4th Joint HiLumi LHC-LARP Annual Meeting

SPS CC test: Analysis of past measurements and outlook to future campaigns including the required instrumentation

Hannes Bartosik and Yannis Papaphilippou

CERN

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Thanks to F. Antoniou, G. Arduini, P. Baudrenghien, R. Calaga, K. Cornelis, O.Michels

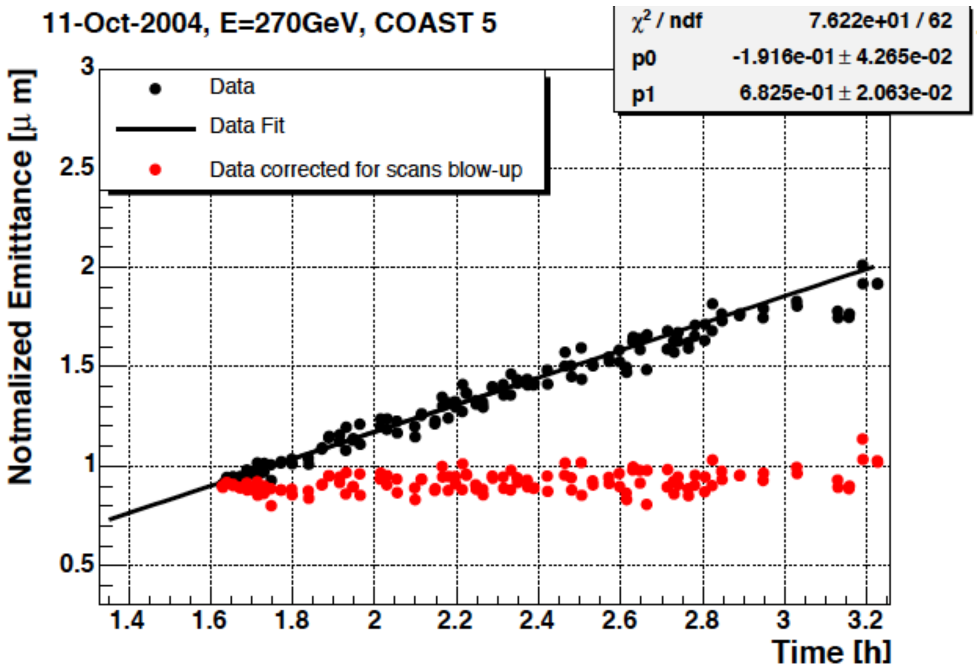
Outline

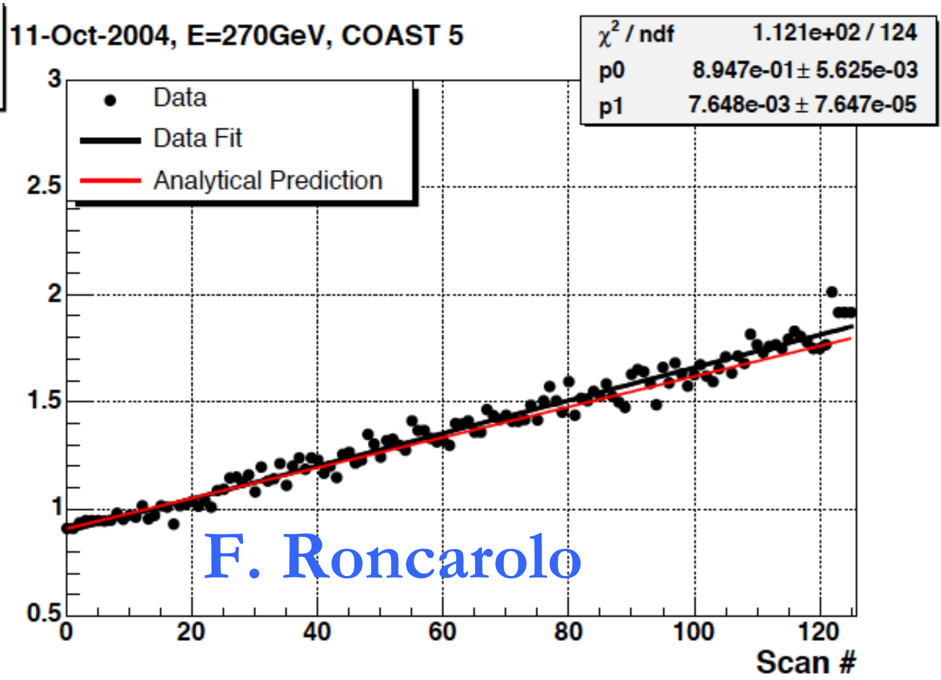
- Motivation
- Review what has been done in the past
  - MDs with coasting beam
  - Possible sources for emittance growth in SPS
  - Simulation studies
- Possibilities for future studies
- Requirements on beam instrumentation

Motivation

- Primary concern for the LHC upgrade with crab cavities is emittance growth driven by phase (and amplitude) jitter of crabbing mode
  - Dedicated noise studies performed in KEKB
- Essential to test crab cavities in SPS prior to a final implementation and quantify associated emittance growth
- Experiments carried out to measure the natural emittance growth in the SPS
  - Distinguish the effect of crab cavity noise on the long term emittance growth

