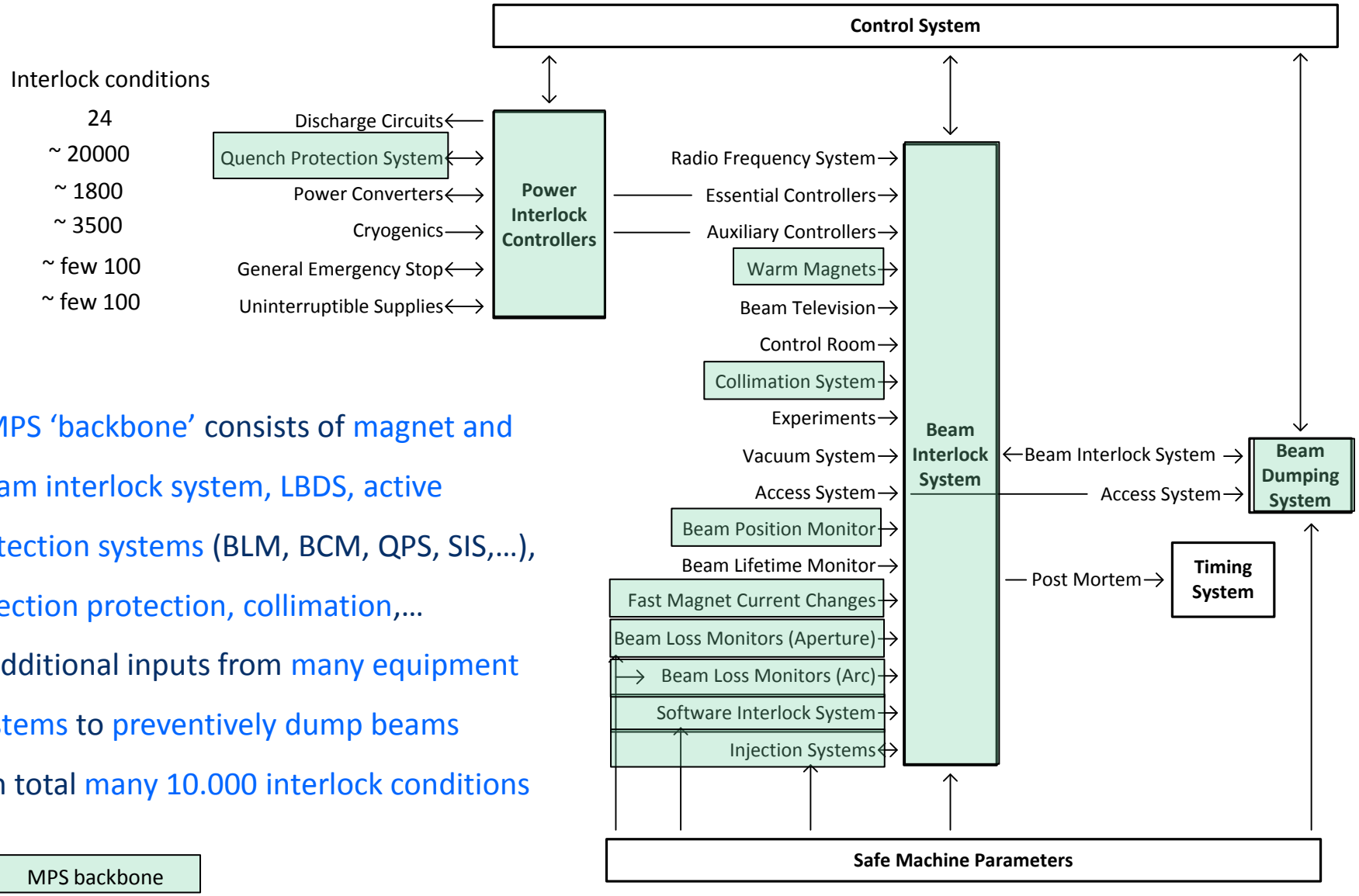
S01 – Lessons from 2011 Machine Protection

M. Zerlauth LHC Performance Workshop February 2012

Thanks to : rMPP and MPP members, D.Wollmann, W.Hofle, S.Redaelli, K.Fuchsberger, J.Uythoven, B.Todd, B.Goddard, R.Schmidt , J.Wenninger, et al

- Machine Protection System - reminder
- MPS response in 2011
- Dependability of MPS backbone
- Issues and areas of upcoming improvements
- MPP/rMPP and ramping intensity in 2012

