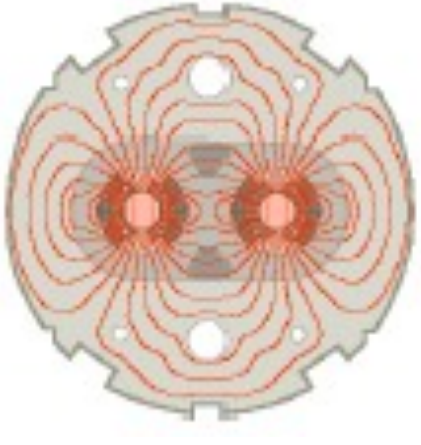
A & T Seminar: Machine Protection Workshop Summary
June 13th, 2013
CERN, Geneva, Switzerland

MP workshop: Summary of S4: Collimators and Movable Devices and S6: Operation after LS1

Stefano Redaelli and Jörg Wenninger, CERN-BE

Many thanks to the scientific secretaries,
V. Chetvertkova (S4) and M. Albert (S6),
and to the chairmen of the other sessions.



List of talks and speakers

Presentation title	Speaker
Session 4: LHC Collimators and Movable Devices	
Movable Devices	S. Redaelli
Settings Generation, Management and Verification	G. Valentino
Beam-based validation of settings	B. Salvachua
Collimator Hierarchy Limits	R. Bruce
Updated Robustness Limits for Collimator Materials	A. Bertarelli
Session 6: LHC Operation after LS1	
Post LS1 operation	G. Arduini
Update on beam failure scenarios	J. Uythoven
Post LS1 operational envelope and MPS implications	M Solfaroli
Software tools for MPS	K. Fuchsberger
Interlocking strategy versus Availability	L. Ponce

S4: Collimator and movable devices

- LHC Moveable Devices (S. Redaelli)
- Settings generation, management and verification (G. Valentino)
- Beam-based validation of settings (B. Salvachua)
- Updated robustness limits for collimator materials (A. Bertarelli)
- Collimator hierarchy limits: assumptions and impact on machine protection and performance (R. Bruce)

Synergy with various talks on dump and injection topics

Many thanks to speakers and V. Chetvertkova!

LHC movable devices

About **500 movable devices** are installed in the LHC that could touch the beams!

This includes: collimators, beam instrumentation, vacuum valves, safety systems, experiment detectors...

Classify in two categories: operational (settings) and non-OP (in/out) devices.

Clearly, each requires a proper **interlock strategy** for the operation with unsafe intensity!

Table 2: Inventory of Objects in the LHC and Transfer Lines

Name	Description	N°.	Position	Type	Comment
TED	Stopper	4	TI8/TI2	IN/OUT	Needs extraction interlock while moving
TBSE	Safety Stopper	1	TI8	IN/OUT	Needs extraction interlock while moving
BTV	Screens	18	TI8/TI2	IN/OUT	Limitation on extraction intensity with Al screen. Needs extraction interlock while moving
VV	TL Vacuum Valves	14	TI8/TI2	IN/OUT	
TCDI	TL Collimators	14	TI8/TI2	Mobile	
VV	Ring Vacuum Valves	249		IN/OUT	Veto activation with circulating beam
VVX	Fast Valves	2	IR8	IN/OUT	Very fast acting
VVX	Passive Valves	2	IR2	IN/OUT	Mechanical action only. Remote Status available
BTV	Injection & Matching Screens	13	IR2/IR8/ IR3/IR4	IN/OUT	Veto movement with circulating beam Limit on the number of turns vs. injected intensity
BWS	Wire Scanners	4	IR4	IN/OUT	Limits on intensity vs. energy
	RF Electron Stoppers	4	IR4	IN/OUT	Linked to LHC Access Safety System
	Safety Stoppers	2	IR6	IN/OUT	Linked to LHC Access Safety System
BEUV	Alignment Mirrors	2	IR4	IN/OUT	
VV	Dump line Vacuum Valves	4	IR6	IN/OUT	Dump Circulating beam on activation
BTV	Dump Line Screens	6	IR6	IN/OUT	Veto movement with intensity above a threshold Veto acceleration with screens in above threshold
TCP	Primary Collimators	8	IR3/IR7	Mobile	
TCSG	Secondary Collimators	30	IR3/IR7	Mobile	
TCT	Tertiary Collimators	16	IR1/IR5/IR2	Mobile	
TCLP	Absorbers	8	IR1/IR5	Mobile	Absorbers for Physics regions
TCLA	Absorbers	16	IR3/IR7	Mobile	Cleaning region absorbers
TCSP	Scrapers	6	IR3/IR7	Mobile	For special use.
TCDQ	Protection Elements	2	IR6	Mobile	Protect cold aperture from bad dump.
TCS	Protection Elements	2	IR6	Mobile	As above
TDI	Injection Protection	2	IR2/IR8	Mobile	
TCLI	Injection Protection	4	IR2/IR8	Mobile	
XRP	Totem Roman Pots	24	IR5	Mobile	Set at 10s in during stable data taking
XRP	Atlas Roman Pots	8	IR1	Mobile	
VELO	LHCb Vertex Locator	1	IR8	Mobile	At around 5mm from beam axis during data taking
ZDC	Alice Detectors	2	IR2	Mobile	Outside the beam vacuum.
BBLR	Beam-Beam Compensator	8	IR1/IR5	Mobile	Not baseline
	Total	**476**			

LHC Project Workshop - 'Chamonix XIV'

OBJECTS CAPABLE OF TOUCHING THE BEAMS

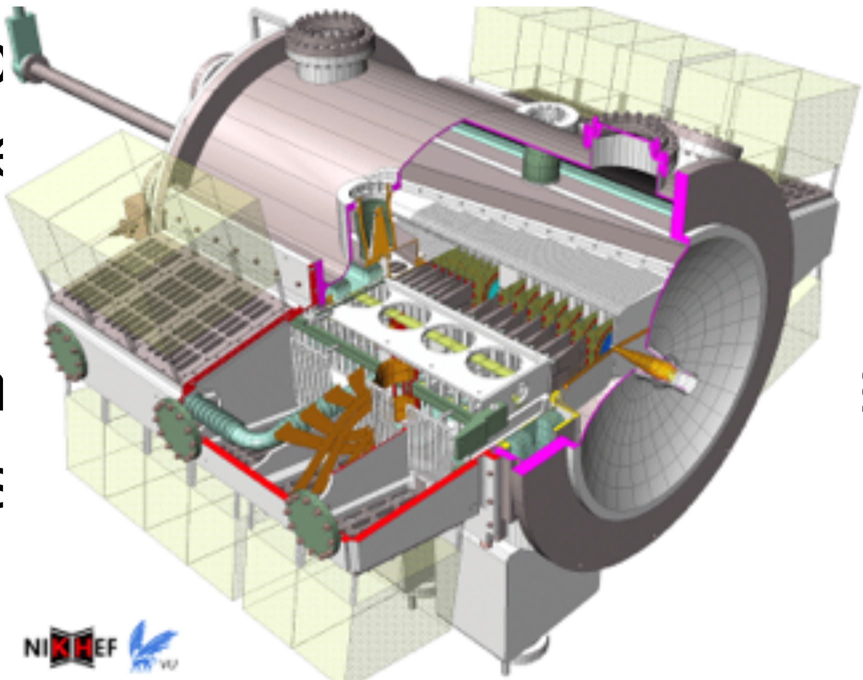
P. Collier, CERN, Geneva, Switzerland

See also my talk at the 2010 MP external review.

S. Redaelli

LHC movable devices

LHCb VELO



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experiment detectors...

Motorized triplet foot

Classify in two categories:
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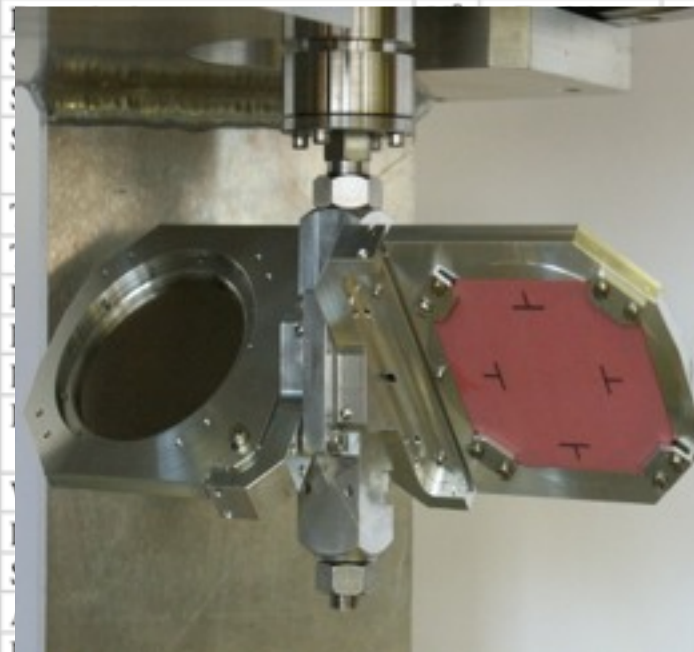
Table 2: Inventory of Objects in the LH...



