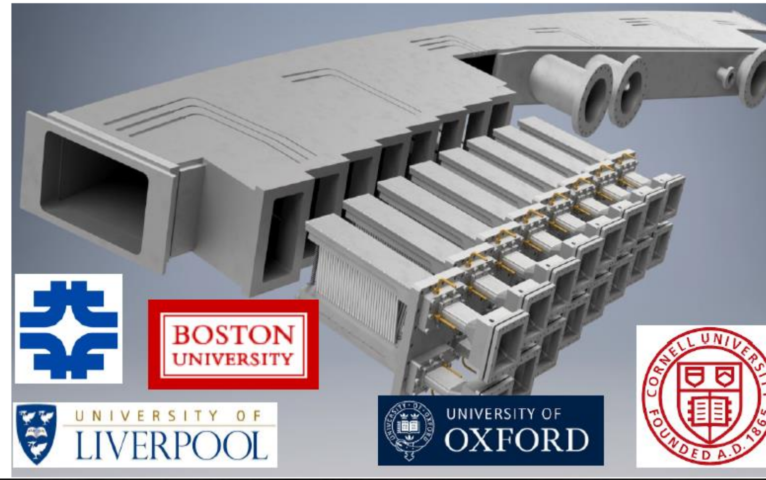
The g-2 Tracker Software.

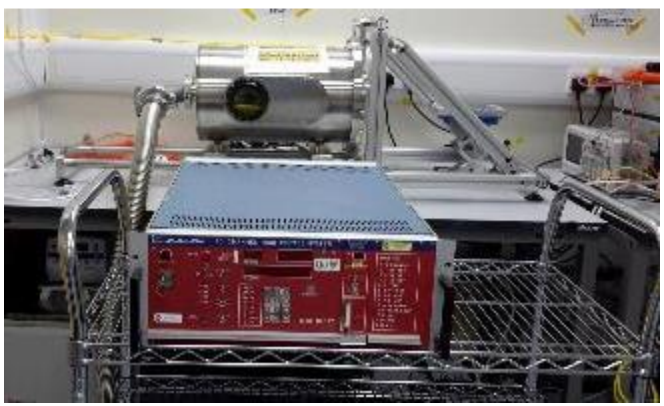
Barry King. University of Liverpool.

- **MUSE meeting. 28 Sept. 2016 Pisa, Italy.**

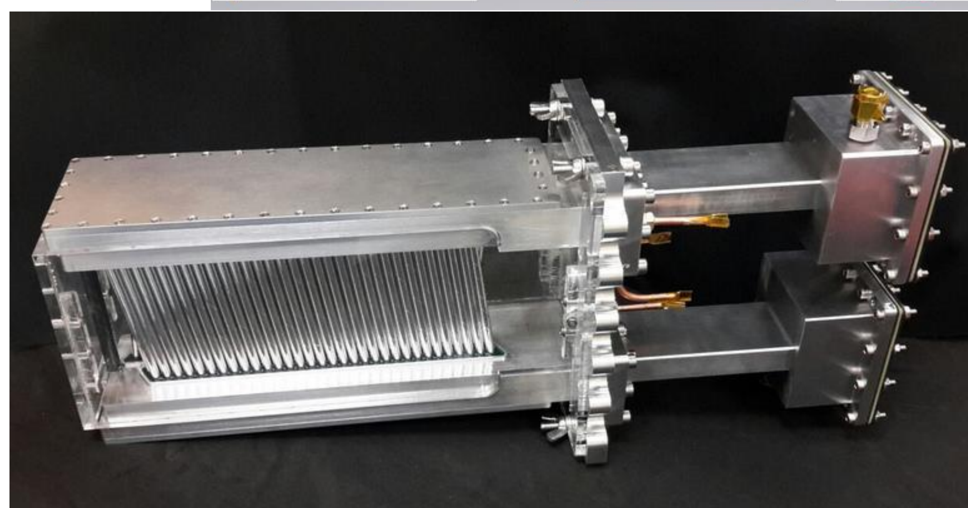
The g-2 Experiment at Fermilab

3 Trackers being built in Liverpool for g-2.
Each consists of 8 4-layer Straw Modules.
Reconstruct trajectory and momentum of positrons from muon decays.
Determine the muon decay point to reduce systematic errors on muon g-2 measurement.
Tracker based muon EDM measurement.





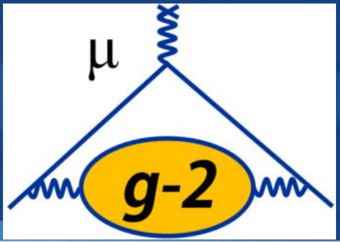
Vacuum Tank + HV for Module Testing In Liverpool prior to shipping to FNAL.

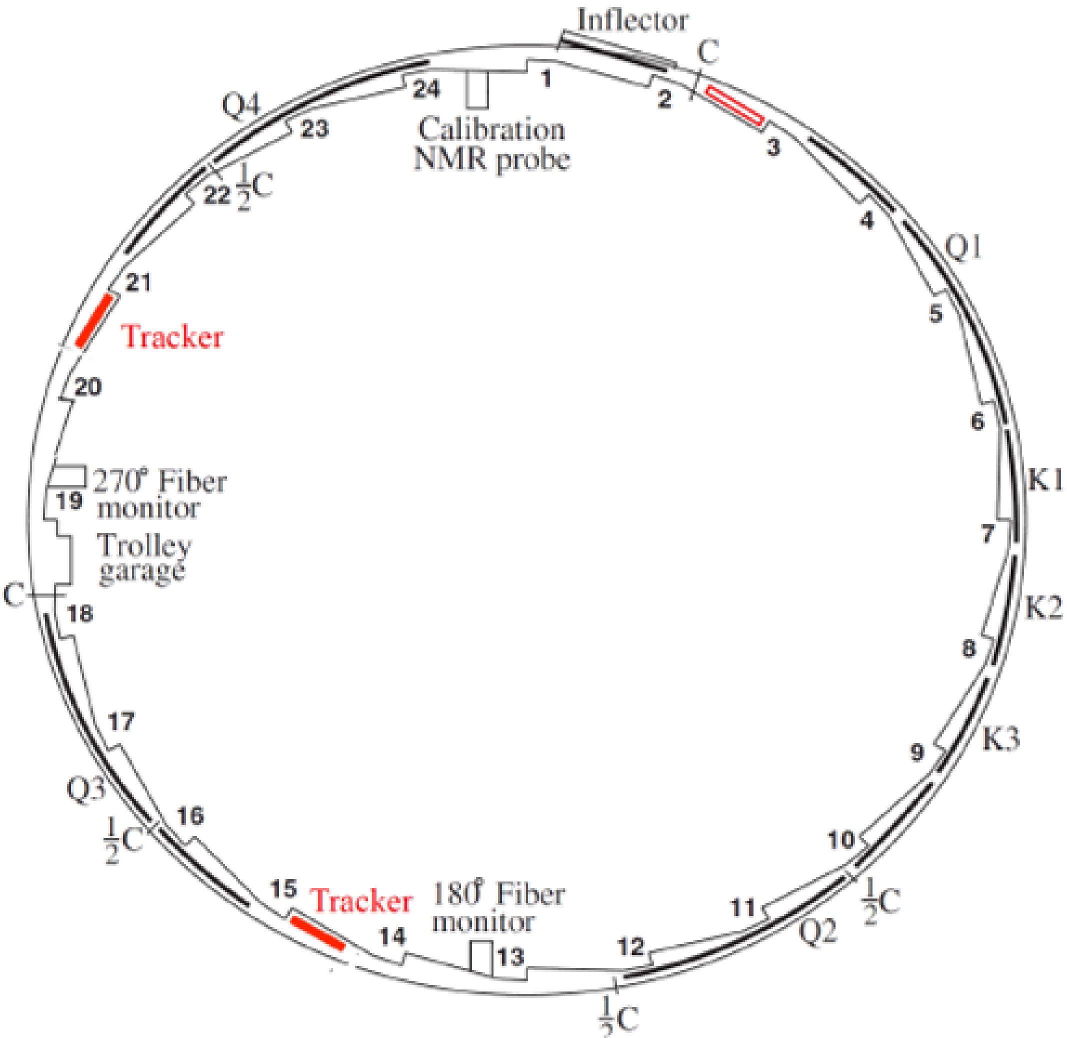


4 layers of 32 straws, 7.5° stereo angle

Two of the Liverpool Workers.

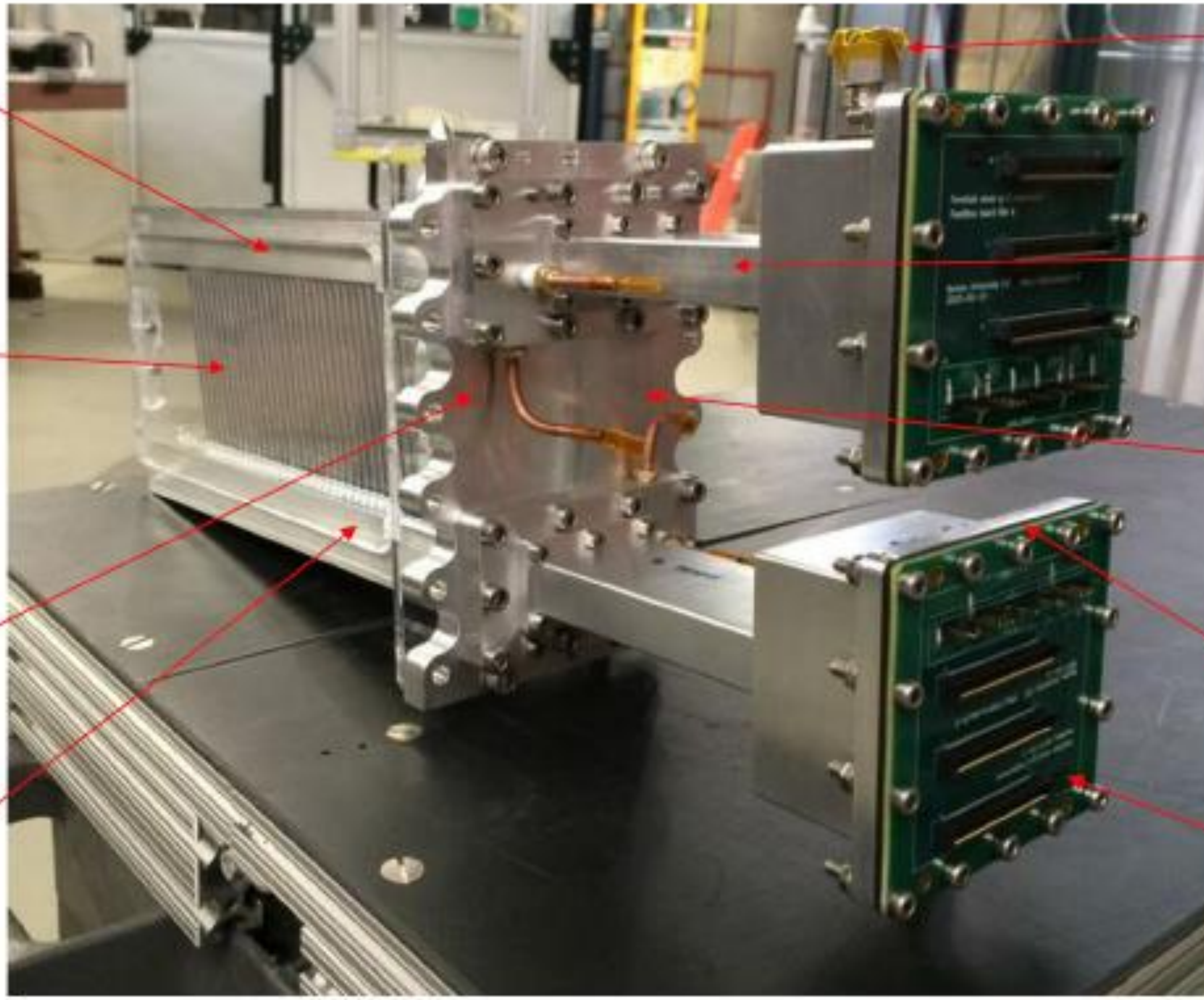
g-2 Experimental Setup.



