1 Calibration Strategy for LHC Startup

1.1 Electromagnetic Calorimeter

The electromagnetic calorimeter consists of 75568 $PbWO_4$ scintillating crystals with a target inter-calibration precision of better than 0.5%.

At startup, pre-calibration will be from test beam (9 barrel supermodules at much better than 1%) and from cosmic rays (remaining 27 super-modules at 1.5% precision). The knowledge of ECAL endcaps pre-calibrations from laboratory measurements will be about 15%.

With an integrated luminosity of the order of 10pb^{-1}, inter-calibration of crystals at a constant pseudorapidity will be performed using the homogeneity in ϕ of the energy deposited in minimum bias events, and later on di-jet triggers. A minimal set of information required to feed the algorithm is extracted with a dedicated filter at the minimum bias L1 rate in the high level trigger farm. An expected intra-ring inter-calibration precision of 1-3% can be reached with O(10M) triggers.

The inter-ring calibration will be obtained using Z→ee events: 10pb^{-1} of data are sufficient to obtain a precision of 2-3%. The same dataset can also be used to determine the absolute energy scale with high accuracy. It will also be possible at this stage to profit from comparison and combination between the first in-situ values and pre-calibration.

With an integrated luminosity of $10\text{-}100\text{pb}^{-1}$ the precision reached from ϕ-symmetry will be improved upon using the mass constraint for the decay of neutral pions in two photons. To take full advantage of this technique neutral pions will be parasitically selected in the high level trigger farm and the data processed similarly to the minimum bias events. Studies performed so far indicate that a precision of 1% can be reached in the ECAL barrel.

A laser monitoring system will be employed to measure the radiation-induced transparency variation of the crystals at a level of 0.2%. However, transparency variations are not expected to be significant for luminosities less than $10^{32}\text{cm}^{-2}\text{s}^{-1}$.

1.2 Hadronic Calorimeter

The precision obtained from pre-calibration from radiation source data are expected to be around 5%.

In the initial start-up phase ($\int L < 10\text{pb}^{-1}$), channel-to-channel calibration within rings of HCAL towers will be performed using the ϕ-symmetry of event activity from minimum bias events. This is expected to give an inter-calibration precision of around 2-4%. Deconvolution of the contributions from noise and signal will be required, with noise measured separately during pedestal runs and time slices prior the signal during data taking. Isolated charged hadron tracks in QCD di-jet, minimum-bias and τ events will be used to calibrate between rings and to set the energy scale by comparing the energy measured in the calorimeters to the tracker momentum measurement. A dedicated HLT filter has been developed for this procedure. In addition, the balancing of jet energies in QCD di-jet events will be used to calibrate forward regions of the detector which cannot be calibrated using tracks.

With an integrated luminosity of between 10 and 100pb^{-1}, the energy scale for reconstructed jets will be more accurately determined using γ+jet and Z+jet events.

1.3 Inner Tracker and Pixels

Calibration of front end electronics will be performed rapidly at Point 5 using charge insertion runs between beam fills. Processing will occur online, using dedicated DAQ machines for strips, and using the HLT farm for pixels (due to the higher data volume), with constants being transfered directly to ORCON. Lorentz angle and dE/dx fine tuning will be performed using single muons and lower pt tracks from minimum bias, potentially selected using the same event filter as used for the alignment, but with strip and pixel cluster information additionally stored. A statistics of few thousand tracks per module, compatible with a 10pb^{-1} integrated luminosity, should be enough to obtain precise calibration constants.

1.4 Muon Chambers

For the barrel drift tubes, interchannel synchronization will be rapidly performed using test pulses during the machine abort gap. Time pedestals and drift velocity will then be calibrated, for each SuperLayer, using single muons selected using the same filters as used for muon alignment. 10pb^{-1} of minimum bias data using the trigger path of single muons which is expected at 10^{32}cm^{-2}s^{-1} is sufficient to perform this calibration.

Calibration of the endcap CSC front end electronics will be performed rapidly at Point 5 using test pulse signals between beam fills. Processing will occur online using using dedicated DAQ machines, with constants being transfered directly to ORCON.

