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

Minimum Hardware Commissioning of Sector 1-2 & 2-3 and Machine check-out
Beams at 450 GeV/c
<table>
<thead>
<tr>
<th>Month</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct</td>
<td>Operations testing</td>
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</table>
| Nov   | Full Machine Checkout  
       (Access, Vacuum, Equipment Tests, Cycle and Set, BIC and INB)  
       Beam Commissioning to 450GeV  
       16 days estimated, 60% efficiency assumed |
| Dec   | Engineering run (Collisions at 450GeV + Ramp Commissioning) |

- **End 2007**
- **05.09.06 Machine plans - Alignment workshop 4**
- ** Shutdown**
  - Hardware Commissioning 450GeV
  - Engineering Run 450GeV
  - Calibration run 450GeV
  - Machine checkout 450GeV
  - Beam commissioning 450GeV
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

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Bunches</th>
<th>Bunch Intensity $[10^{10} \text{p}]$</th>
<th>Total Intensity $[10^{14} \text{p}]$</th>
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<tr>
<td>One pilot bunch</td>
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<td>0.5</td>
<td>0.00005</td>
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<td>43</td>
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<tr>
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<td>0.06200</td>
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<td>Scenario 75 ns</td>
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<tr>
<td>Scenario I: 25 ns</td>
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<td>4.0</td>
<td>1.10000</td>
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<tr>
<td>Scenario II: 25 ns</td>
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<td>5.0</td>
<td>1.40000</td>
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<tr>
<td>Nominal 25 ns</td>
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<td>11.5</td>
<td>3.20000</td>
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## Phases

<table>
<thead>
<tr>
<th>Phase</th>
<th>Main Objectives</th>
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<tbody>
<tr>
<td>1</td>
<td>First turn</td>
</tr>
<tr>
<td>2</td>
<td>Establish circulating beam</td>
</tr>
<tr>
<td>3</td>
<td>450 GeV - initial</td>
</tr>
<tr>
<td>4a</td>
<td>450 GeV - measurements</td>
</tr>
<tr>
<td>4b</td>
<td>450 GeV - system commissioning</td>
</tr>
<tr>
<td>5a</td>
<td>Two beam operations</td>
</tr>
<tr>
<td>5b</td>
<td>Collisions</td>
</tr>
<tr>
<td>6</td>
<td>Increase intensity</td>
</tr>
</tbody>
</table>

**End TI2, TI8, injection, BPMs, BLMs, thread first turn, polarity check,**  
**Closed orbit, chromaticity, energy matching, tune,**  
**RF, control & correction, transverse diagnostics, linear optics checks, BLMs, beam dump, machine protection,**  
**Beta beating, aperture, field quality checks, transfer functions,**  
**RF, transverse feedback, BLMs to MPS, tune PLL, collimators and absorbers,**  
**Parallel injection, separation bumps, instrumentation and control,**  
**Establish collisions, luminosity monitors, collimation, solenoids,**  
**Collimators, LFB, multi-batch injection**
### Time

<table>
<thead>
<tr>
<th>Phase</th>
<th>Beam time [days]</th>
<th>Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 First turn</td>
<td>4</td>
<td>1 x Pilot</td>
</tr>
<tr>
<td>2 Establish circulating beam</td>
<td>3</td>
<td>1 x Pilot</td>
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<tr>
<td>3 450 GeV – initial</td>
<td>3</td>
<td>1 x Pilot++</td>
</tr>
<tr>
<td>4a 450 GeV - consolidation</td>
<td>1-2</td>
<td>1 x Pilot++</td>
</tr>
<tr>
<td>4b 450 GeV – system commissioning</td>
<td>2-3</td>
<td>1 x Pilot++</td>
</tr>
<tr>
<td>5a 2 beam operations</td>
<td>1</td>
<td>2 x Pilot++</td>
</tr>
<tr>
<td>5b Collisions</td>
<td>1-2</td>
<td>2 x Pilot++</td>
</tr>
<tr>
<td></td>
<td>16 days</td>
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</tr>
</tbody>
</table>

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 $156 \times 4 \times 10^{10}$
  - Interleafed with low intensity single beam MD
    - ramp to 1.1 TeV etc
Machine Configuration

- **Optics:**
  - $\beta^* = 11$ m in IR 1 & 5, $\beta^* = 10$ 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

<table>
<thead>
<tr>
<th></th>
<th>Reasonable</th>
<th>All out max</th>
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<tr>
<td>$k_b$</td>
<td>43</td>
<td>156</td>
</tr>
<tr>
<td>$i_b \cdot 10^{10}$</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>$\beta^*$ (m)</td>
<td>11</td>
<td>11</td>
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<tr>
<td>intensity per beam</td>
<td>$8.6 \cdot 10^{11}$</td>
<td>$1.6 \cdot 10^{13}$</td>
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<tr>
<td>beam energy (MJ)</td>
<td>.06</td>
<td>1.1</td>
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<tr>
<td>luminosity</td>
<td>$10^{28}$</td>
<td>$3 \cdot 10^{30}$</td>
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<tr>
<td>event rate $^1$(kHz)</td>
<td>0.4</td>
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</tr>
<tr>
<td>$W$ rate $^2$ (per 24h)</td>
<td>0.5</td>
<td>70</td>
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<tr>
<td>$Z$ rate $^3$ (per 24h)</td>
<td>0.05</td>
<td>7</td>
</tr>
</tbody>
</table>

Several days

1. Assuming 450GeV inelastic cross section $\rightarrow 40mb$
2. Assuming 450GeV cross section $W \rightarrow l\nu$ $\rightarrow 1nb$
3. Assuming 450GeV cross section $Z \rightarrow ll$ $\rightarrow 100pb$
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 (2σ) 0.88E-3 to ~1.1E-3 with concomitant decrease in bunch length
Beam spot – transverse

