High Pressure Gas TPC R&D

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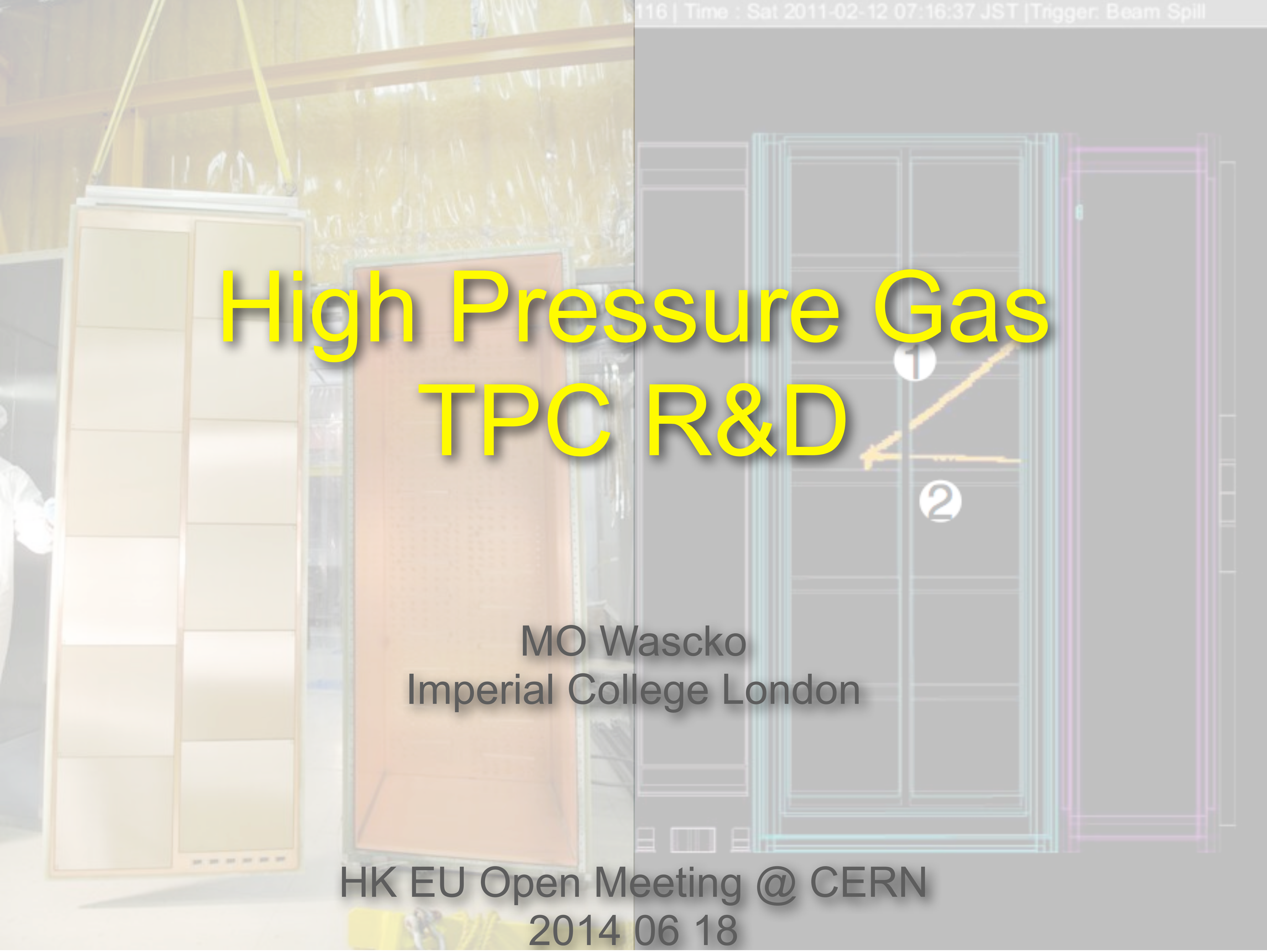
Imperial College London

HK EU Open Meeting @ CERN
2014 06 18



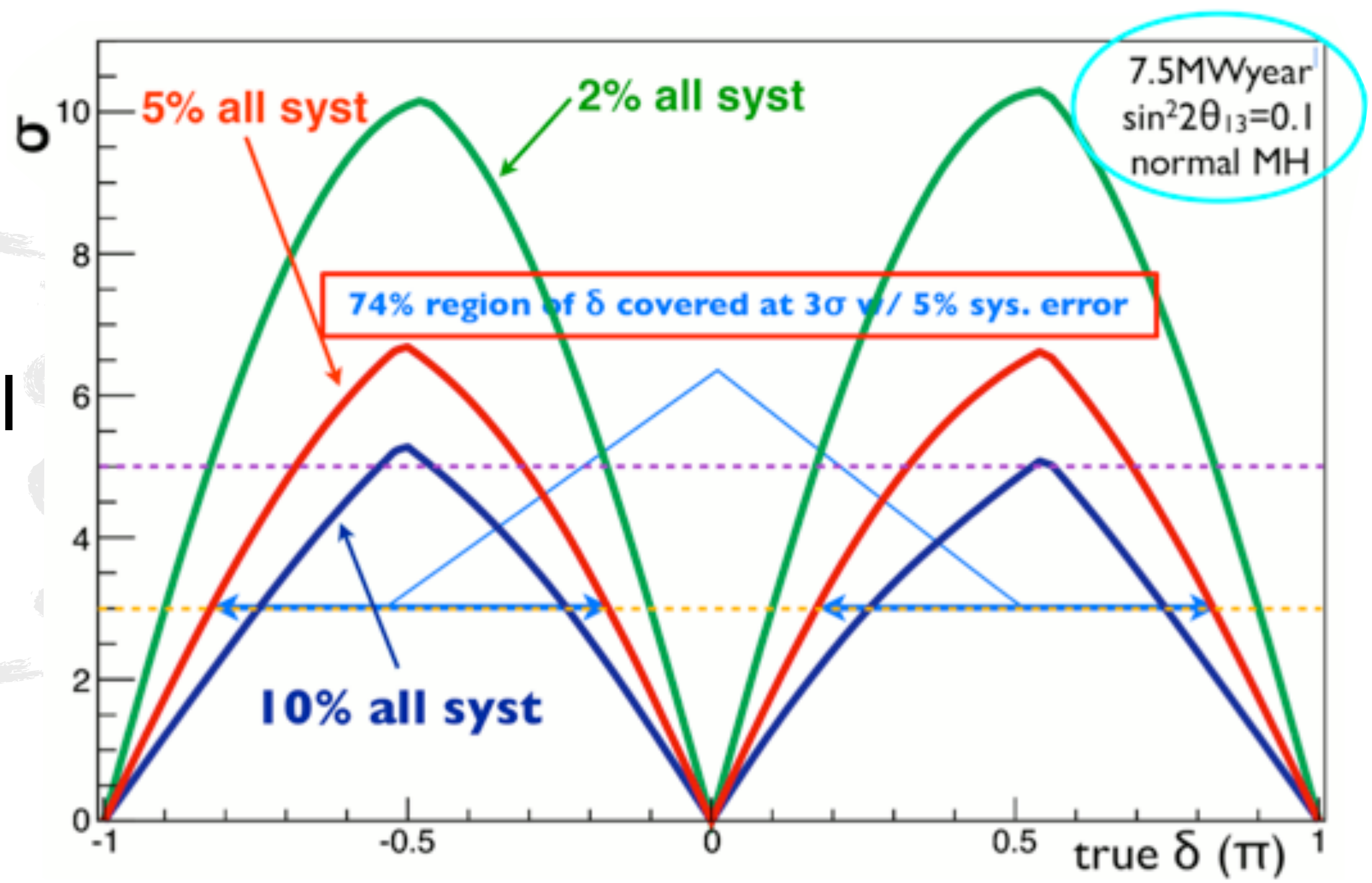
Outline

- Motivation
  - neutrino-nucleus interaction systematics
- Properties/Advantages of HPTPC
  - event rates
  - detection thresholds
- Status and next steps

Motivation: xsec systematics

- Current T2K ν_e appearance xsec systematics at ~8% level
- CPV sensitivity improved dramatically with 2% overall systematics
- Systematics driven by discrepancies between interaction models and data

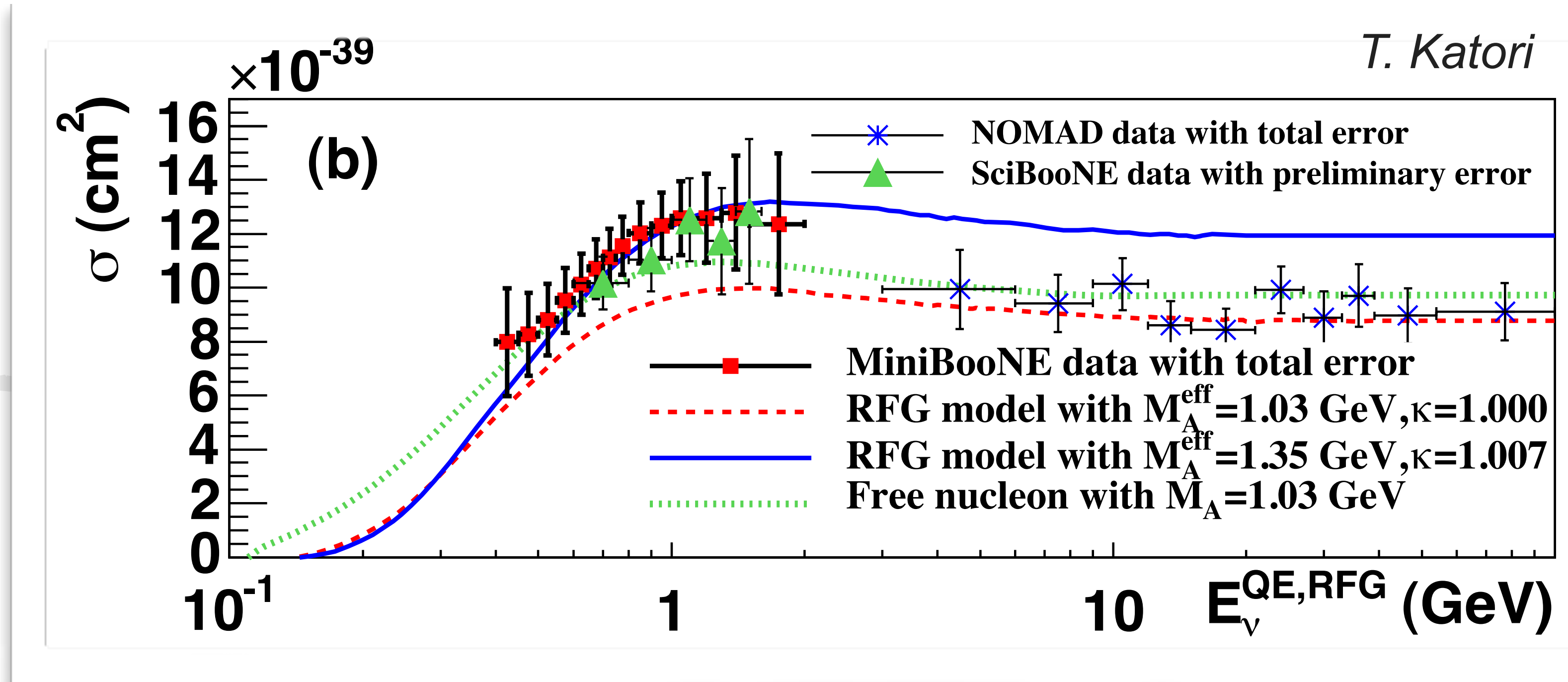
➡Need better models in generators, and better data for tuning models



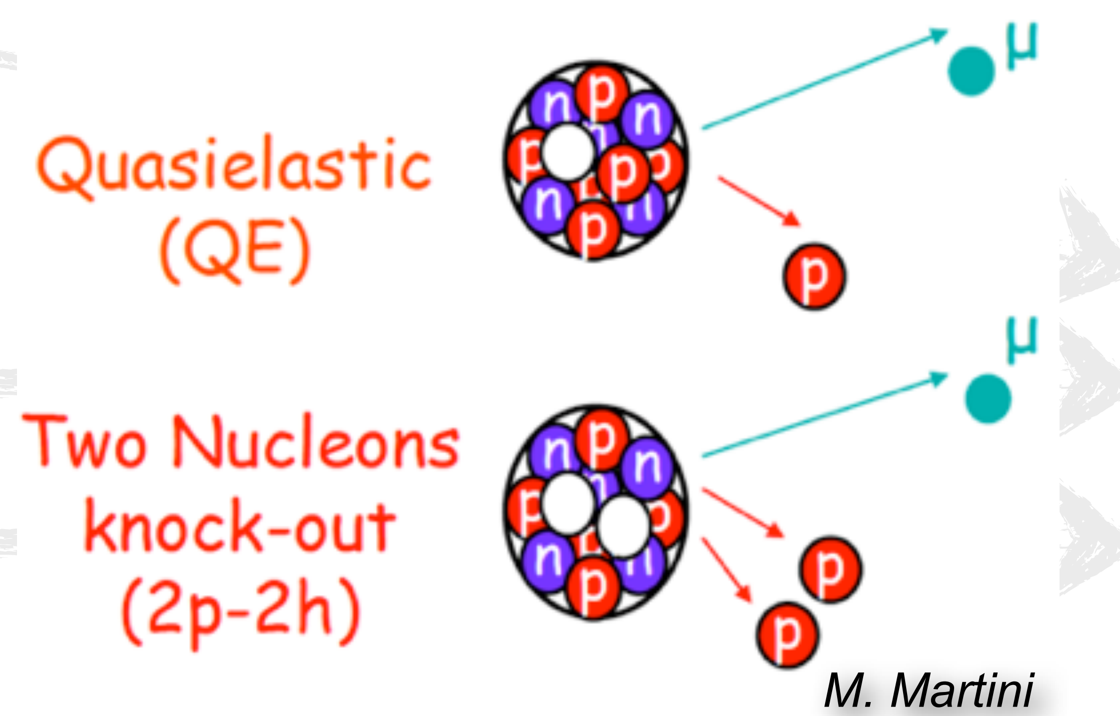
HK CPV sensitivity

Cross-section systematics

- Recent 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 publications
- Misidentified events are not reconstructed correctly—results in biased E_ν



arXiv:1002.2680 [hep-ex]

