Towards a high-precision luminosity measurement for the 2016 proton–proton data-taking period at $\sqrt{s} = 13\,\text{TeV}$

Joscha Knolle, Rafael Sosa & Oleksii Turkot

Luminosity Measurement

Luminosity

$$\frac{\mathrm{d}N}{\mathrm{d}t} = \mathcal{L} \cdot \sigma$$

event rate — cross section

- measure for collision rate
- important input to cross section measurements
- calibrated with Van der Meer (VdM) method
- monitored over full run period

Normalization

Cross sections of the luminometers are calibrated in a dedicated VdM fill.

Systematic Uncertainties

XY correlations	0.9 %
Beam current calibration	0.3 %
Ghosts and satellites	0.4 %
Length scale	0.8 %
Orbit drift	0.4 %
Beam-beam deflection	0.4 %
Dynamic $\beta^\star$	0.5 %

Integration

The calibrations are extrapolated to physics run conditions and their validity over all of the run period is evaluated.

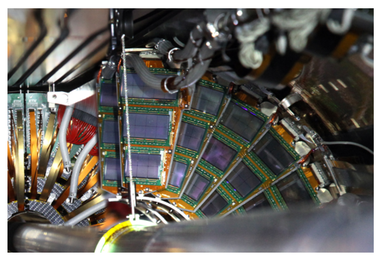
Systematic Uncertainties

Internal stability	0.5 %
Cross-detector stability	1.5 %
Linearity	0.6 %
Dynamic inefficiency	0.3 %
Afterglow corrections	0.9 %
CMS deadtime	0.5 %

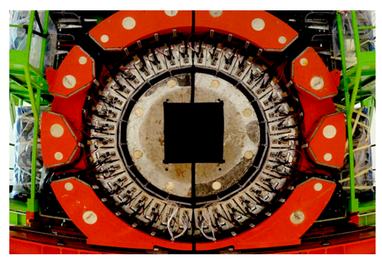
Cross-Detector Stability

Luminosity Detectors (Luminometers)

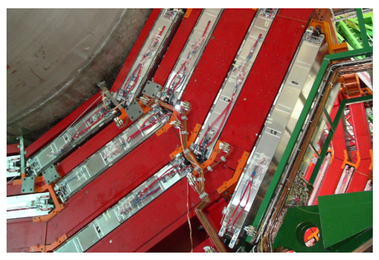
Pixel Cluster Counting

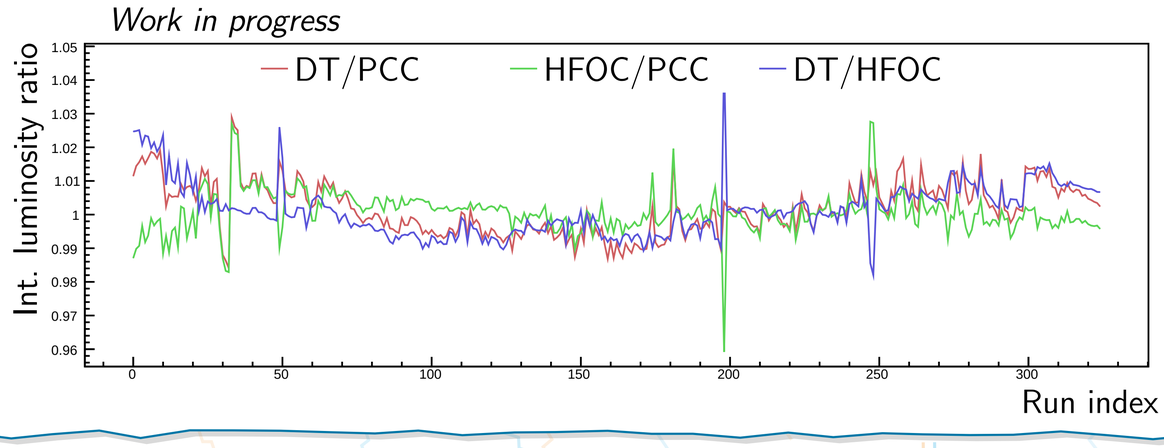


HF (OCcupancy-based)



