Performance of Track and Vertex Reconstruction and B-Tagging Studies with CMS in pp Collisions at sqrt(s)=7 TeV

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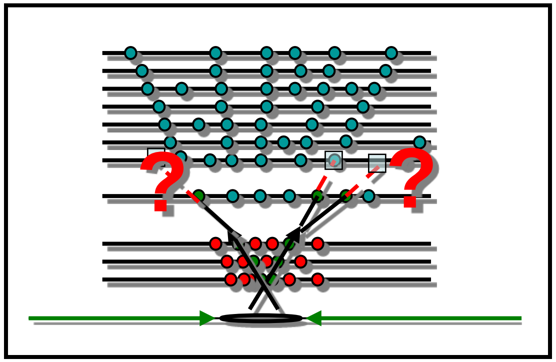
On behalf of the CMS collaboration

CMS Tracking in a nutshell

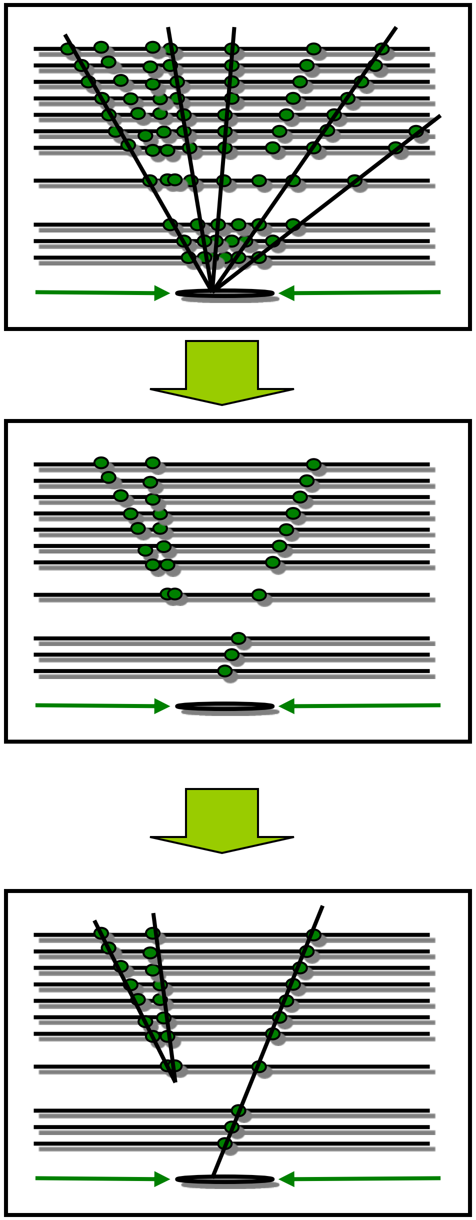


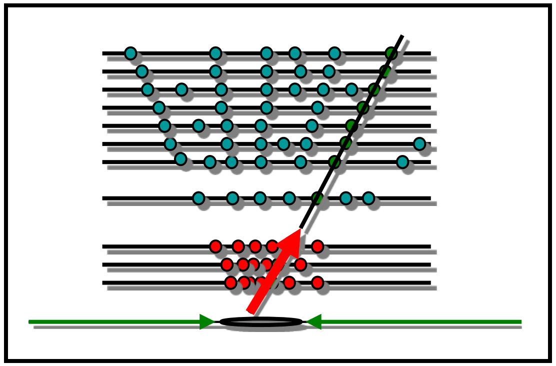
Seeding starts from innermost pixel layers.

Inside-out trajectory building

Iterative tracking
with hits-removal

(6 iterations like this)



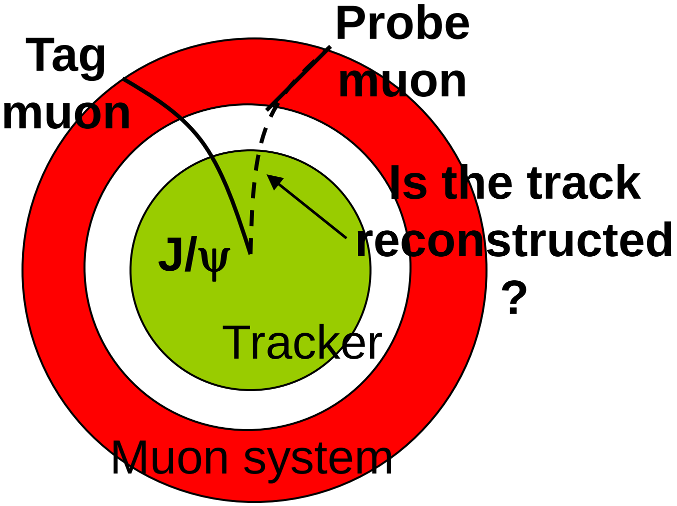


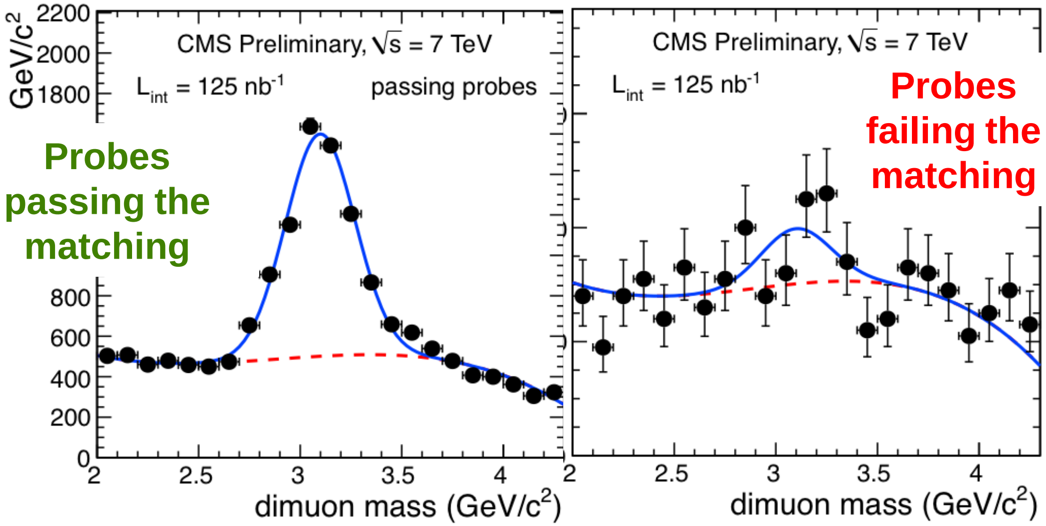
Final fit using **Kalman Filter/Smoother**.

Parameters propagated through magnetic field inhomogeneities using **Runge-Kutta propagator**

Track Parameters (q/p,eta,phi,dz,d0)

Tracking Efficiency for muons (from J/ψ)





Reconstruction efficiency in the Tracker is estimated from the ratio of the yields of probes that either pass or fail the matching with a Tracker track.

$$\boxed{\epsilon_{\mathrm{T}}\epsilon_{\mathrm{M}} = \frac{\epsilon - \epsilon_{\mathrm{F}}}{1 - \epsilon_{\mathrm{F}}}}$$

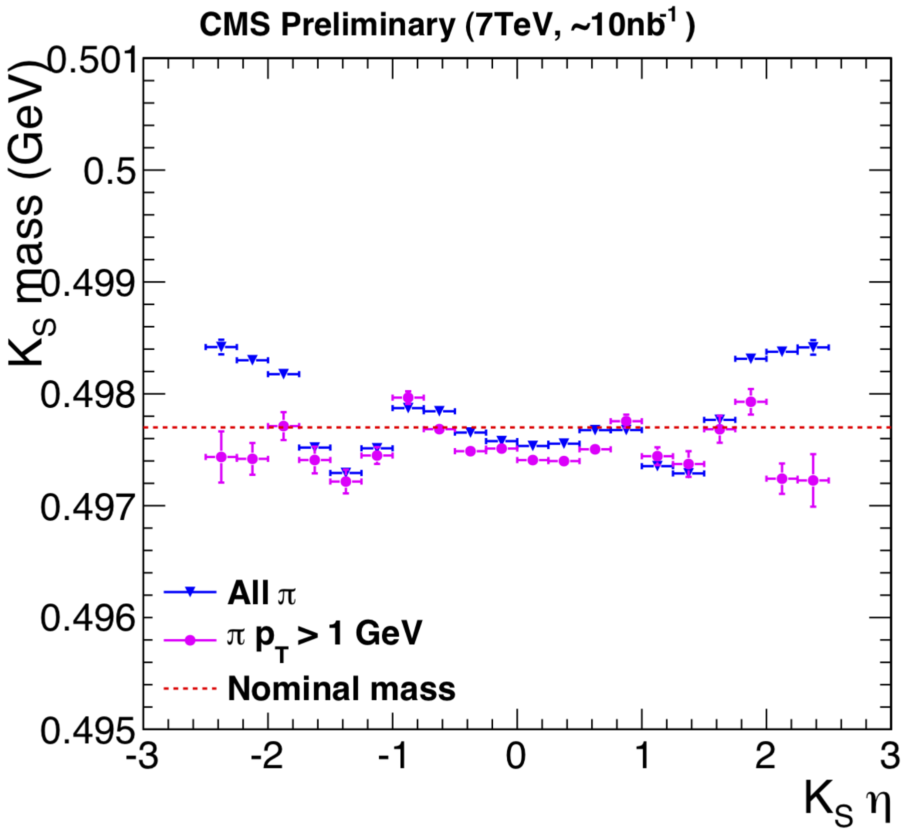
random matching

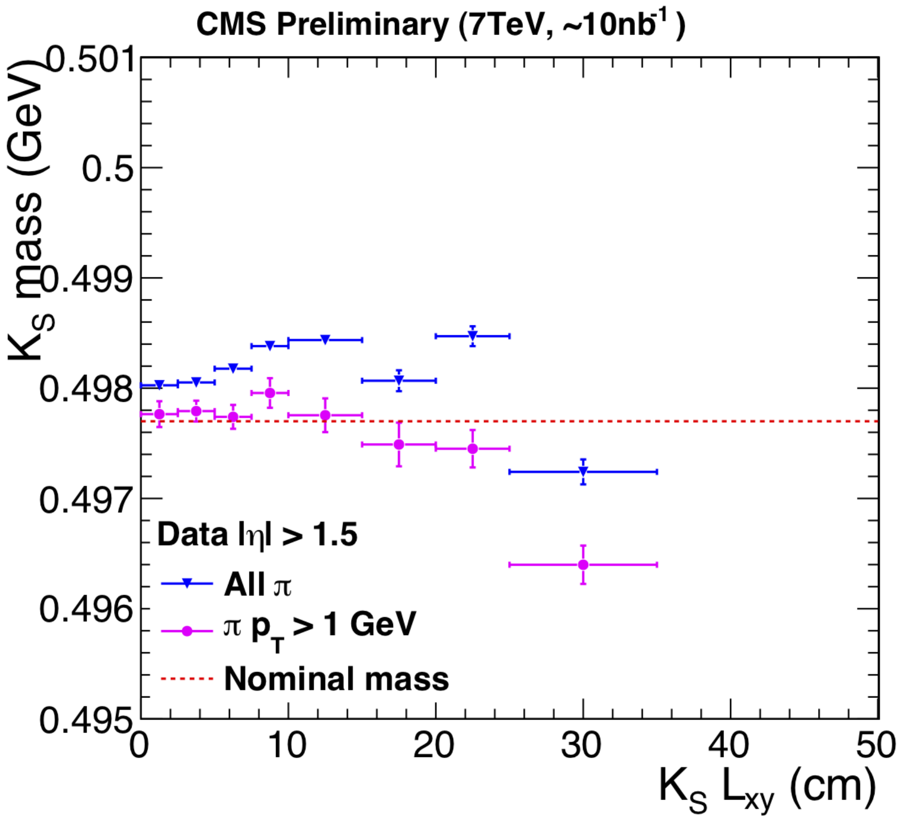
Tracking efficiency

Region	Data Eff. (%)	Sim Eff. (%)	Data/Sim
$0.0 \le \|\eta\| < 1.1$	$100.0^{+0.0}_{-0.3}$	$100.0^{+0.0}_{-0.1}$	$1.000^{+0.001}_{-0.003}$
$1.1 \le \|\eta\| < 1.6$	$99.2^{+0.8}_{-1.0}$	$99.8^{+0.1}_{-0.1}$	$0.994^{+0.009}_{-0.010}$
$1.6 \le \|\eta\| < 2.1$	$97.6^{+0.9}_{-1.0}$	$99.3^{+0.1}_{-0.1}$	$0.983^{+0.009}_{-0.010}$
$2.1 \le \|\eta\| < 2.4$	$98.5^{+1.5}_{-1.6}$	$97.6^{+0.2}_{-0.2}$	$1.010^{+0.015}_{-0.016}$
Combined	$98.8^{+0.5}_{-0.5}$	$99.2^{+0.1}_{-0.1}$	$0.996^{+0.005}_{-0.005}$

Measured tracking efficiency close to 99% and compatible with simulation

Momentum scale from K_s mass





Above p_T=1 GeV/c, the data reproduces the K_s mass within 0.3 MeV over the full eta range.