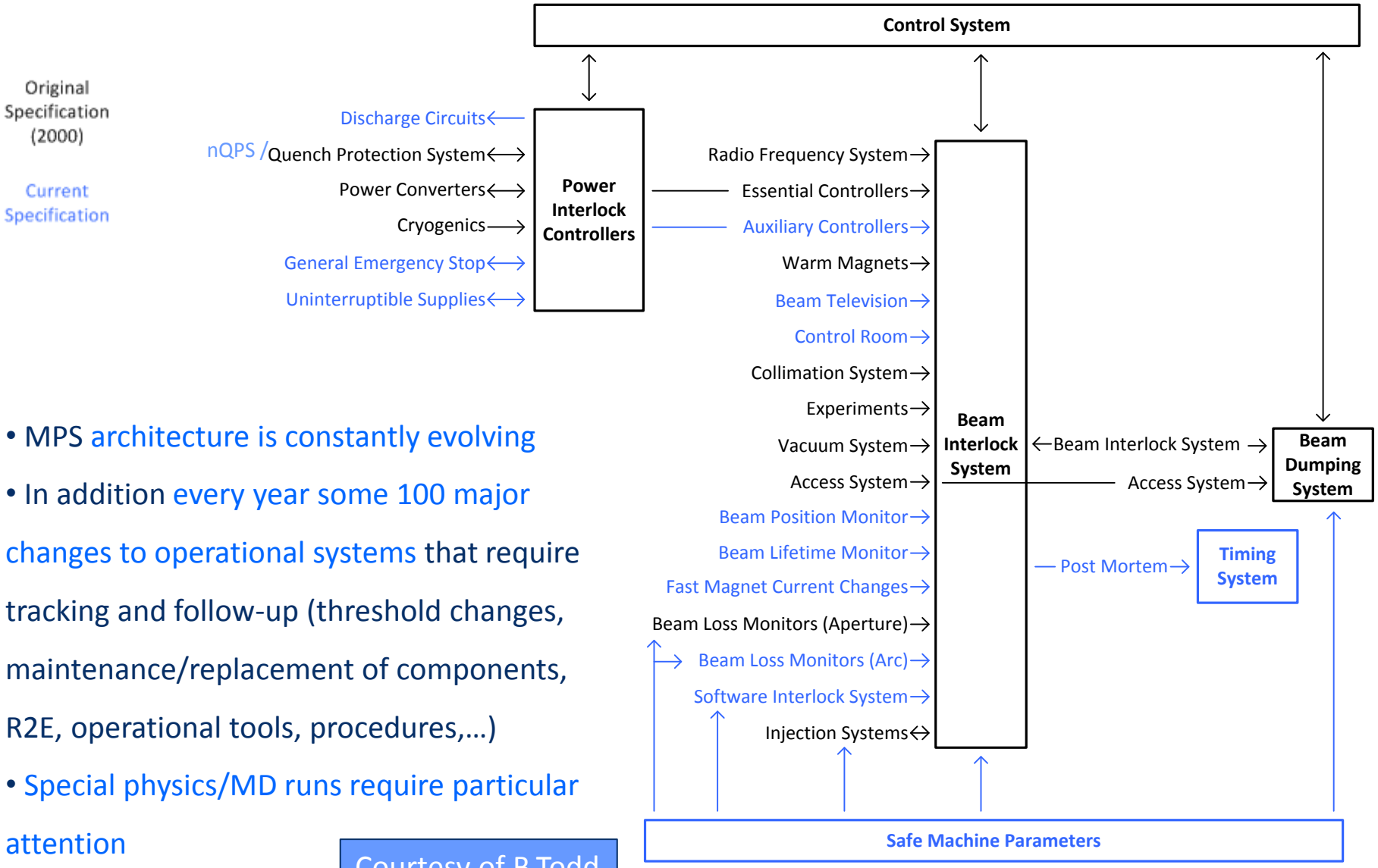
LHC Machine Protection System



- MPS 'backbone' consists of magnet and beam interlock system, LBDS, active detection systems (BLM, BCM, QPS, SIS,…), injection protection, collimation,…
- Additional inputs from many equipment systems to preventively dump beams
- In total many 10.000 interlock conditions

MPS backbone

LHC MPS over time



- MPS architecture is constantly evolving
- In addition every year some 100 major changes to operational systems that require tracking and follow-up (threshold changes, maintenance/replacement of components, R2E, operational tools, procedures,…)
- Special physics/MD runs require particular attention

Courtesy of B.Todd

Review of Protection dumps

1200 beam dumps were cleanly executed during 2011 (-10% wrt to 2010)

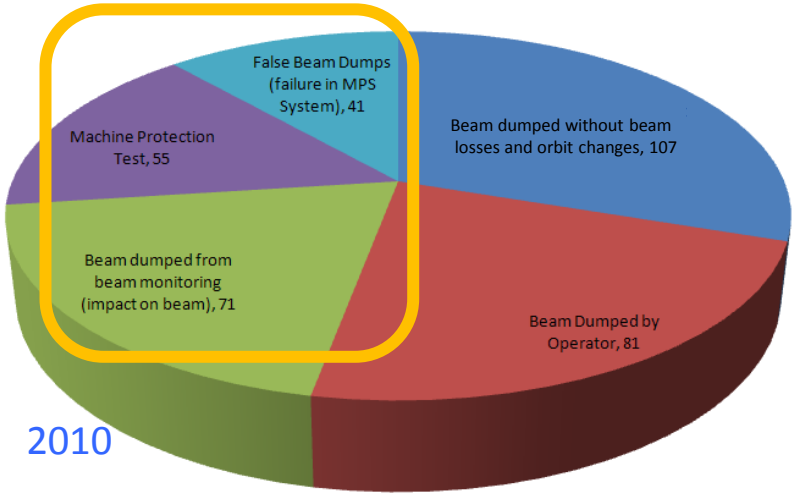
40% more successful ramps to 3.5TeV

~ **Factor of 3 less dumps caused by beam losses, orbit changes,…** -> confirm 2010/11 improvements

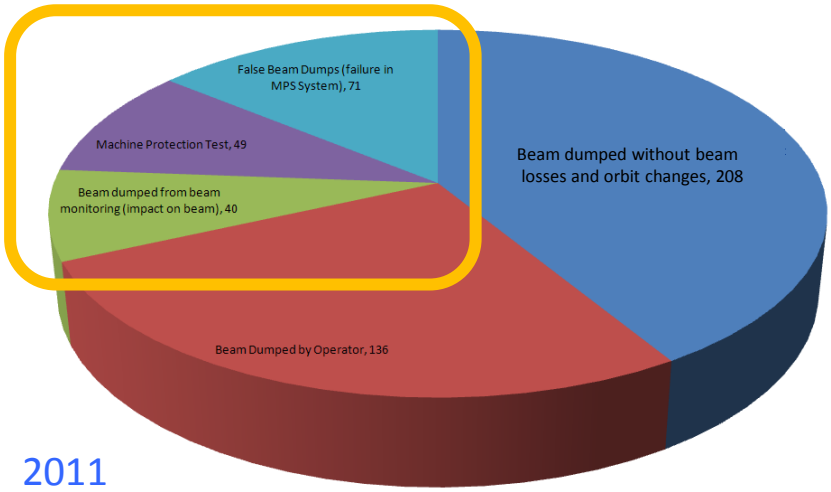
No beam induced quench with >100MJ beams @ 3.5TeV in 2011 (including all 'quench' tests)

No equipment damage observed (apart from kicker erratic causing damage in SDD calibration of ALICE)

MPS response of all dumps from 3.5TeV meticulously analyzed and validated – Initiating system always identified, but sometimes not fully clear why it triggered ('spurious' triggers, SEUs,…)



