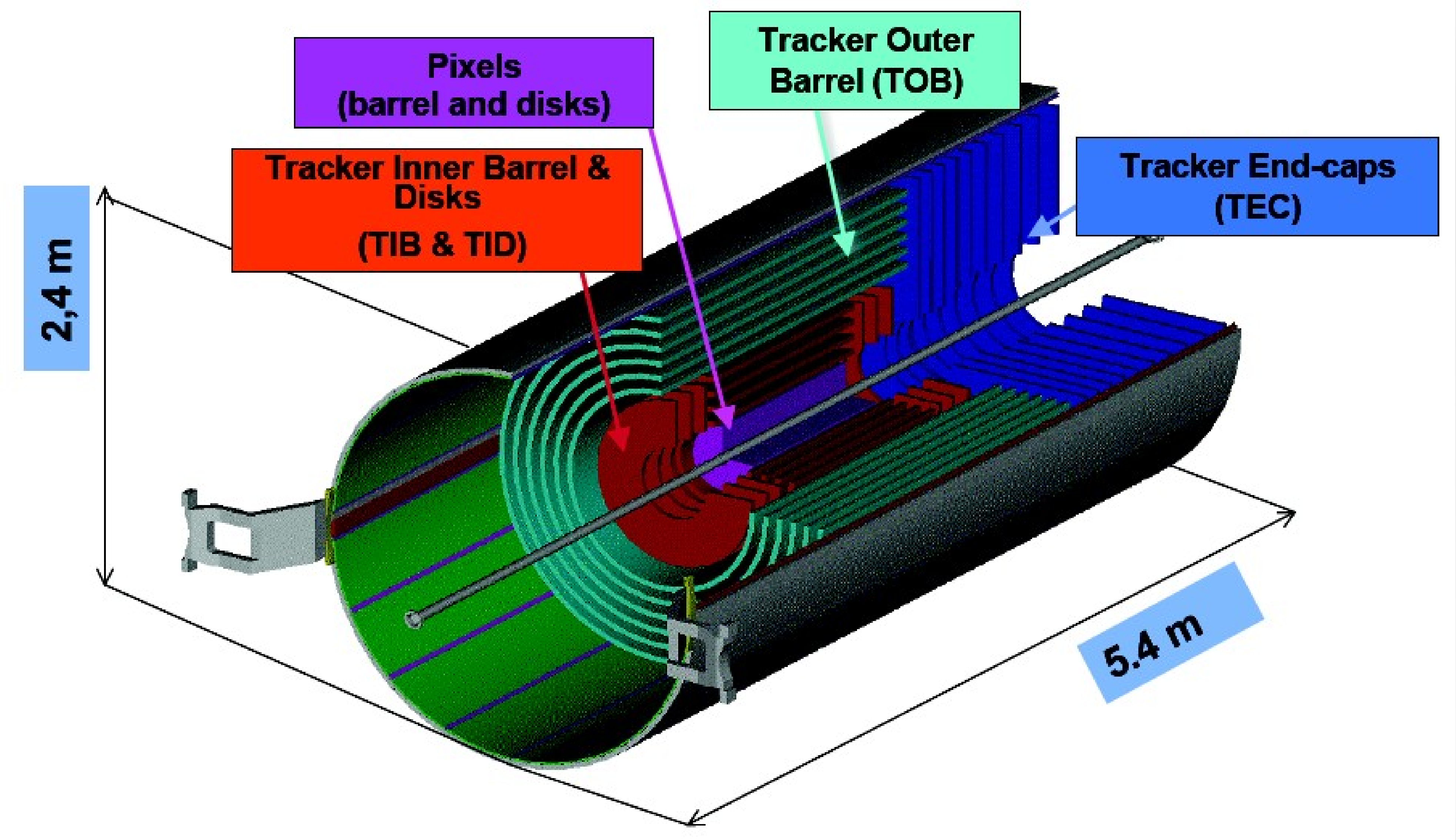
The CMS tracking algorithms and their performances in cosmic ray data

Antonio Tropiano,
Università di Firenze and INFN,
on behalf of the CMS collaboration

Summary

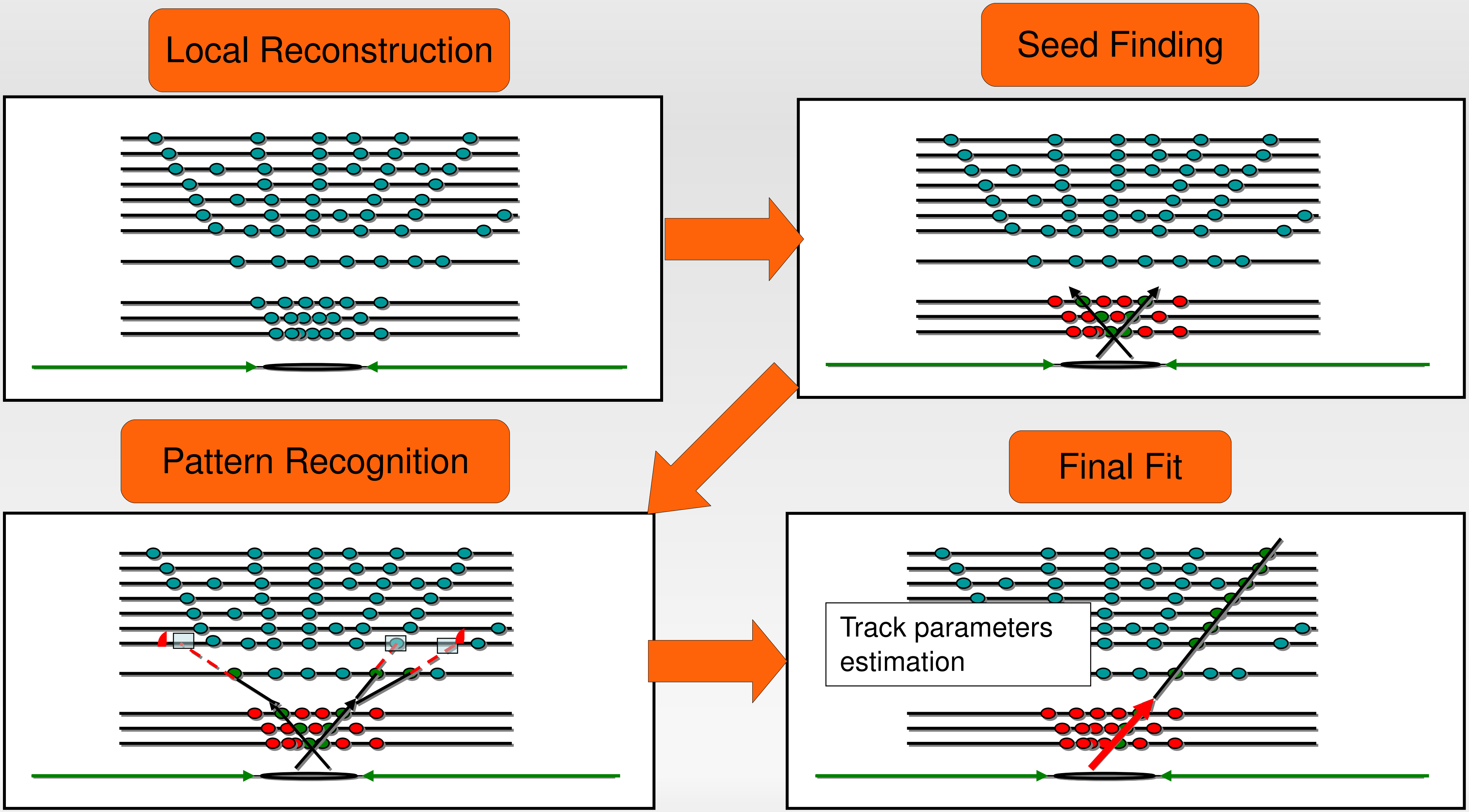
- **The CMS tracker layout**
- **The CMS tracking algorithms**
- **The tracking performances with simulated collisions**
- **The tracking performances with cosmic ray data**
- **Conclusions**

The CMS tracker detector



The CMS Tracking Algorithms

CMS tracking steps



The CMS Tracking Algorithms

CMS tracking algorithms for collisions

- **Combinatorial Track Finder (CTF)**

  - **Seeding**: done using the innermost layers of the tracker (pixels and first layers of TIB).
  - **Pattern recognition**: Kalman Filter based propagation and update of the trajectory parameters on more external layers. Search for hits in narrower windows as the track approaches external layers.
  - **Final fit**: done running two Kalman filter in the opposite senses (inside-out and outside-in).

- **Road Search**

  - **Seeding**: done using mostly the two most inner and outer strip tracker layers.
  - **Pattern recognition**: based on predefined *roads* used to collect *clouds* of hits around each road.
  - **Final fit**: identical to CTF one.

- **Others**

  - **Deterministic Annealing Filter**: track reconstruction for high p_T jets.
  - **Gaussian Sum Filter**: track reconstruction for electrons.

