# LHC Beam Instrumentation & Future Developments

Workshop on Optics Measurements, Corrections and Modeling for High-Performance Storage Rings

21st June 2011, CERN

Rhodri Jones

(CERN Beam Instrumentation Group)

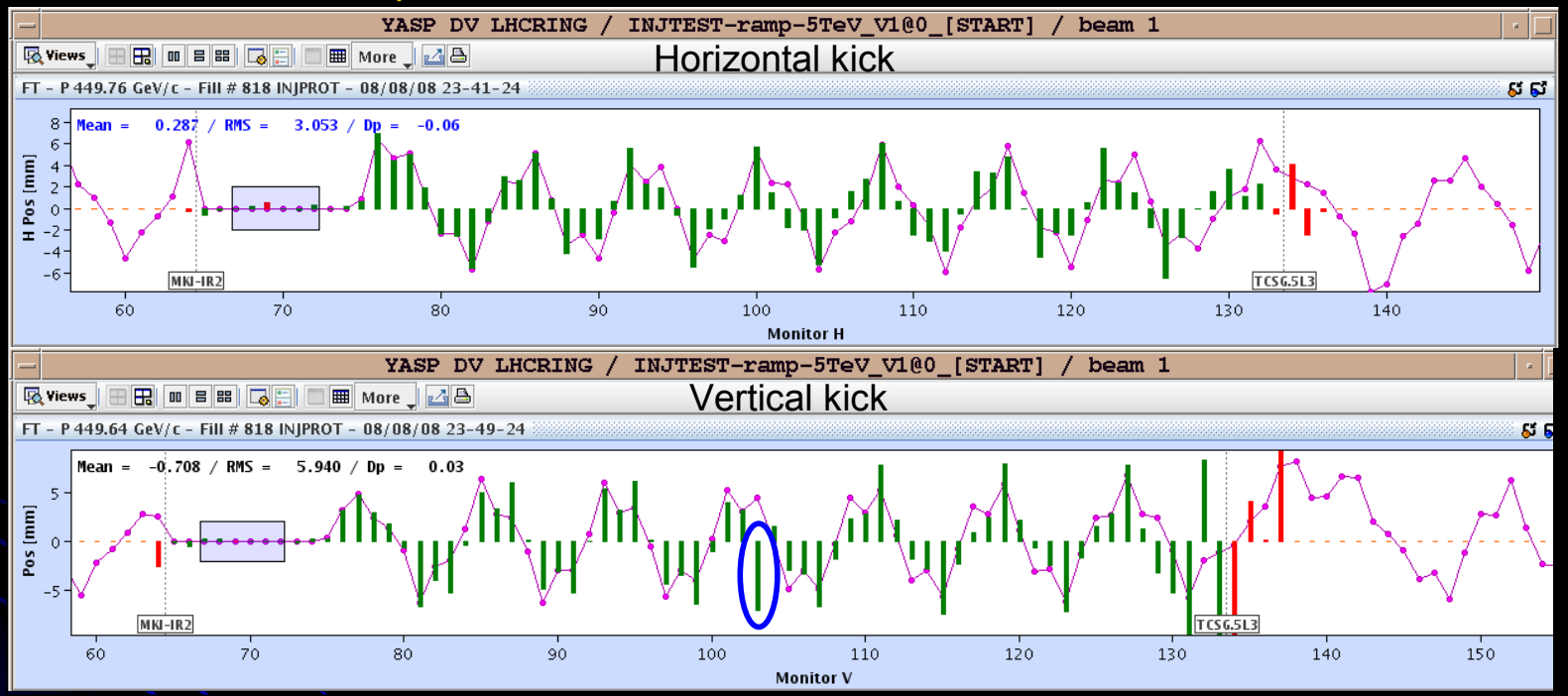
# Outline

Limited to main systems for optics related measurements

- Existing Systems
  - LHC BPM system
  - LHC Tune system
- Possible Future systems
  - Continuous LHC β-beat measurement system
  - LHC Injection Matching

# LHC BPM System Performance I

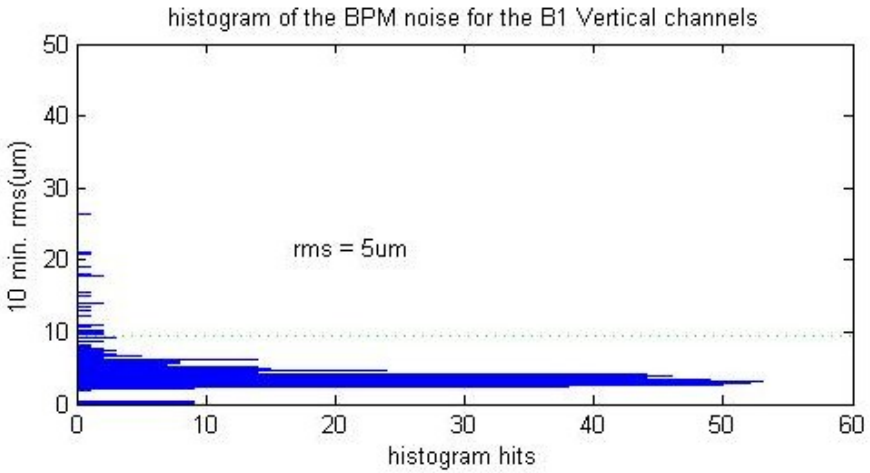
- On line analysis of BPM Data
  - Powerful on-line tools developed by the CERN Operations crew
  - Polarity errors easily identified with 45° BPM sampling
  - Quick indication of phase advance errors

