LARP Instrumentation

in Perspective of the LHC Commissioning and Operation

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on behalf of many many contributors

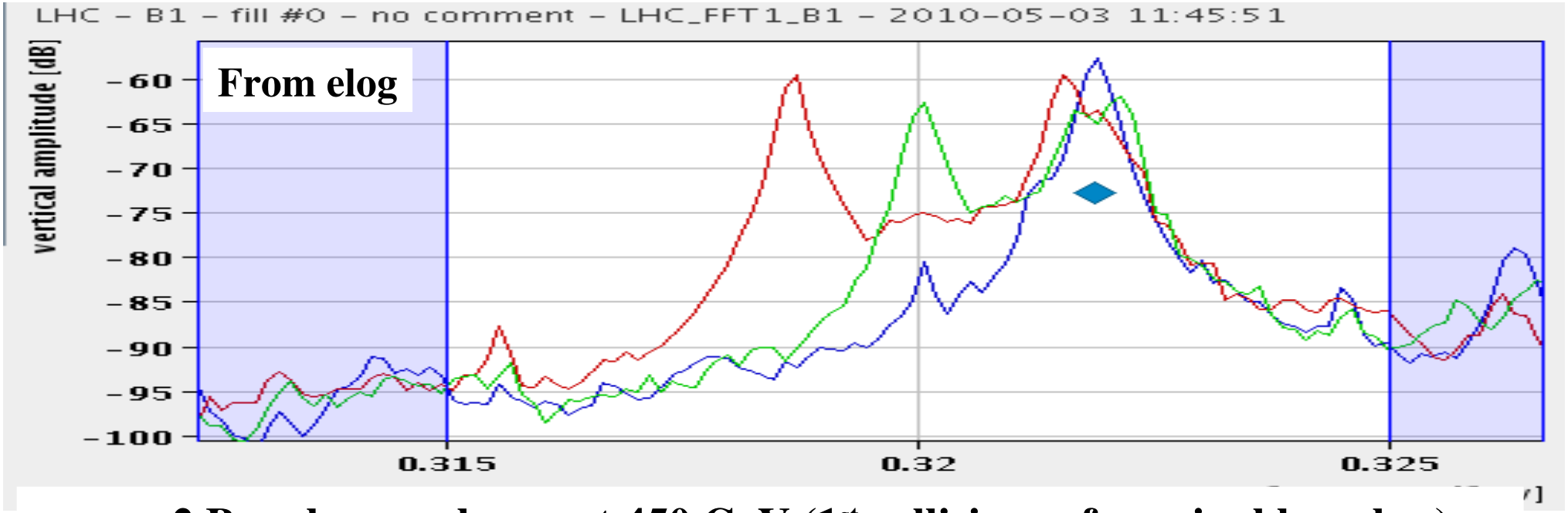
LARP CM15 at SLAC (Nov 1st 2010)

Introduction

- LARP delivered/contributed to
  - BBQ (tune, chromaticity, coupling)
  - AC dipole (optics)
  - Synchrotron light monitor (profile, abort gap monitoring)
  - Luminosity monitor (luminosity, crossing angle)
  - Schottky monitor (tune, chromaticity, momentum spread)
- All taking data.
- Some are operational, some are getting ready.
- This talk presents examples of recent measurements during the commissioning and operation.
- Contributions from many people.
- Details of the synchrotron light monitor and luminosity monitors are given in talks of Alan and Alex on Tuesday.

LHC base-band-tune (BBQ) system

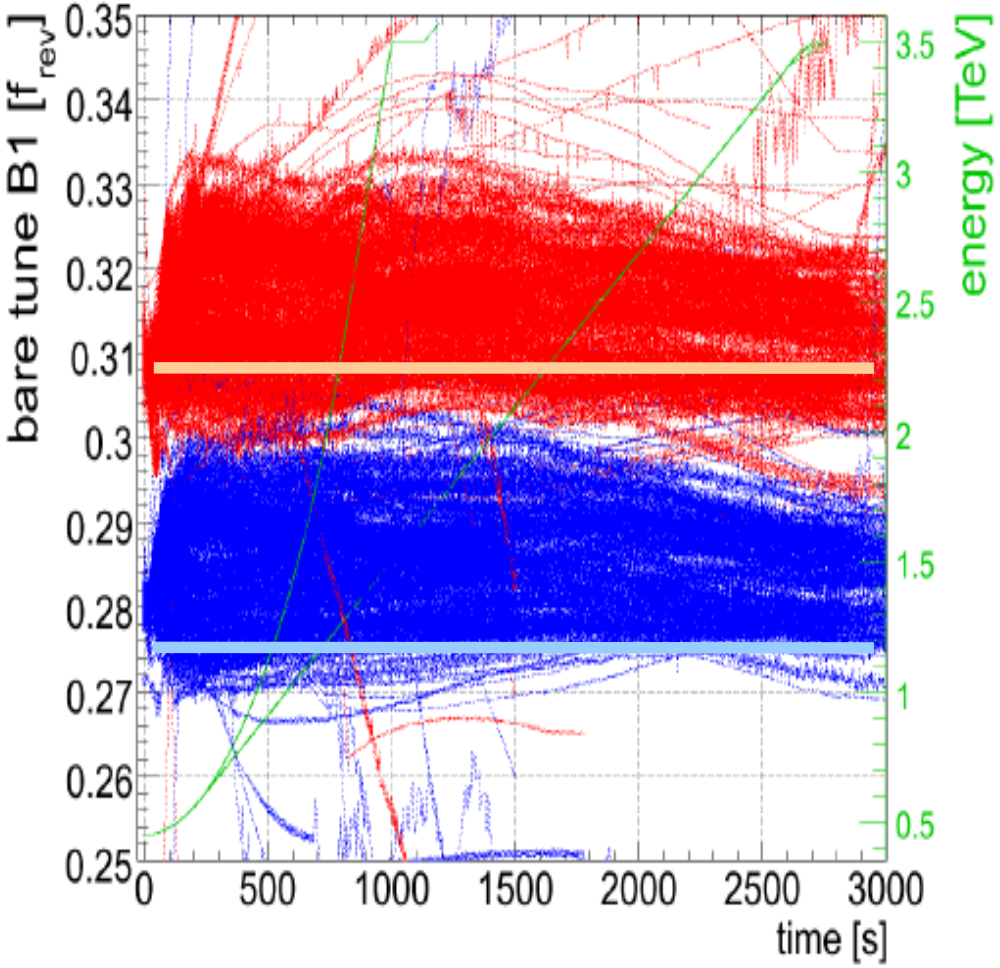
- Measure and control (feedback) tune and global coupling.
- Also measures chromaticity with RF-modulation.
- One of the most important instruments, must be ready from day 1 and always available.
- BNL lead the R&D and provided the ideal development site in RHIC, speeding up the commissioning (of not just BBQ but LHC itself).

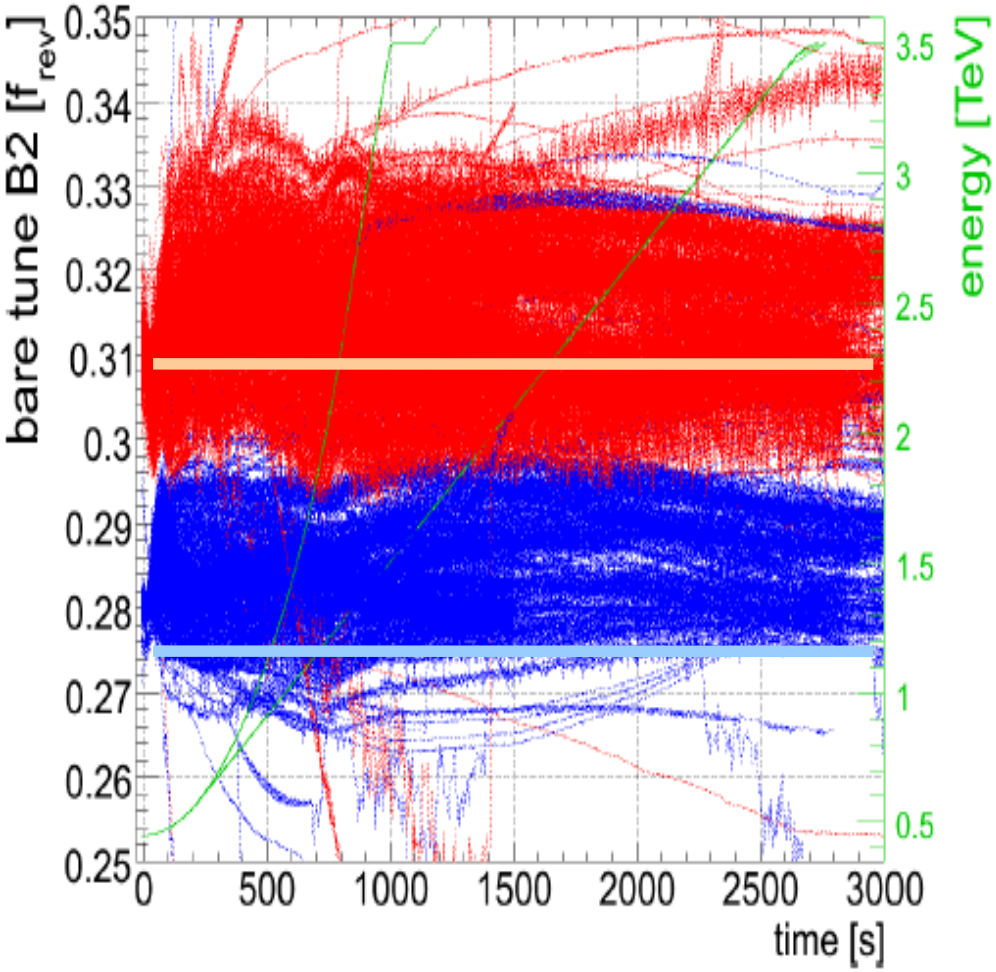


- **2 Bunches per beam at 450 GeV (1st collisions of nominal bunches)**
- **Bunch 1 collide at 1 and 5, no collision for bunch 2**
- **Bunch 1 collide at 1, no collision for bunch 2**
- **No collision for bunch 1 and 2**

