Summary for
Single particle effects I (head-on)

K. Oide (KEK)

Beam-beam effects under the influence of external noise (30')
Kazuhito Ohmi (KEK)

Beam-beam effects with a high pile-up test in the LHC (30')
Georges Trad (Universita e INFN, Roma I (IT))

Measurements of the effect of collisions on transverse beam halo diffusion in the Tevatron and in the LHC (30')
Giulio Stancari (Fermi National Accelerator Laboratory)

K. Ohmi

- Emittance growth caused by random noise in the offset at collision + nonlinear beam-beam force. (theory, simulation)
- Noise in the rf phase of crab cavity.
- Intrabeam scattering.
- Nonlinear response of coherent beam-beam oscillation modes.

Emittance growth caused by random noise

Weak-strong model:

$$\frac{\langle \Delta J^2(N)\rangle}{N} = \left(\frac{N_p r_p}{\gamma}\Delta x\right)^2 \frac{1}{8}\sum_{k=0}^{\infty} \frac{(2k+1)^2 G_k(J)^2 \sinh\Theta}{\cosh\Theta - \cos(2\pi(2k+1)\nu_x)},$$

$$= \left(\frac{N_p r_p}{\gamma}\Delta x\right)^2 \frac{1}{8}\sum_{k=0}^{\infty}(2k+1)^2 G_k(J)^2 \quad \text{for } K(n)=\delta_{0n}$$

$$\Theta = -\ln(1-1/\tau)$$

does not depend on tunes if the noise is white.

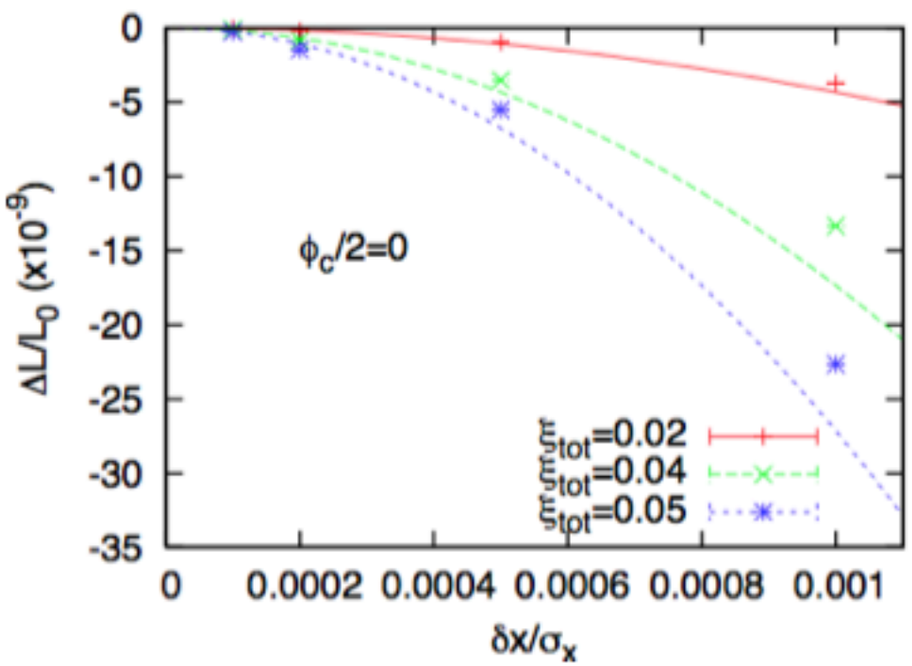
Strong-strong model:

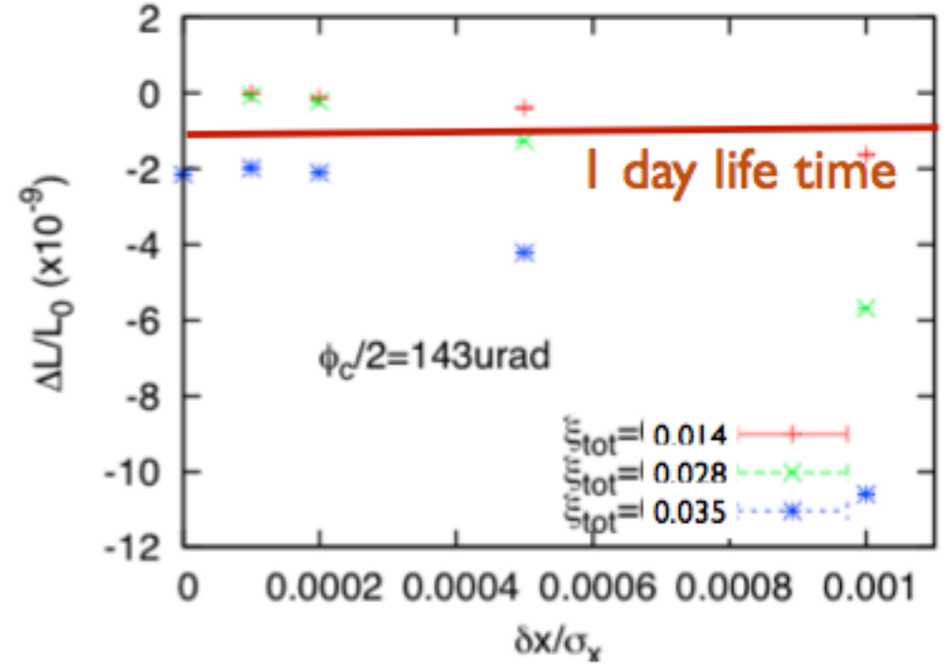
$$\frac{\delta\varepsilon}{\varepsilon} \approx \frac{K}{\left(1+\frac{G}{2\pi|\xi|}\right)^2}\frac{\delta x^2}{\sigma_x^2} \qquad G = 1/\tau \qquad \Delta x^2 = \frac{\delta x^2}{2G}$$

$K = 0.089$: form factor

Simulation w/wo crossing angle

- Weak-strong simulation
- Quadratic dependence on $\delta x/\sigma_x$ and ξ. $\tau=1$
- Critical noise amplitude, 0.02% for ξ=0.04-0.05.
- Degradation due to noise depends on ξ, and little depends on the crossing angle.





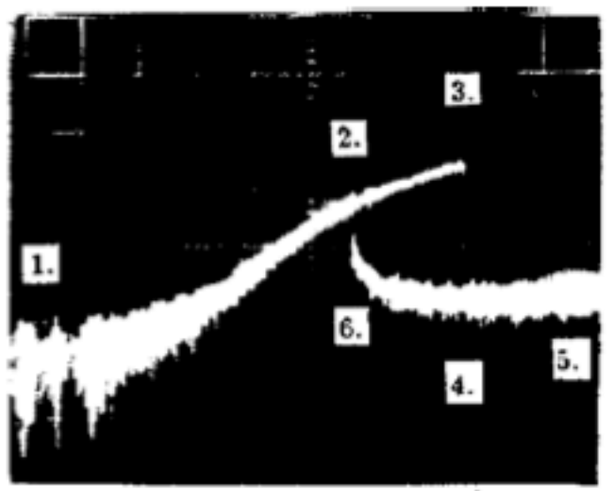
Tolerance for the crab cavity noise

- $\Delta x/\sigma_x$=0.002 for the design parameter N_p=2.2x10^{11} and τ=1. $\Delta\varphi_{RF}$=4x10^{-4} rad.
- $\Delta\varphi_{RF}$=4x10^{-4} τ rad, because of the scaling of τ, $\Delta x \sim \tau$.

