

# Schottkys

Experience from an ICE member...

An instrument from BI+ Fritz +Tevatron

A lot of material and help from Mathilde Favier

# Reference : F. Casper CAS 2008

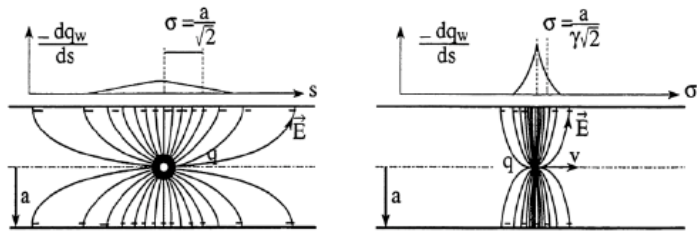


Fig. 4: Electromagnetic field of slow and fast beams (from Ref. [8])

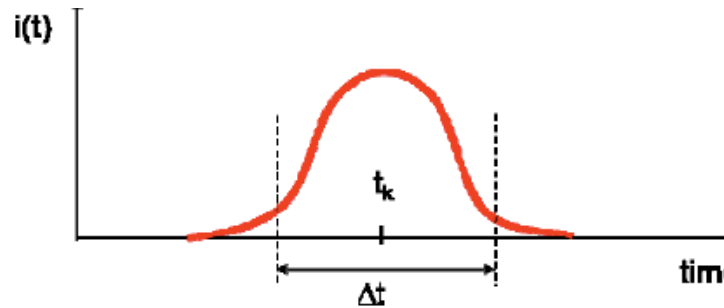
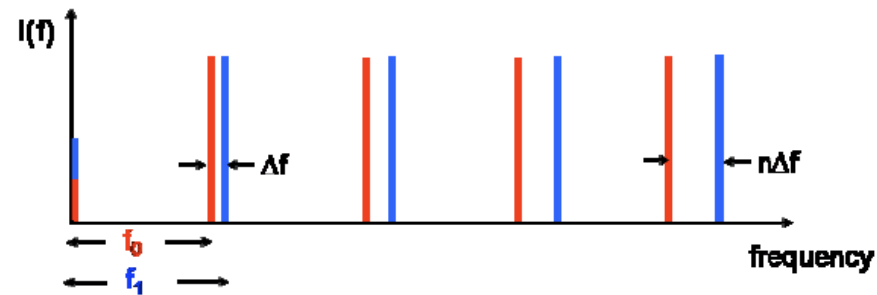
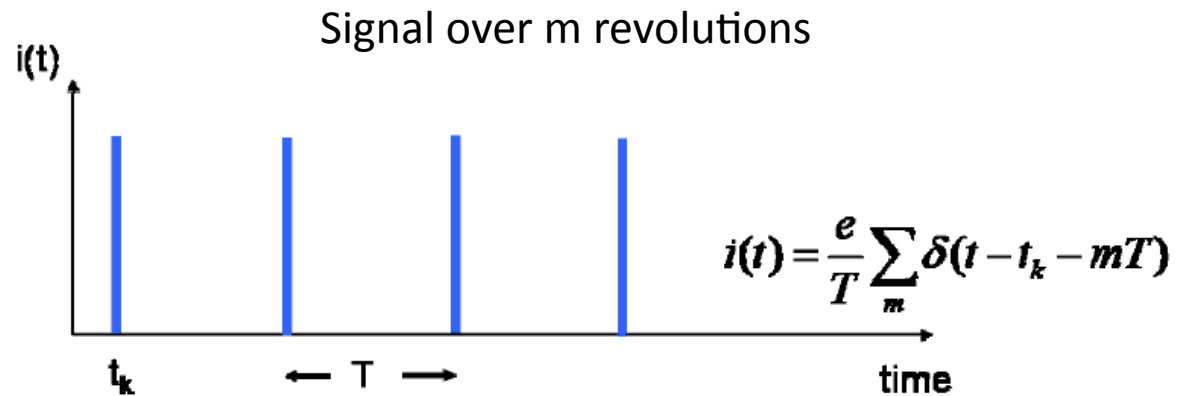


Fig 5: Pick-up signal of a single particle

Coasting beams

Single particle circulating with constant freq will induce a certain signal on a pick-up at its passage  $t_k$



A **second** particle of revolution frequency  $f_2 = f_0 + \Delta f$  is added

Fig. 6: A single particle and two particles with a slight frequency offset  $\Delta f$

Second particle at a slightly different frequency will give a signal at  $\Delta f$  with  $\Delta f$  increasing at each harmonic of the revolution frequency  $f_0$

For a large number of particles the signal will give:

