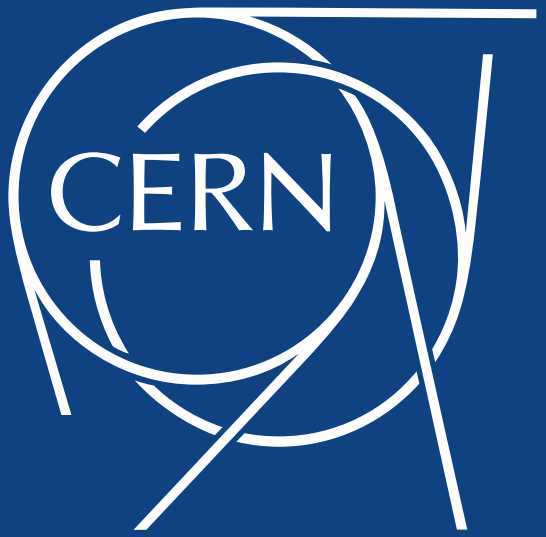

CERN

Beam Diagnostics – Key Challenges

LHC Performance Workshop (Chamonix 2016)

F. Roncarolo for the BE-BI group

Contents

- Review of BI diagnostics
  - ✓ Status/ Achieved performance
  - ✓ Remaining issues of operational systems
  - ✓ Development of additional functionalities or totally new devices/systems

References & Acknowledgments

Evian (link) presentations

E.Bravin - Doiagnostics

T.Lefevre – BI for Machine Protection

G.Trad – Beam Profile Measurements

T.Levens – Instability DIagnostics

M.Kuhn - LHC Emittance Growth until Stable Beams

M.Hostettler - Luminosity, Emittance Evolution & OP Scans

T.Pieloni - Beam-beam Head-on and Long Range

Special thanks to

E.Bravin, B.Dehning, L.Jensen, R.Jones, T.Lefevre, L.Soby, G.Trad, R.Veness, C.Zamantzas, J.Wenninger

Many others BI colleagues

The two co-chair of the session

Will not cover

- Schottky
  - ✓ High potential, path to operational systems – see Evian
- BGI
  - ✓ Aim at operational system for IONs
- BGV
  - ✓ Demonstrator tests 2016
- Feedbacks
  - ✓ Highly improved after LS1, plan SW improvements
- BLM thresholds
  - ✓ See Evian and B.Auchmann this workshop
- BCT DC
  - ✓ 2016: 24bit ADC, no need for sensitivity changes

Beam Position Monitors (BPM)

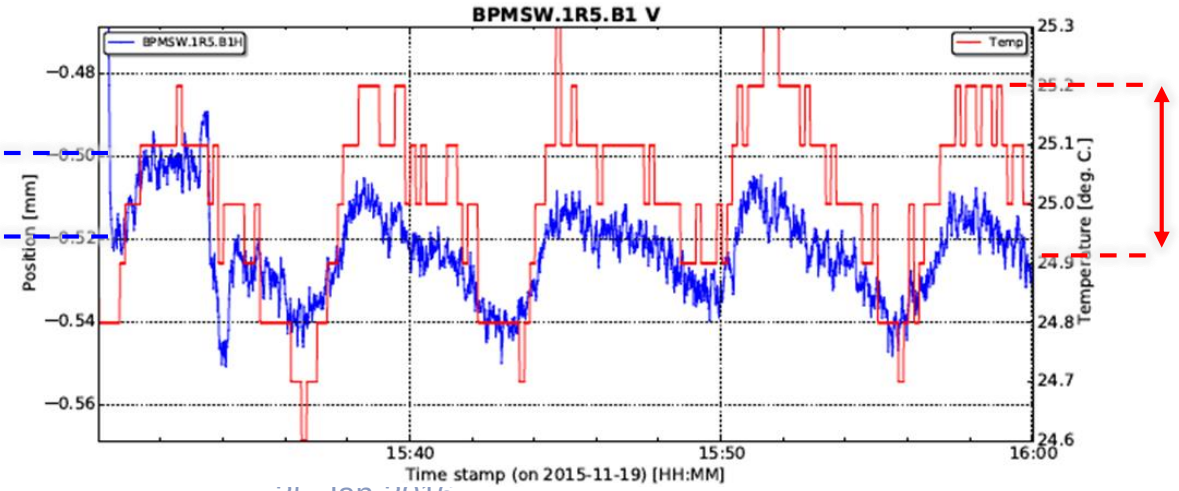
2015 Overall performance – reliability very good

- 48 channels masked at the end of the run (out of 2160, ~98% available)
- Temperature controlled racks significantly improved stability

Remaining issues

- Interference between ‘orbit’ and ‘capture’ modes
  - Firmware + FESA upgrade, to be tested at start-up
- Investigate the absolute scale of the BPMs using bumps (MD requested)
- Residual beam position error (~20um) due to poorer temperature regulation in some racks – being addressed→ Looking at even better cooling

20 um



0.3 degrees

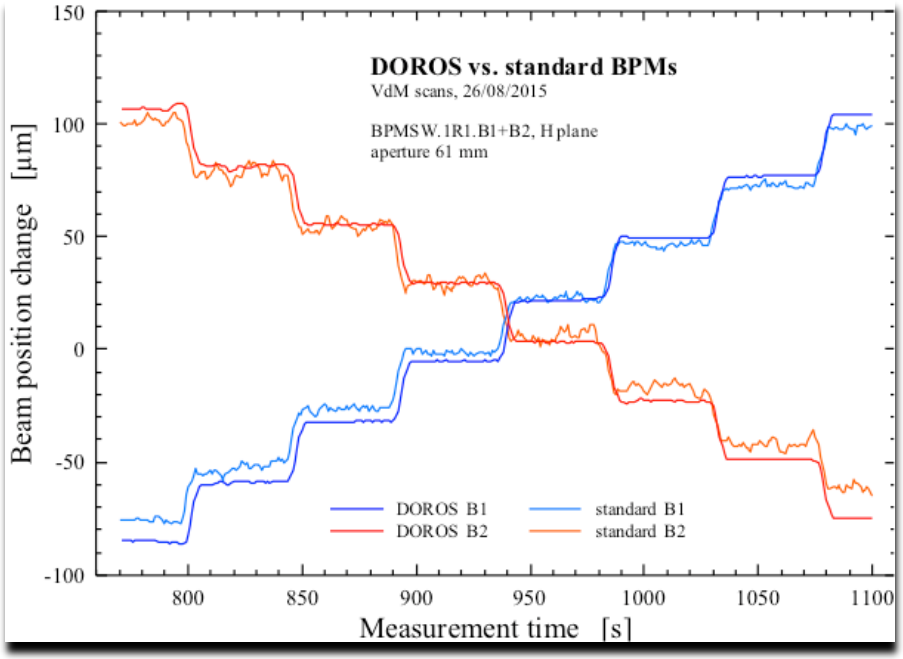
BPM – New Diode ORbit & Oscillation System (DOROS)

