Vertex 2012,
16-21 September, Jeju, Korea

Tracking and Vertexing performance in CMS

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

Outline

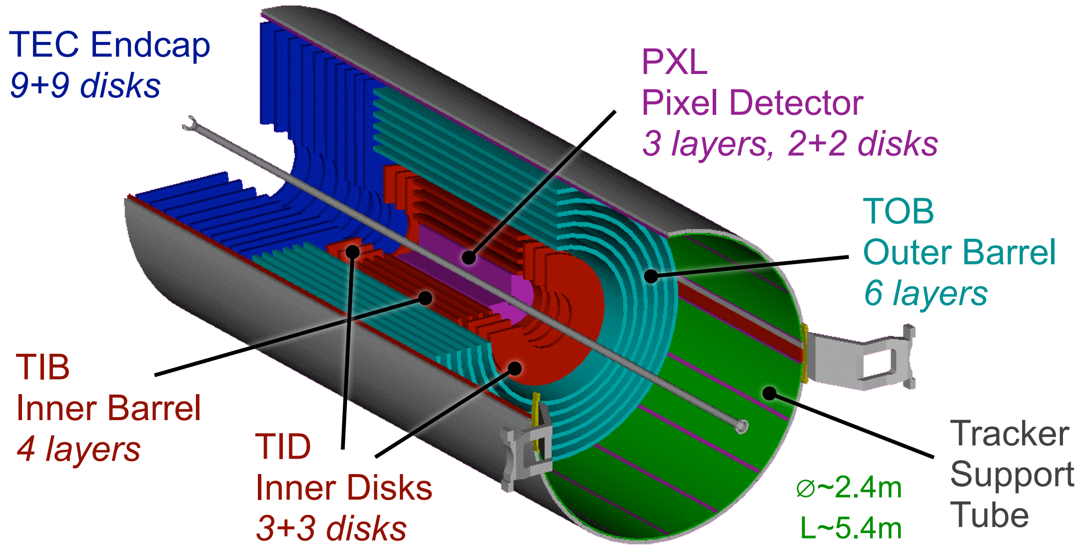
Tracker description

Track and vertex reconstruction

Tracking and vertexing performance

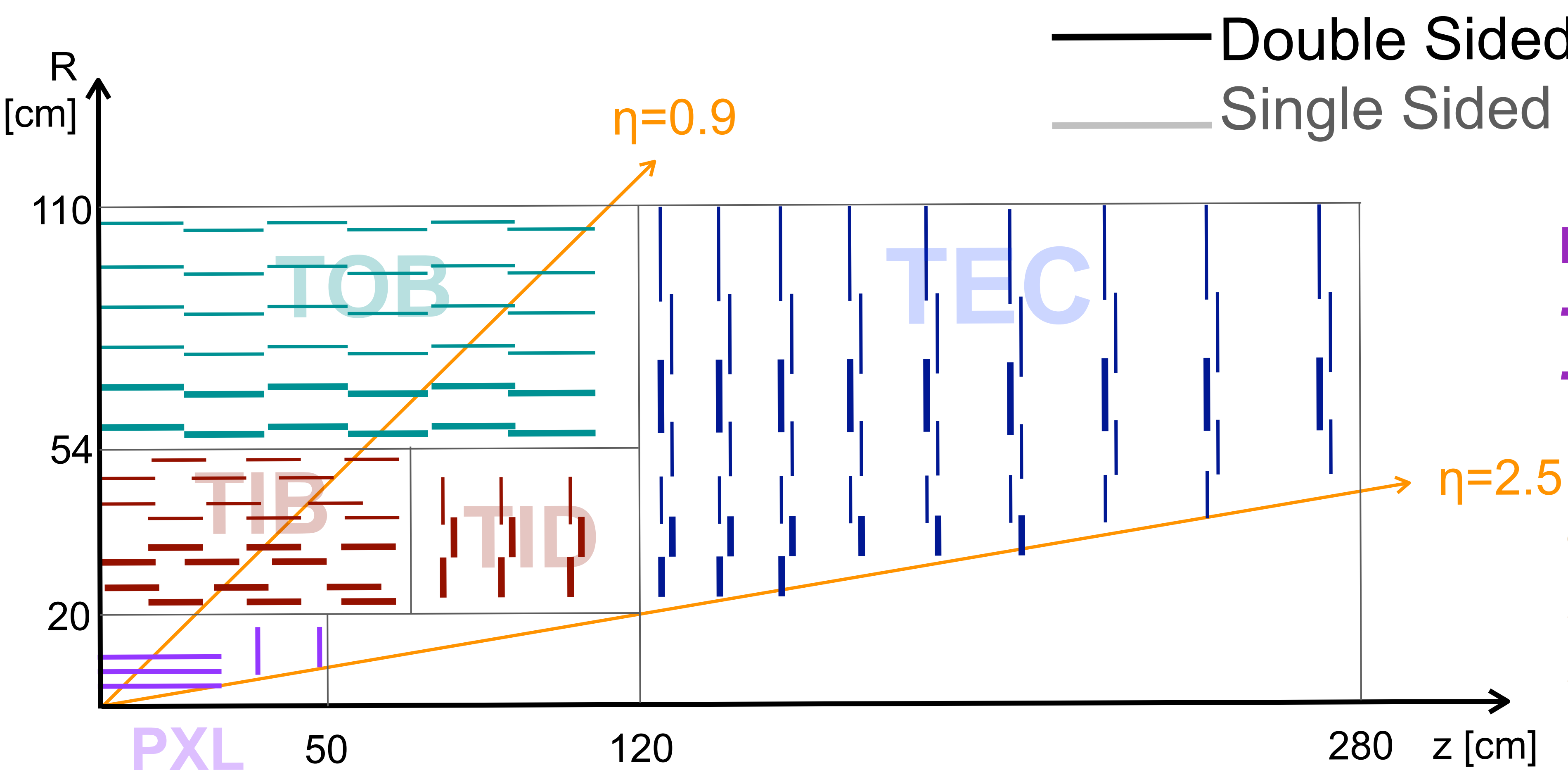
Tracking at HLT

CMS tracker detector



Largest silicon tracker ever built.
Active area: ~200 m^2
In operation since July 2008.

Immersed in a 3.8 T magnetic field.
$\sigma(p_T)/p_T$~1-2% (at p_T=100 GeV/c)
IP resolution~10-20 µm (at p_T=10-100 GeV/c)



Pixel detector:
- 66M readout channels
- 100x150 µm^2

Strip detector:
- ~9M readout channels
- 80-205 µm pitches

***A. Tropiano*, Tracking and vertexing performance in CMS, Vertex 2012, Jeju**

Tracker Performance

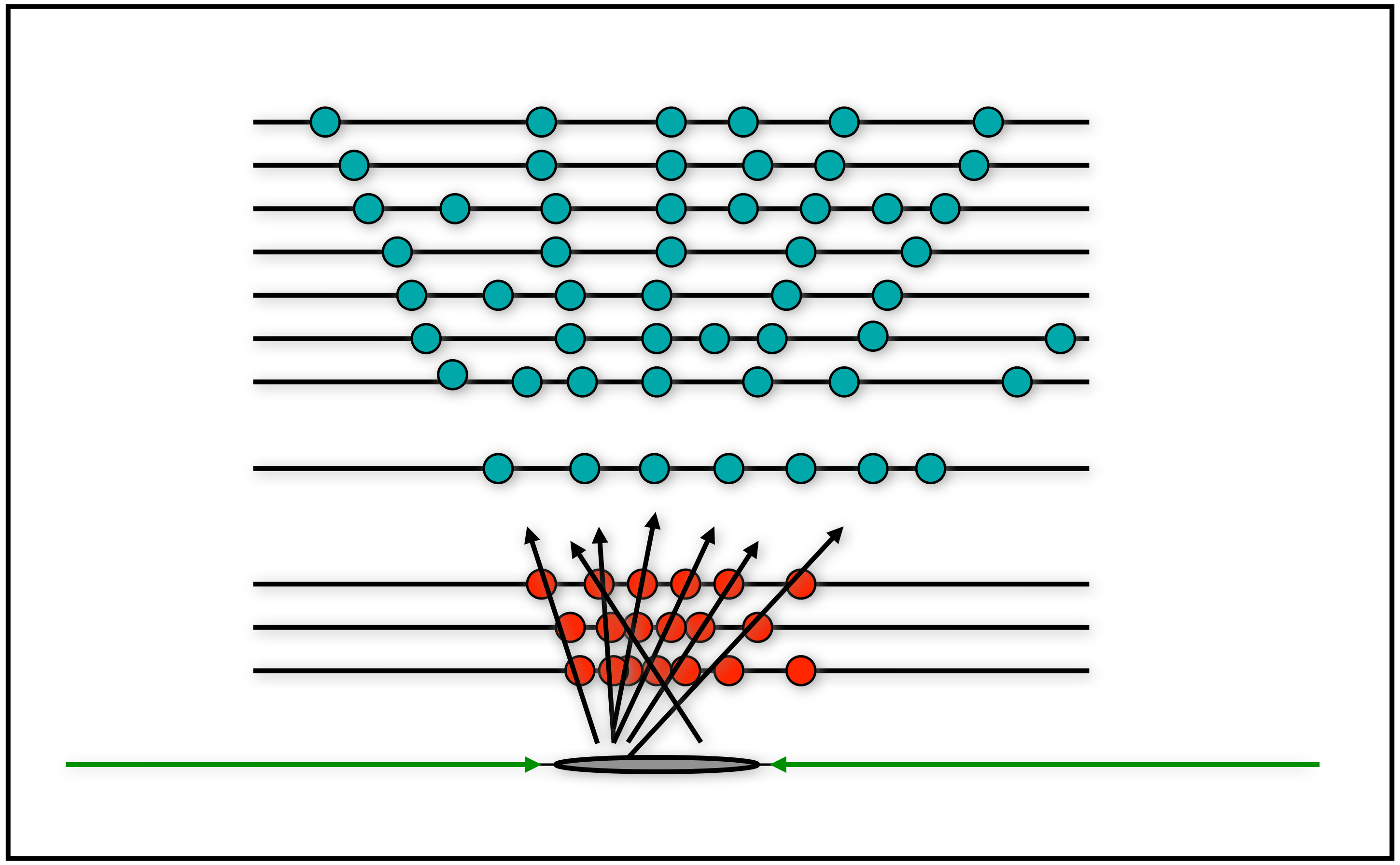
Operation and Performance of the CMS Silicon Strip Tracker

Gero Flucke
(on behalf of the CMS Collaboration)

Operational Issues of the Present CMS Pixel Detector

Seth Zenz
Princeton University
On Behalf of the CMS Collaboration

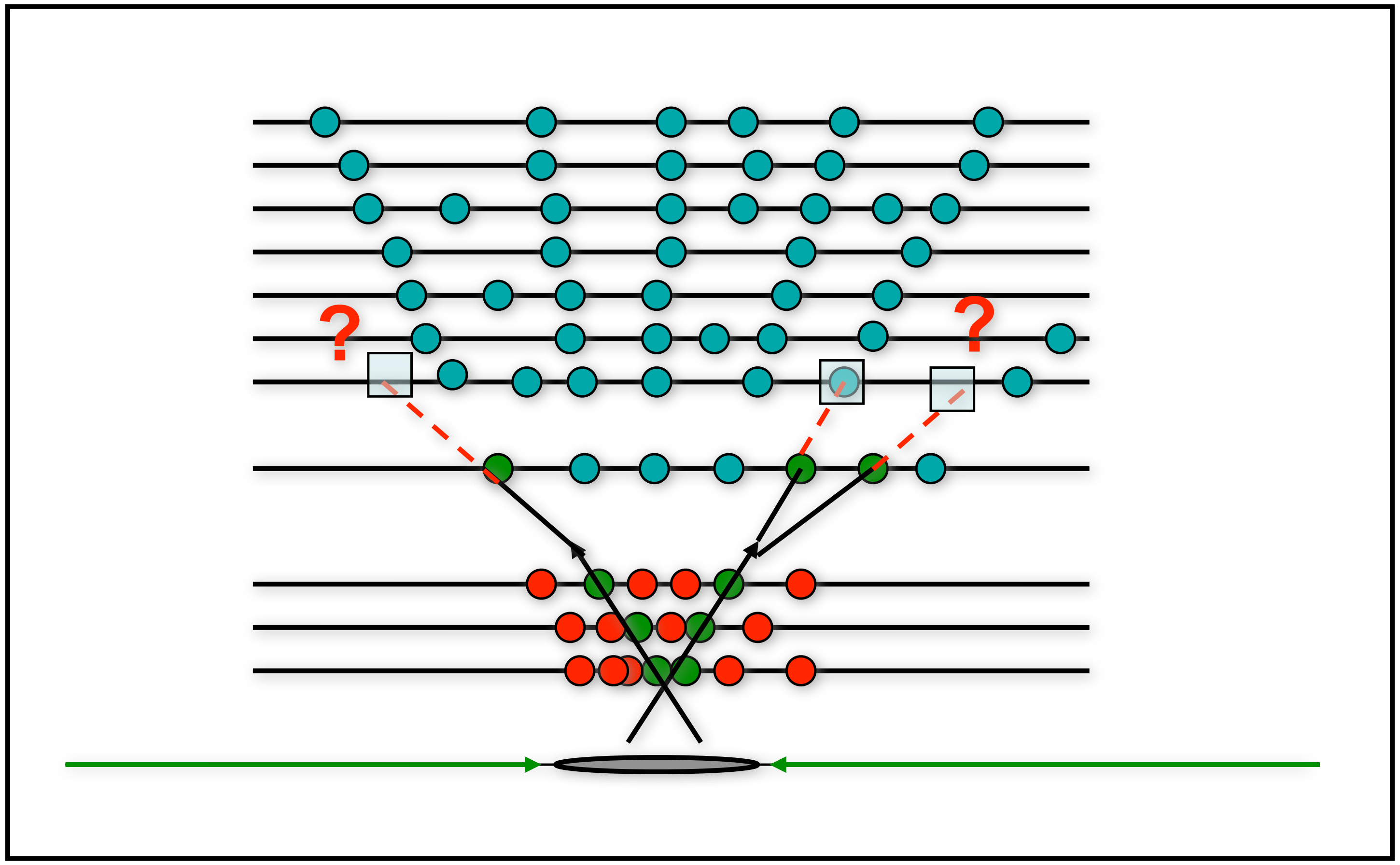
Track reconstruction



Seeding

Starts from the pixel layers.
Made from hit triplets or pairs with the beamspot.
Seeds not compatible with the beamspot are discarded.

