LHC commissioning

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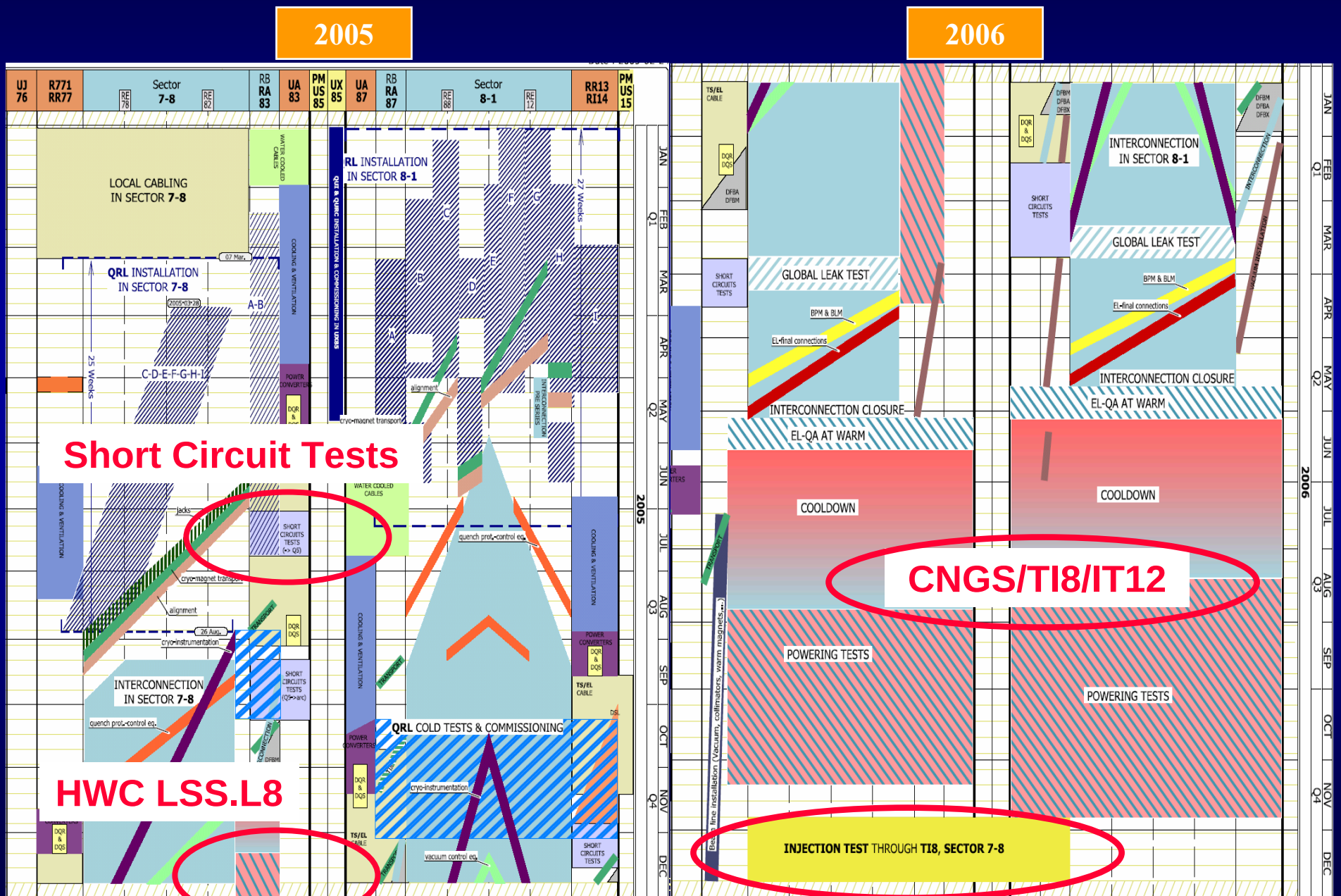
AB-OP

