Instrumentation Performance in the LHC in 2015 & wishes for the future

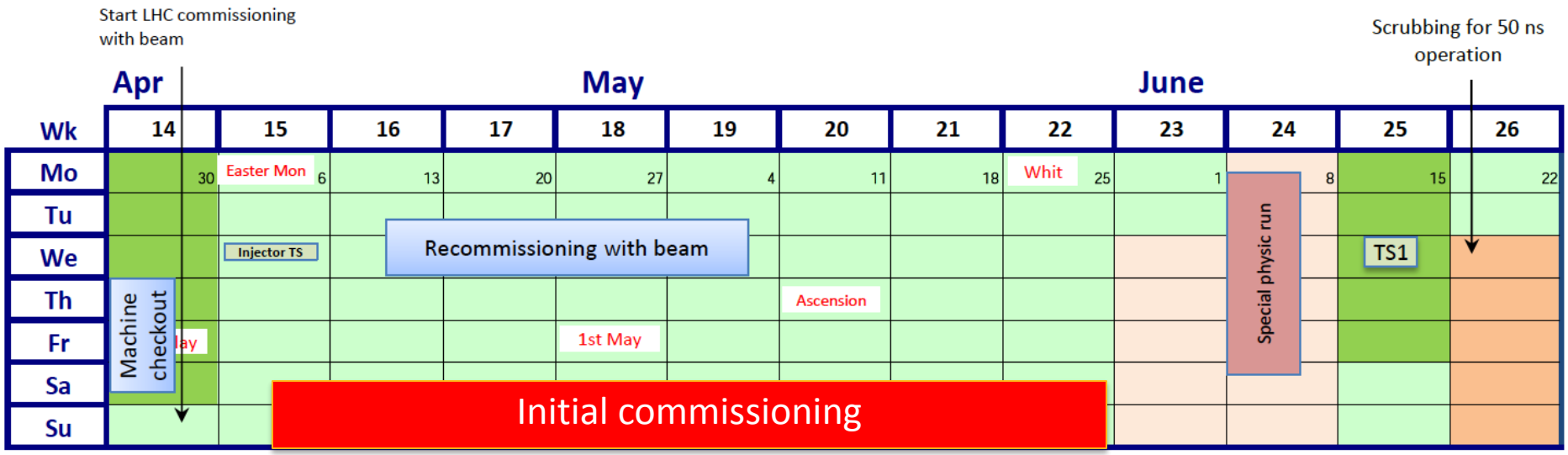
R. Giachino CERN BE/OP

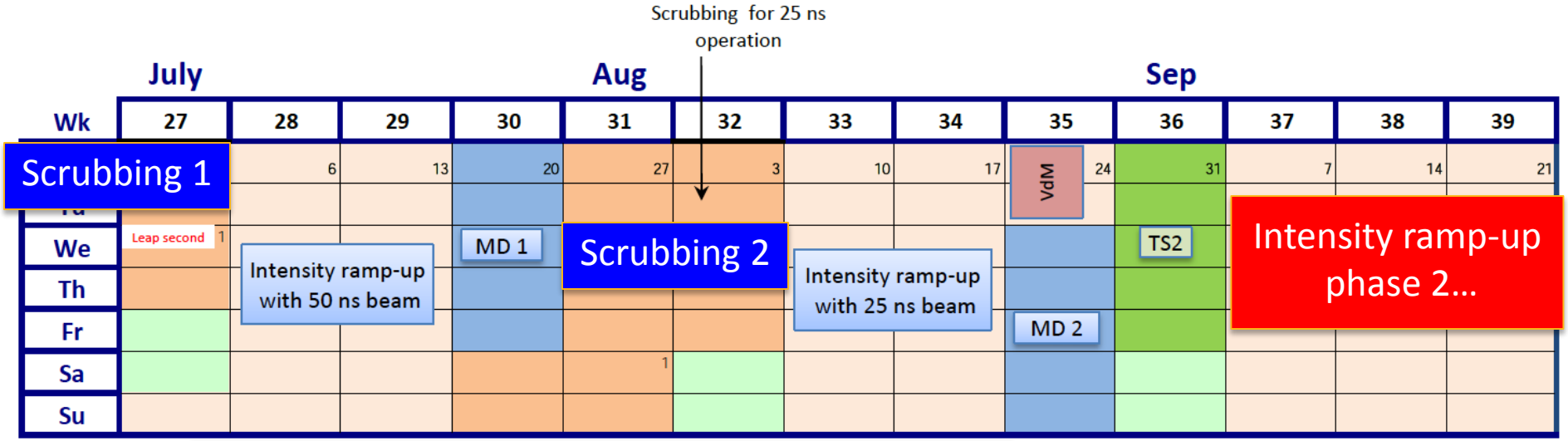
BI/Day 2016

Outline

1. **LHC Operation after LS1**
2. **LHC Operation in 2016**
3. **Status of the Instrumentation**
4. **Wish list**
5. **Special diagnostic for machine development**
6. **Conclusions**

2015 schedule Q2/Q3





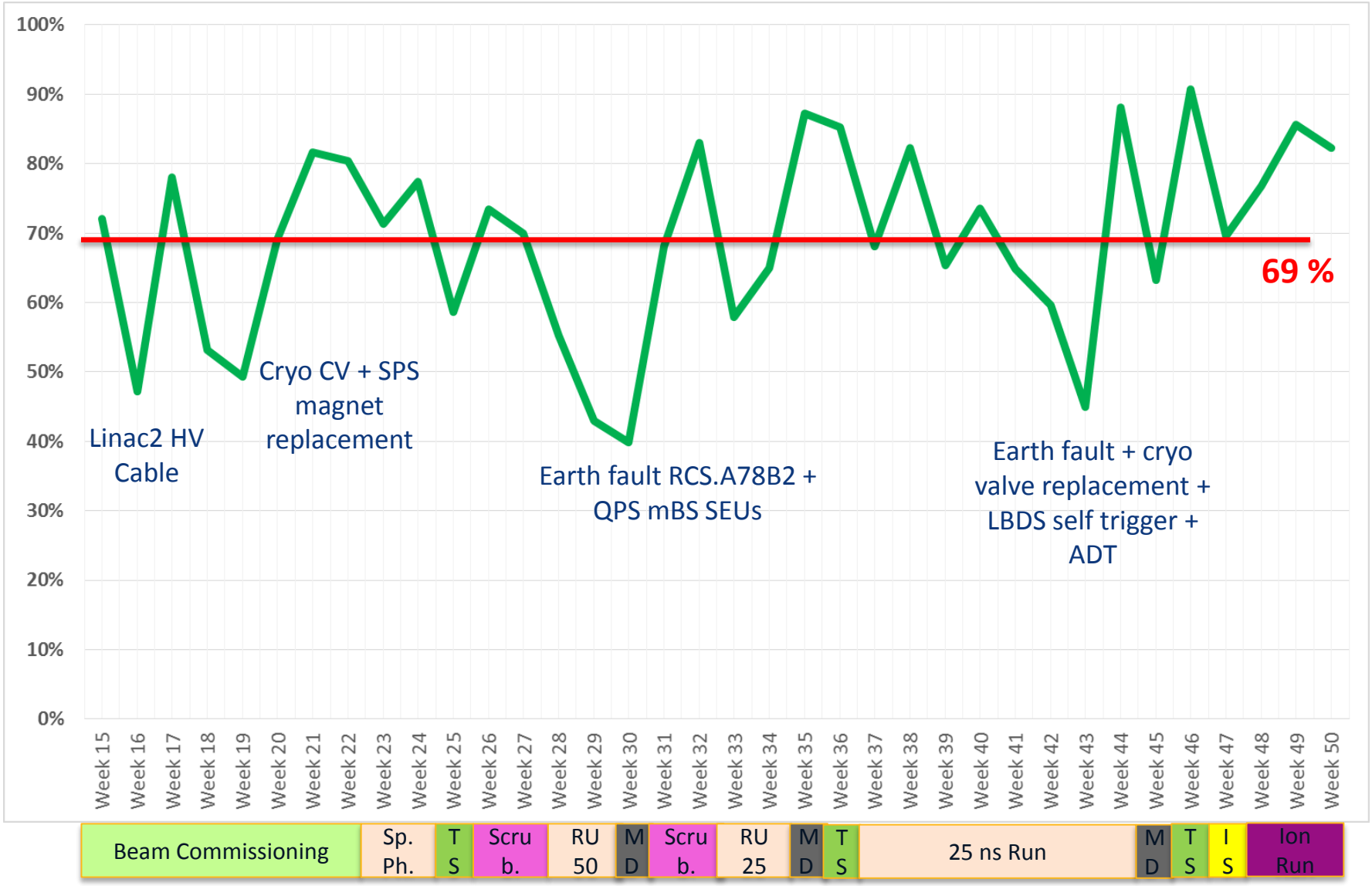
Operation 2015

- Energy 6.5 TeV, 2*80 cm
- Nominal 25 ns beam, I = 2244 bunches
- High electron cloud, huge beam screen heat load, hard life for Cryogenic
- Operating with high chromaticity, octupoles, ADT throughout the cycle to combat instabilities
- Good transmission through the cycle
- Good luminosity performance - beam-beam OK
- Acceptable emittance growth
- UFO rates down

Operation 2015

- **Availability** reasonable
- **Mature** system performance
  - QPS, RF, Cryogenics, ADT, Power converters Collimation, **BI**, Controls, LBDS, injection, TDI…
- **Operational efficiency is good**
  - injection, cycle, decay and snapback, feedbacks
- **Proven machine protection**

