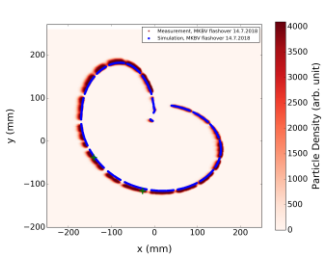
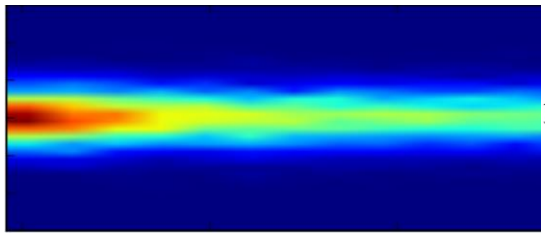
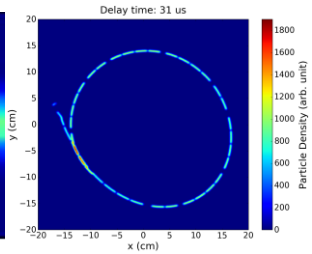
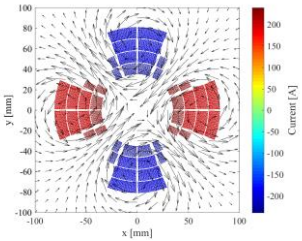
MPP, rMPP experience during Run 2

J. Uythoven, J. Wenninger, C. Wiesner, D. Wollmann, M. Zerlauth



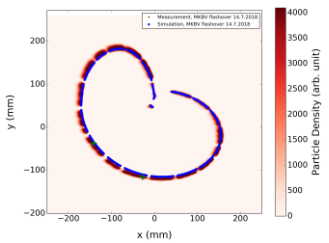


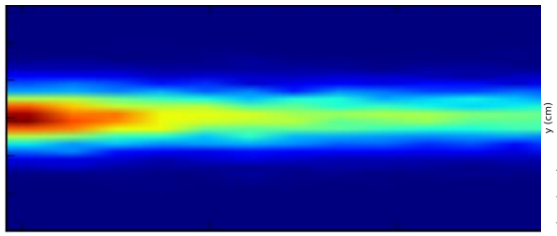
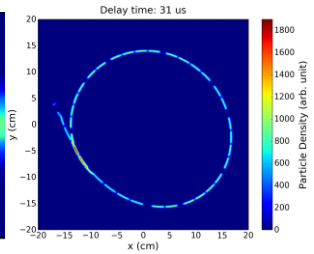


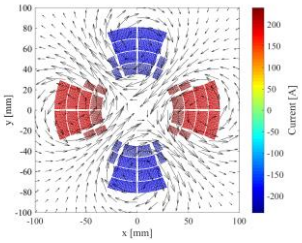


Outline

1) MPP and rMPP: role and experience
2) Intensity ramp-up and cruise checklists
3) Major event reports and major events 2016-18
4) Emergency and commissioning procedures
5) From Run 2 towards Run 3
6) Conclusions and follow-ups

