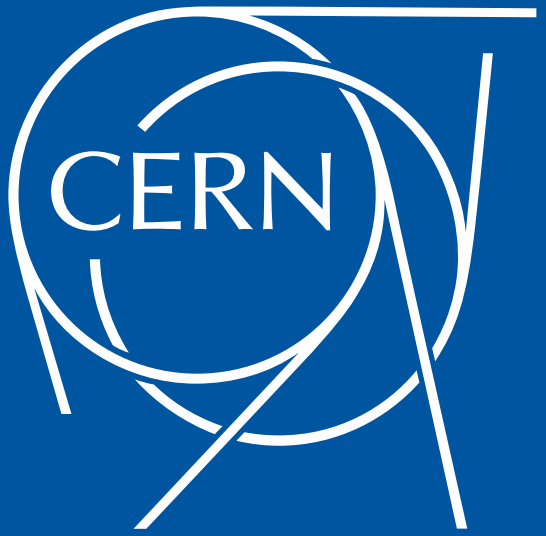
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Have we been operating safely in 2015?

D. Wollmann,
CERN/TE

Acknowledgments: rMPP, MPP, A. Apollonio, W. Bartmann, D. Belohrad, D. Kleiven, T. Lefevre, I. Romera, R. Schmidt, J. Uythoven, J. Wenninger, M. Zerlauth, …

Outline

- MPS commissioning
- Beam dump causes
- Intensity ramp-up and issues
- MDs versus Machine Protection
- Ion Run
- Outlook 2016
- Conclusions

MPS commissioning after LS1

MPS System	MPP presentation	Approval Status
Collimation System	13.05.2014	Released
Injection Protection System	24.10.2014	In work
Beam Interlock System	25.04.2014	In work
Powering Interlock System	31.01.2014	Under approval
Vacuum System	31.10.2014	Engineering check
Beam Dump System	21.03./13.05.2014	Updated procedure received
FMCM	31.01.2014	Under approval
BLM System	24.10.2014	Engineering check
Warm Magnet Interlock System	21.02.2014	Under approval
Safe Machine Parameter System	25.04.2014	Updated procedure received
Software Interlock System	31.01.2014	In work
Beam Current Change Monitor	30.01.2015	Draft procedure

MPS commissioning procedure update:

- **Review of MPS** (re-)commissioning procedures via MPP.
- Detailed discussion of all system

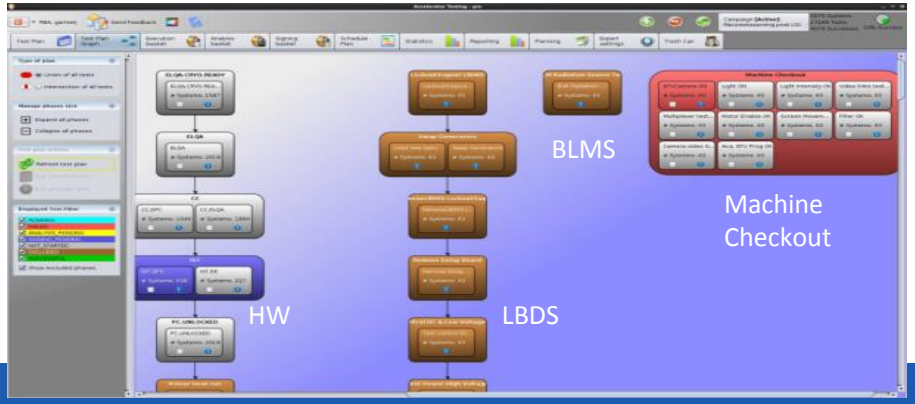
Commissioning follow-up:

- Google docs and Excel (SIS, Injection, LBDS, BLM …)
- ACCTESTing (PIC, WIC, FMCM, Collimation partially)
- MTF for documentation of results (Collimation)

→ Review status **before intensity ramp-up** MP Workshop on readiness of the Machine Protection Systems for MJ beams (12.06.2015)

→ **Clean up procedures** and **define tests** for each system for 2016 start by end of YETS 2016.

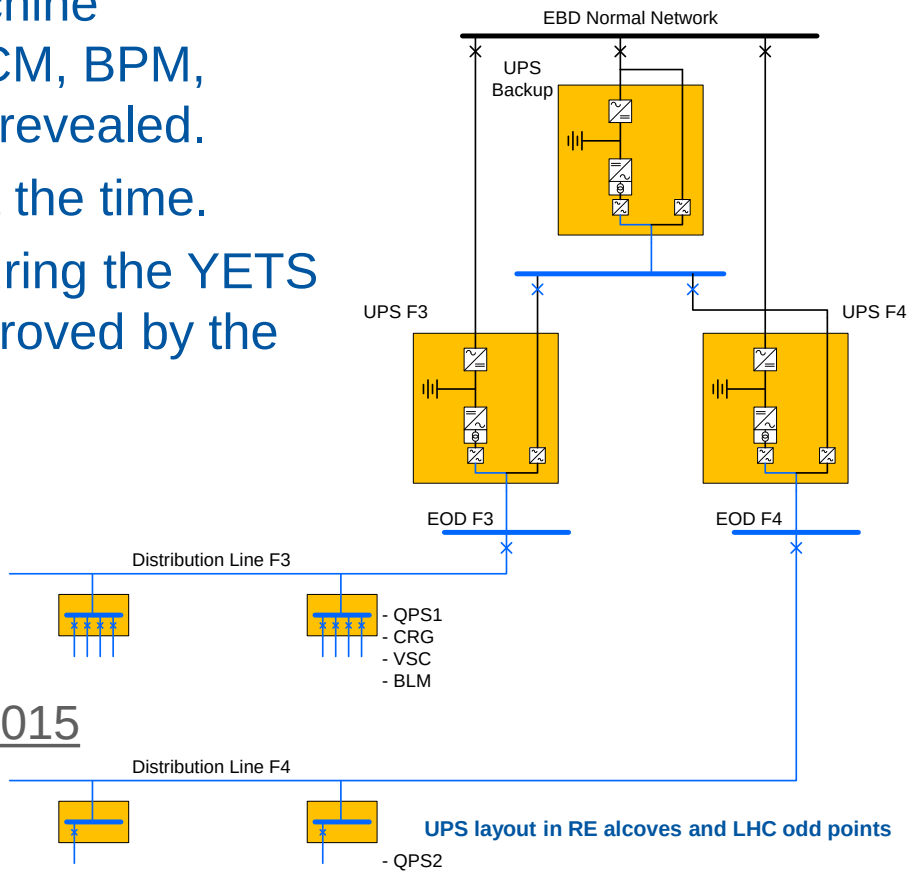
→ Continue **transition to ACCTESTing.**



