

LHC commissioning

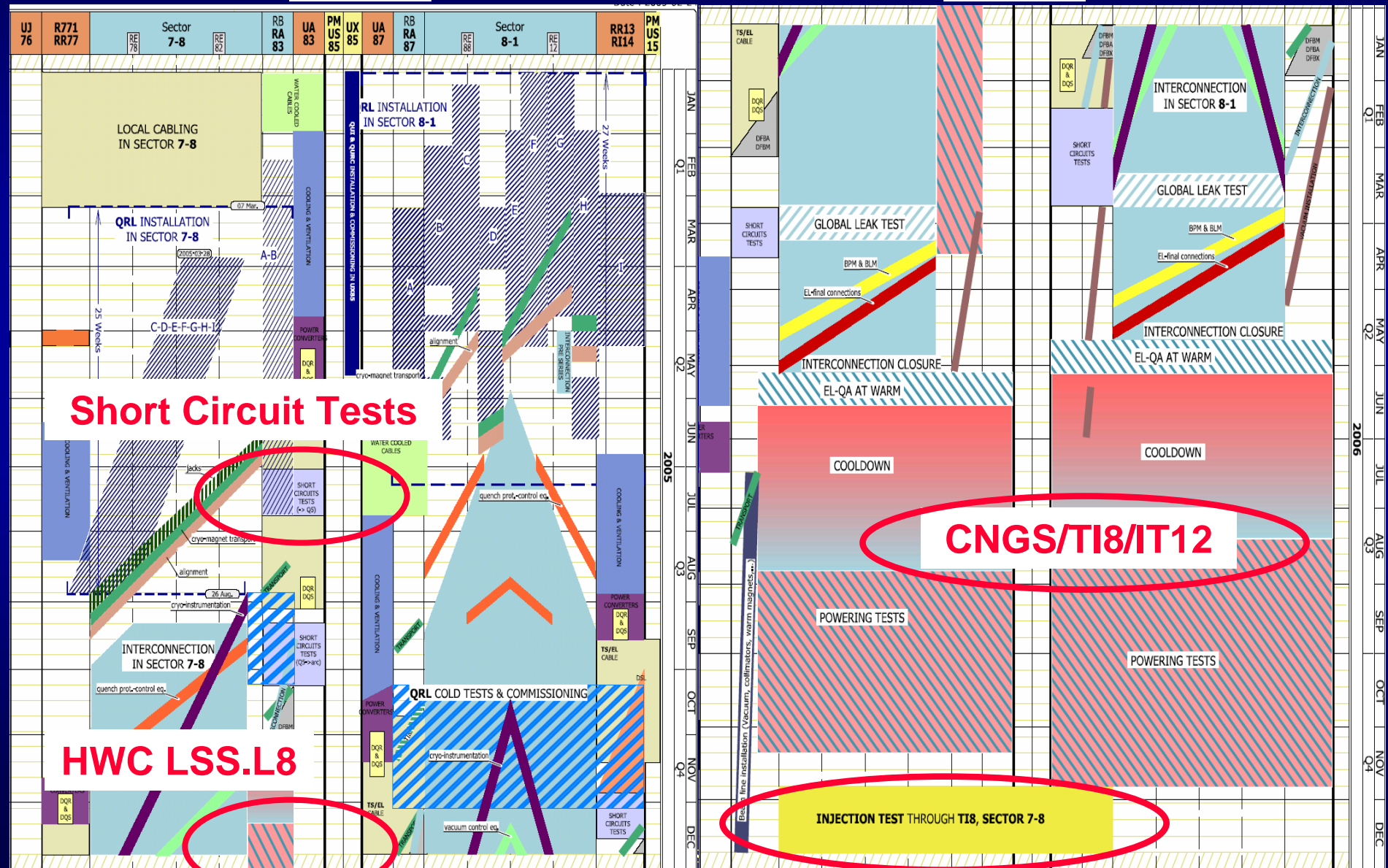
Mike Lamont
AB-OP

22nd June 2005

Detailed planning for 7-8 and 8-1

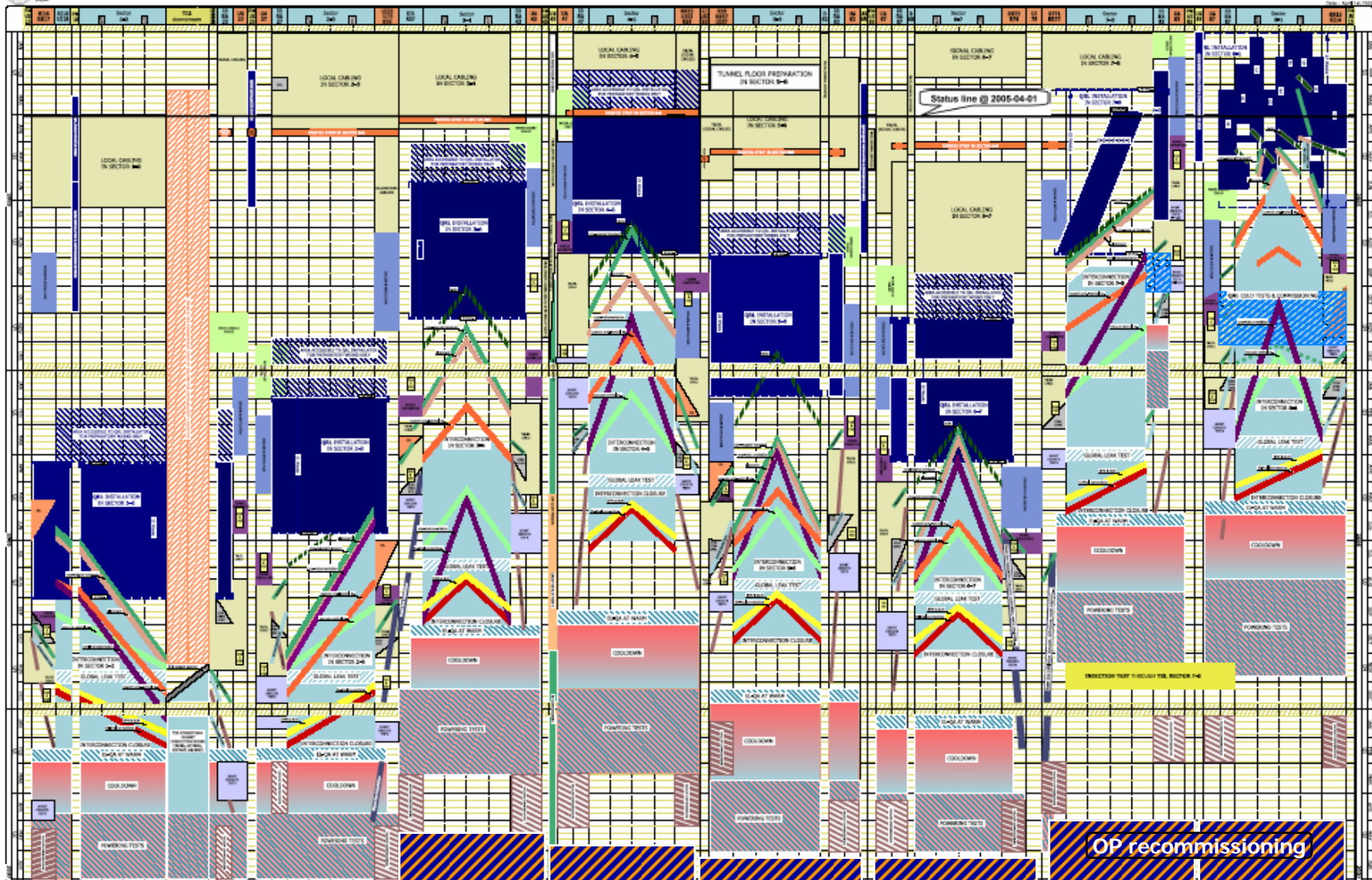
2005

2006



LHC Construction and Installation General Co-ordination Schedule

Status line @ 2005-04-01



OP recommissioning

Machine Checkout

Beam

Preparation

Obvious that meticulous preparation will be key if we are to stand half a chance of efficient commissioning

→ 6 weeks machine checkout following HWC

Clear aim to commission/fix/test everything that can be - **before beam.**

LHC - 2007

ID	Task Name	Start	Finish	Duration	May 2007				Jun 2007				Jul 2007				Aug 2007			
					5/6	5/13	5/20	5/27	6/3	6/10	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19
1	HARDWARE COMMISSIONING	1/1/2007	6/29/2007	26w	[Blue bar from 5/6 to 6/24]															
2	SYSTEM TESTS	1/1/2007	7/31/2007	30.4w	[Yellow bar from 5/6 to 7/22]															
3	MACHINE PROTECTION	4/2/2007	6/29/2007	13w	[Yellow bar from 5/6 to 6/24]															
4	RF CONDITIONING/COMMISSIONING	1/1/2007	6/29/2007	26w	[Yellow bar from 5/6 to 6/24]															
