Updates on counter-rotating muon beams in the high-energy acceleration chain

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9th Meeting of Task 6.1 MuCol Design Study

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MuCol

CERN

International MUON Collider Collaboration

Outline

1. General aspects of counterrotating bunches
2. Simulations with FM wakefields from CR
3. Cavity voltage modulations (more in L. Thiele's presentation)
4. Changes of the momentum compaction factor
5. Summary

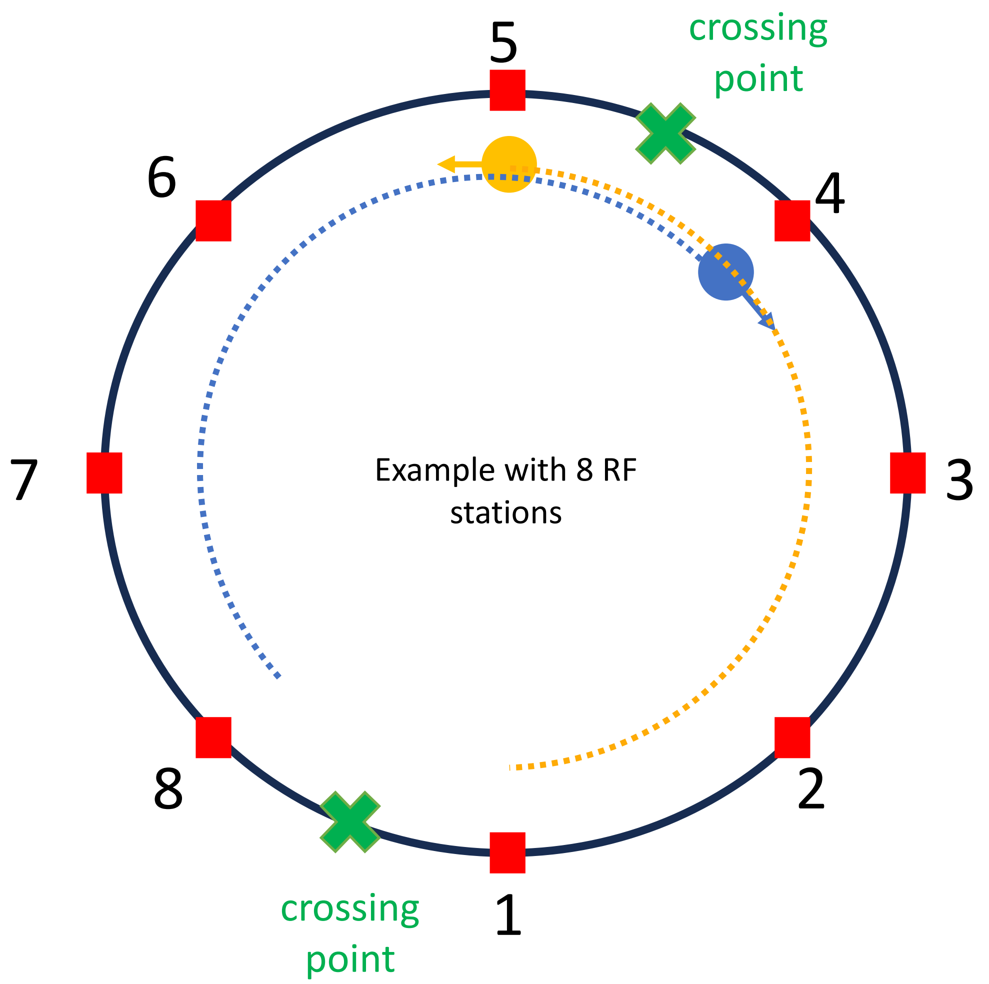
General situation

- In the RLAs, the co-propagating bunches are separated by odd multiples of π
- In the RCSs, the bunches are counterrotating (CR)

→ In the standing wave cavities, the bunches must pass with a relative offset of multiples of 2π

- The positioning of the bunch crossing points with respect to the RF stations is an important assumption as it defines the intensity effects affecting the other bunch, the HOM power scales with I^2

