Progress Report for the Energy Spectrometer Test Experiment at ESA

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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 magnetic spectrometer using high resolution beam position monitors (BPM) has been proposed. A prototype spectrometer chicane using 4 dipole magnets is now commissioned at the End Station A (ESA) in 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, as well as analysis results from the BPM commissioning runs in 2006.

1 Introduction

The design of the ILC is obviously driven to a large extent by the precision physics programme it is aiming for. The uncertainty on the energy of the colliding electron and positron bunches contributes directly to the systematic error on e.g. top quark threshold scans [2], making a precise energy measurement of the beam of crucial importance. At LEP2, an energy spectrometer was successfully commissioned, achieving an accuracy of 1.2×10^{-4} [3]. Dipoles 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. High resolution RF cavity BPM systems are therefor preferred to strip-line or button BPMs as these can easily achieve resolutions well below a micron [5], needed for a precision energy measurement.

As a proof of principle, a test beam experiment (T-474/491) was proposed at ESA at the Stanford Linear Accelerator Centre (SLAC) focusing on studying the achievability and more importantly the stability and systematics of this type of energy measurement in a LINAC.

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The aim is to pinpoint operational issues and provide a practical guideline to 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 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 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 corrector magnets 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 in 2007 with the full spectrometer chicane during two data taking runs in 2007. The experimental setup as of July 2007 is depicted in figure 1. The BPM system consists out

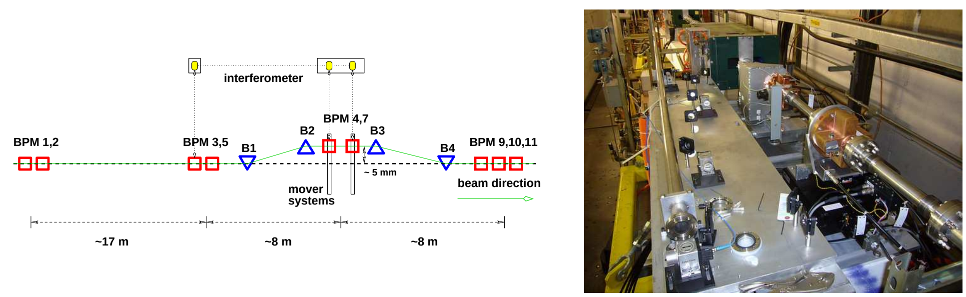

Figure 1: The T-474/491 beam line setup as of July 2007 showing the relevant BPM stations and dipole bending magnets (B). An interferometer monitors the horizontal mechanical stability of BPM 3 and BPMs 4 and 7 at the chicane centre.

of different S-band cavity BPMs, all having resonant frequencies of about 2.9 GHz. BPMs 3,4 and 5 are prototype BPMs for the ILC main LINAC [4] 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 TM110 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 sampling ADCs. Further extraction of the position and tilt information was done using algorithms in software [6]. 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 37 inch long dipole magnets. Their characteristics were studied during a measurement campaign [7] 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 centre axis. The magnets are equipped with NMR probes to monitor their field. 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 commissioning runs in 2006, various hardware upgrades were implemented to better understand the systematic effects that were observed during the BPM commissioning (cfr. infra). A calibration tone system was deployed where the BPM processor electronics were fed inbetween machine pulses with a triggered, constant level CW tone so it became possible to monitor gain drifts in the electronics e.g. due to temperature variations. Two “energy”-BPMs were commissioned at high dispersion points (500 mm) in the ESA extraction line and the signal coming from a toroid was directly plugged into the main data acquisition to have bunch charge information on an event by event basis. Furthermore, two Helmholtz coils were commissioned enabling us to perform fast calibrations for the BPM system. The interferometer that was installed already 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 basically is the minimum change of beam position which the BPM can detect. 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).

What is more important howver 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 a hour long measurement of the resolution and the residual offset at the centre of chicane location 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.

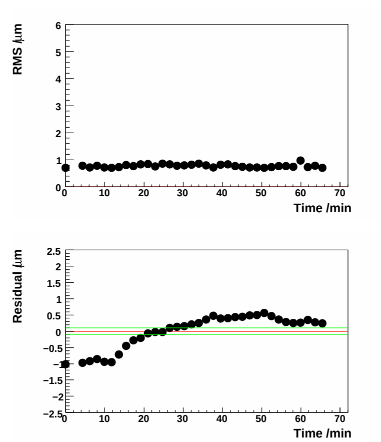

Figure 2: The stability of the resolution and the residual offset over the course of an hour.

Understanding these drifts was the underlying motivation of installing the calibration tone system (cfr. supra). 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 [7]. Detailed systematic and stability analysis with the extensive data set taken in July is in progress.

4 Summary

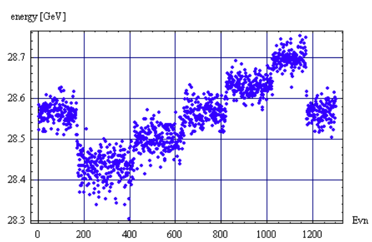

Figure 3: Energy scan as seen by the spectrometer

The energy spectrometer test experiment (T474/T491) SLAC's End Station A has now fully commissioned it's setup during two runs in March and July 2007 and taken it's first good spectrometer data. The analysis of the data taking 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 micron over the course of an hour. In depth understanding of the nature of these systematics is now possible thanks to hardware upgrades such as a calibration tone system. With the data taking during the March and July runs in 2007, the analysis which will provide the "proof of principle" for the ILC magnetic chicane spectrometer, is now fully underway.

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