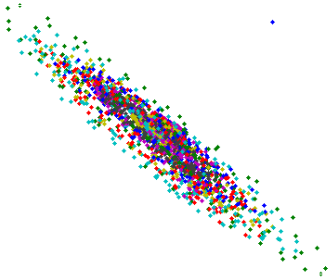
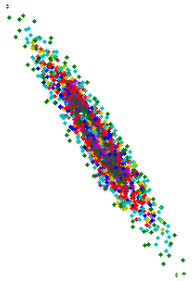
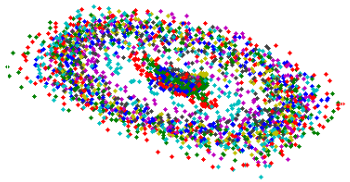


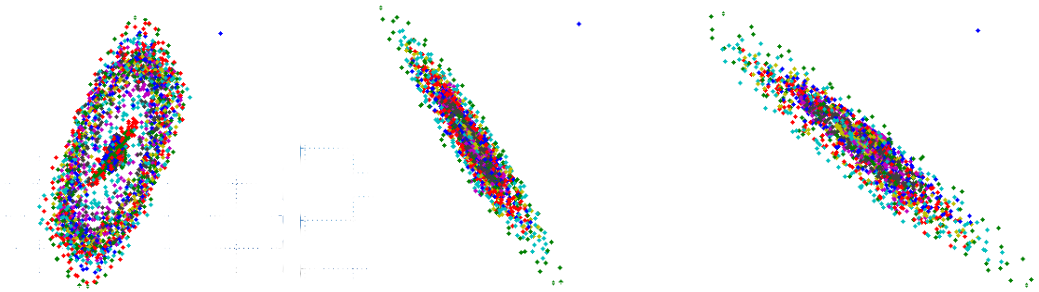




LHC transverse feedback

W. Höfle, G. Kotzian, T. Levens, D. Valuch

Special thanks to:
A. Boucherie, A. Butterworth, J.C. Guillaume, D. Jacquet, M. Jaussi, C. Julie, V. Kain, F. Killing, E. Montesinos, C. Goncalves Perez, A. Rey, Novatel Telecomunicaciones team, X. Serrano, T. Wlostowski



ADT pre-LS1

- Primarily designed for:
  - Damping of injection oscillations
  - Damping of oscillations driven by coupled bunch instability
  - Important role in preservation of the beam's transverse emittance

- Since the LHC start in 2008 it grew into (view from the CCC):

Injection oscillation damping

Injection cleaning

Abort gap cleaning

Transverse blow-up (used for loss maps)

Instabilities detection (with the damper PU)

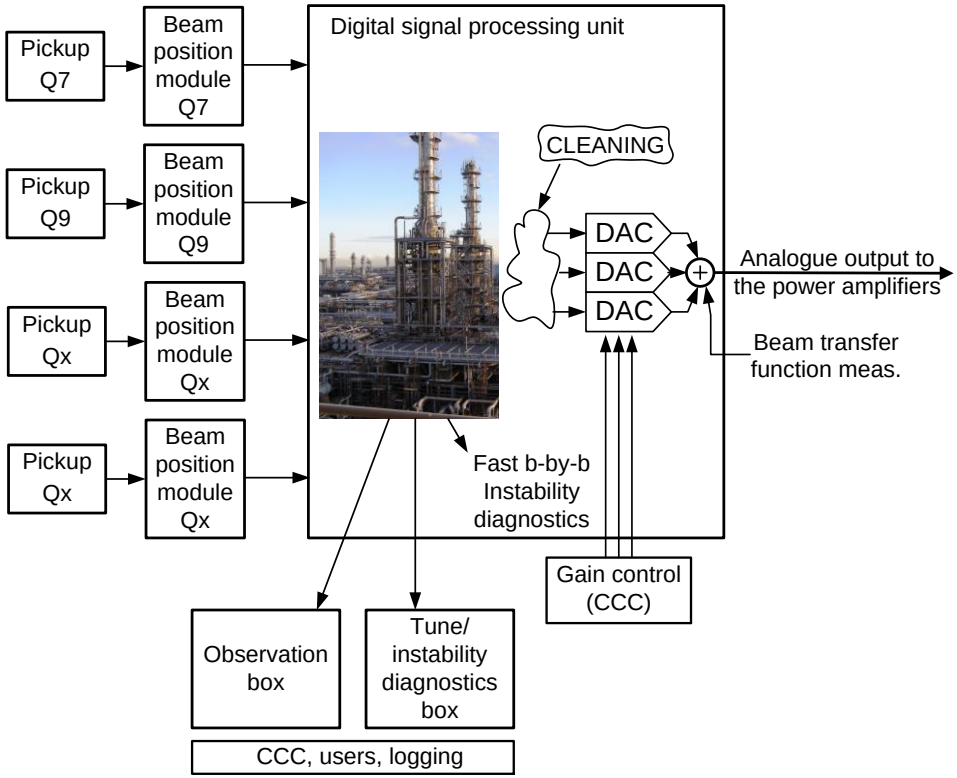
Tune measurement

Slide: Delphine Jacquet, LHC Beam Operation Workshop, Evian 2012

ADT during the LS1

ADT post-LS1 (main features)

- Combination of four pickups
- Implementation of all features added during run I
- More powerful digital signal processing
- Separate control for all features with high resolution calls for independent output DACs
  - Transverse feedback loop
  - Witness bunches
  - AG/IG cleaning, excitation
- High bandwidth links to external observation devices
- Complementary data processing algorithm to detect anti-symmetric intra-bunch motion



New features for Run II

- Four pick-ups per beam, per plane, located at point 4
  - ECR for Q7-Q8 pickup swap with BPF system - approval in progress
  - All BPCRs existing, only question of connecting them to ADT

B1 horizontal	Q10L	Q9L	Q8L	Q7L	Q7R	Q8R	Q9R	Q10R
		b = 111 m		b = 106 m		b = 133 m		b = 153 m
		existing		existing		new		new

B1 vertical	Q10L	Q9L	Q8L		Q7R	Q8R	Q9R	Q10R
	b = 175 m		b = 155 m		b = 161 m		b = 142 m	
	new		new		existing		existing	