Courtesy I. Romera

UPS test

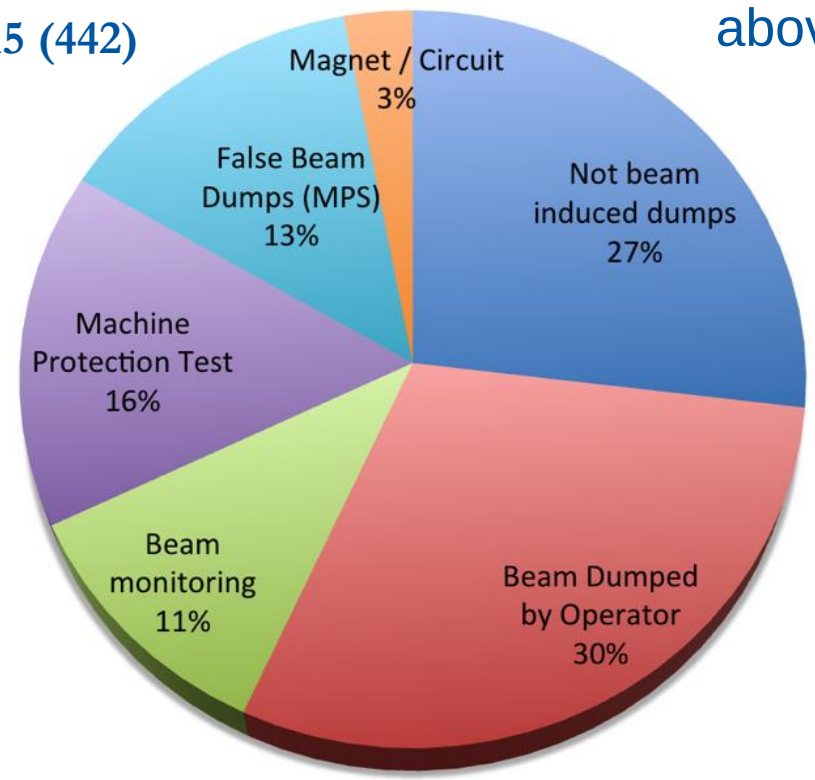
- Campaign to **validate the redundant UPS power** distribution for LHC equipment systems after LS1.
- **Important non-conformities** on Machine Protection (QPS, BIS, PIC, WIC, FMCM, BPM, BLM, Collimation, PC) systems were revealed.
- Test on LBDS was **not conclusive** at the time.
- A new UPS campaign will be done during the YETS and repeated **on a yearly basis** (approved by the LMC).

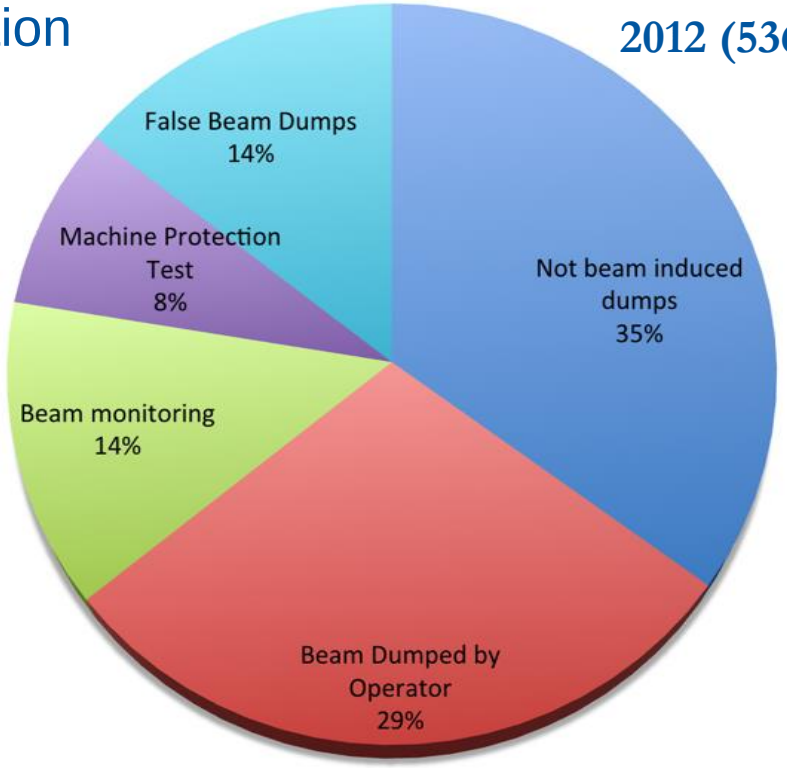


- Report on UPS test results to LMC 25.03.2015
- Test report EDMS 1505860
- Test procedure EDMS 1405966

Beam dump causes 2015 versus 2012

above injection



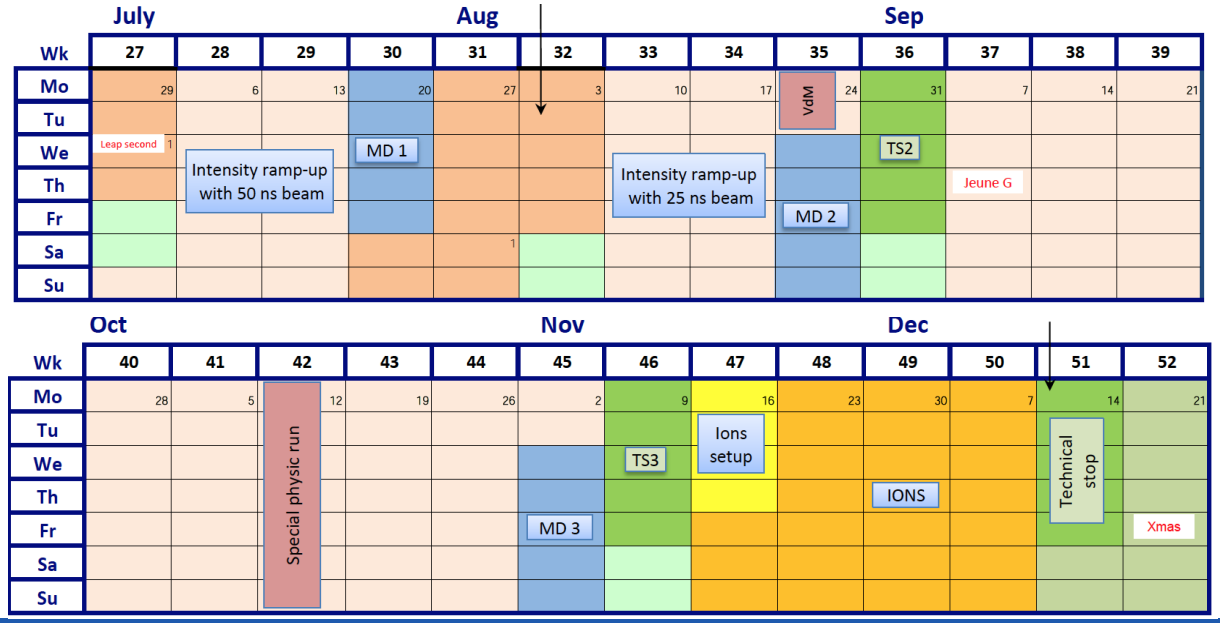


2015 commissioning and ramp-up year compared to production year 2012:

