High pressure gas TPC simulation

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DUNE ND Meeting

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Overview

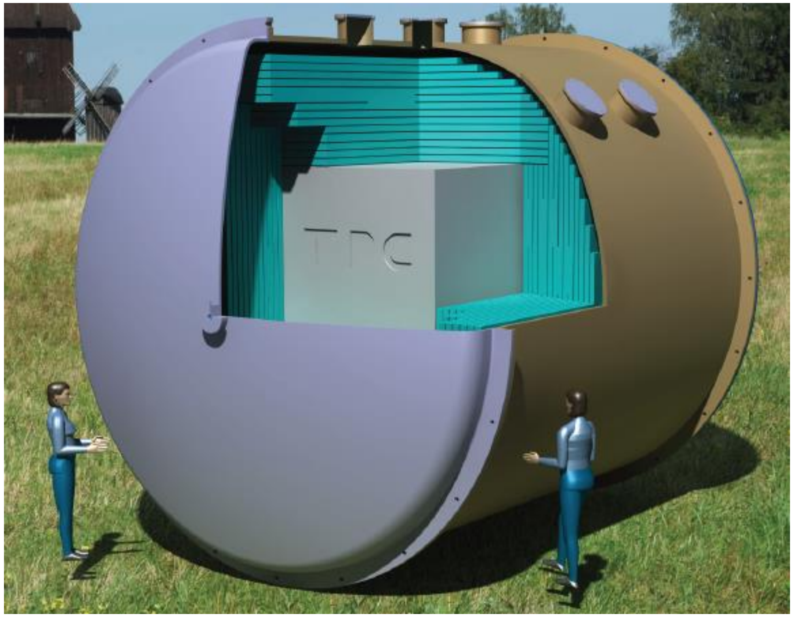
- Benefits of high pressure (HP) gas TPC
- HP gas TPC simulation
  - Status, tools available, repository
- First simulation results
  - Event rates
  - Signals and backgrounds

Benefits of HP gas TPC

- Magnetized and ~4π coverage
- Same target as the DUNE far detector
- Pressure and target flexibility
  - He, Ne, Ar, CF4 can be used to study A-dependence and FSI
- Excellent PID
- Low density and low thresholds
  - Sensitivity to $<$ 100 MeV/c protons and $<$ 25 MeV/c muons and pions
  - Model testing and generator tuning
    - 2p2h, spectral functions, FSI
    - 1π and high mass resonance

HP TPC for neutrino experiments

- HP TPC has also been considered as a near detector for other proposed neutrino oscillation experiments (LBNO, Hyper-K, T2K-Upgrade, DUNE etc)
- Simulation framework developed by T. Stainer *et al* for LBNO
  - https://dpnc-indico.unige.ch/indico/getFile.py/access?resId=0&materialId=1&confId=354



Global effort on HP Gas TPC

- Effort to build a common simulation framework for all the HP Gas TPC experiments
  - Barcelona meeting https://indico.ifae.es/conferenceDisplay.py?confId=169
- Within the UK we will start having common Dune-Hyper-K meetings to combine the efforts in a join simulation framework
  - Timescale of the two projects may not be the same

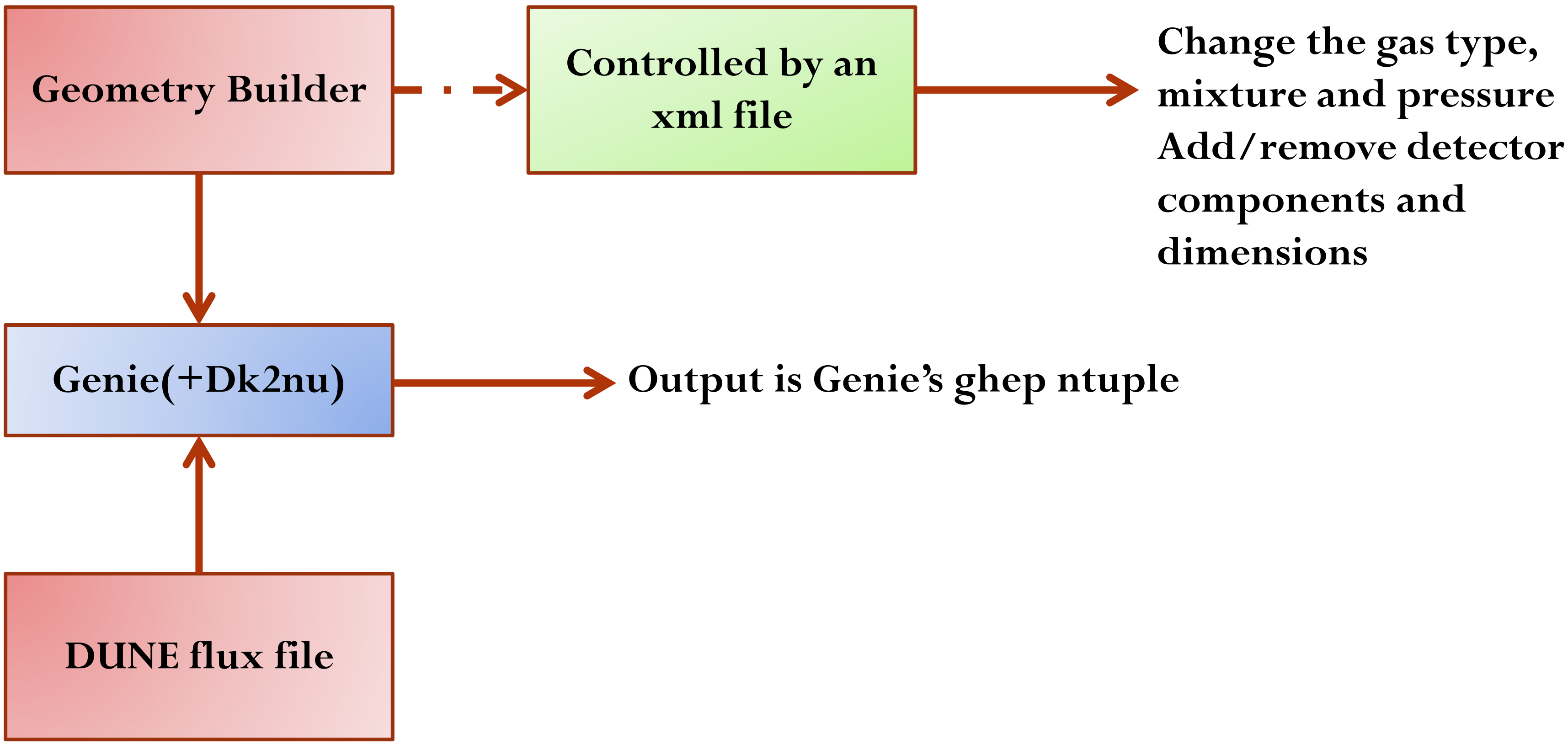
Adopting the HP TPC simulation to DUNE

- Major updates to adopt the LBNO simulation to DUNE
  - Update against recent GEANT4 release, 4.10.*
    - Code won't compile with older versions of GEANT4
  - Update against the latest ROOT 5 release
  - Update against the latest virtual MC packages for the geometry interface and readout
    - Virtual Geometry Model (VGM) and geant4_vmc
    - Older root/geant versions may require different versions of VGM and geant4_vmc
  - General software bug fixes
  - Tested against Genie 2.8.4(6)