2010



2011

Nota bene: All statistics only counting fills with E > injection

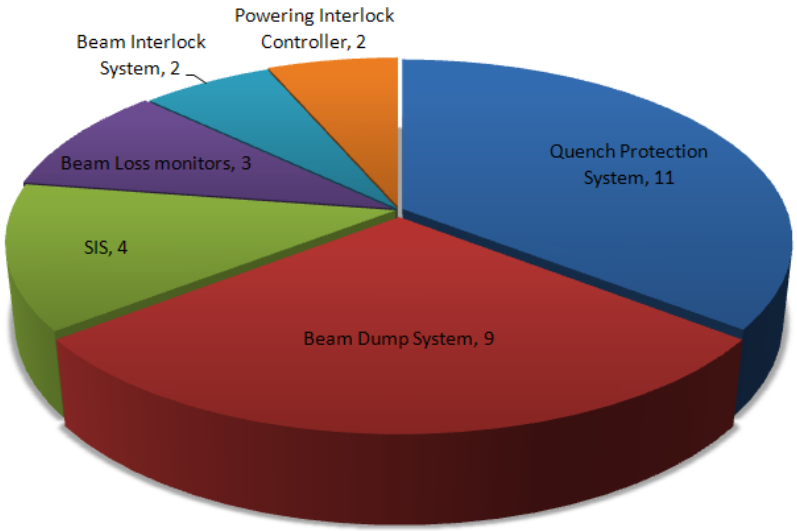
Dependability of MPS backbone

Complexity and high level of safety in MPS systems comes at certain cost, i.e. false positives

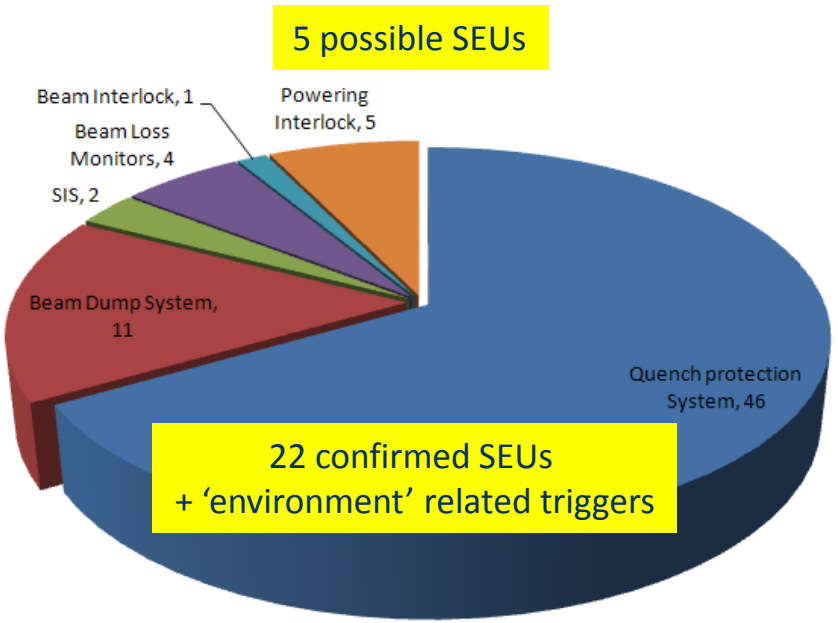
False triggers of most MPS backbone systems remained (surprisingly) constant with time

95% of false dumps in 2011 above injection energy (< thresholds,…)

Increase of false positives from QPS + interlock to large extend due to R2E -> See talk of R.Denz