B2 horizontal	Q10L	Q9L	Q8L		Q7R	Q8R	Q9R	Q10R
	b = 158 m		b = 96 m		b = 150 m		b = 101 m	
	new		new		existing		existing	

B2 vertical	Q10L	Q9L	Q8L	Q7L	Q7R	Q8R	Q9R	Q10R
		b = 160 m		b = 167 m		b = 151 m		b = 180 m
		existing		existing		new		new

New features for Run II

- Estimated improvement in S/N (reference: 1 pick-up @ β =100 m)

$$\frac{S}{N} = 20\text{dB} \times \log_{10} \frac{\sum_{n=1}^{N} \sqrt{\beta_n / 100\text{m}}}{\sqrt{N}}$$

	Run 1 (2 PU) Q7,Q9	Run 2 (4 PU) Q7,Q9,Q10	Run 2 (4 PU) Q7,Q8,Q9,Q10	Additional improvement with BI swap
H.B1	3.8 dB	5.6 dB	7.0 dB	1.4 dB
V.B1	4.2 dB	7.4 dB	8.0 dB	0.6 dB
H.B2	4.4 dB	5.9 dB	8.0 dB	2.1 dB
V.B2	4.9 dB	6.6 dB	8.2 dB	1.6 dB

W. Hofle, G. Kotzian, D. Valuch: PU Choices for ADT - Plan for Run 2. LBOC 14.4.2014

New features for Run II

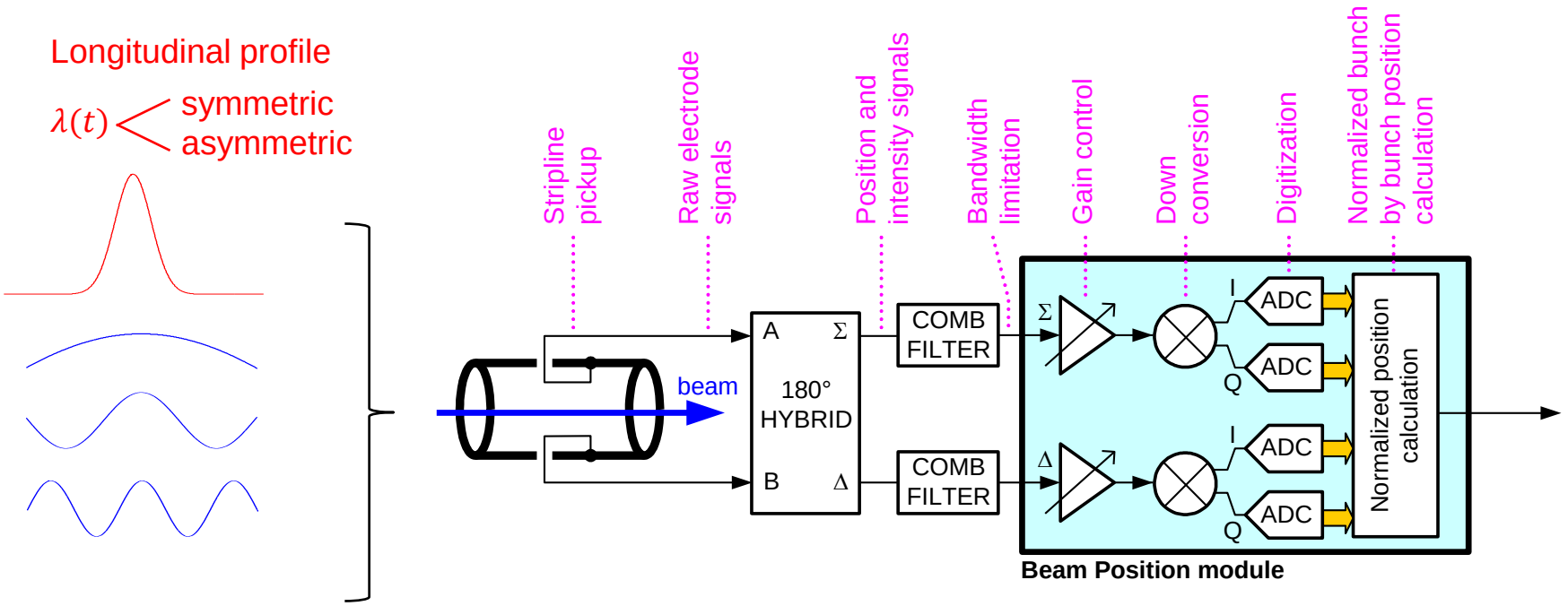
- More powerful signal processing hardware for advanced functionality
- Separate control for all features with high resolution calls for multiple independent output DACs
  - Better “gain modulation” within turn
  - Standard/high bandwidth treatment of different bunches/trains
  - Cycle independent AG/IG cleaning - Cleaning automation!
  - Independent treatment of witness bunches, tune measurement with excitation etc.

New features for Run II

- Fast on-the-fly data analysis, can detect intra-bunch, symmetric oscillation patterns, bunch-by-bunch, within few turns and generate a trigger

- Alternative data processing algorithm can also give hints on anti-symmetric oscillation patterns... and generate a trigger (see G. Kotzian et al: Sensitivity of LHC ADT to intra-bunch motion, BE-ABP-HSC meeting, 22.1. 2014)

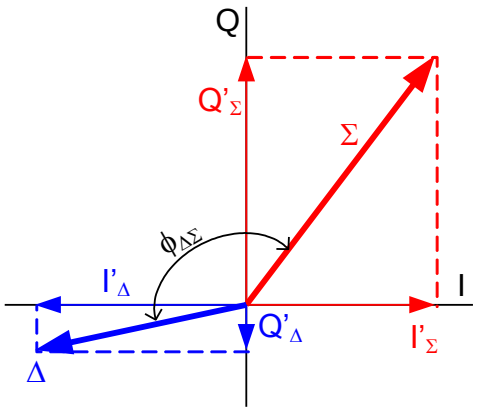
Complementary data processing algorithm



Transverse oscillation → Movement of centre-of-charge → Normalized transverse position $\mathrm{x}[n]$

