Electron cloud instabilities at injection

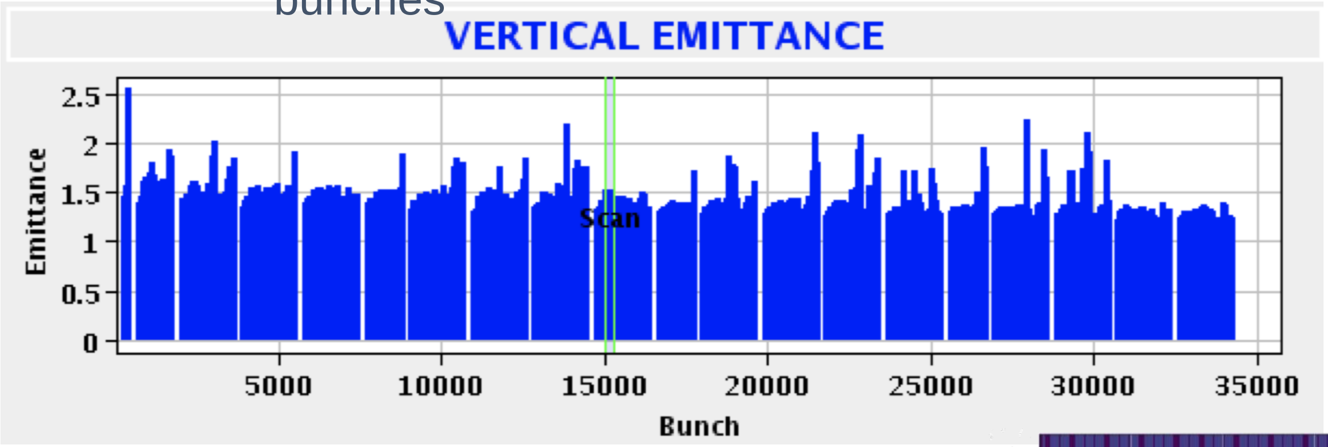
G. Iadarola, L. Mether, E. Métral, L. Sabato

Outline

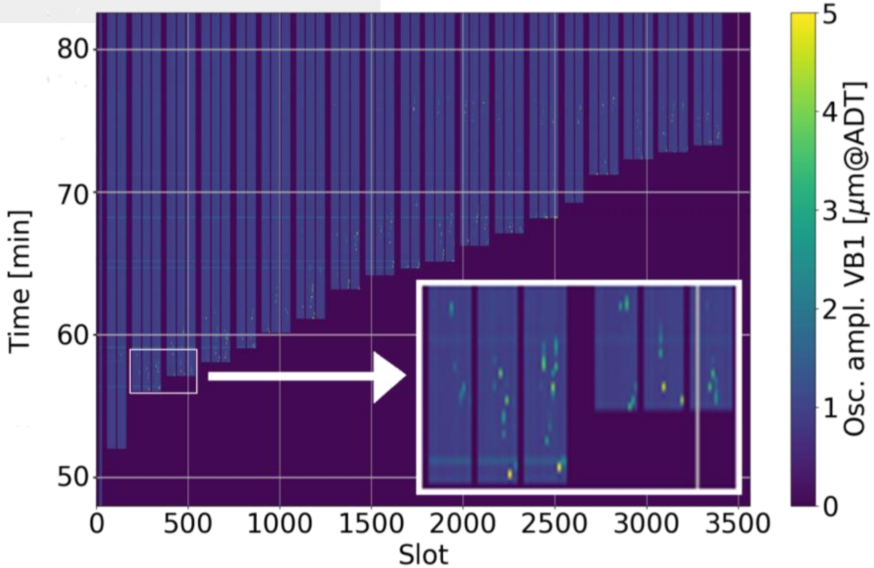
- **Introduction**
- **Instability dependence on the bunch intensity**
  - Dipole magnets
  - Quadrupole magnets
  - Experimental observations with trains of 12b
- **Effect of the transverse emittance**
- **Conclusions and final remarks**

In Run 2 **weak instabilities were often taking place at injection energy**:

- Well contained (but never fully suppressed) using high chromaticity (15-20) and high octupole current (~50A)
- Impact on performance was very modest as the blow-up was relatively small (w.r.t global blow-up in the ramp) and affecting a small number of bunches



Observed instabilities have a **single-bunch nature**



For more info: X. Buffat, "Transverse Instabilities", Evian19
L. Sabato and G. Iadarola: "Single bunch instabilities at injection energy", e-cloud meeting #71

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e-cloud in the main dipoles – single bunch instabilities

In the main dipoles, when the bunch intensity is increased, the **electron density at the beam location is strongly suppressed**

