LHC Commissioning with Beam
Overall Strategy

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AB-OP

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Chamonix XIV B.D.S.

1989 – LEP commissioning

- 14th July: First beam
- 23rd July: Circulating beam
- 4th August: 45 GeV
- 13th August: Colliding beams

Outline of Run II Tevatron Commissioning

(work in progress!)

M Church 4/06/01

-

High Energy Testing -- **Complete**

++ Retrain B1,B2,C4,D1,E2,F4 dipoles and L.B. quads (Tev group)

Dipole bus: Maximum ramp rate is 16 GeV/sec (as in operations). With main bus not ramping run C49 activate (file #1) and load DFG's from C50 (file #16), if not already done. Use C49 file #19 to change Tecar flattop energy to 900 GeV (see Instruct in Decelerate aggregate in Studies sequencer.) Turn Tevatron on to ramping state to 900 GeV (Recovery aggregate in Collider Sequencer). (L.B's will still be off, so make sure HE lead flows for L.B. quads are off.) Studies Sequencer has appropriate aggregates for training Tevatron up to 1010 GeV. Ramp dipole bus to 900, 950, 980, 1000, 1010. Stay at 900, 950,980,1000 for ~5 minutes each time; stay at 1010 for 2 hours. Watch lead voltages via T33. (Verify that T33 scaling is correct.) Also monitor lead temperatures (F14 <33>, <34>). Adjust lead flows in frig buildings if required. Make small adjustments to V and R limits from T33 only if necessary. (Save to Coll file from T32.) Remember that only A4 has HTS leads and does not have adjustable lead flows. If quench occurs above 950 GeV, start over with a 950 GeV ramp.

Previous training quenches in warmed houses are at B13L(950 GeV), E26U(990 GeV), F48L(1005 GeV), F46U(1010 GeV), F42L(1010 GeV), B22L(1015 GeV), and B15L(1020 GeV). Magnet swapping and recoolers have been installed in some of these houses, so training performance may be different than in the past.

2-ϕ pressures should be: A1=11, A2=8, A3=9, A4=11, B1=10, B2=10, B3=11, B4=11, C1=10, C2=10, C3=11, C4=9, D1=11, D2=11, D3=10, D4=9, E1=9, E2=10, E3=11, E4=10, F1=11, F2=11, F3=10, F4=10.

(Note: E4 was not retrained after the beamvalve replacement.)

Motivation - TI8

- Beam down – first shot.
- Full set of measurements
  - optics, aperture etc.