5	ACCESS/INB	7/23/2007	7/31/2007	1.4w													[Yellow bar from 7/23 to 7/29]			
6	MACHINE CHECKOUT	6/14/2007	7/31/2007	6.8w													[Blue bar from 6/14 to 7/22]			
7	TI8	7/2/2007	7/30/2007	4.2w													[Green bar from 7/2 to 7/22]			
8	CHECKOUT	7/2/2007	7/13/2007	2w													[Green bar from 7/2 to 7/9]			
9	WITH BEAM	7/23/2007	7/30/2007	1.2w													[Green bar from 7/23 to 7/29]			
10	T12	7/16/2007	8/2/2007	2.8w													[Blue bar from 7/16 to 8/2]			
11	CHECKOUT	7/16/2007	7/26/2007	1.8w													[Blue bar from 7/16 to 7/22]			
12	WITH BEAM	7/26/2007	8/2/2007	1.2w													[Blue bar from 7/26 to 8/2]			
13																				
14	LHC COMMISSIONING WITH BEAM	8/1/2007	10/30/2007	13w													[Red bar from 8/1 to 10/30]			
15																				

EXIT HWC

EXIT CHECKOUT

EXIT TI8/TI2

Objectives

Commissioning the LHC with beam - Stage One

- Establish colliding beams as quickly as possible
- Safely
- Without compromising further progress

Take two moderate intensity multi-bunch beams to high energy and collide them.

