Internal Review of the LHC Machine Protection System:
The Beam Dumping System

Jan Uythoven

For the LBDS Team

LBDS Statistics 1 March to end April 2010

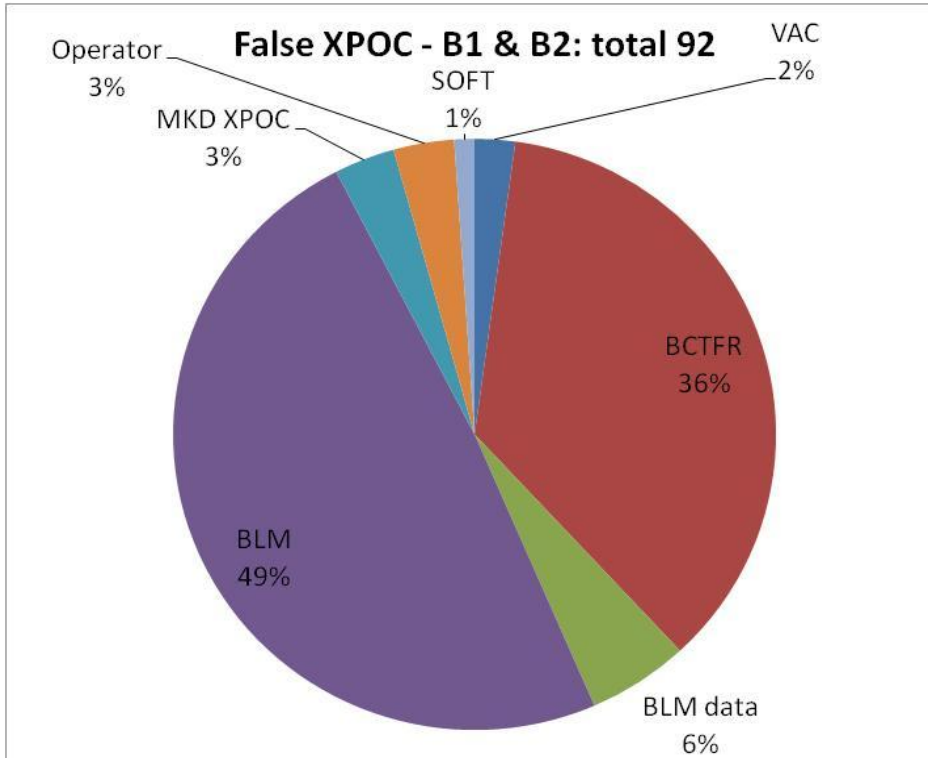## (No time to update, but conclusions are still valid)

- **Beam 1:**
- 1689 Dumps
- XPOC false 13 %
  - -/- Tests (10 %)
    -/- Loss (1.6 %)
- **1.1 % real XPOC faults left**
- **5 Internal Dump requests** or system faults
  - 0.3 %
- Energy distribution:
  - 1459 at 450 GeV
  - 54 at 3.5 TeV
  - 11 at other energy
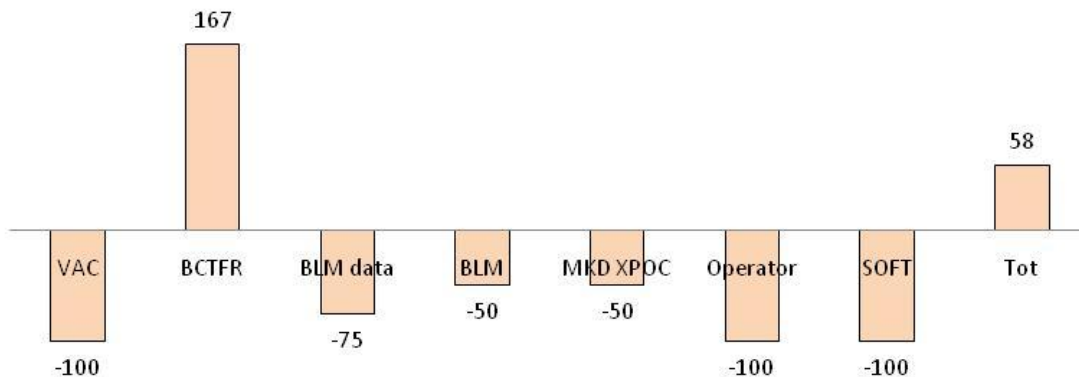 - 165 Test (no energy)

- **Beam 2:**
- 1715 Dumps
- XPOC false 10 %
  - -/- Tests (7.6 %)
    -/- Loss (1.1 %)
- **1.6 % real XPOC faults left**
- **11 Internal Dump requests** or system faults
  - 0.6 %
- Energy distribution:
  - 1531at 450 GeV
  - 55 at 3.5 TeV
  - 10 at other energy
  - 119 Test (no energy)

Jan Uythoven, TE/ABT

Total of False XPOCs, B1 + B2: 92

False XPOC - B1 & B2: total 92

Pie chart values:
- Operator 3%
- MKD XPOC 3%
- SOFT 1%
- VAC 2%
- BCTFR 36%
- BLM data 6%
- BLM 49%