pattern $x(t)$ < even symmetric / odd symmetric

Complementary data processing algorithm

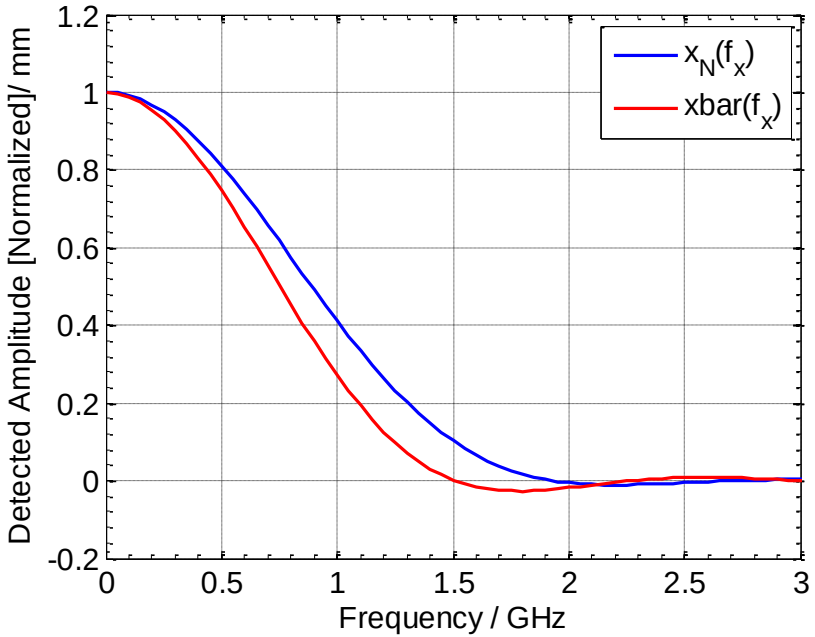


Normalized position as currently implemented in the BeamPos HW

$$x_N = \frac{I_\Delta I_\Sigma + Q_\Delta Q_\Sigma}{I_\Sigma^2 + Q_\Sigma^2}$$

Movement of centre-of-charges

$$\bar{x} = \int_{-\infty}^{\infty} x(t)\lambda(t)\,\mathrm{d}t$$

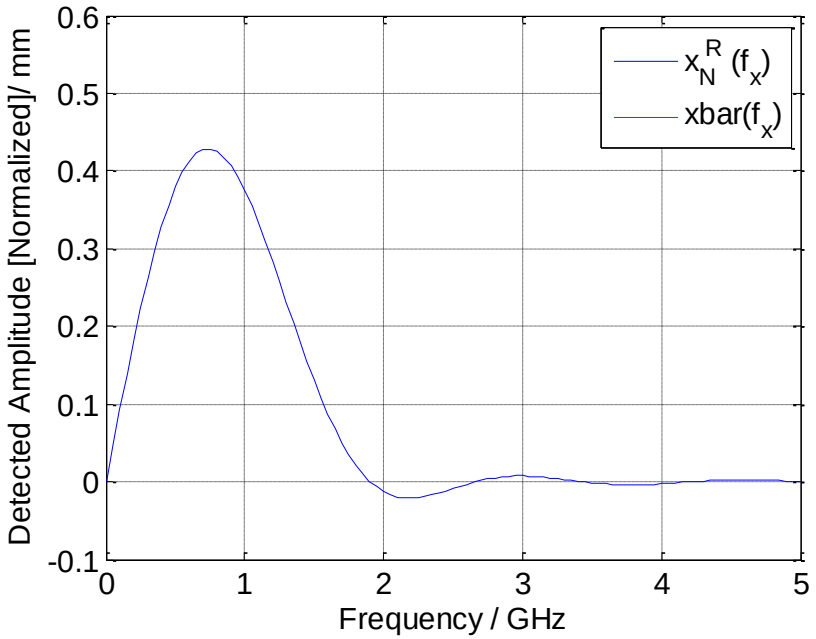


- The current normalization scheme **sees only symmetric (even) oscillation** patterns (needed for the closed loop feedback)
- Damper sensitivity to symmetric intra-bunch motion is a function of the longitudinal beam spectra
- For the anti-symmetric case no oscillation amplitude is detected, **odd modes not visible to the damper**

Complementary data processing algorithm

Alternative processing scheme to detect and indicate anti-symmetric oscillations:

$$x_N^R = \frac{Q_\Delta I_\Sigma - I_\Delta Q_\Sigma}{I_\Sigma^2 + Q_\Sigma^2}$$



- This algorithm **can detect odd-mode** oscillations
- None of the algorithms can resolve the original oscillation frequency, and absolute oscillation amplitude accurately (except m=0)
- But they **can detect activity** and **distinguish between symmetric** (even) **and asymmetric** (odd) **modes of every bunch → trigger!**

