Orbit, Tune, Chroma, BTF & Schottky

T. Levens

Presenting a summary of work carried out by many other people. Thanks to them all.

Outline

- Provide an overview of the available instrumentation for measuring:
  - Orbit
    - Standard BPMs
    - DOROS BPMs
  - Tune
    - BBQ
    - BTF
    - Schottky
  - Chromaticity
    - Radial modulation
    - Schottky
- Provide examples of past measurements
- To serve as a primer for discussions about the instrumentation needs…

Orbit

Contact: Manfred Wendt

WBTN electronics installed on all "standard" LHC BPMs

Available measurement modes:

1. Asynchronous Orbit
   - Average beam position over T seconds for all bunches
   - Used in the orbit feedback
2. Synchronous Orbit
   - Average selected bunch over T sec
   - Put into operation for p/Pb
3. Capture
   - Bunch by bunch and turn by turn position
   - Used for optics measurements and IQC

New firmware deployed end 2016 – orbit mode resolution should now be improved by better averaging

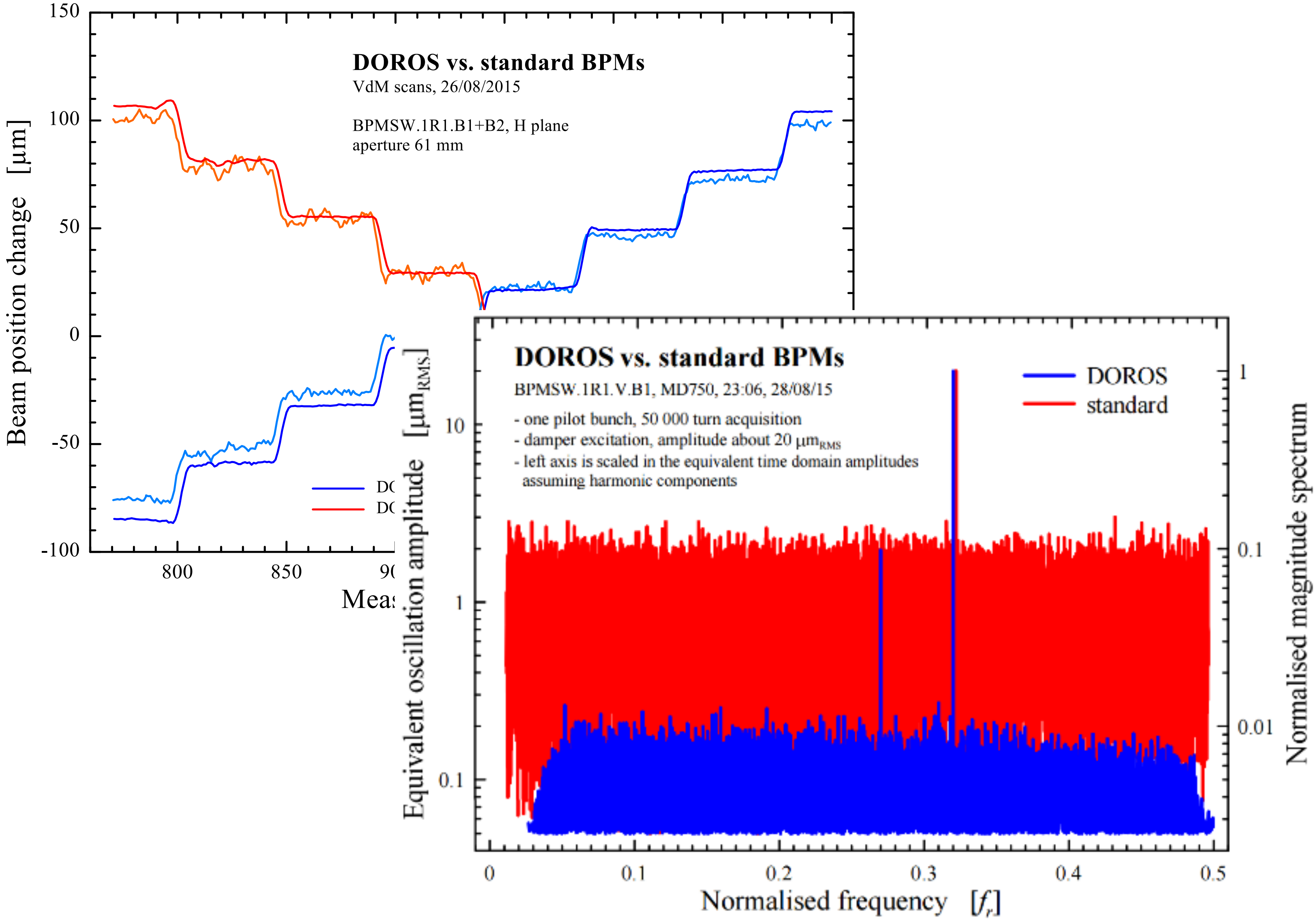
Orbit – DOROS

Contact: Marek Gasior

- **DOROS** – **D**iode **OR**bit and **OS**cillation
  - orbit measurement
  - local betatron coupling measurement
  - beta-beating measurement
- DOROS was primarily designed for the collimator BPMs and optimised for:
  - precise beam orbit measurement for small beam offsets
  - sub-micrometre resolution
  - robustness and simplicity
  - price to pay: only turn-by-turn acquisition
- DOROS currently installed on:
  - all collimators with in-jaw BPMs (including the BBLR wires)
  - Q1 BPMs in P1, P2, P5, P8
  - Q7 & AFP BPMs in P1
- "Order of magnitude" orbit sensitivity:
  - pilot ~1um
  - nominal ~0.1um

Orbit – DOROS

Contact: Marek Gasior



Tune - BBQ

Contact: Marek Gasior

Operational tune system used for tune feedback

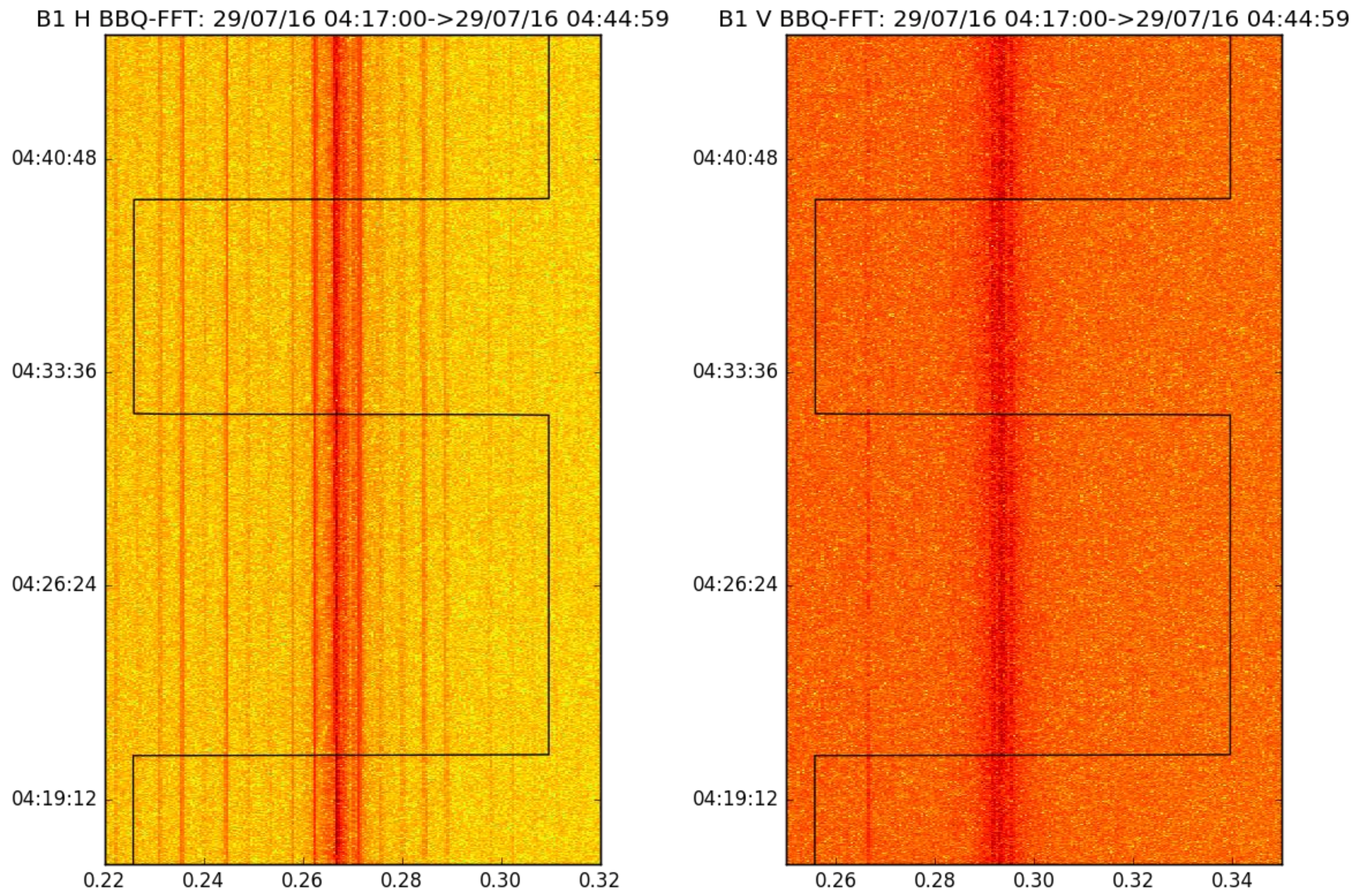
Optimal machine parameters

- Best measurements with the “high-sensitivity” system
    - Pilot up to a small number of nominal bunches
    - Correct time constant must be selected (expert setting)
- The damper must be off to avoid SNR degradation
- Sharpness of tune peak enhanced by low chroma

Excitation options, tested in MD1447

- No excitation $<1e^{-4}$
- Chirp
- MKQA kicks $<1e^{-5}$

All TCSGs scan 1 (no chirp)