The CMS Tracking Algorithms

Iterative tracking: the CMS standard track reconstruction algorithm

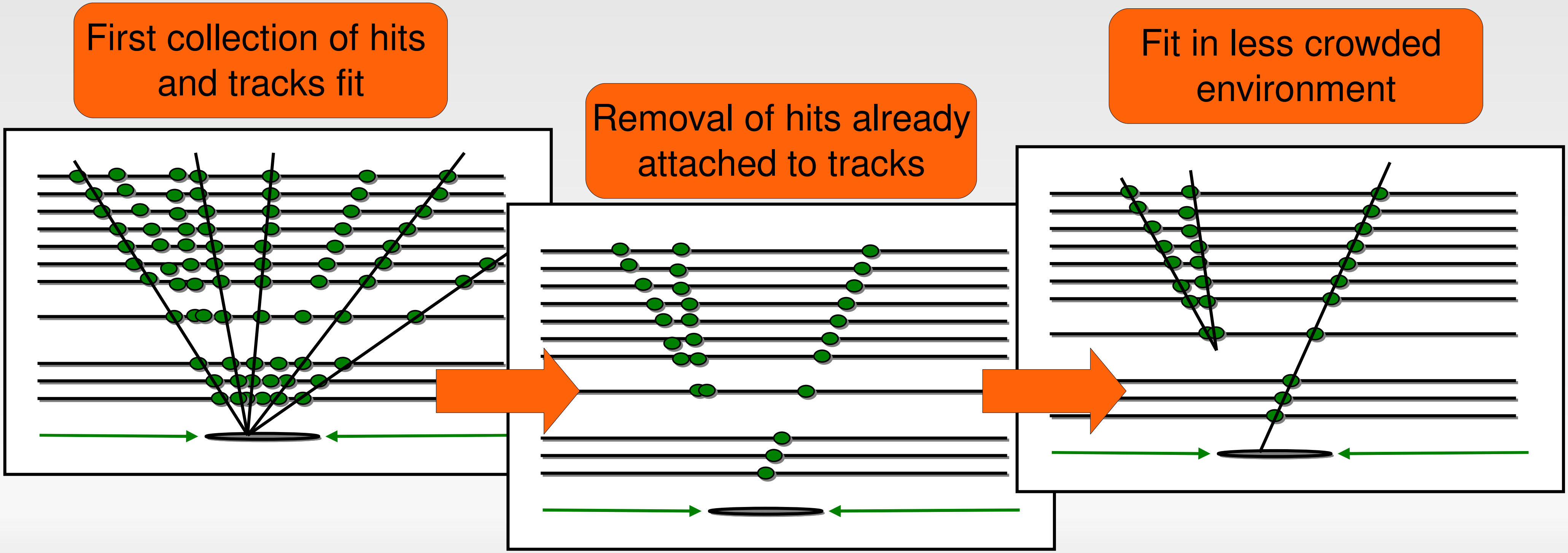
- **Iterative tracking**

  Essentially an iterated CTF. The track reconstruction is repeated several times, each time with different settings. In the latest version of software it is made of 6 steps.

  - **steps 0 and 1**: reconstruction of primary particles with p_T > 600 MeV

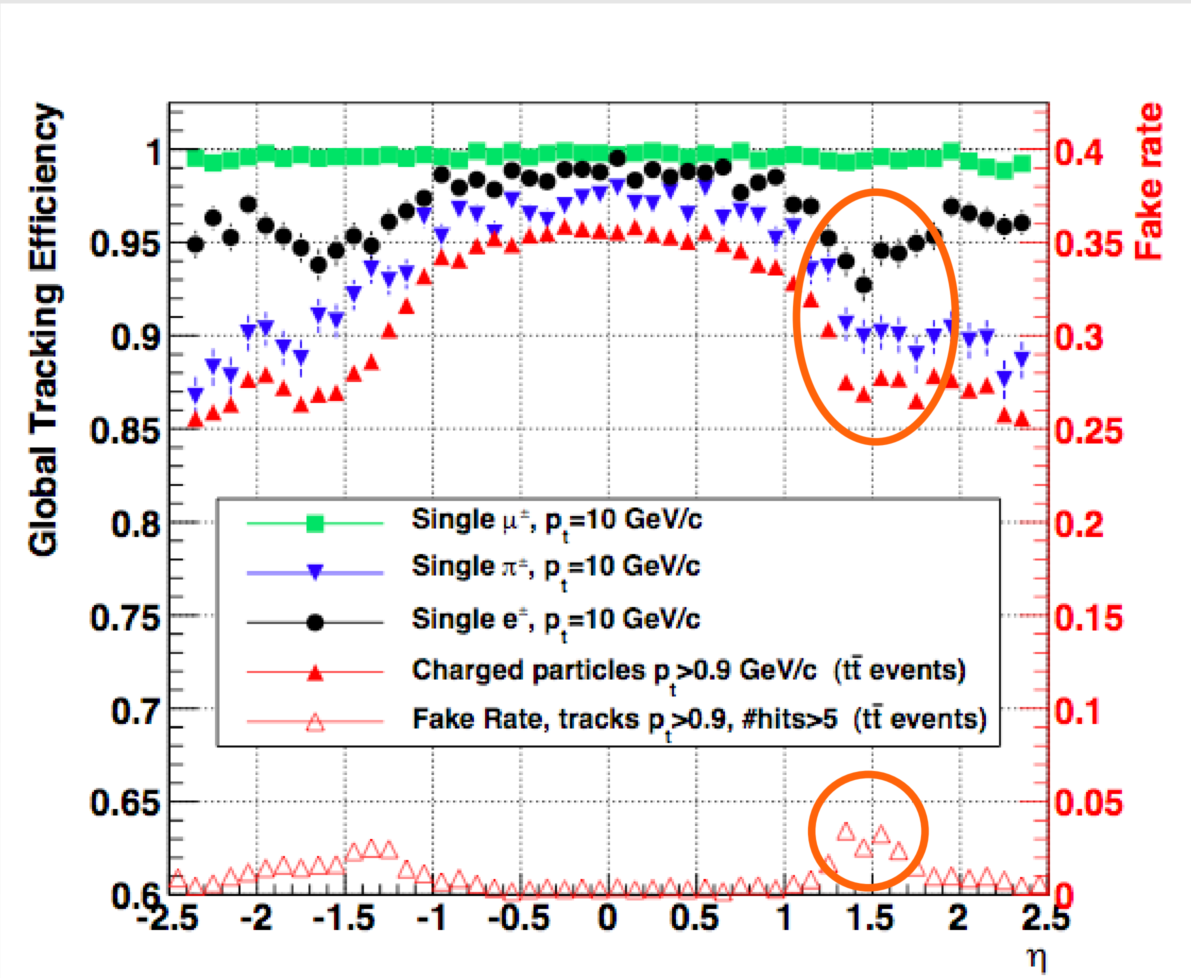
  - **step 2**: reconstruction of primary particles with very low energy.

  - **step 3 to 5**: reconstruction of detached tracks.



Tracking Performance in Collisions

Tracking efficiency for simulated collisions

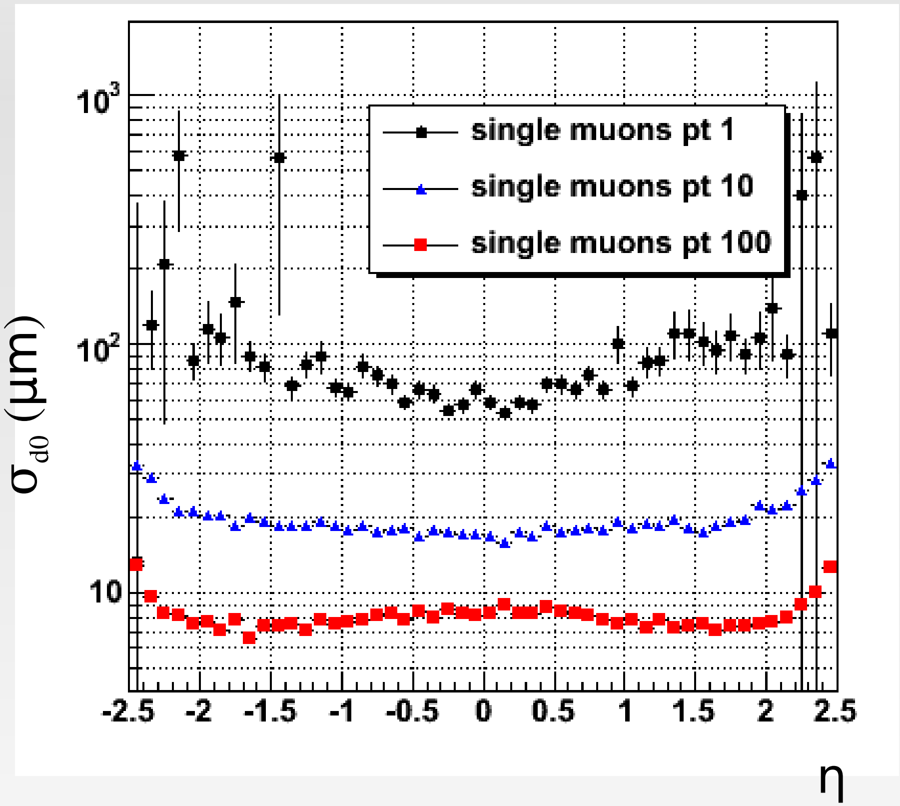


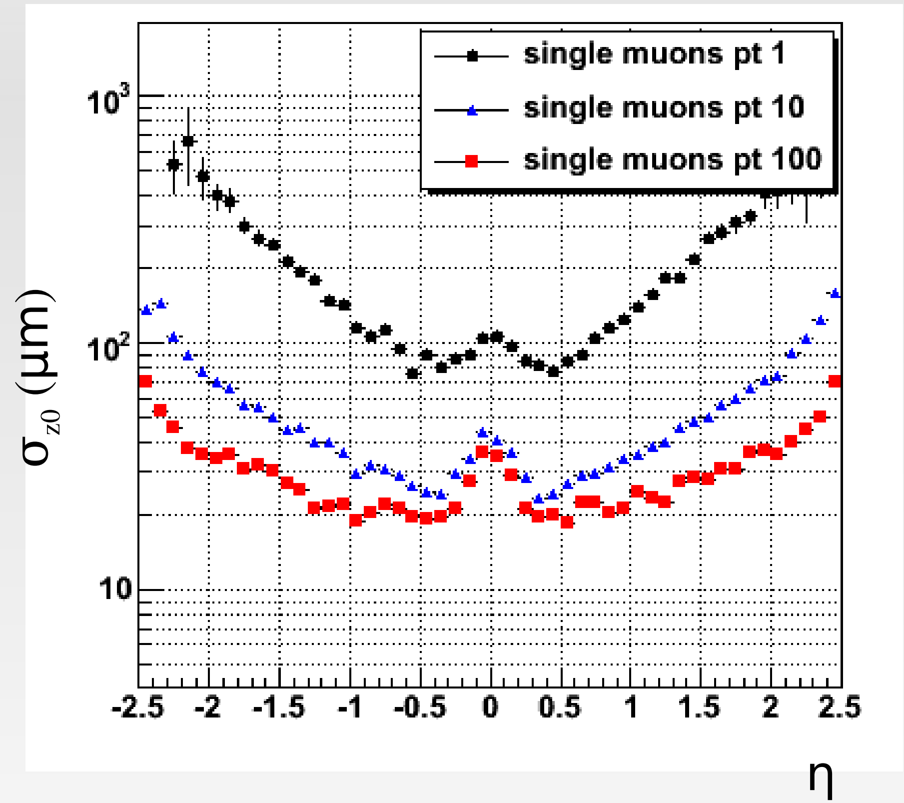
Slight degradation of tracking performances in the transition region between barrel and endcap.

