# LHC commissioning and interaction with the experiments

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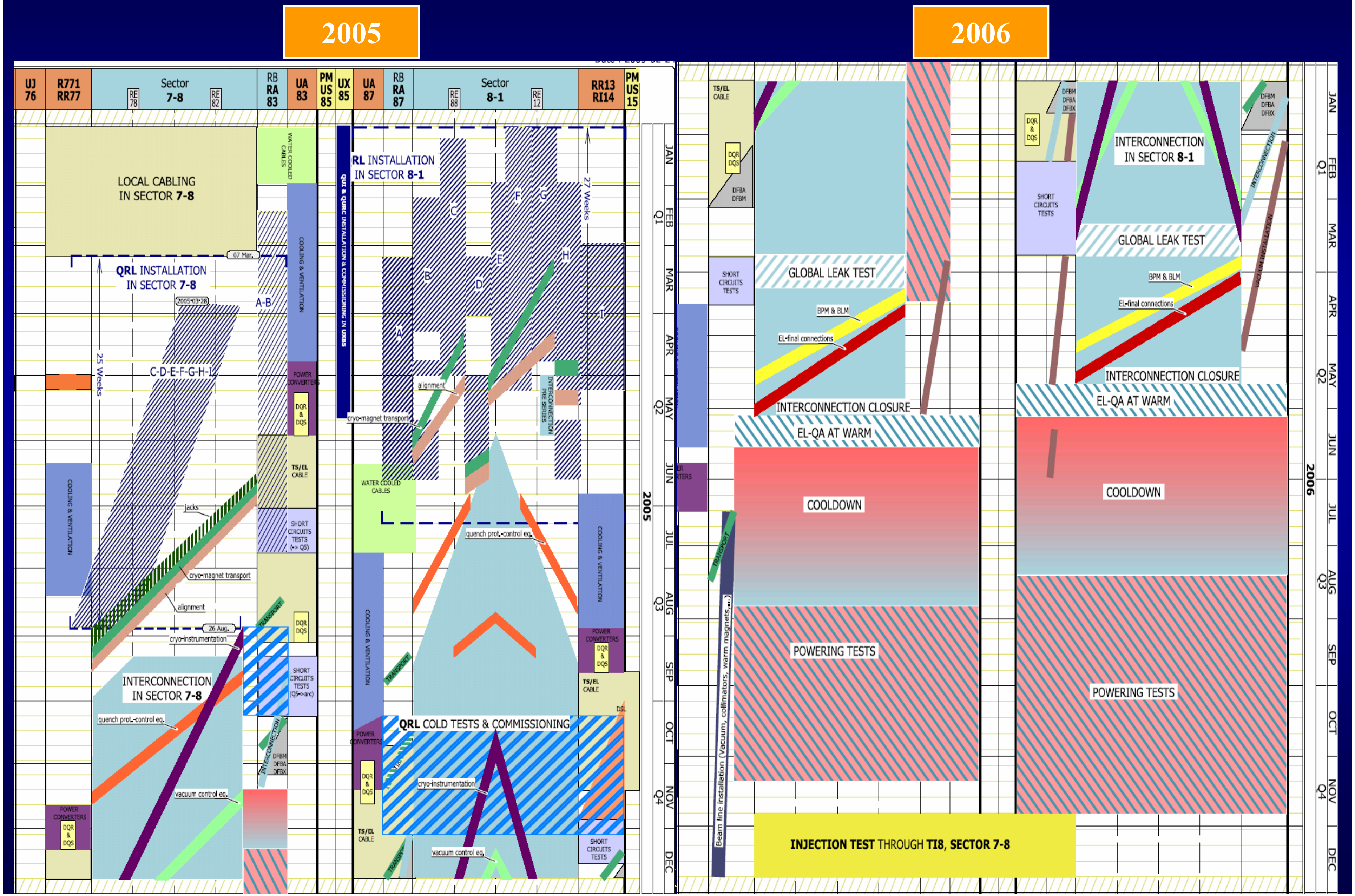
AB-OP