More Specifically

43 on 43 with 3 to 4 x 10¹⁰ ppb to 7 TeV

- **No parasitic encounters**
 - No crossing angle
 - No long range beam
 - Larger aperture
- **Instrumentation**
- **Good beam for RF, Vacuum...**
- **Lower energy densities**
 - Reduced demands on beam dump system
 - Collimation
 - Machine protection
- **Luminosity**
 - 10³⁰ cm⁻²s⁻¹ at 18 m
 - 2 x 10³¹ cm⁻²s⁻¹ at 1 m

Beam

- **Pilot Beam:**
 - Single bunch, 5 to 10×10^9 protons
 - Possibly reduced emittance
- **Intermediate single:**
 - 3 to 4×10^{10} ppb
- **4 bunches etc. pushing towards...**
- **43 (to 156) bunches**
 - 3 to 4×10^{10} ppb

Will stepping up & down
in intensity/number of
bunches through the
phases

The challenge

- **EQUIPMENT**
 - Collimators/TDI/TCDQ etc.
 - Beam Dump
 - Power converters,
 - Kickers
 - RF, TFB, LFB
 - Spectrometers & compensation
- **INSTRUMENTATION**
 - Distributed systems:
 - BLMs, BPMs,
 - Standalone:
 - BCT, BTV, AGM, BIPM, BWS, Schottky..
 - Tune, Chromaticity, Coupling
 - Luminosity monitors
 - Radiation Monitors
- **REFERENCE MAGNET SYSTEM**
- **MACHINE PROTECTION**
- **VACUUM, CRYOGENICS, QPS**

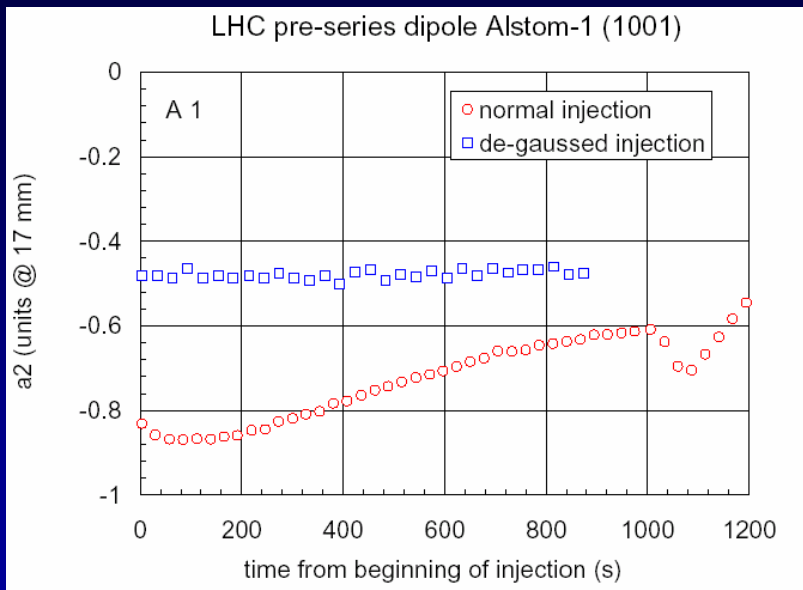
Settings, functions,
monitoring, display,
post mortem, control,
acquisition,
concentration,
archiving, alarms,
interlocks



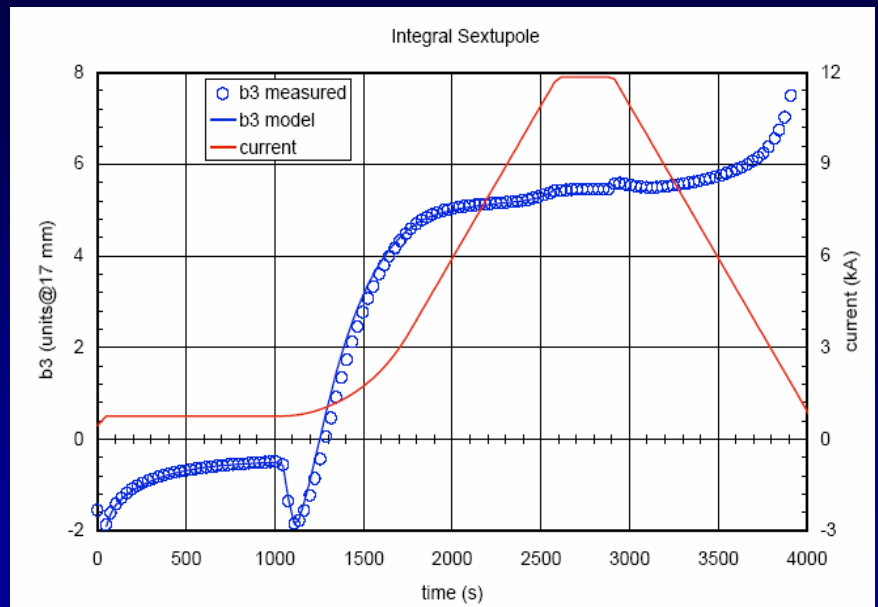
**Driving the machine
through the cycle**

