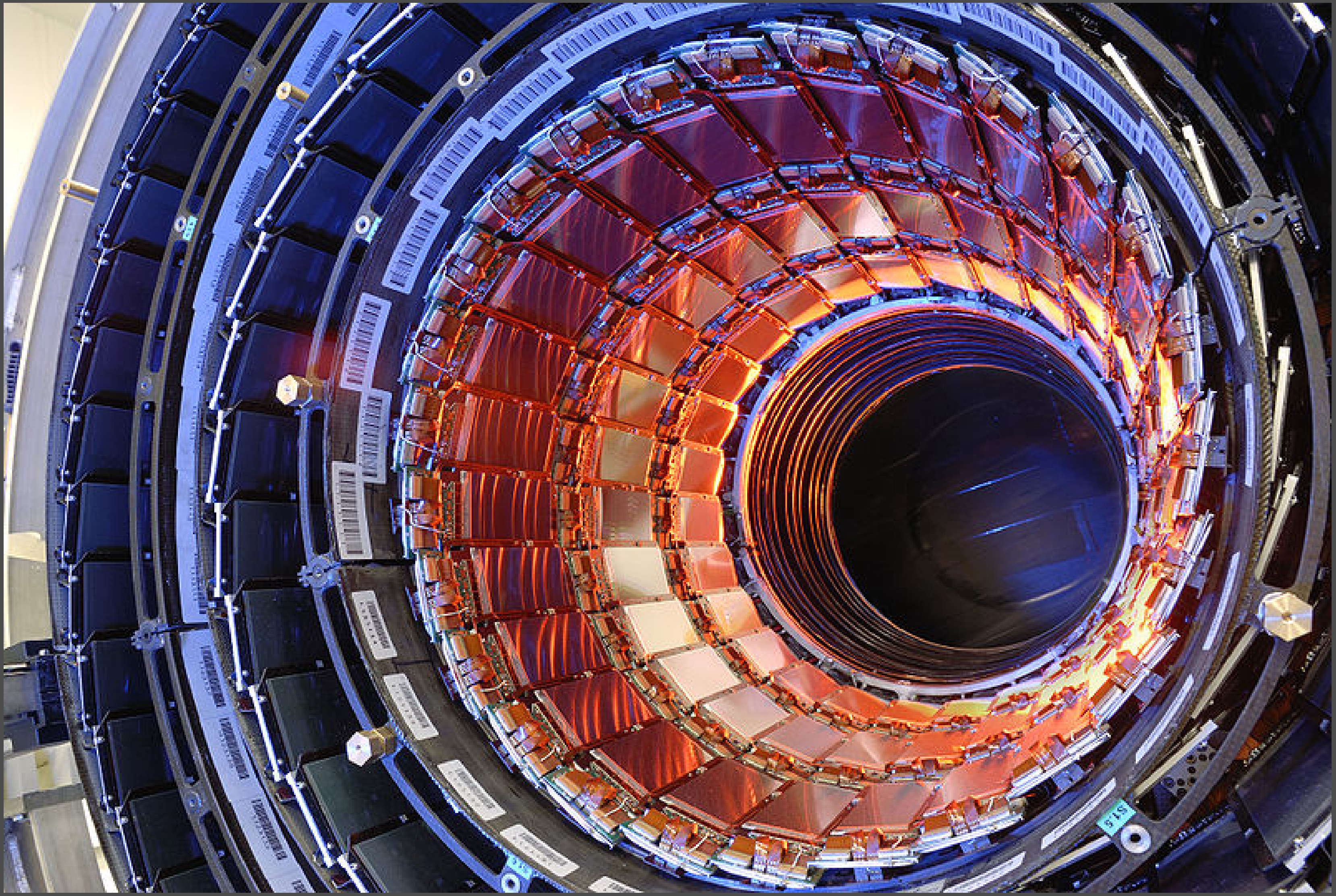


Performance of the CMS Silicon Tracker

Matthew Chan (MIT)
On behalf of the CMS Collaboration

June 6, 2011

RD11, Firenze

Outline

- CMS Tracker Overview
- Track Reconstruction and Efficiency
- Primary Vertex Reconstruction
- Track Impact Parameter
- B-Tagging

CMS Tracker

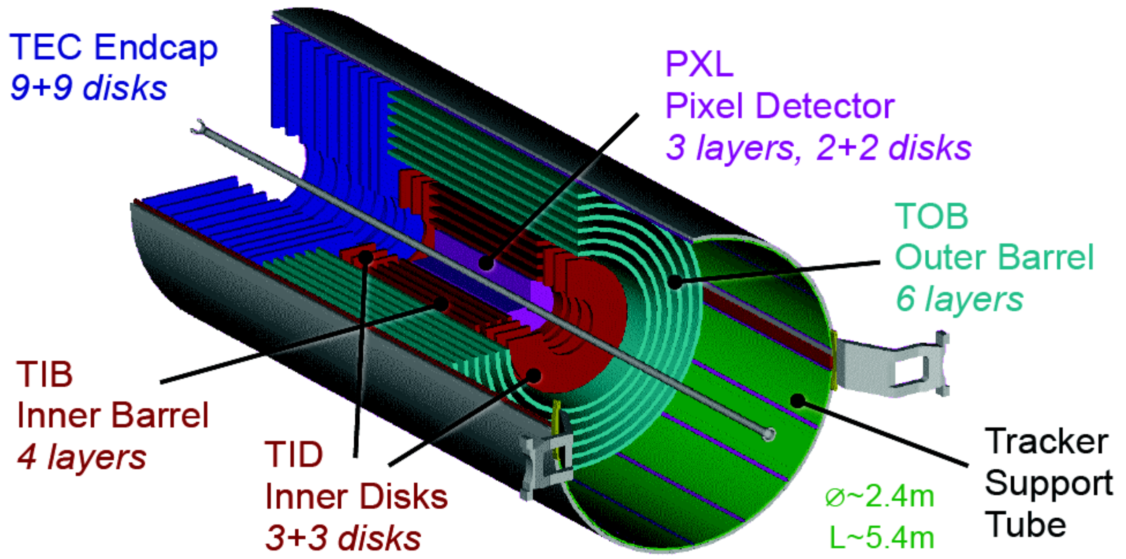
Pixel Detector

66 million channels

Pixel size: 100x150 μm^2

Inner radius: 4.4 cm

Outer radius: 10.2 cm



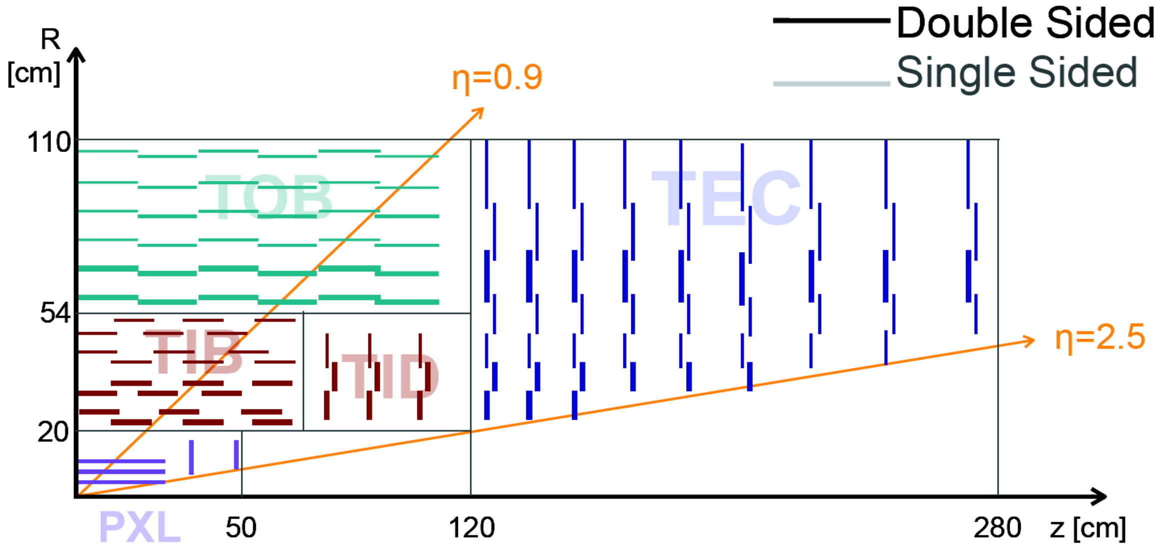
Silicon Strip Detector

9 million channels

Silicon area: 200 m^2

Inner radius: 25.5 cm

Outer radius: 1.2 m



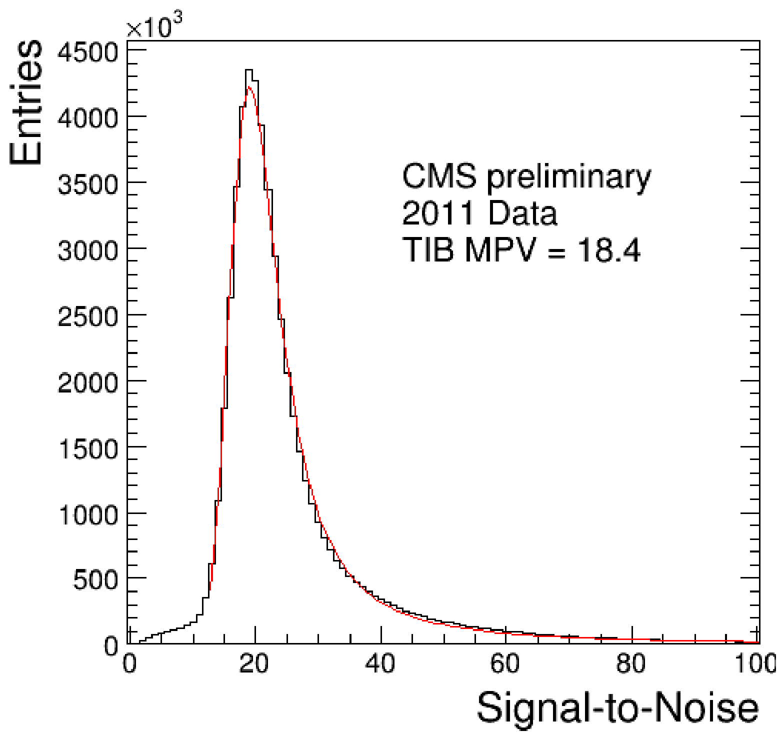
Signal to Noise

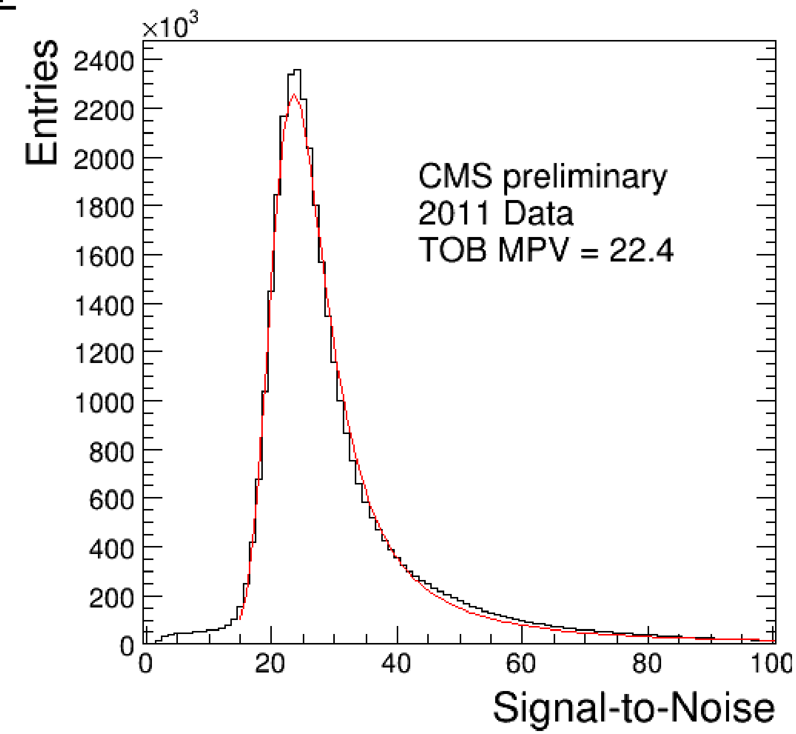
- Signal-to-noise:
  Cluster signal / noise of strips
- Cluster required to be part of a track

2010 Signal-to-Noise

Tracker Section	S/N
TIB	19.4
TID	18.5
TOB	22.5
TEC+ / TEC- (thin)	19.1 / 19.4
TEC+ / TEC- (thick)	23.4 / 23.9

