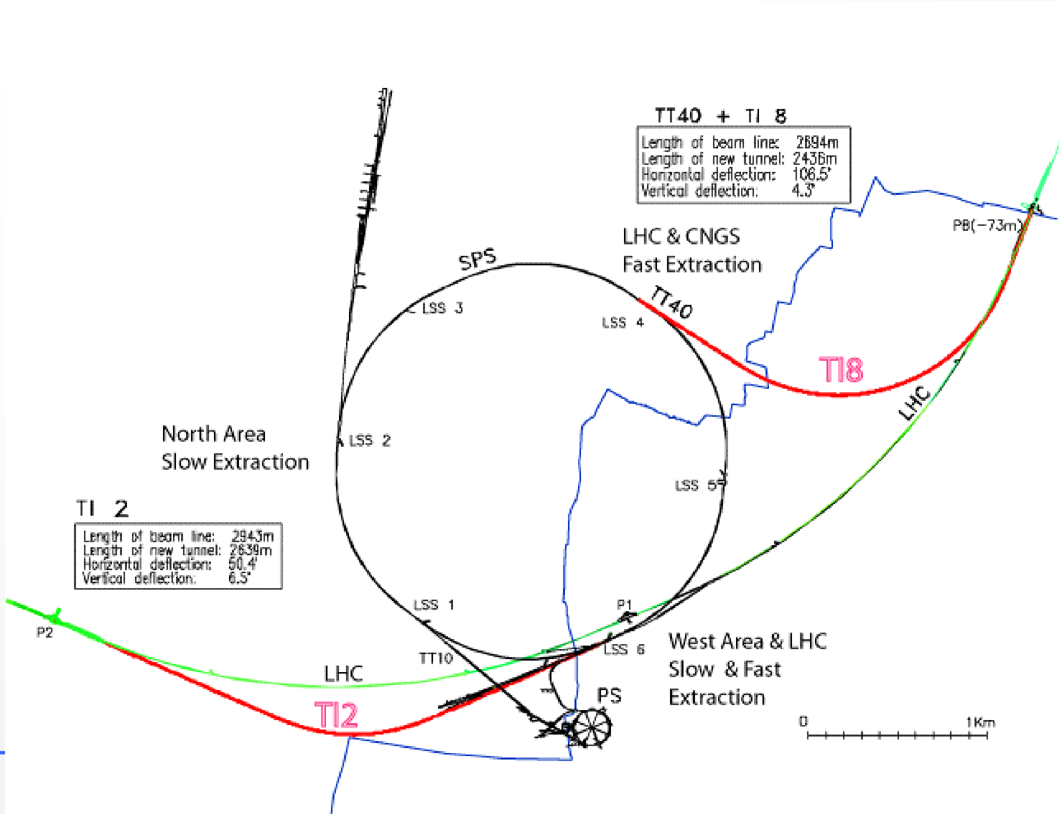
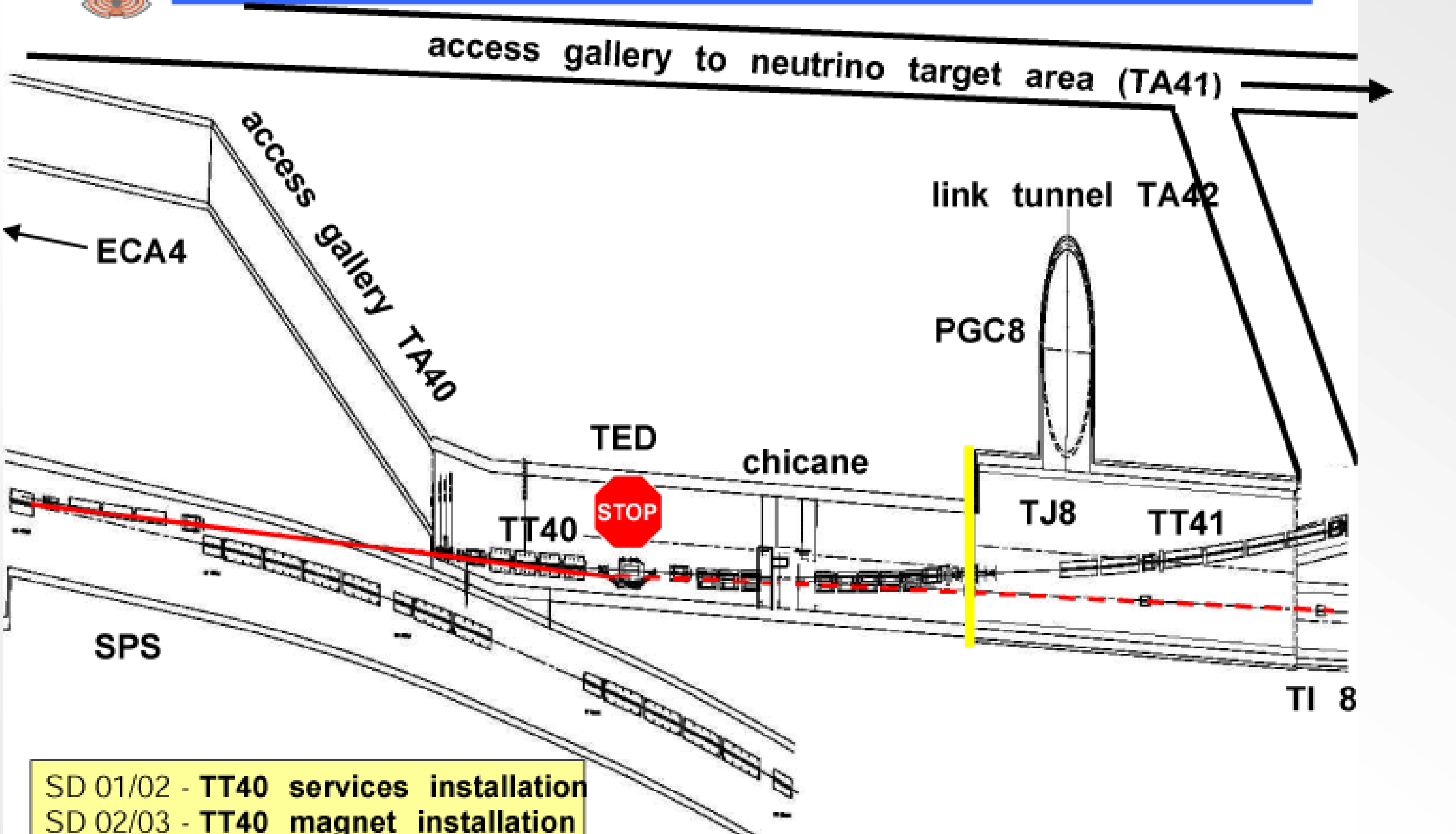
Beam tests

