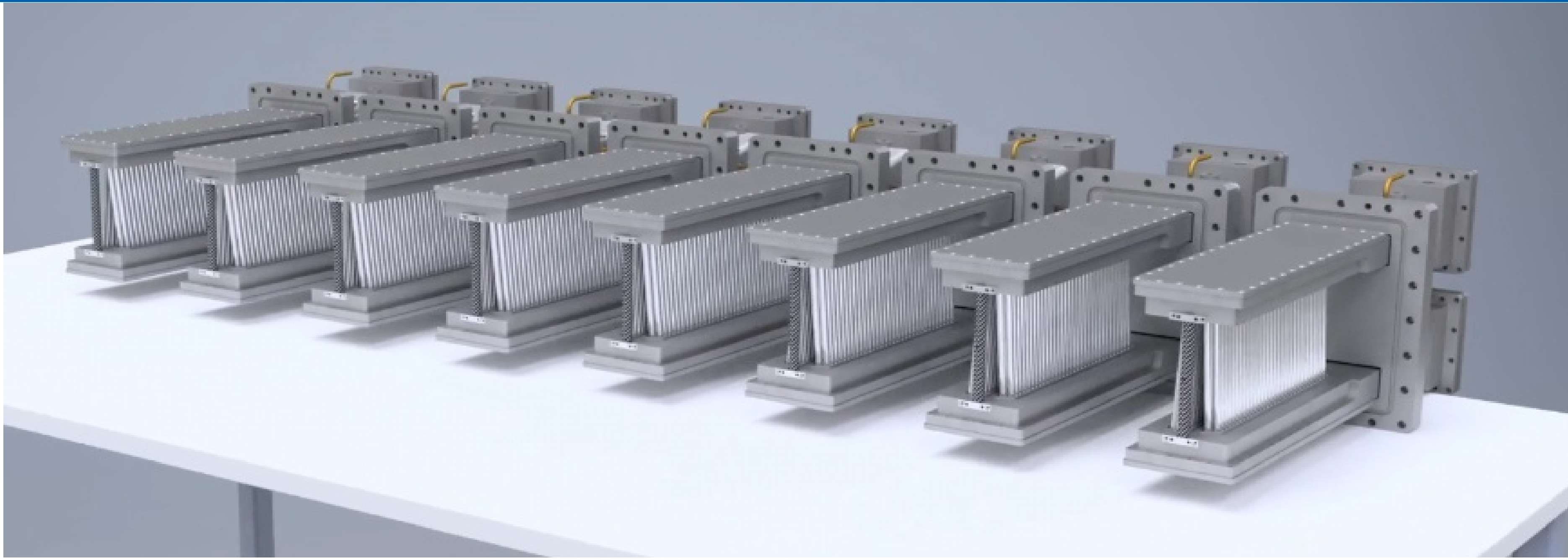


Tracking in the Muon g-2 Experiment

Tammy Walton

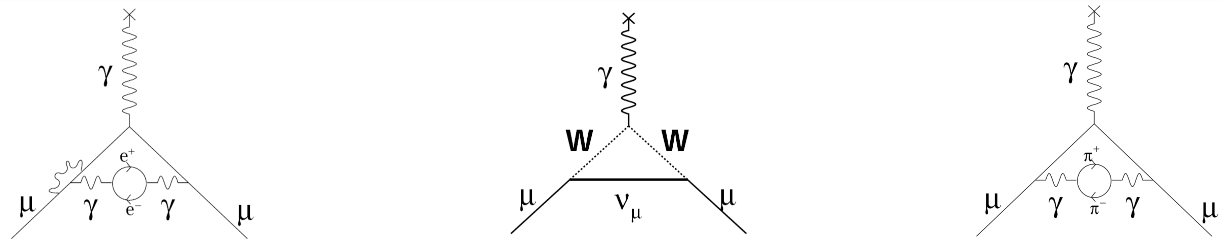
CHEP 2016 Conference

Oct. 10-14, 2016

Motivation

$$\vec{\mu} = g \frac{e}{2m_\mu c} \vec{S}$$

Tool for probing physics



QED　　Electroweak　　Hadronic

$a_\mu = g\text{-}2/2$

a_μ(theory) = 116 591 802 (49) x 10^{-11} (0.42 ppm)

a_μ(exp) = 116 592 089 (63) x 10^{-11} (0.54 ppm)

The Muon g-2 at Brookhaven measured an ~3.6σ deviation with the Standard Model.

Hints of physics beyond the Standard Model ?!

The FNAL Muon g-2 → experimental uncertainty 140 ppb → >5 σ

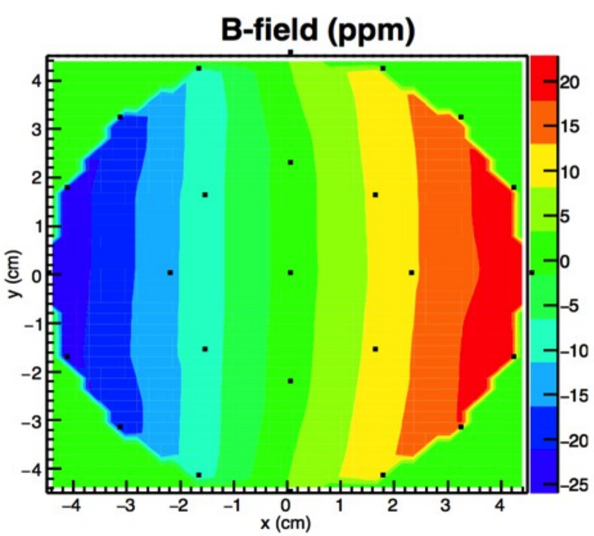
Experimental Overview

Measuring the muon anomalous magnetic moment:

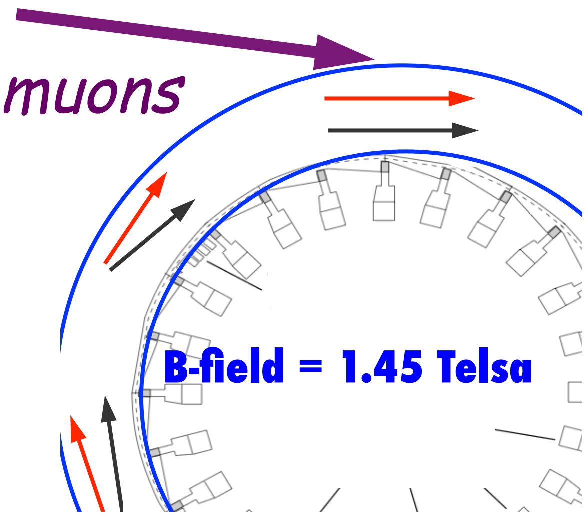
$$a_\mu = g\text{-}2/2$$

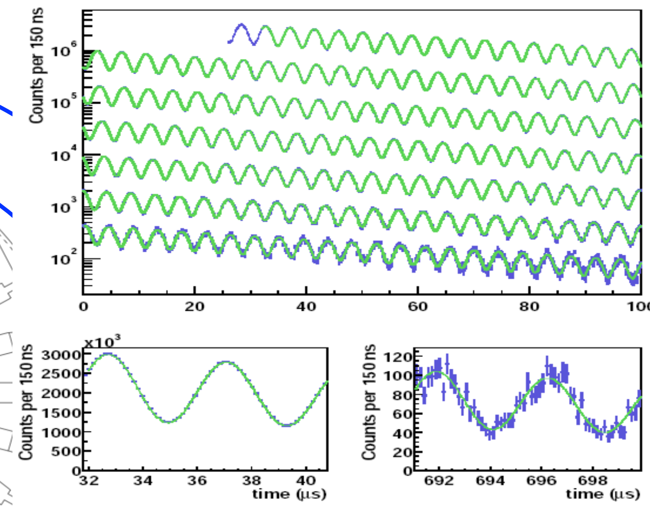
Inject a polarized μ^+ beam in a storage ring with an uniform B-field

