LHC Online Chromaticity Measurement - Experience After One Year of Operation

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Many thanks to M. Betz, G. Iadarola, M. Wendt

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For the sake of completeness – The LHC

Installed in 26.7 km LEP tunnel

Depth of 70-140 m

Lake of Geneva

LHC ring

CMS, Totem

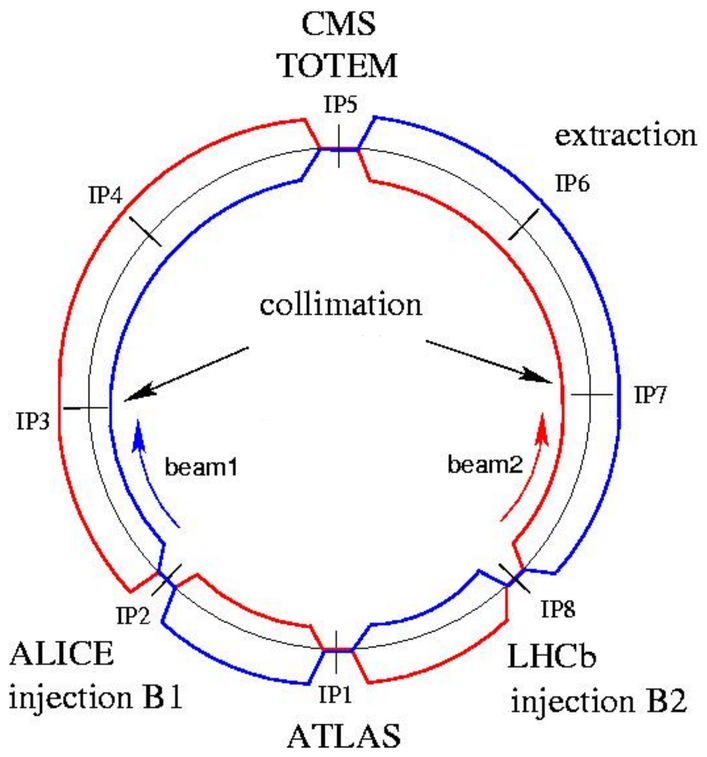
Control Room

SPS ring

LHCb

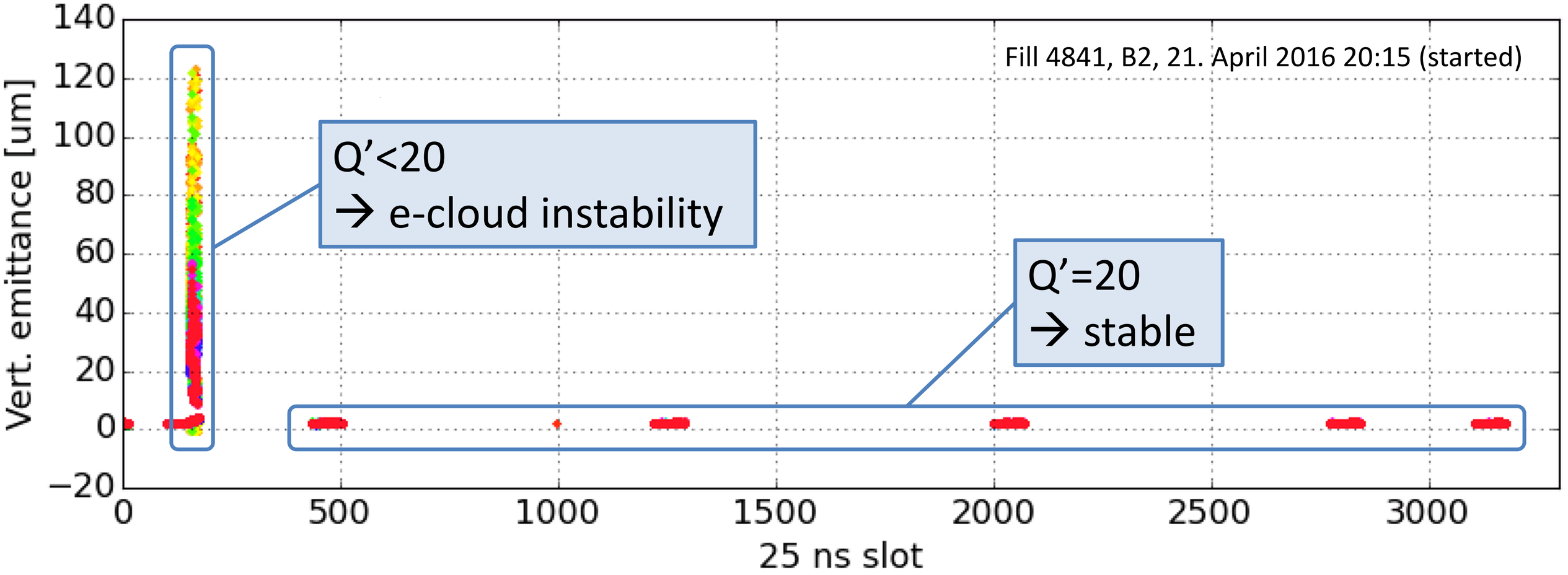
ALICE

ATLAS, LHCf



Motivation – Living with the e-cloud I

Example: First Fill with 72b trains



