Machine Protection during Run 2016
Review of MP strategy

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J. Uythoven, A. Verweij, J. Wenninger, M. Zerlauth…

Outline

- Intensity ramp-ups and validations
- Operation in degraded mode:
  - TDE leak
  - Suspected inter-turn short
- New fast failure: Quench heater firing with circulating beam.
- Machine Developments
- Changes to core MP system
- Conclusion

Intensity ramp-up 2016

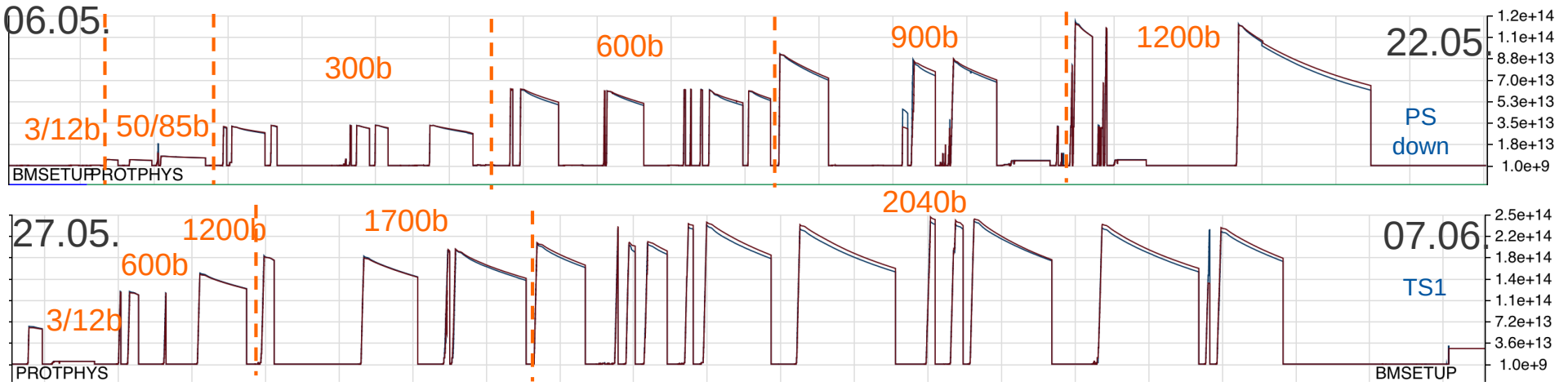
The plan:

Intensity **ramp-up >12b:** 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
MP dominated
Intensity dominated



- **> 1700 b / 200 MJ after 15 days** (excluding PS stop)
- Careful check of **high energy beam dumps** and documentation in **7** intensity **ramp-up**, **4** intensity **cruise check lists** (EDMS). One check list for scrubbing. One **ion checklist** pending.
- Ion ramp-up: One **intermediate intensity** step after validation with ~50/25 nominal bunches equivalent → ~200b p / ~200b Pb.

Standard ramp-up scenarios after stops of nominal operation

Without massive HW + SW interventions

Scenario 1

- One fill with either **pilot bunches or max 2-3 nominal** bunches into SB (cycle revalidation etc.).
- One fill with **600 bunches** and 2 - 5 hours of stable beams (known intensity step to disentangle wrong settings, de-conditioning, etc. from intensity dominated effects at full intensity).
- **Back to pre-stop** intensities.

