EXPERIMENTS REQUIREMENTS AND LIMITATIONS FOR POST-LS1 OPERATION

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Abstract

The LHC will resume operation for physics in 2015, after a two year long shutdown, with an energy target of 13 TeV and a peak luminosity target of ~10^{34} cm^{-2}s^{-1}. The physics goals will be rich, with difficult precision measurements of the properties of the newly found Higgs boson, as well as of other equally important phenomena predicted by the standard model. With the higher energy, the experiment communities will also be looking for physics beyond the standard model. The two programs, which sometimes have diverging demands on the accelerator, need to be reconciled to guarantee the highest scientific output of the LHC. In this talk, we review the running scenarios for the Proton-Proton and Heavy Ion collider runs after LS1, in particular with respect to the issues related to bunch spacing (pile-up, triggers and reconstruction efficiency), but also to other aspects like bunch length, filling schemes, leveling, etc., as well as the experimental and technical challenges in the different scenarios.

PHYSICS GOALS

2012 has been a crucial year for all LHC experiments, in particular considering the subsequent long shutdown. Big scientific achievements were attained, starting from the discovery, by the ATLAS and CMS collaborations, of a new fundamental boson of mass of approximately 126 GeV, which is now understood to be the long sought after Standard Model Higgs boson [1], to major results on CP violation and rare decays in the b sector by LHCb [2]. These achievements turn into a rich set of new physics goals for after LS1.

Difficult precision measurements of the properties, in particular mass, spin and coupling constants, of the newly found boson are ahead of us (e.g. see Fig. 1 for the boson mass). Precision measurements of other important phenomena predicted by the standard model (or deviations thereof), will require even more efficient detectors and triggers.

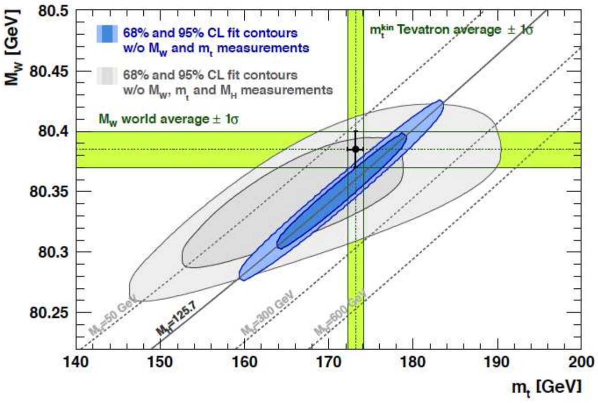

Figure 1: The direct measurent of M_H, together with the world average W and Top mass values (M_W and M_t), are remarkably consistent with the SM predictions.

The higher energy might open the way to the possibility of detecting new physics beyond the standard model (see Fig. 2).

These different goals pose many, sometimes diverging demands on the experiments and the accelerator. The running scenarios for the pp collider run after LS1 may become even more important in guaranteeing the best physics results. In particular, the bunch spacing and related issues (pile-up, trigger and reconstruction efficiency) may well prove a crucial choice in terms of exploiting the LHC potential at best. Decision on the bunch length, filling schemes, the use of β* leveling or otherwise, also require careful analysis with respect to the physics goals.

Many experimental and technical challenges are ahead of us in any of the different scenarios.

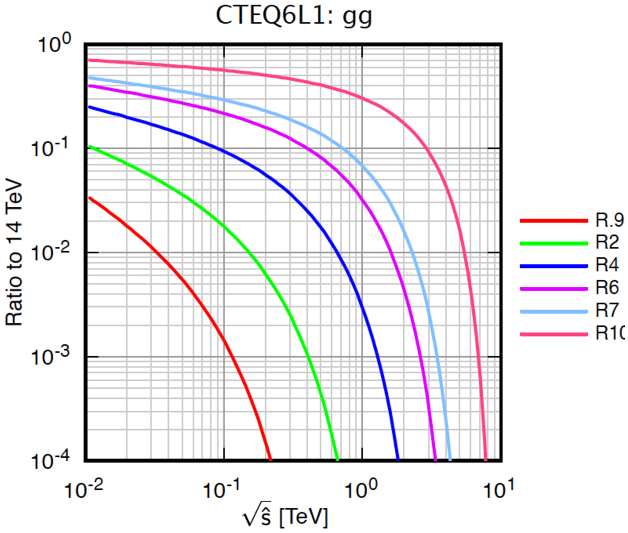

Figure 2: Ratio of parton luminosity for various center of mass energies relative to 14 TeV. For an object of mass 1 TeV, the parton luminosity is 10 times higher at 13 TeV than at 8 TeV.