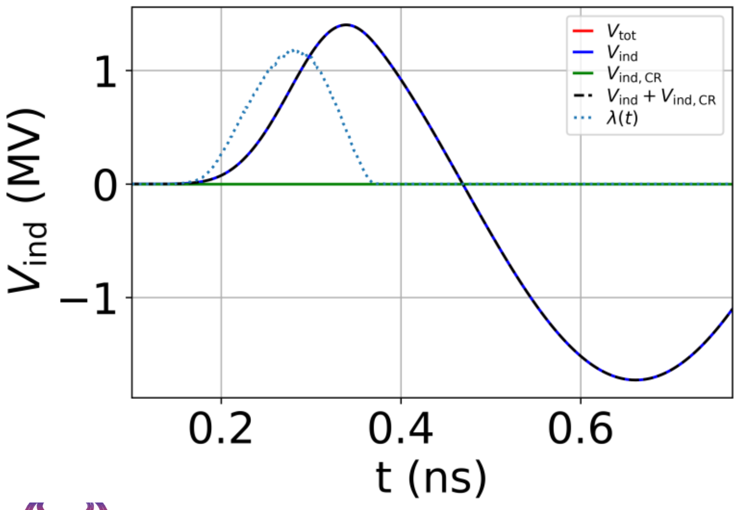
→ Bunch crossing points in the middle of the arcs optimal



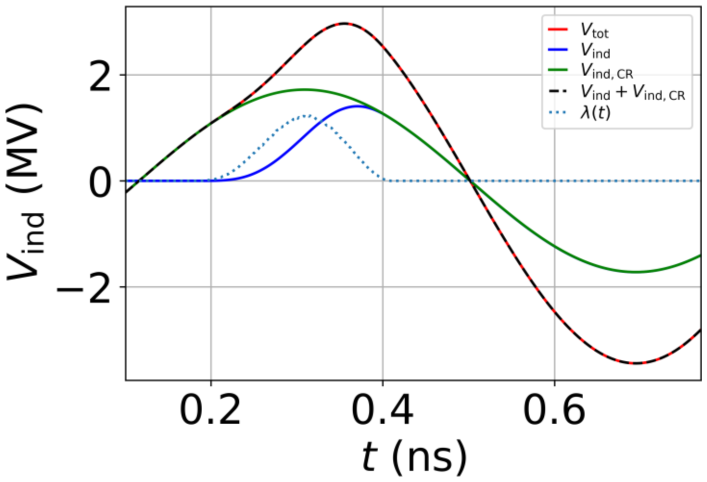
Wakefields of the CR bunch

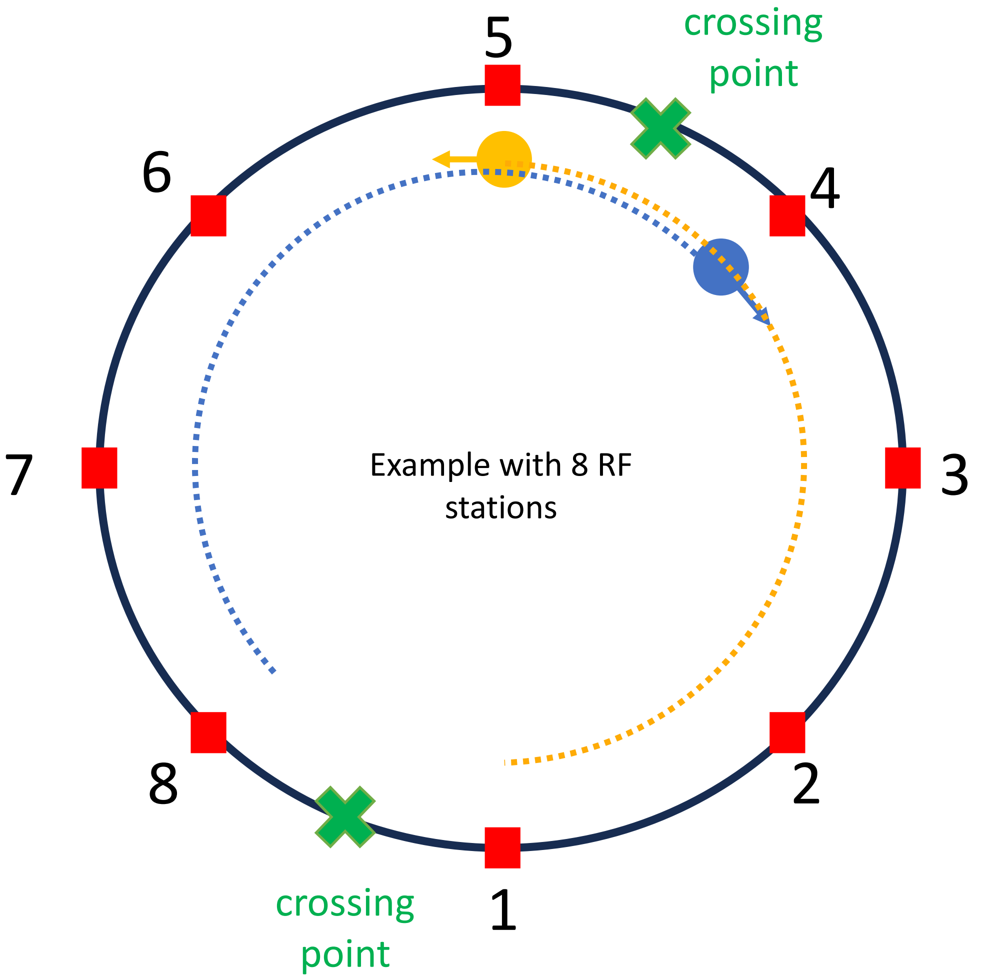
- **Use of ‘standard’ cavity and RCS parameters**
- **Re-use the intensity effect calculations for multi-turn effects for one bunch in BLonD**
- **Calculate in addition wakefields at the time of the passage of the CR bunch in the future**
- **Apply it to the other beam at the moment of passage**

