LHC machine plans

Mike Lamont

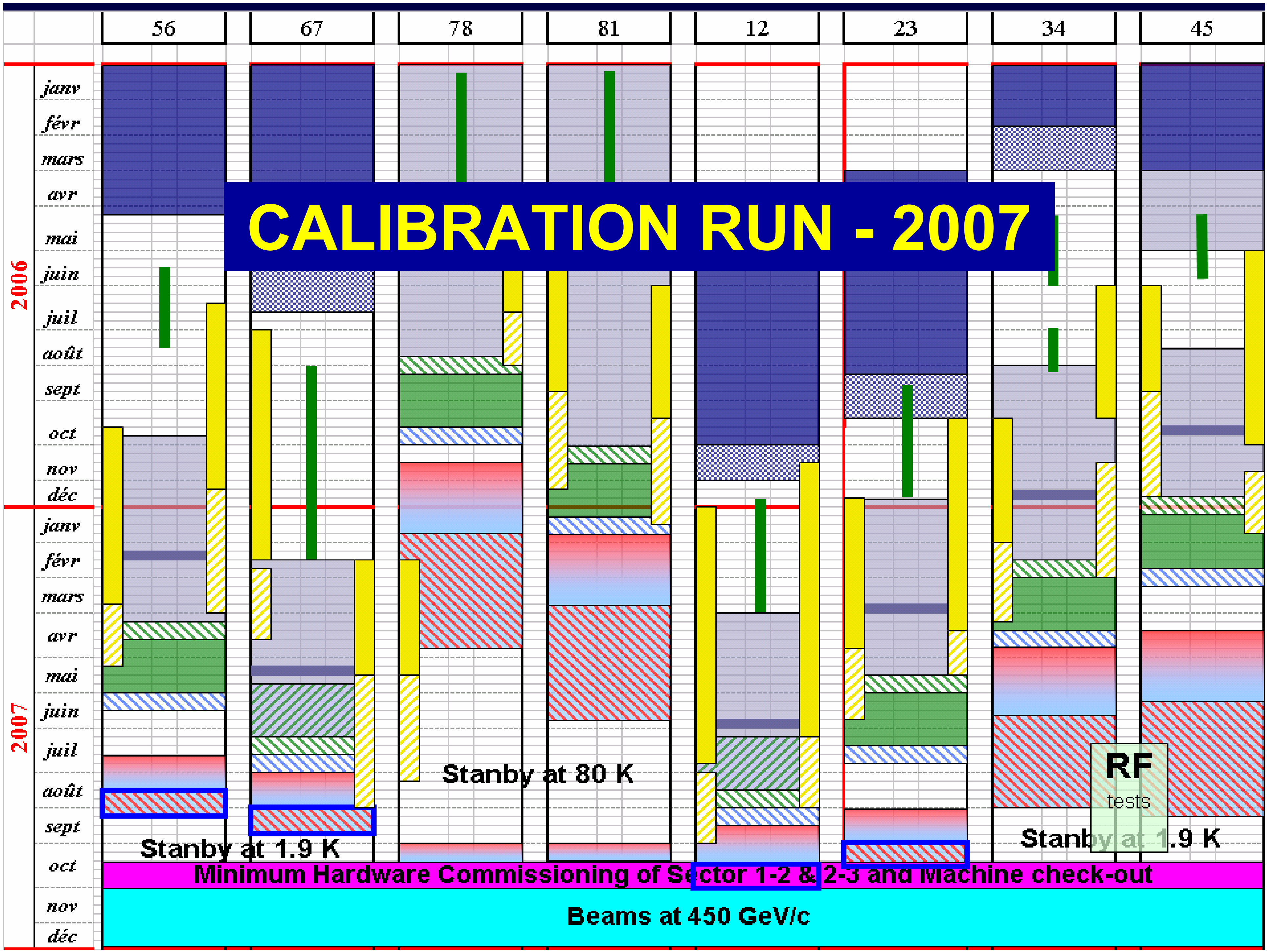
Mixed Bag

- Single beam operations in 2007 (and 2008)
- Details of 450 GeV running in 2007
- Machine Parameters (if already known)
- Collision to single-beam operation ratio for 450 GeV

- Knowledge of size and absolute position of beam spot from machine in 2007 (and 2008 - if different)

- Machine Background Simulation/conditions in 2007 (and 2008 startup)
- Expected beam gas interactions and beam halo muon/hadron rates in 2007 (and 2008)
- Are there already plans to provide machine background simulation for 450 GeV running in 2007?

- Can the experiment dipole magnet switched on to full field ?
- Can the LHC-b VELO be closed at all with no squeezed beam, aperture 5mm ? with magnet on ?


CALIBRATION RUN - 2007
56
67
78
81
12
23
34
45
2006
2007
janv
févr
mars
avr
mai
juin
juil
août
sept
oct
nov
déc
Stanby at 80 K
Stanby at 1.9 K
RF
tests
Minimum Hardware Commissioning of Sector 1-2 & 2-3 and Machine check-out
Beams at 450 GeV/c

End 2007

	56	67	78	81	12	23	34	45
Oct						Minimum HWC		
	Operations testing				Minimum HWC	Operations testing		
Nov	Full Machine Checkout (Access, Vacuum, Equipment Tests, Cycle and Set, BIC and INB)							
Nov / Dec	Beam Commissioning to 450GeV 16days estimated, 60%efficiency assumed							
Dec	Engineering run (Collisions at 450GeV + Ramp Commissioning)							

0

Installation Hardware Commissioning	Hardware Commissioning 450GeV	Engineering Run 450GeV	Shutdown

Machine checkout 450GeV	Beam commissioning 450GeV	Calibration run 450GeV

450 GeV – Calibration Run

- **Aims:**
  - Commission essential safety systems
  - Commission essential beam instrumentation
  - Commission essential hardware systems
  - Perform beam based measurements to check:
    - Polarities
    - Aperture
    - Field characteristics
  - Establish collisions
  - Provide stable two beam operations
  - Interleave with further machine development, in particular, the ramp.

