RTPC Simulation Studies for Tagged Deep Inelastic Experiment

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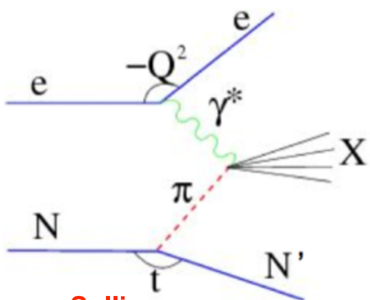
SBS Collaboration Meeting,

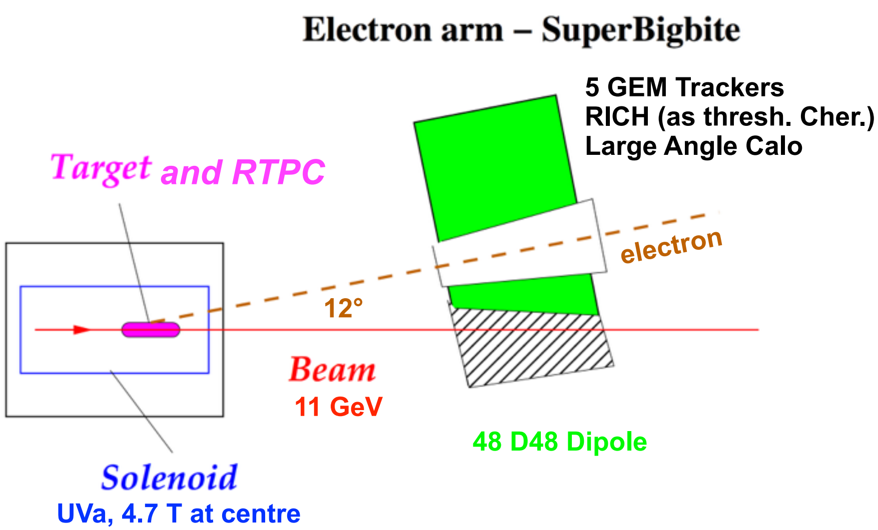
Jefferson Lab, 22/07/16

Tagged DIS Measurement with RTPC and SBS

- Measure DIS cross section, detecting high W^2, Q^2 e^- scattered from H_2 and D_2 targets while tagging low-momentum recoil and spectator protons in coincidence
- Probe mesonic content of the nucleon structure function
- Access to pion structure function via Sullivan process N(e,e'N')X, described by e^- scattering from pion cloud of nucleon N (initial nucleon at rest)

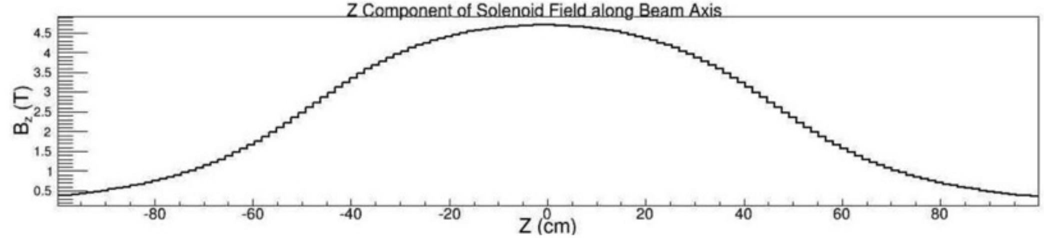


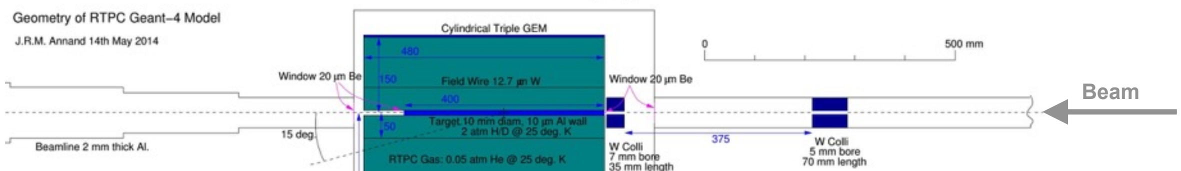
Sullivan process



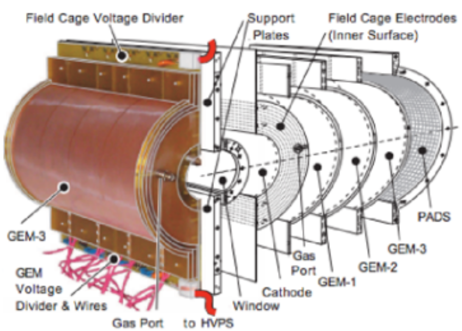
- Straw gas target (10μm Al cylinder; 5mm radius; 10μm Al end-windows; 400mm length; 77K; 1atm H_2 or D_2)
- Radial Time Projection Chamber for proton detection; large angular and kinematic coverage - detailed study of Sullivan process as a function of proton momenta and angles
- Solenoid (from UVa) surrounding target/RTPC
- SBS for e^- detection
- HCal-J for neutrons in calibration runs

RTPC Design





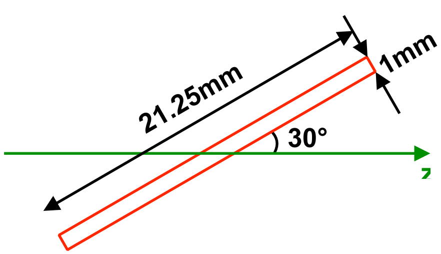
TDIS Target + RTPC



BONUS and CLAS eg6 RTPC

TDIS RTPC:

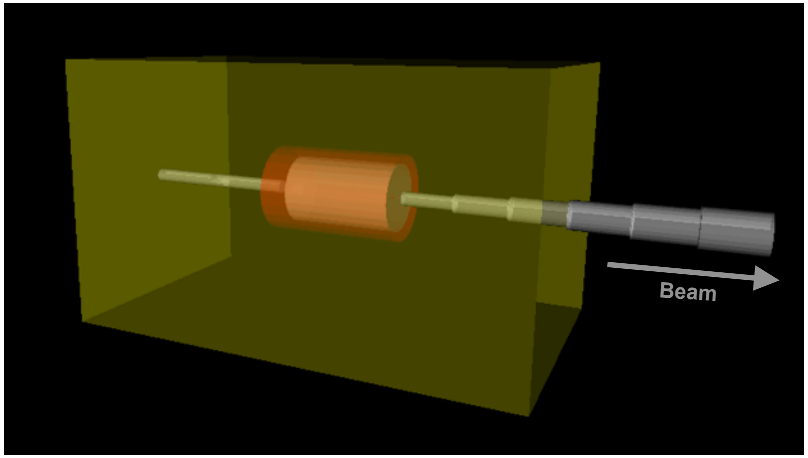
- Length 40cm; cylinder with radius 15cm
- "Straws"/field wires at r=5cm to set up drift region from 5cm to 15cm
- Gas: 90% He, 10% CH_4 (or similar) as quencher
- Temperature 77K; pressure 0.2atm
- Drift electrons amplified and detected by triple layer cylindrical GEMs at r=15cm



GEM Readout:

- Strips in UV pattern
- Strip length 21.25mm, pitch 1mm, 30° angle w/ z-axis
- ϕ-coverage per strip 0.007698 rad
- z-coverage per strip 18.40 mm
- 816.2 to cover 2π in ϕ in each layer
- 22 to cover 400mm in z-direction in each layer

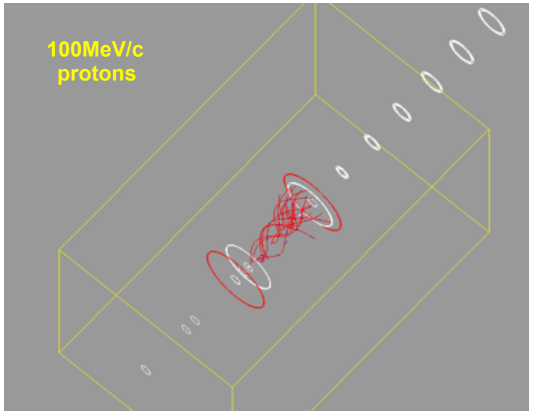
Geant4 Geometry

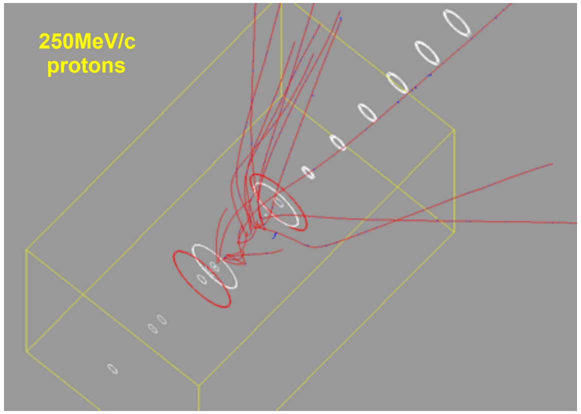


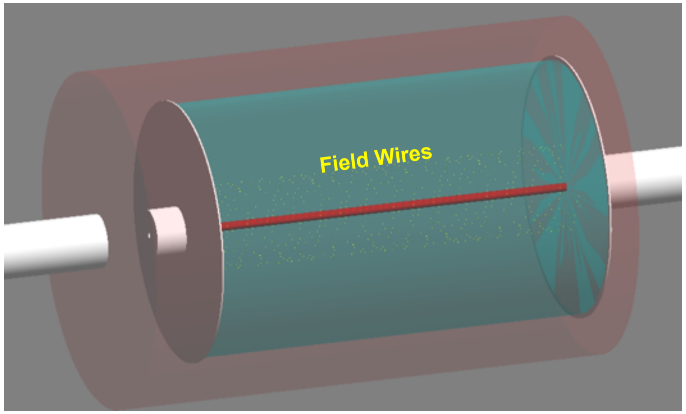
- Geant4 (4.10.01.p02) geometry developed J. Annand, for in-depth study of background processes and rates

Proton background rates

Target	θ_p (deg.)	$70 < p_p < 250$ (MHz)	$p_p > 250$ (MHz)	$150 < p_p < 400$ (MHz)
^{1}H	30 - 70	2.3	7.4	6.3
^{2}H	30 - 70	357	20.1	64
^{2}H	100 - 140	204	3.1	–
^{27}Al	30 - 70	0.37	0.0	0.05
^{27}Al	100 - 140	0.10	0.0	–







- **For studying RTPC Geant4 set-up used to track protons and their energy deposit**
- Incident protons generated using Monte Carlo event generator
- Generated along length of target volume
- Gaussian smeared momentum distribution with standard deviation 1MeV/c
- 3 incident proton momenta values studied: 100, 250, 400 MeV/c
- Generated over polar angles 30 - 70°