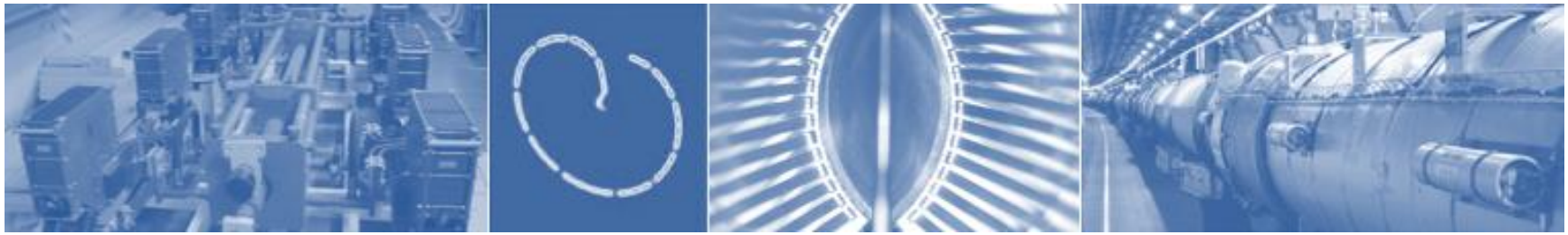




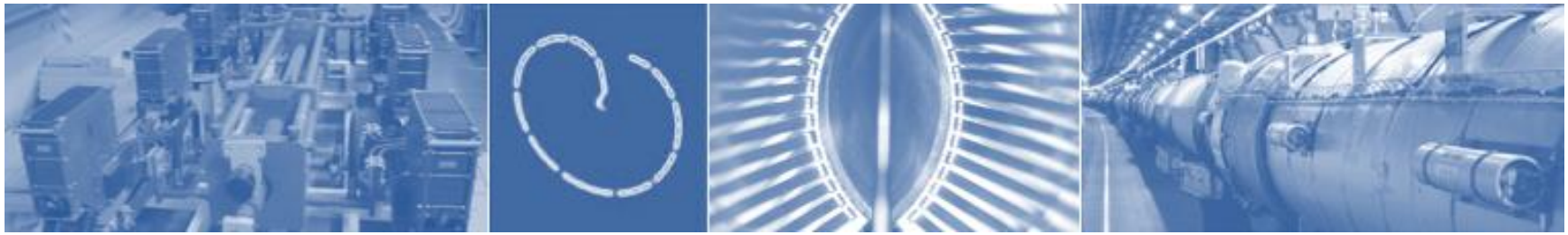
MPP: Mandate and Introduction

- Machine Protection Panel (MPP) active since the design phase of the LHC.
- Mandate:
  - **Verify the proper commissioning and ensure the coherent integration of all relevant MP systems.**
  - **Approve all essential elements in the machine interlock chain.**
  - **Identify and document the relevant failure scenarios.**
- Chair/deputy: D. Wollmann/J. Wenninger (since 2016).
- Reports to the LMC (LHC), the IEFC (injectors), and relevant bodies for future upgrades (HL-LHC) and new accelerators (FCC).
- Homepage includes all presentations, minutes, list of action, …



MPP: Activities and Experiences

- 78 MPP meetings since 2015 → ~20 meetings per year.
- MPP workshops 2013/2015 (See M. Zerlauth's talk).
- Fruitful and successful collaboration between MP equipment teams, OP and MP experts: **No damage occurred in the LHC during Run 2!**
- MPP activities focused on LHC and SPS.
- However, increased cooperation with injector experts.
  → *Extension to LINAC4/PSB/PS to be discussed.*

