LARP

BNL - FNAL - LBNL - SLAC

LARP BEAM INSTRUMENTATION

A. Ratti (LBNL)

Presented at the DoE review of LARP

Fermilab

Jun. 1-2, 2011

Outline

Overview of LARP instrumentation

Experience from beam commissioning – Hardware updates

- Sync Light Monitor

Beam Operations

- AC Dipole – Optics measurements
- Schottky – Beam Beam
- Lumi – IP optimization

LTV/Toohig Impact

LARP

Advancing Accelerator Technology

Major contributions to the field:

Benefiting the LHC and US colliders

- The AC dipole concept came from LARPs collaborations

  now installed in all three hadron colliders

- The luminosity Monitor is designed to survive a level of radiation 100x larger than ever seen before
- Synch light monitoring on proton storage ring – world first – from PEPII experience to light from Pb ions!
- Tune and Coupling feedback is a world first, accomplished in RHIC
- The LHC Schottky monitor lead to the upgrade of the Tevatron system

Graduate students and post-docs actively involved

- 1 PhD on AC Dipole, then Toohig fellow
- 1 Graduate student in Lumi
- Several student projects in Lumi
  - Best project award at Sep 2009 APS-CA meeting

Evolution with LHC commissioning

2008-9

- Presented hardware commissioning results
- Preparing for beam commissioning

2010

- Beam commissioning results from all instruments

Now

- All instruments operational
- Developing control room applications

Impact on LHC Commissioning

LARP's instruments continue to play a very important and visible role:

- AC Dipole
  - Due to the LHC's slow cycle (~1 hr for ramp up, ramp down, squeeze, precycle…), the AC dipole (non destructive) is **<u>the only probe to beam optics above injection</u>** energy
  - ***β*-beating and local coupling** have been measured and corrected for *β*-squeeze with the AC dipole
- Synchrotron light monitors
  - Actively the main **abort gap monitor**
- Schottky monitors
  - Increasing presence: beam-beam, chromaticity measurements
- Luminosity monitors
  - Now the only instrument to measure collision rate to **optimize IP**
- Tune tracker
  - Essential element during the **ramps**

Synchrotron-Light Monitors

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Two applications:

- BSRT: Imaging telescope, for transverse beam profiles
- BSRA: Abort-gap monitor, to verify that the gap is empty
  - When the kicker fires, particles in the gap get a partial kick and might cause a quench.

Two particle types:

- Protons and lead ions

Three light sources:

- Undulator radiation at injection (0.45 to 1.2 TeV)
- Dipole edge radiation at intermediate energy (1.2 to 3 TeV)
- Central dipole radiation at collision energy (3 to 7 TeV)
- Spectrum and focus change during ramp

Sync Light Monitor

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November-December 2010: First run with lead ions

- Synchrotron light images from **lead**

November: Duplicate optical table set up in lab

- Detailed study of imaging

January 2011: Shutdown work in the tunnel

- New “slow” camera with a 25-ns gate, intensifier for “fast” camera
- Camera translation stage added for precise focus
- Thorough check and adjustment of component positions and alignment
- Longitudinal density monitors

March-May: Measurements with beam

- Bunch-by-bunch beam size
- Longitudinal structure

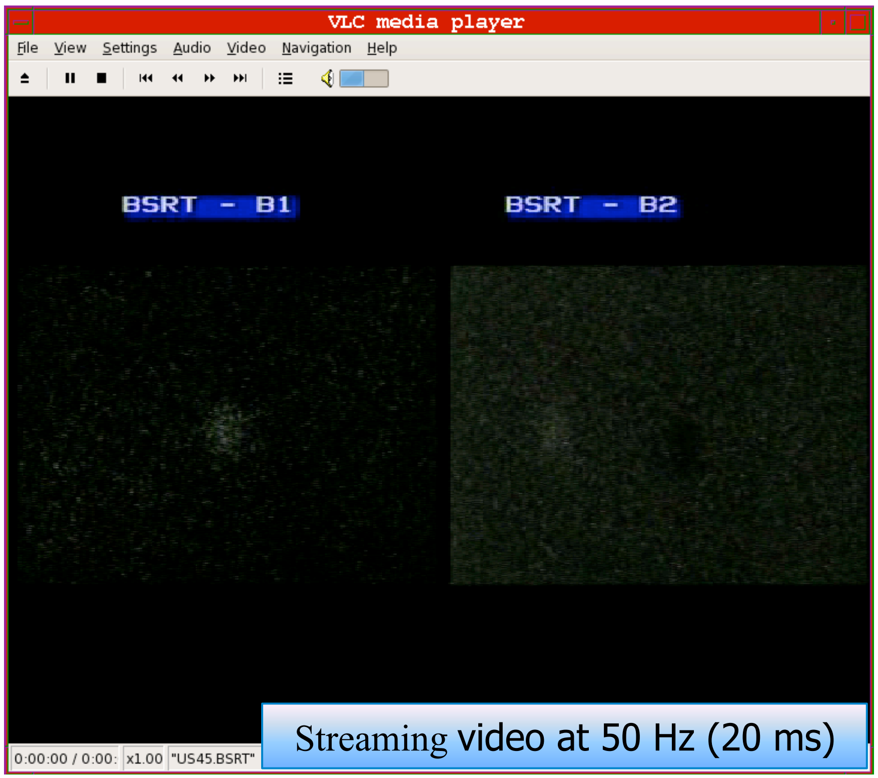
Summer: Testing upgrade ideas at SLAC (SPEAR3 ring)

- Halo monitor and rotating mask

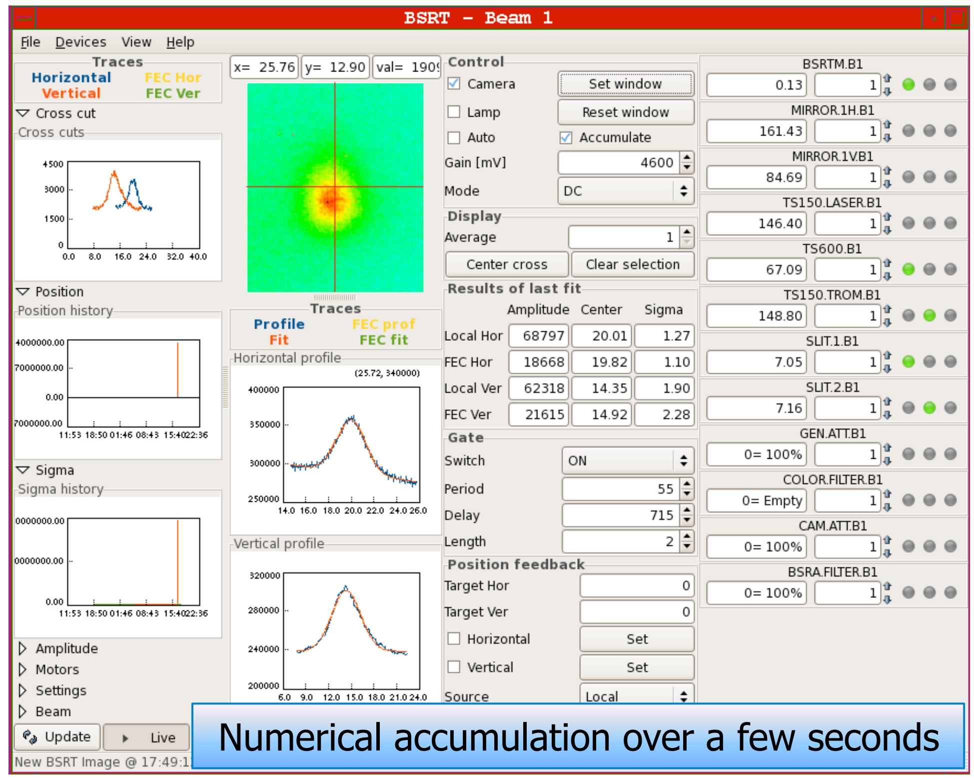
A. Fisher

First Images of Lead Ions at Injection

- 2010 Nov 10: Light from 17 bunches, integrated over 20 ms
- Images are faint, since most emission is infrared at this energy
  - Original prediction: 1-s integration needed for a clear image of a single bunch
    - Equivalent to 20-ms integration of 50 bunches
    - 1-s integration directly on the CCD would require only an additional logic pulse



Streaming video at 50 Hz (20 ms)



Numerical accumulation over a few seconds

Calibration vs Wire Scanners

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Wire Scanners (WS)

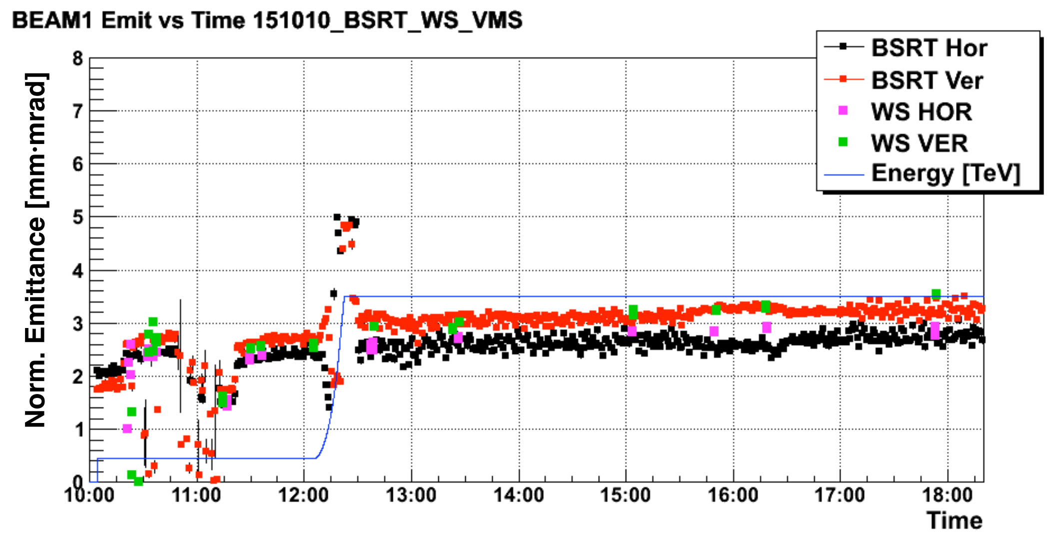
- Reference for LHC transverse profile measurements
- Can be used with just over 10^{13} protons without causing wire damage or a quench

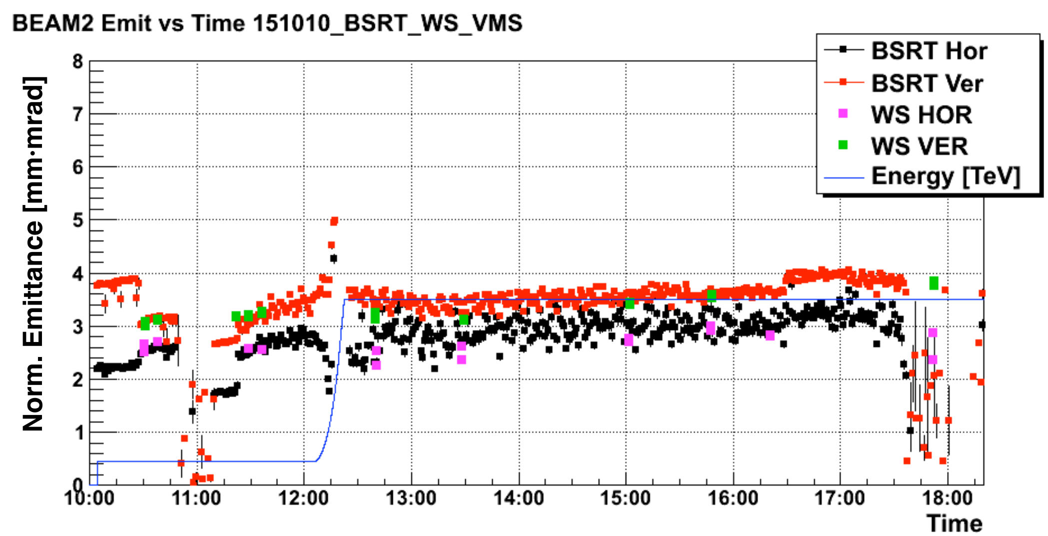
BSRTS calibration vs WS

- Measured for each beam and plane, as a function of energy
- Corrections applied in quadrature to BSRT beam-size data

