450 GeV Calibration Run

Mike Lamont

05/07/06

450 GeV – Calibration Run

- Fastest safe path to low intensity collisions
  - Commission essential safety systems
  - Commission essential beam instrumentation
  - Commission essential hardware systems
  - Perform measurements to check:
    - Polarities
    - Aperture
    - Field characteristics

Operations motivation

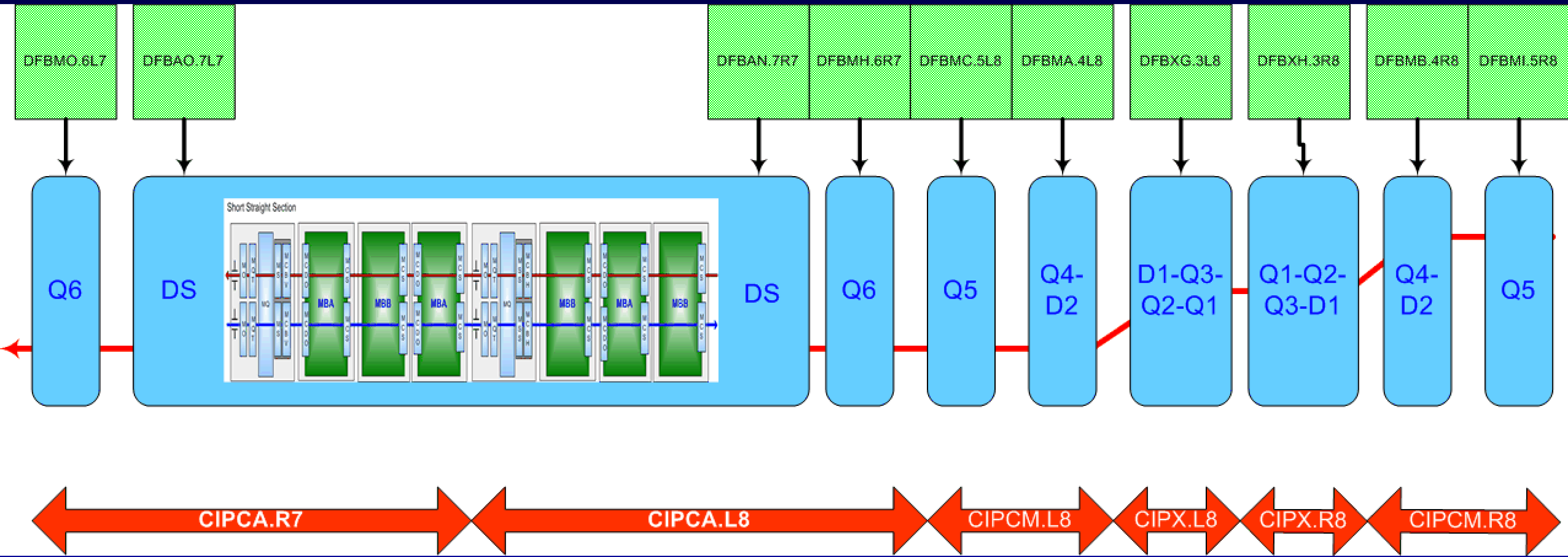
- Get to wrestle with the full machine with a important window for post-run consolidation
- Chance to check aperture etc. with a built in window to address problems
- Could also do in MD:
  - First part of ramp (to 1.1 TeV)
  - Get a handle on reproducibility etc.
- Could also do parasitically:
  - Commission beam instrumentation (PLL etc.)
- Skip non-essential
  - Mop up in interleafed MD

Hand over from HWC

- **Individual system tests**
  - **Cryogenic Production and Distribution; Power Converter short circuit tests; Evacuation; Leak tests; Closure of the interconnects with the thermal shields and the MLI; QPS checks. Alignment**
- **Commissioning of continuous arc cryostat & LSS cryostats (Q6.R7, Q6.L8…, inner triplet, etc.)**
  - **Cryogenics, Vacuum, QPS, PIC, Powering.**
    - **Cool-down,**
    - **Leak Tests,**
    - **Electrical Quality Assurance,**
    - **Tests prior to powering,**
    - **Powering (QPS, PC, MPS) of all circuits one by one,**
      Magnets, busbars, DFBs, services, UPS, AUG, controls…
    - **Powering of all the circuits of a sector in unison**
    - **Power converters:** protection, calibration, ramp tests performed
    - Interlocks, compatibility tests, protection tests

Clearly expect a safe machine with main circuits commissioned to 1.2 TeV

Handover from HWC



Plus

- **Kickers, Septa, Collimators, Absorbers, Beam dumps**
- **RF including power systems, low level, cavities, transverse feedback etc.**
- **Beam Instrumentation**
- **Machine protection system**
- **Controls etc…**

Machine Checkout

Curtailed.
But OP need to get their paws on the commissioned sectors ASAP

14 days

System	To do - full ring
Access	Commission full ring, EIS tests, Acceptance tests, operation. Debug its numerous sub-systems and test all the operational procedures.
Beam Hardware	
Kickers	Inte
Septa	Inte
Power Converters	Cyc Trac