2 Alignment Strategy for LHC Startup

2.1 Tracker

Build and survey information provide already relatively precise information in advance of the LHC machine startup, in particular regarding positions of detector modules relative to the higher level structures (e.g. rods and petals), though these numbers vary across the different sub-detector parts. The higher level structures are expected to have remaining misalignments roughly of the order of 500 μm. One month of cosmics running is expected to deliver about 10 million alignment tracks for the tracker, with about 35000 passing the pixel tracker. This will mainly benefit the alignment of the larger structures of the barrel detectors. Since cosmic muons cover a relatively narrow range of track angles, the improvement of the rod alignment will depend on the azimuth angle of the rod, and can be expected to reach a level of about 200–500 μm. For the same reason, cosmic muon samples by themselves have very limited power in resolving systematic distortions of the internal alignment, attributed to so-called weakly defined modes. The tracker end cap disks are expected to benefit from the measurements of the laser alignment system, which has an intrinsic resolution at the level of 100 μm. It is therefore expected that the initial alignment of the tracker higher level structures will be at least at a level of about 200–500 μm along the directions of measurement at the startup of luminosity operation.

As soon as the machine can operate with sufficiently low background, initial running even at rather low luminosity (e.g. 10^{28} cm^{-2}s^{-1}) should give access to millions of pileup-free minimum bias events within a few days, which can be used to improve the alignment of the tracker for higher level structures, and will in particular provide the pixel tracker with a first track sample of large statistics. This will also have an important effect on the relative alignment of barrel and end caps. Much depends however on a thorough understanding of the tracking itself. At about 10 pb^{-1}, a sample of roughly 200000 J/Ψ decays will permit detailed performance studies and allow for optimization of the tracking procedures, which will in turn improve the input to the alignment algorithms. One can expect that the alignment of the higher level structures will improve typically to the order of 100 μm.

With large samples of tracks from minimum bias events, also access to module level may be possible and lead to a further reduction of hit residual spreads. The LHC beam line constraint may be helpful. However, addition of event types with different track topology, as cosmics and halo muons, is prerequisite to overcome systematic limitations from weakly defined modes. At several 100 pb^{-1} finally, significant numbers of Z^0 decays to muon pairs will become available, and besides being a clean source of tracks with large transverse momentum, they provide additional mass and vertex constraints, which in combination with other event types will provide the means to improve the module alignment towards the design level.

2.2 Muon System

The initial alignment of drift tube and cathode strip chambers relative to wheels and disks from quality control measurements and photogrammetry without magnetic field, is known at precisions of about 500 μm over short distance scales, and about 1 mm at large scales. Powering of the magnet with the closed detector, however, is known to change the geometry in particular in longitudinal direction: the end cap disks have been seen to bulge by up to 14 mm in the magnet test, while the effect in the barrel is below the mm-level. For the rϕ direction of the barrel, generally much smaller movements than in Z have been observed. Several weeks of collecting cosmic muons will play an important rôle in improving the internal alignment in the barrel, while for the end caps, beam halo muons from early running are expected to have a similar effect. The optical alignment system measures and monitors the positions of muon stations at a precision of about 200–350 μm in rϕ, depending on the position, and about 1 mm in Z (possibly better as indicated by first measurements). This system will will in particular give an accurate picture of the stability of the geometry versus time, and can help considerably in defining the geometry before the first collision data. Cosmic and halo muons will also provide some degree of track-based alignment of the chambers relative to the wheels and disks.

Alignment with tracks from proton-proton collisions will rely largely on muons of high transverse momentum from Z and W decays and other QCD origins. At low integrated luminosity, less than a thousand of such muons will already permit a rough alignment of wheels and end cap rings, approximately at about 1 mm for translational and 0.3 mrad rotational precision in the transverse plane. The initial 10 pb^{-1} of integrated luminosity will result in a first detailed absolute alignment of the individual chambers. A further significant increase of statistics will also allow checking the precise alignment at the superlayer and layer levels. As with the tracker, weakly defined modes pose a potential systematic limitation also for the muon system, and the combination of track-based alignment with survey and optical alignment system measurements is important to overcome this issue.