Tune feedback vital to the ramp

Courtesy of R. Steinhagen





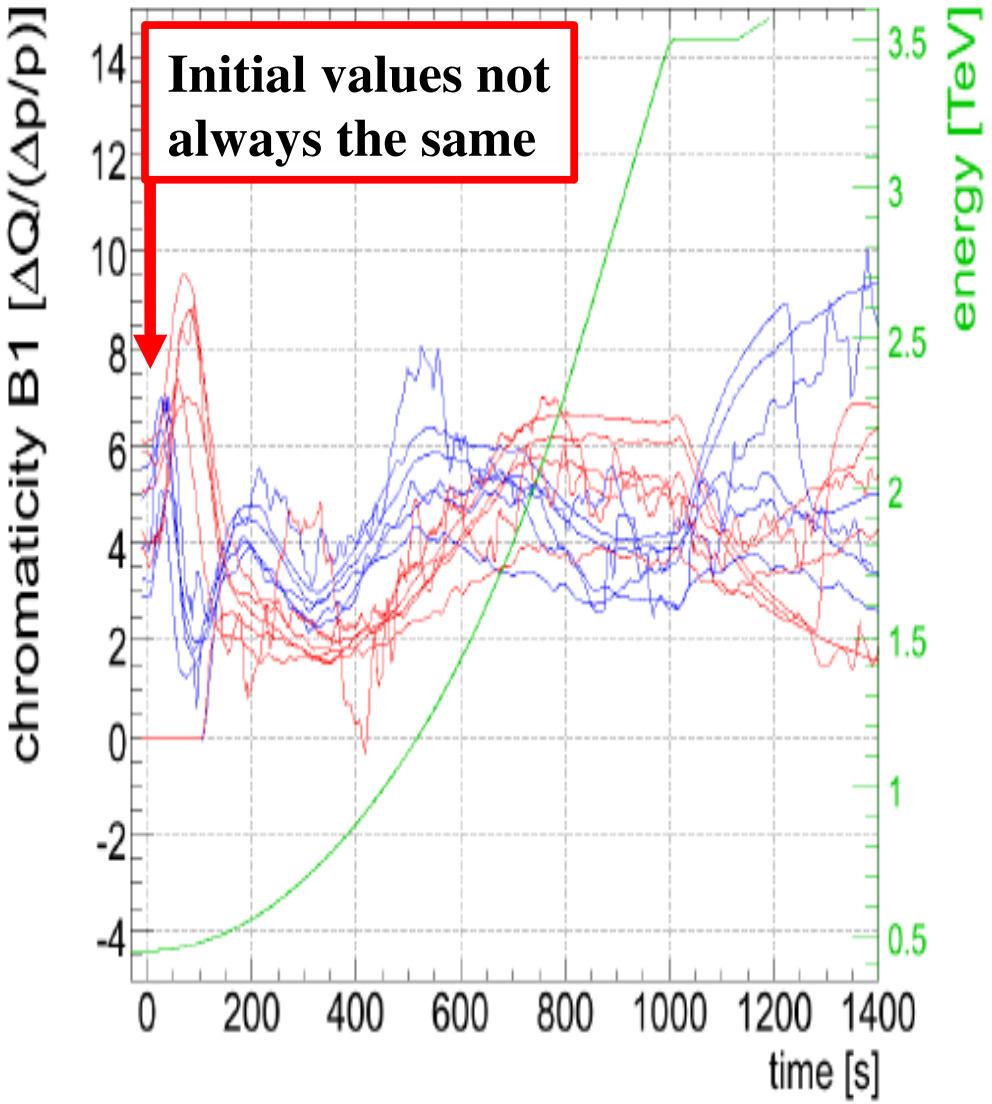
Q-feedback keep tunes +/-0.003 from the nominal values.

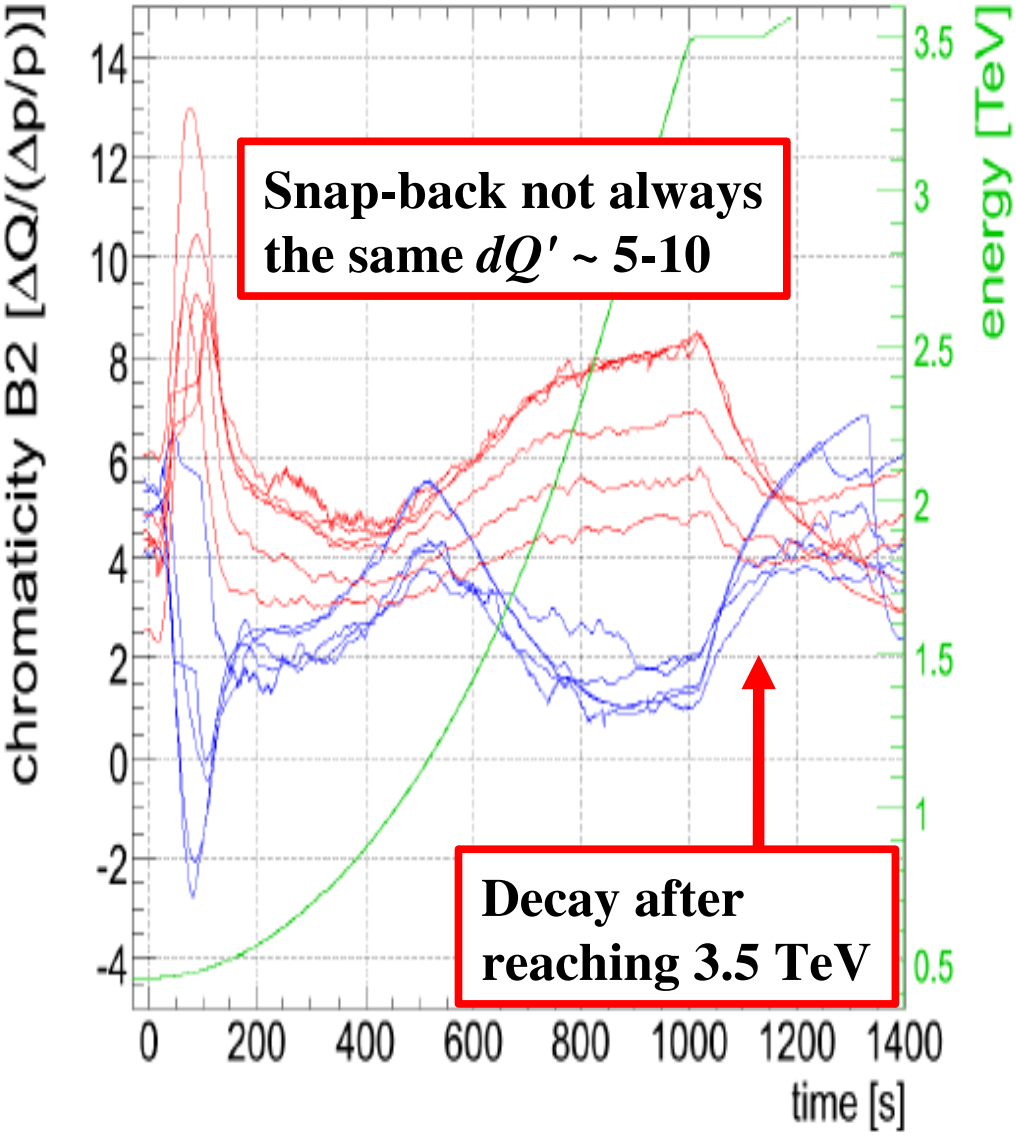
The plot shows **IF** without *Q*-feedback, out of **191** ramps

- **56** of B1 and **83** of B2 hit low order resonances (coupling, 3rd, 4th)
- **150** of B1 and **157** of B2 exceeded dQ = +/-0.01 (tolerance).

Chromaticity during the ramp

Courtesy of R. Steinhagen





- Only several dedicated measurements.
- Q'-feedback demonstrated at RHIC but needs RF-modulation...

AC dipole

AC dipole:

- Exciter for optics measurement.
- **Almost non-invasive**, **no decoherence** ← perfect for the LHC.
- First demonstration in AGS, followed by RHIC, SPS, and Tevatron.

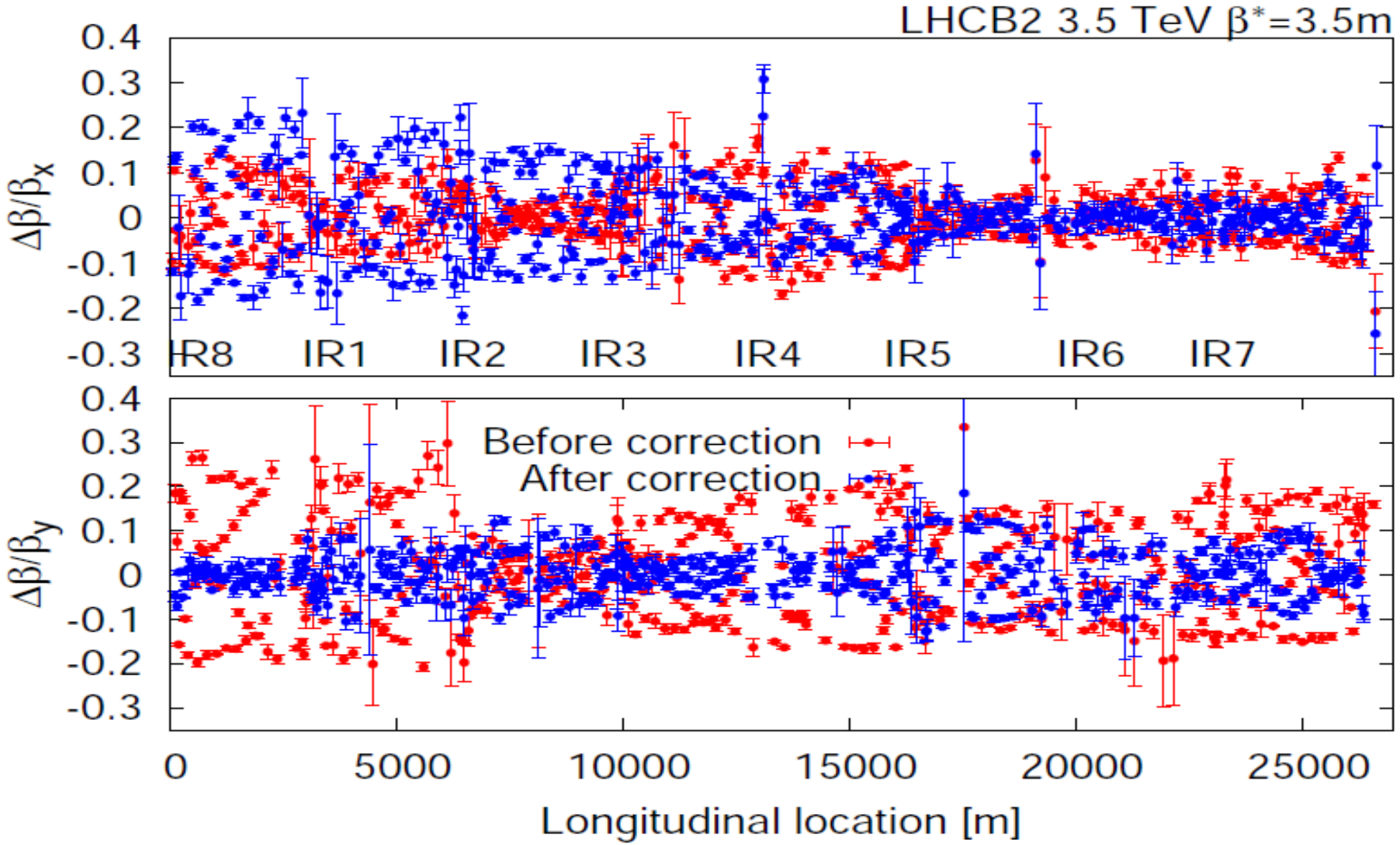
LHC AC dipole:

- Total 4 (2 planes per beam) installed at IR4.
- FNAL solution (existing kicker + audio amp) further developed by CERN.
- Frequency tuning solutions provided by BNL.
- A Toohig fellow contributed commissioning, measurements, algorithm.
- **Primary probe to the beam optics**.
- Operational since March and handed over to TE-ABT Group.

