Performances of the small ILD

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Abstract

ILD (International Large Detector) is a system of particle detectors which is being developed for the ILC (International Linear Collider). ILD combines excellent tracking and finely-grained calorimetry systems. This gives ILD the ability to reconstruct the energy of individual particles, known as the Particle Flow approach. The precision that can be achieved by ILD is ideal for studies in particle physics which call for accurate measurements of particles and their properties.

The ILD Optimisation group is concerned with optimizing the overall design of the detector and important beam parameters in view of the physics requirements.

The purpose of this project was to check the performances of a new ILD whose TPC outer radius is 1460 mm, which is smaller than the standard one.

Contents

1 Introduction

In this report the performances of a new ILD will be discussed. Figure 1 shows a schematisation of the ILD concept, which is meant to provide the following components [1]:

- a multi-layer pixel-vertex detector (VTX), with three super-layers each comprising two layers;
- a system of strip and pixel detectors surrounding the VTX detector. In the barrel, two layers of Si strip detectors (SIT) are arranged to bridge the gap between the VTX and the time projection chamber. In the forward region, a system of Si-pixel and Si-strip disks (FTD) provides low angle tracking coverage;
- a time projection chamber (TPC);
- a system of Si-strip detectors, one behind the end-plate of the TPC (ETD) and one in between the TPC and the electromagnetic calorimeter (SET). These provide additional high precision space points;
- a highly segmented electromagnetic calorimeter (ECal);
- a highly segmented hadronic calorimeter (HCal);
- a system of high precision calorimetric detectors in the very forward region (LumiCal, BeamCal, LHCal) to extend the calorimetric coverage to almost 4π, measure the luminosity and monitor the quality of the colliding beams;
- a large volume superconducting coil surrounding the calorimeters, thus creating an axial B-field;
- an iron yoke, instrumented with scintillator strips or RPCs, returning the magnetic flux of the solenoid and, at the same time, serving as a muon filter, muon detector and tail catcher;
- a sophisticated data acquisition (DAQ) system which operates without an external trigger, to maximise the physics sensitivity.

The new ILD (ILD_s1_v01) is meant to differ from the previous version in a smaller TPC outer radius. Its main parameters, expressed in mm, are listed in Table 1.
The performances of this "small" detector were checked through the new release v01-17-10 of the ILC software. Three main steps were followed:

- validation of the simulation and digitisation in the calorimeters;
- validation of the simulation and reconstruction in the tracking system;
- checking the detector energy resolution performance.

List of envelope parameters for ILD_s1_v01					
Detector	Inner radius	Outer radius	Half length Min.z, Max.z[1]	Additional parameters	
VXD	16.0	60.0	177.6	VXD_cone_min_z VXD_cone_max_z VXD_inner_radius_1	80.0 150.0 24.1
FTD	25.1	328.9	2350.0	FTD_outer_radius_1 FTD_outer_radius_2 FTD_min_z_0 FTD_min_z_1 FTD_min_z_2 FTD_cone_min_z FTD_cone_radius	152.8 299.7 177.7 368.2 644.2 230.0 184.1
SIT	152.9	324.6	644.1	SIT_outer_radius_1 SIT_half_length_1	299.8 368.1
TPC	329.0	1460.0	2350.0		
SET	1460.1	1479.9	2350.0		
ECal barrel	1495.0	1680.0	2350.0	ECal_symmetry[2] ECal_HCal_symmetry	8 8
ECal endcaps	400.0	1740.8	2450.0, 2635.0	ECalEndcap_symmetry	8
ECal endcap rings	250.0	390.0	2450.0, 2635.0	ECalEndcap_symmetry	8
HCal barrel	1710.0	3040.7	2350.0	HCal_inner_symmetry	8
HCal endcaps	350.0	3040.7	2650.0, 3937.0		
HCal endcap rings	1790.8	2809.3	2450.0, 2635.0	HCalEndcapRing_symmetry	8
Coil	3070.2	3820.2	3872.0		
Yoke barrel	4424.0	7725.0	4047.0	Yoke_symmetry	12
Yoke endcaps	300.0	7725.0	4072.0, 7373.0	YokeEndcap_symmetry	12

[1] "Min.z" and "Max.z" are, respectively, the positive z-coordinates of the beginning point and the end point of the subdetector at issue, computed with respect to the origin of x, y and z axes. This is the center of symmetry of the whole detector (see Figure 1).

