Emittance preservation in the injectors

Frank Tecker, with many thanks to:

Contents

- Emittance evolution of operational beams
  - BCMS (before/after constant bucket area)
  - 8b4e
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- Emittance measurements
- Emittance studies
- Perspectives for 2018
LHC Supertable data

SPS data with large spread
LHC data calculated from emittance without accounting for leveling
Constant bucket area (CBA) in the PS

- to keep bunches longer and mitigate space charge
- Tested in 2016, together with optimized working point
- Introduced from 5/08 in MD beam, 9/08 in oper. LHC4
- PS inj -> FT: no horizontal blowup!
- BCS with CBA from the start
Constant bucket area in the PS (2)

- **reduces also vertical PS inj -> FT blowup**
- clear reduction in LHC emittances in H and V

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8th LHC Operations Evian Workshop
Horizontal summary

- Blowup in PSB -> PS transfer
- no significant further increase
Vertical summary

- Blowup in PS from injection to flat top
- no significant further increase
Vertical blowup PS Inj -> FT

- BCS beam had some fills at lower intensity (not much data)
- Smaller blowup for lower intensity
- Just touching space charge limit? WP optimization
- To be verified…
Deconvolution

- Profile measurements in presence of Dispersion (both WS and SEMs)

\[ x = x_\beta + D \frac{\Delta p}{p} \]

- Assuming Gaussian profiles:

\[ \sigma_\beta = \sqrt{\sigma_m^2 - D^2 \left(\frac{\Delta p}{p}\right)^2} \]

- Large error for bigger dispersive part

- Better estimation by deconvolution with measured momentum profile (assuming Gaussian betatronic profile)

- Application by J.-F. Comblin now available

G.Sterbini
PSB Comparison WS/SEM-Grid

- Emittance measured at PSB SEM grid is **systematically larger by ~10%** than the correspondent measurement at the PSB WS

- 1/V and 3/V
  - lower wire speed
  - higher measured discrepancy
  - will be exchanged during YETS

G.-P. Di Giovanni
WS/SEM comparison – PSB/PS

- Emittance from **PS SEM-grids** seems already **larger than** the **PSB WS** and **PSB SEM-grids**

V. Forte
PS BGI - Horizontal

- Very interesting instrument, tested in MDs
- 1 of 4 detector chips has broken cable – will be repaired in YETS
- Allows time-resolved transverse profile measurements
- Average over down to ~50 turns
- Beam size in agreement with WS
- Shows about constant profile size from injection
- Cannot distinguish between fast oscillation and filamented equilibrium

S. Levasseur, H. Sandberg, J. Storey

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Blowup sensitivity to mismatch

• **Missteering:** \( \Delta \varepsilon = \frac{\Delta x^2 + (\beta \Delta x' + \alpha \Delta x)^2}{2 \beta} \) (also kicker flatness)

• **Twiss:** \( \varepsilon = \varepsilon_0 \frac{1}{2} \left[ \frac{\beta_m}{\beta_0} + \frac{\beta_0}{\beta_m} + \left( \frac{\alpha_m}{\beta_m} - \frac{\alpha_0}{\beta_0} \right)^2 \beta_0 \beta_m \right] \)

• **Dispersion:** \( \Delta \varepsilon = \frac{\Delta D^2 + (\beta \Delta D' + \alpha \Delta D)^2}{2 \beta} \left( \frac{\sigma_p}{p} \right)^2 \)

• **Energy:** \( \Delta \varepsilon = \frac{D^2}{2 \beta} \left( \frac{\Delta p}{p} \right)^2 \) @1 mm mrad: 14% for 0.5‰
Betatron/Dispersion matching

- Operational optics has large dispersion mismatch
  - 25% emittance growth expected for BCMS
- optics with matched dispersion is mismatched in Twiss
- dedicated MD using non-PPM quads to check sensitivity around optimized matching
- should clearly reduce emittance
Betatron/Dispersion matching

- Dispersion matched optics could slightly reduce H emittance
- PS WS with RF OFF and ON show big difference in horizontal and small in vertical plane – not understood
- conditions to be verified, work ongoing

BCMS 0.9 eVs (~0.9e-3 dp/p) and chromaticy-free cycle (I~83e10ppb)
Blowup by Missteering