LHC optics:

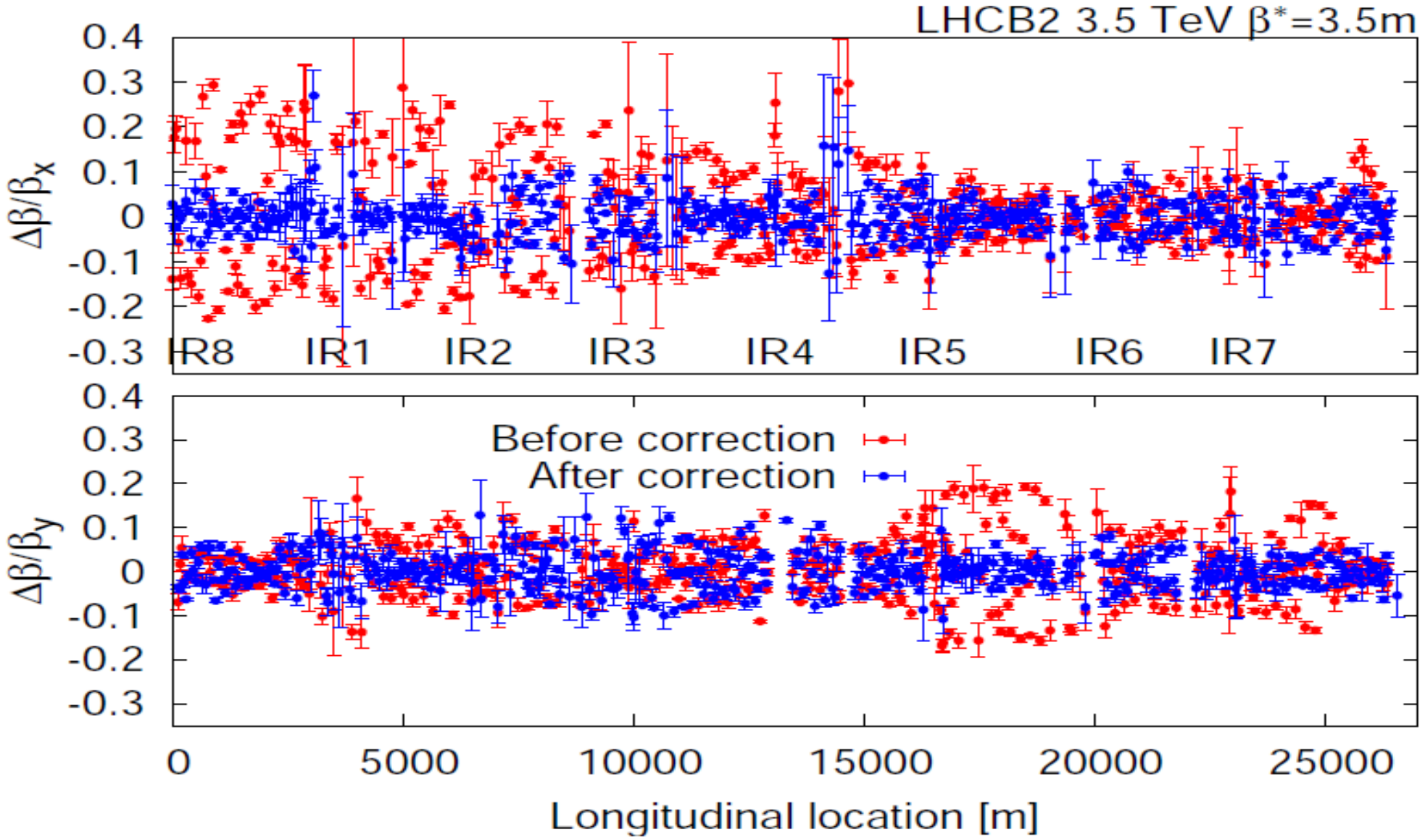
- IR corrections for the injection and squeeze.
- Global corrections for the squeeze → ~<15% β-beating (on the spec).
- Measurement during the ramp.
- Agreement with magnet/alignment (re)measurements:
  - Hysteresis of warm magnets at IR3 and 7.
  - Quad roll at IR5.
- Next year and beyond?

Beam2 β-beating: as far with local corrections



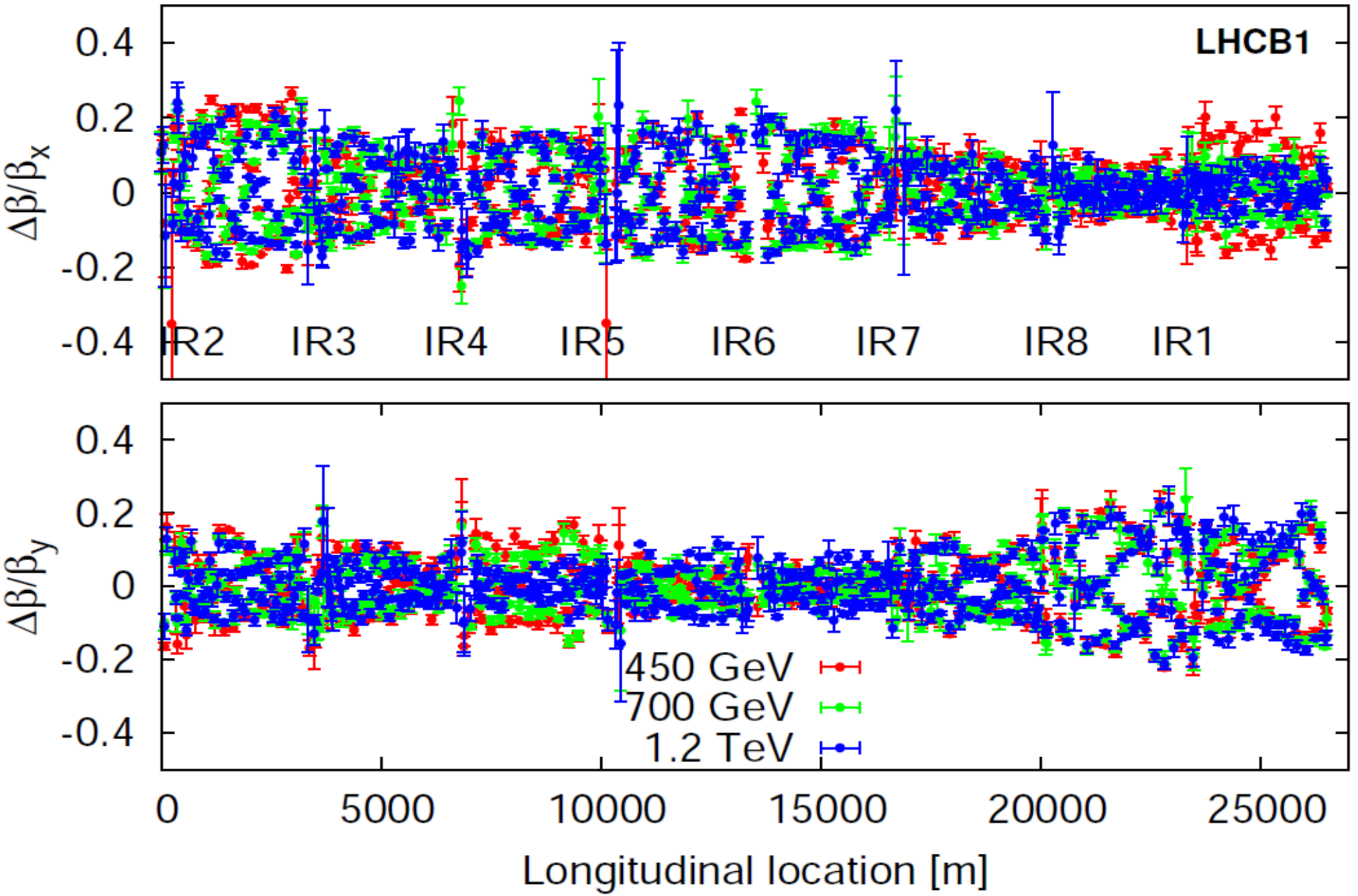
- Local corrections at IR1, 5, 2, 8, and 6.
- Need the global correction at some point...

Beam2 local + global corrections

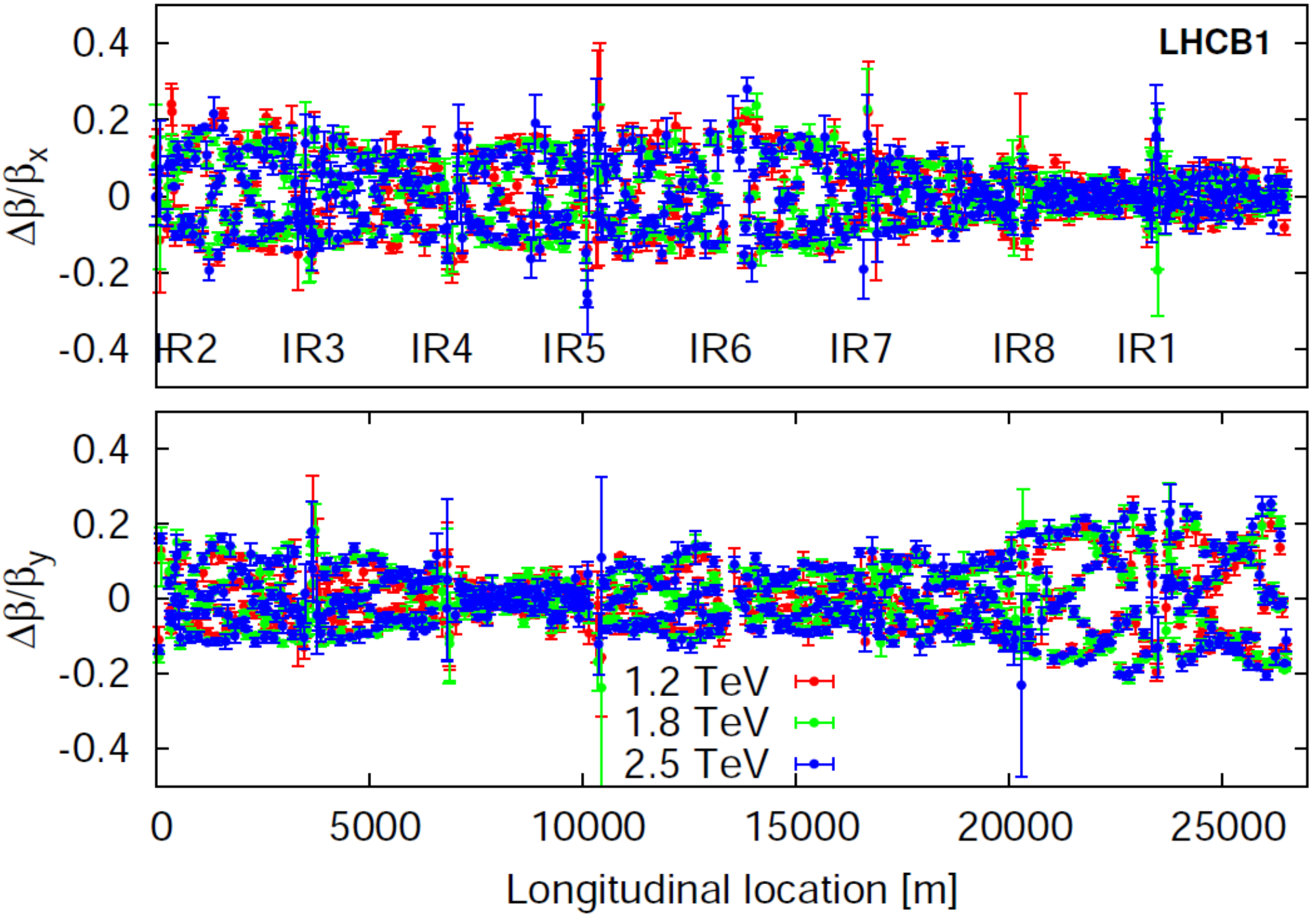


- On the level of the specification (~<15%)
- Fight for the signal quality?

