LHC Commissioning with Beam Overall Strategy

mostly Mike Lamont

AB-OP

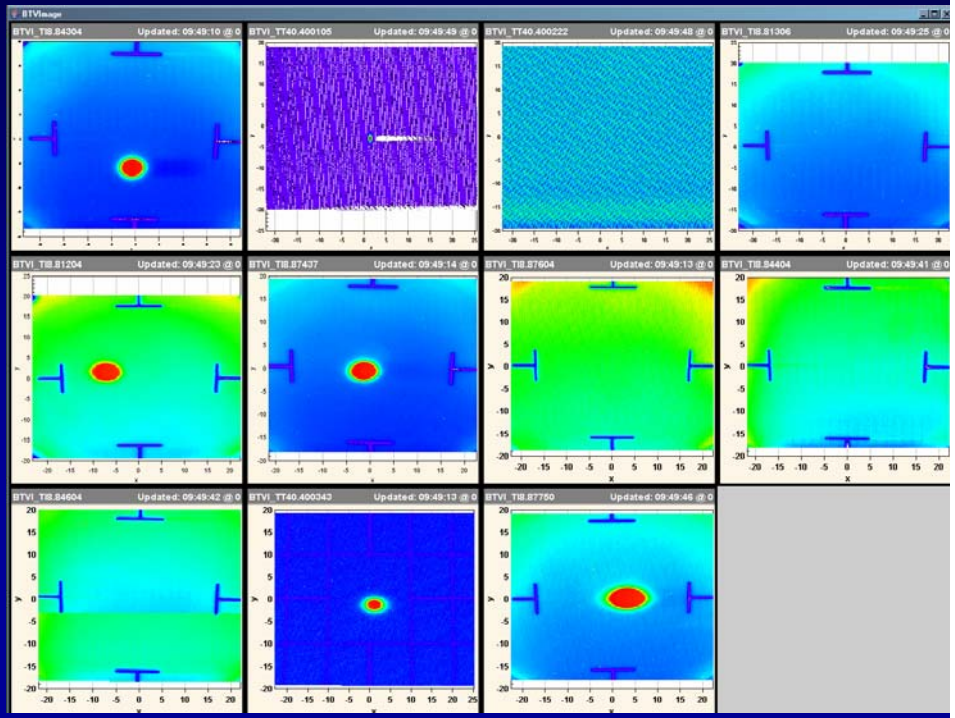
6th April 2005

a little from Elvin Harms

17 August 2005

Commissionig has begun - TI8

- **Beam down – first shot**
  - **Sept/Oct 2004**
- **Full set of measurements**
  - **optics, aperture etc.**



Lionel Mestre

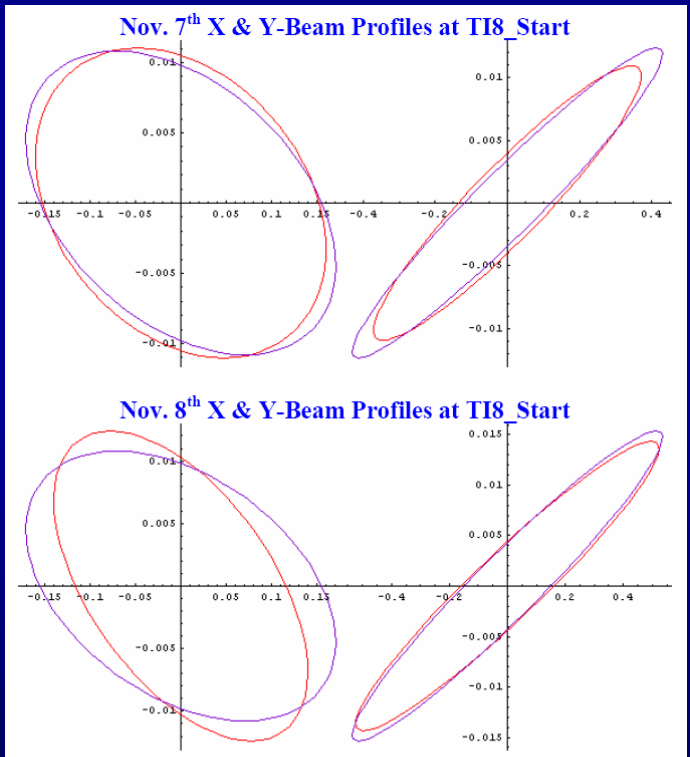


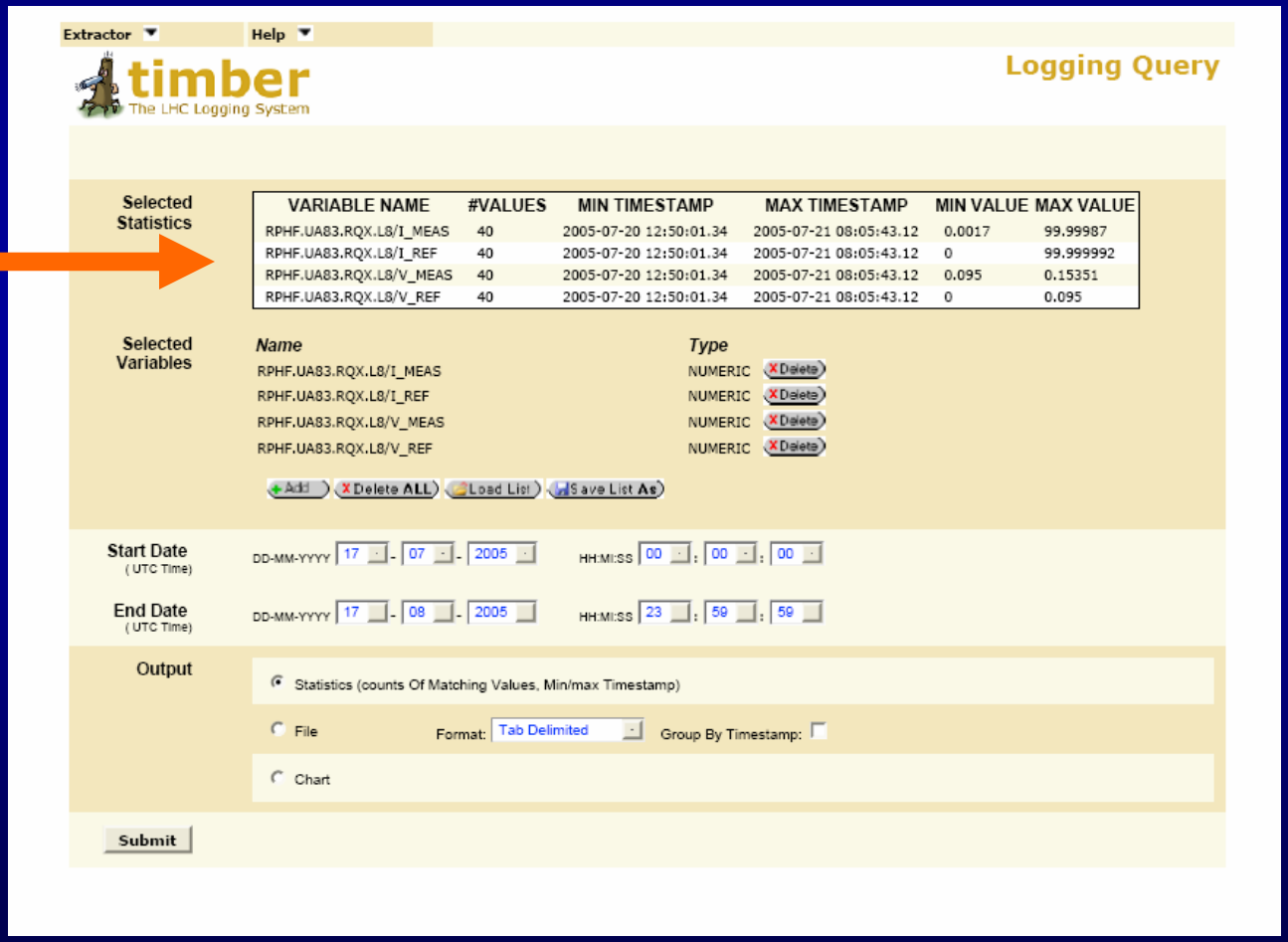
Figure 2. Comparison between Design & Measured Beam Profiles of 07/11 (top) and 08/11 (bottom); Actual beam size; units: mm & mrad (red: measured, blue: design)

What does this tell us?