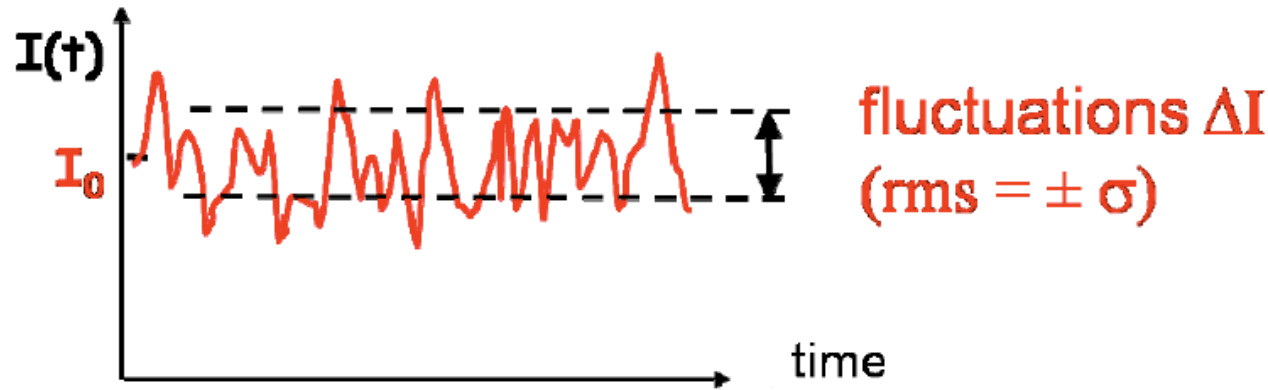


Fig. 7: Illustration of mean current  $I_0$  and fluctuations  $\Delta I$

For Gaussian and non-Gaussian distributions

For a large number of particles with non-Gaussian distribution the signal will be of the type: **Schottky bands**

The band height is arbitrary at this stage

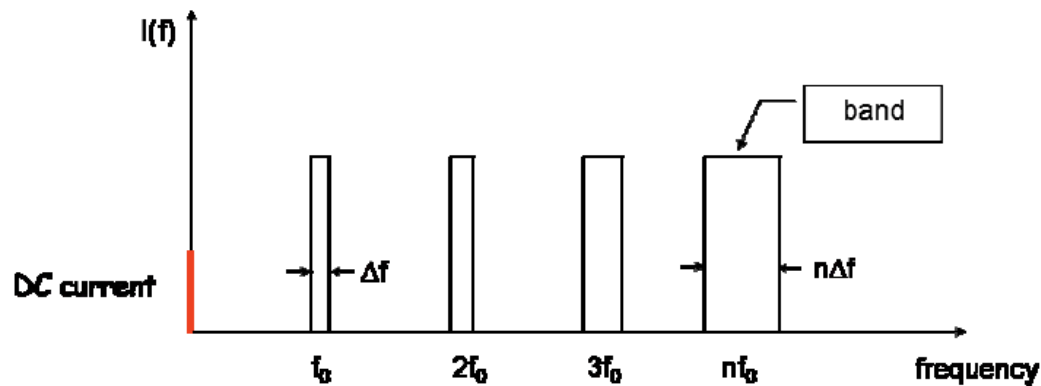


Fig. 8: Spectral density distribution for a large number of mono-energetic particles

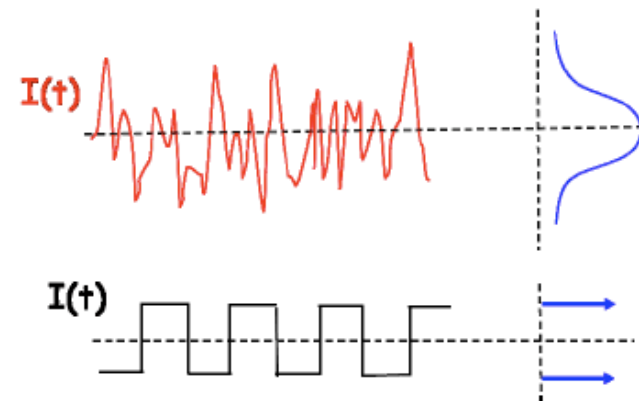
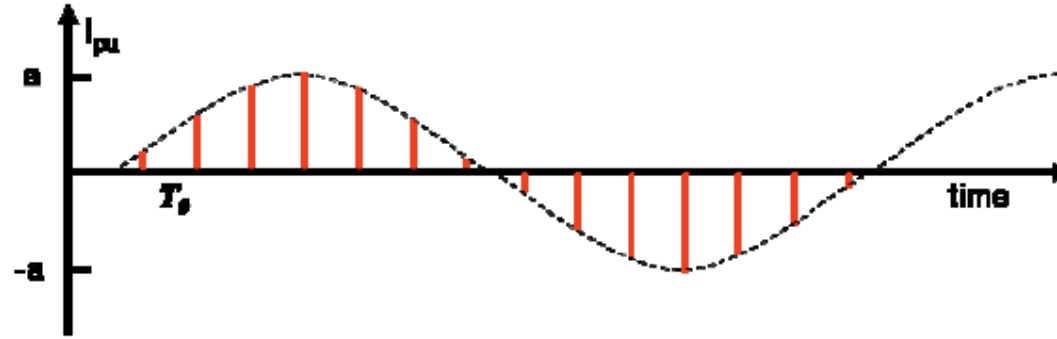