Beam1 beta-beating 0.45 – 1.2 TeV



Beam1 Beta-beating 1.2 – 2.5 TeV



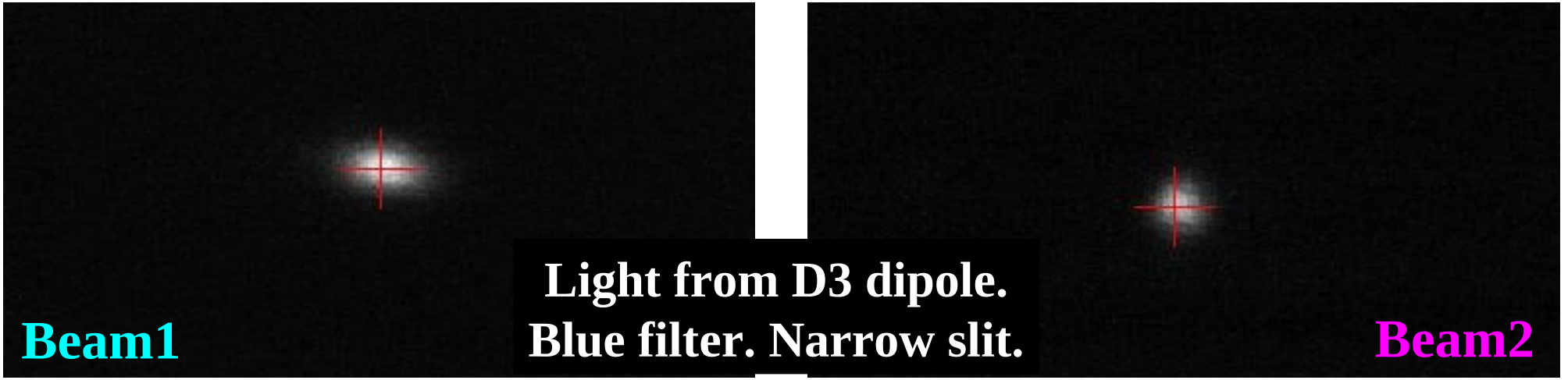
Synchrotron light monitor

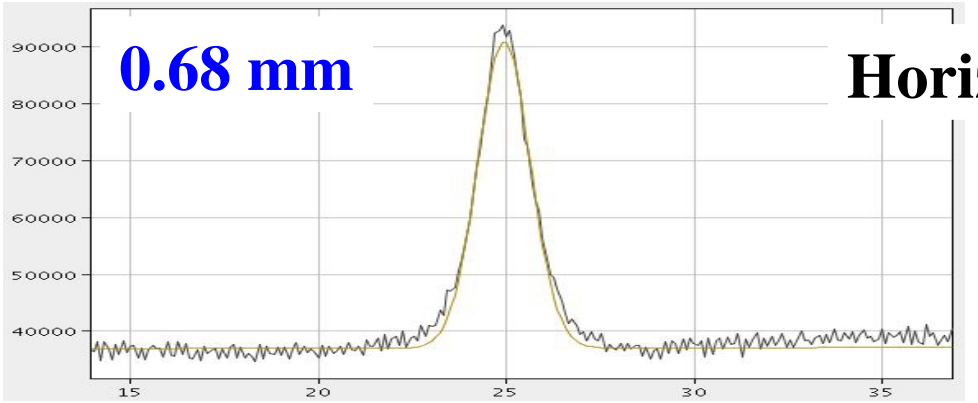
- Applications:
  - Transverse beam profiles (**non-invasive**, **bunch-by-bunch**, **up to the full intensity**)
  - Abort-gap monitor (10% of light is detected by gated PMT)
  - Longitudinal density monitor (in development)
  - Halo monitor (future)
- Three light sources, changing during the ramp:
  - Undulator radiation at injection (0.45 - 1.2 TeV)
  - Dipole edge radiation at intermediate energy (1.2 - 3 TeV)
  - Central dipole radiation at collision energy (3 - 7 TeV)
- For both protons and heavy ions.
- Main contribution from SLAC.
- Details in Alan's talk on Tuesday.

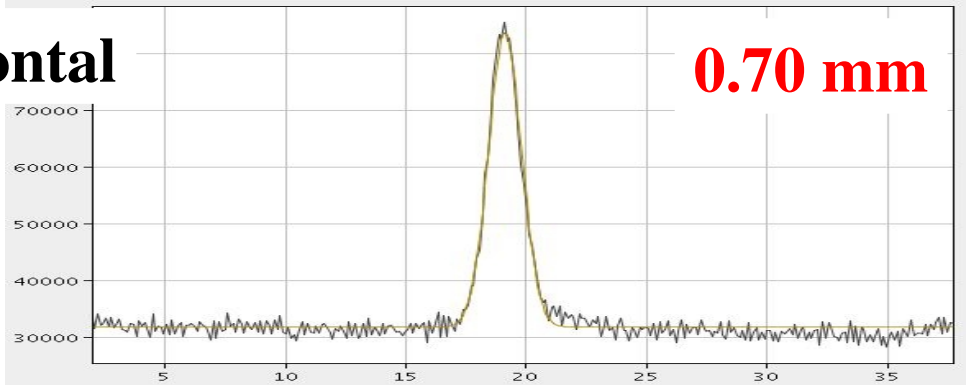
Abort gap cleaner / monitor

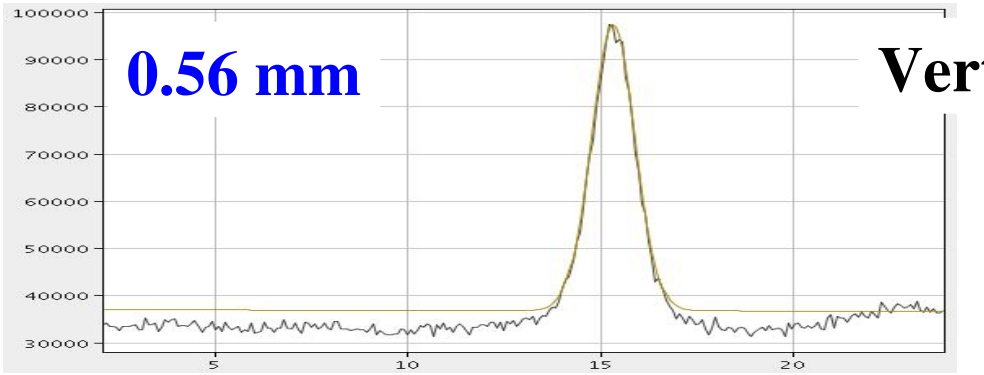
- 3 μs abort gap for the abort kicker rise time.
- Particles uncaptured or out of the bucket may cause quench when the beam abort.
- Former successes in RHIC (stripline) and Tevatron (e-lens).
- Use dampers to excite on tunes.
- Tests ongoing:
  - Successful tests in October.
  - Not tested with tune feedback yet.
  - Vital for 30 MJ?
- Contributions from LTVs from FNAL and SLAC (tracking simulation and monitoring).
- Measurements of 2^{nd} order chromaticity and detuning help?

