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Preliminary Consideration of three-bunch Operation

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On behalf of the RF team

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Assumptions

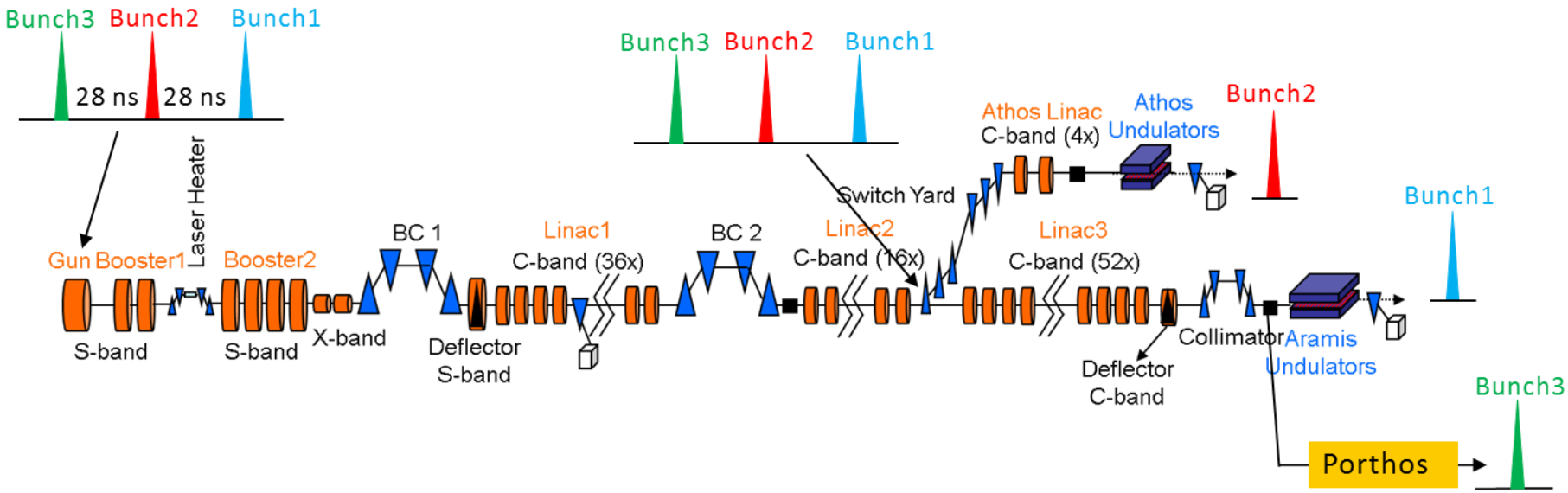
1. Focus on three-bunch operation – the proposed methods could be too complicated for 4 or more bunches. Energy gain reduction in C-band stations are one of the bottlenecks for bunch-train operation.
2. The bunches are separated by at least 28 ns – known tuning range from the two-bunch operation experiences.
3. Assume the three bunches all operate at 100 Hz, the same as the RF pulse repetition rate.

Preliminary Requirements

1. The three bunches should be tuned independently. The required tuning range will be specified by beam dynamics (and limited by RF system).
2. The energies of the three bunches should be the same at chicanes and switchyards.
3. The three bunches will have similar charges.
4. The beam parameters (energy, arrival time, energy spread or bunch length) of the three bunches should be tunable at the Gun exit, BC1 and BC2.
5. The Linac3 should be used to tune the energy of the Aramis and Porthos bunches to be the same. Is the energy spread a concern here?
6. The three bunches will be setup in a combined shift. It is not avoidable to affect the later bunches when adjusting an earlier bunch.
7. In operation, the effects on the later bunches when adjusting an earlier bunch should be compensated.

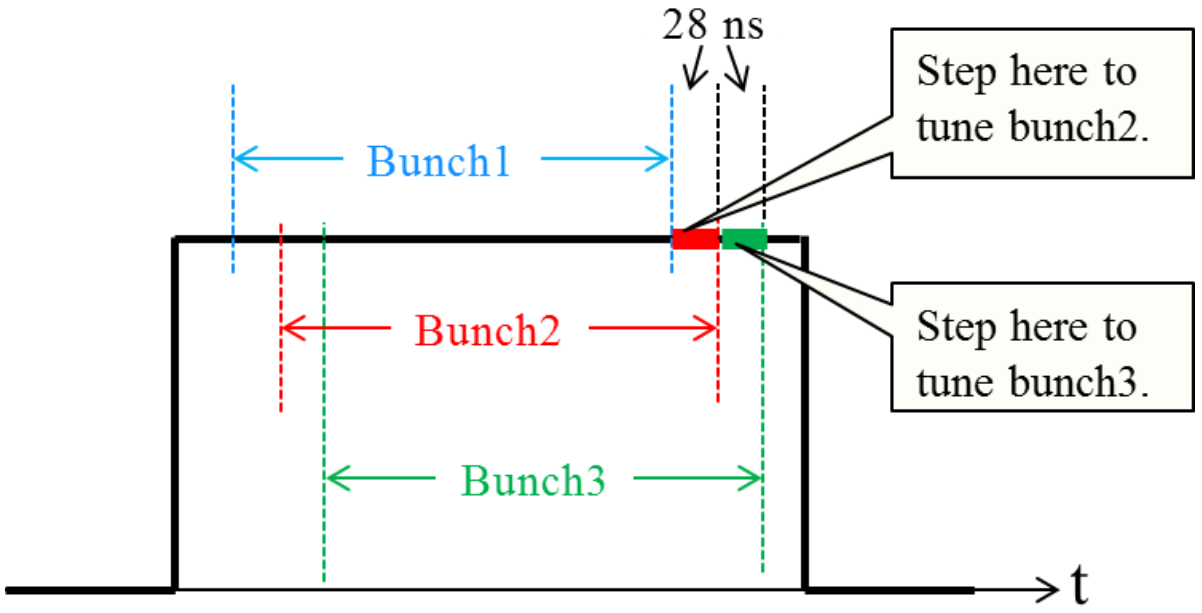
Bunch Assignments

- Bunch1 for Aramis, Bunch2 for Athos, and Bunch3 for Porthos.



