Progress Report for the BPM Energy Spectrometer Test Experiment at ESA

B. Maiheu[1], C. Adolphsen[8], R. Arnold[8], S. Boogert[7], G. Boorman[7], M. Chistiakova[2], V. Duginov[5], F. Gournaris[1], C. Hast[8], M. Hildreth[6], Yu. Kolomensky[2], S. Kostromin[5], K. Kumar[9], A. Lyapin[1], D. McCormick[8], D. Miller[1], N. Morozov[5], J. Ng[8], E. Petigura[2], M. Sadre-Bazzaz[2], H.-J. Schreiber[4], M. Slater[3], Z. Szalata[8], M. Thomson[3], M. Viti[4], D. Ward[3], M. Wing[1], M. Woods[8]

[1] *University College London, UK*
[2] *University of California, Berkeley and Lawrence Berkeley National Laboratory, USA*
[3] *University of Cambridge, UK*
[4] *Deutches Elektronen Synchrotron (DESY - Zeuthen), Germany*
[5] *Joint Institute for Nuclear Research (JINR), Russia*
[6] *University of Notre Dame, USA*
[7] *Royal Holloway University of London, UK*
[8] *Stanford Linear Accelerator Center (SLAC), USA*
[9] *University of Massachusetts Amherst, USA*

The main physics programme of the International Linear Collider (ILC) requires a measurement of the beam energy with a relative precision of 10^{-4} or better. To achieve this goal a spectrometer using high resolution beam position monitors (BPM) and accurately monitored bending magnets has been proposed. A prototype spectrometer chicane using 4 dipoles is now commissioned in End Station A (ESA) at SLAC, intending to demonstrate the required stability of this method and investigate possible systematic effects and operational issues. In this contribution we will describe the experimental setup for this ESA test experiment (T-474/491), which has been finalised during two runs in 2007, and present results from the BPM commissioning runs in 2006.

1 Introduction

The design of the International Linear Collider is driven by the broad precision physics programme of electroweak, Higgs, QCD and possible SUSY measurements. The uncertainty on the energy of the colliding electron and positron bunches contributes directly to the systematic error on e.g. top quark W and Higgs masses [2], making a precise energy measurement of the beam of crucial importance. At LEP2, an energy spectrometer was successfully commissioned, achieving an accuracy of 1.9×10^{-4} [3]. Dipoles in the bending sections of the storage ring were used to induce a deflection of the lepton beam. With accurate knowledge of the total integrated field of these bending magnets together with a measurement of the deflection itself, one can derive the energy of the beam. The ILC energy spectrometer has similar design requirements in terms of accuracy, however to limit the emittance growth due to synchrotron radiation in the beam delivery system, the introduced dispersion in the spectrometer chicane has been restricted to 5 mm. Also, at the ILC the measurement has to be done in a single shot. High resolution RF cavity BPM systems are therefore preferred to strip-line or button BPMs as these can achieve resolutions well below a micron [4], needed for a precision energy measurement.

As a proof of principle, a test beam experiment (T-474/491) was proposed [5] at ESA at the Stanford Linear Accelerator Center (SLAC), focusing on studying the achievability and more importantly the stability and systematics of this type of energy measurement in a linac. The aim is to identify operational issues and provide practical guidelines for constructing the ILC energy spectrometer.

End Station A provides an ideal facility for ILC test experiments. It features a 28.5 GeV electron beam with a bunch charge of 1.6×10^{10}, an energy spread of 0.15 %, a repitition rate of 10 Hz and a nominal bunch length of about 500 μm, all (except energy) similar to the ILC baseline specifications. The incoming beam orbit is stabilised both in horizontal and vertical planes using a feedback system consisting of 4 RF cavity BPMs as well as 4 corrector magnets equipped with trim coils. These trim coils can also be used for a rough calibration of the BPM system.