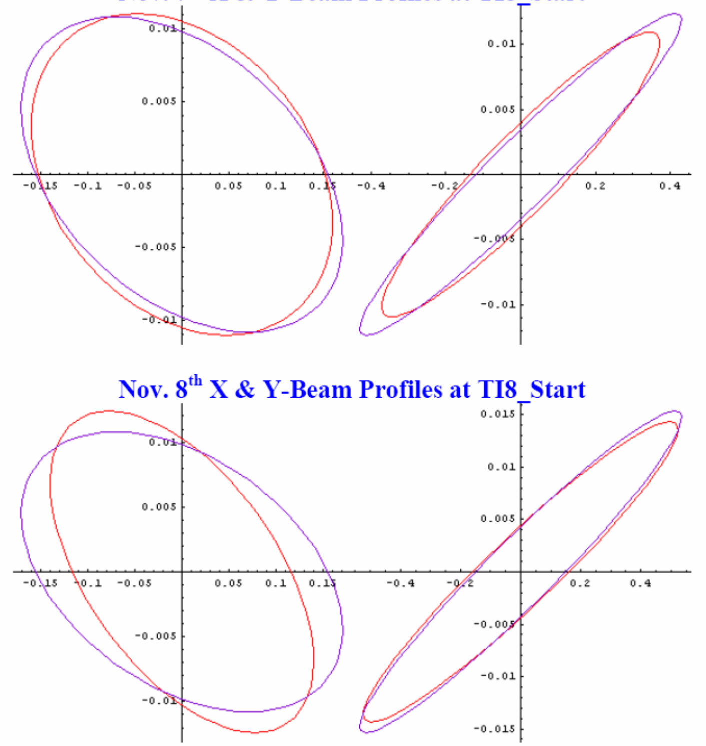
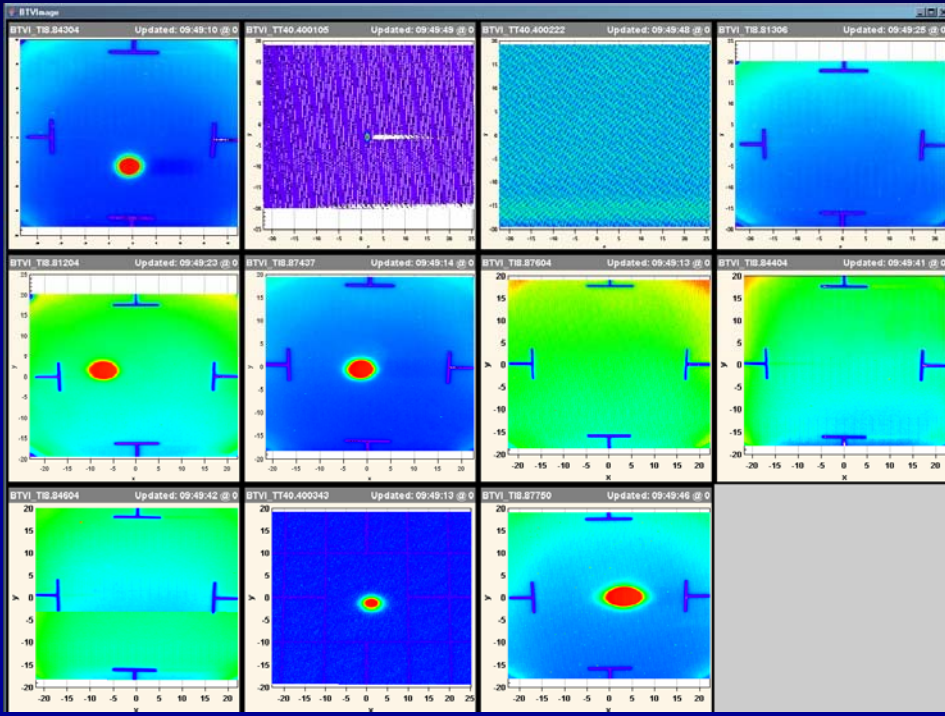


Figure 2. Comparison between Design & Measured Beam Profiles of 07/11 (top) and 08/11 (bottom); Actual beam size; units: mm & mrad (red: measured, blue: design)



Lionel Mestre

What does this tell us?

Yu-Chiu Chao

TI8

Tells us that quite a few things were done right

- **INSTALLATION**
- **HARDWARE COMMISSIONING**
  - Survey
  - Technical services
  - Vacuum
  - Equipment
- **MACHINE CHECKOUT**
  - Preparation of incoming beam
  - Controls
  - Beam Optics/Energy
  - Instrumentation
  - Settings
  - Interlocks & Machine protection
  - Access
  - Radiation monitoring

Volker Mertens and team

TI8

- OBJECTIVES
- PREPARATION
- PLANNING
- STAGING
  - BEAM: extraction tests 2003
- PRACTICE
  - Dry runs
  - BEAM: CNGS extraction 2004