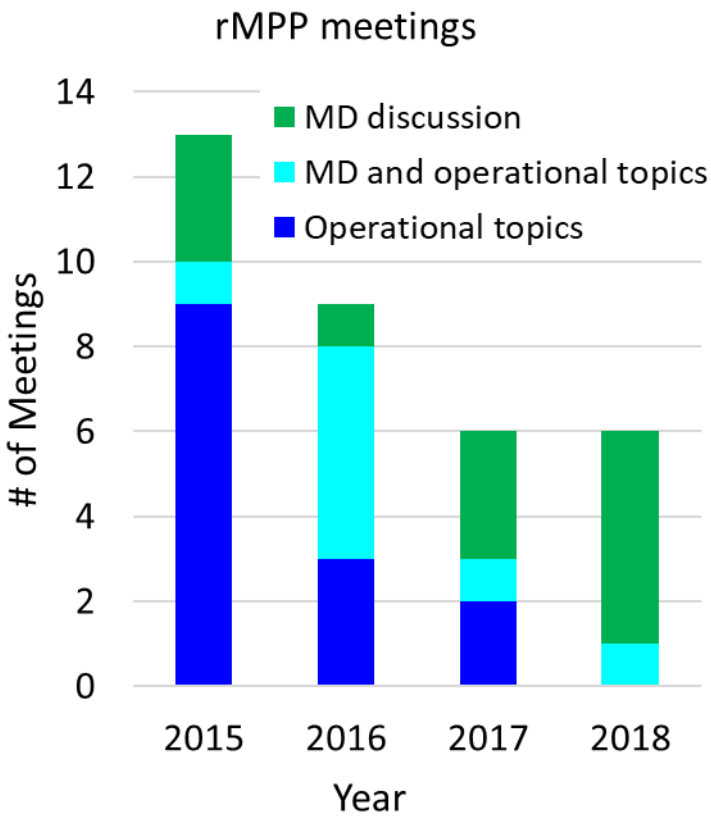


rMPP: Mandate and Introduction

- restricted MPP (rMPP) introduced during Run 1 (2010) as **complementary body to the MPP**.
- Supports LHC operations and equipment teams for MP related questions, in particular when a **timely decision** is required. Reports to the LMC.
- Mandate (204th LMC):
  - Evaluate the **allowable operational envelope** (no. bunches, total intensity, injected intensity, bunch pattern, β*...) as a function of the commissioning state of the machine.
  - Define and document the required boundary conditions and **steps for intensity increases**. Final approval of intensity increase by LMC.
  - **Define boundary conditions for MDs and special (physics) runs** related to machine protection.
  - **Discuss MP related issues that arise during operation and require timely reaction.**
- Chair/deputy: M. Zerlauth/J. Uythoven (since 2016).
- Presently, 13 members from MPE, MP3, RF, BI, OP, COLL, ABT, LPC. To be updated during LS2.
- Minutes and MD/operational procedures in EDMS.

rMPP: Activities and Experiences

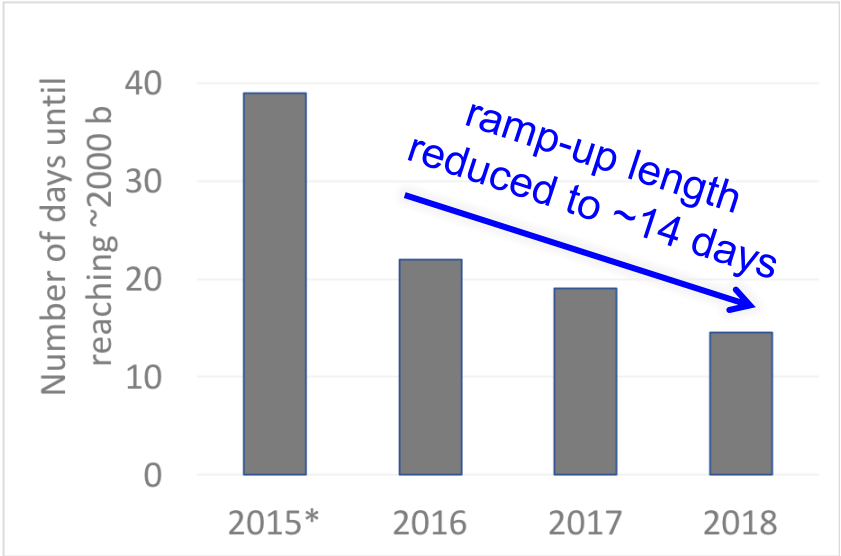
- Important role during **commissioning, after TS, (E)YETS, change of configurations and intensity ramp-ups** (intensity checklists). ✓
- Review and approval of **MP critical MDs**: ✓
  - Successful approach of detailed MD procedure discussion, adjustment and implementation with MD organizers and EiCs.
  - No damage caused during MDs, even though non-standard operation.
- To be improved: **stronger involvement for Special Runs**, including recovery procedures and discussion of short-term changes. (✓)