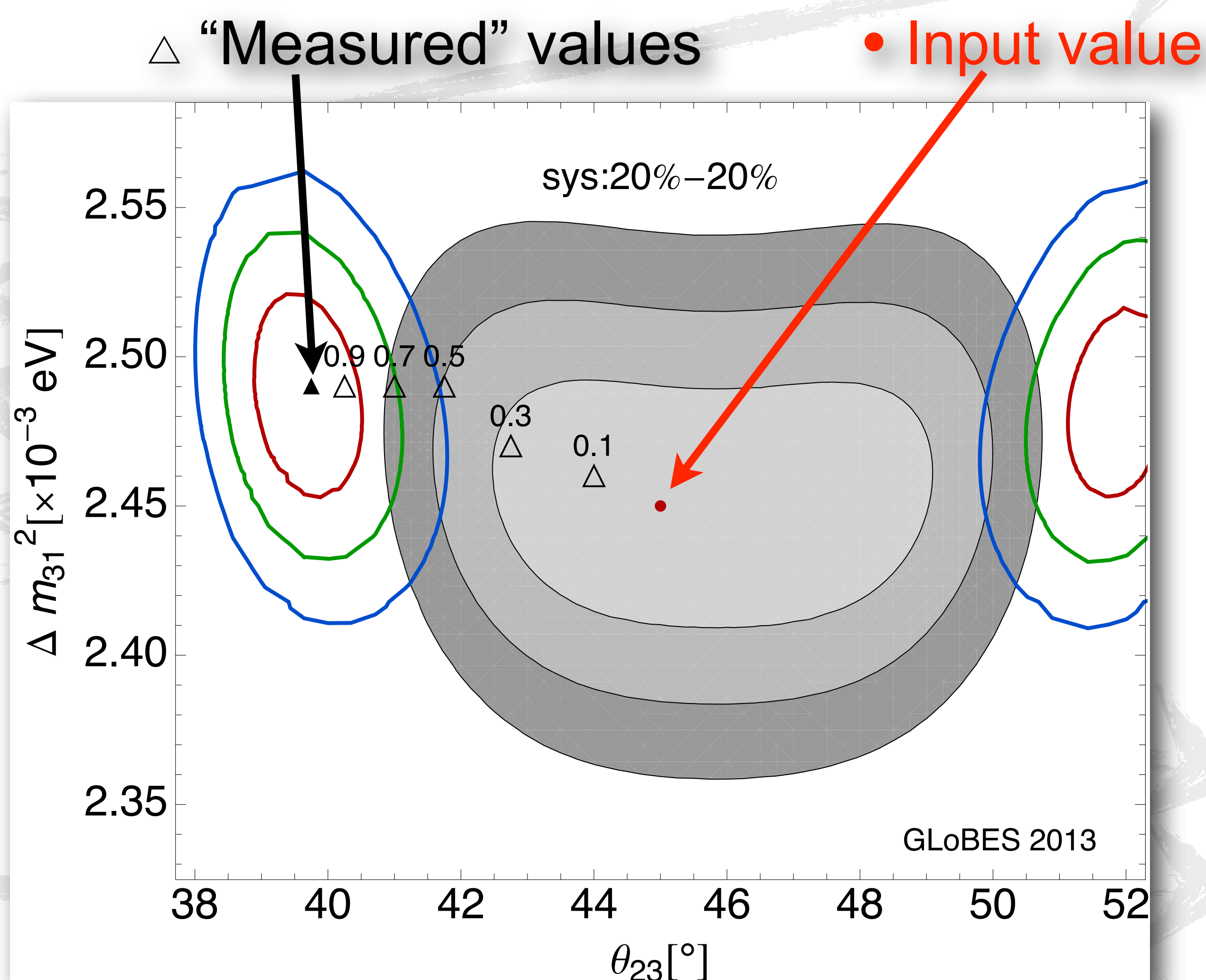


arXiv:0910.2622[hep-ex]

Effect on oscillation experiments

- Example: ν_μ disappearance with generic nuclear effects
  - Parameterise fraction of nuclear effects that are neglected
- Shifts the measured values of θ_{23} by 5° degrees and Δm^2_{31} by .05 eV^2
  - Can change interpretation: true maximal mixing can appear as non-maximal
- Danger!
  - These effects **do not cancel** in near-far extrapolation
  - ➡Using the wrong model at near and far detector does not accurately simulate Nature

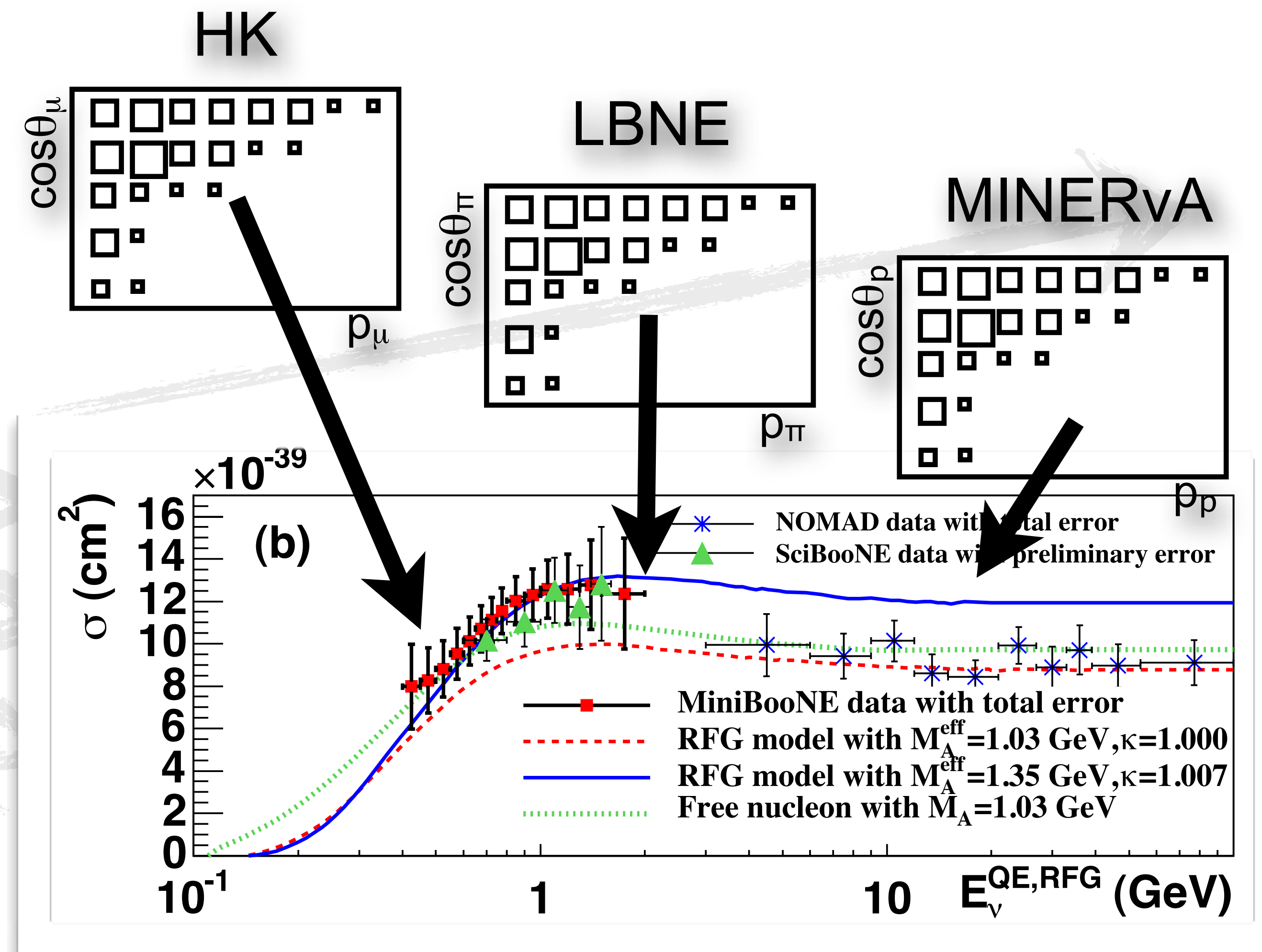
Coloma & Huber, arXiv:1307.1243 [hep-ph]

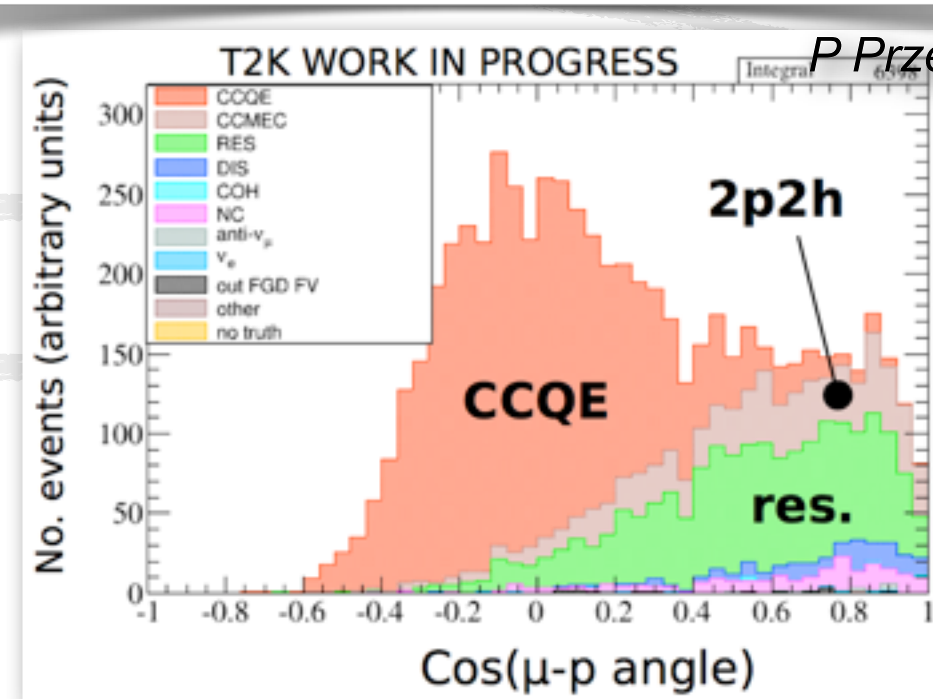


Growing Consensus

- We need broad coverage
  - Model independent measurements spanning full phase space (E_ν, Q^2) and many nuclei
- Need sufficiently low energy thresholds for recoil nucleons to separate 1p1h from 2p2h events
  - Also need sufficiently good theoretical models to robustly predict spectra!

➡ Gas TPC provides unique opportunities to address issues



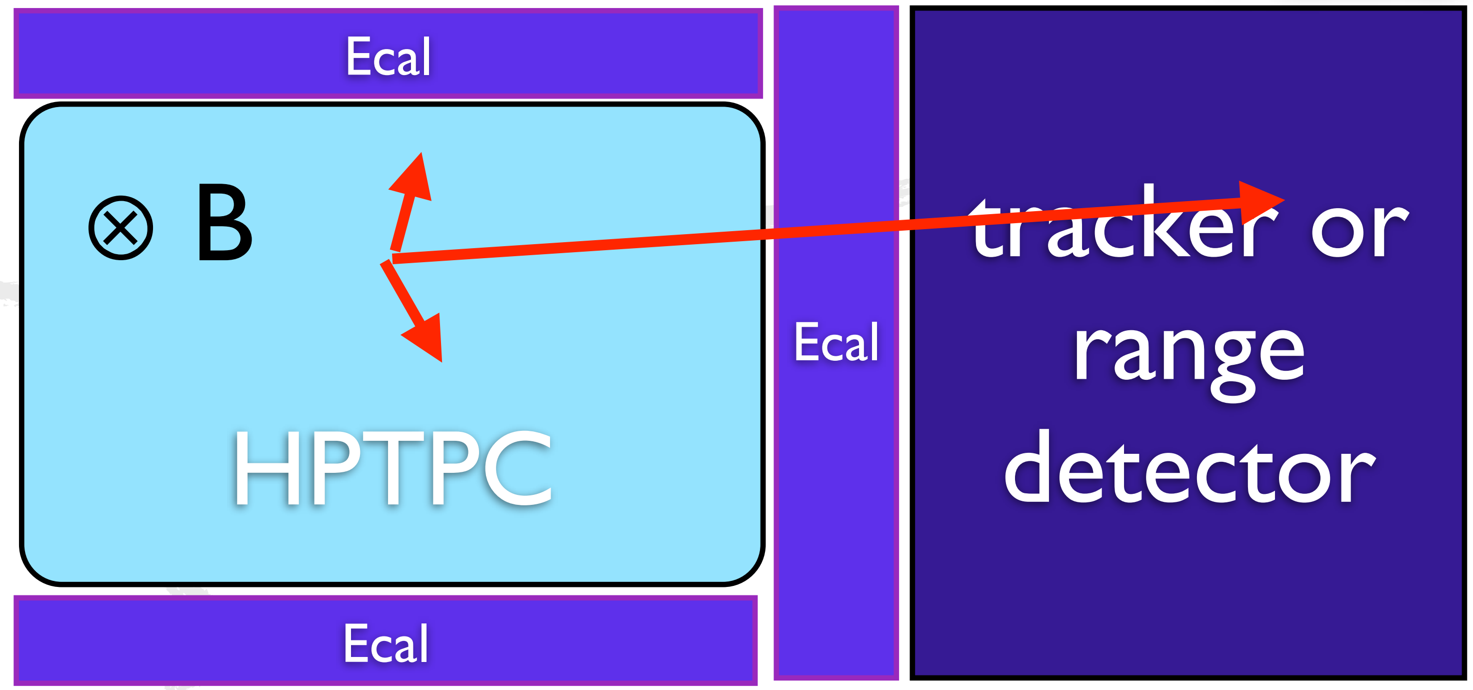


P Przewlocki

Basics of Gas TPC

- ~4π coverage
- Easily magnetised
- 3D reconstruction
- Target flexibility
- Low momentum particle detection threshold
  - Good for model discrimination, generator tuning
- Synergy with dark matter

F. Sanchez



Baseline concept is 8 m^3 magnetised volume with ND280 micromegas readout, surrounded by ECals with tracking down stream. *This configuration must be optimised.*

Presented at T2K ND280 upgrade workshop, NuInt14.

Not a new idea! Already explored by NF, LBNO, NuSTORM...