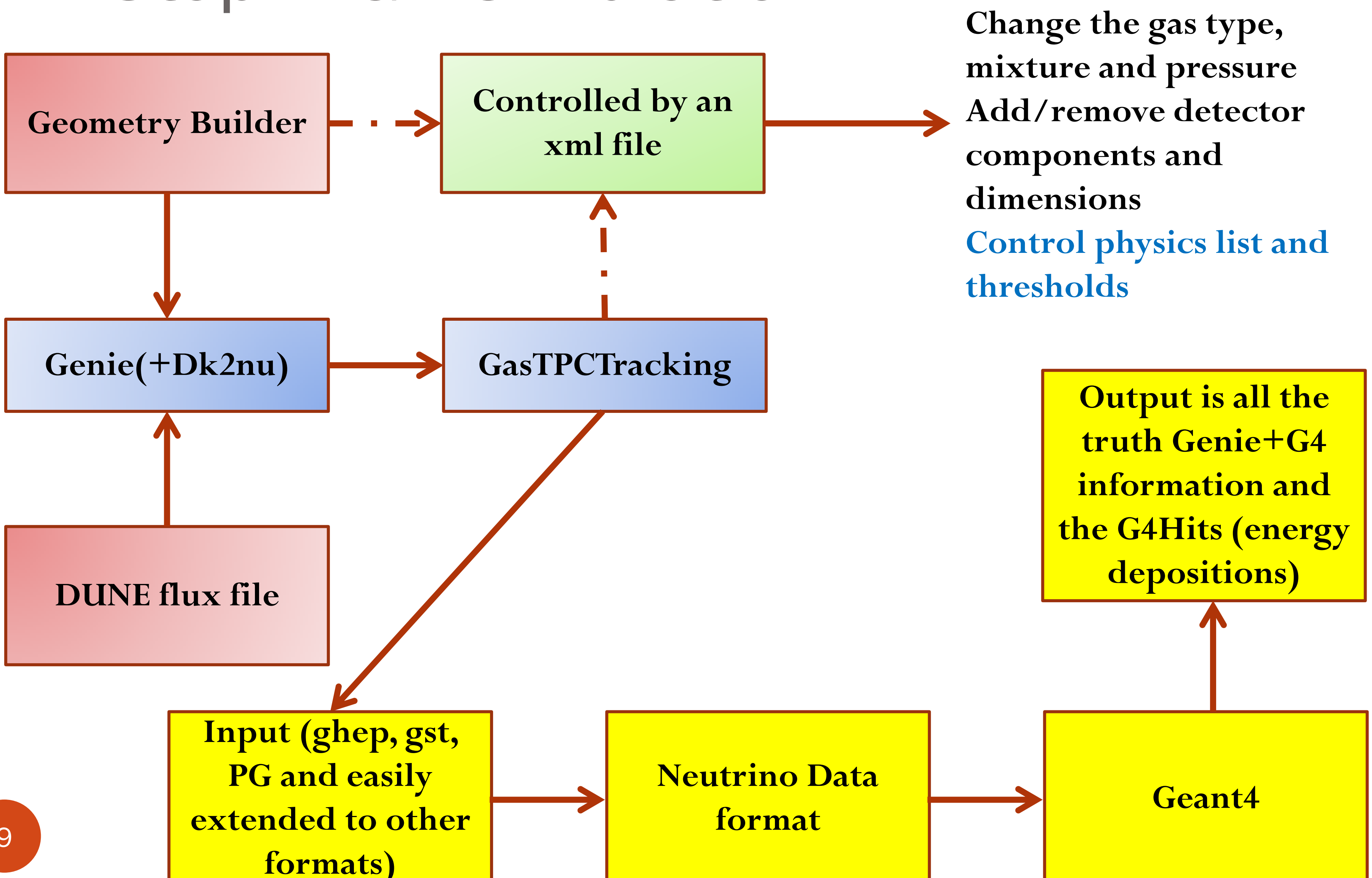
Update the flux and Geant4 simulation

- Code cleaning
  - Update GEANT's physics lists and optimize in terms of speed/physics output
    - For example low energy thresholds
  - Remove old/unused code
  - Give option to checkout, compile and run only some parts of the software
    - For example ignore GEANT4 for studies at the generator level
  - Check dependency against third party software
- Use Genie's NuMi flux driver instead of flux histograms
- Add particle gun option

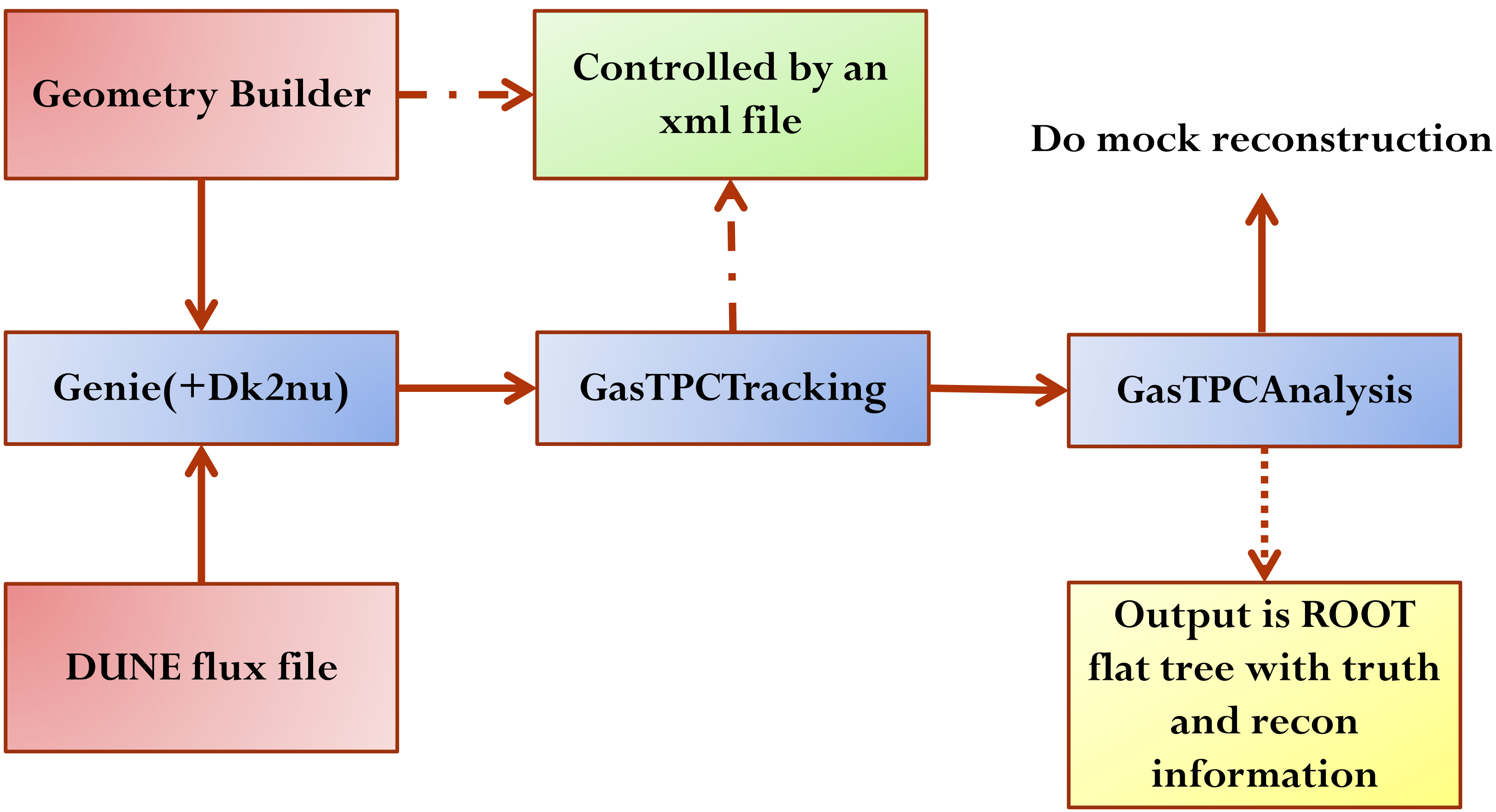
How to run the HP Gas simulation: Step1: Produce vertices