$$\Delta\varphi = \frac{\omega_{RF}\Delta x}{c\theta_c/2}$$

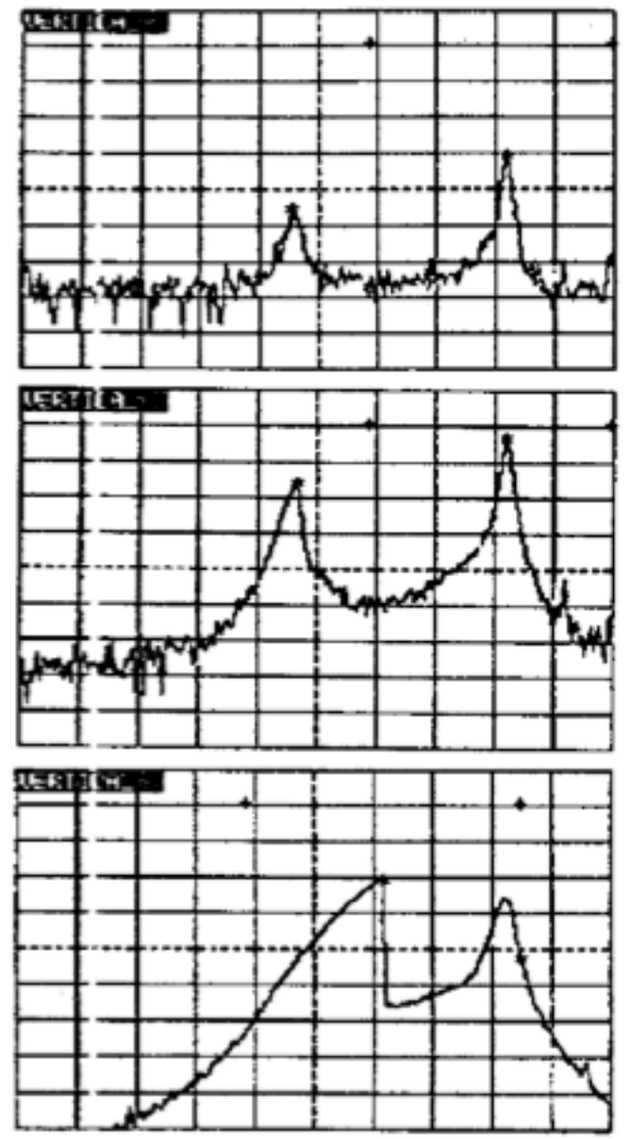
- Measurement in KEKB, 1.7x10^{-4} rad ~~at~~ higher than 1kHz (τ=11). One order of the tolerance.

Jump phenomenon in Beam-beam system Ieiri and Hirata, PAC89



H: 1 kHz/div.
V: 10 dB/div.

Figure 1. Hysteresis phenomena of the π-mode.



a) D=-30 dB

b) D=-15 dB

c) D= 0 dB

Figure 2. Resonant curves of the π- and the 0-modes with three relative deflector amplitudes, D=-30 dB, -15 dB and 0 dB. The right peaks show the 0-modes and the left the π-modes. The start frequency is 26 kHz and the stop is 41 kHz. The horizontal scale is 1.5 kHz/div. and the vertical is 5 dB/div.

- Jump phenomenon was seen in beam oscillation response in colliding beams of TRISTAN.

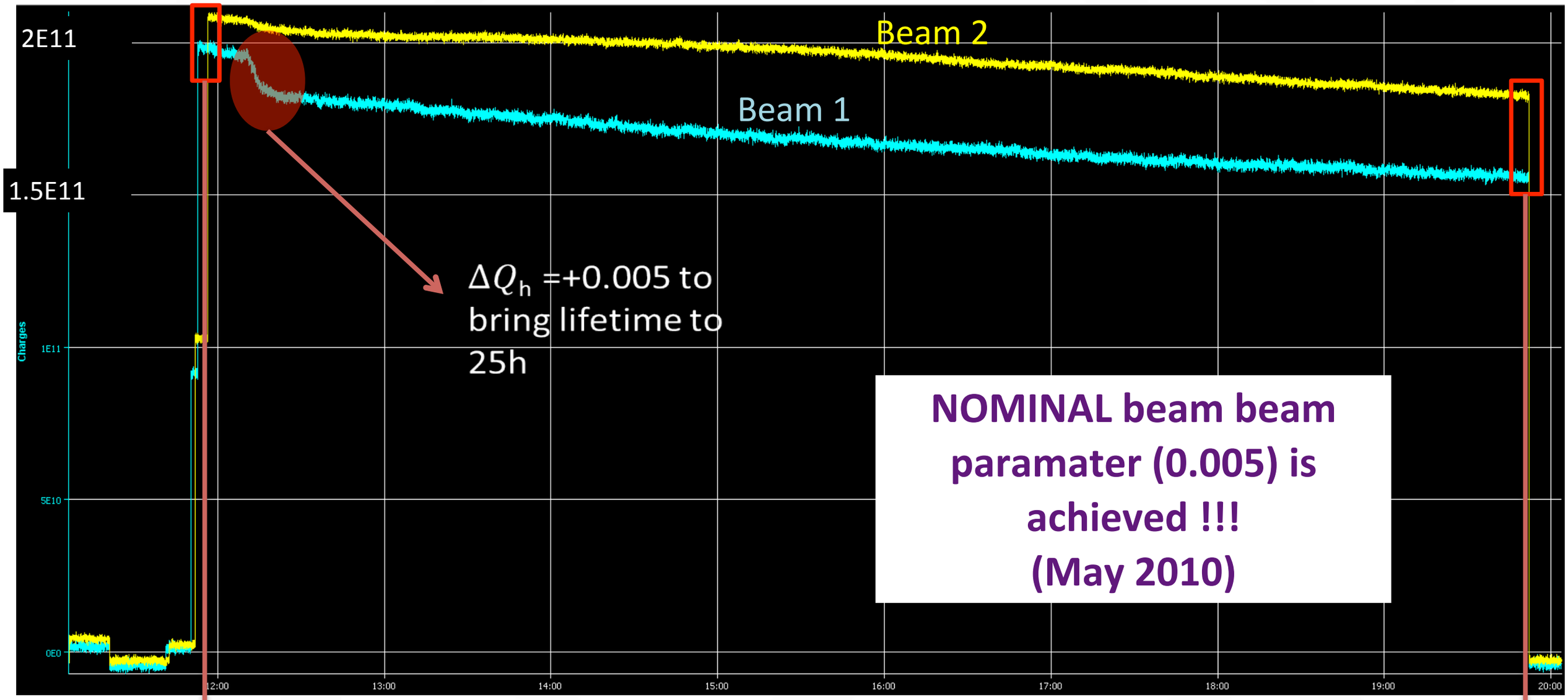
Summary

- Review of beam-beam effects under influence of noise.
- Simulation of beam-beam noise for crossing collision in LHC.
- Tolerance of the crab cavity noise. It shoule be safe.
- The response for a sinusoidal noise (excitation). Good agreement of measurement and simulation.

