Track Reconstruction and Experience with Cosmic Ray Data in CMS

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On behalf of the CMS Collaboration

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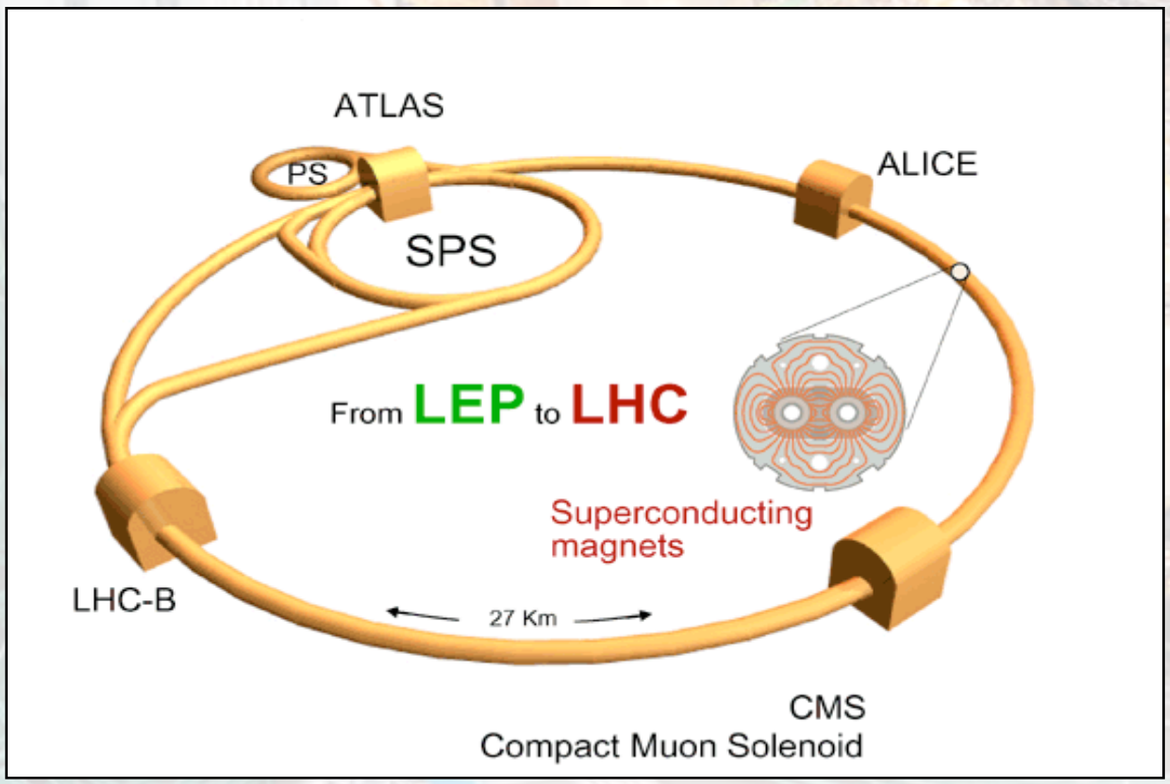
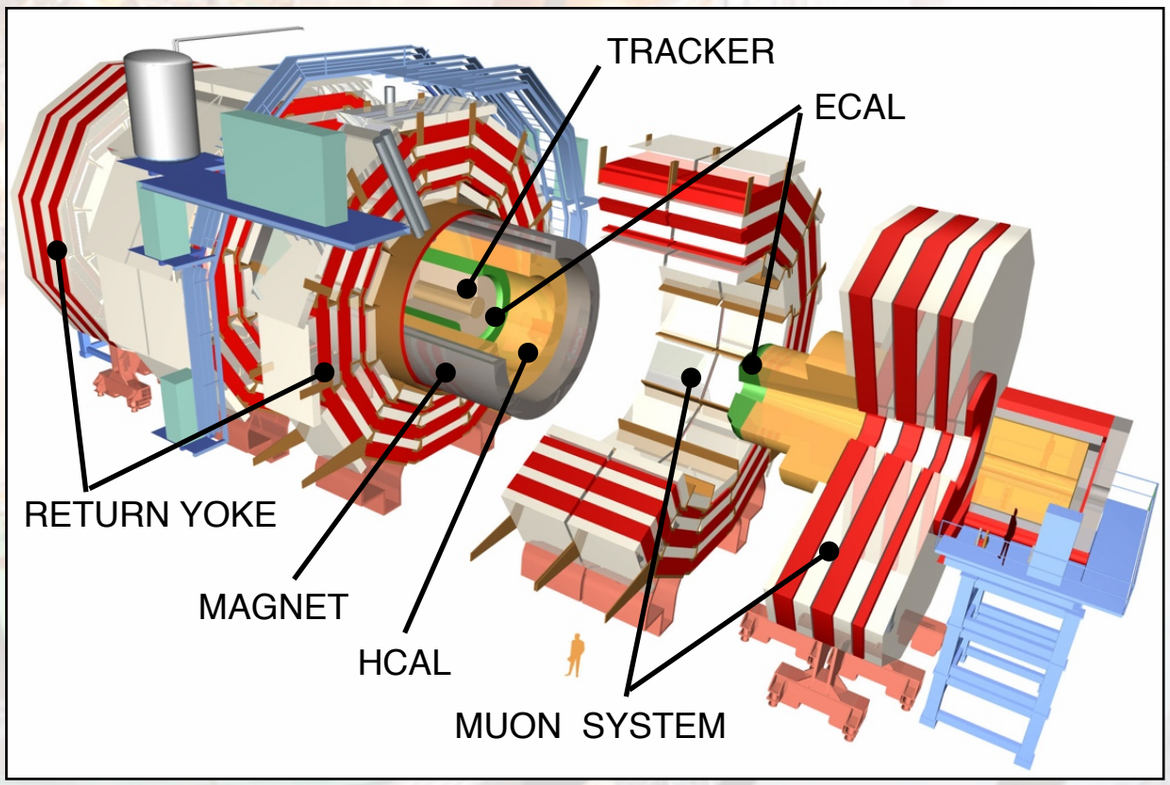
Outline

- LHC and CMS
- CMS Tracker
- Track reconstruction algorithms at CMS
- Magnetic Test and Cosmic Challenge (MTTC)
- Tracker commissioning at the Tracker Integration Facility (TIF) at CERN
- Conclusions

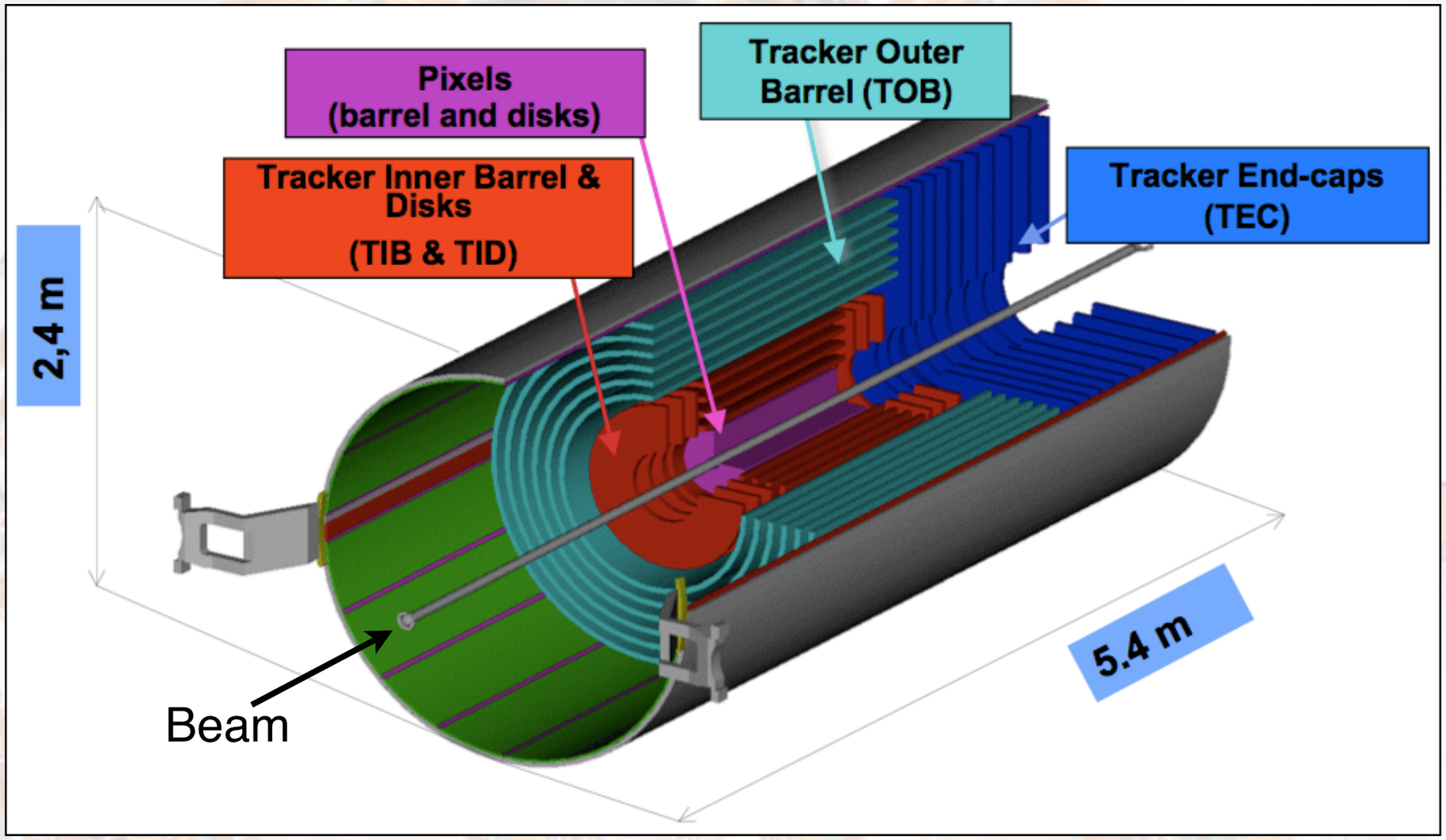
CMS Detector at LHC

- Large Hadron Collider at CERN (Geneva, Switzerland)
  - Proton-proton collisions
  - Beam energy: 7 TeV
  - Circumference: 27 km
- Compact Muon Solenoid
  - One of 4 detectors at the LHC
  - Width: 22m; Diameter: 15m
  - Weight: 14,500t





CMS Tracker



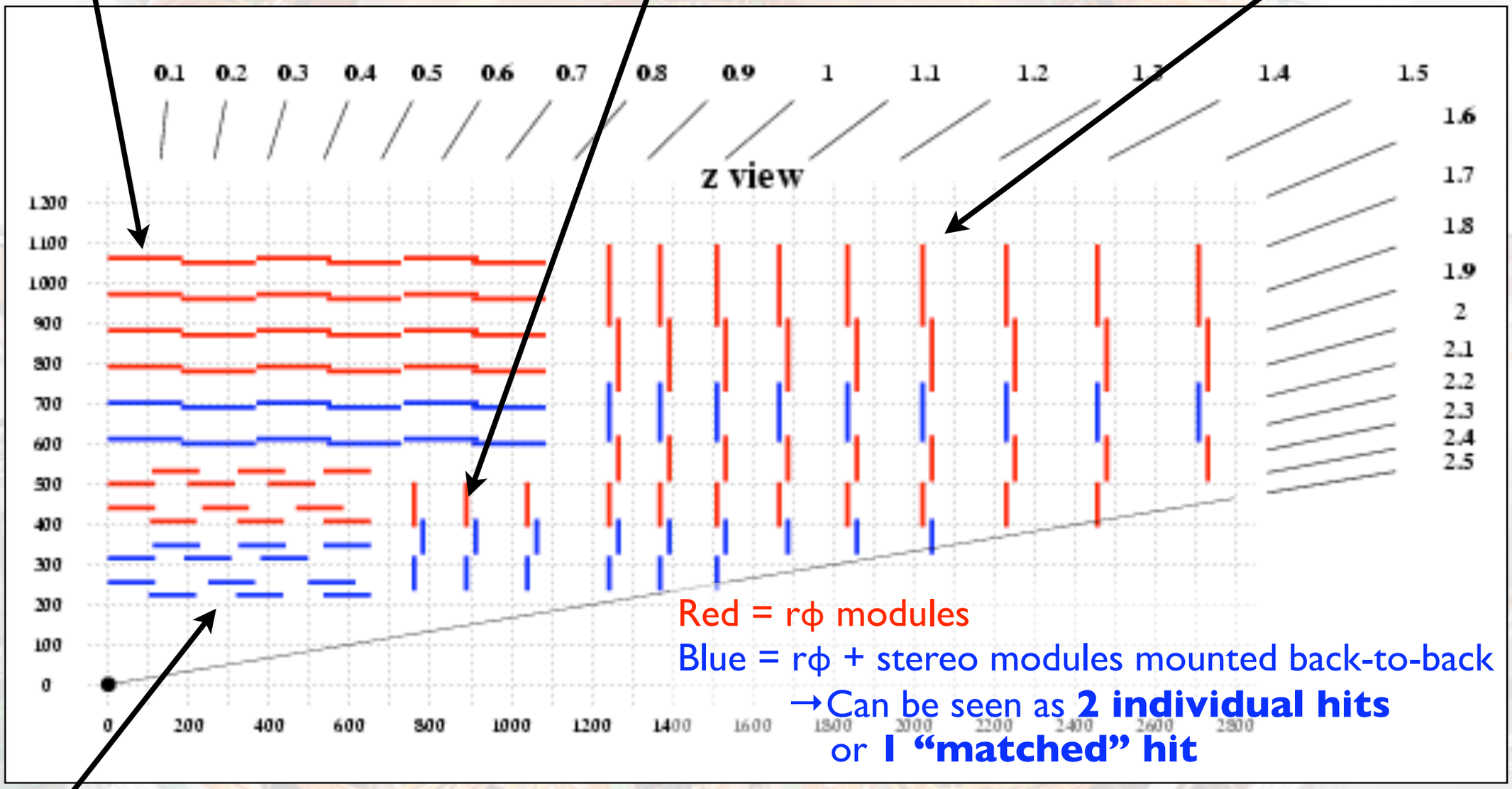
- Volume: 24.4m^3; Area: 200m^2 → Largest silicon detector
- Read-out channels:
  - Strip detectors: 11 Million
  - Pixels: 48M (barrel) + 18M (disks)
- Operated in B=4T magnetic field and below T=-10°C to encounter radiation damage

CMS Silicon Strip Tracker

Outer Barrel (TOB)
6 layers, 5208 modules
500µm Si

Inner Discs (TID)
3 discs, 3 rings, 816 modules
320µm Si

Endcap (TEC)
9 discs, 4-7 rings, 6400 modules
1-4: 320µm Si, 5-7: 500µm Si



Inner Barrel (TIB)
4 layers, 2724 modules
320µm Si

- Strip lengths range from ~10 cm (inner layers) to ~20 cm (outer layers)
- Strip pitches range from 80µm (inner layers) to 200µm (outer layers)

Track Reconstruction & Algorithms at CMS

- Track reconstruction at CMS
  - Local reconstruction:
    - Strip and pixel signals are clustered → hit positions with associated errors
  - Global reconstruction:
    1) Seed finding: Fast and rough estimate of track parameters using minimal information
    2) Pattern recognition: Iterative process starting from the seed parameters and collecting hits which are compatible with the track
    3) Final fit
- Two general algorithms for track reconstruction in LHC collisions:
  - Combinatorial Track Finder (CTF)
  - Road Search

