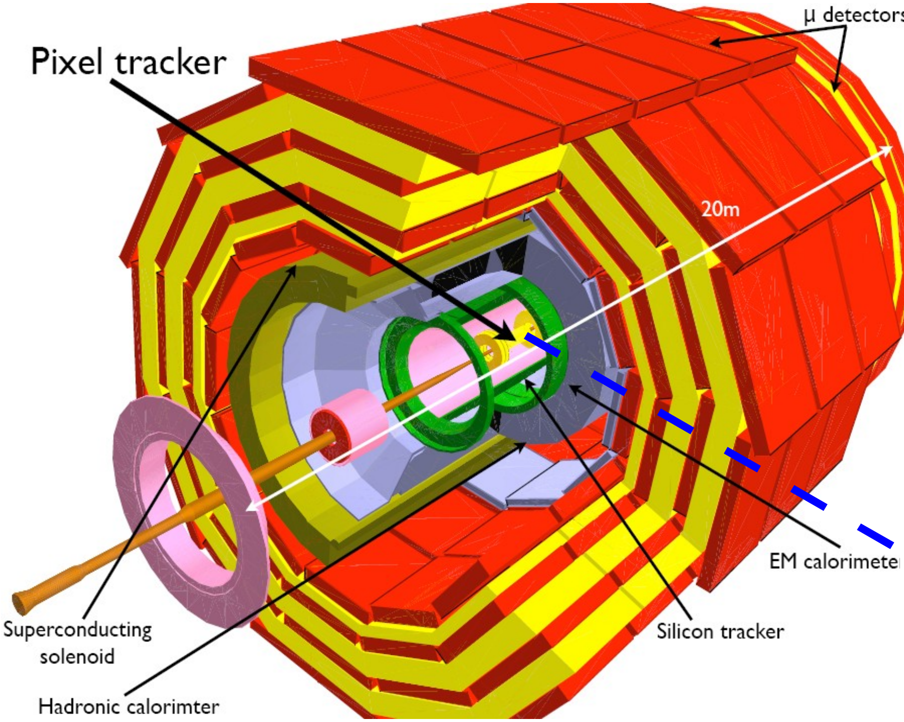
CMS b-tagging and tracking commissioning and cosmics

For the CMS collaboration,
Jean-Roch Vlimant,
University of California, Santa Barbara.

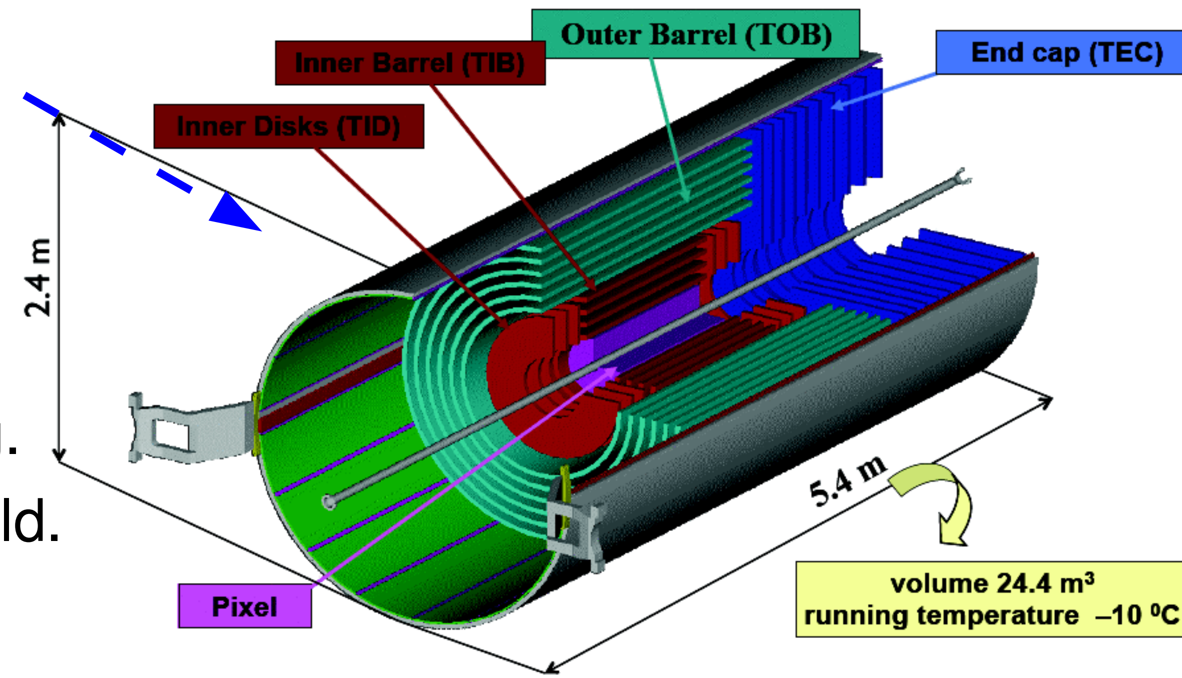
Outline

- Track reconstruction in CMS
- Expected tracking performance from the simulation of CMS.
- Observed performance of CMS tracking with cosmic data.
  - Hit reconstruction efficiency.
  - Reconstruction efficiency.
  - Track parameters resolution.
- b-tagging algorithms in CMS.
- Expected b-tagging performance for LHC start-up.

CMS Silicon Tracker

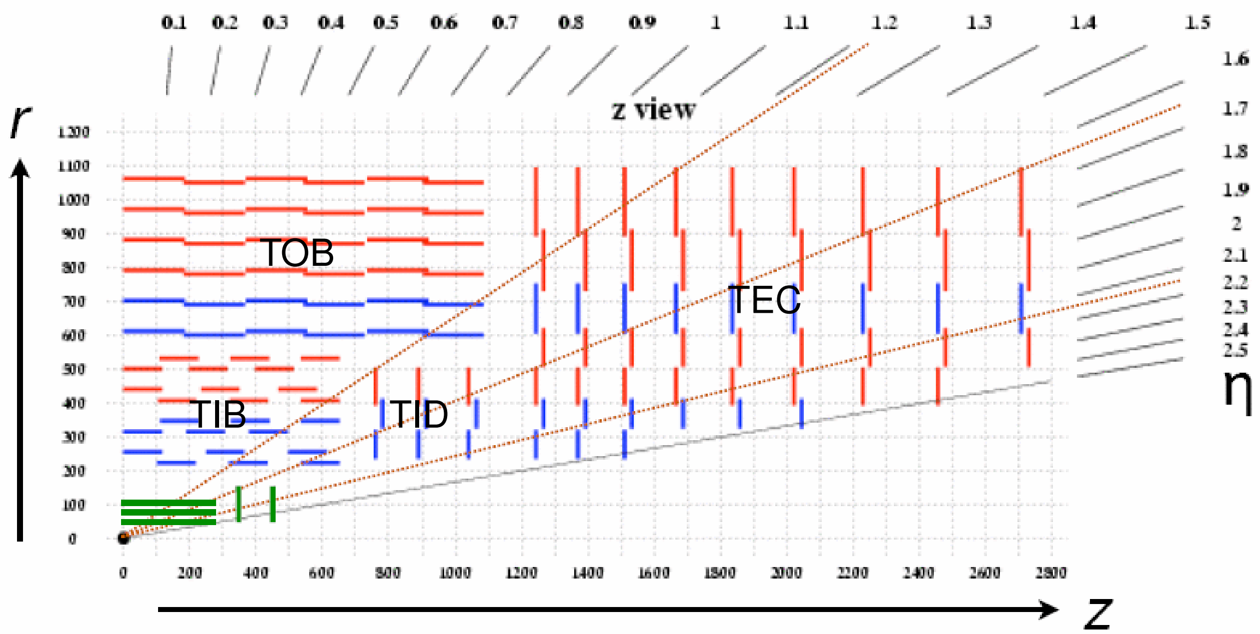


- Pixel detector : 66M 100×150 μm^2 channels
- Strip detector : 9.3M 80→180 μm pitch strips

