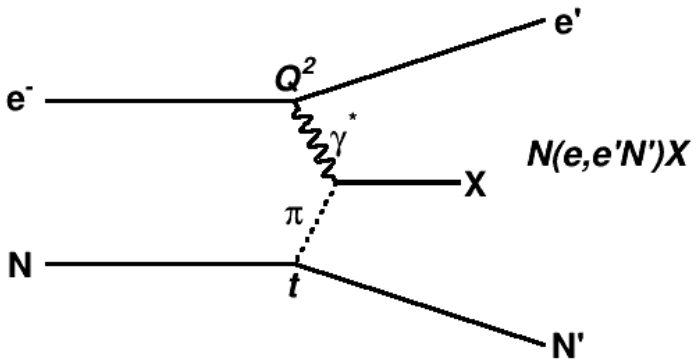
A Detector Study for Tagged Structure Function Measurement in Hall A

Geant-4 simulation of an RTPC Recoil-Proton Spectrometer for use in $N(e,e'N)$ experiments with BigBite & Super BigBite

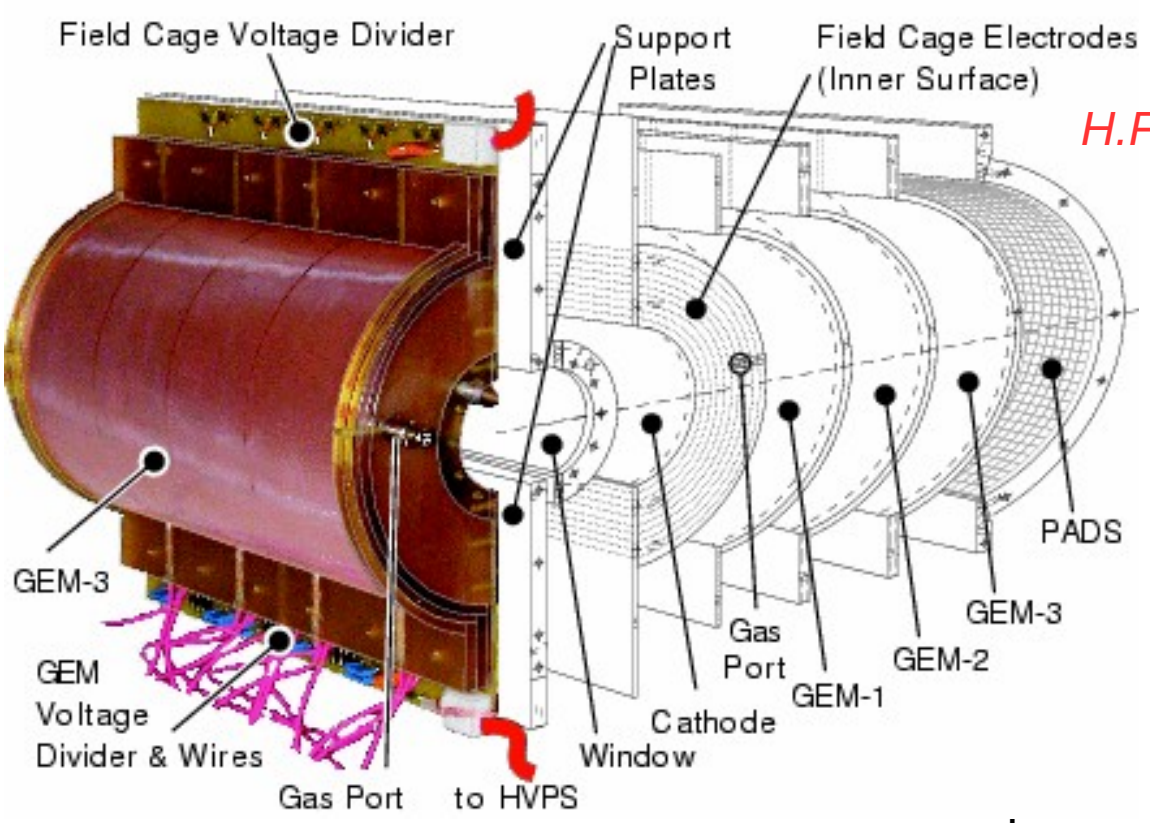
John R.M. Annand

Introduction

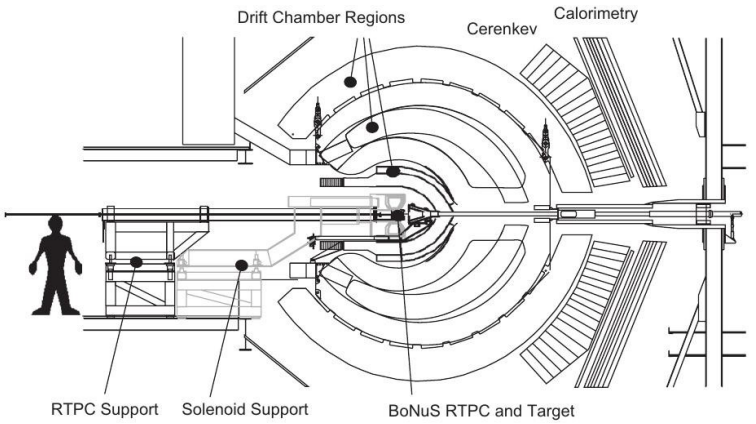


- Access Pion structure function by *N(e,e'N')X ("Sullivan Process")*
  Tagg the process by detecting the low-momentum recoiling nucleon
- Kinematics: low -t (<0.2 $(GeV/c)^2$) essential to extrapolate reliably towards pion pole
  Recoiling nucleon has low momentum ~100 MeV/c (T = few MeV)
- Expect low cross section for kinematics of interest. High luminosity ~10^{37} necessary for reasonable run time
- Recoil tagging requires specialist, low-stopping-power spectrometer viz. BONUS, Hall-B....Radial Time Projection Chamber (RTPC)
- What luminosity can a RTPC surrounding a "straw" target withstand ?
- What is the impact of background processes

The Bonus Spectrometer



H.Fenker et al., NIM A592 (2008), 273



- Bonus used in conjunction with CLAS to measure neutron F_2 structure function. *N Baillie et al. PRL 108, 142001 (2008).*
- "Neutron" target was deuterium
- Tagg electron interactions with quasi-free neutron by detection of the low momentum recoiling spectator proton
- Hall B luminosity relatively low 10^{34} cm^{-2} s^{-1}. Hall A ~ 10^3 higher?