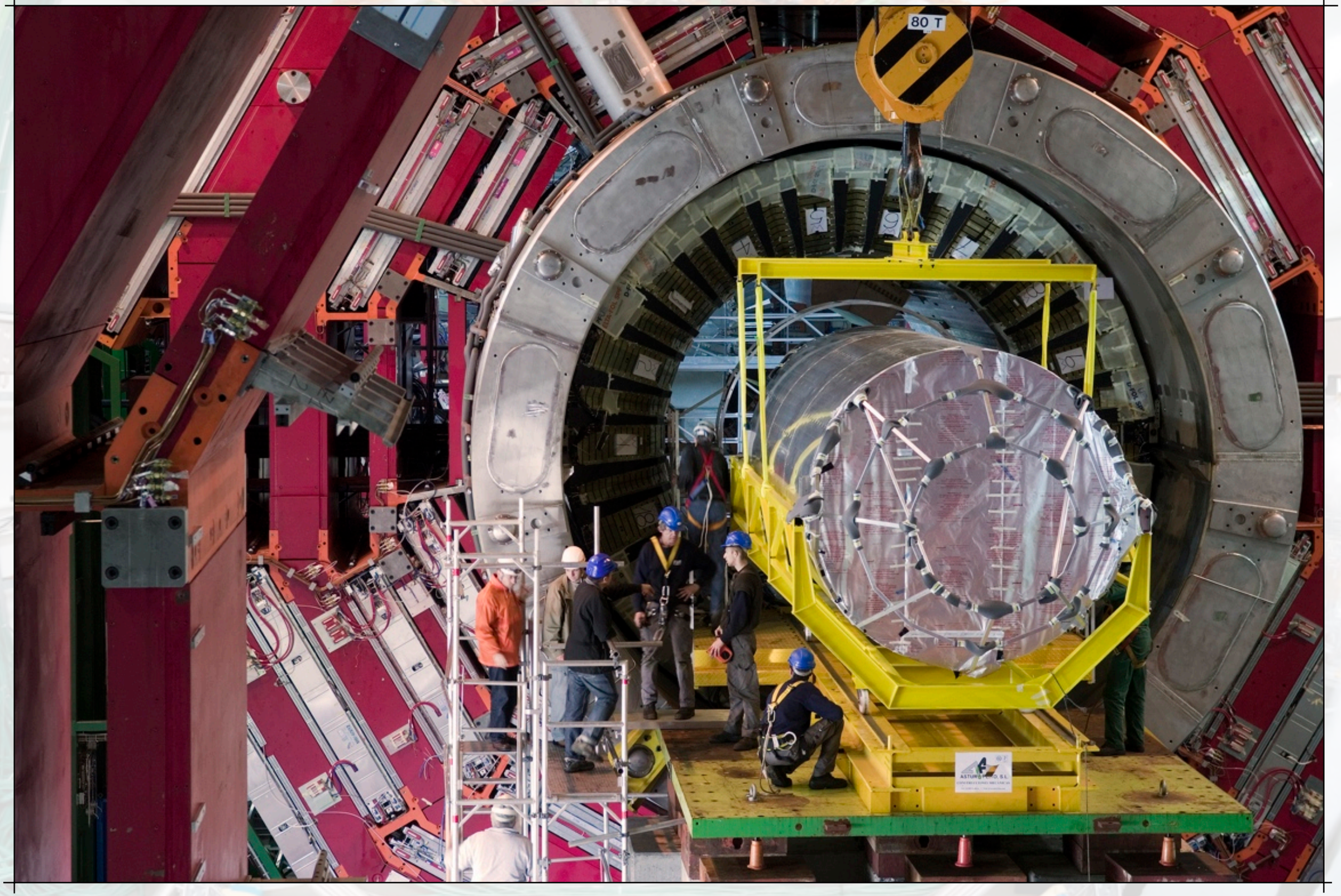
  → Modified for cosmic ray tracking
- One dedicated cosmic ray tracking algorithm:
  - Cosmic Track Finder (based on assumption of one track)

Track Reconstruction & Algorithms at CMS

- Cosmic ray tracking:

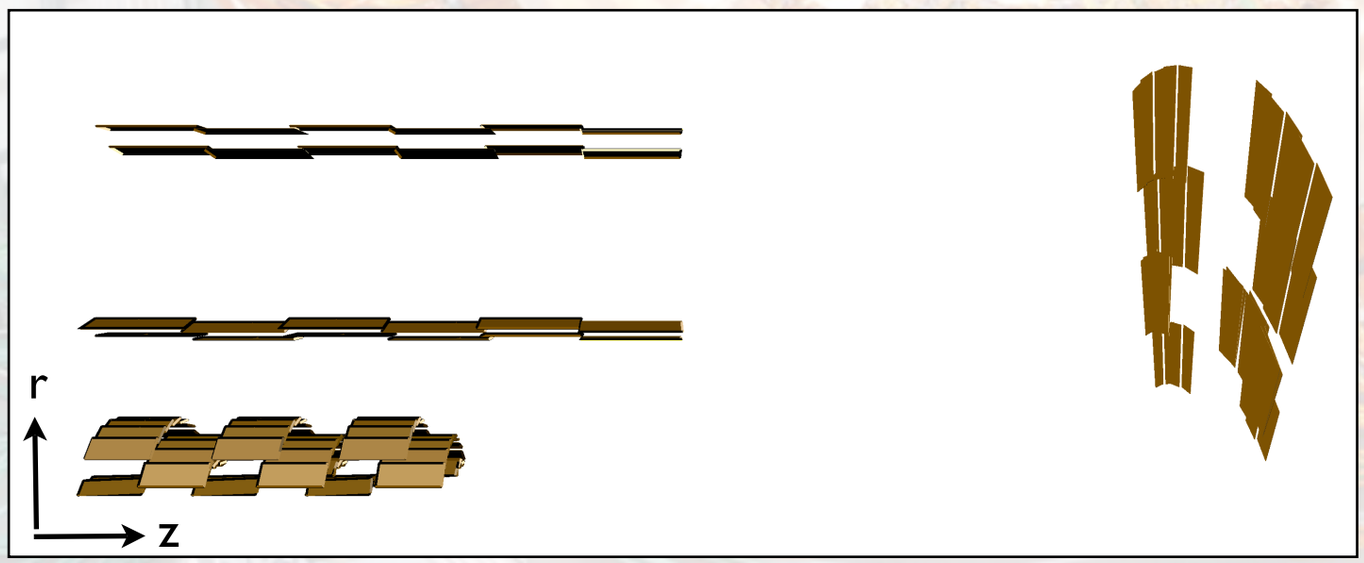
	Cosmic Track Finder	CTF	Road Search
Seed Finding	Geometrically compatible pairs/tripletts of hits in dedicated seeding layers.	Combination of two/ three geometrically compatible hits in consecutive layers.	Combination of hits in inner and outer layers.
Pattern Recognition	Order all hits with respect to vertical direction. Propagate trajectory to next surface and evaluate all hits on using a χ^2 estimator.	Track-follow approach: re-evaluate the trajectory parameters every time a new hit is associated and narrow search window on the next tracker layer.	Collect hits in all layers along seed hypothesis. Build trajectory starting from single hit layers.
Final Fit	Kalman-Filter Fitter & Smoother		
	Only one track per event.	Multiple tracks per event possible.	

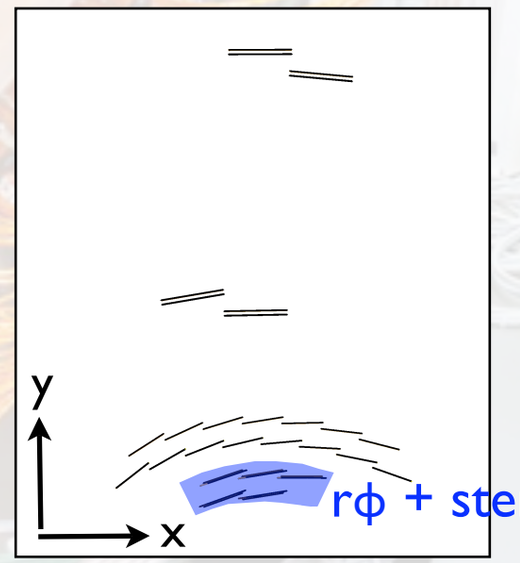
Magnetic Test and Cosmic Challenge (MTCC)



Magnetic Test and Cosmic Challenge (MTCC)

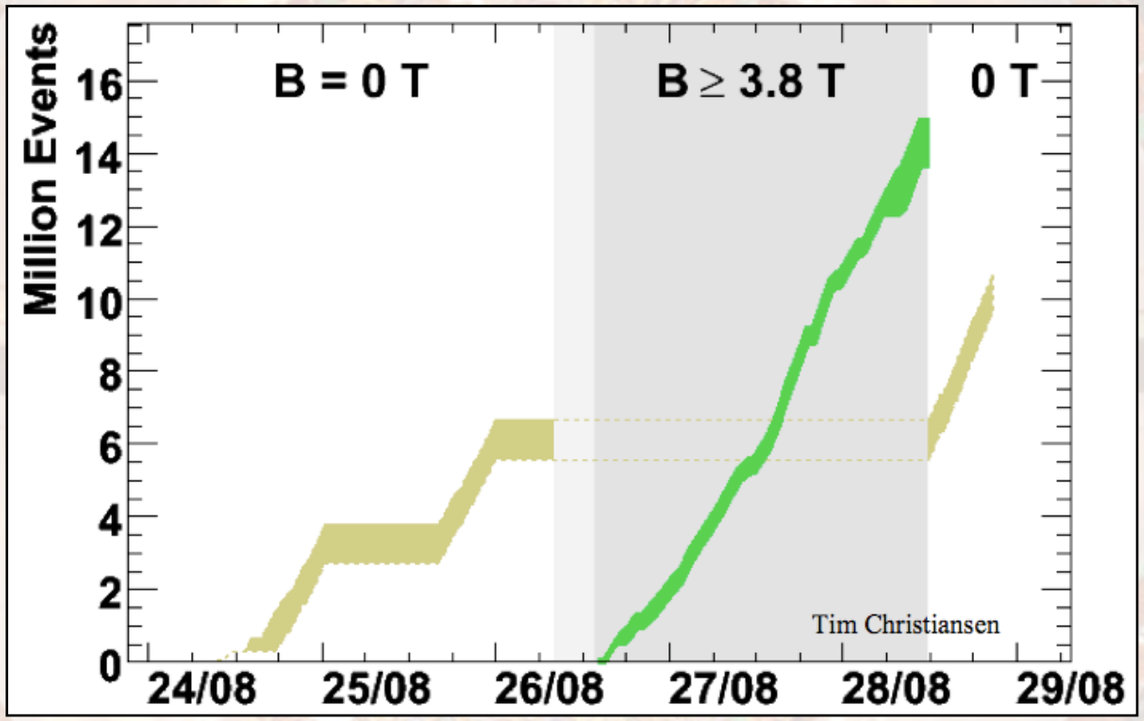
- Primary goal: Commissioning of the CMS magnet
- Fraction of the silicon strip tracker operated at room temperature in a comprehensive slice test involving all CMS sub-detectors (except Pixel Tracker)
  - Cosmic muon triggering provided by the muon system
  - Magnetic field: up to 4 T
- Tracker setup:
  - 133 (prototype) modules representing TIB, TOB and TEC
  - 82k electronics channels, 0.75m^2 active area





Magnetic Test and Cosmic Challenge (MTCC)

- Five days of global data taking in August 2006
  →25M events were recorded at multiple B field values

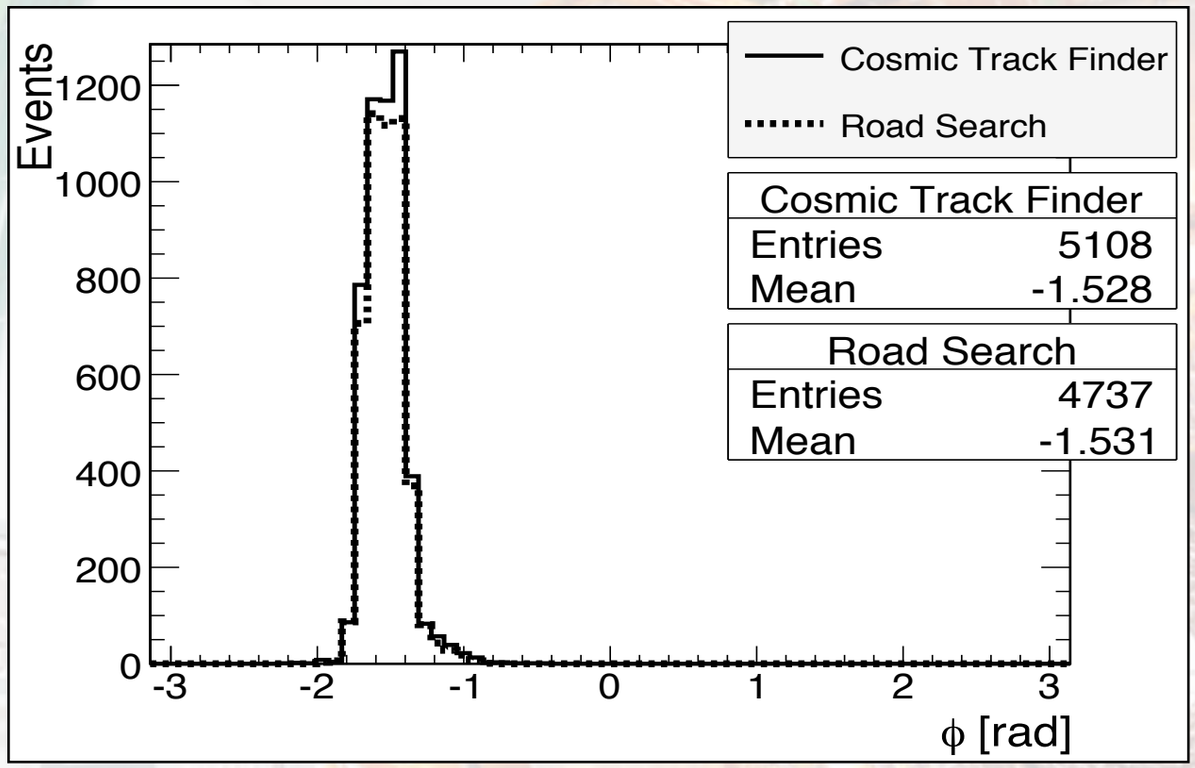


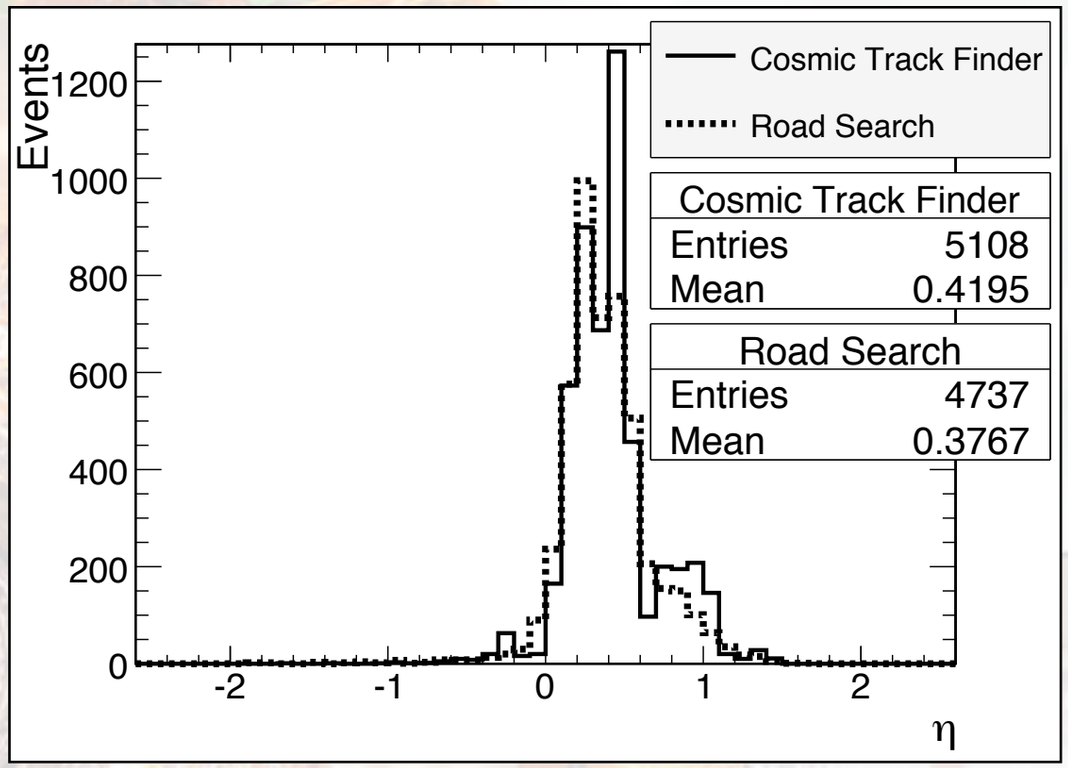
- Two tracking algorithms were deployed:
  - Cosmic Track Finder
  - Road Search algorithm

