Relative bunch population and ghost charge measurements from LHCb beam-gas rates

Jaap Panman
CERN
For the LHCb collaboration

LHCb beam-gas data
Bunch-to-bunch normalization
Ghost charge measurement
SMOG preview
LHCb detector geometry
(beam 1 from the right)

Important for the following:
- VELO (vertex detector)
- Trigger detectors:
  - forward (beam 1): calorimeter
  - backward (beam 2): PU sensors in VELO

High precision vertex location measurements with VELO

Close proximity of vertex measurements to beamline (6 mm)

Good acceptance close to beam direction
Detail of VELO with PU sensors
PU used for the trigger
VELO is the main track-reconstruction device for this analysis

Beam 1 from left
Asymmetric VELO geometry asymmetric performances for the two beams
Vertex resolution depends on number of participating tracks and $z$

Vertex resolution for beam-beam events at $z = 0$ as a function of $n$

$z$ dependent vertex resolution for beam 1 and beam 2 events
Measurements in 2011

- Intermediate energy
- 7 TeV data
  - May
  - October

Concentrate here on the October data
Increased statistics compared to physics running by switching off the pumps near the VELO
Factor 5 pressure increase

Counting beam-gas interactions as measure of the beam intensity works if:
- There is no background (e.g. beam-beam interactions)
- Trigger efficiency is independent of $\mu$ (average interaction rate)
x vs z-coordinate of vertex distributions

FW (blue), BW (red), both (black) track asymmetry used to select the events

Outside the central region, events are always asymmetric due to acceptance!
z-coordinate of vertex
distributions

FW-BW track asymmetry used
to select the events

Features in the beam-beam
data are due to the trigger
For BB the trigger only accepts
events with a vertex with
$|z| > 300\,\text{mm}$
The BB peak is coming from
pile-up.

RF±1-main background visible
Shaded regions are used for
normalization
Compare single beam with beam-beam and “empty” slots in beam-gas region

Average profiles are very similar

Also the beam in the “empty” slots has a similar width (difference < 10%)
Simple event counting – normalized to the total count per beam

Use shaded normalization regions (no background)

Vertex count per bunch ID
Compare with FBCT
Red points are from colliding pairs
Black points from single bunches

LHCb preliminary
Display the ratio of BG/FBCT versus BCID (counting at LHCb)

Typical statistical errors for BG counting
- beam 1 bunches: 1.8%
- beam 2 bunches: 1.2% (better acceptance)

But $\chi^2$/ndf is close to 1.6
So there are additional systematic errors
Display the ratio of BG/FBCT versus FBCT

No clear slope
Display the ratio of BG/FBCT versus the BQM bunch length measurement

No clear slope
Fill 1653

Fit to slope BG/FBCT in time slices

Jaap Panman (CERN)

LHCb beam-gas rates

LumiDays 2012
Fill 1658

Fit to slope BG/FBCT in time slices
Fill 2234

Fit to slope BG/FBCT (lst 3 hours)

Beam1 1-par fit:
data points: 36
Slope = 1.0945 +/- 0.0398
\( \langle N_{pp} \rangle \approx 8.4 \cdot 10^{10} p \)
\( \chi^2 / ndf = 1.4950 \)

Beam2 1-par fit:
data points: 36
Slope = 1.0144 +/- 0.0190
\( \langle N_{pp} \rangle \approx 8.3 \cdot 10^{10} p \)
\( \chi^2 / ndf = 1.5824 \)

Total currents (DCCT)
\( N_{tot,1} \approx 302 \cdot 10^{10} p \)
\( N_{tot,2} \approx 298 \cdot 10^{10} p \)
“ghost charge” can be measured by counting beam-gas events in the nominally empty slots.

Trigger efficiency may vary for different RF buckets in a bunch-slot.

Measurement done in 2010
Shifting phase of digitization gate

Some systematics enter here due to potentially different conditions

Beam 1 (blue), beam 2 (red)
z-coordinate of vertex distributions

Simplest: shaded regions are used for normalization of all slots

<table>
<thead>
<tr>
<th>Fraction (in %)</th>
<th>Beam 1</th>
<th>Beam 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>first hour</td>
<td>0.797 ± 0.056</td>
<td>0.579 ± 0.030</td>
</tr>
<tr>
<td>last 3 hours</td>
<td>0.780 ± 0.028</td>
<td>0.574 ± 0.015</td>
</tr>
</tbody>
</table>

Raw numbers: Sum of empty slots divided by sum of filled slots, no trigger corrections etc.

We see no increase of ghost charge in this fill!

(Statistical errors only)
For final numbers some corrections need to be made
Corrections:

Trigger efficiency: 0.87 (0.73) for beam 1(2)

Important input from LDM: RF buckets equally distributed over slots for ghost charge (Adam Jeff)

Correction for DAQ problem: slot 1007 rejected in readout (2.8% using FBCT)

Improve statistical error by accepting all events for empty slots and single beam slots (beam-beam slots are counted in shaded region and corrected)

Compare to LDM data in same period

Fraction (in %)

<table>
<thead>
<tr>
<th>Method</th>
<th>Beam 1</th>
<th>Beam 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDM</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>last 3 hours</td>
<td>0.87</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Statistical error is <2%

Systematic error is 10–20%

Error dominated by trigger efficiency systematics

Rates are consistent with LDM
In fills 1653 and 1658: Beam-gas ghost rate evolution clearly seen
Separate count of slots near the filled bunches also displayed
## Ghost charge measurements during the VDM scans in fills 1653 and 1658

<table>
<thead>
<tr>
<th></th>
<th>UTC Epoch time [s]</th>
<th>Raw Ghost Charge [%]</th>
<th>Trig. eff. corrected Ghost Charge [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Middle of scan</td>
<td>Duration of scan</td>
<td>beam1</td>
</tr>
<tr>
<td><strong>Fill 1653</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALICE</td>
<td>1301217420</td>
<td>4080</td>
<td>0.57 ± 0.04</td>
</tr>
<tr>
<td>ATLAS</td>
<td>1301221710</td>
<td>3660</td>
<td>0.56 ± 0.06</td>
</tr>
<tr>
<td>CMS</td>
<td>1301225760</td>
<td>3600</td>
<td>0.64 ± 0.03</td>
</tr>
<tr>
<td>LHCb</td>
<td>1301230380</td>
<td>5040</td>
<td>0.70 ± 0.04</td>
</tr>
<tr>
<td><strong>Fill 1658</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATLAS</td>
<td>1301270730</td>
<td>2800</td>
<td>0.18 ± 0.03</td>
</tr>
</tbody>
</table>

Earlier fills – 1653 and 1658 summary
Gas injection system: fill beam pipe in VELO region with a little bit of Neon

Tested and validated together with LHC vacuum group

Installed and ready for use in 2012

Very extensive safety: prefilled volume emptied through narrow restriction
Test during p–Pb run of 2011

Observe the expected rate increase of a factor 100
(Pumps-off alone gives an increase of a factor 5)

Great potential for fast and more precise measurements
- Beam-gas event statistics increased in 2011 by switching off pumps
- Ghost-charge measurement available and consistent with LDM
- Bunch-to-bunch intensity ratios can be obtained by event counting
- Bunch-to-bunch rates are similar to FBCT measurements
- SMOG was tested in 2012
- A further factor 20 in rate was achieved
- SMOG will be used in 2012 and will enhance all dedicated BG measurements