→ this **strongly mitigates single-bunch instabilities**

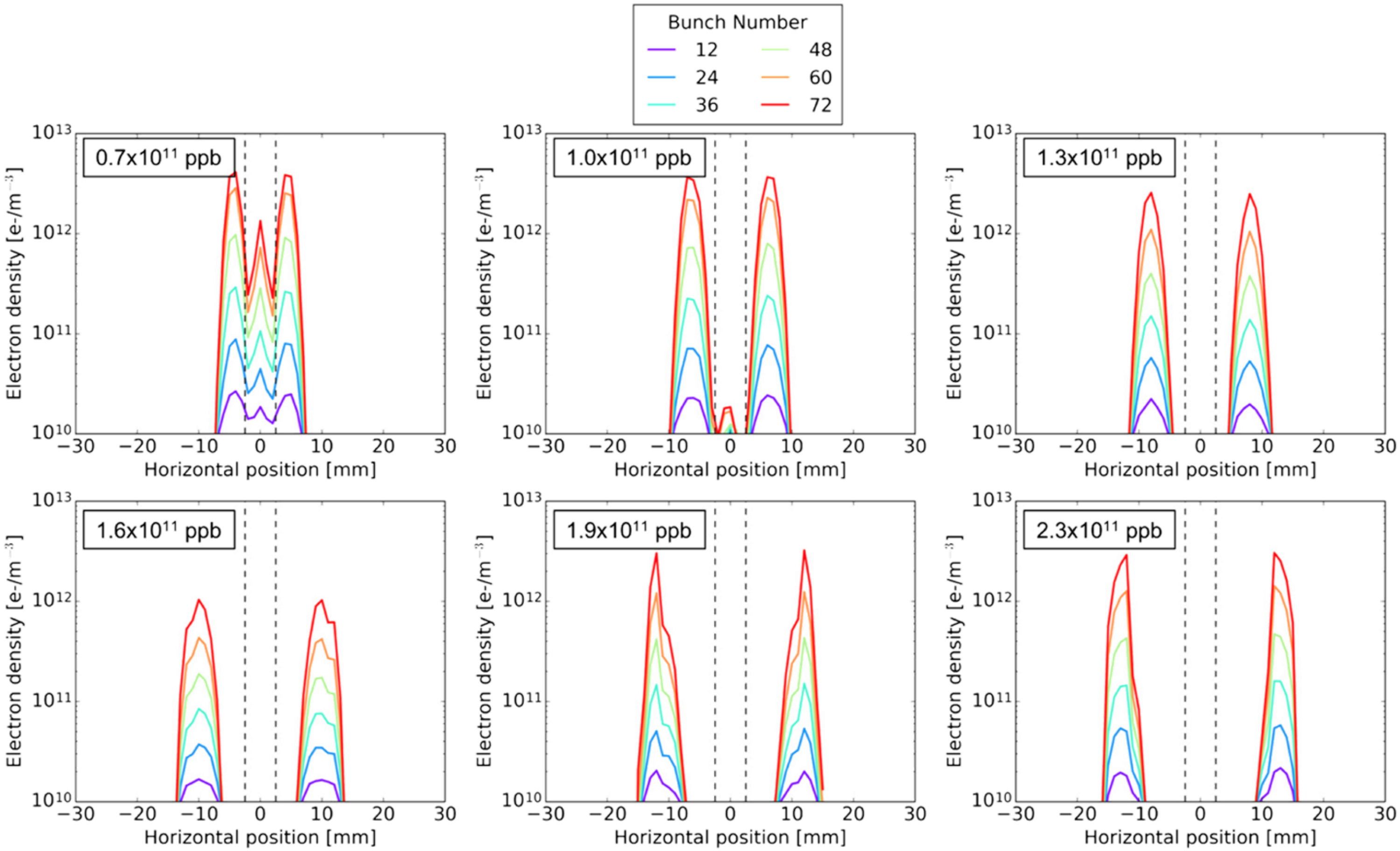

FIG. 8. Horizontal electron density profile in a dipole magnet for different bunch intensities. These snapshots have been taken for selected bunches along the bunch train (as labeled). The vertical dashed lines delimit a distance of ±2.5 mm from the beam position ($x = 0$).

For more info: https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.21.061002