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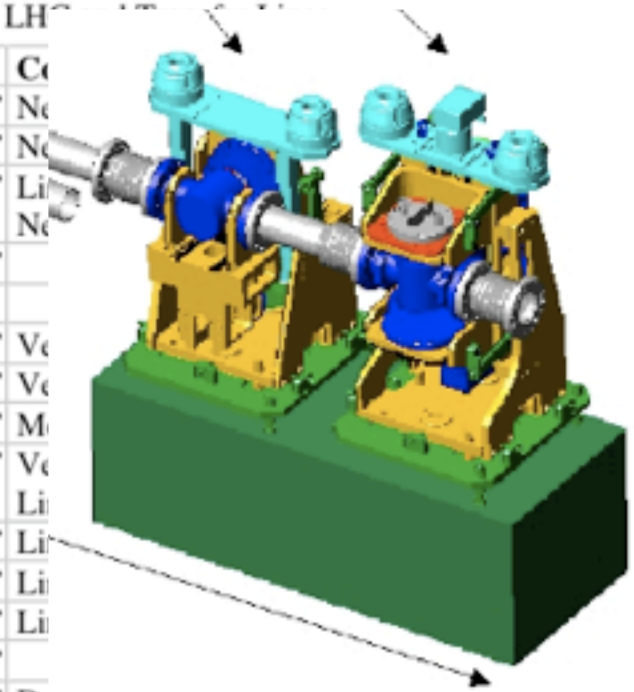

Name				Type	C
TED				/OUT	N
TBSE				/OUT	N
BTV				/OUT	Li N
VV				/OUT	
TCDI				obile	
VV				/OUT	V
VVX				/OUT	V
VVX				/OUT	M
BTV				/OUT	V Li
BWS				/OUT	Li
				/OUT	Li
				/OUT	Li
BEUV				/OUT	
VV	Dump line vacuum valves			IN/OUT	D
BTV	Dump Line Screens	6	IR6	IN/OUT	Veto movement with intensity above a threshold
T				M	
T				M	
T				M	
T				M	
T				M	
T				M	
T				M	
T				M	
T				M	
T				M	
X				M	
X				M	
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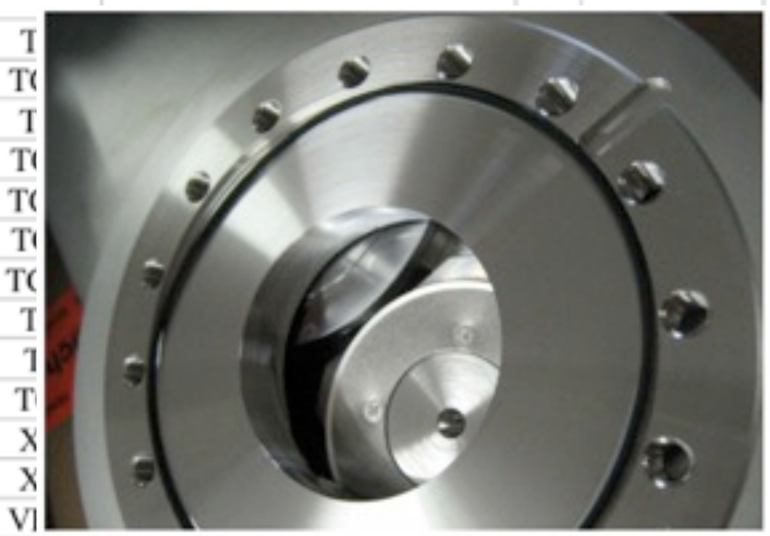

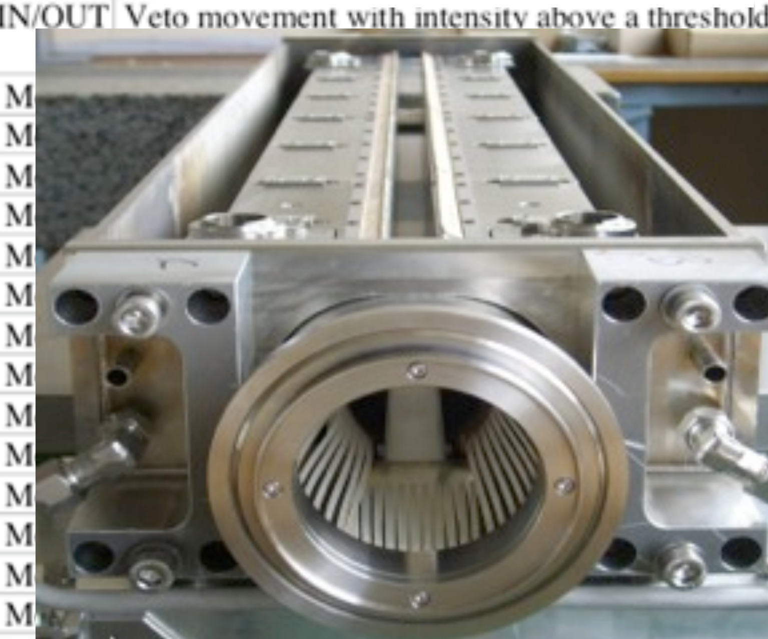

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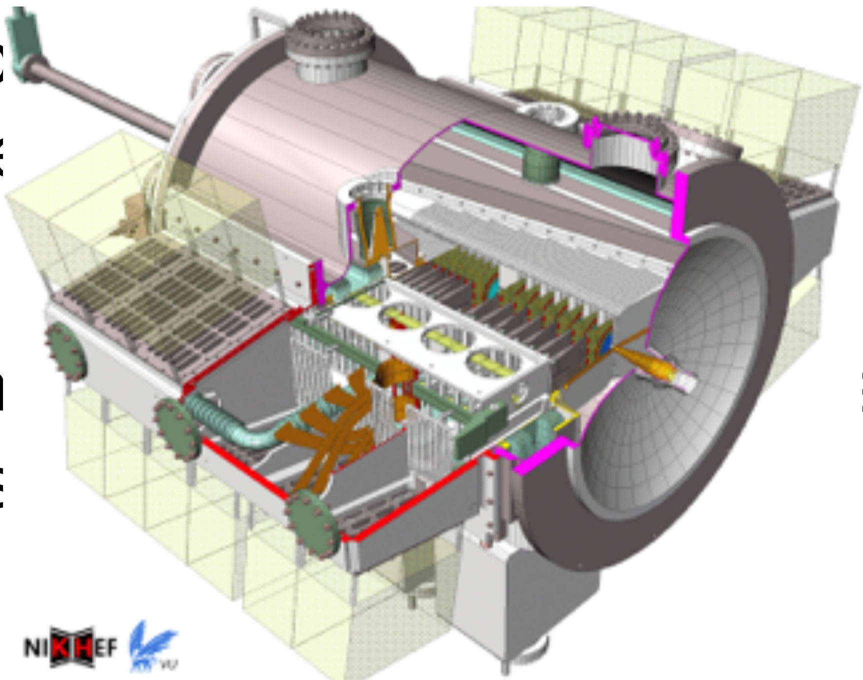

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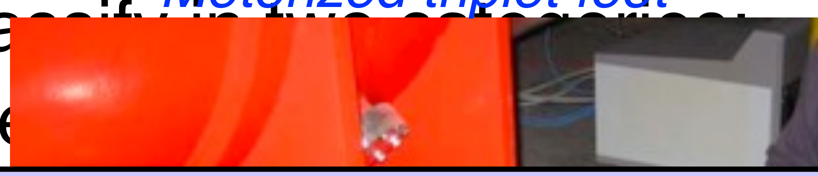
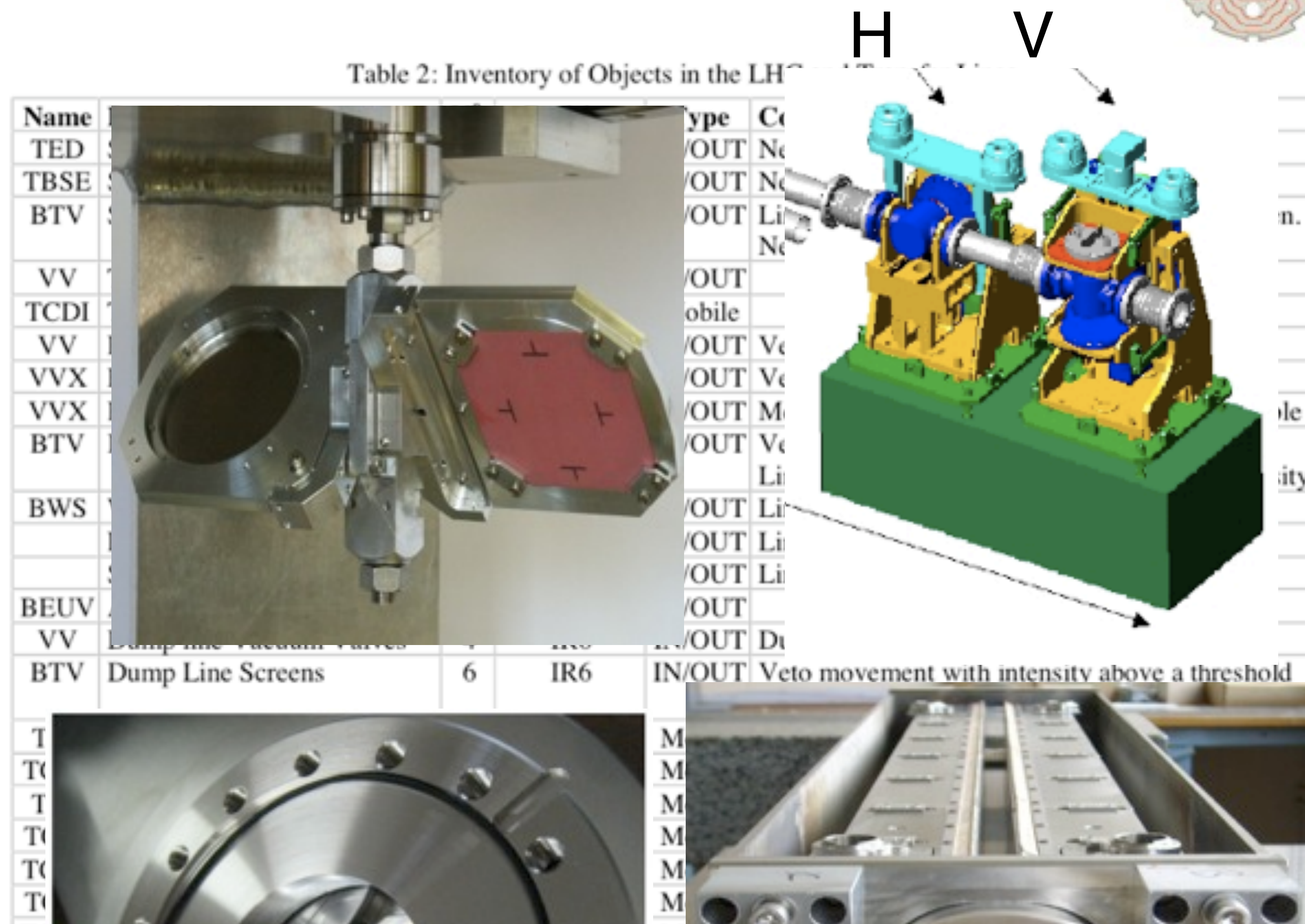
Th… …am ins… va… experiment detectors…

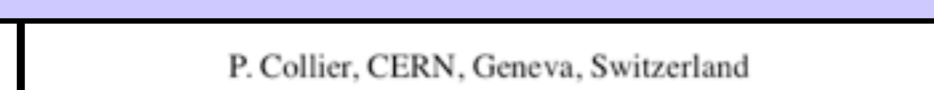
Motorized triplet foot



Classify in two categories: ope… …on-



- One outstanding issue: **fast vacuum valves in IR4**
  MPP followup: **decided** not to have them in the LHC *(M. Zerlauth, LMC 22/05/2013)*
- Interlocking of other movable devices considered **adequate**.
- Watch out for LHCb-VELO aperture upgrade in LS2! So far, outside of OP control.
- Identified some **weaknesses** of the **controls/procedures** for critical settings handling.
- Important change for collimators: **18 new collimators with integrated BPMs**!

