MD Proposals for Emittance Studies

Input to Run 3 - MD Days 2020

Basic ideas - no detailed technical description of the proposed MDs

I. Efthymiopoulos
for the HSI LumiTeam,
and input from J.Wenninger, G.Trad, F.Roncarolo
Emittance Evolution in LHC cycle

• What do we know - Summary results from Run 2

Based on BSRT emittance data, averaging over selected fills where the calculated initial luminosity matches that measured by the experiments

Note:

• Reduction in 2018 BCMS emittances at injection compared to previous years
• At Stable Beams, the 2018 BSRT emittances are lower by ~15% compared to what required to match the luminosity measured in the experiments i.e. BSRT calculated luminosity overestimates that from the experiments
Emittance Evolution in LHC cycle

- **What do we know** - Summary results from Run 2

- **at FB**
  - 8-18% growth

- **at Ramp**
  - 11-30% growth

- **at Stable Beams**
  - ~2% growth/h
  - Good agreement with the improved model up to the $\beta^*$ changes

- Plots by S. Papadopoulou
Emittance Evolution in LHC cycle

• How much to we understand? - Flat bottom

Extra emit. blow up (on top of IBS) for 3 batches of 48 bunches

Emittance growth at FB:

Table 2: Measured and extra emittance growth at FB.

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<tbody>
<tr>
<td>Measured</td>
<td>0.71</td>
<td>0.64</td>
<td>0.73</td>
<td>0.61</td>
</tr>
<tr>
<td>on top of model</td>
<td>0.34</td>
<td>0.64</td>
<td>0.41</td>
<td>0.61</td>
</tr>
<tr>
<td>on top of model&amp;e-cloud</td>
<td>0.24</td>
<td>0.44</td>
<td>0.17</td>
<td>0.41</td>
</tr>
</tbody>
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Missing: 50% [-0.1-0.2 µm/h] beyond predictions (IBS + e-cloud)
• 30% could be attributed to noise

Bunches in train affected by e-cloud
First bunch in train - no e-cloud
Emittance Evolution in LHC cycle

• How much to we understand? - Collisions

Emittance growth in collisions:

Table 3: Measured and extra emittance growth in collisions.

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<tbody>
<tr>
<td>Measured</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>0.05</td>
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<tr>
<td>on top of model</td>
<td>0.02</td>
<td>0.07</td>
<td>0.03</td>
<td>0.09</td>
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</table>

• Missing: 50% [0.02µm/h] beyond predictions with the updated model (IBS+burn-off+coupling+noise)
• no e-cloud dependence (bunch position)
MD Requests for Run 3

• With the studies performed throughout Run 2 we substantially improved our luminosity model and the understanding of the emittance growth mechanisms during FB and in collisions

• The remaining effects will be further studied during Run 3
  • Impact of noise in FB and in collisions
    See presentation by G. Sterbini on noise study MDs
  
  • Impact of e-cloud (losses)
    Ongoing simulation studies to estimate the effect, see presentation by G. Iadarola, et al.
    • Note: The e-cloud contributions will be further mitigated with the foreseen hardware improvements for HL-LHC

• For Run 3 MDs we propose initially to focus on the emittance growth during the ramp
  • It represents the larger contribution in the cycle
  • Understanding and possibly reducing or eliminating this growth would have an important impact to the integrated luminosity.
    • 30% lower emittance in both beams and planes \(\implies\) \(~67\%\) increase in initial luminosity at start of collisions!
    • Having lower emittance at SB opens possibilities for further optimised running scenarios with significant impact on integrated luminosity

• Reminder: for HL-LHC, a total growth from injection to SB of 25(35)\% for H(V) is assumed in the baseline parameters. Today we are slightly above this target!
MDs for $\varepsilon$-growth studies in the Ramp

**Step 1**

*Improve and validate the emittance (beam size & profile) measurements*
- Improve optics precision to validate measurements and calibrate WS & BSRT
- Explore capabilities for q-BPM analysis, and/or other methods and tools

**Step 2**

*Measure and understand if growth is linear or in steps vs energy*
- e.g. effects at the ramp startup, or during specific manipulations during the ramp, impact of longitudinal emittance, …
- difference between single and multiple bunch effects (trains), brightness, …