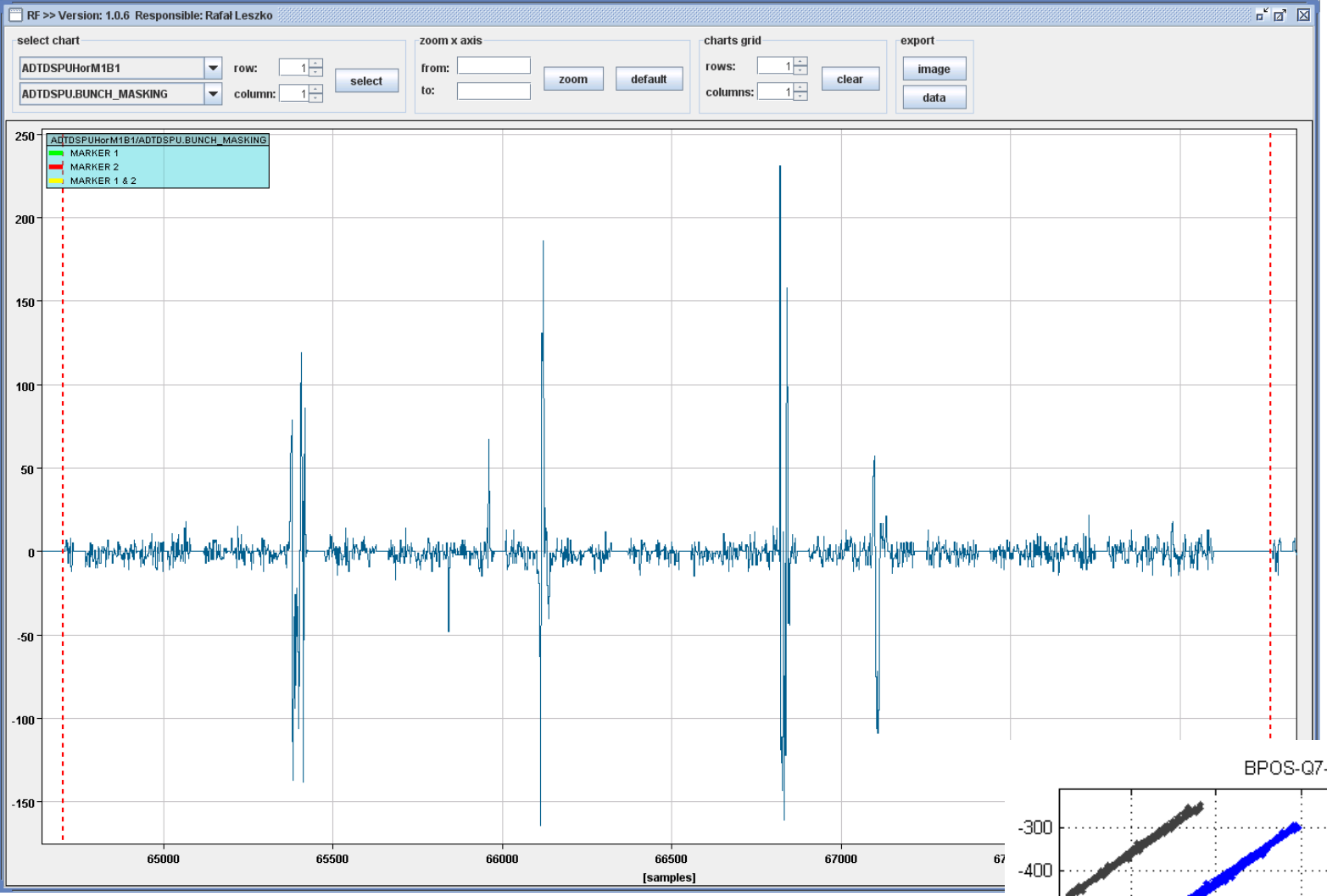
ADT “observation box”

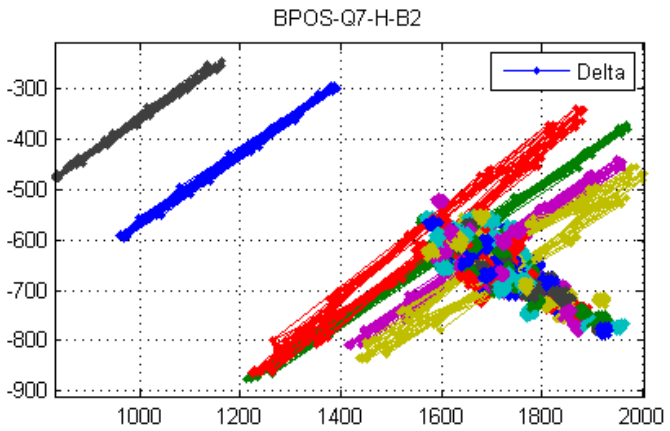
- Motivation:
  - Bunch-by-bunch data available within the ADT blocks
  - Difficult to extract, or store due to very high data rates
  - Difficult to do sophisticated data analysis directly in the ADT FPGAs
  - Large data polling may interfere with the ADT function

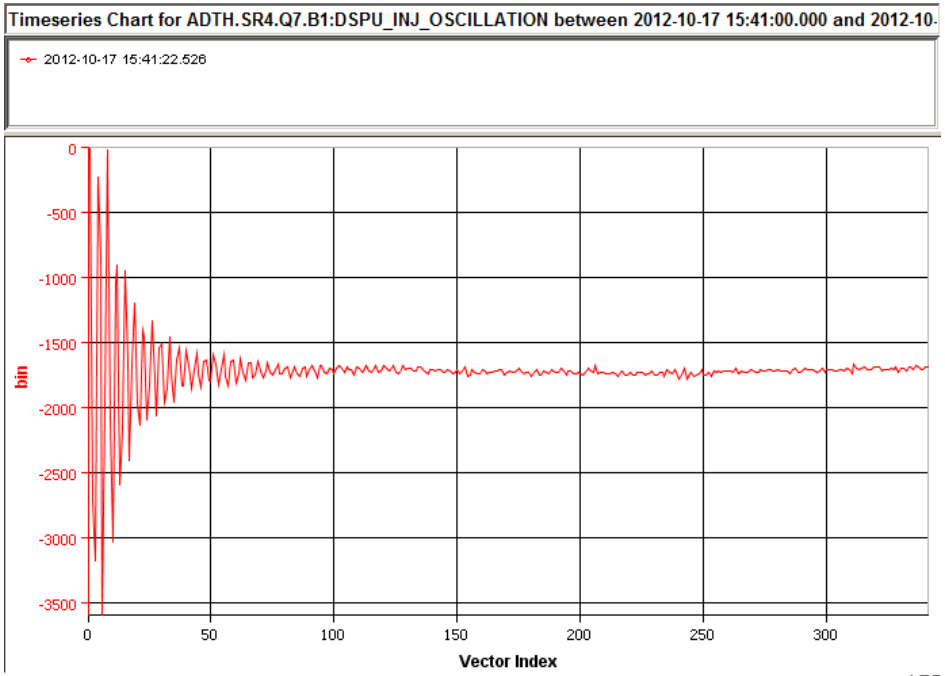
ADT “observation box”

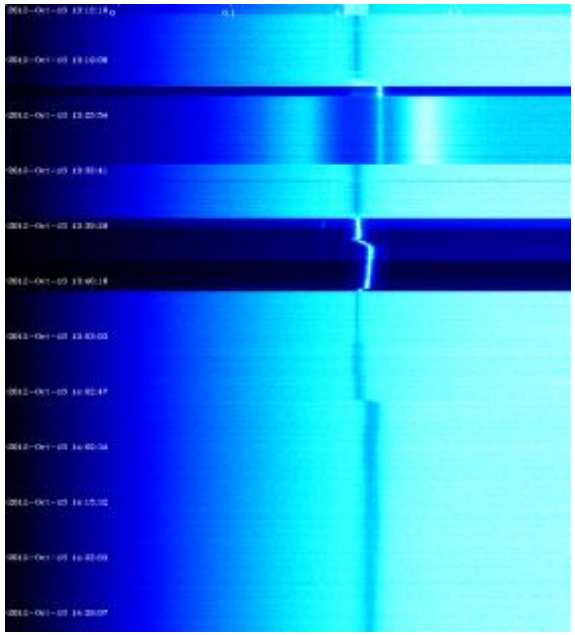
- A project proposed by the ADT team: stream the full rate data to an external computer(s):
  - Unlimited buffer length *
  - Unlimited number of buffers with different trigger/freeze conditions *
  - Unlimited scalability *
  - Continuous, online analysis of the transverse (and longitudinal) motion, all kinds of fixed displays…
  - Allows massive number crunching e.g. for tune measurement
  - Storage of a full 40 MHz, bunch-by-bunch data for an entire fill for offline analysis
  - …**and can generate/receive a trigger**

