Online Luminosity Control and Steering at the LHC

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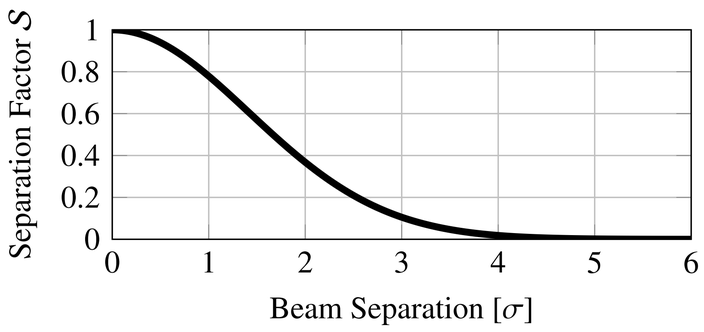
The LHC Luminosity Control Stack

The LHC luminosity control software stack controls and optimizes the Luminosity at the LHC Interaction Points (IP). This is achieved by adjusting the beam separation, crossing angle, or squeeze factor (β^*) at an IP.



Luminosity at an IP (Gaussian beams):

$$\mathcal{L} = \frac{f_{\text{rev}} N_1 N_2 n_{\text{bunch}} \gamma}{4\pi\beta^* \varepsilon} \mathcal{G}\mathcal{S}$$

... where:

- f_{rev}: revolution frequency
- $N_{1,2}$: bunch intensities in beam 1 and beam 2
- n_{bunch}: number of colliding bunches
- β^*: squeeze (β) function at the IP
- γ: relativistic factor
- ε: normalized transverse emittance

... and with the reduction factors:

geometric factor for a **crossing angle** α:

$$\mathcal{G} = \left(1 + \left(\frac{\sigma_z}{\sigma}\frac{\alpha}{2}\right)^2\right)^{-0.5}$$

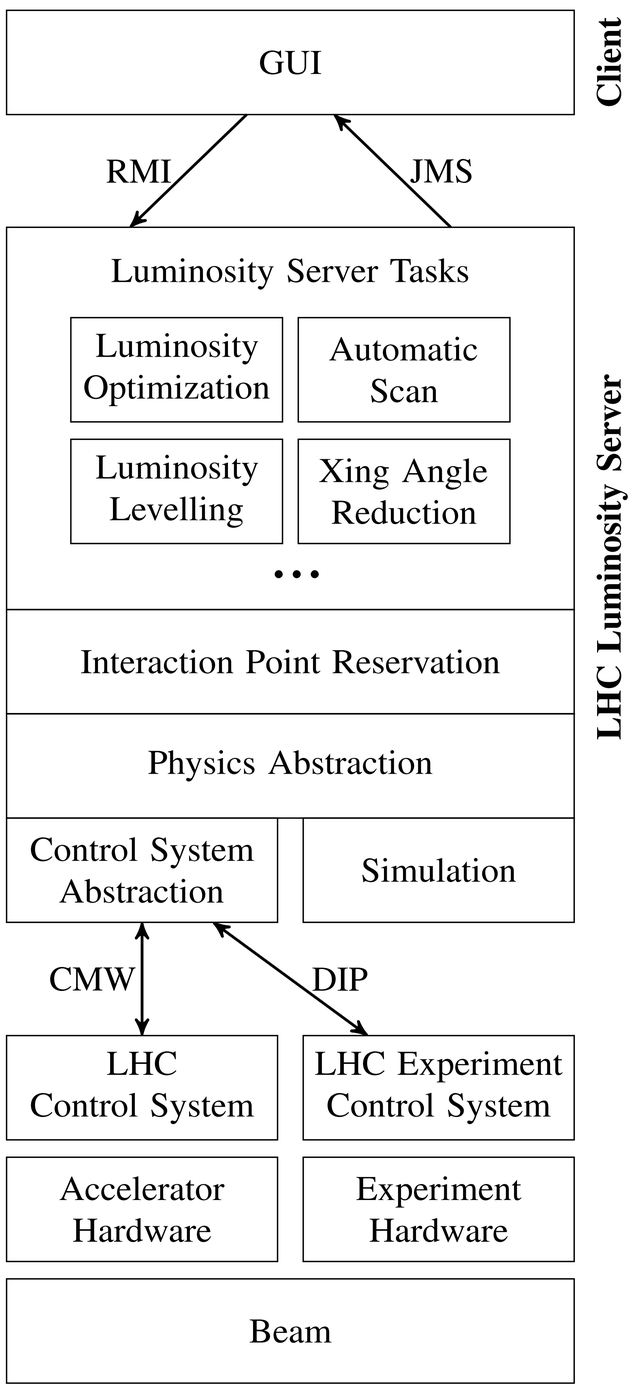
separation factor for a **separation** d:

$$\mathcal{S} = \exp\left(\frac{-d^2}{4\sigma^2}\right)$$

(Beam size σ, bunch length σ_z. In case of both a separation and a crossing angle an additional correction is needed.)

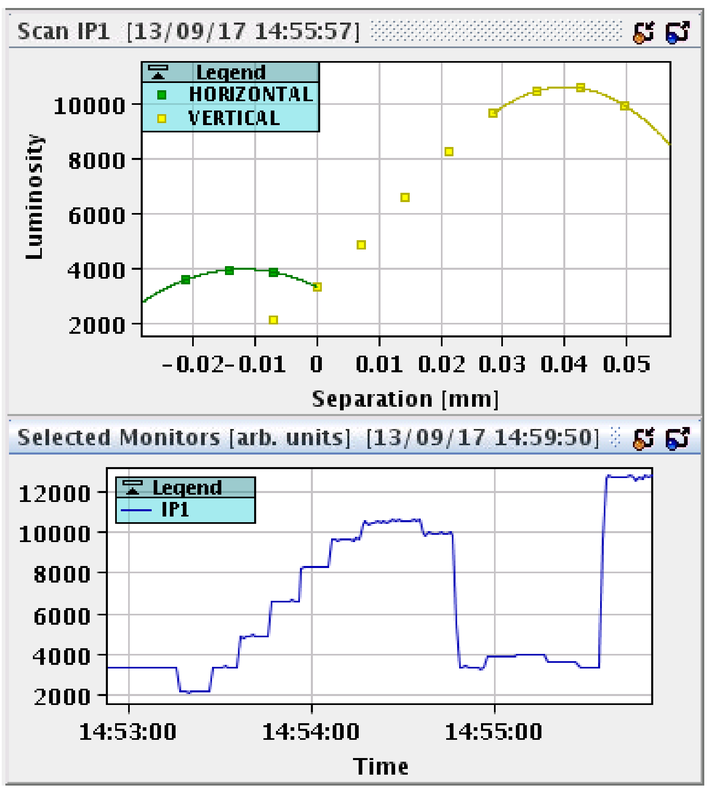
Architecture

The LHC luminosity control software stack follows a **client-server** architecture. The **interface to the control system is abstracted and can be replaced by a simulation** for easier testing and development.



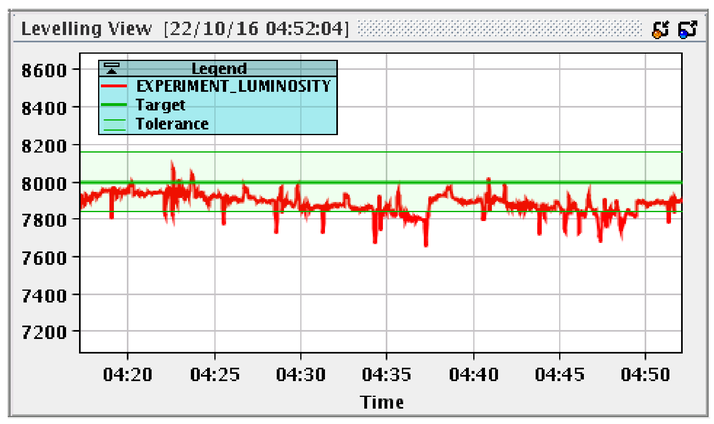
Luminosity Optimization

Scan the beam separation while acquiring the luminosity signal to **find the beam head-on position giving maximum luminosity**.