→ We need very good handle on chroma

Courtesy: G. Iadarola

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Introduction/History

$$\Delta Q = Q'.\frac{\Delta p}{p}$$

$$\frac{\Delta p}{p} \propto \frac{\Delta f}{f}$$

- Simple Chroma display already available in Run 1
- (Even Feedback foreseen, never implemented)
- →Functionality to modulate RF already available

→ Development of new, more integrated, chroma measurement tool started in 2015.

Tune-signal flow

Working horse: "Base Band Tune Measurement System" *

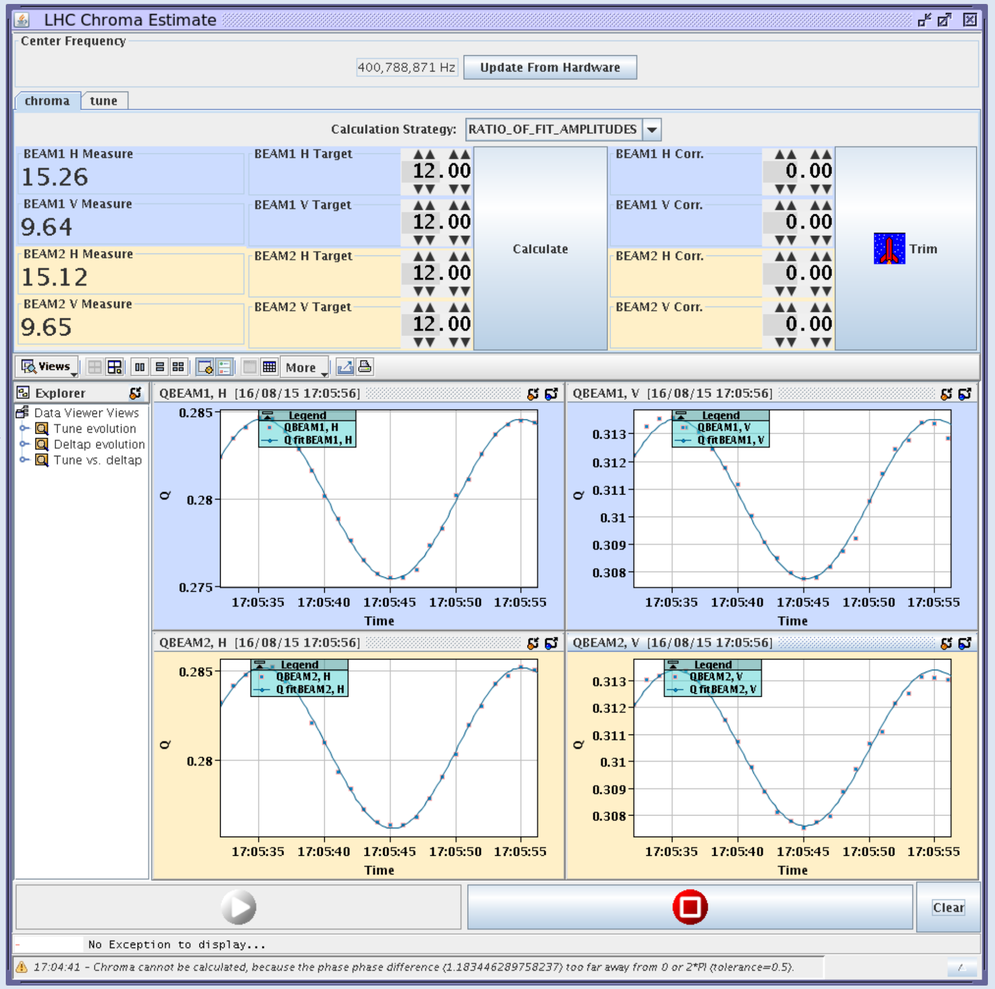
BBQ (High Sensitivity)