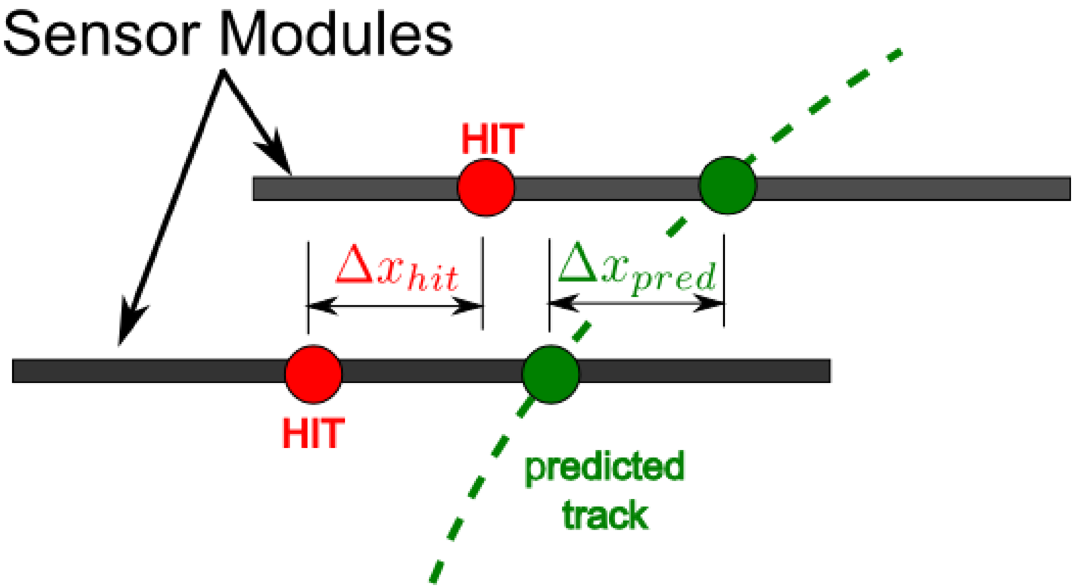
<u>2011</u>



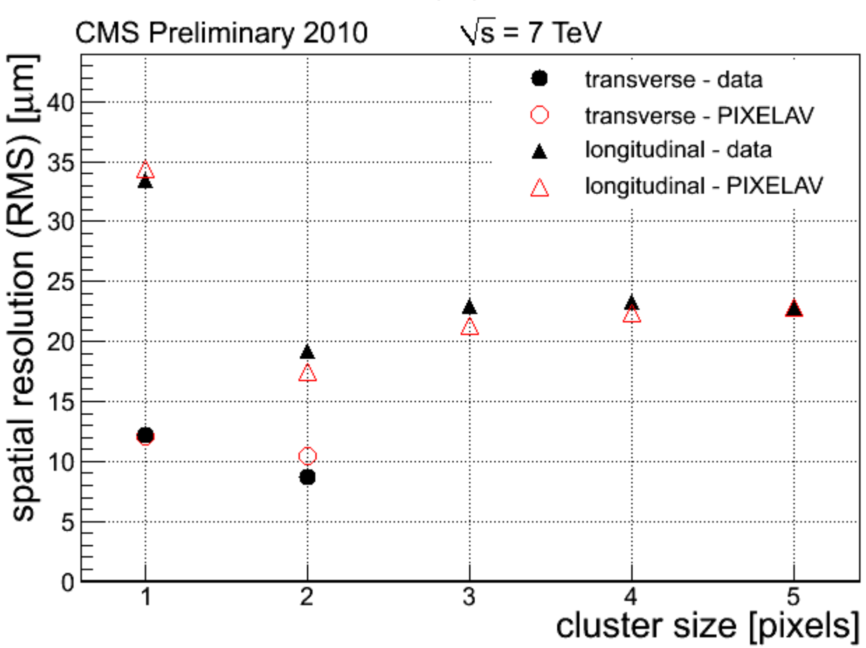


Hit Resolution

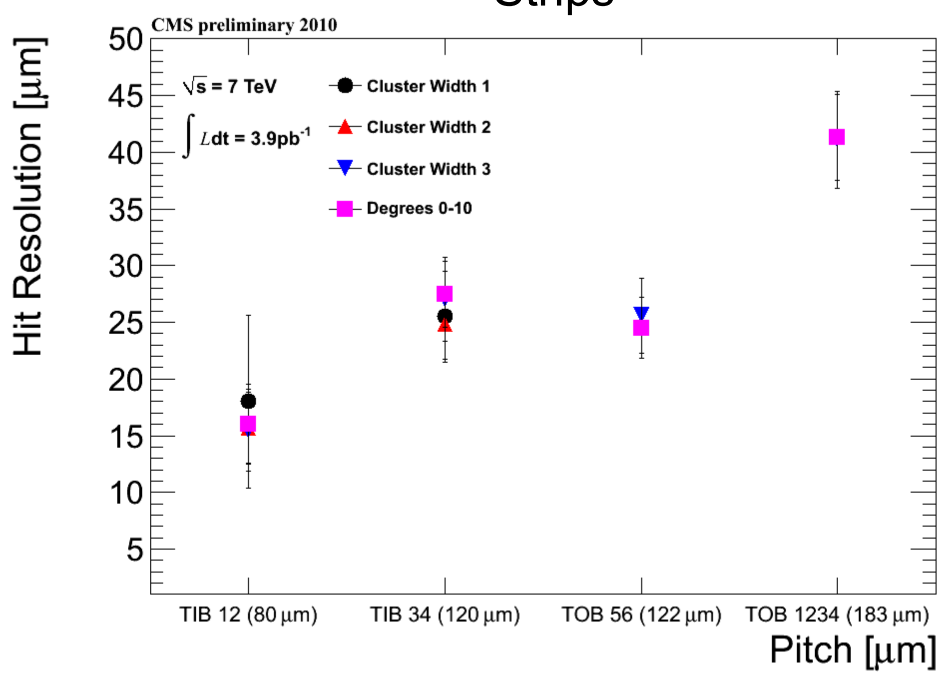
- Hit resolution measured from module overlaps
- Pixel hit resolution ~ 9 – 35 μm
- Strip hit resolution ~ 15 – 45 μm



Pixels

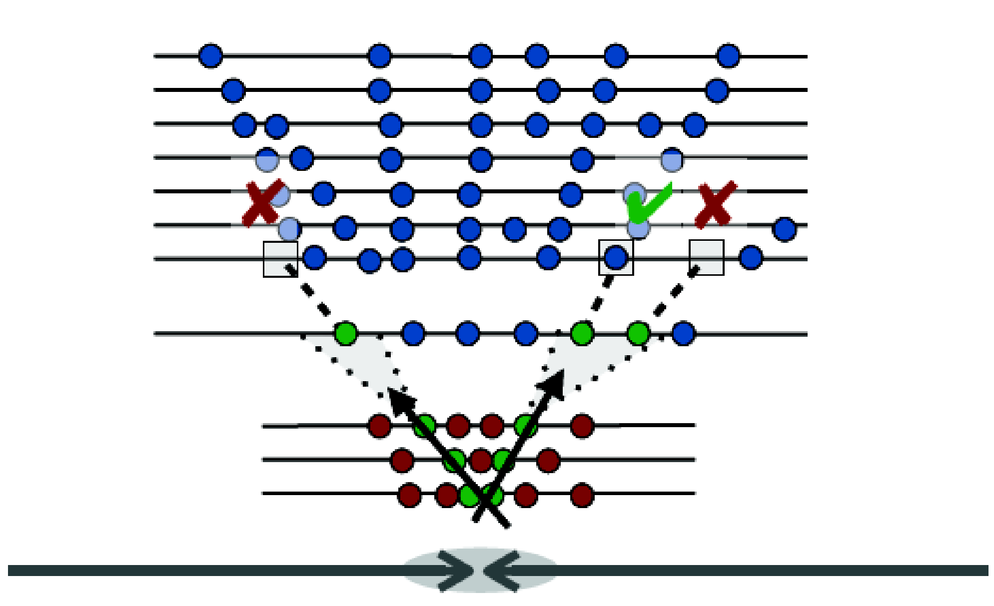


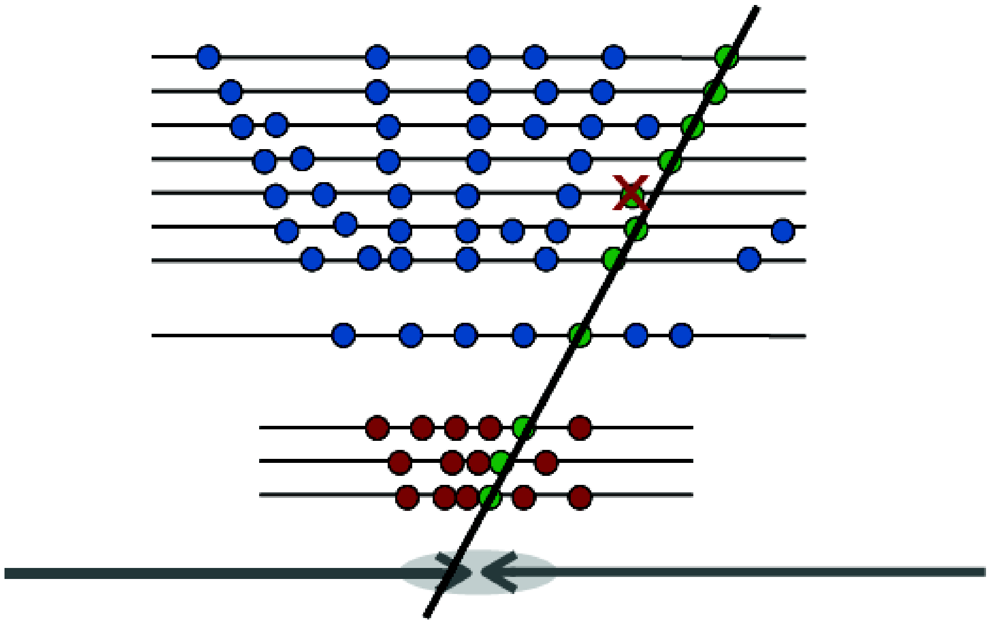
Strips



Track Reconstruction

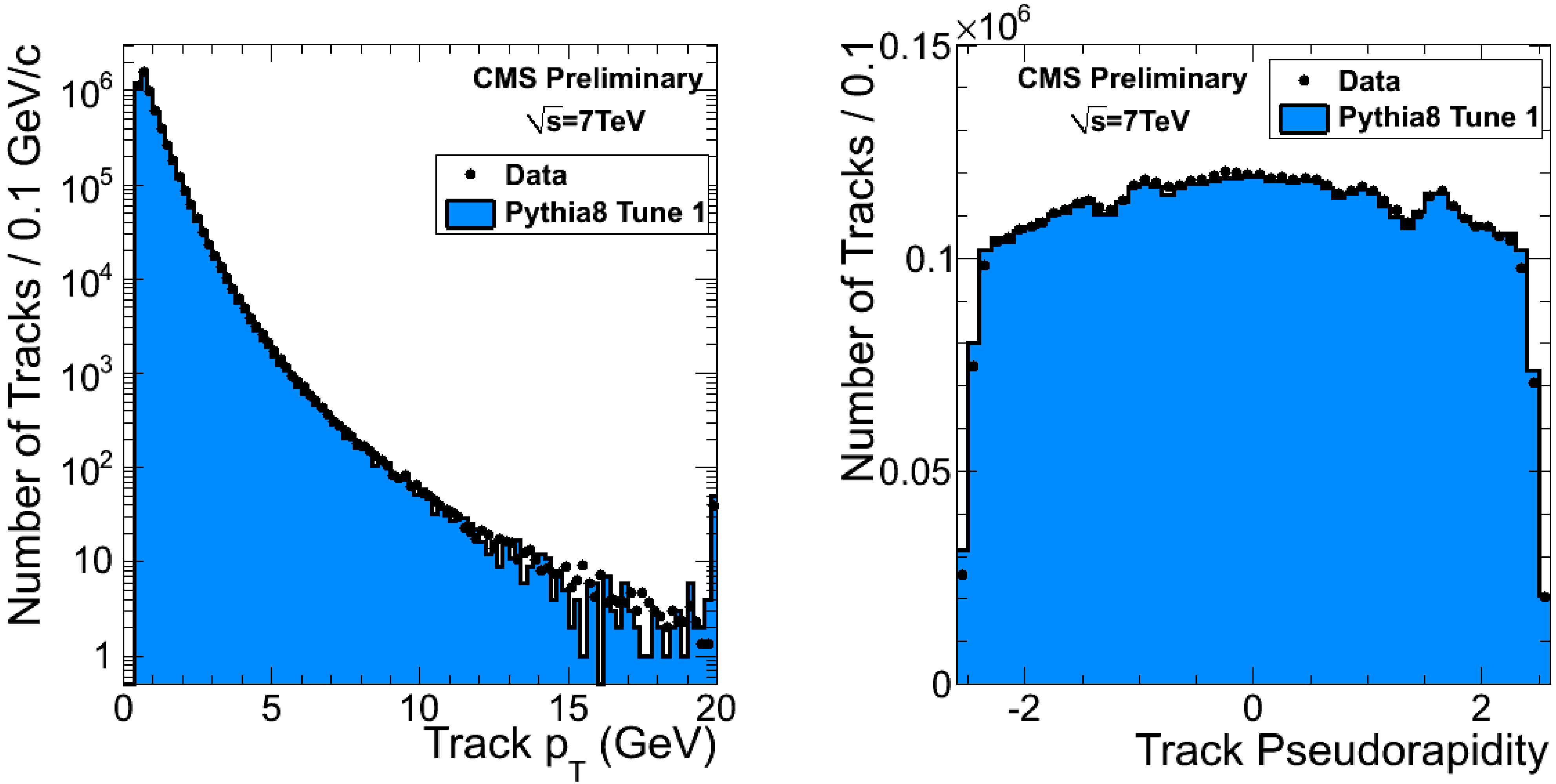
- Pixel seeding (pair or triplet)
- Kalman filter-based pattern recognition
- Iterative tracking