Momentum scale at higher energy ranges also explored with decays of Φ and J/Ψ.

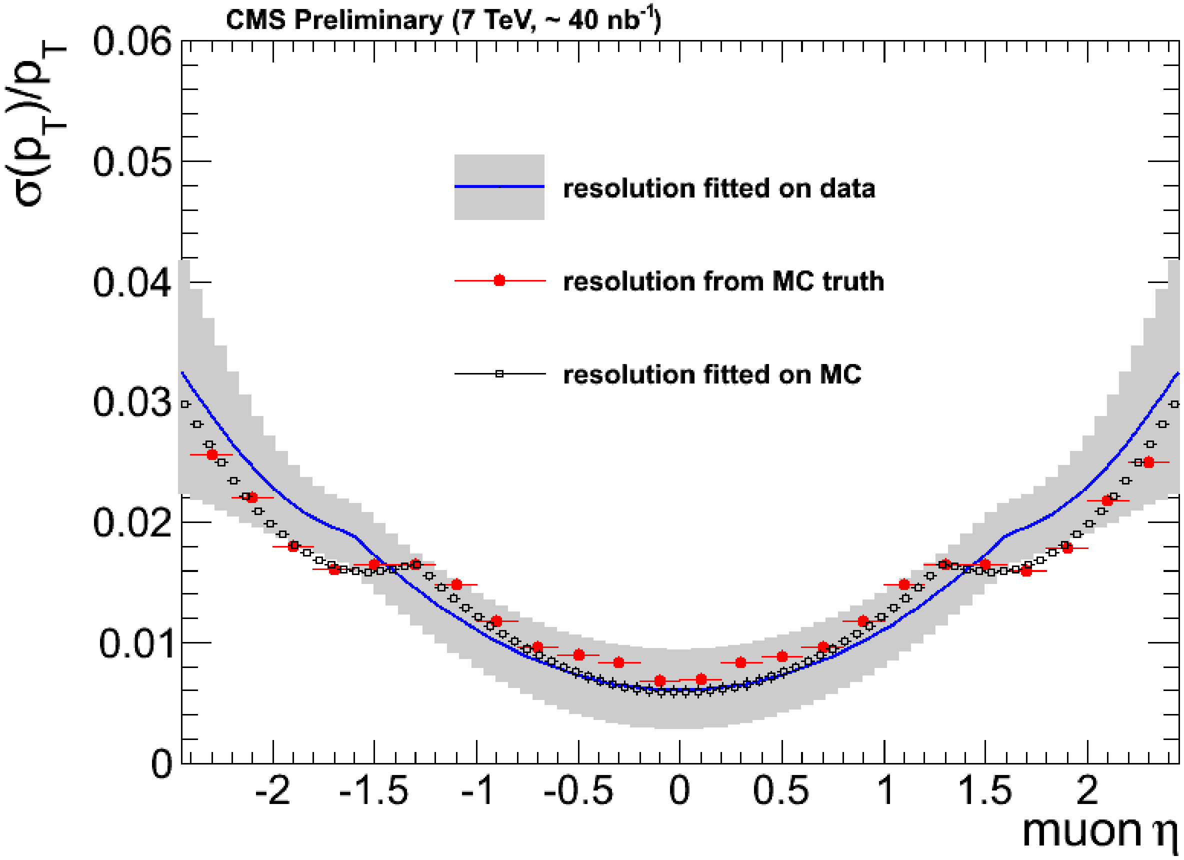
Agreement at the 0.6 per-mil level

Estimate of Transverse Momentum resolution from J/ψ width

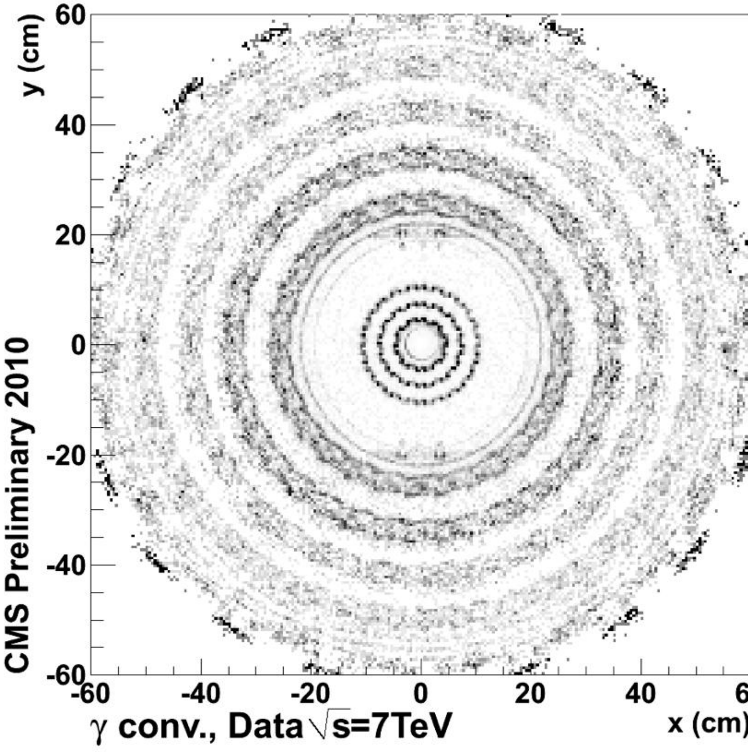
A set of functions describes the expected dependence of the p_T resolution on track kinematics.

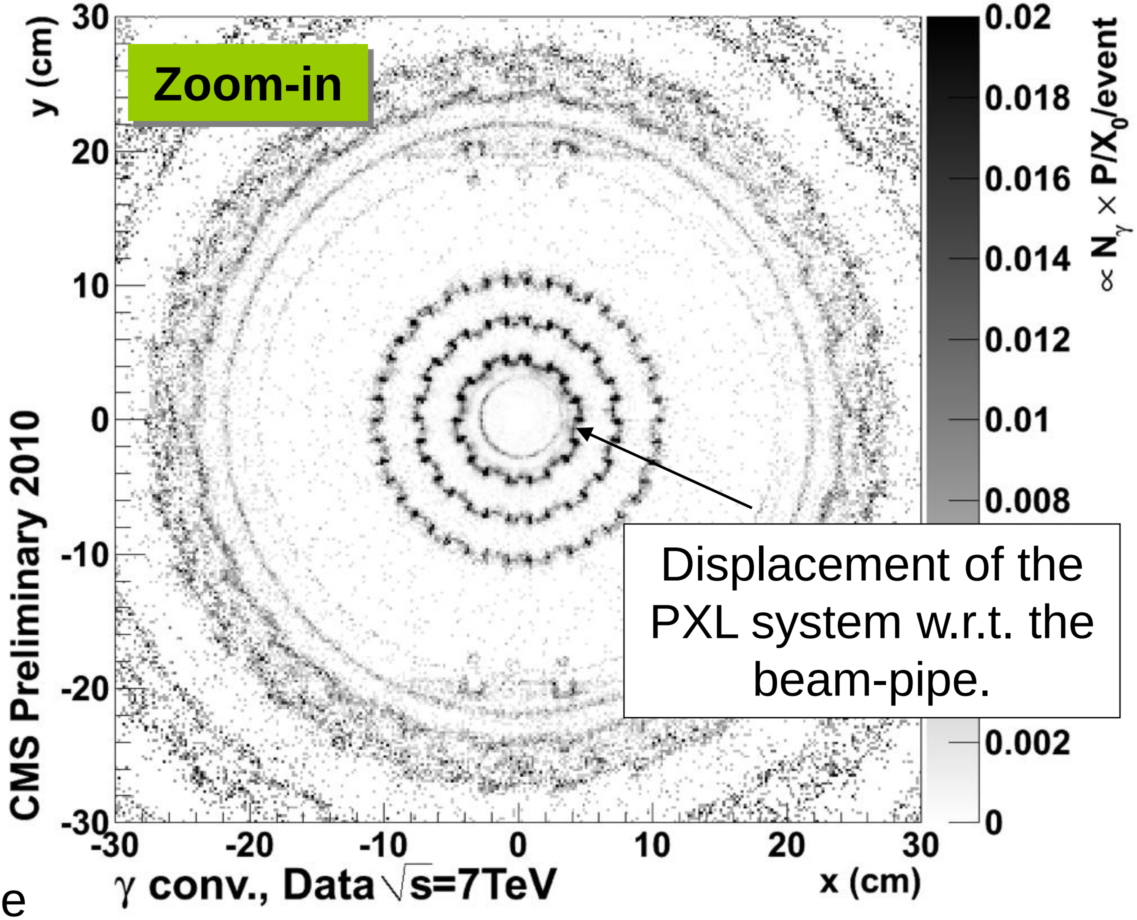
J/Ψ width expressed as a function of the kinematics of the 2 tracks.

The best estimate of the p_T resolution is then determined through an unbinned likelihood fit of data.