[2] "Symmetry" refers to the shape of the subdetector at issue (e.g. 8 stands for "octagonal").

YokeEndcapPlug	300.0	3040.7	3981.5, 4072.0	YokeEndcapPlug_symmetry	12
BeamCal	20.0	150.0	3475.0, 3695.0	BeamCal_thickness BeamCal_tubeIncoming_radius	220.0 15.0
LHCal	100.0	325.0	2680.0, 3200.0	LHCal_thickness	520.0
LumiCal	80.0	195.2	2500.0, 2630.7	LumiCal_thickness	130.7

Table 1: List of envelope parameters for the "small" ILD. Further information can be found in [1] and [2].

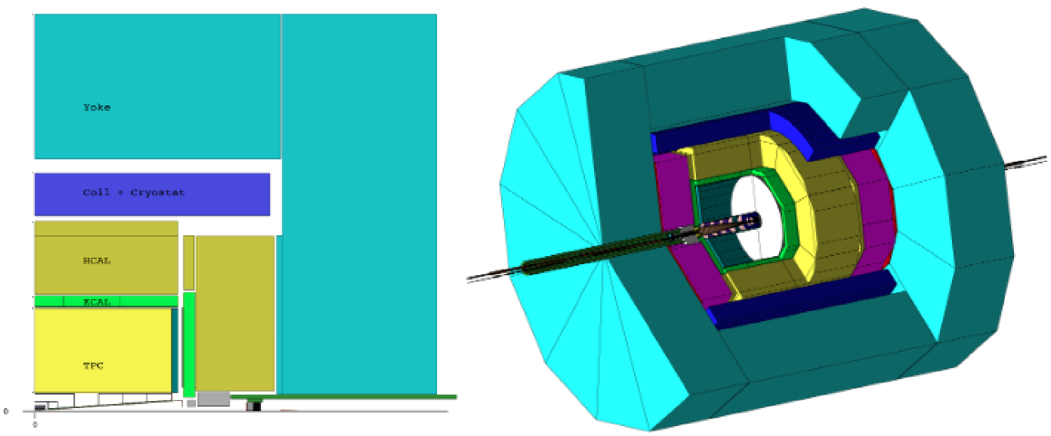

Figure 1: Schematization of the ILD concept. From the inside to the outside, the detector components are the: VTX, SIT, TPC, SET, ECal, HCal and Yoke. In the forward region the FTD, ETD, LumiCal, LHCal and BeamCal are shown.

2 Validation of the simulation module ILD_s1_v01

The purpose of this step was to check the results from the simulation of high energy events in the small version of the ILC detector. This validation was accomplished both for the calorimeter and the tracking system. The latest includes all the subdetectors from the VTX to the ETD and the SET.

2.1 Calorimeters

The spatial coordinates of the simulated hits cannot exceed the size of the subdetectors where the hits happen. In other words, the digitisation information must be in agreement with the detector parameters shown in Table 1. In order to accomplish this validation for the calorimeters system, one-thousand $Z \longrightarrow uds$ generated MC events of energy 500 GeV were simulated in the ILD small model, and then reconstructed with Marlin using the processor named "validationProcessor". The source code of the processor was updated by implementing an algorythm which returned the digitisation information. To validate the simulation the following subdetectors were taken into account:

- ECal (barrel, endcaps and endcap rings);
- HCal (barrel, endcaps and endcap rings);
- Yoke (barrel and endcaps);
- LumiCal;
- BeamCal;
- LHCal.

The digitisation information got from the events simulation and reconstruction is shown in Table 2. All the parameters are expressed in mm.

