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ESPEC : Precision energy spectrometer

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Abstract

A brief summary of the scientific output and deliverables of the EUROTeV, diagnostics work-package (DIAG), energy spectrometer task (ESPEC).

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1 Introduction

This work-package aim was to develop an Cavity Beam Position Monitor (BPM) based energy spectrometer. The deliverables of the task included the following.

1. Development and testing with beam of required nm-precision cavity BPMs;
2. Development of magnetic chicane-based spectrometer with relative precision of better than 10^{-4};
3. Design of spectrometer magnet;
4. Design of complete test spectrometer with eventual beam test;
5. Conceptual design of BPM-based spectrometer for ILC applications;
6. Studies of use of spectrometer in unfolding true luminosity spectrum.

Members of the EUROTeV ESPEC group were involved in three distinct experimental systems during 2005-2009. These had different specific goals but all aiding the delivery of the work-package deliverables

- NanoBPM, project to test the best achievable resolution of a cavity BPM system;
- Energy spectrometer tests BPM T474 : Full spectrometer test beam system based on a 4 magnet chicane system
- ATF2 : Large (approximately 40) cavity BPM system : Long term performance, stability and applicability of cavity systems;

In order to achieve the physics goals of the ILC a fractional energy resolution of $< 10^{-4}$ is required, which implies that a BPM resolution of better than 100 nm is needed, accompanied by corresponding stability. These three different projects are discussed in chronological order with reference to ESPEC deliverables and science goals.

2 Nano BPM (2005-2006)

In order to gain the necessary experience with Beam Position Monitors (BPMs) and their ultimate precision, the EUROTeV ESPEC group was involved in a programme of research at the High Energy Physics Laboratory, KEK, in Japan. Our work at KEK, using a 1.28 GeV extracted electron beam at ATF, has been carried out in collaboration with the nanoBPM group. The objectives are to test monopole suppressing RF cavity beam position monitors and to assess their performance. We used two triplets of BPMs in the beam, and by comparing the apparent position of the beam on one BPM of a triplet with the position predicted from the other two, it is possible to assess the resolution and stability of these devices. At ATF, we have observed resolutions of order 20 nm, and stability at the level of 40 nm over a period of two hours [1, 2], verifying the overall performance characteristics of cavity BPM systems for use in the spectrometer.

3 End Station A spectrometer study (T474, 2006-2007)

The End Station A (ESA [4, 5]) facility in SLAC provided a facility to test a full spectrometer prototype (test beam experiment T474[6, 7]). We focused ESPEC efforts on the following tasks

- Detailed analysis and characterisation of SLAC beam position monitors for the data taken in 2006/2007;
- Full tests of the spectrometer system;
- Design, fabrication and beam test of a beam position monitor to meet the requirements of the spectrometer;
- Design and integration of the 4 magnet chicane into the ILC baseline and reference design reports;
- Simulation of the spectrometer system and beam-line using Geant4 and BDSIM.

The analysis of the 2006 data on the beam position monitor (BPM) systems deployed at the End Station A (ESA) in SLAC has been completed. We demonstrated sub-micron resolution and micron level stability over 20 hours for a 1 m long BPM triplet. We found micron-level stability over 1 hour for three BPM stations distributed over a 30 m long baseline. The understanding of the behaviour and response of the BPMs gained from this work [3] has allowed full spectrometer tests to be carried out, lead by a EUROTeV funded researcher M. Slater.
During 2007, a combined running time of about five weeks at ESA was exploited for spectrometer tests. For the data-taking period in March 2007, four dipole magnets were commissioned and installed in the beam-line, thereby completing the full spectrometer system. In order to check the spectrometer, the energy of the beam was scanned in 50 MeV steps, clearly indicating a resolution of $< 2 \times 10^{-3}$ [8]. This scan was clearly tracked by the spectrometer. For the data-taking period in July 2007, the BPM optimised for the spectrometer, designed by Liapine (UCL), was installed in the beam-line. The BPM broadly performed as expected but suffered from some manufacturing problems, which compromised the performance [9].
A simulation of the spectrometer system was developed, which was compared with spectrometer data taken during 2007. This will also allow us to consider different designs of the spectrometer, e.g. different BPMs and magnets or even a radically different layout and compare the impact on physics of the different designs. The package also includes all tools needed for simulating BPM responses and so could be used in other applications where BPMs are used. Based upon the spectrometer design at ESA, the pre-collision energy energy diagnostics have been implemented in the ILC reference design [10].
The ESA program was terminated early due to budget constrains in both the US and UK. A paper on just the BPM system was published during 2008 and the full spectrometer data samples are still being analysed and will be published during 2009. The resolution