- BLM: Beam in the abort gap or losses at injection
- BCTFR: No data
- BLM data: No data
- Operator: Dumped with BIS loop open
- MKD XPOC: MKD generator 'drifts'
- Vac: No vacuum data
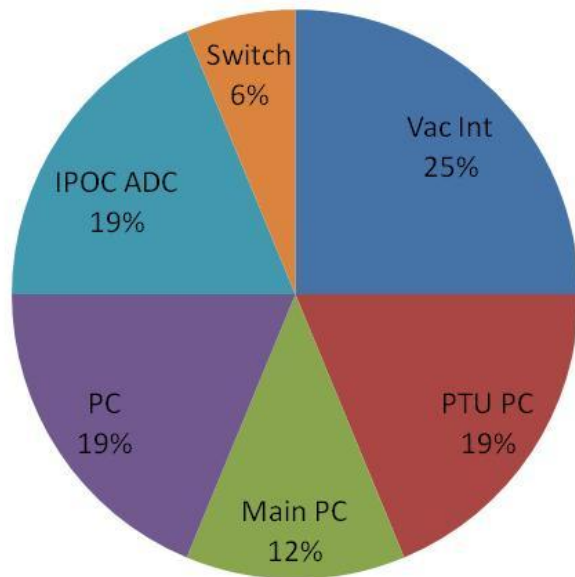- Soft: Analysis error in MKD module

Relative Change XPOC error April vs. March [%]

Bar chart values:
- VAC: -100
- BCTFR: 167
- BLM data: -75
- BLM: -50
- MKD XPOC: -50
- Operator: -100
- SOFT: -100
- Tot: 58

Since 'Direct Get' on FBCT: OK
Only no data when FE is down (about once per week).

Total of Internal Faults B1 + B2: 16

LBDS Internal Faults: total 16

- Vacuum: Vacuum glitches MKB interlock, filtered
- IPOC ADC: cards failing, all cards replaced
- PTU PC: problem C, all exchanged
- Main PC: Stability problem
- PC: 5 V or 15 V, replaced
- Switch: surveillance problem, switch was ok

**Relative change internal faults April vs. March [%]**
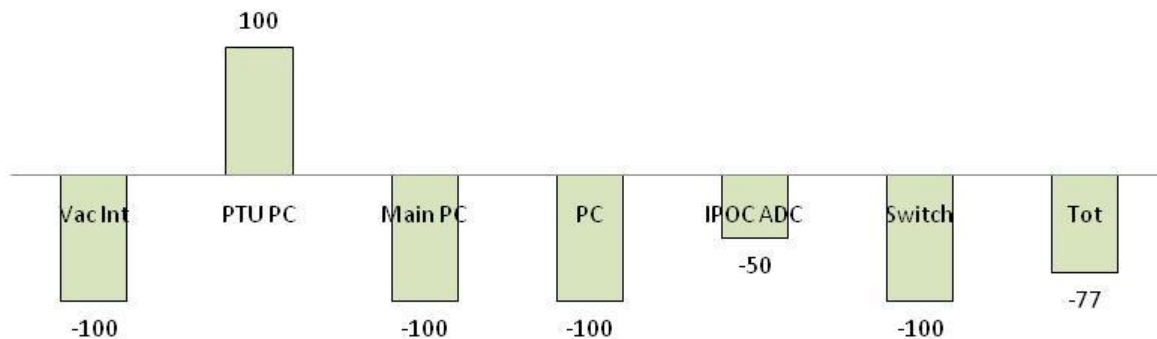
Vacuum glitches are now filtered. Only once error, last week, when glitch > filter time constant (some seconds)

Beam Dumps Statistics

- At the moment almost all false XPOC are due to beam in the abort gap giving losses above XPOC BLM thresholds
  - 1.0 – 1.5 % of all dumps
- Internal faults due to hardware was about 0.5 % of dumps
  - MKB vacuum glitches: now filtered
  - IPOC ADC – now all replaced
  - PTU failures – now all replaced
  - PC stability (main and compensation power converter)
  - 5 V power converter – all replaced
  - 1 switch surveillance failure
- (Sub)systems changed BEFORE real failure due to early indication by XPOC:
  - Three MKD generators were exchanged after 'bad trends' detected with XPOC. Inspection has shown contact erosion problems