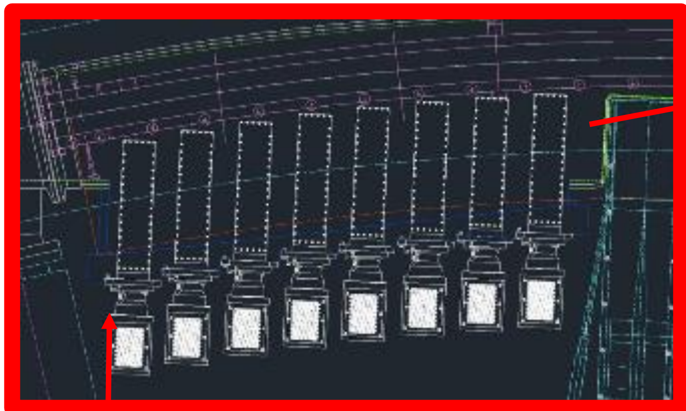


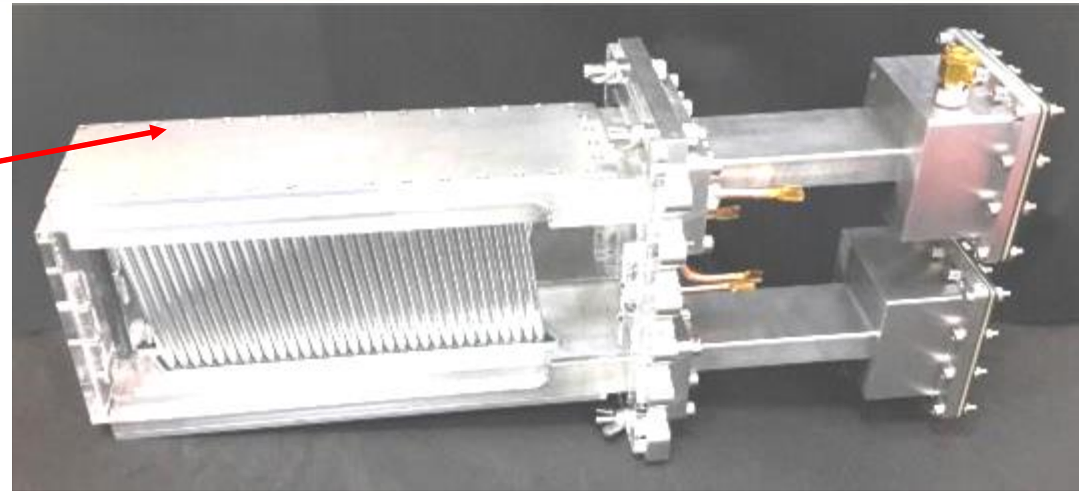
- 15m diameter storage ring.
- Calorimeters at 24 locations evenly spaced around the ring.
- Tracking stations in front of 3 calorimeters.

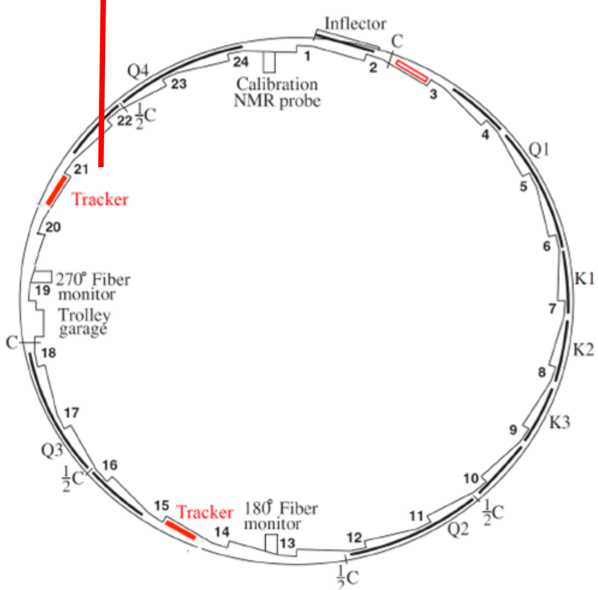
A Tracker Module



g-2 Experimental Setup

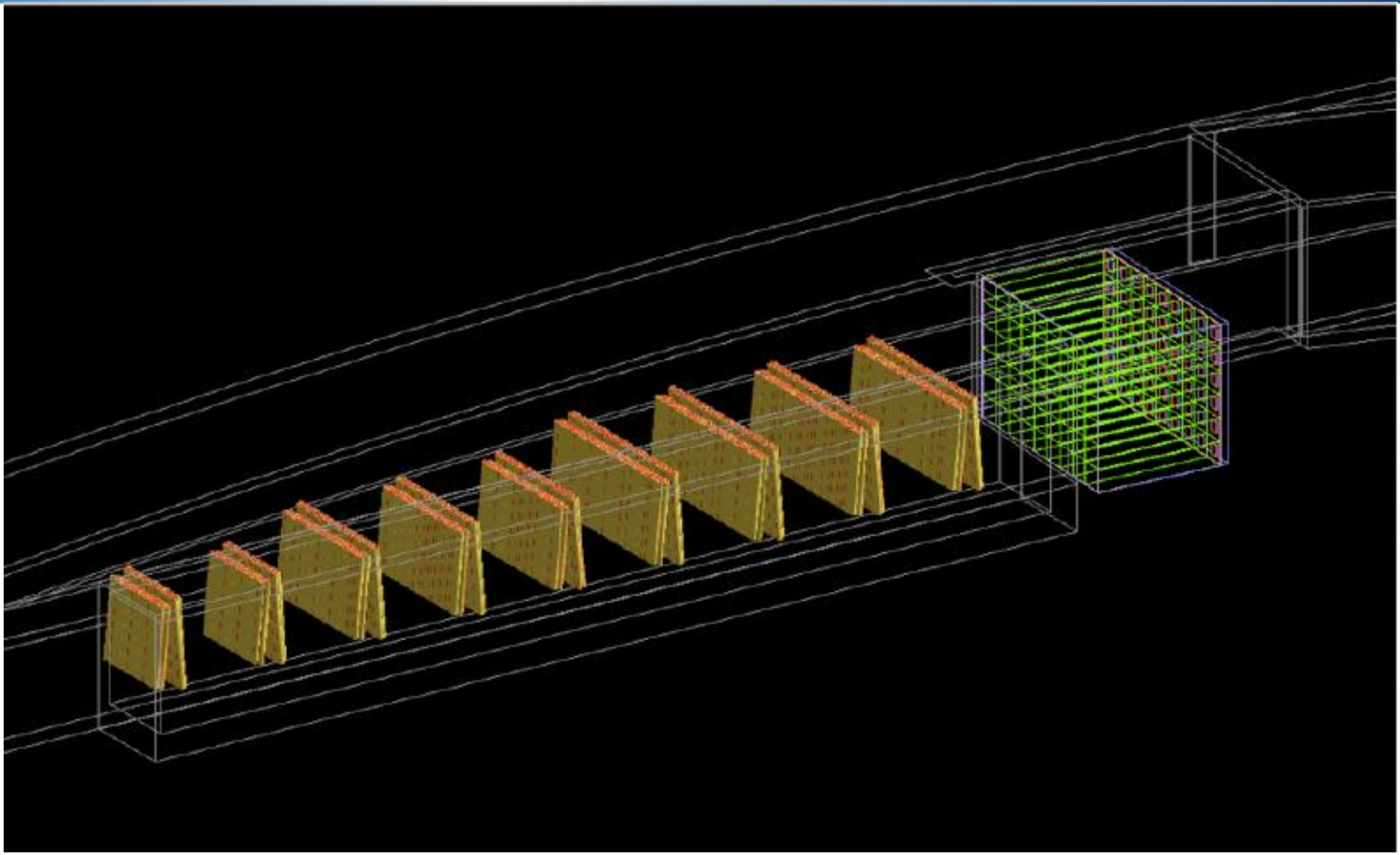






- **3 locations around g-2 ring : 30, 120 and 300 degrees.**
- **8 tracking modules at each location.**

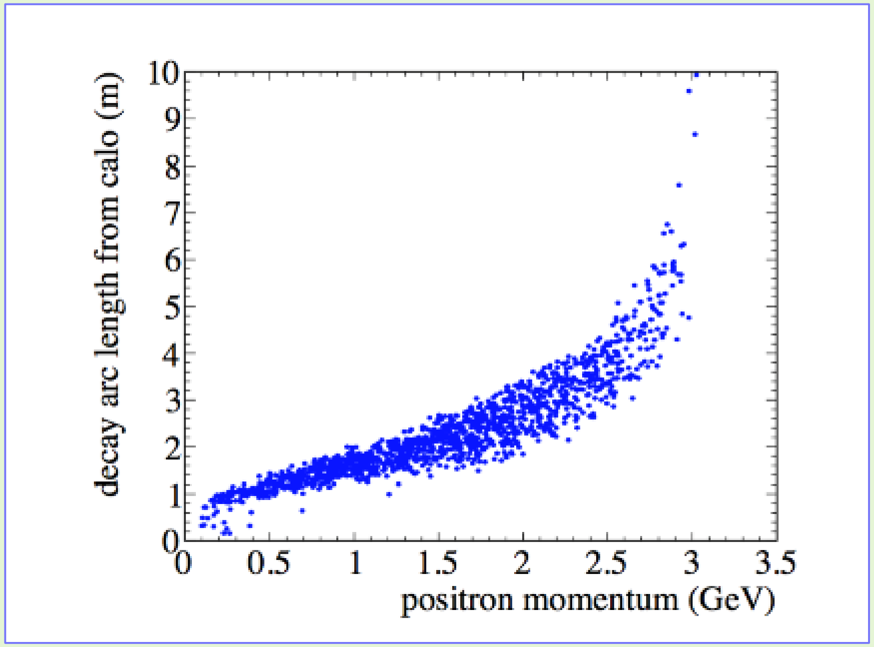
Simulation of Tracker + Calorimeter



Why have tracking detectors?

3 Main Physics goals associated with the trackers

- Physics goal 1: measure the muon beam profile at multiple locations around the ring, as a function of time throughout the muon fill
- Physics goal 2: reduce several important systematic uncertainties associated with the g-2 measurement
- Physics goal 3: identify any tilt in muon precession plane away from vertical – indicative of muon EDM



Why have tracking detectors?

