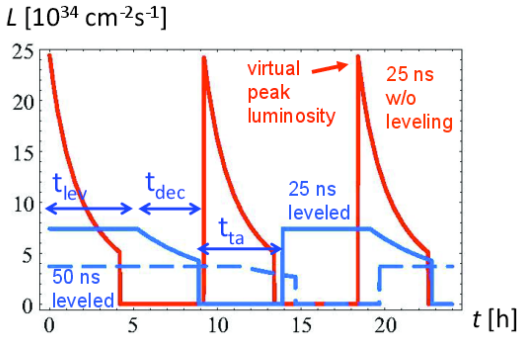
Measurement and Simulation of Luminosity Leveling in LHC via Beam Separation

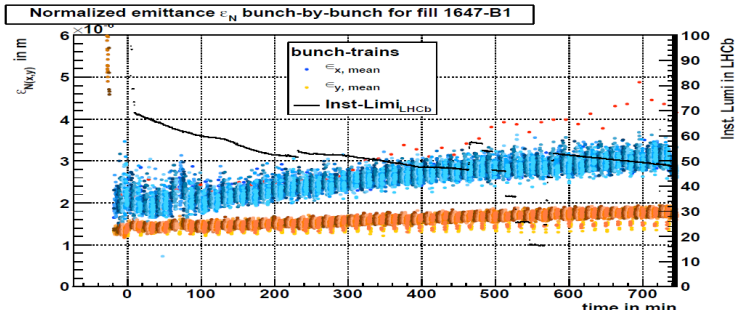
S. Paret, J. Qiang, LBNL
R. Alemany, R. Calaga, R. Giachino, W. Herr, D. Jacquet, G. Papotti, T. Pieloni, L. Ponce, M. Schaumann, CERN
R. Miyamoto, ESS

Outline

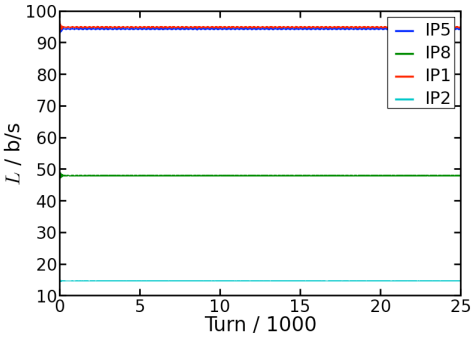
- Luminosity



- Collisions with offset in LHC



- Simulation of experiment



- Alternatives

Luminosity (L)

- Measure of productivity of a collider
- **Instantaneous Luminosity** (per collision):

# of particles/bunch

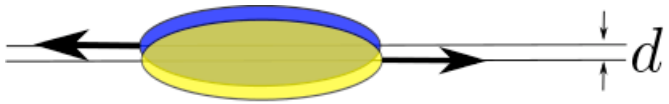
$$L_0 = \frac{N^2 f_0}{4\pi\epsilon\beta^*}$$

β function at collision point

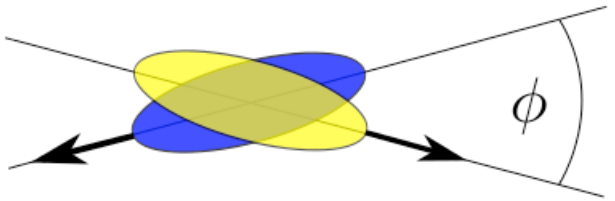
- Total production: **Integrated Luminosity =** $\int L\,\mathrm{d}t$

Collisions with Offset and Crossing Angle

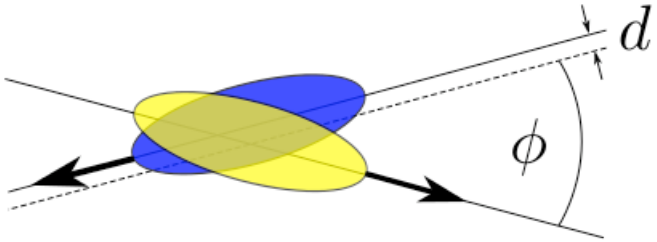
- Separation(offset) *d*



- Crossing angle ϕ



- Offset and crossing angle



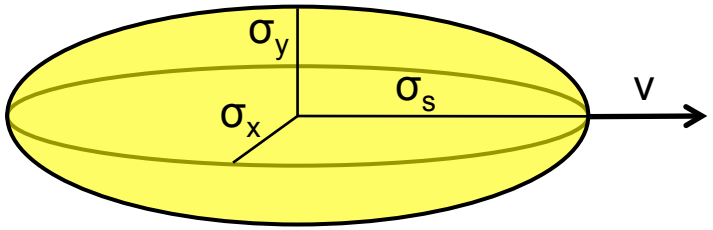
➔ Reduction of *L*

Luminosity with Offset and Crossing Angle

Reduced *L* with offset in *x* and crossing angle in *y* [1]:

$$L(d_x, \phi_y, \sigma_x, \sigma_y, \sigma_s) = L_0 \frac{e^{-\frac{d_x^2}{4\sigma_x^2}}}{\sqrt{1+\zeta^2}}$$

where $\zeta = \frac{\phi_y}{2}\frac{\sigma_s}{\sigma_y}$



[1] W. Herr, CERN-2006-002, CERN report, 2006

Luminosity Leveling

Target of *High-Luminosity LHC* upgrade:

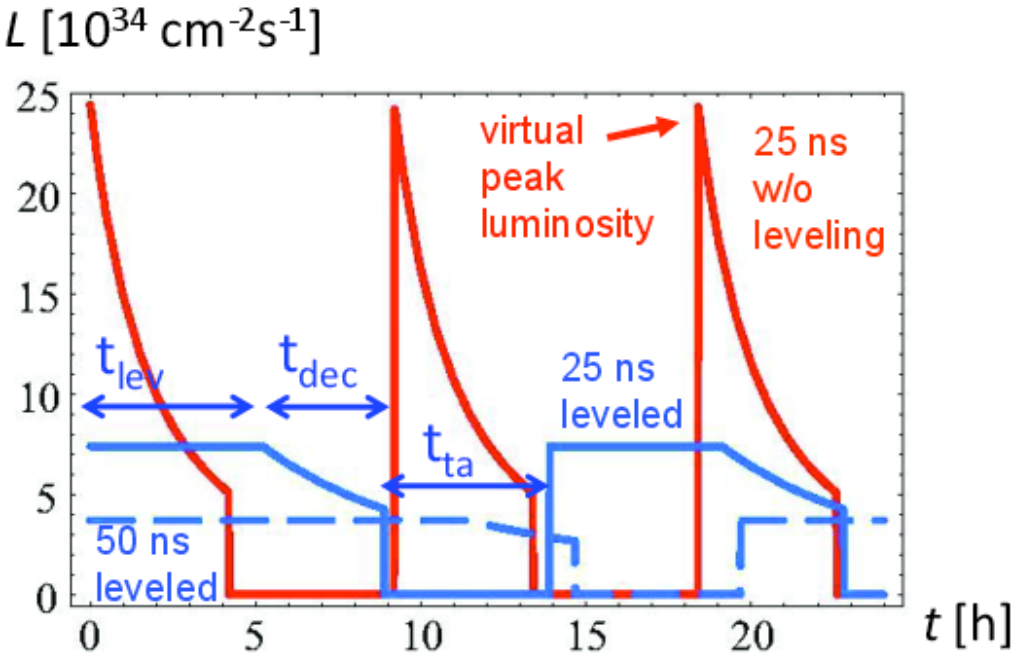
Increased integrated luminosity [2]

Problems:

- Limited **pile-up** capacity of experiments limits *L*
- Peak ***L* decays** quickly

➔Moderate constant *L* preferred:

Luminosity leveling



Courtesy O. Brüning [2]

[2] O. Brüning and F. Zimmermann, MOPPC005, IPAC12

Leveling Options

- Requirement: Reduce *L*
  - Reversibly
  - Locally
- Possible parameters:
  - Beta function
  - Offset
  - Crossing angle
  - …

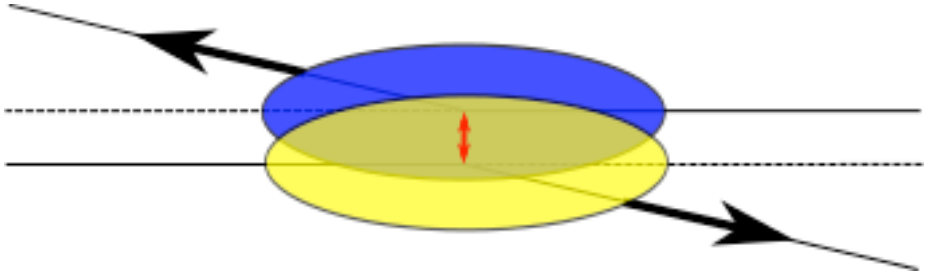
$$L_0 = \frac{N^2 n_b f_0}{4\pi\epsilon\beta^*}$$

$$L(d_x, \phi_y, \sigma_x, \sigma_y, \sigma_s) = L_0 \frac{e^{-\frac{d_x^2}{4\sigma_x^2}}}{\sqrt{1+\zeta^2}}$$

