EXPERIMENTS DESIDERATA

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Abstract

An attempt is made to review the LHC experiments desiderata in the current LHC context. The impact on the physics programme of the beam energy and integrated luminosity are reminded. The benefits of making collisions at injection energy are discussed. Some considerations on proton filling schemes and a run scenario for 2009-2010 are given.

INTRODUCTION

The purpose of this contribution was to review the wishes of the LHC experiments for the initial running period, in the light of the current LHC situation. Specific questions were asked by the workshop organizers, here paraphrased as follows:

(a) How much data would be useful at injection energy ? (center-of-mass energy $\sqrt{s} = 900$ GeV)

(b) What would be the minimum amount of data needed in a first run at a given (ramped) energy such as to qualify as a "physics run" ? Which can also be interpreted as: what do the LHC experiments need in order to obtain a physics reach comparable or better than that of the Tevatron experiments, assuming that these will have recorded about $9\ \mathrm{fb}^{-1}$ of data by the end of 2010 ?

(c) What specific wishes from the non-General Purpose Detectors ? (ALICE, LHCb, LHCf, TOTEM)

The rest of this article is organized as follows. One section is devoted to each one of the three points above, sequentially. Then, a section discusses proton filling schemes for the first physics run. The subsequent section briefly addresses heavy ions. Some concluding remarks and a summary are drawn in the last section.

IS A SHORT RUN AT INJECTION ENERGY USEFUL ?

The usefulness of making collisions at $\sqrt{s} = 900$ GeV has been discussed repeatedly, see for example in Ref. [1]. The consensual opinion of the LHC experiments can be summarized as follows:

- the experiments request collisions at $\sqrt{s} = 900$ GeV during the initial beam commissioning phase, provided
- the time invested remains in the noise of the beam commissioning schedule, and
- safe and stable beams are used to make collisions (i.e. the relevant interlocks and handshake signals between machine and experiments must be working).

All LHC experiments are interested in such collisions. Therefore, an LHC filling scheme with at least two bunches per beam must be used. Short periods of 900 GeV collisions (of about 8 hours) should be planned in, when appropriate. These collisions should take place *as early as possible*. There is no strong requirement to push the luminosity beyond what can be obtained, very early on, with a single colliding bunch pair per Interaction Point (IP) with bunch charges of close to 10^{11} p/bunch and at injection optics, i.e. with $\beta^* = 11(10)$ m in IP1+5 (IP2+8). This would result in a luminosity of approximately $L \approx 10^{28}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, i.e. an inelastic rate of about 500 Hz and several million inelastic events collected in 8 hours (depending on the experiment's trigger capabilities). These collisions will be used mainly for time and space alignment of the detectors, and for the comparison of basic distributions with Monte Carlo expectations (multiplicities, momentum distributions, angular distributions, etc.).

PHYSICS REACH VERSUS ENERGY AND LUMINOSITY

The production cross section of massive systems is best summarized in Fig. 3 of Chapter 1 in Ref. [2], which shows the cross section as a function of center-of-mass energy $\sqrt{s}$ in pp and $p\bar{p}$ collisions for different processes. The heavier the system, the steeper the dependence of its production cross section on $\sqrt{s}$. For example, in the energy range accessible to the LHC, the production of top-antitop quark pairs ($2m_t \approx 350$ GeV) or of hypothetical Z' bosons of mass $m_{Z'} = 1$ TeV are considerably more affected by a reduction of $\sqrt{s}$ from 14 to 10 TeV than the production of a hypothetical Higgs bosons of mass $m_H = 160$ GeV. Therefore, the integrated luminosity needed for ATLAS and CMS to set limits on hypothetical particles comparable to those that the Tevatron experiments will reach by the end of 2010 depends strongly on the mass of the considered object and on the energy at which the ATLAS and CMS will acquire these data. For illustration, three specific examples are described below.

Note that, in what follows, the numbers quoted for integrated luminosity refer to data taken by the LHC experiments in good machine and detector conditions (all inefficiencies taken out).

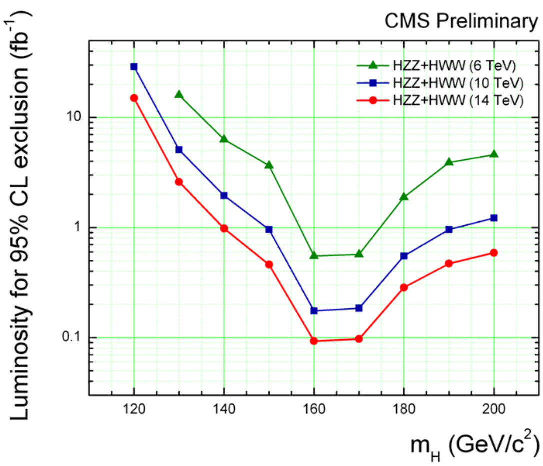

Figure 1: CMS-estimated integrated luminosity required to obtain a 95% CL exclusion limit as a function of assumed Higgs boson m_H and for a center-of-mass energy of 6 TeV (green), 10 TeV (blue), 14 TeV (red). Courtesy of CMS Collaboration.