Geant-4 Model: Radial-Field TPC

Start with simple model to determine where the main sources of background in the RTPC will come from

Gas H_2/D_2 Target, 25° K, 2 atm

Container 15 μm Kapton

400mm long × 5mm radius

I_e = 50 μA → L_N ~ 10^{37}

He gas 25° K, 0.05 atm

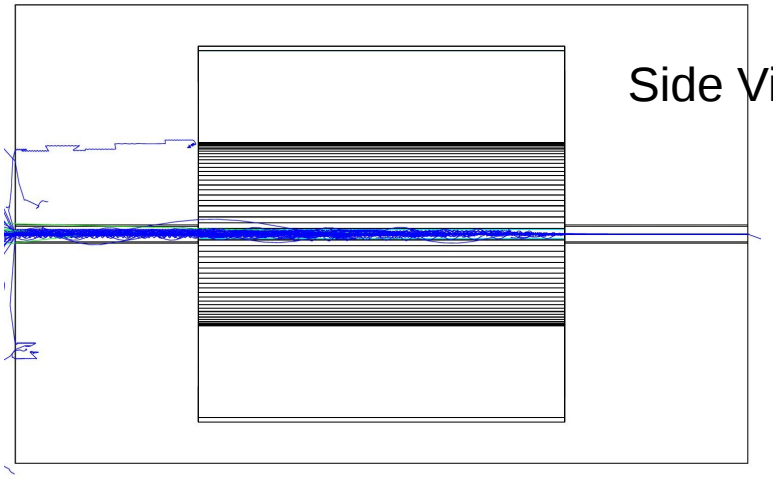
Ring of 100 12.7 μm W wires

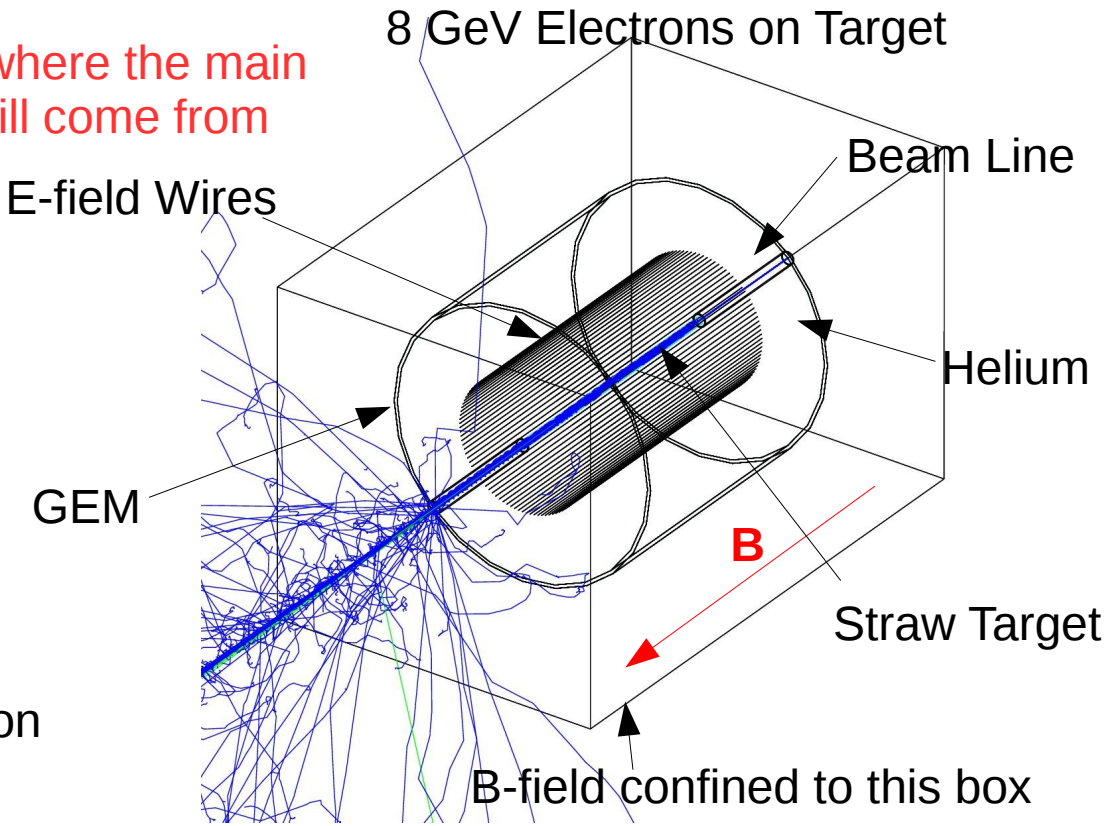
Divides He volume in 2

r = 5 - 100mm, r = 100 – 200mm

Outer cylindrical GEM detects ionisation

Produced in outer He volume



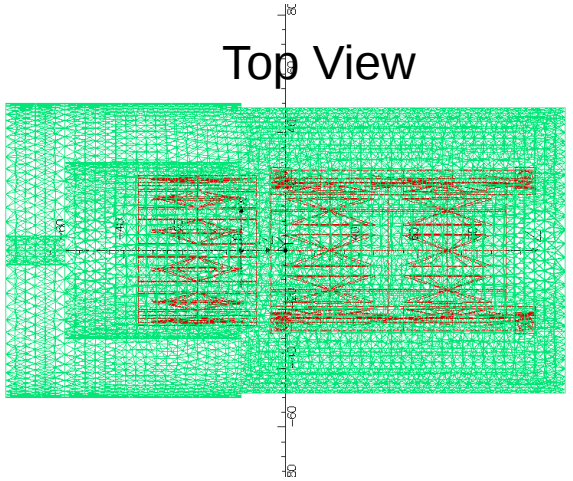


T

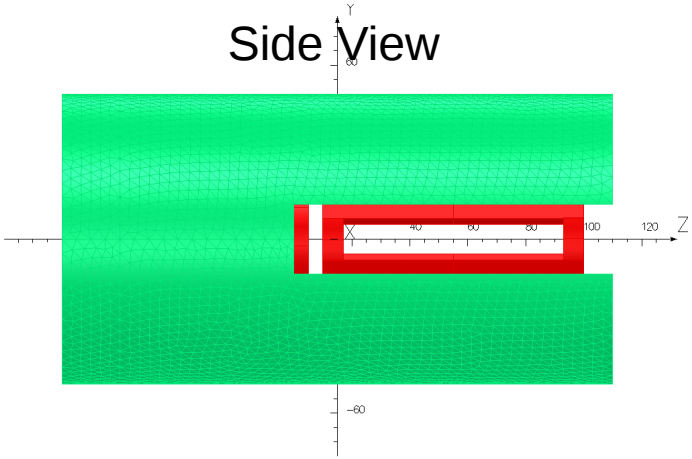
- 1st calculations employed idealised 2 T uniform longitudinal magnetic field
- Background in RTPC strongly dependent on configuration of field.
- Results presented here employ a field map generated in TOSCA by Bogdan Wojtsekowski

Idea for Solenoid (Bogdan Wojtsekkowski)