Total 2 fills for ramp-up

With massive HW + SW interventions

Scenario 2

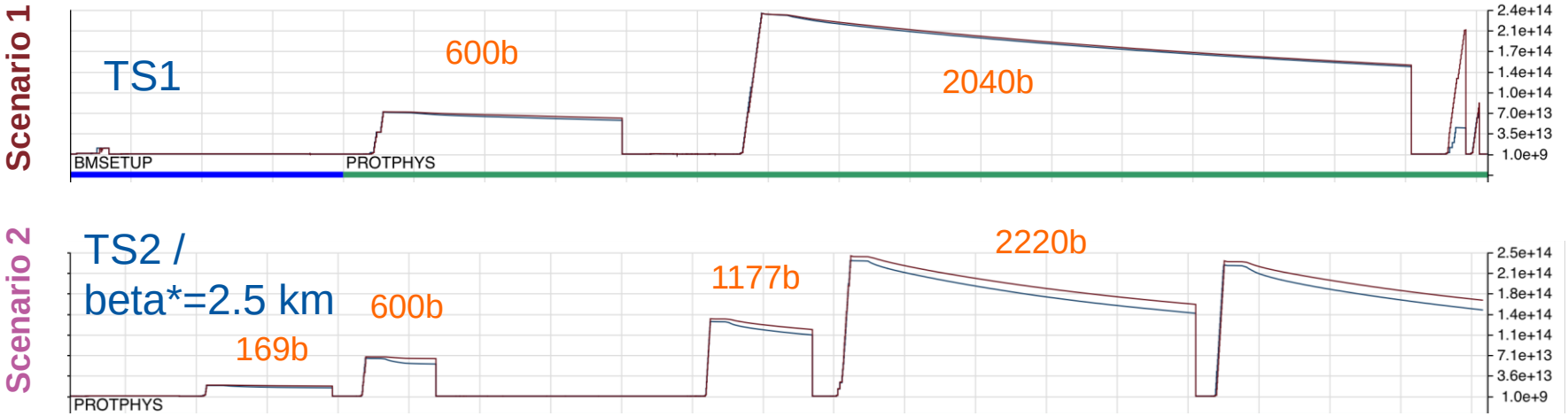
- One fill with either **pilot bunches or max 2-3 nominal** bunches into SB (cycle revalidation etc).
- One fill with ~**50 bunches** and about 1 - 2 hours of stable beams.
- One fill with **600 bunches** and 2 - 5 hours of stable beams (known intensity step to disentangle wrong settings, de-conditioning, etc. from intensity dominated effects at full intensity).
- If > 2000 bunches reached, one fill with about **half max number of bunches** and about 5 hours of stable beams.
- **Back to pre-stop** intensities.

Total 3-4 fills for ramp-up

Presented 265th LMC (01.06.2016)

Ramp-up after stops, TS and MDs

- **Scenario 1** applied: after **PS stop, TS1, MD1, MD2, MD4**
- **Scenario 2** applied: after **MD3/TS2**
- **Not applied** after 2 days stop for inter-turn short investigation in A31L2 (→ only low intensity cycle before stepping to > 2000b)



Proposal:

- Use **2017 same standard ramp-up** scenarios following the positive experience in 2016.
- **Apply scenario 1** also in case of **configuration changes** in future (e.g. switch back to 4 Z TeV after 15 days in 6.5 Z TeV).
- **Ensured systematic analysis** also after short ramp-up fills.

Loss maps and Asynch-dumps – Strategy 2016

- **Commissioning**:
  - **Betatron** loss maps (B1/2, hor /ver) at **each step** during cycle & **continuous** during **ramp & squeeze and squeeze**.
  - **Off-momentum** (positive / negative) at **selected steps** during cycle
  - **Asynchronous dump** tests at **selected steps** during cycle
- **After technical stops**:
  - Betatron loss maps / Off-momentum loss maps / Asynchronous beam dump tests: **reduced sets at selected steps** in cycle
- Periodical validations:
  - **Foreseen every 3 months** → re-validation only **done after technical stops** due to excellent reproducibility of machine (orbit, collimator positions through cycle).

Overview table for commissioning

	450 GeV			6.5 TeV						
LM	Inj.Prot.In	Inj.Prot. Out	Ramp & Squeeze	FT	Squ	EoS	TOTEM	Coll.I	Coll.II	XRP
B1H	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
B1V	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
B2H	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
B2V	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
+dp/p	OK	OK	Not needed	OK	Not needed	OK	OK	Not needed	Not needed	OK
-dp/p	OK	OK	Not needed	OK	Not needed	OK	OK	Not needed	Not needed	OK
Asynchr.	OK	Not needed	Not needed	OK	Not needed	OK	OK	OK	Not needed	OK

See also talks of D. Mirachi and A. Mereghetti for more details.