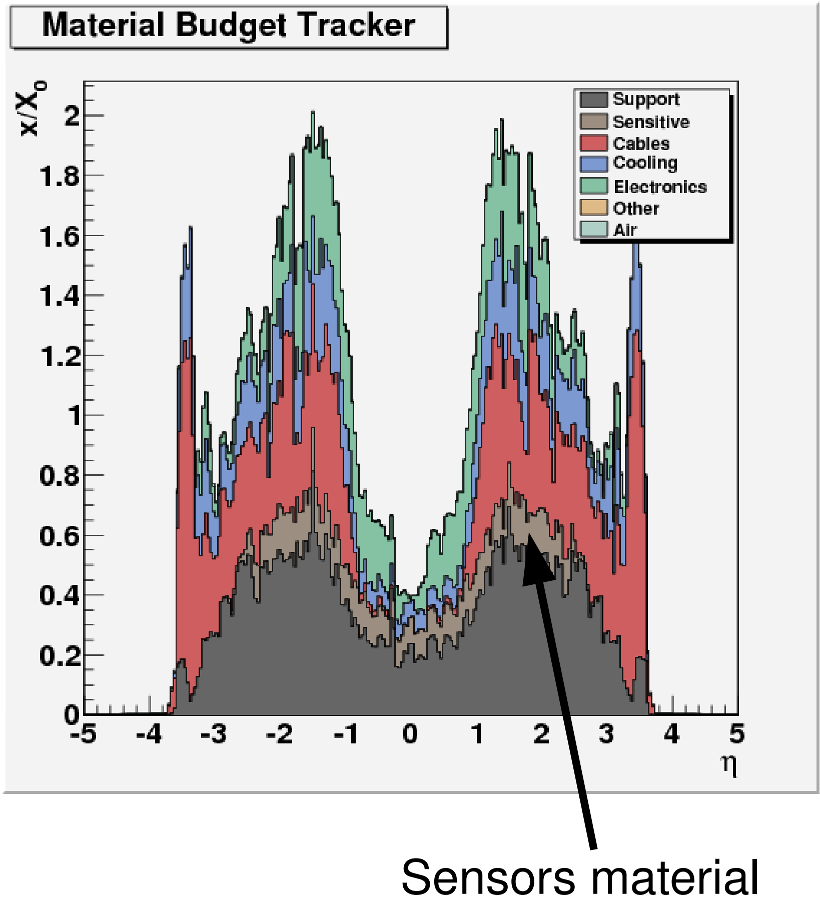


- Fully Silicon based inner tracking.
- Track curvature from a 3.8T B field.

Track Reconstruction in CMS



Pixel modules, stereo strip modules, single-sided strip module



- Few, but precise, measurement points.
- Non negligible amount of dead material inside the tracker volume.

Tracking Software in CMS

Main tracking algorithm.

- Combinatorial Track Finder (CTF) used in iterative steps

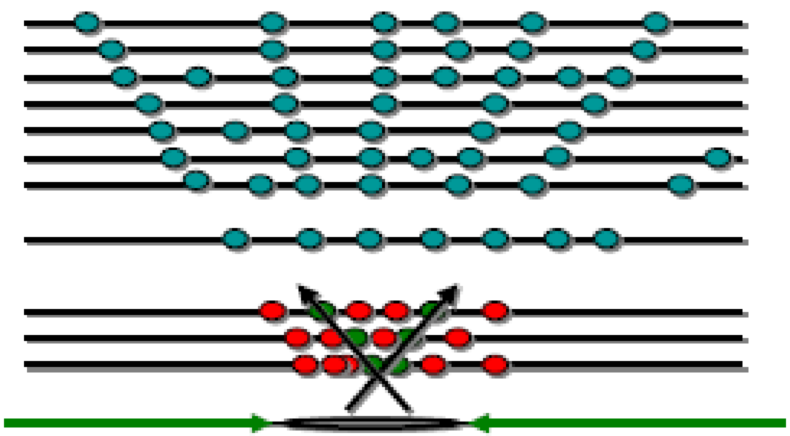
Alternative tracking algorithms.

- Road Search (RS)
- Single track pattern (CosmicTF, cosmic only)

Other dedicated tracking algorithms

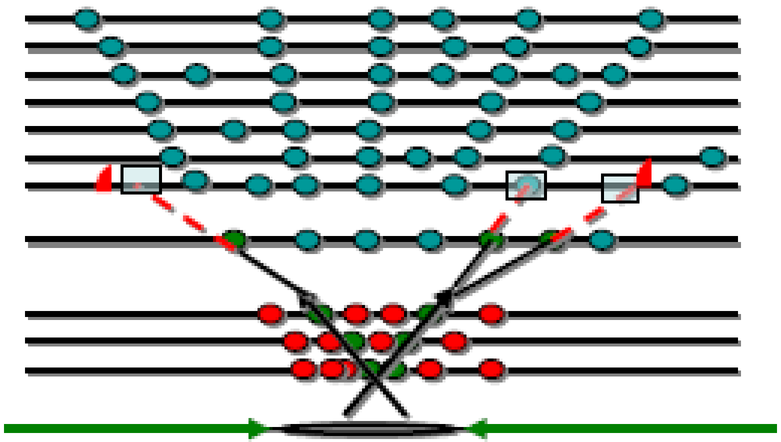
- GSF : Gaussian Sum Filter (electron fit)
- DAF : Deterministic Annealing Filter (tracks in jets)
- MTF : Multi Track Finder (tracks in jets)

Combinatorial Track Finder



Seed finding

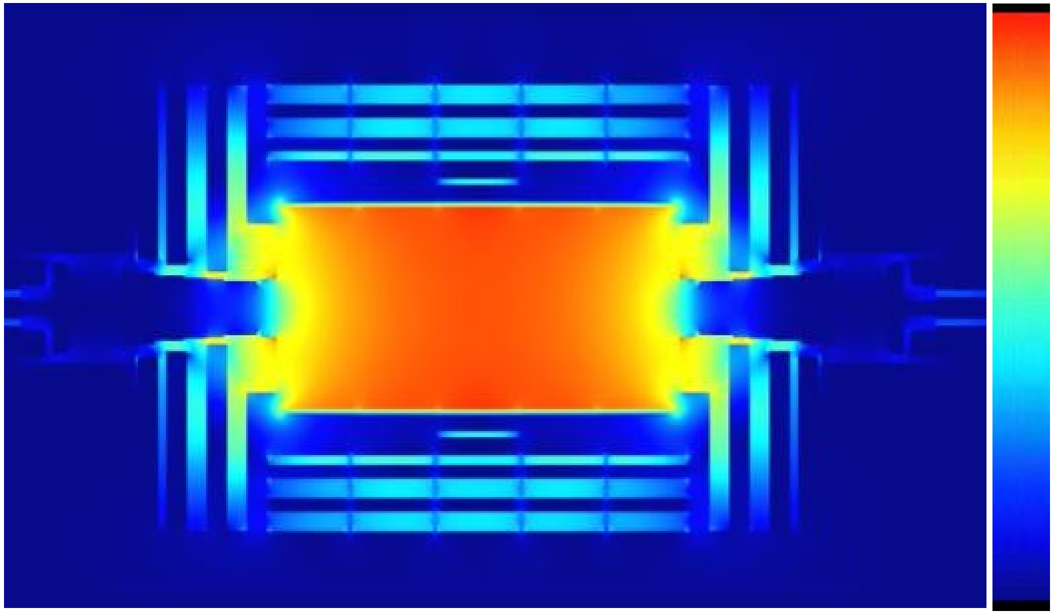
- Can consider primary vertex (depending on the step)
- Using combination of pixel, strip or mixed hits.



Pattern Recognition

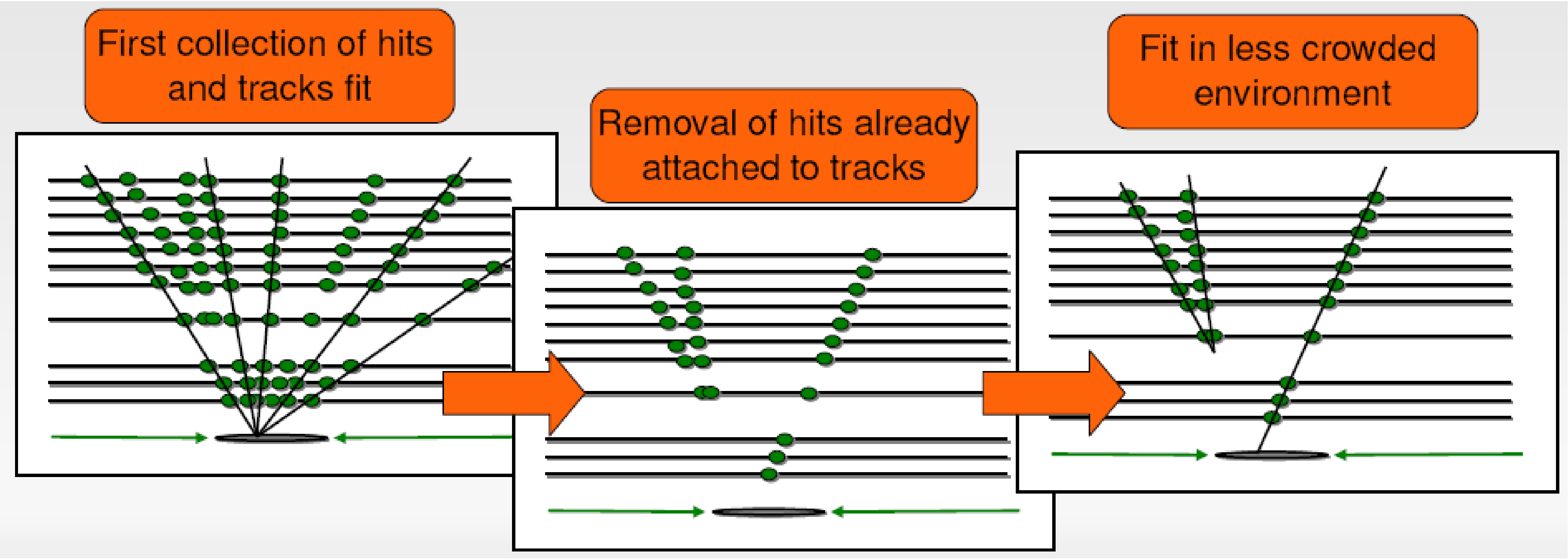
- Hit compatible with predicted track position are added (Kalman update) to the trajectory.
- Alignment uncertainty taken into account.