e-cloud in the main dipoles – single bunch instabilities

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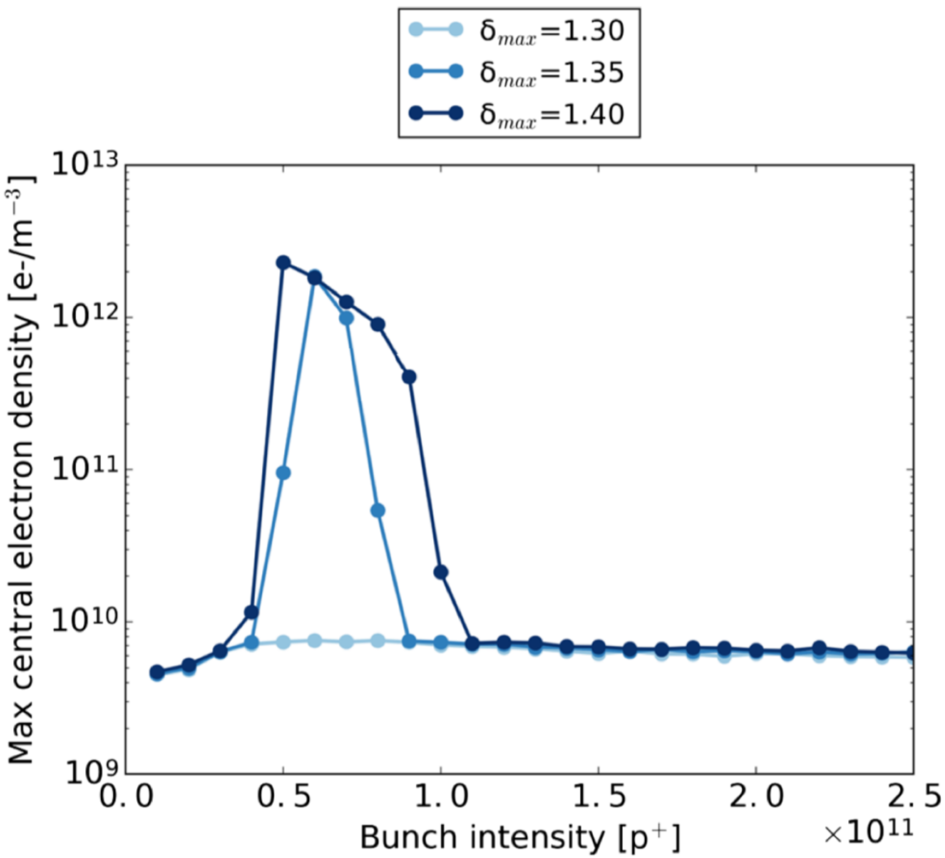
The **critical intensity range is 0.5-1.0 x 10^{11} p/bunch** as observed during stable beams in 2016 (instability disappeared later, probably due to scrubbing)



2016 instabilities

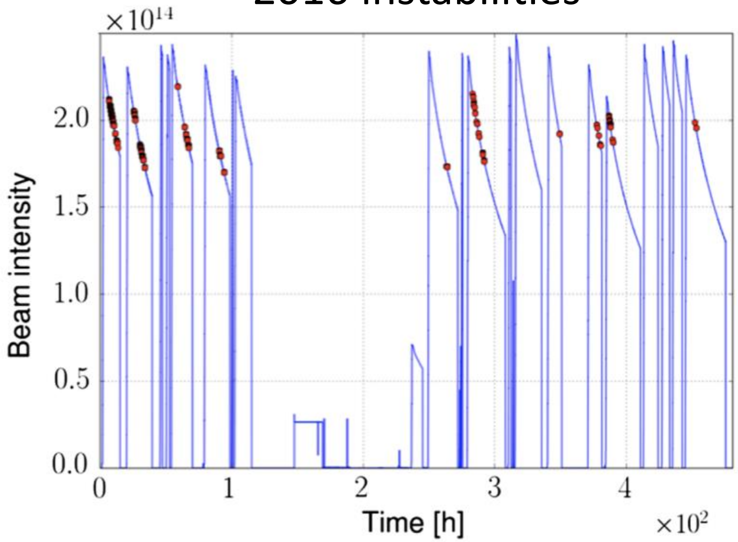


FIG. 4. Beam intensity evolution over time for several physics fills. The red points indicate when emittance blowup was observed in each fill. Most of the instabilities occurred in a range of beam intensities which corresponds to bunch intensities between 1×10^{11} and 0.7×10^{11} ppb.

