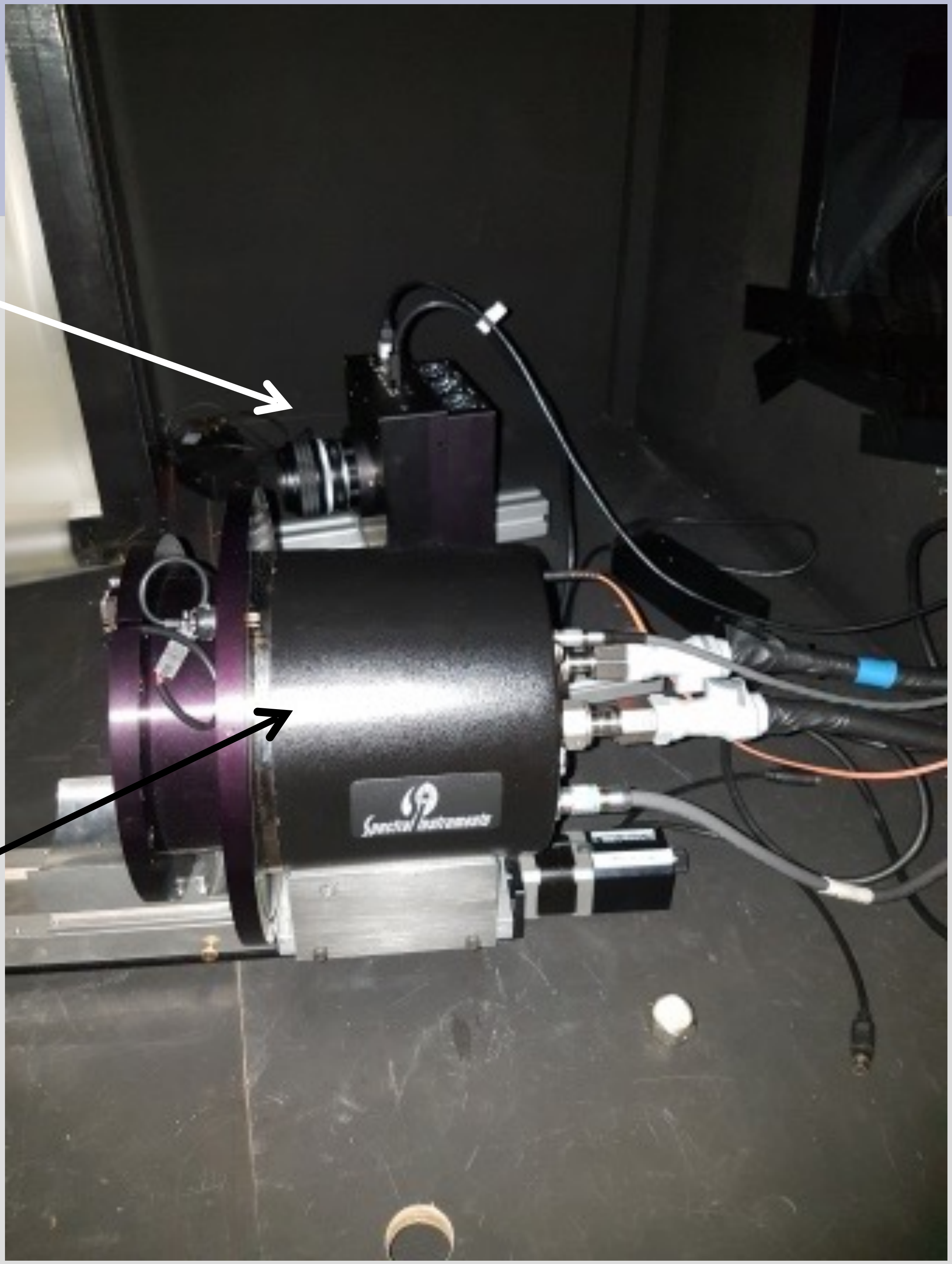
- **DM TPC is resurrecting at the moment: hardware + software.**
- **DAQ & Slow Control computers have been restored and configurated to work at RHUL.**
- **1S and 4S Cameras have been installed into the DarkBox test setup**
- **Work in progress on Software in order to wake up Slow control and DAQ programs**
  - **1 step: to run DM TPC DAQ program on test setup in RHUL with 4S Camera**
  - **2 step: to develop HP TPC DAQ, which should work with 1S Camera under linux (has never been done before, requires efforts to be implemented).**

Yu. Shitov (Imperial College London)

Cameras in blackbox

4S

1S



DarkBox test setup @ RHUL

DAQ computer

Main page of HP TPC monitoring & DAQ web-interface

Yu. Shitov (Imperial College London)

Conclusions

- HPTPC is a complementary approach to solving xsec error issues for CPV search
- HPTPC is a good fit for the existing ND280 facility
- Building 1m3 prototype for HPTPC R&D in UK
  - Will become a test bench for further collaborative R&D efforts
- Developing international collaboration toward building HPTPC *neutrino* detector
- UK R&D focussed on reducing the cost while maintaining best performance

Outline of HPTPC Session

11:45–11:55	HPTPC overview	Morgan Wascko
11:55–12:05	1m3 prototype progress	Mark Ward (MOW)
12:05–12:15	HPTPC Simulation	Zach Chen-Wishart (MOW)
12:15–12:25	TREx Reconstruction	Sammy Valder
12:25–12:35	HPTPC Sensitivity Progress	Will Parker


