Study of an Algorithm for Energy Flow Studies in the SiD Detector

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Motivation for Particle Flow Studies

- Jet Energy Resolution
  - **Jets are important for Precision Measurement at LC**
  - **Explore EWSB in the Process**

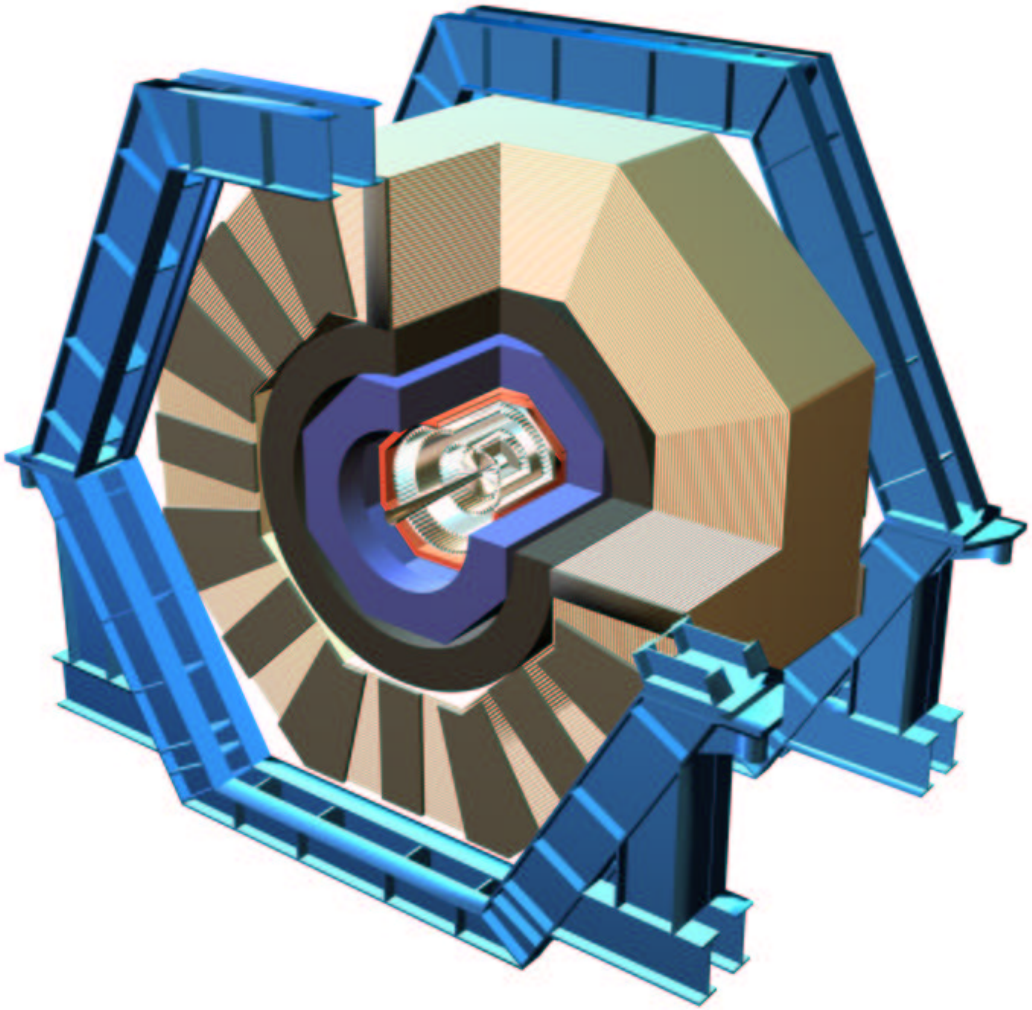
$$e^+e^- \rightarrow \nu\nu \mathrm{W}^+\mathrm{W}^-$$
$$e^+e^- \rightarrow \nu\nu \mathrm{Z}\mathrm{Z}$$

    - Requires Z,W Identification (Hadronic Decay Modes $\sim 70\%$)
    - Can't use traditional Constraint Fits ($\sigma_\mathrm{E}/E \sim 75\%/\sqrt{E}$)
  - **Goal: High Precision Measurement of Jet Energy ($\sigma_\mathrm{E}/E \sim 30\%\sqrt{E}$)**
- Reconstruction of Long Lived Particles (K^0_S, Λ, SUSY Particles, etc...)

Motivation for Particle Flow Studies

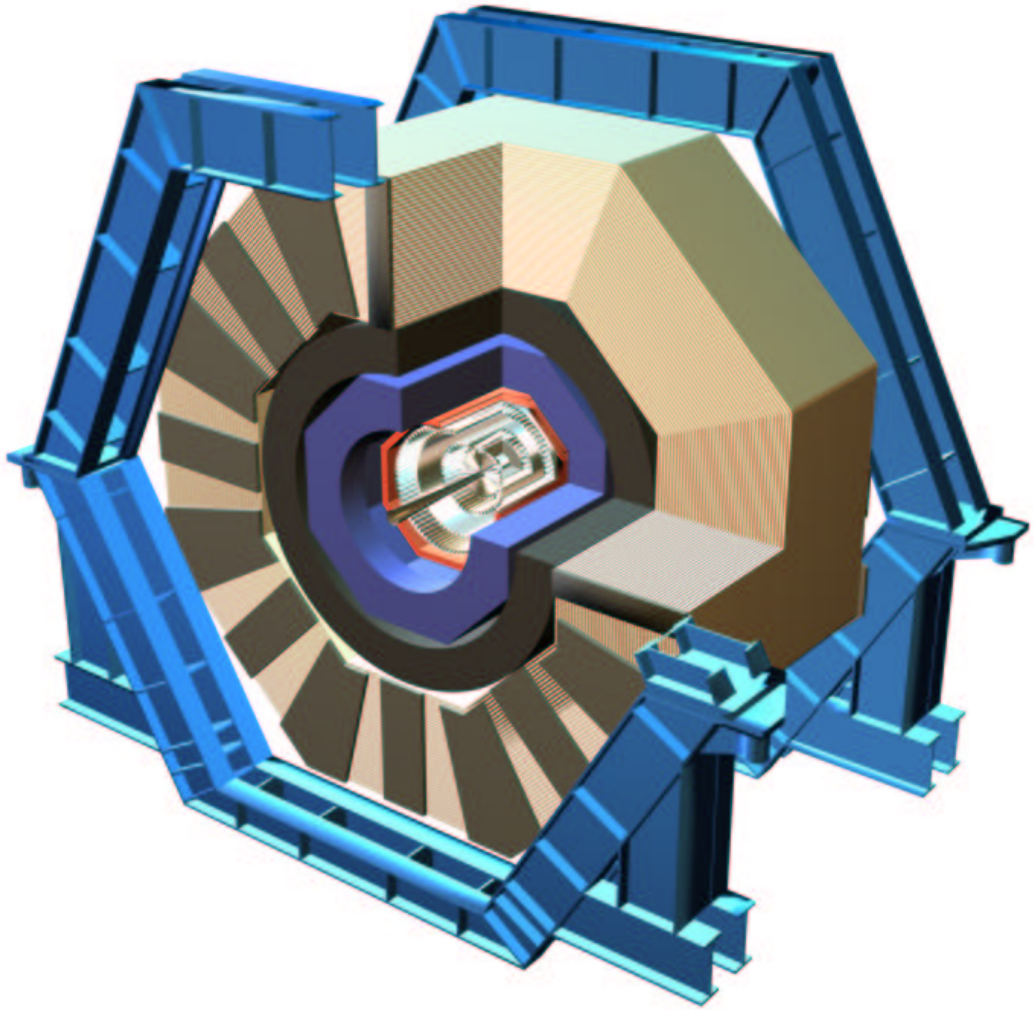
- Reconstruction of Jet with good Energy Resolution at LC Energy.
  - **Charged Particles**
    - $\sim 62\%$ of jet energy
  - **Photons**
    - $\sim 25\%$ of jet energy
  - **Neutral Hadrons**
    - $\sim 13\%$ of jet energy
- Dense Calorimeter
  - **Optimal Separation of Photons and Hadrons**
  - **Measure Shower Development longitudinally**