- Noise lines in B1H and B1V affecting the measurement

N. Biancacci

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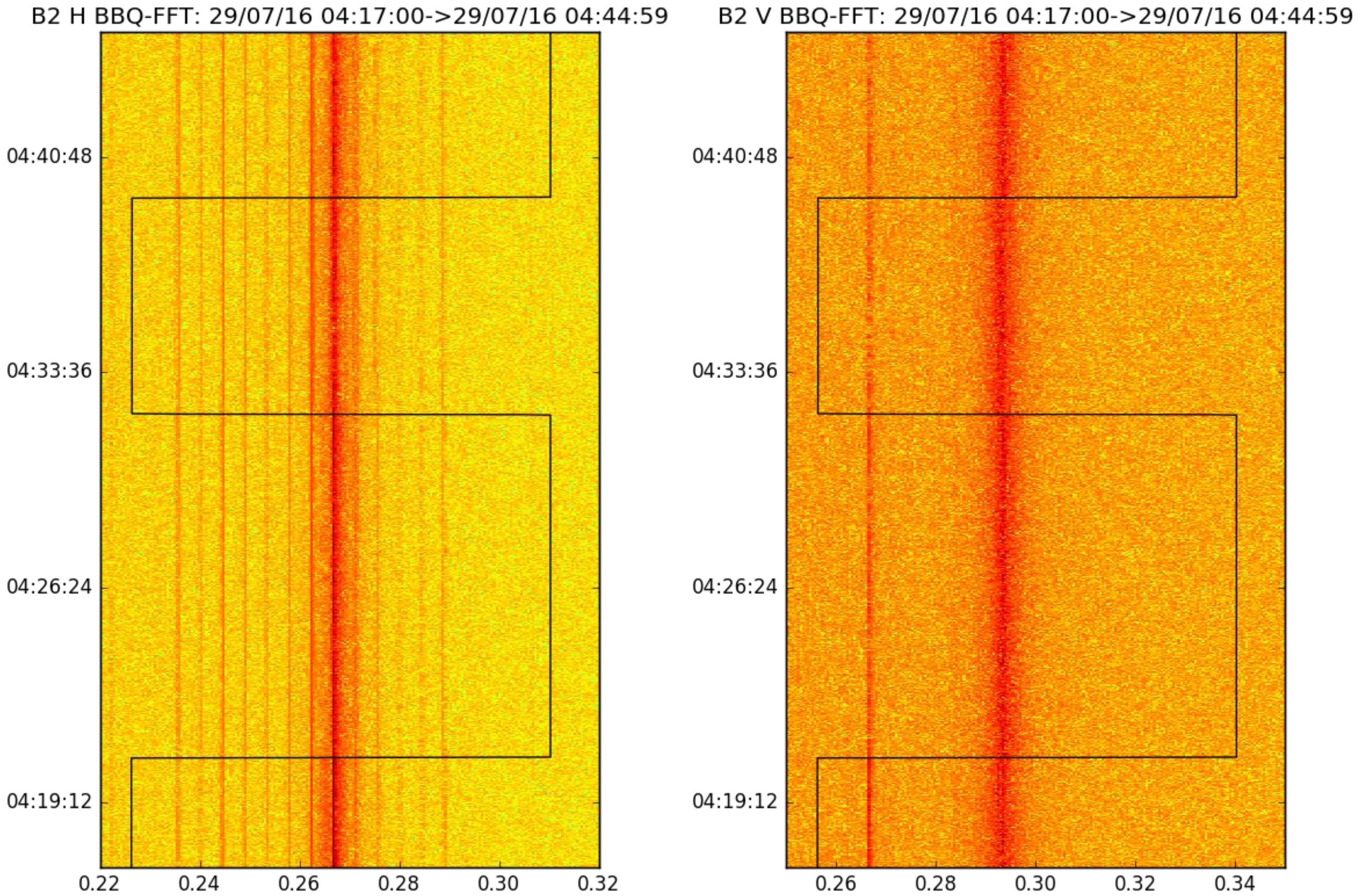
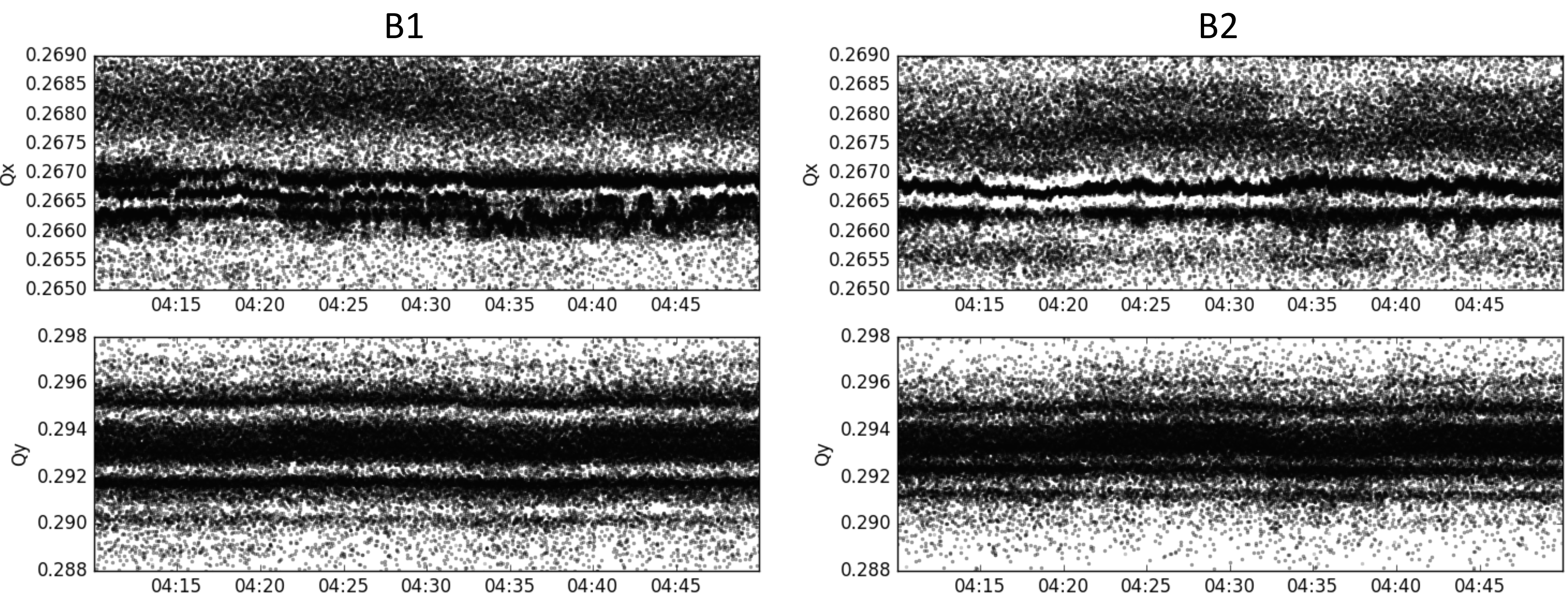


- Noise lines in B2H and B2V affecting the measurement

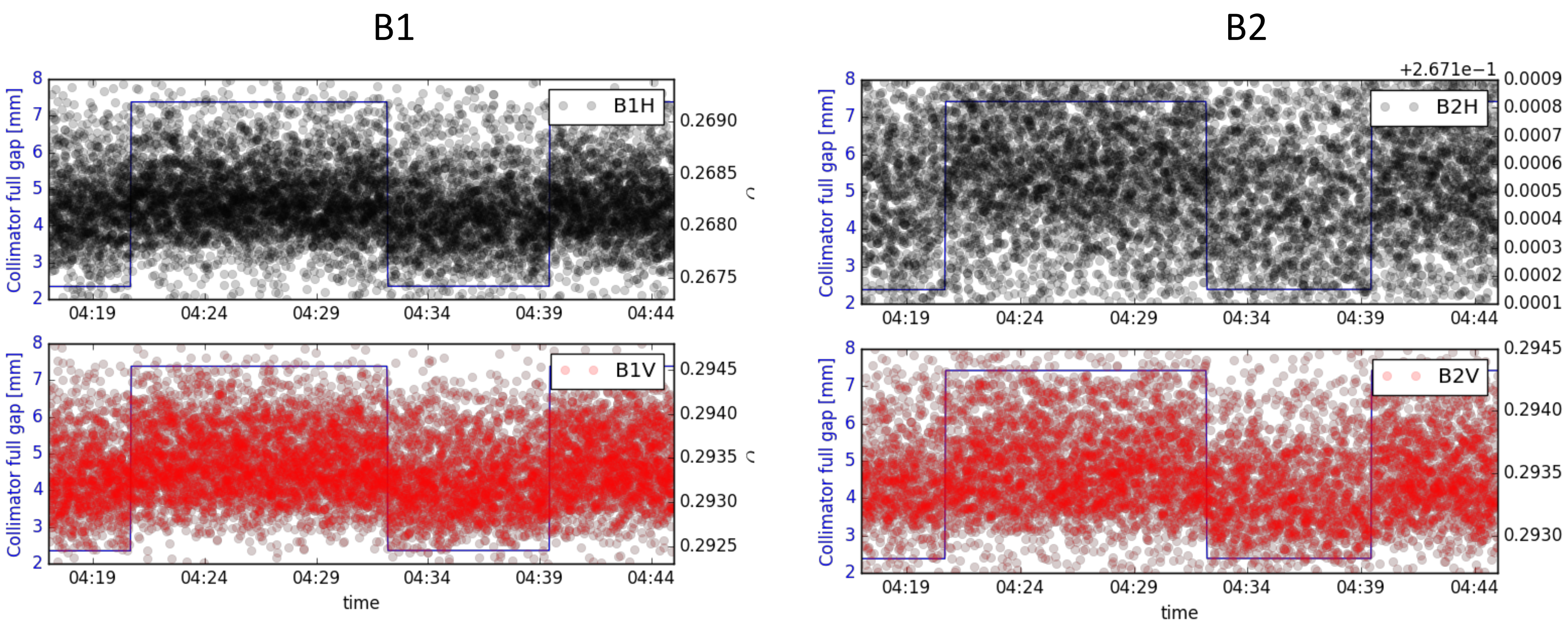
All TCSGs scan 1 (no chirp)



- We can get rid of few of them after SUSSIX analysis and selecting a narrow tune window -> Not always doable.