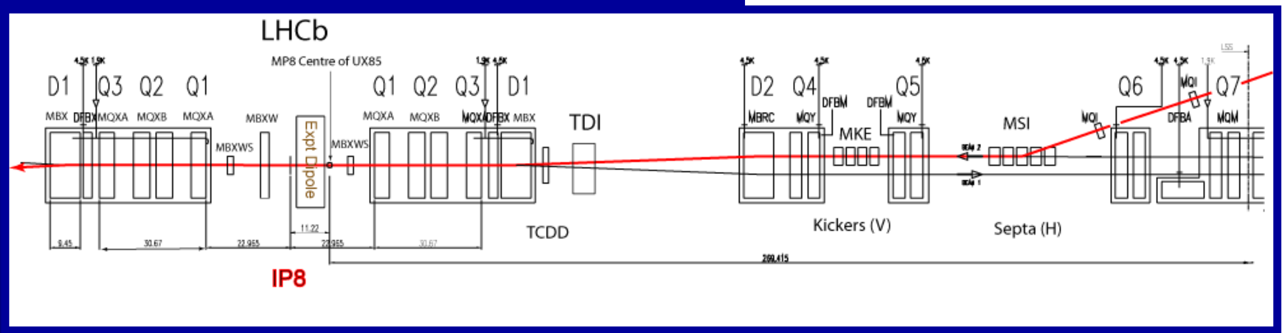
SATURDAY
30th April 2005

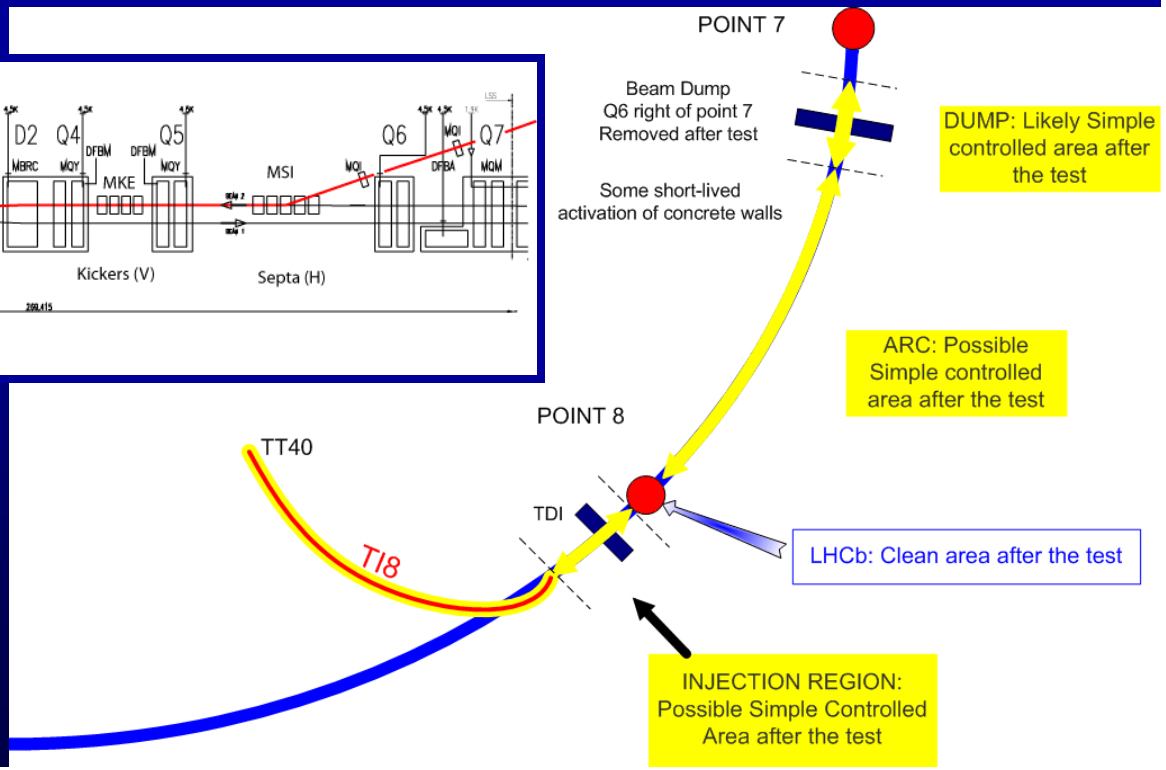
# Detailed planning for 7-8 and 8-1



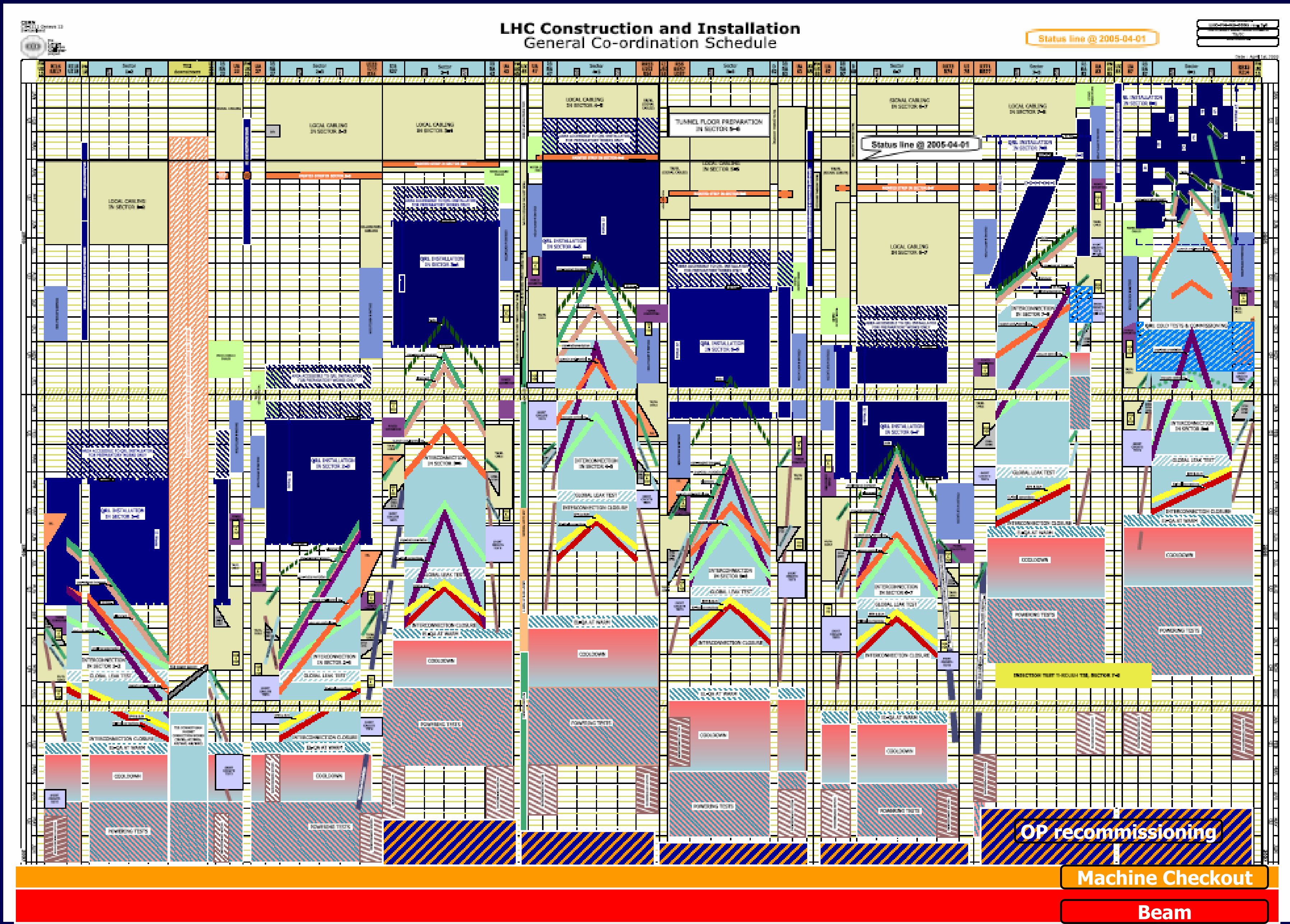
# Sector Test

- **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
OP recommissioning
Machine Checkout
Beam