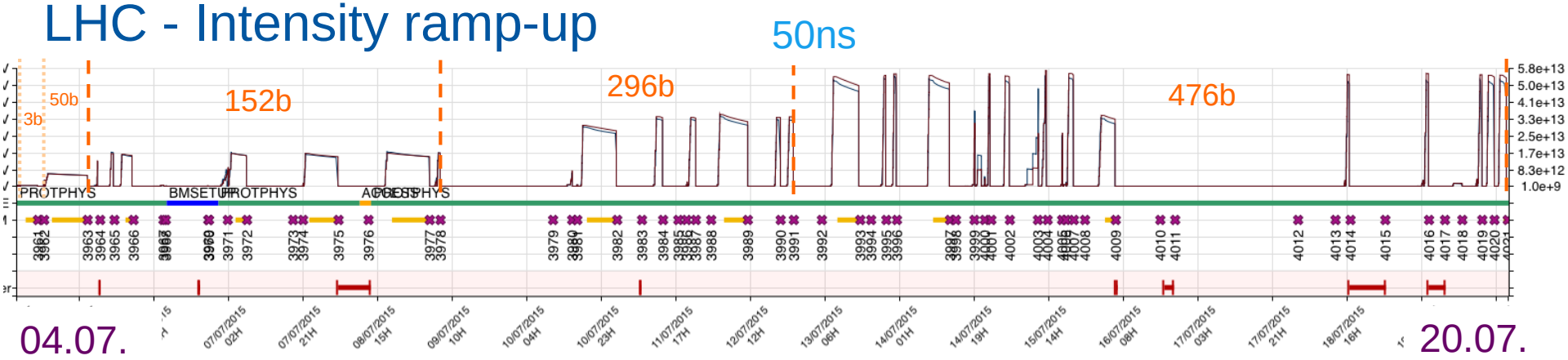
- Machine Protection Tests doubled.
- False beam Dumps by Machine Protection Systems stable (LBDS, PIC, BLM, BIC, SIS, QPS, FMCM).
- End of fill dumps stable.
- Dumps due to beam monitoring (beam losses, UFOs, instabilities, orbit) reduced.

Initial proposal for intensity ramp-up in 2015…

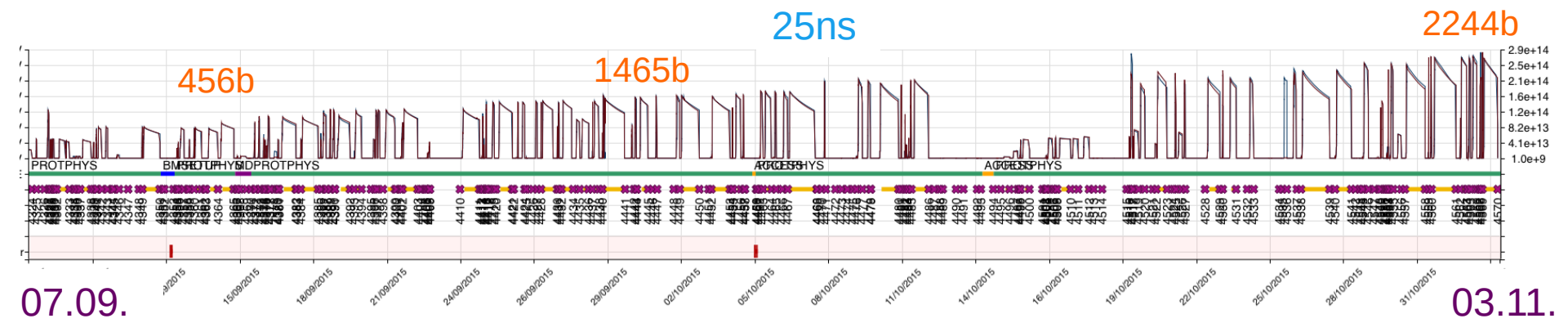
- 50ns (~9 steps to 1380b)
  - 3 – 12 – 48 – 144 – 288 - 480 –768 –1092 – 1236 – 1380
- 25ns (~11 steps to 2800b?!)
  - 3 – 12 - 48 – 72 - 144 – 288 – 432 - 588 –1164 –1740 – 2316 - 2748
- Updated – Proposal 25ns (MPP 04.08.)
  - 3 – 72 - 144 – 288 – 432 - 588 –1164 –1740 – 2316 – 2748



LHC - Intensity ramp-up



- 50ns up to 500b dominated by **hardware and software** issues in Machine Protection systems → **debugging** phase
- 25ns dominated by **intensity and beam related** issues.
- Careful check of each **high energy beam dump** and documentation in 17 intensity ramp-up check lists (EDMS).



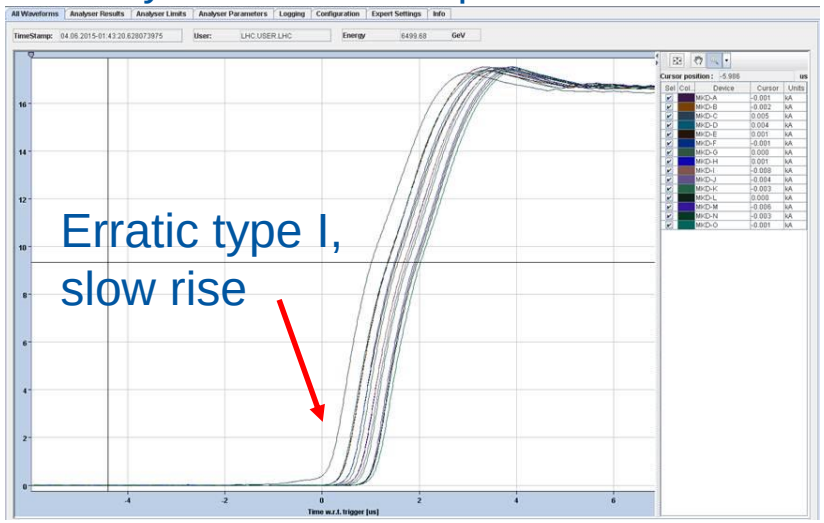
Some Issues during intensity ramp-up (detailed list below)