Magnets	Transfer functions, harmonics, cycling etc.
RF	Cavity conditioning, Interlocks, Controls, synchronisation with injectors, pre-pulses, low level control [cavity control, synchro, beam control, longitudinal damper], transverse damper, power systems and diagnostics
RF - TFB	
RF - LFB	
TCLI	Interlocks, control, monitoring.
TCDQ	Interlocks, ramp & squeeze, control, monitoring.
TDI	Interlocks, control, monitoring.
Collimators	Monitoring control, synchronized movement, ramp & squeeze, tests
Beam Dump	Tests of timing, post-mortem system, inject and dump mode, energy meter. XPOC, interlocks. Reliability tests.
Machine protection	
Beam Interlock Controller, WIC.	Equipment interfaces, links, logic, controls. Client interfaces [Vacuum, access, PIC, Dump, BLMs, FMCM, Experiments, Injection systems etc.]. In and out of test mode. Fill blown system wide tests.
Safe Beam Flags. Safe beam parameters	Distribution. Tests.
Beam Energy Meter	Interface, tests.
Software Interlocks	Acquisition. Logic. Reliability. Tests.
Controls	Signal acquisition Logging Post Mortem Fixed Displays Equipment control Settings generation and download Alarm system Slow timing, fast timing, synchronisation Alarms, logging, post mortem, fixed displays Equipment control & access Analogue acquisition Software: measurements, trajectory acquisition and correction, ramping etc. etc. Sequencer, injection management Procedures for sliding bumps etc. etc.
Controls infrastructure	Networks, front-ends, timing, FIP, servers, databases etc.
Instrumentation	
Beam Loss Monitors	Interloc
Beam Current Transformers	Pre-con
Beam Position Monitors	Concen
Wire Scanners	Pre-con
Synchrotron Light Monitor	Pre-con
Screens	Pre-con
Tune measurement	Pre-con
Chromaticity measurement	
Abort gap monitor	
Radiation monitors	Acquisi
Residual gas monitors	Pre-con

Accelerator systems	
Beam Vacuum	Monitoring, instrumentation, valve control, interlock tests.
Cooling and Ventilation	Monitoring.
Cryogenics Plant	Recovery, communications.
Cryostat Instrumentation	Monitoring, logging, post mortem, analysis.
Electrical Network	Monitoring.
Insulation Vacuum	Monitoring, logging.
Powering Interlock	Ring wide tests. Parallel failure.
QRL Instrumentation	Monitoring, logging, interlocks, recovery.
QRL Vacuum	
Quench Protection	QPS, Energy extraction: displays, diagnostics, post-mortem, recovery.
Miscellaneous	
Radiation Monitors	
Radiation protection	
Experiments	Data interchange, Beam aborts, injection inhibits

Table 1: Key objectives of machine checkout

Magnets

Need limited cycling capabilities in order to reset magnetic history

- Need to be able to cycle main bends, quads, sextupoles to 1.2 TeV equivalent
  - ~ 1900 A in main bends, ~16% nominal
- Similarly need to be able to cycle insertion quads, separation dipoles etc. to ~20% of nominal
- Would expect correction circuits ≤ b3 to fully commissioned to full current:
  - This includes all orbit correctors.
  - Could make do with 10-20% of Imax if really necessary.

Required Circuits

Main dipoles	MB
Separation dipoles (warm & cold)	MBRB MBRC MBRS MBW MBXW
Spectrometer compensation	MBXWH MBXWS MBXWT
Orbit correctors	MCBH MCBV MCBY MCBX MCBC
Sextupole spool	MCS
Lattice Quad	MQ
Insertion quads	MQM MQMC MQML
Lattice skew	MQS
Tuning quads	MQT
Dispersion suppressors quads	MQTL MQTLI
Twin aperture warm quads	MQWB
Inner triplets	MQXA MQXB
Wide aperture insertion quads	MQY
Lattice sextupole	MS