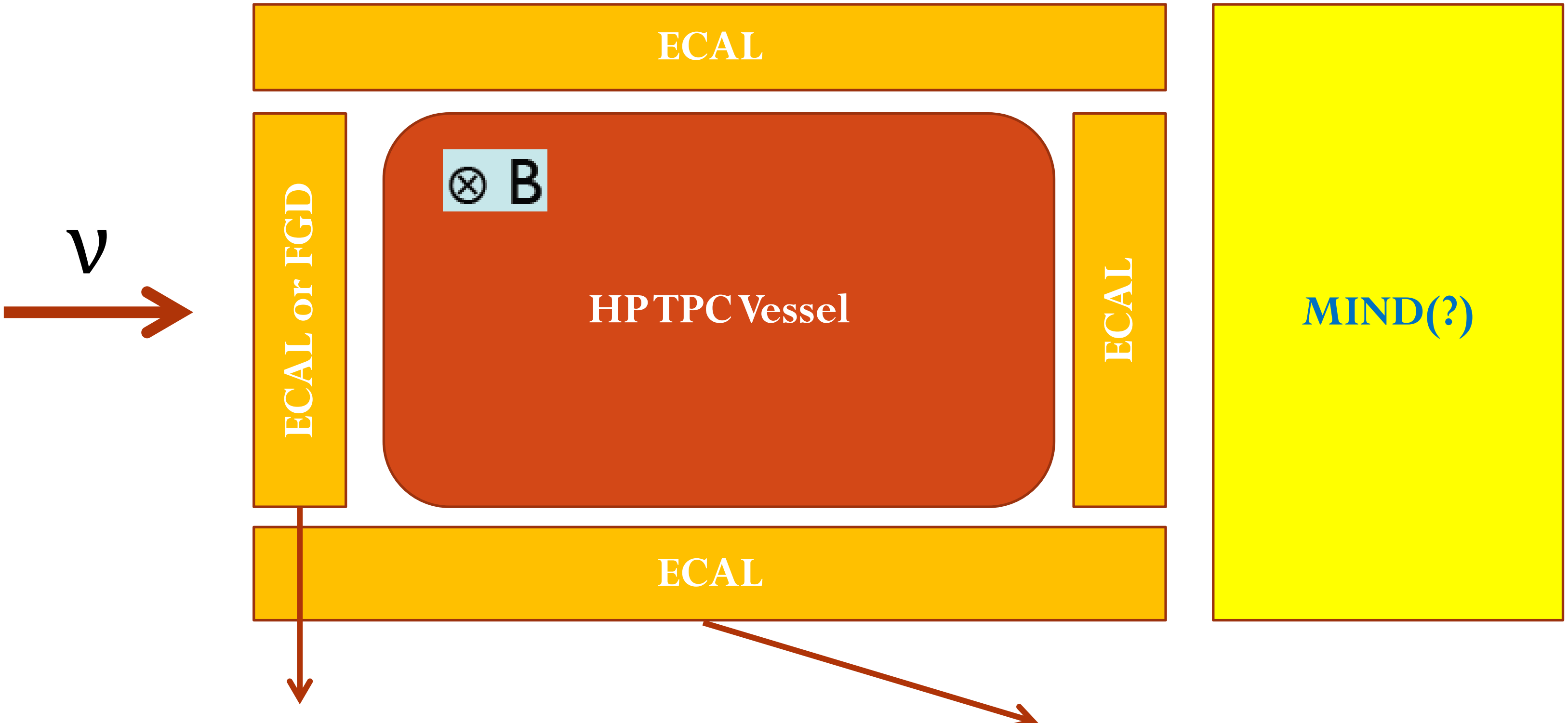
Step2: G4 simulation



Step 3: Mock reconstruction



Basic design of the HP TPC for DUNE



Could also be another target for neutrino interactions

HP TPC is surrounded by the ECAL for neutral particle containment

ECAL can provide additional target for neutrino interactions

ECAL inside the vessel is another (challenging) possibility

HP TPC simulation for DUNE

- Near detector located 459m from the target
- Test and debugging production of 1.5×10^{19} POT for forward horn current (FHC)
- Flux files provided by Laura Fields
  - "Nominal" beam simulation version v3r3p5 at 200kA
- Simulate only the HP TPC gas volume and the vessel
  - Flux+Genie(+Dk2nu)+Geant4
    - Code in https://github.com/DUNE/wp1-neardetector
  - $4.0\times4.0\times4.0$ m active volume
  - 20 bar, ~550 kg, $0.035 g/cm^3$
  - ~35k events/1.5×10^{19} POT in the gas volume
  - ~10 times more events in the 10 cm thick aluminium vessel
    - 70% give some activity in the HP TPC

The vessel

- Composite materials appear a very attractive solution to build a low density vessel
  - Reduce pile-up
  - Reduce out of TPC background
  - Reduce the shield for gammas going in the Ecal
- 5cm thick honeycomb aluminium panel is now considered for the vessel
  - 10 times lighter than custom aluminium
  - Large strength to weight ratio (larger than steel)
  - Used in many applications
  - For safety reasons the vessel must hold at least four times the gas pressure (80 bar)

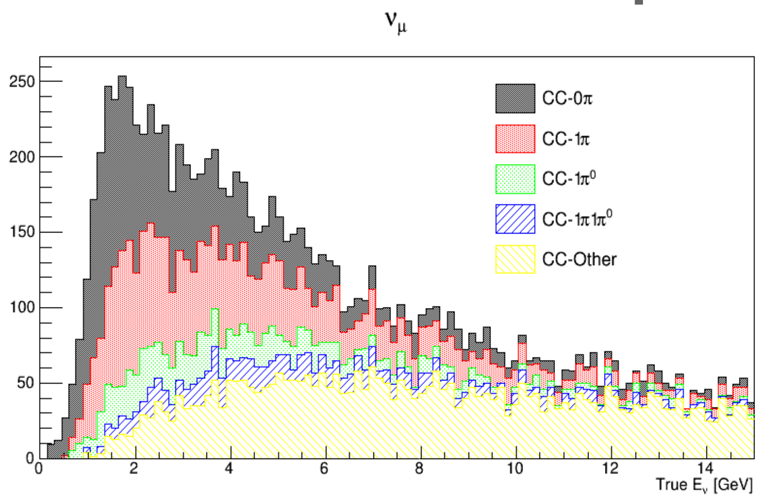
Mock reconstruction

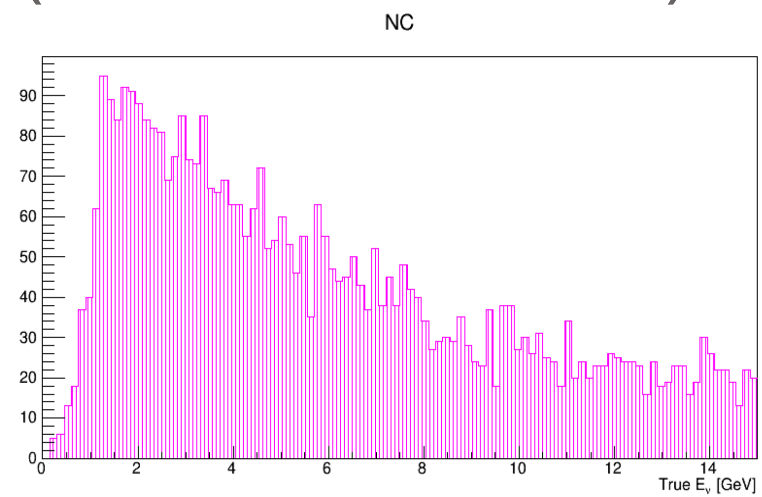
- Momentum resolution
  - Sagitta $s=B\times L^2/(26.7\times p_t)$
  - $\sigma_s = 0.05$mm, $\sigma_L = 0.6$mm (from T2K)
  - Smear s and L and calculate p_t
  - Then $p = p_t/\sin\Theta$, with Θ the polar angle between the track and the magnetic field
  - This method also provide a first estimation of the charge confusion if Sagitta $< \sigma_s$
- Angular resolution = 0.2 rad
- dE/dx resolution = $5.4\times L^{-0.37}$
  - Effective track length L = track length$\times$pressure
- Still to add
  - Recon efficiency (almost complete)
    - Low energy electrons might be an issue
  - dE/dx parameterization

