Implementation and experience with luminosity levelling with offset beams

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OUTLINE

- Motivation
- Implementation
- Operational experience
- Conclusion
MOTIVATIONS

Design luminosity for LHCb and Alice is much lower than CMS and Atlas

- High peak luminosity can cause detector HV trips for Alice
- For LHCb, high peak luminosity and high pile-up is not a protection issue but has an impact on data quality.
- High luminosity causes premature ageing of the detectors
- Optimization of $\beta^*$ and crossing angle at each interaction point not enough

Luminosity leveling

- $\beta^*$ leveling: complicated, implication on machine protection
- Beam offset leveling: relatively simple, large range

Integrated luminosity of Alice and LHCb can be maximized by delivering constant luminosity during the fill

For details, see Richard Jacobsson presentation in this session: Future wishes and constraints from experiments
Parameters input from experiments via DIP* gateway

Target Lumi \([10^{30}\ \text{cm}^{-2}\text{s}^{-1}]\)
- LHCb proton typical target = 400 \([10^{30}\ \text{cm}^{-2}\text{s}^{-1}]\)
- ALICE pPb typical target = 100 \([10^{27}\ \text{cm}^{-2}\text{s}^{-1}]\)

Instant Lumi \([10^{30}\ \text{cm}^{-2}\text{s}^{-1}]\)

Leveling Step Size \([\sigma]\) (optional)
- LHCb step size during ramp lumi = 0.2 Sigma (10.3 µm)
- LHCb step size when stable lumi = 0.03 Sigma (1.5 µm)

Data quality (if bad quality leveling not permitted)

Leveling Request (if no request leveling not permitted)
LEVELING USER INTERFACE

Luminosity Scan Application

Select Beam Process: PHYSICS-LOWBETA-2011_V1@56.[END]

Settings

- Lumi Data [16/10/11 02:50:44]
  - Leveling Status: Acquisition
  - VETO from Experiment: VETO
  - Data Quality: OK
  - Target Lumi: 390.00
  - Current Lumi: 385.24

Lumi Statistics [16/10/11 02:50:08]

- Number of Data: 10
- Target Lumi Mean: 390.00
- Target Lumi Std [%]: 0.0
- Current Lumi Mean: 377.05
- Current Lumi Std [%]: 0.0
- Relative Difference [%]: -3.3
LEVELING ALGORITHM

1. Bring beams into collision with a predefined IP2 & IP8 separation
2. Optimize luminosity in IP1 and IP5, optimize IP2 & IP8
   Crossing Plane
3. Application parameters:
   Step Size, Max Relative Diff., ...
4. Start leveling
5. Read Target and Instant Lumi from exp and check stability
6. If lumi in range
   Compute relative difference between target and luminosity
   If lumi in range
   Manual operator confirmation
   If lumi out of range
   Compute relative difference between target and luminosity
   If lumi out of range
6. Read Target and Instant Lumi from exp and check stability
7. Compute relative difference between target and luminosity
8. If lumi in range
   Compute the separation step needed (positive or negative) and send a trim via LSA
9. STOP if:
   max of step reached,
   step too high
   leveling no more effective
Luminosity scan application

Request a change of position in mm for a given beam and plane

LSA TRIM package

High level knobs in mm

Compute Corresponding corrector settings

HW parameters in Amps

Send new settings to Hardware

Correctors

LSA Database Settings and trim history

**LSA is the software infrastructure for the CERN accelerator's control**
LHCB WITH CROSSING AND SEPARATION IN Y AND X PLANES

TRIM LSA HIGH LEVEL KNOBS

B1 sep scan X plane Knob [mm]
B2 sep scan X plane Knob [mm]
B1 sep scan Y plane Knob [mm]
B2 sep scan Y plane Knob [mm]

COMPUTE AND SEND CURRENT IN THE CORRECTORs

Exemple:
IP8 Vertical plane

RCBV6.L8B1 RCBV54.L81
RCBV55.L8B2 RCBV54.R8B1
LHCb with crossing and separation in Y and X planes

TRIM LSA HIGH LEVEL KNOBS

B1 sep scan X plane Knob [mm]  B2 sep scan X plane Knob [mm]  B1 sep scan Y plane Knob [mm]  B2 sep scan Y plane Knob [mm]

COMPUTE AND SEND CURRENT IN THE CORRECTORS

Exemple:
IP8 Vertical plane

RCBVS 5.LBB2  RCBVS 4.L81  RCBVS 4.RBB2  RCBV6.RBB2

RCBVS 5.LBB2  RCBVS 4.L81  RCBVS 4.RBB2  RCBV6.RBB2

IP8
LHCb with crossing and separation in Y and X planes

Lumi scan application

TRIM LSA HIGH LEVEL KNOBS

B1 sep scan X plane Knob [mm]
B2 sep scan X plane Knob [mm]
B1 sep scan Y plane Knob [mm]
B2 sep scan Y plane Knob [mm]

