DARHT-II ENERGY ANALYZER*

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Abstract

A energy analyzer system is being built for the DARHT-II accelerator similar to the energy analyzer used on the Astron accelerator [1]. This system consists of a scattering wire, magnetic bend, and null signal detector. The wire thickness of 40 mil carbon and the scattering angle of 11 degrees is chosen for good signal to noise ratio. The dipole bend angle is 60 degrees, with a 30 cm radius of curvature. The image-plane focal distance is chosen for the required energy resolution. The energy resolution and acceptance are 0.1% and ±5% with a time response of 10 nsec. The wire must survive the 2usec 2kA, 18.4 MeV DARHT-II beam. The MCNP code [2] was used to study the wire scattered properties. The scattered beam fills the available 1x2 cm dipole aperture. The dispersion normal to the beam direction is 0.43 cm/%. The detector is a PIN diode array which determines the beam position on the chip. This array consists of 40 2.5x0.1x0.25 mm bins with a gain in excess of 10000. The system will be installed in the space between the debris blocker and the cruncher solenoid up-stream from the shuttle dump [3].

1 Introduction

We have developed a energy spectrometer for DARHT-II based on an instrument developed for the Astron Accelerator some 30 years ago. We propose to locate the spectrometer downstream of the Debris Blocker in front of the Shuttle Dump, figure 1. The preliminary specifications of the analyzer are:

Energy Resolution	≈ 0.1 %
Energy Acceptance	± 5 %
Relative accuracy/repeatability	≈ 0.1 %
Absolute accuracy	< 1 %
Time response	< 10 ns

Consideration was given to minimizing perturbations of the primary DARHT beam when the analyzer is not in use.

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* This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

The instrument uses a small rod or wire placed transverse to the beam to scatter a tiny fraction of the primary beam into a secondary beam line. The secondary line is 11 degrees from the main line. The scattered beam travels one meter through an adjustable aperture located in front of an analyzing magnet that bends the scattered beam 60 degrees further from the main beam and focuses it to approximately a 1 mm wide strip at the plane of a PIN detector array ≈ 34 cm away. The image of the scattering wire at the detector plane is approximately a 1x 10 mm ellipse. The detector array is 4 cm long in the bend plane and is located transverse to the scattered beam. The energy acceptance of this detector array intercepts electrons within ± 5% of the central ray energy and amplifies the scattered beam current by a factor greater then 10,000. Calculations suggest that the energy of the scattered beam can be determined with a resolution of approximately 0.1% by electrically determining the transverse position the secondary beam strikes the detector array.

2 Scattering wire

Because of the higher DARHT beam energy, obtaining adequate signal at the detector required a scattering rod or wire that was about 1 mm in diameter if carbon or 0.5 mm diameter if titanium. However, the temperature of the carbon wire could increase by as much as 1000 degrees C and titanium would not survive a 2 cm diameter DARHT beam at full current and pulse width. As a consequence, if required we propose to expand the beam to 7 cm diameter thereby dropping the beam current density by a factor of 10 when the scattering wire is present by turning off focusing upstream of the wire, figure 2. The energy lost in the scattering wire is not negligible and can amount to as much as 1 or 2%. Fortunately, the Monte Carlo code calculations indicate that the energy spectrum is spread by only about 0.5%. When the analyzer is not in use, the scattering wire is withdrawn from the main beam line to avoid perturbing the primary beam.

3 Magnet

The bend magnet is based on the design of an existing Los Alamos magnet. The principal difference is that the gap is increased from 1 to 1.5 cm. This will permit the insertion of a separate aluminum vacuum chamber with inside dimensions of 2 cm width by 1 cm height. It also will permit the insertion of a precision Hall effect Gauss meter in the magnet gap for precise determinations of the bending magnetic field. The beam enters and exits normally to the magnet with a 30 cm radius of curvature in the magnet under nominal conditions. This provides a bend plane focusing of the beam some 30 cm past the magnet exit, figure 3.

4 The Detector

The detector was designed for operation at very low rep-rate. It consists of a 0.25 cm wide by 4 cm long strip of silicon biased to approximately 500 Volts. The strip is segmented every 0.1 cm to form 40 0.25x0.1 cm sections orentiated transverse to the detected beam as indicated in figure 5. The strip is 250 um (0.025 cm) thick and is p-doped on front and n-doped on back to form a PIN array. Energy deposited in the detector from the scattered beam creates electron hole pairs in the silicon which are swept out by the bias voltage. Calculations suggest that a current gain greater than 10,000 should be expected. The time response of the detector is predicted [4] to be approximately 10 nsec.

