Electron and muon reconstruction for momentum below 1GeV using the BESS magnet

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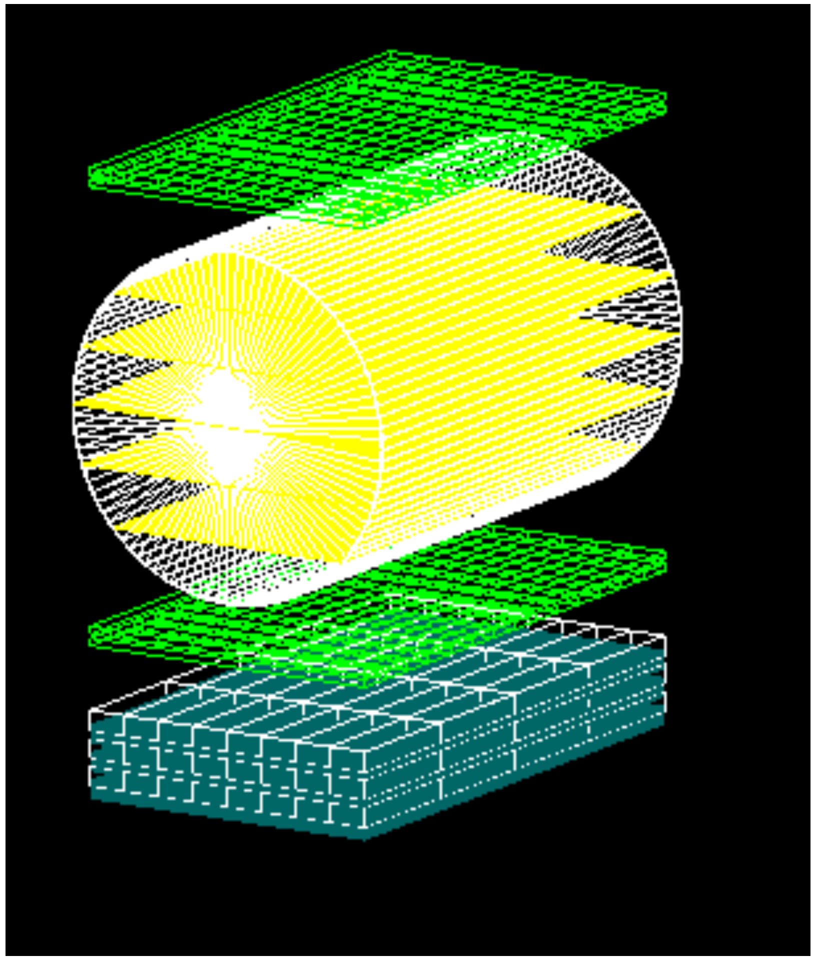
Outline

- Introduction
- Detector
- BESS magnet
- Track reconstruction of electron and muon
- Summary

Introduction

- Goal to distinguish electron and muon at low momentum (< 1 GeV) in the cosmic ray
- Electron and muon are charged fermions that can be detected with tracker, calorimeter and muon detector
- In high energy regime (i.e in collider) with high momentum, they behavior differently in the detector
- At low momentum region (<1 GeV), no study has been done to separate them in reconstruction

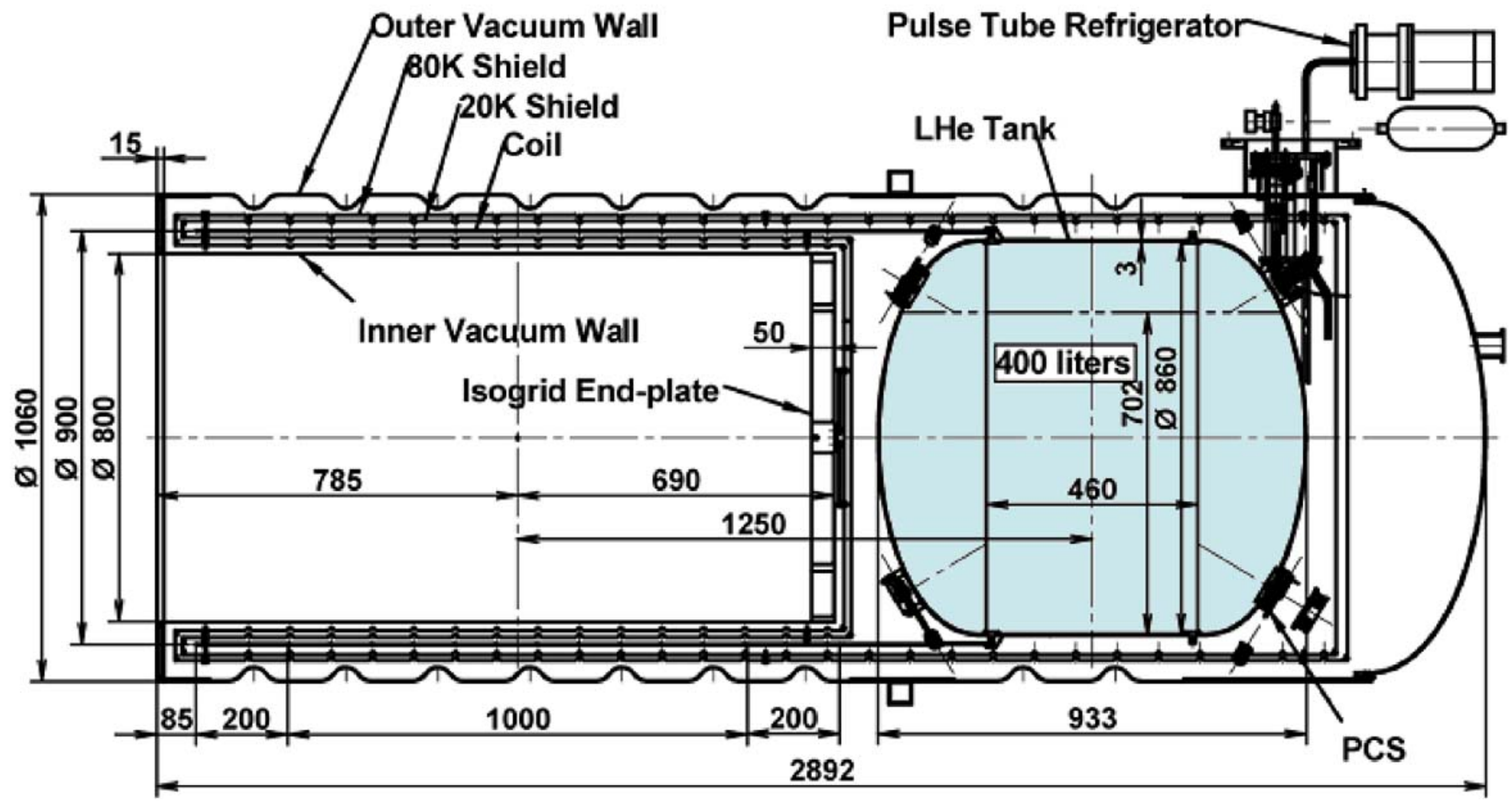
Detector



Geant4 10.1.p02

- Tracker inside the BESS magnet (yellow planes):
  - 5 layers of silicon
  - thickness of 300µm each, length: 1.4m
  - distance between layers is 15cm
- 2 TOFs (time of flight detector, green boxes): for trigger the event
  - one above and the other below the magnet,
  - plastic scintillator (PolyVinylToluene)
  - Thickness: 20cm, length: 1.4m
- The electromagnetic calorimeter (bottom block): to distinguish electron and muon
  - 2 Absorbers and 2 scintillators in sandwich
  - Absorber: Pb, thickness: 5cm
  - Scintillator: plastic , thickness: 2cm
- White cylindrical is the BESS magnet