Reduction of systematic errors associated with the trackers

- From the TDR:

Uncertainty	E821 value	E989 goal	Role of tracking
Magnetic field seen by muons	0.03 ppm	0.01 ppm	Measure beam profile on a fill by fill basis ensuring proper muon beam alignment
Beam dynamics corrections	0.05 ppm	0.03 ppm	Measure beam oscillation parameters as a function of time in the fill
Pileup correction	0.08 ppm	0.04 ppm	Isolate time windows with more than one positron hitting the calorimeter to verify calorimeter based pileup correction
Calorimeter gain stability	0.12 ppm	0.02 ppm	Measure positron momentum with better resolution than the calorimeter to verify calorimeter based gain measurement
Precession plane tilt	4.4 μRad	0.4 μRad	Measure up-down asymmetry in positron decay angle

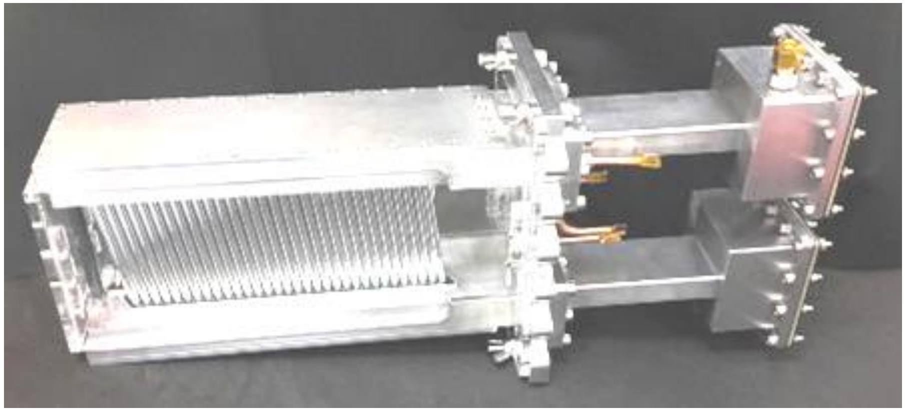
Goal 1

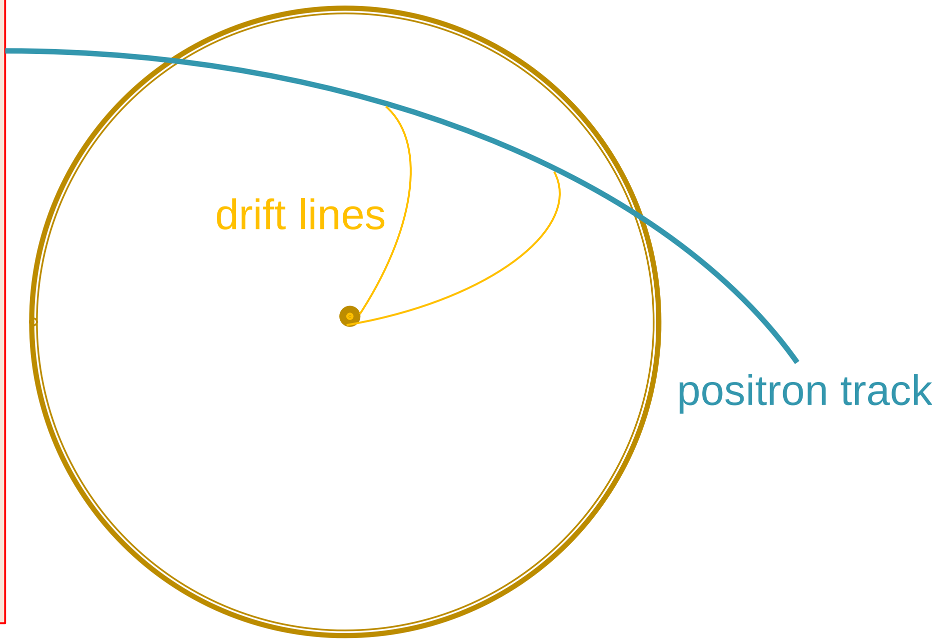
Goal 2

Goal 3

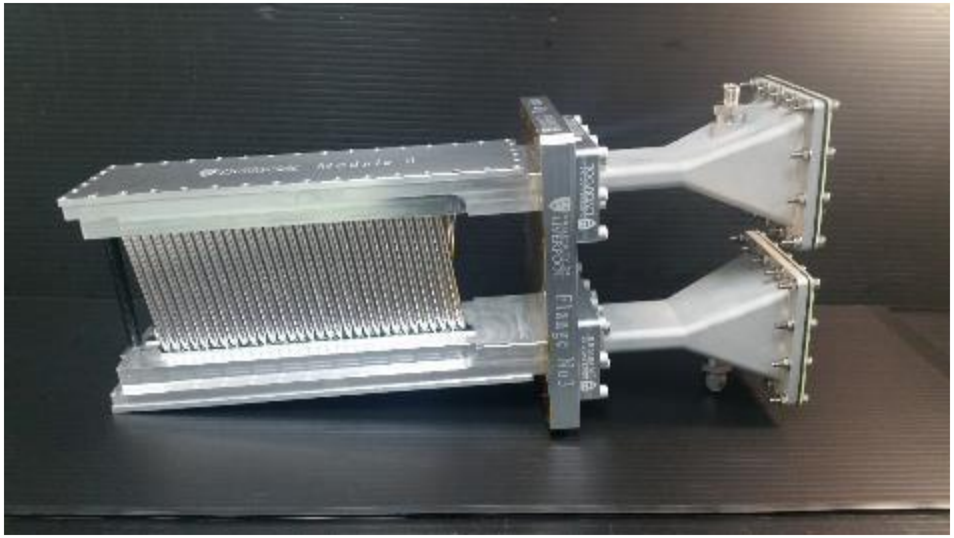
How do straw trackers work?

- 4 layers of 32 straws
- 7.5º stereo angle for vertical resolution
- Straws filled with 50:50 Argon-Ethane gas mixture
  - Argon: drift gas
  - Ethane: quench gas
- Ionisation electrons drift towards 25 micron tungsten rhenium wire in straw centre creating a hit.





Tracker Design.

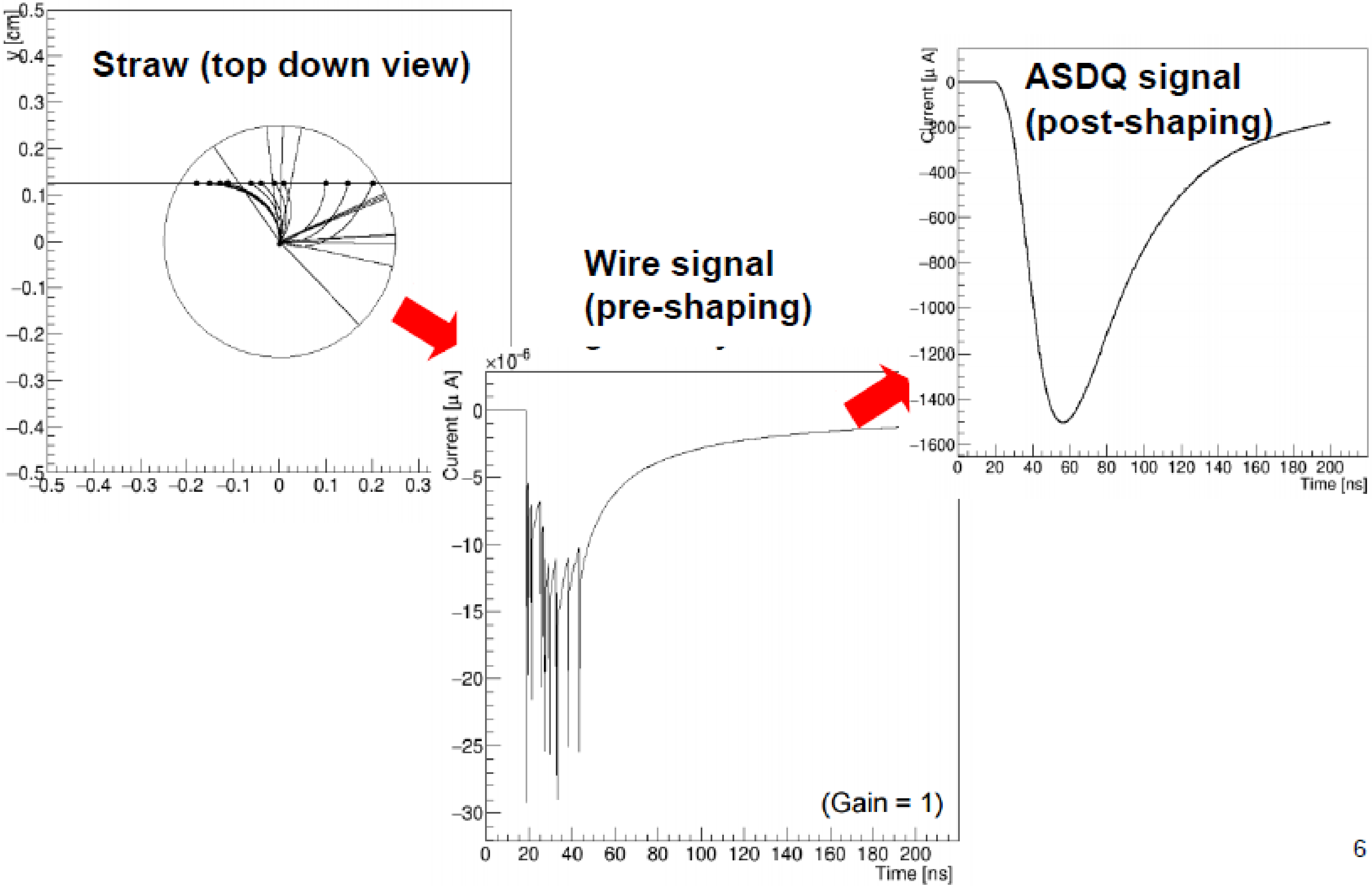


Choice of stereo angle based on a tried and tested design.

Detector Behaviour modelled - Garfield.

