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DARHT Axis 1 Time-Resolved Injector Energy Measurement

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The Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility provides flash radiography capabilities using electron Linear Induction Accelerators (LIA's). The strict requirements for flash radiography require a detailed understanding of the LIA's performance, including precision measurements of the injected electron beam energy. The DARHT Axis 1 injector of produces a 3-4 MeV, 1-2 kA, 80-ns-FWHM electron beam. Injector capacitive monitors (EVACSUM) are summed to give the injector beam energy. Calibration of EVACSUM was last done in 1999 and is needed. In addition, the flatness of the injector drive voltage is controlled by a peaking capacitor in a Blumlien that is charged by the prime power tank. Time resolved measurements are used to optimize the value of this capacitor.

Spectrometer Description

Figure 1 shows a 3D drawing of the permanent magnet spectrometer assembly [Ref 1]. It consists of a collimator at the electron beam entrance, a vacuum chamber for beam transport and a removable 60-degree sector magnet constructed by SABR Enterprises [Ref 2] that is used to analyze the momentum of the incoming electron beam. There are electron detection planes located on the straight-through port and on the 60-degree ports. The planes are designed to accept phosphor screens or GAF Chromic film for time integrated measurements. For this experiment, screen/film is replaced by scintillators for time-resolved measurement using a streak cameras. The spectrometer was absolutely calibrated with a negative ion source [Ref 1].

[1] Nevada National Security Site

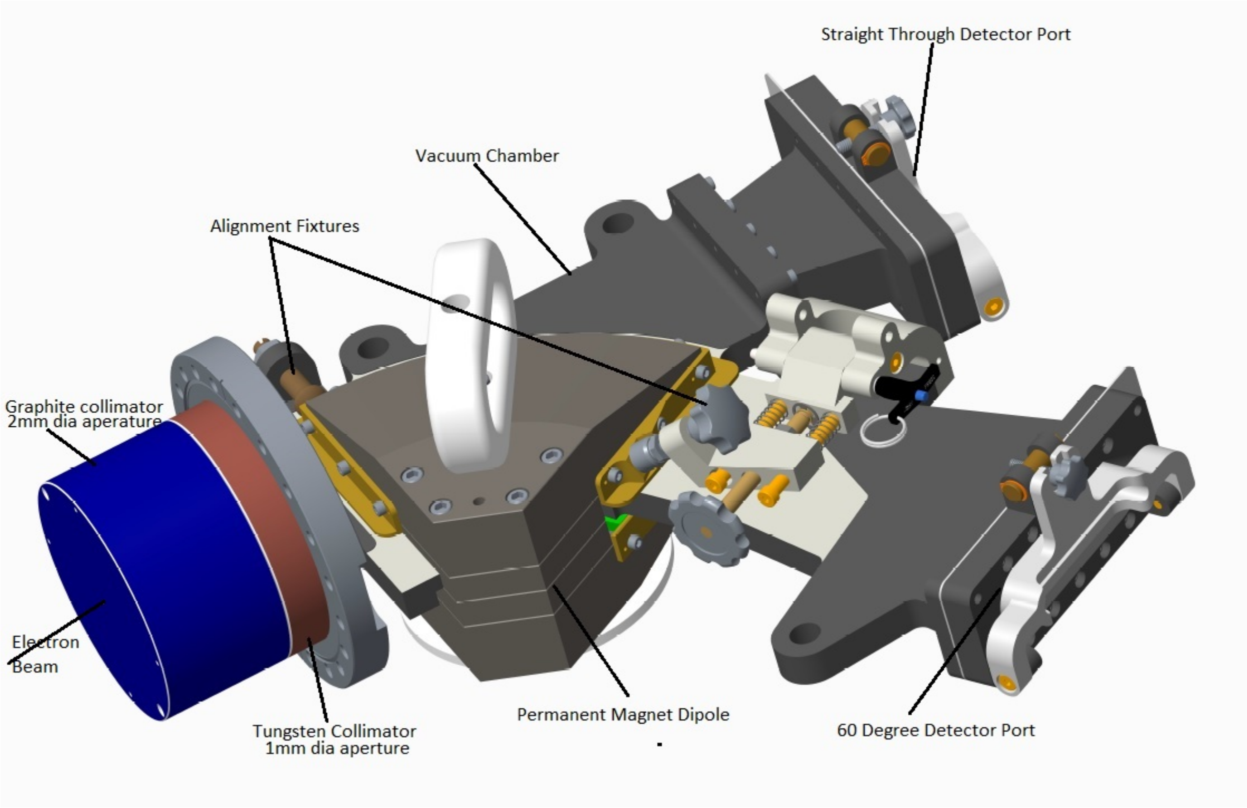


Figure 1. Schematic of CePMSpec.

Injector Set-up

Figures 2 and 3 show the spectrometer mounted on the front of the injector. For alignment to the accelerator, it is hard mounted to a ridged output flange. Small adjustments (~1-2mm) can be made using threaded support rods on the spectrometer. Injector vacuum was 1e-6 Torr or less for all of the data collection. Figure 3 shows a cross section of the injector with the spectrometer attached. The distance from the cathode to the entrance aperture of the collimator was 120cm. The size of the beam on the collimator was controlled by the anode magnet. The anode magnet was set at 210A producing a beam of 0.42 cm-diameter according to XTR [Ref 3]. The magnet current was adjusted to produce optimum light intensity on the streak camera.

