Report on LHC Experiment Protection

More info here:

http://indico.cern.ch/conferenceDisplay.py?confId=97671

Many thanks to the experiments' **B**eam **I**nterlock **SU**pervisors for preparing the material presented here

ALICE: Antonello di Mauro

ATLAS: Siegfried Wenig

CMS : Richard Hall-Wilton, Nicola Bacchetta

LHCb: Richard Jacobsson

LHCf: Daniela Macina

TOTEM: Mario Deile

Outline / scope

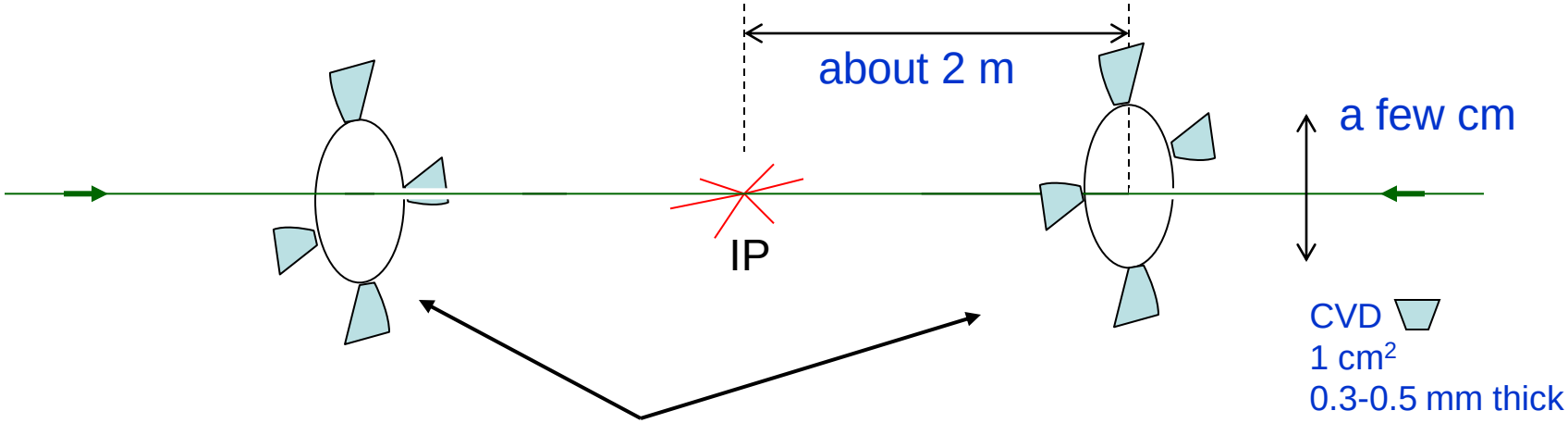
- No attempt to “review” each experiment’s protection system
  - Systems are the experiment’s responsibility (at least up to CIBU)
  - System have been tested, commissioned and shown to work, first without beam, then with beams (thanks for the given opportunities!).

- Focus on experience with beams (past 6 months) and on diamond detector systems

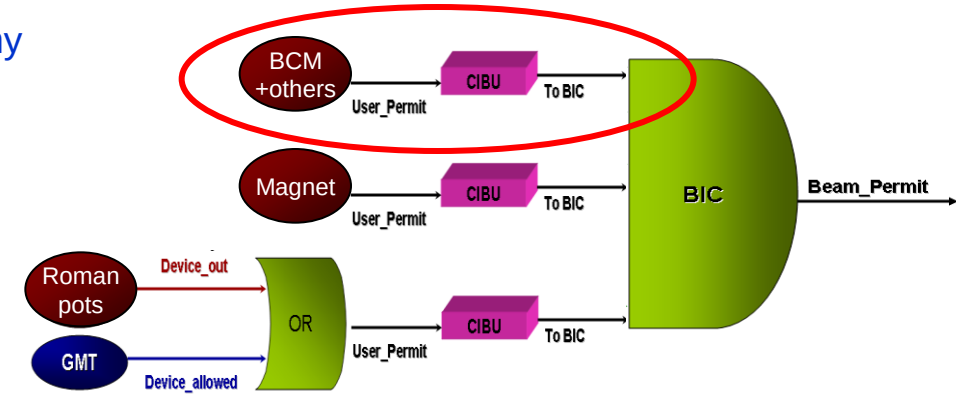
  - Performance of protection
    - Some experiments have various detectors used for monitoring (not connected to CIBU). Not emphasized here.

  - Any relevant issues ?

Typical LHC Experiment Protection System



- One Beam Conditions Monitor (BCM) on each side of IP:
  - Stand-alone system using a few polycrystalline CVD diamond pads
  - UPS powered, with few minutes autonomy
  - Post-Mortem analysis capability
  - FPGA-based dump logic:
    - input: measured rates
    - output: `UserPermit` signal
  - Unmaskable input to local BIC
  - On trigger, dump both beams



- BCM protects against circulating beam failures, not against injection and extraction failures, though it will be ON during injection (for fast feedback).

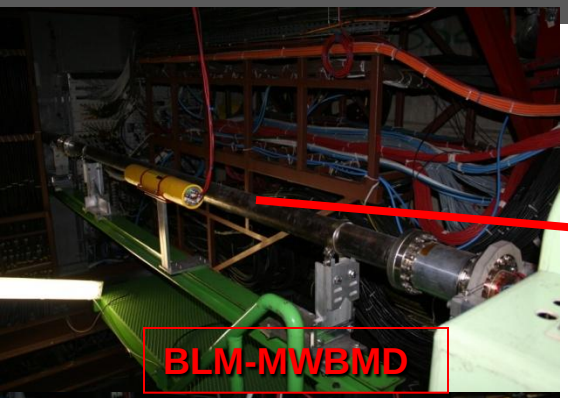
Summary of thresholds

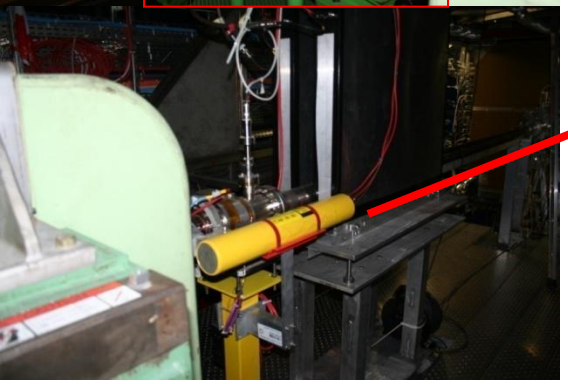
Experiment	Time scale	Threshold (uA)	Nominal lumi (uA)
ALICE	80 us	0.25	~ 0.001
	1.28 ms	0.01	
ATLAS	40 us	0.46	~ 0.01
CMS	40 us	10	~ 0.01
	5.2 s	1	
	83 s	0.3	
LHCb	80 us	2.5 - 10	~ 0.005 – 0.02
	1.28 ms	0.03 – 0.12 ??	

Beware:

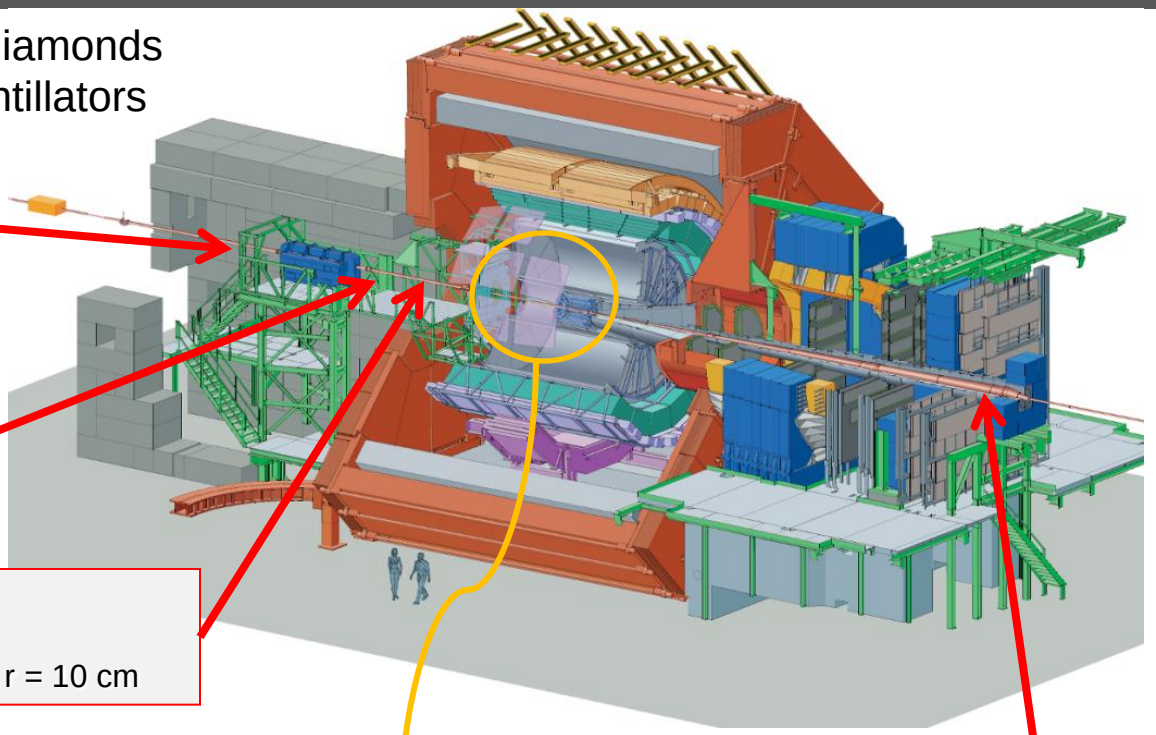
- Different diamond detector thicknesses or different operating bias voltages
- Different geometries (positions relative to IP)
- Different correlations to the most sensitive detector to be protected
- Algorithmic abort logic not shown here