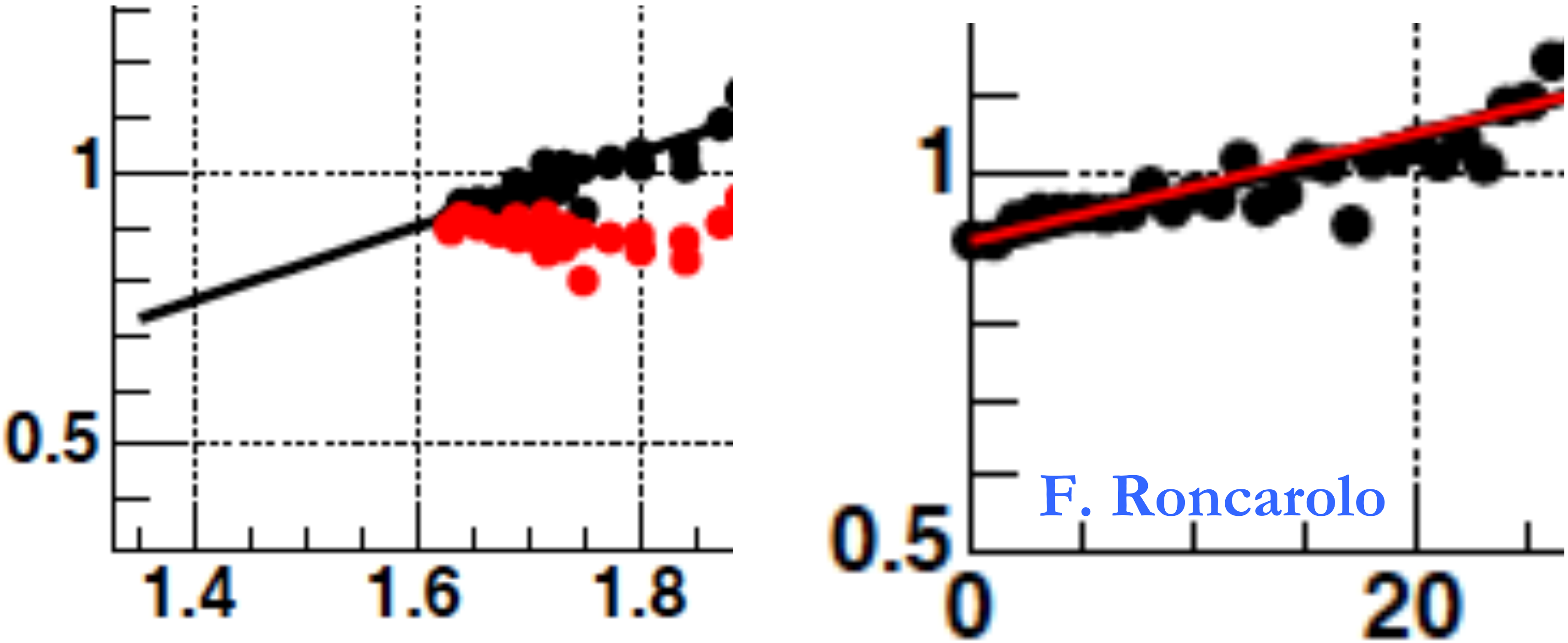
2004 measurements





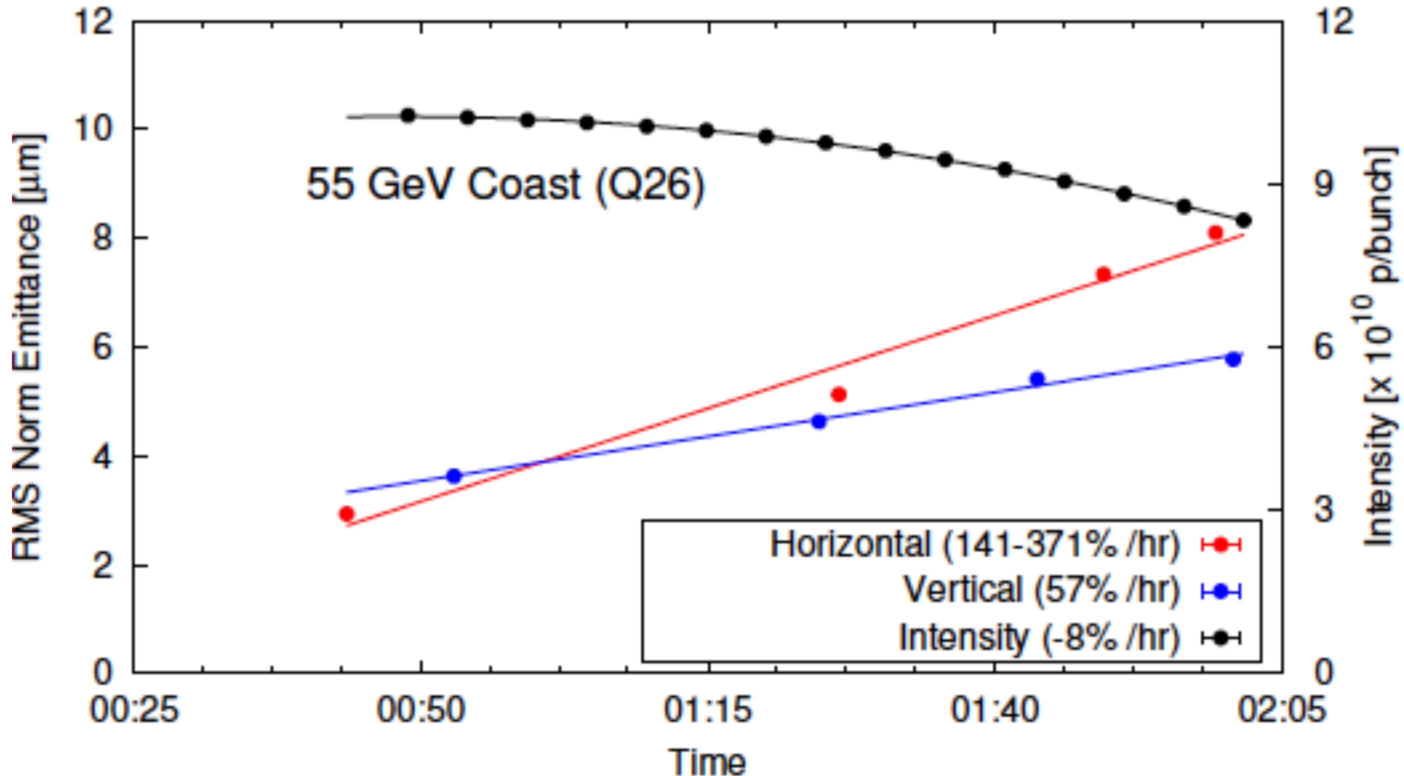
- Evolution of the emittance fitted to growth due to multiple Coulomb Scattering on the wire scanners
- Different models of mCS were used (impact parameter) and chosen the one that was more consistent with data for different cycles

2004 measurements



- Evolution of the emittance fitted to growth due to multiple Coulomb Scattering on the wire scanners
- Different models of mCS were used (impact parameter) and chosen the one that was more consistent with data for different cycles
- In particular, at the first part of the coasting beam MD (large number of wire scans), the fitting of the model seems to overestimate the wire effect

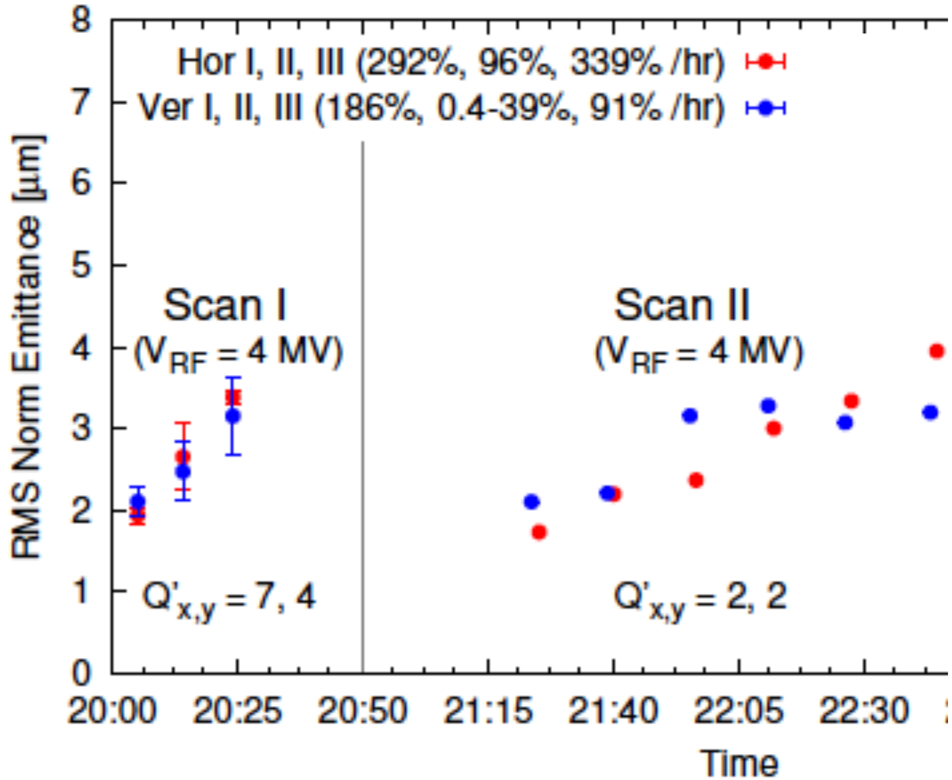
55 GeV coast (Sep. 2010)



R. Calaga, et al.

- Single bunches with **1.1e11 p** and **~3 µm** emittances
- Parabolic evolution of intensity loss
  - Observed in SPS, e.g. for LHC ion beams, when beam is blown up due to horizontal integer resonance and develops non-Gaussian tails
- Large emittance growth especially in the **horizontal** plane
  - Similar observations with 55 GeV coasts @ the LHC tunes and half the intensity, during October 2010, for the BBLR wire experiment

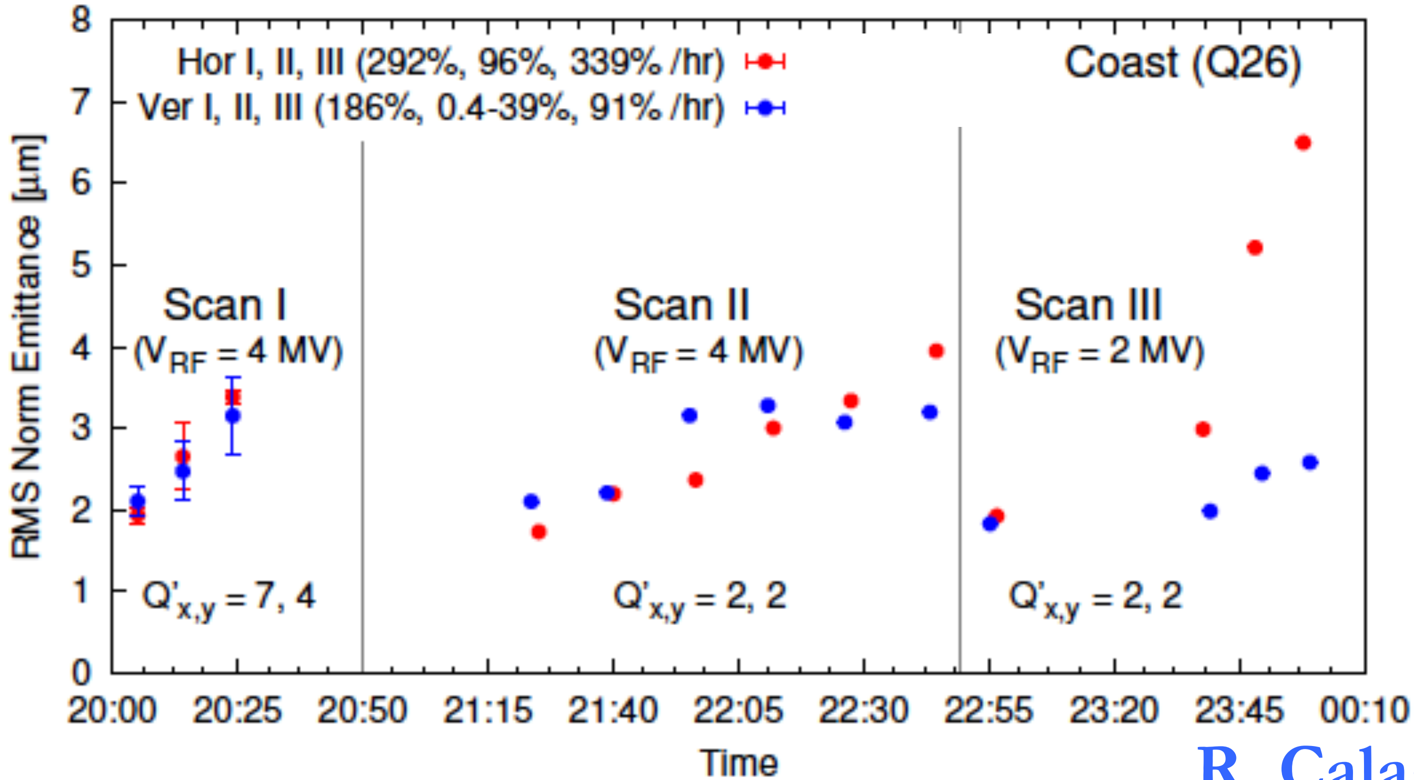
120 GeV coast (Oct. 2010)



R. Calaga, et al.

- Injected 12 bunches with **5e10 p/bunch** and emittance of **~1.5-2 μm**
- Clear blow-up with high chromaticity, reduced for lower chromaticity