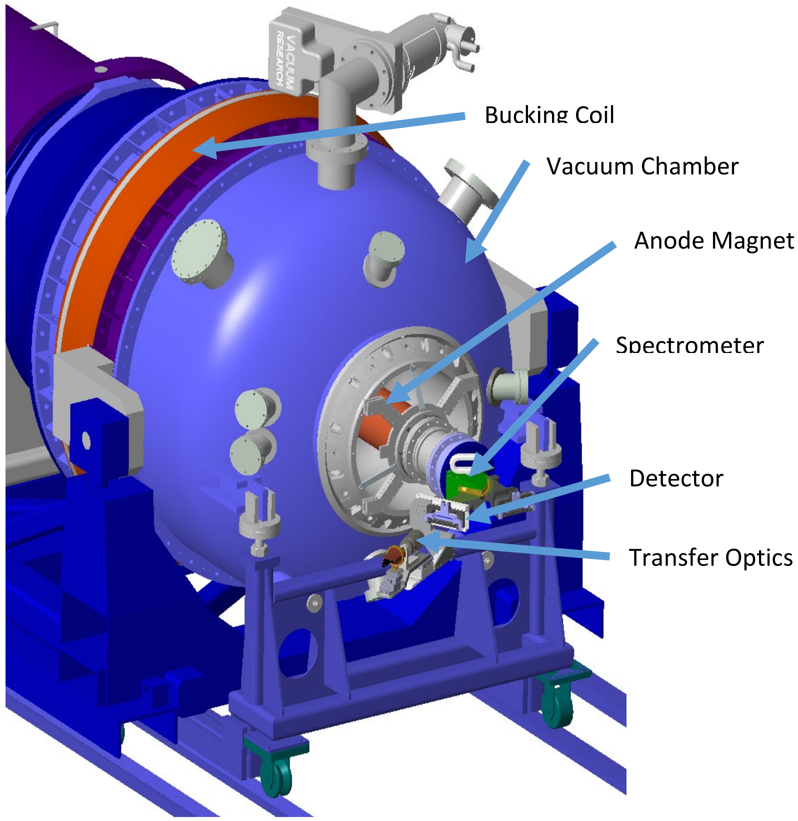


Figure 2. Injector –Spectrometer layout

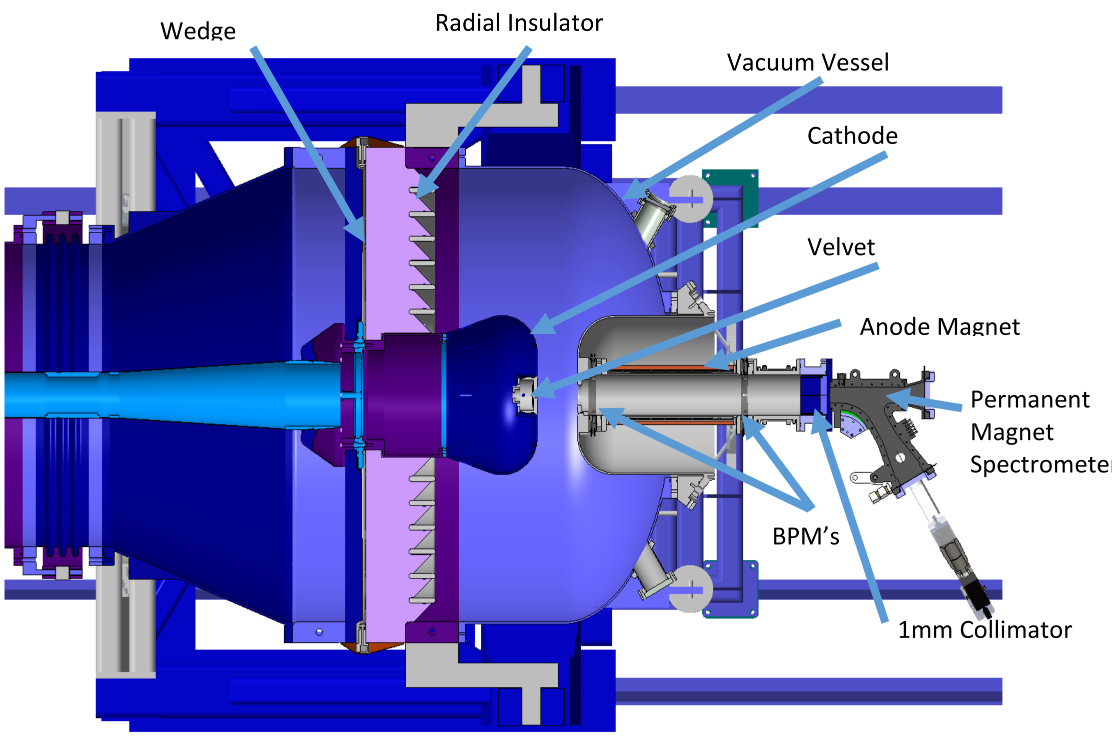


Figure 3. Injector/Spectrometer cross section.