The SiD Detector



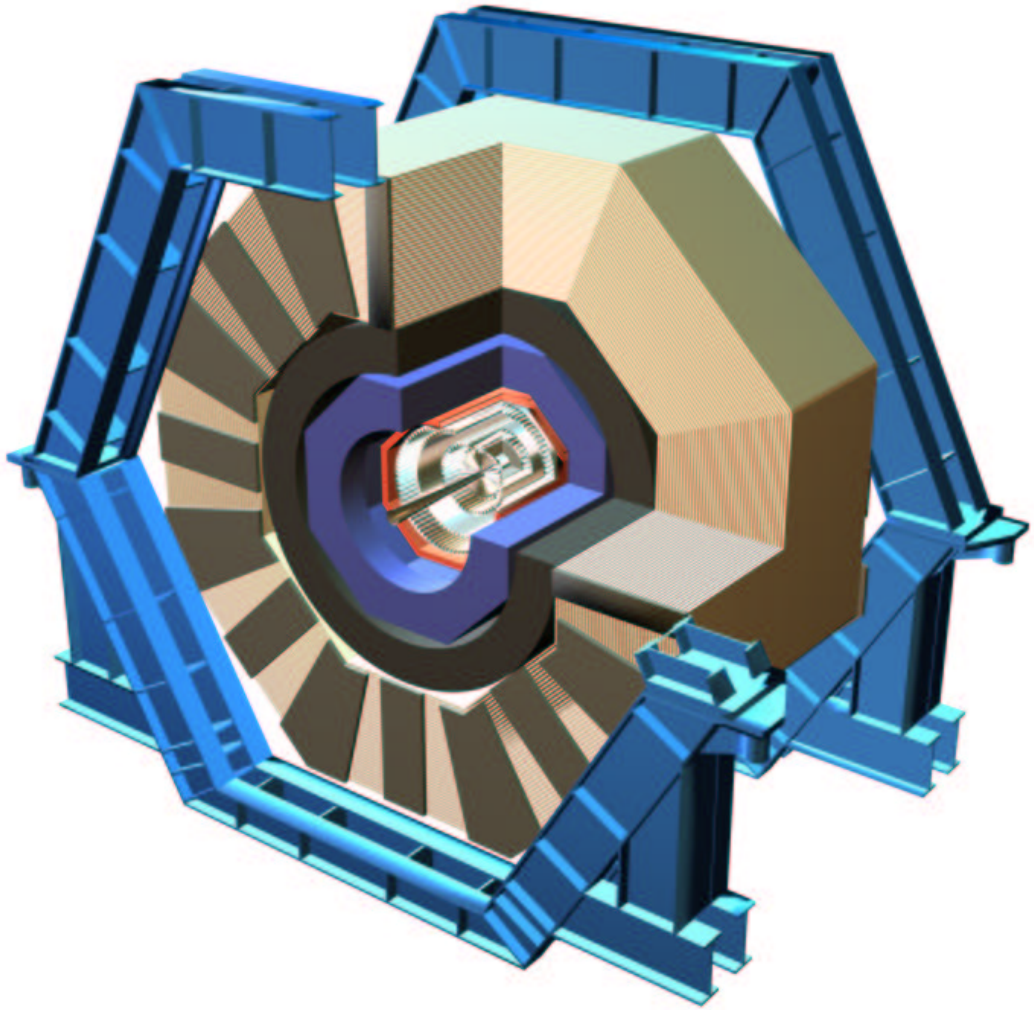
- Central Tracking System
  - **Multi-layer Si Vertex Detector**
    ~ 1 **cm** $\rightarrow 7$ **cm Radius, 5 Layers**
  - **Si-Strip Tracker**
    ~ 20 **cm** $\rightarrow 125$ **cm Radius, 5 Layers**

The SiD Detector



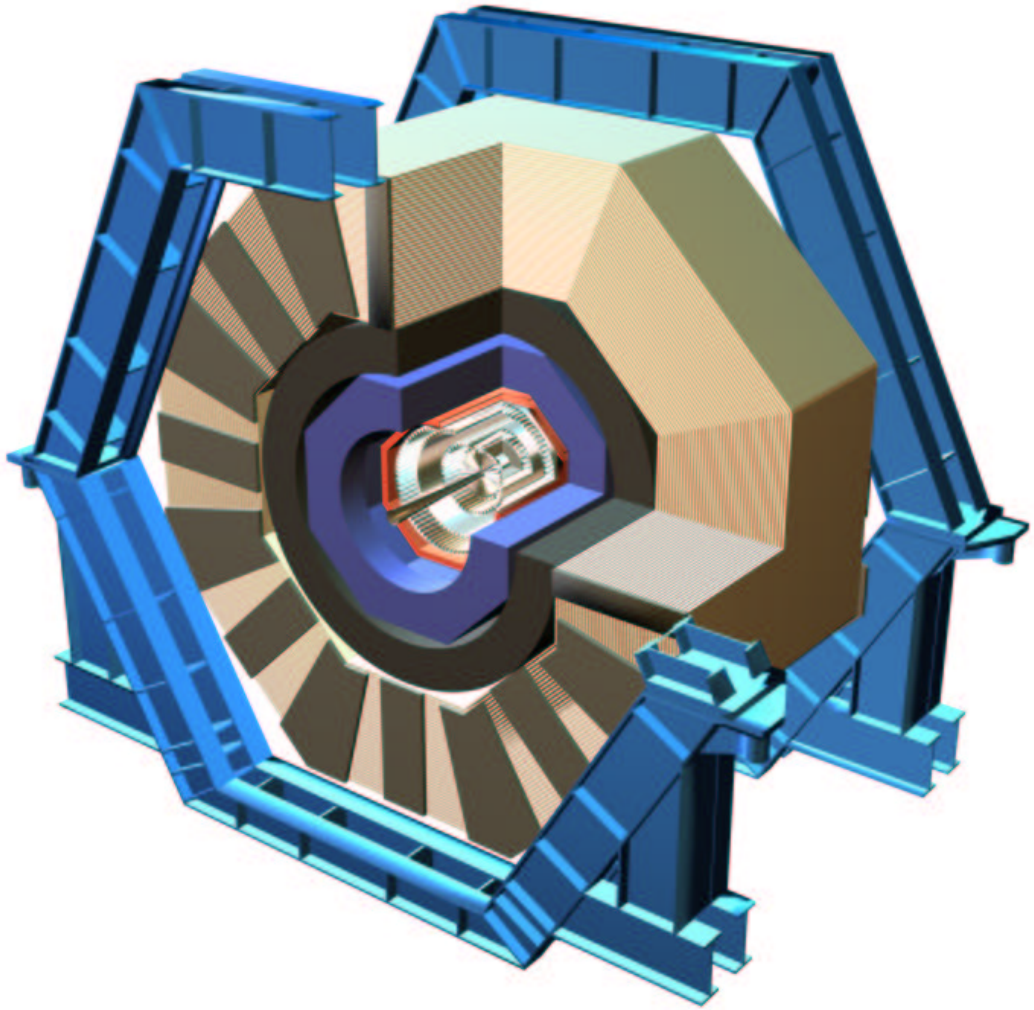
- Central Tracking System
- Electromagnetic Calorimeter (EMC)
  - **30 Layers,** ~ 125 **cm** $<$ **R** $<$ ~ 140 **cm**
  - **W(0.25cm)/Si(0.04cm)**
    ~ 20 **E.M. Interaction Length (**X_0**)**
    ~ 0.8 **Had. Interaction Lengths (**λ_I**)**
  - **Cell Size:** $\sim 5\mathrm{mm} \times \sim 5\mathrm{mm}$

