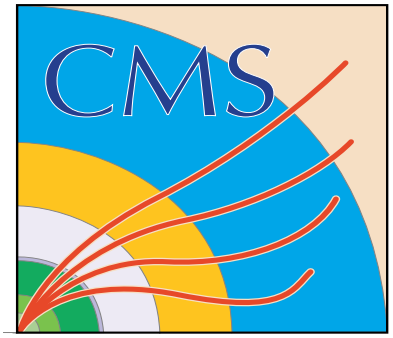
CMS Tracking Detector

LHCC

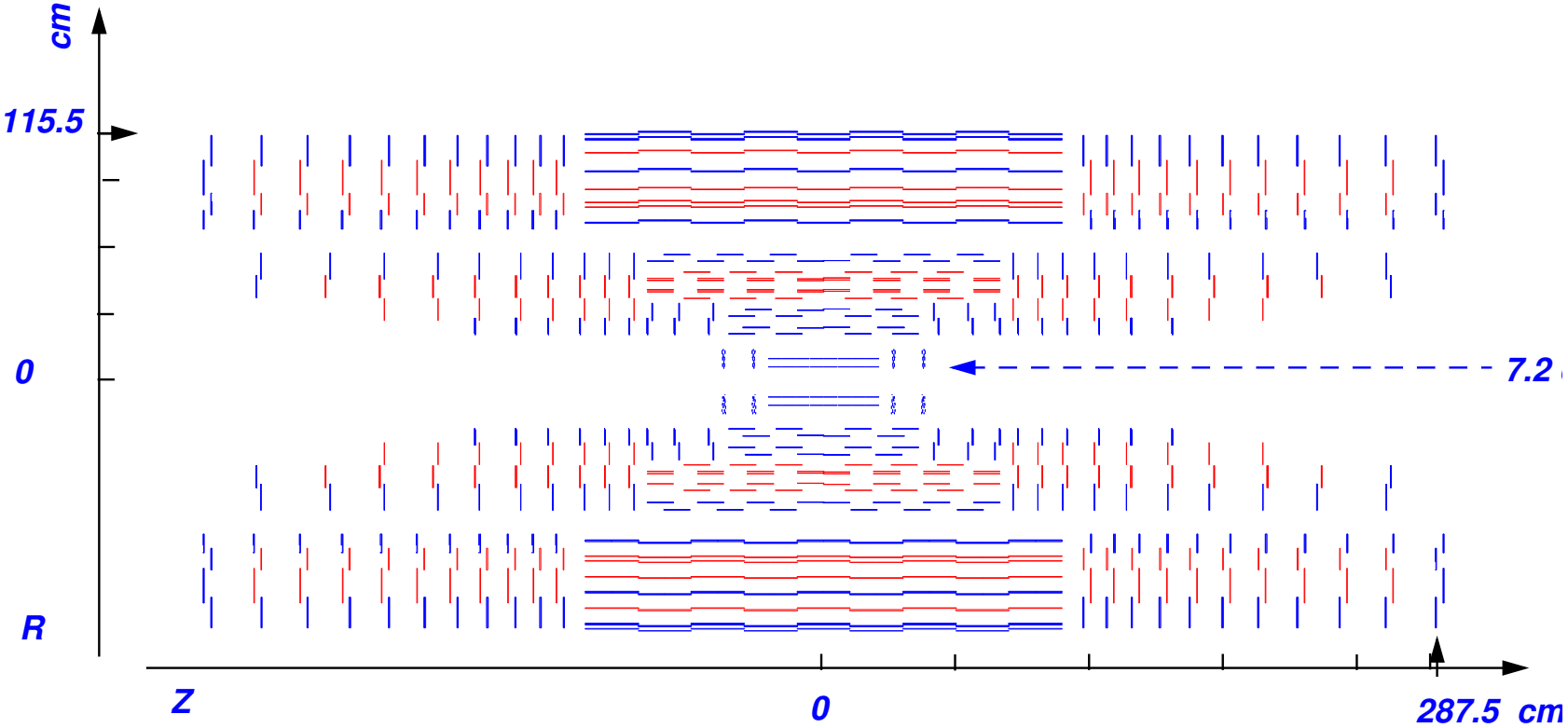
7th May, 1998



- ***Tracker Layout***
- ***Material Budget***
- ***Simulated Performance***

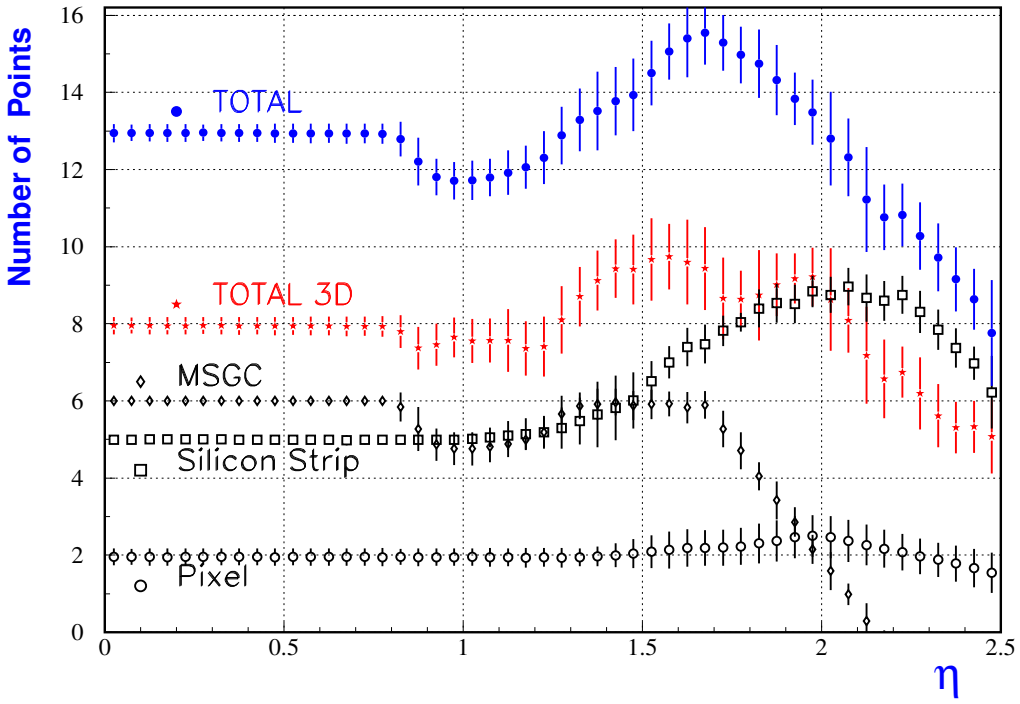
Alessandra Caner - CERN

CMS PHASE II Tracker Layout



	Channels ($\times 10^6$)	*R-ϕ pitch* (μm)	*Stero pitch* (μm)
Pixels	*32.8*	*150×150*	
Silicon strips	*5.2*	*62/83/125*	*125/250*
MSGC	*6.6*	*200*	*400*

Geometrical Acceptance



Barrel Tracker

* Barrels fully hermetic in R-ϕ.
* 13 points at $|\eta| < 0.8$, 8 of which are space points (3D).
* z-overlaps optimised in strip barrel detectors, 2.5 % gaps in Pixel barrel.
* ~7 % reduction of silicon and improved hit z-resolution by the introduction of silicon mini-endcaps.

