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LHC Beam Dumping System

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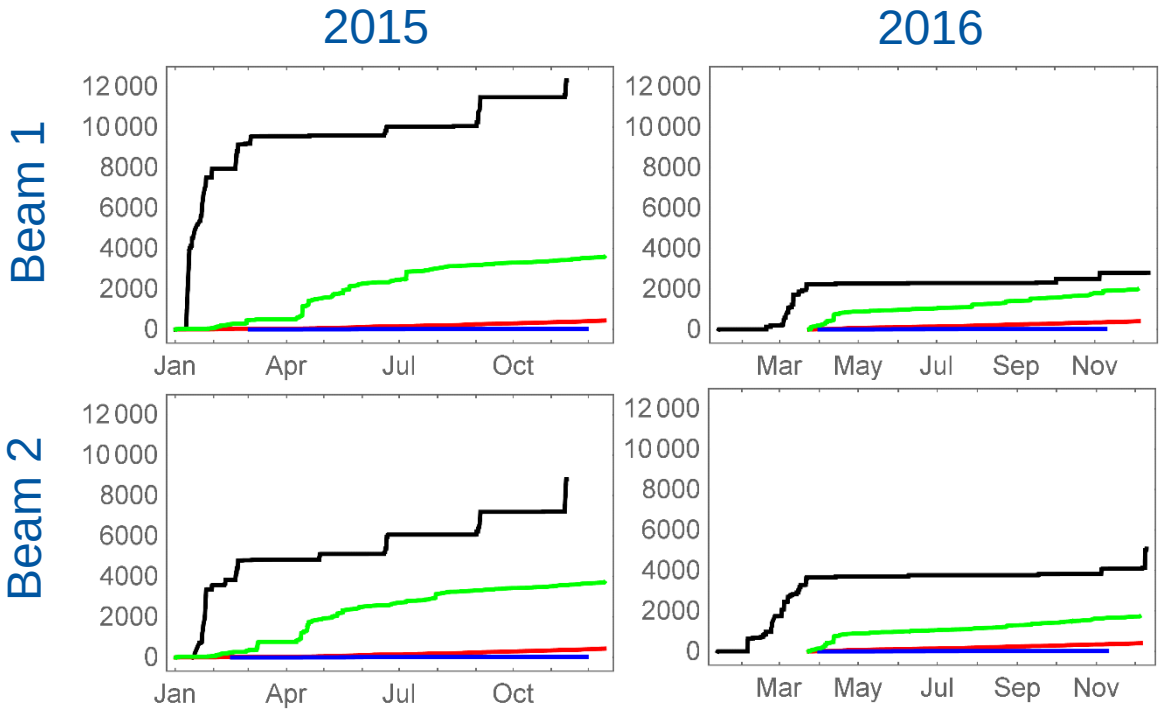
And many thanks to all our TE-ABT colleagues involved in LBDS operation and maintenance !

On the menu today

- LBDS operational statistics 2015 / 2016
- Review of main LBDS faults in 2015 / 2016
- Upgrades planned for EYETS
- Limitation for 7 TeV operation: Reliability run at 7 TeV
- Dry Run (Reliability Run with LOCAL BIS loops)
- Startup at end of EYETS : Cold Checkout / Commissioning with Beam

LBDS operation statistics

Nb of dumps at various energies



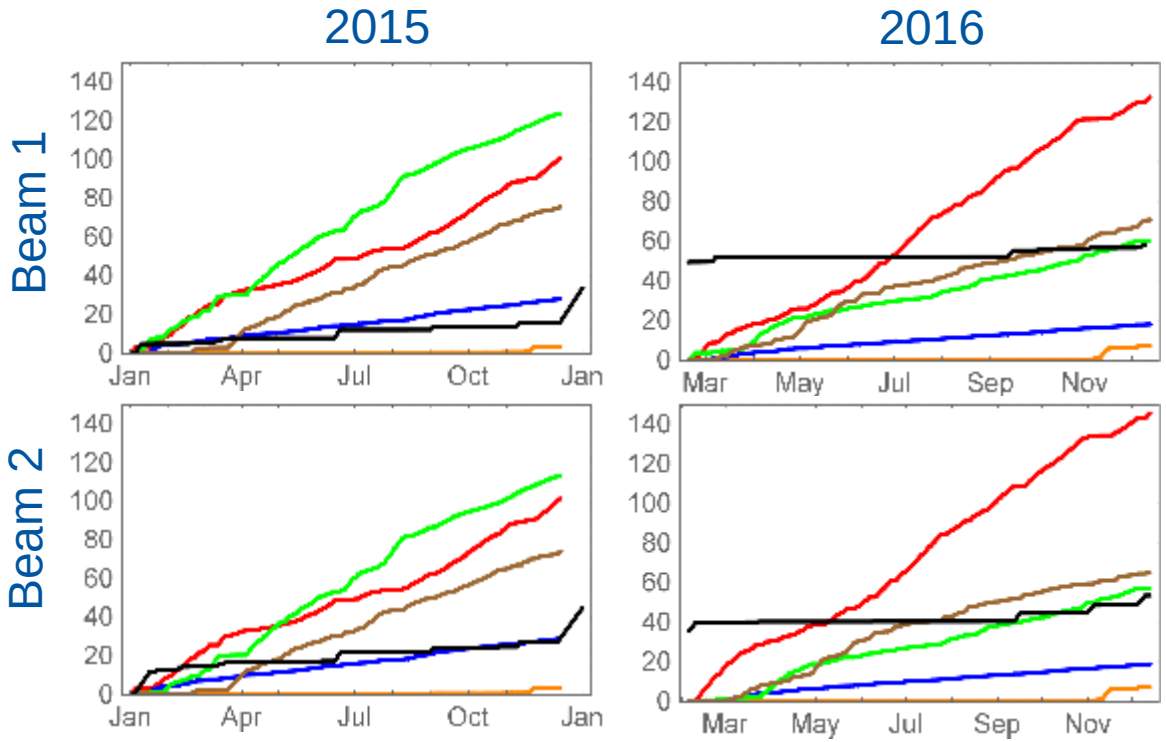
B1 Total	*LOCAL*	*INJ*	*FT*	*RAMP*
2015	12321	3582	441	31
2016	2805	1984	407	21