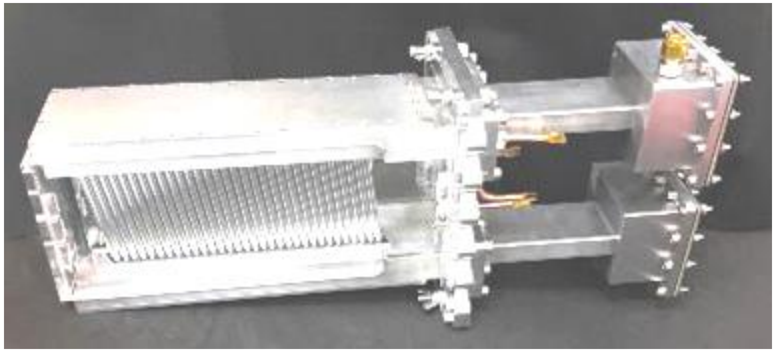
- Using GARFIELD to model drift times

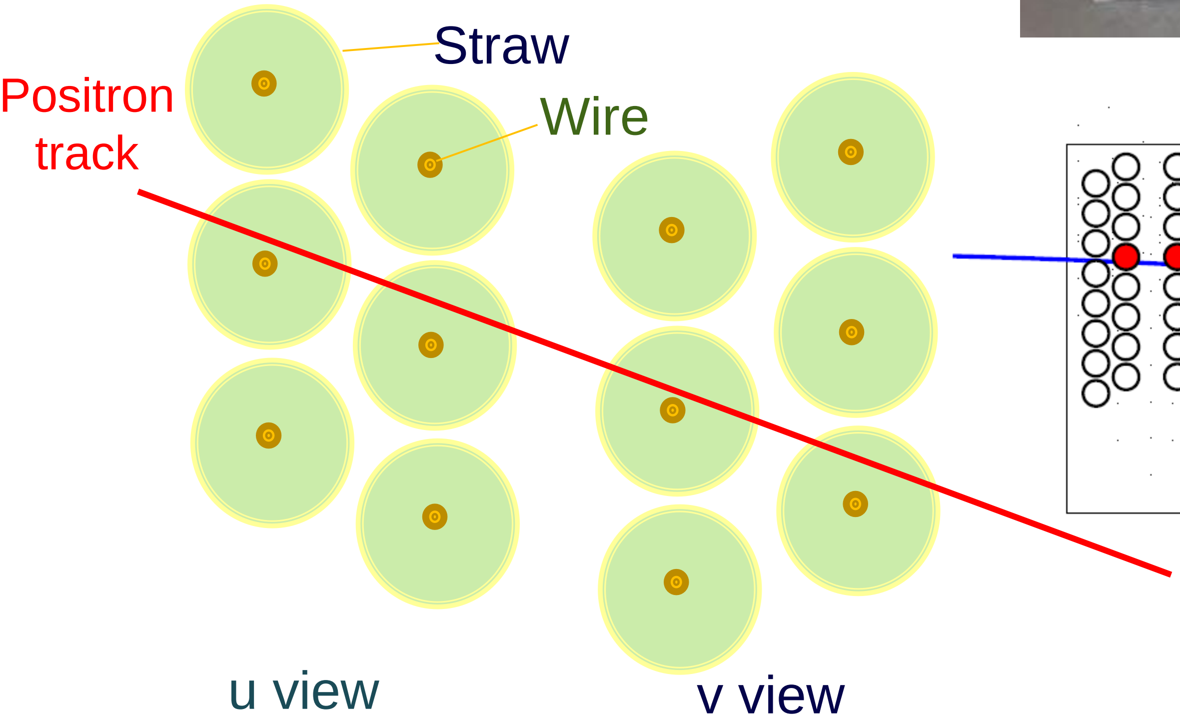
Primary ionisations → Electron/ion drift → Avalanche → Electronics

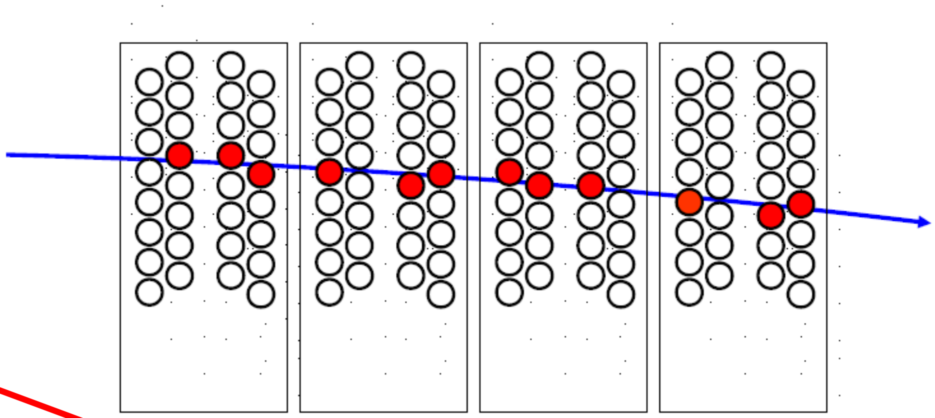


Track Fitting

- When a particle passes through straws it creates hits in those straws







Track Fitting Challenges.

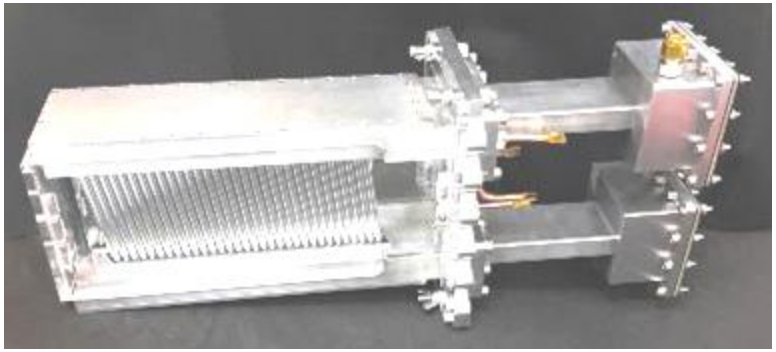
Large variation in B field across the tracker.
- single helix fit is insufficient.

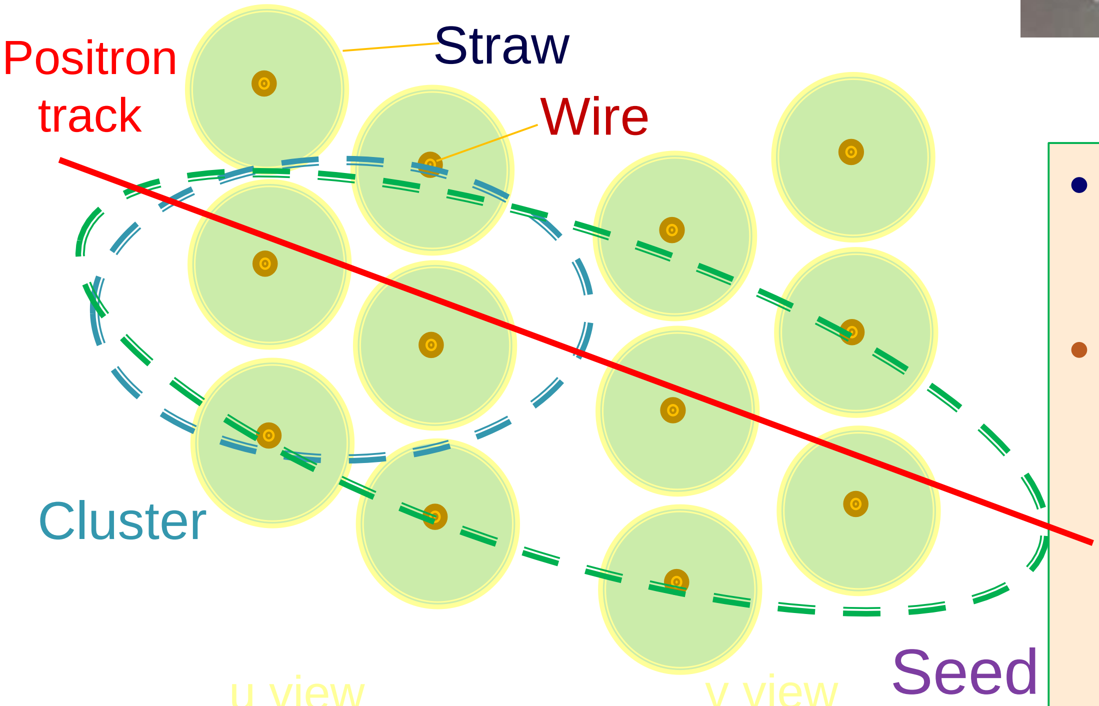
No t0
No entry time of particle into tracker available.
must be determined on a track by track basis either as part of the fit or from timing checksums in adjacent straws.

No fixed interaction point.
- Many tracks will not pass through all straw modules.
Use correct hits in track fits whilst rejecting secondaries.

Track Fitting in a single module

- 4 layers of 32 straws
- 7.5° stereo angle for vertical resolution

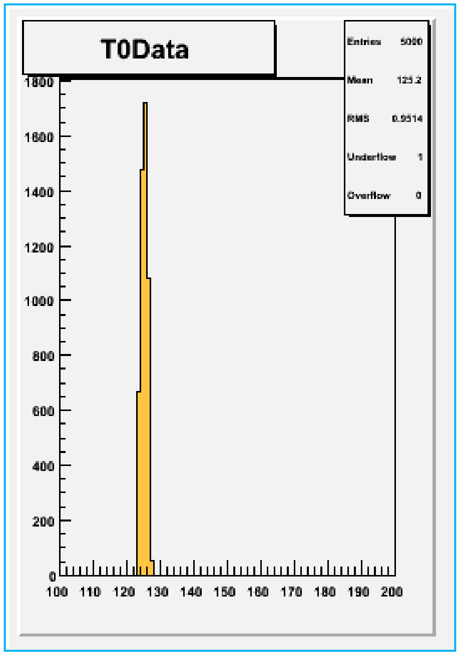


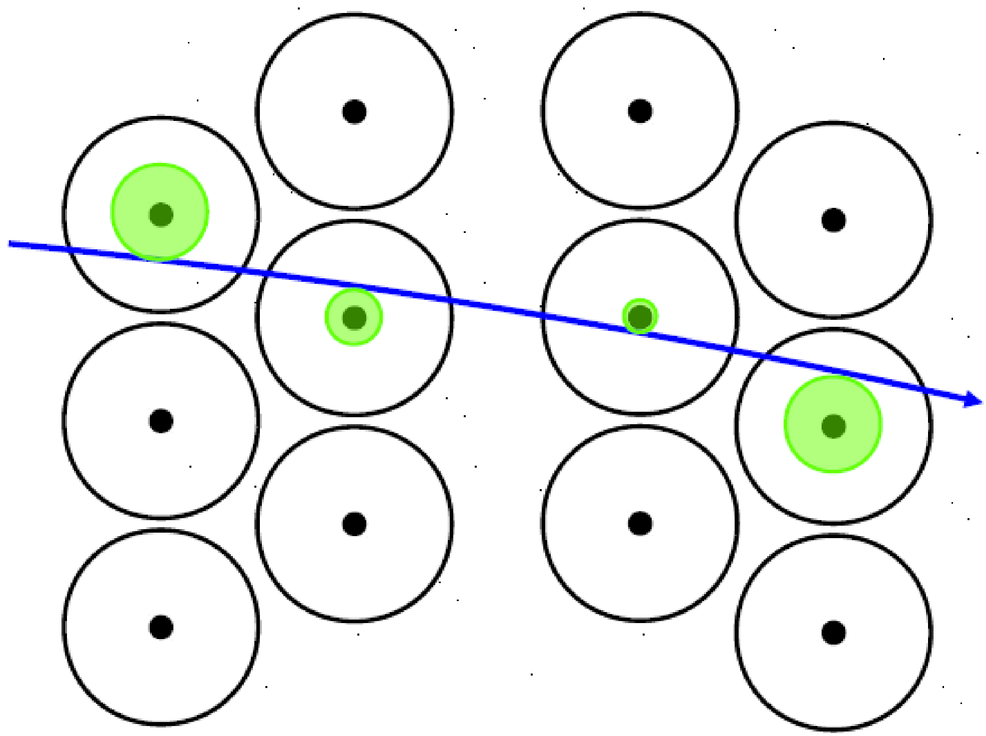


- Group clusters in the same module into seeds
- Can do this using "Time Islands" of hits within ~ 60 nanosecond windows since the maximum drift time is ~ 50 nanoseconds.

Track Fitting in a single module

Use hit times and t0 estimate to get drift circles.



