Stability of LHCb luminosity counters

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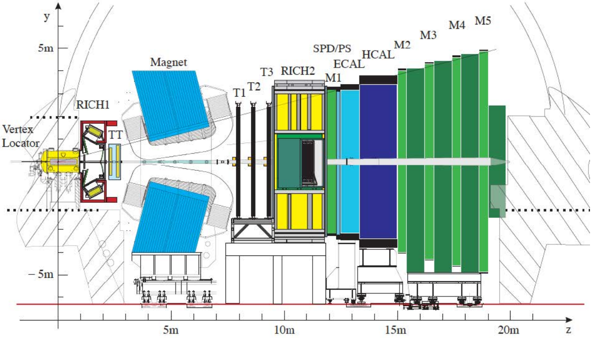
Outline

LHCb experiment

- Single-arm forward spectrometer, $2 < \eta < 5$ (40% of b-hadron in 4% solid angle)
- $\sim$45kHz $b\bar{b}$,$\sim$1MHz $c\bar{c}$ pairs at $13\,\mathrm{TeV}$ and $\mathcal{L} = 4 \times 10^{32}\mathrm{cm}^2\mathrm{s}^{-1}$
- Excellent tracking, vertex and PID performance
- Sophisticated hardware (Level 0) and software (High Level) triggers



JINST 3 (2008) S08005

LHCb luminosity measurement

- Crucial for production measurement
- Luminosity measurement was used in 54 LHCb papers:

Run1

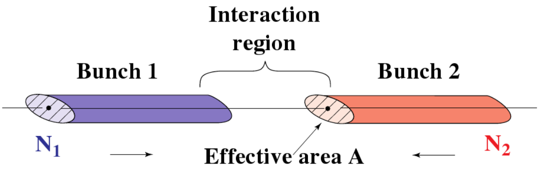
topics	W, Z	Υ	$J/\Psi, \Psi(2S)$	c	b	t	Beyond SM
$N_{publication}$	14	6	12	4	5	2	2

Pile-up monitoring at LHCb

- Counting pile-ups μ:
  - *N* interaction per bunch crossing (LHCb: $\mu \approx 1$)
- Measured in ∼1kHz random events with "luminosity counters" :
  - VELO: *N* tracks, vertices, upstream hits, backward hits
  - SPD pre-shower : *N* hits
  - Calorimeters : transverse energy
  - Muon : *N* muons
- μ was measured with "log-zero" (zero count) method:
  - μ satisfied Poisson distribution
  - $\mu = -\log(P(0))$, P(0) is the fraction of empty events
  - Small beam-gas background is estimated from non-colliding bunches and subtracted with : $\mu_{vis} = \mu_{bb} - \mu_{be} - \mu_{eb}$

Method for luminosity measurement

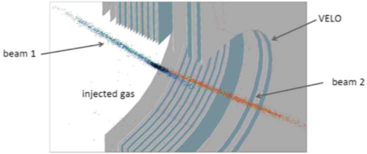
- Two kind of approaches:
  - Indirect: Use previous measurement or theoretical prediction of the absolute value of the interested cross section (e^+e^- collider)
  - Direct: Use the geometric properties and particle distributions inside the colliding beams (hadron collider)
- Luminosity can be determined with:
  $\int \mathcal{L}dt = N_1 N_2 f \int \int \rho_1(x,y)\rho_2(x,y)dxdy = \frac{N_{vis}}{\sigma_{ref}}$
  - f is the frequency of collisions, $N_{1,2}$ are bunch populations, $\rho_{1,2}$ are bunch profiles

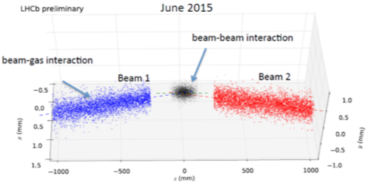


- At LHCb the luminosity is measured by absolute calibration (σ_{vis}) and relative monitoring (N_{vis})

Absolute calibration of $\mathcal{L}$–Beam gas imaging (BGI)

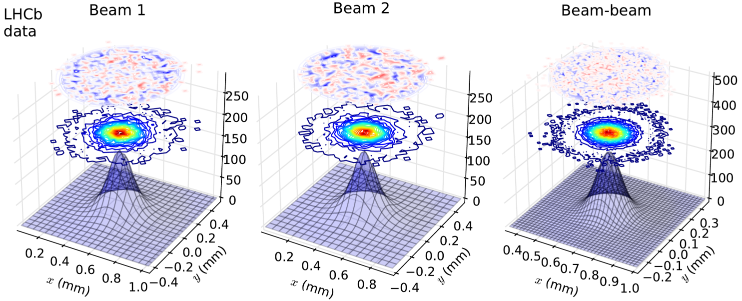
- Main difficulty : $\int\int \rho_1(x,y)\rho_2(x,y)dxdy$
- Find $\rho_{1,2}$ from beam images recorded with beam-gas interactions [NIM A 553 (2005) 388]
- Inject a tiny amout of gas using injection System for Measuring the Overlap with Gas (SMOG)
- SMOG can be used as a fixed target (for heavy ion physics)





Absolute calibration of $\mathcal{L}$–BGI

- Beam profiles are unfolded with VELO spatial resolution



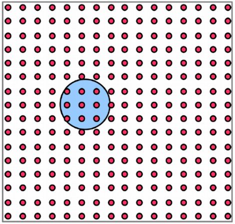
2D fit for one bunch pair as an example. Pulls are shown by color in $\pm 3\sigma$ range in the top.