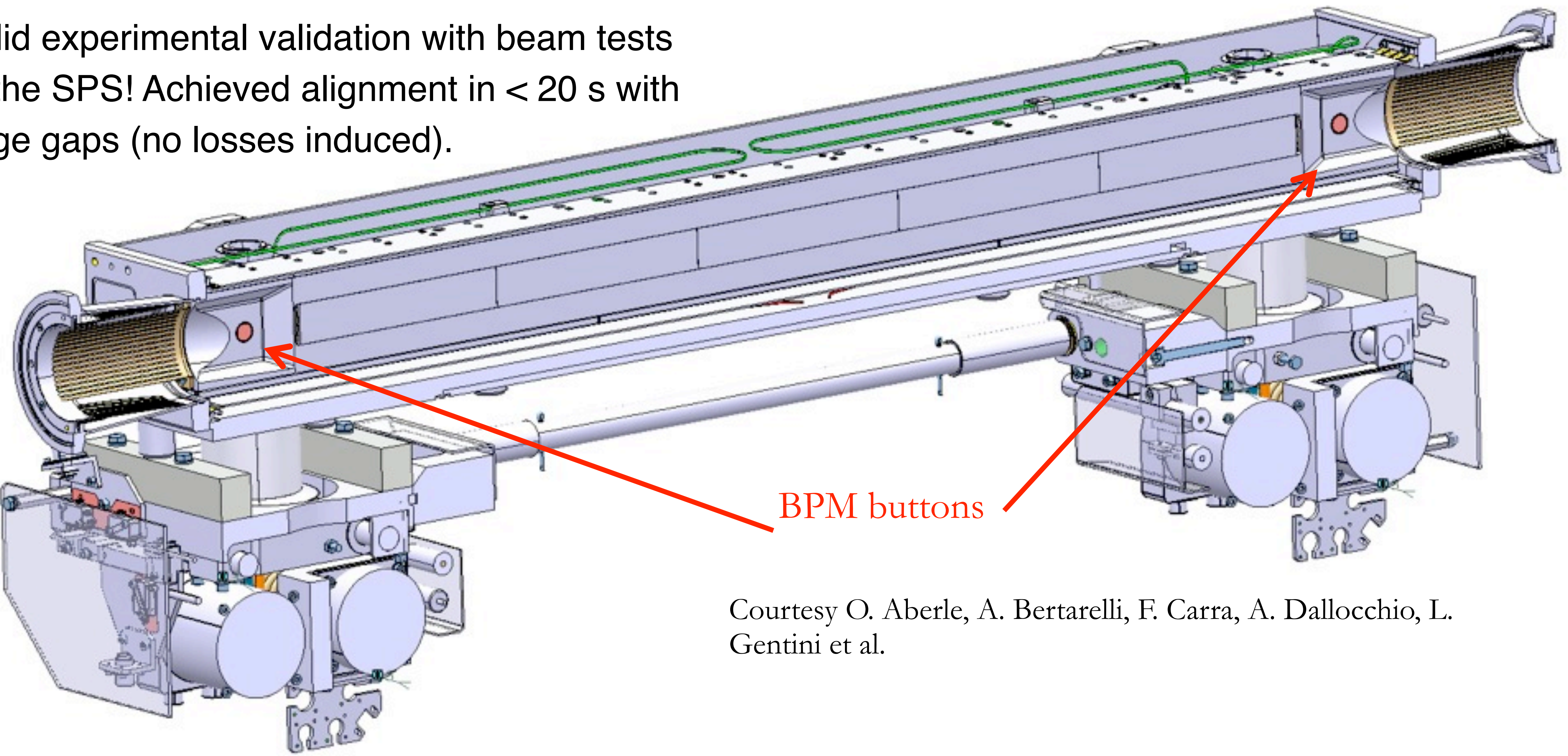


external review.

S. Redaelli

BPM embedded collimators

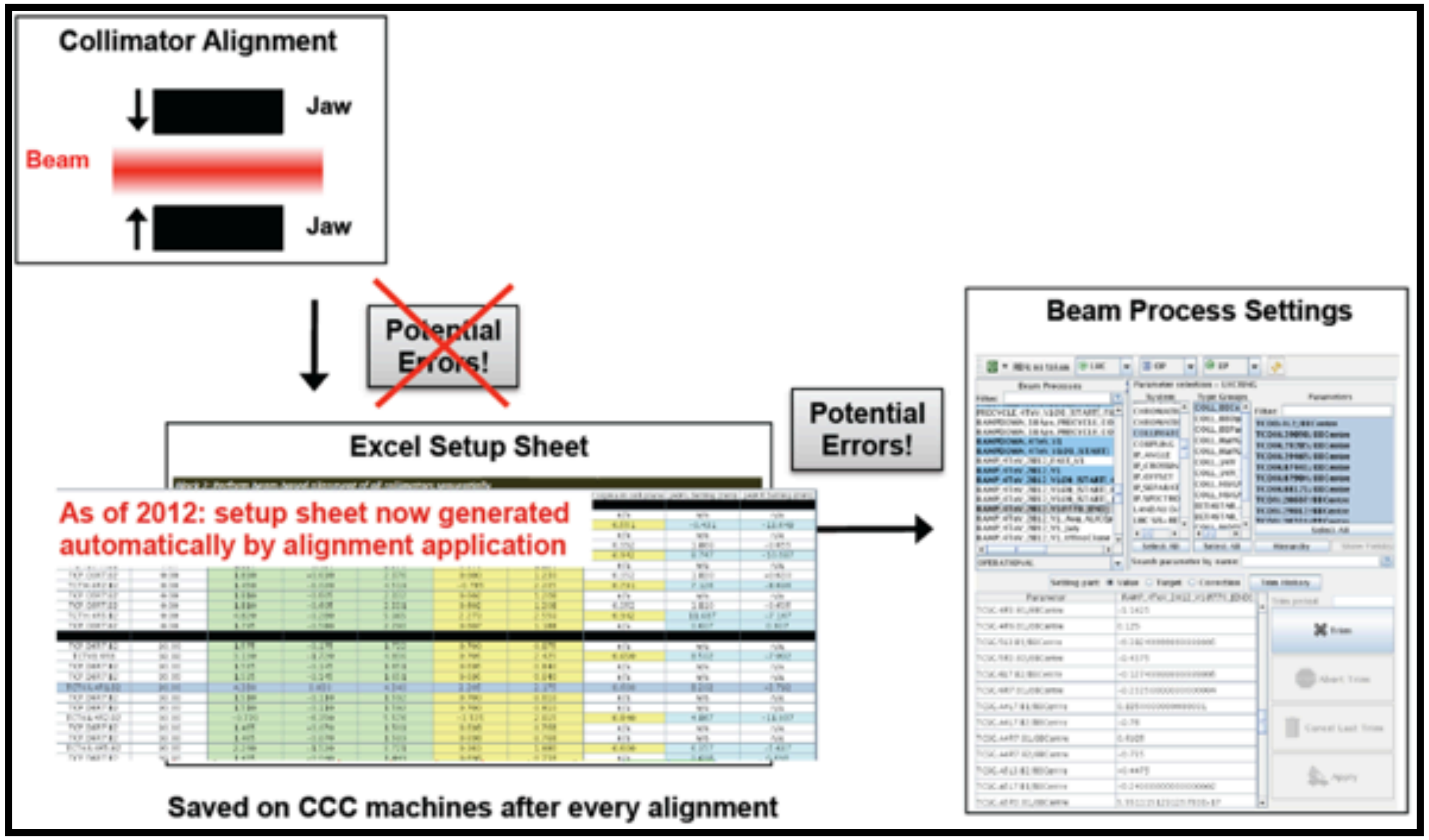
- **16 Tungsten TCTs** in all IRs and the **2 Carbon TCSGs in IR6** will be replaced by new collimators with **integrated BPMs**.
  - **Gain**: can align the collimator jaw without "touching" the beam ➙ no dedicated low-intensity fills.
  - ➙ *Drastically reduced setup time => more flexibility in IR configurations*
  - ➙ *Reduced orbit margins in cleaning hierarchy => more room to squeeze β*: ≥ ~**30 cm (R. Bruce)***
  - ➙ *Improved monitoring of local orbit and interlocking strategy*
- Solid experimental validation with beam tests at the SPS! Achieved alignment in < 20 s with large gaps (no losses induced).



Courtesy O. Aberle, A. Bertarelli, F. Carra, A. Dallocchio, L. Gentini et al.

