TDIS RTPC Simulation Studies Update

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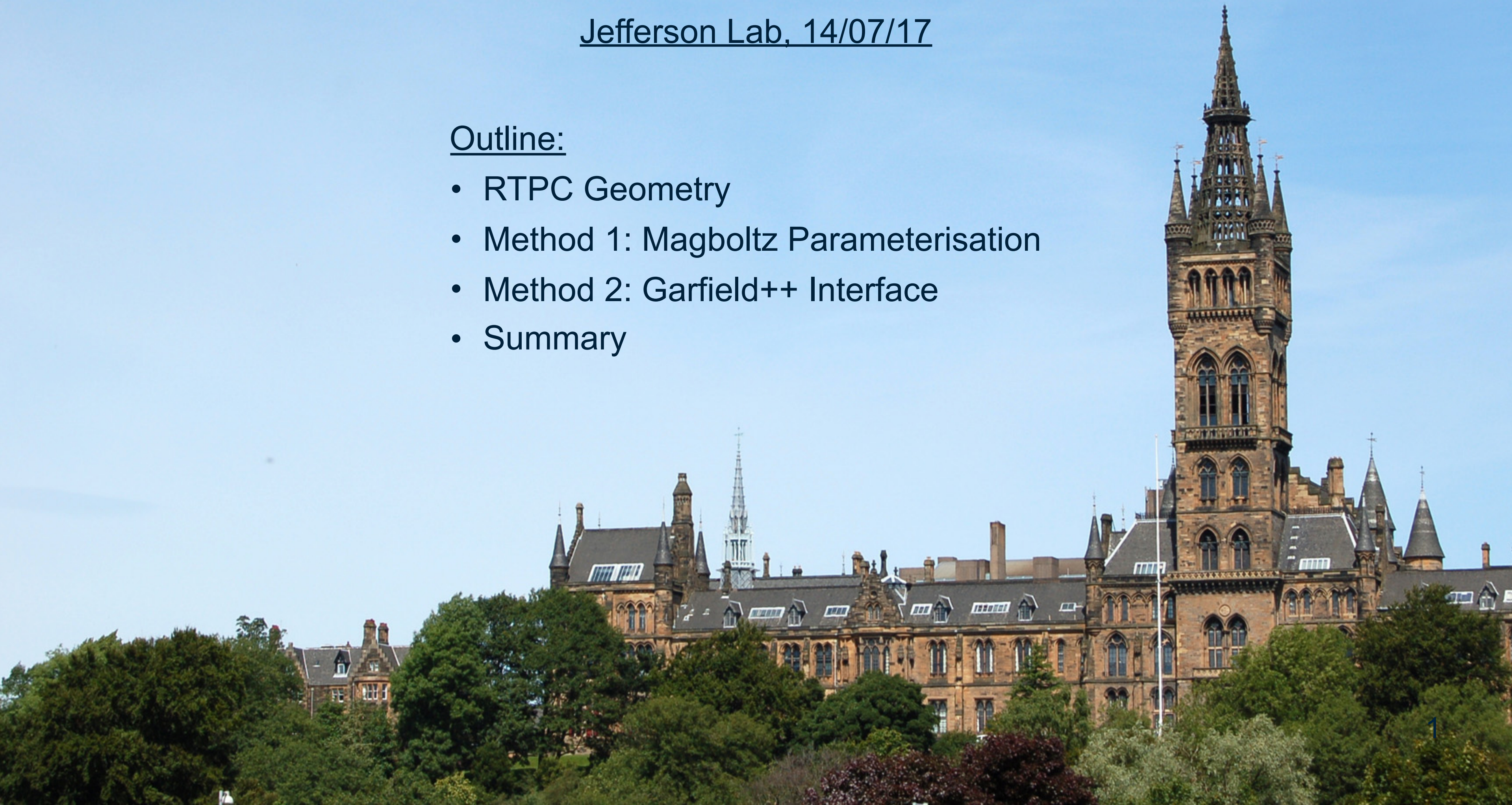
SBS Collaboration Meeting,

Jefferson Lab, 14/07/17

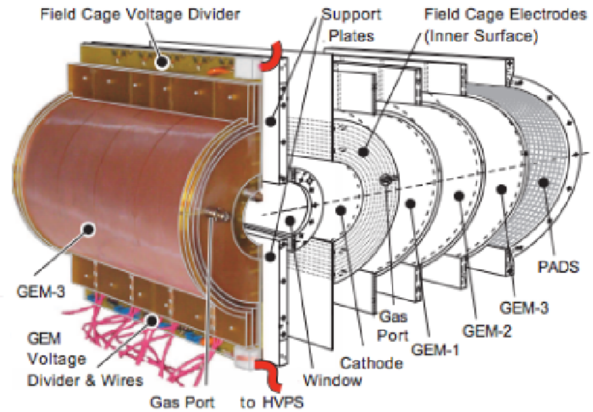
Outline:

- RTPC Geometry
- Method 1: Magboltz Parameterisation
- Method 2: Garfield++ Interface
- Summary

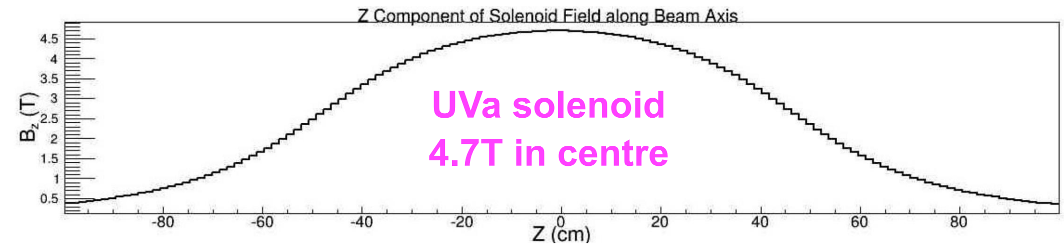


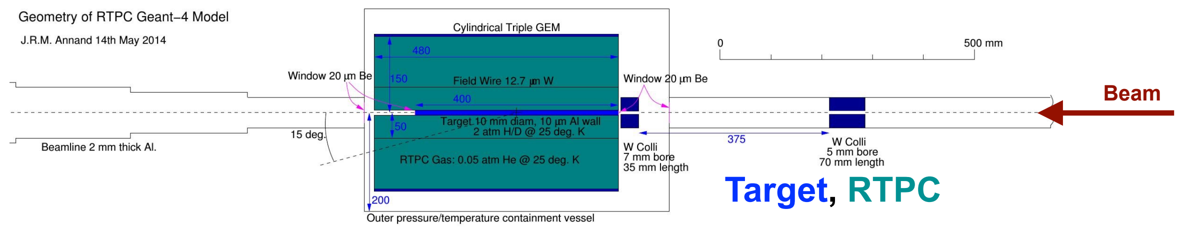
RTPC for Recoil Proton Detection

NIM A592 (2008) 273

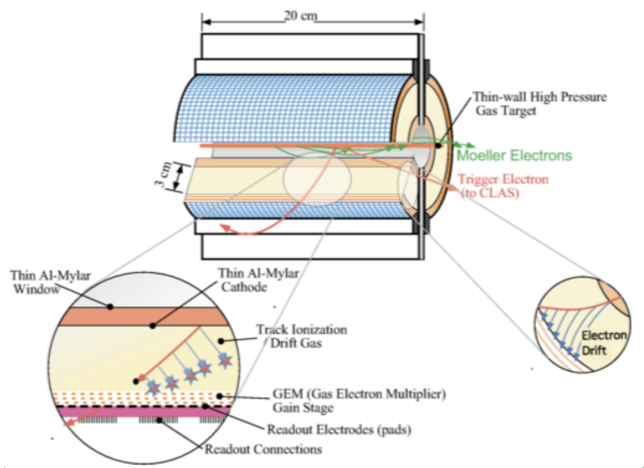


CLAS BONUS and eg6 RTPC





Target, RTPC



TDIS RTPC:

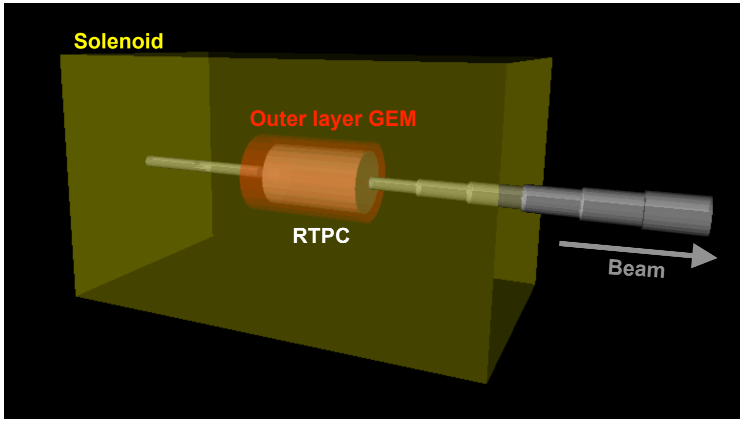
- Based on RTPC from Hall B BONUS, CLAS eg6

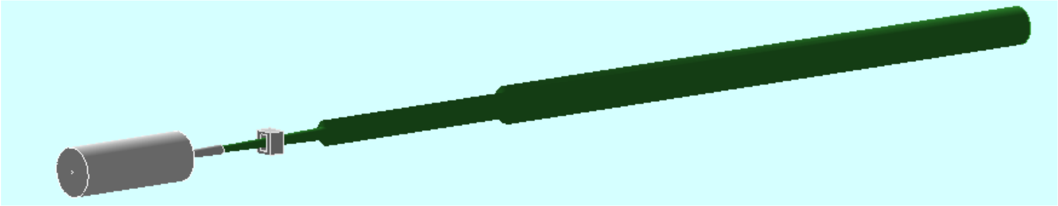
- Length 40cm; radius 15cm; drift 5cm to 15cm
- Gas: 90% He, 10% CH_4, temp 77K; pressure 0.15atm
- Electric field ~500V/cm in drift region

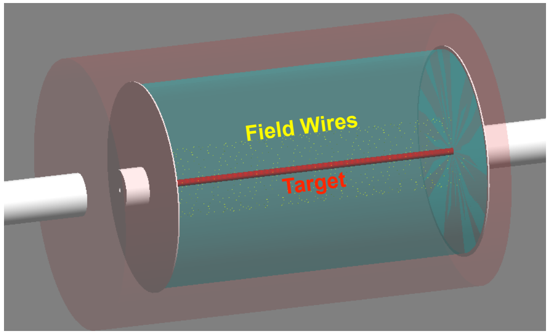
- Triple layer cylindrical GEMs at r=15cm
- GEM readout: UV strips, 21.25mm length, pitch 1mm
- Angular resolution 0.2°; coordinate resolution <1mm; time resolution 10ns

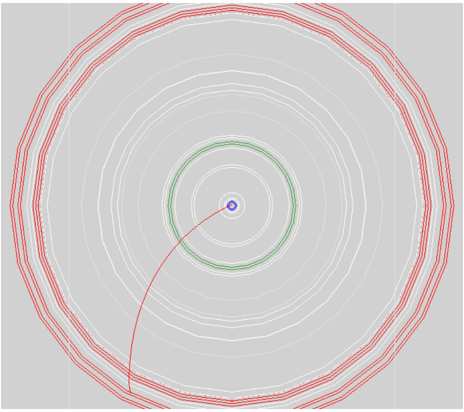
- Large angular & kinematic coverage, low-momentum reach

Geant4 RTPC Geometry Updates









- Realistic RTPC Geant4 geometry developed (J. Annand)
- Most recent updates (2v4):
    - exit beam pipe/more beam line material, extra RTPC casing, curved target exit window, curved spherical Al exit wall, Geant4 TOSCA chord finding algorithm

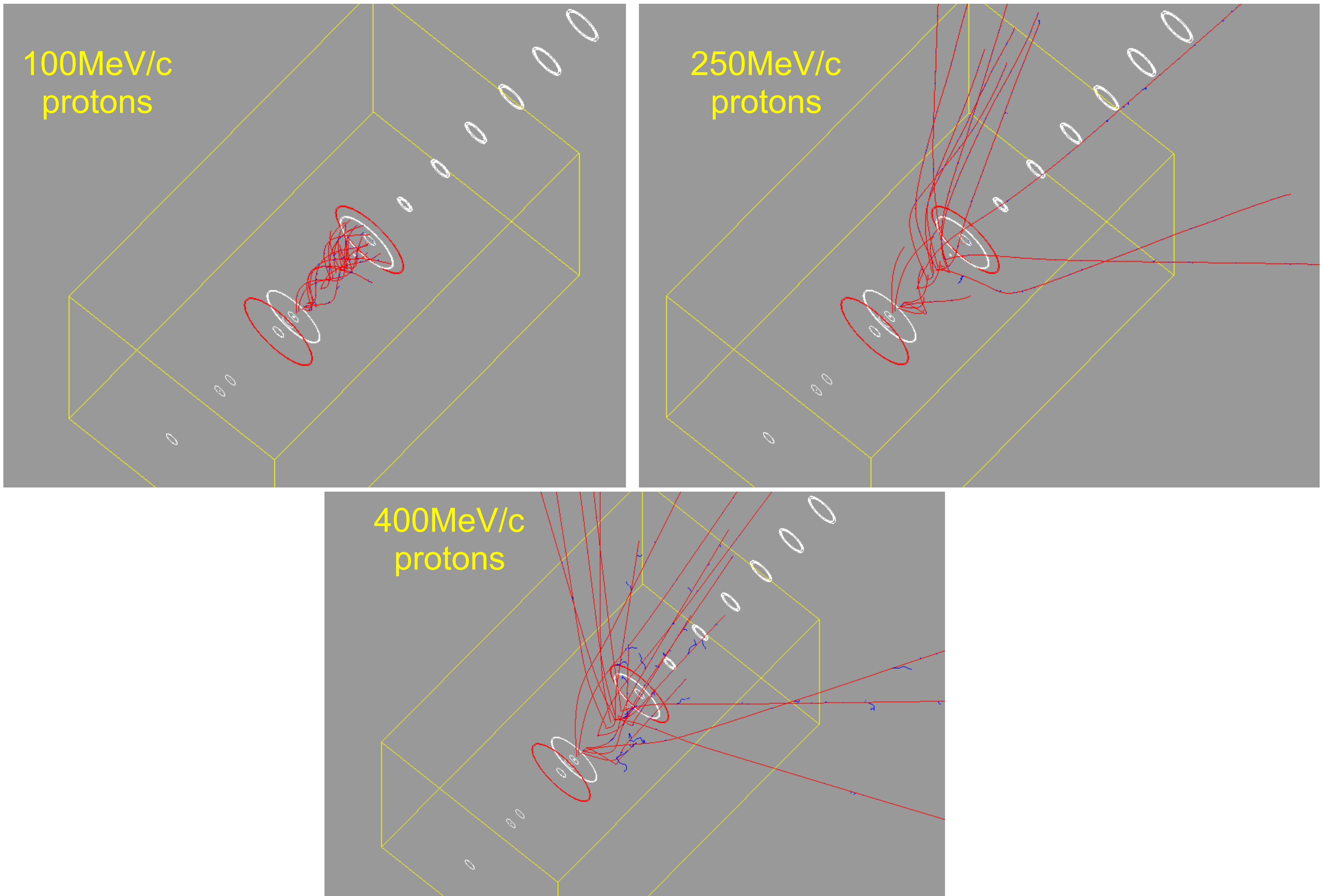
- Background soft proton rate very high, especially with ^{2}H target (MHz)

