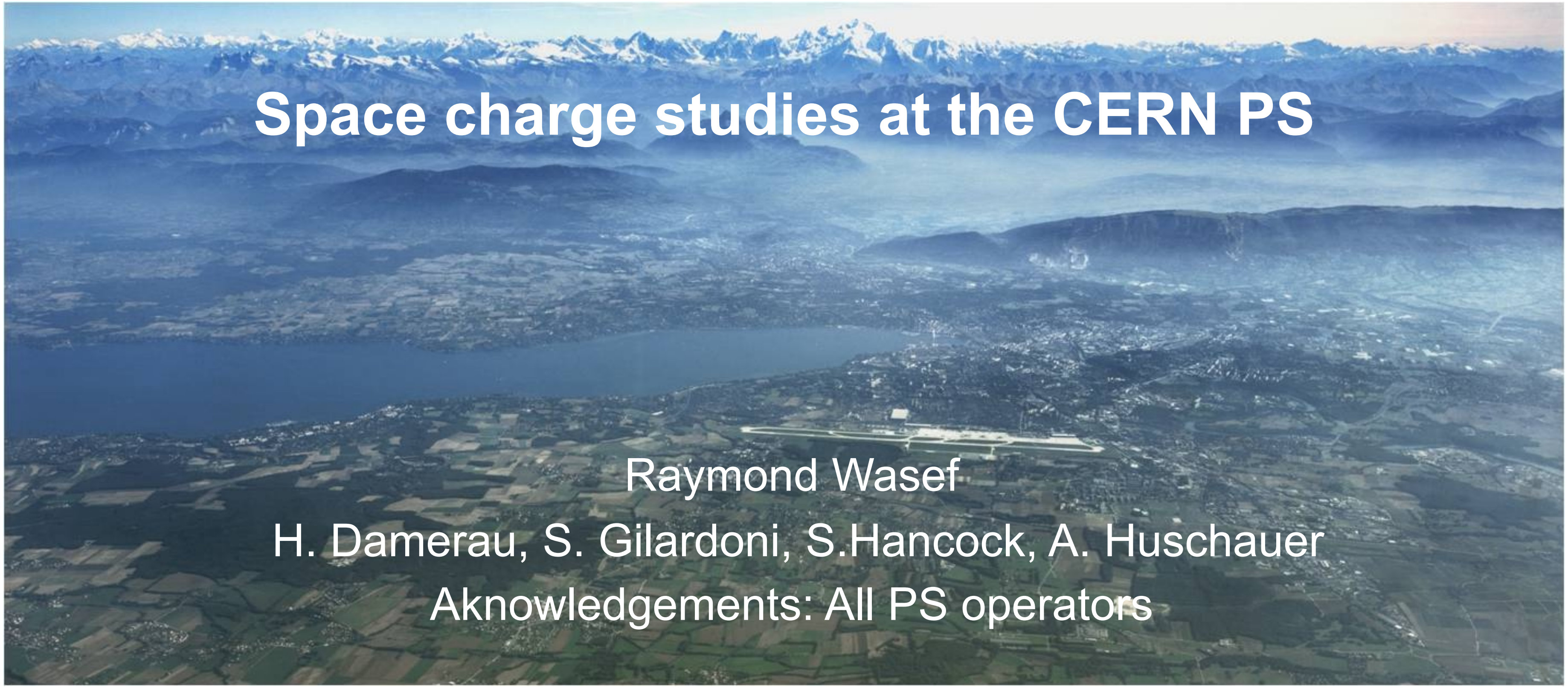
LHC Injectors Upgrade

CERN

LHC Injectors Upgrade



Space charge studies at the CERN PS

Raymond Wasef
H. Damerau, S. Gilardoni, S.Hancock, A. Huschauer

Aknowledgements: All PS operators

OUTLINE

I. Space Charge at Injection

II. Measurement settings

III. 4th Order resonance (4qy=1)

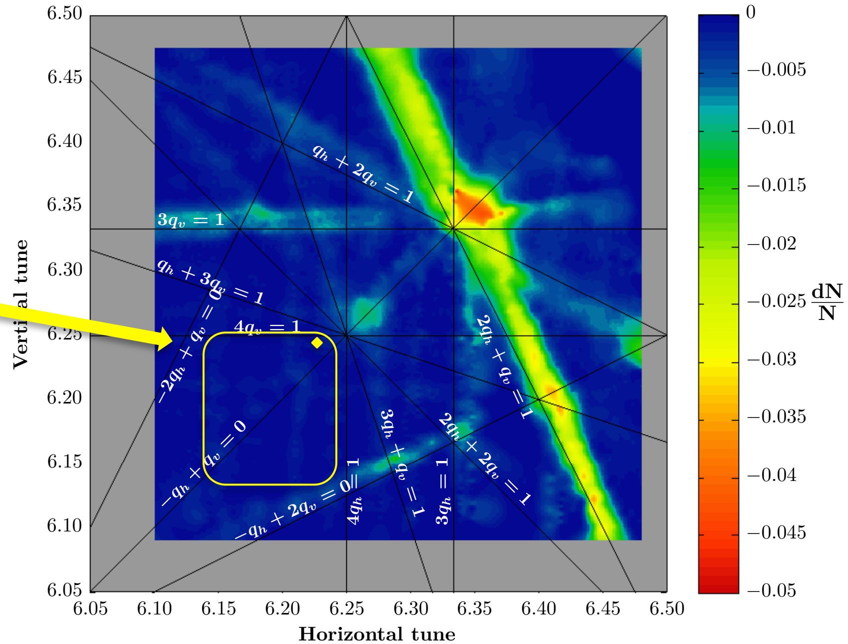
IV. Results

V. Conclusion

I. Space Charge at injection (1.4 GeV)

- Current injection energy: 1.4 GeV

Current operation area

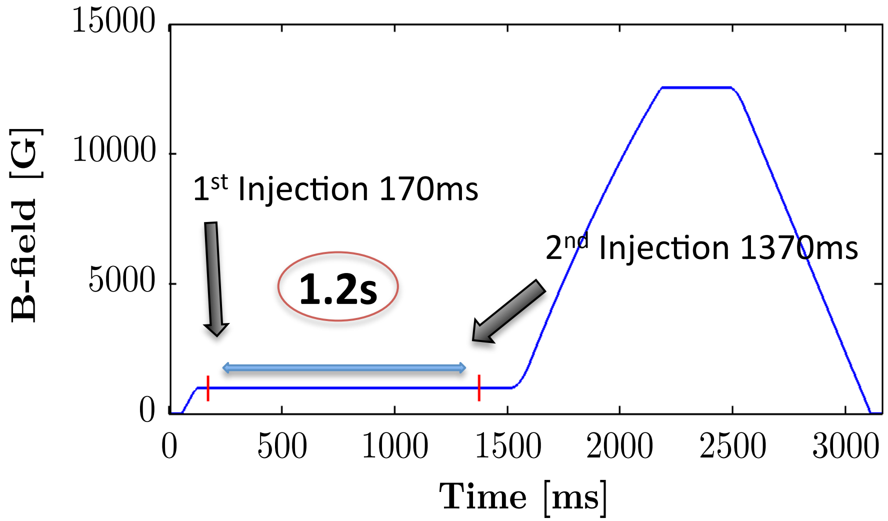


- Estimated tune-spread of current operational beam~(0.2 ; 0.28)

