STATUS OF THE LHC SCHOTTKY MONITORS

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Introduction

- **Beam =** Large, but finite number of individual particles typically moving in both, a coherent and incoherent, manner.
- **Schottky noise :** based on the statistical fluctuations of these finite number of charge carriers.
- **LHC has Bunched Beam:**
  - Look at the individual motion of particles inside a bunch.
- **Schottky system =** Non destructive way to determine important beam parameters such as: **Tune, Chromaticity, Emittance and Momentum Spread**.

OVERVIEW

I/ WHAT IS SCHOTTKY NOISE?

- a) Longitudinal Schottky Noise
- b) Transverse Schottky Noise

II/ THE LHC SCHOTTKY SYSTEM

- a) Analogue Signal Processing
- b) Schottky Spectra

III/ MEAUREMENTS

IV/ ISSUES & LIMITATIONS

- **CONCLUSION**

I/ WHAT IS THE SCHOTTKY NOISE?
a) Longitudinal Schottky Noise

- Consider 2 particles circulating in a machine:
  - The first one has charge *e*, velocity *v* and revolution time $t_0 = 1/f_0$.
  - The second one has a slightly different energy and hence revolution frequency f_1. With $\mathbf{f_1 = f_0 + \Delta f}$.

Looking at the Longitudinal Spectra :

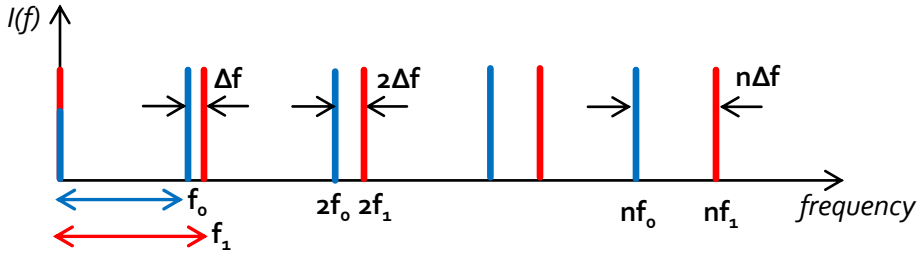


Fig 1: two particles with a slight frequency offset Δf .

- For a subset of N particles with random initial phase and a revolution frequency spread of: ***fo + Δf/2***.

The **power spectral density of the noise** in the n[th] band is:

$$\frac{d\langle I_n \rangle^2}{df_r} = 2e^2 f_r^2 \left(\frac{dN}{df_r}\right)$$

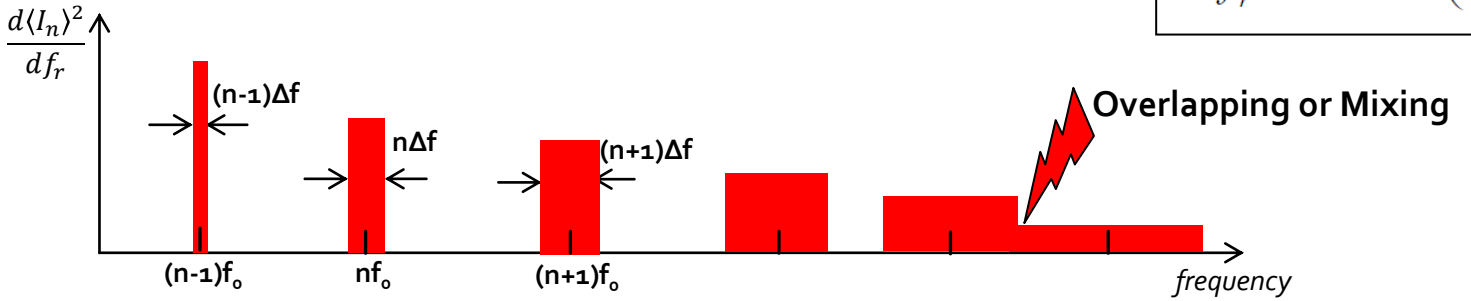


Fig 2: *A schematic picture of longitudinal Schottky bands*

I/ WHAT IS THE SCHOTTKY NOISE?
b) Transverse Schottky Noise

- **For a bunched beam two signal contributions:**
  - Amplitude modulation du to *betatron oscillations.*
  - Time (frequency) modulation due to *synchrotron oscillations*.