Important for debugging

Important as milestones

LHC Beam Commissioning

- OBJECTIVES
- PREPARATION
- PLANNING

- KEEP IT SIMPLE
- PHASE IT
- KEEP IT SAFE

Objectives

Commissioning the LHC with beam - <u>Stage One</u>

- 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 definition to follow

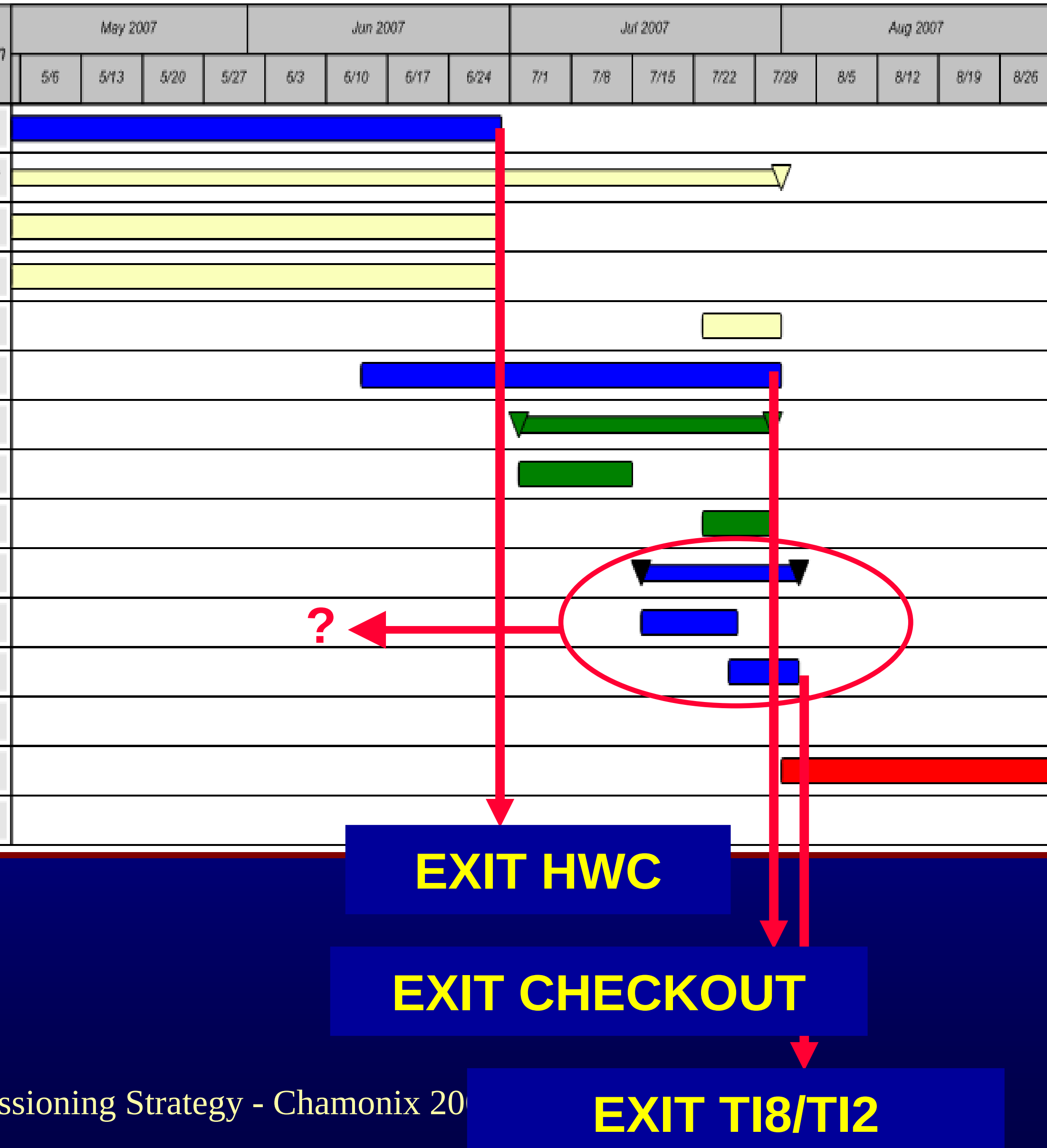
Preparation

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 HWC - 1

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 CCR clearly defined etc. etc.**

Exit HWC - II

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

Machine checkout

- By Operations
- With support of equipment specialists, HWC team etc.
- From the PCR

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

This where operations get serious

Exit machine checkout - 1

- 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 - 2

- **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 - 3

- **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 - 4

- **Settings etc.**
  - **calibrations, optics, transfer functions, ramp, squeeze…**
- **Radiation monitoring**
- **Access system**
  - **INB, EIS**
  - **Operation**
- **Experiments**
  - **Data interchange**
  - **Beam aborts**

Exit injectors and transfer lines

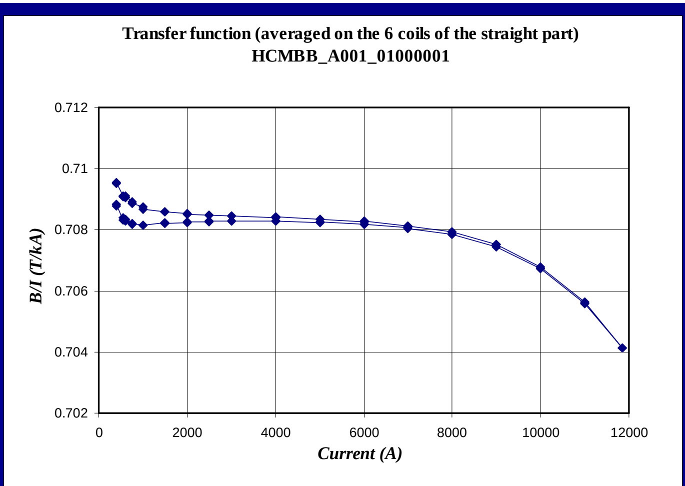
- **SPS LHC cycle**
  - **All requisite beams available**
  - **Beam quality**
  - **Delivered when required**