BBQ (Gated)

BBQ (On demand)

BFSU Tune Feedback

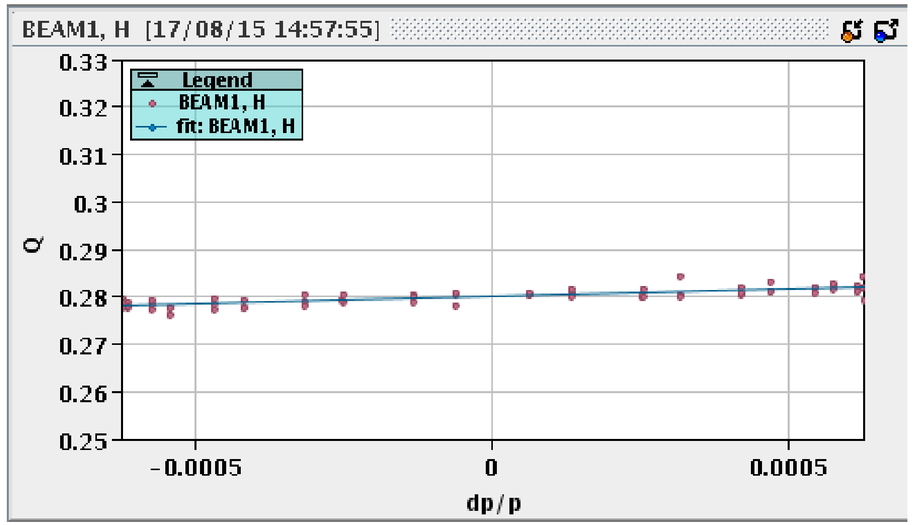
Chroma App



[*] M. Gasior, R. Jones, "High Sensitivity Tune Measurement by Direct Diode Detection", Proceedings of DIPAC 05, Lyon, France.

Version 0 – the naive approach

Linear Fit to Q vs momentum offset



$$Q(t) = Q_{\mathrm{om}} + Q' \cdot \frac{\Delta p}{p}(t)$$

Chroma

On-momentum tune

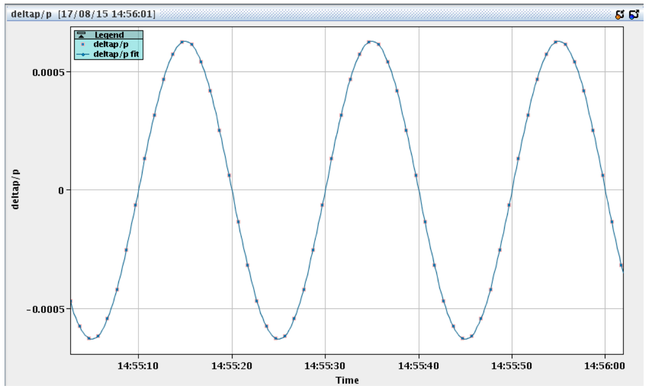
Momentum - Offset

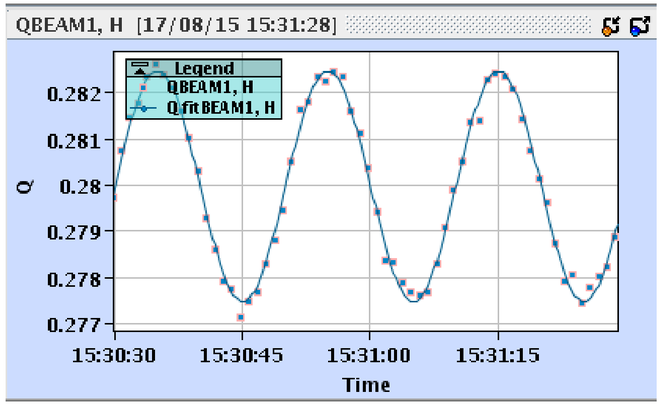
Works with both: Manual RF trims or e.g. sine-modulation

→ Problematic when acquisition of frequency ($\frac{\Delta p}{p}$) and the tune (Q) are not well aligned.