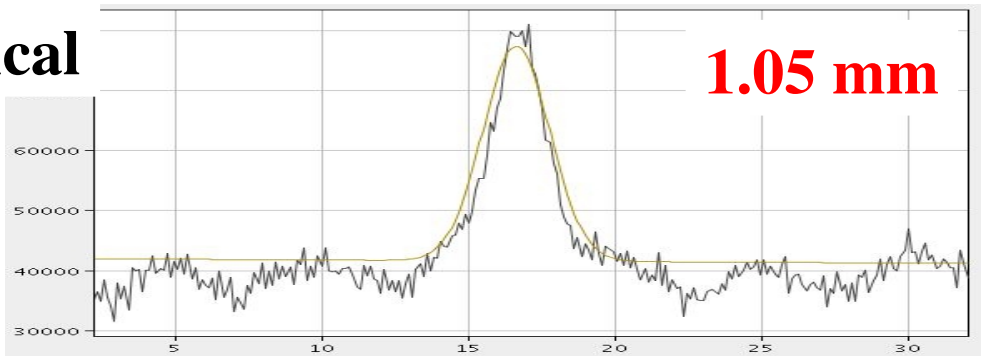
Beam profile measurements at 3.5 TeV







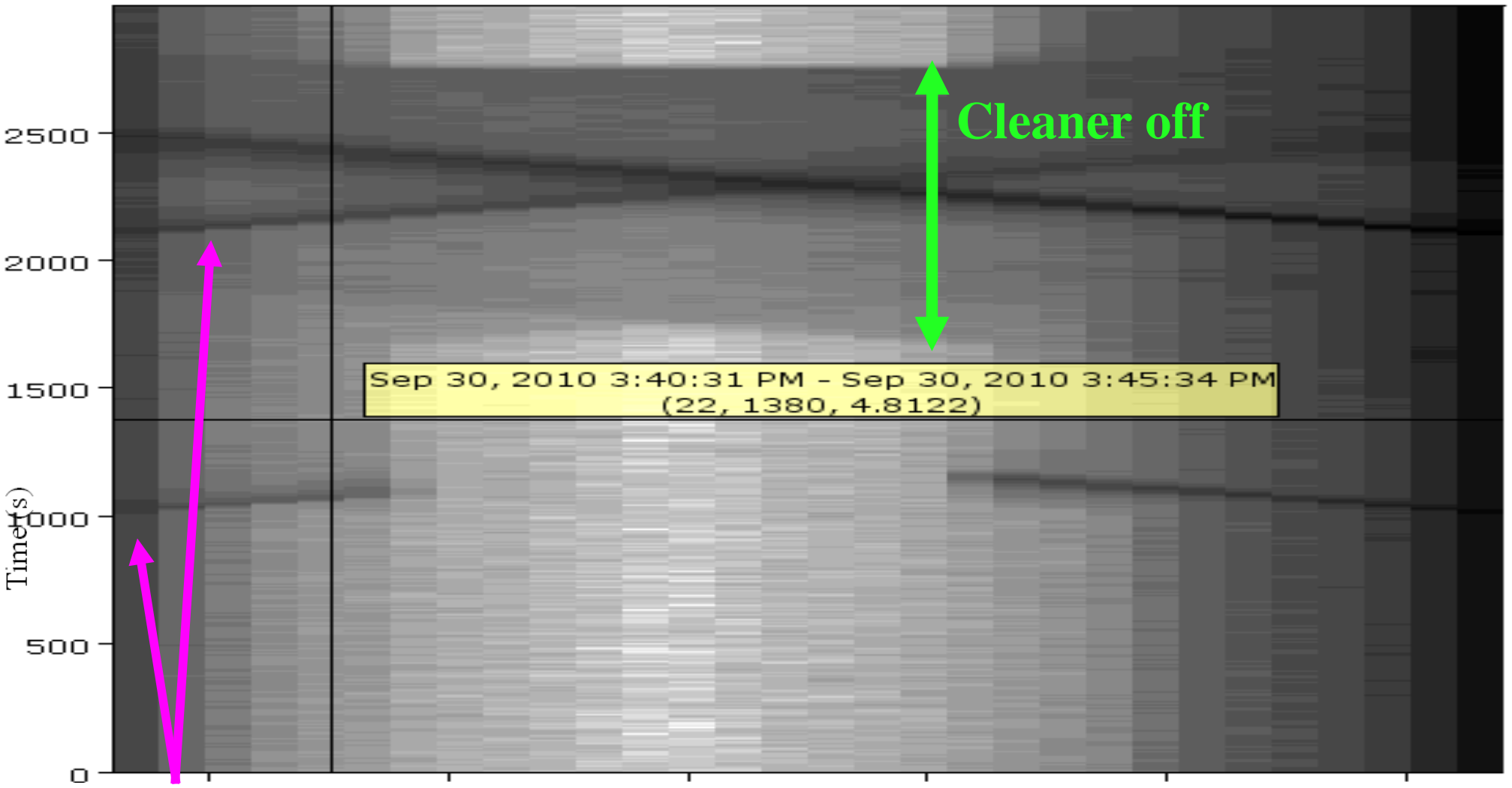




Courtesy of A. Fisher

Test of abort gap cleaning

2 bunches 3 μs apart (darker = more protons)



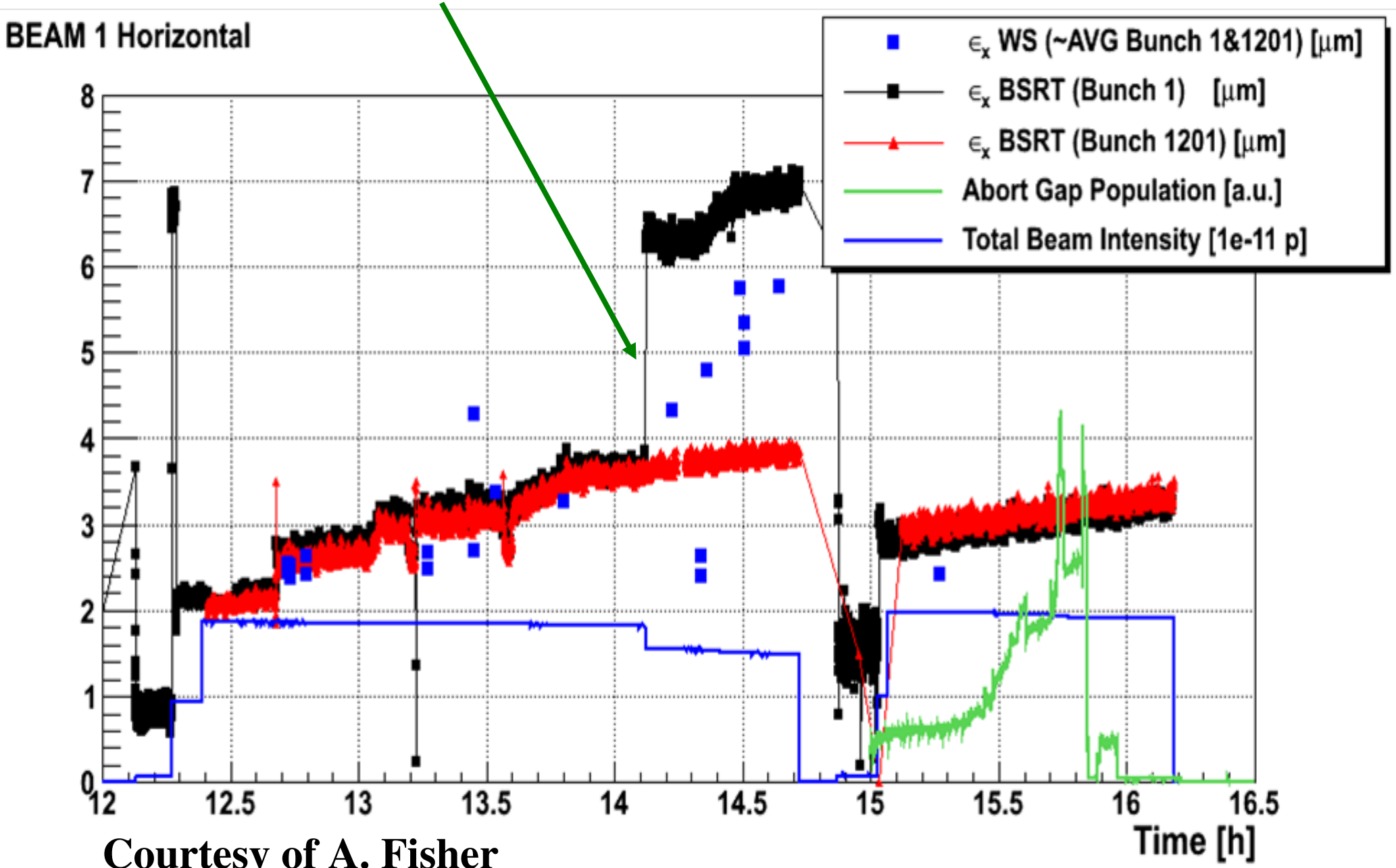
Courtesy of A. Fisher

RF voltage lowered

→ high / low momentum particles leak into the abort gap

Emittance growth during the cleaning

Wider cleaning pulse blew up bunch 1 (trailing edge effect?)



Courtesy of A. Fisher

Luminosity monitor

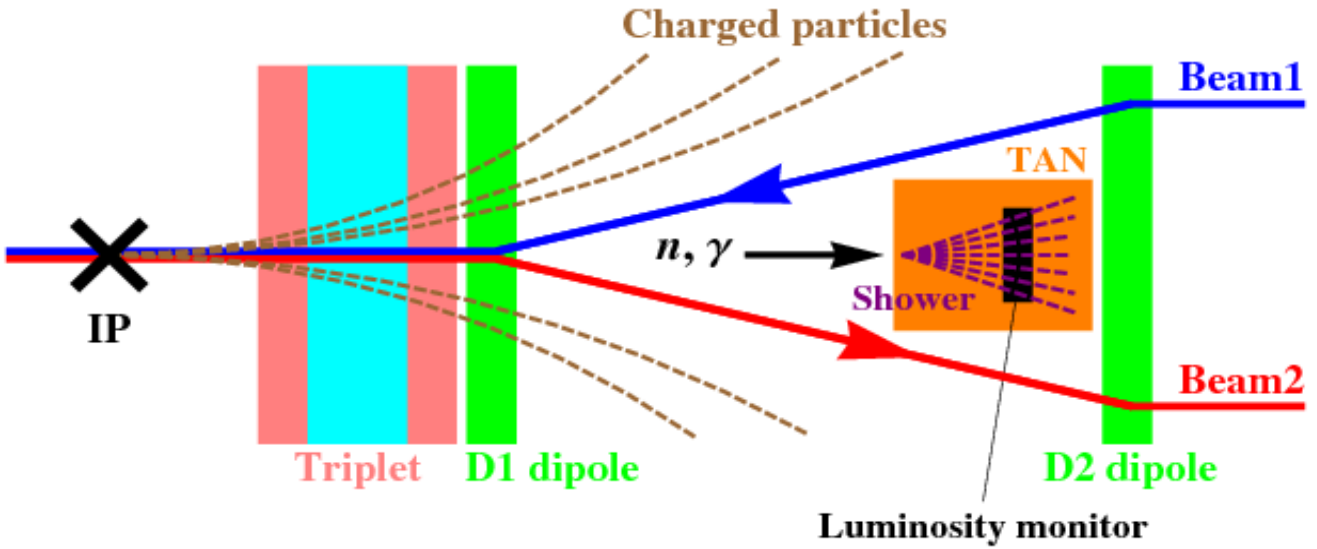
LHC luminosity monitor:

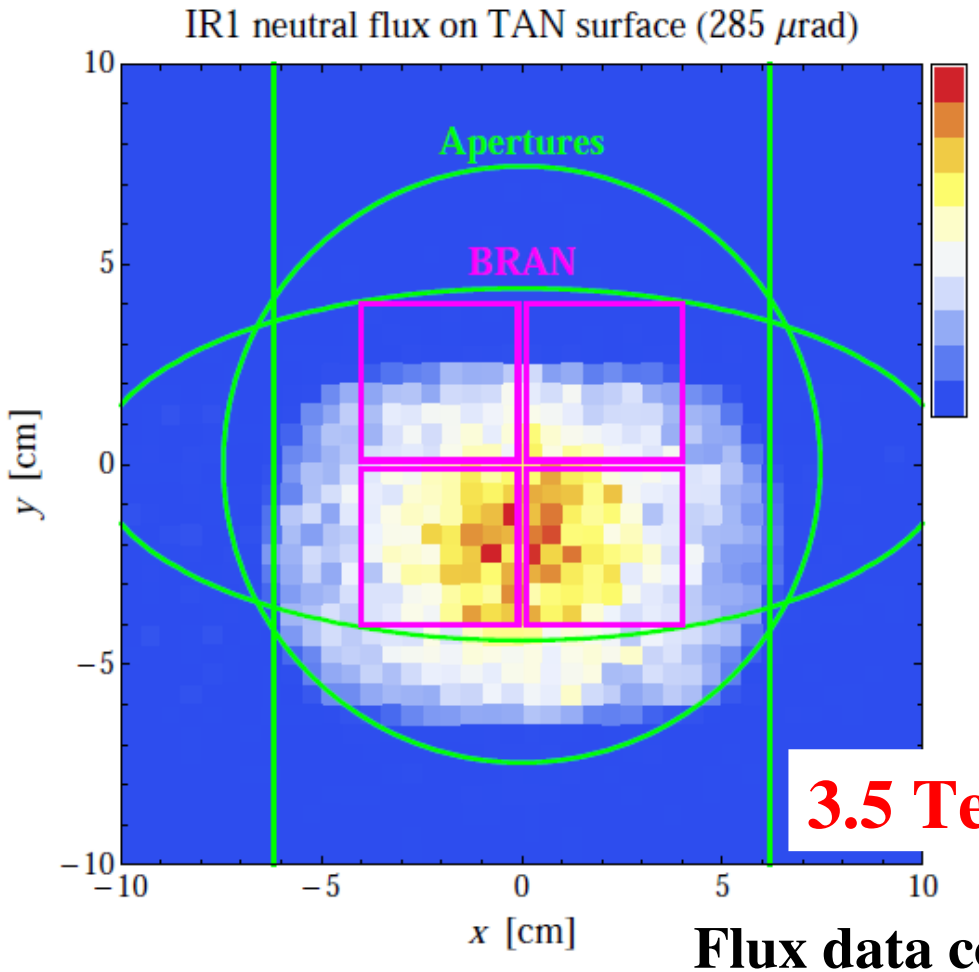
- 4 ionization chambers in both sides of IR1 and 5.
- **Bunch-by-bunch** measurements of neutral particles'
  - · Rate (low multiplicity)
  - · Average intensity (high multiplicity).
  - · Coincidence
- Quadrant structure → **sensitive to the crossing angle**.
- **Only forward monitor at high luminosities**.
- Detectors provided by LBL. Application provided by CERN.