The SiD Detector



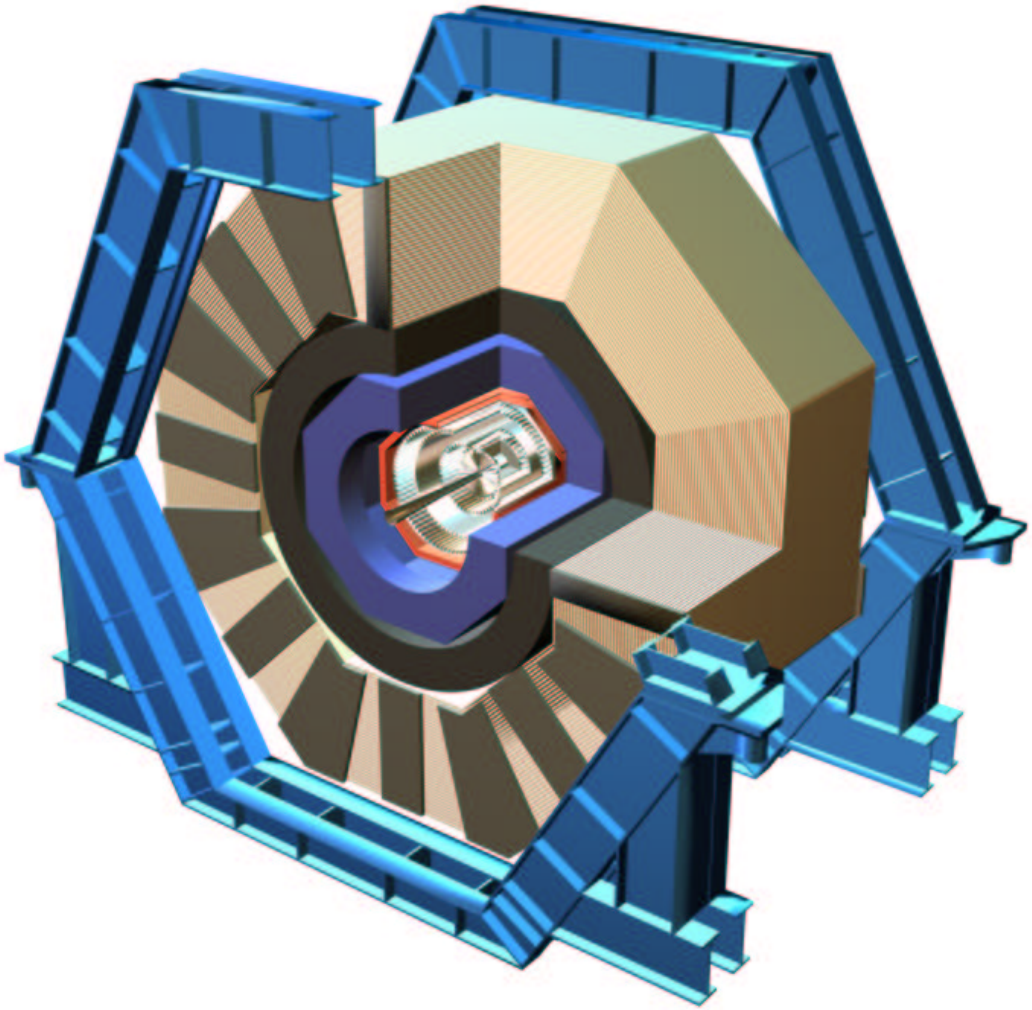
- Central Tracking System
- Electromagnetic Calorimeter (EMC)
- Hadronic Calorimeter (HC)
  - **34 Layers,** ~ 145 **cm** $<$ **R** < 250 **cm**
  - **SS(20 cm)/Scin(1.0 cm)**
  - $40\mathrm{X}_0, 4\lambda_\mathrm{I}$
  - **Cell Size:** $\sim 1\mathrm{cm} \times 1\mathrm{cm}$

The SiD Detector



- Central Tracking System
- Electromagnetic Calorimeter (EMC)
- Hadronic Calorimeter (HC)
- Solenoidal Coil
  - **5 Tesla,** 250 **cm** $<$ **R** $<$ 330 **cm**

The SiD Detector

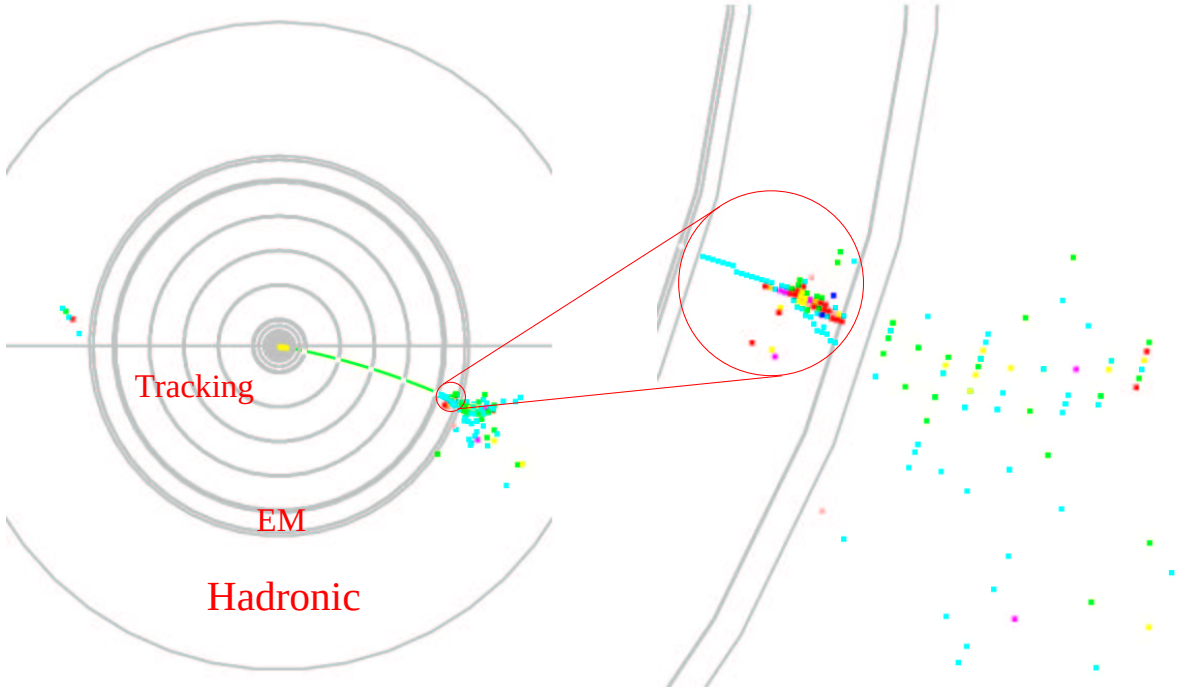


- Central Tracking System
- Electromagnetic Calorimeter (EMC)
- Hadronic Calorimeter (HC)
- Solenoidal Coil
- Muon System (Tail Catcher)
  - 340 **cm** $<$ **R** $<$ 545 **cm**

Analysis Goal

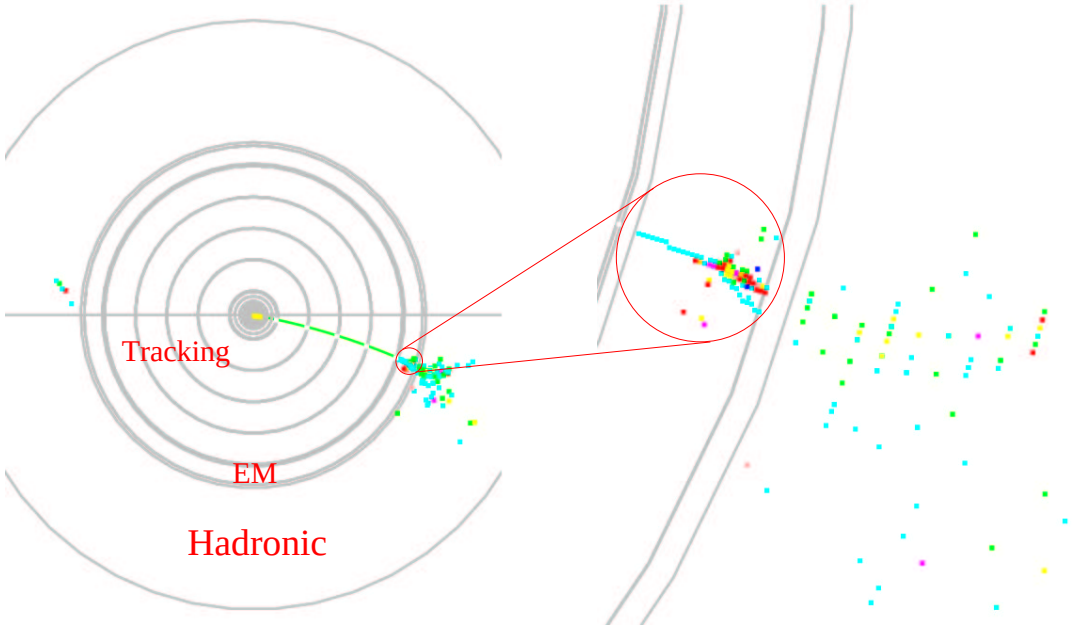
- Identification of MIP Tracks in EMC
  - **MIPs Associated with Tracks**
  - **MIPs NOT Associated with Tracks**
    - Identification of Neutral Hadronic Energy
    - Identification of Long Lived Particles
  - **Identification of Starting Point of Hadronic Shower**
- Studies Based on GEANT4 Simulated Events
  - **Single Pion Tracks**
  - **Events containing K^0_S Decays**
  - **Physics Events containing $\mathrm{t\bar{t}}$ Events**