Streak Camera Set-up and Calibration

A streak camera is an ideal diagnostic for measuring the beam energy as a function of time. It provides a 2-dimensional image where one axis is space and the other is time. In this case, the spatial dimension is directly related to electron energy by way of the spectrometer calibration (Ref 1). A schematic set-up of the streak camera interface to the spectrometer is shown in Figure 4. Light is generated by the 1mm diameter collimated beam striking a 1mm-thick scintillator located at the face of the 60 degree output window. The collimated beam current is calculated to be ~400mA (2.5E9 electrons/ns). The scintillator light is focused by a 105mm F2.0 lens on to a linear coherent fiber optic array. See transfer optics in Figure 2. The other end of the array is interfaced directly to the photocathode of a streak camera. At the photocathode the light is converted to electrons that are accelerated and then transported and deflected as a function of time through the streak tube to the output phosphor. The phosphor is coupled to a CCD array with a coherent fiber bundle.

The system triggering is synchronized with the Axis 1 accelerator. The cooled CCD is cleared and set to accept data ~300ms prior to the opening of the spinning wheel for beam transport. The gate which opens the photocathode and sweep which starts the deflection plates for the streak camera are prompt triggers that occur a few microseconds prior to the arrival of the beam at the spectrometer. Fine timing adjustments are made during initial acquisition. Typically the sweep length and gate width are long to find the light from the scintillator then the sweep time is decreased to achieve better time resolution.

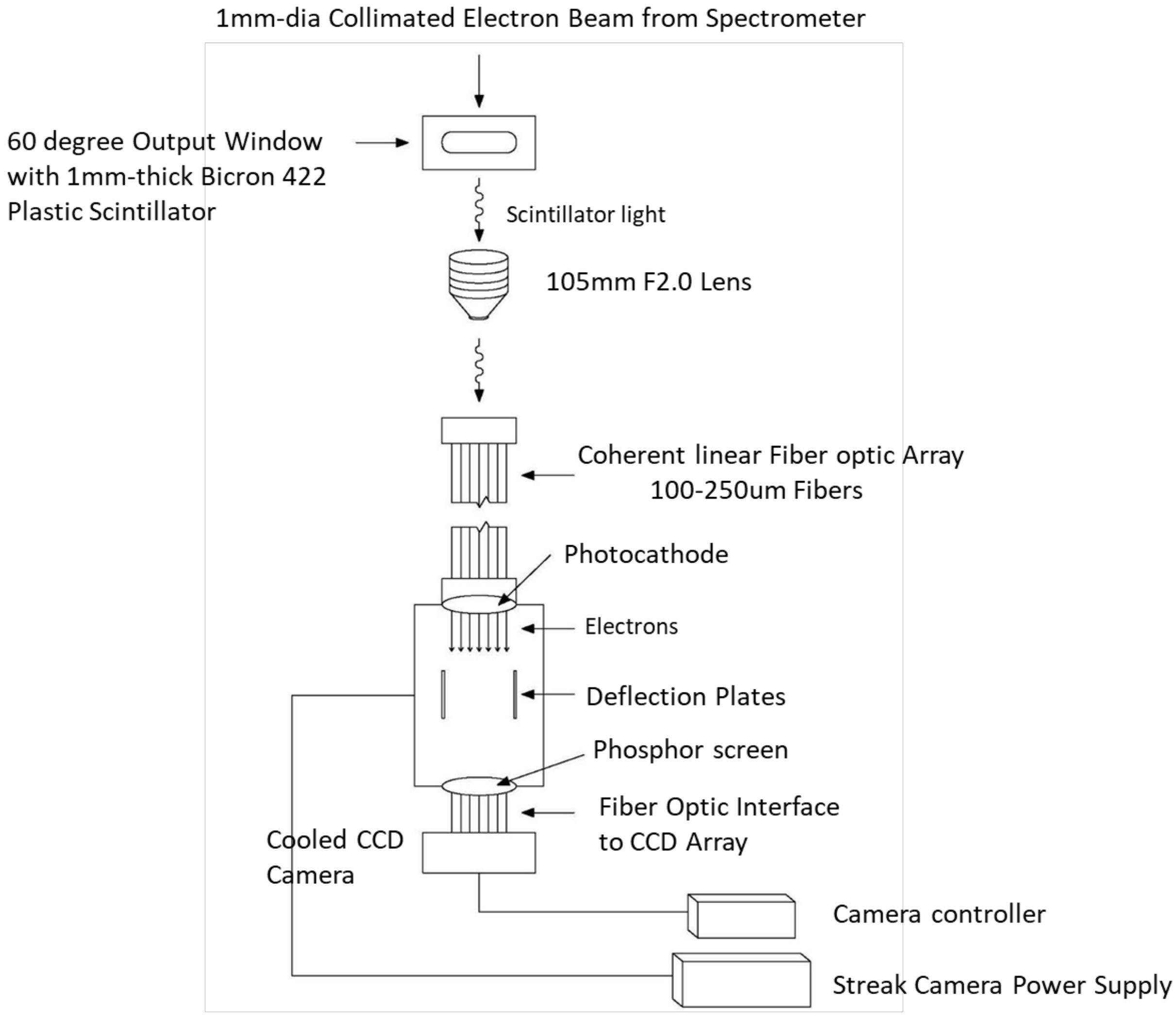


Figure 4. Streak camera schematic.

