STABILITY STUDIES OF THE PSB-TO-PS TRANSFER

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PSB Ejection Lines Review, 24th September 2015, CERN

Scope of review

- Basis is the design as presented in Oct-13 (http://indico.cern.ch/event/274495/)
- Revisit the ejection line design after iterations on integration, magnet design and accordingly optics
- Two presentations:
- Geometry, optics, integration
  - TL geometry, PS injection geometry
    - BT.BHZ10 center of deflection, position of upstream quadrupoles
  - Optics
    - Rematched optics to the PS
    - Dispersion at PSB extraction
    - Upgraded BTM optics versions to improve beam size in BTM.BHZ10
  - Updated list of quadrupole gradients and GFR
  - Overall status of integration
  - Instrumentation/special elements
- Stability studies:
  - Error sources
  - Stability calculations from dynamic errors
  - Emittance growth from different sources and losses

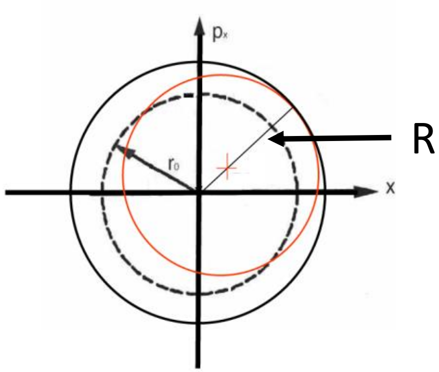
Error sources for delivery precision

- Correctable errors
  - Magnet misalignment
  - Magnet systematic (different laminations, steel,…) and random errors (different transfer function within a series)
  - Long term drifts due to temperature, humidity,…
  - All these errors lead to trajectory variations that can be corrected
  - Since the transfer function is considered correctable → $\Delta I/I = \Delta B/B$

- Uncorrectable (dynamic) errors
  - Random errors:
    Shot-to-shot stability, in particular in view of ppm operation between 1.4 and 2.0 GeV
  - Systematic errors:
    Power converter ripple, kicker waveforms

Stability calculation

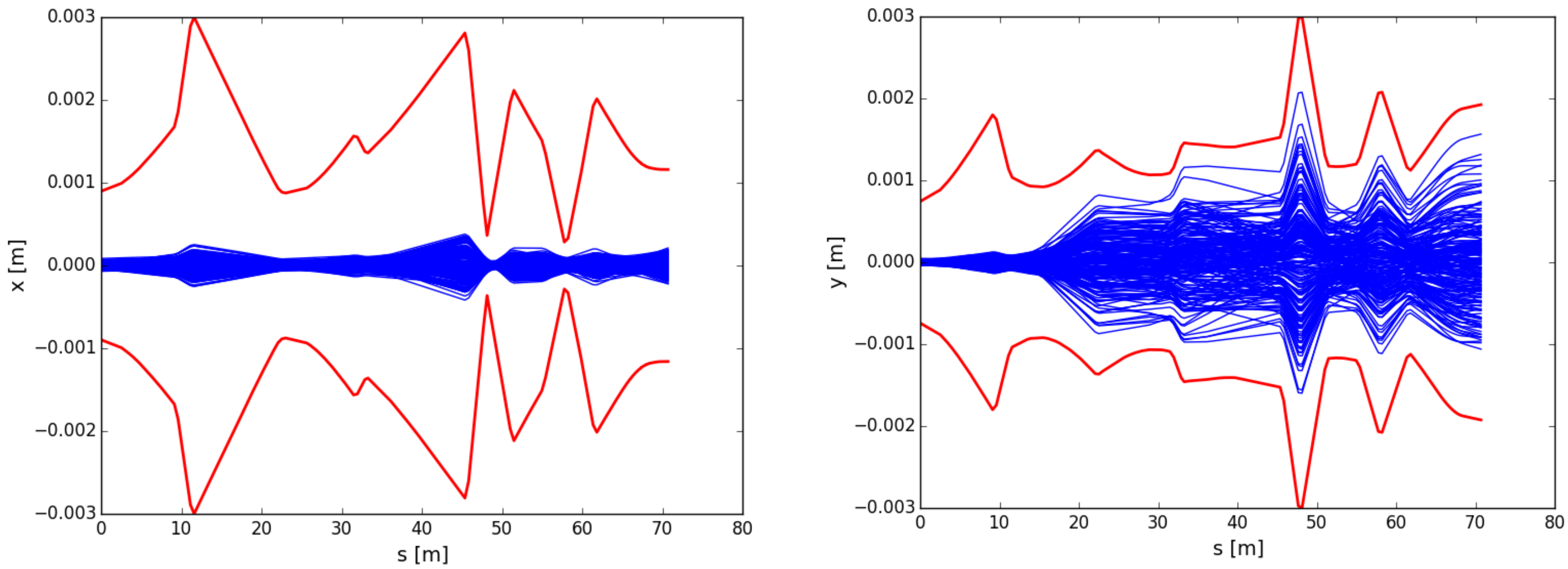
- Assign correctable errors and verify correction feasibility
  - Only limited by BPM readings and correction strategy → checked in Oct-13, OK
- Assume machine free of correctable errors and assign separately dynamic errors to identify the main contributors to delivery imprecision
- Calculate delivery precision of position and angle at PS injection
  - Check aperture in the lines (losses, radiation)
  - Check foreseen margins for CO and betabeat in GFR
  - Calculate **emittance growth from steering error**
- Calculate unavoidable **emittance growth from optics and dispersion mismatch**
- Sum all error sources into **overall emittance growth** and **potential particle loss** for LHC and HI beams