# 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 definition to follow**

# Preparation

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

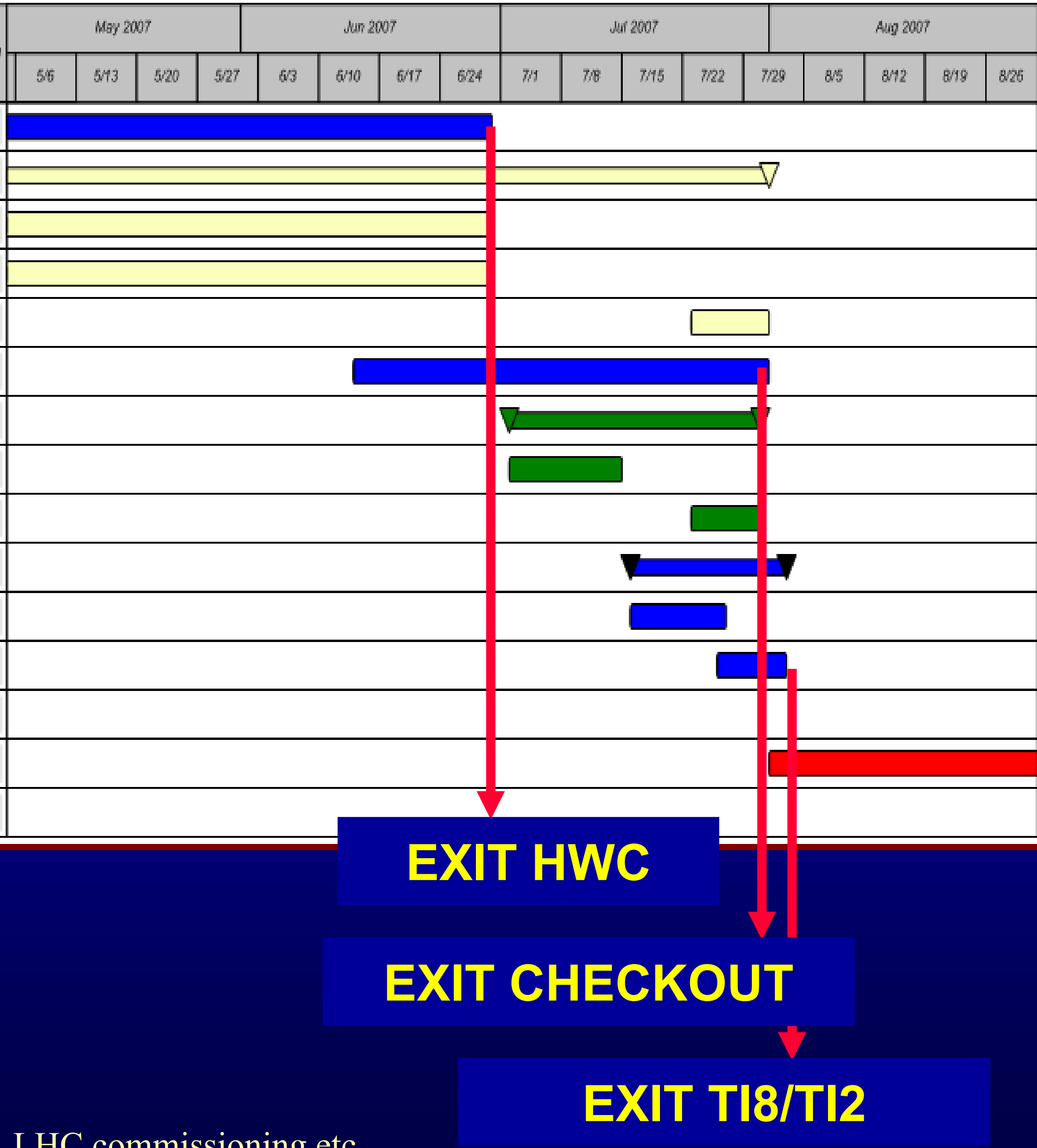
- **Well defined exit conditions from HWC phase**
- **6 weeks machine checkout**