BESS magnet

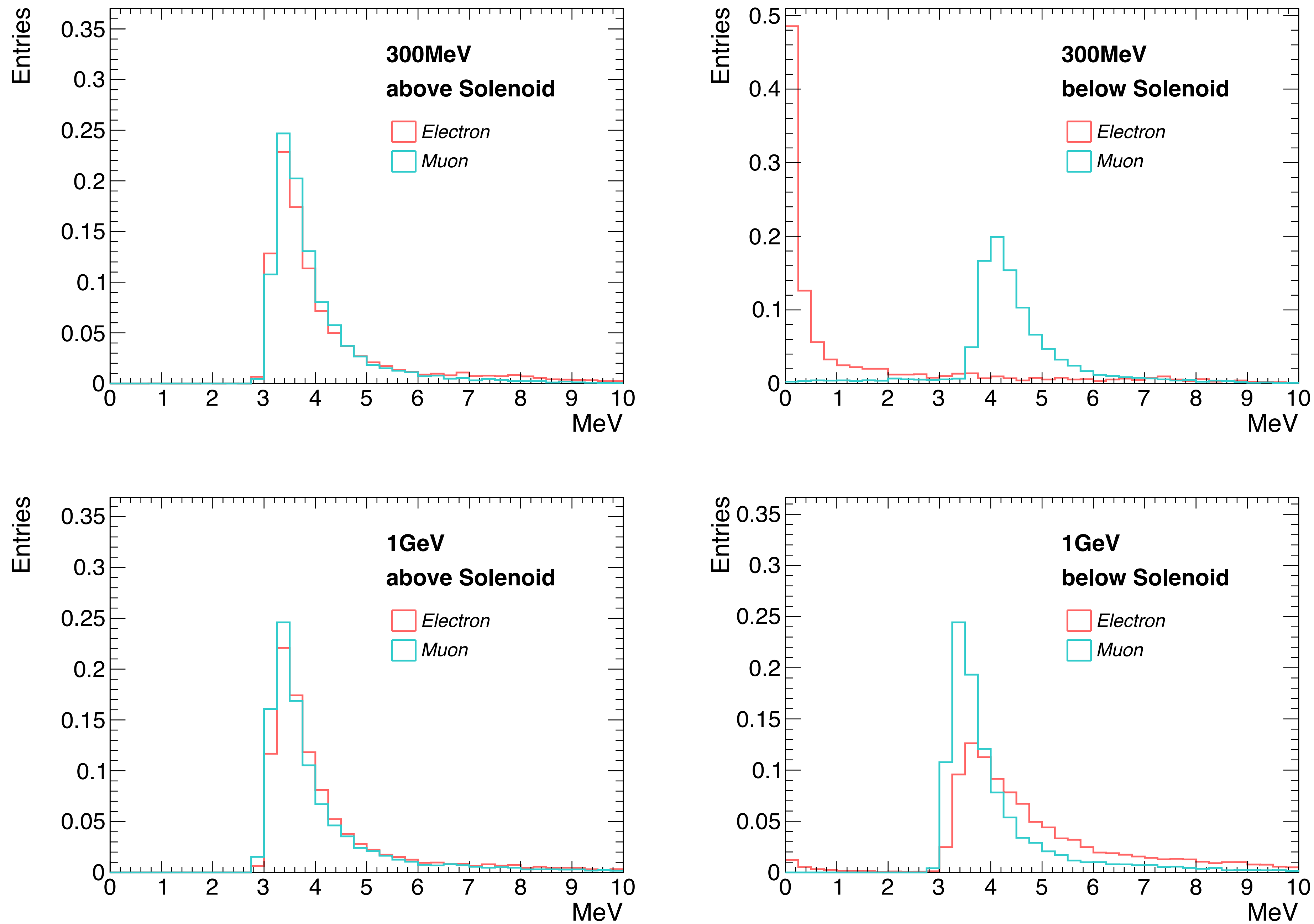


- BESS: The Balloon-borne Experiment with a Superconducting Spectrometer
- It contains a large solenoidal thin-wall superconducting magnet
- The solenoid: length: 1.4m, inner radius: 44.81cm, outer radius: 45.16cm
- The magnetic field: 0.8 Tesla

Electron and muon reconstruction

- Energy deposit in TOFs (for trigger)
- Track reconstruction (presented)
- Energy deposit in calorimeter (next step)

Energy in TOF

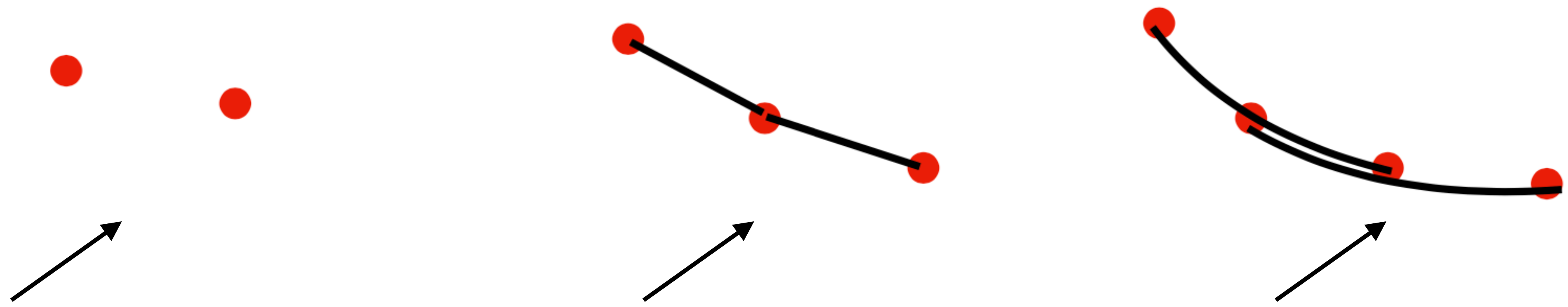


Track reconstruction

- The track reconstruction consists of 3 steps:
    - Track finding
    - Track fitting
    - Track cleaning

Track finding

- Use Cellular Automaton (CA) algorithm with single entity is a cell. Here cell is a hit of a particle in the tracker
- Segments are built from cells (hits). A single hits are considered as a shortest segments and called 1-hit-segments
- When two 1-hit-segments are compatible, they form a longer segment called 2-hit-segment
- Longer segments are created from the previous ones to form 3-hit-segment, 4-hit-segment …



Two 1-hit-segments   Two 2-hit-segments   Two 3-hit-segments

Track finding

- Our tracker is horizontally layered with uniform distance
- The first hit will start from the top layer and search for compatible hits in the lower layer with the criteria of distance between two hits to have 2-hit-segment
- The 3-hit-segments are formed based on the curvature of a particle's trajectory in the magnetic field of 0.8T
- The criteria for hits and segments help to reduce the wrong combinations and subsequently decrease the number of track candidates

Track fitting

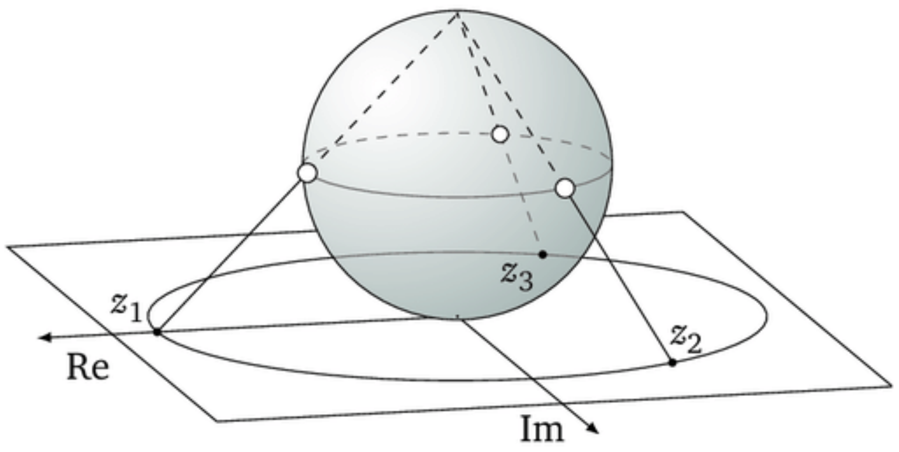
- After track candidates are generated by CA, the fitting procedure is performed to extract track-related information. The procedure is done by using Riemann sphere algorithm.
- The algorithm is non-iteration method, therefore, it should be faster than the traditional Kalman filter fit
- Transform circle in x-y plane to circle on Riemann sphere (South pole is at the origin (0,0,0) and North pole (0,0,1)), using variables:

$$u_i = R_i * cos\phi/(1 + R_i^2)$$

$$v_i = R_i * sin\phi/(1 + R_i^2)$$

$$w_i = R_i^2/(1 + R_i^2)$$

with $R_i^2 = x_i^2 + y_i^2$, $tan\phi = y/x$

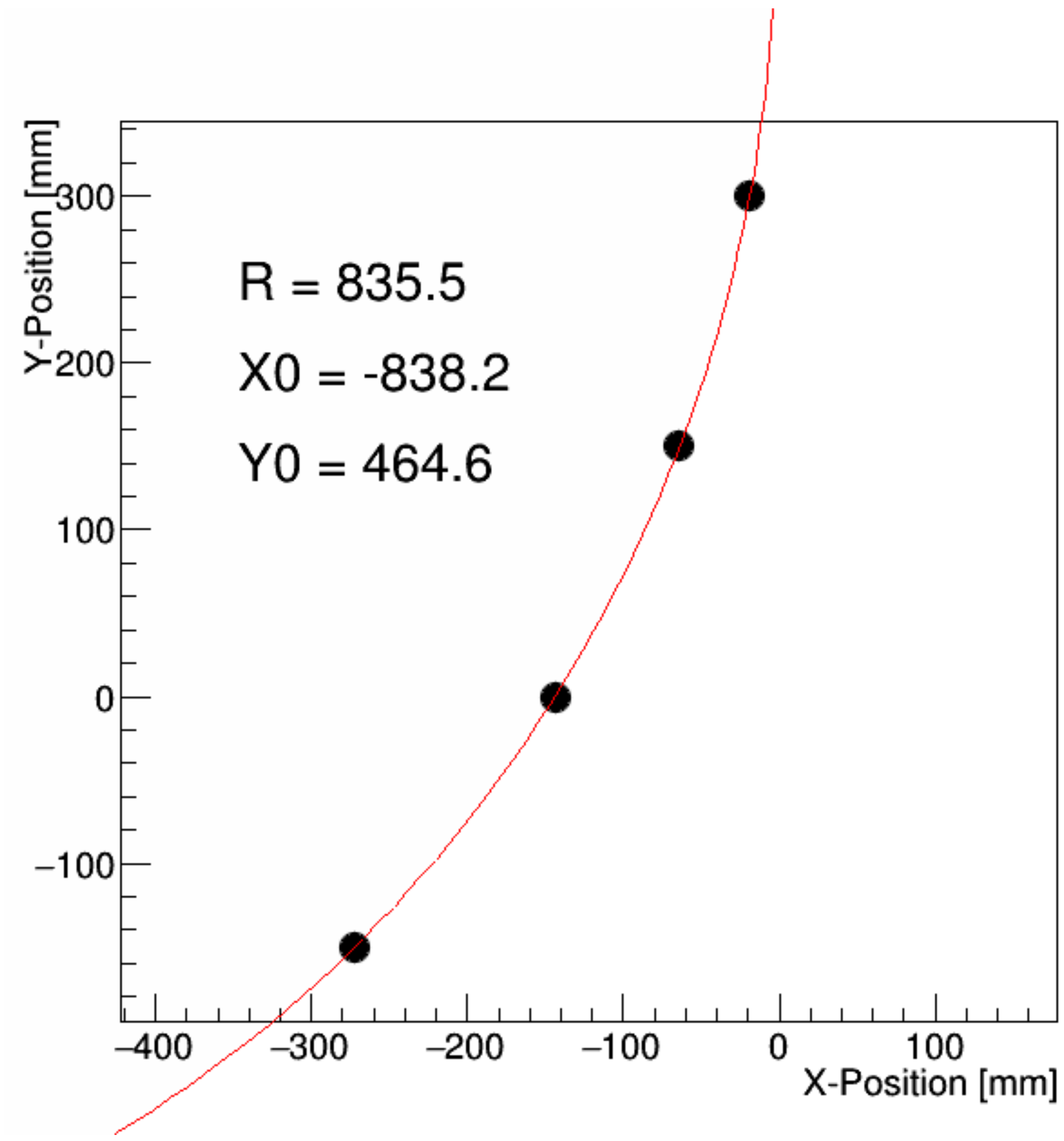


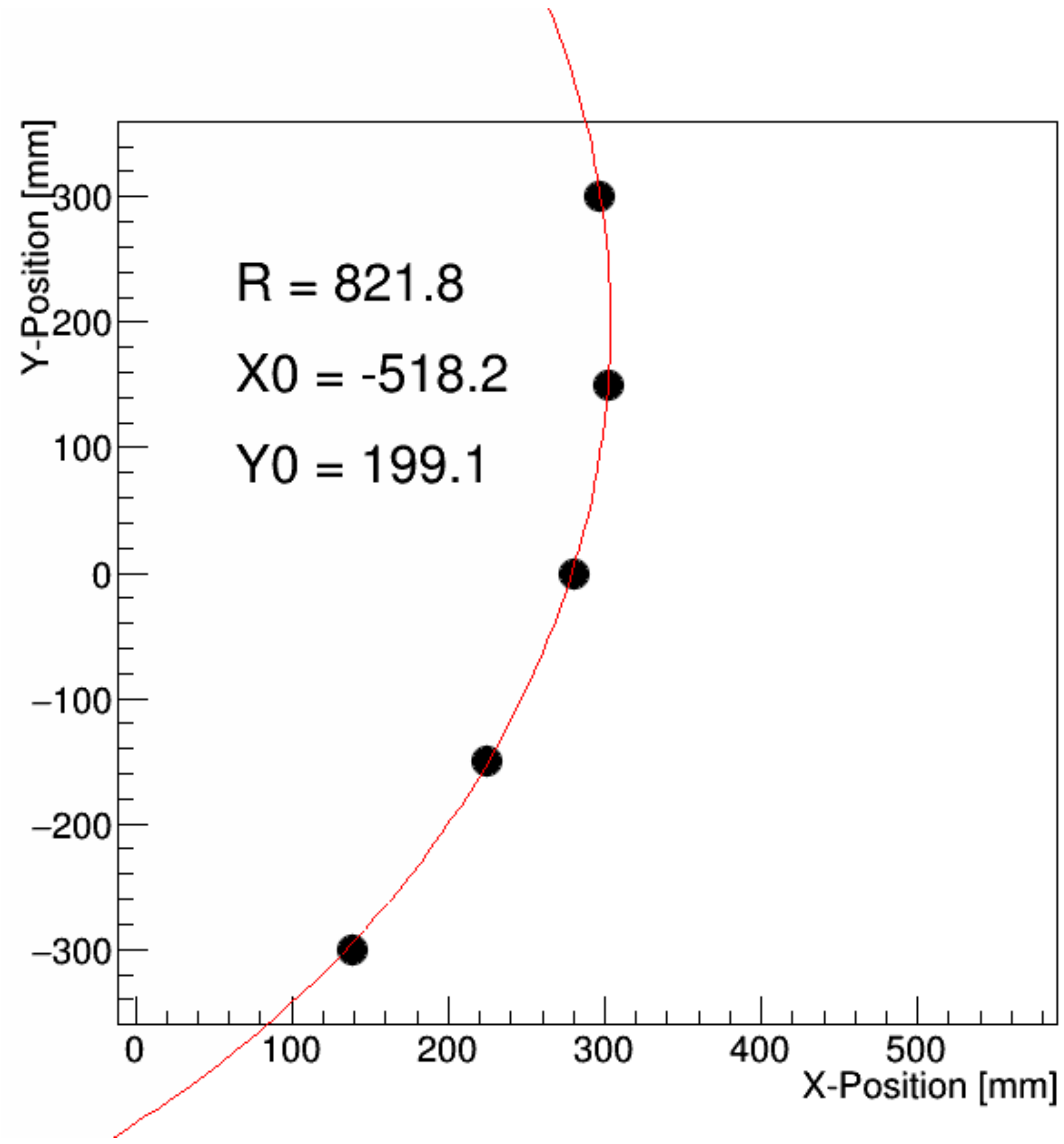
- circle in x-y plan move to find a plane satisfy:

$$c + n_1 \cdot u + n_2 \cdot v + n_3 \cdot w = 0$$

- n1, n2, n3 are component of normal vector of the plane
- From c, n1, n2, n3 the radius and center coordinates of the origin circle are identified

