LHCb Luminosity Monitoring and Control

R. Jacobsson (LHCb)

Reyes Alemany-Fernandez, Fabio Follin (LHC)

Outline
- LHCb physics strategy
- LHCb key requirements
- Luminosity control motivations
- Luminosity monitoring and control implementation
- Performance
- Conclusion

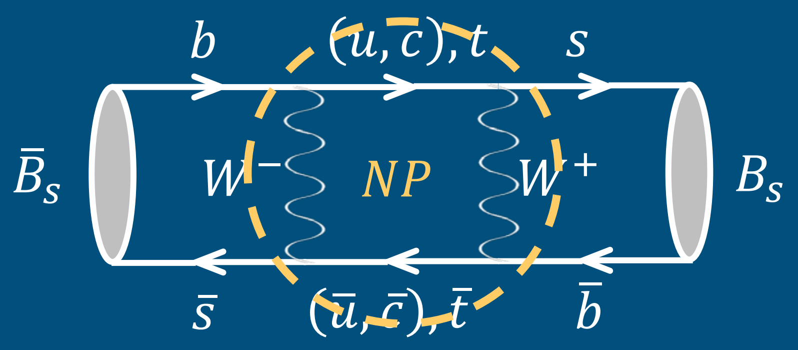
Complementary paper:
"Online Luminosity Optimization at the LHC", F. Follin, R. Alemany, R. Jacobsson, THPPC123

LHCb New Physics Search Strategy

- Focus on measuring *indirect* effects of New Physics in CP violation and Rare decays using FCNC processes mediated by loop (box and penguin) diagrams
  - Strongly suppressed processes allow distinguishing NP sources
  - Virtual effects allow probing energies much higher than the E_{cms} of the LHC
  - ➔ Complementary to the direct searches by Atlas and CMS

Ex. B_s ocillations:

$$\Phi_s^{exp} = \Phi_s^{SM} + \Phi_s^{NP}$$



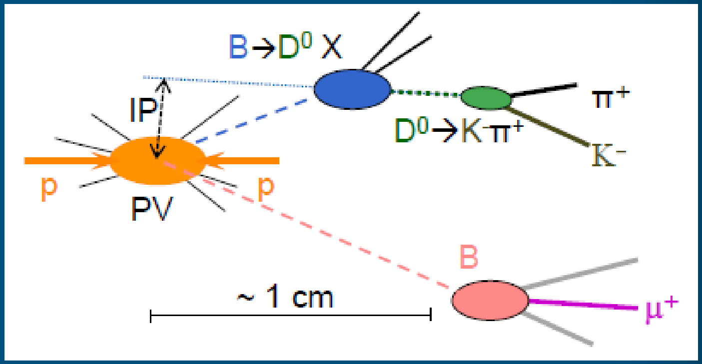
- While initial aim of LHCb was b-physics, has also demonstrated that it can do
  - Charm physics (oscillations, CP violation)
  - QCD physics (PDFs via Z/W production, Central Exclusive Production,...)
  - ➔ In beyond design conditions, LHCb has earned the title of « General Purpose Forward Detector »

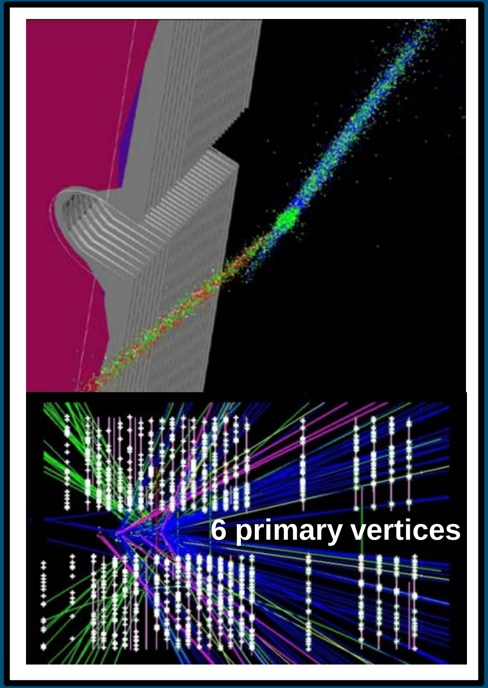
Key Requirements for Flavour Physics at LHC

- Collect high statistics of a large variety of B and D final states in an environment with very large background
  - >100 000 $b\bar{b}$ pairs per second at LHCb interaction point and $c\bar{c}$ production 20x more
  - Fast and efficient trigger for both hadronic and leptonic final states
  - Requires reconstruction of decay chains
- Resolve fast oscillations, background reduction and flavour tagging
  - Very good vertex resolution
  - Determination of track parameters
  - Charge determination and momentum resolution
  - Mass resolution
  - K/π separation in a wide momentum range
  - γ / π^0 reconstruction, electron identification
  - Muon identification

➔ Difficult task in conditions of large event pileup

A typical (tagging) B and (signal) B event





Key Requirements for Flavour Physics at LHC

- Requirements from precision physics programme
  - Accurate knowledge about the integrated luminosity
  - Systematics errors must be negligible compared to statistical errors to reach sensitivity below the predictions of SM.