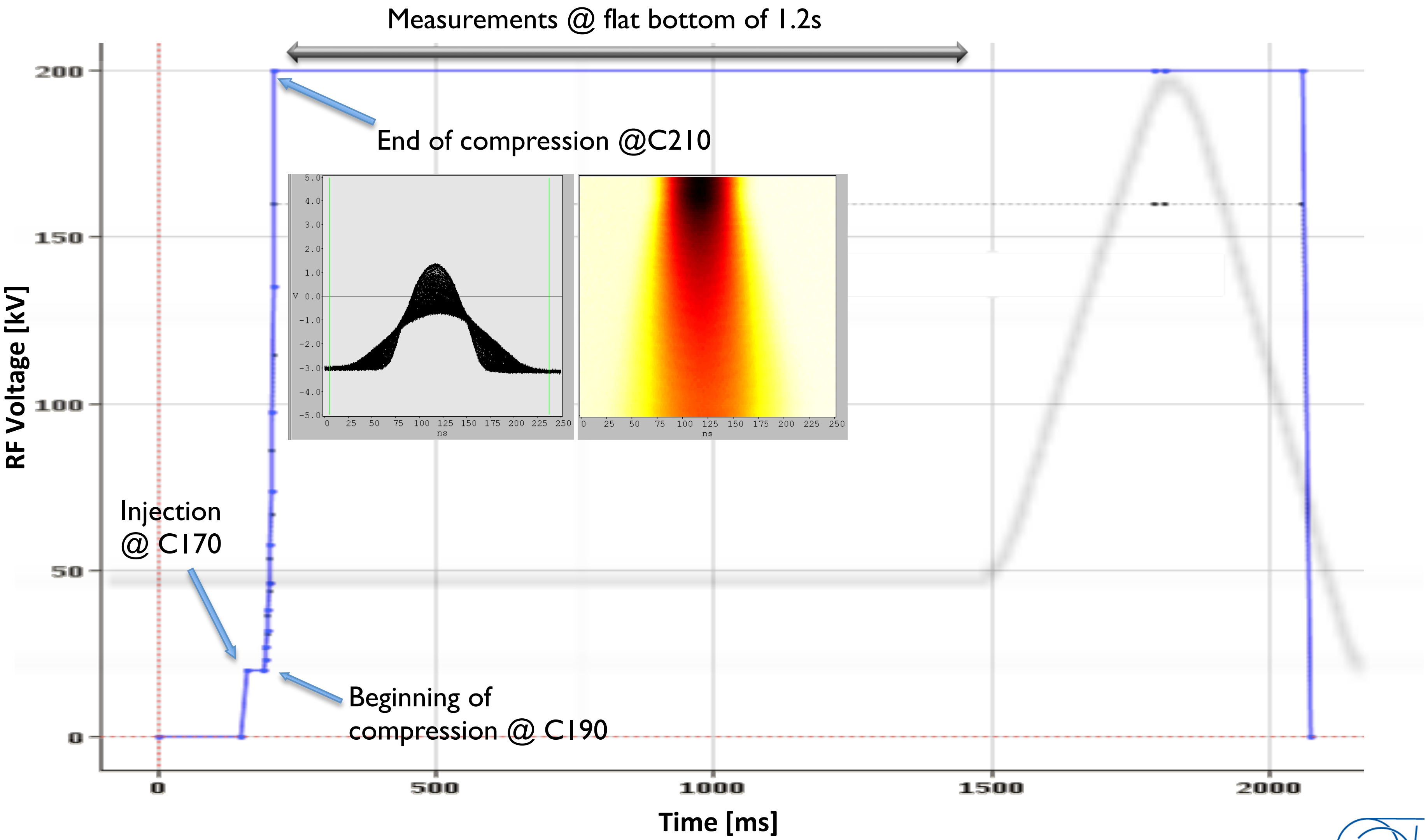
- LHC double batch injection: Long **flat bottom: 1.2s**

- HL-LHC beams requirement: **tune-spread~ .34 - .37**

➔ Importance of the study of the **integer resonance** effect and the tune spread on beams



II. Adiabatic Bunch Compression



II. Measurement settings

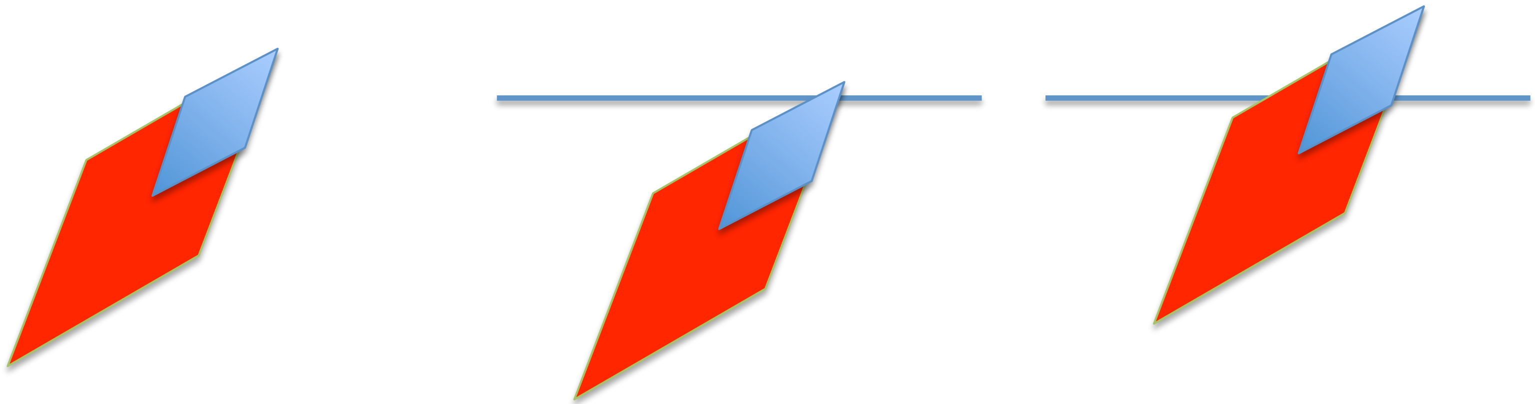
- The **tune-spread** was varied using an **adiabatic bunch compression** (20ms).
- The effect of the integer is observed through the **longitudinal and transverse profiles** as well as **losses.**
- The transverse profile is measured using a **wire-scanner**, which averages the profile over ~2ms and it can only be used **once per cycle**.
- The **emittances** are computed using the a fit of the beam profile from the wire-scanne assuming the optics (β,dispersion) of the model.
- The maximum tune-shift due to space charge is estimated using:

$$\Delta Q_{x,y} = \frac{r_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z}\oint \frac{\beta_{x,y}(s)ds}{\sigma_{x,y}(s)[\sigma_x(s)+\sigma_y(s)]}$$

- While setting the beam, significant **losses** have been noticed near **4qy=1** while none were noticed during the tune diagram measurement.
- After a quick check of the losses and emittances after compression, **(6.23 ; 6.255)** has been chosen as starting working point. (Measured ~(6.228 ; 6.253))
- The 4th order resonance seems to be excited and to have an **intensity threshold.**

III. 4th order Resonance

Testing the effect of the 4qy by changing the population crossing it (Bunch compression @ C1000)