Fig. 9: Illustration of Gaussian amplitude density distribution and non-Gaussian case

One can determine:

- Mean revolution freq
- Freq distribution of particles
- Momentum spread
- Number of Particles  $N$

## Trasverse plane signal



**Fig. 11:** A single particle with betatron oscillation of amplitude  $a$  as seen by a transverse pick-up

The betatron motion results in the particle's wobbling around some reference orbit and thus the transverse position changes every turn. This transverse signal is not seen in the sum output of any pick-up structure (e.g. a pair of strip-lines) but is observed in the Delta, or difference, output. The output signal of such a pick-up has two contributions, one related to the longitudinal phase space and another related to the betatron oscillations.

$$i_{pu}(t) = \frac{e}{T} \sum_n^{\infty} \delta(t - nT + \varphi_k) \times a_k \cos(q\omega t + \phi_k) . \quad (16)$$

The first term under the sum sign is just the same as already seen in the longitudinal phase space discussion. In addition, however, there is an amplitude modulation of this signal due to the betatron motion. This has a frequency of  $q\omega/(2\pi)$ , with  $q$  being the non-integer part of the betatron frequency and an amplitude  $a_k$  representing the oscillation amplitude. The difference response of the pick-up,  $\Delta i_{pu}$ , can therefore be written as

$$\Delta i_{pu} = S_{\Delta} \times a_k(t) \times i_k(t) = S_{\Delta} \times a_k \cos(q\omega_0 t + \phi_k) \cdot \left[ i_0 + 2i_0 \sum_{n=1}^{\infty} \cos(n\omega_0 t + n\varphi_k) \right] \quad (17)$$

## 7 Bunched beams

So far the discussion has been limited to the Schottky noise properties of coasting, i.e., unbunched beams. For bunched beams it is necessary to convolute the transverse spectra obtained in the case of an unbunched beam with the synchrotron spectrum related to the motion of particles in the RF bucket.

It can be seen from Eq. (19) that the total power in each band is constant and proportional to the term  $a_{rms}^2$ , which for an ensemble of particles is nothing more than the rms transverse beam size and is proportional to the transverse emittance. The width of the sidebands is given by

$$\Delta f_{\pm} = (n \pm q) \times df \pm f_0 dq \quad (20)$$

where  $q$  stand for the fractional tune and  $dq/Q$  is the tune spread.

