Multi-batch flat-top simulations

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Acknowledgements:
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Motivation

- All simulated thresholds were obtained for a single batch (mostly 48 bunches)
- The 915 MHz HOMs have $Q=5000$ and $R_{\text{shunt}}=1.7\,\Omega \rightarrow$ long range wake field couples batches
- How does the 915 MHz HOM affect instability thresholds for multiple batches?

Outline

- Multi-batch benchmark simulations with a single resonator
- Single-batch benchmark MPI simulations with full impedance model
Simulation setup for BLonD-MPI

- Flat top, single RF $V_{200}=10$MV, Q20
- 4x72 bunches with 2 Million macro-particles per bunch $\rightarrow$ 0.576 Billion macro-particles
- Simulations only feasible (both in time and memory) with MPI version of BLonD (see presentation by K. Iliakis, LIU-SPS BD WG meeting, 21/02/2019)
- Bunch spacing 5 RF buckets (25ns), batch spacing 50 RF buckets (250ns)
- Only include a single resonator impedance
  - $R = 570k\Omega$, $f_r = 630$ MHz, $Q = 200 \rightarrow$ wake decay time 20 RF buckets (101ns)
  - $R = 1.7M\Omega$, $f_r = 915$ MHz, $Q = 5000 \rightarrow$ wake decay time 348 RF buckets (1740ns)
  - No other impedances!
- Initial bunches were matched including intensity effects
- Scan intensity between 1.0e11 and 2.6e11 ppb; $\sigma_{FWHM}$ between 1.4 and 1.9 ns
- Simulate 1s of flat top (44k turns)
Result $f_r = 630 \, MHz, \, Q = 200$

- 1x72 bunches
- Color: maximum relative bunch length spread (capped at 0.15)
- ‘x’: 2.3s simulations by Alexandre
Result $f_r = 630 \text{ MHz}, \; Q = 200$

- 4x72 bunches
- Color: maximum relative bunch length spread (capped at 0.15)
- Same threshold as for single batch
- Barely any coupling between batches
Result $f_r = 915 \text{ MHz}$, $Q = 5000$

- 1x72 bunches
- Color: maximum relative bunch length spread (capped at 0.15)
- Single batch stable
Result $f_r = 915 \, MHz, \, Q = 5000$

- 2x72 bunches
- Color: maximum relative bunch length spread (capped at 0.15)
- Instability threshold reduces as bunches in second half of second batch becomes unstable
Result $f_r = 915 \text{ MHz}$, $Q = 5000$

- 3x72 bunches
- Color: maximum relative bunch length spread (capped at 0.15)
- Coupling between batches $\rightarrow$ threshold reduces because the third batch becomes unstable
Result $f_r = 915 \, MHz, \, Q = 5000$

- 4x72 bunches
- Color: maximum relative bunch length spread (capped at 0.15)
- Threshold reduces further with fourth batch
Setup for full impedance model simulations

- Flat top, double RF \( V_{200} = 10\text{MV} \) (\( V_{800}/V_{200} = 0.1 \)), Q20
- 1x72 or 4x72 bunches with 1 Million macro-particles per bunch
- Bunch spacing 5 RF buckets (25ns), batch spacing 40 RF buckets (200ns)
- Use same impedance model as Joël
  - 200 MHz feedback modeled by reducing \( R_{\text{shunt}} \) by 26dB
  - No 800 MHz feedback
  - 915 MHz HOMs: two resonators at \( f_r = 914 \text{MHz} \) and \( f_r = 914.8 \text{MHz} \) with
    - 3 section cavity: \( R = 231k\Omega, Q = 3000 \) (likely too pessimistic)
    - 4 section cavity: \( R = 385k\Omega, Q = 5000 \)
- No phase loop
- Initial bunches were matched including intensity effects
- Simulate 100 000k turns of flat top (2.3s)
- Beam considered unstable if maximum relative amplitude spread exceeds 0.07:
  \[
  \frac{\max \Delta \tau}{\tau_{av,inj}} > 0.07
  \]
Single batch

- Single batch threshold is larger by 7% compared to Joël (likely due to different initial bunch distributions; to be studied...)

![Graph showing single batch performance](image-url)
Four batches

- Thresholds for four batches is reduced by 11% because last batches become unstable
Four batches without 915 MHz HOM

- PRELIMINARY!
Testing bunch-matching methods

- Flat top, double RF $V_{200}=10\text{MV}$ ($V_{800}/V_{200}=0.1$), $Q_{20}$
- 1x72 or 4x72 bunches (5 RF bucket spacing), 40 RF bucket batch spacing
- Use same impedance model as Joël
- No phase loop
- Simulate 100 000k turns of flat top (2.3s)
- Simulate with BLoNd-MPI and on batch cluster without MPI
- Match bunches to SPS flat top with $2.24\times10^{11} \text{ p/b}$; emittance $0.65\text{eVs}$ ($4\sigma_{\text{FWHM}}=1.48 \text{ ns}$)
  - Matching method A: `match_beam_from_distribution (mbdf)`; used for full-impedance model simulations
  - Matching method B: `matched_from_distribution_density_multibunch (mfddm)`; used for single-resonator simulations
- Profile resolution 64bins/RF bucket; frequency resolution $1f_{\text{rev}}$
Testing bunch-matching methods

- Different bunch length evolution when using different matching methods
- For same matching method, late-time behavior differs
- Cause under investigation; likely due to differences in induced voltage computations
- Notice that beam becomes unstable in all cases.
Summary

• Multi-batch simulations possible with BLonD-MPI
• Simulations with single high-Q resonator show batch-by-batch coupling
• BLonD-MPI simulations with full impedance model show slightly higher thresholds compared to Joël’s result
• For four batches, thresholds are reduced because last batches become unstable

Next steps

• Systematically investigate effect of different 915 MHz HOM damping
• Investigate why different bunch-matching algorithms yield different long-term behavior
• Simulation of 4x72 bunches along the entire SPS cycle feasible…

Thank you for your attention!