Tune spread before and after compression

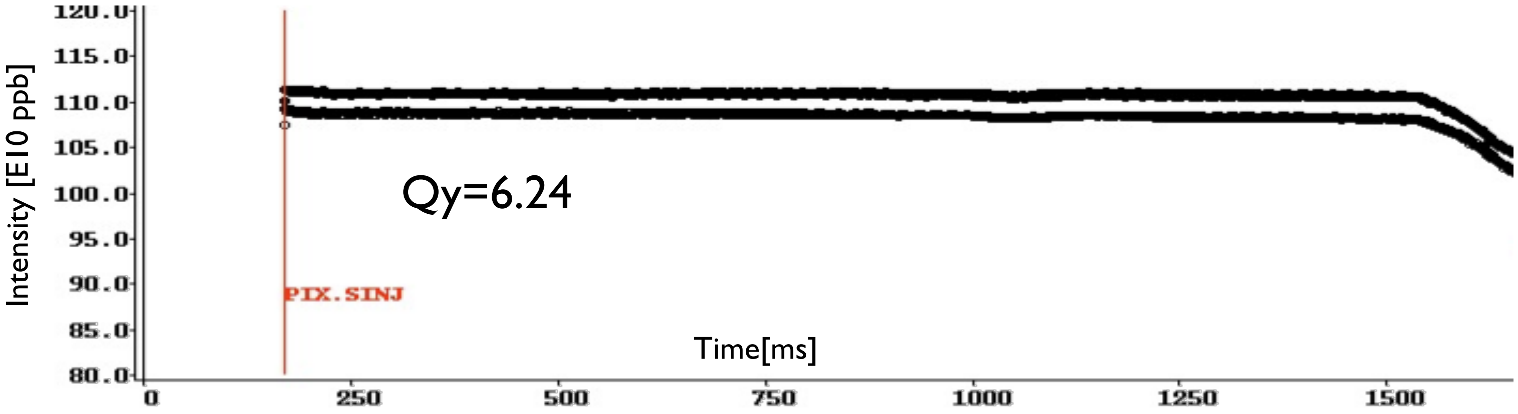
If the working point is close to the resonance, before and after the compression it is mainly the halo crossing the resonance

If the working point is relatively far from the resonance the population crossing the resonance changes after compression

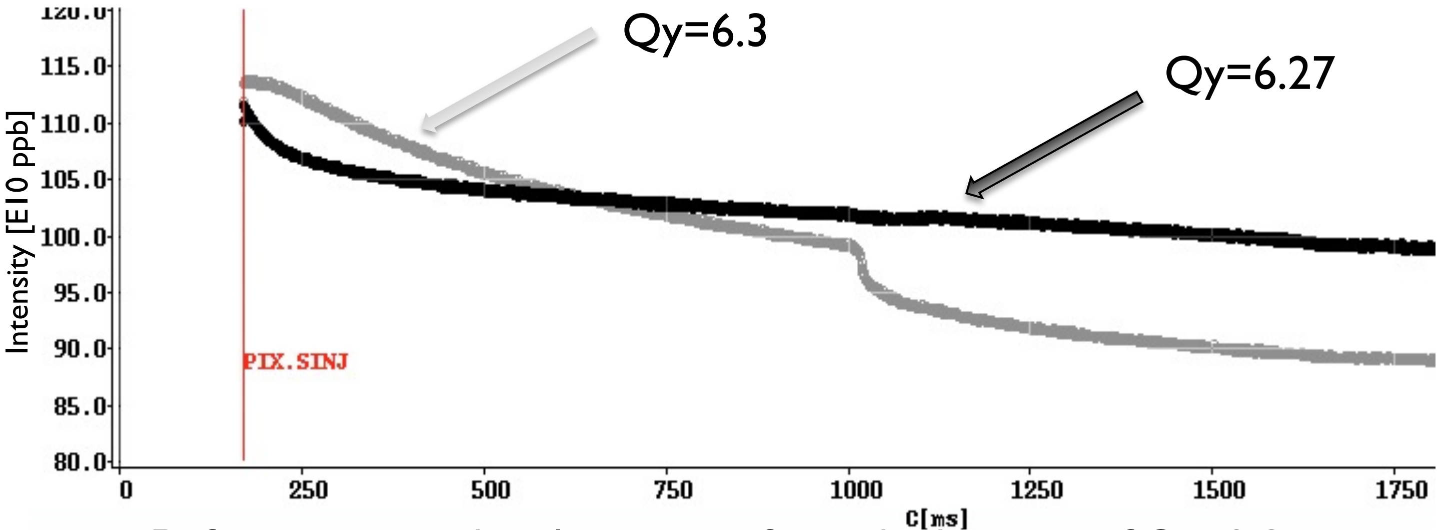
➔ Losses due to the resonance are expected to be different

III. 4th order Resonance

Bunch compression @ C1000



➔No effect of the compression (losses due to change of W.P.)



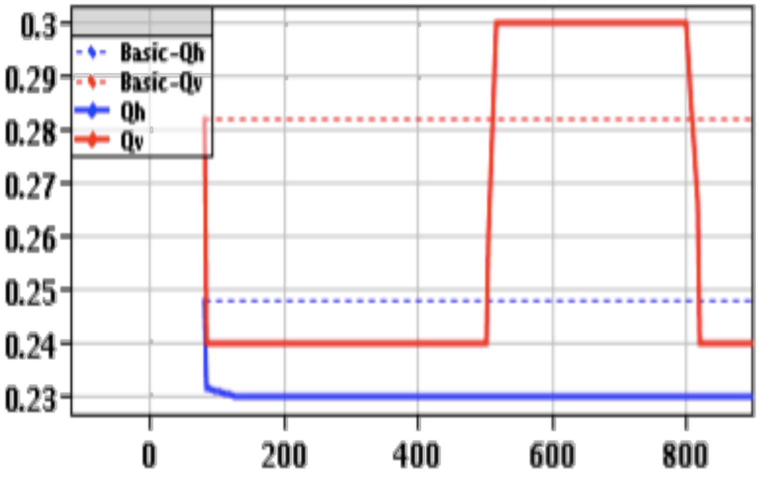
Before compression: losses are faster in the case of Qy=6.27

After compression: No effect for Qy=6.27 but faster losses for Qy=6.3

III. 4th order Resonance

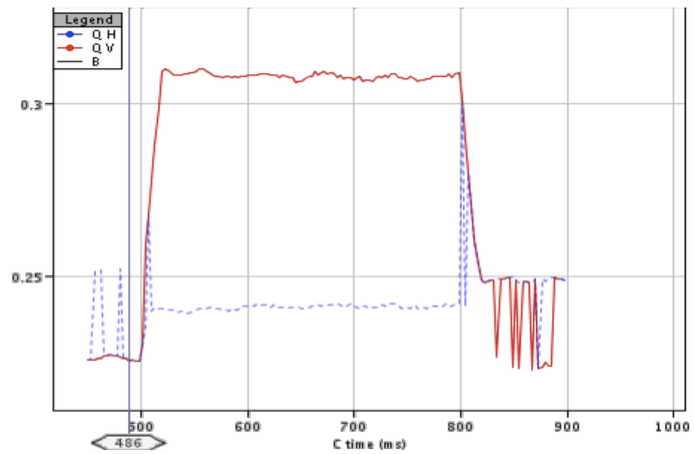
- **Testing if the 4qy=1 is excited by Space Charge:**
  - Bunch compression @ C190
  - Tune step between C500 and C800

