TRANSFER LINES, INJECTION AND EXTRACTION RE-COMMISSIONING

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Outline

- SPS extraction
  - Orbit stability at high energy
  - MSE ripple
  - Non local extraction
- TL commissioning
  - Standard tests
  - News on TCDI setup and validation
  - Optics checks
- LHC injection system commissioning
  - Standard test
  - LHCb vertical crossing angle and impact on TDI, TCLI and TCDI
- LHC extraction system commissioning

SPS Orbit Stability

TL trajectory drifts observed after moving to Q20 optics ➔ SPS Orbit variations at high energy?
Several studies and investigations done and presented at the LIU-SPS Orbit correction Review.

- **SPS orbit at high energy is corrected once per year by re-aligning quadrupoles** until the rms orbit is satisfactory.
  - *Typically 1-2 mm rms for the FT beams.*
- **Orbit correctors are not used**:
  - *The CODs are weak, kicks of ~ 10-15 μrad at 450 GeV,*
  - *If the CODs are used, then interlocks would be required.*
- To avoid moving too many quadrupoles, the MICADO algorithm is used to obtain **efficient corrections with few elements**.
  - *But the effective solution for Q26 FT may not be ideal for Q26 LHC or Q20. To solve this issue a simultaneous minimization of say Q20 and Q26 orbits is required.*

Courtesy of J. Wenninger

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- **Injection dogleg non-closure** for Q20 optics (optimised phase advance for Q26 optics) ➔ correction at high energy possible **after coil reconfiguration of MDHD.11832** (during LS1) ➔ **interlocking needed!**

- With Q20, **4% emittance dilution** from dispersion (1 measurement): acceptable? If not average SPS orbit to be corrected (for HL-LHC maximum 10% allowed over the full cycle up to collision!)

- **Quadrupole displacement** gives a smaller effect with Q20 than Q26 but rms orbit larger for LHC beam than for FT beam (different fractional tunes)
    - Revise **fractional part of LHC beam tune**? Compatible with high intensity beams?
    - **Combined Q20/Q26 corrections?**

- Reference orbit ➔ **automatic correction of beam position and slope** (instead of TL steering) ➔ done with existing interlocked extraction bumpers in LSS4 and LSS6 ➔ **additional constraints in BPM precision and interlock system.**

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Combined Q20/Q26 Correction

- Problem: find an optimum correction for the high energy orbits of Q20 and Q26 (or any other optics combination) → re-alignment.
- Requires a simultaneous correction of 2 orbits (one acquired Q20, one Q26) with 2 different optics (Q20 and Q26) using the same correctors.
- Solution with reasonable (??) effort (i.e. making use of existing UI):
  - *Define SPS as a 2 beam machine where all BPMs are duplicated (exist in both rings) and all correctors are coupled to both beams.*
  - *Load Q20 orbit as say B1 orbit, Q26 as B2 orbit.*
  - *Load Q20 optics for B1, Q26 optics for B2.*
  - *Run standard YASP correction.*

This is the missing & tricky part !

Initially provide an expert tool - improvements depending on success…

Courtesy of J. Wenninger

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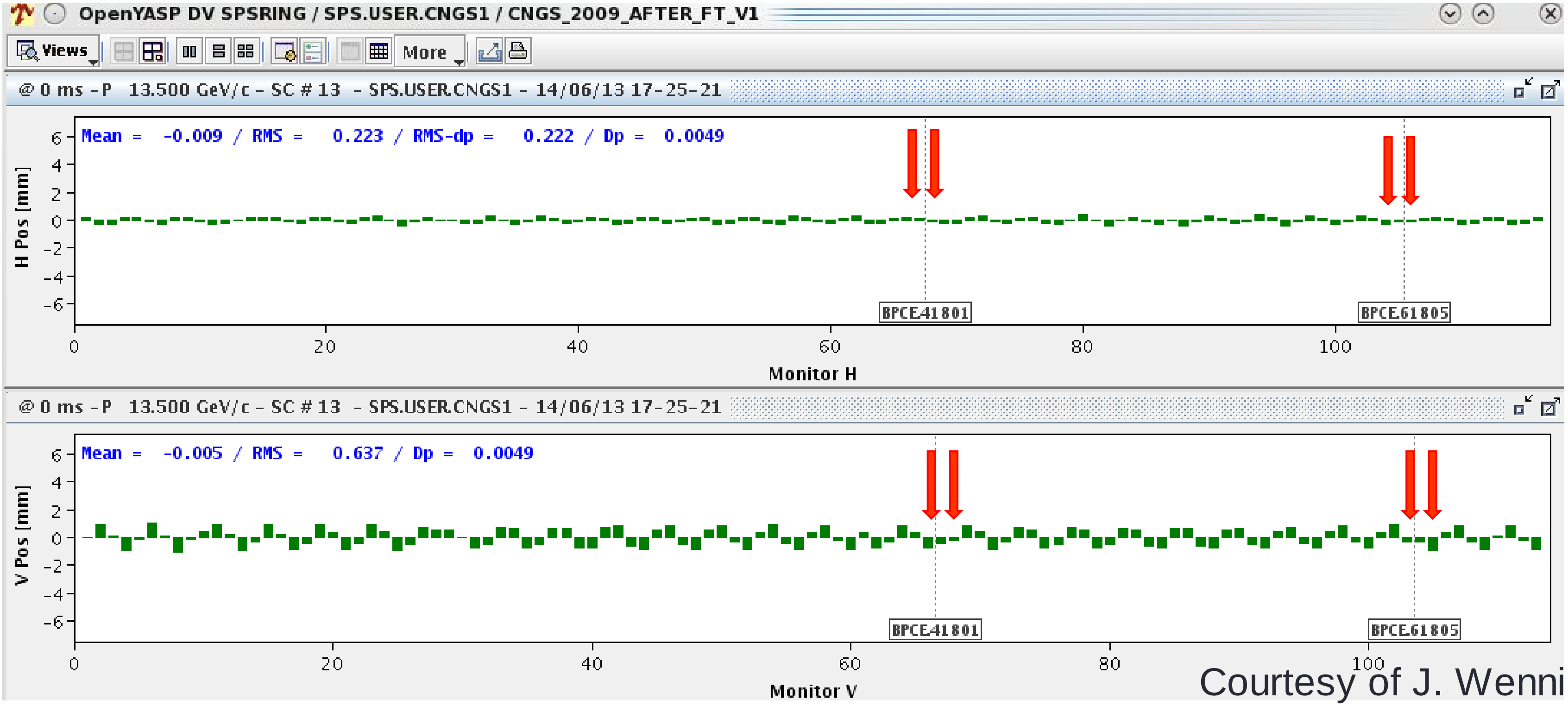
Correction in the SPS Extraction Point