Corrections of 400–500 μm

- Possible sources: camera, digitizer, slit adjustment, diffraction

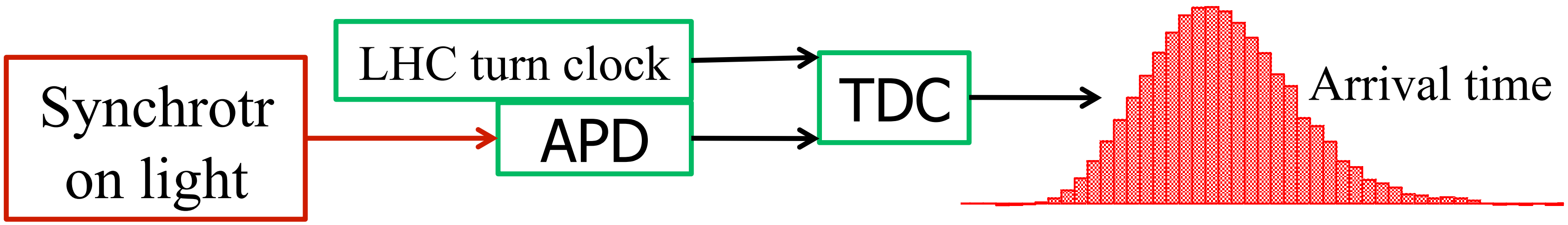




Longitudinal-Density Monitor

Monitor built by Adam Jeff (CERN)

- Photon counting using an avalanche photodiode (APD)
- 1% of the BSRT's synchrotron light
- Histogram of time from turn clock to APD pulse, with 50-ps bins
- Now installed on both beams



Modes:

- Fast mode: 1-ms accumulation, for bunch length, shape, and density
  - Requires corrections for photon pile-up, APD deadtime and afterpulsing
- Slow mode: 10-s accumulation, for tails and ghost bunches down to 5×10^{5} protons (4×10^{-6} of a nominal full bunch)
  - Only 1 photon every 200 turns

LDM Measurement

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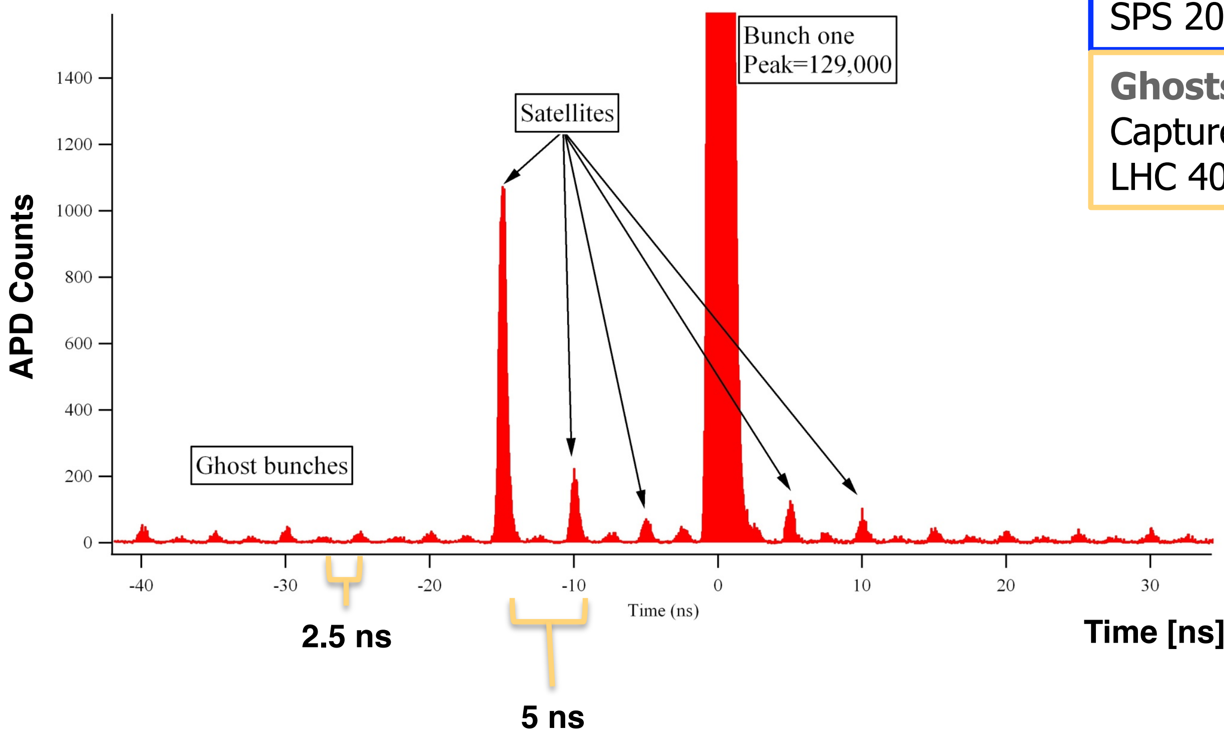
Ions with 10-min integration



Satellites
Capture/splitting errors in the injectors
SPS 200 MHz → 5 ns

Ghosts
Capture/splitting errors in the LHC
LHC 400 MHz → 2.5 ns

LDM is the only LHC system able to see all structures from RF, with enough **dynamic range** and **time resolution** for monitoring satellites and ghosts

Beam-Halo Monitor

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- Halo monitoring was part of the original specification for the synchrotron-light monitor.
  - LARP’s involvement in both light monitors and collimation makes this a natural extension to the SLM project.
- But the coronagraph needs some changes:
  - The Sun has a constant diameter and a sharp edge.
  - The beam has a varying diameter and a profile that is roughly Gaussian
- An adjustable mask is needed. Two approaches:
  - A Digital Micro Mirror Array
  - Rotating Mask
- Tests of possible upgrades will begin this summer on SLAC’s SPEAR-3 ring.

Schottky – Operation with Beam

- Capabilities and Commissioning
  - Non invasive measurements
  - Bunch by bunch transverse measurements
  - Measures single bunch with 10^{11} protons/bunch
  - Verified tunes track with other tune measurements
  - Chromaticities and Momentum spread measured
  - Signal tracking for ramped beam measurements

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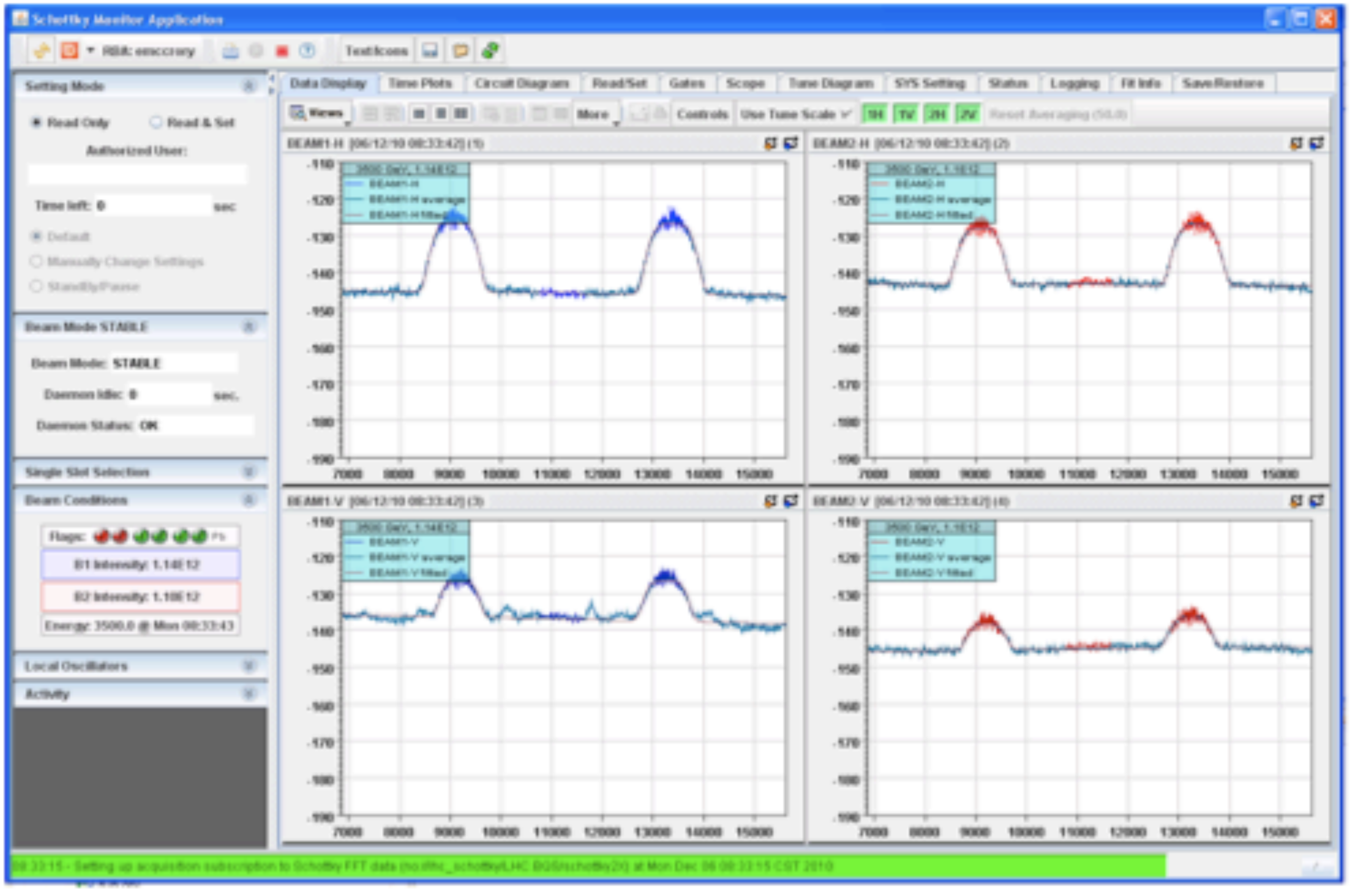
Schottky – Pb Ions Signals

Lead Ions 1.1×10^{12} at 3.5 TeV



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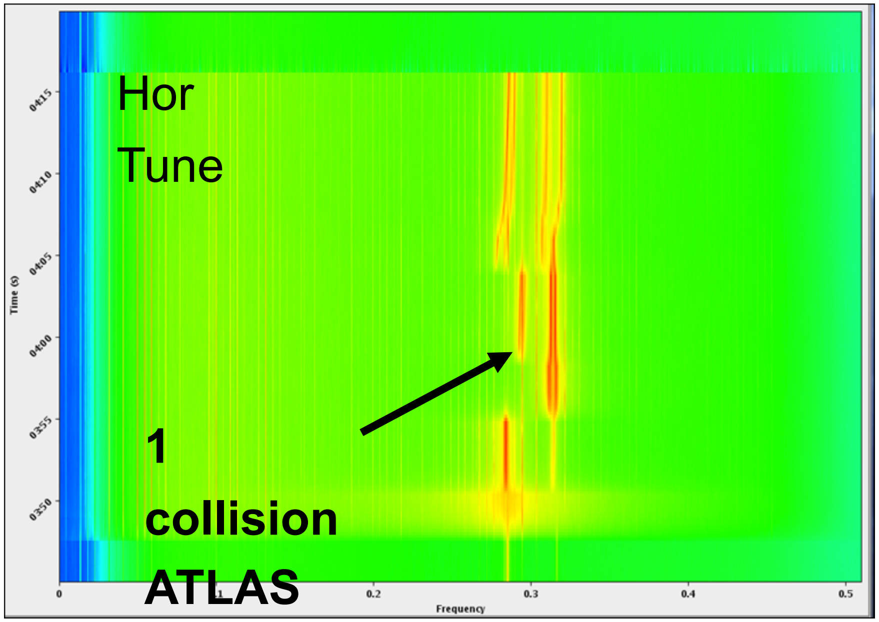
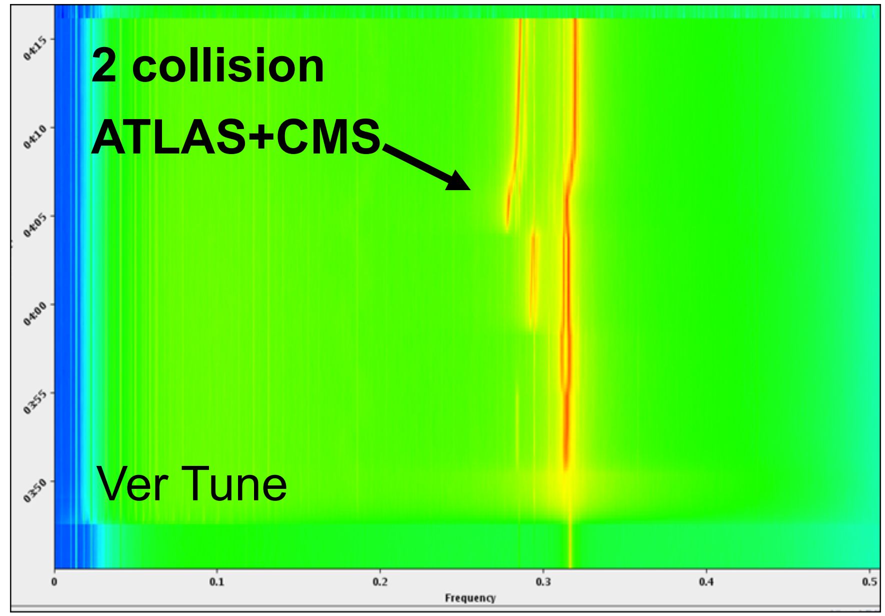
Beam-beam experiment - BBQ