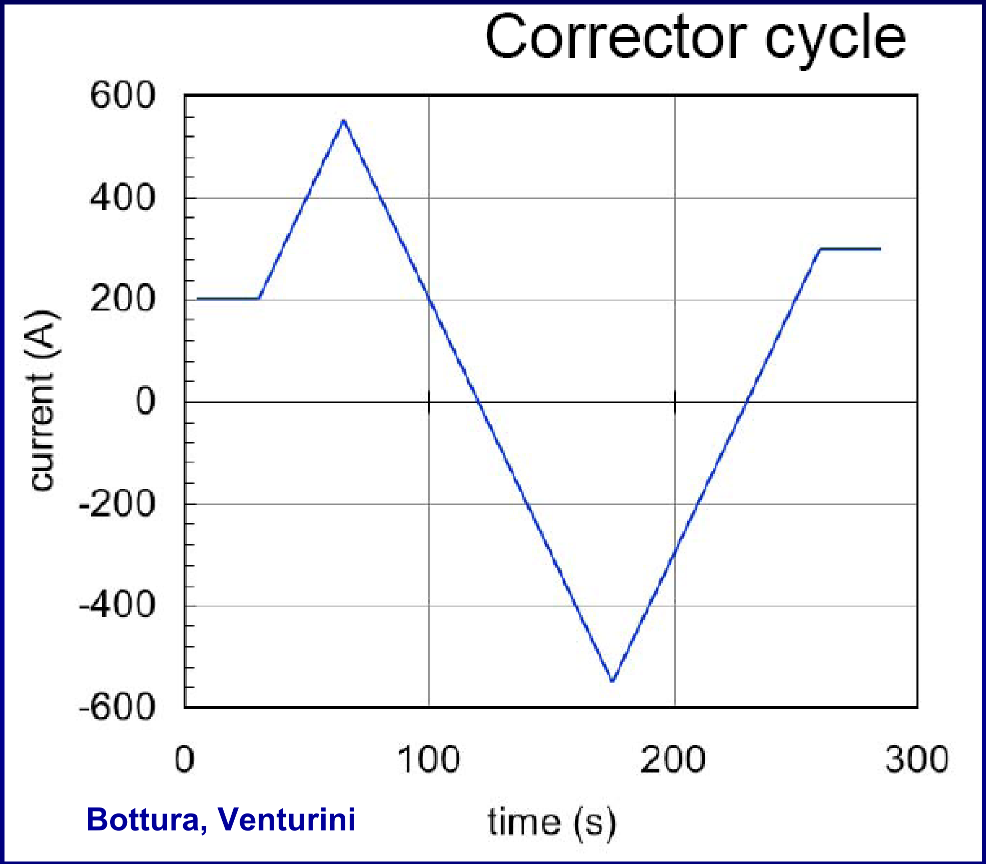
Circuits not immediately needed

Essentially can skip higher order correction… checks in progress

Decapole spool correctors	MCD
Octupole spool correctors	MCO
Skew Octupole - triplet	MCOSX
Skew sextupole - triplet	MCSSX
Sextupole corrector – triplet	MCSX
Dodecapole Spool - triplet	MCBXA
Lattice Octupole	MO
Skew quadrupole - triplet	MQSX
Arc skew sextupoles	MSS

Would expect all circuits for 34 45 78 81

Correctors to nominal



Pre-cycling to the flat-top current brings the corrector on the same hysteresis branch as for the previous shot

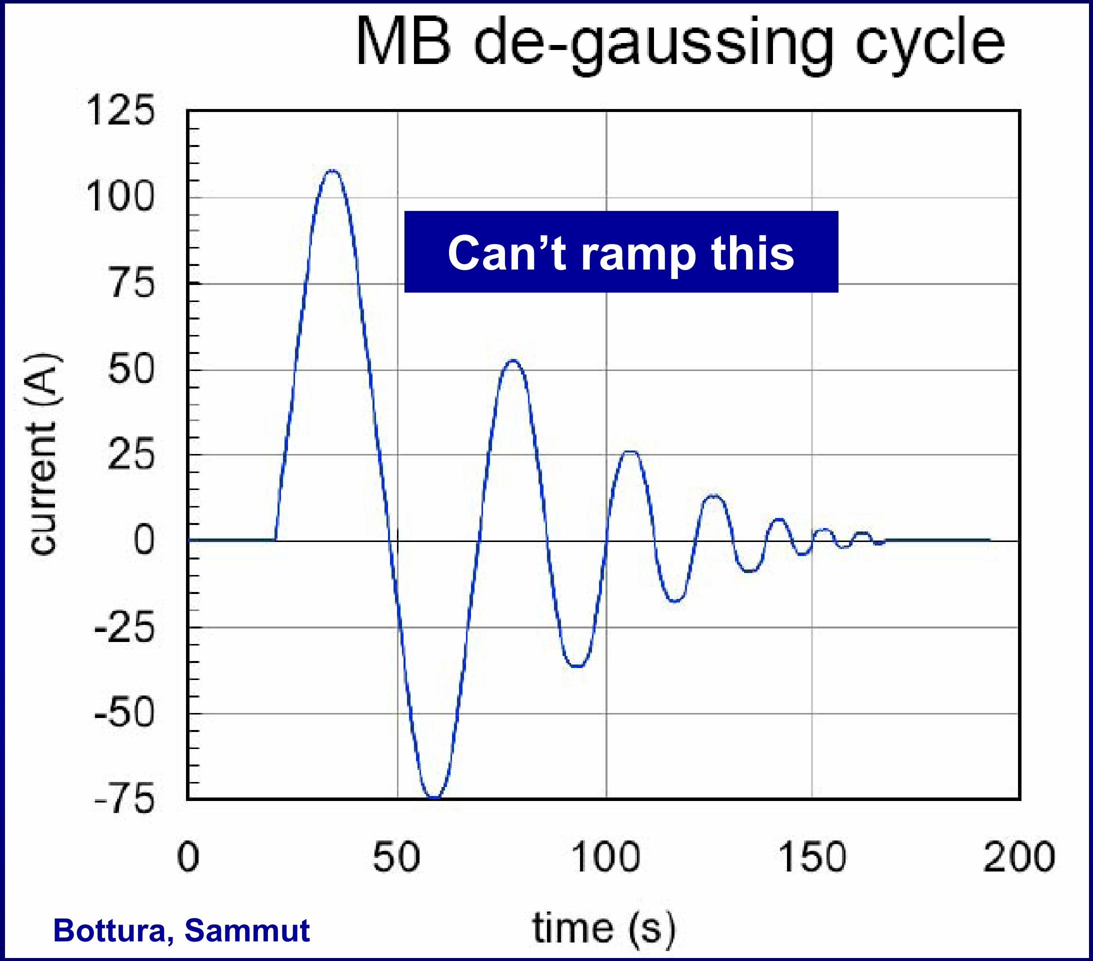
Standard cleansing and setting cycle:
The pre-cycle:
- resets persistent current effects
- insures no hysteresis crossing at new setting

