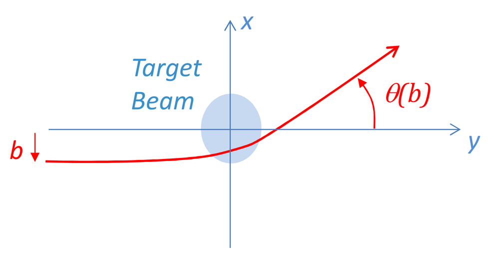
INSTALLATION STATUS OF THE ELECTRON BEAM PROFILER FOR THE FERMILAB MAIN INJECTOR*

R. Thurman-Keup#, M. Alvarez, J. Fitzgerald, C. Lundberg, P. Prieto, M. Roberts, J. Zagel, FNAL
W. Blokland, ORNL

Abstract

The planned neutrino program at Fermilab requires large proton beam intensities in excess of 2 MW. Measuring the transverse profiles of these high intensity beams is challenging and often depends on non-invasive techniques. One such technique involves measuring the deflection of a probe beam of electrons with a trajectory perpendicular to the proton beam. A device such as this is already in use at the Spallation Neutron Source at ORNL and the installation of a similar device is underway in the Main Injector at Fermilab. The present installation status of the electron beam profiler for the Main Injector will be discussed together with some simulations and test stand results.

Theory



Assume $\gamma \gg 1$, no magnetic field, $\rho \neq f(z)$

$$\vec{F}(\vec{r}) \propto \int d^2\vec{r}'\rho(\vec{r}')\frac{(\vec{r}-\vec{r}')}{|\vec{r}-\vec{r}'|^2} \qquad \Delta\vec{p} = \int_{-\infty}^{\infty} dt\ \vec{F}(\vec{r}(t))$$

Assume deflection is very small such that $\vec{r} \approx \{b, vt\}$

$$\Delta\vec{p} \propto \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} dy'\ \rho(x',y') \int_{-\infty}^{\infty} dt\ \frac{\{b-x', vt-y'\}}{(b-x')^2+(vt-y')^2}$$

$$\Delta\vec{p} \propto \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} dy'\ \rho(x',y')\ \mathrm{sgn}(b-x')\{1,0\}$$

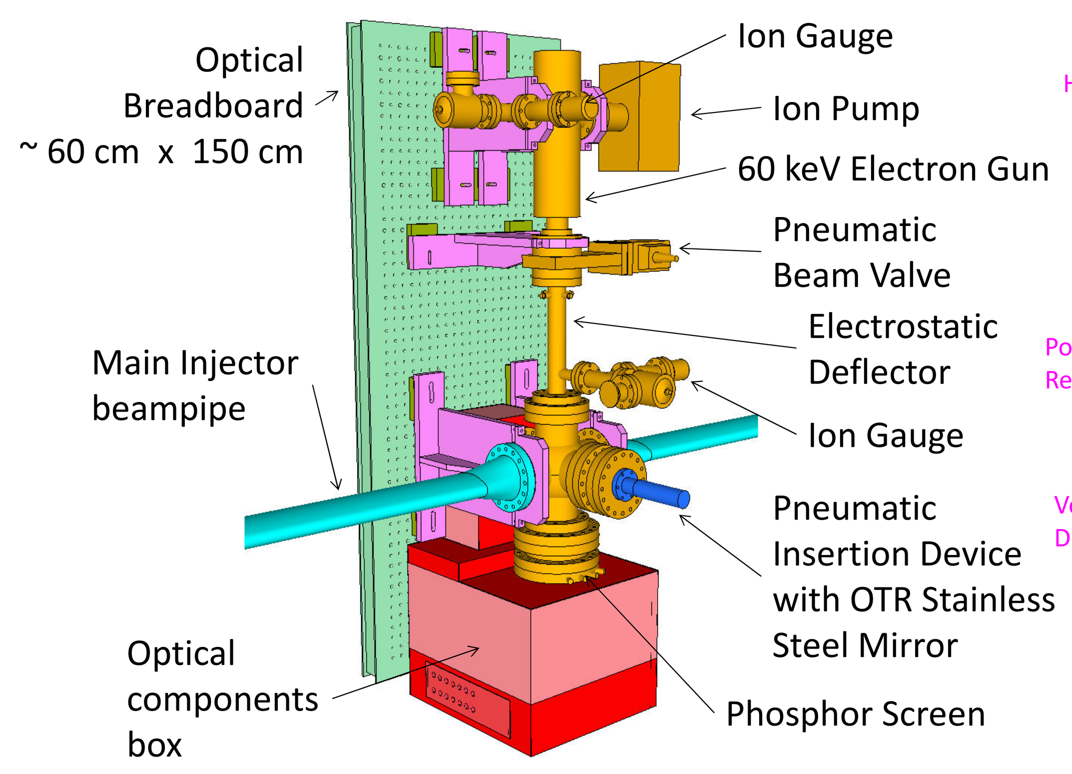
Assume again that deflection is very small such that $\vec{p} \approx \{0, p\}$ and $\theta \approx \frac{|\Delta\vec{p}|}{|\vec{p}|}$