B2 Total	*LOCAL*	*INJ*	*FT*	*RAMP*
2015	8821	3711	437	35
2016	5076	1730	408	21

- A lot of LOCAL test dumps in 2015
- A lot of dumps at injection in 2015
- About same Nb of dumps at FT

- Triggers in LOCAL
- Dumps at FLAT-TOP Energy
- Dumps at RAMP Energy
- Dumps at INJECTION Energy

LBDS operation statistics



Days spent at various energies

B1 Total	***2015***	***2016***
6.5 TeV	100.8	129.9
450 GeV	123.2	60.1
STANDBY	75.7	67.2

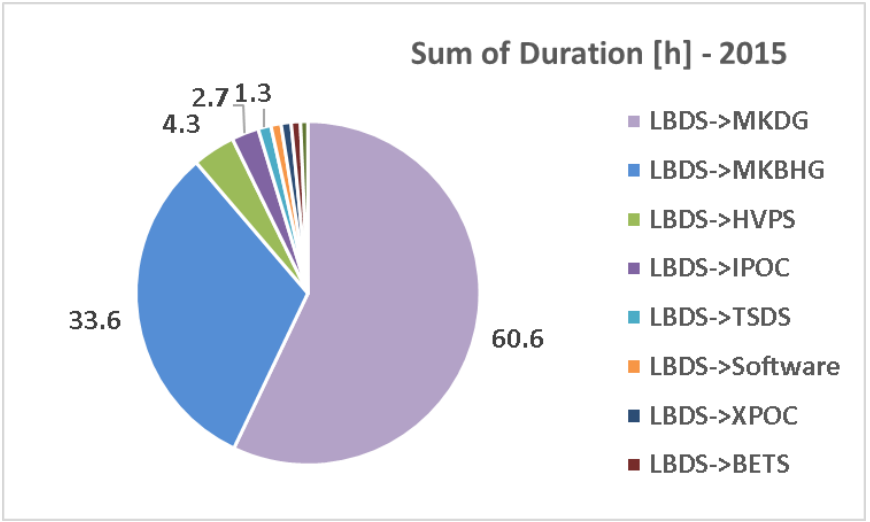
B2 Total	***2015***	***2016***
6.5TeV	101.1	142.8
450 GeV	113	56.9
STANDBY	73.9	64.6

- >30% More time at 6.5 TeV in 2016
- >50% Less time at 450 GeV in 2016

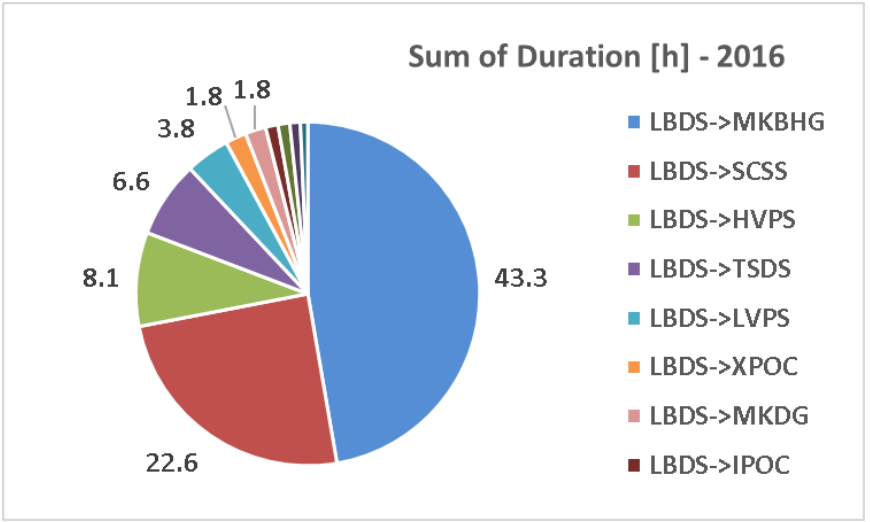
FT	(6.5TeV)
FT-MISC	(2.5/3.5/4 TeV)
RAMP	(0.45 –>6.5 TeV)
INJECTION	(0.45 TeV)
STANDBY	(0.4 TeV)
OFF	(0 TeV)