Track reconstruction



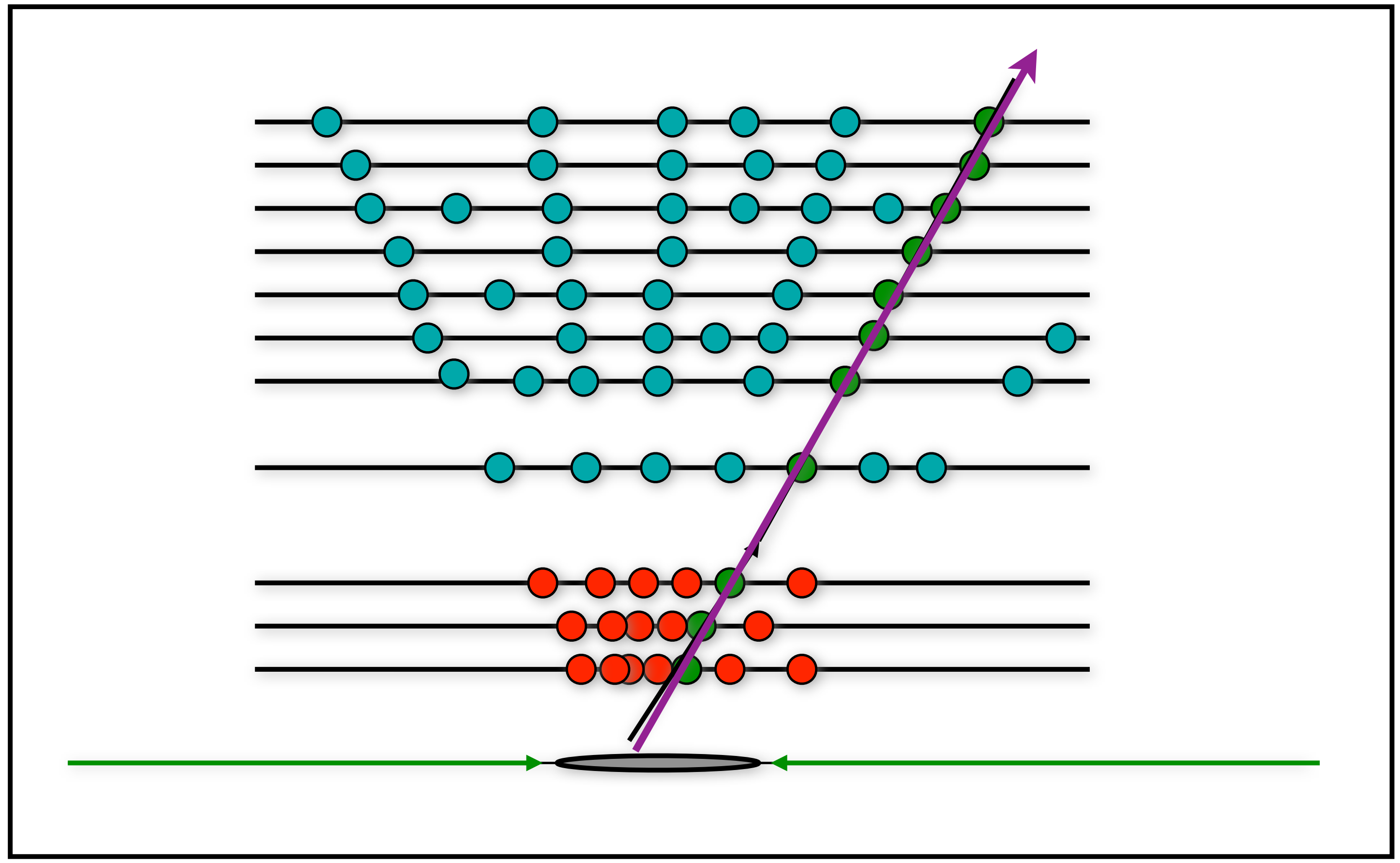
Trajectory Building

Each seed is propagated to the successive layers, using a Kalman filter technique.

Allows for missing hits in a layer.

Propagation continues until there are no more layers or there's more than one missing hit.

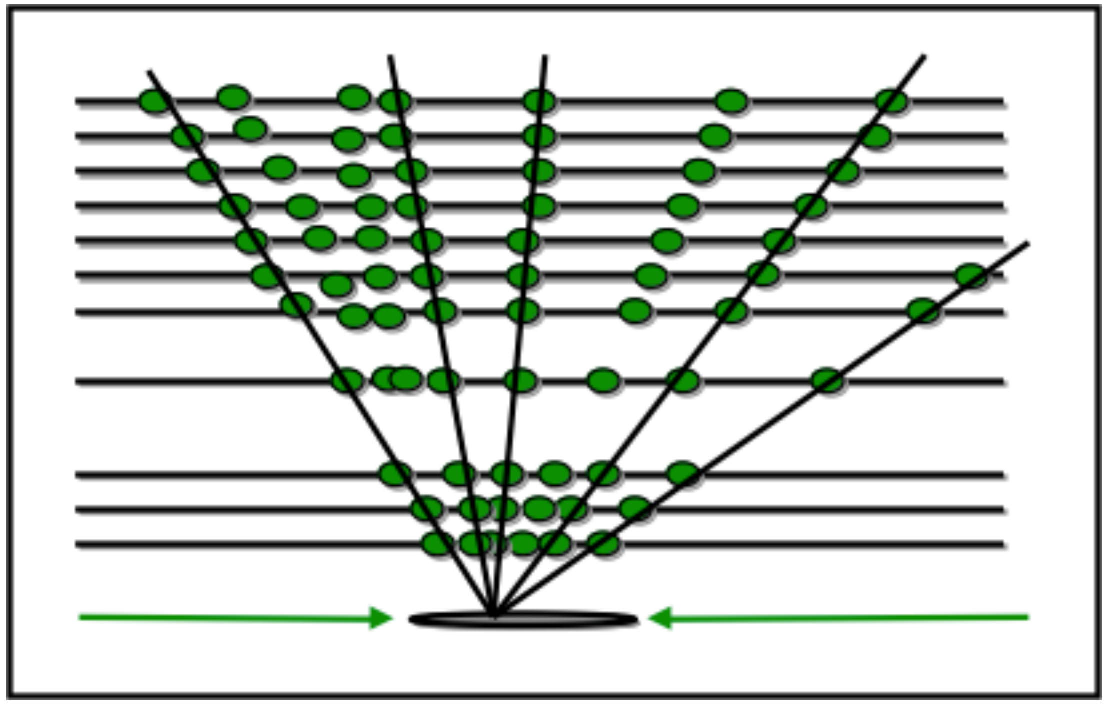
Track reconstruction



Track Fitting

More hits are added and the track parameters estimation is updated every time a new hit is found.
A final fit is performed to obtain the track parameters at the interaction point.

Iterative Tracking

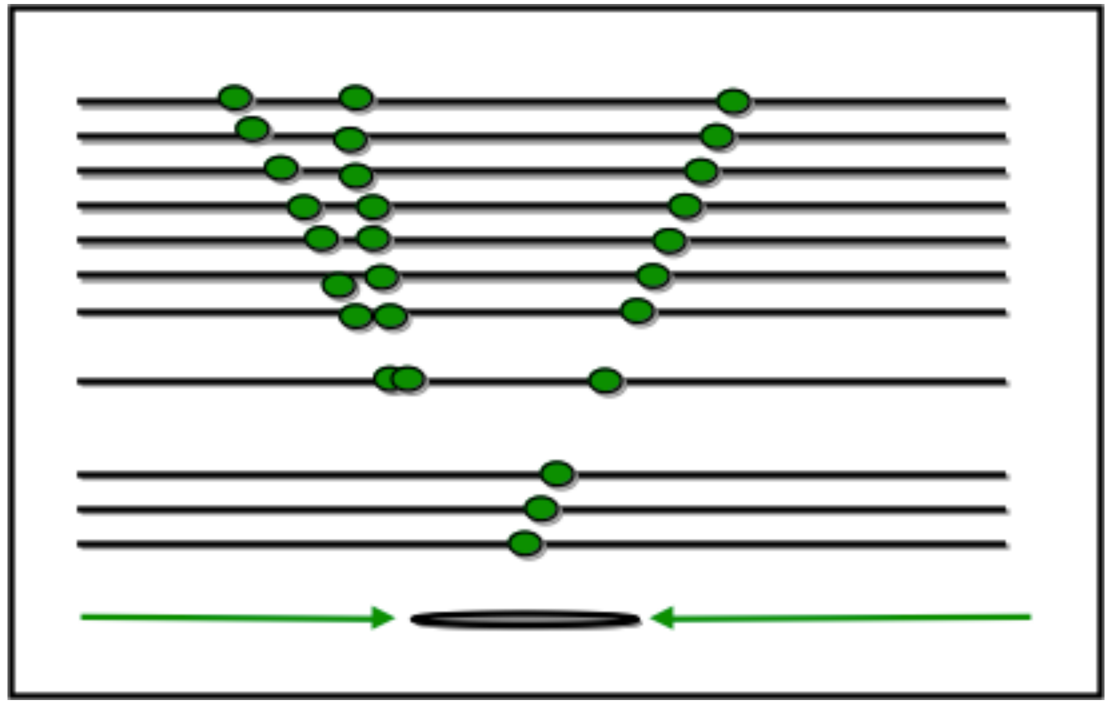


Main Idea

Do the pattern recognition in various iterations:

- start from the high p_T seeds to reconstruct the most energetic tracks.

Iterative Tracking



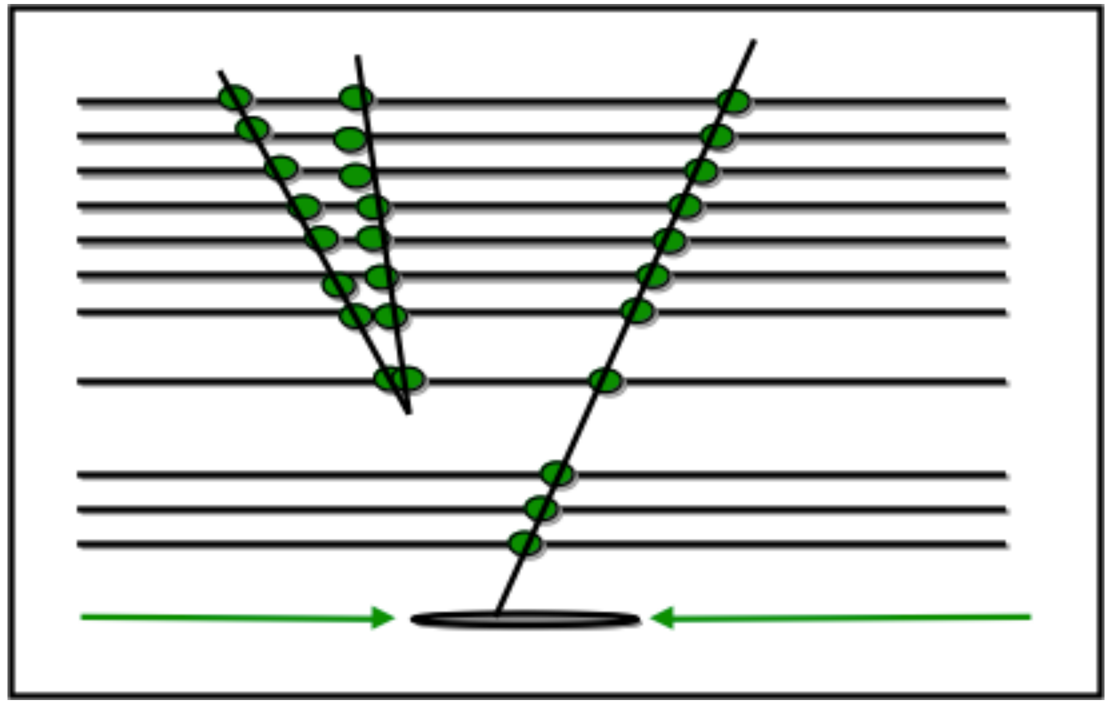
Main Idea

Do the pattern recognition in various iterations:

- start from the high p_T seeds to reconstruct the most energetic tracks.

