Overview of LHC luminosity calibration measurements

- **Introduction:**
  - Why luminosity calibration
  - Luminosity formulae and calibration methods

- **Experimental conditions of LHC calibration measurements**
  - 2009: 450 GeV
  - 2010: 3.5 TeV clear focus

- **Results**
  - 4 interaction points

- **Conclusions and outlook**
Acknowledgements

Many thanks to

- ALICE Collaboration
- ATLAS Collaboration
- CMS Collaboration
- LHCb Collaboration
- LHC machine groups
Direct luminosity determination

Will focus here on the two methods used at LHC:

- **Van der Meer method**
  - based on beam separation scans

- **Beam-gas imaging method**
  - based on beam-gas vertex reconstruction
Why luminosity determination is important

Rate = Luminosity x Cross section

- Allows to determine cross section of interaction processes on an absolute scale
  - At the LHC: Heavy flavour production, couplings of new particles, total (inelastic, elastic) cross section, ...

- Allows to quantify the performance of the collider
  - Important to verify experimental conditions, to understand quantitatively beam-beam effects, ...

Chronology

2009

- All experiments started off with a normalisation based on a generator model including detector simulation

  => uncertainties at the level of 20% for 450 GeV

- LHCb performed first direct luminosity normalisation at 450 GeV using the beam-gas imaging method (see later)

2010

- At 3.5 TeV, started off again with a normalisation based on a generator model including detector simulation

- Then, April-May, performed first direct luminosity measurement at each IP with van der Meer scans (+continuous beam-gas imaging normalisation, LHCb)
Van der Meer’s trick

See Ref. [1]

Consider single circulating & colliding bunch pair with zero crossing angle

\[ R = \sigma \cdot L = \sigma \cdot f N_1 N_2 \int \rho_1(x,y) \rho_2(x,y) \, dx \, dy \]

With transverse displacements \( \Delta_x \), \( \Delta_y \) of one beam w.r.t. the other:

\[ R(\Delta_x, \Delta_y) = \sigma \cdot L(\Delta_x, \Delta_y) = \sigma \cdot f N_1 N_2 \int \rho_1(x-\Delta_x, y-\Delta_y) \rho_2(x,y) \, dx \, dy \]

\[
\int R(\Delta_x, \Delta_y) \, d\Delta_x \, d\Delta_y = \sigma f N_1 N_2 \int \rho_1(x-\Delta_x, y-\Delta_y) \rho_2(x,y) \, dx \, dy \, d\Delta_x \, d\Delta_y
\]

\[
= \sigma f N_1 N_2 \int \rho_2(x,y) \left[ \int \rho_1(x-\Delta_x, y-\Delta_y) \, d\Delta_x \, d\Delta_y \right] \, dx \, dy
\]

\[
= \sigma f N_1 N_2 \int \rho_2(x,y) \, dx \, dy = \sigma f N_1 N_2
\]
**Factorization**

Assume \( x \)-\( y \) factorizable \( \rho_i(x,y) = \rho_{ix}(x) \rho_{iy}(y) \)

\[
L(\Delta_x, \Delta_y) = f N_1 N_2 \cdot \left[ \int \rho_{1x}(x-\Delta_x) \rho_{2x}(x) \, dx \right] \cdot \left[ \int \rho_{1y}(y-\Delta_y) \rho_{2y}(y) \, dy \right]
\]

\[
\frac{1}{h_x(\Delta_x)} = O_x(\Delta_x) \quad \frac{1}{h_y(\Delta_y)} = O_y(\Delta_y)
\]

\[
L(\Delta_x, \Delta_y) = f N_1 N_2 O_x(\Delta_x) O_y(\Delta_y)
\]

Re-use van der Meer’s trick that for \( a=x \) or \( a=y \):

\[
\int O_a(\Delta_a) \, d\Delta_a = \int \rho_{2a}(a) \left[ \int \rho_{1a}(a-\Delta_a) \, d\Delta_a \right] \, da = \int \rho_{2a}(a) \, da = 1
\]

normalised to unity
**Result with factorization**

Measure $R$ while scan $\Delta_x$ (at $\Delta_y = \Delta_{y0}$), then while scan $\Delta_y$ (at $\Delta_x = \Delta_{x0}$)

\[
R(x, y) = \sigma f N_1 N_2 O_x(\Delta_x) O_y(\Delta_y)
\]