CONSIDERATIONS ABOUT P-P BEAM PARAMETERS

Bunch Spacing. A bunch spacing of 50ns will produce twice the in-time pileup for the same instantaneous luminosity, e.g. for 10^{34} $cm^{-2}s^{-1}$ at 14 TeV, we expect μ=27 at 25ns and μ=54 at 50ns.

The study of the newly discovered fundamental boson is going to be the highest priority after LS1. Even with higher pile-up, the H->γγ and ZZ* decay modes would be "relatively" straightforward to trigger and study. Other modes would require good resolution and small systematic uncertainties for jets and τ-leptons. These will be much more difficult to achieve with high in-time pileup: for example, H->ττ: requires low-threshold ττ-triggers, which get spoilt by higher pile-up. ZH->ννbb relies on a trigger on missing transverse energy, whose thresholds will need to be increased with higher pile-up. On the other hand, to meet the physics goals, we would need to maximize the acceptance, which would imply to maintain or even lower those thresholds,. It is thus clear that from a physics perspective, operating at 25ns is strongly preferred.

Besides the general physics arguments, both ATLAS and CMS indicate that the current pile-up figures are close to the limit of what the detectors and the data processing chain can deal with. Inner detectors (Pixels and strips) occupancy increase with pileup is confronted with the limit on the total readout bandwidth. At 50ns and with increased luminosity, leveling will become necessary while, with 25ns, limits will only be hit above 10^{34} $cm^{-2}s^{-1}$. CMS also has estimated that 50ns would require about twice the CPU capabilities of the high-level trigger farm (Fig. 3), and a very significant increase of offline CPU and disk resources in comparison to 25ns, for the same amount of integrated luminosity.

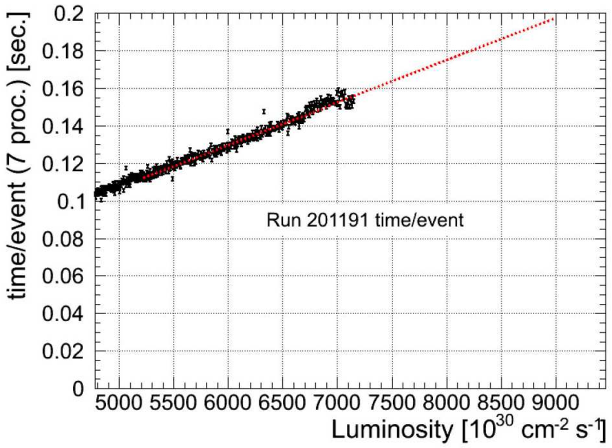

Figure 3: CPU time per event for the execution of the HLT in CMS. The current limit of the CMS farm is 0.19 s per event.

Effects on reconstruction and analysis become dramatic above 10^{34} $cm^{-2}s^{-1}$ at 50ns. These would require fundamental changes to the code and the selection cuts, e.g. raising track reconstruction p_T cut, and rethinking the primary vertex determination strategy.

Some studies also show [3] that the rate for certain inclusive triggers, especially those selecting on the total transverse and missing transverse energy, would not be controllable for pile-up higher than 50.

A special case must be made for LHCb. This experiment performs precision measurements in charm and beauty physics, looking for complex, fully reconstructed decay chains. At both trigger and offline level, high pileup means not only an increase of processing time, but also more ambiguities and ghost tracks, worse vertex, momentum, and mass resolution and, ultimately, a degradation of the signal to background ratio. The situation is exemplified in Figure 4 where the trigger yield for various b-signatures is shows as a function of instantaneous luminosity. The hadronic triggers rapidly saturate above $3{\cdot}10^{32}$ providing no additional signal for the increased triggrer rate.

Squeeze and leveling. In the 25ns bunch spacing scenario, the two high luminosity experiments will be squeezed to smallest β^* possible. The result of tests of the low emittance option beams from the SPS promise peak luminosities in excess of 10^{34} cm^{-2}s^{-1}, in IP1 and IP4, from beams with nominal or higher intensity ($1.15{\cdot}10^{11}$ ppb) and an emittance in collision as low as of 1.9 µm.