2 Experimental setup

The T-474/491 experiment started in 2006 with two BPM commissioning runs and was extended with the full spectrometer chicane during two runs in 2007. The experimental setup as of July 2007 is depicted in figure 1. The BPM system consists of different S-band

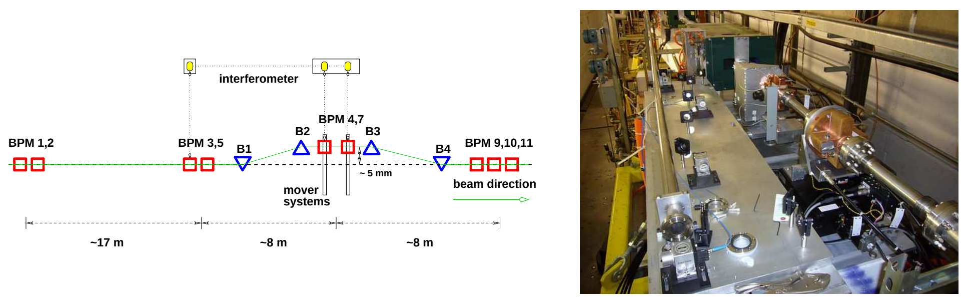

Figure 1: The T-474/491 beam line setup as of July 2007 showing the relevant BPM stations and dipole bending magnets (B). An interferometer monitors the horizontal mechanical stability of BPM 3 and BPMs 4 and 7 at the chicane centre.

cavity BPMs, all having resonant frequencies of about 2.9 GHz. BPMs 3, 4 and 5 are prototype BPMs for the ILC main linac [6] and are cylindrical cavities with a waveguide coupling system providing signals for both horizontal and vertical planes. They are designed to minimise the coupling of modes other than the position sensitive dipole mode. BPMs 1 and 2 and the triplet 9,10,11 are old SLAC rectangular cavities. BPM 7 is a new prototype which has been designed specifically for ILC energy spectrometer purposes in terms of mode suppression, resolution and decay time. The raw RF signals coming from the cavities were put through a system of filters and amplifiers and were down-mixed to about 83 MHz and 23 MHz in case of the BPM7 prototype. The resulting waveforms were digitised using 14 bit 119 MS/s sampling ADCs. Further extraction of the position and tilt information was done using algorithms in software [7], [4]. Both BPM4 and BPM7 are placed on their own 2D precision mover system for both calibration and tracking the beam when operating the chicane as the dynamic range of the BPMs is limited to about $\pm$ 1 mm.

The chicane is formed by four 94 cm long dipole magnets. Their characteristics were studied during a measurement campaign [8] at the SLAC magnetic measurement facility. The field integral for all 4 magnets was found to be uniform at the 10^{-4} level over $\pm$ 15 mm horizontally from the magnet central axis and they are monitored during data taking by NMR probes. The induced fields of about 0.115 T cause a horizontal translation of the 28.5 GeV beam of roughly 5 mm at the centre of the chicane.

Compared to the two runs in 2006, various hardware upgrades were implemented to better understand the systematic effects that were observed during the BPM commissioning (see below). A calibration tone system in which the BPM processor electronics were fed in between machine pulses with a triggered, constant level tone was deployed, so it became possible to monitor gain drifts in the electronics, e.g. due to temperature variations. Two BPMs at high dispersion points (500 mm) in the ESA extraction line were commissioned along with charge-sensitive toroids for event-level monitoring of the beam energy and bunch charge. Furthermore, two Helmholtz coils were installed, enabling us to perform fast calibrations for the BPM system. An interferometer that was already present for the 2006 runs has been relocated to monitor the horizontal mechanical stability of the BPMs at the centre of the chicane as well as one BPM in front of the chicane.

3 Analysis results

Analysis is nearing completion for the BPM commissioning runs in 2006. First of all the resolution of the individual BPMs was assessed and more importantly the precision of the orbit reconstruction, which is of fundamental importance for the energy measurement. The resolution of a BPM is essentially the minimum change in beam position which the BPM can detect in one pulse. Table 1 shows the resolutions for data run 1421. They are defined here as the Gaussian spread of the distribution of the residual offset from the predicted beam position obtained by a linear regression analysis within a triplet or using the entire orbit. For all but BPMs 1 and 2, sub-micron resolutions were measured as well as for the orbit. This meets our requirement for spectrometer studies.

BPM	σ_x	σ_y
1, 2	2.53 μm	4.15 μm
3, 4, 5	0.69 μm	0.61 μm
9, 10, 11	0.25 μm	0.31 μm
Orbit	0.73 μm	0.91 μm

Table 1: The resolution of the BPM stations and orbit reconstruction (run 1421), where we have taken BPMs 1 and 2 and BPMs 9-11 to predict the position in BPM 3.