- Systematic effects from changing running configuration and conditions

  ➔ Attenuated by the initial design specification for nominal running conditions of LHCb
    - Maximize the probability of a single interaction per bunch crossing, minimizing pileup

    ➔ Average number of interactions per bunch crossing $\mu \sim 0.4$
    - Valid up to June 2010…

  - In June 2010, LHC changed commissioning strategy:
    - Commissioning many bunches with low intensity ➔ Commissioning bunch intensity
    - LHCb pileup reached ~3 due to chosen over-focussing!

  ➔ Detector and reconstruction performs well with event pileup

  ➔ Forced a healthy change of strategy in LHCb at all levels

➔ Compensatory measure: Luminosity/pileup control

➔Experiment with luminosity control with separated beams for the first time July 18, 2010 ….. By phone…!

LHCb Luminosity Control

- ***Direct tool to maximize LHCb physics yield***

- Allows optimizing the efficiency of luminosity integration
  - ➔ Running constantly at the optimal pileup for physics
- Stable luminosity (pileup) through fills (no decay!) / over months
  - Same trigger settings
  - Predictable detector performance and ageing

- *Optimum luminosity* is also a function of dynamic readout system parameters
  - Full event readout rate (<1.1 MHz)
  - Average number of interactions per crossing (<2.7)
  - Max readout network through-put (<70 GB/s)
  - High-Level Trigger CPU time/event at 1 MHz, ~30ms in 2011 and ~40ms in 2012
  - Physics trigger overall dead-time (<5%)
  - High Level Trigger output rate to storage (<~5 kHz)
  - Detector stability, still exploring

  ➔ Translate into equivalent luminosity limits which may depend on experimental conditions (e.g. background) and system status

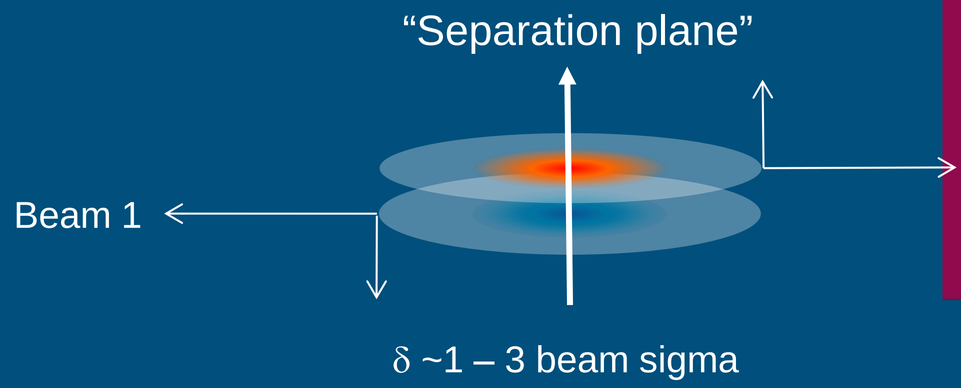
➔ *Target luminosity* determined real-time with slow time constants of O(seconds)