5 Signal Strength

The point design has tended to maximize the amplitude of the detector signal under the philosophy that too much signal is better than too little. Calculations suggest that the signal voltage could be several hundred volts, which is much more than adequate, and more than the PIN detector could provide. An aperture in front of the magnet was included to provide a simple way of reducing the signal if required. Using a smaller scattering wire and/or switching to carbon would also be very effective in lowering signal strength. Notice that all these strategies would improve the resolution of the instrument and carbon would survive much better.

6 Shielding

The PIN detector is sensitive to both the scattered electrons and the x-ray background so shielding will be required. The detector is located just in front of the shuttle dump but its view of the dump is partially occluded by a large focus magnet. Initial scooping shielding calculations suggest that the unshielded x-ray signal will be approximately equal to the detector signal. Thus it appears that the detector must be housed in a shield-enclosure that reduces the background x-ray intensity by 2-3 orders. Some actual measurements of the background x-ray flux on FXR have indicated taht the x-ray background may not be as serious a problem as first thought.

7 Calibration

We estimate that a determination of the absolute energy the DARHT-II beam accurate to perhaps 1% can be obtained from knowledge of the parameters of the analyzer and a measurement of the bending magnetic field. If a more accurate measurement of the beam energy is required, the analyzer could be calibrated using a known beam.

The instrument will first be mounted on ETA II to test the DARHT analyzer with an actual electron beam prior to deployment on DARHT. Calculations suggest that because of the lower ETA II energy, a 10 mil carbon wire will generate approximately the same detected signal as a 40 mil wire used with DARHT II.

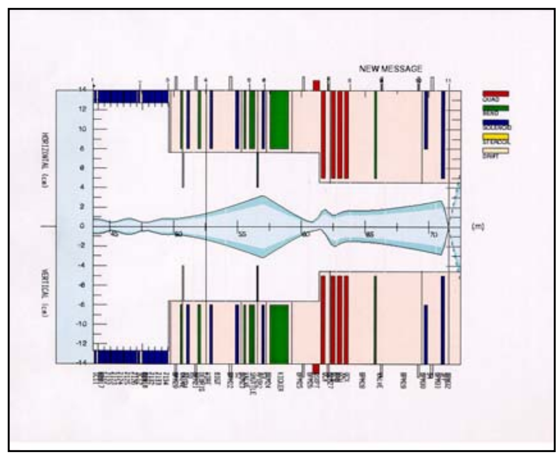

Figure 1) Nominal beamline extending from the exit of the accelerator to the x-ray target. The energy analyzer scattering wire will be located at 52.5 meters and is shown here as the line intersecting the beam.

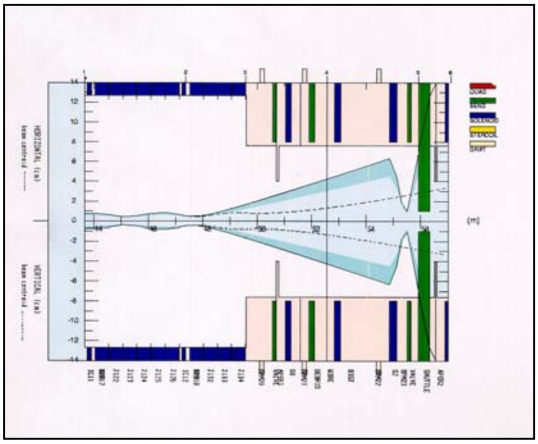

Figure 2) Magnets leading up to the scattering wire are turned off so the beam expands to reduce the current density on the wire shown here as the line intersecting the beam. Dashed line the beam profile with magnets on.