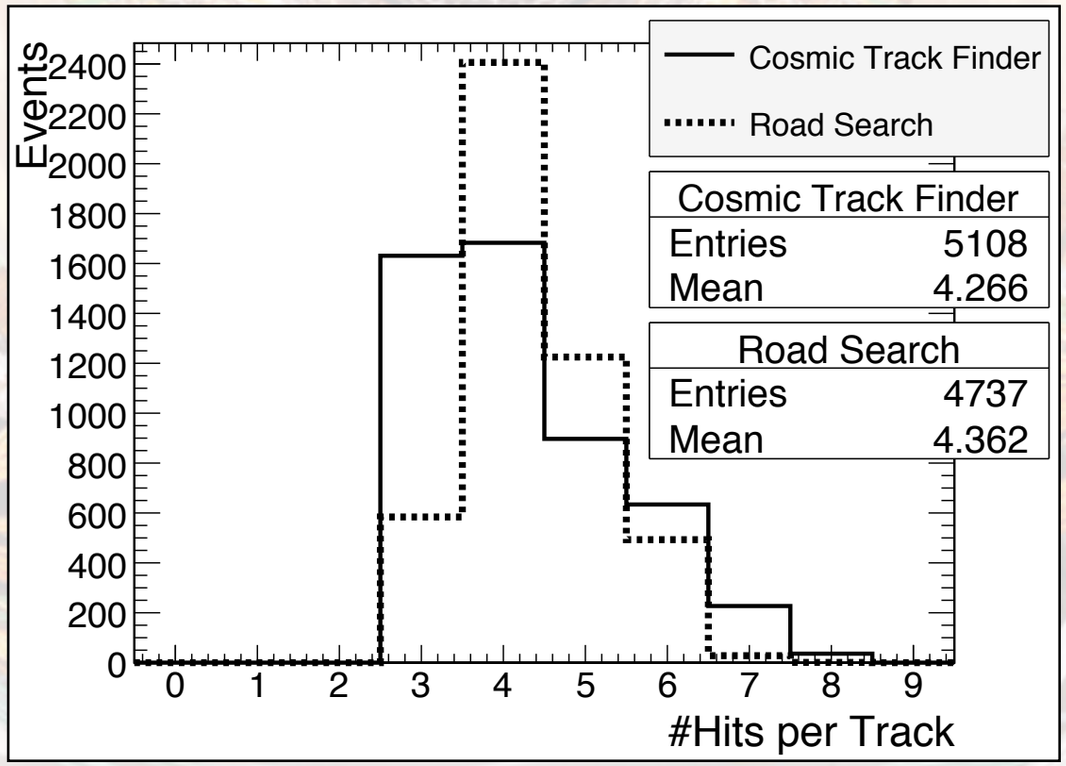
	Number of reconstructed tracks		
	B=0.0T	B=3.8T	B=4.0T
Cosmic Track Finder	5108	3588	583
Road Search*	4737	2343	267