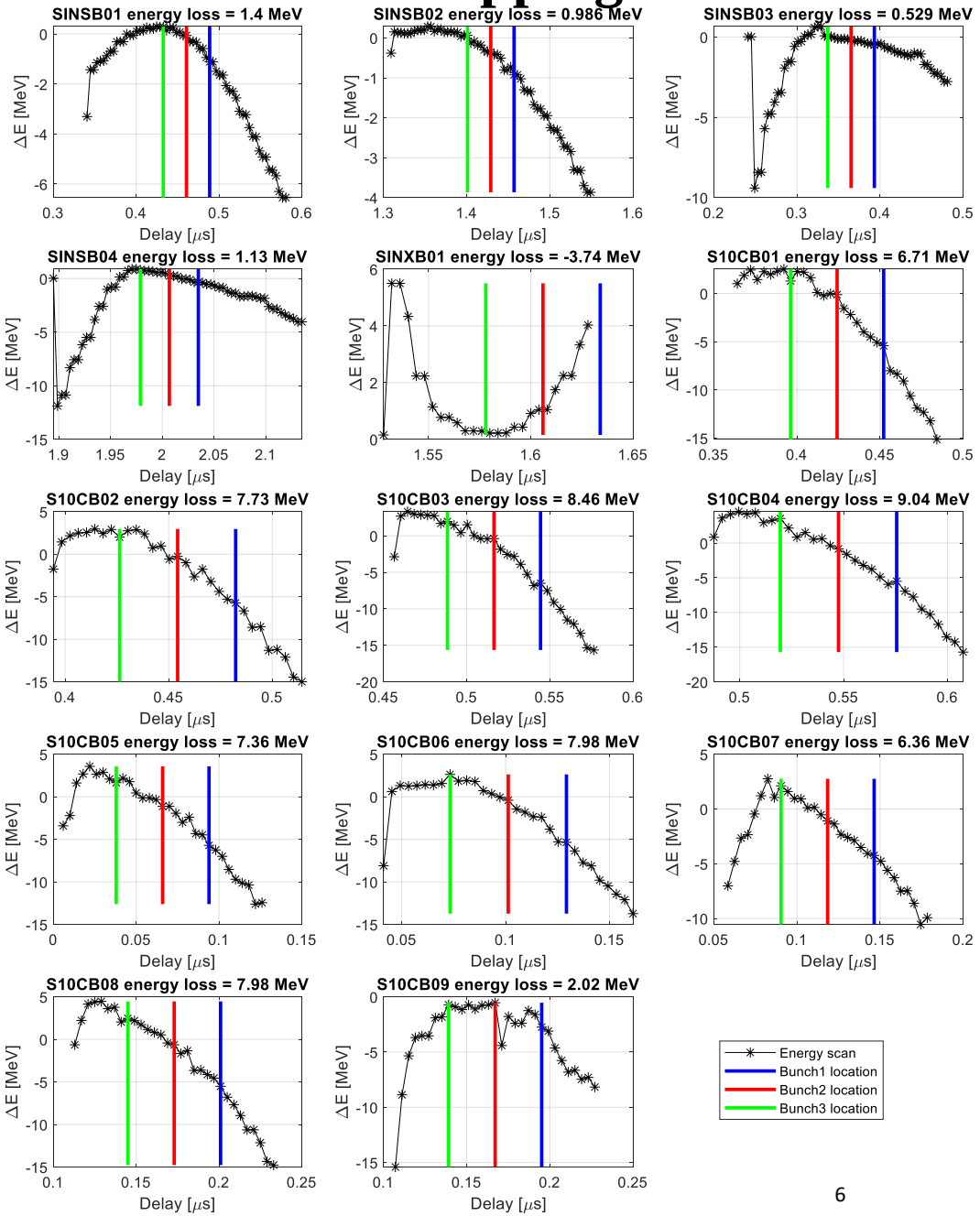
Basic Ideas – Tuning Method

- Use two steps in the RF pulse to tune Bunch2 and Bunch3.
- Similar preparation procedure as two-bunch operation:
  1. Flatten the RF pulse (optional),
  2. Optimize the delay of all RF stations,
  3. Determine the step time in the pulse,
  4. Set the average windows of the RF signals.
- Similar tuning procedure: optimize the macro pulse for Bunch1, then setup Bunch2 and Bunch3 with the steps.