G. Trad

- Beam-beam effects with high pile-up test in the LHC
- LHC commissioning > exploring the beam-beam parameters
- High Pile-up tests at the LHC
- SPS Q20, new scenarios for brightness

Overview



NOMINAL beam beam paramater (0.005) is achieved !!! (May 2010)

	Beam 1		Beam 2	
(µm)	H	V	H	V
Injection	2.2	2.4	3.3	3.7

	Beam 1		Beam 2	
(µm)	H	V	H	V
After LumiScan	2.4	2.7	3.6	4.3

	Beam 1		Beam 2	
(µm)	H	V	H	V
End Coll.	2.9	3.2	4.9	7.4

The Quest continues…

Fill 1765-1766 (May 2011)

GOALS:

- check the feasibilty of colliding high intensity bunches (HO) with a beam beam linear parameter greater than nominal

Setup:

- E = 450 GeV
- β* 11 m in all Ips
- Nominal crossing angles andSpectrometers off in IP2 / IP8
- Q: collision tunes (.31 H .32 V)
- ADT on at injection and off afterwards

3 Tests:

- 1 bunch /beam
- 2 bunches x beam
- 4 collisions x bunch

1.6*10^11 emitt 1.2 microns at injection→ blowup (mainly vertical) end up with average almost 2.2 microns

ξ : 0.009/IP , total 0.018 (collide only IP1,5)

Small tune scan, no lifetime effect, emittance blowup beam 2

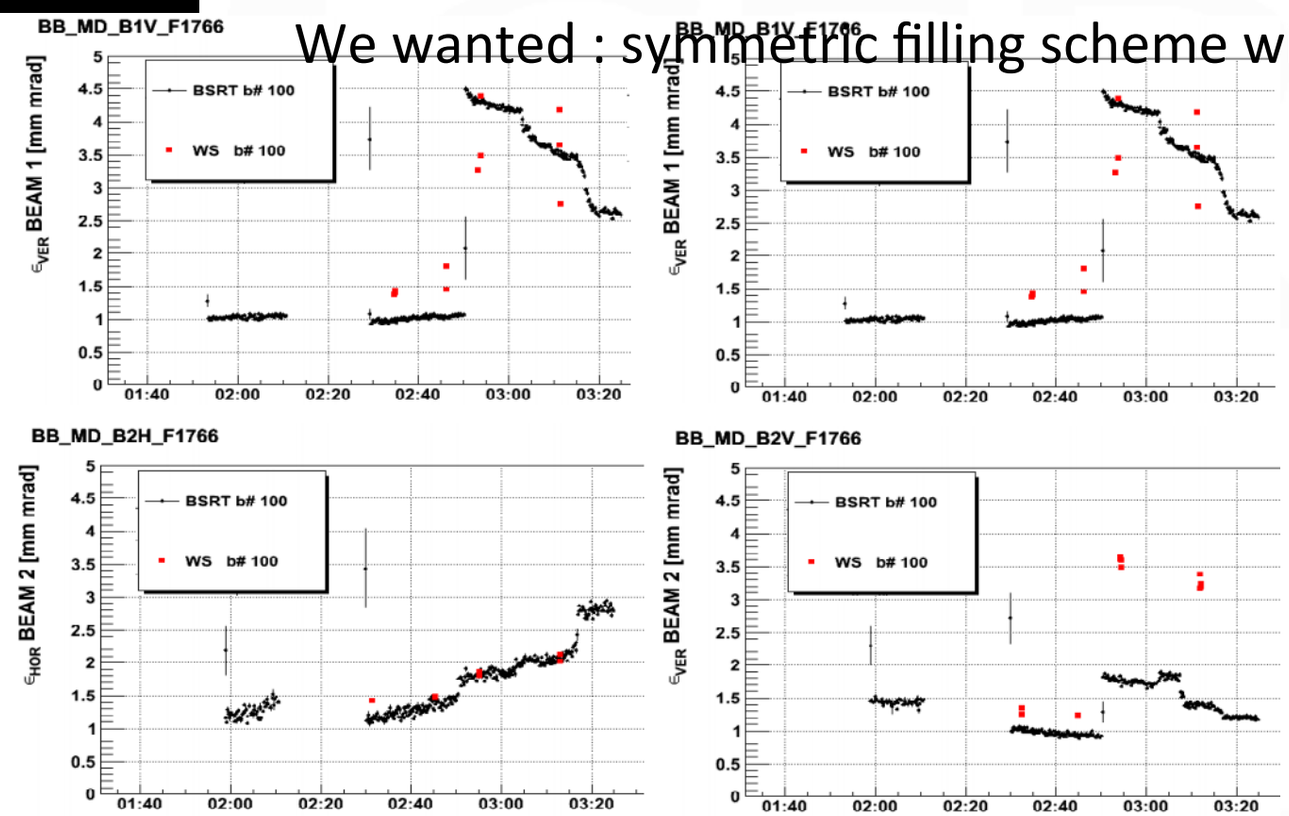
The Quest continues…

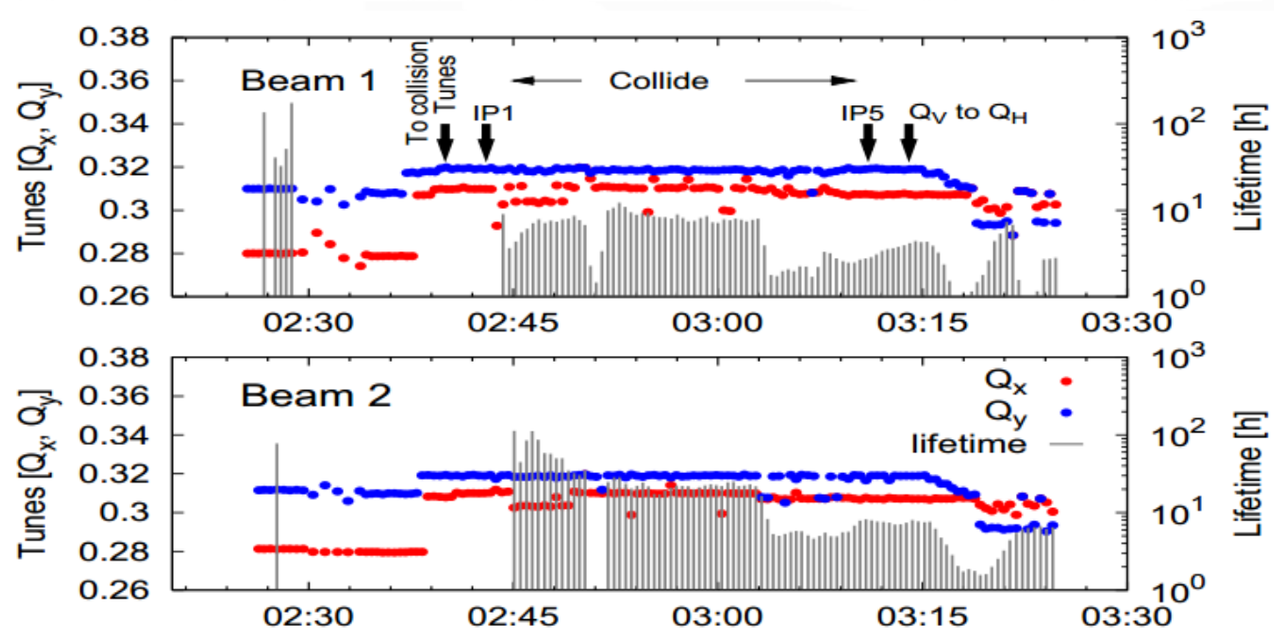
Fill 1765-1766 (May 2011)

Test 3:

Part A

We wanted : symmetric filling scheme with 4 collisions per bunch



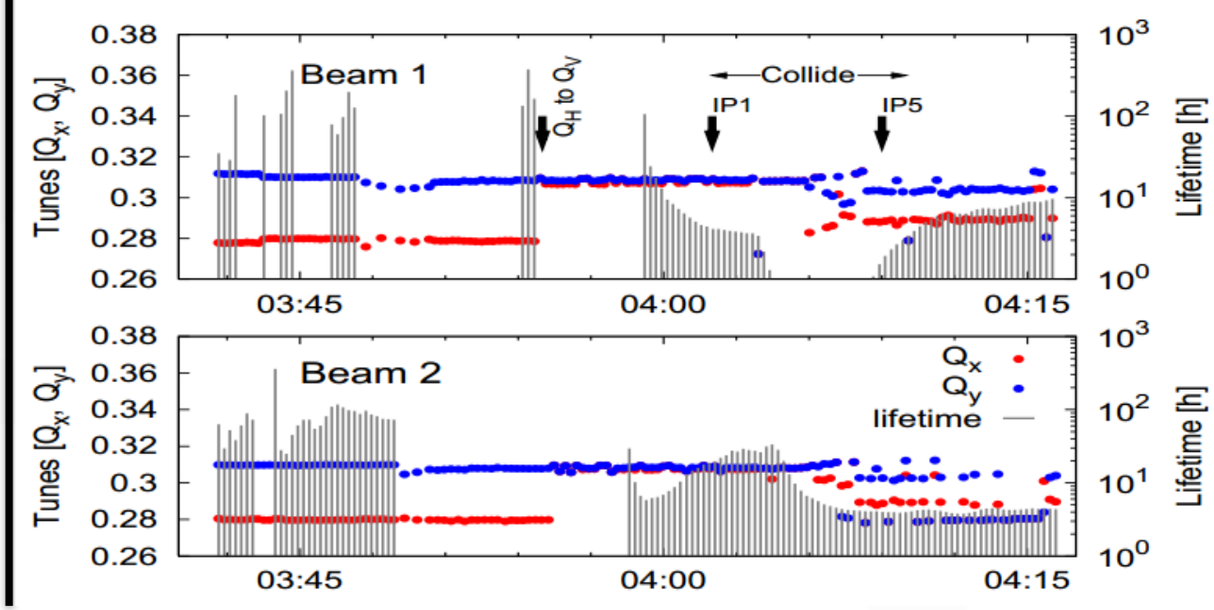


Part B

Machine Protection

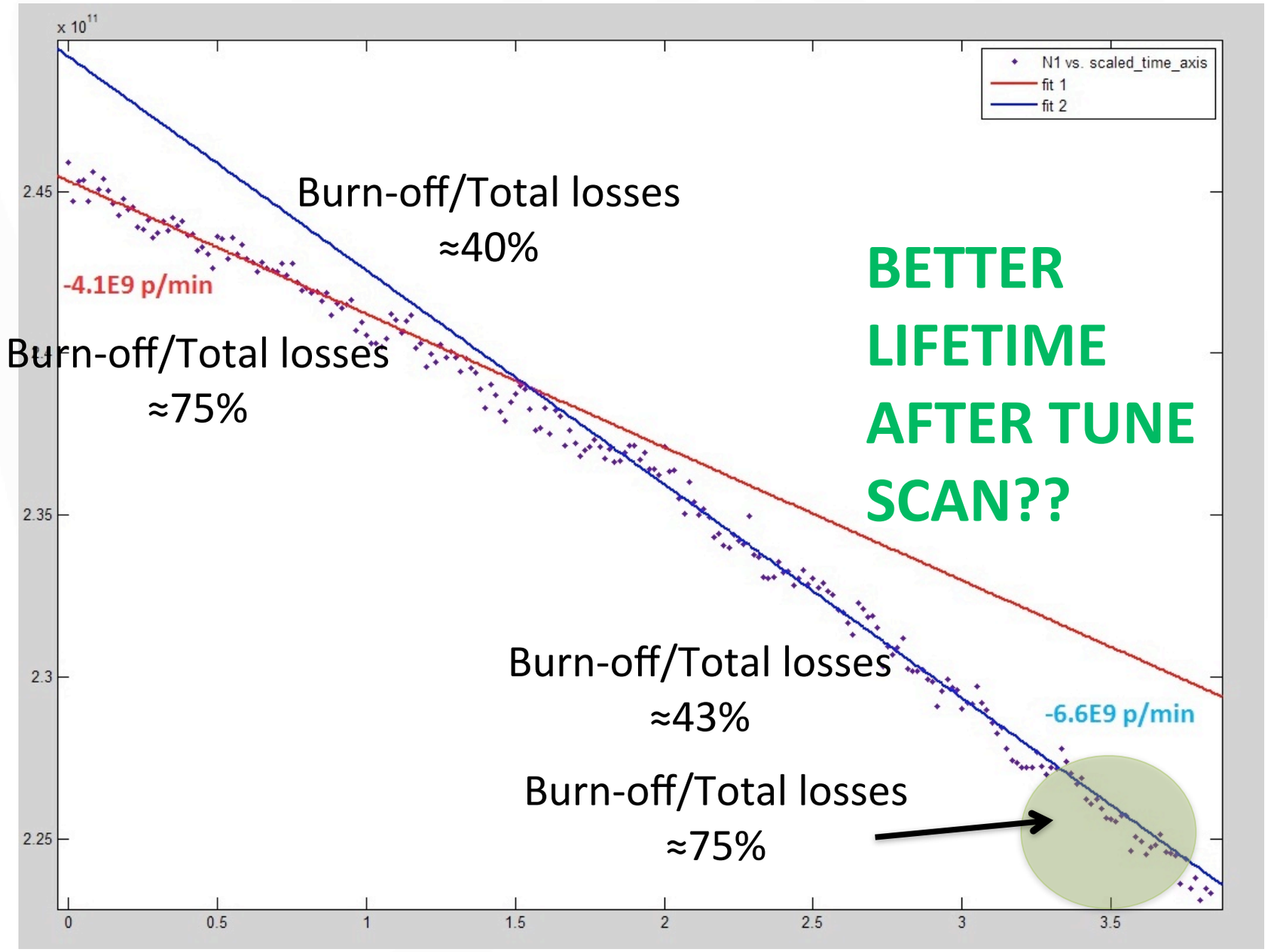
To avoid 10th order resonance tunes moved to .31H .31V