- **Bigger beams at 450 GeV**
  - 290 µm at $\beta^* = 11$ m.
  - 277 µm at $\beta^* = 10$ 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

• Inefficiency of cleaning in IR7 & IR3

See: M Huhtinen, V. Talanov, G. Corti et al
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 H₂O
- 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

![Graph showing available vertical aperture with 7.5 σ and warm marks]
450 GeV: Collimation II

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

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

- **Stage I**
  - Hardware commissioning 7TeV
  - Machine checkout 7TeV
  - Beam commissioning 7TeV
  - 43 bunch operation
  - 75ns ops

- **II**
  - 25ns ops I

- **III**
  - Shutdown

### 2009

- **Shutdown**
  - Machine checkout 7TeV
  - Beam setup
  - 25ns ops I

- **III**
  - Install Phase II and MKB

### Timeline

- **No beam**
  - 2008
  - 2009

- **Beam**
  - 2008
  - 2009
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<th>Month</th>
<th>1</th>
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Hardware commissioning to 7 TeV

Machine Checkout

Commissioning with beam

Physics
## Full commissioning

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Rings</th>
<th>Total [days] both rings</th>
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<tr>
<td>1</td>
<td>Injection and first turn</td>
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<td>2</td>
<td>Circulating beam</td>
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<td>3</td>
<td>450 GeV - initial</td>
<td>2</td>
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<td>450 GeV - detailed</td>
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<td>5</td>
<td>450 GeV - two beams</td>
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<td>Snapback - single beam</td>
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<td>4</td>
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<td>7</td>
<td>Ramp - single beam</td>
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<td>TOTAL to first collisions</td>
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<td>11</td>
<td>Commission squeeze</td>
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<td>12</td>
<td>Increase Intensity</td>
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<td>6</td>
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<td>13</td>
<td>Set-up physics - partially squeezed.</td>
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<td>2</td>
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<tr>
<td>14</td>
<td>Pilot physics run</td>
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</tbody>
</table>

Should benefit from 450 GeV run
Usual stuff

First turn
- Commission injection region
- Instrumentation
- Threading

Establish circulating beam
- Circulating low intensity beam

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

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

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)

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

Two beams to top energy
- Two beams, good transmission to top energy
- Measurements

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

05.09.06 Machine plans - Alignment workshop
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**
<table>
<thead>
<tr>
<th>Sub-phase</th>
<th>Bunches</th>
<th>Bun. Int.</th>
<th>beta*</th>
<th>Luminosity</th>
<th>Time</th>
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</thead>
<tbody>
<tr>
<td>first Collisions</td>
<td>1 x 1</td>
<td>2 x 10^{10}</td>
<td>18 m</td>
<td>4 x 10^{27}</td>
<td>12 hours</td>
<td>0.15 nb^{-1}</td>
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<tr>
<td>repeat ramp - same conditions</td>
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<td>-</td>
<td>-</td>
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<td>2 days @ 50%</td>
<td>0.3 nb^{-1}</td>
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<tr>
<td>multi-bunch at injection &amp; through ramp - collimation</td>
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<td>-</td>
<td>-</td>
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<td>2 days</td>
<td>-</td>
</tr>
<tr>
<td>physics</td>
<td>12 x 12</td>
<td>3 x 10^{10}</td>
<td>18 m</td>
<td>1 x 10^{29}</td>
<td>2 days @ 50%</td>
<td>8 nb^{-1}</td>
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<td>3 x 10^{10}</td>
<td>18 m</td>
<td>3.8 x 10^{29}</td>
<td>2 days @ 50%</td>
<td>30 nb^{-1}</td>
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<td>commission squeeze – single beam then two beams, IR1, IR5</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>2 days</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>2 day</td>
<td>-</td>
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<tr>
<td>physics</td>
<td>43 x 43</td>
<td>3 x 10^{10}</td>
<td>10 m</td>
<td>7 x 10^{29}</td>
<td>3 days - 6 hr t.a. - 70% eff.</td>
<td>75 nb^{-1}</td>
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<td>commission squeeze to 2m collimation etc.</td>
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<td>3 x 10^{10}</td>
<td>2 m</td>
<td>3.4 x 10^{30}</td>
<td>3 days - 6 hr t.a. - 70% eff.</td>
<td>0.36 pb^{-1}</td>
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<td>commission 156 x 156</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 day</td>
<td>-</td>
</tr>
<tr>
<td>physics</td>
<td>156 x 156</td>
<td>2 x 10^{10}</td>
<td>2 m</td>
<td>5.5 x 10^{30}</td>
<td>2 days - 6 hr t.a. - 70% eff.</td>
<td>0.39 pb^{-1}</td>
</tr>
<tr>
<td>physics</td>
<td>156 x 156</td>
<td>3 x 10^{10}</td>
<td>2 m</td>
<td>1.2 x 10^{31}</td>
<td>5 days - 5 hr t.a. - 70% eff.</td>
<td>2.3 pb^{-1}</td>
</tr>
</tbody>
</table>

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

REFERENCES

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

<table>
<thead>
<tr>
<th>Hadrons</th>
<th>Muons</th>
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</thead>
<tbody>
<tr>
<td>$I = I_n$</td>
<td>$I = I_n$</td>
</tr>
<tr>
<td>$1.57 \times 10^8$</td>
<td>$2.66 \times 10^8$</td>
</tr>
<tr>
<td>$\sim 0.6$</td>
<td>$\sim 760$</td>
</tr>
</tbody>
</table>

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

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