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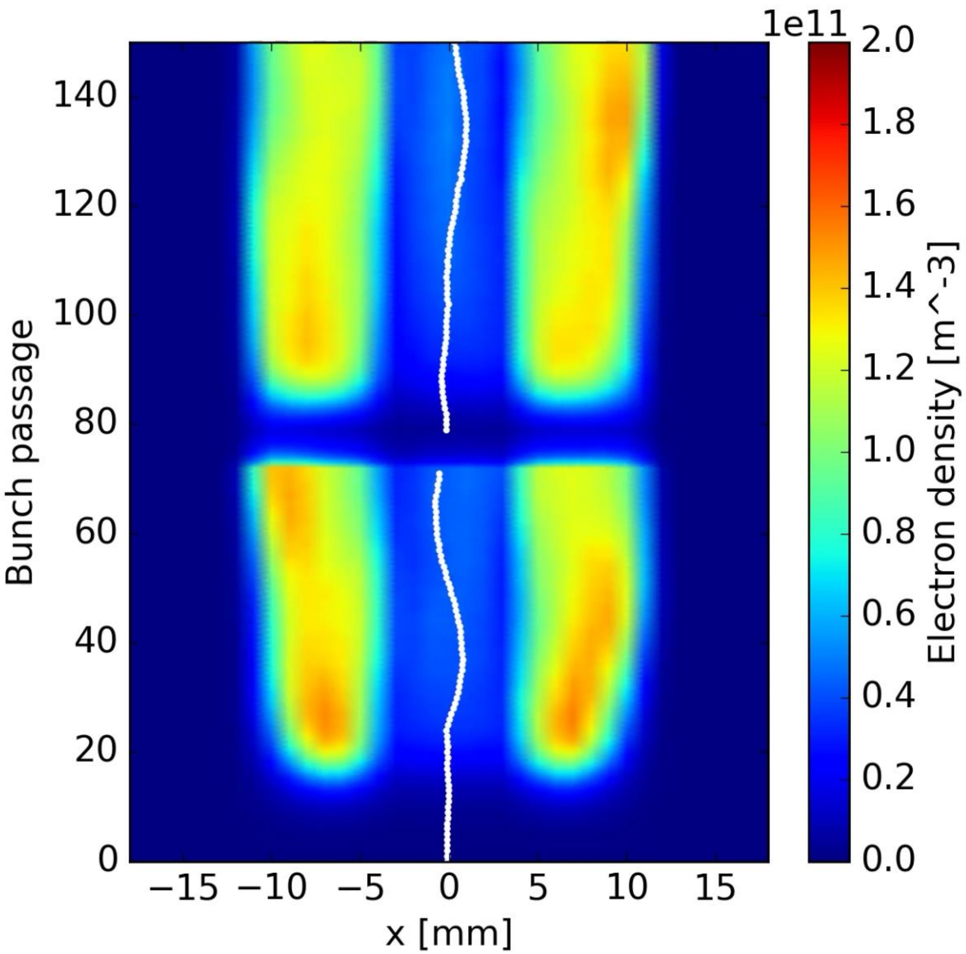
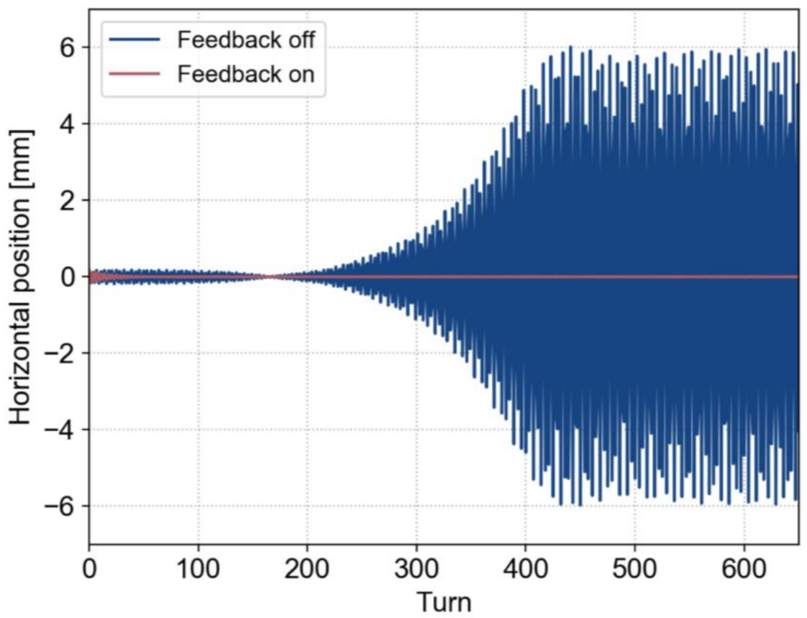
e-cloud in the main dipoles – coupled bunch instabilities

Electrons far from the center can drive **coupled-bunch instabilities**

- Nevertheless, these are effectively suppressed by the ADT





For more info:

L. Mether, "Electron cloud stability: couopled bunch effects", presentation at [HL-LHC WP2 meeting]() 10 Dec 2019

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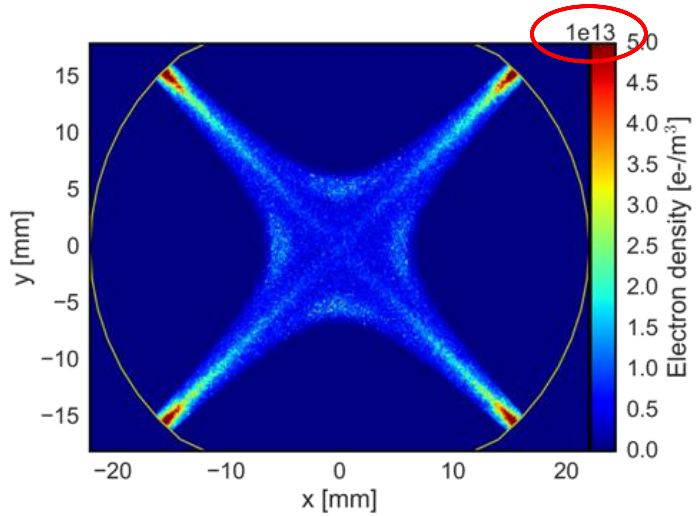
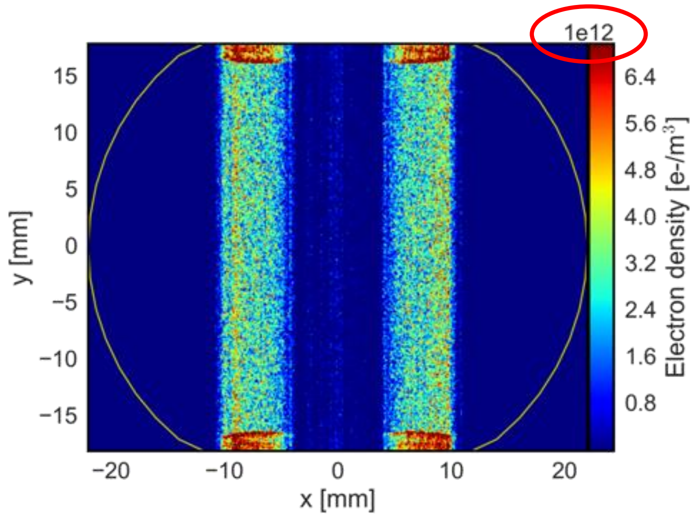
Quadrupoles