With N=1.85E11 ppb
ε=1.3 μm
Achieved ζ=0.017/IP-> total 0.034



High pile-up test

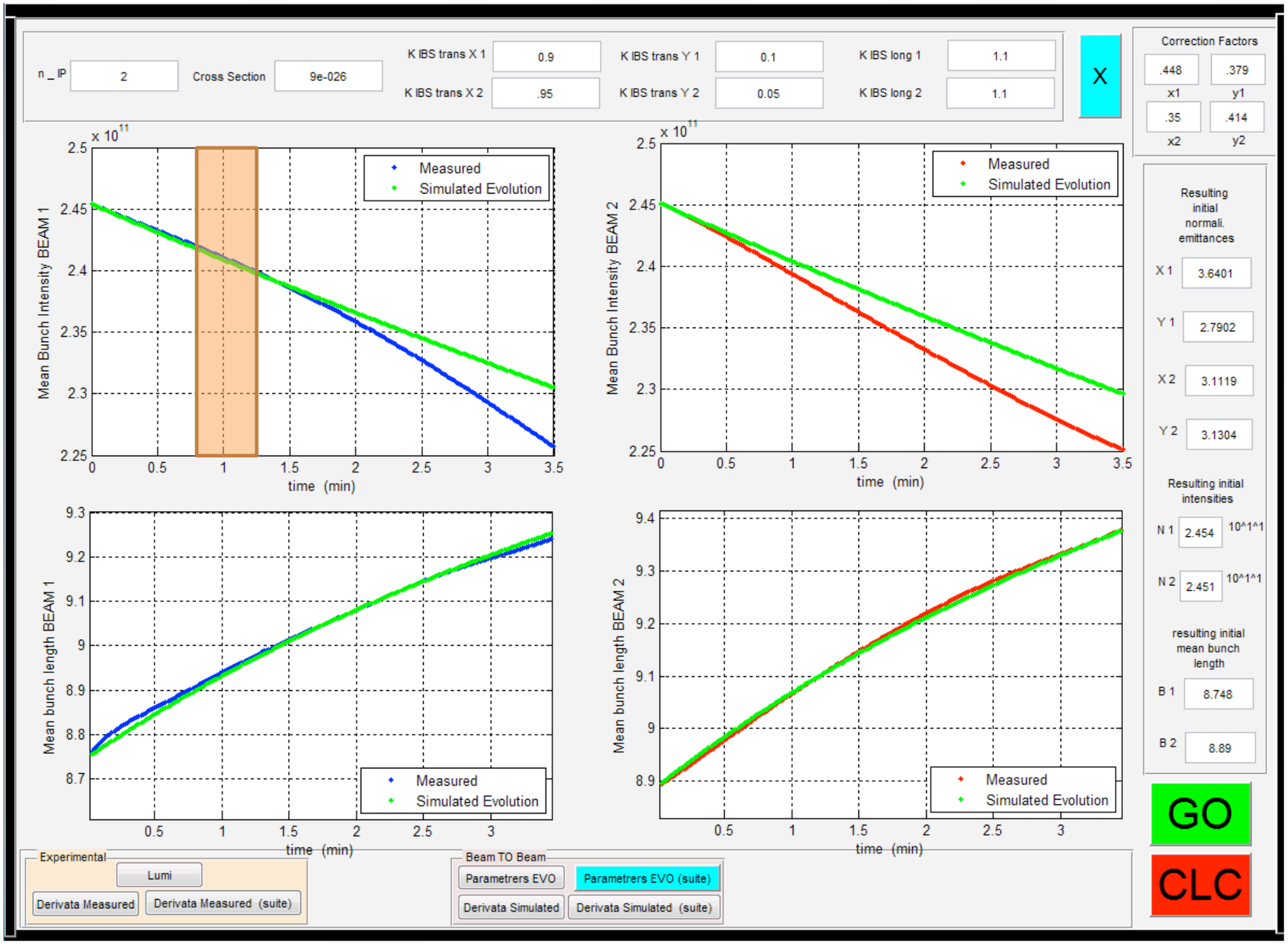
BEAM 2



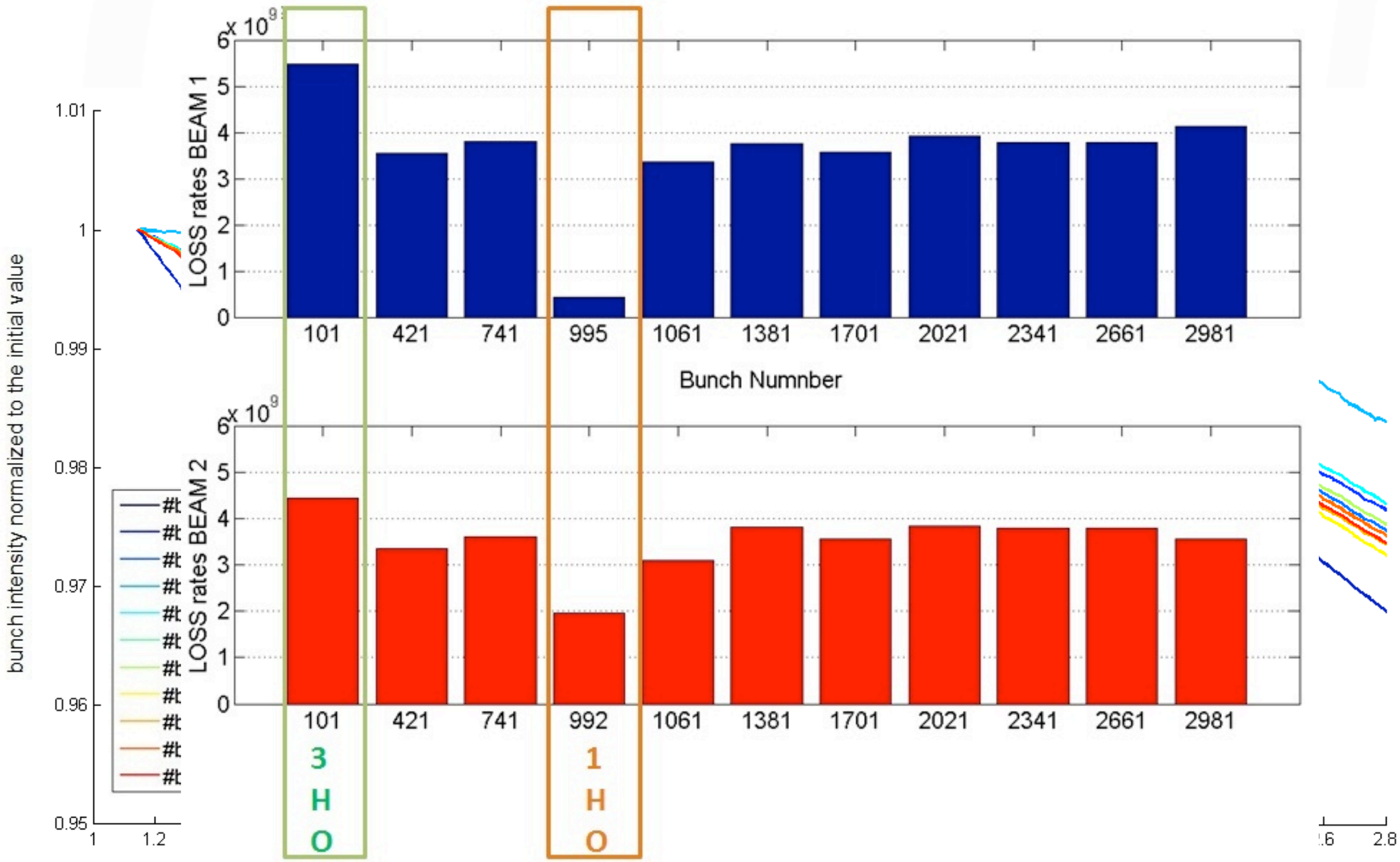
FILL 2201 Filling - Beam Losses - **Simulation**

Tevatron Luminosity Model

$\varepsilon_{x,y}, N, \sigma_P^2$



FILL 2252 Filling - **Losses Observation** - Separation Steps - Emitt. Observation



Brighter Injectors

Mid 2012 SPS passing to the Q20 optics…
Even brighter beams can be delivered to the LHC!

High pile up to be repeated with a goal of:

μ=100

Again, PARASITICALLY, beam parameters were monitored to study the HO b-b factor and its effects on these bright beams.