Higgs boson around 160 GeV

As the last missing particle of the Standard Model, the Higgs boson is being heavily searched for and will be one of the principal aims of the General Purpose Detectors (GPD) at the LHC (ATLAS and CMS). The experimental signature of this particle depends critically on its mass, see e.g. in Ref. [2]. If the Higgs boson has a mass above $\sim$ 135 GeV, it predominantly decays in two weak bosons, one possibly virtual, either $WW^{(*)}$ or $ZZ^{(*)}$. This gives an experimentally clearer signature than in the case of a light Higgs boson with mass around 115-130 GeV, for which the experimentally preferred channel would be the arduous $H \rightarrow \gamma\gamma$. It is in the mass range around 160-170 GeV that the Tevatron experiments will obtain their most stringent exclusion limits. The latest combined CDF+D0 analysis, based on 3 fb^{-1} of data per experiment, reports a 95% Confidence Level (CL) exclusion limit on the cross section for a Standard Model Higgs boson of mass $m_H = 170$ GeV [3]. With about 9 fb^{-1}, the Tevatron experiments may be able to extend the 95% CL exclusion limits on a Standard Model Higgs boson or, possibly, obtain a three sigma observation in the range 150-175 GeV. What should be achieved in order to allow the LHC experiments to compete with these extrapolated Tevatron results ?

Figure 1 shows the estimated luminosity required to obtain a 95% CL exclusion limit at CMS as a function of assumed Higgs boson mass m_H and for a center-of-mass energy of 6 TeV (green), 10 TeV (blue), and 14 TeV (red). The figure shows that an integrated luminosity of approximately 200 pb^{-1} at 10 TeV would be needed for ATLAS and CMS to reach limits comparable to those of the Tevatron experiments. A factor two less data would be required with 14 TeV and about a factor three more data with 6 TeV.

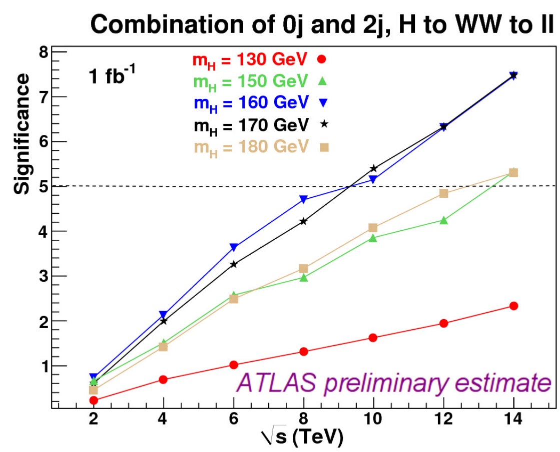

Figure 2: ATLAS-estimated Higgs boson signal significance expected for 1 fb^{-1} of data, as a function of the center-of-mass energy, and for five different assumed Higgs boson masses (m_H). Courtesy of ATLAS Collaboration.

Figure 2 shows the signal significance that could be obtained at ATLAS, as a function of center-of-mass energy, assuming five different Higgs boson masses and an integrated luminosity of 1 fb^{-1}. An observation of the Higgs boson (significance = 5) could be reached with $\sqrt{s} = 10$ TeV, if the boson has a mass between about 160 and 170 GeV. This window would open to 150-180 GeV for nominal LHC energy, i.e. $\sqrt{s} = 14$ TeV.

Z' *boson around* 1 TeV

The Standard Model is generally thought to be the low energy limit of a more complete theory. Many such theories have been proposed, and one of the purposes of the LHC is to experimentally determine which, if any, is the better one. In these various theories, several new particles are often predicted or introduced. A common new particle, which appears under different dresses, depending on the theory, is called Z' due to its similarity with the more familiar Z boson of the Standard Model. It is a (massive) neutral, colorless boson of spin 1, which is its own antiparticle. For a recent review, see for example in Ref. [4]. The CDF experiment recently published 95% CL exclusion limits obtained with $2.5\mathrm{fb}^{-1}$ which rule out such a high mass resonance decaying to e^+e^- with a mass lower than 735...963 GeV (depending on the model assumed) [5].

