TRANSVERSE MODE COUPLING IN THE CERN PS

Measurements of a fast vertical instability at transition crossing

THO1DO2

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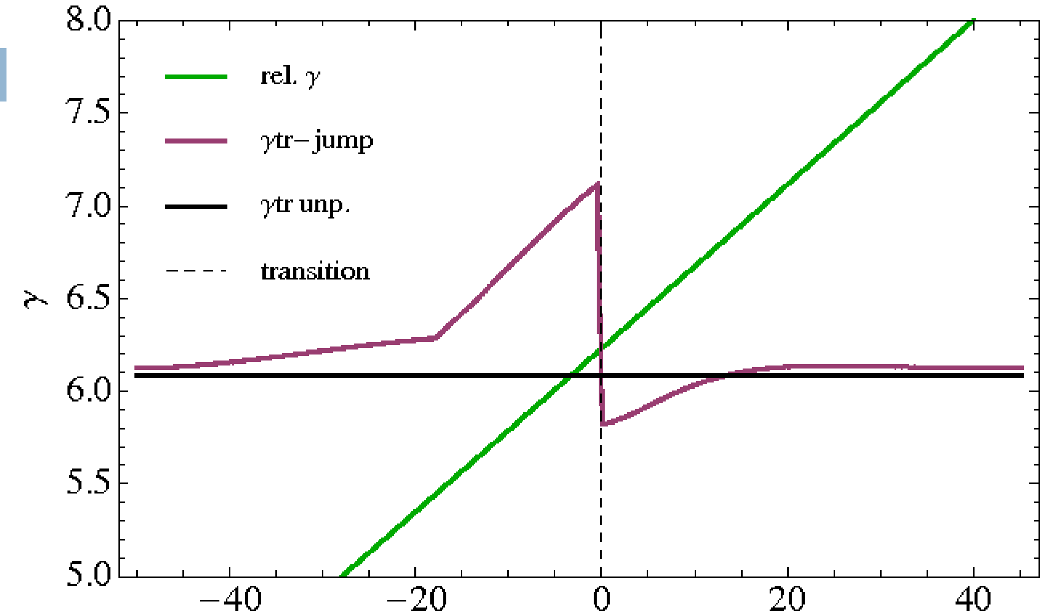
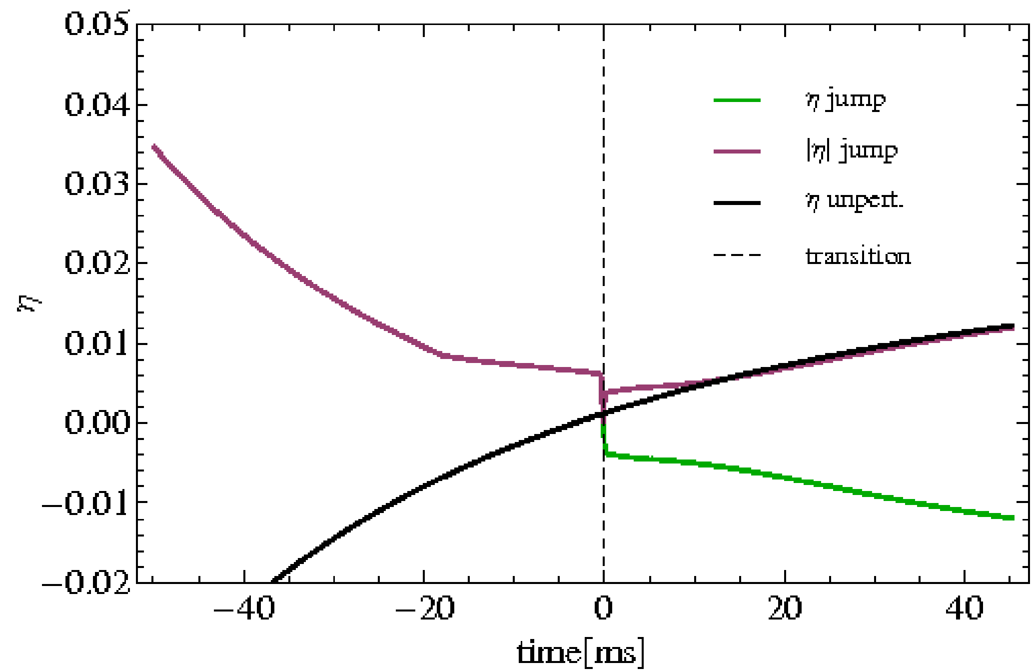
Crossing Transition in the CERN PS

- Asymmetrical gamma jump
- In the past, avoid 'negative mass instability' and longitudinal space charge effect on bunch length.
- Doublets and triplets (combined doublets) quadrupoles in non zero dispersion locations.
- Designed for a Qx,y=6.25 with no tune shift.
- $\Delta\gamma_t$=-1.24 in 500μs
- RF stable phase jump at transition to keep the longitudinal focusing after transition energy