Validation of simulation for ILD_s1_v01 - Calorimeter part				
Detector	Min.r	Max.r	Positive Min.z, Max.z	Negative[3] Min.z, Max.z
ECal barrel	1502.5	1809.1	3.0, 2343.9	-3.0, -2343.9
ECal endcaps	405.0	1860.8	2457.5, 2623.4	-2457.5, -2623.4
ECal endcap rings	246.8	546.4	2457.5, 2623.4	-2457.5, -2623.4
HCal barrel	1731.6	3015.6	30.2, 2334.8	-30.2, -2334.8
HCal endcaps	377.7	3162.2	2671.5, 3917.0	-2671.5, -3917.0
HCal endcap rings	1800.3	3025.4	2465.0, 2597.5	-2465.0, -2597.5
Yoke	4470.5	7937.1	30.0, 4048.0	-30.0, -4048.0
Yoke endcaps	283.0	7865.6	4193.5, 6653.5	-4193.5, -6653.5
LumiCal	61.6	213.4	2502.4, 2631.4	-2502.4, -2631.4
BeamCal	11.3	171.9	3577.6, 3695.7	-3577.6, -3695.6
LHCal	94.3	452.6	2690.6, 3197.6	-2690.6, -3197.6

Table 2: Digitisation information for the ILD_s1_v01 calorimeters.

Comparing Table 1 with Table 2, it can be observed, for instance, that ECal barrel Max.r is greater than ECal barrel outer radius. This can be explained by Figure 2,

[3] "Min.r" and "Max.r" refer, respectively, to the minimum and the maximum radius coordinates of the simulated hits. "Positive Min.z, Max.z" and "Negative Min.z, Max.z" refer, respectively, to the minimum and the maximum positive and negative z-coordinates of the simulated hits.

which shows the way the outer radius and Max.r are defined. The same occurs for other subdetectors.
Looking at Max.z of Yoke, LumiCal and BeamCal and at Min.r of ECal endcap rings, Yoke endcaps and LHCal (Table 2), it looks like they are not in agreement with the respective envelope parameters in Table 1. Nevertheless, in the events reconstruction the validationProcessor used the information contained in a gear file, in which the subdetectors at issue are implemented in such a way that they are composed of elementary squared cells, which have a limited size. In particular, the size is about 5.1 mm for the ECal endcap rings, 30 mm for the Yoke, 10 mm for the LumiCal and LHCal, and 3.5 mm for the BeamCal. As the digitisation returns the value of the cell center coordinates, it can happen that these ones are greater than the coordinates of the subdetectors boundaries.

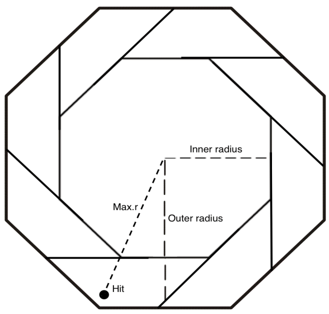

Figure 2: The furthest hit from the center of the subdetector at issue may be greater than the subdetector outer radius.

The last values which seem not to be in agreement with the detector geometry are the LumiCal and the BeamCal Min.r. This can be explained by taking into account the spatial placement of the detector in the global coordination system, where the center with respect to which the hits distances are computed can be different from the center of the detector. This concept is better explained in Figure 3 [4].
The validationProcessor created numerous histograms in root showing the displacement of the hits in all the ILD calorimeters. From these histograms, it was possible to observe the structure of the calorimeters and to see their high granularity, which is one of the ILC main requirements. For example, the ECal barrel part is composed of 8 staves and 5 modules. Each module is composed of 5 towers, and each tower is composed of 30 layers made of pixels called "wafers". Each wafer is a structure of 18x18 sub-pixels (or cells).
Figure 4 schematizes the structure of the ECal, while in Figure 5, Figure 6 and Figure 7 there are some histograms showing the displacement of the hits respectively in the ECal barrel overall structure, in the ECal barrel layers and in the ECal barrel wafers.

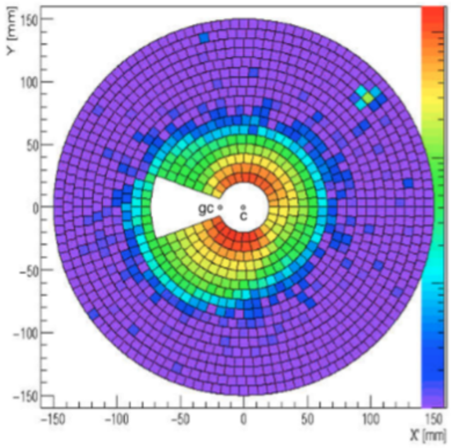

Figure 3: The center "c" of the detector can be different from the center "gc" with respect to which the hits distances are computed in the global coordination system.