Yu-Chiu Chao

Commissioning has begun – Hardware commissioning

- Area 8 power converter short circuit tests (from Field Control Room)



LHC Beam Commissioning

- OBJECTIVES
- PREPARATION
- PLANNING

- KEEP IT SIMPLE
- STAGE IT
- KEEP IT SAFE

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**

and in the process

- **Commission**
  - the Equipment
  - the Instrumentation
  - the Machine protection system

to the levels required.

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

Stage two and beyond definitions to follow

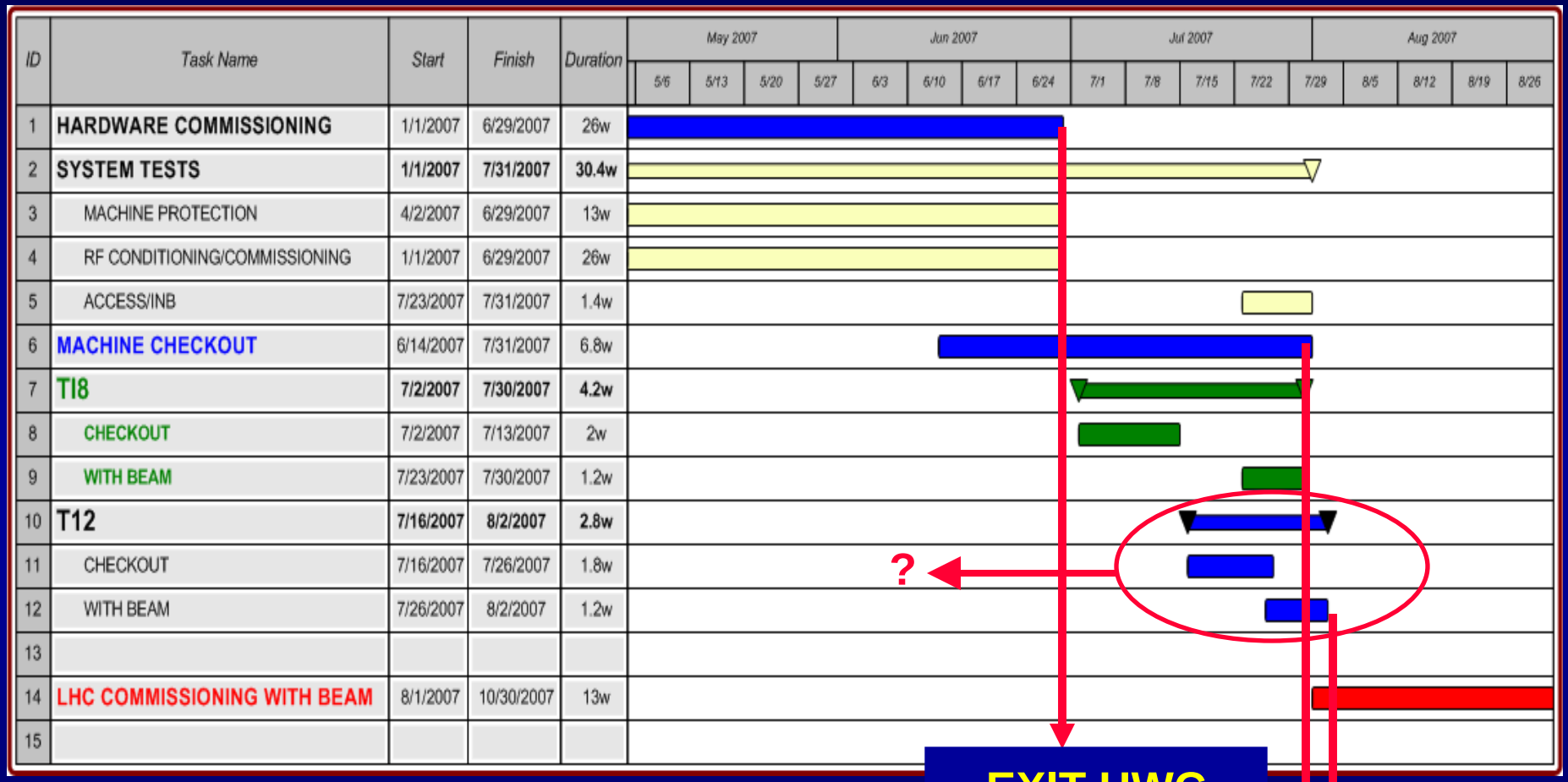
Preparation

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				

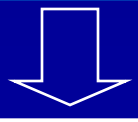


Exit Hardware Commissioning

Given installation, technical infrastructure etc. etc.

- **Implicitly:**
  - **Beam Vacuum [warm & cold]**
  - **Cooling and Ventilation**
  - **Cryogenics Plant**
  - **Cryostat Instrumentation**
  - **Electrical Network**
  - **Insulation Vacuum**
  - **Powering Interlock**
  - **QRL Instrumentation**
  - **QRL Vacuum**
  - **Radiation Monitors**
  - **Software Interlock System**
  - **Access**
  - **Survey/Alignment**

MOVE FROM HWC MODE TO OPERATION MODE



- **Monitoring, logging, display, PM, Diagnostics**
- **Control applications**
- **Coupling between systems**
- **Recovery procedures from CCC clearly defined etc. etc.**

Exit Hardware Commissioning

- All magnet circuits [warm & cold]
- Power converters
- Kickers, Septa
- Collimators, Absorbers
- Beam dumps
- RF
- Instrumentation
- Machine protection
  - QPS, Energy Extraction, Power Interlock Controllers
- Controls

Machine Checkout

- By Operations
- With support of equipment specialists, Hardware Commissioning team etc.
- From the CCC

Drive all relevant systems in a synchronized way through the complete operational sequence

This where operations get serious

Exit Machine Checkout

- RF
  - Pre-pulses, low level control [cavity control, synchro, beam control, longitudinal damper], transverse damper, power systems. Diagnostics.
  - Synchronisation with injectors
- Power converters
  - tracking
  - control, ramping, squeezing, real-time
- Kickers, septa,
- Collimators, absorbers
- Dump:
  - timing, post-mortem, inject and dump
- Beam Instrumentation
  - pre-commission, timing, acquisition tests, interface to control system

Exit Machine Checkout

- **Interlocks & Machine Protection**
  - Equipment interfaces, links, logic, controls,
  - PIC, WIC, BIC, Safe Beam Flags
  - Software interlocks
  - QPS, Energy extraction
    - displays, diagnostics, post-mortem, recovery
  - Energy meter

Exit Machine Checkout

- **Controls:**
  - 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.
  - Controls infrastructure: servers, databases etc.
  - Sequencer, injection management
  - Procedures for sliding bumps etc. etc.