Properties of Gas TPC

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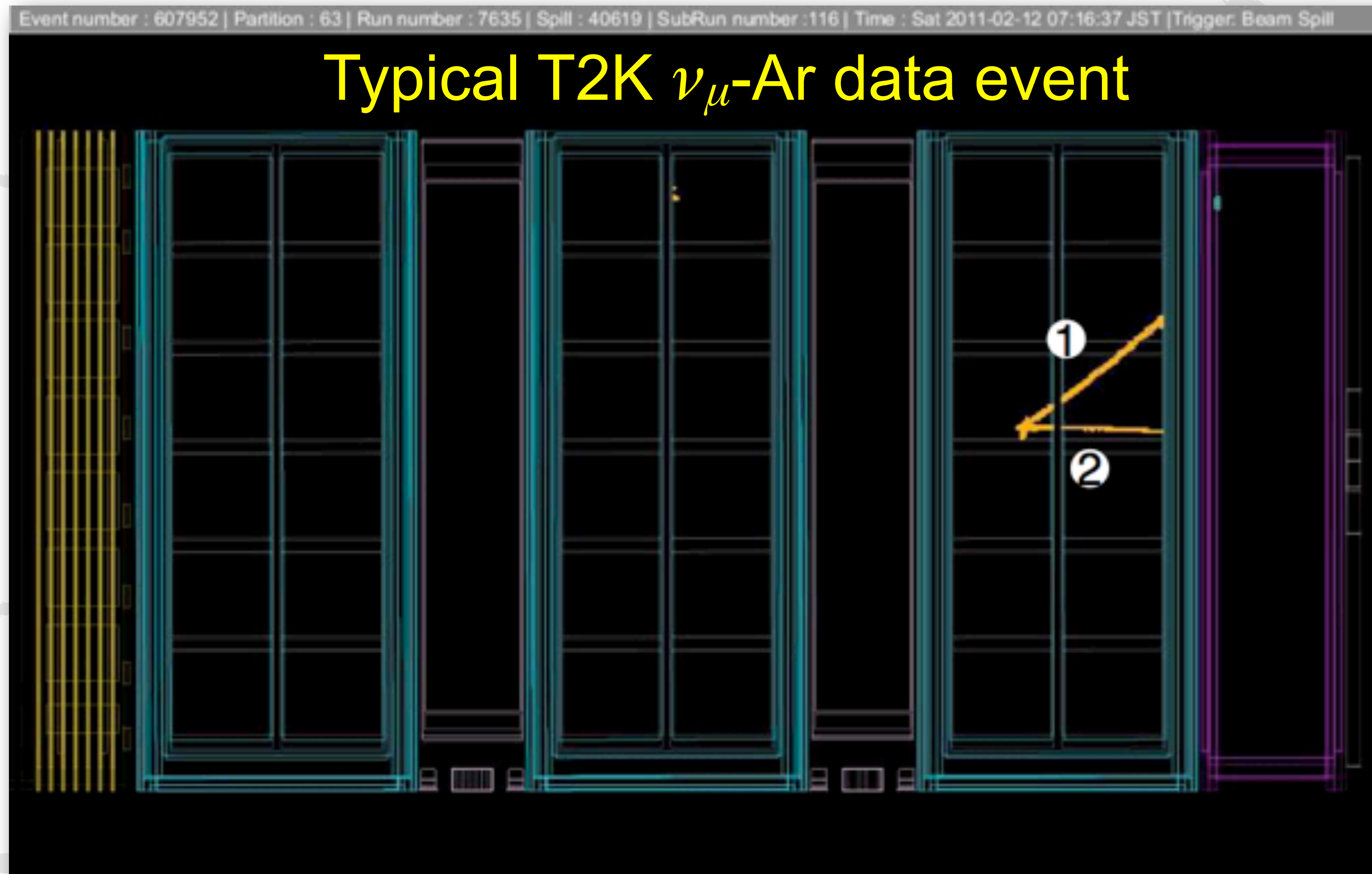

Currently analysing ν_μ interactions on Ar gas in existing T2K data.
P. Hamilton (Imperial), IOP HEP 2014 and NuInt14

Advantages of Gas TPC

- ~4π coverage
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- 3D reconstruction
- ➡ Target flexibility
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EVENT RATES
(SCALED FROM T2K ND280 RATES)

F. Sanchez

2x2x2 m^3 20°C	5 bars	10 bars
He	6.65 kg	13.3 kg
	520 evt/10^{21}pot	1040 evt/10^{21}pot
Ne	32.5 kg	67.1 kg
	2543 evt/10^{21}pot	5086 evt/10^{21}pot
Ar	66.5 kg	133 kg
	5203 evt/10^{21}pot	10406 evt/10^{21}pot
CF_4	146.3 kg	293 kg
	11450 evt/10^{21}pot	22893 evt/10^{21}pot

Advantages of Gas TPC

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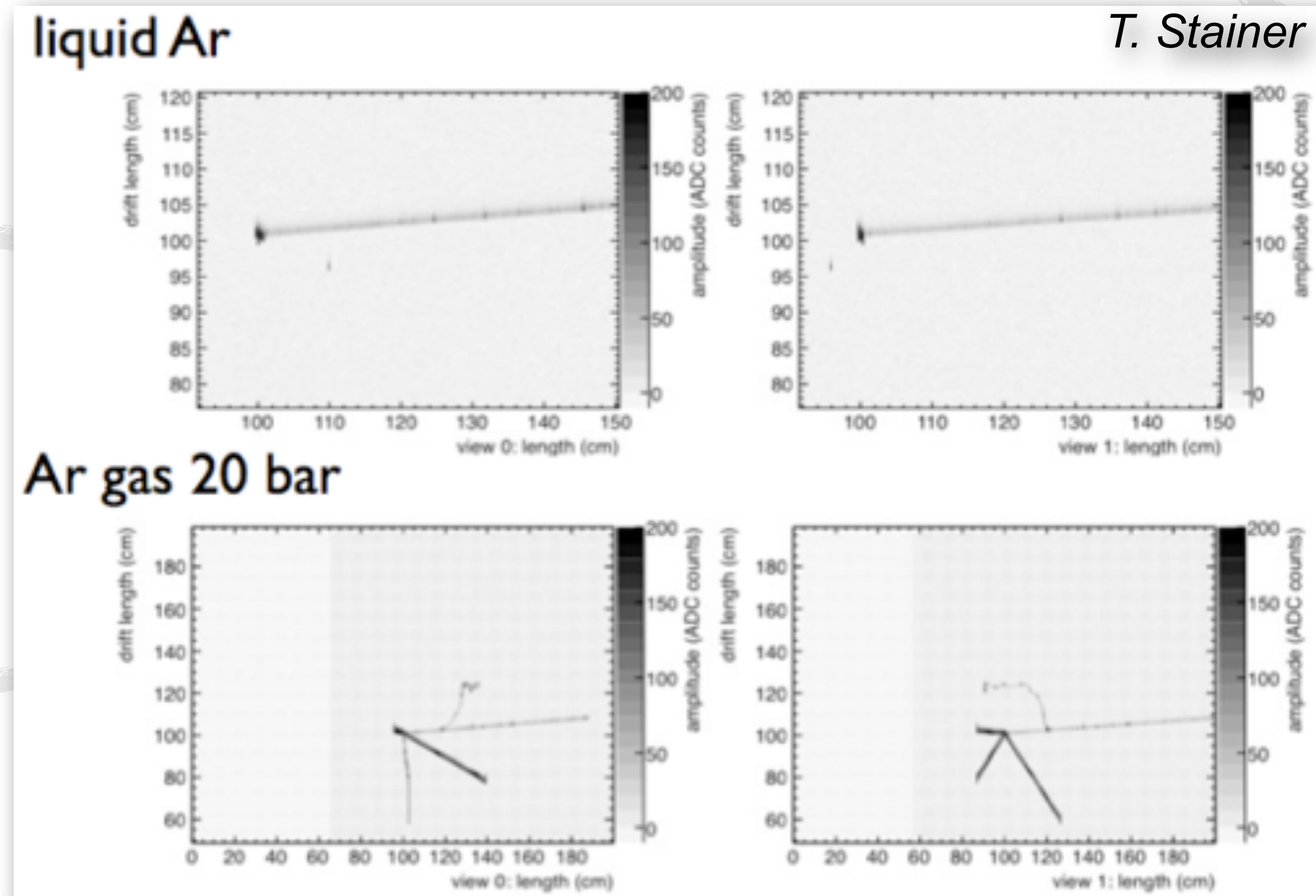

LBNO near detector simulations.

T. Stainer (Liverpool), [IOP HEP 2014]

Advantages of Gas TPC

- ~4π coverage
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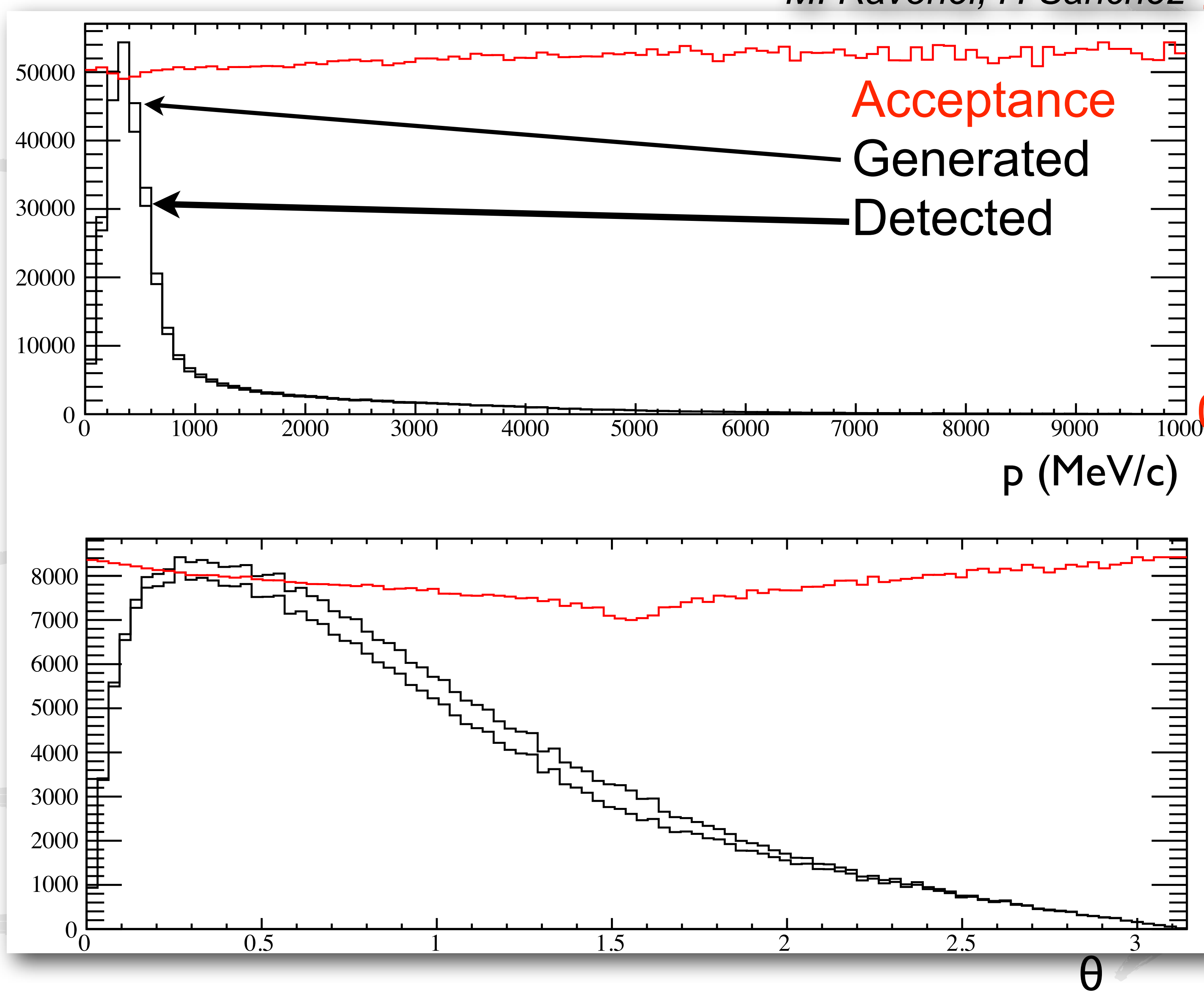
M. Ravonel, F. Sanchez



MUON ACCEPTANCE

Advantages of Gas TPC

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- Easily magnetised
- 3D reconstruction
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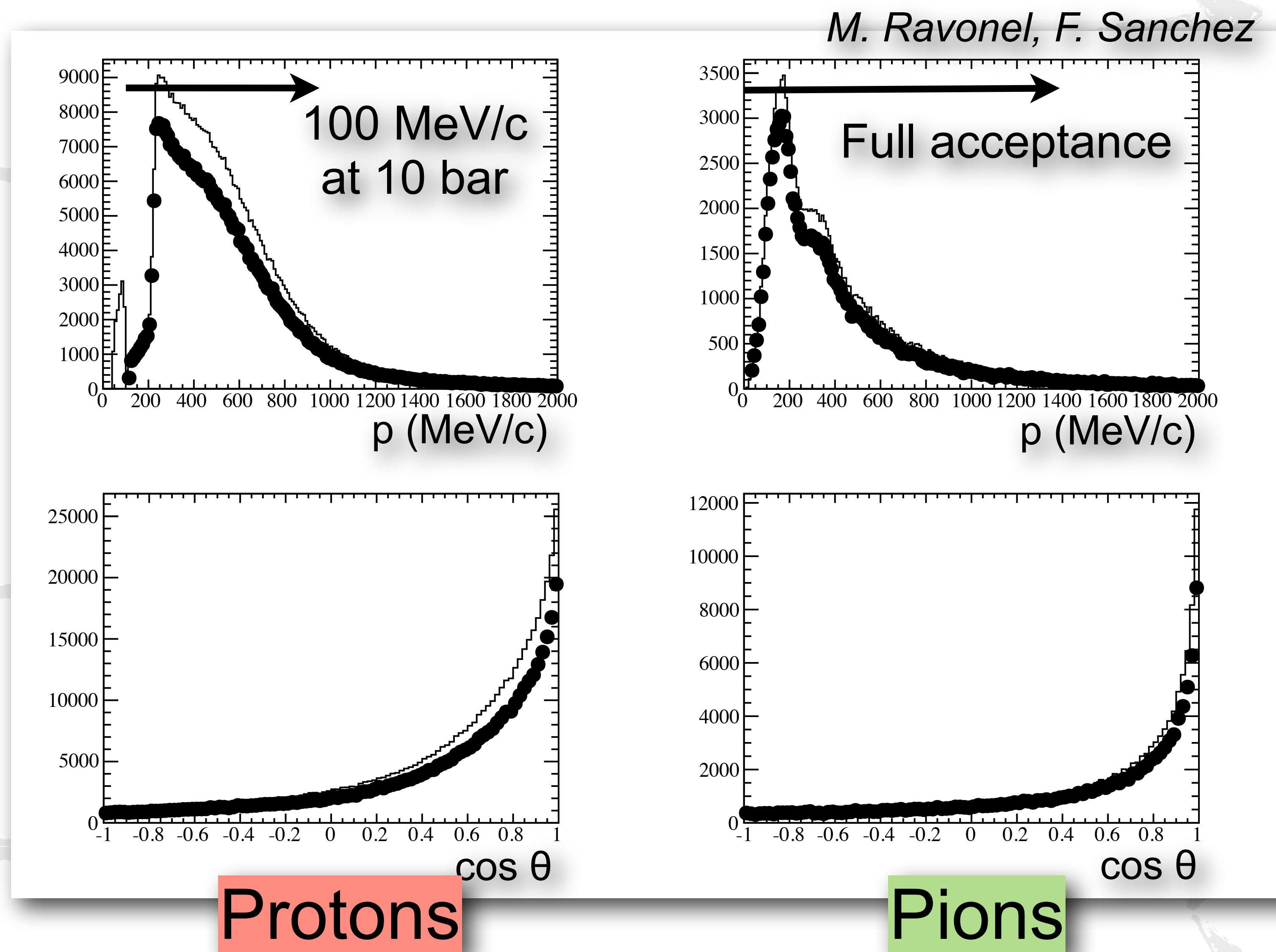