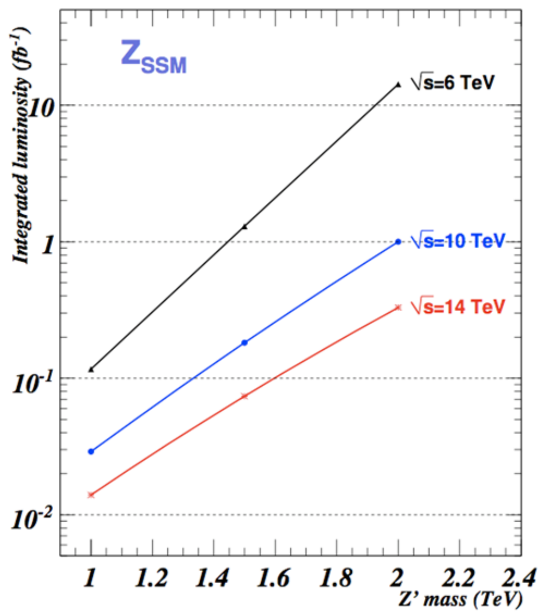

Figure 3: CMS-estimated integrated luminosity required to obtain a 95% CL exclusion limit on the Z' boson in the Sequential Standard Model as a function of the assumed boson mass, for a center-of-mass energy of 6 TeV (black), 10 TeV (blue), and 14 TeV (red). Courtesy of CMS Collaboration.

Figure 3 displays the estimated luminosity required to obtain at CMS a 95% CL exclusion limit on the Z' boson in a selected (benchmark) model, the Sequential Standard Model (SSM)[4], as a function of the assumed boson mass and for a center-of-mass energy of 6 TeV (black), 10 TeV (blue), and 14 TeV (red).

Figure 4 shows, as a function of center-of-mass energy, the estimated luminosity required to obtain at ATLAS a 95% CL exclusion limit on a Z' boson in the SSM model (solid curves) or a 5σ observation of such a boson (dashed curves). Two boson masses have been assumed: 1 TeV (red curves) and 1.5 TeV (blue curves).

From the two above figures, one concludes that an integrated luminosity of about $50\ \mathrm{pb}^{-1}$ would be needed at $\sqrt{s} = 10$ TeV in order for CMS and

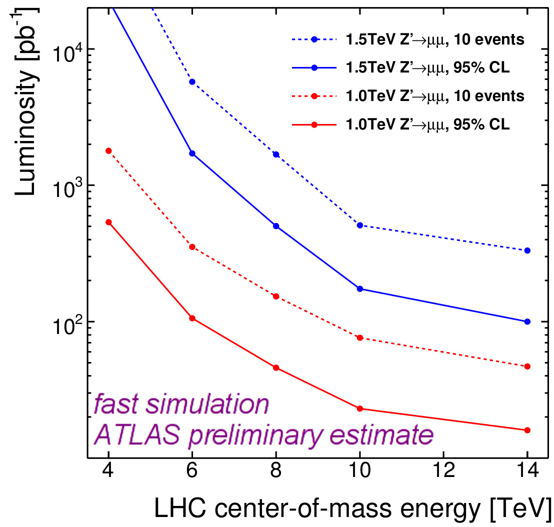

Figure 4: ATLAS-estimated integrated luminosity, as a function of center-of-mass energy, required to obtain a 95% CL exclusion limit on a Z' boson (solid curves) in the Sequential Standard Model or a 5σ observation of such a boson (dashed curves). Two boson masses have been assumed: 1 TeV (red curves) and 1.5 TeV (blue curves). Courtesy of ATLAS Collaboration.

ATLAS to obtain a Z' physics reach comparable to what will be obtained by CDF and D0 with $9\ \mathrm{fb}^{-1}$. A factor 2 (or 4) more data would be needed at 8 TeV (or 6 TeV) compared to 10 TeV for a boson mass of about 1 TeV, and an even larger factor for higher boson masses.

Top-antitop quark pairs

Discovered at the Tevatron in 1995, the top quark is, thus far, the heaviest of all experimentally observed fundamental particles. More than twice as heavy as the W boson, it decays quickly, without forming any ‘top hadron’, and almost exclusively through the weak process $t \to W^+b$. Because of this decay mode, top quarks contribute importantly to the background in many new physics searches. Therefore, understanding precisely top-antitop quark production at the LHC will play a crucial role in establishing exclusion limits or signal discoveries of hypothetical particles. In addition, with the large $t\bar{t}$ samples expected at the LHC, top quark physics measurements (such as the top mass or CKM matrix element V_{tb}) could be greatly improved.