Plus:

- Bias currents

- MD

De-Gauss cycle – short cut



Commission on de-Gauss

First collisions

HWC 450 GeV++

Commission on nominal

Collisions & ramp

Low field

- Some insertion quadrupoles (including inner triplets) at low field
  - Therefore low field quality
  - Tracking in progress (Massimo Giovannozzi)
  - Might need the triplet correctors to improve the field quality of the low-beta quadrupoles at injection
  - Similarly MCDO might be useful

Pre-cycle essential

Sanfilippo

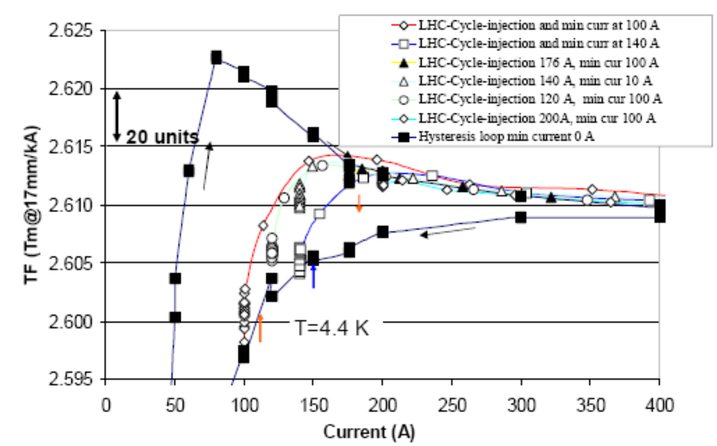


Fig. 3: Hysteretic curves and decay of the transfer function measured at 4.4 K for one MQY with different minimum currents of the pre-cycle and different values of the injection currents. The pre-cycle taken as reference for the measurements (black squares) is that with a zero minimum current.

RQ9.R8B2/I	686.5
RQ9.R8B1/I	708.0
RQ9.R6B2/I	685.3
RQ9.R6B1/I	616.7
RQ9.R5B2/I	613.9
RQ9.R5B1/I	698.2
RQ9.R4B2/I	697.8
RQ9.R4B1/I	540.3
RQ9.R2B2/I	643.0
RQ9.R2B1/I	545.4
RQ9.R1B2/I	613.9
RQ9.R1B1/I	698.2
RQ9.L8B2/I	501.1
RQ9.L8B1/I	651.4
RQ9.L6B2/I	620.3
RQ9.L6B1/I	677.3
RQ9.L5B2/I	700.2
RQ9.L5B1/I	722.8
RQ9.L4B2/I	575.6
RQ9.L4B1/I	667.8
RQ9.L2B2/I	755.0
RQ9.L2B1/I	570.9
RQ9.L1B2/I	700.2
RQ9.L1B1/I	722.8
RQ8.R8B2/I	515.4
RQ8.R8B1/I	656.0
RQ8.R6B2/I	330.2
RQ8.R6B1/I	497.1
RQ8.R5B2/I	710.1
RQ8.R5B1/I	703.0
RQ8.R4B2/I	687.8
RQ8.R4B1/I	659.1
RQ8.R2B2/I	415.6
RQ8.R2B1/I	556.2
RQ8.R1B2/I	710.1
RQ8.R1B1/I	703.0

MQXB2.L8/I	1809.4
MQXB2.R8/I	1809.4
MQXB2.L2/I	1792.7
MQXB2.R2/I	1792.7
MQXB2.L1/I	1640.1
MQXB2.L5/I	1640.1
MQXB2.R1/I	1640.1
MQXB2.R5/I	1640.1
MQXA1.L8/I	1097.9
MQXA1.R8/I	1097.9
MQXA3.L8/I	1097.9
MQXA3.R8/I	1097.9
MQXA1.L2/I	1087.7
MQXA1.R2/I	1087.7
MQXA3.L2/I	1087.7
MQXA3.R2/I	1087.7
MQXA1.L1/I	995.1
MQXA1.L5/I	995.1
MQXA1.R1/I	995.1
MQXA1.R5/I	995.1
MQXA3.L1/I	995.1
MQXA3.L5/I	995.1
MQXA3.R1/I	995.1
MQXA3.R5/I	995.1
RQ8.L1B2/I	811.9
RQ8.L5B2/I	811.9
RQ10.R1B1/I	757.5
RQ10.R5B1/I	757.5
RQ9.L2B2/I	755.0
RQ10.R8B1/I	744.3
RQ10.L2B2/I	743.1
RQ7.L8B1/I	742.8
RQ7.R4B2/I	731.1
RQ10.L1B1/I	729.3
RQ10.L5B1/I	729.3
RQ10.R2B1/I	724.5

etc. etc.