This is due to the large amount of inactive material in this region.
<u>Large interaction lenght:</u> pions inelastically interact and are lost.
<u>Large radiation lenght:</u> electrons lose energy and the pattern recognition can fail.

Tracking Performance in Collisions

Track parameters resolution for simulated collisions





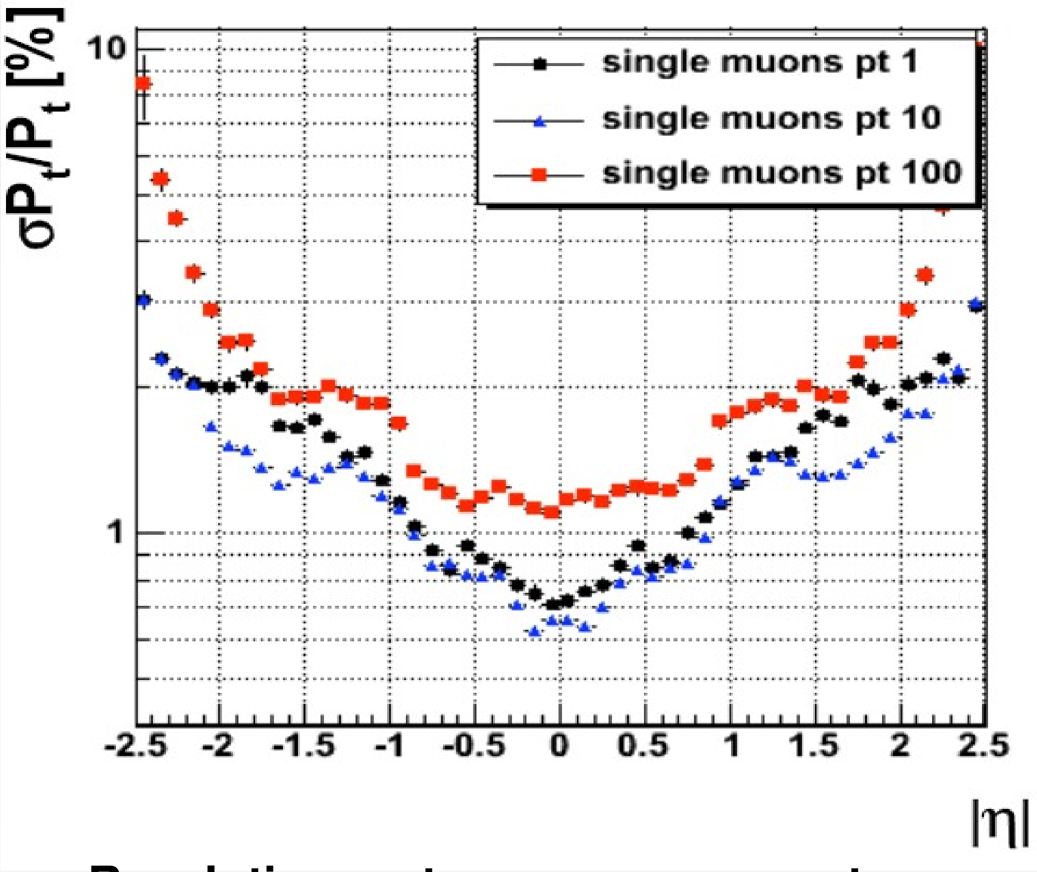
Resolution on transverse impact parameter:

-10 µm for 100 GeV muons

-50-60 µm for 1 GeV muons (barrel region)

Tracking Performance in Collisions

Track parameters resolution for simulated collisions



Resolution on transverse momentum:

-less than 1% in the barrel region for track with p_T 1-10 GeV

-less than 2% for tracks with p_T of 100 GeV

- resolution decreases in the forward region due to the smaller lever arm

CMS tracking algorithms for cosmics

- **CTF for cosmic**

  The seeding is done using TOB and TEC layers, while pattern recognition and final fit are the same as for collisions.

- **Cosmic Track Finder (CosmicTF)**

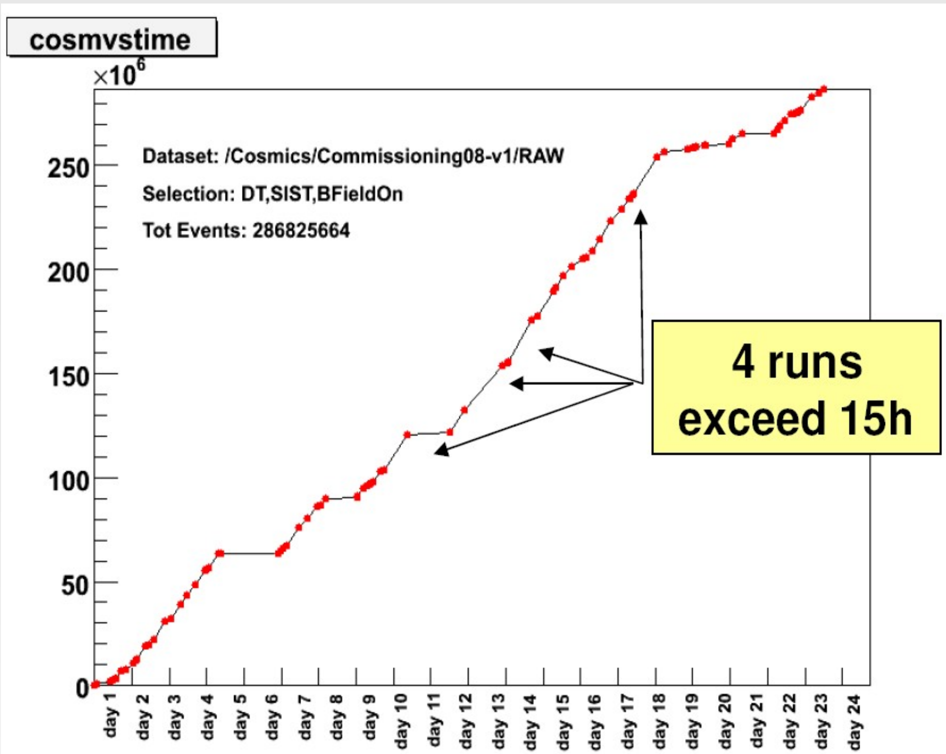
  - This is a dedicated algorithm for cosmics reconstruction only.
  - **Seeding**: done using hits in TIB or hits in TOB.
  - **Pattern recognition**: hits are vertically aligned. A Kalman Filter based propagation on successive layers is performed.
  - **Final fit**: done running a Kalman filter in the opposite direction w.r.t. the pattern recognition. Only one track per event is retained.

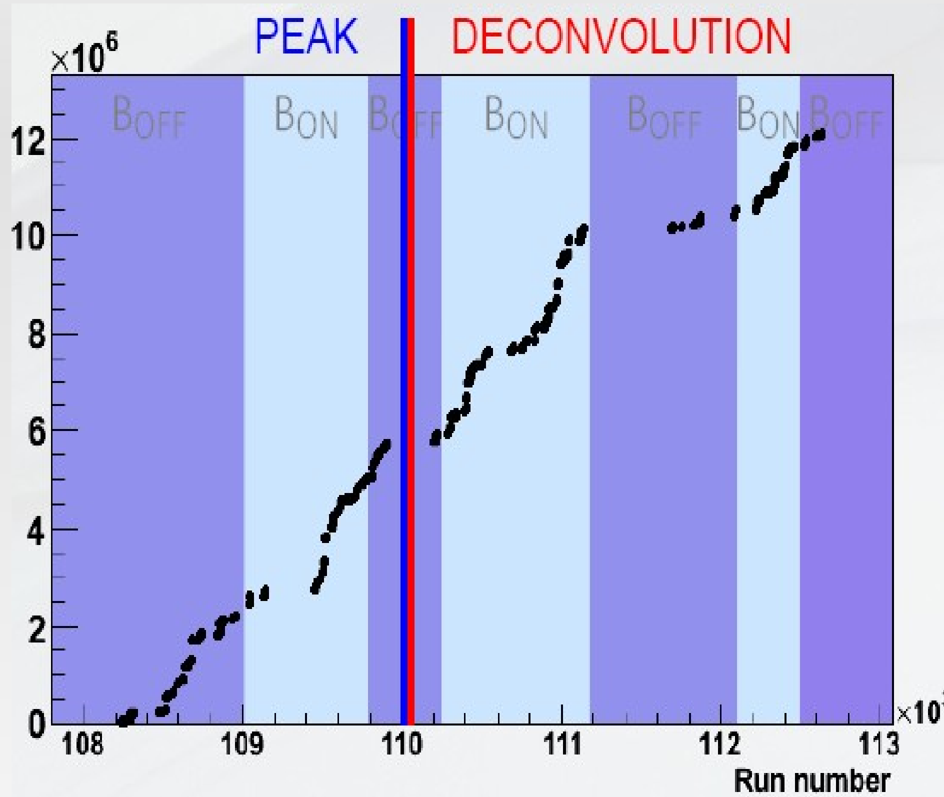
Tracking Performance in Cosmics

- October-November 2008: the whole CMS tracker operated together with the other subdetectors, with the B field at 3.8 Tesla. This exercise has been named CRAFT (Cosmic Run At Four Tesla).
  It was the first operation of the tracker together with all CMS subdetectors.
  Cosmics were triggered by the muon chambers and were used to test the performance of the CMS tracking system.
  Data collected with CRAFT 08 were successfully used to calibrate and test the performance of CMS tracker.
- July-September 2009: the exercise was repeated.
- I will present results related to tracking algorithms performances in CRAFT08 and CRAFT09.