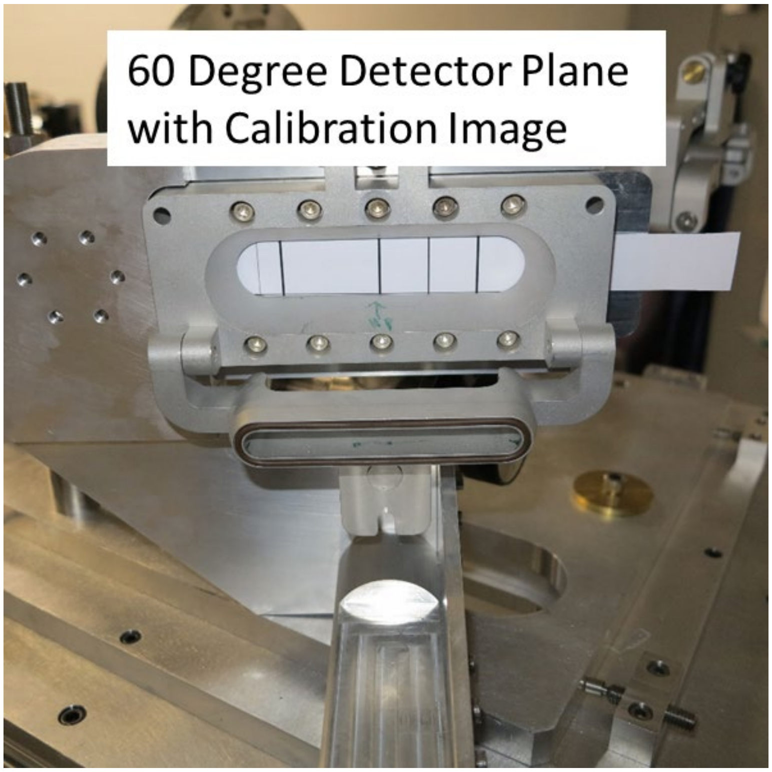


Figure 5. Detector plane with static calibration fixture.

Additional time integrated measurements are made using GAFCHROMIC film (type HD-V2). Film sheets are cut to provide precise seating against the spectrometer output window beneath the plastic scintillators. During operation, the film is exposed and provides a time-integrated record of the spectrometer output. During setup and spatial calibration of the spectrometer, the film is often used to align the fiber-coupled optics to the location where the beam strikes the output window. The film can later be digitized with a scanner and analyzed for comparison with the spatial calibrations developed with the streak-camera system.

A critical part of the spectrometer measurement is transferring spatial information from the spectrometer output to the CCD array. This is accomplished by placing a calibration image on the output of the spectrometer (Figure 5). The dark vertical lines correspond to 0 and +/-40mm. There is also a lighter line at +20mm. The lightest line corresponds to the edge of the vacuum chamber.

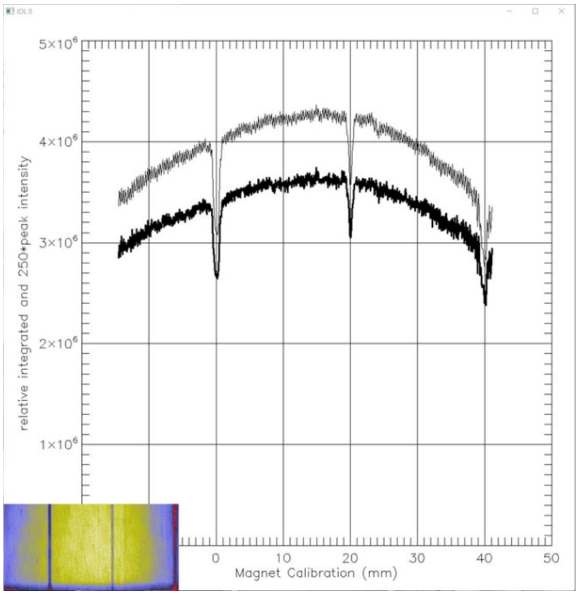


Figure 6. Line scans of static calibration image for peak and temporally integrated distributions.

The bottom of Figure 6 shows the raw CCD image used to extract the calibration information. The two lines in the plot are, the vertically integrated image (light) and the scaled peak of the image (dark) in the horizontal axis. The magnification is determined by adjusting its value to fit the displacement between lines. The reference pixel (zero location) is determined selecting mean pixel of the zero line location. Figure 6 plot indicates the accuracy of translation between pixels an spectrometer output. Figure 7 is another representation comparing the streak camera image with the calibration image.