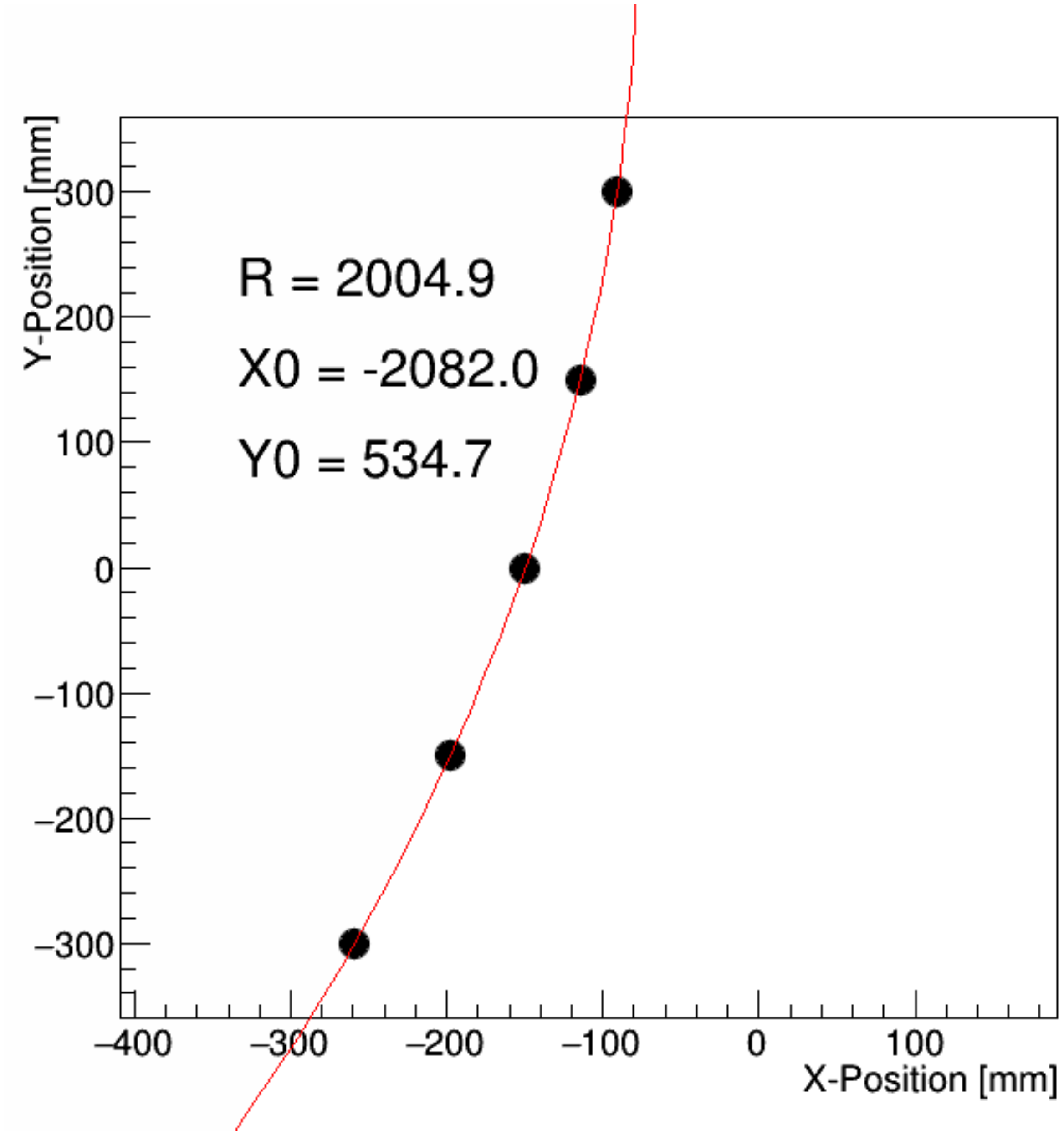
Track fitting

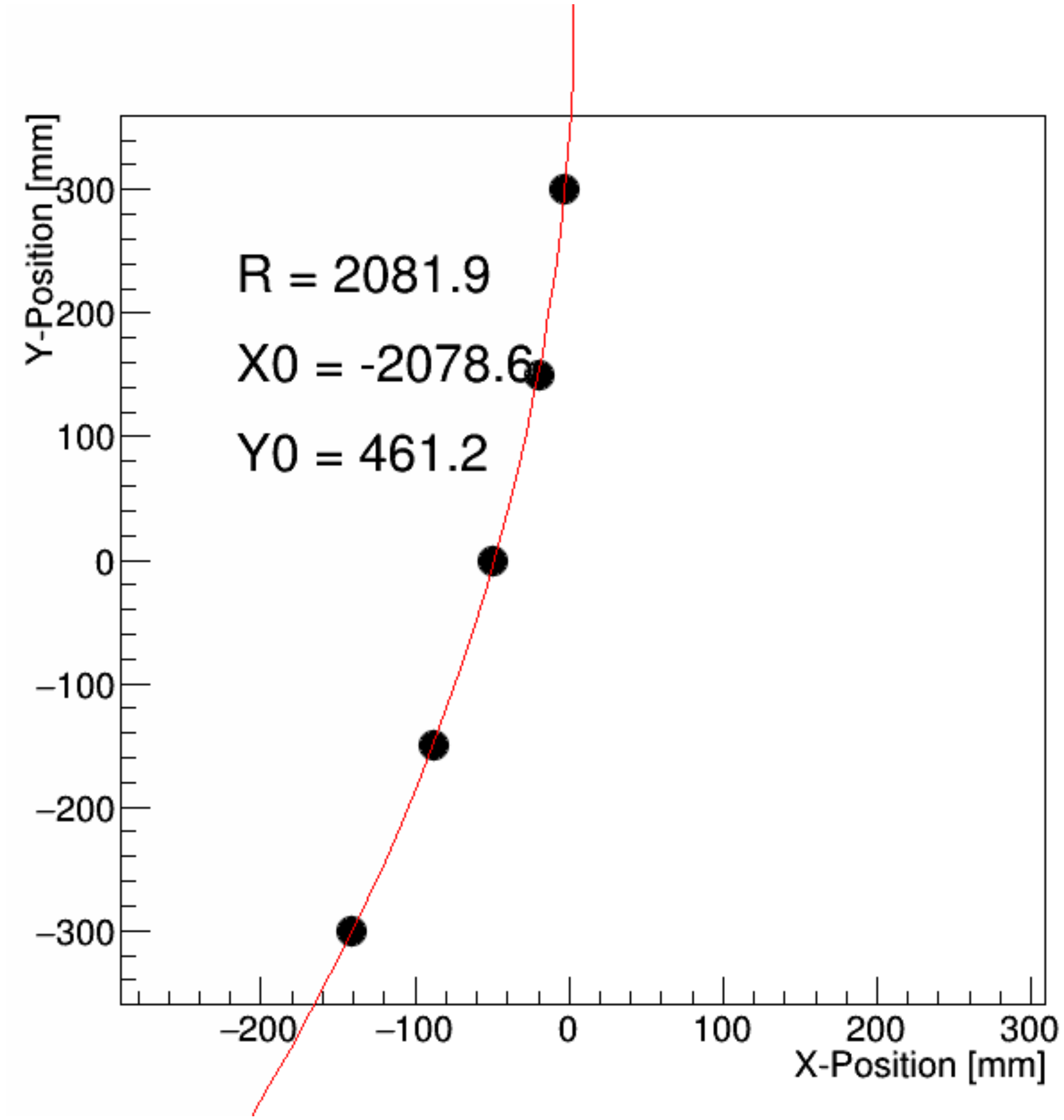




muon with p = 200 MeV for different events

Track fitting

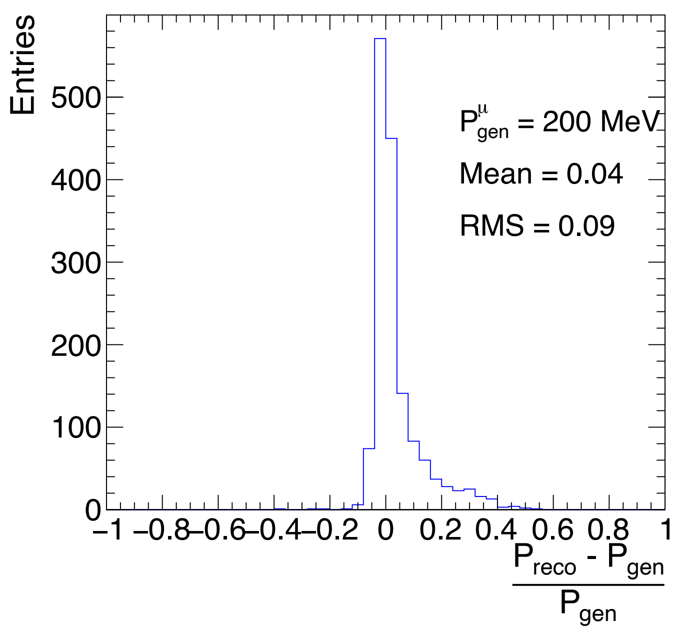


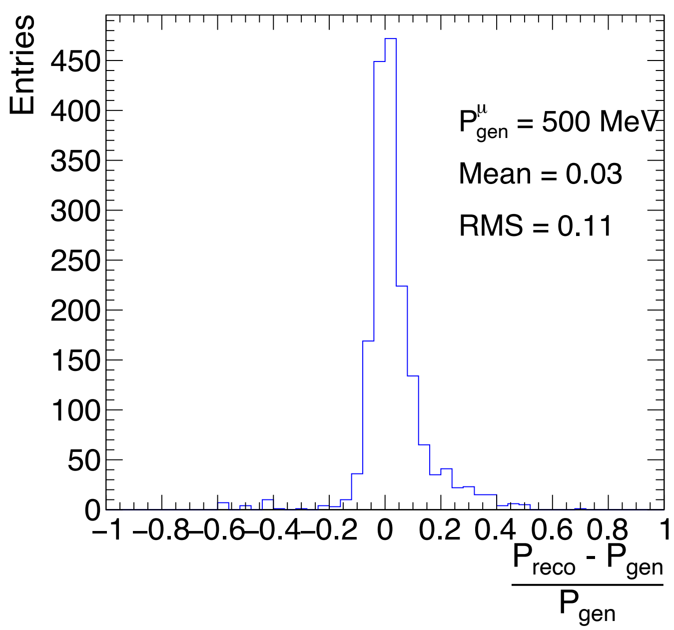