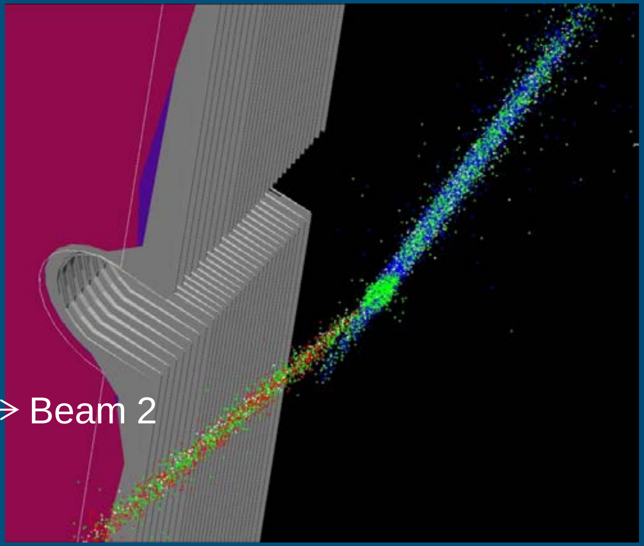
Luminosity Control

- Many ways by which luminosity control may be performed

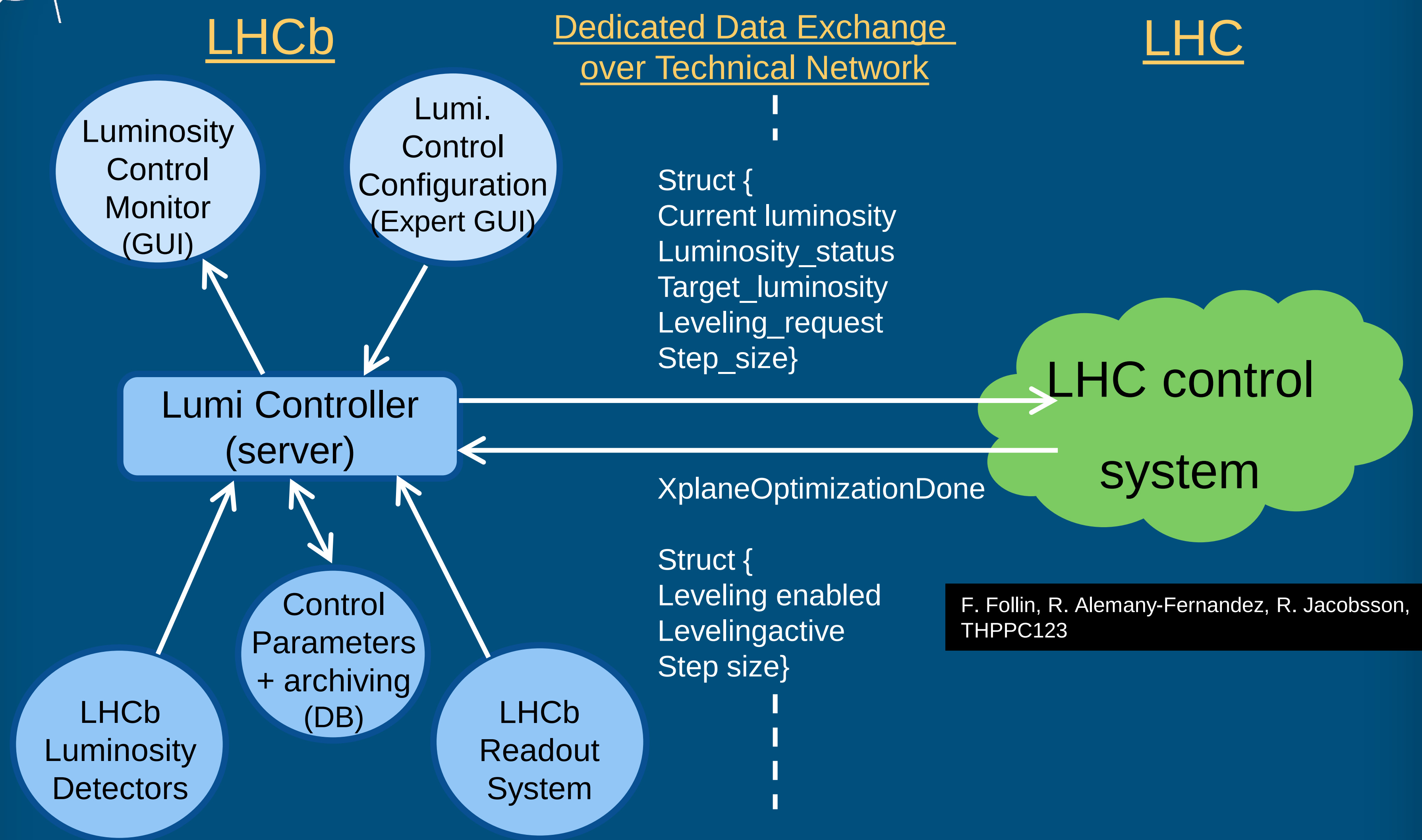
$$L = \frac{n_{bb} * N^2 * f_{rev}}{A} * \mathrm{R}(\beta^*, \theta, \sigma_z, \phi_P, \delta_s, \delta_c, \Delta t)$$

- Simplest consist of semi-continuous adjustment of transversal offset of colliding beams





Luminosity Control Block Diagram



- Luminosity controller based on a state machine which is driven LHC Beam Modes
  - Implementation based on Siemens WinCC OA (former ETM PVSS)