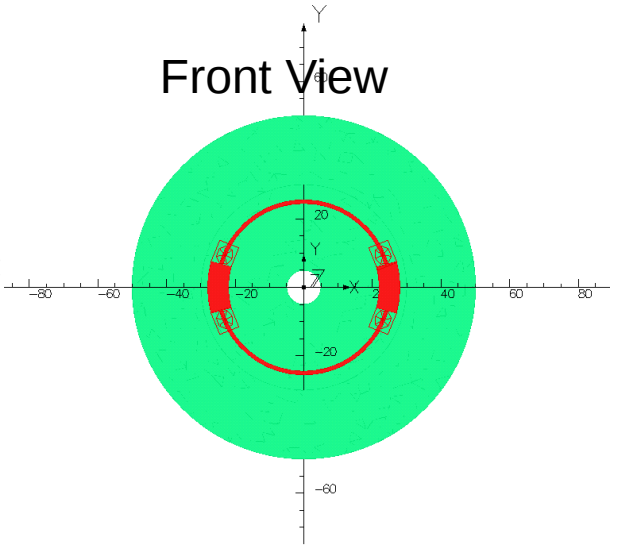
Top View

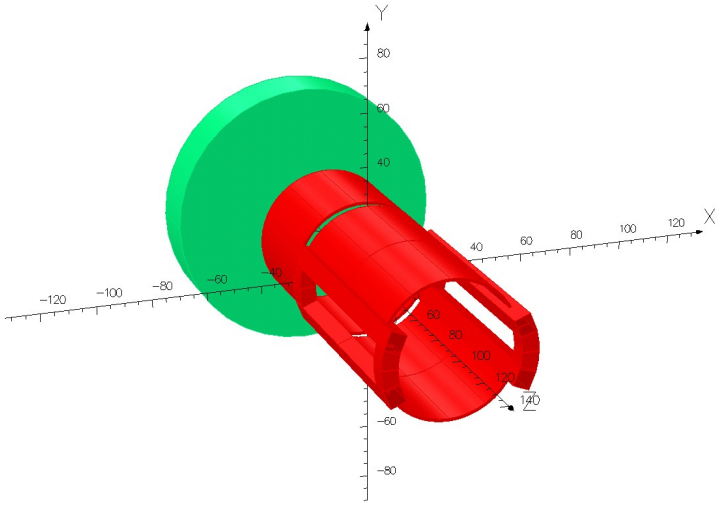


Side View



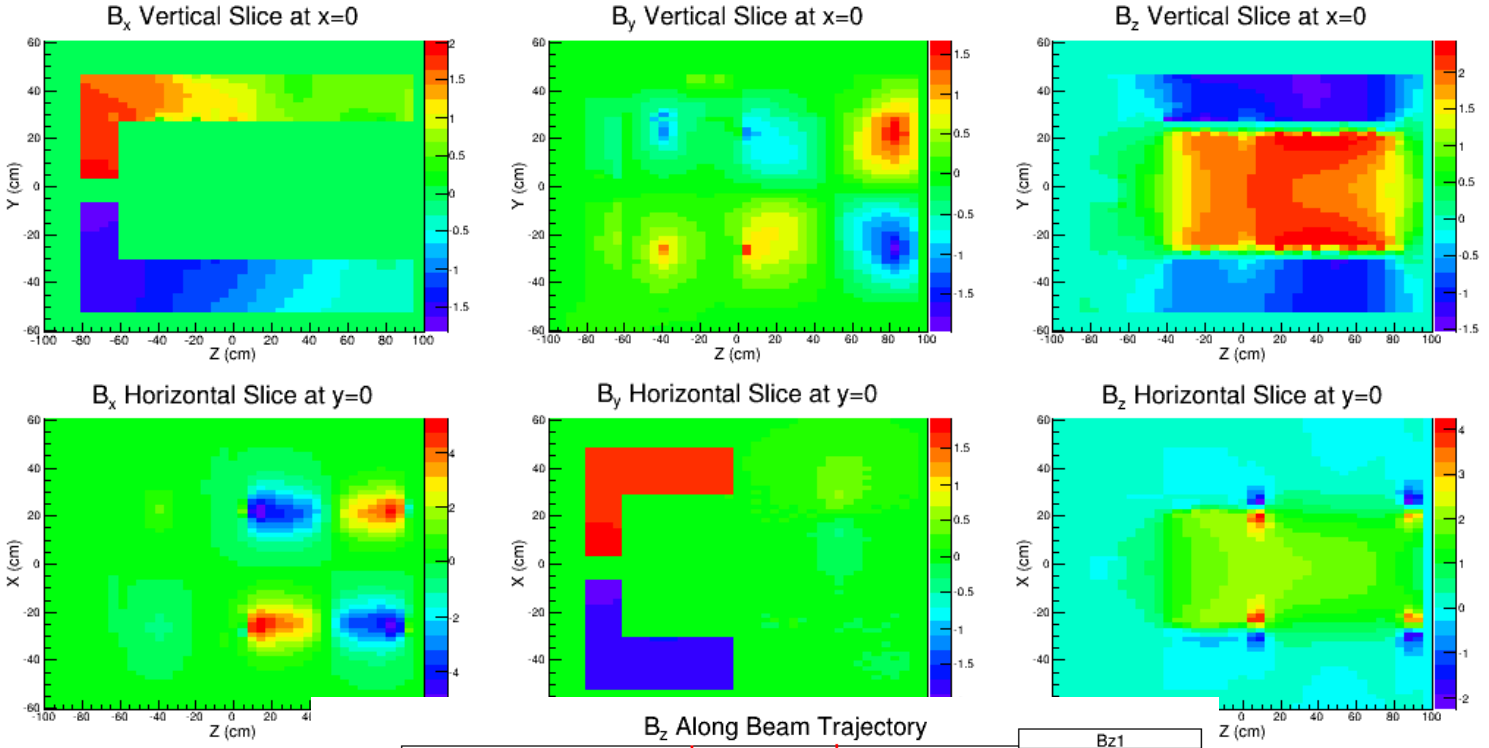
Front View

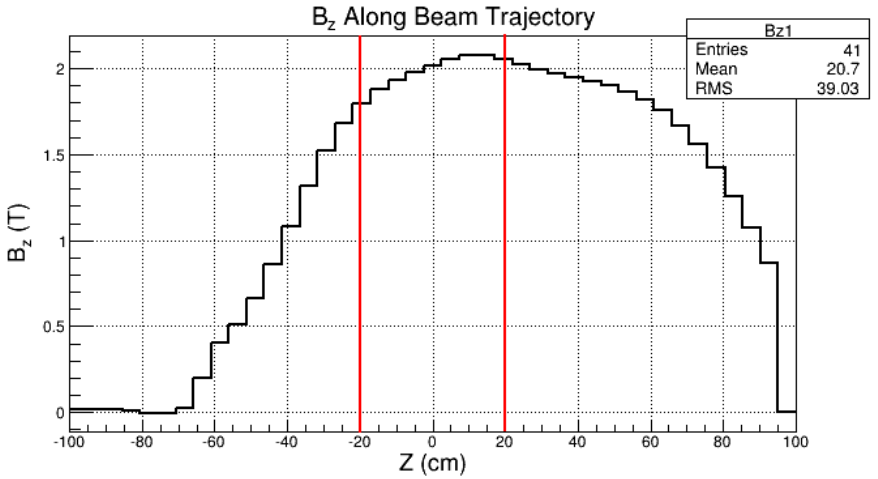




- Superconducting Coils
- Field of B_z~2T in region of target and sensitive detector
- Cut aways to allow passage of e' to SBS or BB

TOSCA Calculation of B Field (B. Wojtsekhowski)





Field map is labelled "**B7**"

Response of the RTPC

Interactions of the incident electron beam with the target

- Möller Scattering. Dominant process. The RTPC magnetic field (ideally along z-axis) also serves to confine scattered electrons to the target region
- Bremsstrahlung. Not confined by the magnetic field. Could potentially cause energy deposit in the outer regions of the RTPC.
  Small probability of γ interaction... but high luminosity
- Bremsstrahlung can also cause $d(\gamma,p)$. High cross section relative to Sullivan process. Especially at few-MeV energies
  Also $^{12}C(\gamma,p)$ in the target walls...high cross section in GDR region
- Higher energy p, n, π will also interact hadronically to produce low energy secondary protons