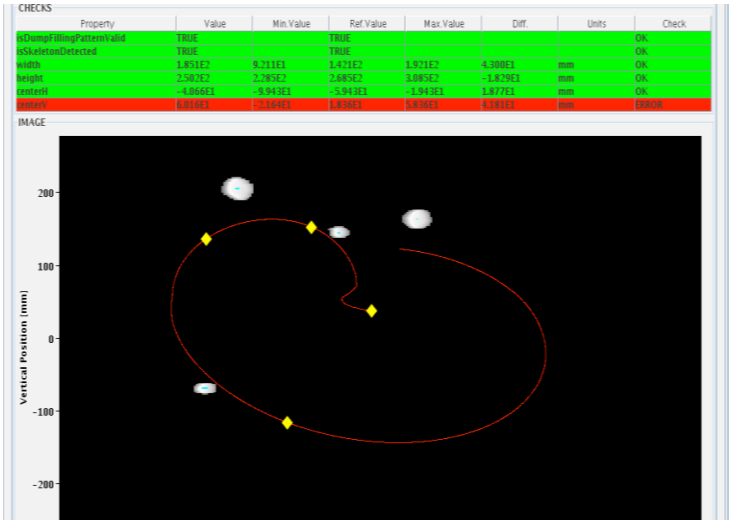
- **Hardware and software** issues in MP systems → **debugging**:
  - **QPS_OK flickering**; BIS timing mis-alignment; Communication problems BLM → SIS; BLM data missing in PM; SBF glitches; ALFA position interlock glitch; QFB 50Hz lines; **BPMS software issues**; **Missing BPM capture data**; Resolver disabled in two collimators; **TCSP.A4R6.B1 heating due to bad cooling pipe connection identified and corrected**; **BCCM false dumps**; **Unbalanced rupture of the Quench Interlock Loop**; BIS: 3 beam dumps due to attenuation of signal in optical fiber; FMCM triggers due to small electrical perturbations; QPS post mortem: missing files, synchronization issues, erratic signas …
- **Intensity and beam related** issues:
  - SEUs on QPS boards (dumps / communication issues); **UFO dumps and UFO induced quenches**; Temperature increase in TDI B2 and TCSP.A4R6.B; Decrease of bunch length at flat top; Instabilities; Blow up of bunches in the first ~300 buckets; Beam screen: cryogenics at the limit reached, but the normalized heat load decreases (conditioning); Disabled temperature sensors and thresholds increase at some collimators; **Losses at TDI reaching >60% of dump threshold** (→ *Detail see talk of F. Burkart);* **Vacuum spikes at TDI IR8 during high intensity operation**; ...
- Others:
  - **Asynchronous beam dump**; Training quenches at flat top; Earth faults in circuits (RB.A78, RCS.A78.B2), Trip of undulator due to offset in U_RES; Malfunctioning of EE switch (RQTF.A56.B2); **Leak at B2 beam dump (TDE)**; **MKB/MKD generator triggers**; MKI flashover

LHC Beam Dumping System 2015

Courtesy J. Uythoven

- 10th May 2015 – 13 December 2015
  - Beam 1: **2185 dump** requests, all **safely dumped.**
  - Beam 2: **2033 dump** requests, all **safely dumped.**
- 4th June 2015: **one and only asynchronous beam dump of the year due to erratic of MKD.**
  - No beam in abort gap.
  - Below the **3/beam/year** announced for 2015 following the extremely valuable reliability run which showed some concerns on the MKD generators.
    - Upgrade of MKD generator switches foreseen for LS2.
  - Did not test the new TCDQ absorbers with real beam in 2015.
  - **MKD switch changed**, total intervention time with tests: 17 hours.
- New Type II erratic characterised in the laboratory. This will be more demanding on TCTs in case of asynchronous dumps → HL-LHC



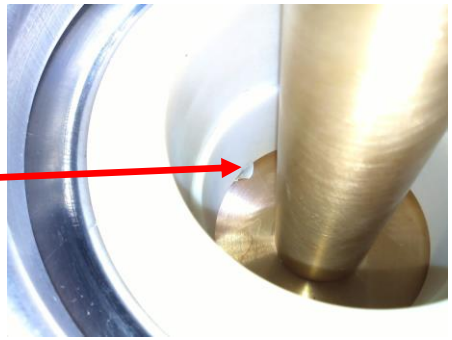


More LBDS 2015

Courtesy J. Uythoven

- 5 Internal dump requests. All due to the same **MKB generator**
  - 26/04/15: First erratic
  - 27/04/15: Second erratic → **switch replacement**
  - 31/05/15: Erratic on replaced switch, piece of glove found
  - 24/10/15: Erratic on same generator: inspection, clean
  - 24/10/15: Second erratic on same generator → **replace generator**

5 months

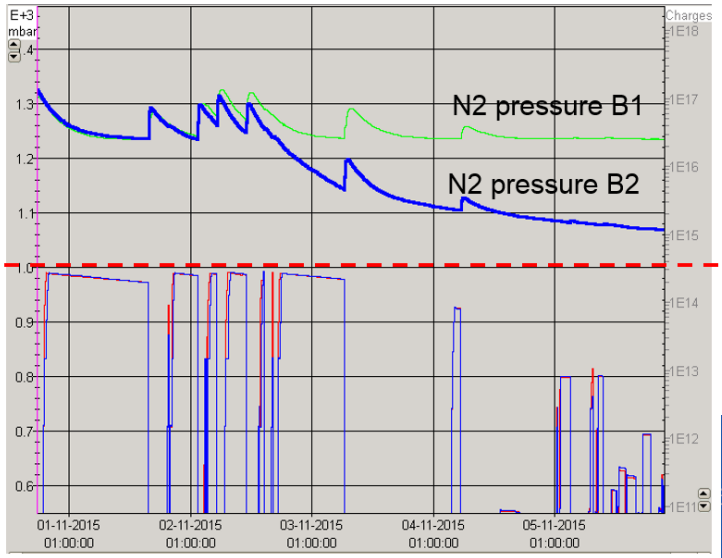


- No other internal dump requests !
- One more **MKD generator was exchanged** coming out of TS1, in the shadow of a cryogenics problem. Broken current pick-up.
- CIBDS
  - **Redundant link between BIS and LBDS**, not going through the TSU.
  - **Worked correctly** guaranteeing additional safety against unforeseen failure modes.
  - Some **initial problems** with arming. Sorted.
  - Dumped 2x as it has proven to be **the most sensitive element** in the chain on BIS frequency.
- Abort Gap Cleaning
  - BSRA working with automatic calibration and checks: **good availability**
  - SIS used to **automatically start cleaning** (used) or dump (not used)
- Interlocked BPMS worked reliably with normal beams → More details in talk by T. Lefevre.