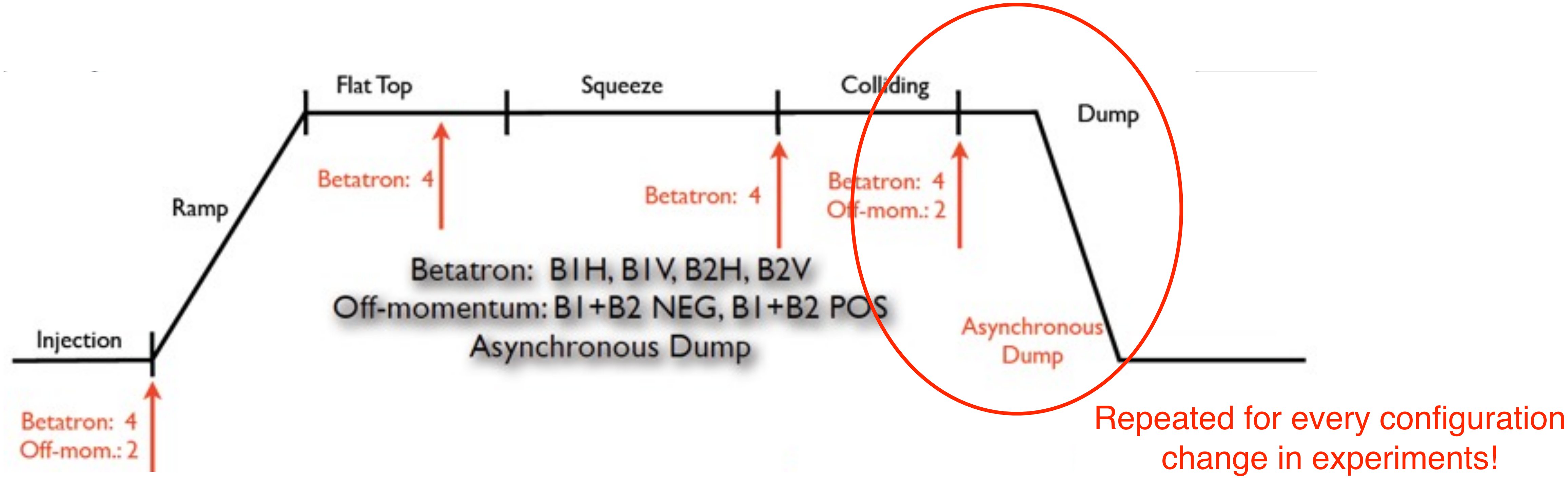
Collimator settings

1. Very few cases with **settings problems**... but potential impact critical!
   - *CHECK, CHECK, CHECK!!!*
2. New **software** for setting checks seems **adequate** to address problems encountered.
   - *Will be developed further to reduce* ***manual interventions, add redundant checks***
3. Great potential from BPM collimator design, but only useful for TCTs + IR6.
4. Proposal of a **new redundant limit for TCT's** under discussion (limits versus IP sep)
5. **Online model** and **aperture meter** should be pursued further (OP+ABP)!
6. Very active discussion about **operational displays**. Adequate for expert usage but could be improved for shift crew operation.
   - *Action on OP side to come up with a proposal of display improvements*



G. Valentino

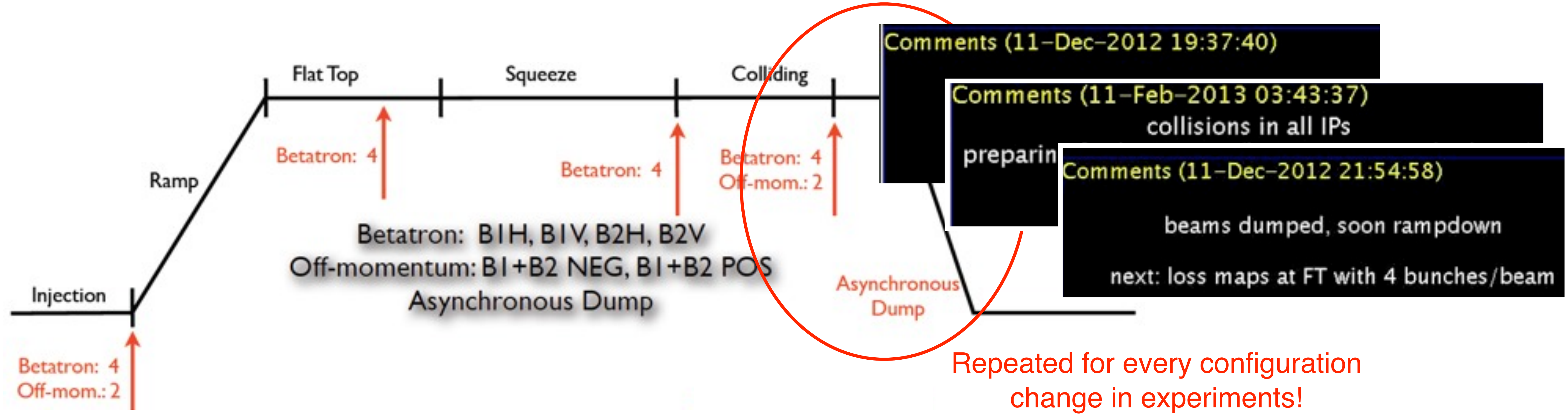
Collimation validation with loss maps



1. About 20 new configurations setup in 2012-13 that required validation!
2. Great improvement for **betatron loss maps (LM's)**, thanks to the ADT excitation.
   - *Very efficient commissioning / collimator alignment / verification in single fills*
   - *Excitation of individual 25 ns bunches → can we do loss maps with full intensity?*
3. No obvious way to speed up **off-momentum LM's** and **asynch dumps** validation!
   - *Some proposals were presented for the off-momentum LM's*
4. Can online monitoring to speed up validation without dedicated LM's? No...
   - *Were we really limited by loss maps?*
5. Clearly, we will need loss maps again after LS1!

B. Salvachua

Collimation validation with loss maps



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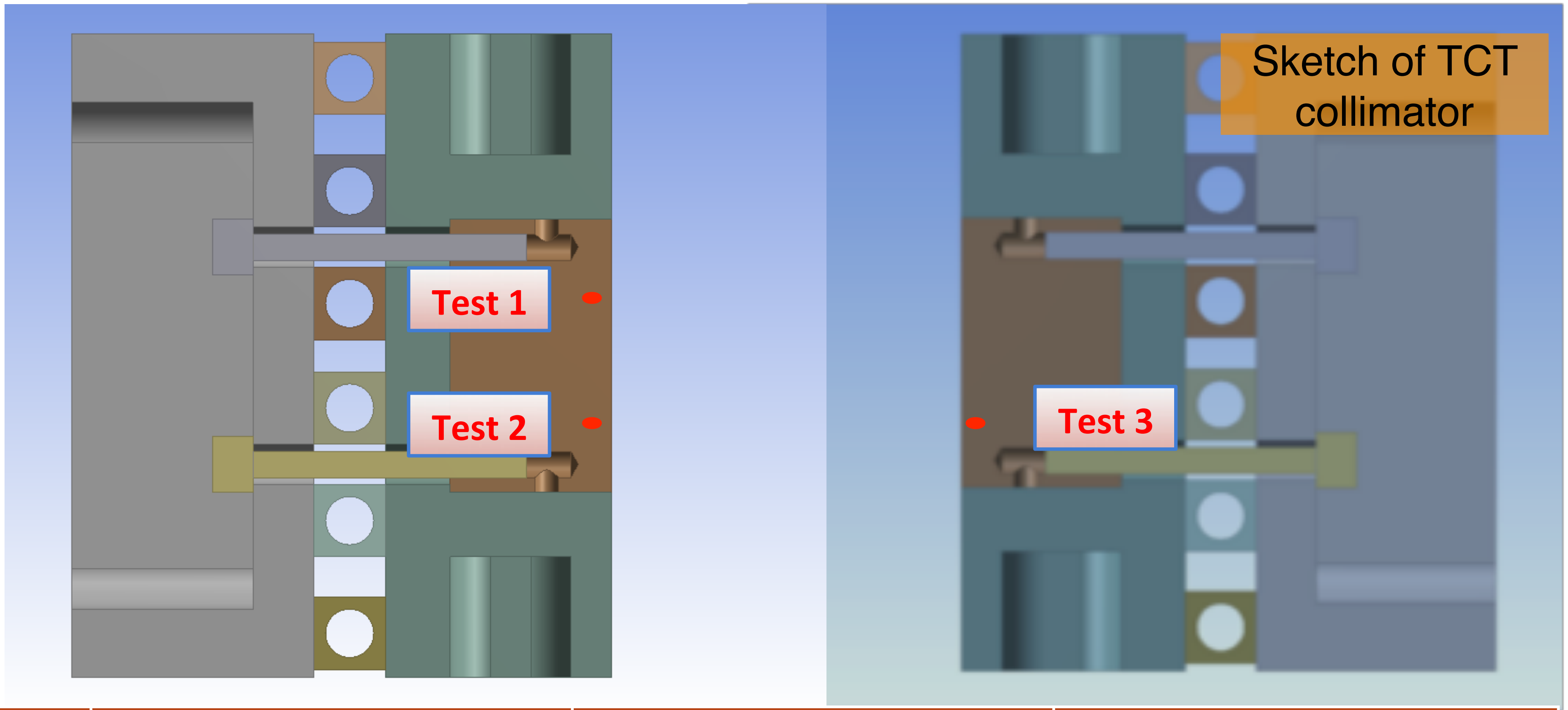
B. Salvachua

Collimator material tests at HRM (1)

- Beam energy: **440 GeV**
- Impact depth: **2mm**
- Jaws half-gap: **14 mm**

A. Bertarelli, *et al*



	Test 1	Test 2	Test 3
Goal	**Beam impact equivalent to 1 LHC bunch @ 7TeV**	**Identify onset of plastic damage**	**Induce severe damage on the collimator jaw**
Impact location	Left jaw, up (+10 mm)	Left jaw, down (-8.3 mm)	Right jaw, down (-8.3 mm)
Pulse intensity [p]	3.36×10^{12}	1.04×10^{12}	9.34×10^{12}
Number of bunches	24	6	72
Bunch spacing [ns]	50	50	50
Beam size [σ_x - σ_y mm]	0.53 x 0.36	0.53 x 0.36	0.53 x 0.36

Address by beam tests the robustness of the TCT (critical for β^* reach).
Complementary dedicated material tests to find "ideal" collimator materials.