Version 1

Individual Harmonic Fits on $\frac{\Delta p}{p}$ and Q





4 Fit parameters

$$\frac{\Delta p}{p}(t) = A_p . \sin(\omega t + \varphi_p) + B_p$$

Initial guess

$$Q(t) = A_Q . \sin(\omega t + \varphi_Q) + B_Q$$

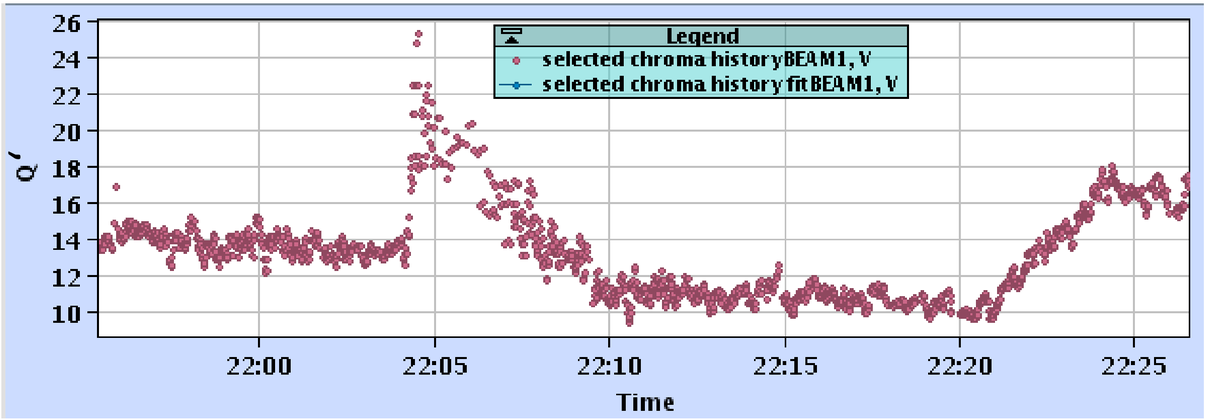
4 Fit parameters

$$\rightarrow Q' = \frac{A_Q}{A_p} . \mathrm{sgn}(Q'), \text{ with } \mathrm{sgn}(Q') = \begin{cases} +1, \text{if } (\varphi_p - \varphi_Q) \bmod 2\pi \cong 0 \\ -1, \text{if } (\varphi_p - \varphi_Q) \bmod 2\pi \cong \pi \end{cases}$$

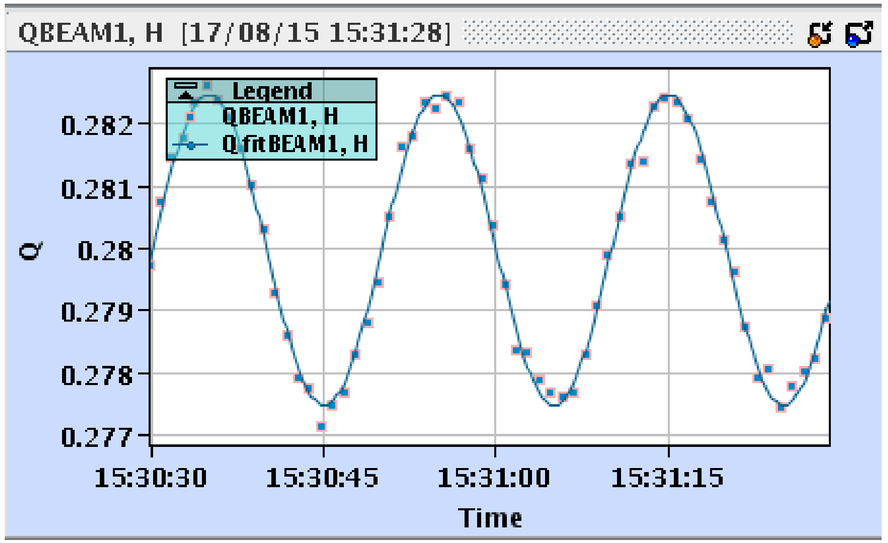
Typical e.g.:
$f = {}^{\omega}/_{2\pi} = 0.08\ Hz$
$A_p = 0.0003$