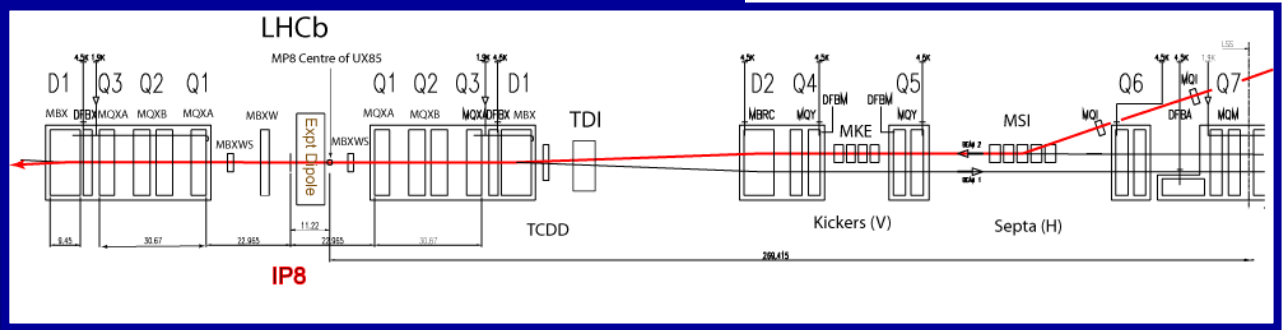
22nd June 2005

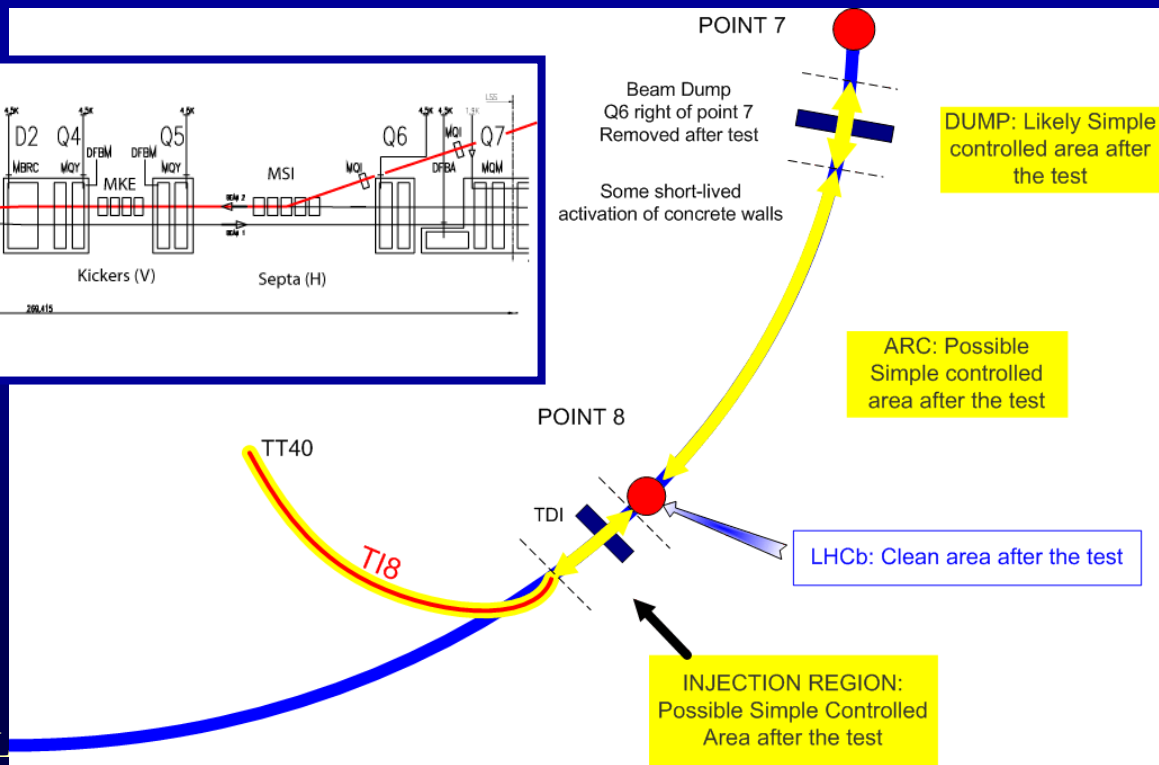
Detailed planning for 7-8 and 8-1



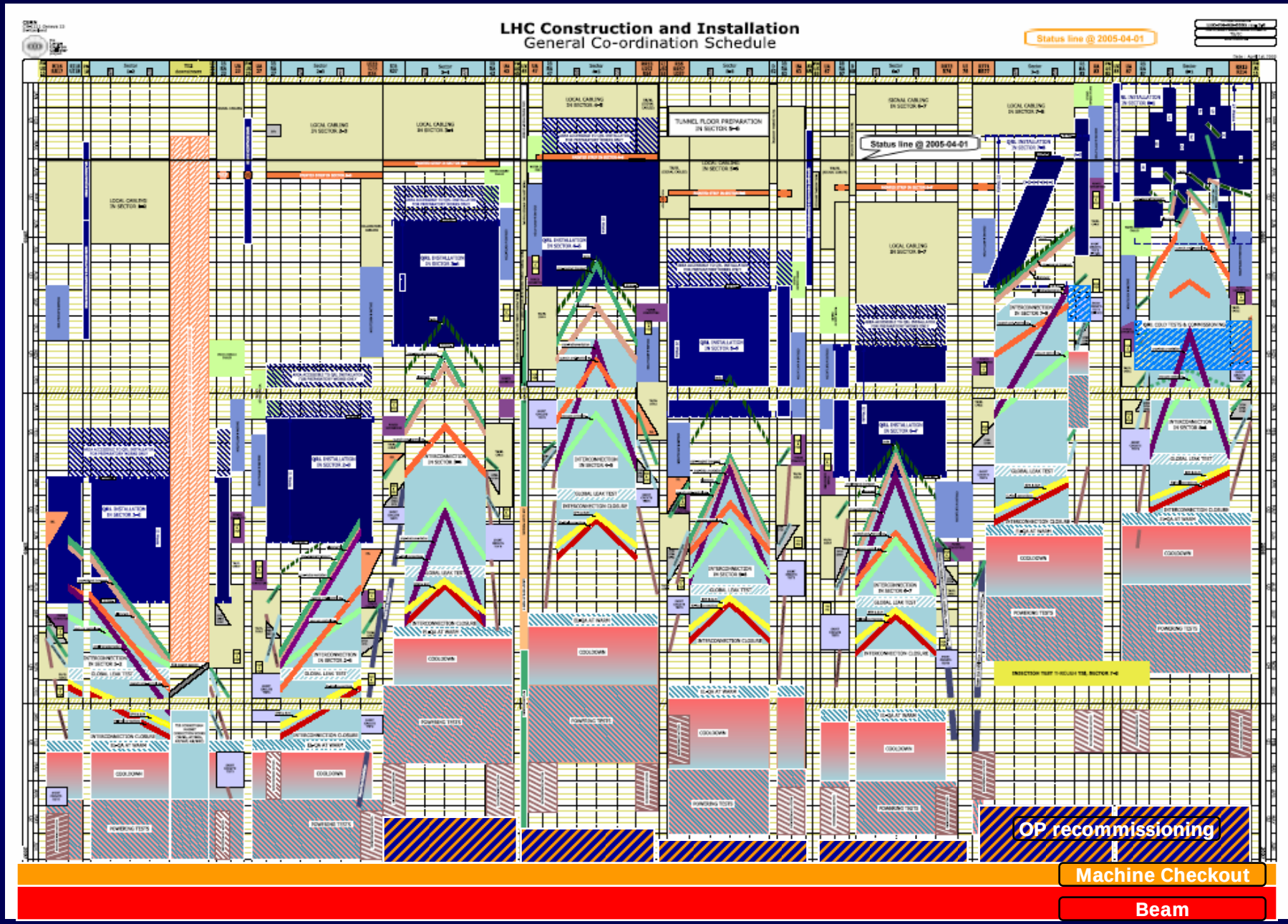
Sector Test

- Rigorous check of ongoing installation and hardware commissioning
- Pre-commission essential acquisition and correction procedures.
  - Commission injection system
  - Commission Beam Loss Monitor system
  - Commission trajectory acquisition and correction.
  - Linear optics checks:
  - Mechanical aperture checks.