Exit Machine Checkout

- **Settings etc.**
  - **calibrations, optics, transfer functions, ramp, squeeze…**
- **Radiation monitoring**
- **Access system**
- **Experiments**

Exit Injectors and Transfer Lines

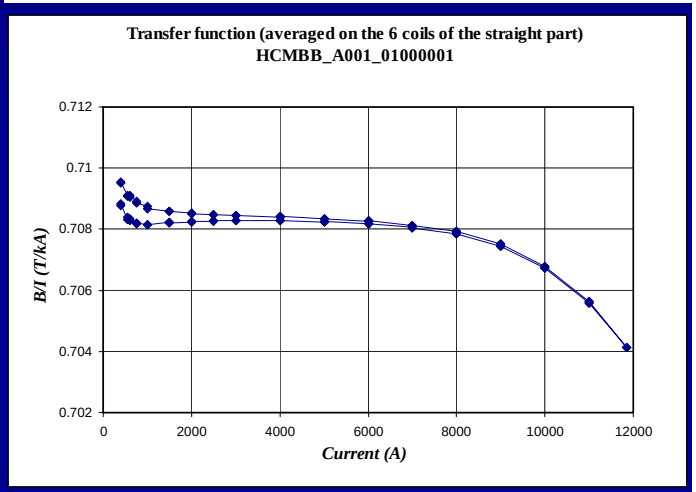
- **SPS LHC cycle**
  - **All requisite beams available**
  - **Beam quality**
  - **Delivered when required**

- **TI8 & TI2**
  - **Fully qualified LHC pilot beams to final TED (retractactable beam stop)**

Pre-beam: Magnets

- **Errors: all circuits, full cycle**
  - geometric, beam screen, saturation
  - eddy,
  - RMS/Persistent currents
    - static model
    - powering history dependent model
    - on-line reference magnets
- **Cycle path – all magnets**
- **Transfer functions**
  - for all magnet circuits
  - hysteresis behaviour for corrector circuits where appropriate
- **Strategy for:**
  - excitation of nested correctors
  - cycling nested pc/magnets

```
b1pM_MBRS  :=     0.0000;
b1gM_MBRS  :=     0.0000;
b2pM_MBRS  :=    -0.1088;
b2gM_MBRS  :=     0.1904;
b3pM_MBRS  :=    -4.1431;
b3gM_MBRS  :=    -2.1825;
```



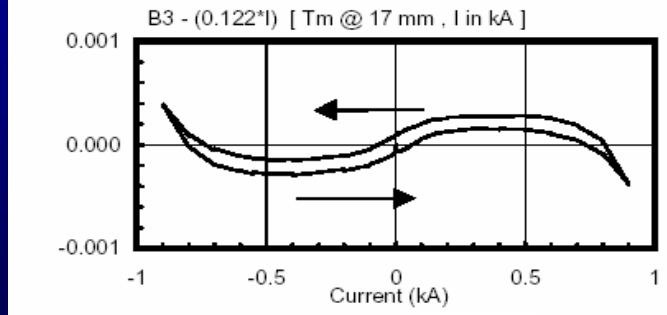


Figure 3 : Field strength of **MCS** corrector : difference between the strength and straight line giving the average to enlighten the hysteresis due to persistent currents.

Planning: with beam

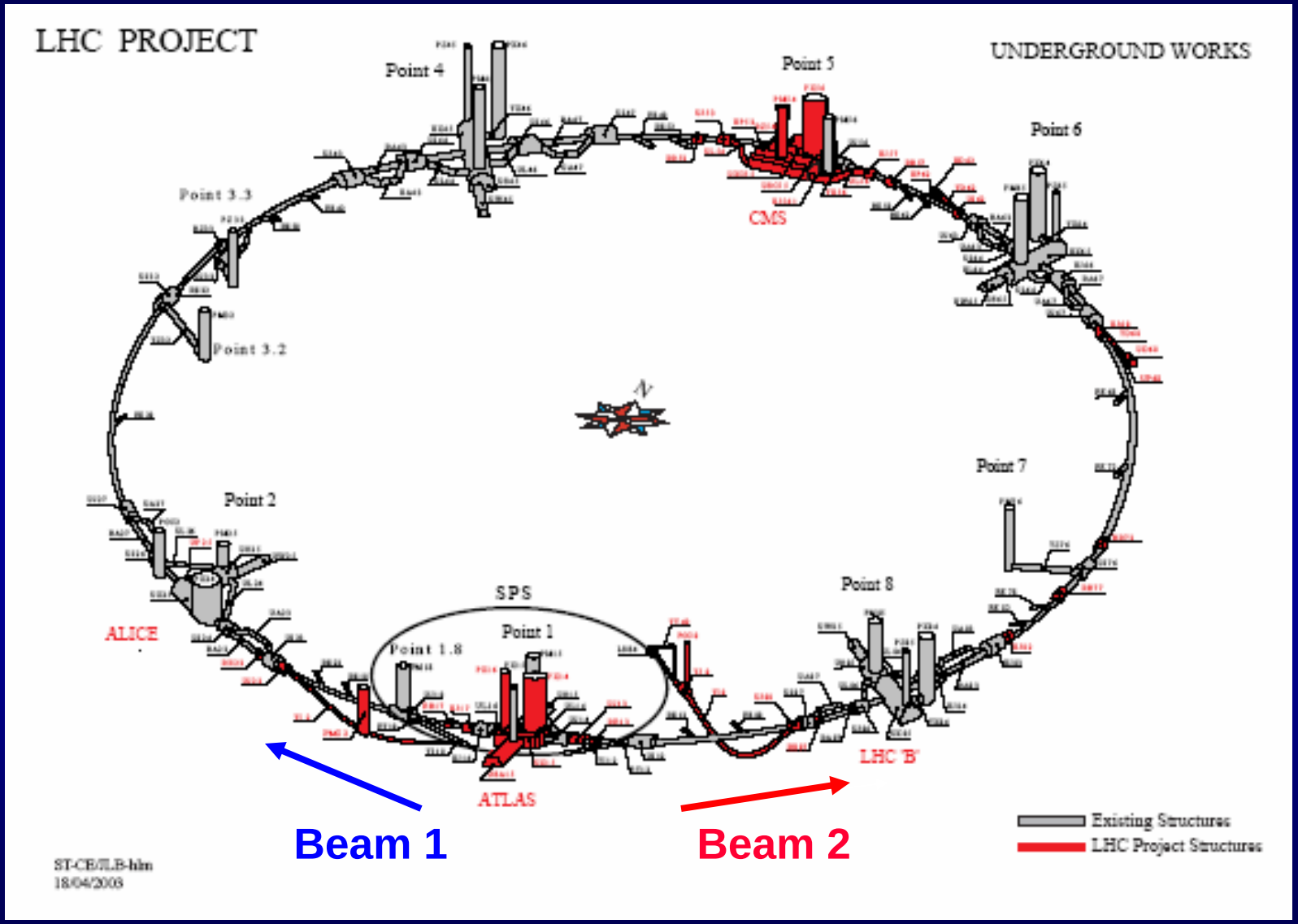
1	Injection
2	First turn
3	Circulating beam
4	450 GeV: initial commissioning
5	450 GeV: detailed measurements
6	450 GeV: 2 beams
7	Nominal cycle
8	Snapback – single beam
9	Ramp – single beam
10	Single beam to physics energy
11	Two beams to physics energy
12	Physics
13	Commission squeeze
14	Physics partially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