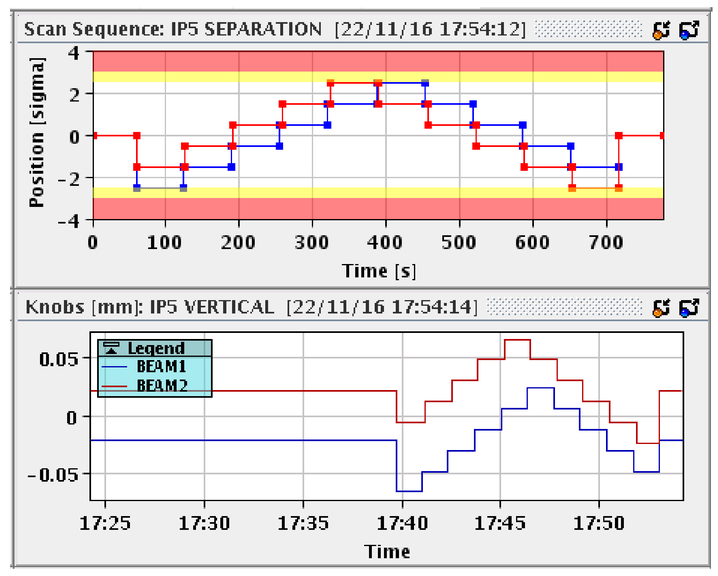
Separation Luminosity Levelling

Keep the luminosity constant at an IP around a target value **by adjusting the beam separation**. This is in particular used for the two low-luminosity experiments (ALICE and LHCb) at the LHC.



Automatic Calibration Scans

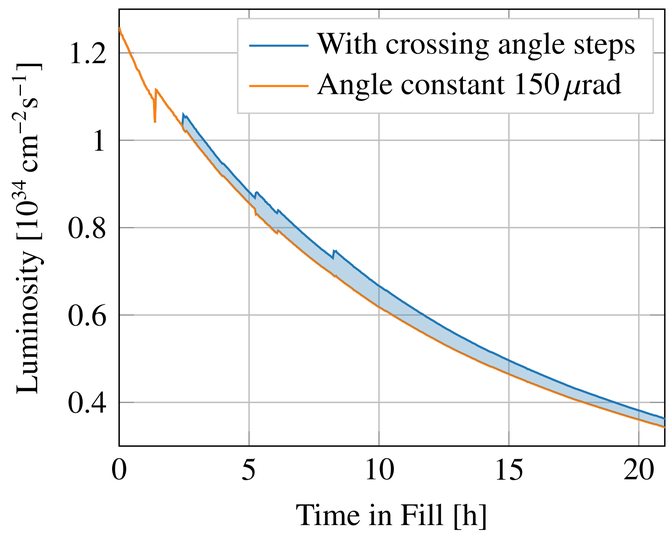
Perform **separation scans synchronized with the experiments** of arbitrary patterns, defined in a Domain Specific Language, to **calibrate the absolute luminosity measurement** using the *van-der-Meer* method.



Crossing Angle Changes & More

Orchestrate multiple systems (e.g. power converters, orbit feedback, collimators) to **smoothly adjust machine parameters** like the crossing angle or β^* while the beams are in collision.

For example with decreasing beam intensities, the crossing angle can be decreased. This is used operationally at the LHC in 2017 and **increases the integrated luminosity by** ~5 %.



In the future, this functionality will be extended to allow **changing the** β^* (squeeze factor). This implies a dynamic change of the machine optics while keeping the beams in collisions.