*smaller geometrical acceptance due to choice of seeding

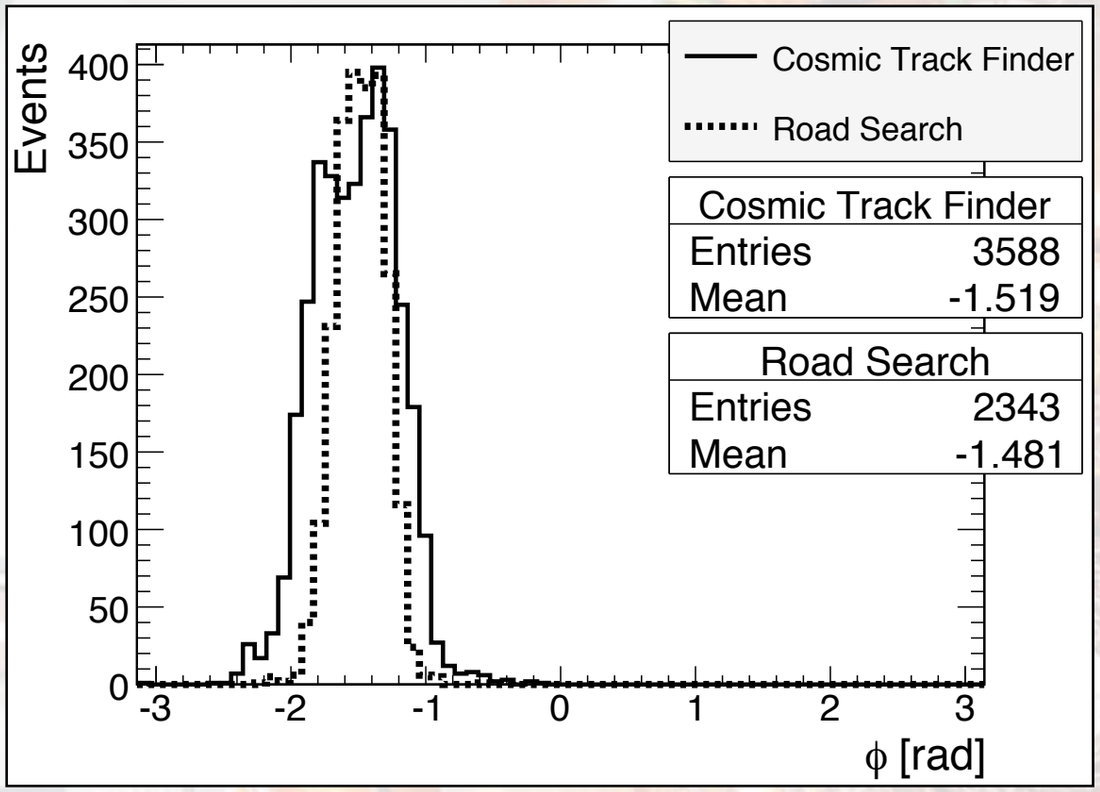
MTCC: B=0T Results

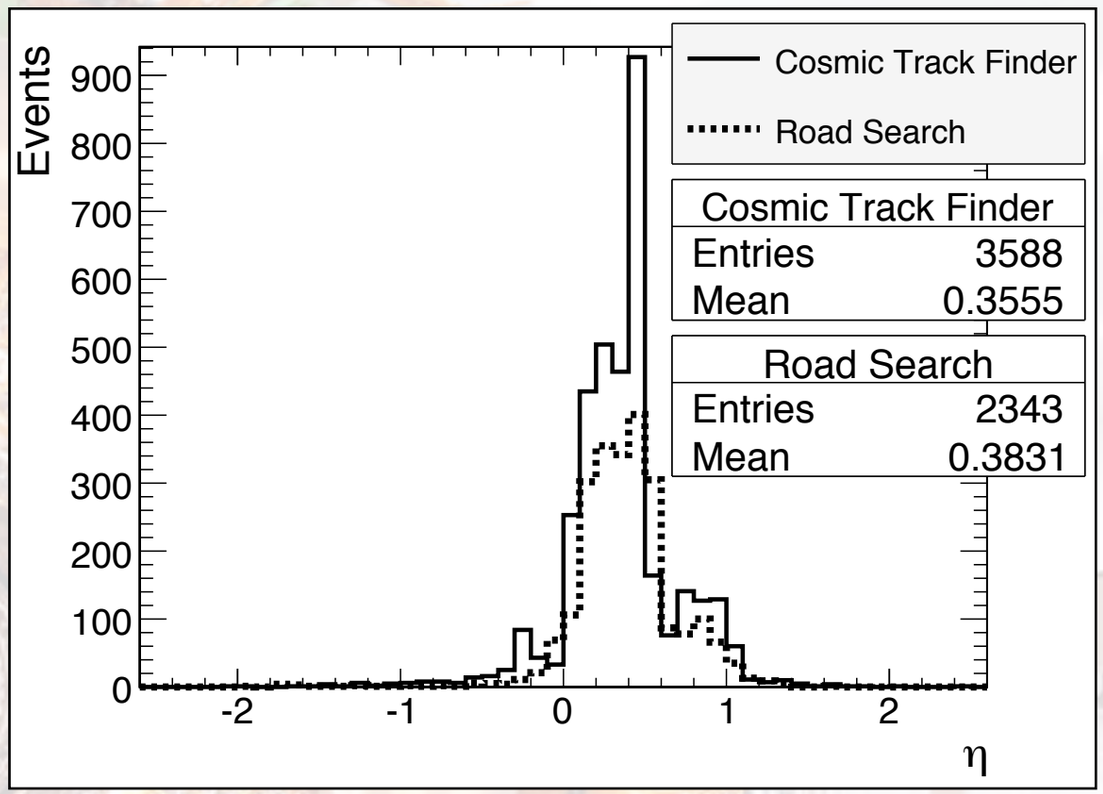


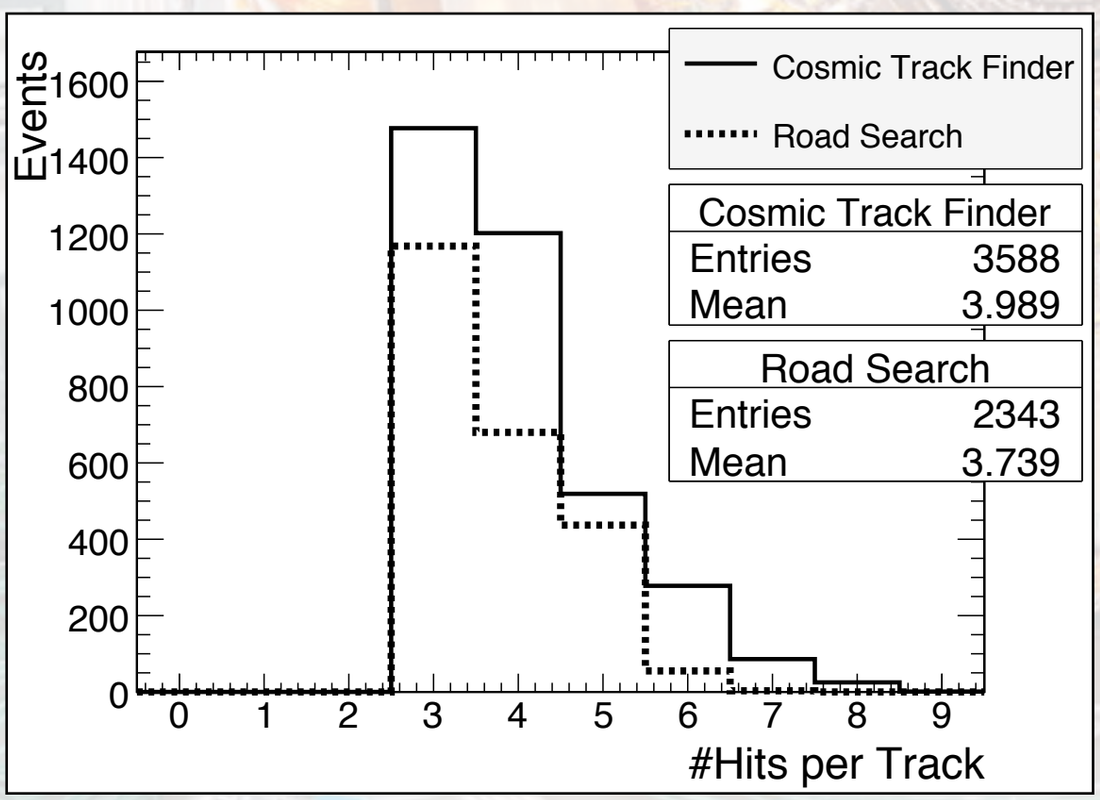


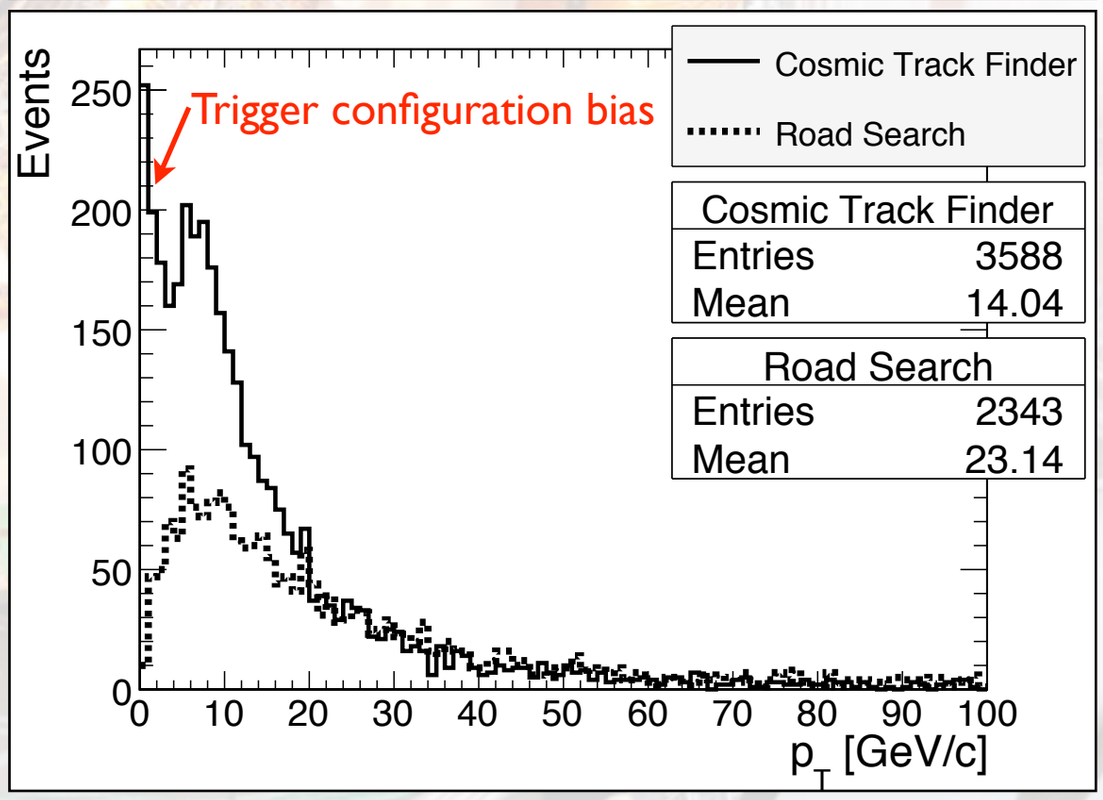


MTCC: B=3.8 T Results

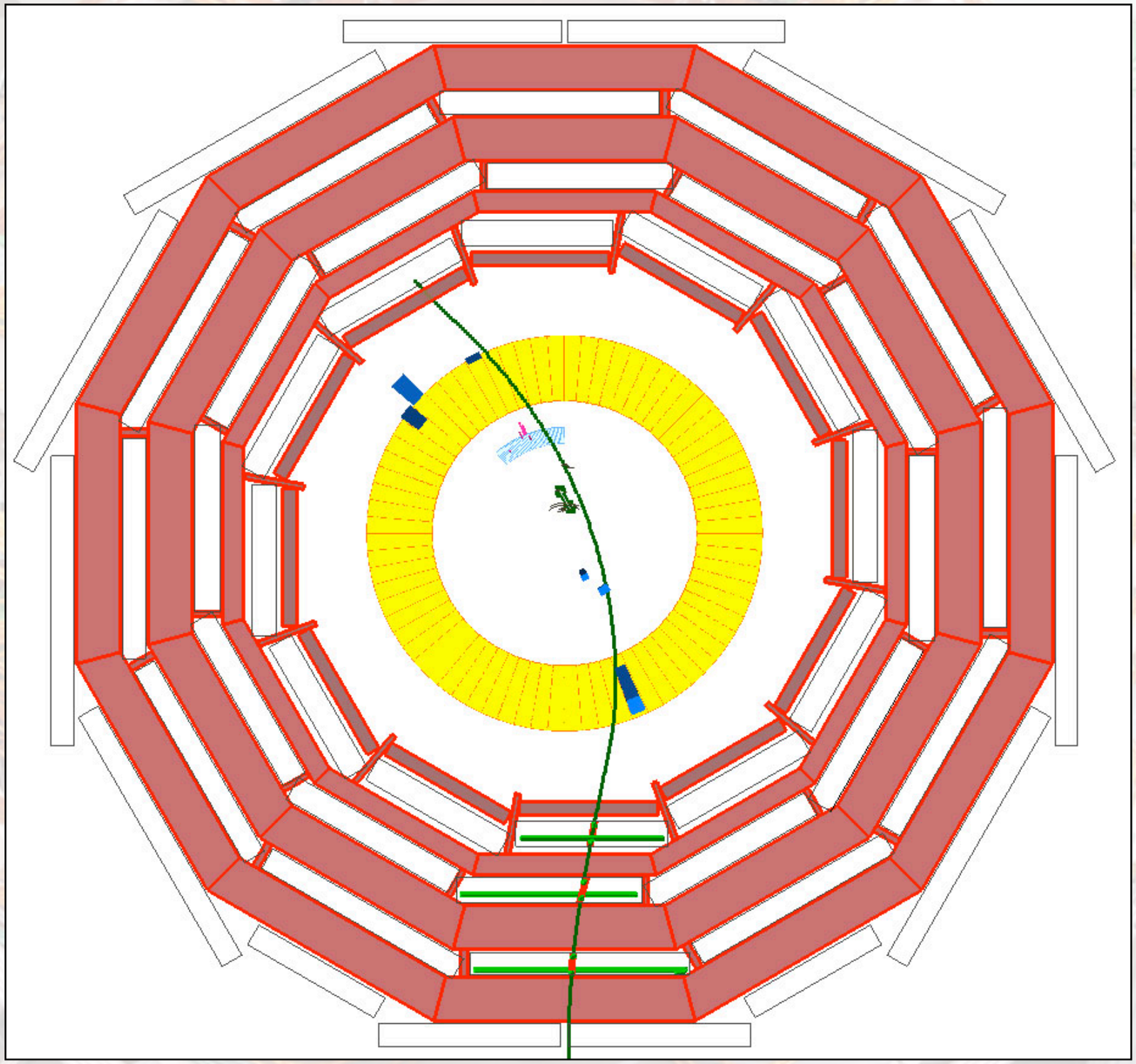






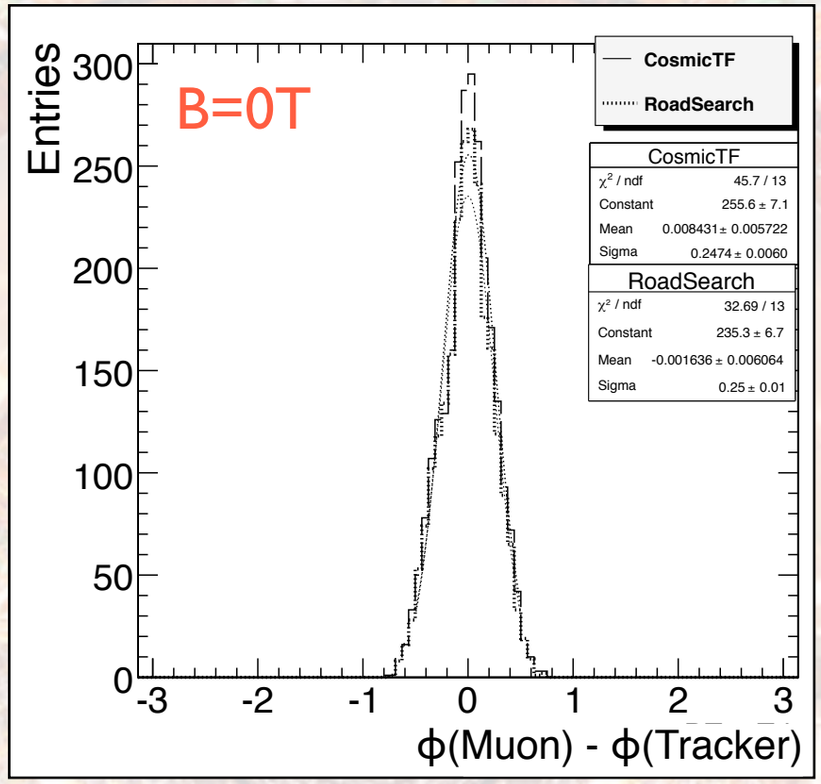


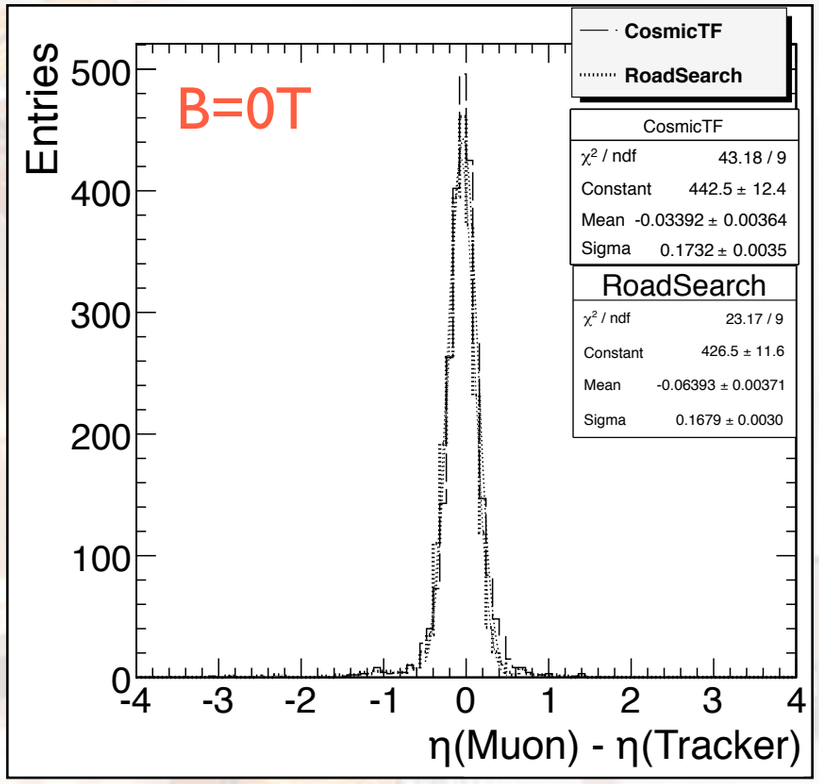
MTCC: Golden Event

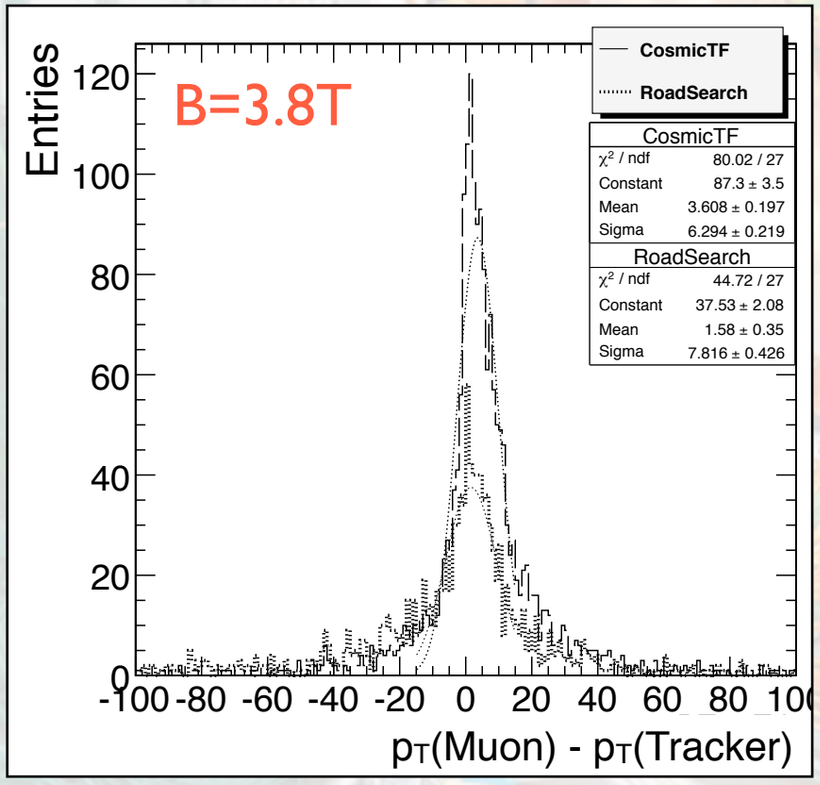


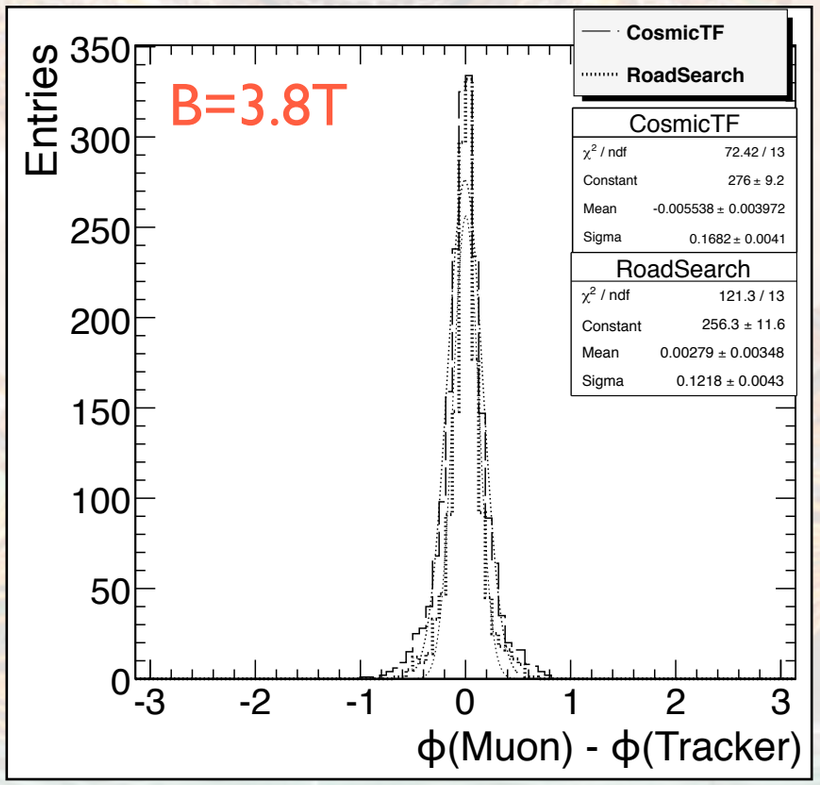
MTCC: Comparison to Muon tracks

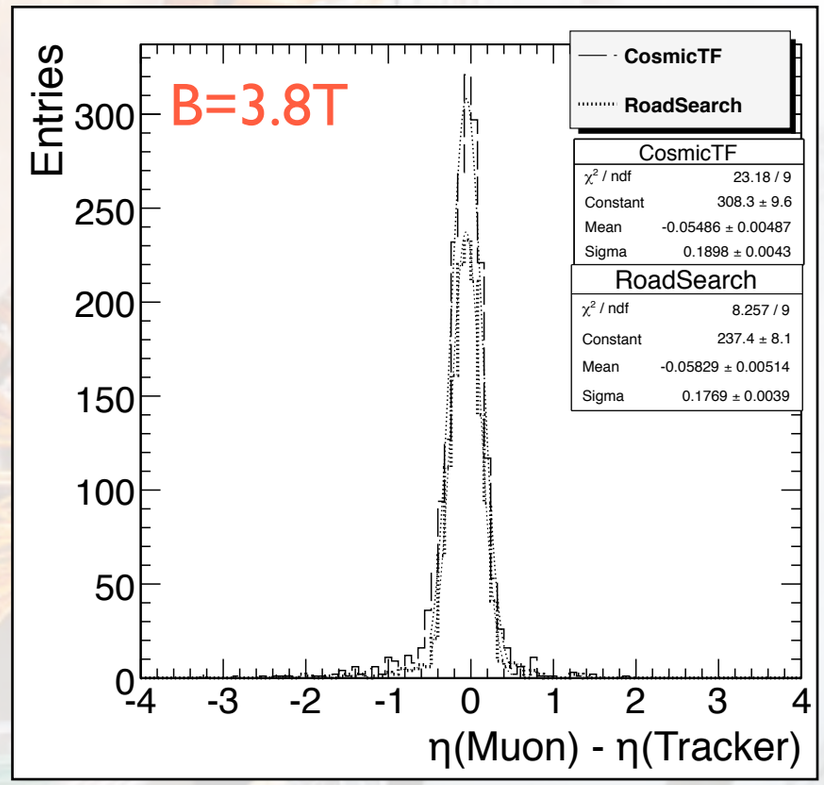
- Use muon system as reference and verify track reconstruction in silicon strip tracker