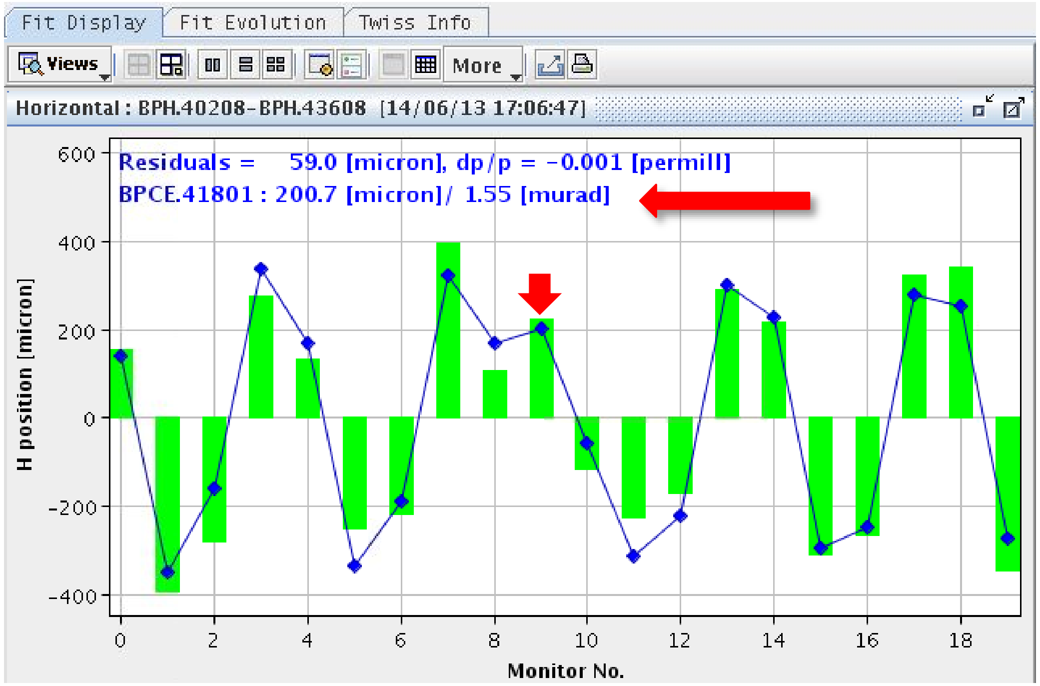
- Determine reference BPM offset wrt reference at the extraction points.
- Trim a correction (existing knobs) ⇔ ‘zero’ reading on ref. BPMs.
  - *Experience on CNGS beam (for which the BPMs work better than for LHC beams) was not very positive – did not replace steering in the line.*
  - *BPM long term stability is critical.*



Courtesy of J. Wenninger

Correction in the SPS Extraction Point

- To reduce the sensitivity to errors of individual BPMs, fit a betatron oscillation across some section around each extraction point and interpolate to the extraction point.
  - *Fit to (orbit – reference).*
  - *Tools available in YASP (for fit), only DB configuration needed.*



Example for LSS4:

- ***Fit over sextant 4.***
- ***Interpolate to BPM in cell 418 (and 416).***
- ***Use available knob(s) to trim at extraction point.***

Easy to setup & test

Courtesy of J. Wenninger

Correction in the SPS Extraction Point

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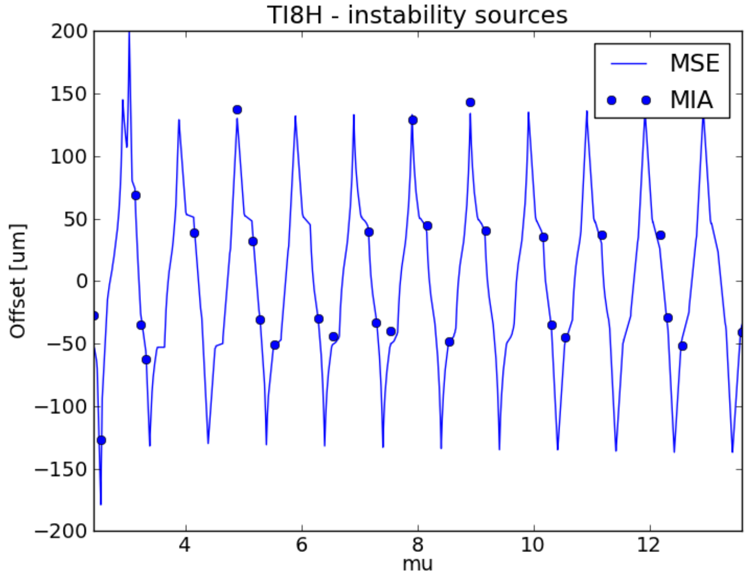
  - *Fit to (orbit – reference).*
  - *Tools available in YASP (for fit), only DB configuration needed.*

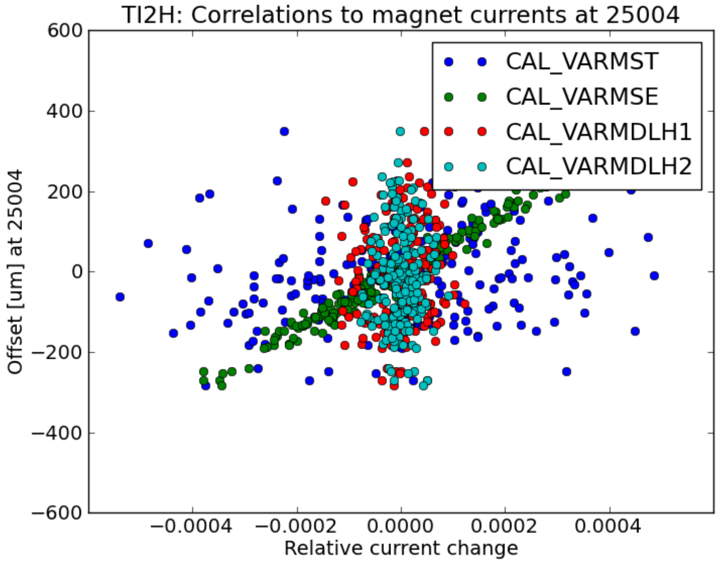
- Another alternative is to (try to) correct the high energy orbit globally with extraction bumpers.
  - *Not sure this will always work, since the bumper are installed very locally in the LSS.*

Courtesy of J. Wenninger

MSE Ripples

- MSE current ripples identified as main source of shot-to-shot TL variations (L. Drosdal):