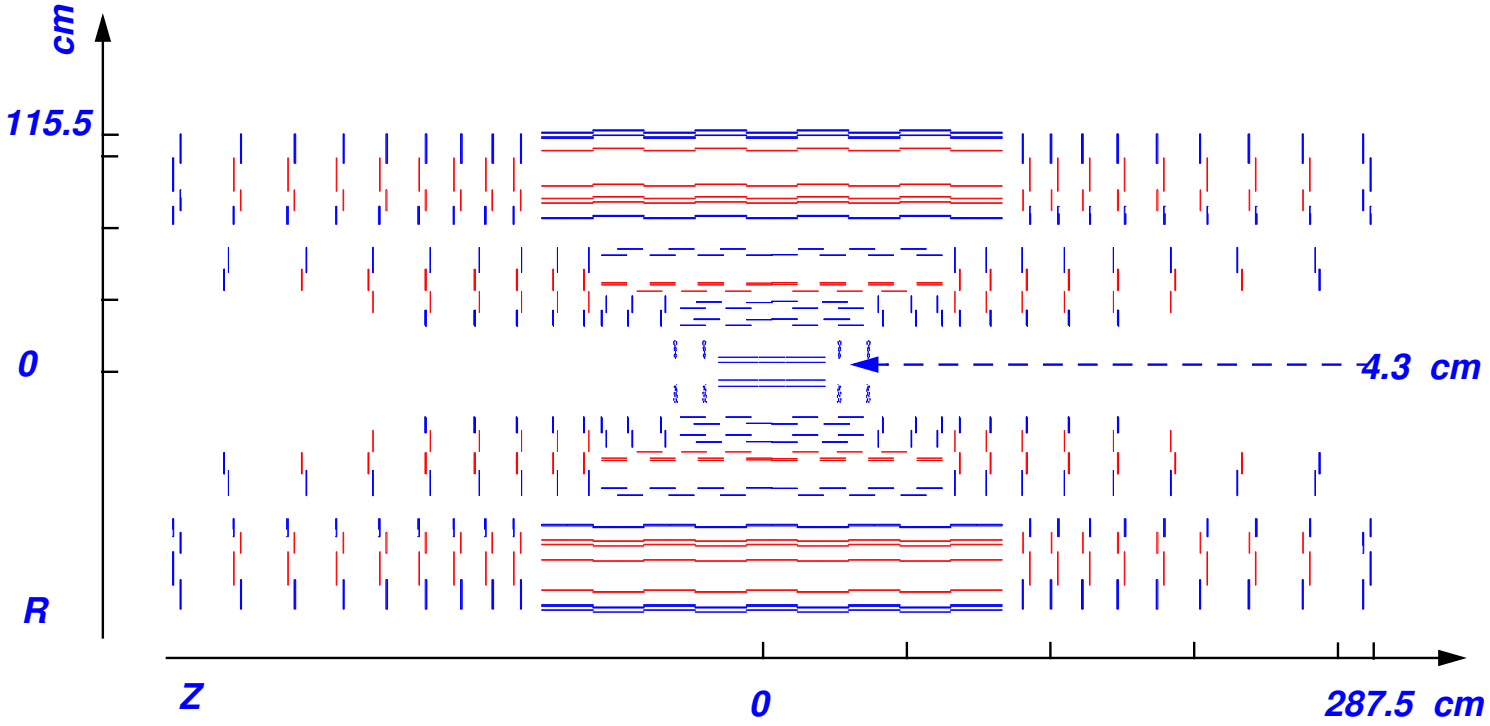
Barrel-Endcap gaps

* Barrel-Endcap gaps are staggered in pseudorapidity.
* Readout hybrids are installed so to maximise the $|\eta|$ coverage of the detectors and minimise the gaps in the Tracker.

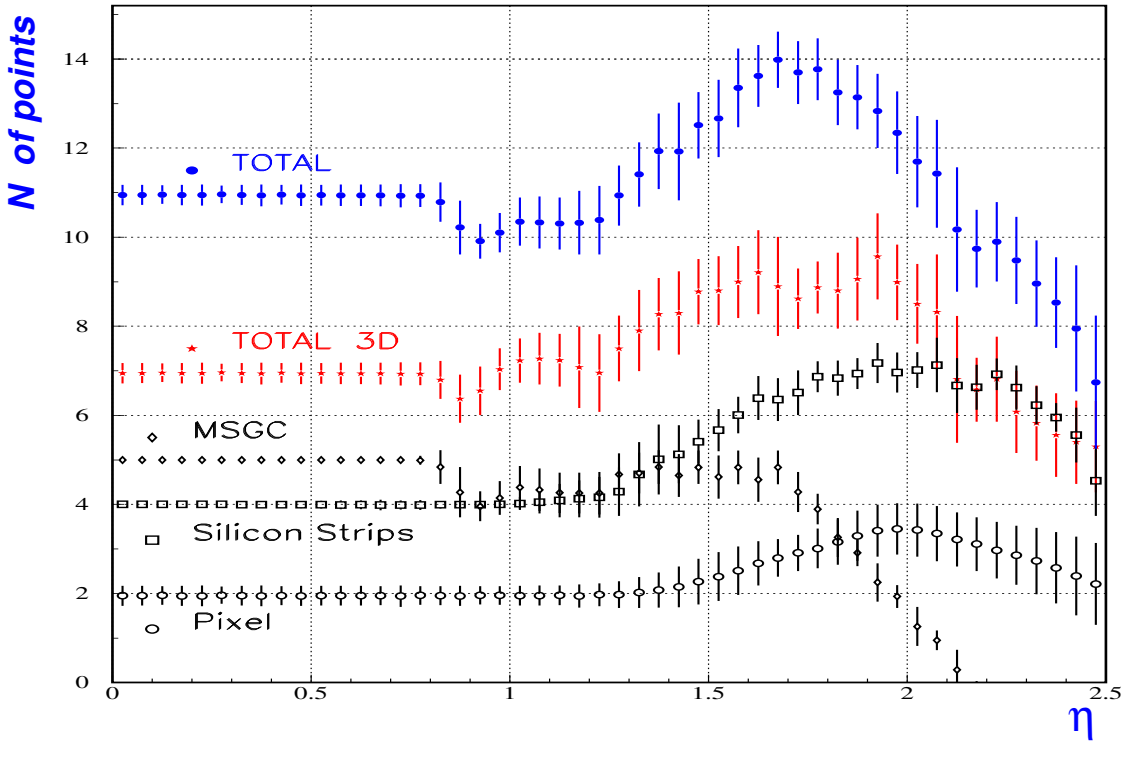
Endcap Tracker

* More than 13 points up to $|\eta| = 2$.
* > 60 % of the points are 3D .
* Each track traversing the Endcaps has 3D hits at the entrance end exit points of the Silicon and MSGC tracking detectors.

CMS Phase I Tracker Layout



Number of readout channels reduced by ~20 % in Silicon and MSGC detectors. The inner Pixel barrel layer is set at 4.3 cm and the number of readout channels is reduced by ~30 %.



Tracker Simulation

The Tracker simulation software relies on the GEANT package to generate physics processes and to transport tracks through the detector.

The geometry model precision is rather good. The granularity of the layout description can be expressed by the total number of volumes used, ~ 94000 vs. the ~20000 actual sensitive modules. The material description is very accurate and consistent with the present hardware knowledge and targets.

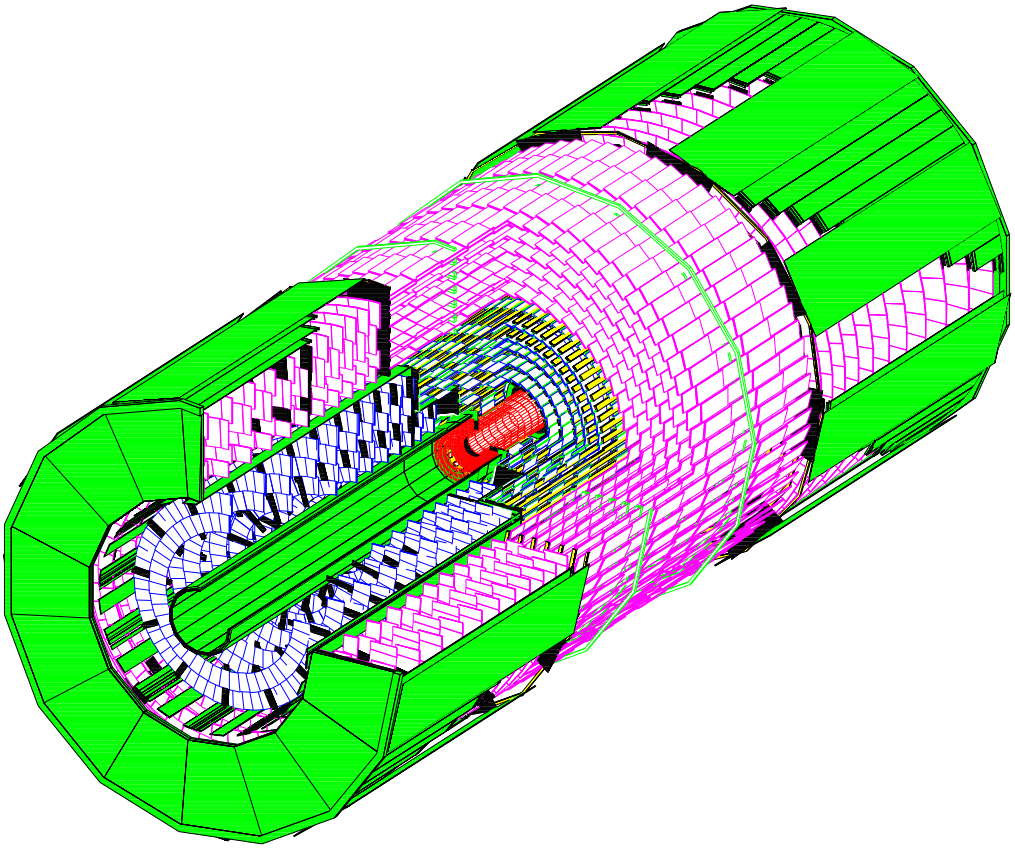
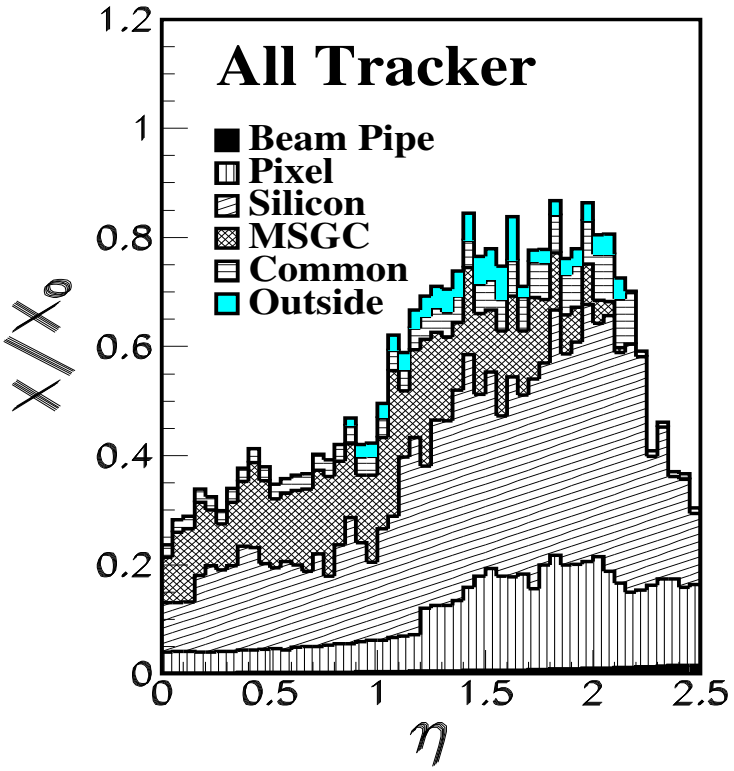