Presently installed on Q1 and TCTs (IP1 and IP5)

Used for

- TCTs alignment
- Track IP position

  (not yet for active steering in YASP)



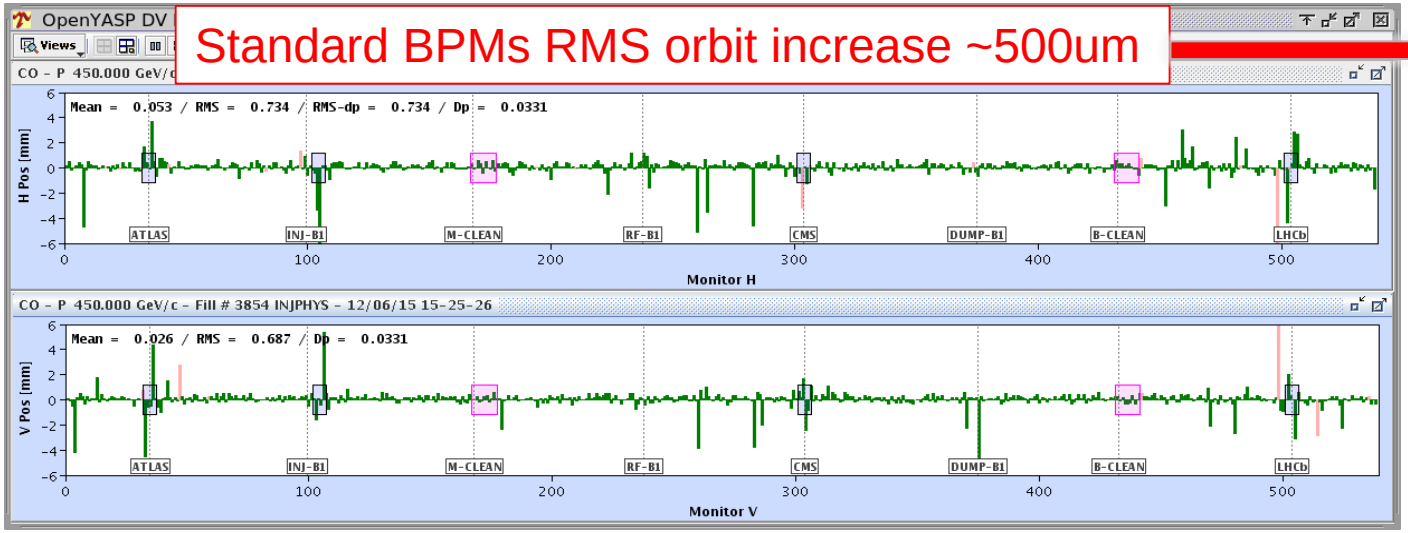
Plans & Wishes for 2016 (key challenges!)

- Fully implement TCT interlock (SIS) - see B.Salvachua this workshop
- Implement IP steering during Lumi Scans
- Turn-by-turn capture data, now an expert tool/setup
  - ✓ Plan to implement operational FESA system (BI-SW)
- Include Doros detectors in feedback loops
  - Tests for coupling measurements (MDs)

Any need / request for more monitors?

BPMs with doublets

BPMs electronics not designed to work with bunch spacing < 25 ns



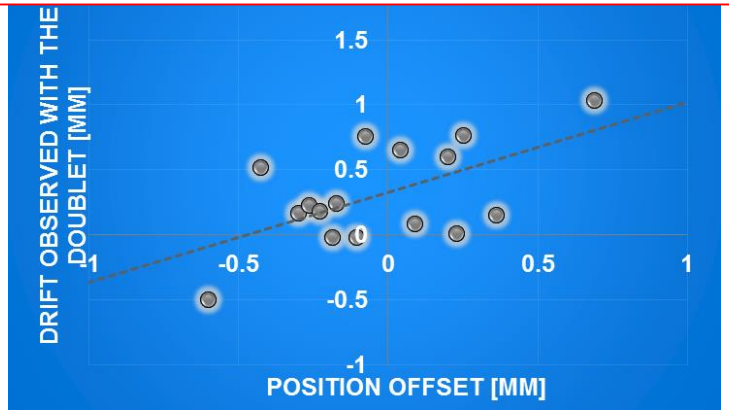
Standard BPMs RMS orbit increase ~500um

Workaround:

Measurement of synchronous orbit on pilot or nominal bunch, to be kept with doublets

Interlock BPMs bunch per bunch offset up to 2mm

- Difficult to adjust offset during doublets run
  - ✓ Need to increase interlock thresholds
- No other solution for the moment
- Work just started on new electronics
  - ✓ **Challenging! - aim at LS2**



Tune Measurements (BBQ)

Status

- Very reliable with bunch gating to cohabit with transverse damper
- Needs some bunches with low damper gain (can end up in collision)

Plans/Challenges

- Beam Transfer Function (BTF) channel to be made operational (successful test in 2015 during beam-beam studies, via expert tools see T.Pieloni @ Evian)
- MD requests:
  - ✓ Calibrate amplitude of BBQ using standard BPMs and DOROS

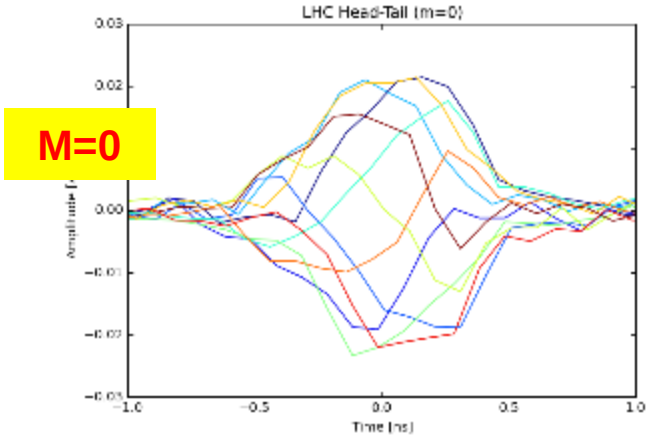
Bunch per bunch tune measurements

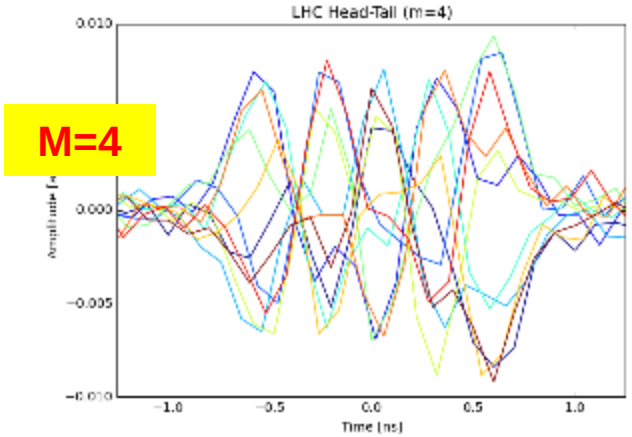
- Difficult with high damper gain
- Option of using damper system (BE-RF OBS-BOX) under study

