BPM Energy Spectrometry for ILC

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for LC-ABD WP 4.2

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Uncertainty on beam energy measurement contributes directly to the uncertainty on the ILC physics output...

Need for:
- energy measurement accuracy $10^{-4}$
- stability and ease of operation
- minimal impact on physics data taking
WP 4.2 mission statement:
Study & design magnetic chicane for beam energy measurement using BPMs for a future linear collider

Royal Holloway University London: S. Boogert
Cambridge: M. Slater, M. Thomson and D. Ward
University College London: F. Gournaris, A. Lyapin, B. Maiheu, S. Malton, D. Miller and M. Wing

\[ \frac{\delta E}{E} \sim 10^{-4} \]
\[ \eta \sim 5 \text{ mm at center} \]
At least \( \delta x \sim 500 \text{ nm} \) needed

NanoBPM@ATF: test resolution, try different analysis methods, BPM stability tests, multi bunch operation, advanced electronics techniques, inclination of beam in BPMs.

-> spectrometer aspects of BPMs can be tested

ESA@SLAC: test stability and operational issues with a full implementation of 4 magnet chicane and 3 BPM stations

-> test of chicane prototype
NanoBPM at ATF

Collaboration with LLNL, LBNL, SLAC and KEK

KEK BPMs on flexure piezo movers (x,y)

BINP BPMs, each on hexapod (x,y,x',y') in SLAC/LLNL frame
BPM signal processing in a nutshell

**Filters, Amplifiers**

**RF**

**Filters, Amplifiers**

**ADC**

**LO**

**Monopole (TM\(_{010}\)) : charge**

**Dipole (TM\(_{110}\)) : charge + offset + tilt**

**Determine Amplitude & Phase**

➢ Fit waveform: \(V = V_0 + A e^{i(t-t_0)} \sin[\omega(t-t_0) + \varphi]\)

➢ Digital Down Conversion (DDC): 
  - Multiply waveform with \(e^{i\omega t}\)
  - Filter out \(2\omega\) component
  - Sample waveform at fixed \(t_0\)Ref \(\rightarrow A, \varphi\)

**Disentangle charge, offset and tilt:**

Normalise signal to Ref (Q) Cavity

Tilt has \(\pi/2\) phase difference to position

**BPM 9x (Old SLAC BPM)**

**BPM 42, y33 corrector scan**
ATF Results: resolution + systematics

➢ 2 stage down mixing, digitizer 14 bit
➢ Precise calibration using hexa-pod movers, cross calibration using corrector magnets
➢ Commissioned nanoGrid system (nm level XY encoder system) to monitor mechanical stability

➢ Best resolution so far:
  ➢ 16 nm
➢ Short and long-term:
  ➢ drifts < 100 nm
➢ Clear systematic correlation seen

Frequency & temperature:
\[ \Delta T \sim 0.25 \text{ K} \rightarrow \Delta \omega \sim 65 \text{kHz} \]
assuming typical offsets of beam
50 nm systematic scale change
ATF Results : Beam inclination in BPM

Important for discussion 3 vs. 4 magnet chicane
data between -1000 and 1000 μrad

No significant change in resolution, however:
clear change in calibration constants!

Further investigation!

IQ Phase

Position Scale

Probably related to Temp

Clear variation with inclination
ATF Results: multibunch studies

Cavity BPMs must work with ILC bunch train...

➢ can we measure energy of individual bunches?

ATF multi bunch data: bunch train of 3 bunches (150 ns) proved difficult to steer down -> saturation...

Simulation work bunch train:

➢ fitting algorithm seems to be performing well
➢ more study needed: phase advance, DDC?
January test run 2006 (4 days): Commissioning of BPMs 31,32 and 1,2 upstream

April run 2006 (2 weeks):
- Commissioning of new ILC prototype linac triplet (BPM 3,4,5), where BPM4 on x,y mover system
- Commissioning of old SLAC BPMs (9,10,11)
- Digitisation/signal processing optimization

July run 2006 (2 weeks):
- Commissioning of Zygo interferometer system (BPMs 3,4,5) + energy BPM24 upstream
- Further optimisation of hardware (down mixing)
- Stability data taking with 10 BPMs, frequent calibrations
BPM systems used in ESA

- Rectangular cavities
  - x and y separated
  - 2.856 GHz, high Q ~ 3000
  - 20 mm aperture (0.8 “)

- C. Adolphsen, Z. Li
- ILC cold linac prototype cavities
  - 36 mm aperture, 2.859 GHz
  - low Q (~ 500)
  - good monopole suppression
**ESA Resolution & stability**

Resolution:
- BPM 3-5: ~ 700 nm in x
- BPM 9-11: ~ 350 nm in x

Prototype:
20k pulses ~ 30 min

Old cavities:
200 nm
Automatic calibration

Corrector scans / setpoint calibration... lot of manual work needed

➢ Automatic setting of correctors with/without feedback
➢ Followed by mover scan on BPM4
➢ Set voltage level for each step in ADC
➢ Still need to implement automatic processing

Important aspect of future spectrometer operation!
Spectrometer BPM prototype

Existing BPM designs not optimal for an energy spectrometer

➢ aperture (machine protection, resolution)
➢ resolution, stability
➢ monopole rejection (electric center stability)
➢ coupling -> decay time (multi bunch)

Designed new prototype (A. Lyapin)

➢ 30 mm aperture, 2.878 GHz, 1.3 MHz bandwidth
➢ theoretical resolution ~ 11.2 nm
➢ Al prototype by UCL workshop, Cu vacuum beam
 prototype by Mullard Space Science Lab (MSSL)

Proposed electronics scheme
Aluminium prototype for new BPM

Al prototype is done & ready for measurements at UCL & RHUL

Waveguide structure

Cavity (upside down)

Feed through

Fully assembled prototype

Alex

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Chicane simulation

Currently most simulation work just generates “sampled waveforms”

Developing core library for full simulation:

- Uses physical units (easily portable between e.g. KEK & SLAC)
- Portability between platforms, e.g. import into LabVIEW
- Simulation of electronics: conversion loss, non linearity, digitization etc...
- Contains analysis routines as well -> simulation & real data analysis based upon identical set of routines

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**Diagram:**

- **Chicane simulation GEANT/BDSIM**
- **Real BPM**
- **Electronics digitisation**
- **Waveform simulation**
- **Electronics digitization simulation**
- **reconstruction**
- **analysis**

- Cavity parameter simulation (GdfidL)
- Already contains a lot of functionality cross check with ESA data production underway

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**Libespec**

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Future plans

Plans for ATF:
- long term stability studies
- multi bunch and additional tilt & spectrometer related tests
- use nanoGrid system to monitor mechanical stability of spaceframe
- new BPMs are planned to be installed to replace the KEK ones

Plans for ESA:
- Install 4 old refurbished magnets in beam line to form chicane (Jan. '07)
- Install & commission new spectrometer BPM prototype complete with temperature readout and x,y mover system
- Commission constant calibration tone system to monitor gain drifts in electronics
- Link BPM stations with interferometer system (M. Hildreth)

Plans for LC-ABD 2:
- Develop BPM triplet to be deployed at mid-chicane location
- Long term tests of UK designed spectrometer specific BPMs