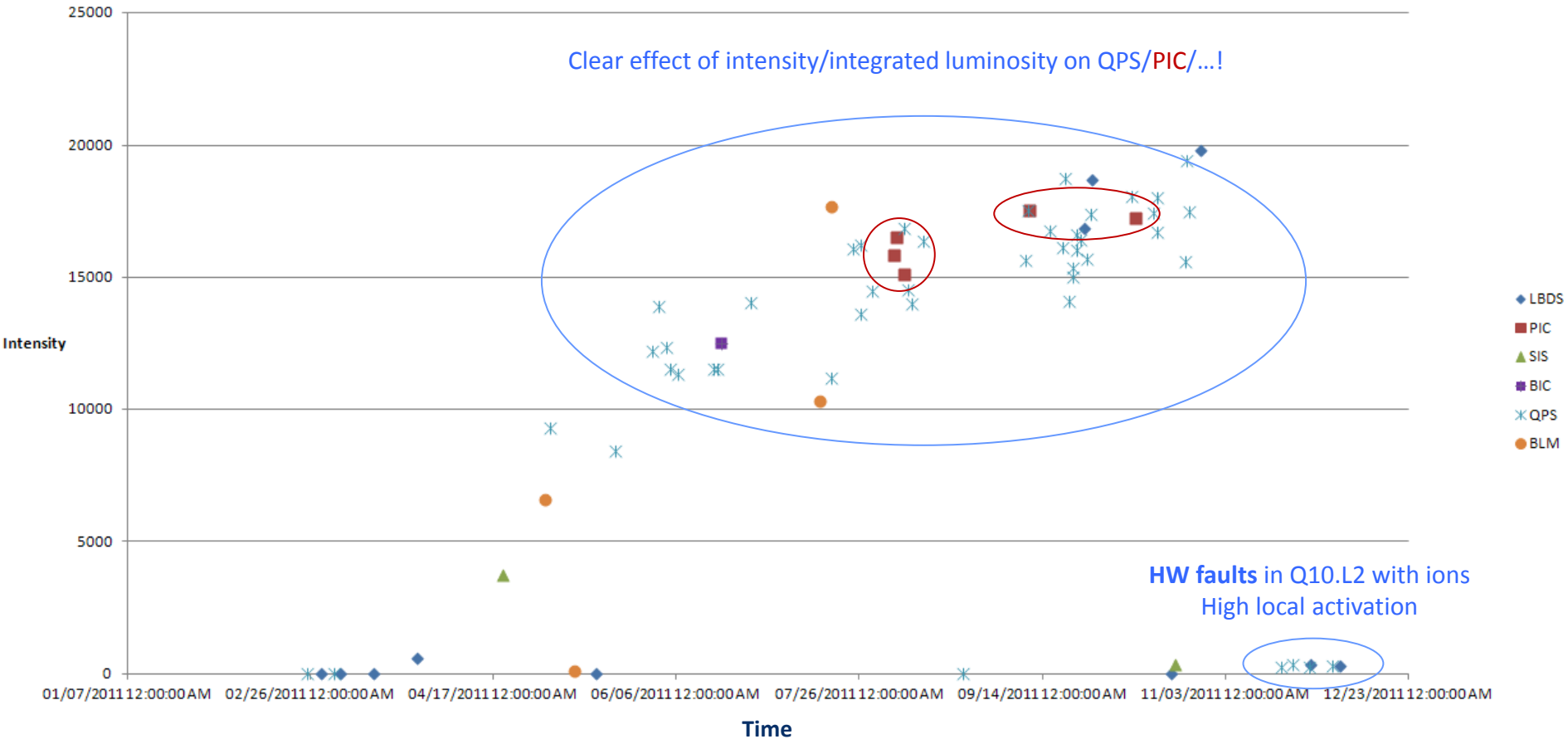
2010 : 8% of fills dumped due to MPS



2011 : 12.6% of fills dumped due to MPS
7.7% not accounting for SEUs

False Beam Dumps from MPS

Occurrence of false dumps of some systems clearly related to increasing beam intensities



Beam dumps by beam monitoring

Some 40 dumps in 2011 by beam monitoring indicate possible improvements of redundant active detection

Mostly slow losses, caused by Vacuum activities, Feedback issues and beam instabilities

Very well protected by BLMs (and QPS), but E>, <β* means tight collimator settings, lower BLM threshold

Maintain current good level of orbit stability -> additional interlocks for orbit corrector current and DIDT

EVENT_TIMESTAMP	ENERGY	MPS_DUMP_CAUSE	MPS_DETECTION	COMMENT
21-NOV-11 08.53.39	3499920	Orbit Feedback	BLM	Unstable OFB in squeeze with gain increase by a factor of 10
04-NOV-11 10.00.29	726600	Orbit Feedback	OP dump	Wrong OFB Parameter ORBIT_REF CHANGING_TIME (1s instead of 680s)
03-NOV-11 02.57.45	3500040	Beam Loss	BLM	Beam Loss during aperture measurements
17-OCT-11 06.58.51	3500040	Transv. beam instability	SIS	High Losses due to bad tune signal (end of ramp and squeeze without QFB)
28-SEP-11 08.56.30	1773720	Transv. beam instability	SIS	OFB problems during ramp
28-SEP-11 08.52.30	629280	Transv. beam instability	SIS	OFB not sending correct trims
20-SEP-11 07.44.34	3500040	Beam Loss	BLM	QFB dragged tune of B2H on resonance
11-SEP-11 04.50.52	3500040	Beam Loss	BLM	Vacuum spike
11-SEP-11 02.56.59	3500040	Beam Loss	BLM	Vacuum spike
25-JUL-11 02.32.30	3500040	Beam Loss	BLM	Orbit oscillations and consequent losses during optimisation
24-JUL-11 03.12.35	3500040	Beam Loss	BLM	Vacuum spike
23-JUL-11 10.14.12	3500040	Beam Loss	BLM	Vacuum spike
09-MAY-11 01.07.45	3500040	Transv. beam instability	BLM	Beam instability after quench test (ADT picking up wrong tune)
08-MAY-11 06.22.17	3500160	Beam Loss	BLM	Beam instability in B2V at end of coupled bunch instability MD
28-APR-11 09.20.22	3500160	Beam Loss	BLM	Vacuum spike
25-APR-11 08.40.04	3500040	Beam Loss	BLM	Vacuum spike
20-APR-11 02.26.26	2930880	Transv. beam instability	BLM	Horizontal beam instability with 2-3 s risetime
16-APR-11 11.58.41	3500040	FB 2	SIS	Orbit reference change applied in 1s instead of 385s, excursion in B2H
14-APR-11 05.37.30	3500160	Transv. beam instability	BPM6	Beam instability during IP scan

Nota bene: Not showing dumps of BPM in IR6 following too low bunch intensity (x4) & UFO dumps (x17 - see T.Baer)

DIDT

Beam Current Change Monitor was vital part of MPS systems for e.g. HERA

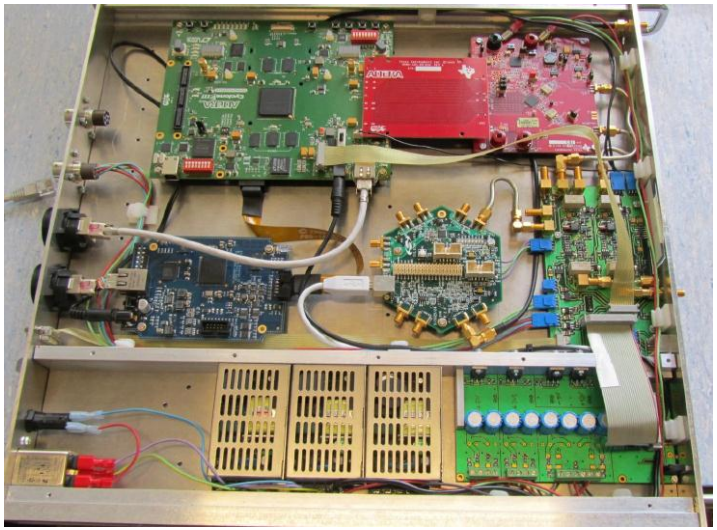
Proposed for use in LHC MPS in 2005 (EDMS Doc. 359172)

With HERA like system, changes of < 0.1% of total beam current could be captured in 10 turns