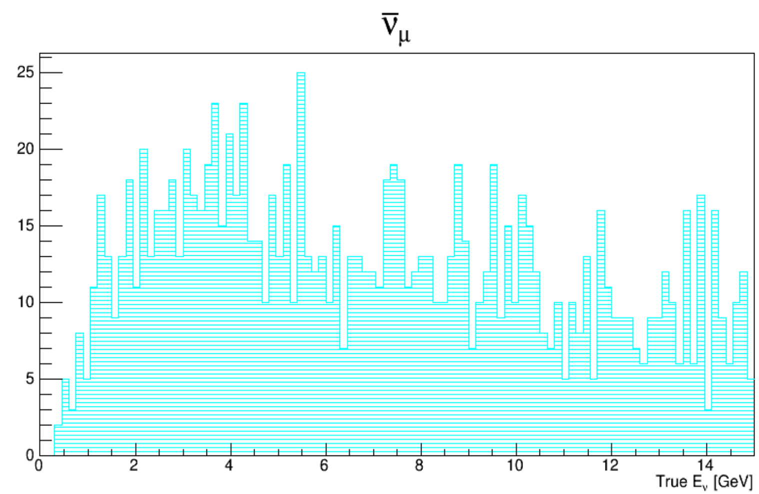
Pile-up in the near detector

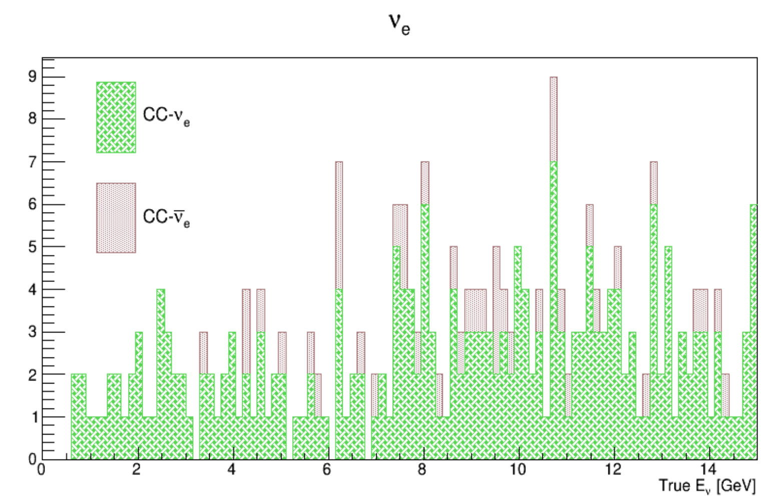
- For every 1 neutrino interaction in the HP TPC Ar Gas
  - ~10 neutrino interactions in the vessel (from simulation)
  - ~125 neutrino interactions in the ECAL (estimated)
    - Assuming 30cm pure scintillation detector
  - ~625 neutrino interactions in the magnet (estimated)
    - Assuming 50cm iron
- Challenges
  - Veto against charged particle tracks coming outside the HP TPC volume
  - Reconstruction of ECAL neutral clusters

FHC true topology (1.5×10^{19} POT)