ALICE BCM system

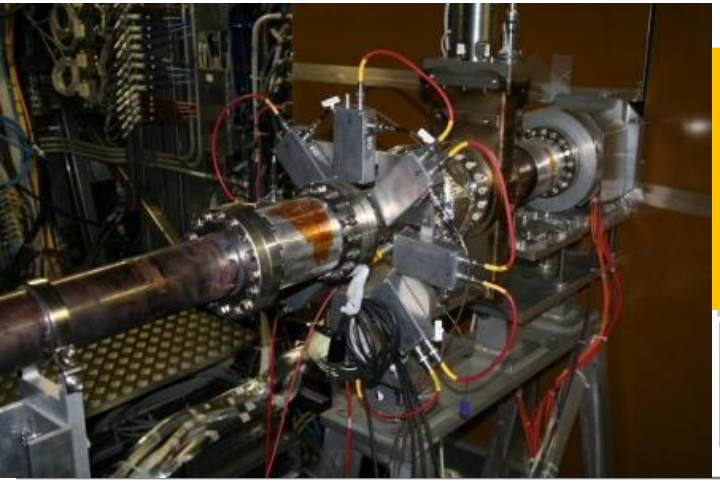


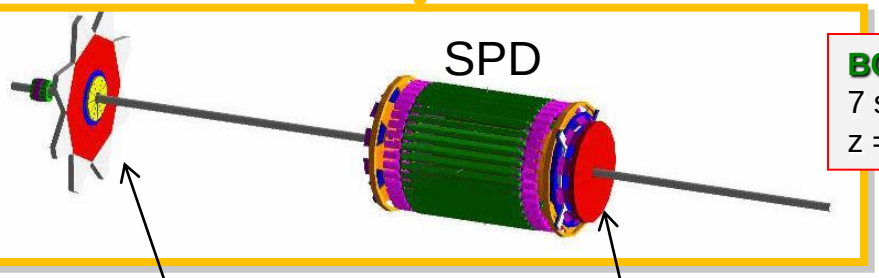


BCM = diamonds
V0 = scintillators



BCM-A
8 sensors
z = + 6 m, r = 10 cm





BCM C
7 sensors
z = -18.5 m, r=10 cm

V0A
r_{in}=8 cm, r_{out}=100 cm

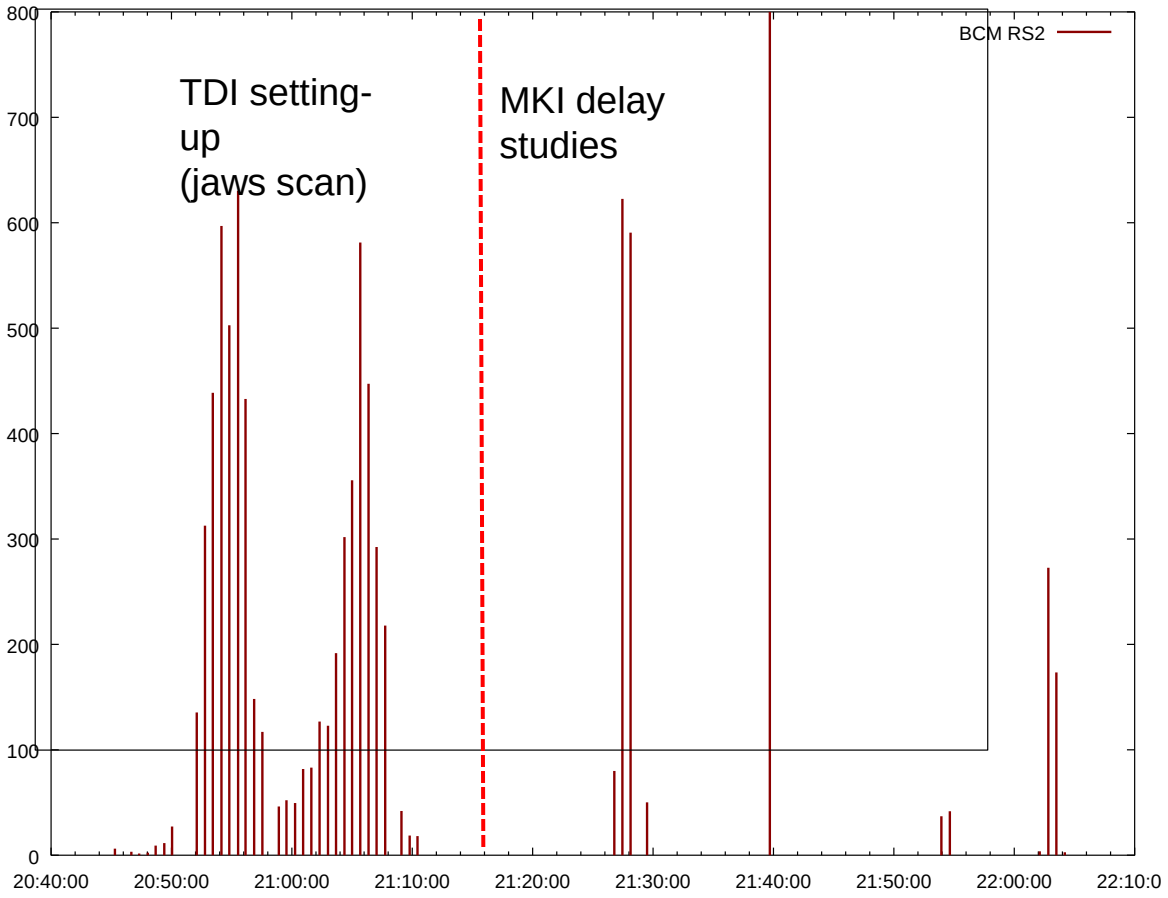
V0C
r_{in}=8 cm, r_{out}=76 cm

ALICE BCM system status

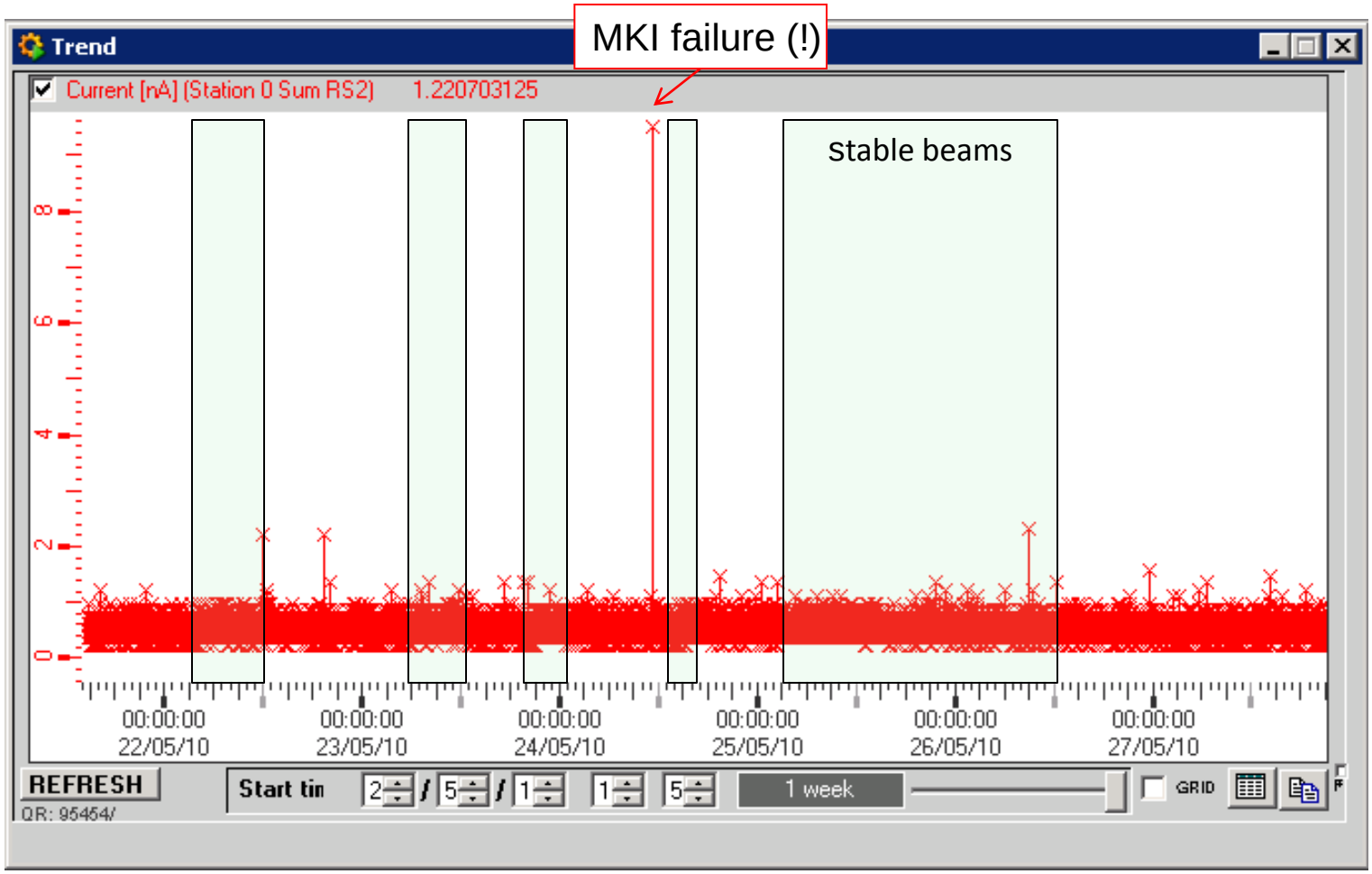
- BCM system “commissioned” using TDI grazing events, beam dumped within 3 turns by lowering thresholds
- Typical sensitivity: 1 nA RS2 (80 μs integration) => ~100 p/cm^2
- Beam dump logic:
  - Fast abort on RS1 or RS2 coincidences:

    dump the beam if 3 adjacent diamond sensors show a current > thr_{RS1} or thr_{RS2} , respectively
  - Slow abort on RS32-Sum (1.28 ms):

    Sorting out the two highest and the lowest of 8 sensors, dump the beam if RS32-Sum > thr_{RS32}
- (Conservative) Thresholds:
  - Fast (RS2): 250 nA (~2.5 x 10^4 p/cm^2)
  - Slow (RS32): 10 nA (~ 10^4 p/cm^2)



ALICE BCM system status

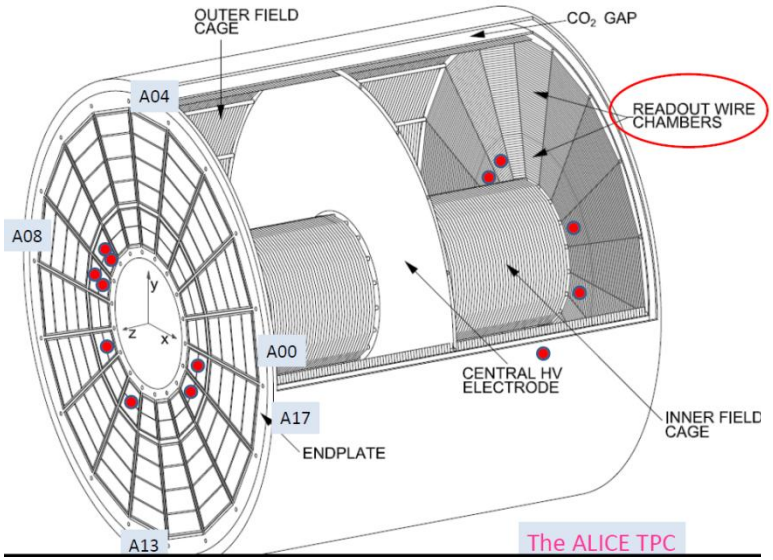


- Noise level: RS2 ~ 0.5 nA
- No large signals (big losses) observed with BCM so far, typically peaks between 2 and 20 nA RS2

ALICE Detector state vs Acc.Beam modes

- All detectors have defined their settings for SAFE and READY states, go READY only on stable beams (exceptions: V0, ITS, EMCAL, PHOS)
  - Here READY means ready for taking physics data (not ready for injection …)
- Transition from READY to SAFE automatically done on change from STABLE BEAMS to NOT STABLE BEAMS
- All other cases managed by shifter via handshake

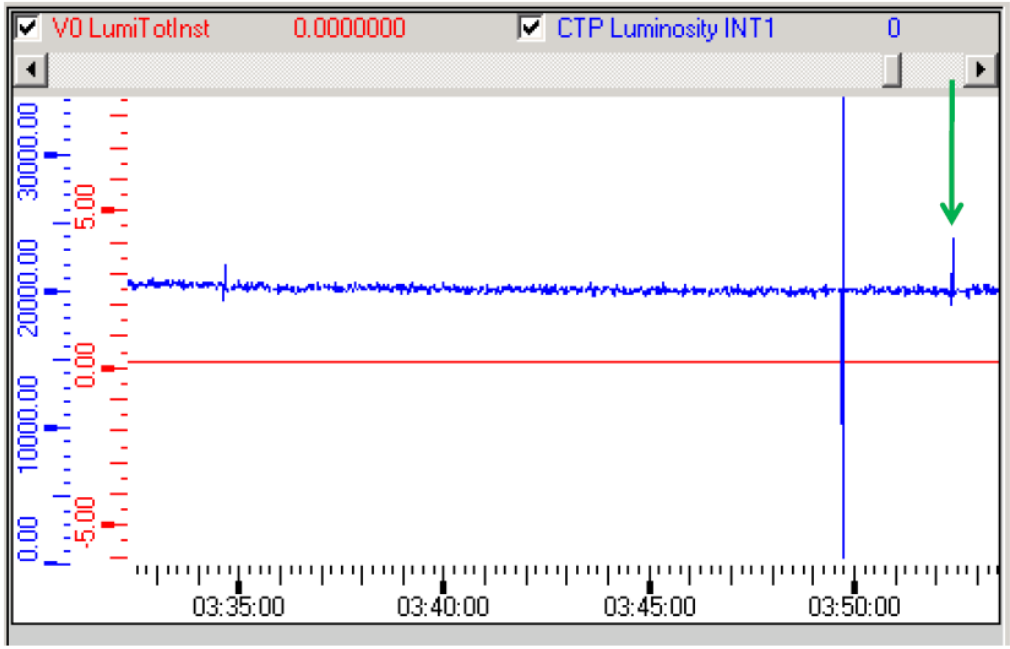
ALICE: gaseous detectors HV trips



- More details presented at last LBS meeting (14 june 2010), see here http://indico.cern.ch/conferenceDisplay.py?confId=97182

IROC A07 25.05.2010 03:52:22:798
Fill 1122: 'MICADO to compensate the lost of the H corrector.
MCBH.30R6B1 (9.081 urad)'