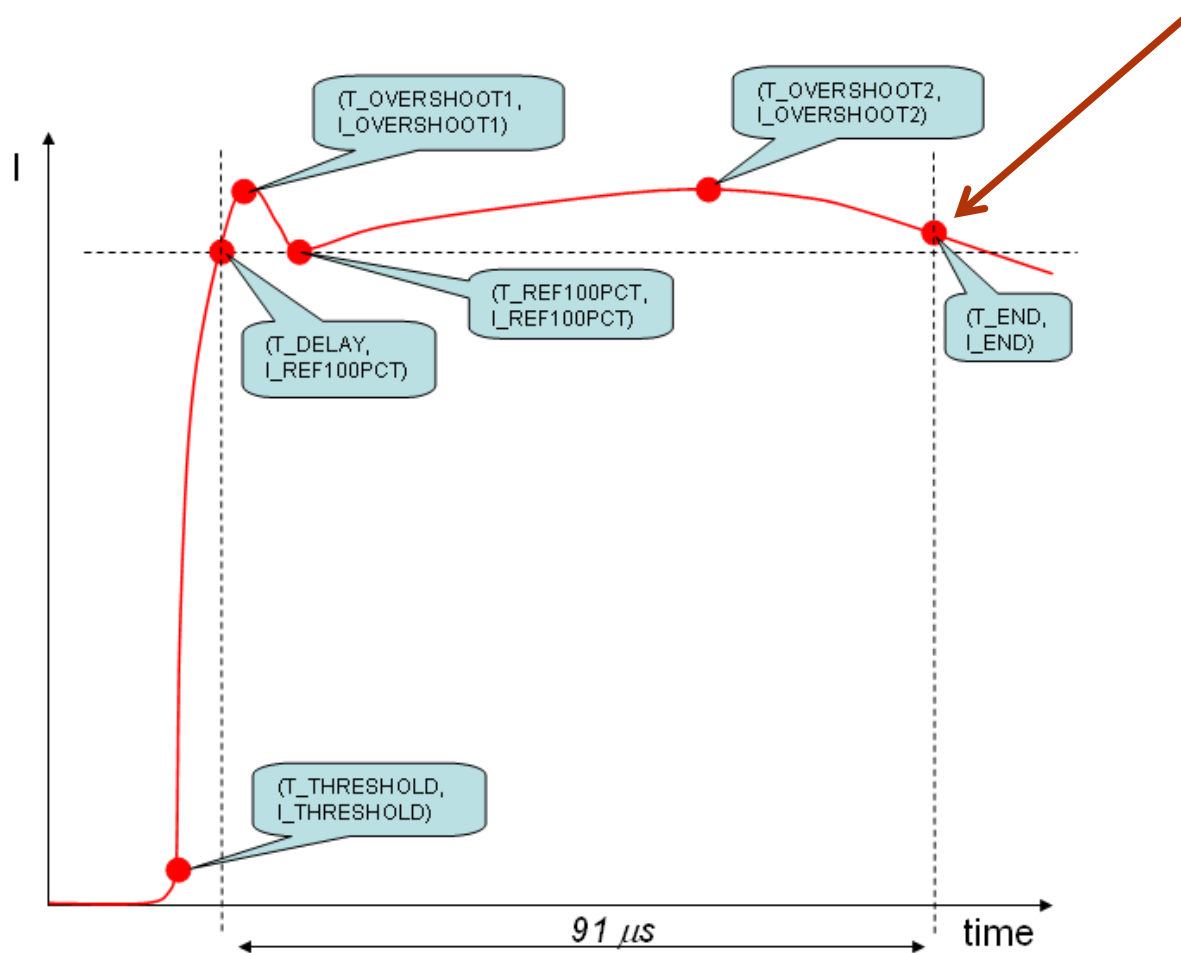# XPOC trend and error leading to generator exchange last technical stop
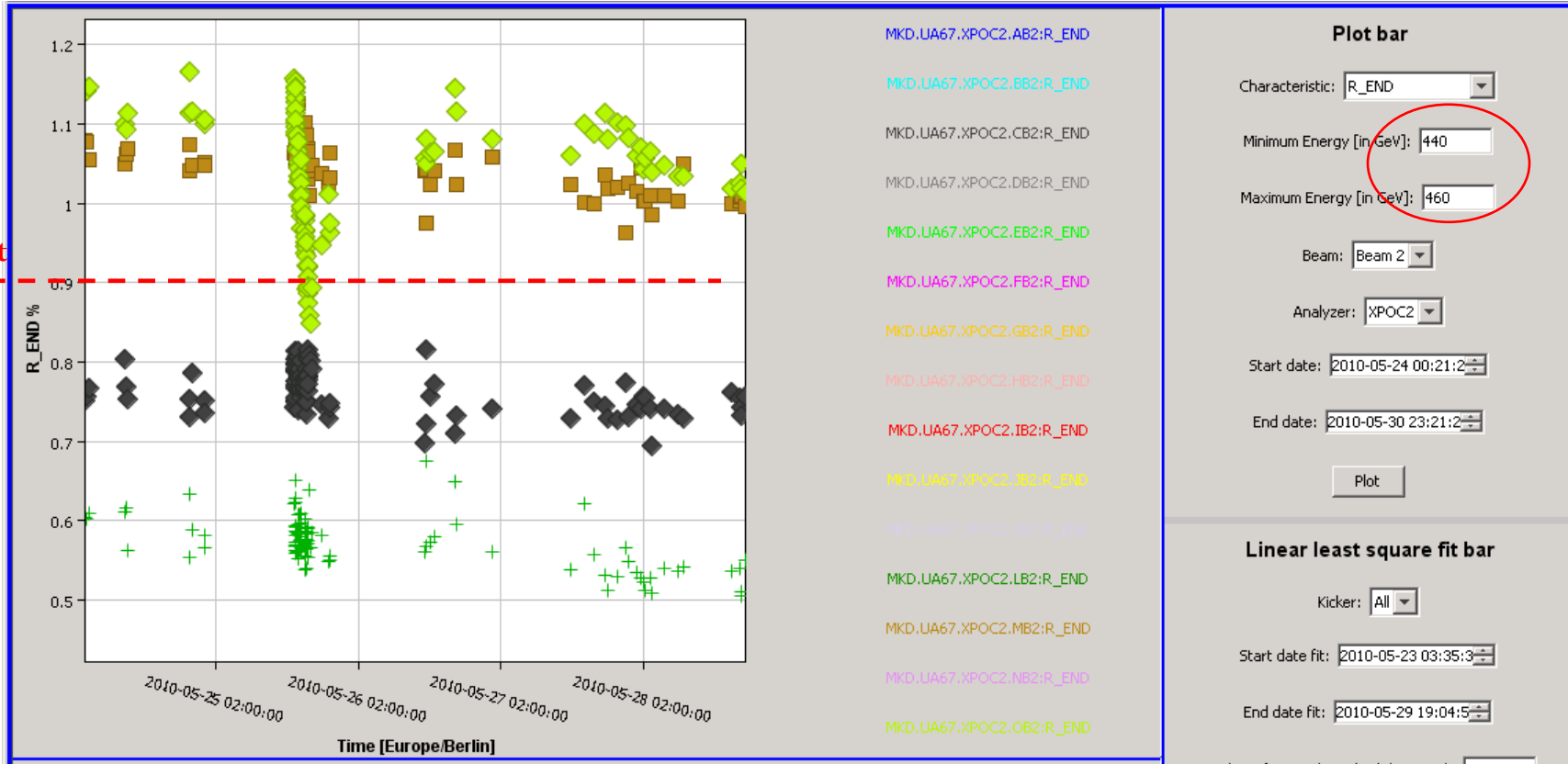
Reference generator O R_end : 1.40 +/- 0.5 %
References gen M: 1.25 %, gen C 0.85 %, gen E 0.69 %