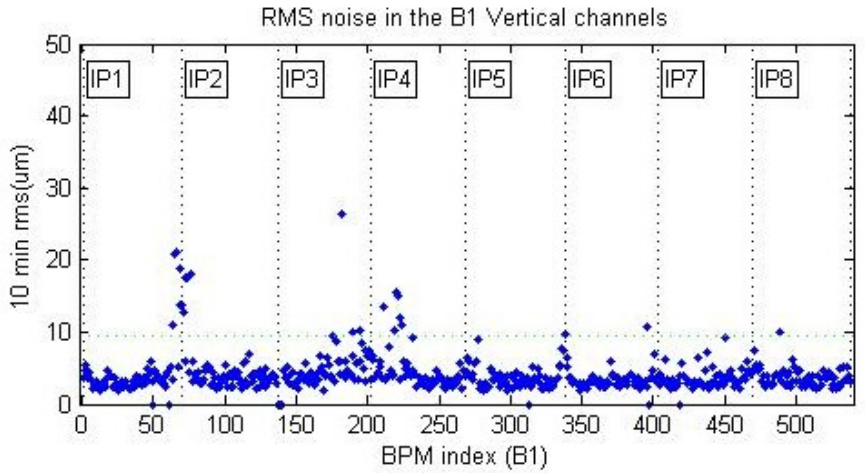


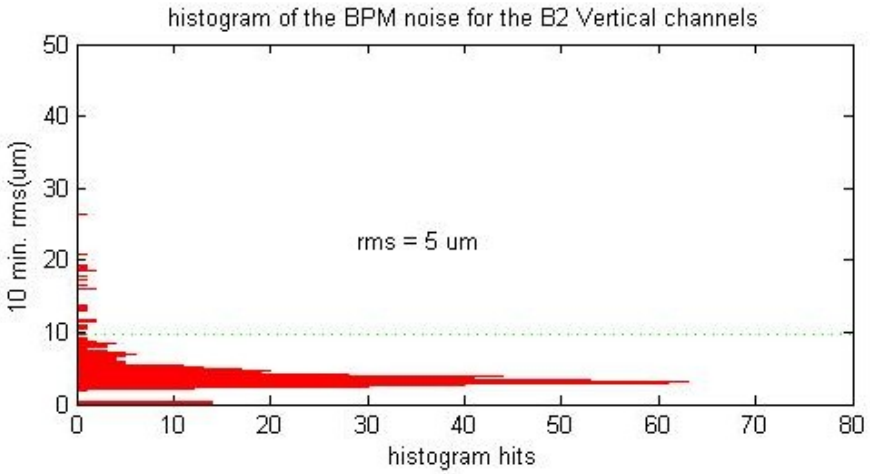

- Some statistics
  - 2009:
    - 4 polarity errors : 2 H to V inversions : 7 BPM mapping errors (LSS8L)
    - 1 B1 to B2 inversion
  - 2011:
    - 18 out of 2152 channels with acquisition problems
    - 50 channels deselected for feedback with physics beams (mainly cross-talk on directional pick-ups)

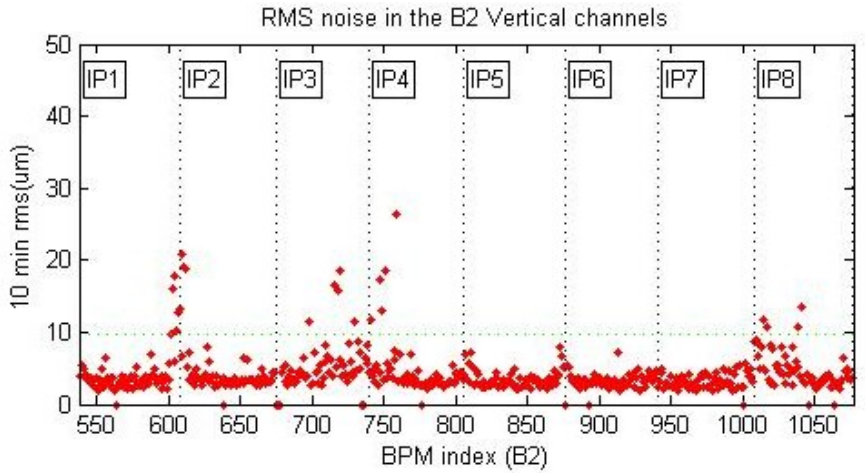
# LHC BPM System Performance II

- Resolution of LHC BPM system in closed-orbit mode is ~5μm rms
- Long term stability better than ~100μm
  - Mainly given by temperature dependence of surface electronics (being addressed)