LBDS Faults downtime

2015: 106 h

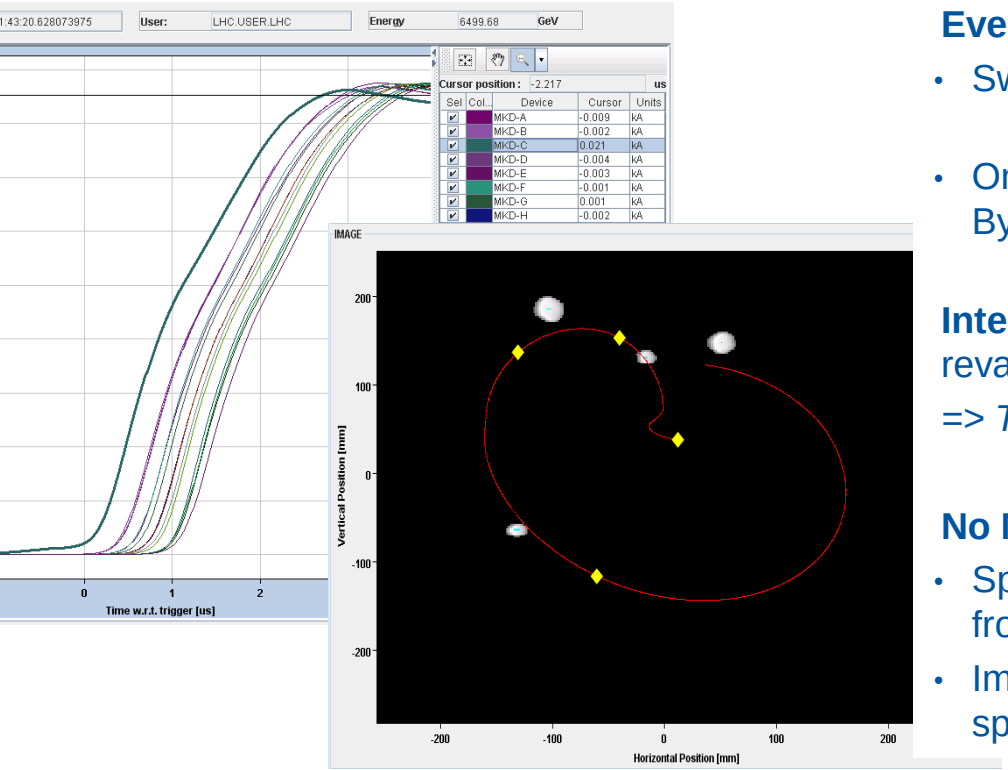


2016: 91.6 h



- Less total downtime in 2016 than in 2015 (With higher constrain on the system).
- Main contributors: MKDG, MKBHG, SCSS (PLC), HVPS, TSDS (TSU)
- One asynchronous dump in 2015 (MKDG), **NONE in 2016**.

MKDG self trigger (= Asynchronous Dump)



Events: **1** in 2015 and **0** in 2016 (04.06.2015):

- Switch self-triggered and retriggered full LBDS
  => *Asynchronous beam dump*
- Only 4 bunches in the machine at 6.5 TeV
  By chance: No beam in abort gap
  => *Clean dump*

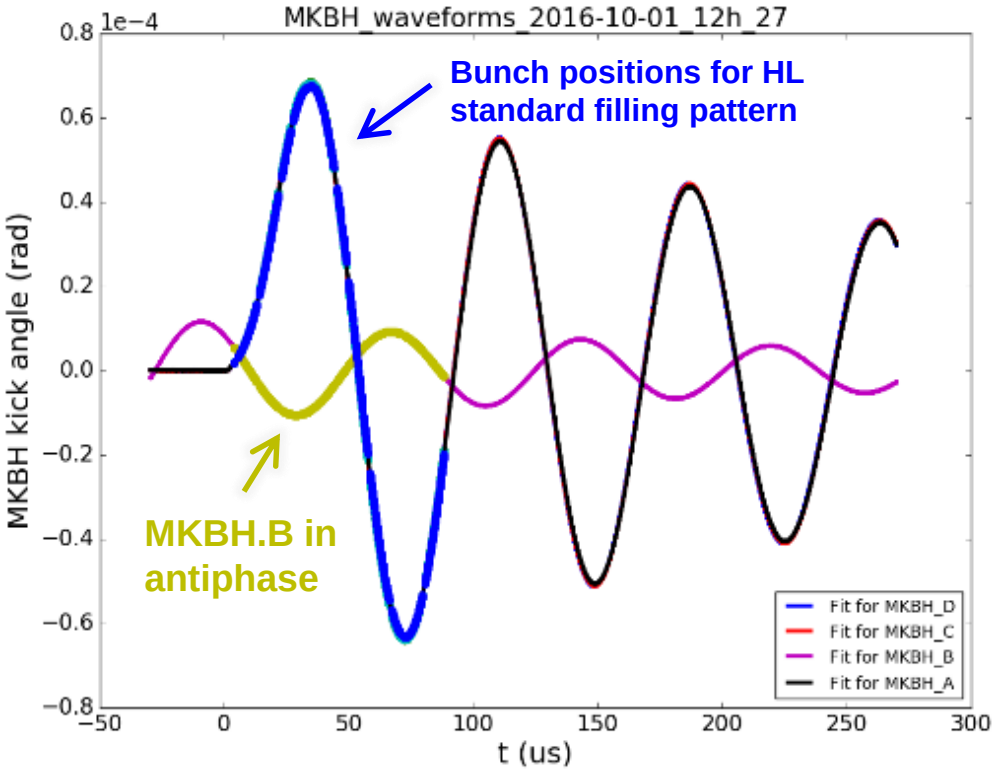
Intervention: The HV switch was replaced, and a full revalidation of the generator was performed.