Same trip, V0



ALICE conclusions

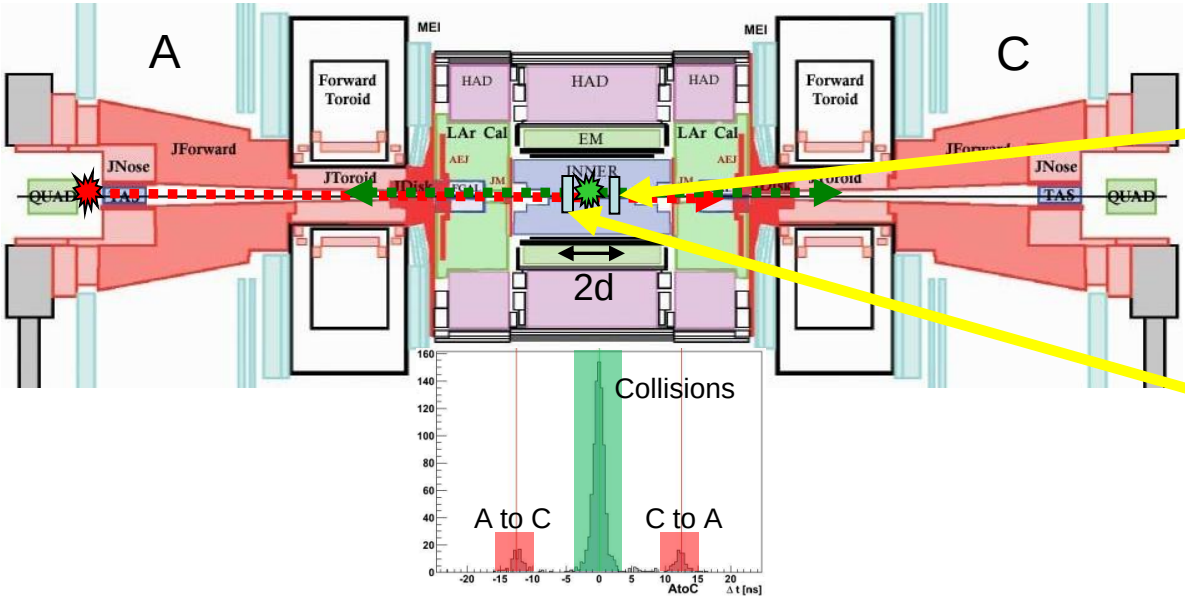
- BCM designed to protect against large losses, however still some margin to reduce thresholds without compromising beam operation
- With increasing beam intensity, several HV trips observed in gaseous detectors (TPC, TRD, HMPID, μ-TRIG), current limits ~ 0.2-5 p/cm^2 s (see C. Garabatos' talk at LBS)
- Planned V0 reconfiguration will allow a more precise background measurement

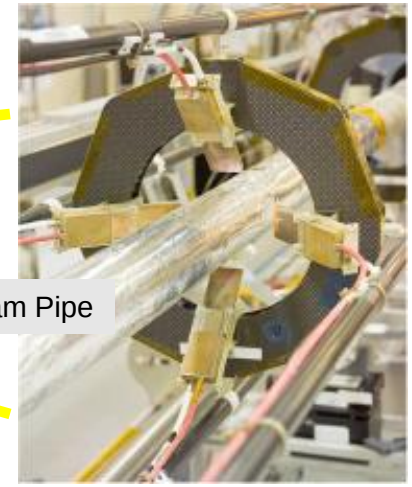
ATLAS

Two systems:

- “BCM” => fast (sub-ns) read-out
- “BLM” => more standard readout … 40 us.

ATLAS BCM System (1)





- Beam Condition Monitors (BCM)
  - 2 x 4 pCVD diamond detectors (10 x 10 mm^2, inclined by 45)
  - z = 184 cm and r = 55 mm
  - Single MIP sensitivity with sub-ns time resolution ➔ Low threshold
    - Sensitive to single bunch crossings
    - Distinguish collisions – background (ΔT(A/C) = 2d/c)
    - Luminosity information, beam condition monitoring
  - Beam abort ➔ High threshold
  - Read out by 2 ROD's (combining thresholds and Side-A/C)

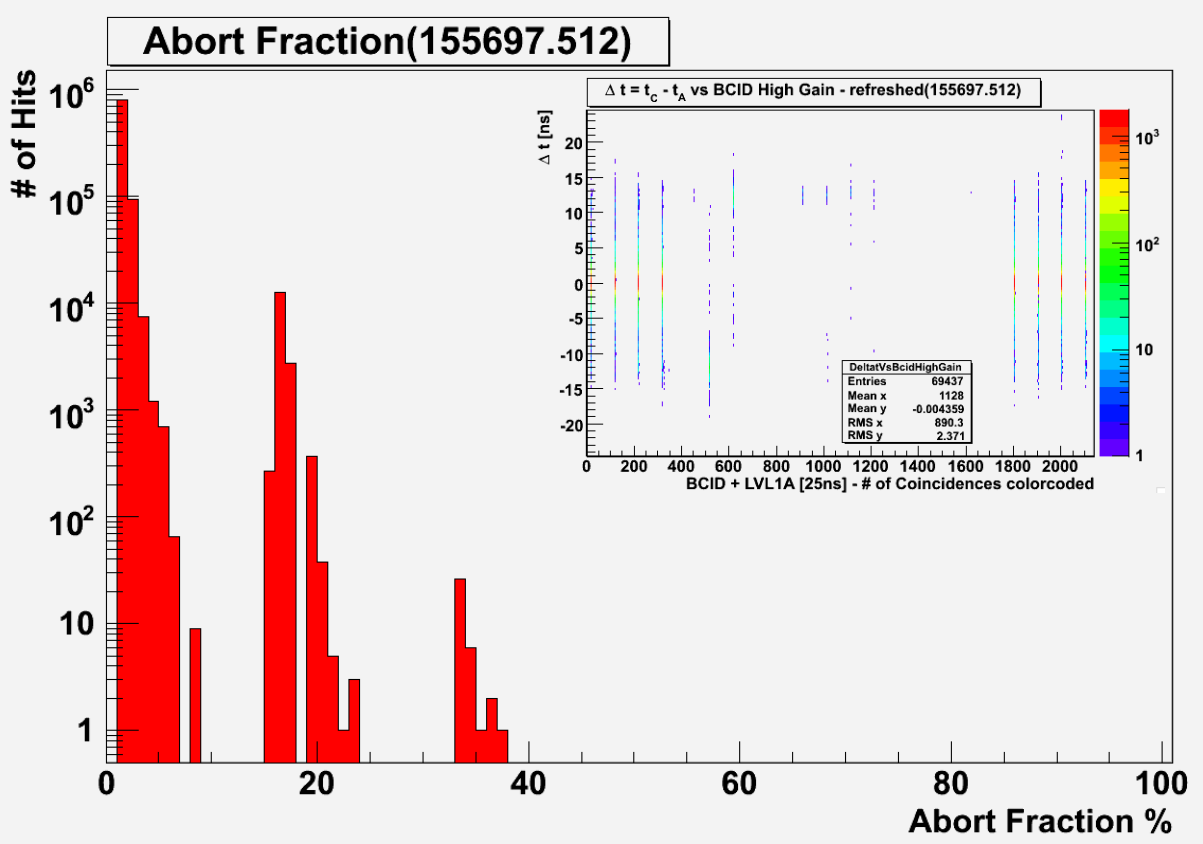
BCM System (2)

- Thresholds
  - Nominal sensitivity (HV 1000 V)
    - Low 1 MIP/cm^2 (0.3 V)
    - High 10 MIP/cm^2 (3 V)
  - Reduced sensitivity (HV 400 V)
    - Low 6 MIP/cm^2 (1 V)
    - High 60 MIP/cm^2 (10 V)
- Beam abort condition
  - 3 sensors above high AND 3 sensors above low threshold for both RODs
- Performance
  - Even reduced sensitivity is incompatible with beam commissioning conditions
    - Masked in ATLAS BIS on 26 March 2010 at 13:41 (but records PM buffer at nom. setting)
    - Prepare for further reduction of sensitivity by factor 25
    - Prepare for abort algorithm with effective integration (x BC out of y)
  - Very good time resolution allows for detailed beam condition monitoring
    - Beam induced background
    - Asynchronous dump
    - Over-injection
    - De-bunched beam

ATLAS BCM Monitoring (1)

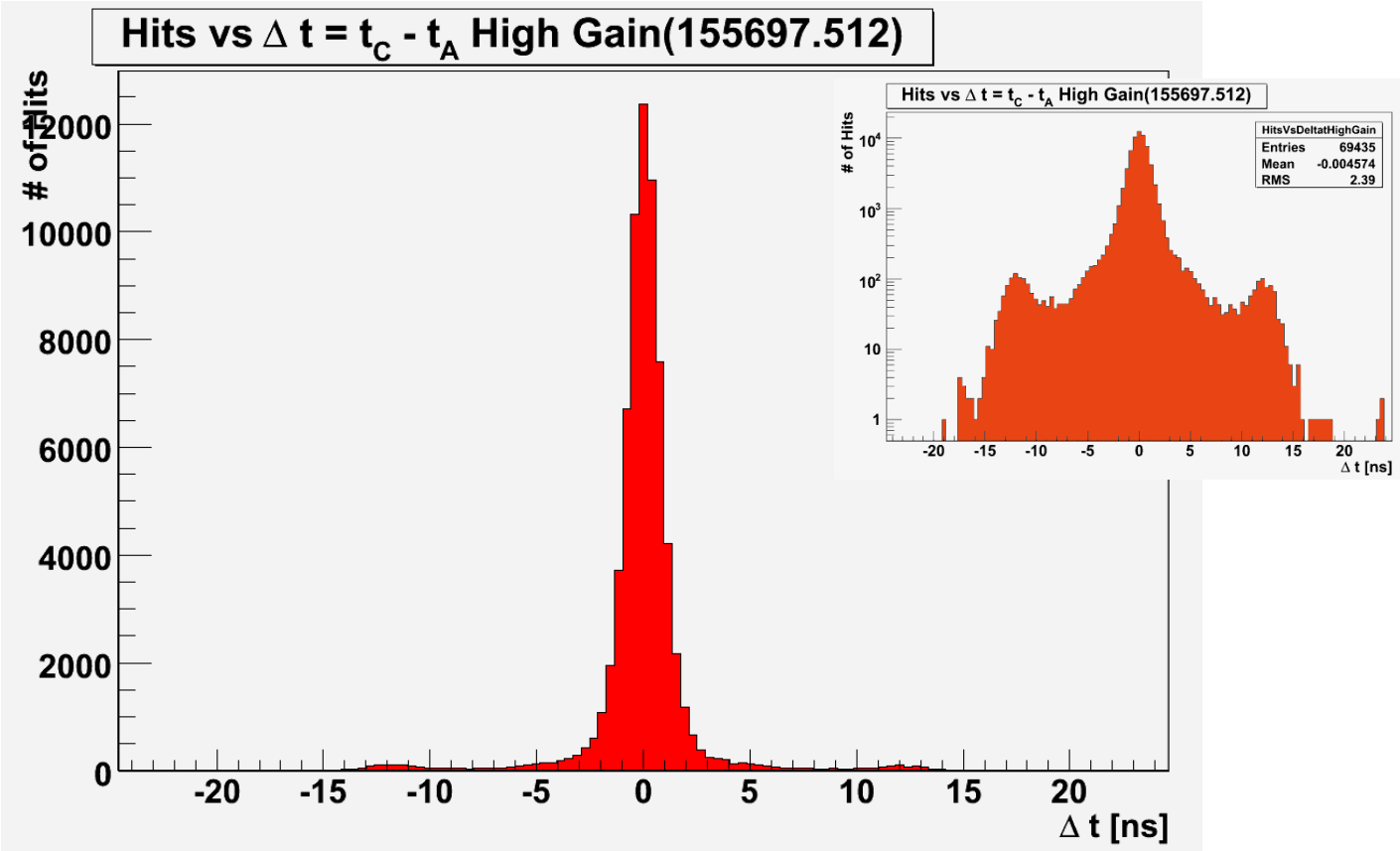
- Percentage of abort threshold
  - 7 TeV
  - 8 colliding bunches