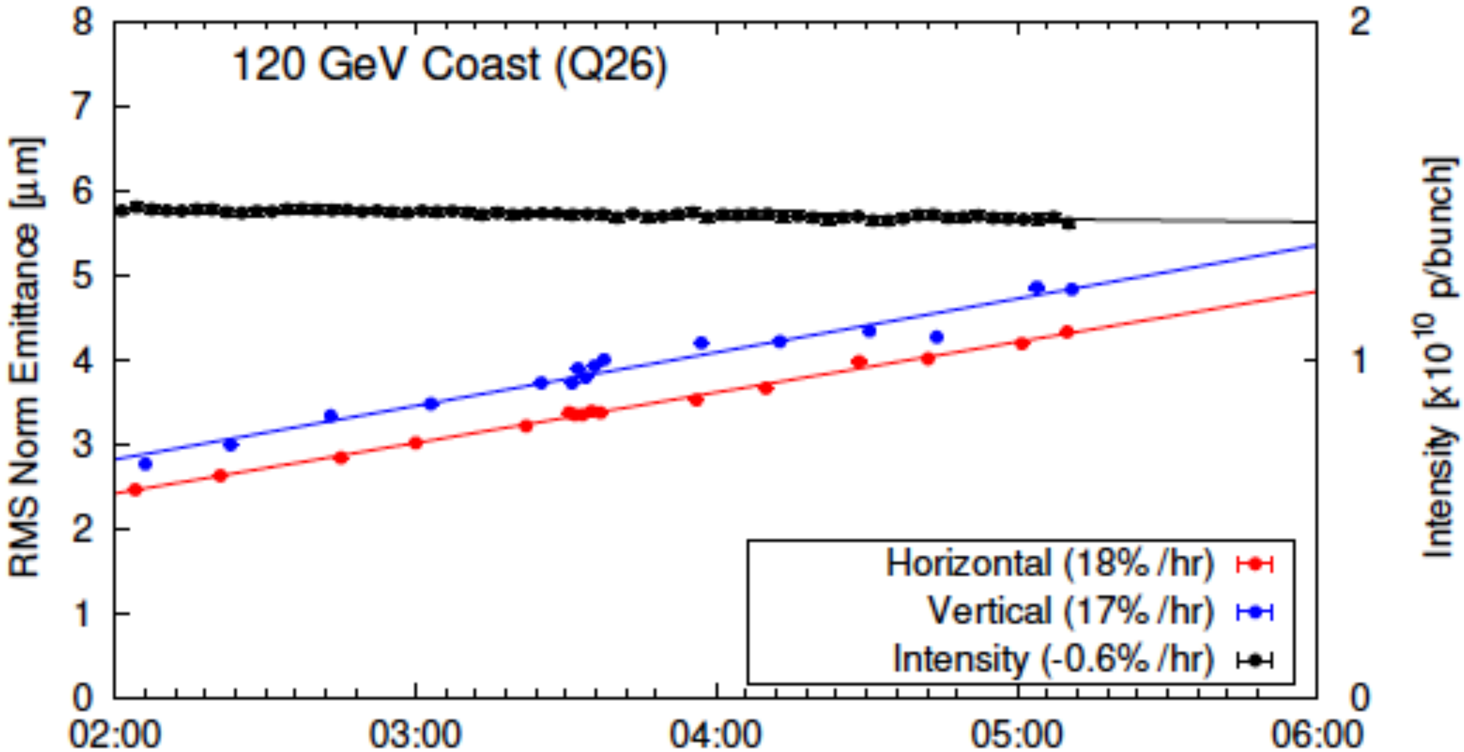
120 GeV coast (Oct. 2010)



R. Calaga, et al.

- Injected 12 bunches with **5e10 p/bunch** and emittance of **~1.5-2 µm**
- Clear blow-up with high chromaticity, reduced for lower chromaticity
- Not a clear interpretation for emittance evolution with low voltage
- Very high emittance blow-up also observed for LHC nominal bunch intensity and similar emittances @ 120 GeV during phase II collimation MD at around the same time and similar experience for UA9 experiment (crystal collimation)

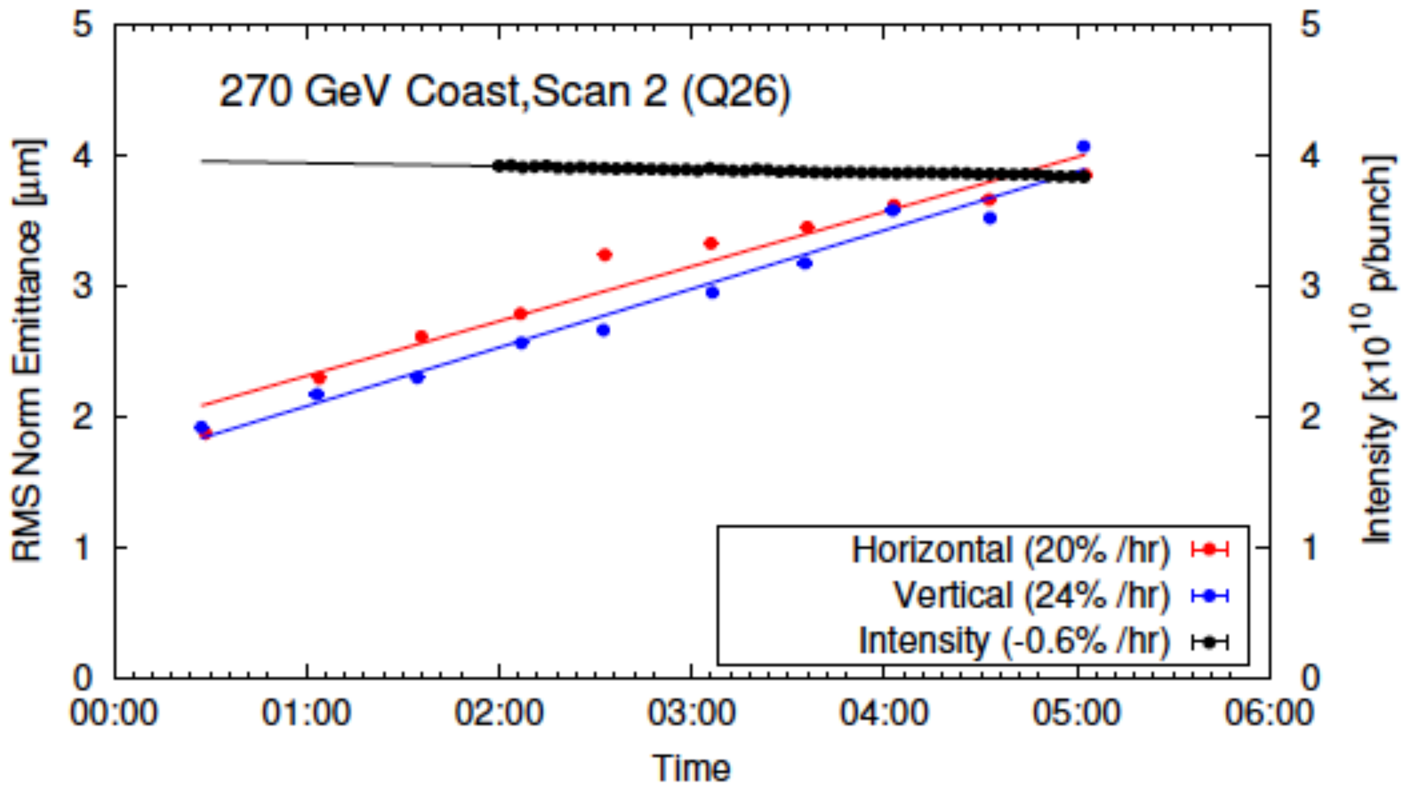
120 GeV coast (May 2011)



- Single bunch with **1.5e10 p** and emittances of around **2.5 µm**
- Lowest emittance blow-up observed in that case (below 20%/h)
- No significant additional blow-up
  - For consecutive wire-scans
  - Different vertical tunes
  - Zero chromaticity (dipole oscillations)

R. Calaga, et al.

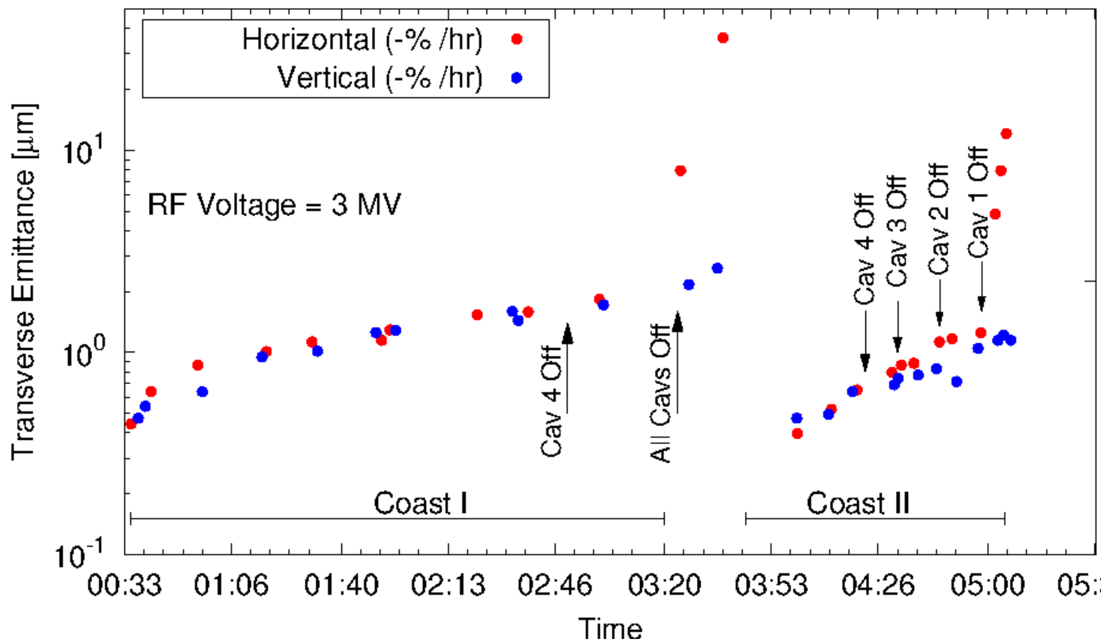
270 GeV coast (July 2011)