**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 | | | | |



# 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

PILOT++

RING 1
RING2

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

## Ramp Single Beam

PILOT++

RING 1
RING2

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

## Two beams to top energy

43 x 43

COLLIDE

- Two beams, good transmission to top energy
- Measurements

## Squeeze

SINGLE
INTERMEDIATE

RING 1
RING2

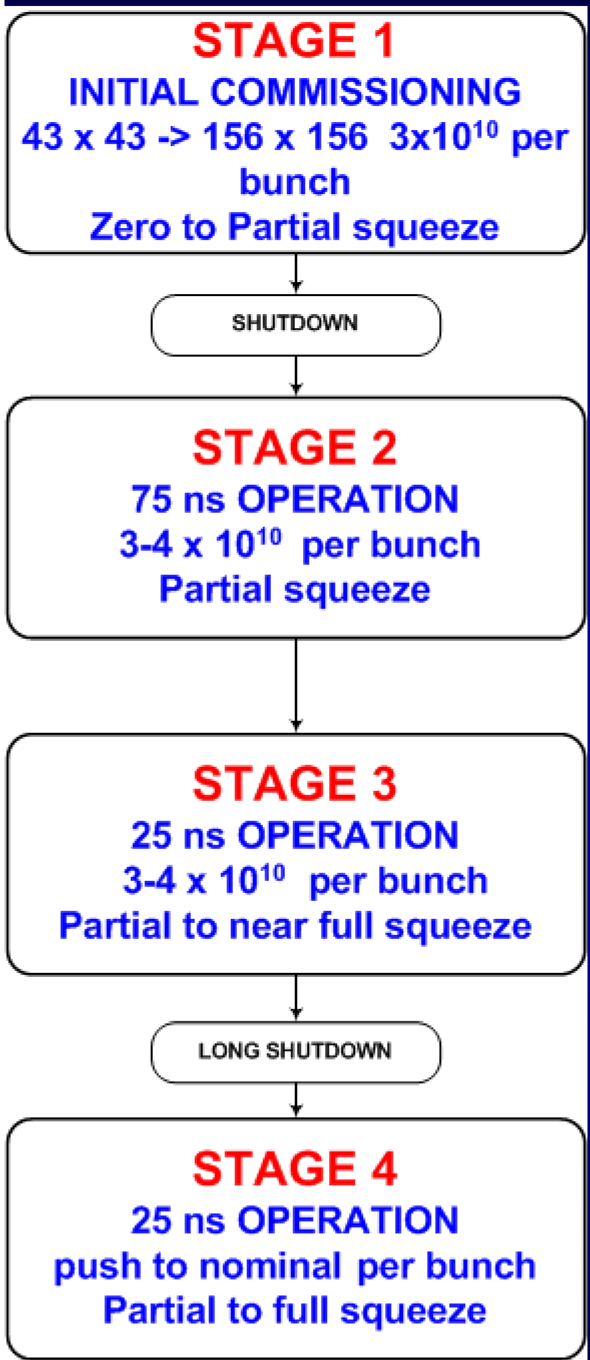
- Single beam - step through squeeze
- Parameter control, measurements

# 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.

# How long?

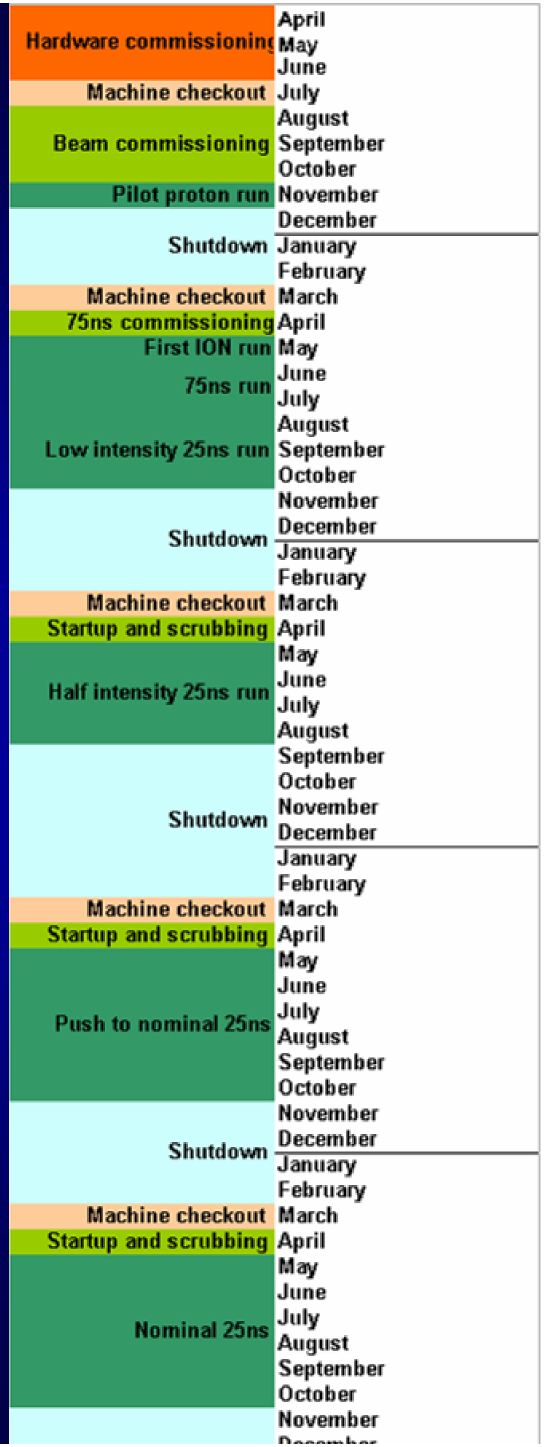
| | Phase | R1/2 | Time [days] | |
|---|---|---|---|---|
| | Injection | 2 | 1 | 2 |
| 1 | First turn | 2 | 3 | 6 |
| 2 | Circulating beam | 2 | 3 | 6 |
| 3 | 450 GeV: initial commissioning | 2 | 4 | 8 |
| 4 | 450 GeV: detailed measurements | 2 | 4 | 8 |
| 5 | 450 GeV: 2 beams | 1 | 2 | 2 |
| 6 | Nominal 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*** |




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 |
| $\beta^*$ 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 ($\mu$rad) | 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 ($cm^{-2}\ s^{-1}$) | $\sim 2\ 10^{31}$ | $\sim 2\ 10^{31}$ | $\sim 1\ 10^{32}$ |