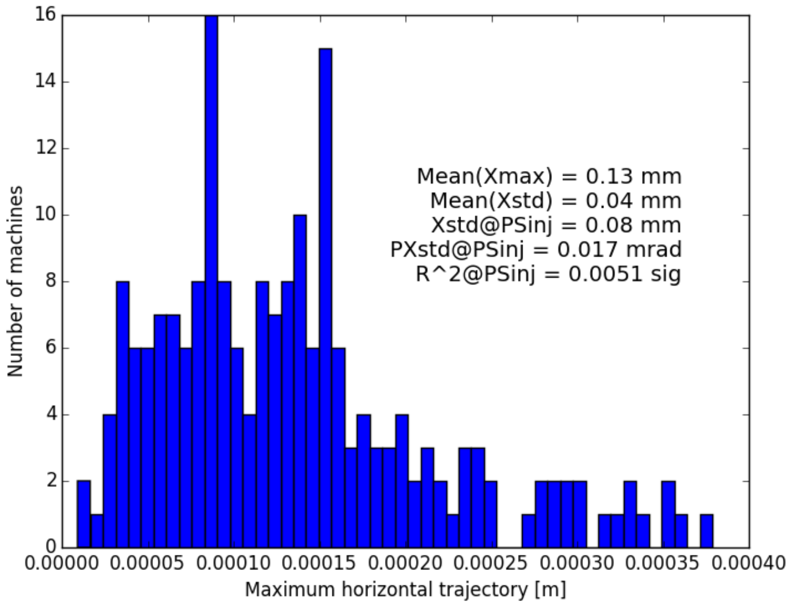
Error source	Tolerance ΔI/I	x rms (mm)	px rms (μrad)	R_x^2/ε_0 [1e-3]	y rms (mm)	py rms (μrad)	R_y^2/ε_0 [1e-3]
Random effects							
PSB orbit ± 0.15/0.10 mm (h/v)		0.04	4	0.4	0.04	2	0.2
BVT10	1e-4				0.08	1	0.3
SMV10	1e-4				0.13	1	1
QNO10	5e-4				0.11	1	1
QNO20	5e-4				0.03	1	0.06
KFA10	3e-4				0.02	1	0.06
SMV20	1e-4				0.01	4	1
KFA20	3e-4				0.01	0	0.02
BVT20	1e-4				0.05	3	1
BT.BHZ10	1e-4	0.07	0.02	4			
All random effects		0.08	17	5.1	0.21	6	4.0
Systematic effects							
KFA10	5e-3				0.39	15	17
KFA20	5e-3				0.22	8	5

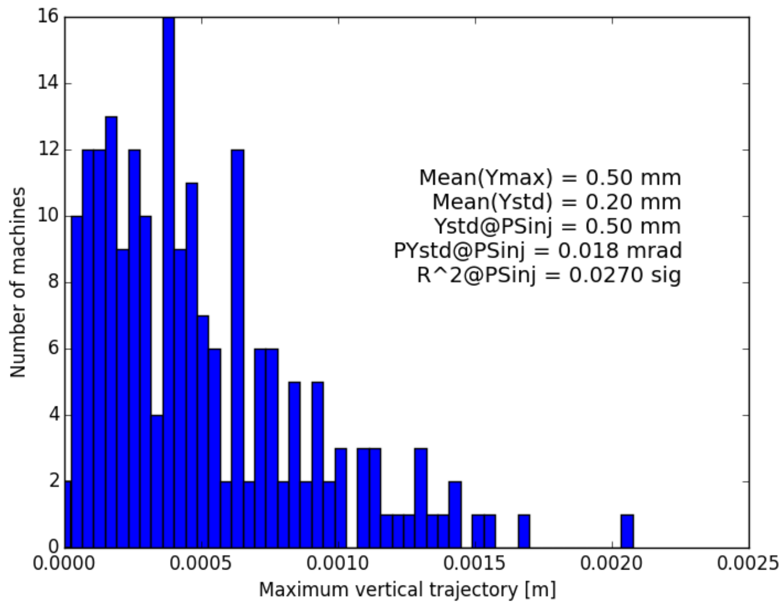
Trajectories for all dynamic errors applied