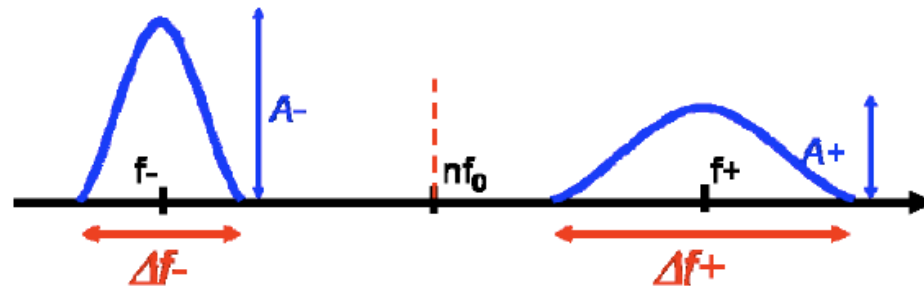


Fig. 13: Example of a Schottky signal with non-zero chromaticity

## What can be measured?

$$q = \frac{1}{2} + \frac{f_2 - f_1}{2f_{rev}}$$

$$\frac{\Delta p}{p} = \frac{1}{\eta} \cdot \frac{W_1 + W_2}{2\pi f_0}$$

$$\xi \propto \frac{W_1 - W_2}{W_1 + W_2}$$

$$\varepsilon \propto A_1 W_1 + A_2 W_2$$

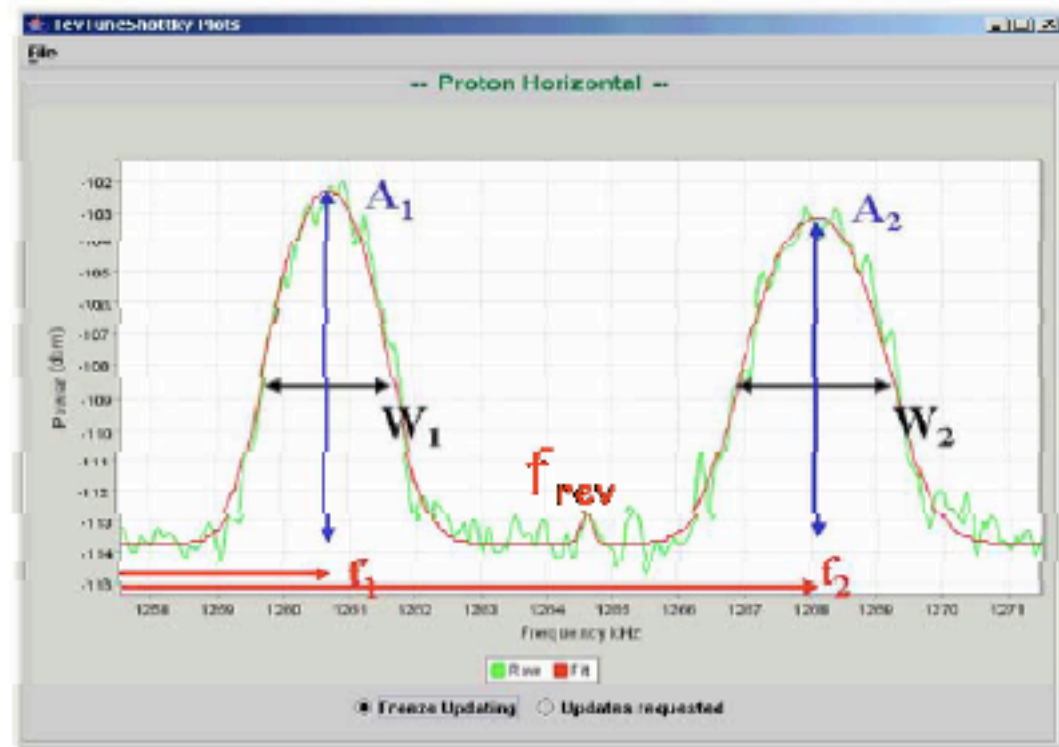
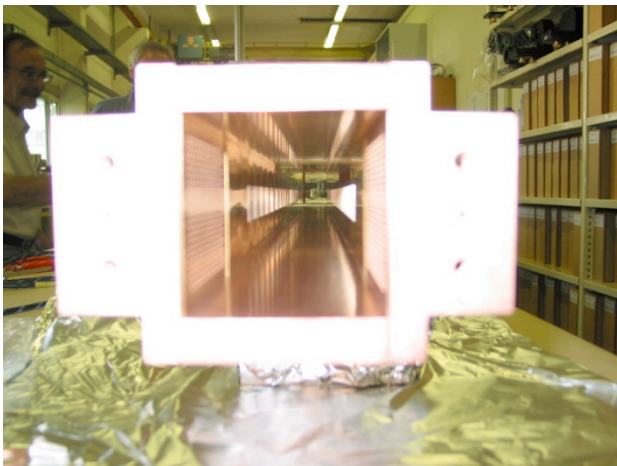
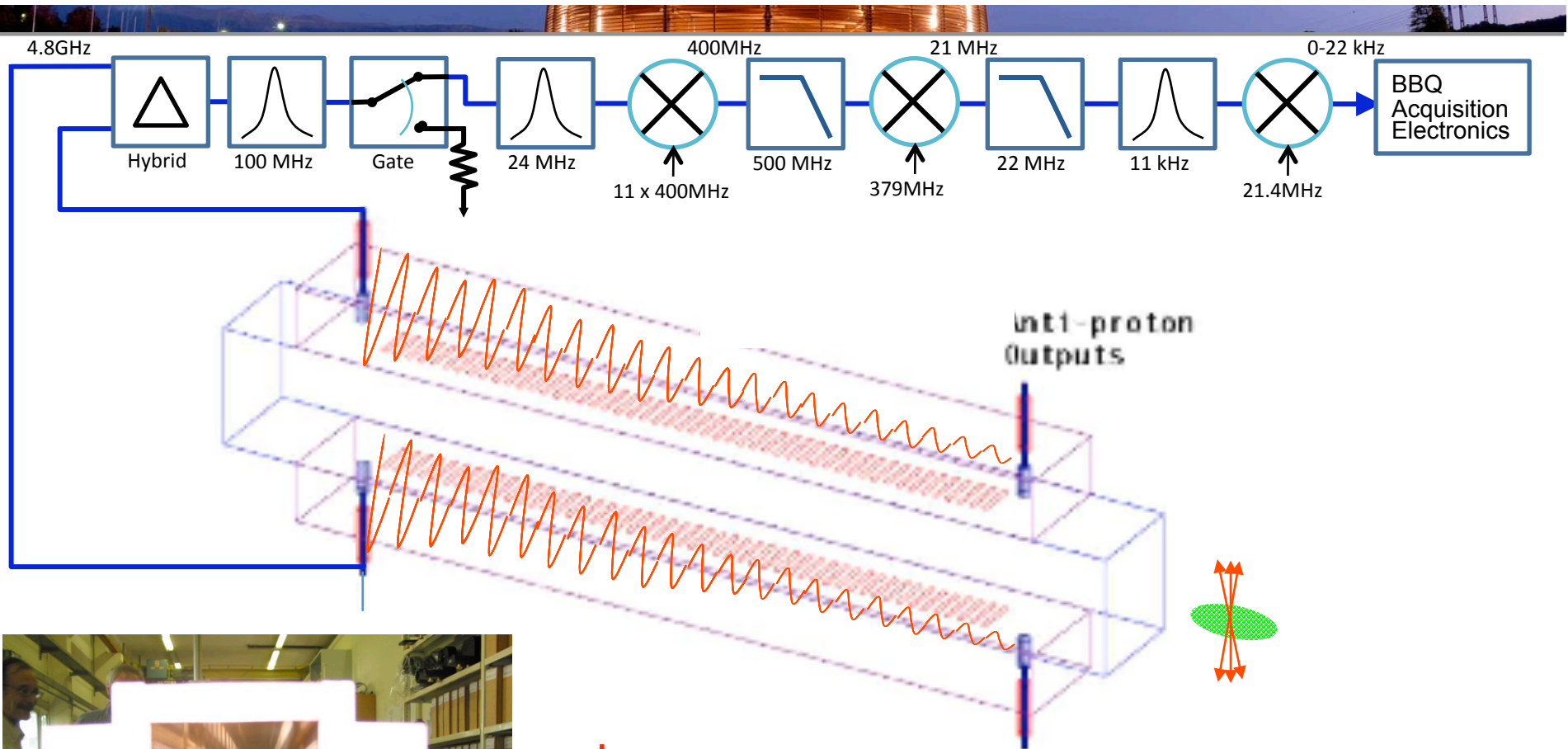
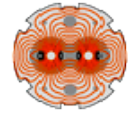