Set tunes



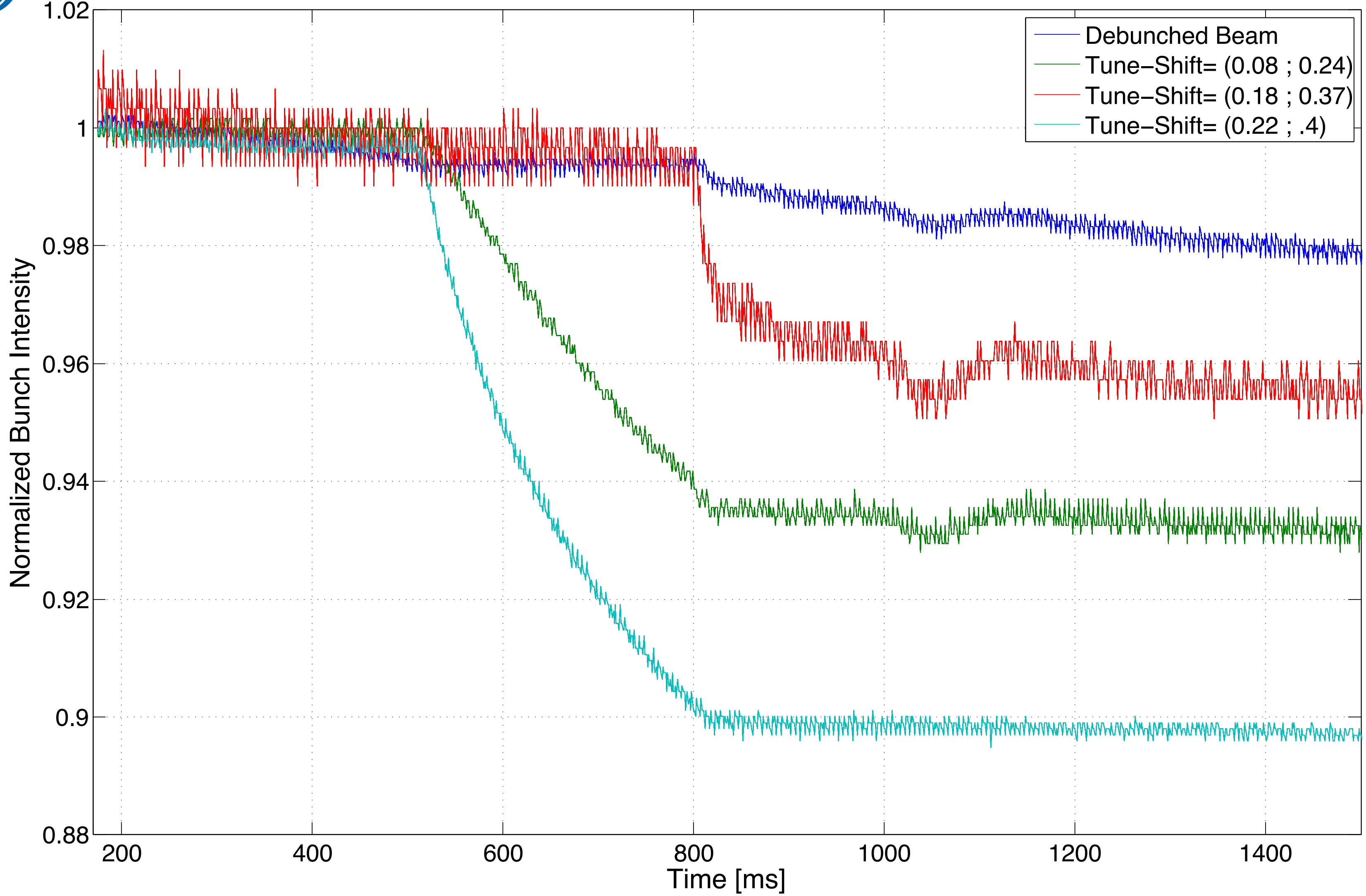
Time[ms]

Measured tunes



- **4 different settings**:
  - I=115 e10 ppb Tune-spread =(.22 ; .4) (for Q21Q23 optics)
  - I=80 e10 ppb Tune-spread =(.18 ; .37) (for Q21Q23 optics)
  - I=35 e10 ppb Tune-spread =(.08 ; .24) (for Q21Q23 optics)
  - I=115 e10 ppb Debunched