- Drift e^- simulations within RTPC (drift times, coverage)
    1. parameterisation using Magboltz
    2. Garfield++

Generated Events

Geant4 to track protons and energy deposit in RTPC

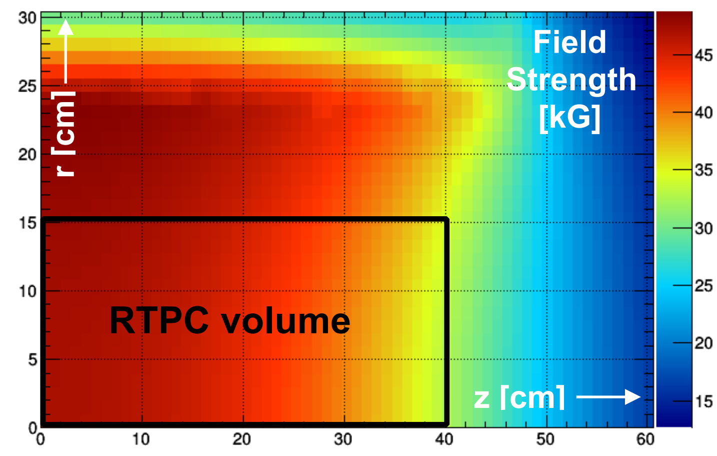
- Protons generated using Monte Carlo event generator
- 3 momenta (matching background studies): 100, 250, 400 MeV/c
- θ=30 - 70° (TDIS range of interest), along length of target



Method 1: Geant4 and Magboltz Parameterisation

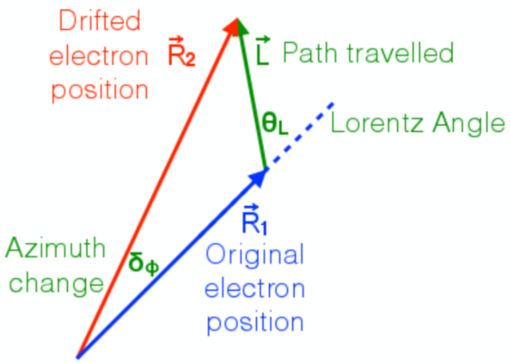
Magboltz
- Solves Boltzmann transport equations for e^- in gases under E and B fields
- Drift velocities v_d, Lorentz angles, transverse diffusion…
- v_d in 3 components: E, ExB, (B=0)

Drift Velocity Map
- v_d for every (r, z) of TOSCA solenoid map
- Nominal settings:He 90%, CH_4 10%, 77K; 0.15atm
- E = 500V/cm; B = 4.7T; θ_{EB} = 90°



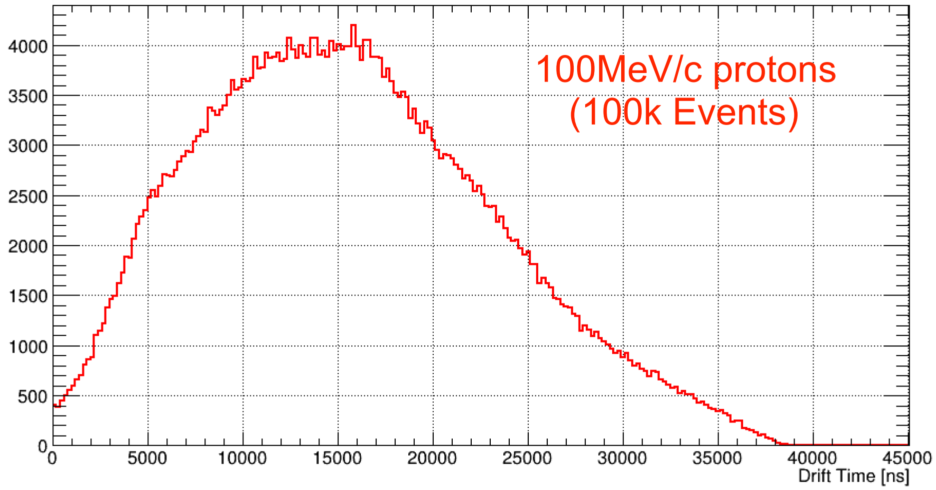
Gas Mix (90:10)	Temp. (K)	Pressure (Torr)	v_d || E (µm/ns)	v_d || ExB (µm/ns)
$^4He:CH_4$	77	114	2.586	9.853
$^4He:CH_4$	293	434	2.589	9.852
$^4He:DME$	293	434	4.346	8.340

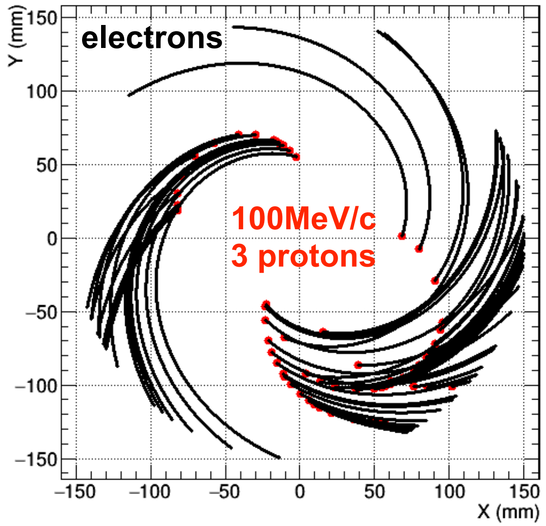
Parameterisation
- Proton tracked step by step in Geant4
- If dE/dR > threshold for ID as proton → ionisation assumed
- Drift velocity map interpolated at (r,z) to find v_d vectors
- Change in path calculated in 1ns time step
- Repeated until GEM reached

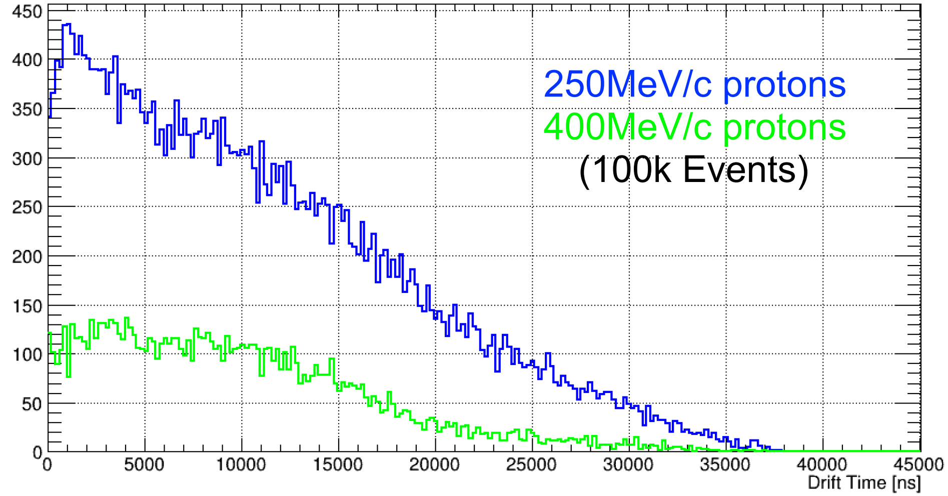


Method 1: Drift Paths and Drift Times

Nominal Settings: $^{4}He:CH_4$ (90:10), 77K, 0.15atm
B-Field = TOSCA map, E-Field = 500V/cm static



