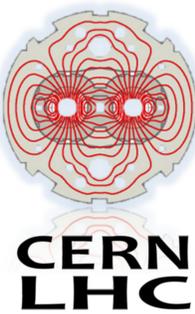


# CAPABILITIES AND PERFORMANCE OF THE LHC SCHOTTKY MONITORS

Authors: Mathilde Favier, Thierry Bogey, Fritz Caspers, Owain Rhodri Jones (CERN, Geneva), Andreas Jansson (ESS, Lund), Jerry Cai, Elliott Simkins McCrory, Ralph James Pasquinelli (Fermilab, Batavia)



## ABSTRACT

The LHC Schottky system has been under commissioning since summer 2010. This non destructive observation relies on a slotted wave-guide structure resonating at 4.8GHz. Four monitors, one for each plane of the two counter-rotating LHC beams, are used to measure the transverse Schottky side-bands. Electronic gating allows selective bunch-by-bunch measurements, while a triple down-mixing scheme combined with heavy filtering gives an instantaneous dynamic range of over 100dB within a 20kHz bandwidth. Observations of both proton and lead ion Schottky spectra will be discussed along with a comparison of predicted and measured performance.

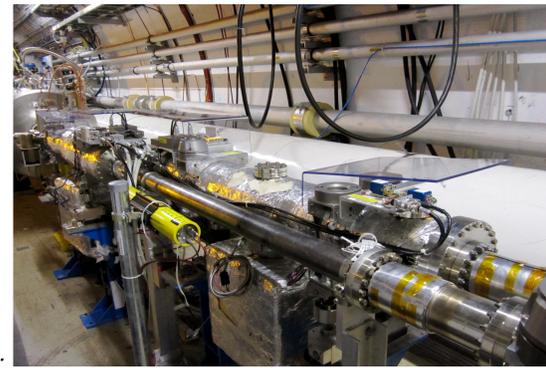


fig 1. Schottky Monitors in the LHC Tunnel at Point 4.

## Analogue Signal Processing Chain

• **Fig2:** Using a Spectrum analyser we can check the signal after the first 100MHz BPF and we clearly see the **150ns Bunch Spacing** (6.666MHz) taken from the LHC physics runs in 2010.

• **Fig3:** The Oscilloscope shows the Pilot signal after the 1<sup>st</sup> LO without gating.

• **Fig4:** The GUI created by Fermilab gives live signals and allows the user to change the settings (Attenuator, Gains...) in order to optimise the SNR.

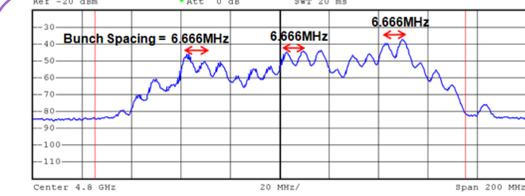


fig 2. Transverse Schottky Signal with a SPAN of 200MHz. What we can see after the 1<sup>st</sup> Band Pass Filter



fig 3. Transverse Schottky Signal from the pilot. What we can see after the 1<sup>st</sup> LO