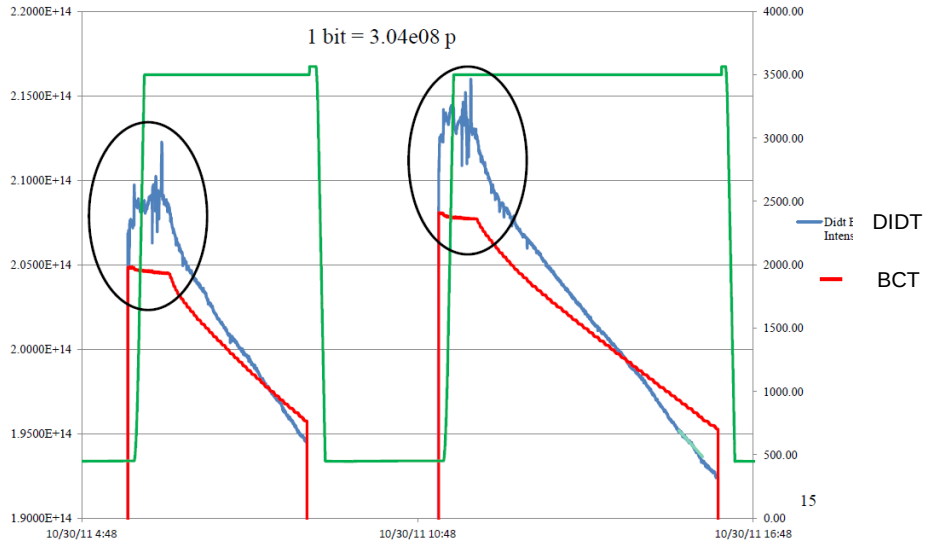
BI started development (with DESY consultancy) mid 2010, for deployment end 2011 + 2012 run

First system installed and data recorded, but showing not understood effects of bunch length,…?

Important to validate and finish soon, as such system adds layer of protection when probing quench/UFO limits with > BLM thresholds



First system now installed in IR4



First measurements during proton runs

Courtesy of M.Pfauwadel, D.Belohrad

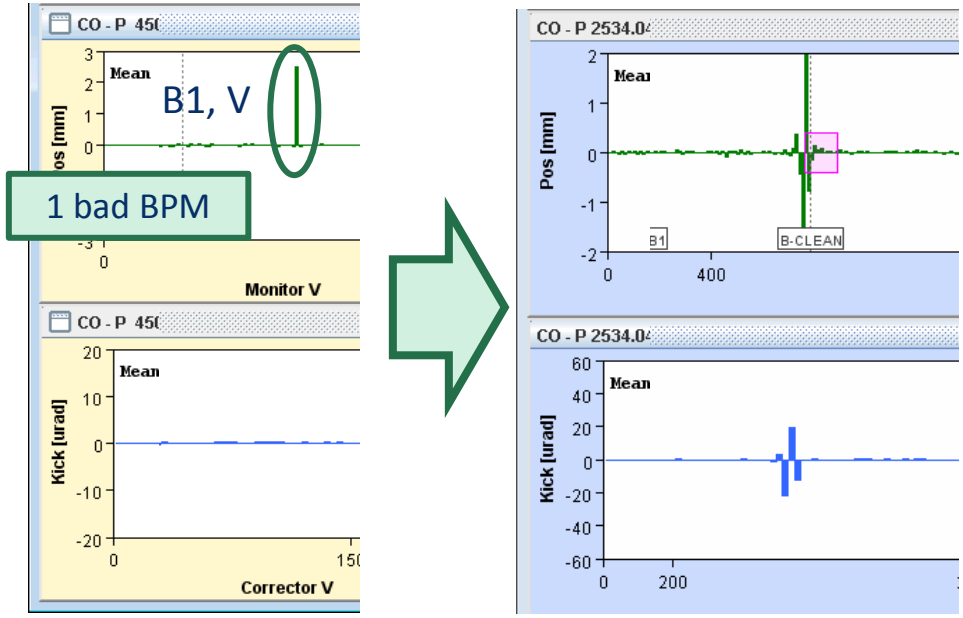
Work ongoing: Novel PC Interlock System

In addition to existing SIS interlocks at injection, ramp, squeeze and SB, new SW interlock system monitoring PC currents to protect against operations- and feedback- failures

Redundant to SIS for arcs, adds protection for LSS 1/2/5/8 due to capability of tracking bump shape amplitude/variations

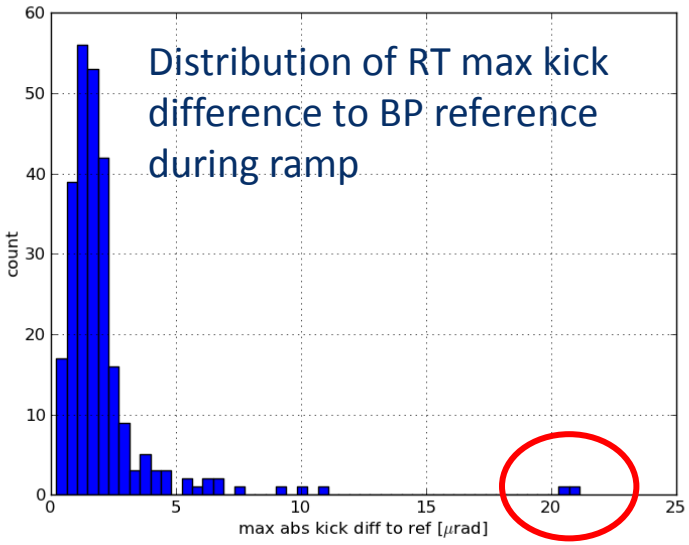
Key interest for all other (non-COD) converters where currently no current tracking is done

Currently under commissioning and testing, after initial experience connection to BIS