Magnet errors, crossing
angles, snapback, ramping,
squeezing, colliding, orbit,
parameter control,
optimisation etc. etc.

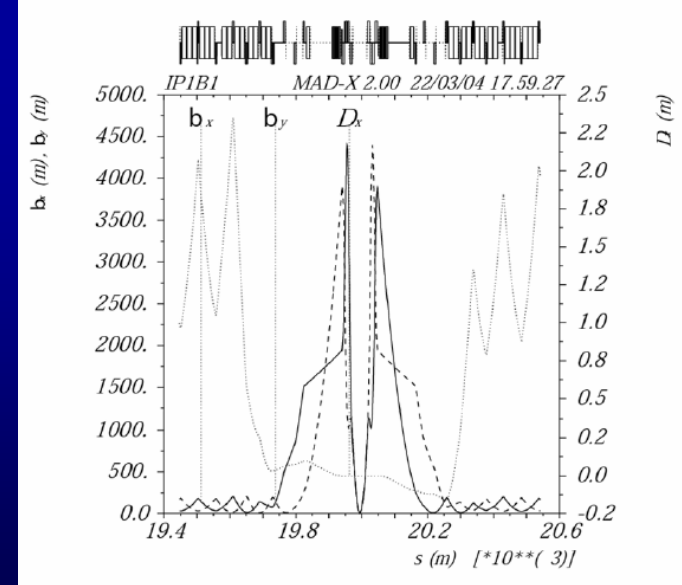
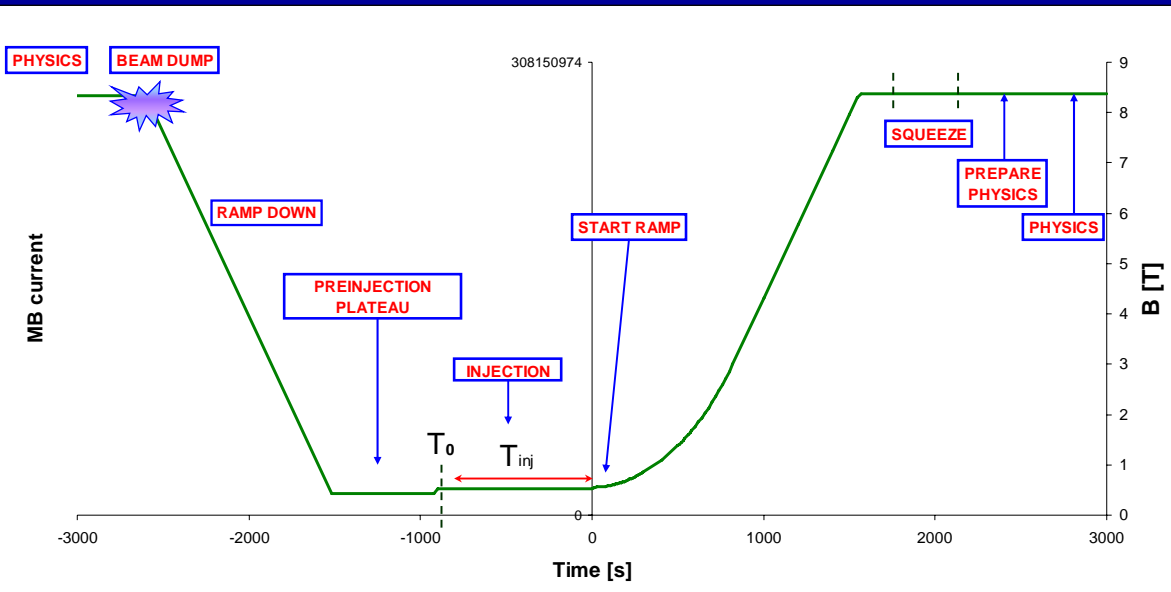