Conclusions: All R_end references dropped, but most on the replaced generator O.
On top of this: generator O had this sudden drop given false XPOCs.

Definition of XPOC R_End

R_END	= 100 x (I_END – I_REF100PCT)/ I_REF100PCT	%

XPOC

- New modules: BTVDD, BPMD, BCT, TSU
  - Operational in 'dev' but difficult to get going reliably…
    - Stability of some BI data
    - Optimisation of applied limits and algorithms
  - New modules help the understanding if things go wrong
  - Should we operate this with tight limits and get many faults?
- PM GUI being extended with more detailed information
- XPOC users GUI being overhauled
- Reset by EIC in case of false XPOC due to unbunched beam

MKD generator performance / exchange

- Two generators replaced during winter technical stop
- One generator replaced week 22 (generator O last slide)
- Performance degradation detected by XPOC
- Found GENERAL problem with erosion of contacts – degradation
  - Recall program
    - Check all contacts and connections
    - Redefine torque etc. for the different contacts
    - Need to make modifications in laboratory
    - Replace 2 spares at each technical stop 2010
    - With 4 spares available in 2011, can replace up to 4 generators at each technical stop

Full *detailed* procedures for generator exchange still missing

Contact erosion series diode stack not sufficiently tightened

Contact erosion on Exit Box
Replaced on 18 out of 30 generators installed
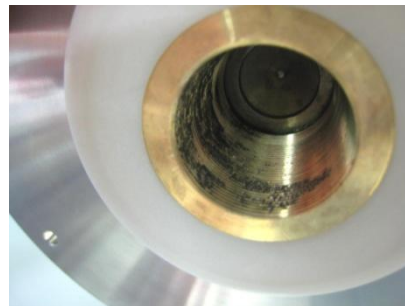
MKB

- Generators (2008 – 2009)
  - Damaged multi-contact on the multi-chip diode which is in parallel with the GTO stack. Solution: multi-contact replaced by soldering

- Magnets (2008 – 2009)
  - Breakdown on araldite insulators between forward and return path of MKB magnet. Solution: insulators replaced by ceramic ones (MKI type)
  - Damaged ground connection of MKB coil. Solution: redesign of the contact and stronger contact tightening
  - Cracks of the MKB coil insulation. Solution: coils ends remoulded with different araldite filler (silica rather than dolomite)

- Vacuum pressure false interlock due to noise on signal solved by filtering and voting solution, but still need to find out why noisy signal

Jan Uythoven, TE/ABT
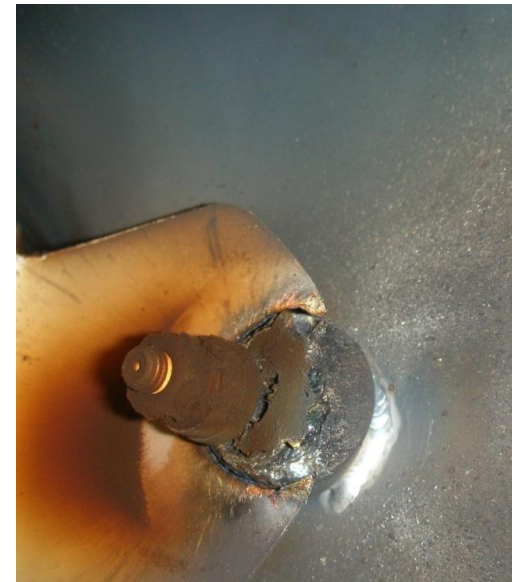
MPS related 'exercises'