\[
R(x_0, y) = \sigma f N_1 N_2 O_x(\Delta_{x0}) O_y(\Delta_y)
\]

\[
R(x, y) = \frac{R(x, y_0) \cdot R(x_0, y)}{R(x_0, y_0)}
\]

\[
R_0 = R(x_0, y_0)
\]

\[
\int R(x, y) \, dx \, dy = \sigma f N_1 N_2 \cdot \int O_x(\Delta_x) O_y(\Delta_y) \, dx \, dy
\]

\[
= \sigma f N_1 N_2 \cdot \int O_x(\Delta_x) \, dx \cdot \int O_y(\Delta_y) \, dy
\]

\[
= \sigma f N_1 N_2
\]
It has been pointed out that the van der Meer method with bunched beams (like at the LHC) can equally be applied to the case with non-zero crossing angle (V. Balagura).

General formula with full crossing angle $\phi$:

$$\sigma = \frac{f N_1 N_2 \int R(\Delta_x, \Delta_y) \, d\Delta_x \cdot \int R(\Delta_x, \Delta_y) \, d\Delta_y}{\cos(\phi/2) \cdot R_0(\Delta_x, \Delta_y)}$$

(here shown for the case with x-y factorized)
Assumptions...

- Beams do not change when they are moved across each other
  - correct for (or neglect) beam-beam effects
  - correct for (or neglect) slow emittance growth
  - correct for (or neglect) slow bunch current decay

- Scan range sufficiently large to cover the distributions
  - negligible tails

- Relation between transverse displacement parameters (magnet currents) and the actual displacement is known on absolute scale
  - calibrate the absolute displacement scale with vertex detectors
Six vdM scan experiments performed so far (in 2010)

Typical procedure:
- Optimized IP luminosity (mini scans) in both planes
- Scanned first plane (X or Y)
- Set optimum on first plane (not always)
- Scanned second plane

For these scans the beam separation was limited to approx +/-6 beam sigmas.

In addition, length scale calibration
- Moved both beams in same direction
- Optimised locally the luminosity
- Compared reconstructed displacement of luminous region (tracking) with the displacement inferred from magnets settings.
- Alternatively: move only one beam relative to other

Remark: IP1+5 had zero crossing angle, while IP2 had 280 urad (vertical plane) and IP8 had 540 urad (horizontal plane).
LHC Measurements at 3.5 TeV/beam (2)

- 6 vdM scan experiments performed so far (in 2010)
- $k_b =$ number of stored bunches / beam
- $n_b =$ number of colliding pairs per IP

<table>
<thead>
<tr>
<th>LHC fill nr</th>
<th>date</th>
<th>IP scanned</th>
<th>$k_b$</th>
<th>$n_b$</th>
<th>N (p/bch)</th>
<th>$\Delta X$, $\Delta Y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1058</td>
<td>Apr 24</td>
<td>IP5 (CMS)</td>
<td>3</td>
<td>2</td>
<td>$\sim 1 \text{e}^{10}$</td>
<td>$\Delta X$, $\Delta Y$</td>
</tr>
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<td></td>
<td></td>
<td>IP1 (ATLAS)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>IP8 (LHCb)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1059</td>
<td>Apr 26</td>
<td>IP1 (ATLAS)</td>
<td>2</td>
<td>1</td>
<td>$\sim 1 \text{e}^{10}$</td>
<td>$\Delta X$, $\Delta Y$</td>
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<tr>
<td></td>
<td>Apr 26</td>
<td>IP8 (LHCb)</td>
<td></td>
<td></td>
<td></td>
<td>$\Delta X$, $\Delta Y$, $X_1,Y_1$</td>
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<td>1089</td>
<td>May 8</td>
<td>IP5 (CMS)</td>
<td>2</td>
<td>1</td>
<td>$\sim 2 \text{e}^{10}$</td>
<td>$\Delta X$, $-\Delta X$, $\Delta Y$, $-\Delta Y$</td>
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<tr>
<td></td>
<td>May 9</td>
<td>IP1 (ATLAS)</td>
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<td></td>
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<td>$\Delta X$, $-\Delta X$, $\Delta Y$, $-\Delta Y$</td>
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<tr>
<td>1090</td>
<td>May 10</td>
<td>IP2 (ALICE)</td>
<td>2</td>
<td>1</td>
<td>$\sim 2 \text{e}^{10}$</td>
<td>$\Delta X$, $\Delta Y$</td>
</tr>
</tbody>
</table>

- $\Delta X$, $\Delta Y$ : moving both beams by same amount (in opposite direction), minus sign indicating a reversed scan direction.
- $X_1,Y_1$ : moving only beam 1
The cross sections that are going to be presented here are **NOT** total or inelastic cross sections.