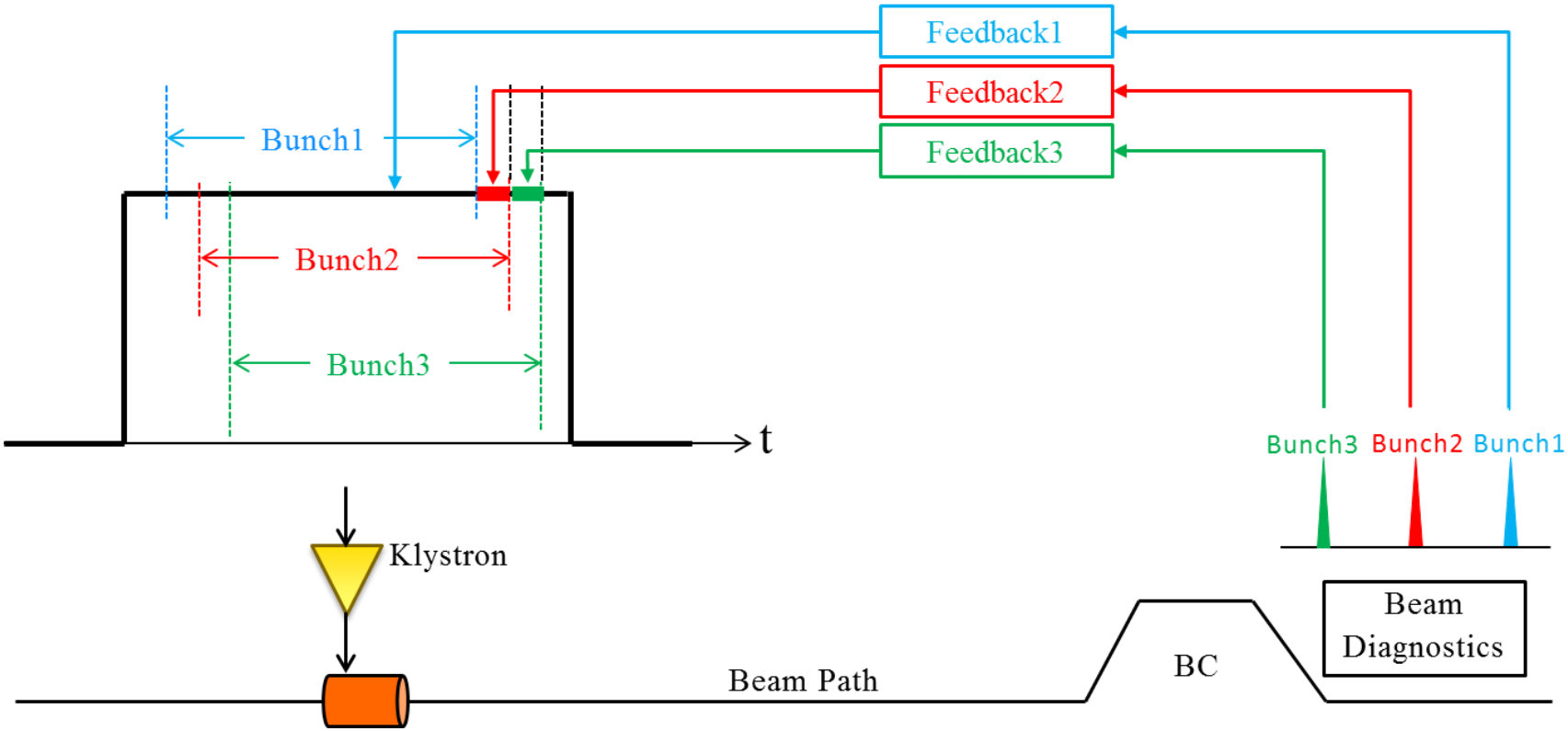
Beam Energy Gain Loss with Stepping

- To provide headroom for step tuning, we should pre-tune the RF pulse delay so that the energy gain: Bunch3 > Bunch2 > Bunch1.
- Loss of energy gain at injector: ~ 1 MeV per station.
- Loss of energy gain at Linac1: ~ 8 MeV per station.



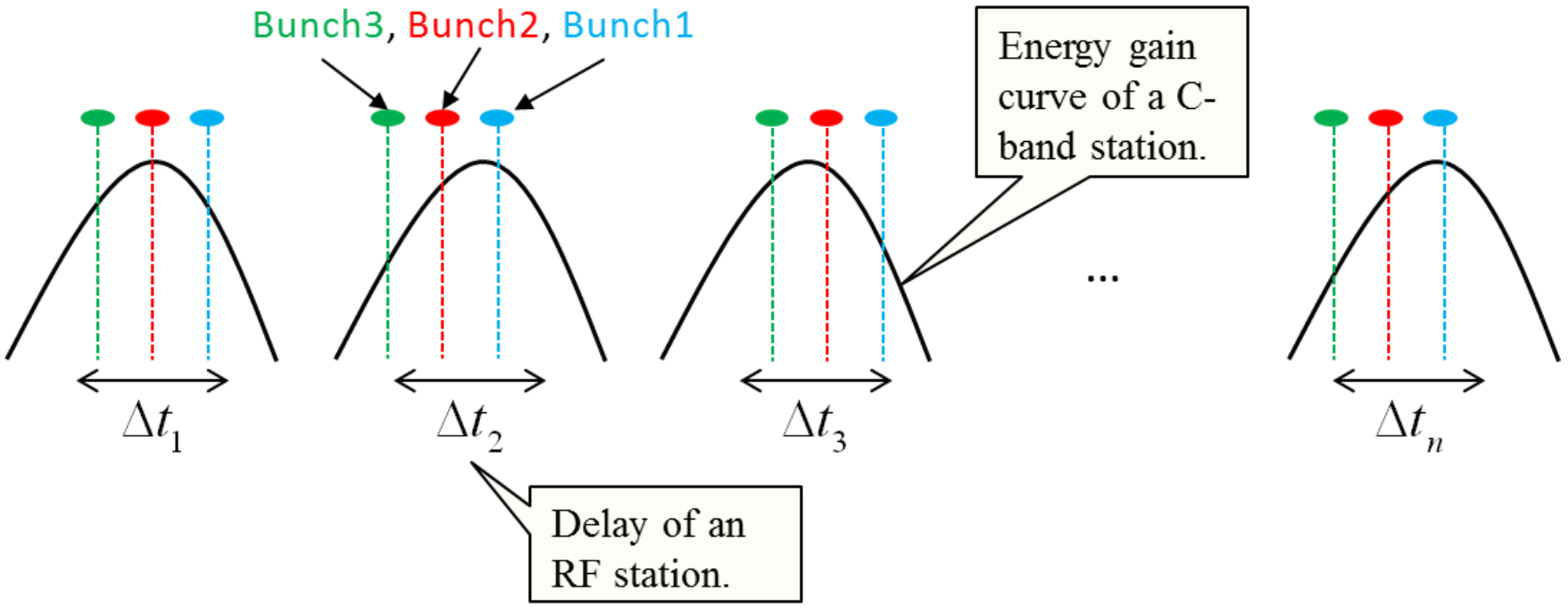
Basic Ideas – Decouple the Tuning

- **Choice 1**: use feedforward to correct the influence to later bunches from the tuning of earlier bunches.
- **Choice 2**: parallel feedback loops running continuously.