- **External** review follow-up 15th June 2009

- MPS system checks with and without beams
  - Following procedures edms document 896392
  - Progress filled in on the Web
  - Conclusions fed into **Internal** review:

- **Internal** review 4th May 2010

Jan Uythoven, TE/ABT

LHC MPS review, 17 June 2010

External LBDS review follow-up 15th June 2009

- 27 out of 47 recommendations of the initial review of January/February 2008 were implemented at that time
- Others under implementation 2009. 'Confident will be followed up'
- Impressed by XPOC/IPOC
- Concerns:
  - Faulty timing transmission RF
    - **Done**: Now check in place in sequencer
  - FPGA code review and FPGA test bench
    - **On-going** for TSU.
    - Depending on experience will do for other systems (BETS)

Jan Uythoven, TE/ABT

Issues from LBDS internal review 4th May 2010

- rMPP invited to participate
- In view of LHC intensity progression:
  - Review critically the system and the problems occurring;
  - Identify any potential issues which could compromise machine protection functionality;
  - Define the short- and medium-term actions needed for the system and its commissioning.
- Identified issues with equipment, controls, SW, procedures, commissioning, operation.
  - 38 TOTAL actions generated (15 completed, 9 in progress)
  - **14 items with MP repercussions (8 completed, 3 in progress)**

14 items with MP repercussions

1. F_rev check in sequencer before arming: **DONE**
2. Formal validation procedures of system after technical stop: **TO DO**
3. Damaged re-trigger resistors (see before): replacement **ONGOING**
4. Erosion of contacts: replacement program for next two years **ONGOING will take long time but trends visible on XPOC**
5. BLMs needed to quantify some MP tests already made: **TO DO, RC filters on some BLMs point 6 installed, but need analysis**
6. Protected sequences and unskippable tasks **ONGOING**
7. TCDQ software issues for movement **DONE**
8. TCDQ position settings check can't be done, software precision issue **ONGOING**
9. Debunched dumps at 450 GeV with 1e11 p$^+$ & analyse: **DONE**
10. Set-up TCSG/TCDQ at 450 GeV and 3.5 TeV: **TO DO**
11. Aperture measurements in Point 6: **DONE**
12. BLM calibration: **DONE** TCDQ **TO DO** TCT
13. MPS test: system off and RF frequency interlock: **DONE**
14. Understand why 15 x 1 MKD knob did not cleanly extract: **Done**

Jan Uythoven, TE/ABT

Beam Dump Performance

- No single beam dump happened which would have lead to any damage with unsafe beam

- No asynchronous dump happened since TSU fix 2009
  - Many dumps with unbunched beam to check performance of protection – see talk Wolfgang
  - Expect about two asynch. dumps per year

- All errors have been seen by surveillance!

- Measurements which give confidence in system
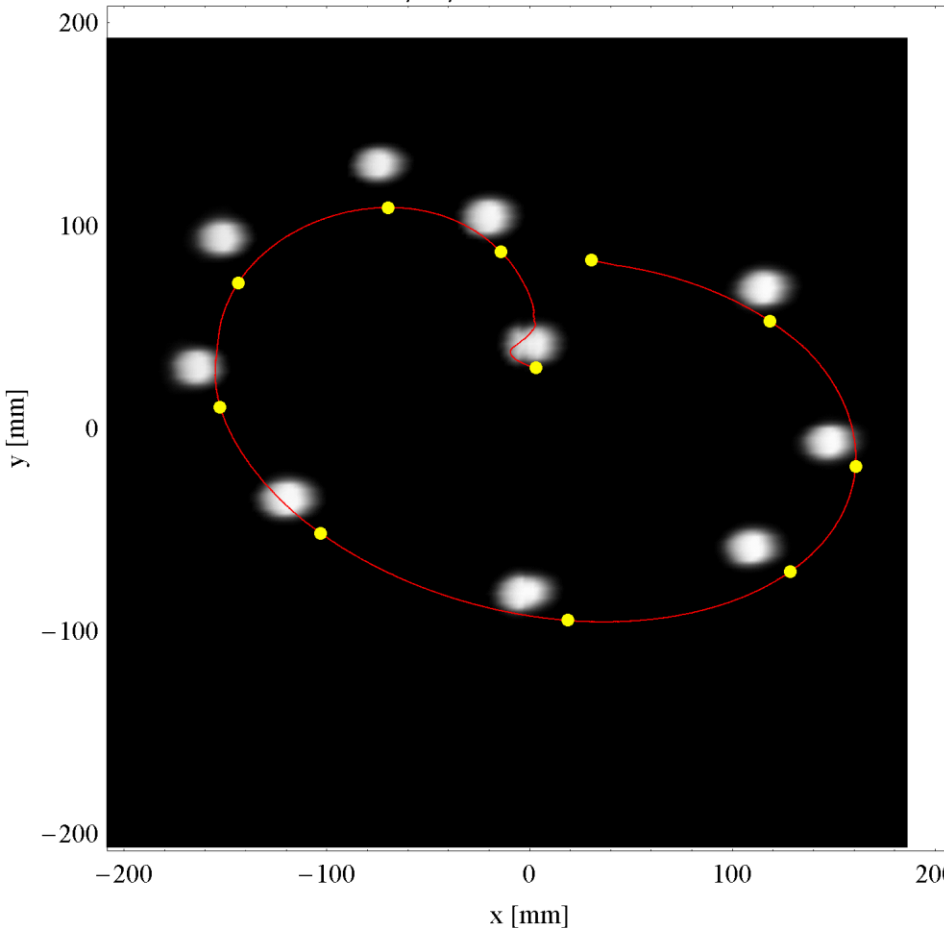
LSS6 Aperture and Dump Lines Apertures according to Models