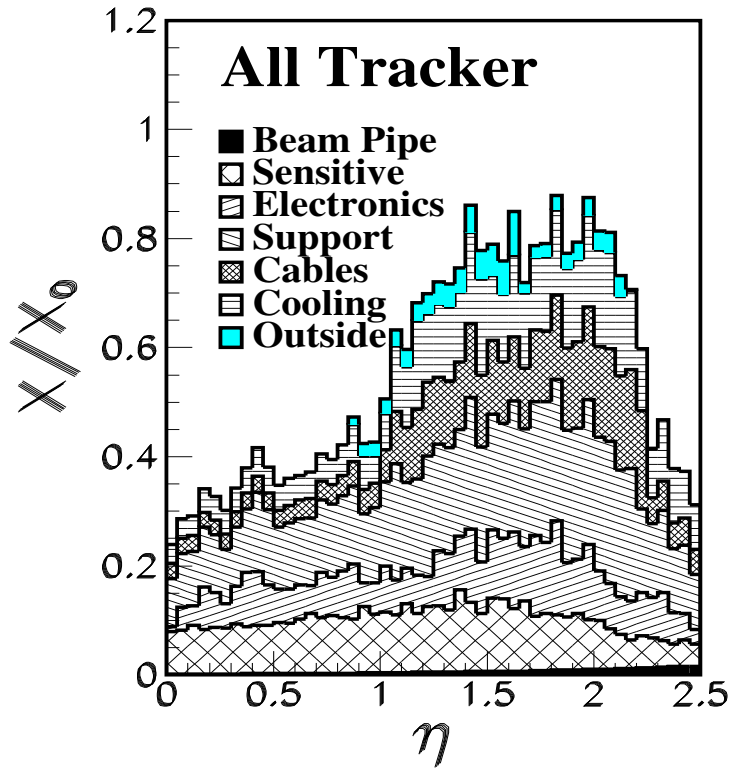
Table 0.1: Readout and high voltage hybrid description for a barrel MSGC detector.

Component	Quantity	x (mm)	y (mm)	z (mm)	Material	X/X_0 (%)
Hybrid	1	64.0	0.15	28.0	Kapton	0.05
	1	64.0	0.15	28.0	Aluminium	0.17
APVs	4 (n)	6.35	0.35	12.0	Silicon	0.02
LV filter	2*n+5	3.2	1.6	1.2	Alumina	
		0.2	1.6	1.2	Ni/Ag/Sn	0.03
Termination	8	3.2	1.6	1.2	Carbon	
Resistors	8	0.2	1.6	1.2	Ni/Ag/Sn	0.01
MUX	1	2.5	0.35	2.5	Silicon	5.0E-4
PLL	1	2.5	0.35	2.5	Silicon	5.0E-4
LVDS	1	2.5	0.35	2.5	Silicon	5.0E-4
Pitch Adaptor	1	60.0	0.5	7.0	Silica	0.07
Connector	2.	23.0	2.2	5.0	Kapton	
	2.	22.3	1.0	1.0	Copper	0.10
Laser Driver	1	0.25	0.35	2.5	Silicon	5.0E-4
Laser array	1	10.0	2.0	15.0	Alumina	
	1	10.0	0.5	15.0	Silicon	
	28	0.25	5.0	0.45	Copper	0.12
HV Switches	1 (16 sw.)	5.0	0.4	2.0	GaAs	
	1	5.0	1.6	2.0	PEEK	2.7E-3
Switch driver	1	2.5	0.35	10.	Silicon	1.9E-3
Resistors	33	3.2	1.6	1.2	Carbon	
	33	0.2	1.6	1.2	Ni/Ag/Sn	0.05
Total						0.64