- **TT40**
  - 2 x 24 hours, September/October 2003
- **TI8**
  - 4 x 24 hours, September 2004
- **LHC Injection test (?)**
  - 2 weeks, April 2006
- **TI2 commissioning**
  - April 2007
- **LHC commissioning**
  - April onwards 2007



TT40



SD 01/02 - **TT40 services installation**
SD 02/03 - **TT40 magnet installation**

2003 Extraction Test

Objectives:

- **Verify equipment functionality**
  - Bumpers,
  - Extraction Kickers,
  - Extraction Septa,
  - Beam Instrumentation (Beam loss monitors, position monitors, profile monitors, BCT),
  - Magnetic elements,
  - Power converters,
  - Interlock system…
- **Extract beam from the SPS into the first part of TT40 onto TED:**
  - pilot beam foreseen for the most part
  - Up to 2.5 x 10^{11} ppp allowed for
  - Nominal emittance (or larger to simulate CNGS beam)
- **Verify extraction bump and trajectory in the line**
- **Measure acceptance of extraction channel**
- **Measure reproducibility of trajectory**
- **Double batch extraction – 50 ms interval for CNGS**
- **Effect of extraction kicker ripple**

Shake out

ALREADY A INTERESTING INTEGRATION EXERCISE

- HW and SW interlocks
- Services: ventilation, cooling…
- Access
- Vacuum
- Dump & shielding,
- Cabling, electronics
- Control system
  - Logging, timing, applications, alarms, acquisition etc..
- Injectors
- Radiological protection

Scheduled to hold extraction tests with beam in second half 2003 – 2 days scheduled – 8/09 and 1/10 (27/10 in reserve). Situation well in hand.

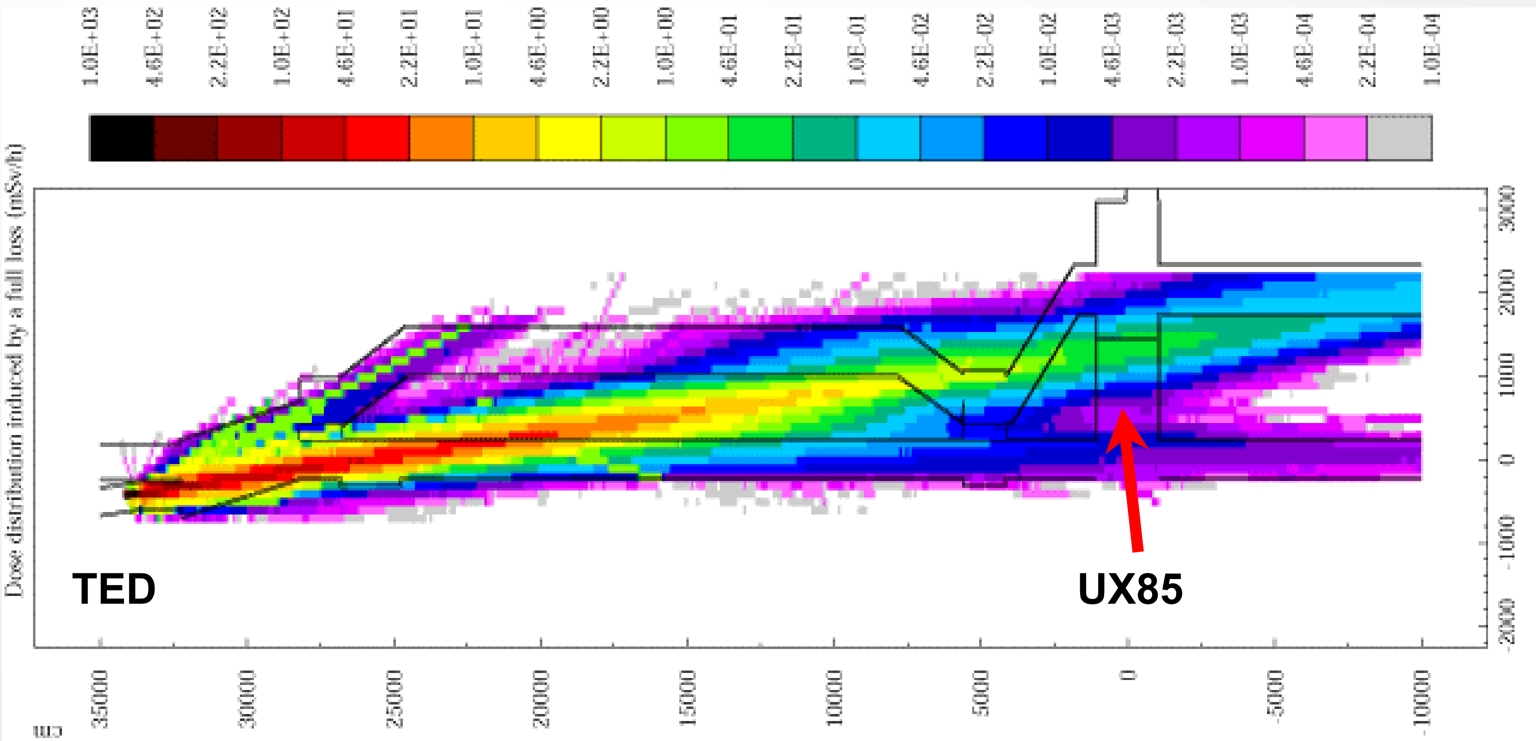
TI8

- September – October 2004
  - Limited cooling ∴ not continuous pulsing
- 4 x 24 hours (long weekend)
- Aims:
  - Verify equipment functionality: Beam Instrumentation, Magnetic elements, Power converters, Interlock system, control system, surveillance systems, vacuum (2.7 km of beam line)
- Extract beam to TED at end of TI8:
  - pilot beam foreseen for the most part
  - Up to 2.5×10^{11} ppp allowed for
- Trajectory acquisition and correction, reproducibility of trajectory
- Commission beam instrumentation
- Optics in line, matching etc. etc.