, 17 June 2010
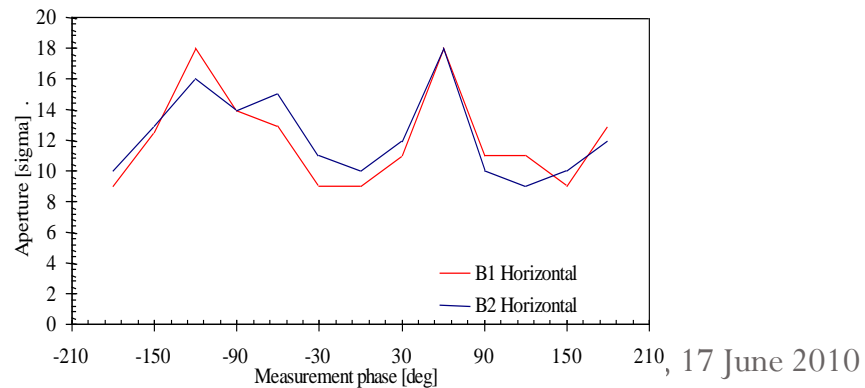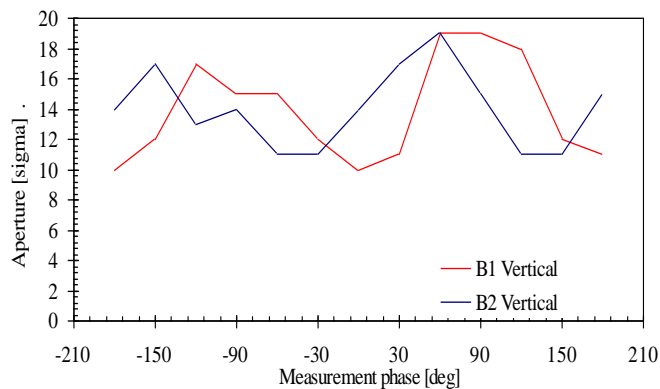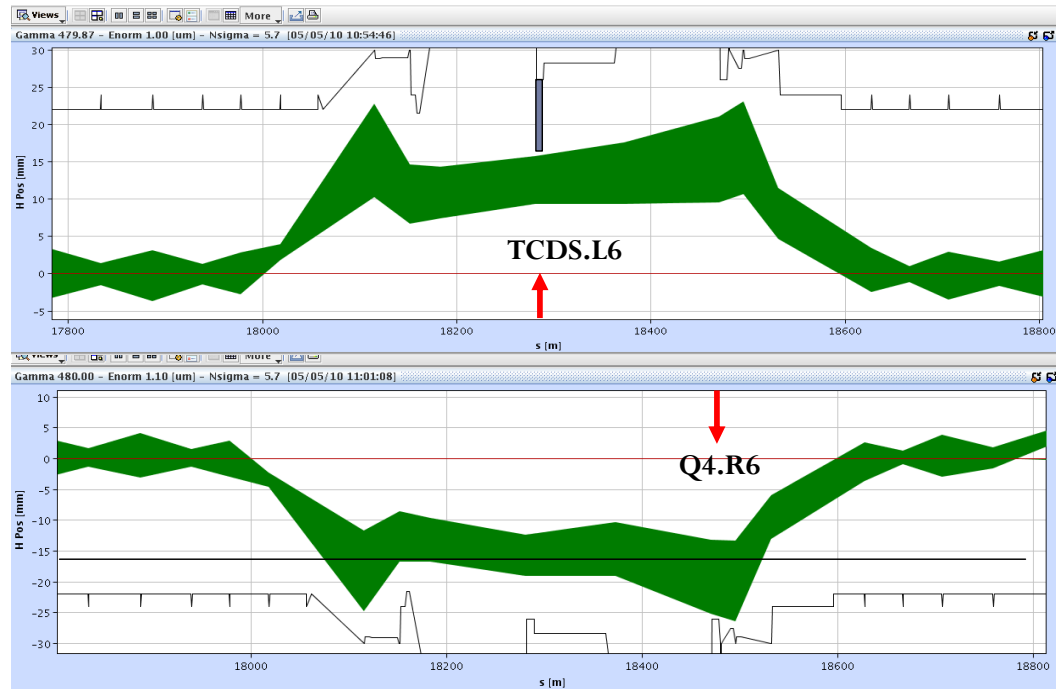