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

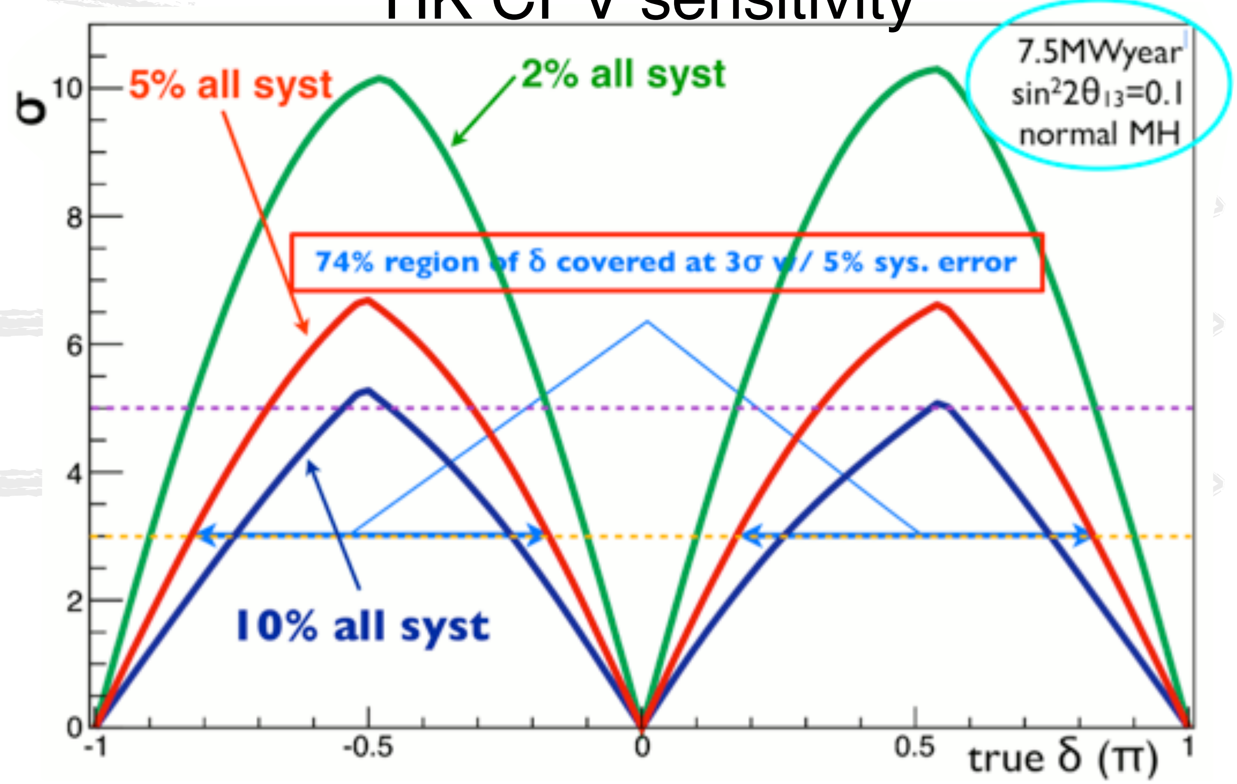
- 2016 T2K OA xsec systematics at 6-7% level
  - **this table does not include biases from 2p2h effects**
- CPV sensitivity improved dramatically with ~2% overall systematics
- Systematics driven by discrepancies between interaction models and data
  - What will we find with newer/ better data??