$$\zeta = \frac{\phi}{2}\frac{\sigma_s}{\sigma_x}$$

Beam-beam effects with offset

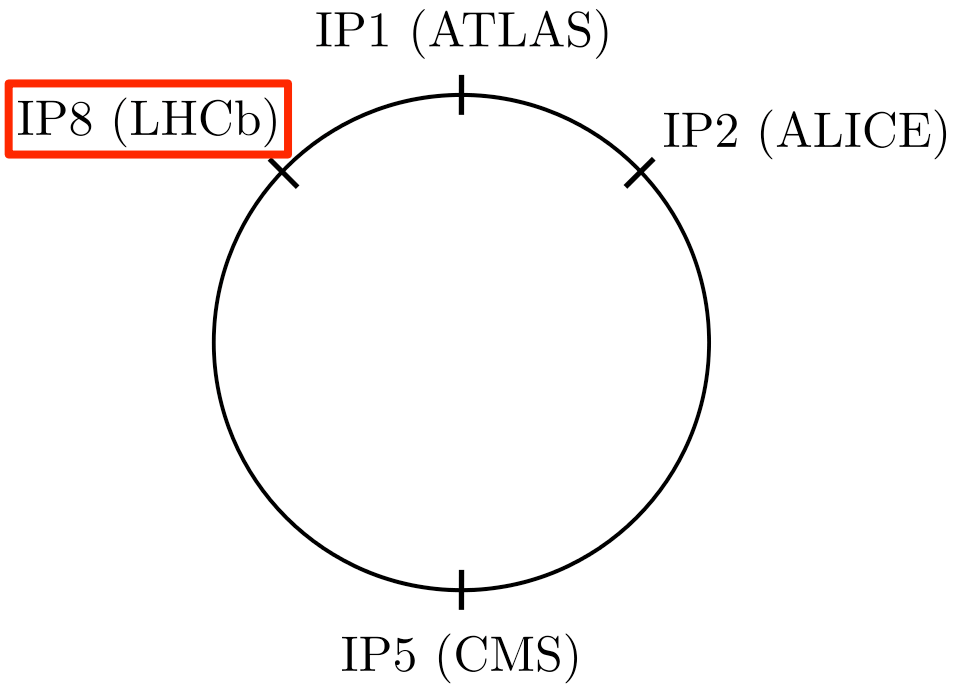
- Loss of symmetry
- Coherent beam-beam kick
  ➔ Deflection
- Decoherence
  ➔ Emittance growth [3]



[3] T. Pieloni et al., WE6PFP039, PAC 2009

Experimental Setup

- Collisions in 4 interaction points (IPs)
- Separation varied in IP8
  0 to 2.5 σ_x in 0.5 σ_x steps
- Measurement of emittance
  and *L* at all IPs