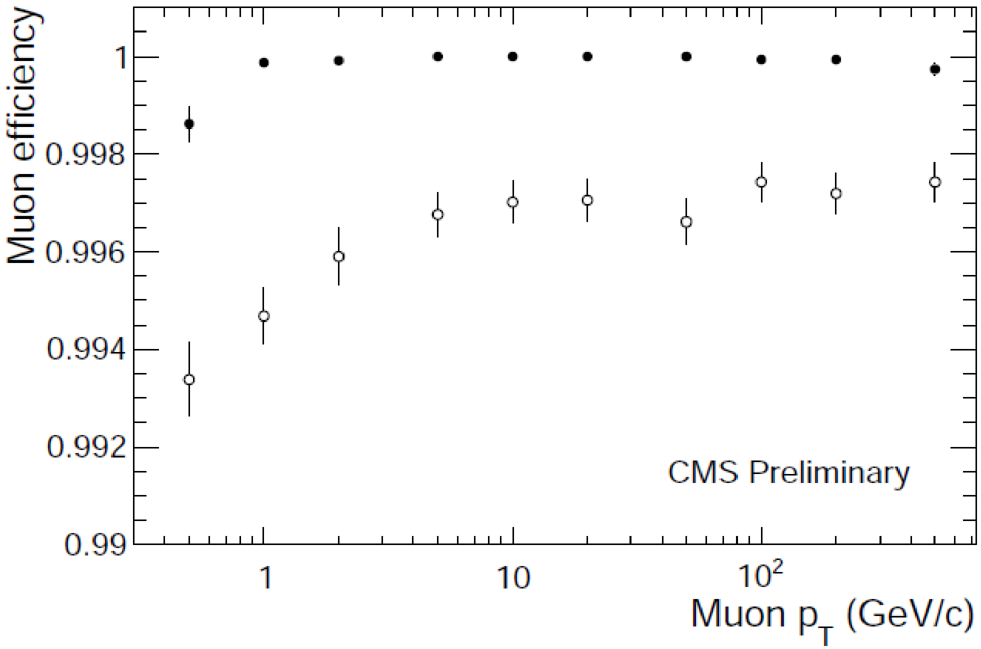
Track Simulation vs Data

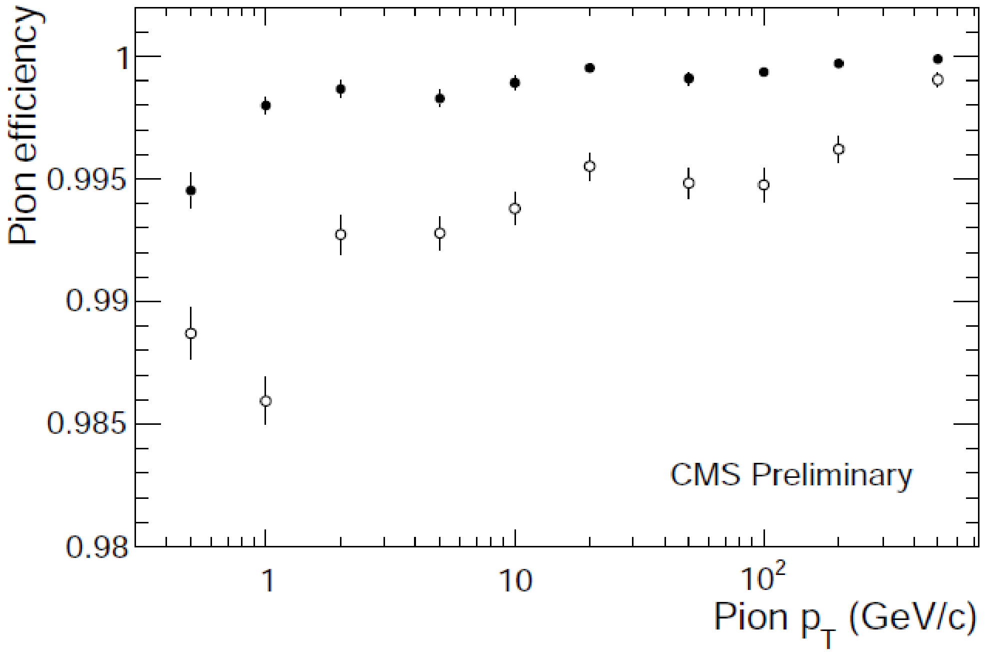
Pythia 8
GEANT4



Efficiency from Embedded Tracks

- Embed simulated tracks in real minimum-bias events
- Test if track is still reconstructed
- Measures robustness of tracking against background and noise
- Over 99% for muons and pions