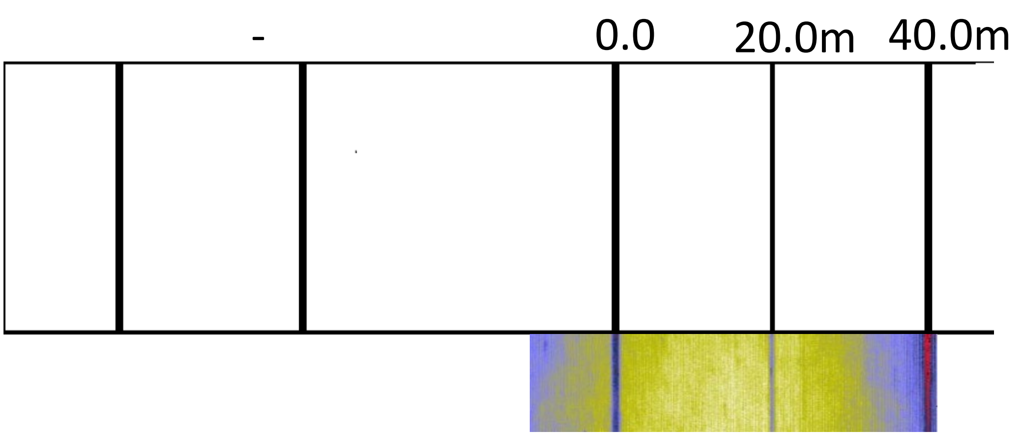
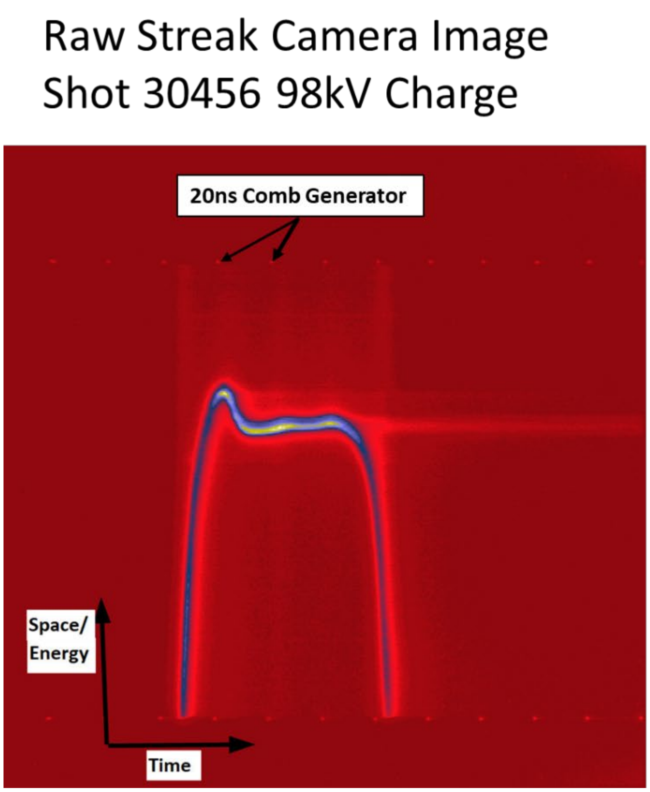
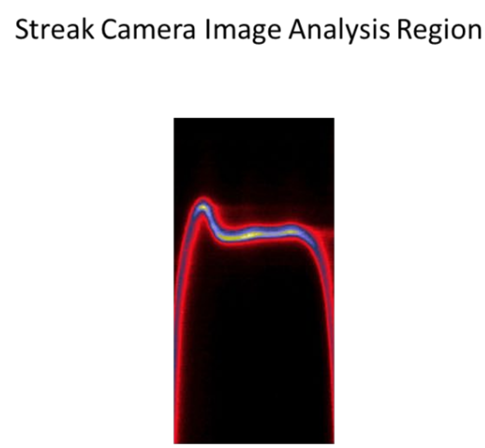


Figure 7. Streak compared with static calibration image

Measurements

A raw CCD spectrometer streak waveform is shown in Figure 8a). The image is oriented so that time is in the horizontal direction (increasing from left to right) and space (energy) is in the vertical direction. Qualitatively, the waveform is peaked at the front. Time calibration marks spaced by 20ns are also shown on Figure 8a). The time calibration marks are produced by a comb generator external to the streak camera. The Injector parameters for Shot 30456 were: Charge Voltage 98kV, Diode Voltage from EVAC Monitor 3.49MV, Beam Current at BPM2 1.57kA and Anode Magnet Current 210A. The second image in Figure 8b) is the raw data with constant background subtraction and cropped over the region of interest.