Loss maps and Asynchronous-dump - Experience

	Betatron loss maps	Off-momentum loss maps	Async. dump tests
Commissioning	100*	12	12
After TS1	20	3	4
After TS2	24	5	4
p-Pb 4 Z TeV	20	6	6
p-Pb 6.5 Z TeV	16	4	6
Pb-p 6.5 Z TeV	24	8	8
Total Proton run	144	20	20
Total Ion run	60	18	20
Total 2016	**204**	**38**	**40**

*breakdown: 32 classical betatron loss maps, 36 loss maps during ramp & squeeze, 32 loss maps during during squeeze

- **Impressive amount** of loss maps and async. dump tests performed in 2016!
- **Systematic,** regular and **timely** follow-up.

- Betatron loss maps having **significantly smaller operational foot print** than off-momentum loss maps and asynchronous beam dump tests.
- **Important to gain confidence** in the protection of the LHC with **beta* of 40 cm** AND **relaying on phase advance**.

Loss maps and Asynchronous-dumps - Proposals

- Based on 2016 experience **review and re-define standard (minimal) scenarios** for commissioning, technical stops and configuration changes.
- **Simplification of cycle** would allow to **reduce required #** of loss maps.
- **Separate validations** required by machine protection from **performance studies.**

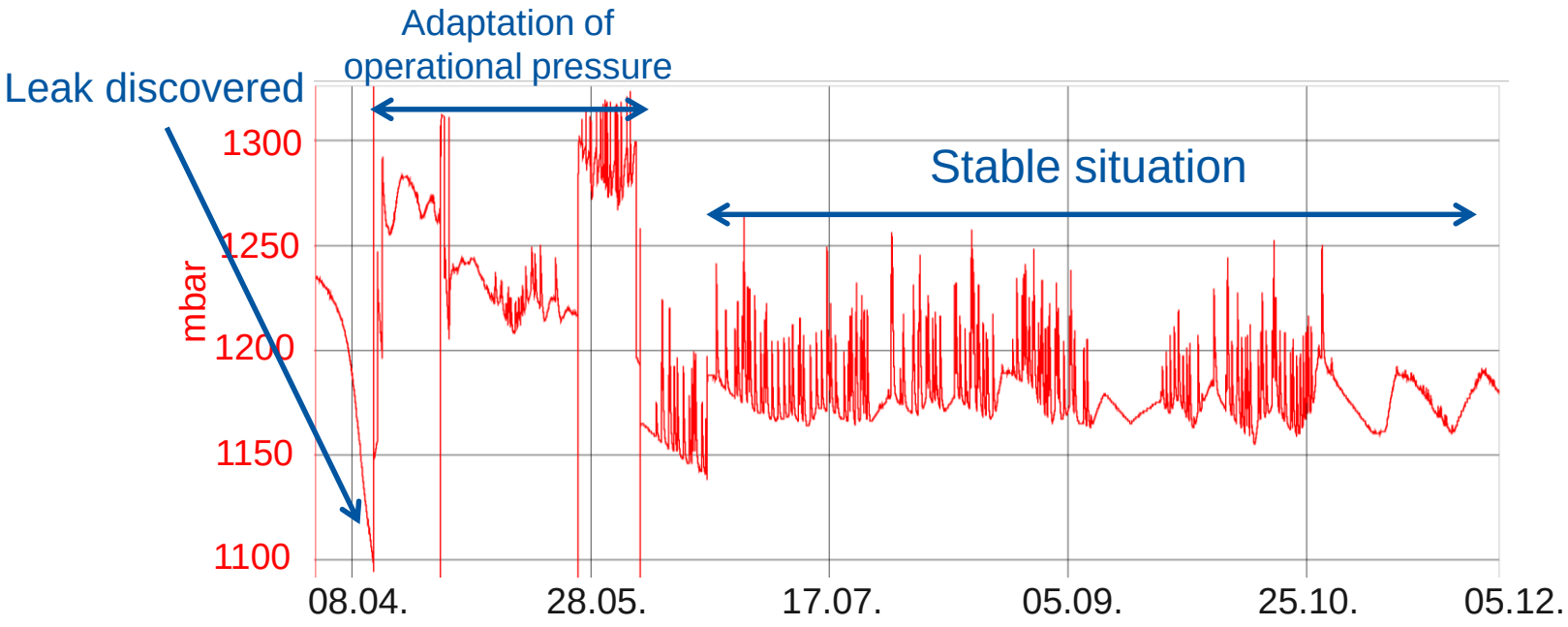
- Study options to **further automatize analysis** of loss maps and async. dump tests → how to **further involve OP?**
- **Study use** of **regular production fills and dumps** to **validate** correct settings of protection devices.
- **Un-mask interlock** of DOROS BPMs in TCTs and TCSP and implement (Java) automatic analysis.

