LHC Injectors Upgrade

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Space charge studies and impact on performance

Raymond Wasef , Alexander Huschauer
In collaboration with, S. Gilardoni, H. Damerau, A. Molodozhentsev, F. Schmidt, G. Franchetti
On behalf of the LIU-PS project team

CERN

OUTLINE

I. Tune Diagrams

II. Space Charge at Injection

III. Simulation Tools

IV. Machine Development (M.D.)

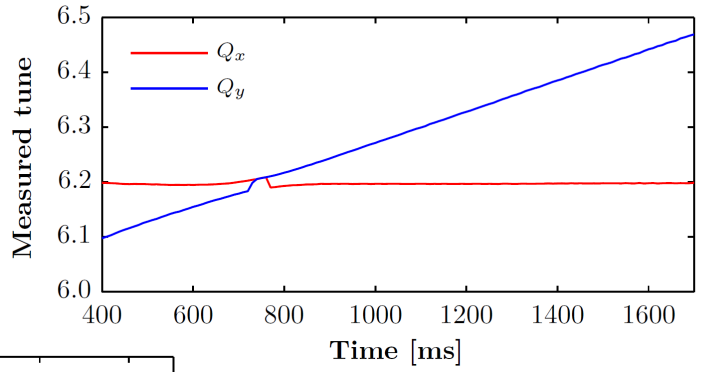
V. Summary and Conclusion

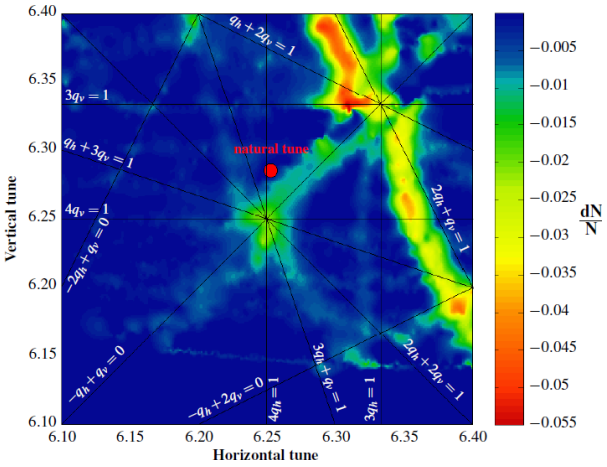
I. Tune Diagrams