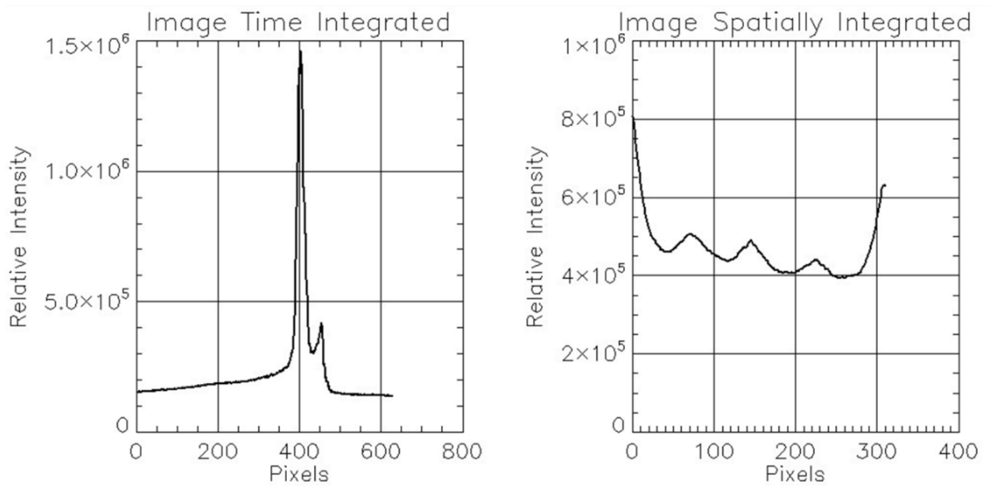


a) b)

Figure 8. Raw streak camera image with comb generator and image cropped for analysis.

Integration of the image in the horizontal dimension of Figure 8 b) is shown in Figure 9 a). There are clear peaks in the spatial dimension which is related to the electron energy. Integration in the temporal dimension shows the time variation of the pulse in Figure 9 b). The structure appears to be due to light modulation in the streak image.

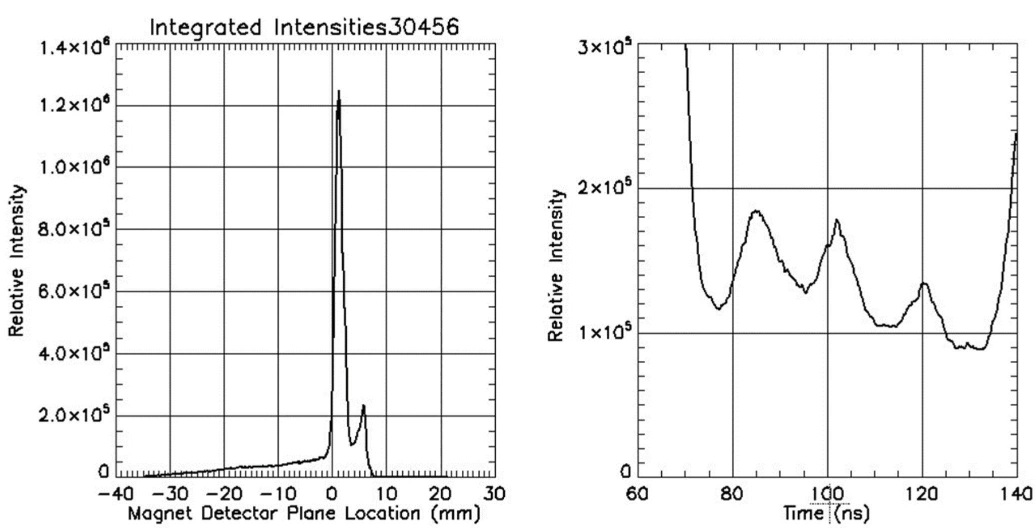
Horizontal and Vertical Integrated Plots for Shot 30456 98kV Charge
(Raw Data)



a) b)

Figure 9 Raw integrated intensity distributions a) in time and b) in space. The time integration (a) provides an identification of the most probable energy observed on the pulse. The space integration (b) provides an indication of total light intensity as a function of time.

The images are shown in Figure 10 a) and b) with calibration results included. This yields spatial and temporal information. The spatial information can be converted in to time integrated energy. The temporal result simply gives the pulse length because of the light modulation



a) b)

Figure 10 Integrated distributions with space a) and time b) calibrations. Background subtraction is included.

A sample of the technique for extraction of time resolved data is shown Figure 11. Two different temporal slices of the intensity are extracted from the cropped image, Figure 8b). The mean and the rms width of the time slice distribution are calculated. Also, the location of the peak of the same distribution is determined. These pixel values (mean and peak) are converted to spatial data using the calibration discussed earlier. Each time slice is analyzed over the entire image.