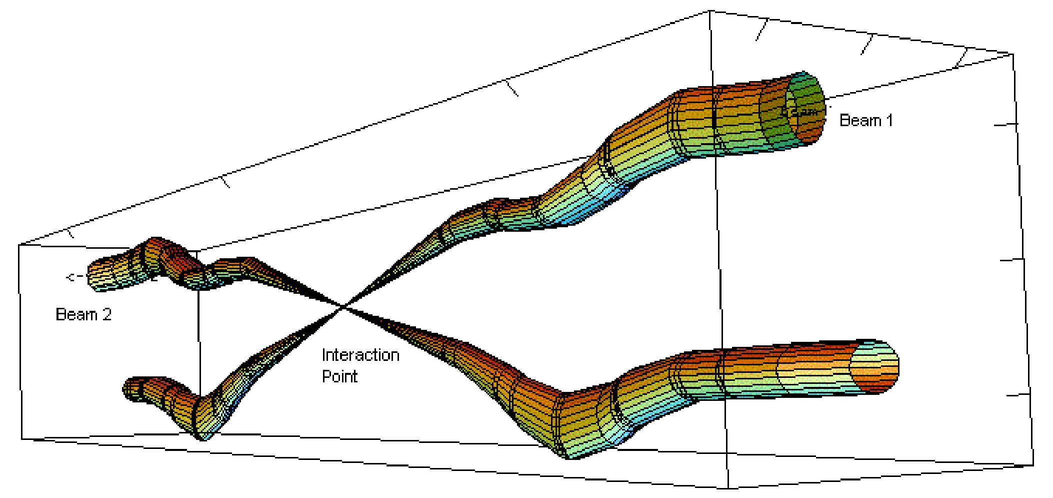
# Stage 3 – 25ns Luminosities

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

# Machine/Experiment Interface

- Beam monitoring through injection and squeeze: strategies for the protection of the experiments' most inner detectors
- More generally, issues associated with machine backgrounds
- Interaction with TOTEM and its roman pots; commissioning of high-beta beams




Relative beam sizes around IP1 (Atlas) in collision

# Tevatron

**Picking up from Jeff Spalding's talk on Thursday**

- Radiation
  - SEB
  - Roman pots
- Fast Beam Losses
  - SI damage
- Messy aborts [serious]
  - Kicker pre-fires
  - Beam in the abort gap
- Background [annoying]
  - Up stream - Halo scraping

- Monitor potentially dangerous accelerator systems [TEVMON]
  - If it's dangerous for you it dangerous for us
  - Shouldn't we be doing this

# Requests from Experiments

- Single beam runs
- Early operation:
  - As fast as possible to stable operations with 25 ns bunch spacing, L ~ $10^{33}$ $cm^{-2}s^{-1}$ [pile up]
  - However, they'll take anything
  - Displace some bunches during 43/156 for collisions in LHCb
- Tune luminosity, spectrometer magnets, and β*
- LHCb:
  - squeeze with low bunch intensities [single event per crossing, 2 1032 @ 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

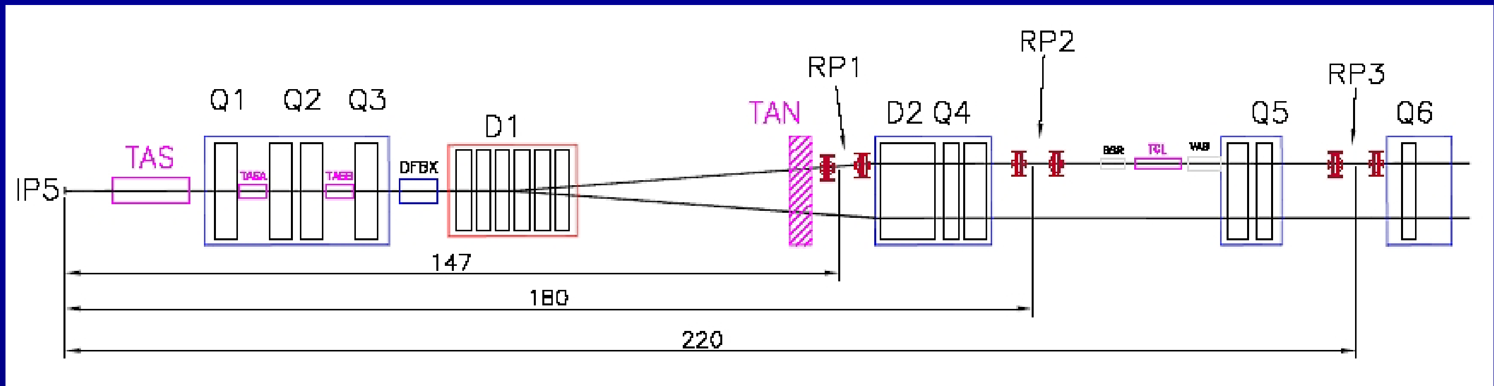
- **75 ns:**
  - 2 weeks sufficient [synchronisation, background studies]
  - Avoid pile up
  - LHCb
    - to 25 ns ASAP [avoiding loss in B rate]
    - again tuning beta* to 2 m if possible

- **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.

# Magnets

- **Magnets**
  - **Spectrometers OFF during initial commissioning**
  - **ON during injection in routine operation**
  - **LHCb: polarity change every fill**
  - **Alice: Polarities [solenoid and dipole] changed 1 to 4 times per year. ON/OFF or intermediate**

# Nominal Cycle – Beam Loss

- **Injection**
  - Losses at injection: injection oscillations, RF capture
  - Big beams, lower dynamic aperture, full buckets, un-captured beam, long range beam-beam, crossing angles, persistent current decay
  - Won't be pretty. 10 hours lifetime will be good.
- **Start ramp**
  - Un-captured beam: lost immediately (~5% total)
  - Snapback: chromaticity, tunes all over the place
- **Ramp**
  - Things should calm down, assume 10 hour lifetime
- **Squeeze**
  - Tunes, chromaticity, collimator, TCDQ adjustments – expect some lifetime dips
- **Collide**
  - Beam finding, background optimisation
- **Physics**
  - Collisions, beam-gas, halo production
  - Synchrotron radiation damping will help against IBS, noise

# Monitoring

- Essential beam monitoring
  - Beam Loss Monitors
    - connected to interlock system
  - Beam Position Monitors
    - selected few to interlock system
    - orbit feedback to ensure stability in cleaning regions
  - Beam Current Transformer
    - dI/dt monitored – connected to interlock system
    - Safe Beam Flag
  - Beam Condition Monitors
    - Experiments – connected to interlock system
  - Abort Gap Monitor

- Radiation
  - Controls – electronics
  - Personnel

# Essential message

**We have to collimate:**

Less than 0.1% of protons lost can escape and can impact on the SC magnets, which otherwise quench

