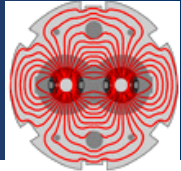


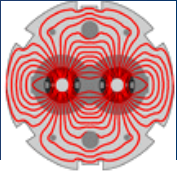
# Commissioning and Operation of the machine protection system

L. Ponce

Acknowledgements: M. Zerlauth, J. Wenninger, D. Wollmann, V. Chetvertkova, G. Valentino, B. Salvachua, M. Solfaroli, M. Pojer, MPP members



- MPS commissioning procedures
- Setup from pilot to first collisions
  - How we plan to do it
  - How we did it
- New setup beam flag definition
  - Implications for MPS setup and validation
- Intensity ramp-up
- Switching to 25ns



- Series of detailed commissioning procedures from 2009 used to coordinate tests during Machine Check Out and commissioning with beam
- Update of the procedures with Run1 experience is required:
  - Implementation of LS1 changes + new features
  - Adaptation to actual intensity steps/ramp-up
  - Revision of test periodicity

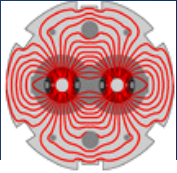
MPS procedure	MPS System
LHC-OP-MPS-002	Collimation System Commissioning
LHC-OP-MPS-003	Injection Protection System Commissioning
LHC-OP-MPS-004	Beam Interlock System Commissioning
LHC-OP-MPS-005	Powering Interlock System Commissioning
LHC-OP-MPS-006	Vacuum System Commissioning
LHC-OP-MPS-007	Beam Dump System Commissioning
LHC-OP-MPS-008	FMCM Commissioning
LHC-OP-MPS-009	BLM System Commissioning
LHC-OP-MPS-010	Warm Magnet Interlock System Commissioning
LHC-OP-MPS-0xx	Safe Machine Parameter System
LHC-OP-MPS-014	Software Interlock System
LHC-OP-MPS-0xx	Beam Current Change Monitor

- New procedure for FBCCM to be added

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- N Not to be repeated (eventually only executed at beginning of run, but not after Christmas or technical stops)
- S To be repeated only after longer shutdowns during a run (e.g. Christmas stops)
- T To be repeated after every Technical Stop (including longer shutdowns during a run)
- P Periodical repetition required, like 1 x per month; details to be defined in text
- O To be repeated when LHC optics/crossing scheme is changed

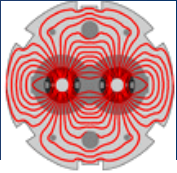


- Recommissioning of BLM system with beams:
  - Direct BLM test : in the procedure but never tested for Run1 (time consuming)
  - Check of dump triggered by BLM for each crate: either with shots on nearby collimators, or by decreasing the threshold

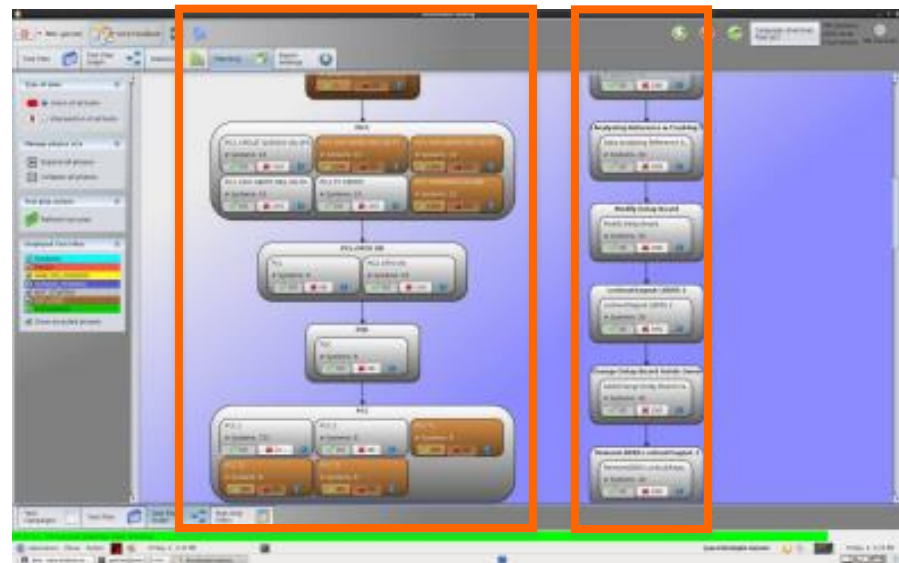
## 8.1.1 CONDITIONS REQUIRED TO PERFORM TESTS

- The impact conditions of the beam must be known to be able to perform comparisons with simulations.
- The optics must be known (measured and/or corrected).
- The transverse emittances must be measured.
- The orbit should be well corrected (< 3 mm) and measured.
- Beam energy: 450 GeV.
- Beam intensity: probe bunch of  $2\text{-}5 \times 10^9$  p<sup>+</sup>.
- Test #2 requires two accesses to the LHC tunnel.