Radiation Length

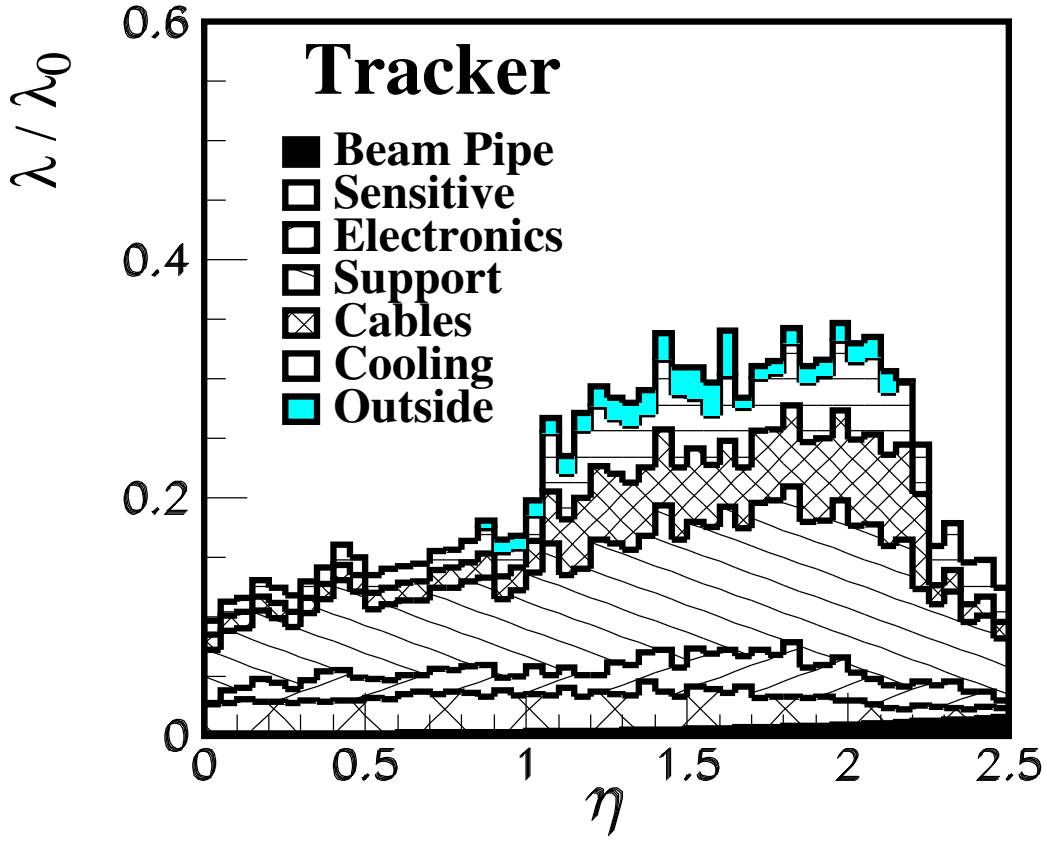
PHASE II Tracker Layout





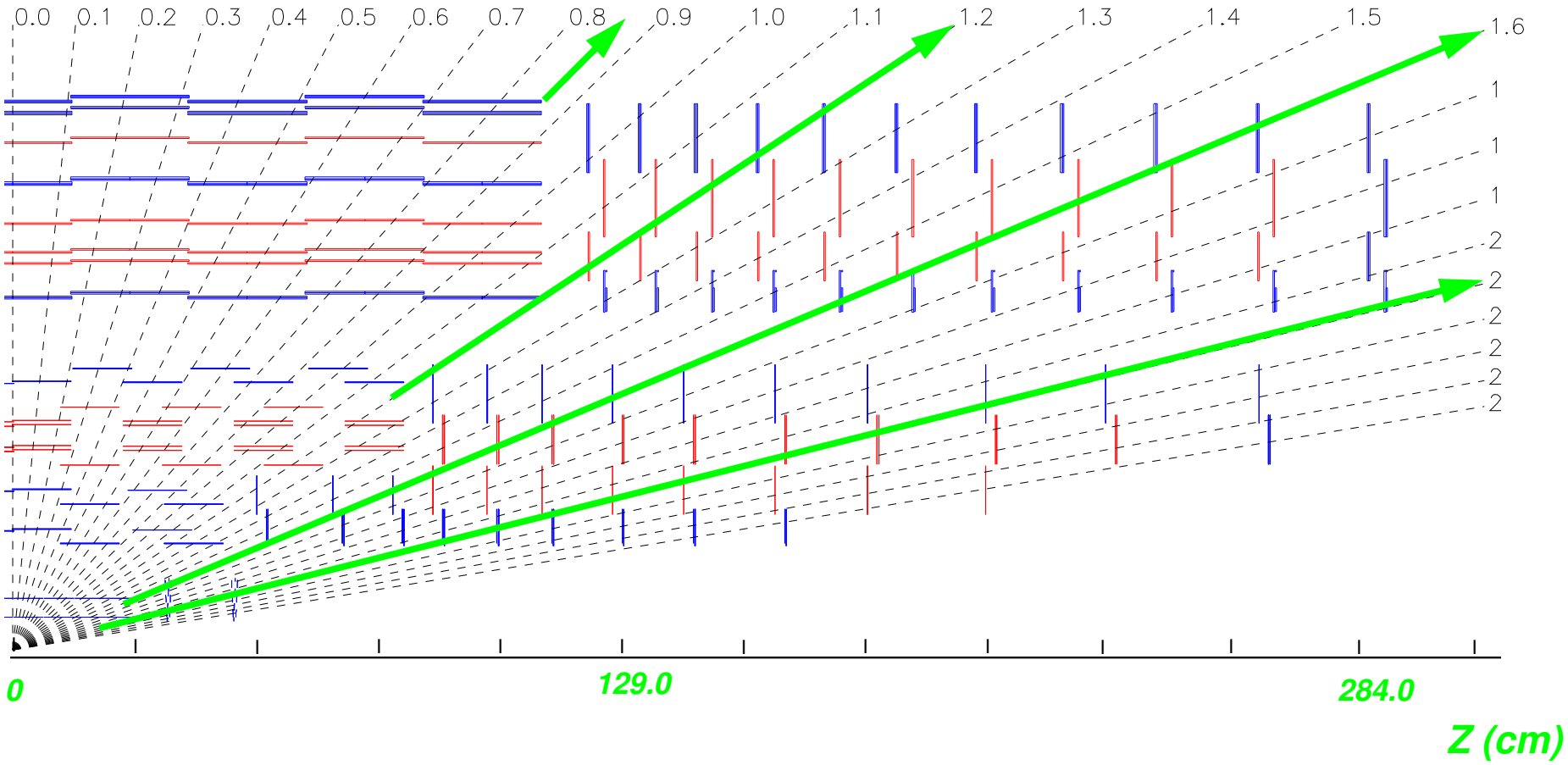
Interaction Length

PHASE II Tracker Layout



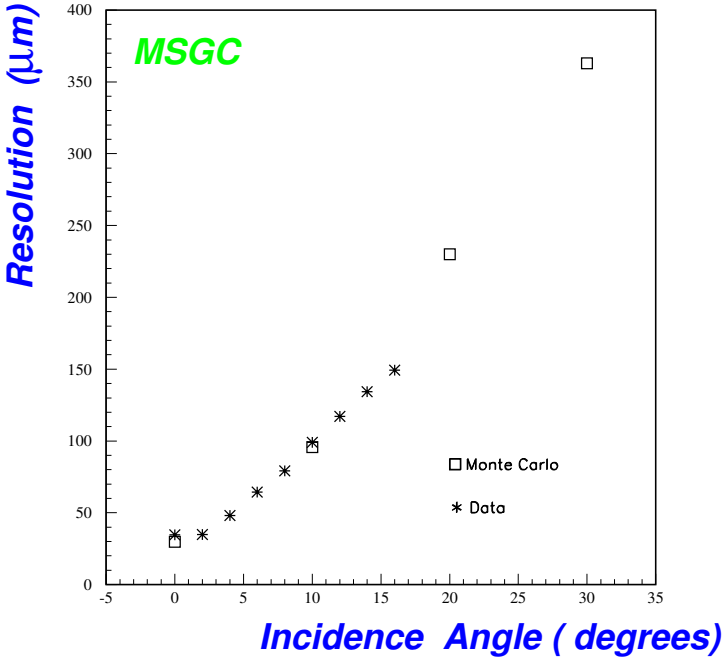
The fractional interaction length of the Tracker material is dominated by aluminium , carbon and silicon .

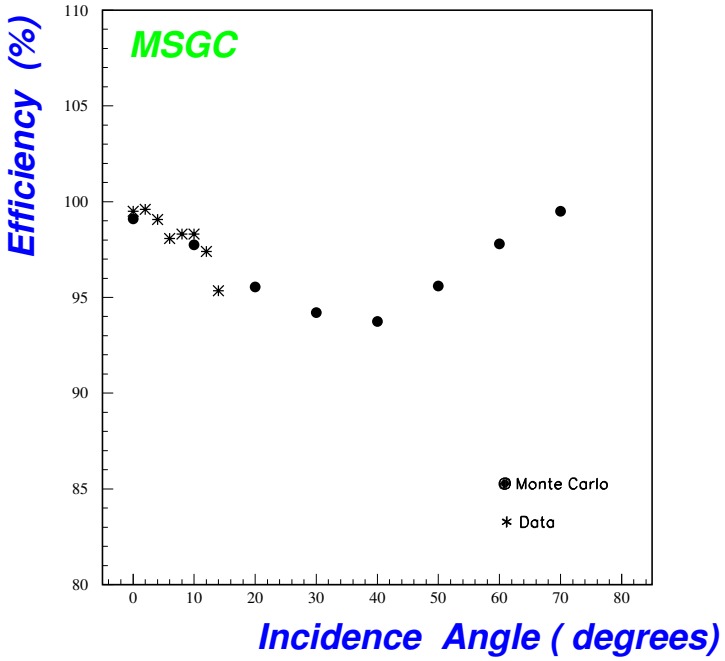
PHASE II Tracker Layout



Detector Simulation

The simulation of pixel and strip detector response makes use of GEANT propagation and effects, together with dedicated simulation packages handling charge amplification and diffusion in active volumes. The quality of the simulation model is checked against beam test data .





	S/N	"Dead strips"
Silicon Strip	10 - 12	1 %
MSGCs	20	2 %

S/N is the ratio of the total cluster charge to the noise of one strip

Track and Vertex Reconstruction

The track finding strategy for the CMS Tracker exploits a small number of high precision hits. The typical hit multiplicity at high luminosity conditions amounts to ~40000 clusters.

The combinatorics problem is solved by using a two step approach during the patter recognition phase. The first step of the procedures developed for the CMS Tracker involves the definition of a preselected search road. The hits contained in this road are subsequently analysed by Kalman filtering.

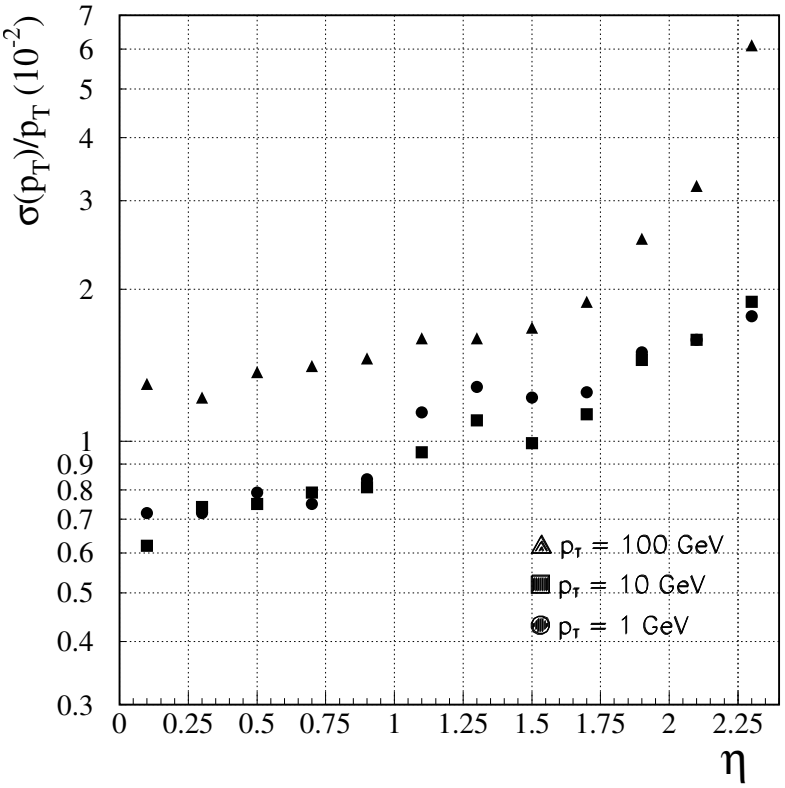
Presently, two backward and one forward propagation packages have been developed . The latter is especially suited to reconstruct short tracks and further work could lead to fast track finding algorithms.

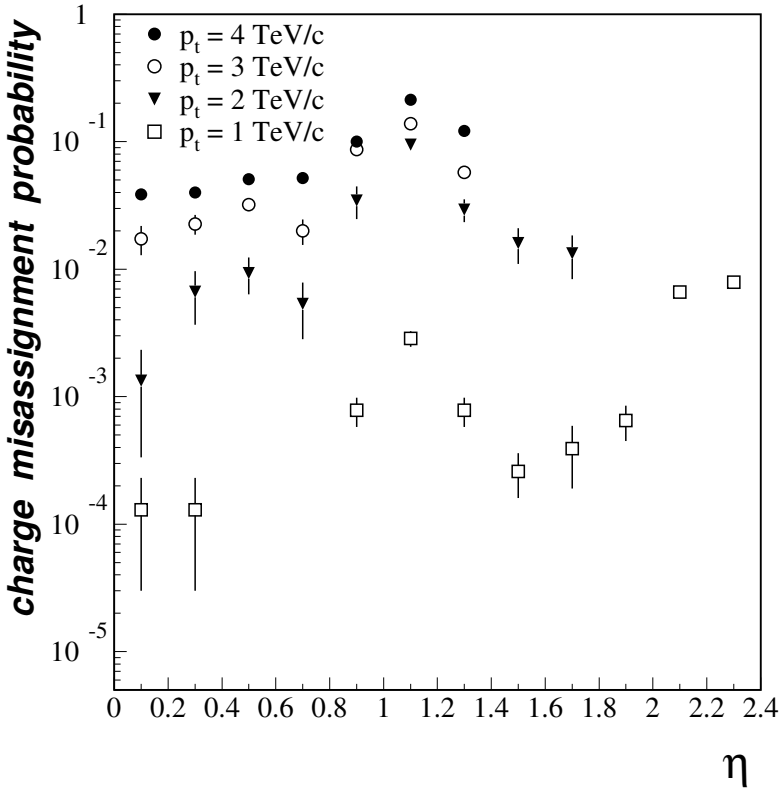
Reconstruction time / event for hard interaction @ high luminosity

p_T^{cut} (GeV/c)	GTF (s)	CM (s)	FKF (s)
2.0	146	80	17
0.9	670	390	37
0.5			55

Primary vertex finding relies on good track reconstruction and a relatively simple approach has been developed in CMS. A more complex and general approach is used to identify V_0 as well as heavy flavour vertices, at all luminosity conditions.