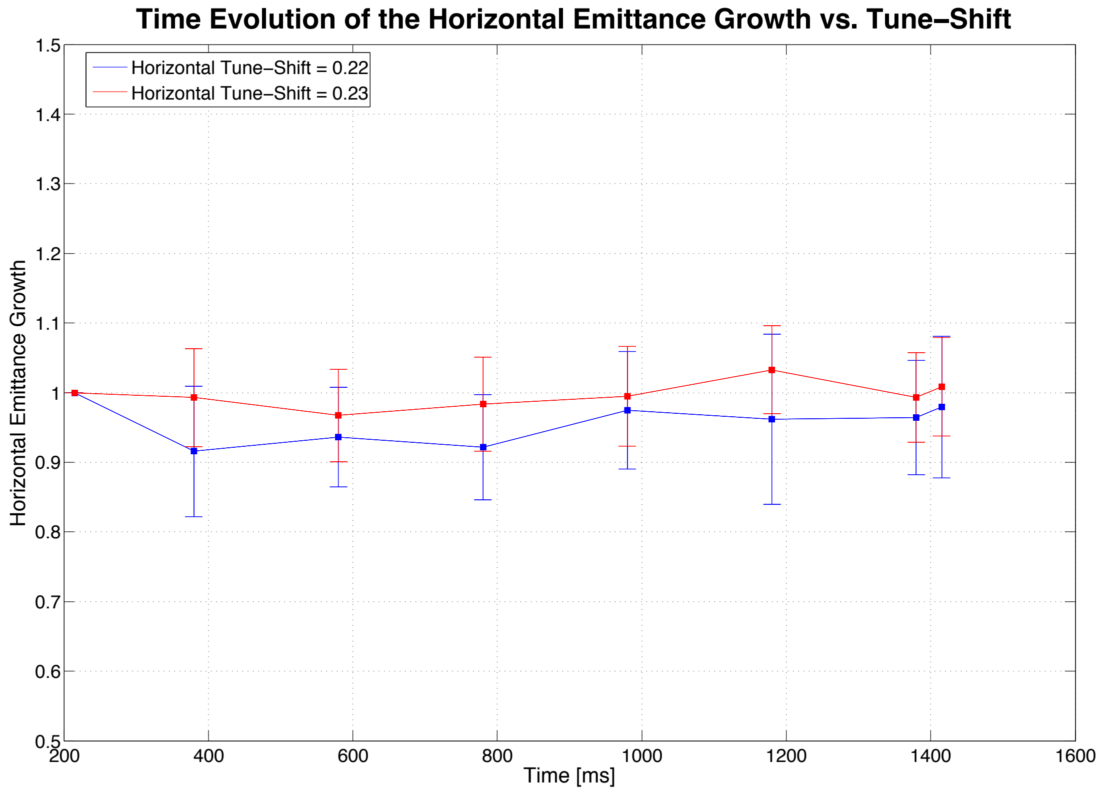
III. 4th order Resonance



➔ The 4th order resonance seems to be excited by space charge

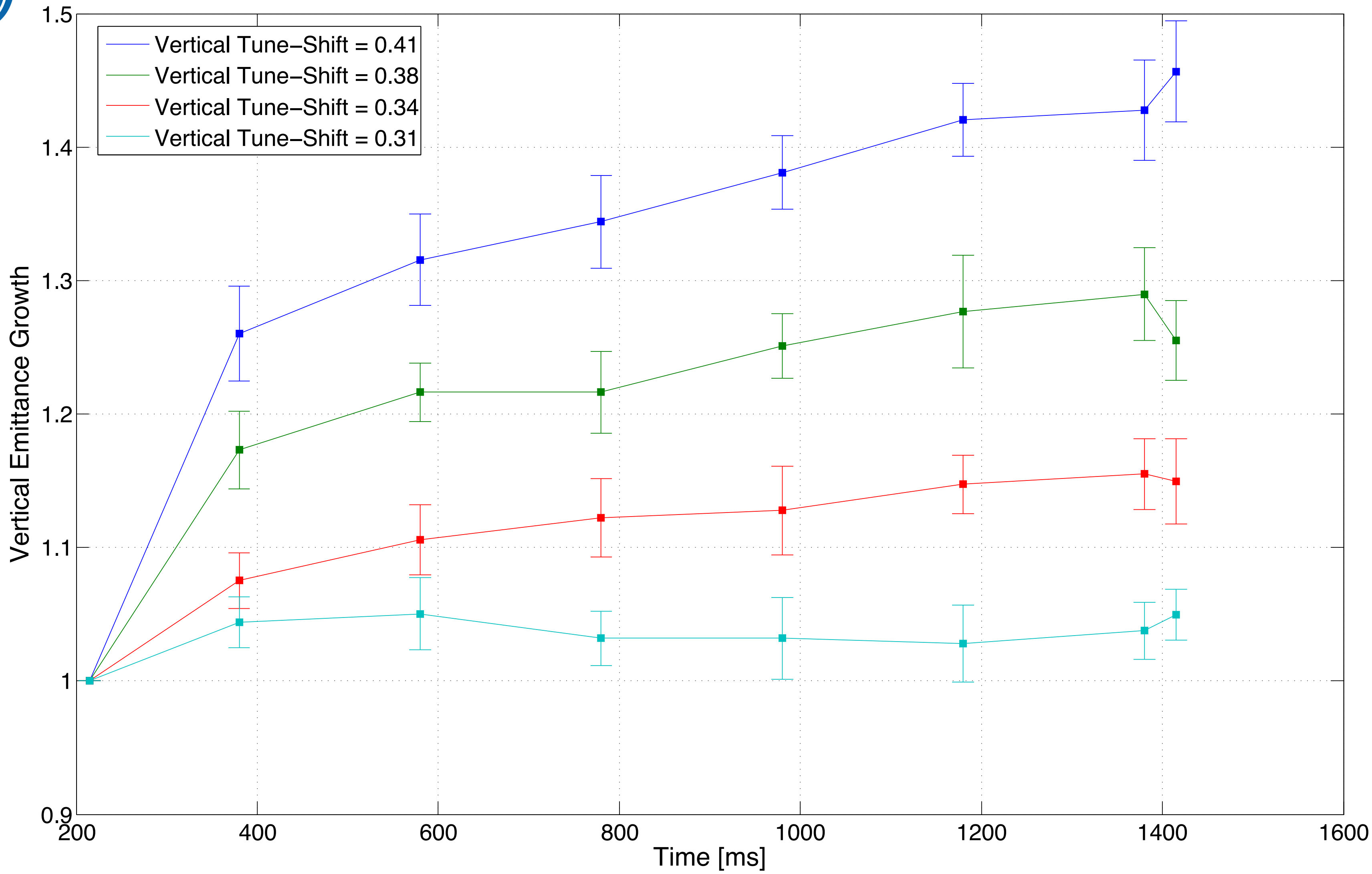
IV. Horizontal emittance behavior

- **Beam used:**
  I=1.15e12 ppb; $\varepsilon_{h,normalized}$=1.6μm; $\varepsilon_{v,normalized}$=1.25μm; Δp/p(1σ)= 0.95E-3 ; full bunch length=185ns

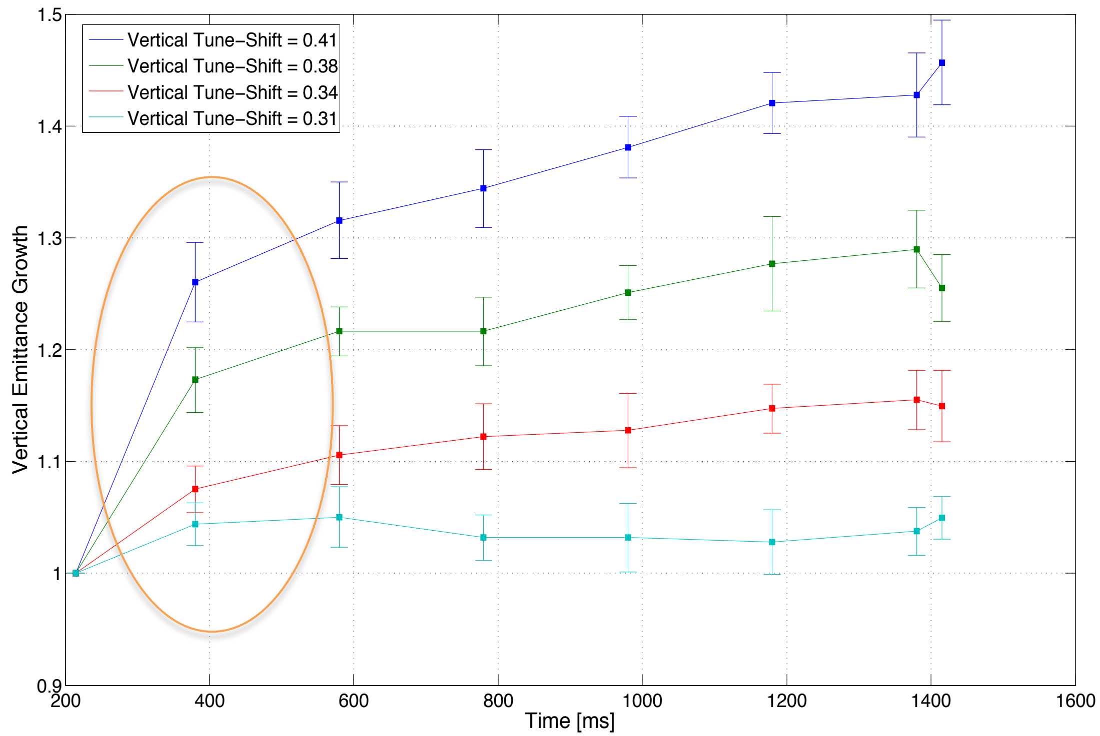


Since the horizontal detuning is always **less than .23** (Qx=6.23), no relevant change has been noticed in the horizontal plane. Therefore, only the vertical emittance is shown in the following results

