Collimation margins and $\beta^*$

R. Bruce, R.W. Assmann, W. Herr, D. Wollmann

Acknowledgment:
Introduction

- Main limitations when going to smaller $\beta^*$
  - Magnetic limits: max gradient in quadrupoles and chromaticity
  - Beam–beam limit …
  - Aperture limit: decreasing margins in triplet when decreasing $\beta$. Present LHC limit! New regime compared to other machines
Importance of collimation for $\beta^*$

- Triplet aperture must be protected by tertiary collimators (TCTs)
- TCTs must be shadowed by dump protection
- Dump protection must be outside primary and secondary collimators
- Hierarchy must be satisfied even if orbit and optics drift after setup $\Rightarrow$ margins needed between collimators

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Influence of collimation

- Possible values of $\beta^*$ depend on the settings of all collimators and therefore on machine stability and frequency of collimation setups!
- To optimize $\beta^*$, we have to review
  - Triplet aperture
  - Machine stability and necessary margins in collimation hierarchy
Aperture calculations

Using 2 methods: reference R.Bruce,R.Assmann, Evian 2010

• $n_1$ (theory based, adding uncertainties)

• scaling of measured injection aperture
  • Assume *pessimistically*
    injection aperture = global limit $+ 2 \sigma$
  • Only one plane matters with good approximation - reduce to 1D
  • Scale beam size to pre-collision
    \[ |u_i| + n_i \sigma_i = |u_p| + n_p \sigma_p \]
  • Solve for top energy aperture

• 2011: new local triplet aperture measurements. Ongoing work to refine calculations

MQXB.B2L1
s= -40.8 m
2mm separation

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Margins in cleaning hierarchy

• Orbit: separate analysis on following slides

• 10% $\beta$–beating. Bias in correction at TCT–triplet wanted

• Positioning error (small!)

• Setup error (small!)

• Small lumi scans can be included in the margin

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Orbit stability in 2010

- Check *reduction* in margin during all fills with stable beams
  - Relative change needed between both devices (collimators or aperture)
  - Consider change w.r.t. *reference orbit* used during setup
- For margin TCT–aperture, take phase advance into account (only one jaw relevant)
Margins between collimators

- Analysis shows
  - 99% of the time in stable beams, all triplets except IR2 are shadowed by the TCTs with a 1.6 $\sigma$ margin
  - 99% of the time in stable beams, all horizontal TCTs are shadowed by the dump protection with a 1.1$\sigma$ margin
  - We should not reduce the margin between IR7 and dump protection
  - We should not reduce the margin between primary and secondary collimators in IR7 (possible loss in cleaning efficiency)
Damage risks

• What does a 99% coverage mean in terms of damage risks?
  • Assume 1 asynchronous dump per year
  • Assume 1% of the time the margin dump–TCT is violated (uncorrelated to async. dump)
  • Assume 1/3 of the time spent in stable beams
    => 1 event in 300 years could be dangerous for the TCTs
  • Assume 1% of the time the margin TCT–triplet is violated
    => 1 event in 30000 years could be dangerous for the triplets
  • This considers only orbit. Simultaneously all other errors have to add up pessimistically at both locations.
    => The real risk is much lower!
  • In case of the TCT being hit by a bunch there is no catastrophic damage, most likely it will be scratched and we can use a spare surface (see talk A. Bertarelli in Chamonix)
Proposed margins and settings

Summing *linearly* we get the margins

<table>
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<tr>
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<th>2010</th>
<th>2011</th>
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<tbody>
<tr>
<td></td>
<td>(σ)</td>
<td>(mm)</td>
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<tr>
<td>triplet–TCT</td>
<td>2.5</td>
<td>0.9–2.1</td>
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<tr>
<td>TCT–TCSG IR6</td>
<td>5.7</td>
<td>3.5–4.4</td>
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<tr>
<td>TCSG IR7–TCP</td>
<td>2.8</td>
<td>0.6–1.6</td>
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<tr>
<td></td>
<td>2.3</td>
<td>1.1–2.7</td>
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<tr>
<td></td>
<td>2.5</td>
<td>1.3–1.8</td>
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<tr>
<td></td>
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and the settings

<p>| | | | | | |</p>
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<tbody>
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<td>TCP IR7</td>
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<td>TCS IR7</td>
<td>8.50</td>
<td>TCS IR6</td>
<td>9.30</td>
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<tr>
<td>TCT</td>
<td>11.80</td>
<td>aperture</td>
<td>14.10</td>
<td></td>
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Assuming IP2 remains at larger margins. Proposed settings very similar to what was used in 2010 run with $\beta^*=2.0\text{m}$
• For 3.5 TeV: 
  \( \beta^* = 1.6 \text{m} \)

• Reducing BB separation to nominal 9.5\( \sigma \) (real emittance smaller!) allows 
  \( \beta^* = 1.5 \text{m} \)

• 2011: \( \beta^* \) reduced from 3.5\( \text{m} \) to 1.5\( \text{m} \)

• Factor 2.3 gain in luminosity
Can we go even lower?
Can we go even lower?

- If machine stability improves, smaller margins in hierarchy possible
- Moving in primary collimators closer to beam (smaller than nominal emittance!) and the rest of the system gains aperture
  - Recently qualified tight settings in MD (primary collimators at 4 nominal $\sigma$) with one bunch
  - Possible to operate with these settings in physics? Impedance? Lifetime?
- Refined analysis underway including more recent aperture measurements and MD results
- In upgrade scenario, new optics and magnets allow much smaller $\beta^*$ (S. Fartoukh et al)
- Upgraded collimators with built–in BPM buttons allow collimators to be quickly re–centered without touching beam
  - Prototype installed in the SPS
Collimators with built-in BPMs

- Factor 1000 reduction of setup time – more frequent setups possible
- Less strict requirements on long-term orbit stability.
- More flexibility for local IR orbits (crossing angle, separation for luminosity leveling, etc.).
- Allows reduction of margins between collimator families, as collimators can follow slow orbit drifts
  - tighter collimator settings possible with better cleaning
  - Smaller β* – Maybe only way to allow nominal margins!
  - To have full benefit, BPMs must be implemented in all collimators!

Courtesy A. Bertarelli, A. Dallocchio et. al
Recent MD with prototype in SPS

- Excellent agreement between different alignment methods (BLM and BPM).
- Discrepancy ($< 70 \, \mu m$) dominated by step size ($50 \, \mu m$).
- No effect of showers seen on BPMs so far
- Very promising concept, although not main focus of review

Conclusions

• $\beta^*$ is dependent on margins in collimation system. Present limitation on $\beta^*$ in the LHC!

• Choice of $\beta^*$ should maximize performance without risking safety

• A review of both aperture estimates and all margins allowed $\beta^*$ to be reduced from 3.5m in 2010 to 1.5m in 2011

• Future improvements from collimation possible
  • With present machine (ongoing work)
  • With upgraded collimators with BPM buttons

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