Induced voltages in RF station 1:



Induced voltages in RF station 5:

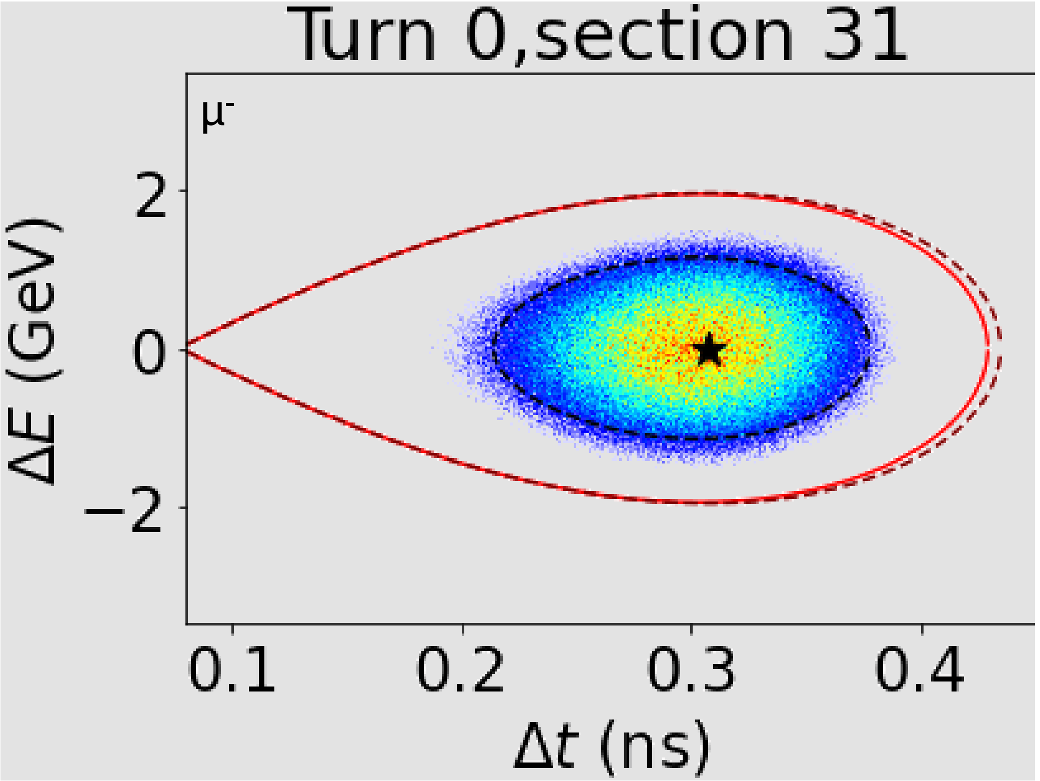


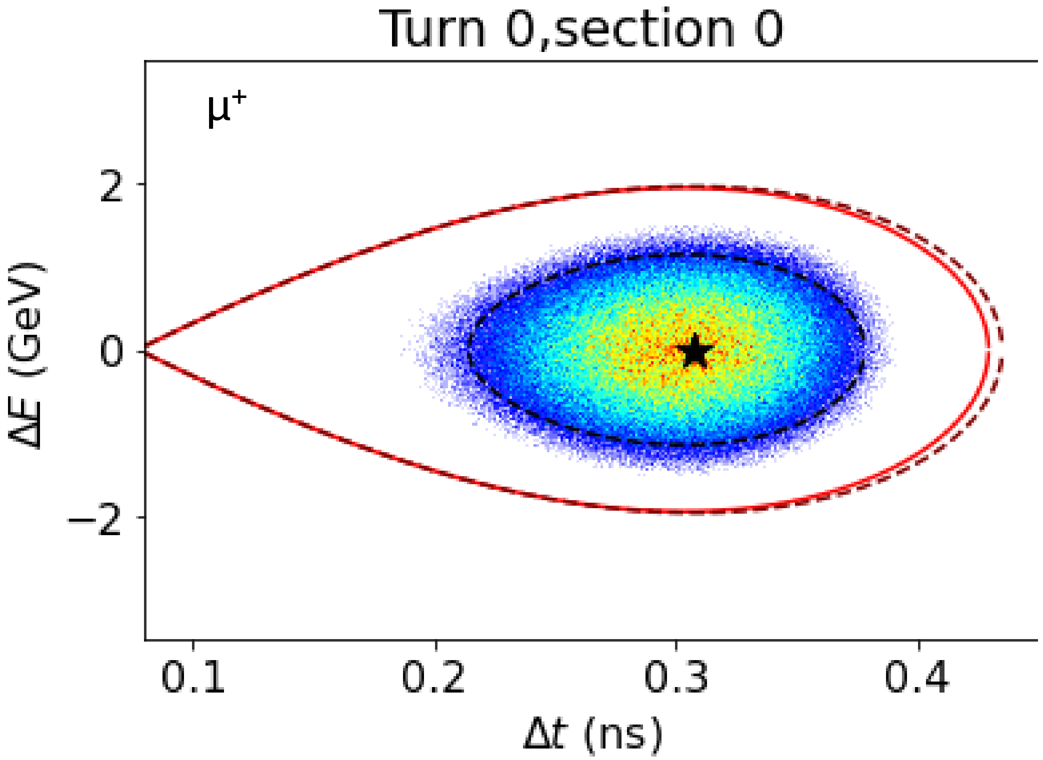


Simulation example

Exemplary longitudinal phase spaces for μ^- and μ^+ bunch for 32 RF stations:

RCS1



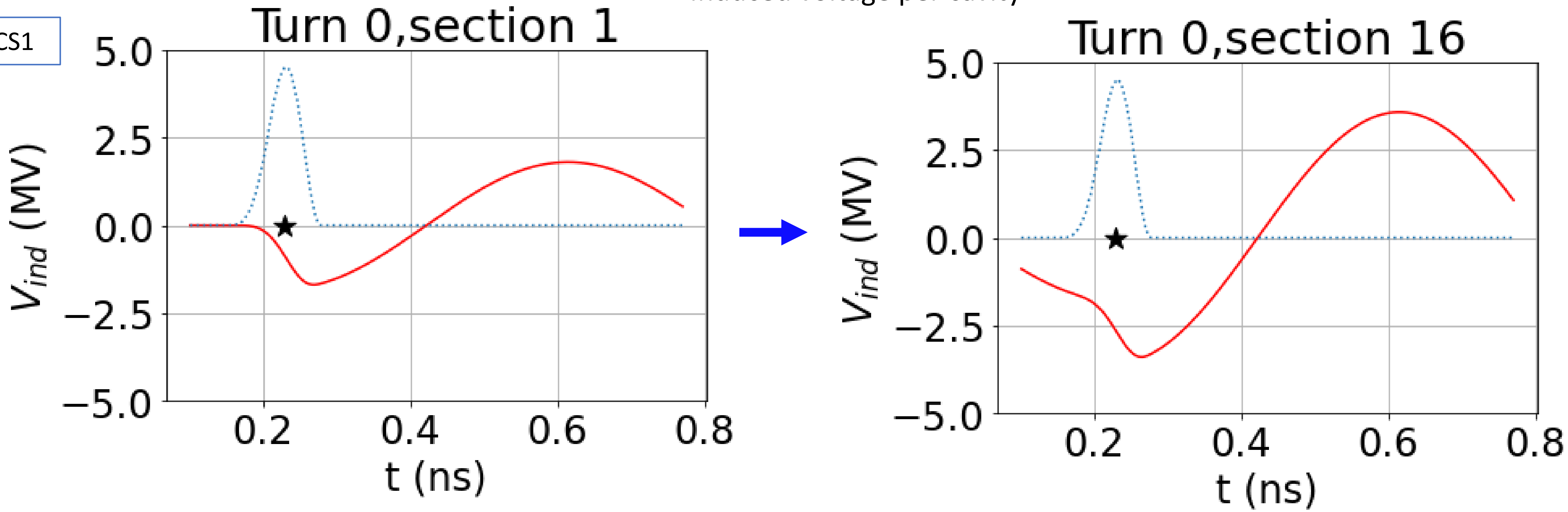


Simulation results

For the fundamental mode (FM), and a relative **phase offset of 0**, the fundamental mode wakefields from the CR bunch are therefore **also in phase** and build up:

Induced voltage per cavity

RCS1



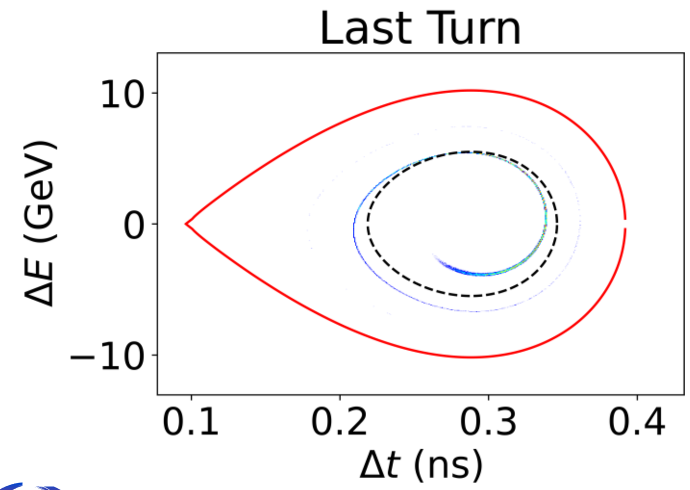
Simulation results (1)