Electrons in the **arc quadrupoles** are expected to be the **strongest source for instabilities at 450 GeV**, as the quadrupolar field concentrates a large electron density around the beam location

→ Studied **extensively with macroparticle simulations** over the last years

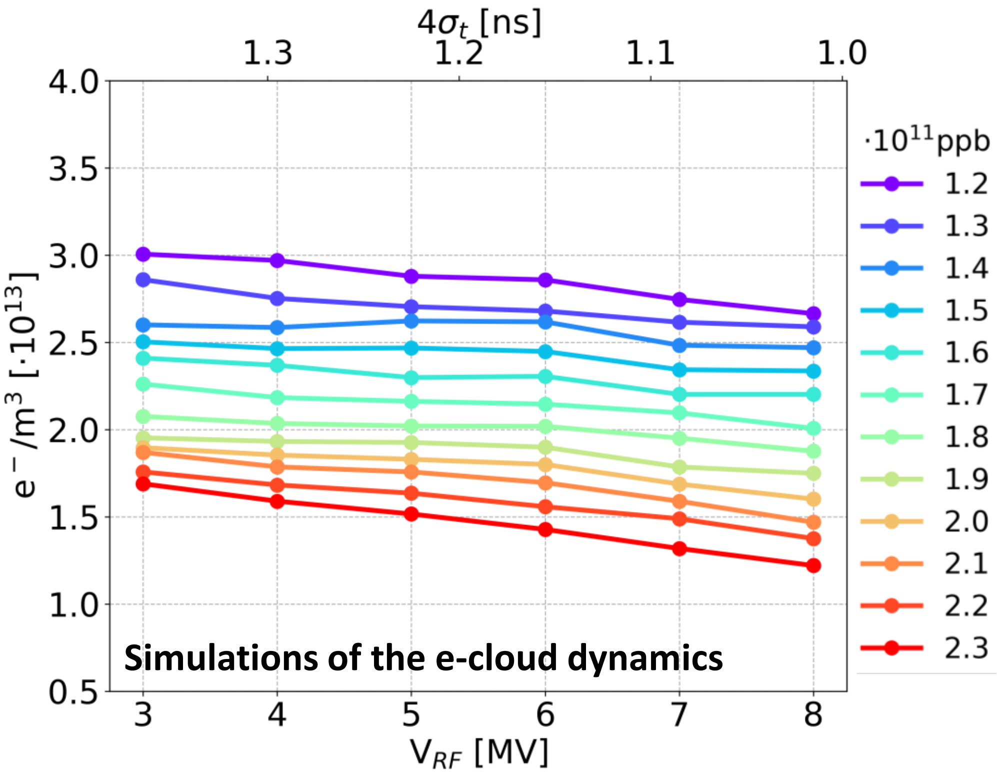


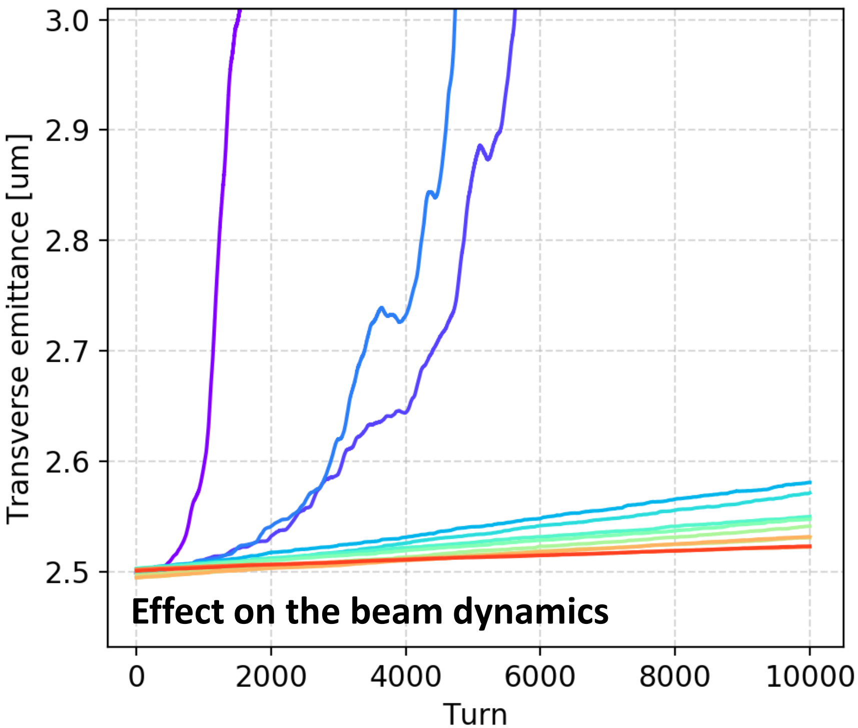


For more info:

L. Sabato, "Electron cloud stability: Single bunch effects", presentation at [HL-LHC WP2 meeting] 10 Dec 2019

- Fortunately, also in the case of the quadrupoles, the **increase in bunch intensity has the beneficial effect**
  - The **electron density is reduced**
  - The **instability is mitigated**





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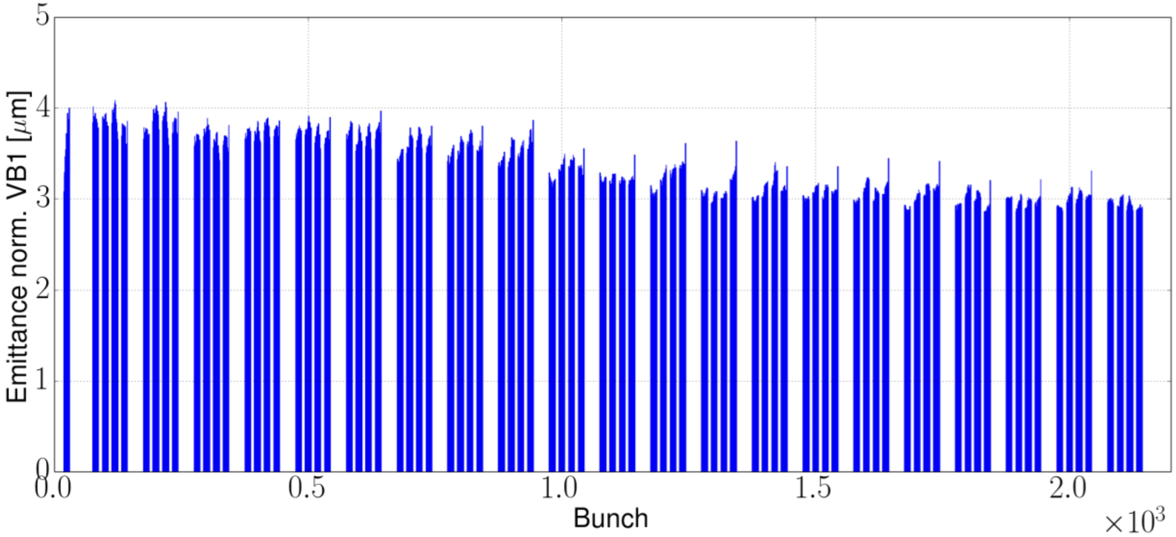
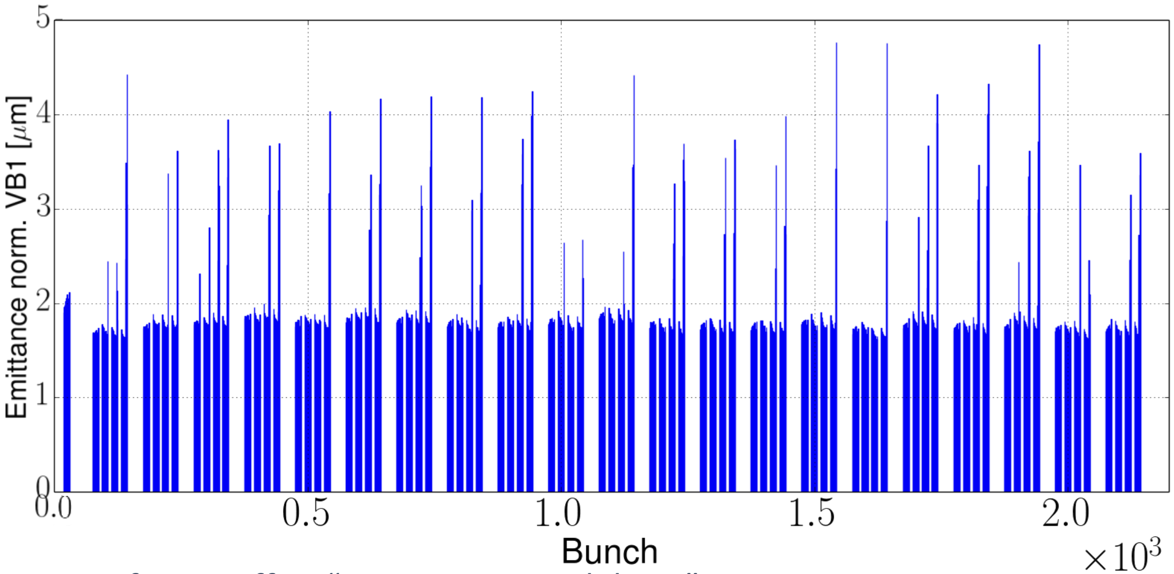
Experimental observations with trains of 12b