2015 Availability



Operation 2015

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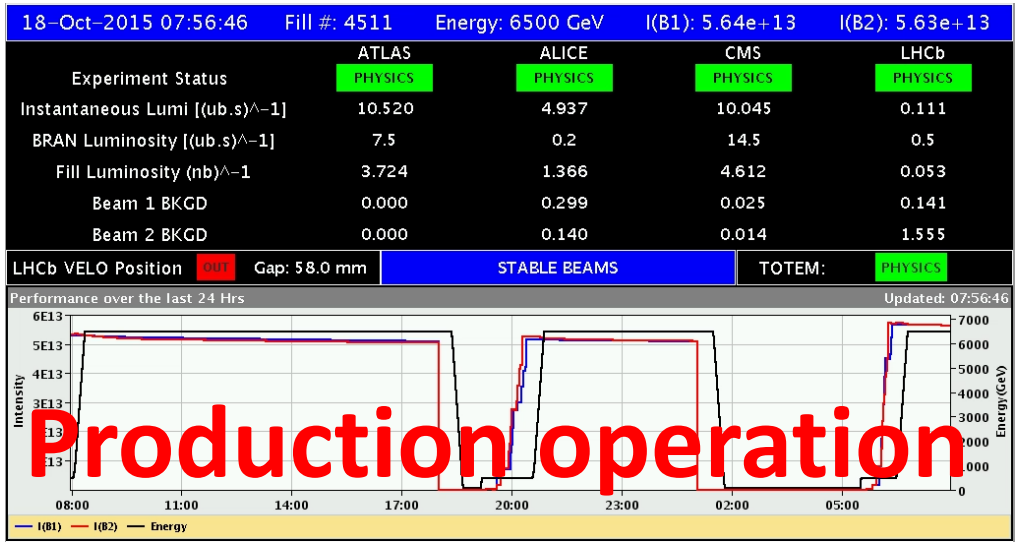
- **Operational efficiency is good**
  - injection, cycle, decay and snapback, feedbacks
- **Proven machine protection**
- **Challenges**
  - High e-cloud, UFOs, ULO, instabilities, (beam induced heating), R2E

Short term - 2016

- Stable, safe operations
- Electron cloud mitigation
- Energy 6.5 TeV, **40 cm**
- Nominal 25 ns beam, **2748 bunches**, 288 bpi
- Reasonable availability
- Excellent OP efficiency



Operation strategy

- **Choose a not too challenging operating regime that will allow stable and reproducible production**
- Keep avoidable interruptions to production to a minimum (while remaining flexible)
- **Don't compromise:**
  - Machine safety
  - "Remarkable cleaning stability with 6.5 TeV beam thanks to excellent machine **reproducibility**"

Operation Strategy

Continued improvement: incoming for 2016

- Set-up efficiency
  - Collimation (full validation for squeeze and collide in 1 fill) and still pushing
- Machine protection
  - BCCM, Collimator BPM interlock, continued vigilance
- Beam performance
  - Emittance growth, instabilities, good control of key parameters, reduction of chromaticity and octupoles,

Initial commissioning

Global machine checkout

450 GeV recommissioning

Ramp

System commissioning

- Transverse dam
- RF
- Beam i ntation
- Fe

Beam based measurements

- Optics meas. & correction
- Magnet model meas. & correction

Looking for people hunting Easter eggs in the CCC

BI status seen from OP

LHC beam instrumentation was in general very reliable in 2015 thanks to a careful equipment tests & common start up commissioning with Beam.

No **R2E failure** on instrumentation

RAM is essential to maintain and improve **Reliability and Availability**

Quality of displaying data (MMI) is essential on a control room, fixed display structure is important as the quality of the measurement.

High quality **Orbit** monitoring since beginning of LHC and 2015 was a good year.

Lifetime measurement is paramount on a collider machine especially during the critical BP like Squeeze or start Collision and Physics.

Tune measurement is now a mature tool to rely during all phase of Operation and machine development.

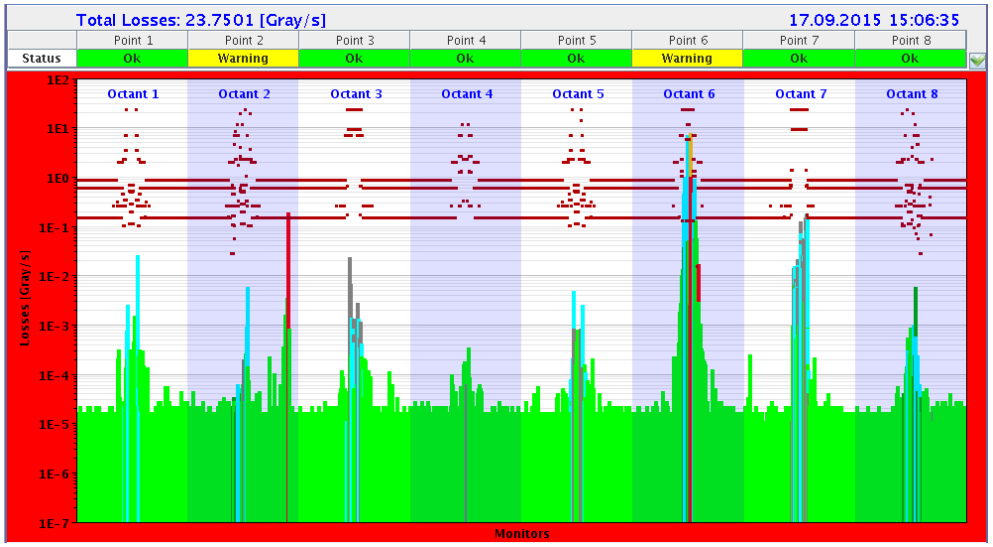
BLM

Very **reliable system** heavily used for our **Machine Protection.**
During loss maps setting up is vital.
Used on UFO/ULO measurement & investigation

BLM threshold adjustments protons is fine
IONS need more accurate adjustment we were often dumping on Collimators…

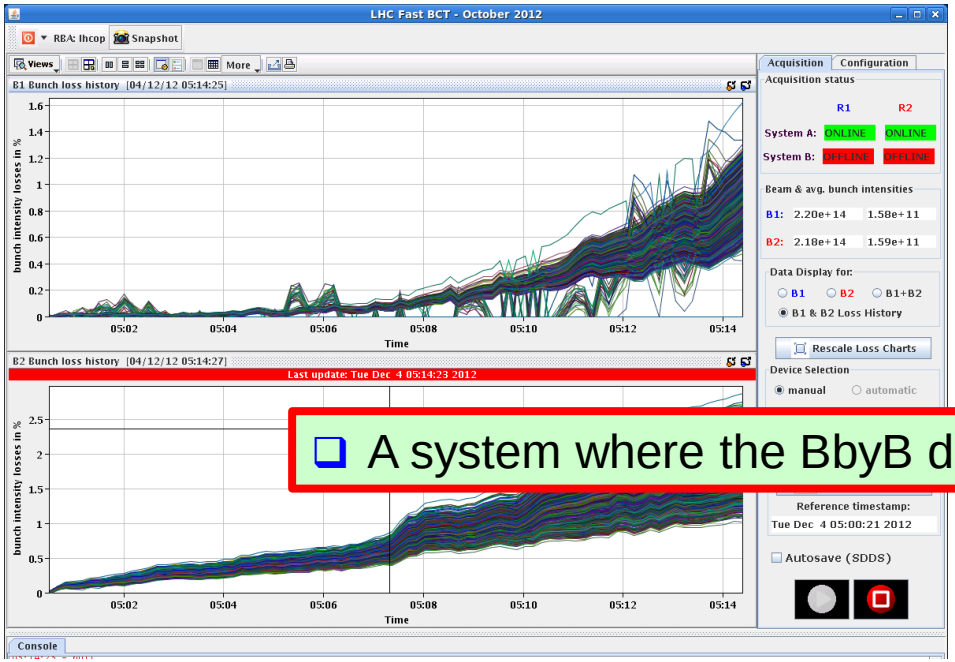
Improvements: Speed up the BLM sanity check process.

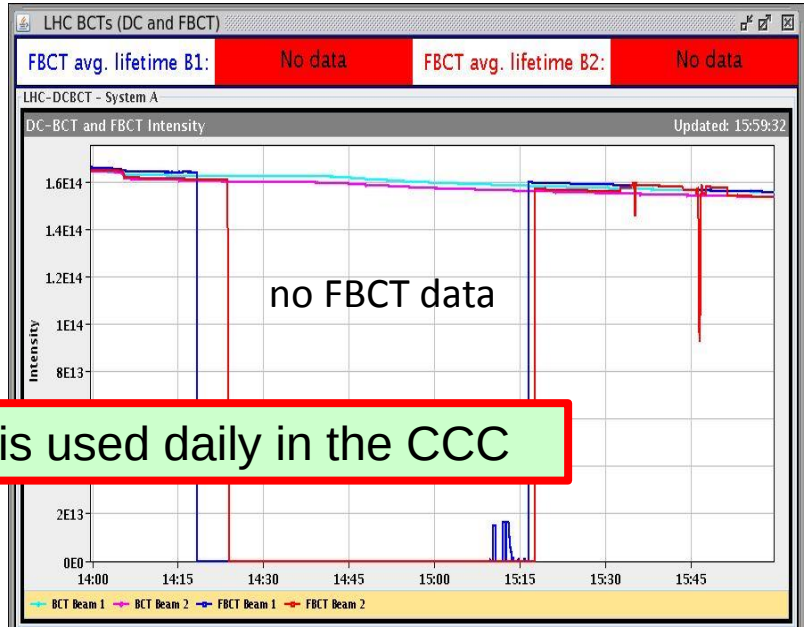
Diamond BLM very useful to have a Bunch /Bunch measurement injected beam, It would be nice also in the ring



FBCT and DC-BCT in 2015

- FBCT data not always reliable
  - needed expert interventions throughout the year (phasing, gain adjustments etc.)
- During a major part of 2015 only the BLM lifetime was used.
- New lifetime sources/devices (FBCT & DC-BCT) operational in September
  - Algorithm ok for STABLE BEAMS need improvement the rest of the LHC cycle
- FBCT total beam intensity and DC-BCT not always in agreement.