  - Field quality checks.
  - Test the controls and correction procedures
- Hardware exposure to beam will allow first reality checks of assumptions of quench limits etc.





2 weeks Nov-Dec 2006


LHC Construction and Installation
General Co-ordination Schedule
Status line @ 2005-04-01
Status line @ 2005-04-01
OP recommissioning
Machine Checkout
Beam

Preparation

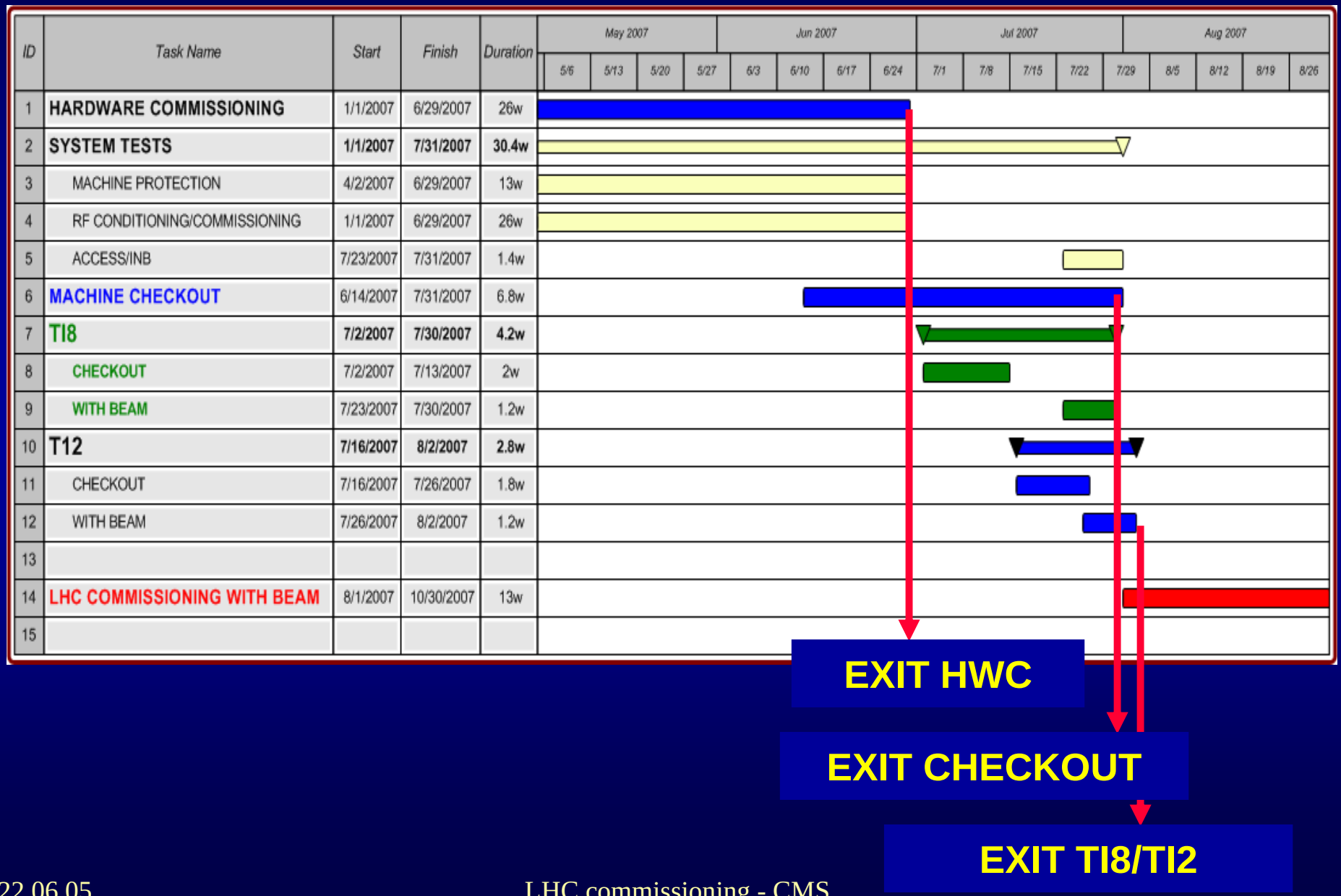
Obvious that meticulous preparation will be key if we are to stand half a chance of efficient commissioning

