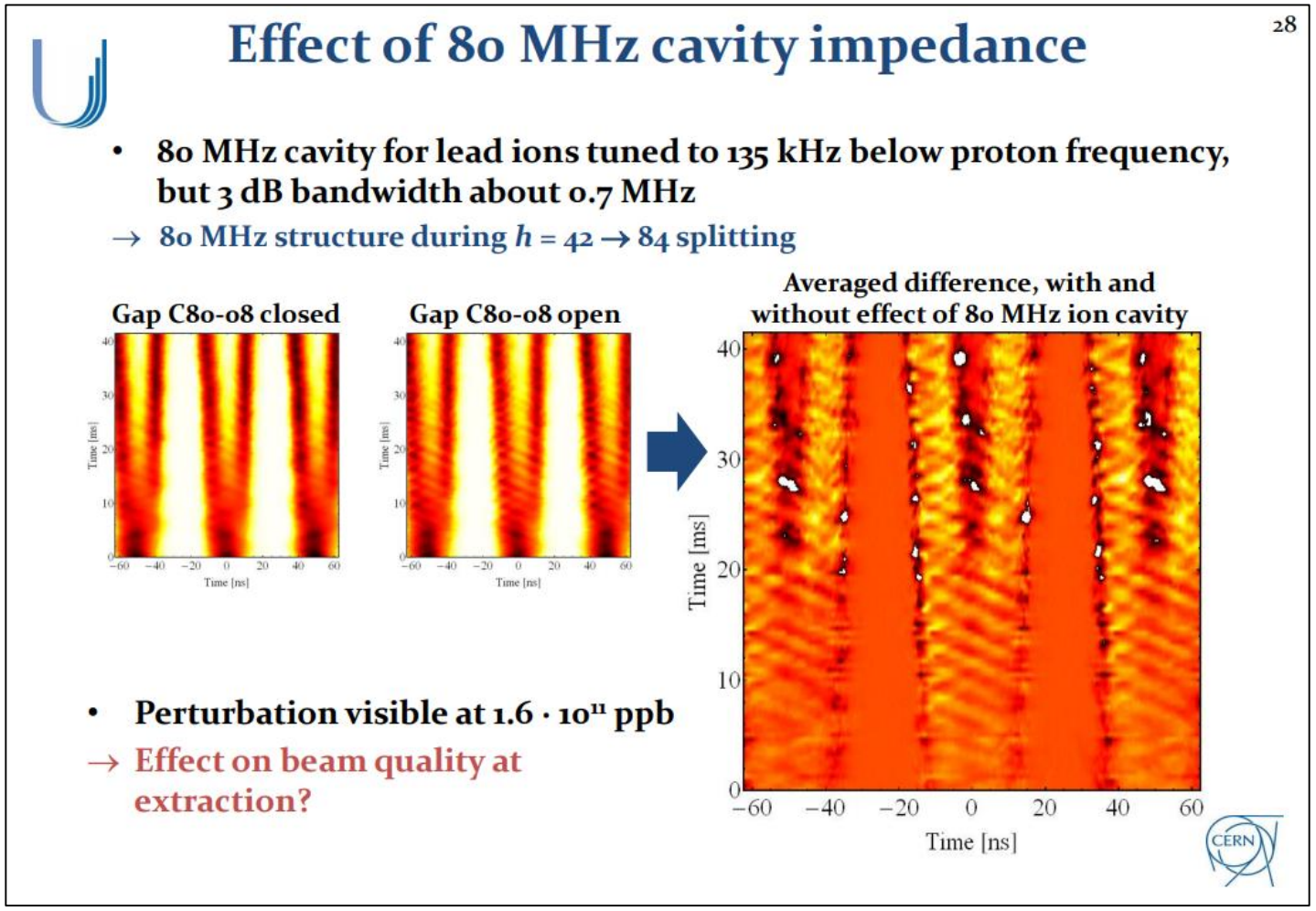
PS 80 MHz cavity impedance measurements (beam based)

A. Lasheen, H. Damerau

Introduction and motivation



- 3x80 MHz cavities available in the PS
- 2 used for proton operation (gaps always open) + 1 used for ion operation (gap opened only for ion operation)

https://indico.cern.ch/event/603263/ H. Damerau, MSWG 03/02/17

Introduction and motivation

80 MHz cavity impedance

29

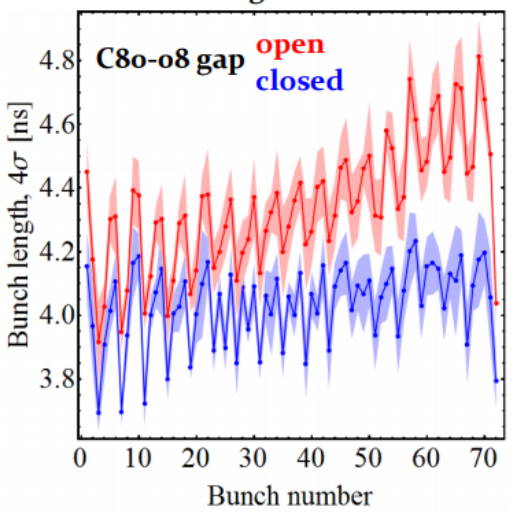
Emittance at arrival on flat-top (4 final bunches)

Cavities with gap open	ε_{RMS} [eVs]
C40-78, C80-88, C80-89	0.231
C40-78, C80-88, C80-89 and C80-08 (at ion frequency)	0.238

Average bunch length at extraction

Cavities with gap open	$4\sigma_{Gauss}$ [ns]
C40-78, C80-88, C80-89	4.03
C40-78, C80-88, C80-89 and C80-08 (ion frequency)	4.34

Bunch length at extraction



http://cds.cern.ch/record/1141522/files/AB-Note-2008-052-MD.pdf

→ **Minor emittance blow-up at arrival on flat-top, but**

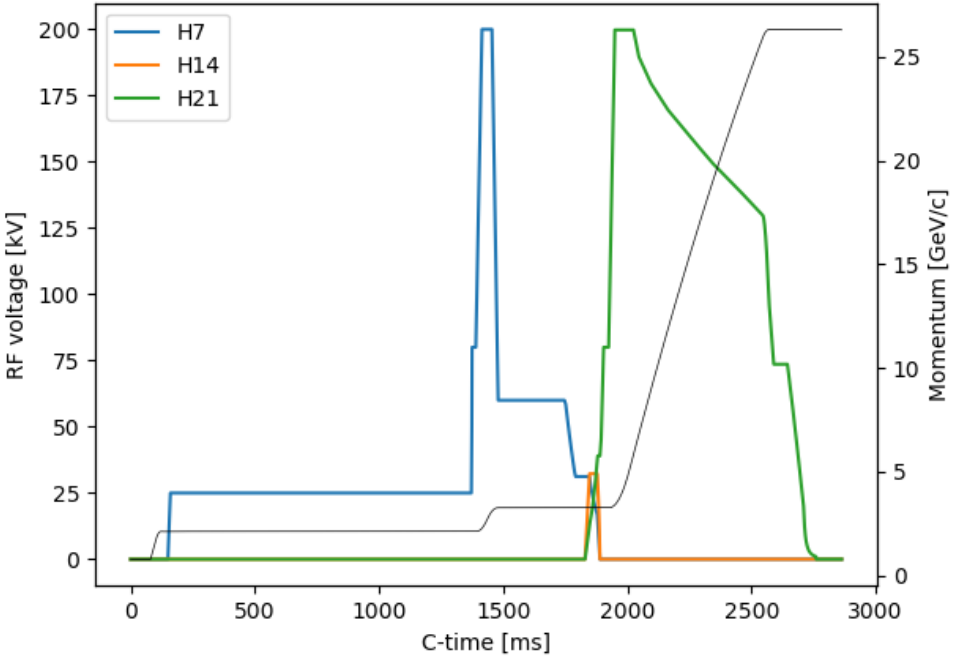
→ **~0.3 ns longer bunches due to impedance of additional 80 MHz cavity**

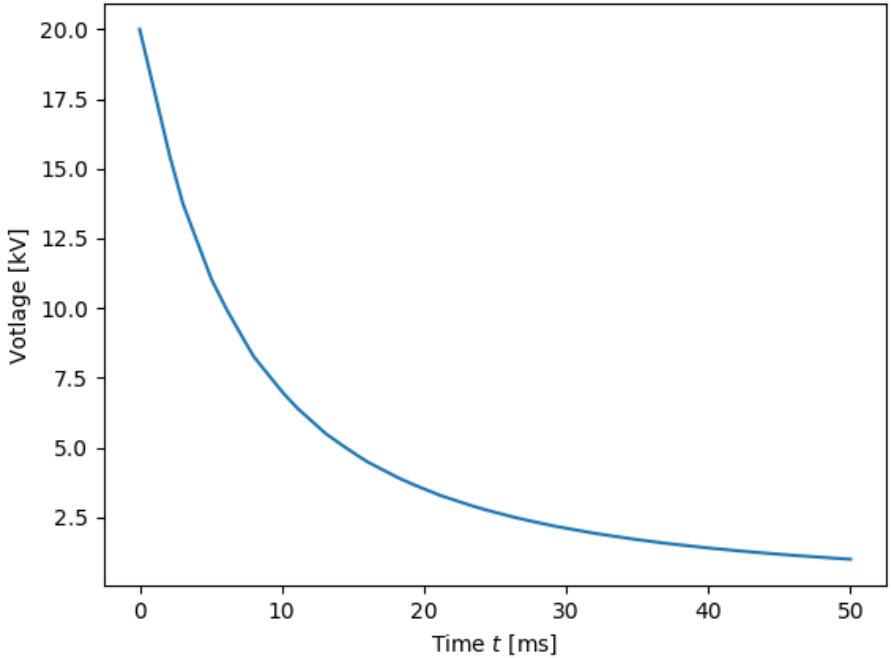
→ **Expect improvement with new multi-harmonic feedbacks**