$$\eta = \alpha_p - \frac{1}{\gamma^2} = -\frac{\Delta f/f_0}{\Delta p/p_0},$$



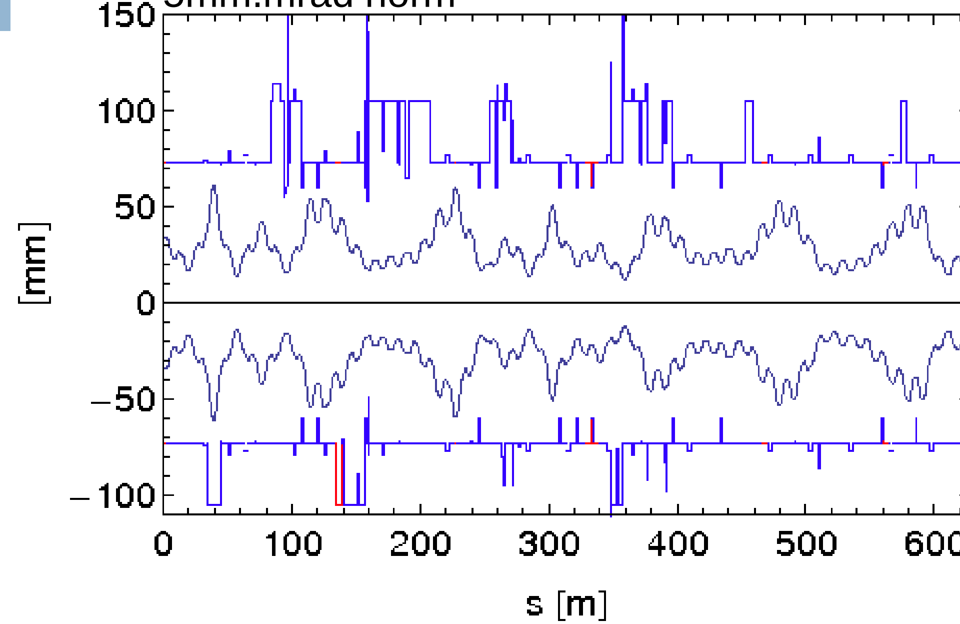


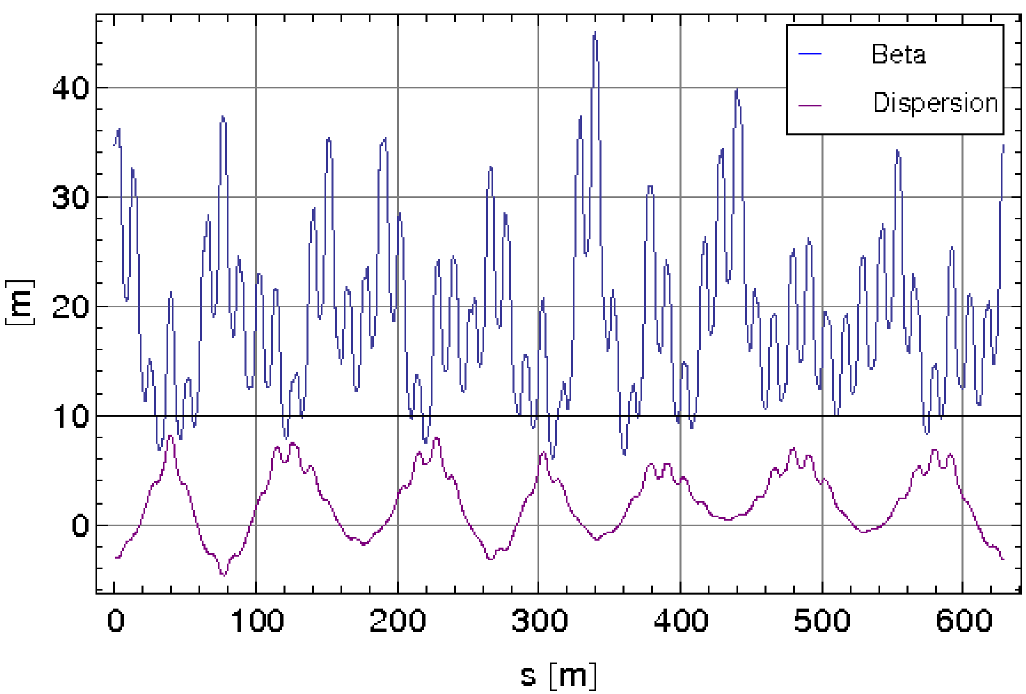
Crossing Transition in the CERN PS

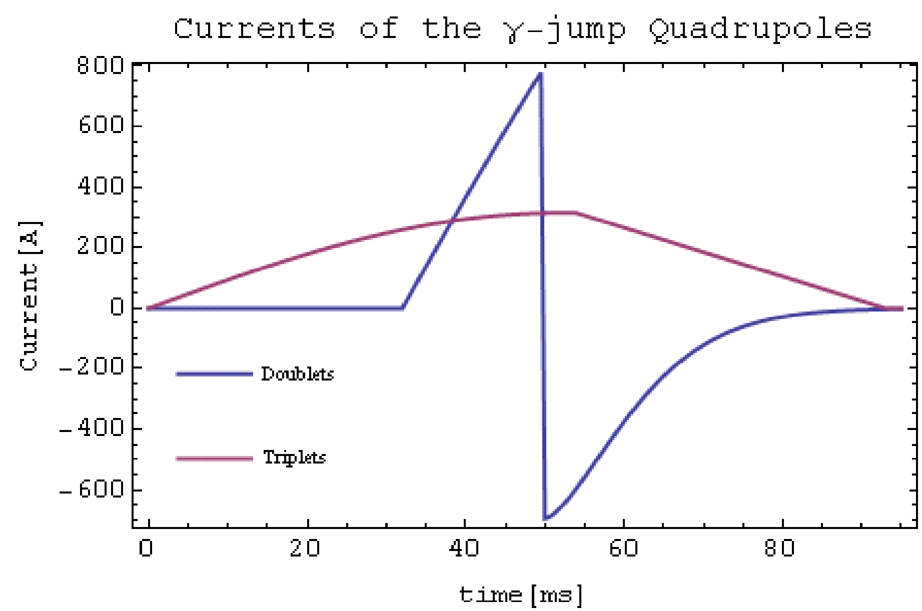
- However …

- Increase the Hor. beam size
- Localized beam losses
- High intensity beams fill the aperture

Hor. beam envelop Hor. Emittance (1sigma) 5mm.mrad norm

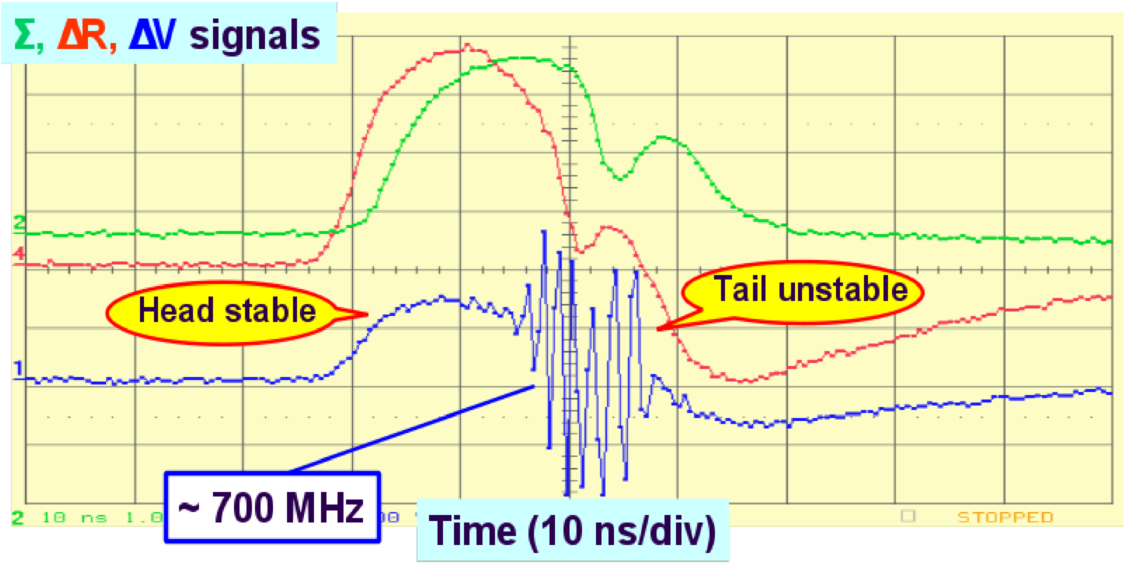






Motivations

- Understand the dynamics of the fast instability at transition (no synchrotron motion) **with/without gamma jump**
- Improve stability of high intensity beams with gamma jump without compromising the longitudinal density.
- Predict also transverse stability of the ultimate LHC beam in the PS at transition crossing



Instability suppressed by increasing the longitudinal emittance

> 2.1 eVs are needed for 7e12 p/b
Single bunch
E. Metral, S. Hankock
(PS/RF Note 2002-198)

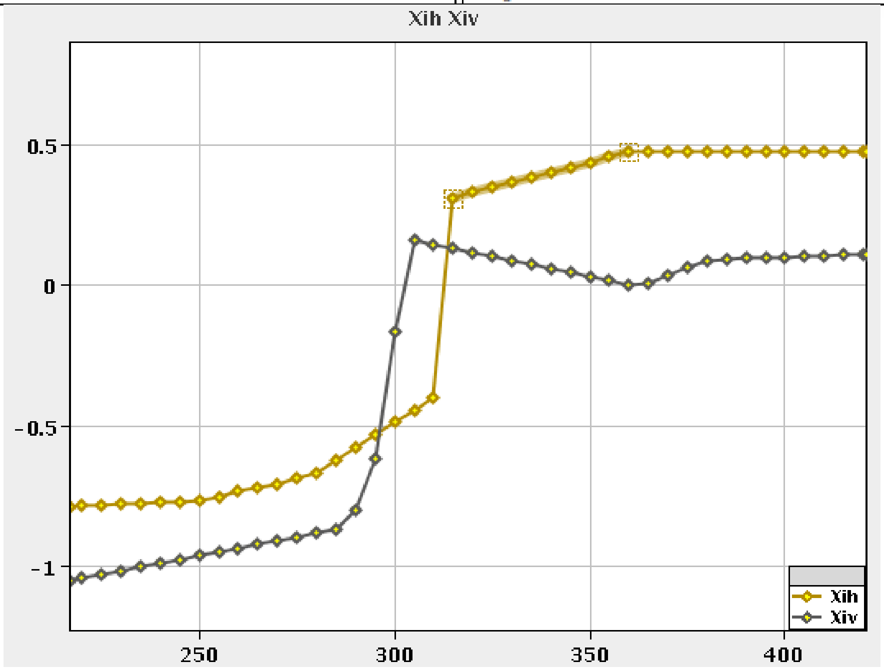
Courtesy E. Metral

Instability measurements without gamma jump: beam setting-up

- No gamma jump
- Tuning the transition timing
- Almost zero vertical chromaticity 'plateau' , create ideal condition for the fast vertical instability
- PS magnets = combined function magnets
- Working point controlled by Pole Face Winding
- No vertical chromaticity measurements around transition energy over 15ms.