=> *Total downtime:* ***13 h***

No MKD self-trigger in 2016:

- Spark surveillance method and various measures taken from LS1 seems to have paid off !
- Implementation of the continuous surveillance of sparking activity is planned for LS2

MKBHG self trigger (= Synchronous Dump)



Events: **5** in 2015 / **2** in 2016 (+ 1 preventive generator exchange):

- Switch self-triggers so capacitor is discharged
- The BETS detects it and requests a beam dump
- Other MKB can be triggered in phase opposition
  Ex: Loss of 1 Gen + 0.2 Gen in phase opposition
  => ~70% Total horizontal dilution
  (Not the worst case, see later)

Intervention: The generator is cleaned or exchanged, then a full revalidation of the generator is performed.
*=> Longest downtime (over 7 events): **17 h***

- MKBH faults in 2015 were spread over the year, but in 2016 both faults occurred within a month ☹ !

MKBHG self trigger – Retrigger coupling

Events: **0** in 2015 and **0** in 2016 **(but 1 identified in 2016 in LOCAL, No Beam)**

- During reliability run of MKBH at 7TeV, one MKBH did a self-trigger and the two generators next to it were triggered few microseconds after

  => **up to 3 MKBH self-triggered** !

- The last MKBH generator can be triggered in phase opposition

  => Possible reduced total horizontal dilution down to 10%

Investigation: From first analyses in laboratory and tests in the tunnel:

- The coupling comes from grounding problem on the MKBH generators.
- A first workaround was tested successfully (insulation of retrigger boxes), to be further validated.

=> This problem should be fixed during EYETS.

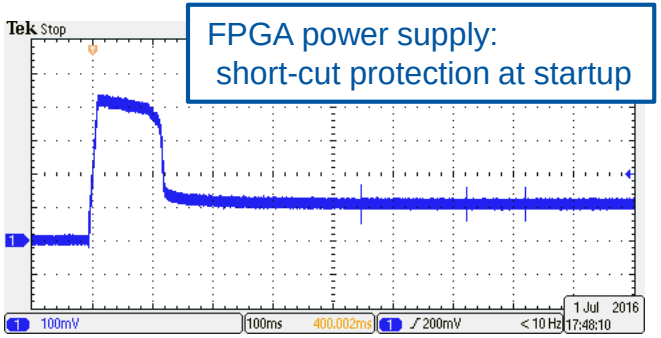
We also need a way to detect any degradation of the ground circuit in the future…

Strategy for MKB retrigger - Impact on TDE

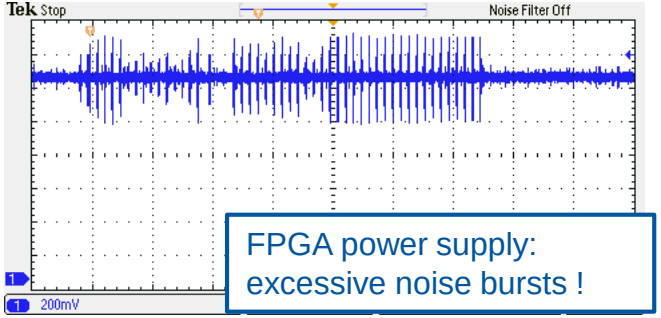
Strategy	Max. horiz. deflection, 1 self trigger	Max. horiz. deflection, 2 self triggers	Required Changes
Current situation: BETS reacts with delay time < 1ms	63%...87% (for BETS delay > 220 us)	27%...77% (for BETS delay > 220 us)	None (current situation)
Directly request **synch. dump** (do no retrigger MKBs)	53%...95%	5%...90% (Remark: should get better for erratic of 3, 4)	Reduce BETS detection delay? …
Directly request synch. dump and **retrigger all MKBs** (within <1us)	80% (Change of phase relation between MKD&MKB possible → change of TDE pattern).	80% (Change of phase relation between MKD&MKB possible → change of TDE pattern).	- Install dedicated MKB retrigger line - Reduce BETS detection delay? …
Directly request **asynch. dump**	Close to nominal for TDE. But losses in IP6.	Close to nominal for TDE. But losses in IP6.	Trigger signal MKB to MKD (?)
Increase **delay time**, e.g. >1.5ms	~75%	~50% (Remark: will get worse for erratic of 3, 4)	Introduce additional time delay (~1ms ?)…
Increase **damping factor**	→ 75% ? (small change of TDE pattern)	→ 50% ? (small change of TDE pattern)	Hardware changes, resistor? ...
Remove “**fast path**” (to reduce risk of multiple triggering)	No change for synch. dump; TDE pattern (slightly?) changed for asynch. dump.	No change for synch. dump; TDE pattern (slightly?) changed for asynch. dump.	Remove “fast path”

Courtesy C. Wiesner

TSU failure



FPGA power supply:
short-cut protection at startup



FPGA power supply:
excessive noise bursts !

Events: **0** in 2015 and **1** in 2016
On 01.07.2016 dump on TSU failure.
=> Synchronous dump was properly performed by redundant TSU.

Intervention: Exchange of faulty TSU + Revalidation of the TSDS from CCC, dump from all TSU clients (BRF, BETS, SCSS, BLM, Inject&Dump):

=> *Total downtime:* ***7 h***

Investigations: Found power supply ***shortcut*** through FPGA.
High level of ***noise*** on the FPGA power supply was also noticed.

=> Will be corrected during EYETS.