These cross sections are **detector-dependent cross sections** that, once calibrated, are used for monitoring the luminosity on an absolute scale.

These are typically “visible cross sections” (include geometrical and trigger acceptance, and possibly a reconstruction efficiency)
Beam-gas imaging method

Again, luminosity

\[ L = f N_1 N_2 \ 2c \ \cos^2(\phi/2) \ \int \rho_1(r,t) \ \rho_2(r,t) \ \ d^3r \ dt \]

- Beam interacts with residual gas around the interaction region
- Reconstruct beam-gas interaction vertices
  => sample transverse beam profile
  measure \textit{individually} the \( \rho_1 \) and \( \rho_2 \) and rebuild the overlap
  (measure also \( \phi \) and hourglass effect and and and…)
- Strength with respect to van der Meer method:
  \begin{align*}
  & (a) \text{ non disruptive, } \textit{do not affect the beams} ! \\
  & (b) \text{ can run fully parasitically during physics running time }
  \end{align*}
  => potentially smaller systematics uncertainties

Requires:
- (1) \text{ vtx detector resolution smaller (or at least comparable) to the beam sizes}
- (2) \text{ residual pressure & acceptance must be adapted to this method}
LHCb beam-gas imaging at 3.5 TeV

- 3.5 TeV, 2m optics at IP8, bunch intensity ~2e10 p/bch
- 13 bunches: 8 colliding, 5 not colliding per beam
- $L \sim 2.5 \times 10^8$ Hz/cm² per colliding pair
- 3 hours of data
- $z$ resolution ~ 0.1 mm

![Graph showing beam-gas imaging results](image)

- Expect 540 urad full angle ($\theta_1 + \theta_2$)
- $\theta_1 = 0.000206 \pm 0.000010$
- $\theta_2 = -0.000338 \pm 0.000016$
- $\delta_1 = -0.125 \pm 0.006$
- $\delta_2 = 0.136 \pm 0.011$

1/50 of b1-b2 sample in $z < 20$ cm
LHCb beam-gas combined with lumi region imaging

- Single bunch analysis is important
- Bunch-bunch luminous region can be used to constrain the single beam distributions:
  - Combine data with the beam-gas data
  - Much more stats in the bunch-bunch data

Fitting Luminous region - different bunches
Use the crossing bunches in the IP (-150 < z < 150 mm)

8 distinct colliding pairs
LHCb scans (fill 1059)

- 4 scans
- L0CaloRate corrected for small pile-up effect
- Checked rate at “working point” $R(\Delta x_0, \Delta y_0)$, red points, throughout the scans (~1h)
  - correct for small decay (~30 h life time)
LHCb comparing two scans

Comparison of two scans

1) both beams moved
2) only beam1 (×0.8 smaller step)
LHCb length scale calibration

- Comparing position of luminous region from the two scans (both beams moved vs single beam moved)

=> allows determining the length scale

(removes the beam1/beam2 size differences)
LHCb: deconvoluting two beams

- Using the full vtx reconstruction, the scans can also be used to deconvolute the individual bunch shapes (beam1 and beam2)

Scan 1 only

Profiles visible from moving frame (relevant for luminosity)

Scan 1 / Scan 2

<table>
<thead>
<tr>
<th></th>
<th>x1</th>
<th>x2</th>
<th>y1</th>
<th>y2</th>
</tr>
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<tbody>
<tr>
<td>RMS</td>
<td>37/37</td>
<td>37/36</td>
<td>38/37</td>
<td>45/43</td>
</tr>
<tr>
<td>Frac.1</td>
<td>0.61/0.60</td>
<td>0.73/0.70</td>
<td>0.68/0.69</td>
<td>0.57/0.42</td>
</tr>
<tr>
<td>σ₁ um</td>
<td>27/27</td>
<td>26/25</td>
<td>26/26</td>
<td>25/22</td>
</tr>
<tr>
<td>σ₂ um</td>
<td>43/42</td>
<td>50/46</td>
<td>46/45</td>
<td>55/48</td>
</tr>
</tbody>
</table>
LHCb beam-gas imaging results at 3.5 TeV  