IV. Vertical growth vs. Time vs. Tune-spread



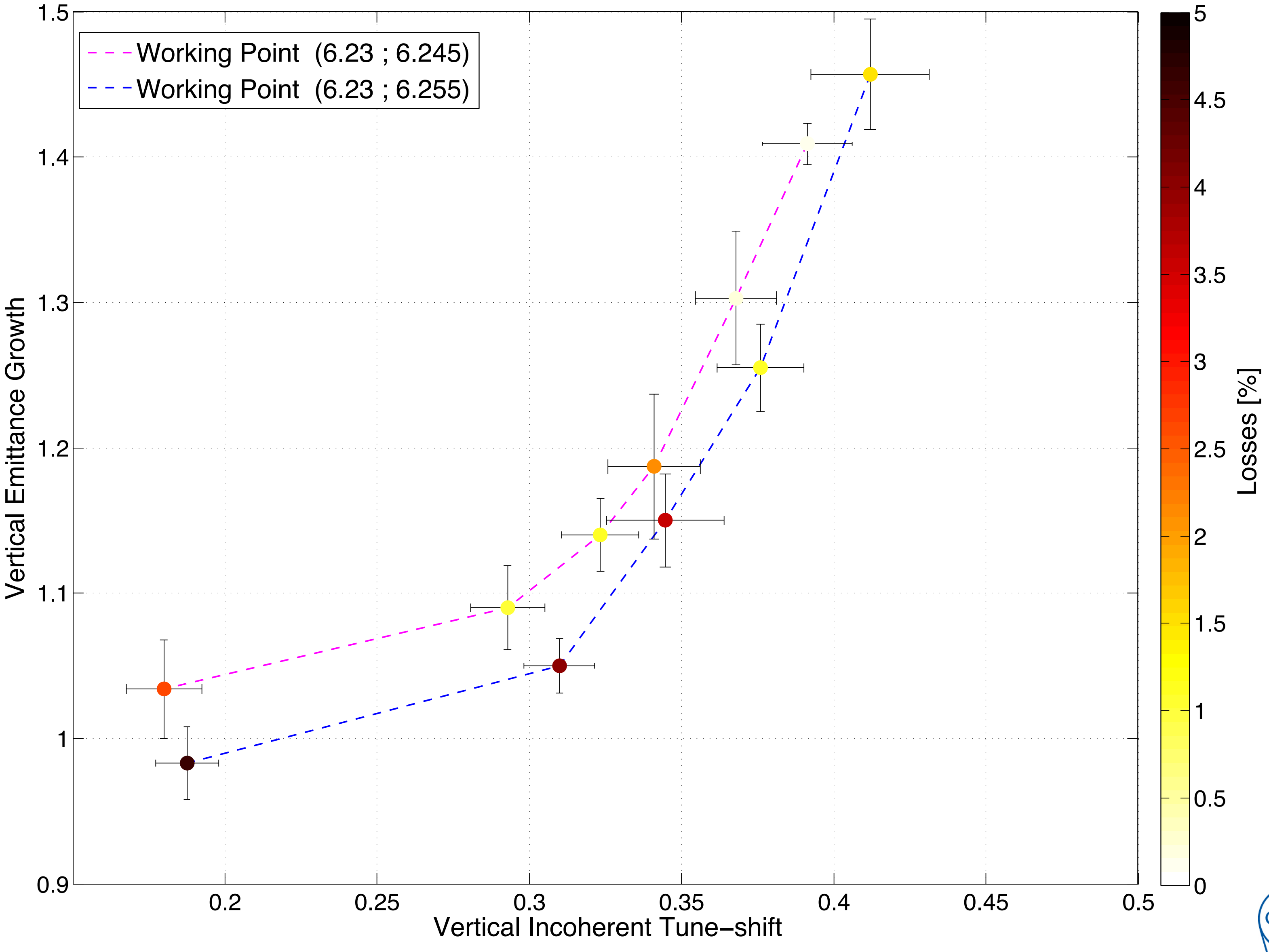
IV. Vertical growth vs. Time vs. Tune-spread



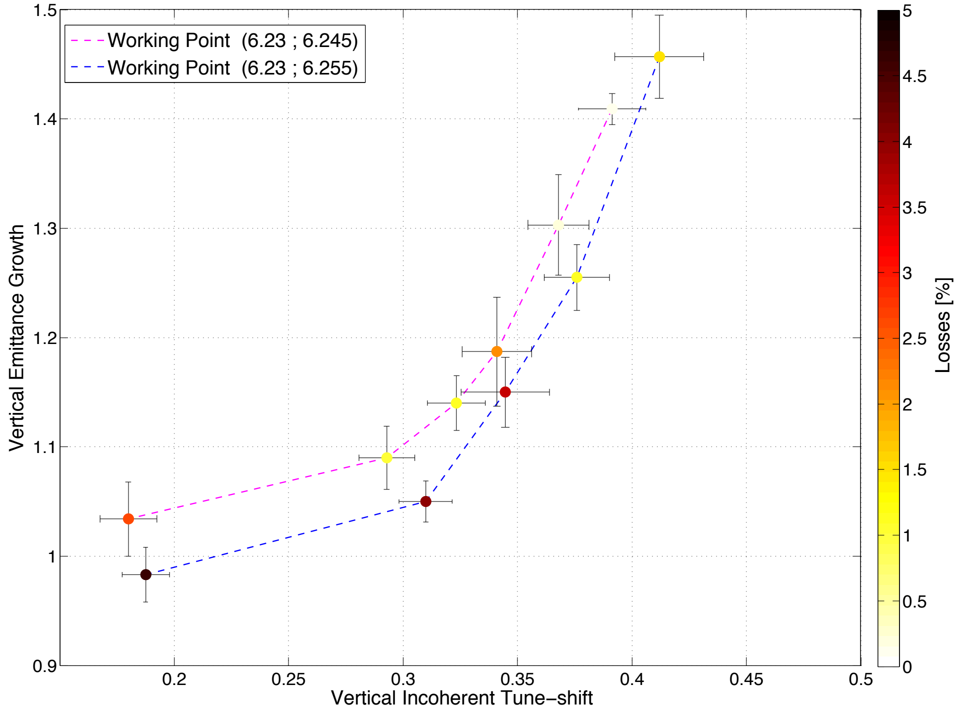
Most of the growth happens during the first 200ms.

➔ Single batch injection could be a possible solution for the LHC beams, the reduce the blow-up at injection.

IV. Vertical growth vs. Tune-spread vs. Losses



IV. Vertical growth vs. Tune-spread vs. Losses



The beam tune-spread is trapped between the 4qy=1 and the integer.

➔ If one increases the vertical tune to avoid growth due to the integer, the losses increase because of the 4th order resonance

➔ There are less losses with higher tune-spread because the proton population becomes smaller on the 4q=1 after compression.

➔ The choice of the working point is a compromise between losses and emittance blow-up

V. Conclusion

- The 4qy=1 resonance seems to be excited by space charge.
- With the current scheme and limitations it is very challenging to meet the HL-LHC requirements (5% blow-up , 5% losses budgets and ΔQ~.34 - .37)

Potential solutions:

Decrease the harm of resonances

- A compensation scheme of the 3qy=1 resonance has been successful. (see A.Huschauer talk) Correcting the 4qy=1, could then allow operation of a very large tune-spread beam.

