MD Proposals for Emittance Studies

Input to Run 3 - **MD Days 2020**

Basic ideas - no detailed technical description of the proposed MDs

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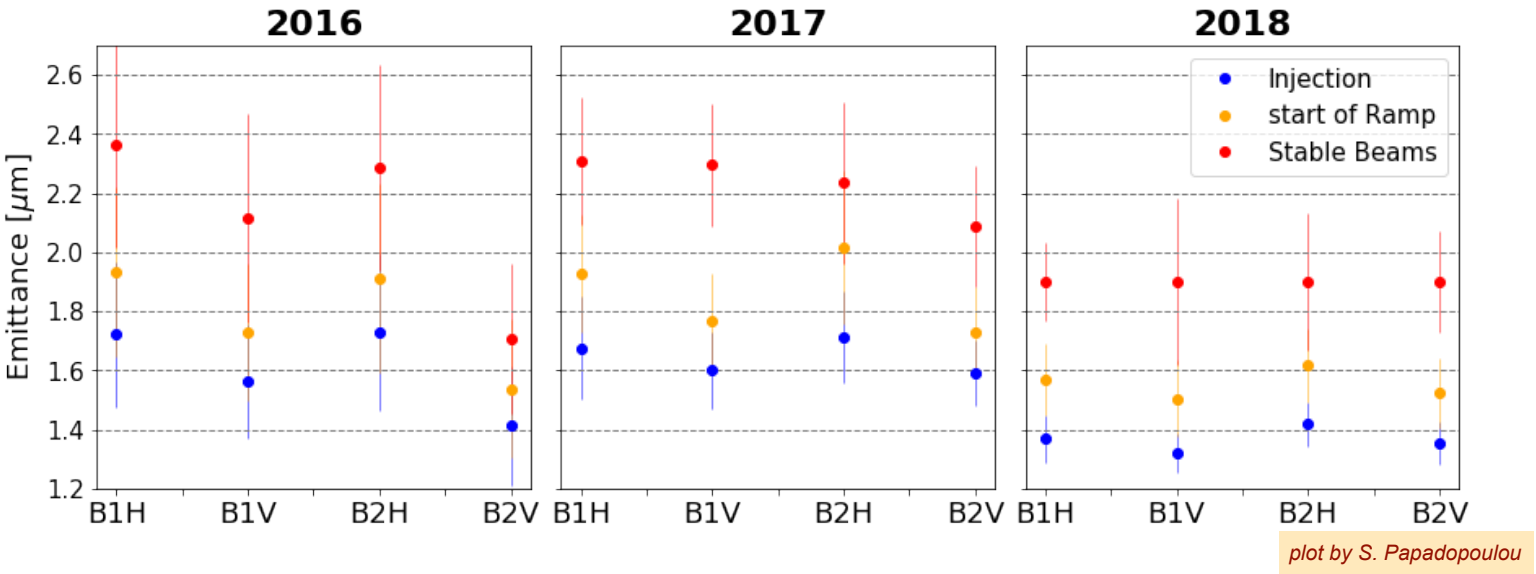
for the HSI LumiTeam,
and input from J.Wenninger, G.Trad, F.Roncarolo

