draft 20161004

Draft of possible answers to the calibration questions for the ILD TPC,

based on the experience at LEP

Introduction

The document 'Questions on Subdetector Calibration and Alignment' by the ILD Executive Team written on 27 July 2016 contains the following explanation. "ILD needs to make progress on understanding the needs for calibration and alignment of the various subdetectors. This has come into focus recently in the context of the request from the ILC Parameters Group to better understand the need for Z running for calibration. We have prepared a response on the Z running issue that is focussed on the relative merit of some running at the Z for calibration and alignment. The draft document has been distributed separately on 18th July. It does not deal much with exactly how much data is needed to adequately calibrate and align the detector. We would like to request input from the subdetector groups on the following questions that are important for evaluating the overall minimal calibration and alignment requirements for ILD."

1 Calibration types

The following excerpt is from Graham Wilson's and colleagues' draft with the title 'Z Running for Calibration and Alignment', written on 5 September 2016, to be submitted by the ILD Detector Concept team to the ILC parameters group.

"There are a number of issues that belong under calibration:
-Inter-calibration of individual detector elements. This channel-to-channel relative calibration is primarily a statistical issue.
-Alignment of all sub-detectors both internally and with respect to each other. This is of central importance for the tracker.
-Absolute energy and momentum scales.
-B-field measurements.
-E, B-field effects / distortions.
-Gas parameter measurement and monitoring (mixture, T, P, dE/dx, drift velocity, t0).
-Monitoring of long-term calibration/alignment.
-Fragmentation tuning."

These will be referred to later, in section 3

2 The questions

The questions asked in the document described in the Introduciton above are:
1. Outline the strategy for alignment and calibration of your subdetector?
2. What calibration and alignment parameters need to be measured with particles (either from collisions or cosmics) for your subdetector?
3. What precision is needed on the calibration and alignment parameters for your subdetector? What is the basis for this assessment?
4. How many usable particles per sub-detector element are needed to establish the calibration

and alignment constants at the above level of precision?
5. What particles and kinematic criteria are needed?
6. What is the smallest solid-angle subtended by an individual sub-detector element?
7. Does your subdetector plan to use power-pulsing?
8. Are cosmics useful for the alignment/calibration of your sub-detector?
9. Are beam halo muons useful for the alignment/calibration of your sub-detector?
10. If power-pulsing is used, what is the effective live-time percentage?
11. Is data with the magnetic field off needed for your sub-detector?
12. On which time-scales do you anticipate that the alignment and/or calibration of your sub-detector will be stable? In particular would it be reasonable to assume that data collected over multiple running periods in multiple years can be used collectively to refine the overall calibration or alignment?
13. Do you foresee particular challenges in the alignment and calibration of your subdetector?

3 Experience at LEP, in Aleph, Delphi and Opal

The word "calibration" below will refer to both alignment and calibration. Procedures similar to those cited here can be used by the ILD TPC.

First, a general comment. As seen from the list of types of calibrations (section 1, there are several, each with errors on the calibration parametery. Z-pole running offers, with its well known energy (e.g., two back-to-back 45 GeV muons from Z→ $\mu\mu$-decays) a perfect alignment constraint, which can be used to reduce the overall uncertainties. The Z running data was also used for the other Aleph, Delph and Opal subdetectors, but mainly the TPC information will be described here.

Aleph

Werner Wiedenmann (CERN/Atlas), one of the main developers of the methods cited here, wrote: 'Muon pairs from Z decays with its kinematic constraints provided a unique reaction to measure residual distributions in the TPC directly with data.' Werner's slides https://wiedenma.web.cern.ch/wiedenma/TPC/Distortions/Cern_LC.pdf contain many more details than can be covered in this note.

The initial basic calculations were done using a few thousand Z→ $\mu\mu$-pairs from from the first run periods at Lep1. Later, at Lep2, corrections to the basic parameters were obtained by fitting them to about one thousand Z→ $\mu\mu$-pairs from the Z-pole running for calibration.[1]

Delphi

In Delphi (also having a TPC as main tracker) the methods used were very similar to the ones in ALEPH, using the mu-pairs collected from Z running. In addition, a common UV laser system for the Inner Detector Jet chamber and the TPC was developed, but abandoned in the case of the ID, using instead the extrapolations from the nearby Vertex Detector.[2] For the TPC the 2×6 laser rays, one at a fixed position in each of the sectors, parallel and close

[1] Also, the Aleph TPC had a laser system, which was used for monitoring various parameters, but ended up not being used for alignment.