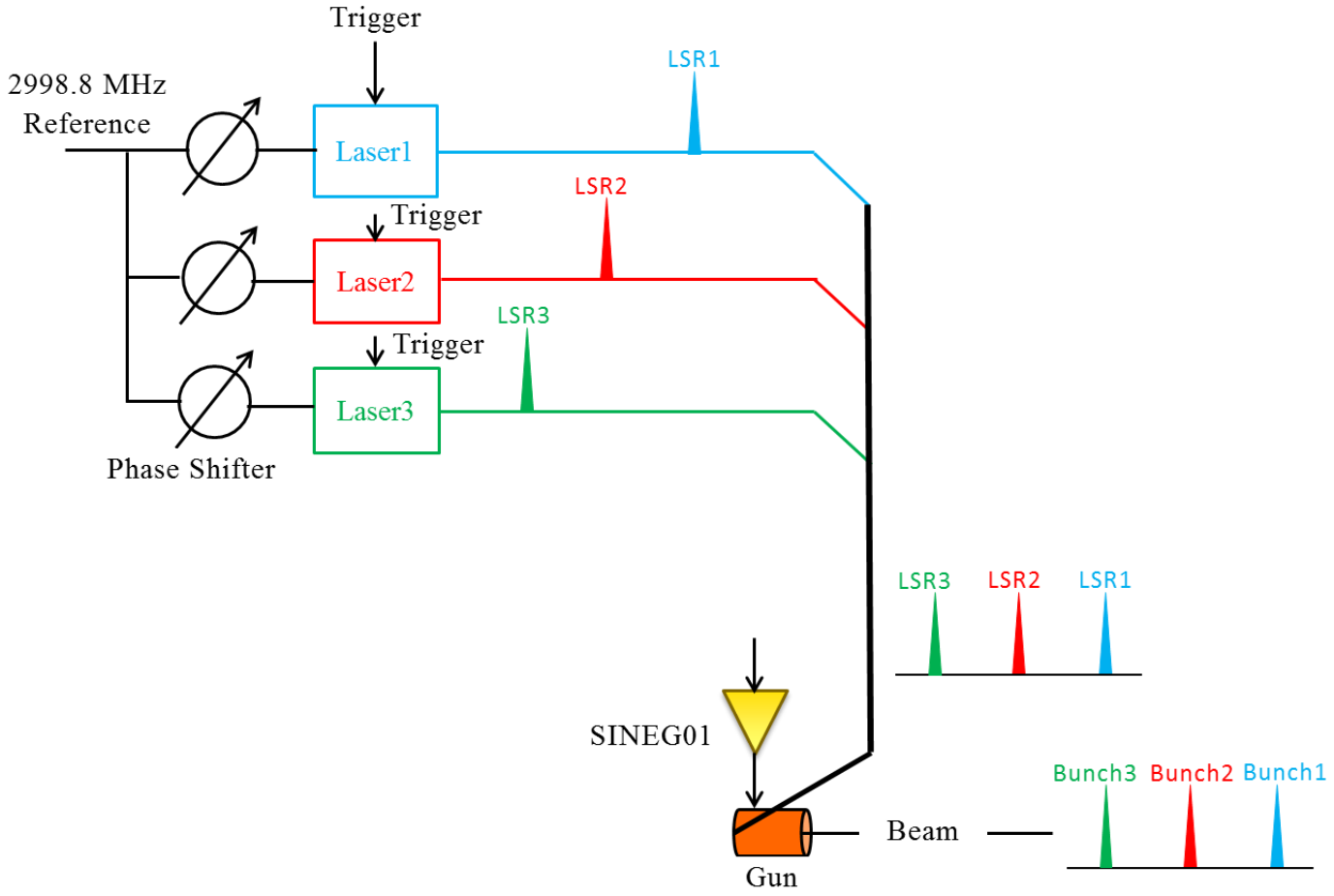
Basic Ideas – Global Optimization

- Linac1 C-band delay and phase slope – 18 knobs to tune 6 beam parameters (energy and compression of each bunch) – a non-linear global optimization problem.



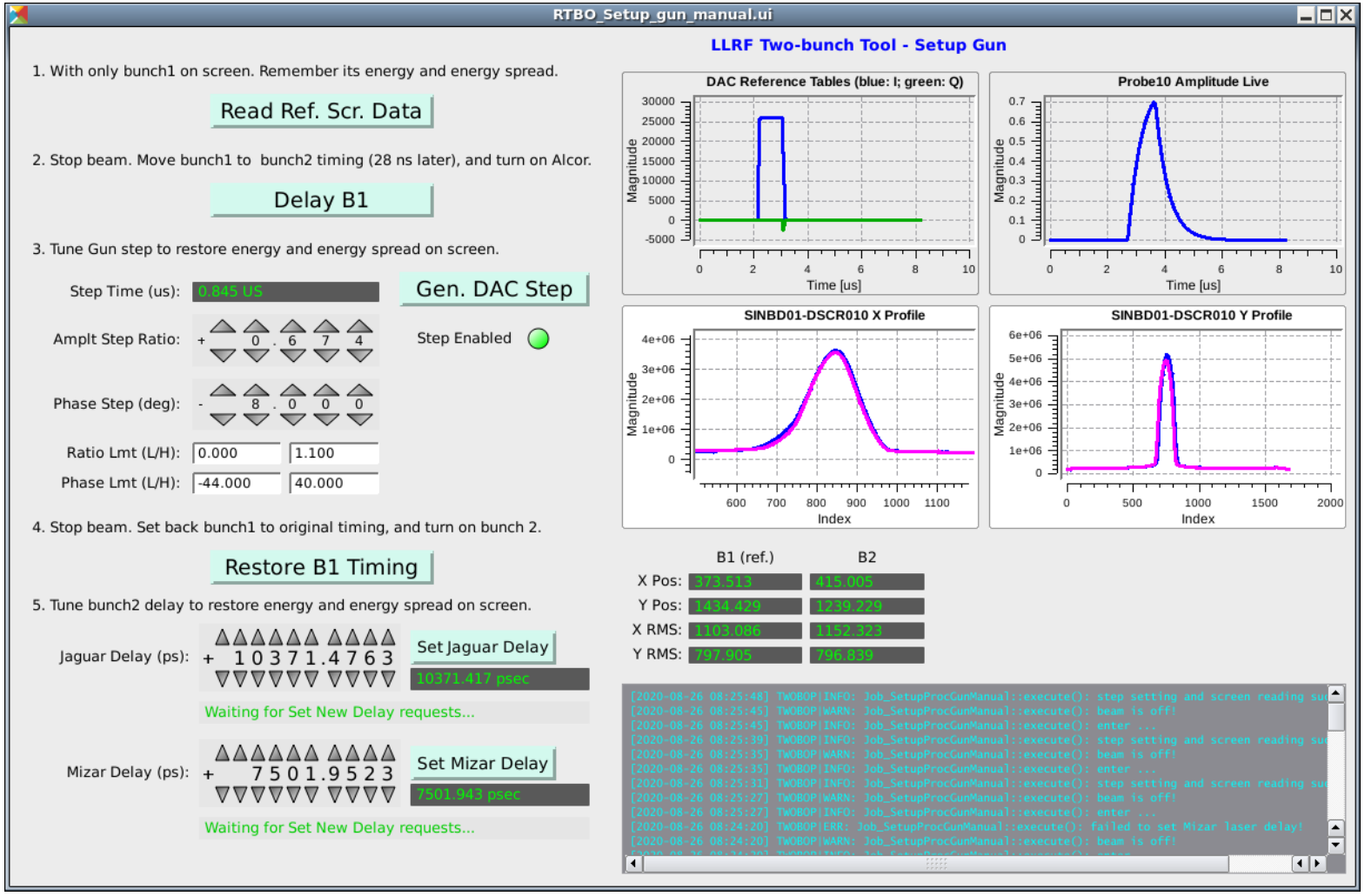
Basic Ideas – Gun/laser Setup Procedure

- **Stage1 – Laser setting**: place three lasers to Bunch1 time one-by-one, tune their fine delays using the LH BAM as reference.
- **Stage2 – RF setting**: switch on the three lasers at nominal timing one-by-one, tune the RF pulse steps using the Gun spectrometer screen as reference.