Fig. 23: Measurement example in transverse phase space from the Tevatron [18]

Powerful tool parasitic DOES NOT PERTURB THE BEAMS!!!



# Schottky Monitoring LHC



*4.8 GHz Slotted Waveguide Structure  
60 x 60 mm aperture x 1.5 meters long  
Gated, triple down-mixing scheme to baseband  
Successive filtering from bandwidth of 100MHz to 11kHz  
Capable of Bunch by Bunch Measurement*

# The data flow

**Schottky Monitor Application**

RBA: mfavier

Text/Icons

Setting Mode

Read Only  Read & Set

Authorized User: mfavier/CERNTSAB48

Time left: 228 sec

Default  Manually Change Settings  StandBy/Pause

Beam Mode NOMODE

Beam Mode: NOMODE

Daemon Idle: 0 sec.

Daemon Status: OK

Single Slot Selection

Beam Conditions

Flags:       p

B1 Intensity: 6.554E14

B2 Intensity: 6.554E14

Energy: 450.0 @ Tue 13:53:35

Local Oscillators

Activity

Spectra Time Plots Circuit Diag. Read/Set Gates Scope Tune Diag. SYS Setting Status Logging Fit Info Save/Restore

Select Schottky Instance to display:  Beam 1H  Beam 1V  Beam 2H  Beam 2V

Circuit Diagram for Beam ONE, H (RUN\_AND\_SET) Settings ENABLED

Beam ONE H

1297169615456

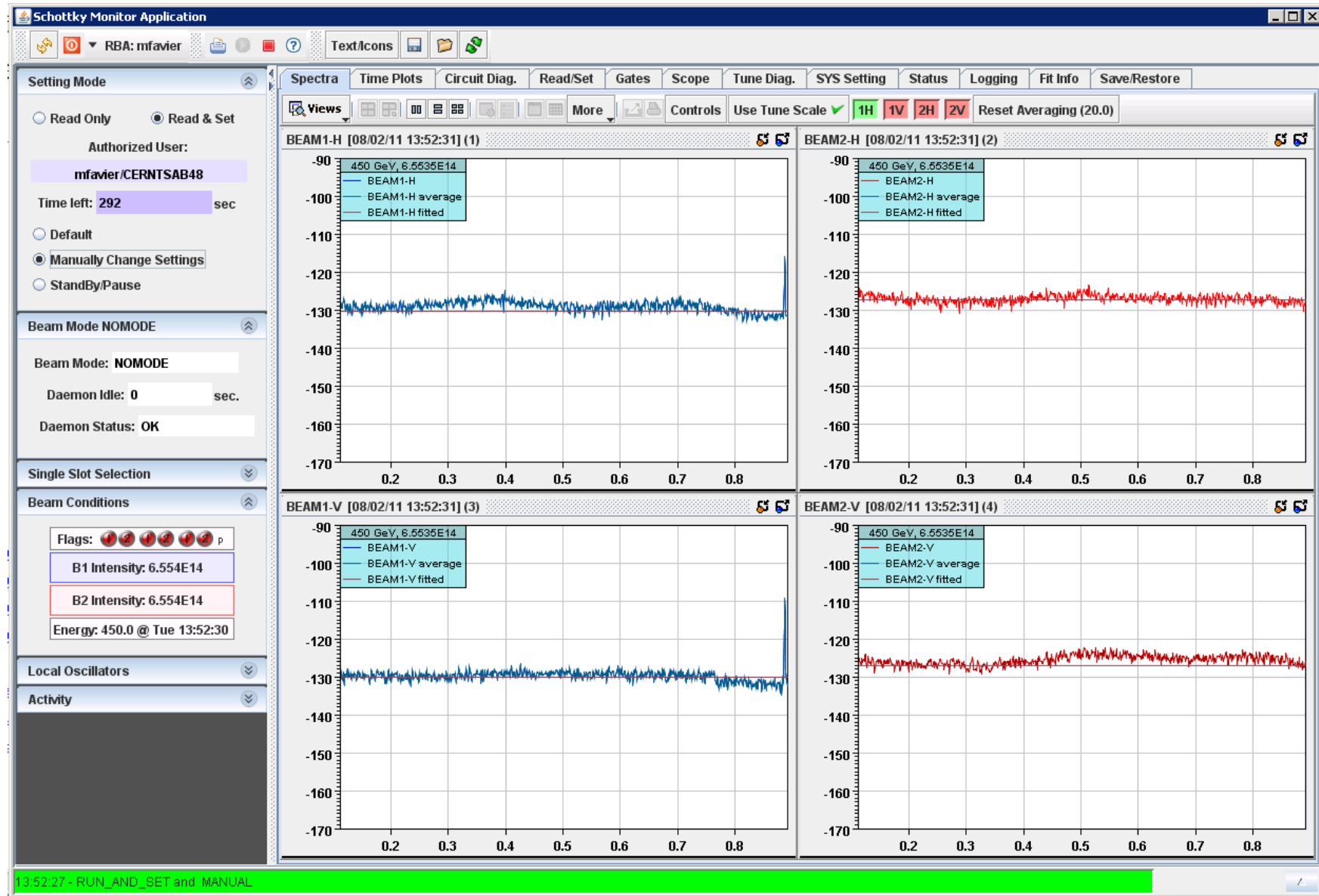
Local Oscillators

Output_B1_21MHz: ON	Output_B2_21MHz: ON	Last Update: Tue Feb 08 13:52:54 CET 2011
Output_B1_400MHz: ON	Output_B2_400MHz: ON	LO Frequency up/down stepper, step size in Hz
Frequency_B1_21MHz: 21.38891	Frequency_B2_21MHz: 21.38891	B1-21MHz: 10.0 Hz up down
Frequency_B1_400MHz: 378.59	Frequency_B2_400MHz: 378.86	B1-400MHz: 11245.0 Hz up down
Power_B1_21MHz: -5.0	Power_B2_21MHz: -5.0	B2-21MHz: 10.0 Hz up down
Power_B1_400MHz: -6.0	Power_B2_400MHz: -6.0	B2-400MHz: 11245.0 Hz up down
Ref_Oscillator_B1_21MHz: EXT	Ref_Oscillator_B2_21MHz: EXT	
Ref_Oscillator_B1_400MHz: EXT	Ref_Oscillator_B2_400MHz: EXT	