- remove the hits associated with the found tracks,

Iterative Tracking



Main Idea

Do the pattern recognition in various iterations:

- start from the high p_T seeds to reconstruct the most energetic tracks.

- remove the hits associated with the found tracks,

- repeat the pattern recognition with looser set of cuts. Find lower p_T, more displaced tracks.

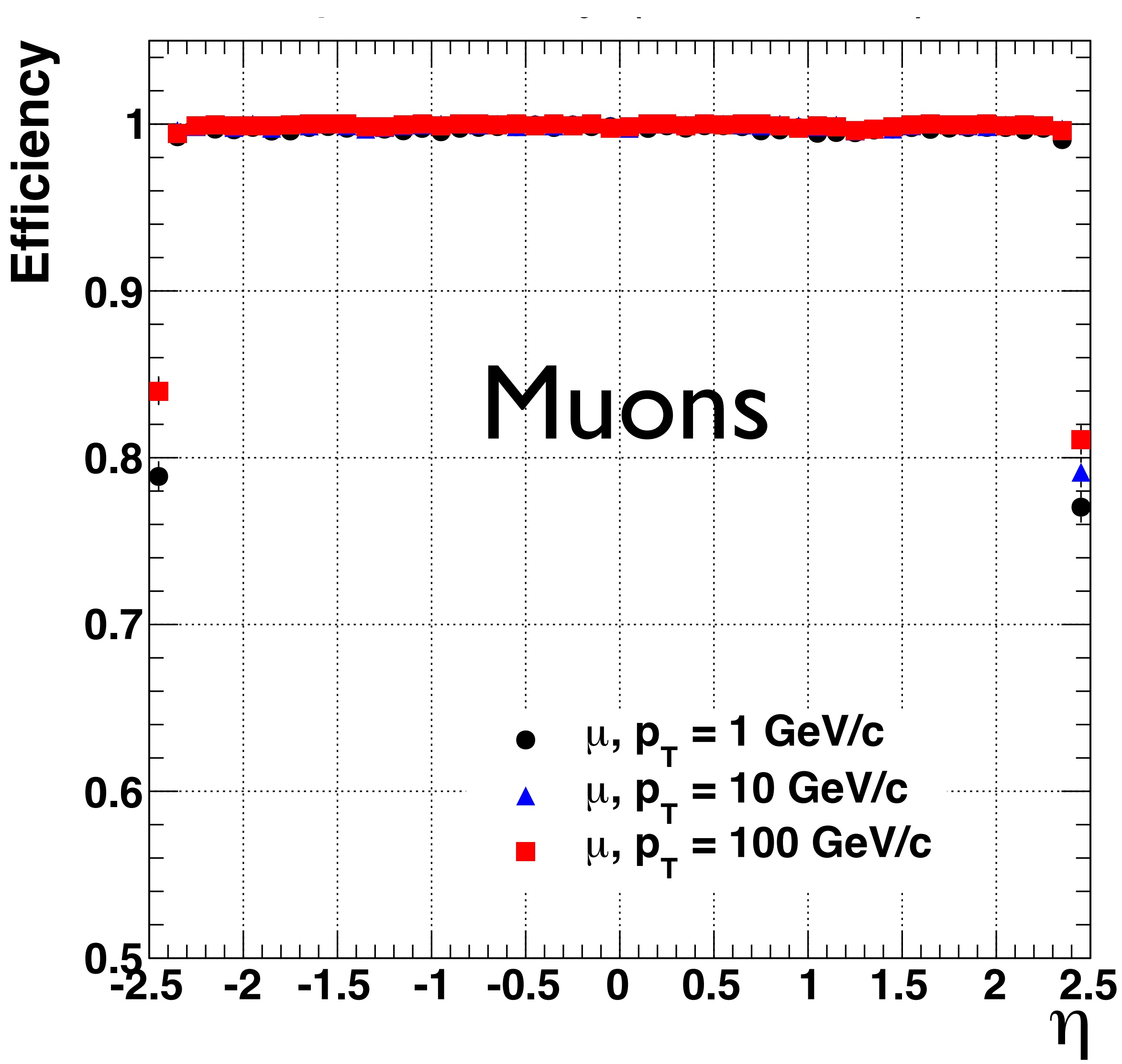
- Track parameters: (q/p, dz, $d0$, η, φ)

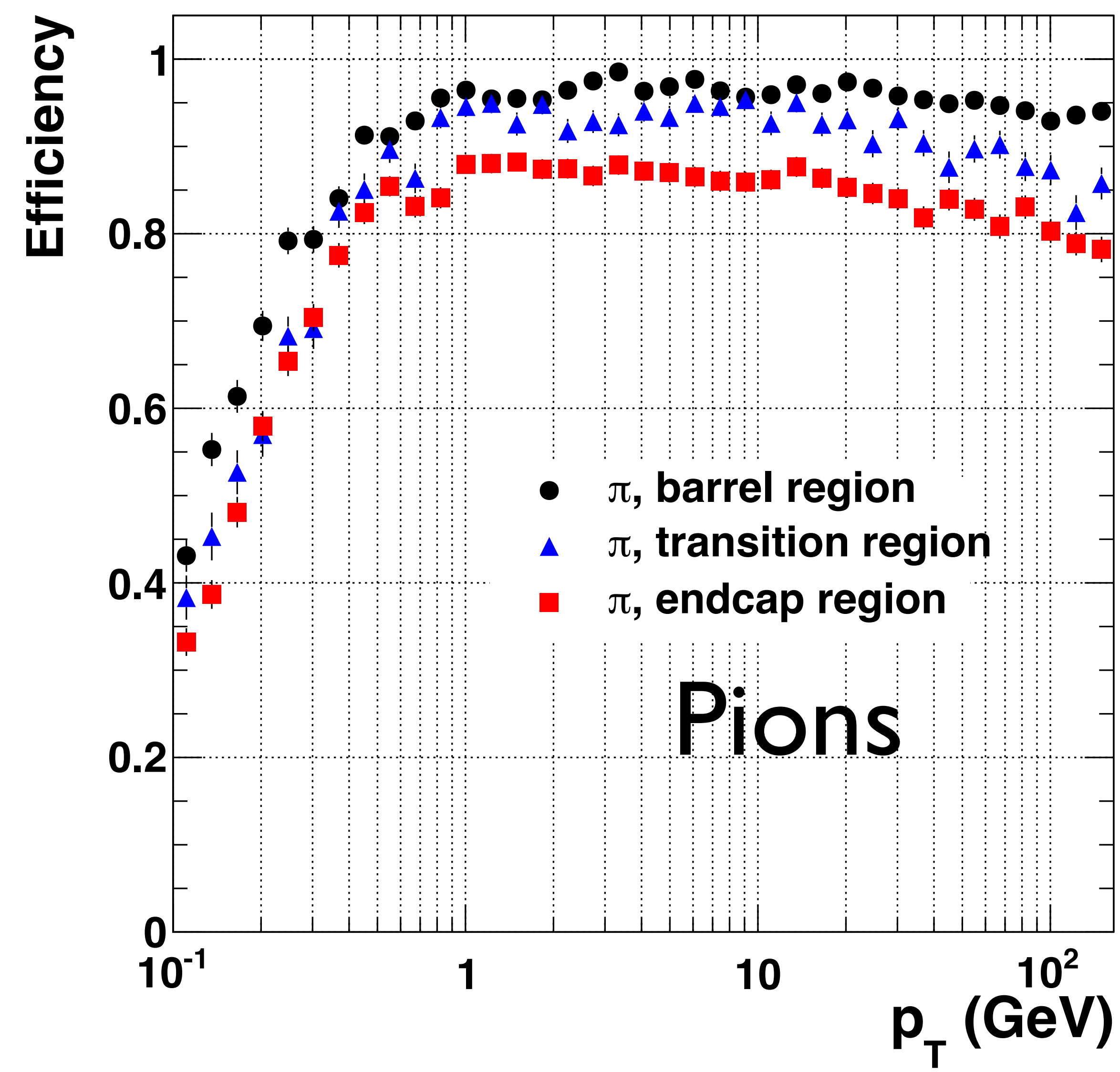
Iterative Tracking (in 2011)

Iteration	Seeds	p_T cut	d0 cut	dz cut
0	pixel triplets	0,8 GeV/c	0,2cm	3,0σ
1	pixel pairs	0,6 GeV/c	0,2cm	0,2cm
2	pixel triplets	0,075 GeV/c	0,2cm	3,3σ
3	pixel,TIB,TID,TEC	0,35 GeV/c	1,2cm	10,0cm
4	TIB,TID,TEC	0,5 GeV/c	2,0cm	10,0cm
5	TOB,TEC	0,6 GeV/c	5,0cm	30,0cm

At the end of each step tracks are filtered based on number of hits, number of 3D hits, number of missed hits, χ^2 of the fit, d0 and dz. Cuts configurable and define collections with different purity.

Tracking Performance





Efficiency is almost 100% for muons. Around 90% for pions.

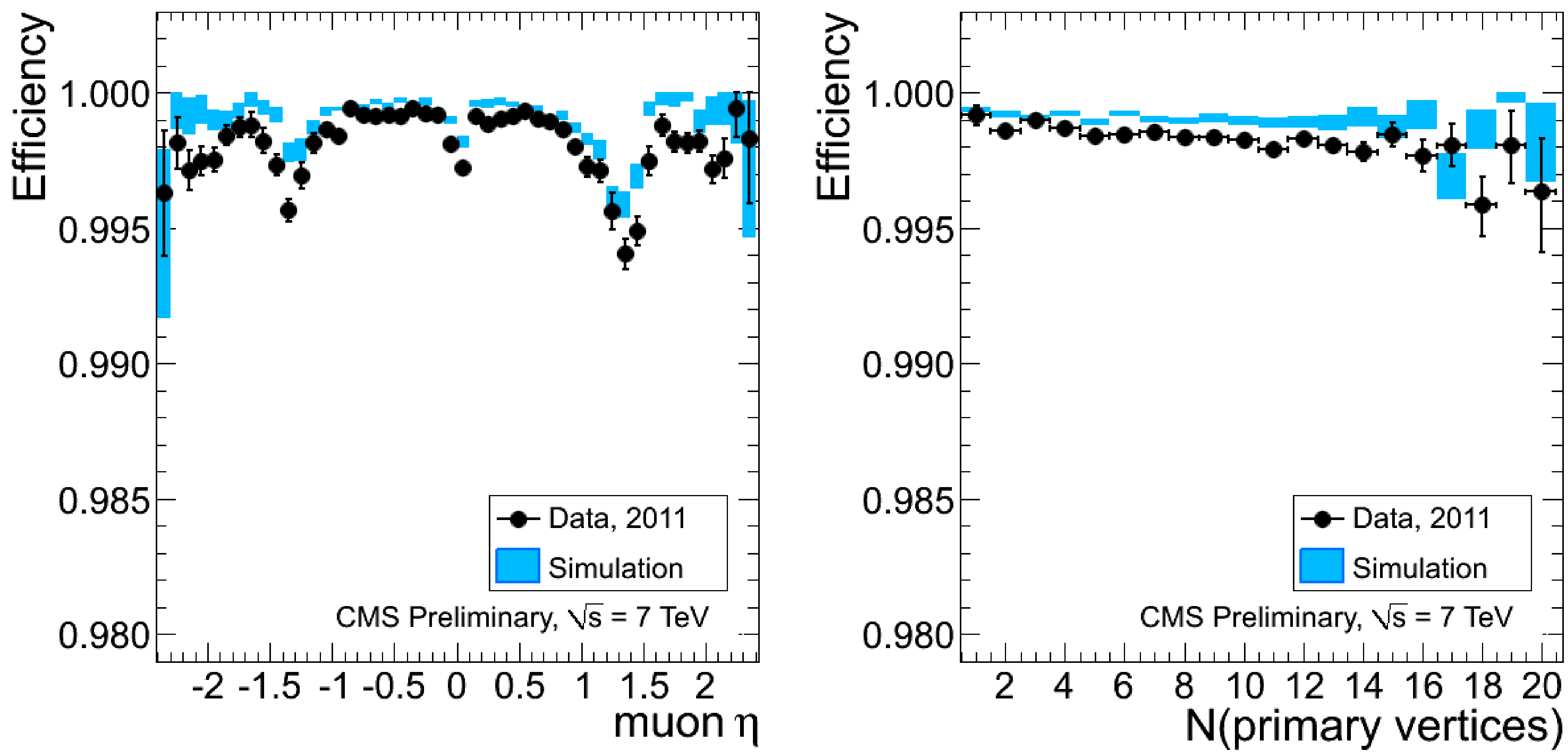
***A. Tropiano*, Tracking and vertexing performance in CMS, Vertex 2012, Jeju**

Tracking Performance

Tracking efficiency for muons measured in Z→μμ events, with a tag and probe technique.