Version 1 – Remarks

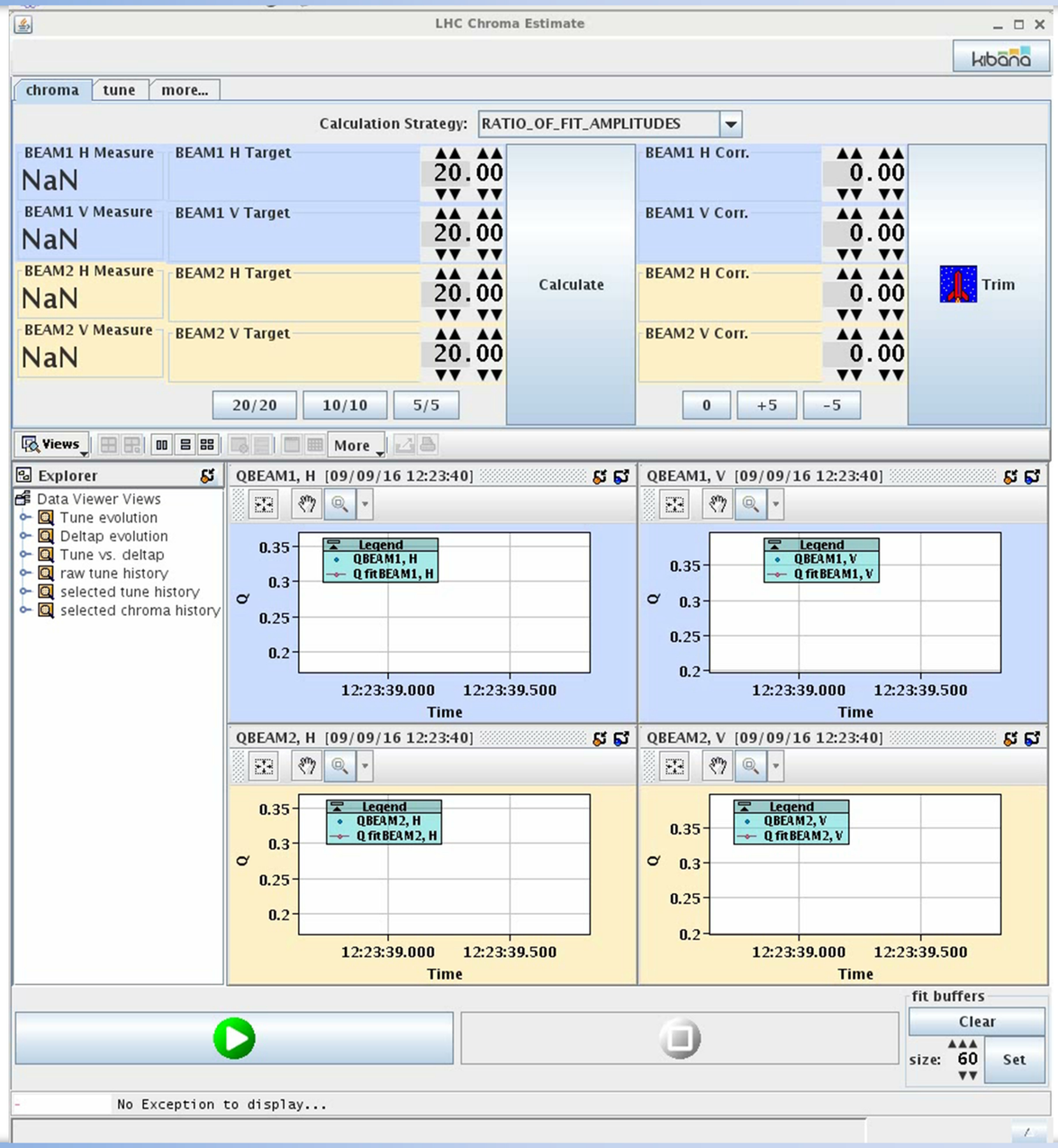
- Used Systematically during each fill and Machine Development:
  - Measure Chroma
  - Calculate Corrections
  - Send to hardware
  - Feed forward and model calibration (chroma traces e.g. during ramp)



- To Improve:
  - Outlier treatment (e.g. 3-sigma rejection, robust fits)
  - Integration with other applications, systematically used at injection (e.g. coupling, injection phase)



Short demo



TUPG30: M. Hostettler, A. Calia, K. Fuchsberger, “Testing the Untestable […]”, these proceedings.