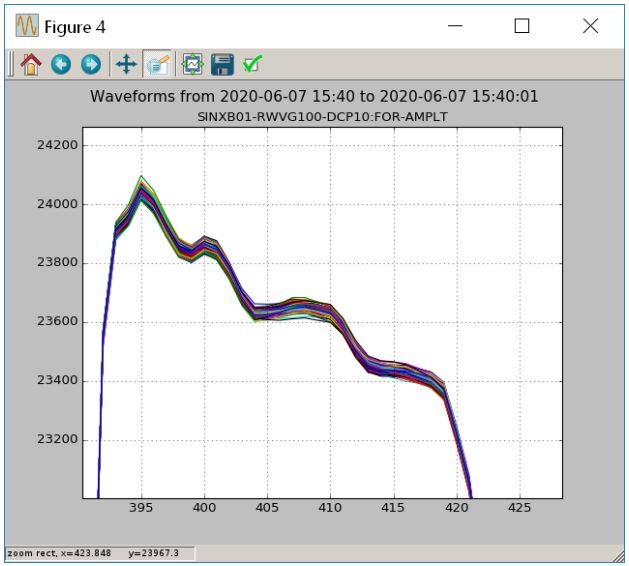
Basic Ideas – Gun/laser Setup Procedure Alternative

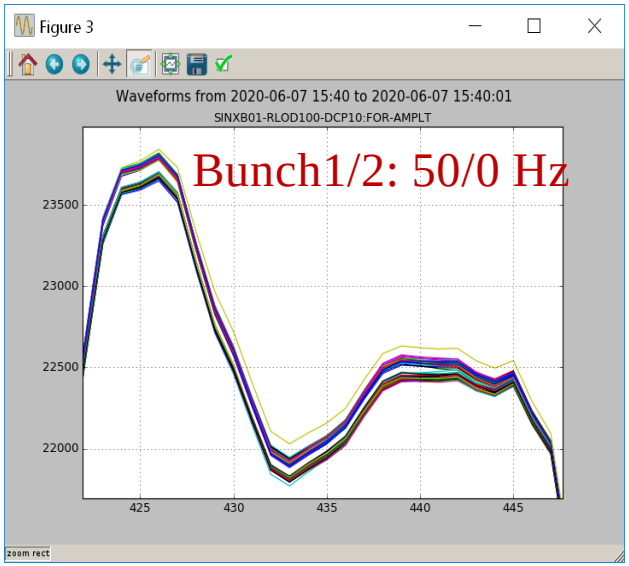
- As the two-bunch operation: two stages of setup but with RF setting first and then the laser delay setting. BAM is not used.