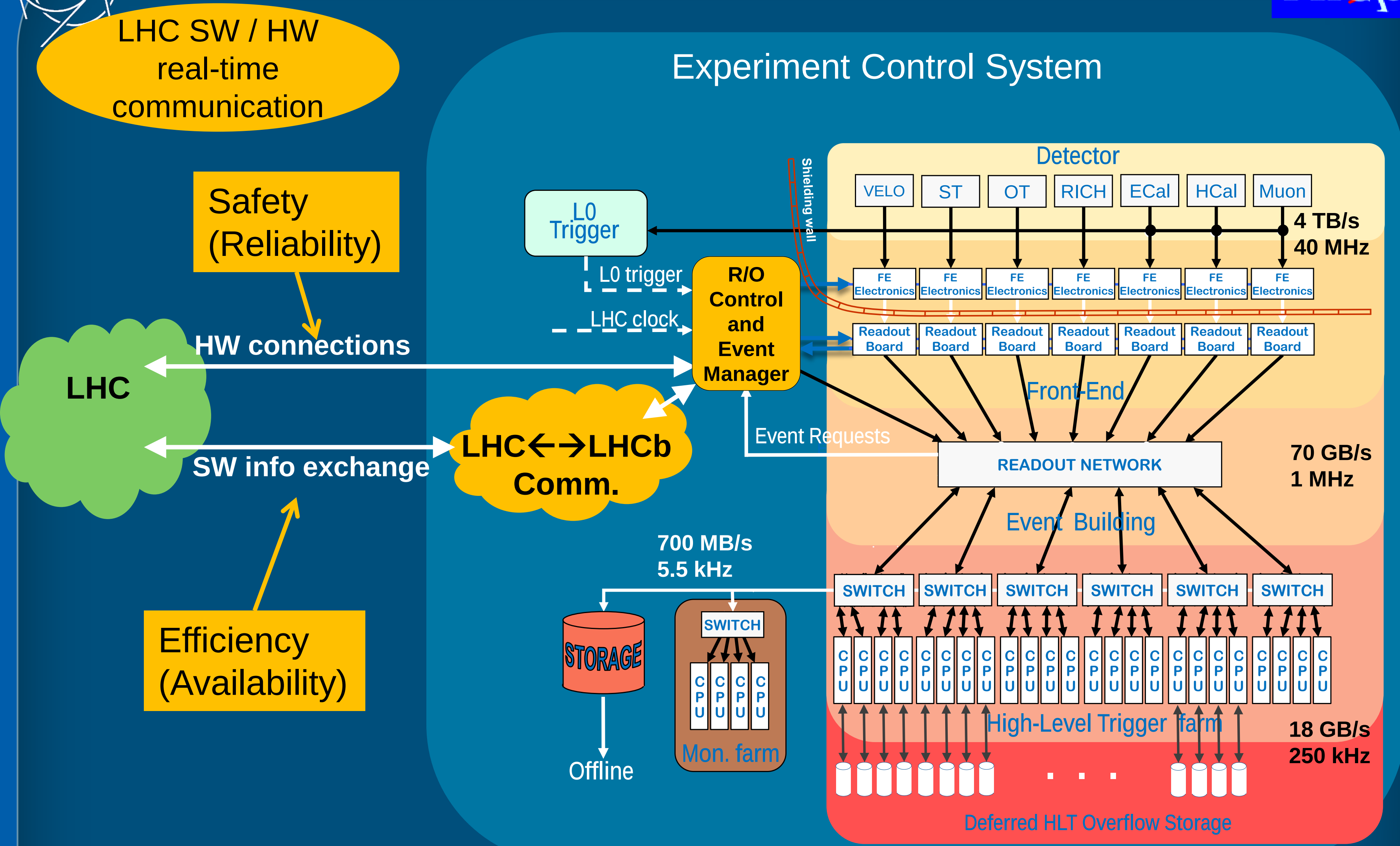
Luminosity Control Protocol

The luminosity adjustment is performed by an iterative procedure:

- LHCb Luminosity Controller publishes:
  - Current Luminosity: Measured luminosity
  - Luminosity Status : Depends on source of luminosity, reliable or not
  - Target luminosity: Dynamically computed by LHCb leveling controller
  - Leveling Request: Dynamical signal requesting leveling to target
    - Request will only ON if the LHCb data acquisition is running, even if it is far away from target
    - If request if OFF, target is not (should not be) considered
    - When luminosity is not reliable, request is OFF whatever target luminosity is
  - Step size [percentage of beam sigma]: Depends on separation

- LHC Luminosity Leveling Application publishes:
  - XPlaneOptimizationDone : Set when the crossing plane optimization has been done
    - *LHCb Luminosity Controller will only start requesting luminosity ramp when this is received*
    - Must always be done before leveling starts.
  - Enable: ON if luminosity leveling application is running
  - Active: Leveling to target is in progress
  - StepSize : Beam movement used in the last leveling step in mm