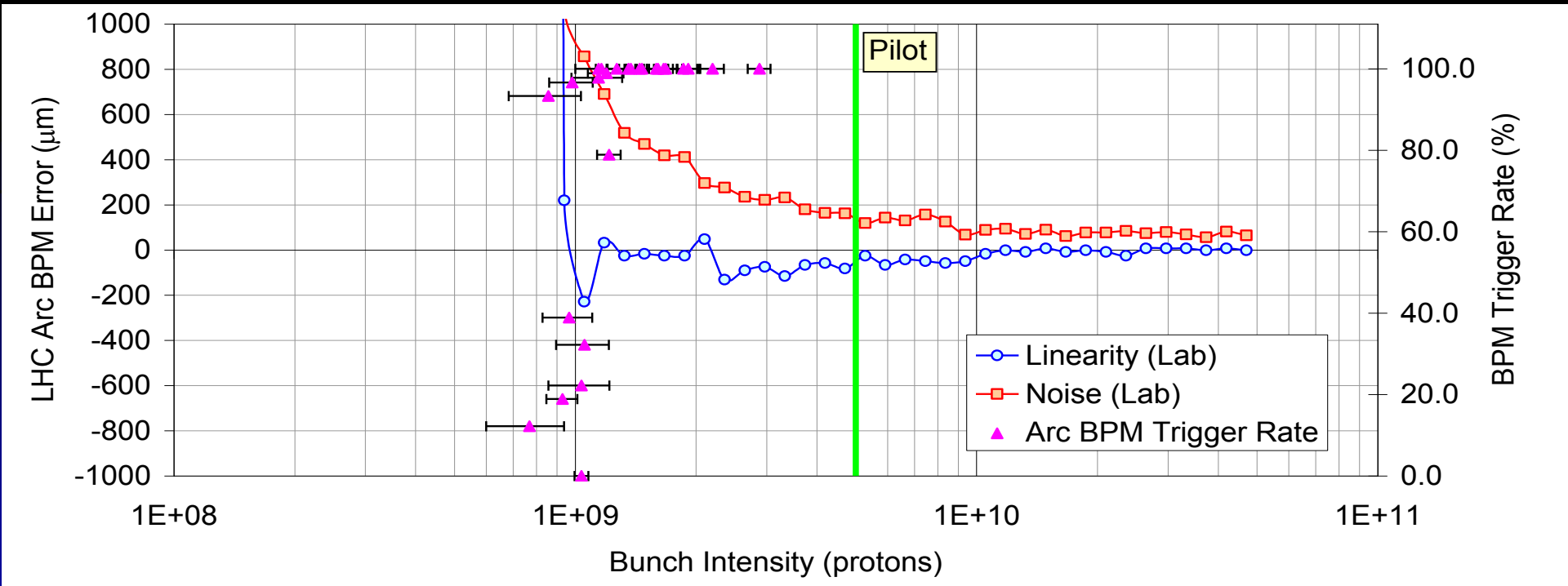




Courtesy E. Calvo

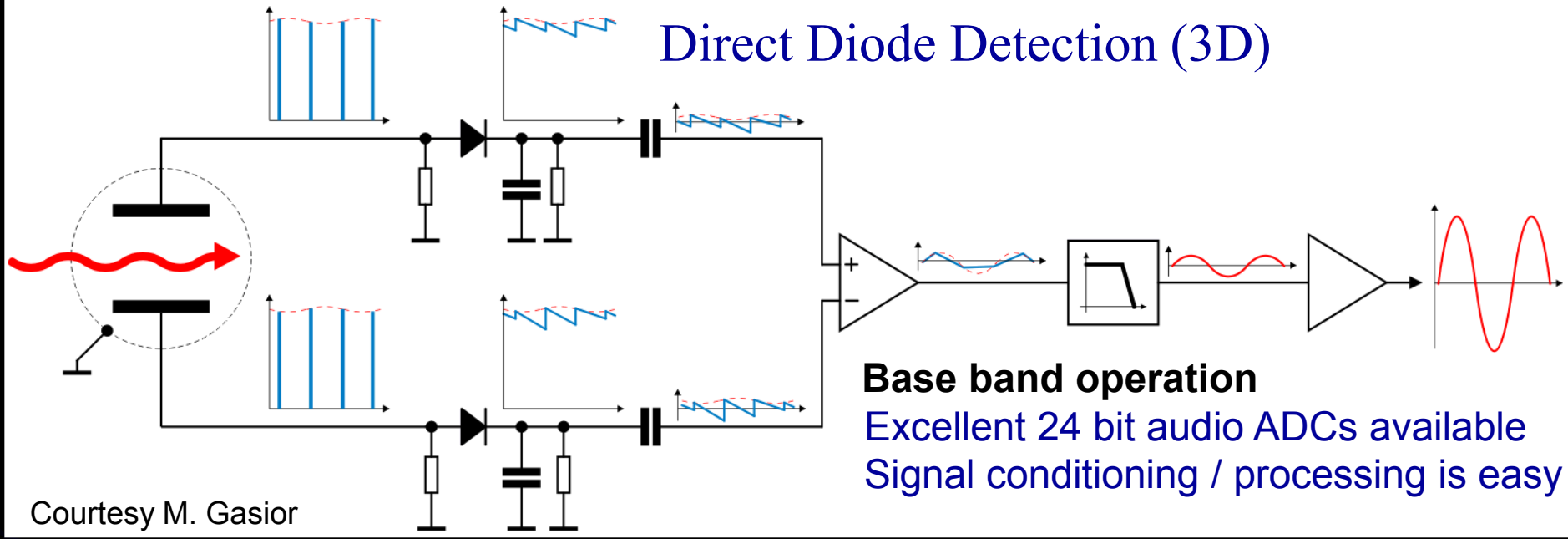
# LHC BPM System Performance III

- Bunch-by-Bunch / Turn-by-Turn Mode
  - Main mode used for optics measurements in LHC
  - Allows up to 128000 samples (bunch × turns) from all BPMs
    - Read-out limited to few thousand turns due to data transfer & concentration issues
  - Requires synchronisation to bunch clock for tagging
    - Automatic phase-in now possible & performed before all optics measurements
  - Resolution
    - From ~200μm rms (single pilot bunch) to ~50μm rms (single nominal bunch)