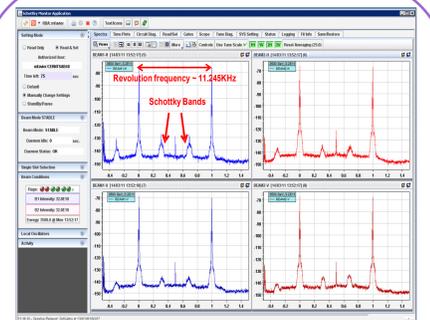
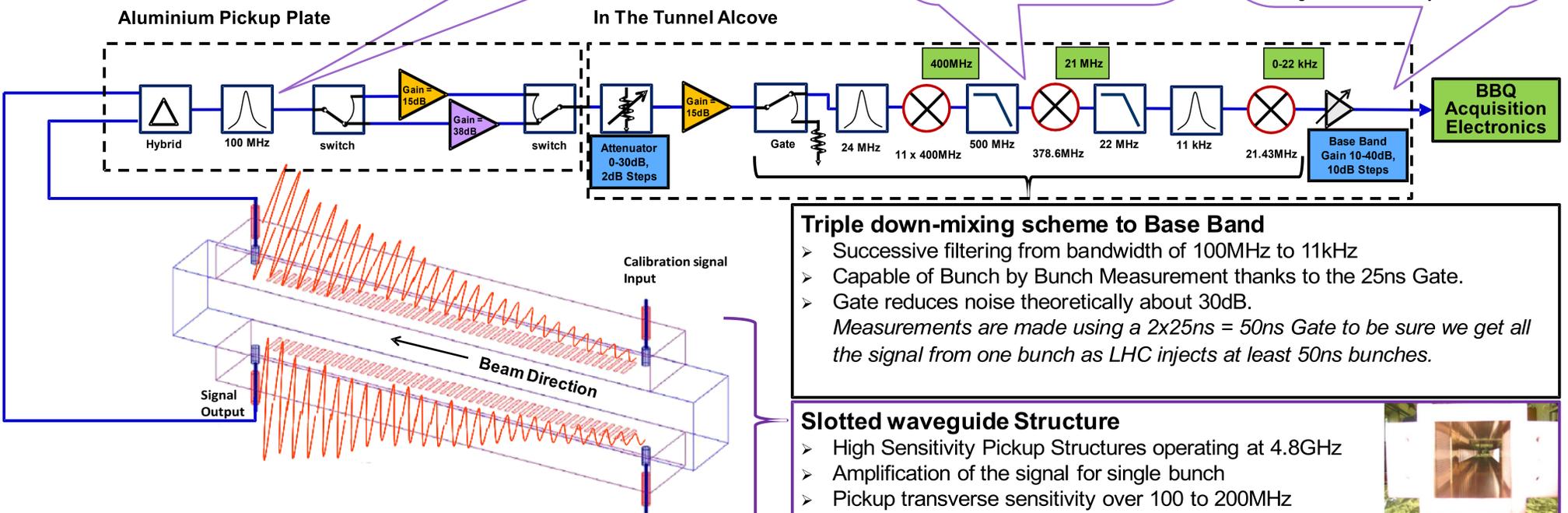


fig 4. Transverse Schottky Signal at the end of the Processing Scheme using the GUI made by Fermilab.



**Triple down-mixing scheme to Base Band**

- Successive filtering from bandwidth of 100MHz to 11kHz
- Capable of Bunch by Bunch Measurement thanks to the 25ns Gate.
- Gate reduces noise theoretically about 30dB. Measurements are made using a 2x25ns = 50ns Gate to be sure we get all the signal from one bunch as LHC injects at least 50ns bunches.

**Slotted waveguide Structure**

- High Sensitivity Pickup Structures operating at 4.8GHz
- Amplification of the signal for single bunch
- Pickup transverse sensitivity over 100 to 200MHz

## Signal to Noise Ratio Study

➤ Gating on a single Bunch → Noise decreases about 17dB, cf fig5.

➤ Using the Preamp (15dB or 38dB) → Increase of the Schottky peaks as expected, cf fig6 & fig7. Measurements are made with Protons with 228 bunches of Protons and a pilot in the machine

➤ Minimum Noise Level → ~-145dB, whatever is the configuration of the hardware, cf fig6 & fig7.

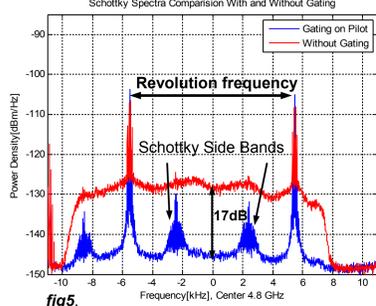


fig5.

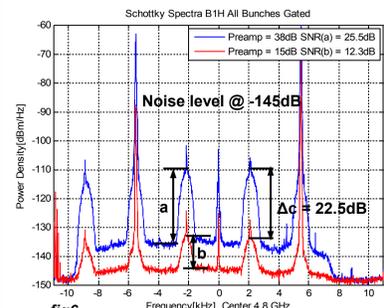


fig6.

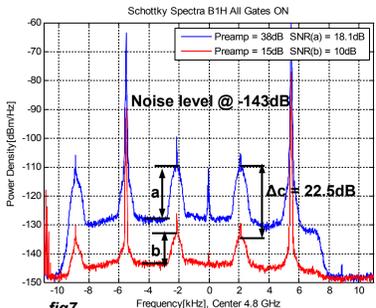


fig7.