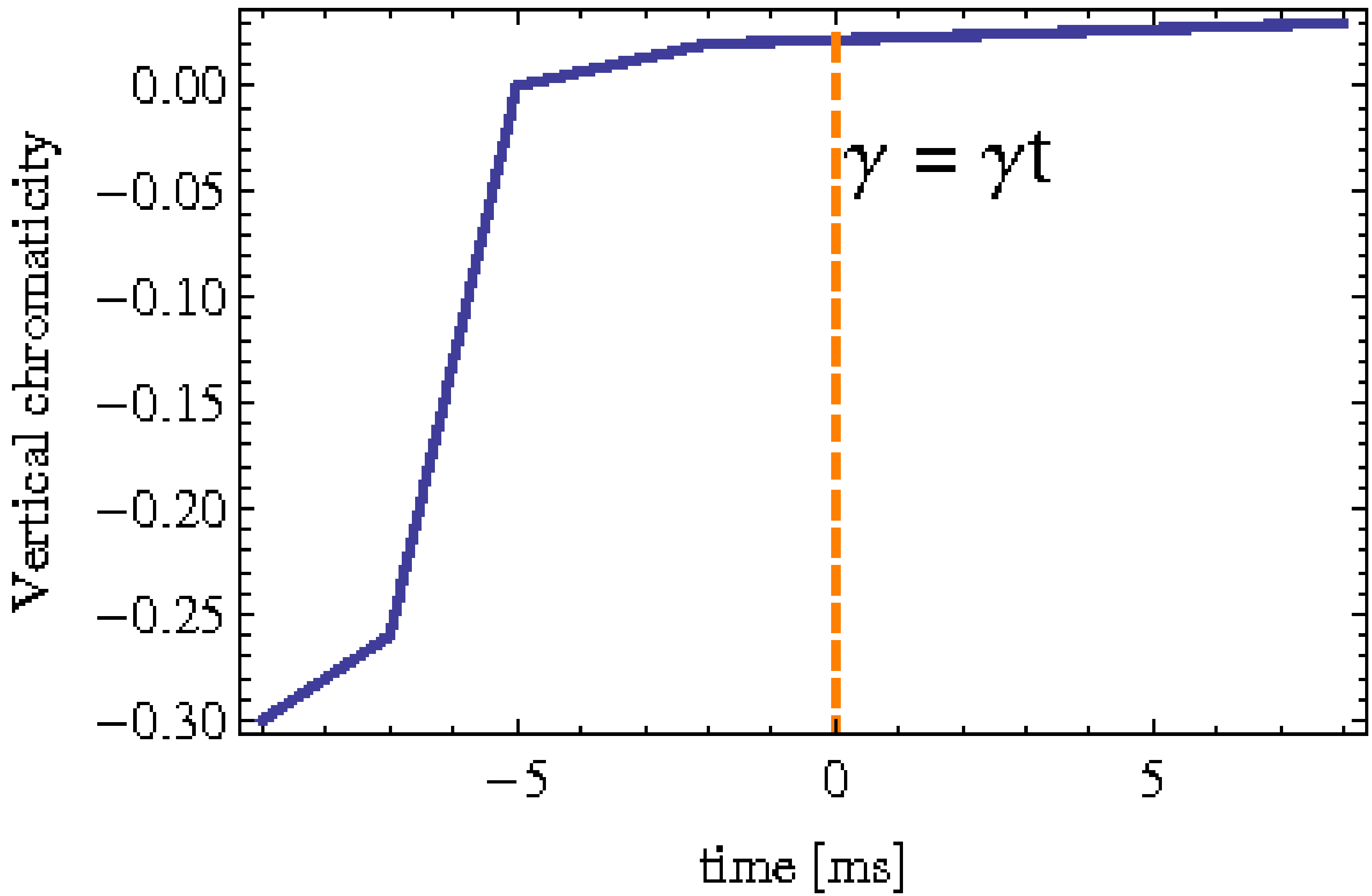
$$\Delta Q/Q=\xi\, \Delta p/p$$

Total energy	$E \simeq 6.1$ GeV
γ_{tr}	6
Transverse tunes	$Q_{x,y}$=6.2
Chromaticities	$\xi_{x,y} \sim 0$
RF Harmonic	h=8
Bunch intensity (single bunch)	$60 \cdot 10^{10}$-$165 \cdot 10^{10}$
Full bunch length	30 ns
Longitudinal emittance	1.50, 1.90, 2.30 eV.s
Transverse $\epsilon_{x,y}^{norm}(1\sigma)$	$\epsilon_x = 1.17 - 2.38$ mm.mrad $\epsilon_y = 1.34 - 2.33$ mm.mrad



Instability measurements without gamma jump: expected vertical chromaticity

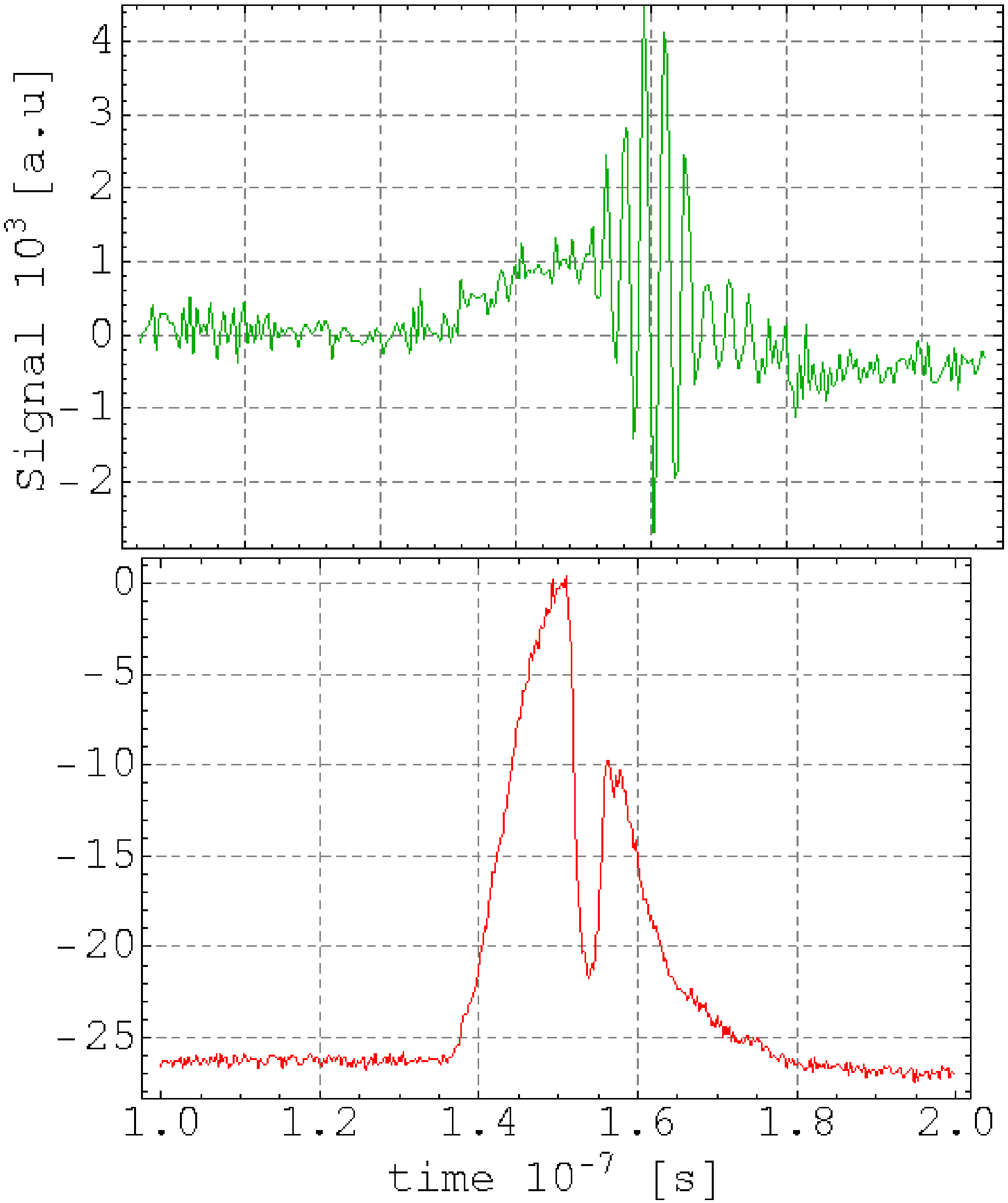
Vertical chromaticity slightly positive at transition