From the Spectral Point of View:

- Each Schottky band has a finite width which results from the spread of revolution frequencies and betatron frequencies:

$$\Delta f_{\pm} = f_0 \frac{\Delta p}{p} [\underbrace{(n \pm q)\eta}_{\sim 136} \pm \underbrace{Q\xi}_{\text{Varies from 1 to 10}}]$$

n : harmonic number
q : non integer part of the tune
ξ : chromaticity
η : slip factor
Q : betatron Tune

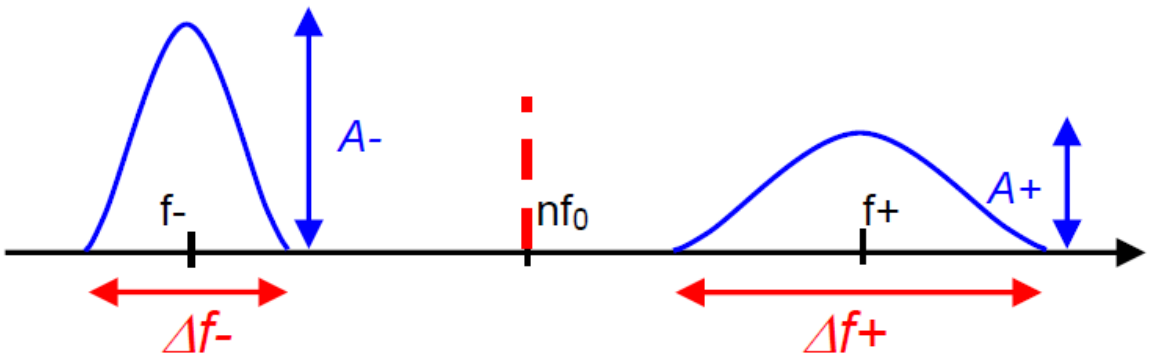


Fig3: *Transverse Spectrum of the Transverse Schottky side bands*

II/ The LHC Schottky System

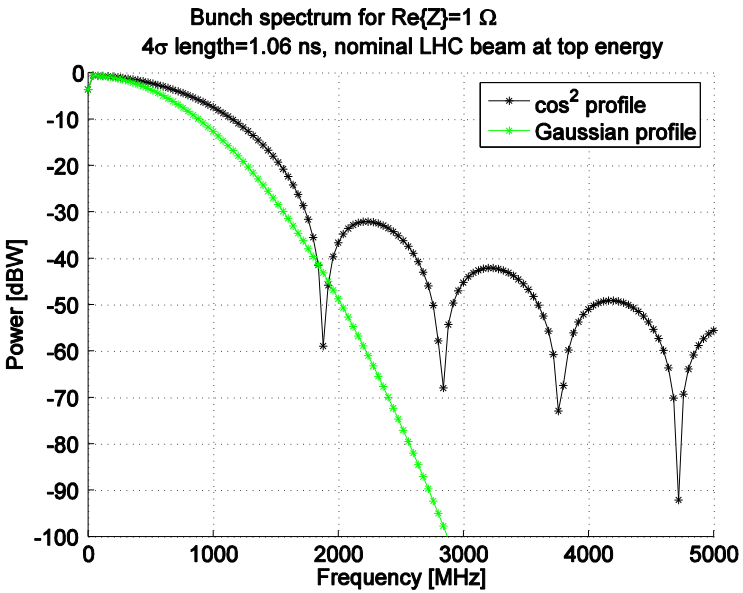


Fig4: *Theoretical bunch spectrum (coherent signals) of a nominal LHC beam at top energy.*

- Too High in frequency ➡ Overlap of the Schottky bands
- Too low in frequency ➡ To much Coherent Signal

Design done for a frequency at 4.8GHz

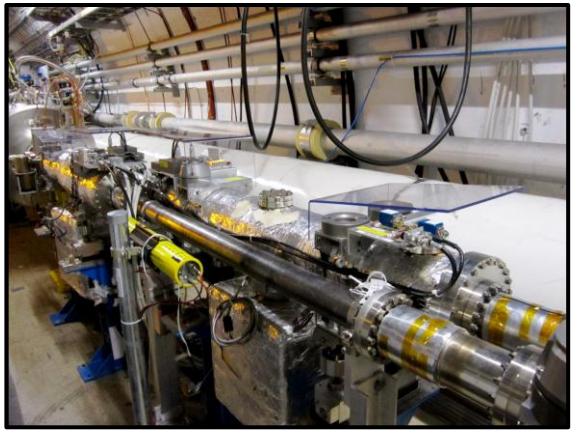


Fig 5: *Picture of the Schottky monitor at LHC Point 4*

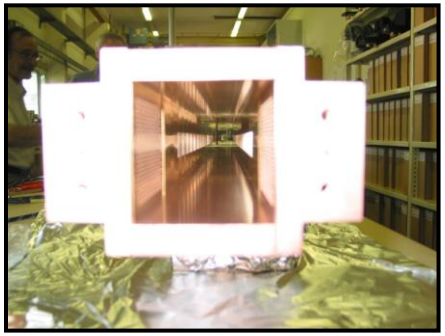


Fig6: *Picture of the Sloted Wave Guide Structure*

- 4 Schottky devices were installed at Point 4 in the LHC. One for each transverse plane for the two beams.
- A high sensitivity pickup operating at 4.8GHz, which corresponds to the 427000 harmonic of the revolution frequency