De-Gauss



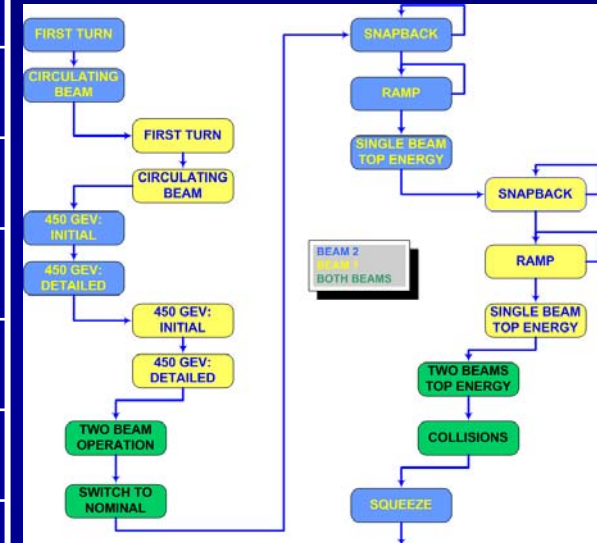
Snapback



Squeeze

PLANNING

- 1 Injection
- 2 First turn
- 3 Circulating beam
- 4 450 GeV: initial commissioning
- 5 450 GeV: detailed measurements
- 6 450 GeV: 2 beams
- 7 Nominal cycle
- 8 Snapback – single beam
- 9 Ramp – single beam
- 10 Single beam to physics energy
- 11 Two beams to physics energy
- 12 Physics
- 13 Commission squeeze
- 14 Physics partially squeezed



Pilot++

At each phase:

- **Equipment commissioning with beam**
- **Instrumentation commissioning**
- **Checks with beam**
 - **BPM Polarity, corrector polarity, BPM response**
- **Machine protection**
- **Beam measurements**
 - **beam parameter adjustment, energy, linear optics checks, aperture etc. etc.**

to the levels required.

Looking for an efficient commissioning path to get us to the above objectives

First turn

- Commission injection region
- Instrumentation
- Threading

PILOT

RING 1
RING 2

Establish circulating beam

- Circulating low intensity beam

PILOT

RING 1
RING 2

450 GeV Initial

- Polarities and aperture checked.
- Basic optics checks performed.
- First pass commissioning of BI performed.
- Phase 1 of machine protection system commissioning performed. .
- Beam Dump commissioned with beam

SINGLE
INTERMEDIATE

RING 1
RING 2

450 GeV Detailed

- Well-adjusted beam parameters, detailed optics checks
- Fully functioning beam instrumentation.
- Machine protection as required for ramp
- RF - beam control loops operational and adjusted

SINGLE
INTERMEDIATE
++

RING 1
RING 2

Two beam operation

- 2 beams, well-adjusted beam parameters,
- beam instrumentation, cross talk etc.

Switch to nominal

- 2 beams, well-adjusted beam parameters,
- beam instrumentation, cross talk etc.

Snapback

- Single beam, good transmission through snapback
- Requisite measurements (orbit, tune, chromaticity)

PILOT++

RING 1
RING2

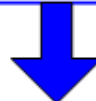


Ramp Single Beam

- Single beam, good transmission to top energy
- **Commission beam dump in ramp**
- Stops in ramp - measurements
- RF

PILOT++

RING 1
RING2



Two beams to top energy

- Two beams, good transmission to top energy
- Measurements

43 x 43

COLLIDE



Squeeze

- Single beam - step through squeeze
- Parameter control, measurements

SINGLE
INTERMEDIATE

RING 1
RING2

Stage 1 - How long?

	Phase	R1/2	Time [days]	
	Injection	2	1	2
1	First turn	2	3	6
2	Circulating beam	2	3	6
3	450 GeV: initial commissioning	2	4	8
4	450 GeV: detailed measurements	2	4	8
5	450 GeV: 2 beams	1	2	2
6	Nominal cycle	1	5	5
7	Snapback – single beam	2	3	6
8	Ramp – single beam	2	4	8
9	Single beam to physics energy	2	2	4
10	Two beams to physics energy	1	3	3
11	Physics	1	2	2
12	Commission squeeze	2	4	
13	Physics partially squeezed	1		
	TOTAL TIME (WITH BEAM)			60

Stage 1 - Luminosities

- 43 to 156 bunches per beam
- N bunches displaced in one beam for LHCb
- Push one or all of:
 - To 156 bunches per beam
 - Squeeze
 - Bunch intensity