Instability measurements without gamma jump: beam setting-up

- Instrumentation: wide band pickup, band width 2.5MHz-1GHz
  (See the "A 1.5 GHz wide-band beam position and intensity monitor for the electron-positron accumulator (EPA)")
- No measurements of the vertical position of the bunch centroid, but of the transverse profile.
- The pickup is acted as filter, to compute the bunch centroid position:

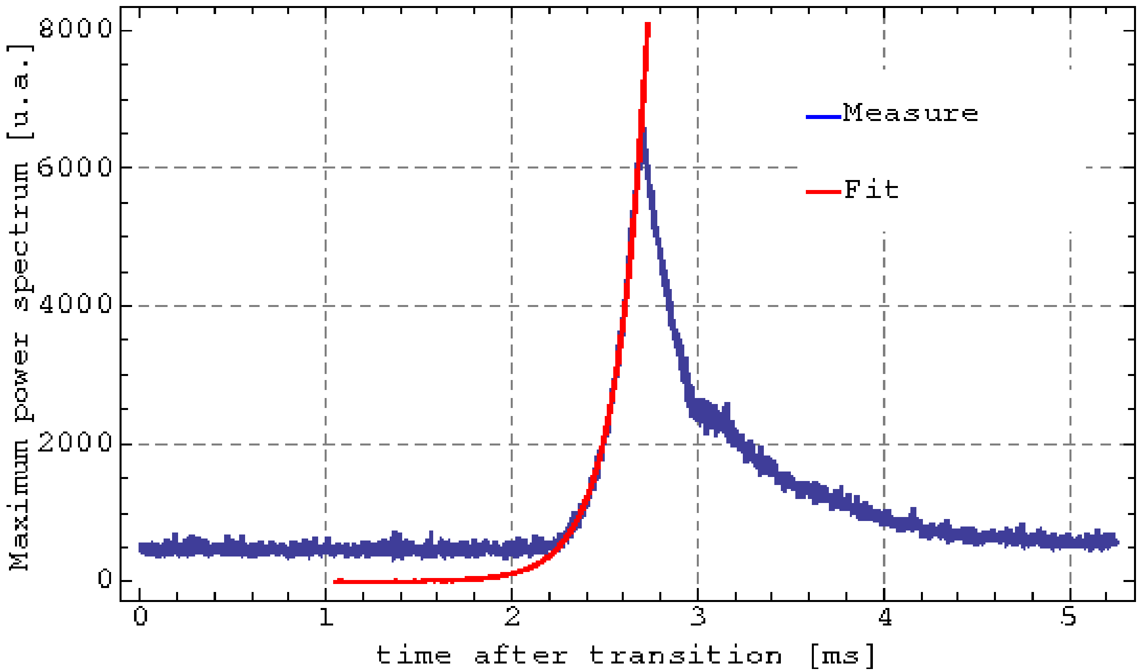
  $\langle y \rangle = \Delta/\Sigma$ where Δ is the difference signal (transverse) and Σ the sum signal (longitudinal)

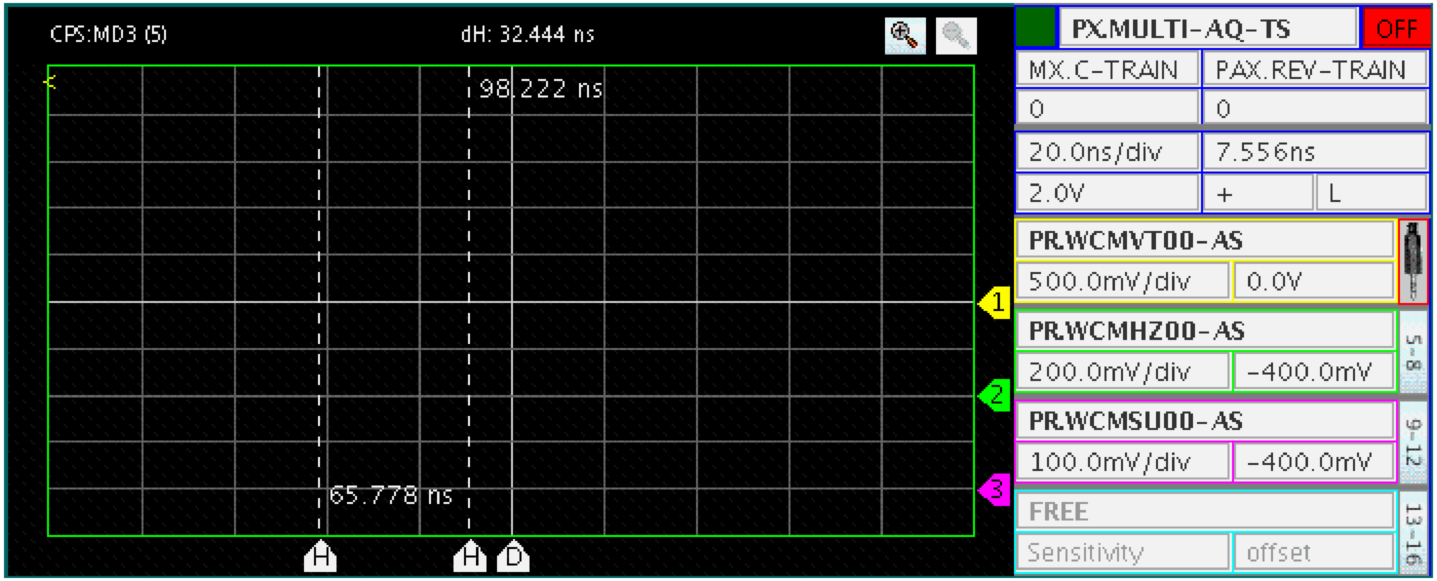


- **<u>For OUR analysis</u>:**

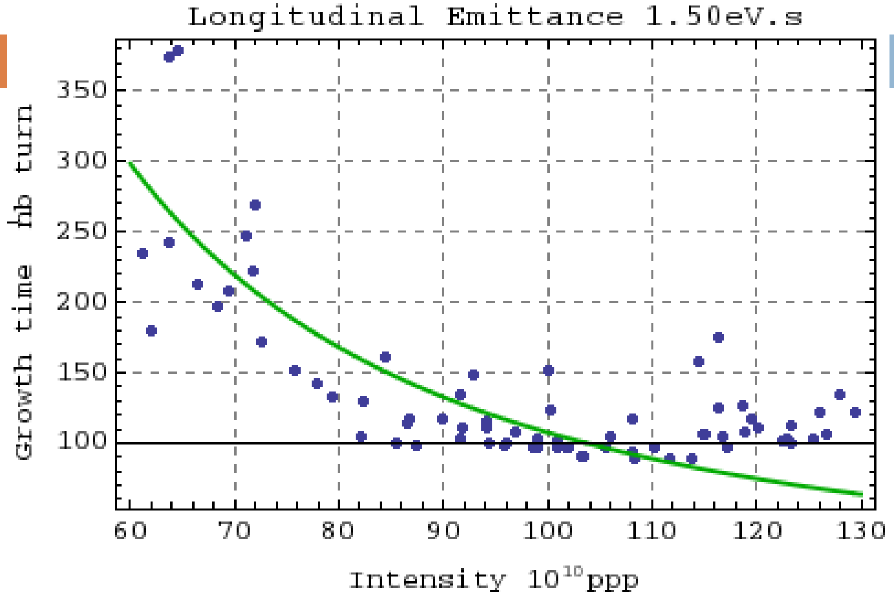
time growth = Max of the instability frequency in the FFT, while a filter is implementing in the analysis.