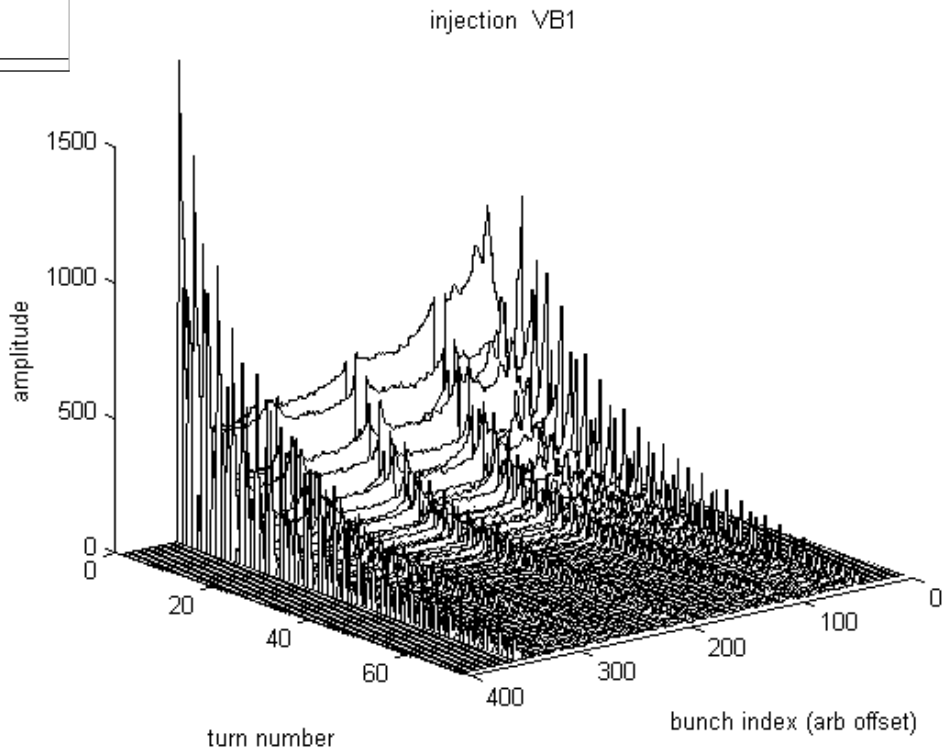
* For exact definition of “unlimited” see the small writing in the technical specs


RF >> Version: 1.0.6 Responsible: Rafal Leszko
select chart
ADTDSPUHorM1B1
row:
1
ADTDSPU.BUNCH_MASKING
column:
1
select
zoom x axis
from:
to:
zoom
default
charts grid
rows:
1
columns:
1
clear
export
image
data
ADTDSPUHorM1B1/ADTDSPU.BUNCH_MASKING
MARKER 1
MARKER 2
MARKER 1 & 2
250
200
150
100
50
0
-50
-100
-150
65000
65500
66000
66500
67000
[samples]


BPOS-Q7-H-B2
Delta
-300
-400
-500
-600
-700
-800
-900
1000
1200
1400
1600
1800
2000


Timeseries Chart for ADTH.SR4.Q7.B1:DSPU_INJ_OSCILLATION between 2012-10-17 15:41:00.000 and 2012-10-
2012-10-17 15:41:22.526
bin
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
0
50
100
150
200
250
300
Vector Index

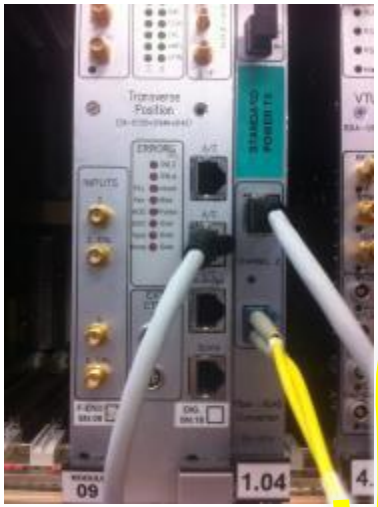



injection VB1
amplitude
1500
1000
500
0
0
20
40
60
400
300
200
100
0
turn number
bunch index (arb offset)

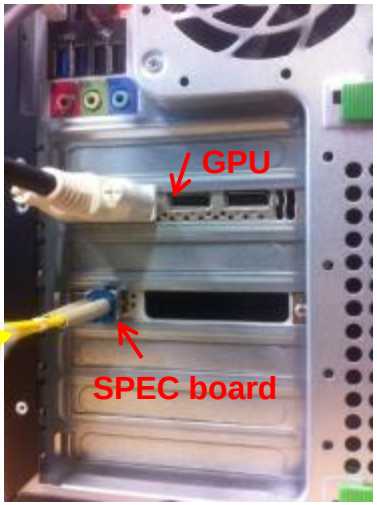
ADT “observation box”

- First results with data transmission and reception T. Levens
- Data processing by graphic chips F. Dubouchet (see. Betatron tune measurement with the LHC damper using a GPU, CERN-THESIS-2013-035)
- Technical specification being defined (ADT, ACS experts)
- Full implementation by the BE/RF/CS section