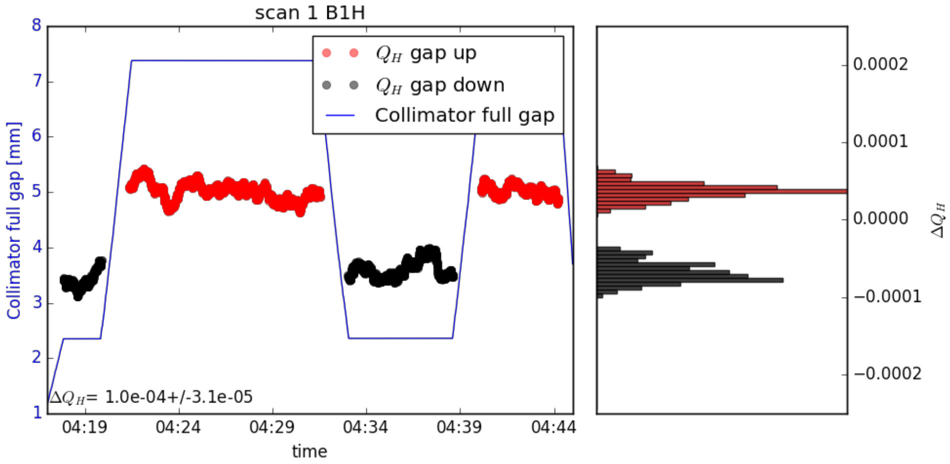
N. Biancacci

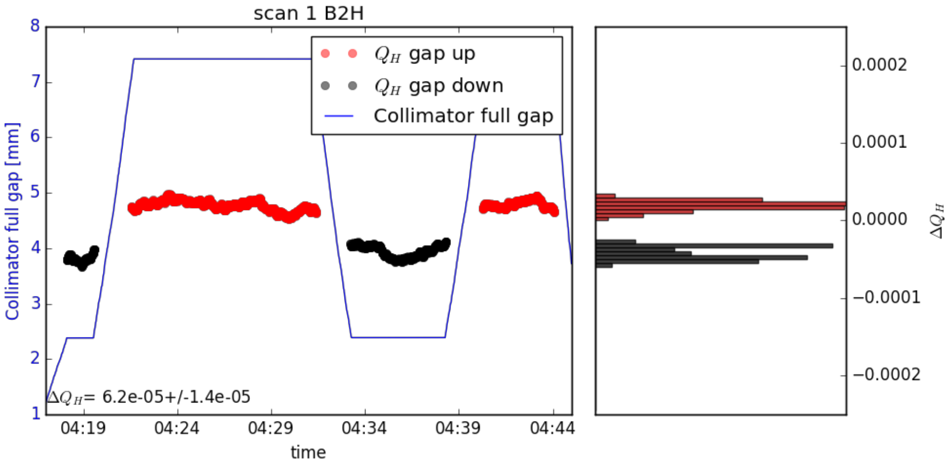
All TCSGs scan 1 (no chirp)

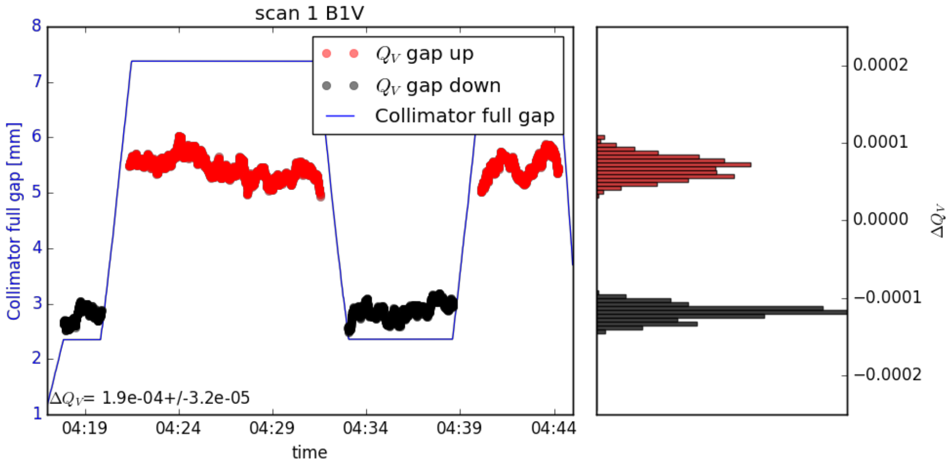


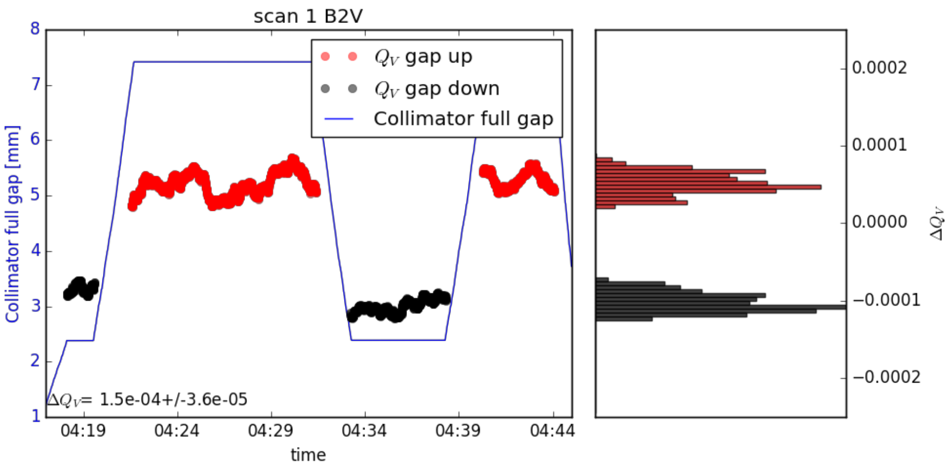
- After refinement the tune shift is clearly visible.
- Moving average can clean out some noise

All TCSGs scan 1 (no chirp)



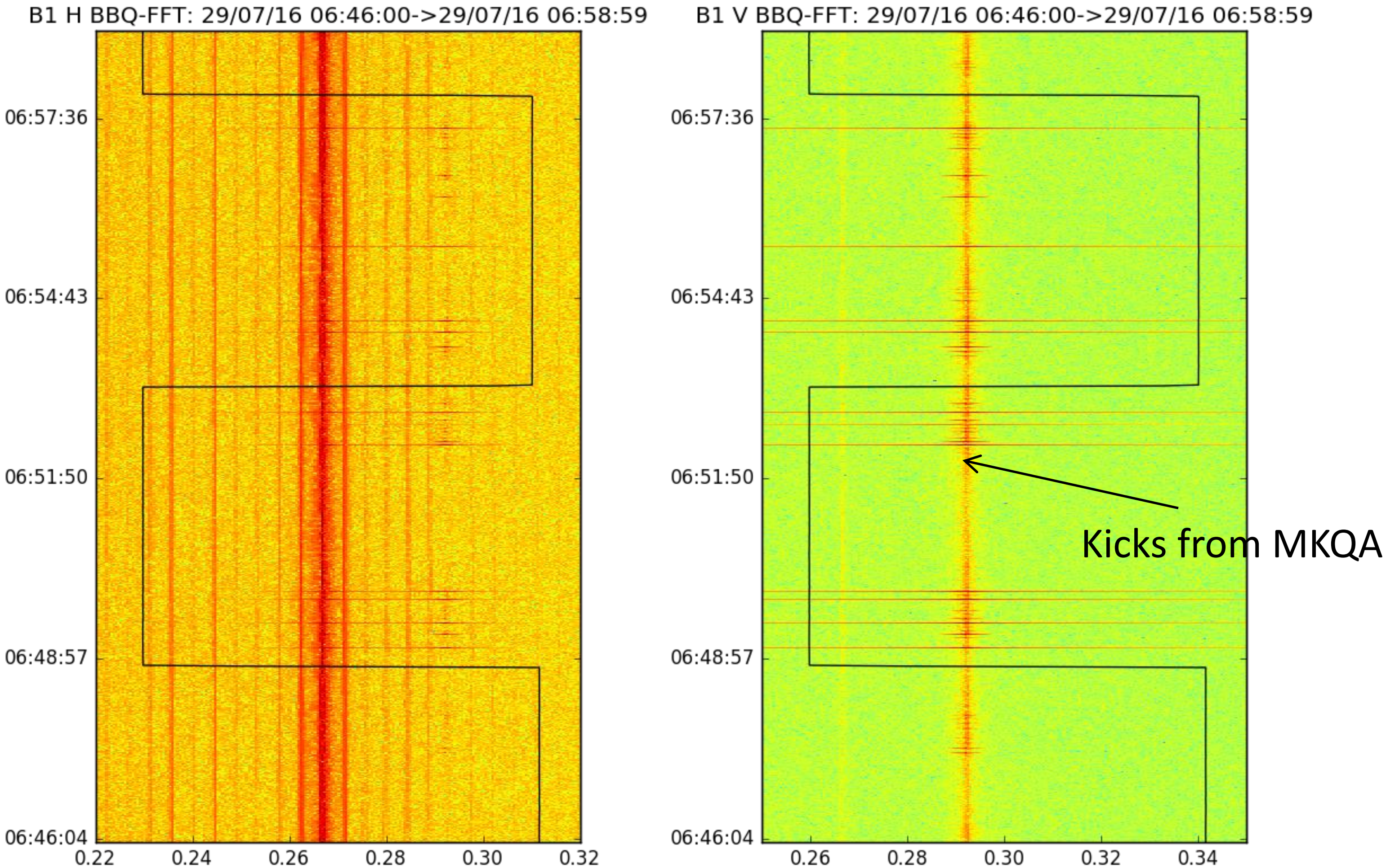






N. Biancacci

TCSG.D4L7.B1
MKQA excitation (BBQ)