Momentum Resolution



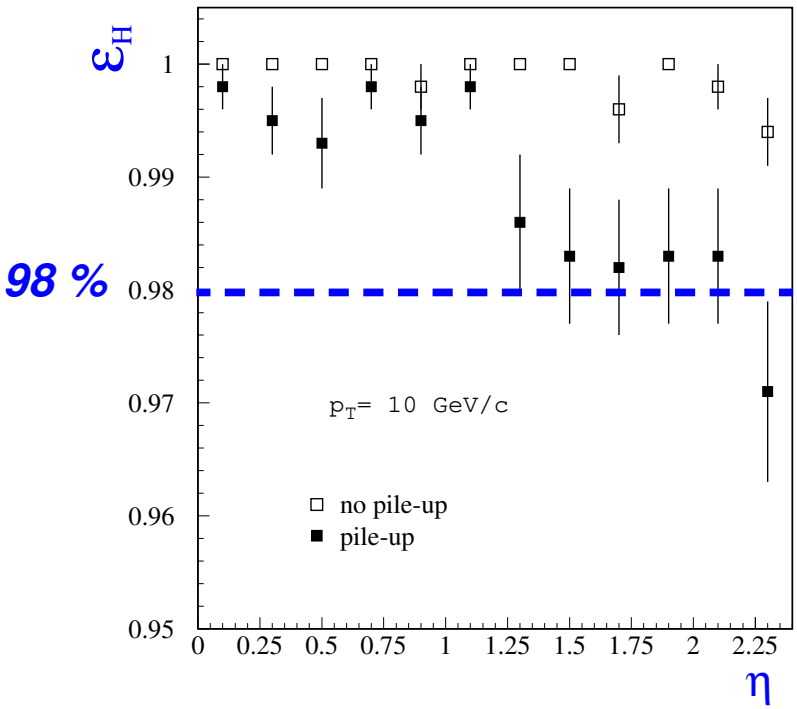


Isolated Muon Tracks

$$\varepsilon_H = \frac{\#\ \text{reconstructed associated tracks with} > 5\ \text{hits}}{\#\ \text{generated tracks}}$$

Associated tracks share more than 50 % of the hits with their parent helix .

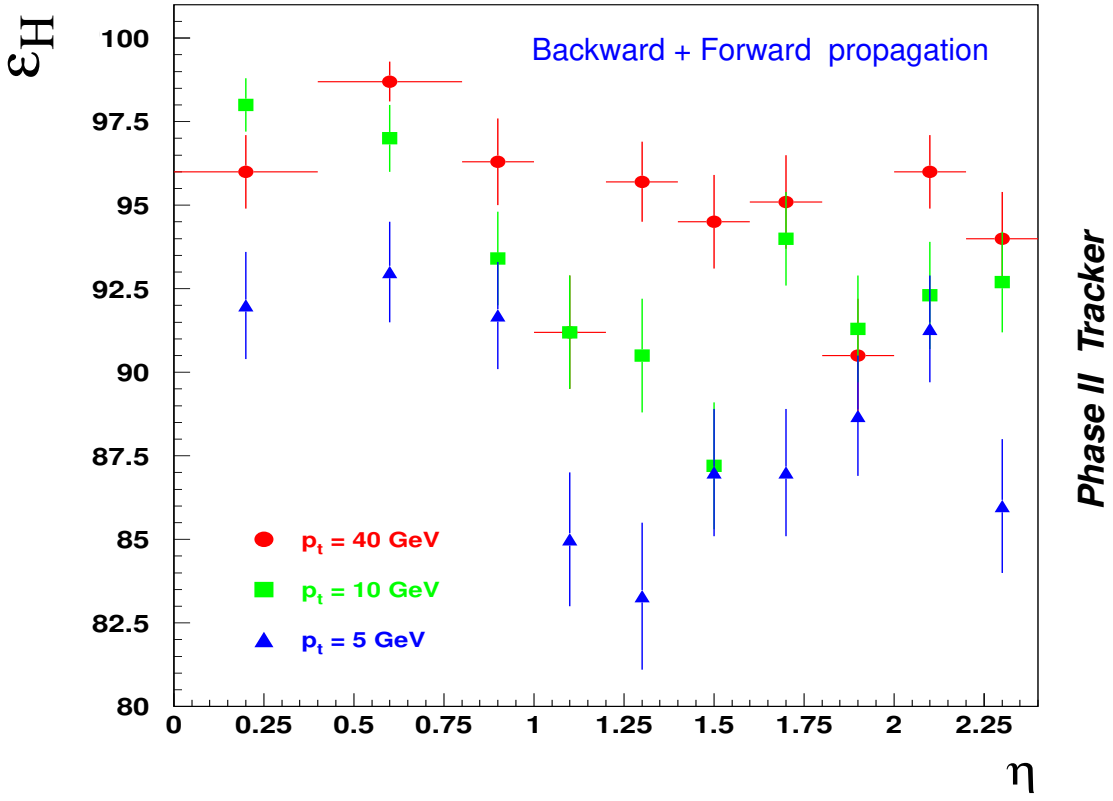
Phase II @ High Luminosity



High luminosity events are generated overlapping 24 minimum bias events in Silicon detectors and 48 in MSGC detectors. Each event is propagated for 500 ns.

Isolated Electron Track

Electrons traversing the Tracker lose energy by bremsstrahlung. On average, the fraction of radiated energy is approximately ~20 % at small η and it increases up to 55 % in the interval 1.2 < |η| <2.2.

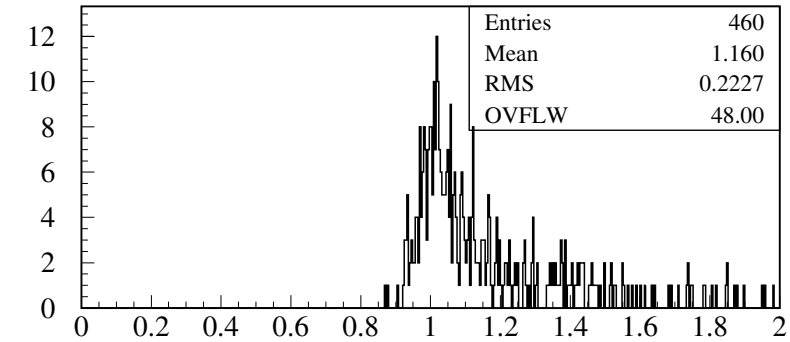


$$\varepsilon_H = \frac{\#\ \text{reconstructed associated tracks with} > 5\ \text{hits}}{\#\ \text{generated primary tracks}}$$

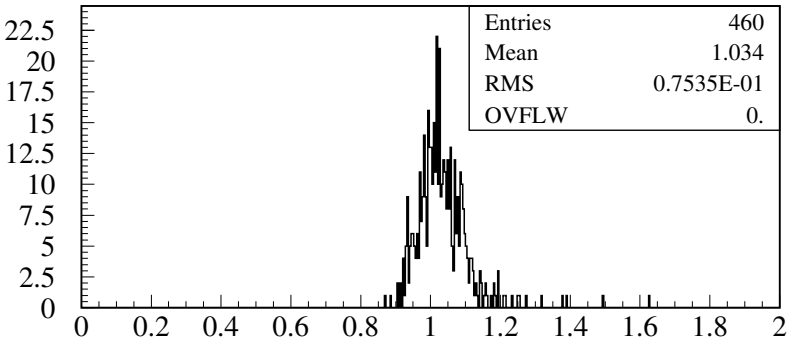
Associated tracks share more than 50 % of the hits with their parent helix.

Isolated Electron Track

The effect of radiation losses on the E/P ratio can also be recovered by bremsstrahlung recovery methods, using the Tracker and ECAL information.