Currents at 1.2 TeV available

Machine Configuration

- Optics: see Stephane Fartoukh
  - Crossing angles off
  - Separation bumps on for two beams
  - Shift bunches for LHCb
  - Solenoids & Exp. Dipoles etc. off (to start with)
  - Commissioning tunes, FiDeL

- Instrumentation
  - Orbit: Synched Acquisition & feed-forward plus GOFB, multi-turn
  - Tune FFT & PLL: Continuous Tune - Chromaticity & Coupling
  - BLMs
  - Transverse beam size – one of SLM, RGM, WS,
  - Luminosity monitors (colliding the beams – under discussion)
  - BCT

Coast

Raise the voltage after all injections to 16 MV for the store

- improve the beam lifetime.

- increase in dp/p is from (2sigma) 0.88E-3 to ~1.1E-3 (if we have the 1 eVs emittance; it might be lower),

Trevor Linnecar

- Mainly affect the arc aperture where n1 will be reduced by 0.8 in the QFs and a bit less in QD's (both due to the nominal H-dispersion and the V and H spurious dispersion).

- In the triplet, with only spurious dispersion, the loss will be only dn1=0.2 (re-increasing beta* by 6% will easily solve this if needed).

- To summarise the first bottom-neck will be a priori the arcs and Ralf will possibly have to close further his collimator: with the magnets we try to stick to n1=7 at QF and 6.7 at QD and generally Ralf works with n1=6 so all his margin will be lost!..

- loss of DA - minor provided Q' and Q'' (not so high with the proposed squeezed optics) is more or less correctly adjusted.

Stephane Fartoukh

Machine Protection

- BIS plus SBF and BPF
- PIC
- LBDS connected to BIS
- User input:
  - Collimators, TCDQ, TDI, injection kickers, PIC, FCDM, BLMs, experiments, access, vacuum…
- BEM
- Software interlocks

Should be commissioned and tested without beam as far as possible

Clearly less critical during initial phases but must be commissioned and tested with beam before pushing the intensity

Phases

	Phase
1	First turn
2	Establish circulating beam
3	450 GeV - initial
4a	450 GeV - consolidation
4b	450 GeV - system commissioning
5a	Two beam operations
5b	Collisions
6	Increase intensity

First Turn

Commissioning for 7 TeV | 450 GeV

Team	Sub-phase	Total Time both rings	Priority	450 GeV Collisions
BT/OP	Commission TI8 & TI2 end transfer line, Commission injection region: kickers, septa, check aperture, instrumentation, beam to TDI.	24	1	Essential
OP/BI	Commission trajectory acquisition and correction, thread beam - first turn, energy matching	48	1	Essential
BI	Commission Beam Loss Monitor system phase 1	12	1	Parasitic
OP/AP	**Orbit response, kicks, trajectory, BPM and corrector polarity checks**	24	1	Essential
OP	Initial aperture checks	16	1	Leave
OP	Momentum aperture	6	1	Leave
COL	Setting up of injection machine protection	12	2	Leave
		6 days		**4 days**

Circulating beam

	Sub-phase	Total Time both rings	Priority	450 GeV Collisions
OP/AP	Adjust chromaticity, close trajectory, establish multiple turns, obtain closed orbit [Inject & dump]	24	1	Essential
OP/RF	Energy matching and correction, B-sps, f-lhc, B-lhc - both rings, RF capture	32	1	Essential
OP/AP	Measure integer tunes, fractional tunes, phase advance per turn	16	1	Essential
		3 days		3 days

450 GeV - initial

Team	Sub-phase	Total Time both rings	Priority	450 GeV Collisions
RF	Beam control loops (Phase, Synchro, Radial). Tuner loop, RF Feedback loop. Synchronisation	24	1	Essential
OP/AP	Test control and correction (corrector polarities, cabling, control system, software, procedures …). Measure & correct orbit.	16	1	Essential
OP/BI	Commission transverse diagnostics - tune measurement [FFT]. Measure and adjust tunes, chromaticity, and coupling.	16	1	Essential
OP/AP	Linear optics checks: check orbit versus kick, phase advance, BPM and corrector polarity.	24	1	MD
BI	Commission beam loss monitors - acquisition, display etc. No connection to BIC for the moment.	12	1	Parasitic
BT	Commission beam dump - phase 1	24	1	Essential
BI	Commission BCTs: lifetime measurement	-	1	Parasitic
MPS	Commission beam interlock system with beam - phase 1. BIC to dump with beam. Test.	8	1	Essential
		5 days		3 days