- For large intensity, the longitudinal emittance blow-up is critical for transfer to the SPS (large losses)
- It is necessary to have a reliable beam coupling impedance model for the 80 MHz cavities, information about the impedance can be obtained from beam based measurements

https://indico.cern.ch/event/603263/ H. Damerau, MSWG 03/02/17

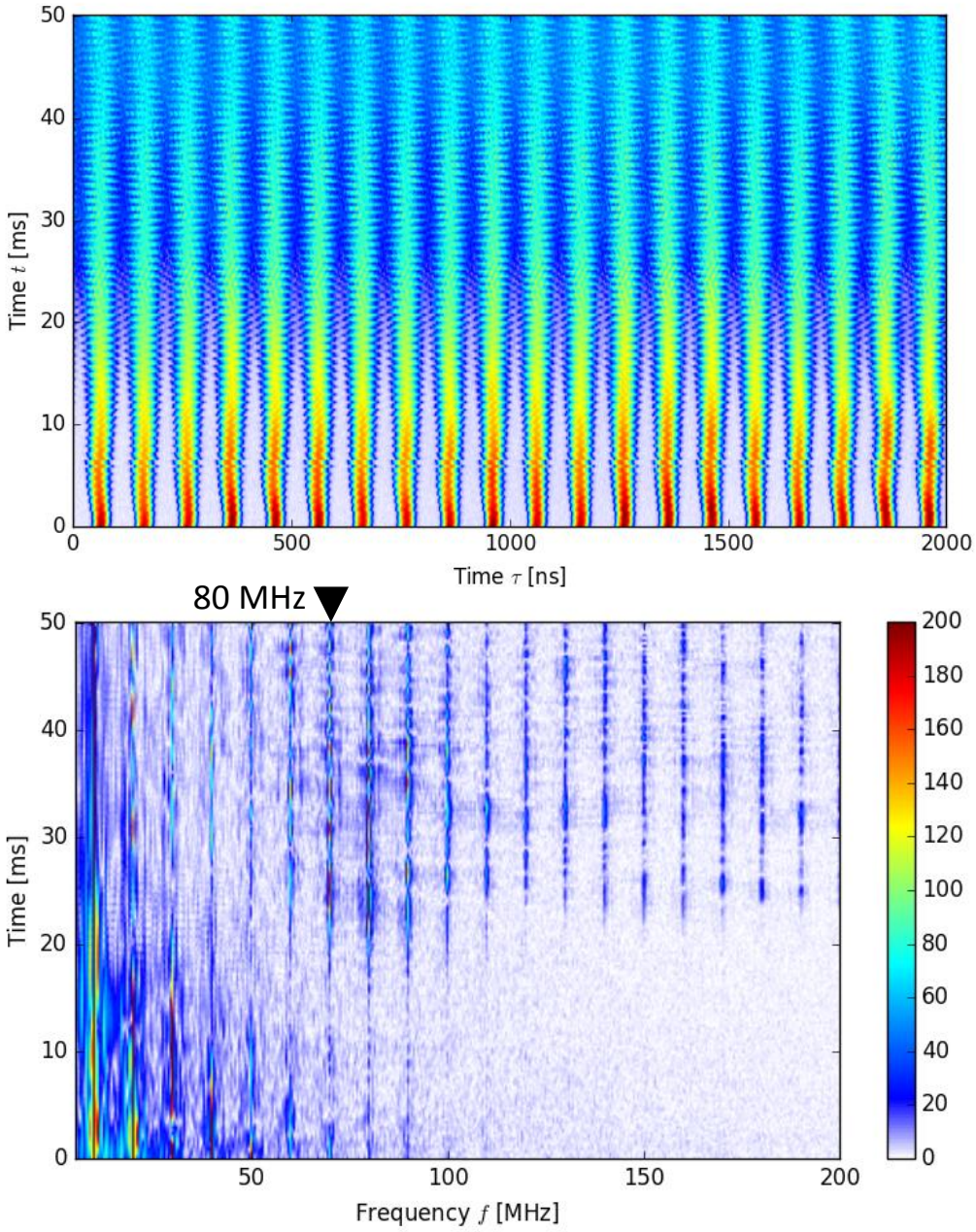
Setup





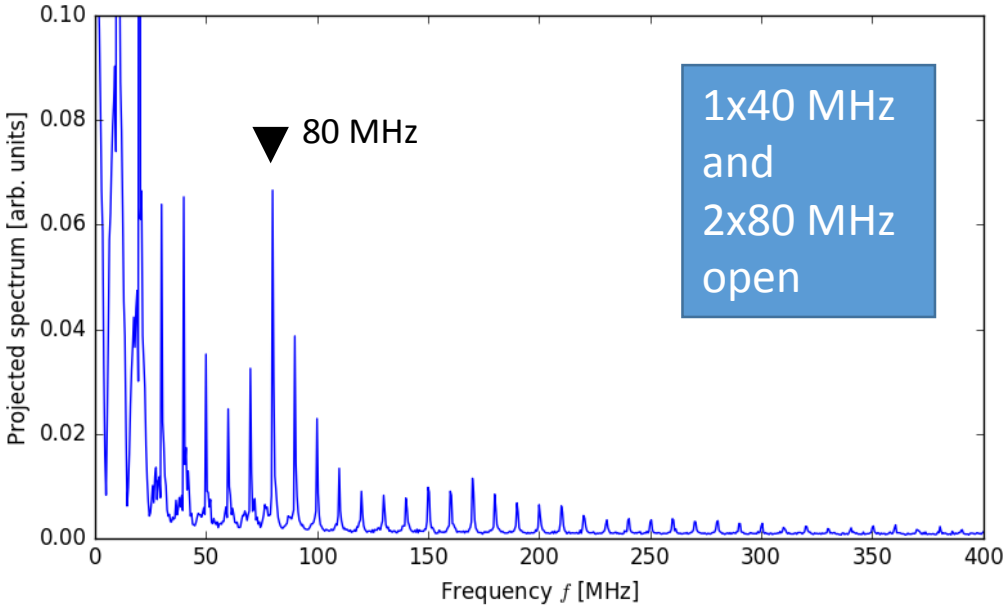
- Measurements done at 26 GeV/c (nominal LHC cycle)
- RF voltage of 10 MHz cavities isoadiabatically decreased to 1 kV in h=21 (then completely shut)
- The beam profile modulation happens in the time frame C_{time}= 2710-2760 ms where the RF voltage is reduced from 20 kV to ~ 2 kV in h=21 with a single 10MHz cavity

Beam profile modulation at 80 MHz

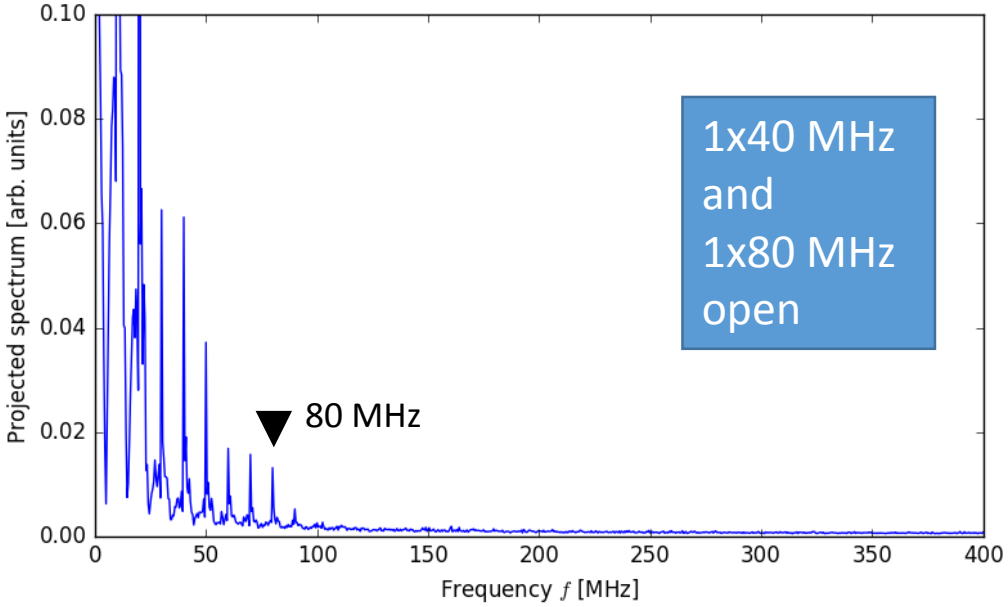


- Modulation starting around t = 25 ms, if at least two 80 MHz cavity gaps are open (C80-08 and C80-88 in this case)

Projected bunch spectrum

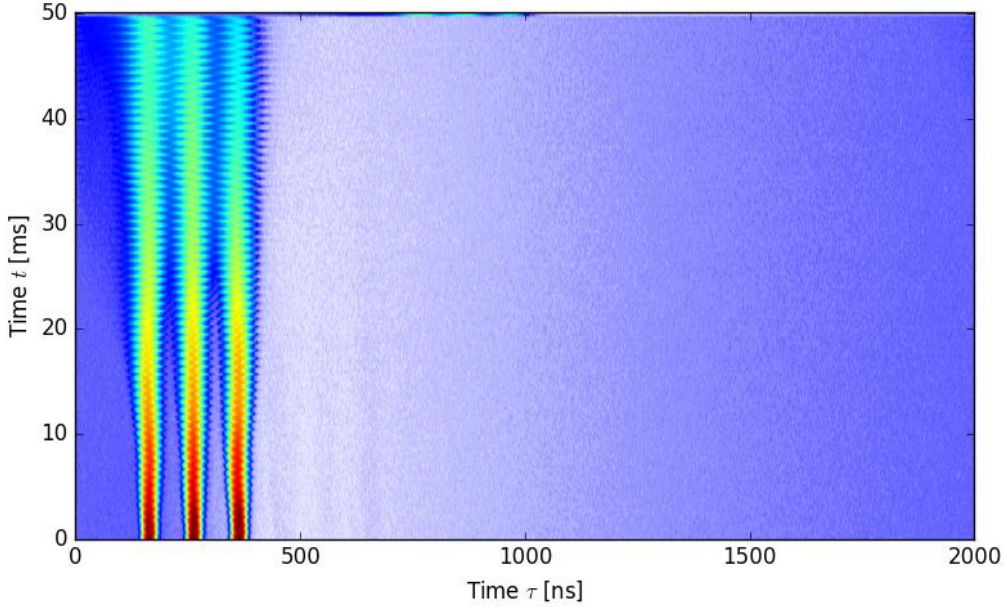


- The projected spectrum is the maximum spectral components at each frequency during the acquisition (50 ms)