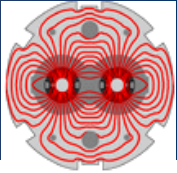
		Action
1	S	MPS functionality of the BLM with beam <ul style="list-style-type: none"> <li>• Decrease thresholds to very low value (trim application).</li> <li>• Create local bump to provoke local losses.</li> <li>• Increase the bump amplitude until the BLM system triggers (respectively lower the threshold further).</li> <li>• Measure delay between the time where the loss signal exceeds the threshold and the time of the beam dump (time stamps in logging DB).</li> </ul> Time estimate: 2h
2	S	Test interface of direct BLMs with the beam dumping system (same test as 7.3.4 of [1]). <ul style="list-style-type: none"> <li>• Reduce the voltage setting of the abort threshold.</li> <li>• Dump the injected beam on the collimator TCDQ and TCSG (with local bump). The threshold must have been lowered sufficiently, to provoke a beam dump request.</li> <li>• Record the beam dump.</li> <li>• This test must be repeated for each beam and for both TCDQ</li> </ul>
		and TCSG. <ul style="list-style-type: none"> <li>• From the amount of lost beam and the BLM reading, deduce the nominal threshold setting.</li> <li>• Are there variations with respect to the impact conditions?</li> <li>• Measure delay between the time where the loss signal exceeds the threshold and the time of the beam dump (time stamps in logging DB).</li> </ul> Time estimate: 2h (without the two accesses: could be scheduled during injection tests)



- Implementation of MPS commissioning to AccTest progressing (barriers, dependent/composed tests,..) but not fully ready for start-up :
  - First type-test implementation for MKD exchange completed
  
- Post LS1 tracking using SharePoint site:
  - MPS site worked fine – driven by few individuals in parallel to coordination, progress & status of advancement not obvious
  - Will capture sequence and dependencies during commissioning
  - Model and use full MPS commissioning in 2015 and first use after Technical/X-mas stops
  
- MPS setup and global MP tests must be repeated when:
  - Beta\* is changed
  - Crossing angle is changed
  - Energy is changed



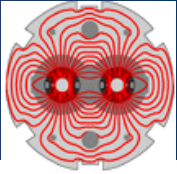
HWC (left) and MKD tree (right) in ACCTEST



- Establish operational cycle with “safe” conditions
  - 450 GeV re-commissioning (both beams capture, orbit)
  - Optics checks, aperture measurements
  - Ramp and squeeze (orbit, optics correction)
  - Collisions
  
- Interleaved MPS commissioning to prepare higher intensities:
  - Collimator set-up and validation (loss maps)
    - ✓ Injection
    - ✓ Flat top
    - ✓ End of squeeze
    - ✓ In collisions
  - LBDS validation (asynchronous beam dump test)
  - Injection protection set-up and validation
  
- Intensity ramp-up:
  - Nominal bunch
  - bunch train



# How we did it in 2012

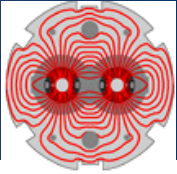


Date	Time	Milestone
Wed 14.03	23:40	<b>Beam 1 injected</b>
Thu 15.03	01:00	Both beams captured, orbit and Q adjusted
	11:00	Optics measured and corrected at injection
	20:00	Reference orbit for flat machine
Fri 16.03	22:44	<b>Both beams 4 TeV</b>
Sat 17.03	16:30	Beam 1 at 0.6 m beta*
Sun 18.03	11:15	<b>Squeeze at 0.6 m beta*</b>
	18:00	Separation and Xing at injection
Wed 21.03	24:00	Collimators set up @injection
Thurs 22.03	20:58	Squeeze with nominal Xing and sep
Sun 25.03	15:00	Injection protection setup
Tue 27.03	06:40	<b>Pilot through all cycle</b>
Fri 30.03	18:30	<b>Collisions, All IPs optimised</b>
Thurs 29.03- Sat 31.03	15:00- 22:00	Collimators aligned @4 Tev, end of squeeze and collisions
Thurs 05.04	00:38	<b>First Stable Beams @4 TeV</b> (3x3 b)