Final fit



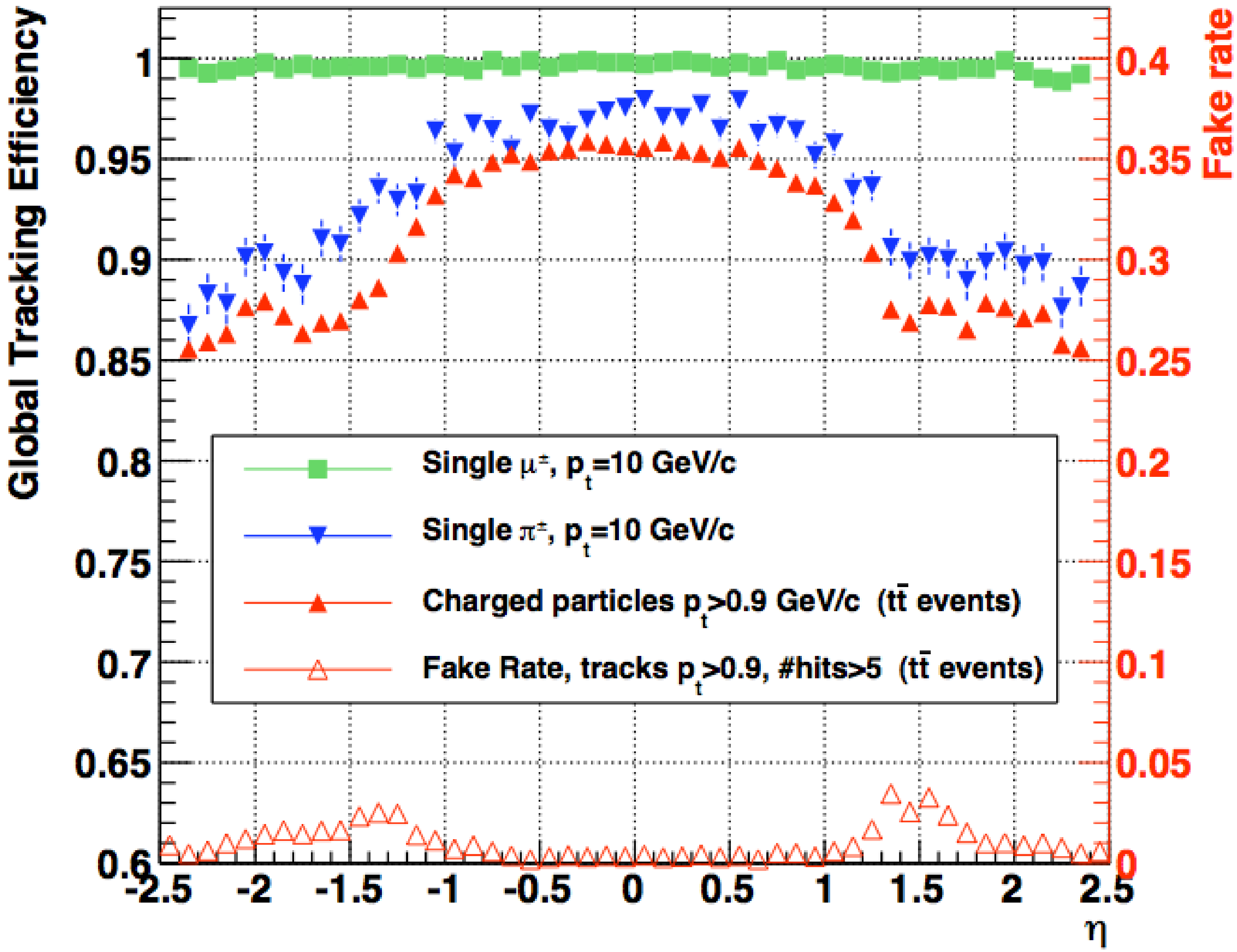
- Kalman Fit taking carefully taking into account the Field non-uniformity and a detailed description of the material budget.
- Alignment parameters errors taken into account.
- Outlier hits are rejected.

Iterative Tracking



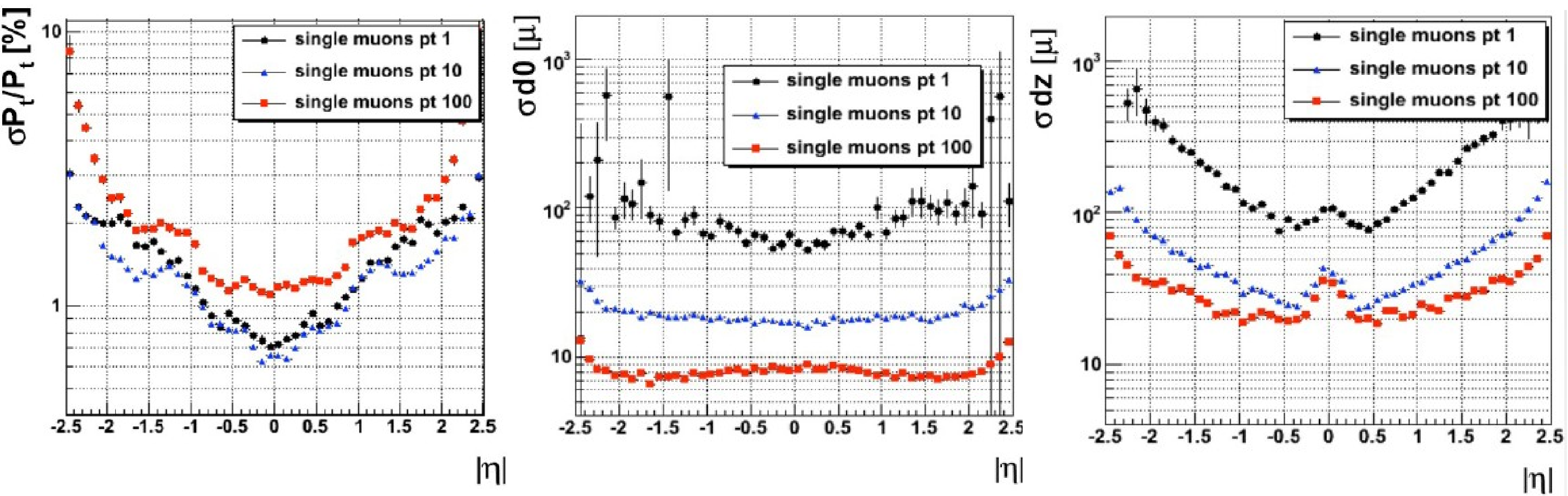
- Track parameter phase space reach increased step after step.
- Limits the number of combinatorics in pattern recognition.
- Increases tracking reach without degrading computing performance.