Simulation and Wonderland Mode

Luminosity simulator control panel

Parameter	Value
Bunch Length [m, 1 sigma]	0.08
Bunch Intensity [ppb]	1.2E11
Revolution Frequency [Hz]	11245.0
Colliding Bunches	2376
Relative Noise Factor	0.004
Absolute Noise Factor	20.0
Zero count rate [Hz/ub]	1.0
Parasitic Sep IP1 B1 H [mm]	0.0
Parasitic Sep IP1 B1 V [mm]	0.0
Parasitic Sep IP1 B2 H [mm]	0.0
Parasitic Sep IP1 B2 V [mm]	0.0

'Wonderland' subscription multiplexer (what's real after all?)

Parameter	REAL	FAKED
DIP.ATLAS/Luminosity#Lumi_TotInst	0.0	10544.2741...
DIP.ATLAS/Luminosity#CollRate	0.0	11501.5820...
LHC.BRANA.4L1/Acquisition#meanLuminosity	0.78880000...	8367.72681...
LHC.BRANA.4R1/Acquisition#meanLuminosity	1.95259999...	12548.9679...
DIP.ALICE/Luminosity#Lumi_TotInst	0.0	571.050293...
DIP.ALICE/Luminosity#CollRate	0.0	56574.5930...
LHC.BRANB.4L2/Acquisition#meanLuminosity	0.0	460.142798...
LHC.BRANB.4R2/Acquisition#meanLuminosity	0.0	703.540743...
DIP.CMS/Luminosity#Lumi_TotInst	0.00160573...	10564.2094...
DIP.CMS/Luminosity#CollRate	0.00160573...	11584.5636...
LHC.BRANA.4L5/Acquisition#meanLuminosity	0.04550000...	8423.87646...
LHC.BRANA.4R5/Acquisition#meanLuminosity	0.44415000...	12505.7487...
DIP.LHCB/Luminosity#Lumi_TotInst	0.0	1883.98797...
DIP.LHCB/Luminosity#CollRate	0.0	2044.83802...
LHC.BRANB.4L8/Acquisition#meanLuminosity	0.0	1536.73487...
LHC.BRANB.4R8/Acquisition#meanLuminosity	0.0	2274.68882...
rmi://virtual_lhc/LHCBEAM1/IP1_SEPSCAN_X_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM2/IP1_SEPSCAN_X_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM1/IP1_SEPSCAN_Y_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM2/IP1_SEPSCAN_Y_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM1/IP2_SEPSCAN_X_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM2/IP2_SEPSCAN_X_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM1/IP2_SEPSCAN_Y_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM2/IP2_SEPSCAN_Y_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM1/IP5_SEPSCAN_X_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM2/IP5_SEPSCAN_X_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM1/IP5_SEPSCAN_Y_MM	0.0	0.0
rmi://virtual_lhc/LHCBEAM2/IP5_SEPSCAN_Y_MM	0.0	0.0

For **development and testing**, the LHC Luminosity Server can run in **full simulation mode** without accessing the LHC control system or any device.

For **dry-runs** and tests e.g. of the LHC-experiment communication (DIP), it can run in **partial simulation ("wonderland") mode** where every aspect and signal can be individually switched between its real and simulated counterpart.

References

[1] R. Alemany-Fernandez, *et al.*, "Separation Scan Application Requirements", EDMS specification.

[2] R. Alemany-Fernandez *et al.*, "The LHCb Online Luminosity Control and Monitoring", IPAC2013, paper TUPFI010.

[3] R. Alemany-Fernandez *et al.*, "Automatic scan application around the LHC interaction points", EDMS specification.

[4] A. Calia *et al.*, "Testing the Untestable: A Realistic Vision of Fearlessly Testing (Almost) Every Single Accelerator Component Without Beam and Continuous Deployment Thereof", IBIC2016, paper TUPG30.