Oct. 2015: ±25ppm



muons





Time spectrum of high energy decay positrons is used to measure

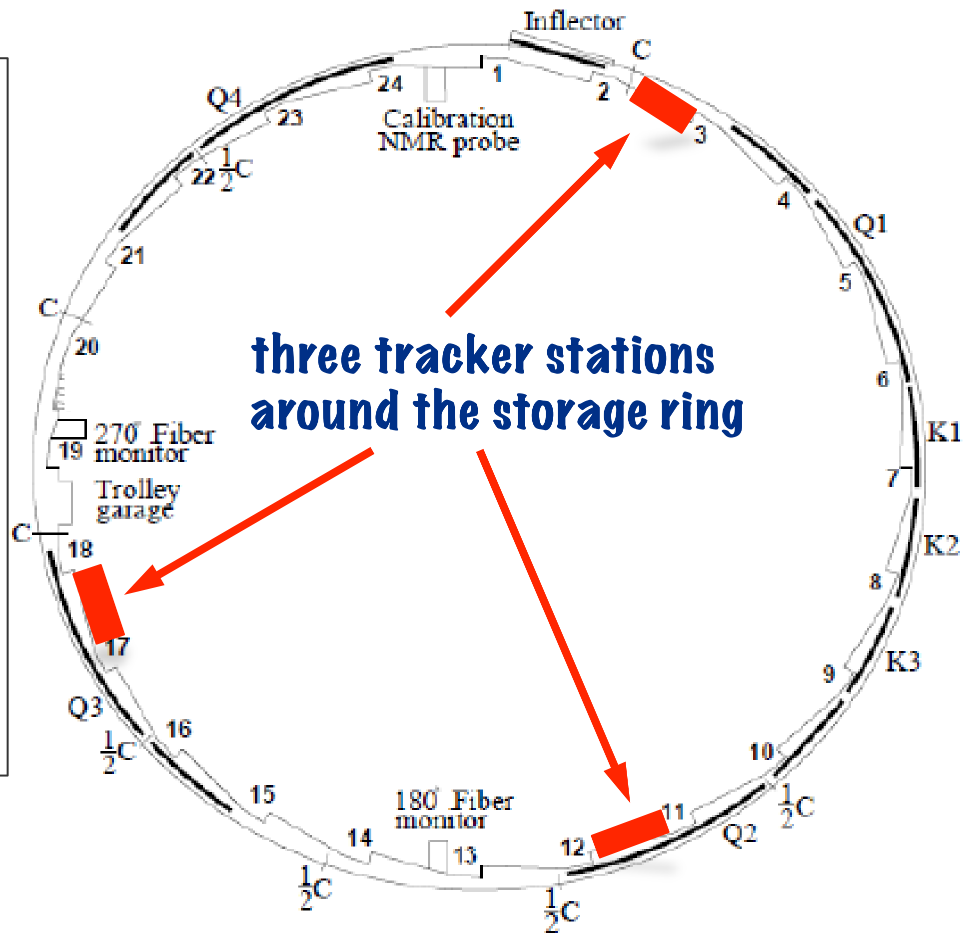
$$\omega_a = a_\mu \frac{eB}{mc}$$

Need to understand the muon beam!

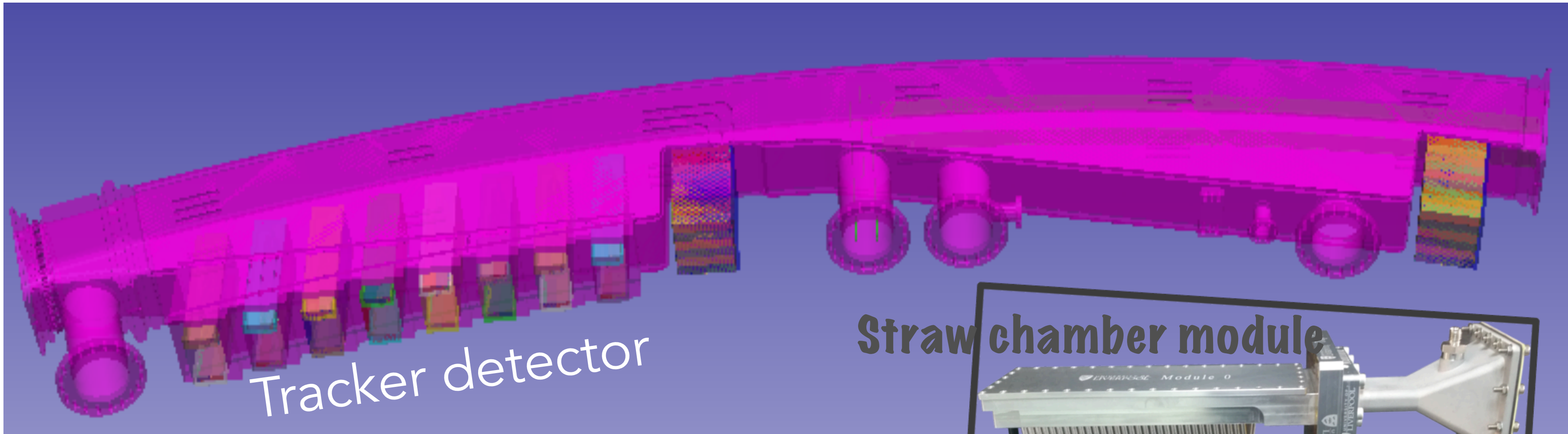
Measuring the Profile of the Muon Beam using Tracker Detectors

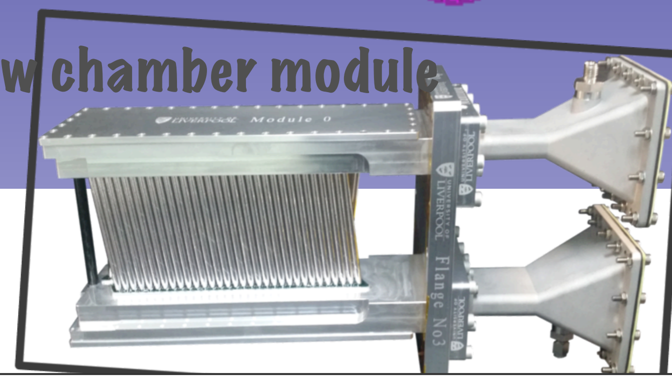
Three tracker detectors are placed around the ring to extract the muon beam distribution. The locations are determined by the beam's view of sight.

The purpose is to reconstruct the trajectories of the decay positrons entering the detector and extrapolate back to the muon decay point.