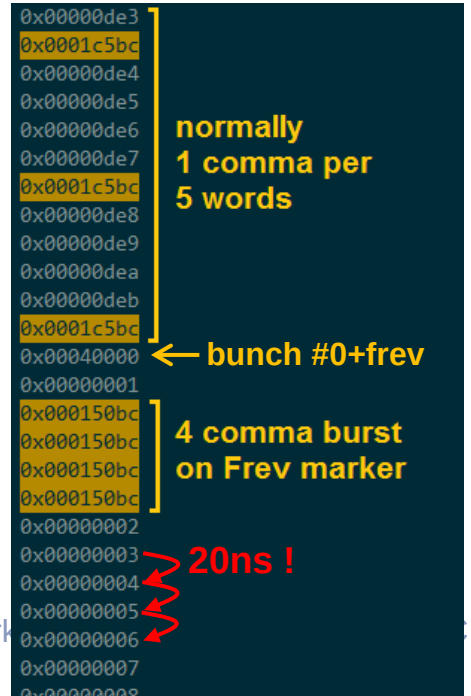
ADT Beam position module



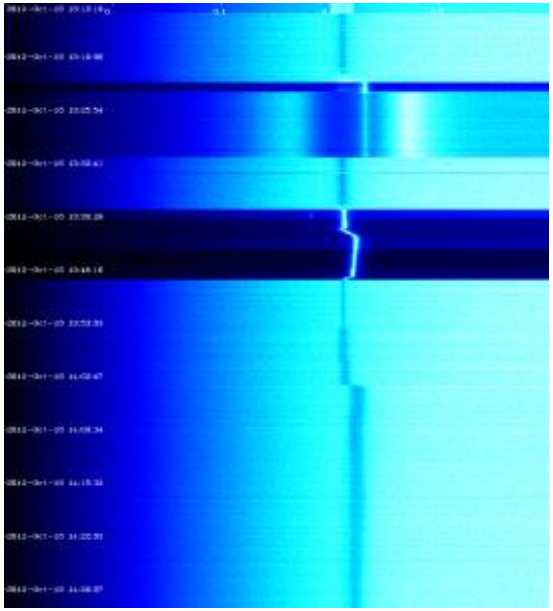
Observation box receiver (PC)



Bunch by bunch data read out via PCIe



Processed data (e.g. tune extraction)



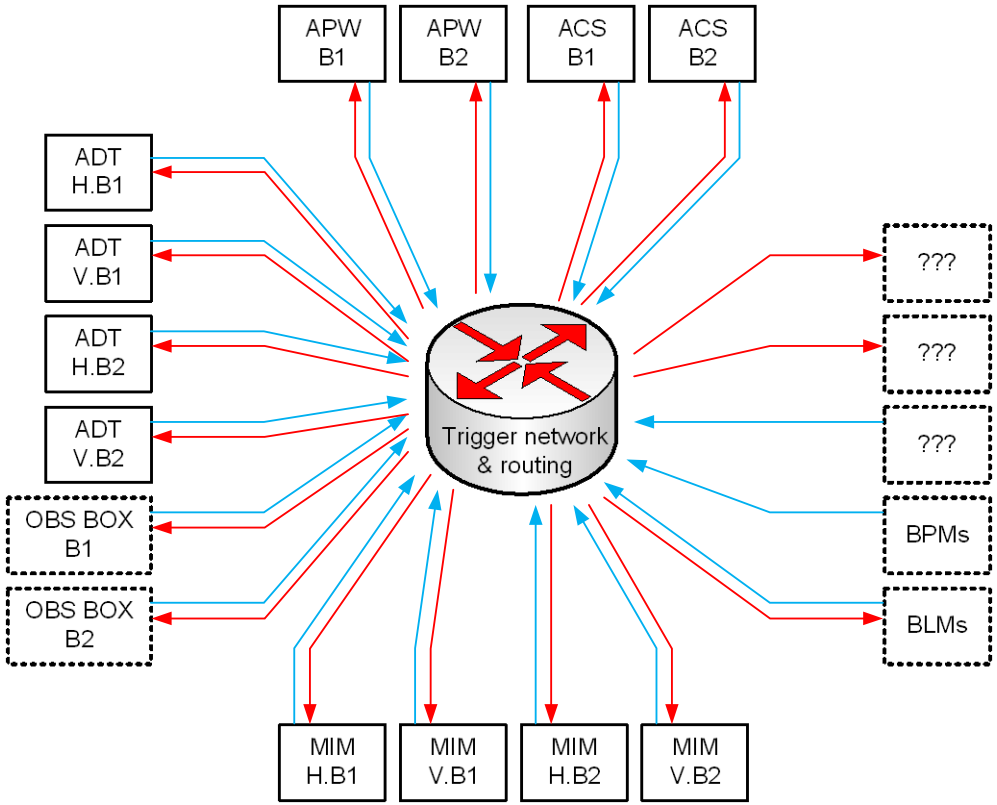
LHC instability trigger network

- Some instruments can analyse signals and generate a trigger. Many instruments in the machine have buffers with a very valuable data. In order to profit from these we need:
  A. Fast, deterministic, configurable, machine-wide trigger distribution network (multiple inputs, multiple outputs)
  B. To collect, store and analyse all those data.

- White rabbit network: a solution proposed and technology provided by the BE/CO group
- Technical specification approval in progress https://edms.cern.ch/file/1377705/1/list-func-spec-v1.0.1.pdf