- **TI8 & TI2**
  - **Fully qualified LHC pilot beams to final TED**

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;



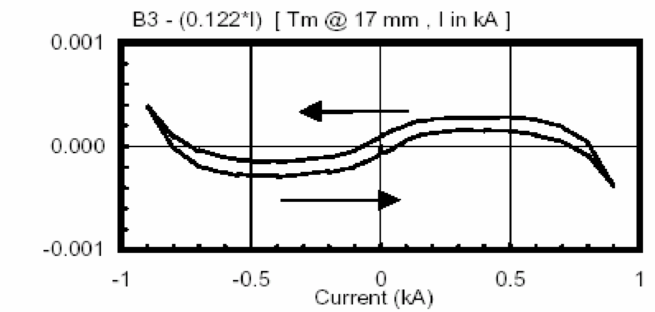


Figure 3 : Field strength of MCS corrector : difference between the strength and straight line giving the average to enlighten the hysteresis due to persistent currents.

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

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

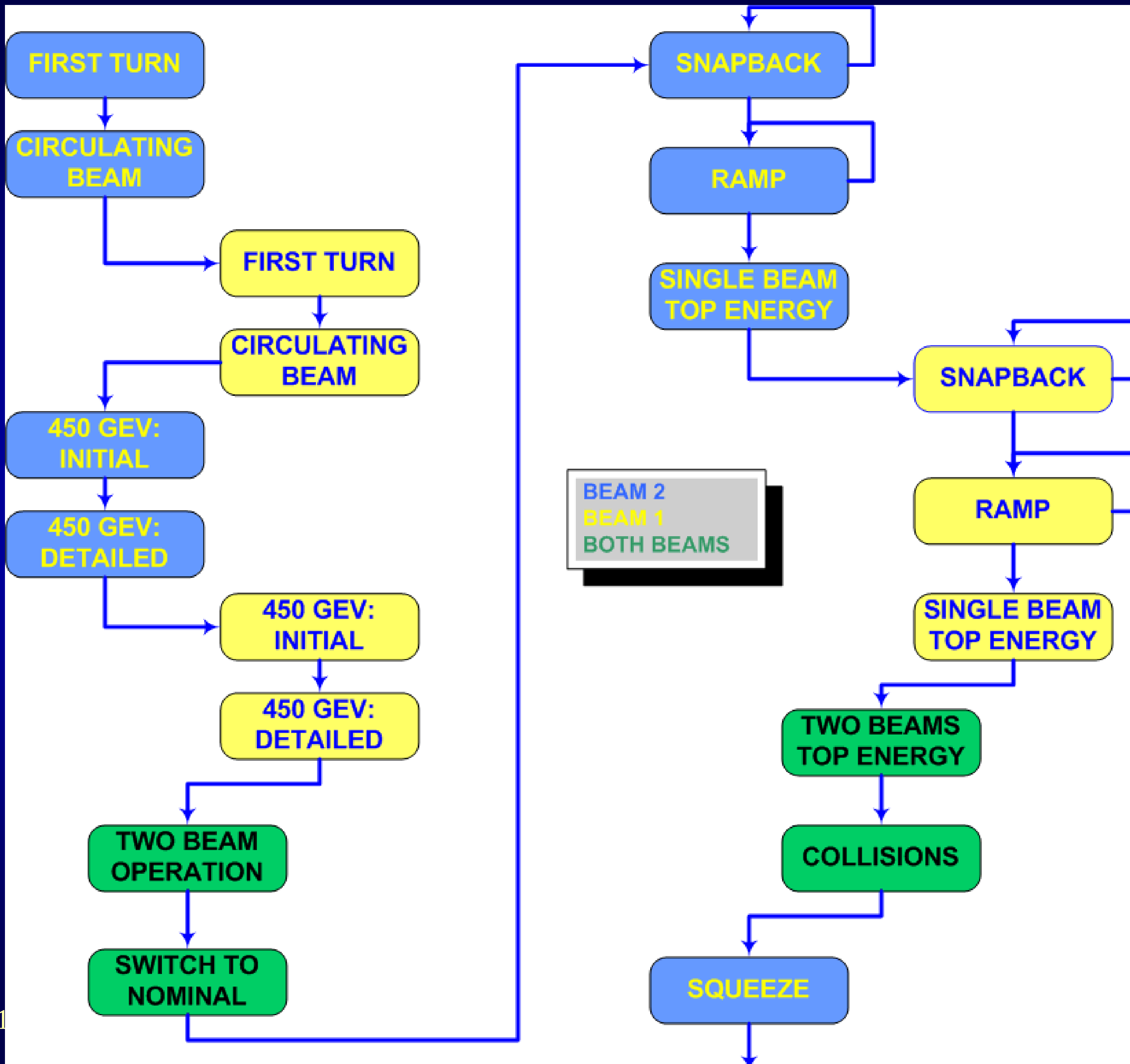
COLLIDE

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:

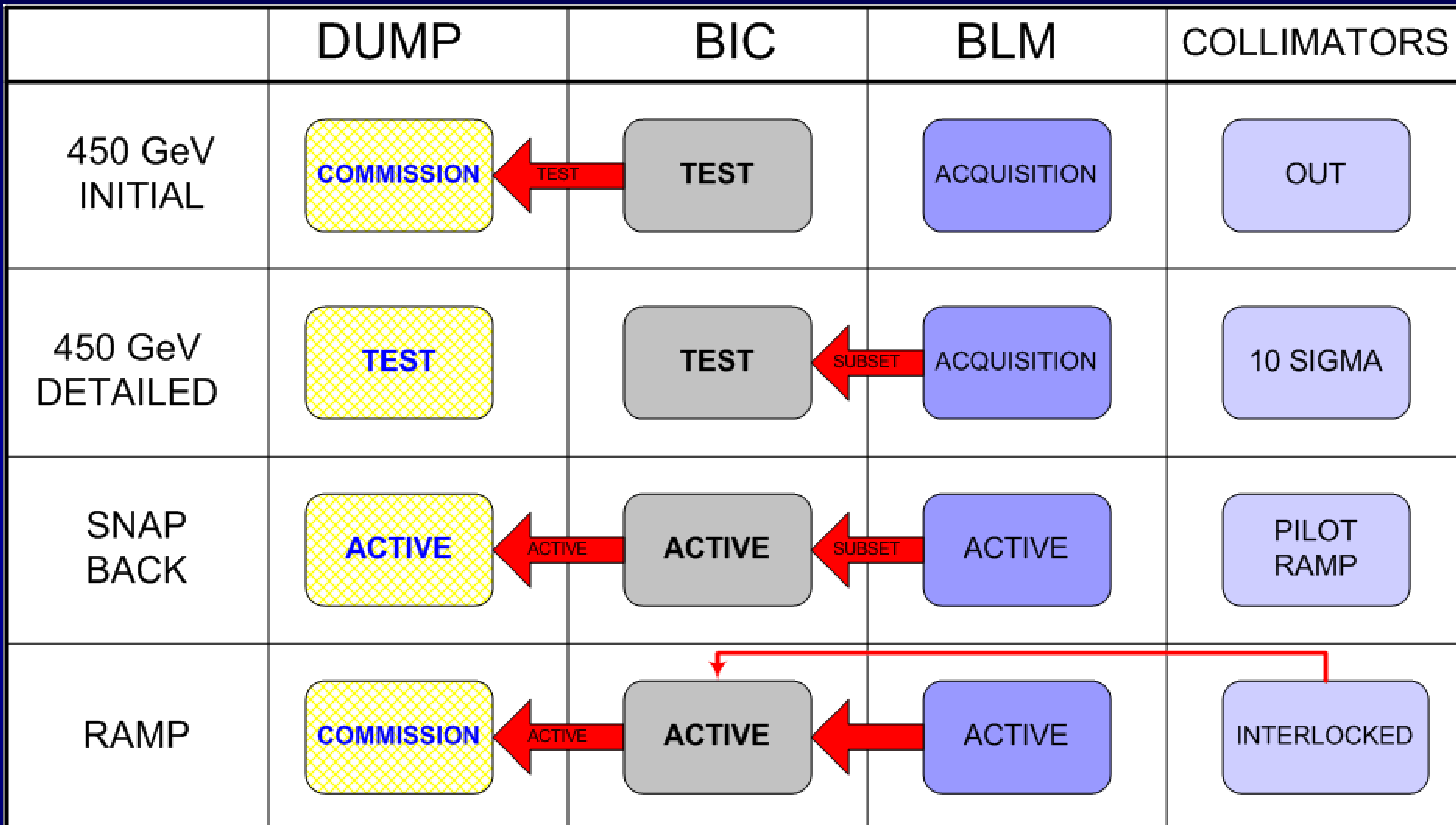
- Equipment commissioning with beam
- Instrumentation commissioning
- Checks with beam
  - BPM Polarity, corrector polarity, BPM response
- Machine protection
- Beam measurements
  - beam parameter adjustment, energy, linear optics checks, aperture etc. etc.