# Controlling Tune & Chromaticity using the Base Band Q Measurement (BBQ) System

## Direct Diode Detection (3D)



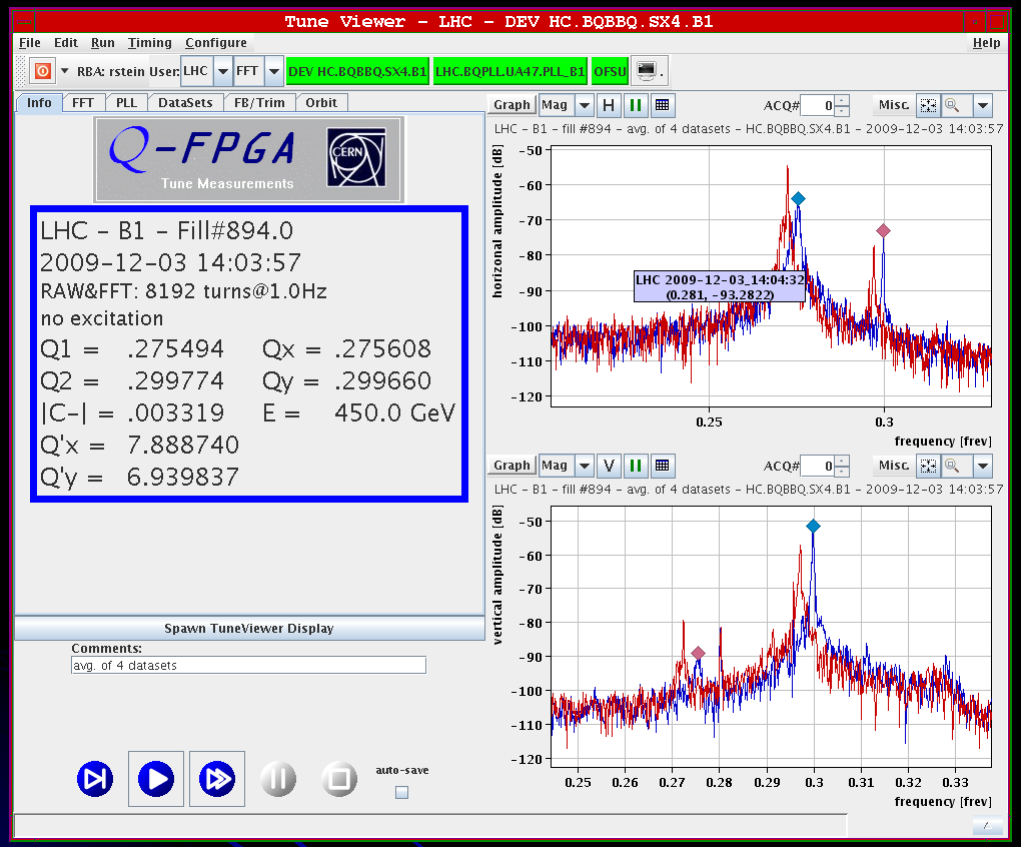
Courtesy M. Gasior

**Base band operation**

Excellent 24 bit audio ADCs available

Signal conditioning / processing is easy

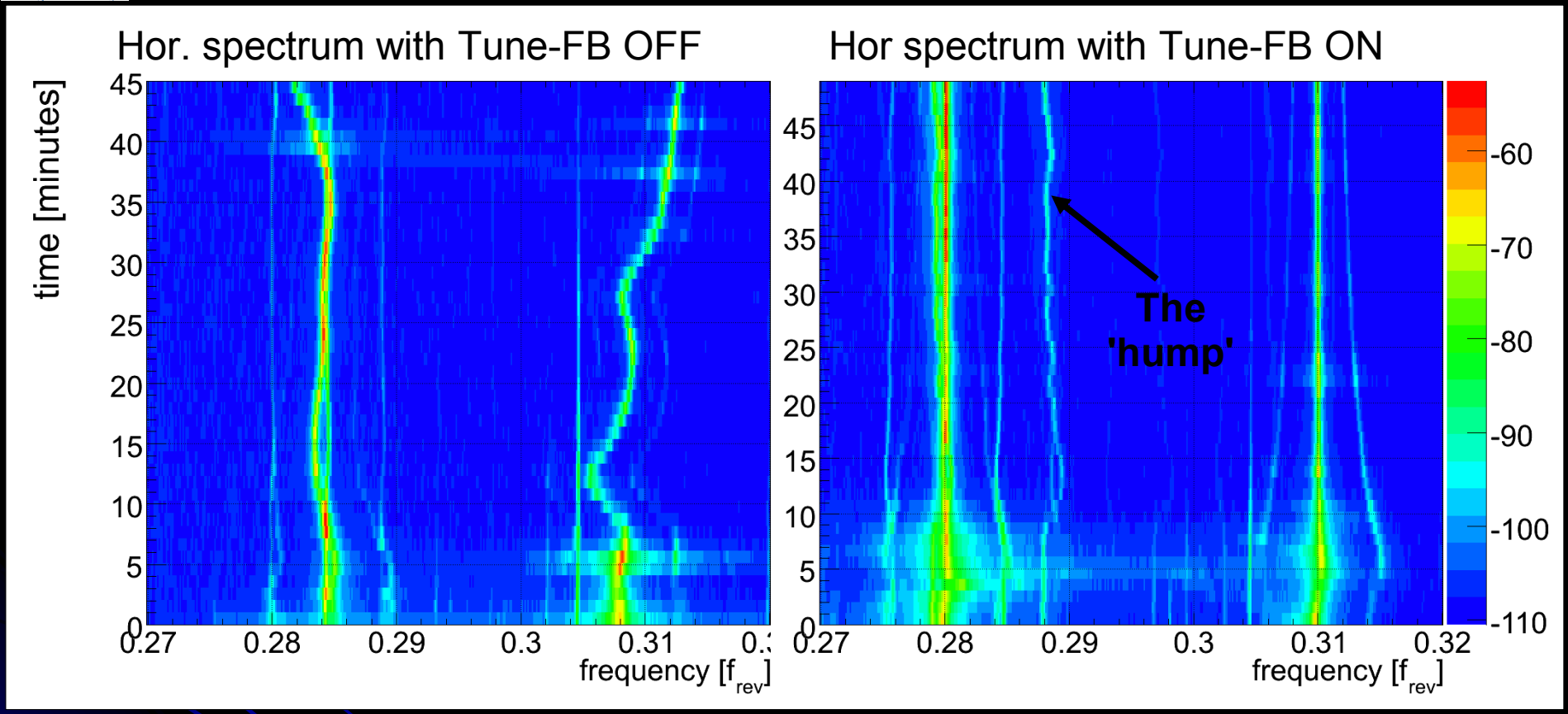

# LHC Tune System Performance




- Base Band Tune (BBQ) Measurement System
  - Extremely high sensitivity
  - Coherent micron level tune oscillations nearly always observed
    - most measurements possible with residual beam oscillations
    - Typical tune measurement resolution in the range $10^{-4}$ … $10^{-6}$