N. Biancacci

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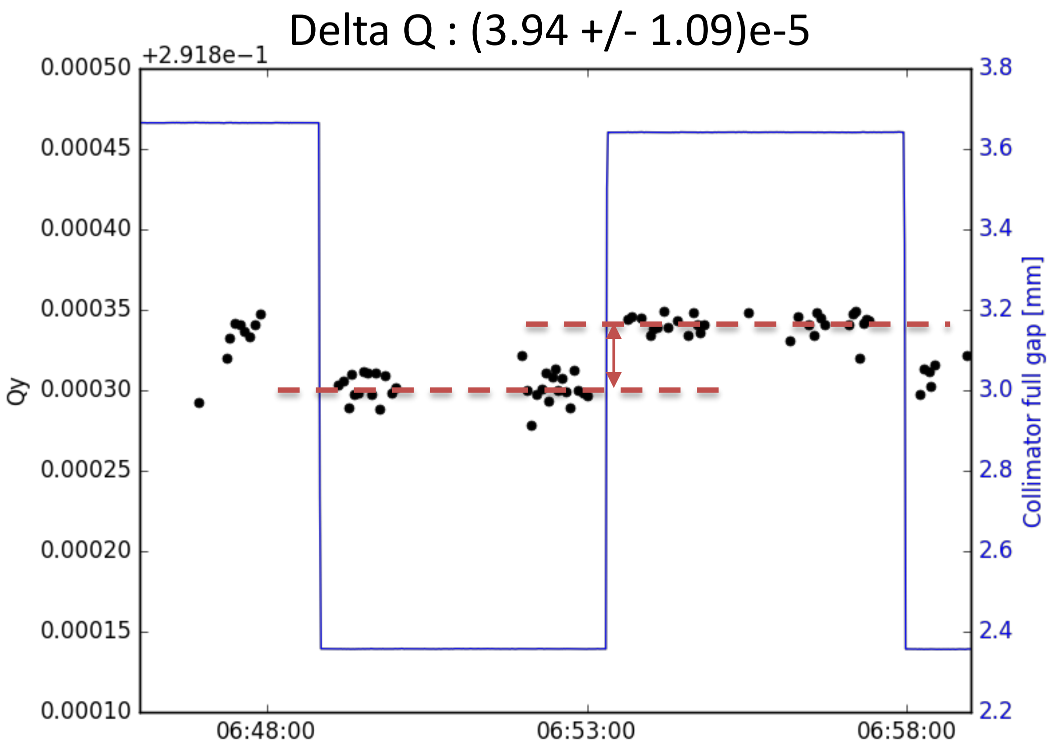
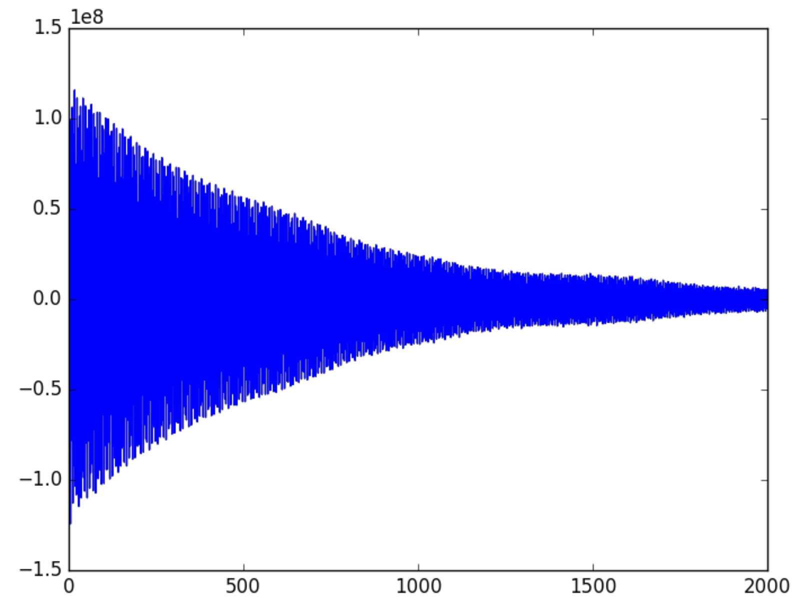
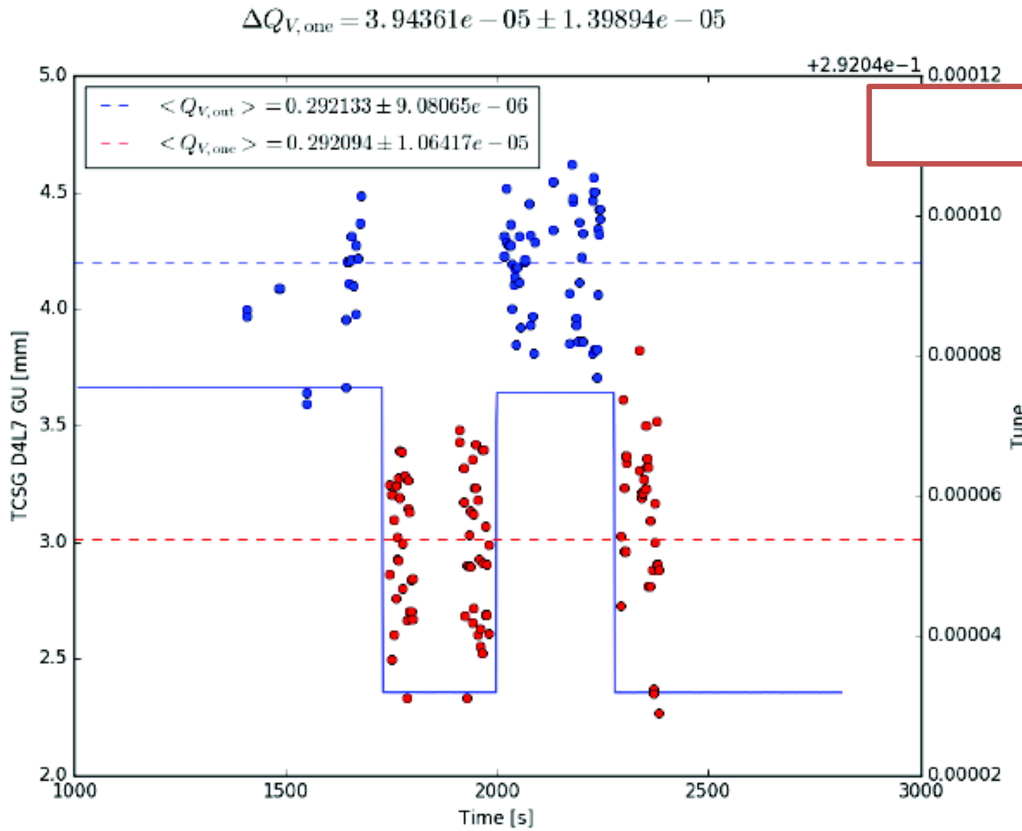




- A nice clean signal from the BBQ can be obtained.
- 2k turns analysis gives accuracy of order of **1e-5**

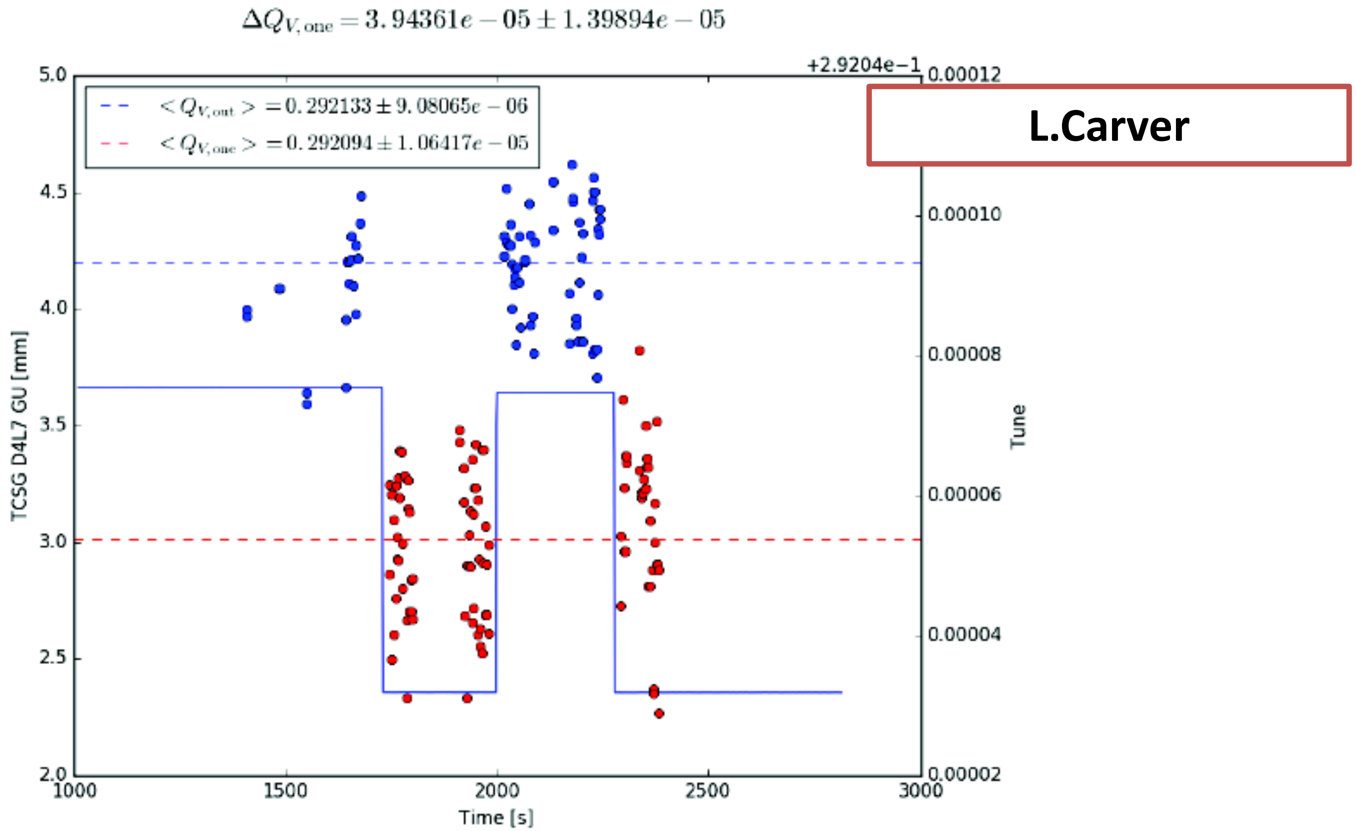
TCSG.D4L7.B1
MKQA excitation (ADT)



L.Carver

- Similar data have been analysed with the same method from the ADT with similar results!
- Other methods applied as well (details in D.Valuch, L.Carver et al. ColUSM 76)

TCSG.D4L7.B1
MKQA excitation (ADT)