II/ The LHC Schottky System

a) Analog Signal Processing

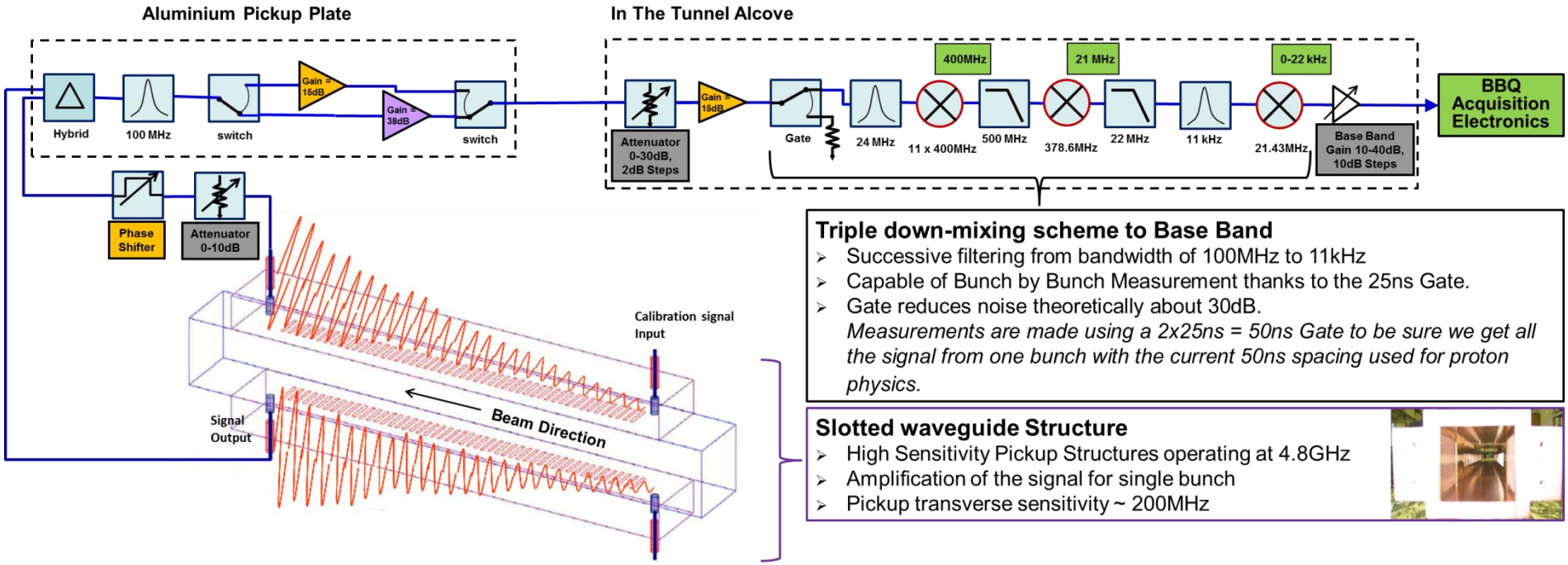


Fig7: *The LHC Schottky analogue treatment Channel*

- Slotted Wave Guide Structure operating at 4,8 GHz.
- Preamplifiers.
- Gate to allow bunch by bunch measurements
- Triple down converter mixing chain plus band pass filtering converting the 4.8GHz signal to baseband.