Proton momentum acceptance range of RTPC

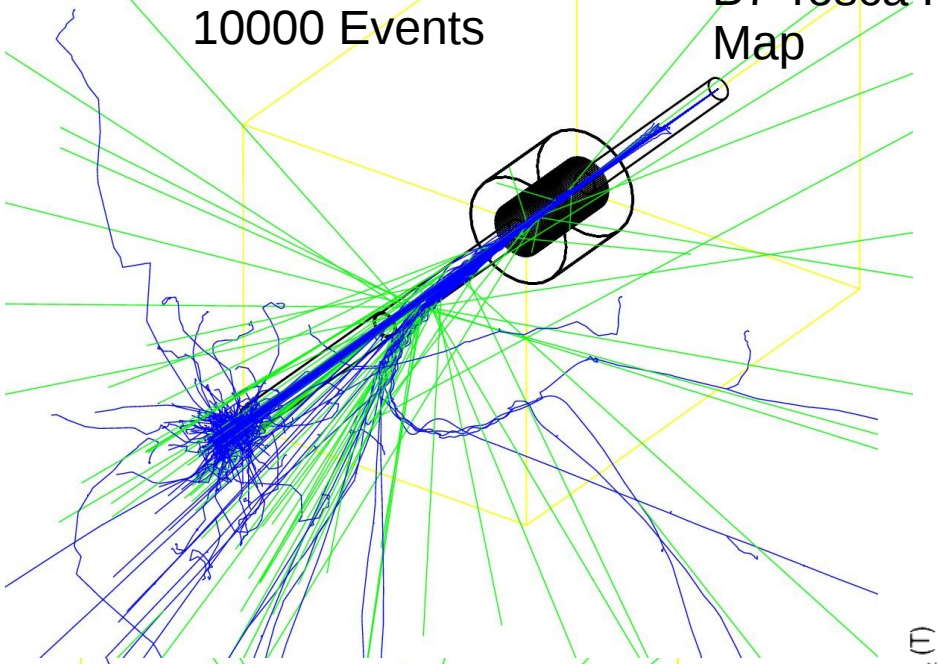
Effect of the RTPC on external detectors

- What is the effect of the (non-uniform) magnetic field on scattered electrons

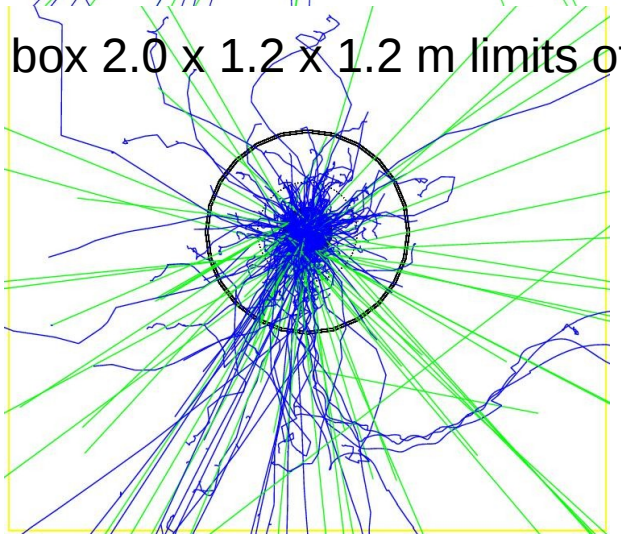
Geant-4 Simulation: Möller Scattering

10000 Events

B7 Tosca Field Map

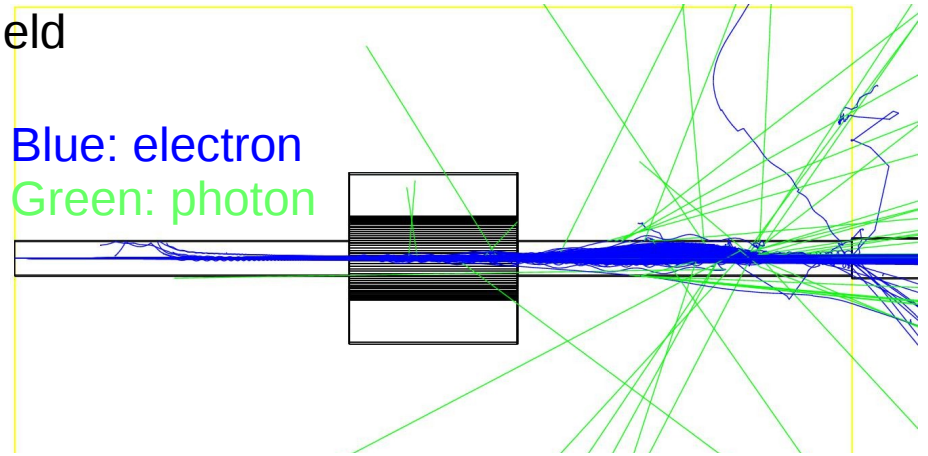


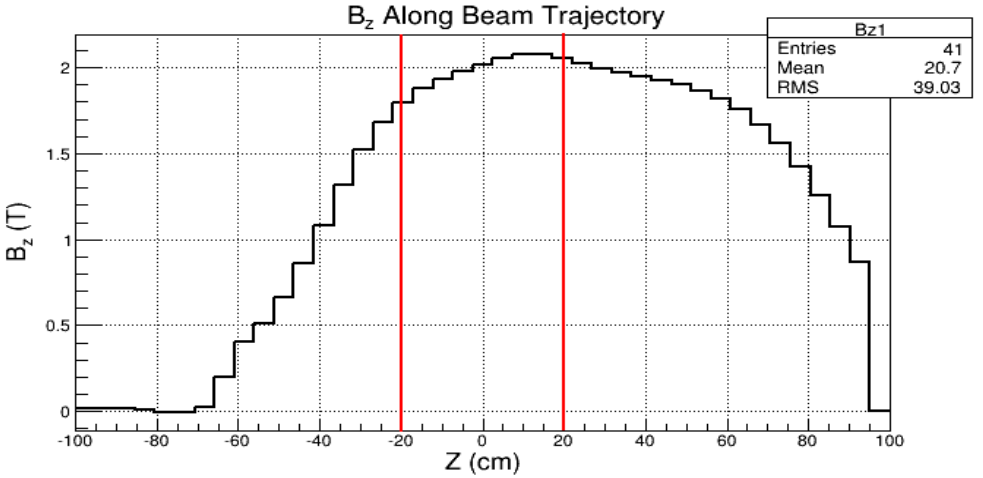
Yellow box 2.0 x 1.2 x 1.2 m limits of B field