Should provide a firm platform for eventual commissioning to 7 TeV and provide lead time for problem resolution.

Beam

- **Pilot Beam**
  - Single bunch, 5 to 10 x 10^9 protons
  - Possibly reduced emittance
- **Pilot++**
  - Single bunch 3 to 4 x 10^{10} protons
- **4, 12 bunches etc. pushing towards…**
- **43,156 bunches**
  - 3 to 4 x 10^{10} ppb

	Bunches	Bunch Intensity [10^{10} p]	Total Intensity [10^{14} p]
One pilot bunch	1	0.5	0.00005
10 nominal bunches	10	10.0	0.01000
Scenario 43 bunches	43	4.0	0.01700
Scenario I: 156 bunches	156	4.0	0.06200
Scenario II: 156 bunches	156	10.0	0.15600
Scenario 75 ns	936	4.0	0.37000
Scenario I: 25 ns	2808	4.0	1.10000
Scenario II: 25 ns	2808	5.0	1.40000
Nominal 25 ns	2808	11.5	3.20000

Phases

	Phase	Main Objectives
1	First turn	End TI2, TI8, injection, BPMs, BLMs, thread first turn, polarity check,
2	Establish circulating beam	Closed orbit, chromaticity, energy matching, tune
3	450 GeV - initial	RF, control & correction, transverse diagnostics, linear optics checks, BLMs, beam dump, machine protection
4a	450 GeV - measurements	Beta beating, aperture, field quality checks, transfer functions
4b	450 GeV - system commissioning	RF, transverse feedback, BLMs to MPS, tune PLL, collimators and absorbers
5a	Two beam operations	Parallel injection, separation bumps, instrumentation and control
5b	Collisions	Establish collisions, luminosity monitors, collimation, solenoids
6	Increase intensity	Collimators, LFB, multi-batch injection

Time

	Phase	Beam time [days]	Beam
1	First turn	4	1 x Pilot
2	Establish circulating beam	3	1 x Pilot
3	450 GeV – initial	3	1 x Pilot++
4a	450 GeV - consolidation	1-2	1 x Pilot++
4b	450 GeV – system commissioning	2-3	1 x Pilot++
5a	2 beam operations	1	2 x Pilot++
5b	Collisions	1-2	2 x Pilot++ ➔
		16 days	

Given an operational efficiency of 60%, this gives an elapsed time of about 26 days.

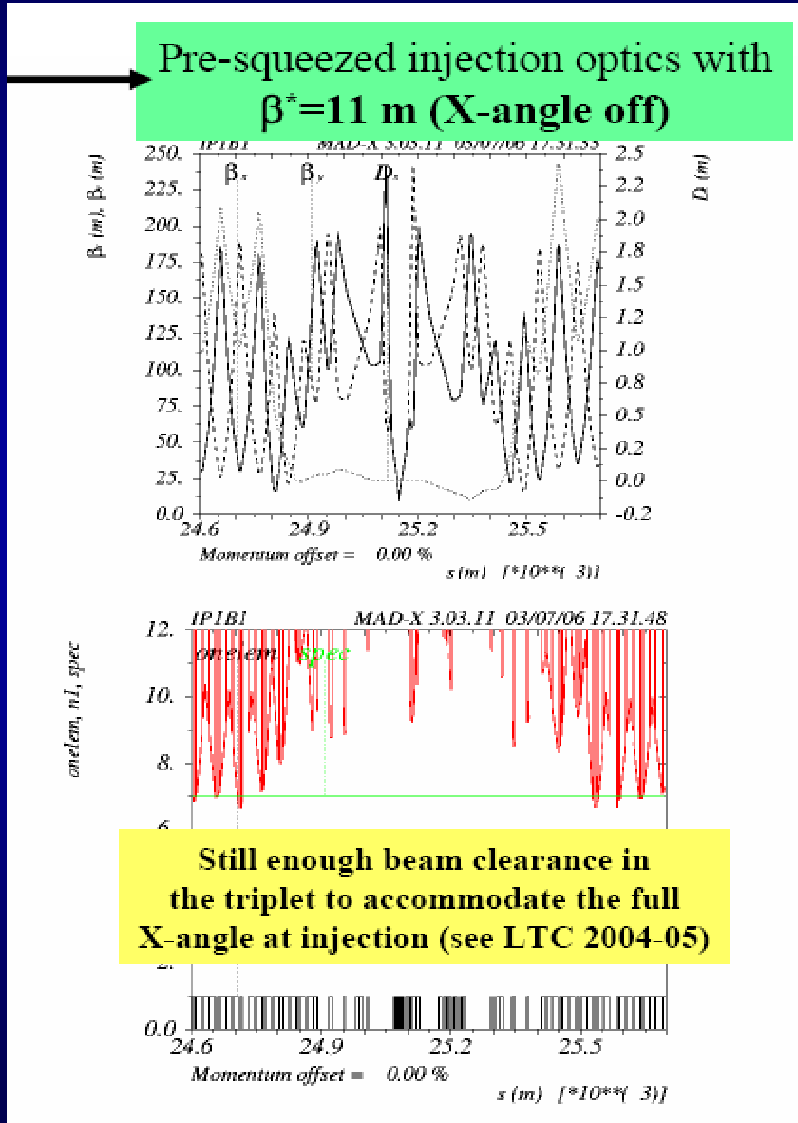
Some opportunities for parallel development and parasitic studies

Calibration Run 2007

- 6 weeks beam time
- 3 weeks beam commissioning
  - Essentially single beam, low intensity for the most part
- 3 weeks collisions
  - Low intensities initially, with staged increase to an optimistic 156 x 4 x 10^{10}
  - Interleafed with low intensity single beam MD
    - ramp to 1.1 TeV etc