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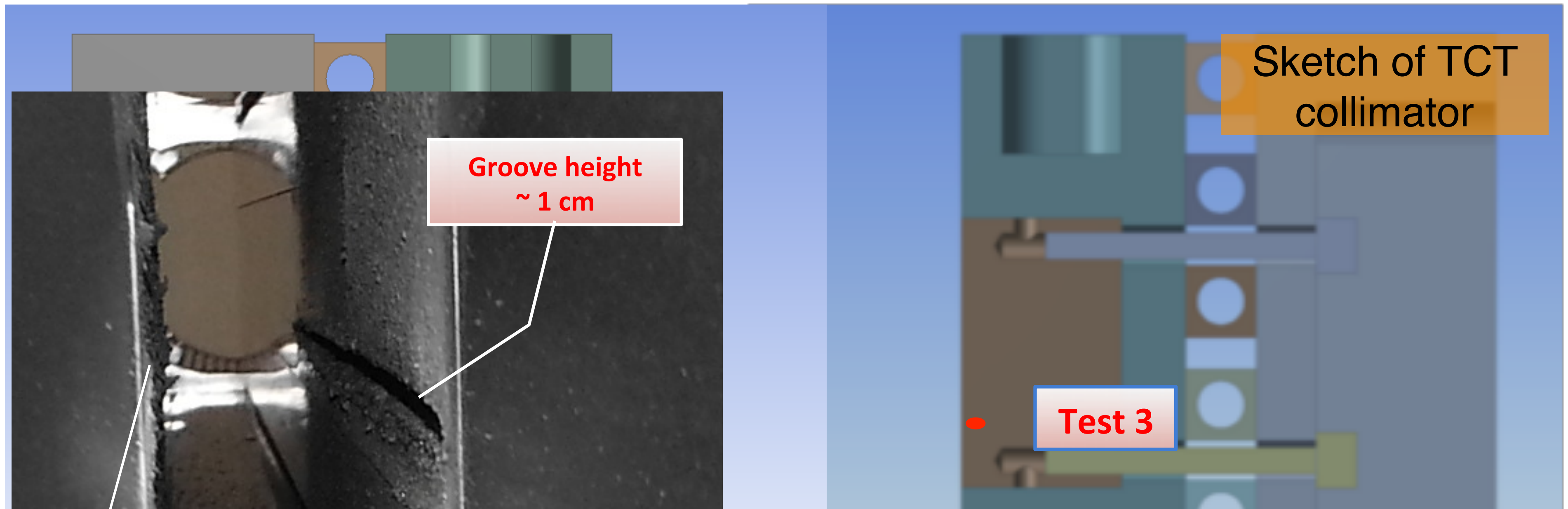

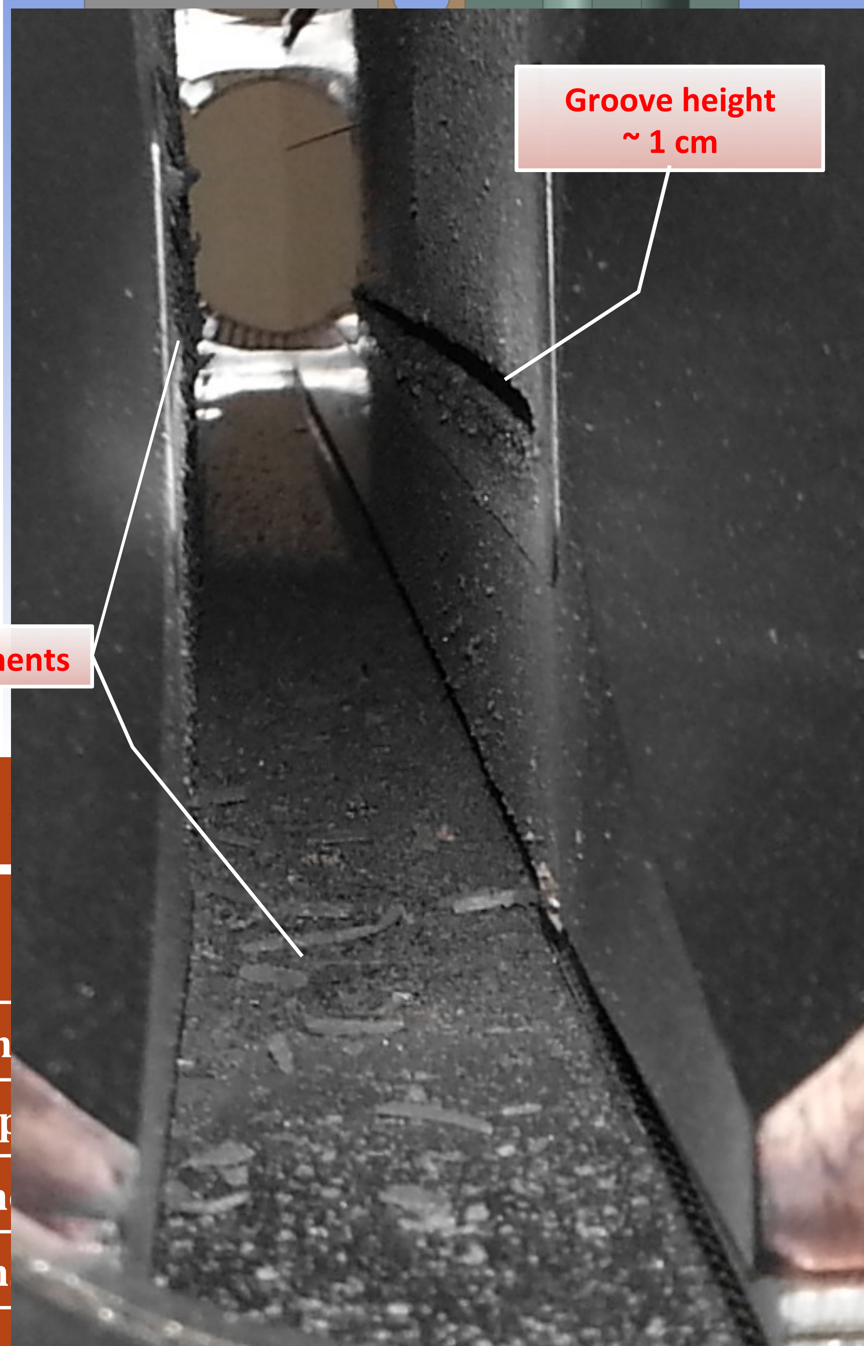

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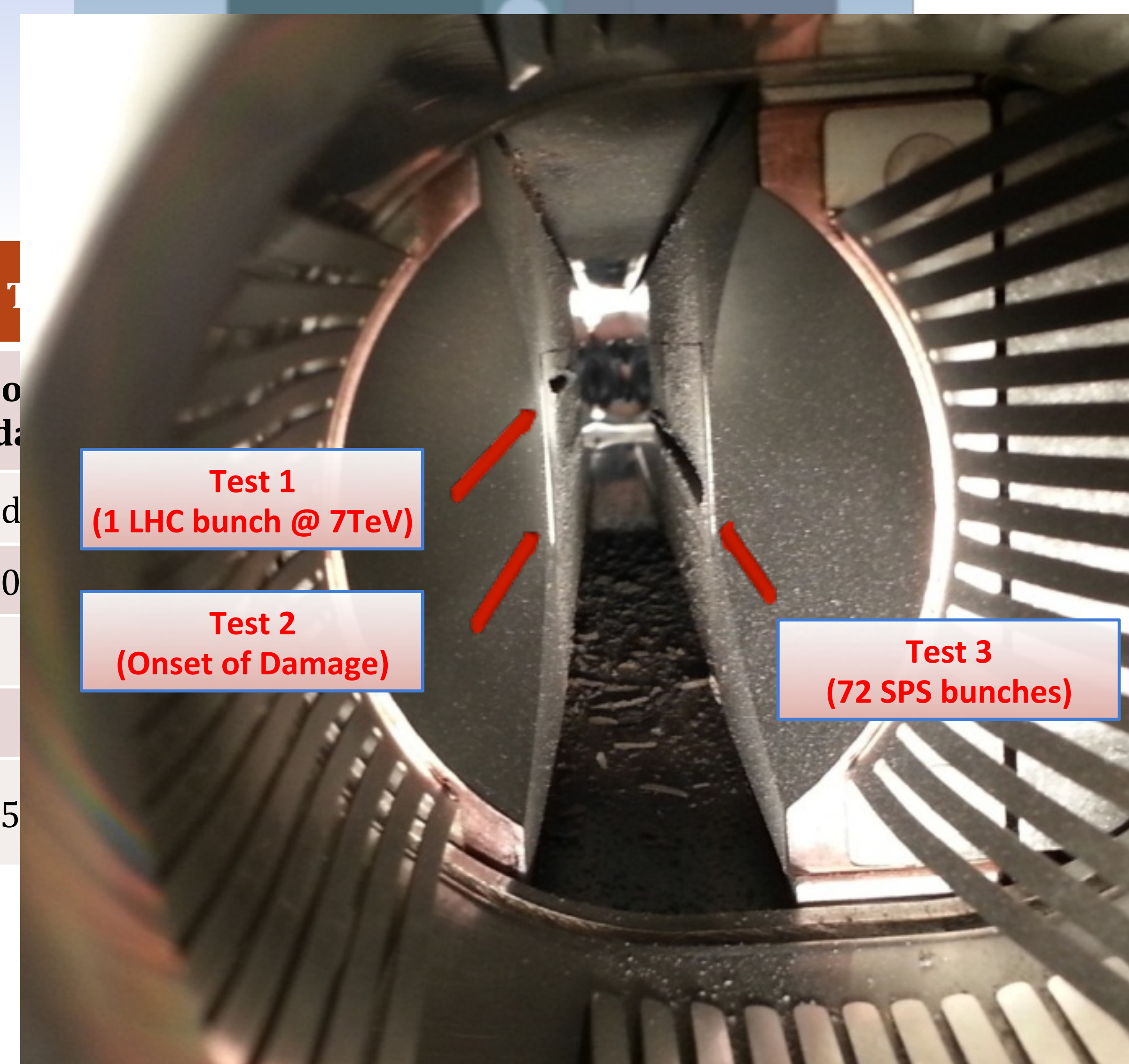
Goal		ify o da
Impact location		w, d
Pulse intensity [p		1.0
Number of bunch		
Bunch spacing [n		
Beam size [σ_x - σ_y mm]	0.53 x 0.36	12	0.5



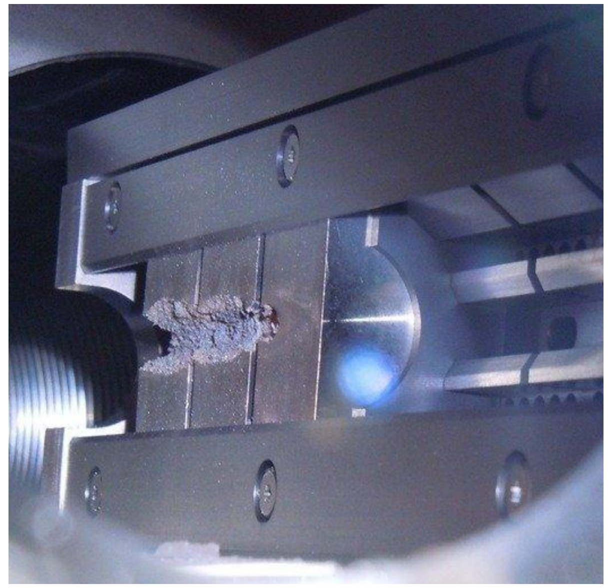
Address by beam tests the robustness of the TCT (critical for β* reach). Complementary dedicated material tests to find "ideal" collimator materials.