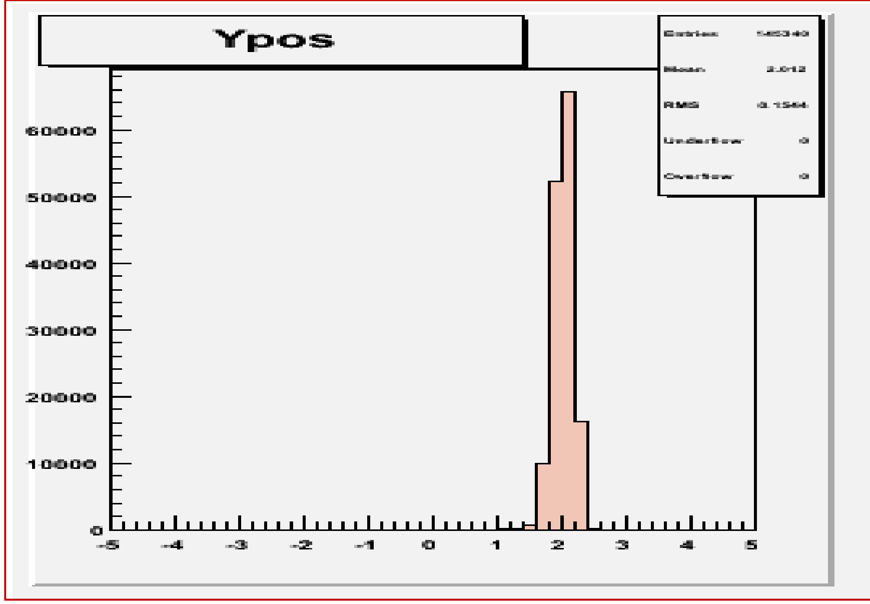


Track Fitting in a single Module

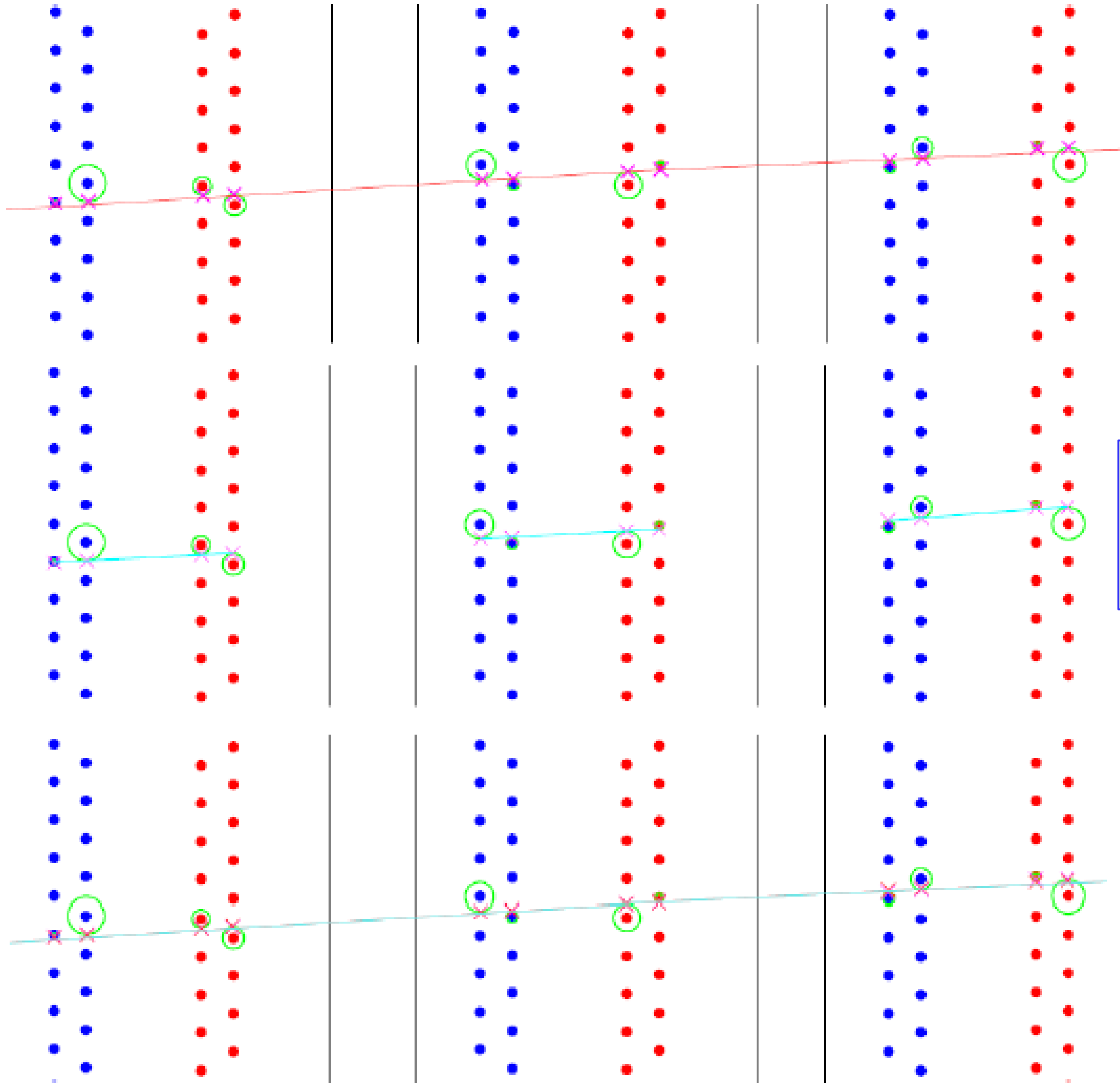
To obtain the vertical coordinate we extrapolate the four tangents to the drift circles in layers 1 + 2 into layers 3 and 4. Determine the residuals to the layer 3/4 hits whilst stepping in hypothetical vertical position.

Resolution on vertical hit position is ~ 1 mm.

Have recently added the possibility to make 3 hit track elements if the missing layer trajectory is consistent with passing through the gap between adjacent straws.



Reconstruction of Positron Trajectories

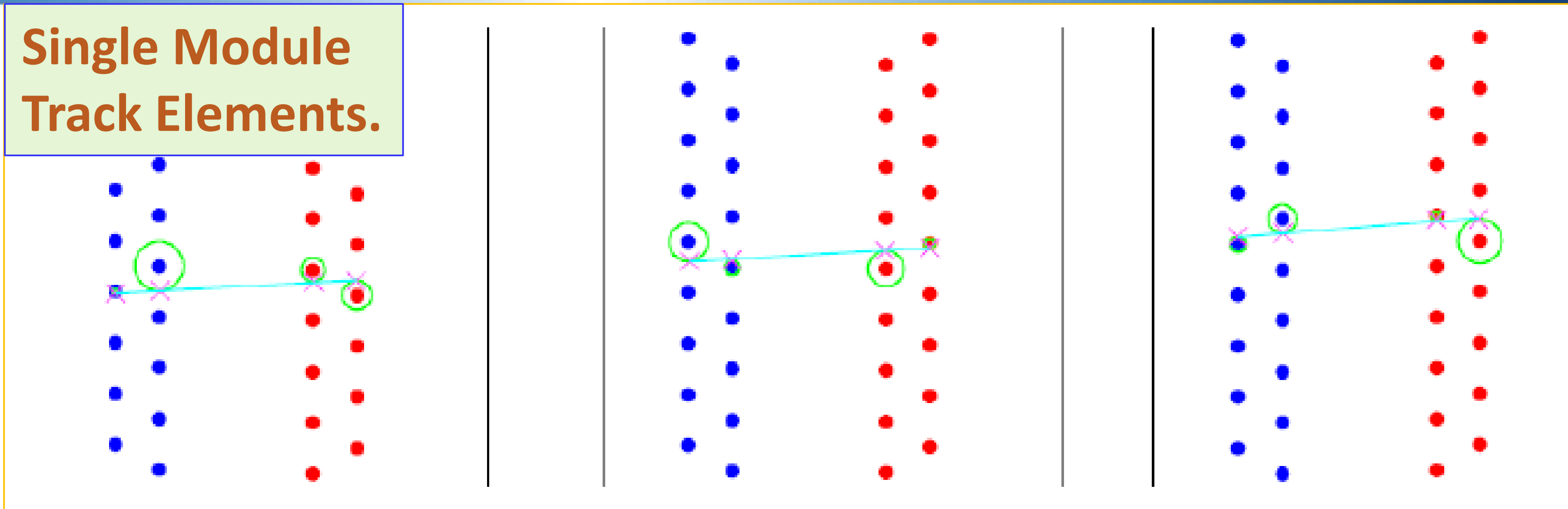


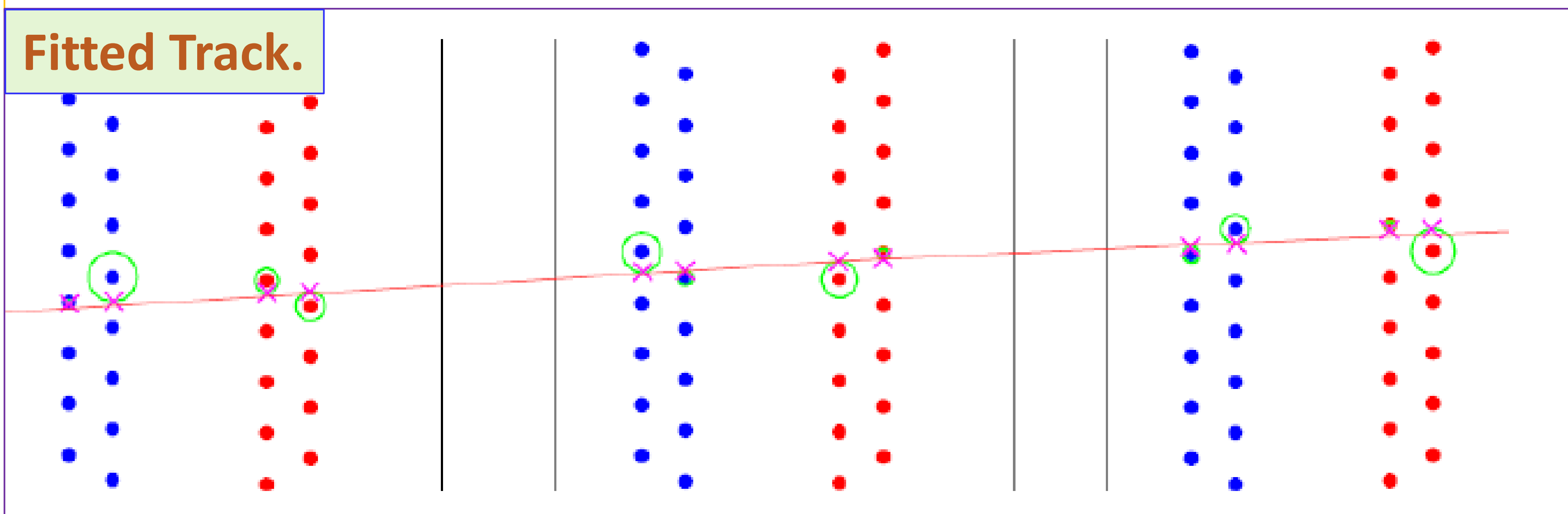
Fitted Track.

Single Module Track Elements.

Truth Track.