Tracking Performance in Cosmics

Number of events collected in CRAFT08 and CRAFT09





- **Number of tracks with hits in the strips in CRAFT08:** ~ 7×10^6
- **Number of tracks with hits in the strips in CRAFT09:** ~ 12×10^6

Tracking Performance in Cosmics

Number of strips and pixels operational in CRAFT08 and CRAFT09

CRAFT08

- Strip tracker
  - -TOB: 98%
  - -TIB/TID: 96.6%
  - -TEC+: 99.2%
  - -TEC-: 97.8%
- Pixels
  - -Barrel: 99.1%
  - -Endcap: 94.0%

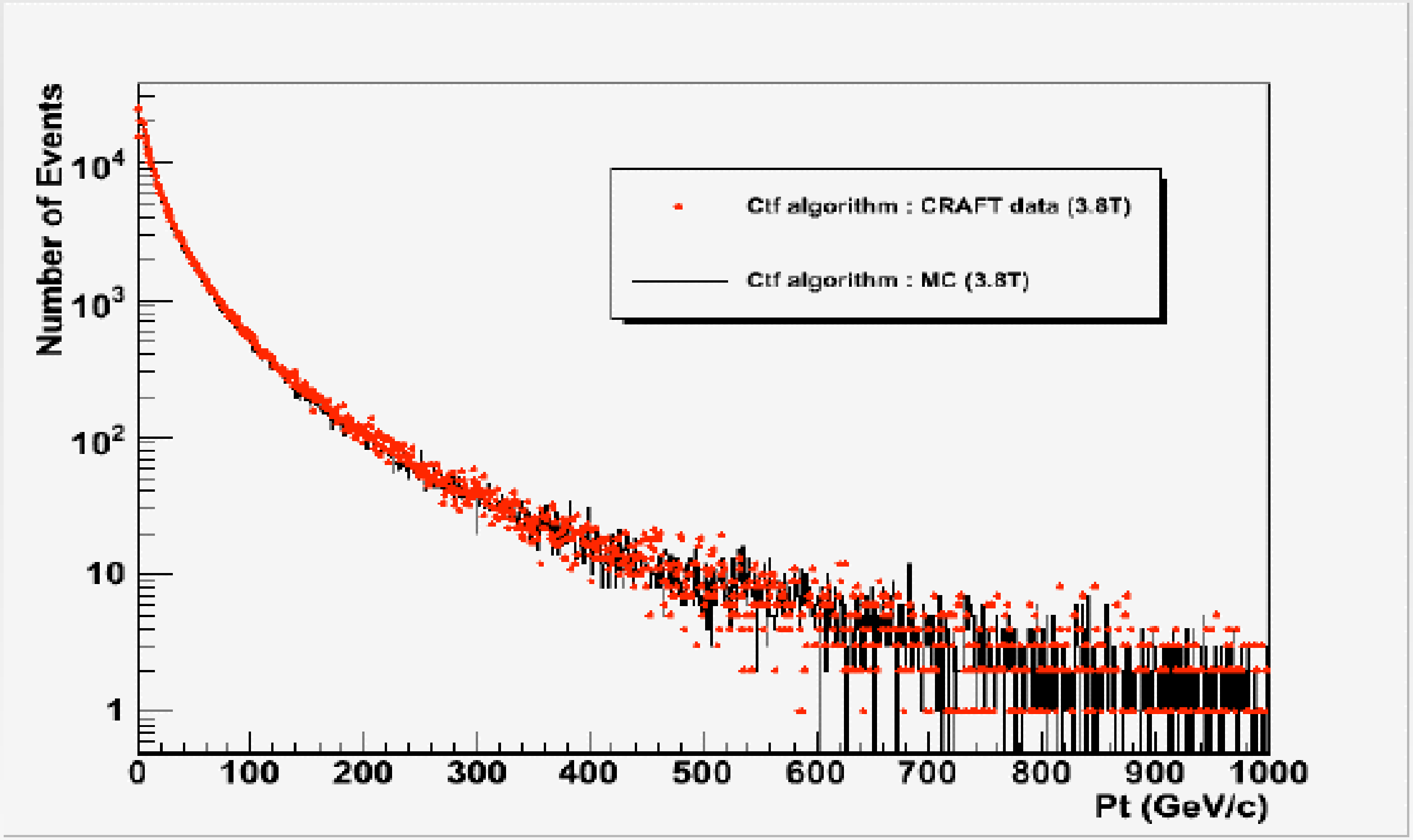
CRAFT09

- Strip tracker
  - -TOB: 98.3%
  - -TIB/TID: 96.5%
  - -TEC+: 98.8%
  - -TEC-: 99.2%
- Pixels
  - -Barrel: 99.1%
  - -Endcap: 96.9%

Most of the inefficient modules were recovered between CRAFT08 and CRAFT09, expecially in pixel endcaps and TEC- regions.

Tracking Performance in Cosmics

Tracks P_T spectrum for CRAFT08 data



Tracks reconstructed with the Combinatorial Track Finder.

Good agreement between data and Monte Carlo.