TDE N2 Leak

Courtesy J. Uythoven

- TDE normally runs at 1.2 bar Nitrogen **overpressure**.
- Nitrogen **leak on TDE B2**. Fixed by **tightening the flange** after some days.
- Manometer on the **bottle was found closed**, causing initial pressure drop.
- The **only** 'interlock' is presently in the **XPOC**.
- The only **gauge is far away from the dump block**, on a long line. Gives the correct pressure in stable conditions…
- To consider
  - Separate TDE N2 overpressure more clearly from other signals in XPOC.
  - Install a second, **hardware interlock** on the TDE pressure.
  - Consider a **second pressure gauge** on the TDE for complementary information.
  - Derive **operational procedure and intensity limits** in case of a leak in the TDE



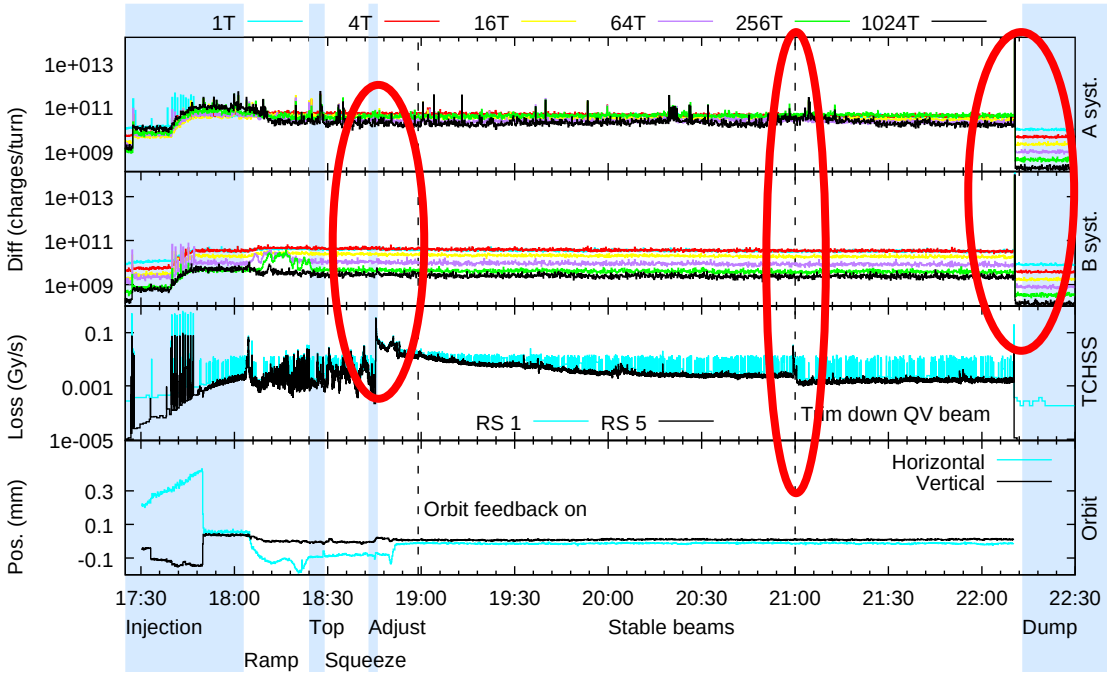
Beam Current Change Monitor (BCCM)

- **Redundant interlocking** of global **beam losses** in addition to BLMs
- System **activated** after test phase during first part of intensity ramp-up (end of August)
- After spurious beam dump (09.10.) **deactivation in BIS**.
- Proposal: Technical **review of system status** end February 2016, if correct functioning is verified → **commission and activate** BCCM in BIS after YETS.

Issues to be understood and solved following 1st operational experience:

- Suspected **phase instability** leading to loss spikes which are uncorrelated to orbit movements or real losses.
- **Intensity dependent** baseline.

→ For details see talk by T. Lefreve



Courtesy D. Kleiven

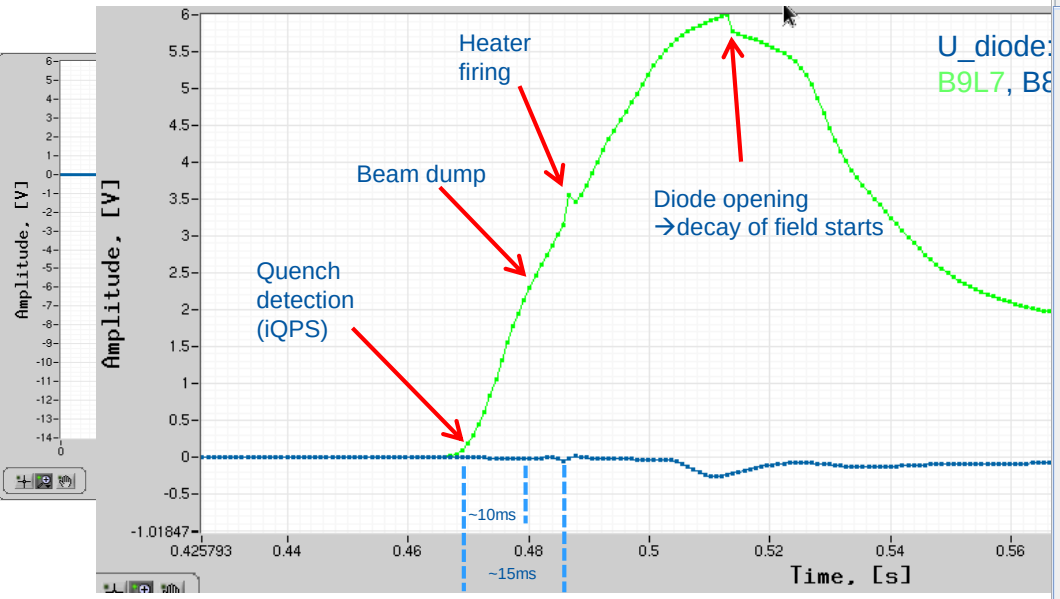
Protection during magnet quenches at 6.5 TeV