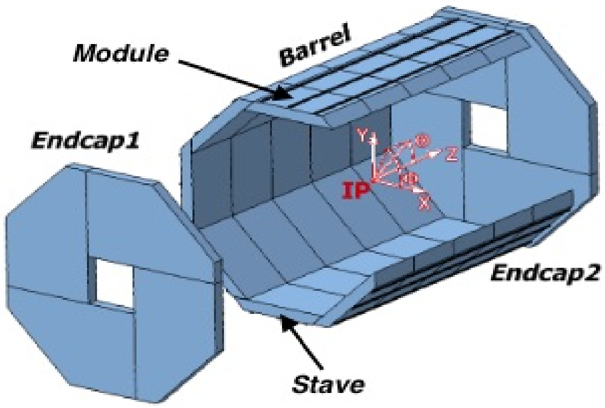

Figure 4: Structure of the ECal.

2.2 Tracking system

In order to check the performances of the small ILD tracking system, the interaction of single generated MC charged particles with the detector was simulated. The particles momentum was chosen to be any of the following values: 1 GeV, 3 GeV, 5 GeV, 10 GeV, 15 GeV, 25 GeV, 50 GeV, 100 GeV. The ejection polar angle of the particles with respect to the origin of the z-axis was chosen to be any of the following values: 10 degrees, 20 degrees, 40 degrees, 85 degrees. After reconstructing the events with the ILDConfig environment, for each combination between the above values of momenta and polar angle, the pull distributions were built for each of the following track parameters: the track curvature ω, the azimuth angle ϕ, the tangent of the polar angle tanλ, the distance z0 from the $e^- - e^+$ beams interaction point along the z-axis and the distance d0 from the $e^- - e^+$ beams interaction point along

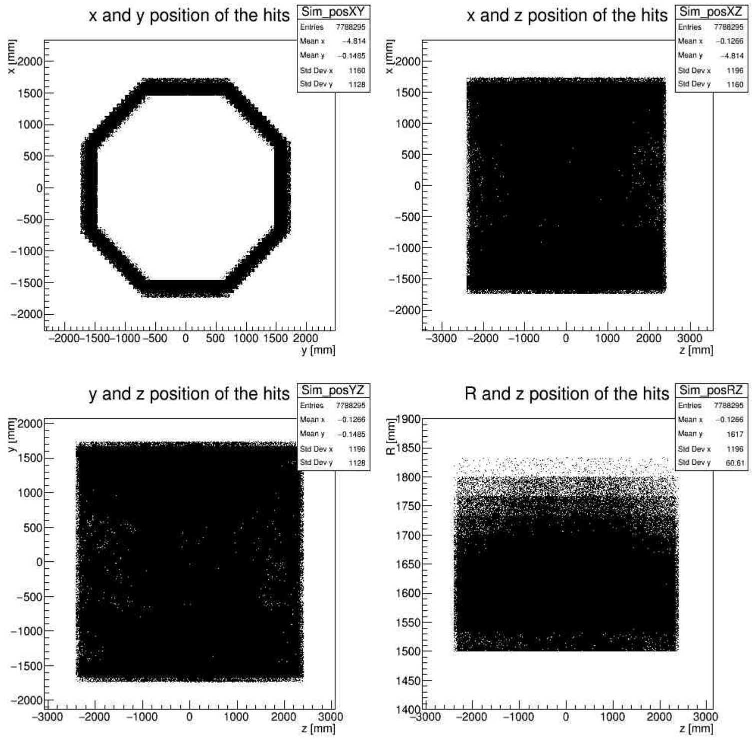

Figure 5: Hits in the ECal barrel system.