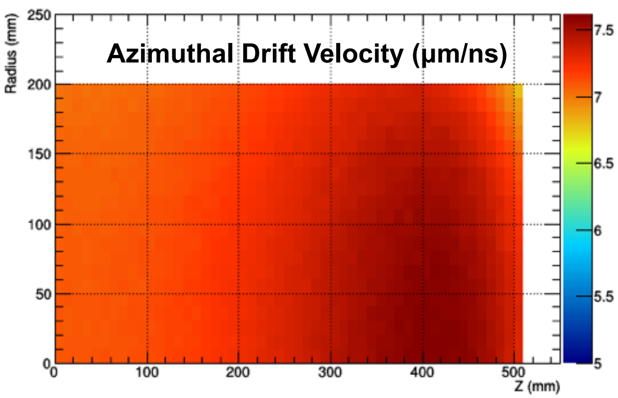
Geant4 and Electron Travel Parameterisation Method

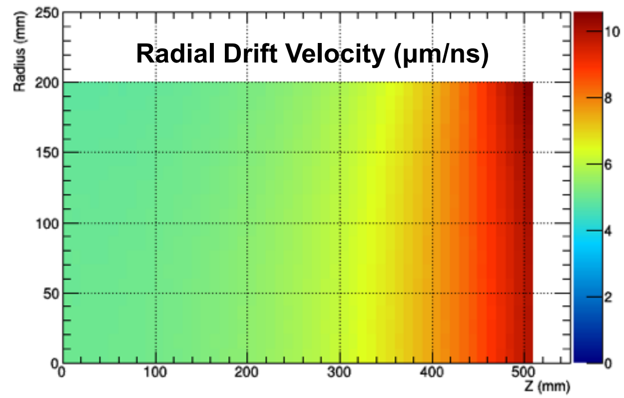
Magboltz (cern.ch/magboltz):

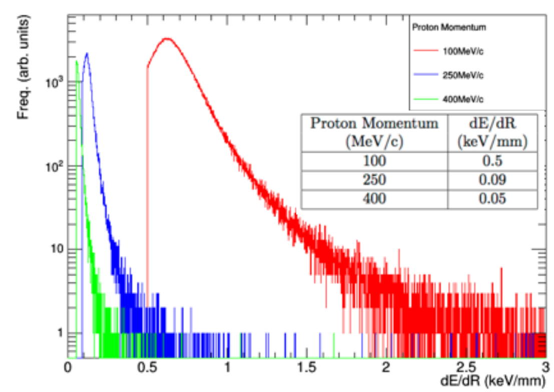
- Geant4 not optimal for drift/diffusion of low-energy ionised e^-
- Magboltz solves Boltzmann transport equations for e^- in gas mixtures under influence of E and B fields
- Computes: drift velocities v_d; Lorentz angles; transverse diffusion…
- v_d in 3 components, along: *E* (radial); *ExB* (azimuthal); B_T (zero/negligible, not considered further)

Drift Velocity Map

- Calculated v_d for every (r,z) point of UVa solenoid TOSCA map
- He 90%, DME 10% (C_2H_6O) (properties similar to CH_4,), 77K; 0.2atm
- E=500V/cm; B=4.7T; θ_{EB} = 90°: **radial v_d = 4.973 μm/ns** ± 0.05%; **azimuthal v_d = 7.076 μm/ns** ± 0.06%

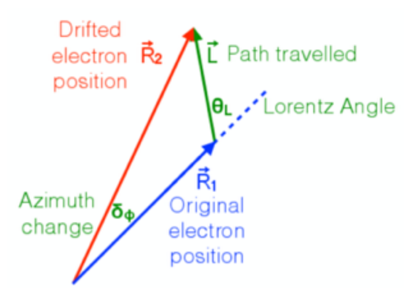




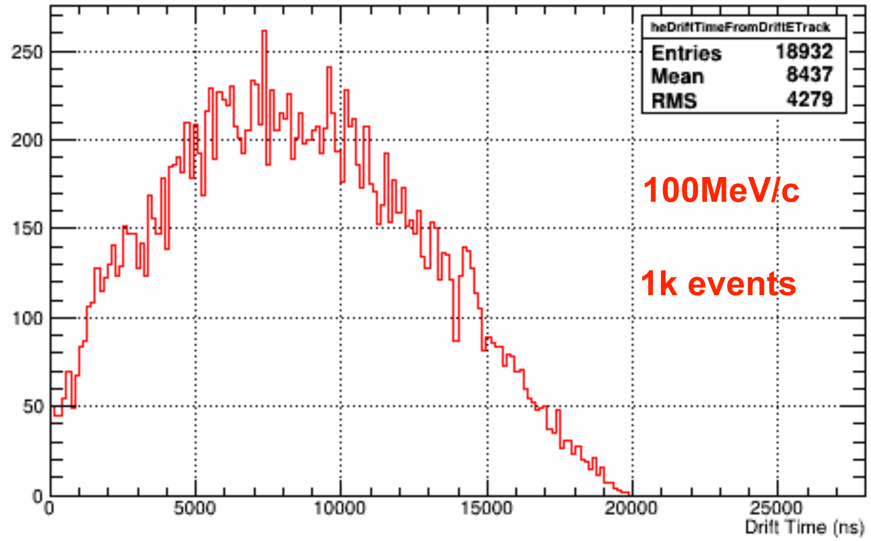


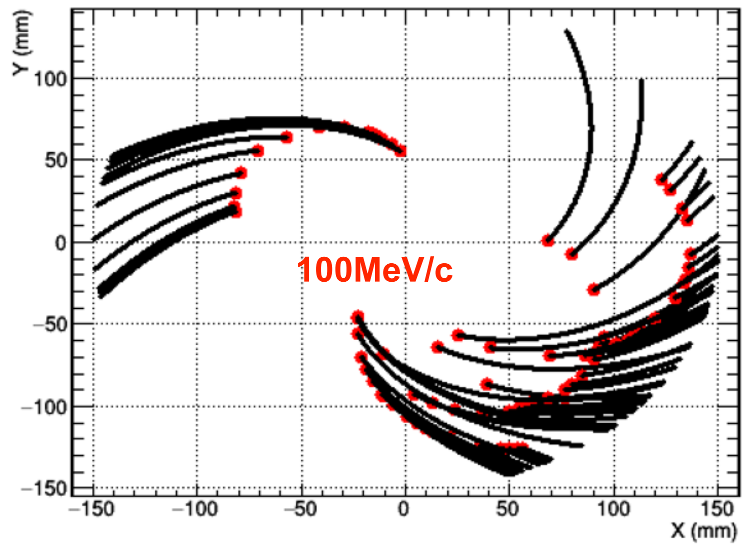
Parameterisation Method (similar to method BONUS 6GeV)