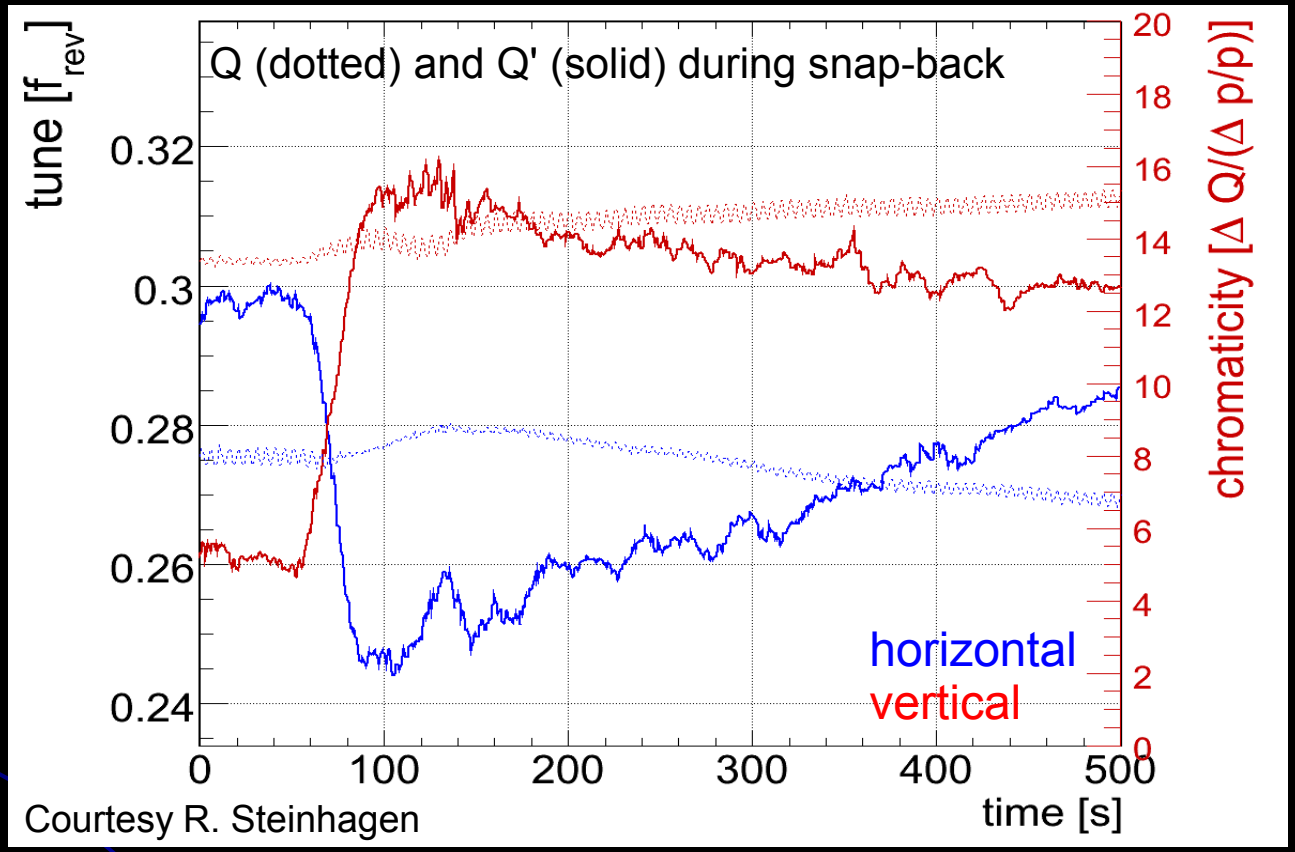
- Issues
  - Cohabitation with transverse damper (ADT)
    - Raises noise floor by 30dB
    - Aggressive damping leads to very broad tune peak

# Tune Feedback in the LHC




- With full pre-cycling the fill-to-fill stability is typically 2-3·$10^{-3}$
- Variations frequently increase up to 0.02
  - Due to partial or different magnet pre-cycles after e.g. access or sector trips
- Tune-FB routinely used for all ramps to compensate these effects
  - Using peak fit on FFT with 0.1..0.3 Hz Bandwidth