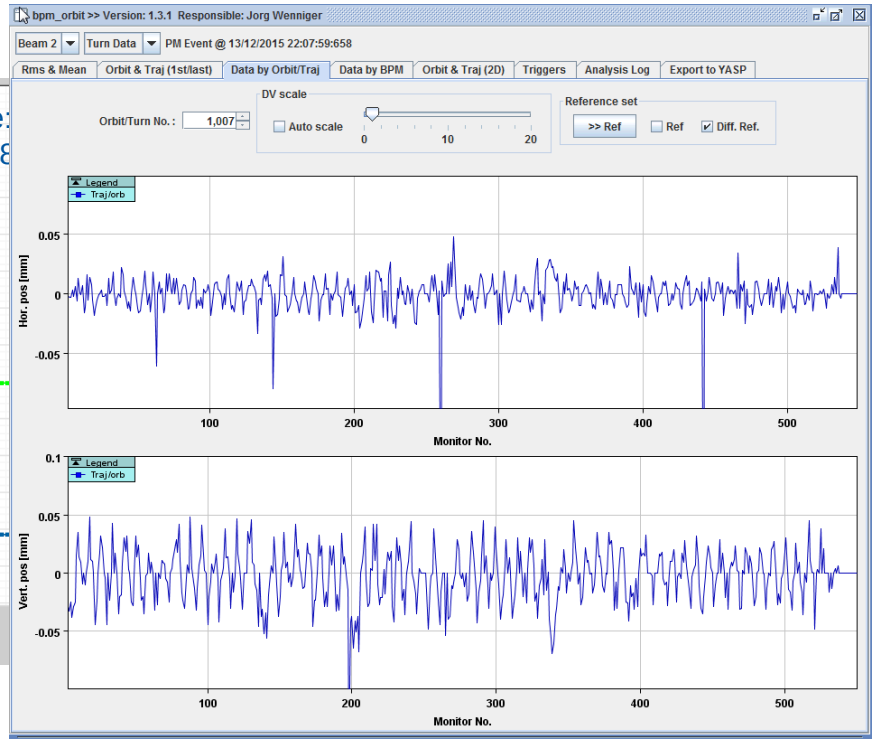
Do we dump the beam before the field decays?

Magnet quenches during run 2015:

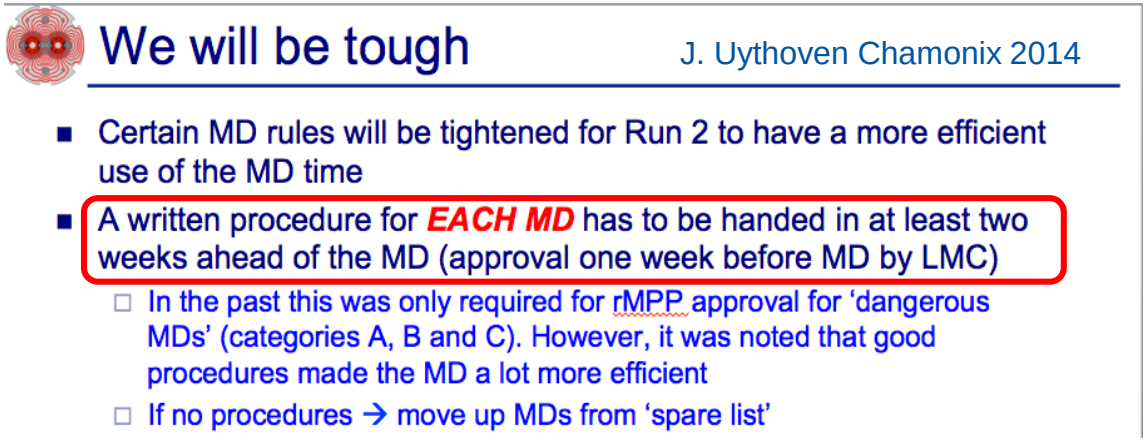
- **7 training** quenches → beam dump via PIC
- **6 beam induces** quenches (3xUFO, 3xULO) → beam dump 4 x via BLMs and 2 x via PIC
- **Q4L6 QT** (inject and dump)
- **1 BFPP QT** → beam dump via PIC
- **1 Collimation ion** quench test → beam dump via PIC

→ No **orbit distortions** observed, when **QPS/PIC** initiated beam dump → **Redundancy** in case of beam induced quenches.





MDs and Machine Protection



We will be tough — J. Uythoven Chamonix 2014

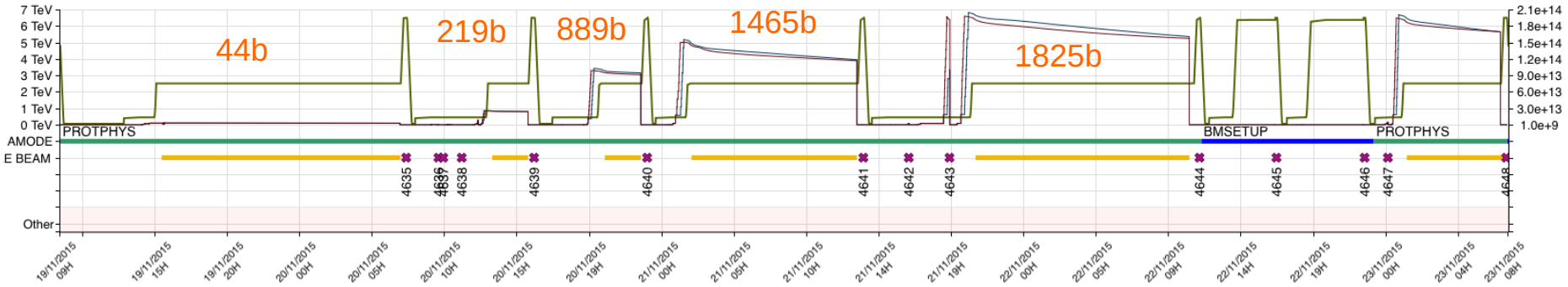
- Certain MD rules will be tightened for Run 2 to have a more efficient use of the MD time
- A written procedure for ***EACH MD*** has to be handed in at least two weeks ahead of the MD (approval one week before MD by LMC)
  - In the past this was only required for rMPP approval for 'dangerous MDs' (categories A, B and C). However, it was noted that good procedures made the MD a lot more efficient
  - If no procedures → move up MDs from 'spare list'

- 50 MD procedures **checked and classified** by rMPP.
- 17 MDs **class C reviewed by rMPP** and documented/**approved** via EDMS.
- Procedures **available ~1 week** before MD block → **tight to ensure** proper checking and necessary discussions/iterations especially for MP critical MDs.
- **Improve coordination/synchronization** between MD scheduling and check of MD procedures to avoid scheduling un-checked MDs.
- Request document also for **MDs outside MD blocks → no MD without procedure**.