Instability Monitors

Head-Tail monitor

- BPM Sum/delta signals with fast oscilloscope (10GSPS)
- Very useful tool to monitor and characterize instabilities
- Challenge: on-line data filtering in order to reduce data storage





BBQ instability trigger

- Detect amplitude increase of BBQ signal at onset of instability. Use as trigger to all instability monitors
- **Challenge**: reduce number of spurious triggers during injection process, injection cleaning, abort gap cleaning

Instability Monitors

Multi-band Instability Monitor (MIM) (see T.Levens @ Evian)

On-line, sensitive intra-bunch instability monitor

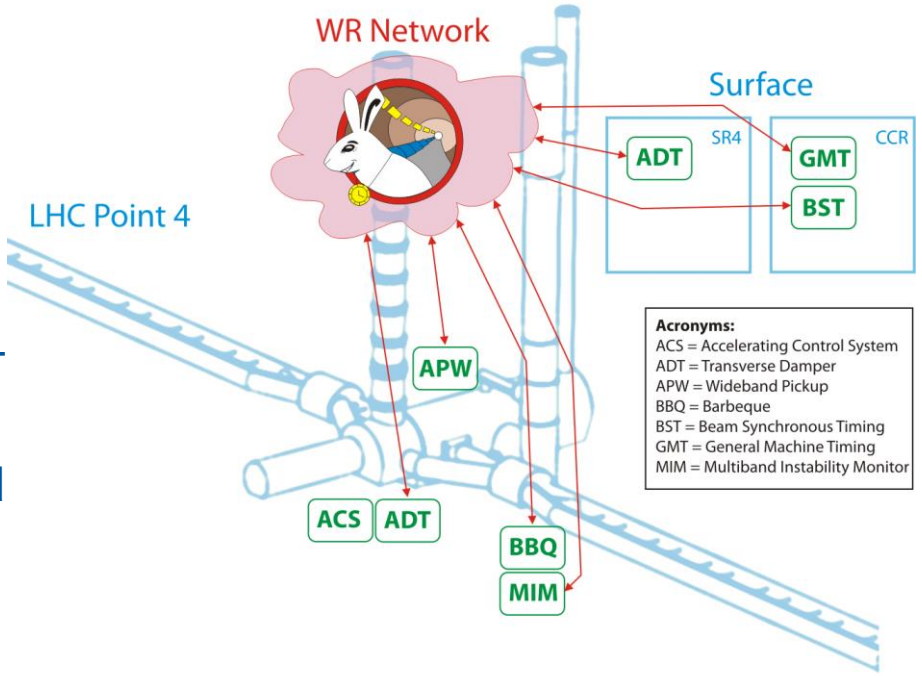
Plan: full installation for all beams/planes once performance is verified.

General plan / challenge

Setup an 'instability monitor' tool for detecting, monitoring and storing (post-mortem) instability events

Based on BI (HT,BBQ,MIM) and RF (ADT OBS box) diagnostics connected to the White Rabbit (deterministic, synchronized Ethernet) network

Common effort by BI, RF, ABP, CO



Beam Loss Monitors (BLMs)

No major HW changes on general BLM system (few more monitors installed)

Injection region (in the ring) BLMs

- See losses from injection collimators → dump circulating beams
- Present solution based on:
  - ✓ shielding @ TCDI, higher thresholds, open TCDI from 4.5 to 5 sigma
- till now no real show-stopper for operation, but :
  - ✓ 288b / injection
  - ✓ high brightness beams

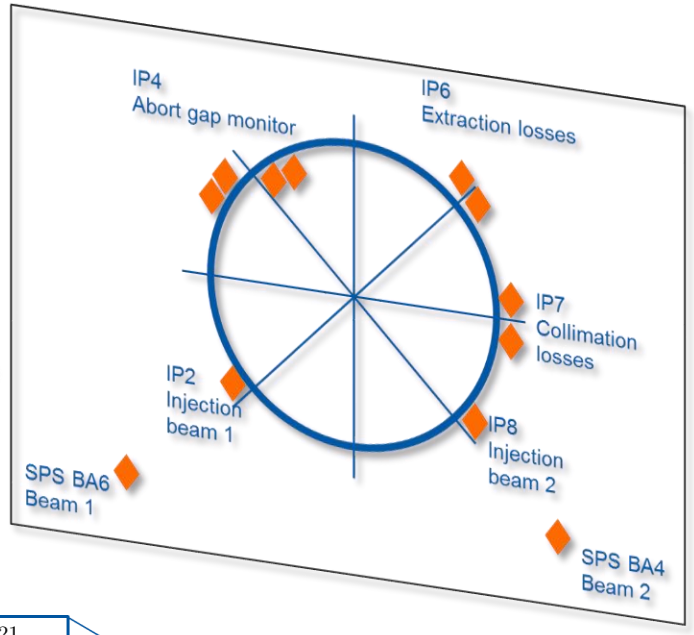
may cause higher losses and/or need to close TCDI to 4.5 sigma

- **Inhibit BLMs during injection process ?**
  - ✓ all BI infrastructure (HW + Firmware) in place to inhibit inj BLMs during a 'settable' time after each injection
    - New Firmware with additional 'inhibit' functionality, deployed (but not activated) only on the two inj. crates
    - **Agreement BI / MPP / Injection team: keep two firmware versions till end of 2016 and then decide on long term**

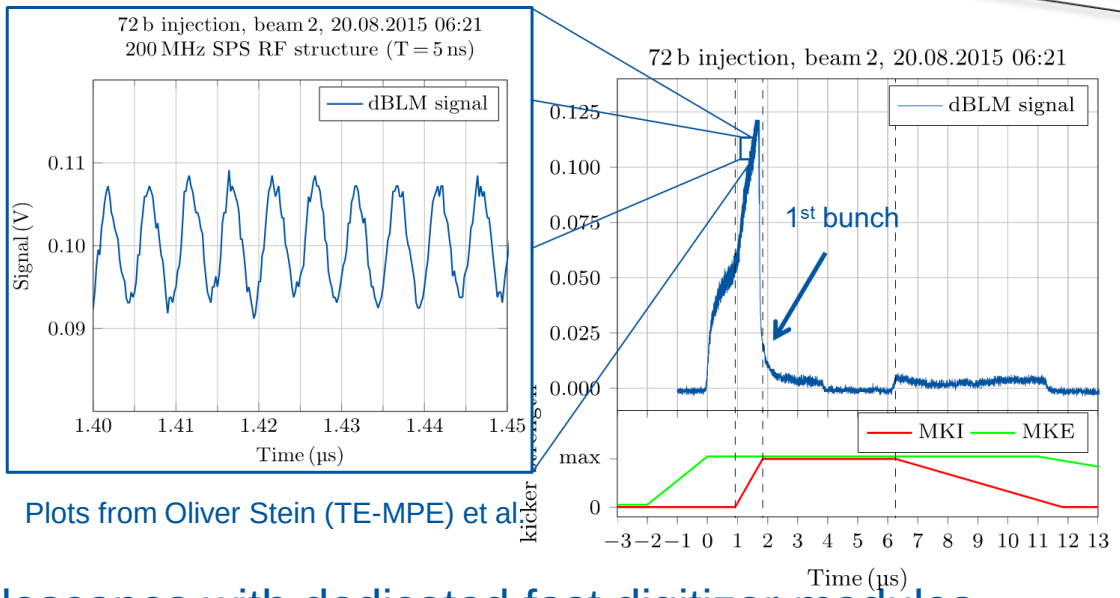
Diamonds BLMs

Diamond detectors + digital scopes + fast acquisition chain

- 12 detector installed
- only way to measure fast (intra-bunch) losses



- allowed characterizing injection losses due to SPS re-captured beam



Plots from Oliver Stein (TE-MPE) et al.