Emittance Evolution in LHC cycle

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

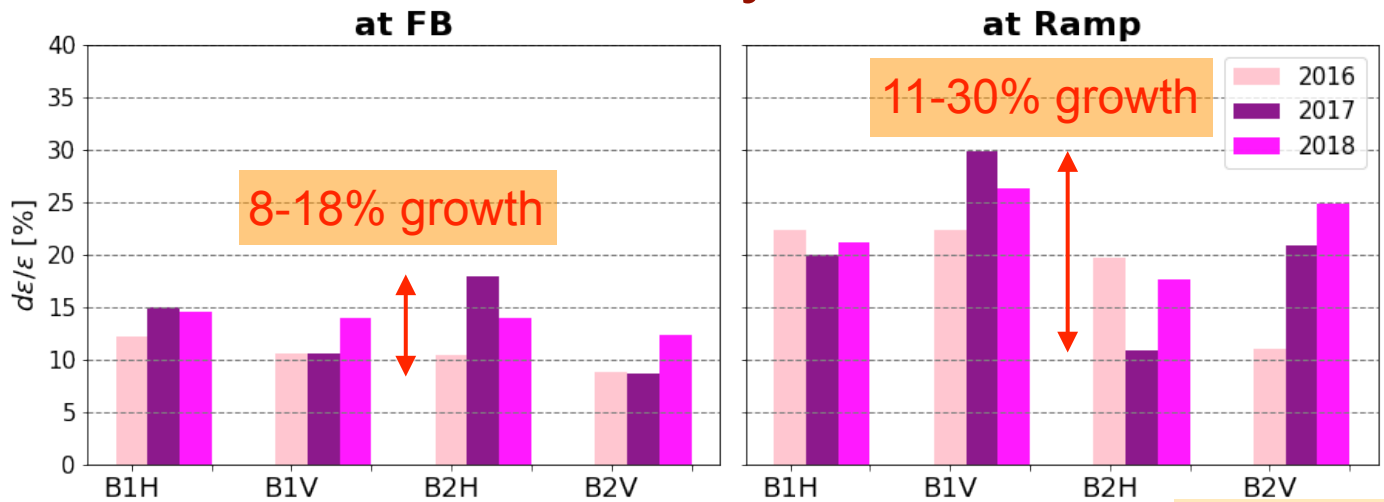


*Based on **BSRT emittance data**, averaging over selected fills where the calculated initial luminosity matches that measured by the experiments*

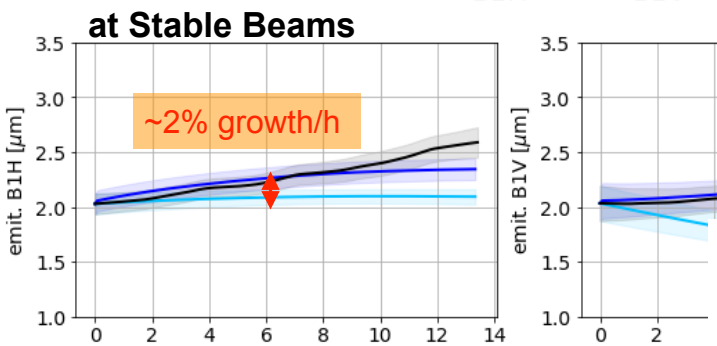
Note:
- Reduction in 2018 BCMS emittances at injection compared to previous years
- At Stable Beams, the 2018 BSRT emittances are lower by ~15% compared to what required to match the luminosity measured in the experiments i.e. BSRT calculated luminosity overestimates that from the experiments