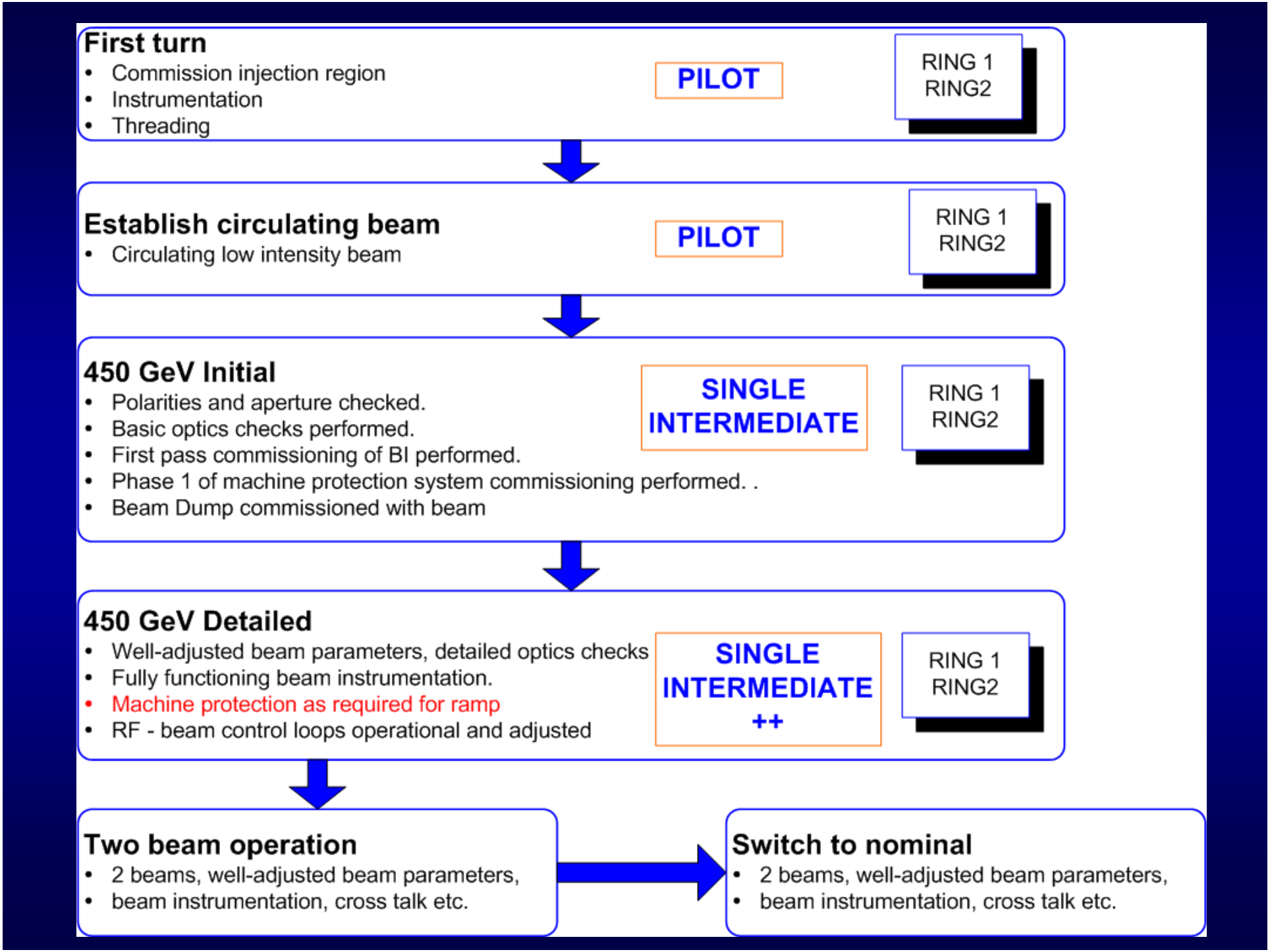
Beam

- **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 bunches**
  - **3 to 4 x 10^{10} ppb**

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

Beam


LHC PROJECT
UNDERGROUND WORKS
Point 4
Point 5
Point 6
Point 3.3
Point 3.2
CMS
Point 2
Point 7
Point 8
SPS
Point 1
Point 1.8
ALICE
LHC 'B'
ATLAS
Beam 1
Beam 2
Existing Structures
LHC Project Structures
ST-CE/ILB-hhn
18/04/2003