Raw E/P distribution



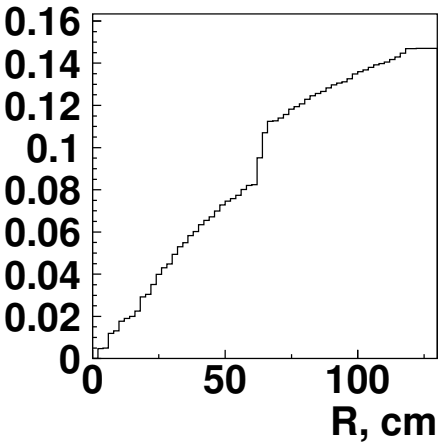
E/P distribution after brems recovery

E/ P

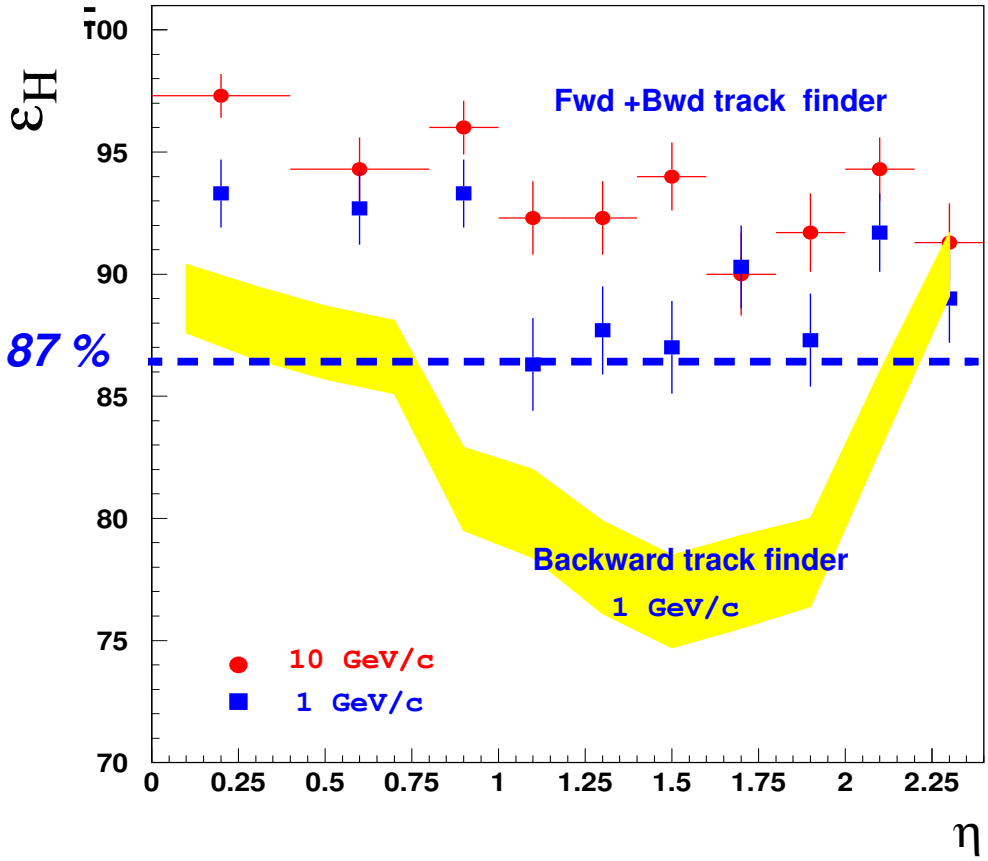
Electrons of p_T= 10 GeV/c in 1.26 < η < 1.35

p_T (GeV/c)	η	$\mathcal{F}_{brems}$ (%)	$\epsilon^{raw}_{E/p}$ (%)	$\epsilon^{corrected}_{E/p}$ (%)
10	0.17-0.26	25.6	82.8	98.0
10	1.26-1.35	50.0	64.1	97.6
40	0.17-0.26	25.1	85.6	94.8
40	1.26-1.35	51.0	67.4	88.6

Isolated Pion Tracks



Probability of π inelastic interaction in the Tracker, cumulative distribution , integrated in η.
Pions of p_T = 5 GeV/c.



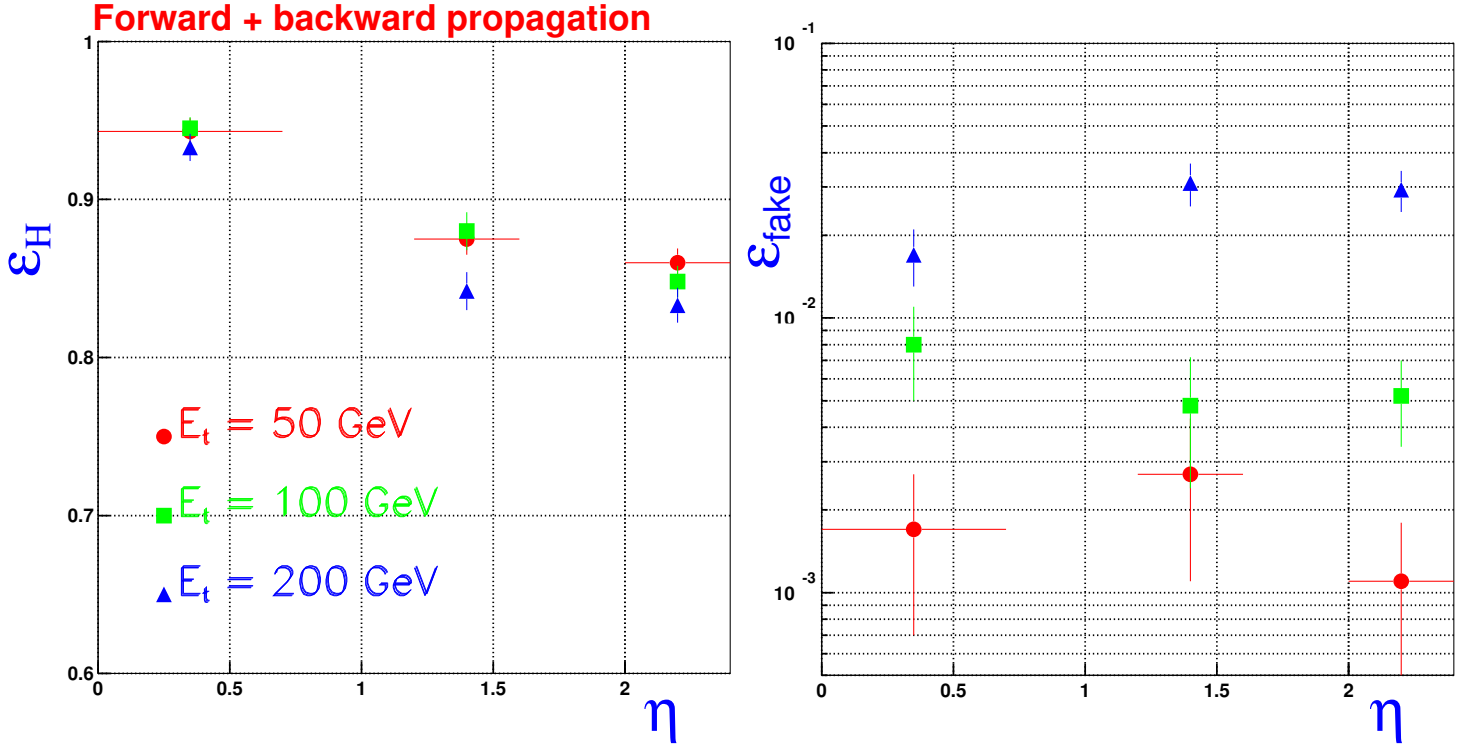
$$\varepsilon_H = \frac{\#\ \text{reconstructed associated tracks with} > 5\ \text{hits}}{\#\ \text{generated primary tracks}}$$

Associated tracks share more than 50 % of the hits with their parent helix .

Tracks in Jets

PHASE I Tracker Layout

Forward + backward propagation



$$\varepsilon_H = \frac{\#\ \text{reconstructed associated tracks with} > 5\ \text{hits}}{\#\ \text{generated tracks}}$$

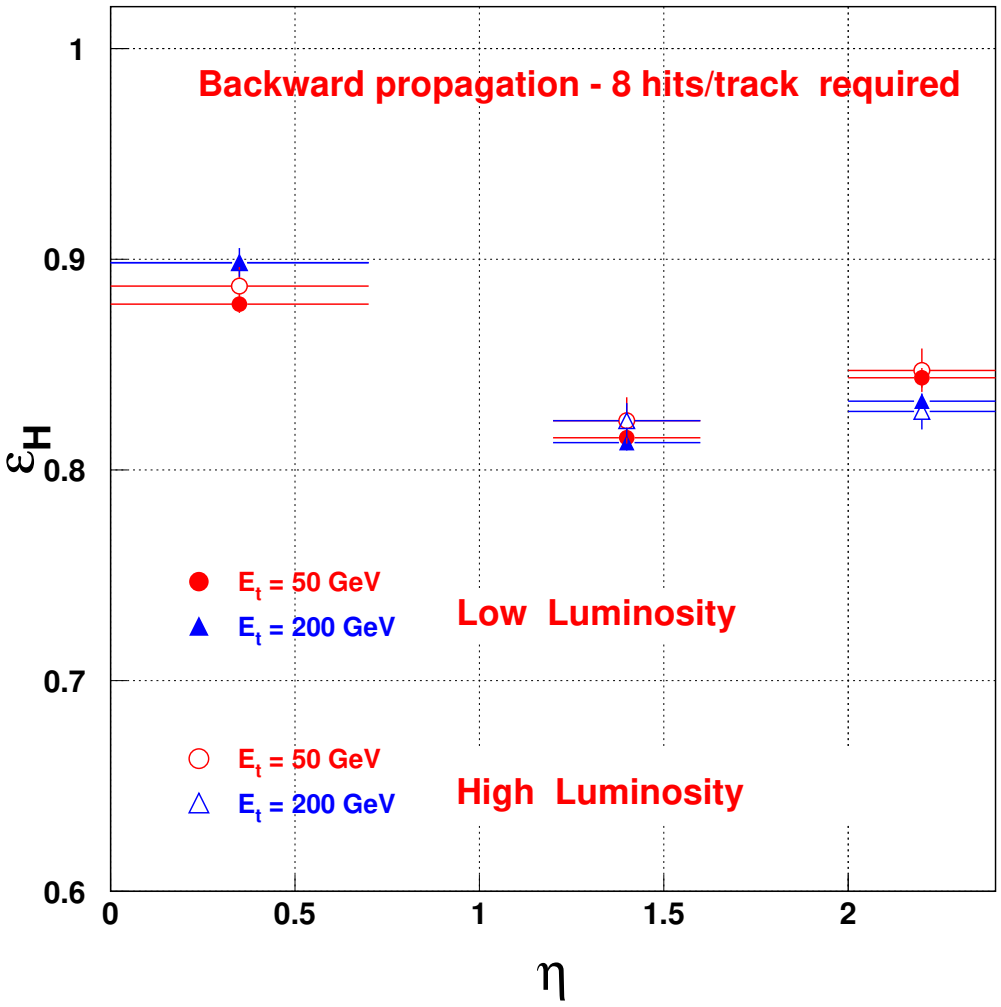
$$\varepsilon_{fake} = \frac{\#\ \text{reconstructed NON-associated tracks with} > 5\ \text{hit}}{\#\ \text{generated tracks}}$$