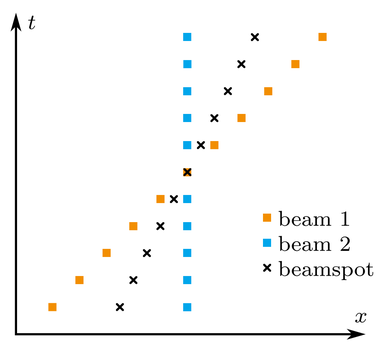
muon Drift Tubes





XY Correlations

Beam Imaging Method

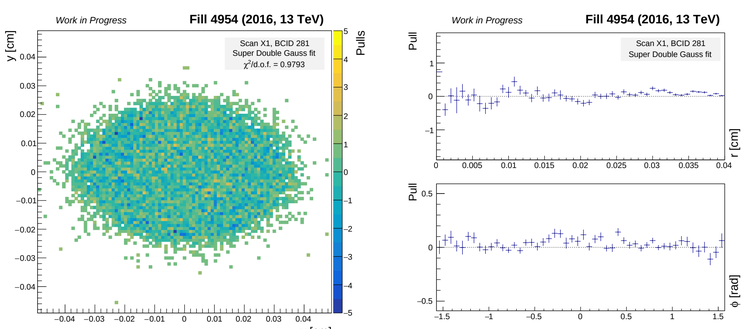


- beam imaging scan: one beam at fixed position, other beam moved across
- probe of scanned component of resting beam's proton density
- 2D beam shapes reconstructed from simultaneous fit of four scans
- modeled with 2D Gaussian distributions including correlation terms

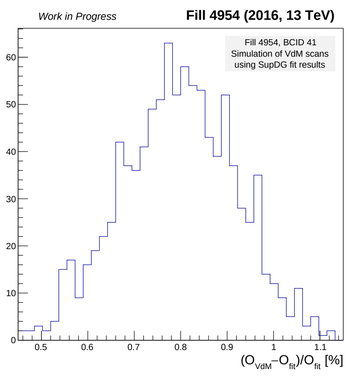
Fit Results

best fit: "Super Double Gauss"

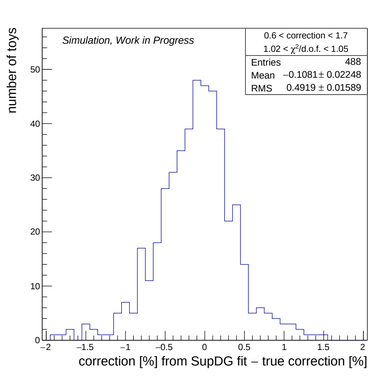
Gaussian with large weight
− narrow Gaussian
(flattens central part)
+ wide Gaussian
(enlargens tails)



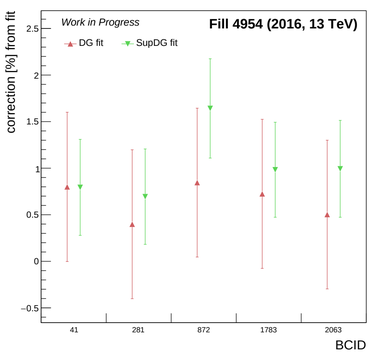
Bias Evaluation

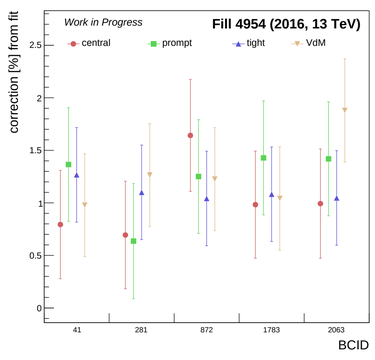


- VdM method biased by assumption of factorizable beam shapes
- ← estimate bias by simulation of VdM scans with reconstructed beam shapes
- → evaluate precision of bias estimation with toy models