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

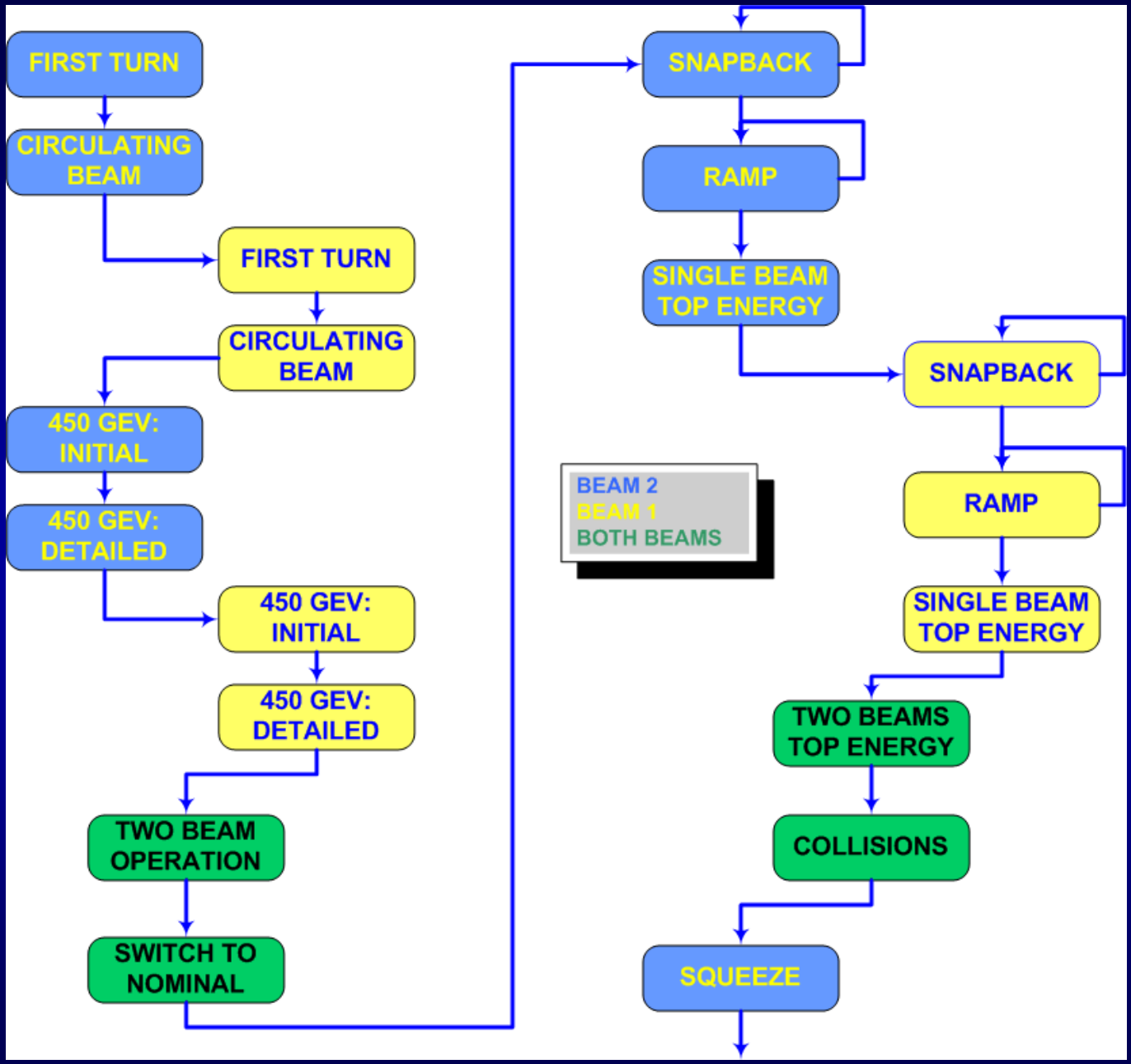
COLLIDE

Squeeze

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

SINGLE
INTERMEDIATE

RING 1
RING2

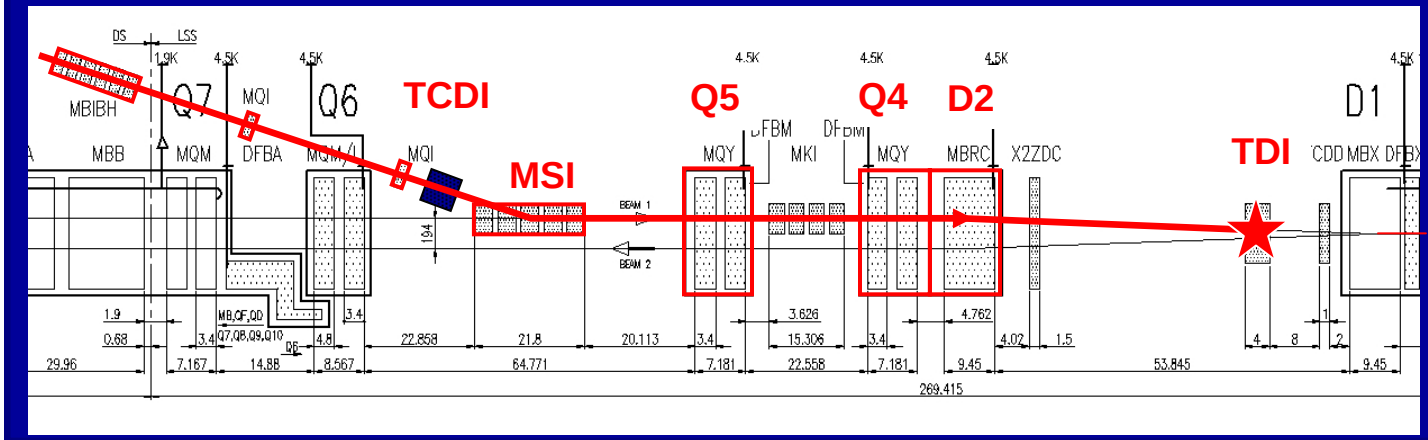

FIRST TURN
CIRCULATING BEAM
FIRST TURN
CIRCULATING BEAM
450 GEV: INITIAL
450 GEV: DETAILED
450 GEV: INITIAL
450 GEV: DETAILED
TWO BEAM OPERATION
SWITCH TO NOMINAL
SNAPBACK
RAMP
SINGLE BEAM TOP ENERGY
SNAPBACK
RAMP
SINGLE BEAM TOP ENERGY
TWO BEAMS TOP ENERGY
COLLISIONS
SQUEEZE
BEAM 2
BEAM 1
BOTH BEAMS

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.

Transfer & Injection

LEFT OF IP2 (H plane)



- **Objectives & importance of preparation [hammered]**
- **System Commissioning:**
  - **Hardware**
  - **Machine Protection**
  - **Beam Instrumentation**
  - **Controls**

Procedure for commissioning with beam

plus time estimate

Transfer & Injection: Issues

- Scheduling of TI2 and IR2
- Keep TI8 operational
- Sector test clearly a big advantage

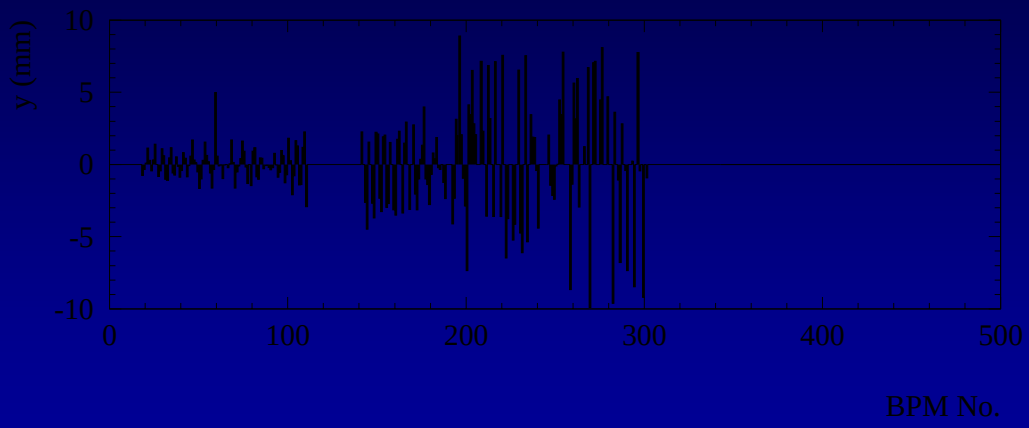
- Machine Protection [general]
  - Including full specification & formal acceptance
  - Imperative that we have a well-defined plan of how to commission the machine protection system with beam.
  - Providing an appropriate level of protection at each commissioning stage.

450 GeV: Initial

Commissioning tunes

Simple machine

De-Gauss cycle



- **Threading, First turn, circulating beam, RF capture**
- **Beam instrumentation:**
  - **BPM, BCT, Screens, Tune**
- **Beam parameter adjustment**
- **First pass optics and aperture measurements**
- **Equipment:**
  - **RF, Beam Dump**

450 GeV: Consolidation

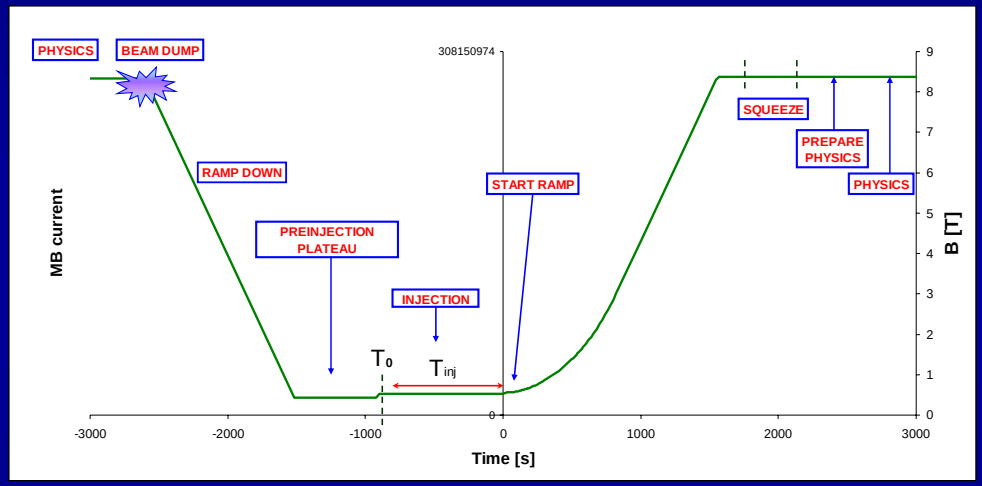
- **Measurements:**
  - Linear optics checks and correction
  - Beta beating, Emittance
  - Non-linear optics, higher orders
- **Equipment**
  - Collimators
  - RF, LFB, TFB
- **Instrumentation**
  - BLMs…
- **Machine Protection system**

Well adjusted 450 GeV machine.