II/ The LHC Schottky System

b) Schottky Spectra

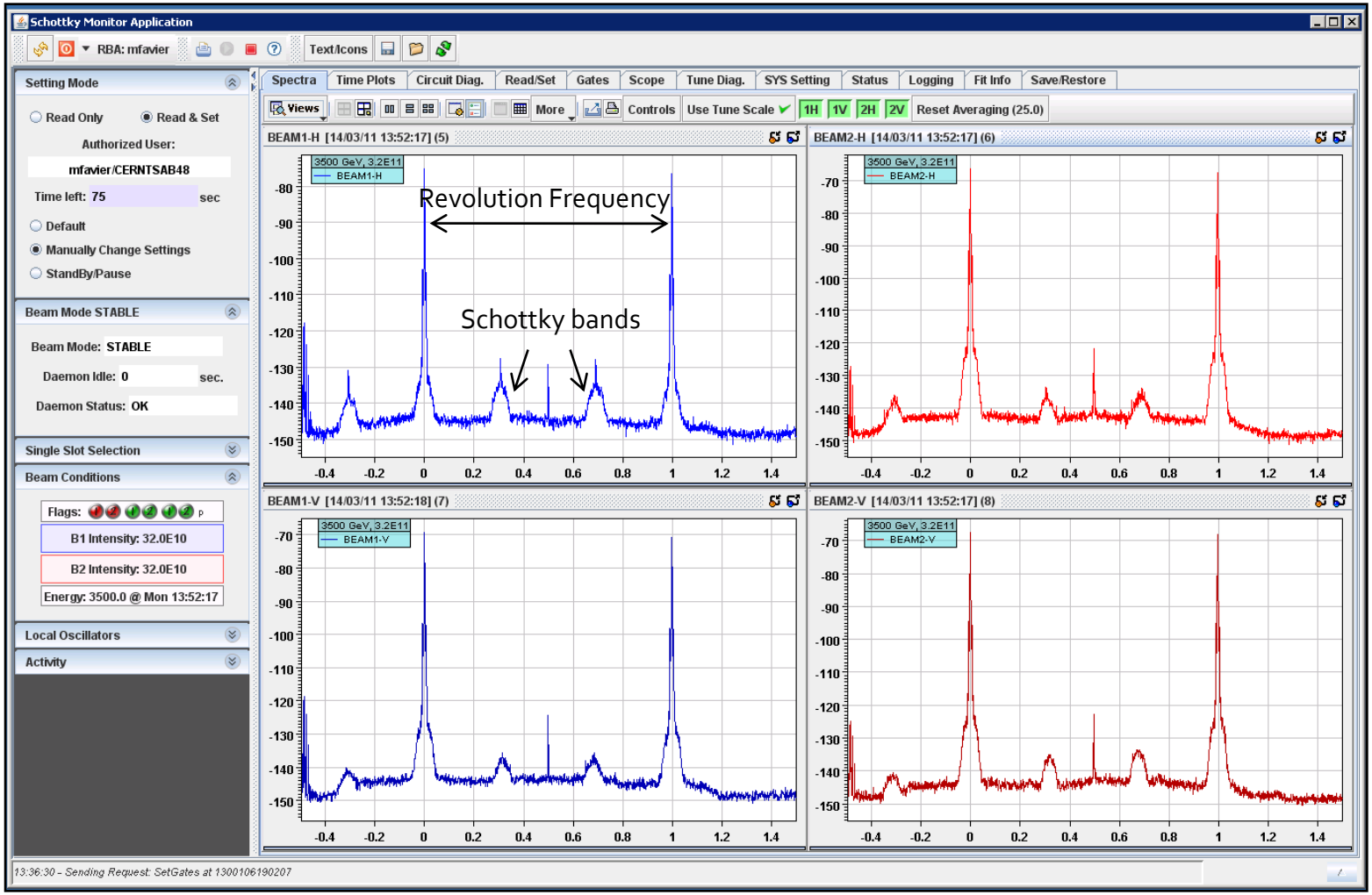


Fig8: *Schottky spectra with protons at stable beam (view from the GUI).*

III/ MEASUREMENTS

- **Spectra → Fit → Beam Parameters**

- **Incoherent Tune**

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

- **Momentum spread**

$$\frac{\Delta p}{p} = \frac{1}{\eta} \times \frac{W_1 + W_2}{2 n f_0}$$

- **Chromaticity**

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