Associated tracks share more than 50 % of the hits with their parent helix .

The estimated tracking efficiency is consistent with the reconstruction performance evaluated for isolated hadrons.

Tracks in Jets

Phase II Tracker - Comparison Low vs. High Luminosity

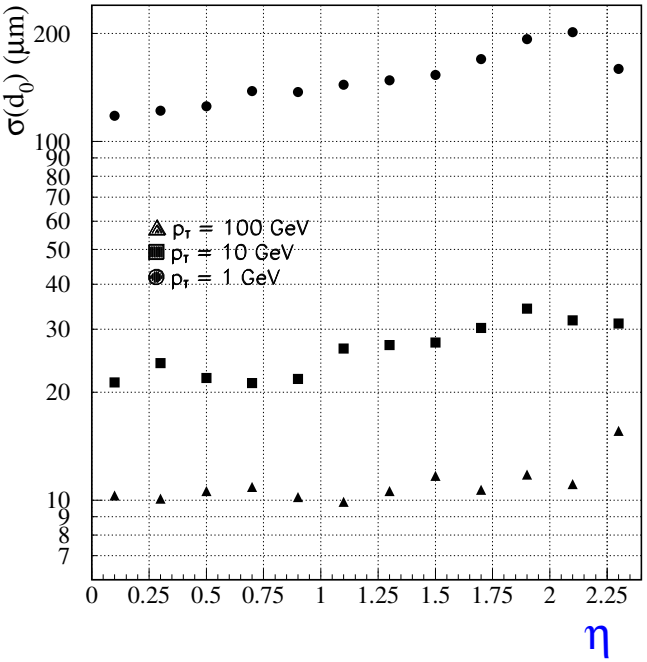


The track fake rates increases in this case by a factor 10, mainly contributed by tracks missing the Pixel detectors . The tracks efficiency is not altered by the high luminosity conditions.

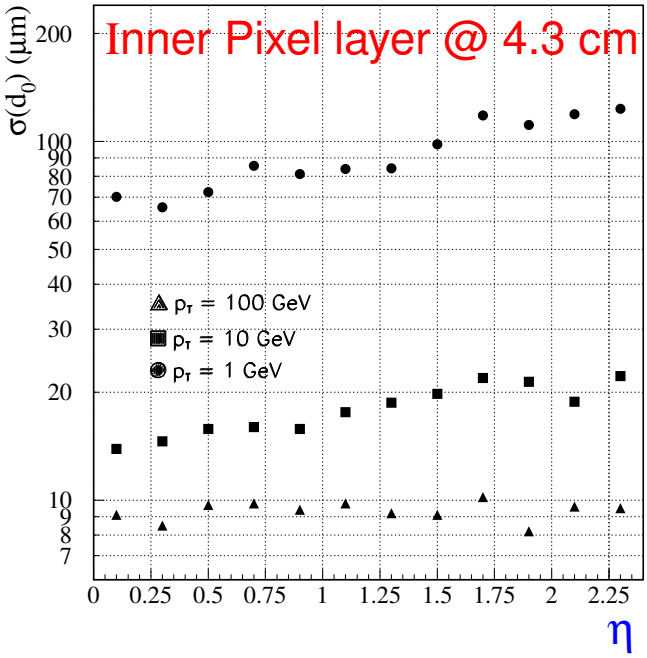
Impact Point Resolution

Transverse Impact Parameter

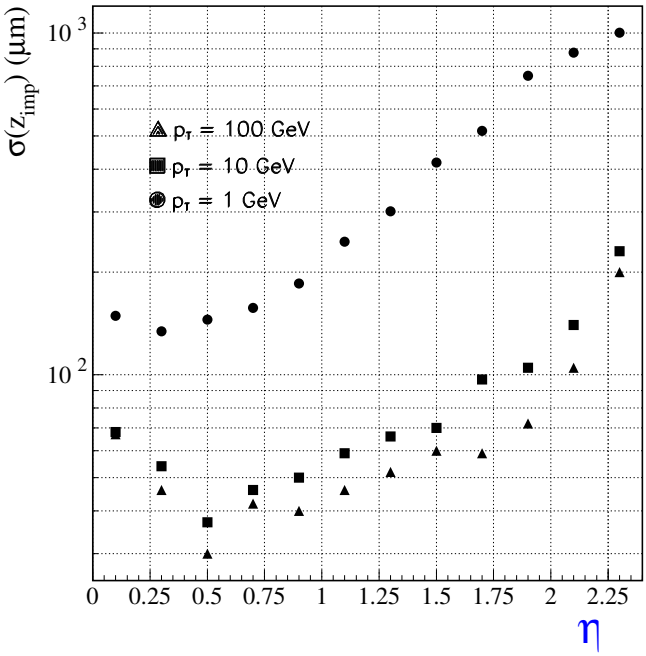
PHASE II

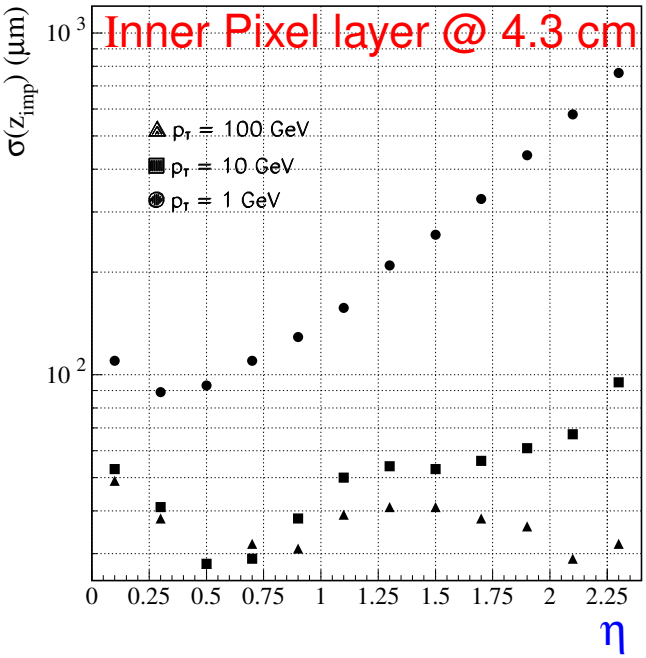


PHASE I



Impact Point z-coordinate





Tagging b-Jets

To identify b-jets CMS exploits the significance of the (signed) impact parameter as well as the reconstruction of secondary vertices.