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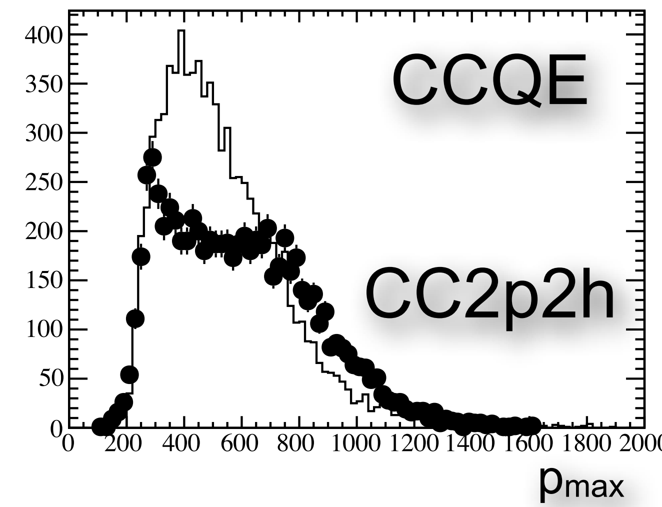
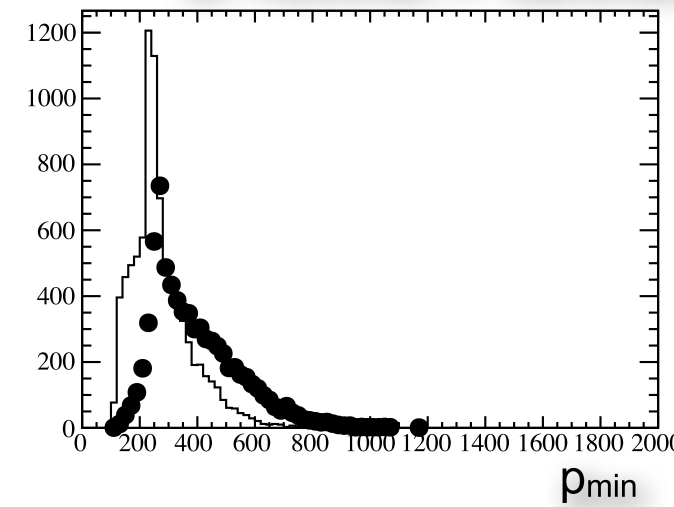
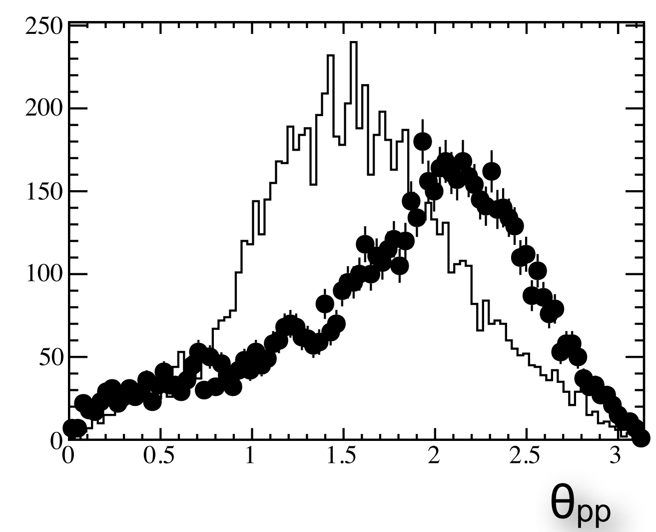






- fully reconstructed events with (only) 2 protons in final state.
- $N_{CCQE+FSI} \sim N_{2p2h}$
- Observables are sensitive to differences.

Advantages of Gas TPC

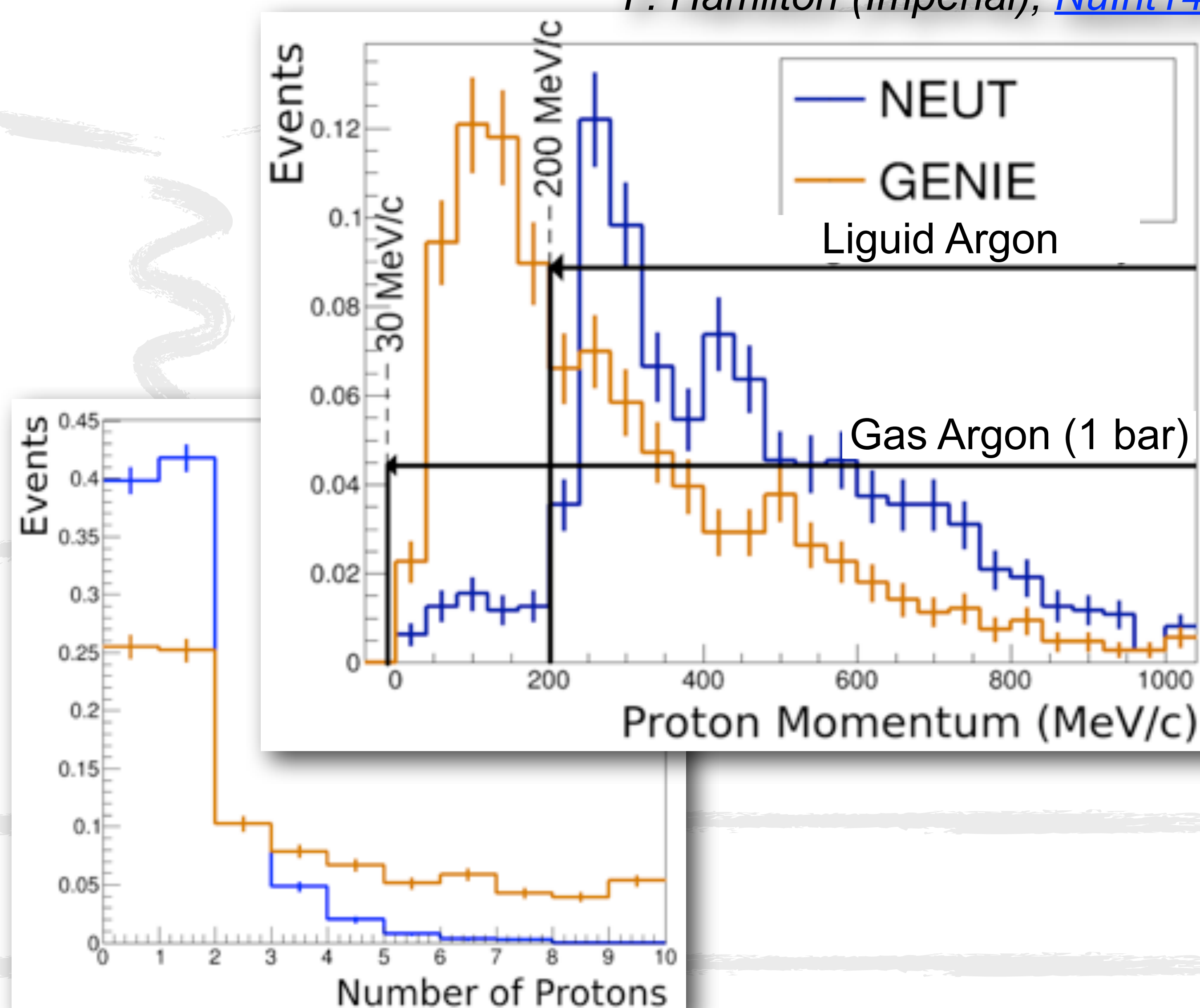
- ~4π coverage
- Easily magnetised
- 3D reconstruction
- Target flexibility

➡ **Low momentum particle detection threshold**

➡ **Good for model discrimination, generator tuning**

- Synergy with dark matter

P. Hamilton (Imperial), NuInt14

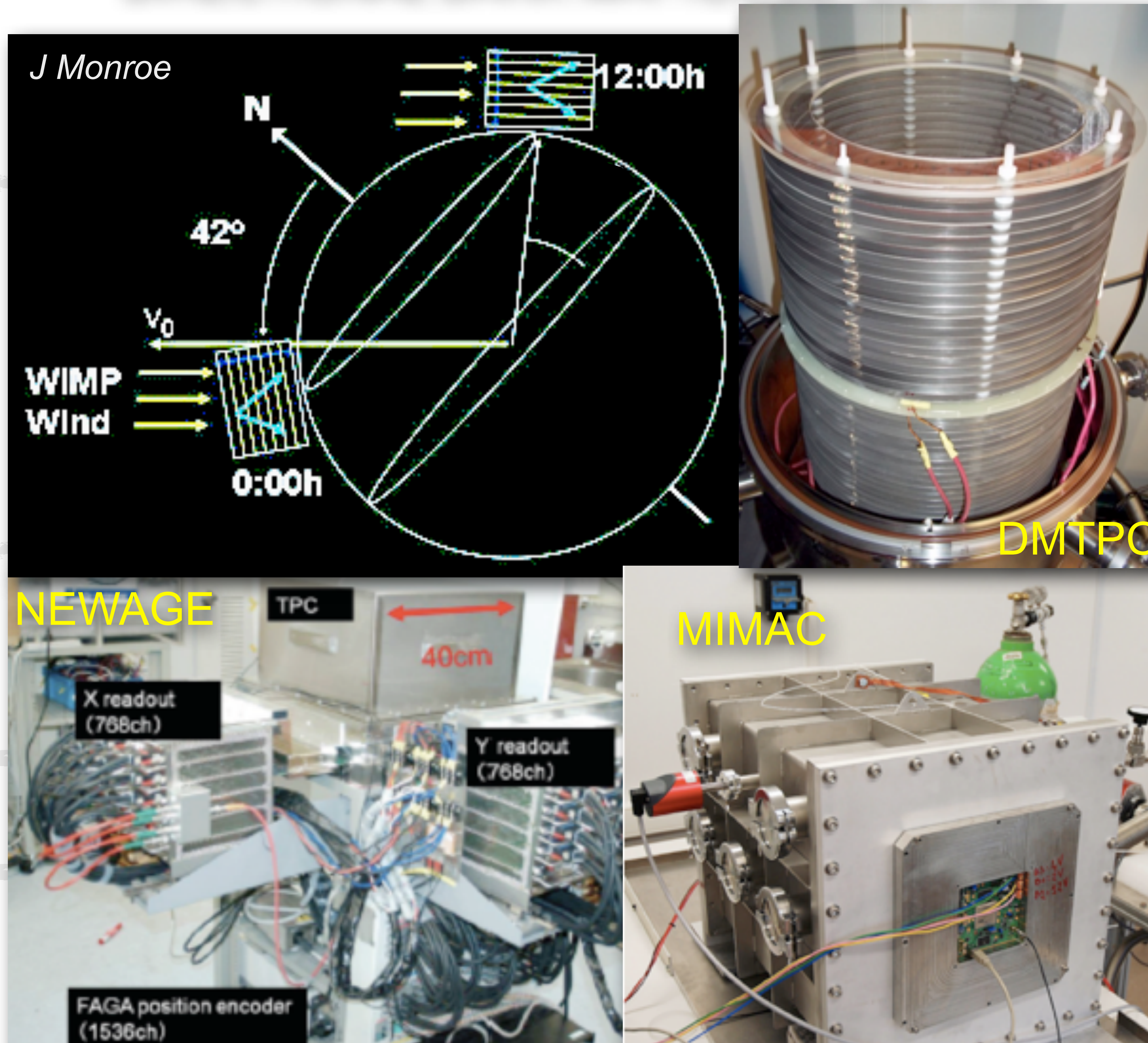


Advantages of Gas TPC

- $\sim 4\pi$ coverage
- Easily magnetised
- 3D reconstruction
- Target flexibility
- Low momentum particle detection threshold
  - Good for model discrimination, generator tuning

➡ Synergy with dark matter

DIRECTIONAL DARK MATTER DETECTION



Conclusion / Path forward

- A high pressure gas TPC is the ideal instrument for disentangling neutrino interaction models and tuning interaction generators
    - Needed to get interaction systematics down to 2% level
- Much work to be done!
    - Optimise detector design
        - Convert useful photons but reduce external backgrounds
    - Honest cost evaluation
    - Explore alternate readout technologies
        - Could provide low cost options

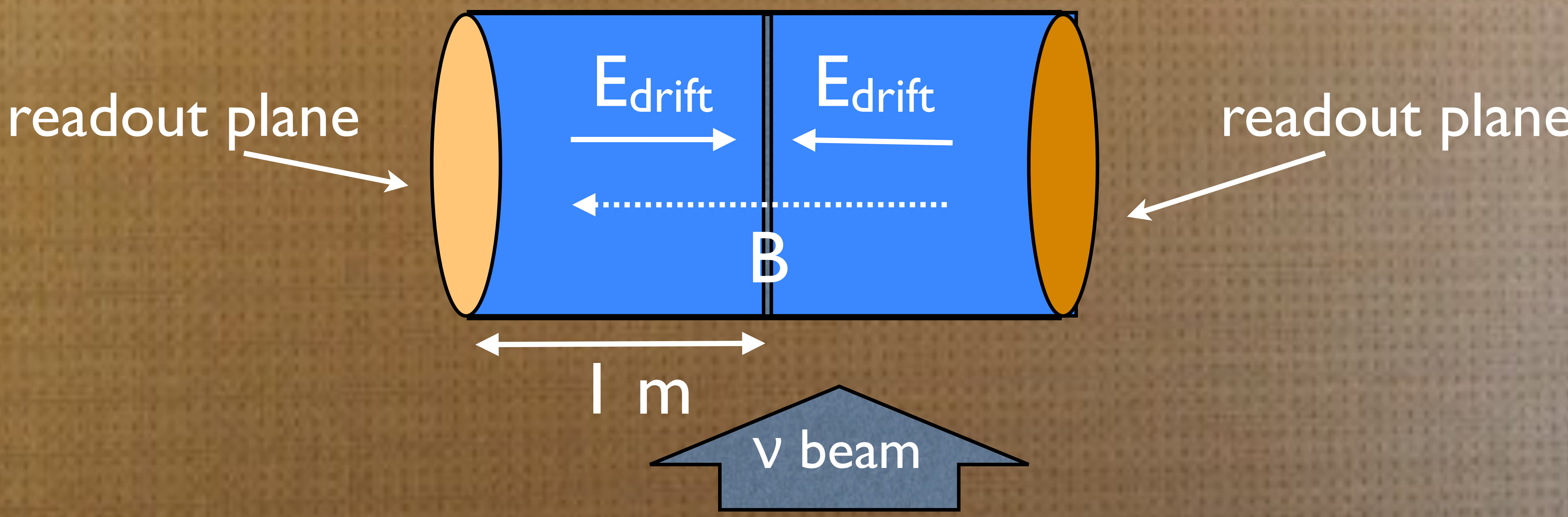
Thank you for your attention!