Operation in degraded mode

- Two examples in 2016 of **systems operating not in nominal conditions** (e.g. TDE-B1 N_2 leak, suspected inter-turn short).
- Time consuming **repairs could be delayed** to foreseen longer stops (EYETS) after
  - Detailed risk analysis and tests.
  - Changing of operational parameters
  - Tightening of interlock levels
  - Implementation of additional interlocks as short/mid-term mitigations.
  - **Vigilant** supervision.
- Positive experience in 2016
- **Other cases** to be expected in **future**.

Operation in degraded mode: N_2 leak in TDE

- Implementation of additional **SIS interlock + BigSister warning** and **iterative adaptation** of operational pressure.
- MPP recommended the implementation of a **hardware interlock** for TDE pressure (see 134th MPP) → implementation **under study by TE-VSC**.
- **Repair of leak** by replacement of flanges during **EYETS.**



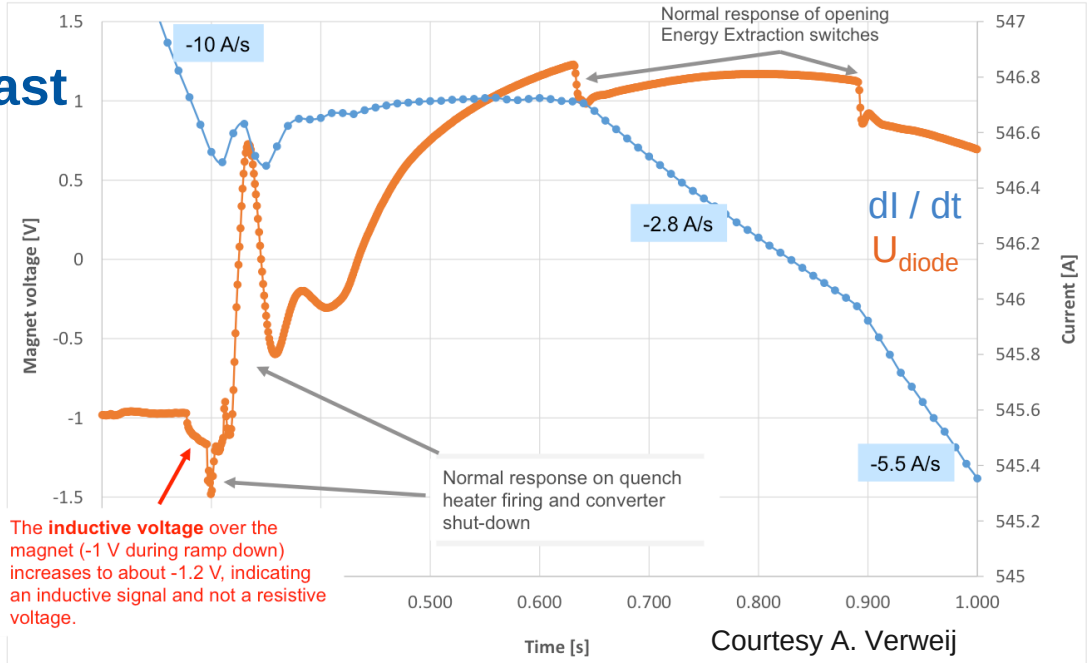
Operation in degraded mode: suspected inter-turn short

- Two **quenches** observed in **A31L2** with **unusual signature** → 547 A (10.06.), 295 A (03.08.)
- Could be explained by **(dis-)appearance of a inter-turn short** → risk of **magnet (and collateral) damage**.
- **Special detection equipment** for improved supervision of the magnet.

Reduce risk of quenches and fast power aborts in sector 12:

- Deactivation of Global Protection Mechanism.
- Reduction of BLM thresholds.
- Increase QPS threshold on MB.A31L2.