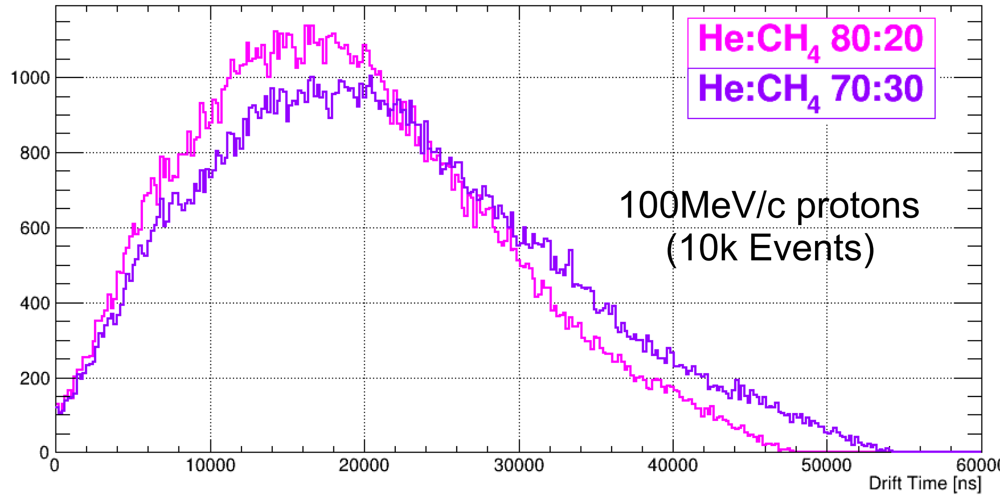




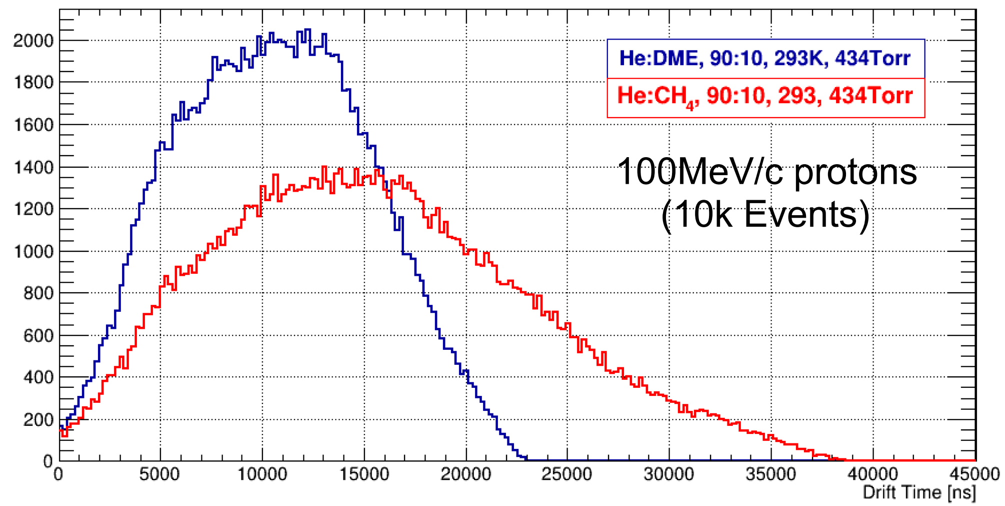
- Limit ~38μs for max drift distance
- Matches crude estimate from radial distance 10cm and Magboltz v_d along E = 2.586 μm/ns

Method 1: Drift Paths and Drift Times

He:CH_4 ratios,
77K, 114Torr

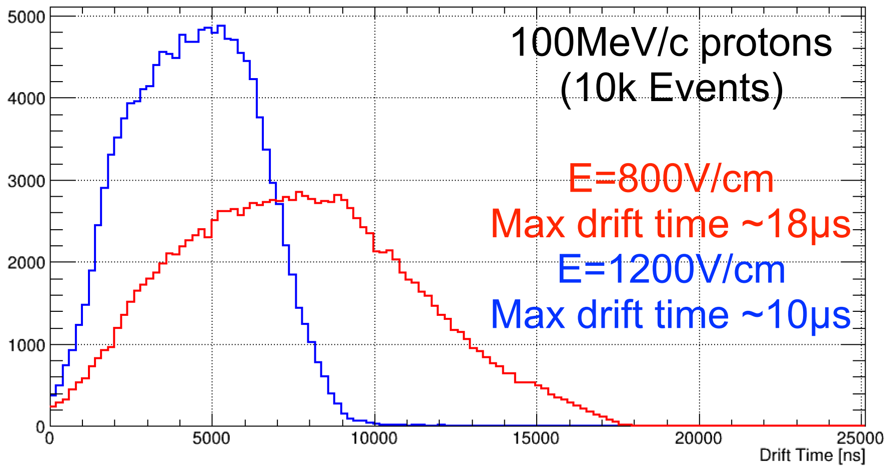


Room Temp,
CH_4 Vs DME



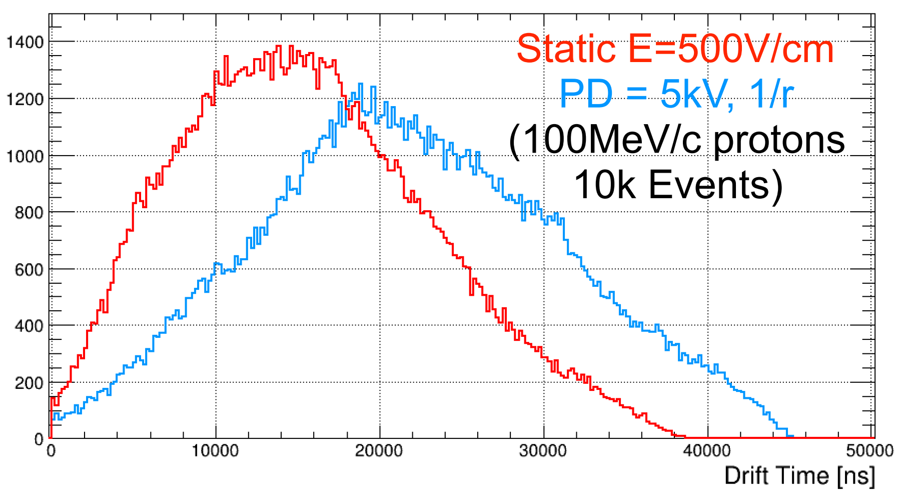
- 90:10 gas mix optimal
- Room temperature and increase pressure does not affect drift times
- DME mix faster for room temp, smaller Lorentz angle, not accounted for different molar masses, 77K<boiling point