Other failures

State Control and Surveillance System (SCSS):

- 2015: NONE
- 2016: 4x Asi-Bus + various PLC problems + 2x HV dividers

=> *Longest downtime:* ***4 h 30***

Asi-Bus power supplies sent to SIEMENS for investigation

High Voltage Power Supply (HVPS):

- 2015: 1x Principal + 1x Compensation
- 2016: 2x Compensation

=> *Longest downtime:* ***3 h***

Failure rate too high for these components
Under investigation with manufacturer

Low Voltage Power Supply (LVPS):

- 2015: NONE
- 2016: 2x PK55

=> *Longest downtime:* ***3 h***

Actions during EYETS:
- Asi-Bus architecture will be renovated.
- Main power surveillance will be added

Intervention Strategy in case of LBDS fault

As LBDS is a part of Machine Protection:

- All internal failures are fatal
- We do not run in degraded mode (we don't mask faults / adjust thresholds…)
- Each faulty element is repaired / replaced
- Recommissioning is done after each repair following procedures
  (Procedures might be improved to reduce intervention time, tbd with MPP)

=> System returns in 'As Good As New' state after every fault / intervention

BAD luck: Many major failures occurred during nights and week-ends ☹

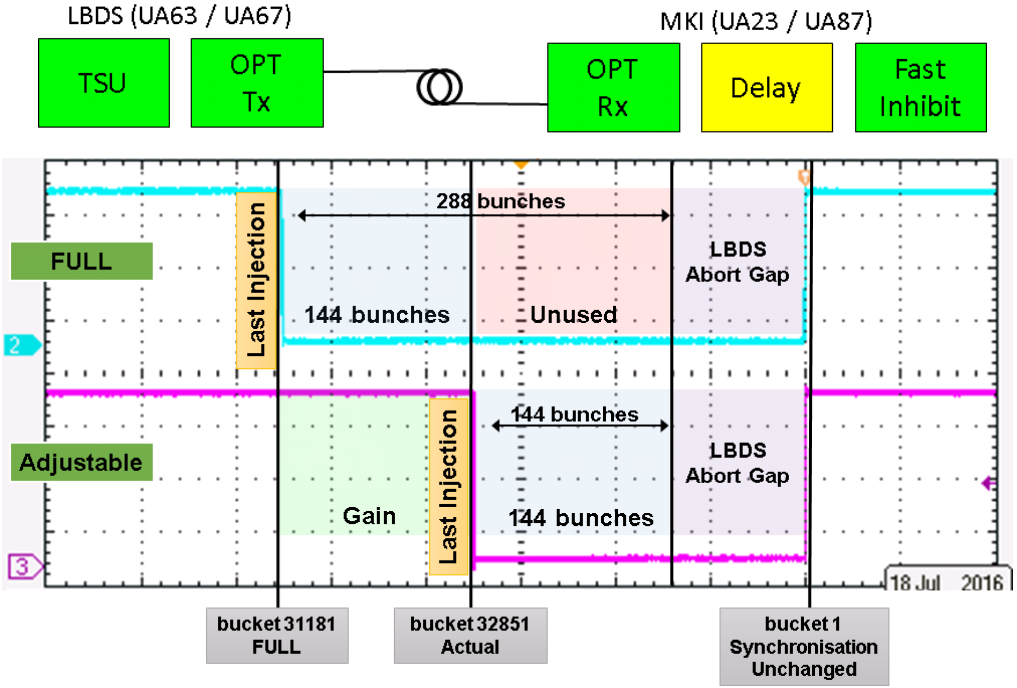
=> Increased intervention time

Upgrades planned during EYETS

- Close MKBH generators to
  - ➔ Prevent dust entering and avoid self-triggers of the HV switch.
- Adding an additional resistor on GTO gate-cathode on MKB
  - ➔ Reduce sensitivity to external disturbances (done on MKDs during YETS 2015/16)
- Add IPOC surveillance on all MKBH generators
  - ➔ Better diagnosis in case of self-trigger of MKBH.
- Consolidation of MKB retrigger line to
  - ➔ Avoid coupling in case of MKBH self-trigger.
- Consolidation of the TSU card + new version of CIBDS card deployed by TE/MPE
- New value of CIBDS trigger delay requested by TE/MPE (from 270us to 300us)
- Renovation of Asi-Bus architecture to
  - ➔ Avoid the recurrent problems encountered.
- Consolidation of the BAGK regeneration mechanism.
- General maintenance on HV generators, replace weakest HV switches, clean all generators,…

- A lot of upgrades foreseen. Request a full revalidation of TSDS and HV Generators
  => Dry-Run with LOCAL BIS loops

Consolidation of variable BAGK



- Implemented during TS1 in 2016, to allow the last injection of 144b, due to TIDV problem and intensity limitation in SPS.
- Modification during EYETS
  - New optical transmission system (BE-RF)
  - Add fine delays at MKIs to regenerate the BAGK signal with lower jitter.
  - Add a continuous check of BAGK frequency and length received at MKI in Fast Inhibit card.
  - All BAGK parameters in LSA database.
- Update and re-validation procedures to be defined

Having beam in the abort gap and dumping it at injection is an accepted failure mode

Reliability run at 7 / 7.1 TeV over X-Mas break

To re-assess performance of ***LBDS for operation at 6.5 TeV*** and evaluate available safety margin:

Min 2 weeks of reliability run at 7 TeV over X-Mas break:

- Simulation of cycles of 24h (Injection: **3h,** Ramp up/down: **1h,** Flat-top 7.1TeV: **20h**) => **>300 h** at **7 TeV**
- System monitored and controlled remotely by experts
- Automatic stop in case a self-trigger is detected for PM analysis
- Available safety margin for continuous operation at 7 TeV not tested
- Will decide if we go to 7.1 TeV when back in 2017

Full upgrade program of HV switches of MKD/MKBH + Triggering foreseen during LS2

Re-commissioning strategy

- Remote reliability run (Local BIS loops needed)
  - Validation TSU and CIBDS upgrades
  - Re-commissioning of LBDS pulse generators
  - Implementation and validation of XPOC analysis on CIBDS signals
- Cold check out
  - Based on LBDS standard machine protection procedures
  - No new functionalities to be tested
  - Sufficient time to be secured
- Re-commissioning with beam
  - Based on LBDS standard machine protection procedures
  - Validation of variable BAGK length mechanism and synchronization (Procedure to be defined)