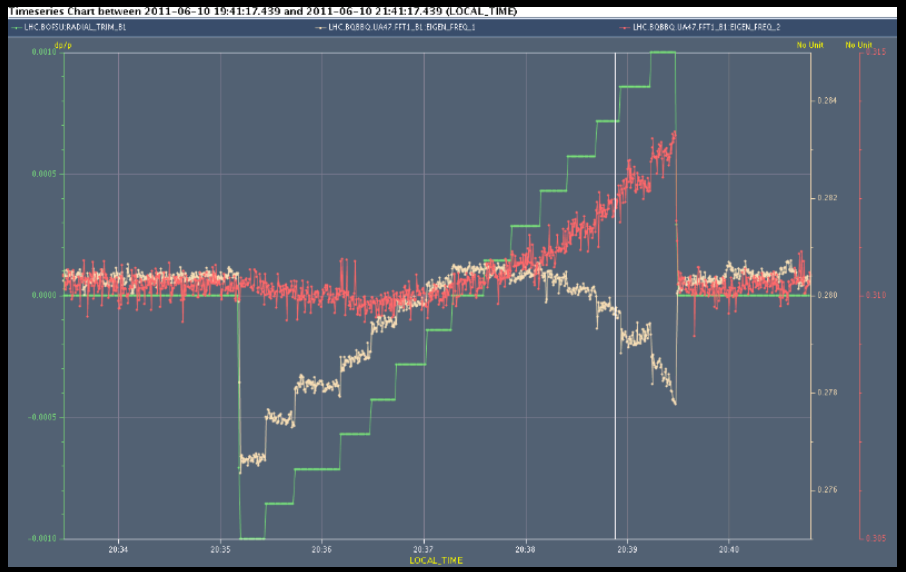
# Chromaticity Measurement in the LHC

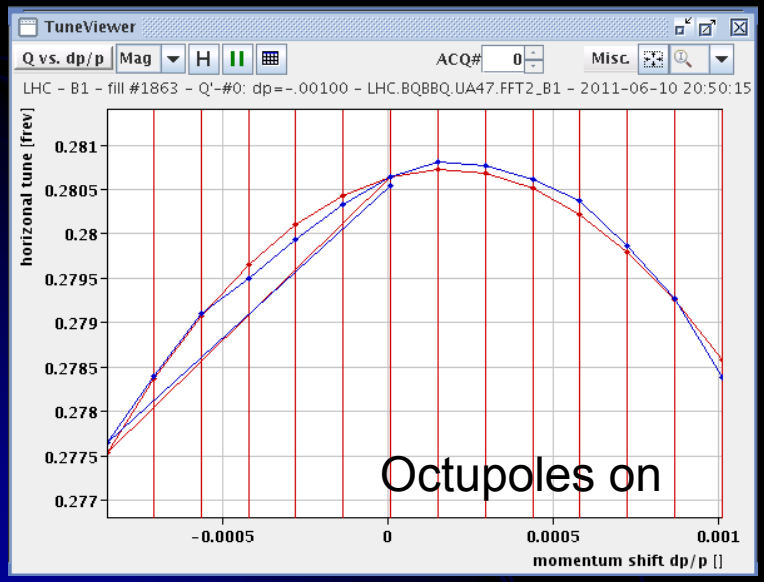


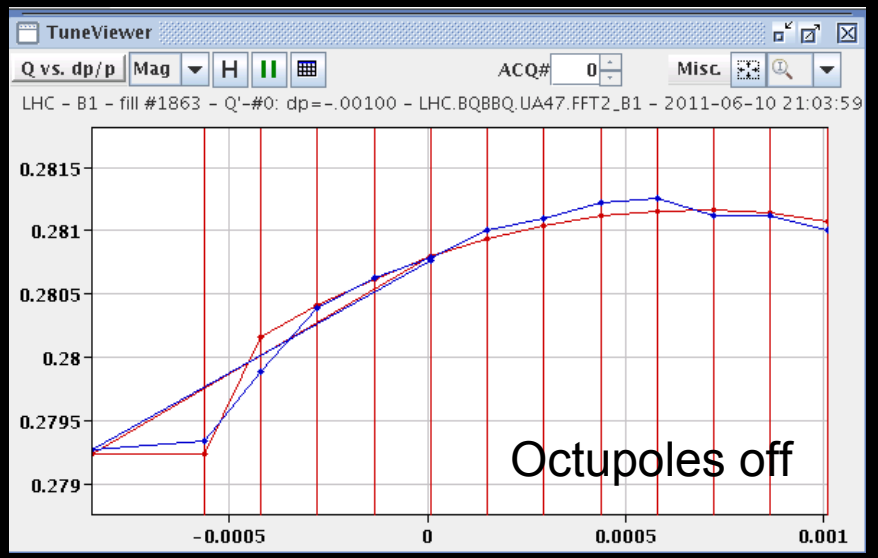

- Q'-Tracker demodulates sinusoidal frequency trims
  - Increased original modulation of Δp/p from $10^{-5}$ @2.5 Hz to $10^{-4}$ @2Hz
    - Mitigates tune stability effects at injection (ΔQres ~ 3-4·$10^{-4}$)
  - Achieved nominal Q' resolution (±1 unit)
    - Used as feed-forward (combined with magnetic model predictions)

# Using the LHC Tune System

- Recent Measurement of Q'' with and without octupoles at injection



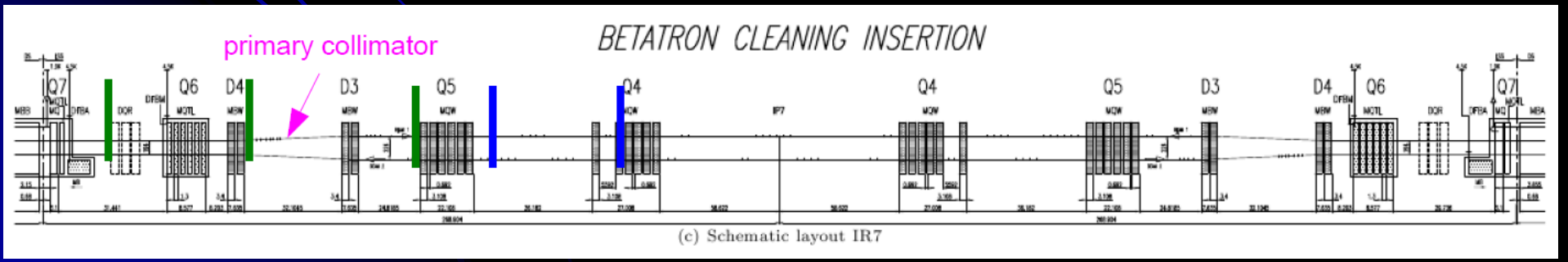



# Future Systems being Developed

# Continuous Beta Beat Measurements

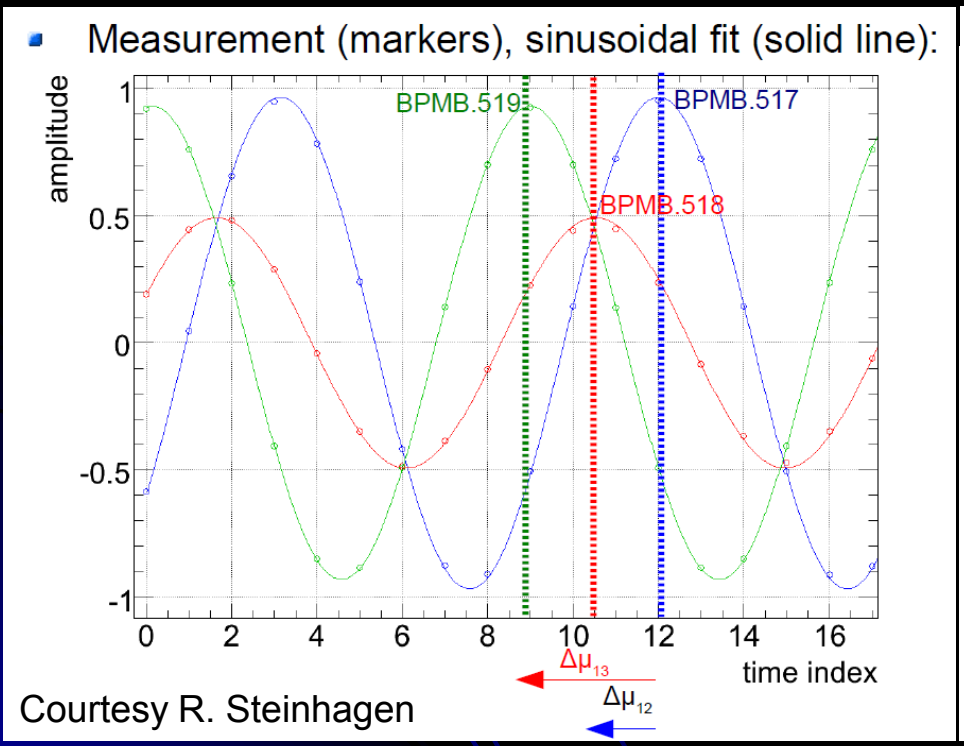
- Makes use of very high sensitivity of BBQ system
  - Test system acquired using audio acquisition module & proliant machine
  - ONLY provides PHASE information
    - No meaningful turn by turn data
- Advantages
  - >100 times sensitivity than phase from standard turn by turn BPM data
  - Minimal excitation required (μm level at any frequency)
- Under test in SPS & the betatron collimation region of LHC
  - Uses 3 dual plane BPMs
    - Phase-advance between consecutive BPMs of $\Delta\mu \approx 45°$
    - In parallel to standard BPM system