Typical for all STABLE BEAMS



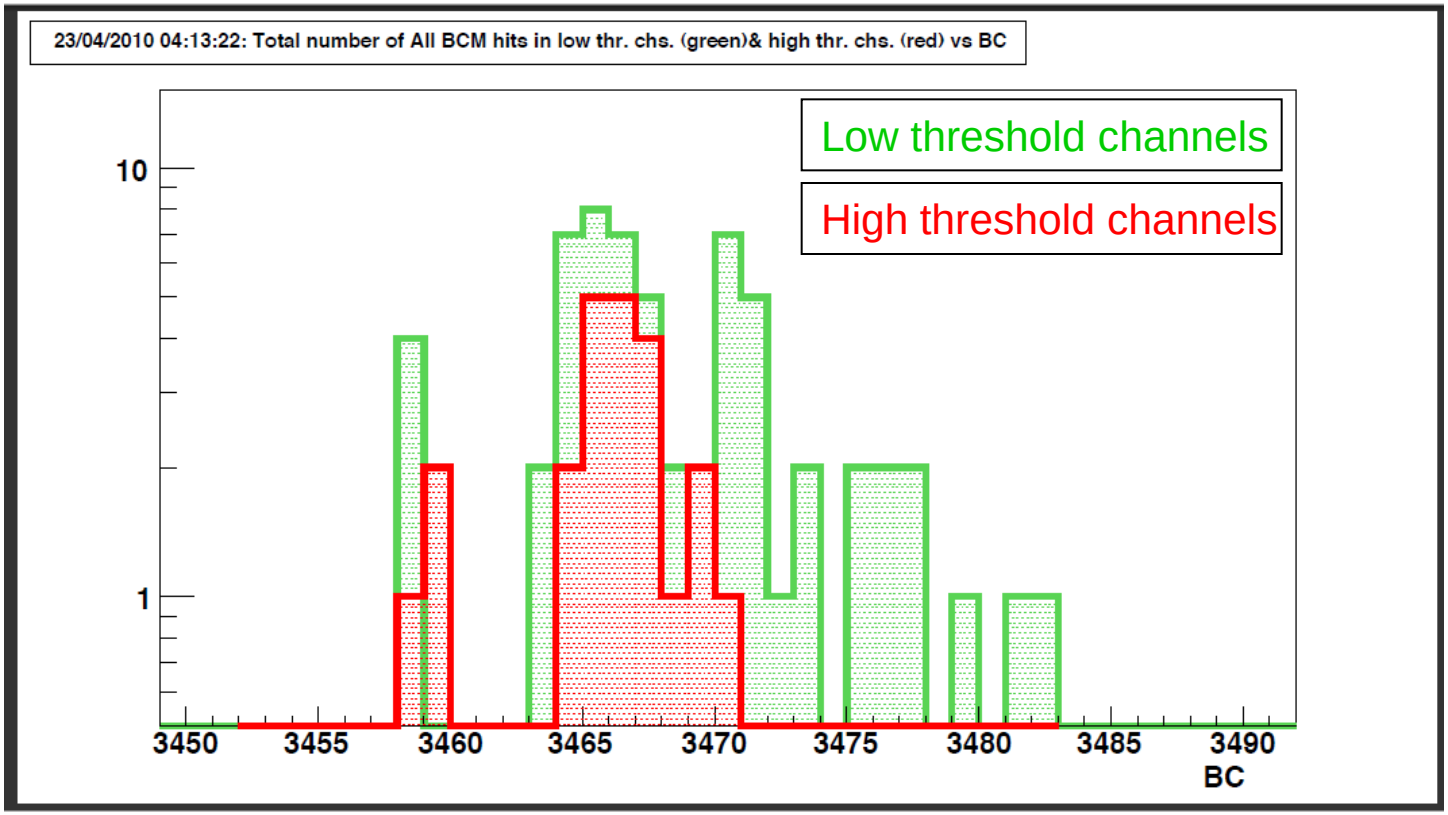
ATLAS BCM Monitoring (2)

- Delta t plot ($t_C - t_A$)
  - 7 TeV
  - 8 colliding bunches

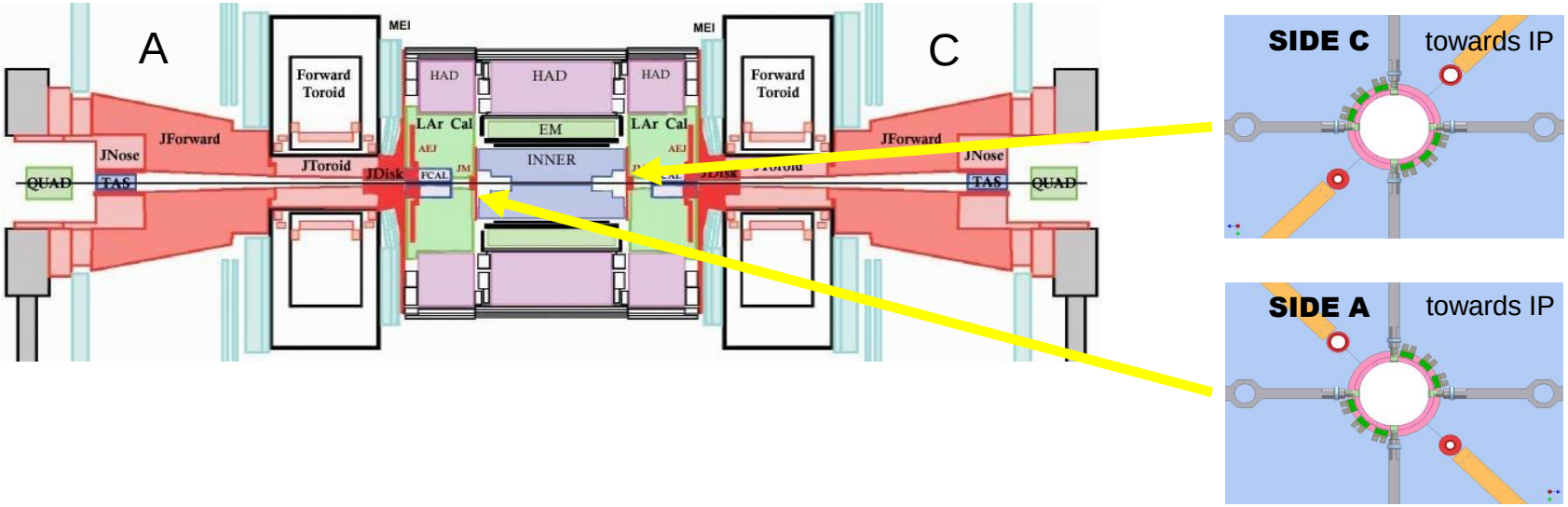


BCM Monitoring (3)

- Asynchronous beam dump 23-Apr-2010 4:13:22
  - Spread over 10-20 bunch crossings
- HV at 1000 V; thresholds at 0.3/3 V



ATLAS BLM System (1)



- Beam Loss Monitors (BLMXD.01L1/R1.CH0N_ATLAS)
  - 2 x 6 pCVD diamond detectors (10 x 10 mm^2)
  - z = 345 cm and r = 65 mm
  - Readout chain of LHC BLM system with modified BLMTC FPGA firmware
    - Abort signal at front panel
    - Receive PM signal
  - All Running Sums, in particular 40 μs integration time

BLM System (2)

- Threshold
  - 3.7 10^4 MIP/cm^2
  - Corresponding to 460 nA and 37 pC
  - Integrated over 40μs
- Beam abort condition
  - 2 out of 6 detectors above threshold (RS0=40μs) on both Sides (A/C)
- Performance
  - Fully integrated in ATLAS BIS 19 April 2010 at 17:45
  - Signal observed during TCT setup (5/6 May)

Detector Damage Thresholds

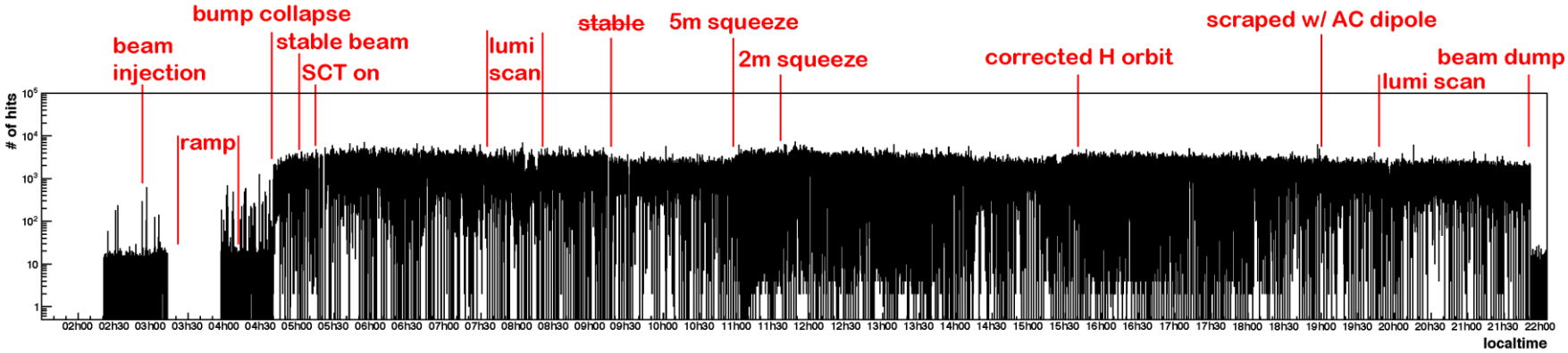
- SCT (Semi Conductor Tracker)
  - Determined by
    - Potential developed across the Oxide
    - Charge injected into the front end chip (ABCD)
  - 2.5 10^4 MIP/cm^2 in 25 ns (with a safety factor 400)
  - Corresponds to 500 times 100% occupancy
  - Occupancies observed up to now

	max. single module	det. average
Splashes	---	10%
Collisions (7 TeV, 2e10 p, squeezed, stable)	10%	1%
Collimator setup	15%	5%
First over-injection studies (7, 12 May)	20%	10%
Flat top on 10 June	30% ←	20%

- Pixel
  - Less critical than SCT
  - 1 10^{10} MIP/cm^2 in 40 ns (measured in test beam)

ATLAS conclusions

- Protection system against detector damage due to beam losses in place
  - BLM response to be confirmed



  - Occupancies well below damage threshold
  - Some high occupancy events not yet understood, though
    - First over-injection studies (7, 12 May)
    - Flat top event last week, 10 June

- Transition to Stand-by mode works fine
  - Via handshake for injection
  - After Stable Beam Flag = FALSE

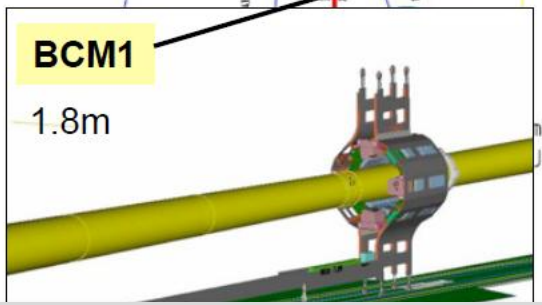
CMS protection devices

BCM2: Leakage current monitor
Location: z=± 14.4m, r=29cm, 5cm
8 stations in φ, 24 sensors total

Readout: 25kHz / 40 us
Front End: BLM tunnel cards

That's the one attached to BIS

BCM1L: Leakage current monitor
Location: z=±1.8m, r=4.5cm
4 stations in φ, 8 sensors total
Readout: 200kHz / 5us
No front end electronics



This one still under commissioning
Not attached to BIS

Sensors: 1cm^2 polycrystalline cvd Diamond

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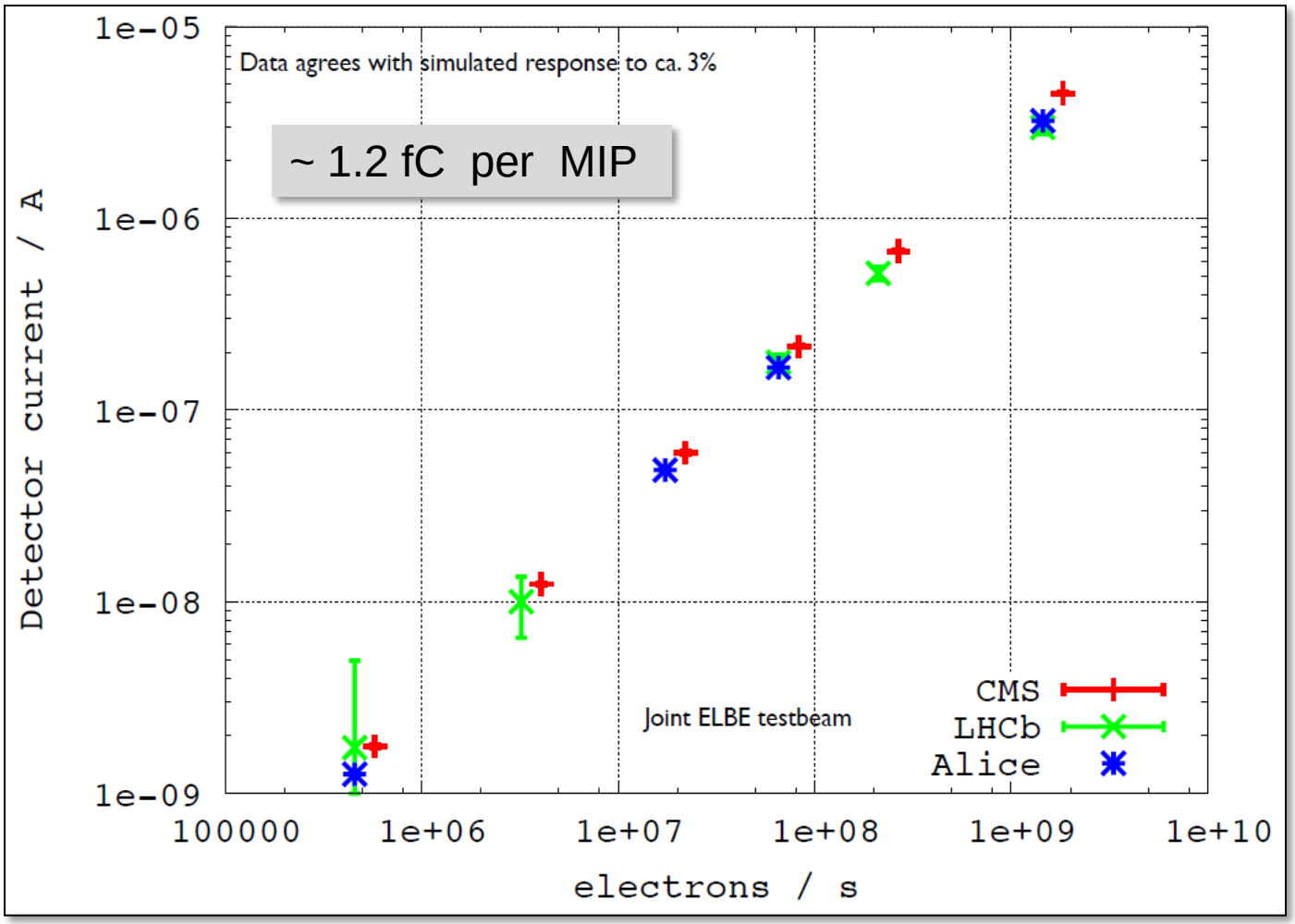
CVD diamond BCM response