→ 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
1	HARDWARE COMMISSIONING	1/1/2007	6/29/2007	26w
2	SYSTEM TESTS	1/1/2007	7/31/2007	30.4w
3	MACHINE PROTECTION	4/2/2007	6/29/2007	13w
4	RF CONDITIONING/COMMISSIONING	1/1/2007	6/29/2007	26w
5	ACCESS/INB	7/23/2007	7/31/2007	1.4w
6	MACHINE CHECKOUT	6/14/2007	7/31/2007	6.8w
7	TI8	7/2/2007	7/30/2007	4.2w
8	CHECKOUT	7/2/2007	7/13/2007	2w
9	WITH BEAM	7/23/2007	7/30/2007	1.2w
10	T12	7/16/2007	8/2/2007	2.8w
11	CHECKOUT	7/16/2007	7/26/2007	1.8w
12	WITH BEAM	7/26/2007	8/2/2007	1.2w
13				
14	LHC COMMISSIONING WITH BEAM	8/1/2007	10/30/2007	13w
15				



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 10^{10} 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**
  - **10^{30} $cm^{-2}s^{-1}$ at 18 m**
  - **2 x 10^{31} $cm^{-2}s^{-1}$ at 1 m**

Beam

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

⊗

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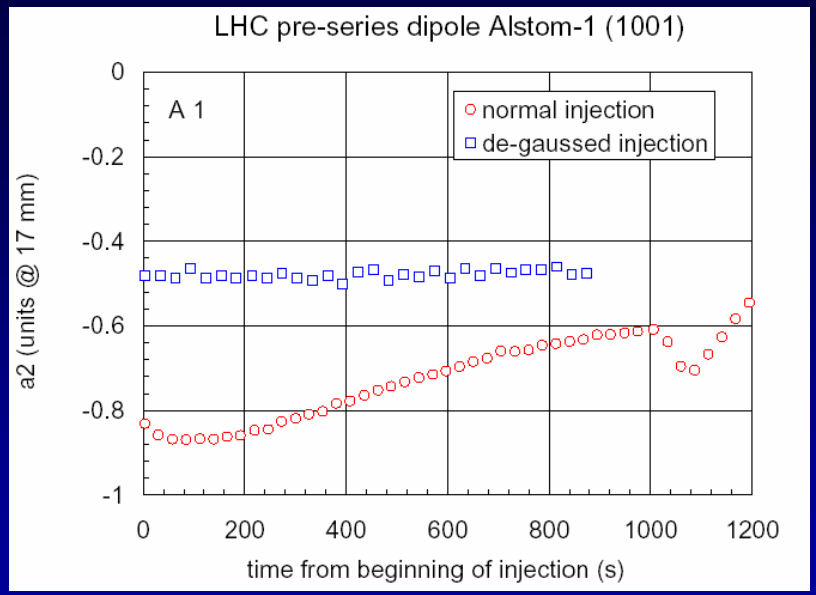
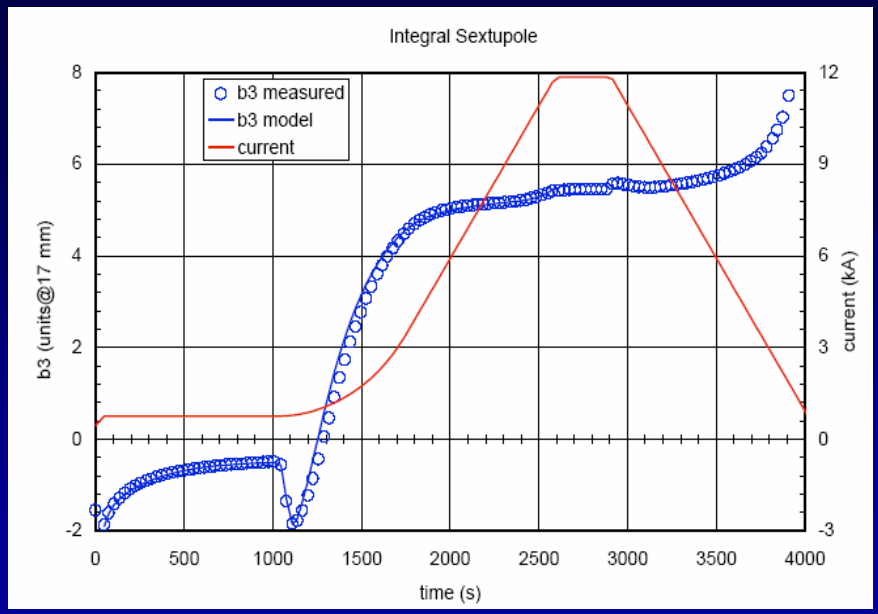
Driving the machine through the cycle