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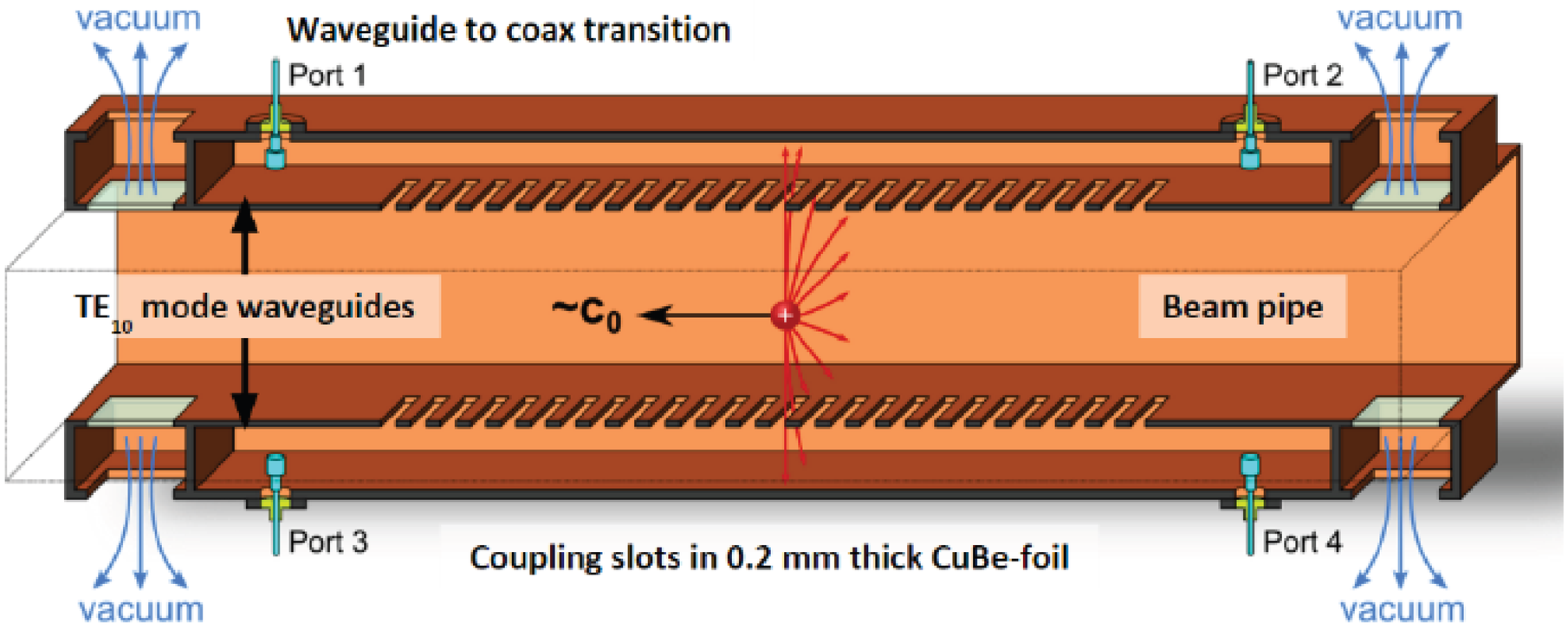
The Future: LHC Schottky

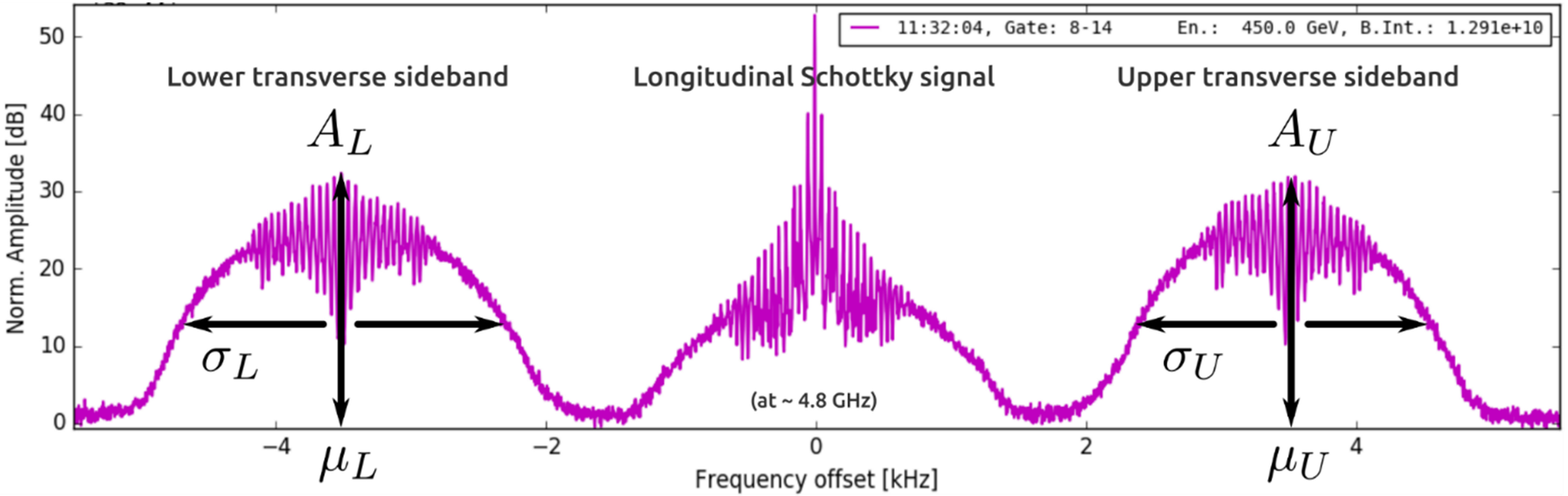
Extracts beam and machine parameters from incoherent particle motion



