Welcome - Joint LHC Machine-Experiment Workshop on the Luminosity Monitoring and Measurement

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Introduction

- Together with the centre-of-mass energy, the luminosity is a key ingredient in an accelerator's design parameters and is of primary interest for the physics.
- The primary aim of the workshop is to review how the machine and the experiments plan to measure and monitor the relative and absolute luminosity during the LHC commissioning and start-up phase.
  - The workshop will focus on the 2007 LHC engineering run at 450 GeV and on the first run in 2008 at 7 TeV.

Luminosity – from Physics Parameters

- Luminosity is defined as the ratio between the interaction rate of a physics process and the production cross-section according to:
- N_{int} is the interaction rate for the process with cross-section σ.
- The counting rate in a detector is $N_{int} \times$ Acceptance of the device.

$$L = \frac{N_{\text{int}}.}{\sigma}$$

Luminosity – from Machine Parameters

- N = number of protons per bunch
- k_b = number of bunches per beam
- f = revolution frequency
- γ = Lorentz factor E/m_0c^2
- ε_n = normalised emittance
- β^* = value of betatron function at the IP
- F = reduction factor caused by the crossing angle (unity for head-on collisions and 0.85 for nominal LHC crossing angle)

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

$$F = \frac{1}{\sqrt{1+\left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}}$$

θ_C = crossing angle
σ_Z = bunch length
σ^* = transverse beam size at IP

Bringing the LHC Beams into Collision

- Use the machine Beam Position Monitors (BPMs) to position the beams with an error of around ±200 μm.
  - This is not accurate enough.
- The collision rate will then be maximised by performing a raster scan around this position with the aid of the collision rate monitor.
  - Systematic scan in both vertical and horizontal directions is needed wit
  - Could be done as $\sigma_{trans.}$ is 100 μm at β^*=18 m and 16 μm at β^*=0.55 m.

Monitoring the LHC Luminosity

- The above equations can be used to calculate the collision rate assuming all parameters are well-known during a run.
- However, drifts and shifts during a run are expected
  - Beam orbit drifts may reduce the integrated luminosity and would need correcting.
  - Only a 5 μm shift of Q1 relative to Q3 would reduce the collision rate by 20%.
- Collision rate must therefore be monitored using dedicated, robust & reliable device - collision rate monitor.
  - Independent of the uncertainties in the beam parameters and optics.

Signal-to-Background

- The limiting factor of the collision rate monitor is the signal-to-background ratio.
- At low bunch currents, the rate to be monitored will be low and the backgrounds relatively higher, particularly at LHC start-up.
- Machine-induced backgrounds may make the collision rate measurements, including the coincidence detection difficult at LHC start-up.

Measurement of the Absolute Luminosity

- Experiments require the absolute luminosity in order to determine the physics cross-sections.
- Use identifiable processes with special low luminosity LHC runs
  - Inelastic rate + forward elastic rate + optical theorem (TOTEM).
  - Absolute normalisation of the hadronic scattering amplitude at t ~ 0 to the exactly calculable Coulomb amplitude (ATLAS/ALFA).
  - Absolute measurement of luminosity will allow calibration of monitors/detectors.
    - Extrapolate to higher LHC luminosities.

Alternative Methods of Luminosity Determination

- Additional well-calculable physics processes
  - QED process of muon pair production by double photon exchange.
  - QCD production of W and Z bosons
- Heavy Ion Interactions
  - Measure the rate of mutual EM dissociation with ZDCs.
- Van der Meer Method
  - Measure interaction rate as a function of the displacement (vertical & horizontal) of the two beams relative to each other.

Conclusion

- The precise measurement of the luminosity and its continuous monitoring is a necessity for the determination of the physics cross-sections.
- Close collaboration is required between the LHC experiments and machine in order to ensure a good luminosity measurement and monitoring.
- Initial LHC running period will be very important in commissioning the luminosity measurements.