Identification of MIP Tracks



- Characteristic Features
  - **Starts as MIP in EMC**
  - **In $\sim 50\%$ of all Events: Shower Starts within EMC**

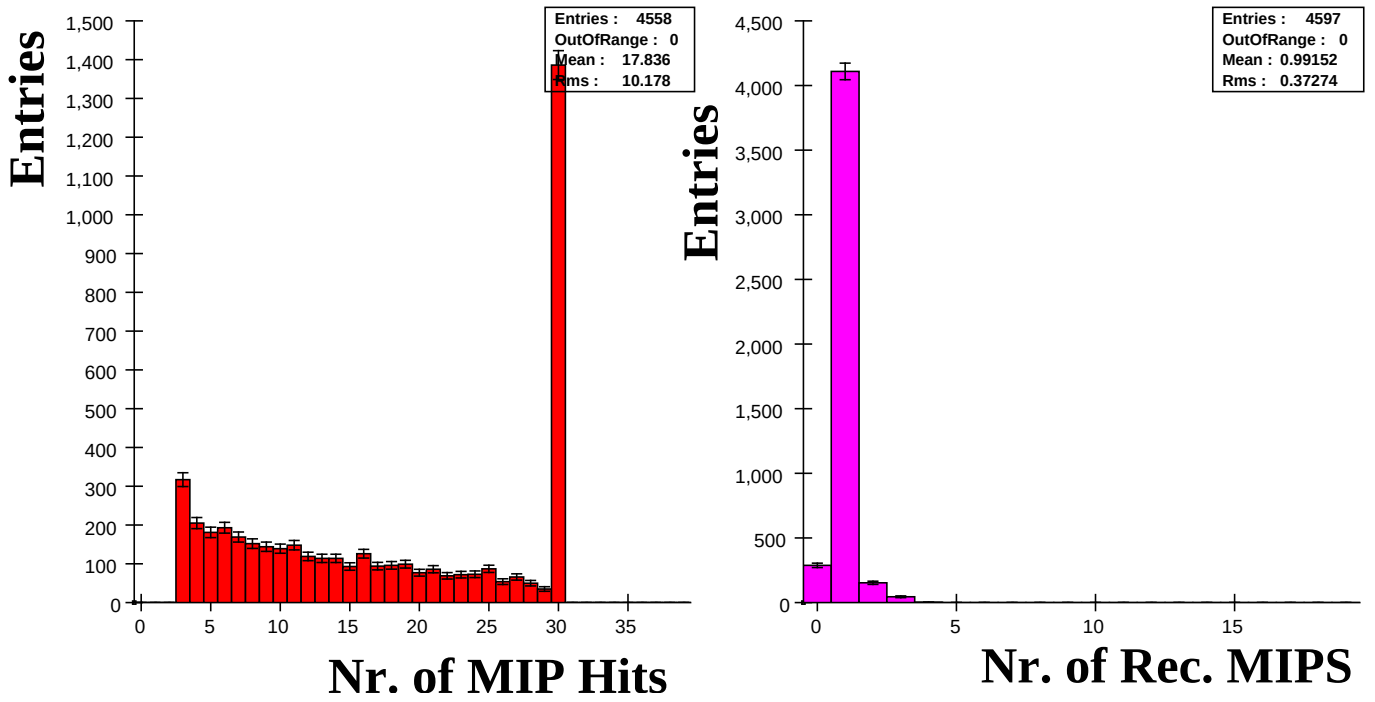
Identification of MIP Tracks



- Selection Criteria
  - > 1 **one Isolated Hit (3x3 Matrix of Cells)in Layers 0/1**
  - **Energy Deposition Consistent with MIP**
  - **At least 3 Hits in Layers 0-3**
- Criteria for MIP Extension
  - **Isolated Hits found**
  - **Second Hit allowed (δ-Rays)**
  - **Gap of One Layer**

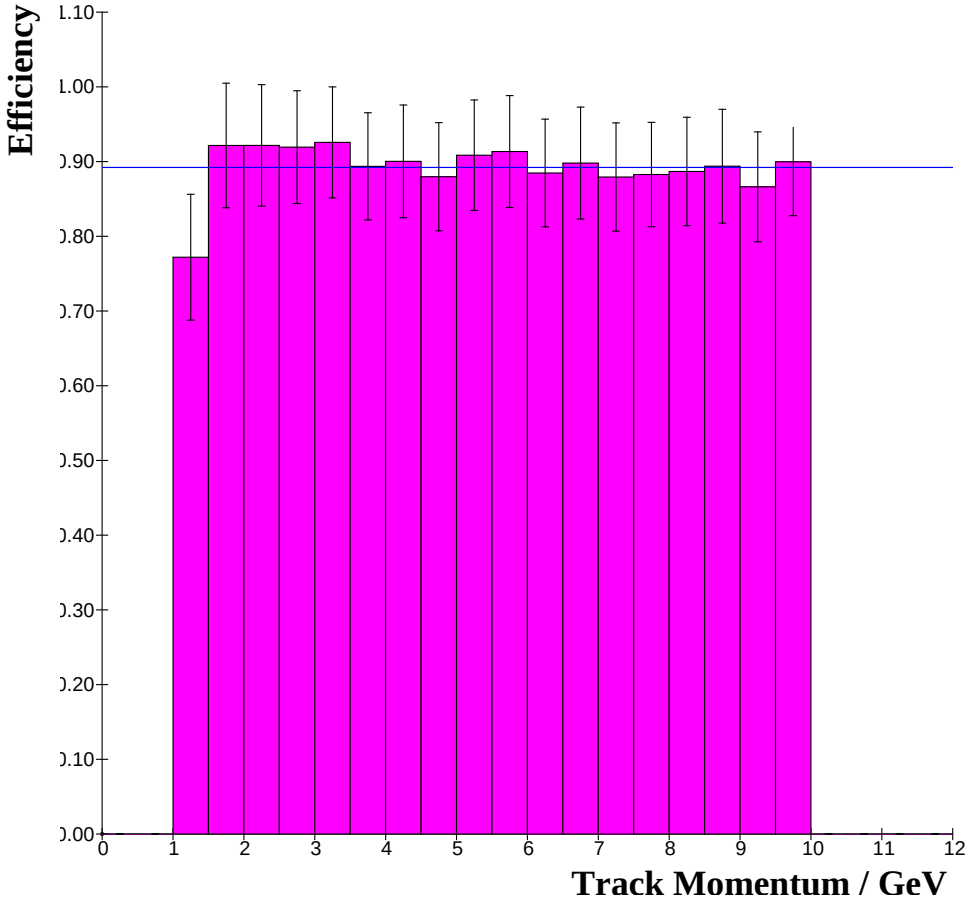
Performance Of Algorithm (I)

- Using Single Pion Events
  - **Restricted to Barrel Region ($|\cos\theta| < 0.8$)**
  - **Energy of Pions** $1\,\mathrm{GeV} < E_\pi < 10\,\mathrm{GeV}$