For 40 us integration this translates into ~30 pA per MIP

(reminder: diamond size ~ 1cm^2)

CMS BCM abort thresholds

ABORT Thresholds for CMS Beam Conditions Monitor

- BCM2 inner diamonds is attached to the LHC Beam ABORT
- BCM1L still under commissioning
  - Use 8 inner BCM2 diamonds.
  - The ABORT is designed to protect against dangerous conditions, not mildly unpleasant conditions
  - Reminder: readout is LHC BLM (i.e. BI group) readout
  - Numbers that follow are set from the beginning of the 2010 run
  - ABORT set on following Running Sums: RS1,RS10, RS12
    - RS1, 40 us, 10 uA, 2050 counts. (fast losses of 3.10^5 MIP equiv.)
      - Protects against fast losses. Levels determined by concern for tracker/pixel
    - RS10, ca. 5s, 1 uA, 26M counts (averaged over 5s). Losses about 3x those expected at nominal luminosity (ca. 10^9 MIP equiv /s)
      - Protects against capacitor discharge
    - RS12, 83s, 300nA, 126M counts (long term bad conditions, averaged over 83s. Losses about 3x those expected at nominal luminosity (ca. 2.10^8 MIP equiv /s))
      - Protects against long-timescale bad conditions
    - There will be an EDMS note on this soon.
- Reasoning behind fast threshold numbers:
  - Concern is fast losses causing damage through massive charge into front-end chips
  - Damage level taken to be >10^9/cm^2/fast loss (<100ns)
    - Level at which CDF saw damage occur
    - Measurements by both pixel and tracker groups showed no unrecoverable damage at this level
  - A safety factor of 1000 is applied to these numbers - ca. 10^6/cm^2/RS1 reading
  - Safety factor is ca. 50% “headroom” (log scale) between nominal luminosity + “danger”

CMS abort thresholds

40 us , MIP per cm^2

- Damage ~1e9
- Abort ~1e6
- Nominal lumi ~1e3

Thresholds - Table of Conversion

Running Sum (RS)	Time	Threshold	Threshold	Threshold	Flux in MIPs	MIP Rate	Dose (Grays)	Dose rate (Gy/s)
(# of 40 us digitisations)	(s)	(counts) (204.8 counts = 1uA)	(Current, A)	(Charge, C)	MIP equiv	MIP/s (Hz)	BLM conversion: 3.62e-9 Gy/ BLMBIT	BLM conversion: 5.40e-5 A/ Gy/s
RS1 (1)	40 us	2050	10 uA	400 pC	$3.3 \cdot 10^5$	$8.25 \cdot 10^9$	$7.42 \cdot 10^{-6}$ Gy	0.19 Gy/s
RS10 (131072)	5.2 s	26 M	0.97 uA	5 uC	$4.1 \cdot 10^9$	$7.9 \cdot 10^8$	0.0941 Gy	0.018 Gy/s
RS12 (2097152)	83 s	126 M	0.29 uA	24 uC	$2.0 \cdot 10^{10}$	$2.4 \cdot 10^8$	0.456 Gy	0.0054 Gy/s

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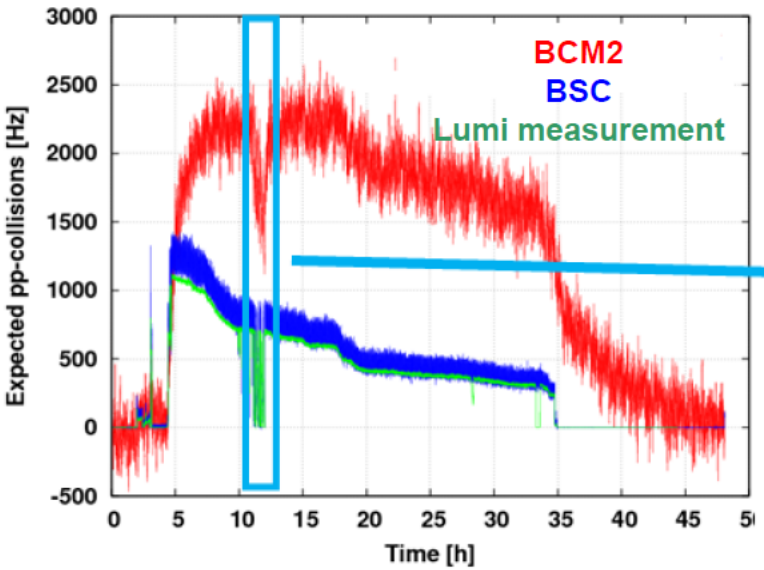
CMS BCM response to lumi

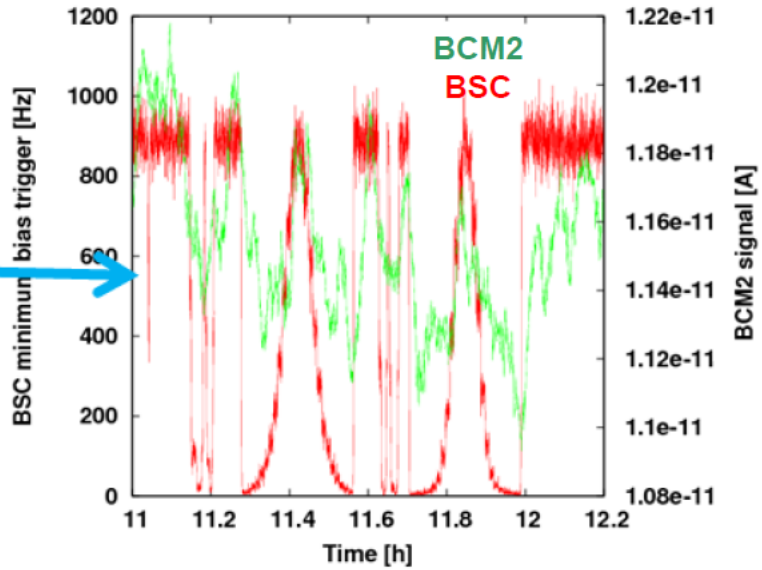
Lower end of Dynamic Range: Luminosity fill observed in BCM2

- **The BCM2 response is correlated with Luminosity :**

Luminosity for Fill 1058 (ca. 2pA)

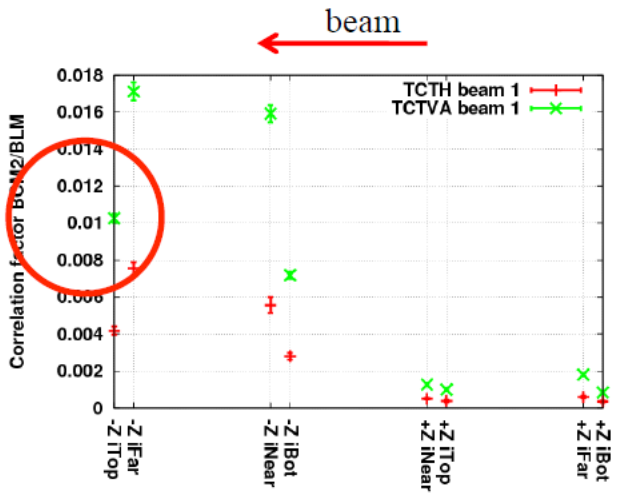


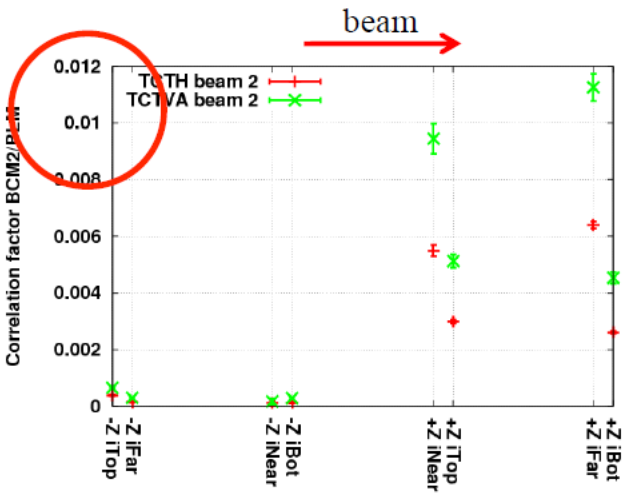
Zoom of the 2 VdM scans.
Clear correlation BSC<->BCM2



BCM2 BLM correlation

- BCM2 signals correlated with LHC BLM at TCT collimators.
- Data from collimator scan
- Clear beam dependence, higher signal on outgoing end.
- Correlation factor ~0.01-0.02, therefore shielding punch through in order of 1 - 2% for TCT losses.
- Ratios approximately the same for all collimator scans and other losses on TCTs.





CMS conclusions

Protection so far ....

- No ABORTS fired by CMS yet
  - (except dedicated tests in 2009 of connectivity of system)
- No conditions so far (for CMS) would have been bad enough to fire ABORT.
- No failures of the system.
- 1 “incident” of unavailability of Beam_Permit for LHC on 29th April 2010
  - After a technical stop. Caused by experts.
  - Solved in ca. 90 minutes after CMS control room was informed, in the shadow of other problems.
- CMS is confident that the BCM protection system is performing correctly.

- ABORTS are clean - losses at CMS are very low.
- However, when the TCDQ was not properly setup at the beginning of 2010 (first few days), losses were seen.
  - Very important for CMS that the TCDQ is correctly set.

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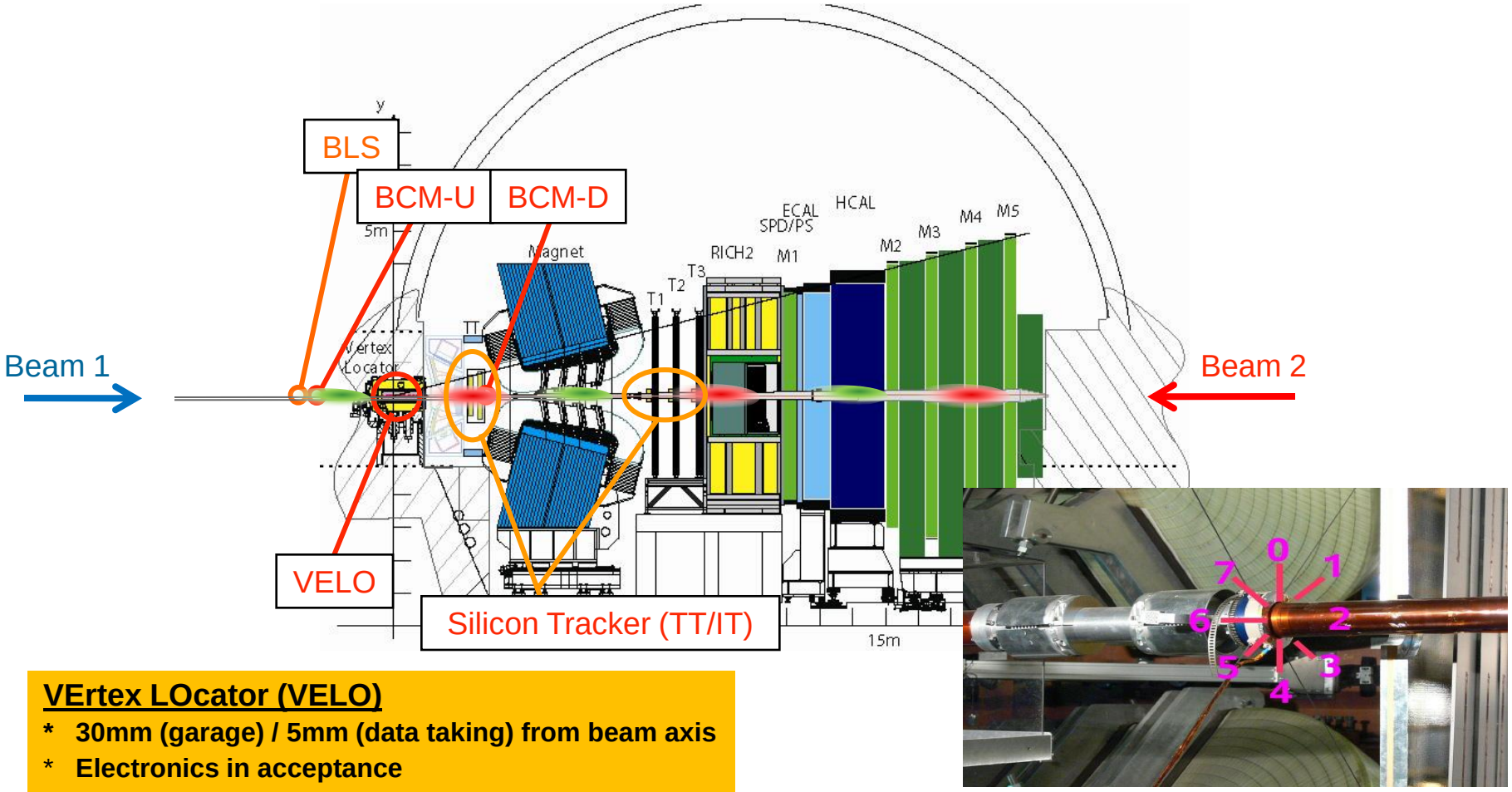
LHCb BCM system