22 days

Pilot

Nominal bunch



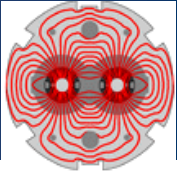
## ➤ 43 MPS tests in the Post Mortem during that 22 days(+ loss maps)

Event Timestamp	Dump Classification	Beam Mode	Beam Energy [MeV]	Operator Comment
20-MAR-12 09.57.52.280239 PM	MPS test	INJECTION PROBE BEAM	450000	Aperture scan at the end of the line
20-MAR-12 10.07.57.080239 PM	MPS test	INJECTION PROBE BEAM	450120	Aperture scan at the end of line in inject & dump.
21-MAR-12 10.01.36.933629 AM	MPS test	INJECTION PROBE BEAM	450120	Test off dump by switching off MKB generator
22-MAR-12 02.42.30.778402 AM	MPS test	SQUEEZE	3999960	MPS test on D1 (FGC fault) with probe beam at 0.6 m beta*. WIC actually triggered first. No visible orbit change. Losses on the TCT in IR1 from the dump as the TCDQ is not set,
22-MAR-12 02.16.38.550377 PM	MPS test	SQUEEZE	4000080	MPS test: triggered the dump of B1 by cutting the RF frequency to the LBDS. beam permits not linked.
22-MAR-12 02.18.23.672114 PM	MPS test	SQUEEZE	3999960	MPS test: switched off Frev distribution (on FESA class level) and dumped B1-probe only as beam permit loops were not linked.
22-MAR-12 08.58.05.378404 PM	MPS test	ADJUST	3999960	dump at beta* 0.6m by FGC.FAULTS on RD1.LR5
23-MAR-12 12.42.39.452874 AM	MPS test	INJECTION PROBE BEAM	450120	Alignment check of TCDQ with nominal bunch.
23-MAR-12 04.38.06.357788 AM	MPS test	INJECTION PROBE BEAM	450120	Moved in TCSG too close during offset check versus TCDQ
23-MAR-12 07.04.45.121992 AM	MPS test	INJECTION PROBE BEAM	450120	MPS test (switching off a BIC crate in the CCR)
24-MAR-12 05.26.21.407019 AM	MPS test	SQUEEZE	3999960	Sent an off to RD1.LR5 (probes at end of squeeze)
24-MAR-12 08.02.03.438601 PM	MPS test	INJECTION PHYSICS BEAM	450120	Asynch dump test at injection with injection protection out. Looks OK and losses on TCTs are good
25-MAR-12 01.23.19.367644 PM	MPS test	SQUEEZE	3999960	We switched off the RD34.LR3: the first signal to trigger is correctly the FMCM.
30-MAR-12 11.14.28.228248 AM	MPS test	SQUEEZE	4000080	Switch off RMSD of B1 for FMCM test.
30-MAR-12 11.16.09.928350 AM	MPS test	SQUEEZE	3999960	MPS test: RMSD B2 off for FMCM test.

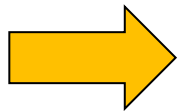
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02-APR-12 06.47.10.782104 AM	MPS test	RAMP	2004360	programmed dump at 2 TeV with 10 pilots in each beams
02-APR-12 06.24.34.973960 PM	MPS test	SQUEEZE	4000080	asynchronous dump test
03-APR-12 02.43.43.866077 PM	MPS test	INJECTION PHYSICS BEAM	450120	asynch dump at injection with inj protection in (indiv in bucket 1)
03-APR-12 03.17.23.446557 PM	MPS test	INJECTION PHYSICS BEAM	450120	Asynch dump test with injection protection out.





- Set-up Beam Flag is defined as the intensity limit to allow masking of pre-defined interlocks:
  - (BLM, IR6 BPM, Coll movements, RF, AC Dipole mode, PIC + some SIS interlocks)
- The intensity of  $\sim 1e12$  p was considered safe
  - factor 2 was applied to this intensity value, due to lower emittance used during operation  **$\Rightarrow 5e11$  p**
- Setup Beam was used for:
  - COLL alignment
  - Loss maps, asynchronous BD test
  - Optics measurement
  - Ramp/squeeze commissioning
  - Chromaticity measurement



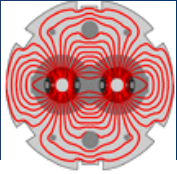
3 different SBFs were defined in 2012 .

