Studies on the measurement of the CMS beam spot

DESY summer student session

Gregor Hellwig

DESY
CMS

Hamburg
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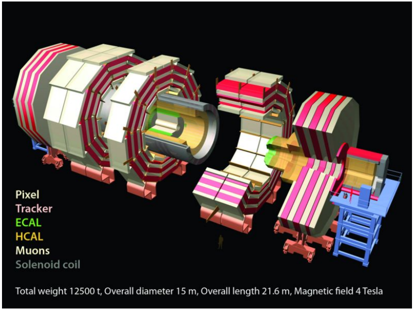
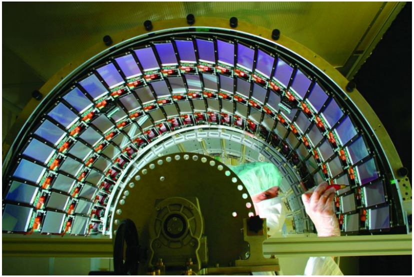
Outline

Compact Muon Solenoid

- one of the large general purpose experiments at the LHC
- recorded first *pp* collisions at 7 TeV cm energy in 2010





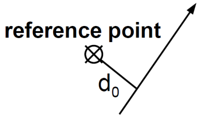
- 1440 silicon pixel & 15148 silicon strip detector modules
- inside of a superconducting solenoidal magnet (3.8 T)
- excellent momentum, angle and position resolution of tracks

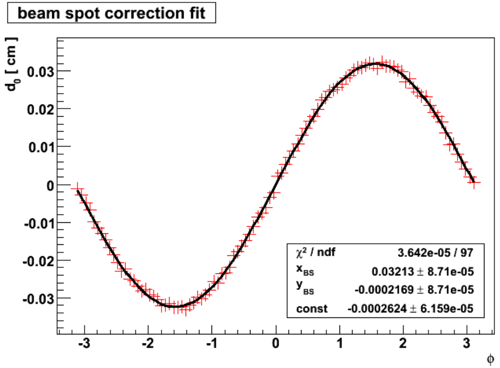
Motivation for Beam Line Studies

- project deals with the beam line inside CMS detector
- beam line is the profile of the interaction region
  - longitudinal extension $\sim$ few cm
  - transverse extension currently $\sim$ 20-50 μm at 7 TeV
- beam line parameters must be known very accurately
- especially one needs to know the beam line width
  - $\longrightarrow$ less trivial to compute in transverse direction
  - $\longrightarrow$ enters computation of important observables (b tagging significances,...)
- main focus: investigation of systematic errors in beam spot measurements (especially beam spot width)

Beam spot position measurement

- first some tests on Monte Carlo data
- d_0: impact parameter, defined as distance between a reference point and the point of closest approach of the track to the reference point

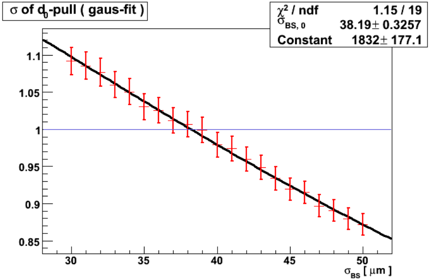




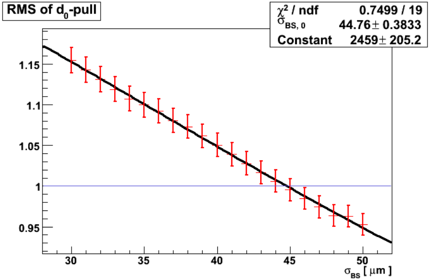
$\Rightarrow$ fit values consistent with Monte Carlo input

Beam spot width measurement

- fit of d_0-pull histogram $\left(\frac{d_0}{\sqrt{d^2_{0,Error}+\sigma^2_{BS}}}\right)$ with Gauss function
- plot σ of the fit and the RMS of the histogram against σ_{BS}
- compare value of σ_{BS} at which σ/ RMS $= 1$ with MC input ($\sigma^{MC}_{BS} = 46\ \mu$m)



(a) Gauss fit ⇒ too small



(b) RMS ⇒ ∼ correct

Beam spot width measurement

- calibration of Gauss fit method although σ_{BS}^{RMS} is closer to σ_{BS}^{MC} because it is less sensitive to outliers

$\Rightarrow$ method works in principle, but depends critically on correct computation and interpretation of $d_{0,Error}$

  $\Rightarrow$ Systematics!