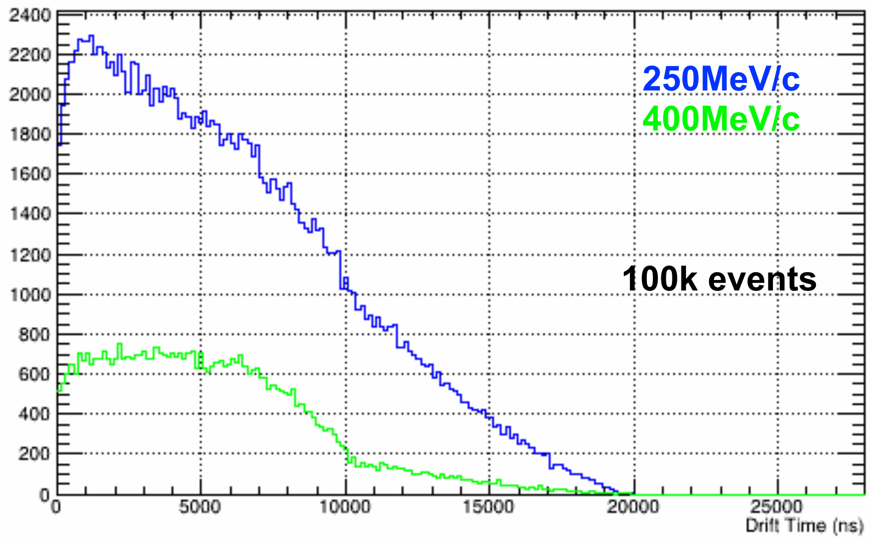
- Proton tracked step by step through RTPC volume
- If dE/dR > threshold (values from previous background studies), ionisation assumed
- Ionisation point assumed as proton step mid-point
- Drift velocity map interpolated to find starting v_d values
- Change in path calculated to find new position of drift electron (using time steps 1ns)
- Repeated until GEM reached



Electron Drift Paths and Drift Times





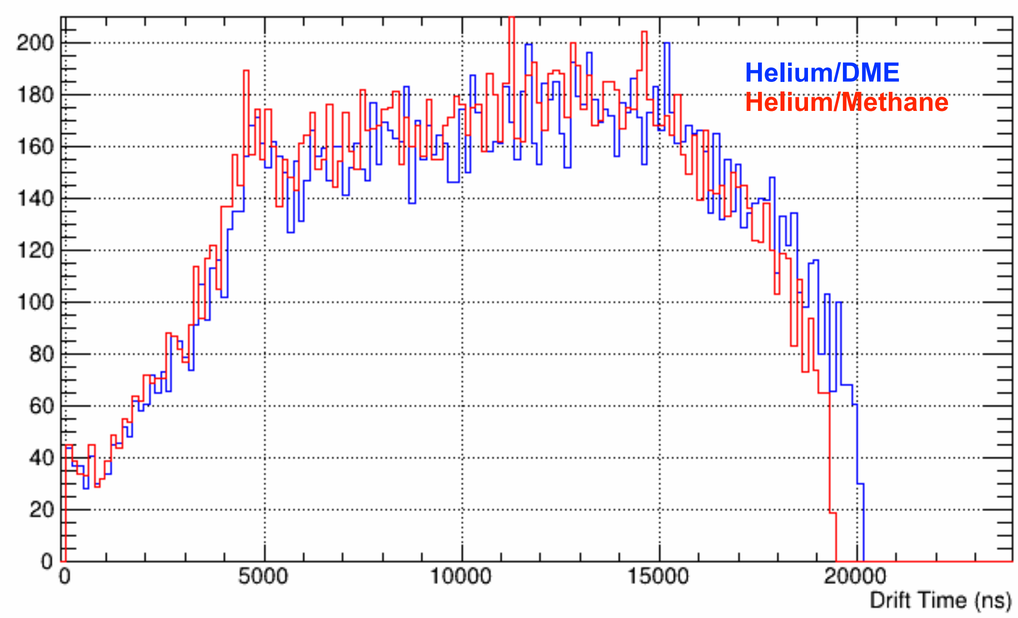


- Upper limit of ~20μs for all momenta
- Matches with crude estimation from maximum radial drift distance 10cm and magboltz radial velocity 4.973 μm/ns
- 100MeV protons more susceptible to field as visible in drift time plot