Measuring the Profile of the Muon Beam using Tracker Detectors





Trackers live in a vacuum chamber (< 10^{-6} Torr) and are placed upstream an electromagnetic calorimeter. Trackers reside in both the uniform and fringe regions of the magnetic field.

Trackers contain 8 modules, where each consists of straw tube chambers (fill with Argon-Ethane gas).

Module consists of :

2 planes: U and V (with straws rotated ± 7.5°)

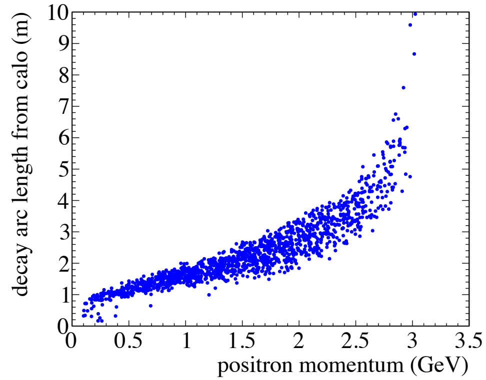
A plane consists of 2 layers of 32 straws.

The layers are offset, so the reconstruction can determine if the particle enters the left or right side of the straw.

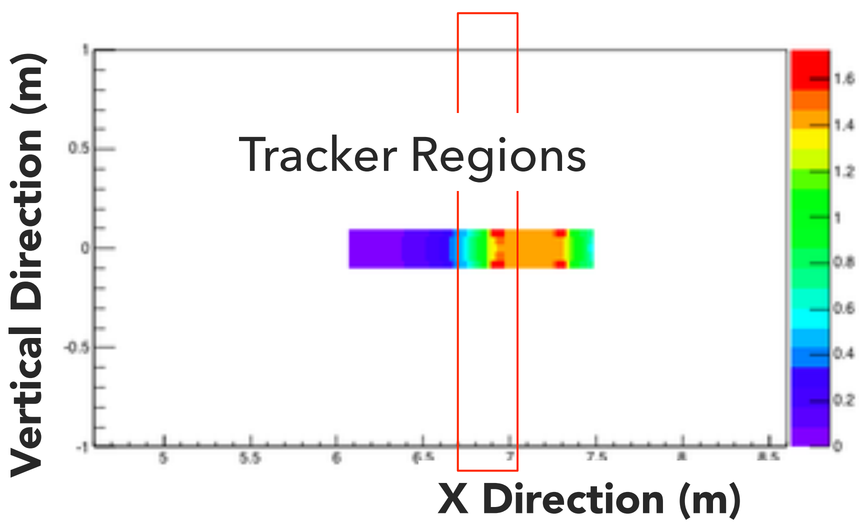
A straw tube:
~8 cm long (fiducial region) with a radius of 2.5 mm. ~1.0 mm gap between straw tubes.

Major Challenges

- The muon decay point ranges from 2-3 meters from the front face of trackers.



- Majority of the tracks enter the fringe region of the magnetic field.



Plot courtesy of R. Fatemi

Tracking Software and Infrastructure

Consist of developers from international and domestic institutions, along with a national laboratory.

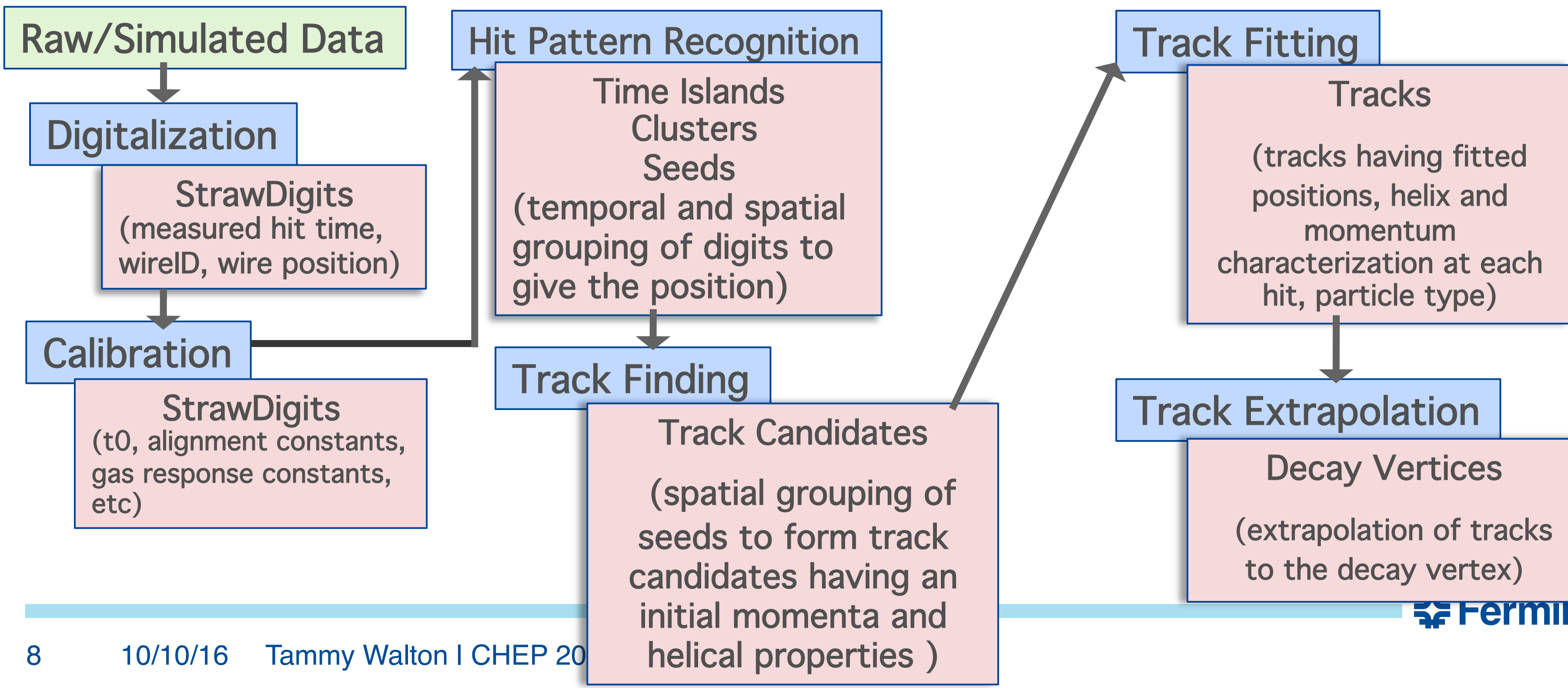
Use the event-processing framework ***art***

Fermilab supported, based on CMS, used by many experiments ranging from neutrinos, muons, and dark matter. J.Phys.Conf.Ser. 396 (2012) 022020

Track Software and Infrastructure

The design of the Tracking Infrastructure is modular :

- operation of multiple algorithms at each track stage
- managable iterations between track stages
- control event model
- developer/user friendly (needed because software frameworks are unfamiliar with a fractional of the collaboration)