In total, 34 rMPP meetings during Run 2

Intensity Ramp-up and Checklists

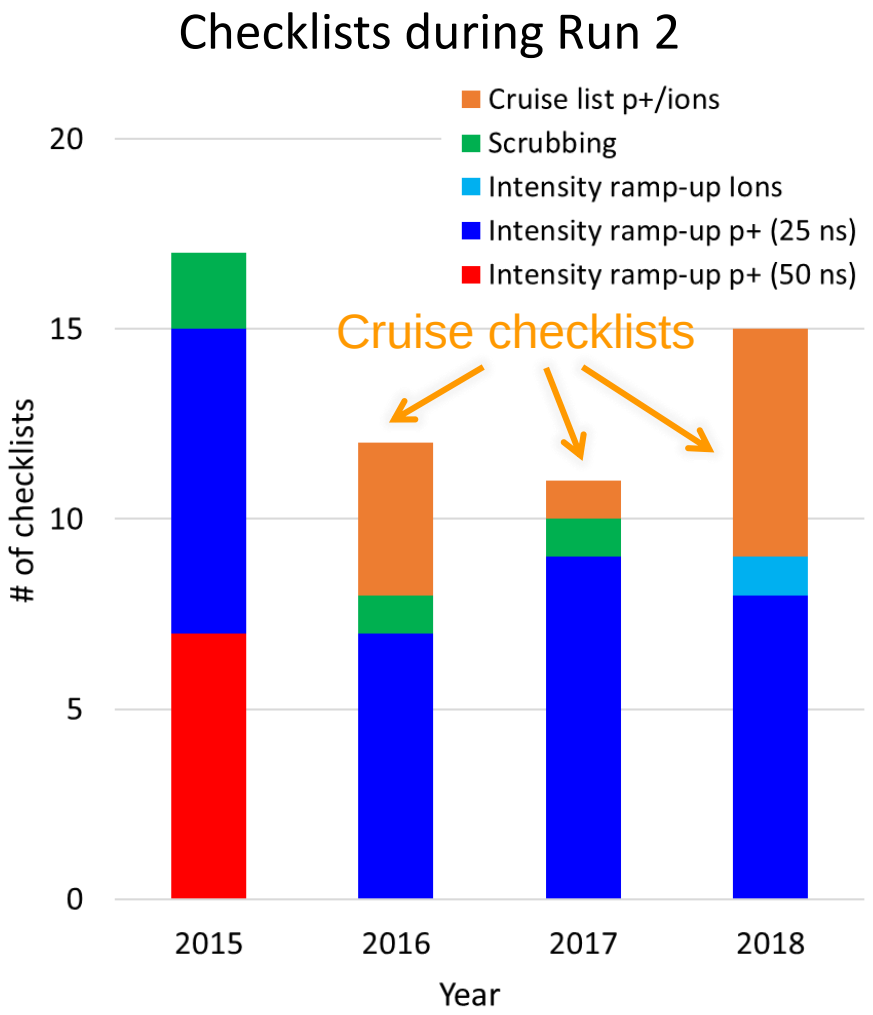
- 2015: Commissioning with 50 ns and 25 ns beams.
- 2016-2018: 7-8 intensity ramp-up steps: 3/12 → 75 → 300 → 600 → 900 → 1200 → 1800 → 2100/2300 bunches.
- Each ramp-up step completed with checklist:
  - Expert checks of magnet powering, interlocks, RF, beam instrumentation, operation, orbit, feedbacks, injection, beam dumping system, heating of equipment, vacuum.
- 44 intensity-ramp-up and scrubbing checklists during Run 2.
- Various issues and non-conformities found during intensity ramp-ups (→ D. Wollmann, Evian 2019).
- Conclusion: Important tool that should be kept for intensity ramp-ups in Run 3.



D. Wollmann, Evian 2019

Cruise Checklists: Experience

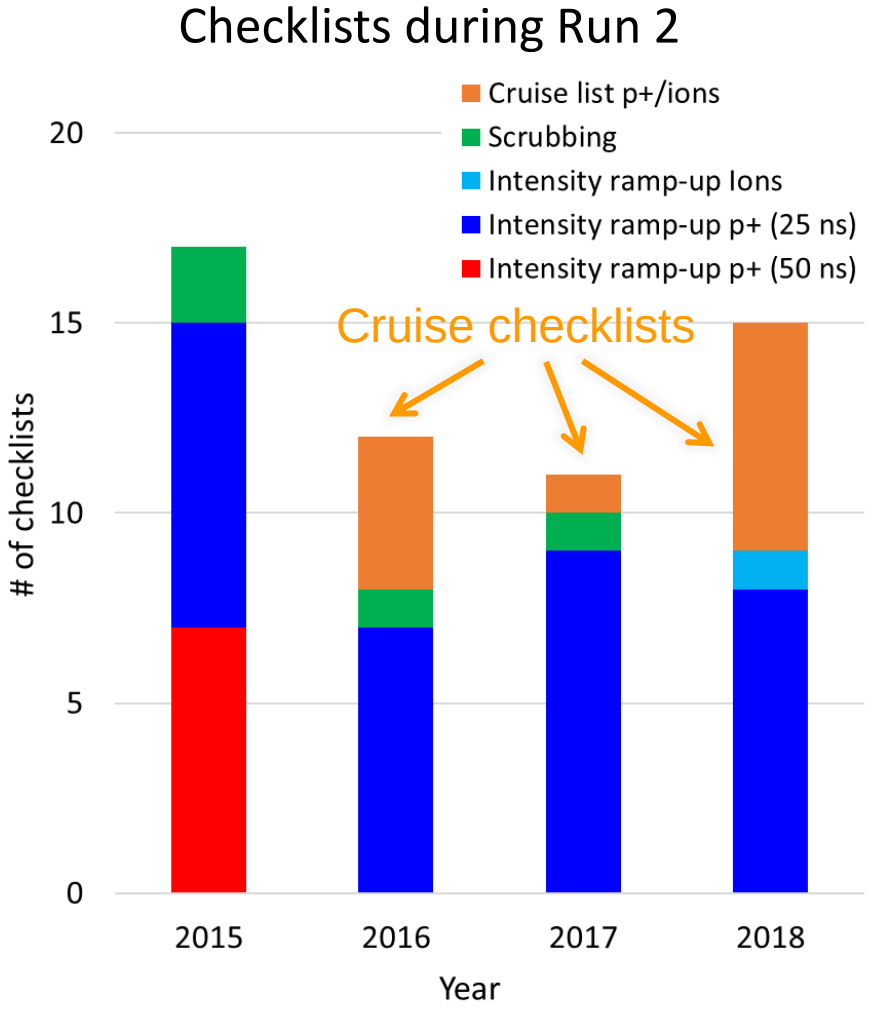
- Additional **Cruise Checklist** introduced for careful **check and documentation of all beam dumps >450 GeV** during periods of **regular operation**.
  - Includes main beam parameters and system-expert checks and comments.
- Verifying **proper functionality of MP systems** and detecting possible non-conformities or uncommon behaviour.
  - Example: Orbit change for several dumps observed → tracked down to missing beam-beam kick → Hardware linking of BIS loops (Beam 1/2) for HL-LHC required.
- Nearly **1,000 dumps checked** for 11 cruise checklists in 2016/17/18 (excluding intensity ramp-ups).
- After completion, released on EDMS.