MB.A31L2 to be **replaced in EYETS**

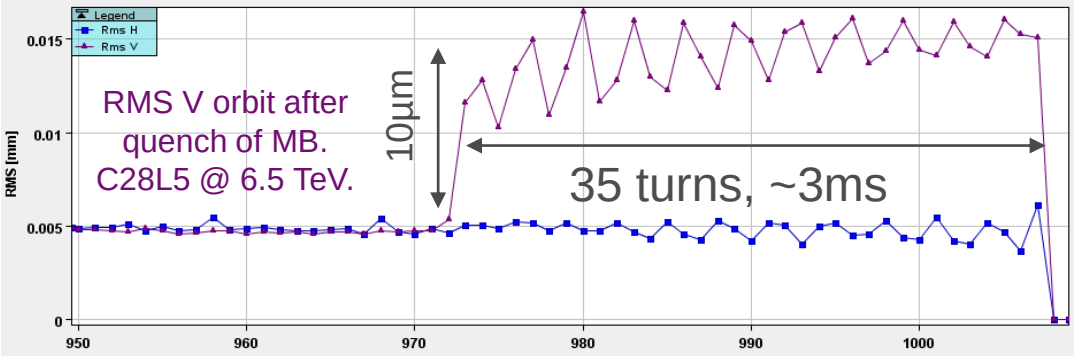


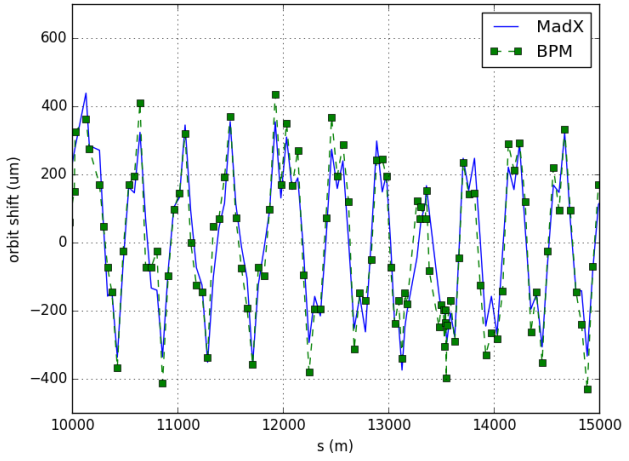
Courtesy A. Verweij

New fast failure: quench heater discharge

- Vertical **orbit kick** observed **after UFO quench** (MB.C28L5, 12.07.), due to **quench heater discharge**.
- Beam circulating still for **33 - 35 turns after** quench heater firing.
- Observation **verified in dedicated MD** @ 450 GeV.
- Non-negligible effect @ 450 GeV, but small @ 6.5 TeV → **important for HL-LHC**.

Kick in sigma	450 GeV (σ)	6.5 TeV (σ)
MB	0.41	0.11
3 x MB	**1.09**	**0.29**
D1 (IP 2&8)	0.23	0.05
D2 (IP 2&8)	0.45	0.11
Triplet (h/v)	0.25 / 0.23	0.013 / 0.015





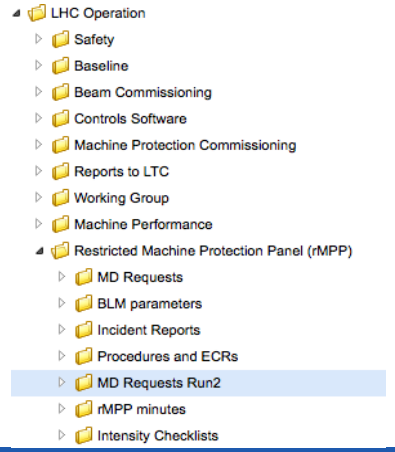
Orbit shift @ 450 GeV due to quench heater discharge in MB.C28L5

Courtesy M. Valette

Machine Developments – Strategy 2016

- Detailed procedure **submitted for all** MDs.
- **Classification of MDs** by machine protection experts + comments to requestor.
  - Class A: setup beam (< 5e11 @ 450 GeV, < 2e10 @ 6.5 TeV) with nominal protection settings. → ~6%
  - Class B: high intensity beam with nominal protection settings → ~68%
  - Class C: high intensity beam and changes to protection settings → ~26%
- **Detailed discussions** of Class C MDs in rMPP, **approval in EDMS**.