Results





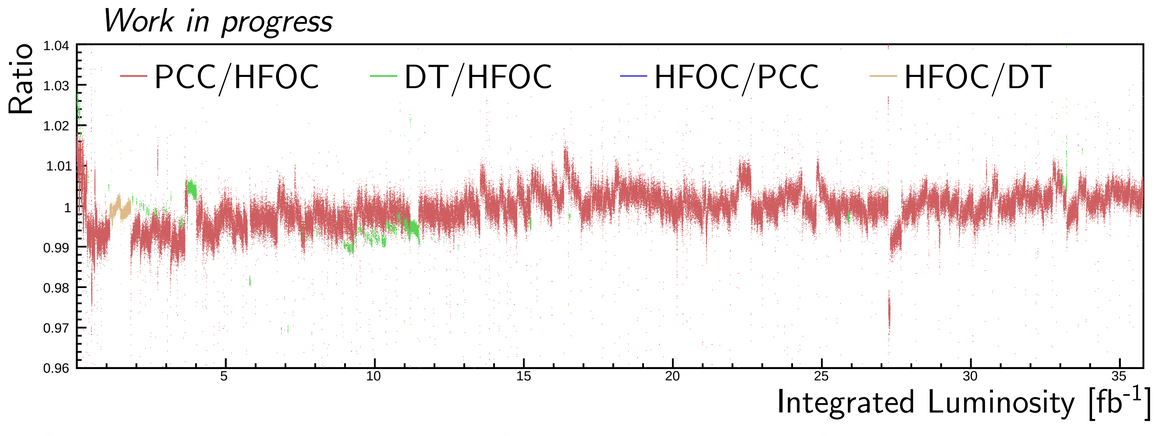
- previously: 0.8 % correction with 0.9 % uncertainty
- improved: 1.0 % correction with 0.5 % uncertainty
- good agreement between different bunch crossings and datasets

↑ Luminometer Ratios

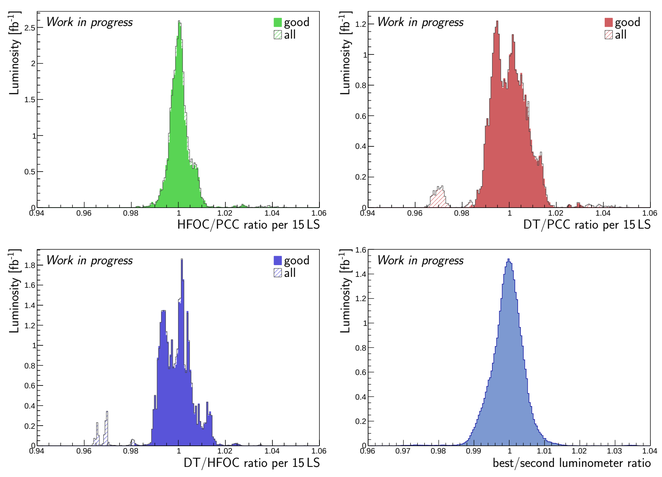
- HFOC, DT are cross-calibrated to PCC ⇒ comparison to identify unstable periods of the detectors
- if only one luminometer disagrees, exclude it from luminosity computation
- DT shows drift over the year ⇒ not a good reference for stability evaluation

Reference Ratio ↓

- "best" luminometer: detector with best intrinsic precision that doesn't show bad behaviour in cross-detector comparison
- "second" luminometer: as reference for evaluation of residual instabilities
- best/second is mostly PCC/HFOC, but important other contributions



Stability Evaluation



Results

RMS of ratio distributions

HFOC/PCC	0.53 %
DT/PCC	0.71 %
DT/HFOC	0.68 %
best/second	0.47 %

- residual instabilities result in uncertainty of 0.5 %
- improvement from inclusion of third luminometer into cross-detector comparisons

Conclusion

So far, the uncertainty on the integrated luminosity, as documented in PAS–LUM–17–001, is 2.5 %.

With these new results, the overall uncertainty could be reduced to 1.8 %.