WHAT WILL WE DO WITH BEAM IN 2009/10?

R.Bailey, CERN, Geneva, Switzerland

INTRODUCTION

The session assessed the situation with beam once the LHC restarts, with a time scope of 2009 and 2010. The desiderata of the LHC experiments were reviewed in light of recent developments and the competition from the Tevatron, and the latest thinking on the LHC machine for both protons and ions was given. With this as a definition of what we would like to do, the readiness to do it in terms of the injectors, LHC commissioning and organisation was investigated.

EXPERIMENTS DESIDERATA

Discussed on several occasions in recent years, collisions at injection energy are now requested by all experiments. This is envisaged to be for a few shifts as soon as possible in the machine start-up, and high intensities are not important. The basic request is to start with a bunch configuration that allows collisions in points 1 2 5 and 8, so a minimum of 2 on 2 correctly arranged around the LHC circumference. Experimental solenoids should be on.

General Purpose Detectors (ATLAS and CMS)

With the Tevatron now running consistently at peak luminosities around 3 10^{32} $cm^{-2}s^{-1}$ at $\sqrt{s}$ of 1.8 TeV, 8 fb^{-1} of integrated luminosity per experiment is expected sometime in 2010. With some 200 to 300 pb^{-1} of data at $\sqrt{s}$ of 10 to 8 TeV, LHC could start competing with this for Higgs masses around 160 GeV. With even half of this data, LHC could set many new limits on hypothetical particles. With 1 fb^{-1} at $\sqrt{s}$ of 10 TeV, LHC could find the Higgs with a mass around 160 GeV.

The overall aim for 2010 is therefore to accumulate a few hundred pb^{-1} at $\sqrt{s}$ of 10 to 8 TeV. It was noted that the higher the energy, the faster the LHC experiments become sensitive.

LHCb

Since the cross section for B production does not vary with energy as drastically as for high mass particles, the request to go to the highest possible energy is weaker. In order to surpass the Tevatron in B_s physics, some 300 to 500 pb^{-1} are needed at $\sqrt{s} > 8$ TeV. A few pb^{-1} are needed at $\sqrt{s} > 4$ TeV to collect a good sample of J/ψ mesons.

ALICE

Again the push to highest proton-proton energies is somewhat weaker than for the General Purpose Detectors. Data will be collected at relatively low luminosities, with around 10^{29} $cm^{-2}s^{-1}$ optimal and an absolute maximum of 3 10^{30} $cm^{-2}s^{-1}$. In order to satisfy these low luminosity requirements, ALICE favours the 50 ns scheme which allows sharing of the bunch crossings between the different experiments as discussed below.

A run with ions is expected late in 2010.

TOTEM (IP5)

The T1 and T2 telescopes will both be ready, as will most of the Roman Pots, and TOTEM plans to operate under all running conditions. As soon as technically feasible, short runs with β^* of 90 m are requested.

LHCf (IP1)

Due to degradation of non radiation hard components, luminosity is limited to 10^{30} $cm^{-2}s^{-1}$.

LHC PERFORMANCE WITH PROTONS

The LHC luminosity is given with the standard formula for round beams, where the parameters have their usual meaning.

$$L = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n \beta^*} F$$

The key parameters determining LHC performance are γ, N, k_b, and β^* and they are strongly correlated. Since smaller emittances could lead to problems, nominal is assumed in all estimates given.

Without crossing angle

In order to minimise the complexity of the LHC at start-up, a configuration without crossing angle (F=1) is envisaged during early operation. In order to avoid parasitic crossings, this in turn limits the number of bunches per beam, which is in any case desirable for machine protection reasons early on. Convenient schemes for the injector complex are with 43 and then 156 bunches per beam. Bunches can be displaced, symmetrically, in order to optimise the collision rate in points 2 and 8 while maximising collisions in point 1 and 5.

Aperture considerations define a relationship between energy and the minimum β^* that can be achieved, which at injection energy limits the β^* to 6 m. For this short period of running, it may be better to leave the machine at the injection optics, which has β^* of 11 m in points 1 and 5 and 10m in points 2 and 8.

At higher energies, at least from the aperture consideration, β^* could be pushed to 1 m or lower. At 5 TeV beam energy, with modest bunch currents around half-nominal, peak luminosities of a few 10^{31} $cm^{-2}s^{-1}$ could be reached.