Cruise Checklists: Outlook

Run 3: **Keep 4-6 weeks period** (as in 2016 and 2018)**.**

- **Flexible check intervals** for certain systems under discussion, e.g. check of orbit, fast beam losses every 2 weeks.
- Ideally, use **dedicated web tool** instead of shared excel sheet.
- Under study if checklists could be included into the ASM tool.
  - Easier to use, easier inclusion of plots and images, and links to AFT, logbook, …
  - Information easier accessible and more visible.



Major Event Reports

→ Follow-up from Evian 2019: Document major MP relevant events with “quality assurance and rigor” (P. Collier, Evian 2019) to learn for future events.

Proposal:

- A major event report should be issued in case of a **machine-protection relevant event** in the LHC or its injector chain that
  - caused **damage** to the machine, OR
  - caused **considerable downtime (>24h)**, OR
  - caused **abnormal fast beam losses**, OR
  - showed that a **machine-protection relevant system did not fulfil its function**.
- The major event report is **issued by the MPP** in close collaboration with the concerned system teams and reported to the LMC or IEFC.
- The major event report should contain in a concise way (1-2 pages):
  - **Analysis of the event**, including the relevant timestamps, operational conditions, beam and system parameters, comparable past events.
  - **Description of the recovery and revalidation procedure**, if applicable.
  - The **lessons learnt** to prevent similar events in the future, including required actions, if any.
  - Links to **additional information** (presentations, Internal Reports, Non-Conformity Reports, …), if required.

Major MP Events 2018*

Event	Damage	Down-time	Abnormal fast beam losses	MP relevant malfunctioning
Multiple injections of high intensity beam on crystal collimators (13./14.10.2018)	No	No	Yes	Insufficient procedural handling
SPS dipole issue (20.8.2018)	Yes	~2d	Yes	Yes
MKBV flashover (14.7.2018)	No	~14h	No	Accepted failure case, but unexpected behavior
Symmetric triplet quench with orbit drift (3.6.2018)	No	~5h	Yes (Fast developing orbit offset in B1, but no change in B2)	No (Correct behaviour of circuit protection verified)
Spurious firing of quench heaters due to injection beam losses (1.6.2018)	No	~few hours	No	Unexpected behavior of QPS (shown to be beam-loss related)