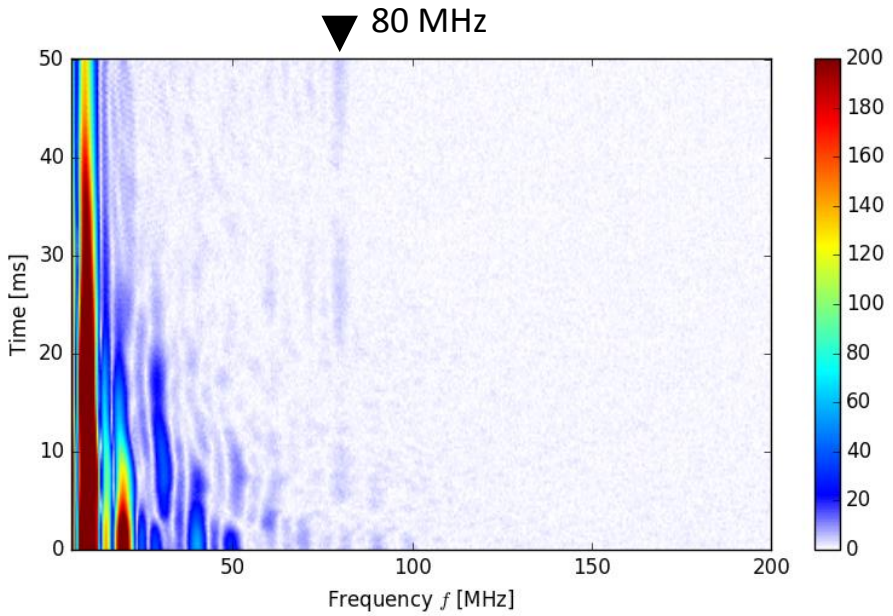


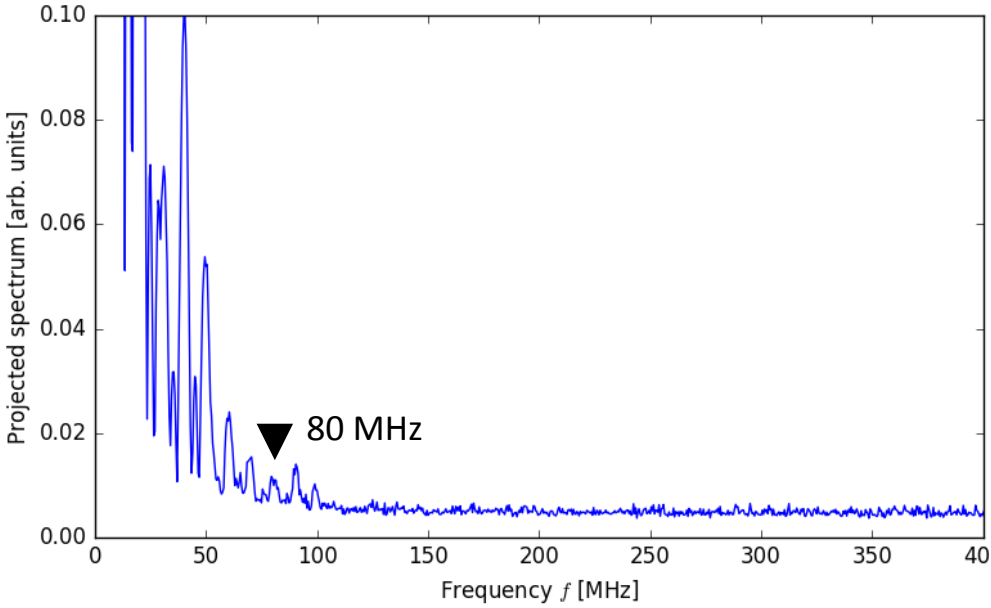
- Presence of the peak at 80 MHz when 2x80 MHz gaps are open vs. only 1x80 MHz