These expectations are **consistent with first tests with high-intensity 25ns beams** (trains of 12b) in 2018 MD



1.8 x 10^{11} p/bunch
Stable with I_{oct} = 0 A



0.7 x 10^{11} p/bunch
Unstable with I_{oct} = 56 A

For more info: X. Buffat, "Transverse Instabilities", Evian19

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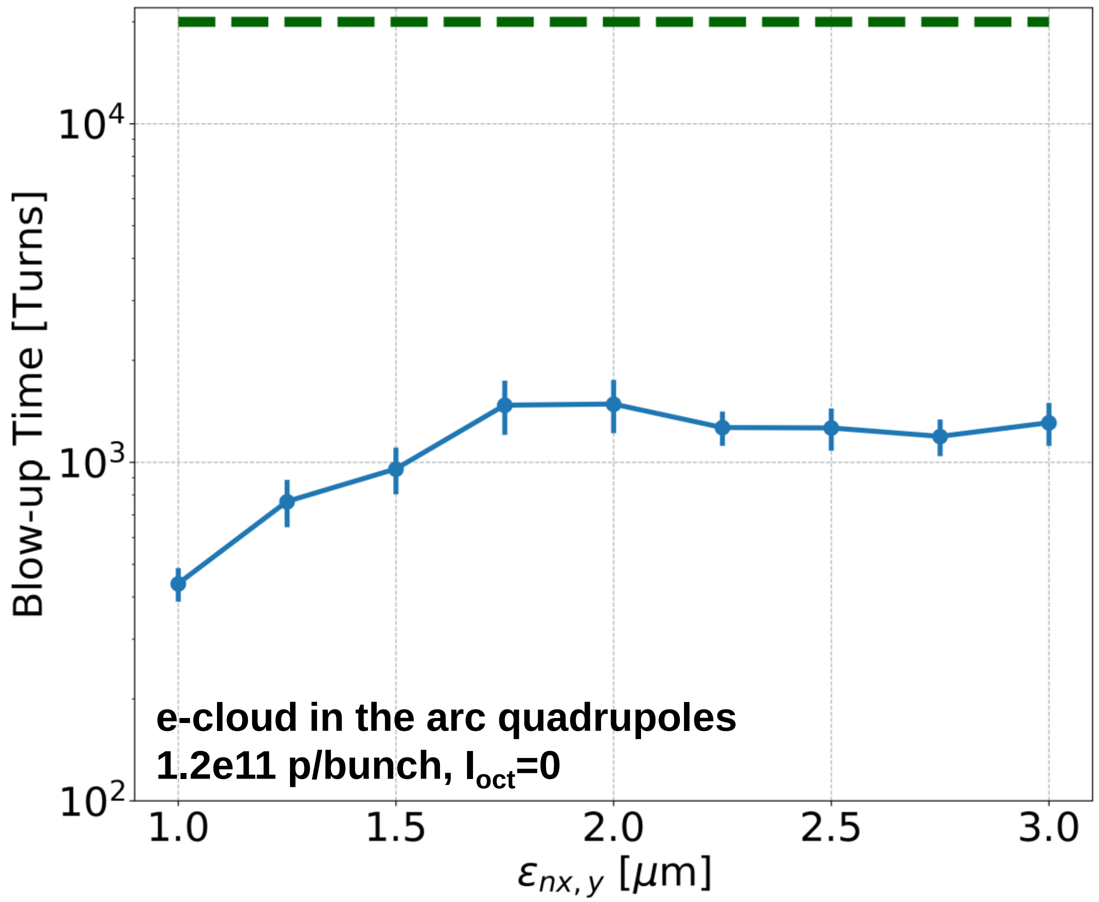
Effect of the transverse emittance

For emittances larger than 1.8 μm the instability risetime is practically **independent of the beam size**

- Nevertheless the **octupoles strength needs to be adapted** to keep the same tune spread (no expected effect on lifetime)
  - This was already **done in 2016** for the transition to the BCMS beams