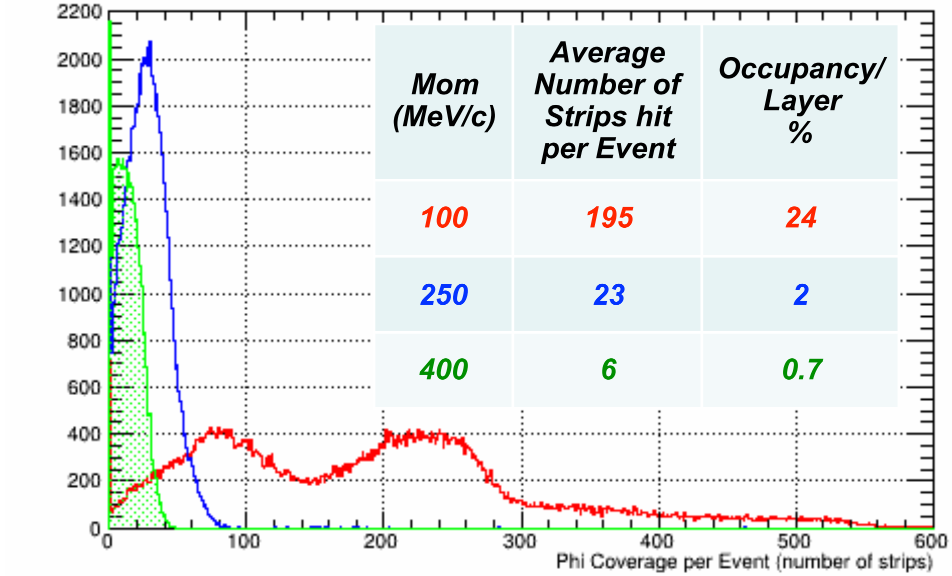
Drift Time Comparison with He/CH_4 Gas

- Drift velocity map generated using He/DME only (expected similar results to CH_4)
- Compare v_d for He/CH_4 and He/DME (90:10) mixes
- E = 500V/cm; B = 4.7T; θ_{EB} = 90°; 77 K; 0.2 atm
- Methane mix slightly faster (upper limit ~19.5μs vs ~20.15μs) but overall two mixtures largely similar
- Geant4 and electron parameterisation code ran with static field values (100MeV/c), i.e. excluding interpolation to find v_d values at each electron step
- Can re-create magboltz drift velocity map as a function of magnetic field for He/CH_4 if necessary

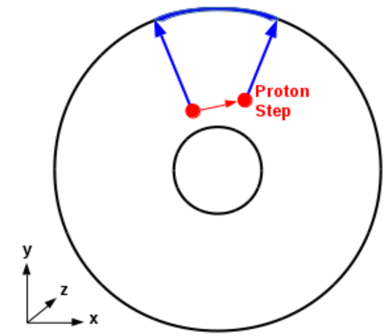
Velocity Component (μ/ns)	Methane Mix	DME Mix
Radial	5.161 ± 0.06%	4.973 ± 0.05%
Azimuthal	4.706 ± 0.01%	7.076 ± 0.06%



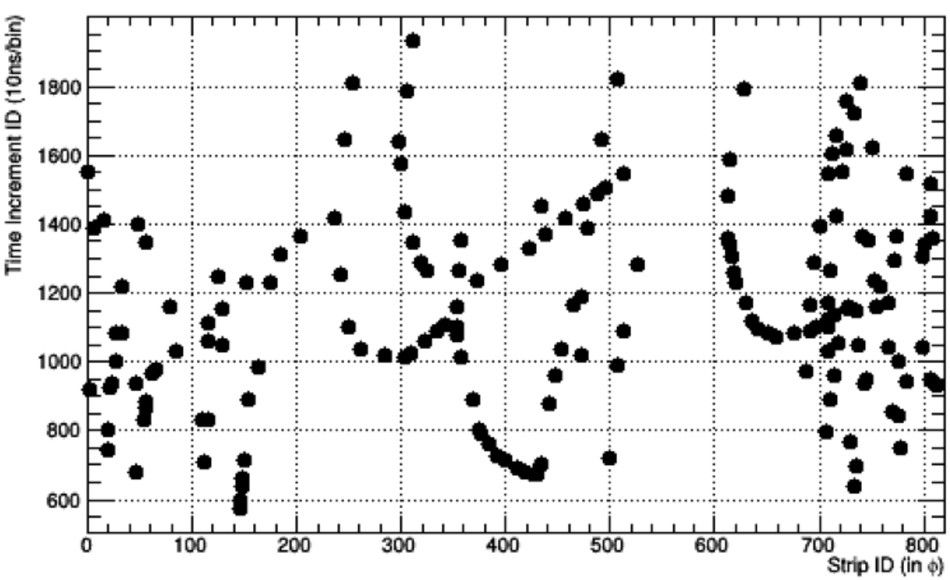
Readout Strip Hits/Event Estimations



Mom (MeV/c)	Average Number of Strips hit per Event	Occupancy/ Layer %
100	195	24
250	23	2
400	6	0.7



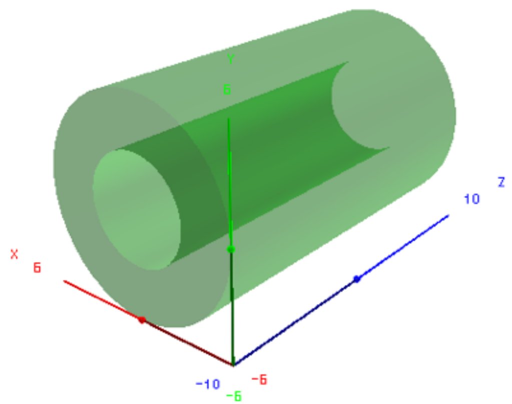
- Phi coverage of entire proton step creating ionisation calculated
- Total strips summed for each event
- Total strips hit averaged over all events