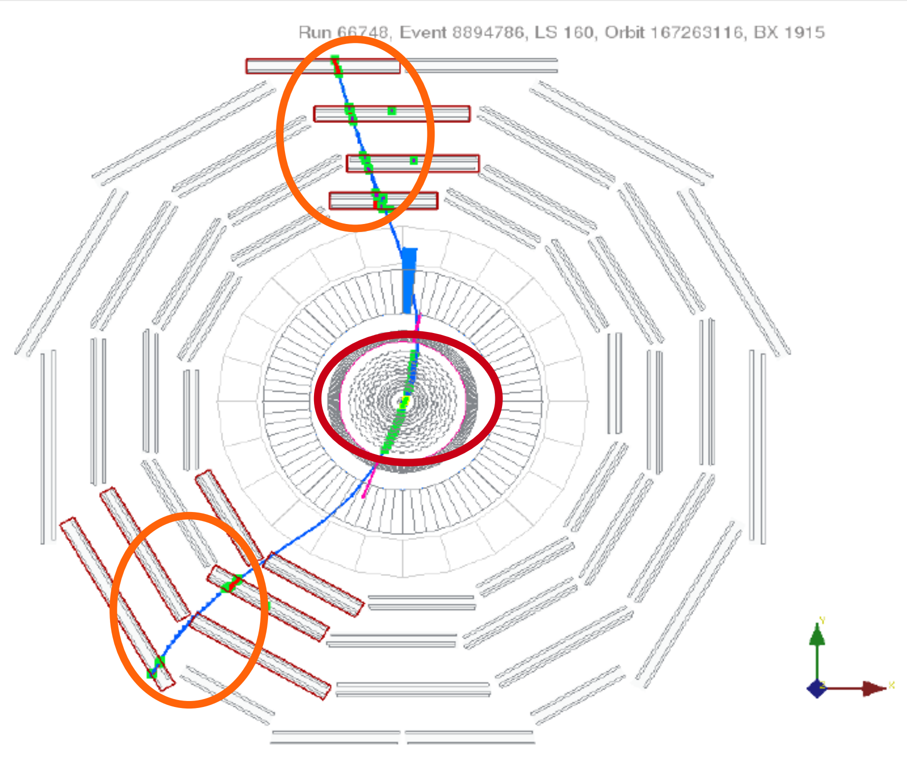
Tracking Performance in Cosmics

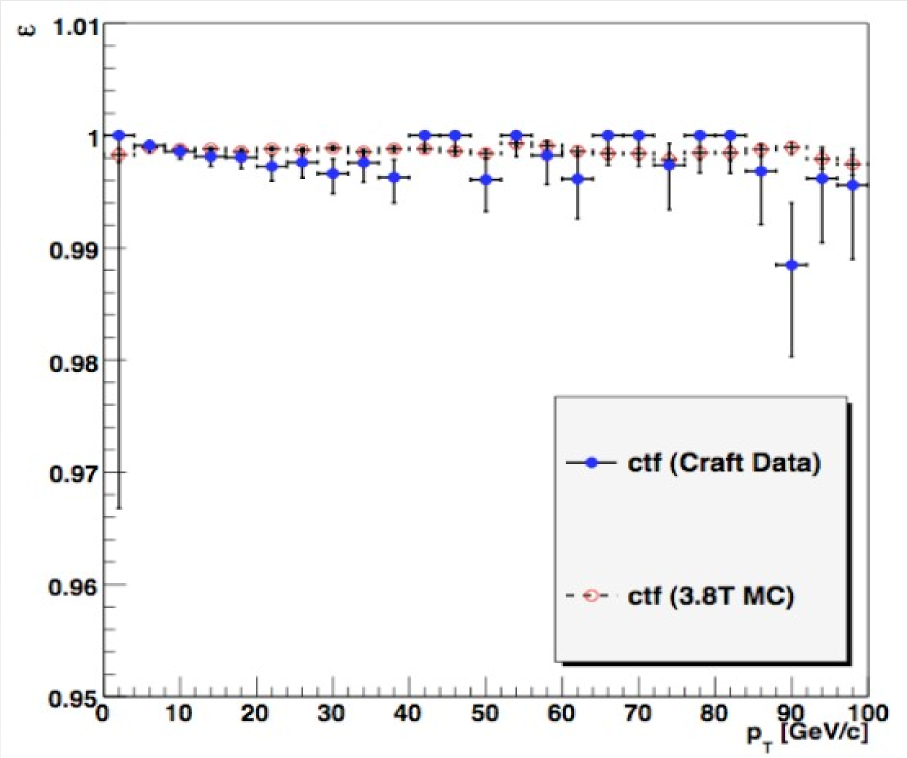
Tracking efficiency for CRAFT data

- **Tag and probe method**
  Efficiency measured by searching for a muon reconstructed in the muon chambers and matching it to a muon reconstructed also in the tracker.
- **Split tracks method**
  Efficiency measured using data from the tracker only. Tracker is divided in an upper and a lower side. Tracks are reconstructed indipendently in both sides of the detector. Then the track in the bottom half is matched to the track in the top half and viceversa. Two efficiencies can be computed.
- **Collision like method**
  Tracks are reconstructed with settings similar to the ones that will be used in collision like reconstruction (i. e. fitting the trajectory from the innermost to the outermost layers). For each cosmic event, two half tracks starting from the center of the tracker are reconstructed. The efficiency is then evaluated matching these two tracks as in the split tracks method.

Tracking Performance in Cosmics

Tracking efficiency with tag and probe method for CRAFT08 data



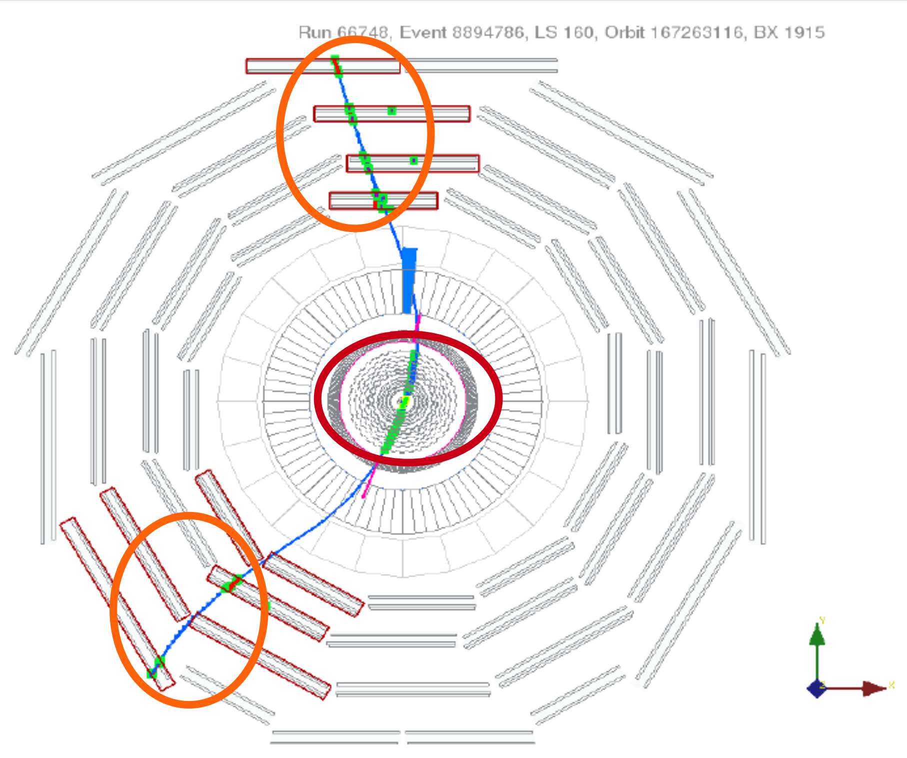


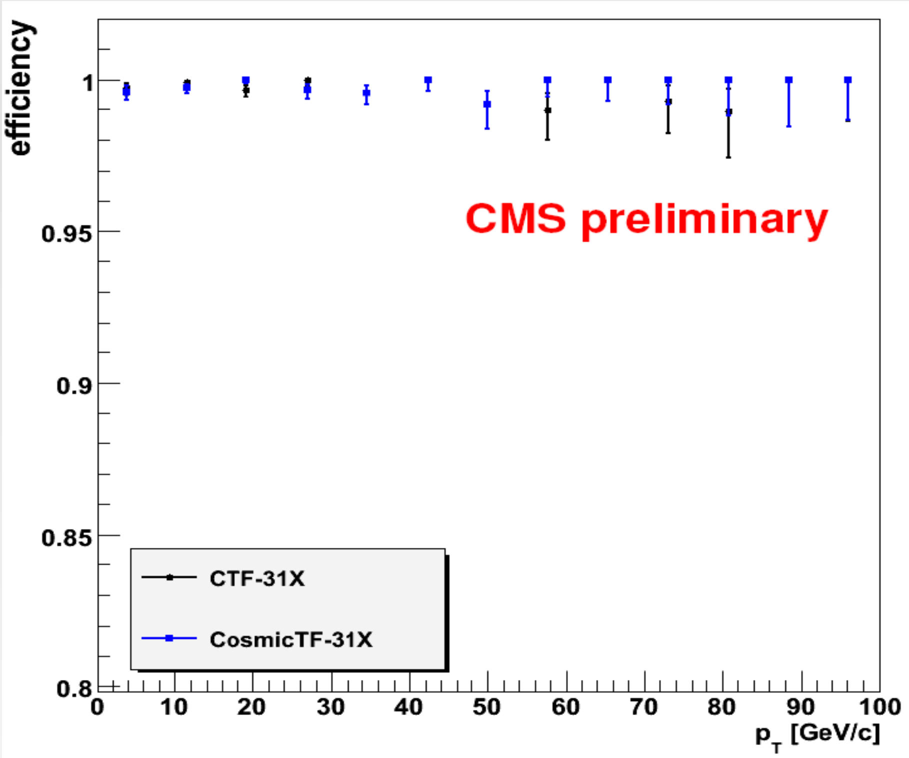
Cuts on the reconstructed muons at the point of closest approach to the beamline

- $|d_z|<30$ cm, $|d_{xy}|<30$ cm, $|\eta|<1$, $0.5<|\phi|<2.5$

Algorithm	Data Efficiency(%)	MC Efficiency (%)
CTF	99,78 +- 0,02	99,8 +- 0,00
CosmicTF	99,47 +- 0,04	99,72 +- 0,01

Tracking efficiency with tag and probe method for CRAFT09 data





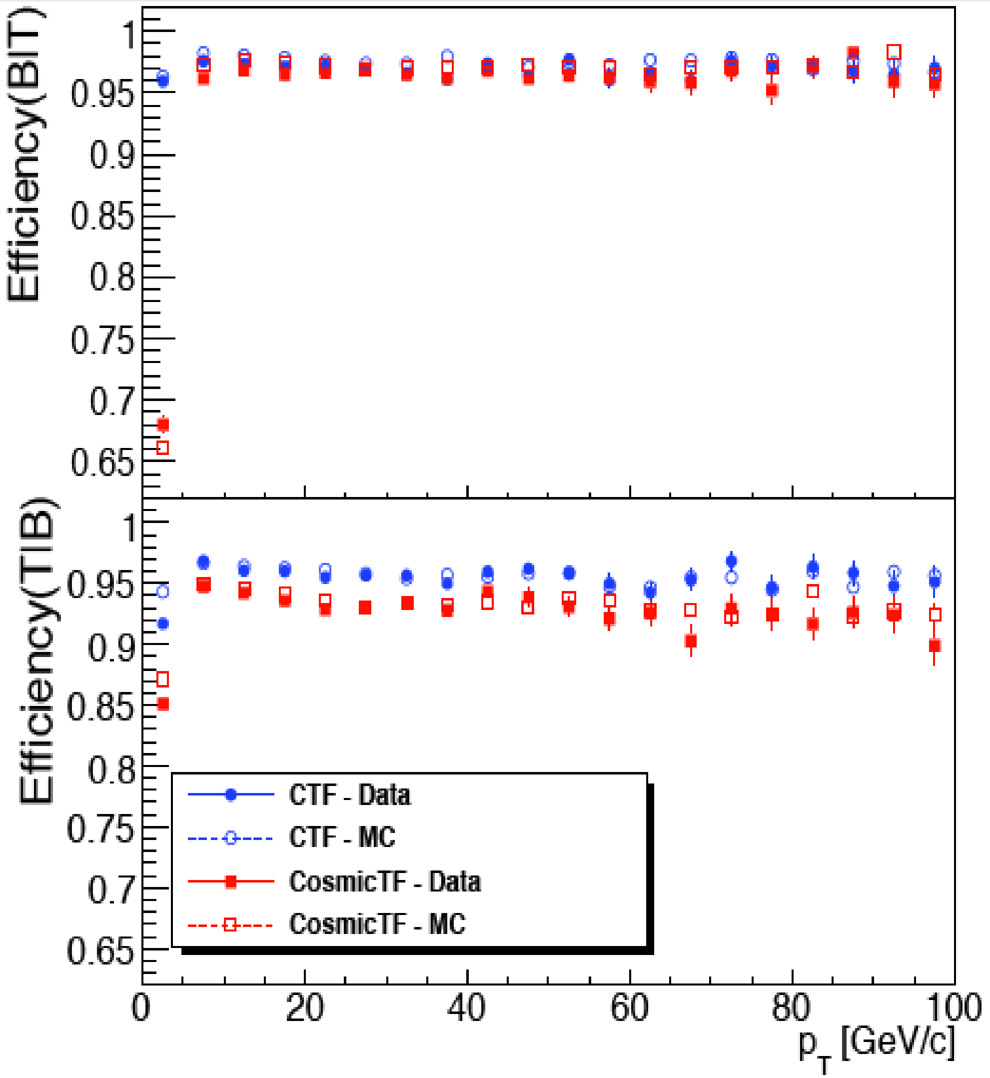
Cuts on the reconstructed muons at the point of closest approach to the beamline