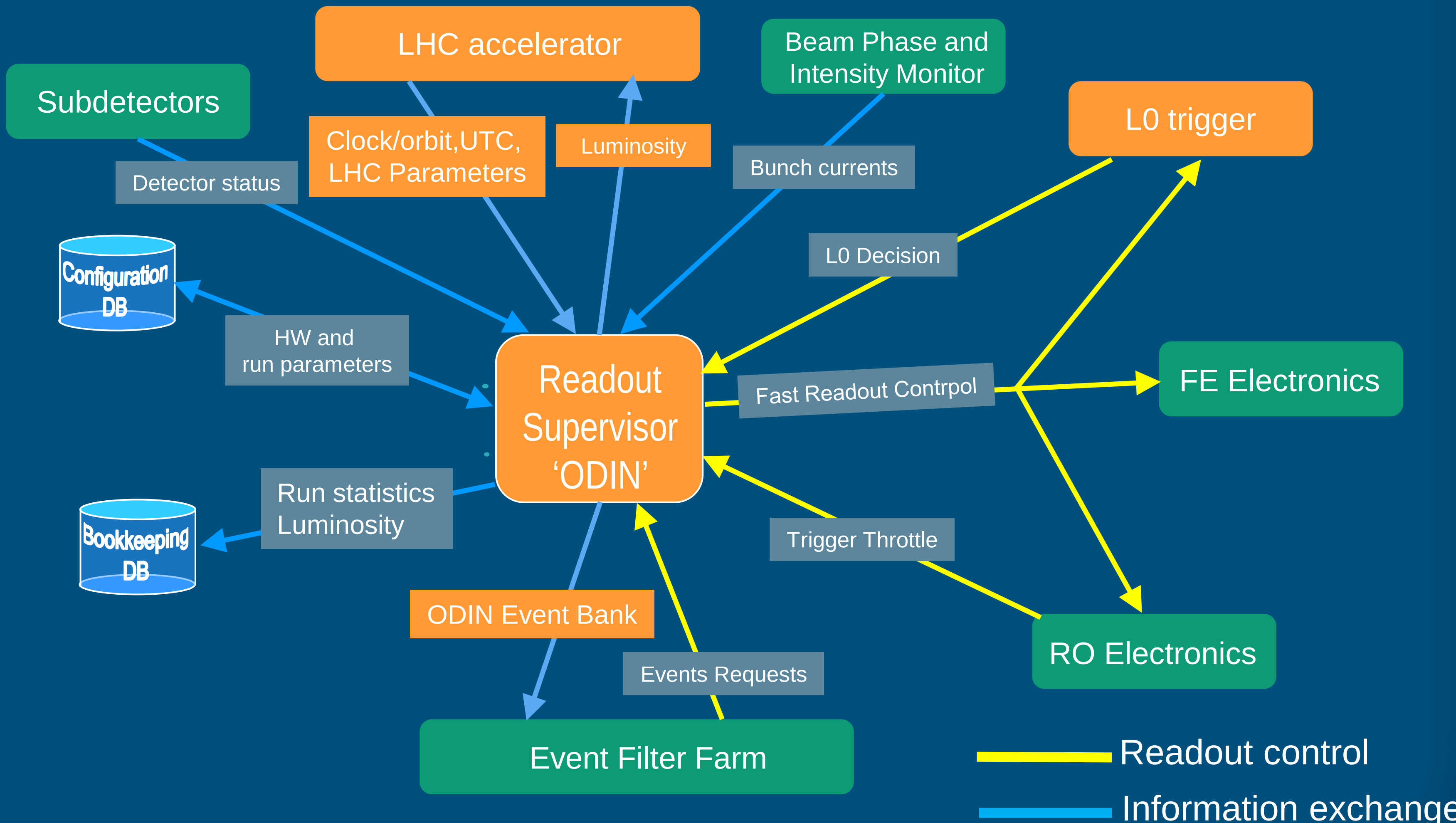
LHCb Online Architecture



- Luminosity monitoring and control are implemented in the LHCb Readout Control hardware and the LHC/LHCb communication control system

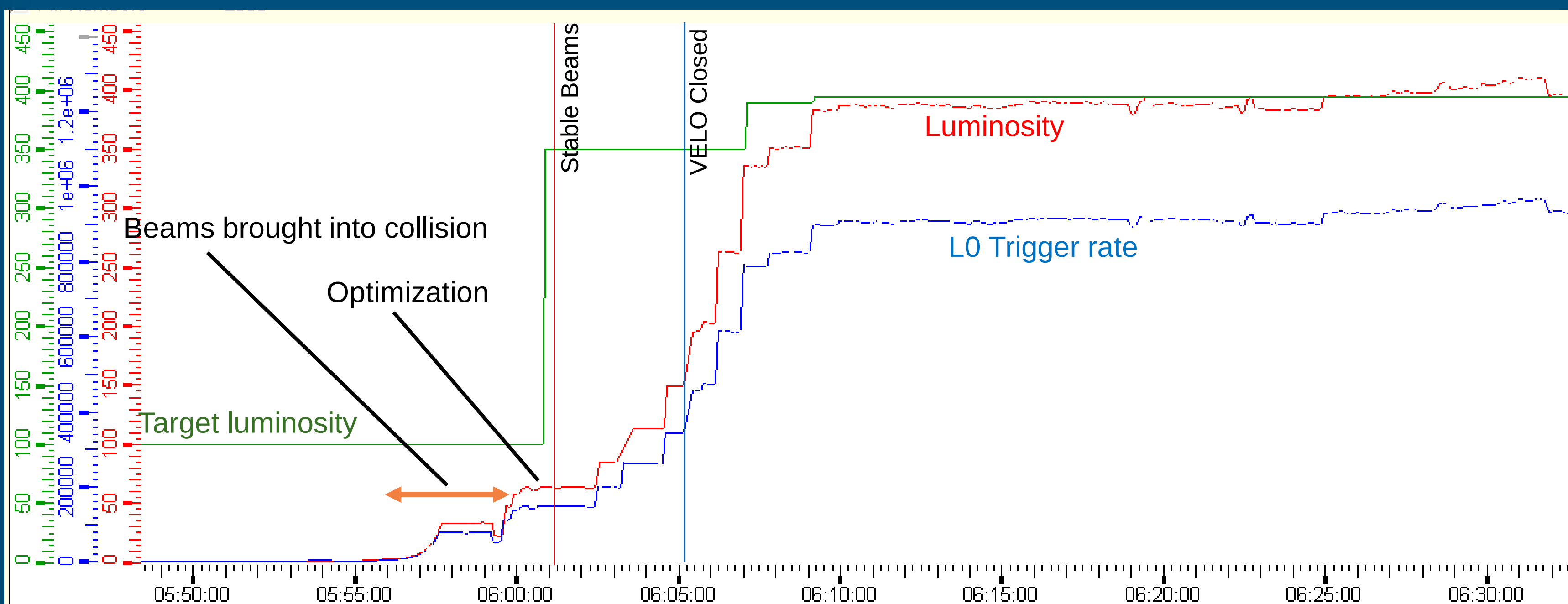
Luminosity Monitoring

- ODIN = Single FPGA-based readout master with two redundant "copies" for fail-over
  - Two different methods for offline and online determination of luminosity