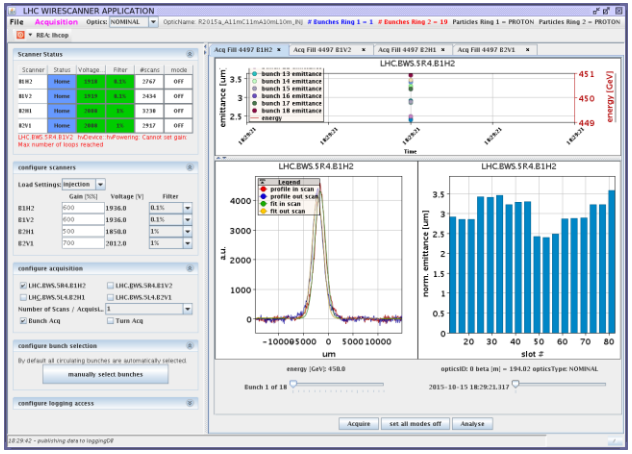
❑ A system where the BbyB data is used daily in the CCC

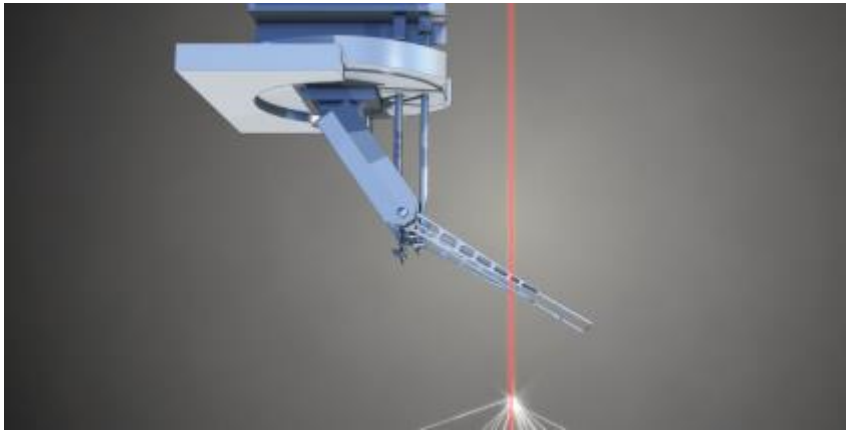
Wire Scanner in operation

Scanning single plane of each beam separately is tedious…
It would be useful to start simultaneously Beam 1 and Beam 2

WS settings better if according to injection pattern
(setting Gains, and Filters, is time consuming).
Bunch selection (now FBCT) to be improved >> better if read directly from the BQM or injection sequencer, now it update slowly.

Availability >> An initial dry scan was needed before each first measurement and after every Gains change to preset high voltage >> WHY!!
Machine studies: Continuous scan on B1/B2 or Plane



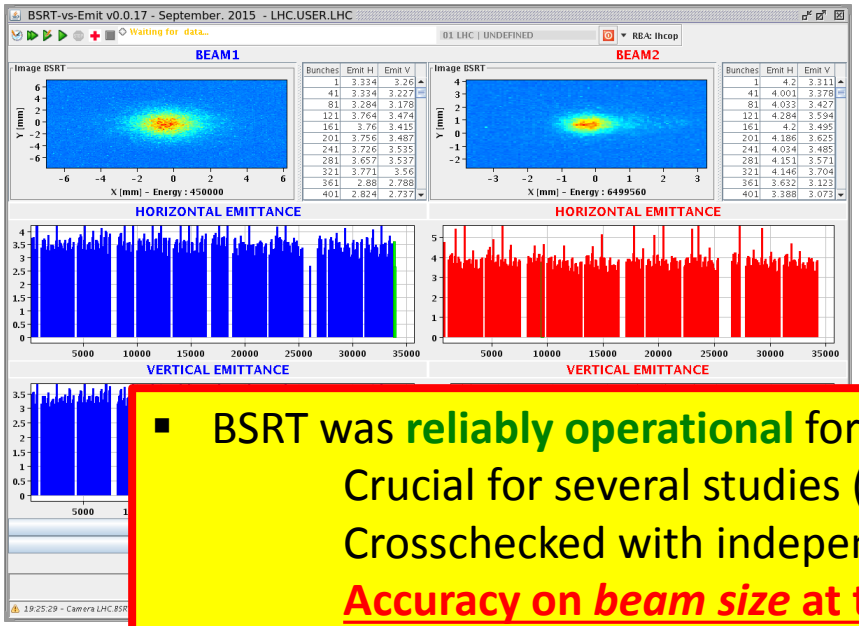


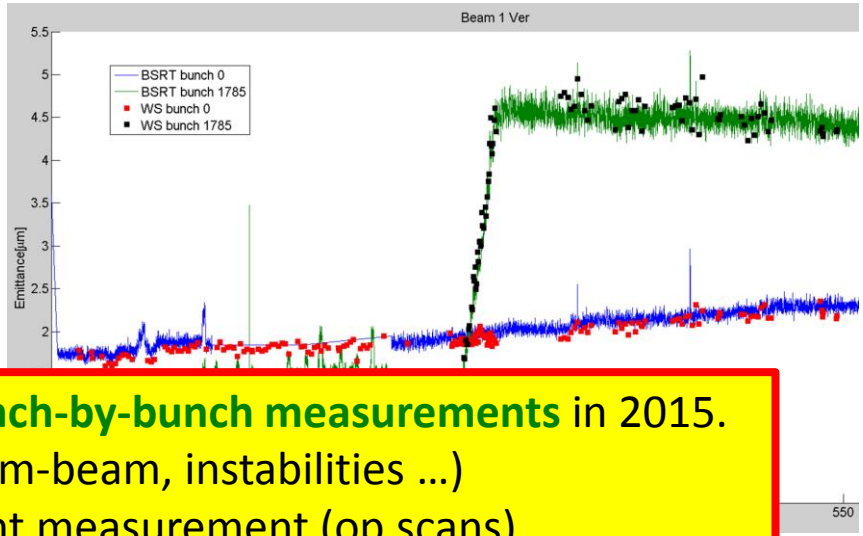
BSRT: extremely useful for Beam quality at injection before ramp.
(crucial to decide to start the ramp)
Desired additional feature >> choose a set of trains to monitor their emittance blowup evolution.

BSRT & TIMBER

It would be useful to have averaged values (min, avg, max, std dev) of measured emittance or beam size. Now only possible with external scripts and tools (matlab, python, …) >> not really practical in operation, for quick analysis

Scan time due to the high number of bunches is lengthy average almost 5 bunch/sec

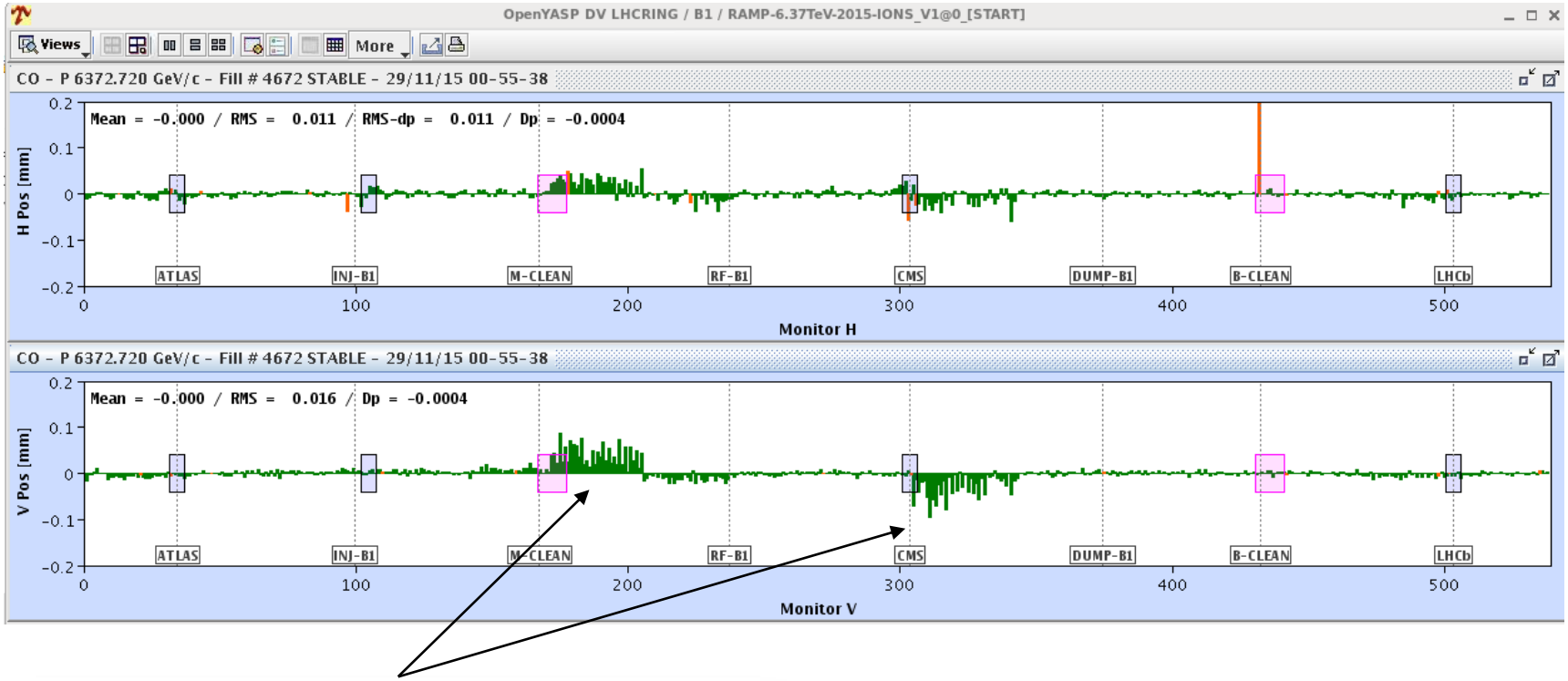




- BSRT was **reliably operational** for **bunch-by-bunch measurements** in 2015.
  Crucial for several studies (beam-beam, instabilities …)
  Crosschecked with independent measurement (op scans)
  Accuracy on *beam size* at the level of 5%

