THE HIGH-RESOLUTION SPECTROMETER AT PEP

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ABSTRACT

A description is presented of the High Resolution Spectrometer experiment (PEP-12) now running at PEP. The advanced capabilities of the detector are demonstrated with first physics results expected in the coming months.

The past year has seen the new High Resolution Spectrometer experiment (PEP-12) rapidly come into operation at PEP. In a brief but marked departure from the major tenor of this conference on jets, I would like to describe this new tool for studying jet properties and other $e^+e^-$ physics.

With first PEP beams arriving in November, 1981, the HRS detector was fully checked out for physics by mid-December. For the rest of the 1981-1982 PEP year, the HRS logged highest quality data with extremely high reliability. Approximately 90% of all the luminosity produced by PEP resulted in good data which was successfully logged on tape during that period.

The High Resolution Spectrometer is a general purpose $e^+e^-$ detector with the emphasis placed, in its current configuration, on charged particle tracking (Fig. 1(a) and 1(b)). It features:

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• Charged particle tracking in a 1.6 Tesla magnetic field with a 2 meter tracking radius and 200 μm spatial resolution. These combine to give Δp/p = 0.1%·p for the central 65% of the solid angle and Δp/p < 0.5%·p for the central 90% of the solid angle. There are a total of 3720 cells in 20 layers, including a newly installed vertex chamber.

• Electromagnetic calorimetry located inside the coil with position resolutions of 2 cm giving ±10 mrad angular precision for both θ and φ. Energy resolutions of ΔE/E = 0.16/√E for the Barrel shower counters (0.6 of 4π) and ΔE/E = 0.20/√E for the End Cap shower counters (0.27 of 4π). An e-π separation of 1-2% was measured in a test beam for electron energies of 1-2 GeV. Forty barrel counters and 40 end cap counters provide segmentation with a total of 200 phototubes.

• Hadron identification is accomplished by time-of-flight for low momenta. A time resolution of στ = 350 psec permits K/π separation to 1.1 GeV/c and p/(K,π) separation to 2.0 GeV/c. In addition, for this coming year, identification of higher momentum particles will be possible with 704 Cerenkov ionization cells which are now installed in the HRS covering 60% of the solid angle. At the highest pressure, these permit (K,p)/π separation between 1 and 4 GeV/c and p/(K,π) separation for momenta greater than 4 GeV/c. We now expect to run them at somewhat lower pressure and set the π-K window to 1.8-6.0 GeV/c. The Cerenkov system provides the HRS with a unique hadron identification capability with high segmentation.

On-line reconstruction capabilities are illustrated in Fig. 2, which displays reconstructed information from all active systems of the detector. Initial background problems encountered at PEP due to RFI pick-up on the drift chamber electronics and due to synchrotron radiation in the drift chambers themselves were rapidly diagnosed and eliminated. The high reliability achieved by the detector in its first year of operations owes much to this on-line monitoring.

The full reconstruction of a "typical" PEP event by the off-line production analysis program is shown in Fig. 3 and, in more detail, in Fig. 4. These figures indicate the tracking capabilities of the present detector and its associated software which have been achieved to date.

Operation of the HRS superconducting solenoid during the first year at PEP has proved extremely reliable. Over 4000 hours of operation at 1.6 Tesla magnetic field (2043 amperes) was obtained with only 1.5 days of physics data-taking lost to magnet problems, with an additional 2 days of unscheduled low field running. No measurable PEP/HRS coupling is observed below 0.5 Tesla and at
On-Line Reconstruction

HRS RUN-2633

EVENT= 20655
DCHITS = 192
NPRNG = 7
SH SUM= 11.2 * 1.1

TRACK MOMENTUM THETA
-5.0 87.0
-0.7 117.8
-0.5 94.7
-4.2 77.1
0.5 109.4
-0.7 97.1
-3.1 101.3

ECODE - 52 NPRNG TOT. ENERGY
TRIG. = F1 F2 F3 F4 56 A2 O1 O

Fig. 2. Example of on-line event reconstruction.

Off-line reconstruction of a typical event.

ECODE - 52 NPRNG TOT. ENERGY
TRIG. = F1 F2 F3 F4 56 A2 O1 O2

Fig. 3. Off-line reconstruction of a typical event.
higher fields the skew quad compensation scheme has minimized impact on the PEP machine. During the course of the year, refrigerator operation became quite routine. A total power consumption of 0.5 MW maintains the full 2000 Amp current as well as our 7000 l liquid helium reserve using the available 20 l/hr excess production capacity.

Advantage was taken of the flexible triggering capability of the HRS to provide comprehensive, minimum-bias triggering at PEP. The dual-level trigger decision required events with 2 tracked particles to be approximately in time (80 nsec) but multiparticle events (≥3) with trajectories going into 80% of the solid angle escaped even this loose requirement. In addition, neutral triggers with 3.3 and 4.8 GeV thresholds made the detector sensitive to a variety of event topologies with very low charged multiplicity. Finally, a special end cap trigger permits triggering on high dip tracks, such as small angle u pairs down to θ = 18°.