VErtex LOcator (VELO)

- **30mm (garage) / 5mm (data taking) from beam axis**
- **Electronics in acceptance**

Silicon Tracker (ST)

- TT~50mm / IT ~ 90mm from beam axis

Beam Conditions Monitors (BCM)

- 2 stations (Upstream/Downstream)
- 8 diamonds in each, 5cm resp 4cm from beam axis

LHCb Powering Scheme

- LHC Beam Modes and Accelerator Modes regrouped into 9 LHCb States

HV Configuration

Subdetector	Injection	S	I	Ramp	S	I	PhysAdjust	S	I	Physics	S	I	Adjust	S	I	Dump	S	I	NoBeam	S	I	MD	S	I	EOF	S	I
ECAL	STANDBY1	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	STANDBY1	☑	☐	STANDBY1	☑	☐
HCAL	STANDBY1	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	STANDBY1	☑	☐	STANDBY1	☑	☐
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RICH2	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☐	☐	READY	☑	☐
TT	STANDBY1	☑	☐	STANDBY1	☑	☐	READY	☑	☐	READY	☑	☐	STANDBY1	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☑	☐	STANDBY1	☑	☐
VELO	OFF	☑	☐	STANDBY1	☑	☐	READY	☐	☐	READY	☑	☐	OFF	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☑	☐	OFF	☑	☐

LV Configuration

Subdetector	Injection	S	I	Ramp	S	I	PhysAdjust	S	I	Physics	S	I	Adjust	S	I	Dump	S	I	NoBeam	S	I	MD	S	I	EOF	S	I
IT	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☑	☐	READY	☑	☐
RICH1	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☐	☐	READY	☑	☐
RICH2	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☐	☐	READY	☑	☐
TT	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☑	☐	READY	☑	☐
VELO	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☑	☐	READY	☐	☑	_ANY_	☑	☐	OFF	☑	☐	READY	☑	☐

LHCb BCM Logic and Thresholds

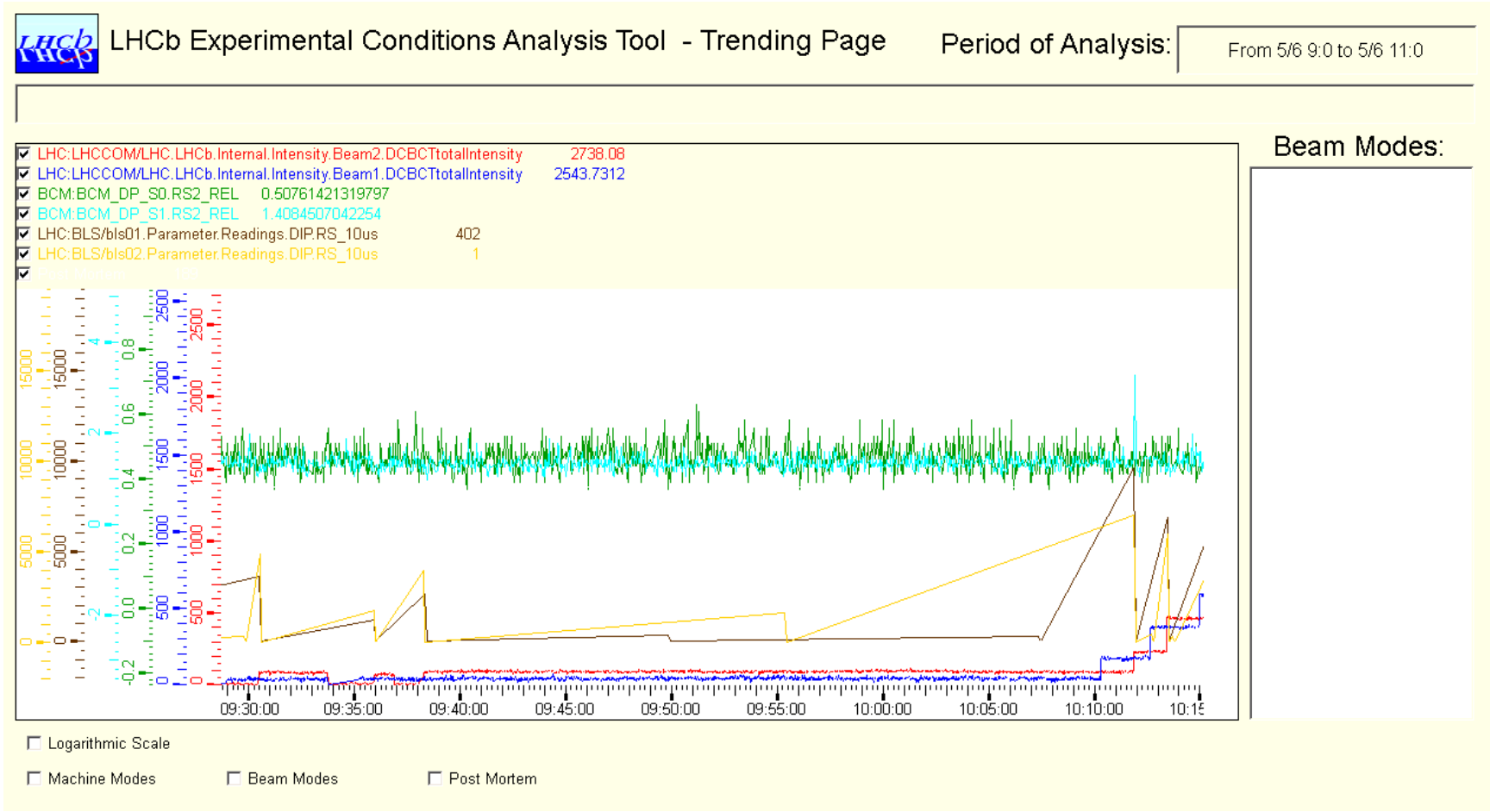
- Two dump logic per station
  - RS2: Three adjacent diamonds over threshold during two consecutive 40us integrations.
  - RS32: Sum of the running sum over 32 consecutive 40us integrations for each diamond after removing the two highest and the lowest diamond sums.

- Minimum bias signal per diamond per 40us
  - Upstream 20.2nA @ nominal running (MIPs eq. $\mathcal{O}(10^3)/cm^2$)
  - Downstream 5.2nA

Dump signal	Threshold [uA]	Eq. current/diamond [uA]	Threshold/MB	~Eq. flux [/cm^2]
RS2_up	10.1 x 3 diamonds	10.1	500	$\mathcal{O}(5x10^5)$
RS2_dow	2.6 x 3 diamonds	2.6	500	$\mathcal{O}(10^5)$
RS32_up	323.2	2.02	100	$\mathcal{O}(10^5)$
RS32_down	83.2	0.52	100	$\mathcal{O}(2x10^4)$