Induced voltages of ~1MV per cavity and turn build up. Example of RCS2:

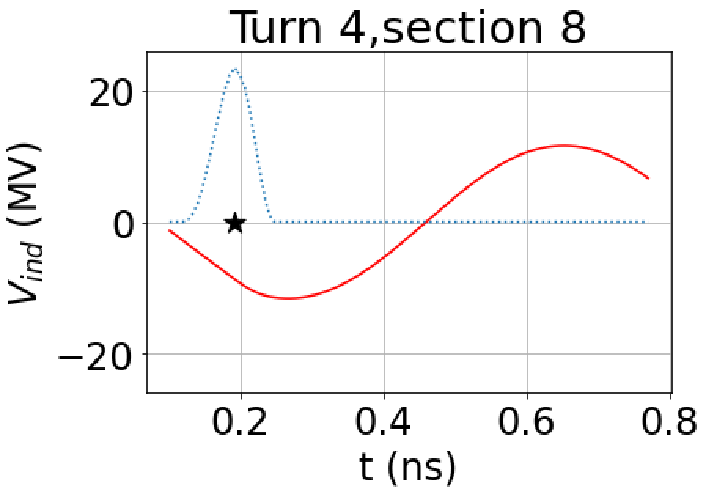
- $n_{\mathrm{RF}} = 32$
- $\phi_s = 45°$
- $\alpha_p = 0.00032$ (value from Lisa Soubirou)
- Only fundamental mode, multi-turn and CR intensity effects, no HOMs

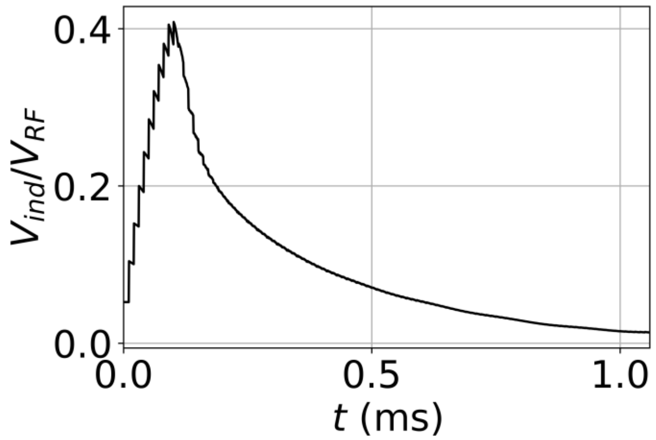
→ No sufficient beam loading compensation, bunch lost