IPV *requires 2 tracks with impact parameter significance 3. Tracks are rejected if they are associated to a primary or a V_0 vertex.*

SV *requires to reconstruct a secondary vertex with tracks that lie within the jet cone (b-tag). The vertex radius must have significance larger than 3.*

USV *measures the ultimate performance of the secondary vertex tagging. To this purpose, the list of secondary vertices generated during the event simulation is retrieved from the Montecarlo kinematics.*

A secondary vertex is selected for b-tagging if:

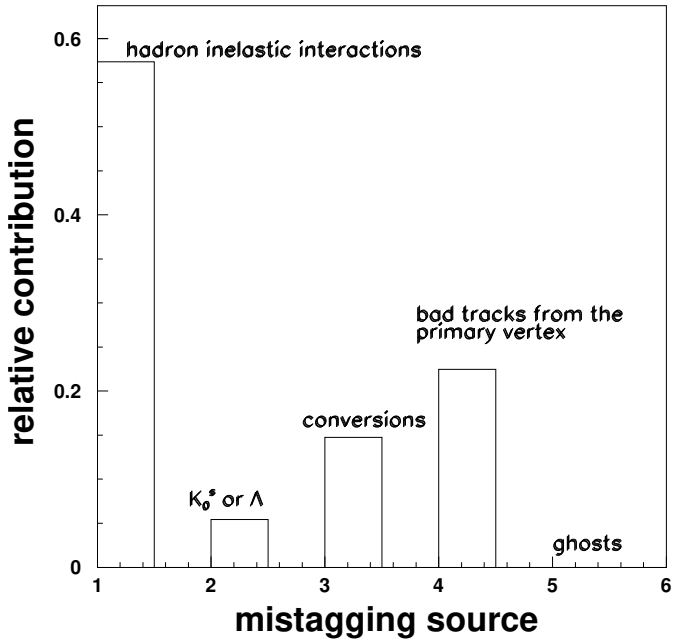
a) *it has at least 2 reconstructible associated tracks: pT>0.9, >5 hits , 2 in the Pixel detector.*

b) *the distance of the vertex from the beam line is >100 μm and less than 3 cm (pipe radius).*

c) *it is not a K_0 or a Λ vertex.*

Tagging b-Jets

analysis of fake tags

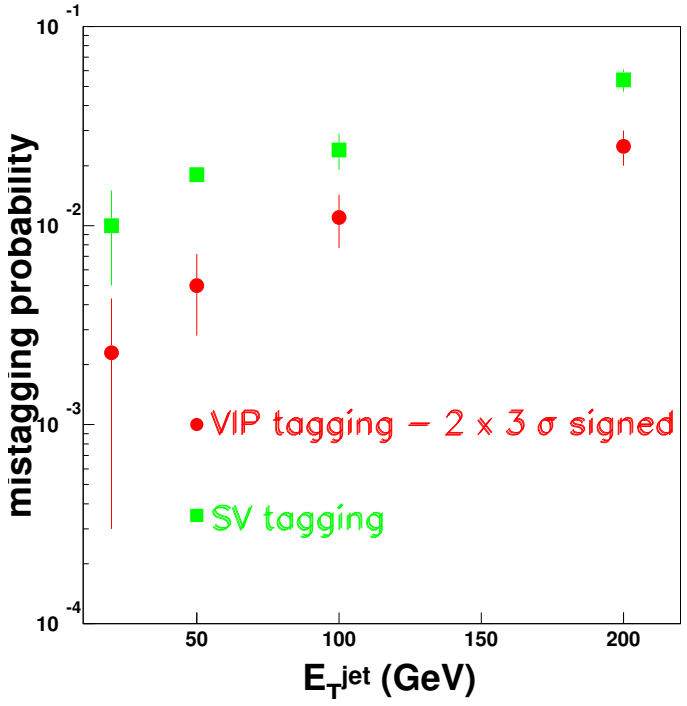


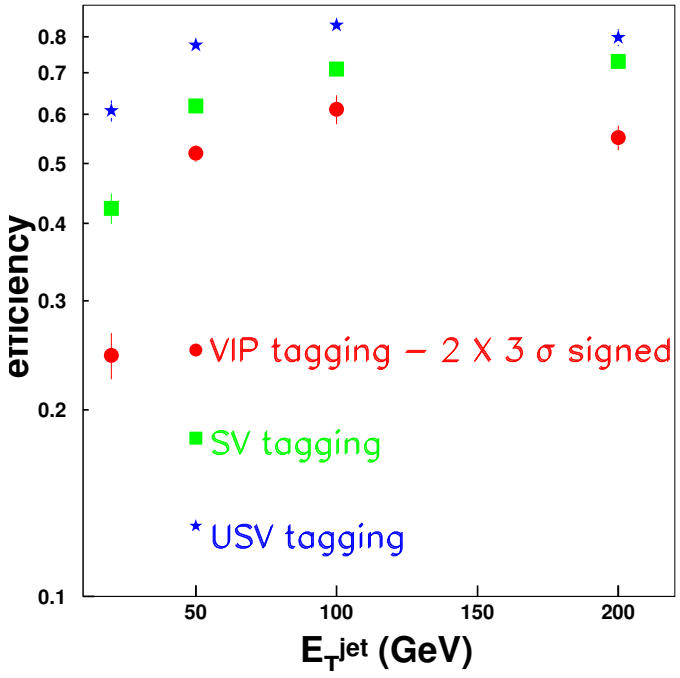
E_T=100 GeV jets

eff. = 62 %

mistag = 1.1 %

~ 78 % of the mistags is contributed by ' instrumental' background



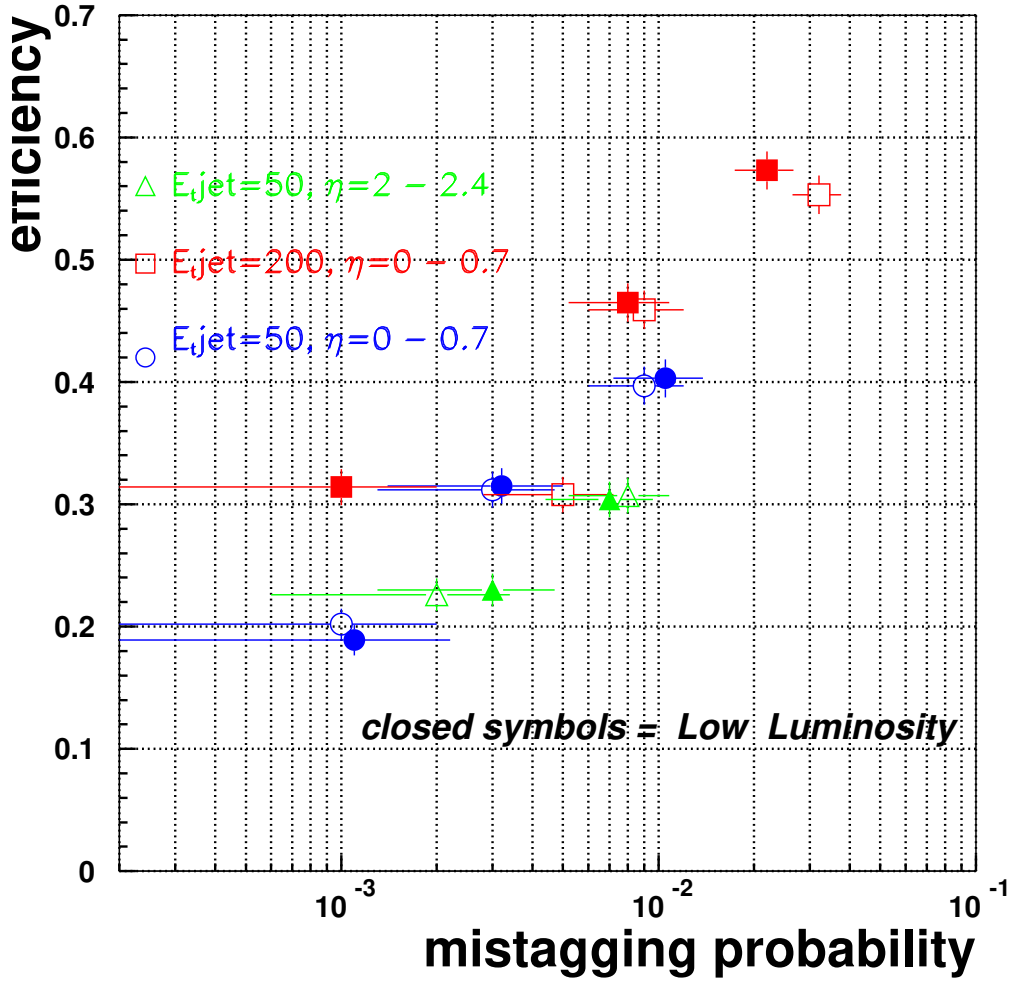


High b-tagging efficicency achievable with mistag-rate of a ~1%.

Substantial improvements underway by upgrade of the secondary vertex finder .

Tagging b-jets

Phase II Layout - Comparison Low vs. High Luminosity



Tracks are reconstructed with backward propagation algorithms and requiring at least 8 hits per track.

Tagging algorithms require N tracks with impact parameter significance S, N, S = 2 - 3.

The b-tagging efficiency and the mistagging rate observed at low and high luminosity are consistent.

Summary

- High p_T isolated tracks are reconstructed with a p_T resolution $\delta p_T / p_T \sim 15\% \times p_T$, gradually degrading to $\delta p_T / p_T \sim 60\% \times p_T$ due the decrease of lever arm (p_T in TeV/c) .

- Isolated muons are reconstructed with efficiency > 98 % at all luminosity conditions and in the whole Tracker range.

- High p_T electrons are reconstructed with efficiency >95 % and radiation losses can be recovered with good efficiency .

- Hadrons are reconstructed with efficiency > 87 % at p_T as low as 1 GeV/c and with efficiency approaching 95 % for 10 GeV/c .
  In the dense hit environment of jets the hadron reconstruction performance is unaltered , up to very high jet E_T values.

- The impact parameter resolution is better than 35 μm for p_T > 10 GeV/c tracks over the full η range. At low luminosity it will be possible to install the innermost Pixel layer closer to the beam line, resulting in a substantial improvement in impact parameter resolution.

- The Phase I Tracker gives good performance at low luminosity conditions even though a noticeable loss of tracking efficiency is observed at large η .

- In the central region we obtain a b-tagging efficiency better than 50 % for high p_T jets (50 - 200 GeV) , with a mistagging probability of about 1-2 %.
  In the endcap region the efficiency is ~10 % lower, at equal purity.
  The b-tagging performance is not affected by the high luminosity conditions and high efficiency is obtained by using very simple algorithms.