Systematic orbit errors

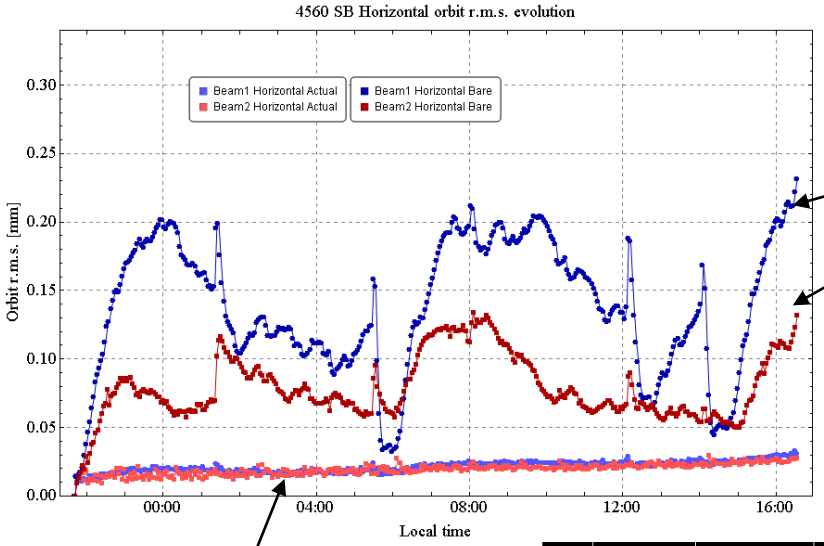
- The orbit quality was improved a lot with the rack cooling. There are remaining effects, smaller by factor ~5-10 wrt Run 1.
  - *This improvement allowed us **to run the OFB in SB !***
  - *Some crates could still be improved, mainly around points 3, 4 and 5.*



Imperfect rack temperature stabilization

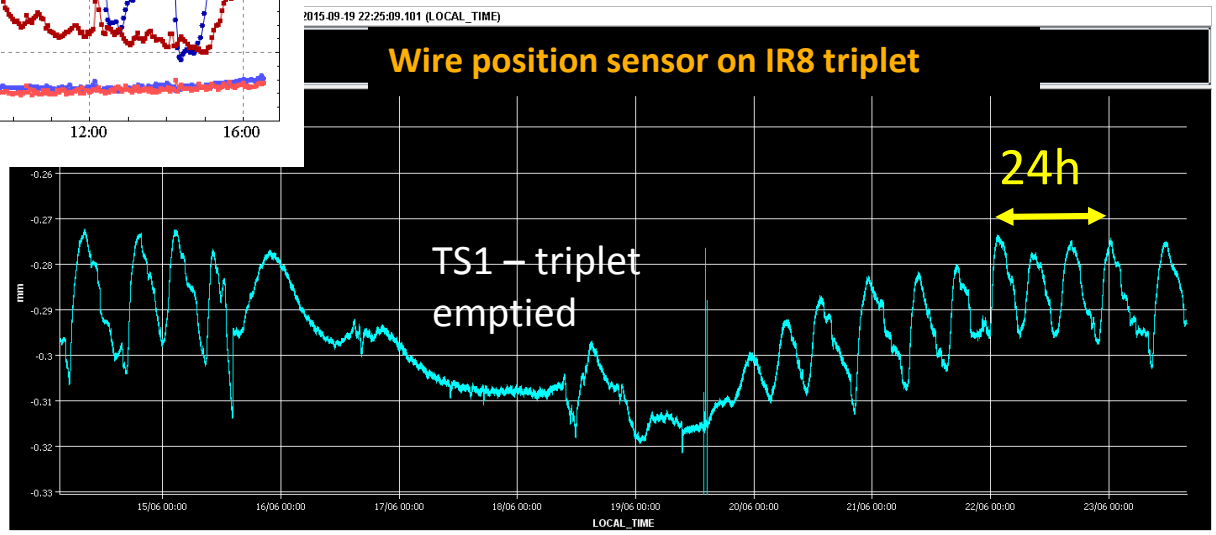
Orbit in stable beams

- The triplet movement in R8 leads to orbit drifts of up to ~0.2 mm rms, period of ~ 8 hours. Present as soon as triplet is filled with Helium. Cause is in the process is being understood.
  - *Compensated by OFB in stable beams (gentle correction, not interfering with lumi scans…).*



Orbit rms without orbit FB (correction unfolded)

Actual orbit rms with orbit FB



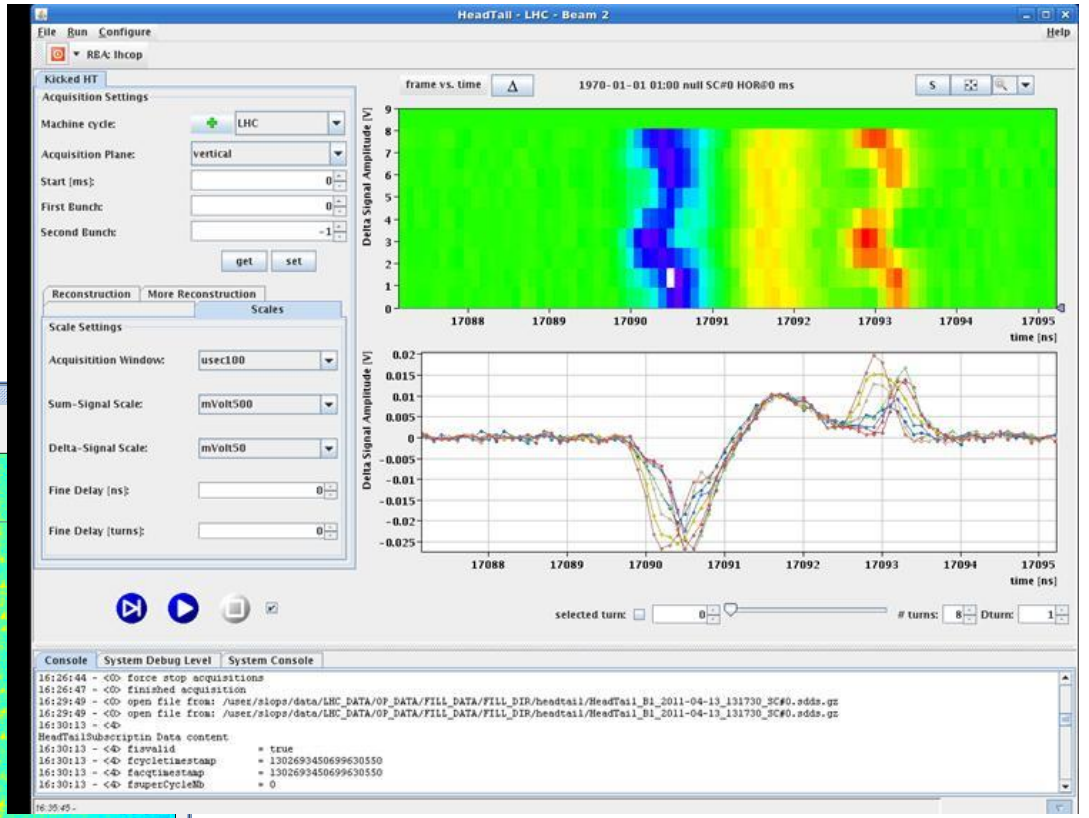
Measurement instabilities

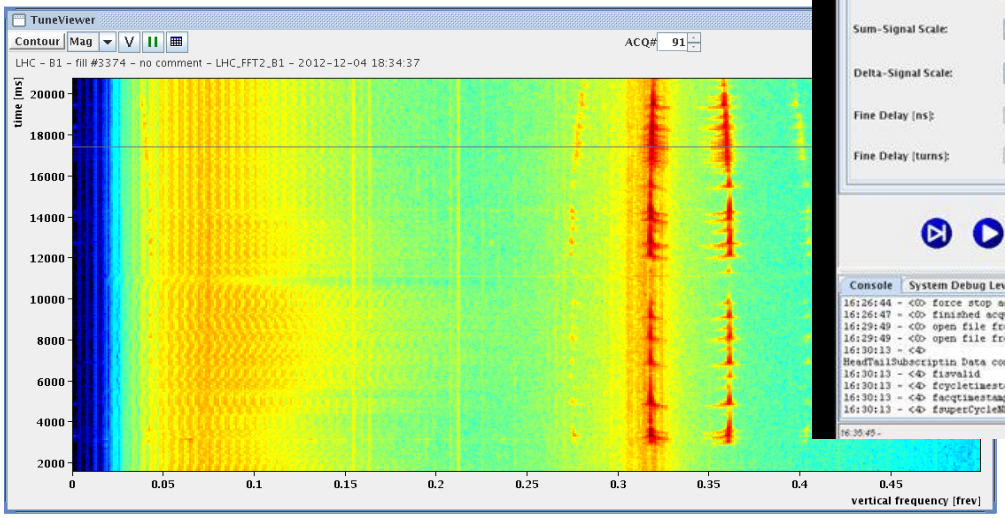
Instabilities 2012
mainly observed by BBQ & Transverse damper activity

The **Head tail monitor** enables to look inside the bunch and understand the type of instability by analyzing the transverse motion. (See Digitizes BPM)

His operational development is paramount as it is the only device that can observe the mode of instability.

Instability mode 1





Benoit Salvant, R.Steinhagen

Headtail monitor

No major hardware change … **but huge progress since 2012**!

→ **simultaneous acquisition in H and V**

→ **instability trigger network** (LIST)

→ **more robust acquisition chain**

Very **useful tool** to catch and identify instabilities during MDs & operation (instabilities at injection).