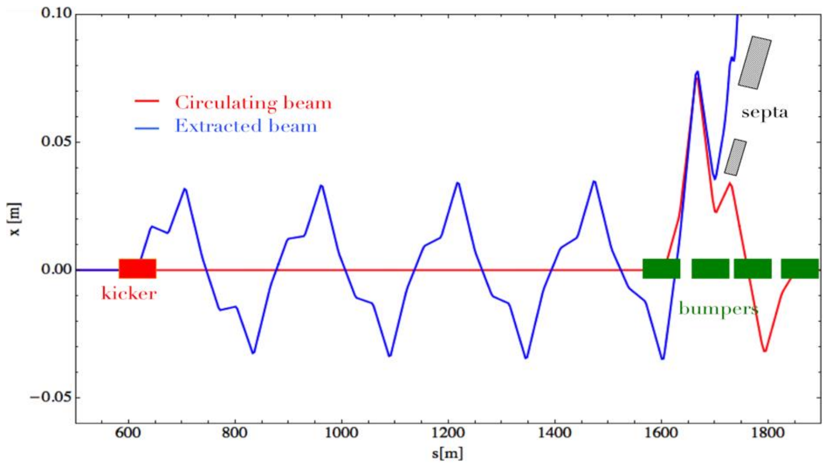


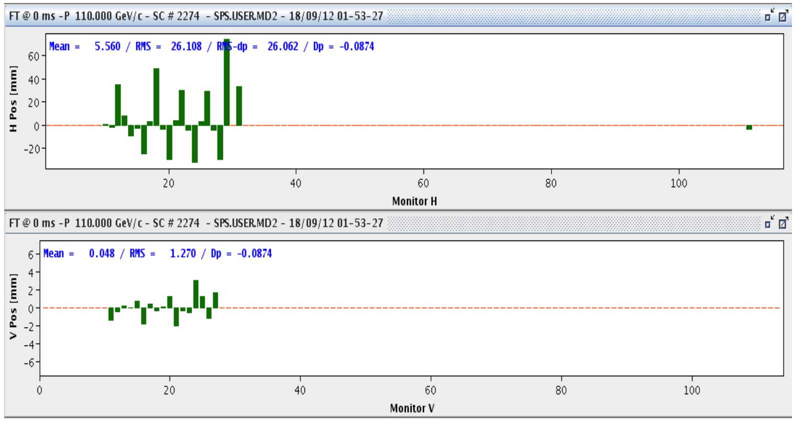


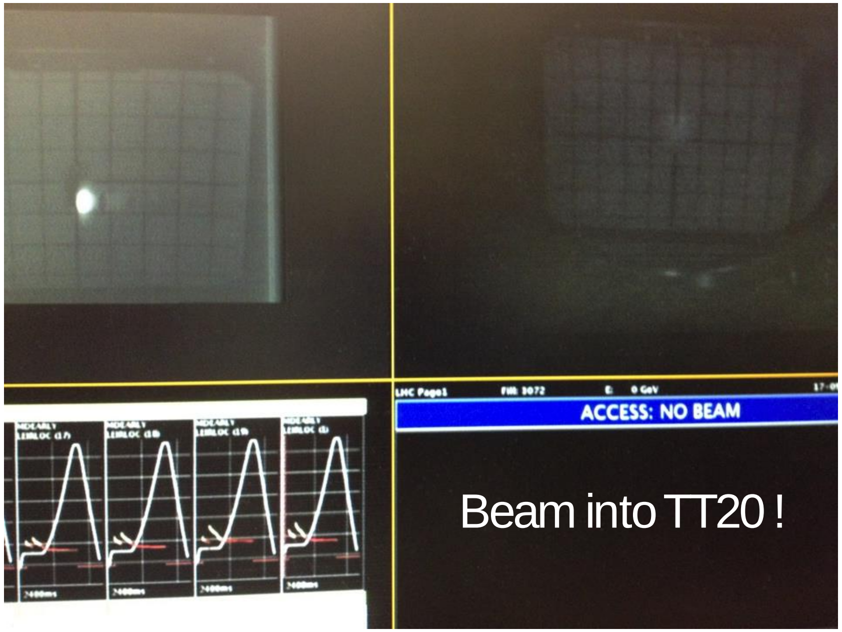
- Studies have been performed on both MSE6183 (Beam 1) and MSE4183 (Beam 2, x2 higher peak-peak ripple): modification of cabling of the output filters, evaluation of optimum number of powering modules, possible improvements of the regulation loop…
- Foreseen improvements (during LS1): starting from previous observations ➔ development of an analytical model for the output filters ➔ validation with simulations ➔ definition of needed modifications
- Extraction tests to check TL stability improvement after modifications

Non local Extraction

- Driving idea: need to perform fast extraction in LSS2 for CENF project but no local kickers, not possible installing additional kickers because of lack of space and to avoid increasing the SPS impedance ➔ using LSS1 kicker to generate the extraction bump (F. Velotti's)







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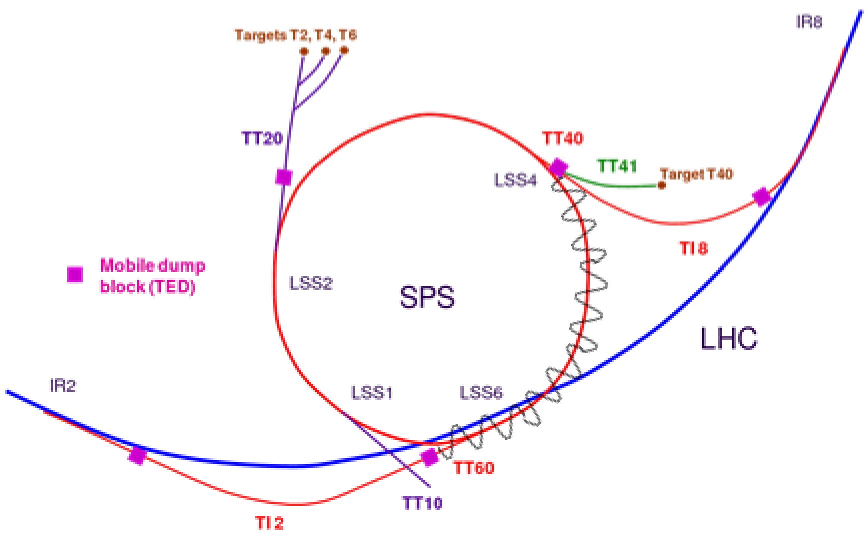
- Use **LSS4 kicker** to generate the **extraction bump for beam 1 in LSS6** (F. Velotti's Phd thesis, start 1st September 2013) ➔ reduce number of kickers and SPS impedance (40% total budget from kickers) in view of operation with high intensity and high brightness beams

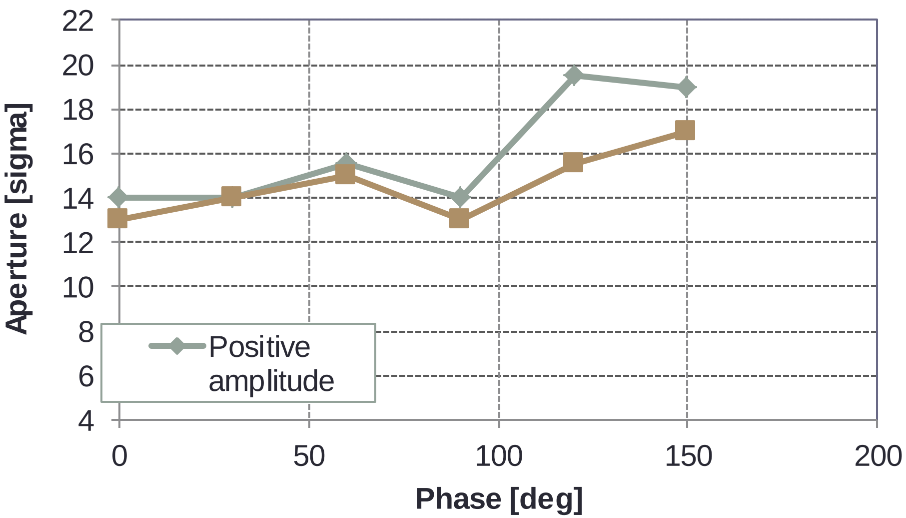
- **Optics calculations** with MAD-x (i.e. **phase advance optimisation**, **Q-split**, **matching** to TLs, **TL stability evaluations**, etc.)

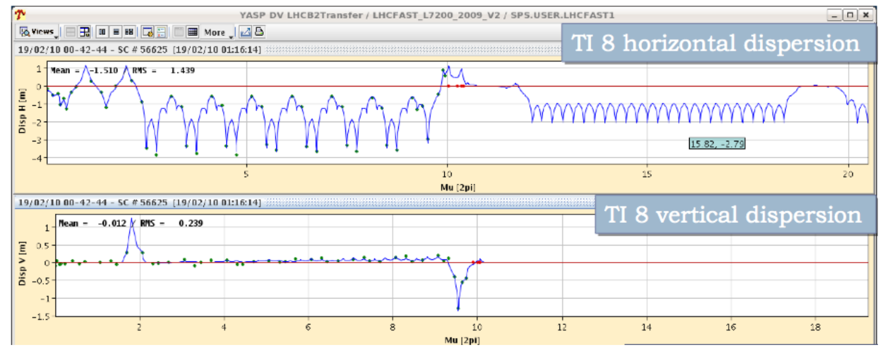
Risk analysis!!