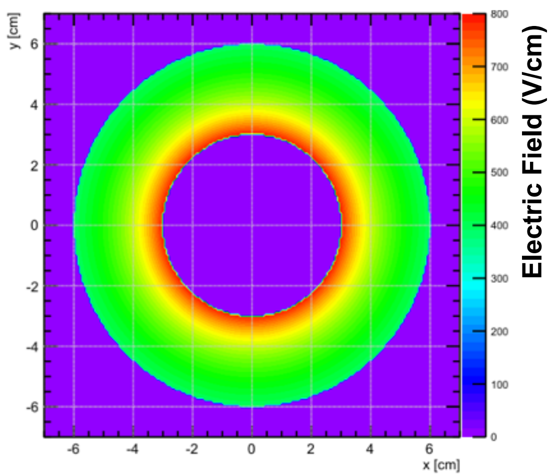
- Parameterised e- from mid-point of proton step drifted to readout strip in phi
- Time of arrival against strip phi ID (left)
- Example for 23 simultaneous 100MeV protons (extreme/unrealistic case for ^{1}H)

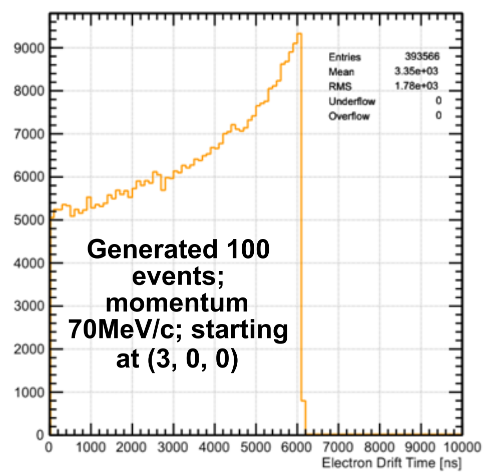
Electron Drift Simulation with Garfield++

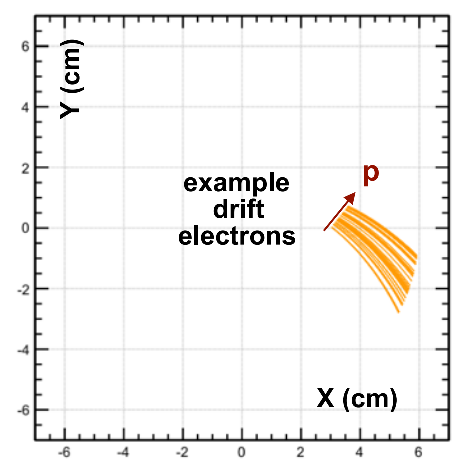
- Garfield++ toolkit for simulation of detectors with gases/semi-conductors as sensitive medium
- https://cern.ch/garfieldpp/, common GEMs/multigap resistive plate chambers, ALICE TPC, BONUS12
- Set of libraries with user interface derived from ROOT
- Heed generates ionisation of fast charged particles using photo-absorption and ionisation model
- Magboltz generates drift properties of particles in medium under influence of E and B fields
- Garfield++ provides interface with Heed and Magboltz and calculates drift/avalanches of e^-

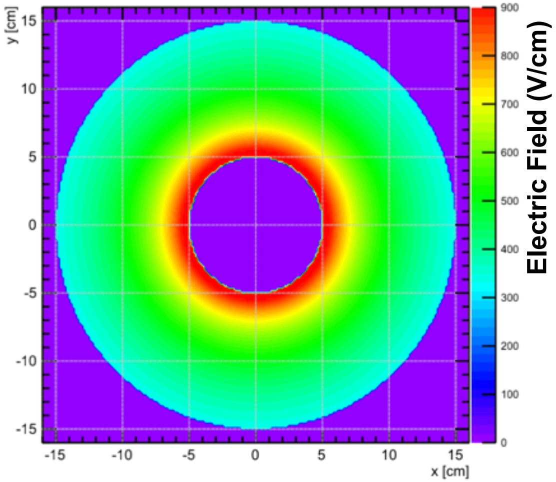


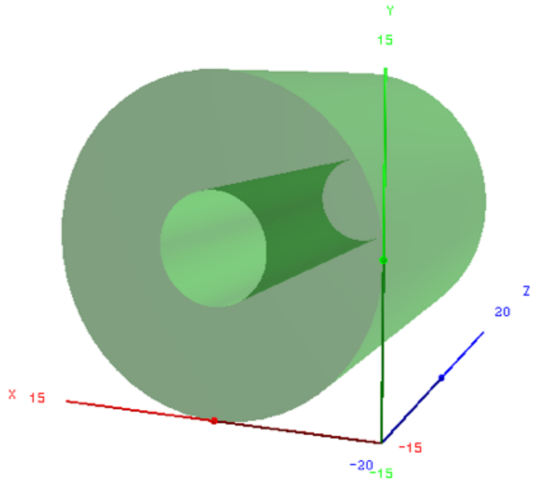
- **Stand-alone BONUS RTPC Garfield++ simulation to confirm method**
- Values for comparison taken from literature
- NIM paper doi:10.016/j.nima.2008.04.047; N. Baillie, J. Zhang theses
- Max. drift time from cathode to GEM ~6μs
- Gas: He 80%, DME 20%; 300K; 1atm
- Inner r=3cm; outer r=6cm; length 20cm
- Magnetic field -4T
- Electric field: two concentric cylinders at different potentials, ~500V/cm in drift region, 800V/cm cathode and 400V/cm 1st GEM
- Typical momentum 70MeV/c











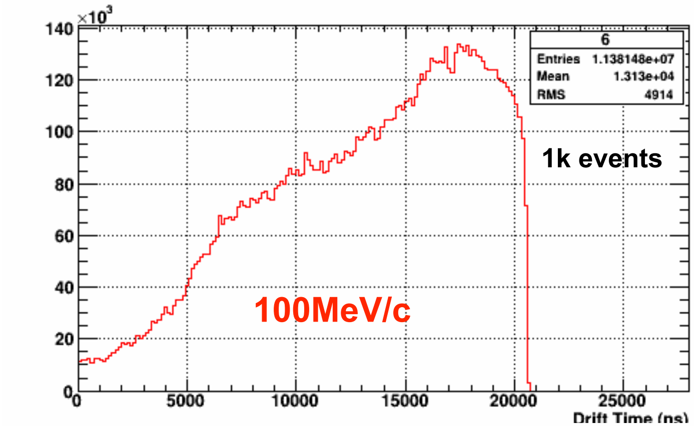
Garfield Model:

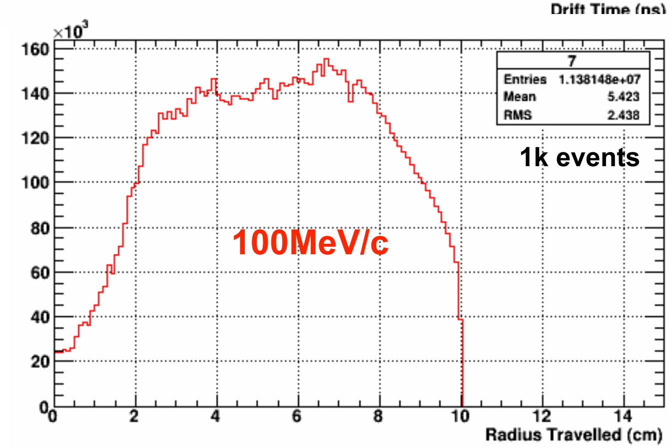
- Roughly 500V/cm field in drift region
- Gas mix as before (He:DME 90:10)
- 77K; 0.2atm

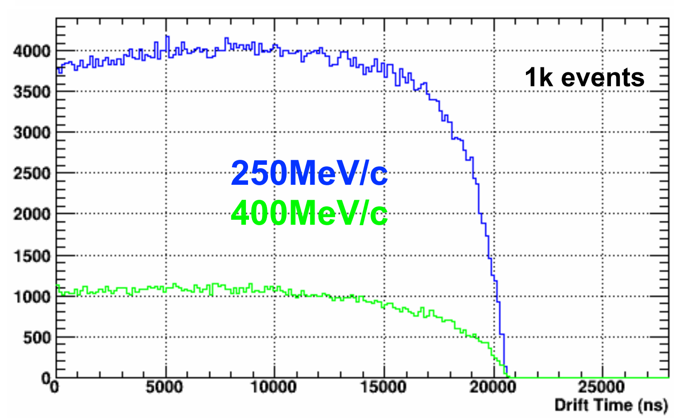
- RTPC drift region in Geant4 designated as region (G4Region) where Garfield++ physics models take over (G4FastSimulationModel)

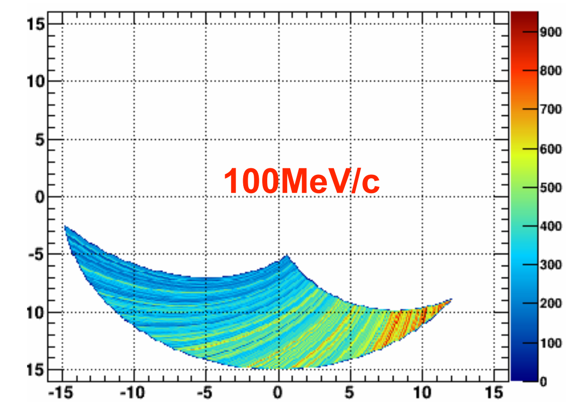
- When tracked proton enters region it is killed, kinematics are input to to Garfield++
- TOSCA field map for solenoid interpolated to find magnetic field at initial proton point
- Proton track created using Heed and ionisation clusters created
- Drift properties provided by Magboltz
- Garfield++ simulates drift electrons
- Drift electrons can be input back into Geant4 as secondary particles (not currently implemented)
- Garfield++ gives access to number of ionisation clusters created and proton energy loss along track. Verification of these numbers requires further study.

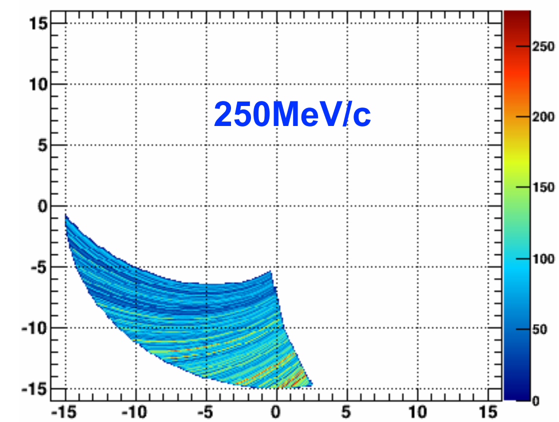
Geant4/Garfield++ Drift Time/Path Results