Measurements

Team	Sub-phase	Total Time both rings	Priority	450 GeV Collisions
BT	Matching between TI8/TI2 and ring. Pilots.	8	2	Leave
AP/OP	**Measure beta beating. Identify and correct local sources of phase advance errors.**	**16**	**1**	**Do**
MA/OP	Check key transfer functions (separation dipoles etc.)	16	1	Later [MD]
AP/OP	**Mechanical aperture checks. Bumps – Check the aperture in the cold machine**	**16**	**1**	**Essential**
OP/MA	Field quality checks. Check design fields, field harmonics, fields due to offsets between beam and magnet	16	1	≤ b3
OP	Momentum aperture	8	2	Do
OP	IR bumps, check aperture in IRs	8	1	Leave
OP/AP	Reproducibility after cycling machine. Effect of magnetic cycle, reproducibility, field model	16	1	Leave
BI/AP	Quench levels and BLM response	24	2	Leave
		5 days		**1-2 days**

System commissioning

Team	Sub-phase	Total Time both rings	Priority	450 GeV Collisions
RF	Loop adjustment	8	1	Do
RF	Transverse damper	8	2	Do
RF	Longitudinal feedback	8	1	Leave
BI	Transverse profile monitors	8	2	Parasitic
BI	Commission beam loss monitors - phase 2, calibration, thresholds. Commission the BLM's around the collimators. Link to BIC	16	1	Parasitic
BI	Tune - PLL	16	1	Do
OP	Closed orbit feedback	16	1	Do later
COL	Adjustment of collimators, orbit stabilization, test positioning procedures, beam loss monitors.	36	1	Essential for Intensity increase
BT	TDI. Position, angle, interlocks	8	1	Essential
BT	TCDQ orbit at 6, position, angle, interlocks	16	1	Leave
MPS	FMCM	4	1	Do
MPS	Test Safe LHC Parameters: Safe Beam Flag, Beam Presence Flag, Safe LHC mode, Safe Energy, Safe Squeezing Factor	8	1	Essential (plus parasitic)
		7 days		2-3 days

2 beam operation

Team	Sub-phase	Total Time	Priority	450 GeV Collisions
OP	SPS - switch rings - TI8/TI2 in parallel – LHC injection	8	1	Parasitic
OP/BT	**Commission separation bumps. Closure of bumps. Check aperture. Check injection region.**	**16**	**1**	**Essential**
OP/AP	Effect of bumps - dispersion, non-closure	8	2	Leave
BI	**Beam parameters: Q split, Q' split, coupling, Beam instrumentation: BLMs, BPMs cross talk etc.**	**8**	**1**	**Do**
OP	**Control system: real-time feedback, orbit correction, orthogonality etc., check energy matching - 2 rings**	**8**	**1**	**Partial Do**
		2 days		**1 day**

Colliding beams

Team	Sub-phase	Total Time	Priority
OP	**Separation bump reduction, check interaction with orbit feedback: points 1,2,5 & 8. Establish collisions**	**4*8**	**Essential**
BI	Commission luminosity monitors (low interaction rates)	8	Parasitic
COL	Collimation setup	-	Optimisation
OP	**Commission spectrometer compensation (compensation At 450 GeV?). Bring solenoids on.**	**2*8**	**Essential**
		2 days	**1-2 days**

Increase Intensity

Team	Sub-phase	Total Time	Priority
COL	Collimators: N1 = 6, N3= 30, NTCDQ = 10 moving towards N1 = 5.7, N2= 6.7, N3 = 30	3*8	MD
TDI	Move towards Ntdi = 6.8	2*8	MD
OP	Multi-batch injection	16	MD
RF	Longitudinal feedback	8	MD
			Spread

Time

	Phase	Beam time [days]
1	First turn	4
2	Establish circulating beam	3
3	450 GeV – initial	3
4a	450 GeV - consolidation	1-2
4b	450 GeV – system commissioning	2-3
5a	2 beam operations	1
5b	Collisions	1-2
		16 days

Given an operational efficiency of 60%, this gives an elapsed time of about 26 days.