13:52:27 - RUN\_AND\_SET and MANUAL



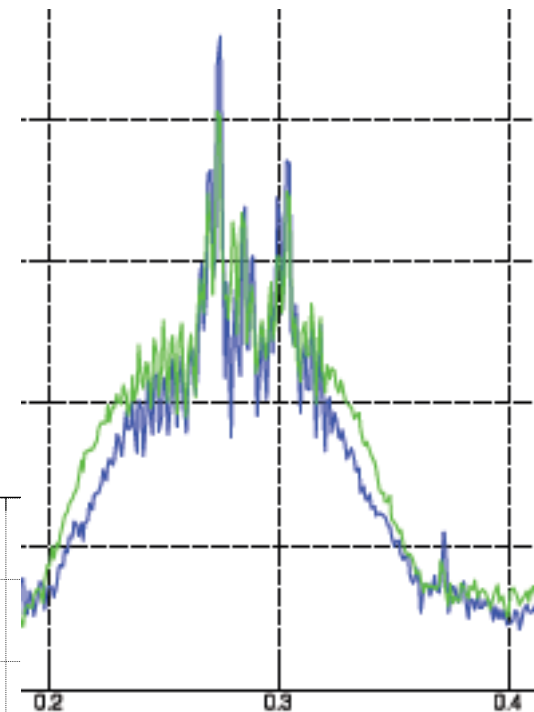
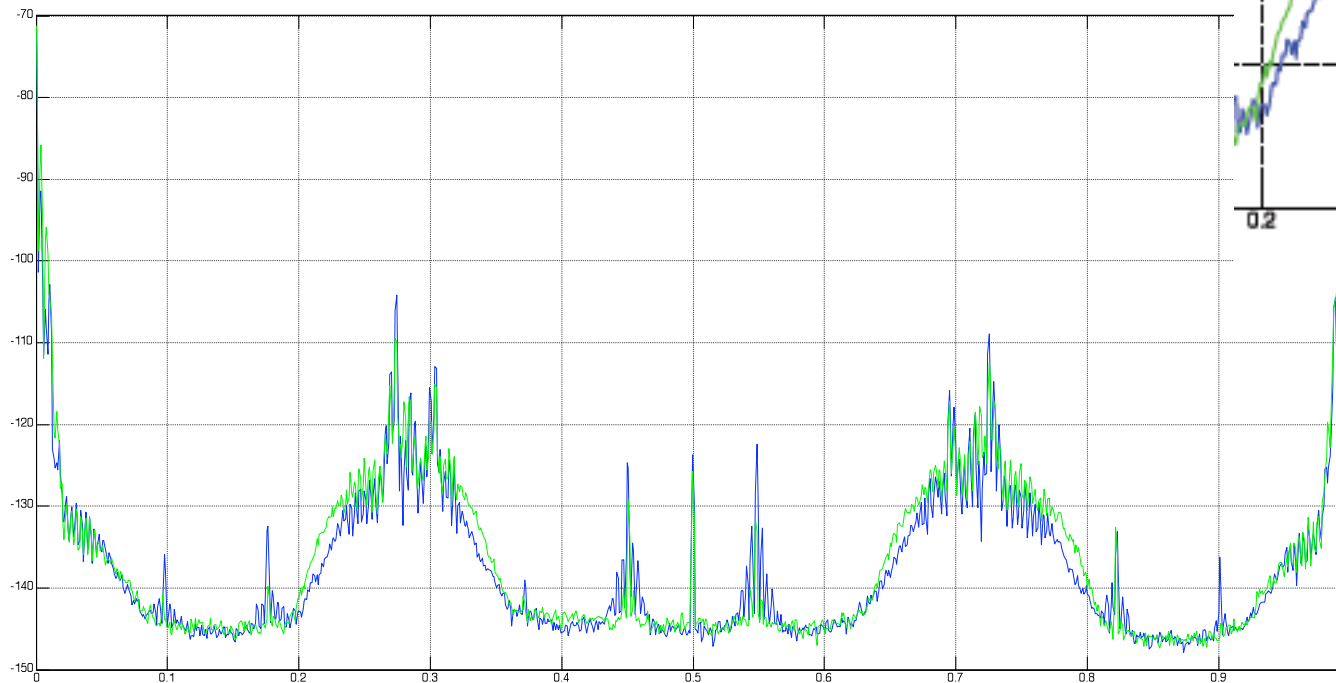
# Bunch spectra