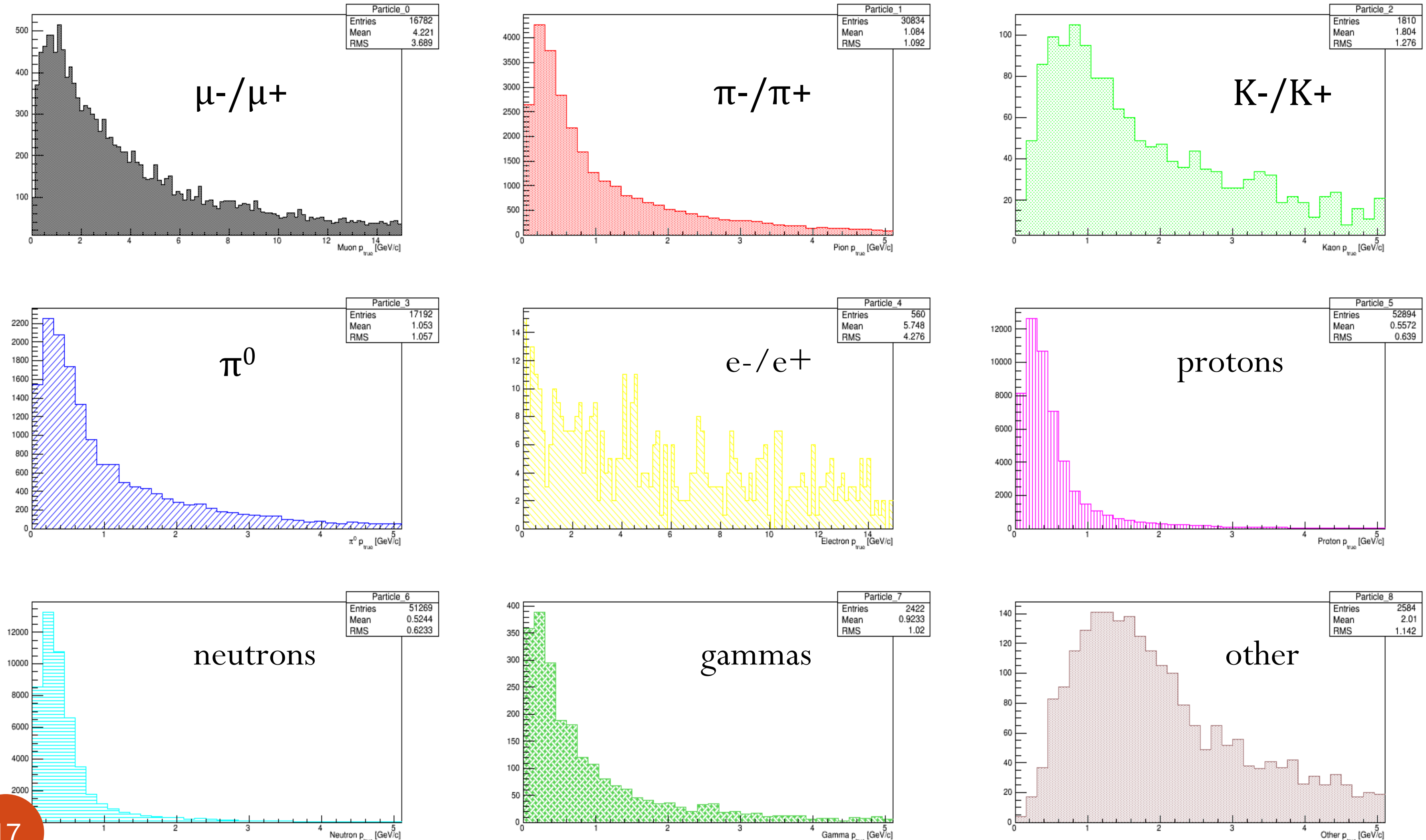




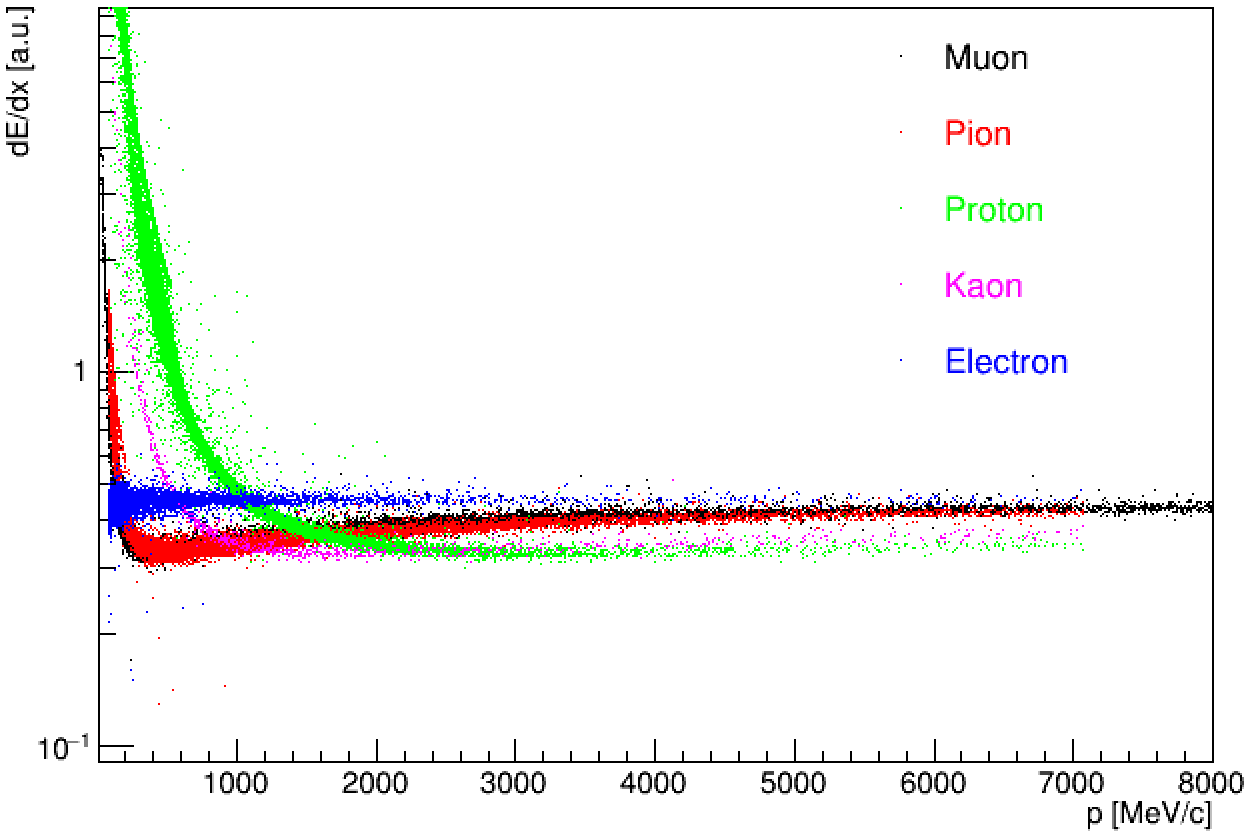




Momentum distributions at the generator level

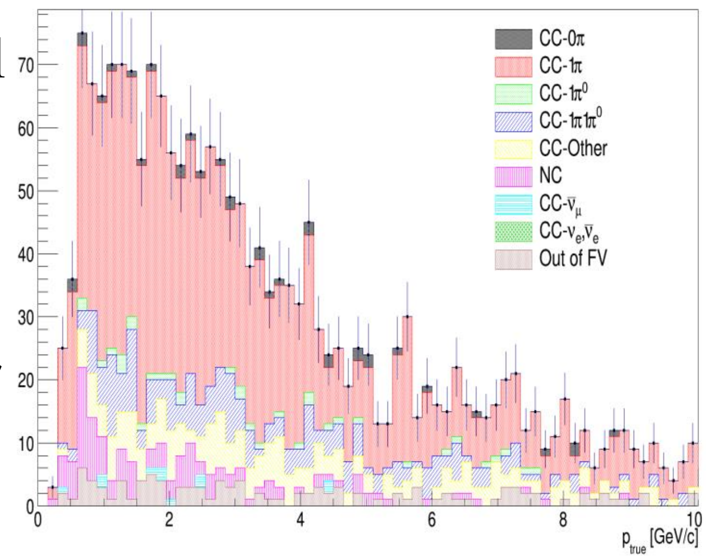


dE/dx in the 20 bar HP TPC



Preliminary example of event selection in the HP TPC – CC1$\pi^\pm$

- Very preliminary non-optimized event selection
  - Fiducial volume box reduced by 70cm from the HP TPC box in all directions
  - Track length > 25 cm
  - P > 25 MeV/c
  - Highest momentum track is μ^- or π^-
  - Only one $\pi^\pm$
  - No tracks starting >15cm from the vertex

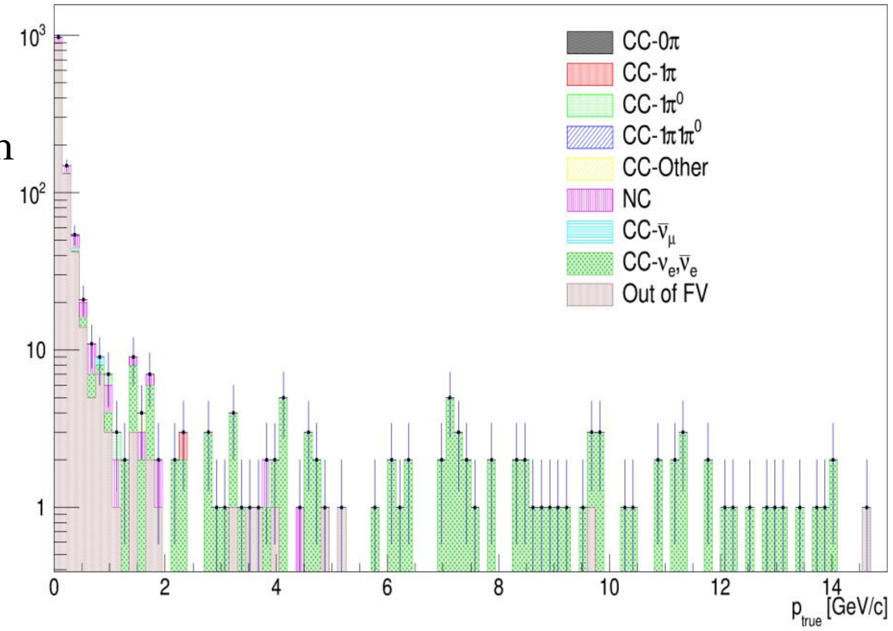


Events /1.5×10[19] POT	Efficiency (%)	Purity (%)	Events with a FS π^0 (%)
2315	22.7	59.6	24.5

Preliminary example of event selection in the HP TPC - CC-ν_e inclusive

- Very preliminary non-optimized event selection
  - Fiducial volume box reduced by 70cm from the HP TPC box in all directions
  - Track length > 25 cm
  - P > 25 MeV/c
  - Highest momentum track is e^-
  - No other e^-/e^+ tracks
  - No tracks starting >15cm from the vertex
- π^0 induced background dominated near the 1st and 2nd oscillation maximum
- Need more careful studies

Events / 1.5×10^{19} POT	Efficiency (%)	Purity (%)
1368	21.6	9.3



Next steps in the HP Gas TPC simulation

- Manpower
  - G.C. and Justo Martin-Albo (University of Oxford)
  - 1 new Liverpool postdoc starting before the end of the year
  - More hands are very welcome!
- Code maintenance and improvements, validation tools, moving to NuTools(?)
- T_0
- Pile-up
- Detector response
- Reconstruction
  - Apply the T2K gas TPC reconstruction
    - Long term plan and depends on the progress within T2K
- Event selection
- Ecal
  - Very important for vetoing the TPC and for neutral cluster reconstruction
  - Which technology is better (plastic, crystal, LAr etc)
    - Performance and cost dependent
  - Add hadronic part
  - Reconstruction is much more complicated (MIPs vs EM Shower vs hadronic shower)
  - Could be a joined effort with the other near detector options

Summary and future plans

- HP TPC provides an opportunity to detect vertex activity beyond the sensitivity of LAr detectors
- First version of the HP TPC simulation for DUNE has been developed
  - Code in github
- Preliminary results look promising