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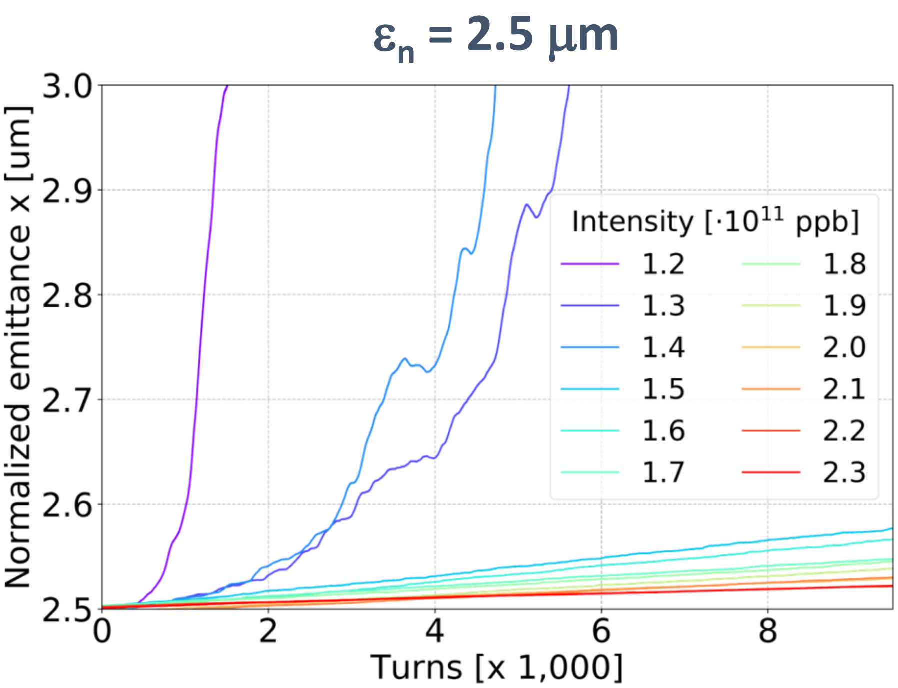
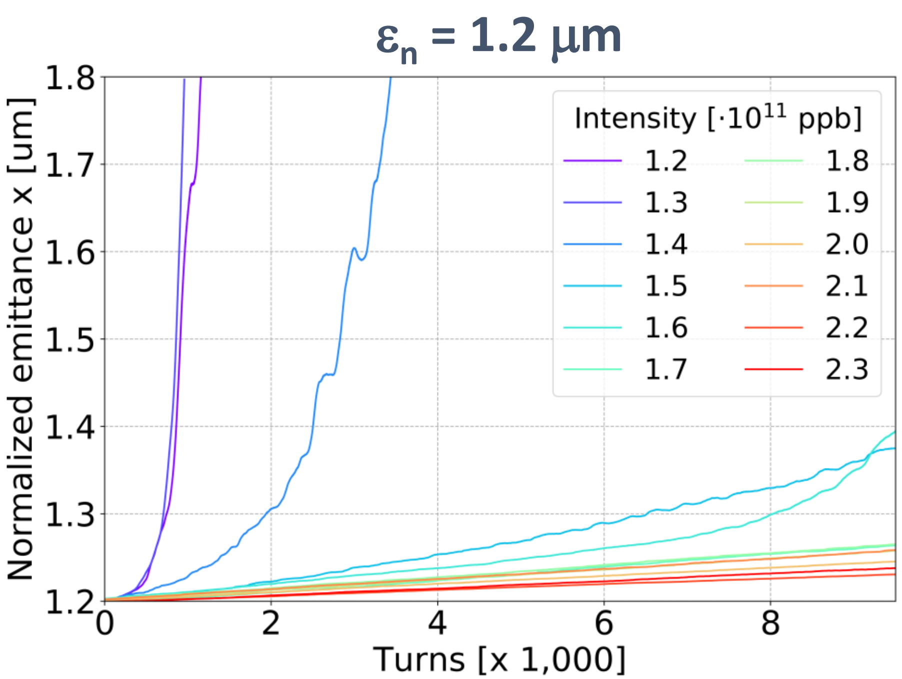
Effect of the transverse emittance

Also for small emittances, the **increase in bunch intensity has a beneficial effect**





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Conclusions and final remarks

The **increase in bunch intensity** is expected to have a **positive impact on the beam stability** over the full range from 1.2 x 10^{11} p/bunch to 2.3 x 10^{11} p/bunch.

After scrubbing, operation in Run 2 with **1.2 x 10^{11} p/bunch** required:

- **ADT** damping time: **<20 turns** (large bandwidth settings)
- **Chromaticity**: **15-20** units
- **Octupoles**: **50 A** (for emittances of ~1.8 μm)
  - **Octupole current needed to be adapted** to follow the change in emittance to keep constant tune spreads

- Taking into account that in the HL-LHC era we will have to go through reconditioning stages after each Long Shutdown, we **propose to use these settings for the HL-LHC operational scenarios** (practically already done), knowing that some optimization might be possible later in the run
- During scrubbing runs and following intensity ramp-up **larger Q'/octupoles might be needed to control instabilities** (possibly at the expense of lifetime)
  - For this purpose itoptics choices should **not degrade the DA w.r.t. to Run 2**

    → this motivated recent checks done by Riccardo and Fabien