Figure 5 shows, as a function of center-of-mass energy, the number of $t\bar{t}$ events expected to be recorded at ATLAS assuming an integrated luminosity of $50\ \mathrm{pb}^{-1}$. Red curve and squares shows

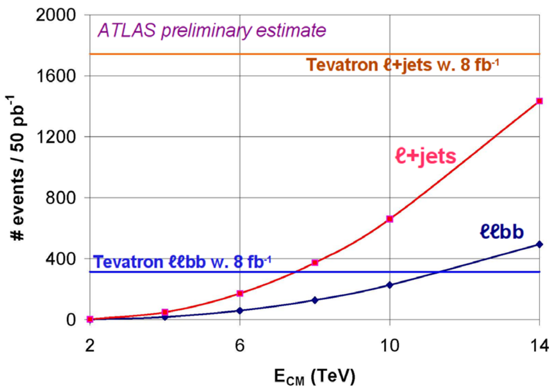

Figure 5: ATLAS-estimated number of $t\bar{t}$ events expected to be recorded with an integrated luminosity of $50\ \mathrm{pb}^{-1}$, shown as a function of center-of-mass energy. Red curve and squares: $\ell + \mathrm{jets}$ final states. Blue curve and diamonds: $\ell\ell bb$ final states. Horizontal lines indicate the extrapolated Tevatron $t\bar{t}$ sample expected for $8\ \mathrm{fb}^{-1}$, with the same color coding. Courtesy of ATLAS Collaboration.

the events reconstructed by $\ell + \mathrm{jets}$ final states, the blue curve and diamonds, shows those reconstructed by $\ell\ell bb$ final states. The horizontal lines indicate the extrapolated Tevatron $t\bar{t}$ sample expected for $8\ \mathrm{fb}^{-1}$, with the same color coding. With $100\ \mathrm{pb}^{-1}$ at 10 TeV, the LHC experiments could match the full Tevatron sample. A factor two less luminosity would be needed at 14 TeV, and a factor two more at 8 TeV.

NON GENERAL PURPOSE DETECTORS

LHCb

The $b\bar{b}$ system being relatively light compared to the systems considered above, its cross section does not vary as drastically in the $\sqrt{s}$ range accessible to the LHC. Accordingly, the request to ramp to highest possible energy is milder for LHCb than for the GPD experiments. An important benchmark channel for 'early physics' at LHCb is the $B^0_s \to J/\Psi\phi$ decay channel, which will allow the experiment to extract several physics observables of the B_s system, most importantly the CP violating weak phase β_s. LHCb expect to collect about 120'000 $B^0_s \to J/\Psi\phi$ with 2 fb^{-1} at 14 TeV [6]. The CDF and D0 experiments have collected each about 2000 $B^0_s \to J/\Psi\phi$ events in 1.35 fb^{-1} [7] and 2.8 fb^{-1} [8], respectively. They will continue to do so and, by scaling these numbers to 9 fb^{-1}, should accumulate approximately 14000 and 7000 such events by end of 2010. Therefore, by simple scaling with the $b\bar{b}$ production cross section (and ignoring differences in detector performance), LHCb will need about 300 pb^{-1} (360 pb^{-1}) of good data at 10 TeV (8 TeV) to challenge the Tevatron experiments in this field. A full simulation study by the LHCb Collaboration resulted in required integrated luminosity numbers about 20% lower than the ones given here.

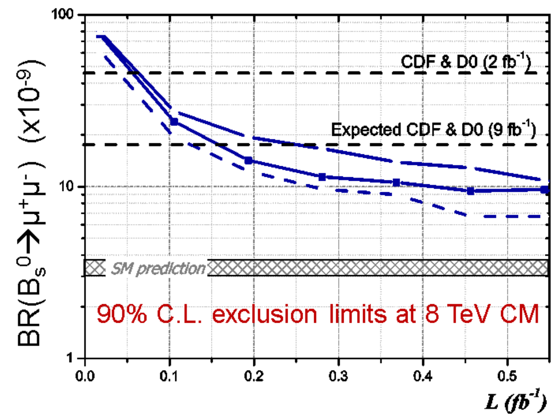

Figure 6: Statistical accuracy achievable at LHCb on the branching ratio measurement of $B_s \to \mu\mu$ as a function of the integrated luminosity and assuming, in this case, a $\sqrt{s}$ of 8 TeV. Courtesy of LHCb Collaboration.