➡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

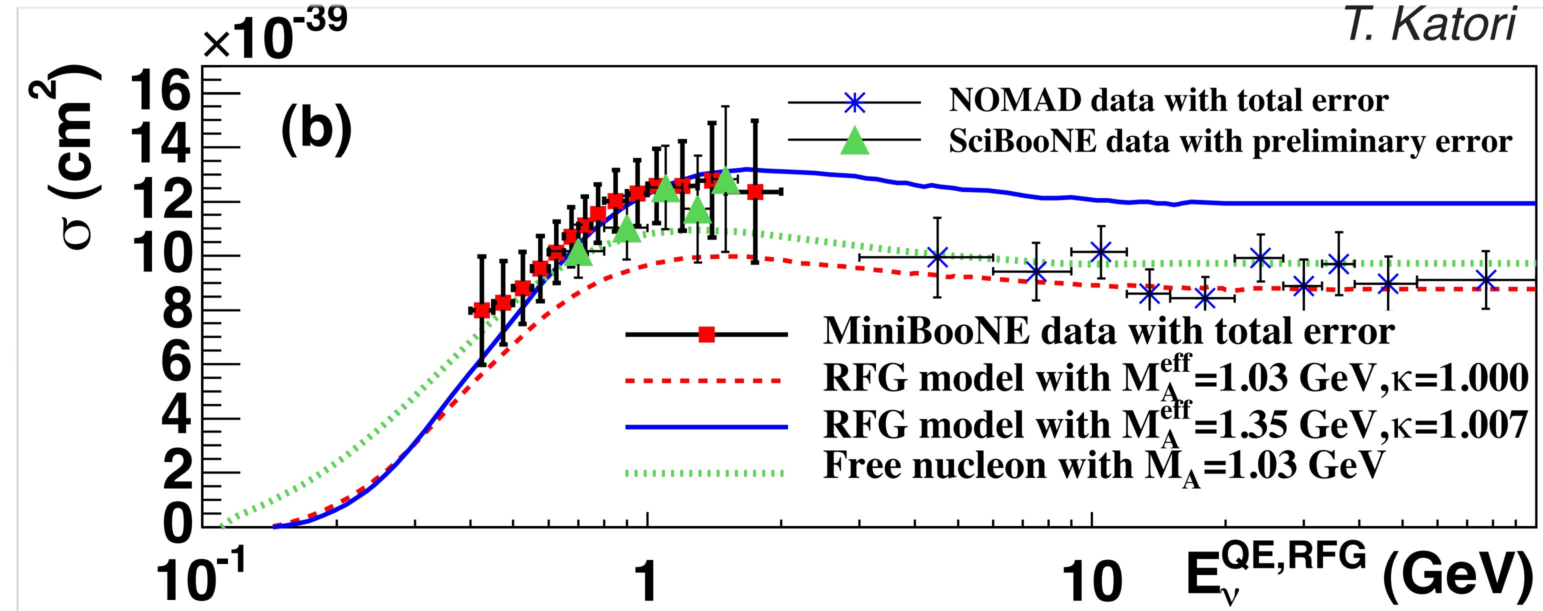


Cross-section systematics

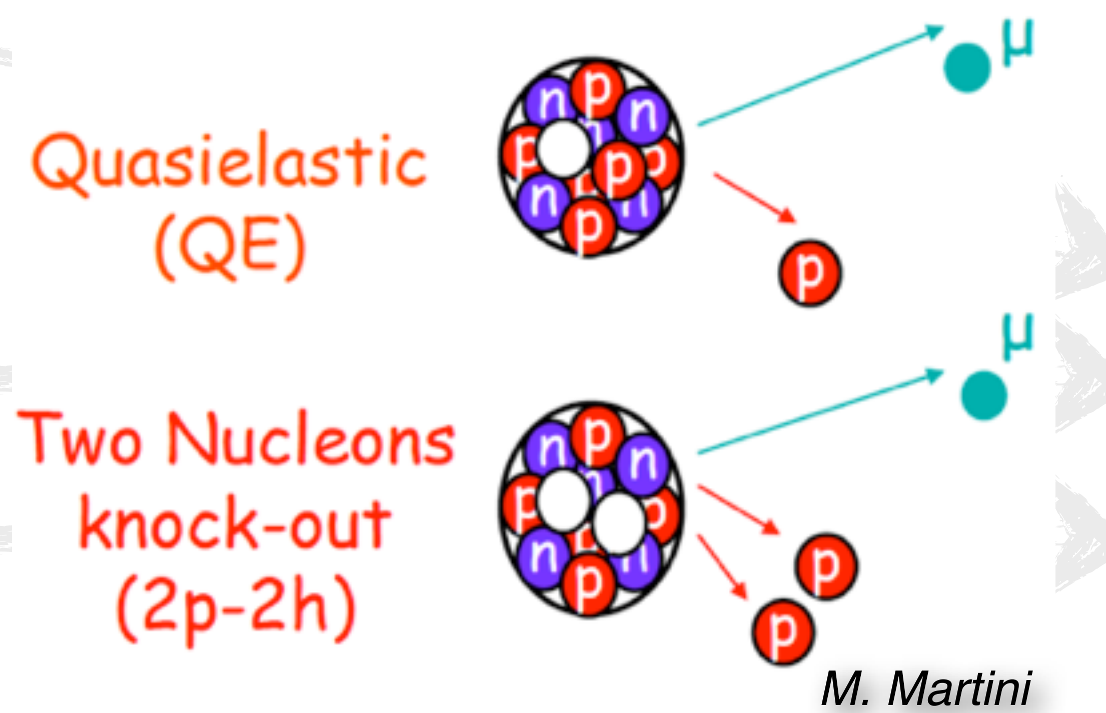
- ν_μ CCQE data show low/high E_ν discrepancies
  - MiniBooNE/SciBooNE & NOMAD
- Explanation: multinucleon scattering—not simulated by neutrino interaction generator MCs

➡ 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!

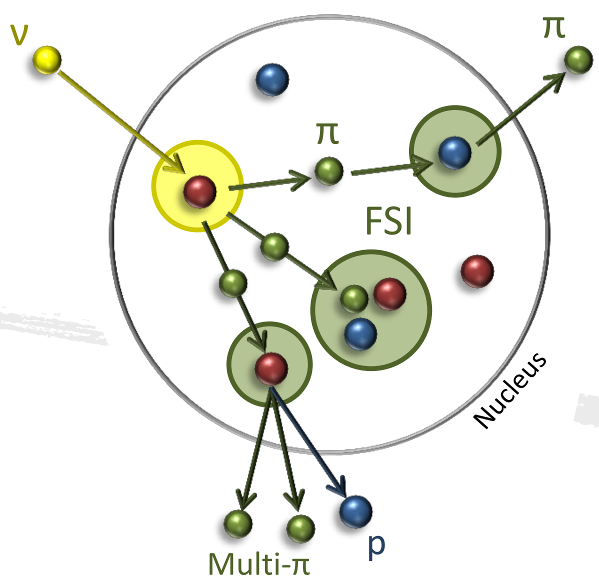


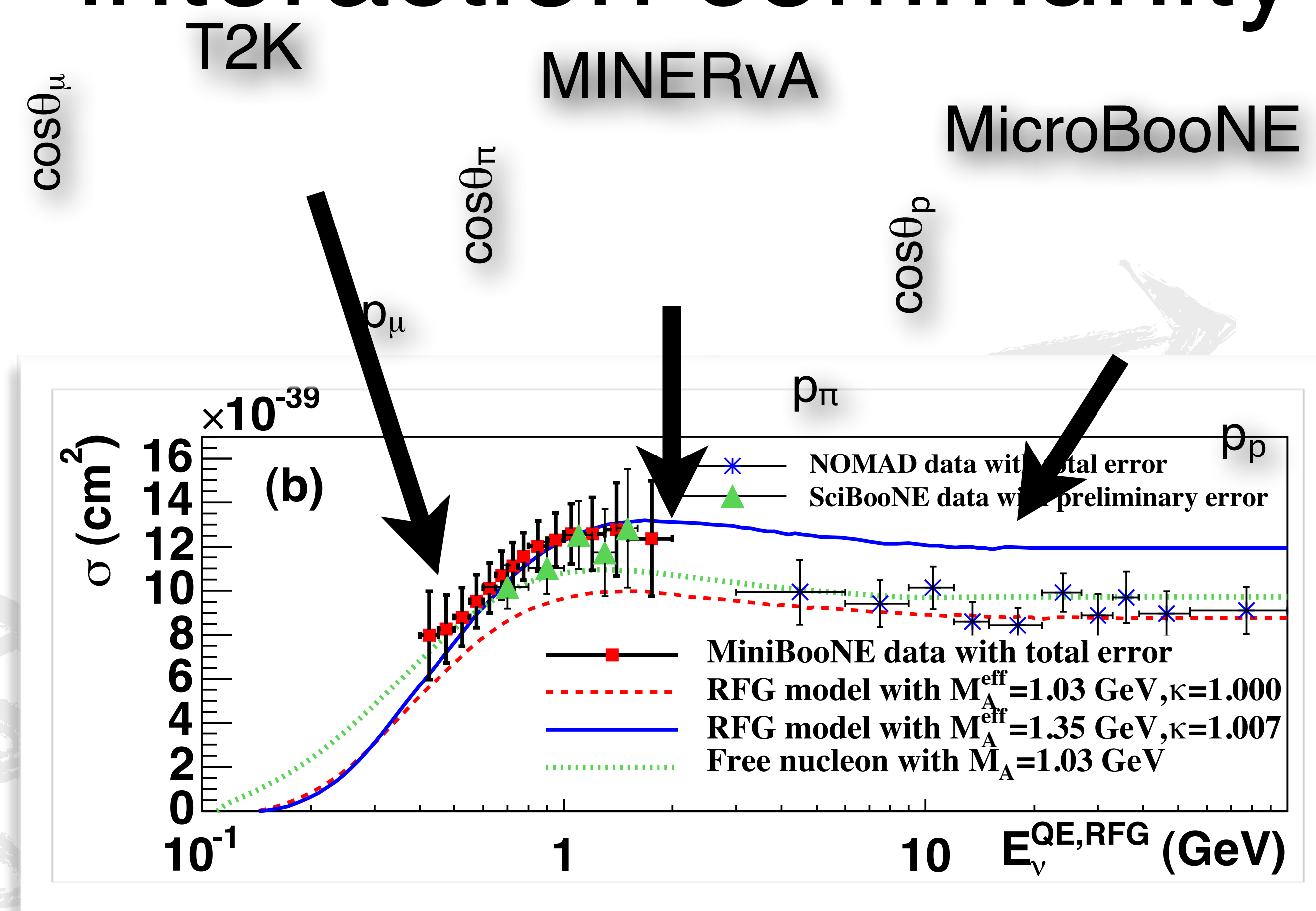
arXiv:1002.2680 [hep-ex]