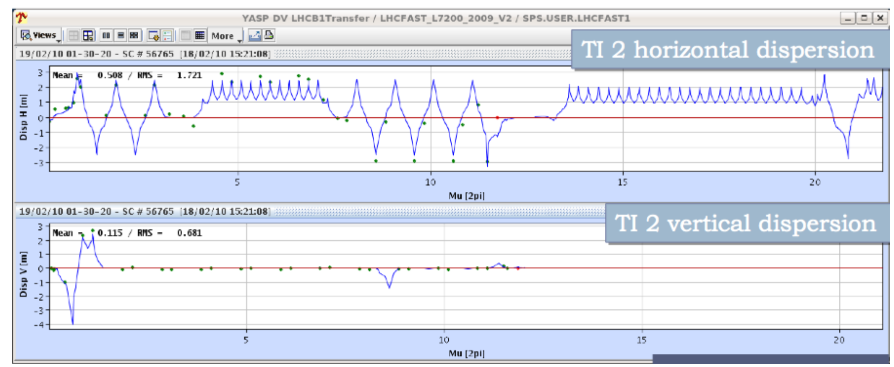


TL Commissioning

- Extraction in steps (upstream TED ➔ downstream TED ➔ TDI ➔ beam into LHC)
- Trajectories correction
- Dispersion measurements
- Aperture Measurements
- Emittance measurements (BTV checks)



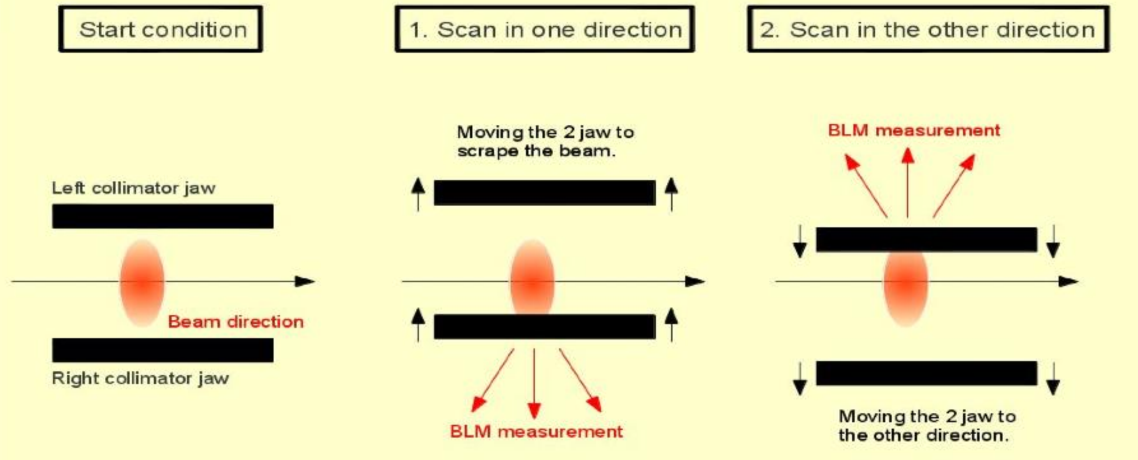




TCDI Setup and Validation

- Reference orbit in LHC established ➔ golden trajectory in TL to minimise injection losses and injection oscillations
- Tool for automatic setup (Y. Le Borgne)

Fixed gap 5 σ (nominal 4.5 σ)



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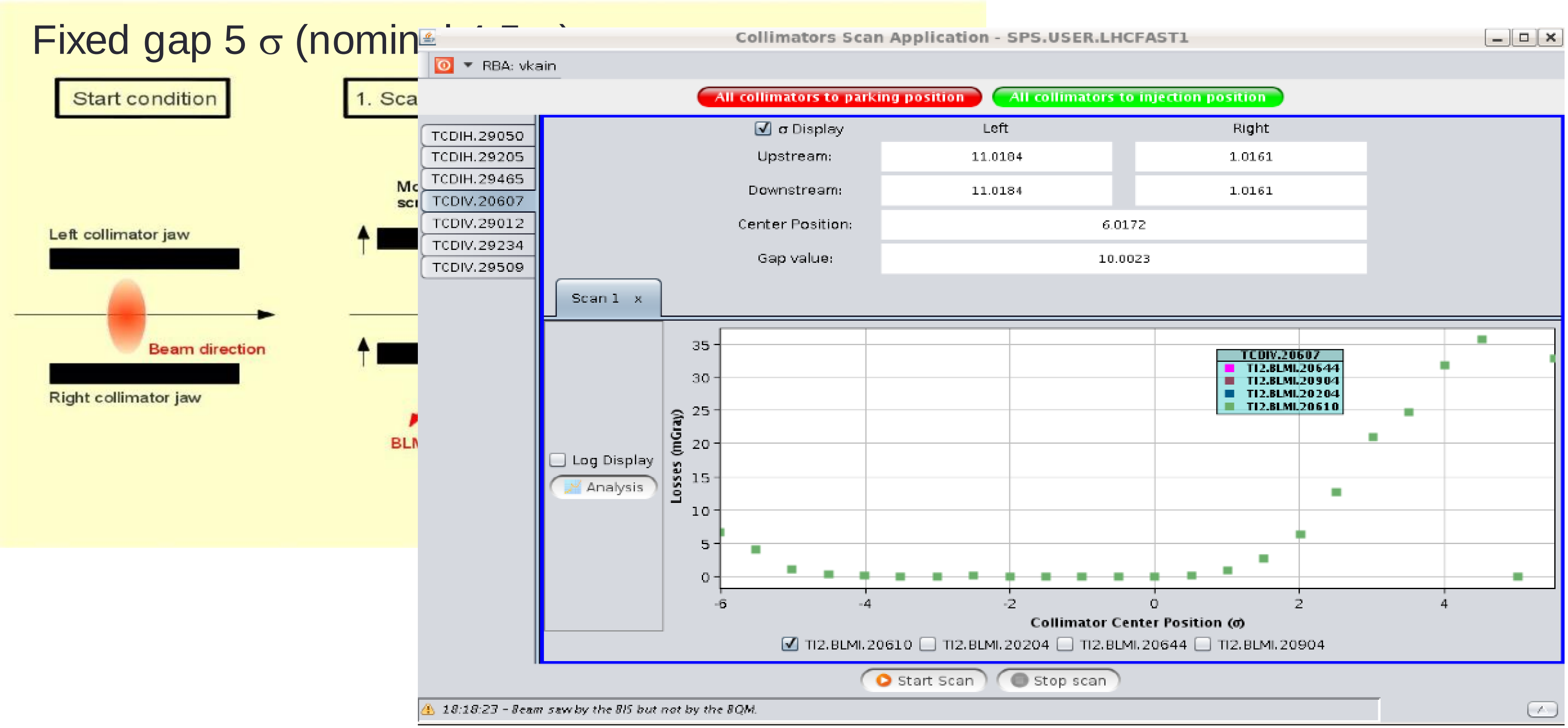