3 bunches

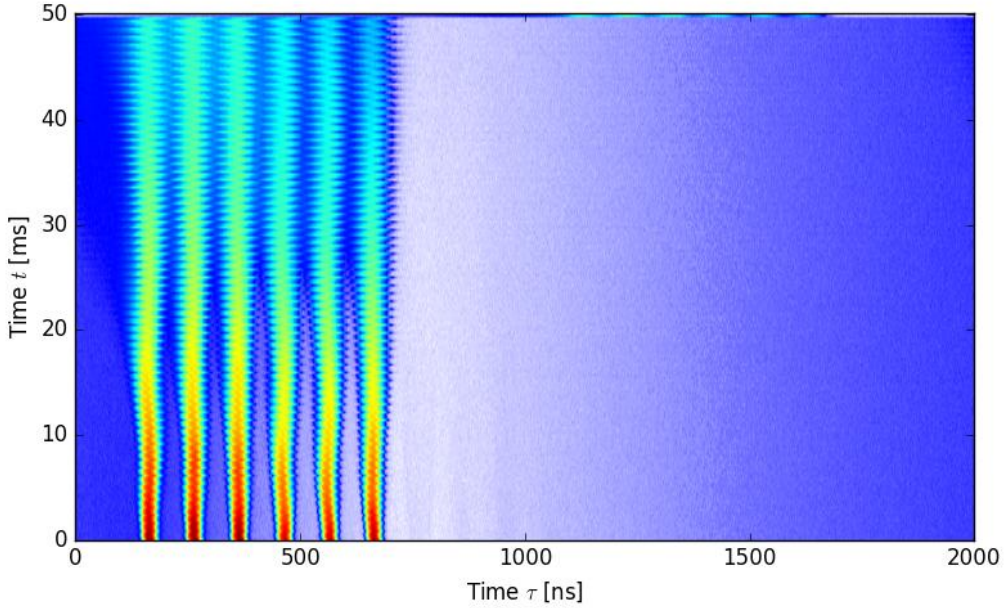


- Scanned the number of bunches from 3 to 21

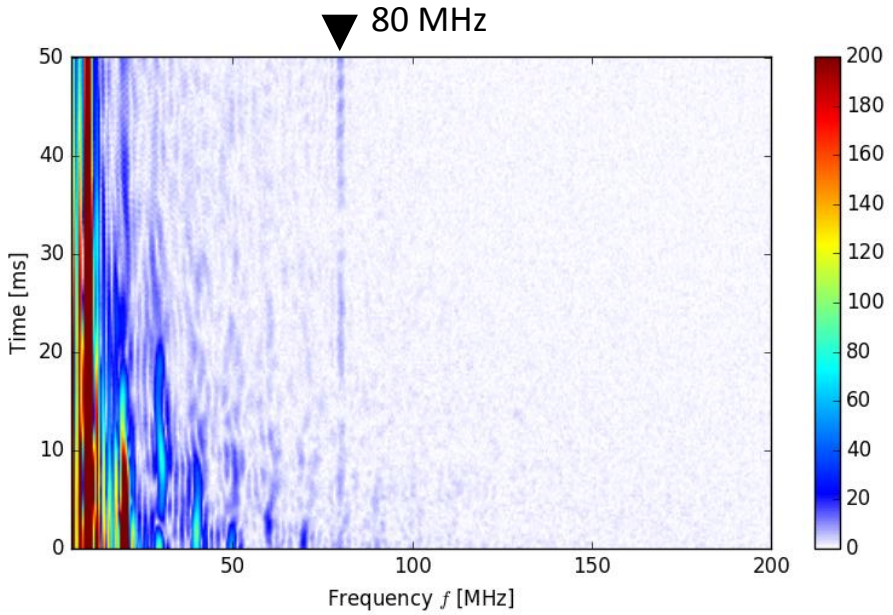


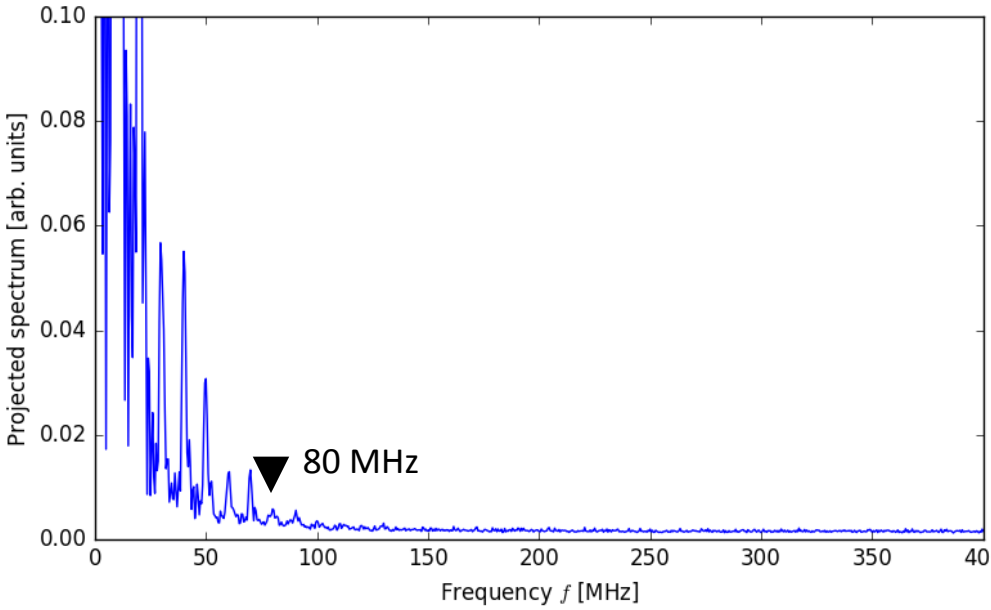


6 bunches

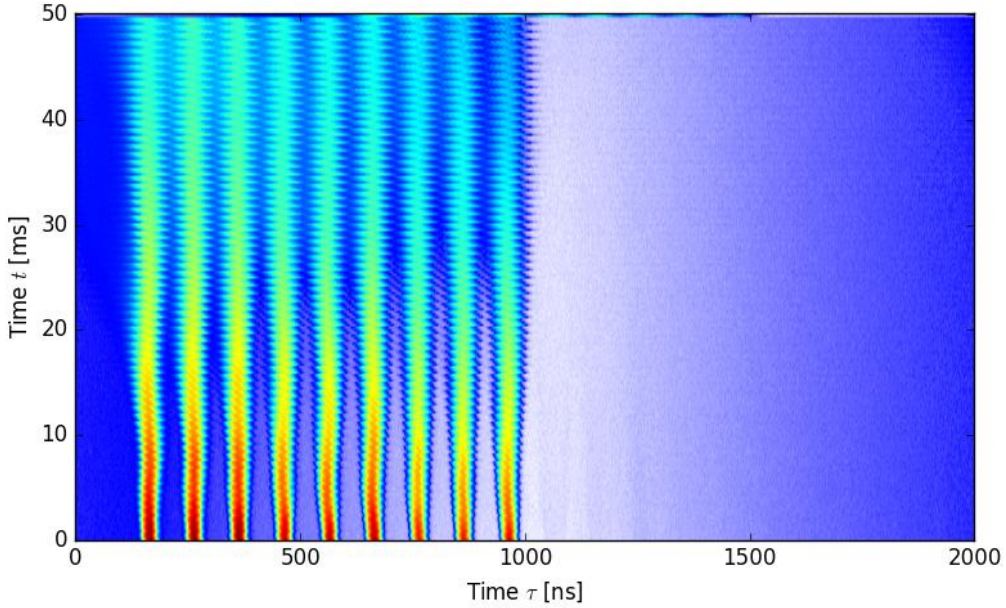


- Scanned the number of bunches from 3 to 21

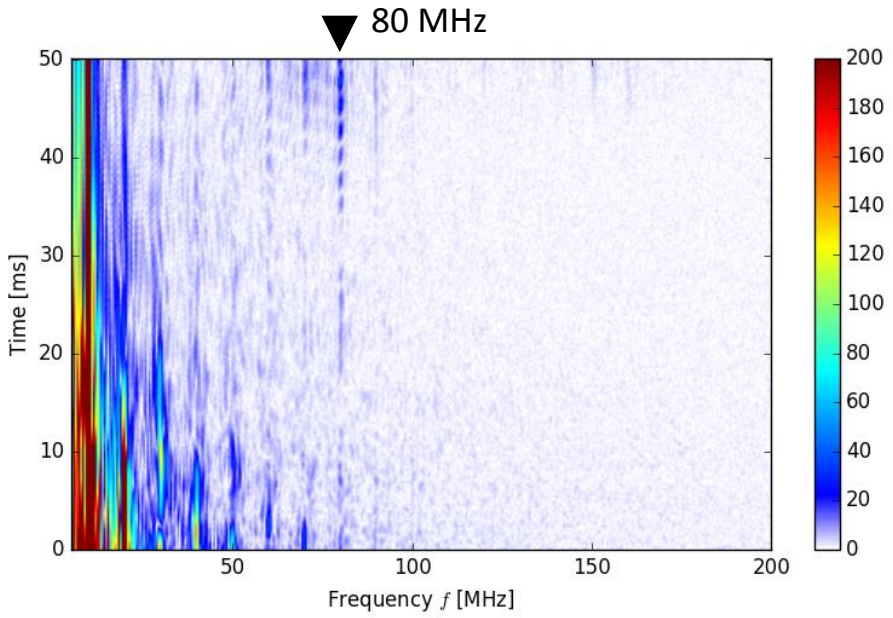


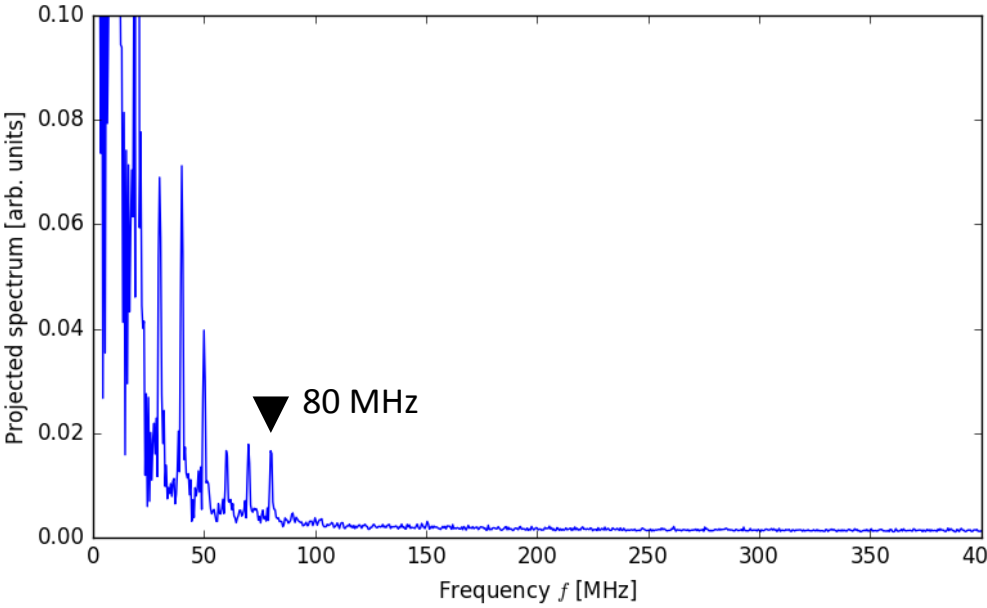


9 bunches

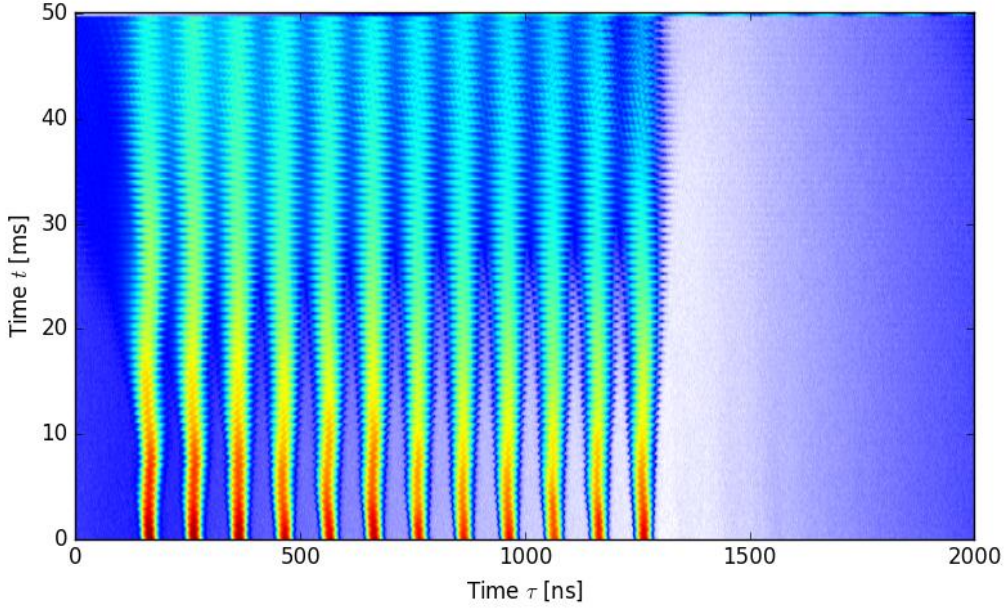


- The peak starts to be visible for 9+ bunches

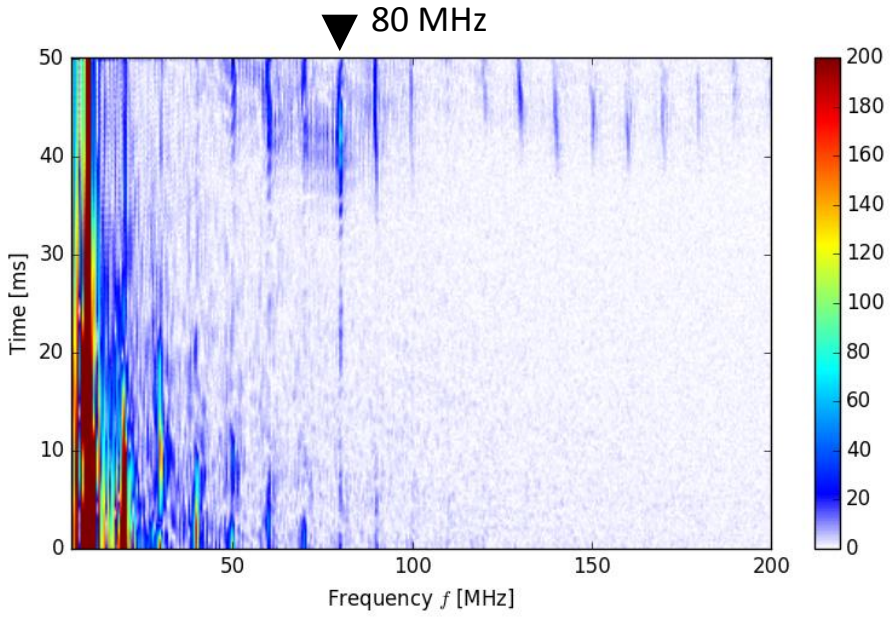


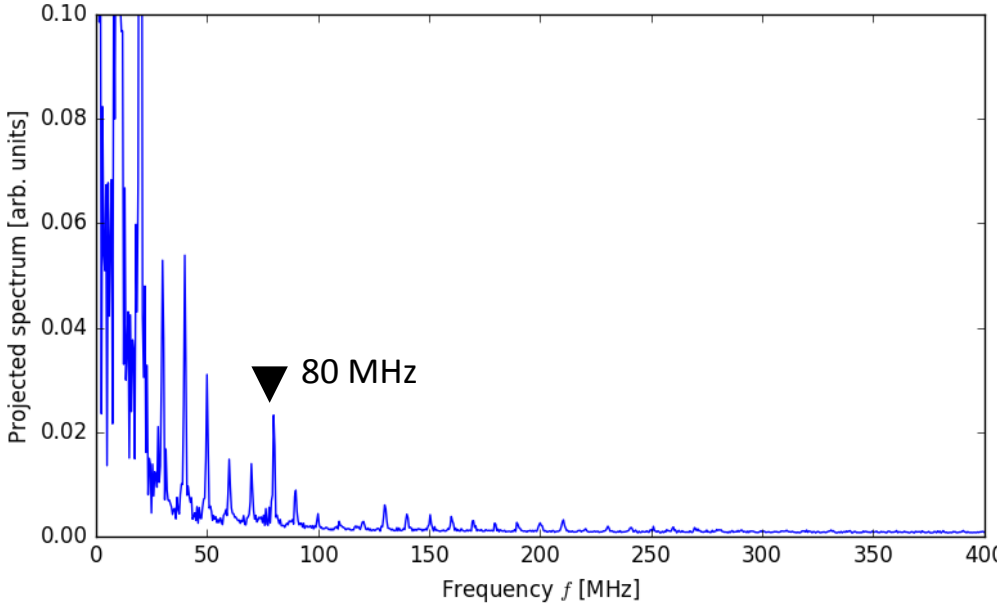


12 bunches

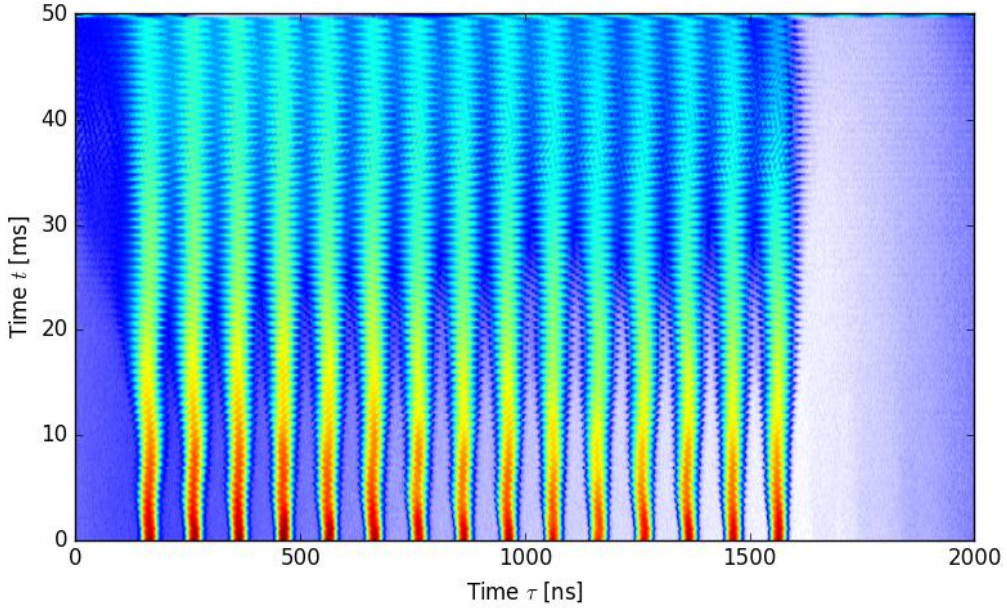


- The peak increases as a function of the number of bunch

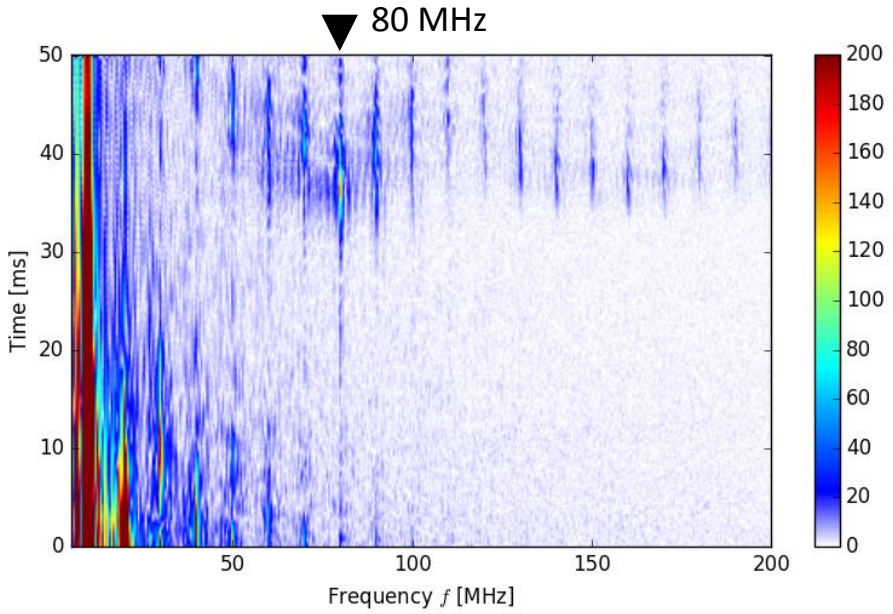