For IP8 the peak luminosity with β^*=10m and tilted crossing (resulting expected angle = 340 µrad) will be $9{\cdot}10^{32}$ cm^{-2}s^{-1} and thus leveling will be required, both for luminosity control and physics optimization (maximizing integrated luminosity, trigger stability). LHCb has tested at the end of the 2012 run the running scenario for 2015: $4x10^{32}$ cm^{-2}s^{-1} at 13 TeV and $\mu \sim 1.0$. At 25ns bunch spacing and with 2200 LHCb bunches (high brightness, no private bunches), multiplicity will increase by about ~20% in going from 8 TeV to 13 TeV.

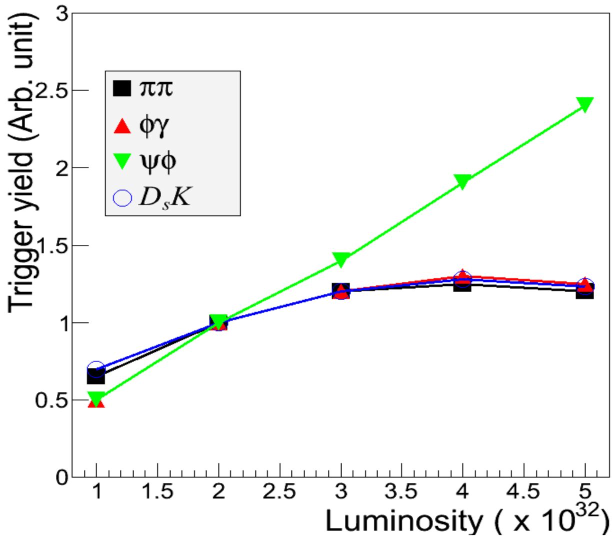

Figure 4: LHCb trigger yield for different B triggers. The yield for the non-muon triggers saturates at about $3{\cdot}10^{32}$ cm^{-2}s^{-1}.

The maximum acceptable detector particle flux will be equivalent to $5.5x10^{32}$ cm^{-2}s^{-1}[1] at 8 TeV. Assuming a luminosity lifetime of about 10h, as today, luminosity will reach that level after 8.5 hours, compared to ~14 hours in 2012. A $\beta^* <$ 10 m (or at least the square root of the product of β^*_x and β^*_y) would at that point become desirable. LHCb deems therefore important to commission a dynamic β^* leveling option for 2015. One proposed solution involves defocusing LHCb in the vertical plane and dynamically reducing β^*_y.

Bunch and luminous region length. The critical parameter for experiments is the luminous region rather than the bunch length, therefore, longer bunches could be partially compensated by larger crossing angles. As a general rule, a shorter luminous region gives more 'merged vertices', thus making it more difficult to reconstruct the primary event vertex. In fact, a moderate increase of the luminous region would probably benefit ATLAS and CMS (not LHCb) tracking and vertex reconstruction at high pile up, but this would come at a price. For example, in CMS, it would also worsen the mass resolution in the H->γγ analysis (benefits vs drawbacks are under study – they will also depend on the pile up conditions). In general, for both ATLAS and CMS, due to the limited acceptance of the inner tracking system, a longer luminous region can cause acceptance and efficiency losses for tracking and photons.

Again, a special case must be made for LHCb: the limited acceptance of the VELO causes some loss of efficiency for "long-lived" B decays, contributing 1/3 of the systematic error in lifetime measurements. So for LHCb a longer luminous region seems not to be an option.

Crossing angles. LHCb will require a vertical external crossing angle to maintain the tilted crossing scheme that was successfully used in 2012. This scheme guarantees the same boost vector amplitude in both polarities, thus simplifying the analysis of systematics. Polarity swaps of the LHCb spectrometer will also be required.

In general, an increase of the crossing angles (for 25ns) will have no other effect on the experiments and is therefore left to the machine to decide.