Goal: identify dangerous resonances

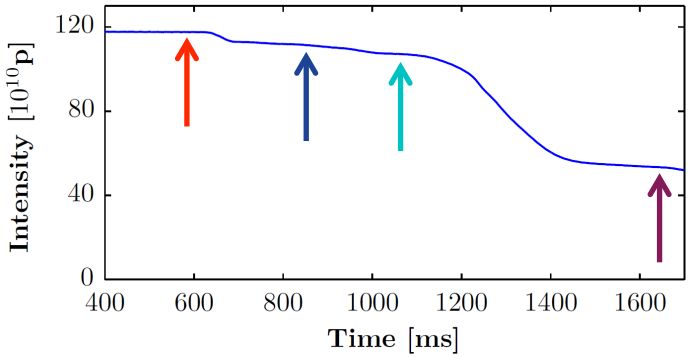
Measurement process

- One tune kept constant along flat bottom
- Dynamic scan of the other

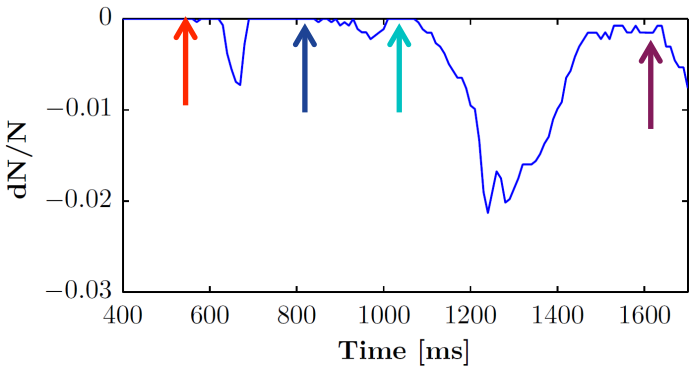




A. Huschauer

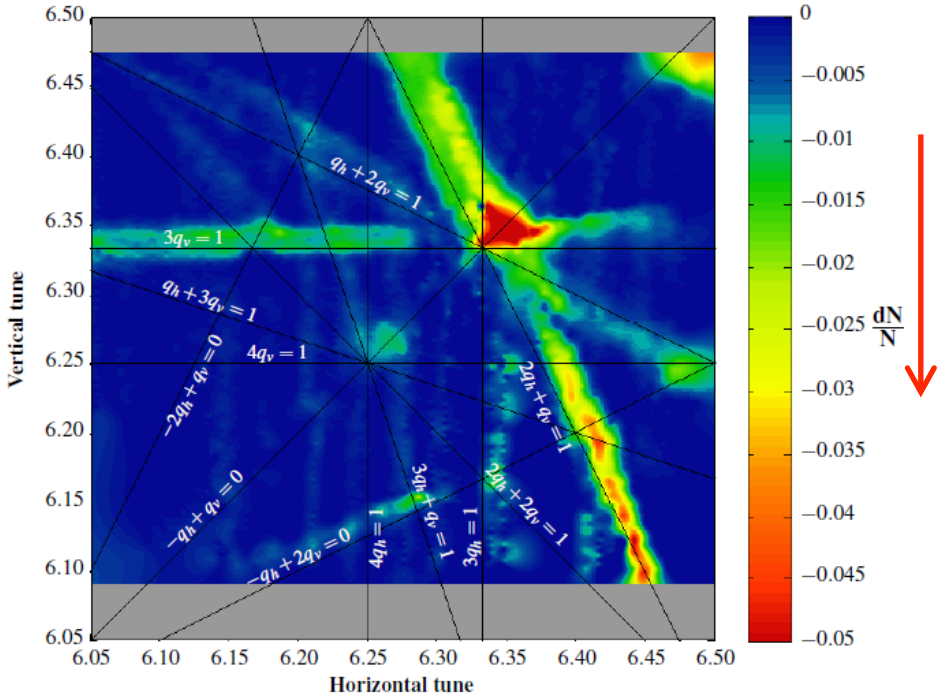


- Intensity recorded throughout the cycle
- Derivative calculated



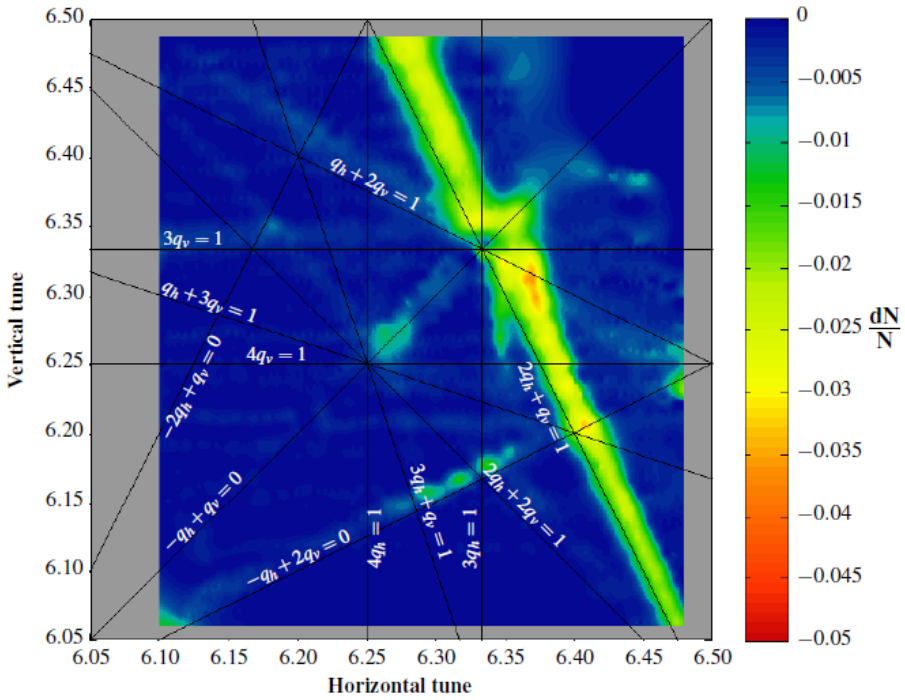
- Normalized by intensity before the respective resonance
- Interpolation on equidistant grid provides tune diagram
- Color scaling informs about losses