IP 1 & 5

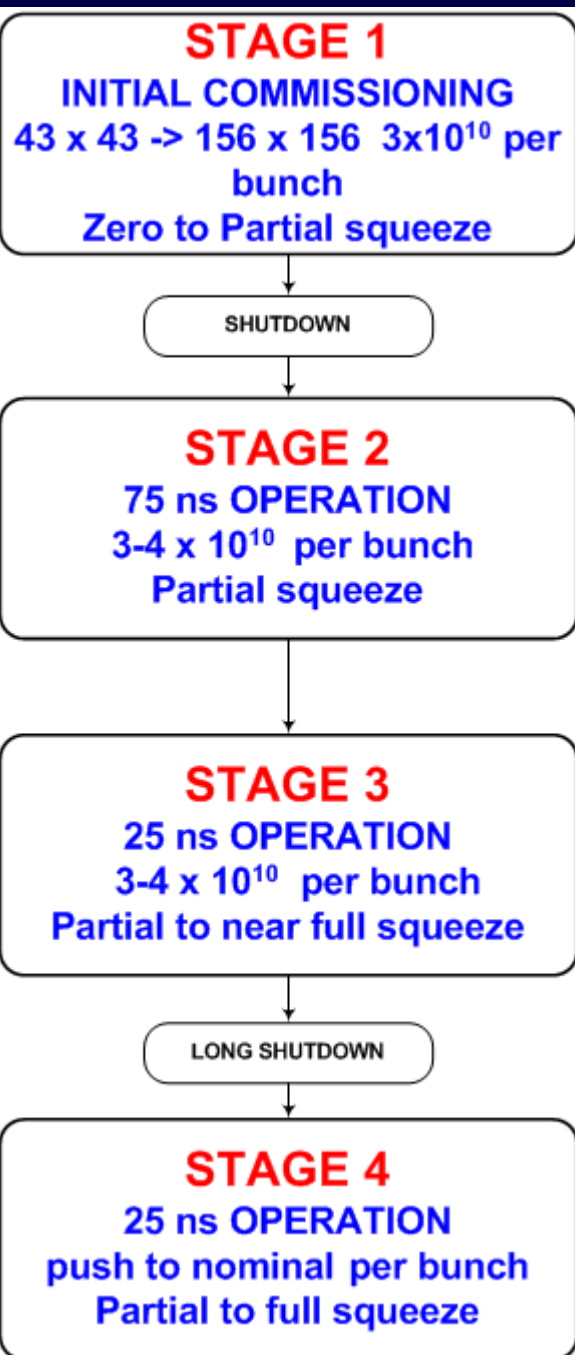
Bunches	β^*	I_b	Luminosity	Event rate
1 x 1	18	10^{10}	10^{27}	Low!
43 x 43	18	3×10^{10}	3.8×10^{29}	0.05
43 x 43	4	3×10^{10}	1.7×10^{30}	0.21
43 x 43	2	4×10^{10}	6.1×10^{30}	0.76
156 x 156	4	4×10^{10}	1.1×10^{31}	0.38
156 x 156	4	9×10^{10}	5.6×10^{31}	1.9
156 x 156	2	9×10^{10}	1.1×10^{32}	3.9

LHCb – stage 1

Displaced vertex – need to displace some bunches in the beam with 43x43 and 156x156

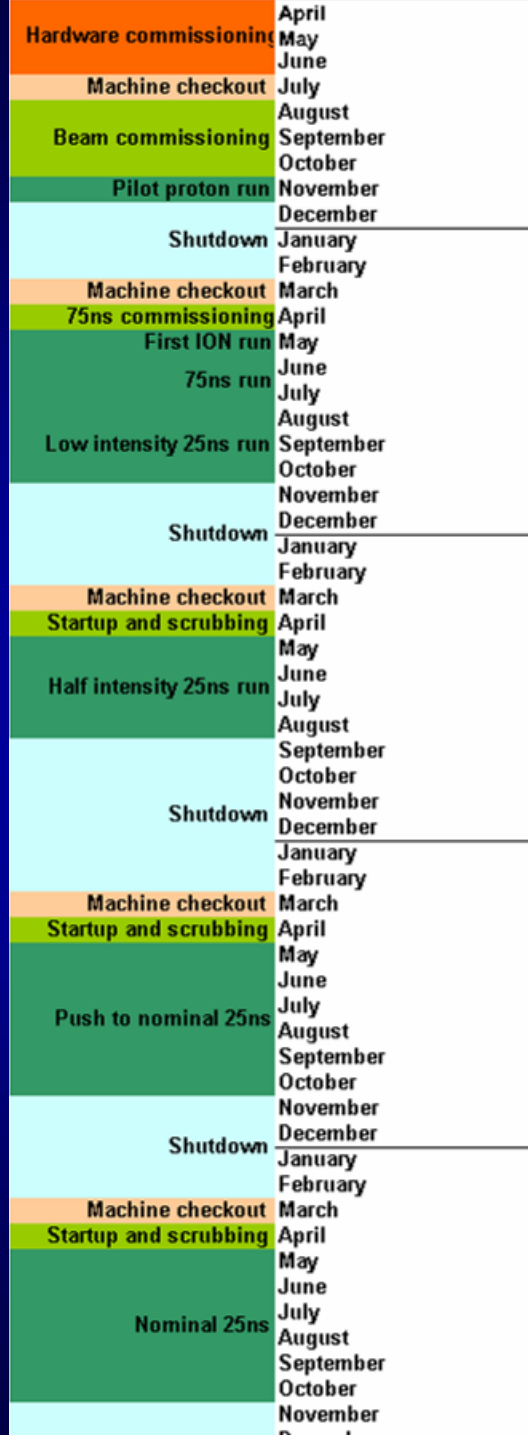
Displaced Bunches	β^* IP8	I_b	Luminosity	Events per crossing
4/43	10	4×10^{10}	1.1×10^{29}	0.15
4/43	2	4×10^{10}	5.7×10^{29}	0.76
12/43	2	4×10^{10}	1.7×10^{30}	0.76
24/156	10	4×10^{10}	6.9×10^{29}	0.15
24/156	2	4×10^{10}	3.4×10^{30}	0.76