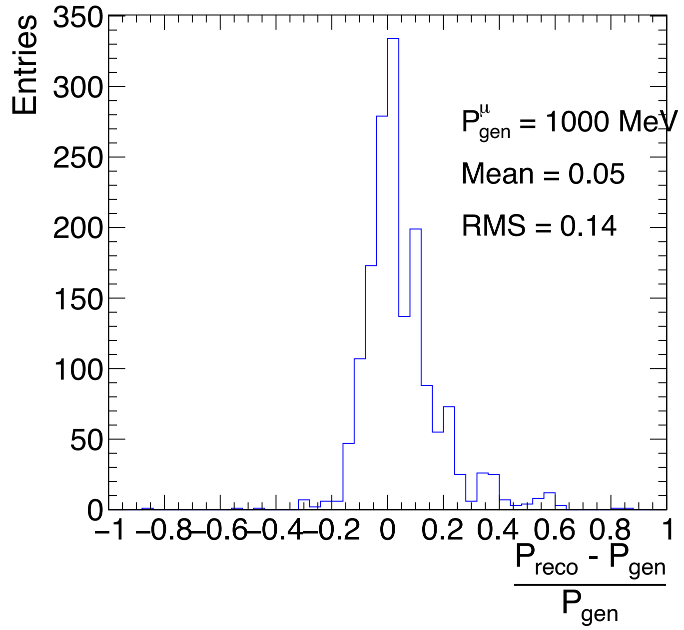
muon with p = 500 MeV for different events

Momentum resolution

- The momentum is calculated using the information extracted from track fitting
- The resolution is defined as: $(P_{reco} - P_{gen})/P_{gen}$