Challenge: replace oscilloscopes with dedicated fast digitizer modules, commissioning expected in 2016

Fast Beam Current Transformers (FBCT)

2015

- Beam current reading dependence on beam position (~1% / mm)
- 'Up-Down' effect on consecutive bunches for 25 ns beams

Tested of Wall Current Monitor (WCM) instead of toroid transformers:

- No dependence on beam position (see plot)
- Shorter pulse response → less 'leakage' between consecutive bunches

2016

All operational systems changed to WCM

Next Challenge: change from analogue to digital integrators (fast digitizers)

- Same as for diamond detectors - Test in 2016 (in parallel to operational electronics)

FBCT Reading

Orbit Position

Beam Current Change Monitor (BCCM a.k.a. dI/dt)

Measuring the change in amplitude of the 40MHz component of beam intensity signals. Calculating changes over 1, 4, 16, 64, 256 and 1024 turns

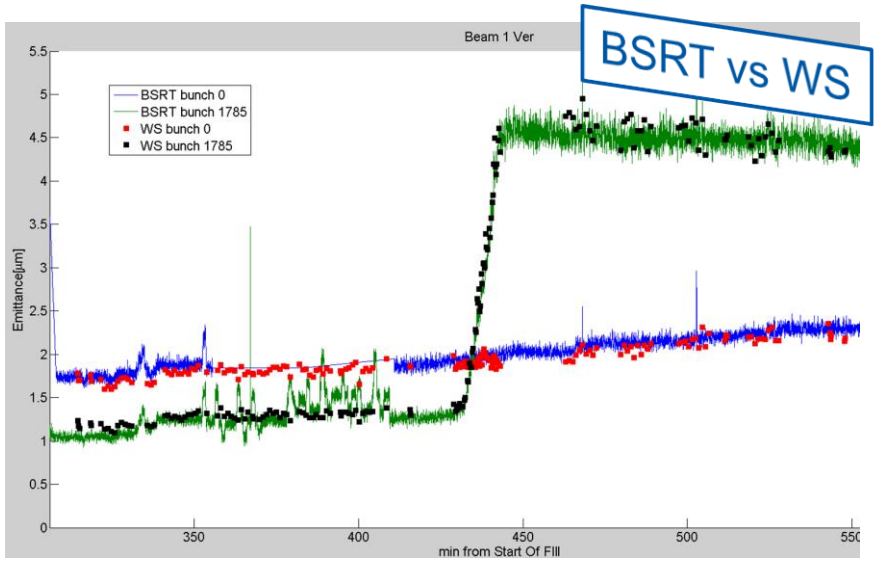
Tested in 2015, caused several false dumps

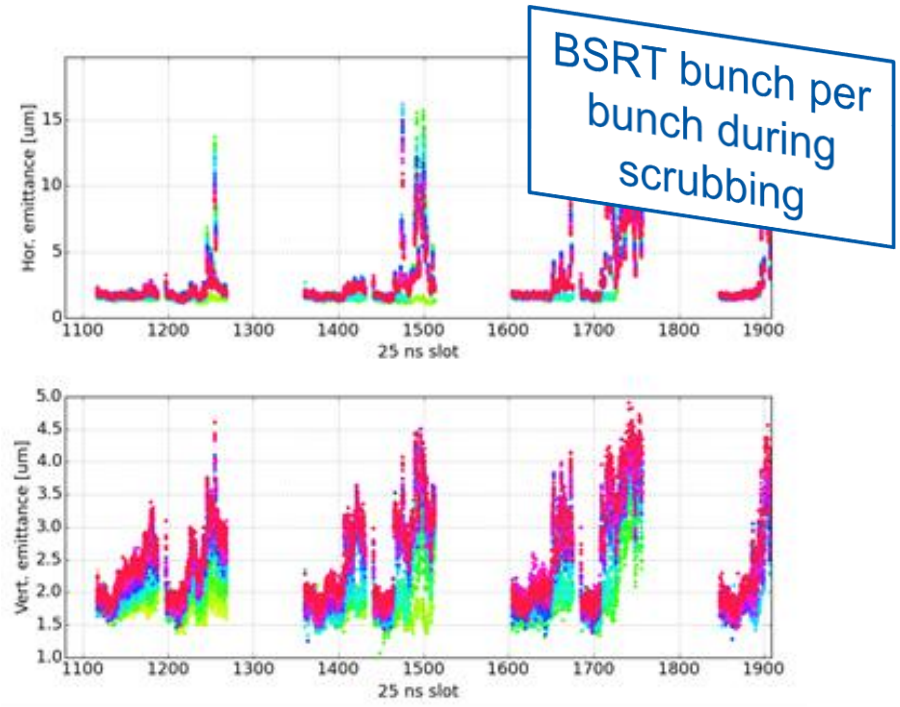
- Due to position dependence of toroids
  - ✓ Expected to be much better in 2016 with new Wall Current Monitors
- Due to firmware errors
  - Being addressed – system review before start-up

Sync. Light Monitors (BSRT)

Imaging systems (HW+SW) performing much better after LS1

- RF heating (→ failures) experienced in Run 1 solved by new extraction mirror design and implementation
- System routinely used, all data logged





BSRT - Pending limits/challenges

Small beam sizes at flat top → diffraction ~= beam size

- Interferometry ?