Another important decay channel is the $B_s \to \mu\mu$ 'rare decay' which, in terms of triggering, is similar to the $B^0_s \to J/\Psi\phi$ channel (di-muon trigger). In the Standard Model, $B_s \to \mu\mu$ (a flavour-changing neutral current) takes place via second order electroweak effects (two boson exchange) and is further suppressed by helicity conservation. Therefore, the Standard Model branching ratio is expected to be tiny, about $3.4 \cdot 10^{-9}$ [9]. Physics beyond the Standard Model could enhance by a large factor this branching ratio [10]. Fig. 6 shows the statistical accuracy achievable at LHCb on the branching ratio measurement of $B_s \to \mu\mu$ as a function of the integrated luminosity and assuming, in this case, $\sqrt{s} = 8$ TeV. Some (for example, supersymmetric) models predict a branching ratio beyond $2 \cdot 10^{-8}$. This value could be just excluded by the Tevatron experiments with 9 fb^{-1} of data. LHCb could obtain a better result with about 200 pb^{-1} at 8 TeV, and possibly observe new physics with 1.5 fb^{-1} if these produce a branching ratio of about 10^{-8} or more. With 10 TeV, the required luminosity is about 15-20% less.

Further practical (nevertheless relevant) notes concerning LHCb:

- In order to perform a first calibration of the detector, LHCb need a sample of J/ψ mesons corresponding to an integrated luminosity of at least 5 pb^{-1} at $\sqrt{s} \geq 4$ TeV.

- If the center-of-mass energy were to be $\sqrt{s} \leq 4$ TeV for a 'zero crossing angle' scheme, LHCb would not be able to close the Vertex Locator (VELO), due to the reduced aperture, unless the internal crossing angle due to the spectrometer (at full B-field) were corrected.

- Because the LHCb detector is arranged horizontally, several subdetectors cannot make use of cosmics data for setting up, in particular the silicon trackers (Vertex Locator, Inner Tracker and Tracker Turicensis). Therefore, LHCb wishes to use some TED calibration runs about one month before circulating beam. This requires closing access to Point 8 and directing the SPS beam onto the TI8 TED block. As observed during the 2008 commissioning period, a bunch population of 1 to $2 \cdot 10^9$ protons produces acceptable track densities at the LHCb silicon trackers. These events are particularly useful to set up the coarse timing and to obtain first alignment coefficients.

- In the 2009-2010 physics run, LHCb would like to take most data with the spectrometer polarity that allows the smallest β^* to be set at IP8 [11]. With this polarity, a β^* similar to what can be obtained at IP1 and IP5 in 2009-2010 should be possible at IP8. However, LHCb also would like to collect some data with the reverse polarity which will boost the understanding of the various acceptance corrections.

ALICE

The study of phenomena in strongly interacting matter at extreme energy densities, using Pb-Pb collisions, may be started at the LHC at energies lower than nominal without much loss of physics potential. Therefore, like for LHCb, for the ALICE Collaboration the physics motivation for reaching the highest possible energy is not as strong as for the GPD experiments. It is reminded here that pp data are an integral part of the ALICE physics programme and will be essential for understanding physics in heavy ion (HI) collisions. A center-of-mass energy of 5.5 TeV for pp corresponds to the nucleon-nucleon equivalent of nominal energy Pb-Pb collisions, and therefore is of particular interest for the HI community. For 820 TeV Pb-Pb collisions[1], the corresponding pp center-of-mass energy would be around 4 TeV. However, running at such specific $\sqrt{s}$ can be delayed to after the first HI run if not done for other reasons on the way to maximum energy.

The ALICE detector will be ready for both pp and Pb-Pb. The ALICE Collaboration wishes to take Pb-Pb data as early as possible (more on heavy ions below). During pp running, ALICE will collect data at a luminosity of $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (for minimum bias physics), and at a maximum luminosity of approximately $5 \cdot 10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (for rare processes), see Ref. [12]. Therefore the 2009-2010 pp run is of particular importance for the physics programme of ALICE, as these luminosities can be more easily and naturally provided than in later years.

The ALICE pp physics programme also includes runs with the smallest possible β^* in which the beam axis is used as a vertex constraint for the measurement of heavy quark production. Therefore, a transverse beam size $\sigma_{x,y}$ of less than about $40\ \mu\mathrm{m}$ would be required, which, at 5 TeV means $\beta^* \leq 2.25$ m. Such a run would optimally take place with only few bunches colliding in IP2 and spaced by more than 100 ns. This can be achieved e.g. with a few bunches displaced for ALICE in the symmetric shift filling schemes (43x43, 156x156) or in the 50 ns scheme with one reduced batch dedicated to ALICE, as proposed in Ref. [13]. ALICE expressed particular interest in these filling schemes since they allow to optimally satisfy their luminosity requirements (while satisfying ATLAS, CMS and LHCb), without the need of defocussing or lateral displacement of the beams in IP2.

