Luminosity Measurement with the CMS Experiment

Joscha Knolle
on behalf of the CMS collaboration

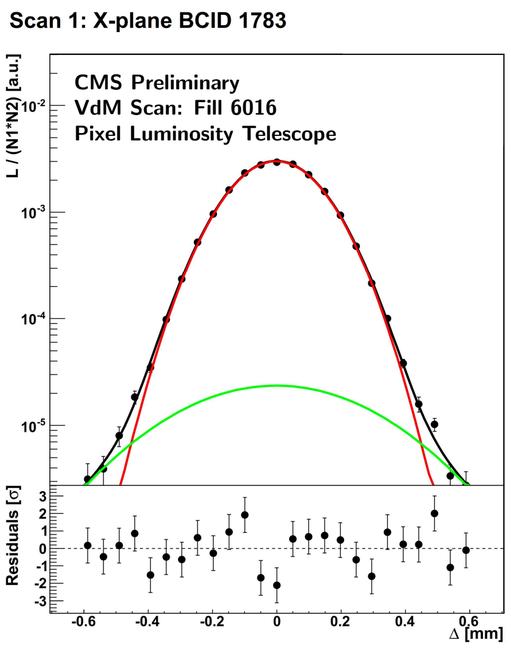
Luminosity

$$\underbrace{\frac{\mathrm{d}N}{\mathrm{d}t}}_{\text{event rate}} = \underbrace{\mathcal{L}}_{\text{luminosity}} \cdot \underbrace{\sigma}_{\text{cross section}}$$

- measure for collision rate
- important input to cross section measurements
- calibrated with Van der Meer method

Van der Meer Method

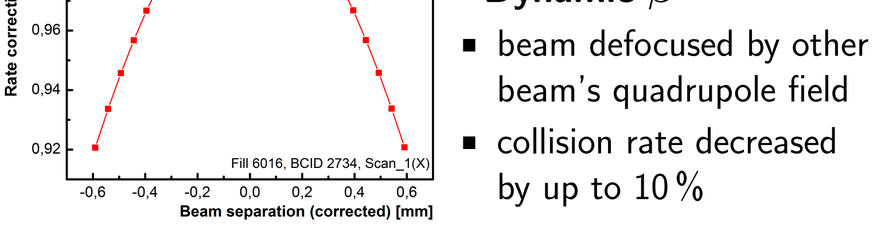
- **Van der Meer scan:** beams moved in steps across each other
- fit to event rate versus beam separation
- transverse width Σ of beam overlap from fit
- calibration constant σ_{vis} from two transverse Σ measurements and beam currents



$$\underbrace{\sigma_{\text{vis}}}_{\substack{\text{visible}\\ \text{cross}\\ \text{section}}} = \frac{2\pi \overbrace{\Sigma_x \Sigma_y}^{\substack{\text{beam overlap size}}} \overbrace{R_0}^{\text{peak rate}}}{\underbrace{N_1 N_2}_{\text{number of protons}} \underbrace{f_{\text{LHC}}}_{\substack{\text{revolution}\\ \text{frequency}}}}$$

Orbit Drift

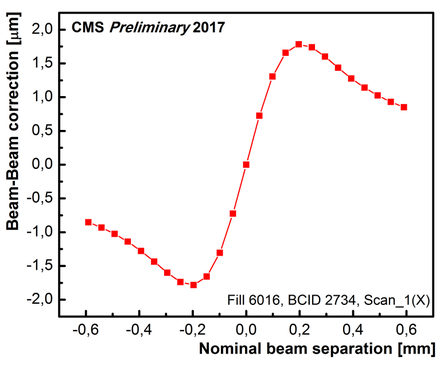
- beams can drift off their nominal positions
- beam separation varies over duration of scan step
- use LHC beam position monitoring systems
- interpolate between head-on positions



Beam-Beam Effects

Beam-beam deflection

- beam deflected by other beam's electrical field
- actual beam separation larger than expected