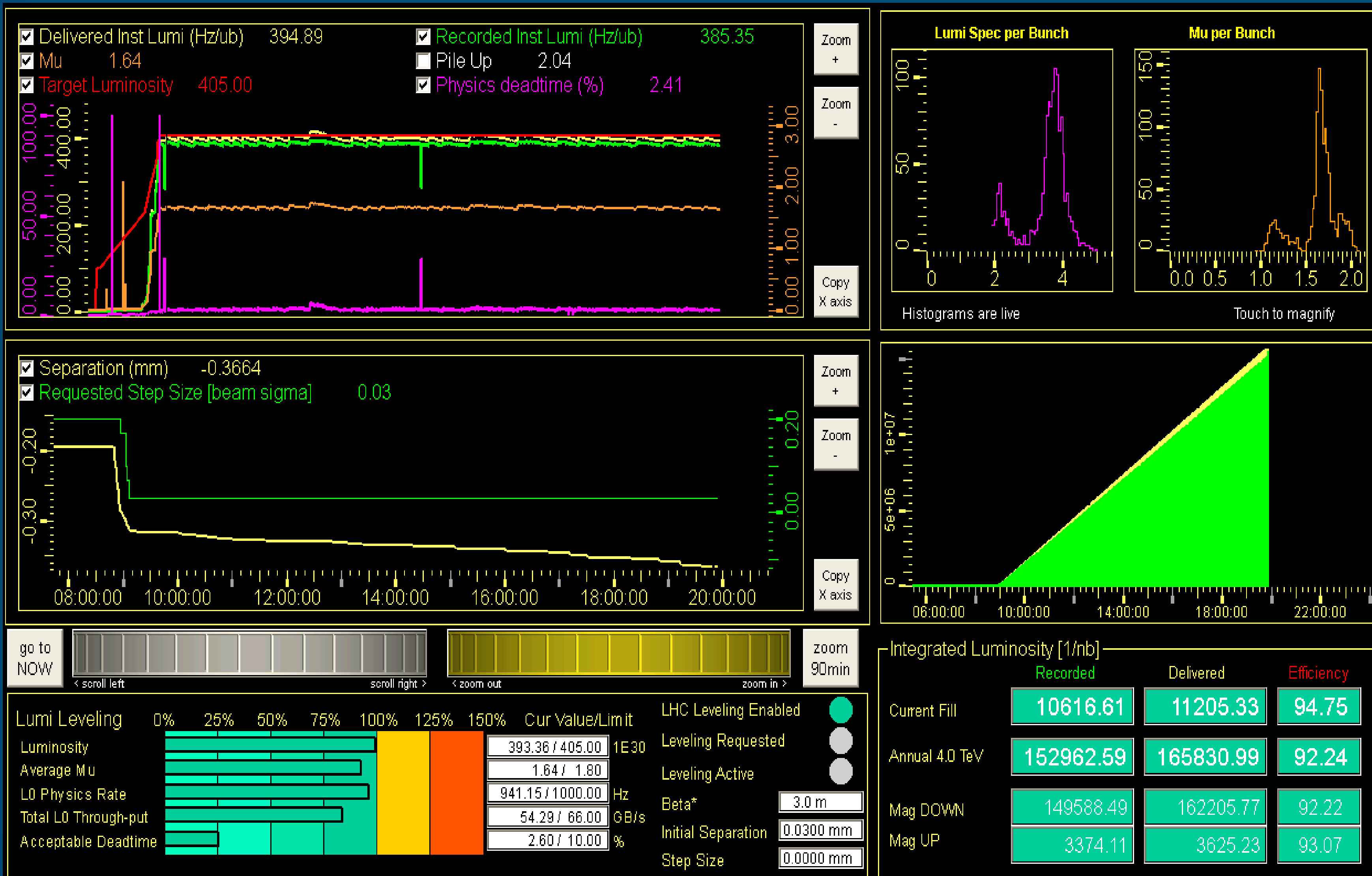
LHCb Luminosity Control Procedure

- ADJUST - idle
  1. LHC luminosity control OFF, LHCb luminosity control OFF
  2. Collapse separation bump to constant offset (e.g. ~2-3σ) → L ~ 1.5×10^{32} $cm^{-2}s^{-1}$ in vertical
  3. Optimize in horizontal (crossing plane) keeping vertical separation constant
- STABLE BEAMS - ramp
  1. LHCb Vertex Locator (VELO) detector closing to its final data taking position with initial luminosity
  2. Luminosity increase to target over a few minutes
- Coast - levelling
  - Continuous publication of instantaneous luminosity and target luminosity
  - Luminosity leveling requested when current luminosity and target different by > ±3%