ご清聴ありがとうございました

水戸の梅の花

Many thanks to:
P Hamilton, F di Lodovico, J Monroe, F Sanchez, T Stainer, for valuable input

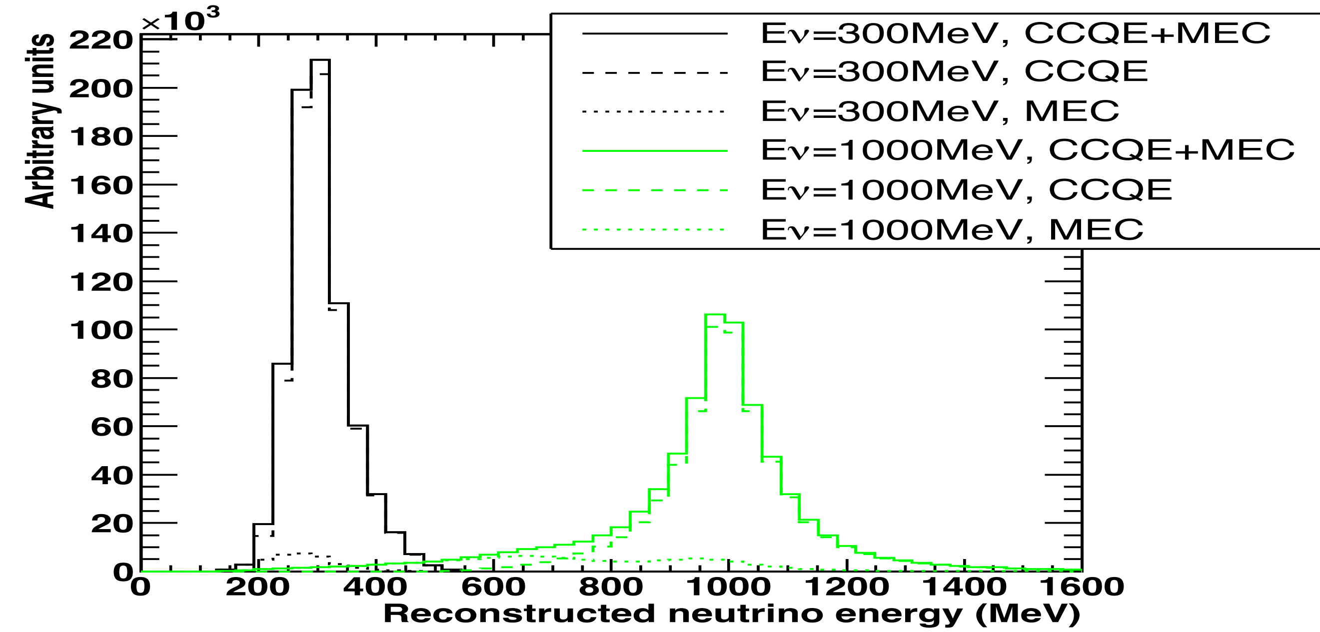
TPC concept

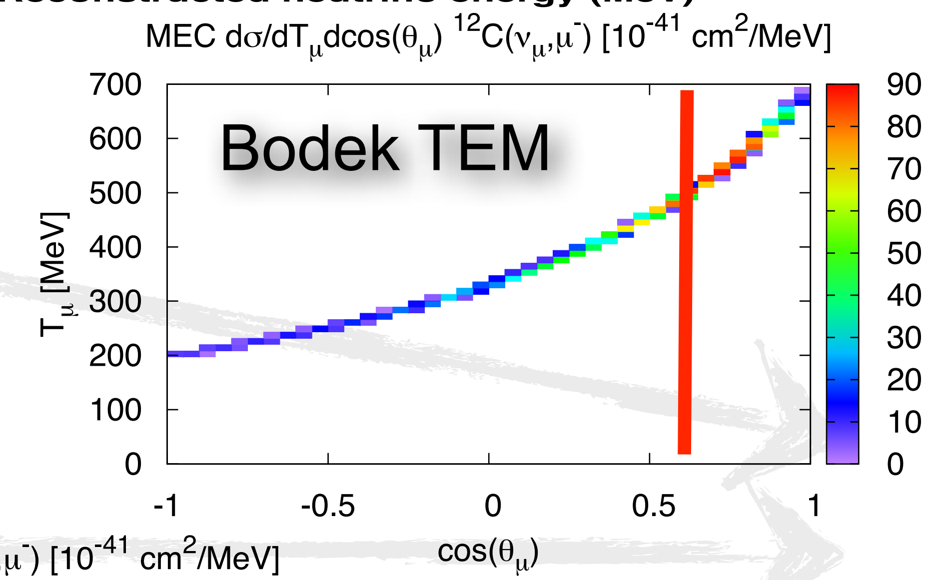


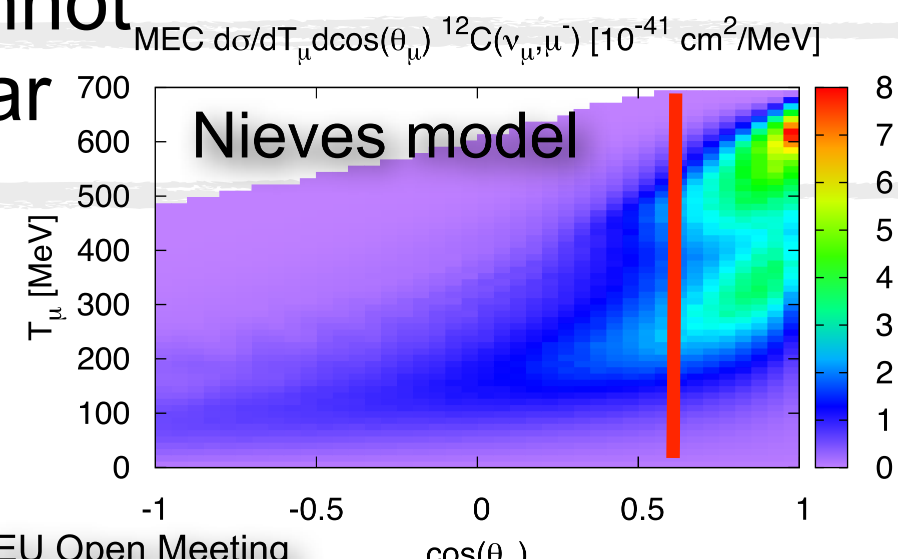
In the hypothesis of central cathode plane and contained in ND280 magnet, we will have ~1m of drift distance

Motivation: unknown processes

- Presence of un-modelled processes in data sample affects extrapolation
- Effects exacerbated by different kinematics in each model
    - Which one matches Nature??
- Changes neutrino energy reconstruction
- Near detector extrapolation cannot fix this even if it is identical to far detector!







HPTPC

M.Ravonel, F.Sánchez

Support/discussions: S.Bordoni, R.Castillo, A.García, M.Ieva, T.Lux

Outline

- Motivation
- Recall September.
- Physics potential:
  - Event statistics
  - Track detection thresholds.
- Final remarks

Motivation

T2K challenges

- Proton yield.
- Anti-neutrino runs balance.
- Neutrino flux shape: NA61 (and a little of ND280 data)
- Neutrino cross-sections (also for ν flux)
    - 2p2h
    - multipion resonances.
    - FSI.
    - Particle re-interaction in detector.

Can we improve ND280 to optimize cross-section measurements?

Cross-sections

- The uncertainties in cross-sections affect:
  - neutrino energy reconstruction.
  - background calculation (Resonant into QE feed down).
  - Acceptance correction (high angle and backward tracks).
- Actual unknowns:
  - 2p-2h
  - FSI and Pion re-interactions at detector.
  - 1π and high mass resonances.
  - Spectral functions.

}

Most of these unknowns can be adressed with low threshold detectors.

TPC

A time projection chamber is a good candidate for these studies:

- + Target = detector.
- + 3D reconstruction capabilities.
- + Possibility to exchange targets.
- + low density → low thresholds
- + excellent PID capabilities.
- + Almost uniform 4π acceptance.
- - low number of interactions → requires high pressure and large volume.
- - requires in addition a magnet or range detectors to measure momentum.

TPC

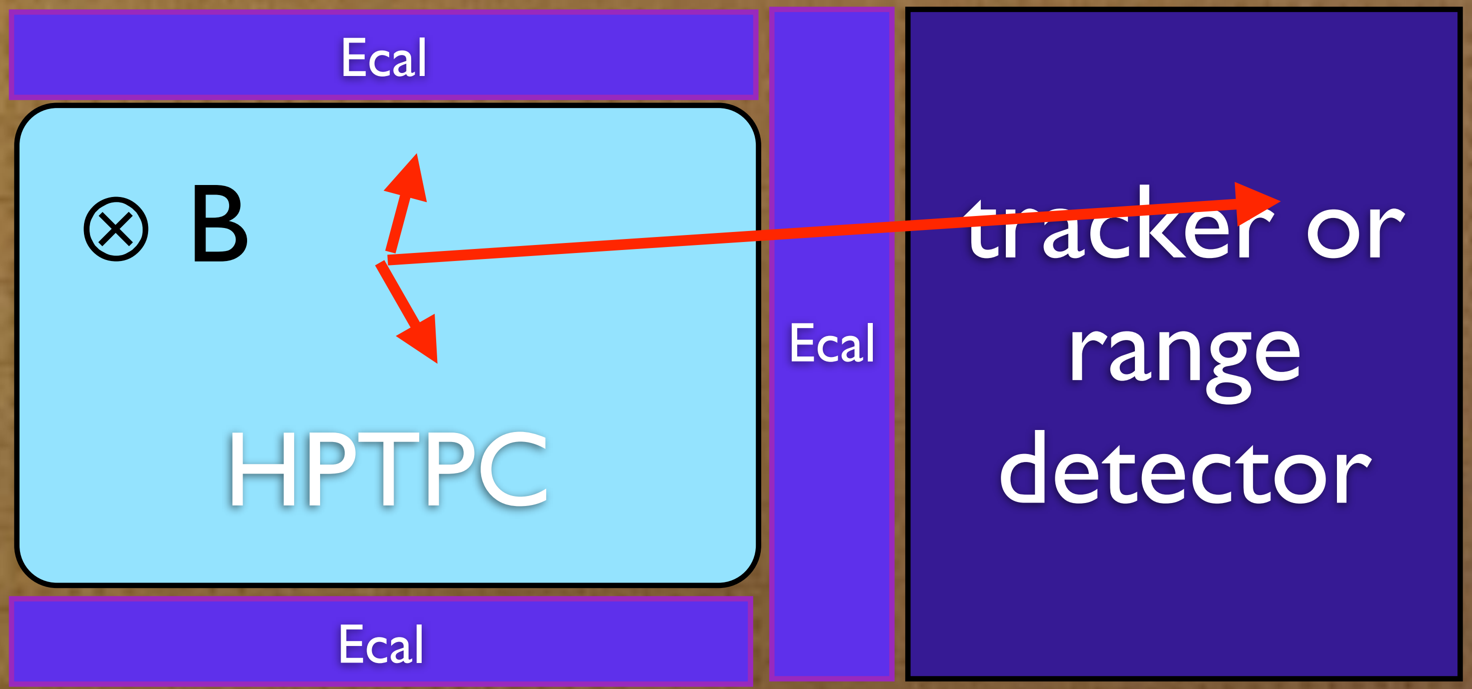
- This is not a new idea (Argon as target):
  - NF near detector.
  - LBNE-LBNO near detector.
  - NuStorm proposal.
- The novelty of this proposal is to explore options of He and Ne as possible targets.

TPC

- In September, we showed the possibility of using a HPTPC as ND280 upgrade:
  - gas mixtures.
  - gas pressures.
  - target mass.
  - simple calculations of particle ranges.
  - vessel with emphasis on photon interaction probability.
  - possibility to reuse T2K electronics (AFTER).

We will show some acceptance and sensitivity studies.

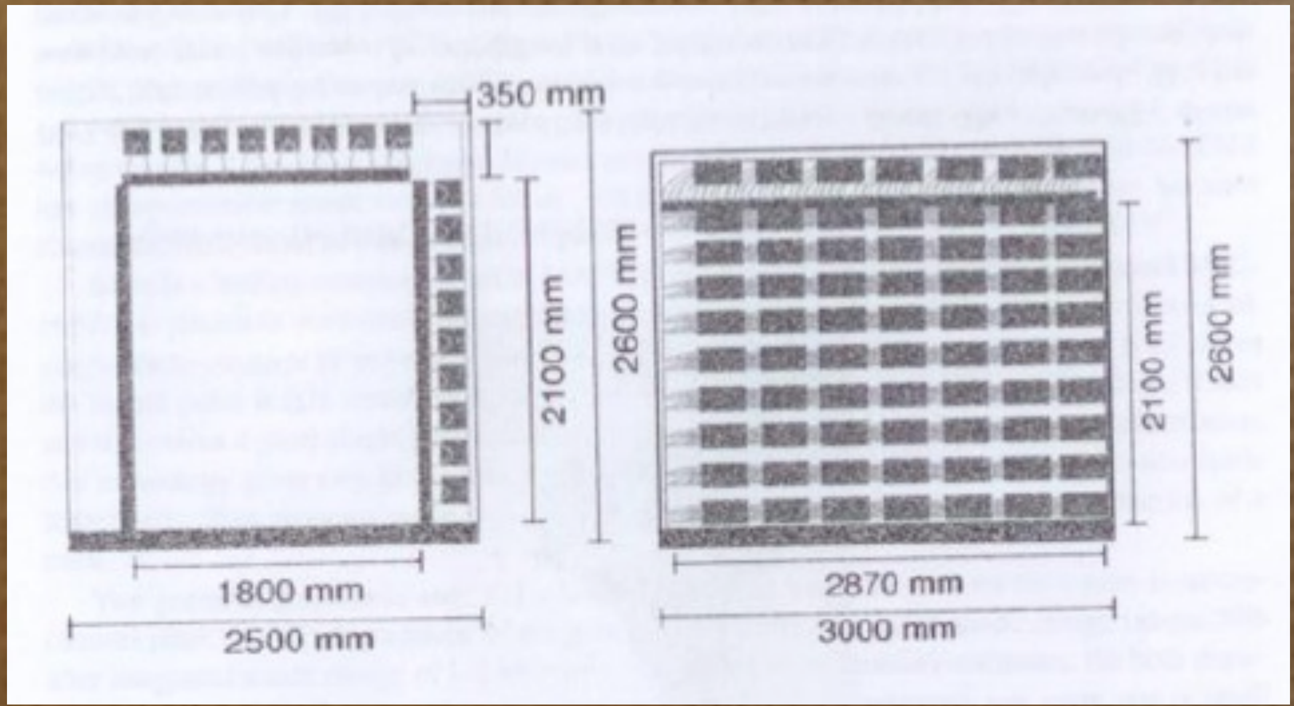
TPC concept



- Low momentum detected inside the TPC.
- Large momentum done with tracker chambers or range detector.
- Calorimeter for neutral energy containment.

TPC concept

- Let's assume that we want to reuse the ND280 magnet.
- The drift has to be along the B field (⊥ to the ν beam).
- The inner basket size is (2.5x2.5 m^2)
- If we leave space for vessel + equipment → ~2 m drift.



Event statistics

Number of events

- FGD 1 Fiducial mass = 831 Kg (Daniel Brook-Roberge's Thesis)
- PoT = 5.9×10^{20}
- N^{obs}= 18404 events (Data selected CC events in FGD1)
    - Purity CC (CC inclusive MC sample) = 90.9 %
    - Efficiency CC = 43.6 %
- N^{CC} = N^{obs} x Purity / Efficiency = 38361 events
- N^{CC} /10^{21} PoT = 38361/5.9 = 65019 events / 10^{21} PoT
- Re-scaling also to 100Kg
    - N^{CC} /10^{21} PoT /100kg = 65019/8.31= 7824 events/100kg/10^{21} PoT

Number of Events

CC events assuming a 8m^3 detector & full FV.