COMPUTE AND SEND CURRENT IN THE CORRECTORS

Exemple:
IP8 Vertical plane

RCBV6.L8B1
RCBV5.88B2
RCBV4.L81
RCBV5.88B2
RCBV5.88B2
LHCB WITH CROSSING AND SEPARATION IN Y AND X PLANES

TRIM LSA HIGH LEVEL KNOBS

B1 Lumi scan X plane Knob [mm]

B2 Lumi scan X plane Knob [mm]

B1 Lumi scan Y plane Knob [mm]

B2 Lumi scan Y plane Knob [mm]

COMPUTE AND SEND CURRENT IN THE CORRECTORS

Exemple:
IP8 Vertical plane
LHCB WITH CROSSING AND SEPARATION IN Y AND X PLANES

TRIM LSA HIGH LEVEL KNOBS

- B1 sep scan X plane Knob [mm]
- B2 sep scan X plane Knob [mm]
- B1 sep scan Y plane Knob [mm]
- B2 sep scan Y plane Knob [mm]

COMPUTE AND SEND CURRENT IN THE CORRECTORS

Exemple:
IP8 Vertical plane

**LHCb with crossing and separation in Y and X planes**

**Lumi scan application**

**TRIM LSA HIGH LEVEL KNOBS**

- **B1 sep scan X plane Knob [mm]**
- **B2 sep scan X plane Knob [mm]**
- **B1 sep scan Y plane Knob [mm]**
- **B2 sep scan Y plane Knob [mm]**

**LSA compute and send current in the correctors**

**Exemple:**

- IP8 Vertical plane

![Diagram](image-url)
LHCb with crossing and separation in Y and X planes

**Lumi scan application**

- **TRIM LSA HIGH LEVEL KNOB**
  - **B1 sep scan X plane Knob [mm]**
  - **B2 sep scan X plane Knob [mm]**
  - **B1 sep scan Y plane Knob [mm]**
  - **B2 sep scan Y plane Knob [mm]**

Compute and send current in the correctors

**Exemple:**
- IP8 Vertical plane

![Diagram](image-url)
- KNOBS exist also in LSA to trim the angle at the IPs
- In operation the angle is kept to 0 for every IPs

Compute and send current in the correctors

Exemple:
IP8 Vertical plane

- KNOBS exist also in LSA to trim the angle at the IPs
- In operation the angle is kept to 0 for every IPs

Exemple:
IP8 Vertical plane


COMPUTE AND SEND CURRENT IN THE CORRECTORS
➢ KNOBS exist also in LSA to trim the angle at the IPs

➢ In operation the angle is kept to 0 for every IPs

Exemple:
IP8 Vertical plane

COMPUTE AND SEND CURRENT IN THE CORRECTORS
- KNOBS exist also in LSA to trim the angle at the IPs
- In operation the angle is kept to 0 for every IPs

**Exemple:**
IP8 Vertical plane

**Computations and Send Current in the Correctors**

```plaintext
```
LHCb with crossing and separation in tilted planes

TRIM LSA PARAMETERS

B1 LEVELING plane Knob [mm]
B2 LEVELING plane Knob [mm]
B1 CROSSING plane Knob [mm]
B2 CROSSING plane Knob [mm]

B1 sep scan X plane Knob [mm]
B2 sep scan X plane Knob [mm]
B1 sep scan Y plane Knob [mm]
B2 sep scan Y plane Knob [mm]

Lumi scan application

Leveling plane
Crossing plane

X
Y
LHCB WITH CROSSING AND SEPARATION IN Y AND X PLANES

TRIM LSA PARAMETERS

B1 LEVELING plane Knob [mm]

B2 LEVELING plane Knob [mm]

B1 CROSSING plane Knob [mm]

B2 CROSSING plane Knob [mm]

B1 sep scan X plane Knob [mm]

B2 sep scan X plane Knob [mm]

B1 sep scan Y plane Knob [mm]

B2 sep scan Y plane Knob [mm]
LHCB WITH CROSSING AND SEPARATION IN Y AND X PLANES

TRIM LSA PARAMETERS

- **B1 LEVELING**
  - plane Knob [mm]

- **B2 LEVELING**
  - plane Knob [mm]

- **B1 CROSSING**
  - plane Knob [mm]

- **B2 CROSSING**
  - plane Knob [mm]

**Lumi scan application**

- **B1 sep scan X**
  - plane Knob [mm]

- **B2 sep scan X**
  - plane Knob [mm]

- **B1 sep scan Y**
  - plane Knob [mm]

- **B2 sep scan Y**
  - plane Knob [mm]

Diagram showing the relationship between leveling and crossing planes, with X and Y axes.
LHCb with crossing and separation in Y and X planes

Lumi scan application

TRIM LSA PARAMETERS

B1 LEVELING plane Knob [mm]  B2 LEVELING plane Knob [mm]  B1 CROSSING plane Knob [mm]  B2 CROSSING plane Knob [mm]

B1 sep scan X plane Knob [mm]  B2 sep scan X plane Knob [mm]  B1 sep scan Y plane Knob [mm]  B2 sep scan Y plane Knob [mm]