arXiv:0910.2622[hep-ex]

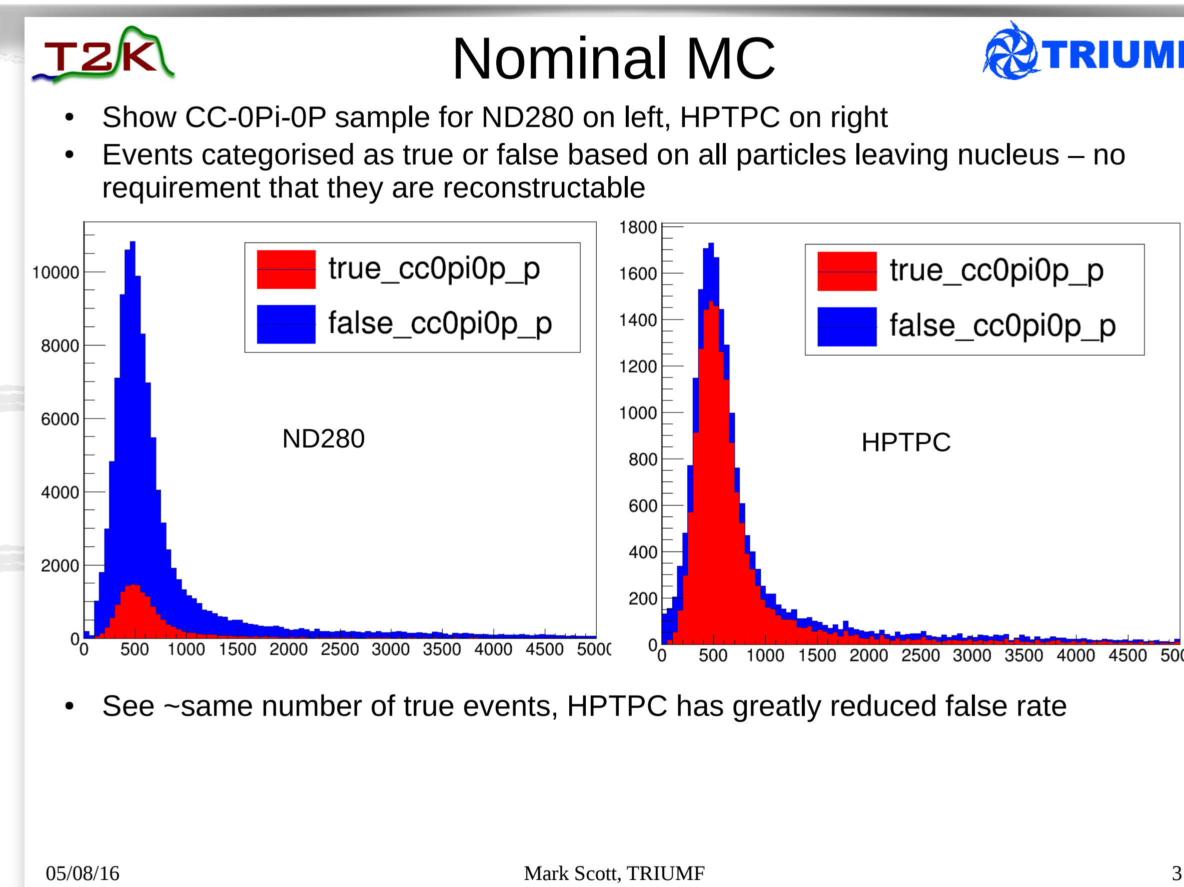
Growing Consensus in ν-interaction community