Fill 2822-2823-2824-2825 (July 2012)

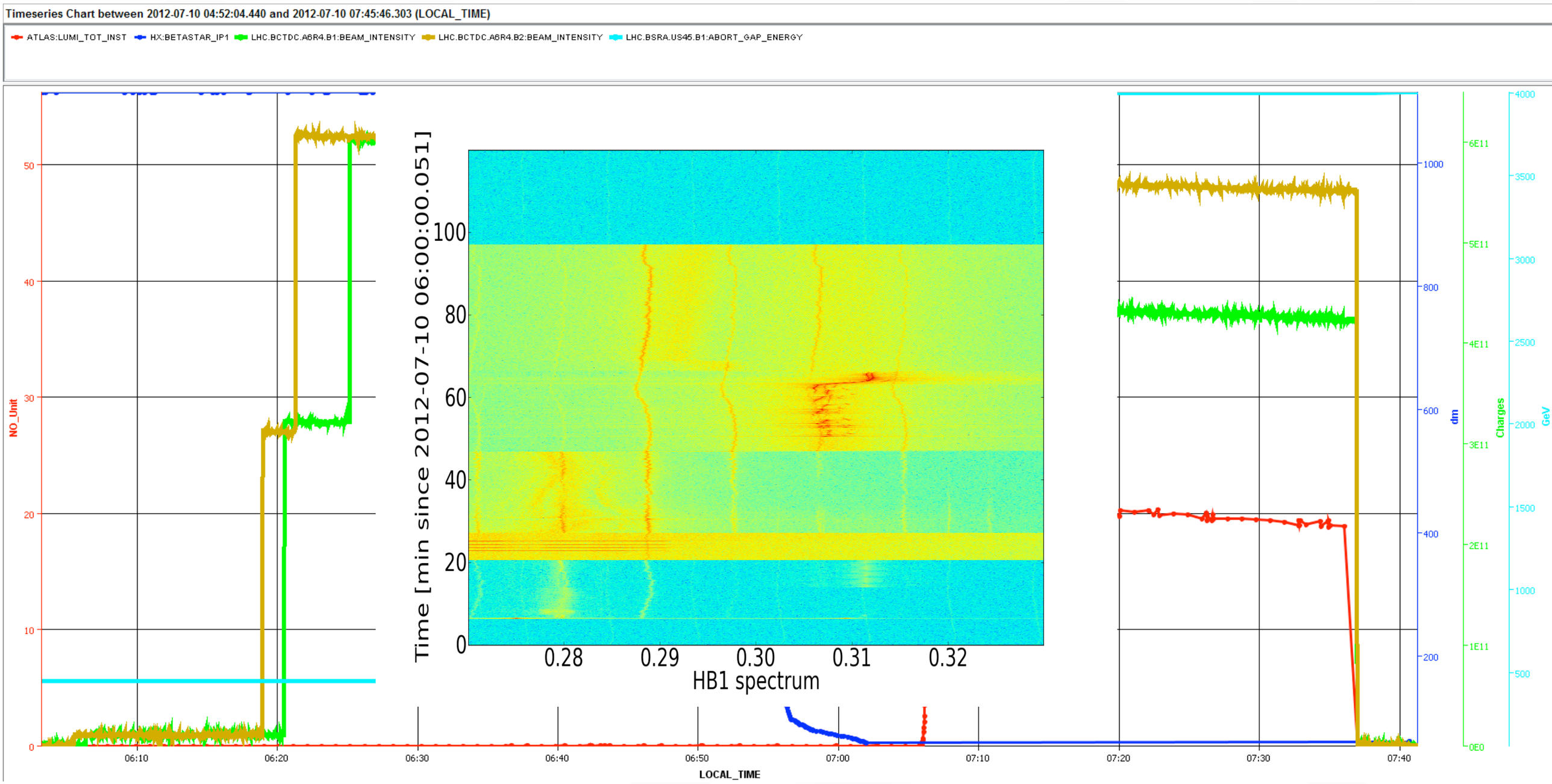
2822 -> 1 bunch 3e11 ppb 2 um emittance
reached stable beams with deteriorated beams. Pile-up 45

2823 -> same configuration + increase chromaticity by 3 units
decided to dump before reached stable beams since the beams were unstable again

2824 -> After discovering the problem, 2bunches 3e11ppb
stayed 10 min in SB . Pile-up 58
B1 not cured yet, B2 reached collisions with 2.2 um emittance

2825 -> Longitudinal Blow-up issue solved, still instability observed during the squeeze causing losses and blow-up.
Pile-up 70 reached in IP1

Longitudinal Blow-up
NOT WORKING



Instability during the squeeze for Beam 1

SUMMARY

Commisioning

Nominal and beyond beam-beam tune shift was achieved without any particular problems

High Pile-up 1

Observed emittance growth at injection energy and more through the ramp.
Vertical emittance growth observed twice in the vertical plane in beam 1 still under investigations for fill 1, since for fill 2 it corresponds to the separation of the beams.
Missing losses contribution to the Luminosity evolution model (not only beam-beam losses ?)
Long Range effects in fill 2252 or just losses from tune resonances?

High Pile-up 2

Systematic studies (parallel separation, leveling and noise excitation) still to be done.
The instabilities that showed up were independently present from the HO tune shift

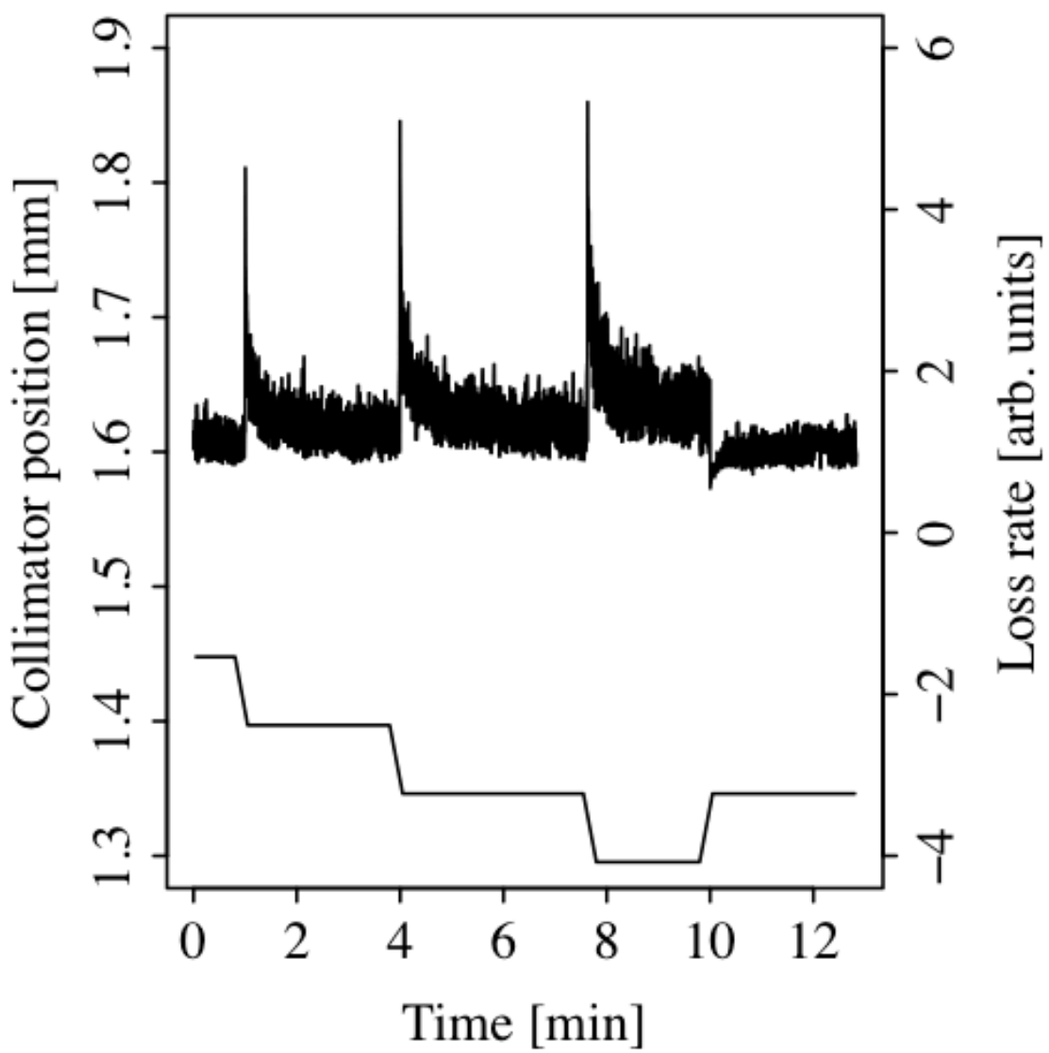
Under the present conditions we do not consider the HO bb interaction as a limit for the LHC performance