Machine Configuration

- **Optics:**
  - β*= 11 m in IR 1 & 5, β*= 10 m in IR 2 & 8
  - Triplet aperture
- **Crossing angles off**
  - 1, 12, 43, 156 bunches per beam
- **Separation bumps - two beam operation**
- **Shift bunches for LHCb**
  - 4 out of 43 bunches, or 24 bunches out of 156
- **Solenoids & Exp. Dipoles etc. off (to start with)**



450 GeV - Performance

			Reasonable	All out max
k_b	43	43	156	156
i_b (10^{10})	2	4	4	10
β^* (m)	11	11	11	11
intensity per beam	$8.6\ 10^{11}$	$1.7\ 10^{12}$	$6.2\ 10^{12}$	$1.6\ 10^{13}$
beam energy (MJ)	.06	.12	.45	1.1
luminosity	10^{28}	$7.2\ 10^{28}$	$4.8\ 10^{29}$	$3\ 10^{30}$
event rate [1] (kHz)	0.4	2.8	10.3	64
W rate [2] (per 24h)	0.5	3	11	70
Z rate [3] (per 24h)	0.05	0.3	1.1	7

Several days →

1. Assuming 450GeV inelastic cross section 40mb
2. Assuming 450GeV cross section $W \rightarrow l\nu$ 1nb
3. Assuming 450GeV cross section $Z \rightarrow ll$ 100pb

450 GeV Beam Spot - Longitudinal

- RMS bunch length at 7 TeV = 7.55 cm, 16 MV

- Nominal 450 GeV
  - RMS bunch length = 11.24 cm
  - RF voltage = 8 MV

- For coast will raise voltage at 450 GeV to 16 MV – increase deltap/p and shorten bunch length
  - deltap/p (2 σ) 0.88E-3 to ~1.1E-3 with concomitant decrease in bunch length

Beam spot – transverse

- Bigger beams at 450 GeV
  - 290 μm at β* = 11 m.
  - 277 μm at β* = 10 m.
- 2 challenges:
  - Colliding the beams – should be able to get them within 150 μm using BPMs
  - Orbit stability
- Vertex position
  - Transverse: 1 mm run-to-run, 3 mm long term
  - Absolute position: approx. ± 400 μm from BPMs

Transverse beam size from one of:
Synchrotron Light Monitor, Rest Gas Monitor or Wire Scanner
plus optics measurements

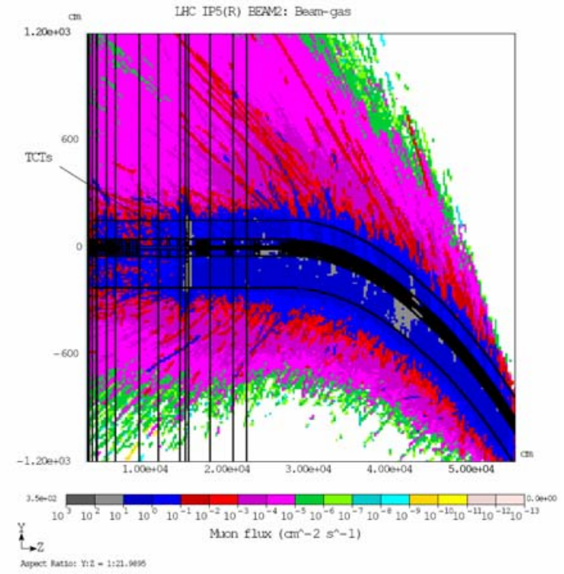
Background

beam gas interactions and beam halo muon/hadron rates

- Residual gas within experiments
  - Baked out – low rates
- Residual gas in LSSs
- Gas pressure in adjacent cold sectors
  - Relative high pressures, elastic scattering

Nikolai Mokhov

- Inefficiency of cleaning in IR7 & IR3



See: M Huhtinen, V. Talanov, G. Corti et al

Vacuum – 450 GeV

	Stage 1	Stage 2	Nominal
Months of operation	4	7	7
Days of operation	100	175	175
Bunches	1/43/156	936/2808	2808
Protons/bunch	10^{10}-9 10^{10}	10^{10}-9 10^{10}	1.1 10^{10}
Protons	10^{10}-1.4 10^{13}	([illegible].7–9.8) 10^{13}	3.2 10^{14}
Current (mA)	0.02 - 25	70 - 80	582
Average current (mA)	8	140	582

n_b	43	156	2808
Start-up	1.8×10^{12}	5.7×10^{12}	4.3×10^{13}
Nominal	4.2×10^{11}	6.3×10^{11}	5.3×10^{12}

Table 3: Average H_2 equivalent residual gas density, [mol/m^3] in the IR1 & 5 at the machine start-up and at nominal operation after the machine conditioning with the beam of different intensity.

A. Rossi LPR 783

The 450 GeV run will be stage 0.

No conditioning, minimal pump-down time in some sectors. Static vacuum.

Vacuum life time shall be larger than 35 h and 50 h for 2007 and 2008 respectively

LSSs

- The base line is still :
  - bake-out of the experiments vacuum chambers
  - bake-out of the rest of the LSS: the maximum will be done.
- In the special case of missing time resources, components at the start of year 1 operation, it might be done with the following priorities :
  - A) LSS 1,2,5,8
  - B) LSS 4
  - C) LSS 3,6,7
- All the LSS will be baked for year 2 of operation.

LSS – no bakeout

- No bake-out - no NEG activation
- Static vacuum (thermal desorption)
- Residual gas dominated by H_2O
- System requires several weeks of pump-down
- Stage 1 conditions: pressure of the order 10^{-8} Torr
- Stage 0 – could be higher – reduced pumping time

Potentially useful background source

- Gas pressure in adjacent cold sectors
    - tertiary collimators not foreseen…

Vadim Talanov & team plan detailed studies, given scenario of collimator operation at the 450 GeV start-up, along with loss maps.

