OPERATIONAL OVERHEAD OF MOVING TO HIGHER ENERGIES

M. Lamont, CERN, Geneva, Switzerland

Abstract

The operational overheads of moving above 3.5 TeV are examined. The costs of performing such a move at the start, or during, the 2011 run are evaluated. The impact of operation with beams above 3.5 TeV on machine protection systems is briefly reviewed, and any potential limitations are enumerated. Finally the possible benefits of increasing the beam energy on the luminosity are discussed.

PREAMBLE

A potential increase of the LHC beam energy is under consideration. In 2011 this potential increase is limited to a step up to 4 TeV from 3.5 TeV [1].

Clearly consideration of the risks coming from the splices dominates the decision of which energy to go to. However other system also have limits that must, in time, be lifted. The BLMs have a limitation in energy between 4 and 5 TeV due to noise on cables. The beam dump system has breakdown along the switches of the MKDs resulting in asynchronous dumps. The team is awaiting isolators to be installed and the present limit is 4.5 TeV.

It is assumed here that the snubber capacitors, energy extraction reconfiguration, QPS tests, IPQ tests, HWC are or will be done to fully qualify any increase in energy. These issues are fully covered elsewhere in these proceedings [1].

The temporal options in respect of an energy increase in 2011 are:

- start 2011 operations at the new energy;
- switch to the new energy during the year;
- leave any energy increase until 2012 or later;
- or possibly perform limited tests in a machine development environment.

RE-COMMISSIONING IN 2011

The re-commissioning in 2011 will see new settings for the ramp & squeeze (to 1.5 m). Relevant experience will be cut and pasted in and the ensemble re-commissioned from scratch. There will be full revalidation of LBDS with beam with specific tests for 4 to 4.5 TeV (BETS, protection) if required. There will be full re-setup of collimation and re-validation. Machine protection tests with beam will take place as usual. There will be configuration and tests of feedbacks, transverse damper, RF and other beam based systems.

If we start at a higher energy, the squeeze will be fully optimized and commissioned for said energy with optimum beta*. [2].

Given this approach, and give or take some details outline below, starting 2011 at a new energy would be almost cost free. Assuming, of course, the readiness of the magnetic circuits, QPS etc.

Machine Protection

Most machine protection systems are energy independent. These include the PIC, BIS, PIC, WIC, and SIS. The FMCM becomes more efficient at higher energy (greater current swing) and a quick verification of, say, a D1 would suffice to re-qualify the system. The BLM threshold tables are used at a higher energy but are already well qualified. The LBDS is OK to go to 4.5 TeV and standard tests at a higher energy would be sufficient. In summary, the MPS teams are fairly relaxed about 0.5 to 1 TeV increase in energy.

Pre-cycle

The precycle and ramp-down precycle combination works with 3.5 TeV values for the MBs, MQs, IPQs, ITs, and IPDs. The settings would clearly take these main circuits up to 4 TeV values. There would be a slightly longer pre-cycle/ramp-down combination but nothing dramatic.

There would be some minor effect on decay at injection and snapback, which could dealt with the usual tools. Diligent off-line preparation would be required as always.

Ramp

The optics do not change in the ramp and the normalized magnet strengths remain constant. The momentum function is a carefully optimized parabolic-exponential-linear-parabolic function of time and is essential function driving the calculation of all strengths to field or gradient. The magnet 'calibration curves' then provide look-up tables to given the required current in a given circuit.

Snapback, tune and chromaticity evolution at the start of the ramp - give or take effects of different the precycle – will be same. Standard procedure would copy in: tune, chromaticity, coupling, orbit, knobs, beating trims, landau damping, separation, crossing angles, non-closure knobs. Offline generation of collimator settings, transverse damper, RF would also be standard and be a natural extension of the lower energy settings.

In summary, a higher than 3.5 TeV ramp should be straightforward. The magnets would be pushing a bit further into magnet transfer functions but one would not expect any surprises. The orbit corrections can be extended at constant kick. The collimator functions can be extended to track emittance reduction with energy. The feedbacks, RF and transverse dampers are still expected to be comfortable.

Low intensity trials to flat-top would be required along with optics checks, validation dumps and loss maps.

Squeeze

The squeeze stitches together matched optics. Parabolic round in and round off over fixed time period of the current functions between match optics ensures smooth, coherent current changes. These current changes respect the time constraints from current decreases in the single quadrant power converters.

The tunes move to collisions tunes during first tens of seconds and operations generally worry about tune feedback, orbit feedback's change of references, chromaticity, coupling, optics corrections and the position of tertiary collimators.

Squeeze reuse

With an increase in energy the MAD optics/strengths remain the same, and the currents more-or-less scaled up with energy, give or take non-linear components in the magnet calibration curves.