Scan speed, present maximum 10 Hz → 10 bunches per second

- New VME frame grabber → 50 Hz (tests in 2016)
- Digital Cameras → 100 Hz, procurements started

Image jitter/noise (mainly affecting B1)

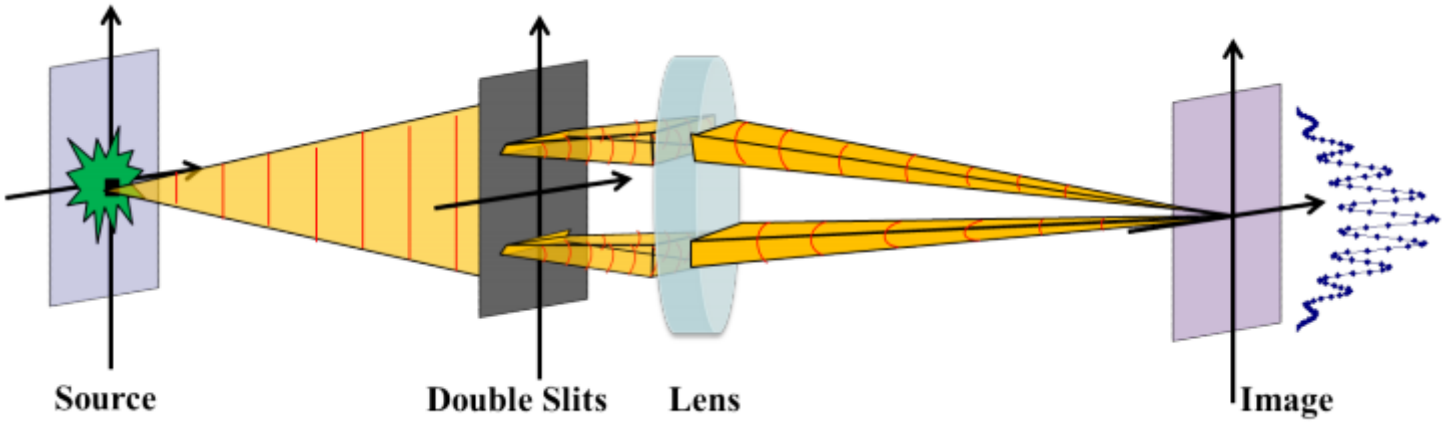
→ need at least 3 acq. per bunch, effective max scan speed 3-4 Hz

- Improve optics design and setup ? After discovering the source!

Measurement during the ramp

- Auto (feed-forward) settings ?
  - Only conceivable for E>2 TeV (light from dipole)
- To be tested in 2016

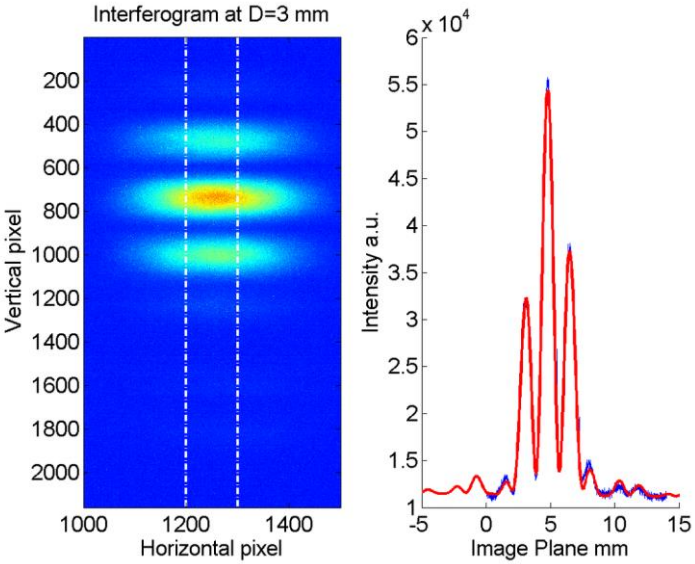
Sync. Light Interferometer (BSRI)



We Vary the slit Separation D ⇨ We observe the fringes

Interferometry tested on B1

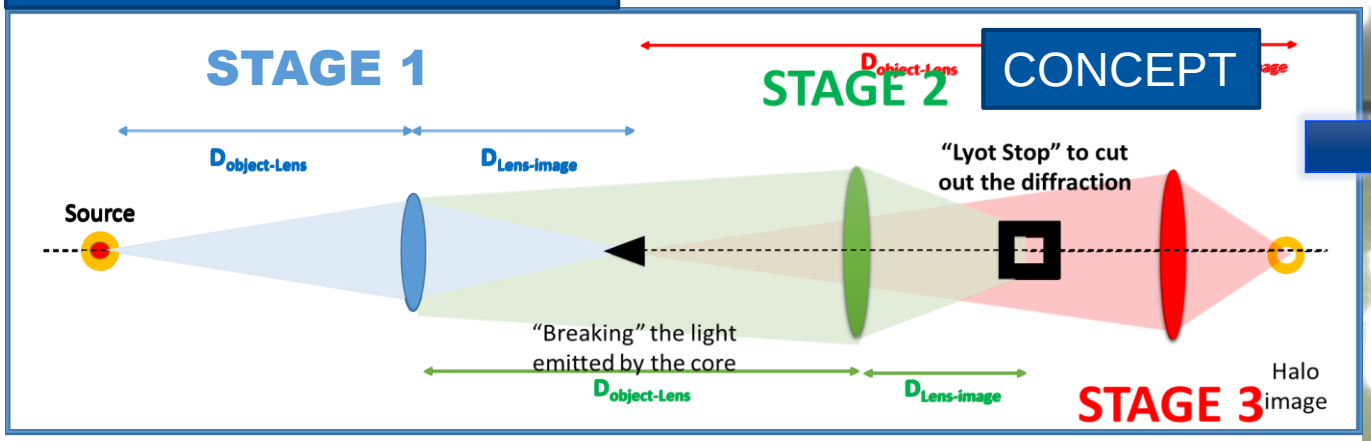
- Beam size can be derived from visibility of fringes
- Method not affected by diffraction
- Results not fully understood in 2015 (comparison to WS)



Sync. Light for Beam Halo

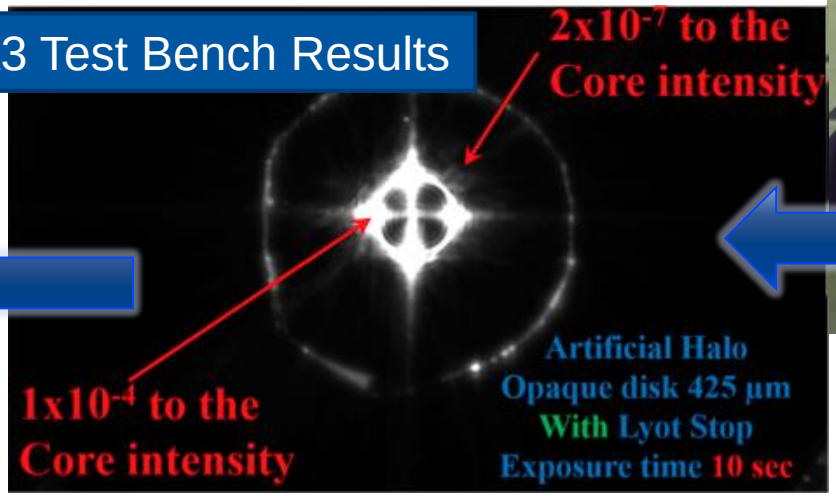
HL-LHC request for a beam halo monitor → ~ 10^5-10^6 dynamic range