Material budget estimate from conversions and nuclear interactions

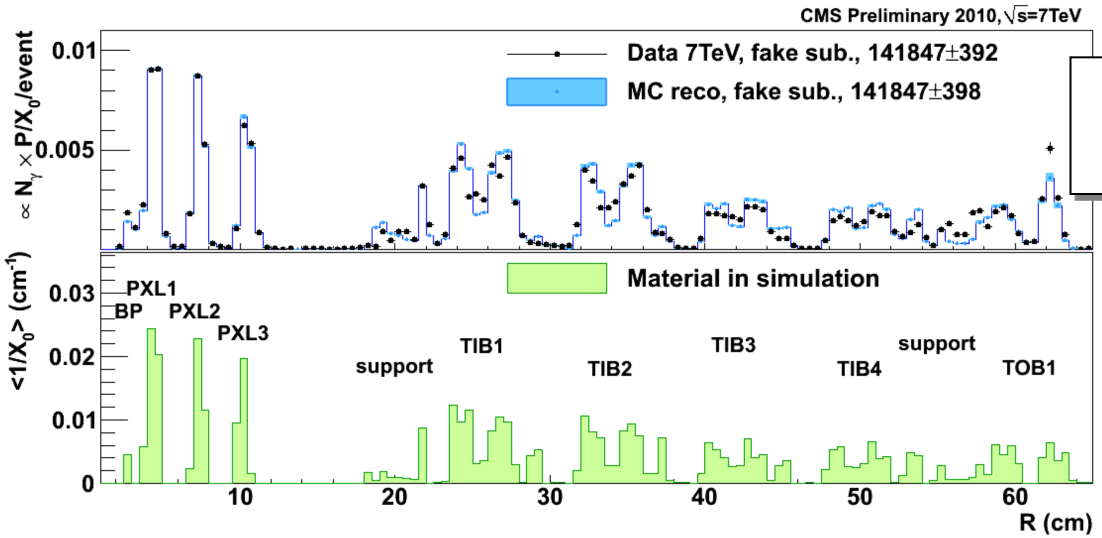




Displacement of the PXL system w.r.t. the beam-pipe.

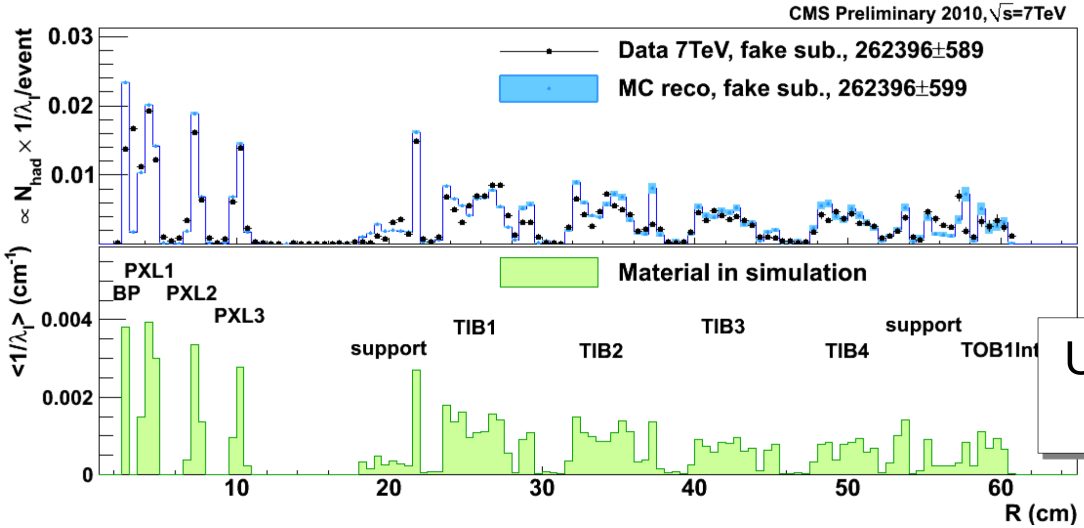
Results corrected according to the expected photon flux and conversion reconstruction efficiency.

Material budget estimate from conversions and nuclear interactions



Using gamma conversions

Similar results by two independent analyses: one based on conversions, the other on nuclear interactions.

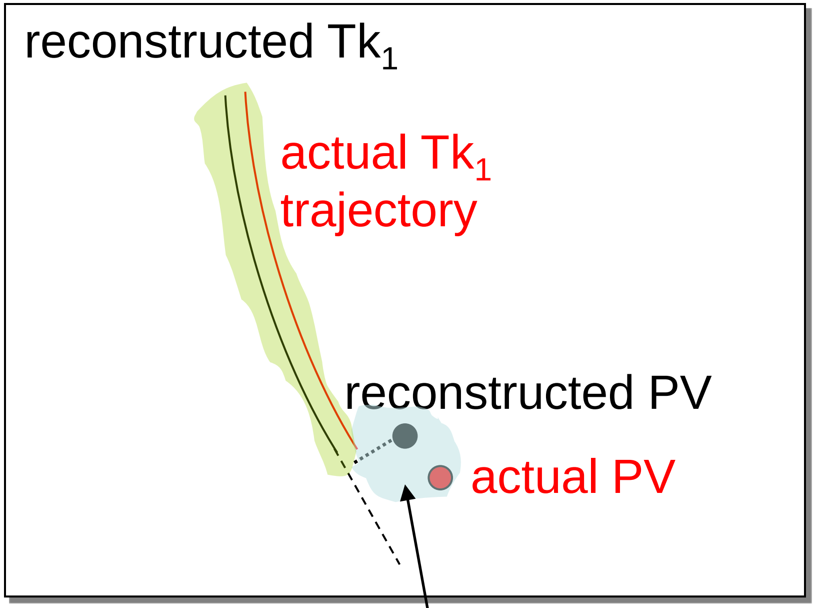


Material budget in data and simulation agree within 10%

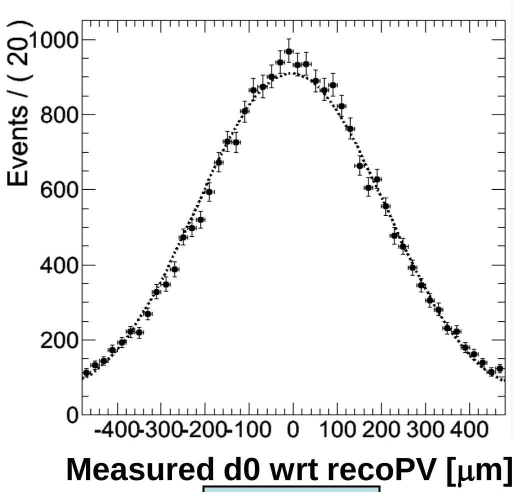
Using Nuclear Interactions

Impact Parameter Resolutions

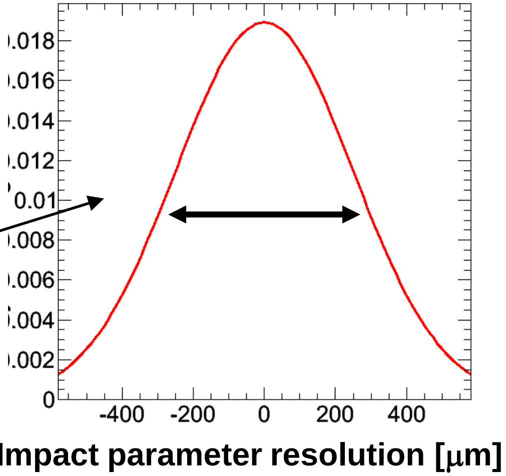
Impact parameter resolution extracted from data evaluating Impact Parameter of tracks with respect to the Primary vertex position.



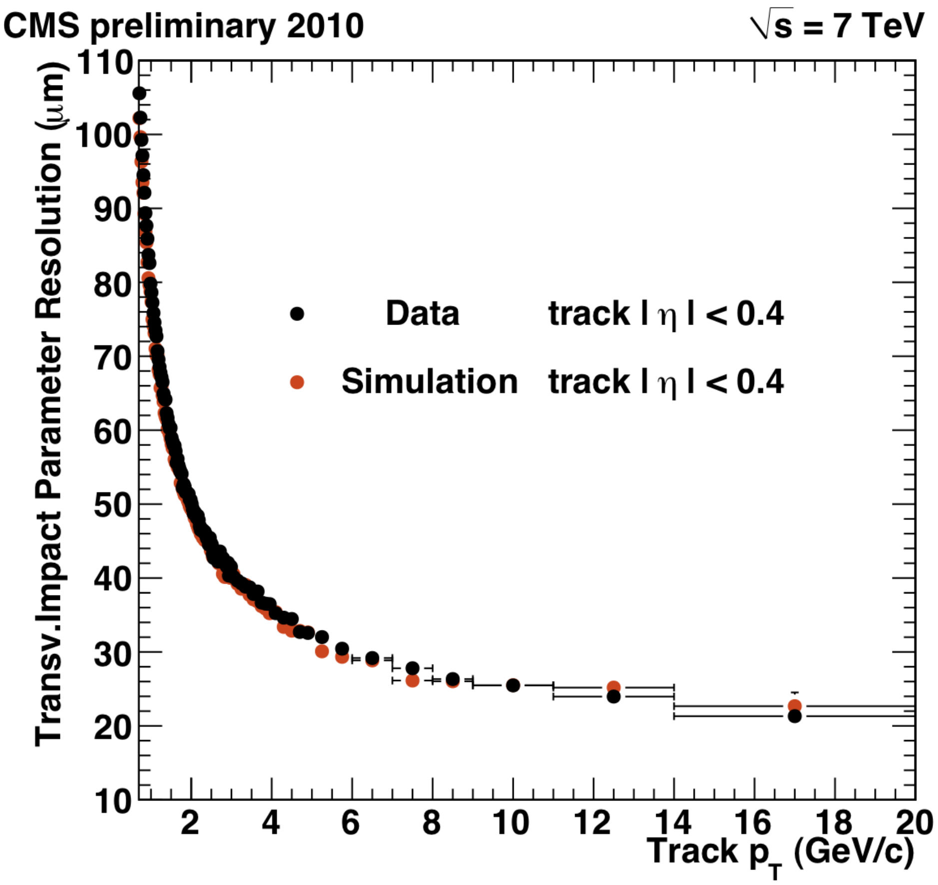
$$d0_{meas} = d0_{true} \oplus \delta(\text{“vertex resolution”}) \oplus \delta(\text{“impact parameter resolution”})$$

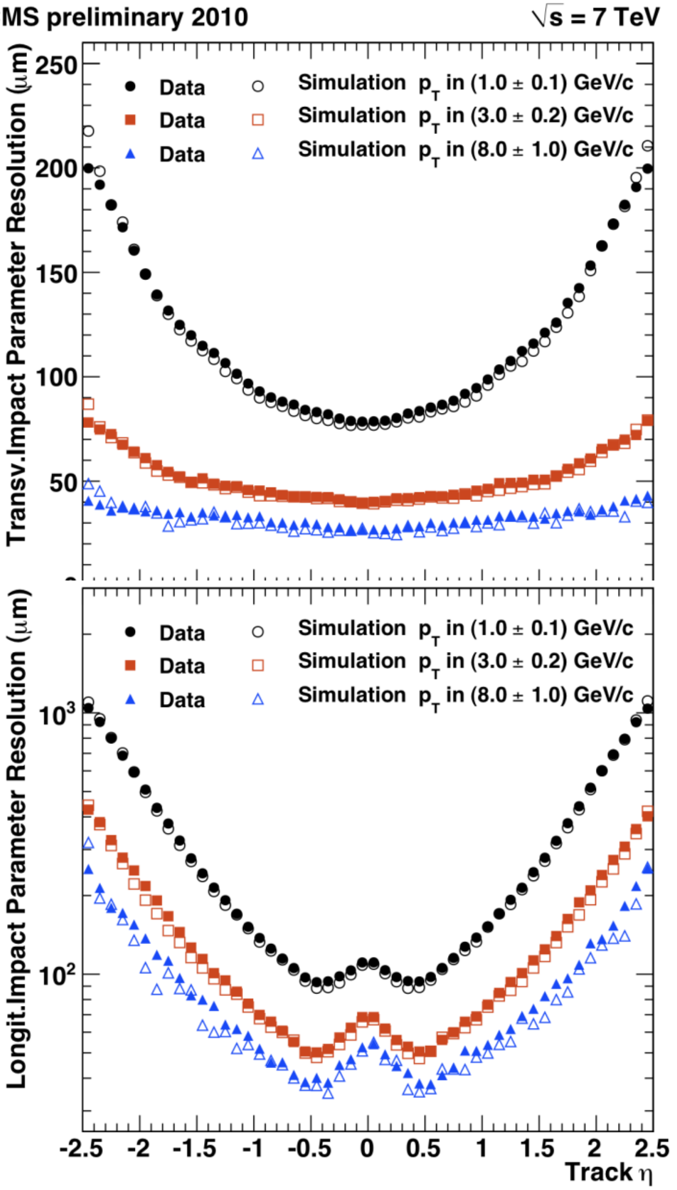


Subtraction of the “smearing” to the vertex reconstruction



Impact Parameter Resolutions (II)