Tag muon *reconstructed in the muon chambers and in the tracker.*

Probe muon *reconstructed with the muon chamber only.*



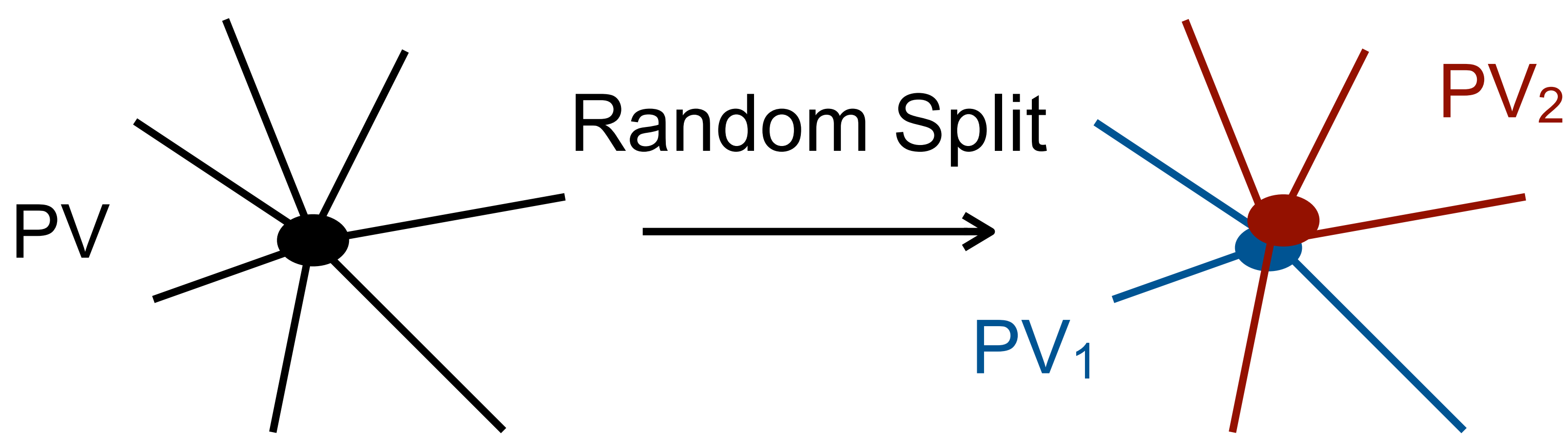
Efficiency is very high and compatible with simulation.

Vertex Reconstruction

Deterministic Annealing Vertexing is used in CMS.
Tracks are soft assigned to vertices, by using appropriate weights.
To avoid finding local minima annealing is performed applying a Temperature on the σ(dz) of tracks.

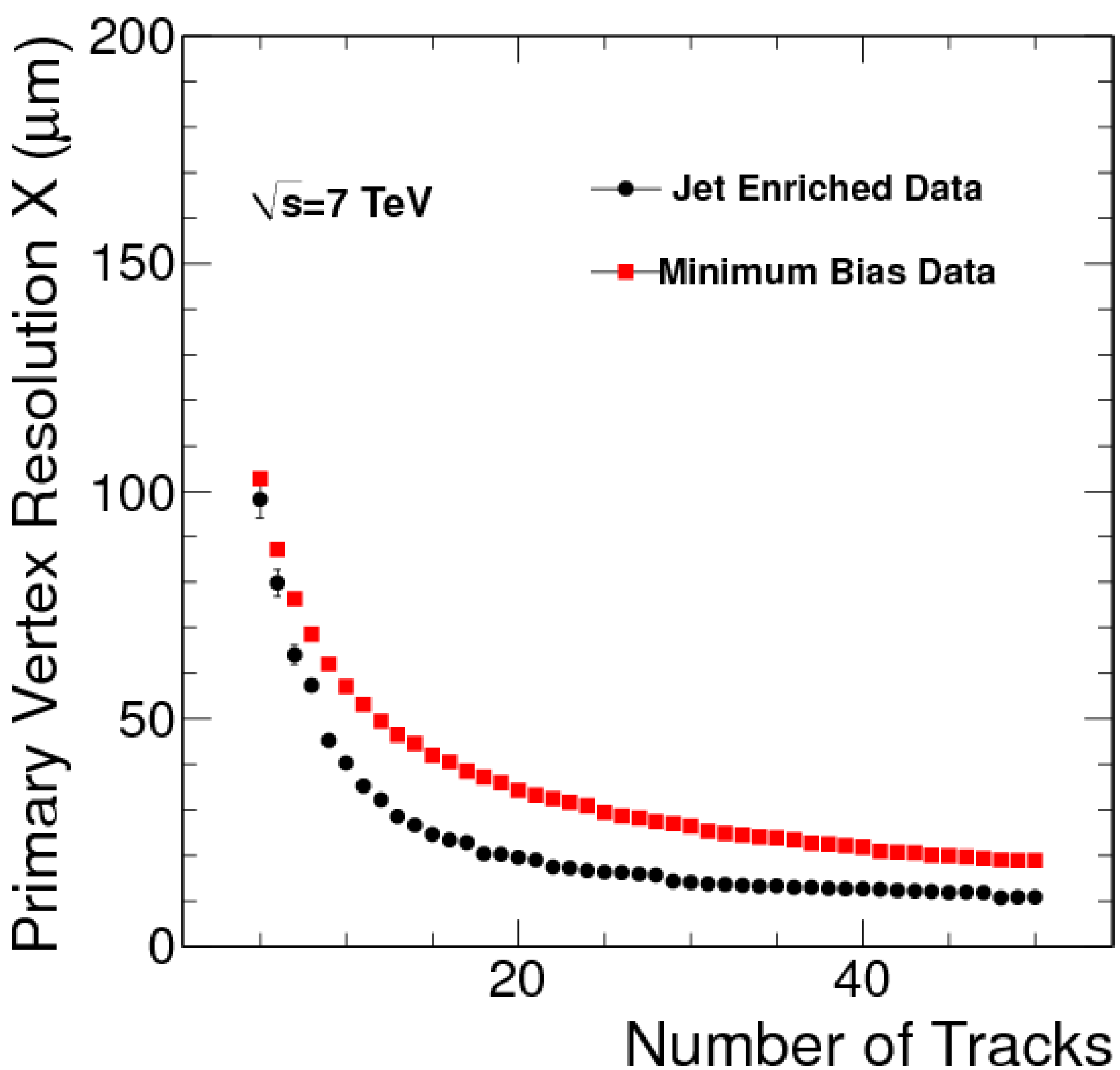
Resolution Measurement

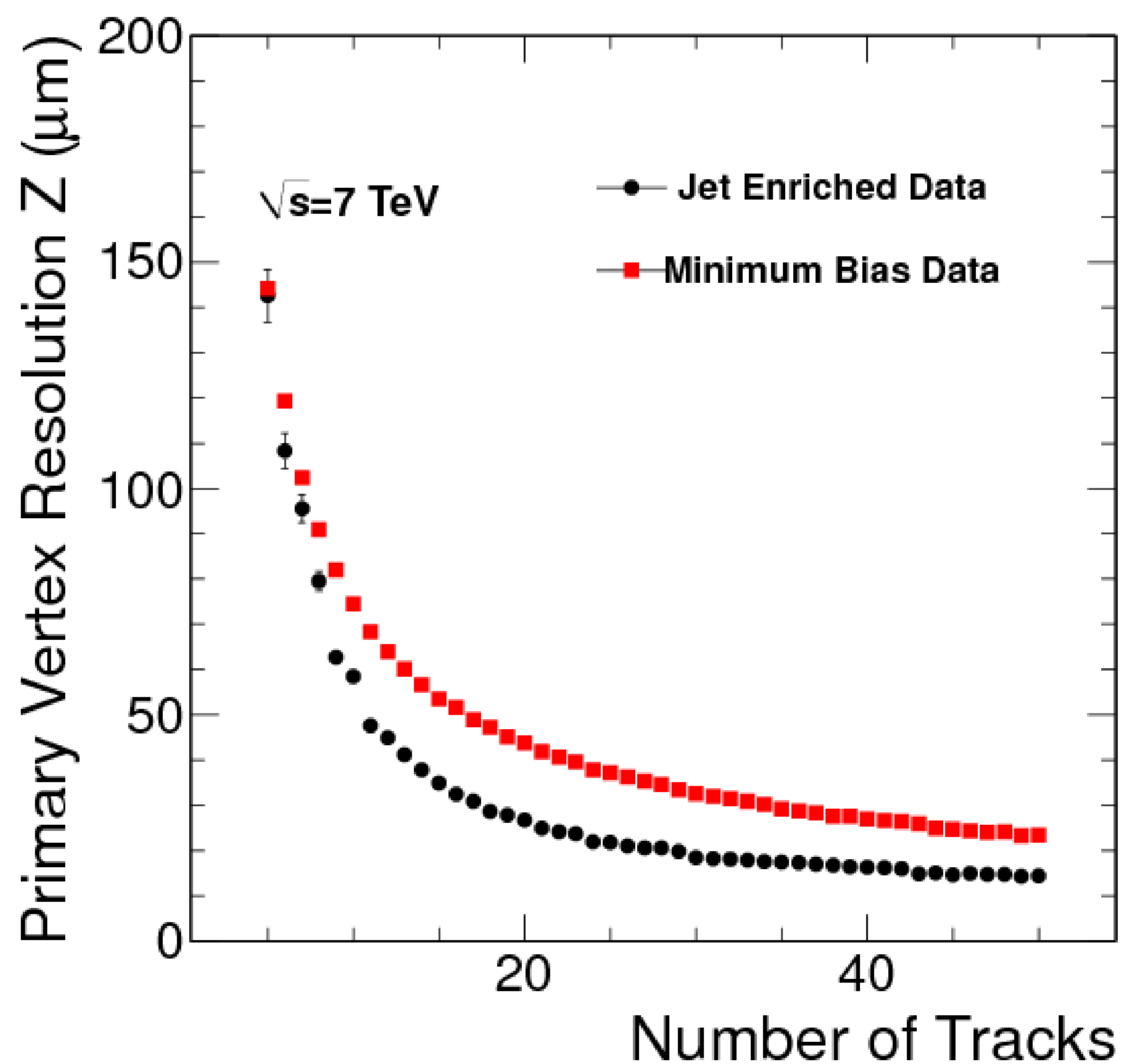
Data driven method:
- split the same vertex in 2,
- fit the 2 primary vertices indipendently.
The position difference gives the resolution.



Vertex Resolution

Primary Vertex resolution strongly depends on number of tracks.
Asymptotic resolution around 10-20 μm.