BBQ Signals





Bunch intensities: ~1.9×10^{11}

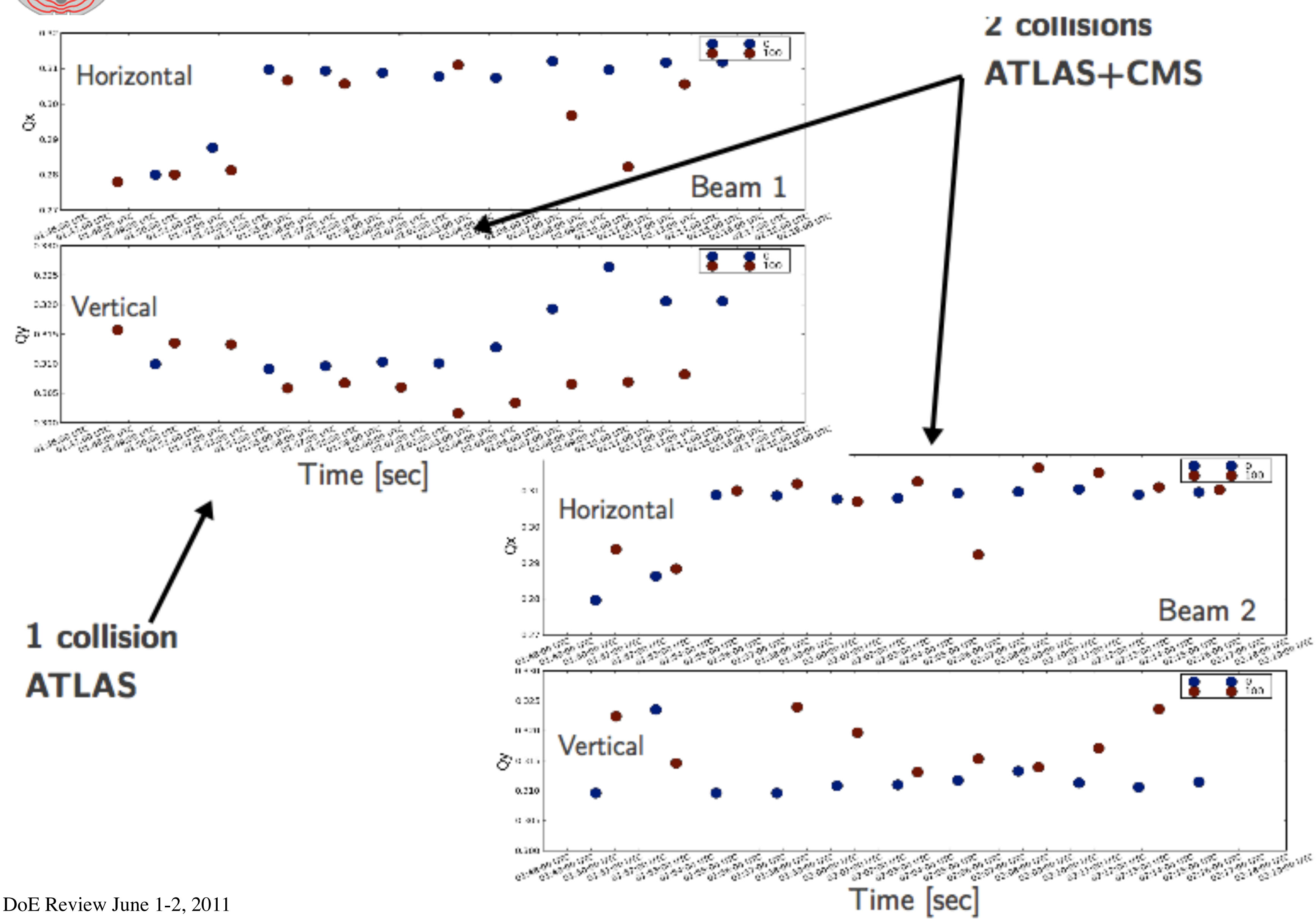
Emittances (x,y): ~1.3mm

Beam-beam tune shift > 0.015/IP

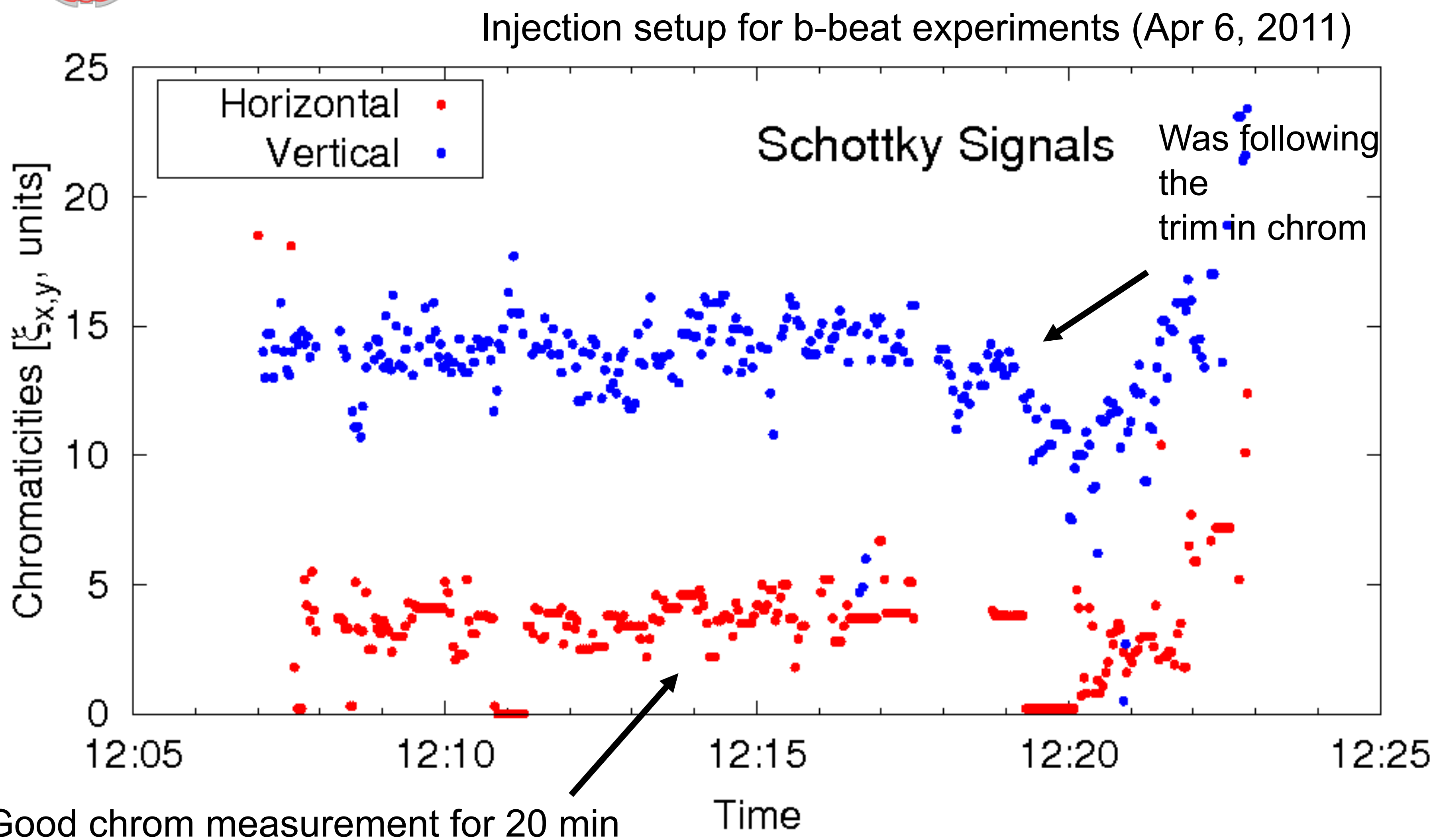
Schottky signal noisy

W. Herr et al.

Schottky Beam Beam Effects measurement



Chromaticity – Pilot Bunch



Good chrom measurement for 20 min

Confirmed by classical radial modulation (horizontal, Beam 2)

Schottky - Status

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Powerful & non-invasive tool

- **System**: Hardware operational
  - Excellent quality for ions (for protons → RF noise & coherent oscillations)
  - Still needs manual input
  - Never all signals (B1/B2, H/V, Intensities diff)

- **Application**: Significant improvements/tools in 2011
  - Continuous monitoring of bunches & trains (Q, Q'...)

Future Plans

- Improve signals reliability (injection/top energy)
- Reduce Expert adjustment → leading to <u>operational</u> tool (like BBQ)

R. Calaga – T. Pieloni

Lumi Status

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As LHC luminosity improves, so do the demands on the lumi monitor system

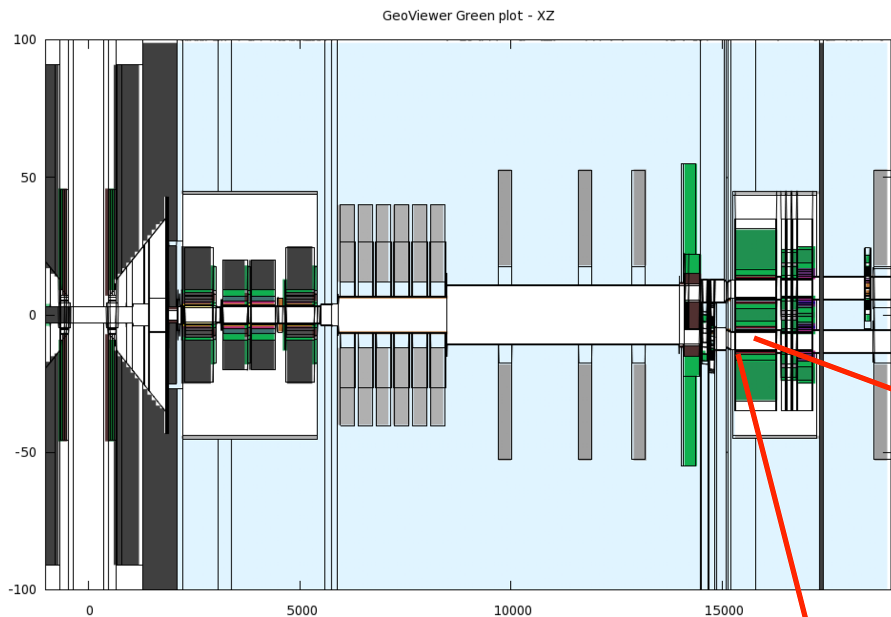
R. Miyamoto supporting LHC operations locally