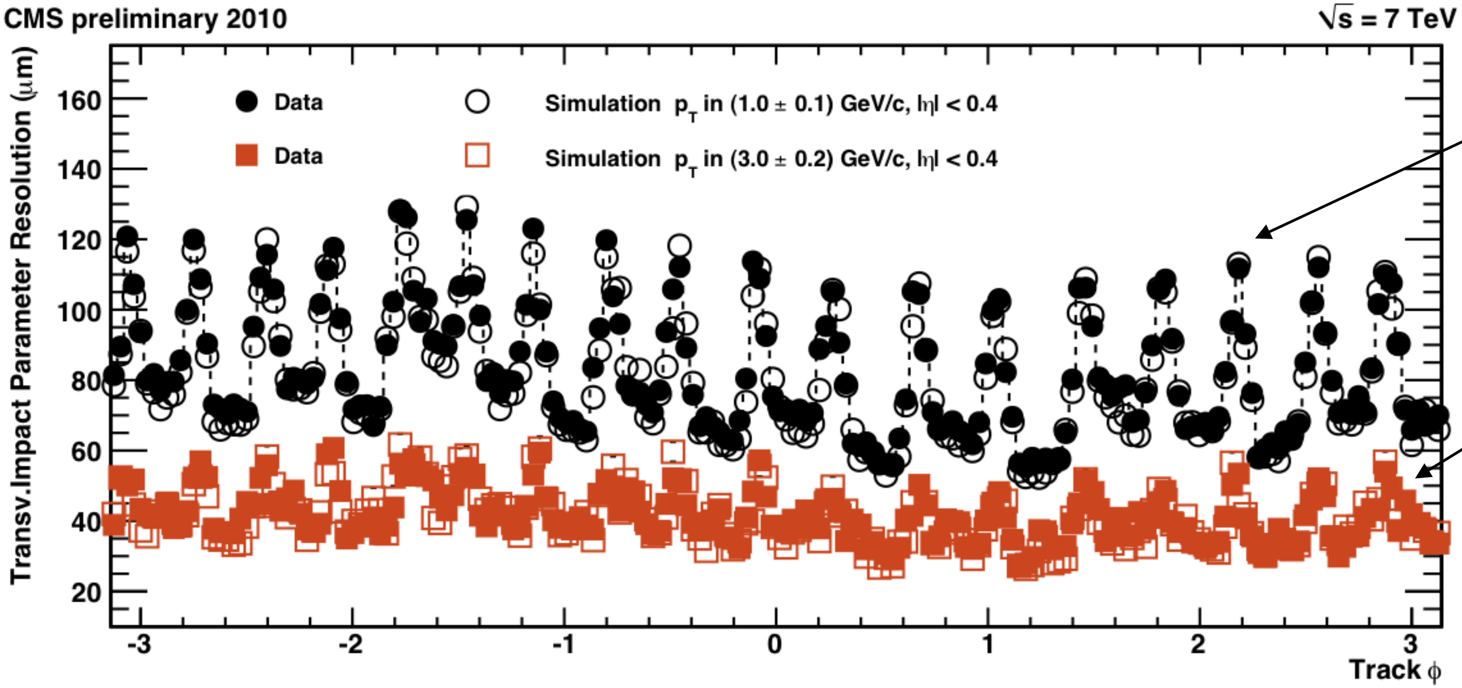


Good agreement between resolutions in DATA and MC for a wide range of track p_T and eta

Impact Parameter Resolutions (III)

The 18 peaks in the resolution correspond to the 18 cooling pipes on the innermost detecting layer of the pixel system.

Sin(ϕ) modulation due to the displacement of the luminous region w.r.t. the center of CMS Tracker.

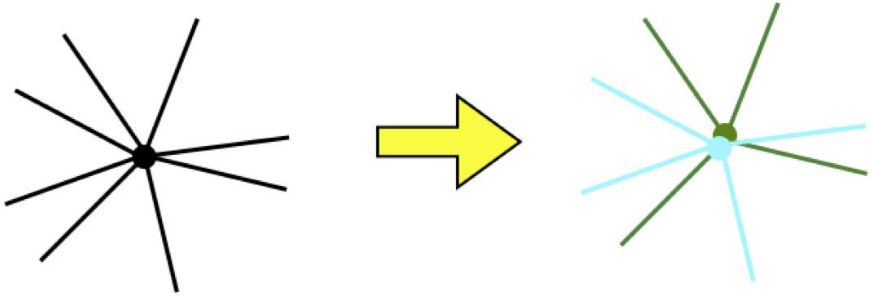


p_T=1 GeV tracks

p_T=3 GeV tracks

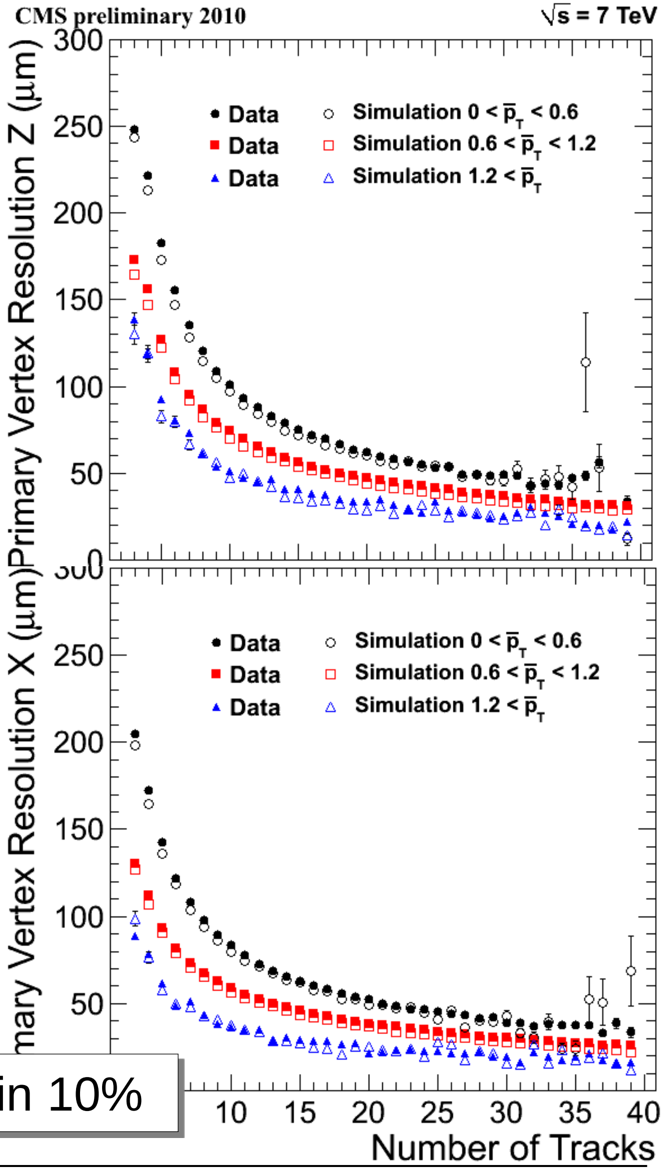
Peaks in the IP resolution are marked only for low energy tracks

Primary Vertex: Position Resolution



Single vertex reconstructed using “all” the tracks

Same collision point reconstructed **twice** using **half of the tracks**



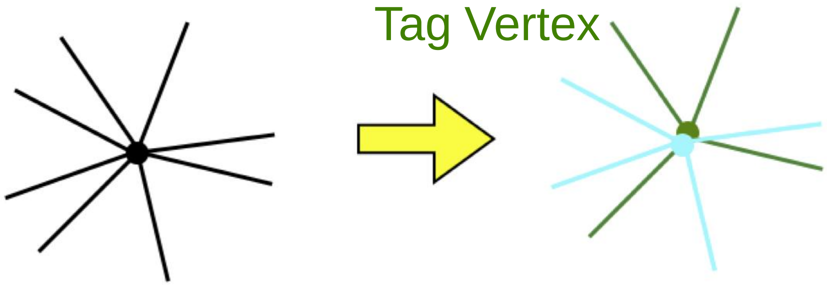
The position of one vertex is compared to the position of the other.

Repeating for many events, the intrinsic resolution of the primary vertex fitter is estimated directly from data.

Not shown: Pull distributions have widths equal to 1 within 10%

Primary Vertex (II) Reconstruction Efficiency

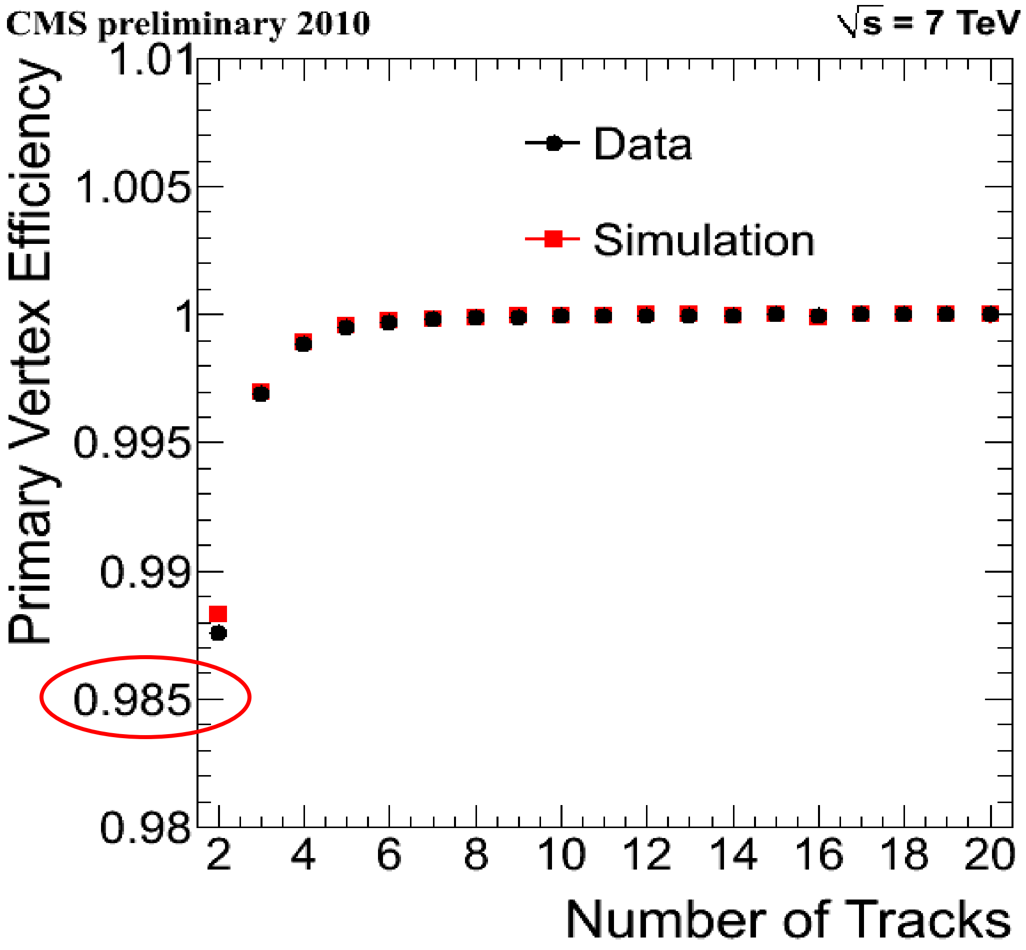
Same technique also used to estimate, from DATA, the PV reconstruction ***efficiency***.