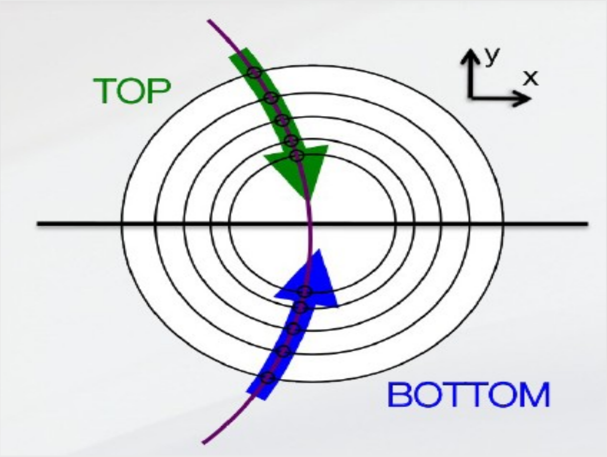
- $|d_z|<30$ cm, $|d_{xy}|<30$ cm, $|\eta|<1$, $0.5<|\phi|<2.5$

Algorithm	Data Efficiency(%)
CTF	99,8 +- 0,1
CosmicTF	99,8 +- 0,1

Tracking Performance in Cosmics

Tracking efficiency with split tracks method for CRAFT08 data



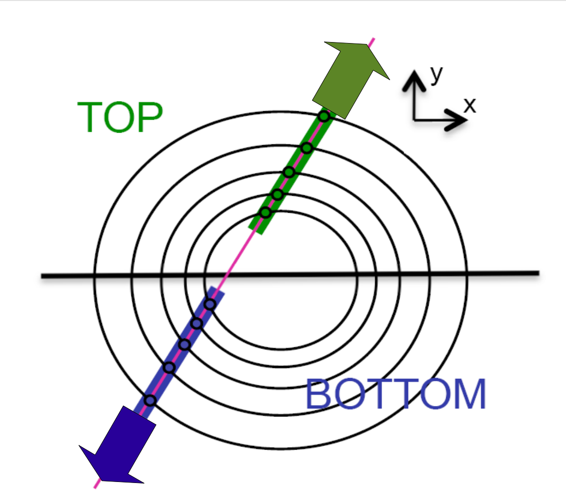


Efficiency(T|B) is lower than efficiency(B|T) due to some TOB4 inactive regions used for seeding

	CTF		CosmicTF	
	Data	MC	Data	MC
$\epsilon(B\|T)$ [%]	97.03±0.07	97.56±0.04	94.01±0.10	93.41±0.06
$\epsilon(T\|B)$ [%]	95.61±0.08	95.79±0.05	92.65±0.11	93.19±0.07

Tracking efficiency with inside out method for CRAFT08 data

Only the efficiency of the CTF is measured



Both seed finding and pattern recognition efficiency can be measured with this method.
Track reconstruction efficiency close to 100% and in agreement with MC.

	Data	MC
Seed finding efficiency [%]	99.17 ± 0.12	99.30 ± 0.08
Pattern reconstruction efficiency [%]	99.79 ± 0.06	99.64 ± 0.05
Track reconstruction efficiency [%]	98.96 ± 0.13	98.94 ± 0.09

Tracking Performance in Cosmics

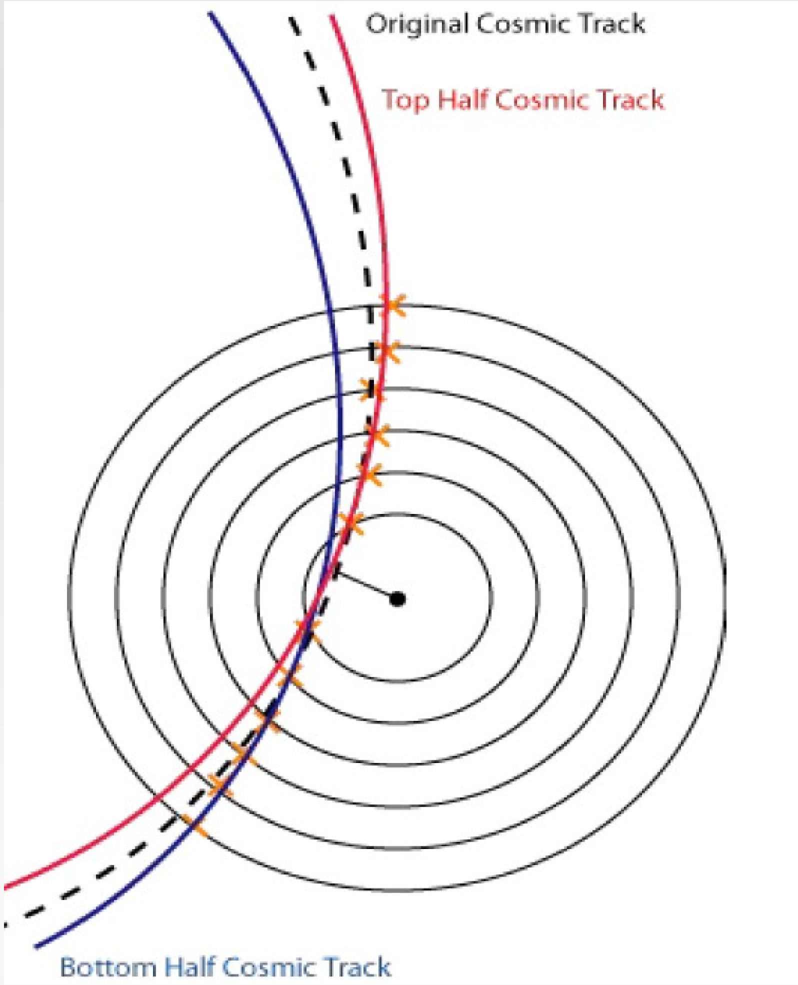
Track parameters resolution using split tracks

- **Track resolution using split tracks**

  Tracks fully reconstructed are split at the point of closest approach to the nominal beamline.

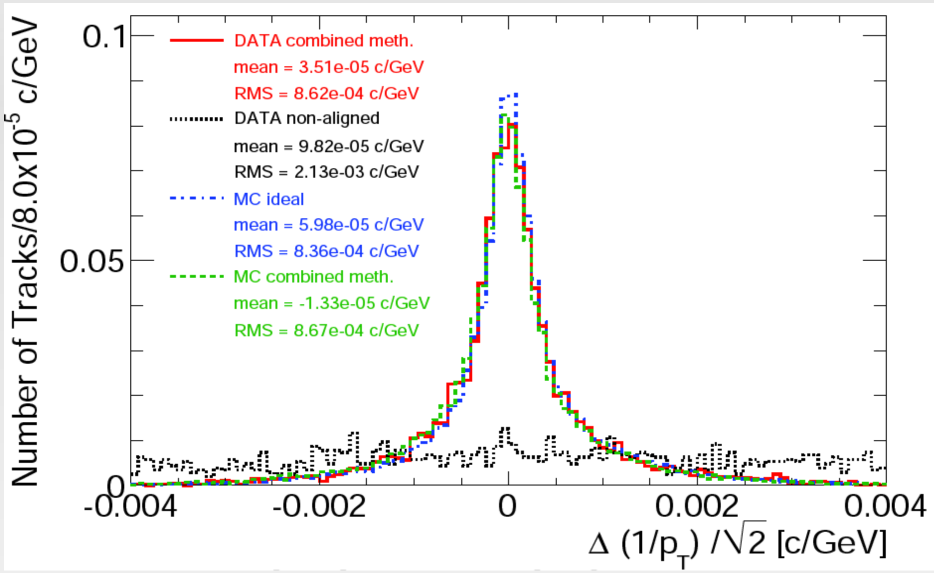
  The top and bottom legs are refitted indipendently.

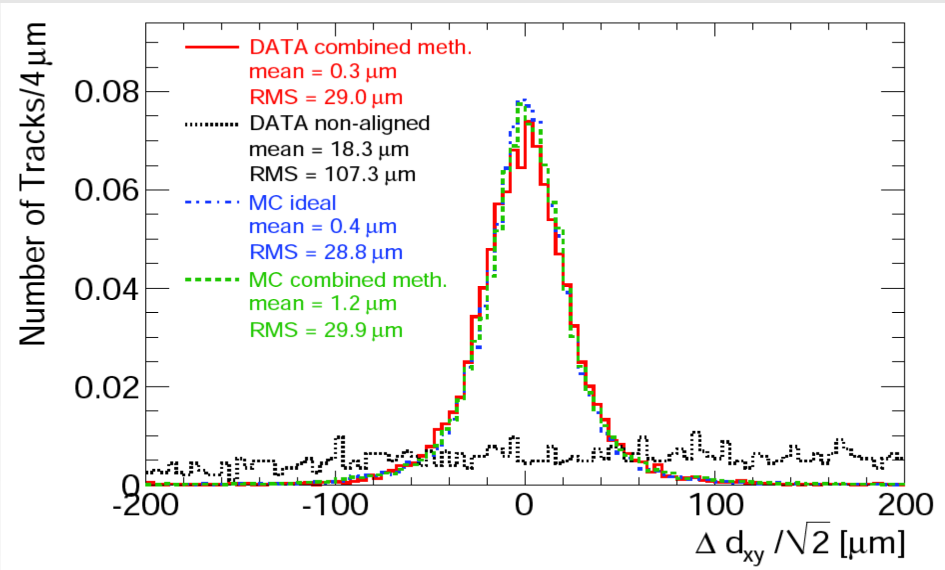
  Then they are propagated to their respective points of closest approach to the beamline and compared.