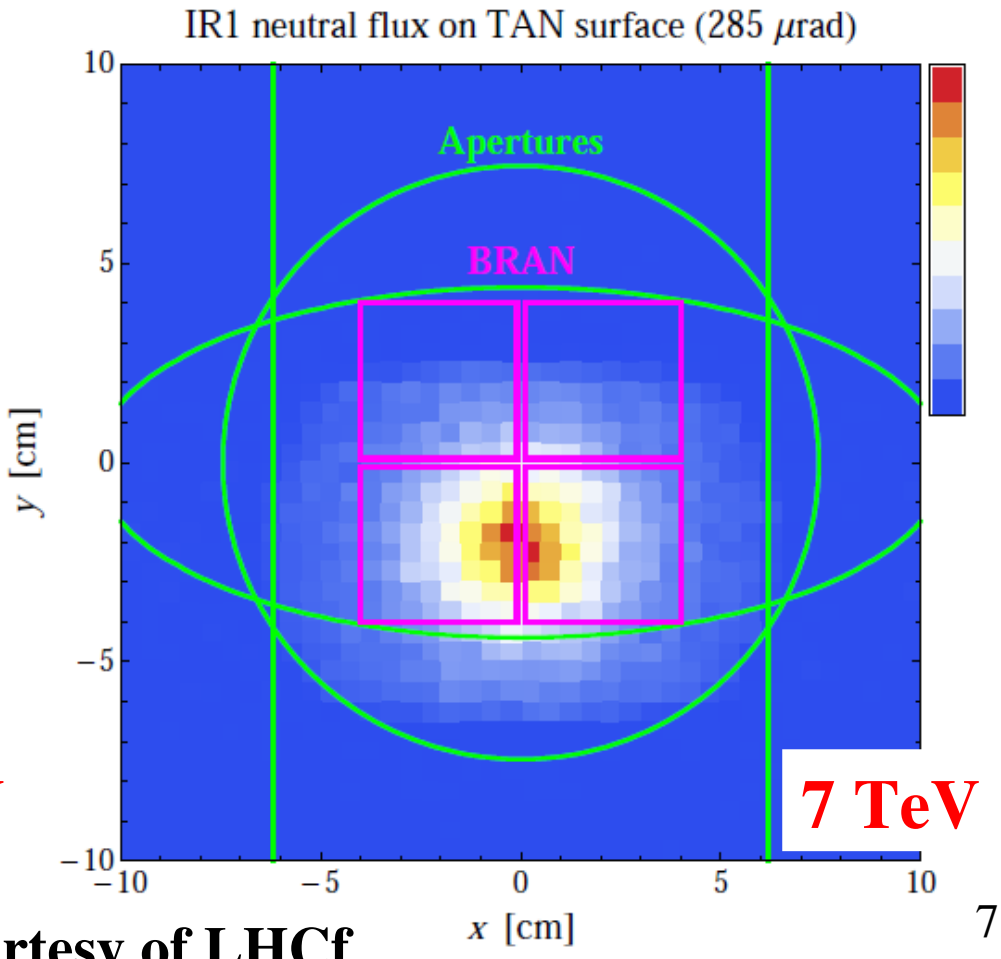
Status:

- All chambers installed and taking data.
- Minor issues (some in software, attenuation, …)
- Understand multiplicity important?
- Details in Alex's talk on Tuesday.