## Close-up view of the Schottky Bands

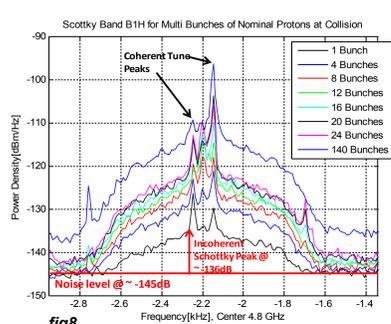


fig8.

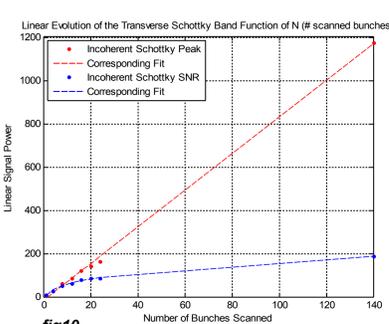


fig10.

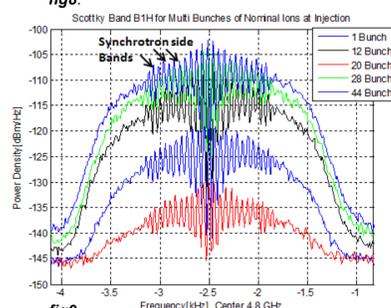


fig9.

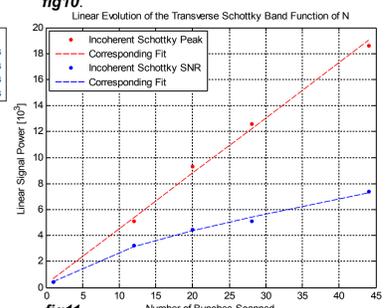


fig11.

➤ The transverse Schottky Signal is following the function:

$$SNR_t = \frac{e^2 N^2 f_0^2 a_{rms}^2}{kT \Delta_f} \cdot \frac{2 Z_{\Delta}}{d^2 N_f} \cdot \frac{G}{RG+1-R}$$

Gate Contribution

➤ Fig10 & 11 show that the Incoherent Schottky Peak increases proportionally to the number of Bunches measured, N, (cf red curves).

➤ The SNR should be constant when gating is employed on multiple bunches. However, for the measurement of a few bunches the SNR is reduced as the noise does not reduce in proportion to the signal (cf fig10 & 11, blue curves).

## Application : Tune Measurements for Beam-Beam studies

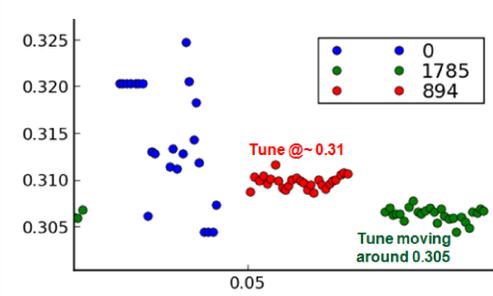


Fig 12. Schottky Tune measurement for Beam-Beam Studies

• The measurement of the Tune is given by the position of the Coherent Schottky Peaks.

• **Fig 12:** The plot shows us the Tune measurement of 1 Pilot Bunch (blue), and 2 nominal bunches (green and red). The difference in Tune measurement between those 2 Nominal bunches is explained because, bunch 1785 is colliding in ATLAS and CMS, and bunch 894 is only colliding in ALICE experiment.

## CONCLUSION

The LHC 4.8GHz Schottky monitor:

- Only monitor in the LHC capable of measuring bunch by bunch tunes.
- Useful for beam-beam studies, (expected tune dependence on number of collisions clearly visible).
- Extensively used during the recent scrubbing run to evaluate electron cloud build-up along trains of bunches by observation of the induced tune shift.

The Gating:

- Functionality has proven to substantially increase the available signal to noise, without however reaching the predicted 30dB gain for single bunch operation.
- The noise floor is currently not determined by the front-end amplifier and hence a future improvement would be to increase the gain of this first stage.