I. Tune Diagrams



A. Huschauer

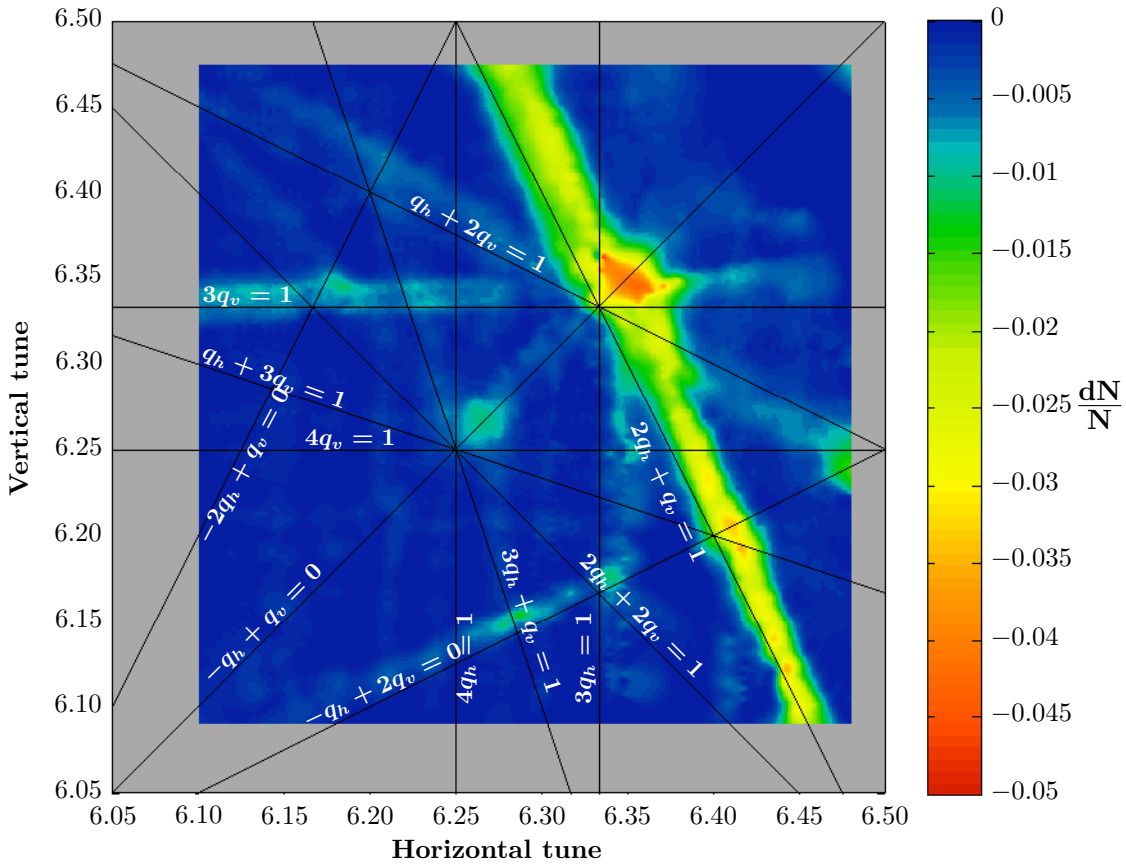
scan direction



I. Tune Diagrams

Tune diagram obtained by combining both scan directions:

A. Huschauer

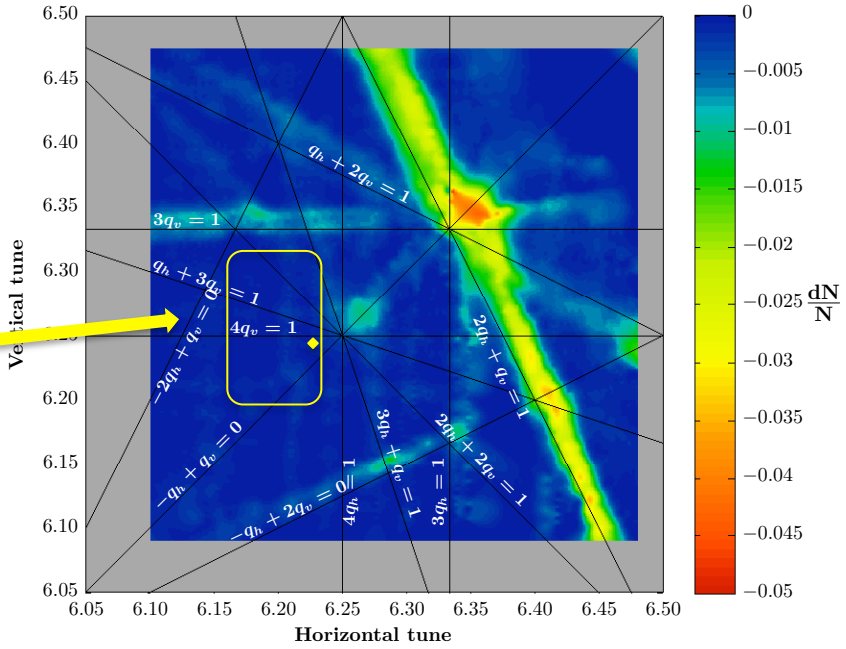


II. Space Charge at injection (1.4 GeV)

Current injection energy: 1.4 GeV

Typical tune-spread ~ (0.18; 0.25)

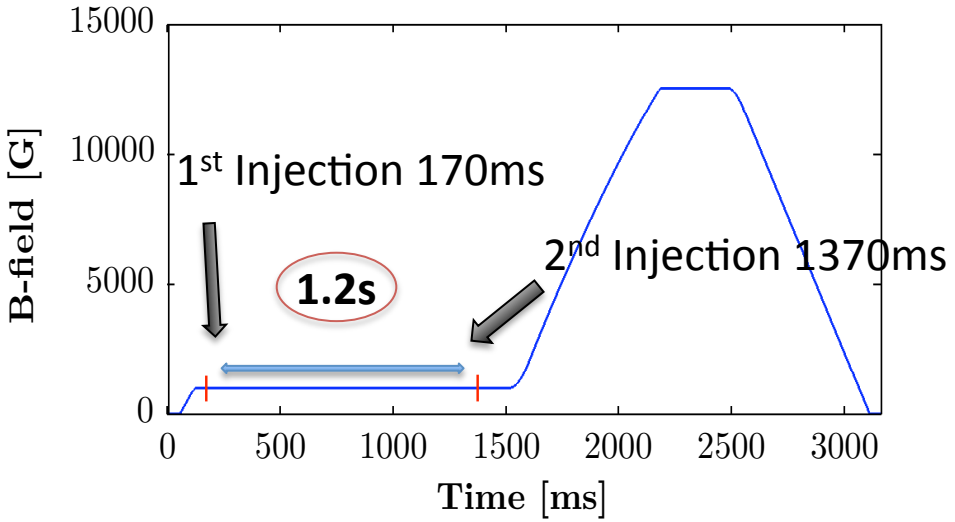
➔ Interesting operation area



LHC double batch injection:

Long flat bottom: 1.2s

➔ Very important effect on LHC beams



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)

III. Simulation Tools

- Simulation code: PTC-ORBIT

  ORBIT : Space-Charge simulation code

  PTC : Tracking code (Non-linear dynamics)

  (Collaboration with A. Molodozhentsev (KEK))

- Current status:
  - A convergence study has been done and the simulation parameters have been set for LHC beams
  - A new magnet model and error distribution are being prepared to be able to reproduce the real lattice and resonances