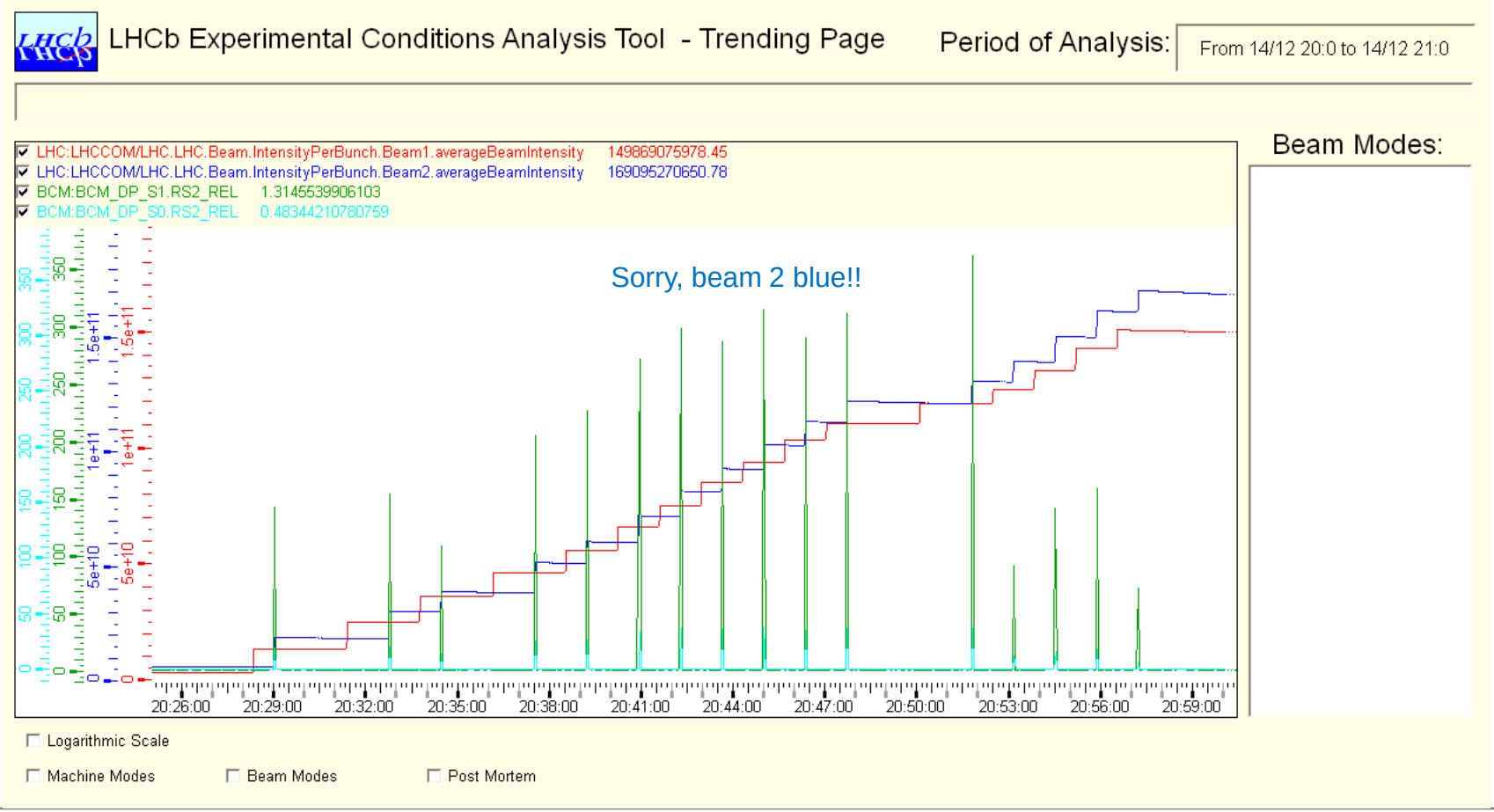
LHCb vs Overinjection

- Spikes observed <1% of dump threshold



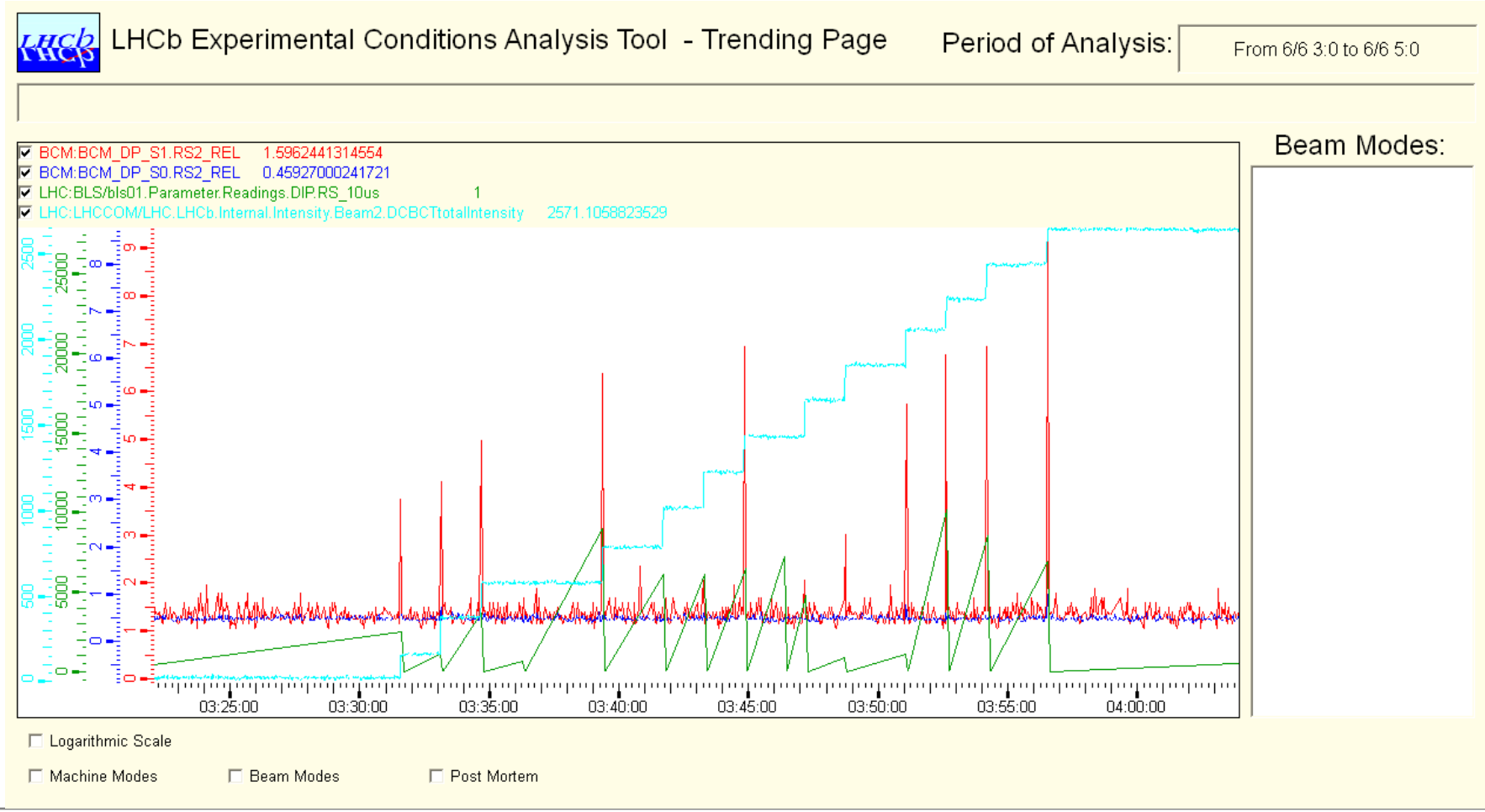
LHCb vs Many bunch injections

- Dec 14, 2009: Increasing background spikes observed on each injection
  - Reached at the end 35% of dump threshold
  - Beam intensities was about 10^{10} per bunch, 16 bunches
  - Effect from circulating beam?



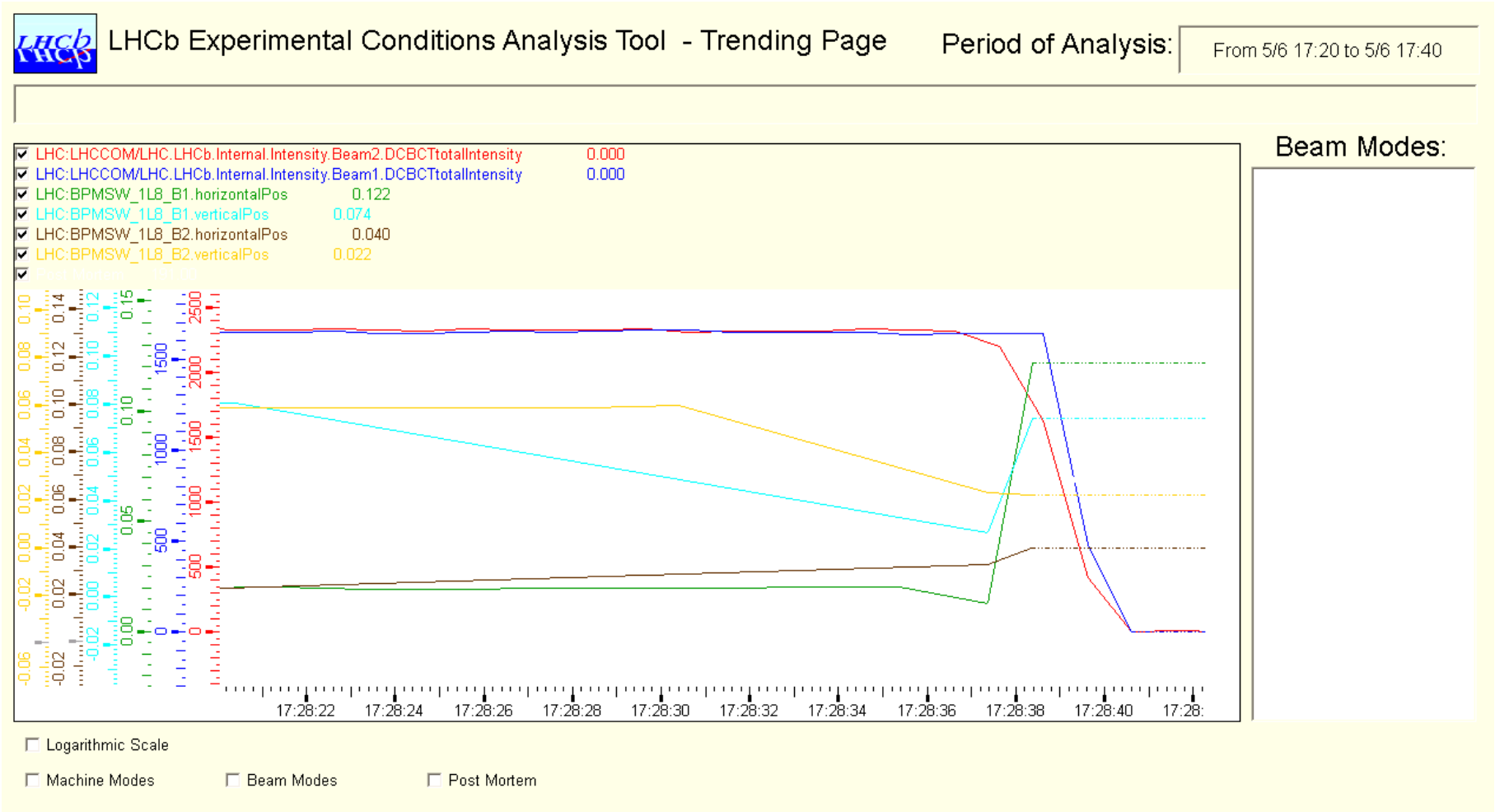
LHCb vs Many bunch injections

- June 6, 2010: Increasing spikes still observed but much less
  - BCM reaches 1% of dump threshold
  - Beam intensities was about $2*10^{10}$ per bunch, 13 bunches
  - Relation with bunch ID? The four growing spikes are 100 BXID apart.



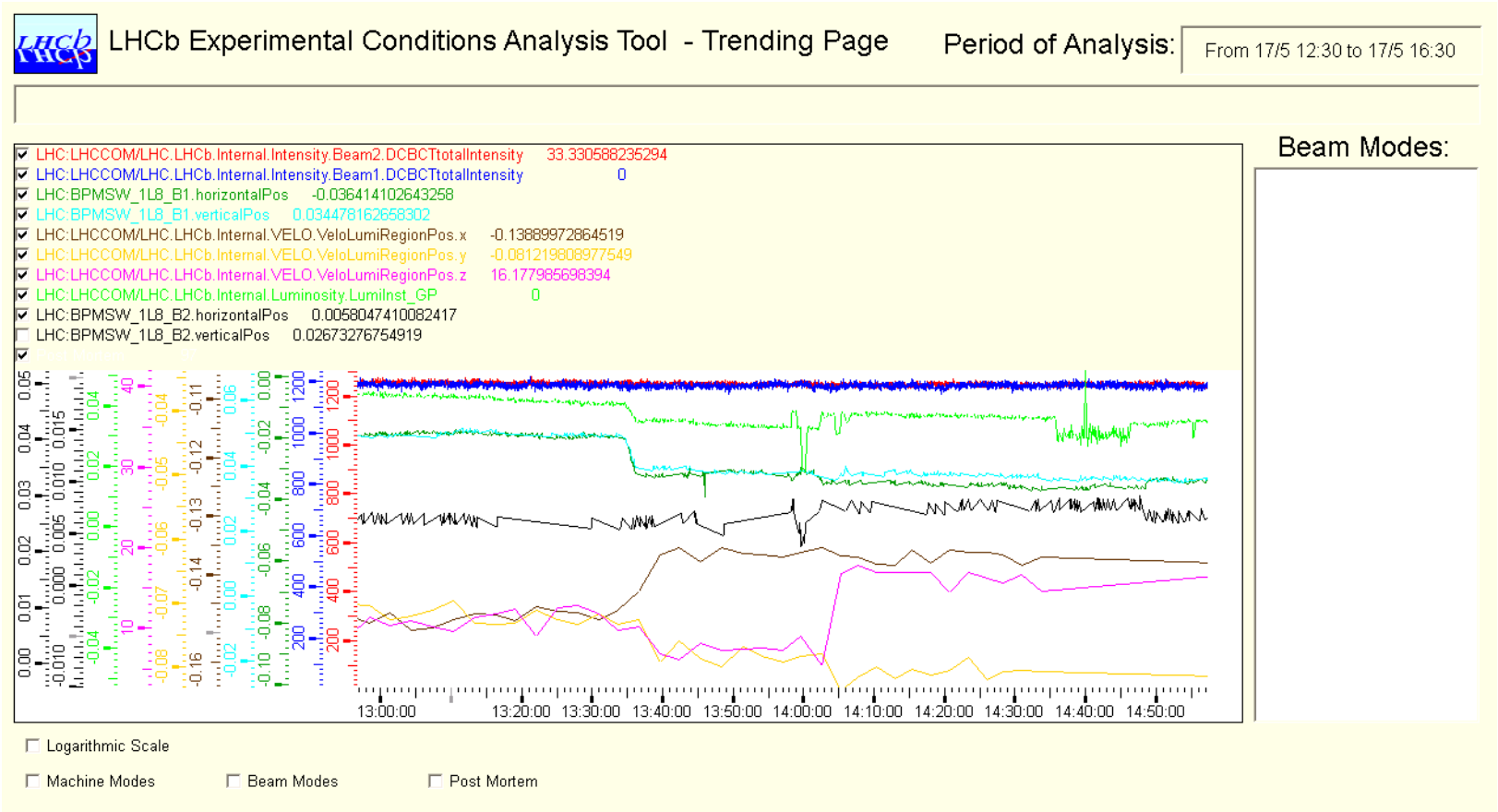
LHCb vs Orbit Corrector Trips

- Orbit FB reset all trims June 5, 17.28
  - Beam movement of up to 1mm horizontal and 0.5mm vertical (beam 1) at LHCb