Lumi monitor concepts

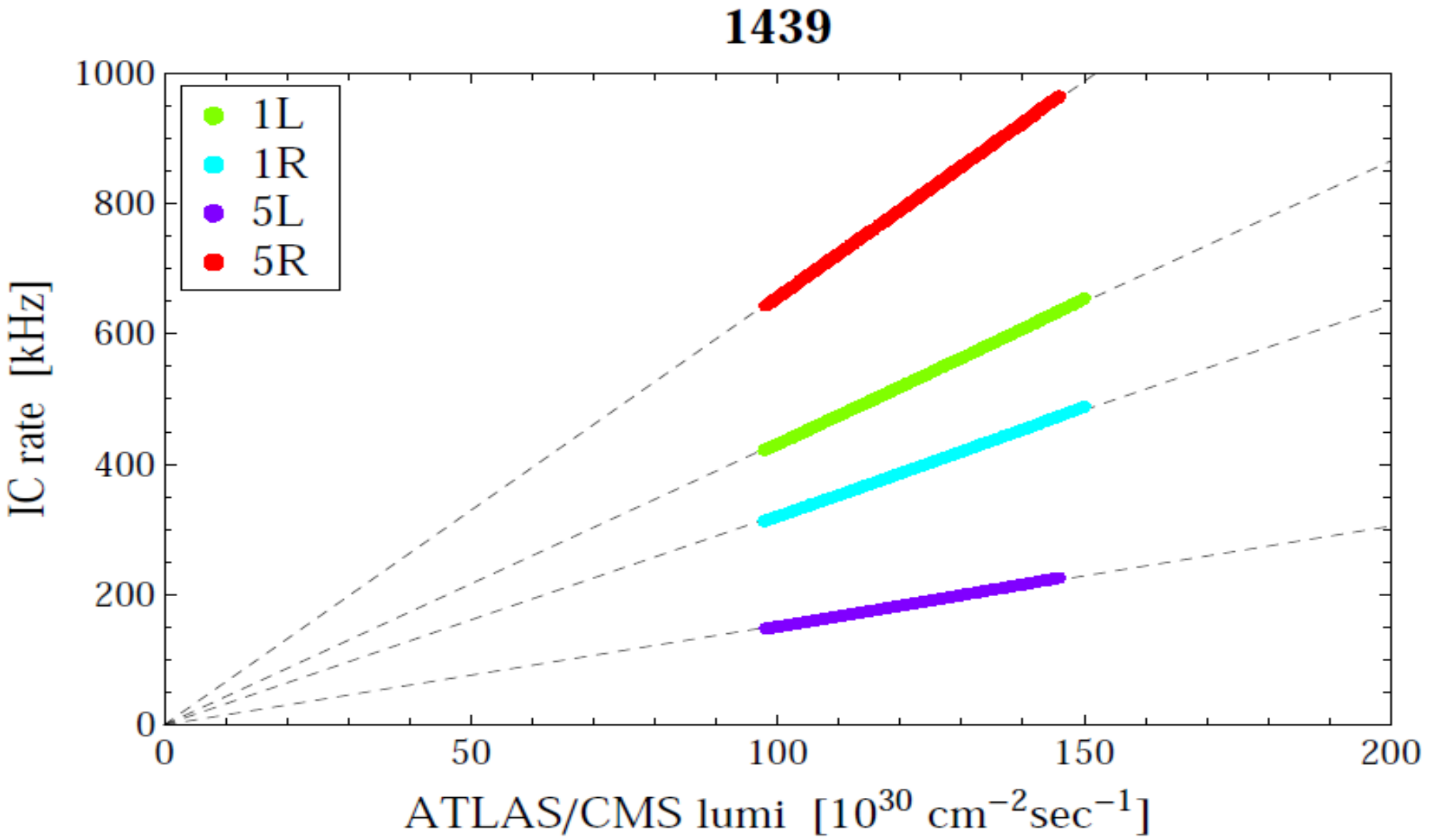






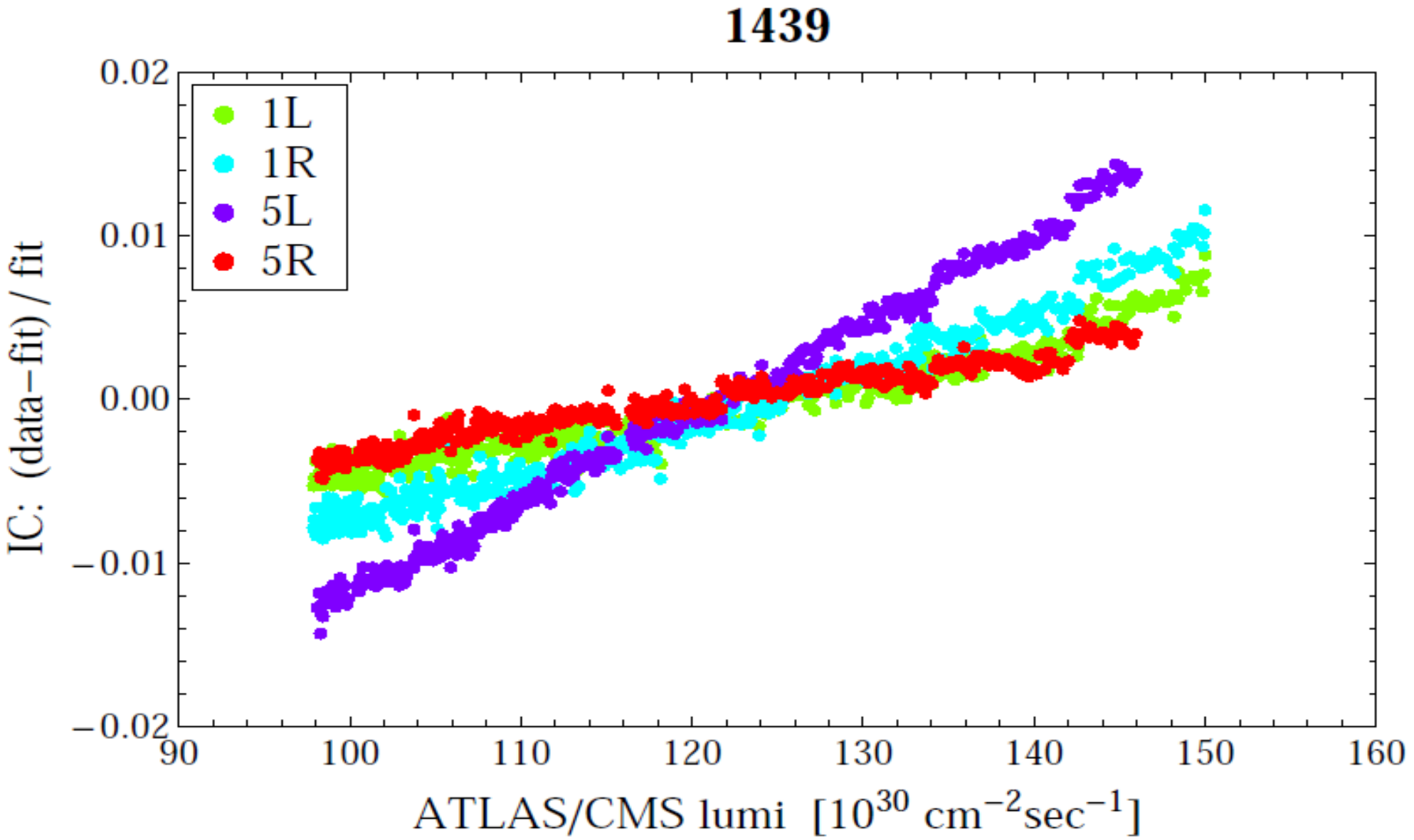
Flux data courtesy of LHCf

Correlations with experiments



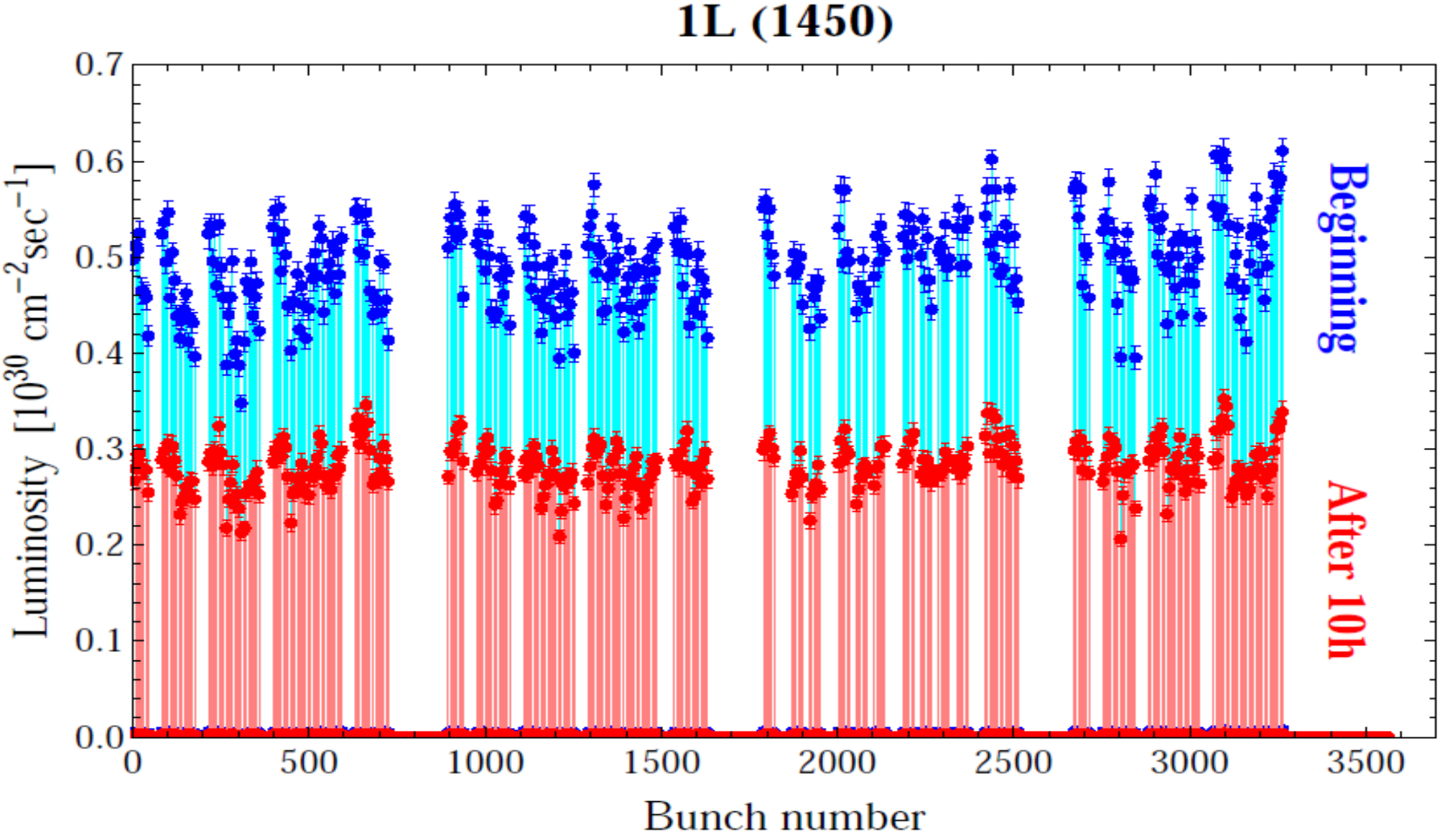
Assuming 60 mb: L ~ 10^32 → R ~ 6 MHz,
295 bunches → multiplicity ~ 1.8, efficiency 1.5-5% per *pp* col.

Multiplicity?



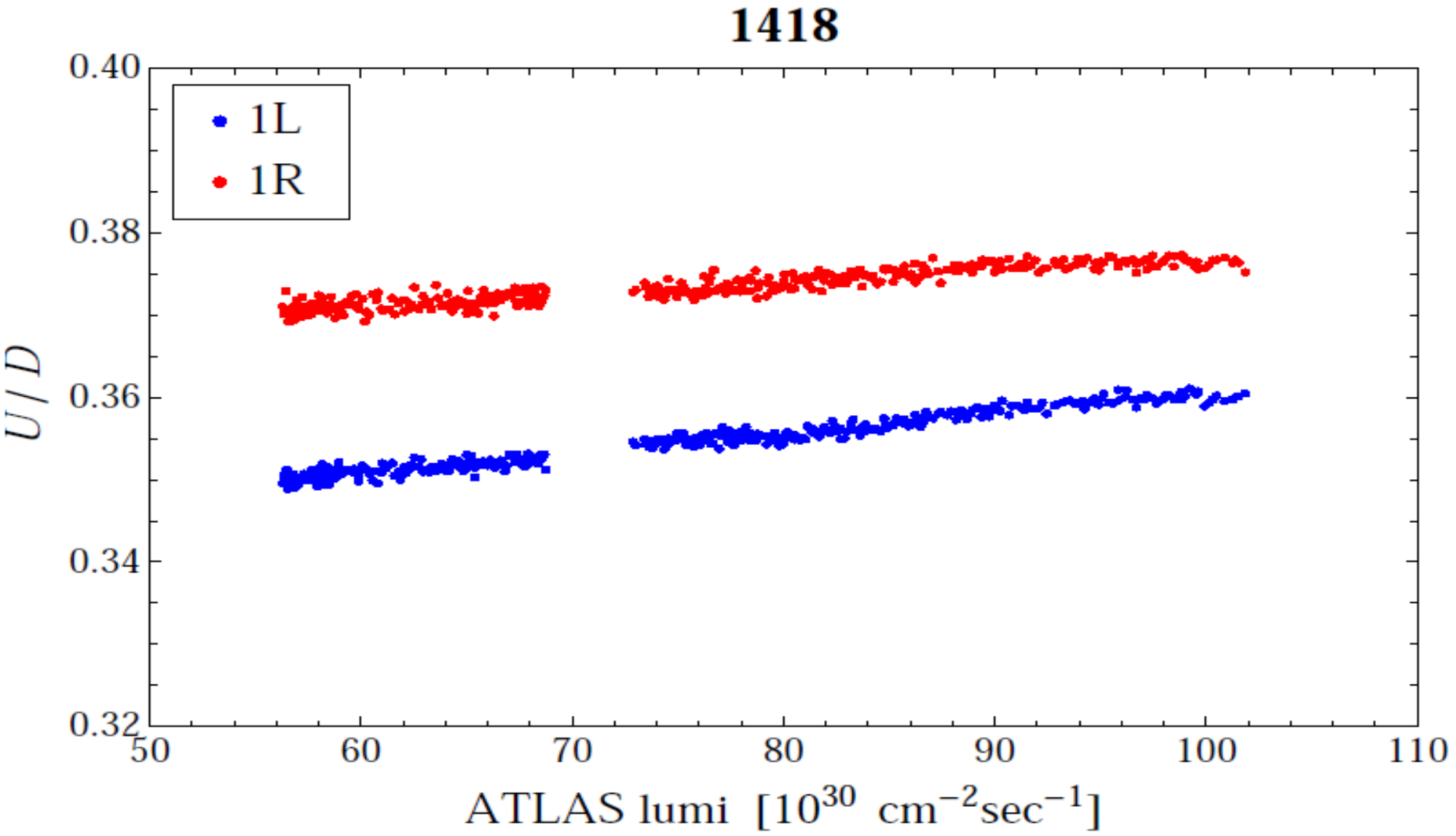
- **For low multiplicities, two competing effects on the rate .**
- **Deviations not quantitatively explained.**

Bunch-by-bunch measurement



- **Interesting to see correlations with intensities, emittances, …**
- **Data can be checked on live and easily accessed.**

Up-down asymmetry at IR1



- **Drift real? (Multiplicity?)**
- **Crossing angle scan possible?**

Schottky monitor

LHC 4.8 GHz schottky:

- **Non-invasive bunch-by-bunch** measurements of tune, chromaticity, *dp/p*, ...
- Inspired by success of the Tevatron's system.
- 4.8 GHz chosen for impedance and bandwidth.
- Led by FNAL, delivering the electronics and software (through LAFS). CERN built the beamline hardware.