If triggered correctly, it can give information on:

→ which bunch(es) get(s) unstable

→ (can also be inferred from FBCT indirectly and ADT if triggered)

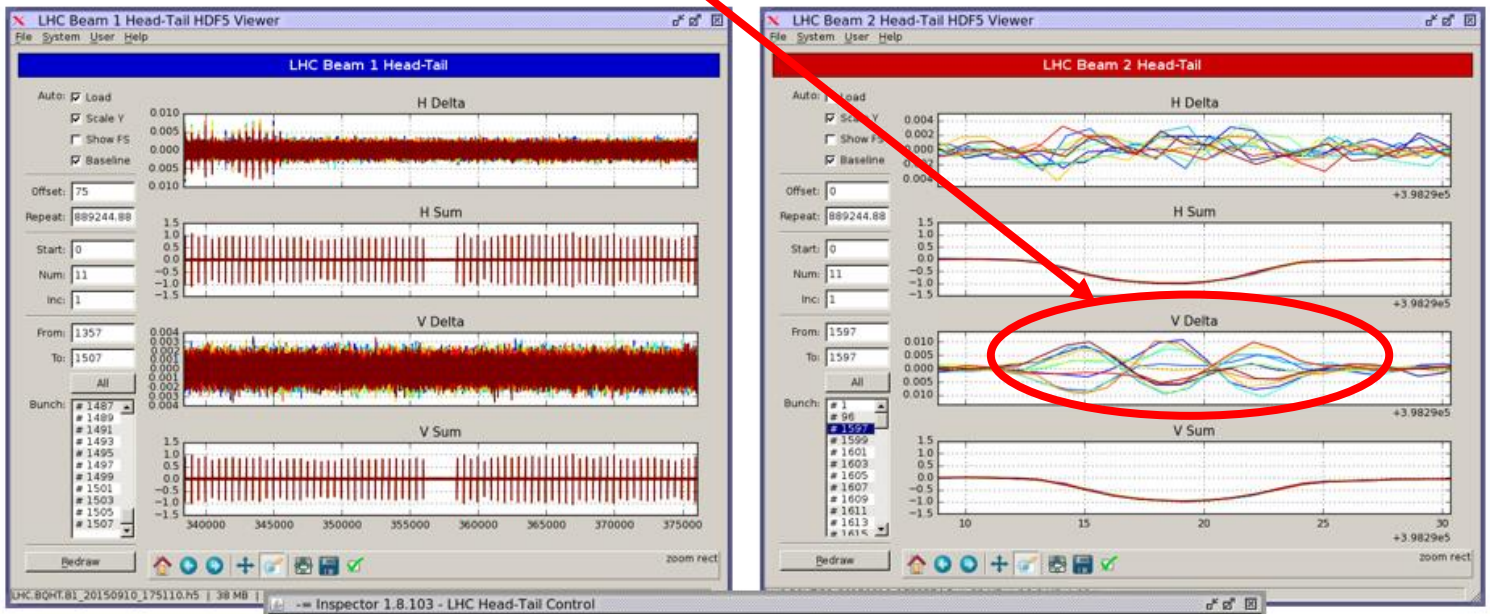
→ whether it is a coupled bunch instability

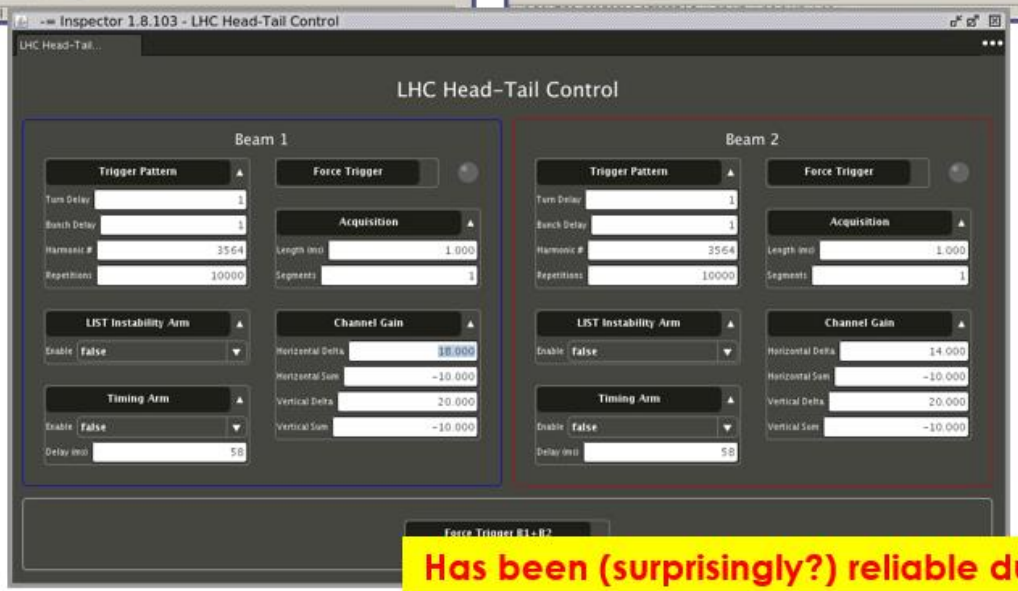
→ (can also be inferred by ADT if triggered)

→ how each bunch gets unstable

→ (HT monitor is the only device that allows identifying the radial mode of a Headtail instability by looking at the number of nodes)

Vertical instability with intrabunch mode 2



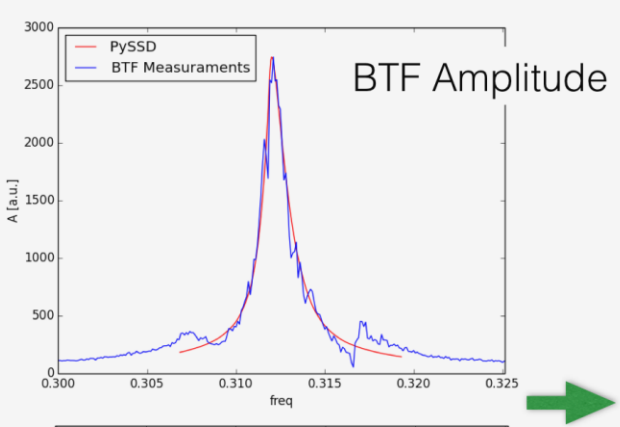


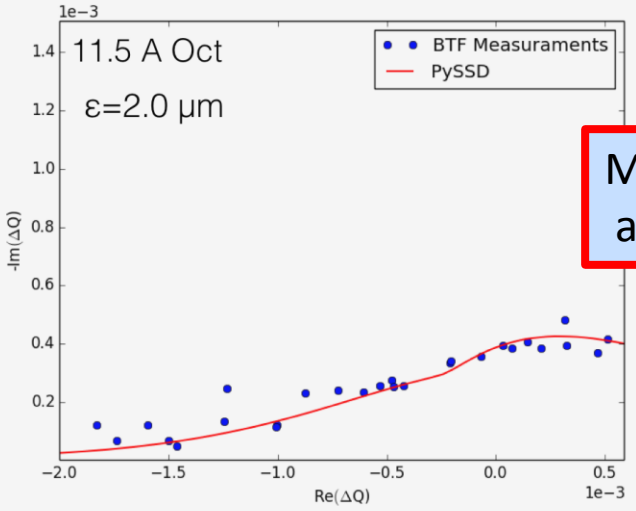
Courtesy Tom Levens
Evian 2015

Has been (surprisingly?) reliable during 2015…

Beam Transfer Function

- **Beam Transfer Function**
  - Useful at LHC to understand the tune spread.
  - Study beam beam coherent modes normally Landau damped, not visible on BBQ
  - 2015 we started to implement this technique very promising.





Measured stability diagram at injection without Damper

Wish List:

- Excitation amplitude calibration
- Bunch by bunch measurements
- B2 vertical signal fixed
- More flexible GUI

Tatiana Pieloni & Claudia Tambasco

I wish….I wish….

- Diamond detector (BLM) : ABP expert for the tune measurement it need bigger data buffer (now limited to 30ms, can be pushed to 1s)
- Emittance measurement bunch by bunch at high energy (BSRT calibrated)
- Trigger on demand to analyse the instability
- Automatic measurement to be adapted to new instabilities situation
- Schottky measurement >> much better
- Beam Transfer Function work in MD not yet operational
- Crystal detector measurement of “tails” at larger amplitude (non destructive)
- Head tail monitor : not yet operational, need to acquire both plane both beam at the same time, efficient triggering and adequate gain needed.

Situation in 2012

Required observable	ADT	BBQ	BSRT	Diamond detector	Fast BCT	HeadTail monitor	MIM frequency analysis	Schottky monitor
Average tune before the instability								
Average **tune during the instability**								
Bunch by bunch **tune before the instability**								
Bunch by bunch **tune during the instability**								
Bunch by bunch **instability growth rate**								
Average **chromaticity**								
Intrabunch motion							?	
Coupled bunch motion							?	
Bunch by bunch **transverse emittance** (relative)								
Bunch by bunch **transverse emittance** (absolute)								
Bunch by bunch **intensity/losses**								
Could be used as **trigger**								

Working well
Promising (data logging/triggering issue)
Should be improved (hardware/signal quality issue)
Not working
Not relevant

Situation in 2015

Required observable	ADT	BBQ	BSRT	Diamond detector	Fast BCT	HeadTail monitor	MIM frequency analysis	Schottky monitor
Average tune before the instability								
Average **tune during the instability**								
Bunch by bunch **tune before the instability**								
Bunch by bunch **tune during the instability**								
Bunch by bunch **instability growth rate**								
Average **chromaticity**								
Intra-bunch motion							?	
Coupled bunch motion							?	
Bunch by bunch **transverse emittance** (relative)								?
Bunch by bunch **transverse emittance** (absolute)								
Bunch by bunch **intensity/losses**								
Could be used as **trigger**								