Note: displacing bunches will lead to a concomitant reduction in the luminosity at the other IPs



Year one[+] operation:
 Lower beam intensity/luminosity:
 Event pileup
 Electron cloud
 Phase 1 collimator impedance etc.
 Equipment restrictions
 Relaxed squeeze, lower intensities, 75 ns. bunch spacing

Phase 2 Collimation
 Full Beam Dump
 Scrubbed



Stage 2 – 75ns

- **Parameter tolerances:**
 - will necessarily tightened up. Optics/beta beating under reasonable control (and measured)
- **Commission crossing angles. Re-commission ramp and squeeze**
- **Injection:**
 - long range beam-beam, effect on dynamic aperture,
- **Need for feedback**
 - orbit plus adequate control of tune and chromaticity through snapback.
- **Lifetime and background optimization in physics**
 - with a crossing angle and reduced aperture needs to be mastered.
- **Bunch train bunch-to-bunch variations, implications for beam instrumentation.**
- **Emittance conservation through the cycle**
 - has to be well under control & we have to be able to measure it. Associated BI has to be fully commissioned.
- **Squeeze**
 - only partially commissioned up to now, needs to be well mastered including the implications of crossing angle and long-range beam-beam.

Plus Machine Protection etc

Give us a month...



Damage limit at 450 GeV:
1 full nominal batch » damage limit

Verena Kain

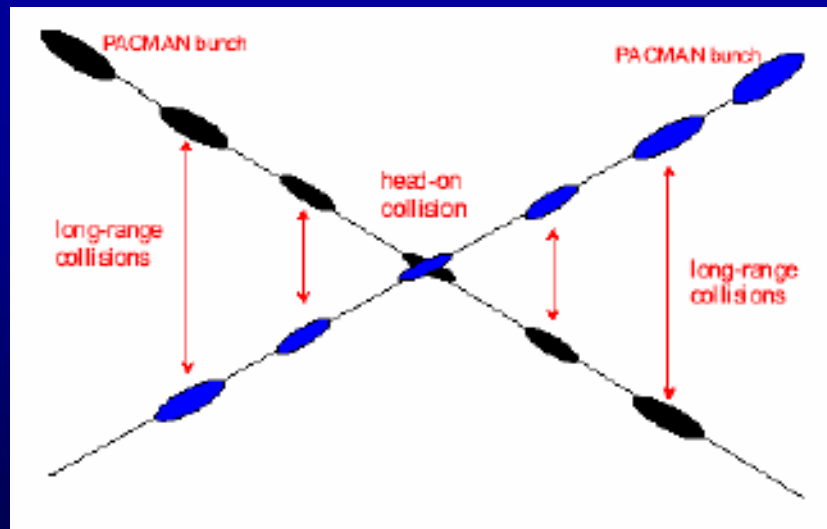
25th of October: MSE trip during high intensity extraction. Damage of QTRF pipe and magnet.

~25cm long hole in chamber



75 ns - performance

Bunches	β^*	I_b	Luminosity	Events per crossing
936 x 936	10	4×10^{10}	2.3×10^{31}	0.13
936 x 936	4	4×10^{10}	5.6×10^{31}	0.32
936 x 936	2	4×10^{10}	1.1×10^{32}	0.64



Stage 3 – 25ns Luminosities

- Start with bunch intensities below electron cloud threshold [?!]
- Increase bunch intensities to beam dump & collimator limit
- Tune IP2 and IP8 to meet experimental needs

Number of bunches per beam	2808	2808	2808
β^* in IP 1, 2, 5, 8 (m)	0.55,10,0.55,10	0.55,10,0.55,10	0.55,10,0.55,10
Crossing Angle (μrad)	285	285	285
Bunch Intensity	$3 \cdot 10^{10}$	$5 \cdot 10^{10}$	$1.15 \cdot 10^{11}$
Luminosity IP 1 & 5 ($\text{cm}^{-2} \text{s}^{-1}$)	$\sim 7 \cdot 10^{32}$	$\sim 2 \cdot 10^{33}$	10^{34}
Luminosity IP 2 & 8 ($\text{cm}^{-2} \text{s}^{-1}$)	$\sim 4 \cdot 10^{31}$	$\sim 1 \cdot 10^{32}$	$\sim 5 \cdot 10^{32}$