Ramp MD will required some consolidation and extra system commissioning

Parallelism

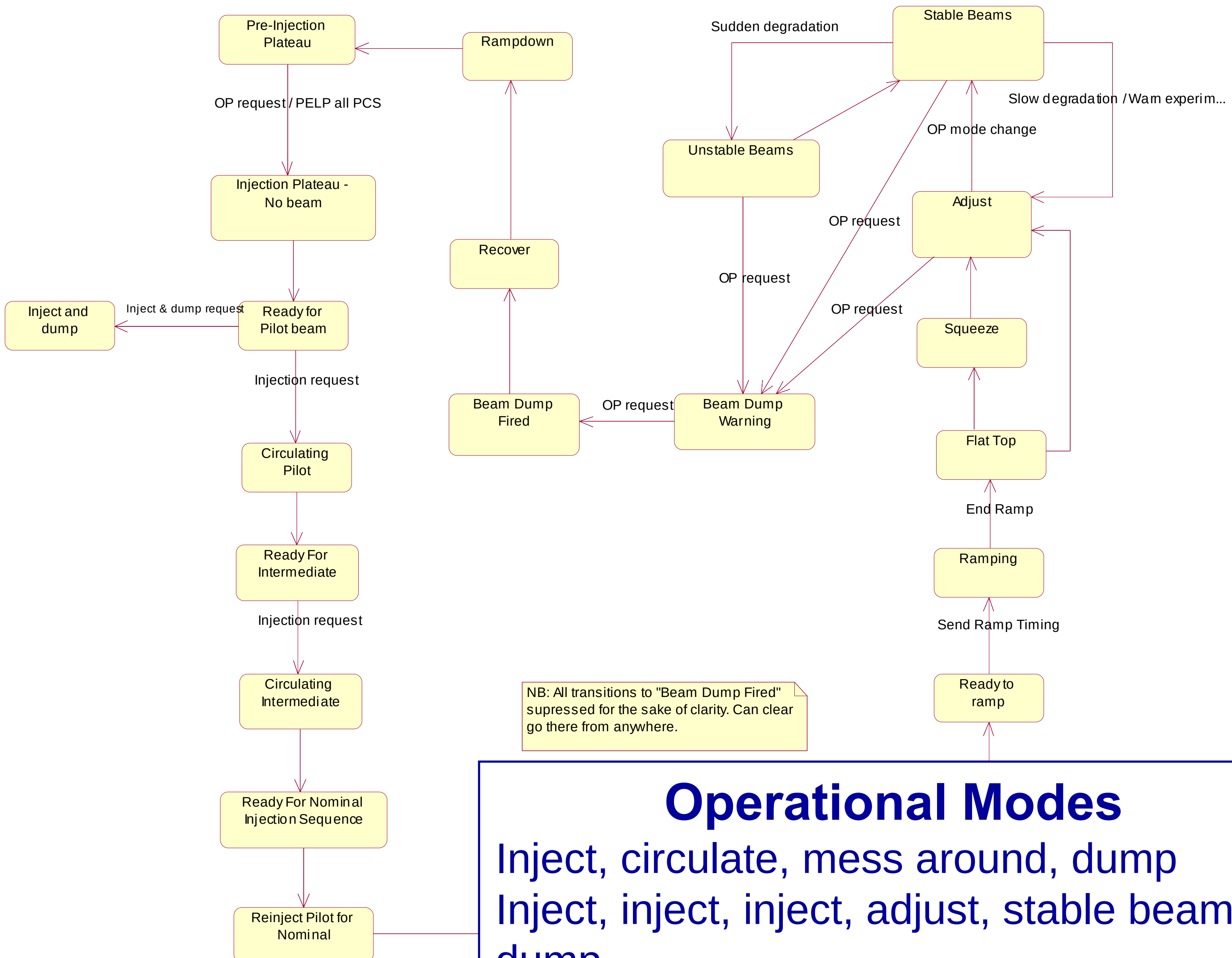
- Opportunities for parallelism, parasitic development
  - Injection region of beam 1 with ongoing commissioning of ring 2.
  - Parasitic beam instrumentation commissioning:
    - transverse beam profiles, beam loss monitors, orbit acquisition, BCT lifetime.
  - Collimators: ring 2/ring 1, momentum/betatron cleaning.
  - RF: ring 1/ring 2. Could imagine RF working on beam 2, BI on ring 1 etc.
  - Orthogonal scans etc.

Full commissioning

		Rings	Total [days] both rings
1	Injection and first turn	2	6
2	Circulating beam	2	3
3	450 GeV - initial	2	5
4	450 GeV - detailed	2	12
5	450 GeV - two beams	1	2
6	Snapback - single beam	2	4
7	Ramp - single beam	2	8
8	Ramp - both beams	1	3
9	7 TeV - setup for physics	1	2
10	Physics un-squeezed	1	-
	TOTAL to first collisions		47
11	Commission squeeze	2	6
12	Increase Intensity	2	6
13	Set-up physics - partially squeezed.	1	2
14	Pilot physics run		

Clear that calibration run will be very useful and allow the commissioning of many systems.