Tune-spread estimation

- Operational LHC-50 (August 2012):

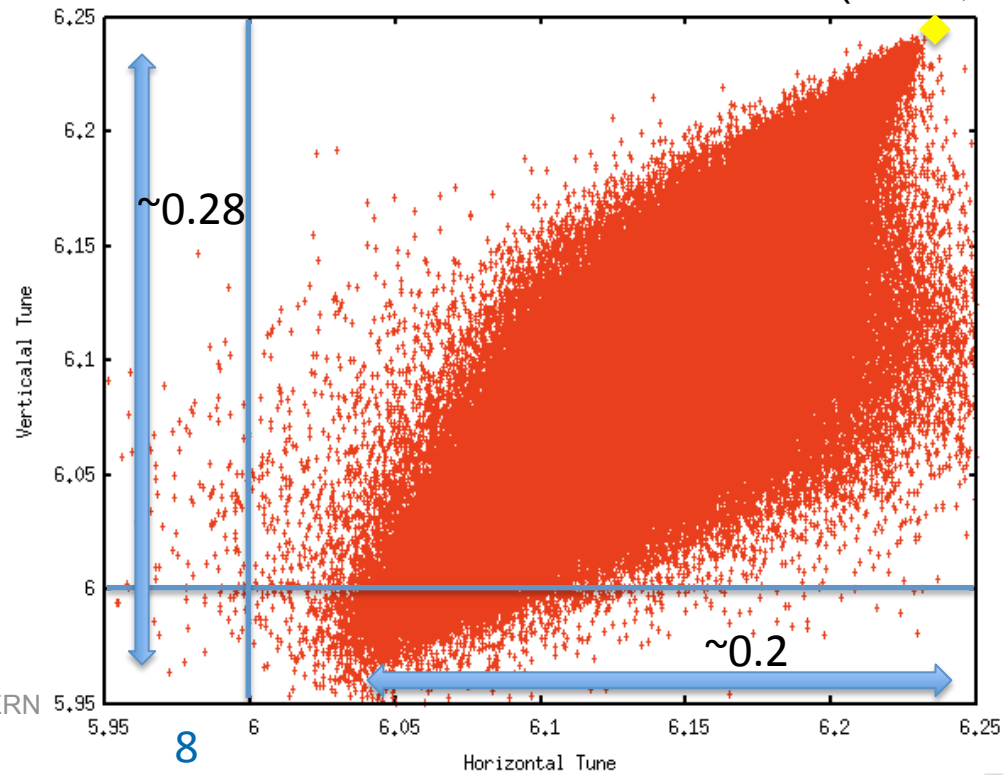
  105E10 p/b ; $\varepsilon_{normalized}$=1.5μm; $\Delta p/p_{(1\sigma)}$= 1.25E-3 ; full bunch length=180ns

  working point (6.235 ; 6.245)

- Laslett tune-spread:

$$\Delta Q_{x,y} = \frac{r_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z}\oint \frac{\beta_{x,y}(s)ds}{\sigma_{x,y}(s)[\sigma_x(s)+\sigma_y(s)]} = (0.19 ; 0.28)$$

- From PTC-ORBIT:

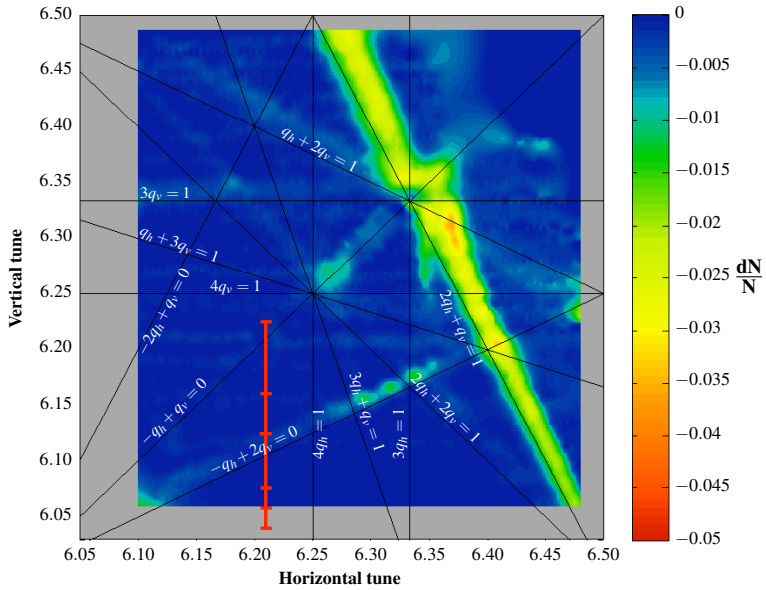


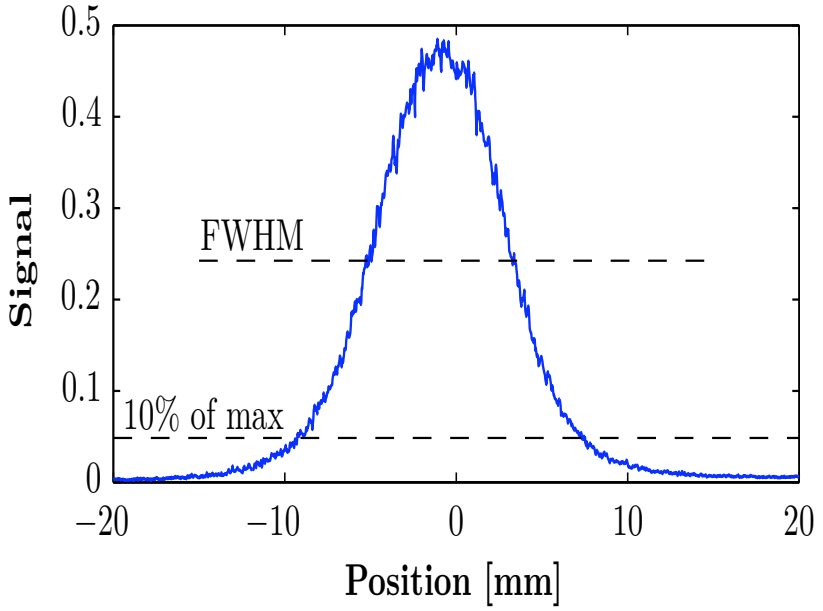
➔Very good agreement

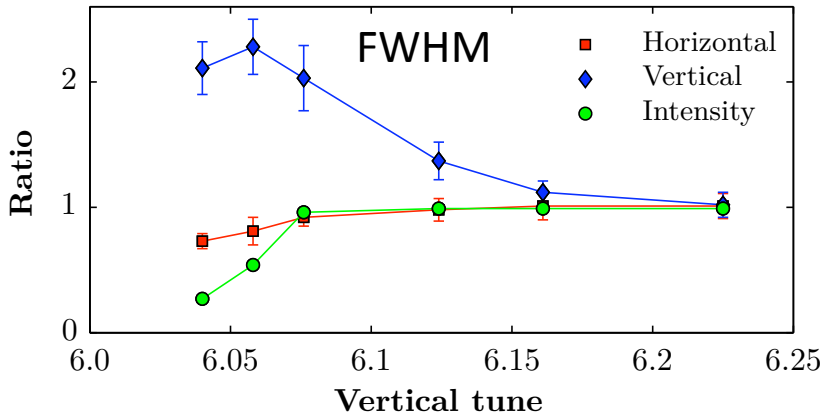
IV. MD: Integer Resonance Scan (14/06/12)