Decrease the tune-spread

- Use of flat bunches to decrease the tune-spread.
- New optics with a larger dispersion to decrease the tune-shift. (since the beam pipe is much larger than the LHC beams)

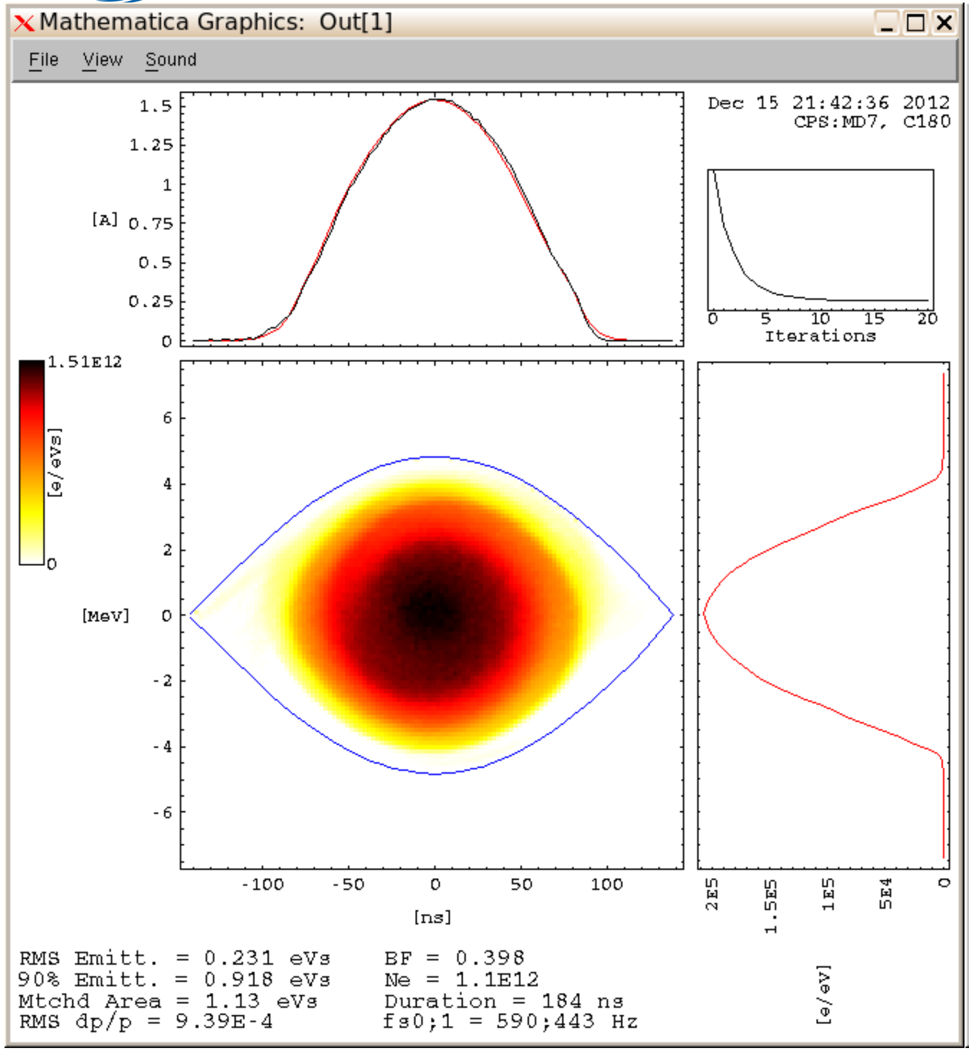
LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!

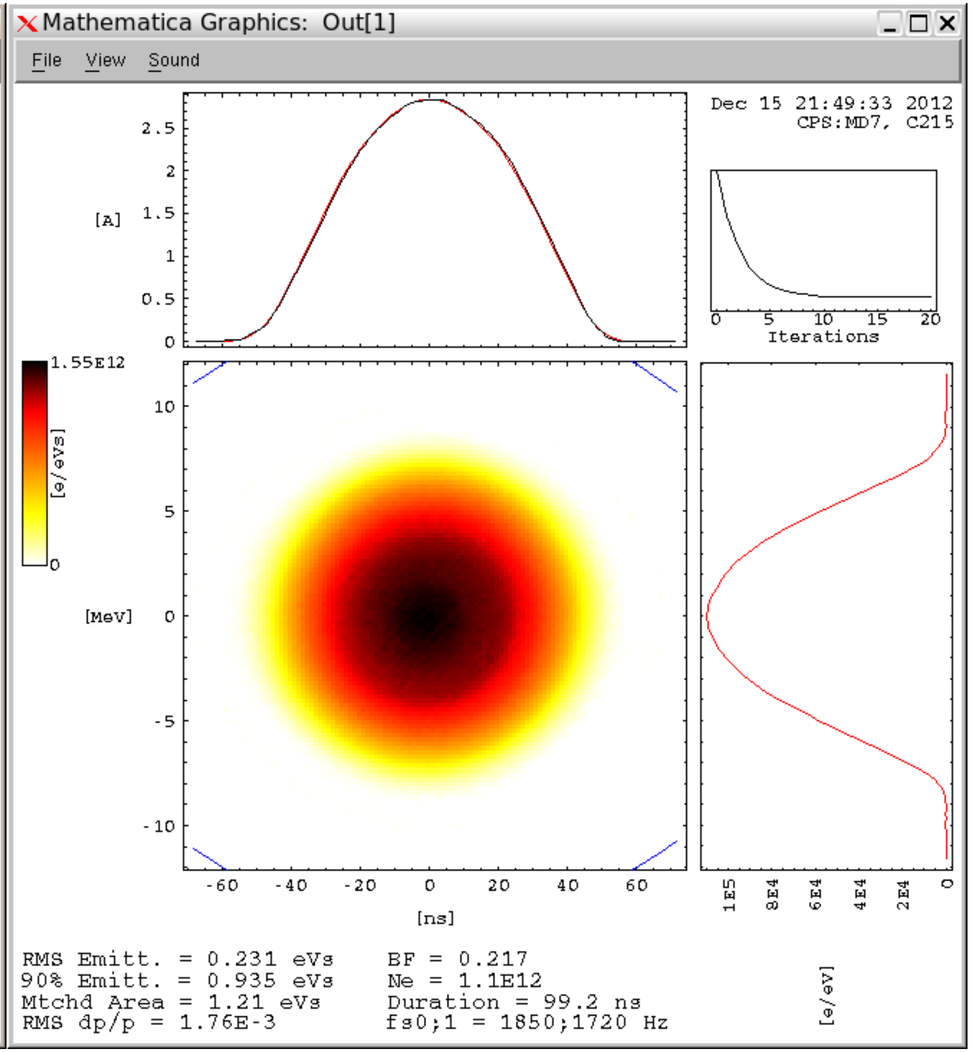
CERN

Backup Slides

Longitudinal profile before/after compression



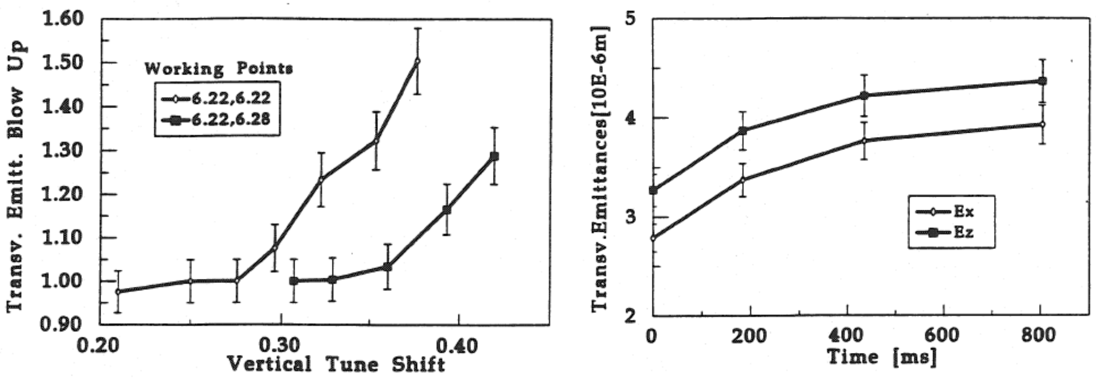
Before compression



After compression

Effect of integer resonance

The effect of the integer resonance on high space charge beams is very important since most operational beams are close to/on the integer and the HL-LHC Beams will have even a larger tune-spread.