Longitudinal phase space



Induced voltage per cavity





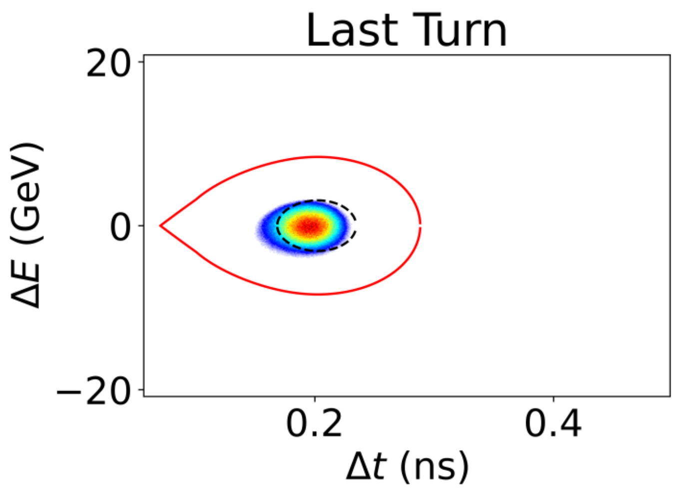
Simulation results (2)

Providing more voltage by decreasing the synchronous phase:

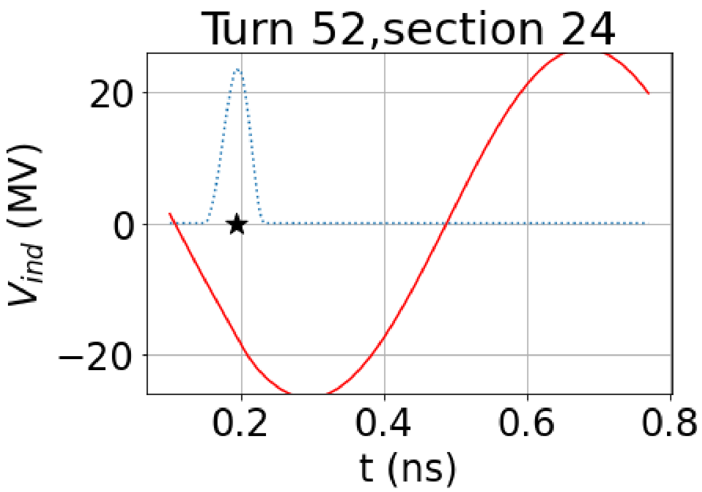
- $\phi_s = 33°$ (30% more total RF voltage)
- Other parameters unchanged

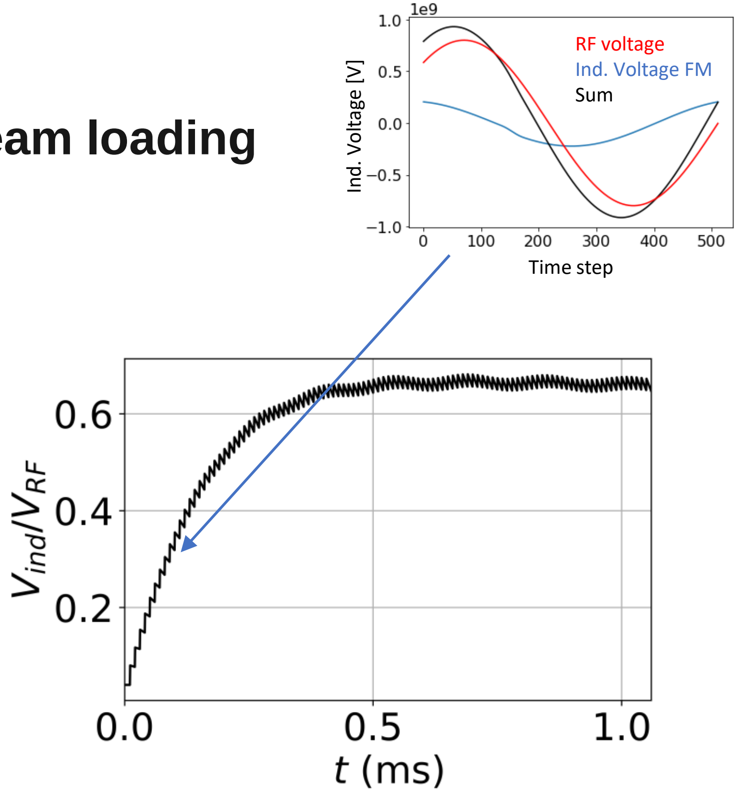
→ **Bunch is transported, the fast synchrotron motion mitigates the beam loading**