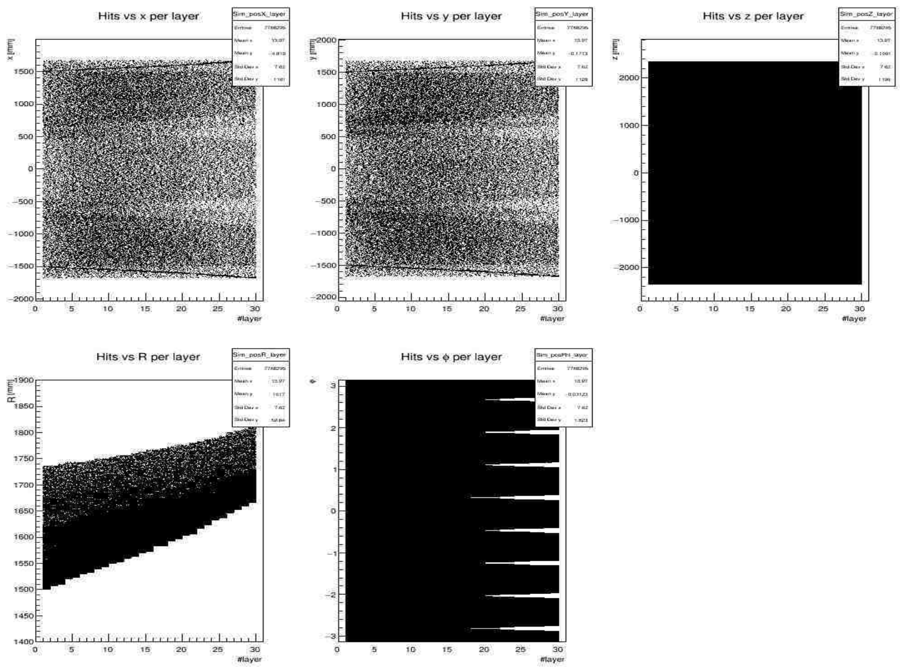

Figure 6: Hits in the ECal barrel layers.

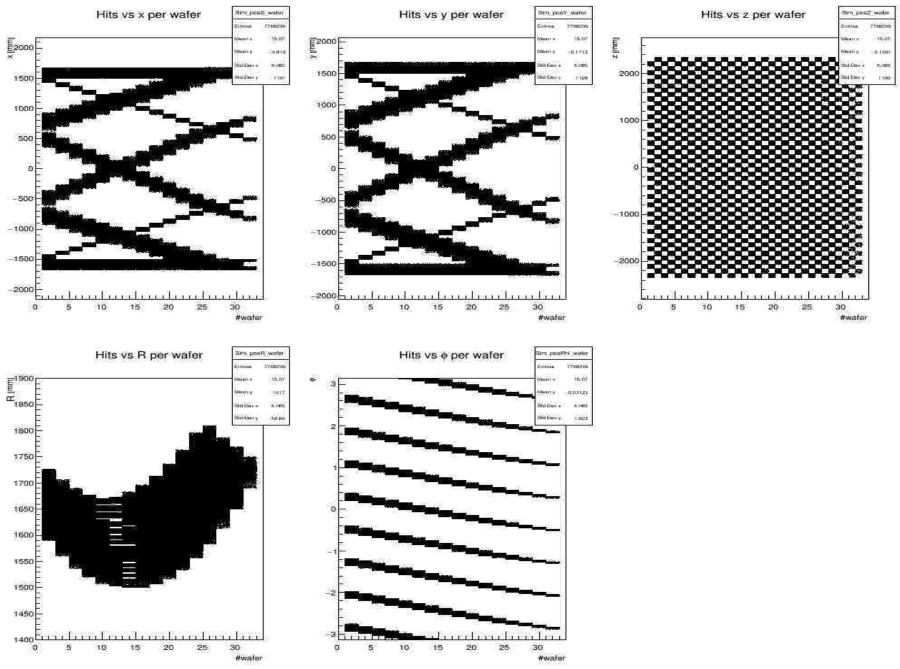

Figure 7: Hits in the ECal barrel wafers.

the ϕ - r plane. Figure 8 shows the pulls for a 10 degrees and 100 GeV momentum particle, while Figure 9 shows the pulls for a 85 degrees and 5 GeV momentum particle. Each pull was fitted with a gaussian curve.
While the pulls in Figure 8 show a mean close to 0 and a sigma close to 1 as expected, the pulls in Figure 9 show a mean and a sigma far from the expected values, and some of those pulls follow a distribution which cannot even be fitted with a gaussian curve.
The simulation of the same particles was tried again changing the parameters of the ILD to the following values:

1) TPC outer radius = 1808.0 mm, B-field nominal value = 3.5 T along z-axis (which are the parameters of the ILD_o1_v05 standard model);

2) TPC outer radius = 1700.0 mm, B-field nominal value = 3.5 T along z-axis.

In the first case, the reconstruction returned pulls whose mean and sigma were in agreement with the expected values, while in the second case the pulls mean and sigma were completely in disagreement with the expected ones. It turned out that the reconstruction does not work properly when the parameters of the ILD standard version are changed.