Expected Tracking Efficiency



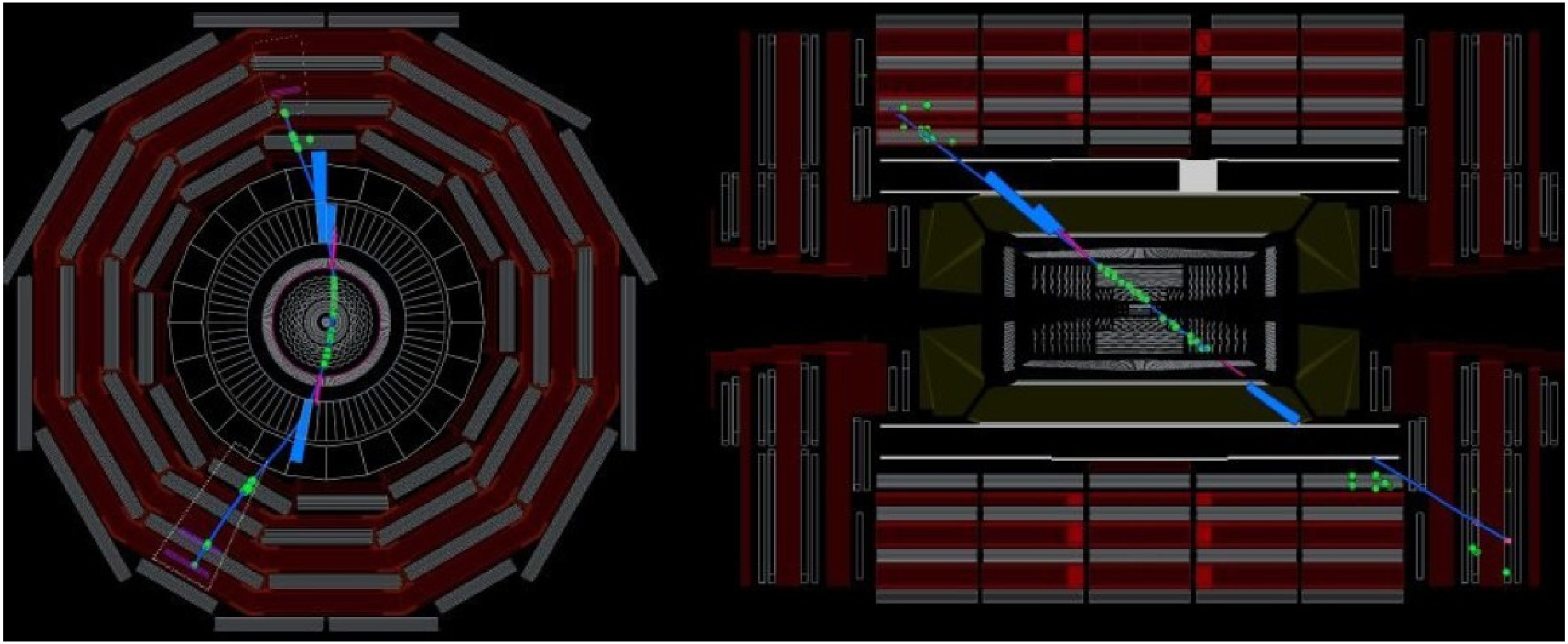
- High efficiency in the barrel
- Decreased efficiency due to more inactive material in the endcaps.
- Increased fake rate in the transition region.

Expected Track Parameter Resolution



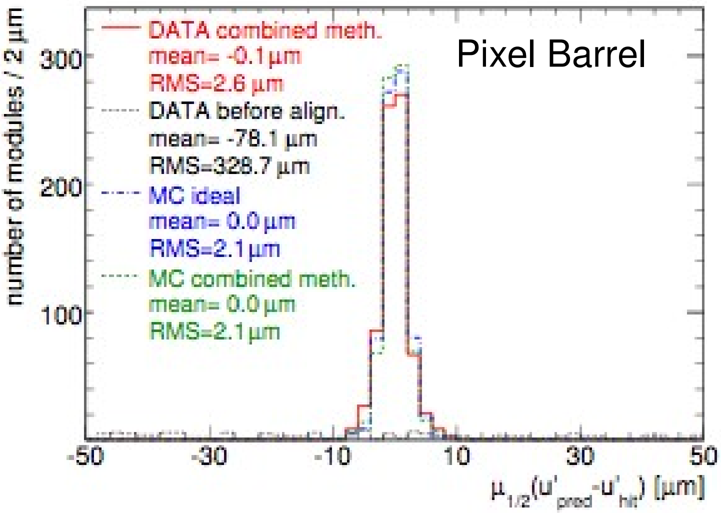
- Resolution on transverse momentum at the percent level degrades with smaller lever arm in the forward region.
- 10 μm to 100 μm transverse impact parameter resolution, uniform, thanks to the silicon pixel detector.
- Longitudinal impact parameter resolution feature due to mono-pixel hits.

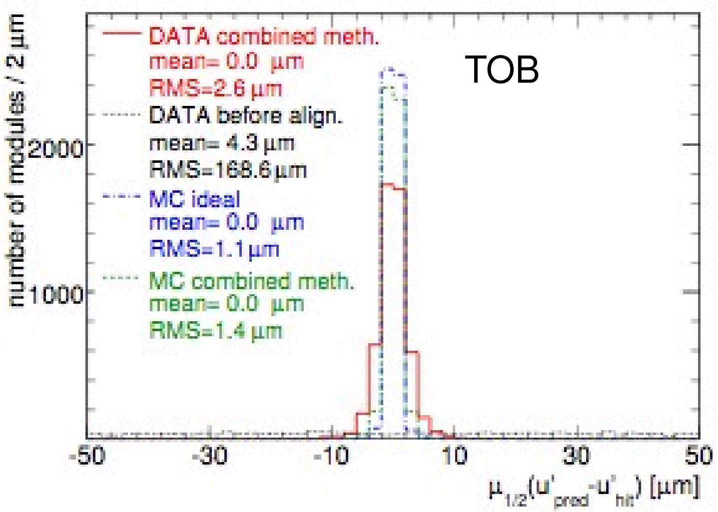
CMS Collecting Cosmic Data



- Multiple cosmic runs were taken for detector commissioning.
- Two campaigns of stable data taking with B-field on were done.
  - ~10^7 tracker tacks accumulated during both campaign.

Observed Tracker Alignment



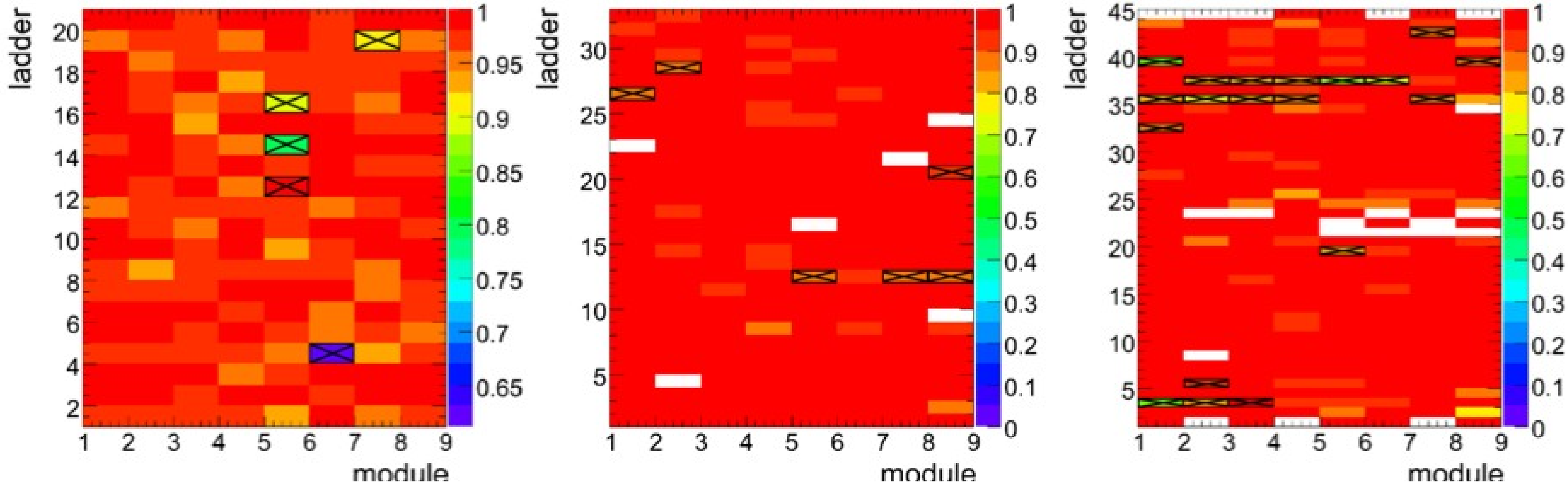


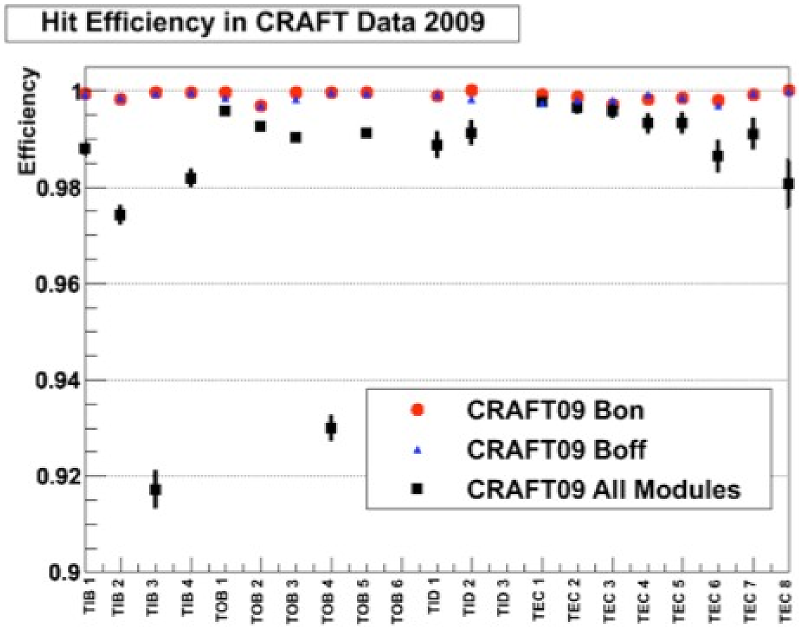
- "Millipede II" and "Hits and Impact Points" are used to perform track-based alignment.
- Cross check with laser survey.