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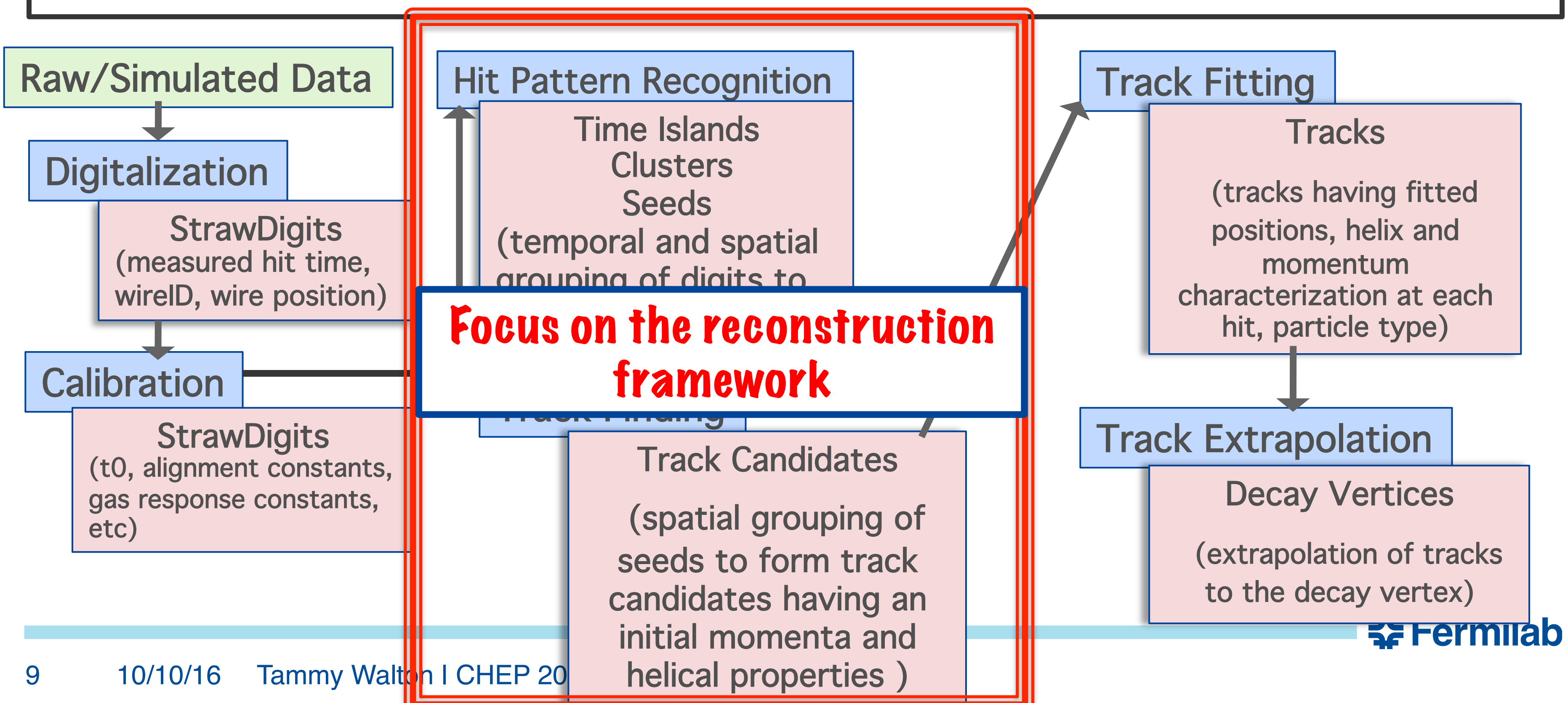
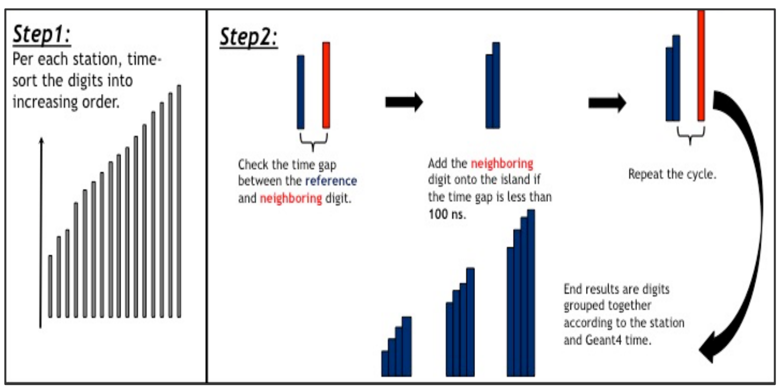
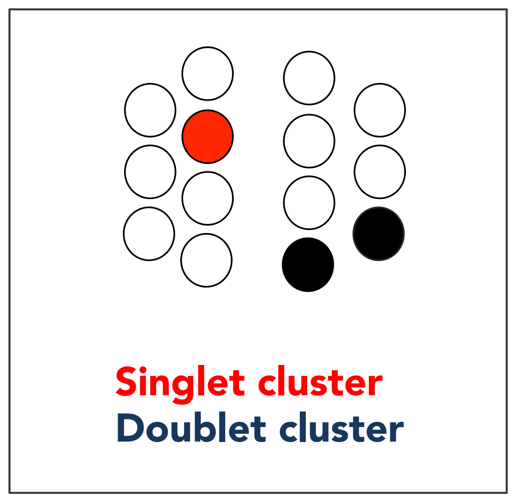


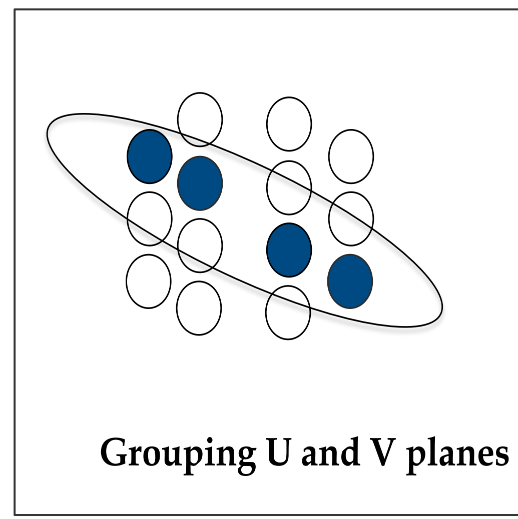
Reconstructing Tracks : Hit Pattern Recognition

Hit Pattern Recognition

Time Islands
Clusters
Seeds
(temporal and spatial grouping of digits to give the position)