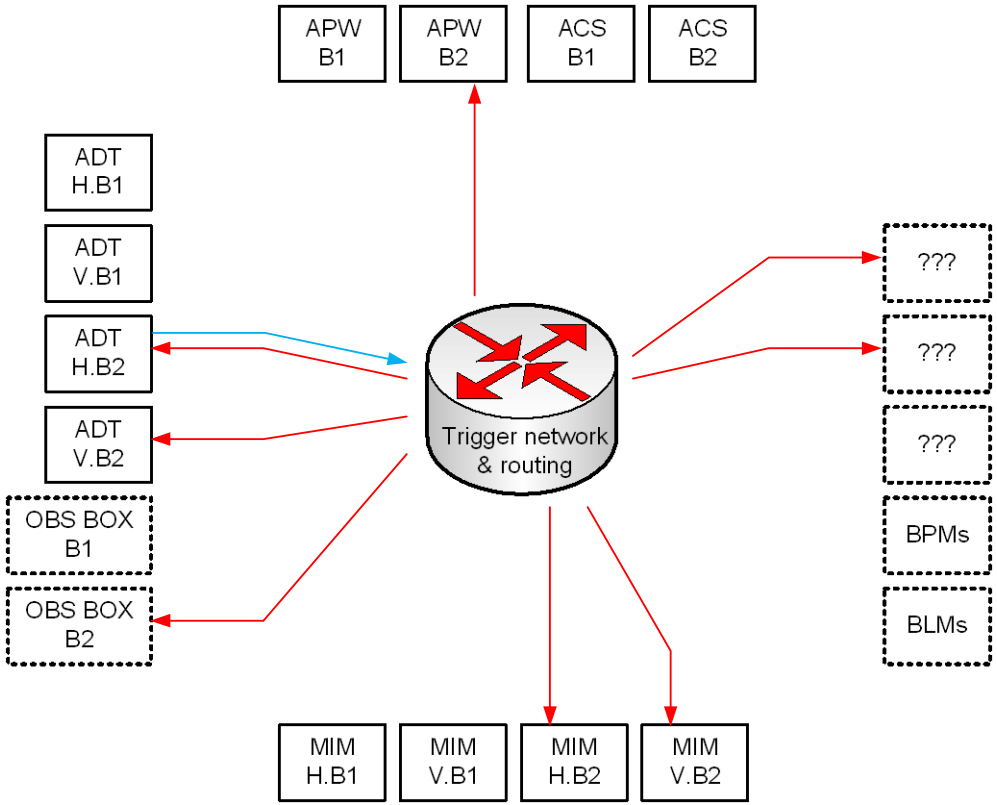
- HW paid by RF operations budget (2013), and BI MIM budget.
  - Installation ongoing – operational by end of LS1

Instability trigger network functionality



- A set of observation instruments can be located anywhere in the LHC or CCC
- Many of them can generate a trigger
- Many of them can receive trigger and freeze a data buffer

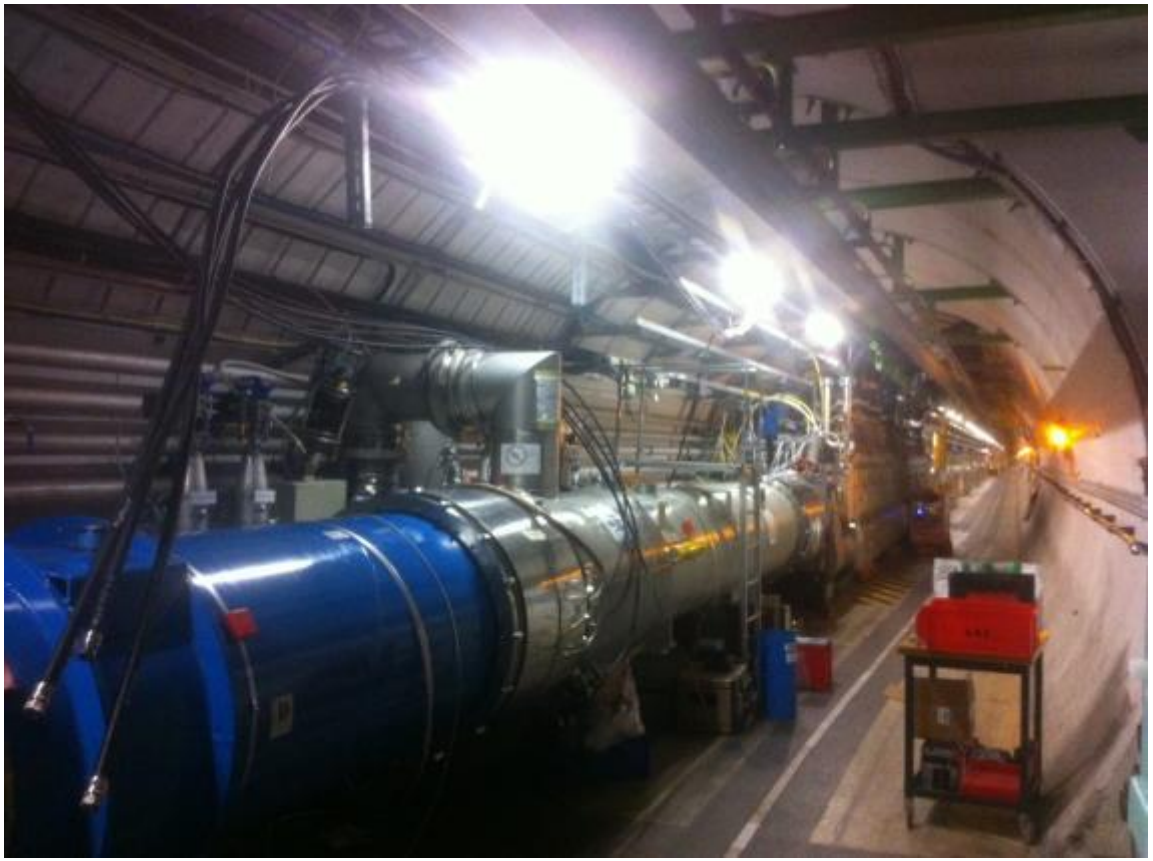
Instability trigger network functionality



- Trigger propagation path has to be defined
- E.g. ADT, horizontal, B2 detected an activity
- System should freeze only relevant devices
- Sequence of triggers has to be time-stamped and each trigger originator identified
- Indicate to CCC that the data needs to be collected

Current status

- The tunnel work (coaxial cables, pickup-swap) almost finished
  - Excellent job by the EN-EL contractor Novatel Telecomunicaciones



Current status

- Low level RF system of the pre-LS1 ADT is fully conserved

Current status

- New ADT Low level RF hardware – synergy with the SPS damper upgrade works

DARC
Damper Renovation Campaign

- New digital “SPS damper everything” board is being tested now – series production will be launched very soon
- The HW design will be reused for LHC
- No showstoppers so far

ADT current status

- Firmware work – no showstoppers, we can re-use already existing blocks from the current ADT

- Control software – FESA
  - HW development supported by FESA 2.10 (tools available, needs flexibility for short development cycles).
  - Final project has to be migrated to FESA 3.