- **Emittance**

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

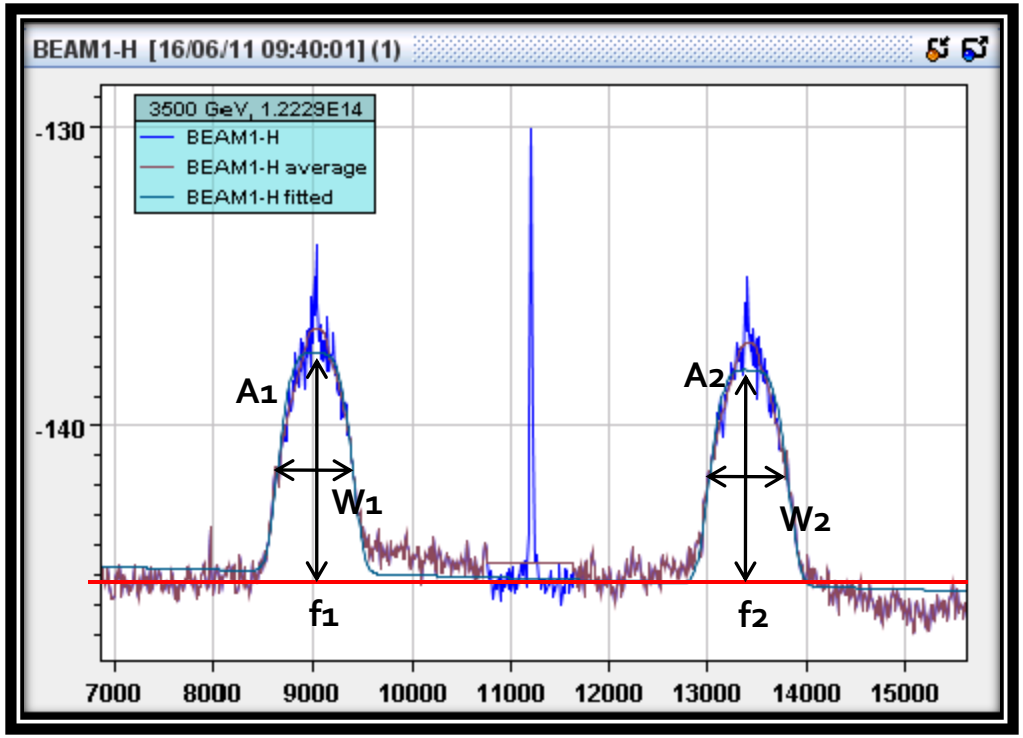
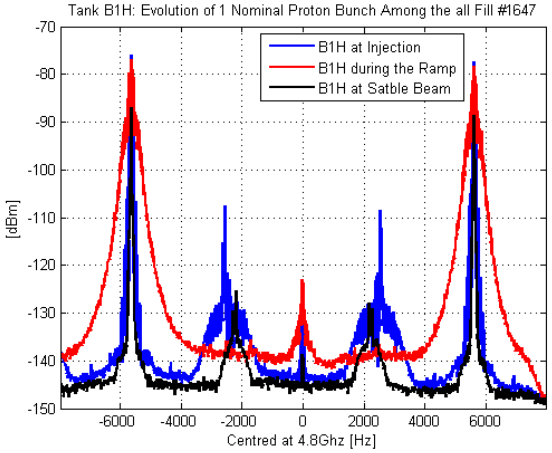
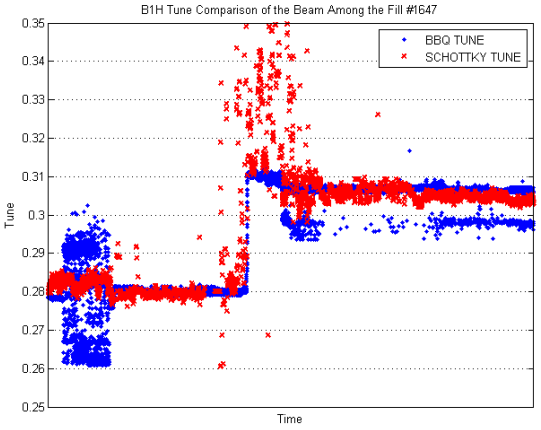


Fig 9: Zoom on the Schottky bumps, B1H *spectra with protons at stable beam (view from the GUI).*

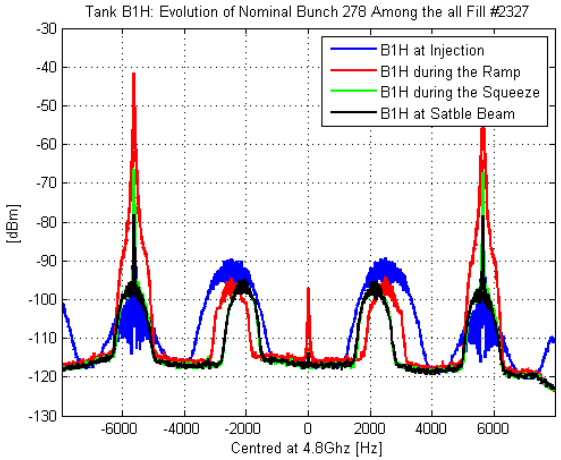
III/ MEASUREMENTS

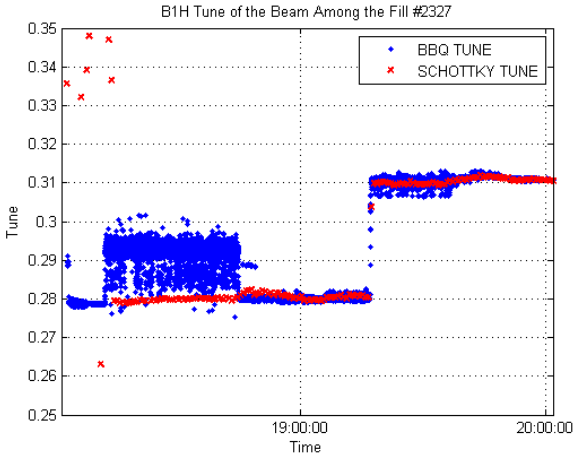
- **Protons and Ions Measurements**
  - **Proton Spectra**