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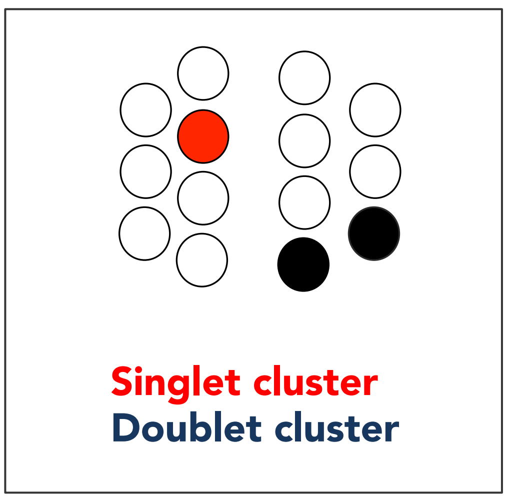
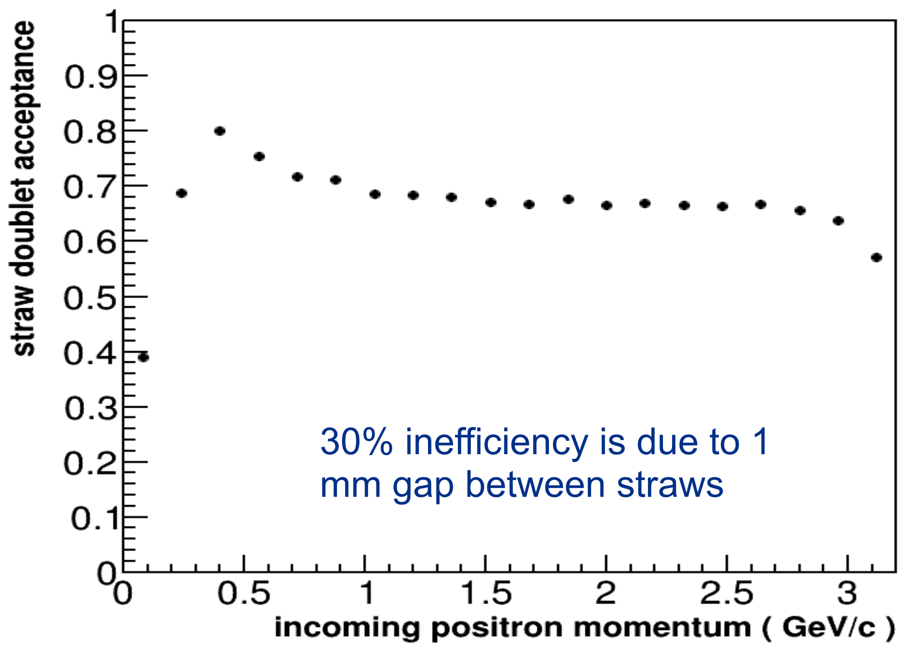




Reconstructing Tracks : Tracking Stages

Track Finding

Track Candidates

(spatial grouping of seeds to form track candidates having an initial momenta and helical properties)

Track Fitting

Tracks

(tracks having fitted positions, helix and momentum characterization at each hit, particle type)

Track Extrapolation

Decay Vertices

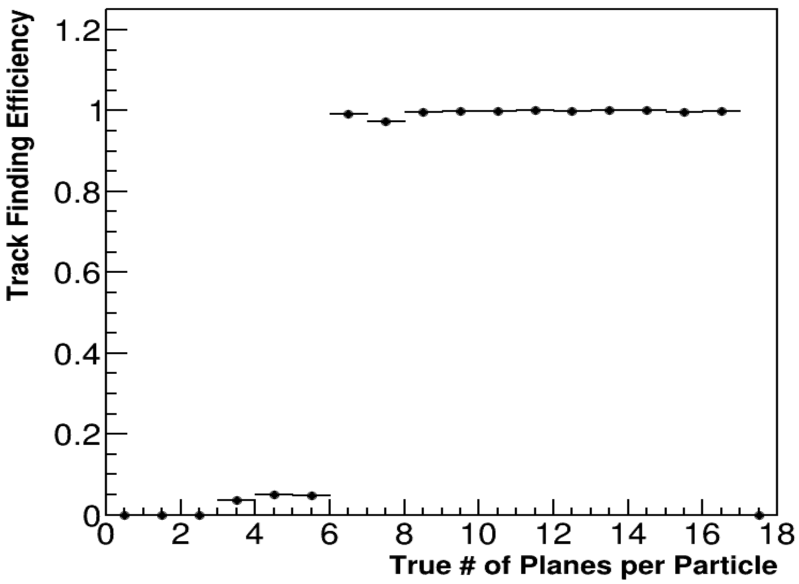
(extrapolation of tracks to the decay point)

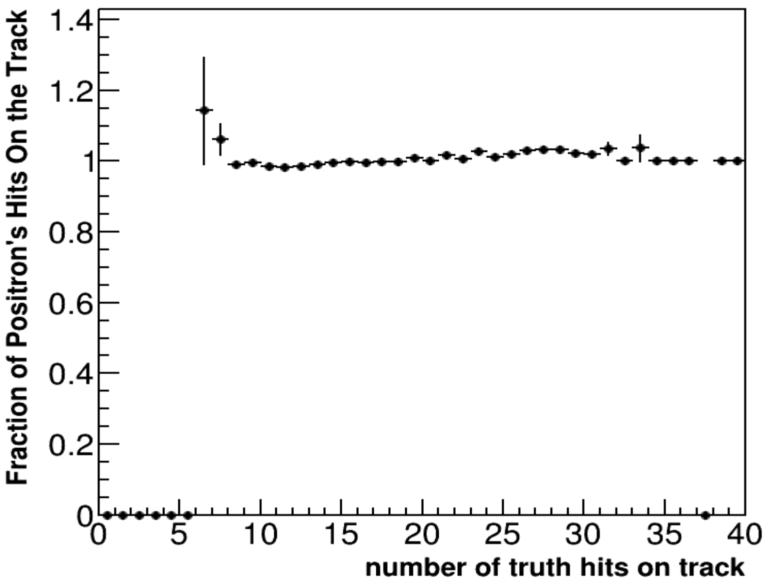
Reconstructing Tracks

Track Finding

Track Candidates

(spatial grouping of seeds to form track candidates having an initial momenta and helical properties)





Reconstructing Tracks

Track Fitting → Track Extrapolation

Tracks

(tracks having fitted positions, helix and momentum characterization at each hit, particle type)

Decay Vertices

(extrapolation of tracks to the decay vertex)