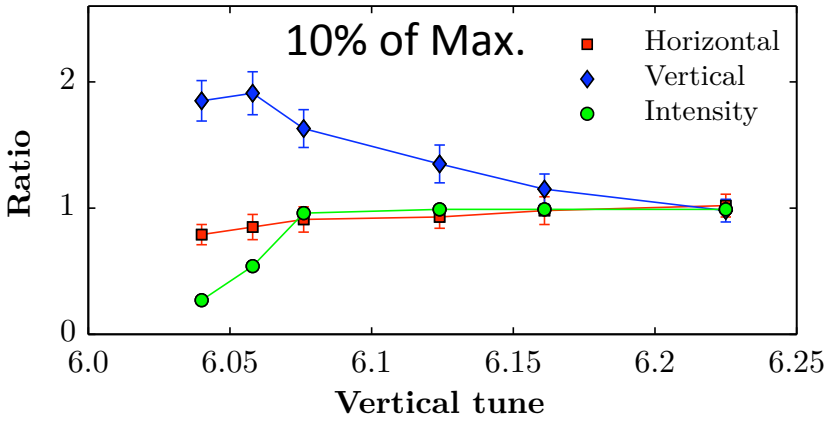
Laslett ΔQ = (0.176 ; 0.26)
PTC-ORBIT ΔQ = (0.17 ; 0.23)