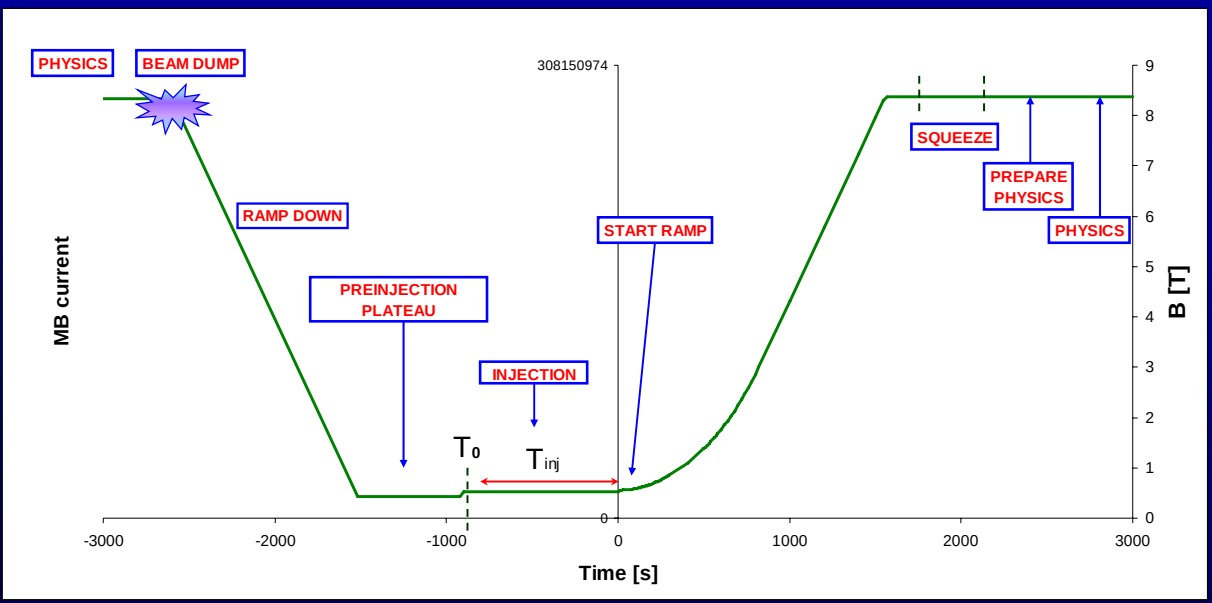
Magnet errors, crossing angles, snapback, ramping, squeezing, colliding, orbit, parameter control, optimisation etc. etc.