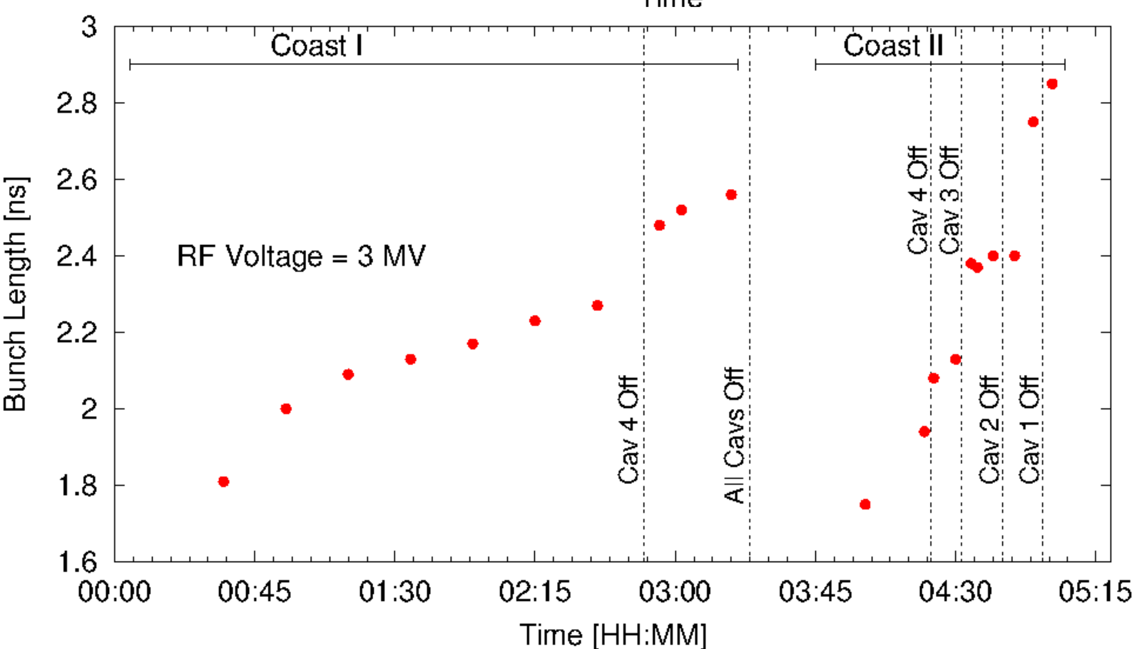


- Single bunch with **4e10 p** and emittances of around **2.0 µm**
- Similar "low" emittance blow-up observed as @ 120 GeV
- Not agreeing with 2004 measurement interpretation

R. Calaga, et al.

270 GeV coast (June 2012)





R. Calaga, et al.

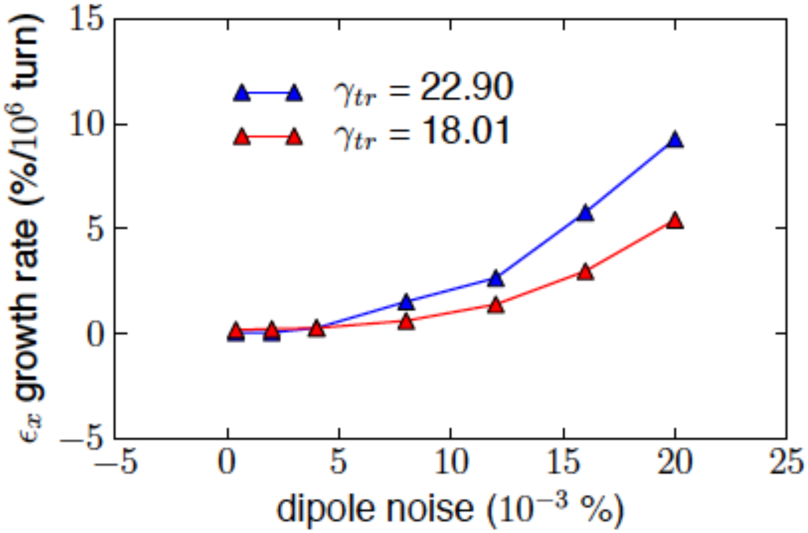
- Single bunch with **1-2e10 p** and very small emittances (**<1.0 μm**)
- Linear evolution of both transverse emittances over time
- As before, there is no clear picture when cavities are switched off especially for horizontal plane
- Bunch length follows a logarithmic growth (when all cavities are on)
  - Is this a signal of IBS?
- Measurements with Q20 optics unsuccessful

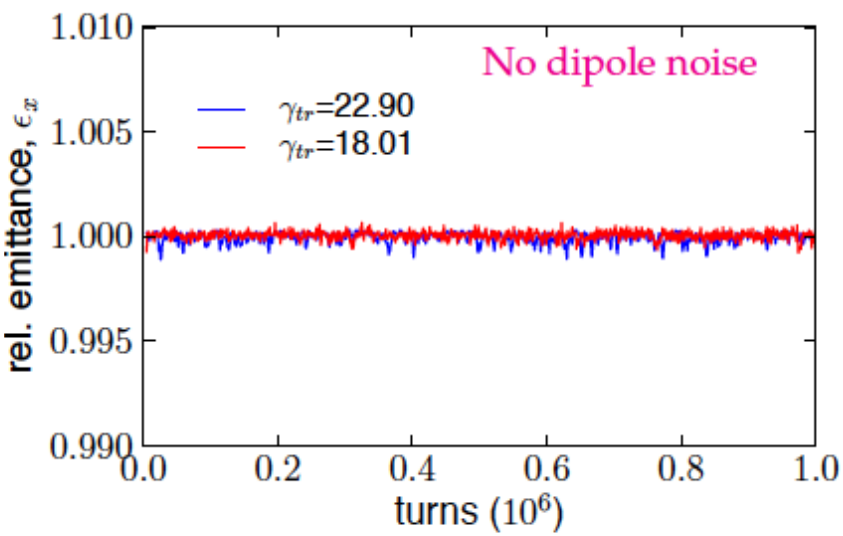
Summary of measurements

- Quite important emittance blow-up at low energy
  - Coasts at high energy (120 - 270GeV) much better
- Very high emittance blow-up observed at “nominal” LHC intensity
  - Smaller emittance growth for low intensity
- Chromaticity largely affects blow-up, even at high energy
  - Should be tuned to as low values as possible
- Consistent blow-up between 120 and 270 GeV
- Logarithmic evolution of bunch length
  - Effect of IBS?

Simulations for emittance growth

H. J. Kim and T. Sen





- Gaussian distribution with 10000 particles, 106 turns (23 seconds).
- Model: sextupole + dipole voltage ripple (white noise)
- Emittance growth only in horizontal plane
  - Vertical and longitudinal emittance growth is insignificant.
- Emittance growth is (2 times) less in Q20
  - Sextupole strength of Q26 is 40% larger than Q20
- Small emittance growth for nominal LHC bunch due to space-charge at 55 GeV
- No effect of tune-modulation at 120 or 270 GeV
- Large emittance growth due to mCS with gas molecules at 120 GeV
  - Uniform vacuum pressure considered which does not represent real machine behavior (1 order of magnitude of pressure variation)

Simulations summary

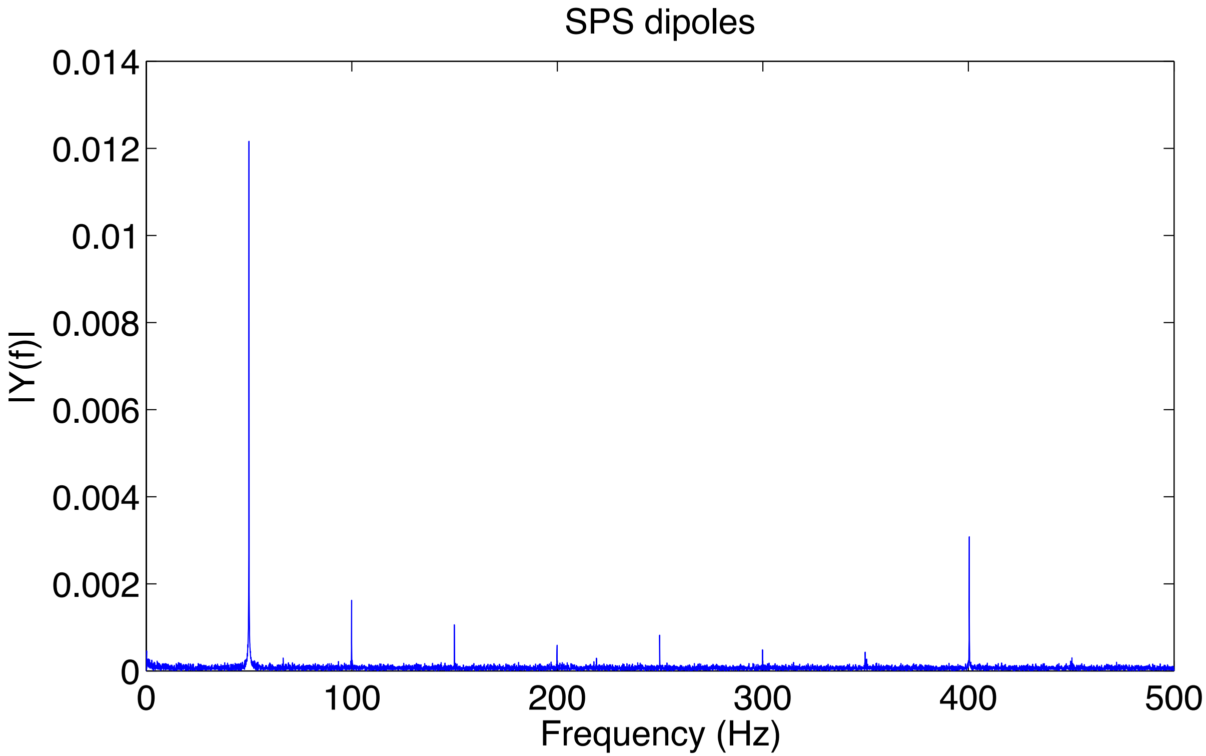
H. J. Kim and T. Sen

Sources	Comment	Likelihood
Dipole noise	Needs large coupling for vertical emittance growth	weak
Tune modulation	Simulations do not show much effect	?
Intra-beam scattering	Needs large coupling for vertical emittance growth Intensity dependent	weak
Space charge	Simulations do not show much effect Intensity dependent	weak
Vacuum	Estimates show large effect Explains independence of growth on intensity, tunes and transeverse plane	strong