Tag Vertex

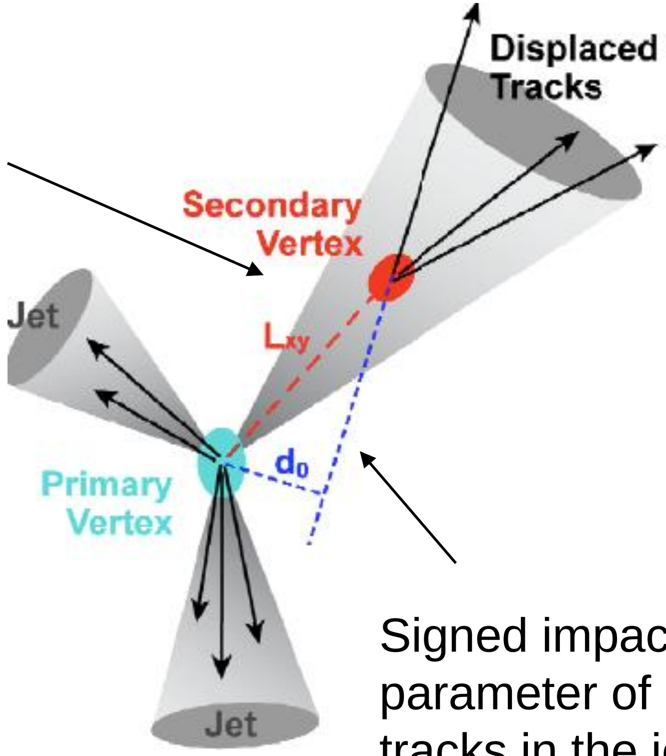
Is there a probe vertex ?

PV efficiency = #probes / #tags



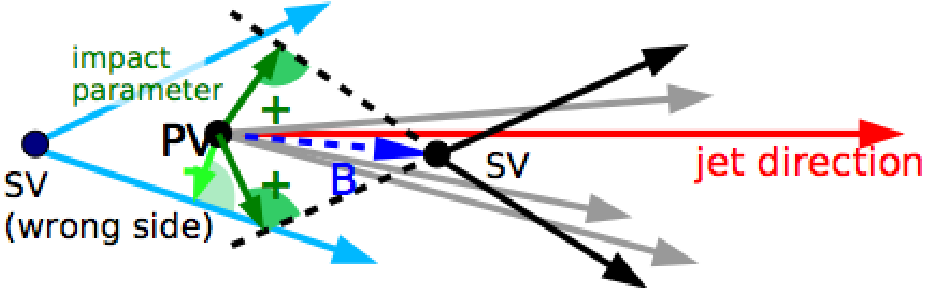
Main Observables used by B-tagging algorithms

Signed decay length of secondary vertexes

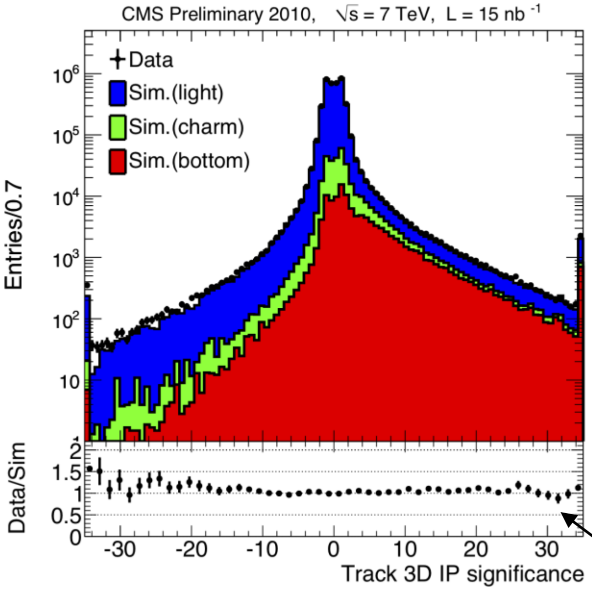


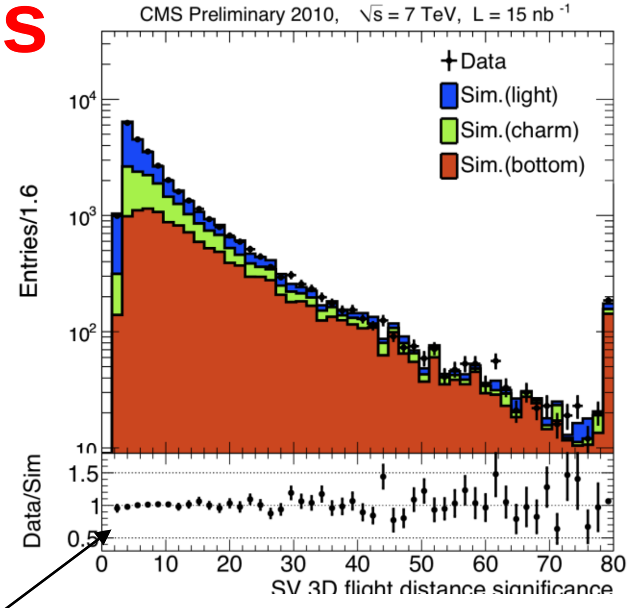
Signed impact parameter of tracks in the jet

Signs of Impact parameter and of vertex decay length are defined according to jet direction

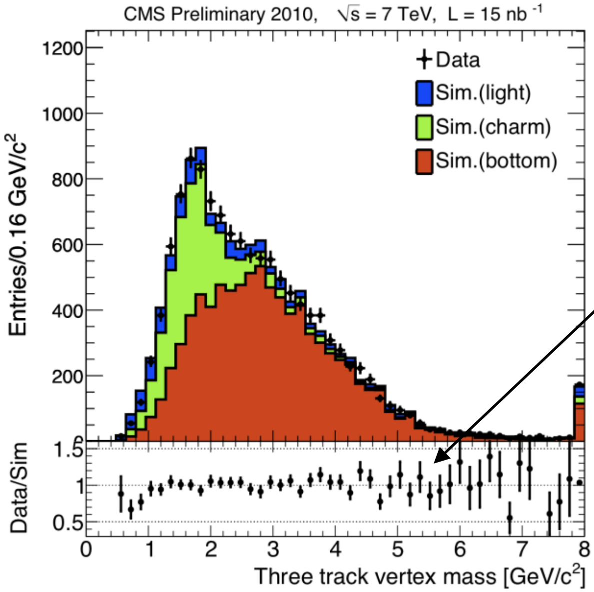


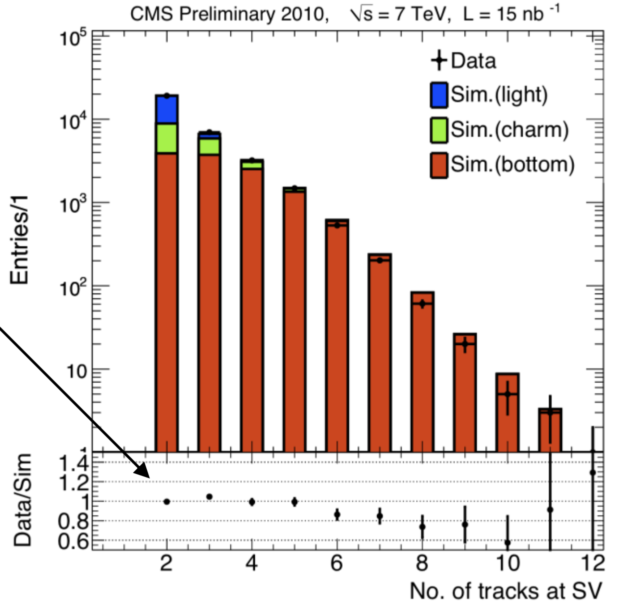
Data/MC comparison for B-Tagging observables



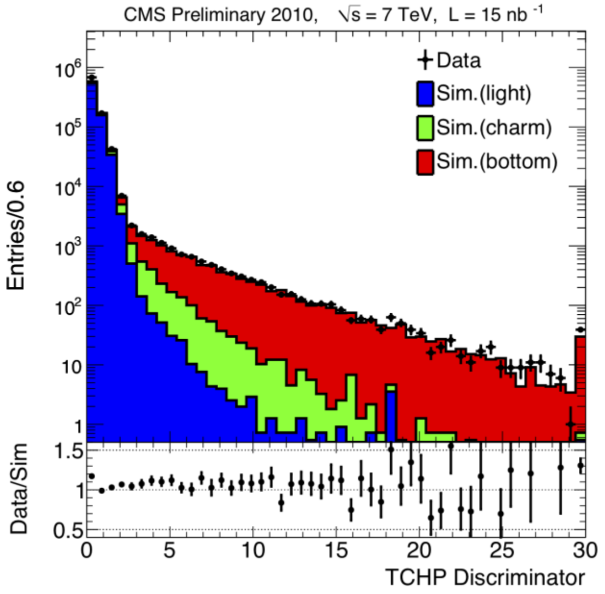


DATA/MC ratio is close to 1 for all observables (including those not shown)





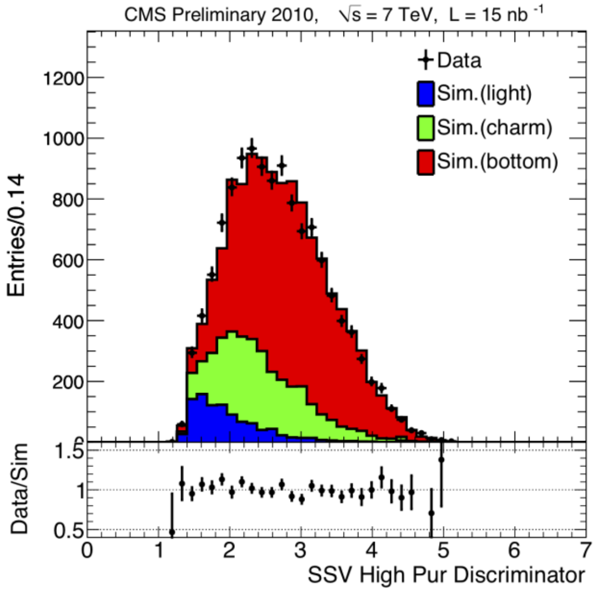
Data/MC comparison for Tagging Discriminators



Track Counting Algorithm

tags jets containing N tracks with Impact Parameter (IP) significance exceeding S