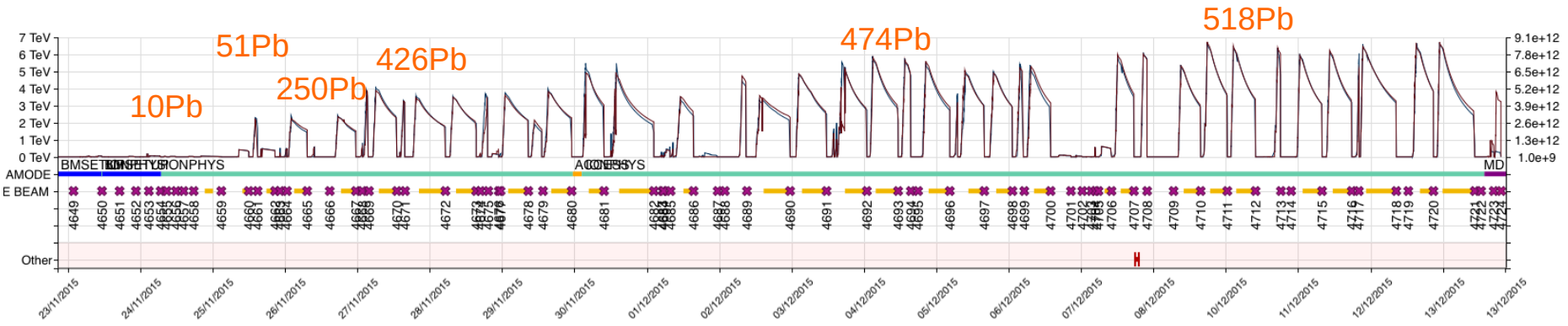
2.51 TeV reference run & 6.37 TeV/Z ion MP strategy

- **New machine settings** and **fast intensity ramp-up** without check list procedure to allow max physics production → **stretching to ensure correct operation** of all MP and related systems.
- **Max stored beam energy** achieved 2015:
  - Protons @ 6.5 TeV: ~280MJ; Protons @ 2.51 TeV: ~84MJ; Ions @ 6.37 TeV/Z: ~9MJ
- **Optics changes and validations** well under control, some (minor) challenges:
  - **Limiting beam losses** by BLMs on **cold magnets** and TCTs, as IR7 thresholds allow 200kW losses for protons;
  - **Increased un-buched beam** due to not optimal RF phase loop;
  - **ADT gain** for abort gap cleaning adjustments required;
  - BLM thresholds flat top correction down to 6.37TeV;

2.51 TeV reference run



Ion run



Outlook 2016

- Intensity **ramp-up:** 3 fills, 20h stable beams, check list.
- **Interleave** increase of **injected intensity**.
- 3 – 12 - 48/72 - 288 - 570 – 860 - 1200 –1700 – 2300 – 2800

Establish cycle (1 fill a few hours SB)

MP dominated (3 fills 20h SB)

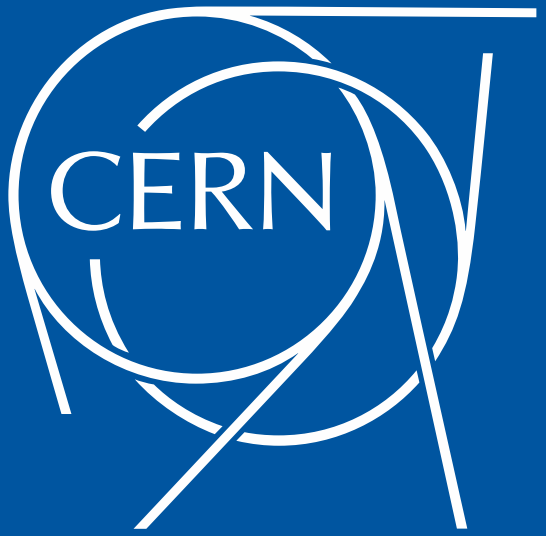
Intensity dominated (Intensity increase in small steps check lists at mentioned intensities)

- Review/**update re-commissioning** needs of MP systems after YETS.
- Consider **dedicated BLM thresholds** at IP7 collimators and TCTs for **Pb**-p-run with experience from 2015.
- **Improved synchronization** between MD **scheduling** and **machine protection** checks.
- **Commission BCCM** together with other MP systems for 2016 operation.

Conclusion

- **MPS ensured safe operation** with up to **~280MJ** stored beam energy in 2015.
- **Intensity ramp-up** following **successful commissioning** of machine protection and related systems.
- **Ramp-up** first dominated by **hard- and software** issues in MP systems → **debugging** phase, followed by more and more **intensity and beam related** issues.
- **Check lists** to document issues during intensity ramp-up proved very useful and went **extremely smooth → THANKS** to all contributors.
- **LBDS reliably dumped beams** more than 2000 times per beam. Only **one asynchronous** beam dump experienced.
- Beam induced **quenches**: QPS/PIC **ensure dump** before beam is affected.
- **Machine development**: procedures for each MD very useful, improve synchronization MD **scheduling ←→ MP check**.
- Ion run: (significantly) **lower stored beam energy** but fast intensity ramp-up leaves **less time to optimize** all systems before reaching **max. intensity**

→ Limit total number of configuration changes.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50ns Intensity ramp-up - Issues

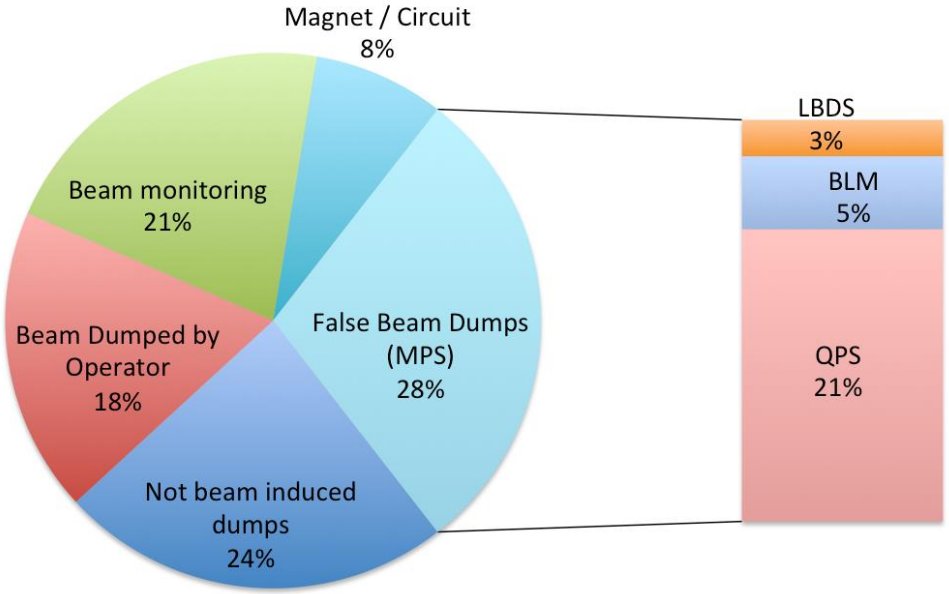
- **Magnet Powering**
  - SEUs in QPS board for splice protection → trips of RBs sectors OR partial trip of sector by PIC due to intermittent opening of quench loop → beams dumped but RBs staid powered → **Replacement of boards** in TS2 AND activation of opening **13kA EE switches via SIS**.
  - QPS_OK flickering → **signal masked**
  - Transient earth fault in RB.A78
  - Earth fault in RCS.A78.B2 → **circuit condemned**
- **Interlocks and PM**
  - **BIS: timing mis-alignment** between LHC and INJ BIC → done
  - **Communication** problems between **BLM crates and SIS** (due to Ufo study buffer) → mitigated via **FESA class update**
  - UFO dumps → intensity dependent
- **RF**
  - Problems with phase loop caused beam to de-bunch → dump due to losses.
- **Beam Instrumentation**
  - **Glitches of SBF** due to noise on one B2 DCCT → solved
  - **BLM PM data missing** for R2, R3, and in IP6 → one fill with lower intensity. → solved via roll-back → **PM data collection module** being extended to check data collection and **send automatic emails**.
- **Collimation**
  - Spurious **ALFA dump due to glitch of position** measurement (LVDT) → solution implemented, to be re-**discussed in next MPP**.
  - **Resolver disabled** in TCTPH.4R2.B2, TCSG.A4L7.B2 → replaced?
  - LVDT drifts on some collimators (~50um)
  - Temperature sensor disabled on TCTPV.4R8.B2
- **Operation and Feedbacks**
  - Problems with **QFB (50Hz lines)** → filter reviewed → solved
  - **Orbit drifts** due to movement of triplet R8 → effect mitigated by slow orbit feedback in collision
- **LBDS**
  - Asynchronous beam dump (MKD erratic B2, generator C) → generator exchanged
  - BPMS software issues (FESA) prohibited to change interlock limits → solved
  - XPOC: PM BLM data missing; TSU data arriving too late → solved
- **Injection**
  - **Missing BPM capture data of injection oscillations** → improved but still issues visible → strategy to be discussed in next MPP
- **Heating of Equipment**
  - Decrease of bunch length at flat top
  - **TDI B2 temperatures increase steadily** during the fill
  - **TCSP.A4R6.B1 shows a different thermal dynamics** than all other collimators