If it is possible to use the same squeeze skeleton, we could use the same strength functions and simply re-scale with a new momentum function. This would sacrifice fully optimized timings and a few seconds and a small potential reduction of beta* (for example: 1.6 m to 1.5 m going from 3.5 TeV to 4 TeV (approx. 7% in luminosity)[2]). The orbit corrections could also be scaled up and one might hope that the 3.5 TeV reference orbit holds good. Tune, chromaticity and coupling corrections can be folded over, similarly beating corrections.

The hope here is that if beating and orbit are within limits that re-setup of collimators would not be required. (The reduction in emittance with energy would give slightly smaller beam sizes at collimators). The scenario could be tested in MD before making the definitive step up in energy. If the scenario doesn't work, collimator setup would be required.

Stepping up during the year: summary

The required time for re-establishing collision after an energy increase is summarized in table 1. This would amount to around 1 week with 50% machine availability Another week would be required if full collimator set-up were to be required.

Table 1: Estimate of time required to re-establish colliding beams at 4 TeV for a step-up during the year.

Phase	**Task**	**Shifts**
Ramp	Low intensity trials, test beam dump.	1
Flat-top	Orbit and optics checks	1
Flat-top	LBDS – asynchronous dump	0.5
Flat-top	Betatron loss maps & positive off-momentum, negative off-momentum	1
Squeeze	Q, Q', coupling, orbit checks, feedbacks	2
Squeeze	Beating & local coupling checks	1
Collision	Test, test luminosity scans	0.5
1.5 m separated	Betatron loss maps & positive off-momentum, negative off-momentum	1
1.5 m separated	Asynchronous dumps	0.5
1.5 m collisions	Betatron loss maps & positive off-momentum, negative off-momentum	1
1.5 m collisions	Asynchronous dumps	0.5
Total		**10**

Intensity ramp-back up

Following successful commissioning and validation of ramp, squeeze etc. with low intensities some circumspection might be appropriate before going back up to full intensity. A fairly aggressive, staged ramp back up intensity would seem appropriate with validation checks and the normal cross-system checklist. One week would seem reasonable.

BEAM

The effects of increasing energy on the relevant beam parameters are summarized in table 2.

Table 2: variation of key parameters with energy. The last two rows illustrate the change in beam size at the primary collimators.

	3.5 TeV	**4 TeV**	**4.5 TeV**
Gamma	3730.26	4263.16	4796.05
Normalized emittance [mm.mrad]	2.5		
Emittance [nm]	.67	.586	.521
Beta*[m]	1.5		
Beam size at IP [micron]	31.7	29.7	28.0
Number of bunches	930		
Luminosity [$cm^{-2}s^{-1}$]	1.03×10^{33}	1.15×10^{33}	1.28×10^{33}
Beam energy [MJ]	59.9	68.5	77.0
Beam size at beta = 145 m	368.9	345.0	325.3
Beam size at beta = 85 m	282.4	264.2	249.1

- There is a corresponding increase in energy density with energy if the normalized emittance stays the same. Note that with the decrease in assumed normalized emittance, the geometrical emittance approaches the nominal 7 TeV value.
- The decrease in beam size brings some increase in minimum beta* reach [2].

Trade-off

In simple terms, if the increase in energy:

- brings an increase in sensitivity for a given process of x% (choose your channel) [3];
- and brings an increase in luminosity of y%;
- and takes N days to re-commission;
- and takes R days to ramp up back up in intensity;

then we will have run at the increased energy for around $(N + R/2)/(x + y)$ days to make up the time used for the energy step-up. For example to go to 4 TeV with $N = 7$, $R = 7$, $x = 0.25$ (low mass Higgs), $y = 0.13$, it will take around 4 weeks to catch up lost time. The message here is that if the step-up is to be done during the year, it should be done sooner rather than later,

CONCLUSIONS

Given any HWC/QPS/MP3 overheads, starting a new year at a new energy 0.5 to 1.0 TeV above 3.5 TeV is almost cost free from an operational perspective. Full setup from scratch is planned anyway and any additional machine protection tests can be absorbed into normal re-commissioning.

An increase in energy during the year, with successful squeeze re-scaling, would require around 1 week re-commissioning. Without squeeze re-scaling, the additional collimator setup and verification would bring the total up to around 2 weeks. To be able to make up for time lost to re-commissioning, any energy step-up should be made in good time.

The final option is to run the whole of 2011 at 3.5 TeV, which is clearly easiest from an operational perspective. Here we would rely on squeezing harder and an increased number of bunches to lift performance.

REFERENCES

[1] Nuria Catalan Lasheras, What needs to be done to reach beam energy above 3.5 TeV? Commissioning of essential magnet powering and machine protection systems., these proceedings.

[2] Werner Herr, Pushing the limits: crossing angles, aperture and beta*, these proceedings.

[3] Bill Murray, How much Physics benefits from running at higher energies?, these proceedings.