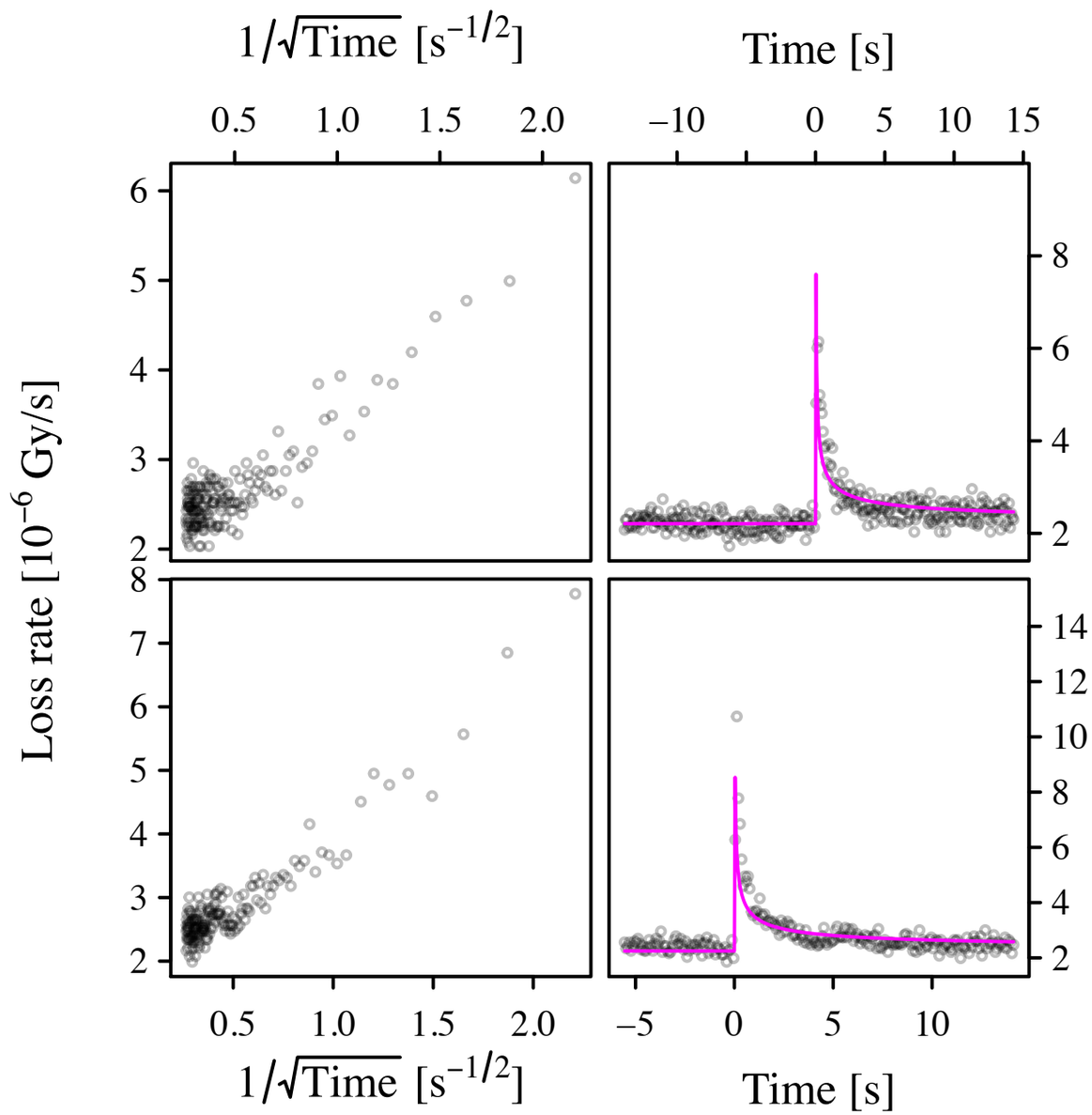
G. Stancari

- Transverse beam halo diffusion.
- The diffusion coefficient is measurable from the transient response of beam loss at a fast in/out of a scraper.
- Compare the diffusion coeffs for LHC and Tevatron with beam-beam on/off.

Stochastic character of halo dynamics

Stochastic nature of halo dynamics often empirically confirmed by relaxation of losses ~ (time)$^{-1/2}$ during collimator setup





Diffusion model of loss rate evolution in collimator scans

Distribution function of tails evolves under diffusion with boundary condition at collimator