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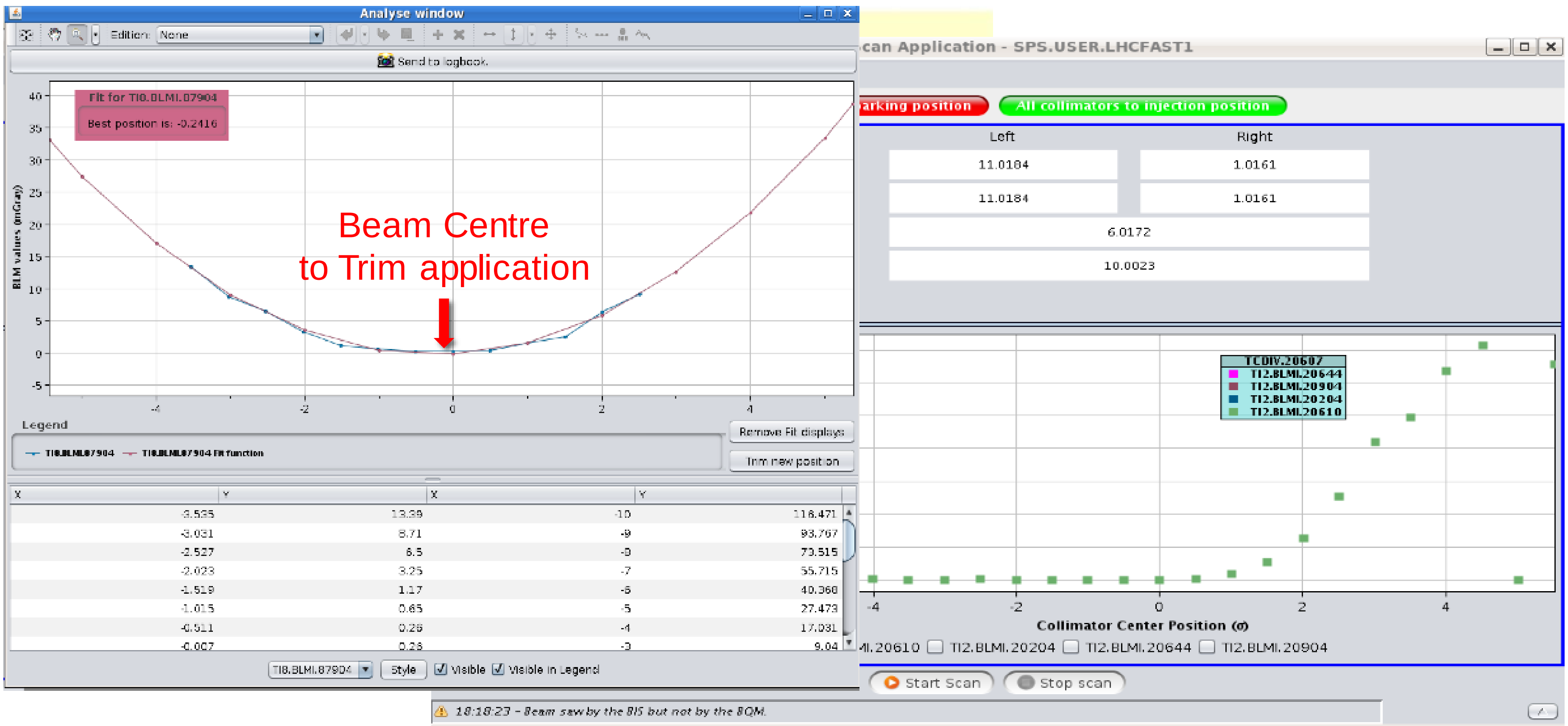

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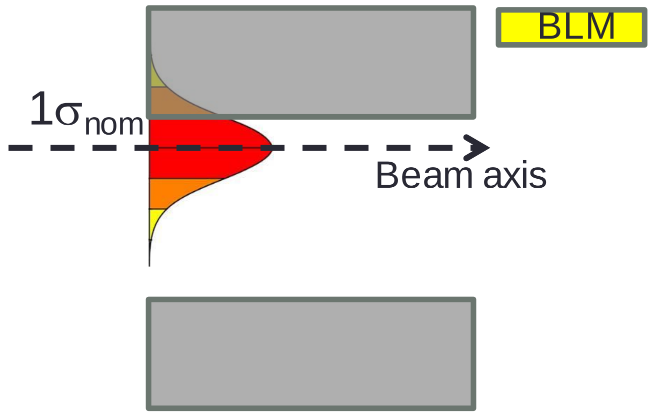
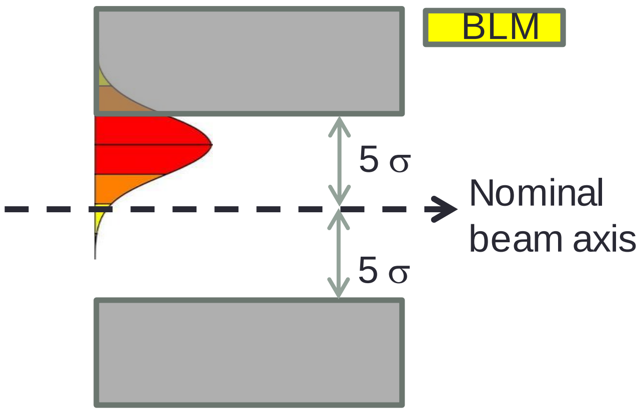
- Validation checks: aperture cut provided by the TCDIs ($< 7.5\sigma$!!)

Calibration



Validation



Jaw at $1\sigma_{nom}$ ➔ BLM reading / intensity ➔ real beam size σ_{real}(measured emittance, dispersion, nominal Dp/p = 1e-4) ➔ intercepted beam

Knob producing 5σ oscillation for different phases 0-30-60…-360° ➔ BLM reading/intensity ➔ intercepted beam ➔σ_{real} cut

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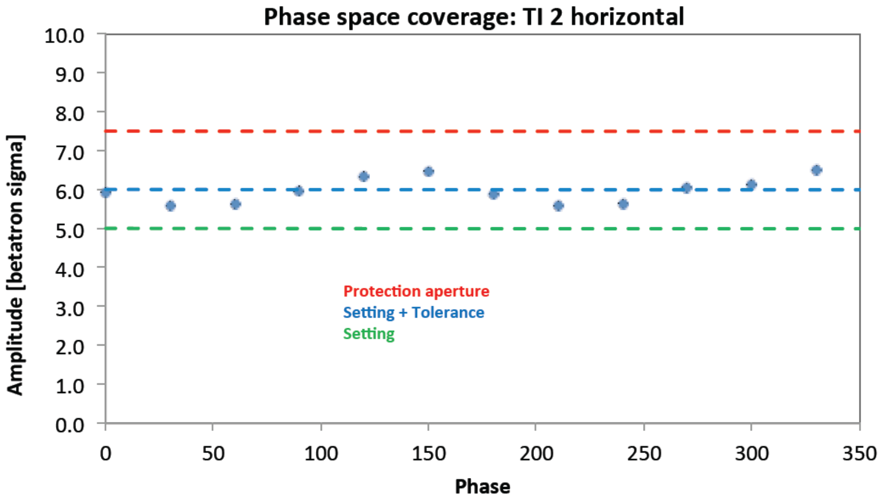
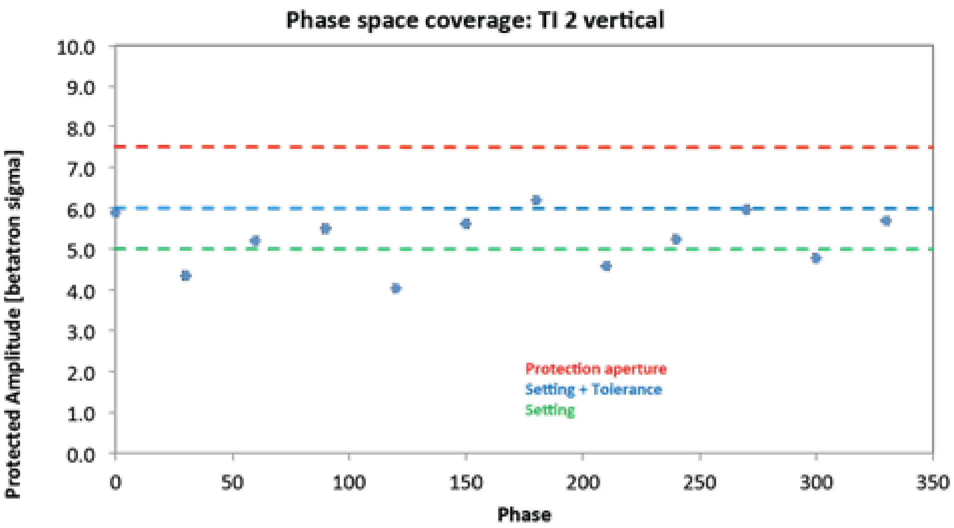


Off line analysis + very basic model + perfect Gaussian beam….