Reconstruction of Positron Trajectories

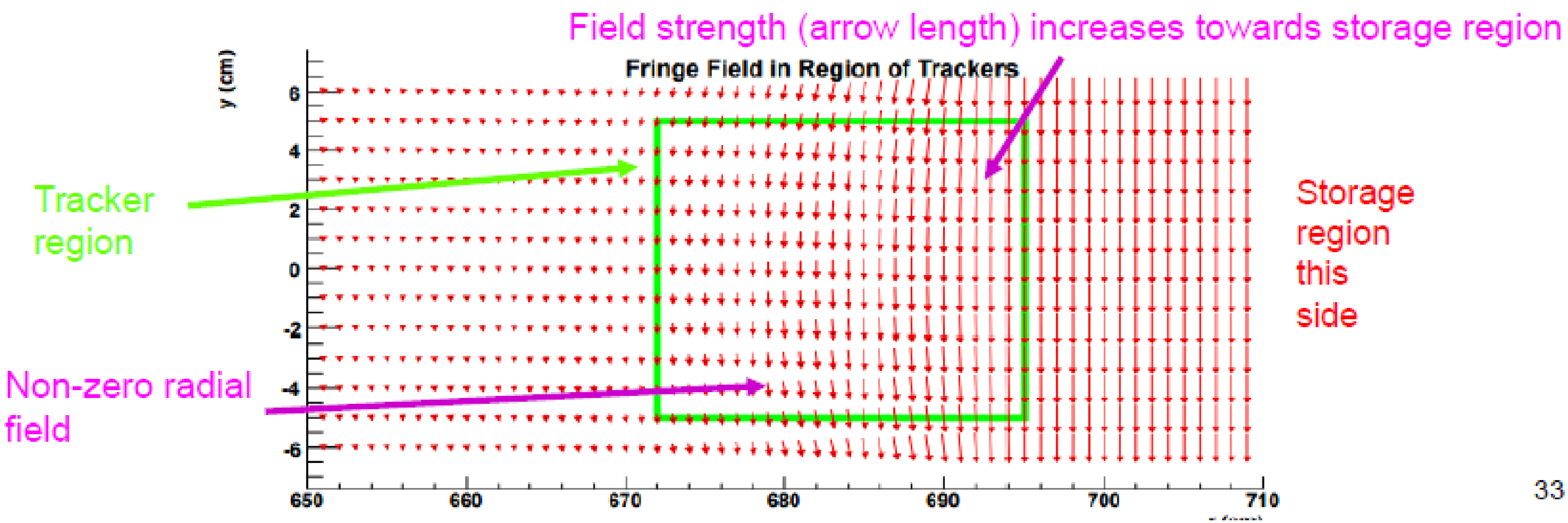




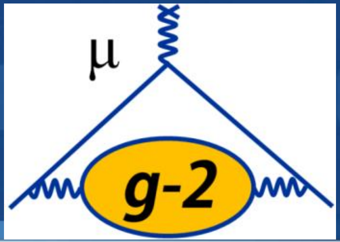
Global Track Fitting.

Major challenge is the varying magnetic field in the tracker region. Doesn’t just vary vertically, but has a varying radial component.

- Now using OPERA fringe field map (DocDB 2736, Brendan K)

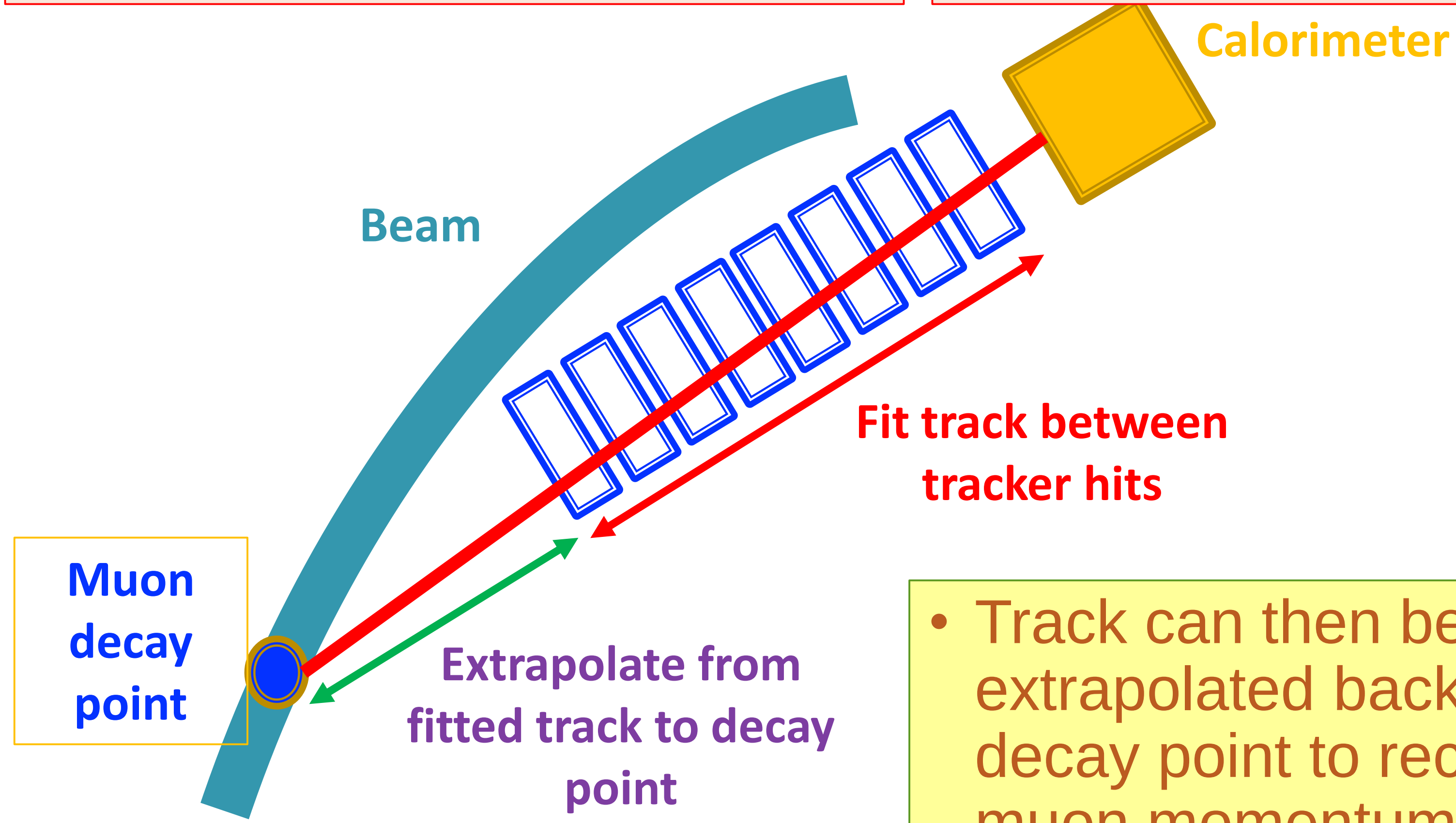


Global Track Fitting



- Track can be fitted between the reconstructed hit points using e.g. Kalman Filter

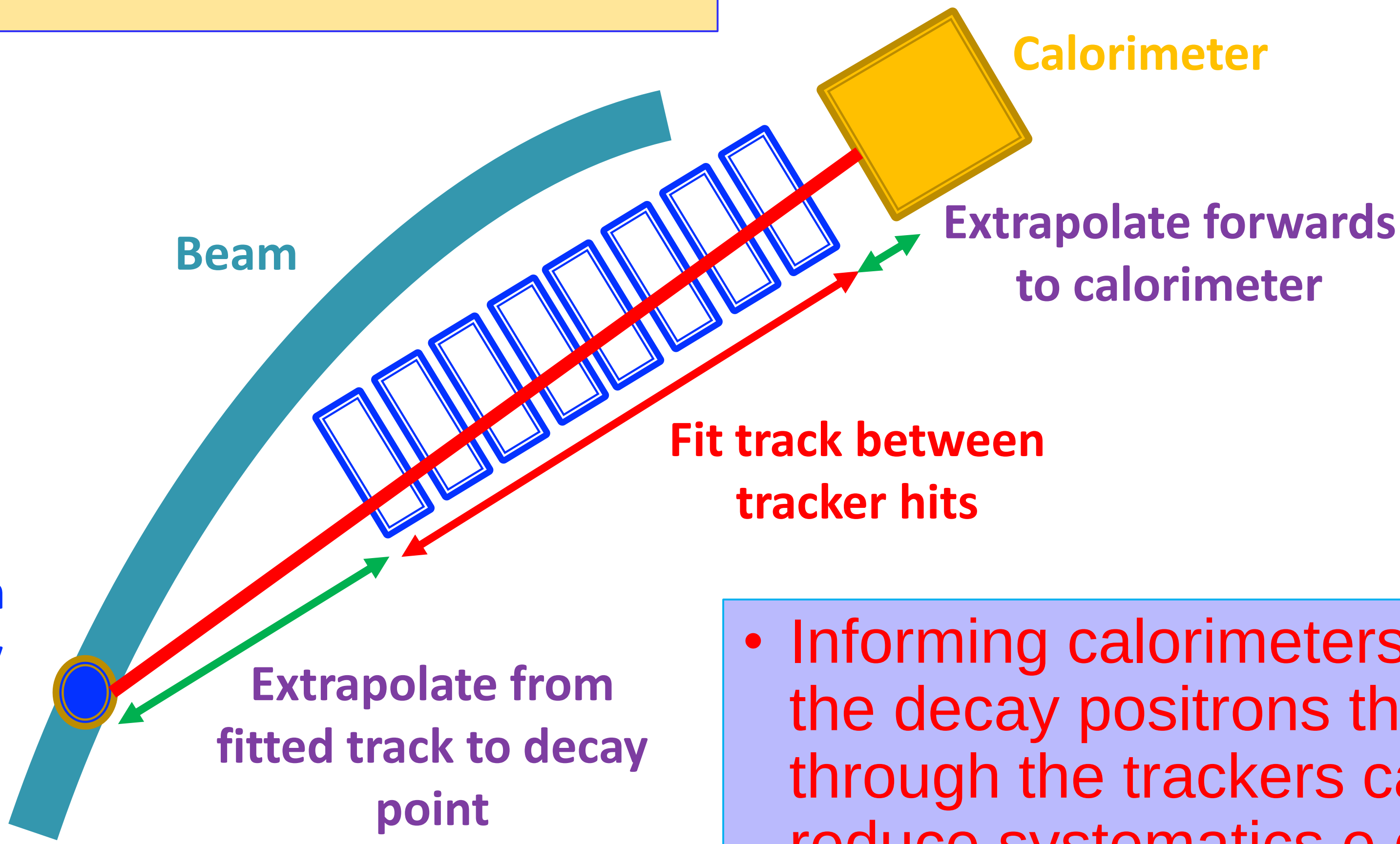
Obtain best estimate of track parameters at first module position (1/p, x, y, dx/dz , dy/dz)



- Track can then be extrapolated back to the muon decay point to reconstruct the muon momentum and position