- Numerous improvements and system tests
- Moving from counting to pulse height mode

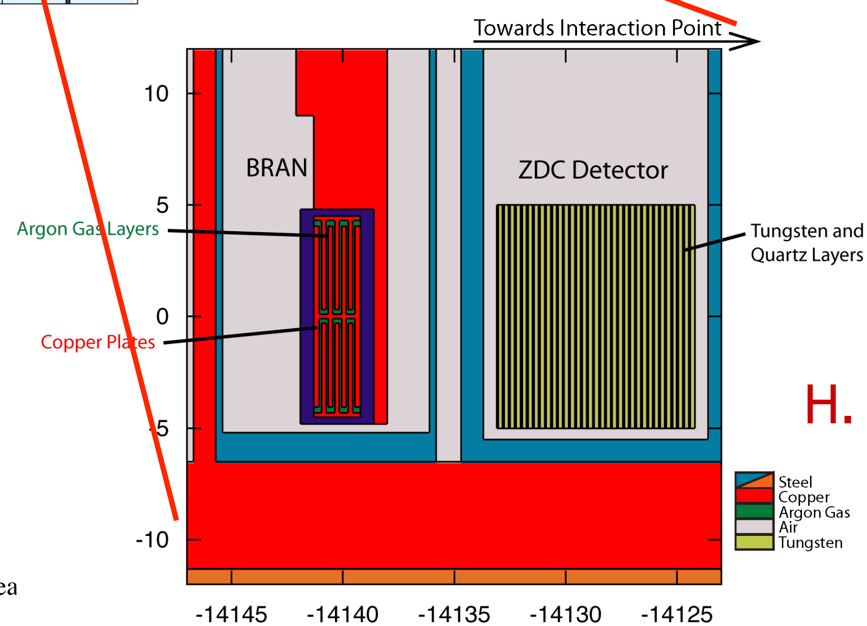
FLUKA model in support of data analysis

Developing operator panel for CCC

FLUKA model of IP



IP model developed at CERN



H. Matis

BRAN model previously developed at LBL

Recent Model Improvements

- Imported the Fluka geometry of IP1
  - Developed at CERN (ATS-note-2010-046)
  - Models from IP to past the TAN
- Fluka 2011 released
  - Simulates collisions
  - Specification of:
    - Ion species
    - Beam parameters (Crossing angle, momentum spread, beam size)
  - Can do arbitrary energy
    - Easily match LHC operating energy
  - Compare pp results with PbPb
    - Excellent tool for understand performance of BRAN and IP
- IP model and Fluka 2011 fully operational at LBNL

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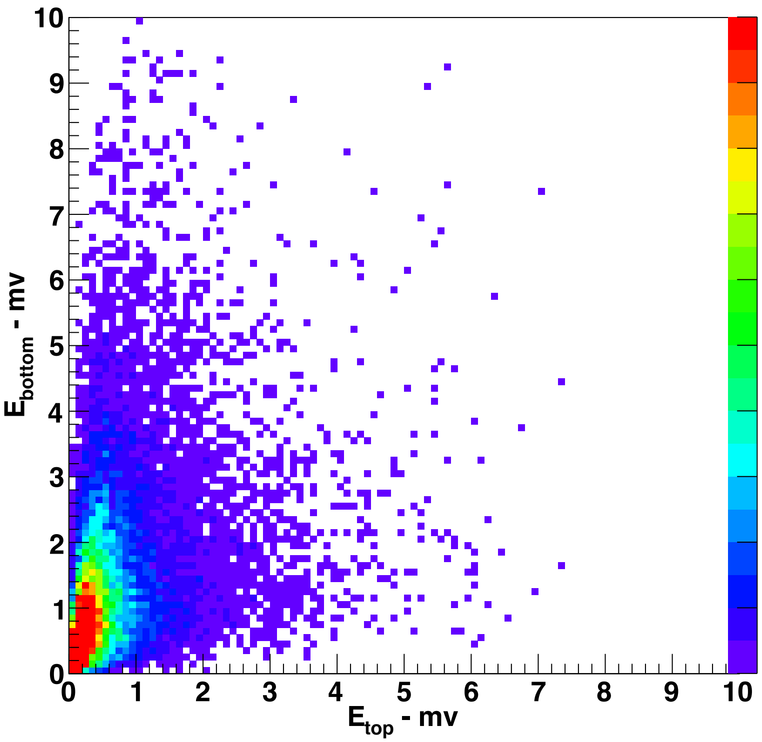
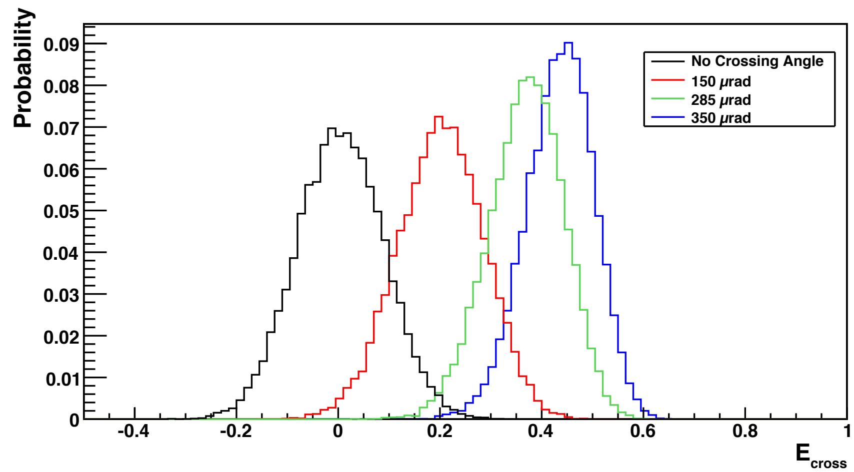
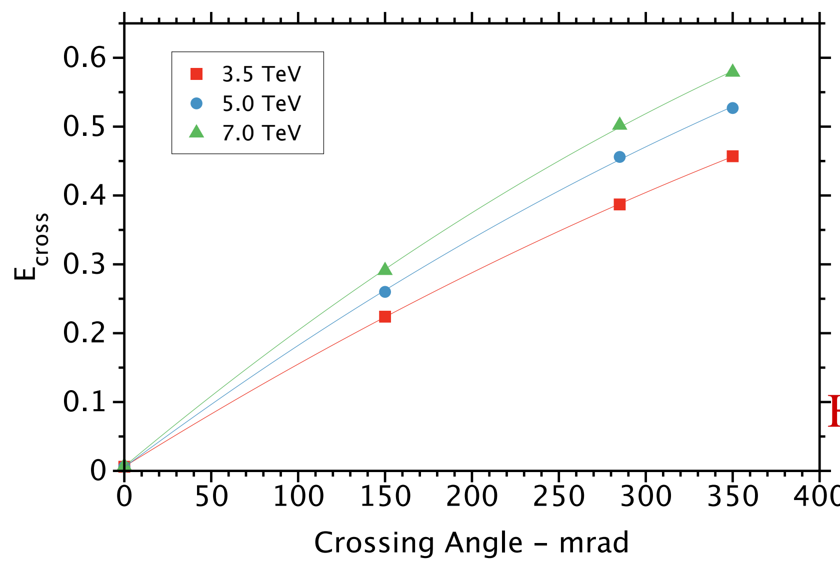
Crossing Angle Modeled in FLUKA

Can measure crossing angle by calculating differences between detector quadrants







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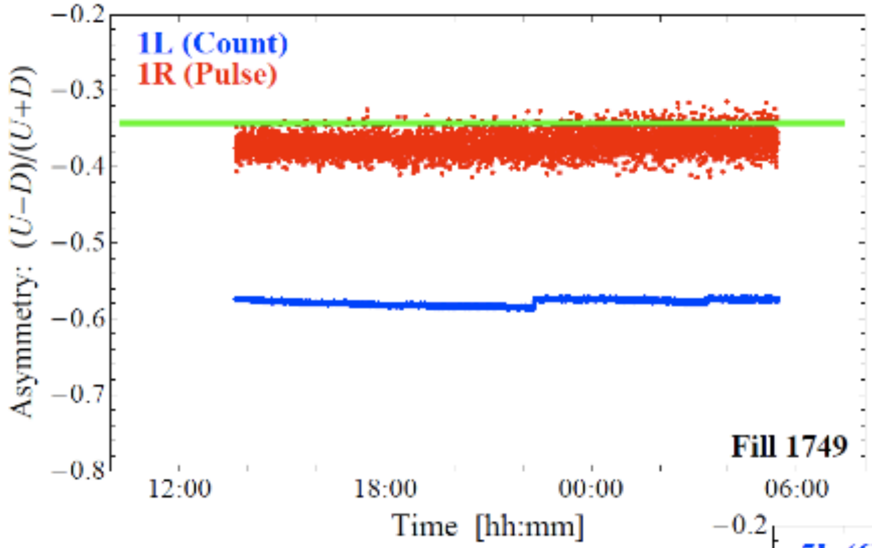
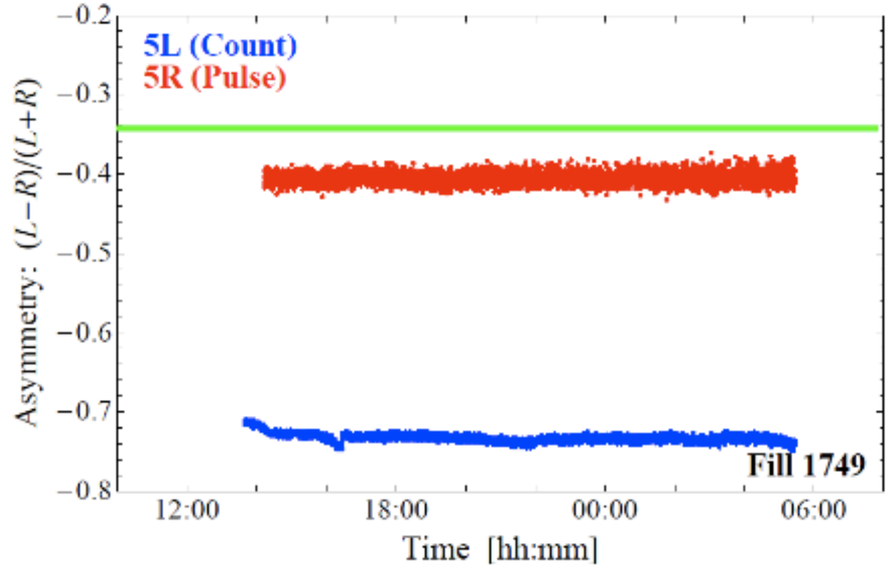
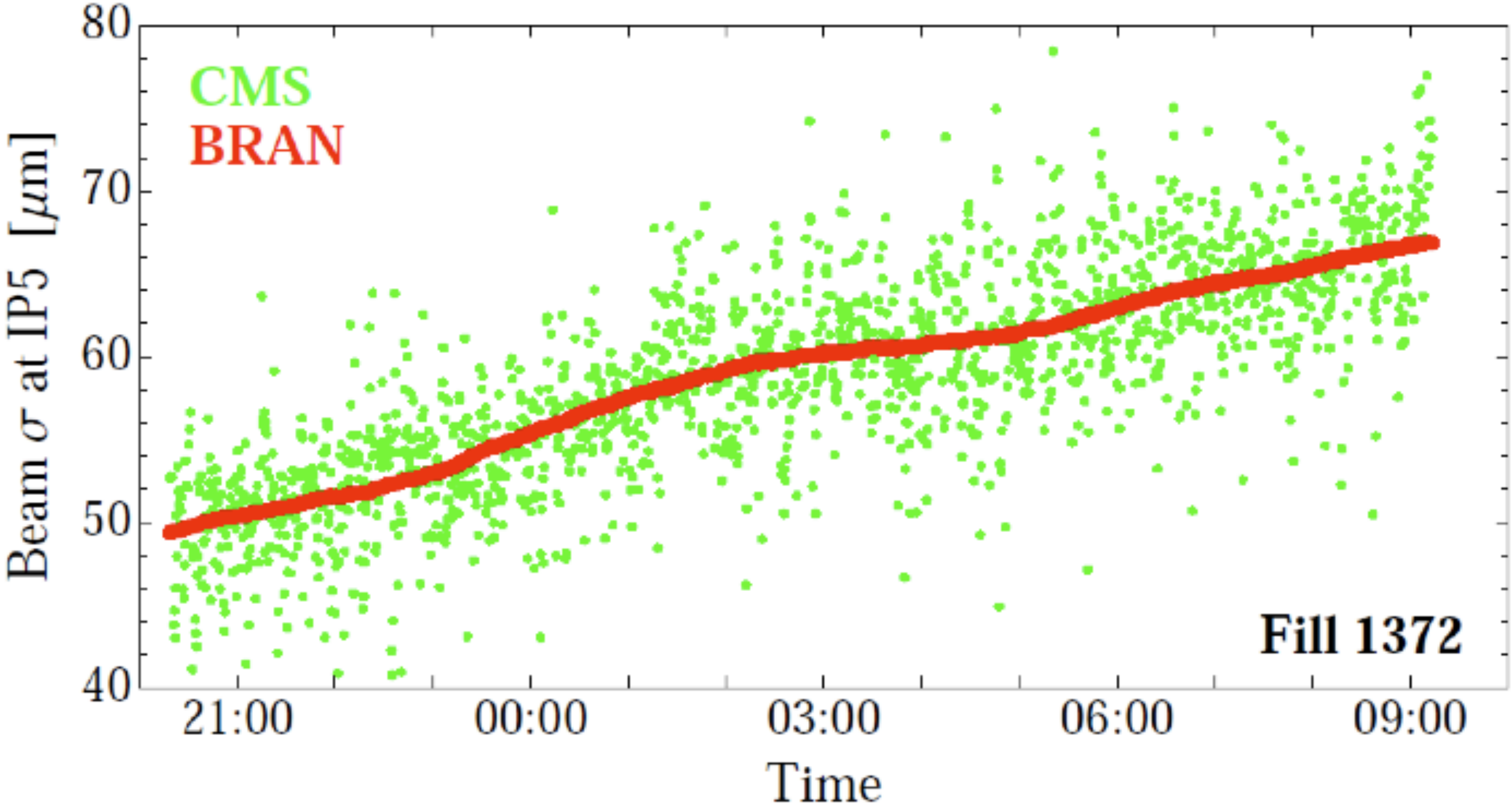
Crossing Angle Measured