TOTEM

TOTEM is a dedicated forward physics experiment, designed to study elastic and diffractive physics in pp collisions. TOTEM will operate under all running conditions. However, for an important part of their physics programme, e.g. the luminosity-independent measurement of the total cross-section, special beam optics with high β^* are mandatory [14].

Concerning detector installation and readiness, the T1, T2 trackers, all RP220 Roman Pots and some of the RP147 Roman Pots will be installed and ready for use in 2009.

The TOTEM programme at $\sqrt{s} = 900$ GeV includes the possibility to move the instrumented Roman Pots to $15\sigma_{x,y}$ from the beams in order to align the detectors using beam halo and diffractive protons (the acceptance for elastic scattering under these conditions is poor). It also includes studies of surviving protons with momentum losses $\xi = \Delta p/p > 0.1$ and studies of event topologies with T1 and T2 (pseudo-rapidity distributions, multiplicities) with the aim of extracting relative cross-

[1] I.e. with the same LHC arc optics as for 10 TeV pp collisions.

sections for the different event topologies.

The programme at high (ramped) energy with early standard optics ($\beta^* \approx 3$ m) repeats all the studies done at 900 GeV. In addition, measurements of elastic scattering at large four-momentum transfers and of central diffraction with ξ down to about 0.02 are foreseen. As soon as technically feasible, TOTEM will request a dedicated run with the $\beta^* = 90$ m optics (possibly reached by gradual defocussing from $\beta^* = 3$ m to higher values). This would allow them to carry out a first measurement of the total pp cross section with the Optical Theorem using T1, T2 and the Roman Pots (to an accuracy of approximately 5%).

LHCf

The aim of LHCf is to study the energy distribution of particles emitted in the 'very forward' region for a better understanding of cosmic ray phenomena [15]. LHCf are interested in all center-of-mass energies, including 900 GeV, although the final goal is to perform the measurements at the nominal LHC energy (14 TeV). The needed integrated luminosity for covering the approved physics programme amounts to $\sim 10\ \mathrm{nb}^{-1}$ at 14 TeV, which can be obtained in a few hours of stable beams at $\sim 10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. Such luminosity can be achieved even at $\beta^* = 11$ m with a single colliding bunch pair.

Because LHCf is based on 2 μs readout, the optimal running conditions are obtained with the 43x43 filling pattern and a luminosity of about $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (or with fewer bunches as long as the probability of more than one pp interaction per crossing stays below ~ 0.0013 which, assuming a total cross section of 100 mb, implies $N^2/(4\pi\epsilon\beta^*) <\sim 5.2 \cdot 10^{23}\ \mathrm{cm}^{-2}$). LHCf would like to take data with both zero and non-zero crossing angle (which enhances the acceptance).

The detector contains non-radiation-hard components which will degrade rapidly after a few pb^{-1} with the detector in the data-taking position. Therefore, when the luminosity will exceed $10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, the detectors will have to be moved away from the beam plane, which considerably reduces the exposure. This displacement can be done remotely, without interrupting beam operation. At $L > 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ the dose rate becomes too severe for the LHCf detector. Before such luminosity is reached, the complete LHCf detector must be dismounted. This will require an access of about 8 hours.

The LHCf Collaboration is potentially interested in taking some data with heavy ions, though possible interferences with other equipment have not yet been assessed.

PROTON FILLING SCHEMES

The luminosity L depends on several parameters:

$$L = \frac{f\, k_b\, N^2}{4\pi\, \beta^*\, \epsilon}\, S \tag{1}$$

where (with values given for the LHC) $f \approx 11245$ Hz is the revolution frequency, k_b the number of colliding bunch pairs at the IP, N the bunch population (here assumed equal for all bunches), and $\epsilon \approx (7\ \mathrm{TeV}/E) \cdot 0.5\ \mathrm{nm}$ the transverse emittance depending on the beam energy E (in TeV). S is a correction factor depending on the crossing angle and on the ratio of longitudinal and transverse bunch sizes.

The two GPD experiments generally require the highest possible luminosity. One of the challenges will be to provide maximum luminosity to ATLAS and CMS while simultaneously satisfying the specific requirements of ALICE (IP2) and LHCb (IP8). As mentioned previously, the optimal pp luminosity for ALICE is about $10^{29}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and the maximum is about $5 \cdot 10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. LHCb require the highest possible luminosity, like ATLAS and CMS, until it reaches approximately $5 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. At this point, LHCb prefer minimum pile-up, while keeping such a luminosity level. New filling schemes have been proposed to optimize the collision patterns for these luminosity requirements [13]. These schemes are further discussed in Werner Herr's contribution to this workshop [16].