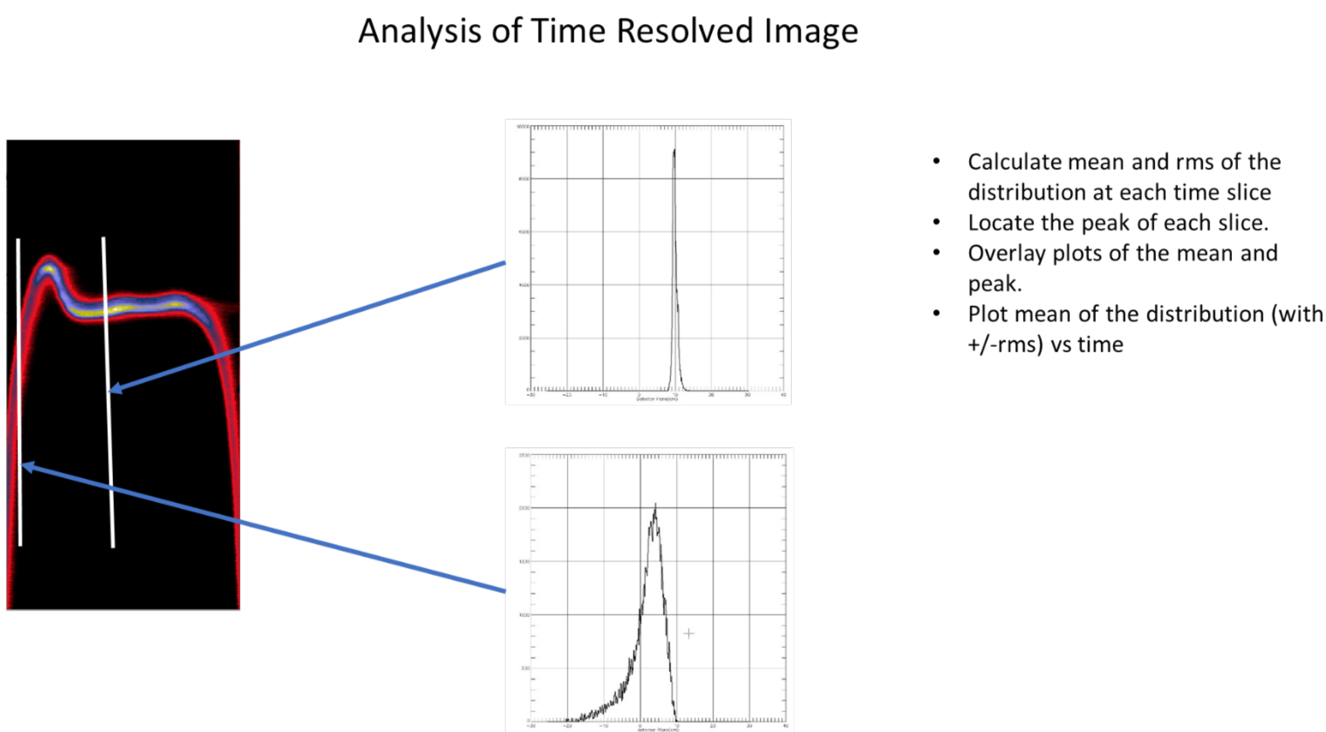


Figure 11 Sample intensity slices taken from a single streak image at two temporal locations.

Results of the complete time and spatially resolved analysis of a single image (Shot 30456) is shown in Figure 12. Peak and mean value of the distribution are over plotted and show good agreement. Deviations in agreement occur in the rise time because of the asymmetry in the distribution (see Figure11). The mean distribution is much smoother over the region of interest and is chosen for the remainder of the analysis.

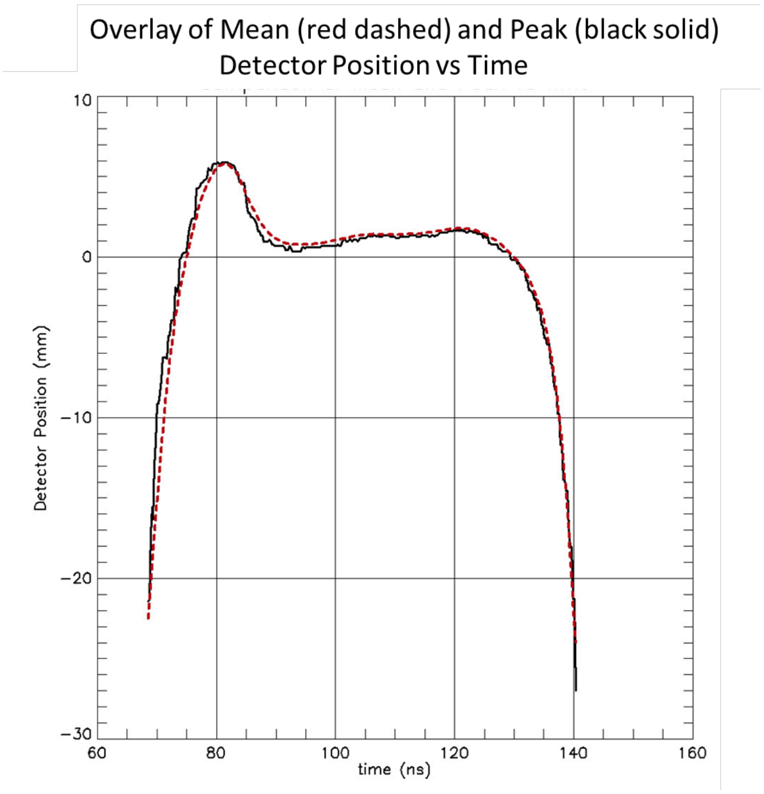


Figure 12 Detector position vs time for shot 30456. Red dashed line corresponds to the mean of the temporal slice. The black solid line refers to the peak at the same time.

Results

Using the spectrometer calibration factor for the 4MeV permanent magnet (Ref 1) and applying it to the result shown in Figure 12, an energy vs. time plot for Shot 30456 is generated and is given in Figure 13. Data are shown with the 60ns flat top region highlighted in red. Dashed lines correspond to the rms width of the distribution from which the mean was extracted. The mean value over 60ns is 3.343+/-0.207 and corresponds to an energy spread of 0.62%.