2x2x2 m^3 20°C		5 bars	10 bars
He	mass	6.65 kg	13.3 kg
	events	520 evt/10^{21}pot	1040 evt/10^{21}pot
Ne	mass	32.5 kg	67.1 kg
	events	2543 evt/10^{21}pot	5086 evt/10^{21}pot
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CF_4	mass	146.3 kg	293 kg
	events	11450 evt/10^{21}pot	22893 evt/10^{21}pot

Expected ~1.6 10^{21} pot/year for ~4 years

Full MonteCarlo

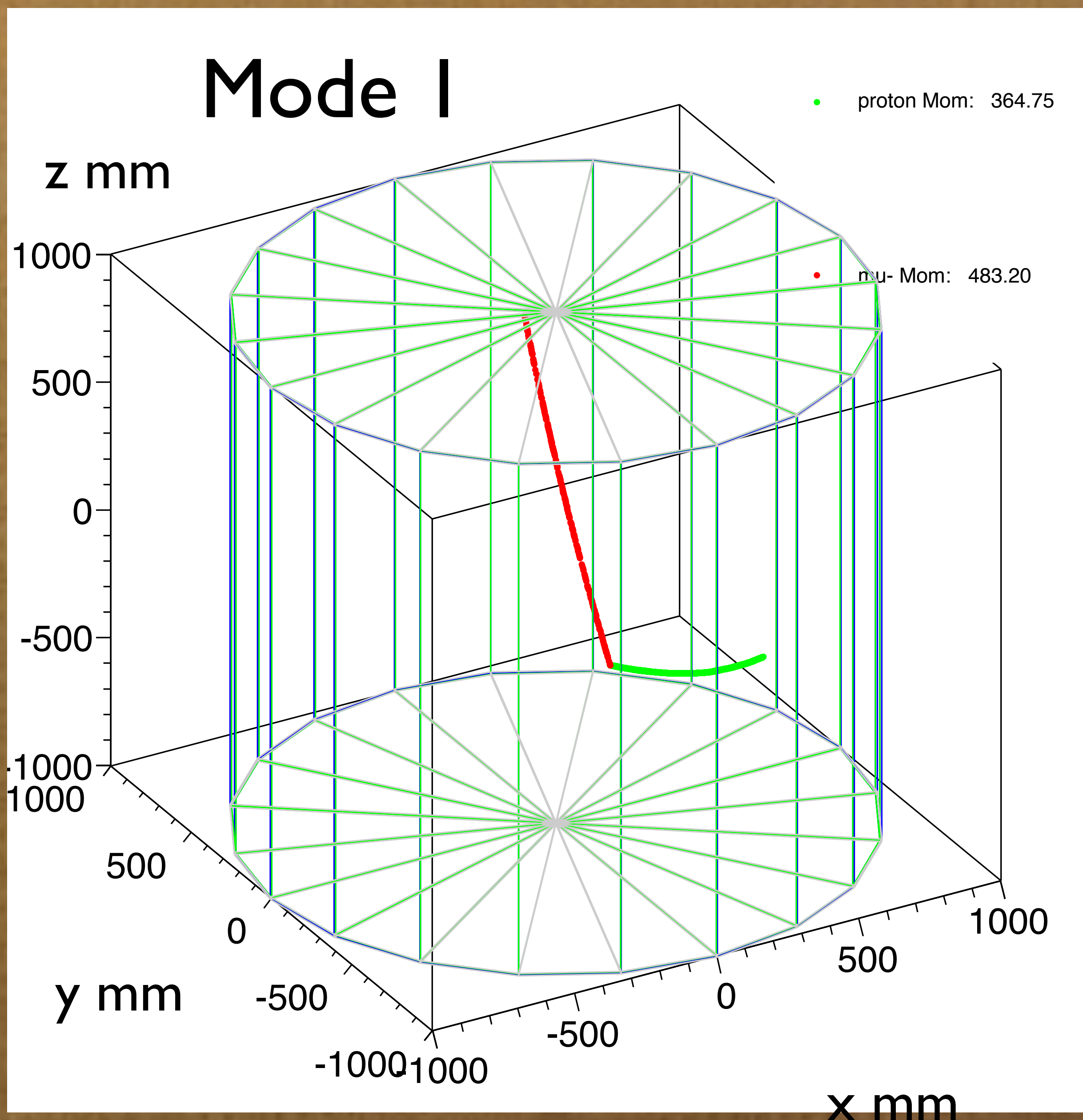
Simulation

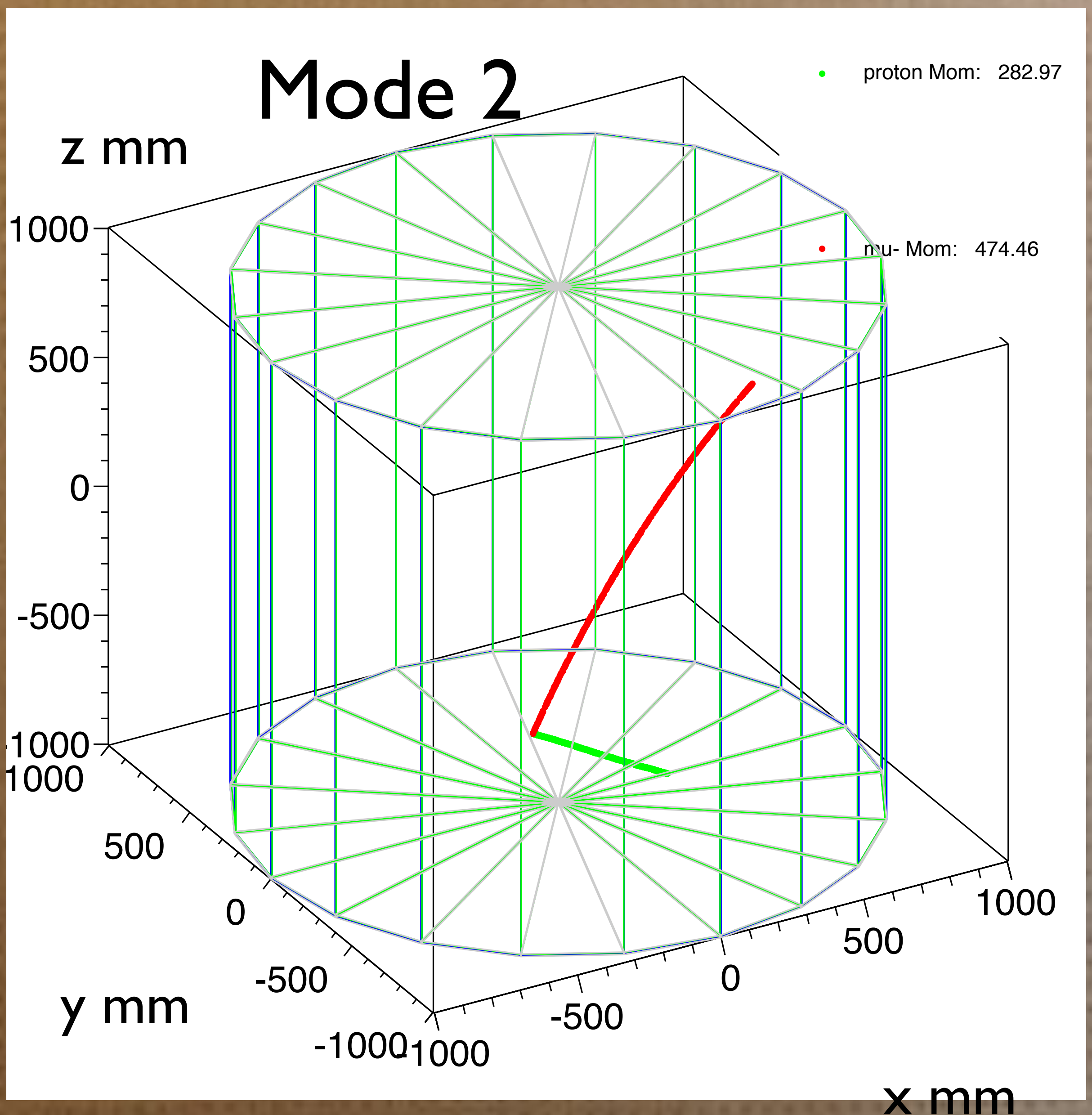
- NEUT event generator (given by Ryan Terry), processed with T2K flux
- For now: 500.000 interactions on Oxygen.

This is OK for threshold studies, needs retuning.

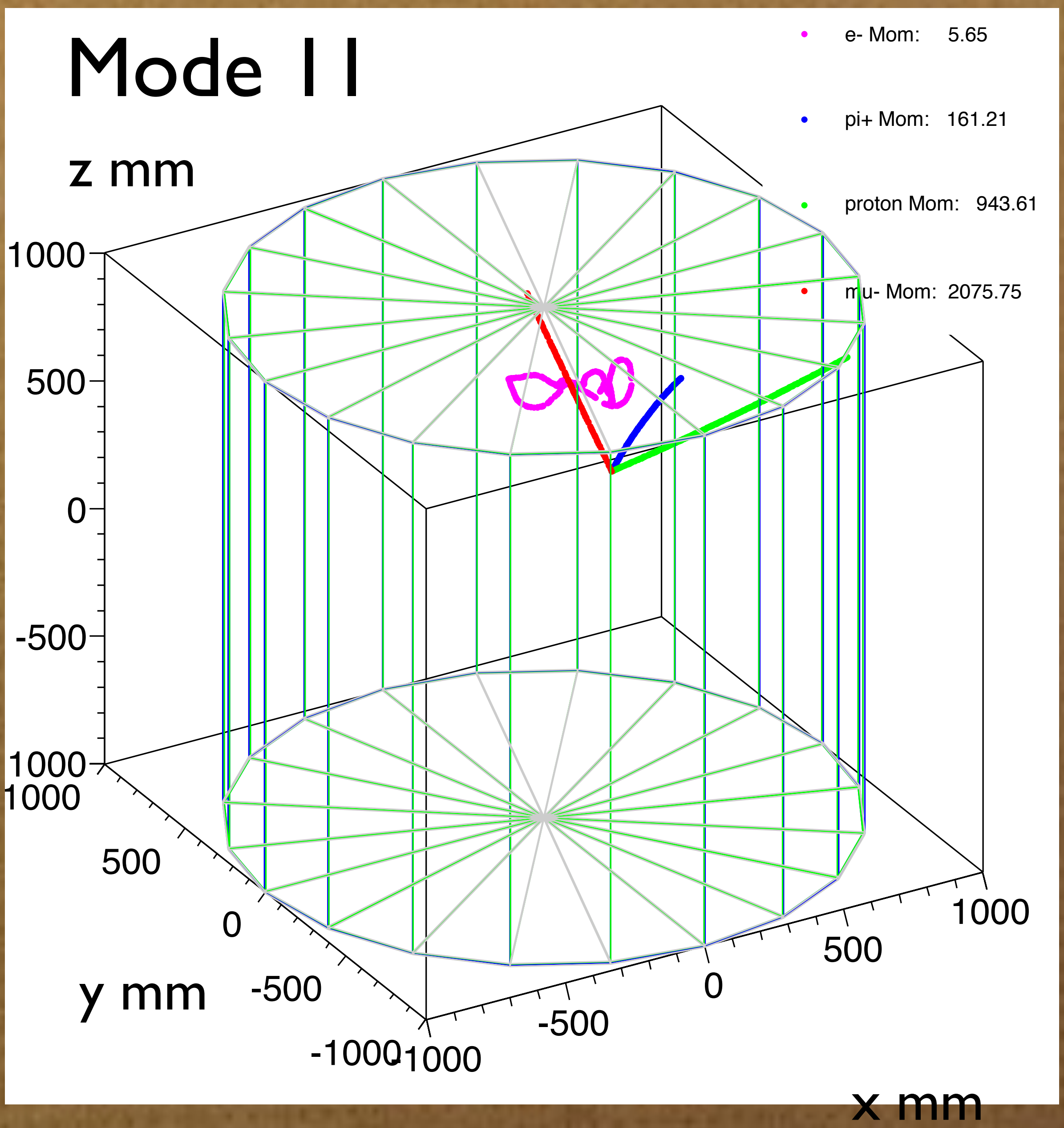
- GEANT4 Propagation of NEUT event in Argon gas with 5 and 10 bars.
- Magnetic field of 0.2 Tesla in the x direction (⊥ ν beam).
- Uniform distribution of interactions in the gas.