Radiation

Simulations have been performed by Radiation Protection Group

e.g. high energy muons…



Graham Stevenson et al

Radiation

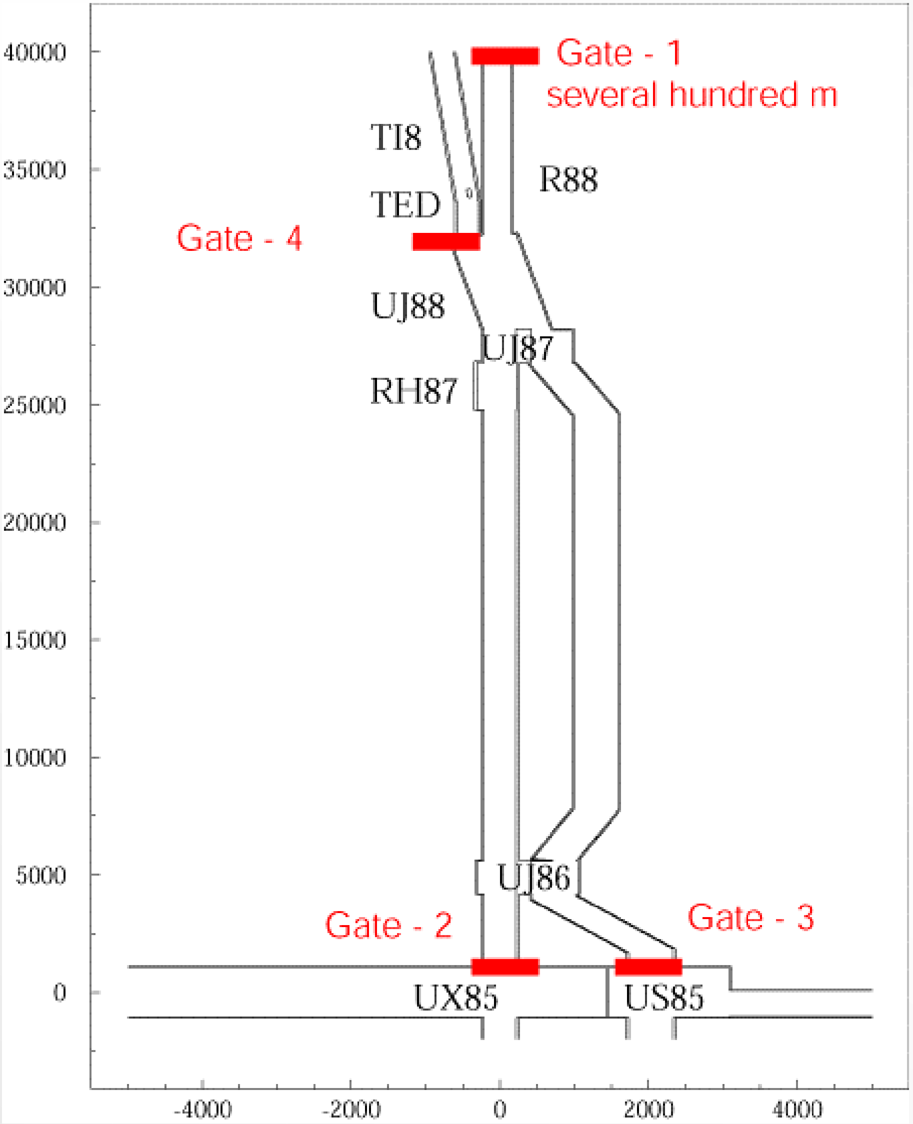
- **Planned intensities:**
  - **Maximum assumed:**
    - **50% x 2.5 x 10^{11} ppp   i.e. 5.4 x 10^{14} protons in 24 hours**

- **Remnant dose rates (after one day irradiation & one day cooling)**
  - **Along side TED: 120 μSv/h**
  - **Downstream face of TED: 3 mSv/h**
  - **Would have a extra beam stop (Iron/concrete) after the TED**
  - **Some irradiation of concrete walls around TED**

- **UX85**
  - **Beamline   2.5 μSv/h**
  - **Downstream face of TED: 1 μSv/h**

After test : area around TED → Simple Controlled Radiation Area

Access



- **Temporary zone at end of TI8**
- **Gates interlocked: cables pulled back to SPS interlock system**
- **Gate 1 prevents access from Point 1**
- **Gate 2 prevents access from UX85**
- **Gate 3 prevents access from US85**
- **Gate 4 at UJ88 junction with TI8 – some form of separation since TED becomes Simple Controlled Area after tests.**
- **Radiation monitors also required in R88, UX85 and US85.**