*without claim to completeness

Major MP Events 2017/16*

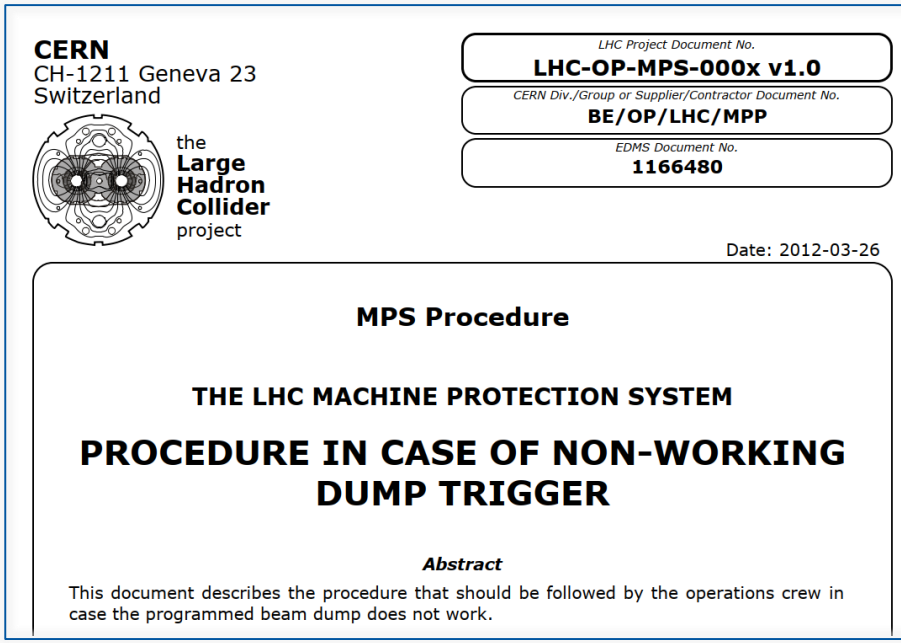
Event	Damage	Downtime	Abnormal fast beam losses	MP relevant malfunctioning
Injection into Abort Gap (4.9.2017)	No	~few hours	No	Yes
16L2 dumps (5.6.2017)	No	Turn-around	Yes, for first occurrence(s)	No
MKI erratic with quench of triplet in IP2 (2.9.2016)	No	~few hours	Losses higher than ususal (grazing impact on TDI)	No
Intermittent inter-turn short in MB.A31L2 (10.8.2016)	(Yes)	>24h	No	Risk of magnet damage in case of quench or fast power abort
TDE leak (2016)	No	Paused high-intensity operation	No	Yes, non-nominal operation conditions

*without claim to completeness

Emergency Procedure

Emergency procedure in case of **non-working beam dump:**

- Procedure currently being updated:
  - Taking into account the latest LBDS changes.
  - As last resort, using ADT to scrape the beam.
- Required: test individual steps, make procedure readily available in the CCC, and train shift crews during beam commissioning.



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the **Large Hadron Collider** project

LHC Project Document No.
LHC-OP-MPS-000x v1.0
CERN Div./Group or Supplier/Contractor Document No.
BE/OP/LHC/MPP
EDMS Document No.
1166480

Date: 2012-03-26

MPS Procedure

THE LHC MACHINE PROTECTION SYSTEM

PROCEDURE IN CASE OF NON-WORKING DUMP TRIGGER

Abstract

This document describes the procedure that should be followed by the operations crew in case the programmed beam dump does not work.

GENERAL STRATEGY

- Force open the BIS loop
- Generate an internal fault in the LBDS
- Scrape the beam away

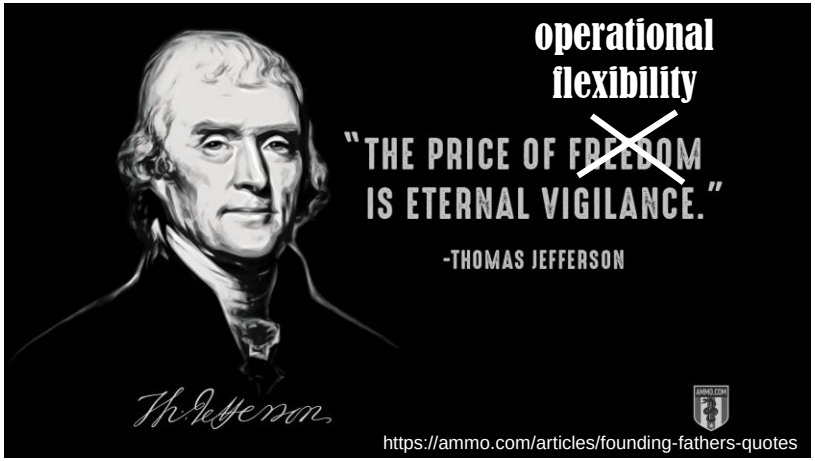
See M. Solfaroli, Update of procedure in case of a non-working beam dump, 169th MPP, 14.9.2018