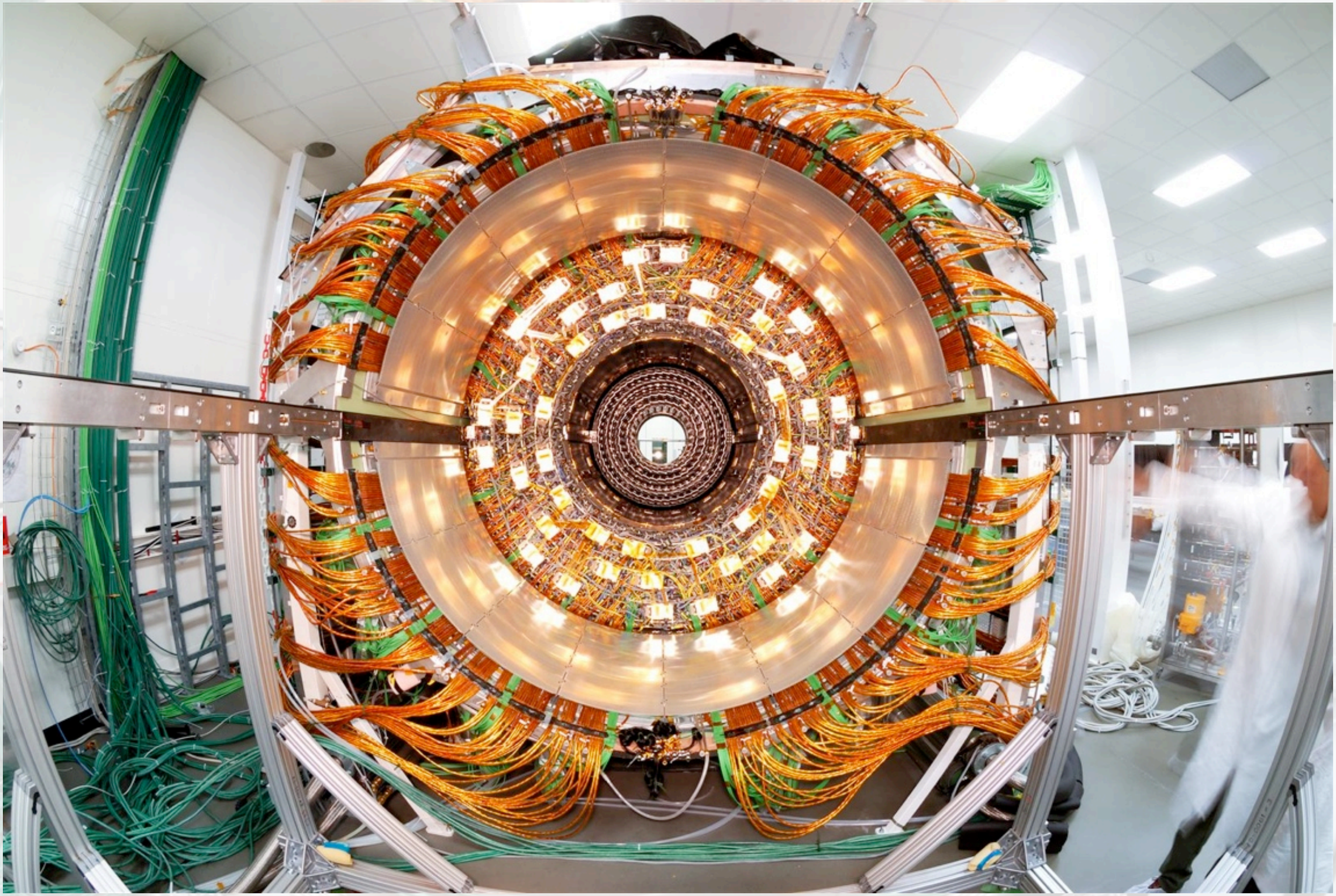






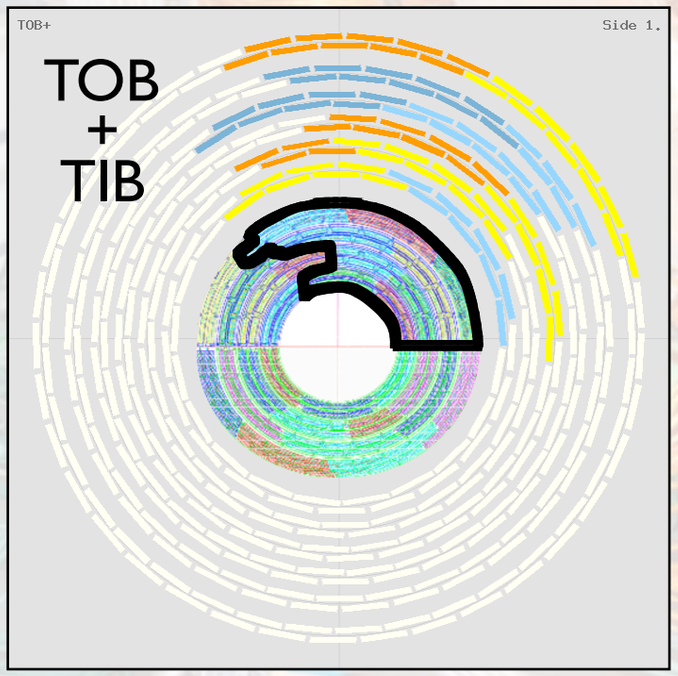


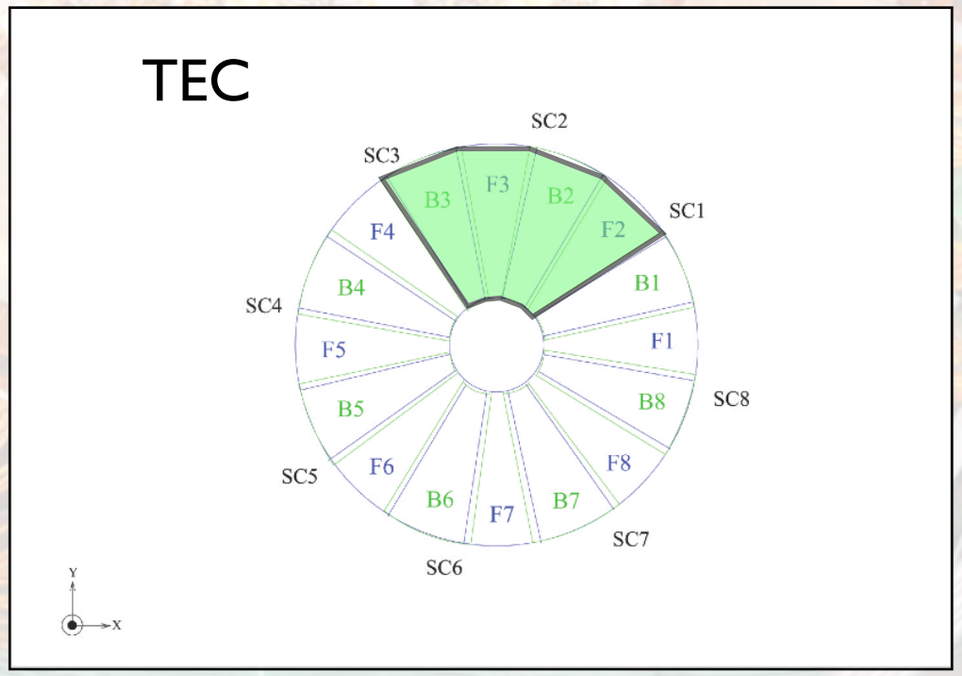
Tracker Commissioning at the TIF



Tracker Commissioning at the TIF

- Commissioning of 15% of the CMS silicon strip tracker from May to July 2007 in dedicated test facility at CERN
  - Cosmic muon triggering provided by scintillation counters
  - No magnetic field present
  - No pixel tracker
- Tracker setup:
  - 2161 modules representing TIB, TID, TOB and TEC
  - 1.3M electronics channels, 24.75m^2 active area





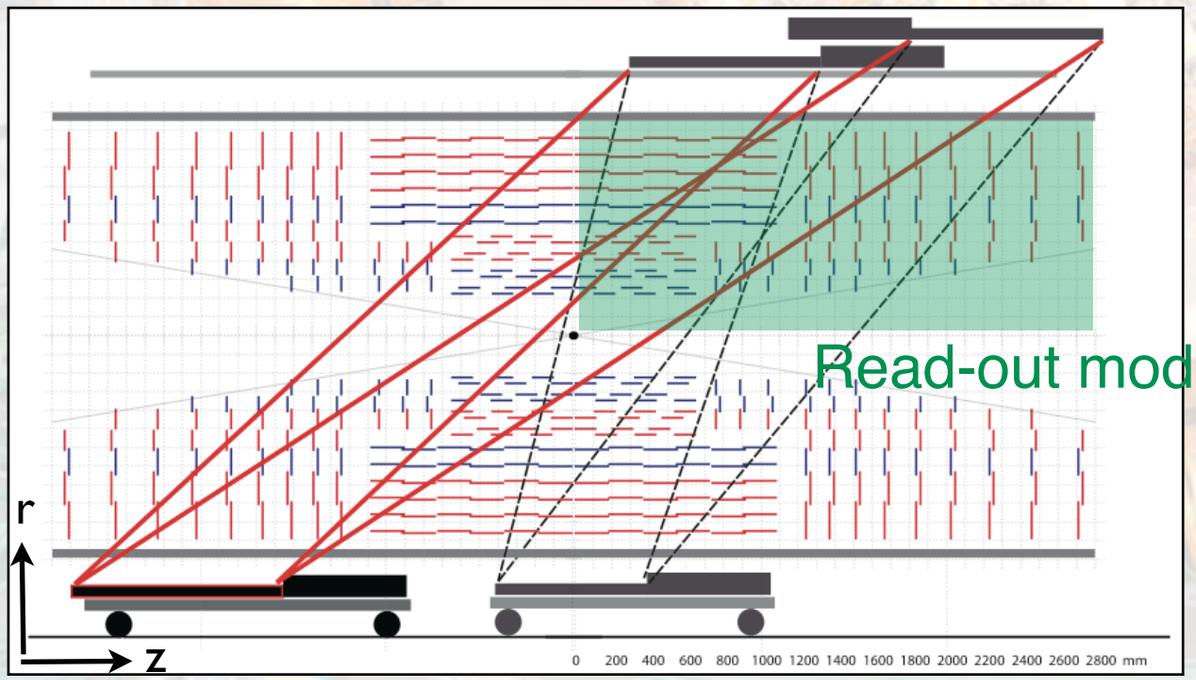
+ 25% TID (not shown)

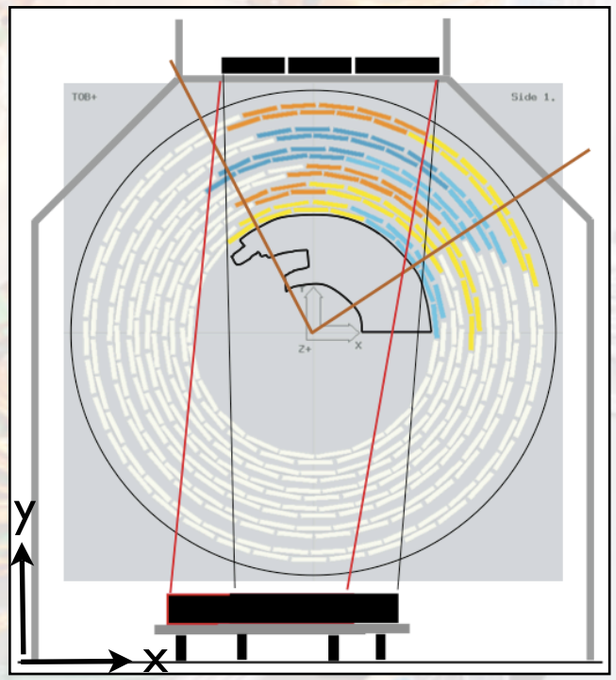
Tracker Commissioning at the TIF

- Over 5M cosmic triggers have been recorded at five operating temperatures
  → 3M single muon tracks have been reconstructed using all three algorithms

Temperature	#Events
15°C	1480k
10°C	990k
-1°C	890k
-10°C	920k
-15°C	650k

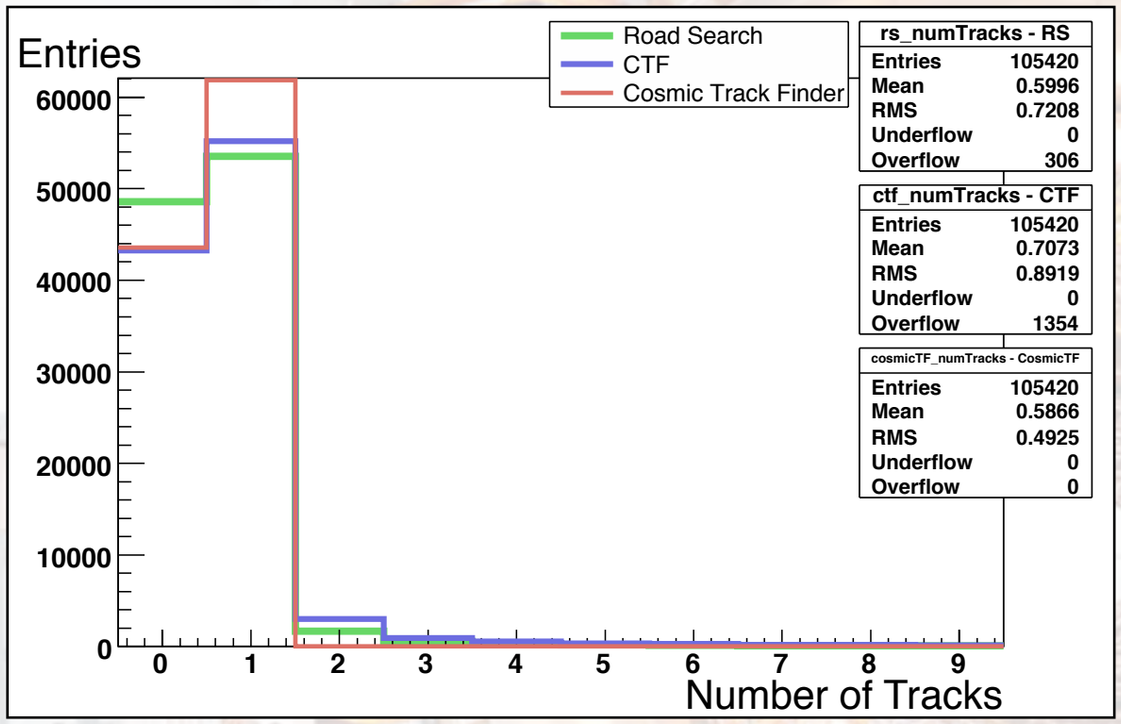
- Flexible trigger geometry (Position A, B & C):