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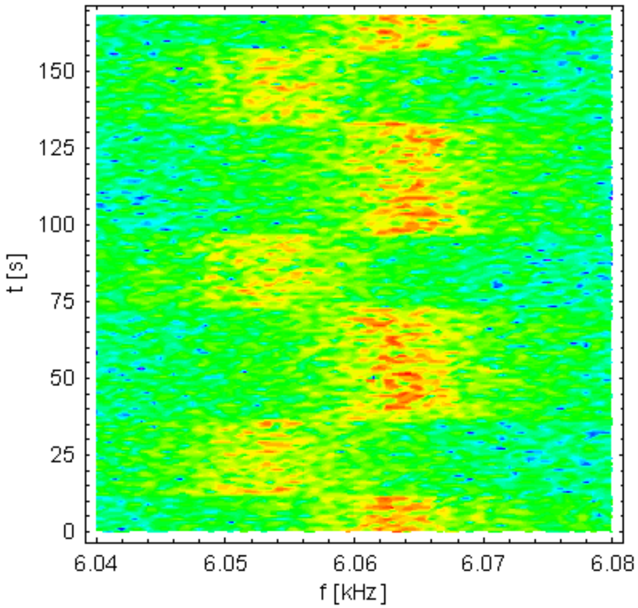
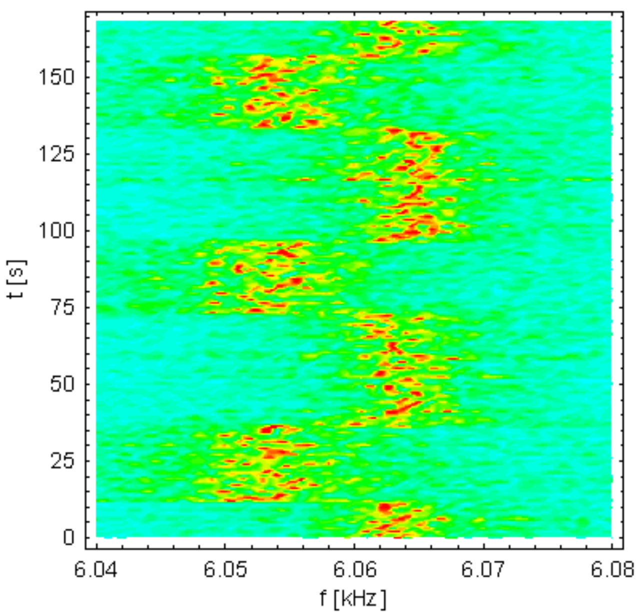
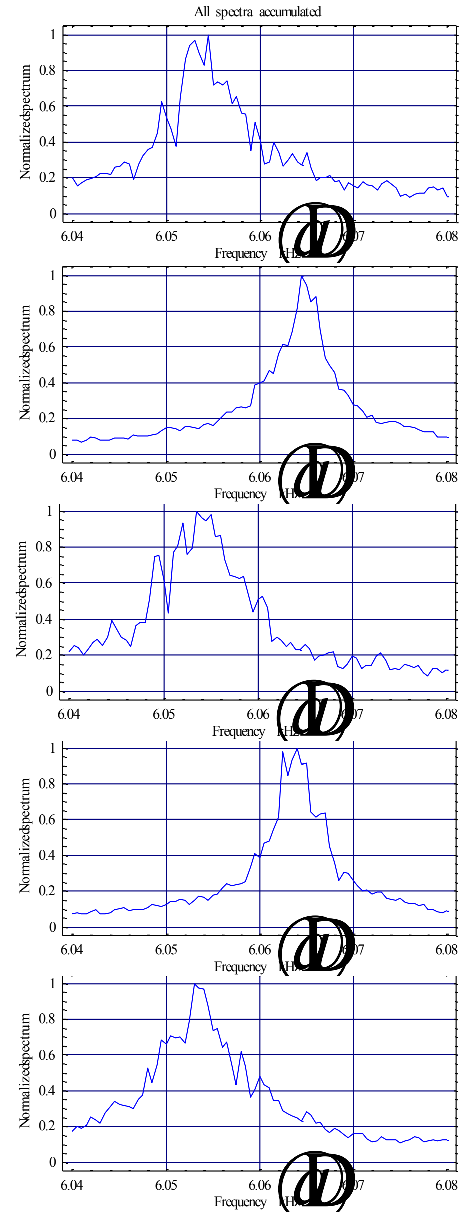






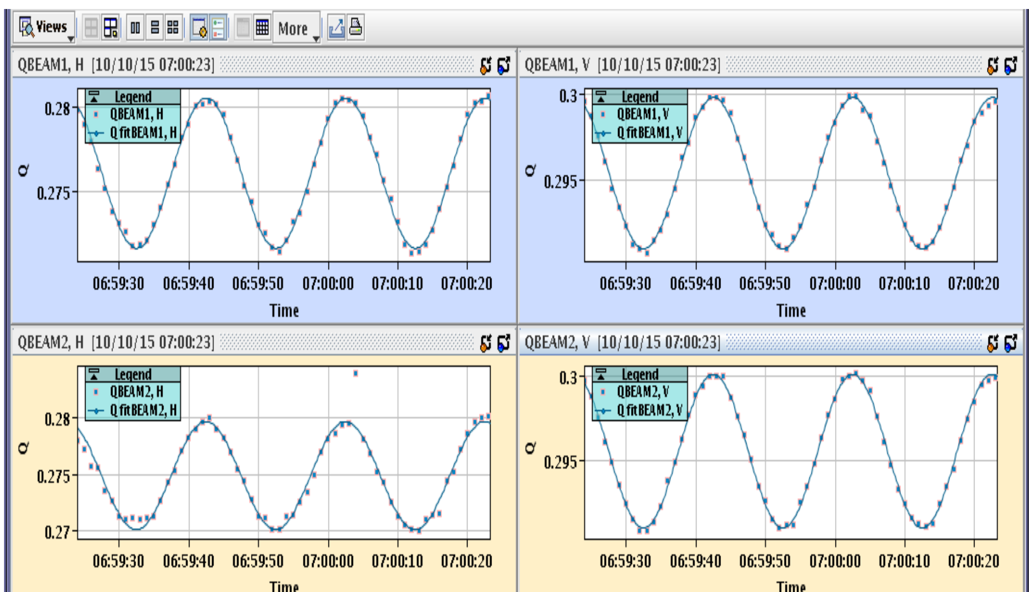
f [Hz]	Δf [Hz]
6053.39	
	10.50
6063.89	
	9.92
6053.97	
	10.76
6064.72	
	10.81
6053.91	

mean
10.5 Hz
$2.4\times10^{-4} f_r$

st. dev.
0.4 Hz
$0.9\times10^{-5} f_r$

Chromaticity

- Operational chromaticity measurements based on sinusoidal RF modulation and fitting of resultant tune modulation
  - Limited to low intensity at 6.5 TeV
- Online fitting in GUI available since 2015, now used operationally
- **Requires good BBQ signal**



Example from the LHC

- Sinusoidal RF modulation at 0.05Hz
- Tune continuously tracked in all planes of both beams
- Chromaticity calculated once acquisition complete

BTF

Contacts: Claudia Tambasco,
Xavier Buffat, Tatiana Pieloni

Beam Transfer Function measurements:

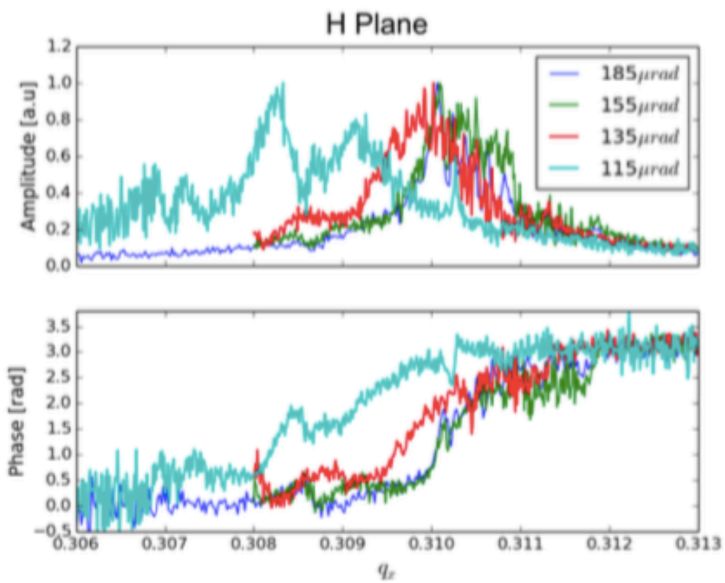
- Excitation of beam with swept frequency
- Synchronous demodulation of BBQ response

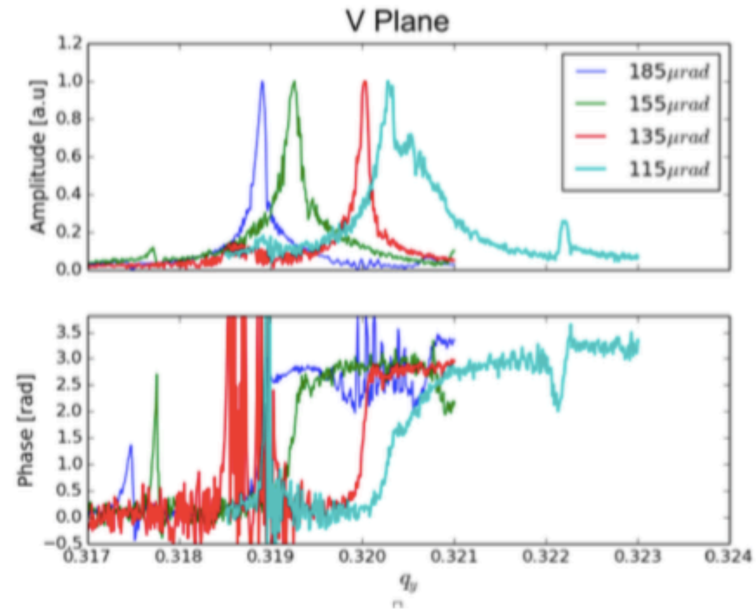
Can measure tune shift, tune spread, stability diagram, …

- First tests during 2015/2016 MDs with "prototype" software/GUI developed by ABP.
- Deployment on operational BBQ systems for 2017.
- New software/GUI under development for 2017 run.
- Requires good quality tune signal – no damper!