Requests from Experiments

- **Single beam runs**
- **Early operation:**
 - Displace some bunches during 43/156 for collisions in LHCb
 - **As fast as possible to stable operations with 25 ns bunch spacing, $L \sim 10^{33} \text{ cm}^{-2}\text{s}^{-1}$**
 - However, experiments will take anything...
- **Tune luminosity, spectrometer magnets, and β^***
- **LHCb:**
 - squeeze with low bunch intensities [single event per crossing, $2 \cdot 10^{32}$ @ 25 ns] to $\beta^* = 2 \text{ m}$
- **Alice**
 - protons, $L \sim 10^{29} \text{ cm}^{-2}\text{s}^{-1}$
 - Stable conditions by β^* rather than separated beam – limits under review

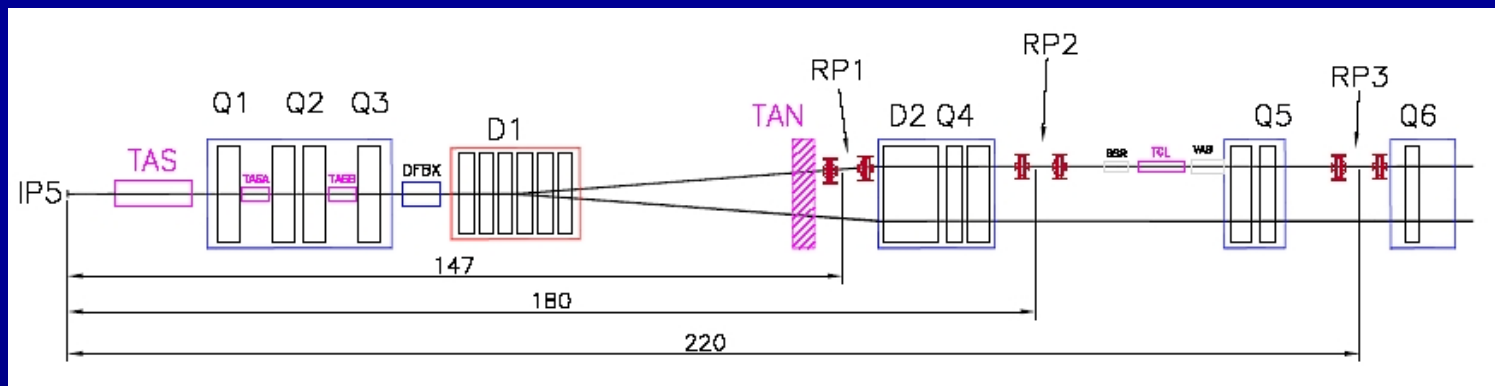
Requests from experiments

- **75 ns:**
 - 2 weeks sufficient [synchronisation, background studies]
 - Avoid pile up
 - LHCb
 - to 25 ns ASAP [avoiding loss in B rate]
 - again tuning beta* to 2 m if possible
- **Low Energy Runs:**
 - Totem: \sqrt{s} 1.8 TeV & 8 TeV
 - Alice: pp @ 5.5 TeV (\sqrt{s} ~ nominal pb-pb)
- **Pb-Pb**
 - Alice: 4 week run after first long shutdown
 - plus collisions in CMS & Atlas

Requests from experiments

- **TOTEM**

- $\beta^* = 1540$ m., 43 bunches, low emittance
- Plus large t elastic scattering at 18 m
 - 3 x 1-day runs at 1540 plus 2 short runs at 18 m
- Roman Pots at 10σ , high beam stability, low BGs



RPs at $\sim 10\sigma$ imply :
collimators must be set to 6/7 s.
 $e^* \sim 1$ mm, ~ 4 times smaller than nominal :
→ collimator gaps ≤ 1 mm

Requires special machine conditions—
similar to polarization at LEP.
The difficulty and challenge of TOTEM
operation is coming from the requested
precision for both optics & beams.

Totem – the challenge

- **Machine setup**
 - Optics: $\beta^* = 1540, 200, 18$ m plus injection, ramp ...
 - 1 to 3 x 24 hours
 - Low emittance beam
 - 2 stage collimation → collimators closed < 1 mm.
- **Stringent accuracy and stability demands**
 - β^* to 1%
 - β at roman pots < 5%
 - Emittance < 1%
 - Crossing angle < 0.2 μ rad
 - Orbit stability 5-10 μ m
 - Energy calibration ~ 0.05%



**Considerable MD
time required**

**Implies a very good control of optics and all key beam parameters,
good performance of beam instrumentation,
beyond that expected in the first months of operation**

See: Operation for TOTEM, J. Wenninger, Chamonix 2005

Conclusions

Commissioning with beam will be somewhat of a challenge

- **PREPARATION**

- **OBJECTIVES**

 - Stage 1

- **PLANNING**

 - Before beam

 - Stage 1...



- <http://cern.ch/lhc-injection-test>
- <http://cern.ch/lhc-commissioning>