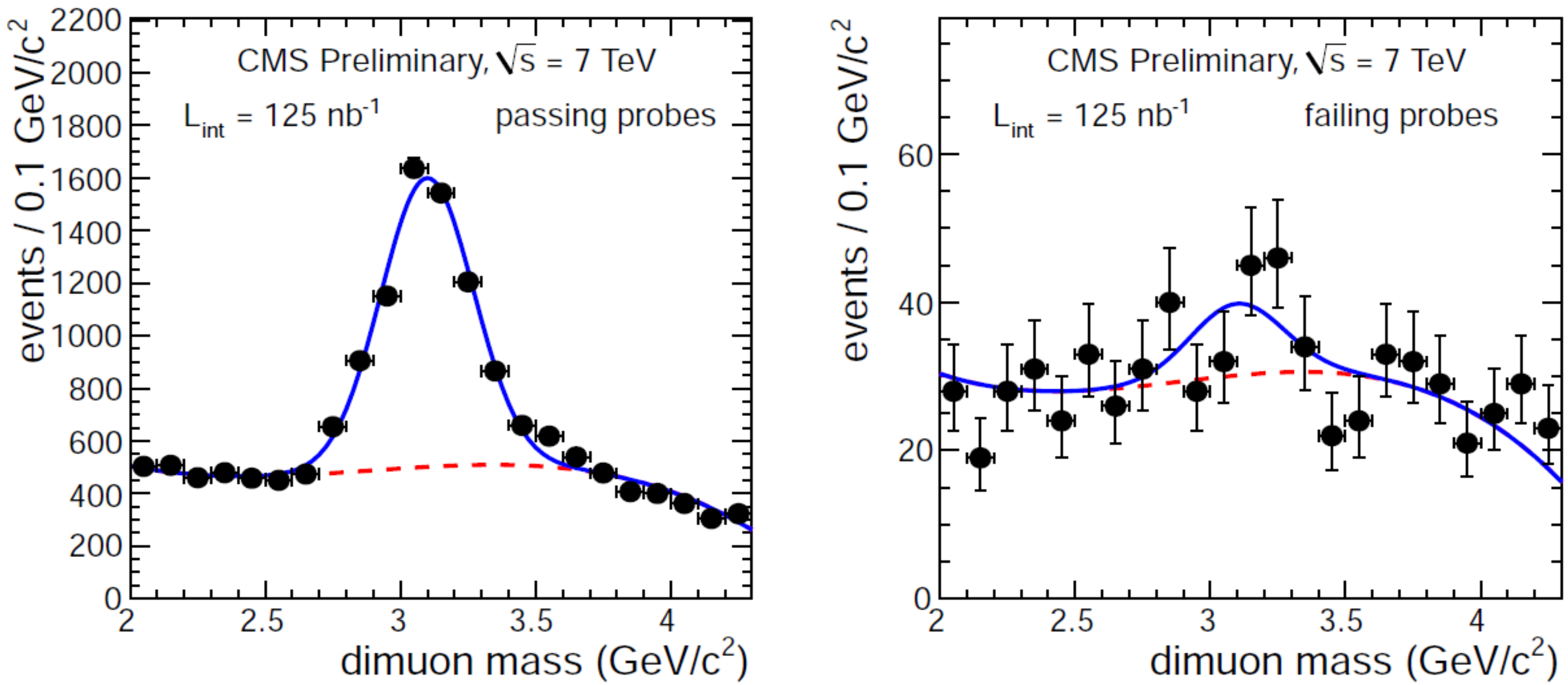




Open circles: Simulated track embedded in data
Solid circles: Simulated events

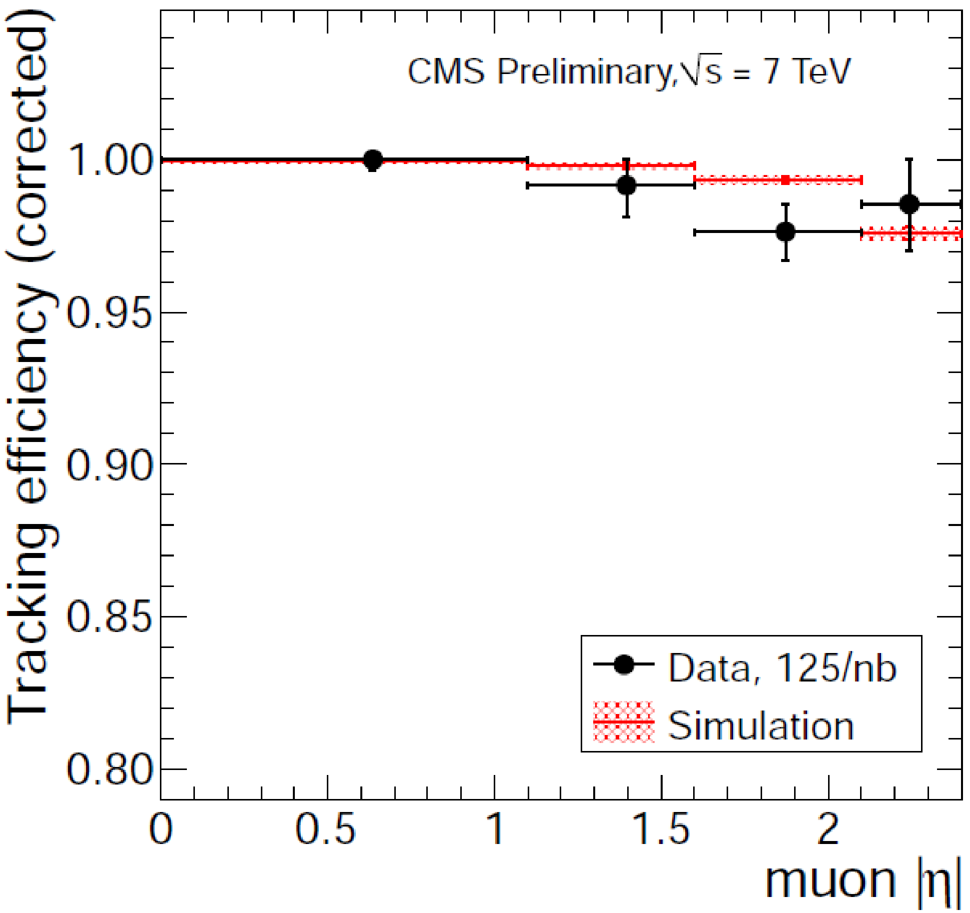
Muon Tracking Efficiency

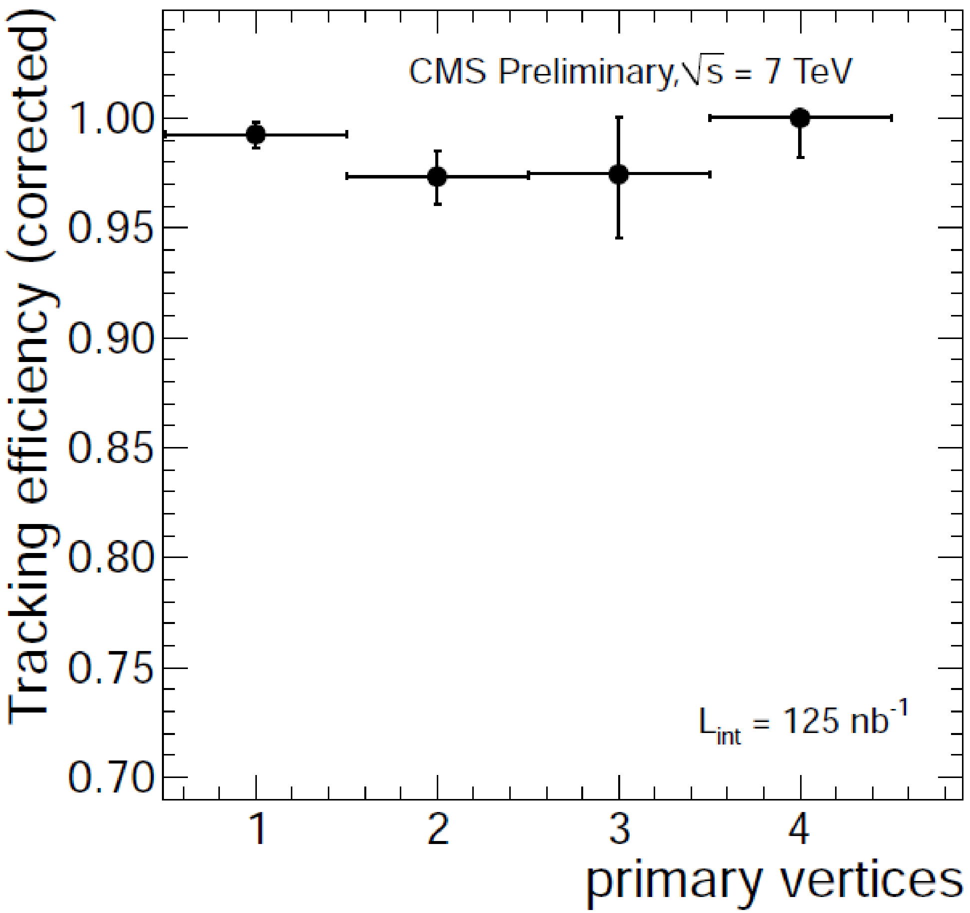
- "Tag and Probe" with $J/\psi \rightarrow \mu\mu$
  - Tag: Muon reconstructed in tracker AND muon chambers
  - Probe: Another muon reconstructed in muon chambers
- Probe muon passes if it matches to a track
- Extract signal yield by applying fit to passing and failing mass distributions
- $\varepsilon = N_{match}/(N_{match}+N_{fail})$



Muon Tracking Efficiency Results

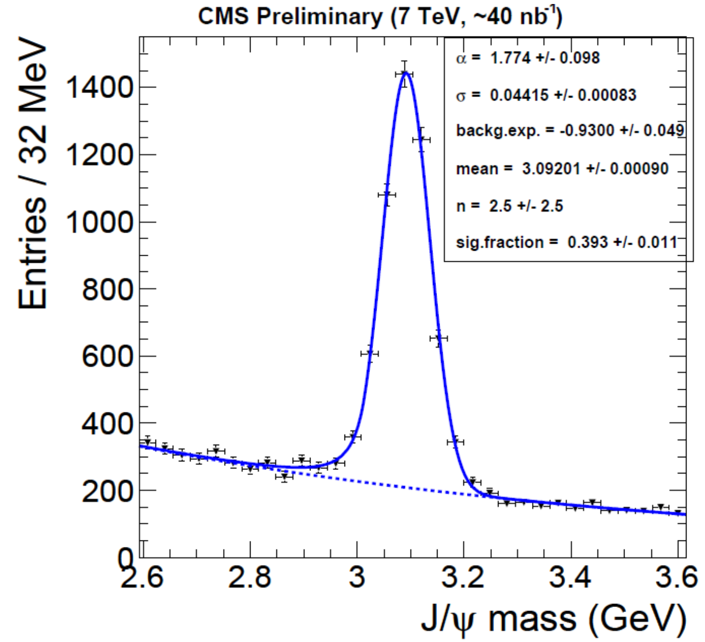
Muon efficiency 98-100%, depending on η



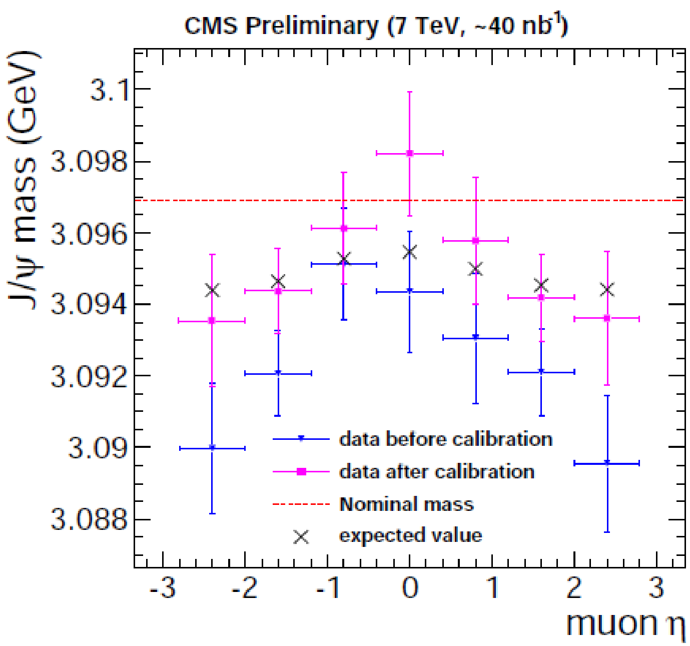


Momentum Resolution

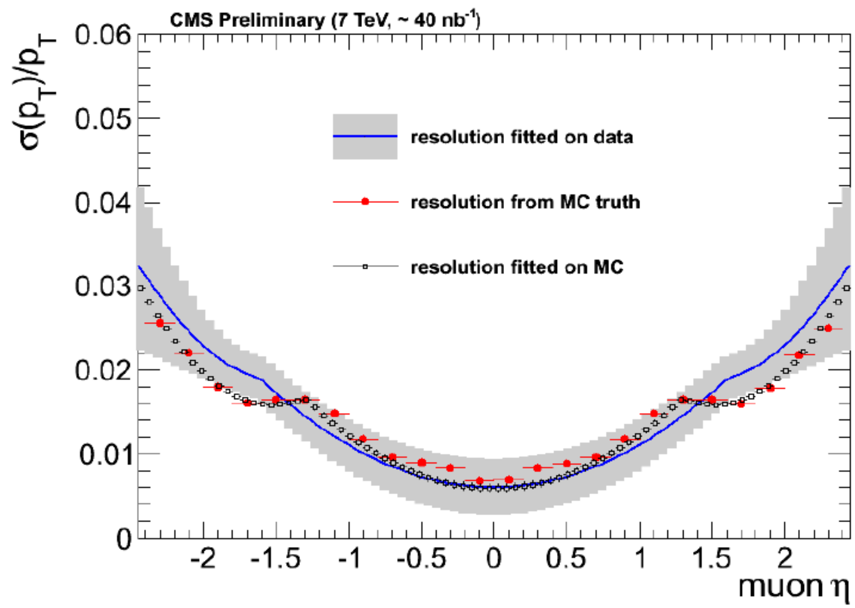
- Momentum scale and resolution extracted from J/ψ line shape
- Scale from shift and width
  - ~ 2 MeV
- Momentum resolution from width
  - 1 – 3%