Coronagraph technique



BA3 Test Bench

BA3 Test Bench Results



Demonstrator system installed on B1
Should be ready for tests at start-up

Wire Scanners (WS)

System extensively used during 2015, improved reliability, reproducibility and accuracy

Mechanical design optimization (for avoiding fork to block on ferrite holder) will be implemented next week

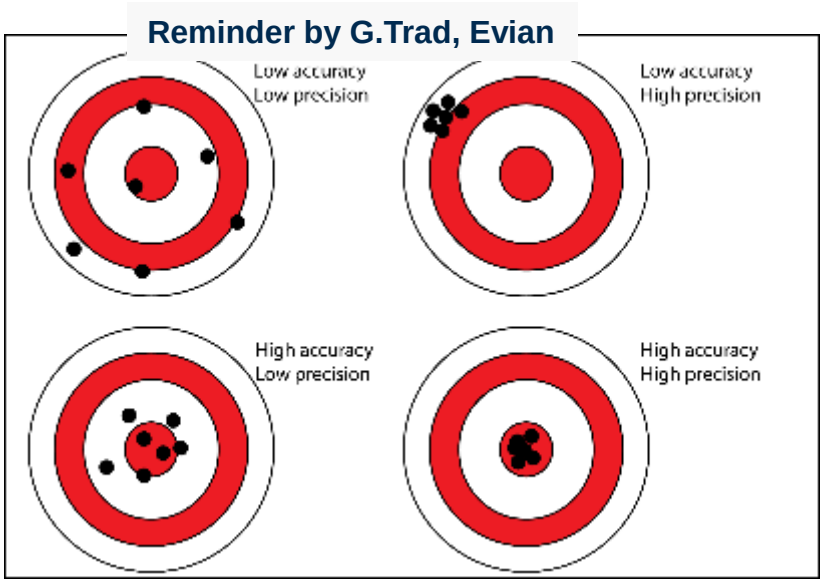
HW + Low and high level control SW still not optimal

- Takes time to make scans
- Can't scan B1 and B2 at the same time

Measurement accuracy

- Relies on wire position determination during a scan
- Calibration with closed orbit bumps, residual scaling error up to ~5 % w.r.t BPMs→ 10% on emittance
  - BPM + WS accuracy + optics between the 2
- Plan: implement an on-situ wire position monitoring (via laser interferometry)
  - Hope to test in 2016

Wire Scanners (WS)



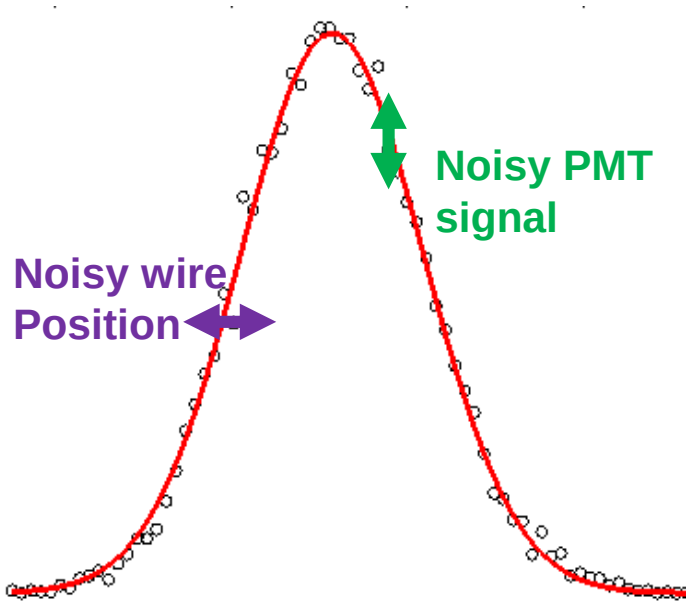
Measurement **<u>precision/reproducibility</u>**: ~10% spread on beam size measurements of same beam

Noise on wire position reading (potentiometer, ~40um noise)

Can be filtered out by using linear fit of wire positions (tested off-line, to be implemented in OP SW)

Noise on amplitude signal (PMT)

Expected to be solved during YETS



General Emittance measurements - RECAP

2015 highlights (Evian)

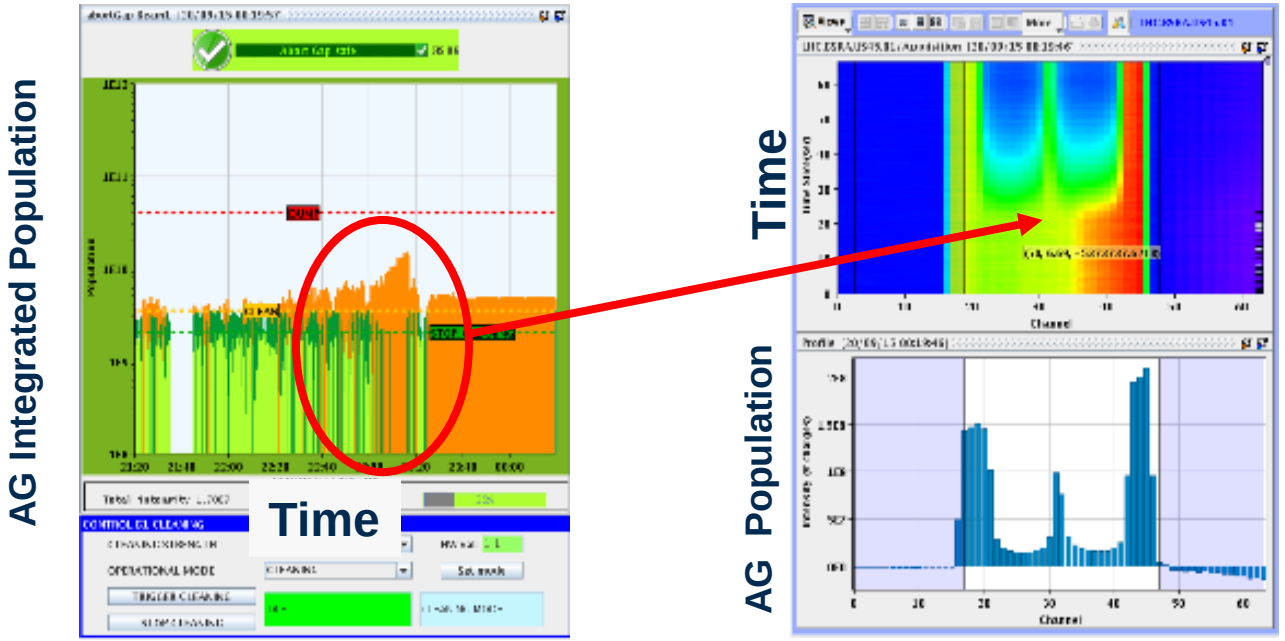
- Emittance measurements via WS, BSRT, Luminosity
- WS meas. accuracy better 10% (not single meas, need statistics)
- WS-BSRT-LUMI agree on absolute and relative emittance at ~ 10%