Injection test in 2006

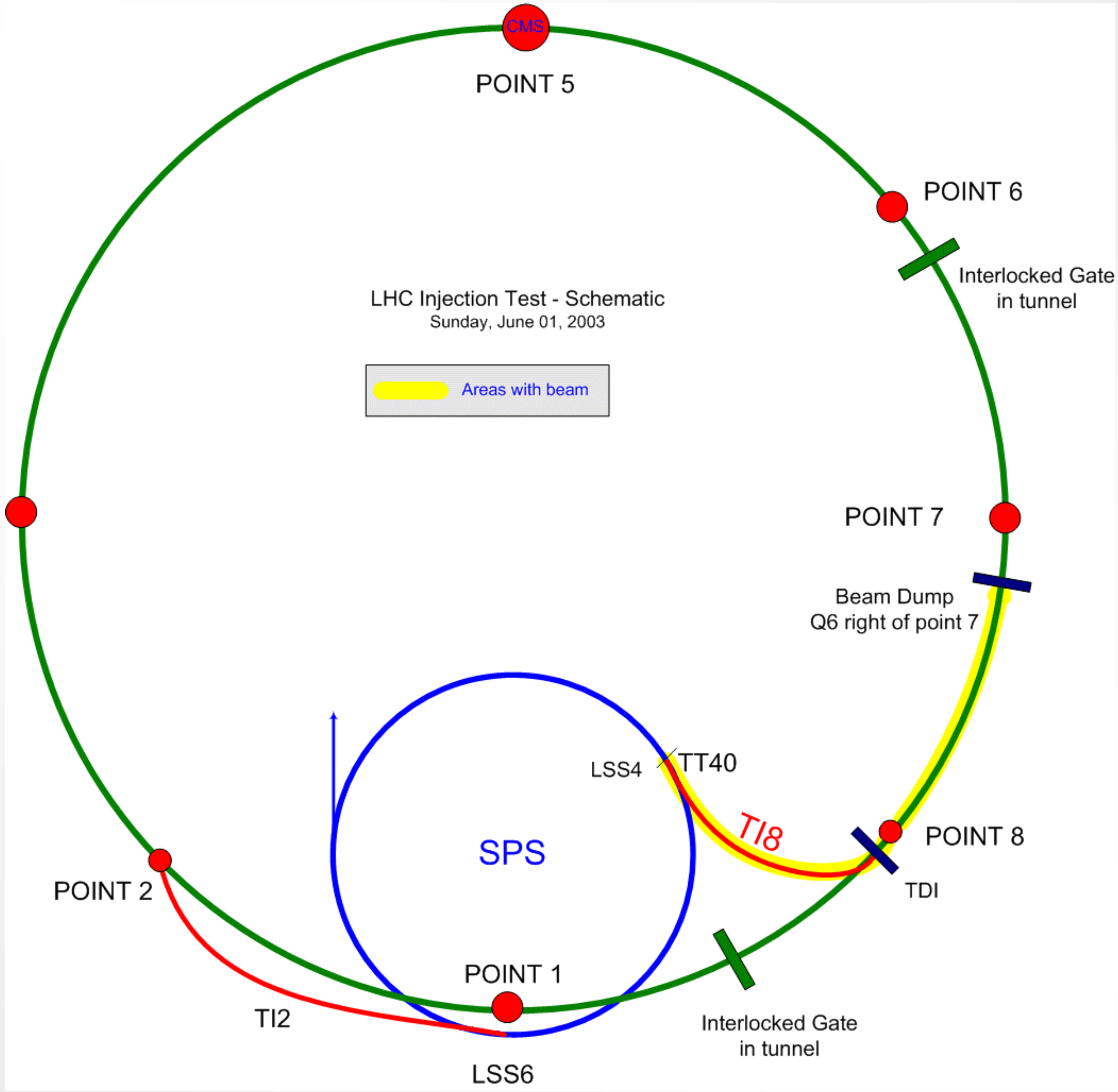
- The installation schedule version 1.7 recently approved includes a ‘possible injection test’ - foreseen in April 2006

- Injection of beam:
  - down TI8,
  - into LHC at the injection point right of point 8,
  - though IP8 (LHCb)
  - through sector 8-7
  - to a temporary beam dump located after the Q6 quadrupole just right of the warm insertion of point 7

- Many good arguments for performing this test (as outlined at Chamonix 2003 session 7)

- Also numerous consequences (some of which were presented at Chamonix 2003 session 4)

Injection Test



Motivation

- **Powerful diagnostic tool**
  - Mechanical aperture checks
  - Field quality checks
  - Test diagnostic systems
  - Test controls, correction circuits, BPMs etc.
  - First hardware exposure to beam, quench limits…
- **Integration - major challenge to bring everything together: full-blown systems tests, highlight oversights, debug.**
  - Magnets, power converters, controls, timing, beam transfer etc.
- **Provide a very important milestone for beam-based instrumentation, diagnostics and control**
- **Public relations**

Strongly endorsed at Chamonix 2003

Impact

Possible consequences for:

- On-going installation of 3-4, 5-6, 6-7
  - before, during and after the test.
  - disruption of installation in sector 6-7
- Hardware commissioning 4-5
  - Test will pull in resources from the above in preparation for the test and during the test itself
- Force the installation schedule of some systems
  - e.g. access and interlocks
- Consequences for installation and commissioning LHCb

- Radiation after the event: 7-8 potentially to be declared simple controlled radiation area with some knock-on effects

- Resources

Reservations expressed at Chamonix 2003

Impact

- Install access gates – time, impact in tunnel
- Install dump and shielding right of point 7
- Commission access system & personnel interlocks
- Recommission sector 7-8 ++ without beam
  - Pull effort from hw commissioning 4-5
- Preparation without beam, very cold checkout, system tests
- Prepare injectors
- Recommission TI8 with beam
- Tests with beam
- Radiation surveys
- Remove dump
- Remove gates from tunnel
- Possible radiation restrictions

Plan

Fully define test conditions

Impact analysis

Elaborate and detail consequences of test.