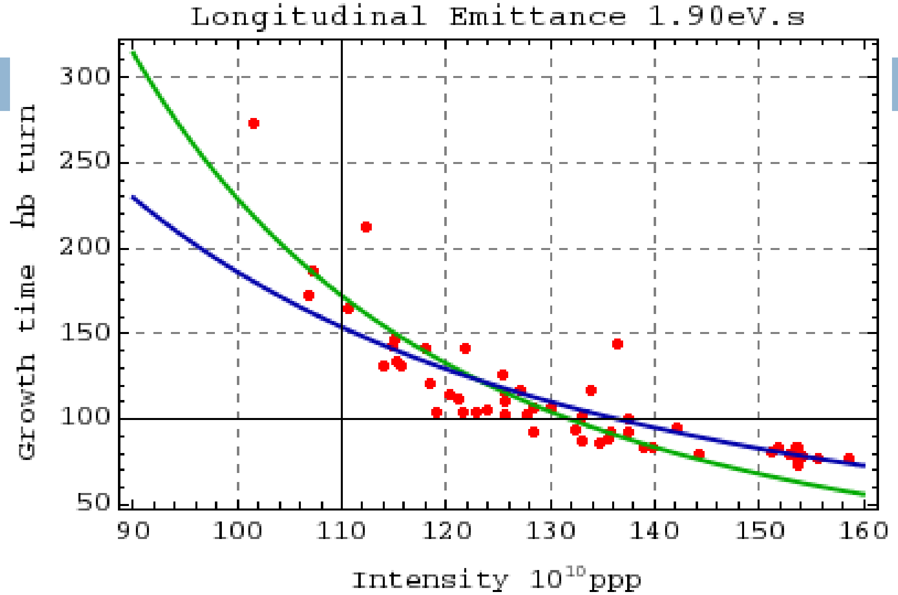
- Vertical instability appears 2 ms after transition in the measurements, whereas depends of the absolute value of |η|