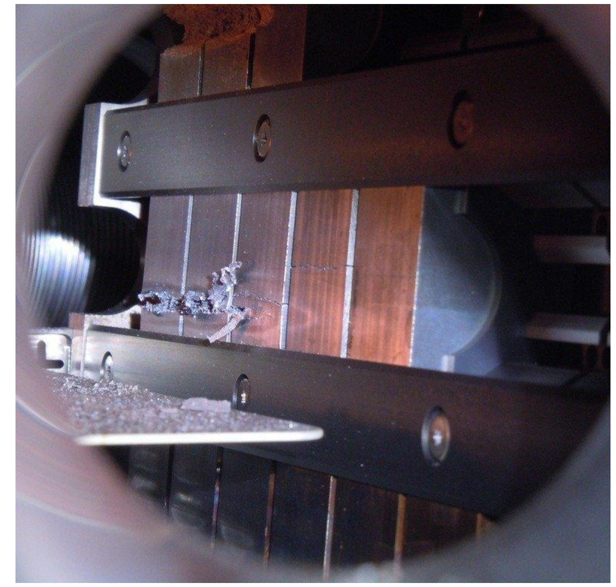
Collimator material tests at HRM (2)

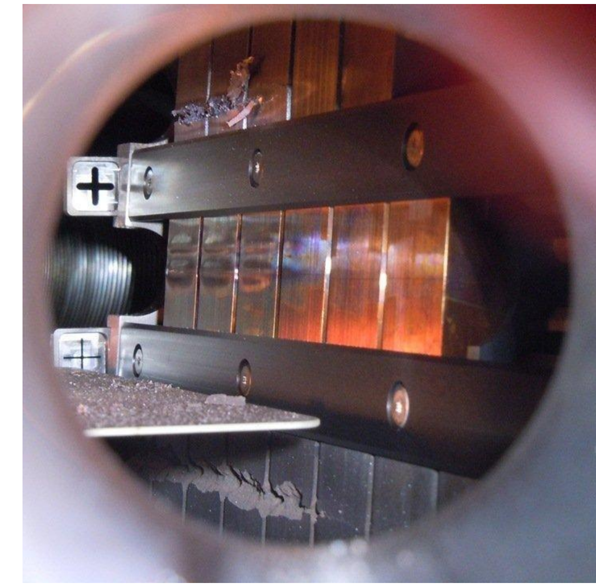
Challenge for the collimator commissioning at 7 TeV that required a few nominal bunches for collision and orbit setup! Need follow up!

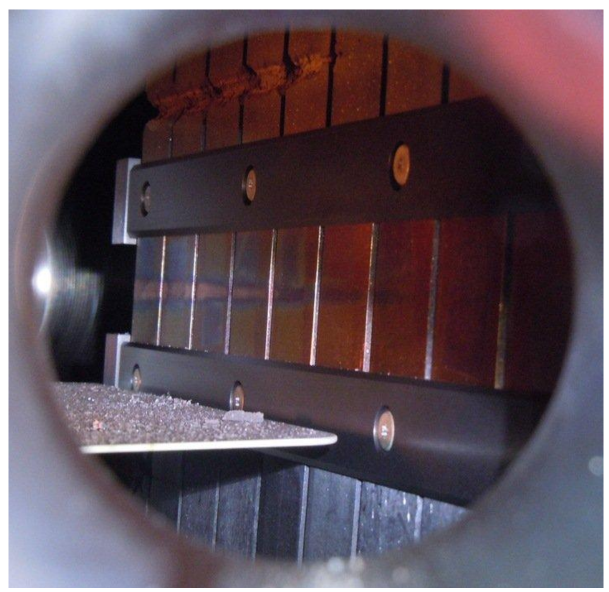
Studied alternative materials for future collimator jaws!

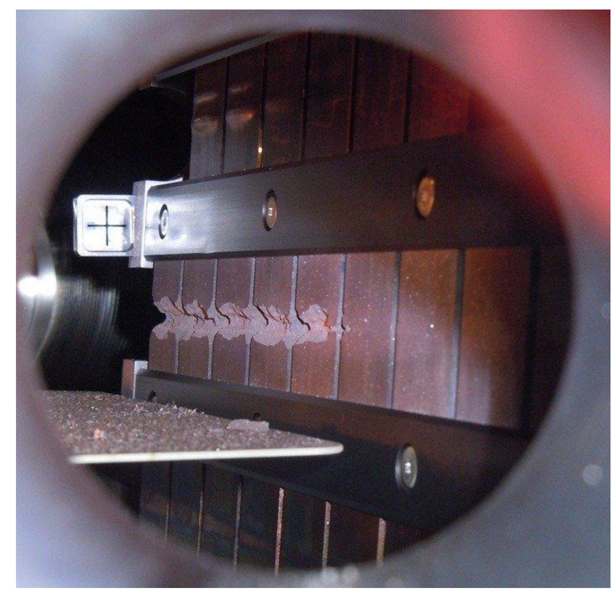
A. Bertarelli, *et al*

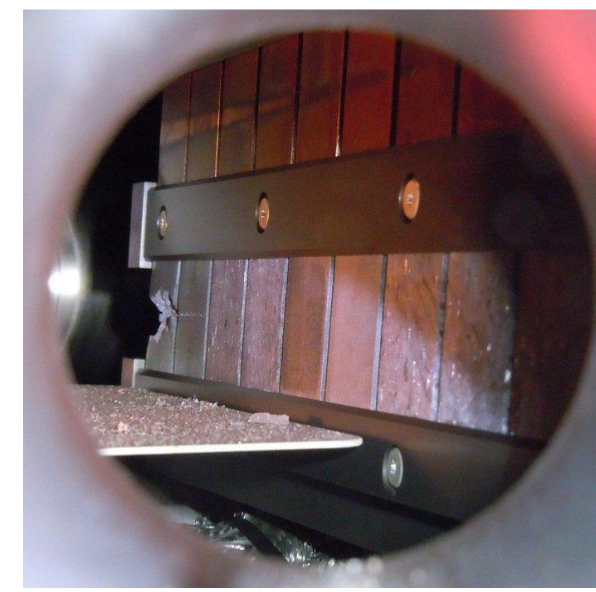

Inermet 180, 72 bunches


Molybdenum, 72 & 144 bunches


Glidcop, 72 bunches (2 x)