Seek project wide approval

JUNE 2003

YES

Detail requirements, consequences and planning

- Minimise the impact and cost:
  - Before, during the test and after
- Maximise the efficiency of the test:
- Ensure the test can be performed safely
- Ensure INB requirements are met

WORKING GROUP REPORTING TO LHCOP

REPORT TO PARIS (INB) MID 2004

Issues

Tests with beam	What? Intensities, inefficiencies
Radiation	Monitoring, limits, expected intensities, status of zones afterwards.
INB	Approval, after the event
Access & Interlocks	Resources, schedule, personnel interlocks, situation after the event
LHCb	Schedule, radiation
Injectors	Timing of the test
Transfer Line	Preparation, re-commissioning
Hardware Commissioning	Resources, operations' training
Impact on hardware installation	Essentially 2 weeks off sector 6-7
Requirements – controls, instrumentation, machine protection, hardware	Baseline
Dumps	Installation, radiation, removal

Timing of test

- PS and SPS will be starting up after 2005 shutdown
  - SPS under energy consumption restrictions unable to pulse before April 1st.
  - Given need for cold checkout & re-commissioning estimate 4 weeks to re-commission
- Injection test pushed to end April unless provision is made to start SPS earlier.

- For LHCb, April 2006 is the most convenient time slot for the injection test.
  - Taken in account in their planning
  - A delay of the sector test by more than 10 weeks beyond April 2006 would jeopardize the LHCb overall commissioning.
  - The interruption to the LHCb installation due to the injection test should not exceed three weeks.

Installation

- **Installation**
  - **Sector 6-7 scheduled:**
    - Cryo-magnet transport
    - Interconnection work
    - Warm MQ, D3, D4 & Q6 in LSS.7L
  - **"2 weeks (not more!) would not create turmoil"**
  - **Main message: Be very careful with possible activation.**
  - **Do not compromise free access through the sector after the test.**

Sylvain Weisz

- **HW commissioning**
  - **Heavy work load.**
  - **Operations are going have to get involved!**

Beam tests

- Setup Beam for the most part
  - Single bunch
  - Intensity: 5 to 10 x 10^9
  - Low emittance: $\varepsilon_n \approx 1.0$ μrad
  - Longitudinal emittance around 0.5 eV.s
- Two main stipulations
  - Don't irradiate LHCb
  - Don't irradiate the ring too much
- Clear aim to minimise losses and use beam sparingly when we know where it's going. Take beam when we need it.
- Possible gentle pushing of intensity to probe quench limits

- ~ 3000 shots giving a totally intensity of 2 x 10^{13} protons

Coupled with preparation time and high operational inefficiencies

Test outline

	Test	Duration [hours]	Intensity	Number of shots	Integrated Intensity	Comments
1	Injection Steering, commission screens, IBMS, timing	12	5.00E+09	144	7.20E+11	TDI in, protecting LHCb
2	Trajectory acquistion commissioning, trajectory correction, threading	24	5.00E+09	288	1.44E+12	To beam dump
3	Linear Optics from kick/trajectory, coupling, BPM polarity checks, corrector polarity checks	24	1.00E+10	288	2.88E+12	
4	Aperture limits, acceptance	12	5.00E+09	360	1.80E+12	Pi bumps, BLMs, BCT
5	Momentum aperture	6	5.00E+09	60	3.00E+11	Move energy of SPS beam
6	IR bumps, aperture	6	5.00E+09	60	3.00E+11	Careful in LHCb
7	Commission normal cycle	12	5.00E+09	100	5.00E+11	
8	Energy offset versus time on FB	12	5.00E+09	100	5.00E+11	Cycle & repeat
9	Study field errors	12	1.00E+10	72	7.20E+11	Collect data, off-line analysis
10	Effects of magnetic cycle, variations during decay, reproducibility	24	5.00E+09	360	1.80E+12	12 cycles
11	Calibrate BLMs	24	5.00E+09	720	3.60E+12	couple with below
12	Multi-bunch injection - determination of quench level	12	3.6E+11	10	3.60E+12	start with pilot and work slowly up… how do we localise loss appropriately?
13	Effects of thermal cycling					Long time scale - low priority
14	Squeeze at 450 GeV					Handle on triplet errors? Coupling?
	TOTAL	180		2562	1.82E+13	
	DAYS	7.5				

Classification of Radiation Areas

- **Areas with dose rates below an average of 2.5 μSv/h are called surveyed areas. There is no restriction on access to such areas.**

- **Simple controlled areas have average dose rates of up to 25 μSv/h.**
  - **They are marked by warning signs and are generally enclosed in physical boundaries. Fairly light restriction.**
  - **Persons <u>working</u> in such controlled areas must wear their film badge all the time.**

Values under revision

Radiation

- RPG have performed simulations using 4.0 x 10^{11} ppp every 14 s. as their all out maximum for the sector test. This scenario represents an extreme case.
- At these intensities: the dose rates for 1 day irradiation and 1 day cooling at 50% efficiency of above rate are calculated for:
  - TED
  - Distributed losses in arcs
  - Repeated localised losses at the dump and in the arcs.

- This dose totals 1.3 x 10^{15} protons in 24 hours.

- Even given the extensive program of tests described above we should be able to keep the total dose down to around 2 x 10^{13} protons over 7 days i.e. scale down RPG group's result by 2%.

Radiation

- Typical dose rates for 1 day irradiation and 1 day cooling (50% efficiency):

- TED
  - Along side TED: 300 μSv/h → 6 μSv/h
  - Downstream face of TED: 7 mSv/h → 140 μSv/h
  - Would have a extra beam stop (Iron/concrete) after the TED
  - Some irradiation of concrete walls around TED

- ARC
  - Assume beam is lost uniformly along the sector between point 8 and point 7: 0.5 and 2 μSv/h. → negligible
  - Assume beam is lost in one dipole: 200 and 500 μSv/h. → 4 and 10 μSv/h

- The scaled down figures would be diluted even further by the extended cooling period

Radiation cont.