Tracking Performance in Cosmics

Track parameters resolution using split tracks



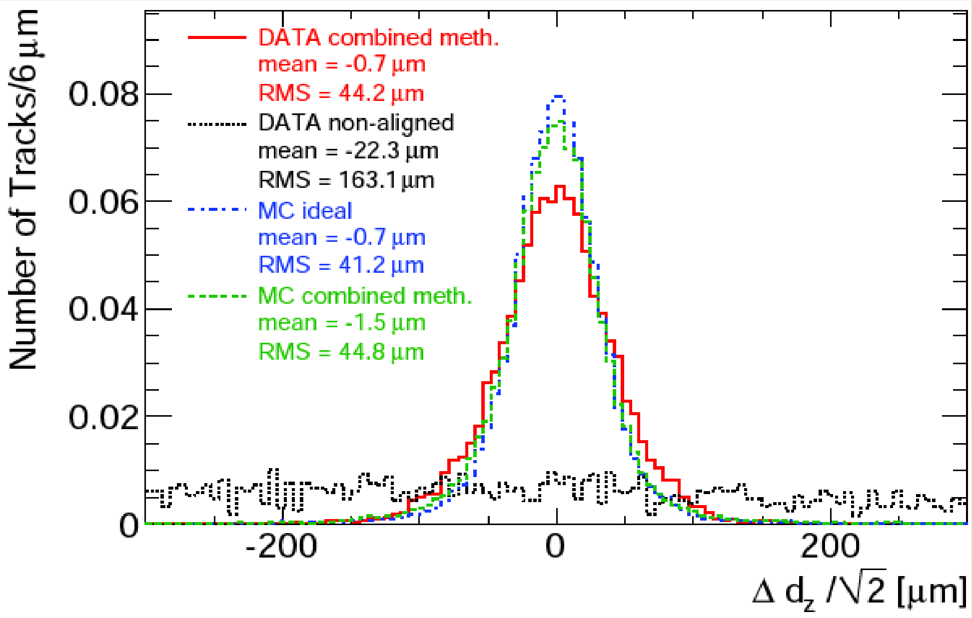


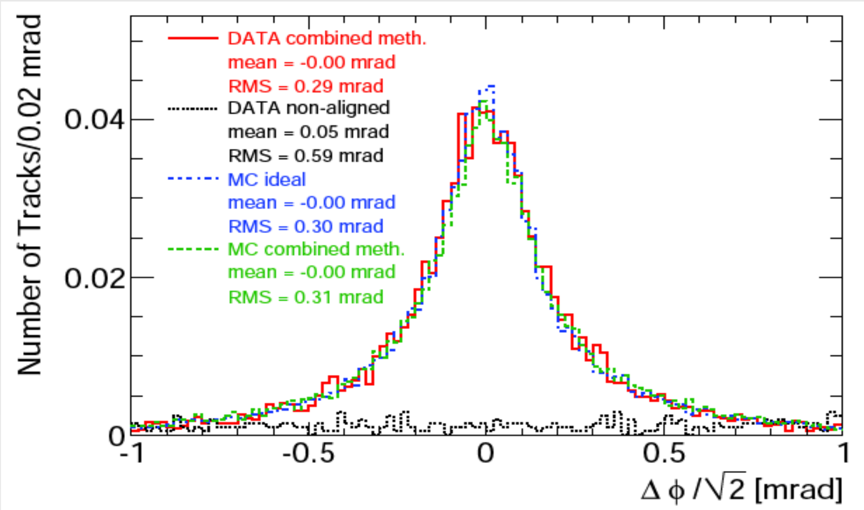
Requirements on the reconstructed tracks

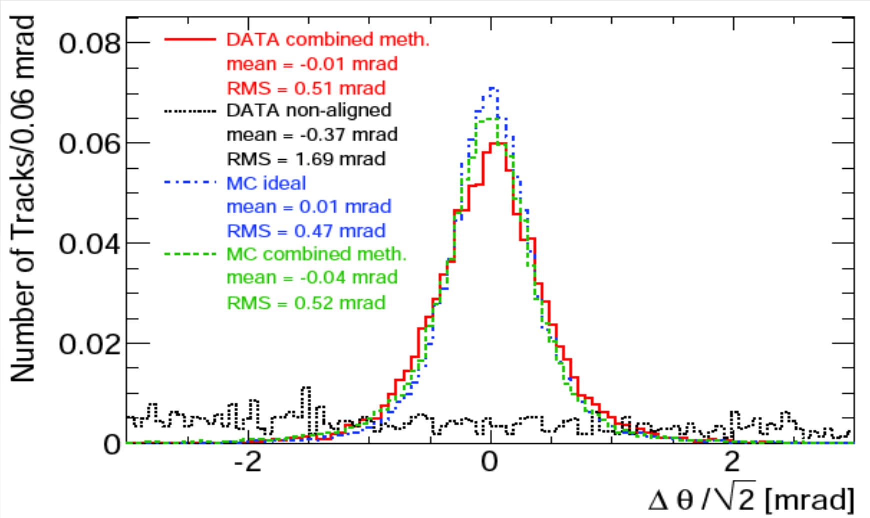
- Point of closest approach to the beamline within the pixel volume.
- PT>4 GeV/c
- χ^2/ndof<100
- N pix. hit>1
- N 2D hit >1
- N hit per split track >5

Residuals obtained after alignment

Track parameters resolution using split tracks







Requirements on the reconstructed tracks

- Point of closest approach to the beamline within the pixel volume.
- PT>4 GeV/c
- χ^2/ndof<100
- N pix. hit>1
- N 2D hit >1
- N hit per split track >5

Residuals obtained after alignment

Conclusions

- Track reconstruction at CMS is a big challenge
- CMS has developed several different tracking algorithms to face this challenge
- The standard reconstruction algorithms have shown excellent performances during CRAFT08 and CRAFT09 data taking
- Waiting for collisions to fully exploit the potential of the CMS tracker

Backup

The Track Reconstruction Challenge

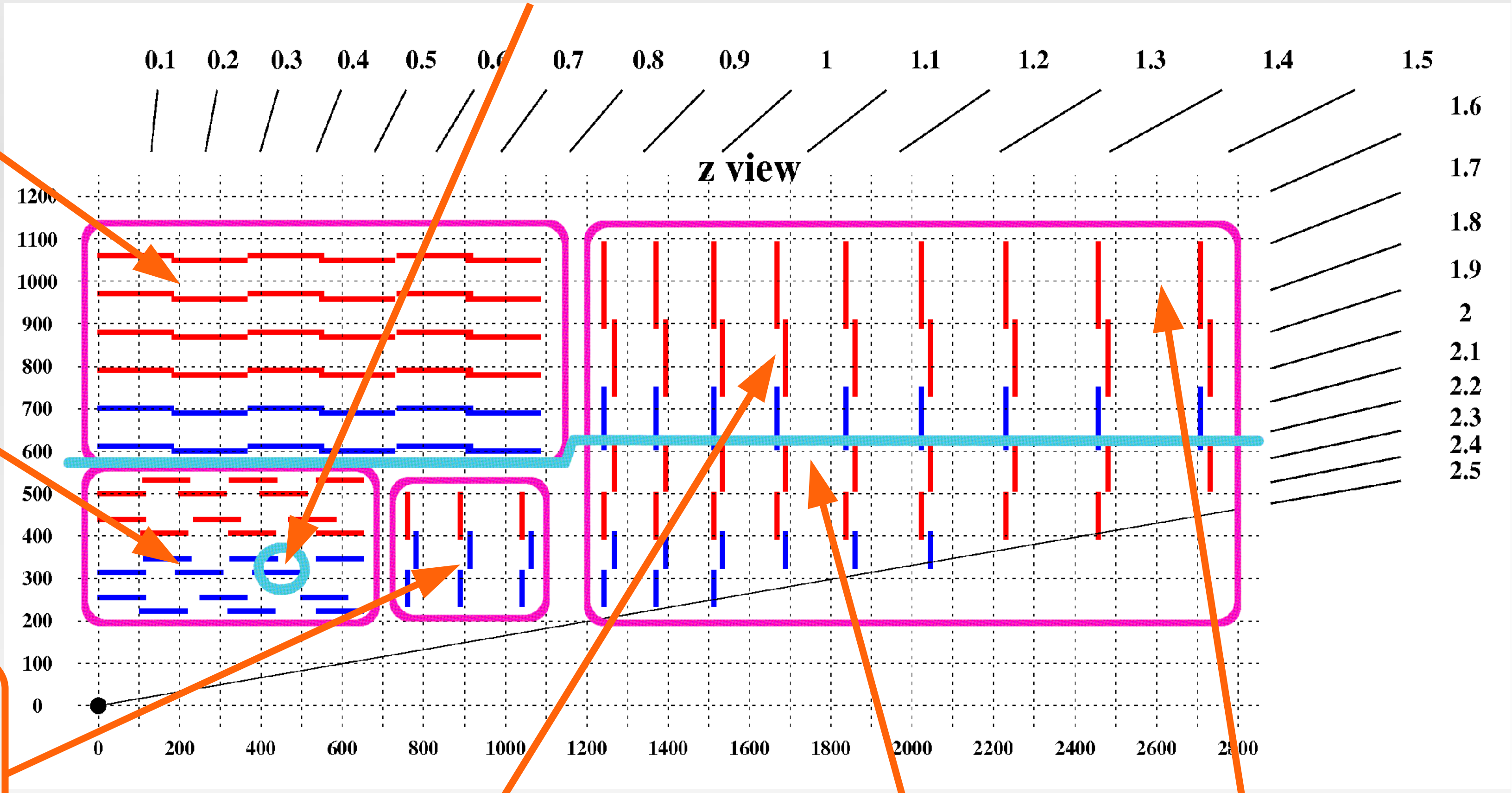
- pp collisions at design luminosity (10^{34} cm^{-2} s^{-1}, 14 TeV)
  - 40 Mhz crossing rate
  - ~20 pile up events per bunch crossing
  - ~2000 charged tracks per bunch crossing
- Great number of charged particles will be produced
- High granularity is needed
- Radiation hardness of detectors is very important
- Material budget is an issue