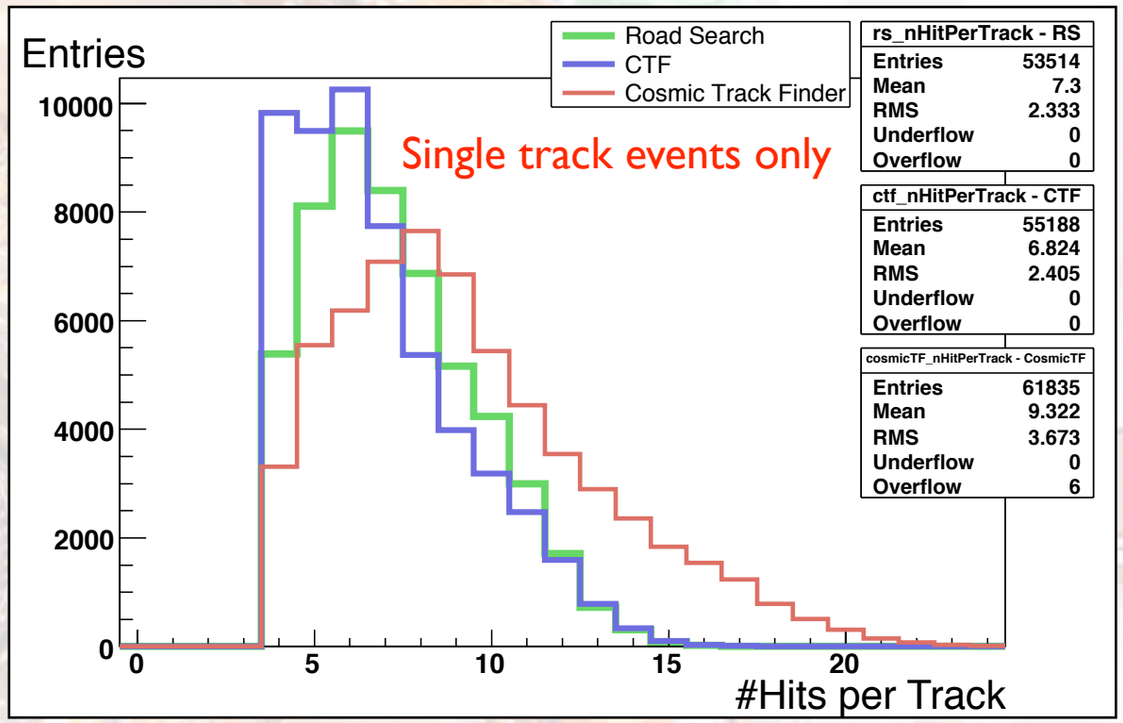


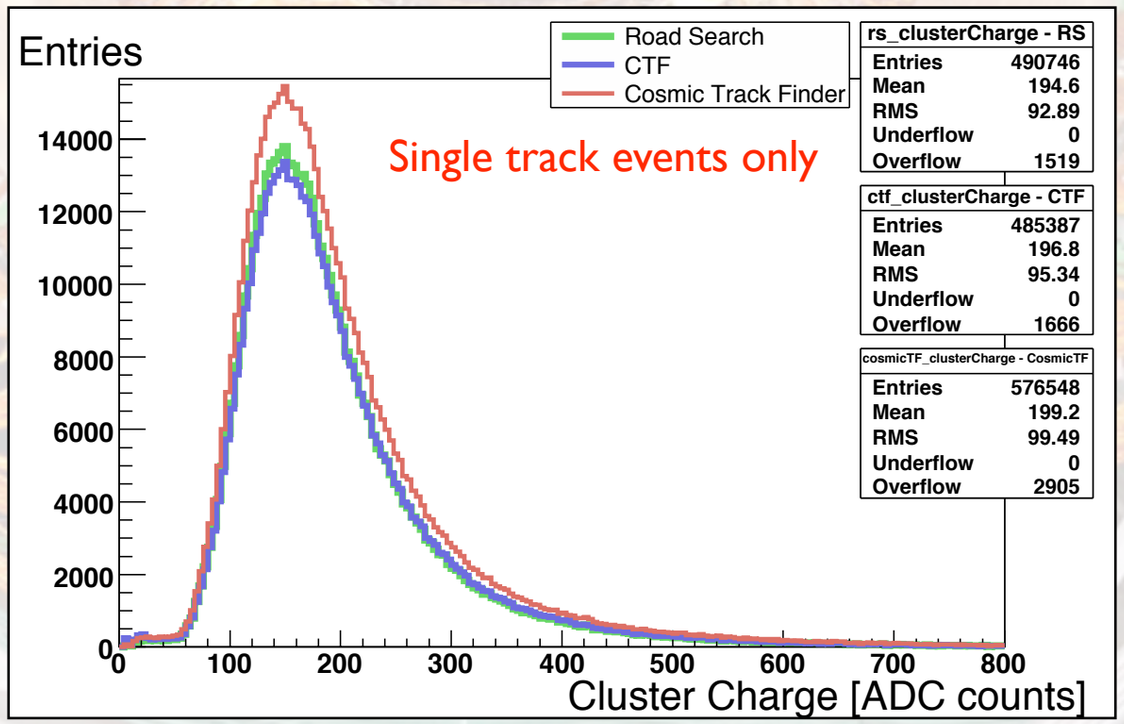


Tracking Performance

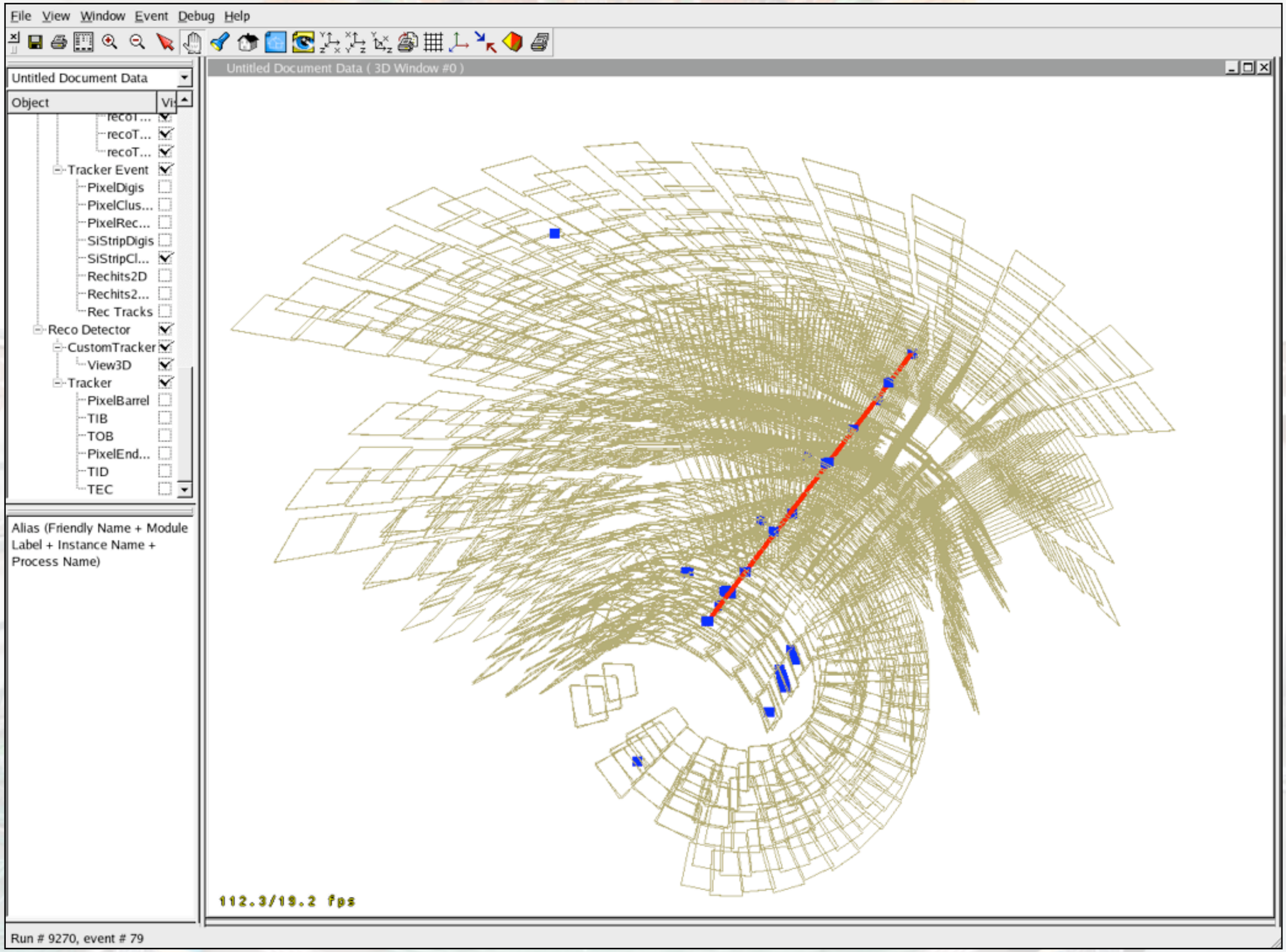
- Example: Results for a run with 105k events (T=-10°C)





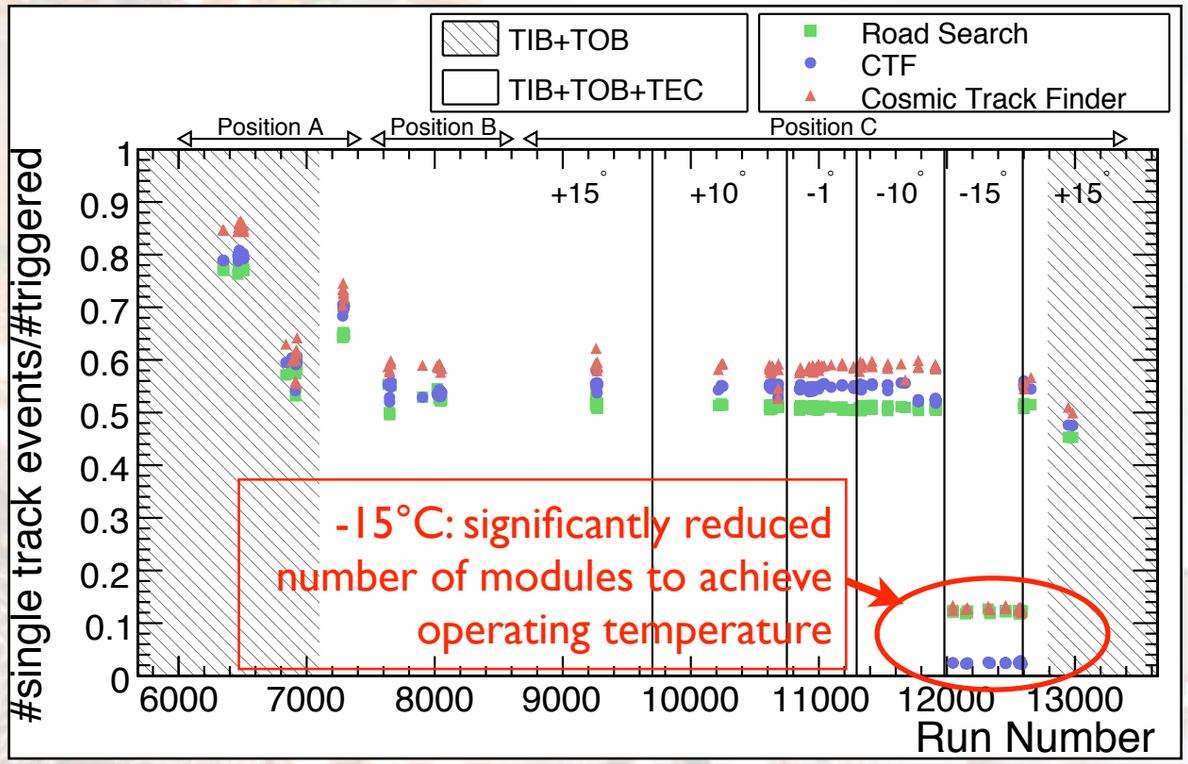


Event Display

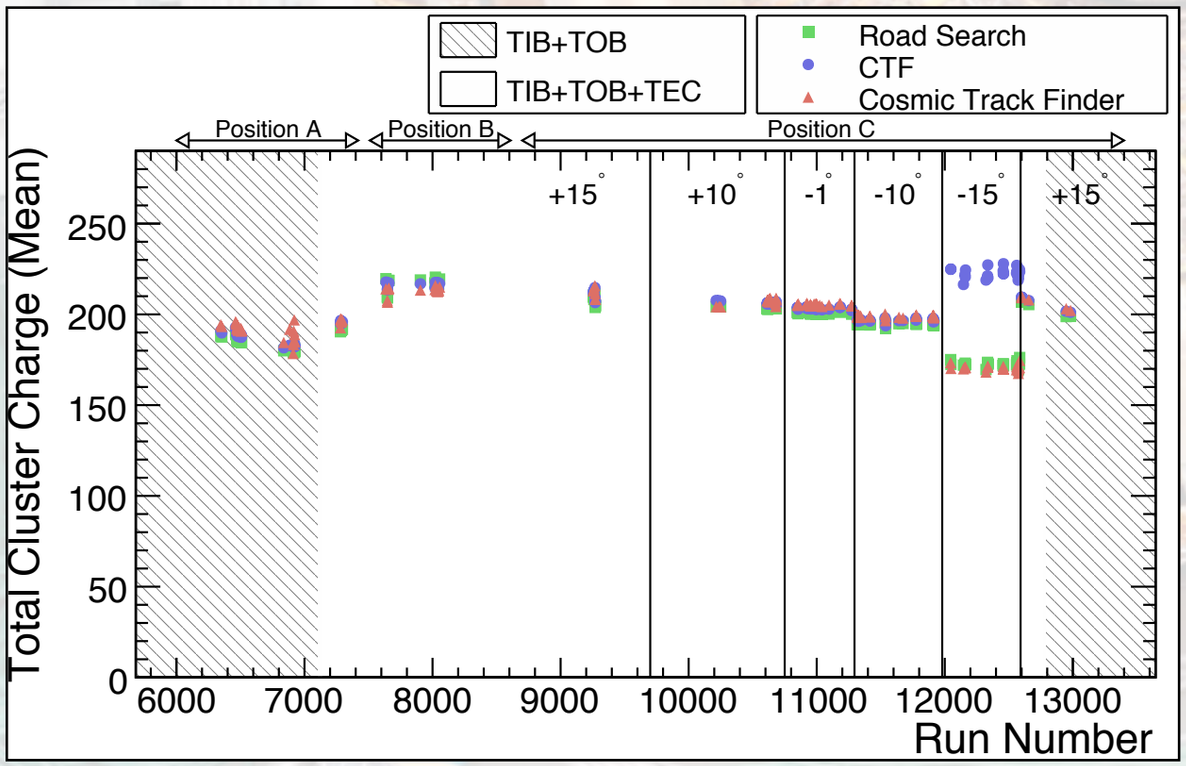


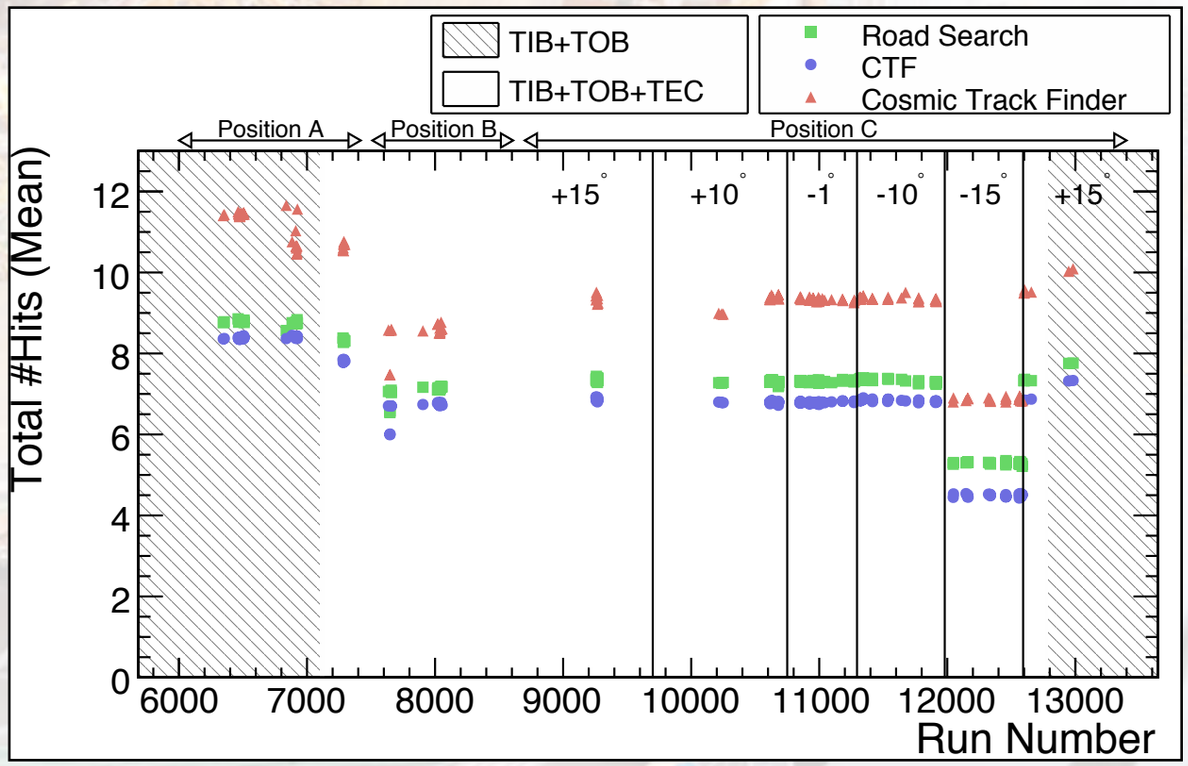
Tracking Performance

- Mean of previous histograms vs. run number to monitor long term stability-term stability