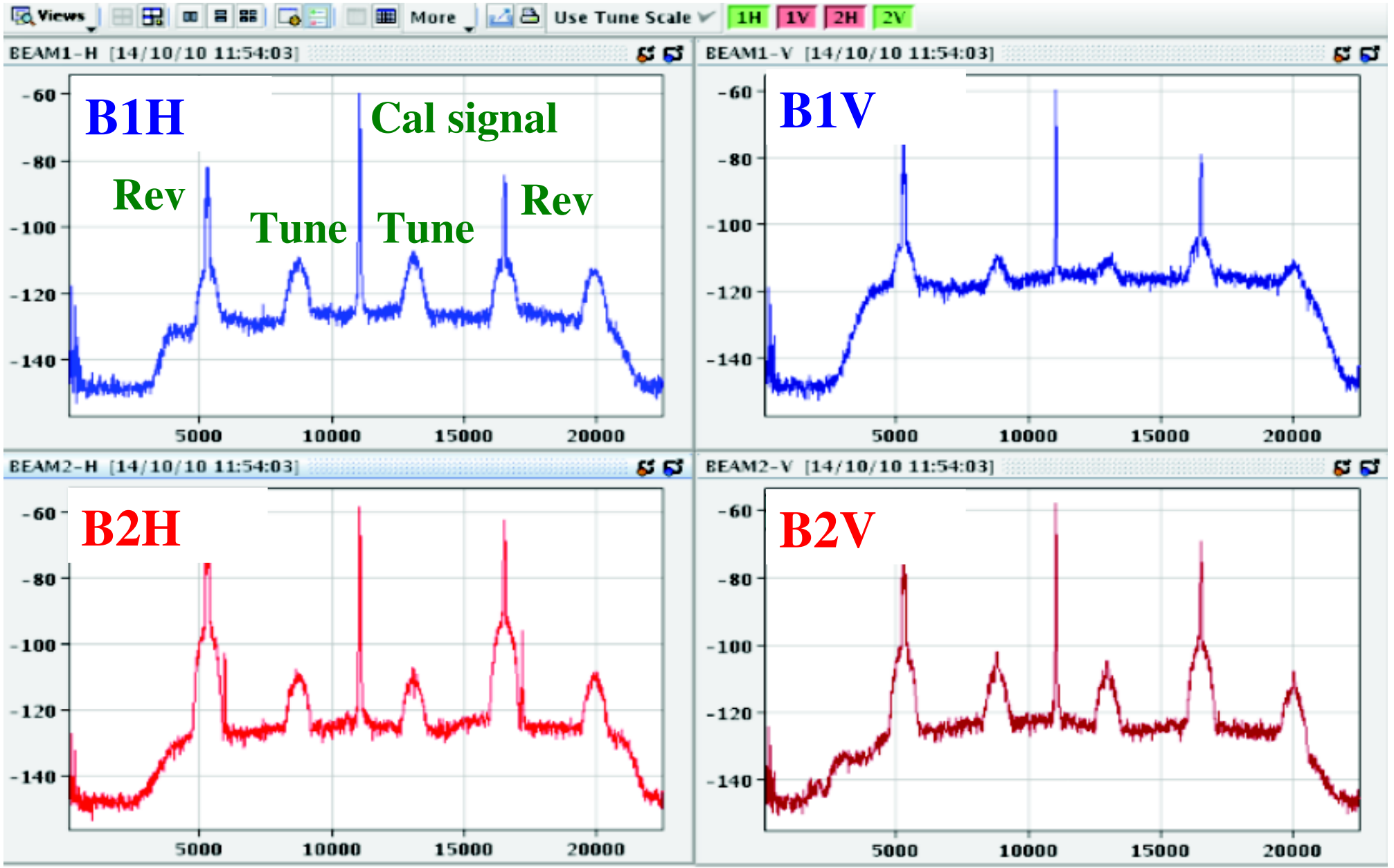
Status:

- Hardware completed in Oct. 2010.
- Application improvement ongoing at FNAL.
- A CERN fellow working on it.

From now:

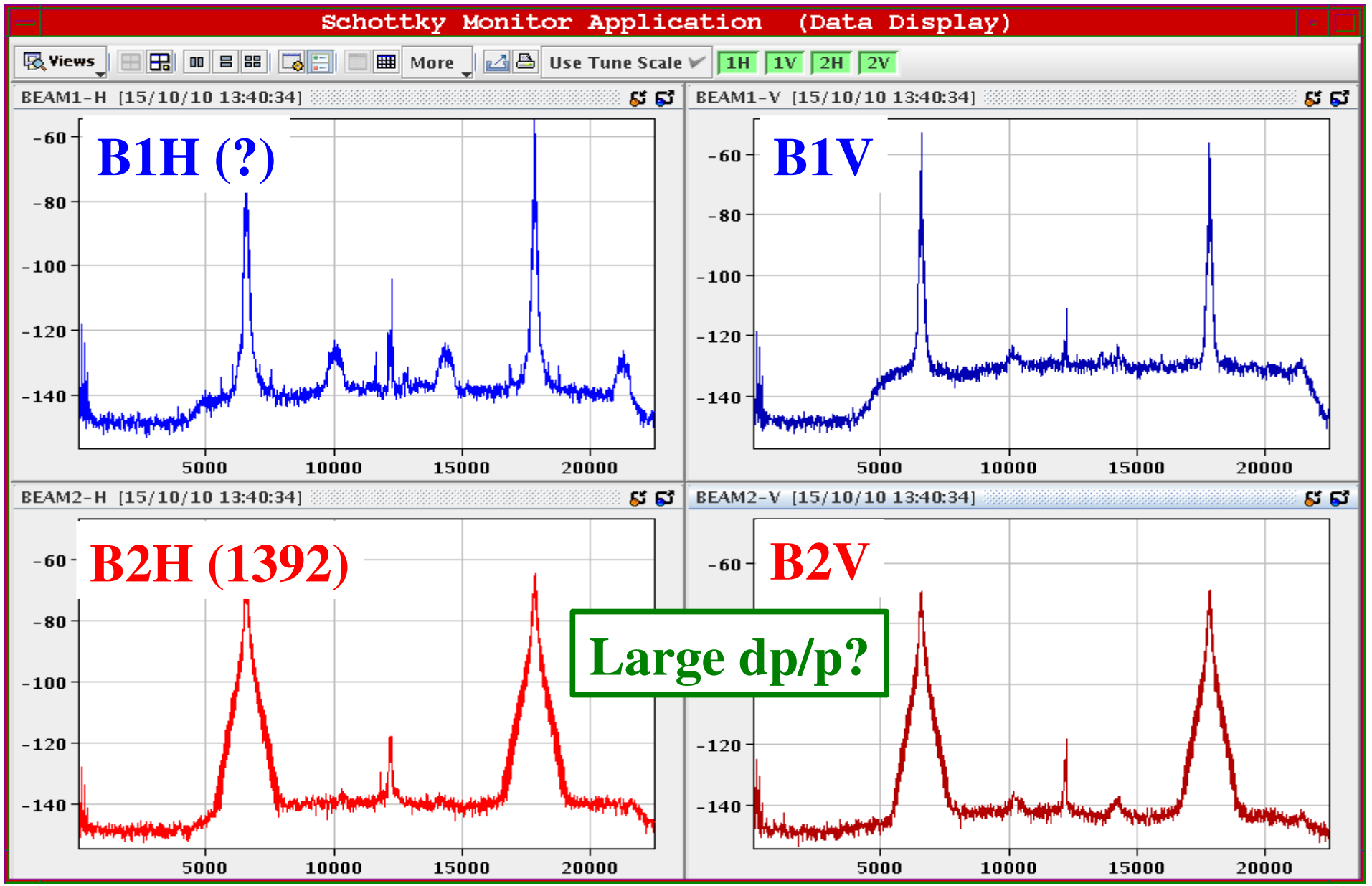
- Correlation with BBQ.
- Strong interest from beam-beam side.

Typical schottky signals



Courtesy of R. Pasquinelli

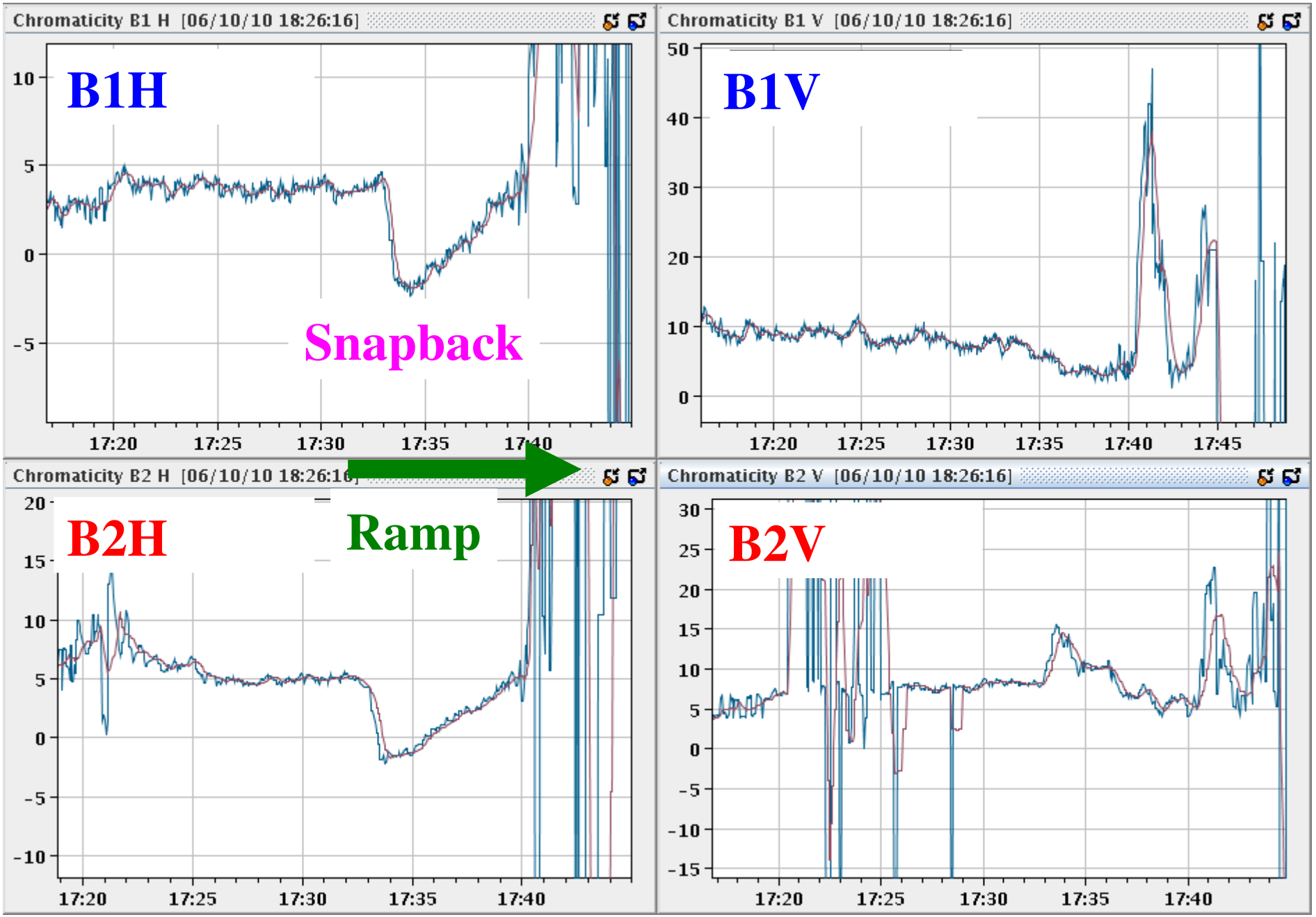
Another example (single bunch @ 3.5 TeV)



From LHC elog

Fat revolution lines observed only for one bunch of Beam2

Chromaticity measurement



From LHC elog

Conclusions

- LARP delivered and contributed to many instruments that are at the core of LHC's beam commissioning and operation: BBQ, AC dipole, synchrotron light monitor, luminosity Monitor and schottky monitor.
- Many made contributions from the early stage of the commissioning and all are operational now.
- Instruments are now handed over to CERN while LARP continues to support their development.
- LHC will have bunch-by-bunch measurements of luminosity, profile, tune, and intensity. Such information is vital in the next year's commissioning / operation.
- LARP instruments are an excellent opportunity to participate in the LHC's commissioning, operation, and development.