SPS Power supply ripple

- Power convertor current regulation much better in the past
  - Used active filters (currently removed) at different parts of the cycle and especially at coasts (p-pbar collider)
  - New digital filter control should allow for better regulation in the future (2015)
- Recently, performed several acquisitions of magnet power convertor currents on 270 GeV coast and flat bottom of MD cycle (26 GeV) in 2014
- Fourier analysis of signal (sampling of 1 ms), show very stable spectrum over time and energies
- Harmonic content of the spectrum below $\mathbf{10^{-6}}$ with respect to DC component (270 GeV)
- Noise level orders of magnitude below harmonic content
  - Should be modeled accordingly

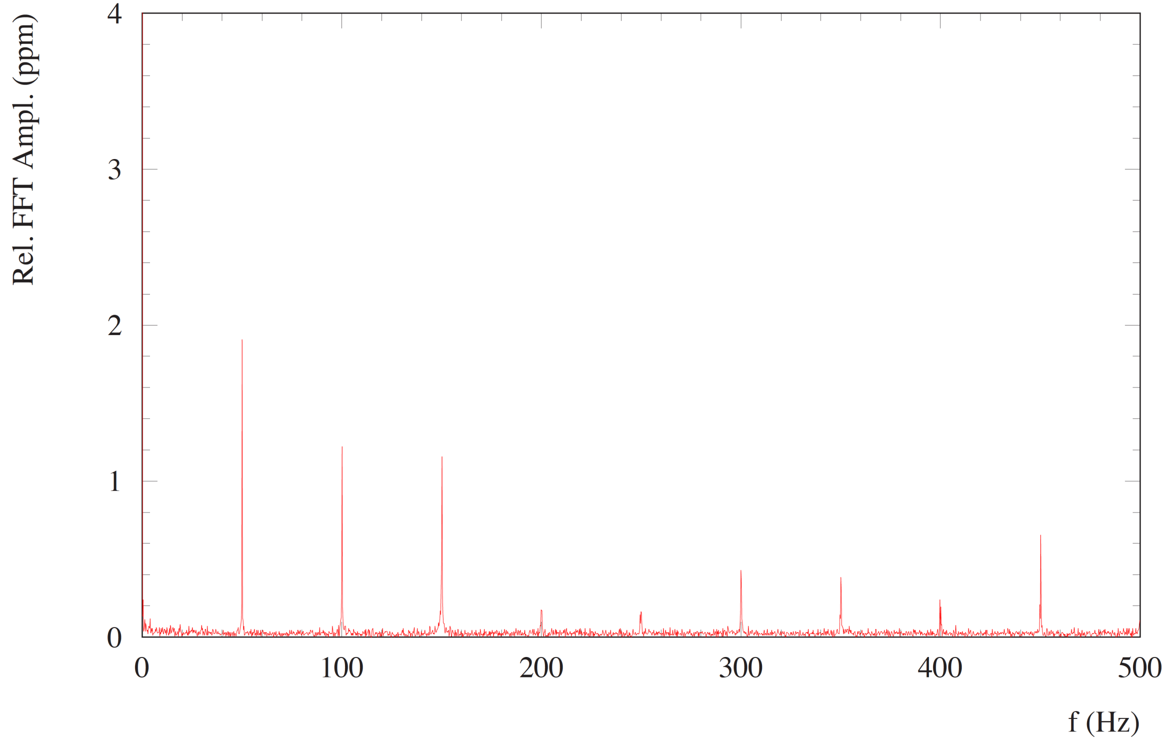
Power supply ripple-dipoles



- 400Hz line should be associated to the **600 Hz** component due to aliasing
  - Expected from the current regulation circuit
- Dominance of **50 Hz** line in **dipole** current spectrum
  - Maybe not directly associated with power convertor behavior

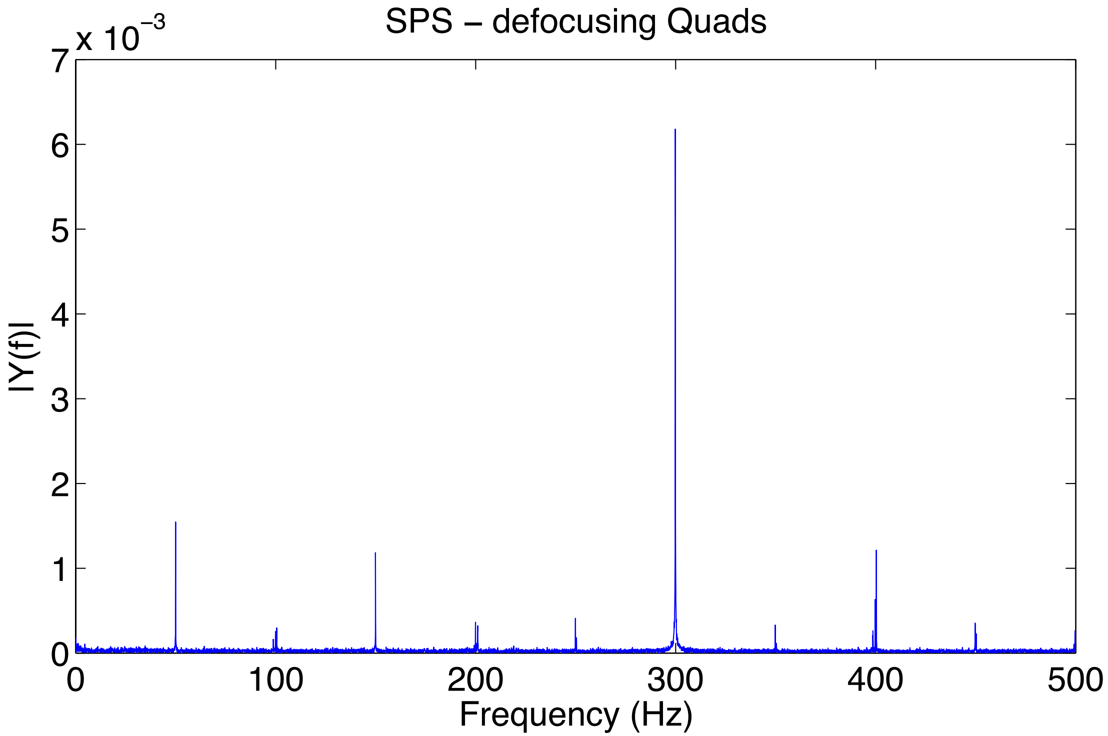
Power supply ripple-QFs

J. Wenninger 2003



- 400Hz line should be associated to the **600 Hz** component due to aliasing
  - Expected from the current regulation circuit
- Dominance of **50 Hz** line in **dipole** current spectrum
  - Maybe not directly associated with power convertor behavior
- Similar behavior for QFs (also in the **past**)

Power supply ripple-QDs



- 400Hz line should be associated to the folded **600 Hz** component due to aliasing
  - Expected from the current regulation circuit
- Dominance of **300 Hz** component in **defocusing quadrupole** current spectrum also expected from current regulation