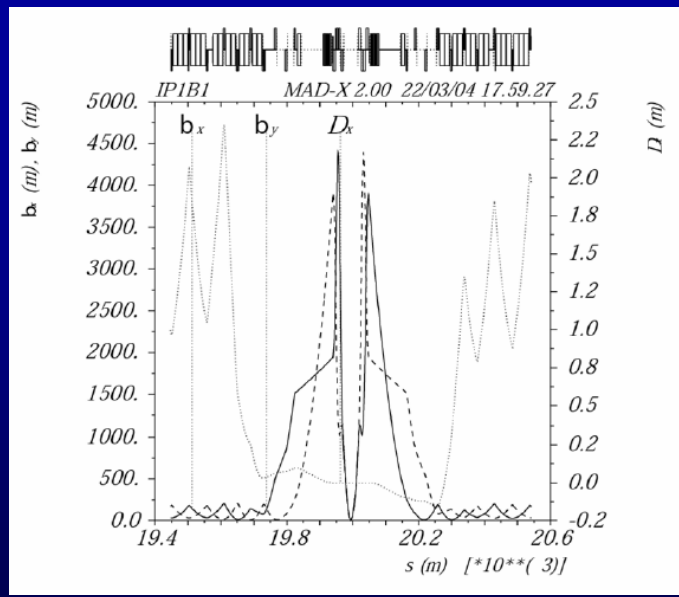


De-Gauss



Snapback

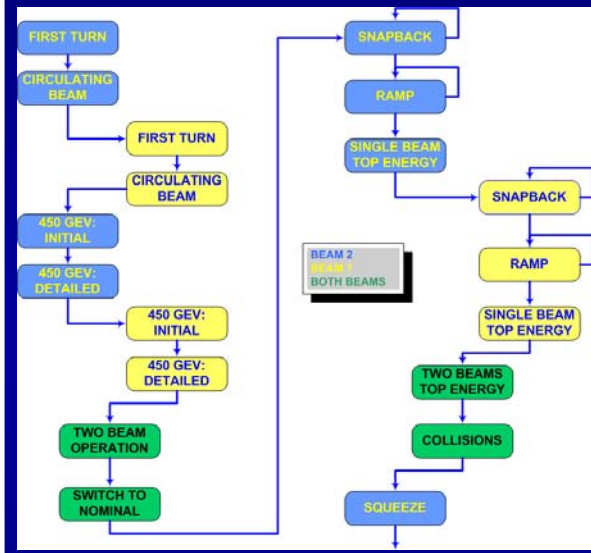




Squeeze

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



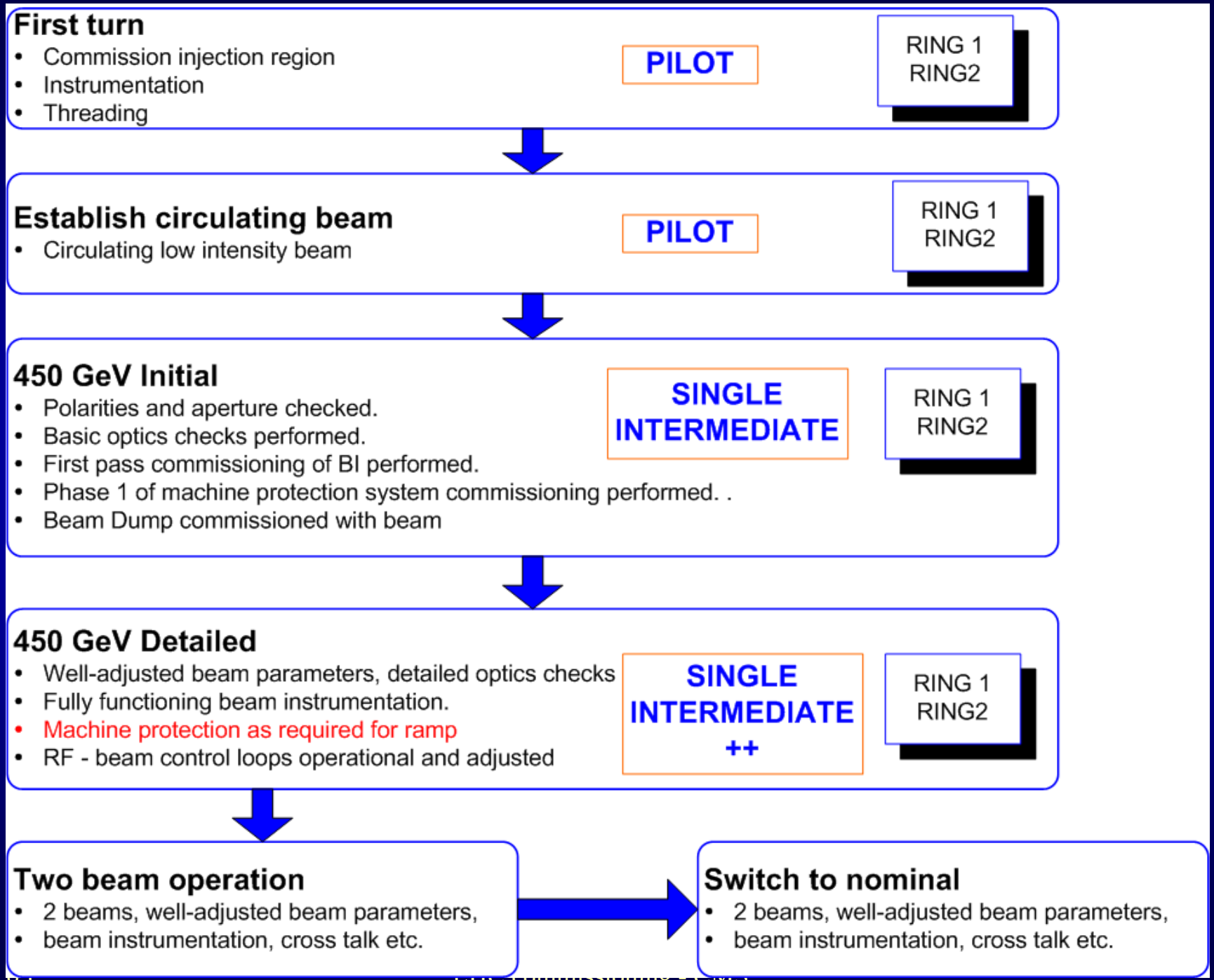
Pilot++

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
RING2
Establish circulating beam
• Circulating low intensity beam
PILOT
RING 1
RING2
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
RING2
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
RING2
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