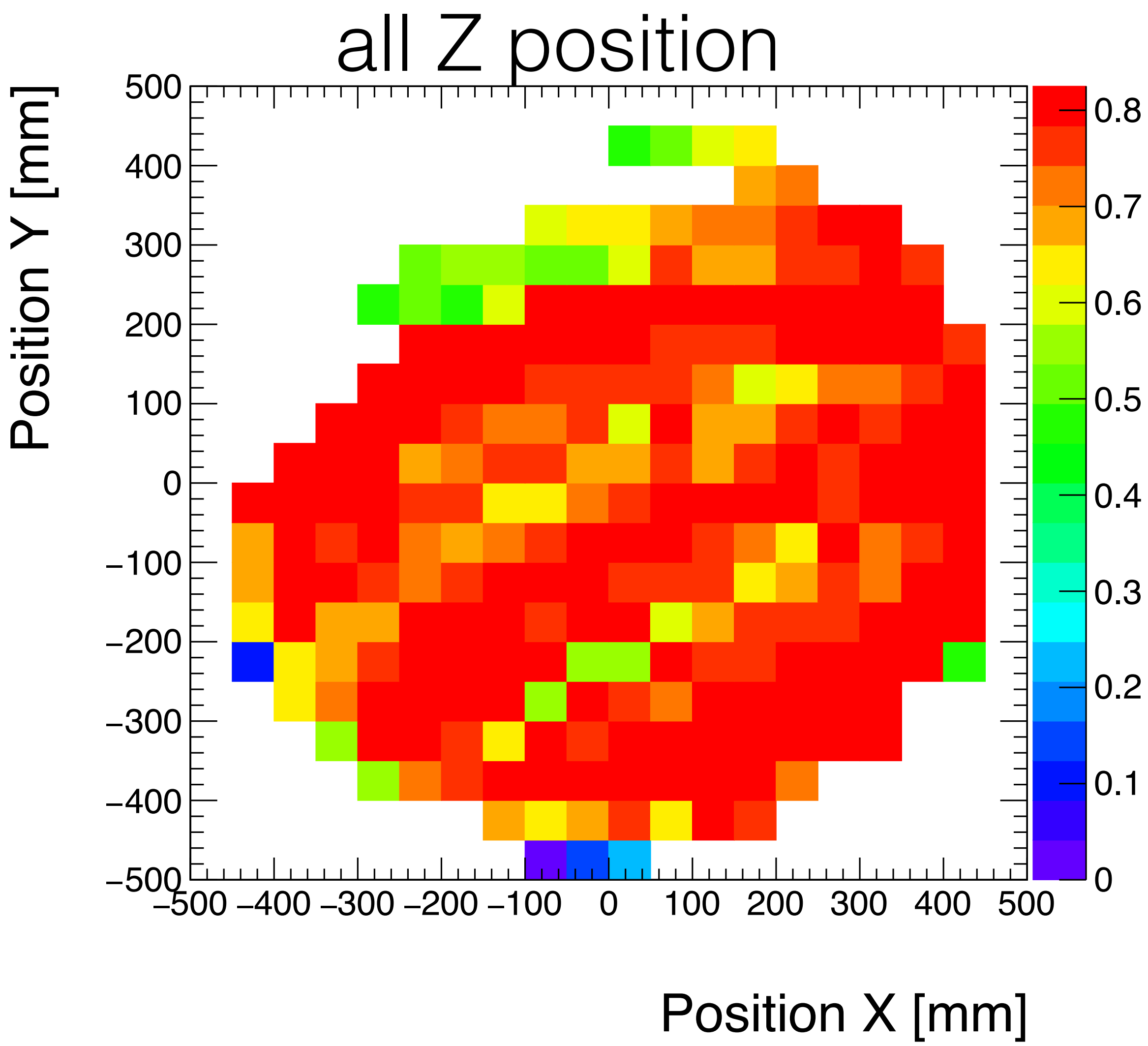


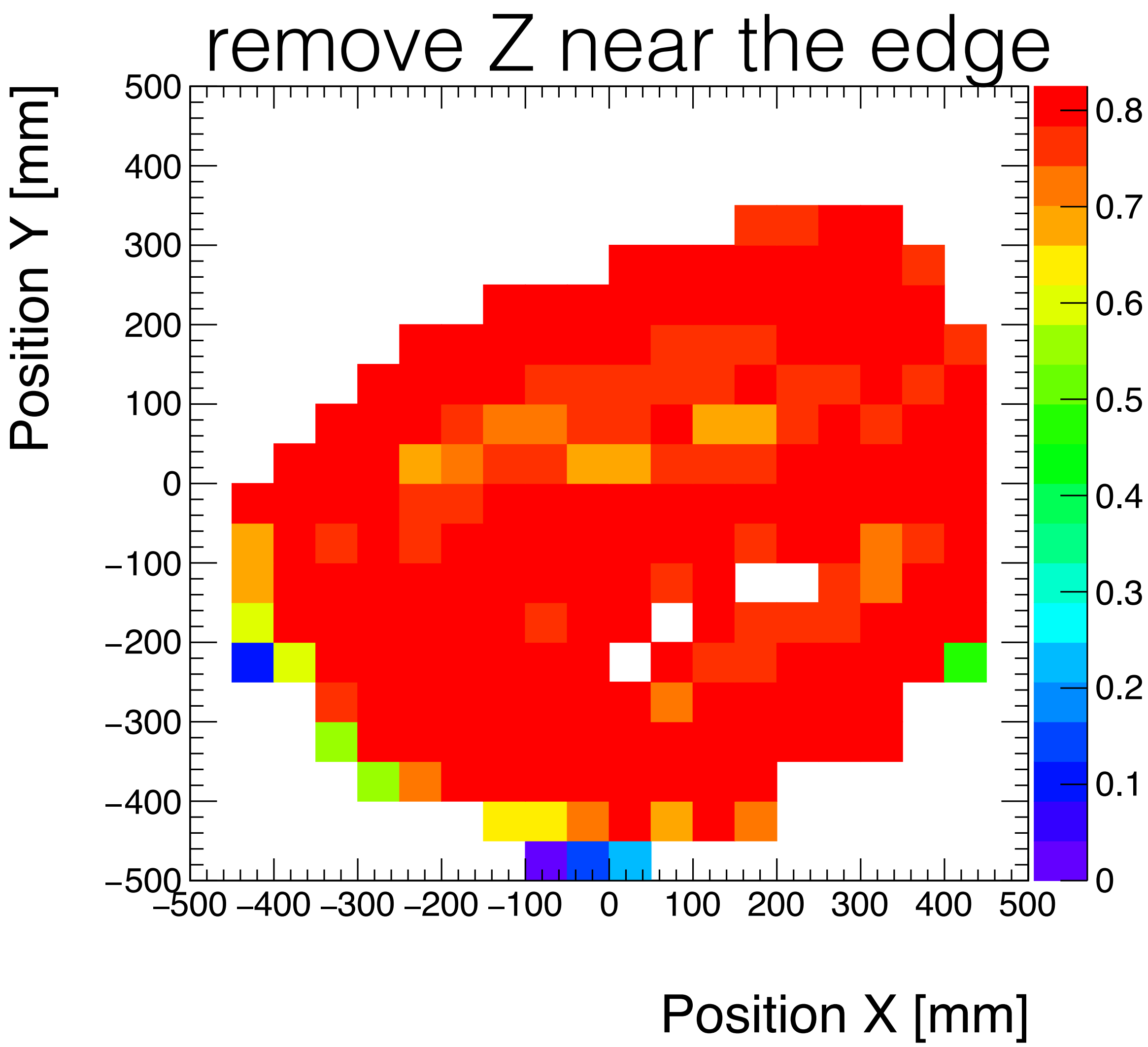




- Awkward behavior, longer tail in the right!
- Something is not correct!
- This procedure was done by assuming the homogeneous magnetic field inside the magnet