W. Herr et al., CERN-ATS-Note-2011-028 MD, 2011, G. Papotti et al., TUPZ025, IPAC 2011

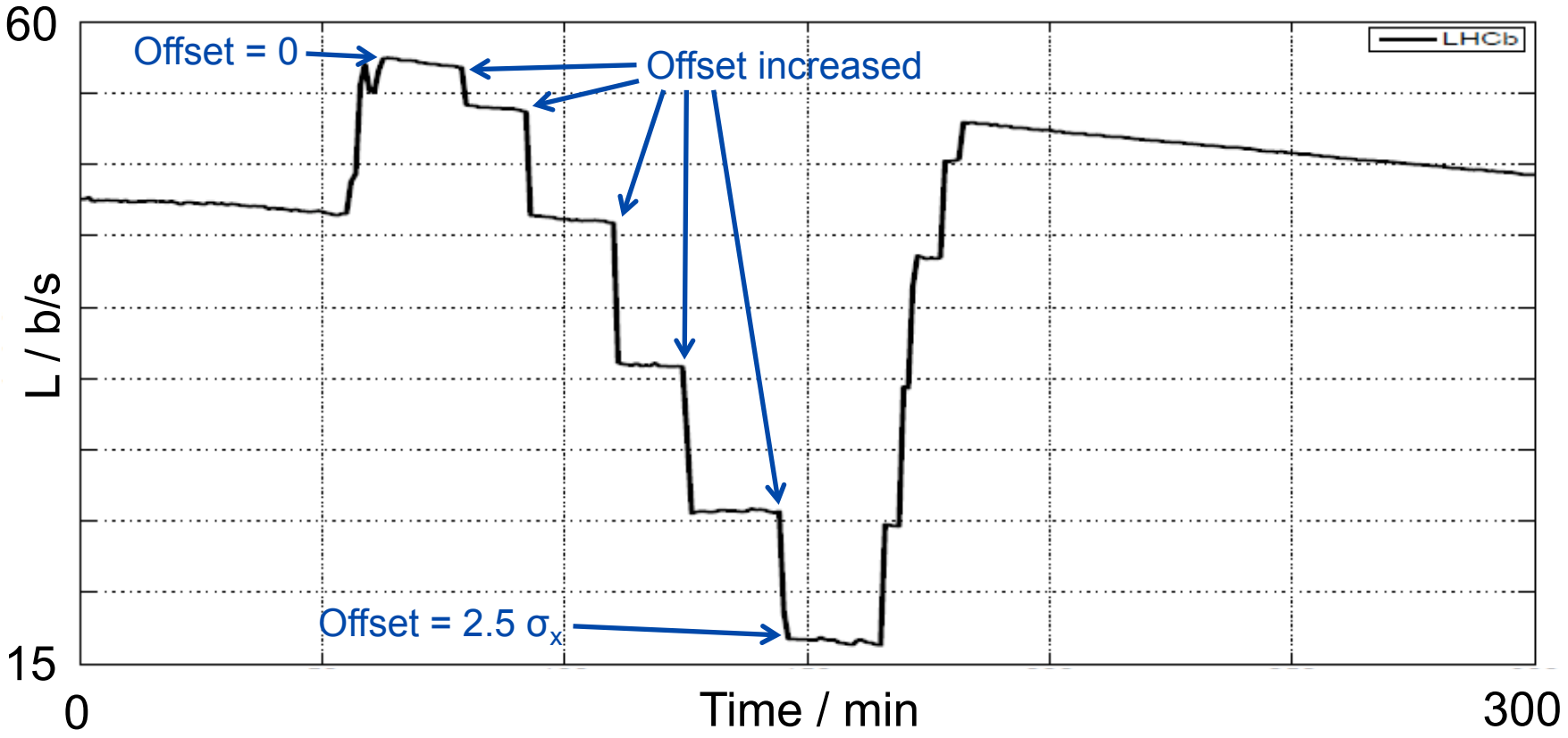
Beam Parameters

Parameter / Unit	Value
Q_x	64.31
Q_y	59.32
N	1.1×10^{11}
σ_s / cm	7.55
$\delta p/p$	1.1×10^{-4}
ϕ / μrad	120
bunch spacing / ns	75