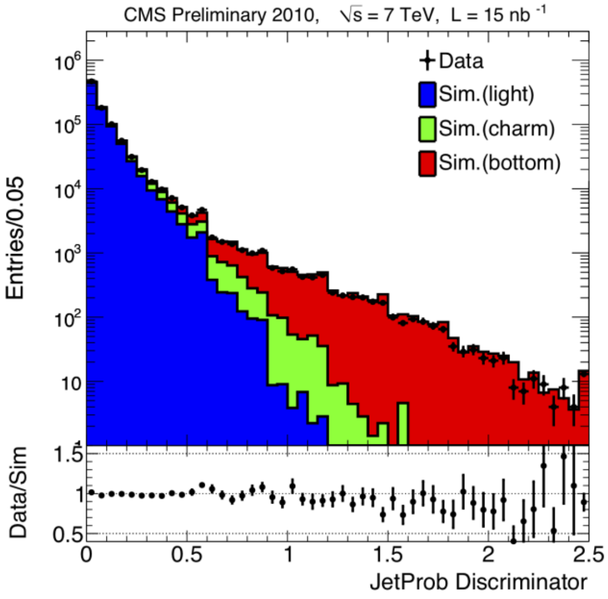
High Purity configuration: N=3



SSV Algorithm

tags jets according to the 3D flight distance significance of the reconstructed secondary vertex

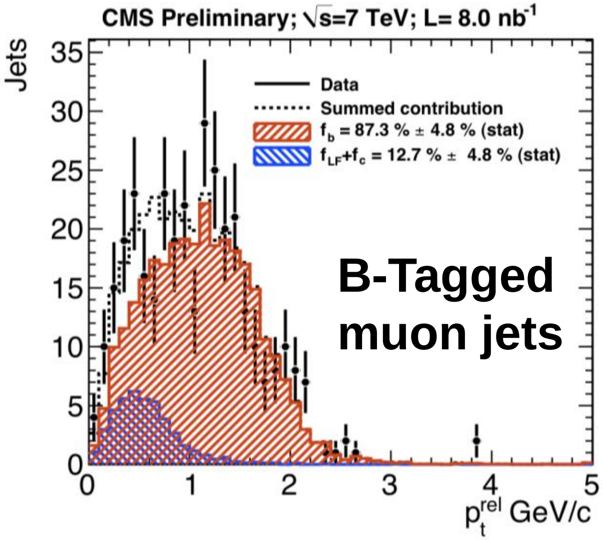
High Purity configuration: Vertices with 3 or more tracks

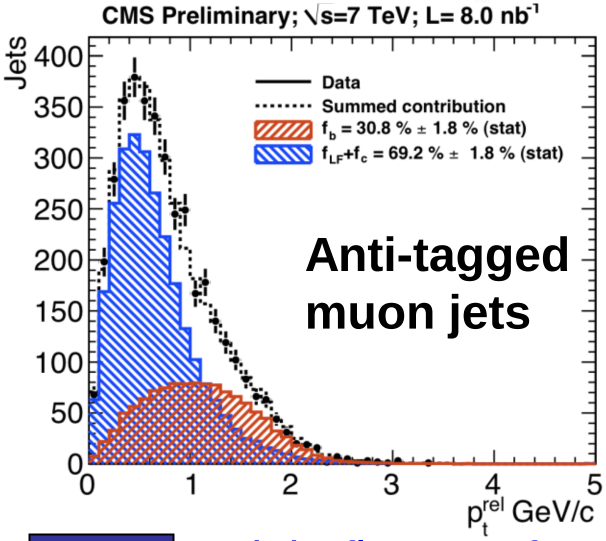


Jet Probability Algorithm

tags jets according to the probability of <u>all</u> the tracks in the jet to originate from the primary vertex, given their IP significances

B-Tagging Efficiency extraction from muon jets





🟦 Light flavor+c fraction

🟥 B fraction

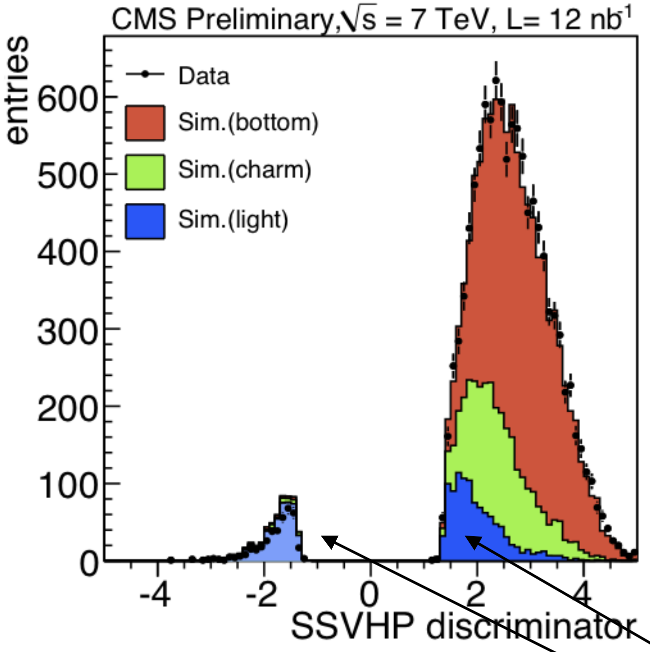
Efficiency is estimated from data fitting the p_T^{rel} distribution of muons in muon jets.

B-fraction is extracted from the fit of data using distribution templates based on MC

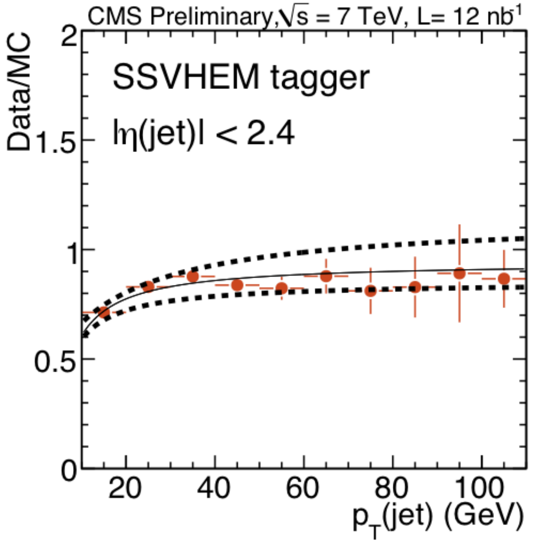
$$\epsilon_b^{data} = \frac{f_b^{tag} \cdot N_{data}^{tag}}{f_b^{tag} \cdot N_{data}^{tag} + f_b^{untag} \cdot N_{data}^{untag}}$$

Tagger+Operating Point	**Scale factor**
SSV algorithm High Purity configuration	0.98 ± 0.08±0.18
Track Counting algorithm High Purity configuration	0.95 ± 0.06±0.19

Estimation of the mistag rate

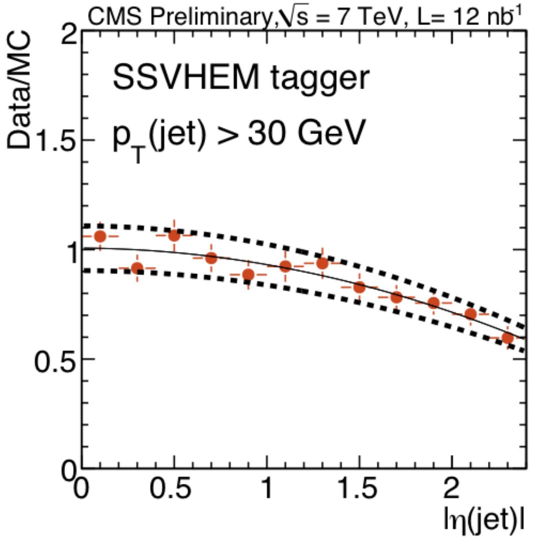


Mistag rate is estimated using negative tags



Aim to estimate LF distribution for positive tags using negative tags

$$\varepsilon^{mistag}_{data} = \varepsilon^{-}_{data} \cdot R_{light}$$



$$R_{light} = \varepsilon^{mistag}_{MC} / \varepsilon^{-}_{MC}$$

R_{light} is from MC and corrects for asymmetry between positive and negative tags distributions

Conclusions

The CMS Tracker and the reconstruction algorithms worked from "day 1" of LHC operation at 7 TeV. The extended period of commissioning with cosmic rays was really valuable for achieving this.

As the integrated luminosity collected by CMS increases, tracking performances are estimated from data in further and further detail.

After collecting about 100 /nb, we have a good understanding of tracking efficiency, momentum and impact parameter resolutions and vertex reconstruction performance.

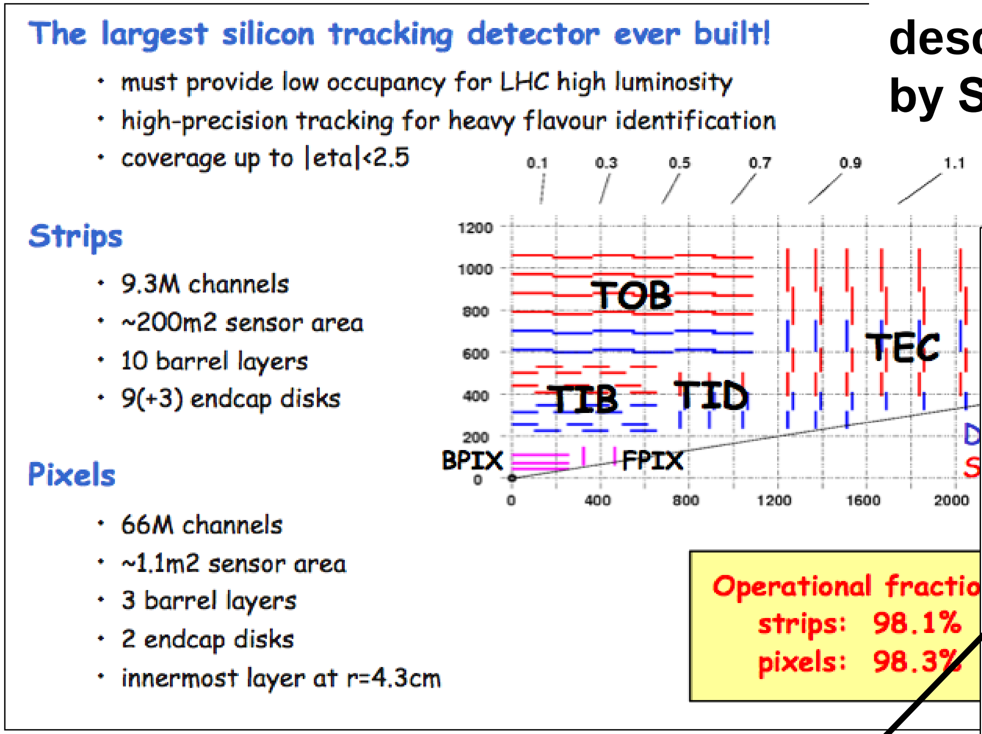
Both B-tagging observables and the performance of B-taggers have been analyzed in data and compared to simulation.

In both the context of pure track/vertex reconstruction and also in that of B-tagging, the agreement between data and simulation has been found excellent.

BACKUP SLIDES

Snapshot of CMS Silicon Tracker

CMS Tracker already described in this session by S.Lowette's talk



The largest silicon tracking detector ever built!