TUPG46: M. Wendt et al, “Improvements of the LHC Schottky Monitors“, this conference.

Chromaticity from Schottky

Chromaticity is proportional to the difference in width of the two transverse sidebands.



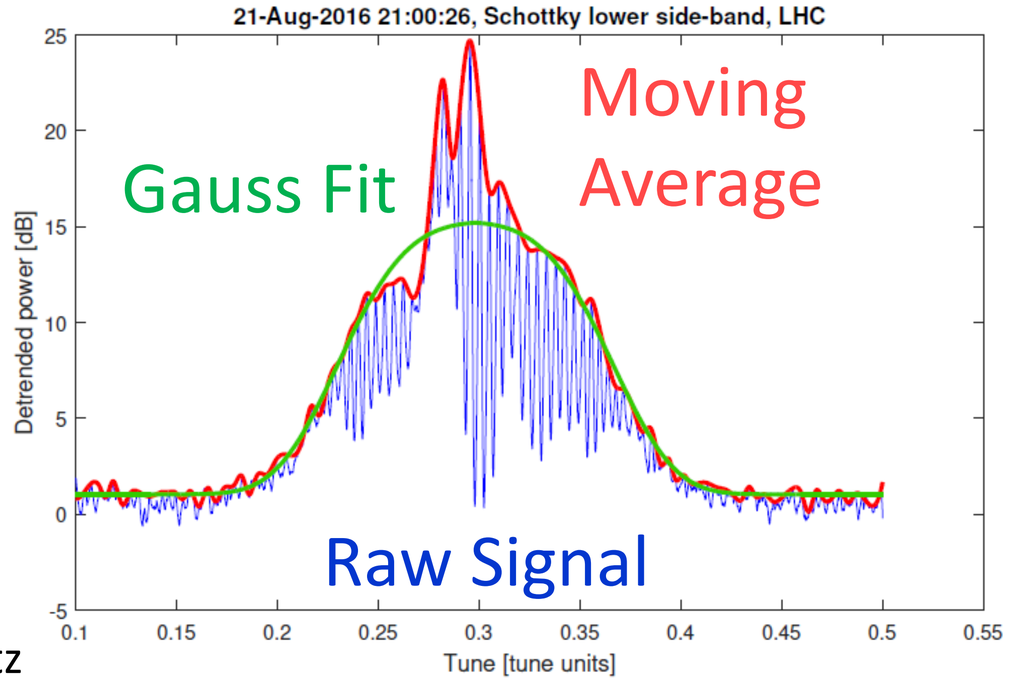
$$Q' = \frac{\sigma_L - \sigma_U}{\sigma_L + \sigma_U} \cdot \eta \cdot \frac{f_C}{f_{\mathrm{rev}}}$$

f_c = meas. freq. (4.8 GHz)
η = LHC slip factor (~ 3.1 82E-4)

