CERN-SPSC-2007-027
SPSC-SR-023

Summary of the 2007 CALICE test beam at CERN

The Calice collaboration is involved in a major programme of R&D into calorimetry for the International Linear Collider (ILC). The aim of the project is to compare the performance of different technologies for electromagnetic and hadronic calorimeters in terms of ILC requirements in a common framework.

The main direction of the collaboration R&D is to study particle flow (PFA) calorimetry, software compensation and individual particle reconstruction. As such, the studies are concentrating on fine granularity calorimeters with a high degree of longitudinal segmentation. These studies include comparison of simulation models with data to measure their degree of agreement, the technical issues of building a detector optimised for PFA calorimetry, and development of algorithms for software compensation and particle flow reconstruction.

For this purpose, a very intense test beam programme is being undertaken for extensive tests of calorimeter prototypes.

Between June and August 2007 the Calice collaboration has successfully commissioned and operated a full chain of calorimeter prototypes in the H6B experimental area at the CERN SPS: electromagnetic calorimeter (ECAL), analog hadronic calorimeter (AHCAL) and tail catcher and muon tracker (TCMT) (Fig.1).

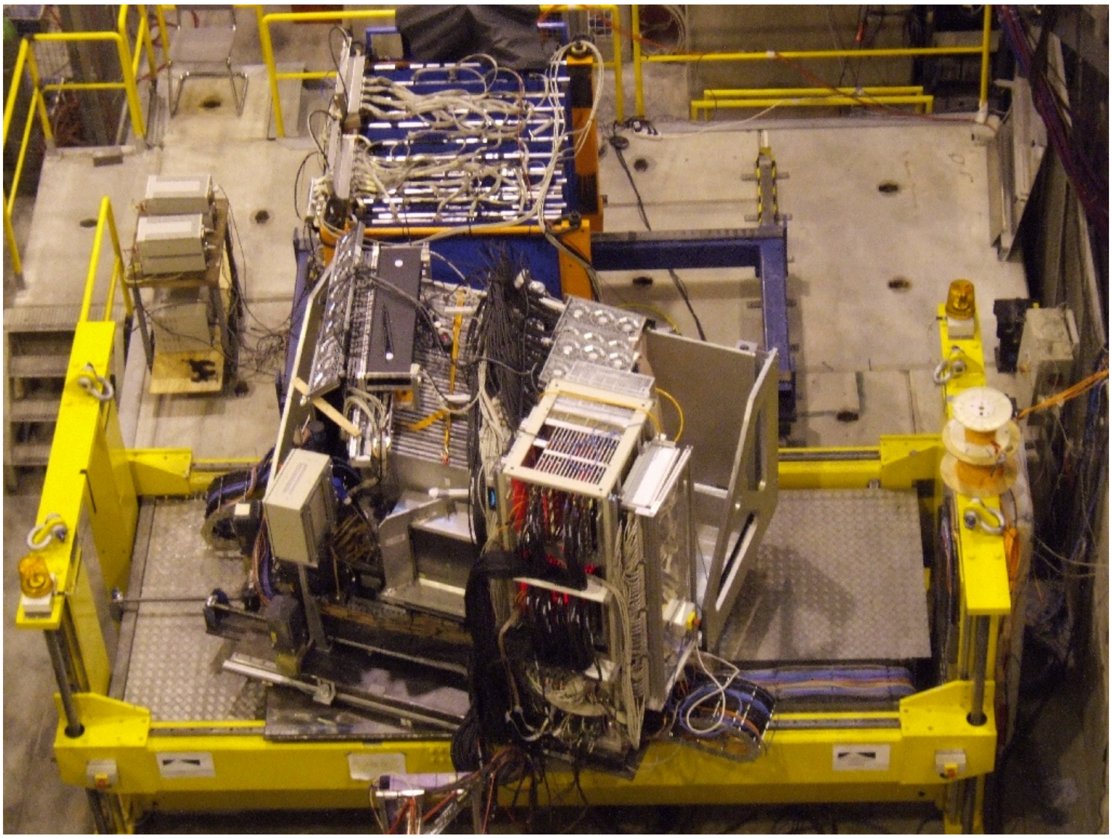

Fig.1: View of the Calice calorimeter prototypes installed in the H6B experimental area at the CERN SPS.