Global Track Fitting

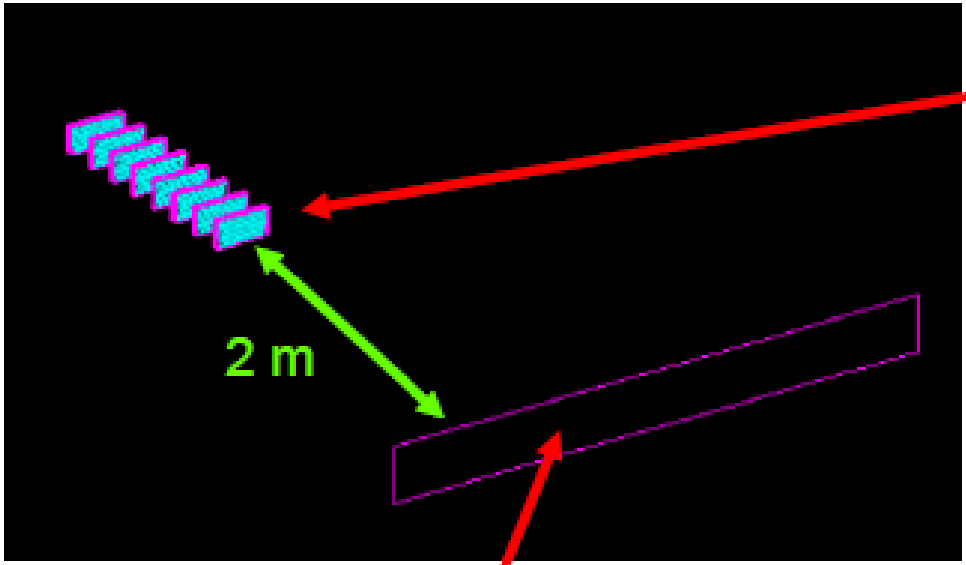
- Tracks can be extrapolated forwards to the calorimeters and matched to Calorimeter clusters



- Informing calorimeters about the decay positrons that pass through the trackers can reduce systematics e.g. pileup

Global Track Fitting (Boston)

- Tracks in straw stereo angle UV coordinate system
- Global fit to all points
- Multiple helices along track (account for varying B field)
- Starting from initial guess, minimize chi2 to fit track

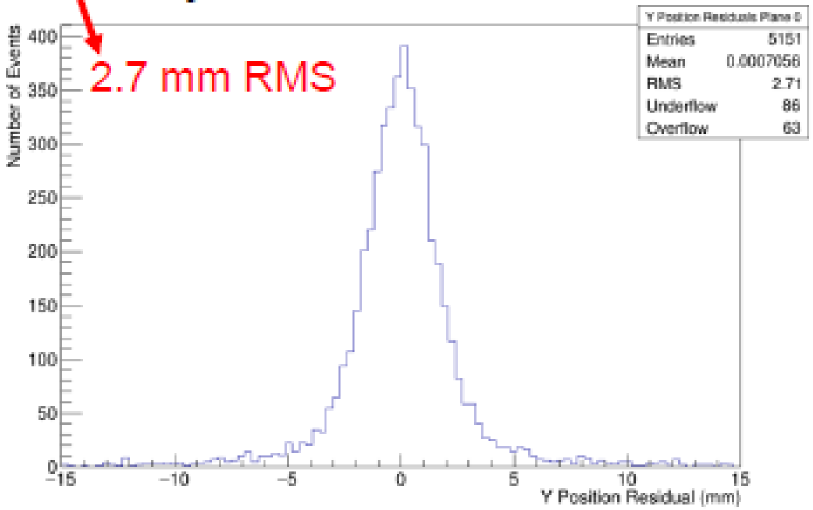


Global Track Fitting (Boston)

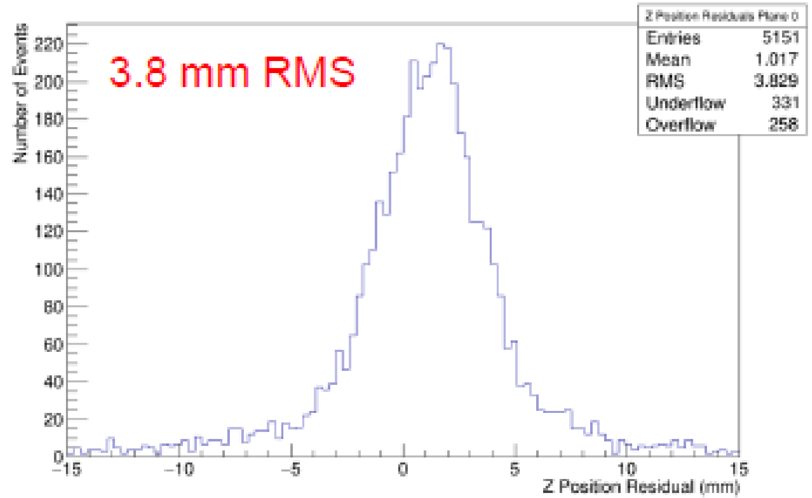
Extrapolate track to decay plane and plot residuals to truth…

Do best vertically

Decay vertex vertical residuals



Decay vertex radial residuals



Straw stereo angle optimised for radial, but fit harder radially due to track curvature

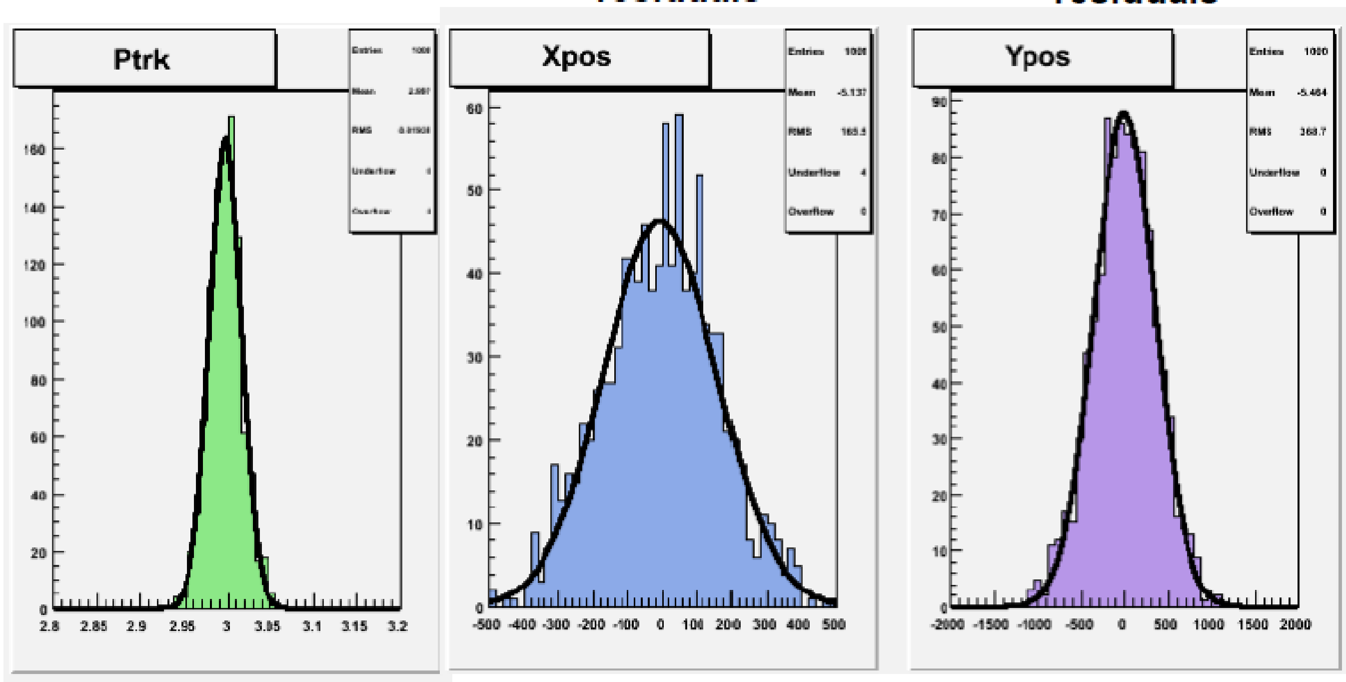
For comparison: BNL tracker achieved **~9 mm** radial resolution

Note that many of these tracks passed through low numbers of straw modules

Kalman Filter Track Fit (Liverpool)

- Comparison of Fitted Track Parameters to Truth.

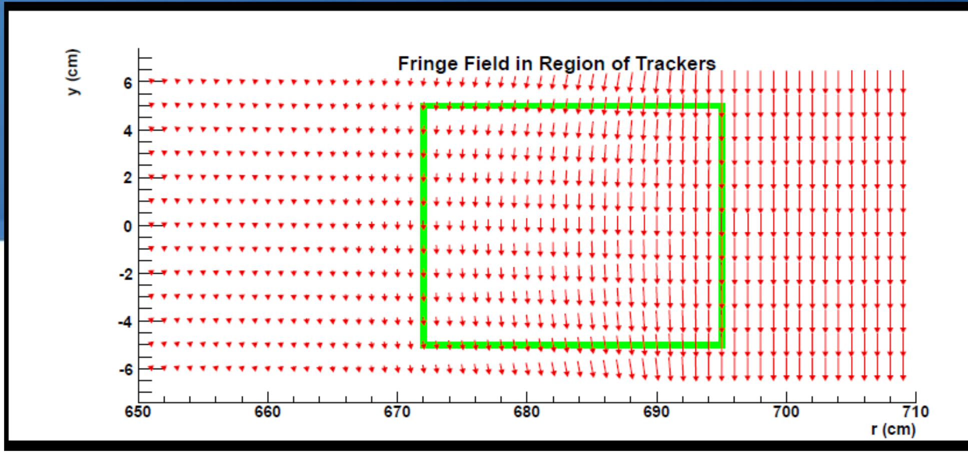
p residuals | **Track point radial residuals** | **Track point vertical residuals**



RMS = 1% | RMS = 160 um | RMS = 350 um

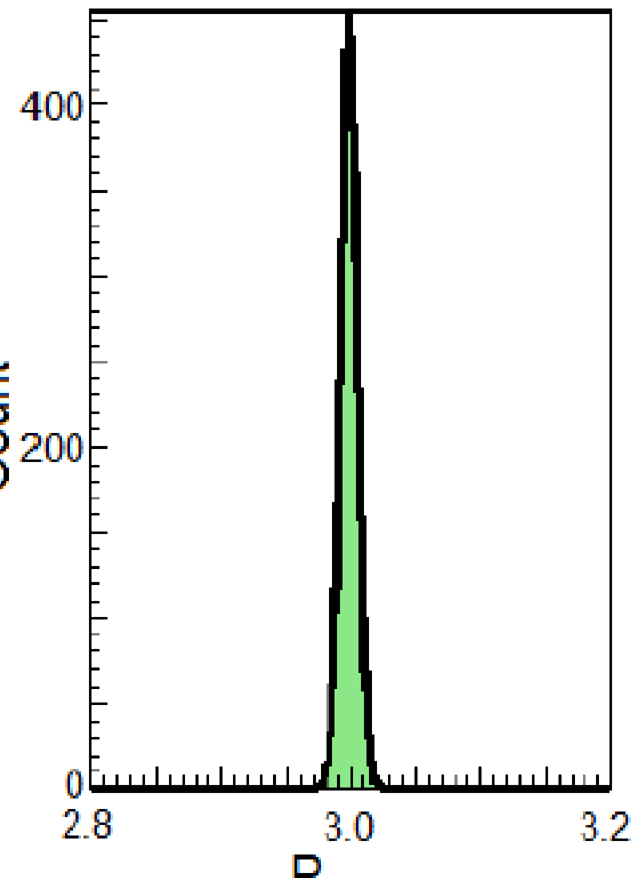
250 um input straw resolution → radial point resolution = 160 um (TDR: < 300 um)