With crossing angle

As soon as more bunches are considered, the machine must be operated with a crossing angle. The size of this angle depends on γ and β^*, and at 5 TeV beam energy operating with a β^* between 1 m and 4 m looks very promising. Schemes with 75 ns, 50 ns and 25 ns bunch spacing are possible, with 936, 1404 and 2808 bunches per beam respectively. Of these, the 50 ns scheme is the only one that allows optimisation of the number of colliding bunches in the different interaction points, notably to provide few in ALICE while providing many in ATLAS, CMS and LHCb. Again with modest bunch currents around half-nominal, peak luminosities of a few 10^{32} $cm^{-2}s^{-1}$ could be reached. With the 25 ns scheme, a peak of 10^{33} $cm^{-2}s^{-1}$ is within reach in points 1 and 5.

Integrated luminosity

With an average instantaneous luminosity of <L> and an efficiency factor η for providing colliding beams, the luminosity delivered in time t is simply

$$\int L dt = \langle L \rangle t \eta$$

Given reasonable machine availability to operation, an efficiency factor for physics of 40% should be possible after the commissioning period of 1 to 2 months.

Taking η of 40%, an average luminosity of 10^{31} $cm^{-2}s^{-1}$ would yield 10 pb^{-1} per month of running. This would correspond to early operation without crossing angle.

Taking η of 40%, an average luminosity of 10^{32} $cm^{-2}s^{-1}$ would yield 100 pb^{-1} per month of running. This would correspond to early operation with crossing angle, for example with the 50 ns scheme.

Hence, given reasonable machine availability, the targets of a few hundred pb^{-1} at $\sqrt{s}$ of 10 to 8 TeV should be within reach in 2010.

RUNNING WITH HEAVY IONS

While the nominal scheme for ions with almost 600 bunches per beam remains challenging, the so-called early ions scheme with 62 bunches per beam is now well advanced. In the LHC the magnetic machine is essentially identical to that for protons. However for certain systems (RF, BI, collimators, vacuum and machine protection) operation with ions presents differences and these systems have been checked and will be ready in 2010.

The commissioning phases with ions have been thought through, and web-based procedures are being put in place. Starting with the LHC machine operating for physics with protons, and with the early ion beam available from the SPS, it is estimated to take about a week to establish first collisions with ions.

In 2010, the injectors and the LHC should be ready for the possibility of an ion run. The present tentative schedule foresees a run at the end of the 2010 run, but this could be advanced in case of unforeseen circumstances.

INJECTORS

Protons

Numerous developments were made through 2008 in the injector complex in order to provide the variety of beams that the LHC could require in 2009 and 2010 (different bunch spacing, different bunch intensities). Of particular note is the production of the 50 ns spaced beam and the controlled blow-up of the transverse emittance in the SPS.

Ions

Preparation of the early ion beam started some years ago and in 2007 bunches of ions were accelerated through the SPS and extracted into the top of the transfer line. However several weeks of setting up are still needed in 2009 to make an ion run in LHC possible. Part of this will be re-commissioning because there have not been any ions in the injector rings since 2007.

COMMISSIONING

Through 2006 and 2007, rather detailed procedures were developed by the LHC commissioning team. These procedures covered the steps to be taken from first beam in the machine through to operation with squeezed beams at high energy. The first phases of the process, injection and first turn, were given further attention in preparation for the series of injection tests performed before the full start-up.

During 2008, several dry runs of numerous accelerator systems were performed, exercising equipment and associated controls software without beam. These proved invaluable to the success of the injection tests which in turn proved invaluable to the success of the few days of LHC start-up from September 10th.

The experience from 2008, together with the (possibly updated) commissioning procedures, gives us confidence that the tools and knowledge are in place to execute a successful start-up in 2009. Machine protection procedures remain largely untested, since all operation in 2008 was made with a single low intensity bunch at injection energy.

ORGANISATION

There were numerous activities that dominated 2008; installation, cooldown, hardware commissioning, system integration, dry runs, machine checkout, injection tests and finally beam commissioning. While in the end it worked, it was not always easy due to such inevitable problems as interference between activities, sharing of resources and time pressure resulting in some activities being performed in non-optimal order.

Lessons can and will be learned from the 2008 experience. Furthermore some changes will have to be accommodated (personnel, access and powering, magnet protection systems).