Leveling plane

Crossing plane

X

Y
LUMI SCAN APPLICATION

TRIM LSA PARAMETERS

- B1 LEVELING plane Knob [mm]
- B2 LEVELING plane Knob [mm]
- B1 CROSSING plane Knob [mm]
- B2 CROSSING plane Knob [mm]

B1 sep scan X plane Knob [mm]
B2 sep scan X plane Knob [mm]
B1 sep scan Y plane Knob [mm]
B2 sep scan Y plane Knob [mm]

LHCb with crossing and separation in Y and X planes
LHCb with crossing and separation in Y and X planes

B1 Leveling plane Knob [mm]
B2 Leveling plane Knob [mm]
B1 Crossing plane Knob [mm]
B2 Crossing plane Knob [mm]
B1 sep scan X plane Knob [mm]
B2 sep scan X plane Knob [mm]
B1 sep scan Y plane Knob [mm]
B2 sep scan Y plane Knob [mm]
LHCb with crossing and separation in Y and X planes

TRIM LSA PARAMETERS

B1 LEVELING plane Knob [mm]
B2 LEVELING plane Knob [mm]
B1 CROSSING plane Knob [mm]
B2 CROSSING plane Knob [mm]
B1 sep scan X plane Knob [mm]
B2 sep scan X plane Knob [mm]
B1 sep scan Y plane Knob [mm]
B2 sep scan Y plane Knob [mm]

Leveling plane

Crossing plane

Lumi scan application
OPERATIONAL EXPERIENCE
WITH BEAM OFFSET LEVELING

21-04-2011: First automatic luminosity leveling in LHCb
OPERATIONAL EXPERIENCE WITH BEAM OFFSET LEVELING

- **24-05-2011**: First automatic lumi leveling in ALICE

- **03-10-2011**: 1 fb-1 of luminosity has been delivered to LHCb
OPERATIONAL EXPERIENCE WITH BEAM OFFSET LEVELING

• 2012 Proton run
  – LHCb tilted plane for collisions: leveling application adapted.
  – Alice used collisions with satellites to reduce its luminosity, leveling was needed only in case of higher satellites.
  – Leveling prepared for Atlas and CMS in case of too high pile-up. Was not needed in operation.

• 2013 Proton-Lead run
  – Used to limit the luminosity of Alice during the few days of low luminosity run.
  – Used at beginning of each pPb fill to ensure the luminosity below requested limit of 1E5 ub/s.
OPERATIONAL EXPERIENCE WITH BEAM OFFSET LEVELING

Weakness

- DIP communication not always reliable and failed to publish experiments parameters -> leveling stopped.

- Luminosity sensible to orbit correction
  - Orbit correction can push luminosity beyond limits and trip detectors
  - Nothing to prevent it in reliable way

- Experiments have to define and publish clearly the parameters they need: perfect for LHCb, but often missing for Alice.

- Should we fully automate the process?
  - Avoid manual action from the control room
  - But OP need to check that the machine conditions are compatible with leveling.
OBSERVED BUNCH BY BUNCH INSTABILITIES

- At the beginning of the 2012 run, bunch by bunch instabilities were observed in the process of putting beams into collision or once already in stable beam.
- This instabilities affected the bunches that were colliding only in IP8.

- Single bunch instabilities observed at the beginning of a stable beam for LHCb private bunches.

- Filling Scheme with only 3 private bunches for LHCb.
- Effect of instabilities clearly observed for B2, bunches lost one after the other.
OBSERVED BUNCH BY BUNCH INSTABILITIES

- Cure
  - Use only filling schemes were bunches colliding in LHCb also collided in IP1 and IP5 -> stabilized by head-on landau damping.

- To reduce instabilities when beams get into collision, operation process adapted
  - First collide in Ip1 and 5 to stabilize the bunches
  - Then tilt LHCb planes and reduce separation in IP8
INJECTION
RAMP
SQUEEZE
STABLE BEAM

- Collide IP1/5
- Optimize IP1/5
- IP8: Tilted planes - Reduce separation (keep lumi very low)
- Optimize IP8 crossing plane – optimize IP1/5
DETAILS OF LHCB LEVELING FOR FILL 3266

Nominal Steps of 0.2 Sigma 10.3 μm

Reduced Step When approaching target

Nominal Steps of 0.03 Sigma 1.5 μm

Initial lumi Leveling start
DETAILS OF LEVELING FOR FILL 3266

Effect of Orbit Correction

Leveling separate the beams
Alice run with pPb
Head-ON: lumi too high

Separate beams manually in defined leveling plane

Start luminosity leveling & DECLARE STABLE BEAM

Beams back to head-on
Leveling becomes inefficient and stops

Leveling OFF

new optimization launched for both planes
CONCLUSION

- Luminosity levelling part of the routine LHC operation for LHCb and Alice
- Luminosity levelling allows to maximize the integrated luminosity while keeping low luminosity peak and low pile-up

More than 2 fb-1 of exploitable data delivered for LHCb in 2012!!
CONCLUSION

- Beam beam effect under control in 2012 if no private bunches for LHCb.

- After LS1: levelling may be needed in all experiments: $\beta^*$ levelling and beam offset levelling will probably be used in some combination.

VERY CHALLENGING FOR OPERATION