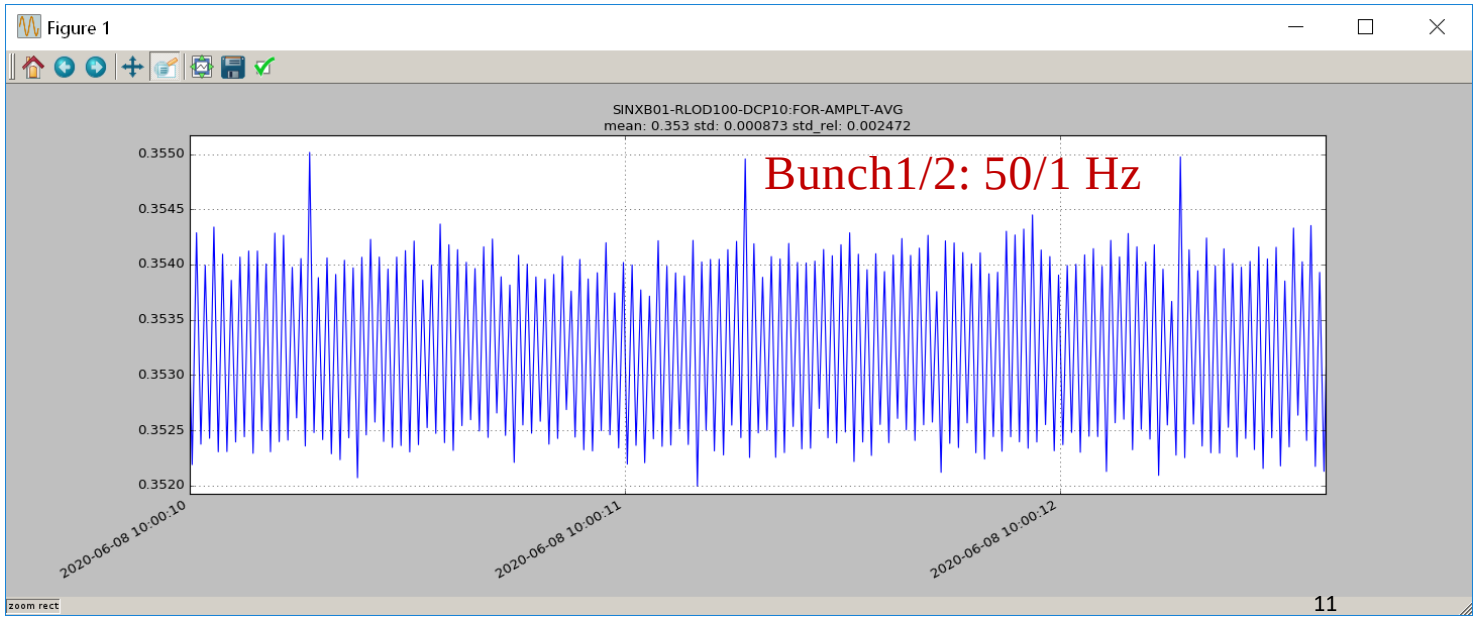


Beam Loading Issue

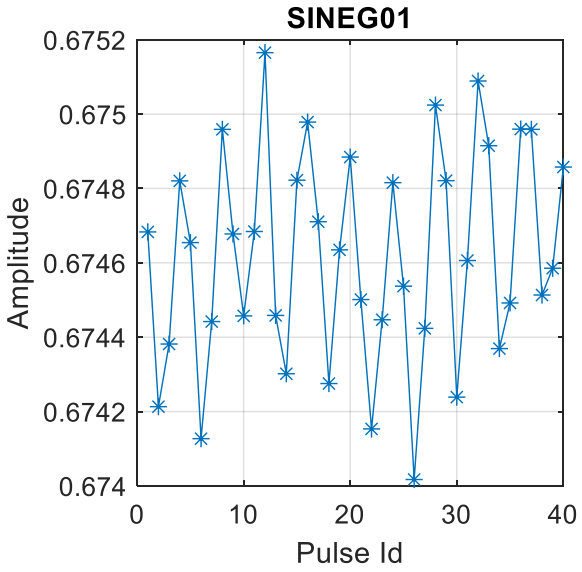
- Beam loading observed in X-band structure.
- Earlier bunch beam loading affects the later bunches.
- Later bunch beam loading affects the earlier bunch via RF feedback.

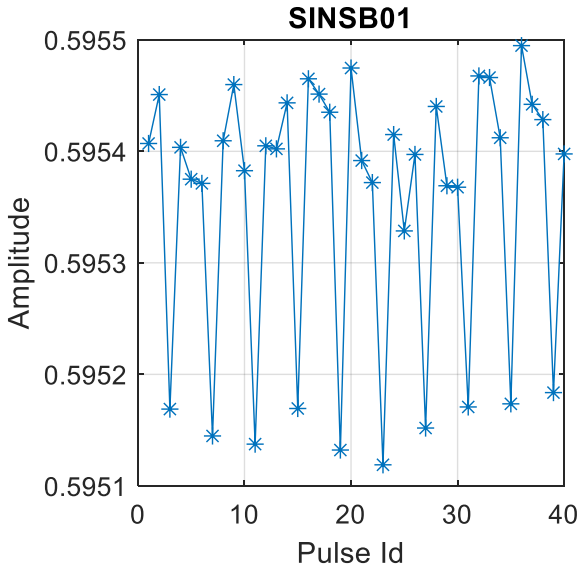


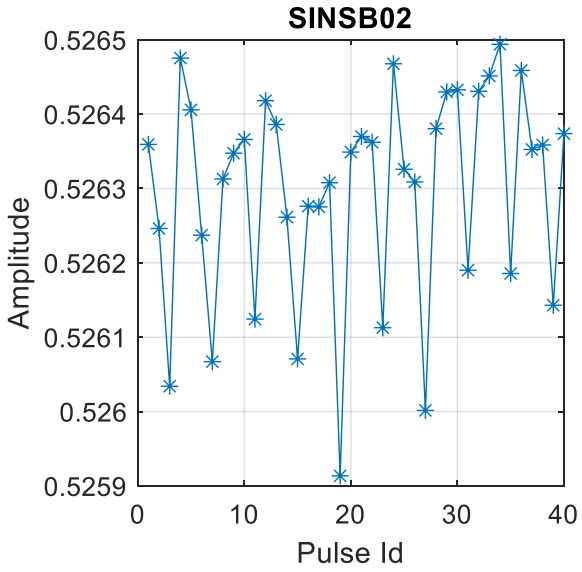


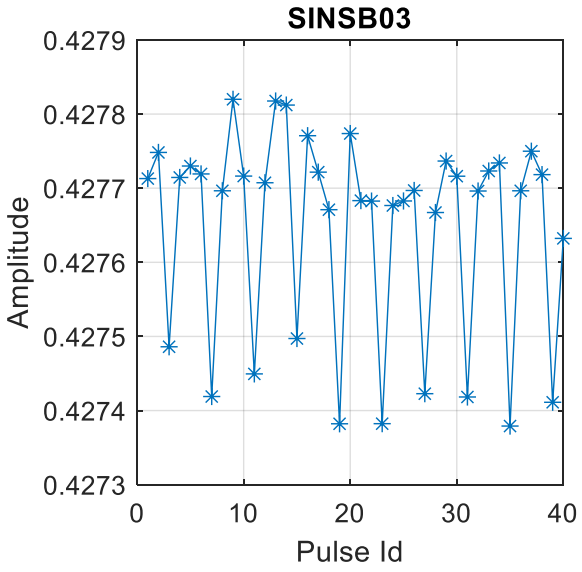


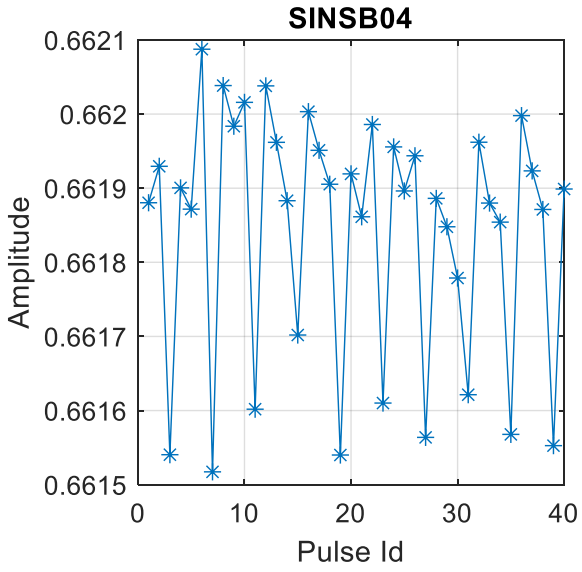
Further Data for Beam Loading – Injector