MD		Classificaton	Comment	Comment	Comment	Comment	
MD232	Long impedance	B	No changes to machine except blow up and long. emittance. Classical B. I wonder if the SPS will be able to prepare the beams - but that is not MPP	Longitudinal impedance measurement with up to 20b in total. Preparation of bunch in SPS to 0.5-2.5E11 and LHC inj , might be difficult with current dump issue. Change of ADT settings	Some high intensity bunches up to 2.5e11 ppb. See if they can make it. As protection is not touched the collimation and BLMs will protect us. B.	Bunch intensities from 0.5-2.5e11p (might be difficult in the current state of the SPS). "setup of ADT for high intensity bunches required --> to be reverted after MD! Longitudinal excitation of beam by sinusoidal RF phase modulation --> turn on abort gap cleaning during MD and check BSRA before the dump, to avoid accumulation of too many particles in abort gap and a quench of magnets during the dump. Class B.	Switch on abort gap cleaning all the time and inject far away from abort gap.
MD1230	Linear coupling stability	B	Usual instability MD, but intensity limited to a single bunch. Not much to say, B.	Single bunch and pilot, tune modification and stabilisation with Octupoles. Risk of losses and dump. Class B.	One nominal, one pilot. Move tunes and octupoles. B.	Pilote and nominal bunches. There is a risk of beam losses due to instabilities, which could cause a protection dump. Class B.	
MD1242	Injection and emittance	B	At injection and no changes to the machine. Class B. I see a potential issue with beam preparation in the SPS for the BCM beam (sparing the dump...?).	Tbc with STI whether 48b BCMS can be prepared in the SPS with current dump limits (setup time and dump). The document is missing the overview table for beam parameters and eventual MPS changes (to be added). Class B.	Injection of trains of BCMS, max 48 BCMS bunches at a time. B.	Procedure comparable to usual injection setup, just with higher brightness beams. Ensure the availability of Diamond data (LHC IP2/8, SPS), which will give additional information of the source of losses. Class B.	Check with Simone that SPS no problem with 48 BCMS considering the TIDVG. Check TIDVG vs. beam preparation.... The document is missing the overview table for beam parameters and eventual MPS changes (to be added).
							Put procedure in edms on Stephane's request. Need more details on coarse collimation settings. The document is



More details on MDs see J. Uythoven's talk

Machine Developments – Experience and Proposals

- 2016 approach **worked well**!
- **Vigilance required** from all involved players.
- **Density and re-scheduling** of MD blocks **challenging** for MD teams and rMPP validation.
- Communication with EIC in advance of MD generally good → **Earlier involvement** of **EIC link** person would be beneficial.
- **General approval** of MD procedures **in EDMS**? → would allow versioning, referencing etc.
- Several ***adhoc* EOF MDs** in last week(s) of proton run → **ALL MDs** should go via **MD coordination → rMPP → OP**. Only like this proper check by machine protection can be ensured.

Changes to core of a Machine Protection System

- Machine Protection Panel (MPP) **comprises experts** from all different MP systems, allowing an **independent view**.
- → Any **changes to the core** of a Machine Protection System should be **discussed in and approved** by MPP

Example from Ion run:

- **Amplifiers added** on interlocked **BPMS (IR6)** to increase dynamic range in **anticipation** of limitations (→ originally foreseen only in case of dumps due to BPMS).
- In discussions with machine protection it was discovered that this **reduced the overall system reliability** level → removal at change of beam directions.

→ **First evaluate** consequences **then implement.**

→ **MPP to be** (more) **proactive** in these situations**.**

Conclusion

- **Intensity ramp-up**: only 15 days to reach >1700b.
- Two **standard ramp-up scenarios** after stops have proven to be efficient.
- Based on 2016 experience: **review** loss map / async beam dump **validation scenarios**.
- **MD procedure** approach **worked well → ALL EoF and parallel MDs** should be covered.
- Requests to operate with systems in **degraded modes to be expected** also in future → case-by-case analysis required.
- Any **changes in core** machine protection systems should be **approved** by MPP.

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