- 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

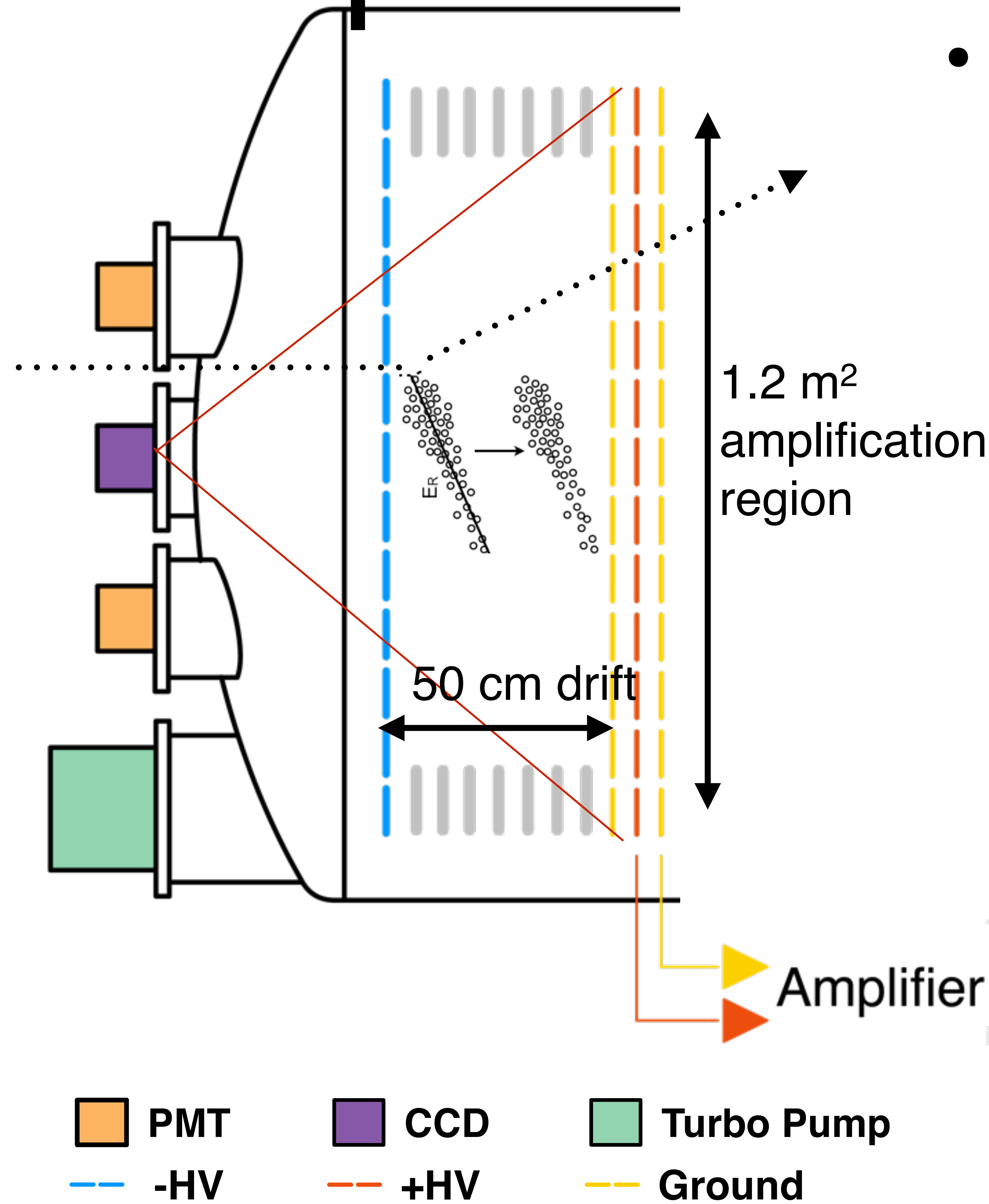


Consolidating efforts

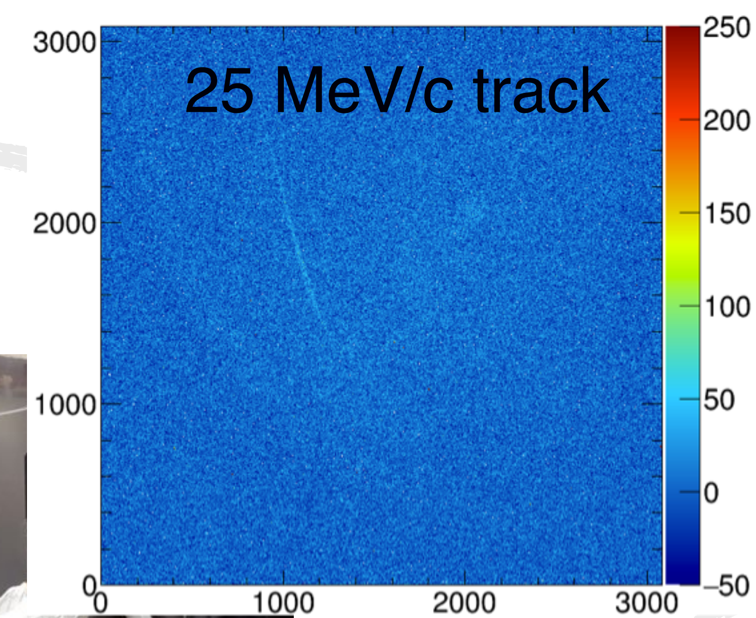
- HPTPC WG meeting established
- Connect and focus several HPTPC efforts
    - Focus on developing physics studies, report on software tools, report on hardware R&D
- Coordinate UK efforts with European and North American work
    - participation from all of the above
    - hope to expand to Japan as 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

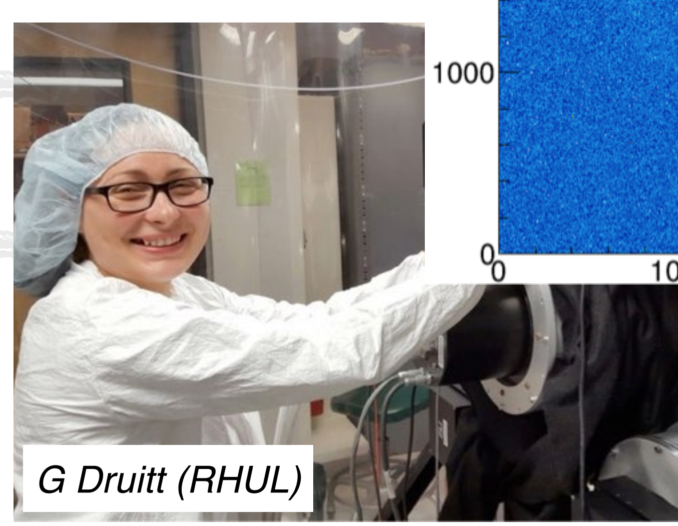
Optical TPC Readout

Imperial
Lancaster
RHUL
Warwick



- CCD images scintillation produced in the amplification region
  - Fairchild 386 16 MPix CCD + lens outside pressure vessel
  - 90 cm object distance
  - results in 1 mm readout pitch with 4x4 readout binning