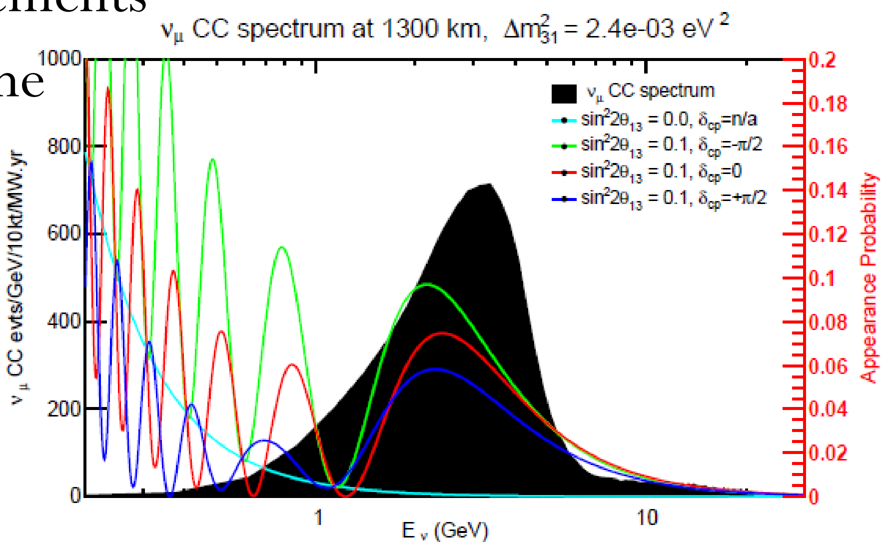
Back up

The new FNAL flux files

- DUNE uses a different flux n-tuple than the other Fermilab experiments
  - Flux files have to be converted to the new flux file format (Dk2nu)
  - At the moment this is only possible by obtaining the Dk2nu package
    - Later Genie releases will have this implemented
  - Change the beam window in GNuMIFlux.xml
  - Run the new gevgen_fnal or gevgen_numi from Dk2nu

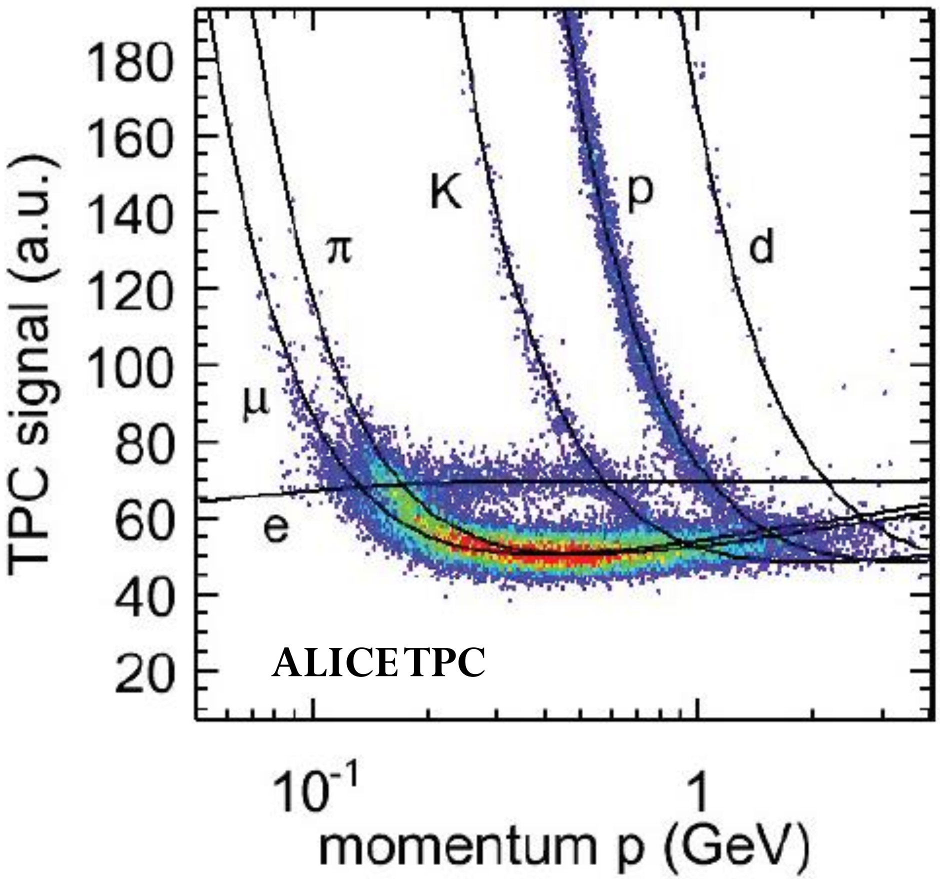
The role of near detector for DUNE

- Constrain the systematic uncertainties for the neutrino oscillation measurements
  - Select various inclusive and semi-inclusive samples for all neutrino species
  - (Anti-)Neutrino energy scale
  - Background channels for the oscillation analysis (π^0,etc)
  - Cover first and second oscillation maximum
- Neutrino cross section measurements
- New physics in the short baseline



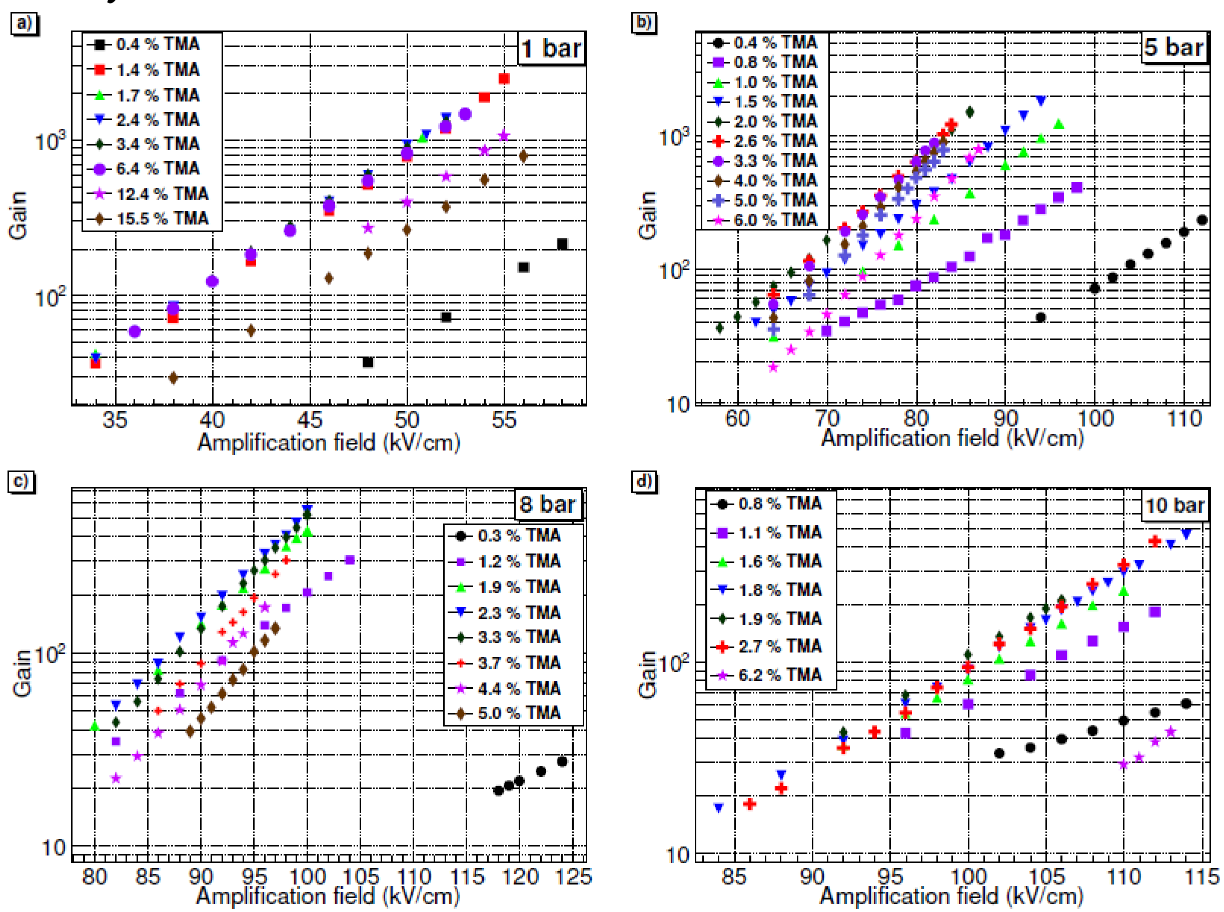
Particle identification using dE/dx

- Proven technology, well understood used for many years
- Advantages
  - Excellent PID in a broad momentum range
  - Very good momentum resolution
- Disadvantages
  - No muon-pion separation
  - Regions where the energy loss curves cross