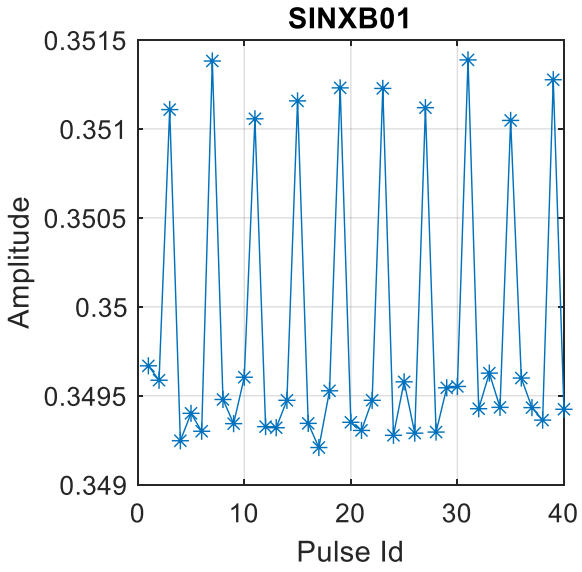






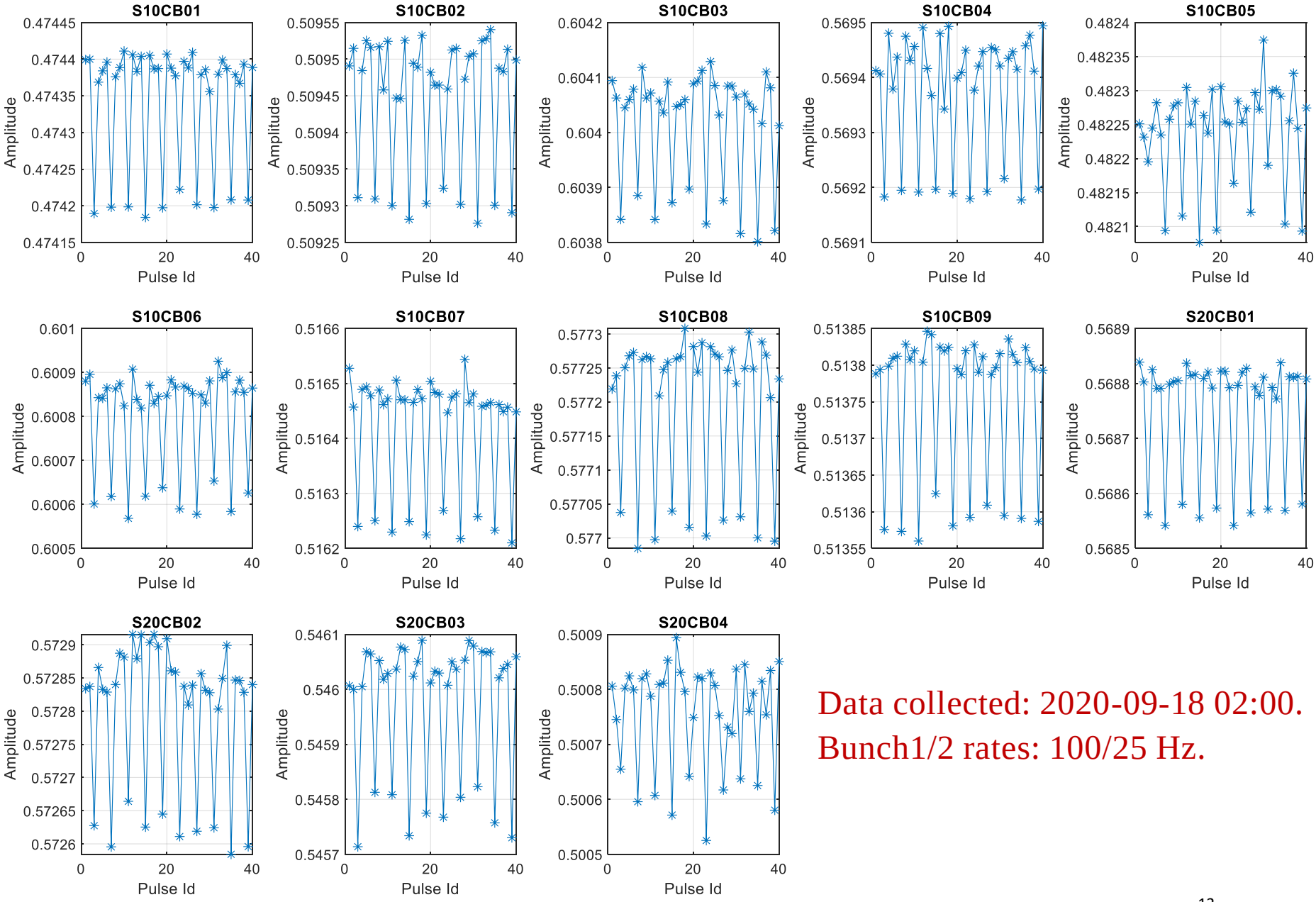






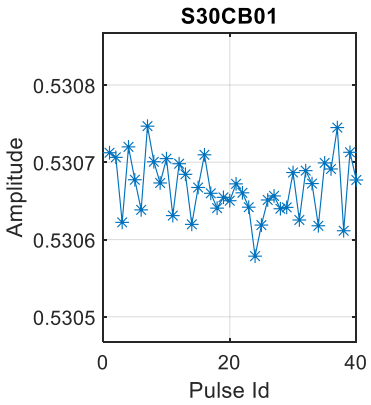
Data collected: 2020-09-18 02:00. Bunch1/2 rates: 100/25 Hz.

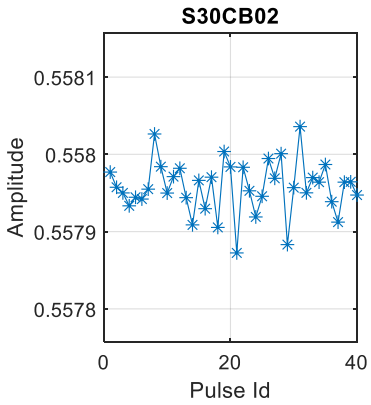
Further Data for Beam Loading – Linac1/2

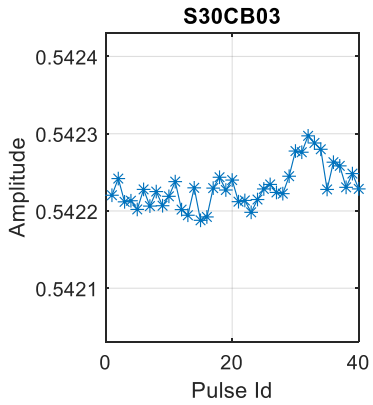


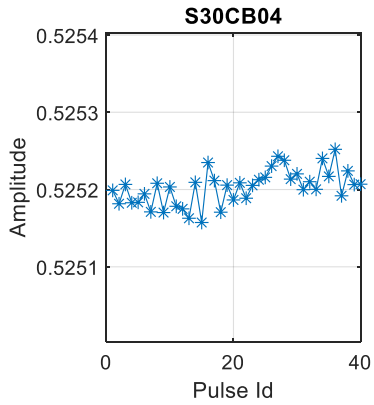
Data collected: 2020-09-18 02:00.
Bunch1/2 rates: 100/25 Hz.

