Injection and Lessons for 2012

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Special thanks to: Collimation, BLM, MPP, OP teams
Outline

2011 Operation

- Injection:
  - How far did we go? 144 and 288 bunches
- Mitigation measures
- Transfer line stability:
  - Shot-by-shot and bunch-by-bunch variations
  - Source of instabilities
  - Steering
  - Improvements
- MKI Failures
- Other issues

- Conclusions and 2012 Operation
### Injection Losses and Intensity Limitations

#### From Chamonix 2011:

<table>
<thead>
<tr>
<th>Loss type</th>
<th>Losses in % of dump threshold B1/B2</th>
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<tbody>
<tr>
<td></td>
<td>8b</td>
</tr>
<tr>
<td>TCDI shower</td>
<td>1/2</td>
</tr>
<tr>
<td>Uncaptured beam</td>
<td>4/2</td>
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**Injection of 144 bunches became fully operational in 2011!**

**B1, max loss 4% dump**

**B1, max loss 62% dump**

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Linear extrapolation for 2011 operation

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**Not optimised**

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**LHC Performance Workshop - Chamonix 2012**

06/02/2012
Injection of 288 Bunches During MD

- 288 bunches (1.05e11 ppb, 2.5-2.7 μm) injected at 30% of thresholds

Beam 1
288 bunches < 27%

LHC Injection Quality Check

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Injection of 288 Bunches During MD

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Beam 1
288 bunches < 27%

Beam 2
288 bunches < 32%
Injection of 288 Bunches During MD

- 288 bunches (1.05e11 ppb, 2.5-2.7 μm) injected at 30% of thresholds

- Still work to be done to optimize beam in the SPS/injector chain and accumulation in the LHC ring and lifetime (RF, transverse damper, chromaticity.....)

- Vacuum activity observed at the MKI during injection

- More statistics needed

- Very promising in view of operation with nominal intensity
Mitigation Techniques

**TL showers:**
- Local shielding between TCDIs and LHC (×2-3)
- Beam scraping in SPS (×2)
- Opening TCDIs (×4)
- Moving/adding TCDIs (under study)
- BLM sunglasses (Little Ionisation Chamber LICs)
- Improve transfer line stability

**Uncaptured beam**
- Local shielding at TDI (under study)
- Injection and abort gap cleaning (×10)
- Carefully monitoring beam quality in injectors (transverse beam size and shape, bunch length, satellites,..)
- BLM sunglasses
Scraping studies showed the importance of the scraping position. The scraper has to cast a shadow on the transfer line collimators. In this way even large emittances can be transferred.

Just increase the scraping when there are losses at LHC injection is rarely the best solution.
Open TCDI Gap: Loss Shower on LHC BLMs for B1

W. Bartmann, Evian 2011
BLM Sunglasses

W. Bartmann, Evian 2011

- Why sunglasses: 
  Unnecessary beam dumps due to TCDI and unbunched beam showers from outside

- Aim of sunglasses: 
  **Factor 5 margin** between **injection losses** and **BLM thresholds** for comfortable operation

- Options:
  - replace certain monitors by LICs and relax thresholds at 450 GeV → no HW modification, certain thresholds constantly higher for 450 GeV (This year)
  - blind out BIS input from certain BLMs while injection via deploying additional energy level, regrouping crates, new monitor flag → need external signal, **threshold change only at injection**, severe changes to SIS or BLM system (longer term???)
BLM Sunglasses – LIC Solution

Potential to increase thresholds by factor 60 by replacing present ICs by LICs

No change to BIS system nor BLM firmware needed

List of monitors to be replaced for B1 and B2 identified

Procedure:

- Replace certain monitors: 7 LICs will be installed before start-up
- Start with present thresholds (be sure to be aware of bad injections)
- Define maximum thresholds for LICs
- Apply increase of thresholds via monitor factor in case unnecessary dumps limit operation
TL Stability: Observation
L. Drøsdal, Evian 2011

![Graphs showing TL Stability Observation](image-url)
TL Stability: Observation

L. Drøsdal, Evian 2011

5 h later – same super cycle composition ➔ Trajectory has changed

➔ Necessary to re-steer the line

- **Tight transfer line collimators** – high losses if trajectory not centered (17 dumps for B1 and 10 for B2)
- **Injection oscillations** have to be below 1.5 mm to respect available aperture in the LHC
TL Stability: Observation