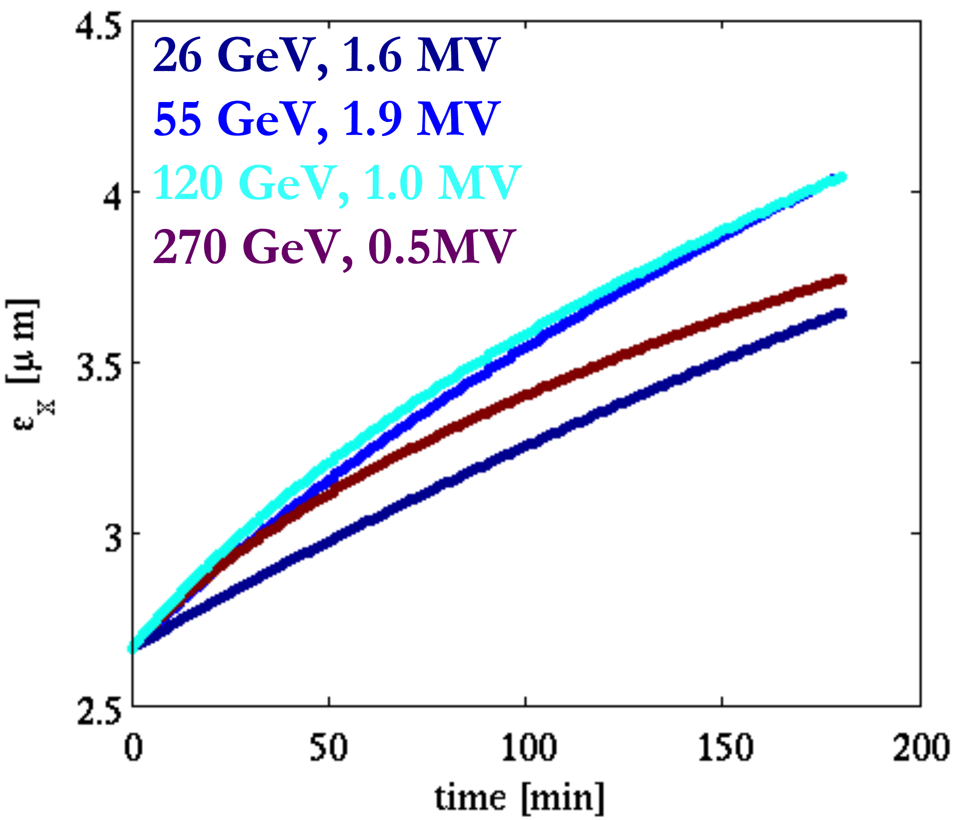
Proposed future studies I

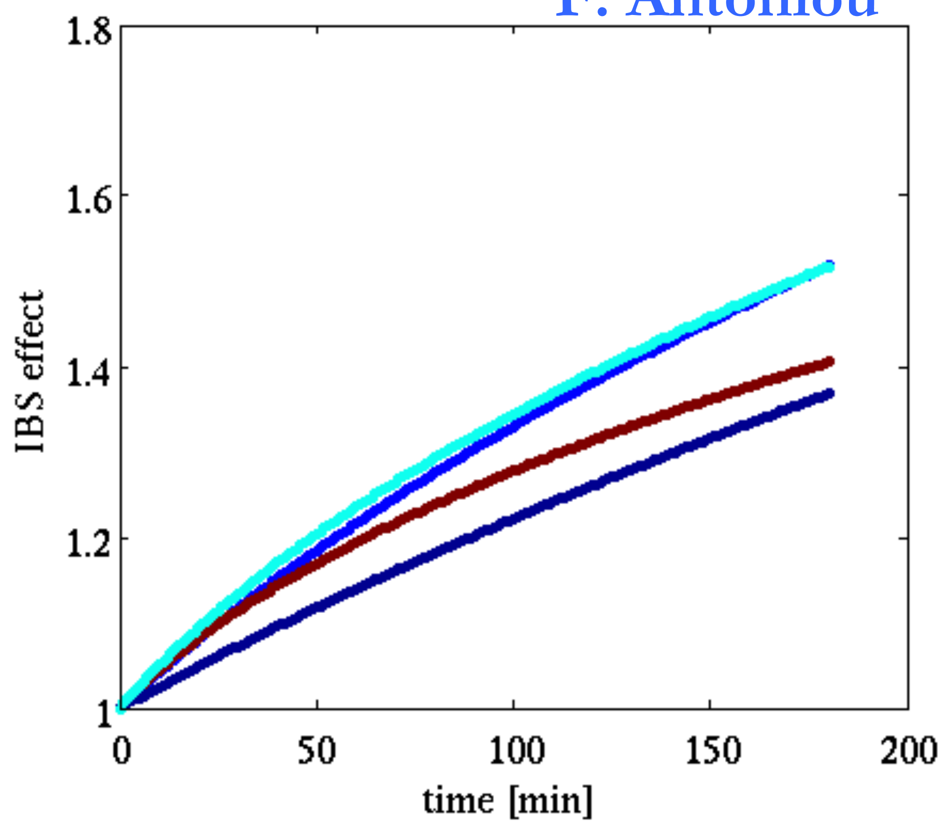
- Simulations
  - Emittance evolution with measured harmonic content of power supplies output
  - Intrabeam scattering evaluation for different energies
  - Effect of gaz scattering simulation for distributed pressure
- Repeat experiment for influence of wire scans on emittance
  - Using different wire scanners, especially the linear
- Evaluating effect of intensity on emittance
  - Injection of 4 bunches of different intensities from pre-injectors
  - Follow evolution (emittance, lifetime)
  - Evaluate brightness effect for different injected emittances (BCMS)
  - Repeat for different optics

Simulated IBS effect

- Recent simulations of IBS effect for different energies and voltages
- Bunch intensity of **1.1e11 p** and ~**2.7 µm** emittances and Q26 optics
- To be continued with parameters fitting measurements

F. Antoniou



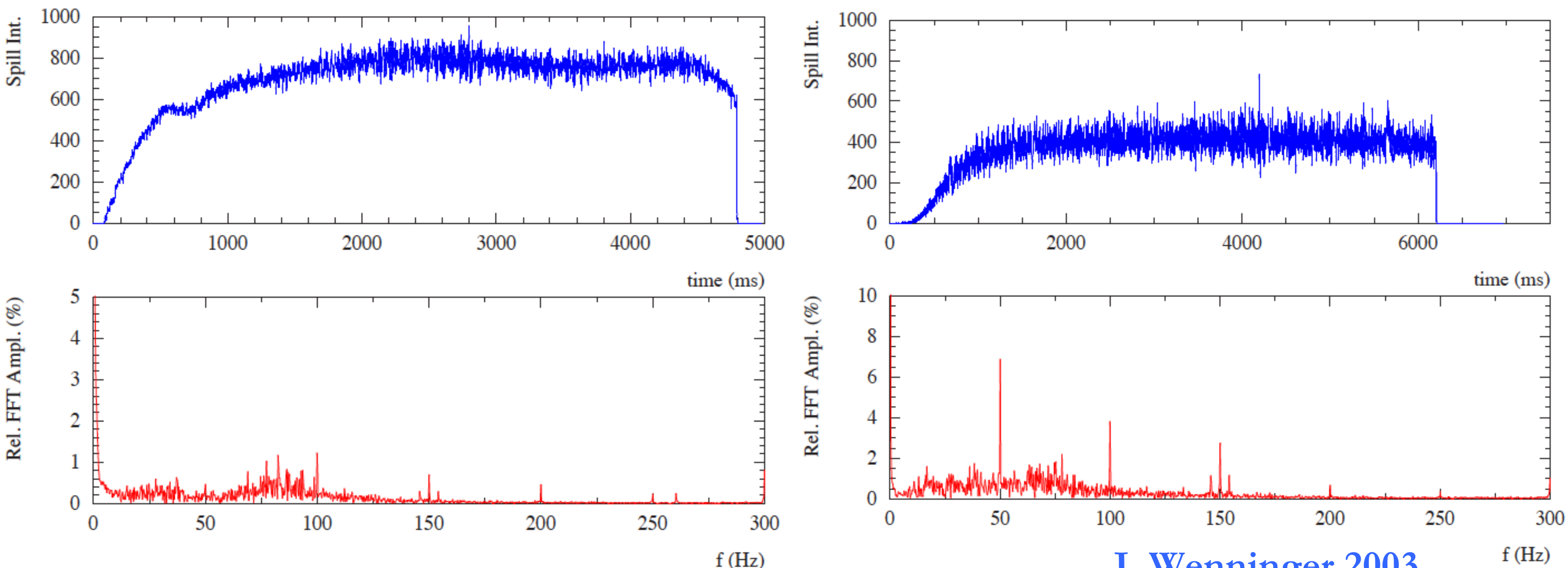


Proposed future studies II

- Evaluate effect of power supply ripple
  - Repeat measurements of power convertor currents with higher sampling rate (2014)
  - Correlate noise content with beam tune spectrum (turn-by-turn data)
  - Use servo-spill quads with different active filter settings for injecting/cancelling 50Hz harmonics on quads
  - Eliminate noise with new digital control of the power convertors (2015)
  - Controlled vacuum "deterioration" and emittance evolution measurement
- Optics at coasts
  - Evaluate effect of coupling
  - Correct amplitude detuning (octupole settings)
  - Measure non-linear chromaticity and develop non-linear model
- Measurement of tail evolution or diffusion (scraper)
- Use transverse feedback in new single bunch mode (see talk by W. Höfle)

SPS Servo-spill quads

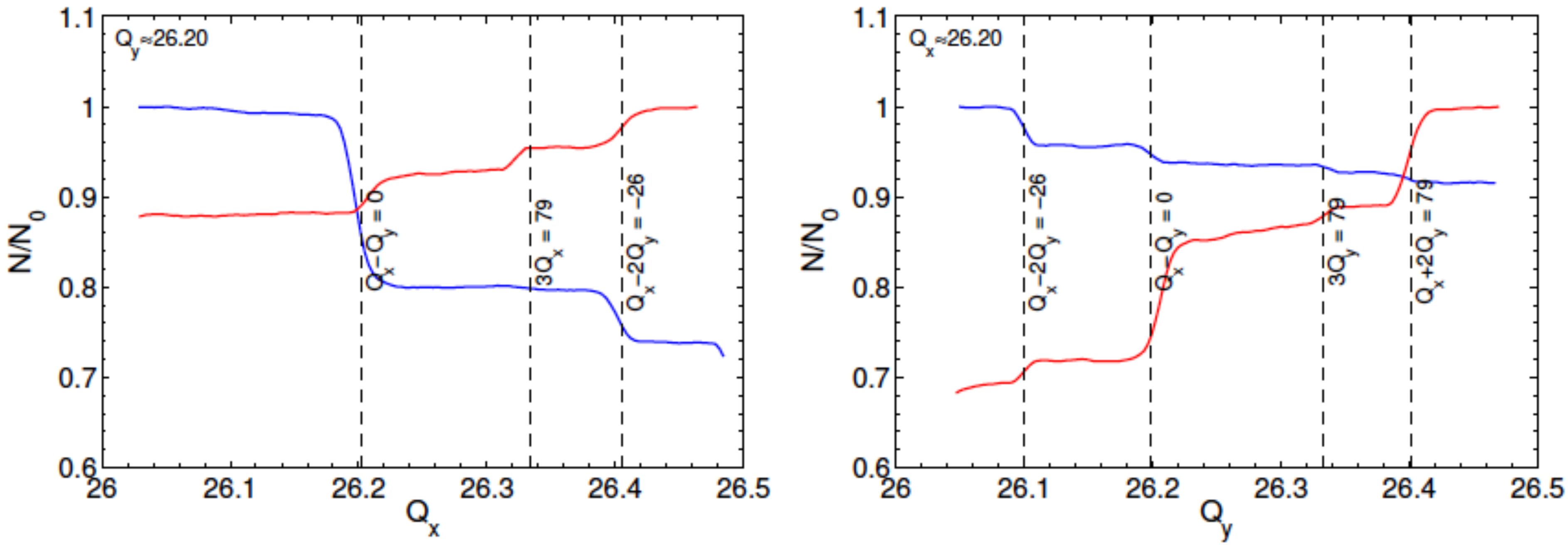
- The servo-spill system controls the intensity of the resonantly extracted beam via a set of 4 QMS quadrupoles installed in position 116
- It is a feed-forward system where a modulation (from 50 to 300Hz), with a determined phase relative to the mains and amplitude is added to the servo-spill quadrupole current
- It may be possible to use it in coasts for reducing power supply ripple