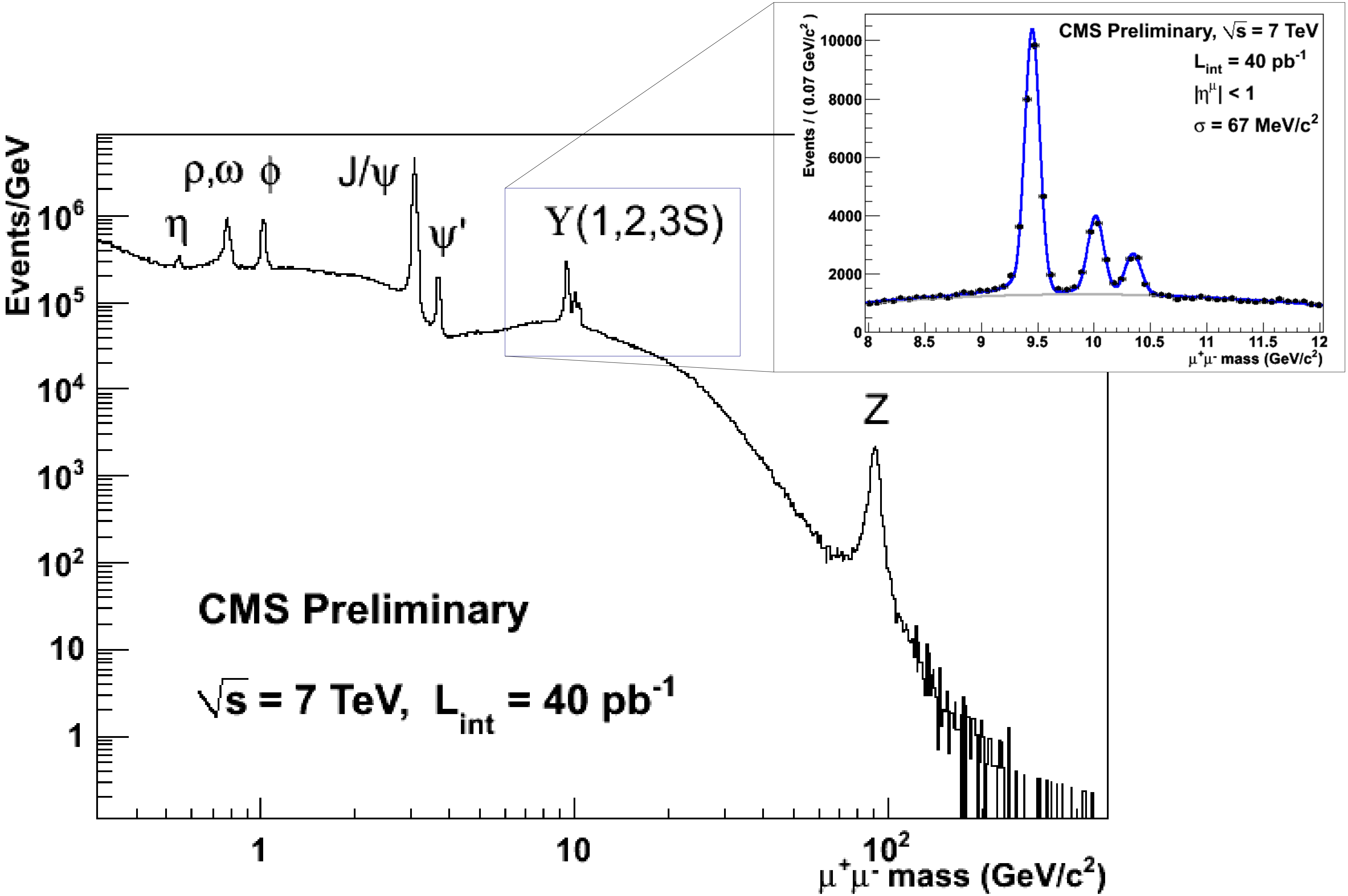
Scale



Resolution

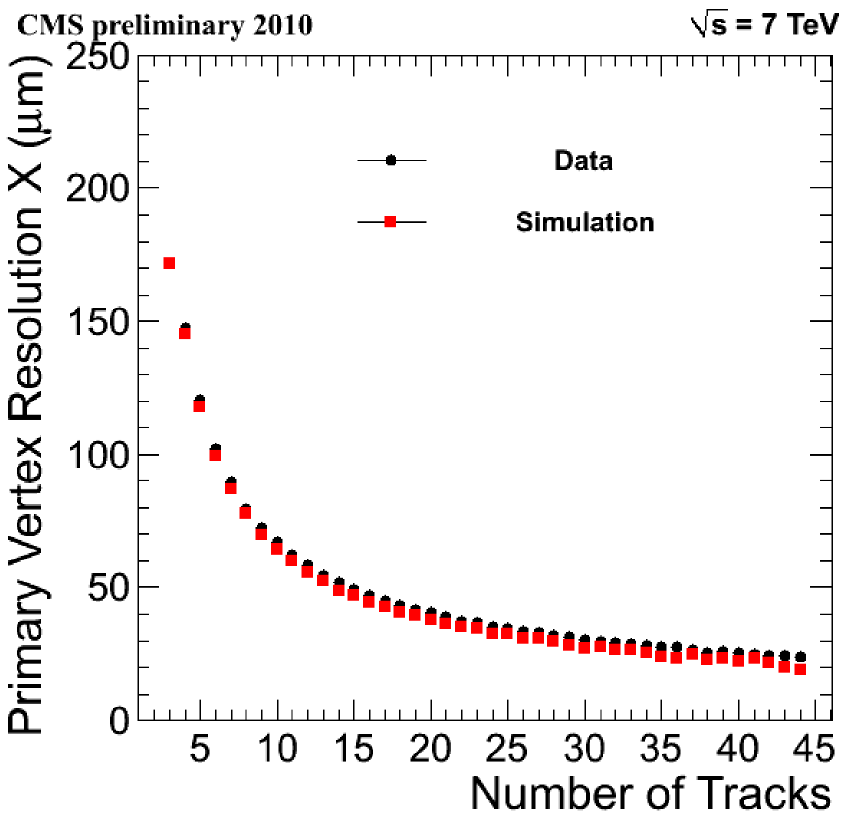


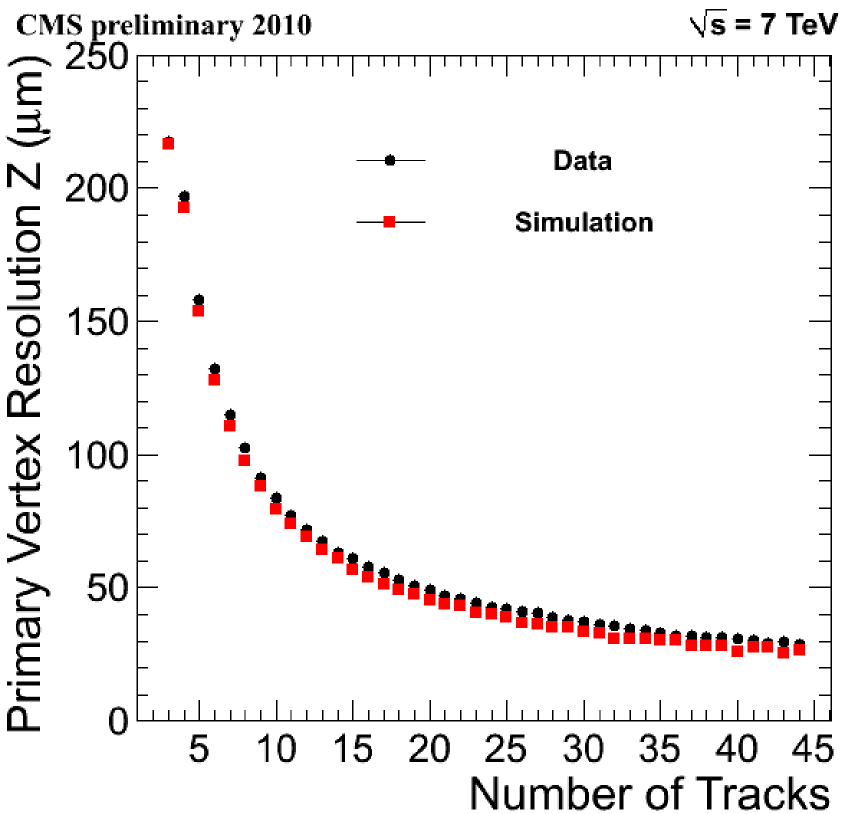
Di-Muon Mass Spectrum



Primary Vertex

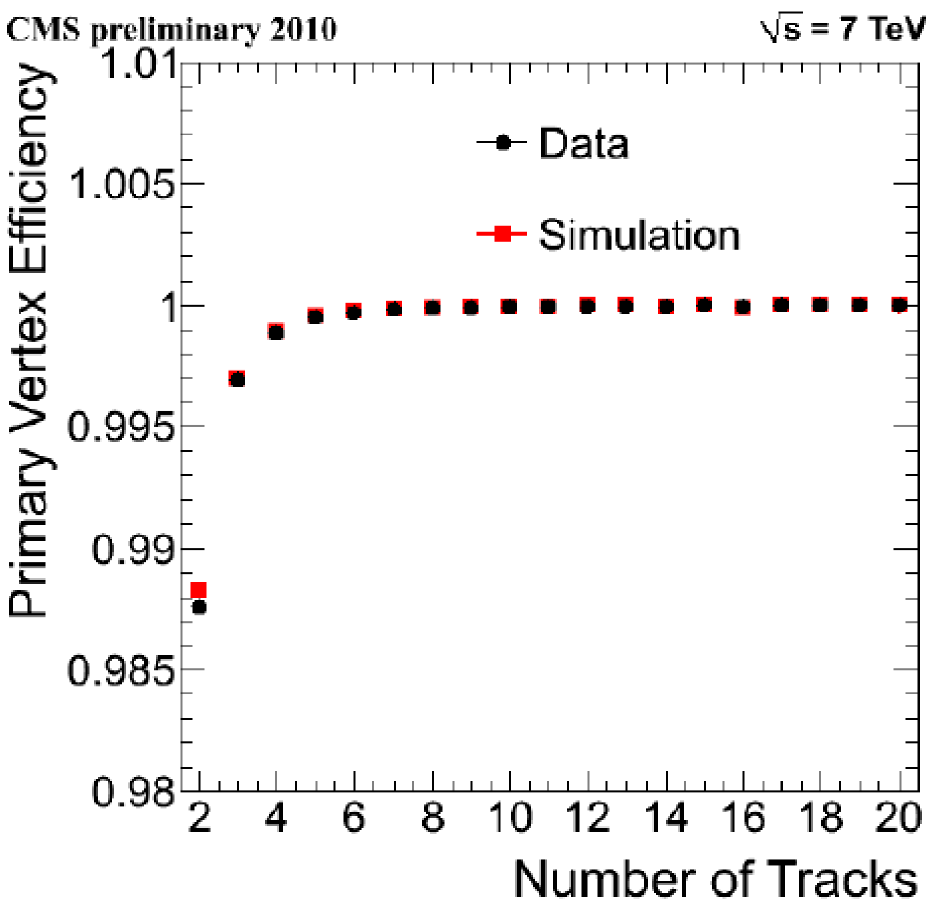
- Adaptive vertex fit on tracks within 1 cm of each other in z
- PV Resolution
  - "Split Method": Each PV randomly split into two equal groups of tracks
  - Each group of tracks is fit separately and compared
  - For PV with more than 30 tracks, σ ~ 25 μm





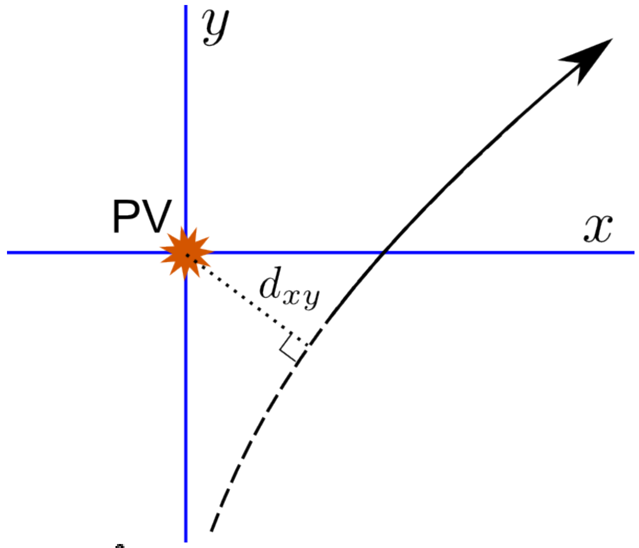
Primary Vertex Efficiency

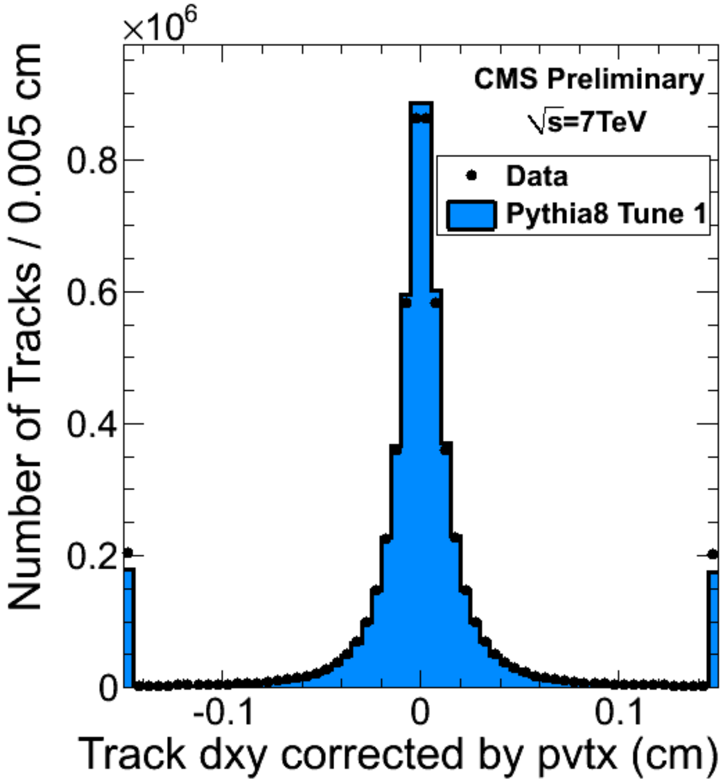
- "Split Method" + tag and probe
- Tracks split in two sets (2/3 tag, 1/3 probe) and fit separately for PV position
- Probe passes if matched within 5 σ_z of original vertex, given that tag also matches
- Efficiency ~ 100% if more than 4 tracks

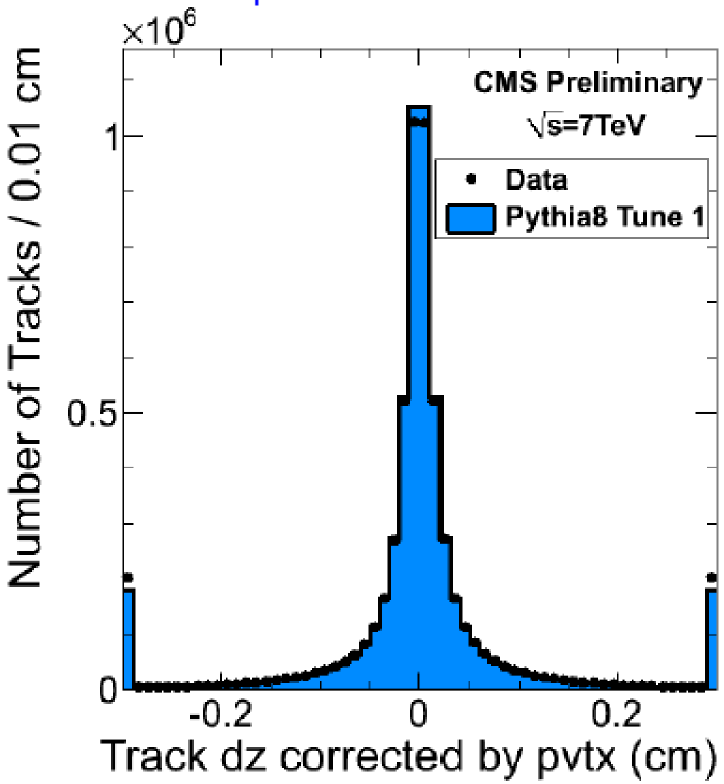


Track Impact Parameter

- Impact Parameter:
  Distance of closest approach
- Positive if PV is to the left when looking along trajectory