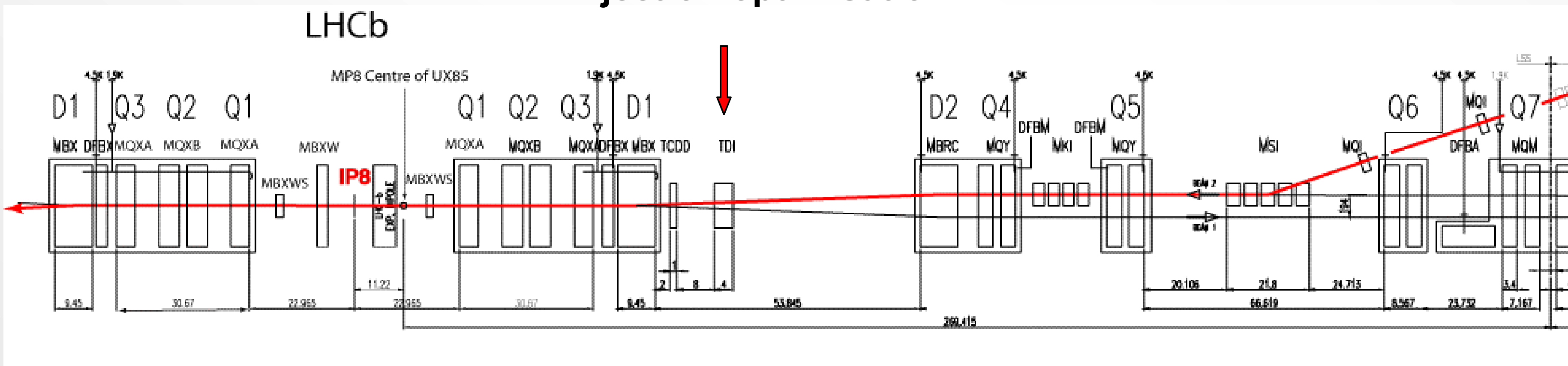
- Even with the higher dose rates:
  - The situation would not be disastrous, the injection region, arc and dump region could be classified as a simple controlled radiation area
  - “If we want the dose rates to be insignificant after 1 month - we should foresee at least one order of magnitude less beam that assumed above.”
  - We anticipate something like 2 orders of magnitude less
- Potential warm spots:
  - Near dump location. Localised losses at the dump will lift levels. Will remove dump. Need to check activation of walls. Thereafter passage should be possible.
  - Around the TDI. Might have to limit number of pulses on to it. Passage possible.

LHCb: radiation

- It has to be ensured that the experimental cavern at point 8 will be treated as a supervised area after the injection test and not as a controlled area.
- It has to be ensured that no part of the beam pipe or nearby detector will receive a radiation dose that would leave either activated after the test.

Reasonable aperture
$\approx$ 50 mm $\approx$ 18σ

TDI: Can be closed as far as possible during injection optimisation

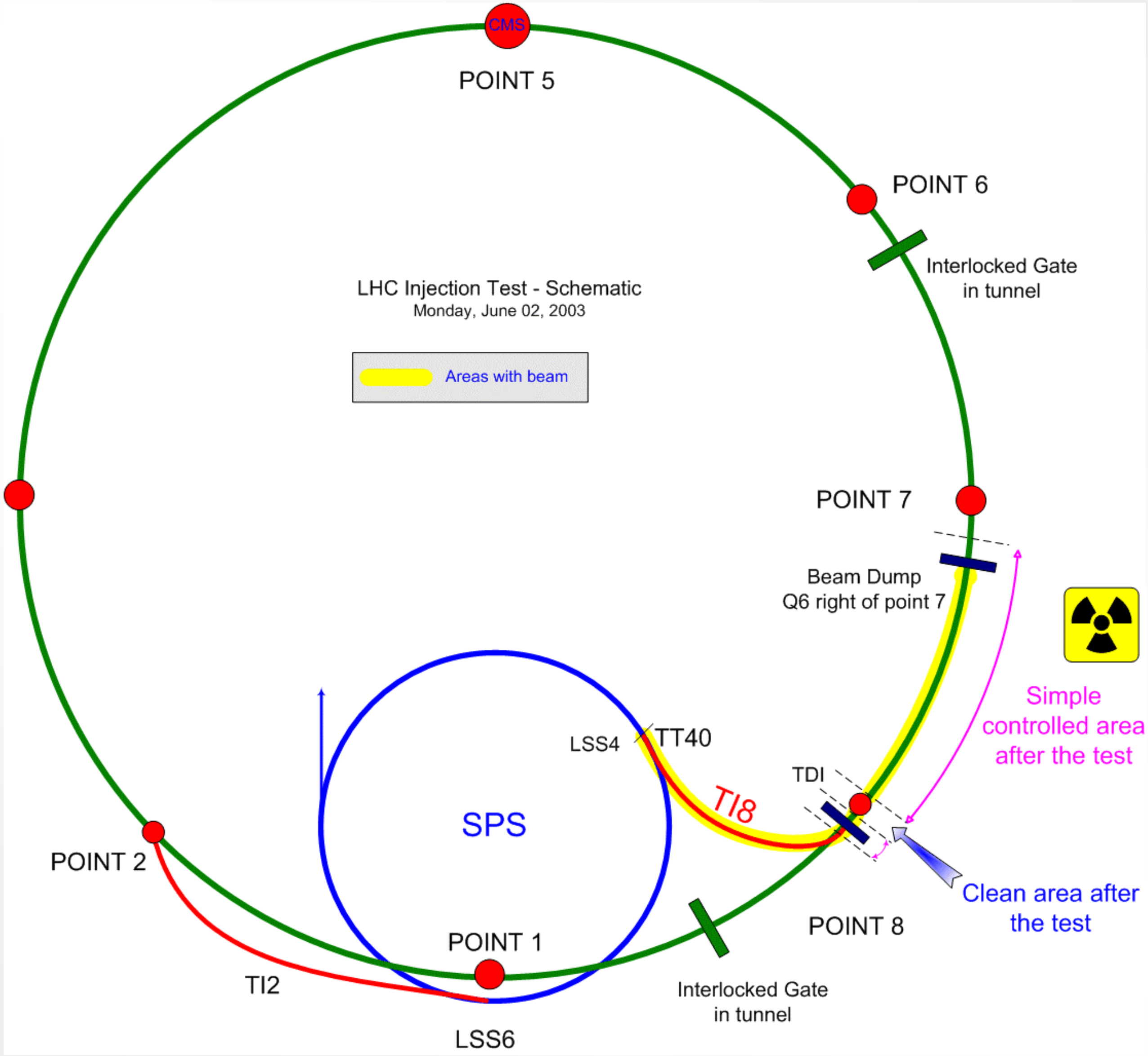


Detuned insertions

Smaller beam size

Low emittance pilots injected

Radiation



CMS
POINT 5
POINT 6
Interlocked Gate
in tunnel
LHC Injection Test - Schematic
Monday, June 02, 2003
Areas with beam
POINT 7
Beam Dump
Q6 right of point 7
Simple
controlled area
after the test
LSS4
TT40
TI8
TDI
SPS
POINT 2
Clean area after
the test
POINT 8
POINT 1
TI2
Interlocked Gate
in tunnel
LSS6