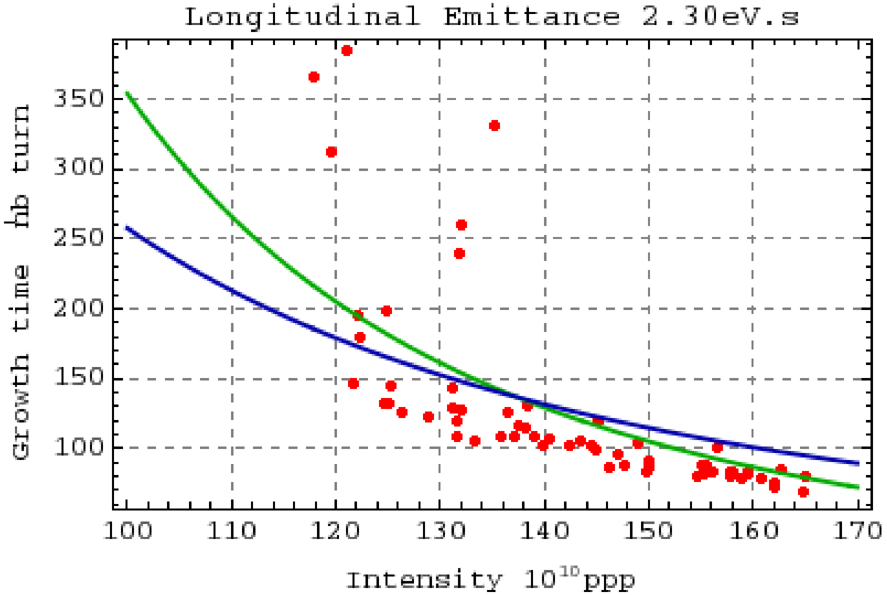


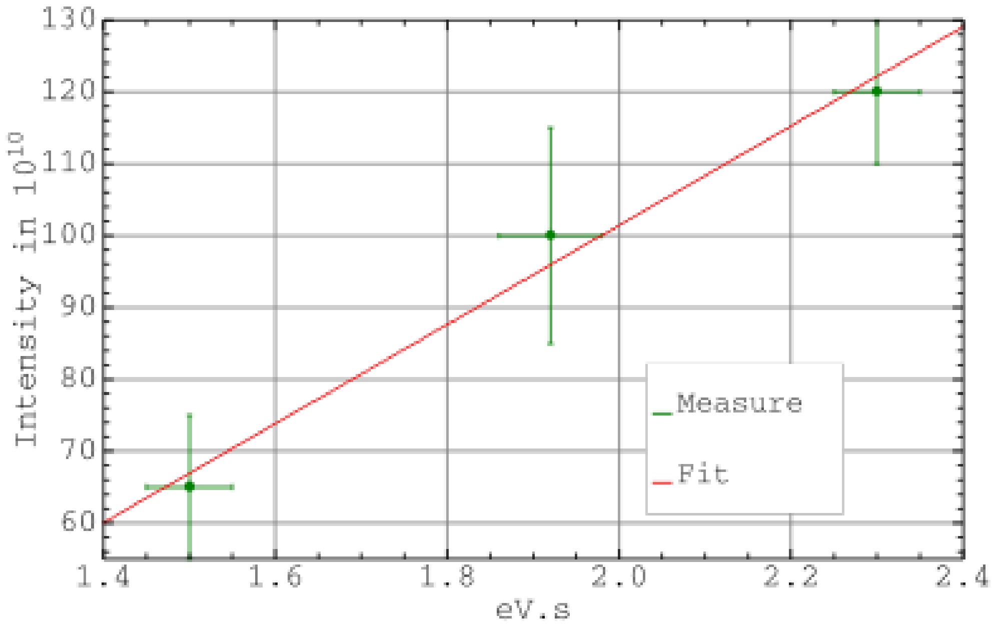


Time growth of the instability









Measurements without gamma jump: summary

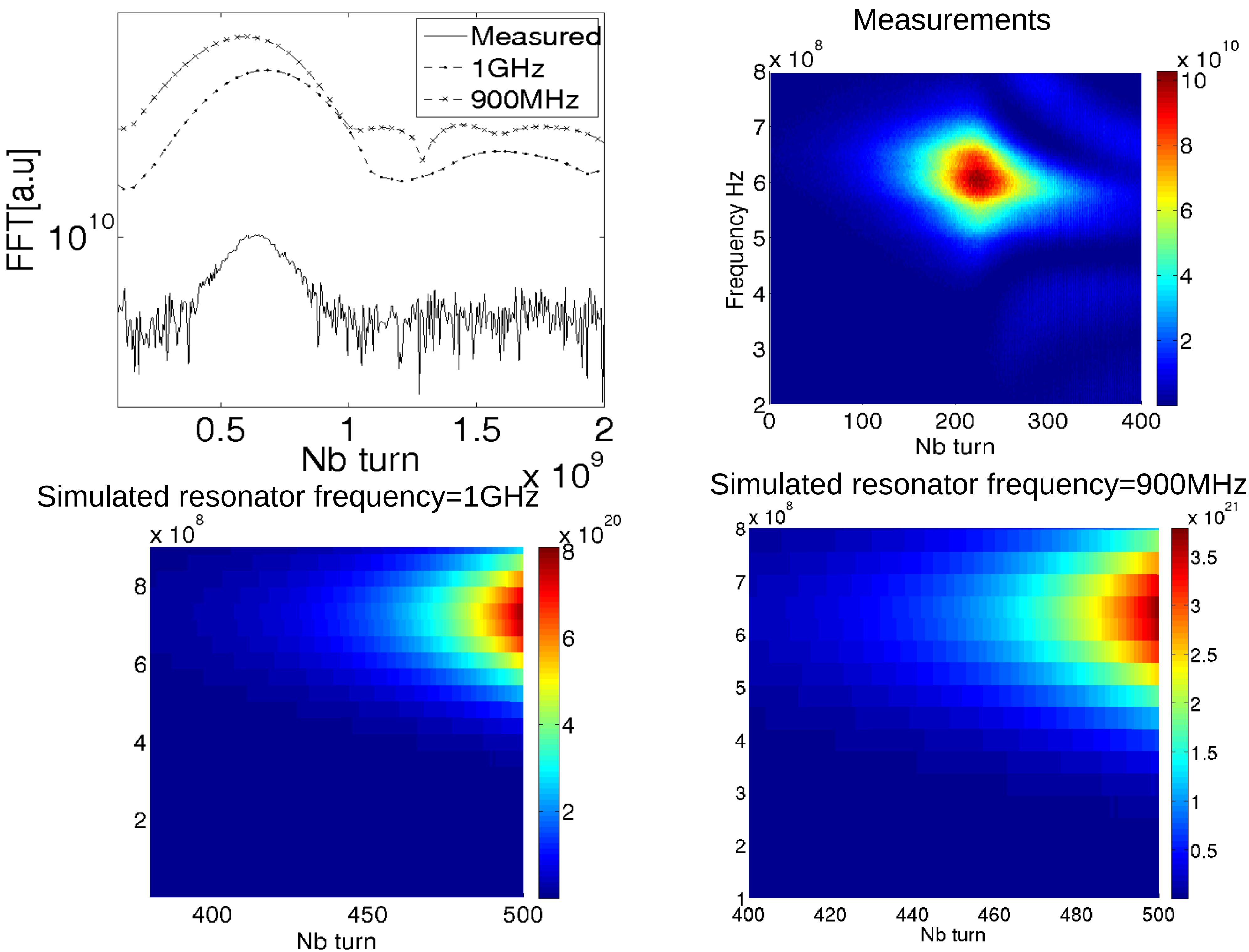
- Vertical fast instability
- Travelling wave with high frequency oscillation pattern ~700MHz: head of the bunch stays stable, while the instability starts in the middle of the bunch, the tail becomes unstable
- No nodes when traces are superposed.
- Without gamma jump, the vertical instability start up to 2ms after transition energy.
- Fast instability , take few turns to develop, much less than one synchrotron period.
- TMCI characteristics.

Instability simulations

Parameters	PS - nToF
R [m]	100
ρ [m]	70
Bdot [T/s]	2.2
Vrf [kV]	200
harmonic	8
el [eVs]	1.50 - 2.3
Nb [e10 p/b]	50 - 150
Є [1σ norm] μm	1- 2.8
Betax=betay[m]	16
Pipe [cmxcm]	7x3.5
Qt	6.25
Hor. & Vert. ξ	0/0-varying
Gamma transition	6.08
Acceleration	46 GeV/c/s

- HEADTAIL code
- Broad band impedance model:

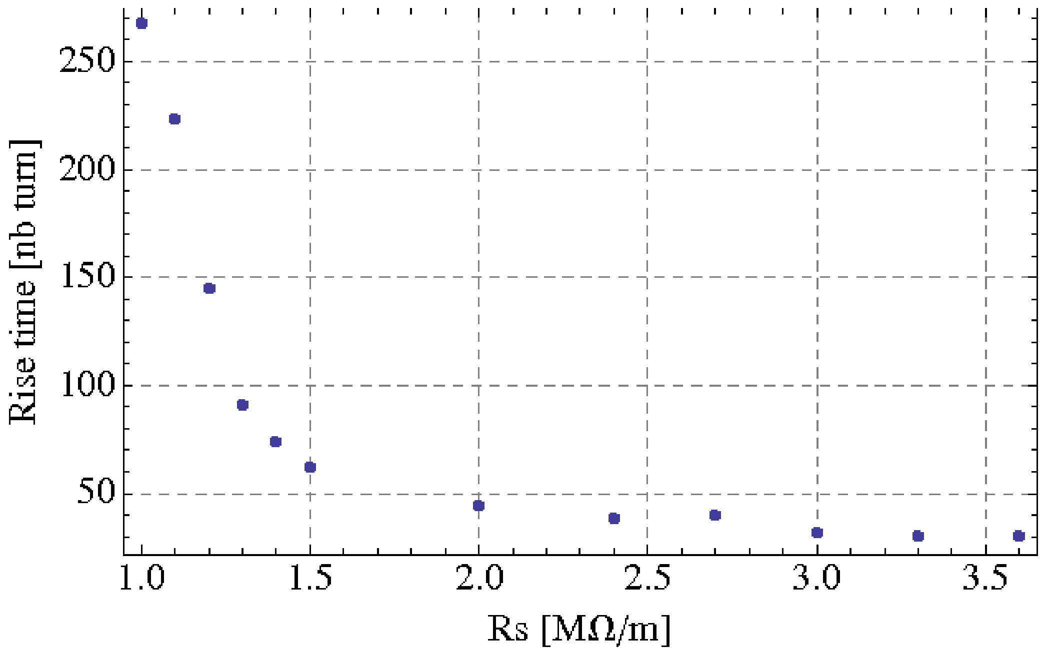
  in the past (1989)
  frequency resonator=1GHz
  quality factor Q=1
  Transverse shunt impedance
  Rs=3MΩ/m
- Flat chamber
- No longitudinal and transverse space charge
- Acceleration
- No higher orders in momentum compaction.
- Chromaticity as in measurements

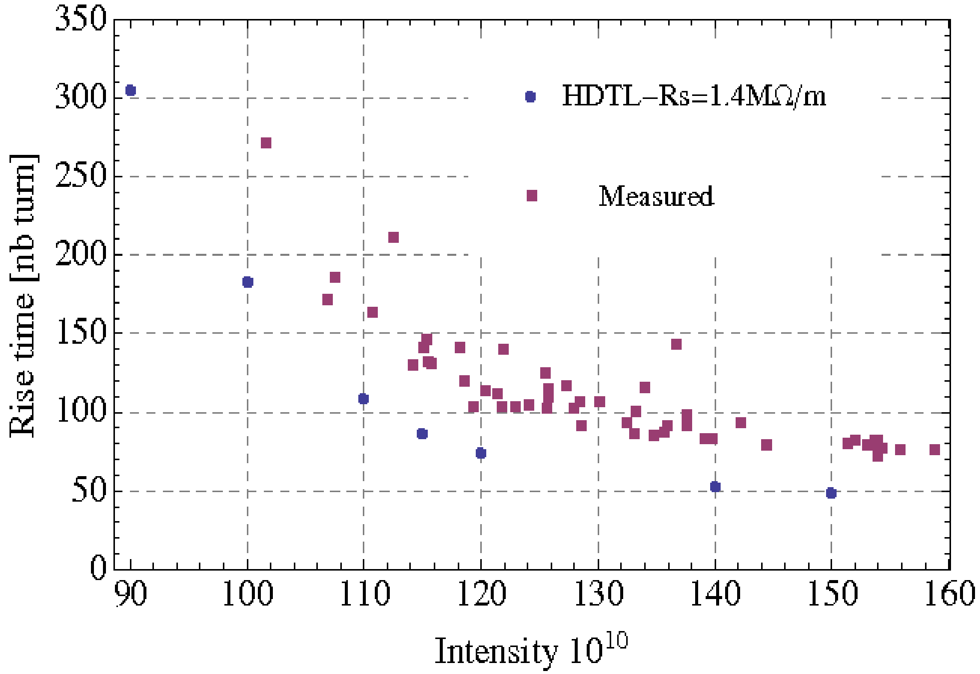


Measured
1GHz
900MHz
FFT[a.u]
10^{10}
0.5
1
1.5
2
Nb turn
x 10^9
Measurements
x 10^8
Frequency Hz
x 10^{10}
Nb turn
Simulated resonator frequency=1GHz
x 10^8
x 10^{20}
Nb turn
Simulated resonator frequency=900MHz
x 10^8
x 10^{21}
Nb turn

Transverse shunt impedance Rs

- Intensity 120e10 protons single bunch
- long. emittance(1 sigma)=1.9eVs
- Time growth in measurements=120 turns (one PS turn=2.2microsecond)
- Resonator frequency=1GHz, Q=1.