STAGE 1
INITIAL COMMISSIONING
43 x 43 -> 156 x 156 $3x10^{10}$ per bunch
Zero to Partial squeeze

SHUTDOWN

STAGE 2
75 ns OPERATION
3-4 x 10^{10} per bunch
Partial squeeze

STAGE 3
25 ns OPERATION
3-4 x 10^{10} per bunch
Partial to near full squeeze

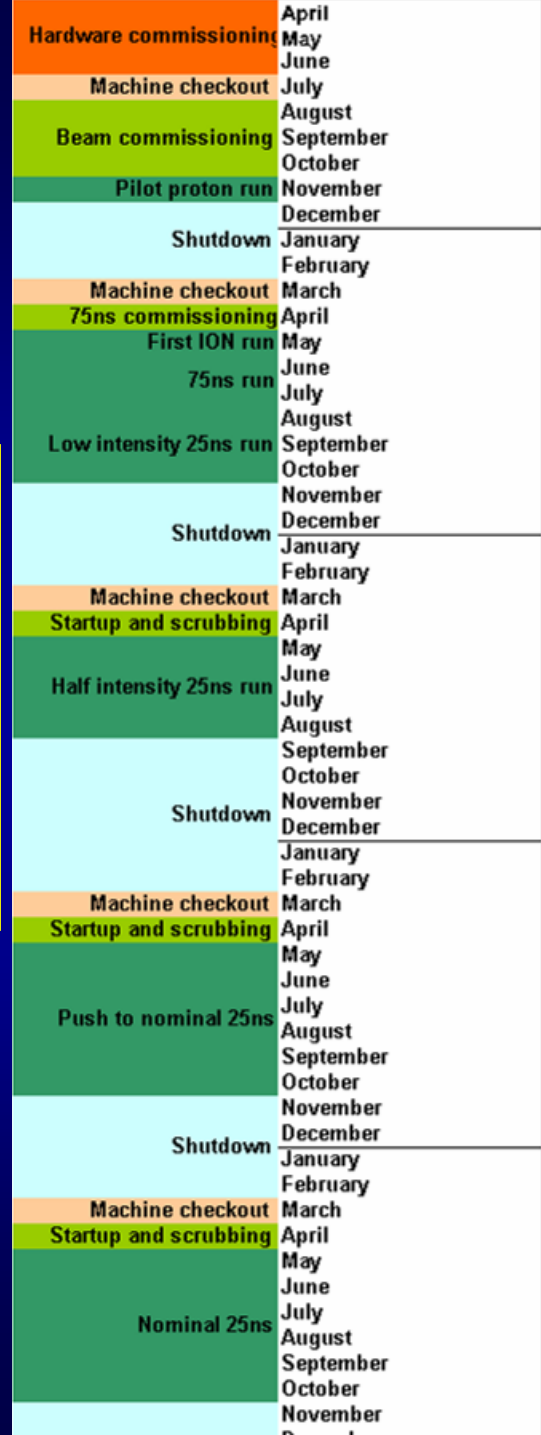
Year one[+] operation:
Lower beam intensity/luminosity:
- Event pileup
- Electron cloud
- Phase 1 collimator impedance etc.
- Equipment restrictions

Relaxed squeeze, lower intensities, 75 ns. bunch spacing

LONG SHUTDOWN

STAGE 4
25 ns OPERATION
push to nominal per bunch
Partial to full squeeze

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.