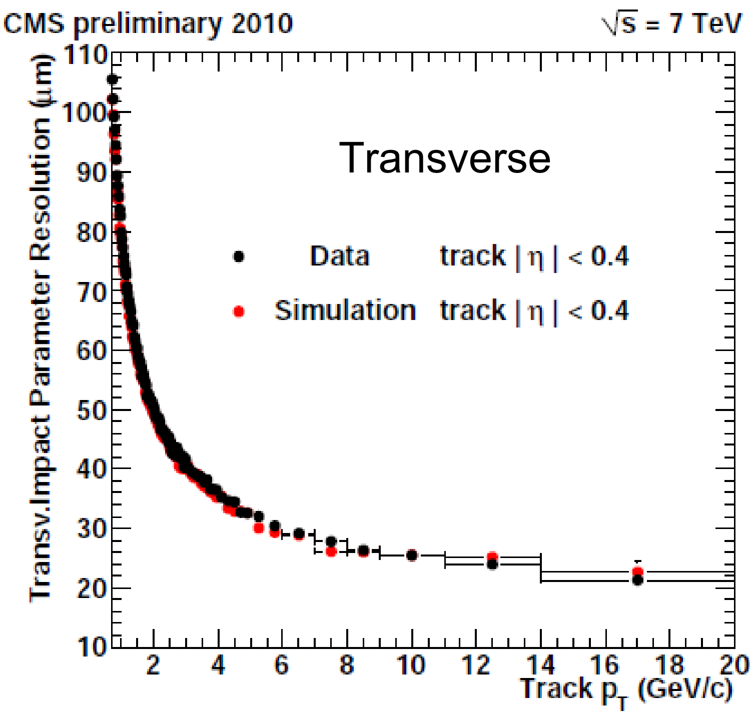


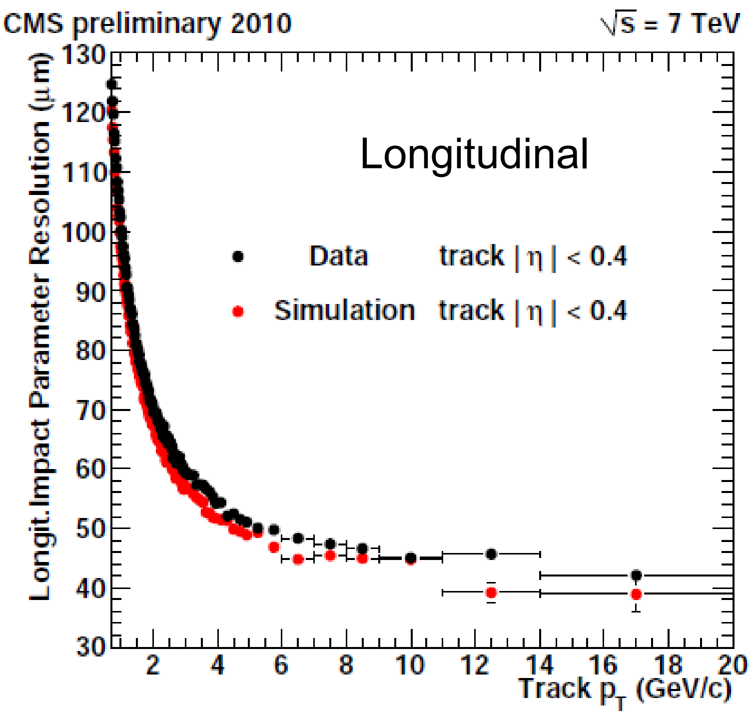
Track Impact Parameter Resolution

Resolution Measurement

1) One track is singled out from PV
2) PV position is re-fit with remaining tracks
3) Impact parameter is calculated for removed track
4) Distribution of impact parameters is fit with double Gaussian: one for PV position uncertainty, one for impact parameter resolution

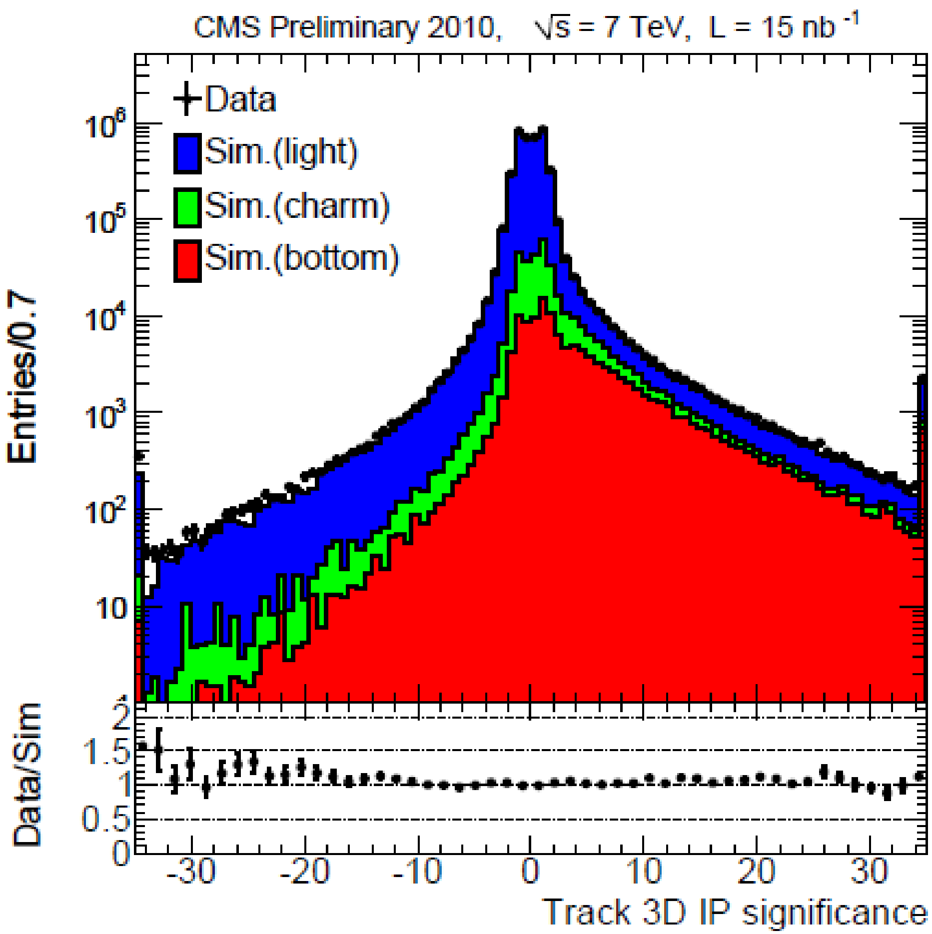
For high p_T, resolution is approximately 25 μm transverse, 40 μm longitudinal

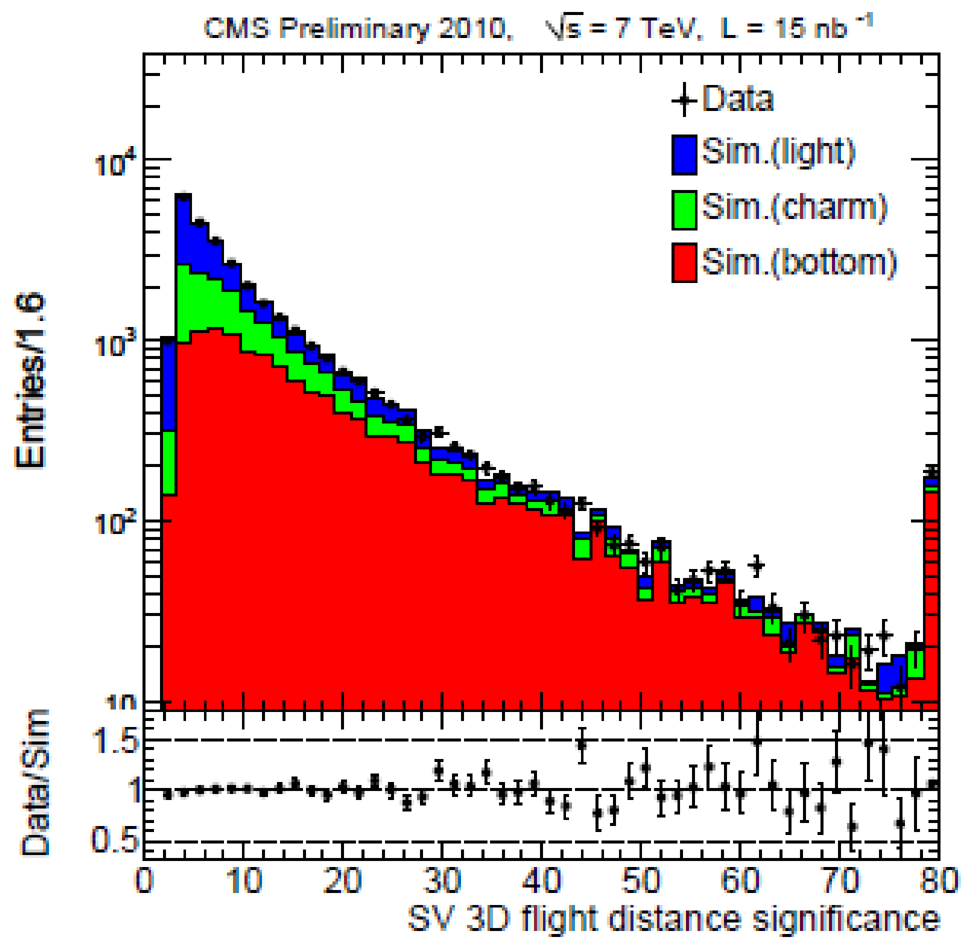




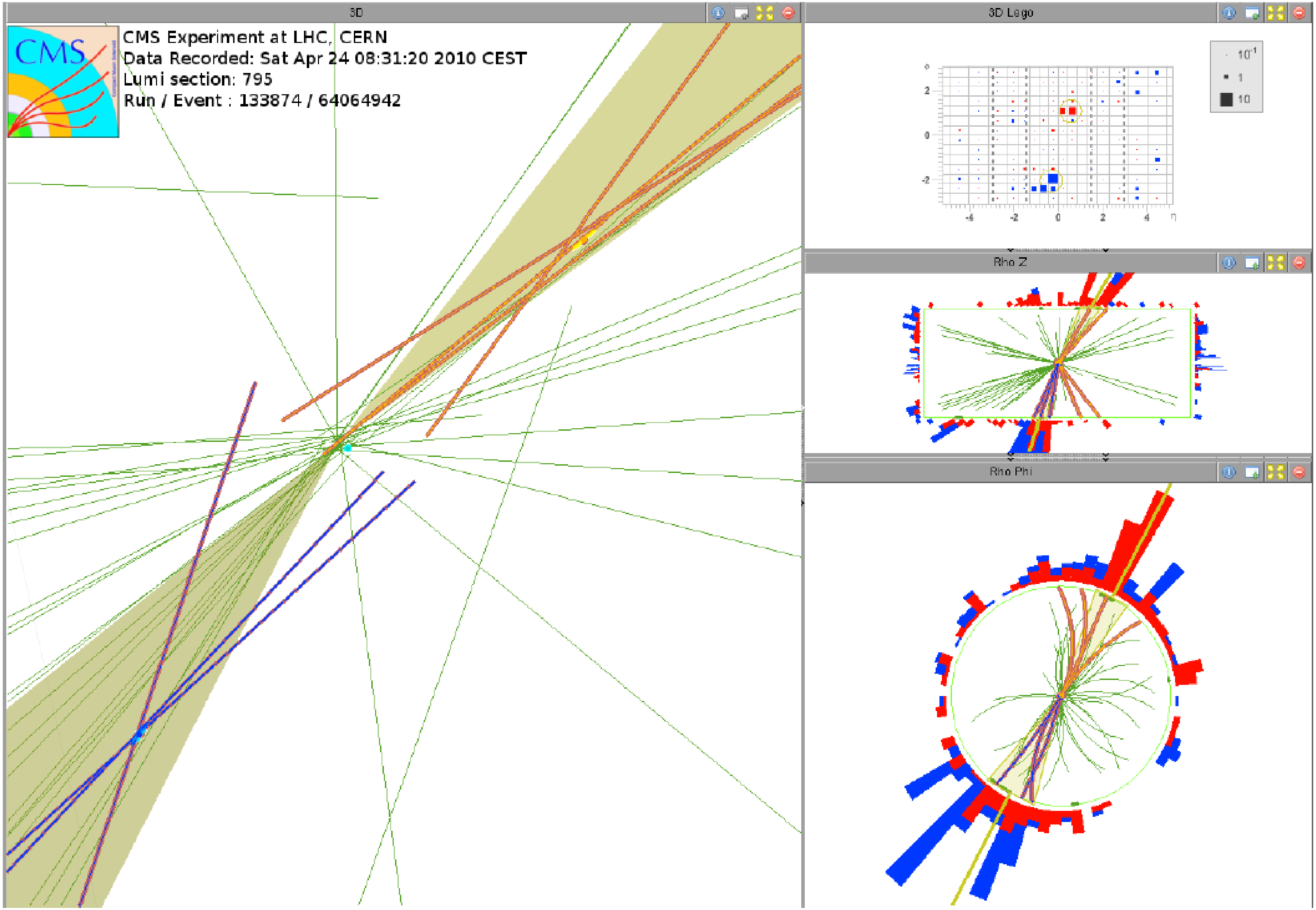
B-Tagging

- B mesons have relatively long lifetimes
- ⇒ Jets from b quarks originate from displaced vertices
- Precise tracking enables the identification (“tagging”) of B-Jets