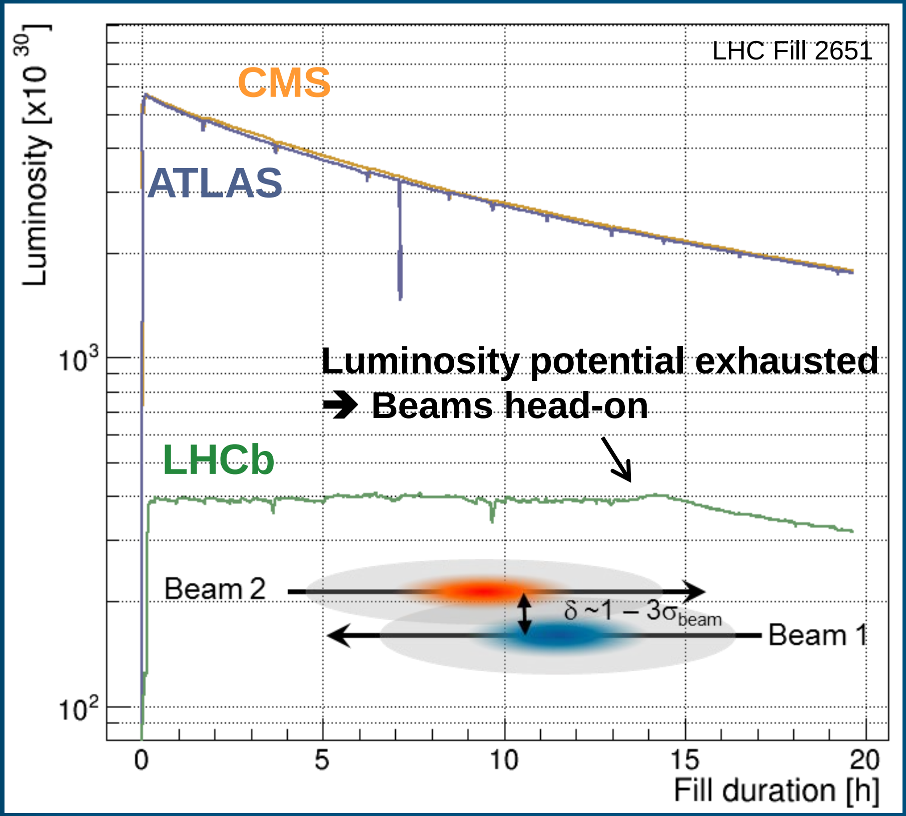


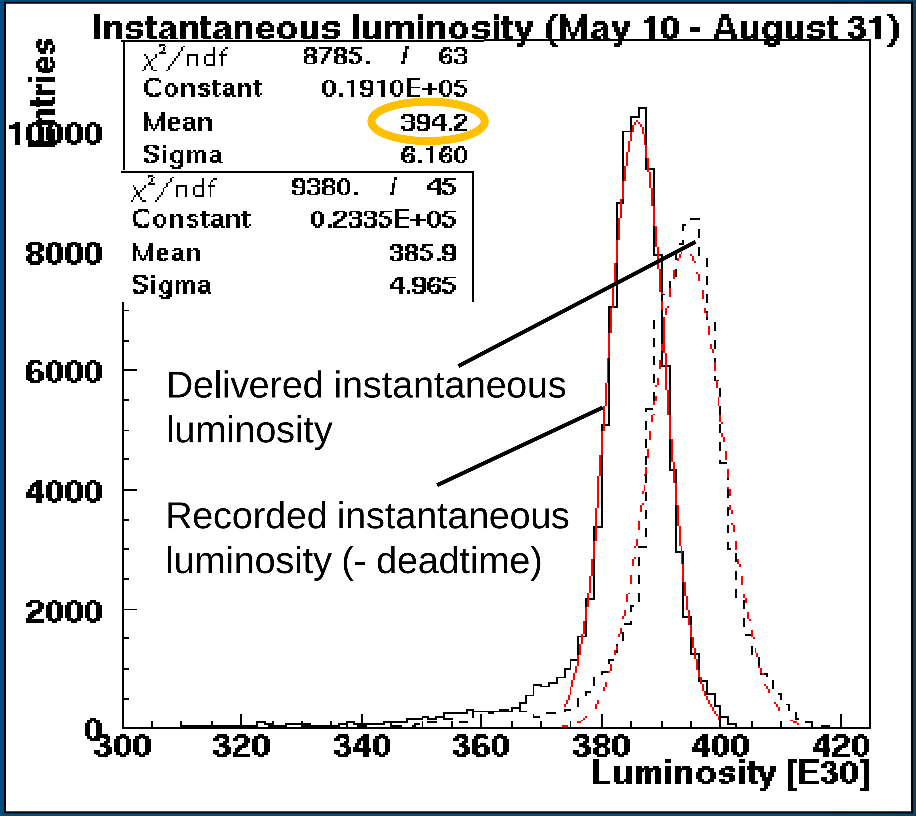
Luminosity Monitor

- Procedure require no actions from the people on shift



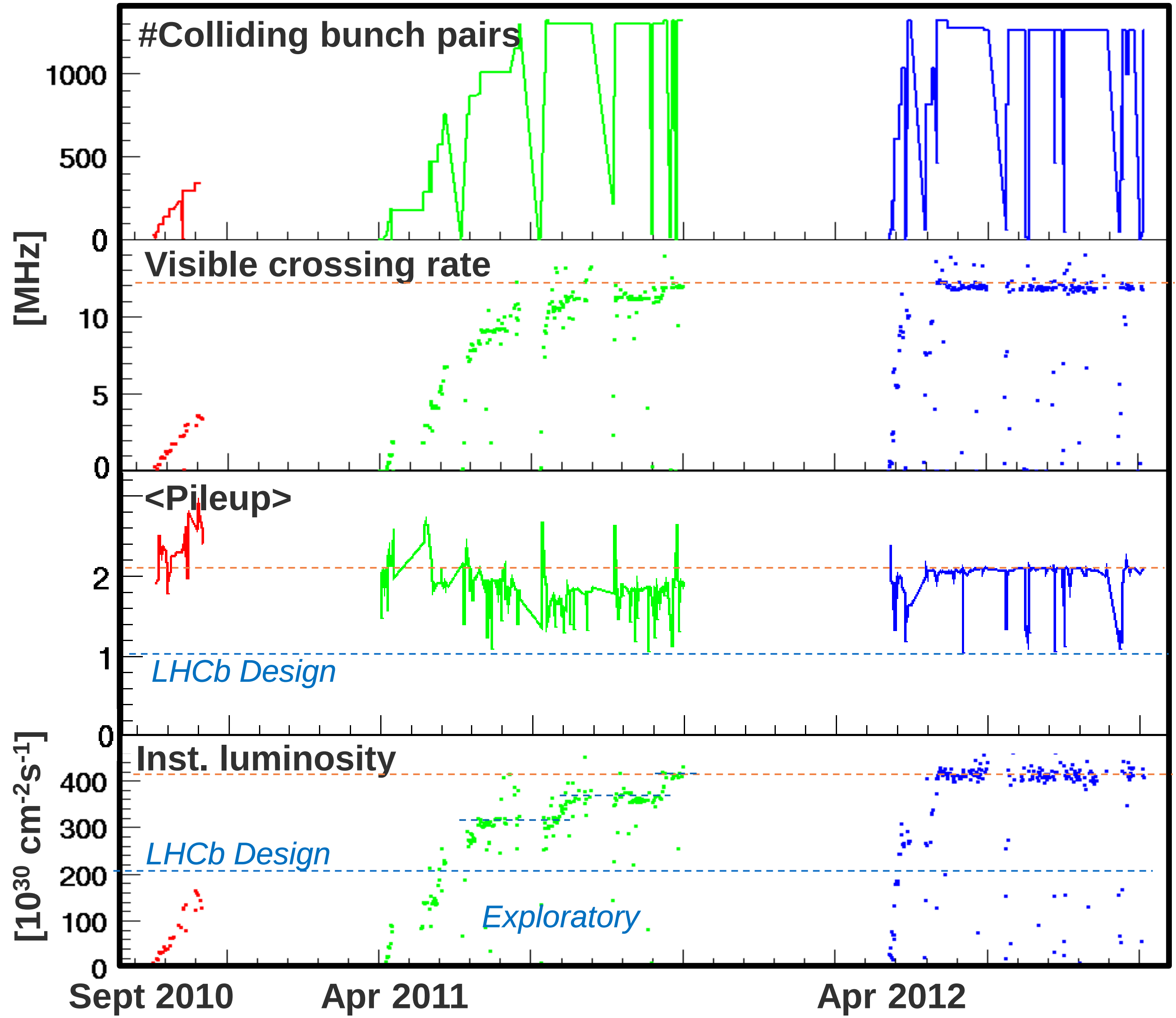
Luminosity Control Performance





- 95% of integrated luminosity in 2011–2012 recorded within 3% of desired luminosity

Running conditions 2010 - 2012



Conclusions

- Luminosity control has been part of routine operation in LHCb 2011 – 2012
  - It has also been used in a similar way for the ALICE experiment
  - Great experience in developing a close feed-back system between experiment and accelerator
  - Allowed LHCb to venture well beyond the design specs and operating detector at twice the luminosity, collecting up 3x more luminosity in Run 1
  - Operating LHCb constantly in the optimal conditions
  - Important reduction in the systematics effects
  - Stability of the detector performance and trigger configuration
  - Luminosity control will continued to be a vital tool for LHCb in the future, both in Run 2 and after the LHCb upgrade
- Important experience to pave the way for luminosity control in the future by all experiments
  - Method of luminosity control may be different but procedure well established
  - Exploiting LHC at maximum benefits from handling procedures with mechanical routine

__Acknowledgement:__

Thanks to