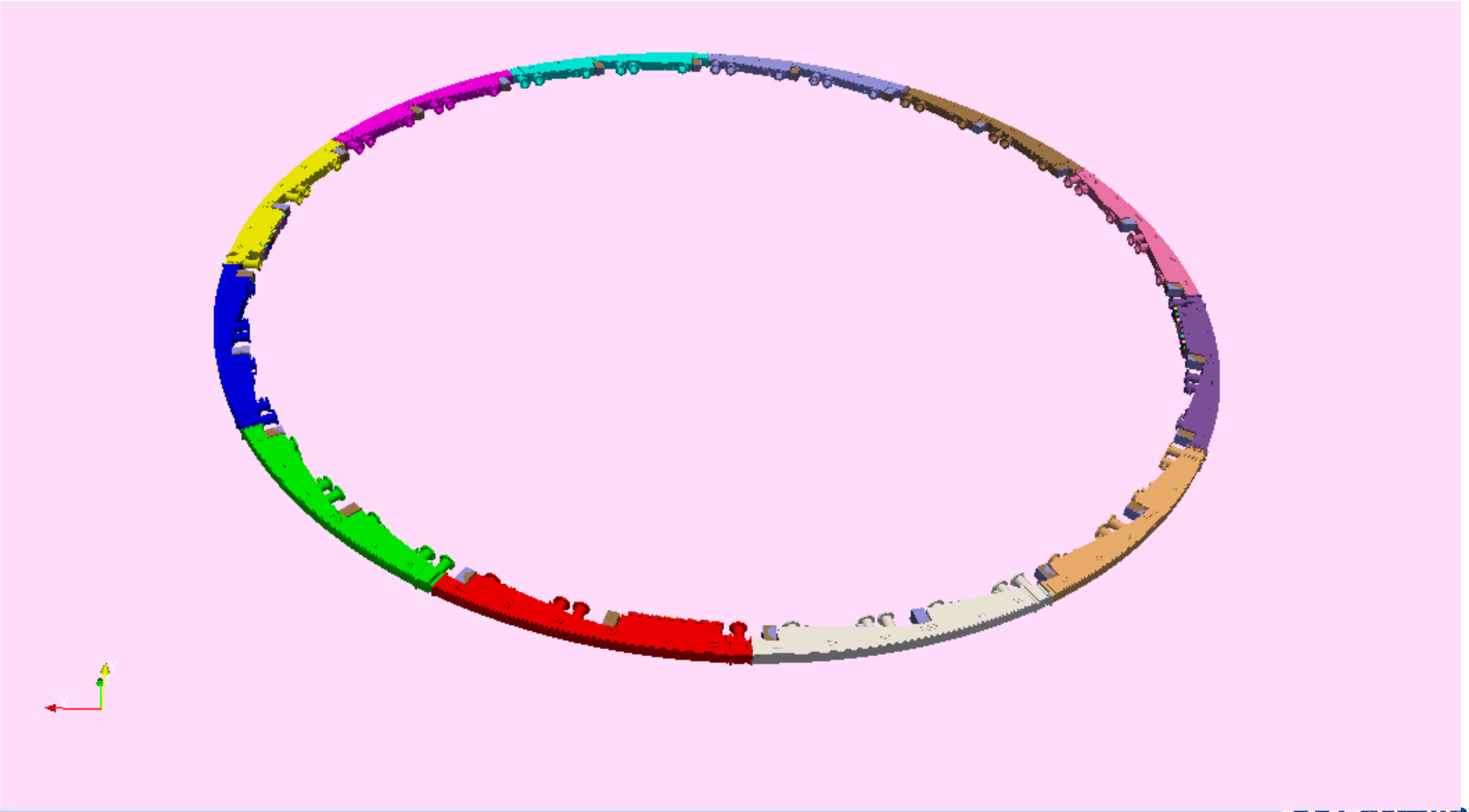
Fitting Algorithms in Progress

- Kalman Filter in uniform B-field
- Kalman Filter in varying B-field
- GEANE
- Karimaki Circle Fitter
- Various Straight Line Fitters

Extrapolation Algorithms in Progress

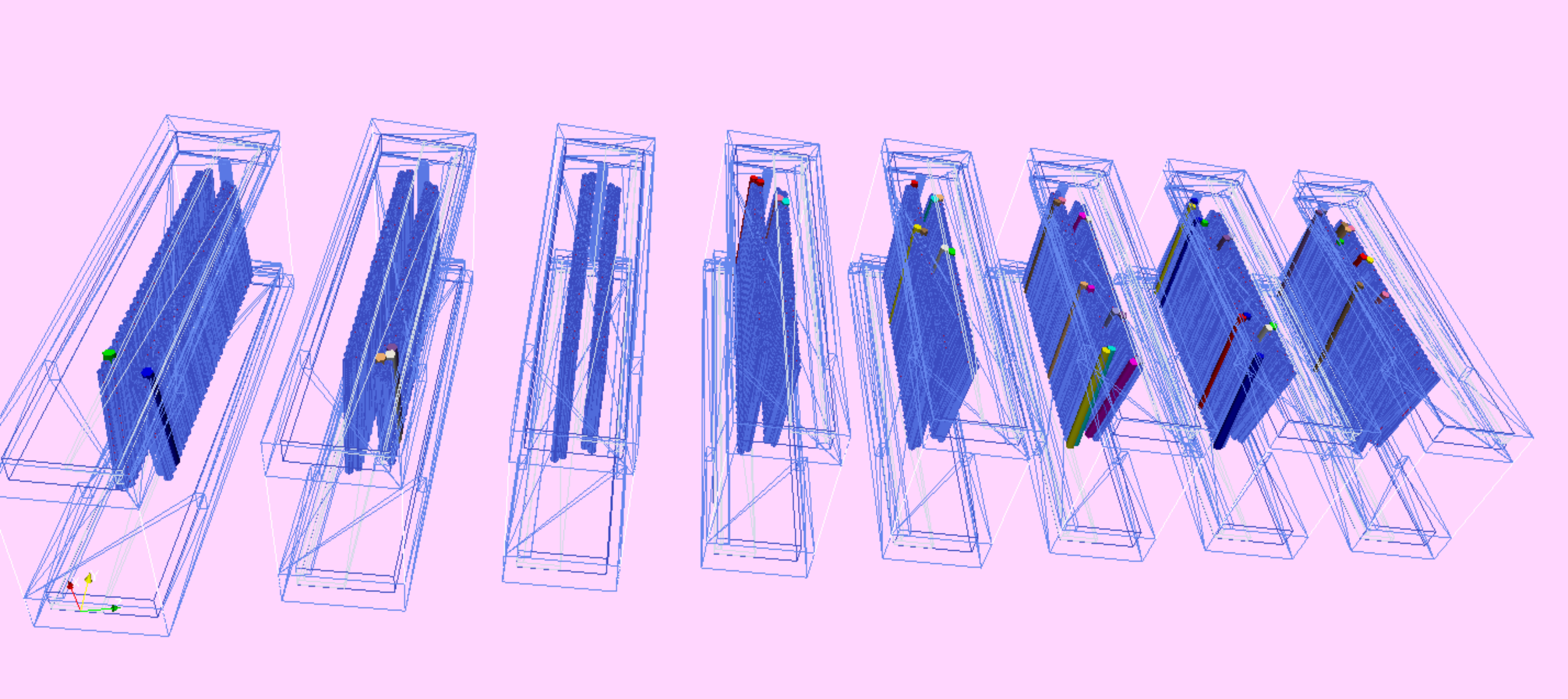
- Runge Kutta
- GEANE

Event Gallery
using Paraview (www.paraview.org)