ALICE operation in proton-proton. ALICE goal for the proton-proton operations after LS1 will be to work at a (leveled) luminosity between 10^{30} and 10^{31} $cm^{-2}s^{-1}$. ALICE operated in 2012 using main-satellite collisions instead of offset main-main collisions as in 2011. Following a discussion in Chamonix 2012 “natural” satellites were used. These were expected to provide sufficient luminosity and were attractive to avoid big separations in IP2 and to optimize the filling schemes. Several problems, including vacuum conditions around IP2 and unpredictable satellite population, resulted in some difficulty for ALICE to collect the desired statistics. Enhancing the satellites during the final phase provided peak luminosities of up to 18Hz/ub, which allowed ALICE to level the luminosity to the desired value. These mode of operation turned out to have several drawbacks: monitoring of the satellite population in the injectors was not possible, hence the quality of the beams was not known until injection in the LHC; also, the luminosity decayed very steeply. Artificially enhancing the satellites resulted as well in several occasional operational issues like high losses at injection. In the (remote) case of a 50ns beam, ALICE has therefore no interest in continuing with the main-satellite scheme after LS1, and would prefer of order 45 main-main collisions with leveling, and a β* as large as possible. With 25ns separation ALICE will naturally get ~2000 main-main collisions and a β* of at least 10m will be required. Larger values (18-30) have been investigated [3] and may not be beneficial (because of an interplay of beam-beam effects and separation with broader beams), such that leveling by large separation seems the only available option. Further analysis will be needed.

SPECIAL RUNS

In addition to the low-beta program for proton-proton physics, very high β* measurements have a potentially very interesting program, the main goal being the study of low-|t| Elastic Scattering at 13 TeV and the measurement of the total p-p cross section. For the success of the high β* program, it is assumed that additional magnet cables will be installed during the 2015-2016 winter technical stop at the latest. In the initial phase, without these cables the focus will be on commissioning the injection and ramp at β* = 90m, with the goal of increasing the number of bunches using crossing angles.

Both TOTEM and ALFA have a long list of interventions and commissioning, to consolidate and expand the current capabilities. In particular, ALFA has plans to address RF-heating aiming at a factor 10 reduction. Active liquid cooling is under consideration.

TOTEM plans to pursue the study of diffractive physics with squeezed beams, leveraging the experience acquired in 2012 with approaching the RPs to 12-14 σ during standard physics runs. Investigations are planned to identify the source of high UFO rate induced by the movement of the horizontal pots.

The LHCf detector will be upgraded with radiation hard GSO scintillators capable of withstanding doses up to 1kGy. The goal is to collect at least 500 nb-1 at √s=13-14TeV with more than 2μs event-to-event interval. This would require an extended initial phase of operation with less than 43 bunch and μ<=0.01. LHCf is also requesting an energy scan for extrapolation to cosmic ray energies (7, 3.5 and 2.2TeV if possible) with a β* = 11m, and instantaneous luminosity less than 10^{29} cm^{-2} s^{-1}. This second part of the running plan will be discussed in the near future.

HEAVY ION PHYSICS

Many important results on heavy ion data have been produced by the ALICE collaboration [4], as well as ATLAS and CMS. For 2015 (and after) only Pb-Pb operation at 13Z TeV is requested. There is a potential for reaching peak luminosities of order 1-2 10^{27}, while ALICE working point after LS1 will be at 10^{27} $cm^{-2}s^{-1}$. For this and other reasons, leveling options in one or more IPs might have to be studied.

CONCLUSIONS

During LS1 some detector will undergo non-minor modifications: e.g. CMS will install new muon and calorimeter triggers and additional endcap muon chambers; ATLAS will install an additional innermost pixel layer. The intensity ramp-up at 25ns period can be used, in general, to commission the triggers and the new hardware and study the detector performance at a new energy. As usual establishing the Standard Model Physics candles at 13 TeV will provide an excellent testing ground for the upgraded components.

If an initial period at 50ns and 13 TeV should be deemed absolutely necessary, it will require an extra luminosity and trigger optimization. All the collaborations agree that this possible period should be kept as short as possible as it will unavoidably affect the physics yield.

In conclusion, 25 ns pp operation is a strong request of all the experiments, as it provides a much cleaner environment for precision physics and is less demanding in terms of computing resources. A bunch spacing of 50 ns should be considered an option only in case of major showstoppers. Optimization of other beam parameters (bunch length, crossing angles) should be carried out during commissioning as needed, as there is a clear demand for stable conditions for data taking.

Experiments accept that the commissioning period for 25ns operation may be longer than usual.

ALICE pp operation at 25ns will require further studies and discussion, as will the special runs program (ALFA, TOTEM and LHCf).

Only Pb-Pb operation at 13Z TeV is envisaged for Heavy Ions in 2015.

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