Monitoring

- Radiation monitoring
  - Radiation Monitors can be provided by TIS
  - Collaboration required to install, cable and monitor
- Beam Loss Monitors
- Beam Intensities
  - Beam extracted, injected and to dump to be logged
- LHCb
  - Monitoring to ensure minimal losses
- RPG survey after the event to ensure cleanliness.

Radiation: conclusion

- The intensities we plan to use are low, with care there should be only a low level of activation
- For prudence we say we are assuming restrictions appropriate to simple controlled area.
- Even with these restrictions transport through these areas is allowed.
- Dump can be removed within a day of test end, concrete in area should have low activation.
- Very careful putting beam through LHCb which will remain a surveyed area.

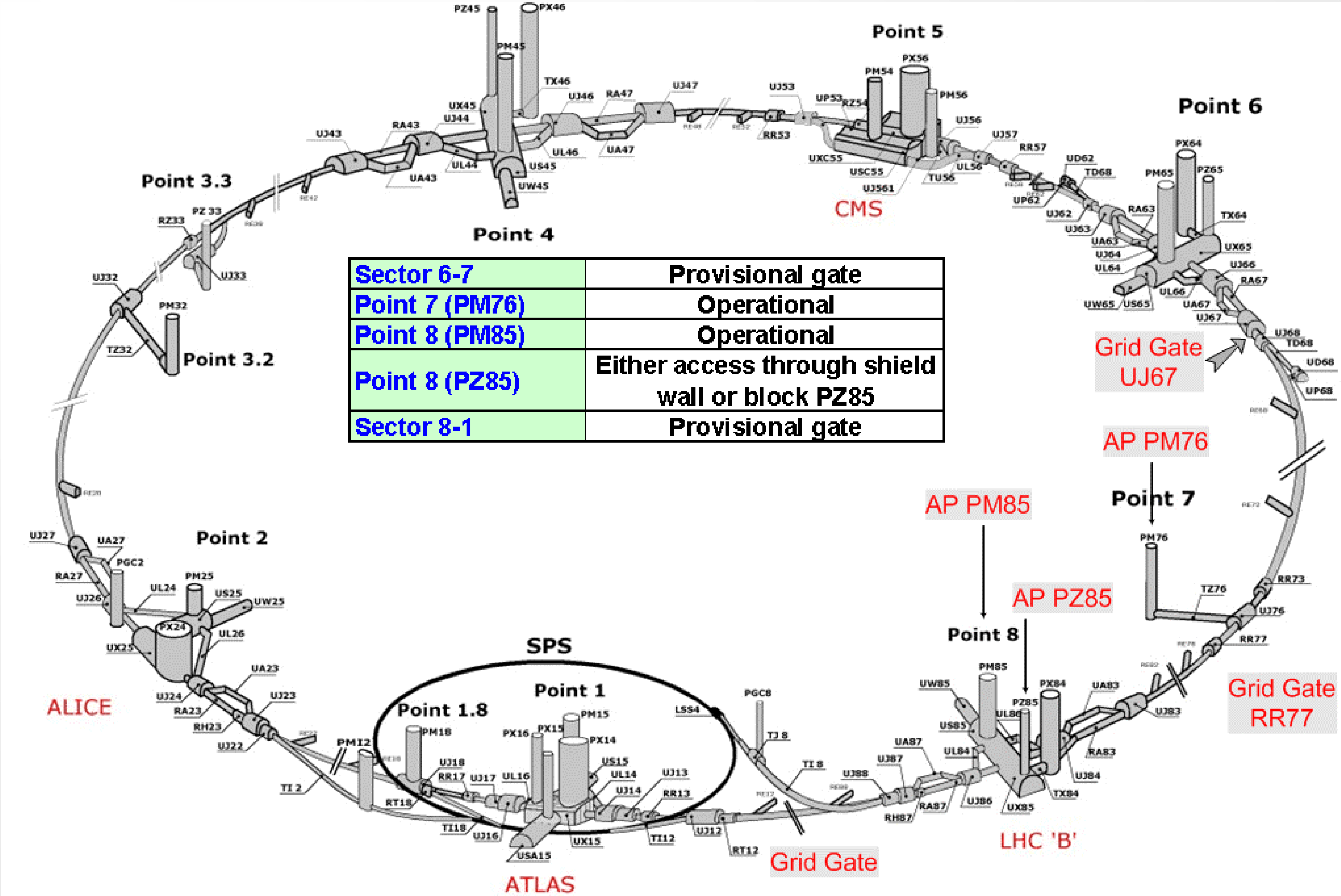
- Monitoring:
  - Radiation monitors provided by TIS to be installed with appropriate logging
  - Beam intensities in & to TED to be logged.

- Survey after to confirm

INB

- Tell them that we are going to perform the test
- Tell them estimated intensities, estimates of likely activation, and estimates of personnel dose.
- Propose, and then discuss with them possible approaches for appropriate restrictions
  - One scenario would be Simple Controlled Area(s)
- Report to be presented in 2004 at the same time as the Dossier de sûreté.