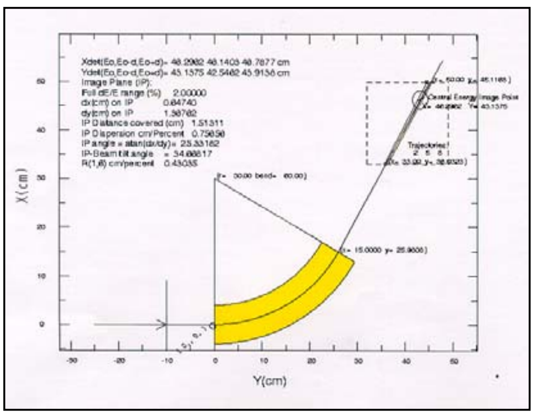

Figure 3) Overall layout of the energy analyzer components. Intensity aperture, dipole magnet, and PIN detector. The scattering wire is off scale to the left.

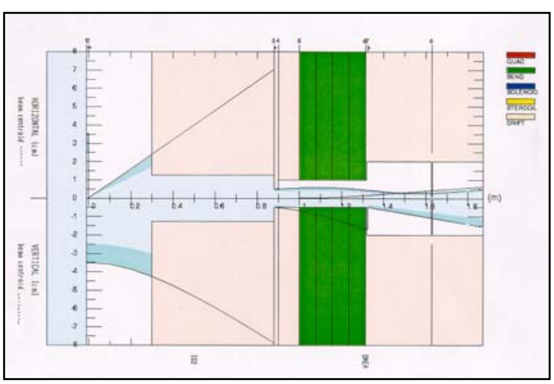

Figure 4) The available aperture varies along the path leading to the PIN detector. The scattered beam passing through the limiting aperture almost fills the available gap of the magnet.

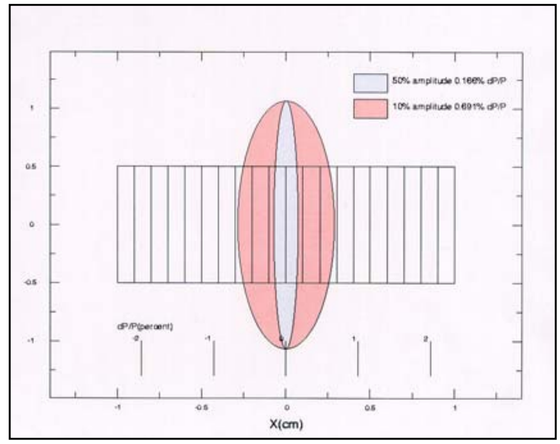

Figure 5) Beam super-imposed on the detector showing the 50% and 10% amplitude foot print. The detector has a 0.1 cm bin size and covers a 1 by 4 cm area. The beam hard edge half size is 0.287 by 1.07 cm, at the 50% amplitude the full size is approximately the detector bin size.

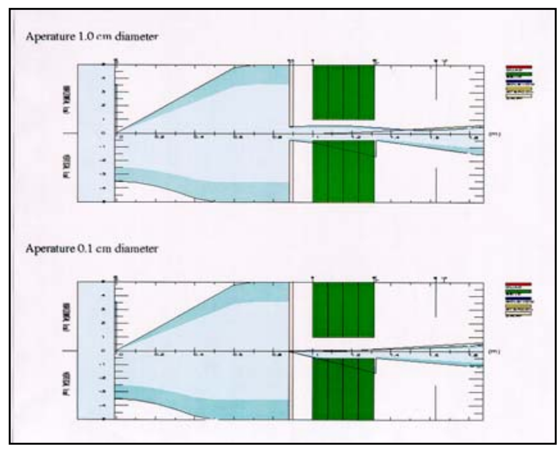

Figure 6) Effect of the collimating aperture on the beam intensity at the detector. Above, 1.0 cm diameter aperture with intensity $i/Io \approx 1.74 \times 10^{-5}\ P(\theta)$, below, 0.1 cm diameter aperture with intensity $i/Io \approx 1.74 \times 10^{-7}\ P(\theta)$.

8 References

[1] T.J. Fessenden, "The Astron On-Line Beam Energy Analyzer", Rev. of Sci. Instruments., 43, 1090, (1972)

[2] "MCNP - A General Monte Carlo N-Particle Transport Code", LA-12625-M, March 1997.

[3] A.C.Paul, G.J.Caporaso, Y-J.Chen, G.Westenskow, W.M.Fawley, E.P.Lee. "The Beamline for the Second Axis of the Dual Axis Radiographic Hydodynamic Test Facility" 1999 Particle Accelerator Conference, New York.

[4] R.W. Kuckuck, "Semiconductor Detectors for use in the Current Mode", UCRL-51011 (1971)