Offset of 25 turns in measurements with respect to HEADTAIL simulations

Benchmark with HEADTAIL: Summary

- **Broadband impedance model**
  Rs~1.4, fr=1GHz, Q=1 → Rough model

- **Coherent tune shift measurements at injection done in 1989 Rs=3MOhm/m: global impedance measurements (Dipolar and quadrupolar part of the impedance)**
A. Burov, V. Danilov, Phys.Rev. Lett., Vol.82, Nb.11

- **In HEADTAIL, rise time calculation, mostly dipolar part fitting.**

- **Strong need of a better PS impedance model like in the SPS**

- **Most of the high intensity beams are unstable (injection, transition …)**

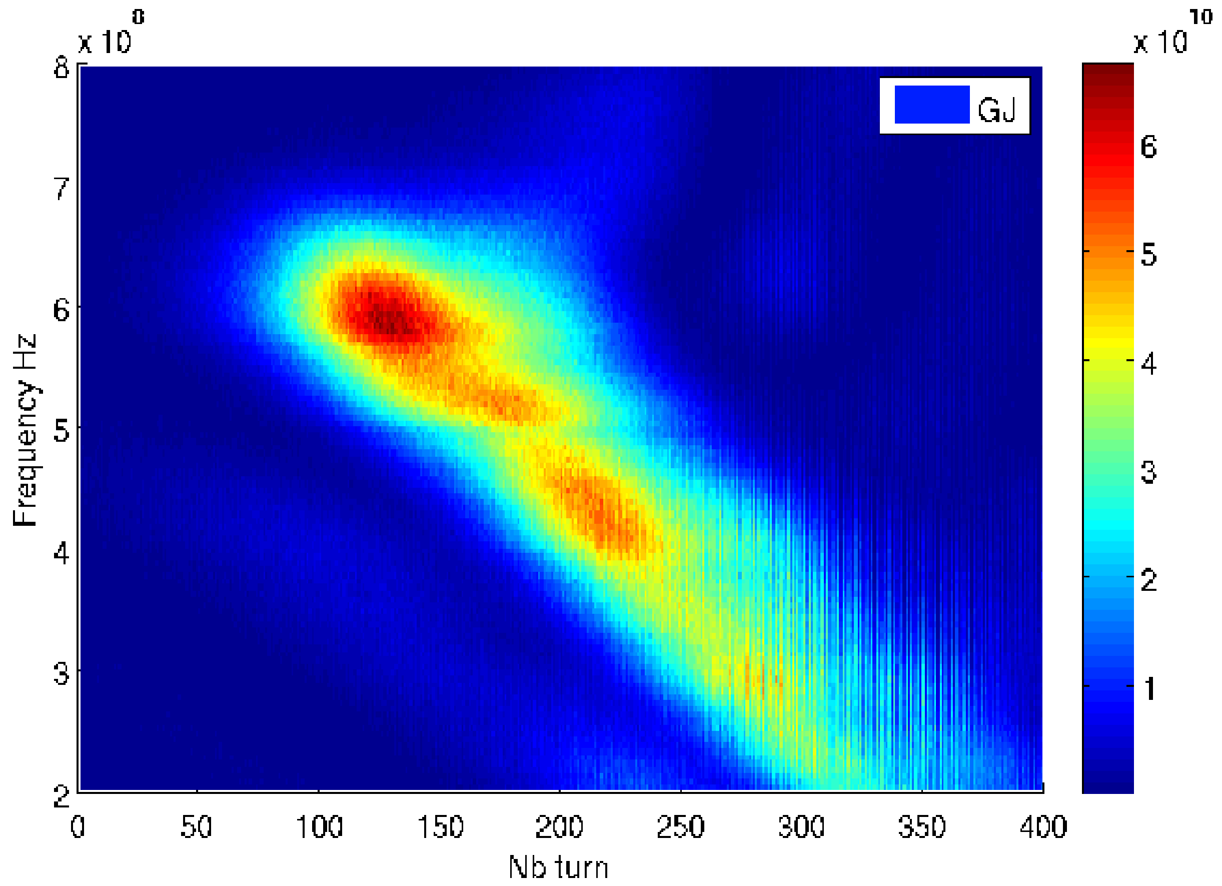
- **Next step: coherent tune shift measurements at injection energy 1.4GeV/c**

Measurements with gamma jump: setting up still on going

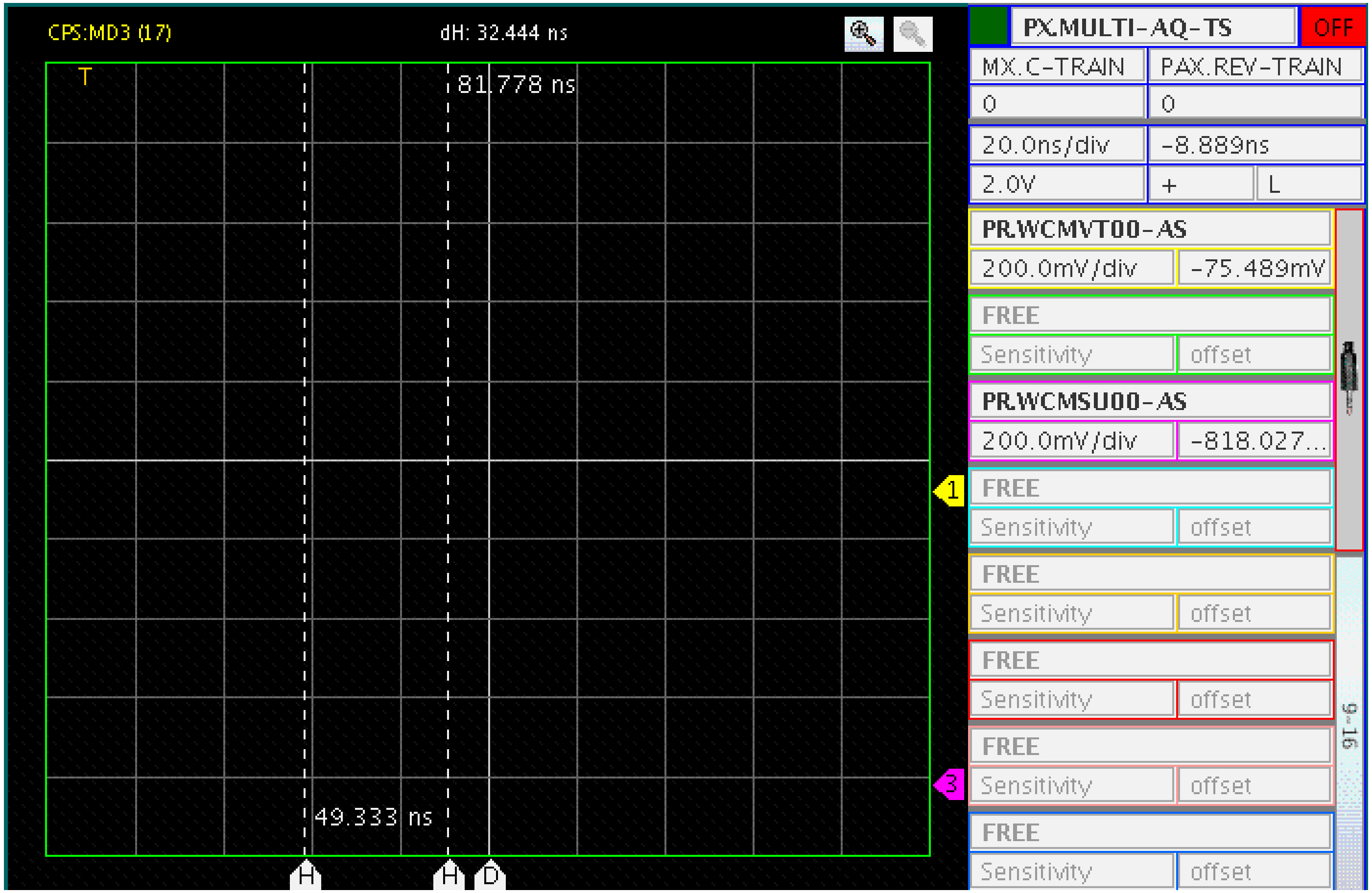
- **Trying to keep the vertical chromaticity plateau**