[2] A word about the Delphi Vertex Detector, which had 3 layers, so not only the overlap regions of the different phi-sectors, but the whole sector surfaces could be used to constrain the internal alignment of the VD, where in the latter case also isolated 3-hit tracks from hadronic Z decays were used.

to the anode (readout) plane, were reflected at the outside radius back to the inner radius, close to the central cathode. In this way, every cathode pad and anode wire detected two hits, from which a very precise determination and monitoring of the drift velocity could be done, to better than 2×10^{-4}.

Opal

The Opal Jet Chamber was clearly a much more complicated detector than ILD-TPC. The Jet Chamber operated at 4 bars in a 0.435T solenoid as a main tracking detector. The Jet Chamber had 24 rϕ sectors separated by planes of cathode wires. Each sector had 160 anode wires parallel to beam axis, with length varying from 3.4m at 26 cm inner radius to 4.1m at outer radius of 1.8 m.

Calibration and alignment were done with Z events at startup. Cathode crossing tracks were used to monitor drift velocity and time offsets during normal running. Drift velocity and Lorentz angle could be determined with a statistical error of 0.01% and 0.1% with these events. Laser calibration/monitoring events were also injected at a rate of 0.04 Hz interleaved with physics events during normal running. During LEP Phase II, the machine energy eventually reached 209 GeV, and each new running period started with Z running for experiments to check calibration and alignment.[3]

3.1 Answers to the questions

1. Outline the strategy for alignment and calibration of your subdetector.
$\Longrightarrow$The initial calculations were done using Z$\rightarrow$ $\mu\mu$-pairs from Lep1. Later, at Lep2, corrections to the parameters were obtained by fitting them to Z$\rightarrow$ $\mu\mu$-pairs from the Z-pole running for calibration.

2. What calibration and alignment parameters need to be measured with particles (either from collisions or cosmics) for your subdetector?
$\Longrightarrow$Aleph: the parameters for the initial calibration, included:
-alignment of the sectors, endplates, global position,
-B-field corrections due to the compensating power supplies of the magnet and to the permeability differences in the endcap iron for the Hcal,
-electric field corrections,
-corrections for the electronic t_0 of the sectors. For the alignment there were about 195 parameters, for the E-field about 60, and for the B-field about 20, for the t_0 about 36. In total, there were about 300 parameters.

Delphi: Methods used for the TPC were similar to the ones used in Aleph.

Opal: There were a total of about 4000 anode wires. OPAL needed to measure and monitor several parameters accurately: Lorentz angle, drift velocity, time offsets, and space time relationship in the Jet Chamber cells.

[3] OPAL also used Nd:YAG lasers situated outside the detector for monitoring. In the centre of each of the 48 half-sectors, parallel laser beams with a spacing of 10 mm in the rϕ plane were injected through quartz windows. Sectors were selected using moveable mirrors outside the Jet Chamber. The beams originated from both sides. Complete laser scans are performed during LEP shut downs.

3. What precision is needed on the calibration and alignment parameters for your subdetector? What is the basis for this assessment?
$\Longrightarrow$Referring to Aleph, after the calibration, the systematic displacements (for example of the muon momentum) from the desired behaviour were smaller than a percent or two. It is not easy to make a general statement about the accuracy of the fits on the individual 300 parameters, but this translates to a several percent accuary on each of them.

4. How many usable particles per sub-detector element are needed to establish the calibration and alignment constants at the above level of precision?
$\Longrightarrow$As mentioned above, about 1000 Z$\rightarrow \mu\mu$-pairs were used at Lep2.

5. What particles and kinematic criteria are needed?
$\Longrightarrow$Z$\rightarrow \mu\mu$-pairs from the Z-pole running.

6. What is the smallest solid-angle subtended by an individual sub-detector element?
$\Longrightarrow$About 2 millisteraradian.

7. Does your subdetector plan to use power-pulsing?
$\Longrightarrow$Yes.

8. Are cosmics useful for the alignment/calibration of your sub-detector?
$\Longrightarrow$Yes, for alignment for other sub-detectors.

9. Are beam halo muons useful for the alignment/calibration of your sub-detector?
$\Longrightarrow$Yes, for alignment with other sub-detectors.

10. If power-pulsing is used, what is the effective live-time percentage?
$\Longrightarrow$About 1 per cent.

11. Is data with the magnetic field off needed for your sub-detector?
$\Longrightarrow$In principle, yes, for disentangling E- and B-field effects, and, yes, for the alignment with the other sub-detectors.

12. On which time-scales do you anticipate that the alignment and/or calibration of your sub-detector will be stable?
$\Longrightarrow$During the time between major changes.

In particular would it be reasonable to assume that data collected over multiple running periods in multiple years can be used collectively to refine the overall calibration or alignment?
$\Longrightarrow$Yes, as explained above in the answer to quesion 1.

13. Do you foresee particular challenges in the alignment and calibration of your subdetector?
$\Longrightarrow$The above description presents a catalog of the various challenges.