- BCMS (coupled) beam with missteering by injection kicker (@185ms)
- RF effect on blowup not understood, conditions need to be verified
- Space-charge effect should be less for larger missteering (larger emittance from fast filamentation)

![Graph showing normalized emittance vs injection kick for X and Y planes.](image)

E. Senes
Turn-by-Turn profile observation

- would be really useful to study injection emittance growth!!!
- new PS SEM-grid multi-turn electronics should be available for MDs only from Oct 2018
- Idea: use **WS** at injection as mismatch monitor
  - fast oscillation in beam size (and position) seen on scan
  - reduced by filamentation
  - bumper non-closure can give a (slow) shift
- Example of INDIV_VdM beam (inj. corrected by YASP) (MD by E. Senes)
Conclusion

- **Constant bucket area** and WP adjustment at 1\textsuperscript{st} PS ramp
  - eliminated horizontal blowup from PS injection to flat-top
  - significantly reduced the vertical blow-up
- **Main blow-up** in **horizontal** at PSB $\rightarrow$ PS transfer, in **vertical** at PS inj. $\rightarrow$ FT
- **LHC** emittance **follows** PS FT emittance without much further blowup
- Difficult to compare measurements at the few-%-level
  - PSB SEM $\sim$10% larger than PSB WS, PS SEM even larger
  - Energy spread contribution is very large
- **Turn-by-turn profile measurement** from PS would be ideal
  - multi-turn SEM-grid from autumn 2018 for MDs
- Automated measurements in all machines would be useful
Points for discussion

- Better **beta/D values**, WP dependent, measured beta-beat from k-modulation and phase advance studies
- **PS energy matching** at startup (new B measurement)
- Any other way to measure **PS TbT profile** (extraction at 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd} turn to transfer line screen? Present SEM 2-turn integration)
- Can produce **lower vertical emittance by reducing coupling** using longitudinal FB and low-chromaticity optics (or nominal chroma)
- **LHC Supertable** remarks
  - norm_emit/ssb just calculated from Luminosity, not adapted with leveling
    => add wire scanner
  - SPS entries very noisy (very small beam size, especially at flat top)
    => would profit from operational BSRT
Thank you very much for your attention!
Vertical emittance evolution 2017

Vertical Emittance ALL

- PS inj
- PS FT
- LHC B1
- LHC B2
- BR1
- BR2
- BR3
- BR4

norm. emittance [mm mrad]

LHC Fill #

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Intensity evolution during 2017
LHC vs PS FT

- No significant blowup in either plane between PS flat top and LHC injection
- Only B1 Vertical is slightly growing
Horizontal emittance in PS

- Comparing OP BCMS with low chromaticity beam

A. Huschauer
Vertical emittance in PS

- Comparing OP BCMS with low chromaticy beam
- lower at flat bottom
- without ramp optimization

A. Huschauer
BCMS brightness

BCMS 25ns

H. Bartosik

Intensity at 450 GeV [p/b] vs. Emittance at 450 GeV [μm]

- PSB brightness
- SPS beam loading and longitudinal instabilities
- SPS (ΔQY = 0.3)
- SPS (ΔQY = 0.21)
Blowup from missteering

- Less than expected for larger kicks
- Less at 185 ms than at 175 ms!

E. Senes

$I = 13 \times 10^{10}$ ppb

$\varepsilon_{x,\text{norm}} = 2.51 \pm 0.12$

$\varepsilon_{y,\text{norm}} = 2.01 \pm 0.03$

$dp/p_{\text{rms}} = 5 \times 10^{-4}$

Expected $a=11.26$

C175

C185
Decoherence / Recoherence

PyHeadTail Simulations, uncoupled by E. Senes

Obvious recoherence after synchrotron period
Beta-beating (PS inj) measured by k-modulation

Found PR.QDW18 with inverted polarity

(vs. 6.21/6.24 nom.)
Dispersion measurements

OPTICS A – BTQNO10 100%

RF OFF

RF ON
Dispersion measurements

OPTICS C – BTQNO10 100%
Dispersion measurements

OPTICS C – BTQNO10 110% → still very good

RF OFF

RF ON