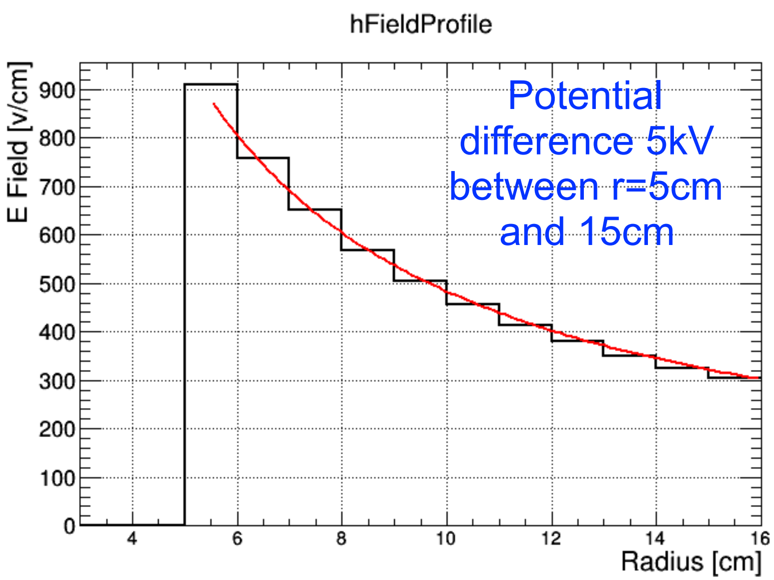
Method 1: Optimising E-Field



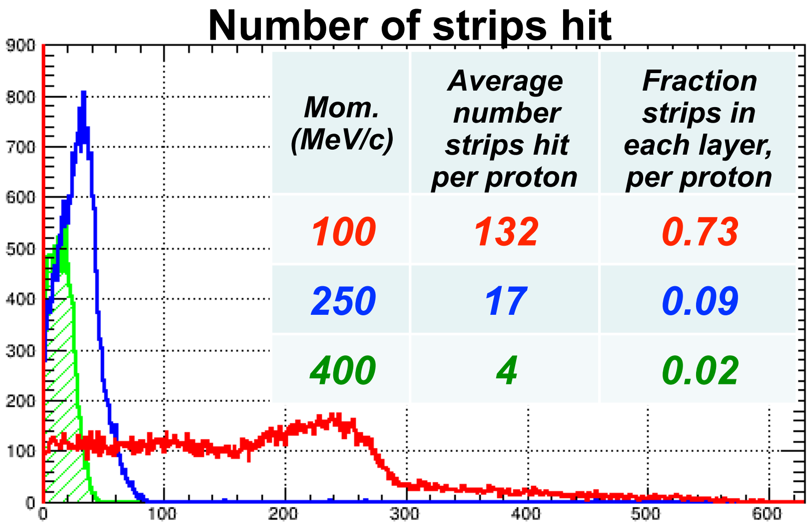
- **Increased field in decreases drift times**
- 18μs with 800V/cm
- 10μs with 1200V/cm

- Upgrade to 1/r E-field dependence
- Worked for <=5kV between r=5cm and 15cm, above this requires further study due to trapping/curling effects





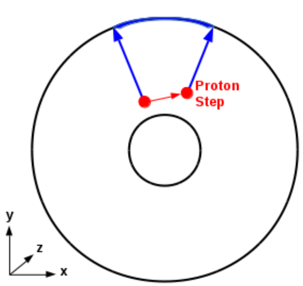
Method 1: Hit Readout Strip Estimations



Mom. (MeV/c)	Average number strips hit per proton	Fraction strips in each layer, per proton
100	*132*	*0.73*
250	*17*	*0.09*
400	*4*	*0.02*

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	–



- Phi coverage of entire ionising proton step in G4
- Total strips summed per proton for each event
- Using ~17 974 strips per U/V layer (817 ϕ, 22 z)

- E.g.: 100MeV/c, 30-70°, single U/V layer:
- ^{1}H, 2.3MHz, assume 10μs achievable:
- 2.3MHz * 20μs * 132 = 3.04×10^{3} strips
- 6.07×10^{3} / 17 974 = 0.17 hits/strip
- 10μs/0.45 = ~59μs between hits

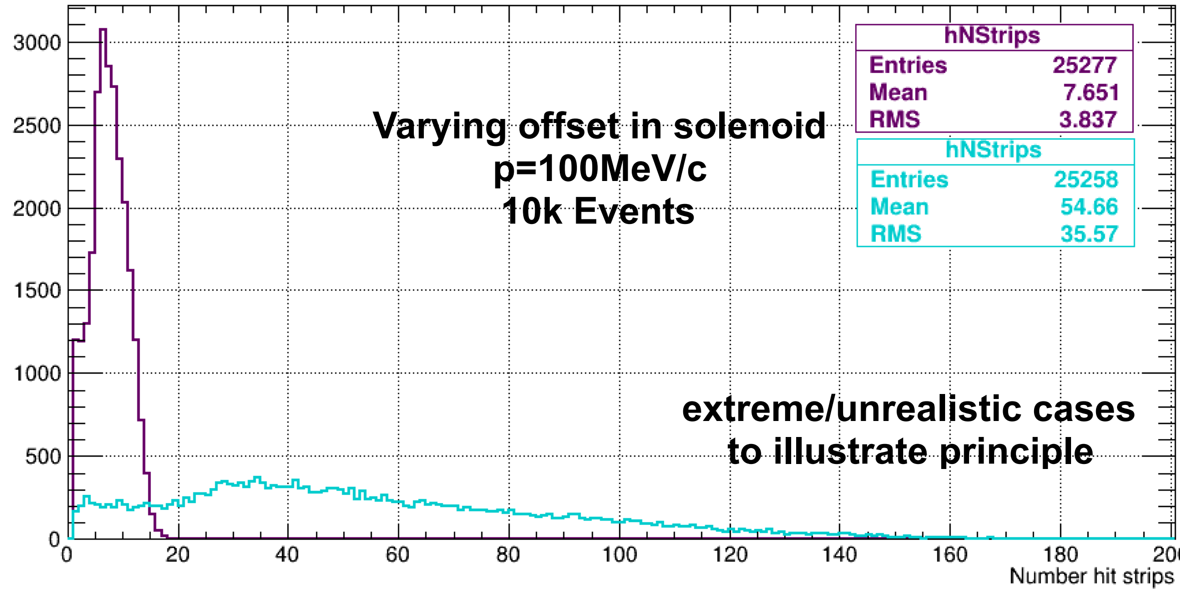
- ^{2}H, 357MHz:
- 357MHz * 10μs * 132 = 4.7×10^{5} strips
- 26 hits/strip; 381ns between hits

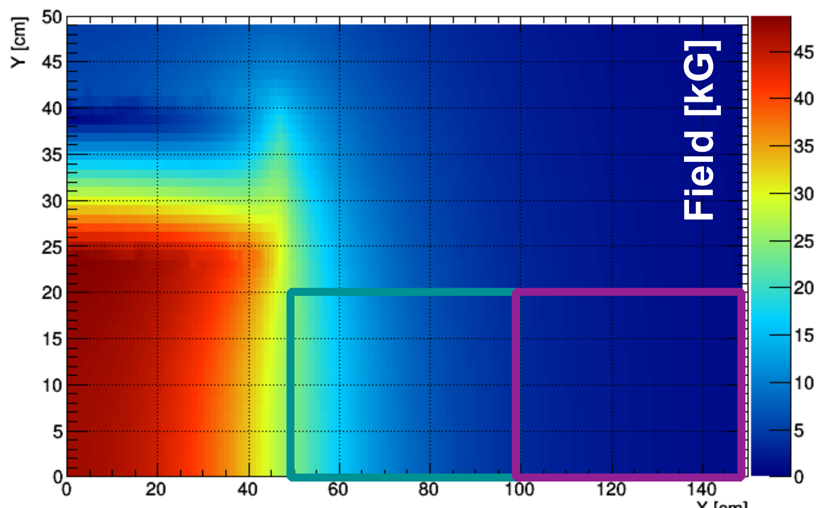
- Numbers could be corrected for coincidence time window for e' in BigBite, DIS rate…

- Factors for study to reduce high strip hits:
  - E-field set-up
  - In-active fins to stop p/e^{-} curling
  - Altering Position in solenoid

Method 1: Offset in Solenoid Field

- Changing RTPC position in solenoid will reduce number of readout strips hit
- Main trade-off will be loss in momentum resolution