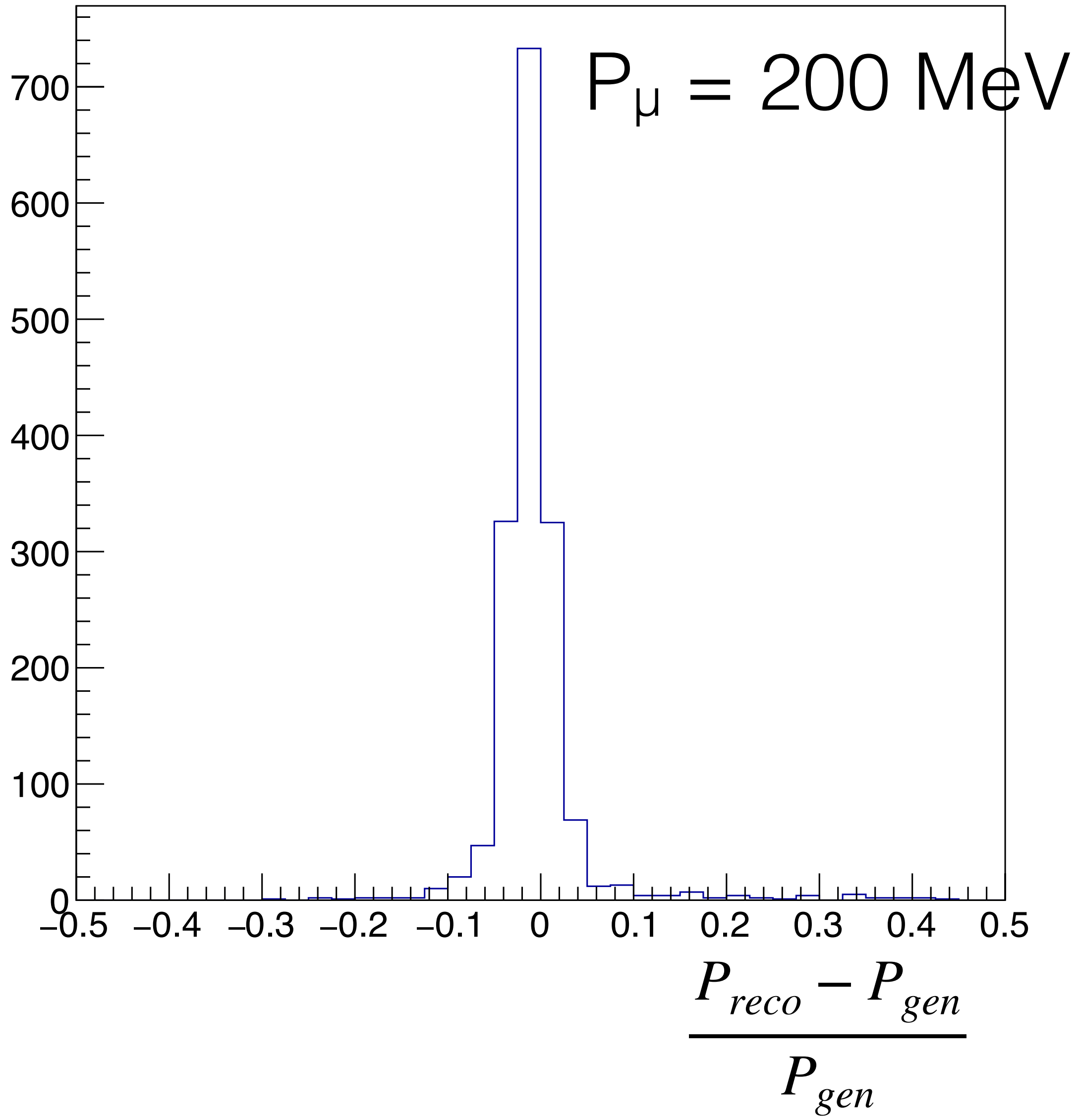
Magnetic field of BESS Magnet

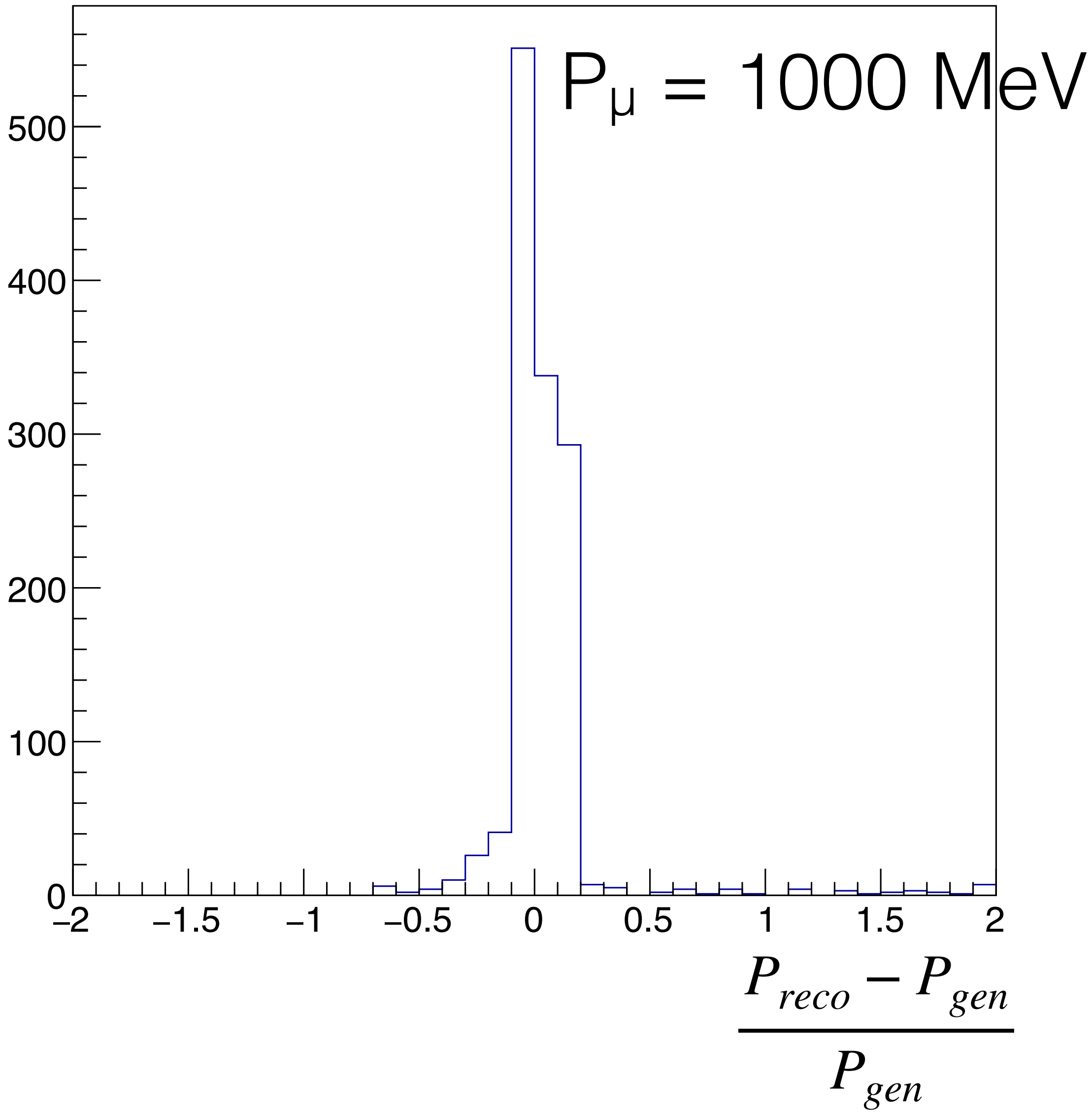




The magnetic field is inhomogeneous in space

Momentum resolution





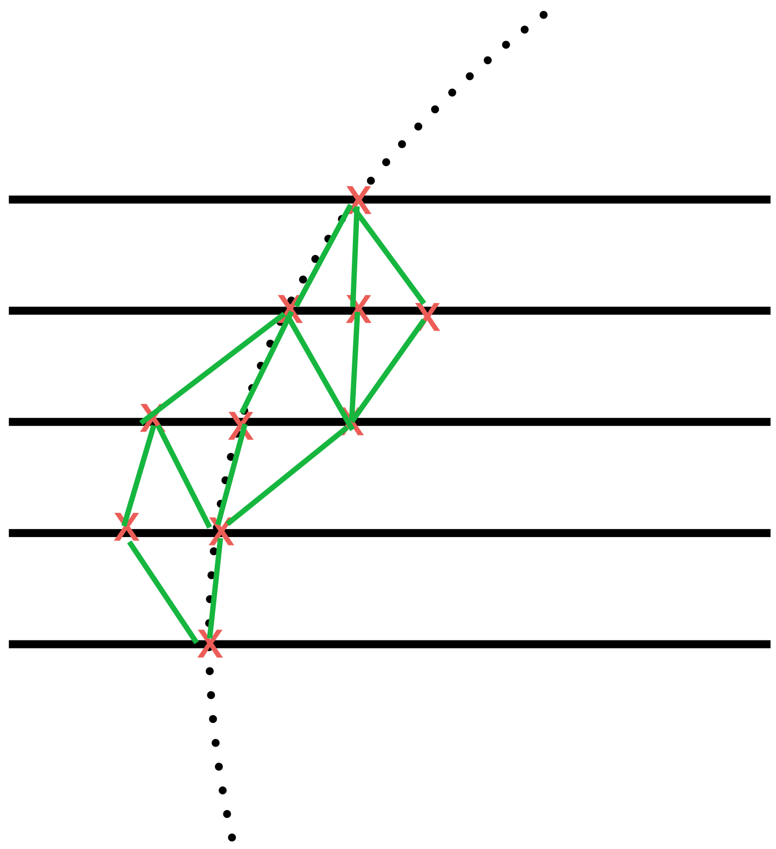
- The resolution of muon momentum using homogeneous magnetic field (0.8T)
- The distribution looks reasonable

Summary

- The detector for cosmic ray at low momentum region was built by Geant4 10.1.p02
- The particle reconstruction was performed up to track fitting stage
- The momentum resolution was extracted for homogeneous magnetic field of the BESS
- Need to modify the algorithm for the case of inhomogeneous B field inside the BESS
- Next step: study energy deposit in the EM calorimeter
- Expected to distinguish electron and muon particle in the region below 1 GeV using information from tracker, TOF and calorimeter