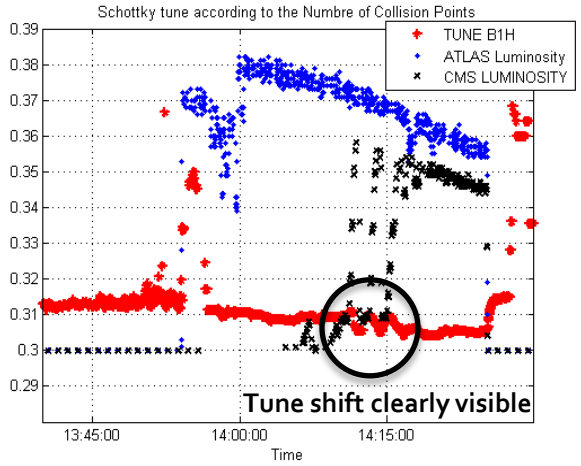


  - **Ion Spectra**





  - **Tune Measurements during the Beam Beam MD**



Proton spectra lost during the ramp.

Reliable bunch by bunch tune measurements on B1H.

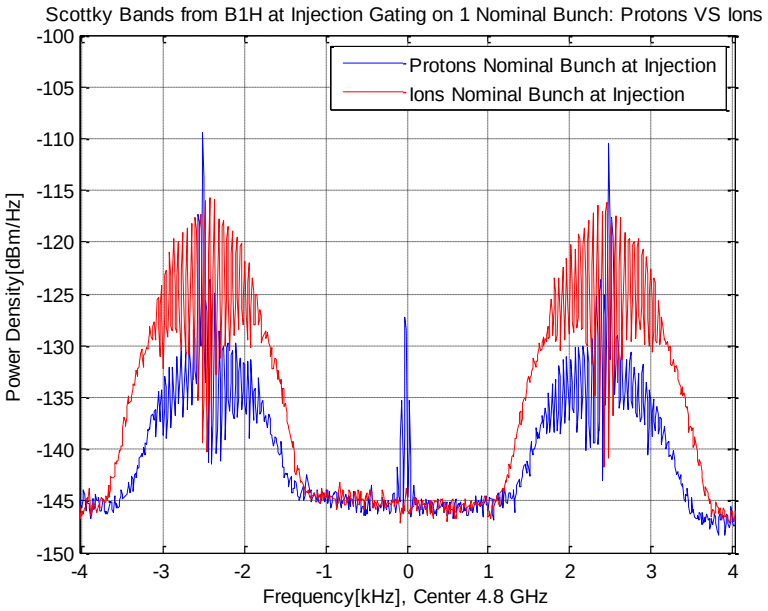
Chromaticity measurements possible but need to be crossed checked.