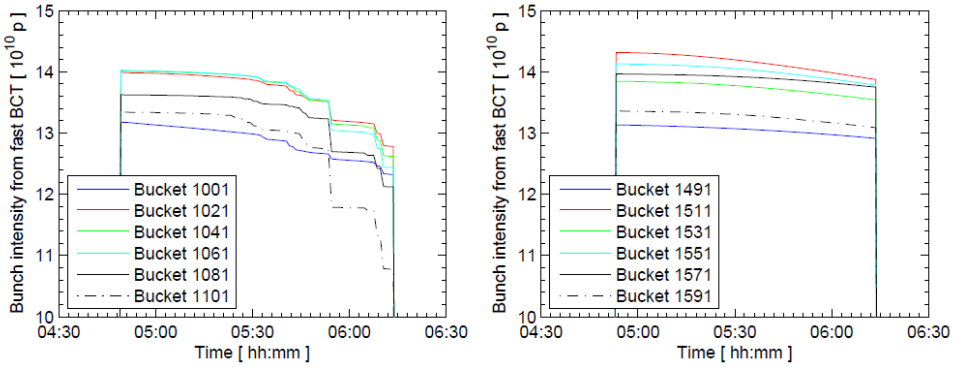
Courtesy of K.Fuchsberger

Fill 1717: Bump >2mm during ramp in IR7

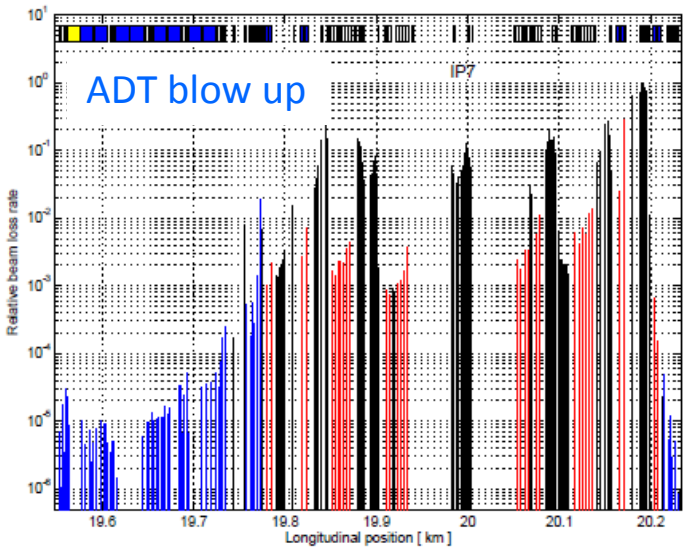


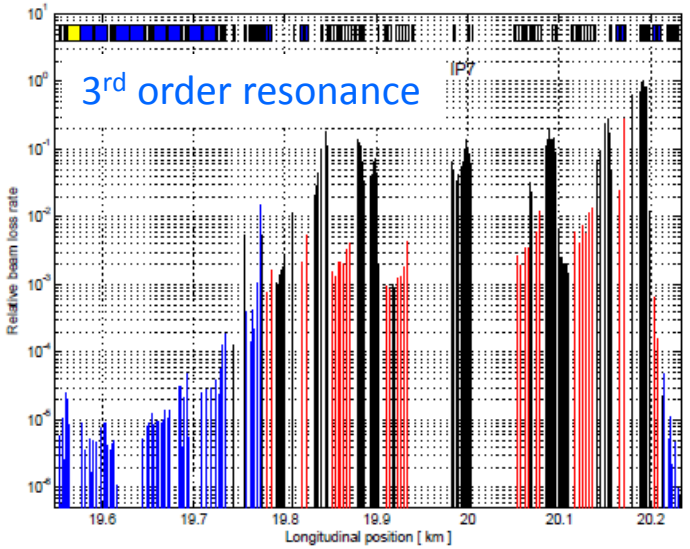
Other improvements for 2012 - ADT

- Considerable work went into finalization and commissioning of transverse damper
- MDs demonstrated selective and very deterministic bunch blow-up
- Allows for abort gap cleaning and increased efficiency when performing loss-maps, quench MDs,…
- System fully operational for both beams, should become default procedure as of start-up 2012 onwards



Blow up of selected bunches during MD (left) and unaffected bunches (right)





Loss-maps performed with ADT and 3rd order resonance method

Courtesy of W.Hofle

Other improvements for 2012 - Abort Gap cleaning

- New procedure to be applied to proton running, from start-up 2012 onwards
- Cleaning ideally left on all the time, but currently costs of a few percent in luminosity
- If AGC switched on with too large abort gap population (~1e12), losses on the TCP risk to dump the beam at worst moment
- Cleaning always to be applied simultaneously to both beams
- Towards fully automated cleaning after LS1:

  -> Need Improved ADT HW + improved reliability of BSRA

- **I_{ag} > 1e10 p+:** LHC announcer to ask for abort gap cleaning to be activated, first at 50% then 100%
- **I_{ag} < 4e9 p+:** Switch cleaning off
- **I_{ag} > 1e11 p+ AND I_{ag} < 1e12 p+** : Manually dump the beams
- **I_{ag} > 1e12 p+**: Logically one should never arrive here

  Don't touch. Wait for decay below 1e12 p+ and dump the beams

Courtesy of J.Uythoven

Other improvements for 2012 - RP review

- Following discussion in Evian/Chamonix 2011, procedure for 'non-working dump trigger' has been prepared and will be implemented and commissioned for 2012 start-up
  - Sequence of actions to be taken by operations to force beam dump at different levels in case of equipment/controls malfunctioning