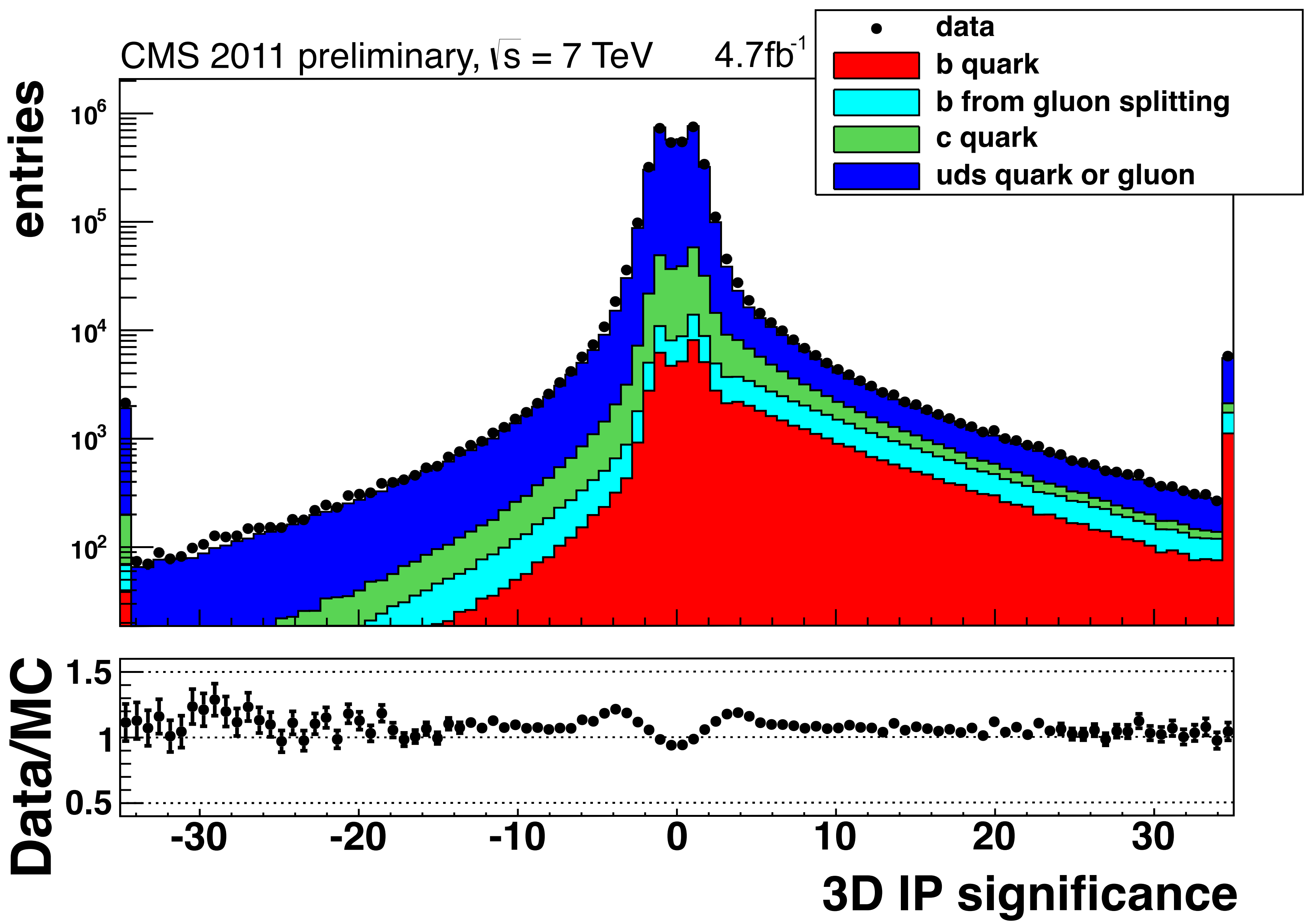




A. Tropiano, **Tracking and vertexing performance in CMS**, **Vertex 2012, Jeju**

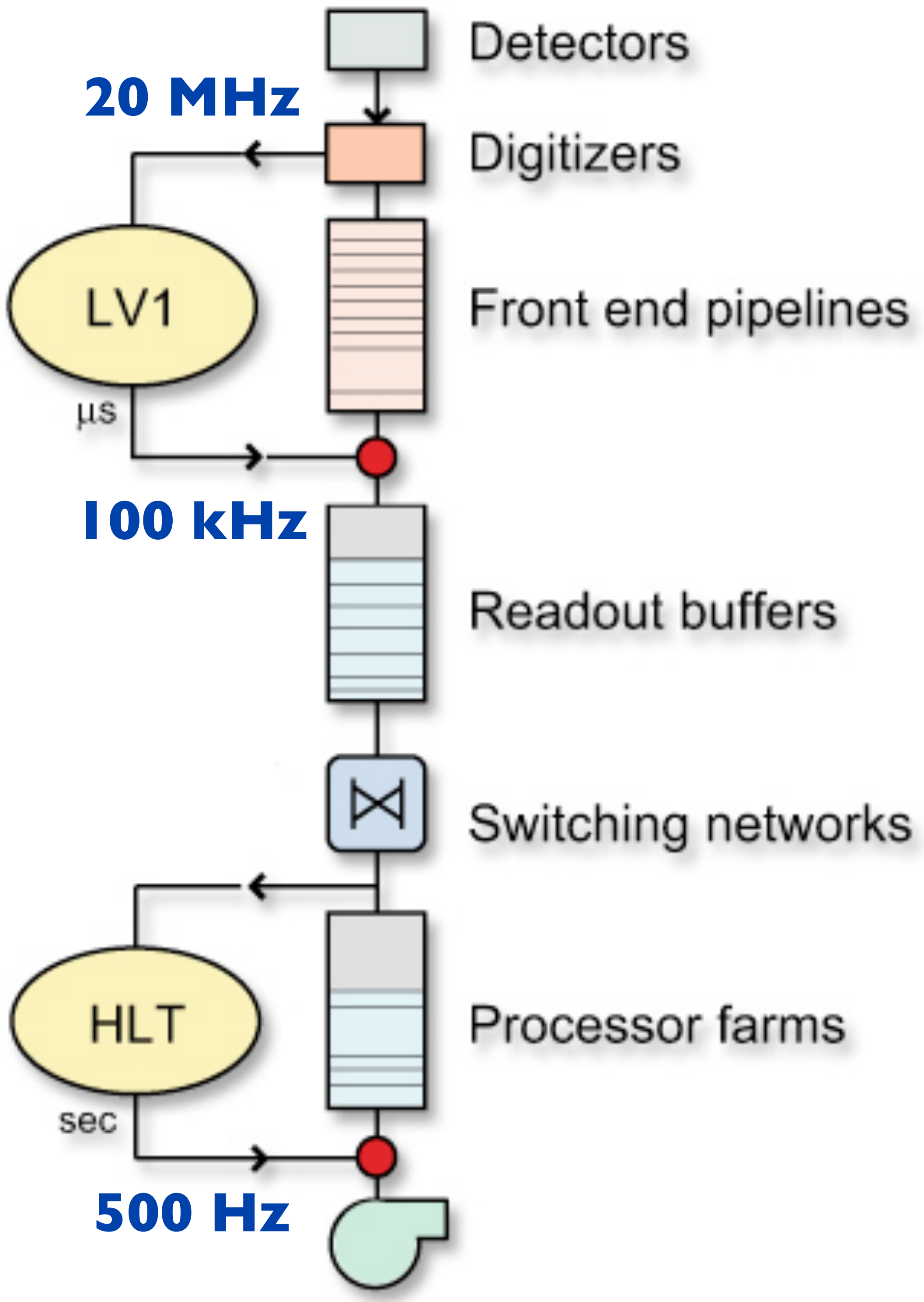
Btagging variables

Impact Parameter significance is the main b-tagging discriminating variable. Need excellent vertexing and tracking.



***A. Tropiano*, Tracking and vertexing performance in CMS, Vertex 2012, Jeju**

Tracking for trigger



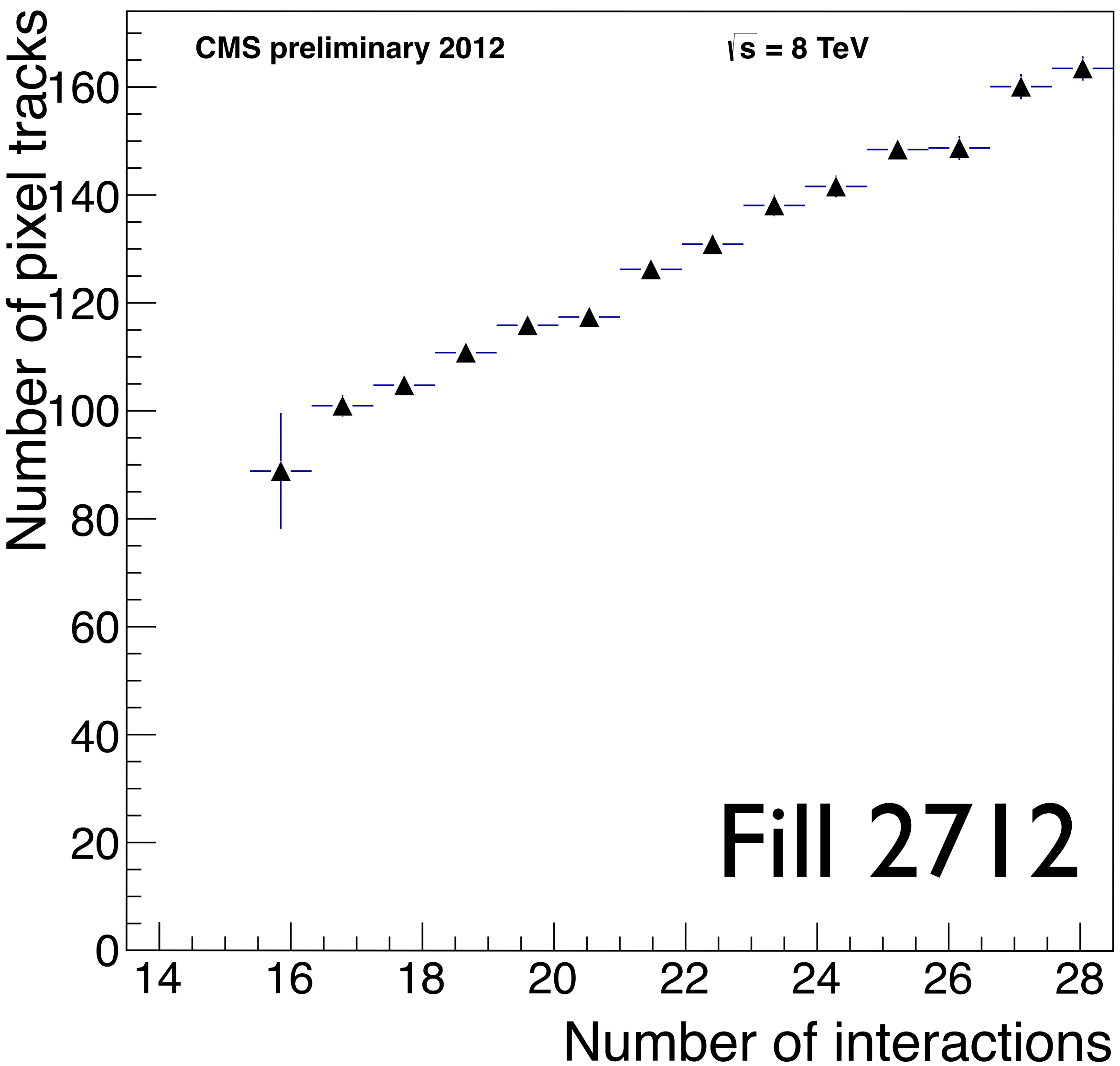
Several use cases for tracking at the ***High Level Trigger*** *(software).*

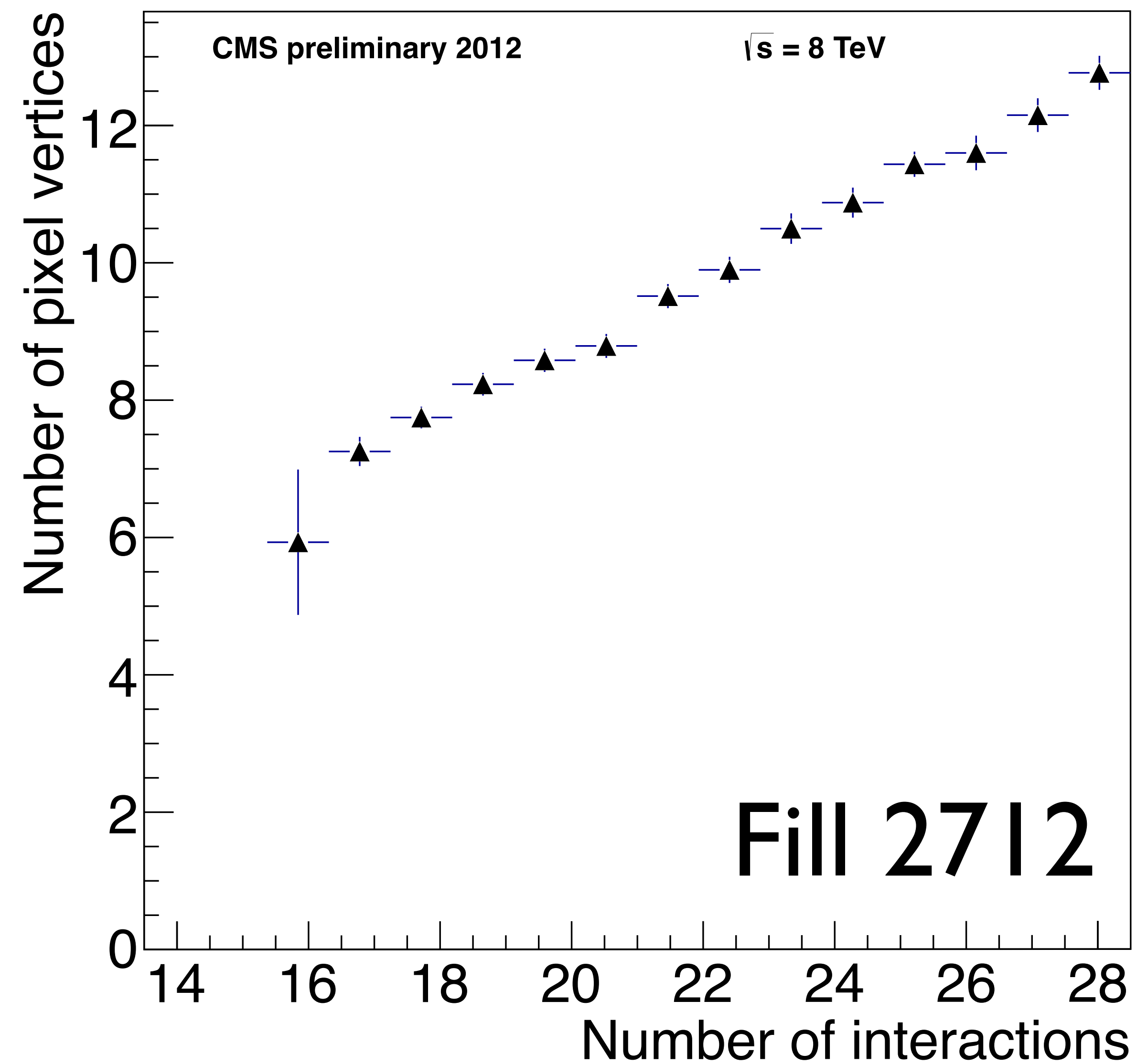
Jet reconstruction: *iterative tracking at HLT improves jet resolution.*
b-tagging*: tracking with pixels or regional tracking, for IP measurements.*
Leptons reconstruction*: to improve resolution hence turn on curves.*

Standard algorithms are too slow to be used online: O(10 s).
Online version much faster: O(100 ms)

Tracking at HLT

***Pixel** based reconstruction for tracks and vertices.*
Useful for reconstructing electrons and muons, for Particle Flow and b-tagging.