- We must use the pulse height for crossing angle measurements.
- Sensitive to the calibration. Calibration adjustment ongoing.

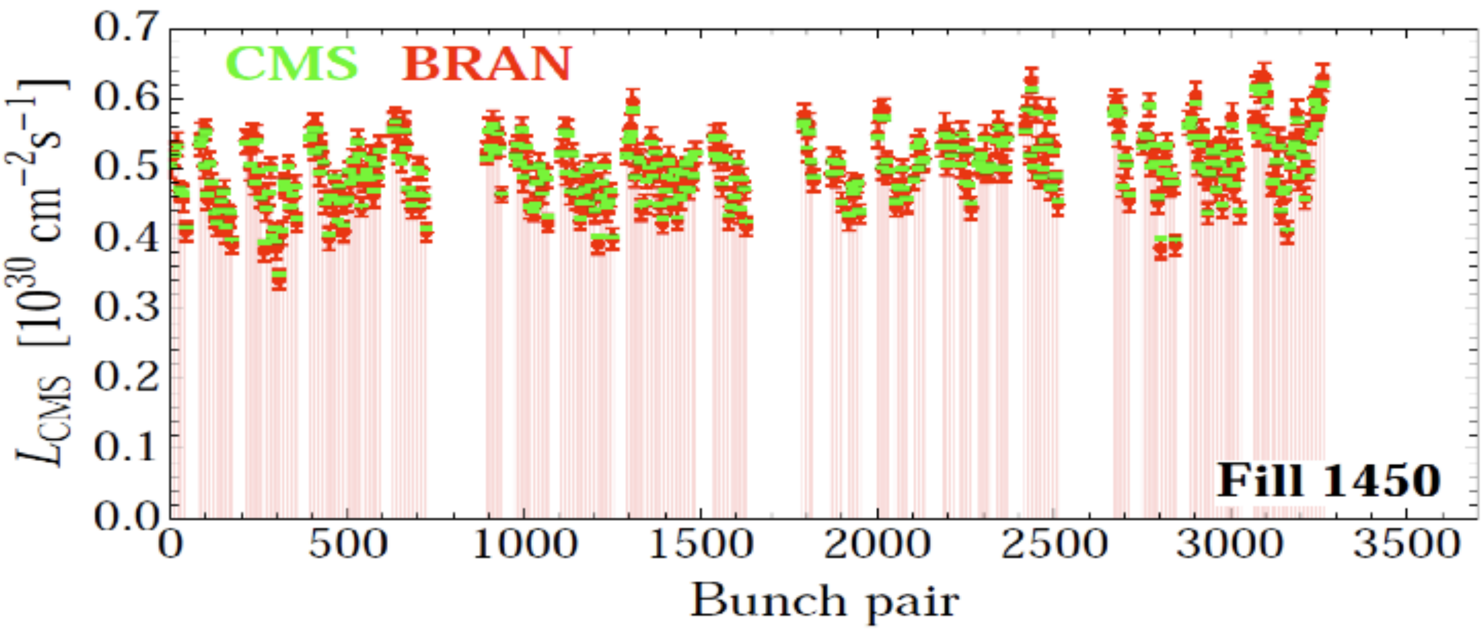


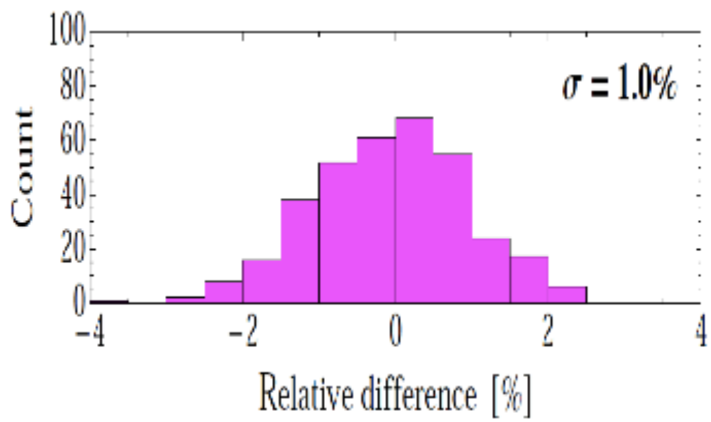
Interaction area evolution – IP5



Specific luminosity plot is part of the operator display under development

Bunch-by-Bunch Luminosity





- ~1% discrepancy for bunch-by-bunch measurement.
- The discrepancy seems to come from the systematic.

AC Dipole Highlights

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In the 2011 run, *β* changed from (3.5,3.5,3.5,3.5) m to (1.5,10,1.5,3) m at IPs (1,2,5,8). This is due to:*

IP1 and IP5: further squeeze allowed after reviewing of aperture at tertiary collimators.

IP2 and IP8: luminosities could exceed design values.

During the re-commissioning in 2011, optics measurements/corrections with **AC dipoles** performed:

Peak β-beating is reduced to ~10% at collision with local + global corrections. β-beating up to flattop is verified to be good enough.

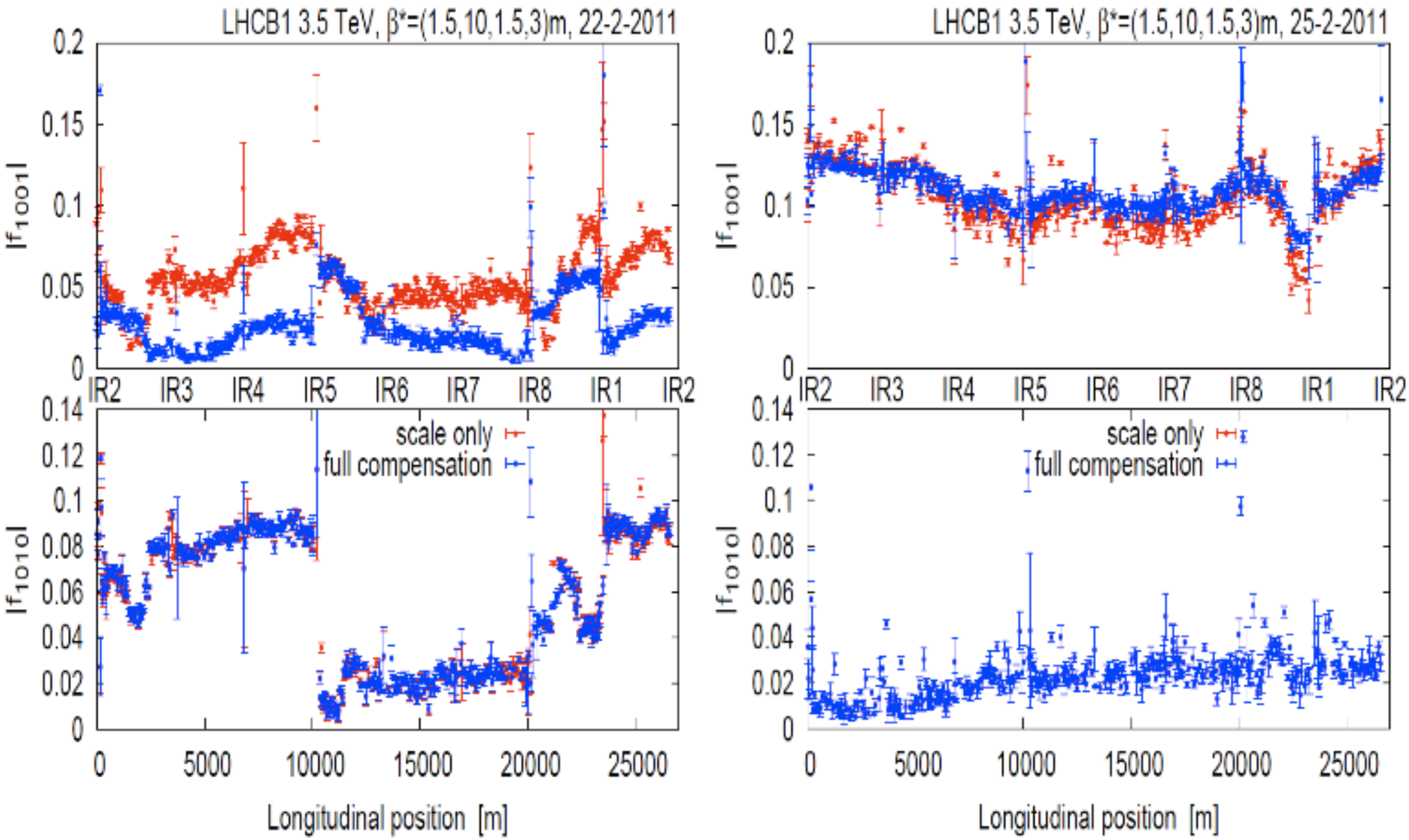
Coupling corrected at collision and later at injection and ramp for B2 during one MD.

Good machine stability verified. K-modulation performed to β^*.