**NORMAL:** Considered to be safe.

**RELAXED:** was established to allow 1 nominal bunch at 4 TeV.

**VERY RELAXED:** was established to allow 3 nominal bunches at 4 TeV.

	450 GeV	4 TeV
Normal	5e11	2.4e10
Relaxed	5e11	1.2e11
Very Relaxed	5e11	3.2e11
Ions	5e11	6.1e9



## ➤ What is needed for orbit measurement:

- Efficient set-up of collisions: 2 nominal bunches
- BPM IR6 new sensitivity limit:  $\sim 2e10p/bunch$
- BPM sensitivity limit (orbit) :  $5e10p/bunch$
- BPM sensitivity limit for collimator:  $5e9 p/bunch$

D. Wollman, MPP meeting 23th

## ➤ What is needed for collimators set-up/ validation

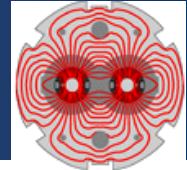
G. Valentino, CWG 18th May

- Intensity “consumed” during full setup:  $\sim 7e10p$
- Intensity “consumed” per transv. loss map (ADT):  $\sim 1e10p$  (8e9 min)
- For the start-up commissioning (1-2 fill per machine mode; 3rd fill for async dump):

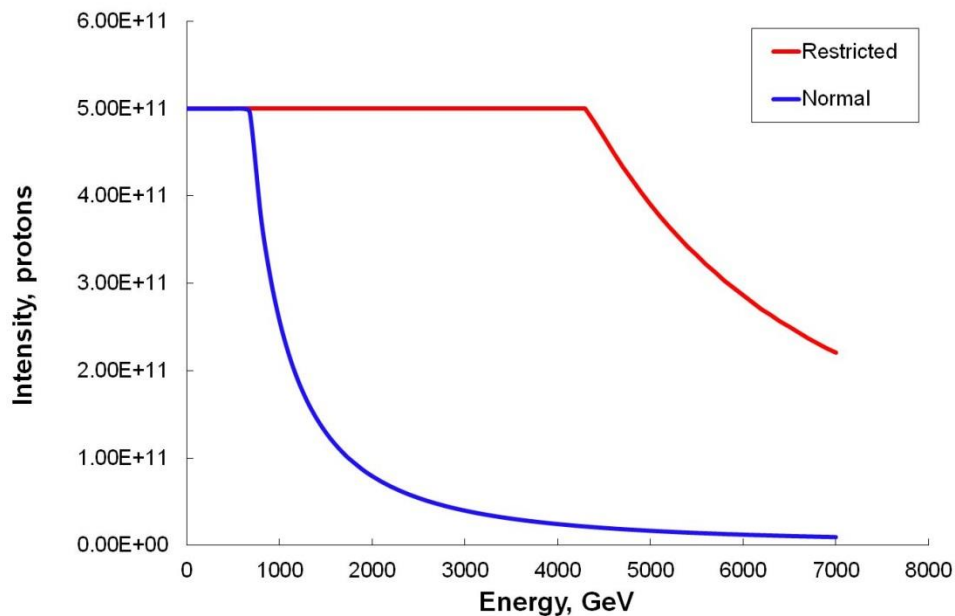
Machine Mode	Alignment		Betatron Loss Maps		Momentum loss maps	
	Intensity (E11)	Bunch Config	Intensity (E11)	Bunch Config	Intensity (E11)	Bunch Config
Injection	2	2 nominal	2	2 nominal (H/V)	2	2 nominal
Flat Top	1.5	1 nominal	1.5	2 probes (H/V)	1.5 / 1*	prev. config / 1 nominal*
After Squeeze	1.5	1 nominal	1.5	2 probes (H/V)	1.5 / 1*	prev. config / 1 nominal*
Collisions	2.2	2 nominal	2.2	2 nominal + 2 non-coll probes (H/V)	2.2 / 1*	prev. config / 1 nominal*

\*if we dump on the first off-momentum loss map and have to re-fill

- For eventual frequent configuration changes which require alignments and loss maps, we can have 1 fill for squeeze + colliding, and inject  $2.5E11 p$  directly from the start.