RMS of DMR (µm)		# of aligned modules
BPIX (x)	2.5	761/768
BPIX (y)	4	
FPIX (x)	13	539/672
FPIX (y)	13	
TIB	3	2555/2724
TOB	3	5102/5208
TID	4	808/816
TEC	8	6346/6400

- Distributions of median/mean of Residuals (DMR) are quality indicators.
- Results from alignment with cosmic tracks almost as good as ideal.

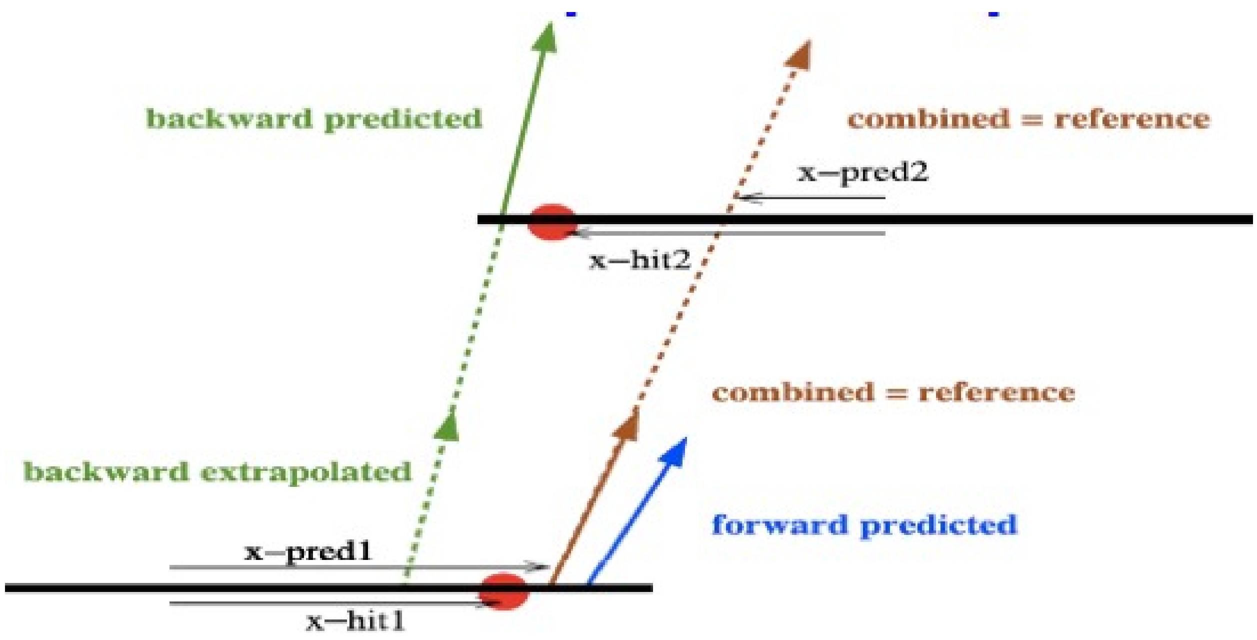
Observed Hit Reconstruction Efficiency





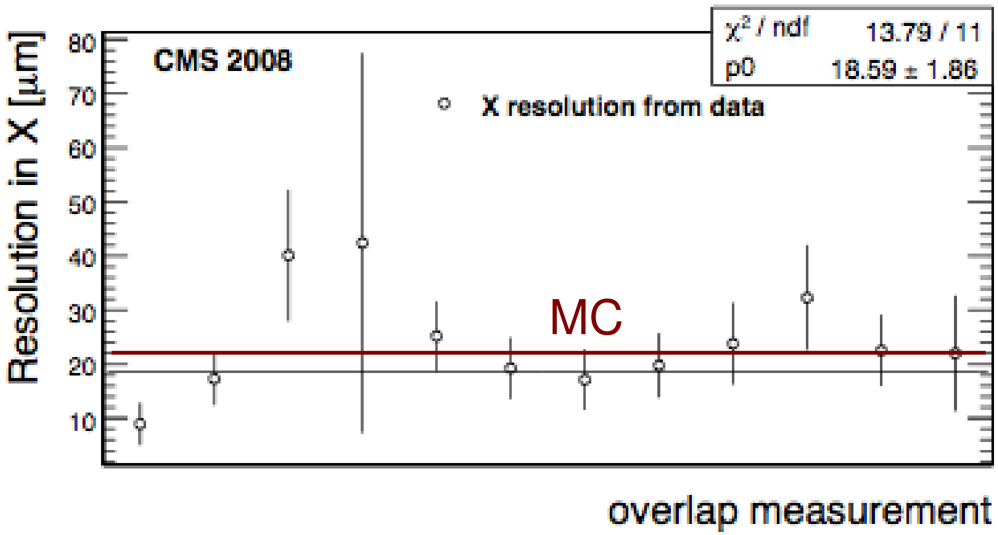
- Extrapolate track to tracker module and check for the presence of a reconstructed hit.
  - Inactive/problematic modules crossed out.
    - Top plots in module coordinate.
- Very high single hit reconstruction efficiency

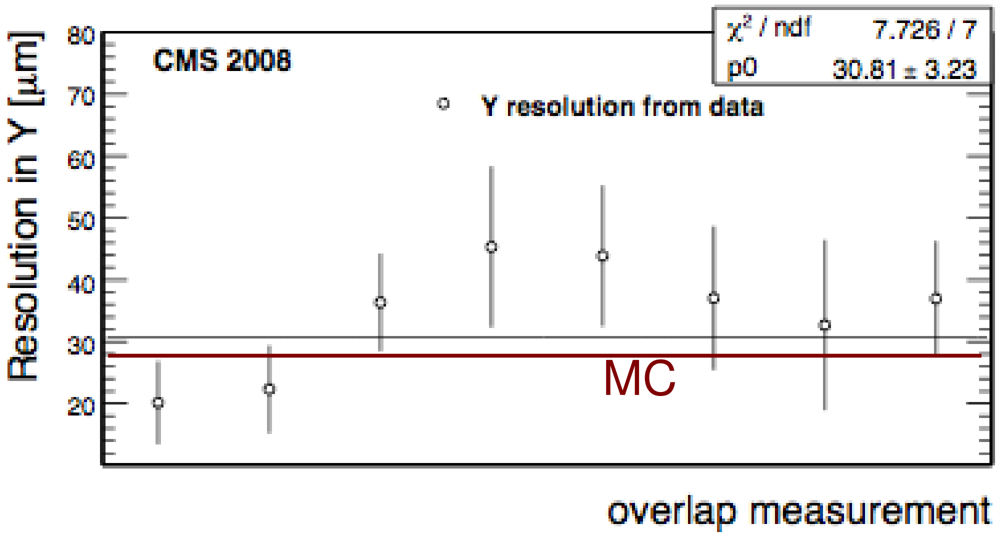
Overlap Method



- Form hit position difference and predicted position difference.
- Form its difference : double difference.
- Subtract the predicted position uncertainty (from the track fit)

Observed Hit Resolution



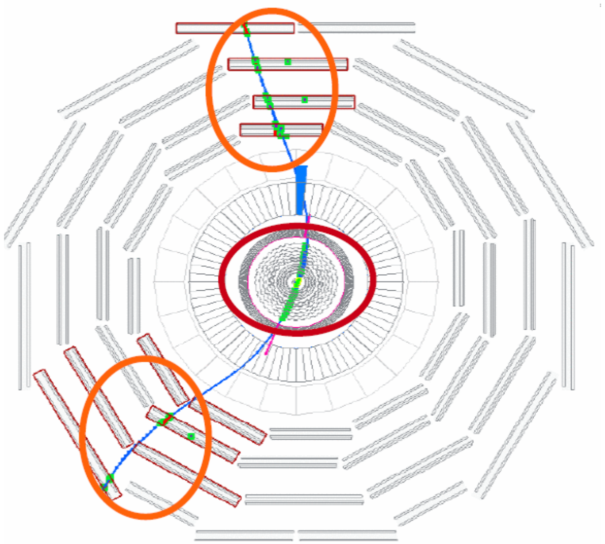


Sensor	Pitch (μm)	Resolution (μm)	Track angle			
			$0° - 10°$	$10° - 20°$	$20° - 30°$	$30° - 40°$
TIB 1-2	80	Measurement	17.2 ± 1.9	14.3 ± 2.3	17.4 ± 3.2	25.7 ± 6.0
		MC Prediction	16.6 ± 0.5	11.8 ± 0.5	12.4 ± 0.6	17.9 ± 1.5
TIB 3-4	120	Measurement	27.7 ± 3.6	18.5 ± 3.1	16.1 ± 3.1	24.1 ± 6.7
		MC Prediction	26.8 ± 0.7	19.4 ± 0.8	17.2 ± 0.3	21.4 ± 2.0
TOB 1-4	183	Measurement	39.6 ± 5.7	28.0 ± 5.8	24.8 ± 6.5	32.8 ± 8.3
		MC Prediction	39.4 ± 1.3	27.8 ± 1.2	26.5 ± 0.3	32.5 ± 2.1
TOB 5-6	122	Measurement	23.2 ± 3.6	19.5 ± 3.6	20.9 ± 6.1	29.3 ± 9.7
		MC Prediction	23.8 ± 0.9	18.0 ± 0.5	19.2 ± 1.2	25.4 ± 1.6

- Observed and predicted resolution are in very good agreement.