- **Transition time changed by several milliseconds ~6ms with gamma jump**

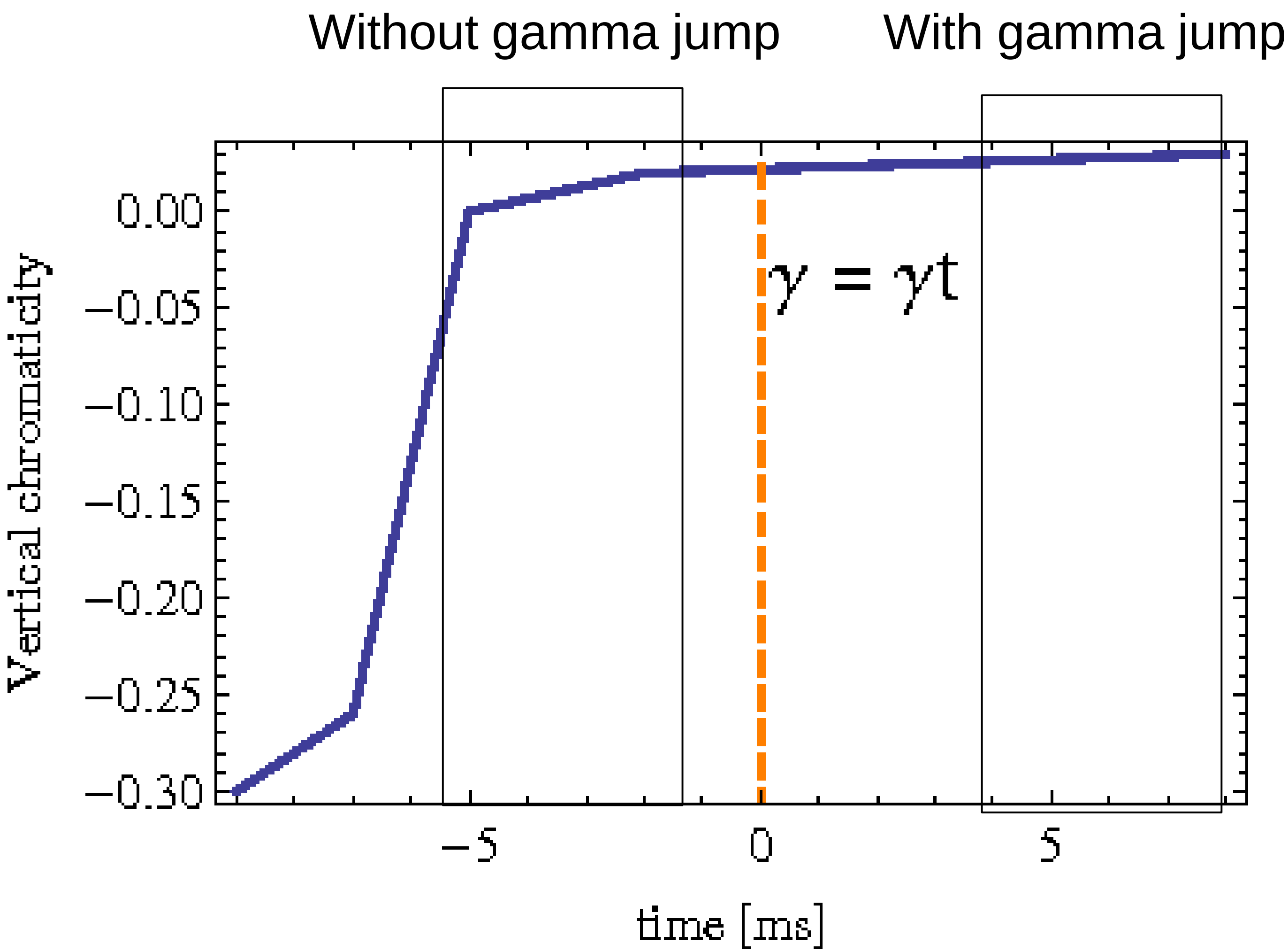
- **Issues to set the beam since losses occur due to the optics distortion.**



Instability measurements with gamma jump



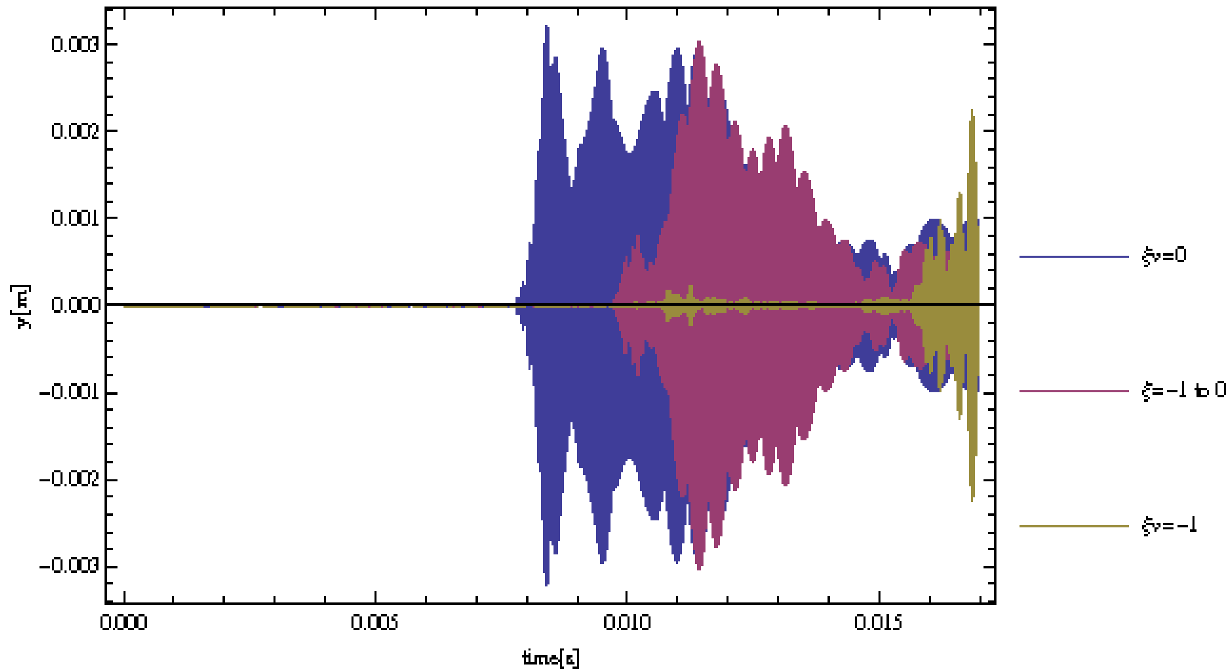
Instability measurements with gamma jump: expected vertical chromaticity



Issues, discussions

Why does the fast vertical instability appears after transition crossing while with gamma jump it appears before ?

2 different ways to cross transition, slow crossing without gamma jump



Compare three cases:
- $\xi v=0$
- $\xi v = -1$ $\eta<0$ and $\xi v = 0$ $\eta>0$
- $\xi v=-1$

→The instability is delayed after transition

- **What about transverse space charge on the instability delay?**
- **Spread in γt, particles cross transition slowly and not at the same time**

Conclusions - Outlooks

- Fast vertical instability believed to be a Transverse Mode Coupling
- Estimation of the vertical dipolar part of the broadband impedance.
- Strong need of a better impedance model for the PS
- The measurements with gamma jump will bring more informations
- Next step:

- Coherent tune shift measurements
- Questions about transverse space charge? (G. Rumolo, MOA2IS02, ICAP06)
- Implement gamma jump in HEADTAIL
- Find an alternative cure for the transverse instability instead of compromising the longitudinal emittance (via chromaticity, new gamma jump scheme etc..)

THANK YOU FOR YOUR ATTENTION