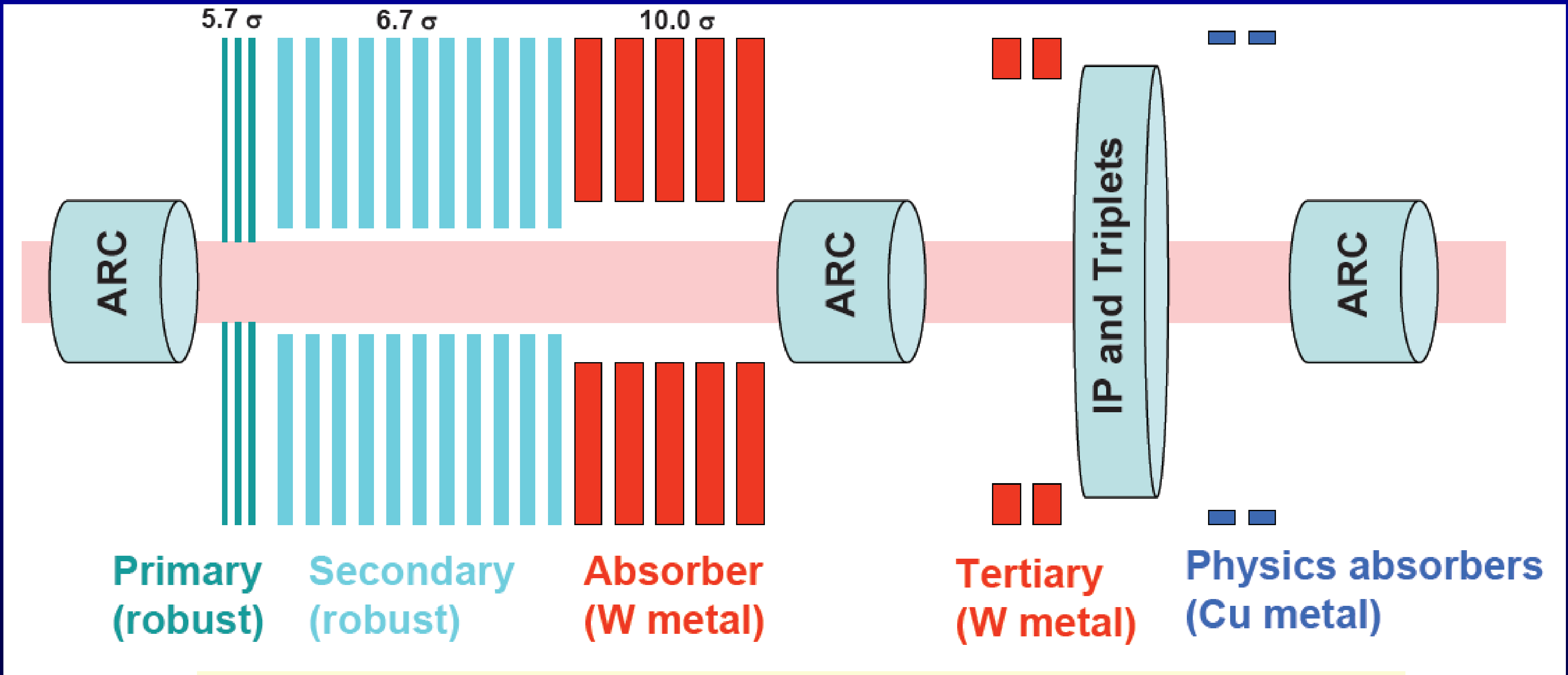
Halo

- Scrape in the SPS, collimate in the transfer lines
- Expect halo generation from
  - RF noise
  - Intra Beam Scattering
  - Optics mismatch
  - Beam-gas
  - Poor parameter control (tune, chromaticity), poor lifetime, stream particles to aperture limit

- Nominally this is cleaned by the collimation system with the resulting tertiary halo potentially finding its way to the experiments insertion – and the tertiary collimators

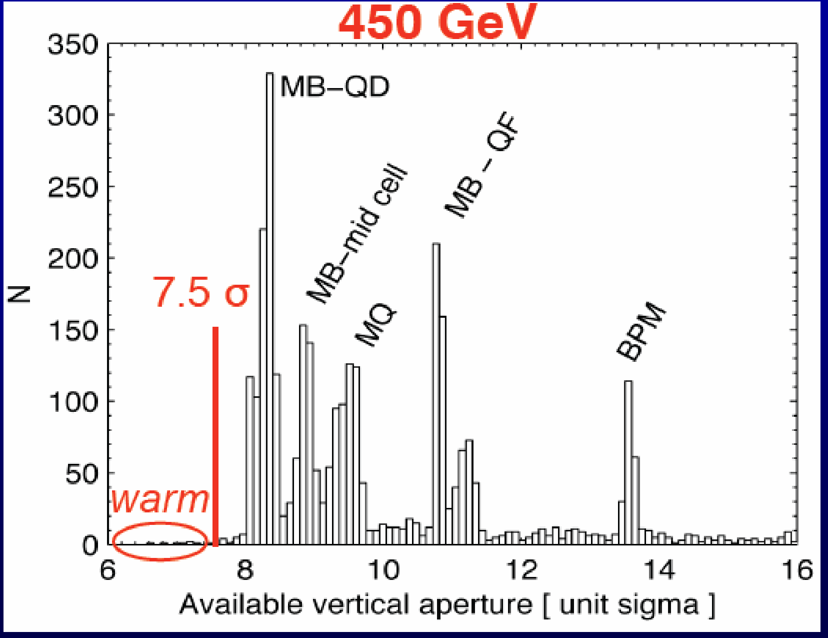
450 GeV - collimators

- Lower intensity, lower energy, reduced demands
- Bigger beams
- Un-squeezed
- Aperture limitation is the arcs, in particular DS



450 GeV: Collimation I

- **With low beam intensity:**
  - Primary collimators: 6σ
  - Secondary collimators: out
  - Tertiary collimators: out
  - Absorbers: out
  - TCDQ: 10σ
  - TDI: out