Working well
Promising (data logging/triggering issue)
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Not working
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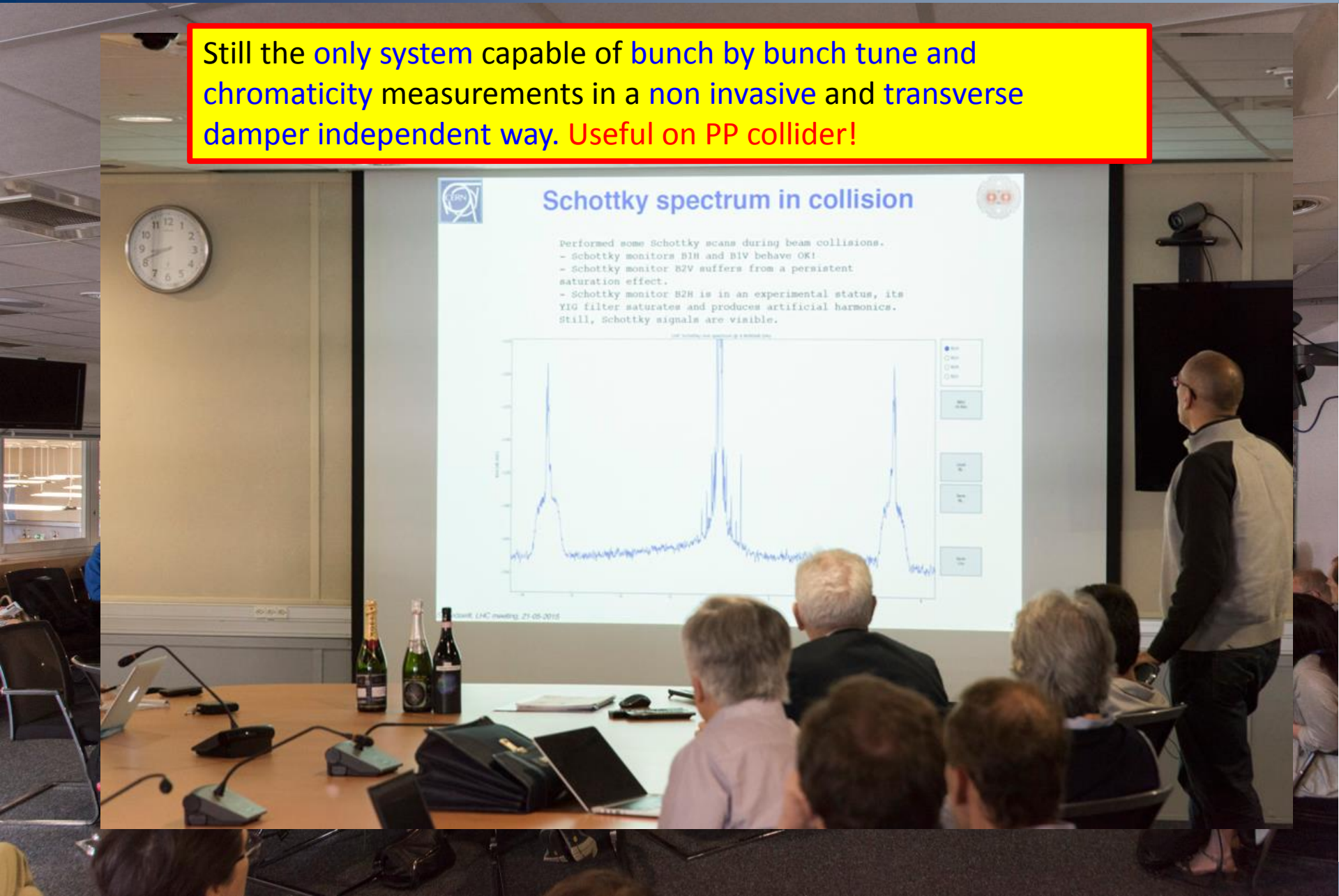
Chromaticity

- **Chromaticity**
- Chromaticity measurement and control extremely important on a proton proton collider. (LHC nominal chromaticity +2 >> now + 15/10)
- **2012 run with** high energy instabilities it reinforced this need.
- 2015 slightly better
- **BBQ** is the only instrument capable to measure it. Now a big hope on schottky
- Chromaticity knowledge (better than 1 unit)
  - bunch by bunch at any time is the key to understand the instabilities issues.
- **Schottky** development should be encouraged to get reliable continuous chromaticity measurements.

First 13 TeV Stable Beams – 8:30 meeting

Still the only system capable of bunch by bunch tune and chromaticity measurements in a non invasive and transverse damper independent way. Useful on PP collider!



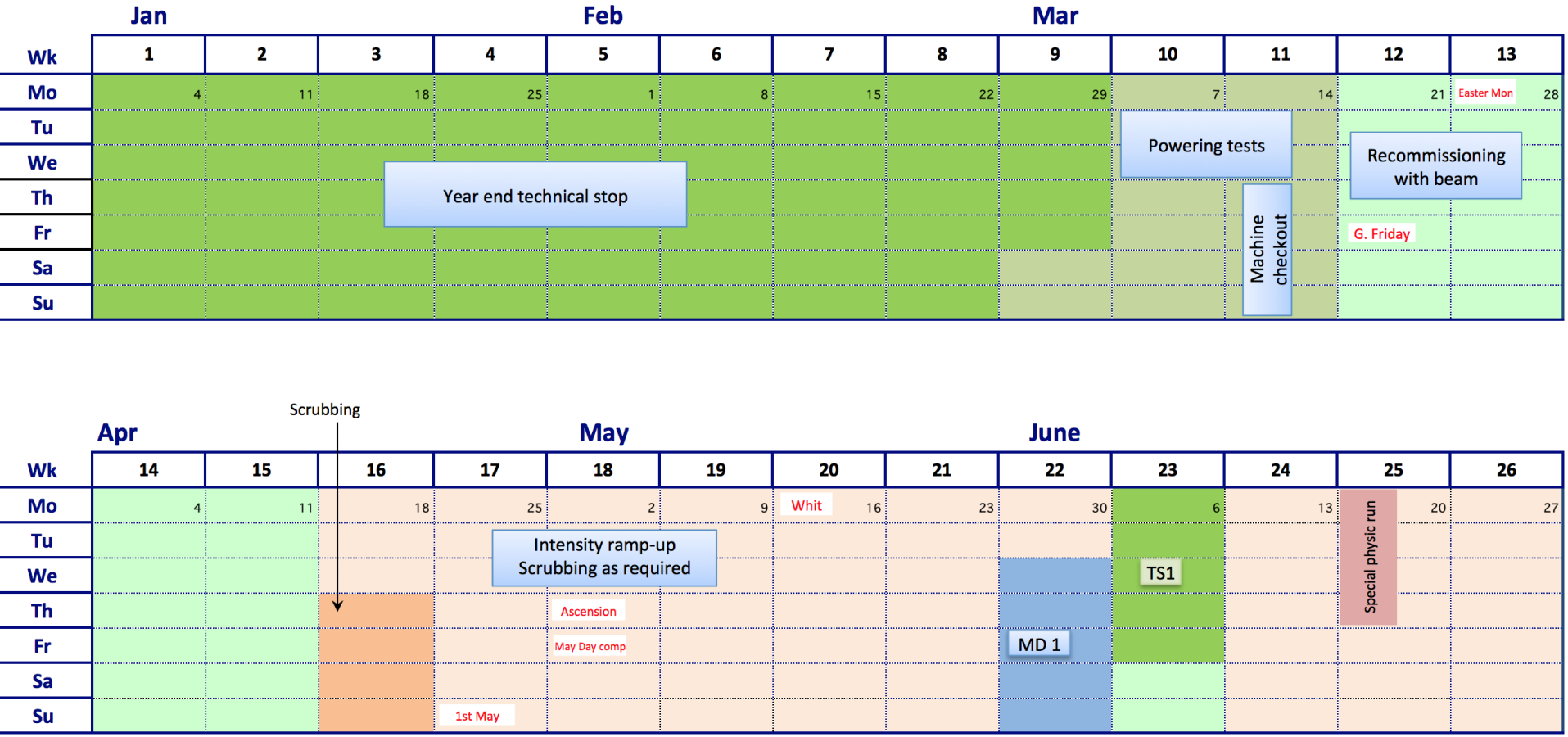
Conclusions

- Excellent collaboration between the **Beam instrumentation & OP team.**
- **The LHC overall performance** is strongly related to the quality of Beam observation and diagnostics.
- **2016 Production run** will demand systems **stability** and high **availability**
- **A** further **step of bunch by bunch** observation will help to investigate the origin of instabilities limiting the LHC performance.
- These tools will allow **to better control the LHC machine parameters** to **mitigate the instabilities** and optimize its operation by **maximizing the integrated luminosity.**