$\Rightarrow$ would like to have a method independent of knowledge of $d_{0,Error}$

The Impact Parameter Correlation estimator

- due to the finite beam line size, the interaction point receives event-by-event a global offset

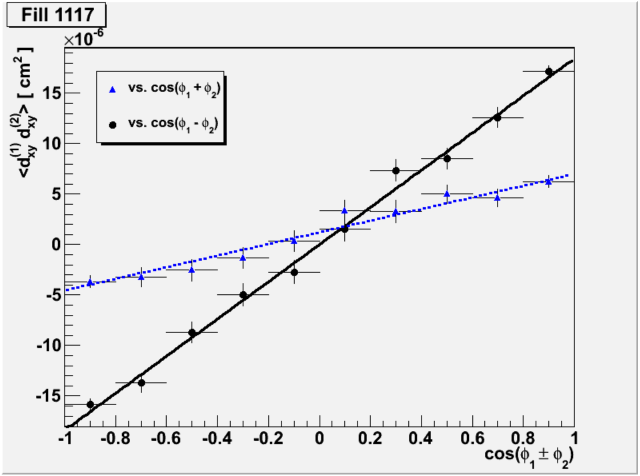
⇒ introduces correlation between tracks from same interaction
  - visible in their parameters computed wrt beam spot
  - strength of this correlation directly connected to beam spot size

- study correlation of impact parameters $d_{xy}^{(1)}$, $d_{xy}^{(2)}$ of track pair from same event

$$\langle d_{xy}^{(1)} \cdot d_{xy}^{(2)} \rangle = \frac{\sigma_x^2 + \sigma_y^2}{2} \cos(\phi_1 - \phi_2) + \frac{\sigma_y^2 - \sigma_x^2}{2} \cos(\phi_1 + \phi_2) \quad (1)$$

- assuming non-correlation of $(\phi_1 - \phi_2)$ and $(\phi_1 + \phi_2)$, both dependencies can be fitted independently
- one does not need the impact parameter resolution to get the value of the beam spot width, it cancels in the calculation of the formula

The IPC estimator (for LHC fill 1117)

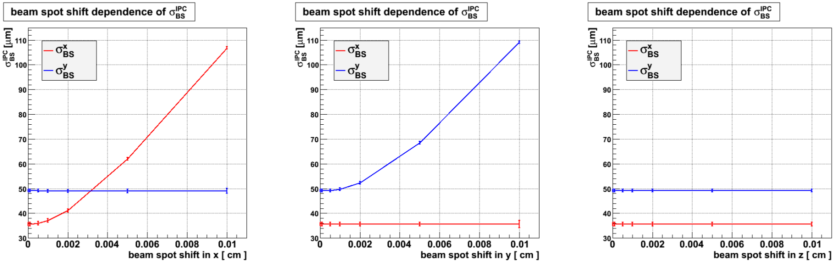


$$\sigma_x = (35.6 \pm 0.8)\ \mu\text{m}$$
$$\sigma_y = (49.2 \pm 0.5)\ \mu\text{m}$$

Analysis of the IPC systematics

- use events from LHC-Fill 1117
- selection of my studies:
  - Shift of the x, y, z-coordinates the Beam Spot in order to estimate the systematic error of this method
  - Cut on the maximal difference Δz between the z-coordinates of the points of closest aproach (PCA) of the trackpair, used to calculate the IPC-estimator
- not shown:
  - Shift of the $\frac{dx}{dz}$- and $\frac{dy}{dz}$-slope of the Beam Spot
  - Cut on the pseudorapidity η
  - Cut on the impact parameter error in order to get a well-defined impact parameter

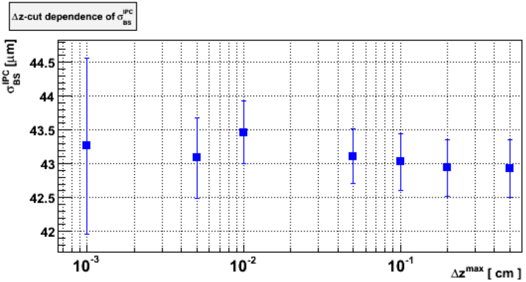
Beam spot shift in x, y, z-direction

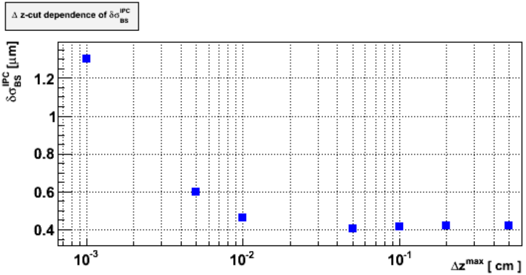


(a) Shift in x (b) Shift in y (c) Shift in z

- shift only affects the beam spot width in same direction
- estimation of systematic error:
  during a run the beam spot position typically changes in the range of 8 μm
  $\Rightarrow$ deviation of σ_{BS} of 1-2 μm
- The systematic error can be reduced, if one determines the beam spot luminosity section-by-luminosity section

Δz-cut





- important parameter for pile-up protection
- cut can be safely tightened to 500 μm
- no contribution to systematic error

Conclusion

- IPC method was applied to 7 TeV CMS data
- systematic studies regarding parameters were performed
  - $\longrightarrow$ parameter dependencies systematically studied
  - $\longrightarrow$ improved setting of Δz cut
- contribution to total systematic error

References

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- photos taken from http://cms.web.cern.ch