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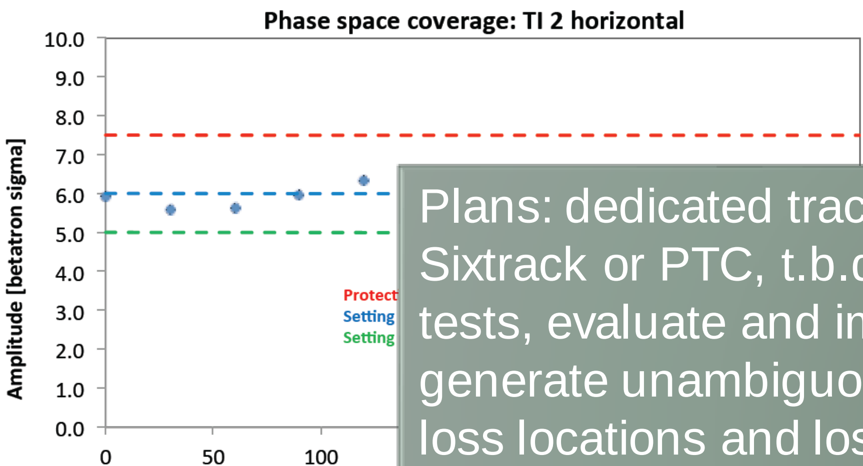

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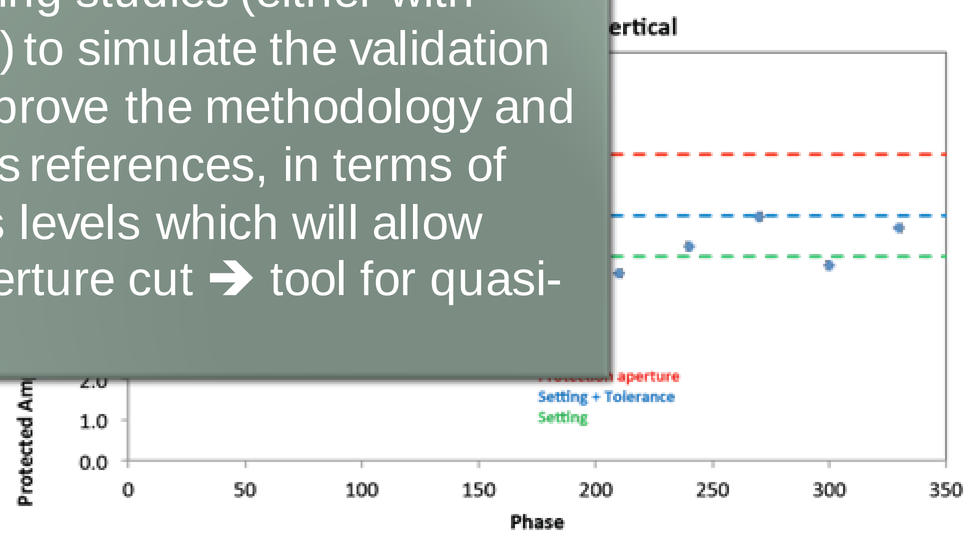
Plans: dedicated tracking studies (either with Sixtrack or PTC, t.b.d.) to simulate the validation tests, evaluate and improve the methodology and generate unambiguous references, in terms of loss locations and loss levels which will allow defining the TCDIs aperture cut ➔ tool for quasi-online analysis



Optics Checks to Avoid Wrong TCDI Settings

- For each TL optics, store ALL quad currents as critical settings in LSA settings. To each optics associate a unique "virtual beta*".
  - Same ref values that are used for the FEI HW interlock.
  - Must be stored on the BP that contains the TCDI settings.
  - In same BP store also the virtual beta* limits for TCDI.
  - Could use the LSA optics ID as virtual beta* !

- SIS reads the reference settings and compares them to the published extraction currents (every cycle).
  - If in tolerance publish virtual beta* value associated to optics.
  - If not in tolerance publish 0.

- On TCDI side read beta* from MTG and check if in limit.

  ➔ Fully data driven system.

Courtesy of J. Wenninger

Machine Checkout & Beam Commissioning

- MP checks without and with beam (https://espace.cern.ch/LHC-Machine-Protection/Lists/MPS%20Task%20List%202012/Resume.aspx)

Phase : Beam Commissioning (127)

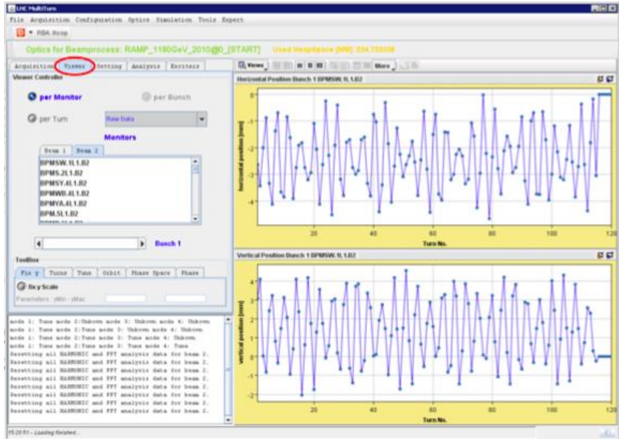
- System : BLM (7)
- System : Collimation (13)
- System : FMCM (3)
- System : Injection-Beam1 (6)
- System : Injection-Beam2 (5)
- System : LBDS-Beam1 (38)
- System : LBDS-Beam2 (38)
- System : MPS Global tests (2)
- System : SIS (6)
- System : SMP (9)

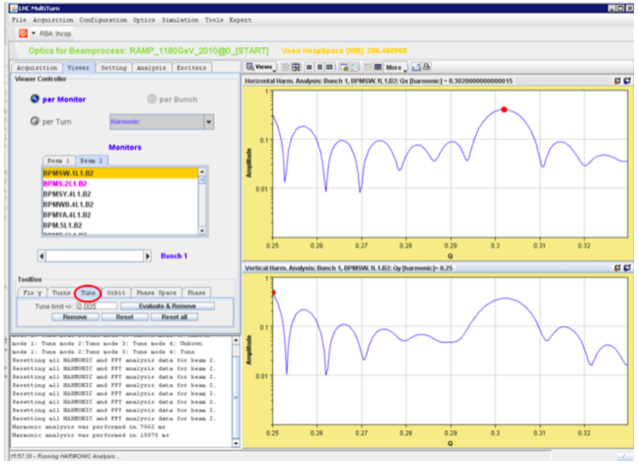
Phase : Machine Checkout (220)

- System : BIS (3)
- System : BLM (1)
- System : Collimation (9)
- System : Experiments (6)
- System : Injection (3)
- System : Injection-Beam1 (25)
- System : Injection-Beam2 (25)
- System : LBDS-Beam1 (54)
- System : LBDS-Beam2 (54)
- System : PIC (4)
- System : RF (2)
- System : SIS (22)
- System : SMP (8)
- System : Spectrometers (2)
- System : Vacuum (1)
- System : WIC (1)