The beam line installation at CERN included locally provided beam detectors (multi wired proportional chambers – MWPC) and custom made scintillation detectors for the experimental trigger. A sketch of the experimental setup is shown in Fig.2.

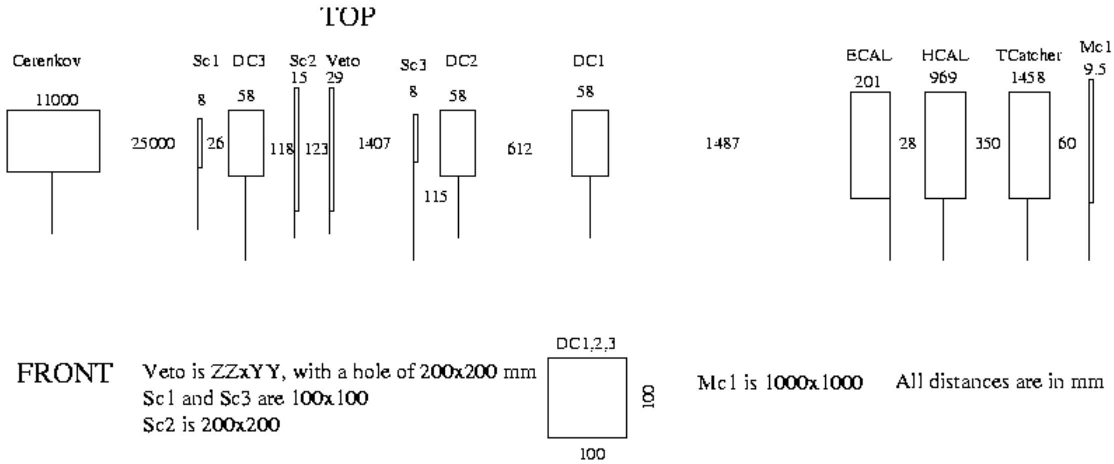

Fig.2: Sketch of the installation for the Calice test beam in the H6B area at the CERN SPS.

The trigger to the experiment is provided by the coincidence of two 10x10cm^2 scintillator plates with photo-multiplier readout. In addition a coincidence with a muon wall downstream of the detector may be used either for muon rejection or as a muon trigger during calibration. The analogue readout of an additional 20x20cm^2 scintillator plate serves as veto for events with double particles or showers initiated in the material upstream of the detector. In order to tag the halo of the beam, an additional 100x100cm^2 scintillator with a 20x20cm^2 hole has been employed as an outer veto. All triggers are digitized and recorded event by event by the VME-based data acquisition (DAQ), and can be used offline for data selection. A threshold Cherenkov counter filled with helium gas has been used to discriminate electrons from pions, in the range 6-20 GeV. The same detector has also been used with nitrogen gas in order to discriminate pions and protons in the range 30-80 GeV. The gas pressure in the 11m long Cherenkov vessel needs to be adjusted depending on the beam energy. With optimal settings, efficiencies of 90% are obtained, going to 30 % with increasing energy. The discriminated Cherenkov signal is recorded as a trigger bit.
For particle tracking, three sets of delay multi-wire proportional chambers provided by CERN have been included in the CALICE DAQ. Three pairs of x and y planes with two wires each are read out for each event by a TDC implemented in the DAQ. The spatial resolution of the tracking system is better than 200μm.

Three calorimeter prototypes have been commissioned on the beam line.
The ECAL was equipped with 30 sensitive layers of silicon pads, corresponding to a total of 54 PCBs. The total number of readout channels was 9072, corresponding to 216 channels/PCB in the central part of the detector and 108 channels/PCB in the bottom part. The total radiation length of the prototype is $24X_0$.
A total of 38 fully commissioned modules of the AHCAL were installed on the beam line; 30 modules with fine granularity (216 scintillator tiles) and 8 modules with coarse granularity (141 tiles) were present. Each tile is readout by a silicon photo-multiplier (SiPM), for a total of 7608 readout channels. The total interaction length of the AHCAL prototype is 4.5λ.