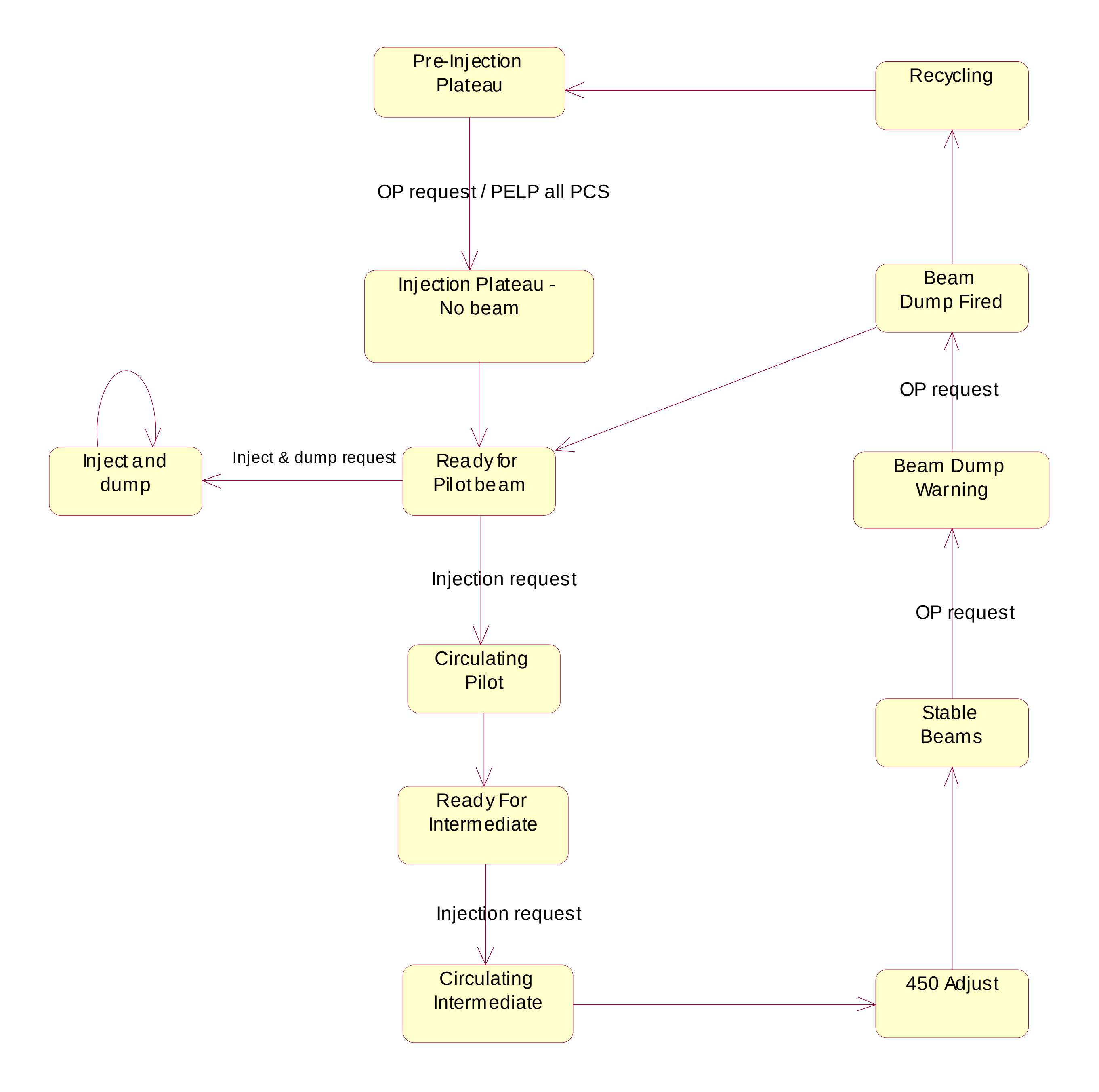
Careful consolidation will be required, however, before pushing to high energy.



Operational Modes

Inject, circulate, mess around, dump

Inject, inject, inject, adjust, stable beams, dump


Pre-Injection Plateau
Recycling
OP request / PELP all PCS
Injection Plateau - No beam
Beam Dump Fired
OP request
Inject and dump
Inject & dump request
Ready for Pilot beam
Beam Dump Warning
Injection request
OP request
Circulating Pilot
Stable Beams
Ready For Intermediate
Injection request
Circulating Intermediate
450 Adjust

Do we need to re-cycle?

- **Either on re-cycle to 1.1 TeV or the de-Gauss**
  - Magnet stability should be good for hours++ (after a wait for the former)
- **However we shall call it a cleansing cycle**
  - It will take 30 – 40 minutes
  - ~ once a shift
  - Cleanses settings as well

Performance

k_b	43	43	156	156
i_b (1010)	2	4	4	10
β^* (m)	17	6	6	6
intensity per beam	$8.6\ 10^{11}$	$1.7\ 10^{12}$	$6.2\ 10^{12}$	$1.6\ 10^{13}$
beam energy (MJ)	.06	.12	.45	1.1
luminosity	10^{28}	$1.3\ 10^{29}$	$4.8\ 10^{29}$	$3\ 10^{30}$
event rate [1] (kHz)	0.4	5	19	120
W rate [2] (per 24h)	0.5	6	21	130
Z rate [3] (per 24h)	0.05	0.6	2	13

Conclusions

- Very useful exercise for operations
  - For many of the same reasons as the Sector Test
  - First pass commissioning of many key systems
  - Wrestle with the ramp etc.
  - Extended period for problem solving and consolidation

- Full beam commissioning to 7 TeV
  - Will undoubtedly go faster and more efficiently
  - Proviso: systematically fill in the blanks and re-commission where necessary