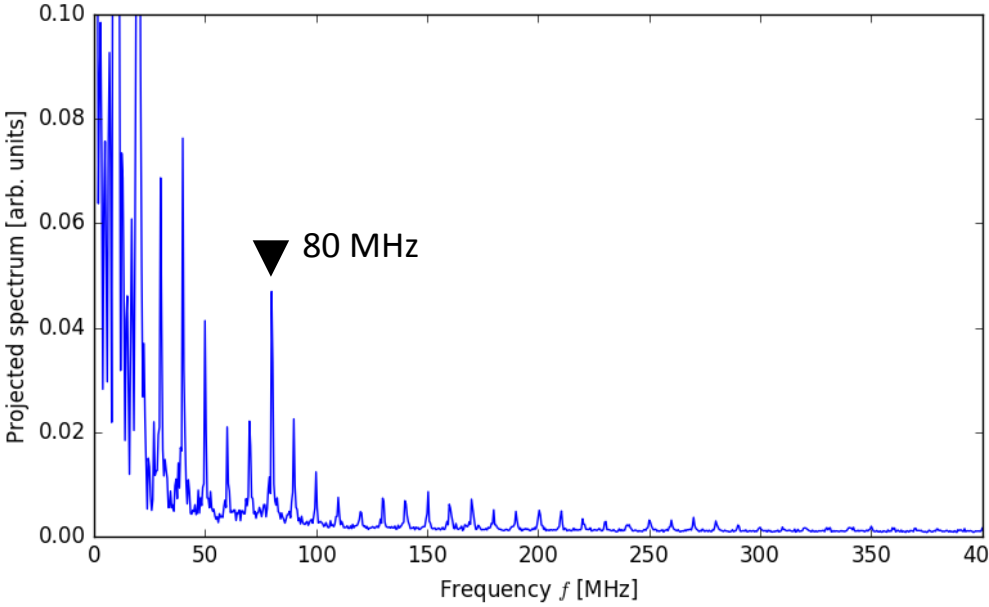


15 bunches

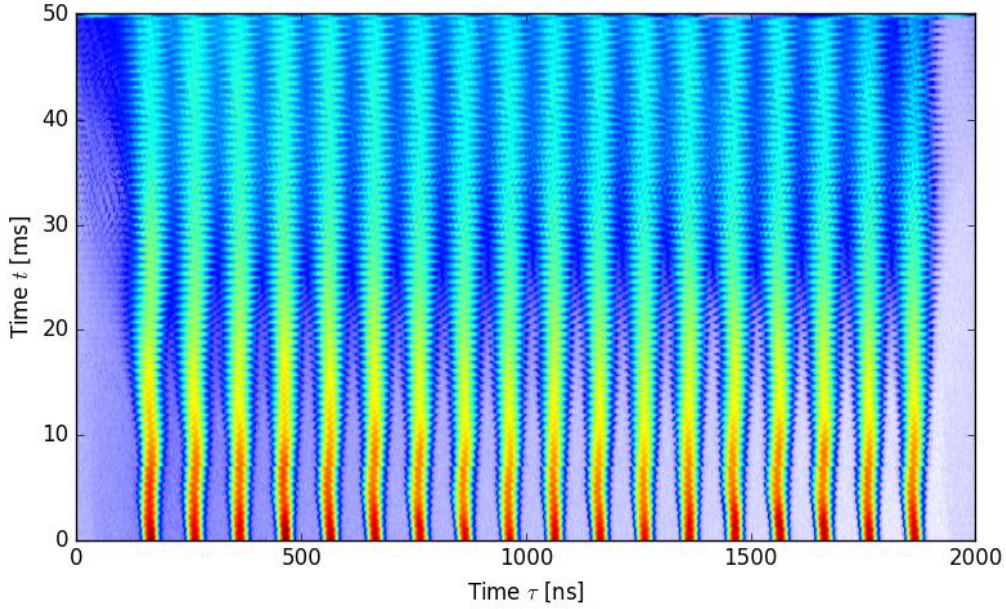


- The peak increases as a function of the number of bunch

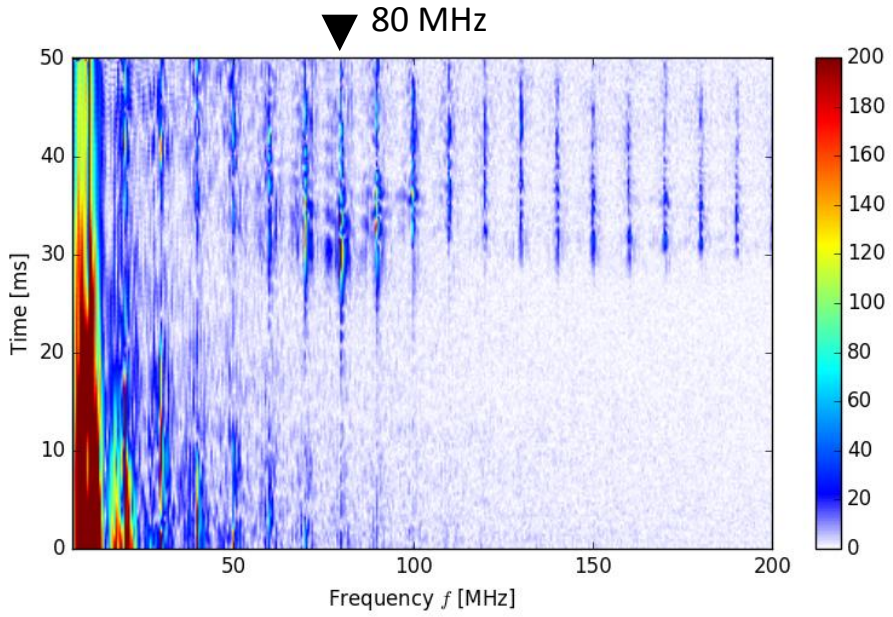


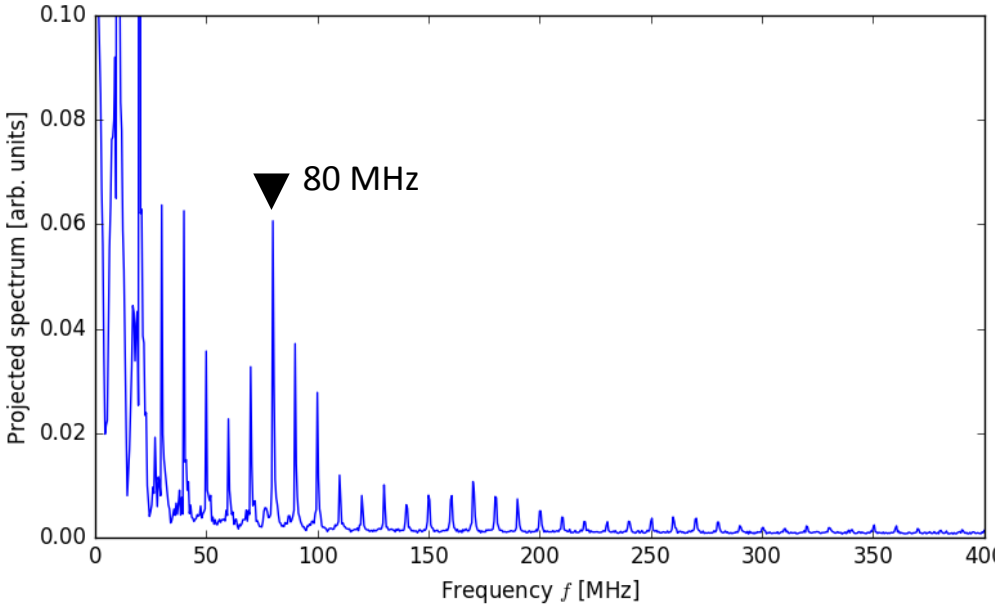


18 bunches

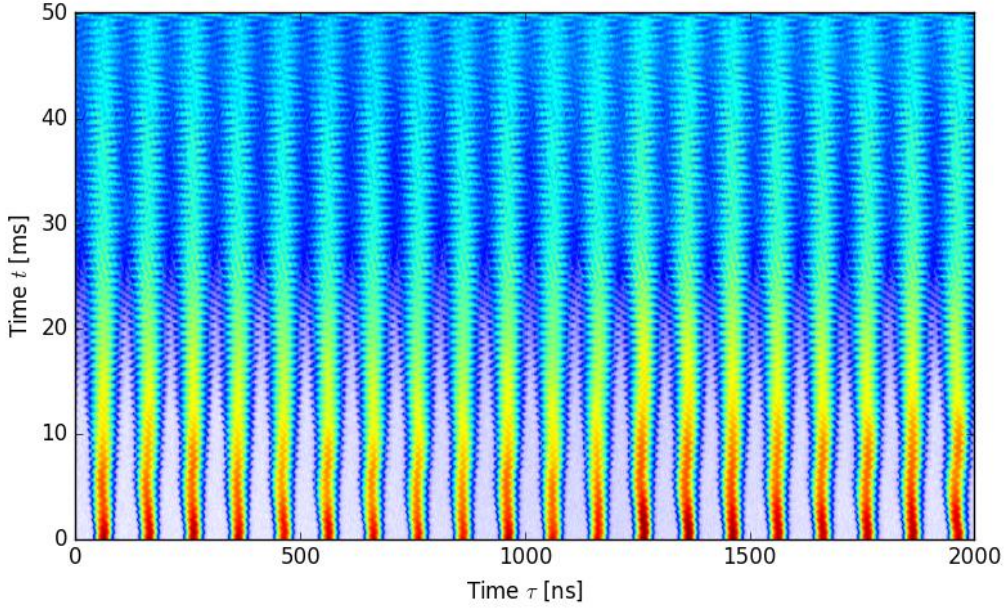


- The peak increases as a function of the number of bunch

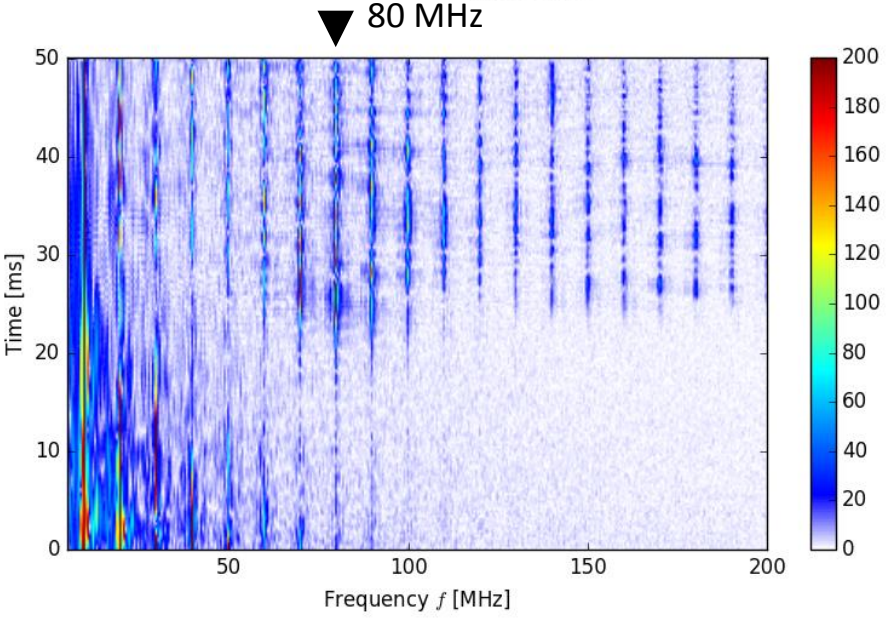


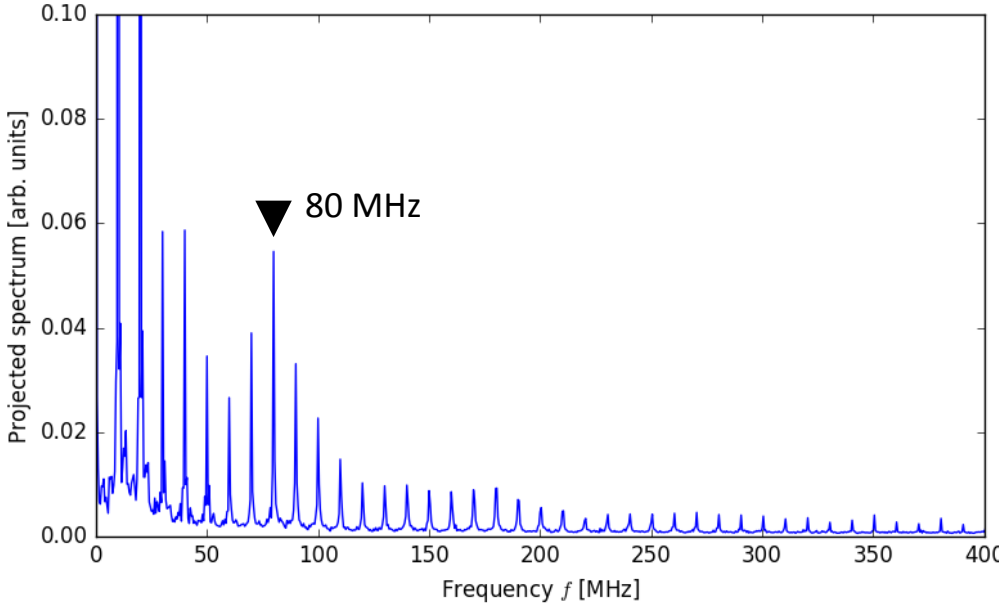


21 bunches

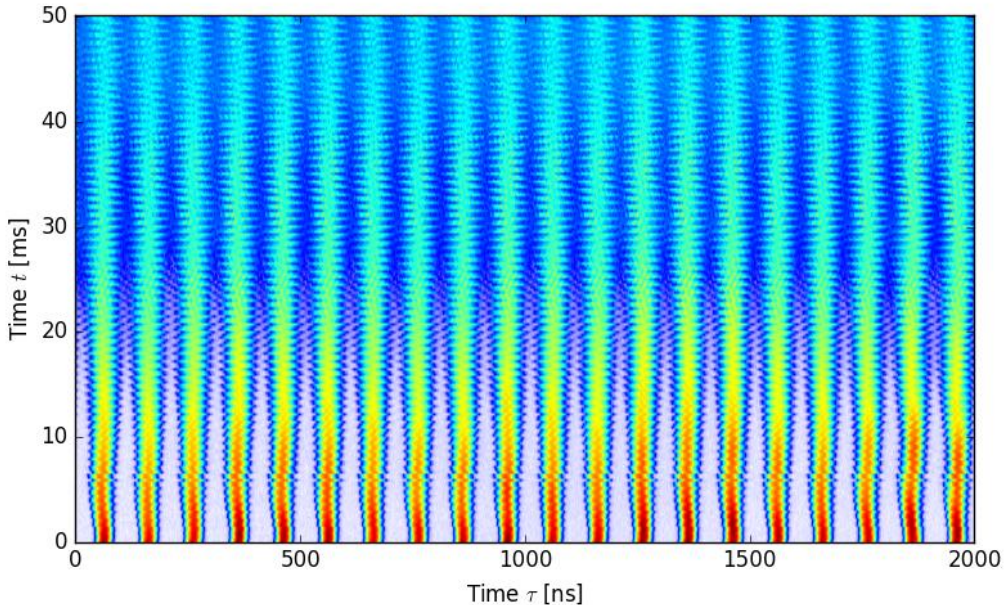


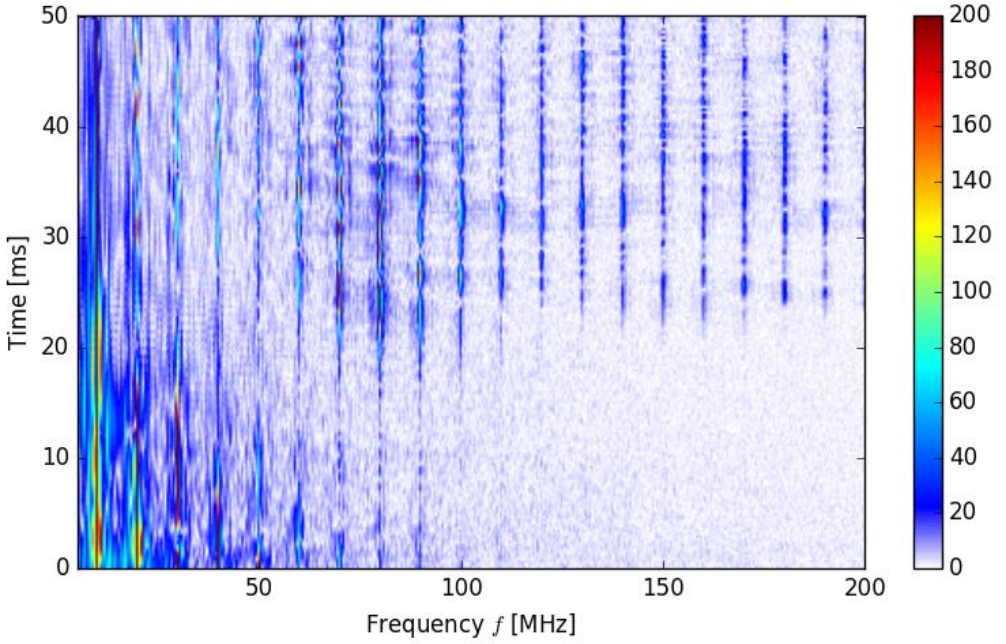
- The peak is visible for 9+ bunches
- NB: all the bunches could not be measured ($T_{\mathrm{frame}} = 2$ µs while $T_{\mathrm{rev}} \approx 2.3$ µs)





Beam profile modulation at 80 MHz





- Modulation starting around t = 25 ms, if at least two 80 MHz cavity gaps are open (C80-08 and C80-88 in this case)
- Depends on the number of bunches
  - ➢ Modulation seen only from 12 to 21 bunches in the machine

Instability growth rate

- Theory: http://cds.cern.ch/record/381423/files/sl-99-008.pdf, E. Shaposhnikova

  - Driven by impedance sources for which $\boldsymbol{f_r \tau_L \gg 1}$ (large resonant frequency in comparison to beam spectrum, the effect of the 80 MHz cavities is more important than the 40 MHz ones for this bunch length)

  - Small momentum spread $\Delta p/p$ (theory assumes a mono energetic beam)

  - Both conditions are achieved in measurements by lowering the RF voltage adiabatically (large bunch, small $\Delta p/p$)