25ns Intensity ramp-up – Issues

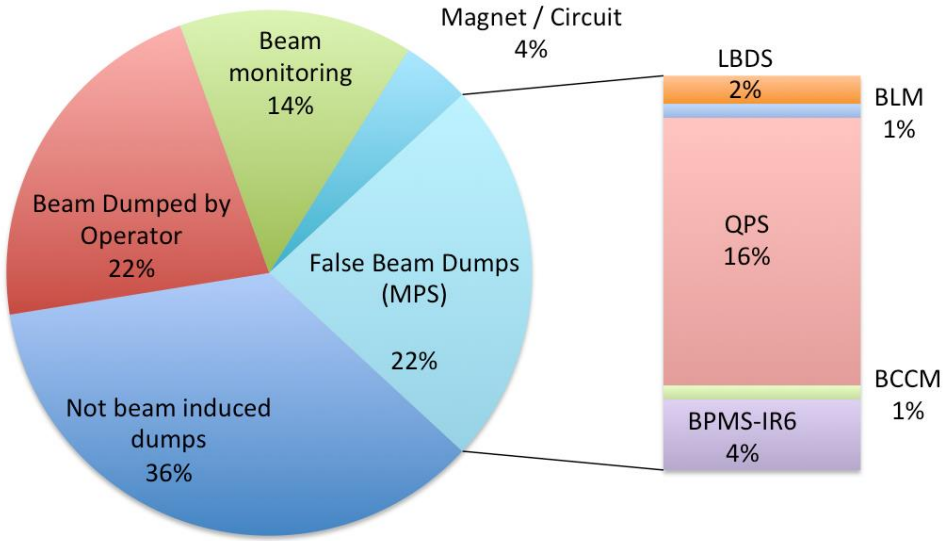
- **Magnet Powering**
  - SEUs in QPS board for splice protection → trips of RBs sectors OR partial trip of sector by PIC due to intermittent opening of quench loop → beams dumped but RBs staid powered → **Replacement of boards** in TS2 AND activation of opening **13kA EE switches via SIS**.
  - QPS_OK flickering → **signal masked**
  - Transient earth fault in RB.A78
  - Earth fault in RCS.A78.B2 → **circuit condemned**
  - Malfunction power supply in **EE switch** of RQTF.A56.B2
  - **Training quenches** at flat top**.**
  - **Trip of Undulator L4** due to slow increase of offset in U_RES → sequencer check re-activated.
  - QPS mBS boards loosing communication due to SEU → resets, sometimes heaters fire
  - Unexplained dump probably due to SEU in QPS-PIC-PC interface.
- **Interlocks**
  - UFO dumps and UFO induced quenches → see talk of B. Auchmann
  - BCCM false dump
  - Unbalanced rupture of the Quench Interlock Loops
  - BLM thresholds: rounding issues discovered
  - BIS: 3 beam dumps due to attenuation of signal in optical fiber → switch to other fiber
  - FMCM triggers due to small electrical perturbations → mitigation in EYETS 2016/17
- **Collimation**
  - Beam dump due to timeout (limit controlling CPU stuck) on TCL6
  - UFO dumps on TCTs → BLM thresholds adjusted.
  - TCSP.A4R6.B1 B1 (IR6) heating up → bad cooling pipe connection identified and corrected.
  - Disabled temperature sensors and thresholds increase at some collimators.
- **Operation**
  - **Instabilities**
  - **Blow up** of B1 bunches within the first ~300 buckets → disappeared after TS2
  - **BBQ-B1** gating on bunches with high gain → not usable below 2-3TeV
  - Orbit drifts in stable beams due to IR triplet drifts mitigated by low gain orbit feedback.
  - **SBF** stuck / flickering (depending on BCT stability) → (partially) mitigated.
- **LBDS**
  - MKD compensation power converter trip during ramp-down → replaced.
  - MKB(HA.B2) self trigger → generator replaced.
  - Leak in B2 TDE → temporarily limiting intensity → solved by tightening bolt in collor flange.
- **Injection**
  - Losses at TDI reaching >60% of dump threshold → *Detail see talk of F. Burkart*
  - Vacuum spikes at TDI IR8 during high intensity operation (as during scrubbing) → increase of vacuum threshold to $8x10^{-6}$ mbar → replacement during YETS
  - MKI flashover
  - On rare occasions inj. oscillation data missing.
  - MKI temperature interlock increased to 52C.
- **Heating**
  - **Decrease of bunch length** during fill → increase of target bunch length at flat top (1.25ns→1.35ns)
  - **Transients on sector 12** increasing with intensity: now 10 W on top of an heat load of 15 W. Abrupt transients appear after injection and disappear during the ramp on most sectors.
  - Beam screen: cryogenics at the limit reached, but the normalized heat load decreases thanks to conditionings. Impedance heat load still negligible.
  - **TDI temperature reaching 80C**.
  - TOTEM pressure increase in both 6L5 and 6R5 when moving roman pots in.

Beam dump causes
50ns ramp-up versus 25ns ramp-up

50ns ramp-up (38)



25ns ramp-up (118)



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