- The best BGI luminosity calibration precision (8 TeV data) : 1.43% [J. Instrum. 9 (2014) P12005]

Absolute calibration of $\mathcal{L}$–Van der Meer scan

- Idea is to integrated out the ρ by sweeping one beam across the plane [CERN ISR-PO-68-31]:

$$\int\int \rho_1(x+\Delta x, y+\Delta y)\rho_2(x,y)d\Delta x d\Delta y dxdy = 1$$



- The σ can interpretative as:

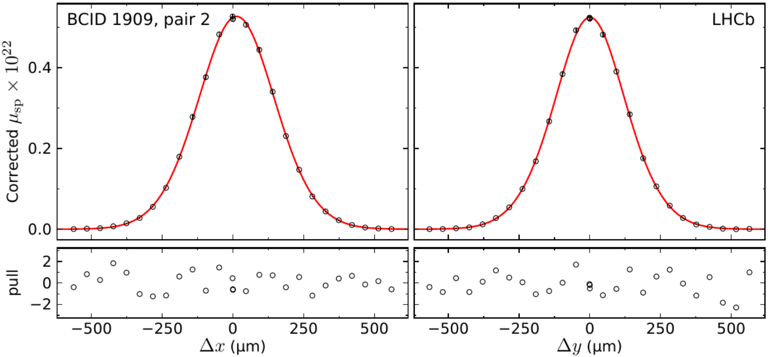
$$\sigma = \int\int \mu(\Delta x, \Delta y) d\Delta x d\Delta y dxdy / N_1 N_2$$

- Works for any $\rho_{1,2}$ and any LHC crossing angle
- If the $\rho_{1,2}$ factorizable in x,y:

$$\sigma = \frac{\int \mu(\Delta x, y_0) d\Delta x \cdot \int \mu(x_0, \Delta y) d\Delta y}{\mu(x_0, y_0) N_1 N_2}$$

- Crossing point "x_0, y_0" may be chosen arbitrarily [NIM, A 654 (2011) 634]

Absolute calibration of $\mathcal{L}$–Van der Meer scan



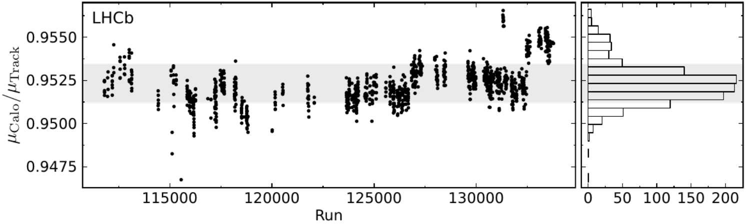
μ in one bunch crossing in X, Y scans, fit to sum of Gaussians.

$$\sigma = \frac{\int \mu(\Delta x, y_0) d\Delta x \cdot \int \mu(x_0, \Delta y) d\Delta y}{\mu(x_0, y_0) N_1 N_2}$$

- Main method for LHCb luminosity measurement

Relative $\mathcal{L}$ monitoring - Counter stability

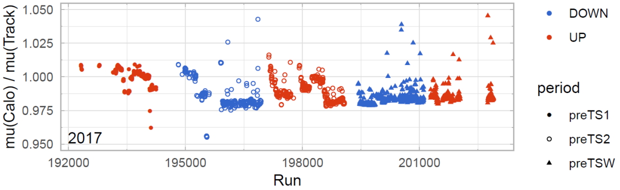
- Ideally pile-up ratio between different lumi counters should be constant
- This allows
  - Powerful cross checks
  - To estimate systematic errors

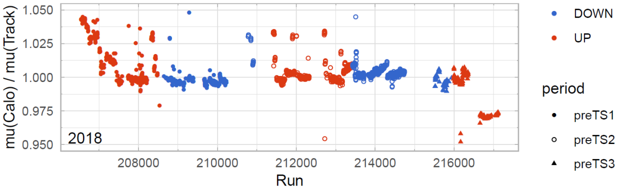


- Systematic uncertainty of counter stability in Run1 is 0.12$\sim$0.14%

Stability problems in Run2

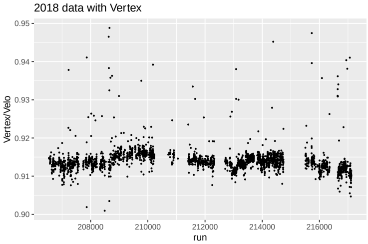
- Instability of CaloEt+SPD gives a large systematic uncertainty in Run2$\sim$3% (in Run 1 similar spread in pp was 0.12$\sim$0.14% only)



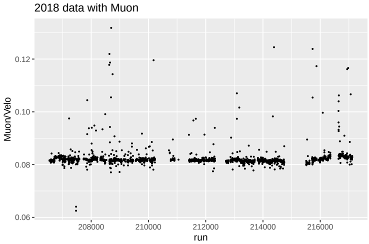


Stability of Velo, Vertex and Muon

- Vertex/Velo is stable across runs $\sim$0.3%
- Vertex has common systematics to Velo, better use other counter : Muon, SPD, CaloEt
- For Muon/Velo the stability is at the level of 4%



Vertex/Velo within fill for 2018.