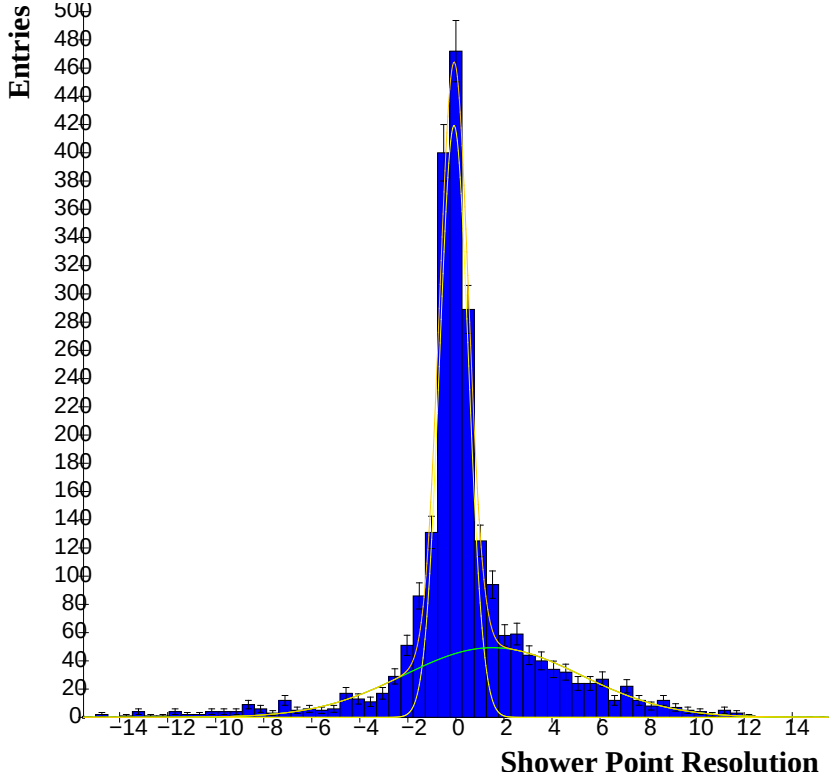


Performance Of Algorithm (II)

- Efficiency vs. Particle Momentum
  - **Normalized to Pions expected to Shower in EMC**
  - $\varepsilon(p) \sim 90\%$
  - **Efficiency independent of Particle Momentum**
  - 1^{st} **Bin: Imperfection in Modeling of Energy-Loss**



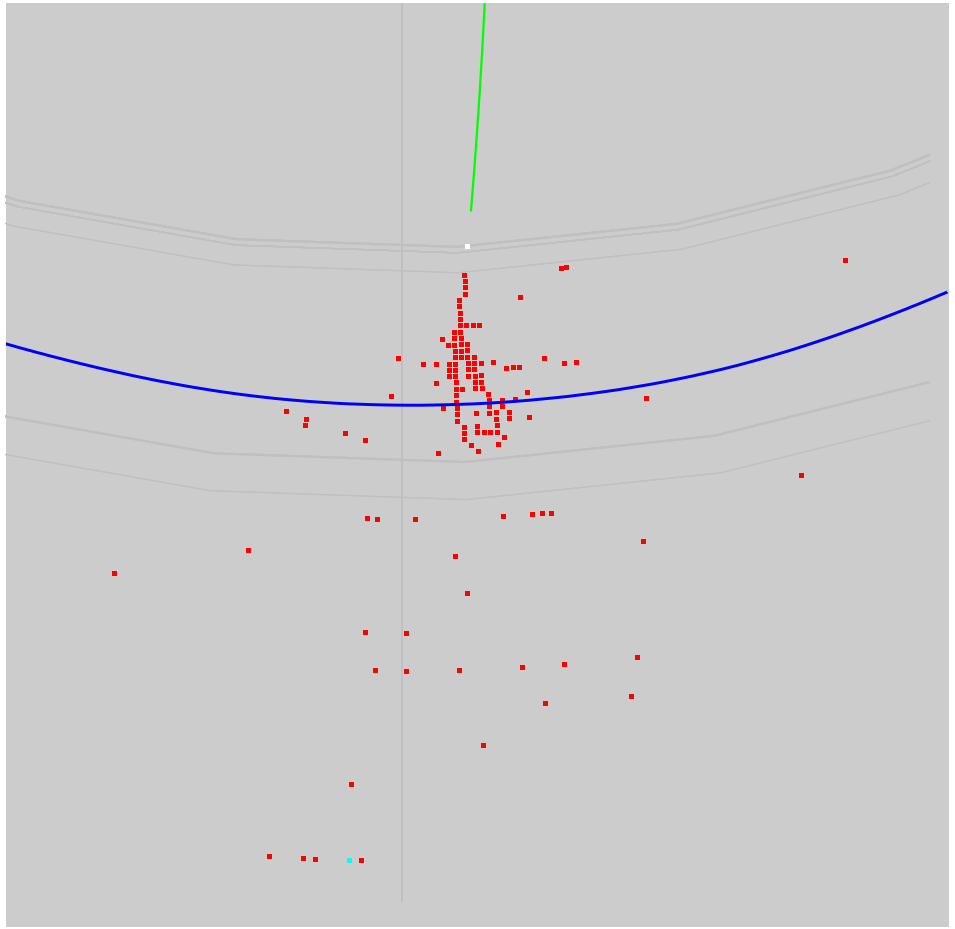
Performance Of Algorithm (III)



- Resolution of Showering Point
  - **Fitted with Double Gaussian**
  - **Resolution** $\sim 0.6\,\mathrm{cm}$ **(**± 1 **Layer).**

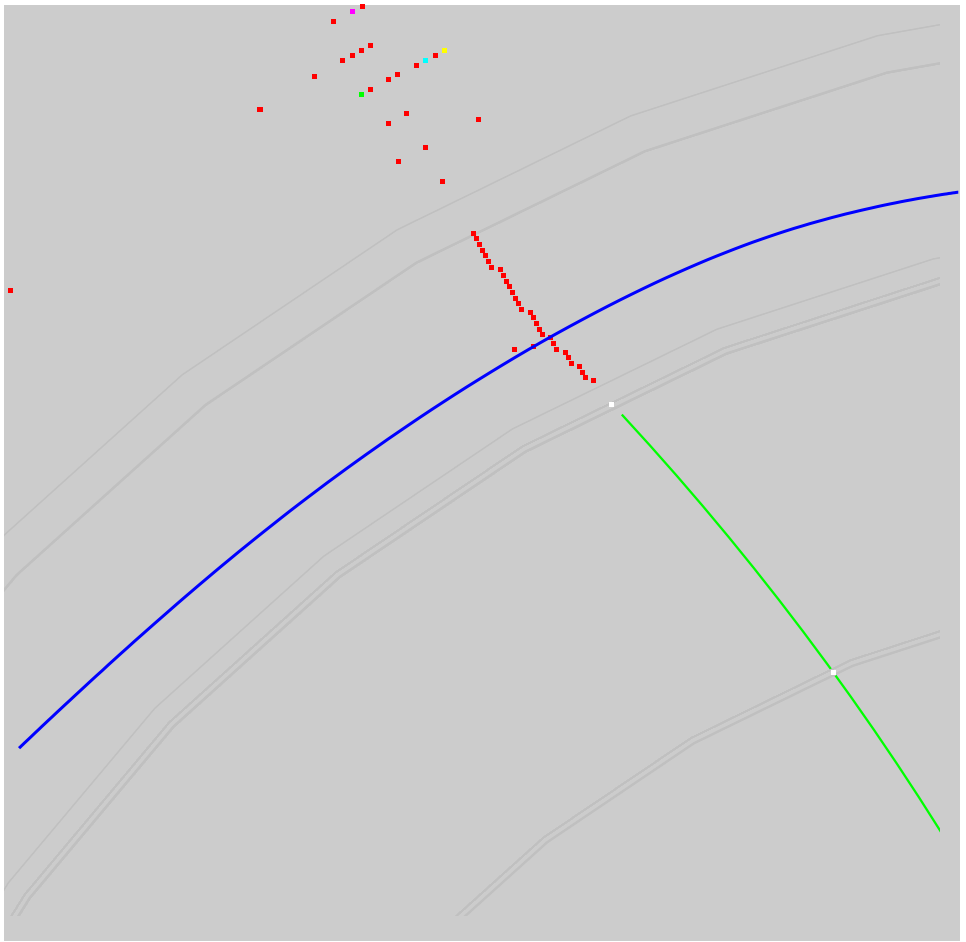
Events in Resolution Tail

- Right-Hand Side Tail:
  - $r_{\mathrm{Shower}} < r_{\mathrm{MC}}$
  - **Hadronic Interaction of Particle**