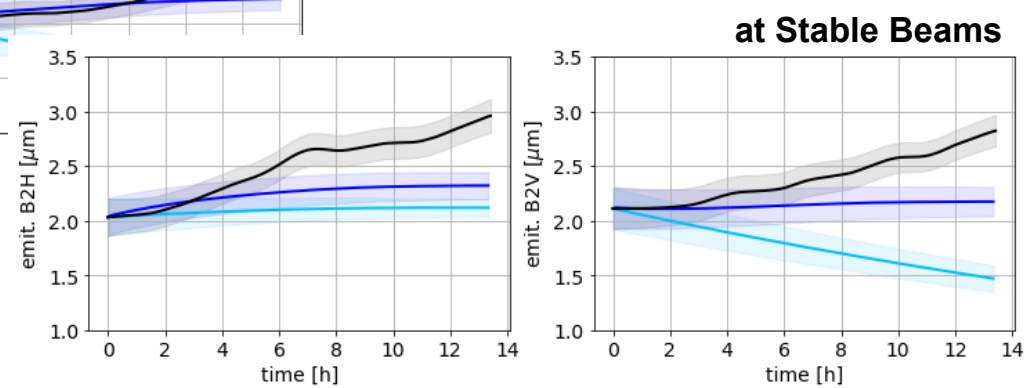
Emittance Evolution in LHC cycle

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



plots by S. Papadopoulou

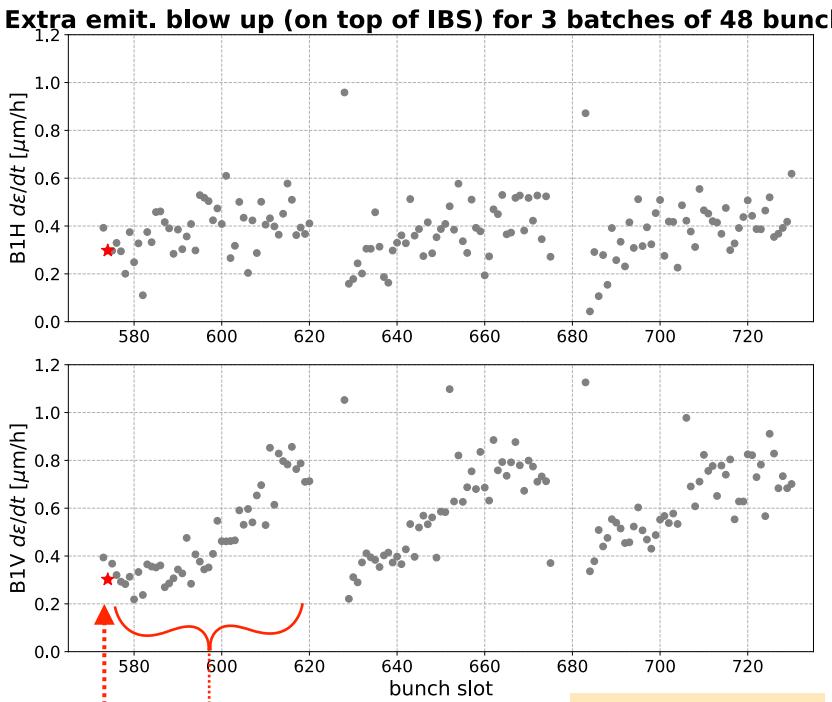




Good agreement with the improved model up to the β changes*

Emittance Evolution in LHC cycle

- **How much to we understand?** - Flat bottom



plot by S. Papadopoulou

Bunches in train affected by e-cloud

First bunch in train - no e-cloud

Emittance growth at FB :

Table 2: Measured and extra emittance growth at FB.

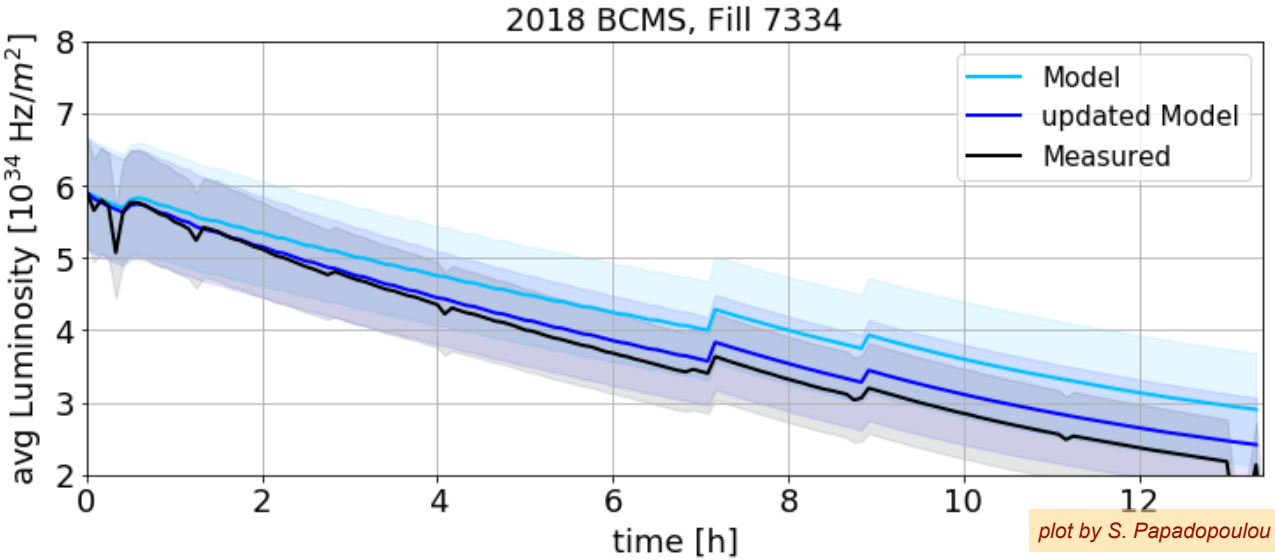
Emittance growth [μm/h]	B1H	B1V	B2H	B2V
Measured	0.71	0.64	0.73	0.61
on top of model	0.34	0.64	0.41	0.61
on top of model&e-cloud	0.24	0.44	0.17	0.41

Missing: **50% [~0.1-0.2 μm/h]** beyond predictions (IBS + e-cloud)

- 30% could be attributed to noise

Emittance Evolution in LHC cycle

- **How much to we understand?** - Collisions



plot by S. Papadopoulou

Emittance growth in collisions :

Table 3: Measured and extra emittance growth in collisions.

Emittance growth [μm/h]	B1H	B1V	B2H	B2V
Measured	0.04	0.04	0.06	0.05
on top of model	0.02	0.07	0.03	0.09

- **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 $\Longrightarrow$ ~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 ε-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