- *the many people from the machine who contributed to the vital task of ensuring the understanding of the effects of operating the LHC with offset collisions*
- *The LHC operators for their particular attention to the LHCb interaction point!*

RESERVE SLIDES

Luminosity determination

- Two different methods for offline and online determination of luminosity
  - ➔ Both implemented in ODIN hardware
  - Offline:
    - Random sampling of beam-beam crossings with observables proportional to luminosity
    - Random sampling of beam1 alone, beam2 alone, and empty crossings for background subtraction.
      - ➔Luminosity trigger implemented in ODIN based on an advanced pseudo-random generator producing two 32-bit random numbers at 40 MHz
      - ➔Events carry special flags that allow offline analysis of any data set
  - Online:
    - Counting of minimum bias trigger condition with maximum acceptance on beam-beam crossings
      - Transverse energy criteria, together with muon minimum bias and noPV condition as stability check
    - Conditions counted on beam1 alone and beam2 alone for background correction
    - Instantaneous luminosity determined from Poisson statistics ($P_0 = e^{-\mu}$)

$$\mu = -ln \frac{1 - \rho_{trg}}{f_{rev} * n_{bb}} \qquad L = \frac{\mu * f_{rev} * nbb}{\sigma_{mbias} * \varepsilon_{det}}$$

  - LHC filling scheme loaded real-time into ODIN sequencer during filling of LHC
  - Online integrated luminosity well within 1% of best value from offline