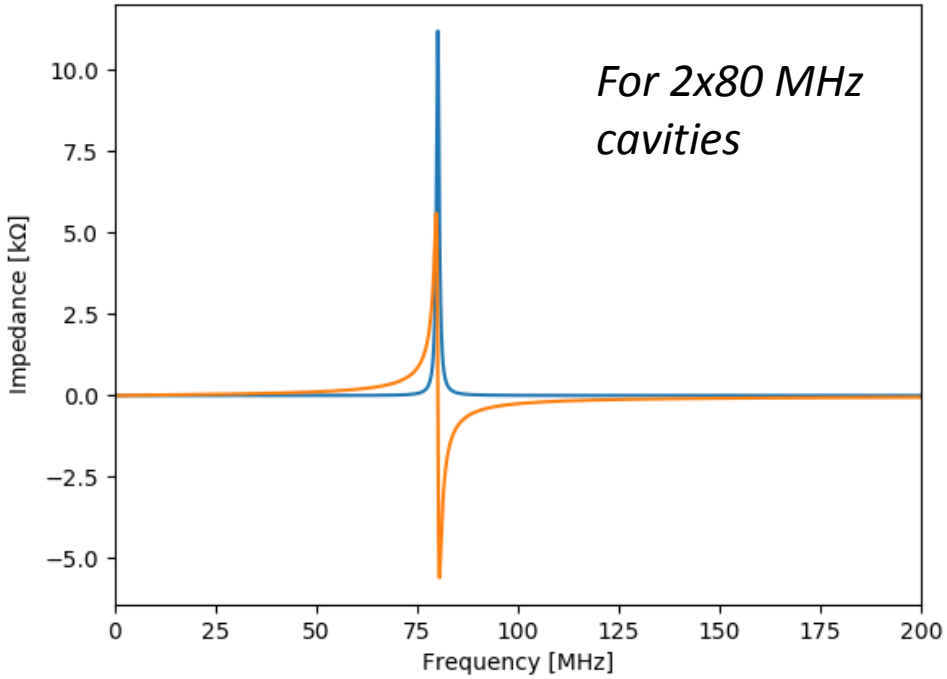
- Growth rate for a coasting beam

$$\mathrm{Im}\Omega = \frac{e\omega_0}{2}\left(\frac{\boldsymbol{N_{tot}}\eta}{\pi\beta^2 E}\boldsymbol{\omega_r R}\right)^{\frac{1}{2}}$$

- Growth rate for a single bunch

$$\mathrm{Im}\Omega = e\boldsymbol{\omega_r}\left(\frac{\boldsymbol{N_b}\,\eta}{16\,\pi\beta^2 E}\frac{\boldsymbol{R}}{\boldsymbol{Q}}\right)^{\frac{1}{2}}$$

80 MHz impedance model

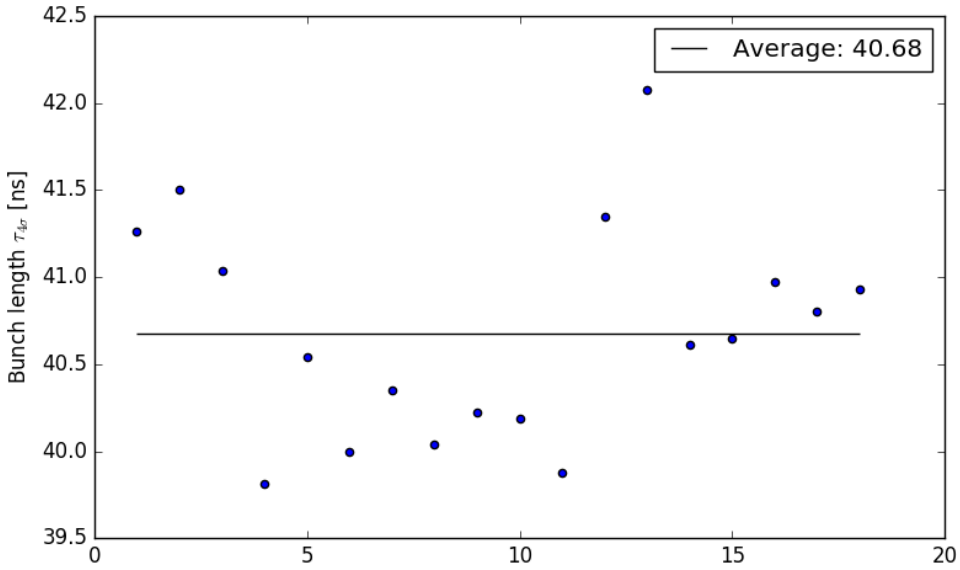


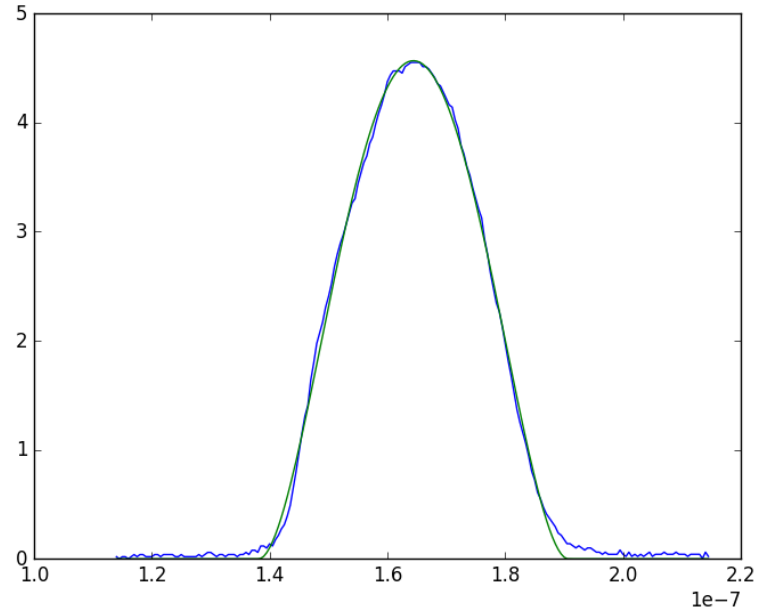
Case (/ cavity)	R/Q	Q
Bare cavity	56 Ω	~36000 [1] ~22600 [3]
+ fast feedback	56 Ω	100 [2][3]

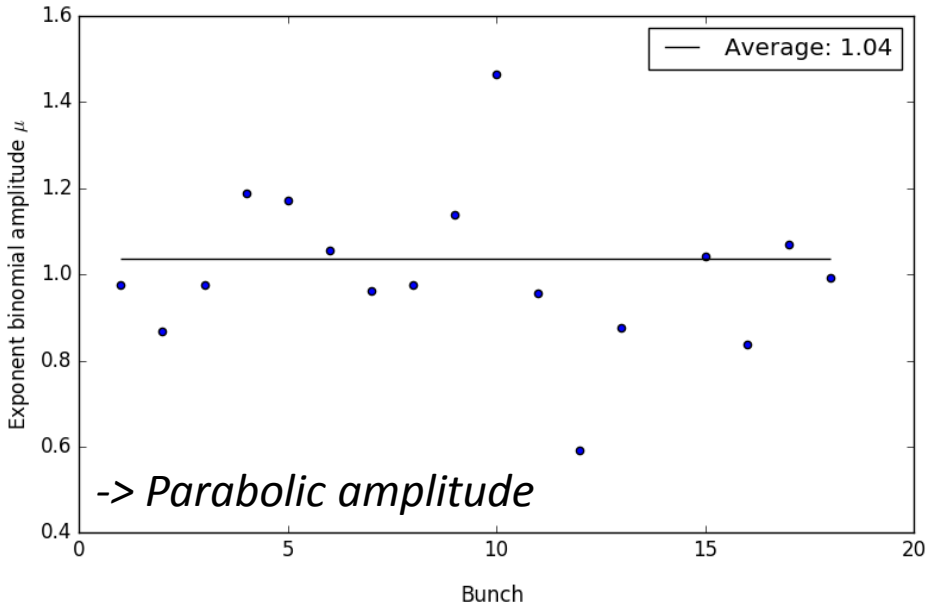
NB: particle simulations below done with extra $\frac{\mathrm{Im}Z}{n} = 18.4\ \Omega$ (https://journals.aps.org/prab/pdf/10.1103/PhysRevSTAB.16.031001)

- References:
  - [1] PS/RF/Note 96-14, R. Losito
  - [2] https://accelconf.web.cern.ch/accelconf/e98/PAPERS/TUP02H.PDF, E. Jensen
  - [3] http://cds.cern.ch/record/449242/files/CERN-2000-003.pdf, p47

Bunch profiles at $C_{\mathbf{time}}$= 2710 ms







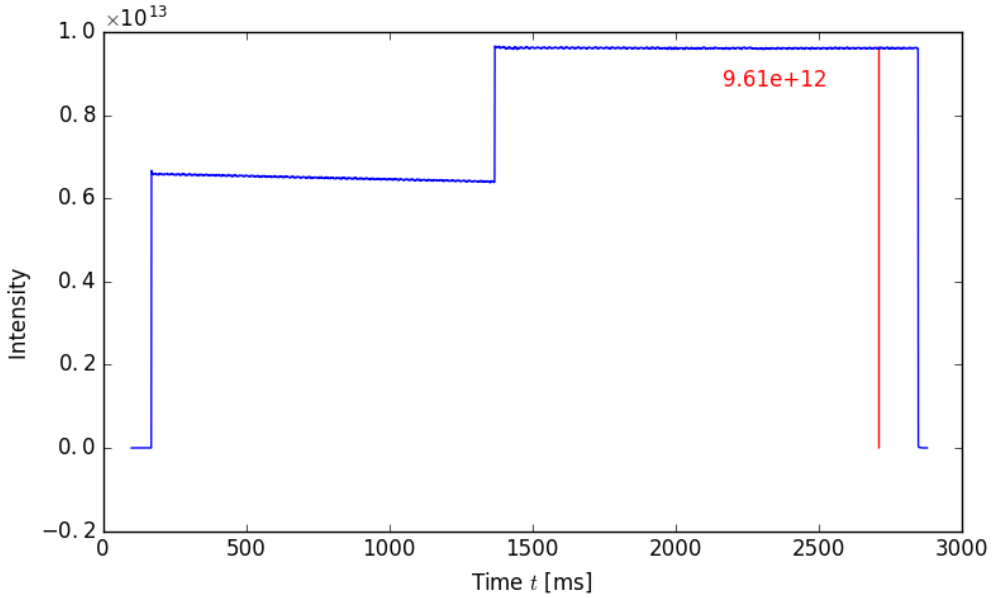
- Binomial distribution

$$\lambda(\tau) = \lambda_0 \left[1 - 4\left(\frac{\tau}{\tau_L}\right)^2\right]^{\mu+1/2}$$

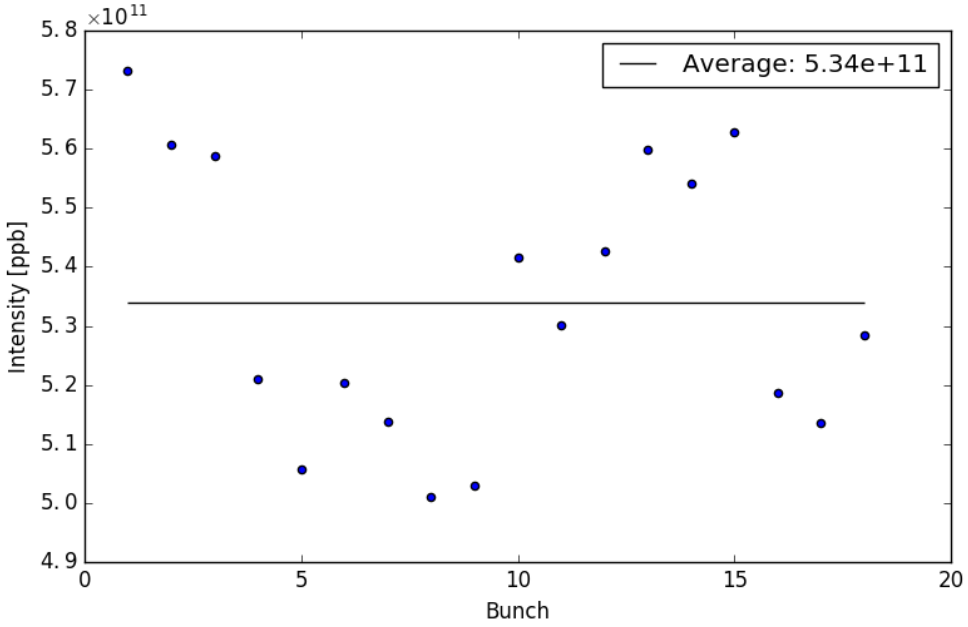
$$\tau_{4\sigma} = \frac{2}{\sqrt{3+2\mu}}\tau_L$$