Muon/Velo within fill for 2018.

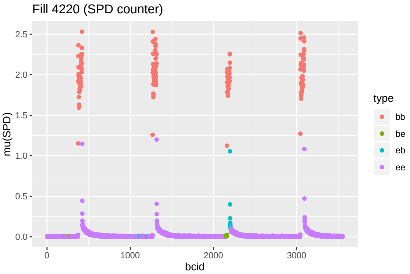
SPD surroundings are activated by irradiation

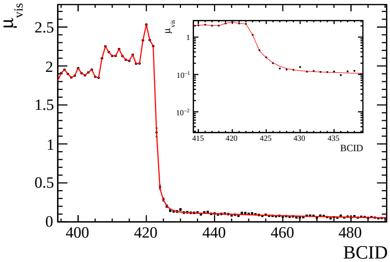
- Fast and slow "after glow" exponentials + (possibly?) spill over
- $\chi 2$ fit to the μ_{vis} distribution

$$\mu_j^{vis} = \mu_j^{true} + \sum_{i<j}^{bb} \mu_{bb,i}^{true}(c_1 e^{\frac{-(j-i)\Delta t}{\Delta T_1}} + c_2 e^{\frac{-(j-i)\Delta t}{\Delta T_2}}) + \mu_{j-1}^{true} * spill\_over$$

where $\mu_j^{true} = 0$ for ee, μ_{bb}^{true} for bb

- Fit example for fill 4220:





SPD after glow not stable (2015 vs 2018)

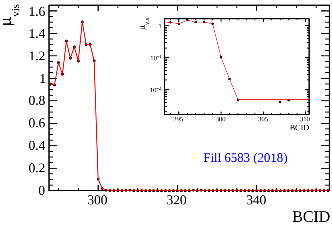
Fill	c_1	$\Delta T_1/25\text{ns}$	c_2	$\Delta T_2/25\text{ns}$	sp
4220 (2015)	0.482	1.492	0.004	71.071	0.383
6583 (2018)	0.939	1.132	0.002	63.082	0.194

Try CaloEt+SPD. Fit function:

$$\mu^{vis}_{bb,j} = \mu^{true}_{bb,j} + \mu^{true}_{bb,j-1} * frac1 + \mu^{true}_{bb,j-2} * frac2$$

Fit results for CaloEt+SPD:

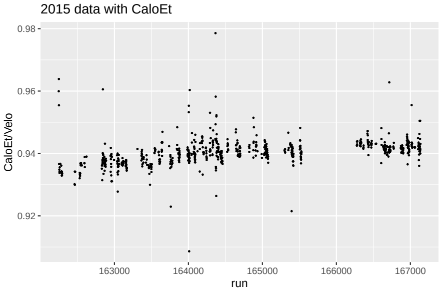
Fill	frac1	frac2
4220 (2015)	4.458e-02	3.022e-03
6583 (2018)	7.635e-02	1.575e-02

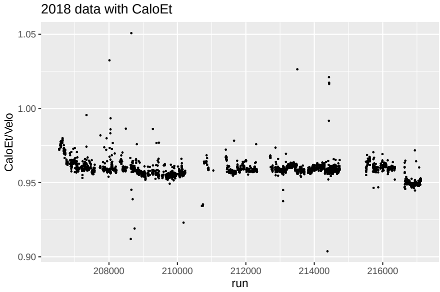


Also not stable, try CaloEt.

Stability of CaloEt across years

- CaloEt does not suffer from after glow or spill over (checked in fills 4220 and 6583), but has large noise in *ee* ($\sim$3%)
- Beam-gas background from beam2 should be small for CaloEt
- Idea : Use $\mu_{bb} - \mu_{be}$ instead of $\mu_{bb} - \mu_{be} - \mu_{eb}$ to cancel *ee* noise
- Standard deviation(SD) for 2015-2018 are 0.48%, 0.40%, 0.61% and 0.73% respectively





Summary

- CaloEt+SPD instability is caused by the activation of the SPD surroundings
- Such effect is unstable across years (Hard to correct)
- Systematics of counter stability is much reduced when using $\mu_{bb} - \mu_{be}$ for CaloEt instead of $\mu_{bb} - \mu_{be} - \mu_{eb}$ for CaloEt+SPD
- Such problems can be avoid if the emittance scans will be added in the beginning and the end of each fill
- Collaboration work with Vladislav Balagura (LLR –Ecole polytechnique/CNRS/IN2P3)

Thanks!