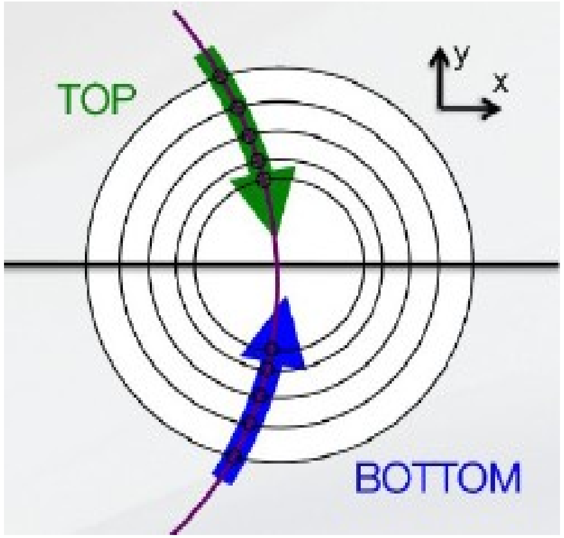
Observed Tracking Efficiency

Muon match method



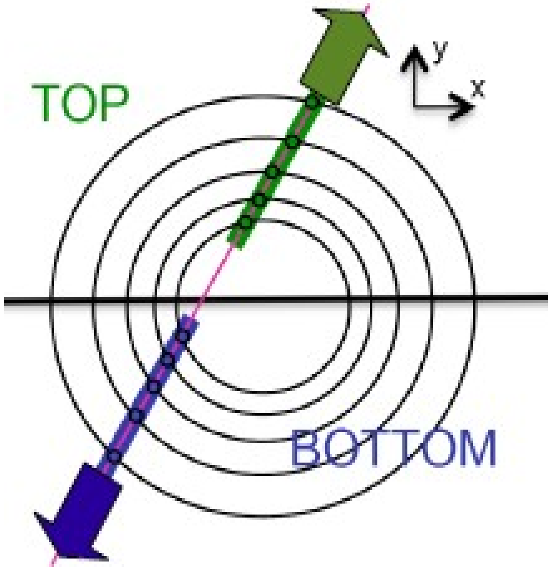
Use track in the muon system only to probe in the tracker volume.

Half Track Method



Reconstruct cosmic tracks in top and bottom separately.

Collision-like Half Track

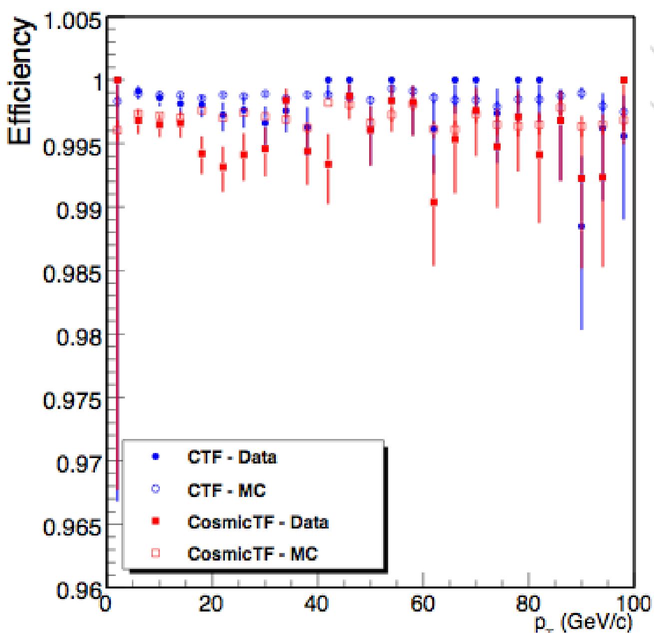


Reconstruct separately both legs of the cosmic track, as if they originates from a collision.

- Each method has its own feature and bias, useful cross check.

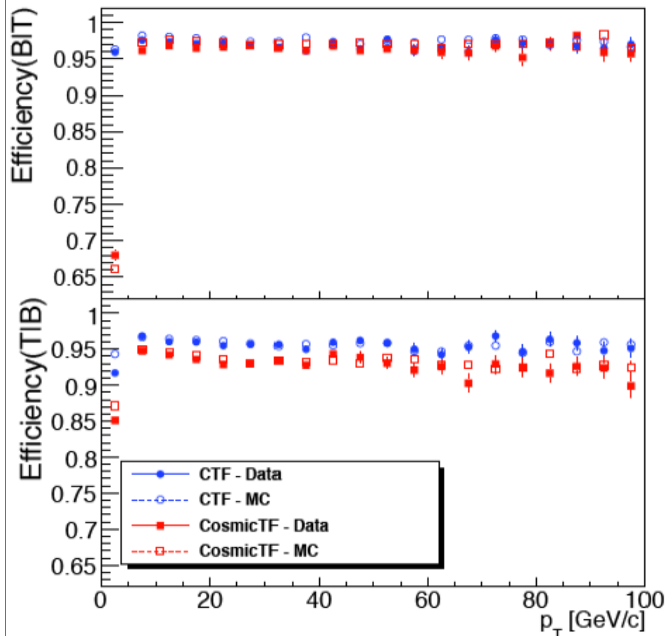
Observed Tracking Efficiency

Muon match method



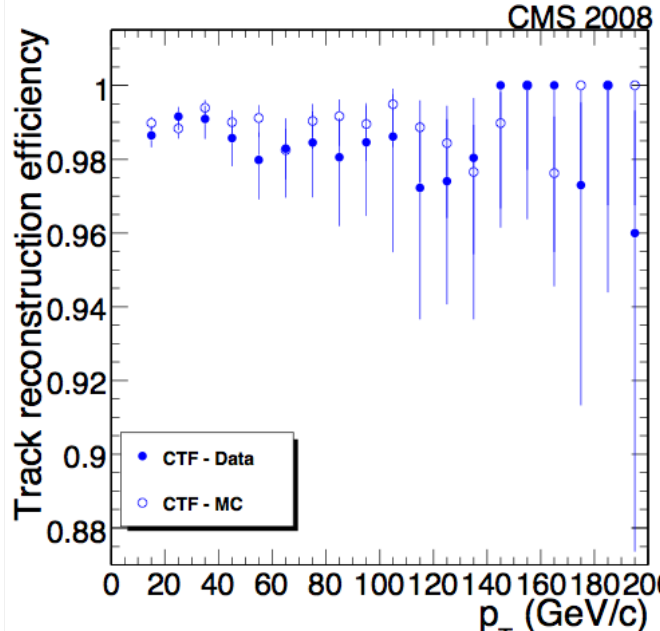
Allows also to compare tracker / muon momentum scale too.

Half Track Method



Inactive part of the detector creates in-efficiencies between top and bottom.

Collision-like Half Track



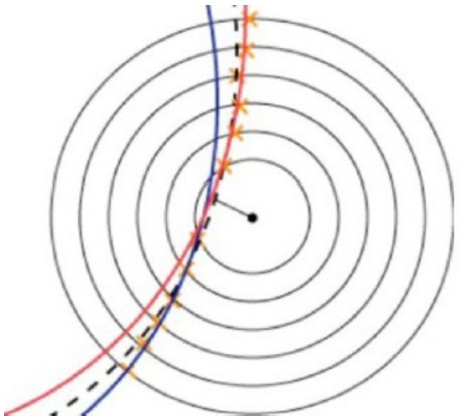
Limited statistics due to acceptance incompatibility of collision like seeding regions and cosmics.