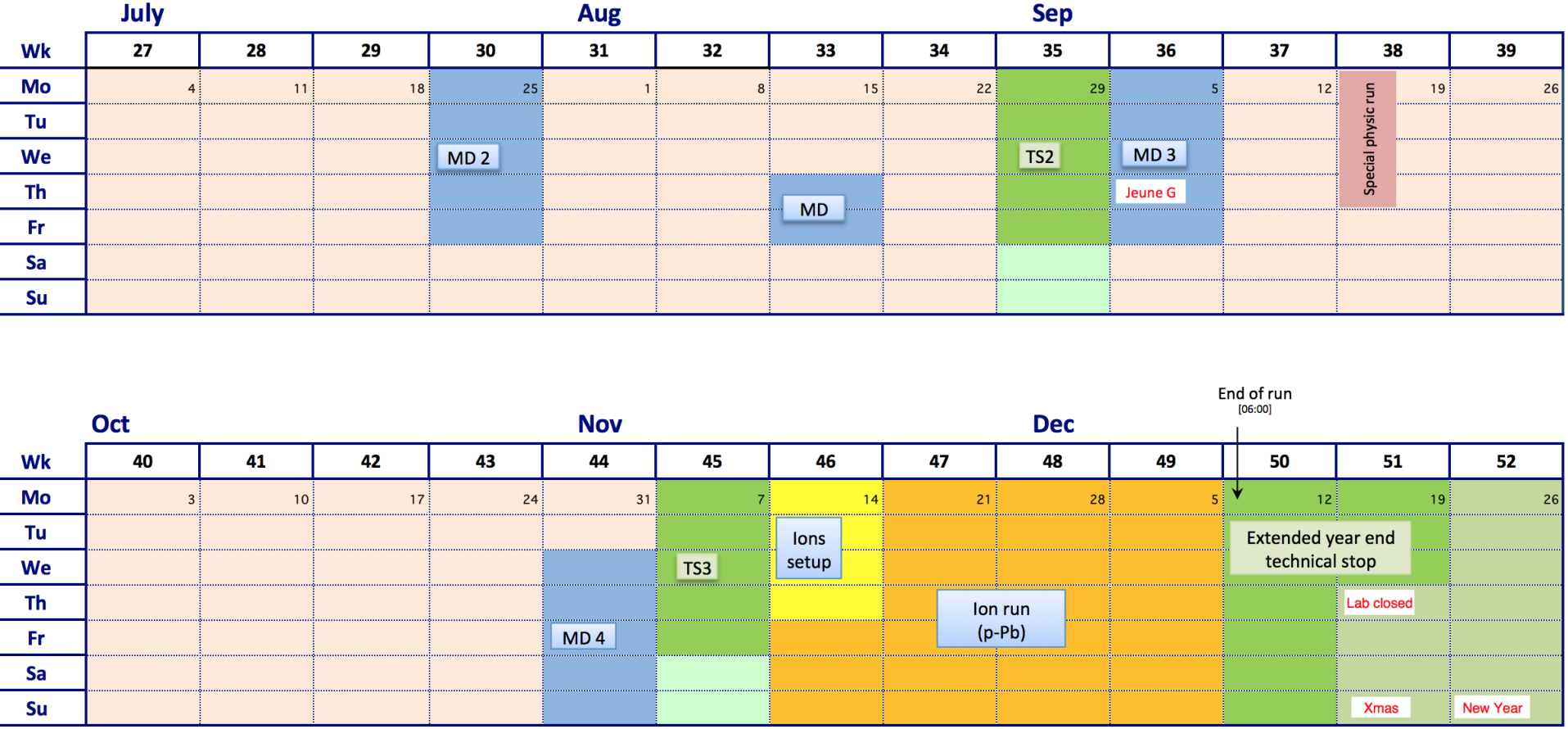
"Outstanding development of beam diagnostics
Tunes (3 instruments), emm (3), Intensity (3), lumi (2), BPM"
Vladimir Shiltsev - Beam-beam workshop, CERN - March 18, 2013

- **Acknowledgements:** Op group, BI group, ABP group, W.Herr, T.Pieloni, J.Wenninger, X.Buffat, B.Salvant, M.Lamont.

2016 Q1/Q2 (v1.1)



2016 Q3/Q4 (v1.1)



Timing of MD2, floating MD, special runs to be determined

2016 version 1.1

Phase	Days
Initial Commissioning	28
Scrubbing: 4 days initially and then as required during ramp-up	7
Proton physics 25 ns	**152**
Special physics runs (high beta*; VdM)	8
Machine development	22
Technical stops	15
Technical stop recovery	6
Ion setup/proton-lead run	4 + 24
Total	**266 days (38 weeks)**

2016 beam parameters (nominal 25 ns)

Energy	6.5 TeV
Bunch spacing	25 ns
Bunch population	~1.25e11
Max bunches/injection	288
Max. number bunches	2748
Nc GPDs	2736
Emittance exit SPS	2.7 mm.mrad
Emittance into SB	3.4 mm.mrad
Beta* GPDs	40 or 50
Crossing angle GPDs	185 or 165

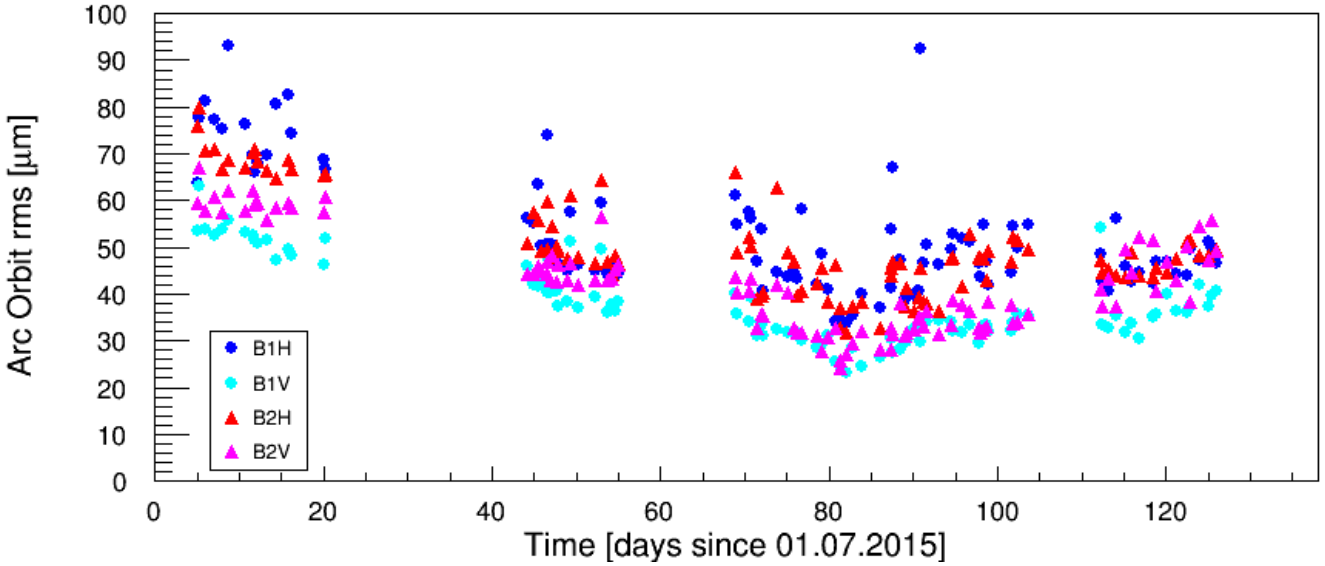
Note the limit of around 1.3e11ppb

record peak luminosity

	2015	2012
energy [TeV]	6.5	4
bunch spacing [ns]	25	50
beta* [cm] (crossing angle [urad])	80 (290)	60 (290)
e*[mm] at start of fill	3.5	2.5
max. bunch population [10^{11} p/bunch]	1.15	1.6
max. number of bunches/colliding pairs IP1/5	2244/2232	1380
max. stored energy [MJ]	270	140
peak luminosity [10^{34} $cm^{-2}s^{-1}$] in IP1/5	~0.5	>0.7

Long term orbit reproducibility

- The evolution of the orbit rms excluding the areas close to IR1, IR2, IR5 and IR8 is an indicator of the long term reproducibility of the orbit – includes BPM errors, rack temperature ground motion, OFB corrections etc



rms over all healthy BPMs except IR1, IR2, IR5, and IR8 wrt reference orbit

reference fill in 25 ns period (t ~ 85).

1 point / fill, ~5 mins after start of SB.

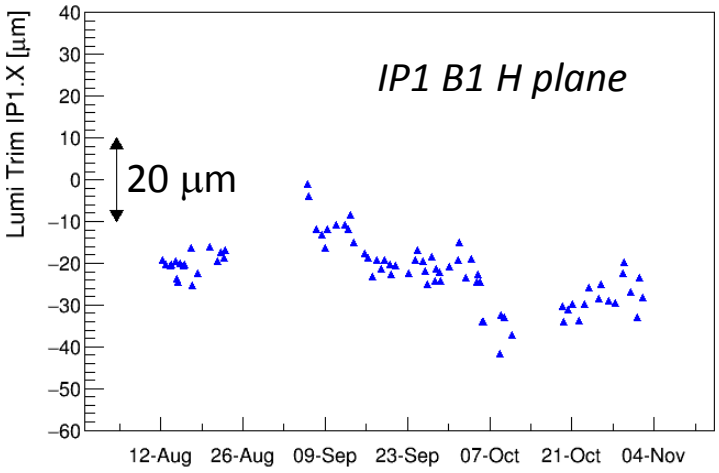
The orbit reproducibility is ~50 μm over 3 months.

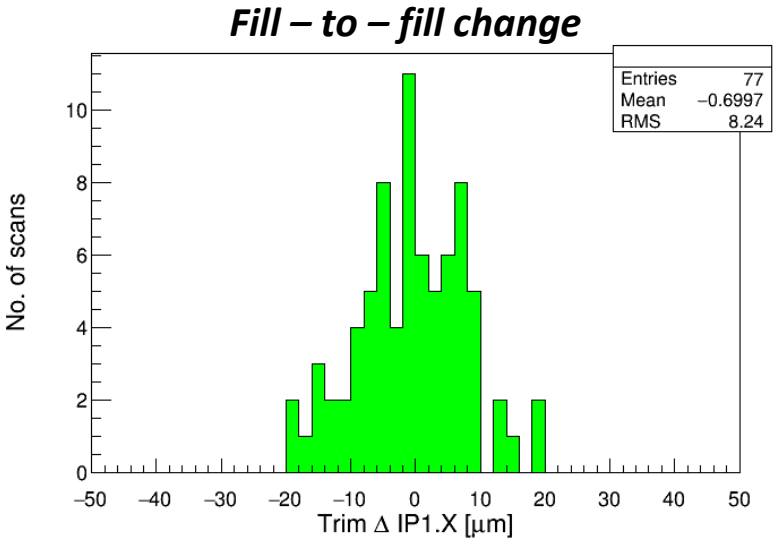
Long and short term reproducibility are quite similar.

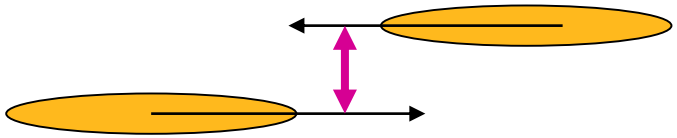
Slightly worse reproducibility in H plane ⇔ IR8 triplet issue.