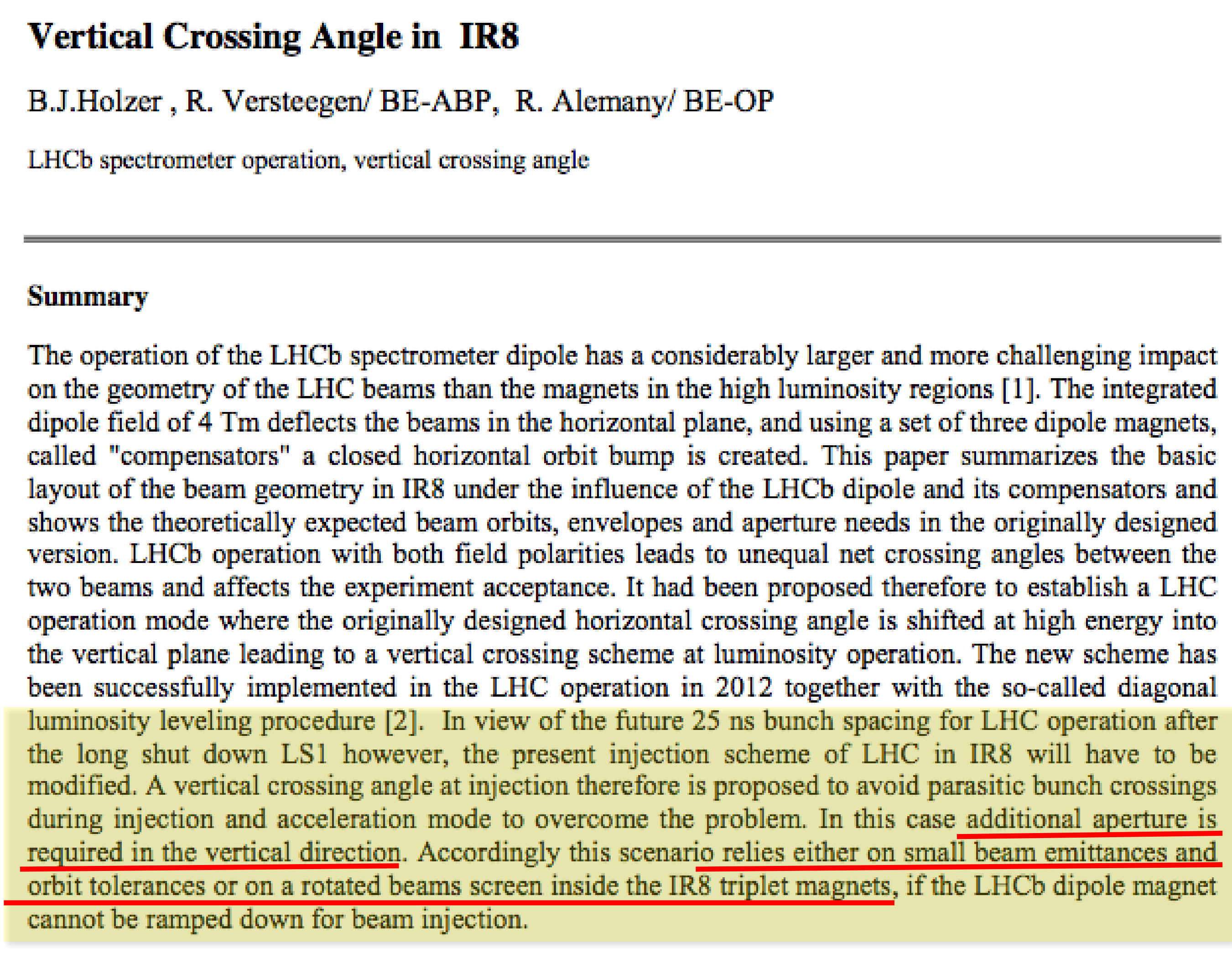
Injection System Commissioning

- Reference orbit in LHC defined ➔ TCLI and TDI setup and validation (same as for TCDI + lossmaps)
- Injection matching and emittance preservation (matching monitors, BSRT, wire scanner)
- Optics measurements (multi-turn application)
- **Aperture measurements** (impact on TCDI aperture!)
- Test IQC (injection oscillations…)
- Test injection cleaning
- Check Injection losses (LICs and Sunglasses)





LHCb new Crossing Angle



Vertical Crossing Angle in IR8

B.J.Holzer , R. Versteegen/ BE-ABP, R. Alemany/ BE-OP

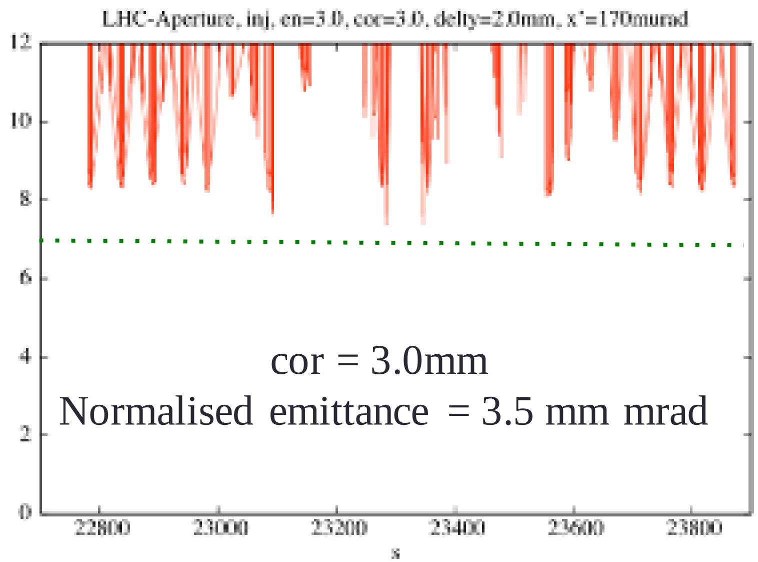
LHCb spectrometer operation, vertical crossing angle

Summary

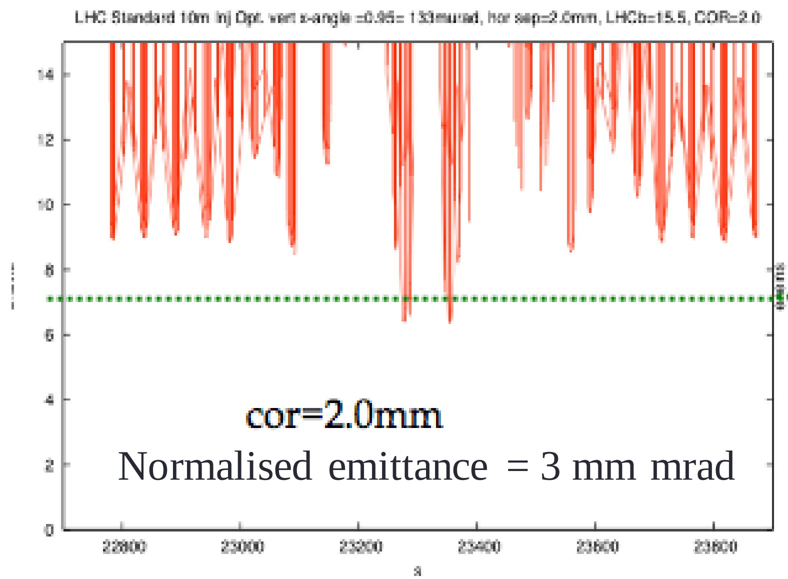
The operation of the LHCb spectrometer dipole has a considerably larger and more challenging impact on the geometry of the LHC beams than the magnets in the high luminosity regions [1]. The integrated dipole field of 4 Tm deflects the beams in the horizontal plane, and using a set of three dipole magnets, called "compensators" a closed horizontal orbit bump is created. This paper summarizes the basic layout of the beam geometry in IR8 under the influence of the LHCb dipole and its compensators and shows the theoretically expected beam orbits, envelopes and aperture needs in the originally designed version. LHCb operation with both field polarities leads to unequal net crossing angles between the two beams and affects the experiment acceptance. It had been proposed therefore to establish a LHC operation mode where the originally designed horizontal crossing angle is shifted at high energy into the vertical plane leading to a vertical crossing scheme at luminosity operation. The new scheme has been successfully implemented in the LHC operation in 2012 together with the so-called diagonal luminosity leveling procedure [2]. In view of the future 25 ns bunch spacing for LHC operation after the long shut down LS1 however, the present injection scheme of LHC in IR8 will have to be modified. A vertical crossing angle at injection therefore is proposed to avoid parasitic bunch crossings during injection and acceleration mode to overcome the problem. In this case additional aperture is required in the vertical direction. Accordingly this scenario relies either on small beam emittances and orbit tolerances or on a rotated beams screen inside the IR8 triplet magnets, if the LHCb dipole magnet cannot be ramped down for beam injection.