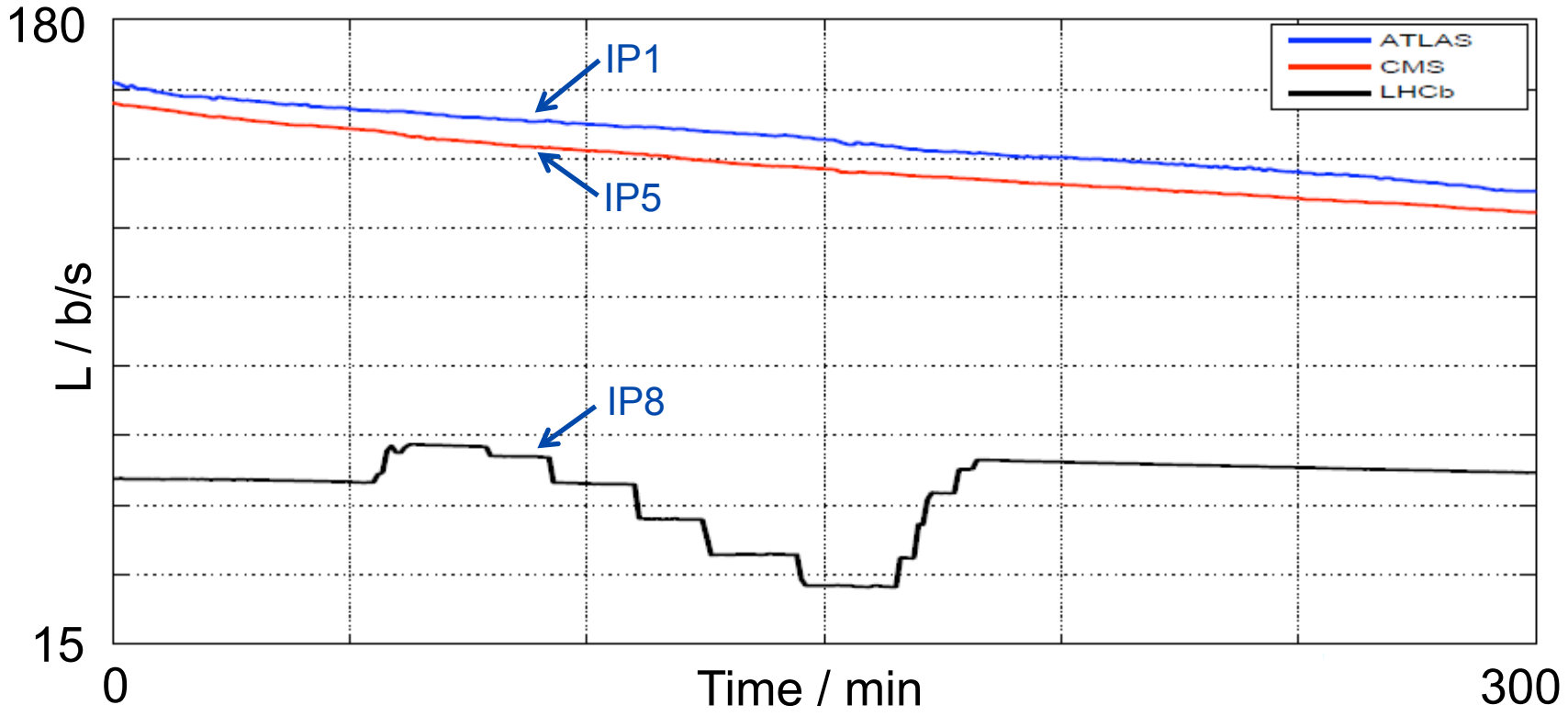
Beam cross-sections at IP8

Parameter / Unit	Beam1	Beam2
σ_x / μm	45	35
σ_y / μm	49	45

Measured Luminosity in IP8 (LHCb)