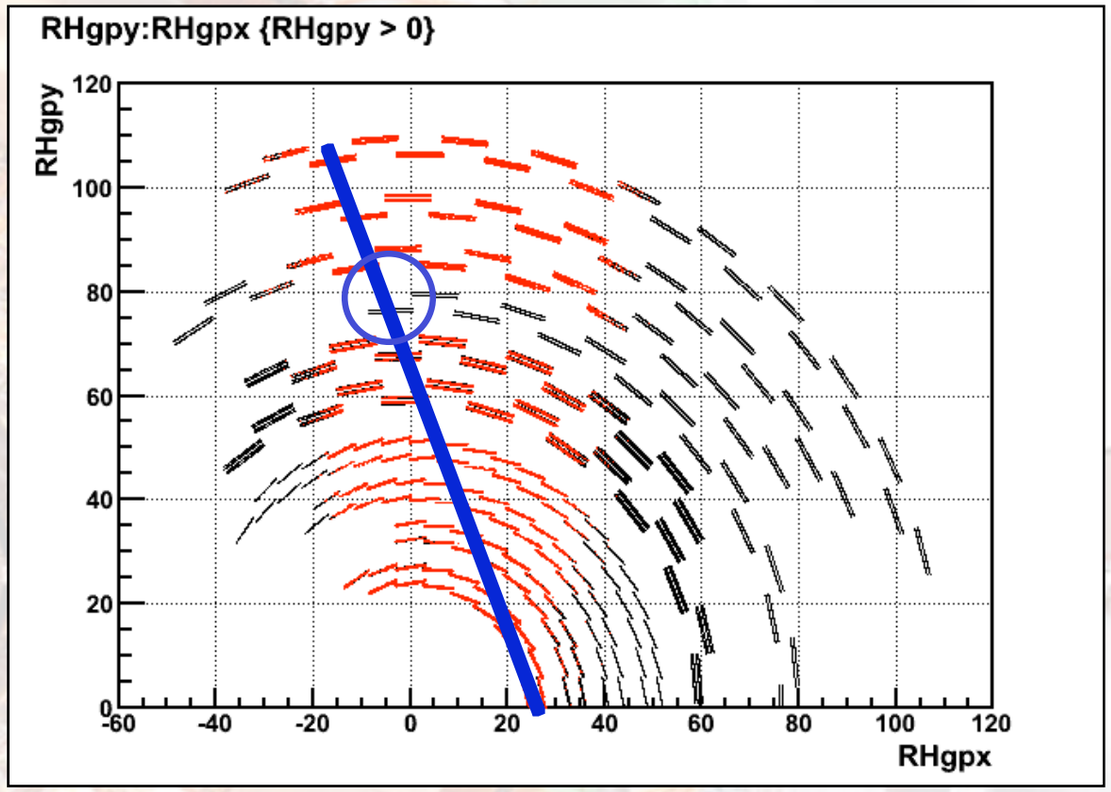
March '07 → July '07





Hit Efficiency Measurement

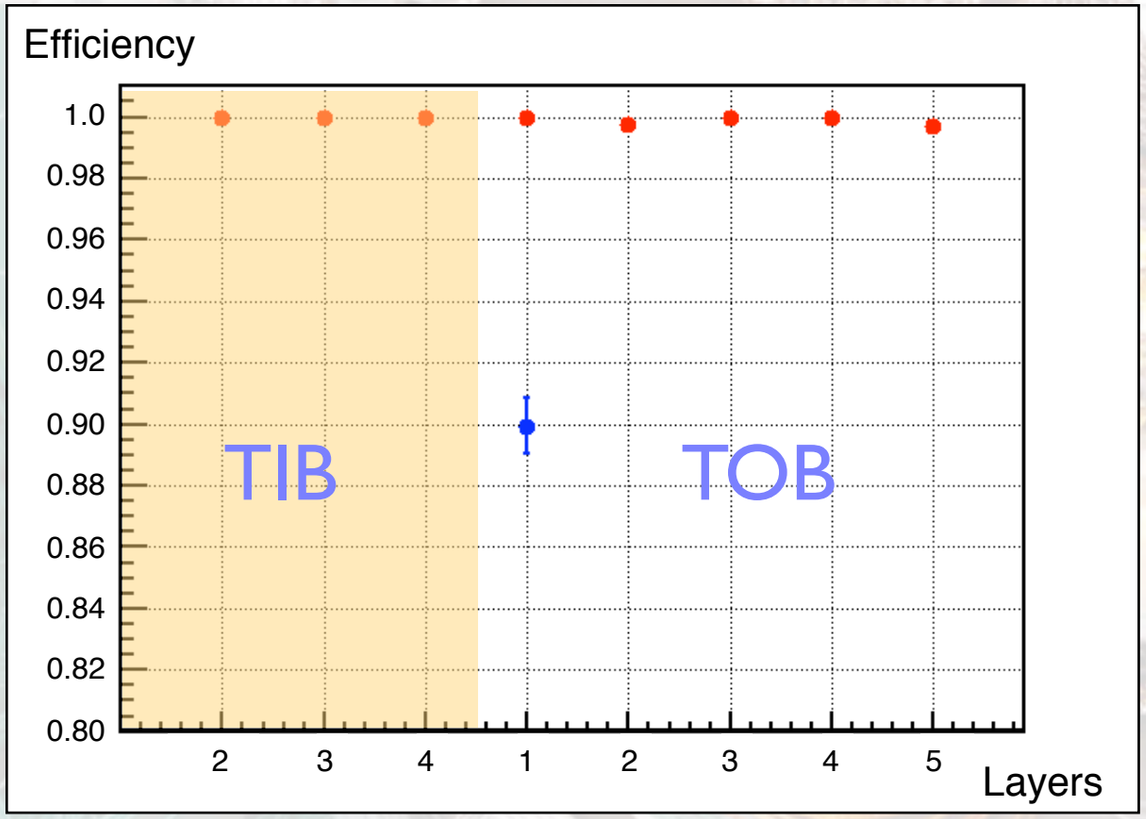
- Methodology
  - Use only single track events
  - Fix innermost and outermost layer (TIB layer 1 and TOB layer 6)
    → Tracks are almost perpendicular to modules

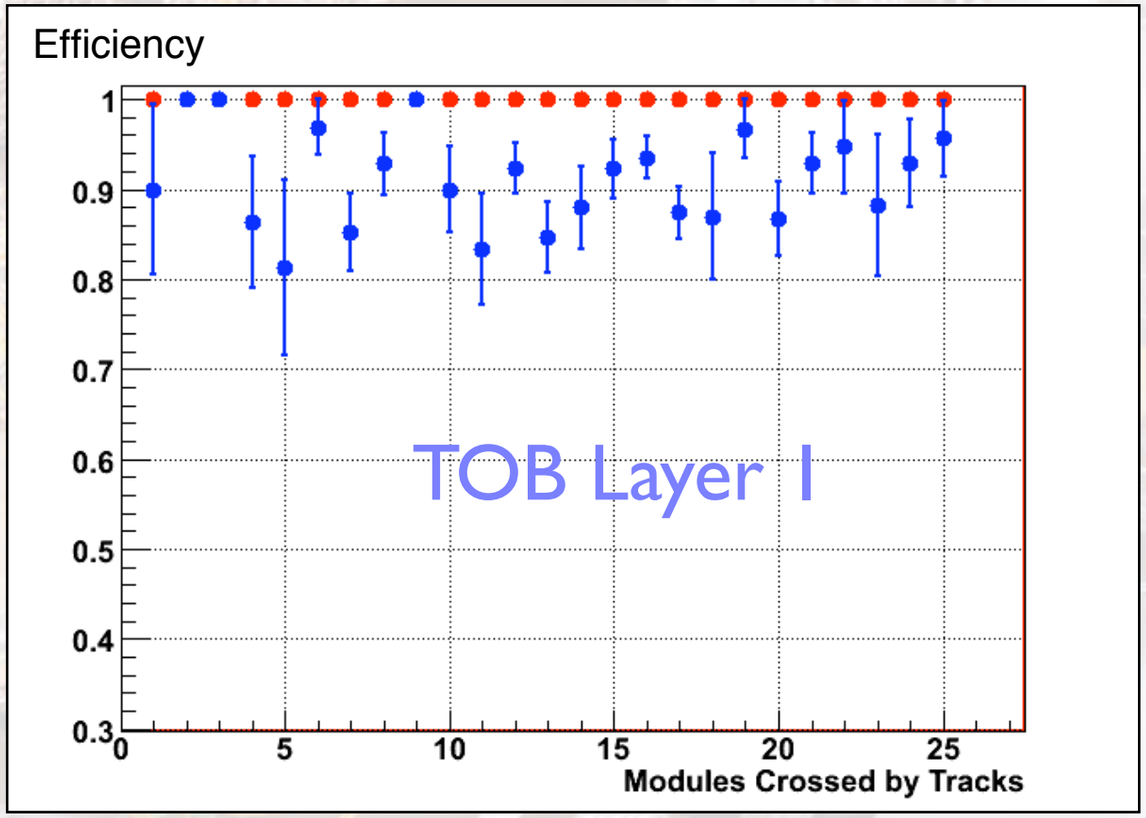


  - Layer under study is excluded from seeding and removed from tracking
  - Hit in layer under study is considered "valid" if it is located within the active area of module that is crossed by the track
  - Exclude inactive/problematic modules

Hit Efficiency Measurement

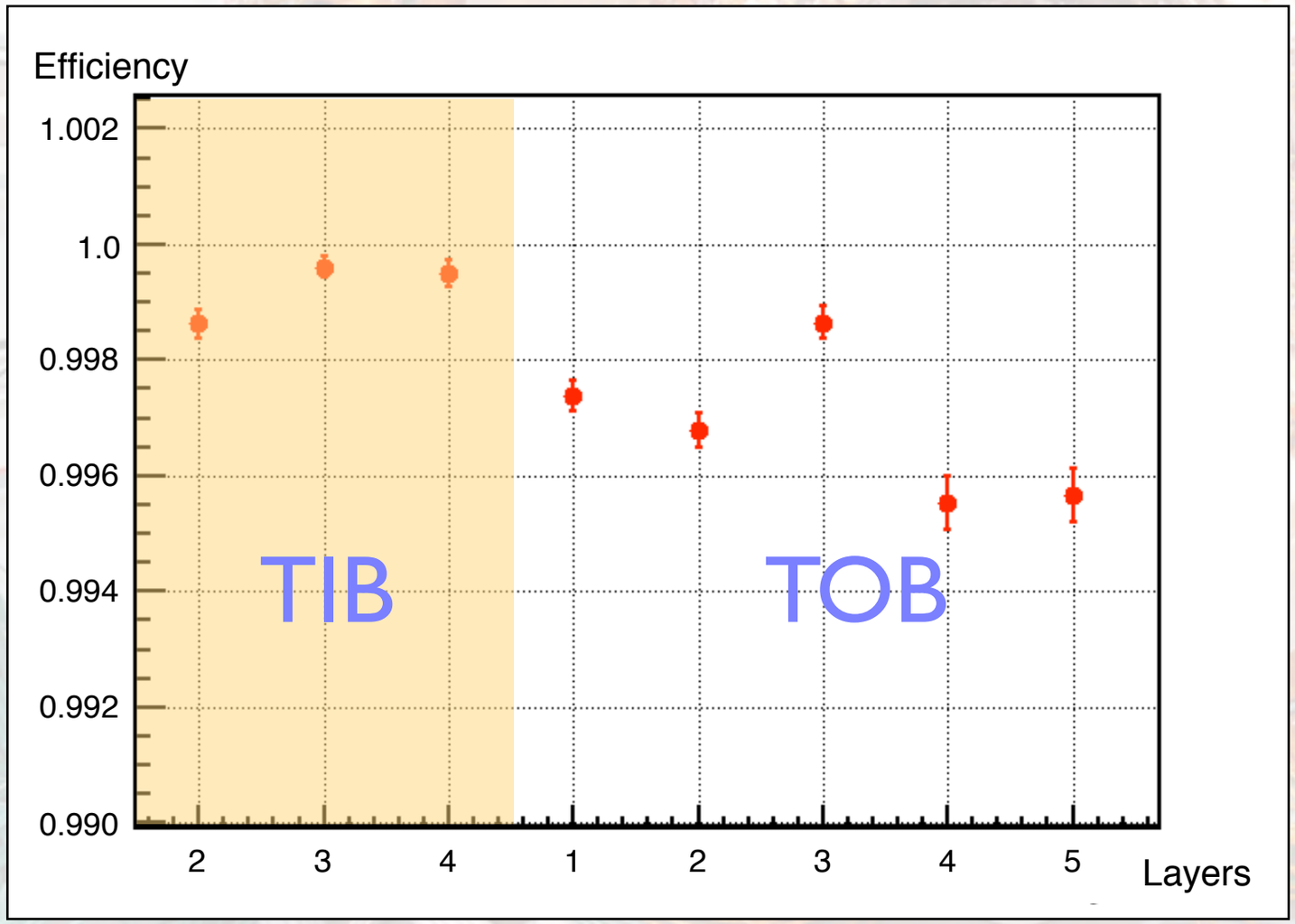
- Cross-check with simulation:
  - Simulation does not contain any inefficiencies
  - Introduce artificial inefficiency for TOB layer 1 of 90%





Hit Efficiency Measurement

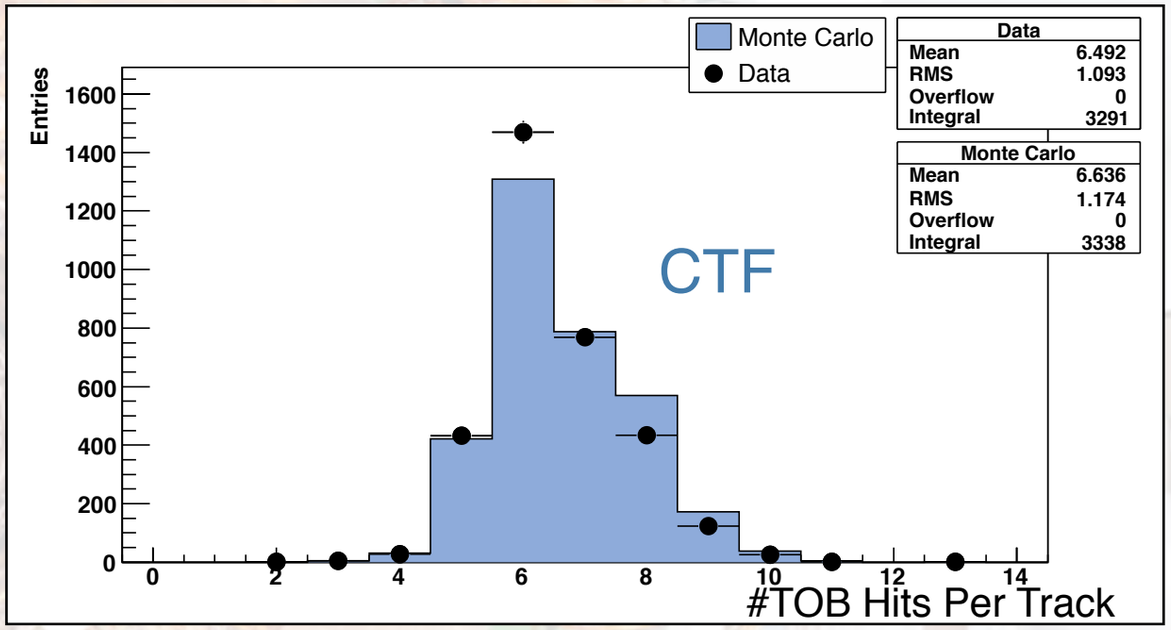
- Results in TIF data:
  → Both rΦ and stereo modules have hit efficiency greater than 99.5%