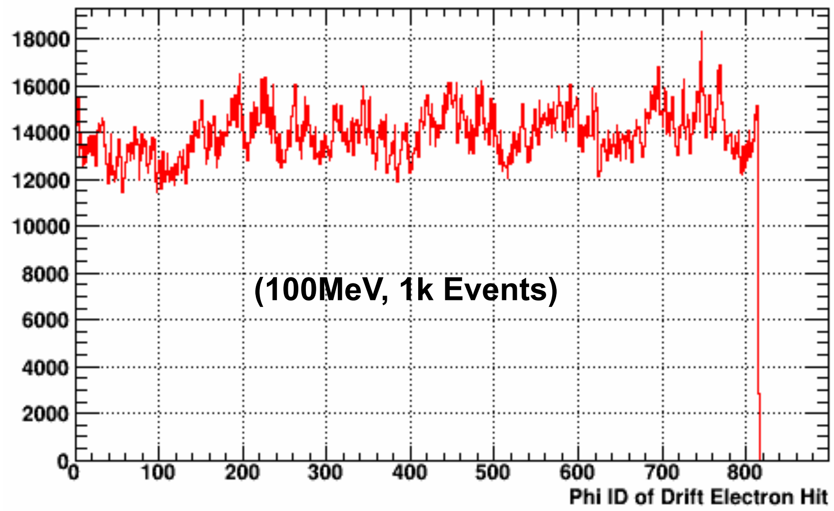




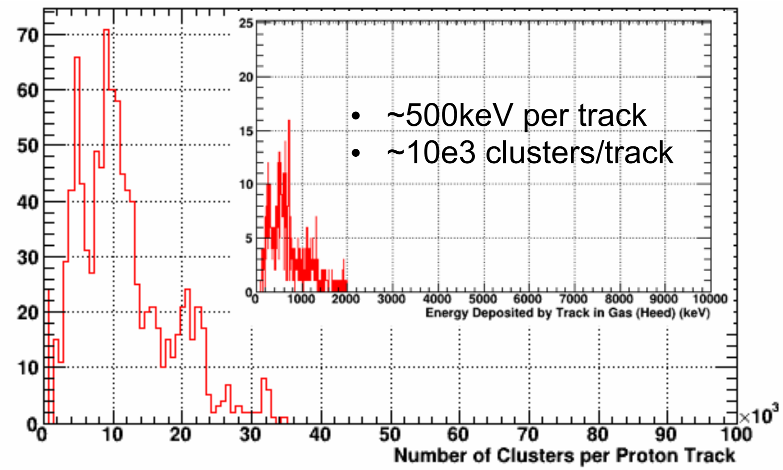
- Upper limit of drift time matches with that obtained from electron parameterisation method

- Different distribution shapes due to Heed for ionisation model
- Could cross-check this by including G4PAIModel photo-absorption and ionisation model in Geant4

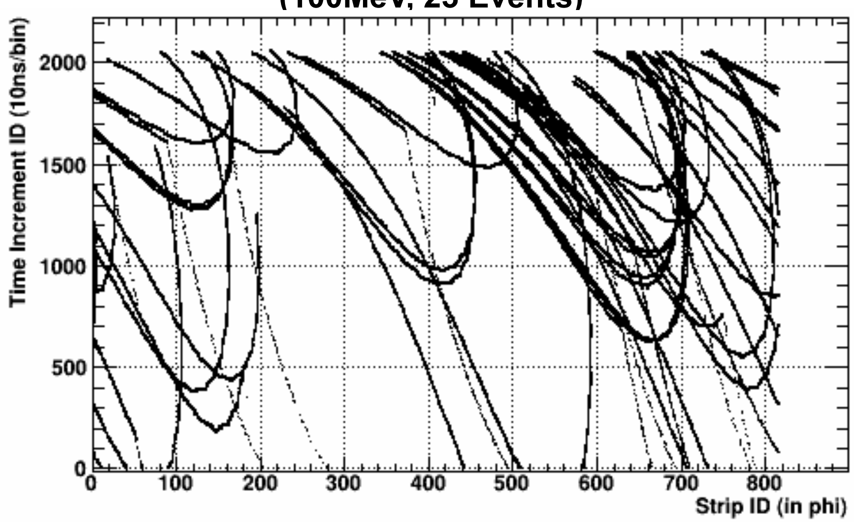
Readout Strip Hits/Event Estimations

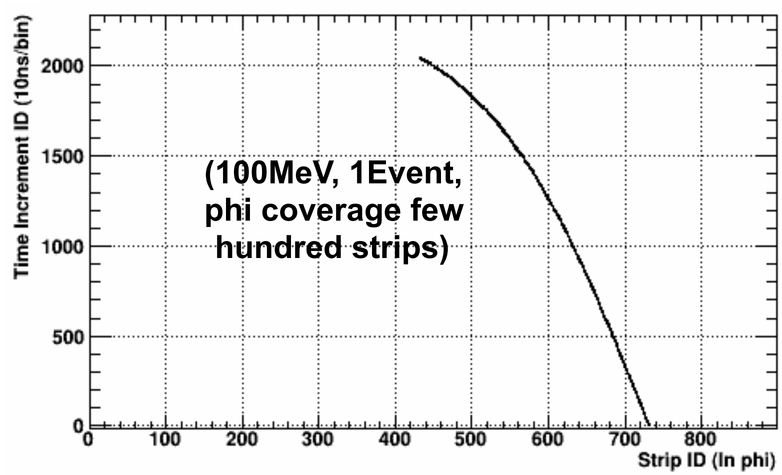


- Phi strip IDs hit by drifted electrons uniform
- Track ID vs Phi ID graph more crowded due to the large number of ionised electrons created by Garfield
- Number of clusters created and energy deposited by tracks in Garfield++ to be verified/studied further



(100MeV, 23 Events)





Summary

- **Simulations of electron drift paths in an RTPC for TDIS are underway/ongoing**

- Two different methods have been implemented:
  - Geant4 has been used to track protons and their energy loss in combination with an electron parameterisation code based on drift velocities obtained with Magboltz
  - Interface between Geant4 and Garfield++ has been developed for direct calculation/handling of ionisation/drift velocities/drift paths by Garfield++

- Initial results between methods agree that maximum drift time from cathode to first GEM layer is ~20μs

- Garfield++ method would yield several advantages, further studies required/ongoing:
  - Verification of cluster yield and energy deposited in Garfield++ simulations
  - Results are **extremely** sensitive to electric and magnetic field, more realistic electric field set-up could be developed (e.g. cathode and 1st GEM voltages/addition of field wires/propriety software to model electromagnetic field)
  - Comparison with any data