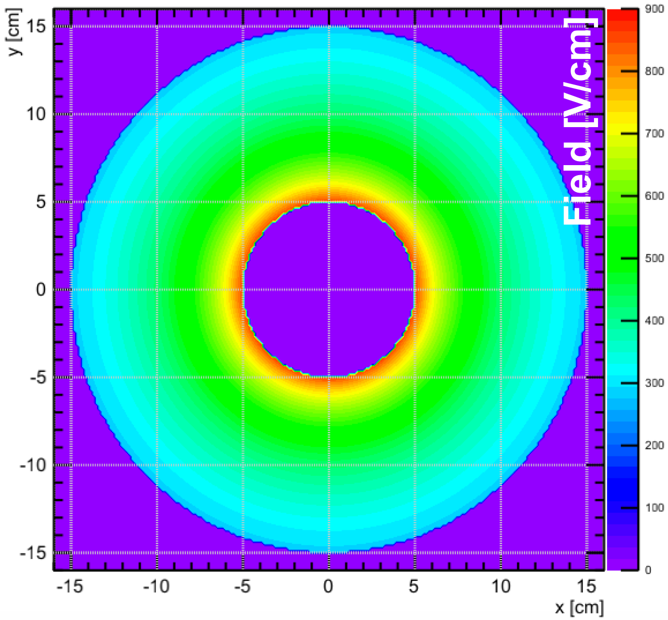


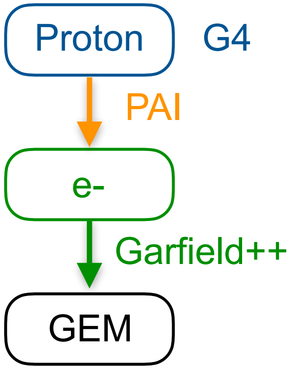


Method 2: Garfield++/Geant4 Interface

Garfield Model:

- ~500V/cm; He:CH_4 90:10; 77K; 0.15atm





Garfield++

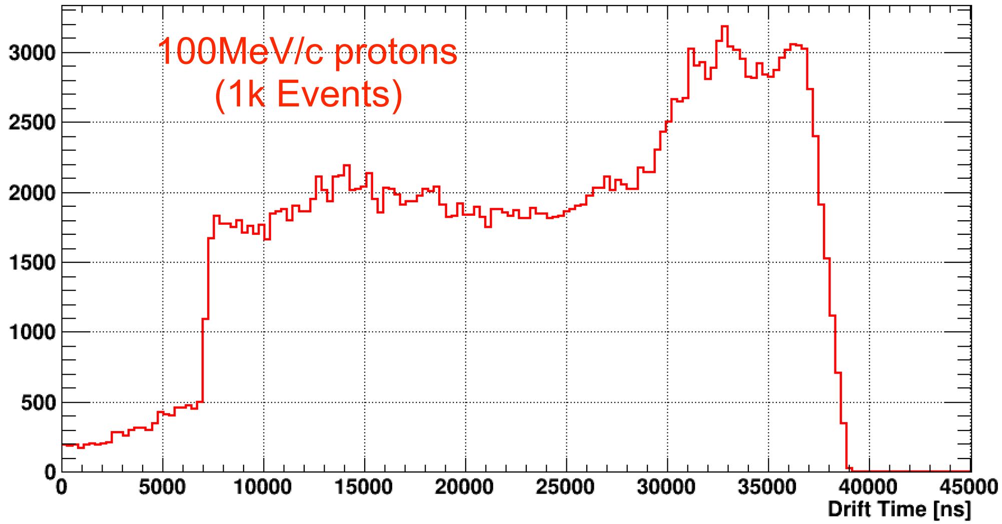
- *Heed* - ionisation
- *Magboltz* - e^- drift properties
- *Garfield++* - drift paths of e^-

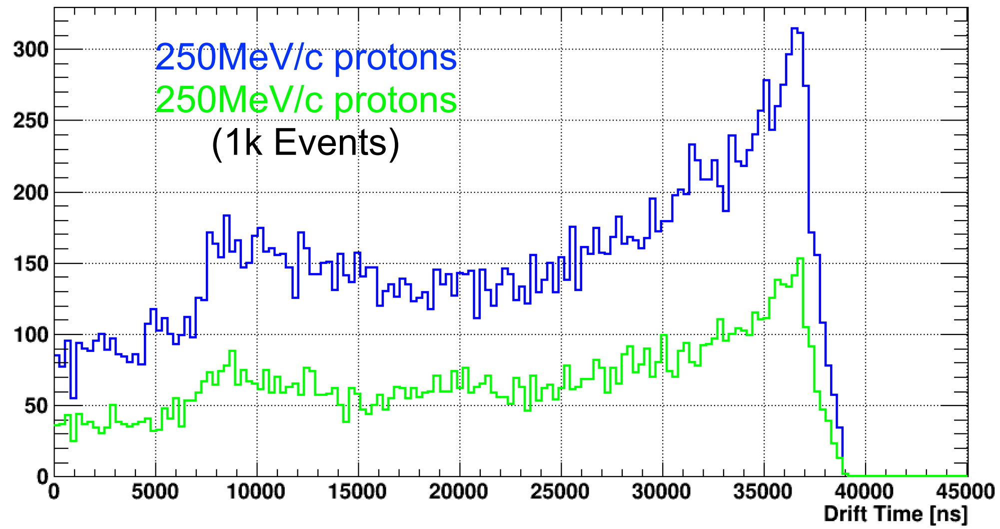
- Energy deposit/transfer with Heed not appropriate for TDIS proton (KE<10MeV)
  - implemented photo-absorption and ionisation (PAI) model in G4 creation of ionisation
  - Energy loss/ionisation yield still likely not accurate, must be checked with data, but e^- drifts by Garfield++ well-modelled

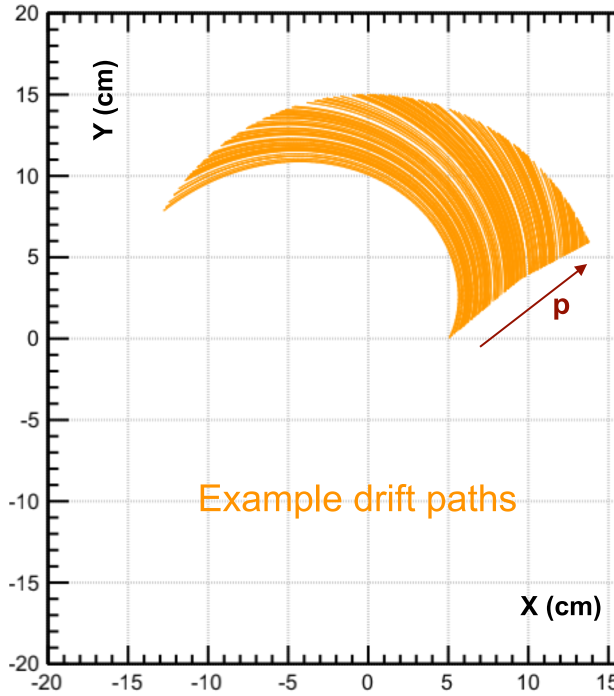
- RTPC designated G4Region:
  - Proton creates ionisation using G4 PAI
  - e^- killed in G4 and drifted by Garfield++

- TOSCA field map interpolated to find B at initial e^- point
- E field from Garfield++ model