Orbit reproducibility in collision

- The BPM quality & orbit feedback determine how well one can reproduce the collisions in the LHC.
- In every fill the beam overlap is optimized for maximum luminosity. The corrections that have to be applied in collision are better than in 2012.
  - *Typical fill-2-fill B1-B2 offset rms is 8 μm < σ/2.*

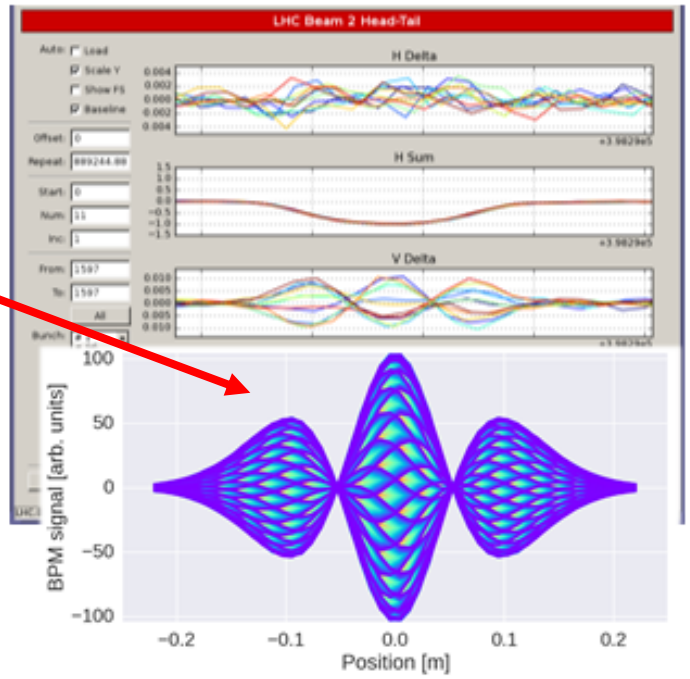






Diagnostics requirements for instabilities

- Important fundamental diagnostics that was always used: FBCT, BSRT, stable phase shifts, wire scanners, BBQ
- New in 2015:
- HEADTAIL monitor with instability trigger:
  - detection of single/coupled bunch instabilities
  - gives intra-bunch motion to be compared with simulations and validate the instability mechanism
  - crucial for specification of wideband feedback systems



PyHEADTAIL simulation

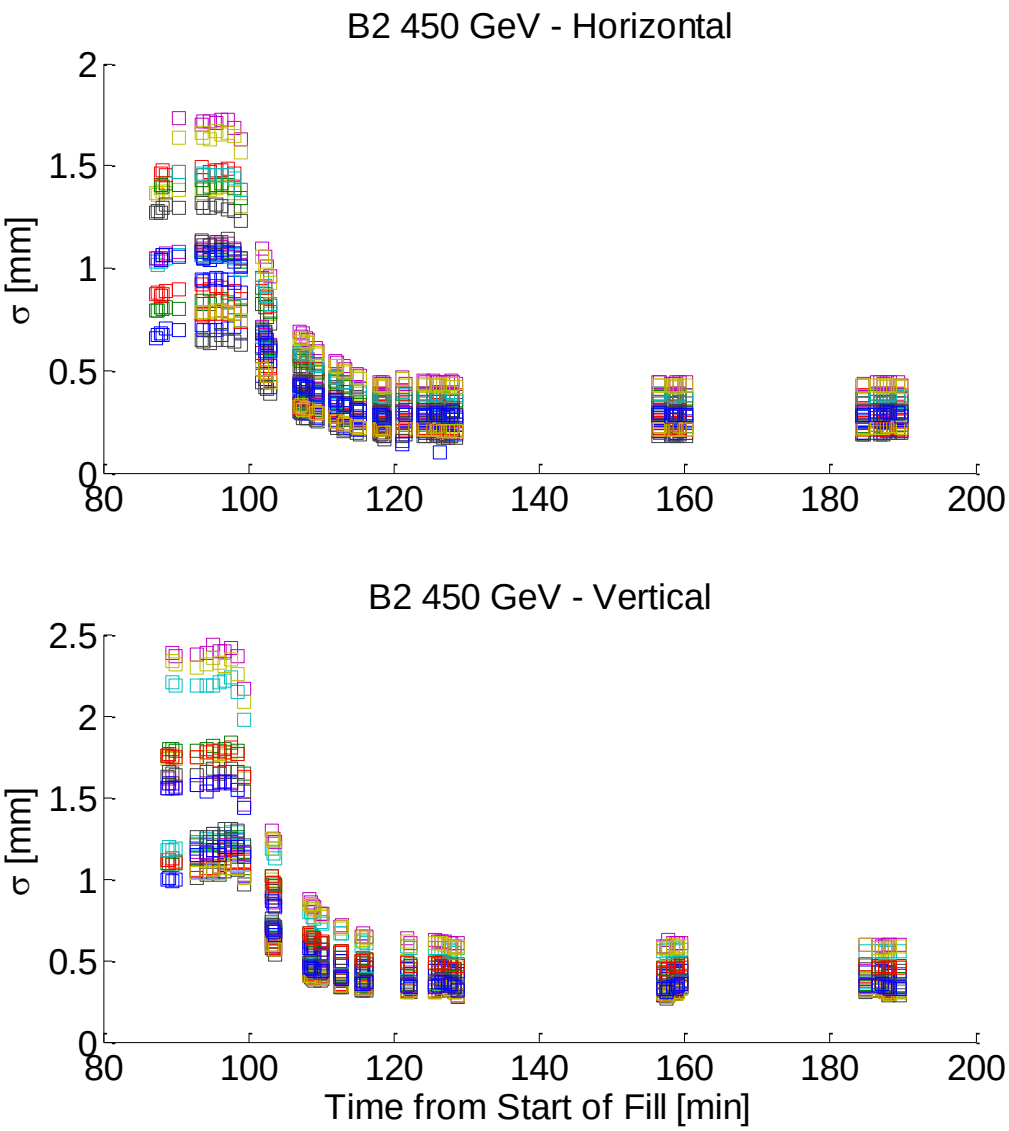
For more details see T. Levens, EVIAN 2015

Performance Run II

This allows a BSRT Calibration During RAMP (from 2 TeV upward)

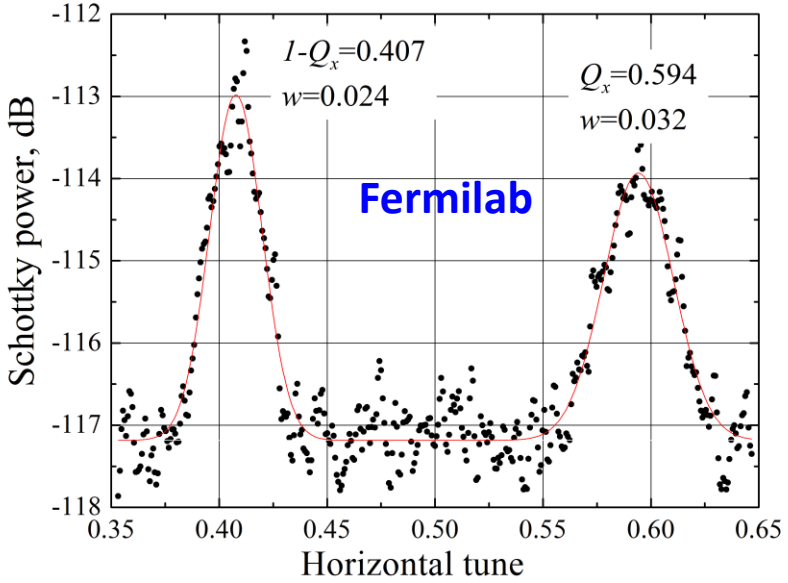
WS

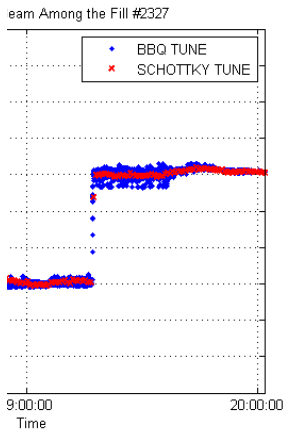
BSRT



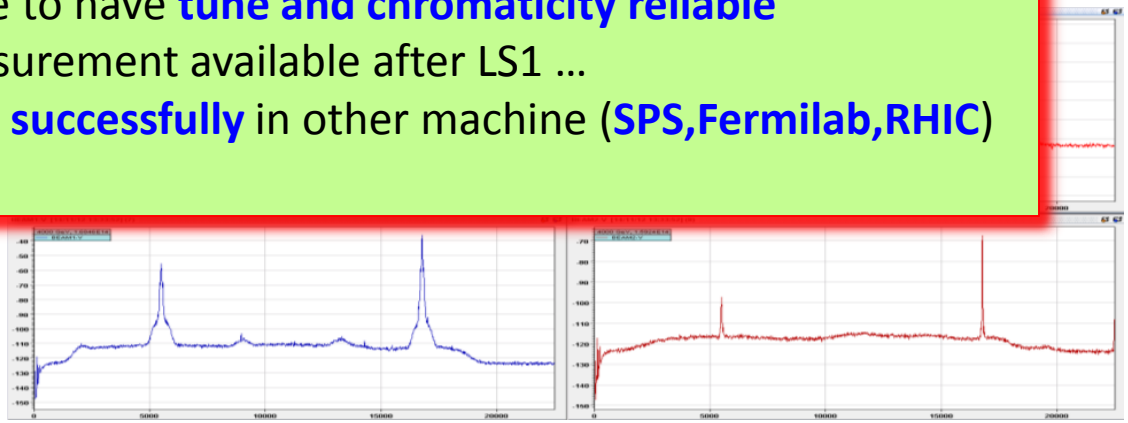
Schottky System

- **Protons Run 2012**
- Signal *good on B1H* for single & multi bunch measurements at injection & *stable beams*
- **Large coherent signals saturate and destroy the pre-amps in the other systems!**
- Still the only system capable of bunch by bun tune and chromaticity measurements in a non invasive and transverse damper independent way





Hope to have **tune and chromaticity reliable** measurement available after LS1 …
used **successfully** in other machine (**SPS,Fermilab,RHIC**)



Rhodri Jones

- **Tune**
- Tune measurement is vital Beam Operation & Beam Beam studies.
- The BBQ system facilitated a reliable commissioning and operation of the LHC.
- Single bunch tune could be measured by Schottky.
- **Transverse Damper ADT buffer measure 72 turns, we need to increase it**

BBQ