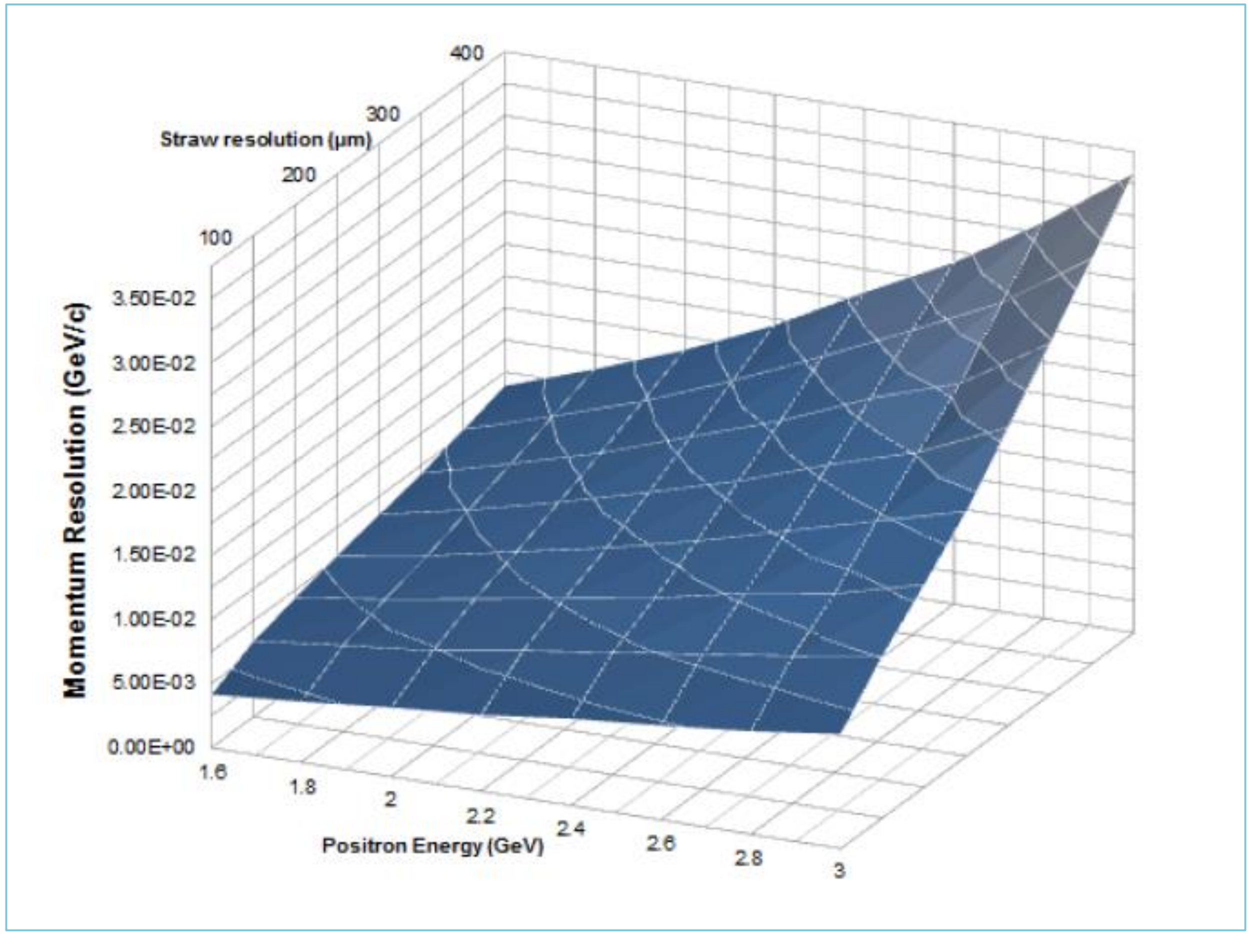
Next step: Track extrapolation



Kalman Filter Fit in Variable Magnetic Field

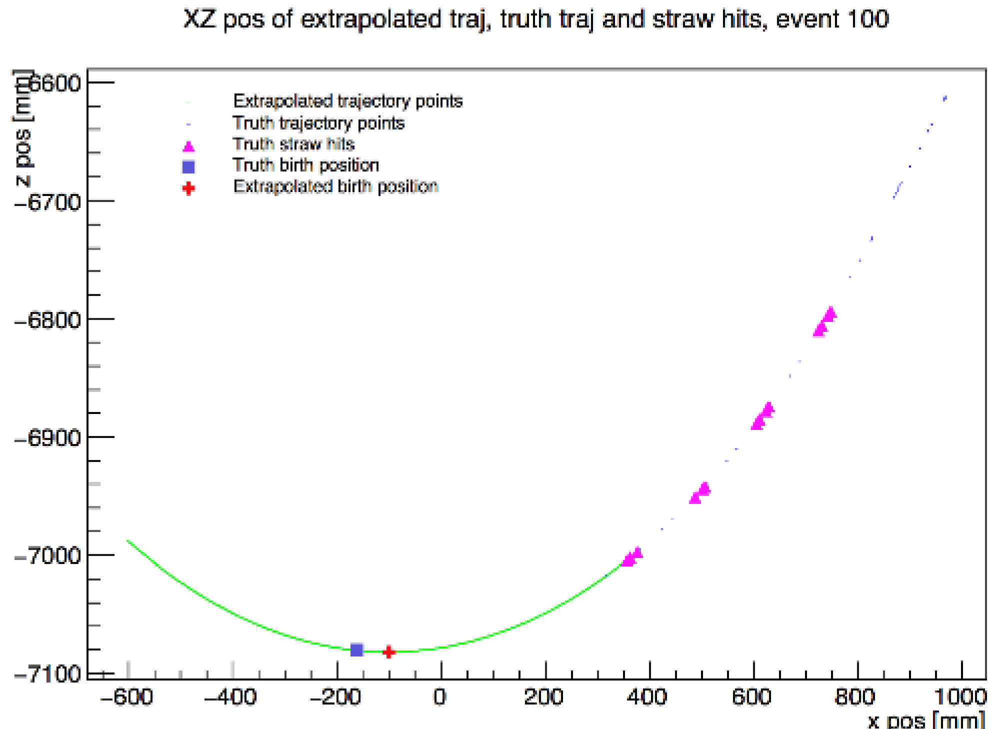
- Have studied KF fit resolution as a function of straw hit resolution.





Track Extrapolation (Liverpool)

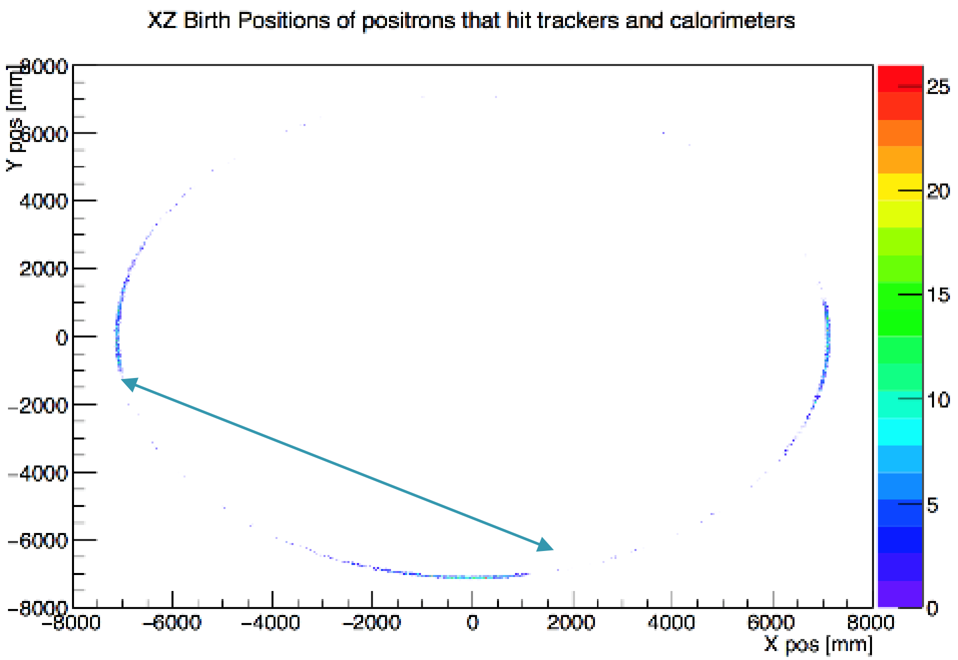
- Using Runge-Kutta track extrapolation algorithm.
- Lookup the magnetic field at each step, and predict the position and momentum of the particle at the next step
- Stop extrapolating when the track momentum is tangential to the magic radius

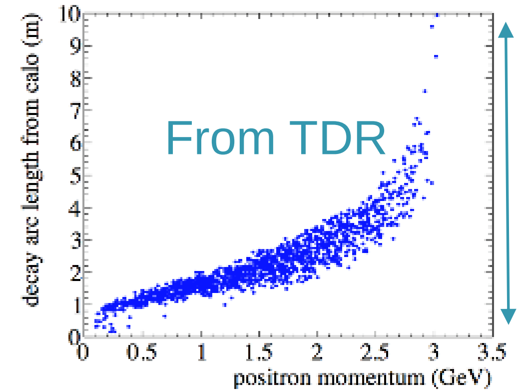


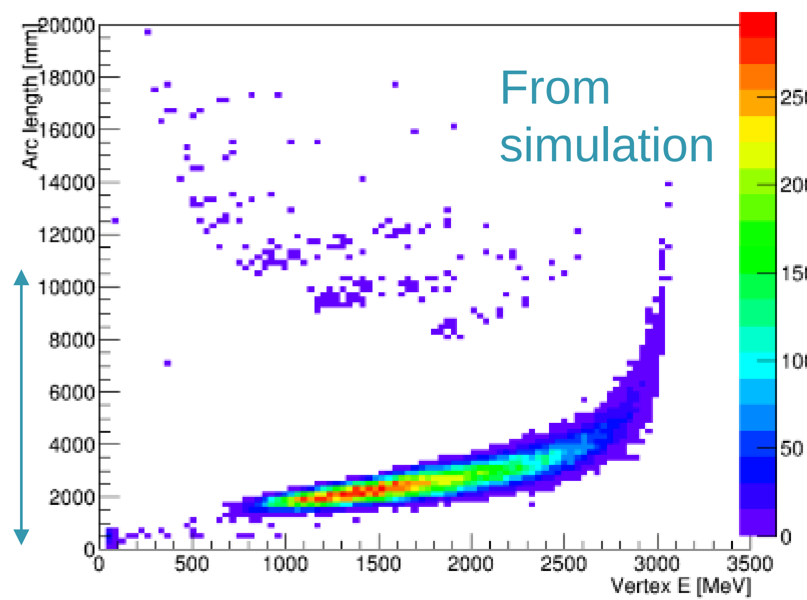
- **Green points show all extrapolation steps**
- **Red marker is first point at which angle between track momentum and magic radius is <0.001rad**
- **Can see from green points that this method successfully reaches the truth decay point (purple marker)**

Physics studies from simulation

Acceptance region of trackers from simulation matches TDR specification







Travelling ¼ ring is an arc length of ~10m

Conclusions.

24 Tracking Modules + 4 spares being built at Liverpool.

- Three prototypes completed, now in full production.
- Simulation software essentially ready.
- Reconstruction of single module Track Elements ready.
- Several Global Track Fits now under development.

  - Kalman Filters, swimming algorithms.

  These exist but not yet in final form.

Major tasks still to be tackled are the detector alignment procedure and track/calo matching.

Good progress being made but busy times ahead.

And finally….


JE SUIS EUROPÉEN


BORRIS jOHNSON
AND DONALD TRUMP?
MA'AM
MAKE IT LOOK
LIKE AN
ACCIDENT 007