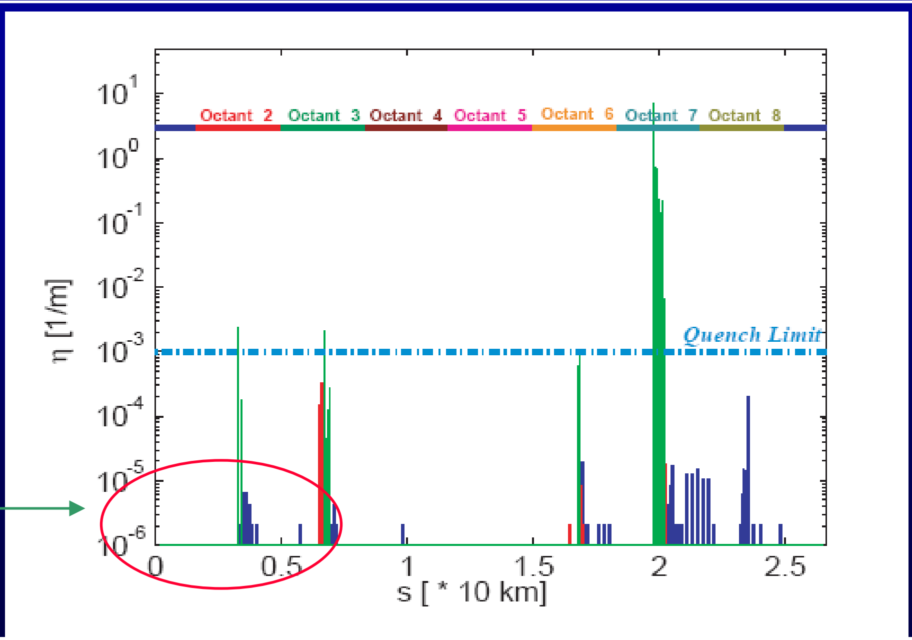


450 GeV: Collimation II

- With an optimistic beam intensity we might see:
  - Primary collimators: 5.7σ
  - Secondary collimators at 6.7σ
  - Tertiary collimators: out
  - Absorbers: out
  - TCDQ: 9σ
  - TDI: 6.8σ

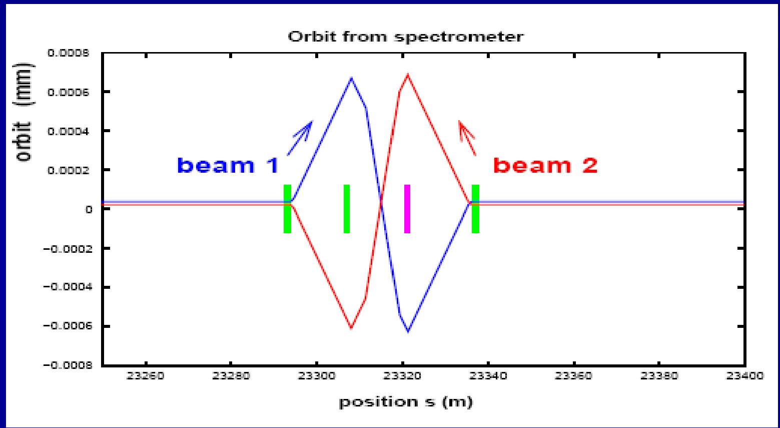
Un-squeezed – tertiary collimators out – aperture limit in the arcs – would expect low halo losses in IRs

TDI – IP2
(out after inj.)



450 GeV – spectrometer magnets

- ALICE – no problems
- LHCb
  - with the crossing angle off, full field should be OK – both polarities
  - VELO to 5 mm…