Summary

- All dump requests properly executed by LBDS. **No asynchronous beam dump.**
- Operation in 2016 was more demanding for LBDS than 2015 (More time at 6.5TeV). **Nevertheless lower LBDS downtime in 2016.**
- Too many MKBH self-triggers, will be addressed during EYETS.
- Problem of MKBH retrigger line coupling to be solved during EYETS.
- Local reliability run at 7 TeV during X-Mas break to re-assess LBDS availability at 6.5 TeV operation and re-evaluate ability to go to 7 TeV.
- Remote reliability run with local BIS loops needed to revalidate the system at the end of the EYETS (Upgrades on MKBH generators, TSDS and CIBDS).
- Standard Cold Checkout / Recommissioning with beam at the end of the EYETS.

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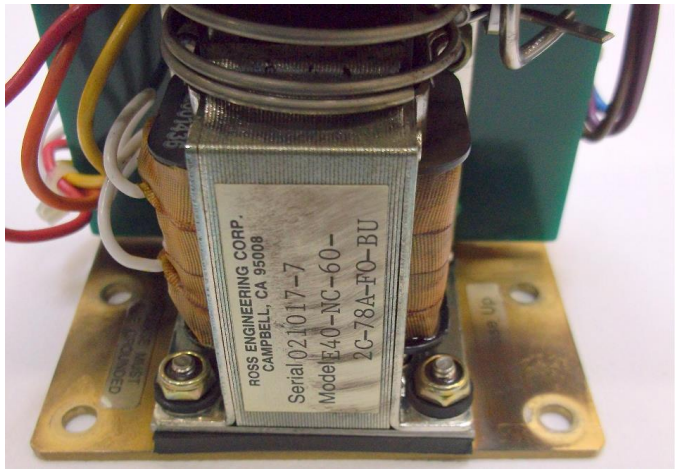
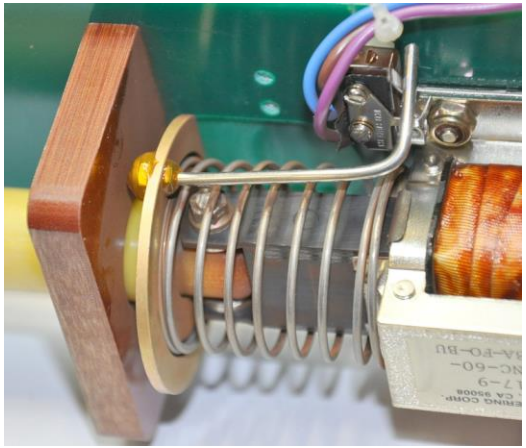
- Spares…

MKD / MKBH self trigger



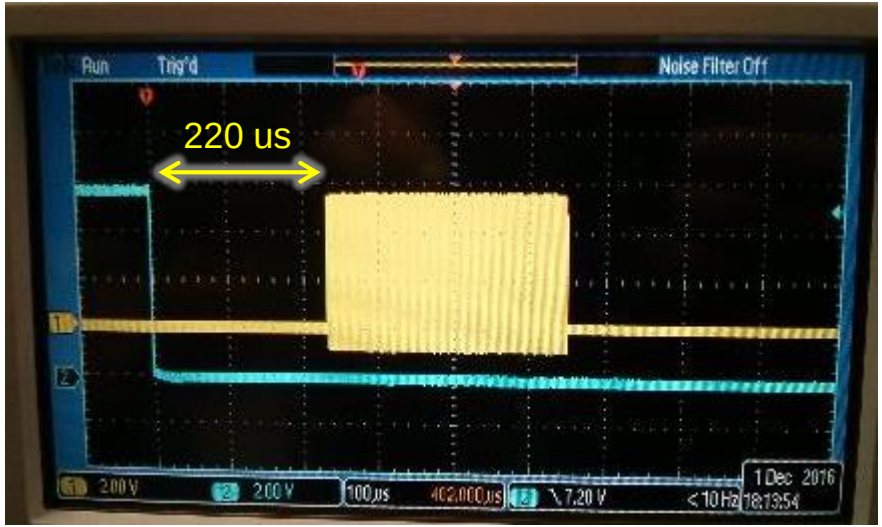


Self trigger most probably due to dust inside generators

Found component (ROSS relay) which generate metallic dust inside top part of generator.
(Metallic spring vibrating at 50 Hz and touching metallic screw underneath).