T. Pieloni

From BTF → Tune Shift and Tune spreads in the LHC

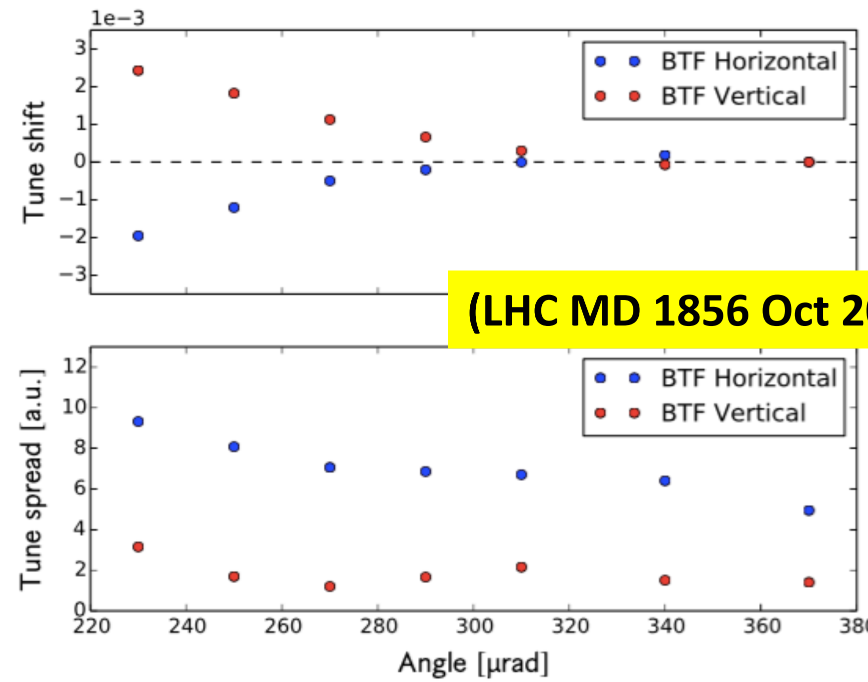




Crossing Angle Scan in weak-strong approximation in the LHC

No calibration of the system, very difficult since very sensitive to beam and machine set-ups. Model to measurements comparison very hard but we found a way!

- **Tune Shifts measurements very precise**
- **Tune spread computed in relative terms (i.e. respect to a starting case in this example Octupoles powered at 478 A)**



(LHC MD 1856 Oct 2016)

T. Pieloni

From BTF → stability diagrams

Predictions of instability thresholds based on computation of the beam Landau damping by calculating the **Stability Diagrams (SD)**

Particle distribution: (Shape of the SD)

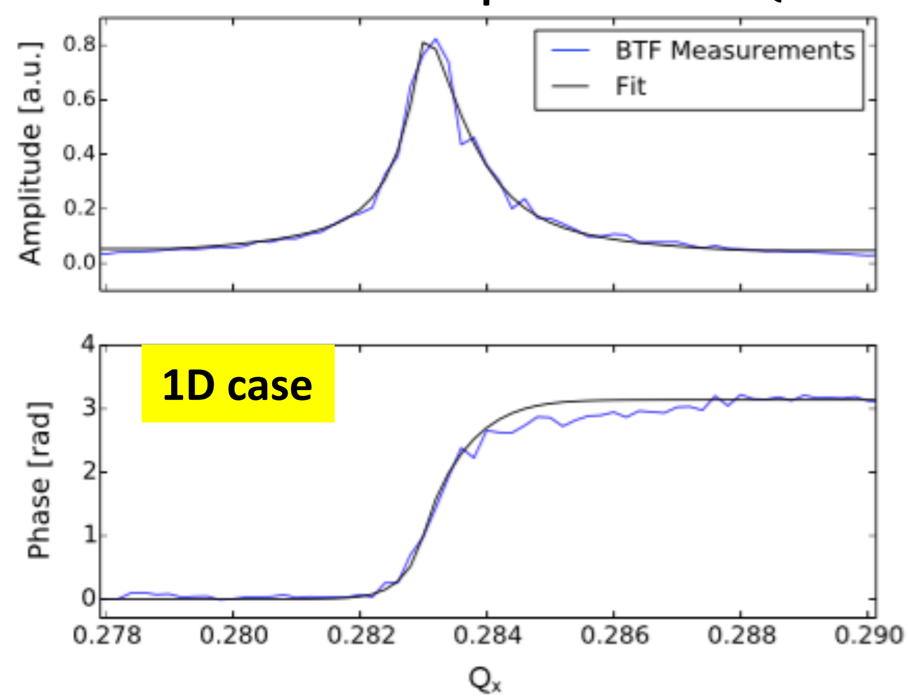
$$\text{BTF}= SD^{-1} = \frac{-1}{\Delta Q_{x,y}} = \int_0^{\infty}\int_0^{\infty} \frac{J_{x,y}\frac{d\Psi_{x,y}(J_x,J_y)}{dJ_{x,y}}}{Q_0 - q_{x,y}(J_x,J_y) - i\epsilon} dJ_x dJ_y$$

Frequency Distribution: (Size of the SD)

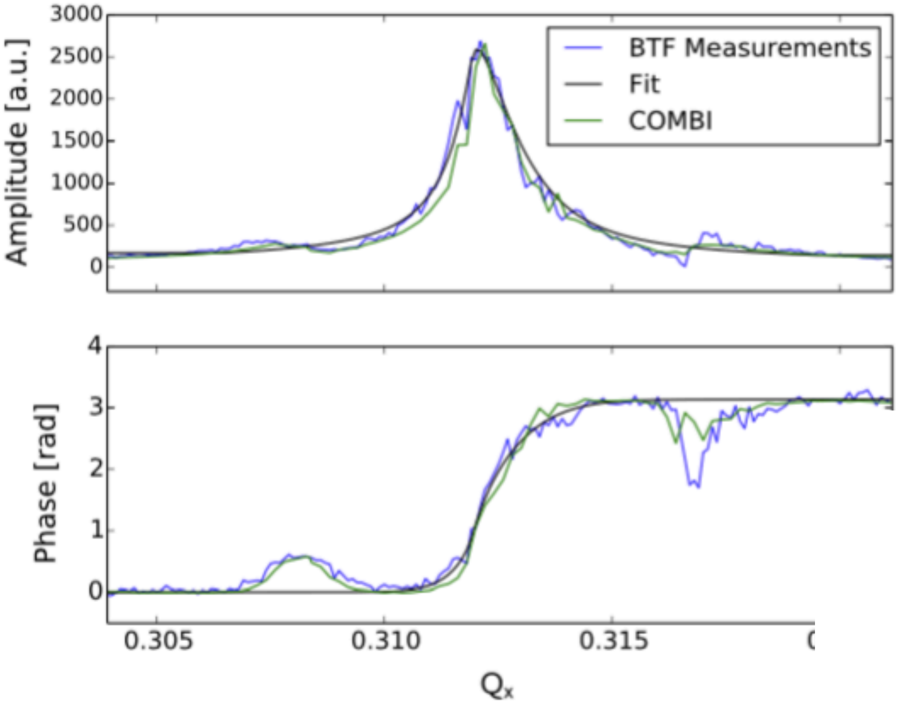
Simulation Tools:

- MAD-X → Frequency Distribution
- PySSD → Semi analytical calculation of the SD
- SixTrack → Particle distribution after long particle tracking
- COMBI → Multi-particles code, BTF simulation

Simplest case no Q'



From BTFs → Stability diagrams Longitudinal motion

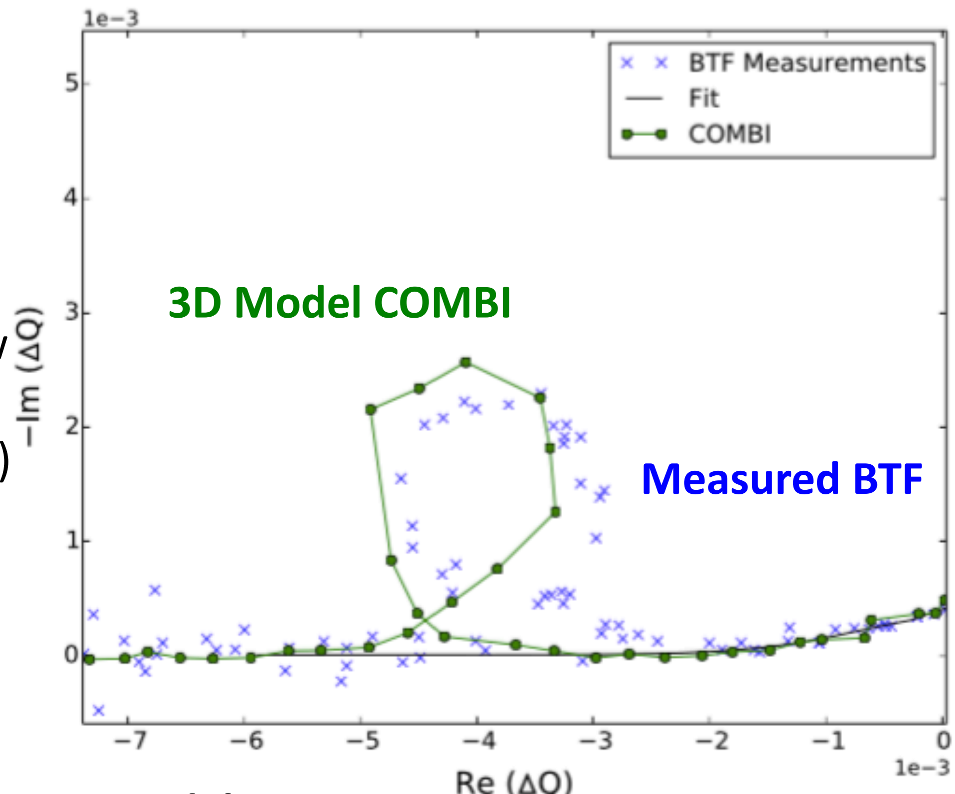


- **Octupole current scan** at Injection well understood and reproducible with tools
- **Measured residual 5 Ampere equivalent spread at Injection**→ consistent with optics measurements team results
- **Longitudinal motion contribution also well represented with 3D Modeling**

On-going work HSC teams:

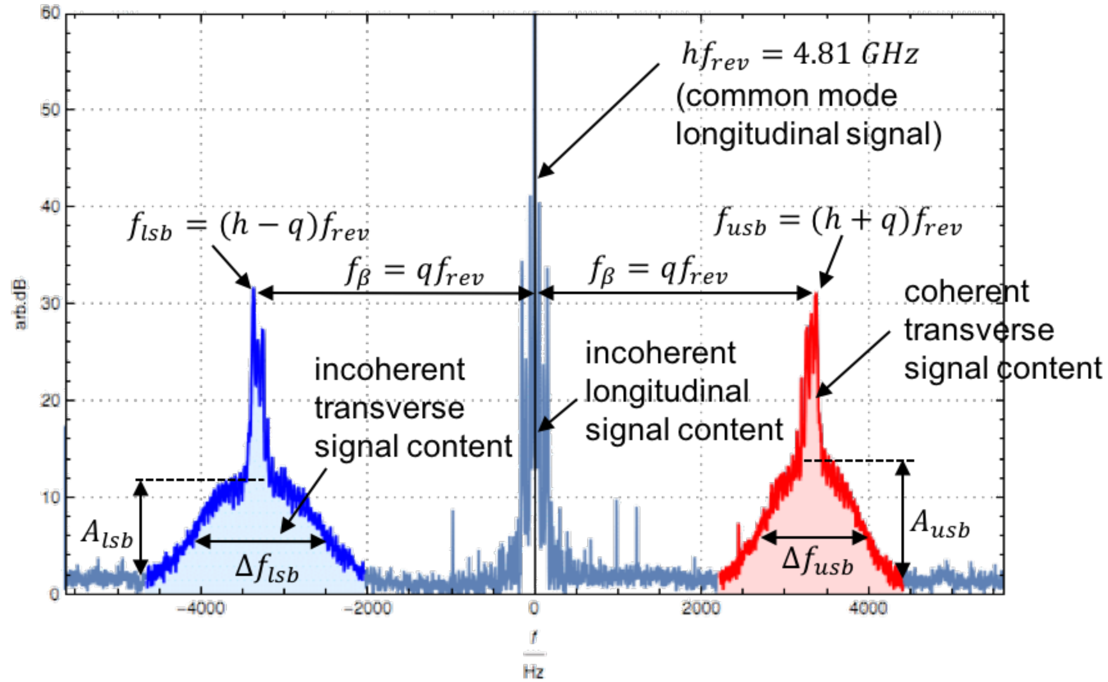
- Modeling of distributions from Sixtrack now implemented in BB models to describe strongly resonant cases (strong long-ranges)
- Still working on improvement of the **LHC model to measurements comparisons** at end of squeeze, collisions and during crossing angles scans

(EPFL PhD Thesis C. Tambasco)



1D Model PYSSD

Schottky Theory



- **Extract the chromaticity from the measured *Schottky* sidebands:**

$$\acute{Q} = \eta\left(h\frac{\Delta f_{lsb} - \Delta f_{usb}}{\Delta f_{lsb} + \Delta f_{usb}} + q\right) \approx \eta h \frac{\Delta f_{lsb} - \Delta f_{usb}}{\Delta f_{lsb} + \Delta f_{usb}}$$

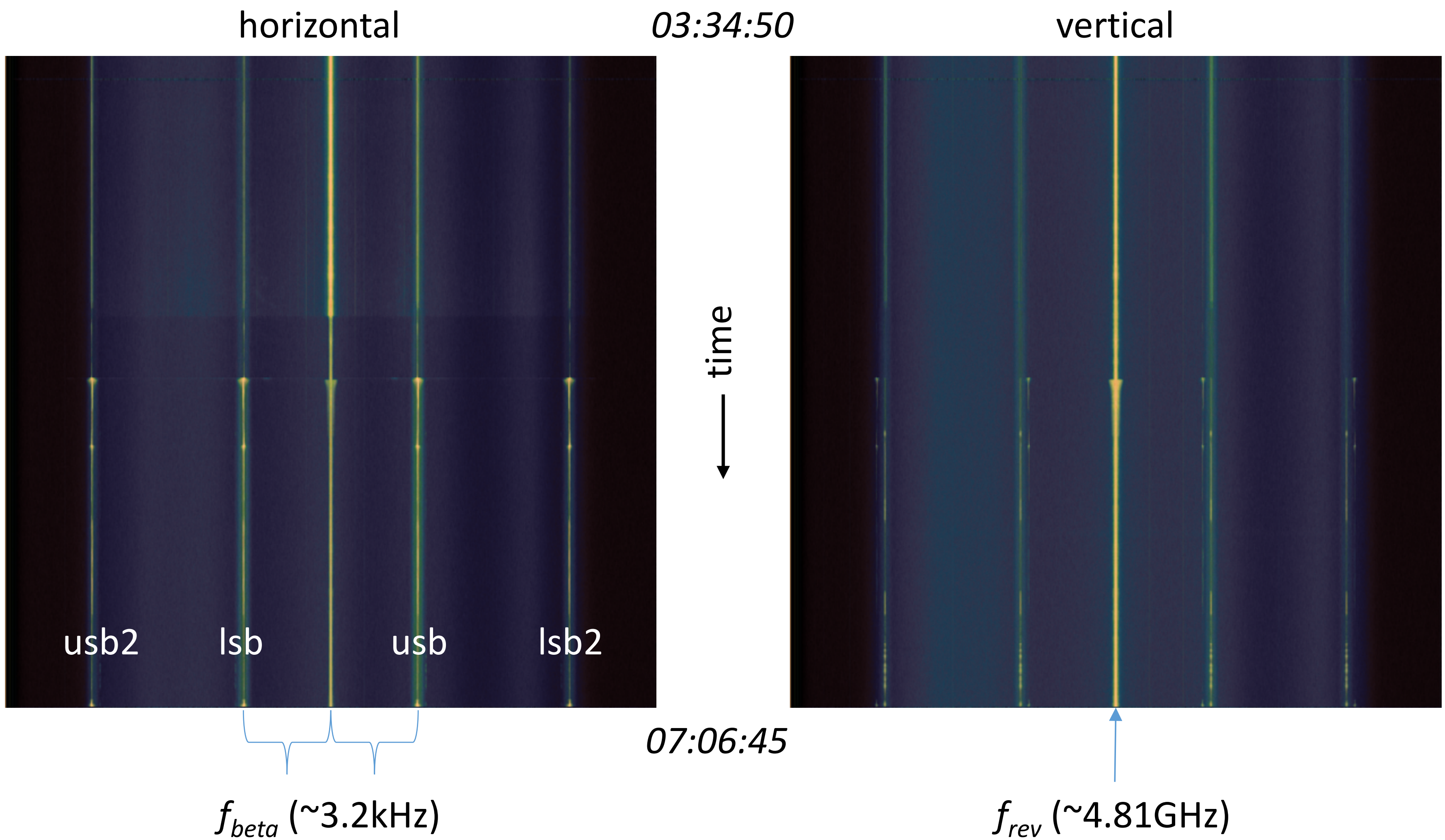
$\eta h \simeq -136$

with: $\eta = -3.184 \cdot 10^{-4}$ (phase slip factor)

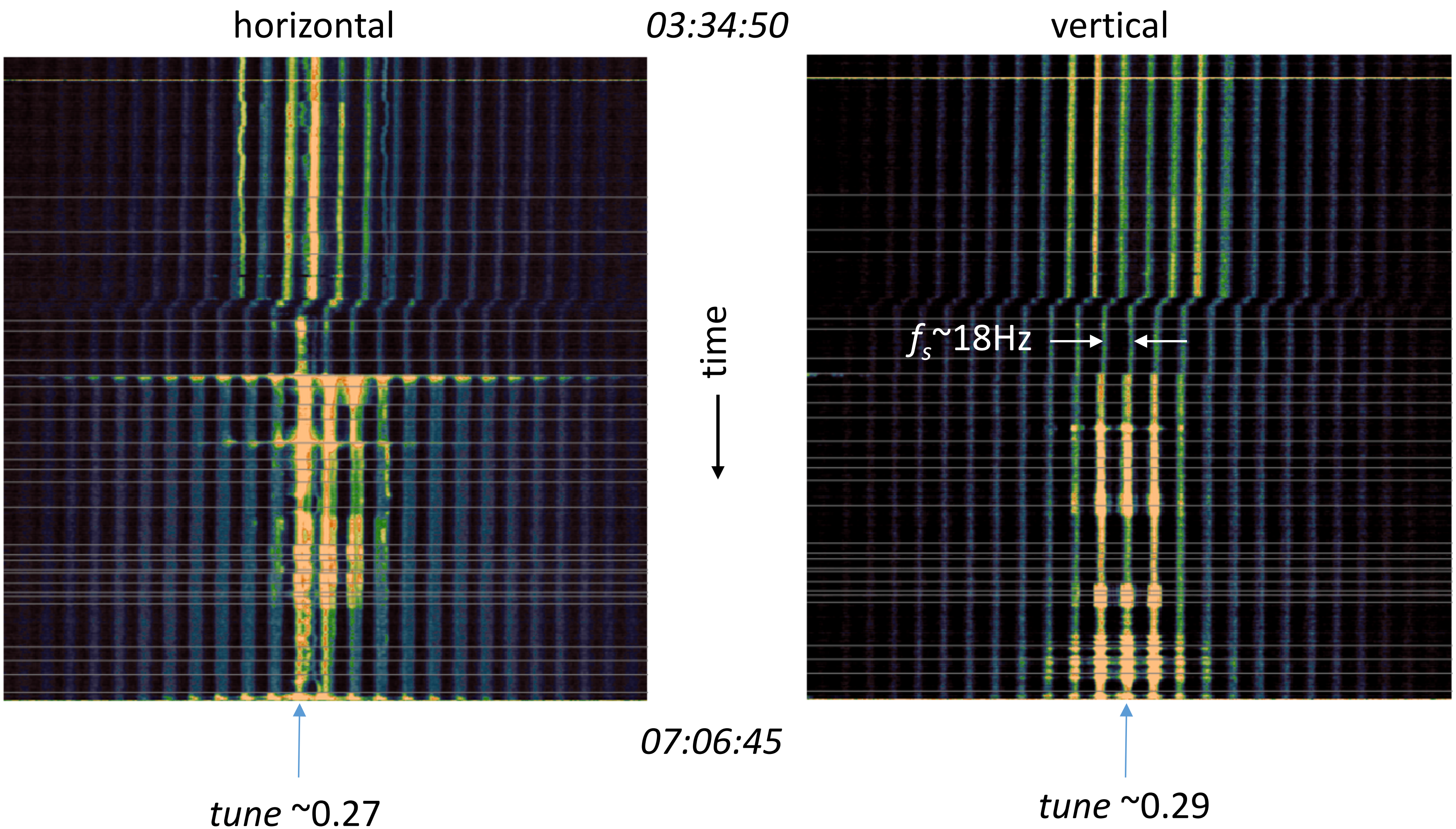
$h = 4.28 \cdot 10^5$ (harmonic number at $f = 4.81\ GHz$)