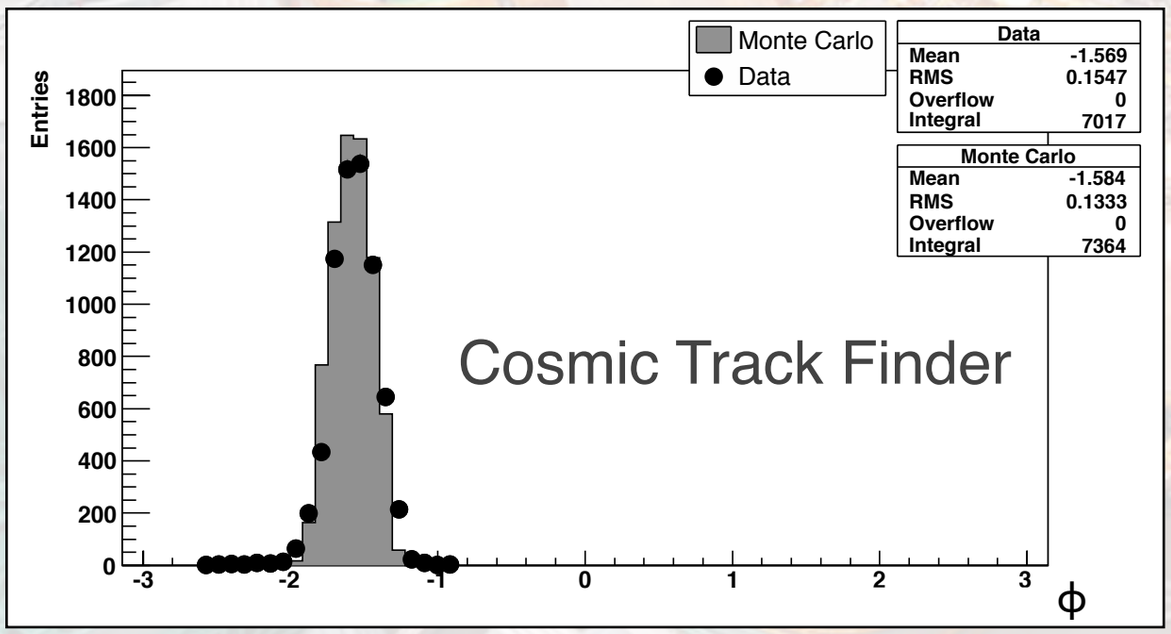


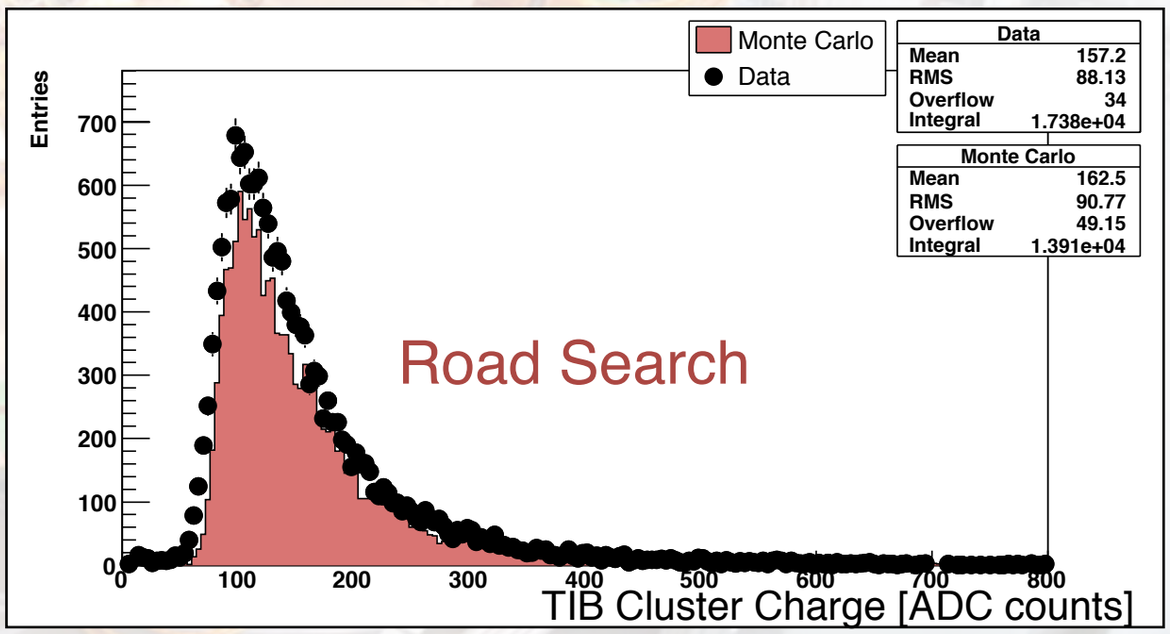
		Efficiency
TIB	Layer 2	99.86%
	Layer 3	99.96%
	Layer 4	99.95%
TOB	Layer 1	99.73%
	Layer 2	99.68%
	Layer 3	99.86%
	Layer 4	99.55%
	Layer 5	99.57%

Data/Monte Carlo Comparison

- Special TIF cosmic muon Monte Carlo sample
  - Module read-out is taken into account
- First comparisons of simulated cosmic ray events to data show reasonable agreement







Conclusions & Outlook

- Conclusions
  - Reconstruction of cosmic muon events is an important first test of the performance of the detector and of the track reconstruction chain
  - Several track reconstruction algorithms have been tested on both MTCC data and TIF commissioning data, allowing us to verify the individual tracking results and to understand the features of each algorithm
  - Track reconstruction software is able to reconstruct tracks and performs as expected
  - The reconstructed tracks are starting point for various analyses (e.g. hit efficiency) and for alignment (→presentation by Gero Flucke)
- Outlook
  - The silicon strip tracker will be moved to the CMS experiment area in October 2007 and fully commissioned
    →Cosmic data taking (together with other CMS sub-detectors) is planned for later this year

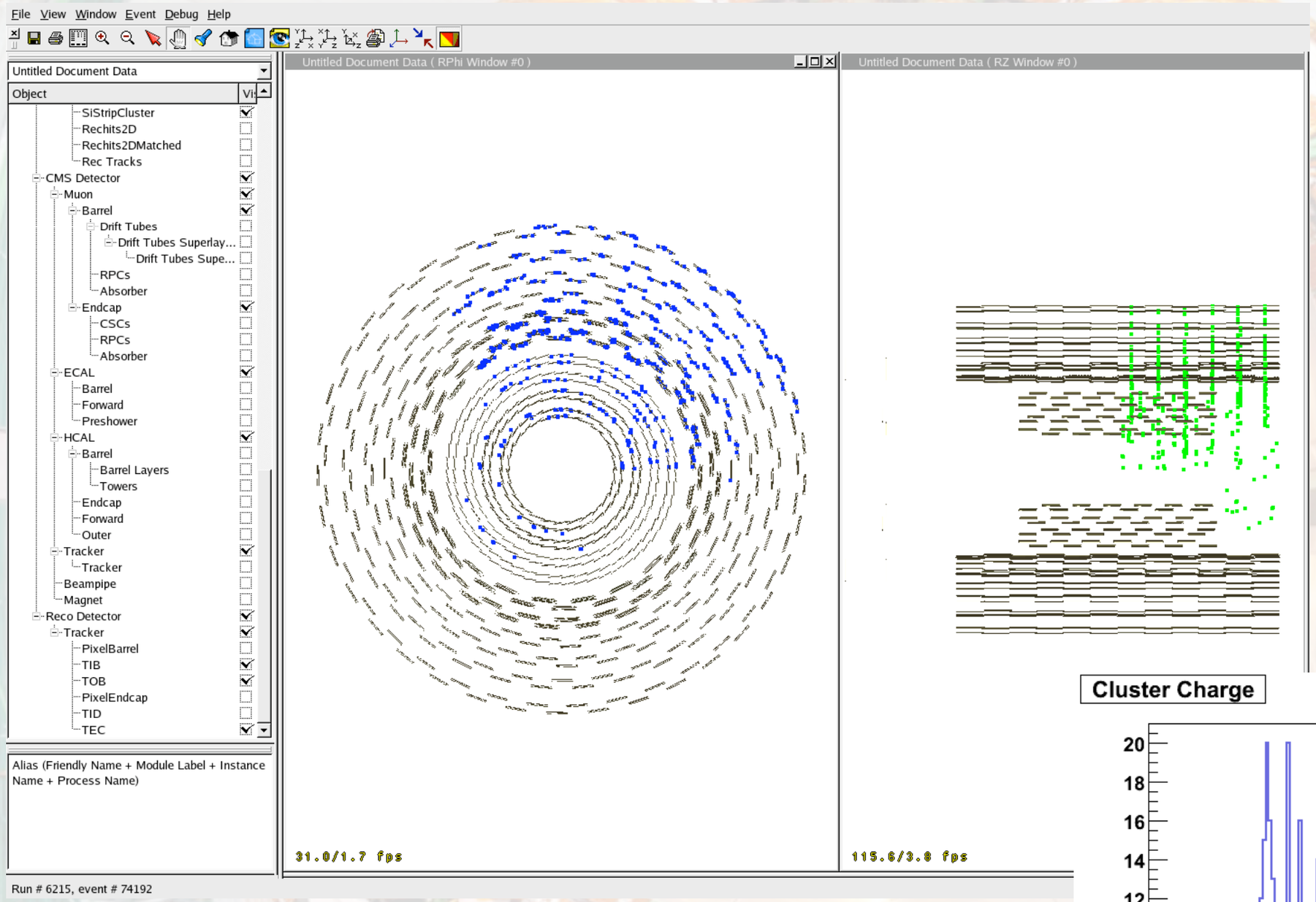
BACKUP

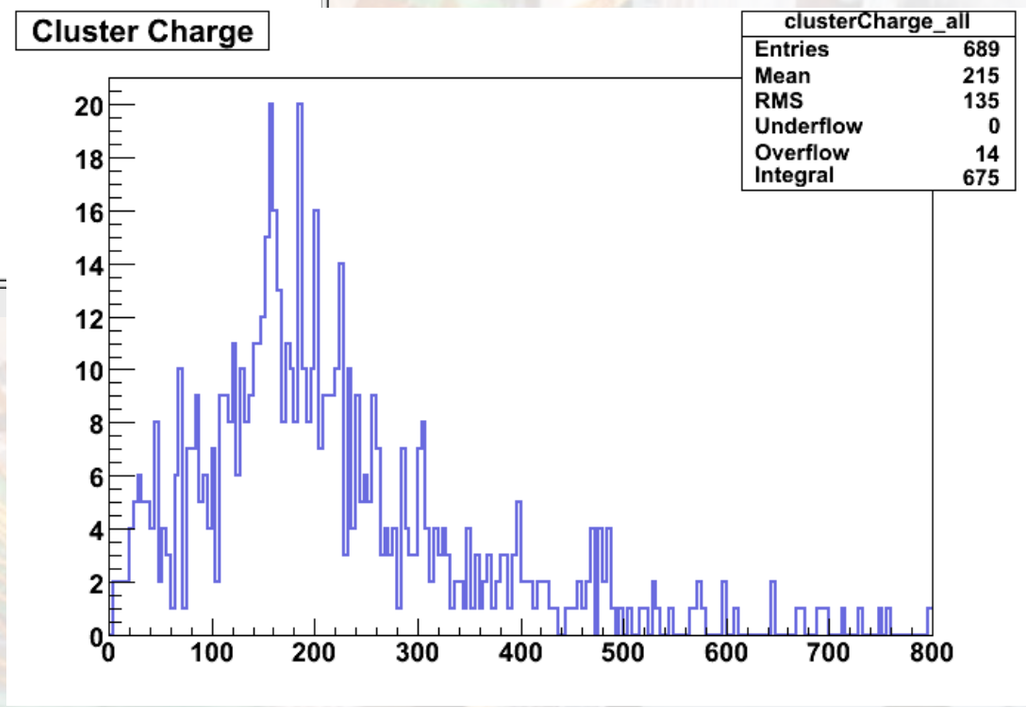
Timing Results for Cosmic Ray Data

- No dedicated optimization of tracking algorithms w.r.t. timing was performed

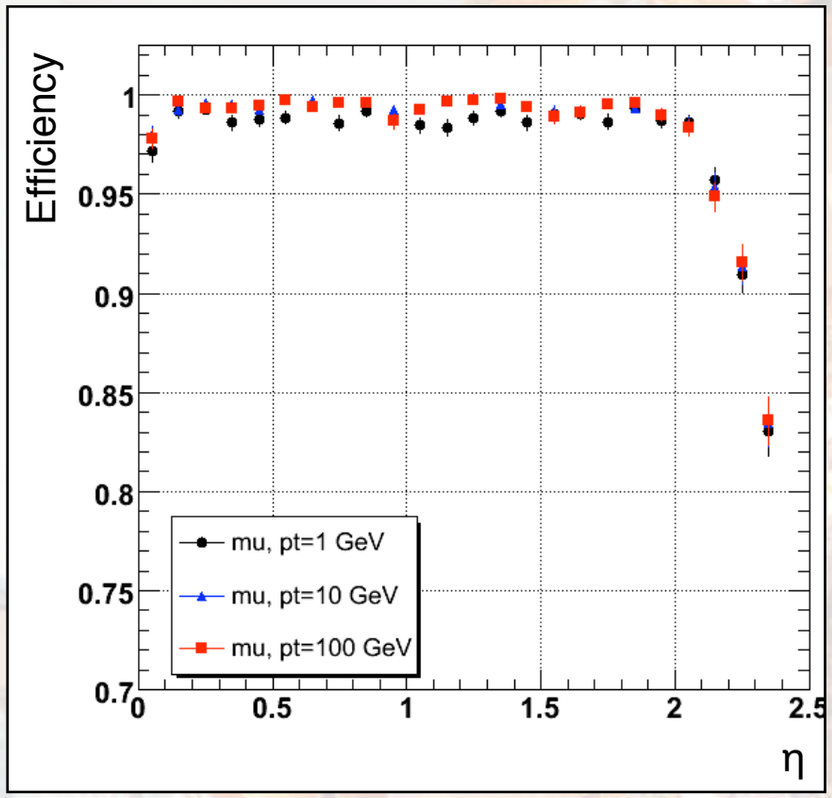
Scintillator Position	Temperature	Time/Event			
		TOTAL	Cosmic Track Finder	CTF	Road Search
A	Room	5.0s	0.06s	0.23s	0.30s
B	Room	5.3s	0.05s	0.33s	0.37s
C	Room	6.2s	0.06s	0.32s	0.44s
C	-10	4.9s	0.05s	0.34s	0.36s

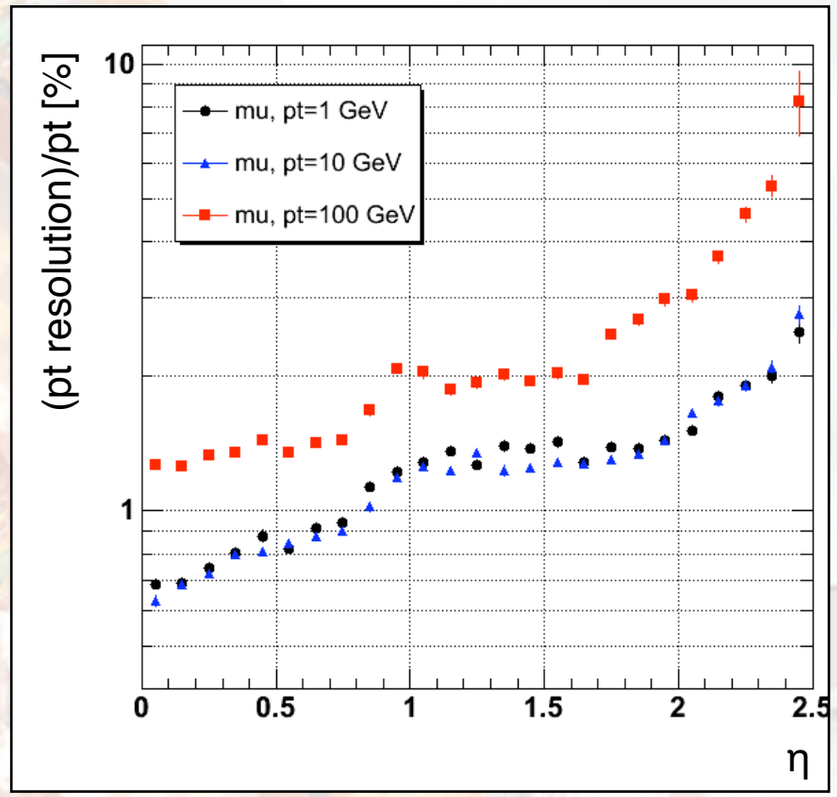
High Multiplicity Events





Tracking Performance





- Efficiency close to 99% up to $|\eta|<2$
- p_T resolution between 0.5% and 2%
- Resolution of impact parameter around 10-100μm