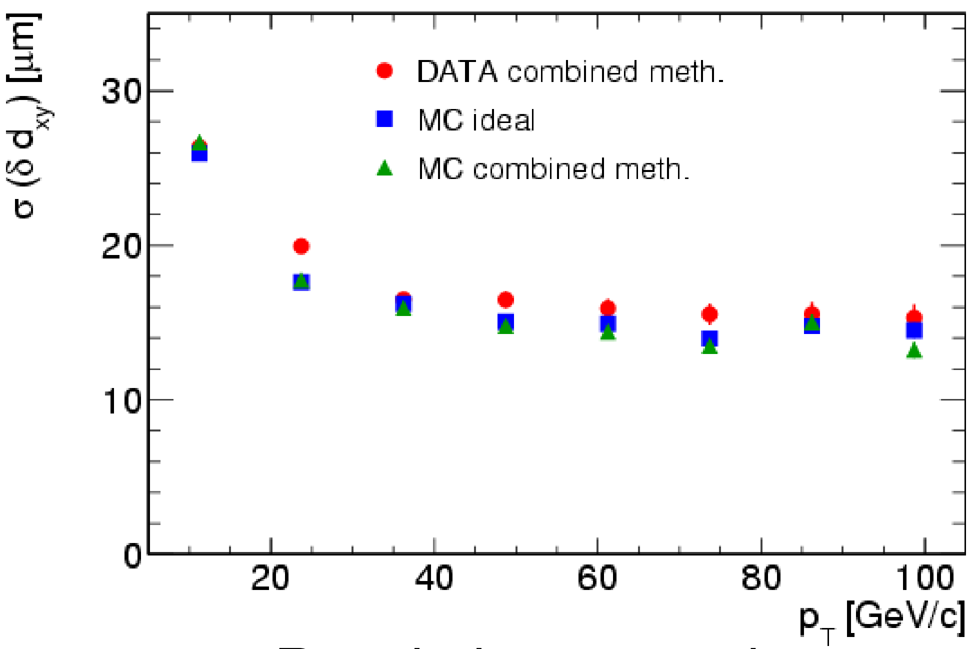
- Observed tracking efficiency is very high
- Data and Monte-Carlo agree well for the different algorithms.

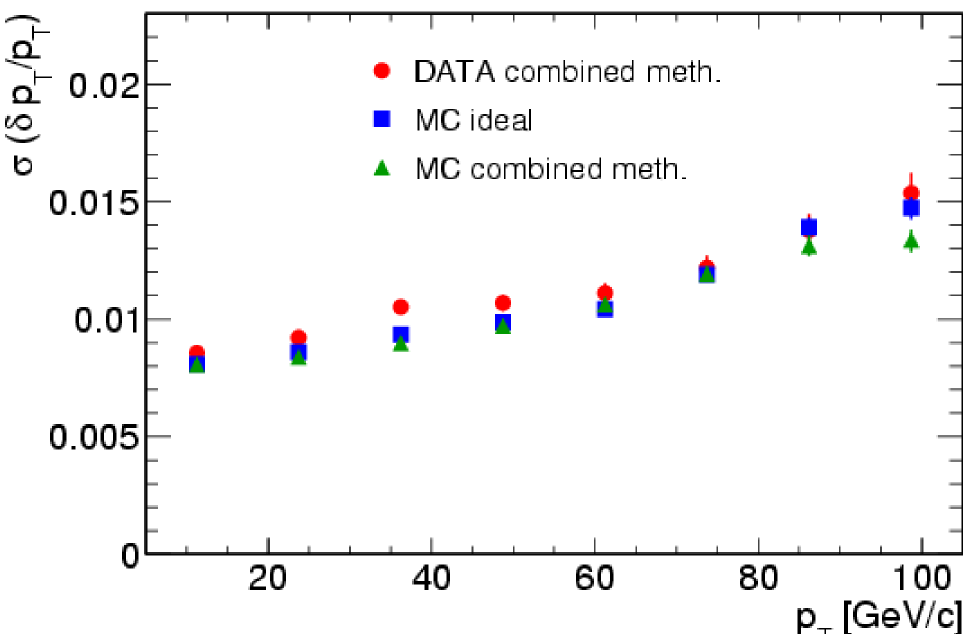
Observed Track Parameter Resolution

Compare track parameters of the two leg of split cosmic tracks

- Original cosmic track
  - **Upper track leg**
  - **Lower track leg**
- Absolute residuals divided by √2





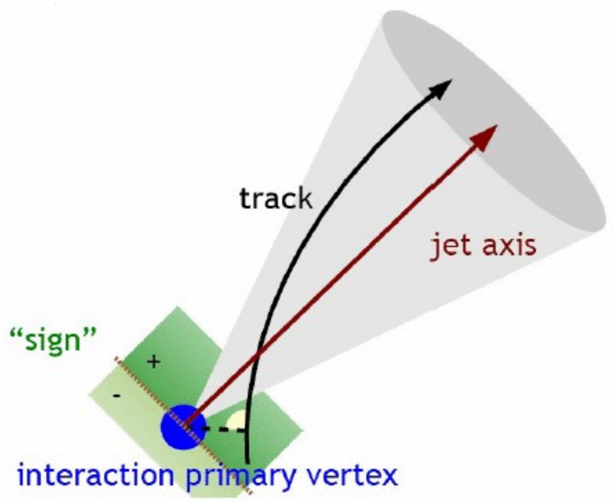


- Resolution on track parameters agree well with ideal predictions.

- CMS tracking has better performance that was expected in startup conditions, close to ideal performance.
- CMS simulation is accurate on predicting tracking behavior.

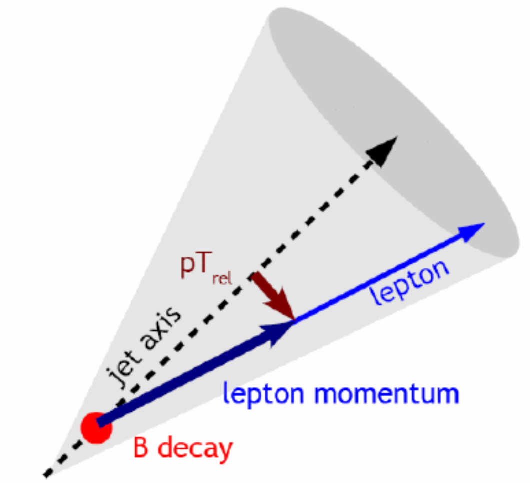
- Tagging of b-hadron decay within jets highly depends on track impact parameter resolution.
- Performance of b-tagging at startup should be close to the one expected from simulation.

CMS b-tagging Algorithms (I)

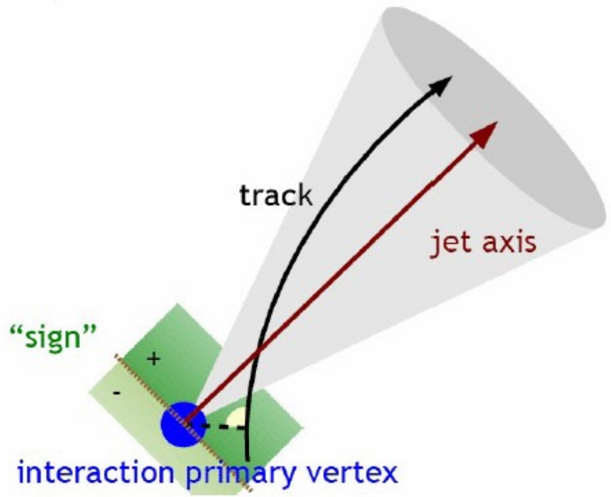


Track Counting
require 2 (high efficiency) or 3 (high purity) tracks with large impact parameter significance.

Soft Lepton
require the presence of a lepton in the jet. Combine the lepton informations into a neural net.