Blue: electron

Green: photon



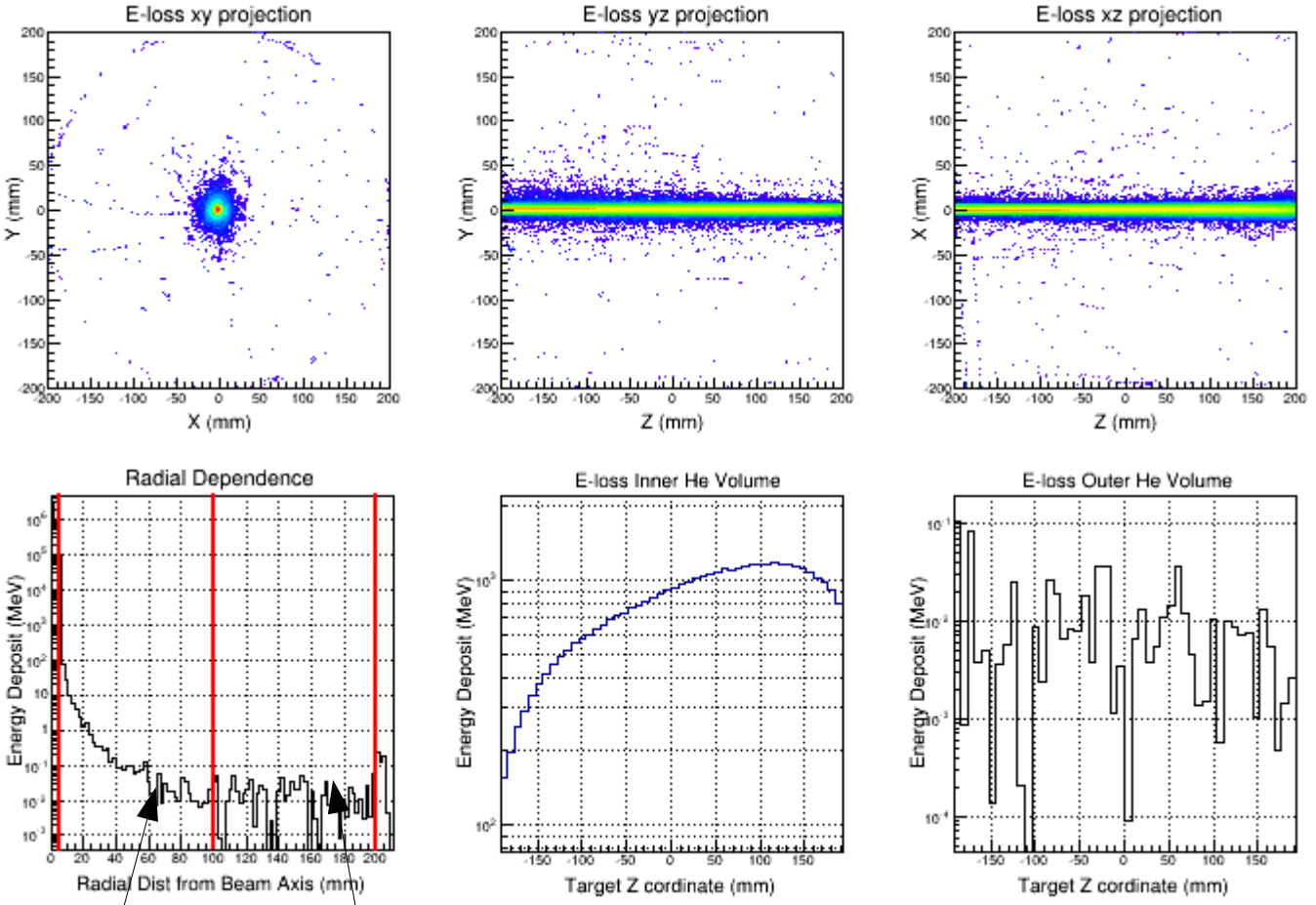


2T confines background in target vicinity

Important that field extends beyond exit of RTPC...back-splash from interactions in beam-line etc.

Distributions of Möller Event
10^7 8-GeV Electrons on Target

B7 Field Map



Inner He

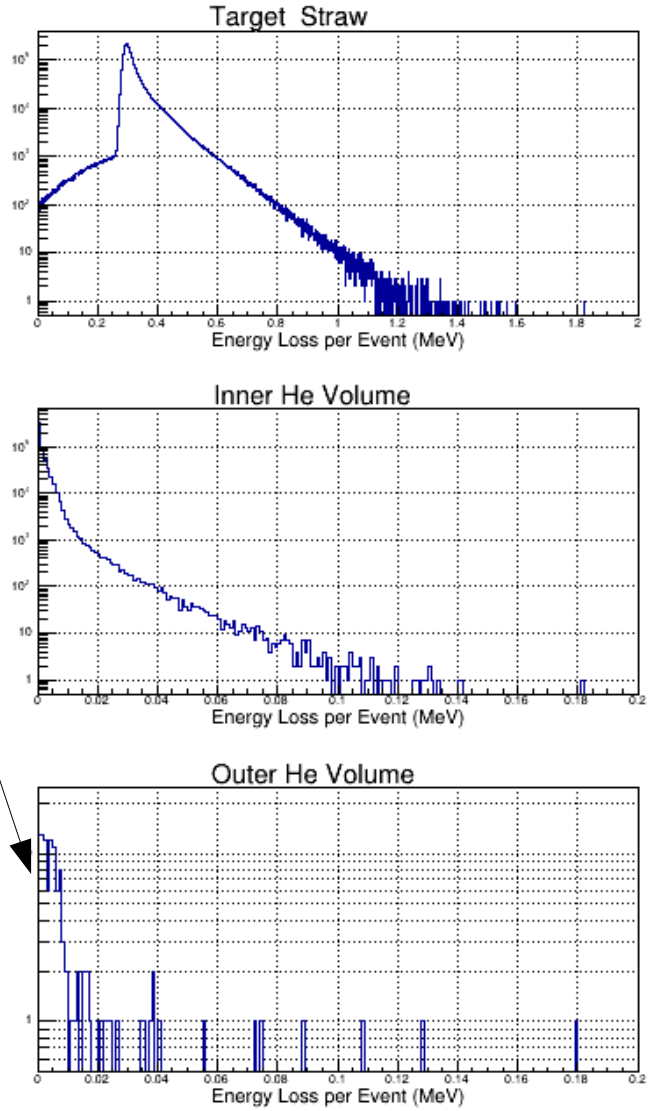
Outer He

Record energy deposit and position at each step during tracking in Geant-4 simulation

Möller Event Rate outer He Volume @ 50 μA
B7 Field $L_N = 10^{37}\, cm^{-2}\, s^{-1}$

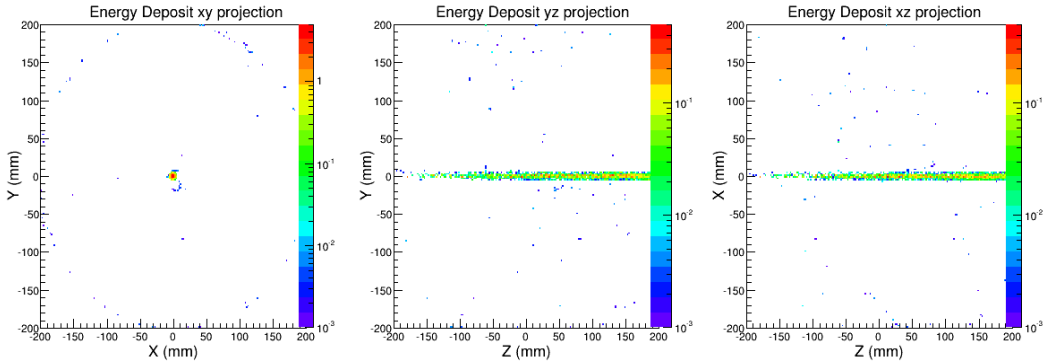
- 10^7 electrons produce 7 events with a total energy loss in outer He volume exceeding 0.05 MeV (18 events above 0.02 MeV)
- 50 μA = 3.1×10^{14} electron/s
- E > 0.05 MeV event rate in outer He = 2.2 x 10^8 Hz
- GEM pixel readout ~3x3 mm pads = 25k pixels
- Mean rate/pixel ~9 kHz
- Can TPC still track reliably? ...minimise drift distance