Events in Resolution Tail

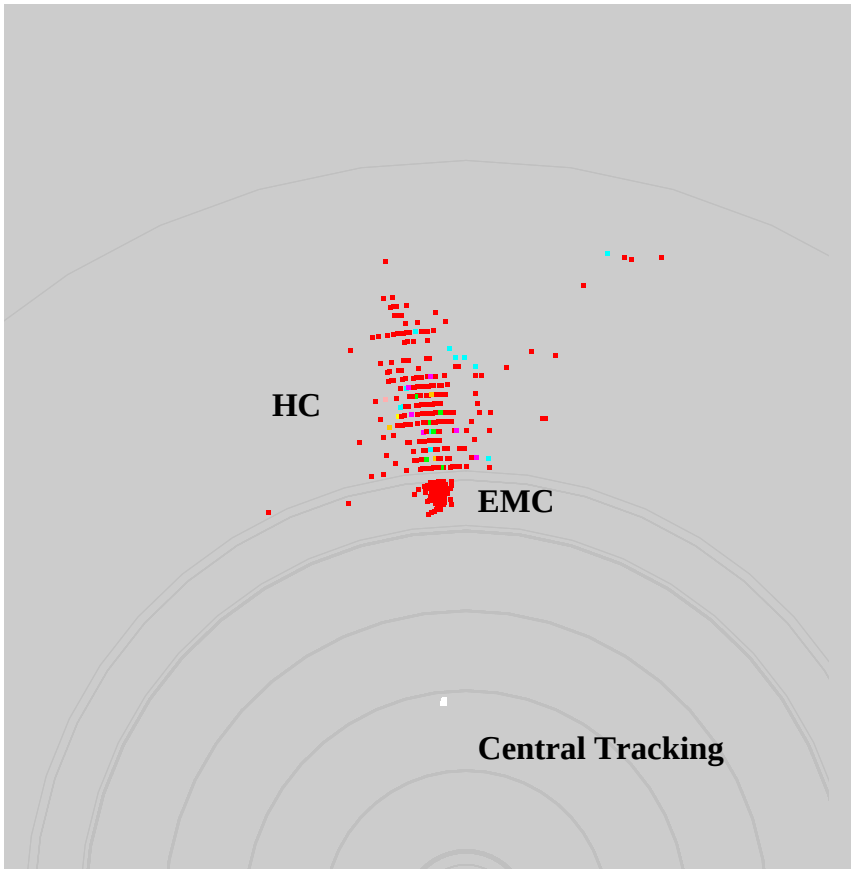
- Left-Hand Side Tail:
  - $r_{\mathrm{Shower}} > r_{\mathrm{MC}}$
  - Decays $\pi \rightarrow \mu\overline{\nu}_{\mu}$

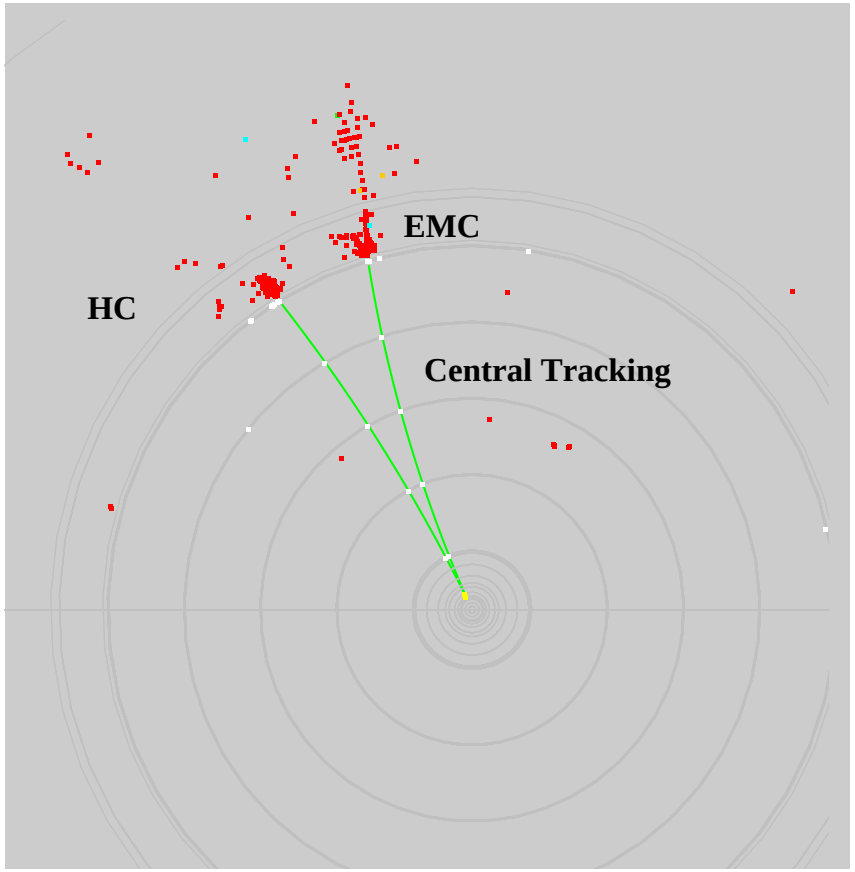


Radius of MC Shower Point

Application to K^0_S Events (I)

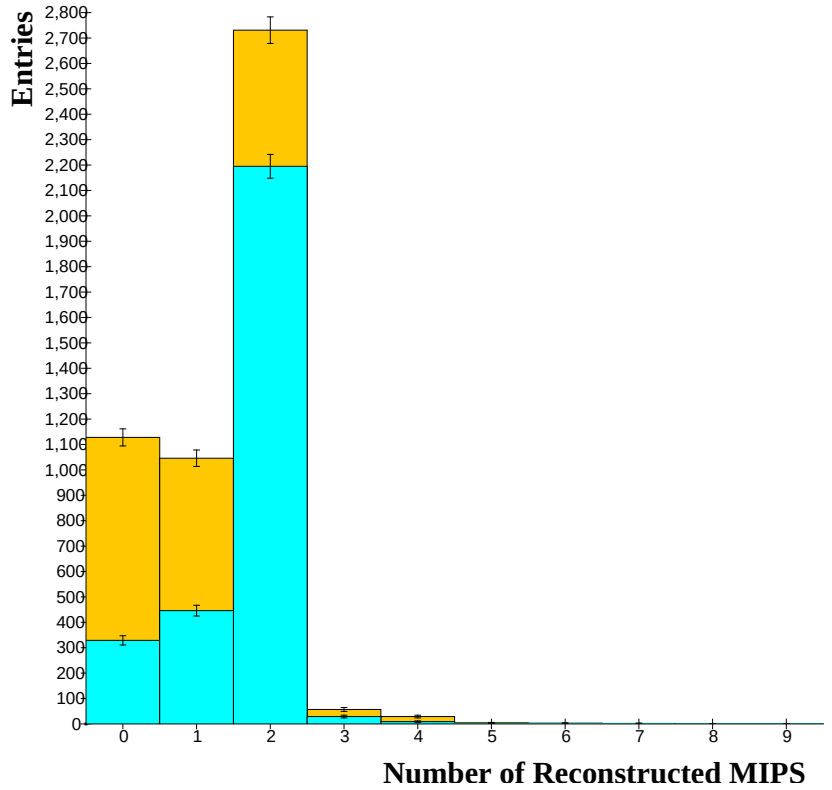
- Events with 0/1 MIP Candidate:



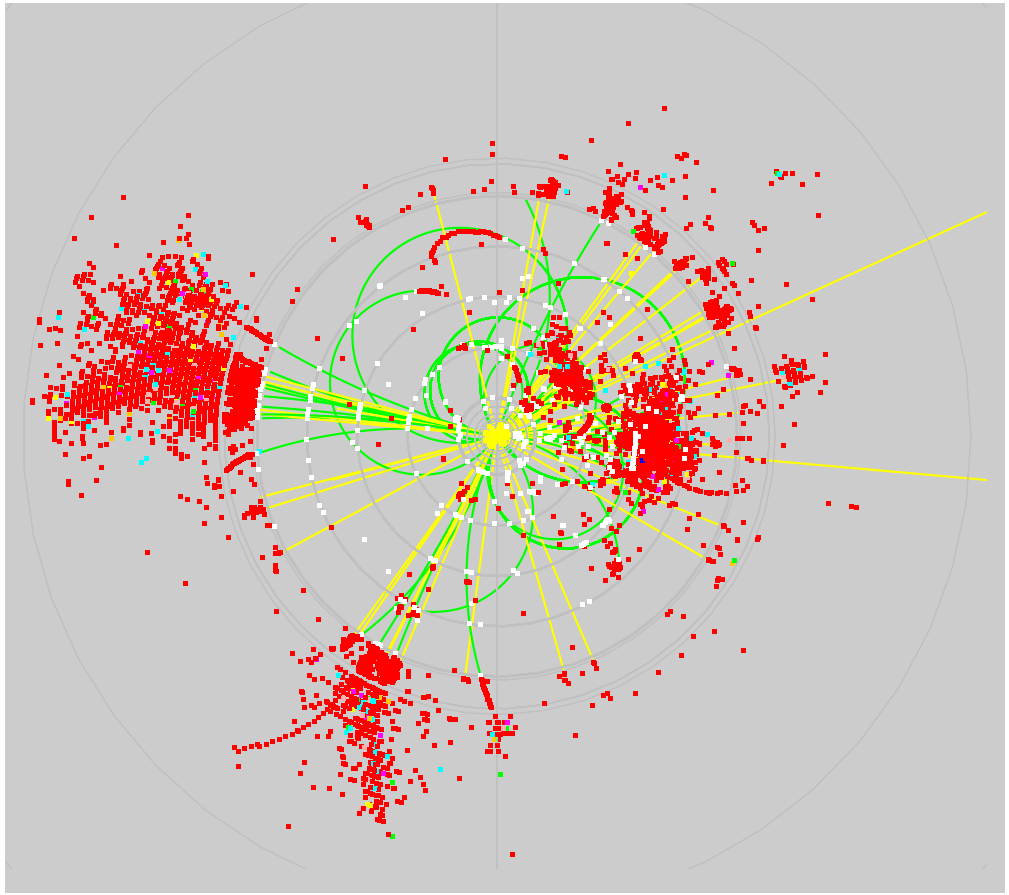


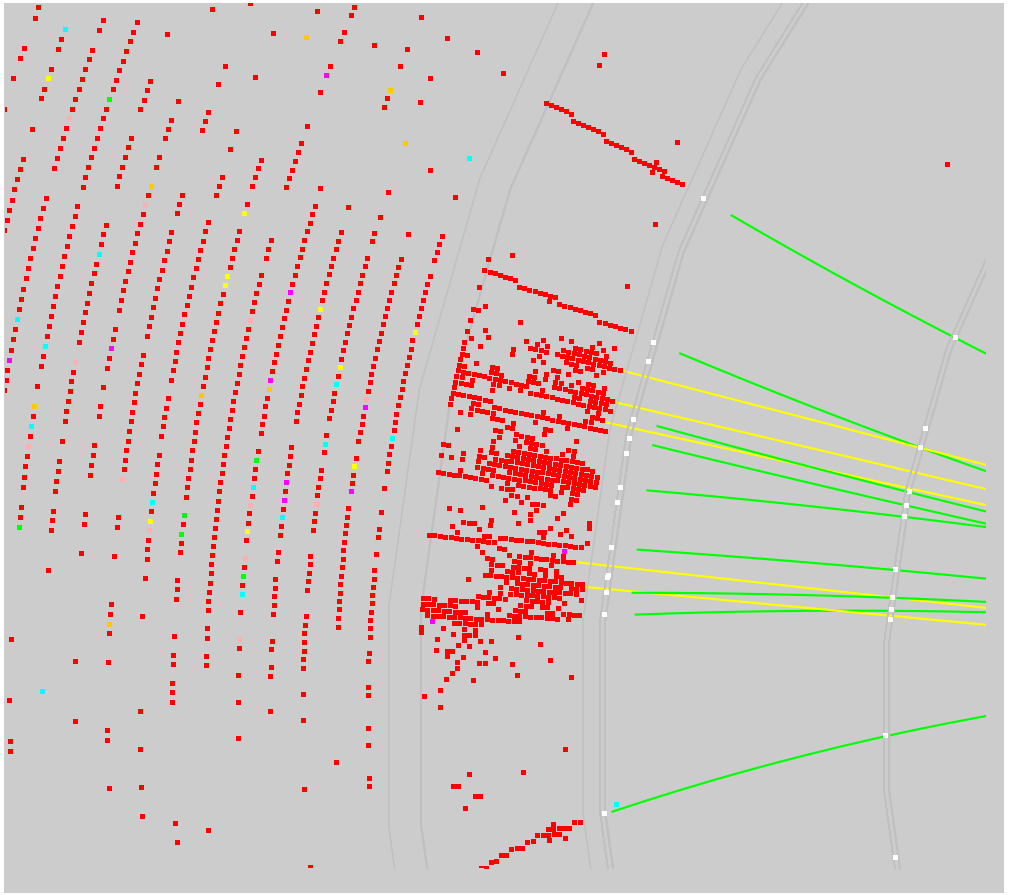
Application to K^0_S Events (II)

- Event Sample:
  Single K^0_S ($E = 25\mathrm{GeV}$)
- Detection Efficiency:
  - **Overall:** $> 50\%$
  - **Relative:** $\sim 75\%$



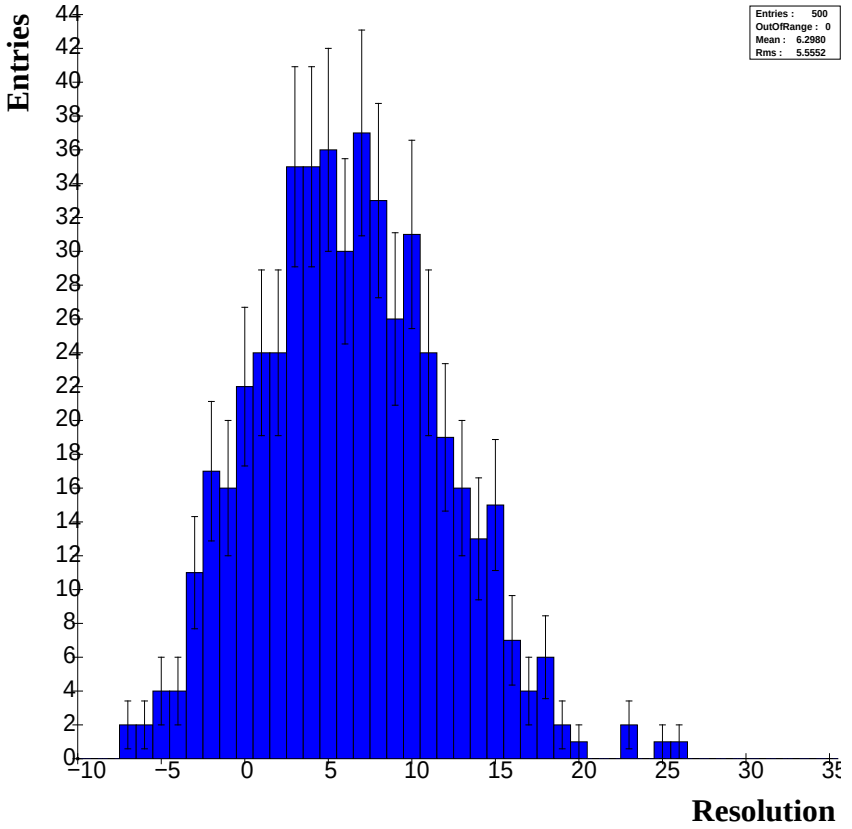
Application to $t\bar{t}$ Events (I)





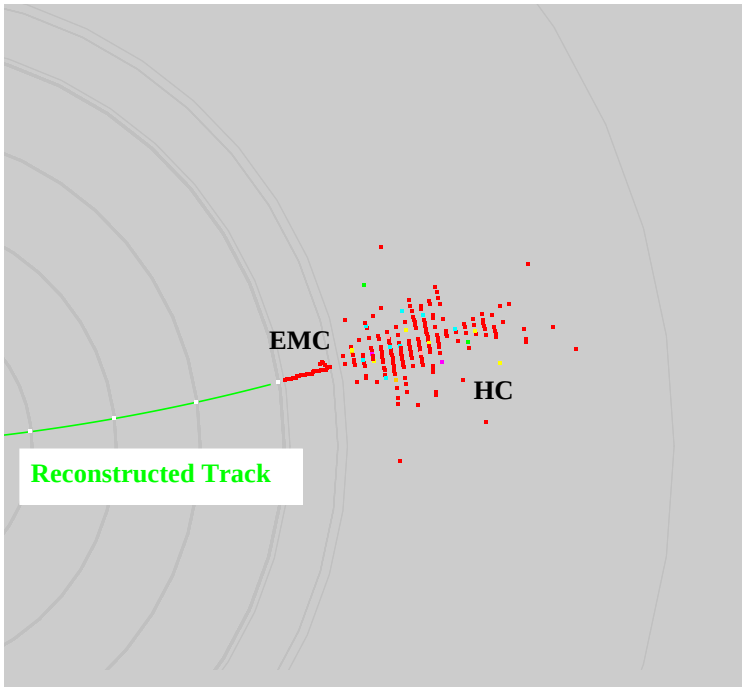
Application to $t\bar{t}$ Events (II)