- The new hardware needs to be ready for the SPS restart
  - All resources (G. Kotzian, D. Valuch) focused here. Invaluable help of T. Levens (now BE/BI).
  - Work on the LHC ADT can begin only once the SPS damper is fully operational (Sept-Oct 2014). Concerns sequences, functions, timings, high level procedures, dry runs, interaction with CCC, observation data, fixed displays
  - Final decision to upgrade (point of no return) in September

ADT re-commissioning plans

- We will be starting up a completely new system
  - New hardware
  - New control software
  - New functionalities

- Re-commissioning will need a significant effort (and time)
  - Preparation of new functions and procedures
  - Define critical settings with all relevant checks
  - Re-commissioning with beam as a function of intensity, 16 pickups(!)
  - Re-commissioning with beam as a function of beam type (bunch spacing, gain)

ADT re-commissioning plans

- Automatic settings management (intensity, bunch spacing)
  - We aim to automatize this
  - However: how much can we rely on the data we get from the machine central control system? (see 2012's experience)

- Based on available resources, staging of the re-commissioning might be necessary
  - Commissioning of the basic functionalities is relatively fast…
  - But we were adding features 'on the fly' for the whole run I. Sophisticated functionality will need time to be properly implemented.
  - Eventually – identify the essential functionality, start with a minimal system, keep adding features.

Summary 1

- ADT undergoes a major upgrade during LS1 to improve flexibility and performance even further
  - Increase # of pickups, more powerful signal processing, dedicated signal paths for witness bunches or cleaning
- Synergy with the new SPS damper developments
  - Hardware, firmware being finalized
- Very limited (human) resources available. Need to restart the injectors first
  - Hardware, firmware (BE/RF/FB)
  - FESA classes and user interfaces (BE/RF/CS)

Summary 2

- Algorithms for fast b-b-b symmetric/anti-symmetric (intra bunch) instability detection are being studied

- ADT observation box
  - B-b-b data storage for unlimited # of turns
  - Potential for sophisticated on the fly data analysis (instability, Q…)
  - Will be used also in the longitudinal plane

- A machine-wide instability trigger distribution network being built
  - ADT, MIM, observation box, other instruments
  - Joint effort of BE/BI, BE/CO, BE/RF

Summary 3

- ADT re-commissioning will be a significant effort of many teams
  (ADT, FESA classes, LSA, sequences, CCC applications, user interfaces, fixed displays)

- In 2008, the LHC was started up by poking hexadecimal numbers into VME registers and staring at the oscilloscopes.

- This is not possible anymore. We need proper tools to efficiently and safely make it operational again.

And finally… Revenge is sweet!

A word of advice to all EICs: Beware how you treat the RF people. Night calls are never forgotten…

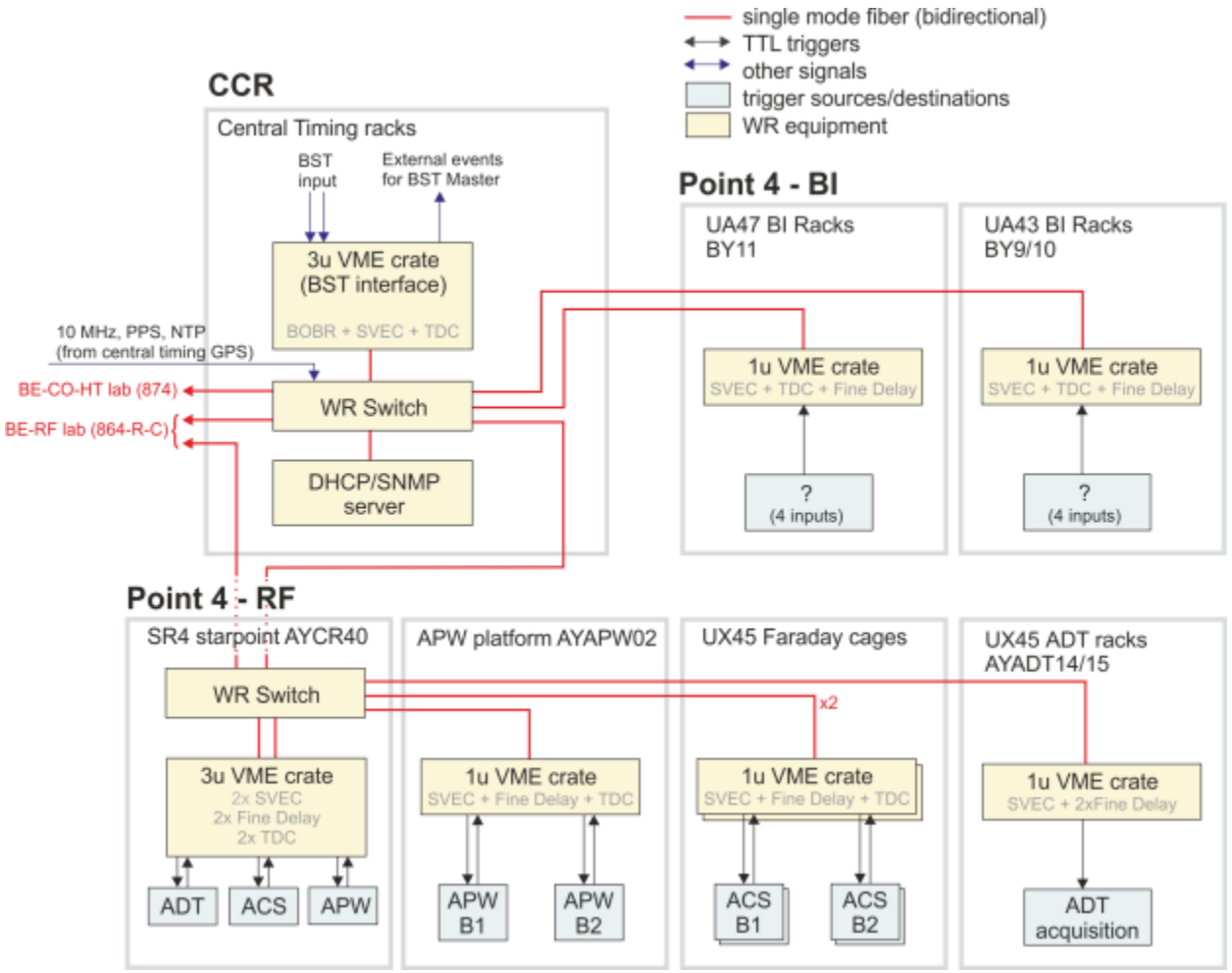
Alick M. mounting RF connectors to the newly installed ADT cables underneath the false floor in SR4

Thank you for your attention!

The ADT team works hard to be always there also during the run II.

www.cern.ch

WR network architecture (initial configuration)



Post LS1 ADT summary