Longitudinal phase space



Induced voltage per cavity

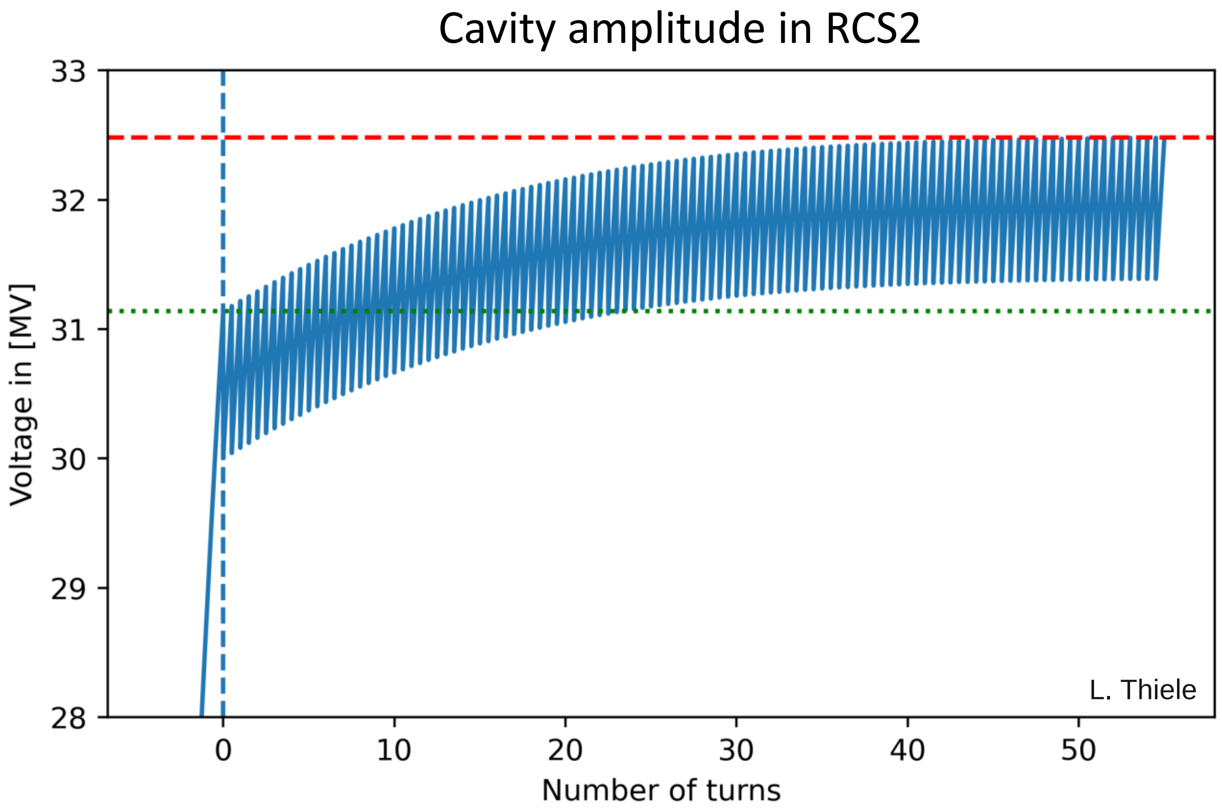




Beam loading compensation

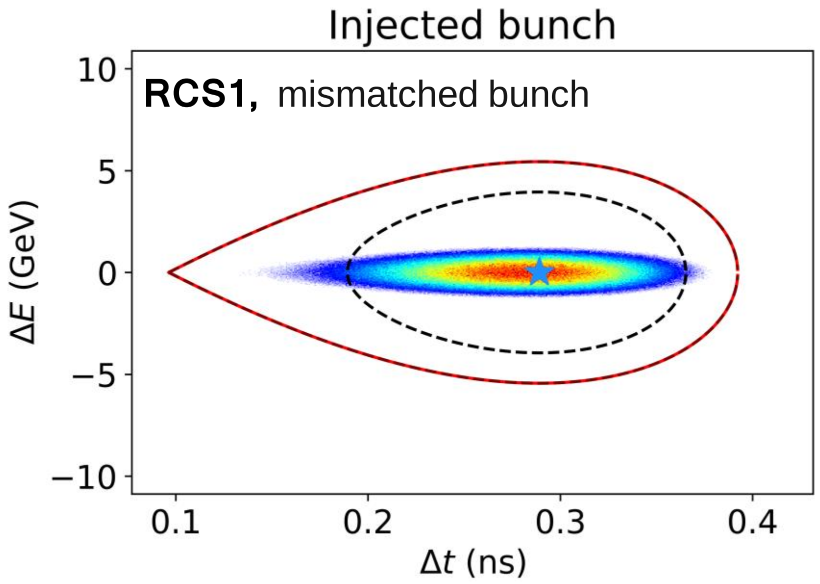
- The linac acceleration scheme together with beam loading leads to a non-constant cavity voltage

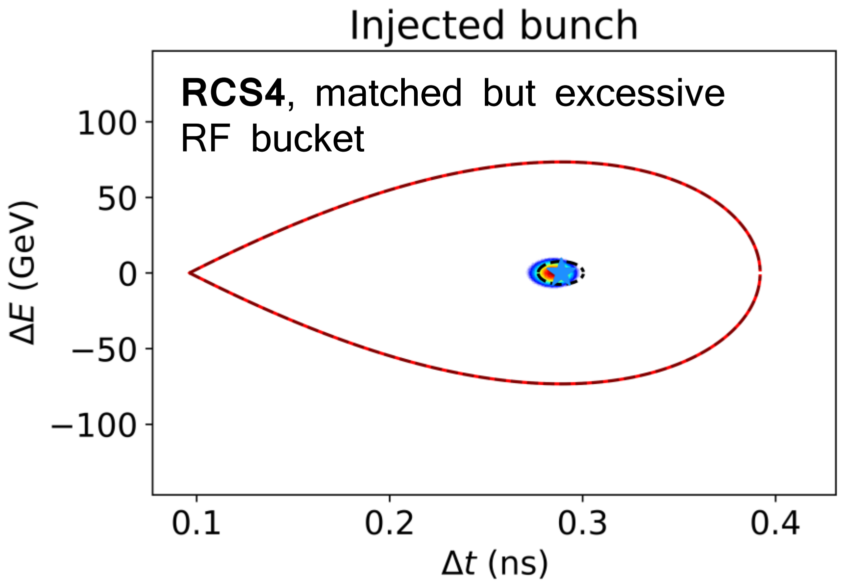
→ Study effect in BLonD with cavity voltage calculated by L. Thiele, see his presentation



Changes of the transition gamma

- The transition gamma was proposed to be changed:
  - RCS1: from 20 to 79 → **15 times smaller momentum compaction factor α_p**
  - RCS4: 8 times larger transition gamma, **62.5 times smaller α_p**
- Large effects on RF, RF bucket, beam dynamics, bunch length, etc.
- Probably strong mismatch in RCS1, extreme changes of the RF bucket in RCS4
- This also affects the transverse studies





Summary

- **The induced voltages of the counterrotating beams build up due to their relative phase offset of 0 ($2n\pi$)**

→ Careful placement/alignment of cavities required, as done for LEP (see paper, section 4.1)

- **Providing larger RF voltages seems to allow for beam loading compensation**
- **Modulation of the cavity voltage from the CR bunch under study**
- **Changes in the momentum compaction factor might have large consequences on the longitudinal and transverse design and will be topic of a dedicated meeting end of June**

Outlook

- CERN summer student from July to August (01/07-30/08):

  Longitudinal beam dynamics simulations for a hybrid RCS demonstrator facility

- Design for 0.1-3 GeV, assuming a fixed ramp rate of 3 kT/s

From 8th WP6.1 Meeting:

- Moderately-sized hybrid (e^-) RCS demonstrator to be constructed and commissioned from 2030 to 2033
- Several purposes:

➢ Test of hybrid RCSs and its beam dynamics

➢ Evaluate fast ramping of magnets

➢ Serve as an injector for an electron storage ring

→ Option to ramp only one half of the magnets and keep the others at a fixed field to simulate a hybrid scheme

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