Key Challenges

- Detailed error characterization of emittance measurements (systematic & statistical, monitors + beam optics)
- BSRT-WS optimization (previous slides), Emittance meas. during the ramp
- R&D on BGV, potentially the best for meas. during the ramp
- Make BGI operational for IONs

Abort Gap Monitor (BSRA a.k.a. AGM)

- 2015: Voltage/Gain calibration check performed by the LHC sequencer before injection, two flags published by BSRA: AG cleaning (start-stop) and beam dump
- AG cleaning triggered by SIS based on BSRA reading. Routinely used in operation

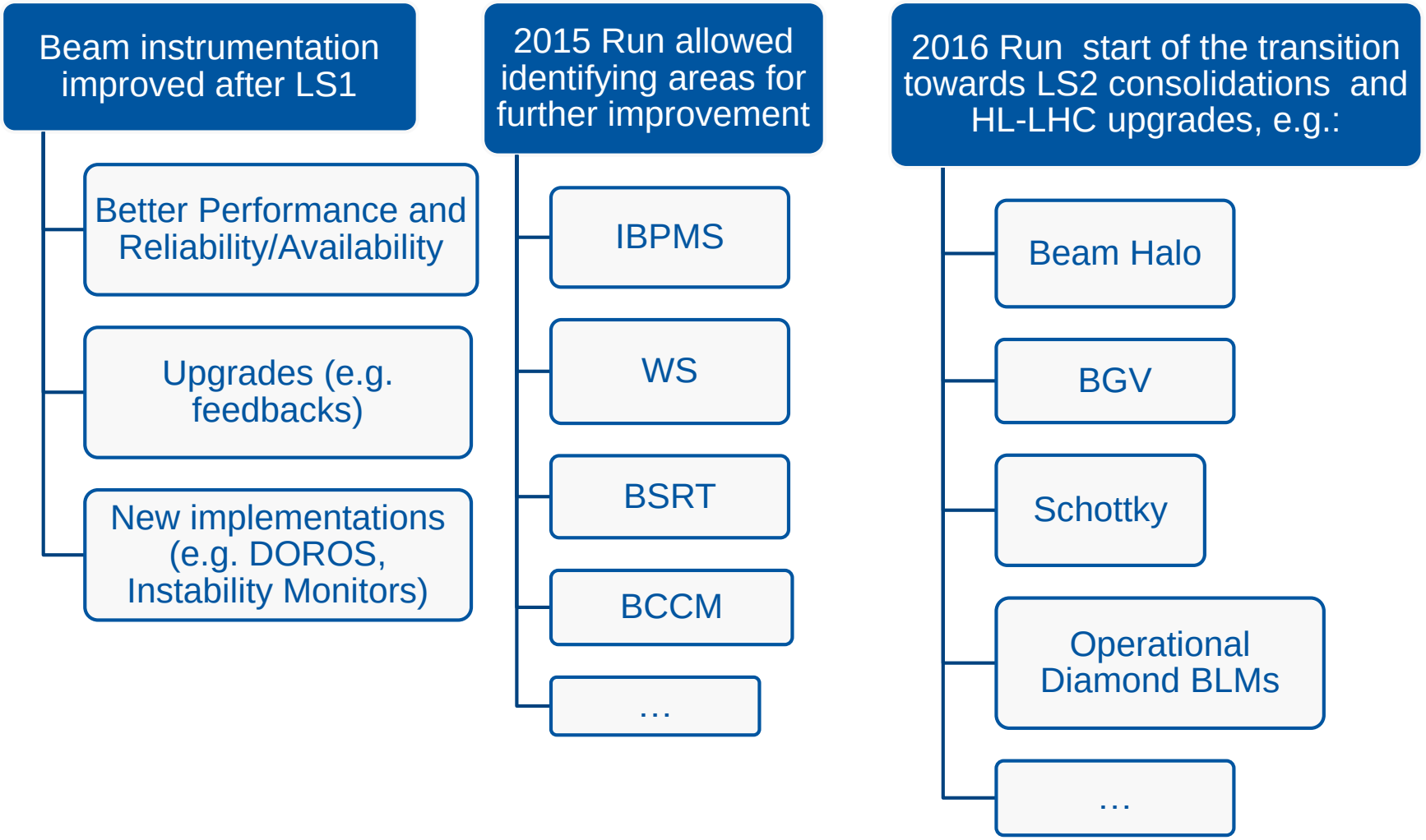


- Next Implementation / challenge
  - ✓ Periodic checks using FBCT reading
  - ✓ **Implement beam dump flag in SIS?**

Luminosity Monitors (BRAN)

- Regularly used to find/verify beam overlap while going in collisions
- IP2-IP8 CdTe changed to Cherenkov detectors
- IP1-IP5 Ionization Chambers start suffering of radiation ageing
  - ✓ Installing Cherenkov detector inside TAN IP1
  - ✓ For sure will need to be replaced for HL-LHC (Cherenkov or other solution)

CONCLUSIONS

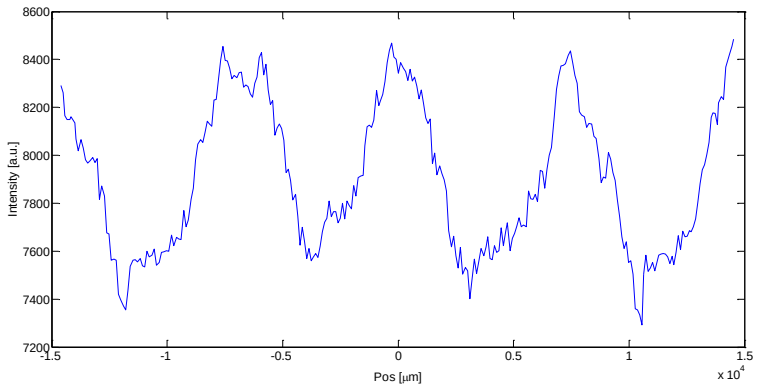


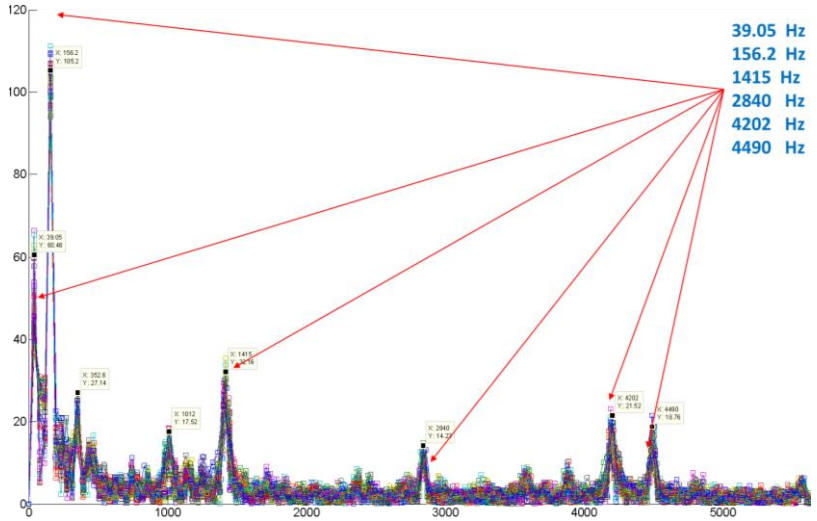
SPARES

BCT DC

- System works nicely
- Safe Beam Flag flickering (→ beam dumps) solved by increasing integration at 6.5 TeV (SBF level ~ BCT noise with short integration time)
- Provides Lifetime (as well as FBCT)
  - ✓ May need some tuning
- Main change for 2016: 24bit system to become operational system
  - ✓ Should ensure to cover all intensities with no gain change → particularly beneficial for VMS