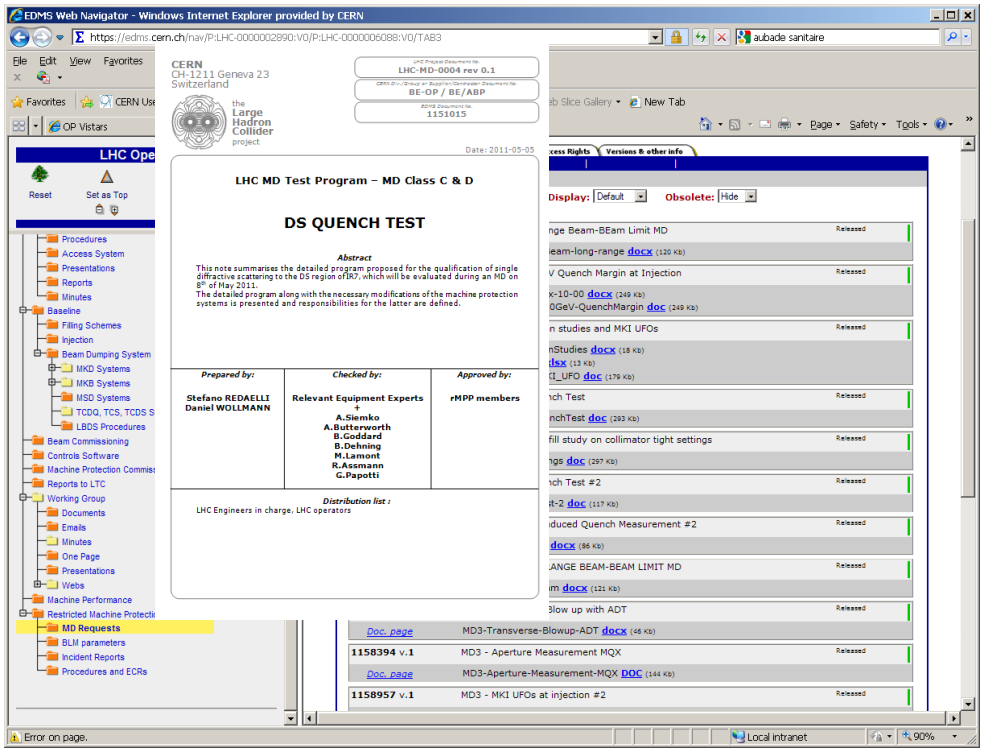
- Issue with RP movements on 6/11/2011 stopped RP operation in 2011 and triggered review between TOTEM/ALFA, Collimator and MPS experts
- Identified actions include
  - additional FLUKA studies for worst case failure scenarios
  - Implementation and commissioning of new state machine
  - New key panel to allow bypassing of position readings only when RP are in home position and motor power disabled (https://edms.cern.ch/document/1183242/1)
  - Improvements to mitigate cross-talk between stopper signals
  - Improved diagnostic and monitoring of all thresholds and limits
- All changes will be fully re-commissioned before operation of RPs will be allowed in 2012

Machine Developments

- Machine Developments per definition explore new machine and machine protection territory!
- MD requestors demonstrated responsibility in proactively providing the required MP documents
- More than 20 documents approved through EDMS for MD periods in 2011
- Preparation phase has proven very useful for MD and Machine Protection teams and often increased the efficiency of the MDs

To be made better for 2012:

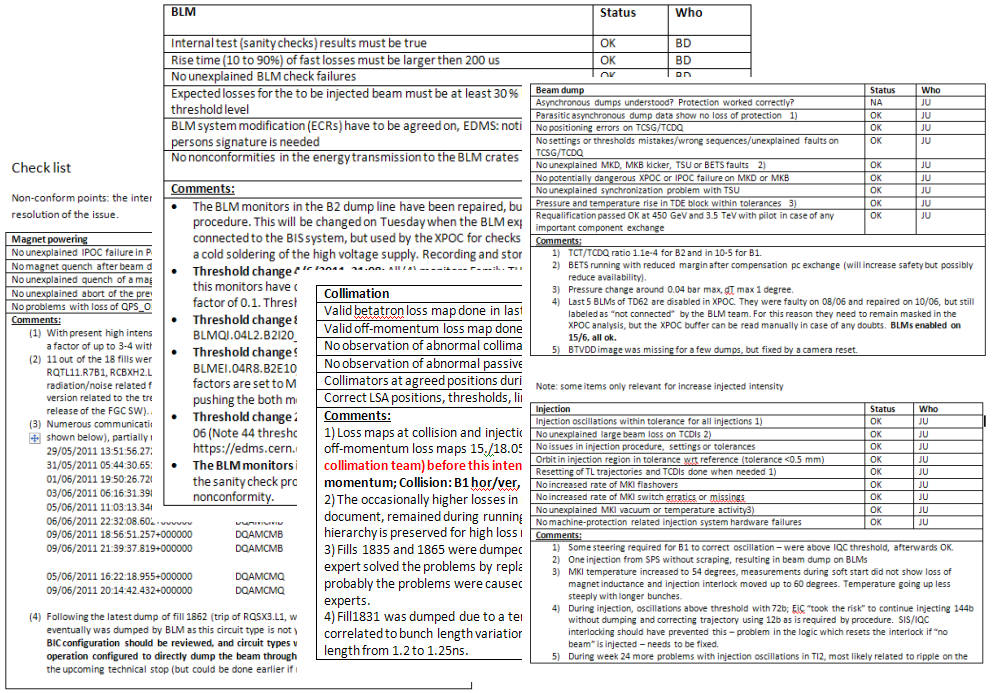
- rMPP classification of requests + preparations of documents tbd more timely before the MD
- Certain flexibility wrt to agreed procedure was useful to increase efficiency (BFPP test, ion quench tests,…) but must not become the default



Role of MPP and rMPP

- Scientific work on MP issues done by MPP, preparing the arguments for decision
- rMPP gathers main players in operation and protection to agree on the way to proceed and operational envelope
- Final decision by LMC
- Propose to continue with this structure for 2012 run, re-discuss after LS1

- Improvements for 2012
  - Formalise ‘standard’ ramp-up after TS
  - Checklists: after the steps with 624b, 840b and 1092b @ 1380b once every 14 days



Check list

Non-conform points: the inter
resolution of the issue.

BLM	Status	Who
Internal test (sanity checks) results must be true	OK	BD
Rise time (10 to 90%) of fast losses must be larger then 200 us	OK	BD
No unexplained BLM check failures	OK	BD
Expected losses for the to be injected beam must be at least 30 % threshold level		
BLM system modification (ECRs) have to be agreed on, EDMS: noti persons signature is needed		
No nonconformities in the energy transmission to the BLM crates		

Comments:

- The BLM monitors in the B2 dump line have been repaired, bu procedure. This will be changed on Tuesday when the BLM exp connected to the BIS system, but used by the XPOC for checks a cold soldering of the high voltage supply. Recording and stor
- Threshold change
- Threshold change
- Threshold change
- The BLM monitors

Collimation
Valid betatron loss map done in last
Valid off-momentum loss map done
No observation of abnormal collima
No observation of abnormal passive
Collimators at agreed positions duri
Correct LSA positions, thresholds, li

Comments:

1) Loss maps at collision and injectio off-momentum loss maps 15./18.0 collimation team) before this inten momentum; Collision: B1 hor/ver,
2) The occasionally higher losses in document, remained during running hierarchy is preserved for high loss
3) Fills 1835 and 1865 were dumpec expert solved the problems by repla probably the problems were caused experts.
4) Fill1831 was dumped due to a te correlated to bunch length variatio length from 1.2 to 1.25ns.