Method 2: Drift Paths and Drift Times

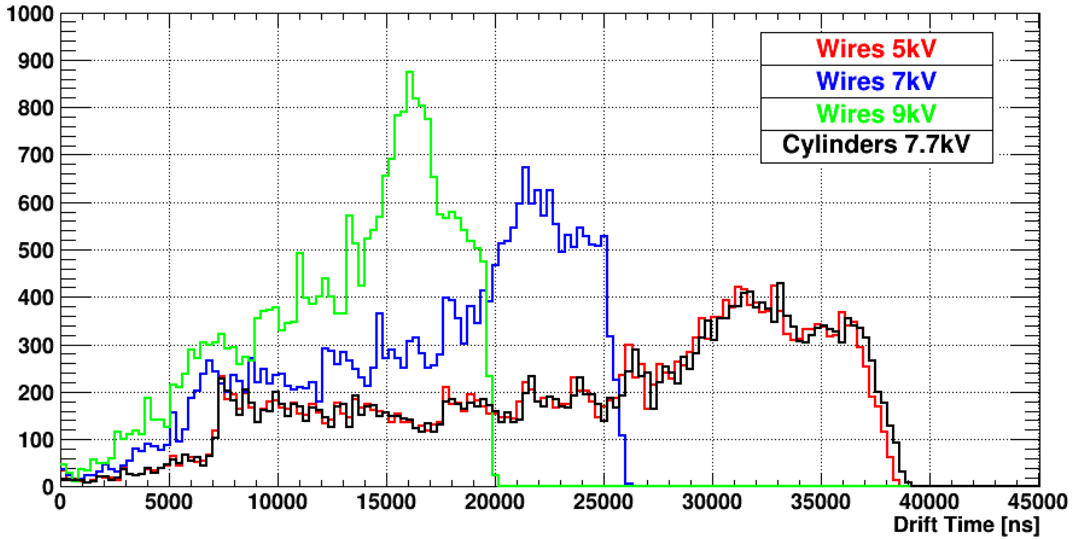






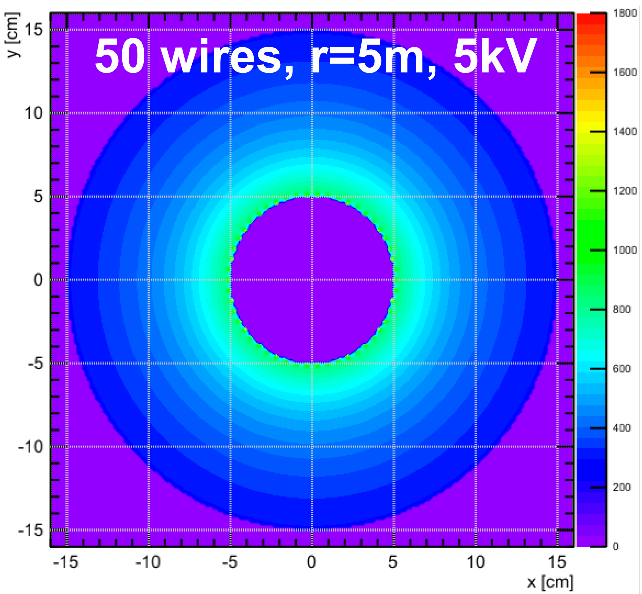
- Variations in shape compared to method 1 caused by e.g., ionisation model, better E-field model
- E-field - 2 concentric cylinders, 7.7kV potential difference

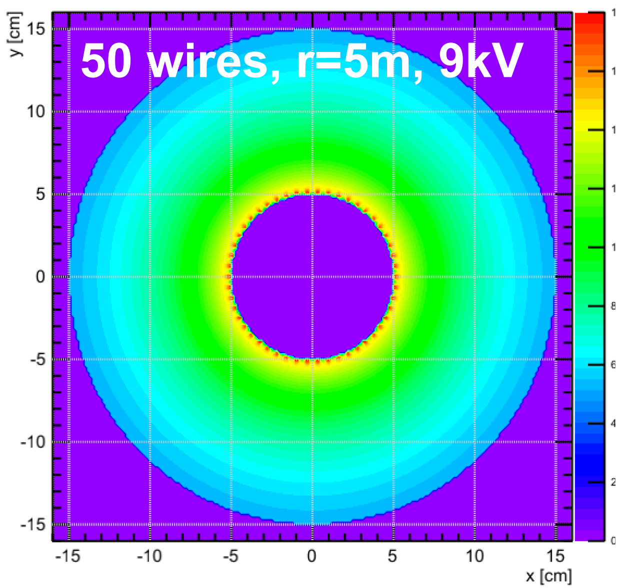
Method 2: Electric Field Set Up

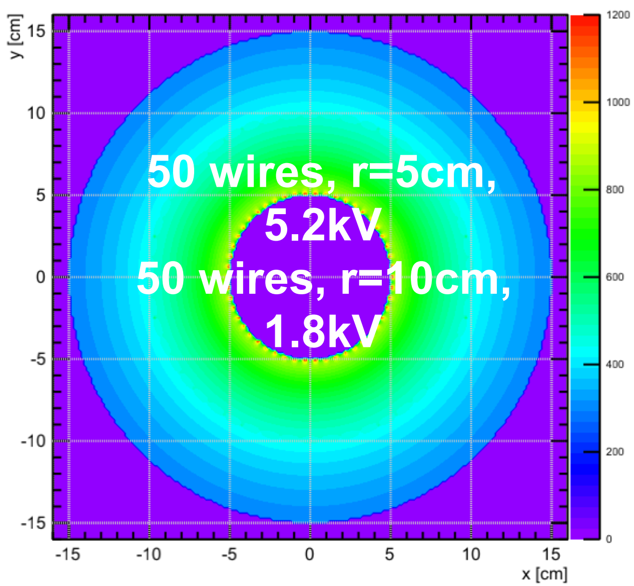


- Drift results extremely sensitive to E-field set-up
- Final config will define times
- Must be studied further to optimise drifts

- Implementations with ring of 127μm diameter field wires







Method 2: Hit Readout Strip Estimations

Mom. (MeV/c)	**Mean Number of Strips Hit per Proton**	**Occupancy in Each U/V Layer per Proton (%)**
100	*149*	*0.83*
250	*22*	*0.12*
400	*11*	*0.06*

- End point of drifted electron used to determine hit strip ID
- Number of different strips hit/proton summed
- Similar numbers to method 1, cross-check

Proton background rates

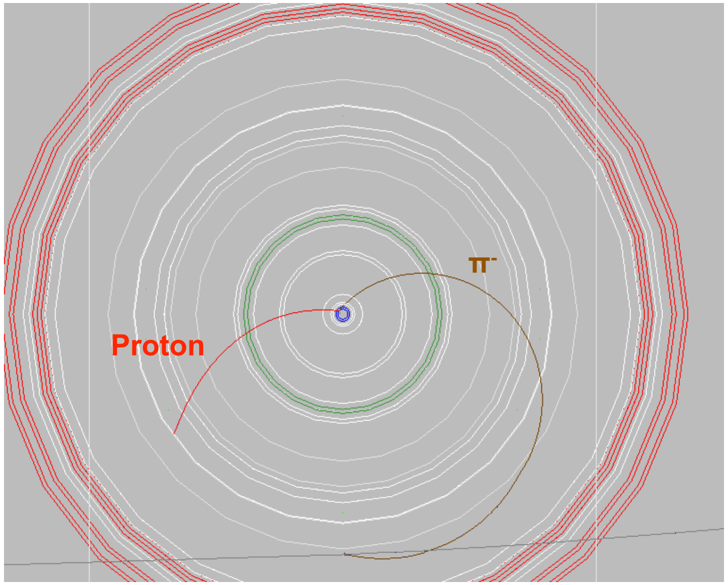
Target	θ_p (deg.)	$70 < p_p < 250$ (MHz)	$p_p > 250$ (MHz)	$150 < p_p < 400$ (MHz)
^{1}H	30 - 70	2.3	7.4	6.3
^{2}H	30 - 70	357	20.1	64
^{2}H	100 - 140	204	3.1	–
^{27}Al	30 - 70	0.37	0.0	0.05
^{27}Al	100 - 140	0.10	0.0	–