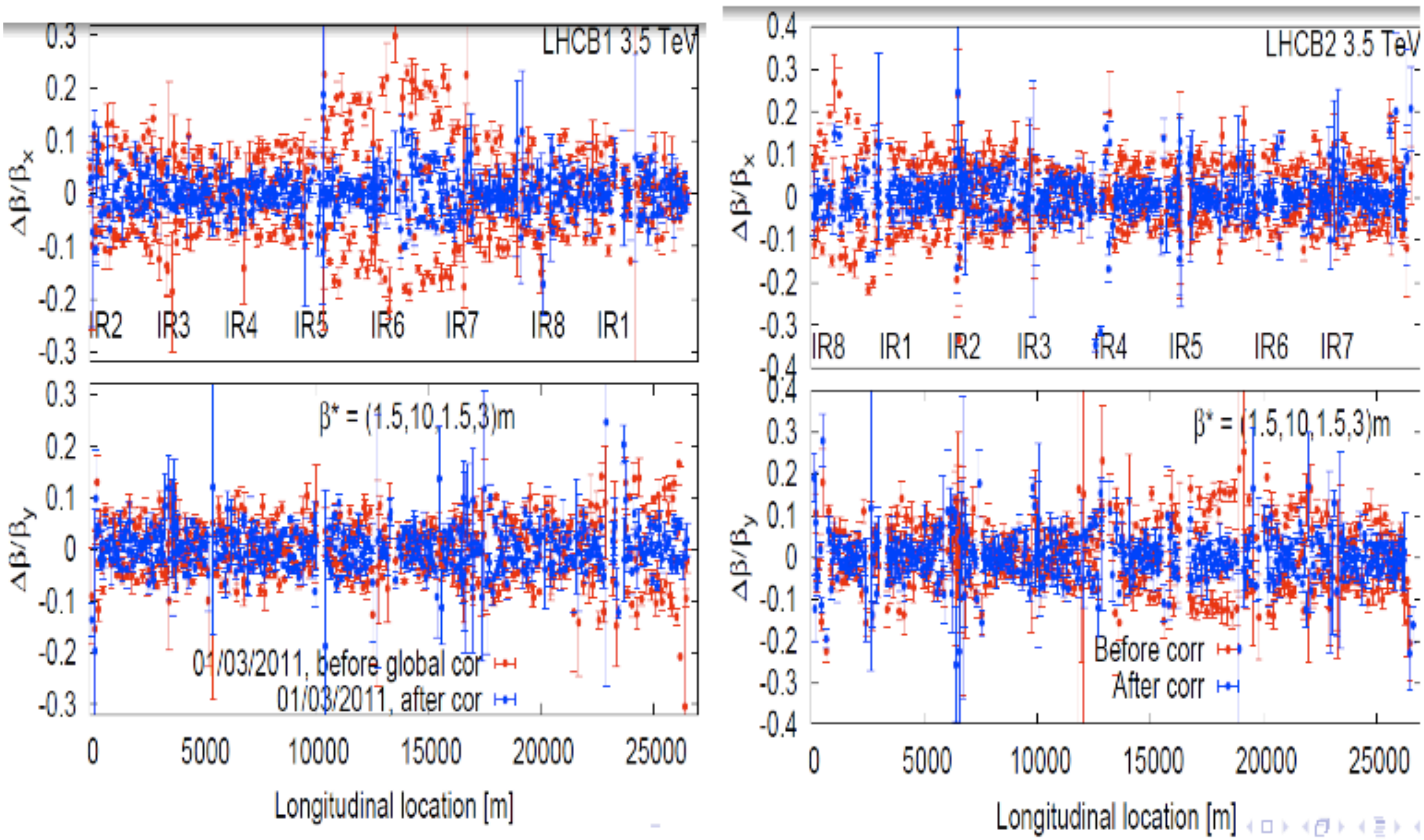
Improved diagnosis tools: GUI, codes, new analytics formula to measure coupling with AC dipoles.

Supported MDs: collision tunes from injection, 90 m β^*, ATS.

Improved Analysis



Global ß-beating Correction at Collision



Achieved ~10% β-beating in both planes for both beams!

Collaborative Efforts

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LARP works with CERN in different ways

1. LARP and CERN equally involved in the developments and implementation
    - AC Dipole – each lab built a system for own collider
    - Tune and Coupling Feedback – System developed and tested in RHIC, CERN implemented in LHC

2. LARP did studies and provided prints, CERN implemented in LHC
    - Schottky Monitor – FNAL built processing electronics modeled after the tevatron's
    - Synch Light Monitor – study by LARP, fabrication and installation by CERN

3. LARP did most of the work, CERN provided local support only
    - Luminosity Monitors

Handoff to CERN

All instruments are completed and fully operational

Last hardware issue resolved during 2010 winter break

Moving into operations requires two champions

- an instrument 'owner' in BE/BI to maintain and enhance the device
- an 'operator' in BE/OP to lead it into operations

LARP's experts continue to develop the performance of the instruments and collaborate with CERN staff

Final Considerations

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Results made possible by **significant contributions** from all labs

This year we spent less than $0.3M of LARP's money

- Lumi monitor initially funded by LBL for 3 years
- AC dipole enhanced by BNL and FNAL
- Schottky monitor - controls interfaces and programming contributed by FNAL (LAFS)
- Synch Light Monitor (and LLRF) – almost entirely funded by SLAC, including one LTV

LARP management helping secure adequate resources in support of the LHC commissioning

LTVs and Toohig fellows

Integration with beam commissioning activities is essential to the success of the instruments provided by the LARP collaboration

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More Considerations

Developing instruments as the LHC performance increases

Toohig + LTVs essential to the process

- AC Dipole, Lumi – R. Miyamoto
- Sync Light – A. Fisher
- Schottky – R. Calaga

Hardware functioning well

- Possible improvements identified and implemented or under study

Developing user applications to contribute to everyday operations

- Lumi, Schottky

Conclusions

Spending roughly \$6.8M of the ~\$70M spent by LARP to date, the instrumentation program has delivered tangible contributions that will help the LHC

- reach design energy
- reach design luminosity

Made possible by collaborations with CERN and contributions of each of the LARP labs

New proposals keep coming but face reducing budgets and competing priorities

This program will advance the US HEP program by

- Enhancing US accelerator skills
- Developing advanced diagnostic techniques that will apply to present and future US programs
- Help maximize LHC performance

Backup + Additional Information

Simulated vs Measured Light Intensity

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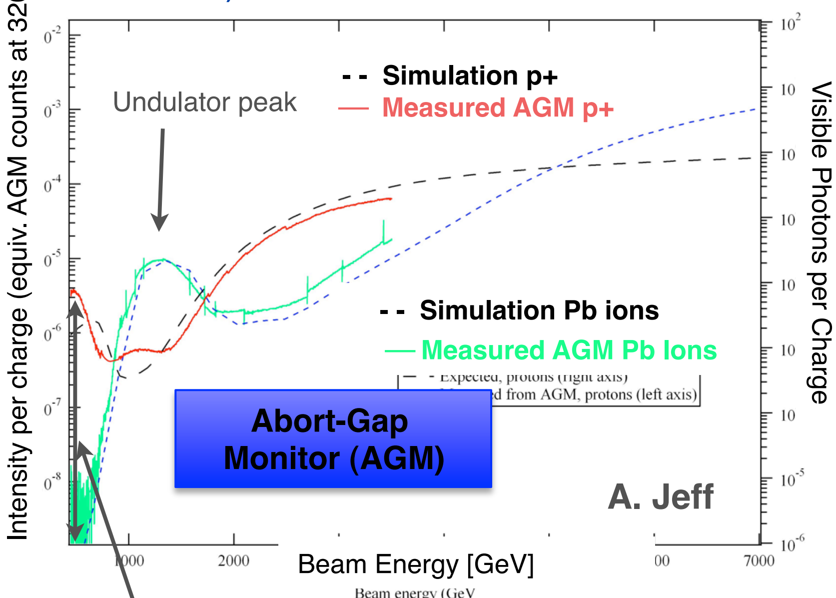
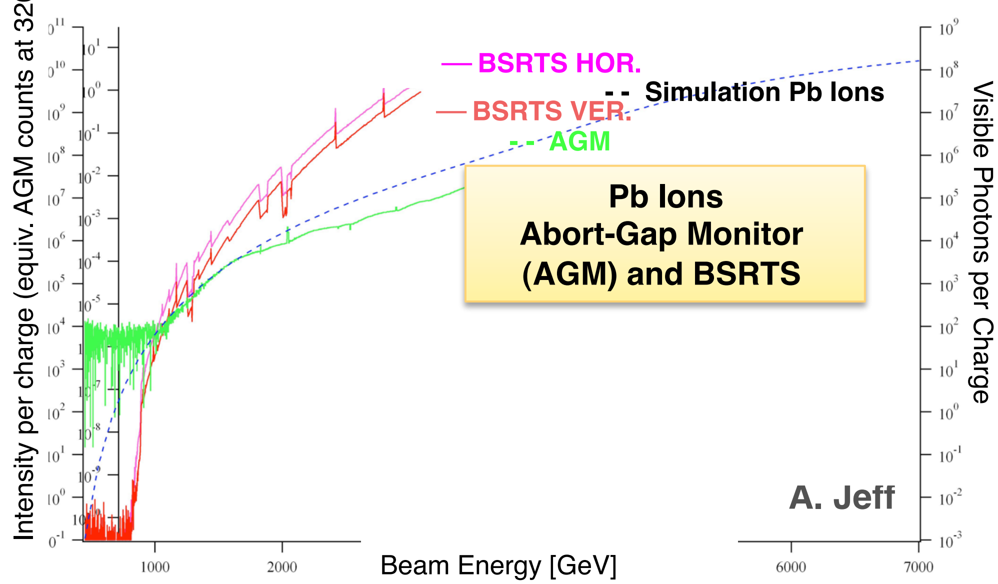
Photons per charge as simulated and measured by **Abort Gap monitor** (that shares light with BSRT)

Photons per charge as simulated and measured by **BSRT** during a ramp with IONS without Undulators



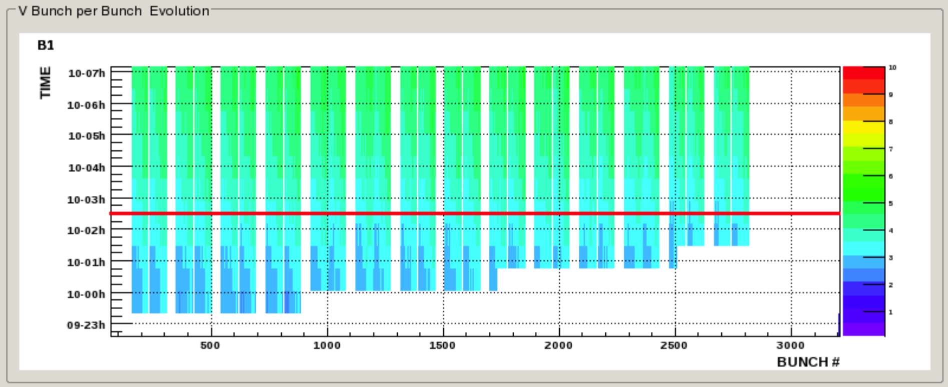


At least a factor of 10^4 between protons and ions at injection energy.

Nevertheless, it was possible to image the ions at injection.

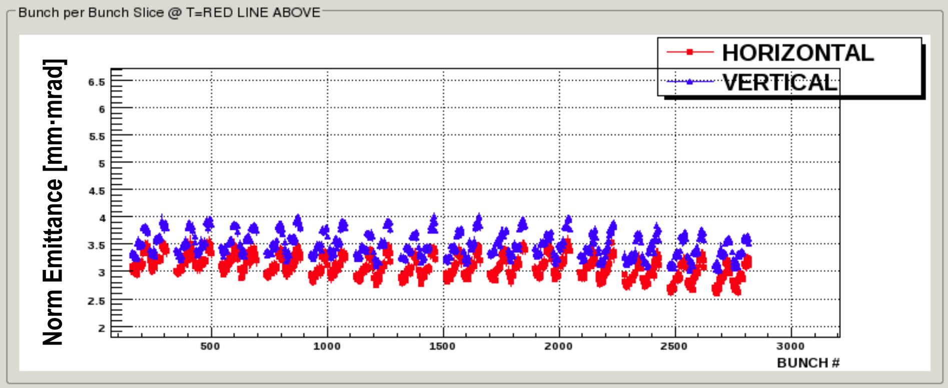
Monitoring LHC Emittance with BSRT

Transverse vertical emittance versus bunch number and time



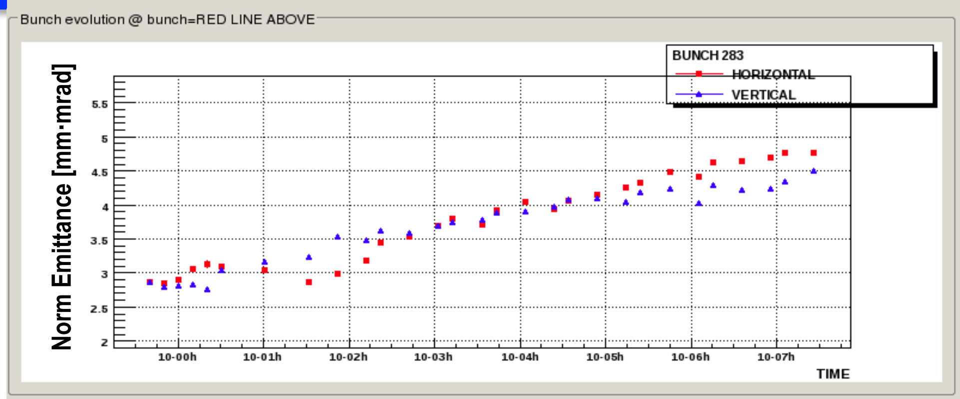
Bunch-by-bunch emittance at a fixed time

Structure comes from injectors. Sawtooth pattern here repeats with PS period.

