Overview of Energy Spectrometers

Progress in Europe and the U.S.

Mike Hildreth

Université de Notre Dame du Lac

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A few words of Motivation:

Energy Calibration needs for Physics at a Linear Collider will be similar to what we had at LEPII:

Threshold Scans:

Kinematic Fits:
Required Energy Precision

• Overall measurement precision is set by the expected statistical and systematic errors of “benchmark” measurements of $m_{\text{top}}$, $m_{\text{higgs}}$:
  – require $\frac{\delta E_{\text{beam}}}{E_{\text{beam}}} \sim 100$-200 ppm
  – (LEP2 achieved $\sim 170$ ppm with a combination of techniques)
• We note that there may be a desire to
  – re-scan the Z lineshape
    • requires $\frac{\delta E_{\text{beam}}}{E_{\text{beam}}} \sim 1$ ppm
  – scan the WW threshold
    • requires $\frac{\delta E_{\text{beam}}}{E_{\text{beam}}} \sim 30$ ppm
  – Both of these would require significantly different accelerator operation, re-optimization of energy-measurement strategies
    – ignore for now!
Other Parametric Considerations

- We will also need a determination of $\delta \Lambda/\delta E$, the differential luminosity spectrum, to $\sim 1\%$ for many of the measurements
  - it’s the Luminosity-weighted $\delta \Lambda/\delta E$ that matters
  - requires spectrometry downstream of IP if this is done with beam instrumentation
  - bhabha acolinearity plus bhabha energy measurements may also be necessary for a full deconvolution of the spectrum

- “Kink” effect in collision exacerbates head-tail energy differences in luminosity-weighted $\delta \Lambda/\delta E$.

- Bias in the $\langle E \rangle$ distribution can be up to $500\text{ppm (NLC)}$!

- very sensitive to beam params.

- See talk by Tim Barklow
This Talk…

- **Focus of work has been:**
  - “LEP-style” BPM-based spectrometers (upstream of IP)
  - “WISRD-style” synchrotron spectrometers (up & downstream of IP)

- **For this talk, I will present an overview of recent developments**
  - loosely centered around DESY, SLAC
  - many university groups involved
  - trans-oceanic collaborations
Prototypical Energy Spectrometers

• “LEP-Type”: BPM based, bend angle measurement

\[ \theta = \frac{e c}{p} \int B \cdot d\ell \]

⇒ “upstream”

• “SLC-Type”: SR stripe based, bend angle measurement

⇒ “downstream”
Spectrometer Magnet Studies:

- 3-D Mafia model of potential steel spectrometer dipole:
  - 300,000 mesh points @ 1cm spacing
  - Results sensitive to
    - manufacturing tolerances
    - core defects
    - support girder, mounting bolts
    - end field screens
  - small shifts between 2D and 3D modelling

  3D modelling confirms 2D results, tolerances
Field Uniformity

- Calculated uniformity better than $2 \times 10^{-5}$ over 11mm central region
- Region of uniformity shifts between 2D and 3D simulations
- (just going to have to measure it!)

$\frac{B}{B_0}$ across horizontal aperture

$\int B dz$ across horizontal aperture
RF Cavity BPMs:

- Cavity BPMs designed so that only dipole mode of main cavity couples strongly to output waveguide.
- 1.5 GHz and 5.5 GHz prototypes constructed for bench tests
- achieved 150nm resolution on 1.5GHz prototype
BPM Prototyping

• 5.5 GHz BPM prototype:
  
• 200nm resolution measured in test stand
  – linearity range: ±700μm
  – resolution and linearity limited by signal processing electronics (expect x2 or x3 improvement)
  – time resolution 16ns
  – sensitivity of 1.9mV/100 nm estimated
More R&D

• 5.5 GHz BPM prototype beginning beam tests
  – right now!
  – “Prototype II” designed with UHV capability
  – ELBE linac in Rossendorf/Dresden
  – results soon!

• TESLA Energy Spectrometer TDR planned for Summer from this design group

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First attempts at incorporating spectrometers into lattice:
BPM-based Spectrometer

Design Considerations:
- limit SR emittance growth
  - 360μrad total bend ⇒ 0.5%
- available space in lattice
  - no modifications necessary, yet
- 10m drift space maximum one can consider for mechanical stabilization, alignment
- 37m total empty space allows for BPMs outside of chicane to constrain external trajectories
- Tiny energy loss before IP
- non-ideal β-variation?

⇒ Constraints lead to a required BPM resolution of ~100nm (Resolution ⊕ Stability)
Design Considerations:

- Secondary IP image needs to be at detector plane for optics to work
- Wide-aperture 3 mrad bends needed to extract SR fans and Compton Endpoint from Stayclear
- Geometry less severe if beam can be collimated to 50% of $E_{\text{nom}}$
- Wigglers + 4 SR detectors can be used to remove prominent WISRD systematic errors from tilts
- Only need upper/lower detector for relative dE/E, E spectrum measmt.
- “off-the-shelf” detector specs
SLAC End Station A Test Program

- BDI equipment tests in “realistic” (=dirty) environment

Existing RF BPMs can be used for stability, resolution tests

5 meter region to mock up IR/forward region with masking, FONT, pair detectors

Beamline components scavenged from SPEAR, other SLAC surplus

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Partial List of End Station A Tests

(still evolving)

1. IP BPM tests
   • Sensitivity to backgrounds, rf pickup
   • Mimic LC geometry, including fast signal processing (but no feedback)
   • Sample drive signal to kickers

2. Energy BPM tests
   • Mechanical and electrical stability at 100-nm level
   • BPM triplet at \( z = 0, 2.5 \) and 5.0 meter spacing. BPMs 1 and 3 define straight line. Monitor BPM2 offset over time scales of minutes, hours
   • 2 adjacent BPMs to test electrical stability, separate from mechanical (analyze existing E158 BPM or LEP-II BPM data for stability)

3. SR stripe tests
   • characterize detector performance and capabilities; scaling to LC configuration

4. LUMON pair/calorimeter
   • mimic pair background with fixed target?
   • mimic pair background with diffuse primary beam of 4-GeV electrons
   • characterize detector response to pair background
   • use MonteCarlo to superimpose 250 GeV electron to determine electron id efficiency

Requests can be processed through “Test Beam Requests” rather than PAC
Hope to have preliminary set of requests by mid-May

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ATF BPM Program

- Nano-BPM Collaboration between US & Japan
- Extensive tests at ATF in the extraction line:
  - 3 SLAC BPMs
  - “pristine” beam
  - multibunch capable
  - Tests of resolutions, stability
  - R&D on electronics, signal processing
  - beam tilt monitoring?

- Latest Results: ~90 nm resolution seen, potentially limited by relative motion of BPMs

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Mechanical Stability

- ATF supports not rigid enough \(\Rightarrow\) LLNL Girder

6-axis positioning

Passive rigid body at 1nm-level

Installed at KEK in Feb

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Monitoring Relative Alignment

- LLNL Girder and KEK Girder (active alignment) must be “linked” to study resolutions, stability
  - same problem as linking two sides of BPM spectrometer
- Zygo heterodyne interferometer:

  Design Specs:
  - 0.3 nm resolution
  - 20 MHz DAQ rate
  - 5m/s velocity

  Should arrive ~now
  - will test, then install in KEK this Fall if all goes well
Supplementary Slides:

- DESY Lattice location:

![Graph showing lattice location and dispersion](image)