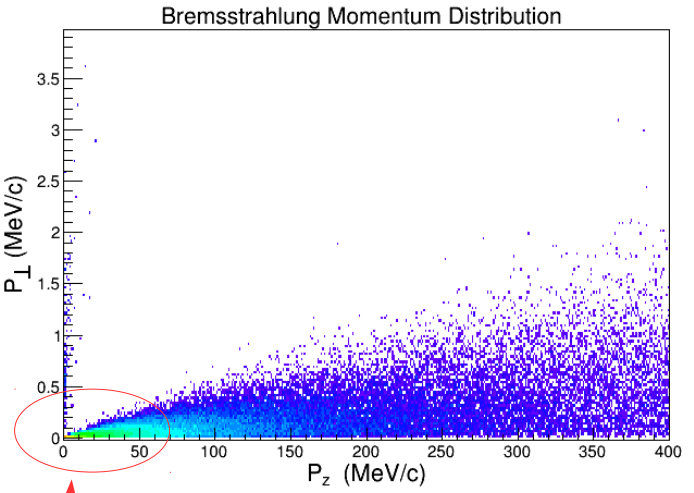
T

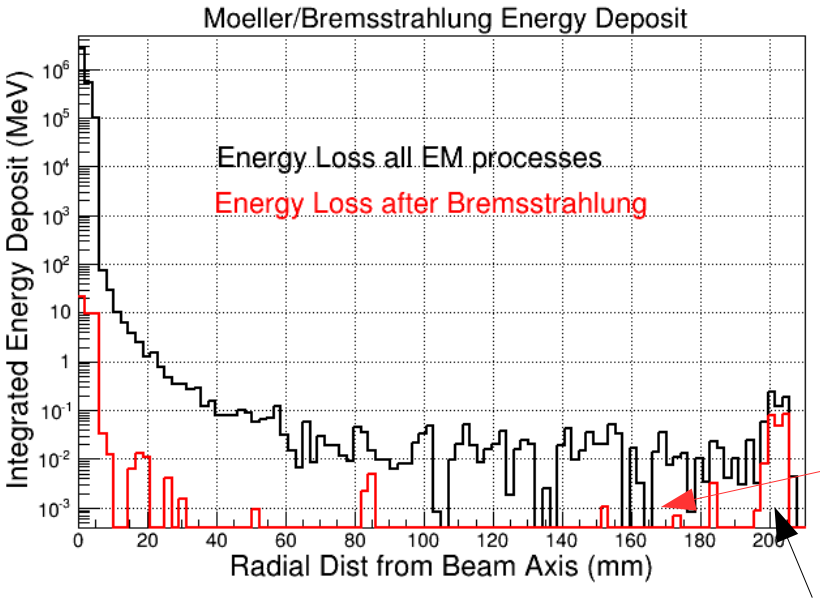


Bremstrahlung: EM Processes

Distribution of post-bremsstrahlung energy deposit in target and RTPC







T

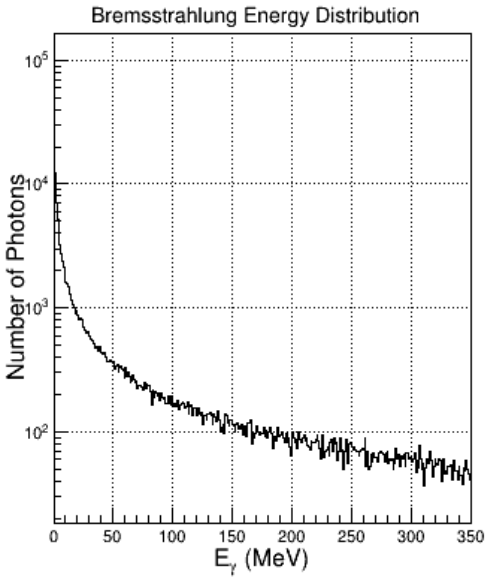
Most of the photons at low momentum
Dominantly forward direction

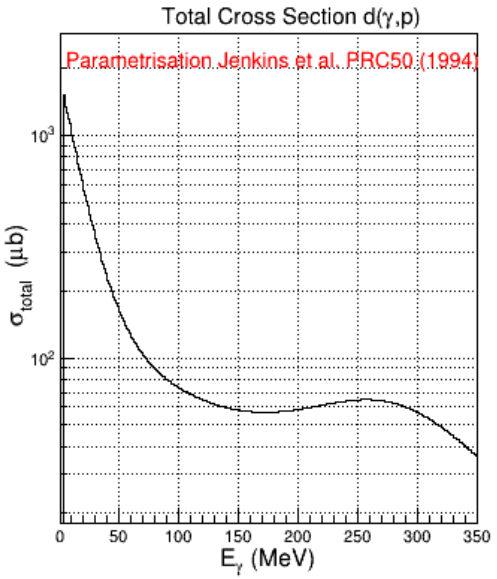
EM processes after bremsstrahlung result in only a small energy deposit, relative to Möller, in the outer He volume.

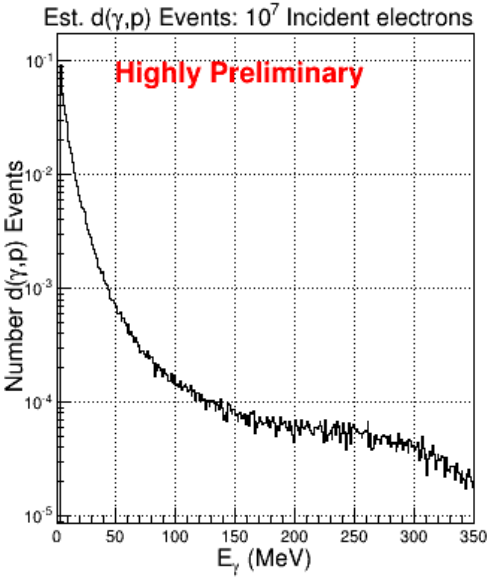
Outer GEM

Bremsstrahlung Hadronic Processes

Deuteron Photodisintegration Highly Preliminary





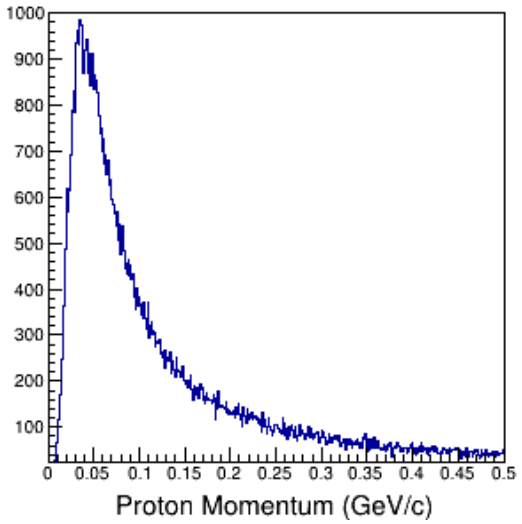


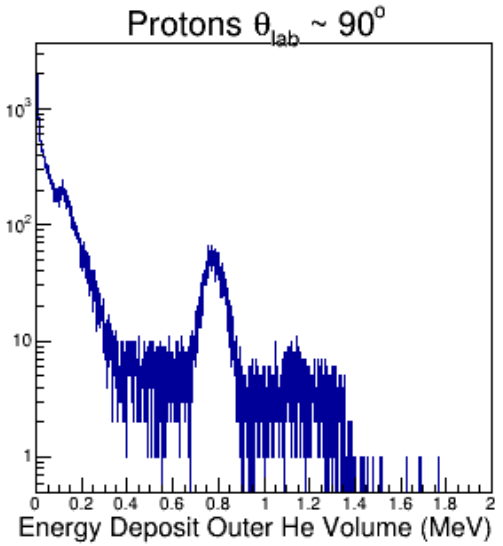
- 10^7 8 GeV electrons on target
- Bremsstrahlung intensity ~ $1/E_\gamma$
- Most of the photons are forward going...
  rough estimate: photons see ~10 cm target material
- d(γ,p) total cross section ~ mb close to breakup threshold
  most produced protons at low momentum
- Potentially MHz total d(γ,p) rate at 50 μA incident beam
- "Load" on RTPC?
  Degree of suppression with e'-p-p vertex condition?