The Silicon Strip Tracker

Detectors overlap, more than one hit per layer

TOB: 6 layers, 5208 modules, 80/180 µm pitch

TIB: 4 layers, 2724 modules, 80/120 µm pitch



TID: 3 discs per side, 816 modules, 97/128/143 µm pitch

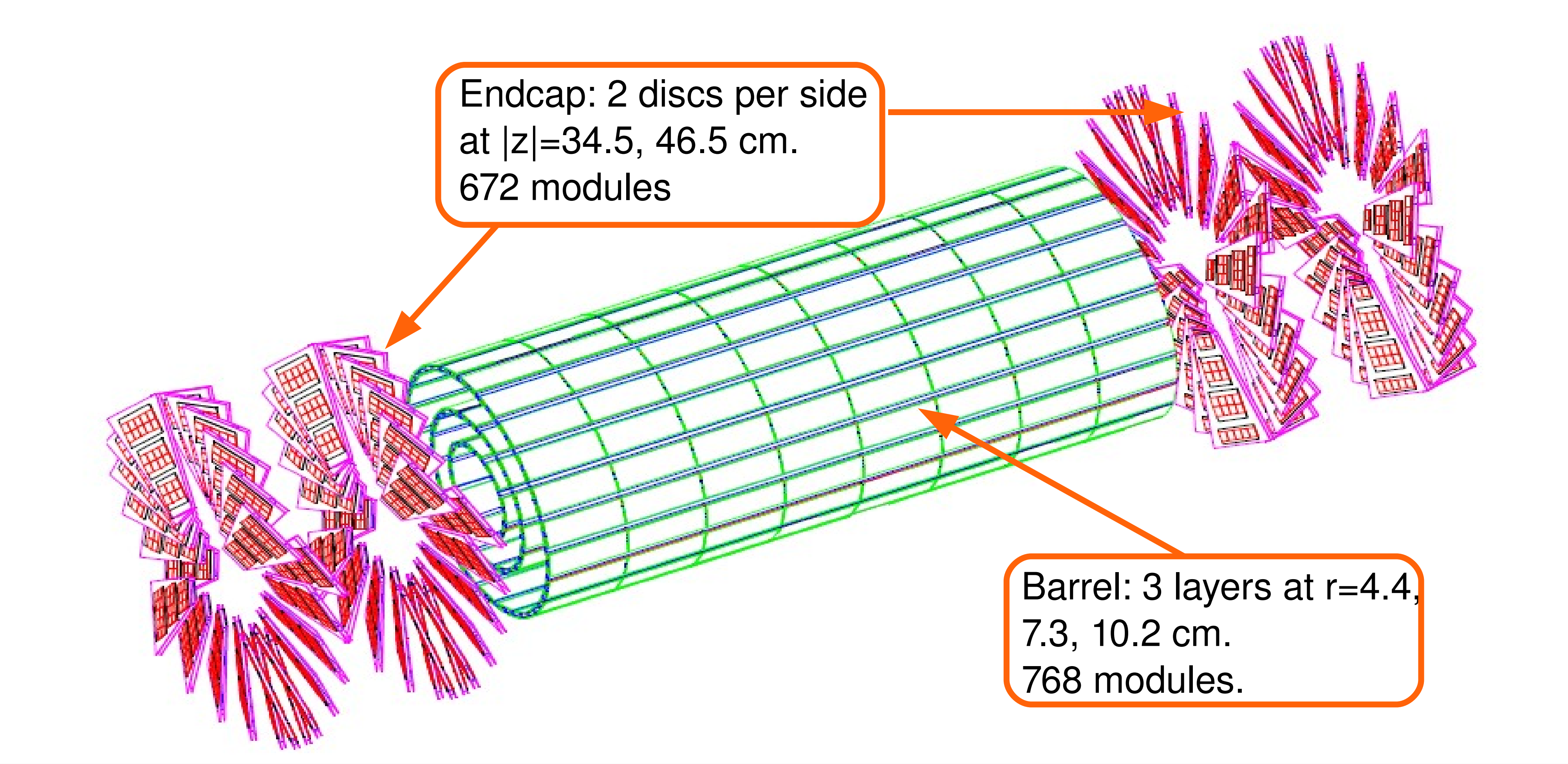
Red: single sided
Blue: double sided

TEC: 9 discs per side, 6400 modules, 96/126/128/143/158/183 µm pitch

Thickness: 320 µm

Thickness: 500 µm

The Pixel Detector



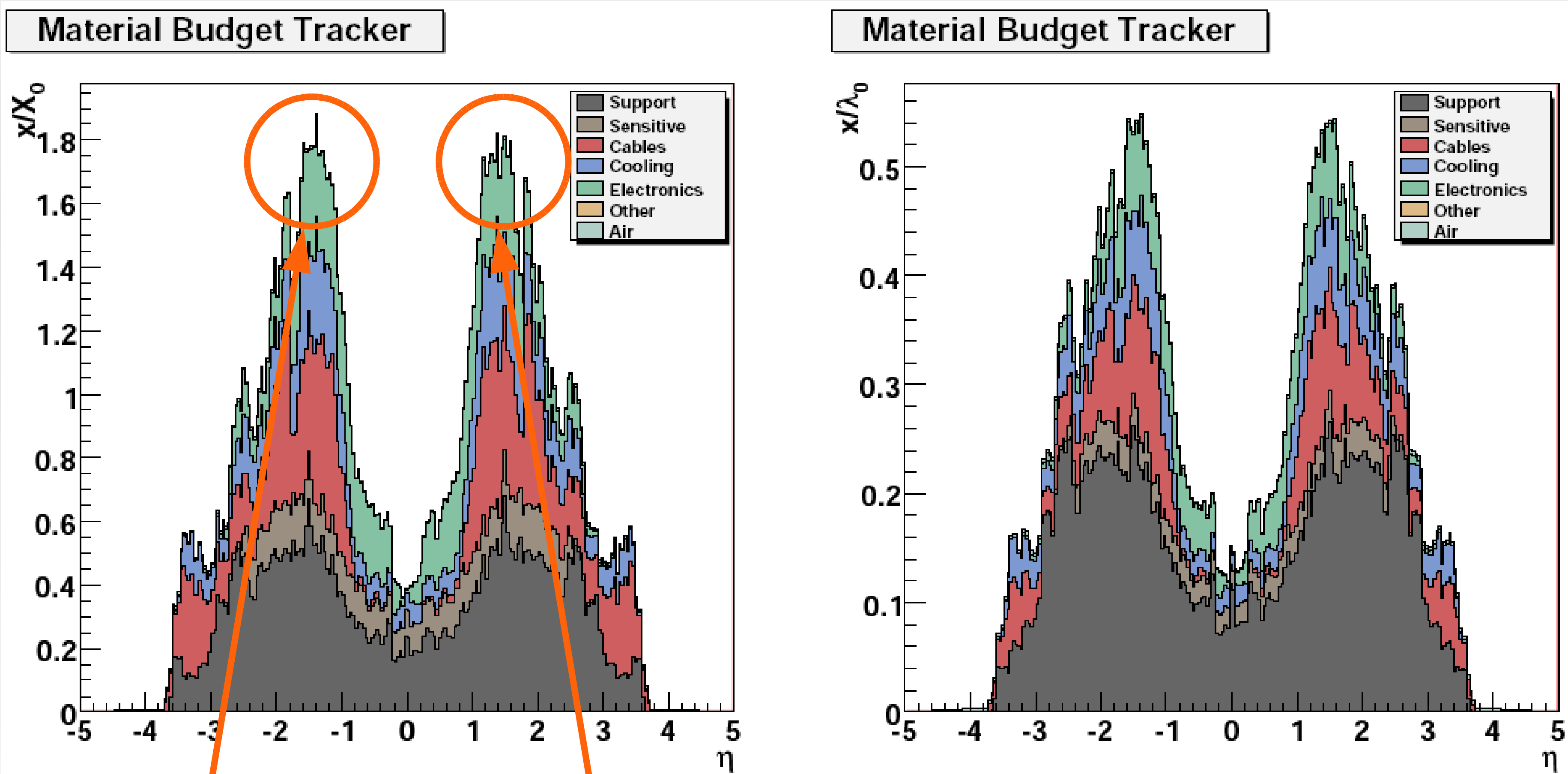
Pixel size is 150x100 μm^2

Total number of pixels is ~66 milions

Modules in endcap region tilted of 20° to benefit from charge sharing.

Hit resolution is 10 µm on rφ, 20 µm on z

The Material Budget



Radiation lenght up to 1.8 in the transition region barrel-endcap

Support	36,00%
Cables	24,00%
Electronics	16,00%
Cooling	14,00%
Sensitive	9,00%

Tracking Performance in Cosmics

CMS tracker status in CRAFT08 and CRAFT09

CRAFT08

- Strip tracker
  - TOB: 98%
  -TIB/TID: 96.6%
  - TEC+: 99.2%
  -TEC-: 97.8%
- Pixels
  - Barrel: 99.1%
  - Endcap: 94.0%

CRAFT09