Machine Protection systems fully tested, approved and operational to take beam into the ramp

Ramp

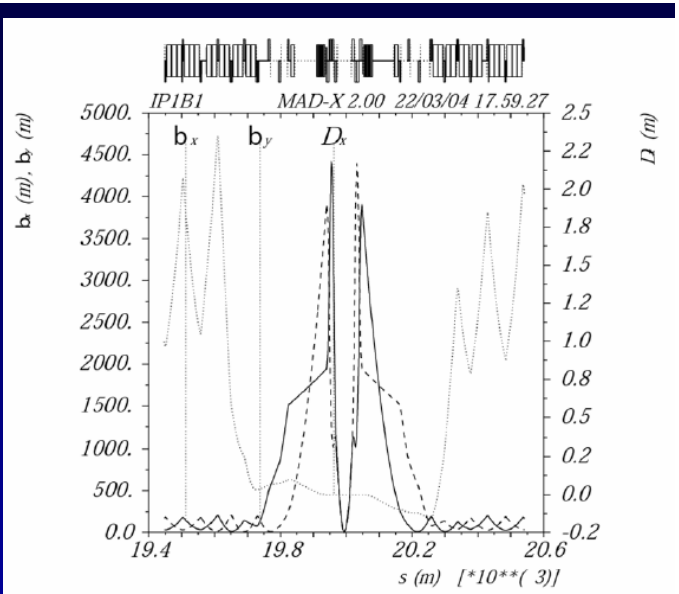
- **Procedure detailed:**
  - Baseline Ramp
  - Power converters,
    - Pre-loaded functions, Real-time
  - RF
  - Dump
  - Timing
  - Stop in Ramp & Squeeze



- **Prerequisites include:**
  - Beam Instrumentation
    - Tune measurement
    - Q' measurement
    - Orbit
  - RMS:
    - predictions of snapback, transfer functions, static errors…
  - Machine Protection

Squeeze

- **Key Requirements**
  - Separation
  - Aperture
  - Smooth powering
  - Avoid low gradients and zero crossings



- **Tight Tolerances**
  - Interplay between gradient errors and limits on tune, beta beating, dispersion, orbit
  - Excellent control required: feedback desirable

- **Time**
  - Given by power converter ramp rates
  - 8.5 minutes per IP
  - plus round off & collimator adjustments

Procedure detailed:

- **Collimators**
- **Power converters**
- **Monitoring**
- **Parameter control**

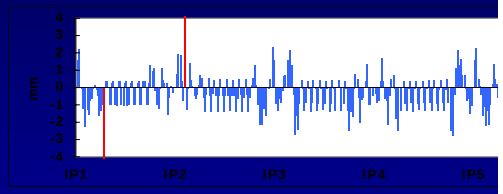
Squeeze

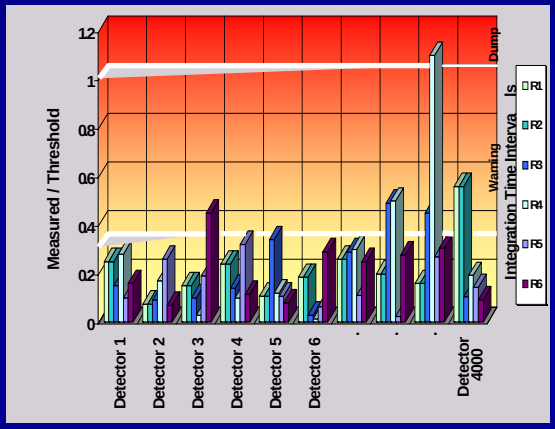
- **Commissioning procedure:**
  - Squeeze one IP at a time without crossing angle
  - One IP at a time with crossing angle
  - Minimise intermediate solutions. **How many matched intermediate steps are required?**
  - Parallel squeeze in more than one IP

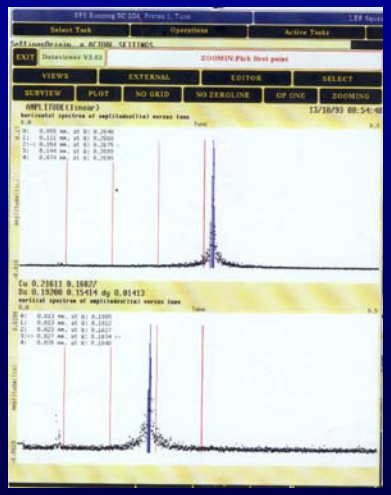
- **Issues**
  - Triplet correction for β^* 0.7 m.
  - Transfer functions and triplet alignment $\rightarrow$ errors
  - Reproducibility of transfer functions at low powering
  - Alignment optics

Critical systems @ Start-up

- **BPMs**
  - Day 0: Orbit on pilot – immediate, turn by turn with Beam Synchronous Timing
  - Systematic check for polarity errors etc.
  - System performance – long term
- **BLMs**
  - Day 0: "slow" monitors – immediate
  - BST for fast loss monitors
  - Calibration, Cross talk…
  - Thresholds - considerable effort
- **BCT**
  - Day 0: DC immediate, bunch to bunch – BST
  - Lifetime calculation – slow!
- **Tune**
  - Tune Day 0: Kick/FFT & multi- FFT
  - PLL – few weeks

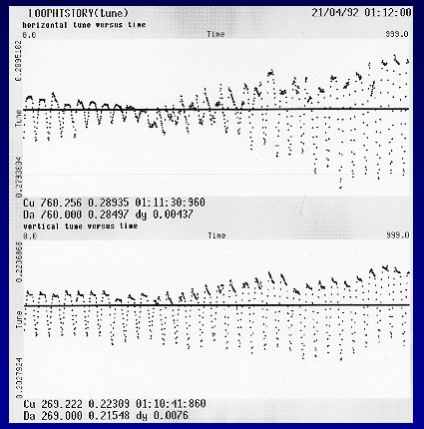




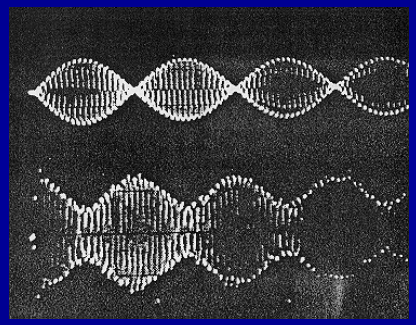


Critical systems @ Start-up

- **Chromaticity**
  - Day 0: Kick/Head-tail (Beam Synchronous Timing)
  - Day 0: ΔQ v Δf
  - Periodic momentum modulation – PLL