Courtesy: M. Wendt, M. Betz

Schottky Status

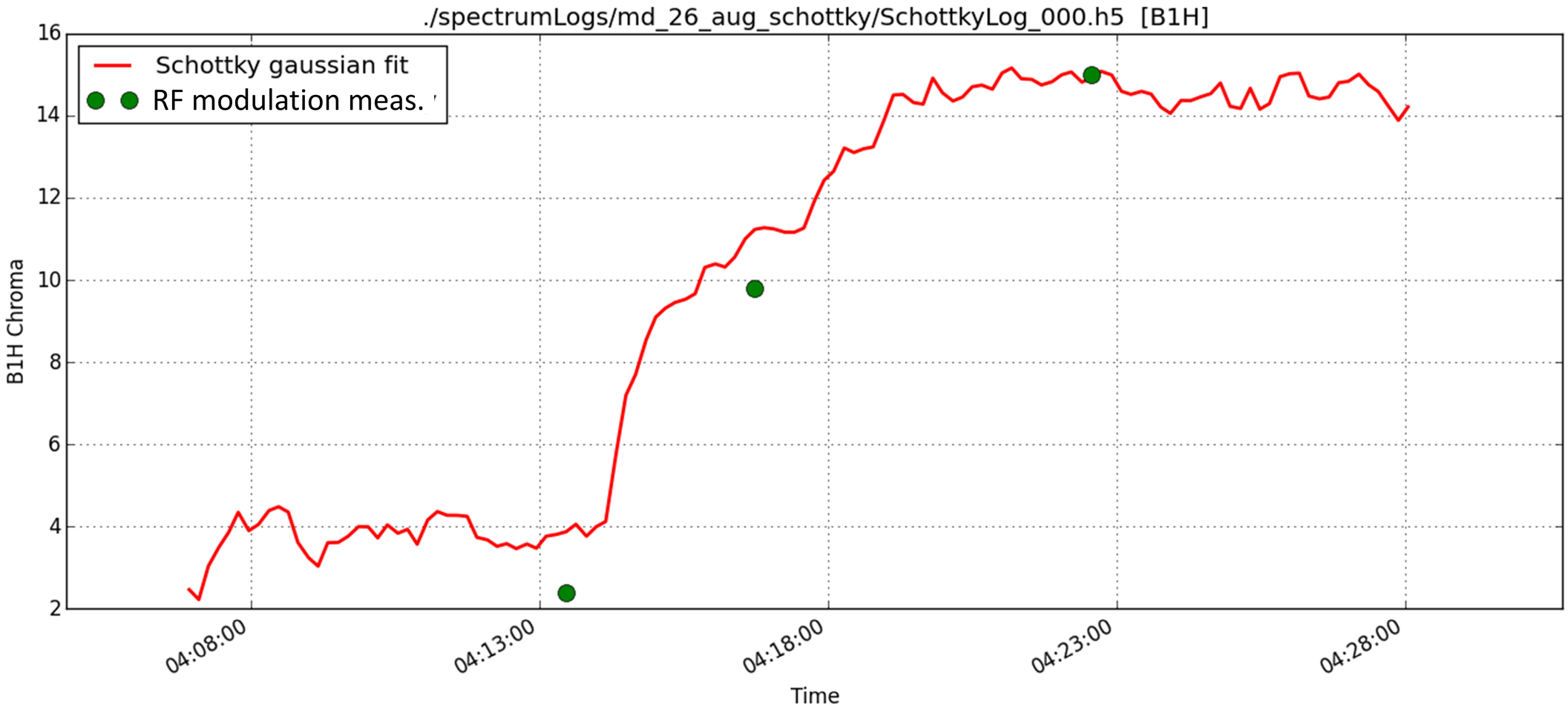
- Tune can be nicely derived from the signal
  (Works even on bunches affected by the transverse damper)
  → Prepared for tests in an operational environment
- Chroma algorithm developed offline with promising results.
  → Planned to be available online end of this year.



Courtesy: M. Wendt, M. Betz

TUPG46: M. Wendt et al, “Improvements of the LHC Schottky Monitors“, these proceedings.

Calibrating Schottky with chroma from RF modulation



→ *Works already vey well at Injection!*

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Summary and Outlook

- Chroma App (RF mod) used every fill. Proved to be very reliable.
- LHC Schottky
  - Only option to get chroma measurement without shaking the beam
  - Tune Algorithm available
  - Chroma Algorithm available soon
  - Works already very well for injection, work ongoing for rest
- Future Plans
  - Outlier detection in Chroma app
  - Integration with other applications
  - Operational integration of Schottky to provide continuous chroma measurement

Thanks a lot for you Attention!

Questions?