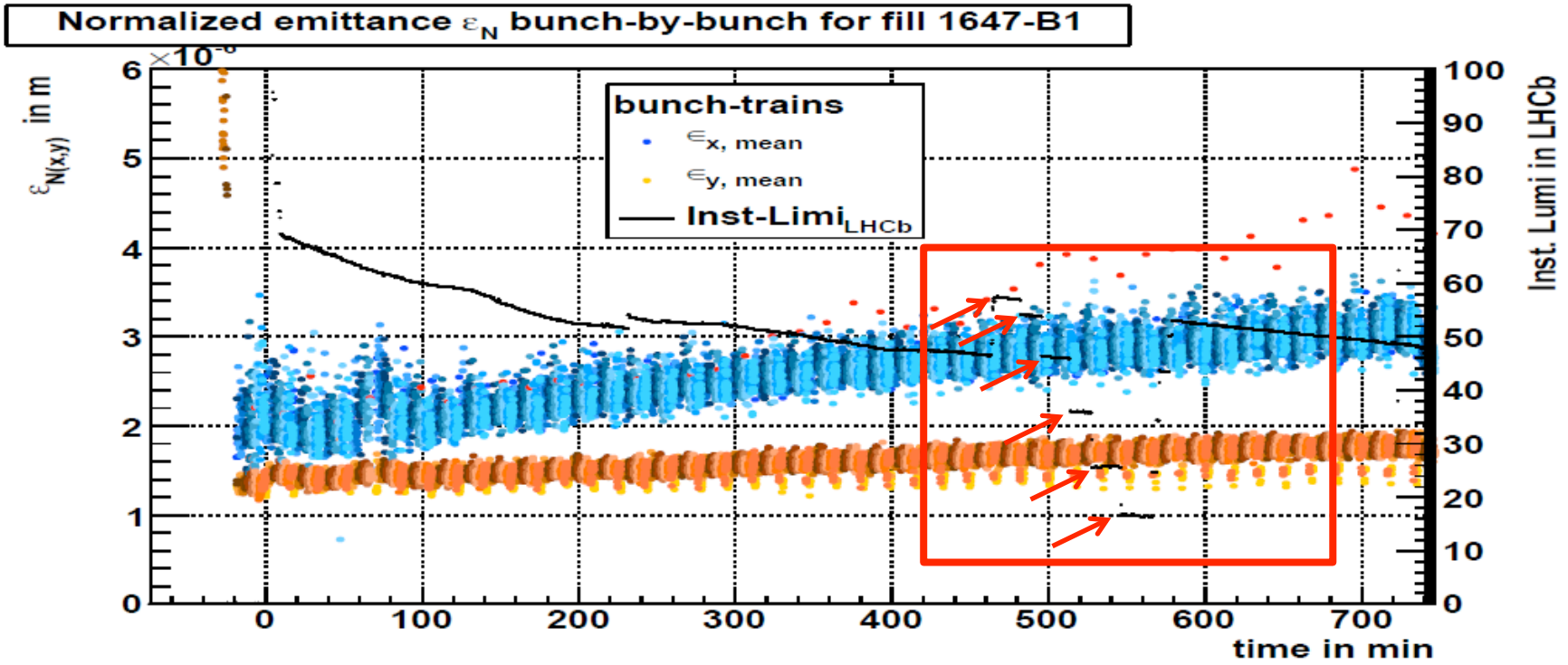


Luminosity in 3 Experiments



Luminosity in other experiments is not affected

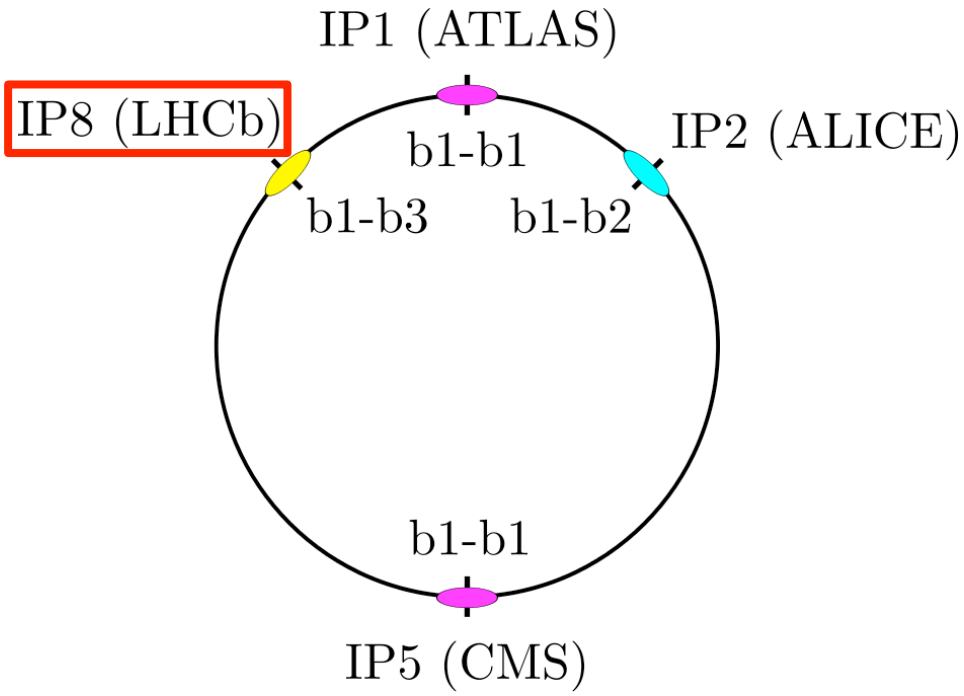
Measured Emittance



Leveling leaves no trace in emittance

Numerical Simulations

- Strong-strong simulations with *BeamBeam3D*
  Self-consistent or soft Gaussian
- Beam parameters and first order beam optics from experiment
- Simplified collision scheme:
  - 1 vs. 3 bunches
  - 4 collisions per turn
- Static offsets at IP8