Beam dump	Status	Who
Asynchronous dumps understood? Protection worked correctly?	NA	JU
Parasitic asynchronous dump data show no loss of protection 1)	OK	JU
No positioning errors on TCSG/TCDQ	OK	JU
No settings or thresholds mistakes/wrong sequences/unexplained faults on TCSG/TCDQ	OK	JU
No unexplained MKD, MKB kicker, TSU or BETS faults 2)	OK	JU
No potentially dangerous XPOC or IPOC failure on MKD or MKB	OK	JU
No unexplained synchronization problem with TSU	OK	JU
Pressure and temperature rise in TDE block within tolerances 3)	OK	JU
Requalification passed OK at 450 GeV and 3.5 TeV with pilot in case of any important component exchange	OK	JU

Comments:

1) TCT/TCDQ ratio 1.1e-4 for B2 and in 10-5 for B1.
2) BETS running with reduced margin after compensation pc exchange (will increase safety but possibly reduce availability).
3) Pressure change around 0.04 bar max, dT max 1 degree.
4) Last 5 BLMs of TD62 are disabled in XPOC. They were faulty on 08/06 and repaired on 10/06, but still labeled as “not connected” by the BLM team. For this reason they need to remain masked in the XPOC analysis, but the XPOC buffer can be read manually in case of any doubts. **BLMs enabled on 15/6, all ok.**
5) BTVDD image was missing for a few dumps, but fixed by a camera reset.

Note: some items only relevant for increase injected intensity

Injection	Status	Who
Injection oscillations within tolerance for all injections 1)	OK	JU
No unexplained large beam loss on TCDIs 2)	OK	JU
No issues in injection procedure, settings or tolerances	OK	JU
Orbit in injection region in tolerance wrt reference (tolerance <0.5 mm)	OK	JU
Resetting of TL trajectories and TCDIs done when needed 1)	OK	JU
No increased rate of MKI flashovers	OK	JU
No increased rate of MKI switch erratics or missings	OK	JU
No unexplained MKI vacuum or temperature activity3)	OK	JU
No machine-protection related injection system hardware failures	OK	JU

Comments:

1) Some steering required for B1 to correct oscillation – were above IQC threshold, afterwards OK.
2) One injection from SPS without scraping, resulting in beam dump on BLMs
3) MKI temperature increased to 54 degrees, measurements during soft start did not show loss of magnet inductance and injection interlock moved up to 60 degrees. Temperature going up less steeply with longer bunches.
4) During injection, oscillations above threshold with 72b; EIC “took the risk” to continue injecting 144b without dumping and correcting trajectory using 12b as is required by procedure. SIS/IQC interlocking should have prevented this – problem in the logic which resets the interlock if “no beam” is injected – needs to be fixed.
5) During week 24 more problems with injection oscillations in TI2, most likely related to ripple on the

Magnet powering
No unexplained IPOC failure in P
No magnet quench after beam d
No unexplained quench of a mag
No unexplained abort of the pre
No problems with loss of QPS_O

Comments:

(1) With present high intens a factor of up to 3-4 with
(2) 11 out of the 18 fills wer RQTL11.R7B1, RCBXH2.L radiation/noise related f version related to the tre release of the FGC SW).
(3) Numerous communicati shown below), partially
29/05/2011 13:51:56.27
31/05/2011 05:44:30.65
01/06/2011 19:50:26.72
03/06/2011 06:16:31.39
05/06/2011 11:03:13.34
06/06/2011 22:32:08.60
09/06/2011 18:56:51.257+000000 DQAMCMB
09/06/2011 21:39:37.819+000000 DQAMCMB
05/06/2011 16:22:18.955+000000 DQAMCMQ
09/06/2011 20:14:42.432+000000 DQAMCMQ
(4) Following the latest dump of fill 1862 (trip of RQSX3.L1, w eventually was dumped by BLM as this circuit type is not **BIC configuration should be reviewed, and circuit types operation configured to directly dump the beam through** the upcoming technical stop (but could be done earlier if

Intensity ramp-up in 2011 and 2012

- Majority of Machine protection tests done with SBF <= 3 nom bunches, requiring relatively little time during ramp-up
- Main driving factor was machine availability up to 768b, initial steps to 912 b and 1092 b set off UFOs, vacuum activities and SEU
- Risk with faster intensity ramp up is not risk with machine protection, but effect of decreasing the efficiency
- Balanced approach to intensity increase allows for probing and resolving of upcoming issues while maintaining certain integrated luminosity (<β*, new collimator settings, < orbit tolerances will need time to master)
- Reduce to 7 steps in 2012
  - 3b for MPS
  - 2-3 fills and 4-6 hours with 48b, 84b, 264b and 624b (cycle validation)
  - 3 fills and 20 hours with 840b, 1092b, 1380b (lumi related problems)

Summary

LHC Machine Protection Systems have been working well during 2011 run
thanks to a lot of loving care and rigor of operation crews and MPS experts

Ever more failures are captured before effects on beam are seen (no losses or orbit movements)

Still no quenches with circulating beam (with ~ 100MJ per beam and 10mJ for quenching a magnet)

Additional active protection will provide further essential redundancy for next years of running (DIDT, PC interlock…)

Maintaining present good level of orbit stability is a primary importance when moving to $<\beta^*$ + tight collimator settings

Still we have to remain vigilant to maintain current level of safety of MPS systems while increasing efforts on increasing MPS availability

Thanks a lot for your attention