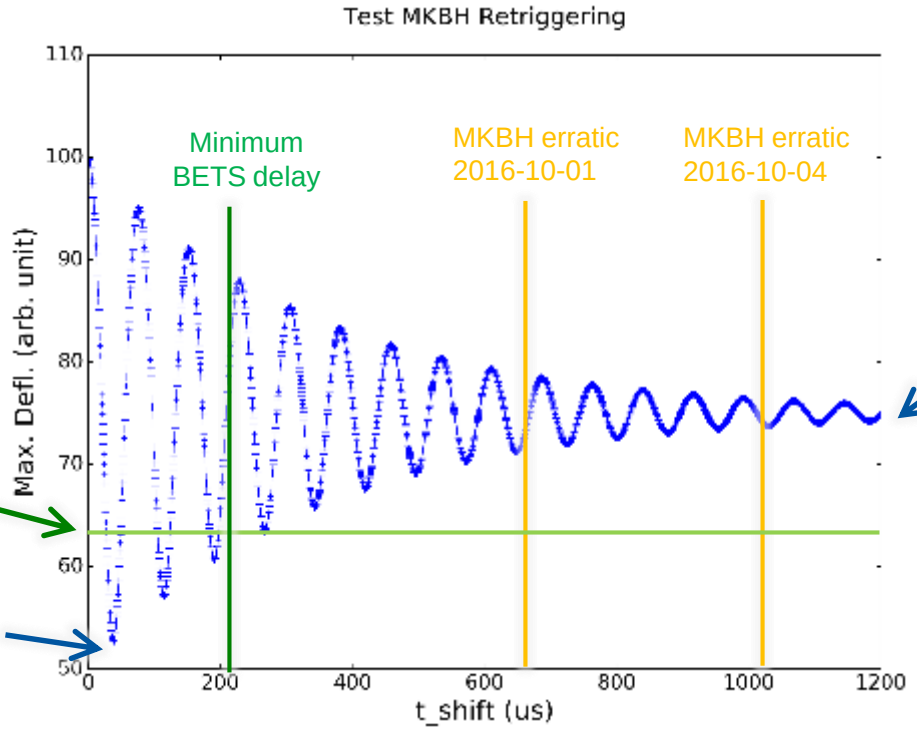
BETS Detection Delay

Minimum **measured** delay time from voltage drop to dump request: **≈ 220 us** over >10e5 pulses (to be confirmed after further analysis)



Measurement, 1.12.2016, N. Magnin

Phase Shift: Erratic of 1 MKBH



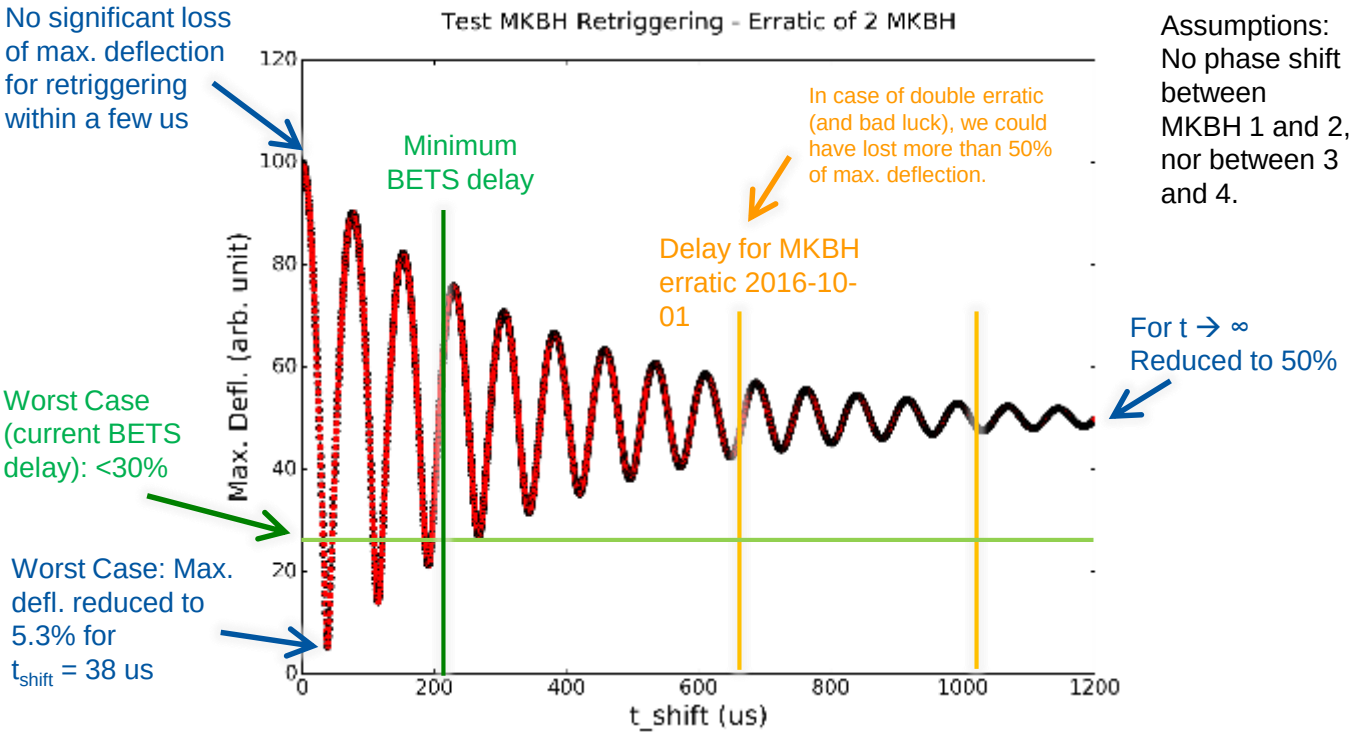
Assumptions:
No phase shift between MKBH 2, 3 and 4