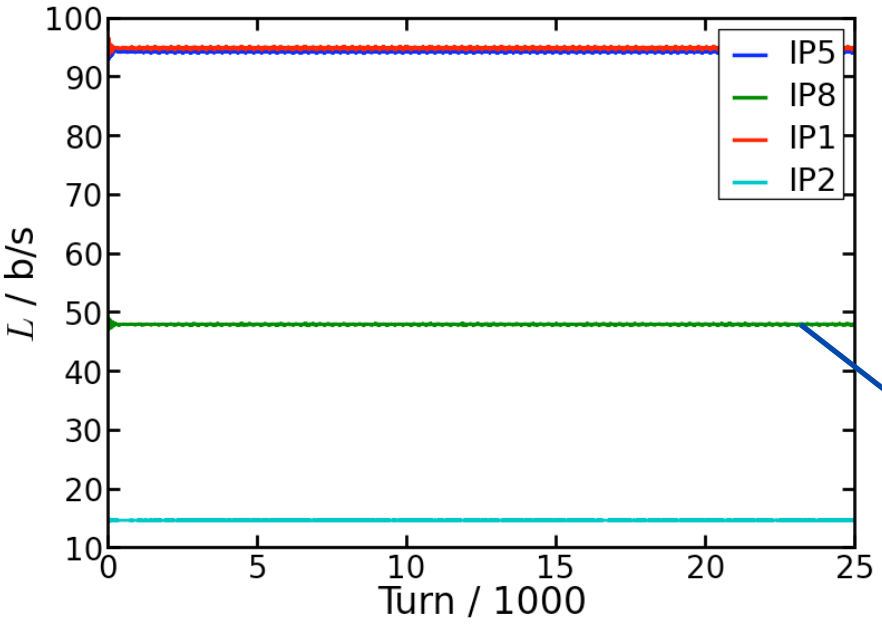


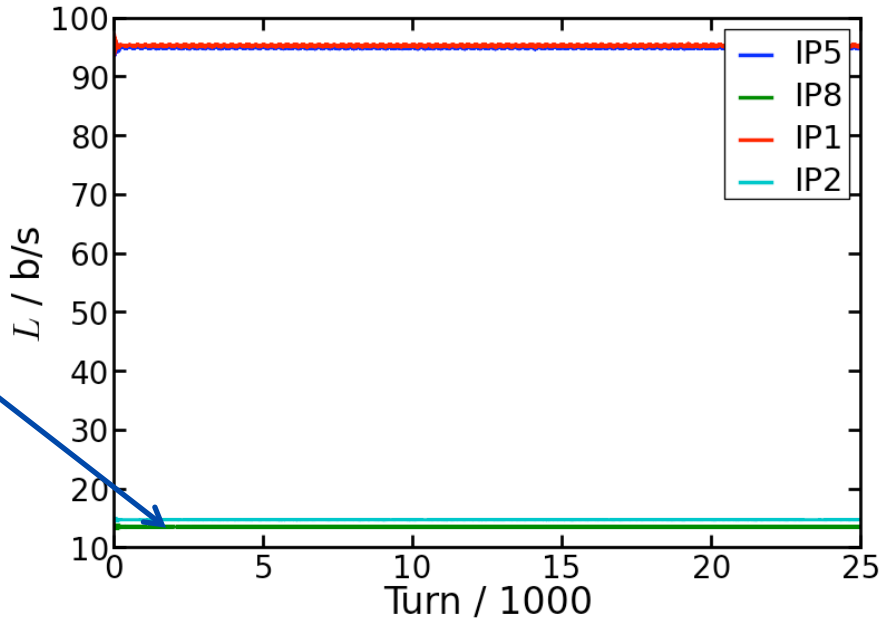
Simulated Luminosity versus Time

Separation at IP8

$d_x = 0$

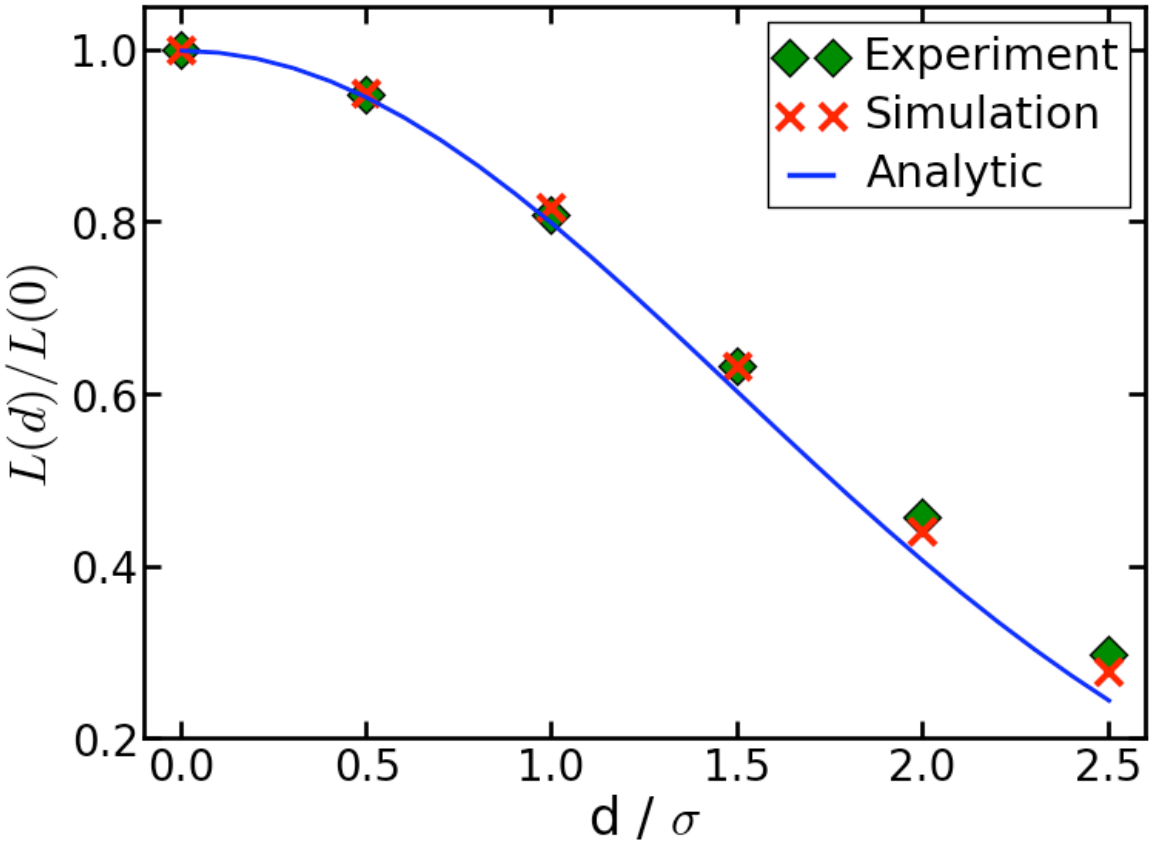
$d_x = 2.5\ \sigma_x$





Luminosity drops only at IP8
All luminosities are stable

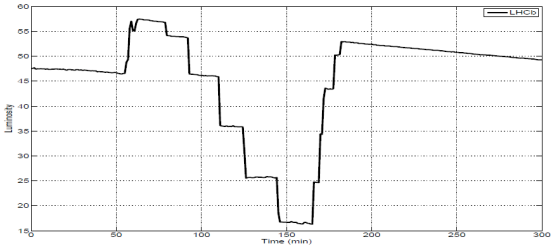
Luminosity vs. Offset

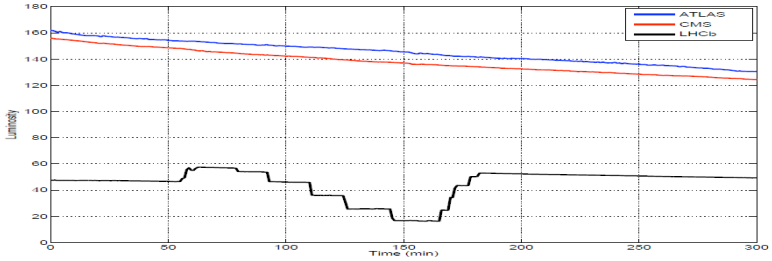


Very good agreement between experiment, simulation and theory

Conclusions

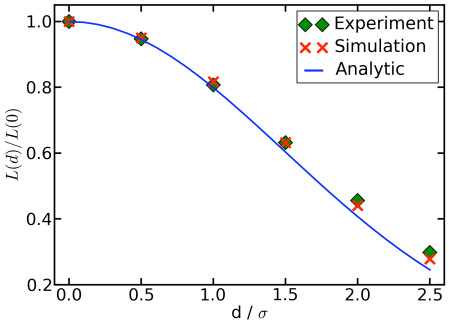
- Luminosity leveling with offset has been demonstrated