The TCMT was completely installed with all 16 active layers fully instrumented and a total of 320 readout channels.
The system, with more than 16000 channels and an acquisition rate capability of 120 Hz (see Fig.3), is a compact HEP experiment in itself.

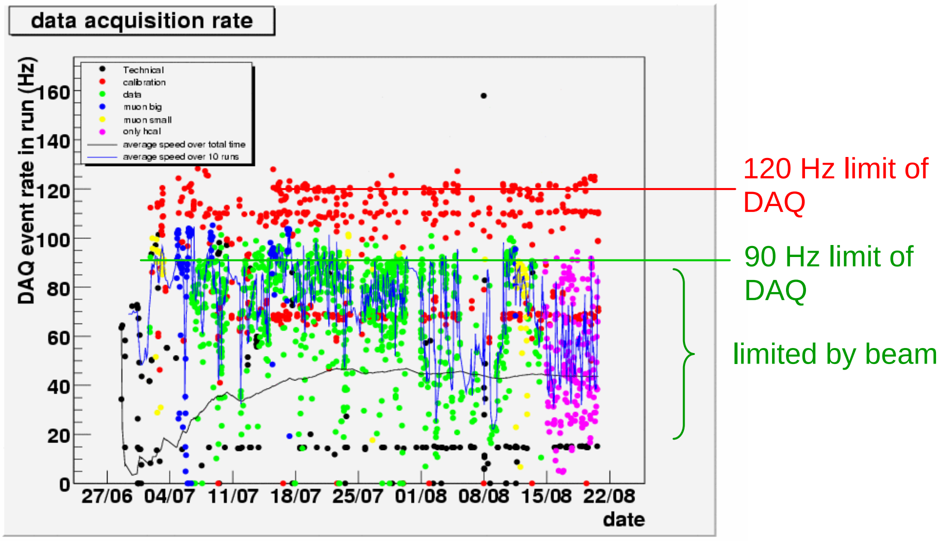

Fig.3: Data acquisition rate for the 2007 Calice test beam at CERN. The average acquisition rate (black line) is ~50 Hz.

During the data taking period, the CALICE detectors had more than 90% up-time, with a beam duty cycle estimated to be about 60% (see Tab.1). The SPS up-time has been excellent, and the beam was available for almost 80% of the total test beam time (7 weeks), as summarized in Tab.1.

Time since 5th of July	4 147 200 sec
14.4s super-cycle	2 389 798 sec
16.6s (20.4s) super-cycle	889 829 sec
Power cuts	86 400 sec
Summer students	57 600 sec
p/e/p data	1 790 698 sec
muons (100x100)	153 976 sec
muons (20x20)	131 752 sec
AHCAL only	365 195 sec
Calibration	318 447 sec
SPS uptime	79.1%
Beam controlled by H6B	76.1% (96.2% of uptime)
DAQ on beamData	62% (81.5% of beam in H6B)
DAQ on calibration	15.1%

Tab.1: Summary of the total data taking time for the 2007 Calice test beam at CERN.

The performance of all beam-line detectors as well as that of the 3 calorimeter prototypes has been monitored online during data taking. A special fast analysis tool has been developed to access in real time the relevant beam and detector qualities. This incredible success for the collaboration was only possible thanks to the combined effort of all the institute members. More than 50 physicists have shared shifts at CERN (see Fig.4). Experts in place and on-call have been permanently available during the three months of commissioning and running.