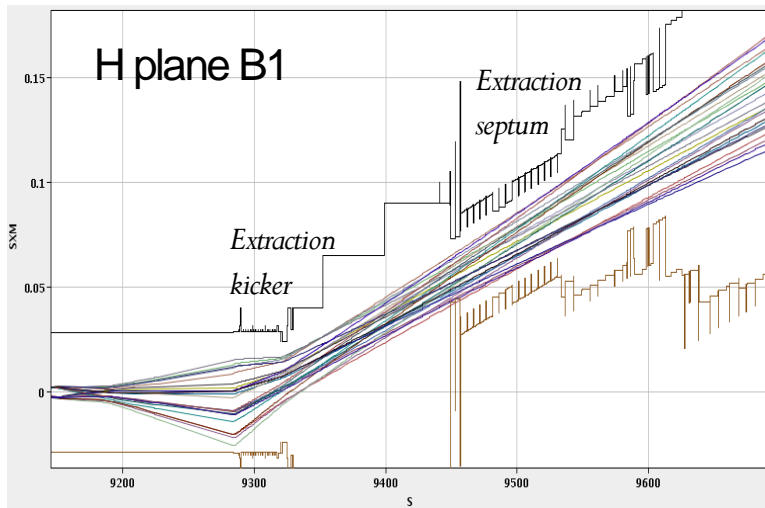
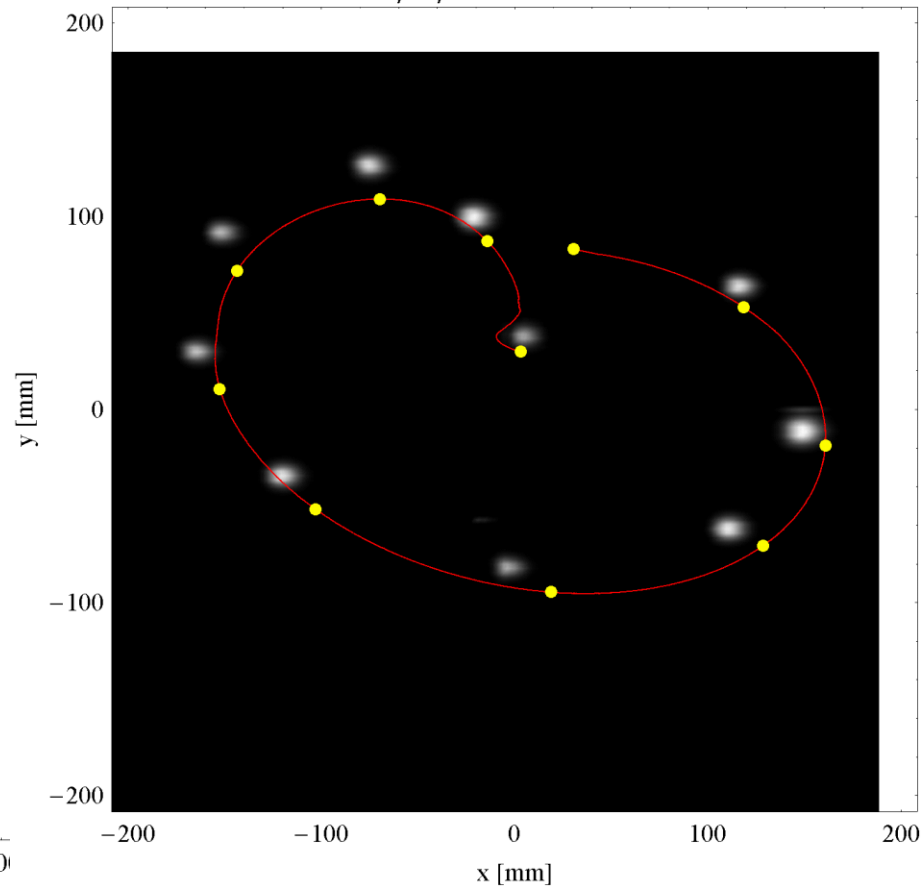# Position of dumped beams on BTVDD (in front TDE) according to calculations