L. Drøsdal, Evian 2011

5 h later – same super cycle composition → Trajectory has changed

→ Necessary to re-steer the line

- Beginning of run: ~ twice a week
- End of run: every second day
- Frequently the same corrector proposed (TI 2: RCIBH.20804, in phase with MSE/MST)
- Offsets drifting back and forth
- Dependence on SPS supercycle?
Dedicated periods of repeated extractions on downstream TEDs with 12 bunches for study of shot-by-shot variations

**TI 2: 82 Shots, 19 June**
- Horizontal plane: max 760 μm
- Vertical plane: max 260 μm

**TI 8: 117 Shots, 2 November**
- Horizontal plane: max 770 μm
- Vertical plane: max 260 μm

→ used data in **Model Independent Analysis** to find strongest Eigenmodes of oscillations
Shot-by-shot Variation Sources

L. Drøsdal, Evian 2011

TI2H - instability sources

TI8H - instability sources

TI2H: Correlations to magnet currents at 25004

TI8H: Correlations to magnet currents at 80704

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Observed variations in the magnet currents:
- Observed MSE variations are large enough to produce this oscillation
- MST is not strong enough
- MKE variations still to be investigated

MSE:
- Low inductance 20 kA circuit
- Power converter ripple was reduced from 18A to 9A \( \Rightarrow \) 30% improvement
- Improvement by factor 2 in H still necessary for both lines (work ongoing)
Bunch-by-Bunch Variations

L. Drøsdal, Evian 2011

- Large bunch-by-bunch trajectory variations observed for TI 8 H – seen on the bunch-by-bunch injection oscillation amplitudes

![Graph showing injection oscillation amplitudes over bunch ID]

- Suspected too large ripple of the horizontal extraction kicker (MKE) waveform

Plot from the IQC B2, 144 bunches Horizontal plane

Variation > 1mm (max)
The MKE4 waveform shows a ripple varying up to 2.5% of kick (max. to min.) at the flattop (4% at initial overshoot) - specification: 1 % flattop ripple!

Need to improve the MKE4 flat-top ripple (PFN)? - Only possible in LS1

Immediate action: change the delay to move the beam to a flatter part of the waveform.
Steering is complicated due to several effects:

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→ In 2011: ~ **30 min – 2 h** to steer (excluding some big outliers)

Estimate 2012 if stability is not improved:

1h steering × 0.5/days × 120 days = **60h**!

Can we improve?
Impact on Operation

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- Reduce sources of instabilities (MSE ripple, adjust beam delay wrt MKE waveform)
- Time for setup during commissioning ➔ new reference trajectory
- Carefully monitoring beam quality in injectors ➔ better detection of bad beam quality early in the chain (longitudinally already well covered by BQM, transv. can be improved)
- Improve IQC references
  - Limits at TL BPM (MD to define them) ➔ easier steering
  - Clear warning level at critical BLMs depending on number of bunches injected (i.e. MSI ≥ 5% with 12 bunches ➔ steering needed )
Injection of $2 \times 36$ bunches spaced by 2.2 $\mu s$
- Breakdown after ~2 $\mu s$
- All 36b of 2$^{nd}$ batch were kicked with 110-125% nominal MKI deflection

Beam was on LOWER TDI jaw and over-kicked, i.e. breakdown in second half of magnet (LHCb signals support this)

Nearly all p+ of the 36b impacted on the TDI/TCLIB (grazing) $\Rightarrow$ 11 magnets quenched

- **MKI HW vacuum interlock** reduced from 5e-8 mbar to **2e-8 mbar**
- New **SIS** to prevent injection if MKI pressure >2e-9 mbar for 50 ns beam (temporary >2.5e-9 mbar for scrubbing with 25 ns beam)
- New $\int P \cdot dt$ interlock implemented (Xmas stop)
- Checked carefully **TDI angular alignments** in IR2 and IR8
- **TCLI openings $\Rightarrow$ TCLIB to 8.3 $\sigma$**
- Solenoids between MKI and Q4/A5 switched ON
Interlocks detected an erratic of the Main Switch of MKI-C (MS-C) and correctly triggered MS’s and DS’s of system (within 2µs), emptying PFN via both ends.