Less than 0.002% of the stored beam intensity can be lost at any place in the ring other than the collimators - > damage

**We have to protect:**

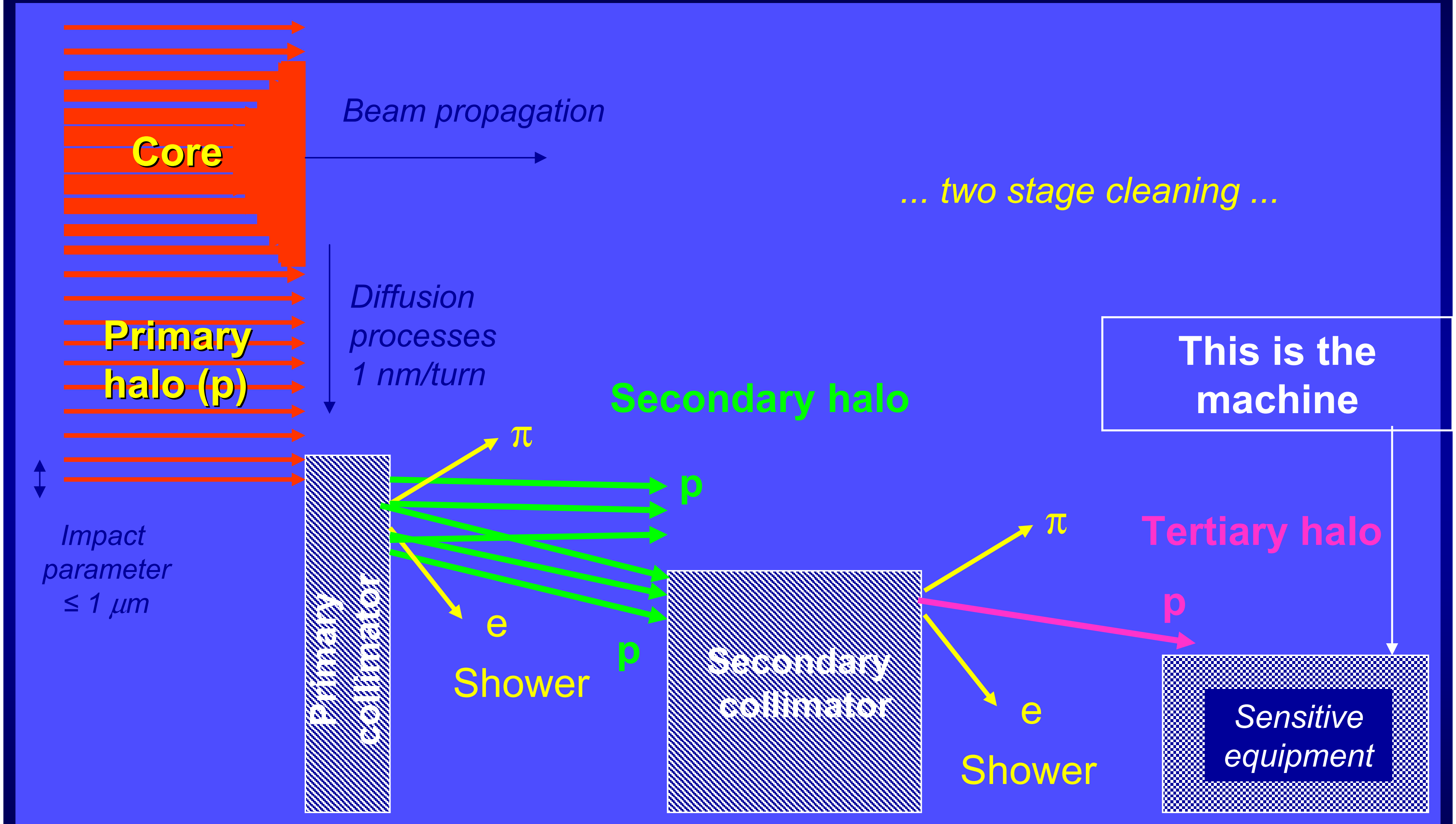
**Injection**

- Pilot and BPF ensures correct settings
- Absorbers and collimators protecting machine (and thus experiments)