Reconstructing Tracks : Digitalized Hits

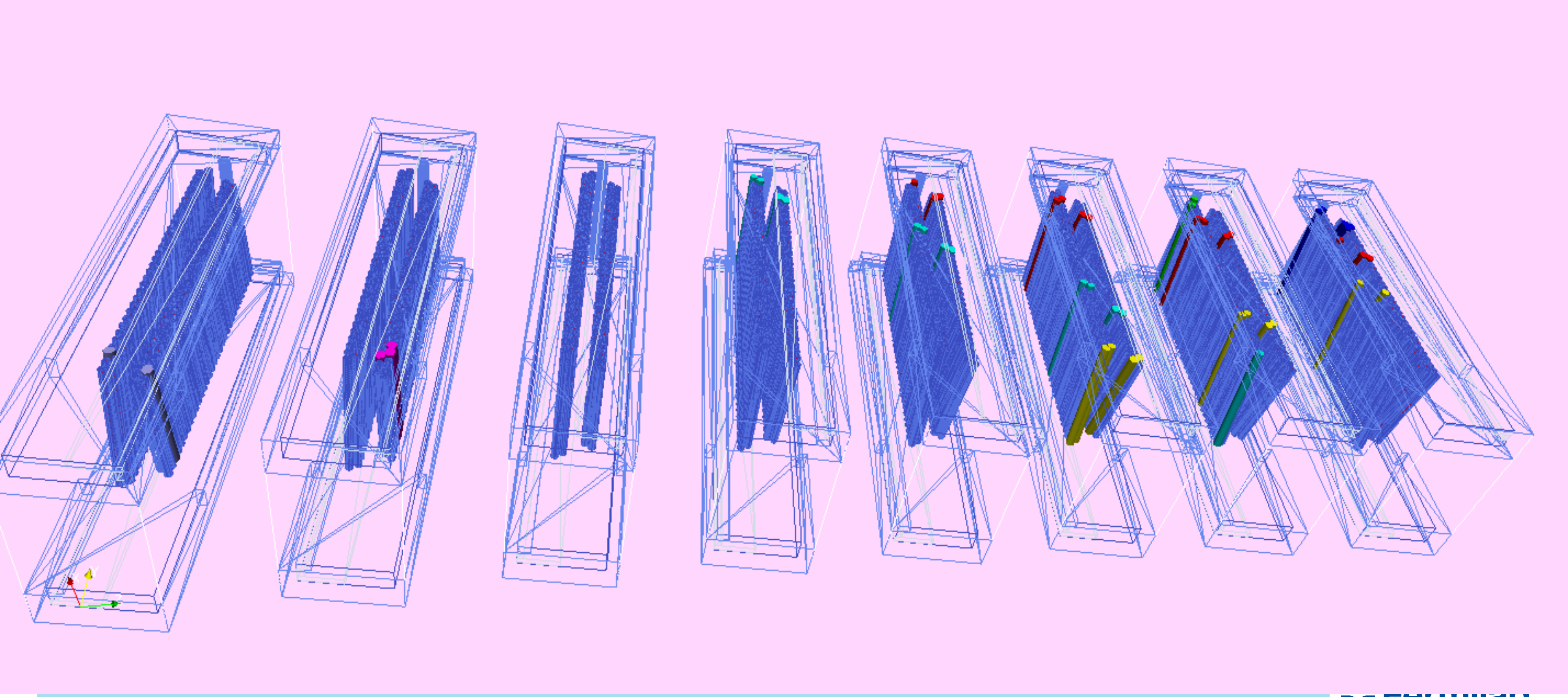
simulated ~10^2 muons per fill
expected ~10^4 muons per fill (12 Hz)