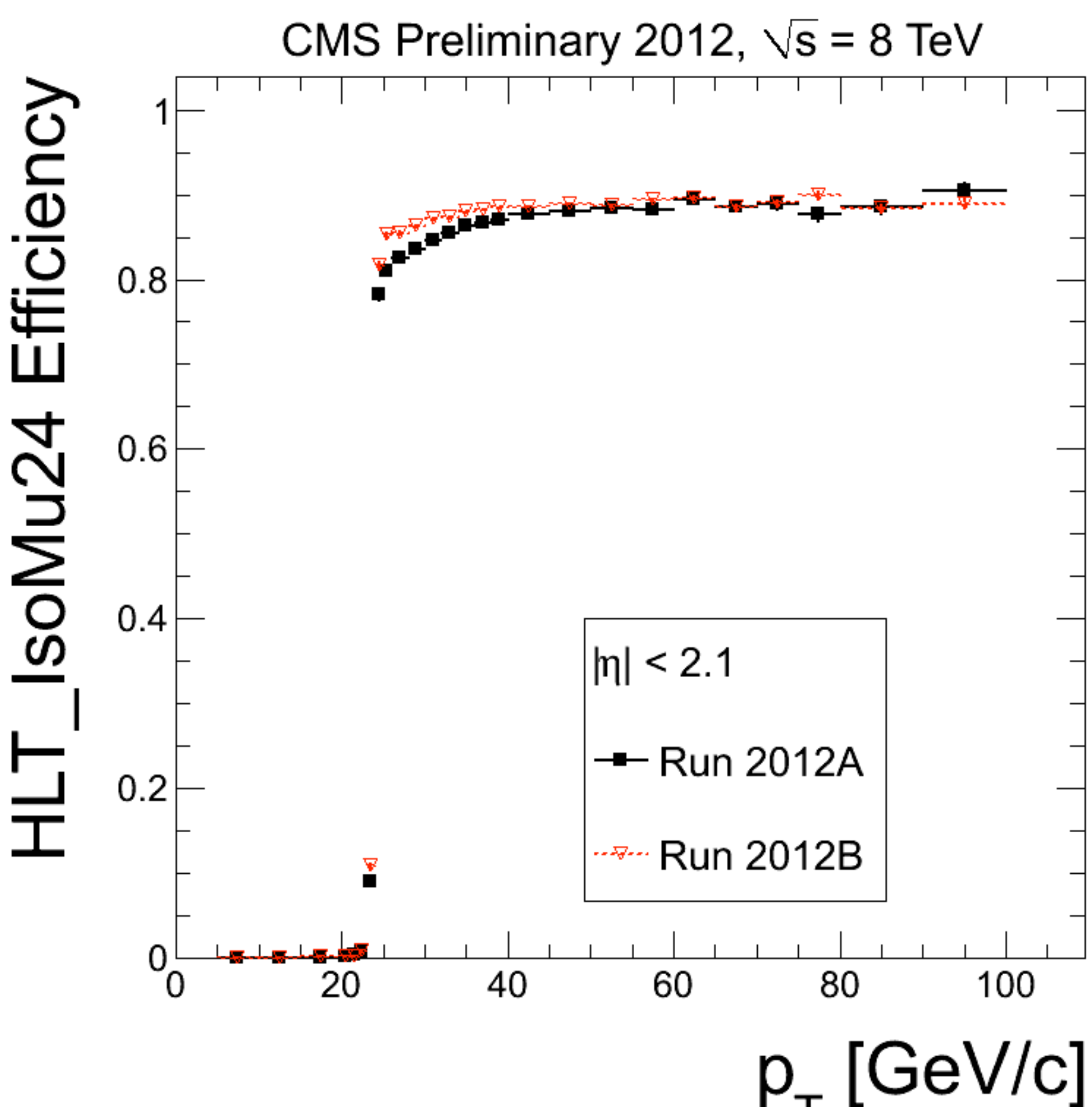


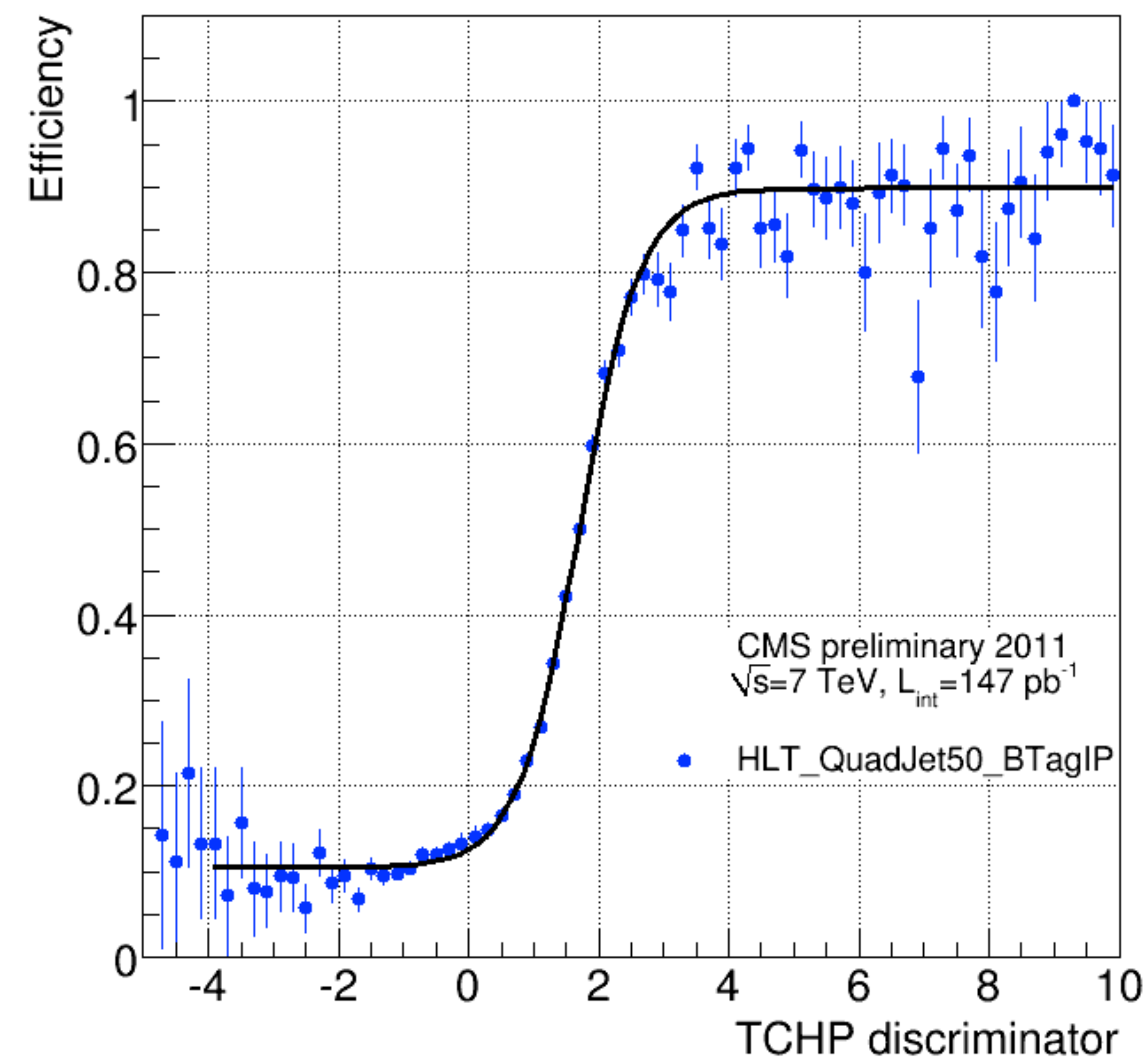
Number of tracks and vertices as a function of the Pile Up, for a single fill.

Tracking at HLT

Muon reconstruction: *thanks also to muon tracking muon triggers have very sharp turn on curves.*

b-tagging: *a 2 step approach (pixel tracks and full tracks) allows to trigger events at low rate and with low CPU timing.*





Summary

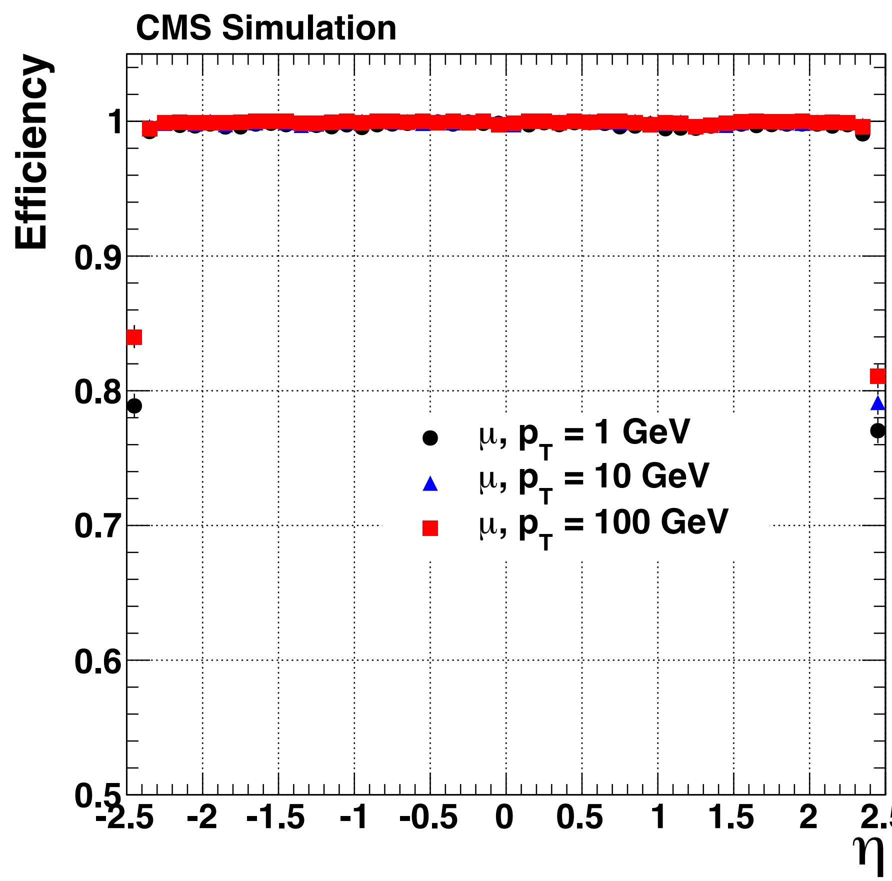
The CMS tracker is a huge and complex apparatus, performing very well (see Gero and Seth presentations for details).

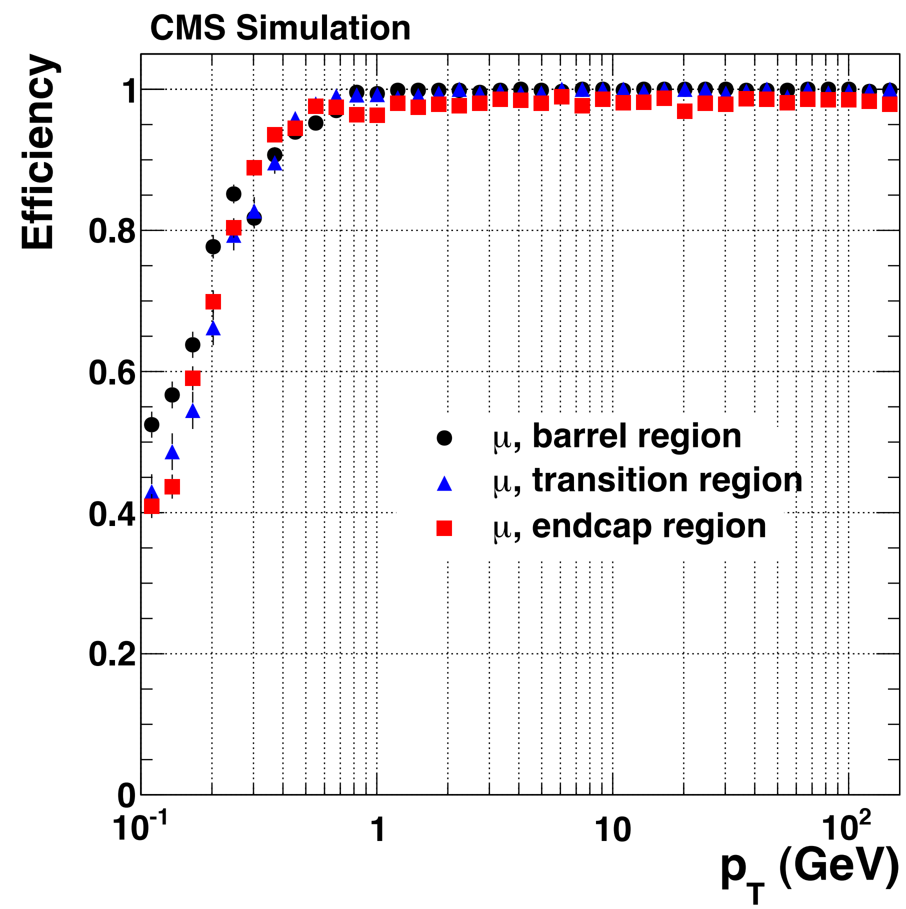
Tracking and vertexing at LHC are very challenging. CMS tracking software is coping well with this task:
- More than 99% muon tracking efficiency.
- IP resolution O(10 μm).