- Contributions for trajectory variation in aperture OK
- Betabeating from uncorrectable quadrupole errors is in the regime of a few percent (20% assumed in the aperture calculation) and therefore negligible compared to the systematic optics differences between the four lines



Distribution of trajectories for all dynamic errors applied





Emittance growth

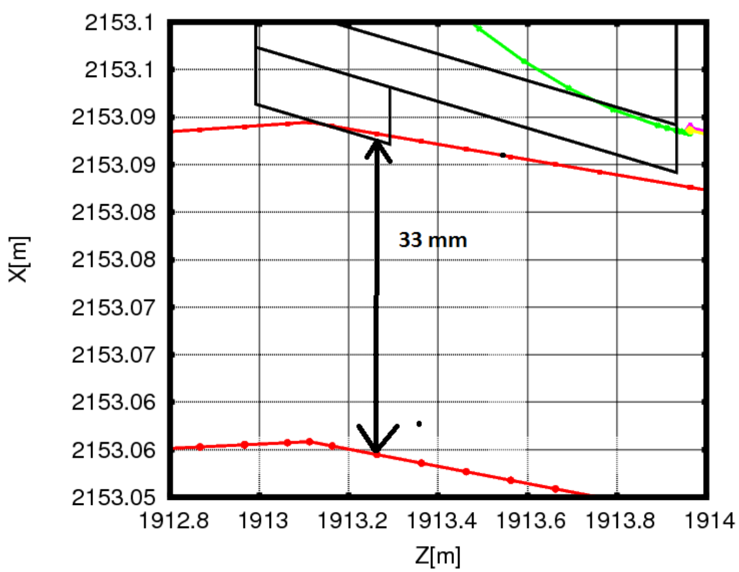
- From steering error at PS injection due to power converter ripple and kicker waveforms
  - R_x^2/ε_0 (random errors) gives 0.005 and 0.004
  - R_x^2/ε_0 (systematic offset) gives 0 and 0.025 (extraction kicker waveform not included)
- From optics mismatch between different lines
- Energy error, geometrical mismatch and coupling negligible
- All error sources considered independent

Error	Emittance growth [%] Present situation (LHC)		Emittance growth [%] LHC beam		Emittance growth [%] HI beam	
	Hor	Vert	Hor	Vert	Hor	Vert
Steering error	0.25	1.45	0.25	1.45	0.05	0.48
Betatron mismatch	4.55	6.81	2.31	0.02	2.0	0
Dispersion mismatch	4.40	8.77	0.09	5.36	0.03	5.25
Total	**6.33**	**11.20**	**2.53**	**5.45**	**2.00**	**5.27**

Particle loss due to emittance growth

- Relevant for HI beams
- Aperture bottleneck at PS injection when bump is fully on:
- 33 mm radial aperture
  - Subtract 2 mm for alignment errors and 1.5 mm for the orbit on the physically available radius
  - Fit 4.2 sigma of HI beam in horizontal plane
- Increase due to steering error negligible → imminent effect on required aperture
- Beam size changes by 0.8% due to optics mismatch after filamentation has taken place
  - Bump is collapsed within 500 turns

- No additional losses expected due to emittance growth



Conclusions for both presentations

- Since last review in Oct-13
  - Iterations on magnet design, integration and update of the optics model
- Resulting changes
  - BT.BHZ10 can be kept at its centre of deflection → TL geometry can be kept
  - Previously moved quadrupoles to make space can be kept at the present location
  - Two locations of integration interferences (QNO20 with wall, QN040 with steerer) to be addressed
  - Locations for extra BLMs identified
  - Position for wideband pick-up in upgraded BTP to be checked
  - Envelope for (new) BPMs required to be included in the integration
- Optics rematched accordingly
  - One quadrupole (BTP.QNO20) due to difference in 4 lines increased GFR, but 25% lower gradient than max → within our margin
  - Specifications for quadrupole gradients, field homogeneity and good field regions as from Oct-13 confirmed
- Specifications for power converter ripple as of beginning 2015 systematically checked and confirmed
  - Random errors for both planes balanced
- Comparison of different sources of emittance growth show:
  - Difference in optics between the four lines is the main cause of emittance growth, in particular the dispersion mismatch
  - Emittance growth from steering errors due to power converter ripple is a minor contributor and can in principle be damped
  - Assuming similar systematic contributions from PSB extraction and PS injection kicker in the horizontal plane as for the recombination kickers gives as maximum expected oscillations to be damped: +/- 1.5 mm in both planes
  - The present mismatch situation is improved, but further optimisation required to balance the contributions from betatron and dispersion mismatch and thus reduce the overall emittance growth
- No additional particle loss due to emittance growth of HI beams