WS PMT noise

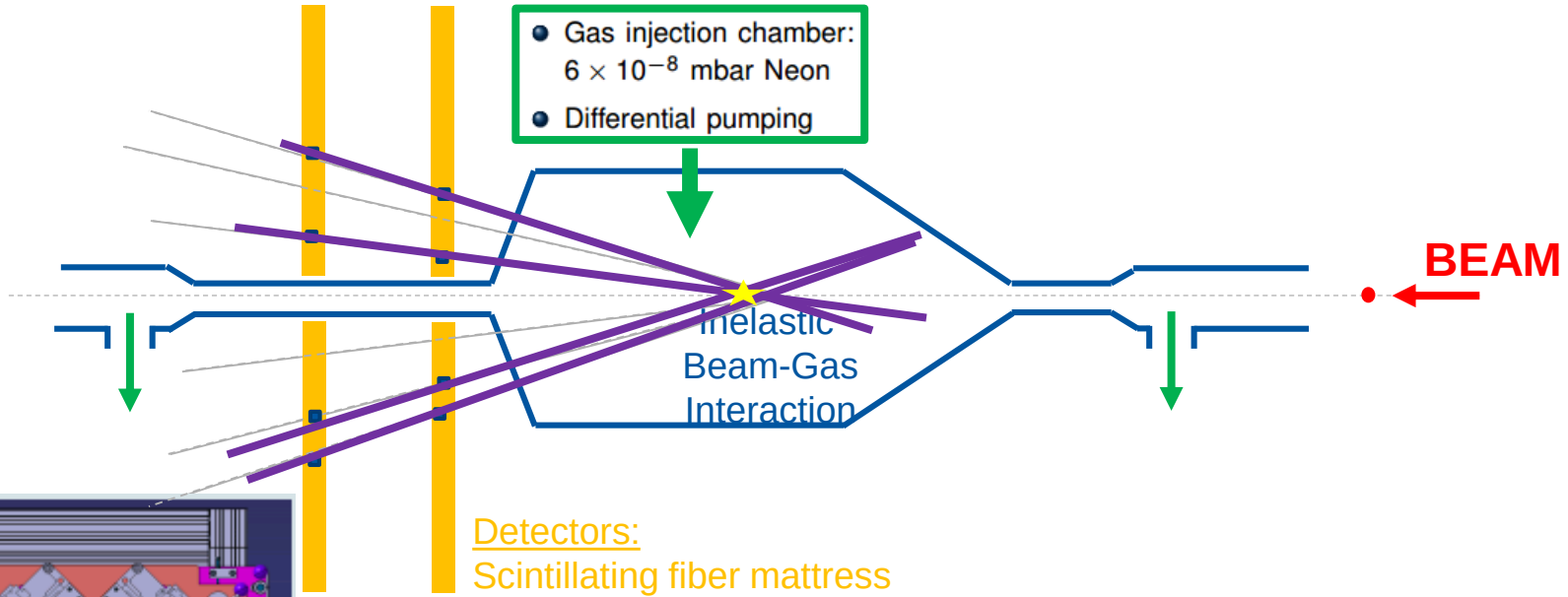

Intensity [a.u.]
Pos [μm]
x 10^4

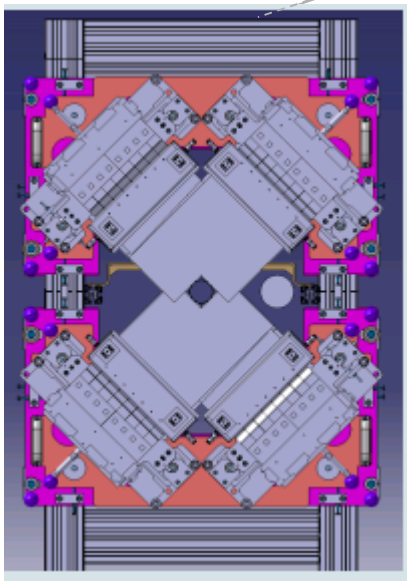

39.05 Hz
156.2 Hz
1415 Hz
2840 Hz
4202 Hz
4490 Hz

BPM – Doros

- Study of coupling measurements with DOROS response to
  - ✓ AC dipole excitation
  - ✓ Small Transverse Damper excitation during physics (MD request)

Beam Gas Vertex detector (BGV)





Detectors:
Scintillating fiber mattress
Coupled to SiPMs
Expected hit resolution ~70µm

- Demonstrator system installed on B2
- Can do bunch per bunch (~xx min integration) also during the ramp

Tune and Orbit Feedbacks

Status

- Feedbacks review during LS1 very successful
- System gain and target values set by the sequencer

Plans/Challenges:

- ✓ orbit feedback gain and target tunes defined by functions, in a very similar mode as magnet power converter functions
  - Feedbacks to become even more robust, being totally autonomous from sequencer
- ✓ Implementation on going, MD request

BGI

- Hard to expect anything for protons with present HW
- Promising results with IONS in 2015
  - ✓ Only way to meas. full ION beam at Injection (not enough light form BSRT)
  - ✓ Profiles available throuout the whol
  - ✓ Not bunch per bunch
- Issues – key challenges to make it operational for IONs
  - ✓ MCP and Camera Ageing

Bunch per Bunch – Functionalities Recap

Real bunch per bunch

- FBCT
- BPM in capture mode
- Diamond BLMs

Gating (on demand, on one or more consecutive bunches)

- BBQ
- Schottky
- BSRT
- WS (up to mx number of bunches)
- BGV

Bunch per Bunch - Tune

- Difficult with high damper gain
- Option of using damper system (BE-RF OBS BOX) under study
- BBQ provides gating, Schottky could do potentially the same

Porting to FESA 3

- BPM
- BTV – In progress, should be transparent
  - ✓ New BTV FESA Class for BTVDD
- BSRT
  - ✓ Started, will be ready to host new video card and digital cameras
- WS
  - ✓ To be started, in parallel to FE porting to LINUX, will provide more selectable bunches
- BBQ
  - ✓ Starting, deployment during 2016
- FBCT, BSRA
  - ✓ Done in LS1