Previous study of the integer (CERN/PS 93-18)

In this study the tune spread has been estimated as following:

$$\Delta Q_y = -\frac{2r_0}{ec}\frac{I_p\beta_y R}{(\beta\gamma)^3}\frac{1}{b(a+b)}$$

With

$$a = \sqrt{2\left[\frac{\varepsilon_x^*\beta_x}{\beta\gamma} + \left(D_x\frac{\sigma_p}{p}\right)^2\right]} \qquad b = \sqrt{2\left[\frac{\varepsilon_y^*\beta_y}{\beta\gamma}\right]} \qquad I_p = 3eN_b/2\tau_b$$

While I am using:

$$\Delta Q_{x,y} = \frac{r_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z}\oint\frac{\beta_{x,y}(s)ds}{\sigma_{x,y}(s)[\sigma_x(s)+\sigma_y(s)]}$$

IV. MD: New Optics

- New Optics during the flat bottom for the LHC double batch injection beams.

  - Current optics for LHC beams ($\varepsilon_{normalized}$=2.5µm; Δp/p= 1E-3):
    -Horizontal Size (1σ) < 4.5mm (while beam pipe size ~ 146mm)
    -Vertical Size (1σ) < 3.5mm (while beam pipe size ~ 70mm)

  ➔ Changing the optics by using the transition triplets:
  Increase of the beam size and therefore decreased tune-spread

  - For one of the future options for the High Brightness LHC-25 beam with: 3.35E12 ppb ; $\varepsilon_{1\sigma,normalized}$=2µm; Δp/p(1σ)= 1E-3 ; full bunch length=180ns ; E=2GeV.
    Tune-spread for current optics = (0.28 ; 0.37)
    Tune-spread for suggested optics = (0.15 ; 0.28)

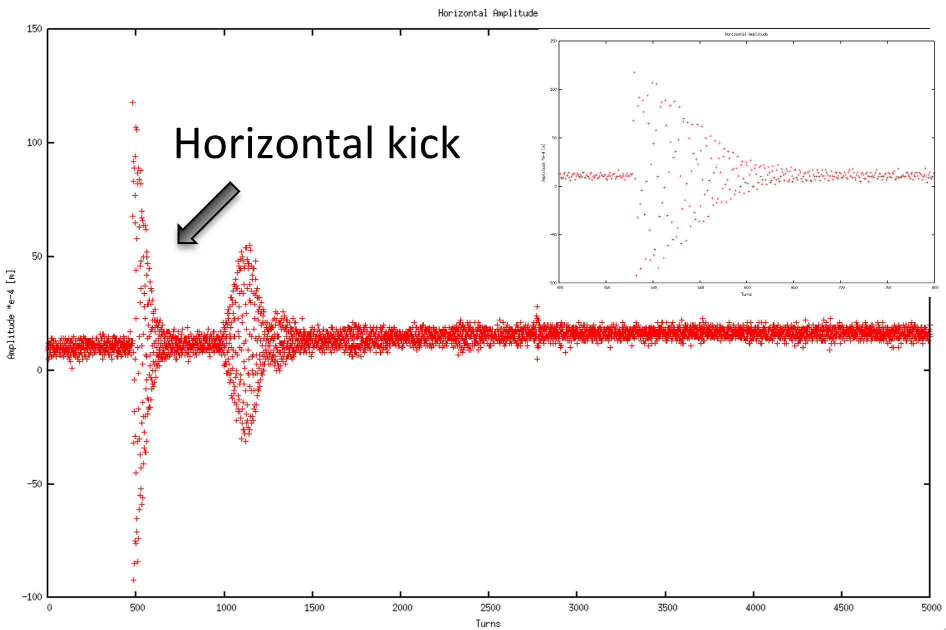
Examples of Operational Beams (1.4GeV)

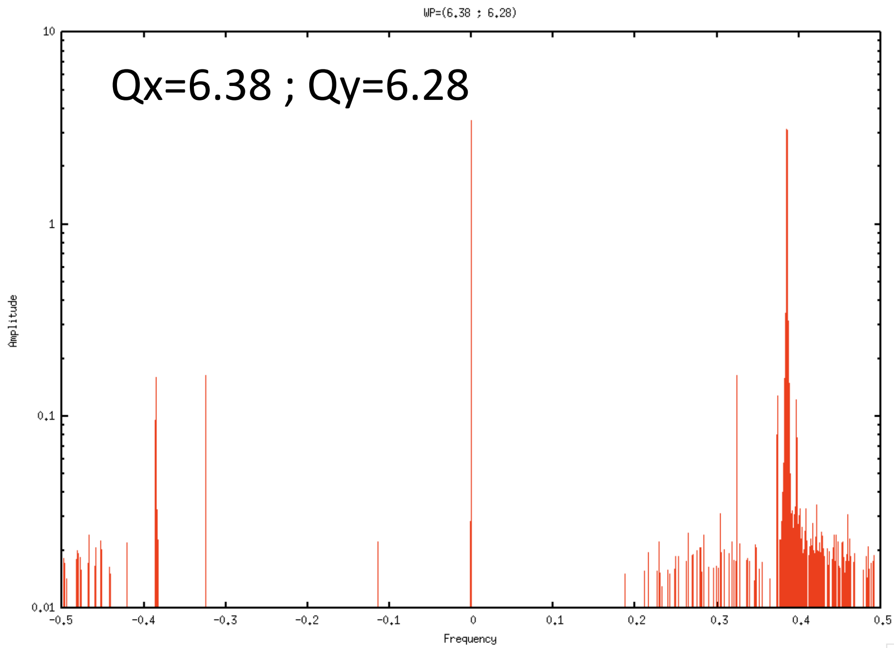
Beam	LHC-50	TOF	AD
Intensity [xE10 ppb]	105	650-850	400
ε horizontal, normalized, 1σ [π.mm.mrad]	1.08	14.5	9
ε vertical, normalized, 1σ [π.mm.mrad]	1.34	7	5
Bunch Length (4σ) [ns]	180	250	180
Δp/p (1σ) [xE-3]	1.25	1.75	1.56
Working point	(6.235 ; 6.245)	(6.14 ; 6.26)	(6.21 ; 6.25)
Max. Laslett Tune-spread $\Delta Q_{x,y} = \frac{r_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z}\oint\frac{\beta_{x,y}(s)ds}{\sigma_{x,y}(s)[\sigma_x(s)+\sigma_y(s)]}$	(0.19 ; 0.28)	(0.18 ; 0.29)	(0.18 ; 0.27)

Currently no significant emittance blow-up nor losses are observed for operational beams that cannot be cured by increasing the vertical tune and adapting the horizontal to remain near the diagonal
(recent change Qx: 6.21->6.235 , Qv: 6.23-> 6.245)

IV. MD: Resonance Driving Terms

- Resonance Driving Terms measurement and compensation study
  - Pencil beam with low intensity to avoid collective effects (LHC-INDIV)
  - Scan different kick strengths and analyze the frequency spectrum of the BPM data turn by turn to try to identify the lattice resonances





- An automatic application is being developed by PS-operators to be able to measure for all reachable tunes.