- must provide low occupancy for LHC high luminosity
- high-precision tracking for heavy flavour identification
- coverage up to |eta|<2.5

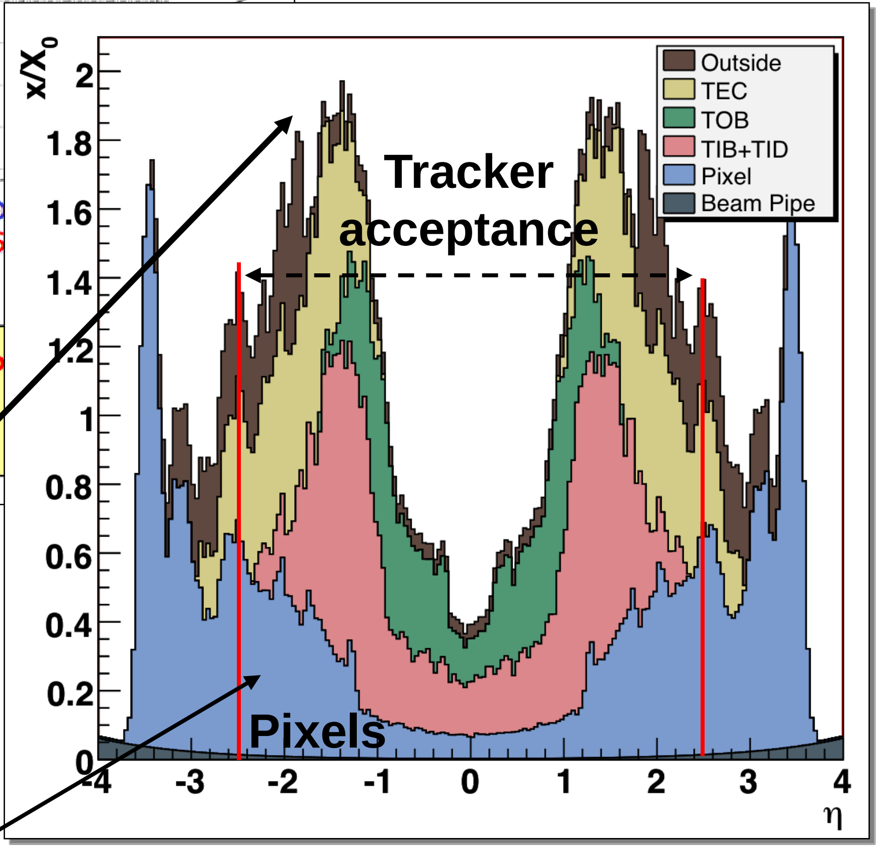
Strips

- 9.3M channels
- ~200m2 sensor area
- 10 barrel layers
- 9(+3) endcap disks

Pixels

- 66M channels
- ~1.1m2 sensor area
- 3 barrel layers
- 2 endcap disks
- innermost layer at r=4.3cm

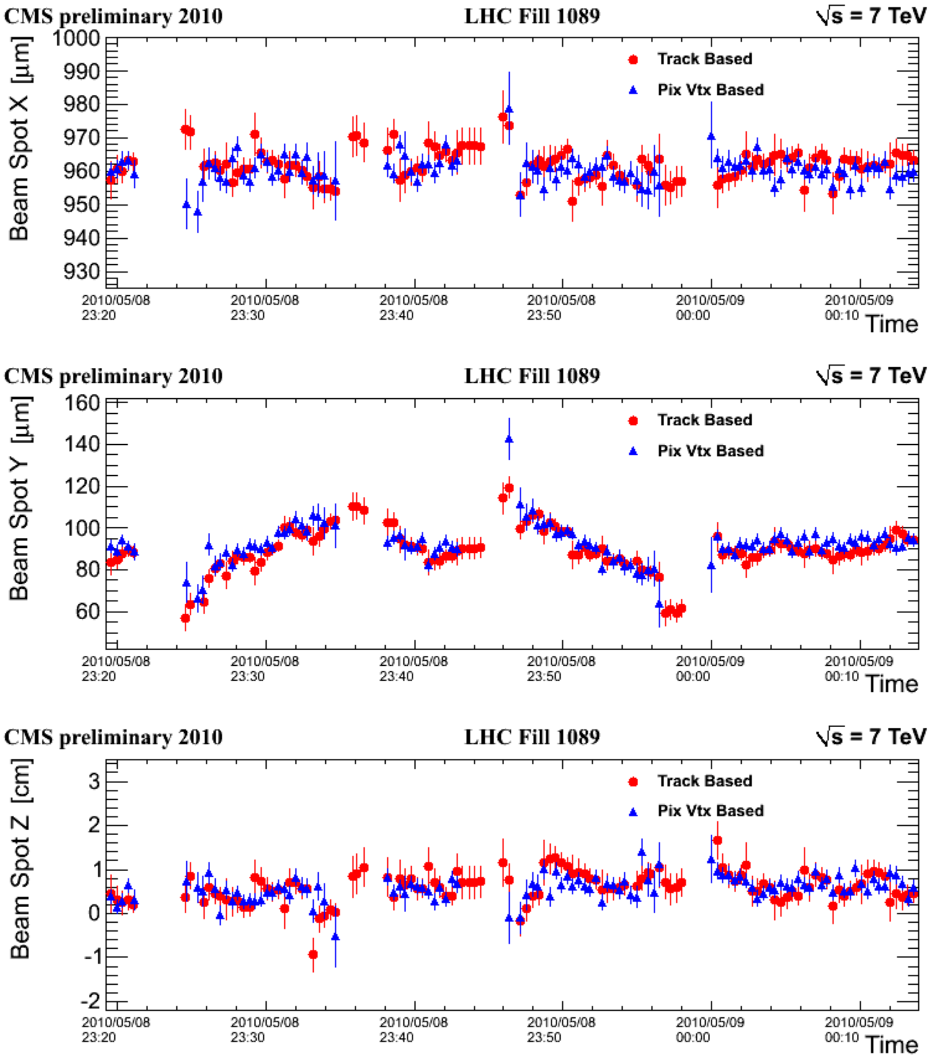
Operational fractio
strips: 98.1%
pixels: 98.3%



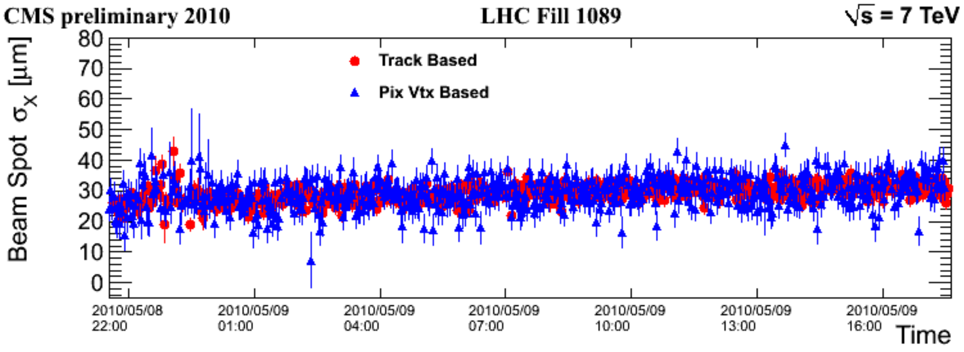
Integrated material budget mostly affects the pattern recognition of charged particle trajectories

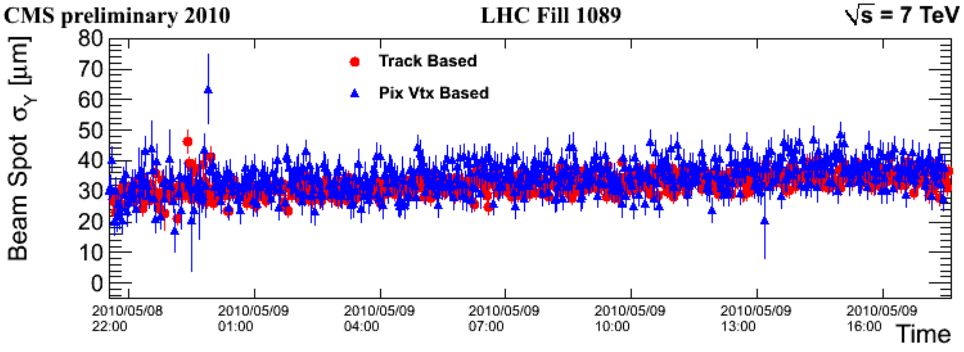
Distribution of the **material in the inner pixels** system affects the measurement of the track **Impact Parameter**