Access



Sector 6-7	Provisional gate
Point 7 (PM76)	Operational
Point 8 (PM85)	Operational
Point 8 (PZ85)	Either access through shield wall or block PZ85
Sector 8-1	Provisional gate

Access

- For sector 7-6, a gate must be installed and interlocked close to Point 6 in UJ67.
- The machine access point at Point 7 (PM76) should be operational.
- The machine access point at Point 8 (PM85) will be operational.
- Either the planned access point between the experimental service cavern and the LHCb experiment must be operational with the shield wall in place, or a new interlocked gate must be placed at the top of PZ85. To be decided.
- A gate in sector 1-8 must be operational & interlocked. Foreseen but could be provisional.
- A means of separation must be placed just to right of point 7 to define the new Simple Controlled Radiation Area. This will include the zone where the dump was installed.

"the access system will be safe and available"

Enrico Cennini

FIRST YEAR - Tentative Planning

- Atlas: shutdown not foreseen, reserve the right with a minimum of 3 months
- CMS: 2.5 months shutdown after the pilot run

Time	Phase
$T_0 \rightarrow T_0$ + 2 months	Setup with single beam
T_0 + 2 months $\rightarrow T_0$ + 3 months	Colliding beams 1x1, 43x43
T_0 + 3 months $\rightarrow T_0$ + 4 months	Low intensity 75 ns and then first 25 ns physics
3 months shutdown	
Physics (~7 months)	Collisions, work towards 10^{33} $cm^{-2}s^{-1}$
Ions	"a few good days Pb-Pb before a long shutdown"

First year – boundary conditions

- No more that ~2 overlapping events during the initial physics data taking:
  - i.e. 10^{33} $cm^{-2}s^{-1}$ at 25 ns
- Only 8 of 20 beam dump dilution module installed
  - Total maximum intensity 50% of nominal for first 2 years
- Electron cloud
  - Bunch intensity to nominal with 75 ns
  - Bunch intensity to 1/3 nominal for 25 ns
- In addition machine protection and collimation favour initial operation with low beam power and low transverse beam density. Clear we will have to move slowly:
  - Learn how to deal with multipole effects, establish a reproducible operational cycle
  - Wrestle with collimation, squeeze, beam-beam, triplets errors, luminosity steering etc. etc.

Luminosity

- Commission machine, first collisions, with single bunch, then…
- 43x43
  - No crossing angle, No electron cloud
  - Bigger tolerances, Lower beam power
  - However only 2×10^{31} $cm^{-2}s^{-1}$ before event pile-up
  - Check out squeeze, reproducibility, triplet quad alignment, transfer functions of separation dipoles, optics in squeeze, luminosity steering etc…

$N_b \sim 5 \times 10^{10}$

- 75 ns
  - Work first with reduced bunch current and reduced β^* before moving to…
  - $N_b \sim 0.5 \times 10^{11}$ at $\beta^* \approx 1$ m. gives 3 to 4×10^{32} $cm^{-2}s^{-1}$ and about 2 events per crossing

$N_b \sim 5 \times 10^{10}$

- 25 ns
  - Reduced $N_b \sim 0.4 \times 10^{11}$ at nominal $\beta^* \approx 0.55$ m. gives 1.2×10^{33} $cm^{-2}s^{-1}$ and 2.3 events per crossing (eventually)

$N_b \sim 4 \times 10^{10}$

Implications

V. Baglin, Chamonix 2003

- **Vacuum – 3 phases foreseen**
  1. **Start-up**

     Below electron cloud threshold ≈ $N_b \sim 3 \times 10^{10}$

     No electron stimulated desorption or heat load on cold parts

     Lower beam current → requested vacuum lifetime decreased below 30 hours

     Warming of beam screen at end of this phase may be required.
  2. **Conditioning of cryo-elements**

     Scrubbing run at 450 GeV
  3. **Post-conditioning**

We might well not pass phase 1 during year 1.

- **Radiation**
  - **Clearly with the maximum total intensity being kept to less that 1/3 nominal (& a lot less for a large part of the year). Irradiation of electronics etc. will be much reduced.**

Implications

- Cryogenics
  - Lower intensity $\rightarrow$ lower heat load from beam loss (given efficient collimation),
  - less synchrotron radiation, lower image currents
- Collimation & Quench level
  - At 7 TeV proton losses rates at 10000 to 1000 times above the quench limit for 0.2 hour and 10 hour beam lifetime respectively.
  - Cleaning efficiency has to be very good.
- Difficult challenges for LHC collimation system can be relaxed during commissioning by:
  - Keeping the total beam intensity to a minimum
  - Not reducing β^* too much
  - Emittances should not be smaller than nominal.
  - A steep learning curve – see Ralph's talk.

$$\tau_q = \frac{N_{tot} \cdot \tilde{\eta}_c}{R_q}$$

Lower energy

- **"It is not possible to reduce the heat load on the cryogenics system significantly by reducing the beam energy"**

Andre Verdier

- **Quench level margin can be increase by:**
  - **Limiting the beam intensity and thus beam losses**
  - **Or by reducing the energy**
    - Not an enormous gain from lower synchrotron radiation
    - Transient losses in triplet: 3.2 TeV to get an order of magnitude
    - Transient losses in dipole: 4.7 TeV to get an order of magnitude
    - Continuous losses: small gain

- **Experiments prepared to accept 10% energy reduction i.e. 6.3 TeV for limited period.**

Conclusions

- **TT40 – September 2003**
  - Work fully in progress
- **TI8 – September 2004**
  - Installation ongoing
  - HW commissioning & beam tests – details to come
  - Radiation and access issues addressed
- **LHC Injection test – April/May 2006**
  - Very careful planning will be required to reduce potential impact – particularly in preparation, & the recovery phase
  - Planned intensities are low, activation should be low, restrictions for transport will be light.
- **First year**
  - Maximum bunch intensity of 3 - 4 x 10^{10}
  - Below or around electron cloud threshold
  - Lower heat load on cryogenics
  - Relaxed demands on collimation efficiency

Acknowledgements

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- Enrico Cennini
- And others…

- The editors of Chamonix 2003