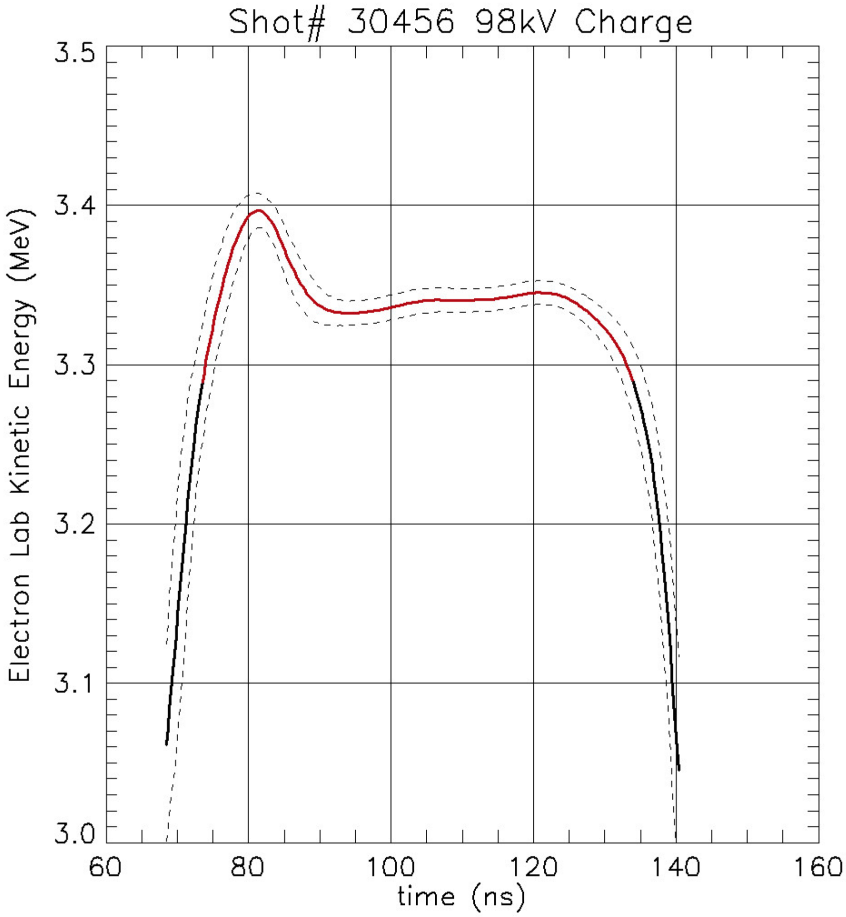


Figure 13 Time resolved electron beam energy showing analysis windows used in Figure 14 for 60ns (red) and 71 ns (black)

By using the time integral of the distribution, the result is shown in Figure 14. The distribution shows two peaks. The high energy peak is due to the variation in energy at the front of the pulse (Figure 13). This result plotted in Figure 14 is cut over 60ns peak (red) as well the full 71 ns (black). The mean value over 60ns is 3.345+/-0.024 and corresponds to an energy spread of 0.72%. This energy spread is larger than the value obtained from Figure 13 because the integration includes all intensities and not just the mean value of intensity.

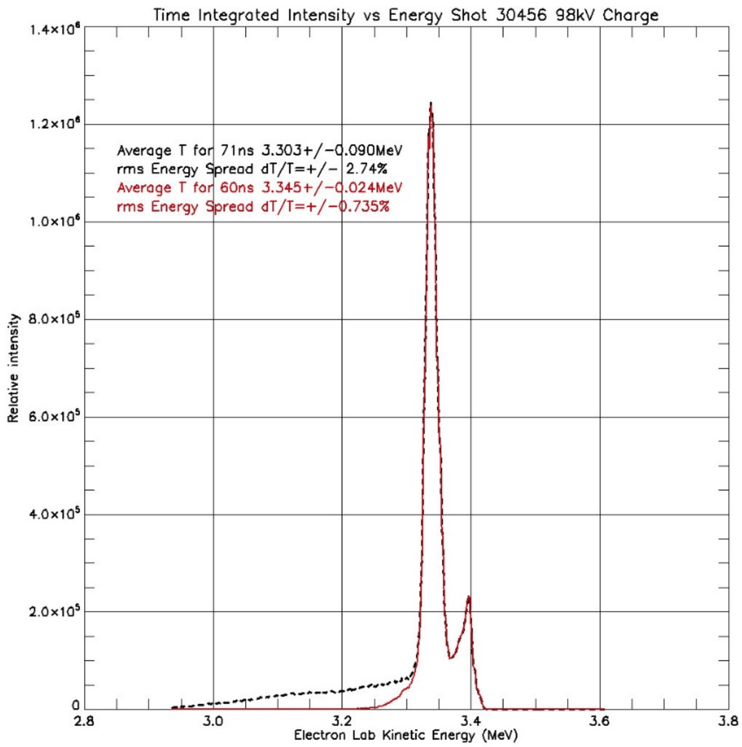


Figure 15 Intensity distribution for temporally integrated spectrometer waveform cut on 60ns (red) and 71ns (black).

References

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