For t → ∞
Reduced to 75%

Worst Case (current BETS delay): 63%

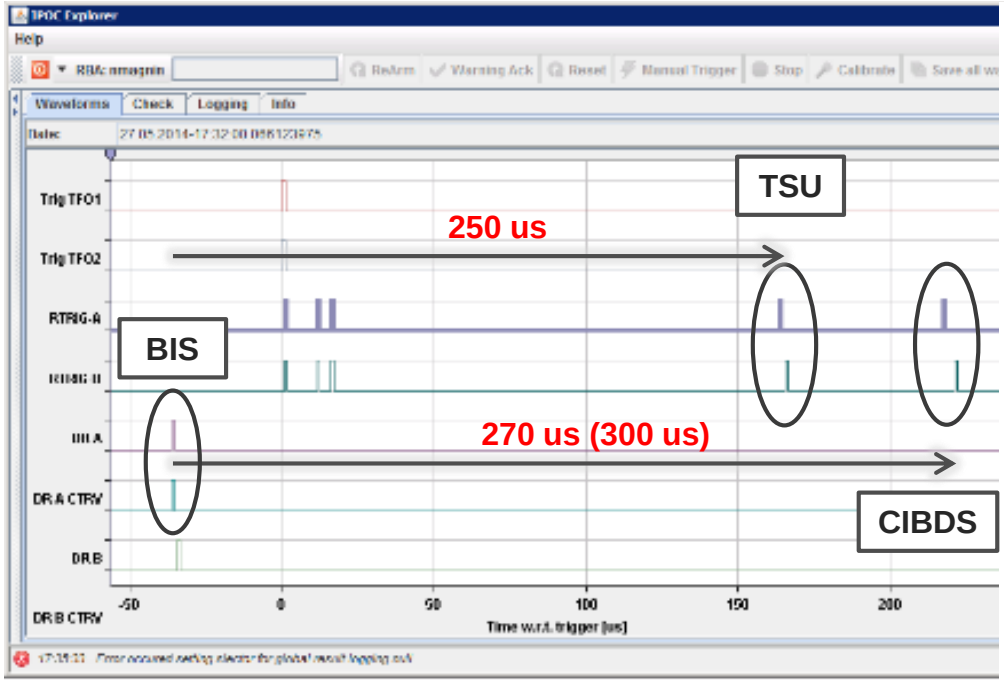
Worst Case (no delay): Max. defl. reduced to 52.6% for t_{shift} = 38 us

Phase Shift: Erratic of 2 MKBH



Assumptions:
No phase shift between MKBH 1 and 2, nor between 3 and 4.

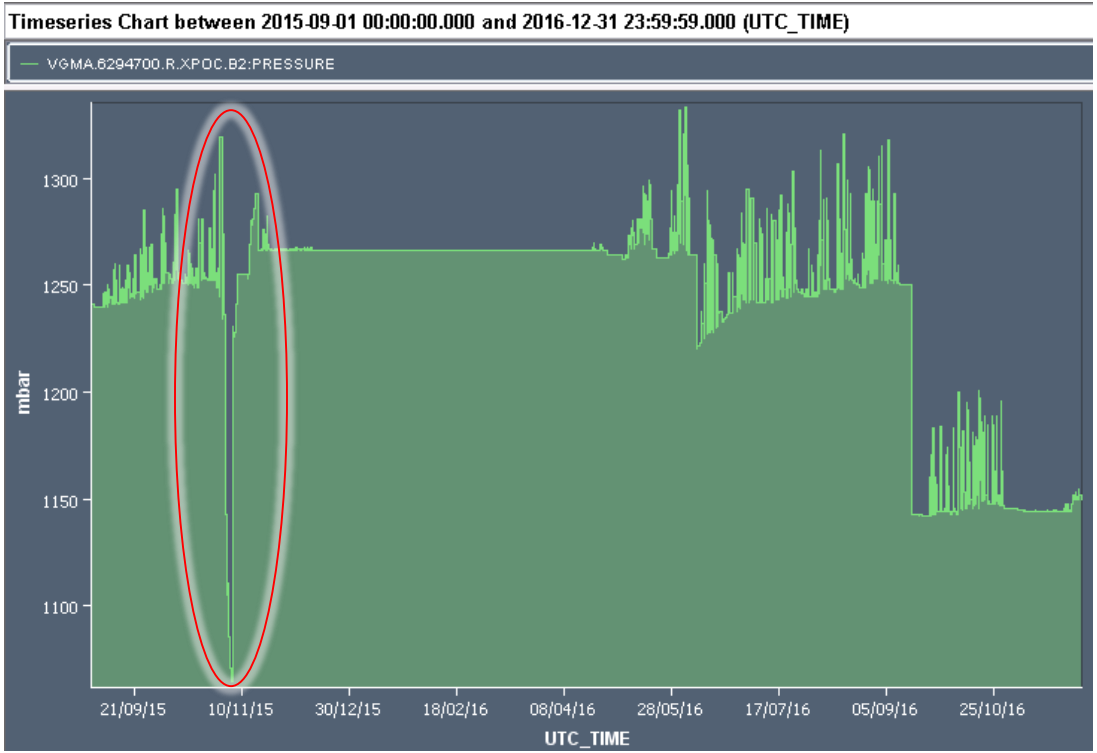
Dry Run – LOCAL BIS loops



After upgrade of **TSU** and **CIBDS** cards:

- Dry-Run in REMOTE, with LOCAL BIS loops, requested by ABT and MPE.
- BETS simulator for energy reference.
- Test of Arm/Dump/Cycles in loop using sequencer.
- Correct behavior of TSU and CIBDS will be checked by IPOC systems.
- Add XPOC surveillance of IPOC results to block sequencer.

TDE vacuum leak



- N2 leak problem in TDE on 11.2015
  = Many XPOC errors
  => *Total downtime:* ***2 h***
- Various VAC interventions to increase the pressure on TDE from bottles.
- Problem under control
  - Today not a limiting factor for operation
  - No hardware interlock for the time being…
    Are we taking an inconsiderable risk?
- STI and VSC will change all gaskets during the EYETS.