- Agreement between two methods (vdm and beam-gas)
- Thin error bars include beam current normalisation uncertainty
- Thick error bars: without beam current normalisation uncertainty

**Putting it together in a plot**

Effective cross-section results (assuming ±8% for the $l^2$ error)

$$\sigma_P = \text{cross section of event with 2 or more RZVelo tracks}$$

![Graph showing cross section calculated per bunch and fill (errors: shape + bct).](image)

- BG average $63.6 \pm 6.4$
- VDM $59.6 \pm 6.0$
- Overall $61.6 \pm 6.2$

**LHCb preliminary**
LHCb beam-gas imaging at 450 GeV

- VELO only half closed around the beams!
- 450 GeV, 10m optics at IP8, bunch intensity ~ 1...2e10 p/bch
- L ~ 1...5 e26 Hz/cm² per pair
- up to 8 colliding pairs + 4 not colliding per beam

Absolute normalisation at 15% obtained (uncertainty dominated by bunch current normalisation)

- observed size
- size after deconvolution of the vtx resolution
- vtx resolution
ATLAS scans (fills 1059 and 1089)

see Ref. [7]

horizontal (fill 1059)

horizontal (fill 1089)
ATLAS scan fits

- Fit with double Gaussian (common mean) and constant bkg
- Similar for Y

$$R_x(x) = \frac{R_x(0)}{\sqrt{2\pi}} \left[ \frac{f_a e^{-(x-x_0)^2/2\sigma_a^2}}{\sigma_a} + \frac{(1-f_a) e^{-(x-x_0)^2/2\sigma_b^2}}{\sigma_b} \right]$$

$$\frac{1}{\Sigma_x} = \left[ \frac{f_a}{\sigma_a} + \frac{1-f_a}{\sigma_b} \right]$$

$$\mathcal{L} = \frac{n_b f r_1 I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$
## ATLAS results

### PRELIMINARY

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>$\sigma_{\text{vis}}^{\text{meas}}$ (mb)</th>
<th>$\sigma_{\text{vis}}^{\text{PYTHIA}}$ (mb)</th>
<th>$\frac{\sigma_{\text{vis}}^{\text{PYTHIA}}}{\sigma_{\text{vis}}^{\text{meas}}}$</th>
<th>$\sigma_{\text{vis}}^{\text{PHOJET}}$ (mb)</th>
<th>$\frac{\sigma_{\text{vis}}^{\text{PHOJET}}}{\sigma_{\text{vis}}^{\text{meas}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUCID_Event_AND</td>
<td>12.40 ± 0.06 ± 1.36</td>
<td>15.7</td>
<td>1.27</td>
<td>16.8</td>
<td>1.35</td>
</tr>
<tr>
<td>LUCID_Event.OR</td>
<td>40.18 ± 0.12 ± 4.42</td>
<td>46.7</td>
<td>1.16</td>
<td>53.4</td>
<td>1.32</td>
</tr>
<tr>
<td>L1_MBTS_1.1_paired</td>
<td>51.87 ± 0.21 ± 5.70</td>
<td>58.4</td>
<td>1.13</td>
<td>68.7</td>
<td>1.32</td>
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<tr>
<td>L1_MBTS_1_paired</td>
<td>58.65 ± 0.23 ± 6.45</td>
<td>66.6</td>
<td>1.14</td>
<td>73.7</td>
<td>1.26</td>
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<tr>
<td>MBTS_1_timing</td>
<td>50.4 ± 0.2 ± 5.7</td>
<td>57.6</td>
<td>1.14</td>
<td>67.8</td>
<td>1.35</td>
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<tr>
<td>Primary Vertex Counting</td>
<td>53.6 ± 0.2 ± 5.9</td>
<td>57.9</td>
<td>1.08</td>
<td>70.0</td>
<td>1.31</td>
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<table>
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<tr>
<th>Scan Number</th>
<th>$\sigma_{\text{vis}}$ (mb)</th>
<th>$\mathcal{L}_{\text{spec}}$ (10^{29} cm^{-2}s^{-1})</th>
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<td>1</td>
<td>12.15 ± 0.14</td>
<td>6.80 ± 0.08</td>
</tr>
<tr>
<td>2</td>
<td>12.55 ± 0.10</td>
<td>4.85 ± 0.03</td>
</tr>
<tr>
<td>3</td>
<td>12.73 ± 0.10</td>
<td>4.88 ± 0.09</td>
</tr>
<tr>
<td>1</td>
<td>39.63 ± 0.32</td>
<td>6.85 ± 0.06</td>
</tr>
<tr>
<td>2</td>
<td>40.70 ± 0.13</td>
<td>4.88 ± 0.01</td>
</tr>
<tr>
<td>3</td>
<td>40.77 ± 0.14</td>
<td>4.92 ± 0.02</td>
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<tr>
<td>1</td>
<td>51.14 ± 0.39</td>
<td>6.78 ± 0.05</td>
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<td>2</td>
<td>52.59 ± 0.16</td>
<td>4.87 ± 0.01</td>
</tr>
<tr>
<td>3</td>
<td>52.64 ± 0.16</td>
<td>4.90 ± 0.02</td>
</tr>
<tr>
<td>1</td>
<td>57.83 ± 0.43</td>
<td>6.79 ± 0.05</td>
</tr>
<tr>
<td>2</td>
<td>59.47 ± 0.18</td>
<td>4.89 ± 0.01</td>
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<td>3</td>
<td>59.43 ± 0.25</td>
<td>4.90 ± 0.02</td>
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<td>1</td>
<td>49.28 ± 0.31</td>
<td>6.76 ± 0.05</td>
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<tr>
<td>2</td>
<td>51.64 ± 0.23</td>
<td>4.87 ± 0.03</td>
</tr>
<tr>
<td>3</td>
<td>51.29 ± 0.24</td>
<td>4.93 ± 0.03</td>
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<td>1</td>
<td>53.48 ± 0.29</td>
<td>6.73 ± 0.05</td>
</tr>
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<td>53.64 ± 0.22</td>
<td>4.89 ± 0.03</td>
</tr>
<tr>
<td>3</td>
<td>53.78 ± 0.23</td>
<td>4.89 ± 0.02</td>
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</table>