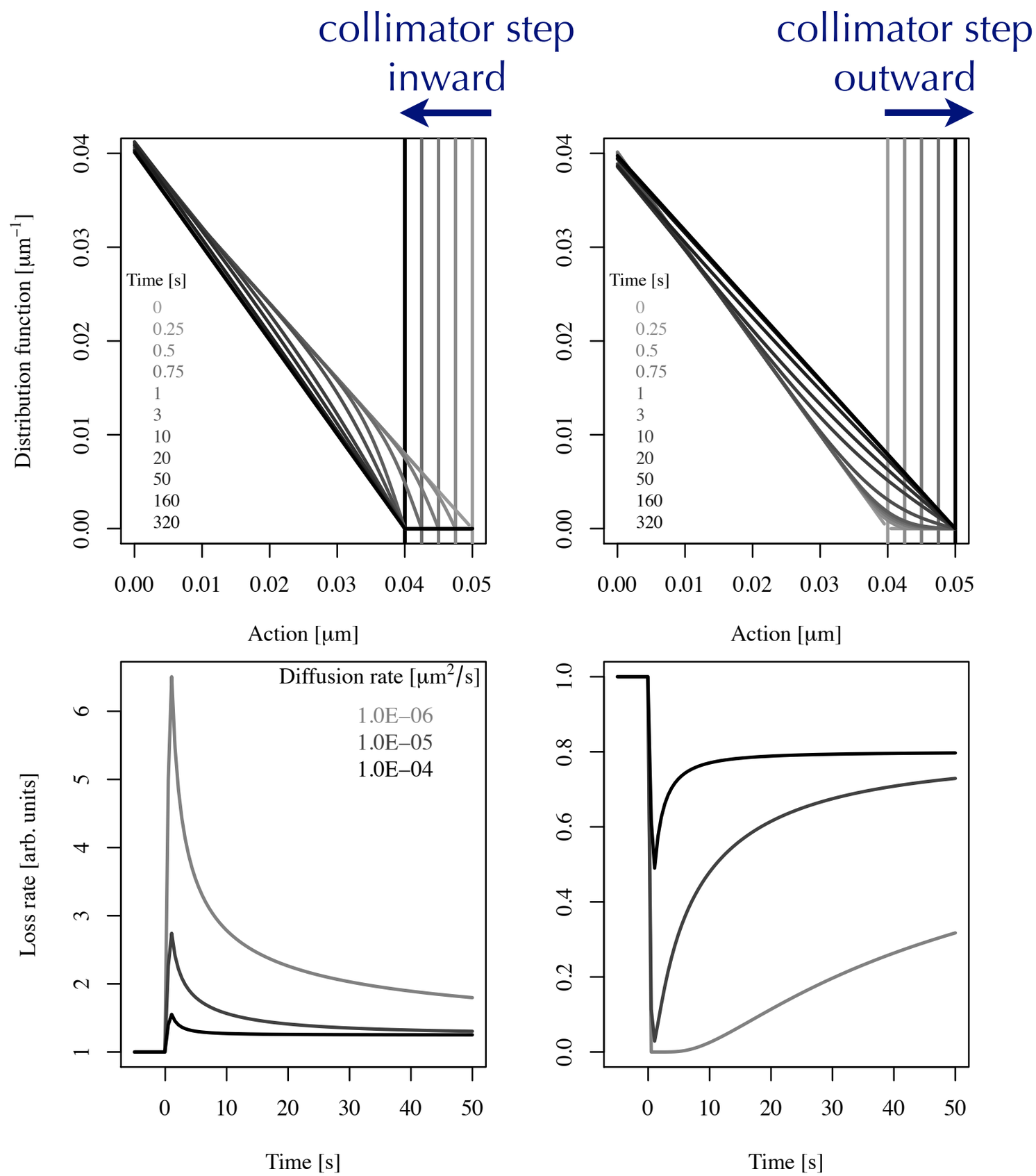
$$\partial_t f = \partial_J \left(D \cdot \partial_J f \right)$$

Instantaneous loss rate is proportional to slope of distribution function

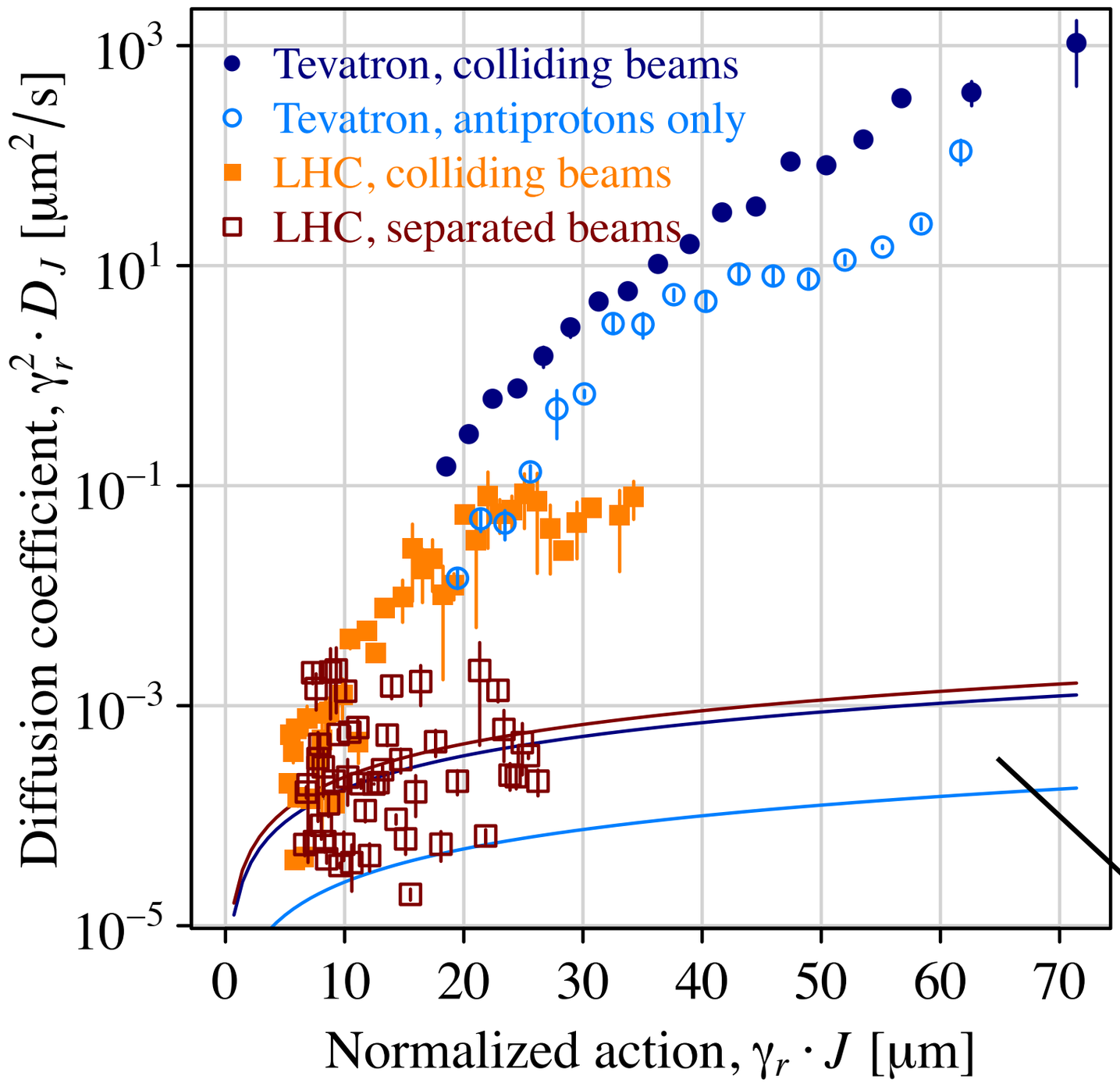
$$R = -k \cdot D \cdot \left[\partial_J f \right]_{J=J_c} + B$$

loss monitor calibration

background rate



Beam halo diffusion rates in the Tevatron and in the LHC



Effect of beam-beam is 1-2 orders of magnitude

Halo diffusion in Tevatron dominated by effects other than beam-beam

Beam-beam still dominates?

Very low noise and nonlinearities in LHC

curves from measured core emittance growth

$$D_J = \dot{\varepsilon} \cdot J$$

Conclusions

- **Halo dynamics** is often **stochastic**, due to the nature and number of effects in real machines
- **Collimator scans** are a sensitive tool for the study of **halo dynamics vs. amplitude**: diffusion coefficients, lifetimes/fluxes, impact parameters, collimation efficiencies, beam populations
- **First measurements of diffusion vs. amplitude** in Tevatron and LHC
- **Tevatron**
  - halo dynamics dominated by effects other than beam-beam
  - collisions enhance diffusion rate by 1 to 2 orders of magnitude
- **LHC**
  - with separated beams, halo diffusion very similar to core: nonlinearities and noise are small
  - in collision (only 1 bunch/beam), diffusion enhancement depends on amplitude, reaching 2 orders of magnitude

Beam-beam still dominates?

Thank you!