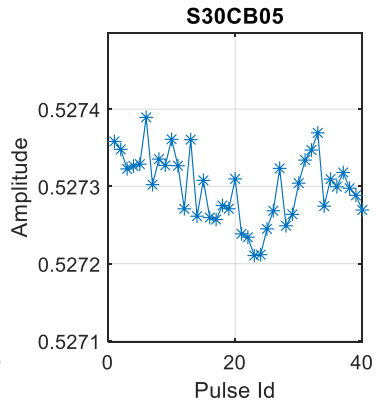
Further Data for Beam Loading – Linac3

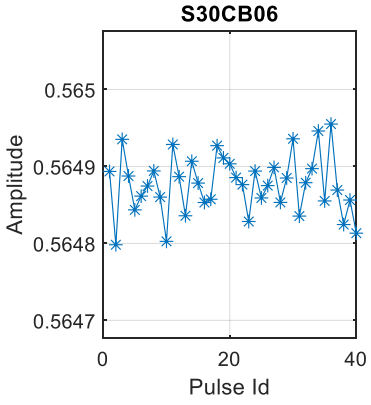


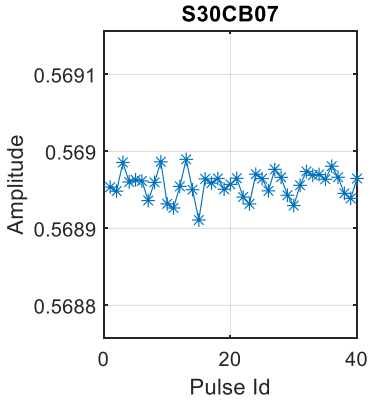


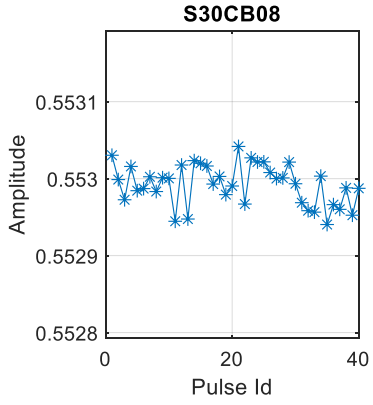


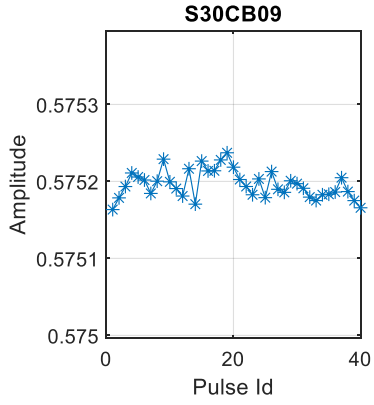


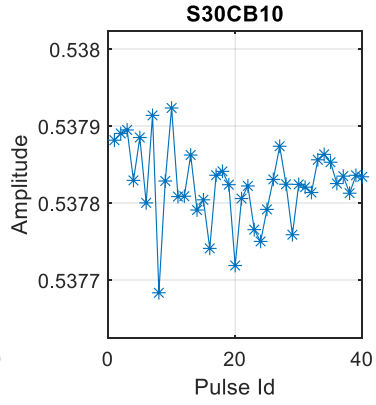


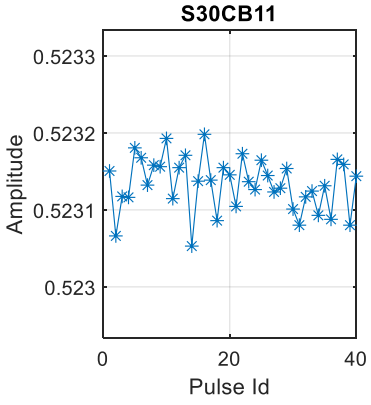


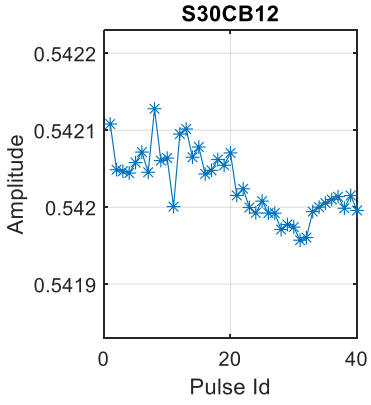


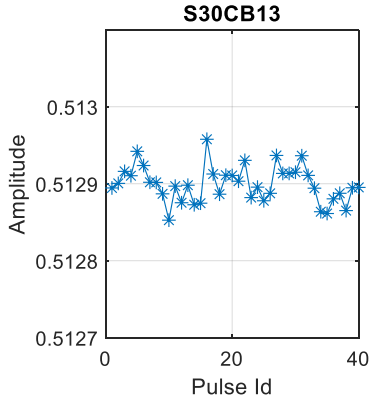












Data collected: 2020-09-18 02:00.
Bunch1/2 rates: 100/25 Hz.

Required Upgrades – High Power RF

- **SINEG01**: increase the RF pulse width or increase the peak power.
- **S-band** and **X-band**: increase the RF pulse widths.
- **C-band**: Increase the peak power (and increase the RF pulse widths).

All need further conditioning of the RF system.

Required Upgrades – LLRF

- Increase the DAC rate to 500 MSPS (optional).
- Update LLRF HLA to support two-step generation.
- Update the two-bunch operation software.
- Improve the timing certainty between the timing, synchronization, Gun laser and LLRF – maintain the step timing after maintenance or shutdown.

Studies to be Done

1. Test the feedforward-based algorithm to correct the influence to Bunch2 when tuning the Bunch1.
2. Test the algorithm to correct the influence via parallel feedbacks on both bunches.
3. Test the Gun/laser setup procedure with LH BAM. The procedure sets the laser first and then the RF.
4. Simulate and test the global optimization (C-band delay and phase slope) with the two-bunch operation.
5. Simulate the step tuning method for three bunches. Study the transfer function between the step settings and the Bunch2 parameters.
6. Simulate the beam loading in Gun cavity, S-/C-/X-band structures.

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Discussions