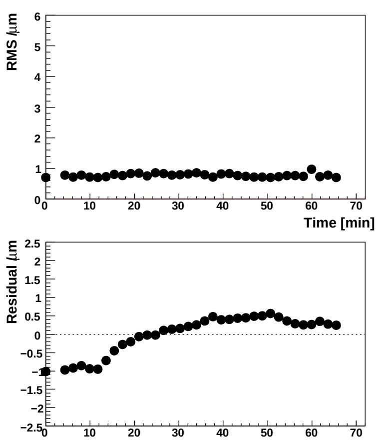

Figure 2: The resolution and residual stability over an hour.

What is more important for the operation of the ILC spectrometer is the stability of this measurement. Temperature and other environmental effects can affect for example the amplitude and phase response of the processing electronics or change the physical shape of the cavity. Ground motion can affect the mechanical stability of the system, rendering the orbit determination less accurate. Results from an hour long measurement of the resolution and the stability of the orbit are shown in figure 2. Even though the resolution itself does not appear to change drastically over the course of an hour, the residual offset itself does. Understanding these drifts was the underlying motivation for installing the calibration tone system discussed above.

During the March 2007 run, the full chicane was commissioned and some first spectrometer data was taken. Figure 3 shows an energy feedback scan in 50 MeV steps, as seen by the spectrometer chicane. Preliminary analysis of this data shows an encouraging energy resolution of about 6.6 MeV or about 230 ppm [8]. Detailed systematic and stability analysis with the extensive data set taken in July is in progress.

4 Summary

The energy spectrometer test experiment (T474/491) at SLAC's End Station A is now fully commissioned and has taken its first good spectrometer data during two runs in 2007. The analysis of the data taken during two BPM commissioning runs in 2006 is approaching completion. So far, we already demonstrated sub-micron precision of the orbit reconstruction with systematic drifts of about 1 μm over the course of an hour. This corresponds to a drift of 200 ppm on the energy measurement. In-depth understanding of the nature of these systematics is now possible thanks to hardware upgrades such as a calibration tone system and an interferometer. The analysis of the data taken during the 2007 March and July runs, will provide a "proof of principle" for an ILC BPM-based spectrometer.

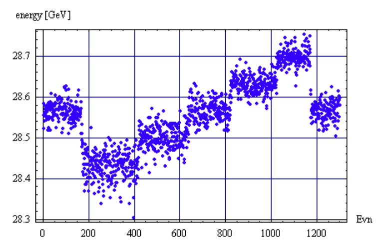

Figure 3: Energy scan as seen by the spectrometer

Acknowledgements

This work was supported by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RIDS-011899 and by the US Department of Energy. We also wish to express our gratitude to the SLAC directorate and especially to the MCC operators for their kind help during the ESA running periods.

References

[1] Slides: Progress Report for the BPM Energy Spectrometer Test Experiment at ESA `http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=451&sessionId=78&confId=1296`

[2] S. Boogert and F. Gournaris, Determination of dL/dE and total CM energy, *These proceedings*.

[3] R. Assmann et al, Calibration of Center-of-Mass Energies at LEP2 for a precise measurement of the W Boson Mass, Eur. Phys. J. **C39** 253-292 (2005).

[4] S. Walston et al, Performance of a high resolution cavity beam position monitor system, Nucl. Inst. and Meth. **A 578** 1-22 (2007)

[5] M. Hildreth et al, BPM-based energy spectrometer, *SLAC Test Beam Request* **No. T-474**. June 11, 2004.

[6] Z. Li, S-Band Cavity BPM For ILC, *Talk given at ALCPG, ILC Snowmass 2005 Conference*, Contribution ILCAW0901.

[7] D. Whittum, Y. Kolomensky, Analysis of an Asymmetric Resonant Cavity as a Beam Monitor, Rev. Scientific Instr. **70** 2300 (1999)

[8] R. Arnold et al., Magnetic measurements and simulations for a 4-magnet dipole chicane for the international linear collider. *Proceedings of PAC07*, THPMS038