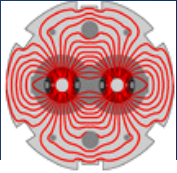
- Based on material tests + Fluka simulation + Run 1 experience
- 2 values (3 bunch config) :
  - **NORMAL SBF:  $1.1e10$**  for ALL users
  - **RELAXED SBF:  $1.25e11$  x 2 bunches** for Special users (Orbit, collision setup, loss maps)
  - **RESTRICTED SBF:  $1.5e10$  x 16 bunches (SIS interlock)** for MDs with MP doc.



D. Wollman, 92th MPP

Limiting intensities for different-level SBFs at 6.5 TeV and 7 TeV

	6.5 TeV	7 TeV
NORMAL	$1.1e10$	$9.4e9$
RELAXED/ RESTRICTED	$2.5e11$	$2.2e11$



- To operate with unsafe beam:
  - Operational cycle must be well established
  - All MPS tests and global protection tests completed
  - Collimators and absorbers should be in place/ validated
  
- Ramping up strategy as in 2011 and 2012:
  - Step up of factor 2-4 max in bunch number (decreasing with increasing bunch number)
  - 3 fills per step (making it to STABLE BEAMS)
  - 20 hours of STABLE BEAMS
  
- IR6 BPM test for each new bunch config
- Sign off checklist before step up
- Meeting of rMPP where practicable

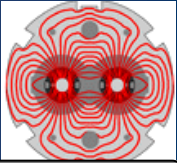
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## LHC intensity cruise – check list

Version 1.4 – 04.04.2012

<b>Bunch pattern / intensity</b>	Mostly 1374/1368 bunches. 50ns_1374_1368_0_1262_144bpi12inj
<b>Start date</b>	21 August 22:52:32 (time of dump)
<b>End date</b>	01 November 20:11:23 (time of dump)
<b>Fill numbers</b>	2992 – 3250 (148 fills)
<b>Comment</b>	This list covers the floating MD, the high beta* and pilot proton-ion run, TS3, MD3 and the 1000m beta* run.

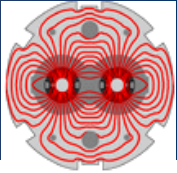
Dump Reason	# of dumps	Comments
QPS	22	
EOF	34	
Cryo	5	
EL Net	8	
RF	4	
PIC	-	
Beam Loss	6	
BLM	3	
Vacuum	7	
PC	10	
Orbit	-	
Feed Back 1 / 2	7 / 1	
Collimators	3	
LBDS	4	



M. Zerlauth, Evian Dec 2011

	Scrubbing run		physics program											
	Apr		May		June		July		Aug		Sep			
Wk	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	28	96 b <sup>4</sup>	1020 b <sup>1</sup>	18	Easter	2	9	EDF glitch <sup>16</sup>	23	30	6	Whit <sup>13</sup>	20	
Tu		50ns inj	3 b					228 b						
We		408 b	48 b		624 b			480 b						
Th			228 b	480 b			Quench HTS			Ascension				
Fr				G. Friday		MD	RD3.LR4	768 b		1st May comp.			1236 b	
Sa		588 b	336 b				AUG							
Su		800 b			768b		TI2	912 b	1092 b					
Wk	26	27	28	29	30	31	32	33	34	35	36	37	38	
Mo	27	4	Power Cut <sup>11</sup>	1380 b <sup>18</sup>	25	1	8	15	22	29	5	12	19	
Tu	1380 b													
We			Pilot											
Th			264 b								J. Genevois			
Fr			840 b											
Sa														
Su		Power Cut	1092 b											