The increase of beam intensity will require careful checks. The choice of physics operating conditions will need to strike a balance between risks, operational efficiency, luminosity and experimental conditions. Most likely, first collisions at ramped energy will occur at 'injection optics' ($\beta^* = 11$ m at IP1/5 and 10 m at IP2/8) with a few bunches per beam (2x2, 3x3, 4x4, ...), such that each IP obtains at least one colliding pair and such that best use is made of each stored bunch. Along these lines, squeezing to a reasonable β^* (3 m ?) could be the first step to increase luminosity without increasing intensity. Similarly, because L is proportional to $N^2\, k_b$, the next luminosity increase should be an increased bunch population which, for the same luminosity gain, would 'cost' a factor $1/\sqrt{2}$ less intensity than an increase in k_b.

The number of bunches could then be brought up, first to 43, then to 156, the latter being the maximum (practical) number of 'equidistant' bunches that can be injected into the LHC without introducing parasitic crossings in the common beam pipe of the experimental insertion regions. In these two 'zero crossing angle' schemes, IP1 and IP5 obtain the maximum number of colliding pairs, while IP8

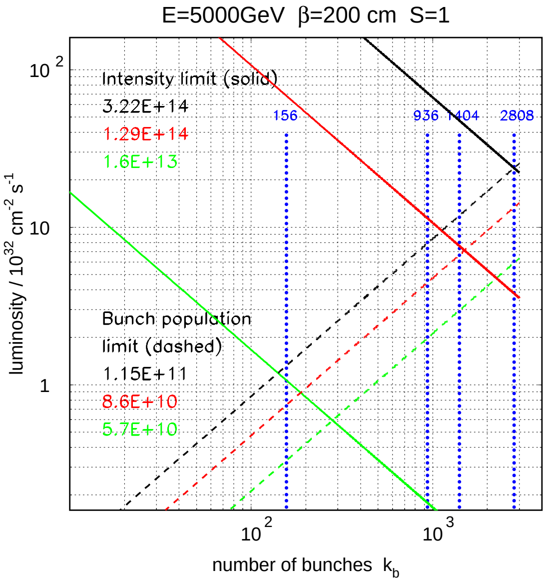

Figure 7: Luminosity as a function of number of bunches k_b assuming a given maximum beam intensity of 0.05, 0.4 and $1\times\mathrm{nominal}$ (solid curves) and a maximum bunch intensity 0.5, 0.75 and $1\times\mathrm{nominal}$ (dashed curves). The four vertical lines indicate the number of stored bunches for the 156x156, 75 ns, 50 ns and 25 ns schemes.

obtains almost half as many, and IP2 just a few pairs. At this stage, assuming $E = 5$ TeV, $k_b = 156$ and $N \approx 10^{11}$, the stored energy per beam would amount to about 12 MJ, i.e. about nine times the energy stored in a Tevatron beam and six times that of a Hera-p beam.

The next luminosity increase (assuming β^* and N have already been pushed) would require the increase of the number of stored bunches, which implies the introduction of a crossing angle. Three bunch spacings have been considered which can be delivered by the injector chain: 75 ns, 50 ns and the nominal 25 ns. If the total beam intensity is limited, maximum luminosity is achieved with less bunches at equal beam intensity, i.e. by squeezing more protons in less bunches. However, bunch intensity is also limited. Therefore, (but somewhat simplistically), given maximum beam and bunch intensities, there is an optimum number of bunches for obtaining maximum luminosity. This is depicted in Fig. 7 which shows the luminosity as a function of number of bunches k_b assuming a given maximum beam intensity of 0.05, 0.4 and $1 \times \mathrm{nominal}$ (solid curves) and a maximum bunch intensity of 0.5, 0.75 and $1 \times \mathrm{nominal}$ (dashed curves). The four vertical lines indicate the number of stored bunches for the 156x156, 75 ns, 50 ns and 25 ns schemes. The correction factor $S = 1$ was assumed (a reasonable assumption for the purpose of this discussion).

Considering that the total stored intensity will be limited initially to a fraction[2] of the nominal intensity ($I_{\mathrm{nominal}} = 2808 \cdot 1.15 \cdot 10^{11}\ p$), it is quite likely that the 25 ns scheme will not be optimal unless the bunch population is severely limited (to less than about $5 \cdot 10^{10}$). At 40% nominal intensity and about $9 \cdot 10^{10}$ maximum bunch population, the 50 ns scheme seems optimal. From the point of view of the experiments, if the intensity were to be limited to an even smaller fraction of the nominal intensity, the optimal fill pattern could still be a 'truncated' 50 ns scheme, as proposed by Werner Herr [16], i.e. a fill scheme with 50 ns spacing but with a reduced number of SPS (and/or PS) transfers. This would allow the intensity to be reduced while keeping the IP1, IP5 and IP8 as high as possible and simultaneously delivering a few colliding bunch pairs for IP2.