The expected momentum resolution for the High Resolution Spectrometer in its PEP configuration is shown in Fig. 5 as a function of momentum. Both the first year's configuration without Cerenkov counters and the present (second year) configuration, with Cerenkov counters installed, are shown. These resolutions can be described by

\[(\Delta p/p)^2 = \sigma^2 + (0.001p)^2\]
Fig. 5. Calculated momentum resolution.

where \( \alpha = 0.0027 \) and \( 0.0063 \), respectively, for the case without and with Cerenkov counters. Progress toward these expectations is shown in Fig. 6 which represents the residual distribution for all 15 inner drift chamber layers and is already characterized by a spatial resolution \( \sigma = 170 \mu \). Although the outer drift chamber is internally characterized at present by \( \sigma = 250 \mu \), or better, present efforts are focused on resolving systematic alignment problems between the inner and outer drift chambers which are constraining the present spatial resolution of the whole system. Just how well the detector is able to do at this stage of the analysis is shown in Fig. 7. This shows the momentum distribution for Bhabha scattered electrons giving a resolution of \( \Delta p/p^2 = 0.18\% \), after unfolding radiative effects. With a vertex constraint and final alignment, we expect to achieve the value of \( \Delta p/p^2 = 0.10\% \) shown in Fig. 5.

Shower counter performance has also closely approached expectations. Figure 8 shows time-of-flight measurements now obtained on this first year's data. For minimum ionizing hadrons shown in Fig. 8(b), whose photostatistics are not amplified by the converter in the shower counter, a resolution of \( \sigma_t = 360 \text{ psec} \) is obtained and the effectiveness of this for hadron separation is shown in the \( \theta \) vs \( p \) plot shown in Fig. 9. The shower energy measured in the barrel for Bhabha scattered electrons is shown in Fig. 10 for the barrel shower calorimeter and in a scatter plot between the two ends in Fig. 11 for the end cap shower calorimeters.
Fig. 6. Measured distribution of residuals in the inner drift chamber.

Fig. 7. Momentum distribution of Bhabha scattered electrons.
Fig. 8. Time-of-flight distributions for (a) Bhabha scattered electrons and (b) minimum ionizing particles.

Fig. 9. $8$ vs momentum for particles in hadronic events.
Fig. 10. Energy distribution in barrel shower counter for Bhabha scattered electrons.

Fig. 11. Energy distribution in the end cap shower counter for Bhabha scattered electrons.

For most of the coming year, the Cerenkov toroids will provide particle separation at higher momentum and the new vertex chamber (396 cells) will help reduce further our trigger rate and provide us with somewhat improved tracking precision.

Data analysis of the 23700 nb^{-1} obtained during the HRS's first year of running at PEP has proceeded on schedule, within the limits of computer resources available to us for production processing up to the present time. Approximately 90% of last year's data has now been processed onto data summary tapes by our production reconstruction program running in the Midwest and at SLAC. In large part, this was made possible by IBM 3081 time provided us
by SLAC for running a fast filtering program which first reduces the number of events by a factor of 5. This mode of operation is expected to continue into the present second year of PEP data, although helped by the reduced trigger rate obtained with the vertex chamber. Some relief for our data processing problem is expected in the first quarter of 1983 with the installation of a VAX 11/750 farm. This will increase the group's available CPU power to better match the power of the detector itself.

While the analysis is at the point of reprocessing the DST's at the next level with more refined versions of the various reconstruction programs, software development has continued apace in the areas of Monte Carlo programs and analysis programs of all sorts for extracting physics from the HRS data. Figure 12 shows the angular distribution of Bhabha scattered positrons, acceptance corrected, currently obtained in the barrel region of the HRS detector and Fig. 13 shows the same for Bhabha scattering positrons in the end cap down to 220°.

The charged multiplicity observed in hadronic events is plotted in Fig. 14 without acceptance corrections and the tuning of jet analysis programs is illustrated with the sphericity vs aplanarity plot of Fig. 15. With resonance reconstruction a prime strength of the HRS, the current status of the detector is typified by the $K^0_S$ mass plot shown in Fig. 16. The observed resolution is $\sigma = 4 \text{ MeV/c}^2$.

![Figure 12: Angular distribution of $e^+e^- \rightarrow e^+e^-$ measured in the barrel shower counter.](image)
Fig. 13. Angular distribution of $e^+e^- \rightarrow e^+e^-$ measured in end cap shower counter.

Fig. 14. Uncorrected charged multiplicity distribution for multihadron events.
Fig. 15. Sphericity vs aplanarity distribution for hadronic events.

Fig. 16. \( K_S^0 \rightarrow \pi^+\pi^- \) effective mass distribution.
Although not obtained with the final reconstruction constants or algorithm, this is already a substantial improvement on K° mass resolutions obtained by previous detectors. Gaining full advantage of the HRS capabilities in this area at PEP will depend, of course, also on suitable integrated luminosities provided by the PEP machine.

As part of a broad e+e− physics program, we are planning a systematic study of the properties of jets in order to confront at the next level QCD and other models being discussed here. These studies include:

- Stable particle content, including baryons
- Leading particle effects
- Resonances ρ, K*, φ, D, D*, etc.
- Charge, flavor and baryon number compensation
- Correlations in rapidity and transverse momentum
- Correlations between jets
- Flavor tagging for identifying quark jets
- Separation of gluon jets

In short, great strides have been made toward the realization of the substantial potential of the HRS detector during its first year of running at PEP. Good physics contributions are anticipated based on this year's data utilizing the detector's unique combination of good resolution and particle identification. It is hoped the coming year's accumulation of truly high integrated luminosities will permit the HRS to open new paths in the physics of the PEP/PETRA energy range.