High pressure gas gain

- Micromegas-TPC operation at high pressure in xenon-trimethylamine mixtures (arXiv:1210.3287)



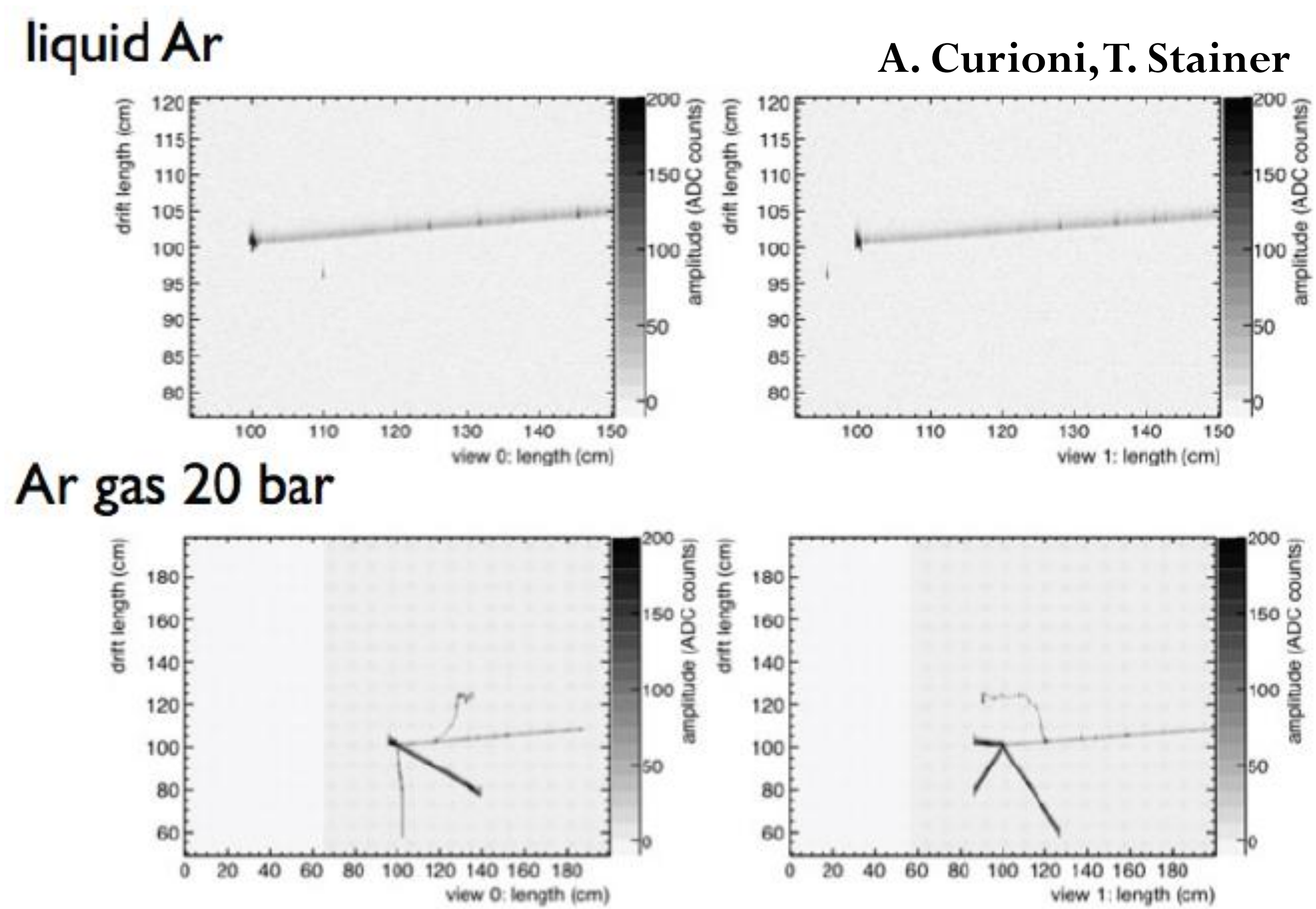
HP TPC T_0

- Need to determine t0 for the time co-ordinate
  - Use the ECAL
    - Issue with low energy tracks
  - Light emitted during ionization
    - PMTs inside the detector
    - Gas mixture light absorption
    - Wavelength < 128 nm
  - Transverse diffusion
    - Number of channels

Detection of soft tracks in HP TPC

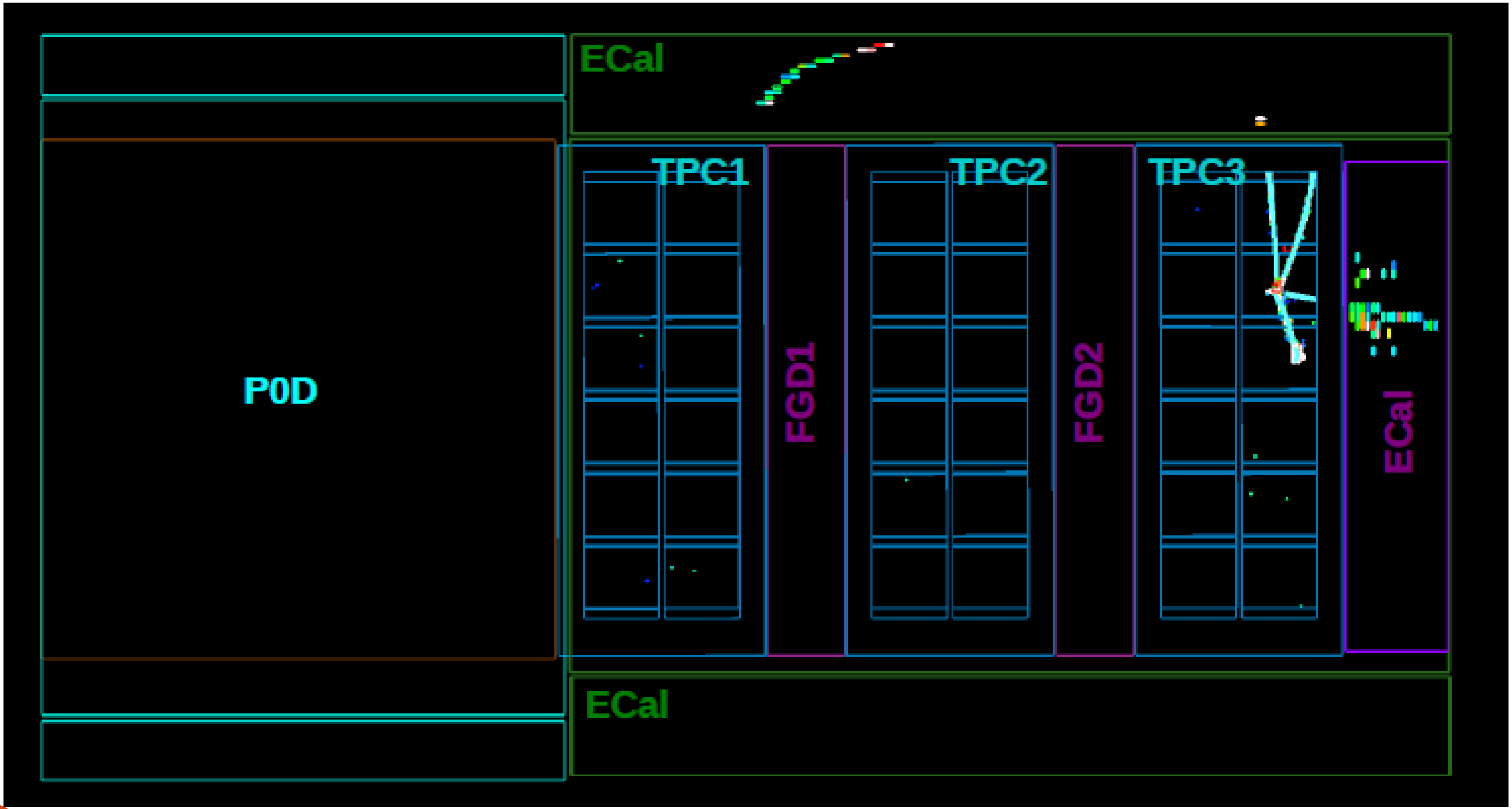
- Soft protons can be undetectable in LAr