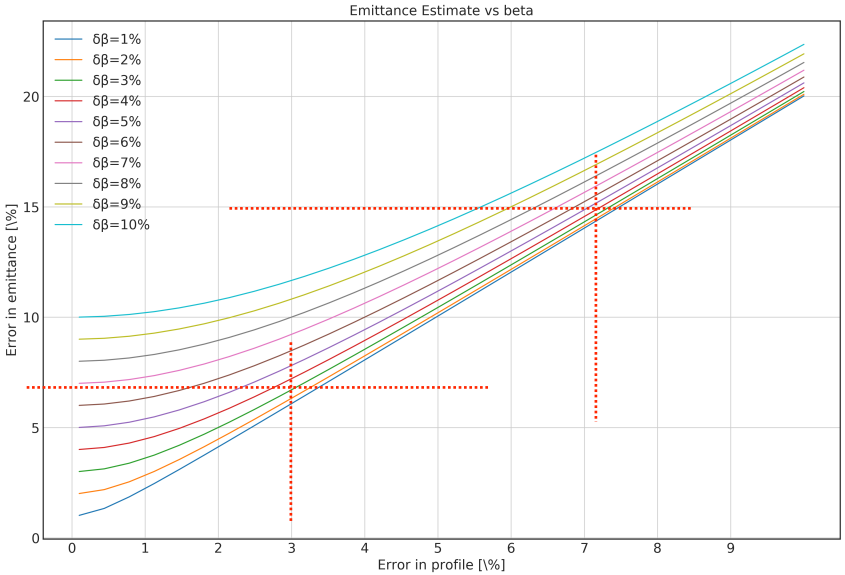
- *Alternate matching schemes, magnetic settings, depending on the findings…*

***Note** : Further MD requests may arise in the course of Run 3 depending on the LHC performance and analysis findings*

MDs for ε-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 (β) contributes to accurately convert the measured beam sizes to emittance
  - A linear total ε-growth of **10-30% or 2-5% / TeV** converts to δσ ~3-7%, for δβ~3% at 3TeV



Options considered

- **RampStopAndMeasure** : Execute a nominal ramp and stop at an energy point to measure emittance and optics (β) 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

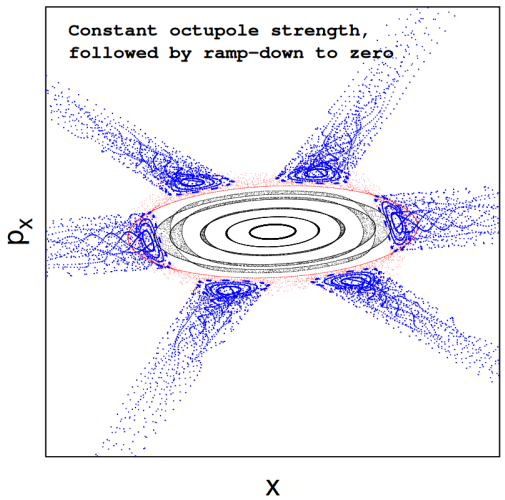
- **Beam configuration:**
  - Start a fill with PILOT bunches for the optics measurements (~1-2 h)
  - Continue with a second fill with the maximum number of bunches (LHCINDIV) that would allow safely using the WS
    - Assuming a limit of 2.5e12 in the total intensity @ 3.5 TeV, we may inject ~20 bunches 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**

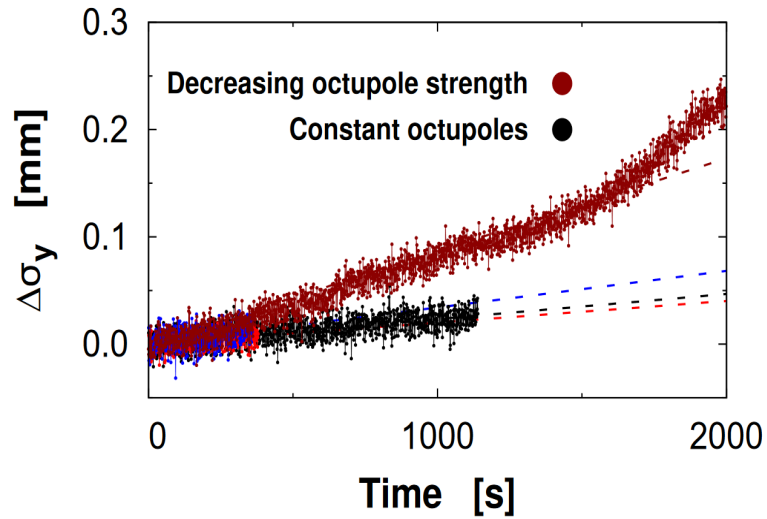
  - Alternatively : fill the machine with LHCINDIVs + the PILOTs for the optics measurements
    - Do first the emittance measurement and then use the ADT to dump the LHCINDIVs and keep only the PILOTs for the optics measurements
      - Interesting idea but new and challenging configuration (time to kill 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 ε-growth studies in the Ramp

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





See presentation by Ewan Maclean

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

MD on ε-scans at High Brightness

- **Motivation**:
  - The experiments use ε-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 ε-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 ε-growth?
        - Few MDs on single bunches and small trains during Run 2, need to continue the validation in view of HL-LHC operation

See presentation by X. Buffat

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

Thank you!