Hence kicker-C pulsed for 6.5µs and 3 other kicker magnets pulsed for up to 4.5µs, emptying PFNs of energy.

Circulating beam was not in IP2 and therefore not disturbed.

Batch was extracted from SPS but saw no kick at MKI2 (current already back to zero in all 4 MKI magnets) and went straight into the TDI upper jaw.

Erratic of MKI2 MSC at 33kV during resonant charging – sending current to one of the four kicker magnets

Interlocks did NOT detect erratic of MS-C: hence no immediate action was taken to turn-on other thytratrons ➔ full 9 µs PFN pulse length to kicker C.

Failure ~500µs into charging process: extraction from SPS correctly inhibited;

Circulating beam was swept over aperture and grazed TDI (~17% of normal kick) for ~8.9µs ➔ 150-190 bunches
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173 bunches - \(2.15 \times 10^{13}\) p+ lost (not dumped)

3 magnets quenched

ALICE: permanent effects on the Silicon Drift Detector
to kicker C.

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ALICE: permanent effects on the Silicon Drift Detector

Hardware problem \(\Rightarrow\) faulty components exchanged + additional diagnostic + faster detection electronics with lower voltage threshold \(\Rightarrow\) no other events in 2011 BUT erratics can occur several times per year!!
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Erratic of MKI2 MSC at 33kV during resonant charging – sending current to one of the four kicker magnets.

Up to a factor of 2-4 higher losses might occur in future years (higher intensity and # bunches, worse impact parameter at TDI).

OK for machine, but main concern is safety for ALICE/LHCb.

Detectors must be sufficiently off during injection!
MKI Temperature Interlock

✓ Magnet **inductance** decreases when reducing ferrite permeability ➔ **magnet strength decreases**
✓ **Rise-time** decreases with reducing inductance and/or capacitance
✓ **Delay** decreases with reducing inductance and/or capacitance

**Softstart (no beam) ➔ measure rise-time ➔ indirect measurement of inductance (temperature)**

**During Xmas stop: new diagnostic to measure delay (more sensitive, better time resolution of kicker waveform)**

**SIS interlock presently 62 °C** (originally 55 °C) cannot be further increased!

✓ MKI Temperature of up to 68 °C measured during physics (10 hours time-constant for ferrite heating and cooling)

✓ Soft-start: OK ➔ injection not Ok ➔ wait for MKI cooling

✓ 24 stripes under investigation for installation during TS in August 2012.
Other Issues Related to Injection System

- UFOs at MKI ➔ several beam dumps at the beginning of the run (T. Baer’s talk, S07 Thursday)

- TDI:
  - Controls problem TDI in IR2: settings different from measured motor position and drift of the position reading triggered by electromagnetic noise
  - Heating Vacuum pressure increase at TDI in IR2 and IR8 when at parking position (±20 mm) ➔ High background in ALICE (shielding?) ➔ new parking position ±55 mm (E. Metral’s talk, S02 Monday)
  - Beam screen deformation discovered during Xmas Stop.

Investigation on cause and solutions ongoing!
Conclusions

- Injection of **144 bunches fully operational**: consistent/better than predictions (some mitigations applied: scraping, TCDI at 5σ, shielding, injection and abort gap cleaning)

- **Successful injection of 288 bunches** for both beams with losses at ~ 30% from thresholds → promising (further mitigations available: new TCDI locations, BLM sunglasses)

- **TL stability** caused a lot of problems:
  - Steering: tradeoff between minimum transverse losses (beam position at TCDI) and injection oscillations → time consuming
  - big shot-by-shot (MSE) and bunch-by-bunch (MKE) variations

- How to **improve TL stability** for 2012 operation:
  - Reduce MSE ripple and optimise delay beam/MKE
  - Dedicated time for setup during commissioning
  - Clearer references in IQC

- Injection Failures:
  - MKI flashover and erratics: magnets quenched, experiments affected...
  - Replaced faulty components, improved diagnostics, safer interlock limits.
  - MKI failures can occur several times per year (according to specifications) → respect safety instruction, time for cooling and reconditioning, interlock limits and experiment off

- TDI heating and beam screen deformation: investigation ongoing to find cause and short (before LS1) and long term solutions
Thank you