A. Curioni, T. Stainer



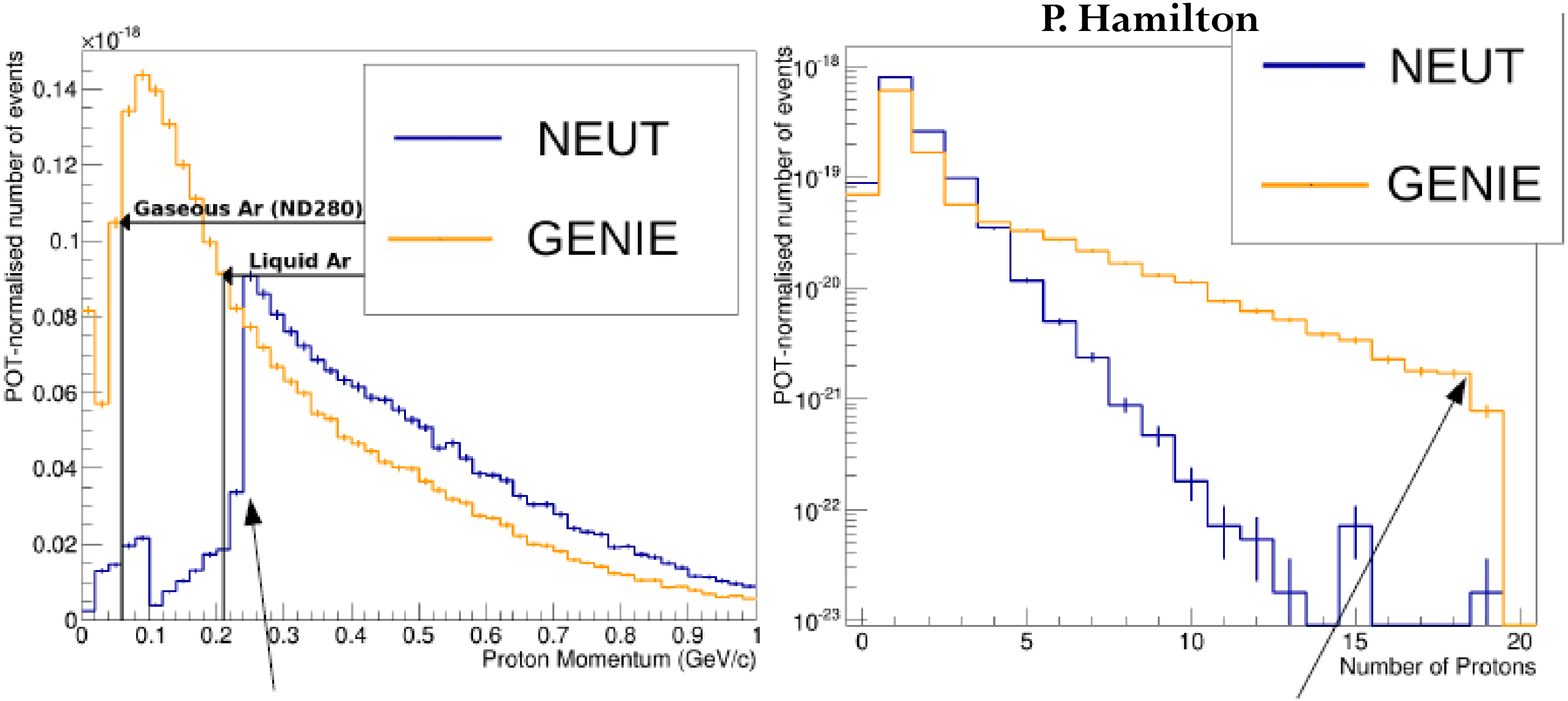
Gas TPC neutrino event in T2K near detector

P. Hamilton



Low energy sensitivity in gas TPC – example from T2K near detector

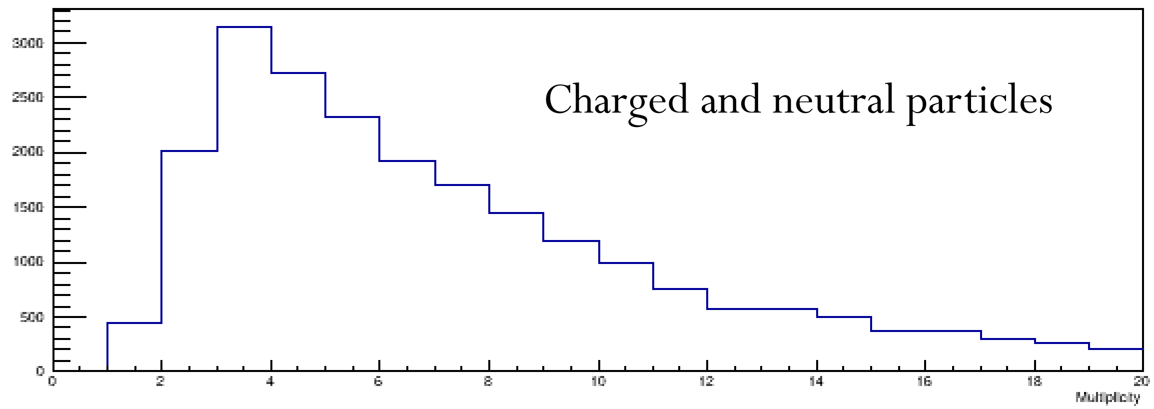
P. Hamilton

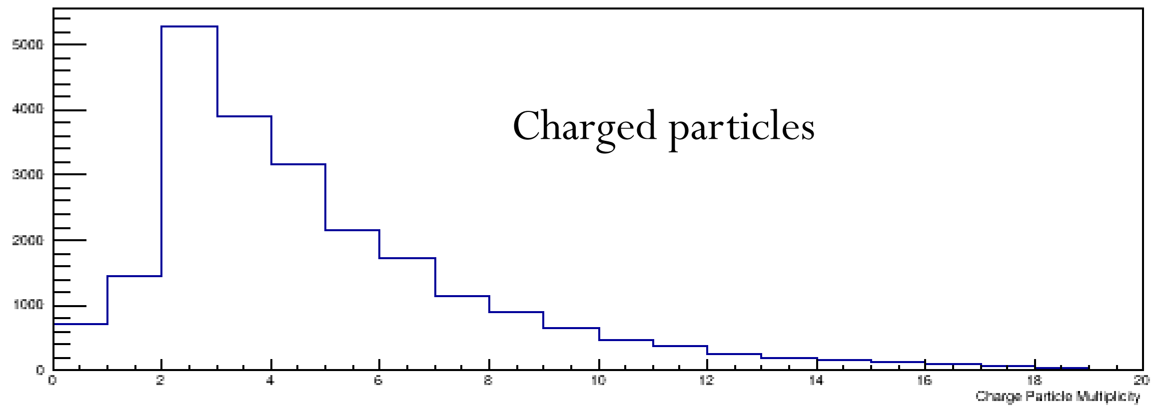


Fermi momentum “cliff”

Ludicrous GENIE multiplicity tail!

Multiplicity at the generator level





Neutrino interactions for FHC in the HP TPC (1.5×10^{19} POT)

Primary state topology	%
ν_μ CC-0π	9.4
ν_μ CC-1$\pi^\pm$	15.0
ν_μ CC-1π^0	4.9
ν_μ CC-1$\pi^\pm$1π^0	4.4
ν_μ CC-Other	30.5
NC	25.0
$\bar{\nu}_\mu$ CC	8.3
ν_e-$\bar{\nu}_e$ CC	2.2

ν_μ interaction	%
CC-QEL	10.5
CC-RES	28.5
CC-DIS	35.9
CC-COH	0.4
NC-QEL	3.7
NC-RES	9.5
NC-DIS	11.3
NC-COH	0.2
Other	<0.1