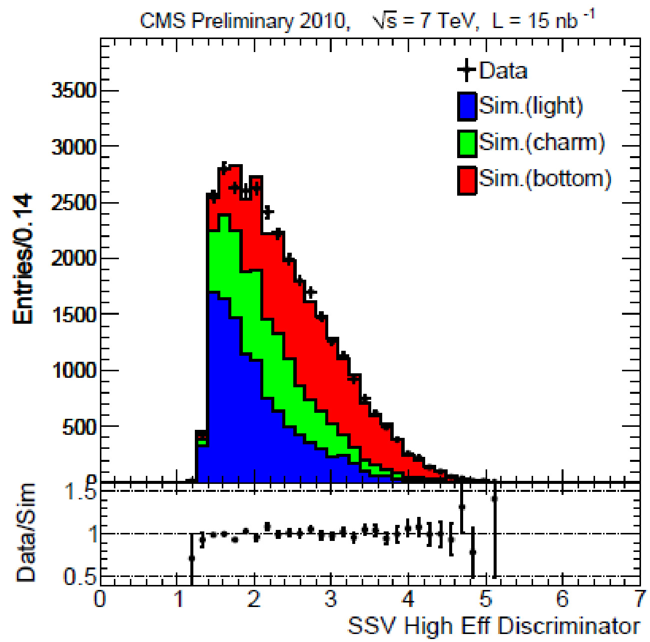


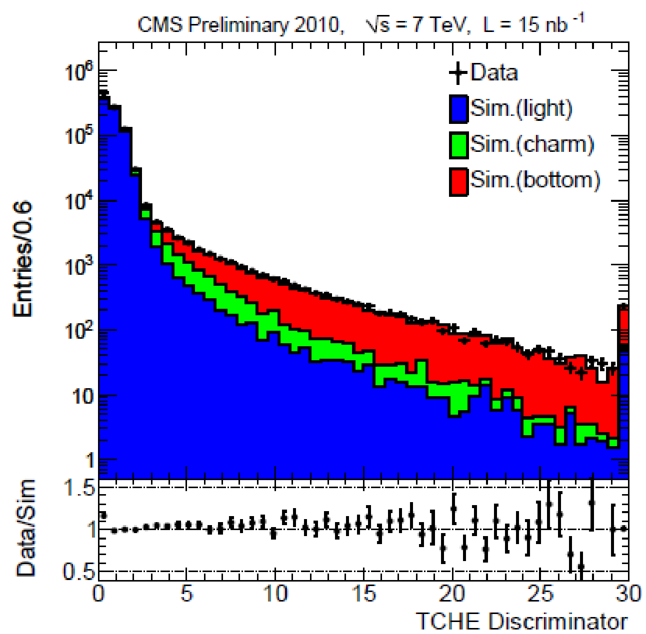


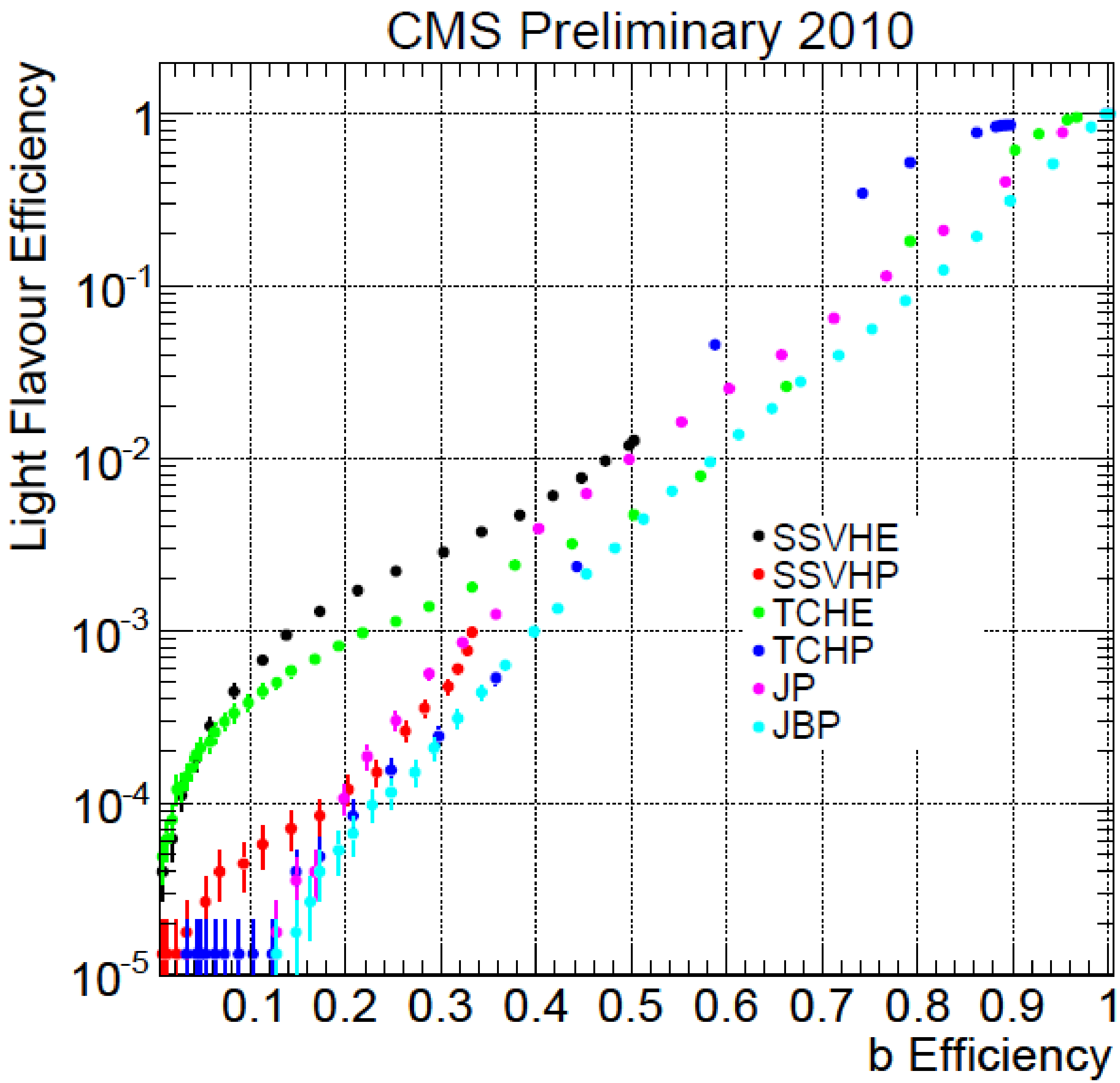
Event Display Showing Two B-Jets



B-Tagging Efficiency



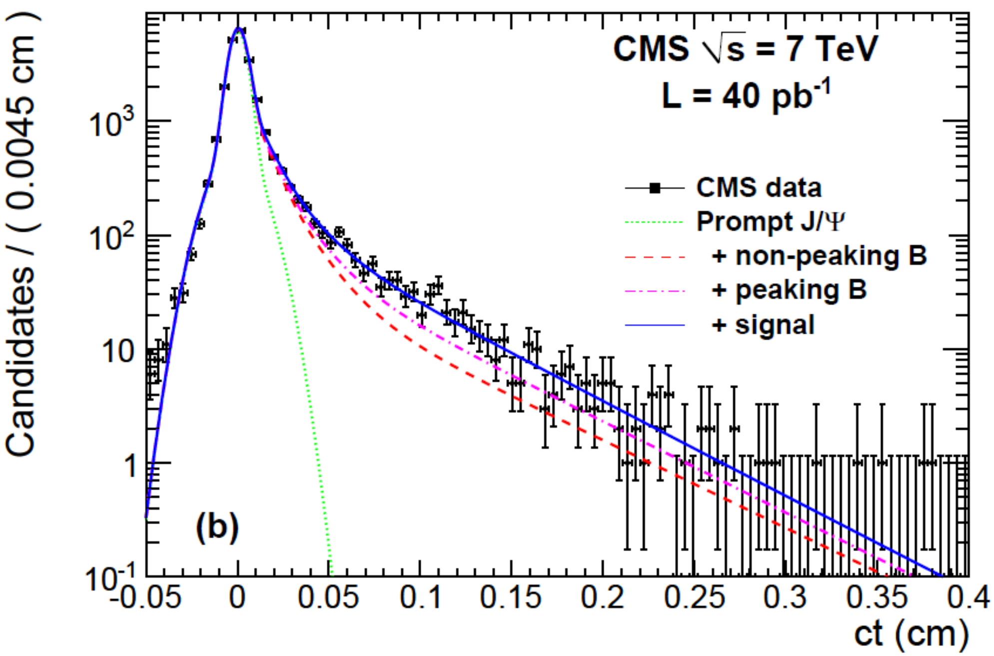




B^0 Lifetime and Cross Section

"Litmus Test" of Tracking

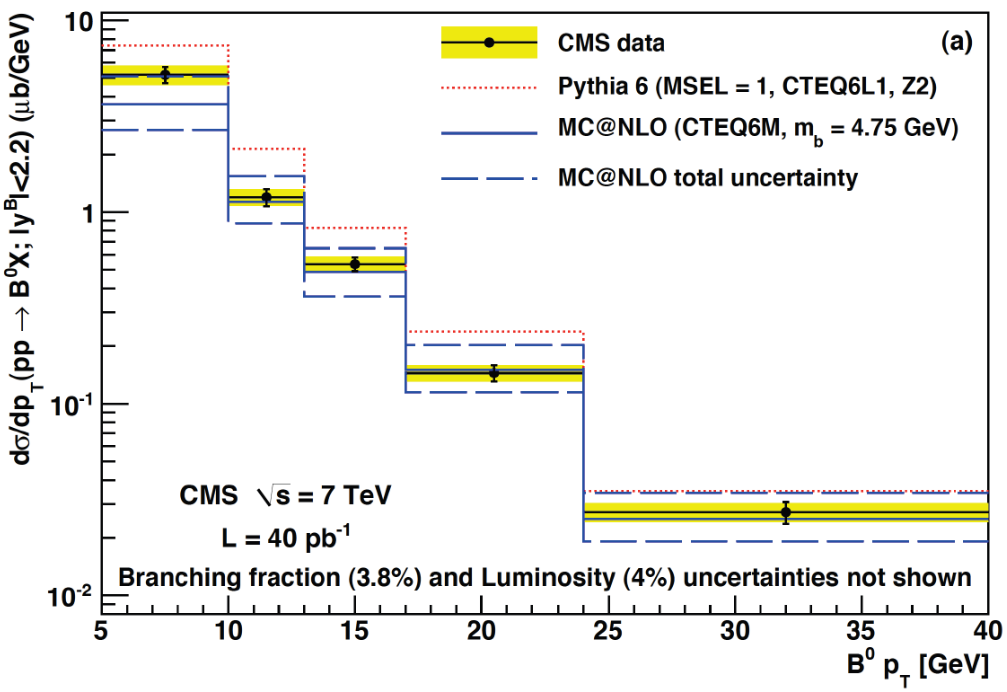
B^0 Lifetime



$c\tau = 479 \pm 22\ \mu m$ (stat)