TD68.BTVDD.689339.B1
2010/03/24 03:23:34.600000

TD62.BTVDD.629339.B2
2010/03/24 03:23:34.600000

Vertical off-set especially at 450 GeV

MSD Septum Calibration Measured vertical beam positions
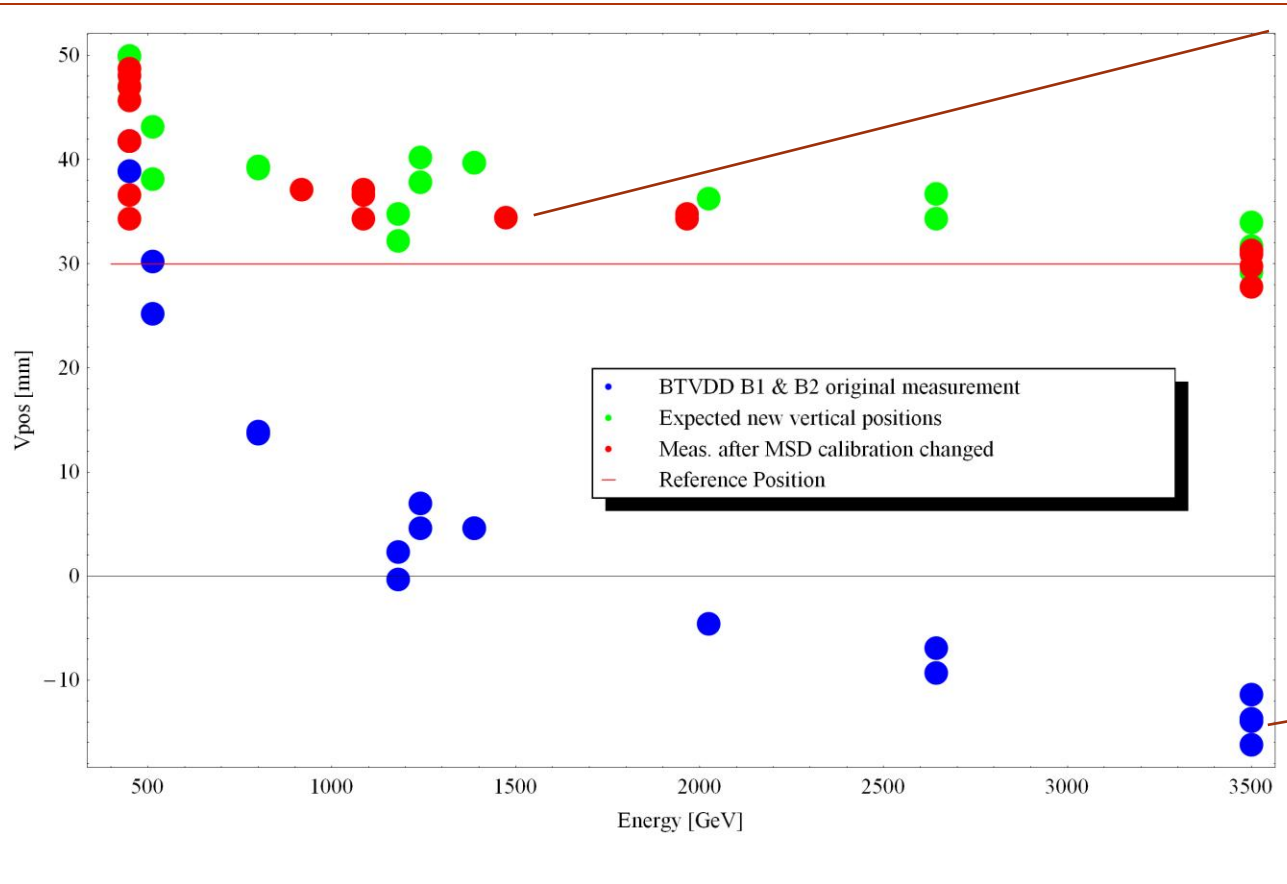
Measured position after technical stop. As expected the error at 450 GeV increased . Actions:
-Recalibration MSD hall
- Check hysteresis MSD
-Effect of MKB

Before change MSD calibration curve in LSA during technical stop 27/4/10

Jan Uythoven, TE/ABT

Evian, 18 - 19 January 2010

Interlocked Beam Instrumentation

- **Interlocked BPMD References**
  - Were set-up once in the beginning of the 2010 run.
  - Ascension weekend 15th May lost 2 ramps on BPMD interlocks
    - Changed lhc.bpmsb.b4l6.b2 from il values -0.26/+6.94 mm to -2.0/4.0 mm. This seemed to be closer to trajectory around which collimators and TCDQ were set-up at that time
  - Needs now to be revisited – check with dump from positions at limit of interlock position and maximum angle:
    - Take into account BPM sensitivity for different bunch intensities
    - 'Final' reference trajectories, squeeze etc.

- **Direct Interlocked BLM** (not via BIS)
    - Not tested

Conclusions
The Positive Side

- No asynchronous dumps since 2009 TSU problem solved. No dumps which would have caused damage with unsafe beam

- All failures detected by XPOC or Internal Interlock, requiring expert acknowledge

- System generally well understood:
  - MPS checks passed
  - Aperture as expected
  - Dump figure as expected

Conclusions
The Negative Side I

- Worries about MKD generator contact erosion
  - But <u>so far</u> always slow trend caught by XPOC
  - Replacement program started but will take into 2011
- Outstanding work:
  - **Interlocked BPMD verification** and Direct BLM check
  - Dumped beam vertical offset at 450 GeV: MSD
  - Detailed check of RC filters BLMs point 6
  - New XPOC modules
  - See talk Wolfgang on dump protection:
    - **Set-up of protection with 1e11 p$^+$ plus verification**
    - **Abort gap monitoring and cleaning operational**

Conclusions
The Negative Side II

- **The Human Part = Weakest Link**
  - Sequencer, unskippable tasks etc.
    - This has to guarantee the hardware settings applied to the system, that the previous XPOC was ok etc.
  - Procedures
    - For coming out of access, after intervention
    - For making generator exchange, tests to be made, checking cables
    - For resetting XPOC, for resetting faults of beam dump equipment

Jan Uythoven, TE/ABT

Additional Slides

Jan Uythoven, TE/ABT

LHC MPS review, 17 June 2010

MKD issues above 5 TeV beam energy: Not an issue for present operation

- Corona discharge along side switch
  - Solution to be installed 2010/2011
- Effect of radiation on switches at high voltages
  - Measurements to be made
  - Upgrade of number of GTO will be difficult in 2012 shutdown

- Cooling of MKD generators not sufficient when running for a longer period at 7 TeV beam energy

Jan Uythoven, TE/ABT