**Step 3**

*Apply alternatives to mitigate the observed growth*
- Alternate matching schemes, magnetic settings, depending on the findings…

**Note**: Further MD requests may arise in the course of Run 3 depending on the LHC performance and analysis findings
MDs for \(\varepsilon\)-growth studies in the Ramp

**Constraints:**

- Challenging to measure the beam profiles during the ramp
  - Latency, changing configurations and calibration of the instruments
- Error in the optics (\(\beta\)) contributes to accurately convert the measured beam sizes to emittance
  - A linear total \(\varepsilon\)-growth of **10-30% or 2-5% / TeV** converts to \(\delta\sigma \sim 3-7\%\), for \(\delta\beta \sim 3\%\) at 3TeV

**Options considered**

- **RampStopAndMeasure**: Execute a nominal ramp and stop at an energy point to measure emittance and optics (\(\beta\)) at the location of the profile measurements (point 4)
  - Measure the beam profile (⇒ emittance) with the WS
    - Calibrate the BSRT at that energy point for later use during physics (trains, multi-bunch effects) looking forward to the possibility of using the WS with trains!
  - Continue with a higher/lower energy point to have a full set of well calibrated and matched points in the ramp
- **LadderRamp**: Special ramp with stops at different energy points
  - Less interesting for initial phase as would require long stops to measure the beam optics and calibrate the WS/BSRT
  - However would allow in a second phase (with small plateaux) taking measurements in short time

*See presentation by J.Wenninger*
MD - RampStopAndMeasure

• **Beam configuration:**
  • Start a fill with PILOT bunches for the optics measurements (~1-2 h)
  • Continue with a second fill with the maximum number of bunches (LHCINDIV) that would allow safely using the WS
    • Assuming a limit of 2.5e12 in the total intensity @ 3.5 TeV, we may inject ~20 bunches of Run 2 intensities (1.2e11) of **variable emittance/brightness like in the BSRT calibration fills**
      • exact number and intensity of bunches to be decided by MP and WS hardware
    • **Aim for a good relative precision wrt FB, optimise configuration for the WS (gain ,filter, …) and the BSRT**
  • **Alternatively**: fill the machine with LHCINDIVs + the PILOTs for the optics measurements
    • Do first the emittance measurement and then use the ADT to dump the LHCINDIVs and keep only the PILOTs for the optics measurements
      • Interesting idea but new and challenging configuration (time to kill the high intensity bunches with the ADT, blow-up of the PILOTs etc..), may not worth it wrt a second ramp…

• **Summary - initial goal:**
  • Obtain a **set of precise emittance measurements (and optics values)** of both beams at the ramp
    • Ideally calibrate the BSRT to be used later for measurements during the physics with many bunches
  • Understand the **evolution**: linear or step increase - identify sources to improve ⇒ later MD sessions
MDs for $\varepsilon$-growth studies in the Ramp

- **Synergies with other MDs**
  - Emittance Growth during the ramp due to non-linear optics

- Continue the work to validate the q-BPM for emittance measurement, in particular during the Ramp

*See presentation by Ewan Maclean*
MD on $\epsilon$-scans at High Brightness

• **Motivation:**
  • The experiments use $\epsilon$-scans to cross check the luminosity calibration transfer from vdM scans to physics
    • Method pioneered by CMS, interest by all experiments in particular for HL-LHC
    • Ideally would like to have $\epsilon$-scans at the beginning and at the end of each fill, as in Run 2
    • Interest to probe PU values close to those in physics data-taking - particular interesting for HL-LHC operation (up to 200 events)

• **Questions:**
  • Is there a brightness (intensity/PU limit) for performing such scans during collisions?
    • Limits from stability, impact on $\epsilon$-growth?
      • Few MDs on single bunches and small trains during Run 2, need to continue the validation in view of HL-LHC operation

• **MD plan:**
  • Beam configuration: once available, collide trains of high brightness bunches (allow some variation in the bunch-by-bunch brightness), and PU
  • Perform $\epsilon$-scans: observe stability issues and measure the absolute and the relative emittance growth

See presentation by X. Buffat
Thank you!