HK R&D work

Imperial, RHUL

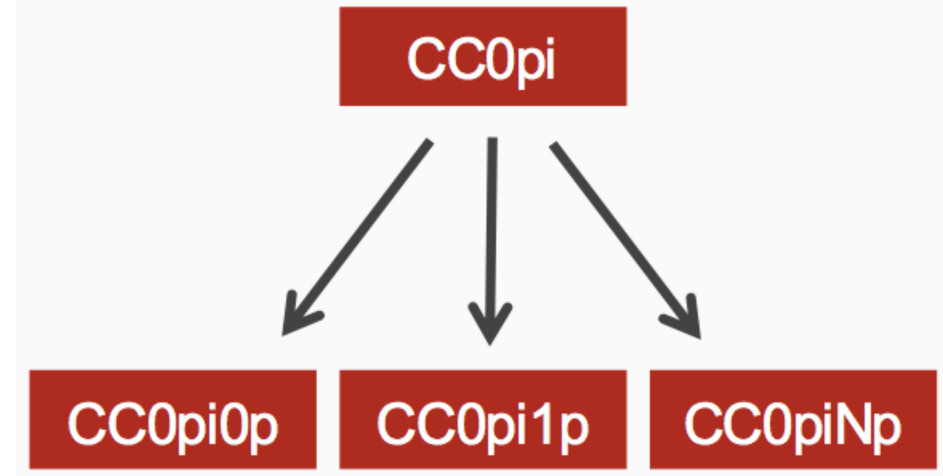
- Goals
  - Fully validated simulation of HPTPC
  - Detector design specification needed to achieve 2% total uncertainty
  - Physics studies of capabilities of HPTPC
- Work Plan

1. develop HPTPC simulation to determine the momentum threshold and PID requirements for HPTPC to reduce CPV xsecs to 2%
2. determine optimum design parameters to achieve physics goals
   - pressure, readout pitch, gas mixtures to achieve consistent timing across target species, readout granularity
3. validate HPTPC detector simulation with measurements of gas physics in relevant range of targets