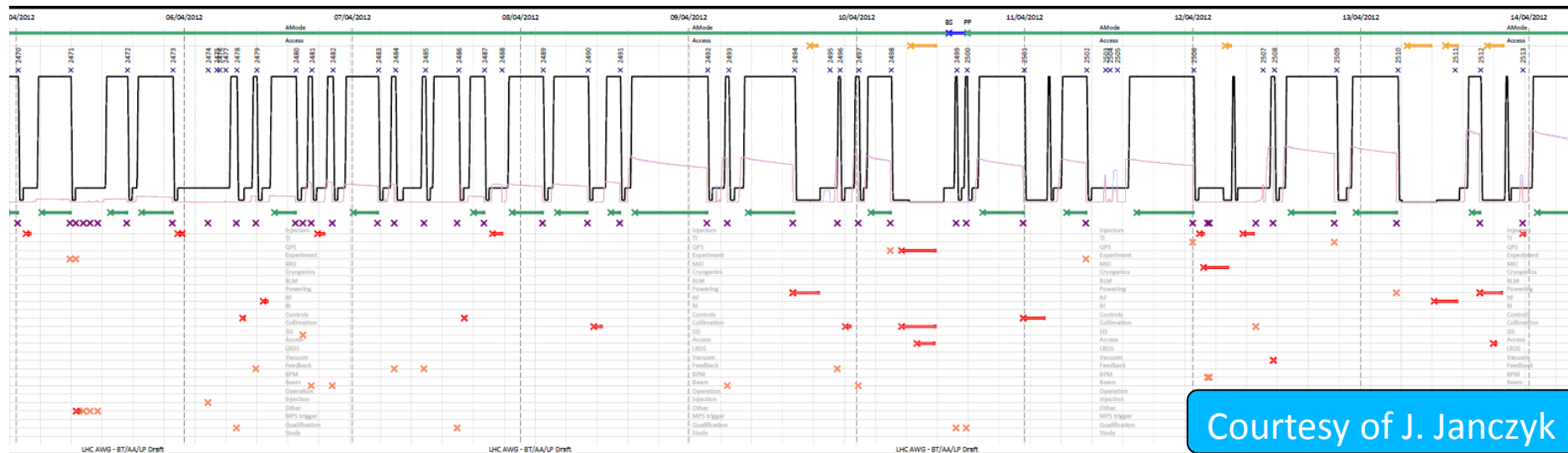
- Main driving factor was machine availability up to 768b, but time allowed to discover & clean up many teething problems at intensities < 1380b:
  - MTG, tune FB, FGC current reading, arc detectors
- Initial steps to 912b and 1092b set off UFOs, vacuum activities and SEU



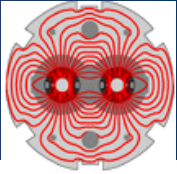
- When everything goes well
- Reduced to 6 steps in 2012 (very good machine availability):
  - 3 bunches for MPS validation
  - 2-3 fills and 4-6 hours with 264b and 624b (cycle validation)
  - 3 fills and 20 hours with 840b, 1092b, 1380b

	Apr			May				June					
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	2	Easter 9	16	23	30	7	14	21	Whit 28	4	11	90 m [12 h]	26
Tu					1st May								
We			1380 b	TS1			VdM scans [48 h]						TS2
Th	3 b	840 b										MD	
Fr	G. Friday	1092 b											
Sa	264 b		MD										
Su	624 b												

47x47 + 84x84 b  
the same day



Courtesy of J. Jarczyk



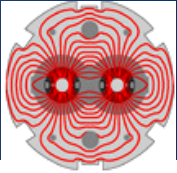
- What we did in 2012 after scrubbing run:
  - Nominal cycle with 3 bunches (new beta\*)
  - Loss maps
  - ADT set-up, BPM IR6 test

Date	Time	Milestone
06.12	11:30	ADT setting
	20:00	228 b injected, scrubbing
11.12	3:30	<b>Collisions @ 1m with 3 nominal b</b>
	5:00	<b>Cycle with 3 nominal for collimators set-up</b>
	18:00	Loss maps
12.12	16:00	TDI alignment checks
13.12	06:15	<b>STABLE BEAMS with 72 bunches (25ns)</b>
	08:30	Loss maps at flat top
14.12	12:30	Loss maps end of squeeze and in collisions
15.12	15:00	<b>STABLE BEAMS with 12+2x48b</b>
	20:00	<b>STABLE BEAMS with 12+4x48b</b>
16.12	09:00	<b>STABLE BEAMS with 396b</b>





# Summary



- We have experience for MPS commissioning for new beam parameters:
  - New energy ( 4 TeV in 2012)
  - New bunch spacing in 2011 (75 ns, 50 ns)
  - Increase of bunch number (till 1380)
- We have well established procedures and reference body (rMPP) for tests to be performed and check list for intensity ramp-up
- New Set-up beam flag values proposed to accommodate machine safety and efficient set-up:
  1. **NORMAL SBF: 1.1e10** for ALL users
  2. **RESTRICTED SBF: 1.25e11 x 2 bunches** for special users
  3. **RELAXED SBF: 1.5e10 x 16 bunches** for MDs
- But we also have a lot of HW/SW changes (new BLM positions and thresholds, QPS, controls...)
- With a bit of optimism, intensity ramp-up with 50ns may look like 2012, but exploring new territory with 25ns may recall 2011.

LHC will have the final word on the MPP recommendations!