The experiments are also interested in taking some data with 25 ns bunch crossing, at the end of the 50 ns run period, in order to prepare the road for nominal conditions.

HEAVY IONS

The commissioning strategy of Pb beams for the LHC was presented by John Jowett in this workshop [18]. As for protons, heavy ions beams will be commissioned in stages. The first stage for a HI physics run uses 'early' beams with $k_b = 62$ (1350 ns bunch spacing), $\beta^* = 1$ m and $N = 7 \cdot 10^7$ Pb/bunch, resulting in $L \approx 5 \cdot 10^{25}\ \mathrm{cm^{-2}s^{-1}}$. Such 'early' beams have already been produced in the full injector chain in 2007 and will be reproduced in the course of 2009.

For most HI runs, the plan is to operate Pb beams with an LHC machine magnetically identical to that used for proton operation (up to the pre-squeeze stage). Time for commissioning the 'early' Pb beams has been estimated to one or two weeks [18]. The injector chain can be set up in parallel to LHC proton running. Given the smaller intensity of Pb beams, compared to proton beams, radioactivation of materials is expected to be considerably smaller during HI running. For this reason, it has been suggested to schedule the HI run after the proton run, in order to benefit from some radioactive cooling just before entering the shutdown period.

A run with Pb beams at the end of the proton run ($\sim$ end of 2010) will allow the LHC HI community, in particular ALICE, to obtain significant physics results in new territory, at more than 20 times the energy of RHIC. With the low luminosity of the early

[2] On paper, for an ideal machine, the Phase I collimators allow up to 43% of nominal intensity to be stored at 7 TeV beam energy [17]. In reality, the limit could be substantially lower.

scheme, the ALICE experiment plans to focus on large cross section observables in minimum bias and central collisions. Signal statistics in this case will be limited by DAQ bandwidth and therefore effective data taking time, not by integrated luminosity.

For example, the STAR experiment has reported results on the elliptic flow v_2/ϵ coefficient which approach the hydrodynamic limit for a perfect fluid [19]. With just a few days of good data, ALICE could obtain important results on the measurement of this coefficient which, if a value larger than the RHIC values were to be measured, would challenge the 'perfect fluid' interpretation of the Quark-Gluon Plasma. About one million central events are required to cover many of the large cross section observables (corresponding to 10^5 effective seconds); whereas at least 10^7 events (10^6 effective seconds) are needed to measure rare hadronic signals (e.g. jet quenching with heavy quarks). In a nominal length Pb-Pb run of 10^6 effective seconds, at the initial low luminosity, also a first low statistics J/Ψ measurement should already be feasible with about 20'000 J/Ψ's collected.

CONCLUDING REMARKS AND SUMMARY

The LHC experiments are ready to take data. They do not need a shutdown during the winter months and largely prefer a continuous run period (of the order of twelve months), starting as soon as the LHC machine is ready to resume with beam commissioning. First collisions at 900 GeV will be precious for doing final adjustments of the detectors before collisions at ramped energy. The pp physics run should take place at the highest possible (and safe) energy and should be long enough for accumulating sufficient data to challenge or surpass Tevatron physics reach. Examples were given which illustrate that, at 10 TeV,

- $50\ \mathrm{pb}^{-1}$ of good data would allow the experiments to set many new limits on hypothetical particles, some more stringent than those of the Tevatron experiments, or could bring the discovery of such particles,
- $200\ \mathrm{pb}^{-1}$ of good data would allow to start competing with Tevatron experiments on Higgs searches around 160 GeV and outrun them on B_s physics,
- $1\ \mathrm{fb}^{-1}$ of good data would allow the Higgs boson to be discovered if it has a mass around 160 GeV.

With considerably less than $50\ \mathrm{pb}^{-1}$ integrated luminosity, such a run would probably no longer qualify as a 'physics run', although it would still be useful for understanding the detectors. Similarly, at a center-of-mass energy below 8 TeV the requirement on integrated luminosity for the 2009-2010 would probably put out of reach the above physics goals. However, given that a luminosity of about $10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ at a center-of-mass energy of 10 TeV corresponds to moderate LHC initial parameters, the target of 200-300 pb^{-1} for the first physics run (2009-2010) seems within reach and, if successful, would have major physics impact, besides being a fantastic achievement of the accelerator groups.

A heavy ion run with 'early' beams at the end of the pp running period would allow to carry out first heavy ion physics.

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