III/ MEASUREMENTS

Protons VS Ions

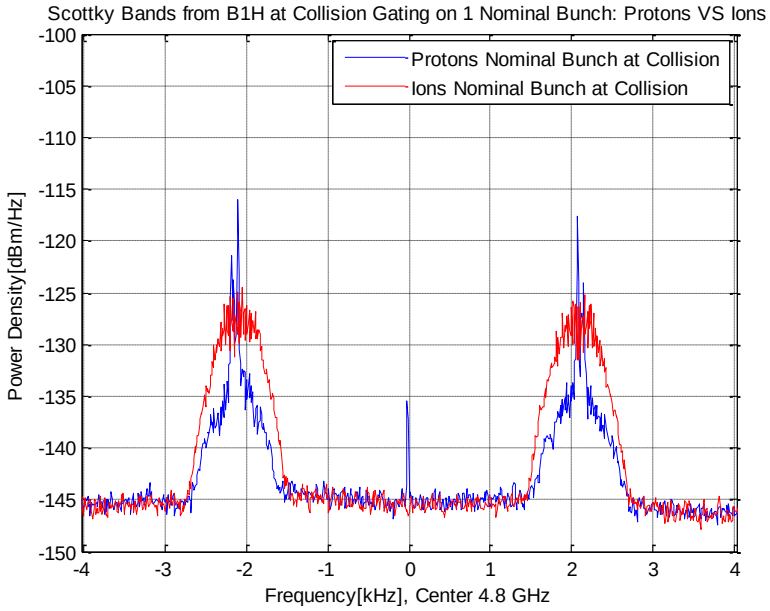
Nominal Bunch at Injection

	Intensity	Bunch Length [ns]
Protons	1.26 e+11	1.19
Ions	6.9 e+09	1.9



Nominal Bunch at Stable

	Intensity	Bunch Length [ns]
Protons	1.20 e+11	1.13
Ions	7.41 e+09	1.7



IV/ ISSUES & LIMITATIONS

- Schottky devices are really sensitive to:
  - Coherent longitudinal oscillations
    - Longitudinal blow-up during ramp
    - No more signal right after the Ramp and Squeeze
      - 30 MINS BEFORE SIGNAL APPEARS
  - Coherent transverse Signal
    - System has 100dB dynamic range but still sensitive to:
      - Bunch position.
      - Bunch Intensity -> Saturation of the Electronic
  - B1H always gives better results, investigation s underway to understand why the other systems don't perform as well!!?
  - Modification have been tested at B2V to reduce the coherent transverse signals.

IV/ ISSUES & LIMITATIONS

- Modification on Pickup plate on B2V:
  - Additional Gate and improved filtering.
  - Avoid the saturation of the Preamp

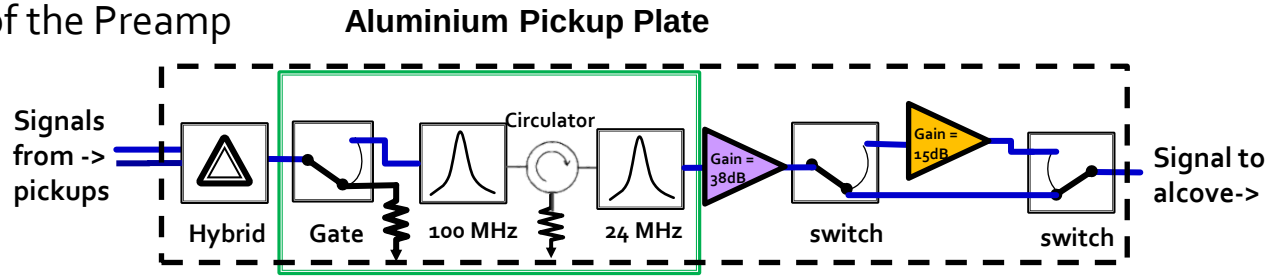


Fig 10: *New electronic installed on the B2V pick-up plate.*

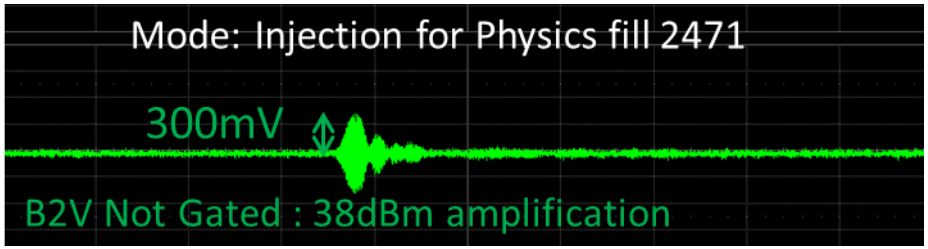


Fig 11: *Amplitude of the signal at injection of nominal protons in B2V before the addition of the Gate.*

- Output Voltage (and hence input voltage) of the front end amplifier is reduced by a factor of 3.