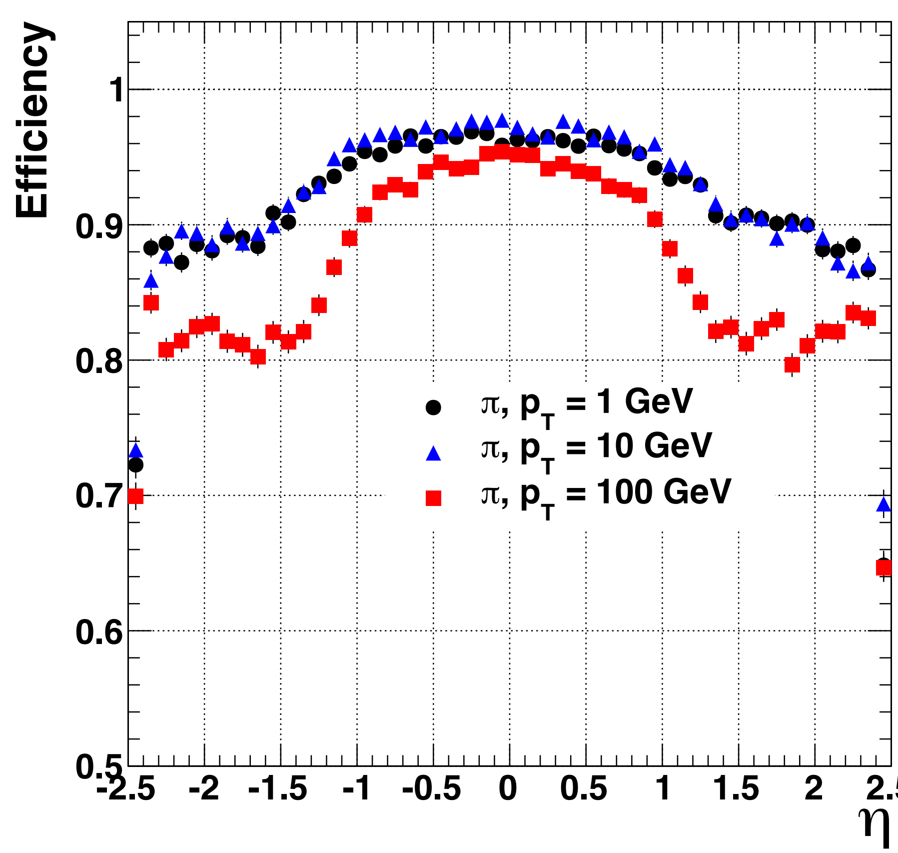
Tracking is widely used at the trigger level. Important for b-tagging, lepton and jet reconstruction. Almost all HLT paths use tracking and/or vertexing. Up to 20% of trigger CPU devoted to tracking in 2012.

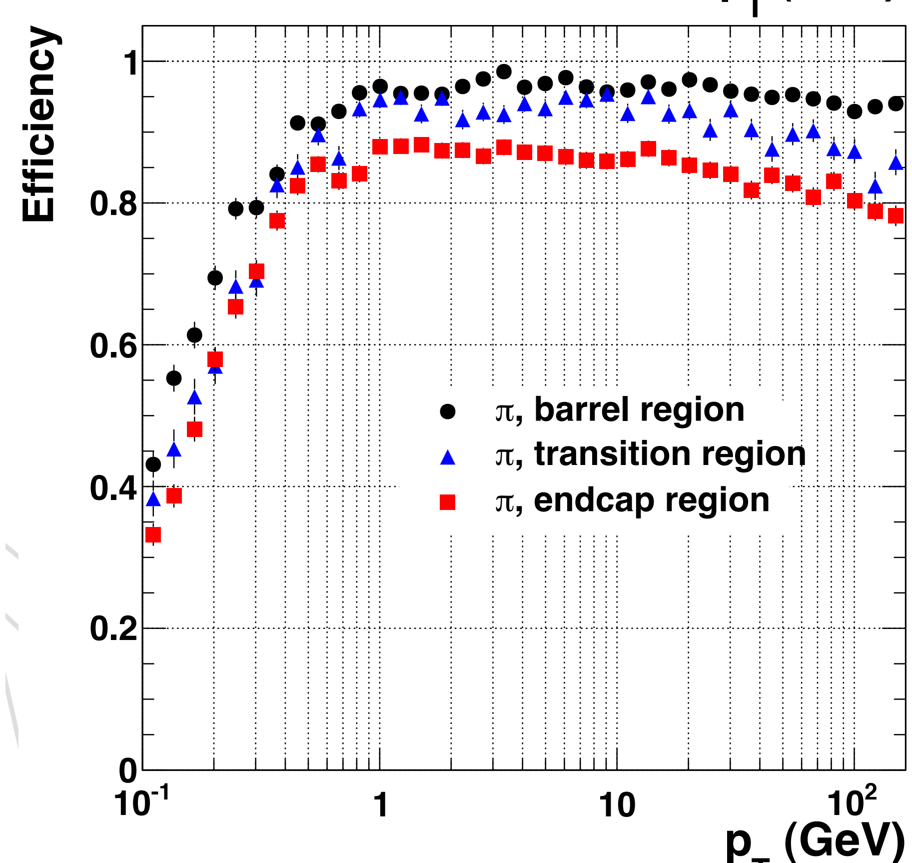
Thank you!

Backup


CMS Simulation
Efficiency
μ, p_T = 1 GeV
μ, p_T = 10 GeV
μ, p_T = 100 GeV
η


CMS Simulation
Efficiency
μ, barrel region
μ, transition region
μ, endcap region
p_T (GeV)


Efficiency
π, p_T = 1 GeV
π, p_T = 10 GeV
π, p_T = 100 GeV
η


Efficiency
π, barrel region
π, transition region
π, endcap region
p_T (GeV)

Backup

Weight definiton

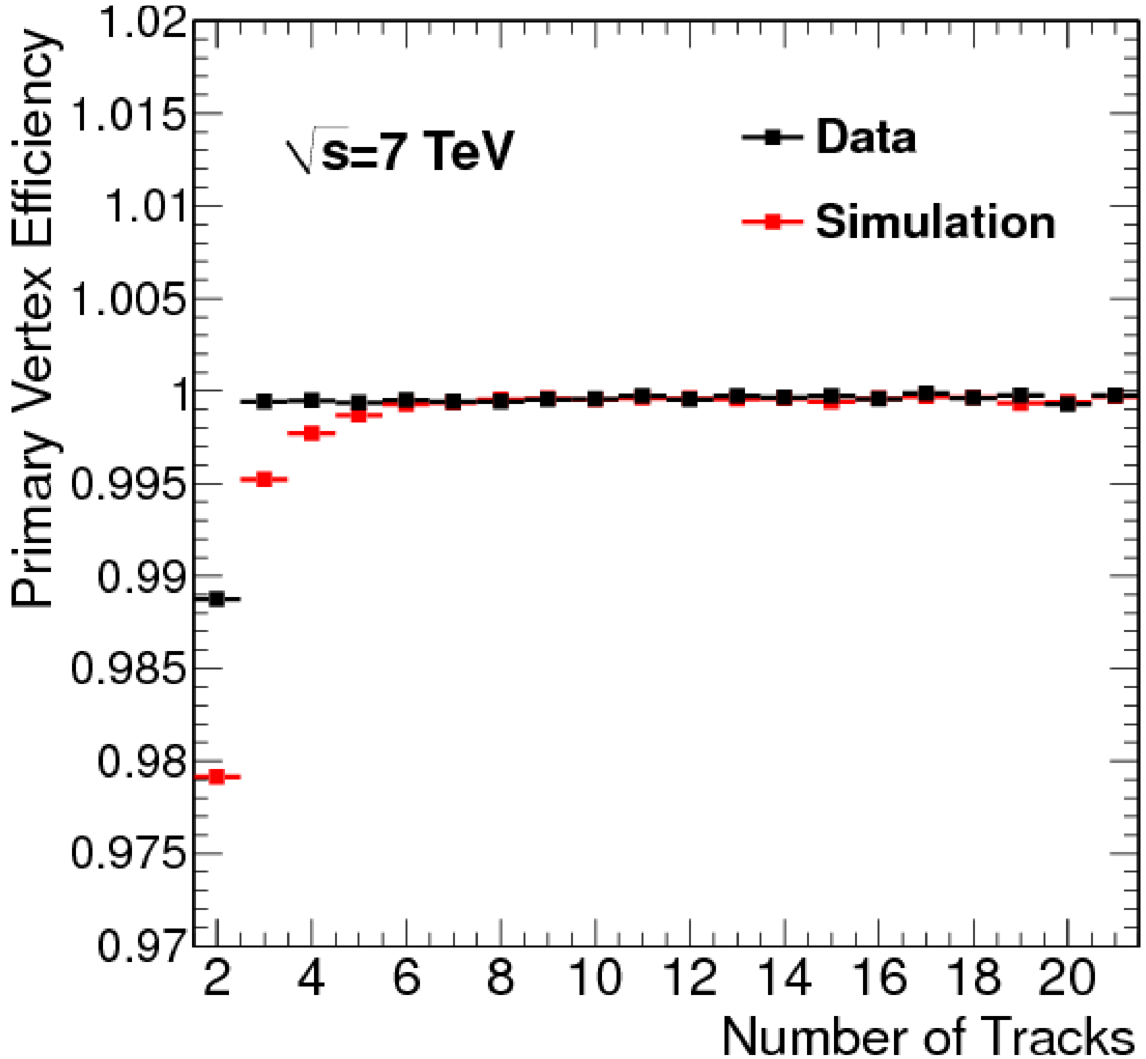
$$p_{ik} = \frac{\rho_k \exp\left[-\frac{1}{T}\frac{(z_i^T - z_k^V)^2}{\sigma_i^2}\right]}{\sum_{k'} \rho_{k'} \exp\left[-\frac{1}{T}\frac{(z_i^T - z_{k'}^V)^2}{\sigma_i^2}\right]}$$