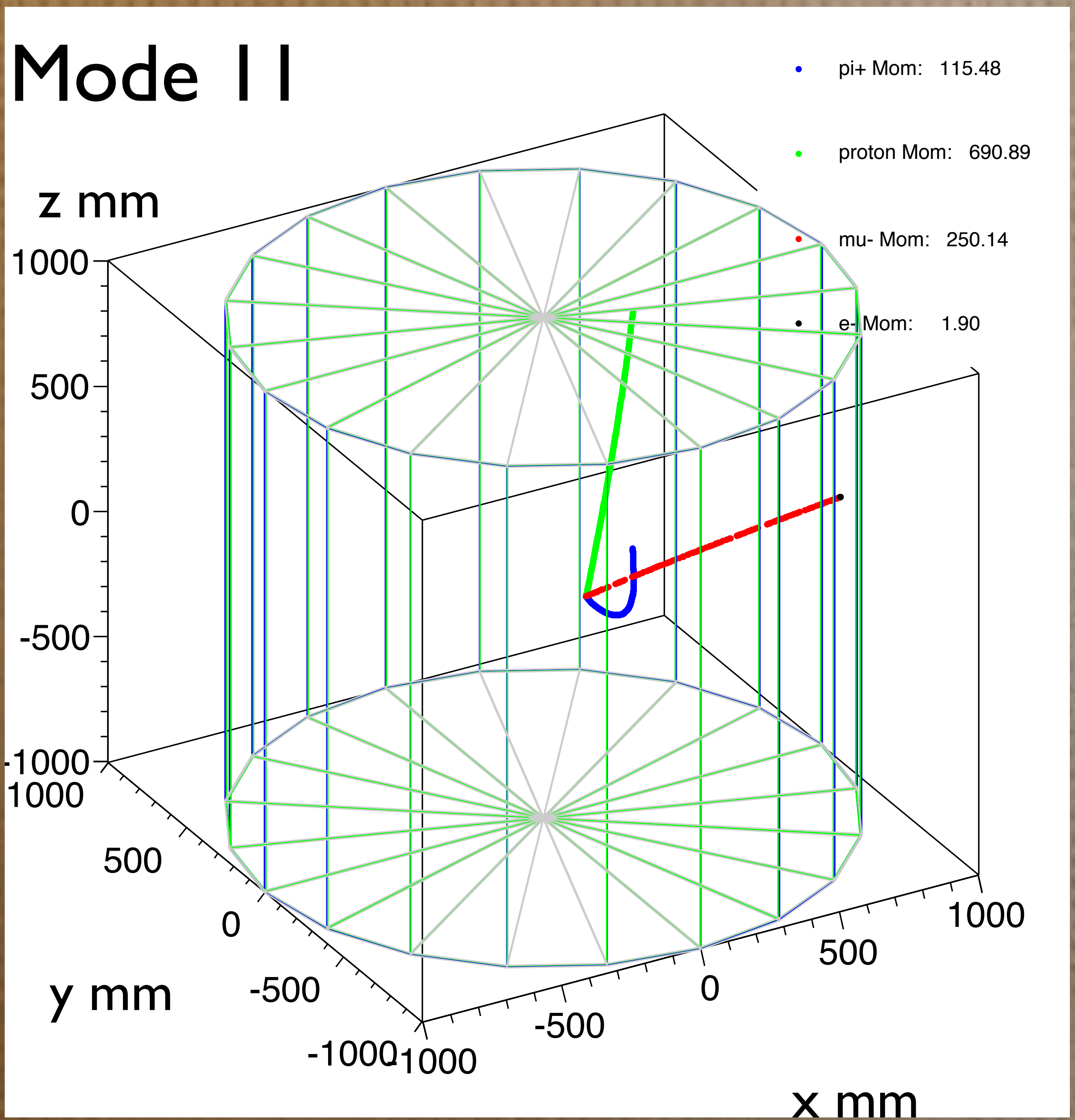
Event display



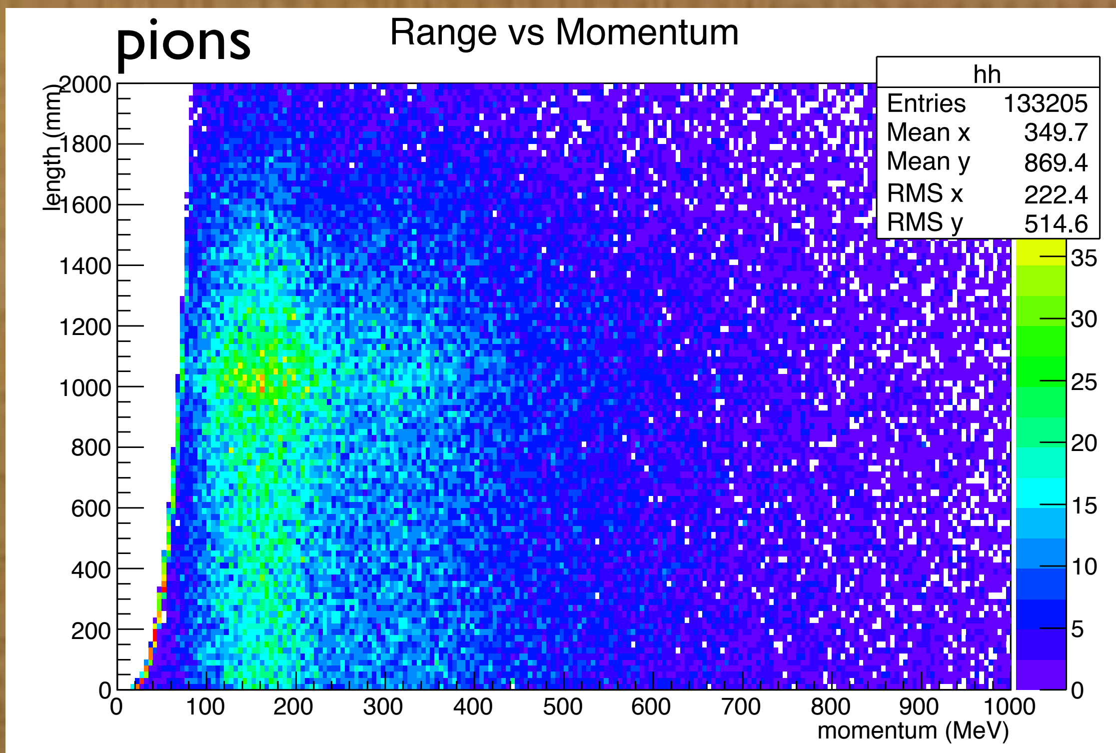


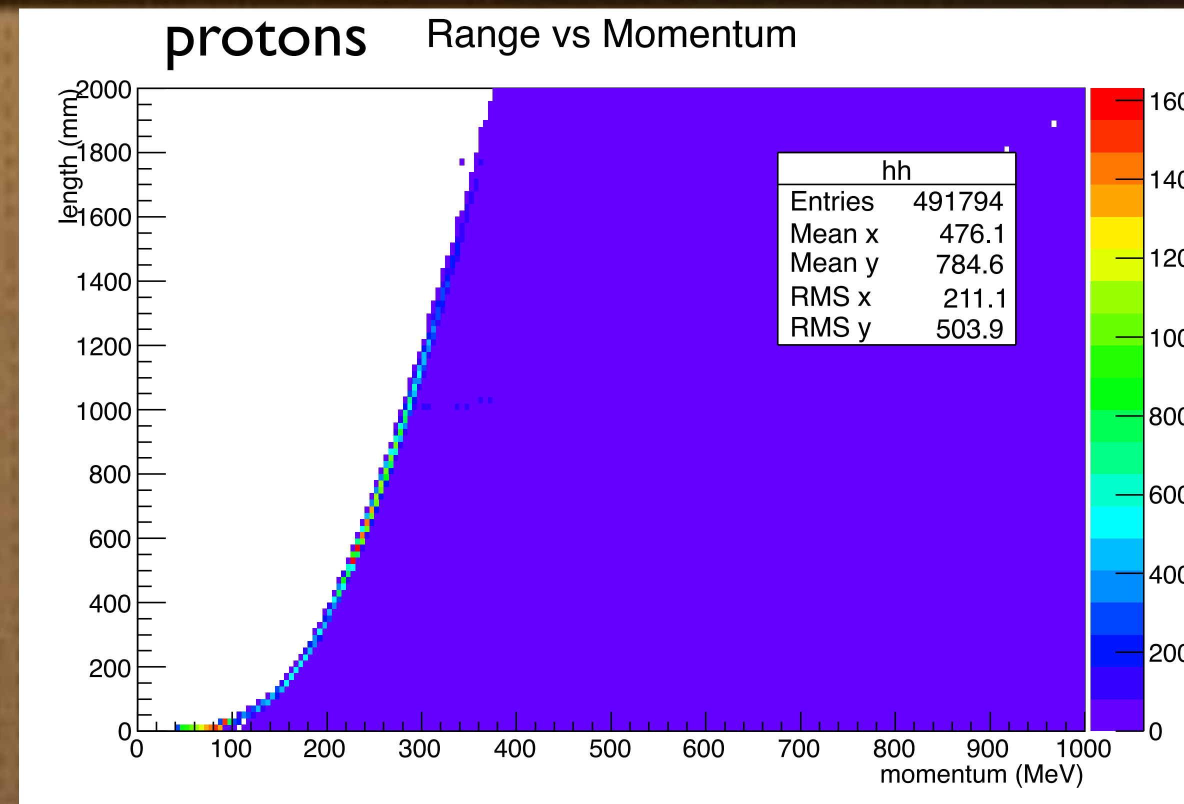
Event displays

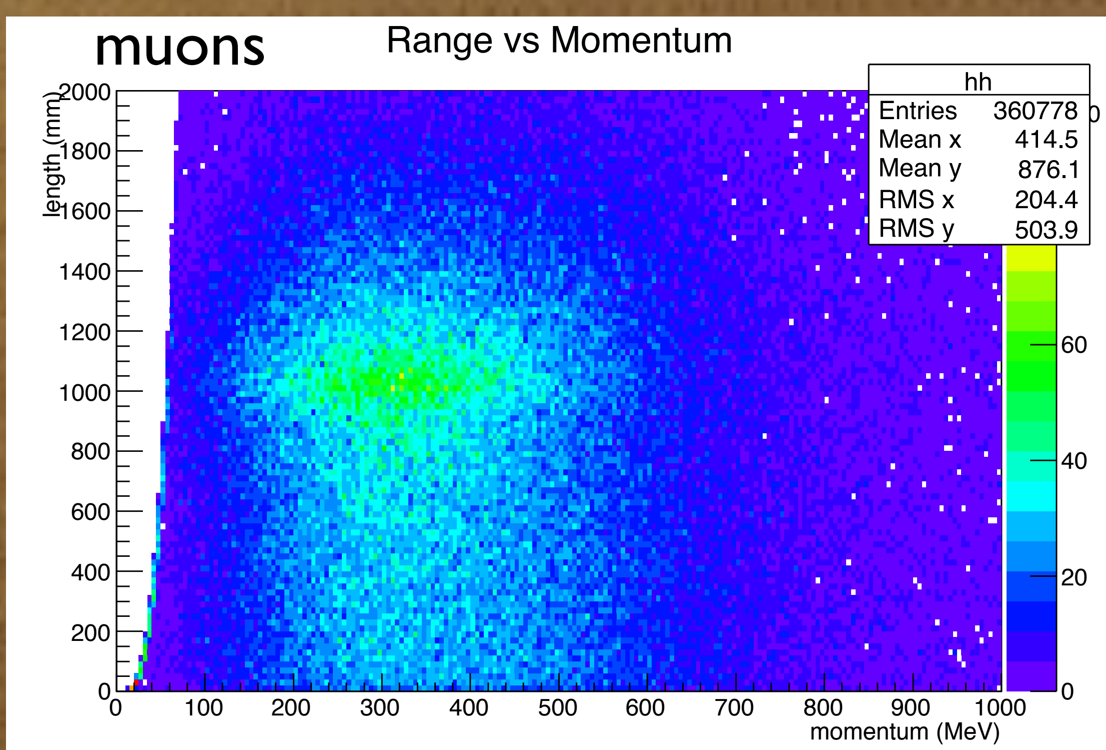




Range vs Momentum







- Muon and pions normally leave the detector.
- Protons normally range out.
- We need to consider both type of measurement: curvature and range.

Performance

Selection criteria

- An event is detected if all protons and pions emitted by the nucleus are detected.
- A particle is detected if fullfils one of the two conditions:
  - If the particle starts and stops inside the gas, the length should be larger than 50mm (~ 5 detector pads).
  - If the particle leaves the TPC, the lenght transverse to the B field should be such that the error in the p_t is smaller than 20%.

Reconstruction criteria

$$\delta k_{\mathrm{res}} = \frac{\epsilon}{L'^2}\sqrt{\frac{720}{N+4}}, \qquad \epsilon = 0.6\ \mathrm{mm}$$

(From ND280 TPC)

δk_{res} = curvature error due to finite measurement

L' = the projected length of the track onto the bending plane

ϵ = measurement error for each point, perpendicular to the trajectory

N = number of points measured along track

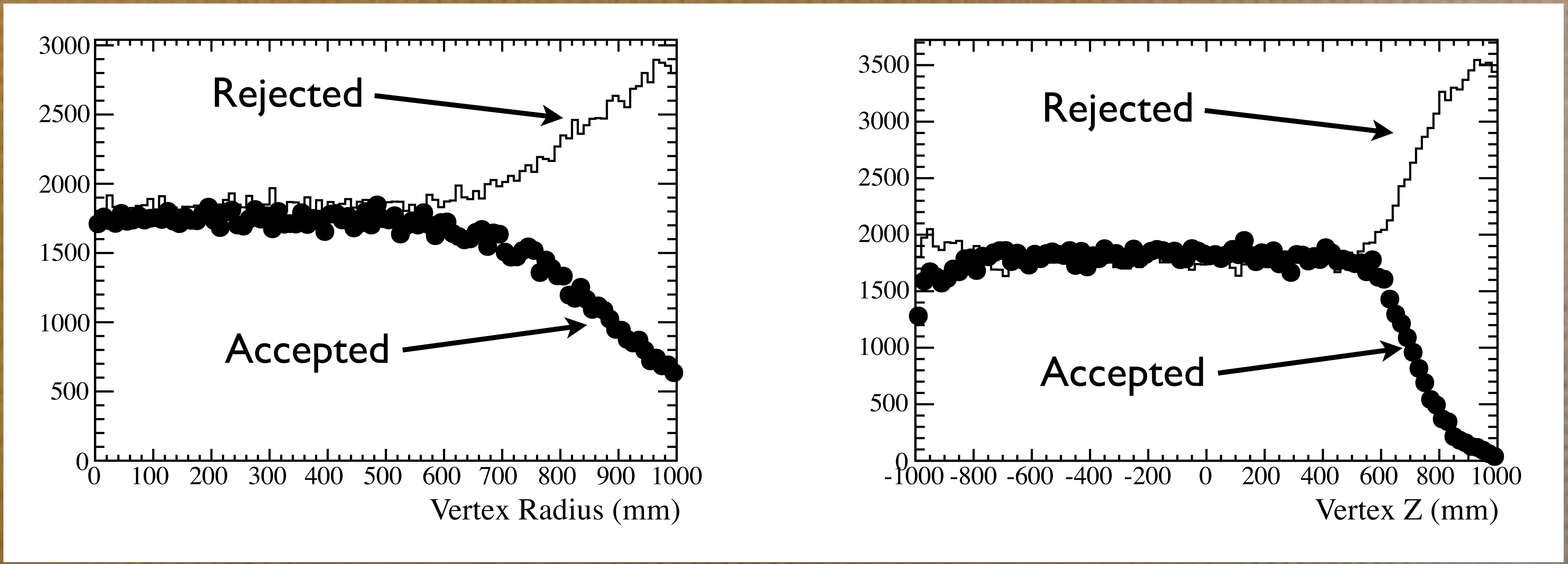
k = curvature of the track

p_t = transverse momentum

B = magnetic field

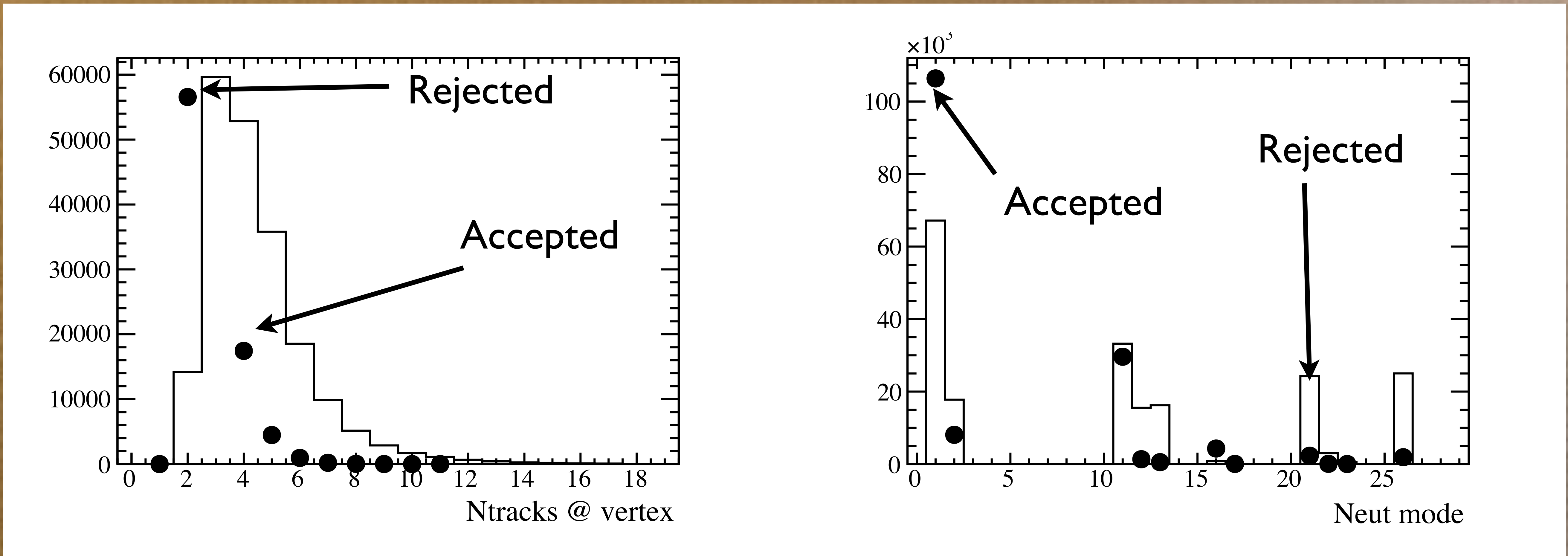
$$\delta k_{\mathrm{res}}/k < 20\%, \qquad k = 0.3B/p_t$$