**Abnormal dump/ beam in Abort gap**

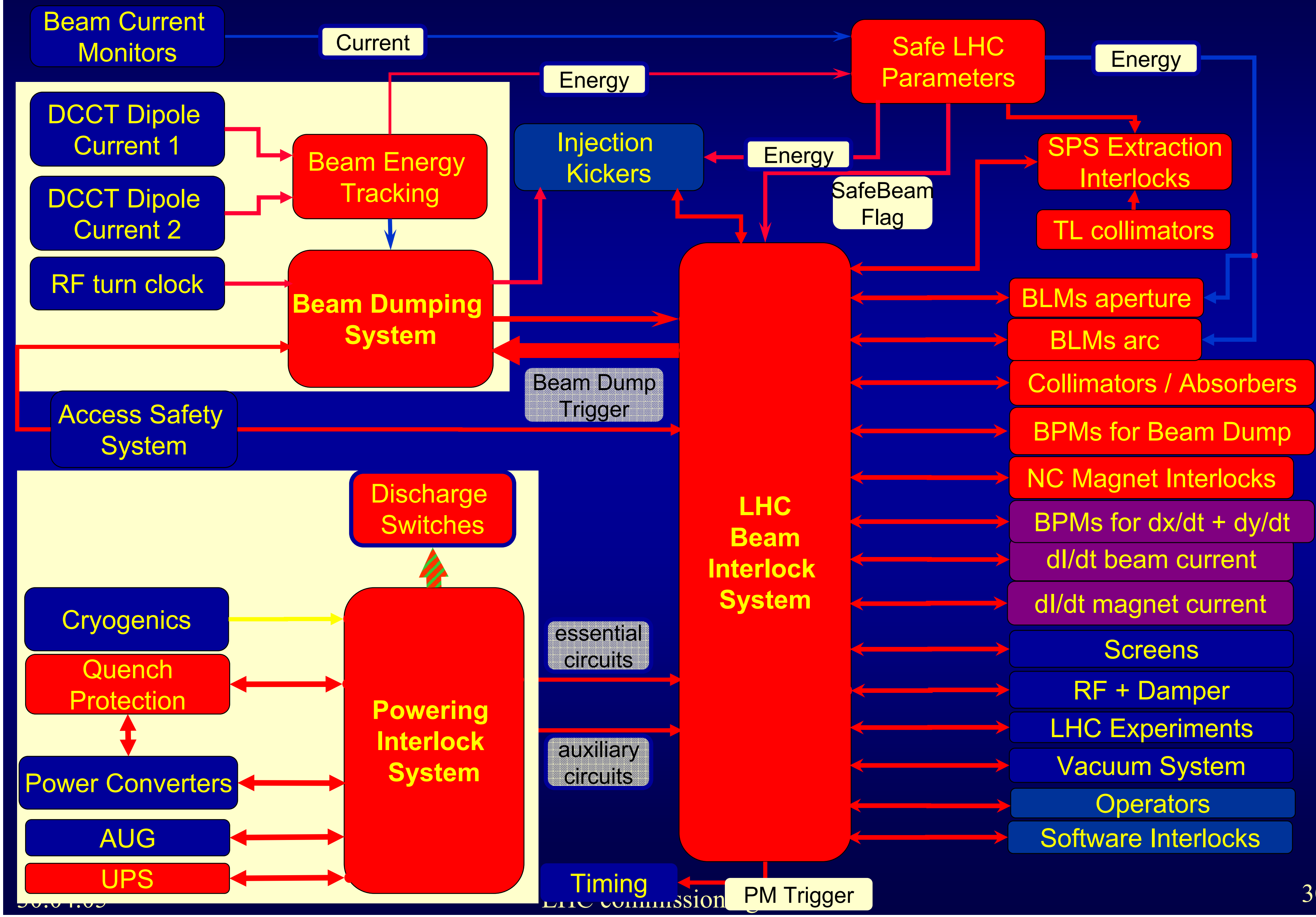
- Collimators & absorbers (re) designed with this in miind

# Collimation



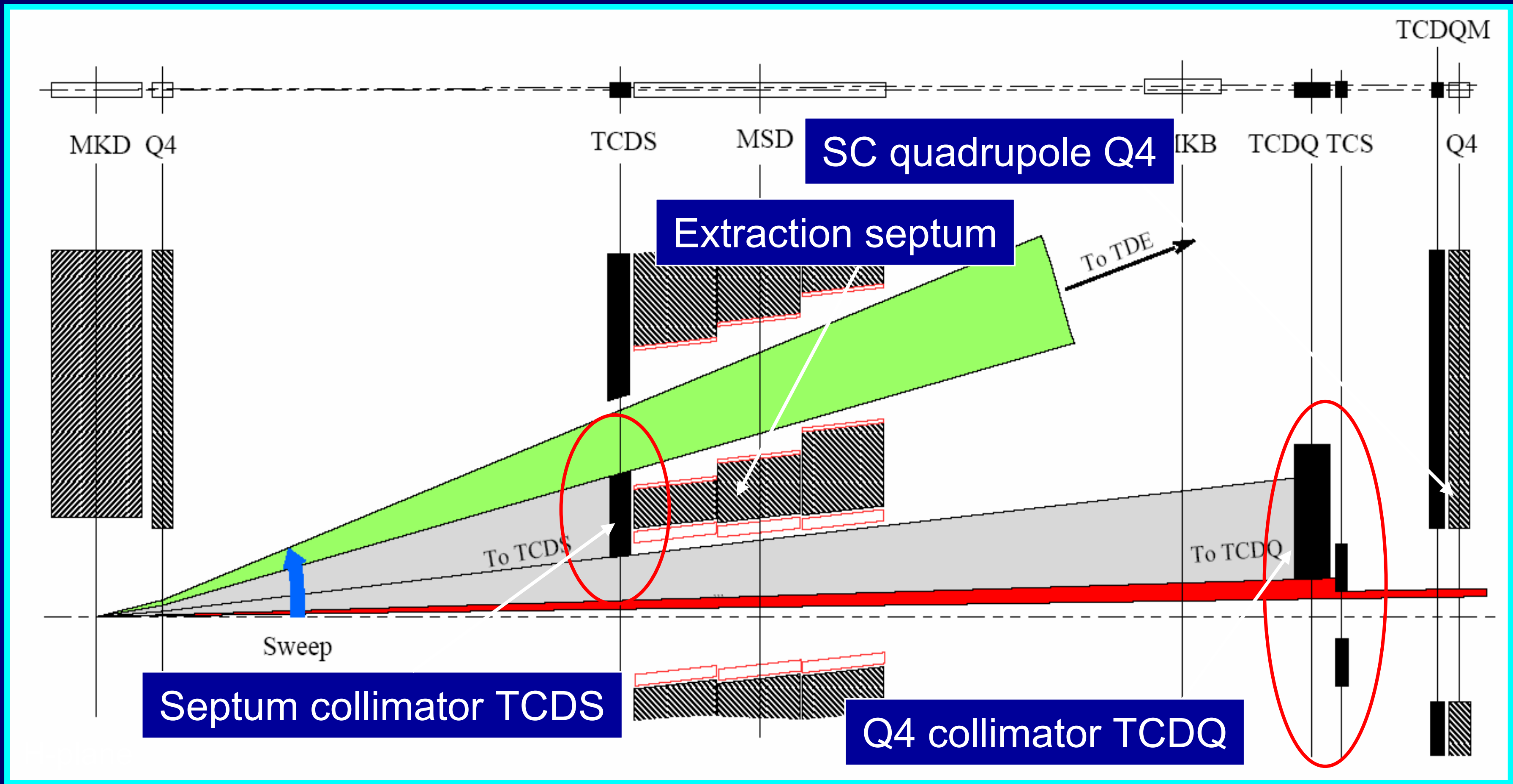

**HAVE TO COLLIMATE AT ALL TIMES**

# Machine Protection Systems and (HW) Interfaces



# Asynchronous dump – pre-fire

- Retrigger remaining 14 kickers in ~700ns
- ~120 bunches swept across LHC aperture




- TCDS (intercepts ~40 bunches) protects the extraction septum
- TCDQ +TCS (~27 bunches) protect Q4 magnet, AND downstream LHC
  - The latter implies precise (±0.5σ) positioning of the jaw WRT beam….