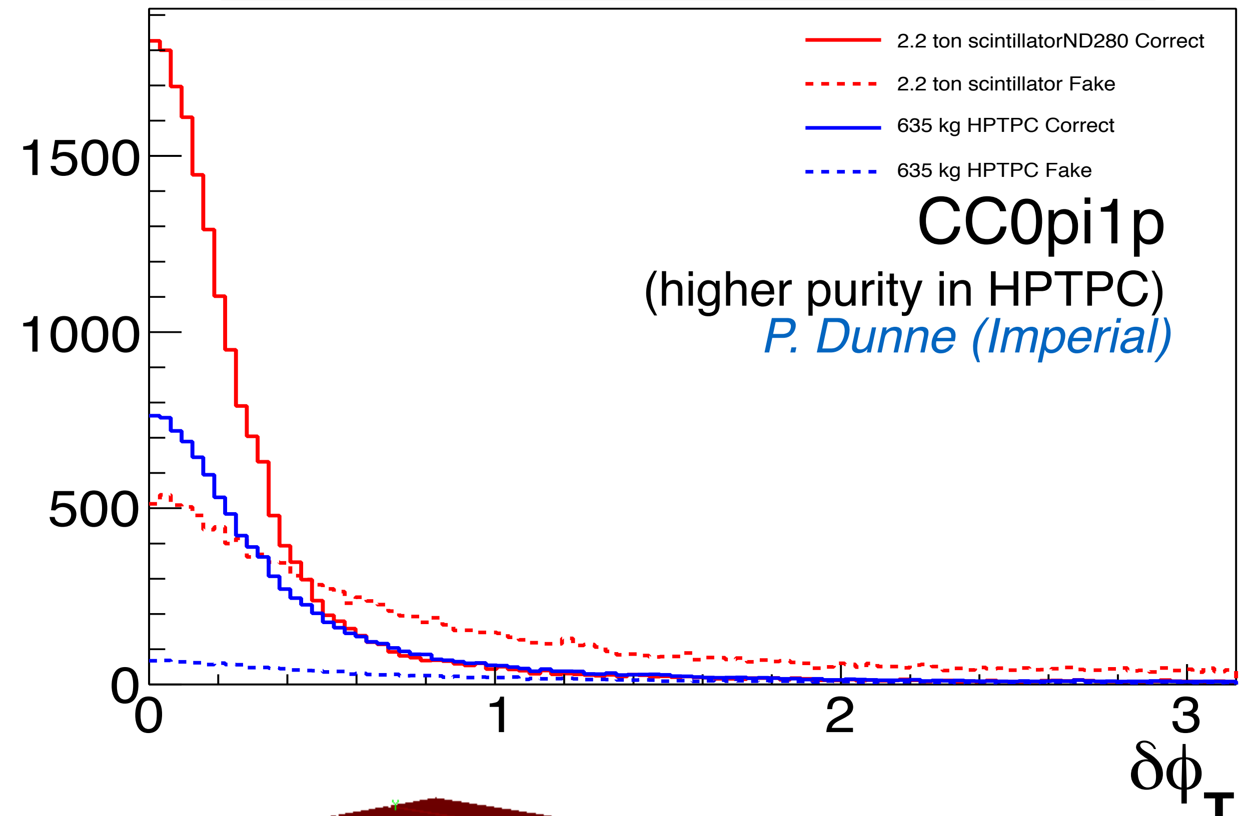
Gas measurements

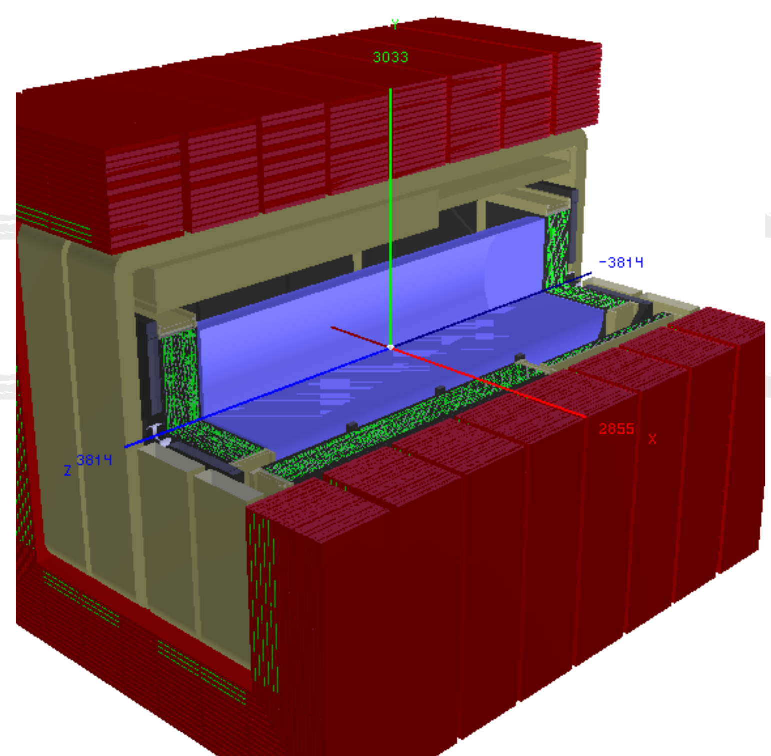
- Gas species:
  - He, Ne, Ar, CF_4, CH_4, CO_2
- Quantities to extract
  - energy deposition (dE/dX) [probably can be calculated]
  - energy ion per pair (W)
  - attachment probability ($\eta\eta$(**E**))
  - gas gain ($G(v/d_{readout},P)$)
  - spread in charge arrival time (Δt: v_d, $\sigma_{T,L}$)
- Timescale
  - Upgrading RHUL test stand for high pressure was not possible
  - Will use HPTPC 1m3 prototype to measure quantities above as part of commissioning work

Physics studies & software



- Performing studies on how we would *actually use* an HPTPC
  - isolating specific event topologies
    ➡xsec model testing and tuning
  - understanding energy recon
    ➡impact on neutrino oscillation sensitivity
  - Studying Xianguo's transversersities
    ➡Improve quality of analysis by using information most efficiently
- Developing full GEANT4 MC for HPTPC neutrino detector





HPTPC in ND280 basket
Yu. Shitov (Imperial)

HK near future work

Imperial, RHUL, Warwick

- Goals
  - Cost-optimised readout for HPTPC near detector conceptual design report.
  - Tools in place for technical design report.
- Work Plan

1. HPTPC Charge Readout Development
   1. Test charge readout plane (Micromegas from Saclay).
   2. DAQ software to use the T2K TPC readout back-end for charge strip readout.
   3. Deploy charge readout plane and electronics in the HPTPC test platform.
2. HPTPC Software Development
   1. software interface of the charge readout data format to existing TREx reconstruction package .
3. HPTPC Beam Test and Data Analysis
   1. data taking in pad vs. strip mode to study particle threshold & track counting, in CERN beamtest in 2018.
   2. measurement of reconstruction degeneracy, impact on efficiency/purity, from strip readout; cost optimisation.

Timeframes for work

R&D | PRD | Pre-Con

- 2017: build 1m3 prototype; gas measurements in 1m3 prototype; micromegas development in low pressure TPC; HPTPC MC development; HPTPC event analysis development;
- 2018: CERN beam test(s); micromegas installation; hadron scattering data analysis; HPTPC OA studies complete; reconstruction software ;
- 2019: Pad v strip data and analysis; realistic cost estimate for HPTPC neutrino detector; Conceptual design for HPTPC .
  - “Construction ready”
- 2021: ND280 upgrade.
- 2026: HK startup.
- 2027/8: HK becomes systematics limited.

HPTPC Event rates

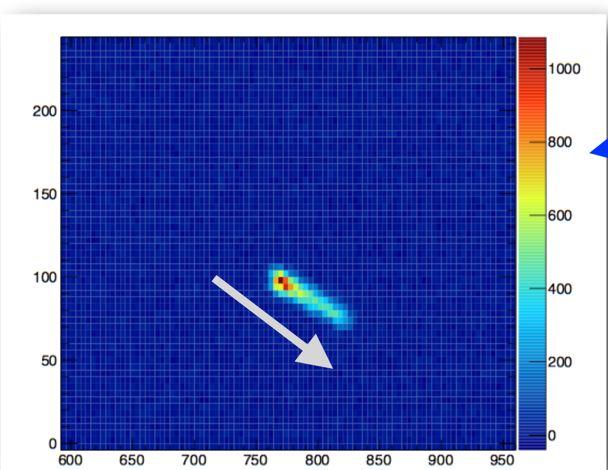
CC-inclusive interactions per 10^{21} POT

Gas	mass, 10 m^3 at 5 bar	J-PARC (0.6 GeV)	FNAL (2-3 GeV)
He	8.21 kg	5.48E+02	1.88E+04
Ne	41.4 kg	2.75E+03	9.42E+04
Ar	81.9 kg	5.47E+03	1.88E+05
CF_4	181. kg	1.21E+04	4.14E+05