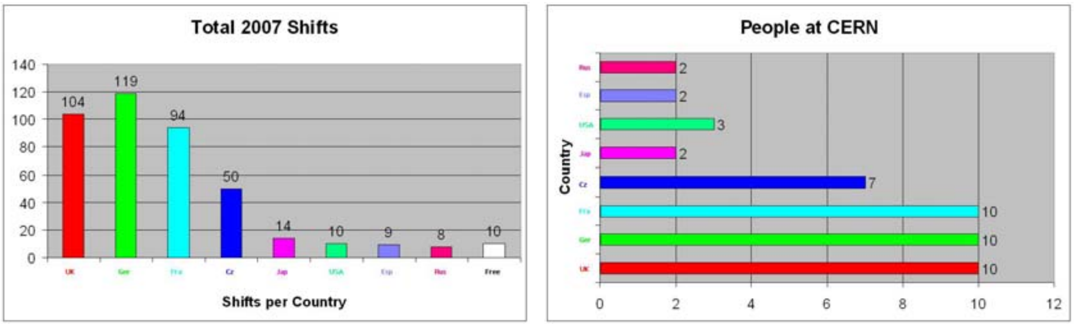

Fig.4: Total shifts and total number of people at CERN for the 2007 Calice test beam at CERN.

The programme for the test beam has been very intense and has been completely fulfilled at the end of the 7 weeks of data taking. The collaboration has collected more than 200 million events (see Fig.5), completing the muon calibration of all components, the electromagnetic program of both ECAL and AHCAL and hadronic program for the combined detector at four different incident angles of the beam (0, 10, 20 and 30 degrees).

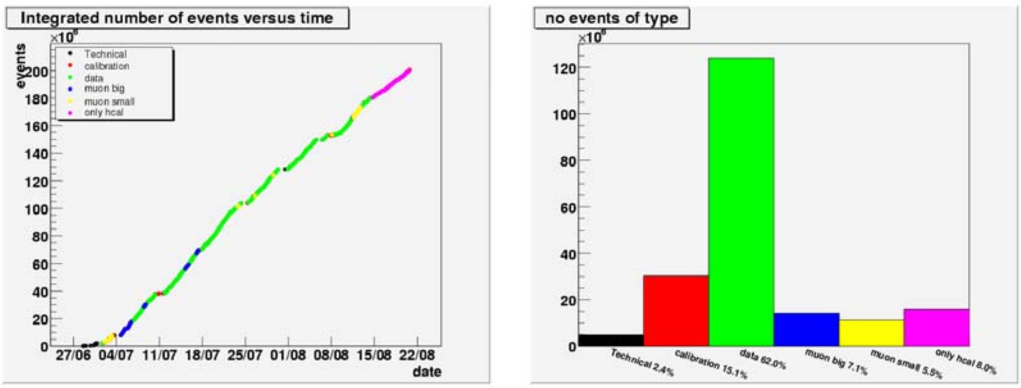

Fig.5: Total integrated luminosity collected at the 2007 Calice test beam at CERN (left). Data types collected during the 2007 Calice test beam at CERN: 62% of the collected data are e/π/proton interactions in the calorimeters.

Both 'minus' (e^-/π^-) and 'plus' (e^+/p^+/proton) beam events have been recorded. A full scan of the calorimeters' front faces has been performed, as detailed in Fig.6.

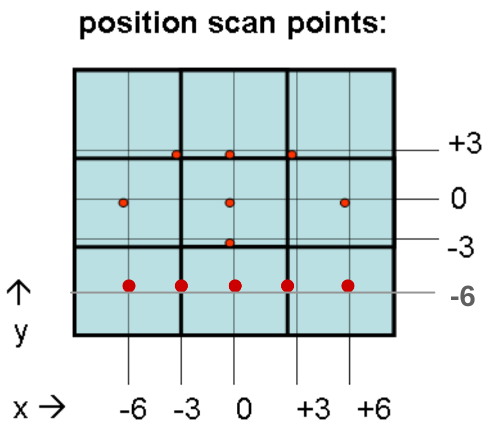

Fig.6: Summary of the position scanning on the front face of the ECAL performed at the 2007 Calice test beam at CERN.

An important part of this year's test beam has been the irradiation of a test ECAL PCB with embedded electronics, to evaluate a second generation prototype of electronics for the ILC. The irradiation has been performed using 70 GeV and 90 GeV electron beams, and doing a complete position scan of the four chips present in the test board, as shown in Fig.7. The test PCB has been inserted in the ECAL structure at the point of the shower maximum.