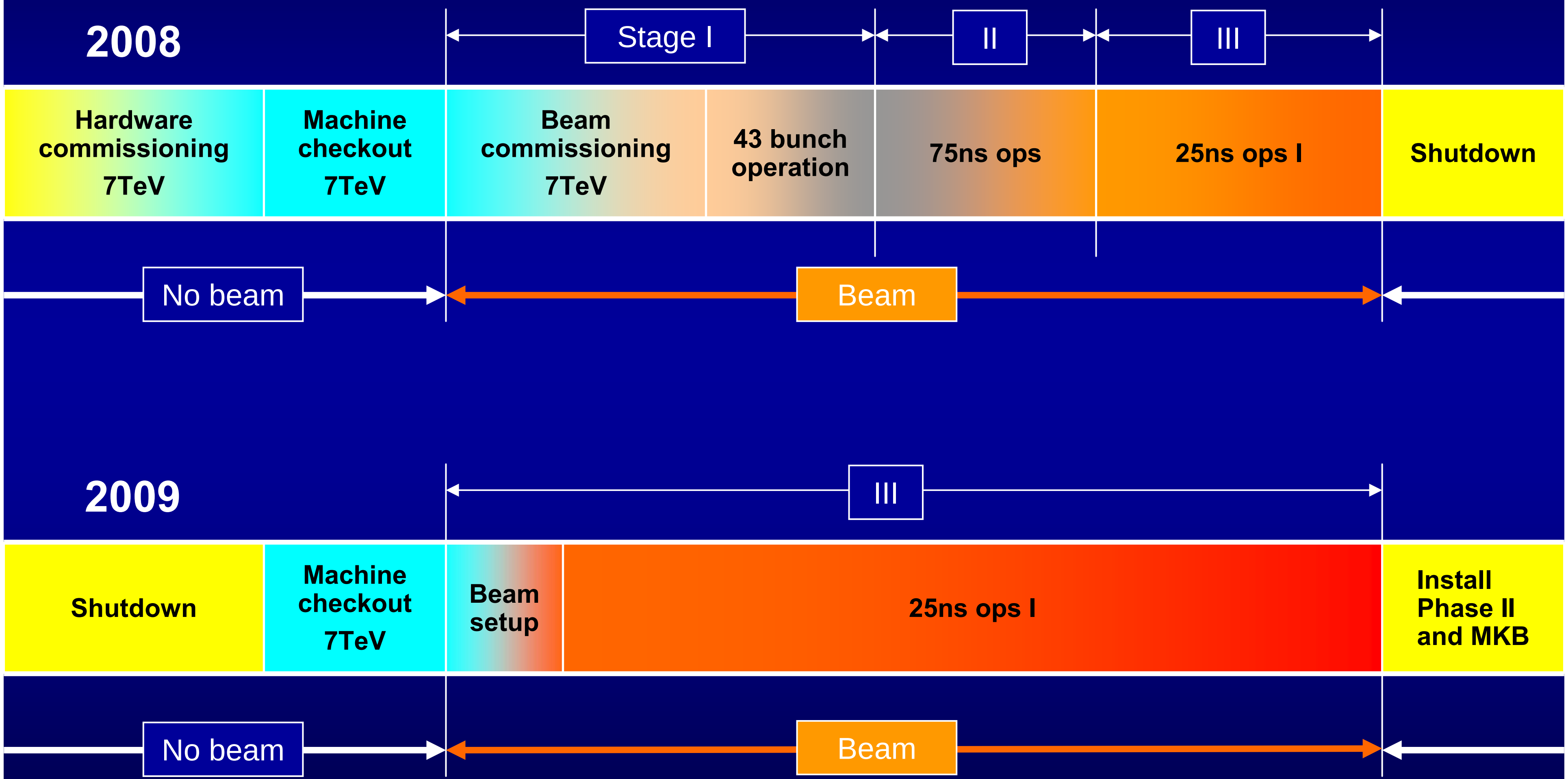


ACTION: The AB-ABP group will estimate the maximum spectrometer bump amplitudes and minimum vertex detector opening that are compatible with the beta* = 11m and beta* = 6m and beta* = 17m optics options at 450 GeV.