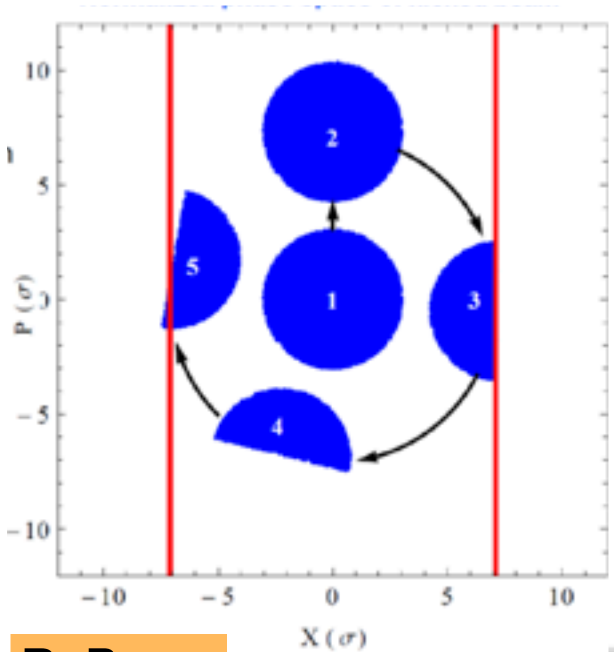

Copper-Diamond 144 bunches


Molybdenum-Copper-Diamond 144 bunches

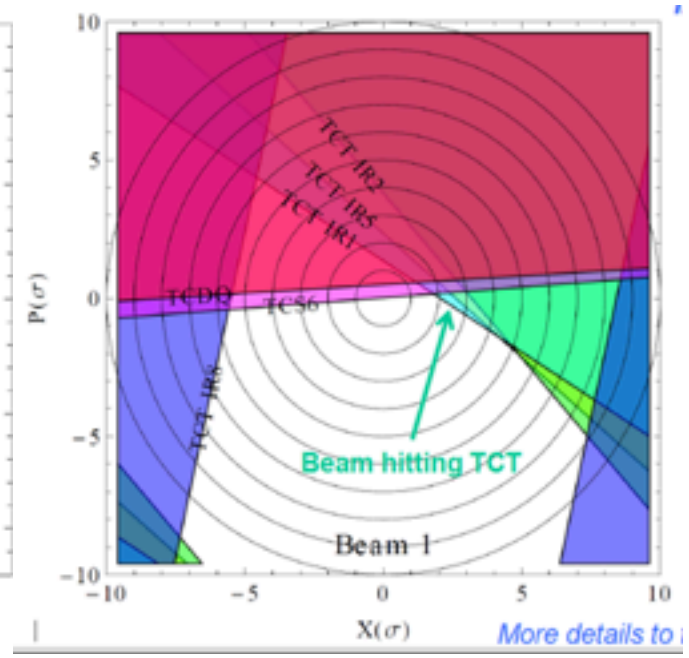

Molybdenum-Graphite (3 grades) 144 bunches

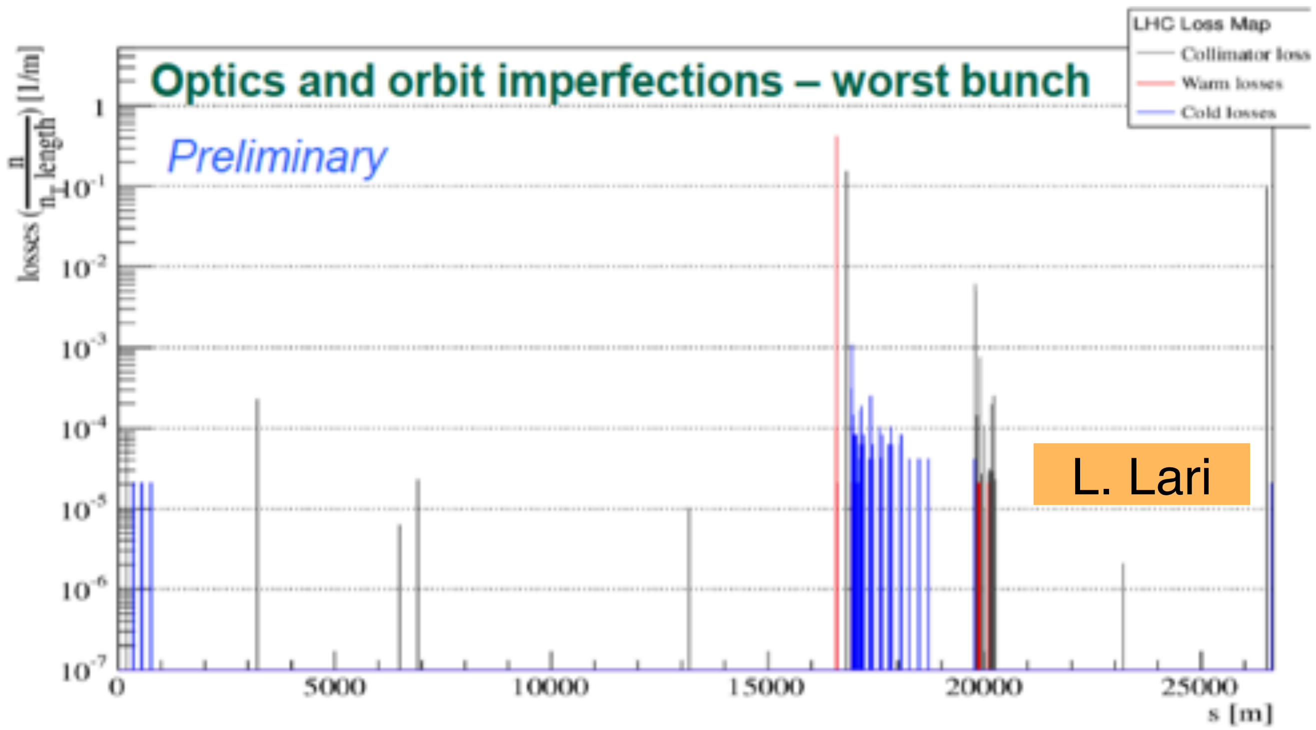
- New damage limits proposed in line with updated accident scenarios (Annecy '13):
  - **Onset of plastic damage : 5×10^{9} p**
  - **Limit for fragment ejection: 2×10^{10} p**
  - **Limit of for 5^{th} axis compensation (with fragment ejection): 1×10^{11} p**

Assumptions for failure modes



R. Bruce





L. Lari

1. Reviewed collimator hierarchy limits and impact on β^*: can achieve **30cm <β^*< 60cm**!
2. Can we **revise** the **failure assumptions** to achieve more realistic failure models?
   - *Done already for 2012 operation (sum of orbit errors: linear vs sum in quadrature)*
3. What can be improved?
   - *Repeat study for post-LS1 cases at 25ns. Optimize phase advances?*
4. Actions from collimation project side: consider **building collimators** based on new materials to replace more exposed TCTs and TCSG's contributing more to impedance
5. Started a **collimator material working group** to establish an executive summary of HRM tests and rank the tested materials. *Chaired by A. Dallocchio. Kick-off meeting in May.*

S6: LHC operation after LS1
(J. Wenninger, M. Albert)

- ☑ Post LS1 operation (G. Arduini)
- ☑ Update on beam failure scenarios (J. Uythoven)
- ☑ Post LS1 operational envelope and MPS implications (M Solfaroli)
- ☑ Software tools for MPS (K. Fuchsberger)
- ☑ Interlocking strategy versus Availability (L. Ponce)

Operation 2015

- After the period of commissioning at low intensity, a running period at 50 ns after short scrubbing run is desirable to re-discover the machine at 6.5 TeV.
  - β^* ~50 cm, nominal bunch intensity, low emittance, pile-up of up to 40.
- We will then switch to 25 ns after additional period of scrubbing (~14 days) and ramp-up the beam intensity (number of bunches).
- There are many options for optics, beta* and cycle configurations.
  - Combined ramp and squeeze,
  - Lower beta* at injection,
  - β^* in some IRs (+ collision during [part of] the squeeze).
- The baseline scenario should be defined by the end of the year.
  - Study implications for OP and MP (collimation etc).

G. Arduini

Expect that this will be followed up with high priority by the LBOC meeting!

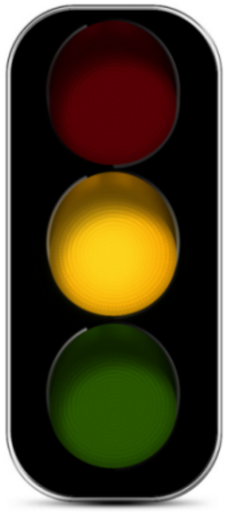
Injectors and beam heating

- The low emittance BCMS scheme beams are very attractive but:
  - Injection: energy density for 50 ns and 25 ns beams is ~35% and 70% higher than for the ultimate beam.
  - 7 TeV: energy density for 50 ns and 25 ns beams is ~2% and 25% higher than for the ultimate beam.
  - In particular at injection we must check all protection devices.
- We need a ‘body’ to follow up heating issues - not necessarily MPP.
  - We should identify issues at an early stage to put in place counter-measures before damaging equipment.

J. Uythoven

Beam failure scenarios

- The Big Three failure scenarios (D1, injection, asynchronous dump) all occurred – with some modifications.
  - However, *weaknesses were detected with equipment related to 2 oo 3 of the Big Three failure modes:*
    - TDI position.
    - LBDS: Trigger and Synchronization Unit and powering.

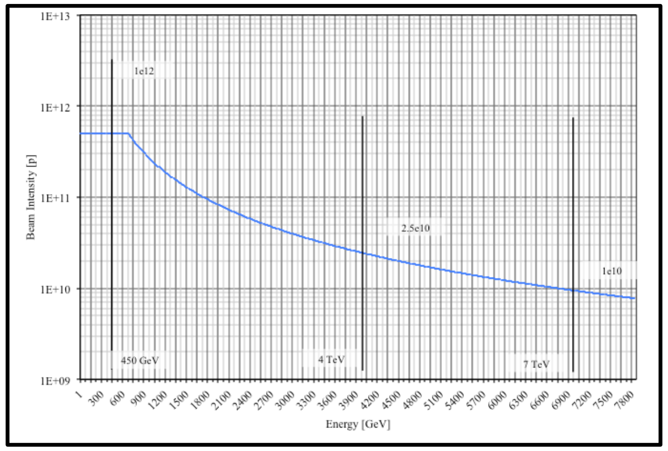


- Unexpected failure scenarios occurred (as expected):
  - Timing system, beam heating, UFOs, abort gap, QPS.
  - We need to further improve our protection against these faults.
    - Heavily relying on the Software Interlock System (SIS).
- After LS1 we must continue to understand each beam dump (post mortem) before continuing operation.

J. Uythoven

Setup beam definition

M. Solfaroli



The setup beam limit defines the max. intensity for which BIS interlocks may be masked.

Simple scaling of the curves from 4 TeV would not allow masking with 3 nominal bunches.

PLUS THE ε FACTOR	4 Tev		7 TeV (maintaining the curves)		7 TeV (maintaining the concept)	
	Allowed intensity	Factor (wrt normal)	Allowed intensity	Factor (wrt normal)	Allowed intensity	Factor (wrt normal)
NORMAL	2.5×10^{10}		1×10^{10}		1×10^{10}	
RELAXED	1.2×10^{11}	5	4.8×10^{10}	5	1.2×10^{11}	13
VERY RELAXED	3.26×10^{11}	13	1.26×10^{11}	13	3.26×10^{11}	34