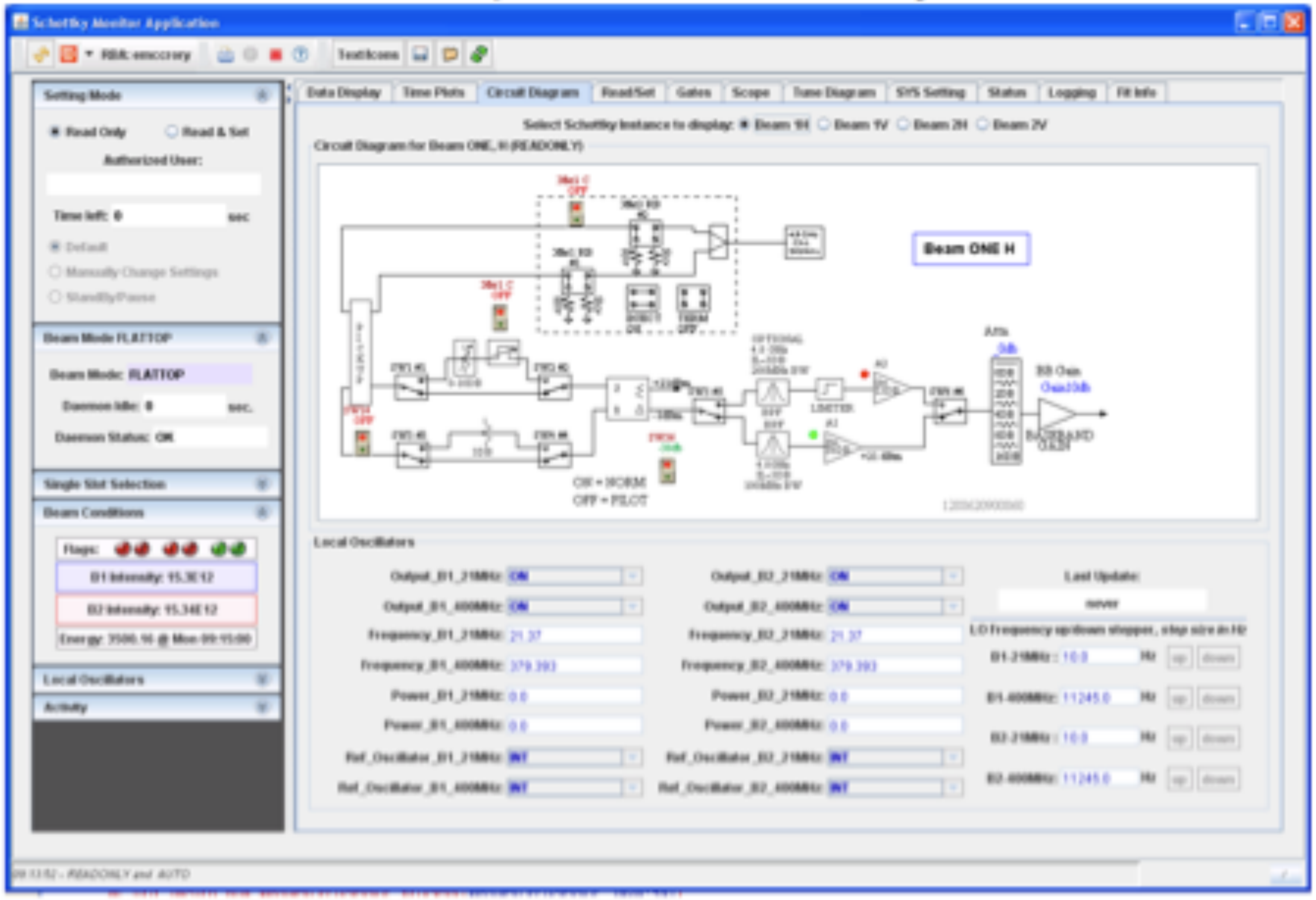


Single-bunch emittance vs time

Emittance reduction between two measurements on the same bunch gives estimate of statistical error.



Schottky – Interactive Graphics Control



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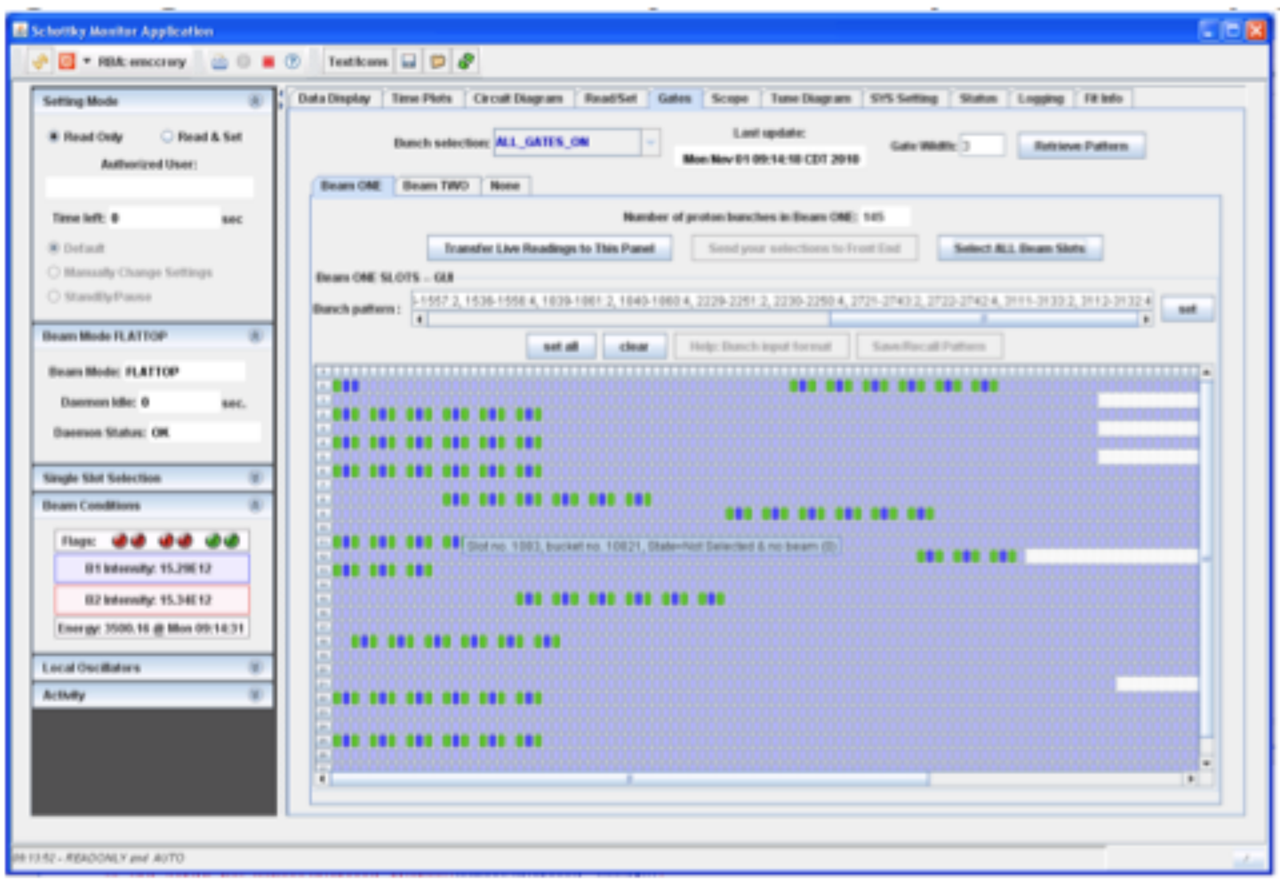
Automated Gating Control

Allows for any number of bunch configurations



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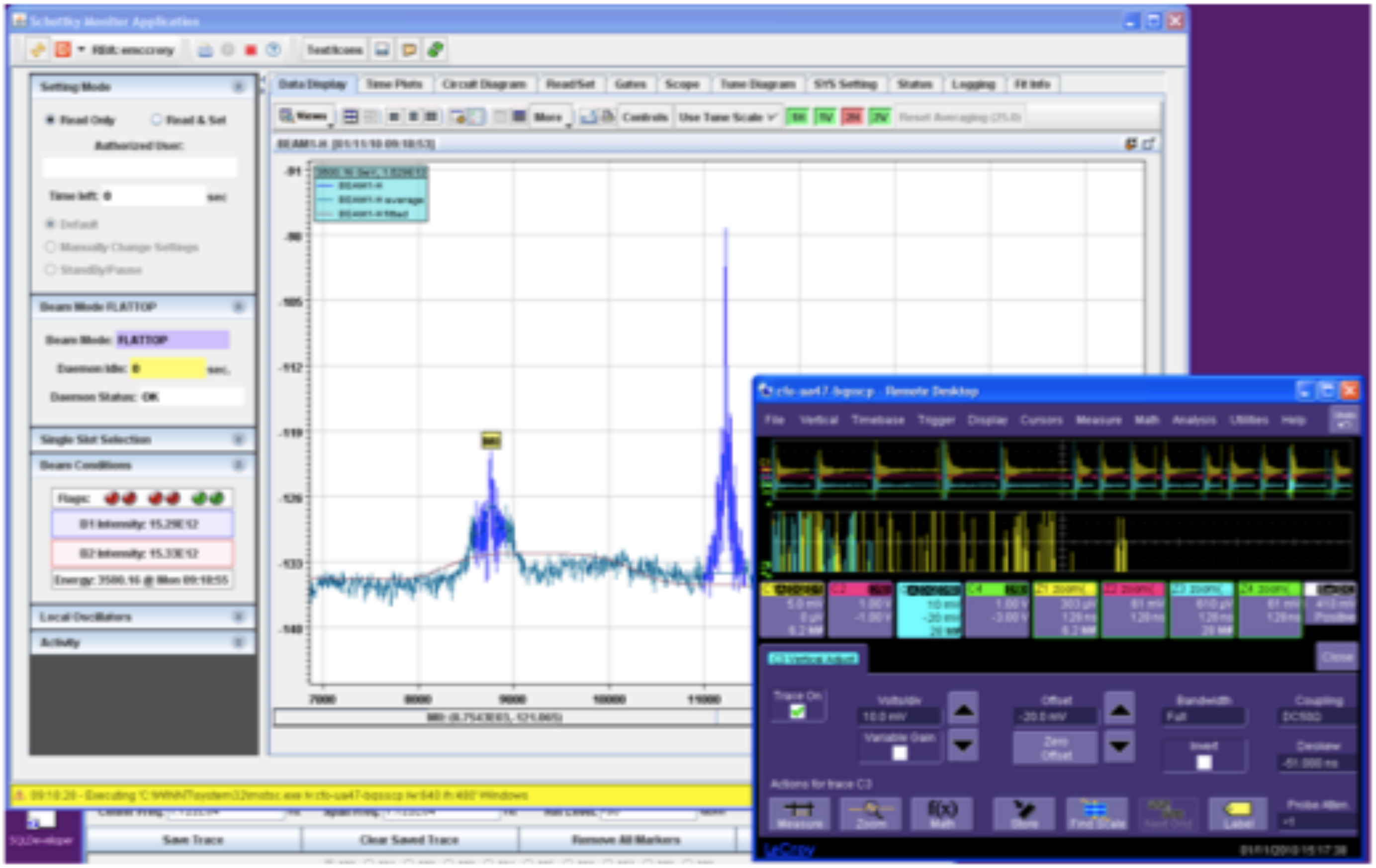
Remote Control of Gate Timing O-Scope