G. Franchetti, A. Huschauer, F. Schmidt, R. WASEF



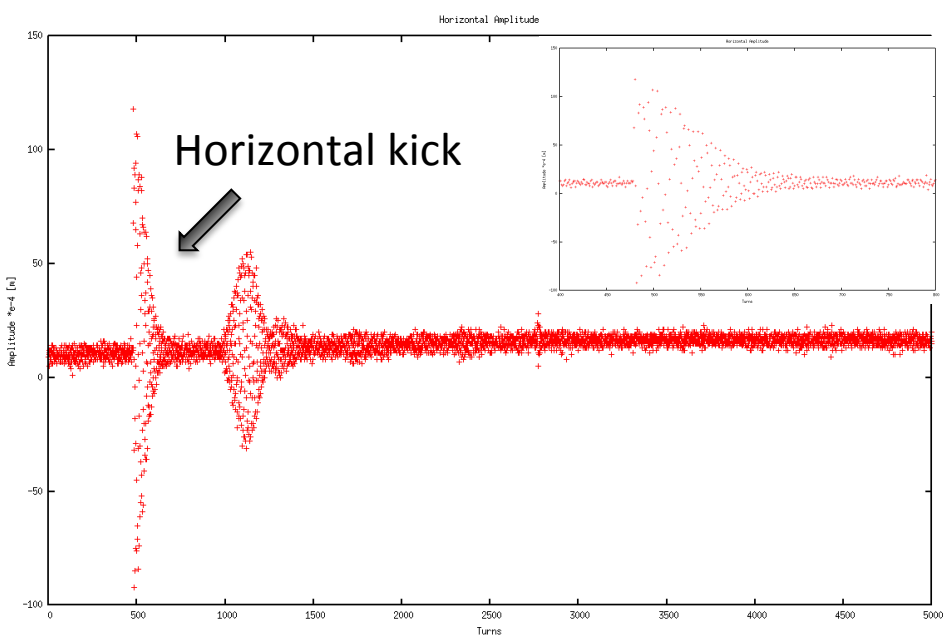


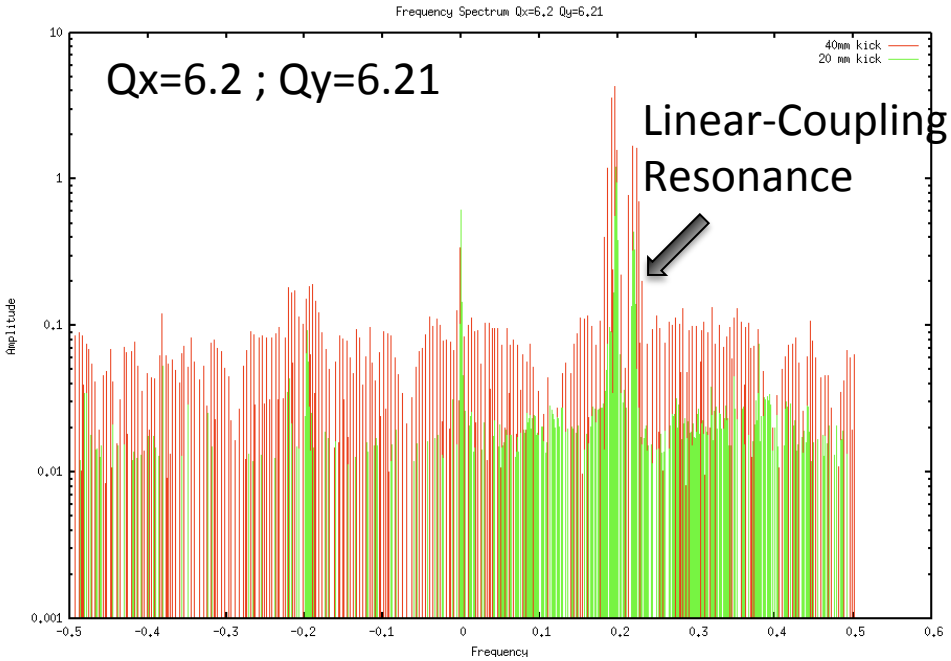




IV. MD: Resonance Driving Terms

- 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.

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; $\Delta p/p$= 1E-3):
    -Horizontal Size (1σ) < 4.5mm (while beam pipe size ~ 146mm)
    -Vertical Size (1σ) < 3.5mm (while beam pipe size ~ 70mm)

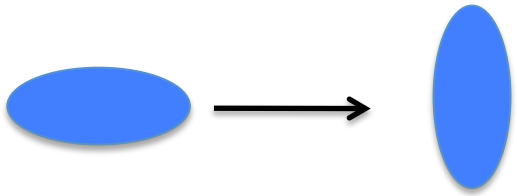
  ➔ Changing the optics by using the transition triplets:
  Increase of the beam size and therefore decreased tune-spread

  - For one of the future options for the High Brightness LHC-25 beam with: 3.35E12 ppb ; $\varepsilon_{1\sigma,normalized}$=2μm; $\Delta p/p(1\sigma)$= 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)

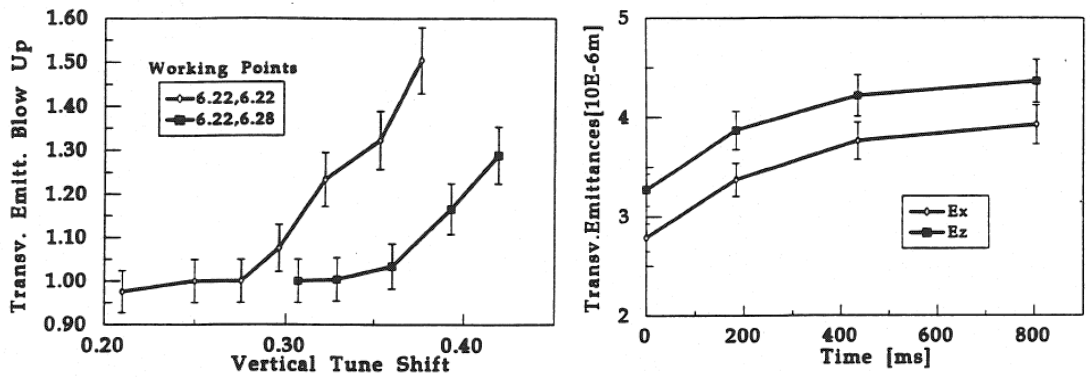
IV. MD: Integer Scan with different Laslett

- Since most beams are close to/on the integer

Method:
- Static scan of different tunes with different tune-spread.
- To produce different tune-spreads: adiabatic shortening of the bunch



- Following the evolution of emittances and intensity to see the effect of the integer resonance as done in CERN/PS 93-18.



V. Summary & Conclusion

- Current maximum acceptable tune-spread ~0.3
- Very Good agreement between: Theory, Simulation and experiment
- Priority: effect of integer resonance on high space-charge beam @ 2GeV with PFW
- Try new optics and measure a tune diagram
- Continue Resonance Driving terms measurement and resonance compensation
- Benchmarking PTC-ORBIT with MD