0.0<|eta|<0.9 barrel

0.9<|eta|<1.4 transition

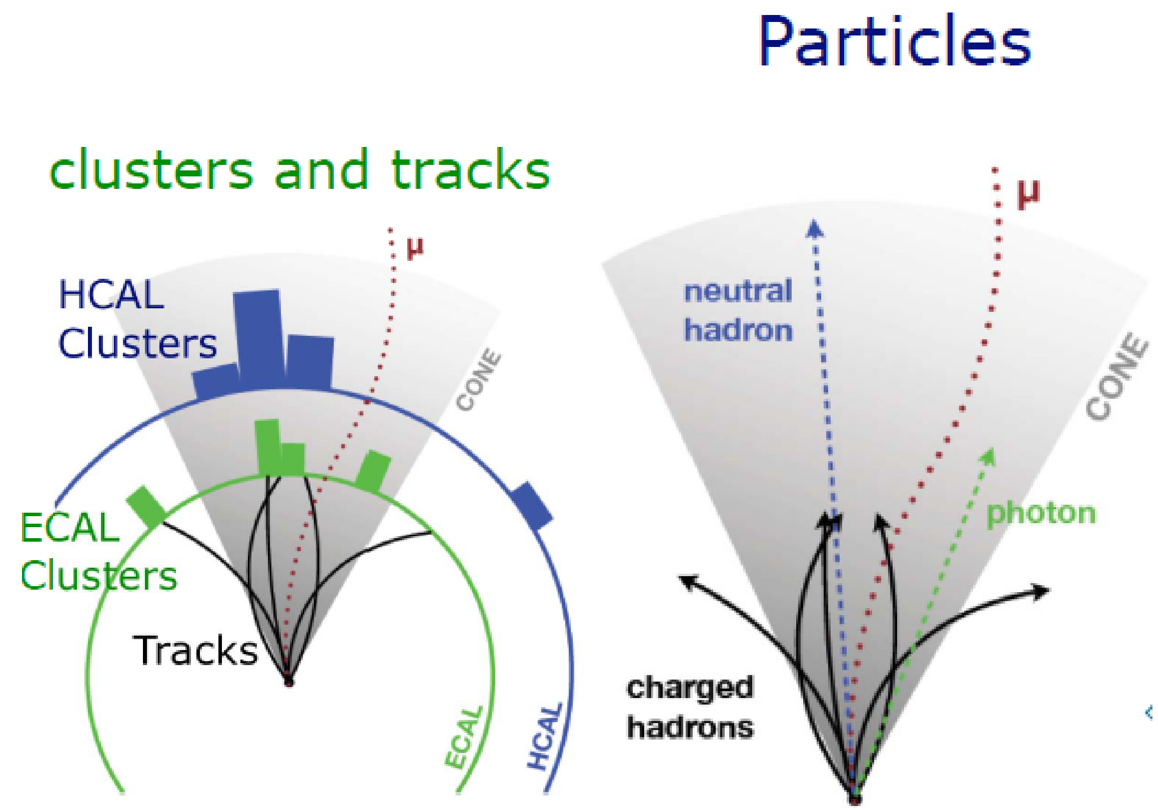
1.4<|eta|<2.5 endcap

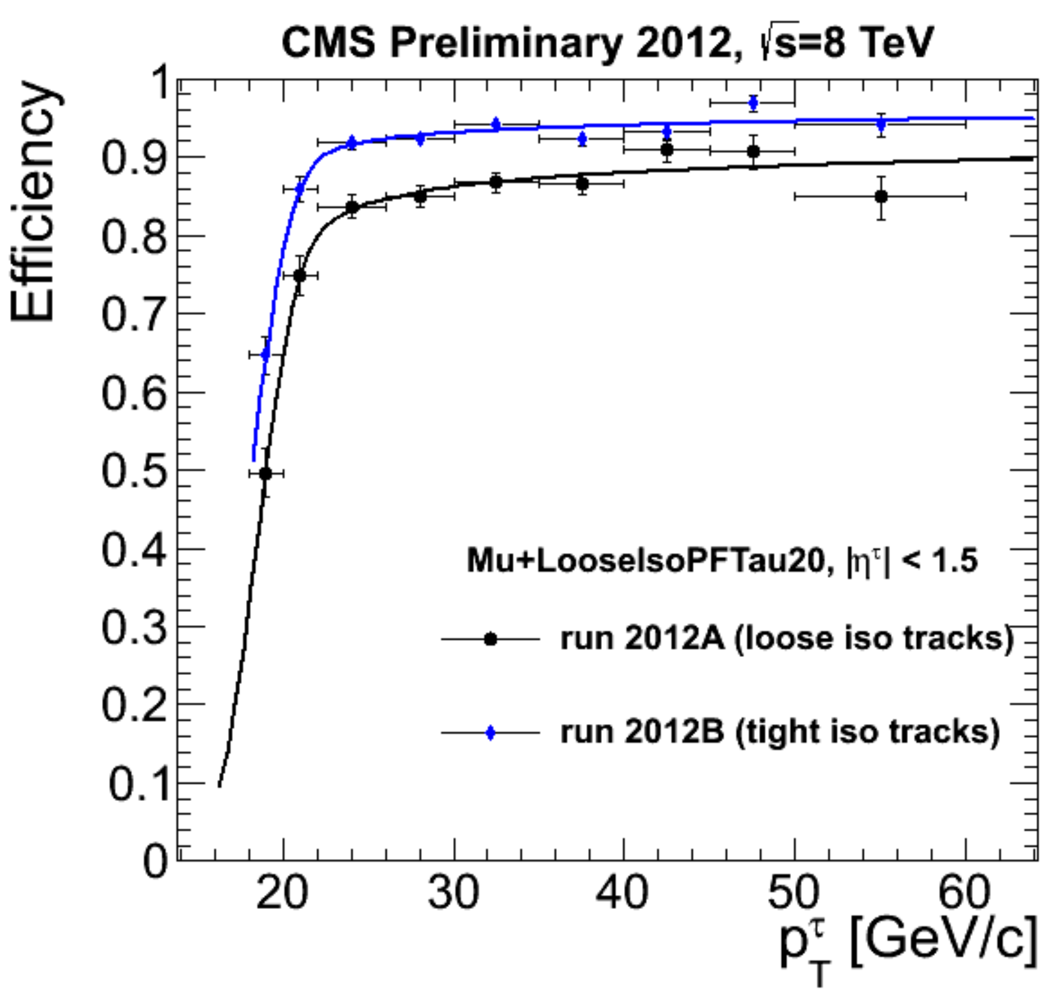
Efficiency measured with a TnP techinique

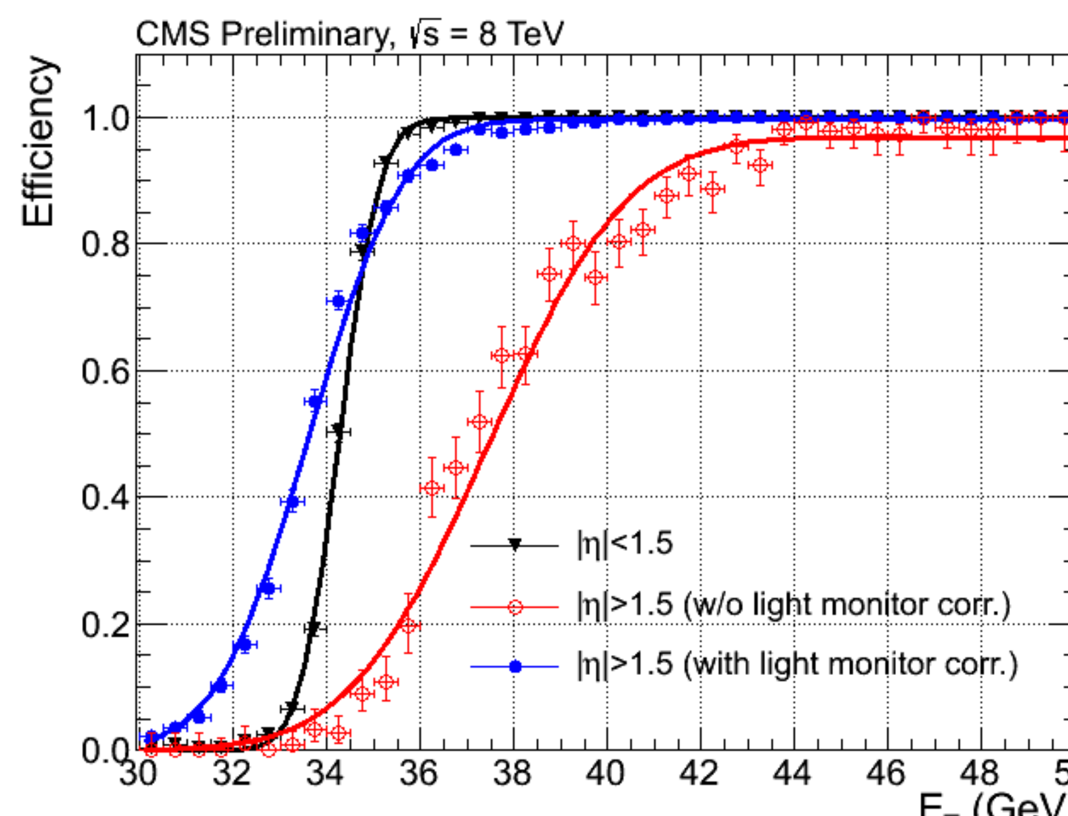


Backup

Particle Flow: *a reduced number of steps is run and the pT cuts on tracks are tightened. Use of isolation improves dramatically tau turn on curves.*

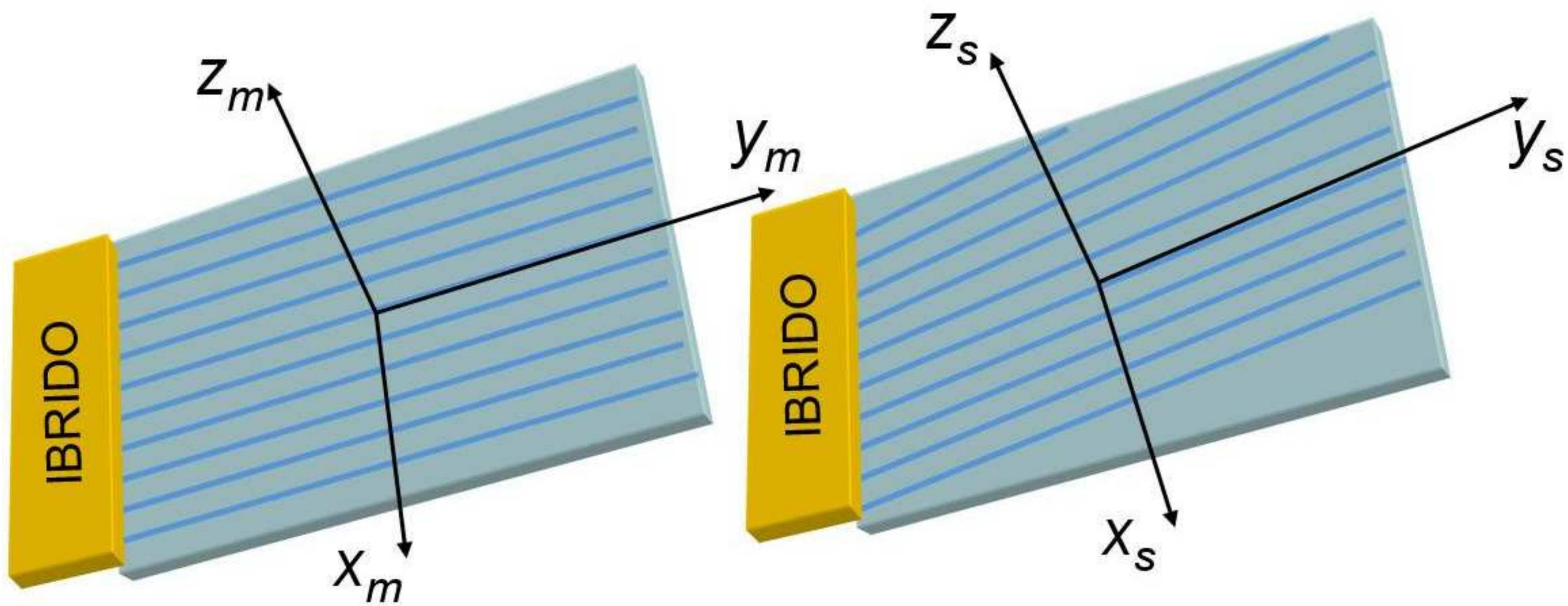






Backup

Double sided modules



collision rate

Transition region

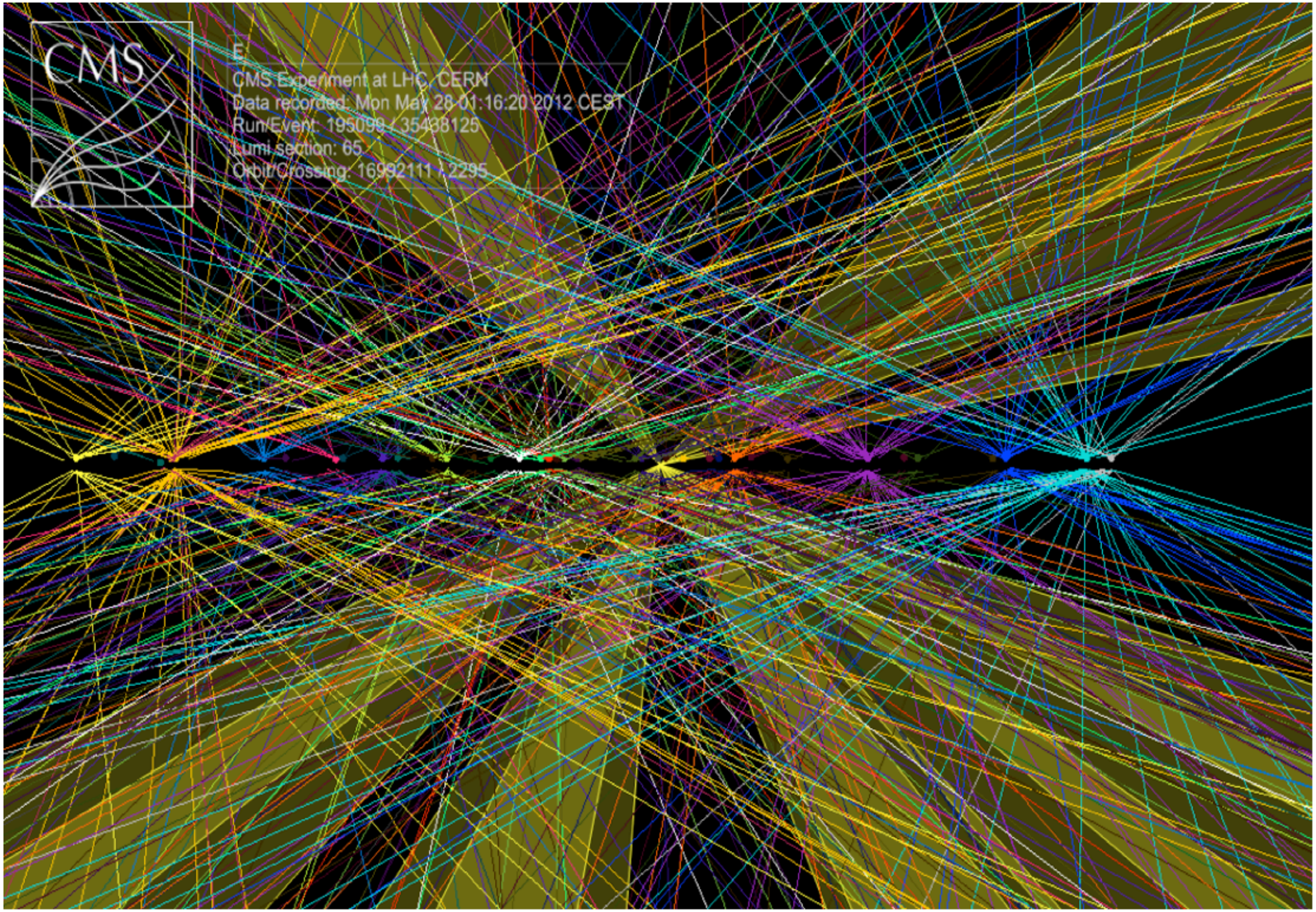
Backup

0.0<|eta|<0.9 barrel

0.9<|eta|<1.4 transition

1.4<|eta|<2.5 endcap

Backup


CMS
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295