- **Coupling**
  - Day 0: Kick/Beam response
  - PLL: closest tune approach

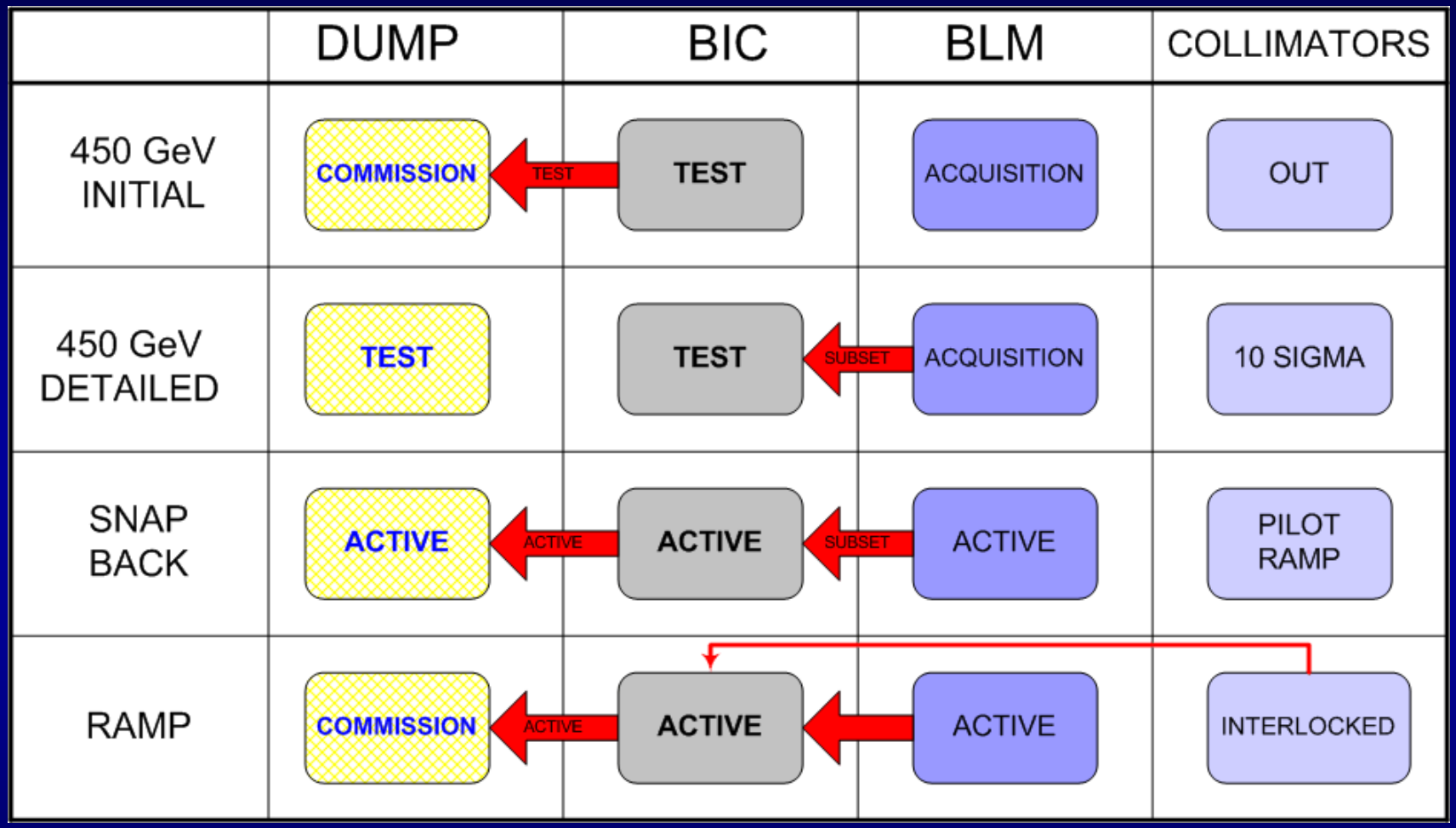


Clear need to get PLL (& BST) working ASAP

Good to see that the basics will be there from the start

Plus: SLM, LDM, AGM, RGM, Wire scanners, luminosity monitors.

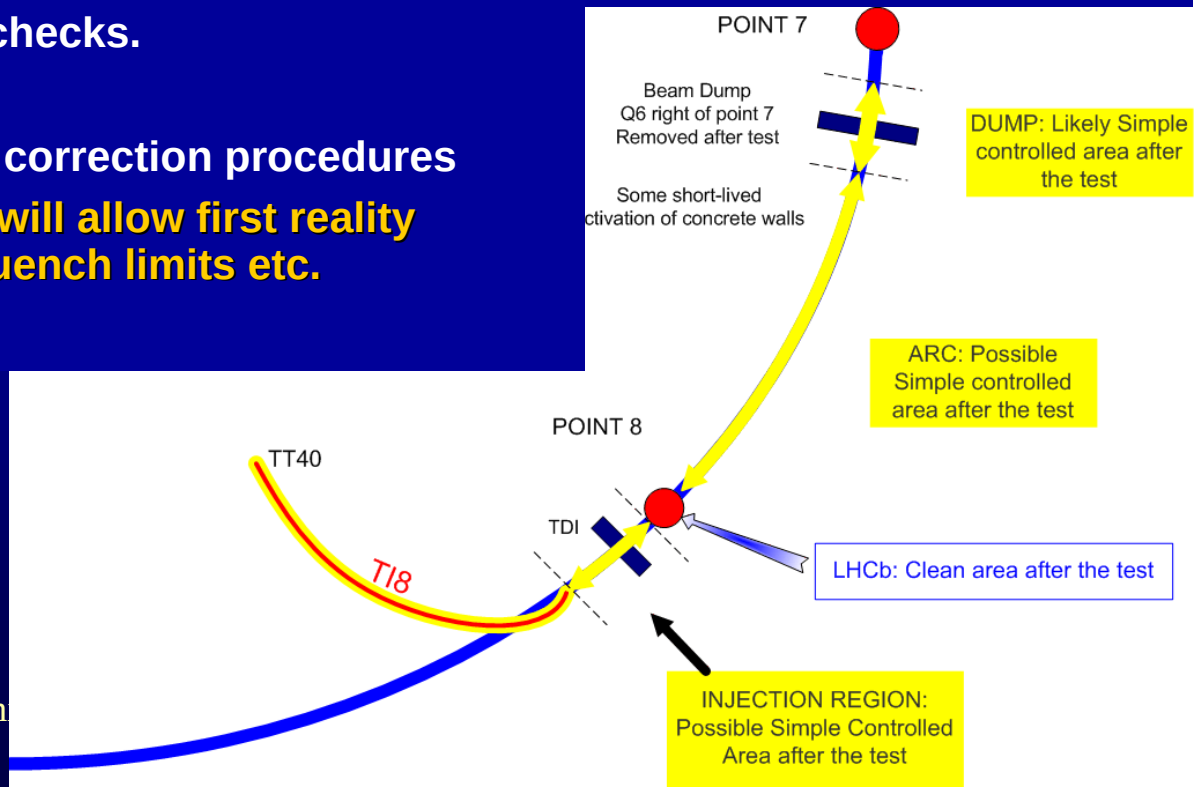
Machine protection



Need a well defined plan for the commissioning and integration of the Machine Protection System