CMS b-tagging Algorithms (II)

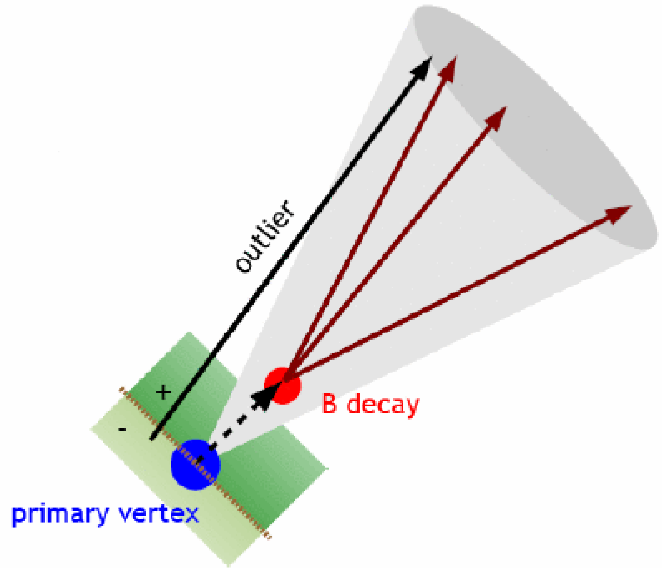


Track Probability

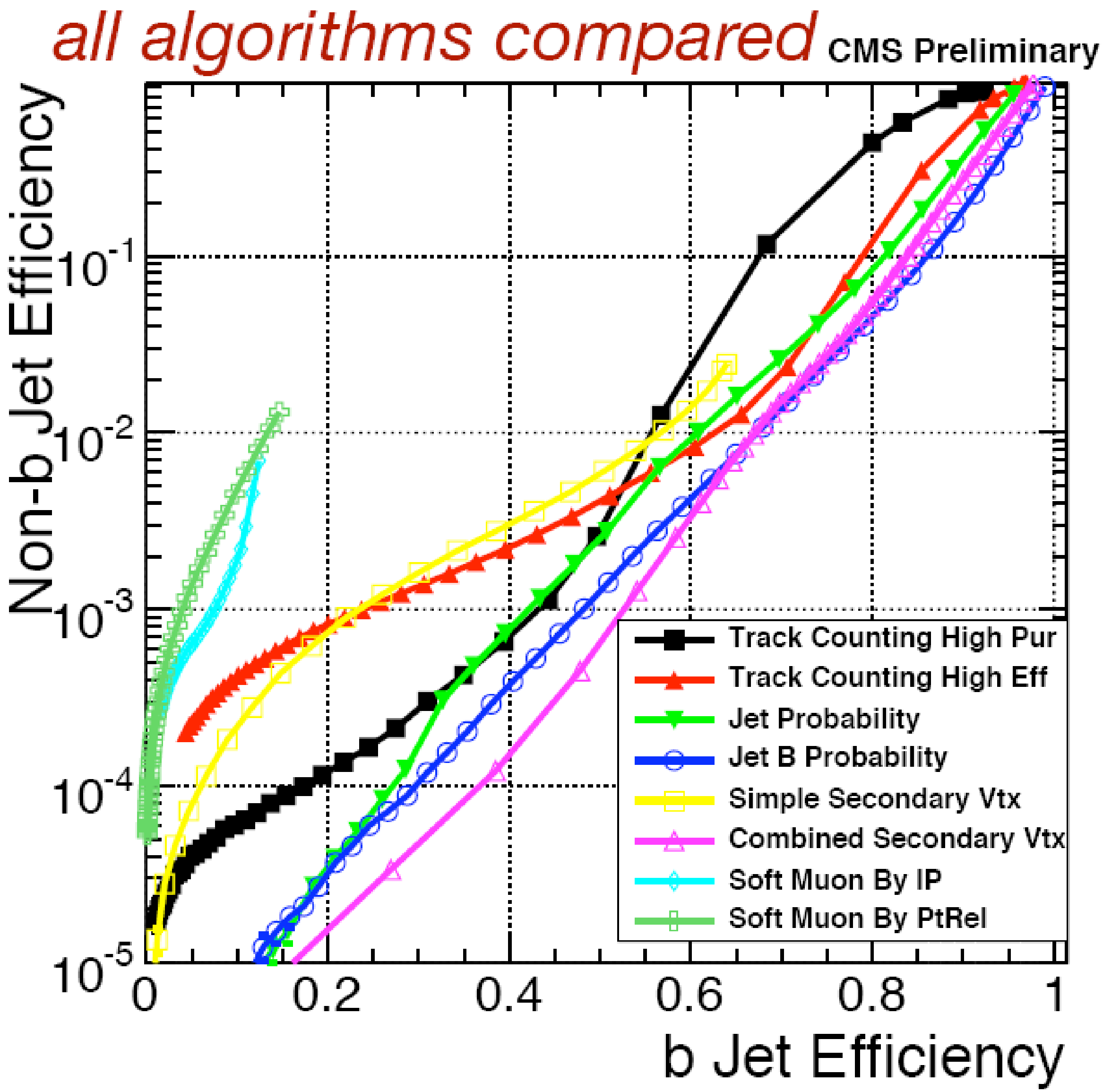
compute combined probability that all tracks in jet come from the primary vertex.

Secondary Vertex

use distance significance as discriminant (simple) or combined information of secondary vertex into a likelihood ratio (combined).

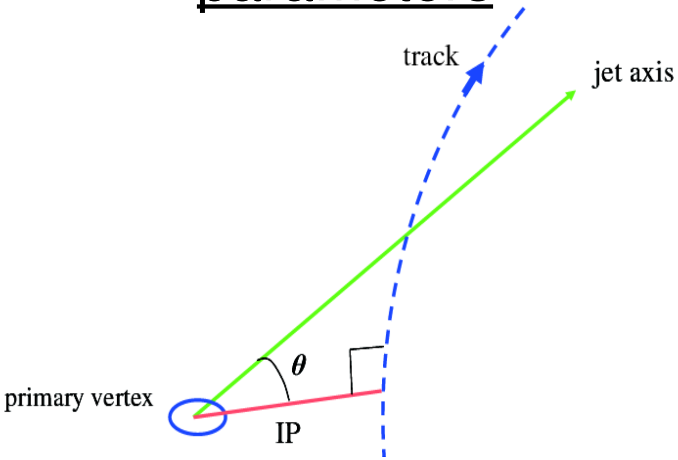


Expected Performances



b-tagging Commissioning

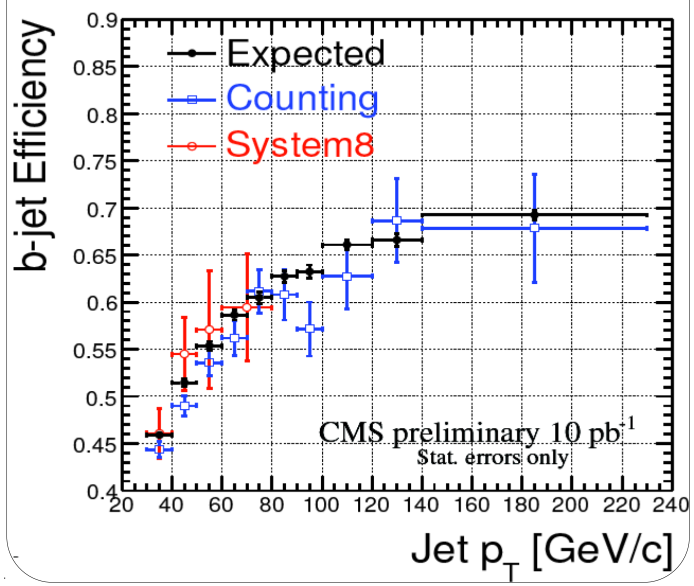
udsg-jet mistag rate from negative impact parameters



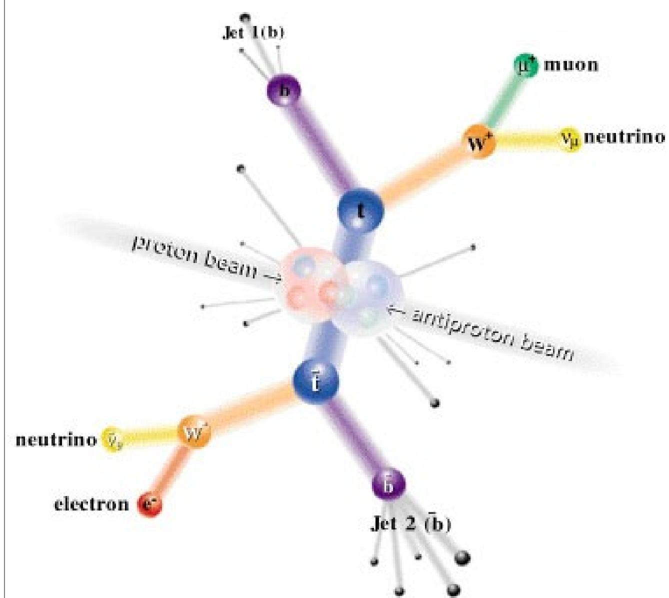
Apply taggers on a sample selected using negative impact parameters to enrich the *udsg* contribution.

Muon-in-jet data sample

- "pT_{rel} template method" : template fit on pT_{rel} .
- "Counting": Template fit on negative tag.
- "System8": solve a system of equation using a sample and its tagged subset.



Top pair events



Channels with at least a leptonic W decay. Use kinematic fit and loose b-tagging of one of the jets to enrich analysis sample.

Summary

- CMS has a robust tracking software.
- Fine tracking performance expected from simulation confirmed with cosmic data. Much better than expected in startup conditions.
- CMS has a diversity of b-hadron taggers, from robust to sophisticated.
- Very good expected performance of b-tagging from simulation can be expected to be confirm with data, according to cosmic data.
- Method to calibrate b-tagging from data ready to be used.