Acceptance



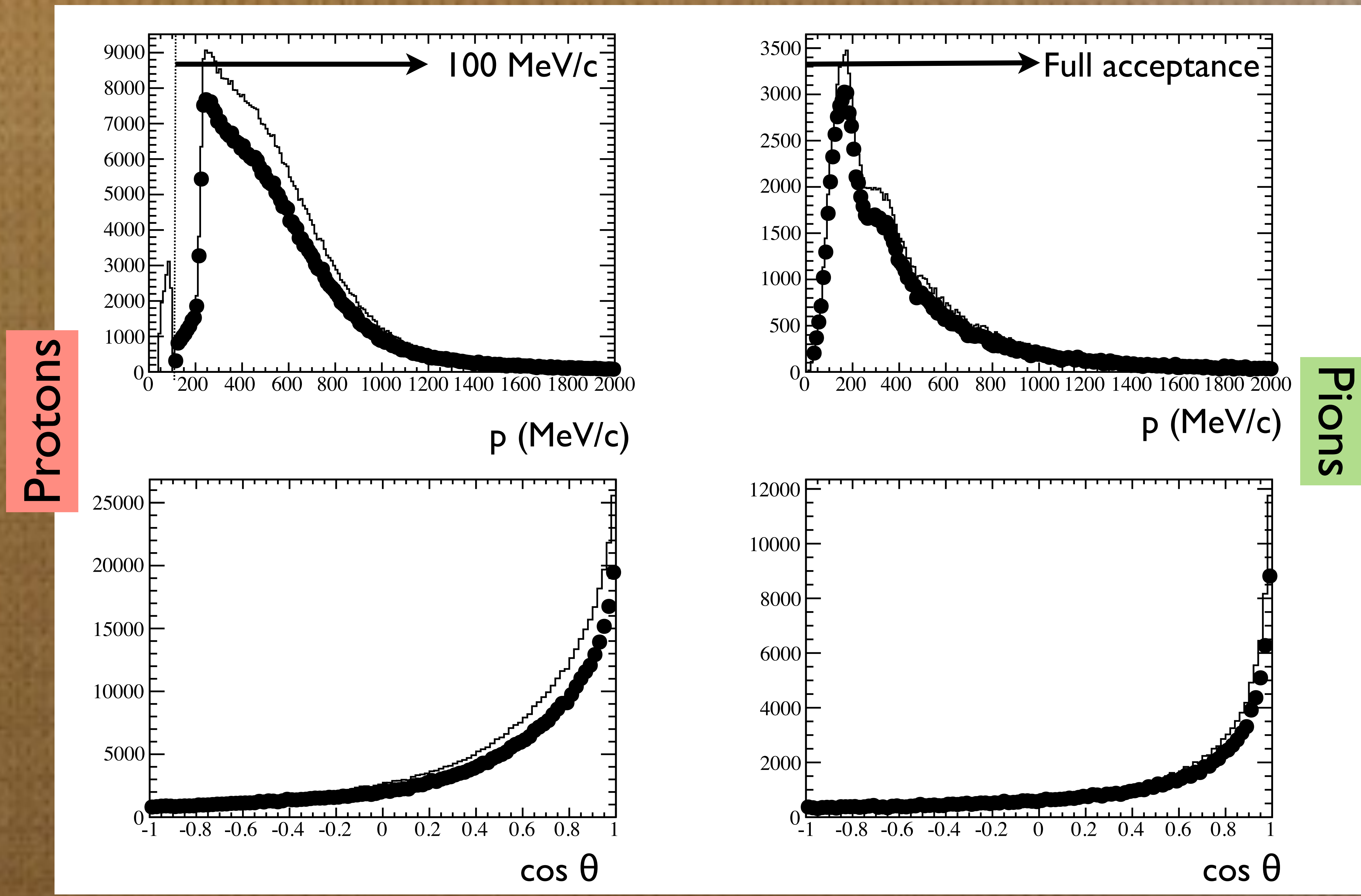
- Total acceptance: ~44%

Acceptance



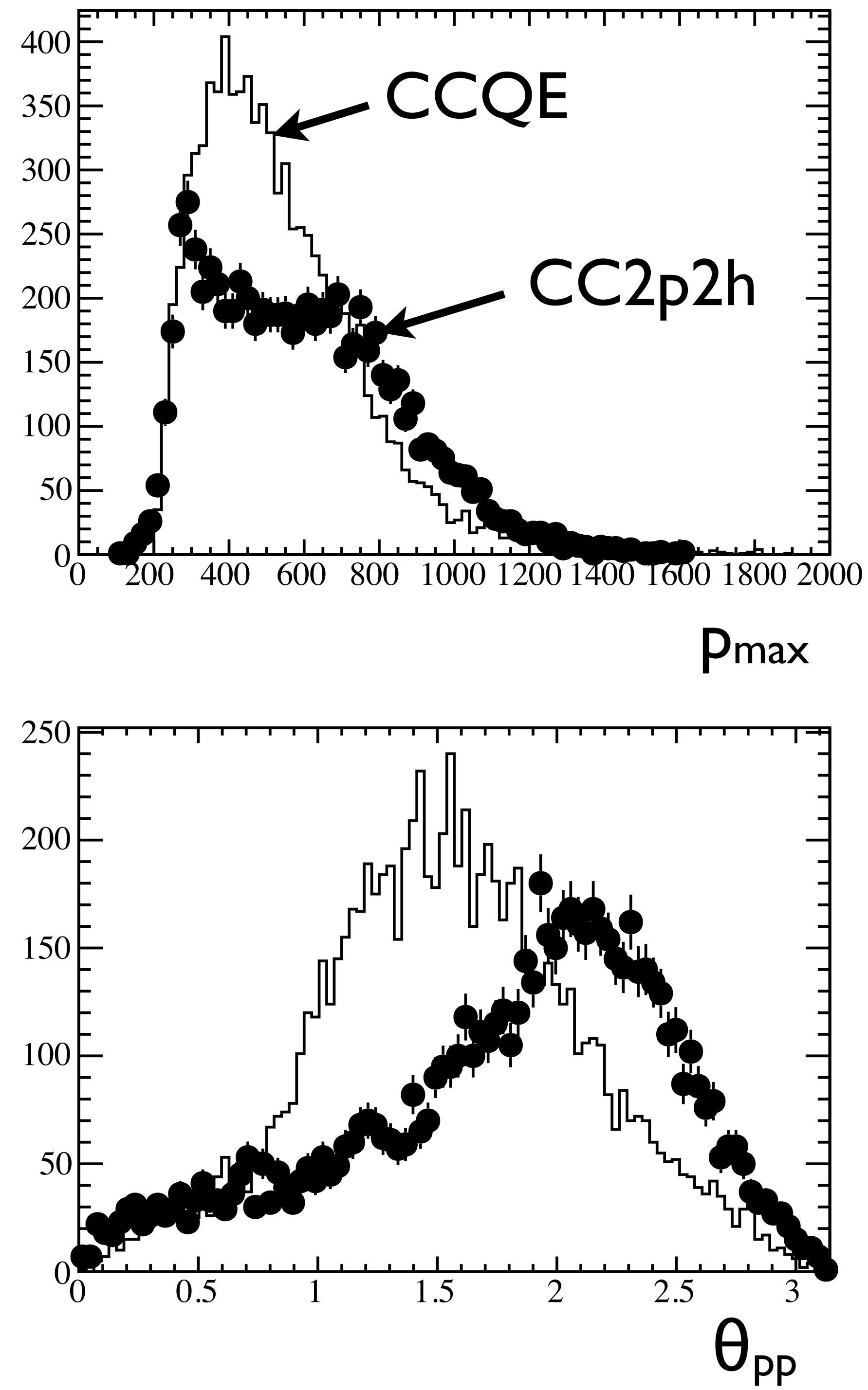
- The acceptance penalize large multiplicities. Mainly pions!
- Many of these pions can be detected with external detectors. The detector surroundings are critical !

Particle by particle



CC2p2h vs CCQE

Simulation 500 kEvt



- fully reconstructed events with (only) 2 protons in final state.
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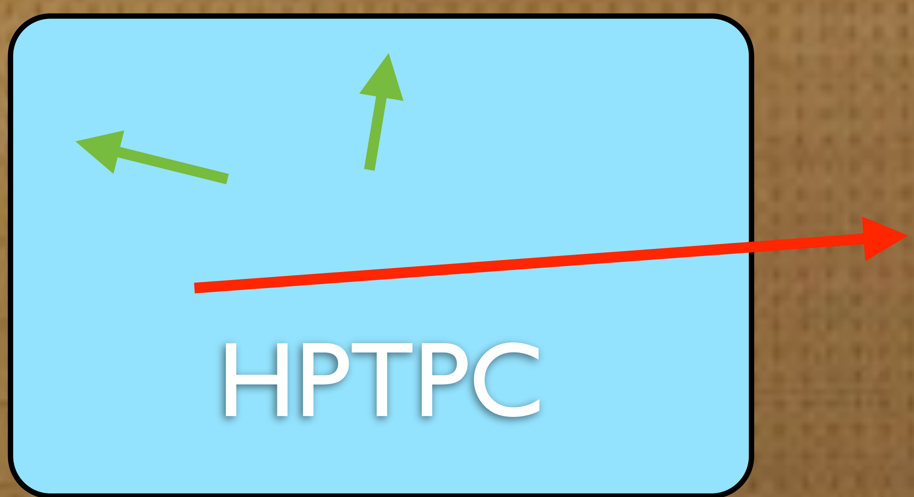
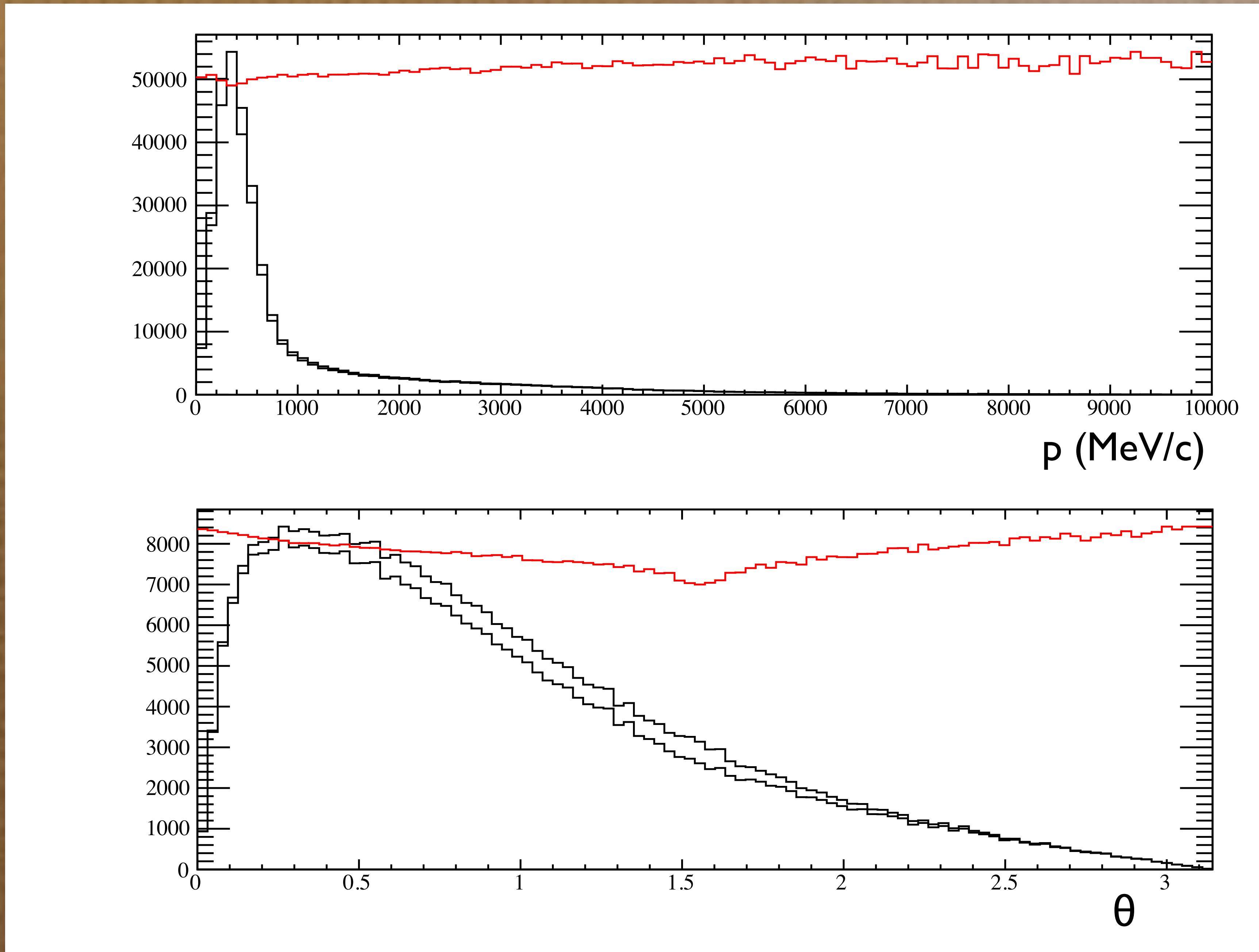
Muon acceptance





- The muon is accepted when:
  - leaving the detector in the forward direction
  - lateral/backward direction the muon is fully contained or has a momentum resolution of at least 20%.

Conclusions & remarks

Potential interests

- The following groups have shown (very informally and preliminary with no commitment at all) interest in this development:
  - Univ. Geneve
  - INFN Bari
  - Saclay (Paris)
  - IFAE (Barcelona)
  - Imperial College (London)
  - KEK (Tsukuba)

Conclusions

- A high pressure TPC will allow to access the low energy nuclear debris and help in the study for neutrino-nucleus interactions:
  - $p < 100$ MeV/C for protons
  - $p < 25$ MeV/c for muons and pions (with no had interactions).
- HPTPC seems to be an interesting detector to study neutrino Nucleus cross-sections.
  - There are observables that allows to distinguish between CCQE and CC2p2h.

Next steps

- Simulation:
  - leakage of photons: relevant to π^0 detection.
  - Advantages of scaping pions.
  - Simulation of a 2x2x2 detector.
  - two track separation and transverse diffusion.
- Cost evaluation:
  - Readout assuming MM & AFTER.
  - Close gas system.
  - Vessel.
- Design:
  - Difference in design and performance if we use ND280 or isolated detector.
- IFAE has started (for other purposes) an R&D on MicroBulk micromegas for high pressure environments.
- KEK has shown interest in the development including small prototype design.
- Next steps in this direction will be discussed in a meeting this week.