Instrumentation – the essentials

- **First turn i.e. immediately**
  - **Screens, BPMs, fast BCT, BLMs**
- **Circulating beams at 450 GeV**
  - **BPMs, DC BCT & lifetime, BLMs**
  - **Transverse diagnostics**
  - **Emittance: wire scanners..**
- **Snapback and Ramp**
  - **Chromaticity, PLL**
  - **Orbit**
  - **BLMs to BIC etc.**

Essential. See Hermann & Barbara's talks

Machine protection



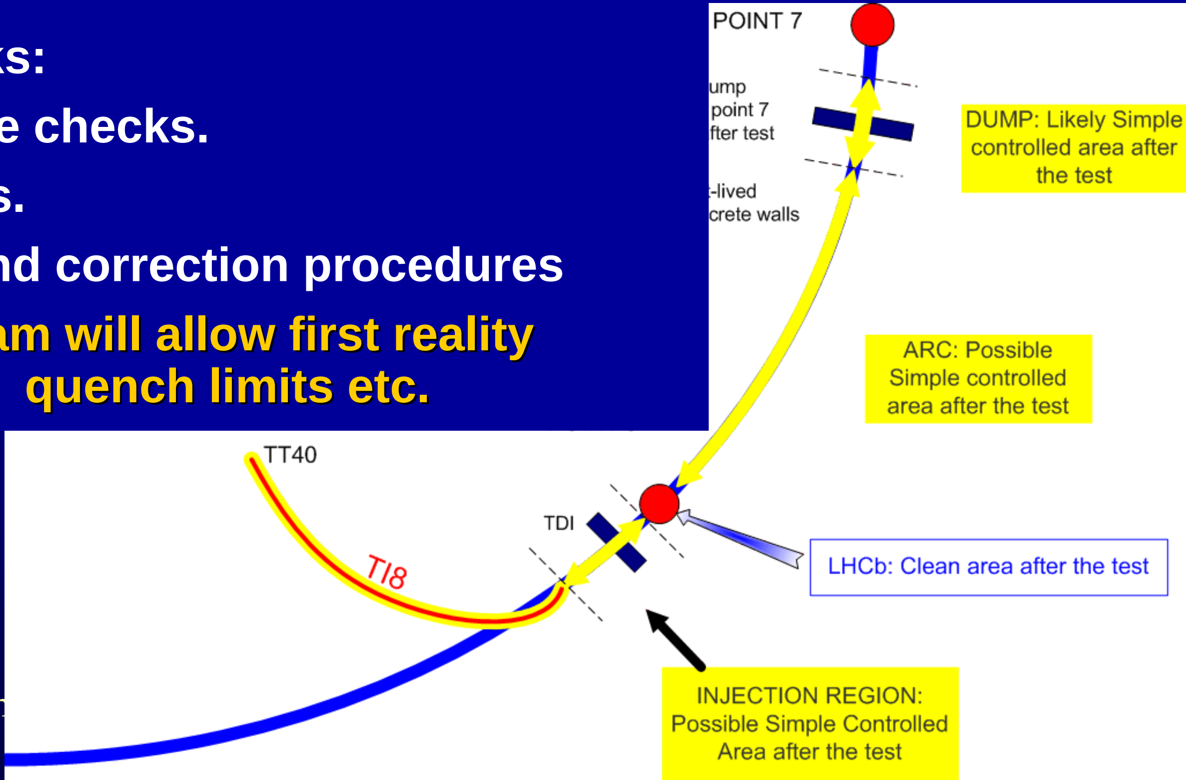
Need a well defined plan for the commissioning and integration of the Machine Protection System

Misc - How long?

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

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.**



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

CONCLUSIONS

- **OBJECTIVES**
  - **Stage 1**
- **PLANNING**
  - **Before beam**
  - **Stage 1**
- **PREPARATION**