J. Wenninger 2003

SPS dynamic tune-scans

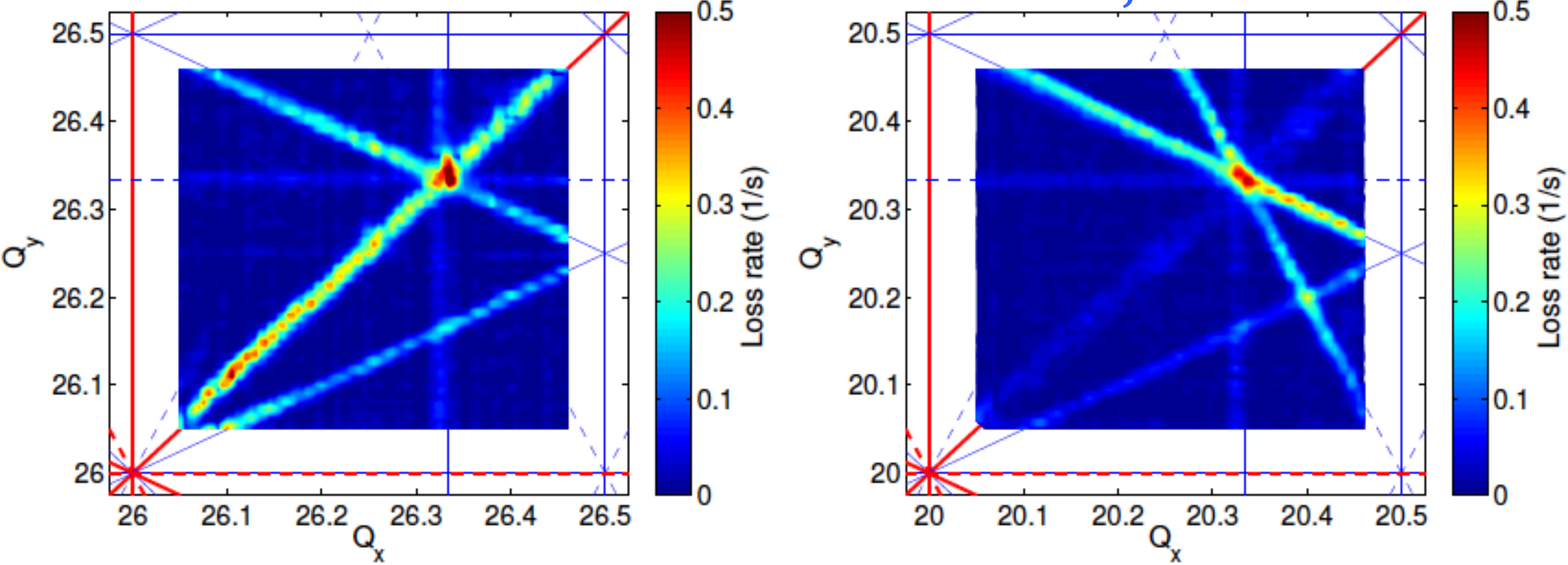
H. Bartosik, PhD thesis



- Intensity evolution during a dynamic scan of the working point in the SPS Q26 optics, for constant vertical (left) and horizontal tune (right)
- The intensity is normalized to the value at the beginning of the corresponding measurement (each curve is recorded on a dierent supercycle).
- Important resonances are indicated by dashed lines.

SPS frequency loss maps

H. Bartosik, PhD thesis

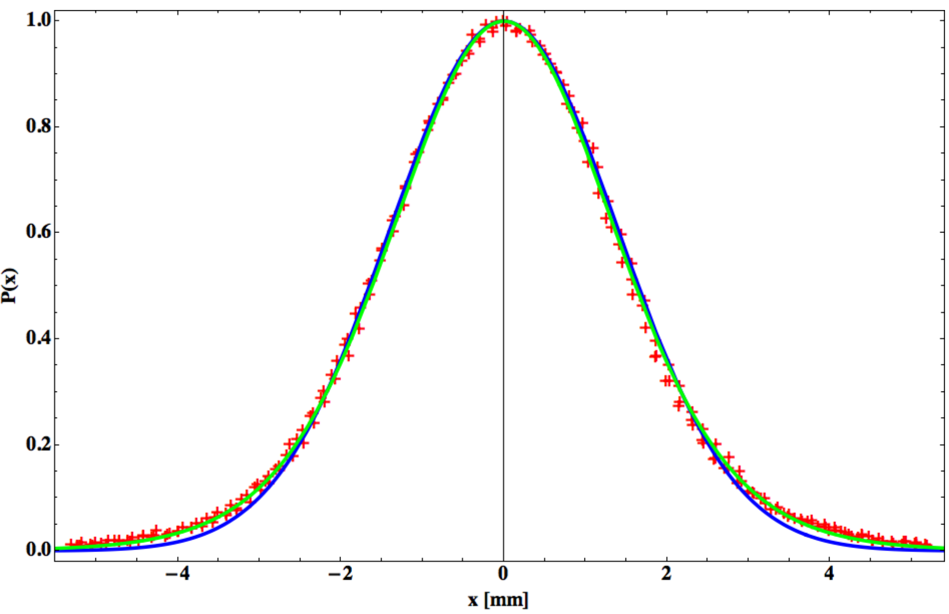


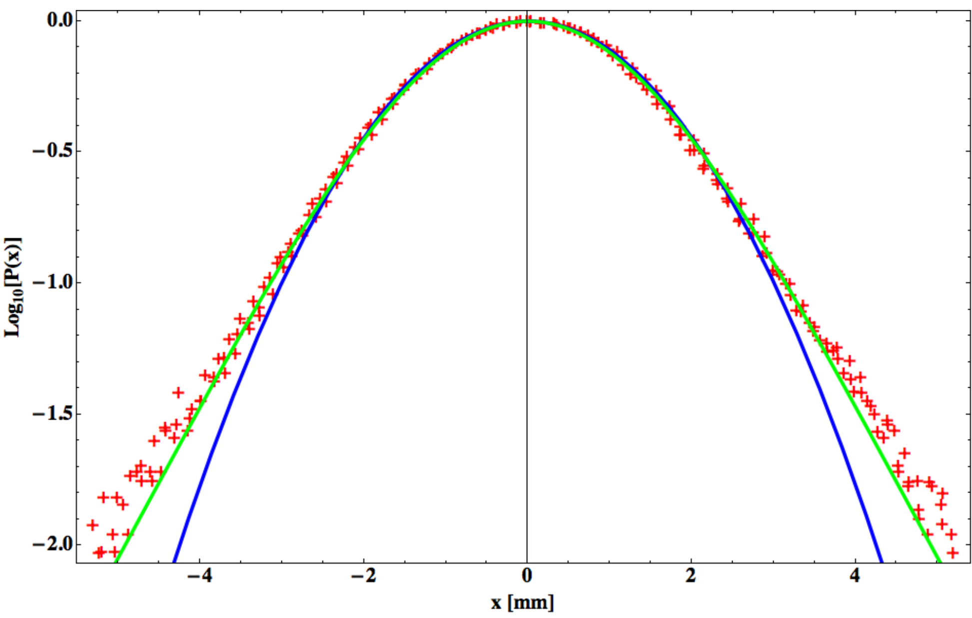
- Experimental tune scans in the SPS with the nominal Q26 (left) and Q20 optics (right).
- Color-code indicates the loss rate during a dynamic scan of the fractional tunes, as (averaging over 4 scan directions)
- Build a non-linear model based on these plots
- Study effect of modulation in both optics

Tail estimation

- Measure multiple beam profiles (over several cycles) in transverse dimensions
- Tails cannot be represented accurately with a Gaussian
- Profile fits quite well to a q-Gaussian, with $q = 1.148 \pm 0.008$ and $\beta = 0.562 \pm 0.004$

$$P(x) = \left[1 - \frac{(1-q)\beta}{2}x^2\right]^{\left(\frac{1}{2}+\frac{1}{1-q}\right)}$$