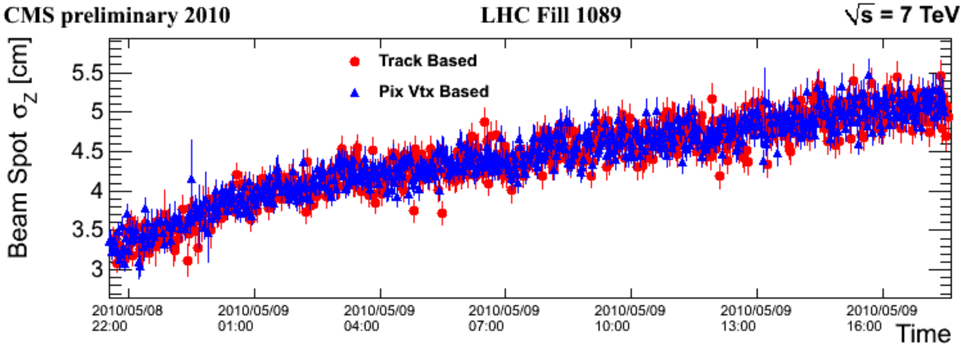
Beam spot position determination

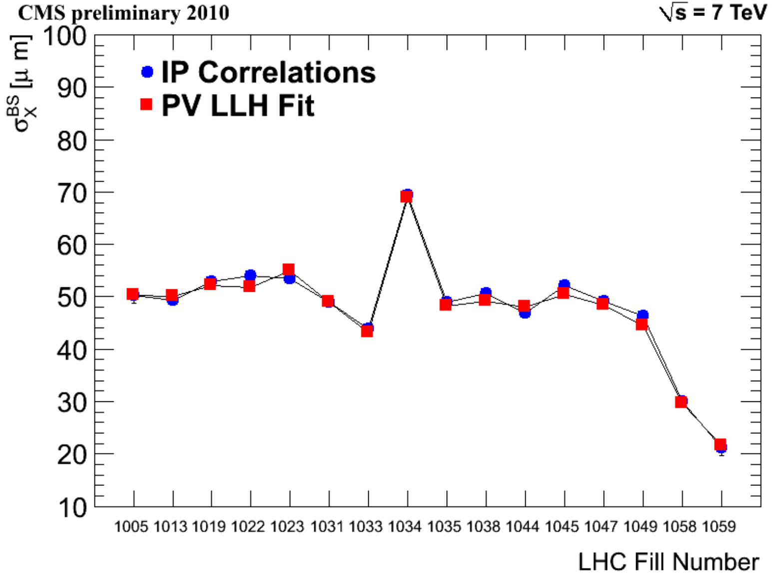


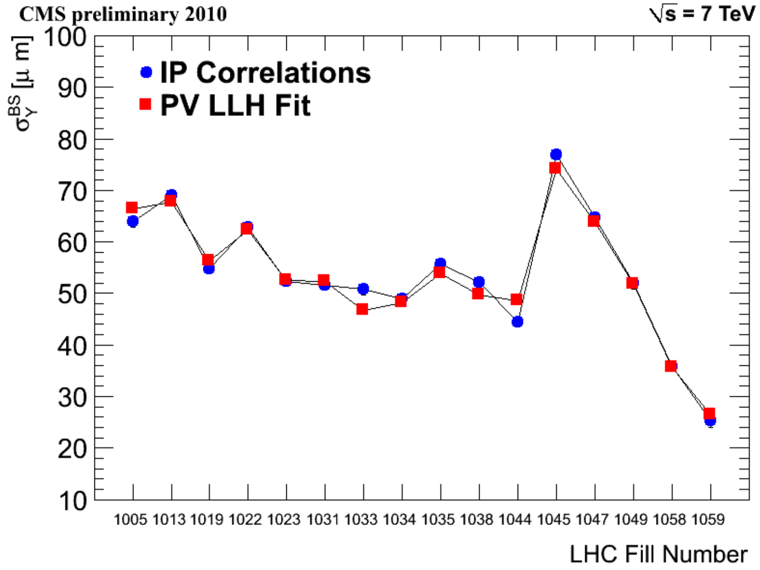
Beam spot width determination









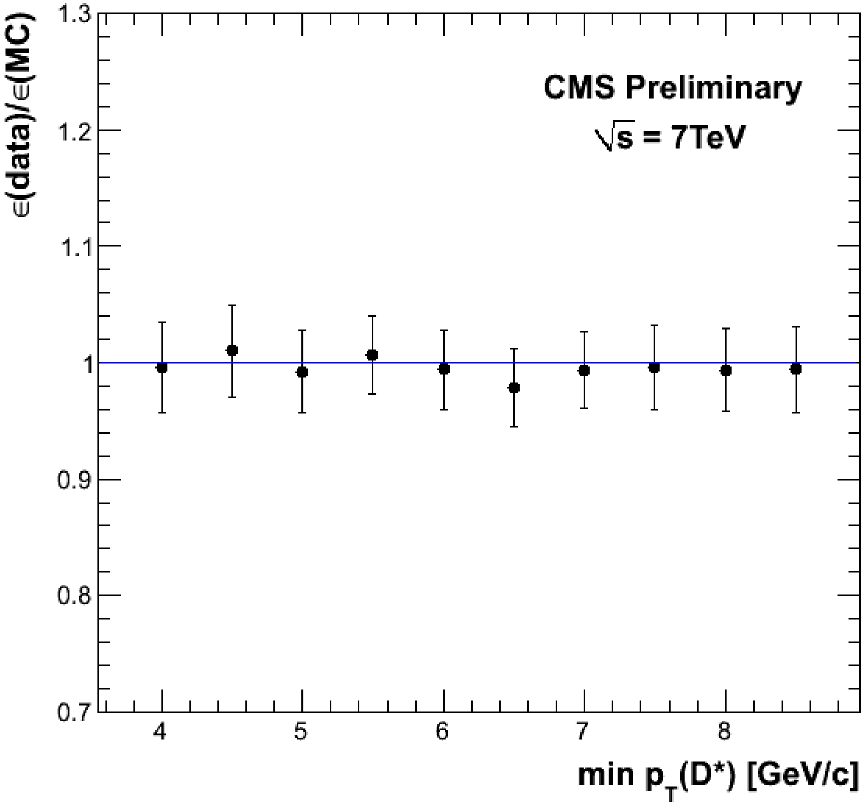


Pion reconstruction efficiency from D^0 decays

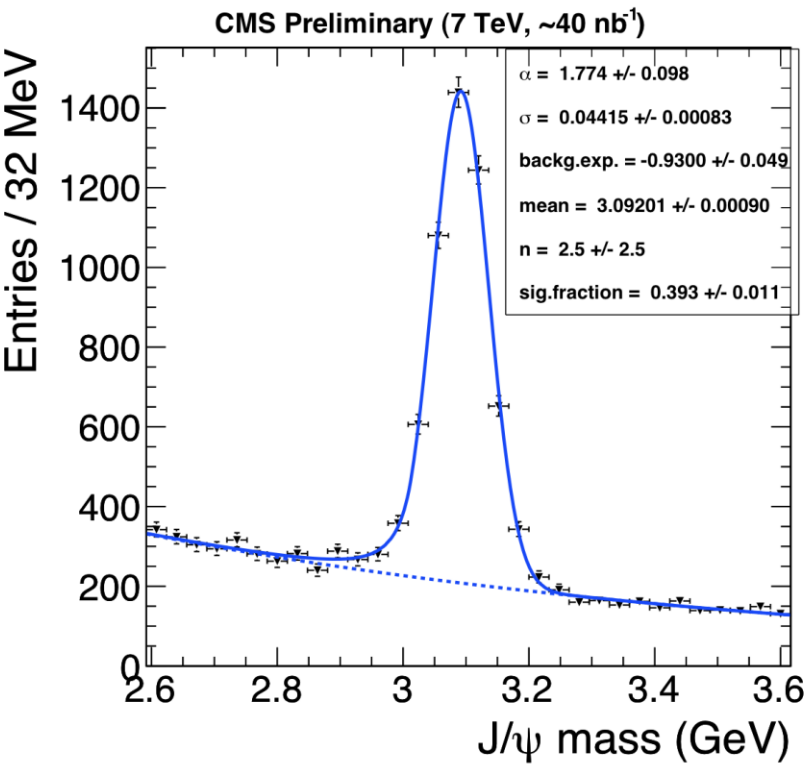
Ratio of yields of D^0--> K 3π and D^0--> Kπ, corrected by tracking efficiency:

$$\mathcal{R} = \frac{N_{K3\pi}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{K3\pi}}$$

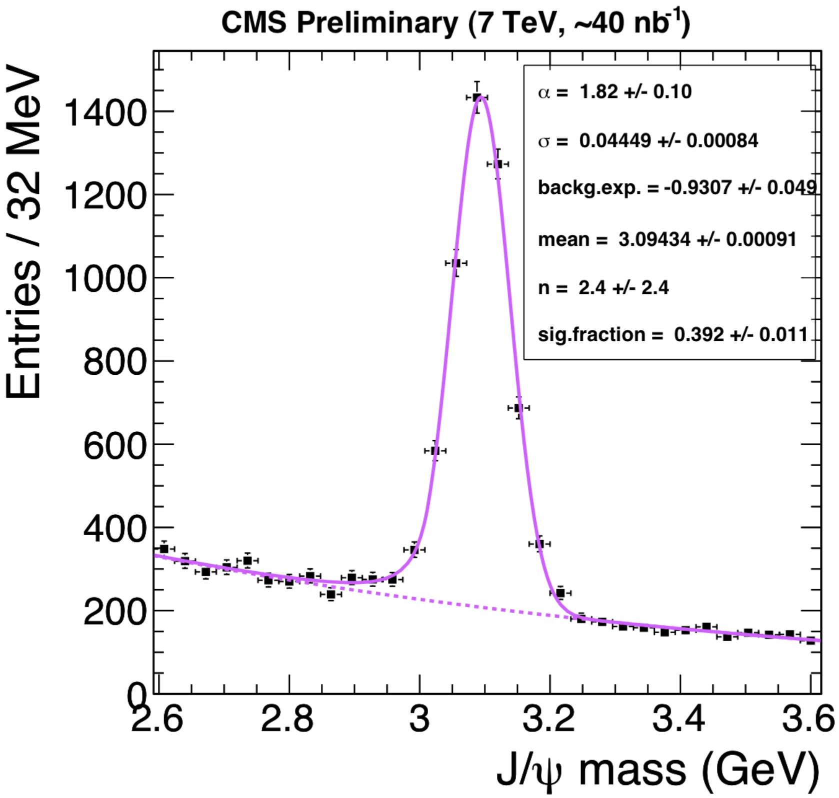
$$\frac{\epsilon(\mathrm{data})}{\epsilon(\mathrm{MC})} = \sqrt{\frac{\mathcal{R}}{\mathcal{R}(\mathrm{PDG})}}$$



Momentum scale correction



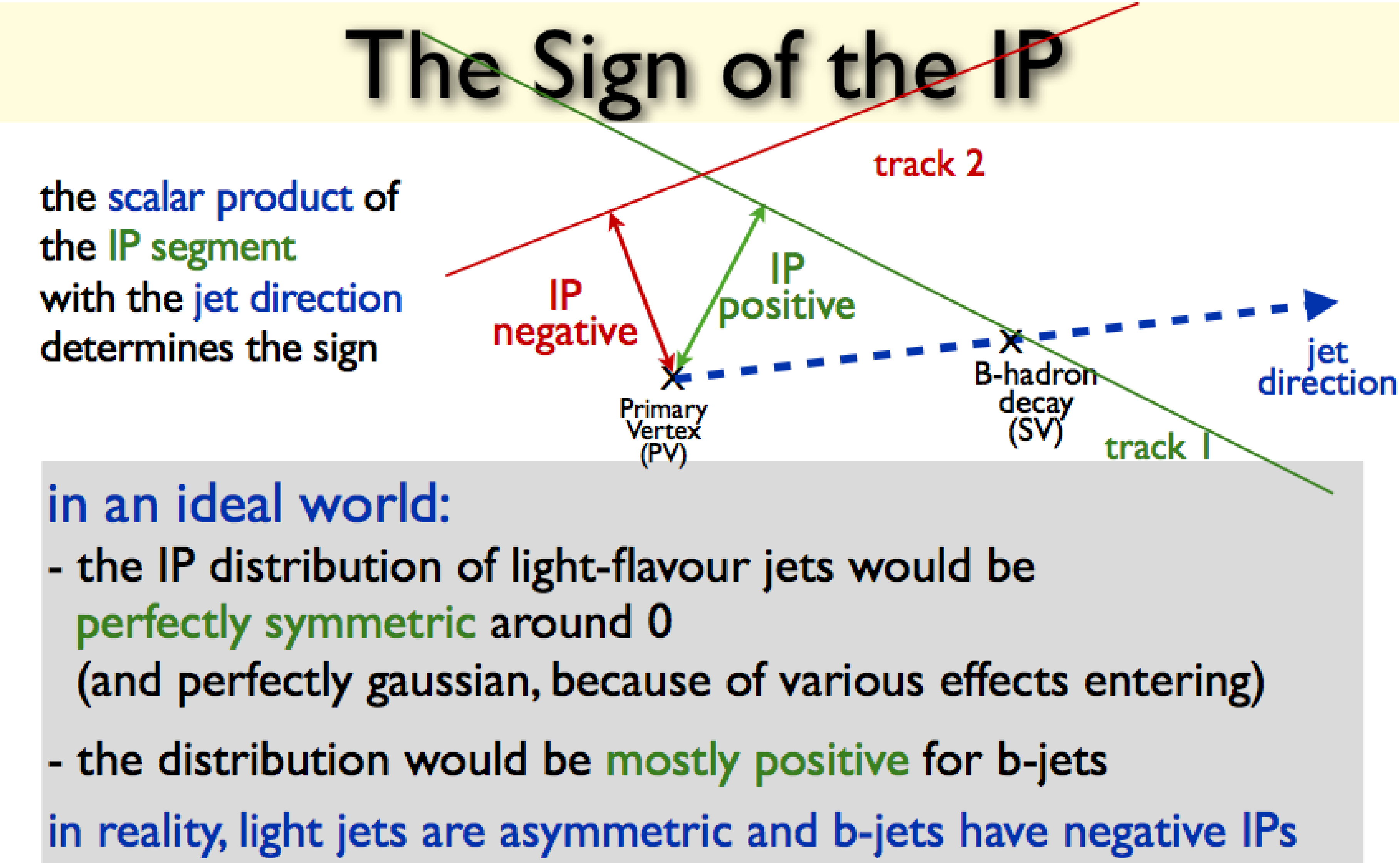
Before momentum scale correction



After momentum scale correction

Mean is not exactly equal to PDG mass value because of FST tail on the left: 2 MeV shift.

Negative Tags



The Sign of the IP

the scalar product of the IP segment with the jet direction determines the sign

in an ideal world:

- the IP distribution of light-flavour jets would be perfectly symmetric around 0 (and perfectly gaussian, because of various effects entering)
- the distribution would be mostly positive for b-jets

in reality, light jets are asymmetric and b-jets have negative IPs