- Used as input for particle simulations

Bunch intensity at C_{time}= 2710 ms

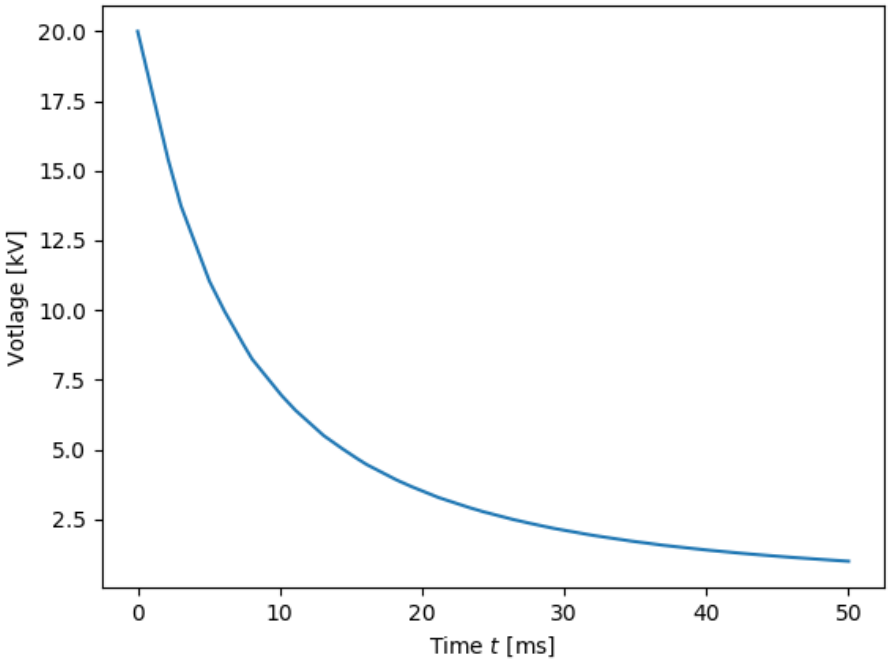


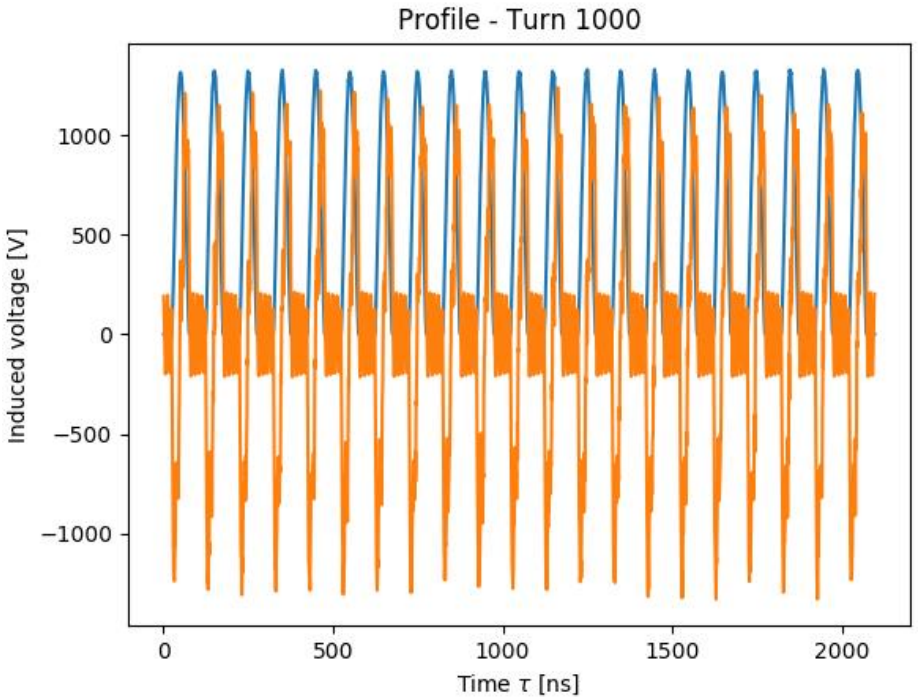
- Total beam intensity
  - $N_{\mathrm{tot}} \approx 9.6 \times 10^{12}$ p



- Intensity bunch-by-bunch obtained by integrating the signal of the bunch profiles, the total signal being normalized to the measured total beam intensity
  - $N_b \approx 5.3 \times 10^{11}$ ppb

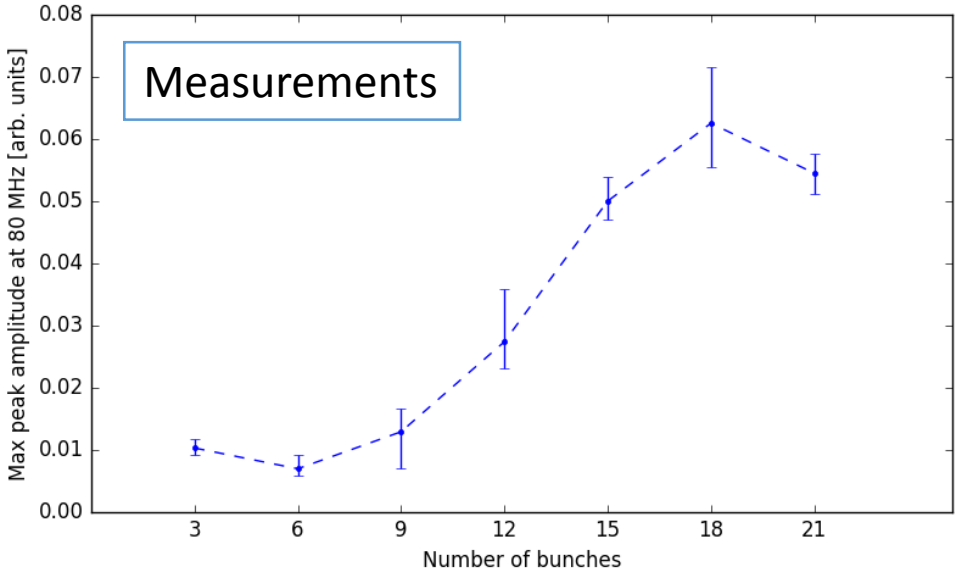
Particle simulations parameters (BLonD)

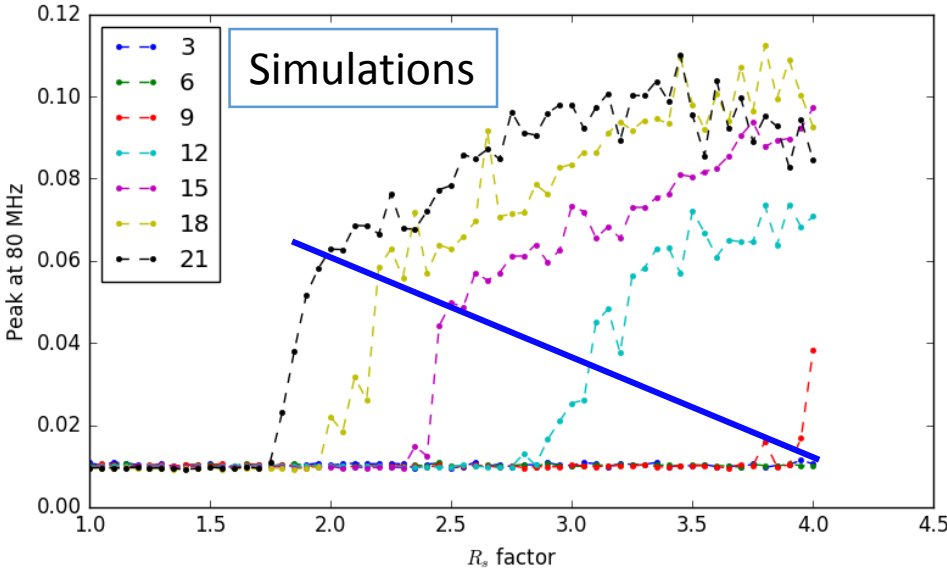




- Particle simulation done only on the 50 ms where the profile modulation is seen
- Bunches are generated matched with intensity effect with the same line density as in measurements (using Abel transform), and the same bunch intensity
- The induced voltage couples several turns, 100 turns of memory for the induced voltage (resolution in frequency of the impedance: ~5kHz, max freq ~670 MHz)

Simulation results





- Simulations were done by scanning the R and Q of the 80 MHz impedance model (keeping R/Q constant), for variable number of bunches (multiples of 3, as in measurements)
- In all cases, the present impedance model cannot reproduce the measured peak
- Depending on the number of bunches, the necessary factor to R (keeping R/Q constant) to reproduce measurements depends on the number of bunches.
  - Does the 80 MHz cavity + fast feedback beam coupling impedance depends on the number of bunches ?

➢ **A factor 2 (for 21 bunches) to 3 (for 12 bunches) is necessary to reproduce the peak measured at 80 MHz**

Conclusions

- It is necessary to have a good representation of the 80 MHz impedance model, it was shown in the past to be responsible of emittance blow-up at flat top when the three cavity gaps are open.

- The present impedance model of the 80 MHz cavities is not sufficient to reproduce the measured line density modulation of the beam, a factor 2-3 on R is required to reproduce measurements.

- Other beam measurements of the impedance revealed than some resistive impedance may be missing from the present impedance model in the ~> 80 MHz region (M. Migliorati et al http://accelconf.web.cern.ch/AccelConf/ipac2016/papers/mopor014.pdf), that would be compatible with the results presented here

- Those measurements could be extended by measuring beam spectrum from the filtered wall current monitor signal around at high harmonic (Schottky-like measurement to observe momentum spread during debunching)

- The next step is to measure the RF voltage in the gaps with a spectrum analyser to evaluate the impedance and compare with the present results to confirm or not that the 80 MHz impedance is larger than expected, using beam based calibration of the cavity probe signal