Results to the LHC Commissioning working group in 2-3 weeks

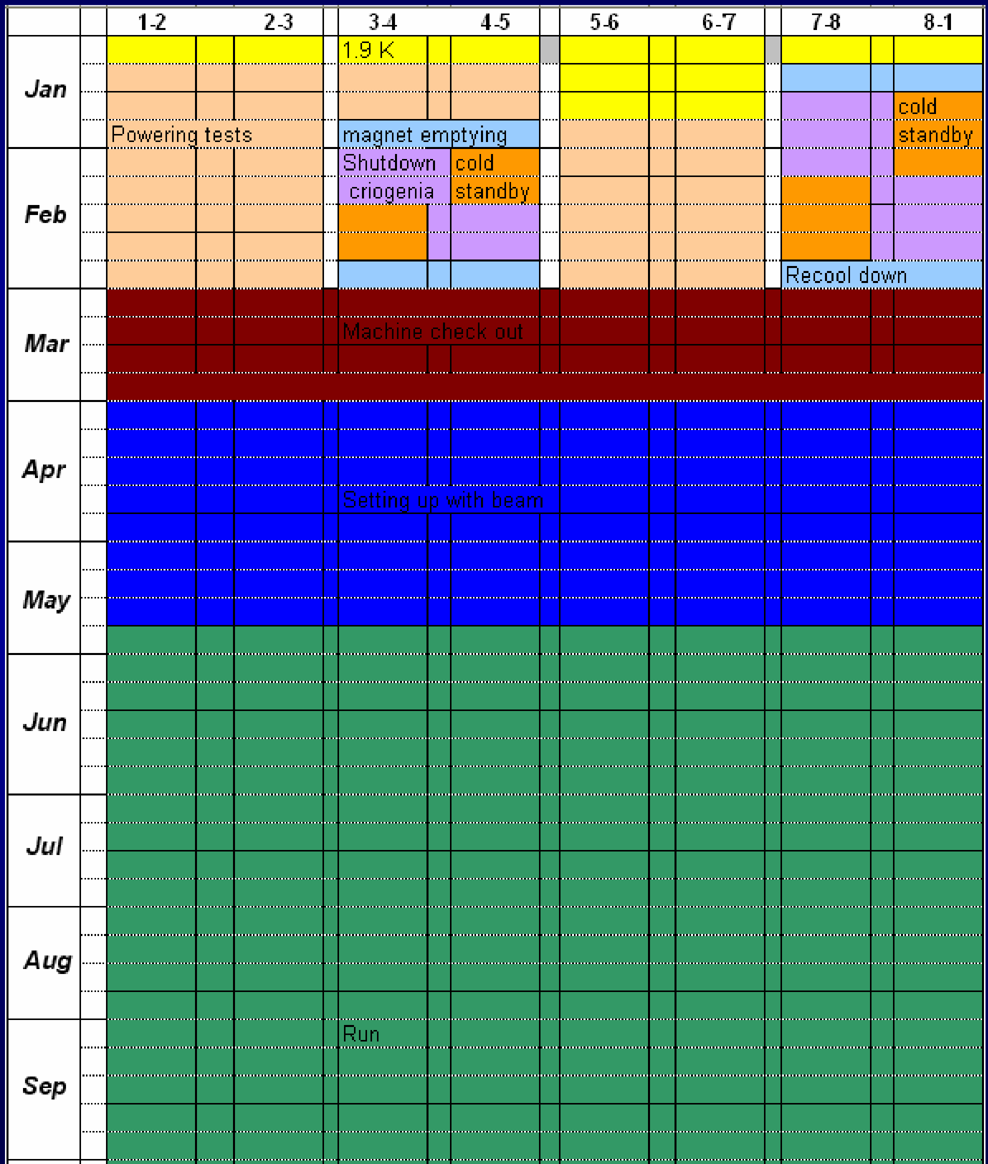
2008

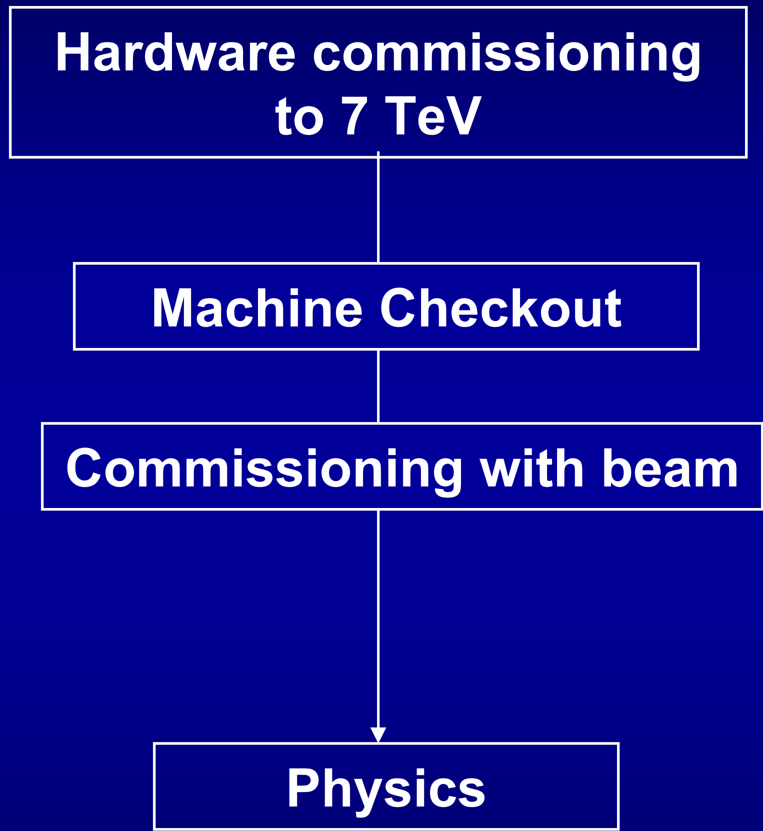
Staged commissioning plan for protons@7TeV



2008

Should look something like…





Full commissioning

		Rings	Total [days] both rings
1	Injection and first turn	2	6
2	Circulating beam	2	3
3	450 GeV - initial	2	5
4	450 GeV - detailed	2	12
5	450 GeV - two beams	1	2
6	Snapback - single beam	2	4
7	Ramp - single beam	2	8
8	Ramp - both beams	1	3
9	7 TeV - setup for physics	1	2
10	Physics un-squeezed	1	-
	TOTAL to first collisions		45
11	Commission squeeze	2	6
12	Increase Intensity	2	6
13	Set-up physics - partially squeezed.	1	2
14	Pilot physics run		

Should benefit from 450 GeV run

Usual stuff..

First turn — PILOT — RING 1 / RING2
- Commission injection region
- Instrumentation
- Threading

Establish circulating beam — PILOT — RING 1 / RING2
- Circulating low intensity beam

450 GeV Initial — SINGLE INTERMEDIATE — RING 1 / RING2
- 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

450 GeV Detailed — SINGLE INTERMEDIATE ++ — RING 1 / RING2
- Well-adjusted beam parameters, detailed optics checks
- Fully functioning beam instrumentation.
- Machine protection as required for ramp
- RF - beam control loops operational and adjusted

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

7 TeV commissioning

- Around 2 months elapsed time to establish first collisions
  - Mostly pilot++, low intensity, single beam, alternate rings
  - No crossing angle
  - No squeeze $\beta^* = 17 - 10 - 17 - 10$ m.
- Stage 1 vacuum conditions
  - Experiments & LSSs should be baked out
  - Other LSSs potentially not
  - See LHC project note 783
- Collimation during initial commissioning
  - Minimal collimation scheme under discussion, probably primary & secondary with no tertiary/absorbers
  - Again expect low halo loss in experiments
- First collisions
  - Pilot++
  - Un-squeezed
- Pilot physics

Pilot physics

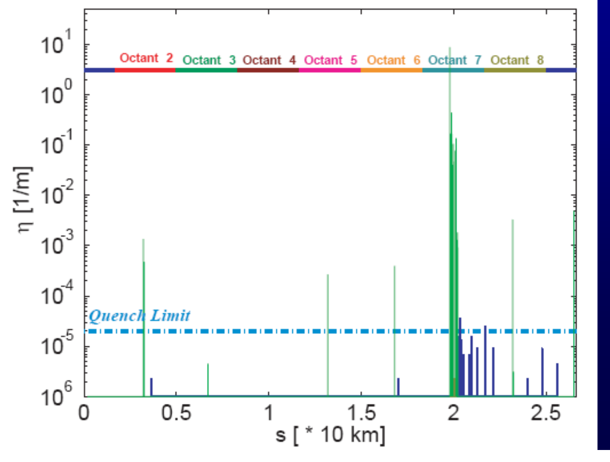
Sub-phase	Bunches	Bun. Int.	beta*	Luminosity	Time	Int lumi
first Collisions	1 x 1	2×10^{10}	18 m	4×10^{27}	12 hours	0.15 nb^{-1}
repeat ramp - same conditions	-	-	-	-	2 days @ 50%	0.3 nb^{-1}
multi-bunch at injection & through ramp - collimation	-	-	-	-	2 days	-
physics	12 x 12	3×10^{10}	18 m	1×10^{29}	2 days @ 50%	8 nb^{-1}
physics	43 x 43	3×10^{10}	18 m	3.8×10^{29}	2 days @ 50%	30 nb^{-1}
commission squeeze – single beam then two beams, IR1, IR5	-	-	-	-	2 days	-
measurements squeezed	-	-	-	-	2 day	-
physics	43 x 43	3×10^{10}	10 m	7×10^{29}	3 days - 6 hr t.a. - 70% eff.	75 nb^{-1}
commission squeeze to 2m collimation etc.	-	-	-	-	3 days	-
physics	43 x 43	3×10^{10}	2 m	3.4×10^{30}	3 days - 6 hr t.a. - 70% eff.	0.36 pb^{-1}
commission 156 x 156	-	-	-	-	1 day	
physics	156 x 156	2×10^{10}	2 m	5.5×10^{30}	2 days - 6 hr t.a. - 70% eff.	0.39 pb^{-1}
physics	156 x 156	3×10^{10}	2 m	1.2×10^{31}	5 days - 5 hr t.a. - 70% eff.	2.3 pb^{-1}
					29 days total	

Background

- Detailed studies exist…
- Nice summary talk by G. Corti and V. Talanov at this year's Chamonix

- See also LMIBWG:
  - cern.ch/lhc-background

- Lot of work going on in the collimation team
  - Loss Maps at 450 GeV & 7 TeV



LHC Project Workshop - 'Chamonix XV'

preparation of this talk.