Recovery Procedures and Automatic Post Mortem

- Recovery and commissioning procedures for MP systems have to be reviewed and updated during LS2.
- Signing of global Post Mortem events:
  - Every dump has to be signed by OP. In case of failing IPOC check, an MP expert has to sign – otherwise the injection inhibit is not removed.
  - However, the injection-inhibit check can be masked directly in the SIS (used for certain MDs with frequent injections,...)
  - To be discussed if this procedure should be kept or modified (masks were sometimes forgotten).

From Run 2 towards Run 3

- Due to the **diverse redundancy** in the machine protection systems, **vigilant** hardware experts, MP experts and OP teams **no damage occurred at LHC** in Run 2!
- Run 3 will bring…
  - …higher beam energy (7 TeV),
  - …higher bunch intensity (up to 1.8e11 ppb),
  - …stored beam energies of up to 500 MJ per beam at the end of Run 3,
  - …smaller and bigger changes in the MP systems,
  - …largely upgraded injectors,
  - …increased operational complexity (beta* levelling, …).
- → Surprises to be expected…
- → Vigilance has to stay up!



Conclusions

- Overall, very good performance of the MPS and its subsystems, with important contribution of the MPP and rMPP members.
- rMPP should get stronger involved for Special Runs, including recovery procedures and discussion of short-term changes.
- Checklists for intensity ramp-ups have been a valuable tool to verify MP readiness for next intensity step.
- Cruise checklists should be issued in 4-6 weeks periods, possibly with flexible check periods. An upgraded tool is under discussion.

Follow-ups

- Open question: should the (r)MPP mandate be extended to the injectors?
- Membership of MPP and rMPP to be updated in LS2.
- Emergency procedure for non-working beam dump to be updated during LS2.
- Commissioning procedures for MP systems to be reviewed in LS2.
- Major Event Reports for MP-related events to be issued from Run 3 on.

Thank you for your attention!

MPP Mandate

The machine protection systems protect accelerator and experimental equipment of the LHC and its injector complex against uncontrolled release of energy stored in the magnet system and the particle beams while at the same time allowing for efficient operation.

The Machine protection Panel (MPP) shall - in conjunction with relevant working groups (MP3, BLMTWG, COLLWG, LIBD ..) and experts of the equipment and operation teams -

- ensure the coherent integration of all relevant sub-systems into the machine protection systems of CERNs existing accelerator complex and its future upgrades
- approve all essential elements included in the machine interlock chain and address questions related to the dependability of the machine protection system
- verify the proper commissioning of all MPS sub-systems and propose in collaboration with rMPP the safe operational envelope of the machine based on the state of commissioning
- define procedures for the operation of the machine interlock systems and required diagnostic tools
- Identify, assess and document relevant failure scenarios of equipment systems and machine components and propose according mitigation measures
- specify functional requirements for additional protection systems to be developed, constructed and tested

The panel shall report to the LMC for all matters related to the LHC and to other relevant bodies for matters related to the injector complex (IEFC), future upgrades (HL-LHC) and new accelerators (FCC).

http://lhc-mpwg.web.cern.ch/lhc-mpwg/

rMPP mandate

Restricted Machine Protection Panel (rMPP) Mandate

- Evaluate the state of the LHC MPS in view of intensity increases and other changes of parameters relevant to machine protection (e.g. changes of optics …).
- Define boundary conditions for intensity increases (no. bunches, total intensity, injected intensity, bunch pattern, β*...). Document decisions (positive and negative) in EDMS. Final approval of intensity increase by LMC.
- Define boundary conditions for MDs and special (physics) runs related to machine protection. Approve EDMS documents for MDs with an impact on MP.
- Anticipate possible bottlenecks that would prevent future intensity increases and initiate appropriate actions (MPP or whatever appropriate).
- Discuss issues that arise during operation related to MP and requiring timely reaction.
- When required, assist operation and machine coordinators for questions related to MP.

204th LMC