Reconstructing Tracks : Time Islands

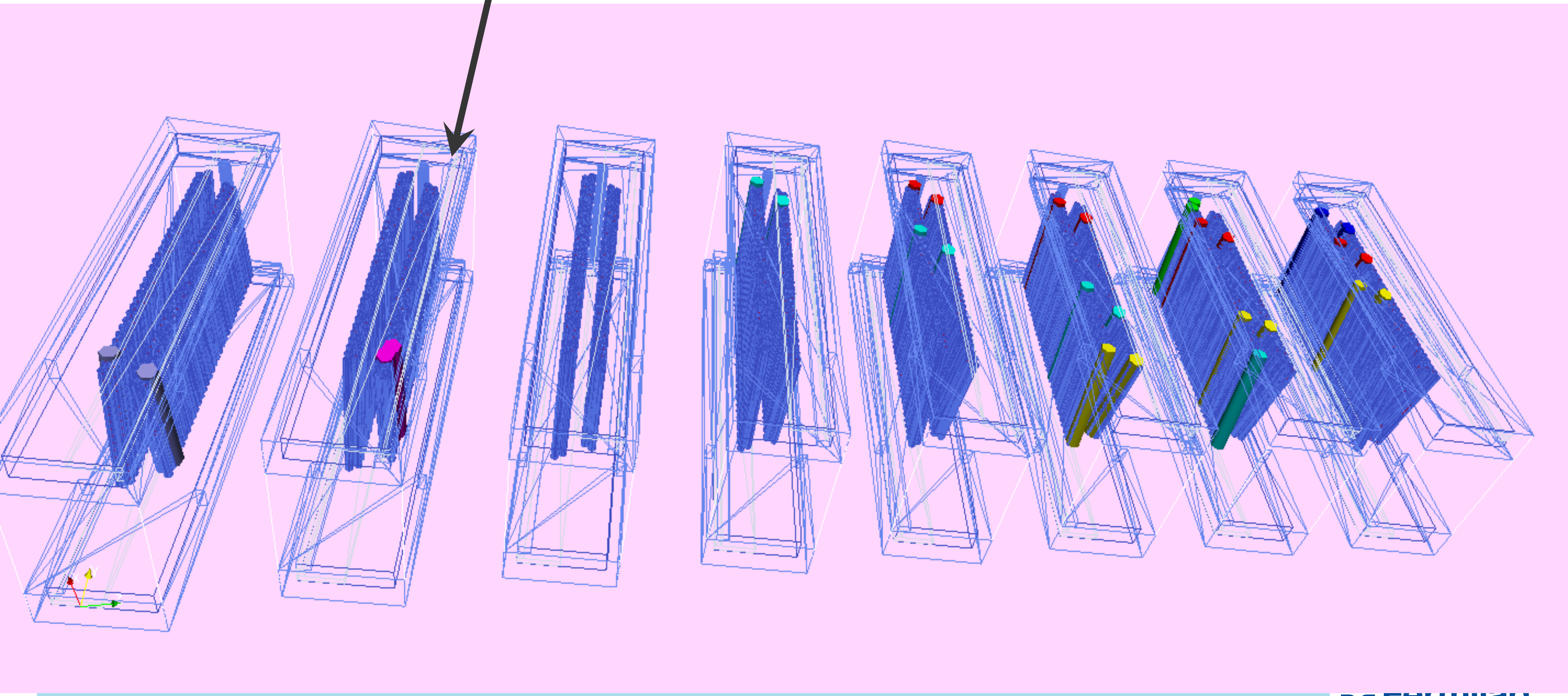
Grouped hits within a time window

- 7 time islands



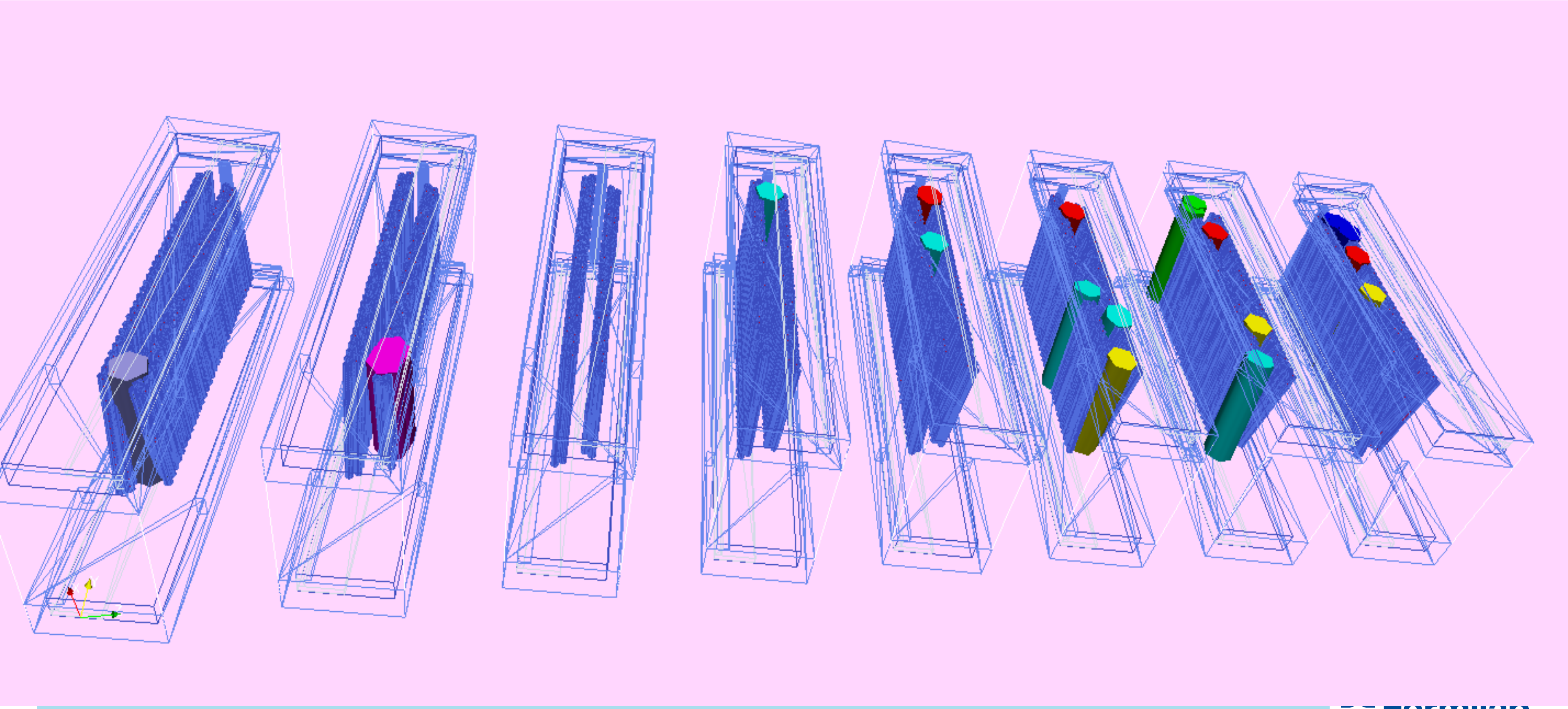
Reconstructing Tracks : Clustering

Clusters share a digitalized hit.

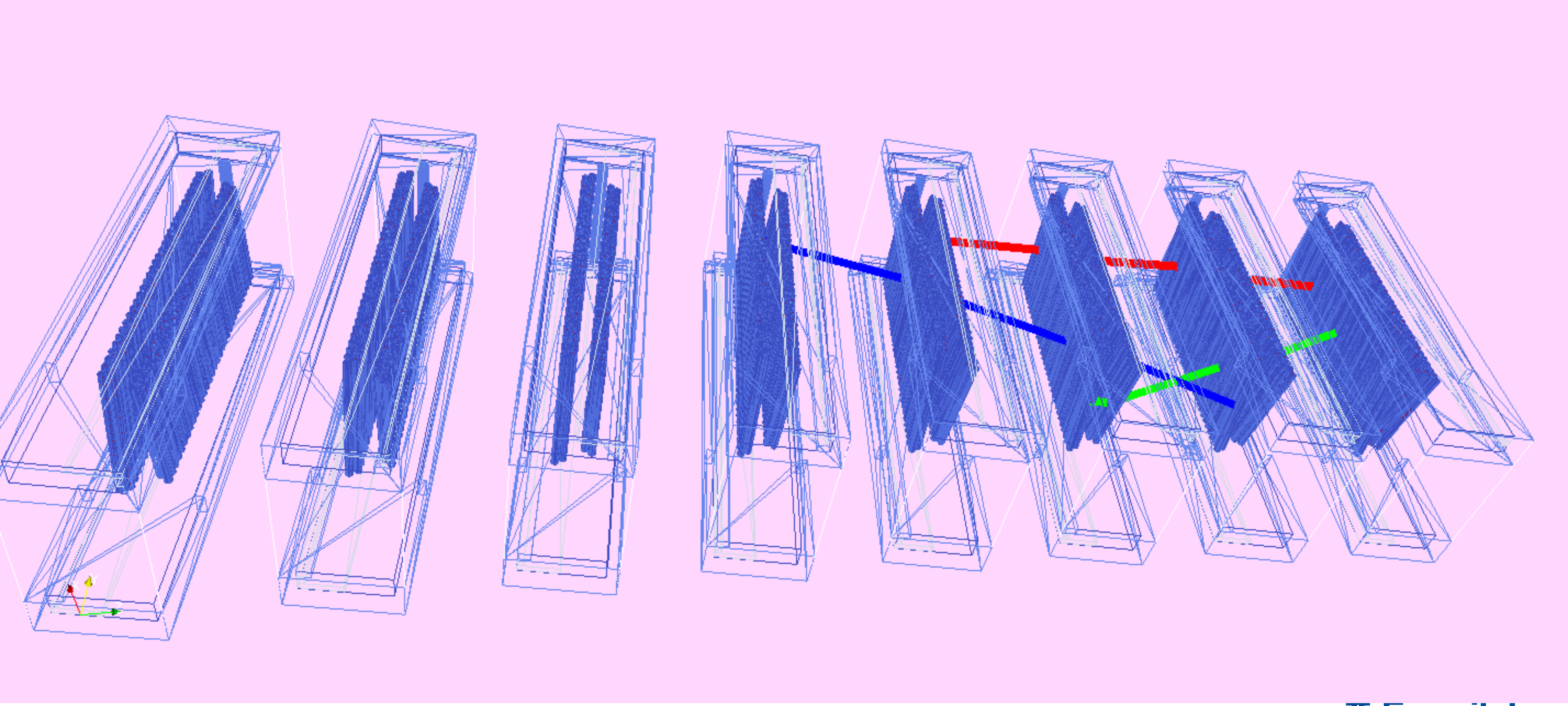


Fermilab

Reconstructing Tracks : Seeding



Reconstructing Tracks : Track Finding



Summary

- It is a very exciting time for the Muon g-2 experiment.
- Start data taking in the Summer of 2017.
- Tracking algorithms are under development and making great progress. However, there are many unique challenges for the reconstruction.
- Tracking will constrain and reduce the muon-beam related systematic uncertainties associated with the measured observables, ω_a and ω_p (magnetic field).

Thank you


CERNCOURIER

Volume 54 Number 9 November 2014

Muon g-2 moves on to a new life

OVERSIZE LOAD

EMMERT

CERN60
Celebrations of 60 years of science for peace p28

CP VIOLATION
Meeting honours 50 years of a major discovery p32

NEW RESULTS FROM AMS
Evidence for a new source of positrons p6

Backup Slides

Expected Systematic Uncertainties

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

Expected Environment of Tracker Detectors

Parameter	value	comments
Impact parameter resolution	$\ll 1$ cm	Set by RMS of the beam
Vertical angular resolution	$\ll 10$ mrad	Set by angular spread in the beam
Momentum resolution	$\ll 3.5\%$ at 1 GeV	Set by calorimeter resolution
Vacuum load	5×10^{-5} Torr l/s	assumes 10^{-6} Torr vacuum and E821 pumping speed
Instantaneous rate	10 kHz/cm^2	Extrapolated from E821
Ideal coverage	16×20 cm	Front face of calorimeter
Number of stations	≥ 2	Required to constrain beam parameters
Time independent field perturbation	< 10 ppm	Extrapolation from E821
Transient (< 1 ms) field perturbation	< 0.01 ppm	Invisible to NMR