- Using six different count rate methods

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty on $\sigma_{\text{vis}}$ (%)</th>
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<tbody>
<tr>
<td>Beam Intensities</td>
<td>10</td>
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<tr>
<td>Length Scale Calibration</td>
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<tr>
<td>Imperfect Beam Centering</td>
<td>2</td>
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<tr>
<td>Transverse Emittance Growth &amp; Other Sources of Non-Reproducibility</td>
<td>3</td>
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<tr>
<td>$\mu$ Dependence</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
</tr>
</tbody>
</table>

NB: 4.5% uncertainty if knew beam current perfectly
CMS scans (fill 1089) see Ref. [8]

Beam Offset vs. Time

Rate vs. Time

GVA time + 2h

-x to +x  +x to -x  -y to +y  +y to -y
Observed beam blow up during scans

- Beam width growth as calculated from the measured emittances during fill 1089 with LHC wire scanners. The slopes from the lines can be used to correctly extrapolate the measured widths to their corresponding values at the zero points of the scan.

- Note the zero-suppressed vertical scale
CMS scan fits

- x to +x

MeanX = -0.00971 +/- 0.0001
hX = 0.82 +/- 0.02
sigX1 = 0.0516 +/- 0.0004
sigX2 = 0.078 +/- 0.002
Chi2/dof = 2.5

+ x to -x

MeanX = -0.01040 +/- 0.0001
hX = 0.75 +/- 0.03
sigX1 = 0.0508 +/- 0.0005
sigX2 = 0.075 +/- 0.001
Chi2/dof = 1.6

- y to +y

MeanY = 0.0034 +/- 0.0001
hY = 0.53 +/- 0.04
sigY1 = 0.0508 +/- 0.0009
sigY2 = 0.0728 +/- 0.0010
Chi2/dof = 0.7