M. Wendt

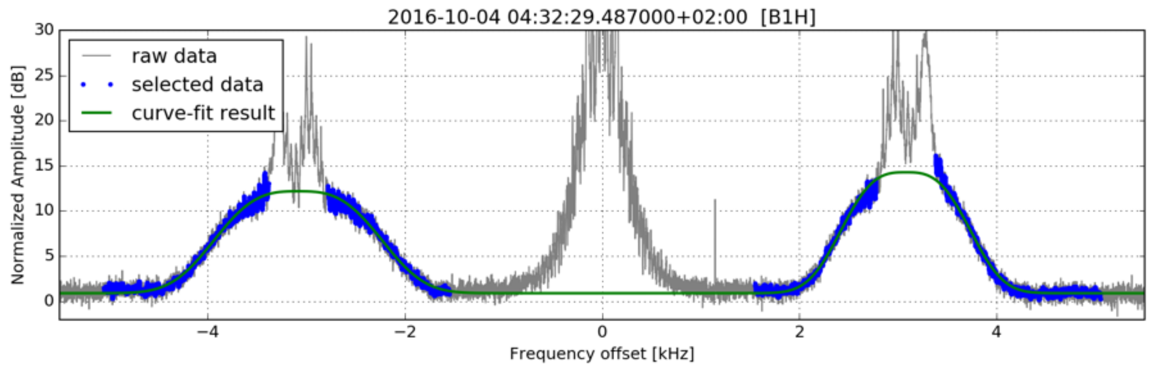
Beam 1 – All Schottky Data MD1447

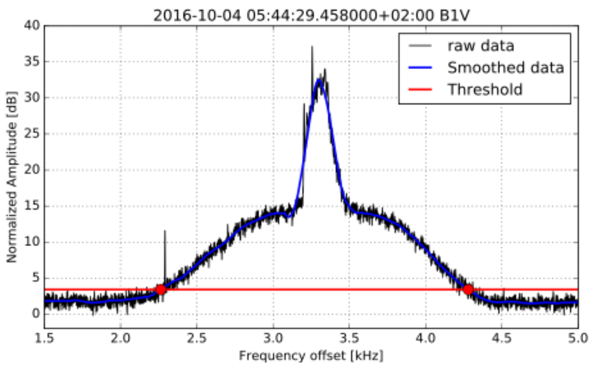


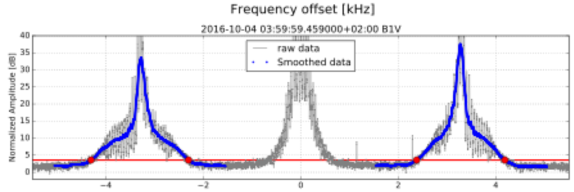
Beam 1 – Schottky Sideband Data

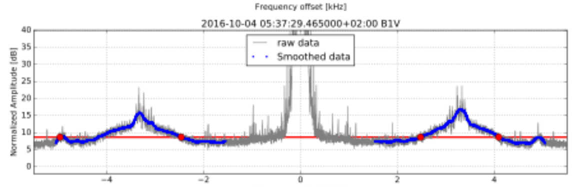


MD1767: Fun with Fitting

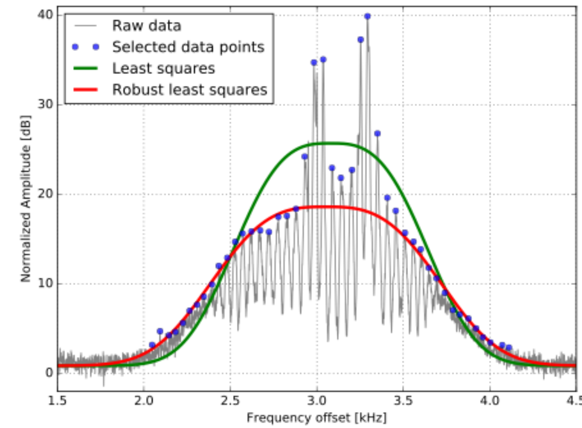




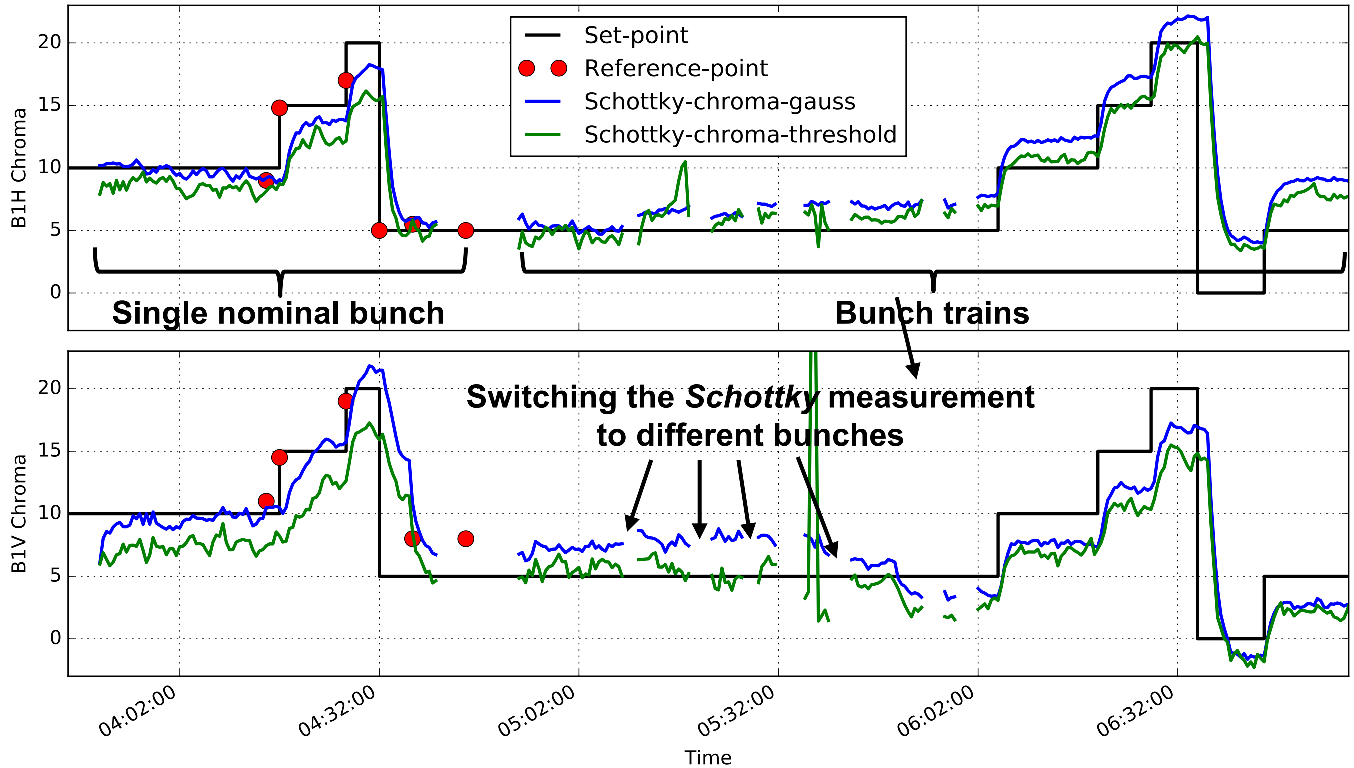


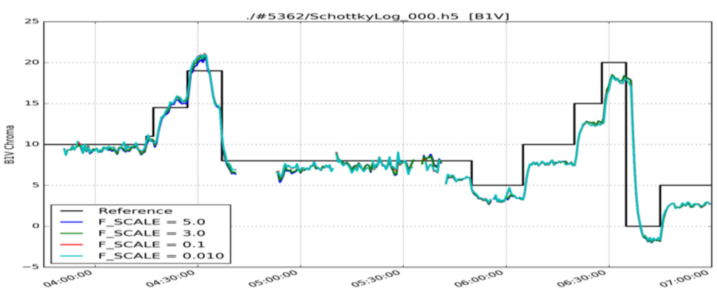


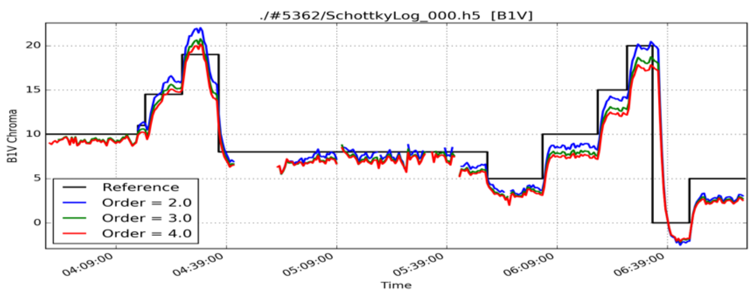
- **Different fitting methods**
  - **Gaussian fit**
    - Least square
    - Robust least square
  - **Threshold fit**
    - With box-car smoothing filter
  - **...**
  - **The all need tweaks**
    - Baseline, noise-reduction, synchrotron lines, coherent signal contribution, etc.



MD1767: Beam 1 Results







Schottky

Contact: Manfred Wendt

- Potentially powerful, non-invasive, measurement of tune and chromaticity
- To obtain decent signal quality:
  - >1e^{10} ppb
  - 30-60 seconds averaging time with stable conditions
- Still an expert tool, requires careful setup
- Work on software and algorithms online fitting of tune and chromaticity is ongoing

Summary

Orbit

- DOROS on in-jaw BPMs allows wire alignment and sub-micron orbit measurement

Tune

- Unexcited ~1e^{-4}
- MKQA kicks ~1e^{-5}

Chromaticity

- Measurement via RF modulation

BTF

- Powerful tool with potential to measure stability diagram

Schottky

- Possibility for non-invasive tune/chromaticity measurements

Note that ultimate performance of instruments often requires special setup. Important to discuss MD plans with the experts in advance.

Thanks!