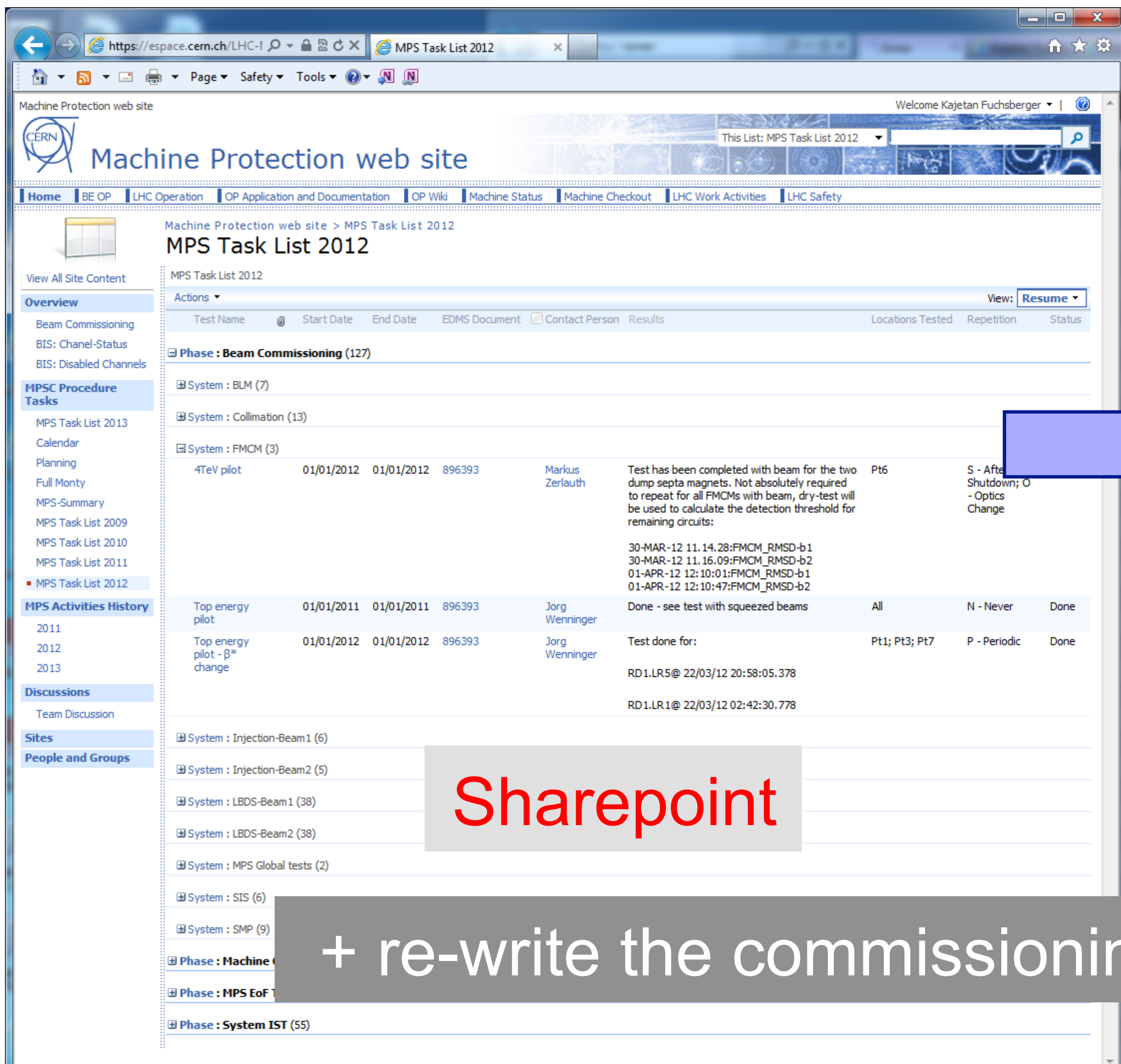
We must review the concept and limits for relaxed and very relaxed safe beam flag ↔ commissioning and MD needs and risks !

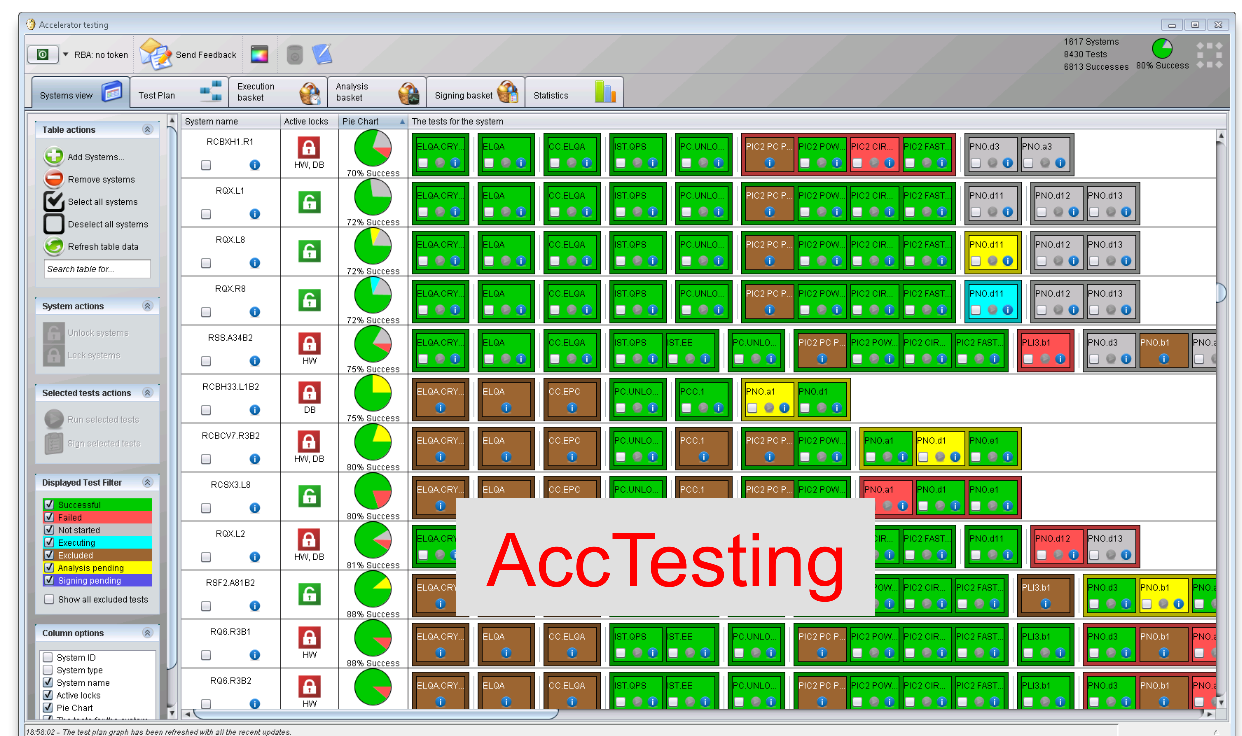
Software tool for MPS - main change

- The tracking of MPS tests will move from a share-point site to DB and JAVA tracking tool.

from here….

to there !





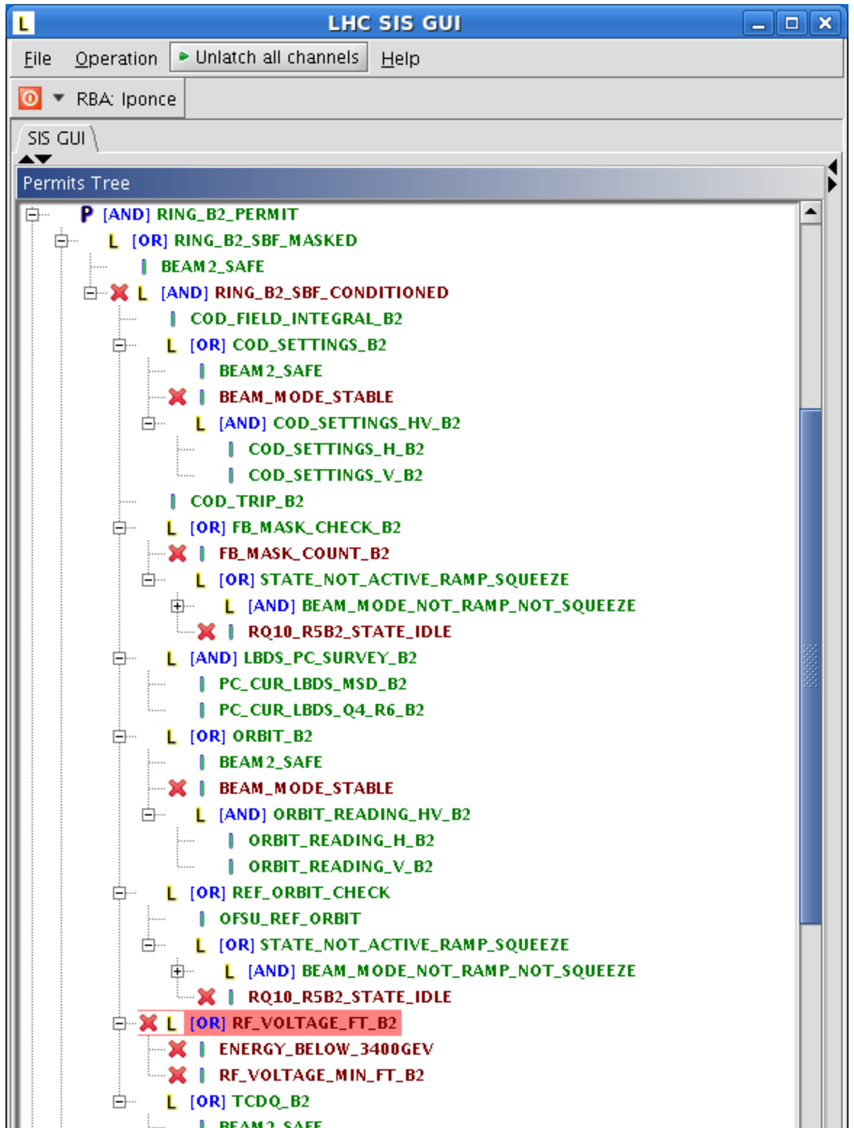
+ re-write the commissioning procedures & model in DB !

K. Fuchsberger

Software interlock system (1)

- The Software Interlock System (SIS) is used heavily in the LHC. It subscribes to ~2700 devices.
  - Used to interlock injection and dump the beams.
  - The core is very reliable, but sensitive to communication errors.
  - SIS provided quick solutions to many problems related to MP that were discovered during operation.

- For LS1 we propose to improve:
  - User interface,
  - Post-mortem information,
  - Masking.



L. Ponce

Software interlock system (2)

- To increase the safety level and reduce issues with communication, some SIS interlocks should be moved to hardware interlocks (after LS1 or bit later):
  - Beam position interlocks at TCSG in IR6.
  - TDI gap interlock.

Already available in collimation software. Further redundancy?

- From the workshop discussions, one has to expect new interlocks to arrive after LS1.

The SIS proved to be working very well and offers a flexibility for “quick” changes ➙ clearly expect to rely on that in the future!

L. Ponce

Conclusions

- The summaries of sessions 4 (collimators and movable devices) and 6 (operation after LS1) of the machine protection workshop were presented.
- Focus on many follow up items that came up. Several actions have already taken place!
- It was not possible to give justice to all speakers in the given limited time...

  Excellent technical results were presented that could not be reported here.

  Thanks a lot to the speakers!
- Many thanks also to the scientific secretaries and to the people who contributed to the active discussions that animated these sessions.