+ y to -y

MeanY = 0.0019 +/- 0.0001
hY = 0.72 +/- 0.02
sigY1 = 0.0546 +/- 0.0004
sigY2 = 0.079 +/- 0.001
Chi2/dof = 1.6
CMS results

$$R_{\text{Scan/MC}} = 1.007 \pm 0.003(\text{stat}) \pm 0.110(\text{syst}).$$

<table>
<thead>
<tr>
<th>Method</th>
<th>Efficiency</th>
<th>Visible Cross-section</th>
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<tbody>
<tr>
<td>Total Cross-section</td>
<td>=100%</td>
<td>71.3 mb</td>
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<tr>
<td>HF Coincidence</td>
<td>63.4%</td>
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<tr>
<td>Vertex Counting</td>
<td>73.6%</td>
<td>52.4 mb</td>
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<table>
<thead>
<tr>
<th>Error</th>
<th>Value (%)</th>
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<tbody>
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<td>Beam Background</td>
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<tr>
<td>Fit Systematics</td>
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<tr>
<td>Beam Shape</td>
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<td>Scale Calibration</td>
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<tr>
<td>Zero Point Uncertainty</td>
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<tr>
<td>Beam Current Measurement</td>
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<tr>
<td>Total</td>
<td>11.0</td>
</tr>
</tbody>
</table>

NB: if perfect current measurement, uncertainty: ~4%!
ALICE scans (fill 1090)

- one horizontal scan
- one vertical scan
ALICE scan fits

- Dashed line in double Gauss shows only primary Gaussian
- Single Gauss does not fit tail, however double Gauss as well (asymmetric tail for Y scan)
ALICE results

- Integrals
  - \( S_x = 152.17 \pm 0.67 \text{(stat.) Hz mm} \)
  - \( S_y = 162.20 \pm 0.69 \text{(stat.) Hz mm} \)

- Zero-separation rate with pile-up corrections applied (<4% correction)
  - \( R_{x\text{-scan}}(0,0) = 986.72 \pm 10.93 \text{(stat.) Hz} \)
  - \( R_{y\text{-scan}}(0,0) = 975.08 \pm 10.87 \text{(stat.) Hz} \)

- Luminosity and cross section
  - \( L = (1.576 \pm 0.027^\text{stat}) \times 10^{32} \text{ s}^{-1}\text{m}^{-2} \)
  - \( \sigma_{v_0} = 62.2 \pm 0.1 \text{(stat) mb} \)
    - used average \( R(0,0) = 980.90 \text{ Hz} \)
    - (cross section visible to V0, where V0 = fwd & bwd scintillator counters, both sides of IP, in coinc)

- Uncertainties
  1. Bunch intensity error dominated by DCCT baseline shifts and scale, 5% per beam
  2. V0 top rate discrepancy for X and Y scan … 2%
  3. Separation has 2 \( \mu \text{m} \) error (known from bump calibration) … 4%

- Overall systematic uncertainties yet to be finalized

- Single and double Gaussian fit results show that the result will stay within systematic uncertainties

- Numerical sum method does not have influence of fitting, and also independent from Gaussian approximations:
  \( \rightarrow \) Use this value as central value

**ALICE** \( \sigma_{v_0} = 62.2 \text{ mb } \pm 0.2 \% \text{(stat.)} \pm 8\% \text{(syst.)} \) (preliminary)
Bunch current measurement

- Both *Van der Meer* and *beam-gas imaging* methods require an absolute measurement of the bunch charge in order to produce an absolute luminosity measurement.

- LHC: each beam current is measured by two types of devices:
  
  **DCCT** (see Ref. [4,5])
  Measures the total current in the machine (also satellite bunches and uncaptured beam).

  **Fast BCT** (see Ref. [4,6])
  Measures total charge stored in a nominal 25ns bunch slot.

If no satellites and no uncaptured beam, then sum of Fast BCT bunch currents = total DCCT beam current (true to <2% level for the measurements presented here)
Bunch current uncertainty

- DCCT and Fast BCT still under commissioning
- Systematics due to:
  - DCCT scale normalisation
  - DCCT random noise (small…)
  - DCCT offset variations (drifts)
  - Fast BCT sensitivity to clock phase
  - Fast BCT numerical algorithms, “spillover”, …
- Currently, conservative estimate => ~10% error into the luminosity
- Largely dominating the luminosity uncertainty
- A more precise quantitative characterization of these errors and of their degree of correlation is still in progress
- May improve in the near future (both more analysis and more measurements)
Conclusions / summary

- First absolute normalisation of luminosity and cross section were performed at the LHC (450 GeV / beam and 3.5 TeV / beam)

- Two methods were used:
  - van der Meer method
  - beam-gas imaging method

- Results accuracy dominated by beam current normalisation uncertainty (~10%, being worked on)

- Potentially, could hope to aim for total uncertainty ~5% (future measurements)
  - will first have to work hard on the beam current normalisation
  - then on other smaller systematic uncertainties
Literature references