LHCb new Crossing Angle

Hor. crossing



Vert. crossing



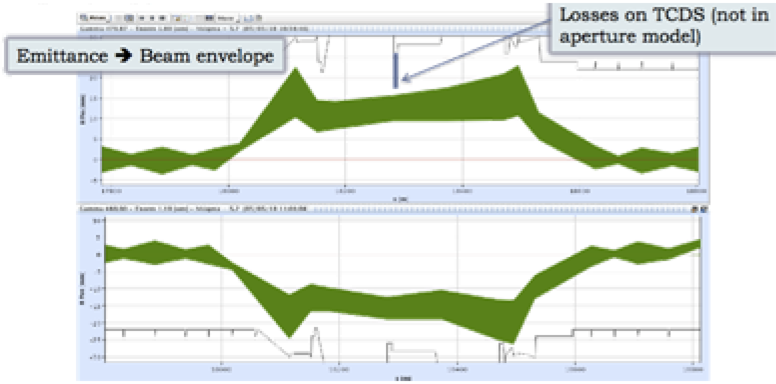
Effects on injection protection collimators?

Further checks!

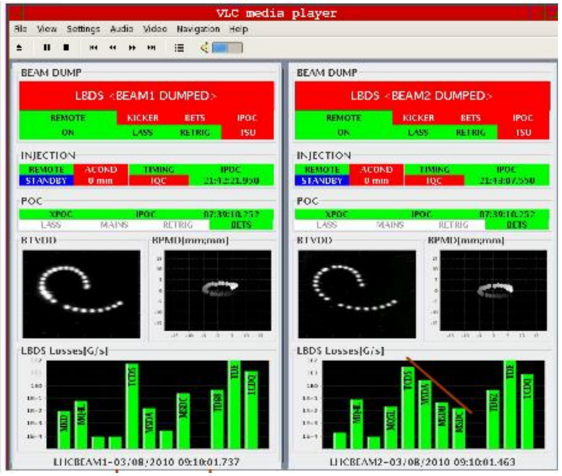
- TDI and TCLI protect the arc aperture ➔ no aperture reduction there but any issue at the triplet in case of injection failure?
- Collimators to be realigned after each polarity flip (1 shift!)
- TCDIs have to protect the injection region aperture➔ 5σ guarantee protection of 7σ aperture ➔ need for a smaller gap? (nominal 4.5σ) ➔ injection losses!

Extraction System Commissioning

- TCDQ-TCSG setup (new TCDQ HW 3 x 3m long CFC blocks, angular scan!!) and validation. Optics change to have exactly 90 deg phase advance wrt kicker really advantageous? Measure real β and real phase advanced needed!! Changes during operation, beta-beat etc…



- Beam losses at extraction



- Beam centered in extraction channel and sweep pattern (2 additional MKB)

- Aperture measurements (circulating and extracted beam)

- Abort gap cleaning: automatic link to BSRA

Summary

- SPS extraction:
  - Need for orbit corrections at high energy for improving stability ➔ interlocking
  - Combined correction for Q20 and Q26 ➔ SPS "2 beams machine" + *initially expert tool ➔ improvements depending on success.*
  - Correction in SPS extraction point (CNGS not successful, still need for TL steering)
  - Fit a betatron oscillation across some section around each extraction point and interpolate to the extraction point ➔ less sensitive to individual BPM errors. *Tools available in YASP (for fit), only DB configuration needed*
  - MSE ripple: improvement works foreseen for LS1
  - Non local extraction to be studied and tested + risk analysis
- TL commissioning:
  - TCDI automatic setup *tool ready*
  - A *new tool* for quasi-online analysis will be studied and developed (ideally tool for fully automatic validation…not for after LS1)
  - Optics checks with virtual beta* ➔ catch TCDI wrong settings. *Existing infrastructures with some modifications*

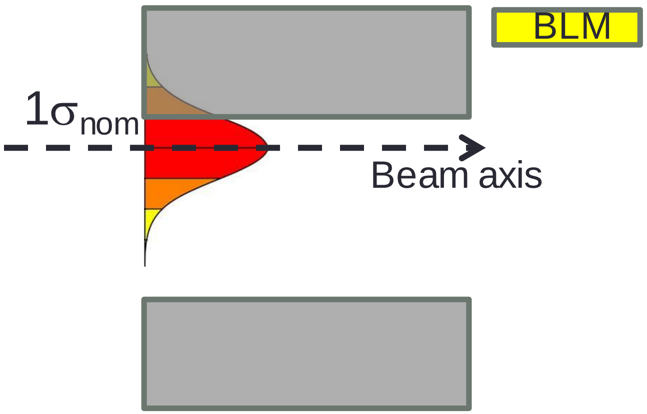
Summary

- LHC injection and extraction system commissioning:
  - Long list of machine checkout and beam commissioning tests
  - Injection:
    - Inj. prot. collimator setup and validation (*new quasi-online tool*)
    - Injection losses
    - Aperture, emittance, mismatch and optics measurements
    - LHCb vertical crossing angle: impact on inj. prot. collimators?
  - Extraction:
    - Aperture measurements
    - Beam losses
    - TCDQ-TCSG setup and validation (new optics?)
    - Abort gap cleaning: automatic link to BSRA possible after LS1

TCDI Setup and Validation

- Reference orbit in LHC established ➔ golden trajectory in TL to minimise injection losses and injection oscillations
- Tool for automatic setup (Y. Le Borgne)
- Validation checks: aperture cut provided by the TCDIs (< 7σ !!)

Calibration



Jaw at $1\sigma_{nom}$ ➔ BLM reading / intensity ➔ real beam size σ_{real}(measured emittance, dispersion, nominal Dp/p = 1e-4) ➔ intercepted beam

Remarks and Use Cases

- TCDI settings, virtual beta* limits and TL optics (quad) references are stored together in a single BP.
  - If the wrong BP is used, the SIS interlock will fail (unless the optics happens to match, but then it is OK).
- Re-use existing infrastructure and concepts. New items:
  - reference settings for TL quads + virtual beta*,
  - new SIS code for the logic
  - Use the published optics ID to check consistency TCDI gaps and expected no. sigma.
- Use Case 1: SPS operates with a single cycle configured for fast extraction.
  - For every cycle SIS checks the currents and publishes beta*.
  - To note that beta* is published AFTER the cycle. In case of cycle change, the FIRST time a cycle is executed the beta* comes from an older cycle.
  - If the cycle has a TL optics that matches, beta* comes out correctly.
  - If the TL optics does not match, beta* is 0.
- Use Case 2: SPS operates with more than one cycle configured for fast extraction (fast extraction timing events are present), and one cycle has ‘wrong’ settings (for example a Hiradmat cycle).
  - After a good LHC cycle, beta* published ok while after the ‘bad’ cycle, beta* published is 0.
  - Here beta* oscillates between 0 and the correct value. Extraction does not work, a bit unstable situation.
  - The publication of ‘0’ could be suppressed by a check of the SPS USER destination – publish only on cycles for LHC. Prevents ‘0’ publication, but depend on extra info.

Courtesy of J. Wenninger

Abort Gap Cleaning and BSRA

BSRA improvements during LS1:

- HW: several improvements to simplify the light path and decrease the need & frequency of re-steering and adjustments (still no redundancy)

- SW: FESA class + additional sequencer tasks to verify the integrity of the signals during injection, perform systematic re-calibration of the measurement at flat top and calibrate the gain curve during the ramp down.

- False positive very unlikely ➔ implementation of an automated dump signal in the SIS can be envisaged

- The SIS should only react to dump trigger with the possibility to skip CMW errors (loss of communication).

- To mitigate the problem of hardware redundancy and to increase reliability of the dump signal ➔ integrate AGP measurements by ALICE (high level of consistency of the trends with the BSRA measurements during stable beams, also absolute measurements are normally within 50% of the BSRA measurement). Functionality of ALICE abort gap population signal with 25 ns operation to be checked.