of existing ESA BPMs was improved to around 300 nm. A EuroTeV note was completed on the design, fabrication and beam tests of the dedicated spectrometer S-band BPM design that is also being used as a prototype final focus BPM. The ILC spectrometer cavity design has been used as a template to develop the S and C band systems deployed at ATF2 and hence more widely the beam delivery BPMs for the whole ILC [11].

4 ATF2 (2008-)

With the closure of the ESA facility the ESPEC task shifted focus to the ATF2 facility at KEK in Japan. The ATF2 [11] will be able to provide ILC like beam (emittance and stability) for delivery to an ILC focus system. The beam line is instrumented with over 30 C-band high-resolution cavity BPM systems and 4 S-Band systems. One main goal of such a facility is to demonstrate the stability requirements of these BPMs for ILC beam monitoring. Furthermore, similar stability is required for a magnetic chicane spectrometer system. The ESPEC group has utilised its experience and hardware from ESA to deliver to the ATF2 :

1. 9 Channels of S-Band mixer electroncs (4 reused from ESA);
2. Complete RF processing code and online analysis for all ATF2 BPM systems (developed using experience from ESA);
3. RF tone calibration system;
4. Complete RF simulations of the BPM and electronics performance.

The ATF2 facility saw first beam during the Autumn of 2008 and the BPM system was commissioned with a resolution of approximately 1 μm. The commissioning process will continue until June 2009, when a complete system operating at high resolution (50 to 100 nm) should be demonstrated. The ATF2 facility will provide sufficient technical tests for the technical feasibility of deploying RF cavity BPMs for the whole ILC including any spectrometer system.

5 Luminosity spectrum studies

The related work on the energy spectrum extraction and its implication for precision physics has resulted in a Ph.D (close to completion by F. Gournaris [12]) on the luminosity spectrum and the impact on the top threshold (the prototypical physics channel that requires high precision energy measurements). This includes the following topics:

1. Top quark differential generator;
2. Luminosity spectrum parameterization program;
3. Bhabha extraction program.

6 Presentations and talks

1. ATF Mini-workshop, KEK, May 2005
2. European Regional Meeting + ILC-BDIR, RHUL. June 2005.
3. Nanobeam 2005 (36th ICFA Advanced Beam Dynamics Workshop) Kyoto. October 2005.
4. LCWS06, Bangalore, March 2006
5. Beam energy spectrometer meeting, Dubna, May 2006
6. EPAC06, Edinburgh, June 2006
7. LC workshop, Vancouver, July 2006
8. Beam energy spectrometer meeting, Yerevan, October 2006
9. EU ILC meeting, Daresbury, January 2007
10. LCWS07, Hamburg, June 2007.
11. PAC07, Albuquerque, June 2007.
12. ESPEC BPM Energy spectrometer, EUROTeV scientific workshop, Uppsala, Sweden, August 2008.
13. LCWS2008, Chicago, Illinois, USA, November 2008

7 Conclusion

Overall the deliverables of the ESPEC package have been fully met and in many case exceeded. A cavity prototype was designed but also prototyped and beam tested at ESA. This design has acted as a prototype for the wider cavity BPM systems required for a future linear collider. This is clearly indicated by the advanced and significant activity in ATF2, where the cavity systems are design descendants of the NanoBPM and ESPEC prototype systems.

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