# Backgrounds

- Collision debris
  - Elastic & Diffractive: emittance growth, collimation, quasi-local loss on aperture limits
- Residual Gas
  - Inelastic in warm & cold section of IRs and adjacent arcs
- Beam Halo
  - Intra Beam Scattering, Touschek effect, Resonances, Long range beam-beam, RF Noise, Electron cloud, Collective instabilities
  - ++ Synchrotron radiation damping will help at 7 TeV
- Imperfect cleaning, lifetime dips

**Necessarily mop most of this up in the cleaning sections**
**Tertiary halo lost on aperture limit conveniently situated in triplets next to experiments.**

# Tertiary Collimators

Around the interaction points in order to protect the superconducting triplets and detectors:

- Leakage from collimator system – tertiary halo
- Some beam from unsynchronised beam abort – inefficiency of MPS at IP6

Primary collimators - 6σ,

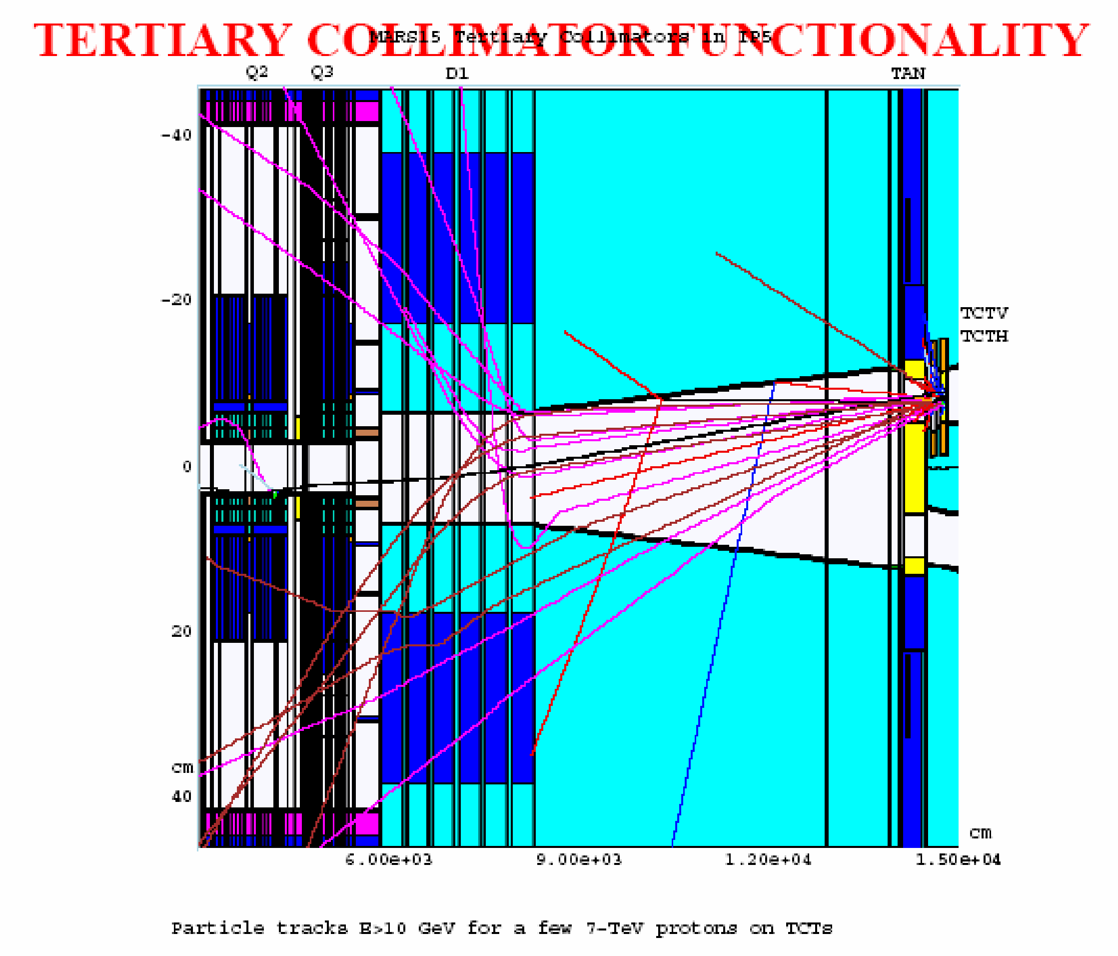
Secondary collimators - 7σ,

Inner triplet - 8.4σ,

Arcs ~ 30σ.

Triplets potentially absorb tertiary beam halo from 8.4 σ to 30 σ

**should not exceed $2\times10^6$ p/s,**



# Beam Interlock System

- Inputs in machine protection system
  - Moveable things
    - Alice's ZDC
    - Roman pots [set by machine OP]
    - VELO
  - BCM
  - Detector Voltage…
  - Spectrometer magnets

- Output
  - Dump request
  - Injection Inhibit

**Response time: 100 μs to 270 μs**

# Conclusions

- Planning for sector test and initial commissioning taking shape:
  - http://cern.ch/lhc-injection-test
  - http://cern.ch/lhc-commissioning
- Experiments' requests need to be carefully prioritised.
- Protection is being taken very seriously indeed
  - Experiments in the shadow of this – but don't take our word for it.

**Thanks to Daniela Macina for her input**