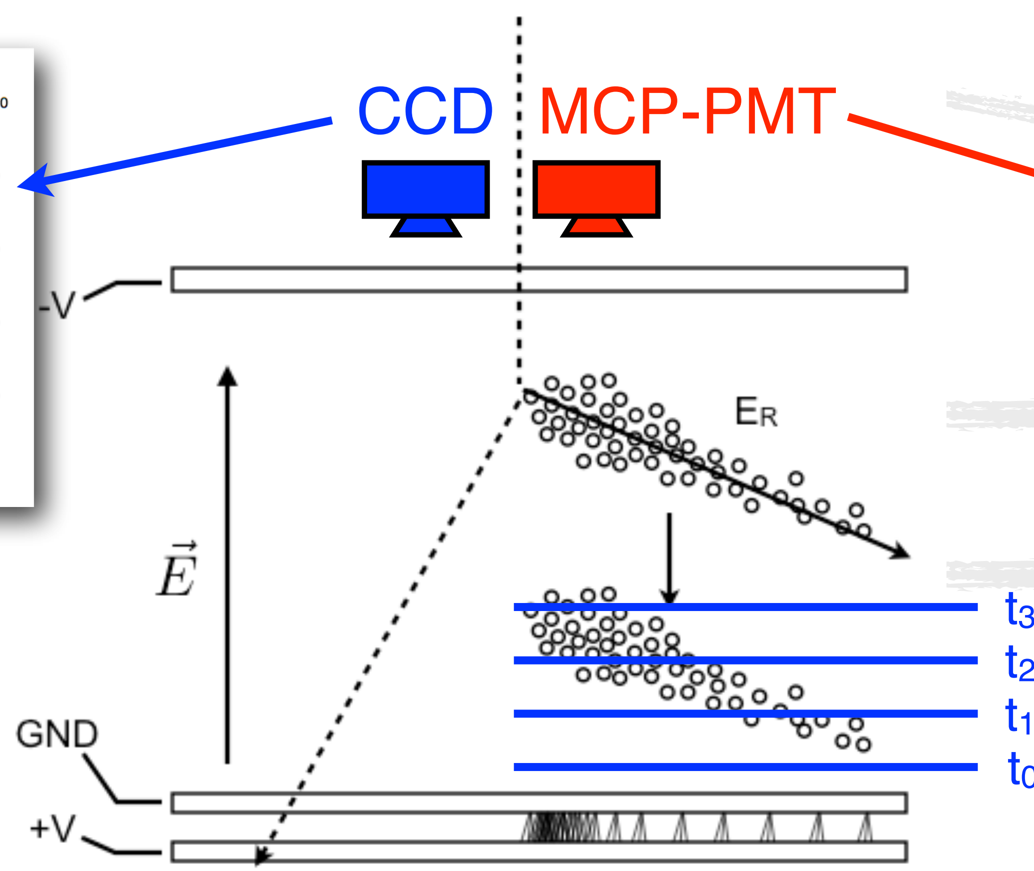
(These J-PARC and FNAL numbers were calculated in a consistent manner.)

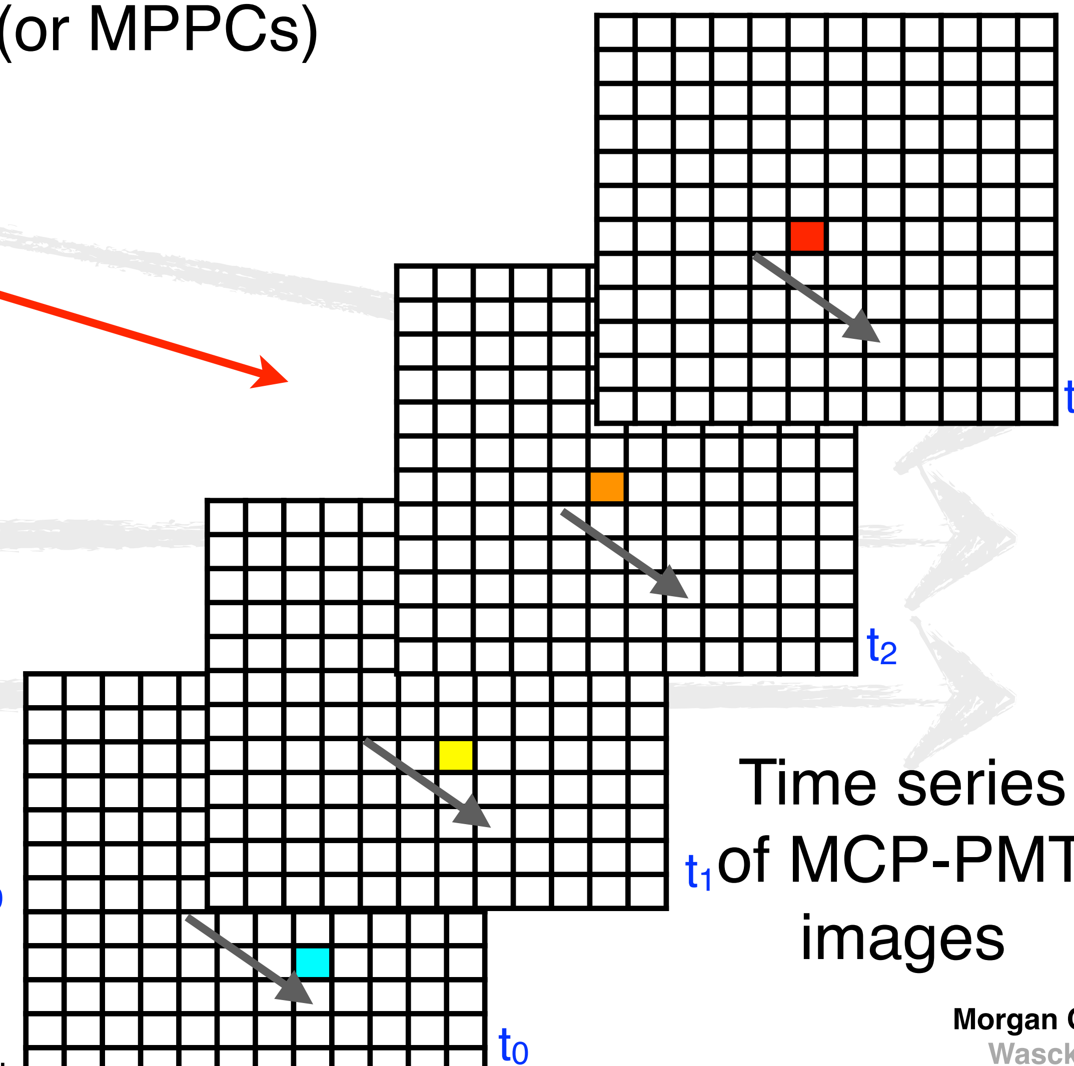
Hybrid optical readout

- **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

M. L. Barker. 1408 Chap-
man Bldg.

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,