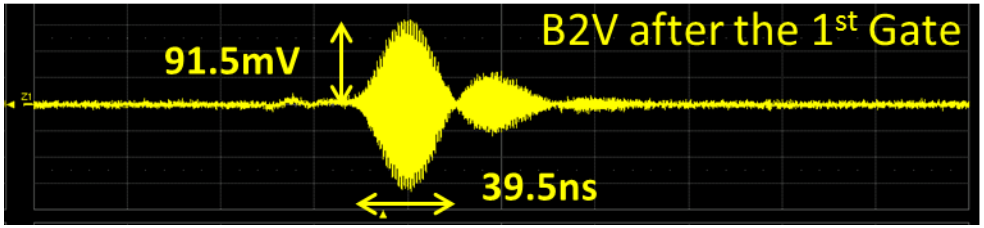
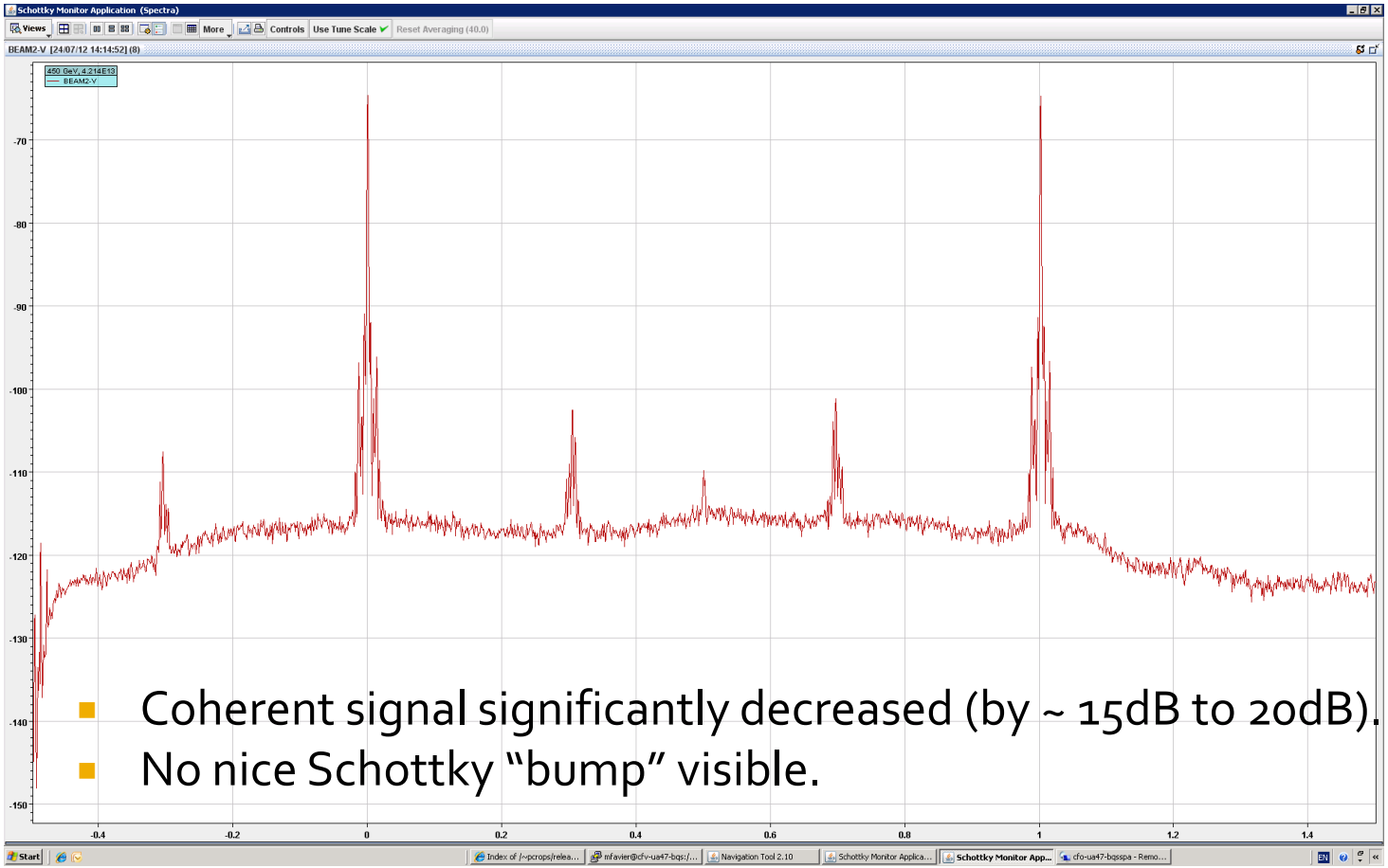


Fig 12: *Amplitude of the signal at injection of nominal protons in B2V after the addition of the Gate on the Pick-up plate.*

IV/ ISSUES & LIMITATIONS

- B2V Spectra at injection for a Nominal bunch with the modified system



- Coherent signal significantly decreased (by ~ 15dB to 20dB).
- No nice Schottky "bump" visible.

CONCLUSION

- Gate needed on the other pickup plates to avoid the saturation of the pre-amplifiers.
- Keep Investigating to understand why B1H gives always better signals.
- **Plan for LS1:**
  - Dismount some of the Schottky devices to investigate more an the wave guide and the pick-up system.
  - Test bench in the Lab.

THANK YOU

ANY QUESTIONS?

Some References

- **Schottky Beam Instrumentation**, Linnecar, T, CERN- PE-ED 001-92, Geneva, CERN, 1992.
- **Schottky Noise And Beam Transfer Function Diagnostics**, Boussard, D, CERN, Geneva, Switzerland.
- **Shottky Signal for Longitudinal and Transverse Bunched Beam Diagnostics**, Fritz Caspers, Jocelyn Tan, CERN, Geneva, Switzerland.
- **The 4.8 GHZ LHC Shottky Pick-up System**, Proceedings of PAC07, Albuquerque, New Mexico, USA.
- **Capabilities and performance of the LHC Schottky Monitors**, M. FAVIER, T. Bogey, O. R. Jones, Proceedings of DIPAC11, Hamburg, Germany.