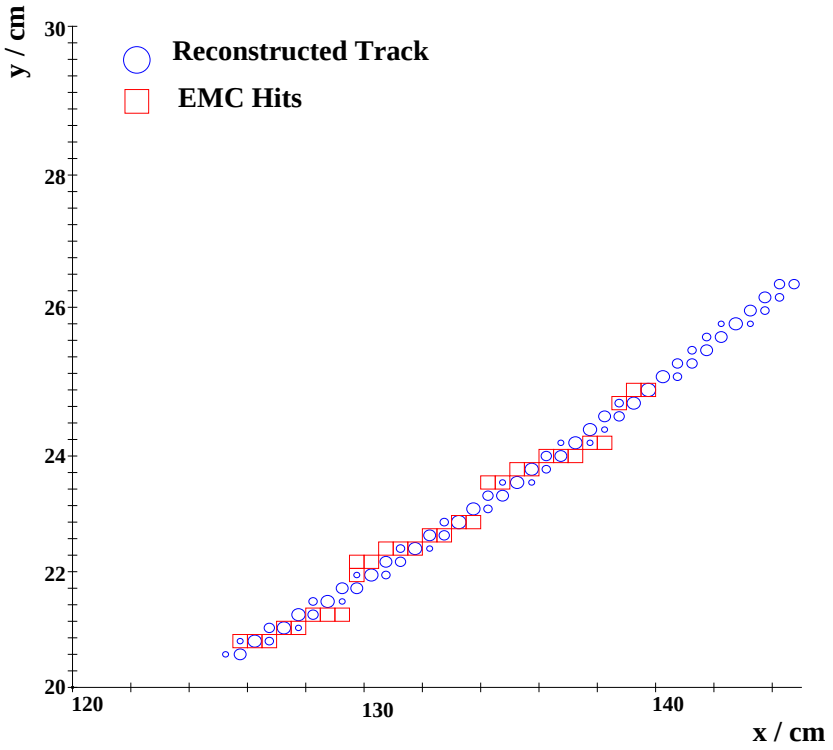
- N.o. MIPS (Resolution):
  (Measured - Reconstruction)
- Refine Algorithm:
  - **Tune Number of Required MIP Hits**
  - **Apply Algorithm**
    Outside $\longrightarrow$ Inside
  - **Use 'Track' Fit to Calorimeter Hits for Combination**



Fit of EMC MIP Tracks (I)

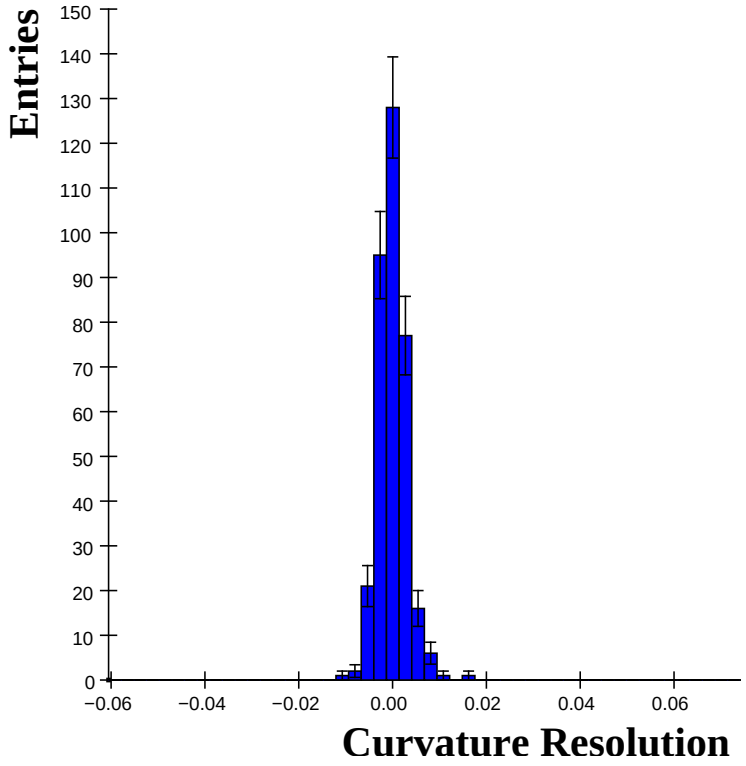
- Use Information of EMC Alone
- Fit Helix Parameters in (xy) and (zy) Plane

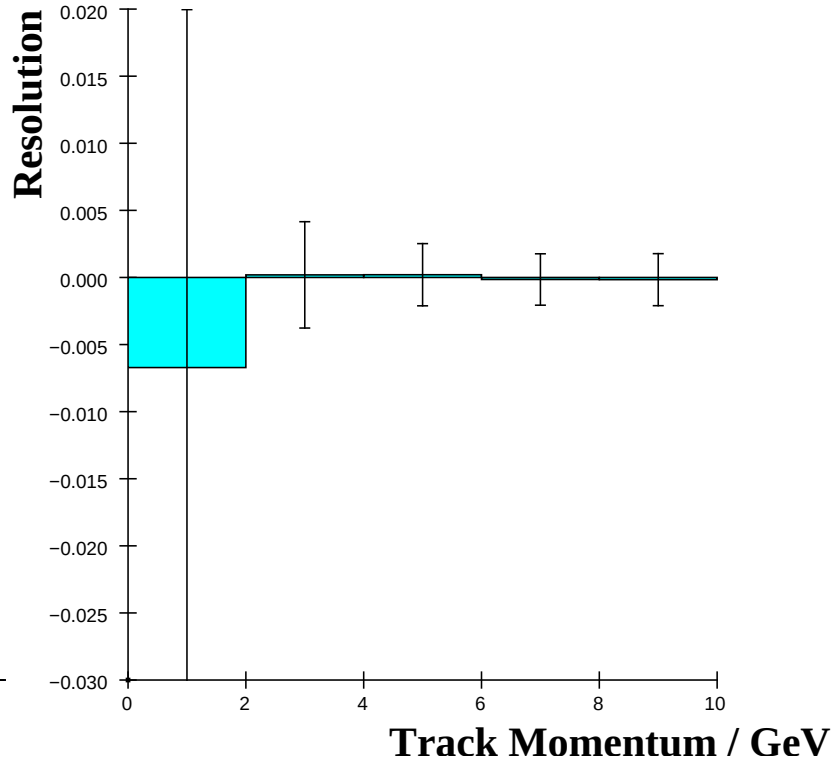




Fit of EMC MIP Tracks (II)

- Curvature (κ) Resolution $(\kappa = 1/\mathrm{Radius})$





Conclusion

- Energy Flow Studies ...
  - **... Based on Events Simulated Using GEANT4**
- MIP Tracking Algorithm Developed
  - **Single Pion Tracks**
  - **Events Containing K^0_S Decays**
  - **Physics Events Containing $\mathrm{t\bar{t}}$ Events**
- Performance
  - **Single Pion Sample**
    - **High Efficiency MIP Tracking ($\varepsilon > 90\%$)**
    - **Reconstruction of Showering Point with High Precision ($\sigma = \pm 1$ Layer)**
  - **Single K^0_S Sample**
    - **High Efficiency Tracking ($\varepsilon > 75\%$)**
  - **Physics Events ($\mathrm{t\bar{t}}$) Require Refinement**
  - **Helix Fit to EMC Hits only – Good p_T Resolution**

Outlook

- Final Goal: Establishing Full ‘Energy Flow Algorithm’ by ...
  - **... Finalize MIP Tracking**
  - **... Implementation of Electromagnetic Shower Identification**
  - **... Add Clustering in Hadronic Calorimeter**
  - **... Aim for Full Jet Energy Reconstruction in WW and ZZ Events.**