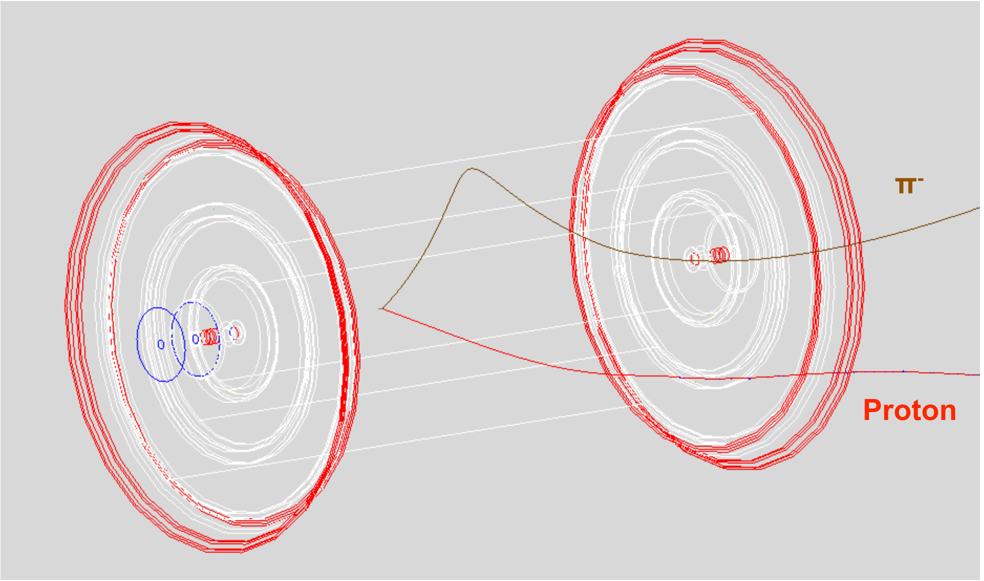
- Eg: 100MeV/c, 30-70°, single U/V layer:
- ^{1}H, 2.3MHz, assume 10μs achievable:
- 2.3MHz * 10μs * 149 = 3.43×10^3 strips
- 3.43×10^3 / 17 974 = 0.19 hits/strip
- 10μs/0.19 = ~53μs between hits

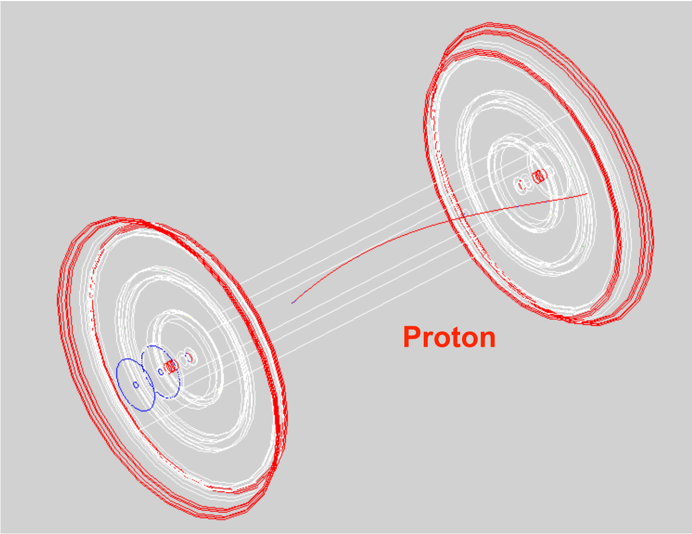
- ^{2}H, 357MHz:
- 357MHz * 10μs * 149 = 5.3×10^5 strips
- 30 hits/strip; 333ns between hits

Event Generator Input

- TDIS event generator from K. Park used to track protons, lambdas, pions through RTPC geometry
- Used to study geometrical acceptance for kaon SF proposal - determined by proton acceptance







Summary

- Updates to realistic Geant4 geometry (2v4)

- 2 drift simulations tested:
  - Parameterisation based on Magboltz
  - Garfield++

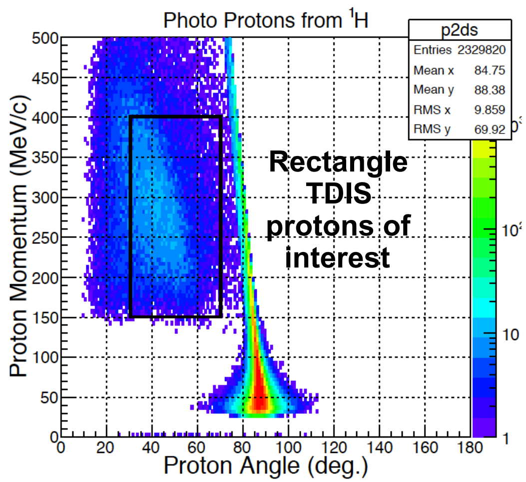
- Nominal conditions yield long drift times, optimising E-field will reduce this

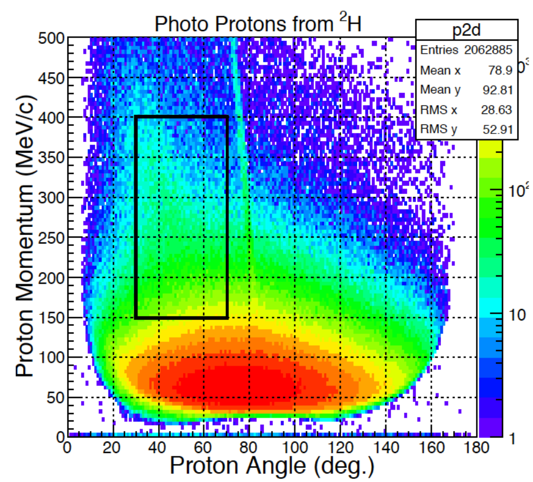
- Occupancies will be high for ^{2}H, possible avenues to reducing this:
  - Drift time reductions, fins to stop curling, position in solenoid, RTPC geometry

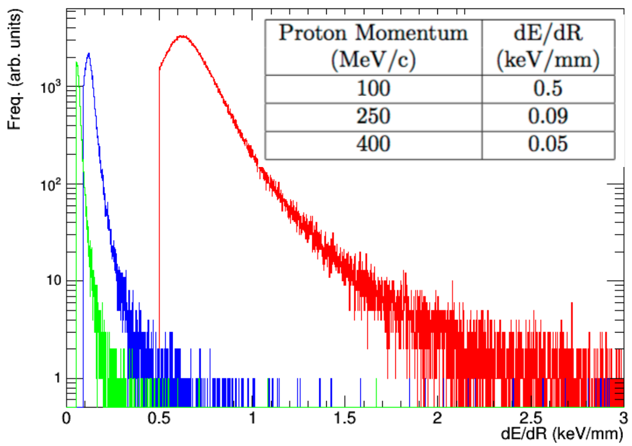
- Garfield++ would yield several advantages:
  - PAI model implemented, but verification of ionisation yield needs data
  - Results are **extremely sensitive** to electric/magnetic field - important future step is more realistic field set-up/studies using finite element analysis software

- Optimisations beginning…

BACK-UP







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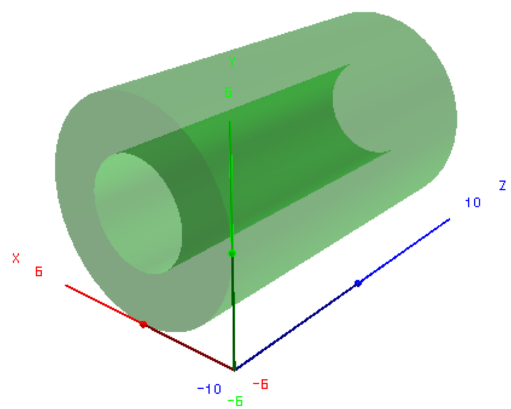
^{27}Al	100 - 140	0.10	0.0	–

- Moeller electrons mostly contained by solenoid
- Dominant background - proton production by photonuclear processes
- ^{1}H target: mostly removed after quasi-elastic cuts.
- ^{2}H target: accidentals separation using time/vertex reconstruction (SBS +RTPC)

Electron Drift Simulation with Garfield++



- **Stand-alone BONUS RTPC Garfield++ to cross-check**
- Values for comparison 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
- E-field: ~500V/cm in drift region, 800V/cm cathode, 400V/cm 1st GEM
- Typical momentum 70MeV/c