$c\tau(PDG) = 457 \pm 3\ \mu m$

B^0 Differential Cross Section



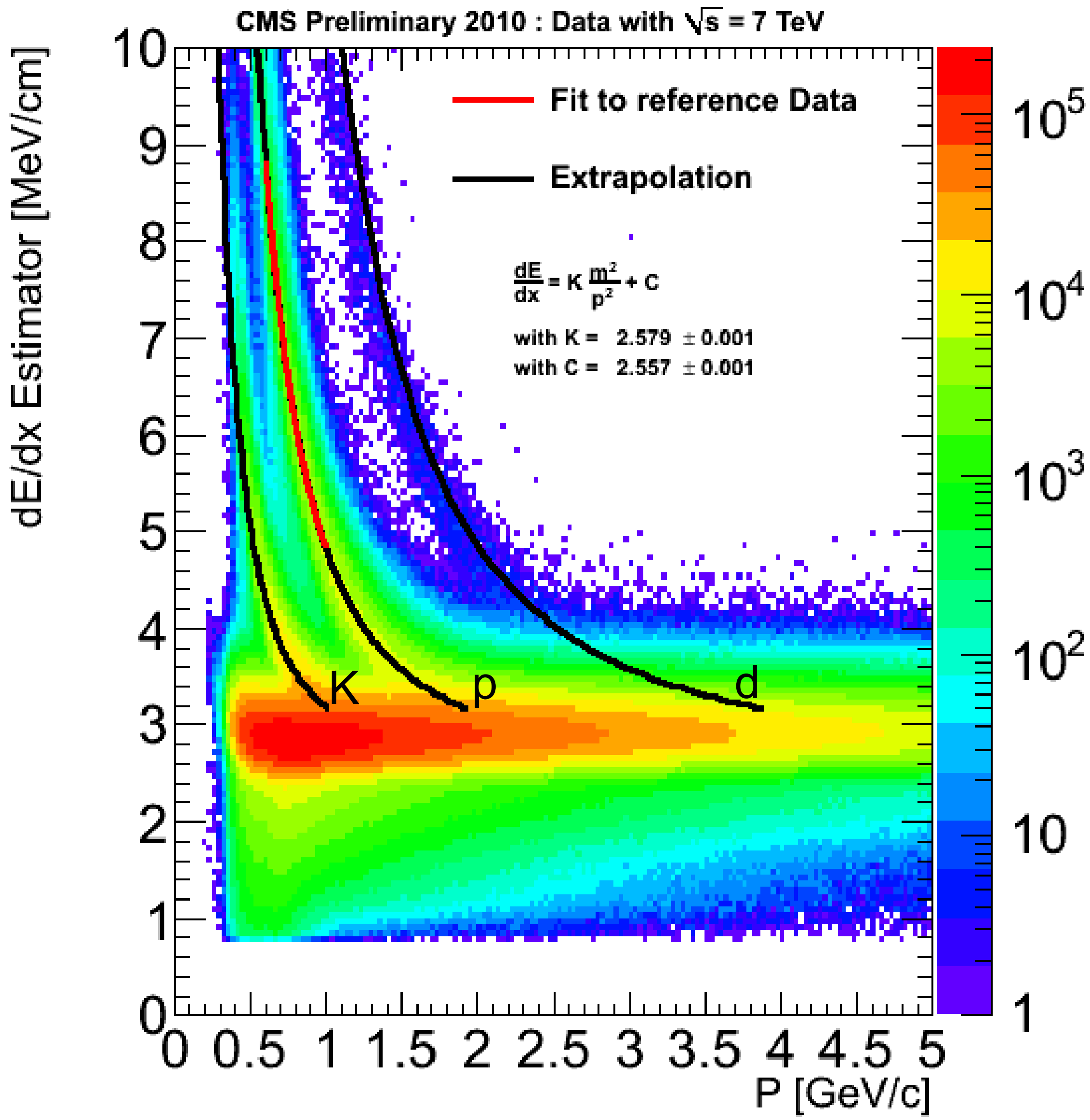
We Have a Great Detector!

- Data-driven techniques to measure tracker performance
- Tracker well-modeled by simulation
- Excellent track reconstruction efficiencies and resolution
- Primary and secondary vertex reconstruction from tracks
- Tracker plays an essential role in CMS physics

Backup

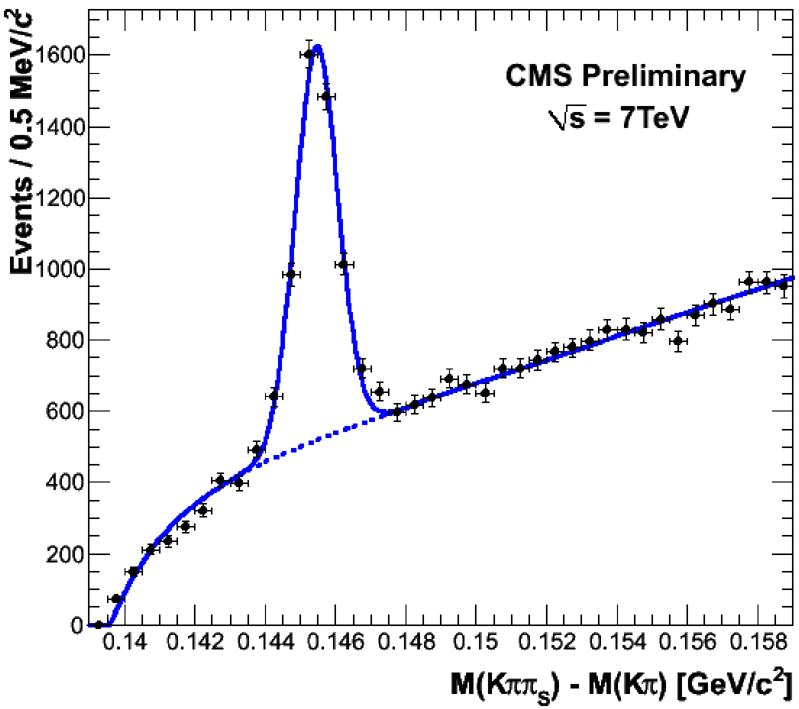
dE/dx

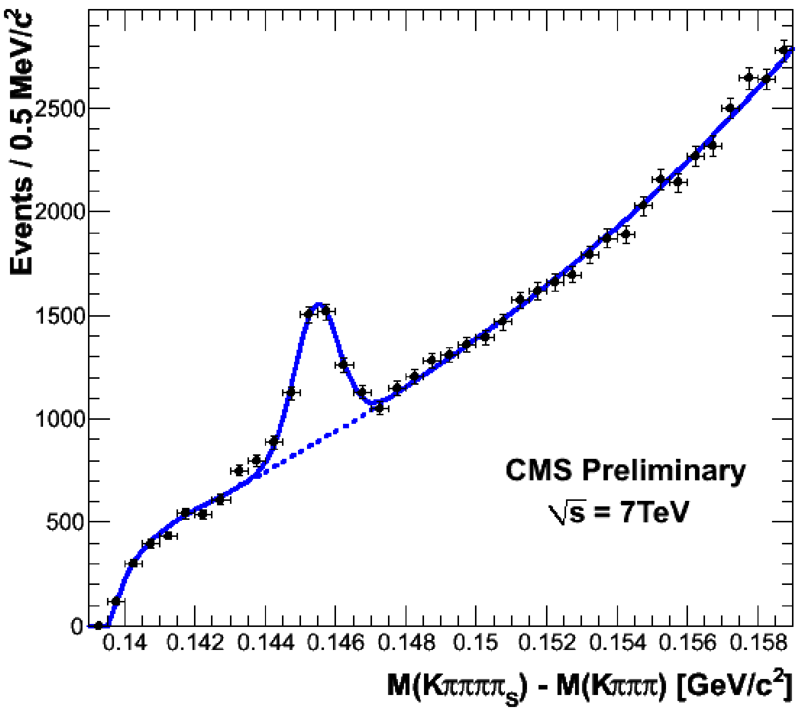
Analog readout of strips makes it possible to measure dE/dx



Pion Tracking Efficiency

- Measure pion track efficiency from D_0 decays
  - Ratio of $D_0 \rightarrow K\pi$ to $D_0 \rightarrow K3\pi$
  - 2 vs 4 tracks $\Rightarrow \varepsilon_{K\pi} = \varepsilon^2$ vs $\varepsilon_{K3\pi} = \varepsilon^4$

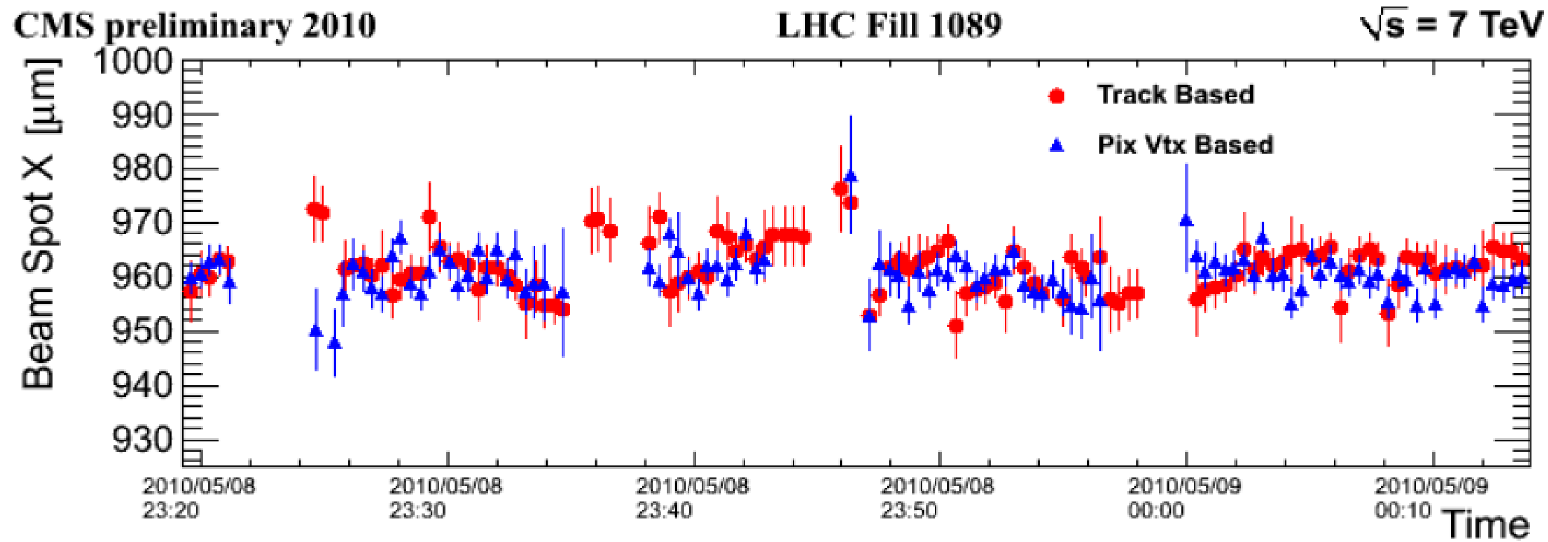


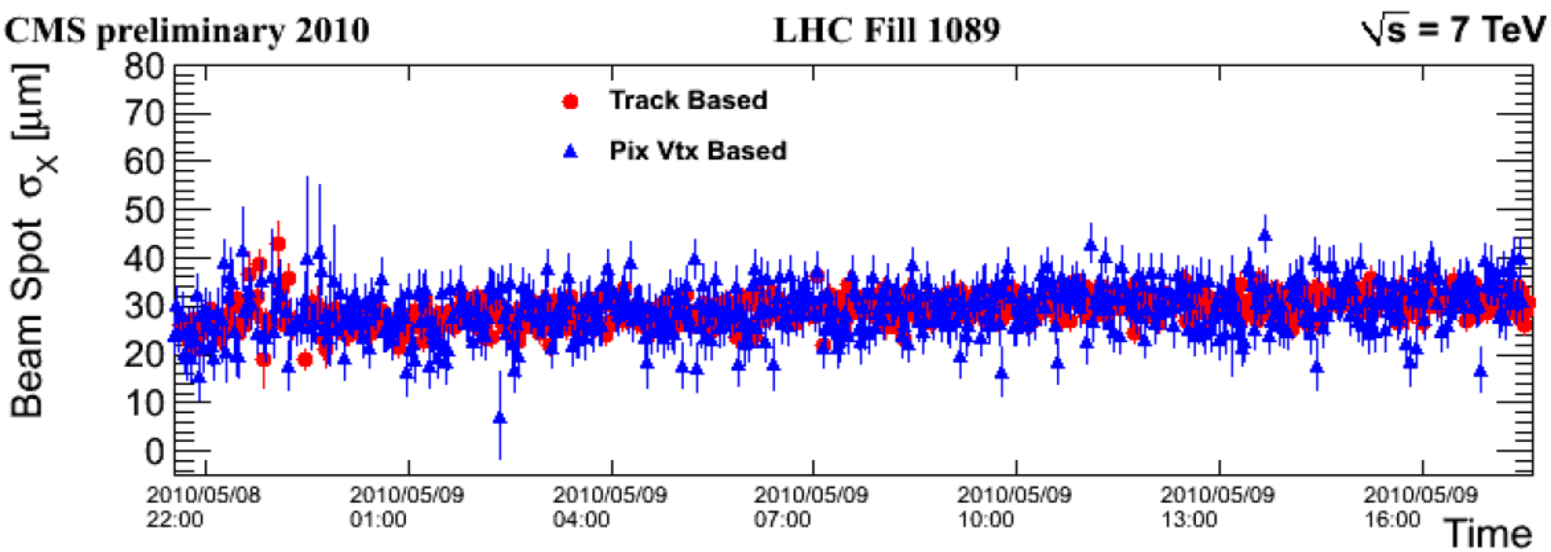


$$\mathcal{R} = \frac{N_{K3\pi}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{K3\pi}} \Rightarrow \frac{\epsilon_{\pi}^{\mathrm{DATA}}}{\epsilon_{\pi}^{\mathrm{MC}}} = \sqrt{\frac{\mathcal{R}}{\mathcal{R}_{\mathrm{PDG}}}} = 1.007 \pm 0.034_{\mathrm{stat}} \pm 0.014_{\mathrm{syst}} \pm 0.012_{\mathrm{PDG}}$$

Beam Line Reconstruction

- Beam spot is 3D profile of luminous region
- Position and width measured by likelihood fit on primary vertex positions





Beam Background Rejection

- Beam gas interactions
- High pixel and strip occupancy
- Tracks have small angles with respect to beam line
- Studied by comparing colliding and non-colliding beams
- Requiring high-quality primary vertex rejects nearly all beam gas interactions