- No side effects have been observed

- Good agreement between experiment, simulation and theory



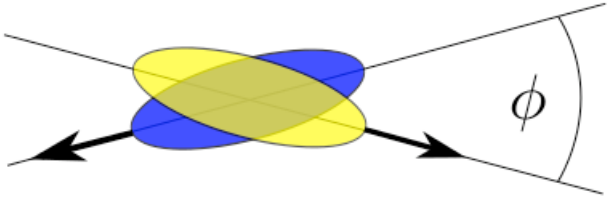
Other Leveling Options

- Leveling via β^*

  Promising according to recent experiment in LHC

- Leveling via ϕ

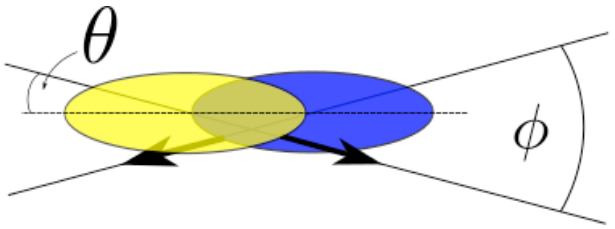
  Unlikely due to constraints to ϕ

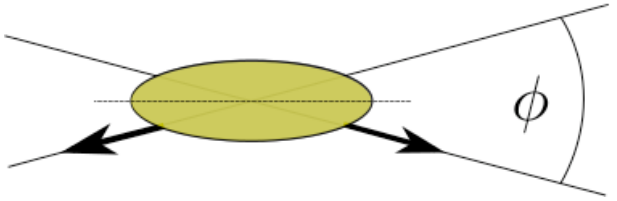


- Leveling via crab cavities

  Partial compensation of luminosity loss due to ϕ

  To be studied …





Thank you for your attention.