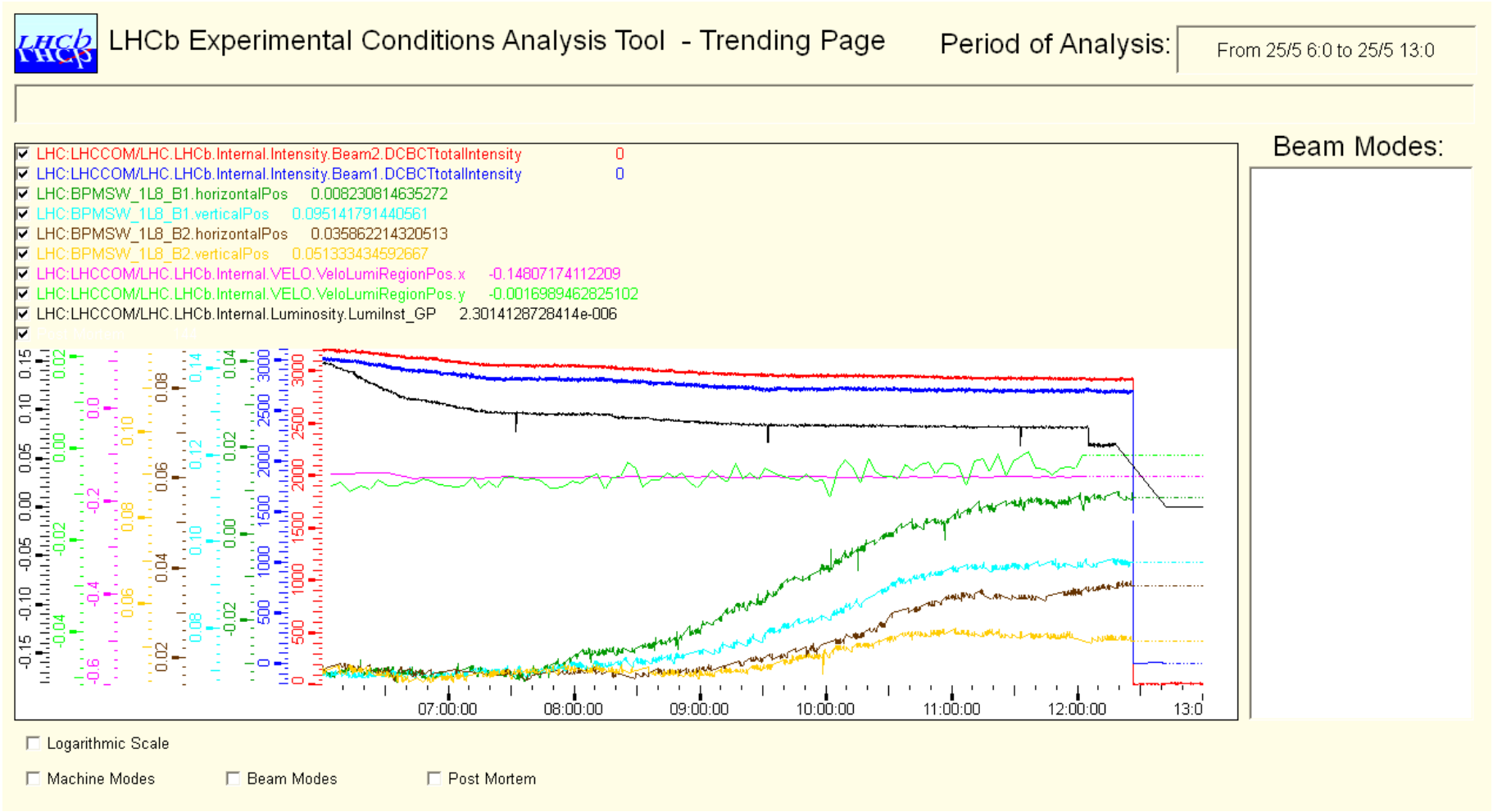
LHCb: Orbit jump

- Unexplained orbit jump on May 17
  - Trigger rate fell of about 550Hz,
  - Beam1 moved by about 120um horizontally and vertically



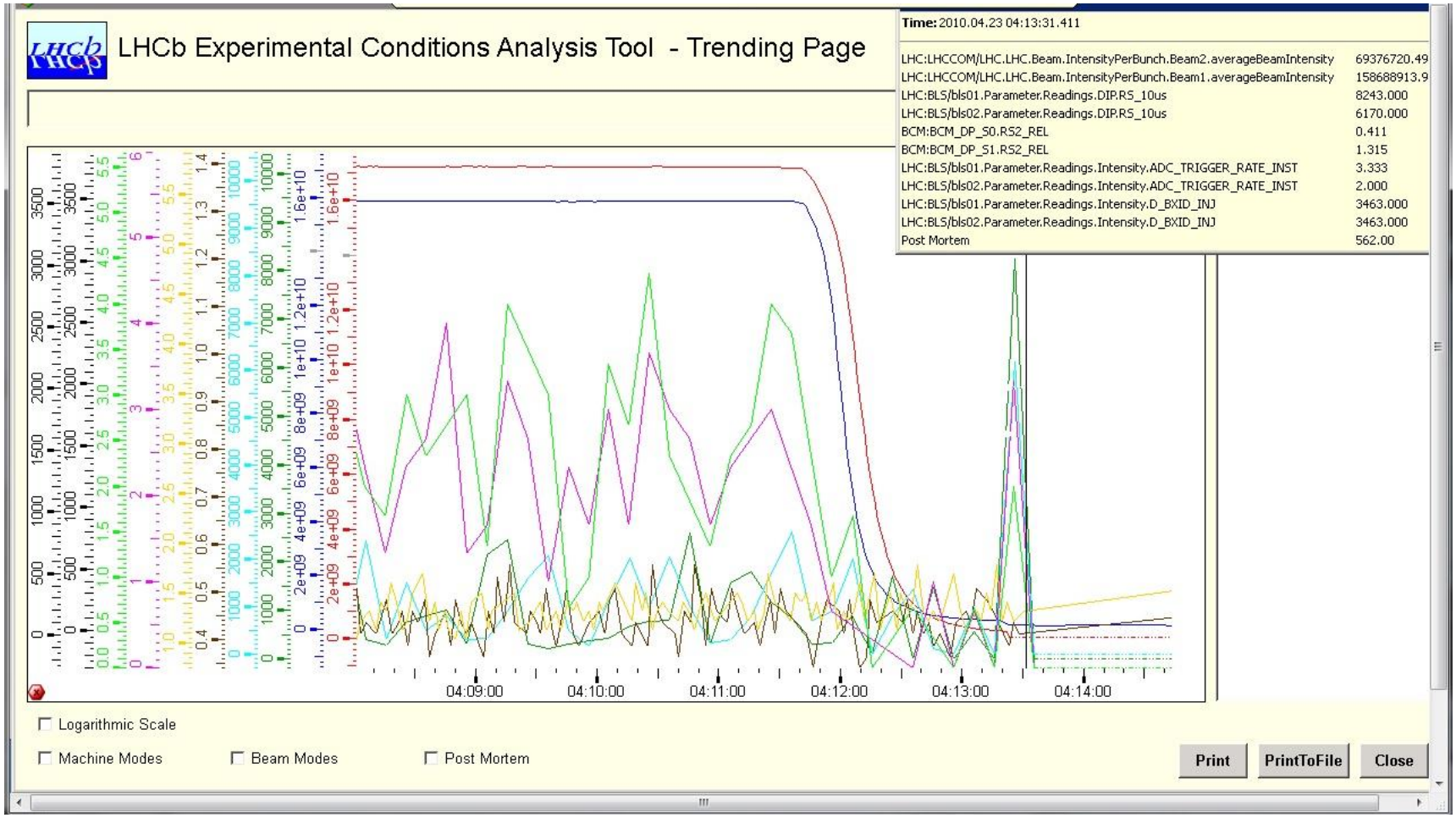
LHCb: False orbit drifts

- VELO relies on BPM-SWs for confirmation and entirely if DAQ is stopped
  - May 25, apparent beam 1-H drift of 0.4mm



LHCb vs Asynchronous beam dump

- Never observed any signal on BCM
- Special 25ns readout on injection/dump of Beam Loss Scintillator prepared to give more info



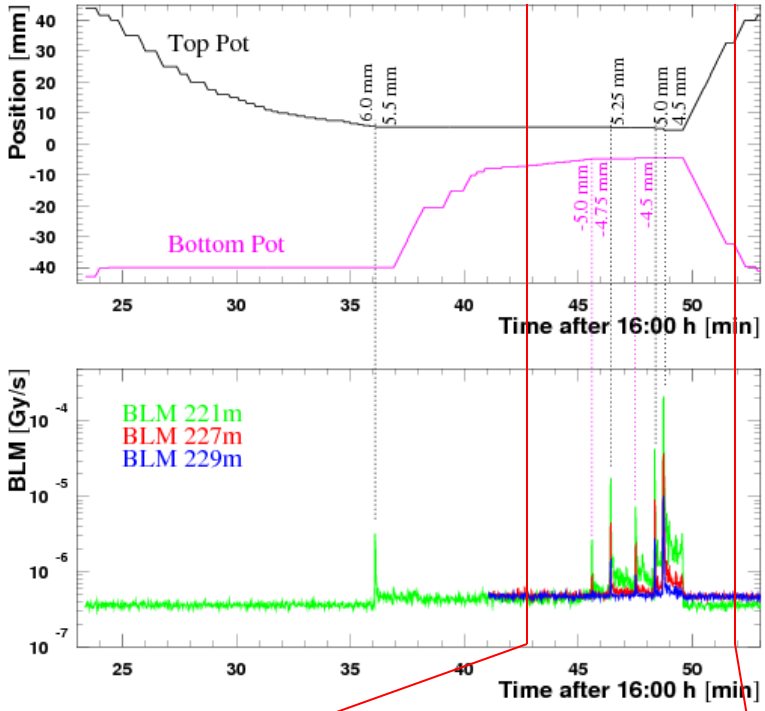
LHCb Conclusion

- We are rather comfortable at the moment
- No sub-detectors have “seen the beam”
- But, still possible that 10000 x $\varepsilon >> 0$

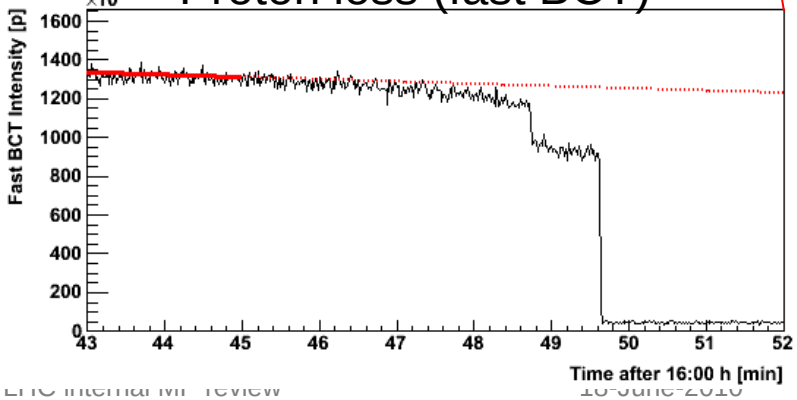
TOTEM

- T1/T2: relies on protection by CMS BCMs
- RPs: rely on nearby machine BLMs
  - protection of downstream magnets against showers from RPs
  - protection of RPs against sufficiently slow beam excursions
- Interlock logic (including movable devices) thoroughly tested/documented : http://deile.web.cern.ch/deile/interlocktest.complete.pdf

TOTEM: BLM Response Calibration / 450 GeV by Scraping



Proton loss (fast BCT)



Test	Sensitivity of BLM at 221 m (RS8) [10^{-12} Gy / p]
29.11.2009	3.75
15.12.2009	6.36
Simulation	2.25

Order of magnitude in agreement but large systematic uncertainties.

To be repeated, in particular at 3.5 TeV !

For details see (to appear soon):

LHC Performance Note 2010-XXX
TOTEM Note 2010-YYY
June 2010

Calibration of the BLM Response at 450 GeV by Beam Scraping with Roman Pots

R.B. Appleby, R. Assmann, M. Deile, J. Kašpar, S. Redaelli

LHCf

- LHCf sensitive to high doses (> 1kGy => 80% light output in scintillators). Would be exceeded by one direct hit pilot bunch.
  - s/w injection inhibit: no beam injected if calo not in garage position
  - (reception problem in the CCC fixed/disappeared)
- Fixed Front Counters switched on as soon as ramp finished.
- Detectors moved in data taking position after stable beam declared.
  - 10 minutes to reach data taking position.
- LHCf relies only on the machine protection system plus some operational procedures. No problem up to now.
- FC rates (available since the end of the ramp) can be nicely related to the beam dynamics and used for offline “beam loss studies” if necessary.

Summary, real vs spurious dumps

= diamond system triggers that caused a beam dump and were not due to real losses seen by diamonds

Not counting the dumps made for testing the BCMs

- ALICE:
  - 0 out of 0 (1 with no beams in the machine, PS fault due to water leak in rack)
- ATLAS:
  - 0 out of 0 (not counting the 3 early BCM dumps…)
- CMS:
  - 0 out of 0
- LHCb
  - 0 out of ~5 for BCM (all triggered on injections, never circulation beam),

    Also:
    - 0 out of 2 by VELO (due to improper procedure during dump handshake),
    - 0 out of 1 or 2 by Magnet (however FMCMs dumped before).

In summary

- Experiment protection systems are operational
  - Teething/learning issue: ATLAS BCM low threshold (solved by replacing with ATLAS BLM)
- No threshold-exceeding beam losses in expts observed so far during stable beams
  - Only real signals causing dumps seen in LHCb (during injections)
- Observations (to be watched out / followed up):
  - ALICE gaseous detector trips (get more events, scrutinize)
  - LHCb seeing increasing losses when piling up bunch injections
    - Much less this year than in 2009, but still visible
  - IR BPMs currently not reliable ("soft" protection issue, used to monitor beam drifts => especially important for VELO/LHCb)