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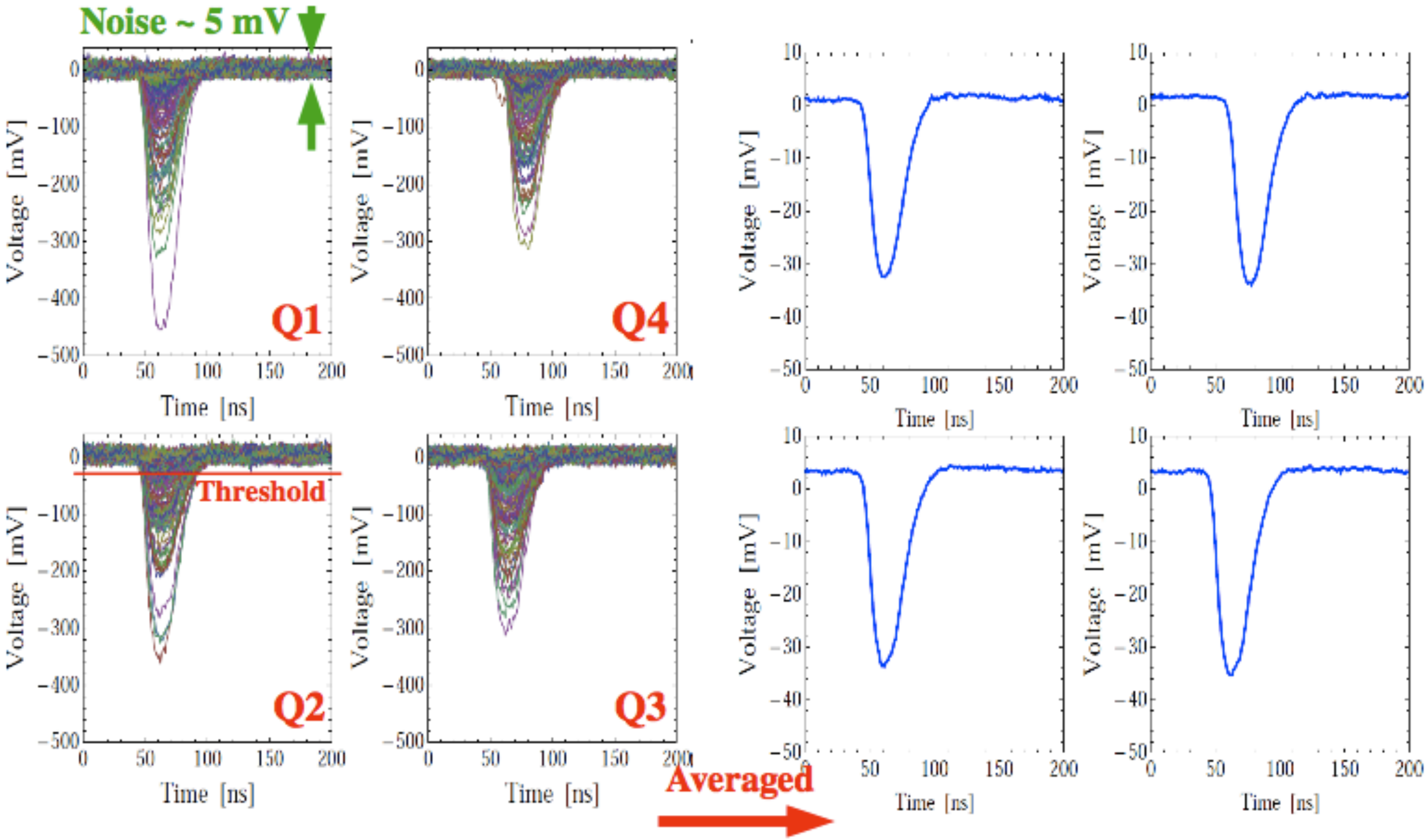
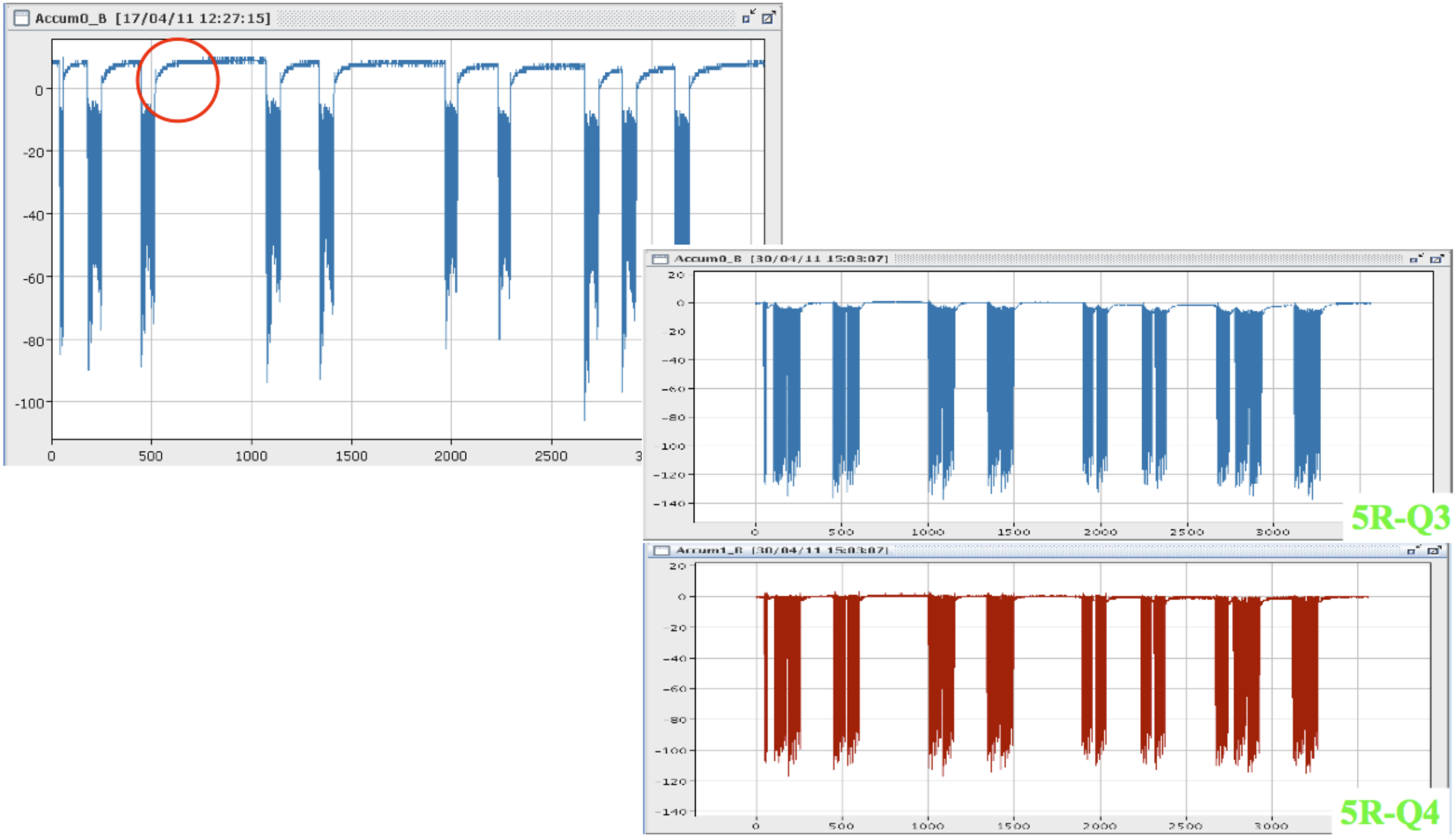
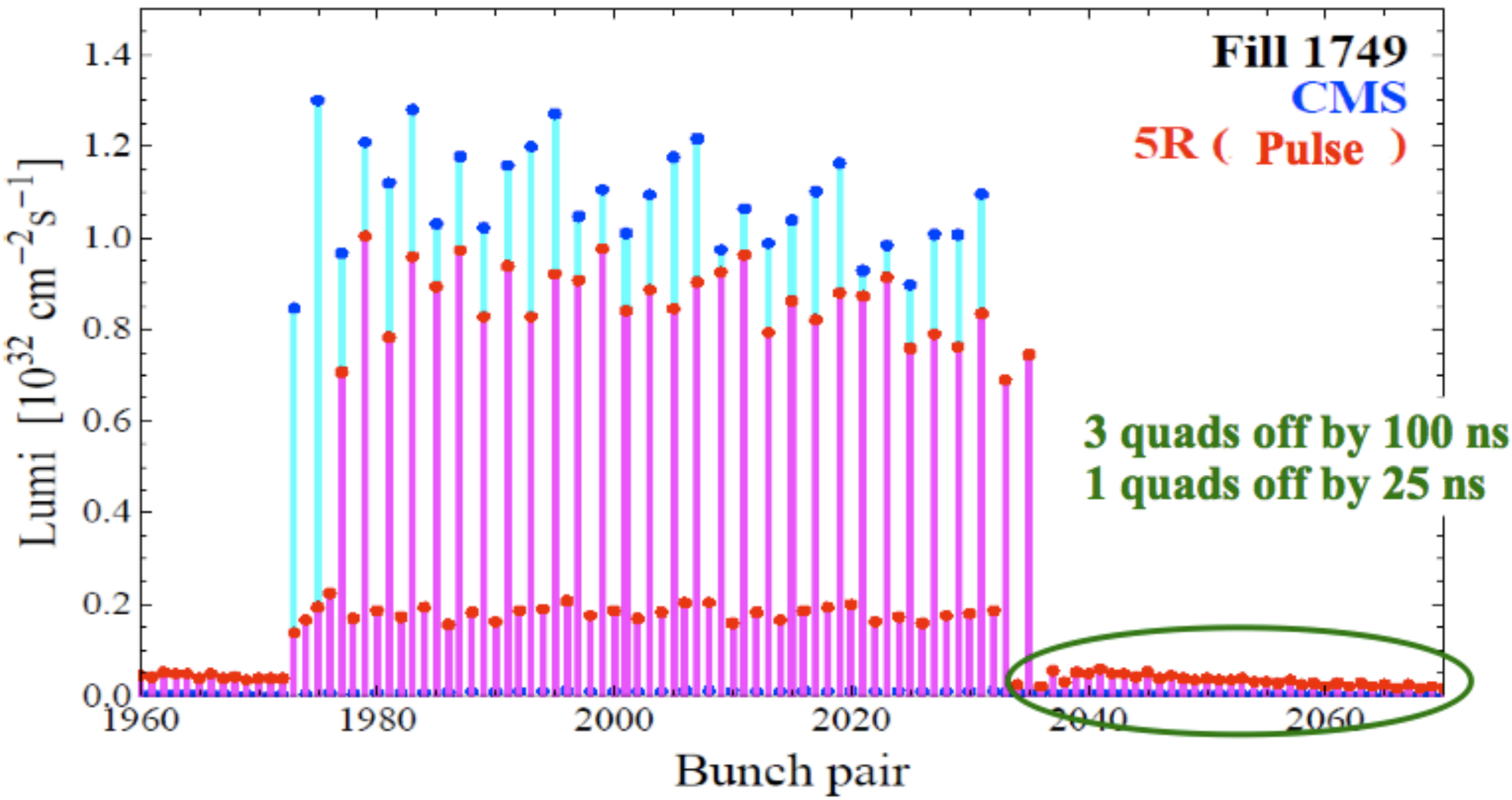
Lumi – Counting and Pulse Height Modes



Pulse Height Readout Adjustments



Readout Timing Adjustments



Operational at 50 ns

R. Miyamoto

B1 Global Correction with SVD fit