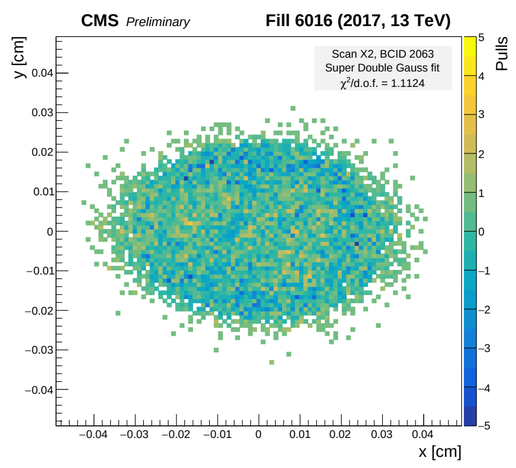


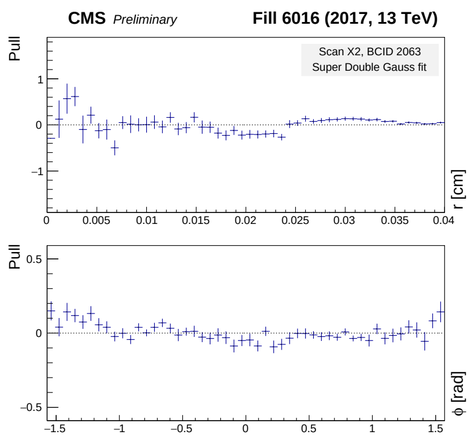
Dynamic $\beta^\star$

- beam defocused by other beam's quadrupole field
- collision rate decreased by up to 10 %

XY Correlations

- Van der Meer method assumes factorizable beam shapes
- **Beam imaging scan:** one beam fixed, other beam moved across
- probe of scanned component of resting beam's proton density
- 2D proton density reconstructed from simultaneous fit
- modeled with 2D Gaussian distributions with correlation terms
- use fit result to compute correction on σ_{vis}
- best fit: Super Double Gaussian (SupDG)

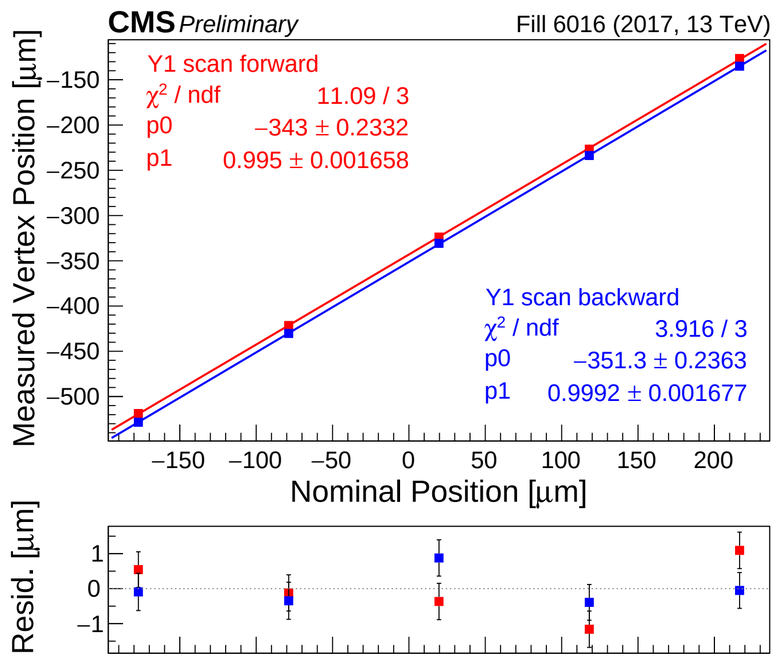




$$\underbrace{-w_N g_N(x,y)}_{\substack{\text{negative narrow, Gaussian, flattens central part}}} + \underbrace{w_M g_M(x,y)}_{\substack{\text{main Gaussian with largest weight}}} + \underbrace{w_W g_W(x,y)}_{\substack{\text{wide Gaussian, enlargens tail}}}$$

Length Scale Calibration

- limited accuracy of nominal beam positions from LHC magnet currents
- use sub-micron accuracy of beamspot reconstruction with CMS tracker
- **Length scale scan:** beams moved back and forth at constant separation
- linear fit to measured versus nominal position
- slope $\neq 1$ used as correction



Bunch Current Measurement

- proton numbers from bunch current measurements with LHC systems
- measurement affected by spurious charges not contributing to collisions

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Scan program