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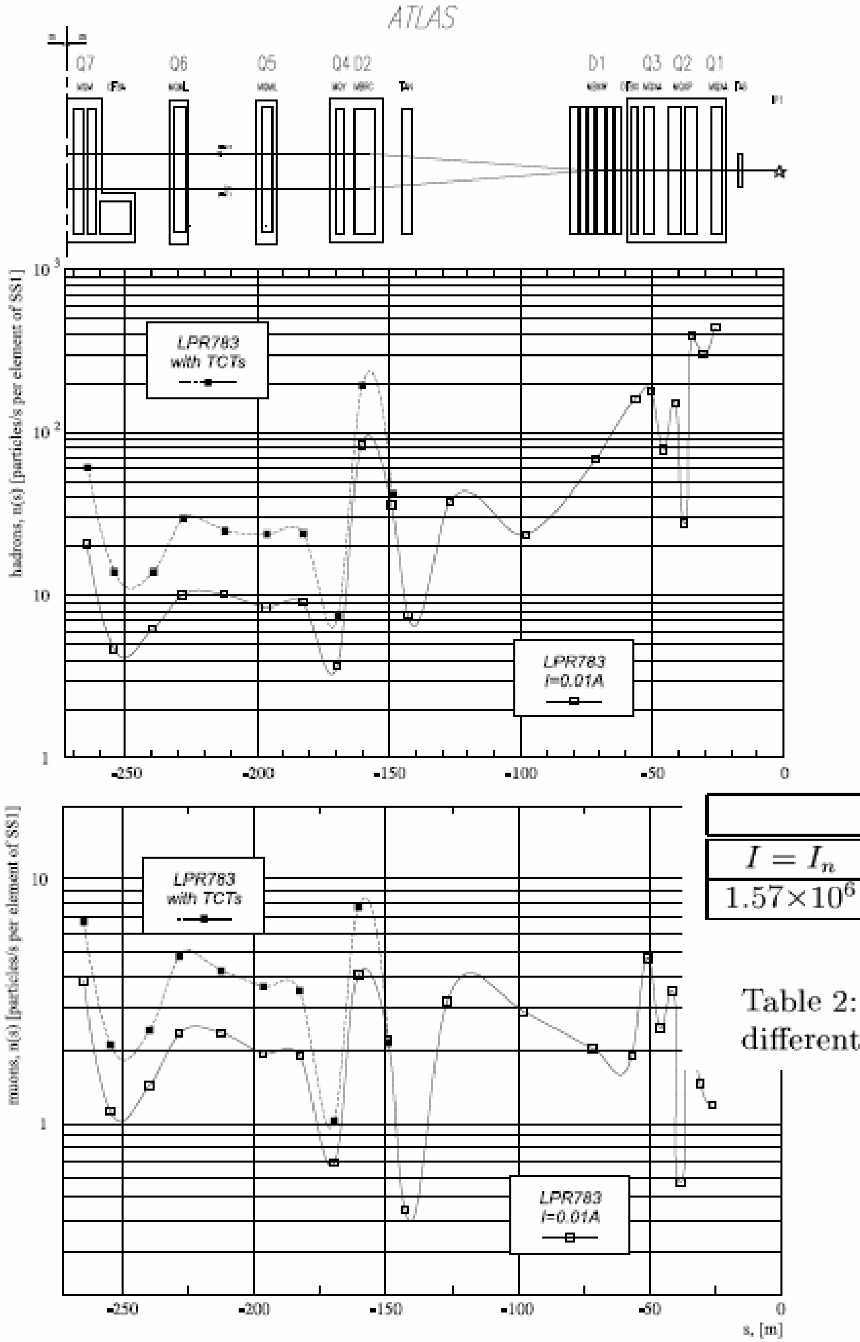

Figure 2: Flux of hadrons and muons [particles/s per element of SS1] at the UX15 entrance as a function of primary interaction distance to the IP1 for the machine start-up with and without collimators in IR1.

Estimation of the machine induced background for the commissioning period with tertiary collimators in the IR1 of the LHC

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Results for 0.01 A [43 x 1.15 10^{11}] and conditions described in LPR 783

Hadrons			Muons		
$I = I_n$	$I = 1/3\, I_n$	$I = 0.01\ A$	$I = I_n$	$I = 1/3\, I_n$	$I = 0.01\ A$
1.57×10^6	2.66×10^6	2.07×10^3	6.77×10^4	8.17×10^4	48.9
	~ 0.6	~ 760		~ 0.8	~ 1390

Table 2: Particle fluxes [particles/s] at the machine start-up with two different values for the current, but without tertiary collimators.

Conclusions

- **450 GeV calibration run**
  - 3 weeks single beam machine commissioning
  - Low beam current but potentially interesting vacuum conditions
  - Minimal collimation scheme
  - 3 weeks collisions with the hope to push over 10^{29} $cm^{-2}s^{-1}$
  - Detailed BG studies planned

- **7 TeV**
  - 6 weeks single/two beam machine commissioning
  - Low beam current but potentially interesting vacuum conditions
  - Un-squeezed initially, with minimal collimation
  - Detailed BG studies already performed and on-going