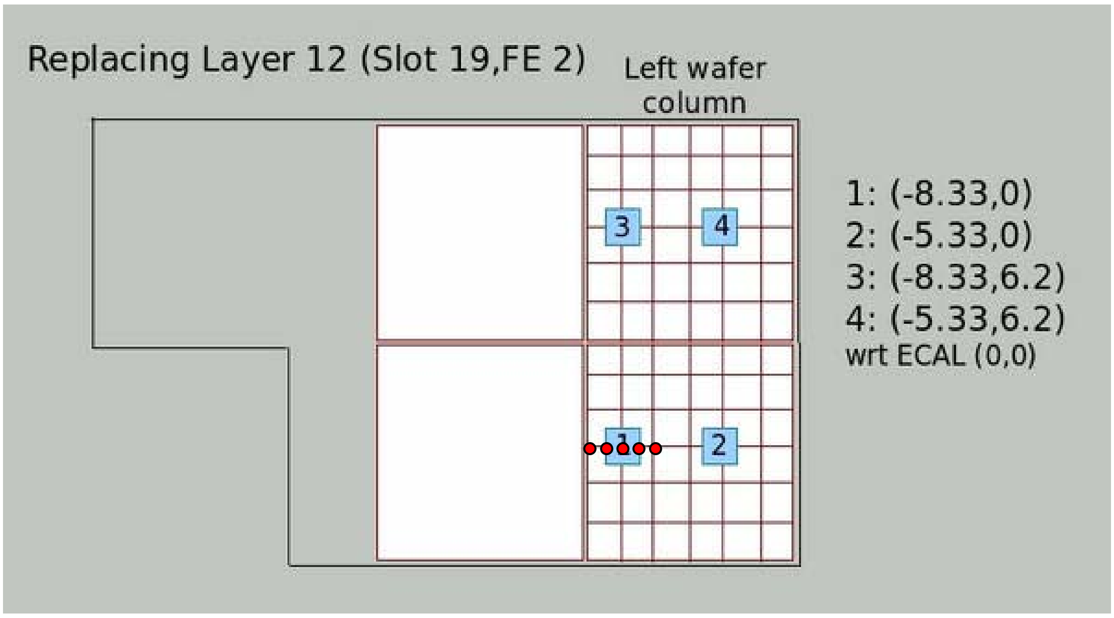

Fig.7: Sketch of the scanning of the test ECAL PCB with embedded electronics performed at the 2007 Calice test beam at CERN.

The most ambitious part of the test beam programme has been the rotation of the ECAL and AHCAL prototypes, with subsequent re-staggering of the active parts of the calorimeters. The success of this part of the programme has been possible thanks to the movable stage on which the ECAL and AHCAL have been installed. This 16 tonnes structure, designed and built at Desy, allowed for the X and Y movement of all the calorimeters. Moreover, the ECAL and AHCAL have been mounted on a steel platform that could be rotated to a maximum of 30 degrees with respect to the direction of the beam. Data have been collected with the ECAL and AHCAL rotated by 10, 20 and 30 degrees with respect to the normal beam incidence direction.

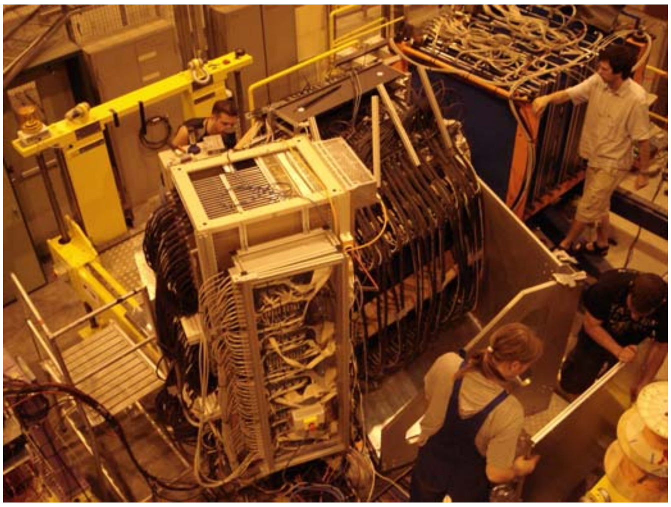

Fig.8: Experts performing the rotation of the ECAL and AHCAL to 20 degrees.