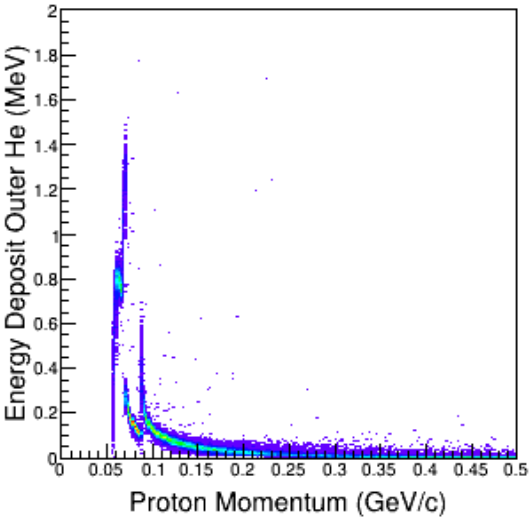
T

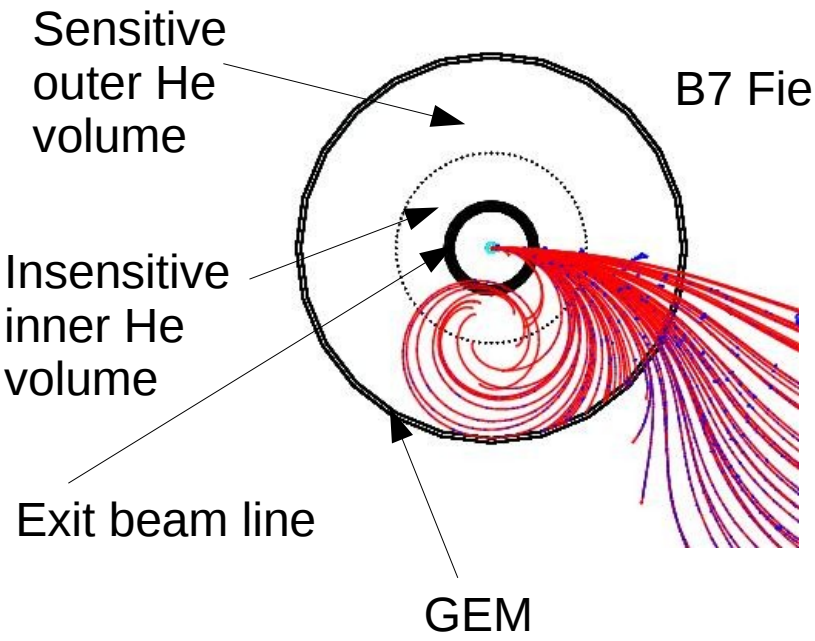
Interactions in kapton
Nuclear (γ,p) cross sections in GDR region up to several mb