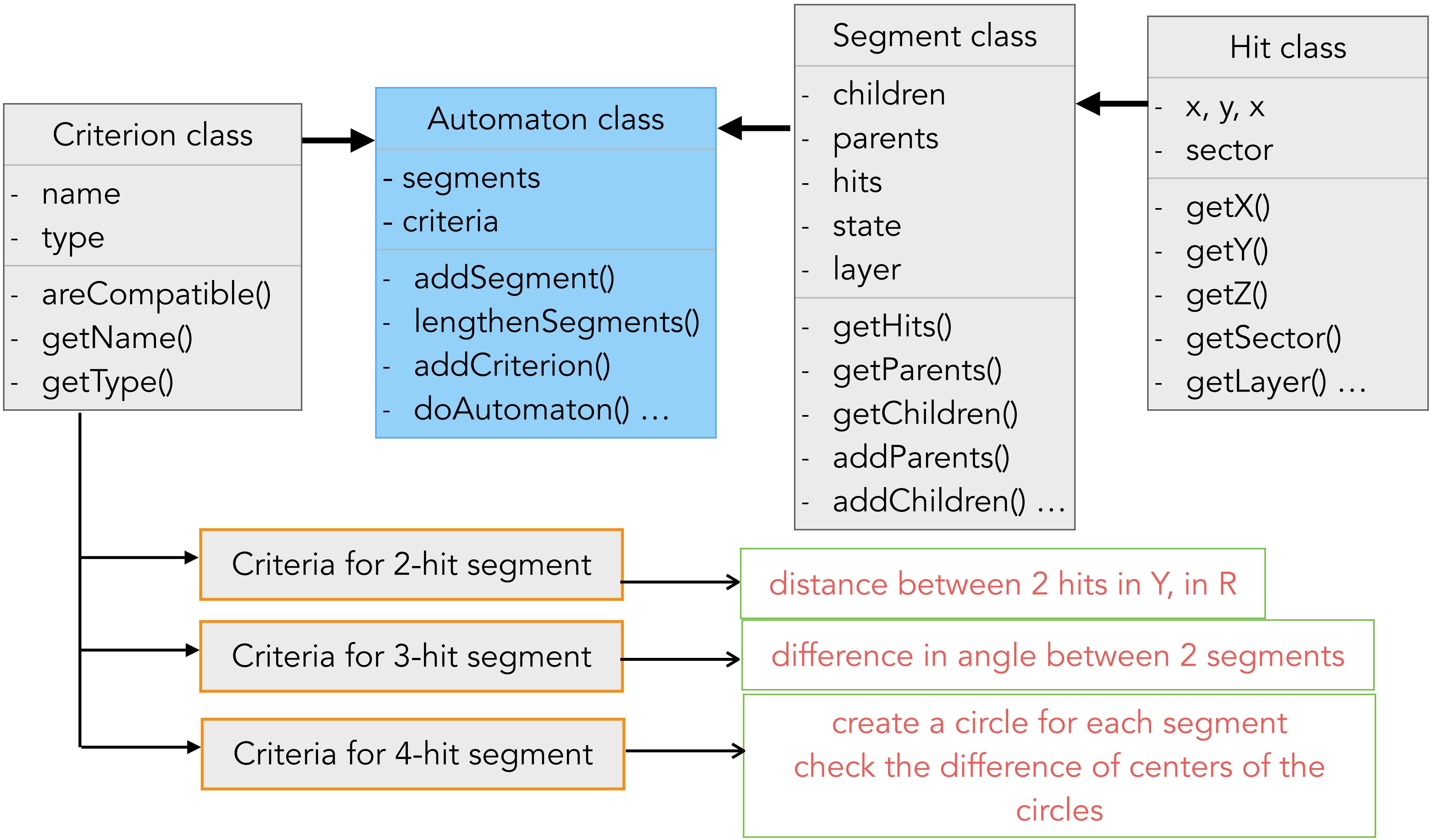
back-up

Cellular automaton track finding

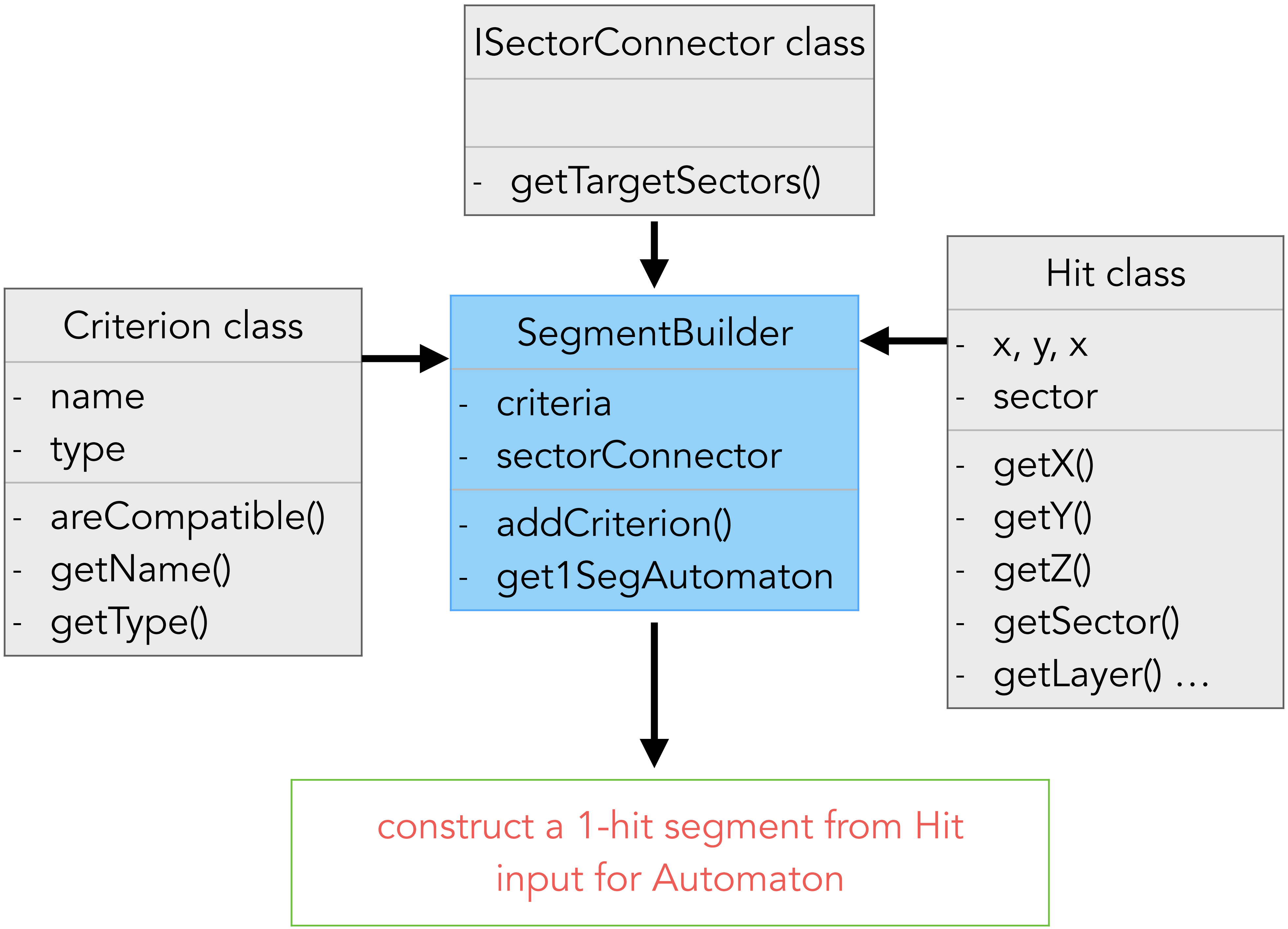


- cell: a straight line connecting two hits of adjacent layers
- the state of cell is indexed by integer number starting from 0
- if the cell has neighbor from inside, the index is increased
- the iteration step stops when no outside cell is found —> track candidates created
- track parameters are estimated by Kalman filter

Work-flow


Criterion class
- name
- type
- areCompatible()
- getName()
- getType()
Automaton class
- segments
- criteria
- addSegment()
- lengthenSegments()
- addCriterion()
- doAutomaton() …
Segment class
- children
- parents
- hits
- state
- layer
- getHits()
- getParents()
- getChildren()
- addParents()
- addChildren() …
Hit class
- x, y, x
- sector
- getX()
- getY()
- getZ()
- getSector()
- getLayer() …
Criteria for 2-hit segment
Criteria for 3-hit segment
Criteria for 4-hit segment
distance between 2 hits in Y, in R
difference in angle between 2 segments
create a circle for each segment
check the difference of centers of the
circles

Work-flow


ISectorConnector class
- getTargetSectors()
Criterion class
- name
- type
- areCompatible()
- getName()
- getType()
SegmentBuilder
- criteria
- sectorConnector
- addCriterion()
- get1SegAutomaton
Hit class
- x, y, x
- sector
- getX()
- getY()
- getZ()
- getSector()
- getLayer() …
construct a 1-hit segment from Hit
input for Automaton

Criteria of hits and segments

- For 2-hit-segments: distance in y-direction, in x-y plane
- For 3-hit-segments: angle between two 2-hit-segments
- For two 3-hit-segments: changes in angle between the two segments

Riemann Sphere algorithm

- Extracting the circle parameters in x-y plane from Riemann Sphere:
  - Center coordinates:

$$x_0 = -\frac{n_1}{2(c+n_3)},\ y_0 = -\frac{n_2}{2(c+n_3)}$$

- Radius of curvature of the circle:

$$\rho^2 = \frac{n_1^2 + n_2^2 - 4c(c+n_3)}{4(c+n_3)^2}$$