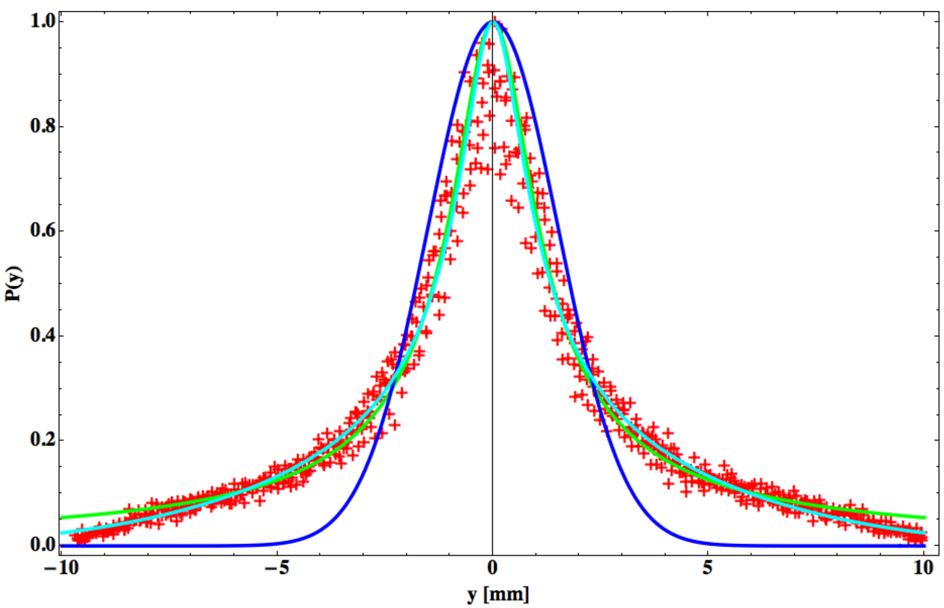


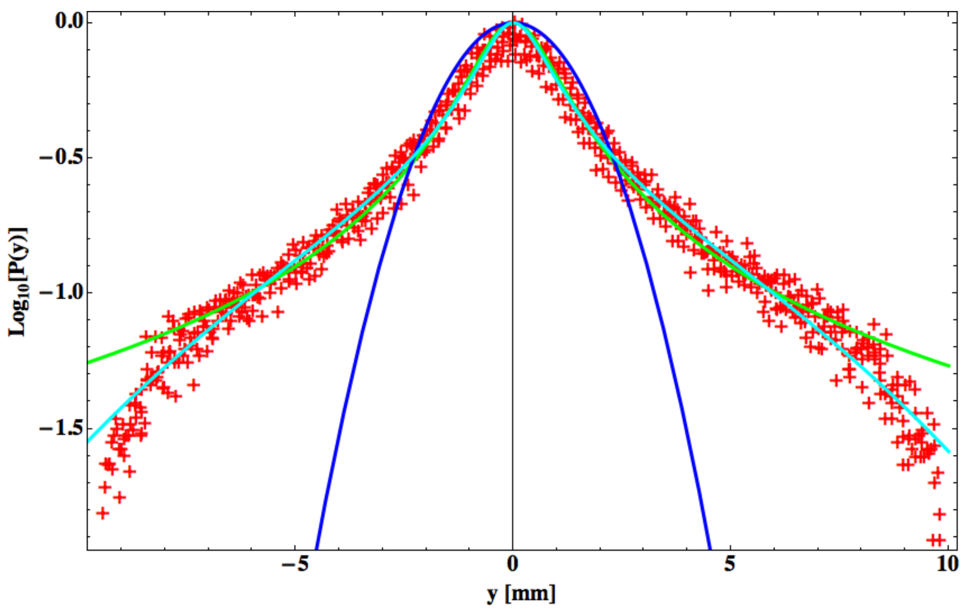


Tail estimation

- Measure multiple beam profiles (over several cycles) in transverse dimensions
- Tails cannot be represented accurately with a Gaussian
- Profile fits to a crossover q-Gaussian, with $q = 2.051 \pm 0.018$, $\alpha = 3.67 \pm 0.22$ and $\beta = 0.813 \pm 0.009$

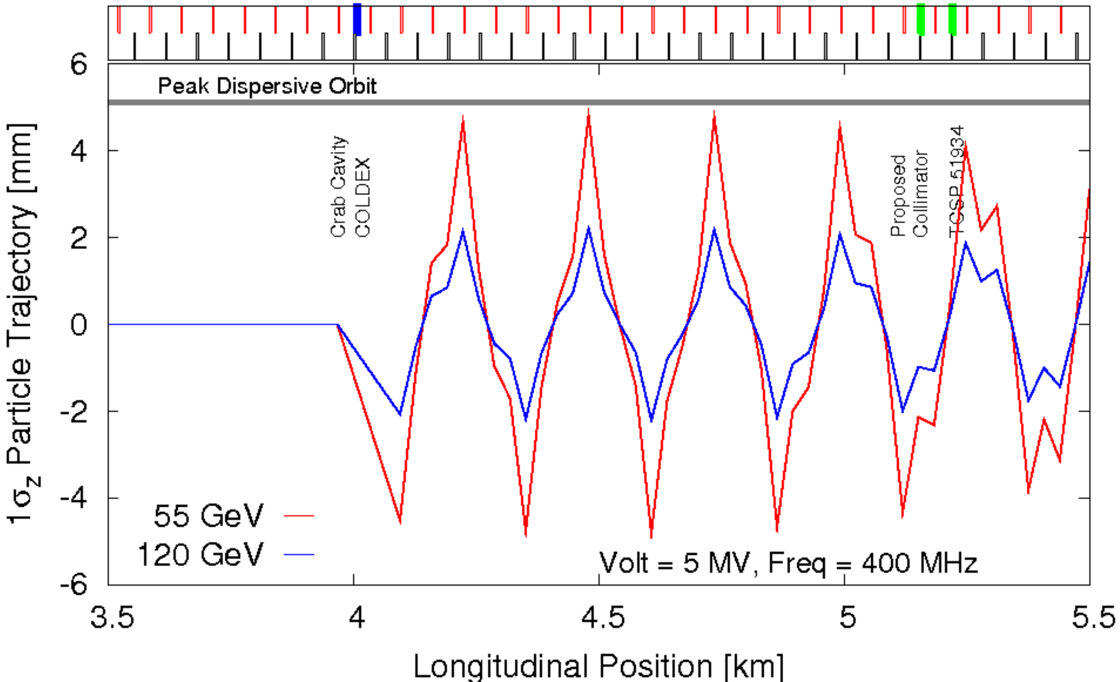
$$P(x) = \left[\left(1 - \frac{\alpha}{\beta} + \frac{\alpha}{\beta} e^{\frac{x^2(-1+q)\beta}{2}}\right]^{\left(\frac{1}{2}+\frac{1}{1-q}\right)}$$





CC Test objectives for beam measurements

- Effect of crab cavities on the beam (Q26 and Q20)
  - Observe crabbing, i.e. longitudinally dependent orbit distortion
  - Effect in tunes, optics, tune-spread and non-linearities (maybe small)
  - Emittance growth (effect of noise)
  - Impedances and instabilities (see talk of N. Biancacci)



R. Calaga

Required instrumentation

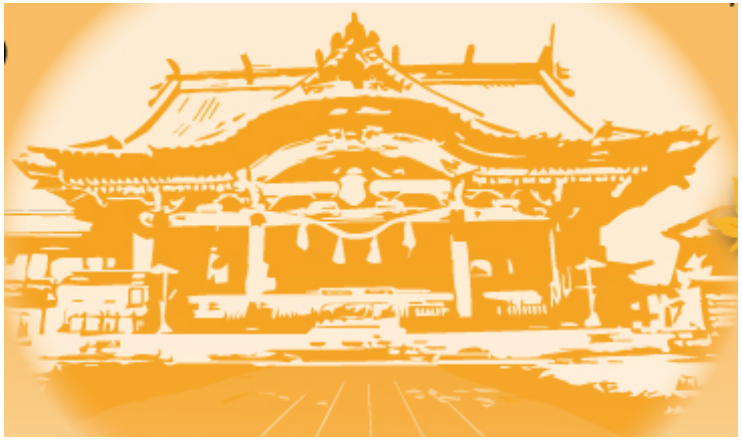
- Linear wire scanner
  - In bunch by bunch mode for injecting more bunches with different intensities and brightness
- Longitudinal profile measurements (wall current monitor)
- Orbit BPMs + Head-tail monitor for orbit control and effect of crab for different voltages
- BBQ and MOPOS system (TBT data) for optics, tune-shift (also with intensity) and non-linearities
- Transverse feedback BPMs (wideband)
- Schottky

Summary

- Emittance growth on coasts observed but not fully understood
  - **Power supply ripple**, IBS (brightness dependence), vacuum,…
- Simulation and measurement plan for narrowing down uncertainties and controlling machine conditions, but also mitigating emittance growth
  - Reduce power supply ripple, use transverse damper in single bunch mode
- Important number of diagnostics are needed for the the measurement campaigns

Thank you very much for your attention

お気遣いありがとうございます。



Spare slides

Summary 2010-2011

	Unit	Exp I	Exp II	Exp III	Exp IV
Energy	[GeV]	55	120	120	270
P/bunch	[10^{11}]	1.1	0.5	0.2	0.2
Number of bunches	-	1	12	1	1
rms norm $\epsilon_{x/y}$	[μ m]	3.1/2.8	1.5-2.0	2.5	2.5
$Q_{x,y}$	-	26.12, 26.18		26.12, 26.18-26.34	26.12, 26.18
RF Voltage	[MV]	3.0	1.0-4.0	4.6-6.5	4.6-6.5

Energy GeV	Intensity [x 10^{11}]	$Q_{x,y}$ -	Voltage [MV]	$d\epsilon/dt$ [/hr]	$d\epsilon/dt$ [/hr]
55	1.0	0.13/0.18	2.0	140%	57%
120	0.5 (12b)	0.13/0.18	2.0-4.0	100-300%	40-90%
120	0.1	0.13/0.18-0.34	2.0-4.0	18%	17%
270	0.4	0.13/0.18	1.5-2.0	20-23%	14-24%