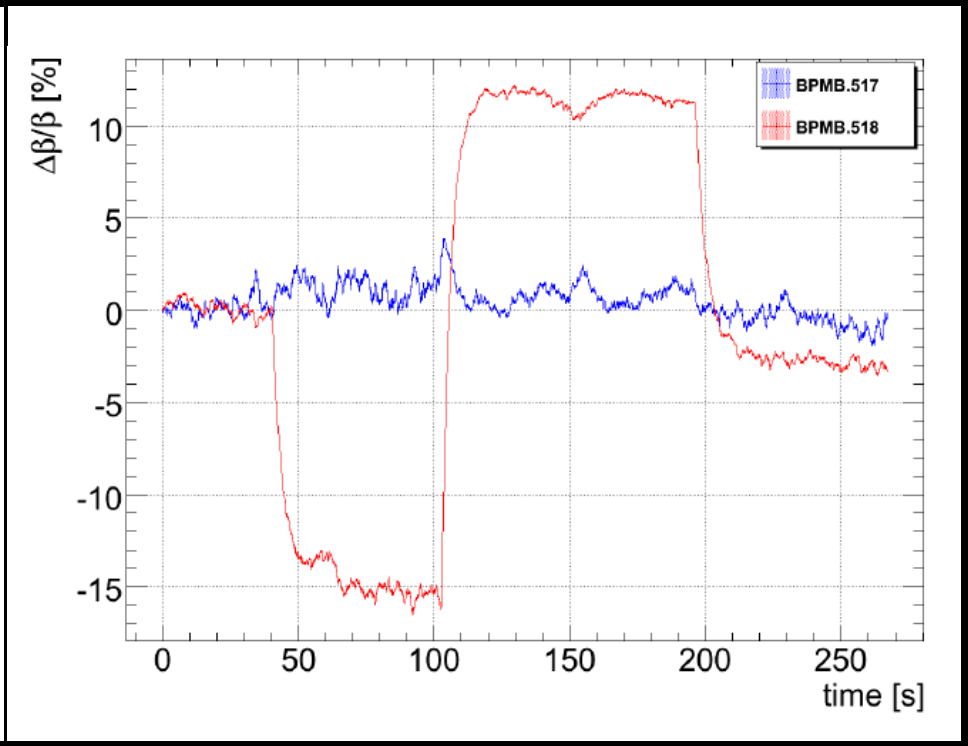
(c) Schematic layout IR7

# Continuous Beta Beat Measurements

- Example from the SPS
  - Quadrupole trim : 0A → +50A → -50A → 0A
  - Hysteresis observed



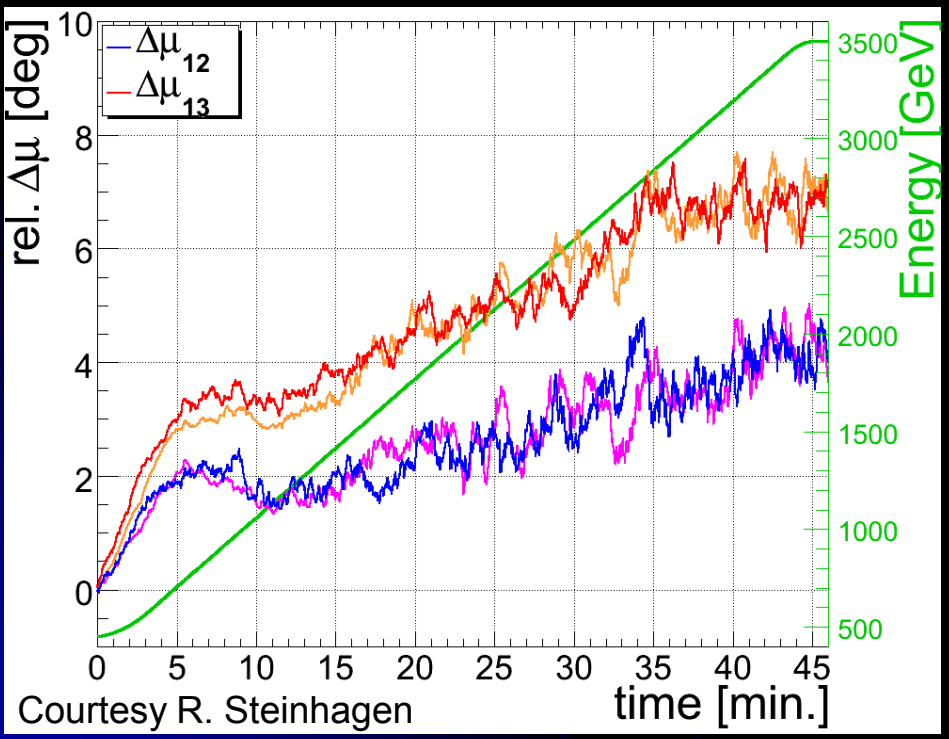

Measured oscillation data
(~10-50μm excitation)