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 in Nov/Dec 2006



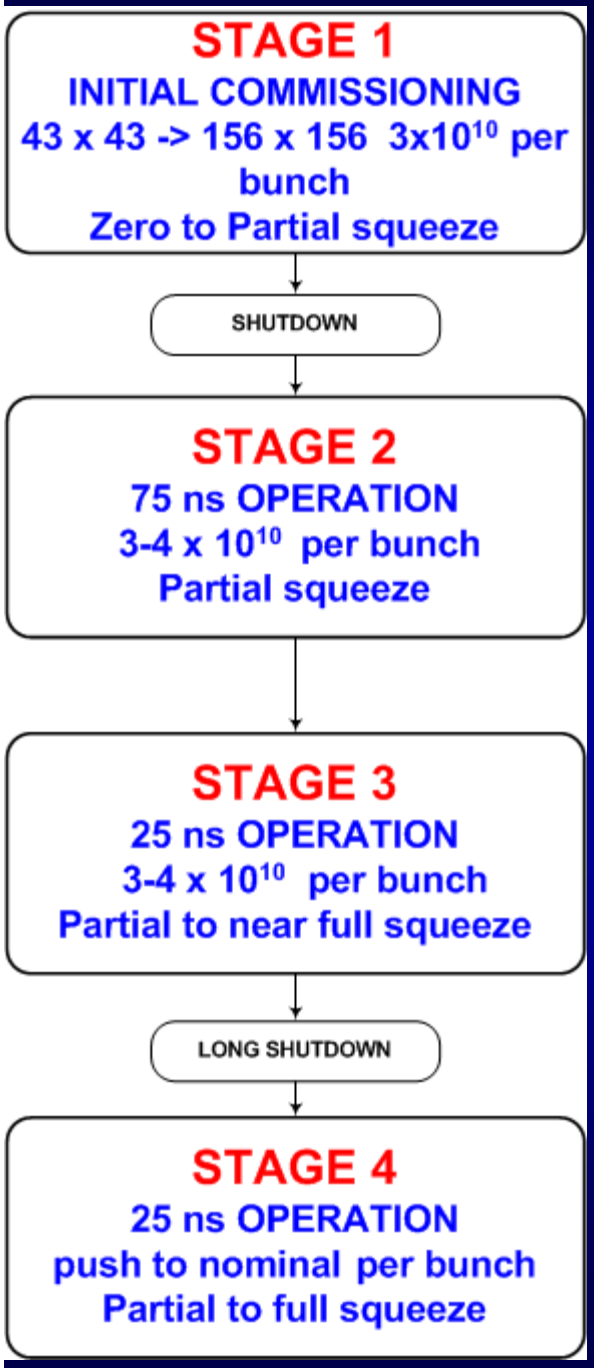
How long?

	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	4
13	Physics partially squeezed	1		
	TOTAL TIME (WITH BEAM)			*60*

Parallelism?

- System tests with HWC ongoing
  - Machine protection
  - Controls
  - RF/Injection/Collimators etc.
- Machine checkout with HWC ongoing
  - Sign over completed sectors to OP
- TI2 commissioning – LHC with beam 2
- HWC – partial LHC with beam 2
  - Implications: dump, radiation protection, access, resources, support etc.
- LHC - partial beam 1 with beam 2

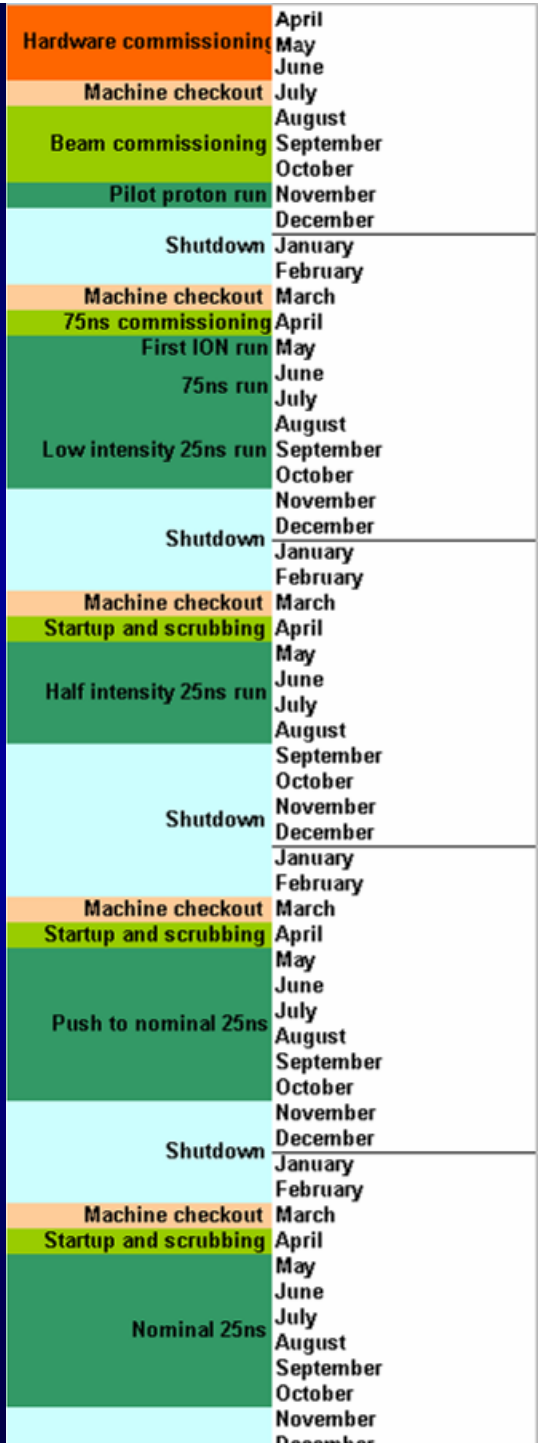
Options need examining



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 1 - Luminosities

- 43 to 156 bunches per beam
- N bunches displaced in one beam for LHCb
- Push one or all of:
  - 156 bunches per beam
  - Partial optics squeeze
  - Increased bunch intensity

Number of bunches per beam	43	43	156
β^* in IP 1, 2, 5, 8 (m)	18,10,18,10	2,10,2,10	2,10,2,10
Crossing Angle (μrad)	0	0	0
Bunch Intensity	$1\ 10^{10}$	$4\ 10^{10}$	$4\ 10^{10}$
Luminosity IP 1 & 5 ($cm^{-2}\ s^{-1}$)	$\sim 3\ 10^{28}$	$\sim 5\ 10^{30}$	$\sim 2\ 10^{31}$
Luminosity IP 2 ($cm^{-2}\ s^{-1}$)	$\sim 6\ 10^{28}$	$\sim 1\ 10^{30}$	$\sim 4\ 10^{30}$

Stage 2 – 75ns luminosities

- Partial squeeze and smaller crossing angle to start
- Luminosity tuning, limited by event pileup
- Establish routine operation in this mode
- Move to nominal squeeze and crossing angle
- Tune IP2 and IP8 to meet experimental needs

Number of bunches per beam	936	936	936
β^* in IP 1, 2, 5, 8 (m)	2,10,2,10	0.55,10,0.55,10	0.55,10,0.55,10
Crossing Angle (μrad)	250	285	285
Bunch Intensity	$4\ 10^{10}$	$4\ 10^{10}$	$9\ 10^{10}$
Luminosity IP 1 & 5 ($cm^{-2}\ s^{-1}$)	$\sim 1\ 10^{32}$	$\sim 4\ 10^{32}$	$\sim 2\ 10^{33}$
Luminosity IP 2 & 8 ($cm^{-2}\ s^{-1}$)	$\sim 2\ 10^{31}$	$\sim 2\ 10^{31}$	$\sim 1\ 10^{32}$

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 ($cm^{-2}\ s^{-1}$)	$\sim 4\ 10^{31}$	$\sim 1\ 10^{32}$	$\sim 5\ 10^{32}$

Conclusions

- **PREPARATION**
- **STAGING**
  - **43 x 43 colliding (in 3 months absolute minimum)**
- **PLANNING**
  - **Before beam**
  - **Phases detailed – work in progress**

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