All data collected during the test beam where immediately processed and reconstructed using the Grid tools. The recorded runs were available from the Desy dcache to the whole collaboration within hours of being collected at CERN. A summary of the total number of runs collected and the total disk space occupied by the data accumulated at the 2007 Calice test beam at CERN can be seen in Tab.2.

Last run	33 1693
Number of runs	1 693
Combined runs to grid	1 693 (100%)
Converted runs to grid	1 693 (100%)
Disk space	8 274 GB
Disk space for converted runs	5 965 GB
Total disk space used	13 TB, 927 GB

Last run	35 0395
Number of runs	395
AHCAL runs to grid	395 (100%)
Converted runs to grid	395 (100%)
Disk space	598 GB
Disk space for converted runs	369 GB
Total disk space used	0 TB, 967 GB

Tab.2: Summary of the total number of runs collected during the 2007 Calice test beam at CERN for the combined ECAL+AHCAL programme (left) and the AHCAL only programme (right)

The final week of the test beam has been devoted to test the AHCAL alone, removing the ECAL from the stage. This has allowed performing important tests of the AHCAL response to both electrons and pions.

A detailed summary of the programme proposed in April at the Calice Technical Board and achieved at the test beam can be see in Tab.3, Tab.4 and Tab.5.

Thanks to the almost on-line reconstruction of the data collected, several checks have been possible to monitor the response of the calorimeters at different energies. The preliminary response for ECAL and AHCAL (with no calibration) can bee seen in Fig. 9.

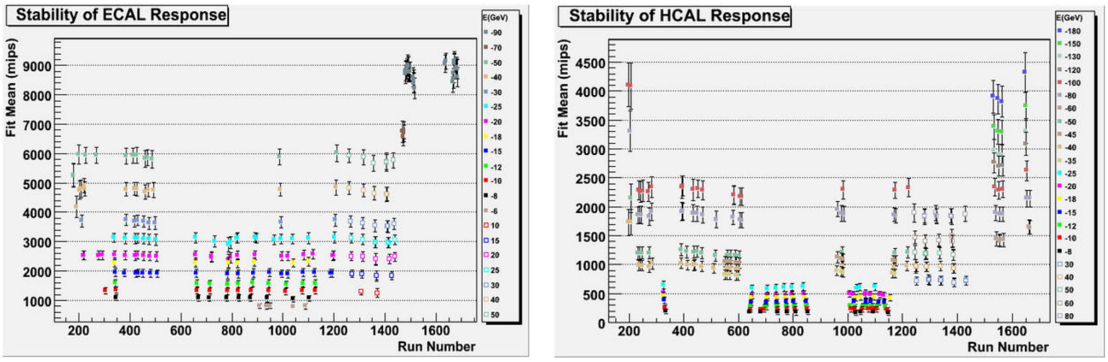

Fig.9: Preliminary results of the stability of ECAL (left) and AHCAL (right).

Conclusion

Between June and August 2007 the Calice collaboration has performed an extremely successful test beam at the H6B experimental area at CERN. More than 200 million events have been collected and all the data are available on the Grid.

The analysis of the data is well under way and preliminary results have already been shown at a recent collaboration meeting. For the ECAL analysis, studies of physics performances (resolution, linearity) are being carried out, and the preliminary results are consistent with what already found in the analysis of the 2006 test beam data, that have been shown at LCWS07 in June this year and are being reviewed internally by the collaboration for publication by the end of the year. Analysis of the detector performances are also on going, with particular attention to the study of noise in the Si detectors. Preliminary results on the irradiation of the PCB with embedded electronics are also being reviewed by the collaboration. For the AHCAL analysis, careful studies are under way on the calibration and temperature dependence of the SiPM detectors. Linearity and resolution are also being carefully looked at. A major part of the analysis of the AHCAL data will also be the comparison with the existing MC models for hadron showers, to improve the simulation of hadronic events in existing MC simulation packages (e.g Geant4).