90 sec integration time per bunch needed: takes some time to go through a train

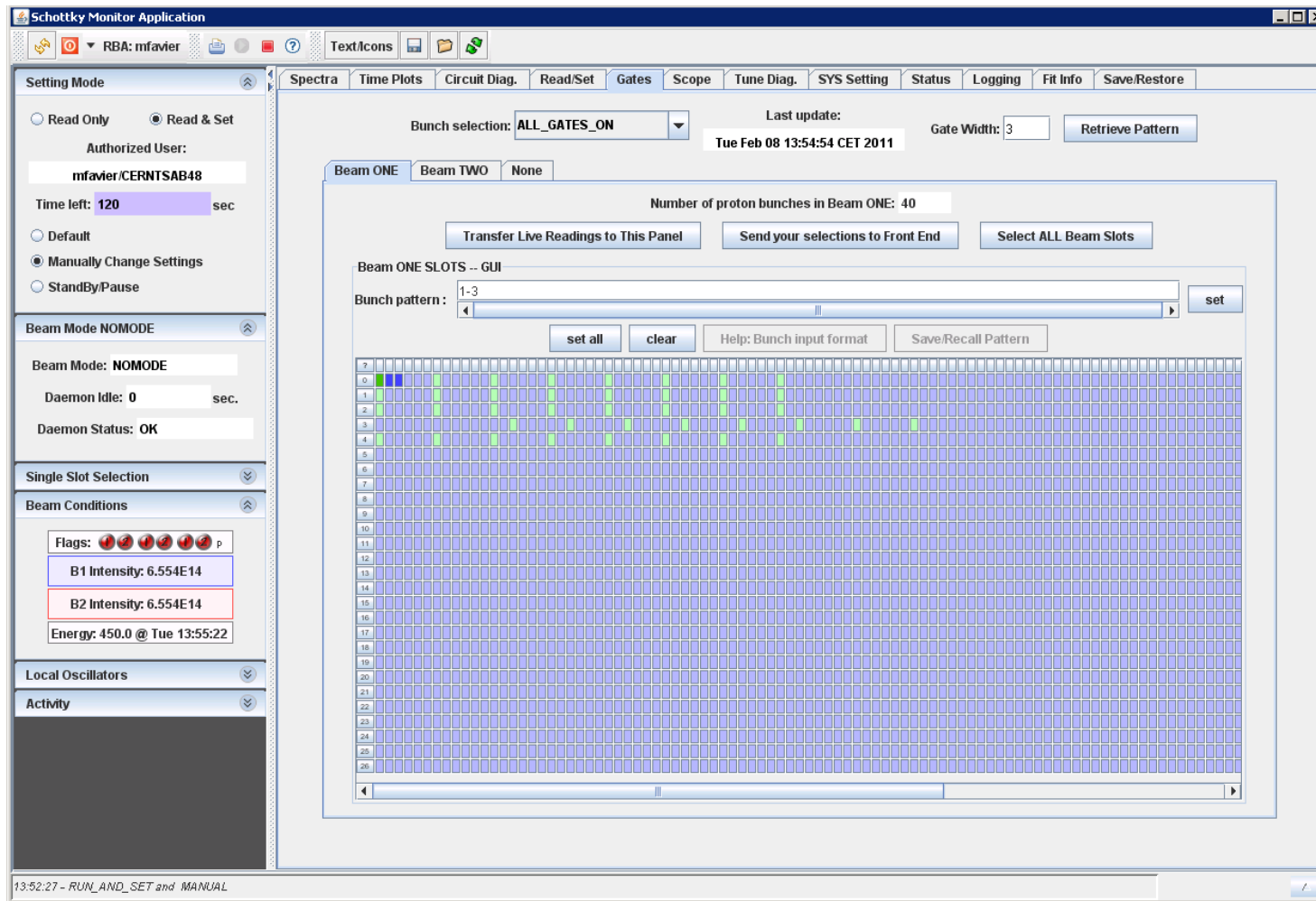
## Tunes of two bunches during e-cloud MDs last November 200

GUI working for IONS after many problems with application!  
Some measurements with protons but no “instability” observed



Mathilde Favier

## Bunch selection, FBCT defines filled slots then clicking technique....



**Bunch selection with play-list from E. Bravin : external application still to be implemented in GUI but working well also like this**

**90 sec integration time per bunch needed: takes some time to go through a train**

## Which other data can be interesting?



Non-integer tunes  
Emittances  
Chromaticity  
Momentum spread

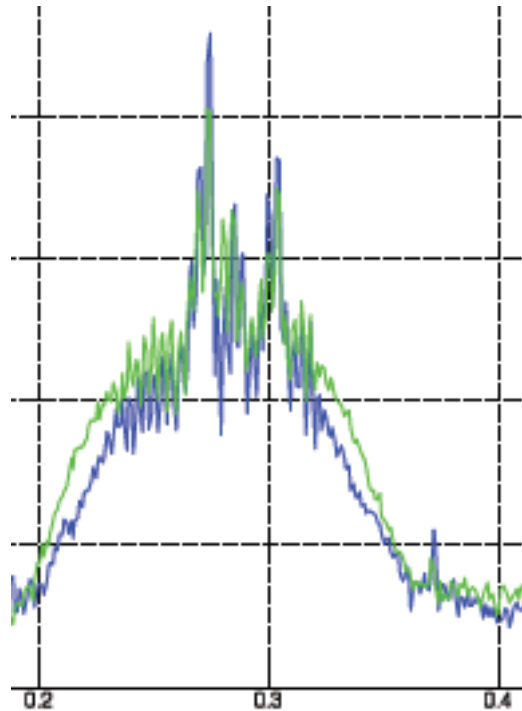
To be “checked/compared”  
with other instruments to  
define limits

## An extra application: ROSALI

JJ Gras, using Mathematica Library

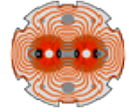
It records the data one need (the same that the one records in Timber) then some analysis can be done.

Mathilde is providing a script to plot the tune spectra for multiple bunches on site for straight comparison of bch to bch .





# Schottky Monitoring



- Status in 2010
  - Schottky made operational towards the end of the year
  - GUI & calculation daemon provided by FNAL
  - Now logging tune, chroma, emittance & dp/p
    - Consistency of emittance & dp/p still to be verified
  - Proton signals not useable during ramp
    - Longitudinal blow-up wreaks havoc!
  - Ion signals text book beautiful!
- Plans for 2011
  - Incorporate automatic bunch cycling on selected bunches in GUI (currently via expert program)