3 Small ILD energy resolution

The final step of this project was to compute the ILD_s1_v01 energy resolution. In order to do this, ten-thousand $Z \longrightarrow uds$ generated MC events of energy 91 GeV, 200 GeV, 360 GeV and 500 GeV were simulated in the ILD small model, and then

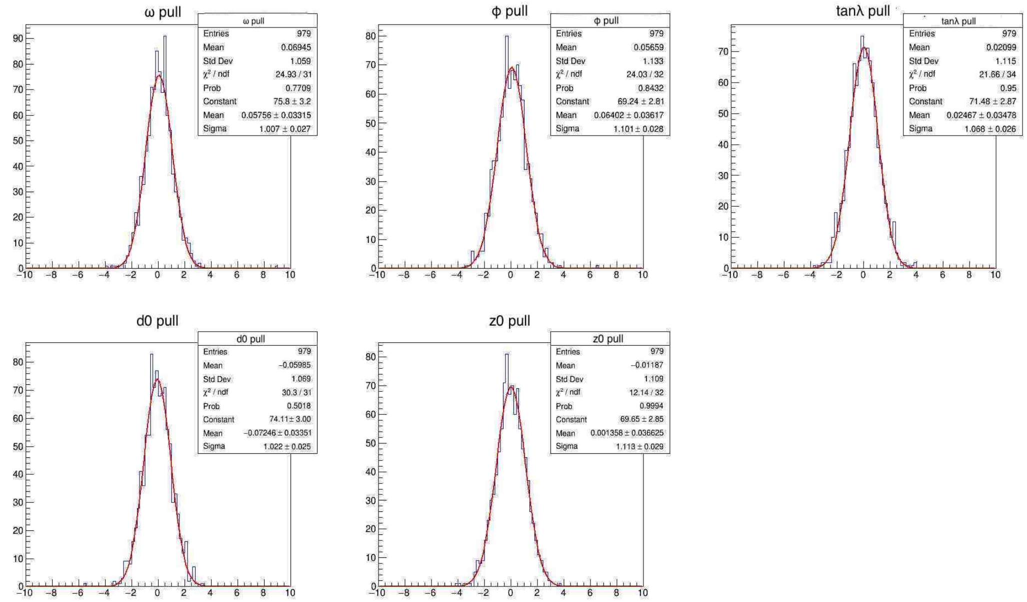

Figure 8: Pulls for a 10 degrees and 100 GeV momentum particle.