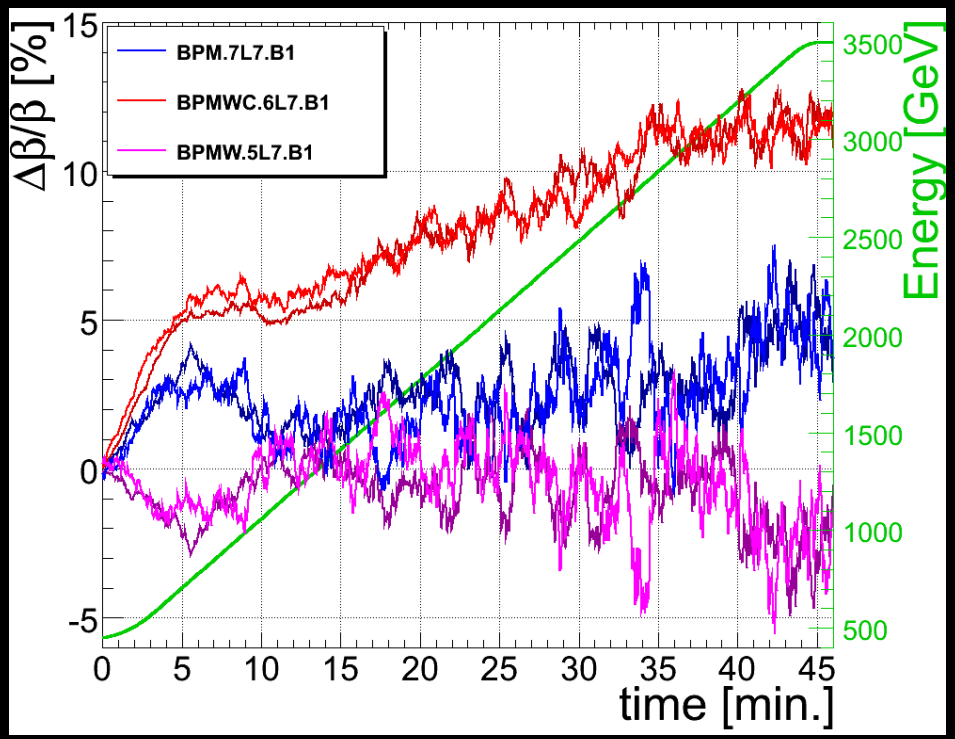



Measured change in β

# Continuous β-Beat Measurements
## LHC Results

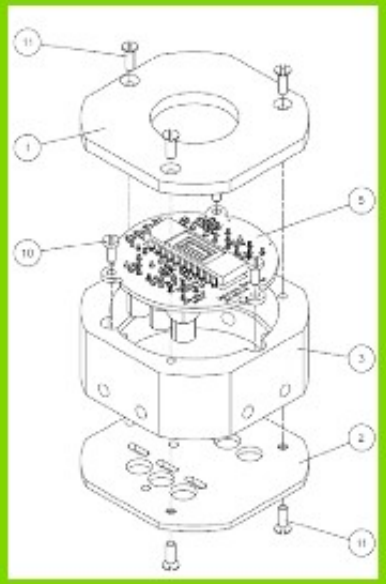
- Pre-cycled machine, off-resonance < 1 μm excitation
  - Excellent phase resolution
    - Reduces with energy due to constant kick strength
- Excellent fill-to-fill reproducibility
  - about 1% provided that the machine was fully pre-cycled



# LHC Injection Matching Monitor

- Turn by turn OTR monitor
  - Permanent 2D profile installation as initially hoped not feasible
    - high cost & low radiation tolerance of fast cameras
  - Developing fast 1D array readout for turn by turn profile measurements

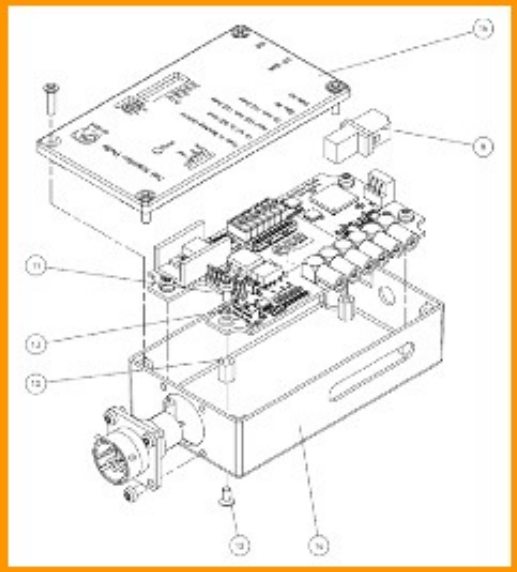


based on *Linear CCD*

-50MHz readout
-adjustable integration time
-good sensitivity
-suitable for LHC and SPS matching study

**GOAL**

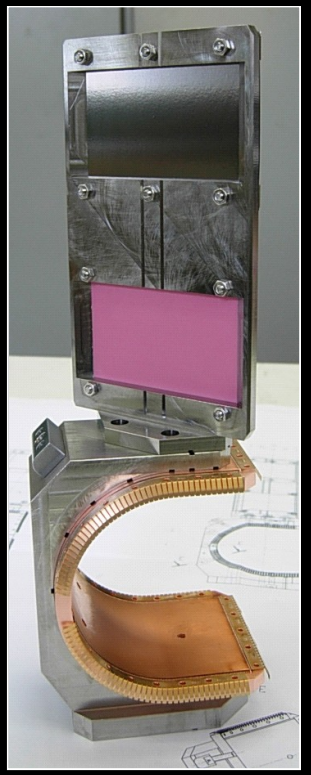
***From an adapted optical line using cylindrical lenses, get a profile directly on the single CCD pixel array***



associated electronics

-ADC
-fast serializer
-fiber optic transmission

Courtesy S. Burger



# Summary

- LHC BPM system performing well
  - Combined with AC dipole excitation provides a very good tool for optics measurements
- LHC Tune system
  - Excellent sensitivity allows measurement without excitation provided transverse damper is not required
  - Combined with RF frequency modulation allows measurement of both first & second order chromaticity
- The Future
  - Continuous β-beta measurement demonstrated
    - Could be deployed in critical locations if required BUT
      - LHC fill-to-fill stability remarkable under full pre-cycle conditions
  - New LHC matching monitor being developed for injection optimisation