Response to Low Momentum Protons







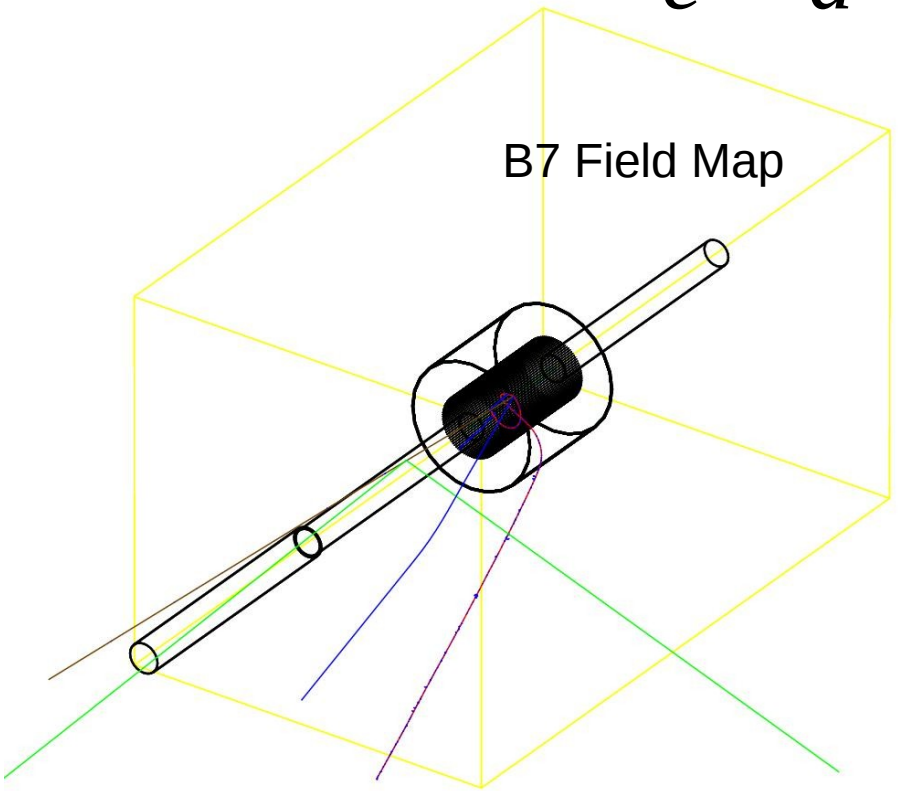


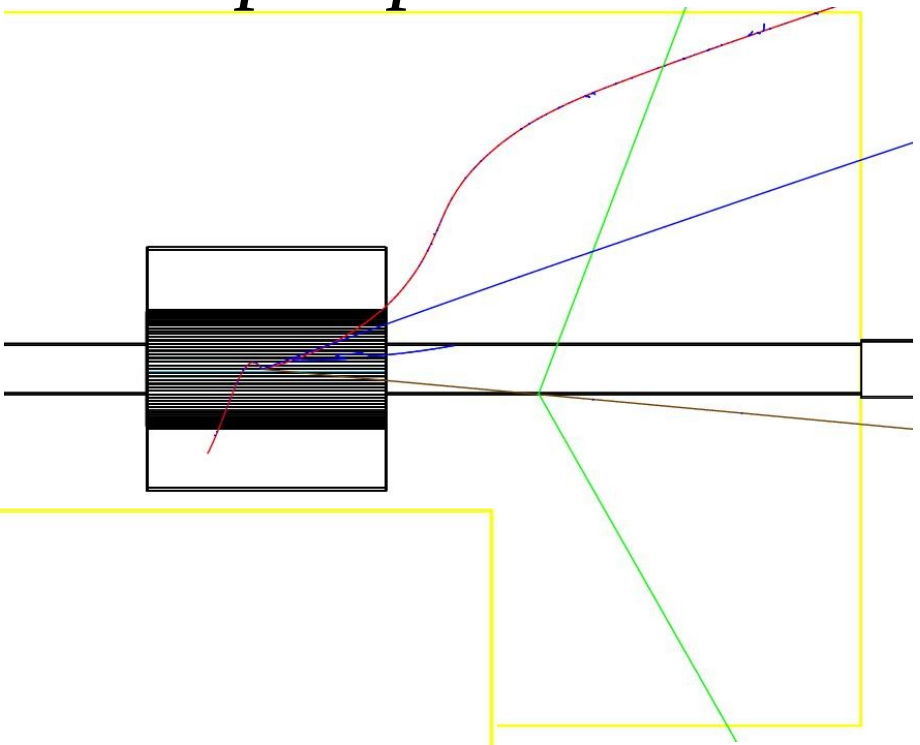
B7 Field Map

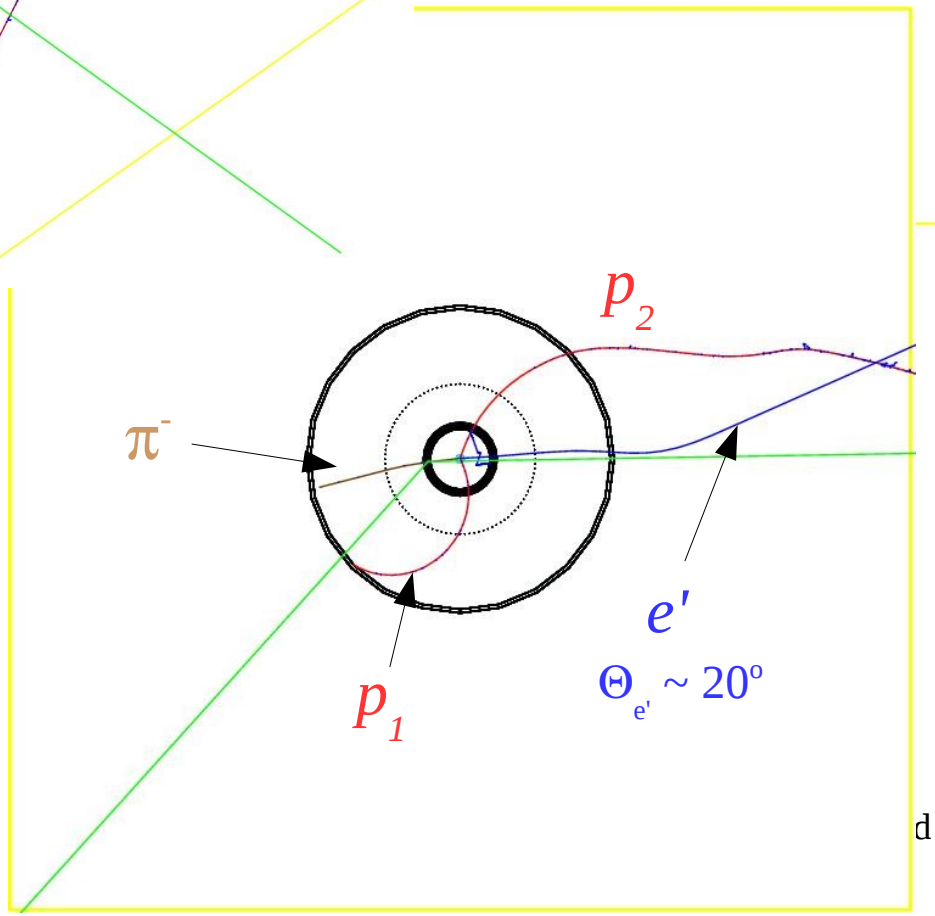
Threshold for detection in outer He ~ 0.055 GeV/c

Apparent structure in energy response due to low momentum protons crossing and re-crossing boundary between sensitive and insensitive He volumes

$$e + d \rightarrow e' + p + p + \pi^-$$

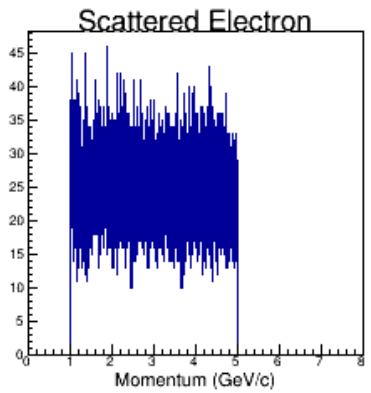


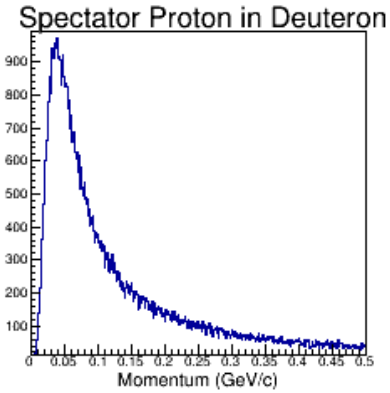


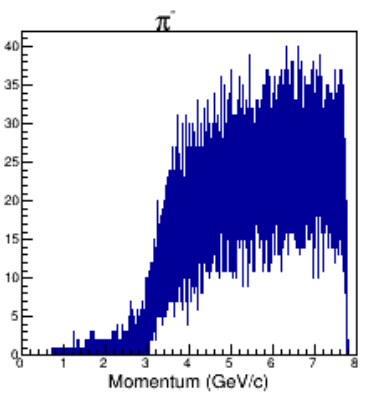


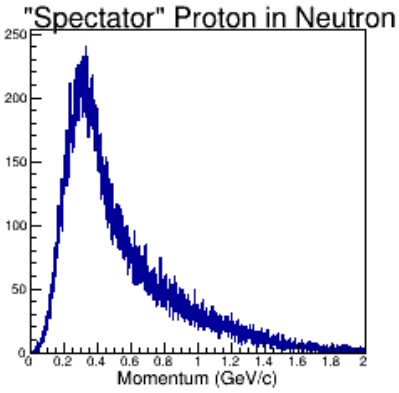
Impact on e' trajectory requires to be quantified

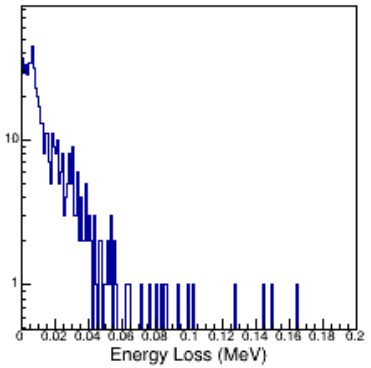
Energy Deposit by $e' + p + p + \pi^-$

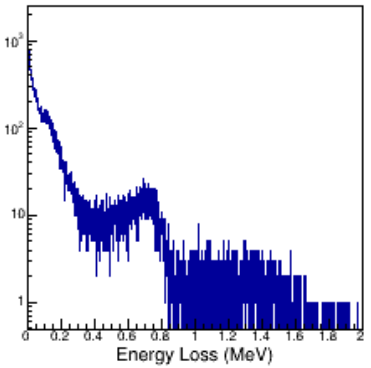


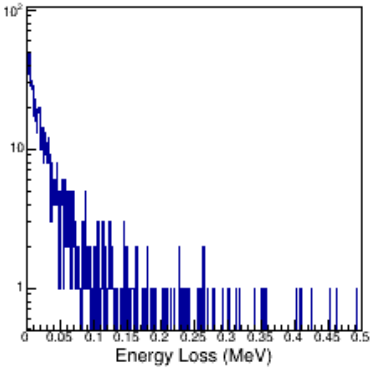


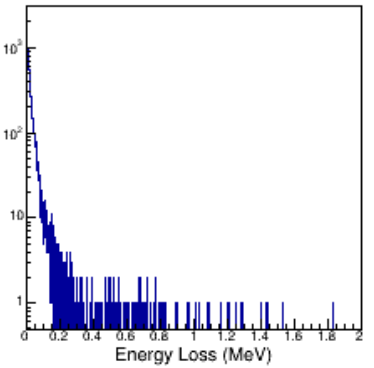












Summary

- B7 Field (B_z ~ 2T) effective in confining Möller inside insensitive part of RTPC.
- Background in sensitive volume sensitive to exit beamline configuration and detail of magnetic field map....even well outside sensitive RTPC volume
- Deuteron photodisintegration could be a significant source of background. Significant rates in the RTPC for low-momentum protons. How well is this suppressed by a e'-p-p vertex cut. More detailed calculation is underway
- Require to make more realistic model of detector, including mechanical support structures, cryogenics..... Parallels with BONuS12 RTPC effort?
- B7 field map has significant impact on e' trajectory at 20^{o} scattering angle. Needs to be further quantified.
- Have mock-up of Sullivan kinematics... “realistic” modelling possible with suitable physics input to event generator.

Thanks for your attention