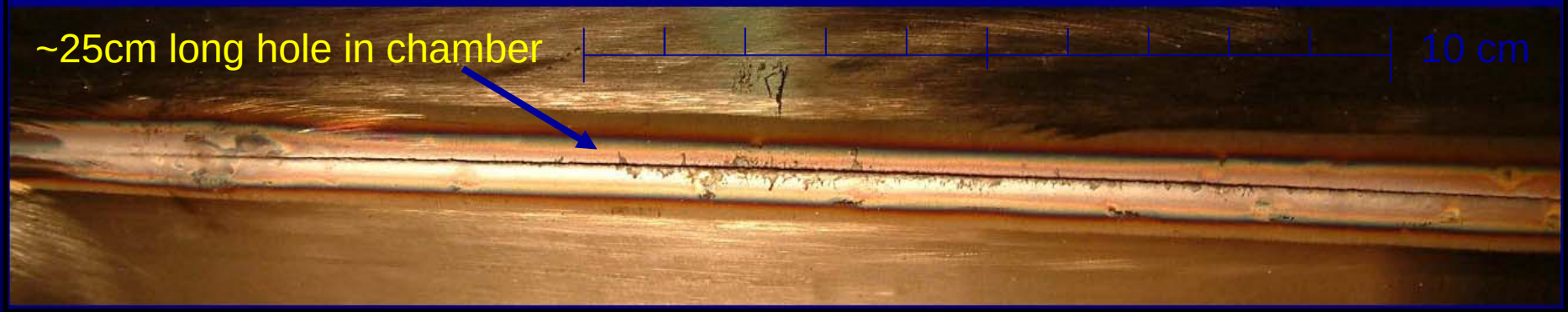
Plus Machine Protection etc

Give us a month…

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

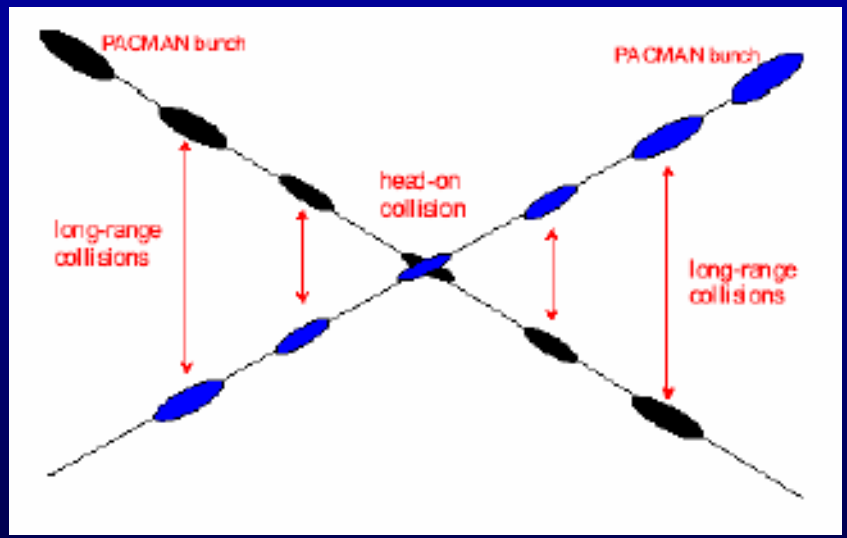
Verena Kain

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



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	$3\ 10^{10}$	$5\ 10^{10}$	$1.15\ 10^{11}$
Luminosity IP 1 & 5 ($cm^{-2}\ s^{-1}$)	$\sim 7\ 10^{32}$	$\sim 2\ 10^{33}$	10^{34}
Luminosity IP 2 & 8 ($cm^{-2}\ s^{-1}$)	$\sim 4\ 10^{31}$	$\sim 1\ 10^{32}$	$\sim 5\ 10^{32}$

Requests from Experiments

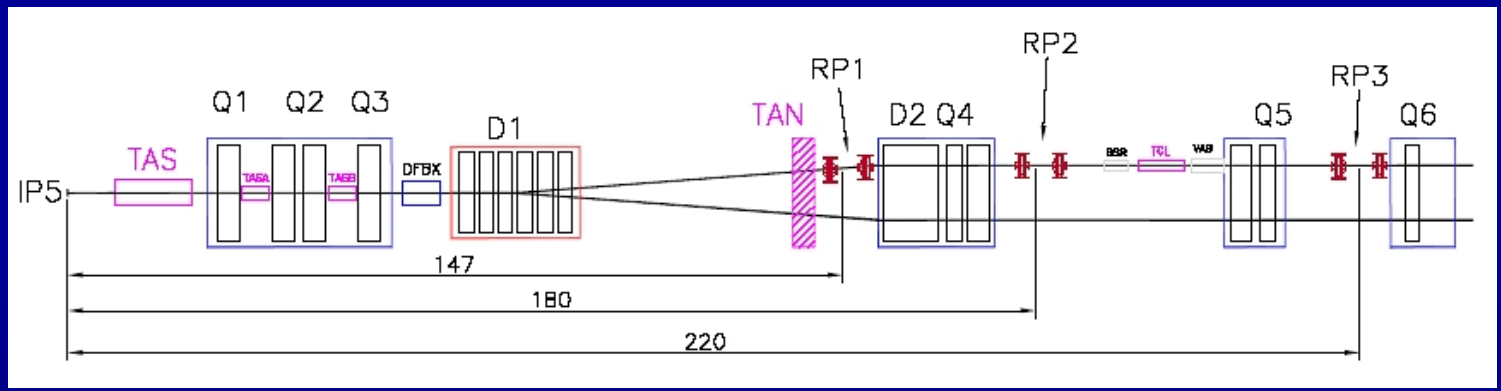
- Single beam runs
- Early operation:
  - Displace some bunches during 43/156 for collisions in LHCb
  - As fast as possible to stable operations with 25 ns bunch spacing, L ~ 10^{33} $cm^{-2}s^{-1}$
  - However, experiments will take anything…
- Tune luminosity, spectrometer magnets, and β^*
- LHCb:
  - squeeze with low bunch intensities [single event per crossing, 2 10^{32} @ 25 ns] to beta* = 2 m
- Alice
  - protons, L ~ 10^{29} $cm^{-2}s^{-1}$
  - 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: √s 1.8 TeV & 8 TeV
  - Alice: pp @ 5.5 TeV (√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 10 σ, high beam stability, low BGs**



RPs at ~10σ imply :
collimators must be set to 6/7 s.
e* ~ 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: β^* = 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 μrad
  - Orbit stability 5-10 μm
  - 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**