	Proposed in TB plan (4 weeks of data taking)	Acheved at the TB (7 weeks of data taking)
Combined physics package: low energy π	π^-: 1M evts @ 6/8/10/12/15/18/20 GeV, 0 deg π^-: 500K evts @ 6/10/12/15/18/20 GeV; 10, 15, 20, 30 deg	- π^-: 1M evts @ 6 GeV, 0 deg; - 1.75M evts @ 8/10/12/ 15/18/20 GeV, 0 deg. - π^-: 400K evts @ 6/10/12/15/18/20 GeV, 10 deg; - 1M evts @ 6 GeV; 500K evts @ 8-20 GeV, 20 deg.
Combined physics package: high energy π	π^-: 1M evts @ 25/30/40/50 GeV, 0 deg π^-: 500K evts @ 25/30/40/50 GeV; 20, 30 deg	- π^-: 1.5M evts @ 25/40/50/60/80/ 100/120/130/150/180 GeV, 0 deg; - 200K evts @ 5/40/45/50/80/ 100 GeV, 0 deg: ECAL on beam line, AHCAL displaced by 6 cm. - π^-: 200K evts @ 35/40/45/50/ 80/100 GeV, 10,20 deg.

Tab3: Combined ECAL+AHCAL physics package for the Calice test beam proposed at the Calice Technical Board (centre column) and achieved at the test beam (right).

	Proposed in TB plan (4 weeks of data taking)	Acheved at the TB (7 weeks of data taking)
ECAL physics package: low energy e	e^-: 1M evts@6/10/15(/20), 0 deg	- e^-: 1M evts @ 6 GeV, 0 deg; ~700K evts @ 8/10/12/15/ 18/20 GeV, 0 deg. - 1M evts @ 6 GeV, 20 deg; ~400K evts @ 8/10/12/15/ 18/20 GeV, 10, 20 deg.
ECAL physics package: high energy e		- e^-: ~2M evts @ 25/30/ 40/50 GeV, 0 deg; - ~200K evts @ 25/30/ 40/50 GeV, 10, 20 deg.
ECAL physics package: high energy e		- e^-: scan of the bottom ECAL layer; ~250K evts @ 90 GeV/pos, 0 deg.
ECAL irradiation package: high energy e	e^-: 1M evts@10/50 GeV, 0 deg	- e^-: ~1.1M evts@70 GeV, 0 deg; - > 5.5M events @ 90 GeV, 0 deg. Position scanning on chip.
ECAL inter-alveolae package: high energy e	e^-: 300M evts@20/50 GeV, 0 deg	- e^-: ~2M evts @ 8/10/12/15/18/20/25/30/40/50 GeV, 0 deg; 6 positions.

Tab4: ECAL physics package for the Calice test beam proposed at the Calice Technical Board (centre column) and achieved at the test beam (right).

	Proposed in TB plan (4 weeks of data taking)	Acheved at the TB (7 weeks of data taking)
AHCAL only package: e/π, all energies	e/π^-: 500-1M evts @ 6/10/15/20/25/30/40/50 GeV, 0 deg	- π^-: 100K evts @ 8/10/12/15/20 GeV, 30 deg; - e^-: 100K evts@6/10/15/20 GeV, 30 deg; - π^+: 400K evts @ 10/15/20/25/30/40/50 GeV, 0, 10, 20, 30 deg; - e^+: 400K evts @ 10/15/20/25/30/40/50 GeV, 0, 10, 20, 30 deg.
π^+/e^+/protons		- e^+: 1.5M evts @ 10/15/20/25/30/40/50 GeV, 0 deg; - π^+/protons 1.5M evts @ 30/40/50/60/80 GeV, 0 deg: position scanning on ECAL front face.

Tab5: AHCAL only and e^+/p^+/proton physics package for the Calice test beam proposed at the Calice Technical Board (centre column) and achieved at the test beam (right).