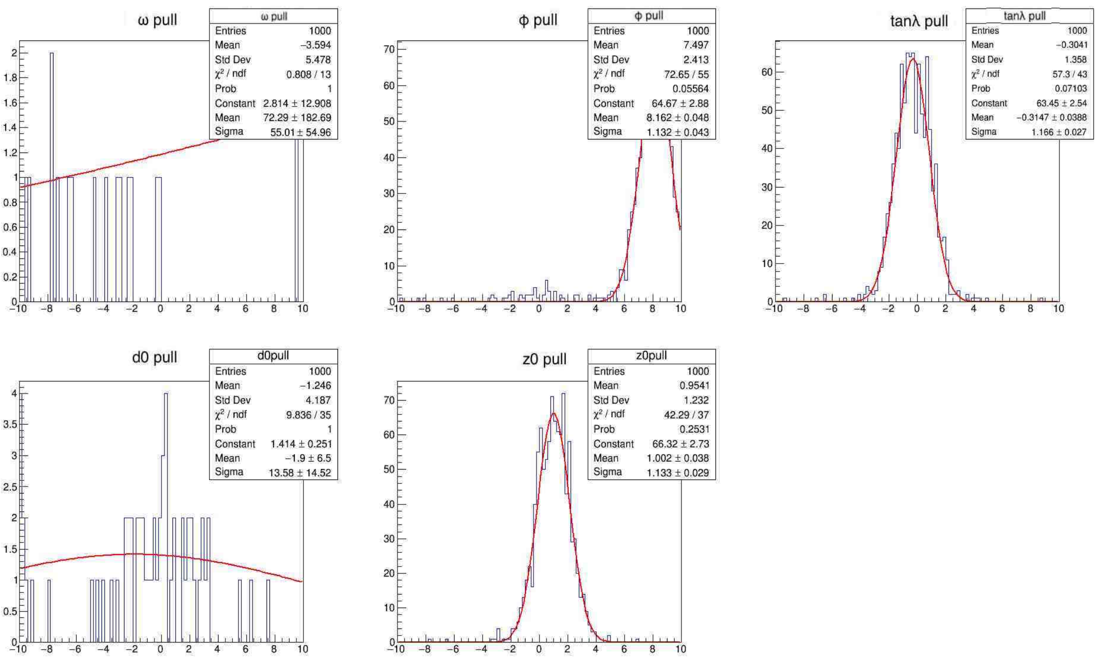

Figure 9: Pulls for a 85 degrees and 5 GeV momentum particle.

reconstructed with Marlin using the ILDConfig processors. For each energy value, the resolution was computed using Pandora PFA (Particle Flow Algorythm [3]), taking into account two classes of events:

1) all the hits in the whole detector;

2) hits in the ILD barrel part (briefly named L7A hits).

The results are shown in the plot in Figure 10. The plot clearly shows how the resolution improves if not taking into account the hits in the ILD endcaps. Nevertheless, the energy resolution was got by taking into account the information from the tracking reconstruction as well. Then, the plot shown in Figure 10 needs to be updated after solving the issues found in the tracking reconstruction, as well as changing the calorimeters calibration constant.

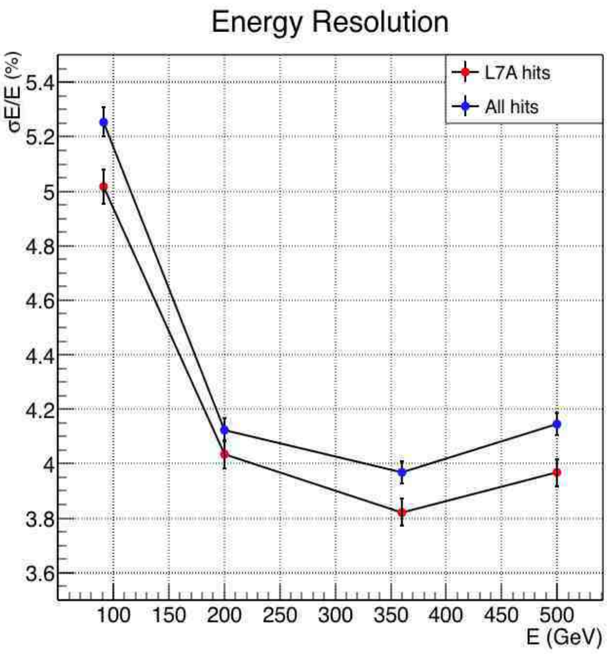

Figure 10: ILD small detector resolution computed using the information from all the hits (in blue) and from the hits in the ILD barrel part (in red).

4 Summary and outlook

In this project, the performances of the ILD_s1_v01 version of the International Large Detector were checked using the new release v01-17-10 of the ILC software.

1) The digitisation information returned after simulating and reconstructing high energy events in the ILD new version is in agreement with the detector envelope parameters in Table 1 if taking into account the way the detector is

built in the gear file used for the reconstruction. The digitisation information has to be checked again after reducing the size of the subdetectors elementary cells.

2) The reconstruction of some events of single charged particles interacting with the ILD_s1_v01 tracking system returns pull distributions whose mean and sigma are not in agreement with the expected values. The reason why this happens is still unidentified, and many parameters and codes need to be checked to understand what the problem is and how to fix it.

3) The ILD_s1_v01 energy resolution improves if not taking into account the information from the high energy particles interactions with the calorimeters endcaps. Nevertheless, the resolution plot in Figure 10 needs to be updated after fixing the issues related to the tracking system and changing the calorimeters calibration constant.

References

[1] The International Large Detector - Letter of Intent. *The ILD Concept Group (February 2010). DESY 2009-87, FERMILAB-PUB-09-682-E, KEK Report 2009-6.*

[2] https://confluence.desy.de/display/ILD

[3] https://indico.in2p3.fr/event/7483/contribution/0/material/slides/0.pdf

[4] http://pubdb.xfel.eu/record/275846/files/MHabermehl_WIMPs_FCalWorkshop_Zeuthen.pdf?subformat=pdfa