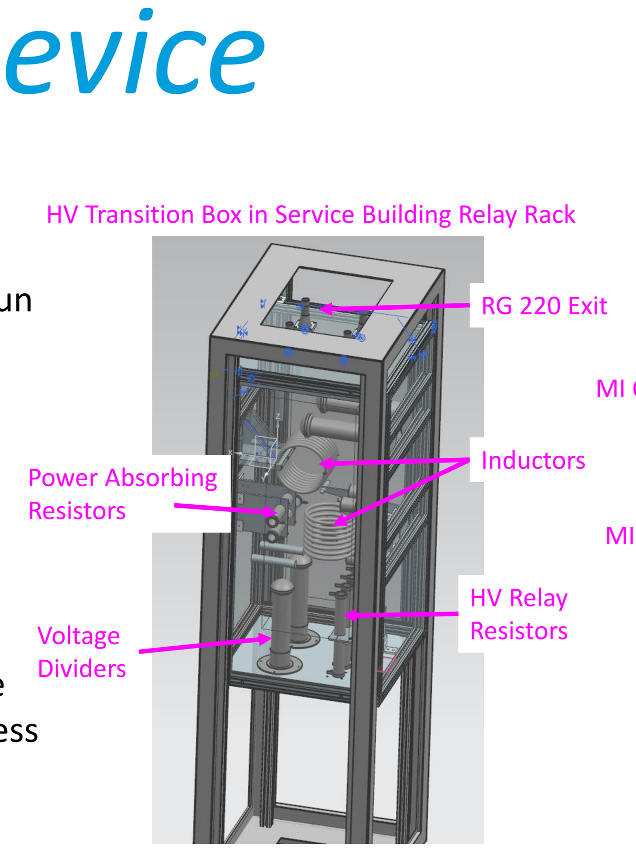
$$\theta(b) \propto \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} dy'\ \rho(x',y')\ \mathrm{sgn}(b-x') \rightarrow \frac{d}{db}\mathrm{sgn}(b-x') \propto \delta(b-x')$$

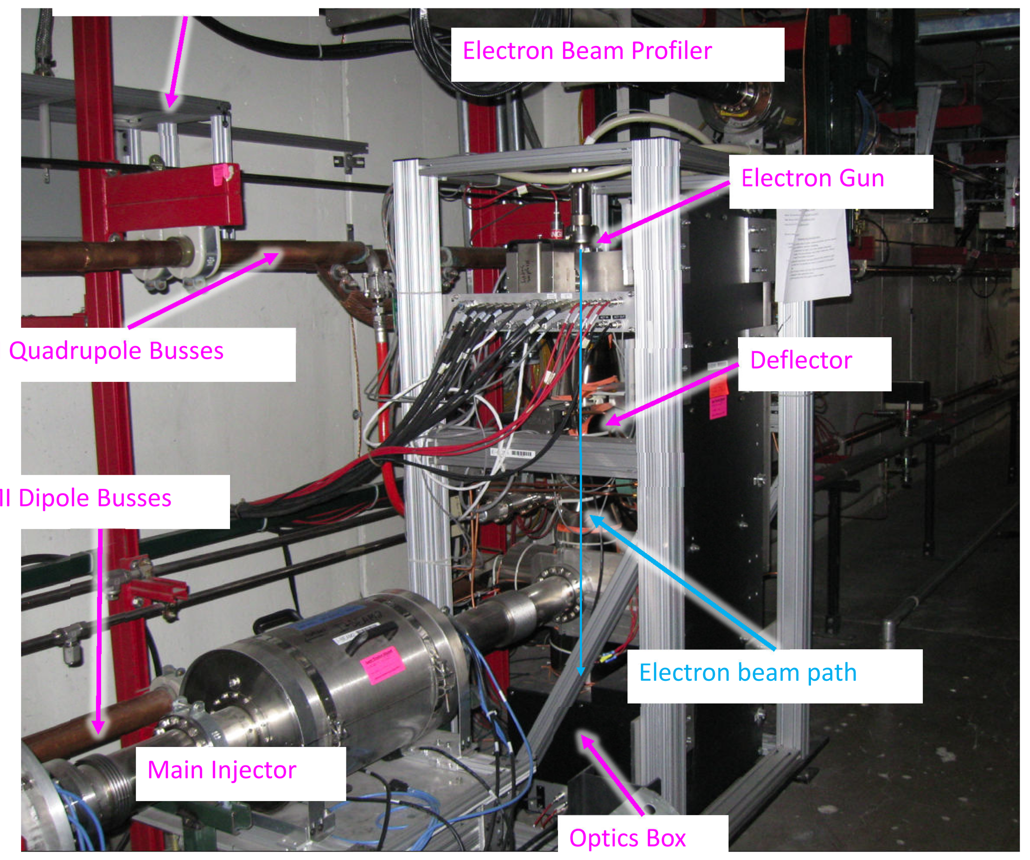
$$\frac{d\theta(b)}{db} \propto \int_{-\infty}^{\infty} dy'\ \rho(b,y') \longleftarrow \boxed{\text{x profile}} \qquad \xRightarrow{\rho=2D\ gaussian} \quad \frac{d\theta(b)}{db} = Gaussian(b)$$

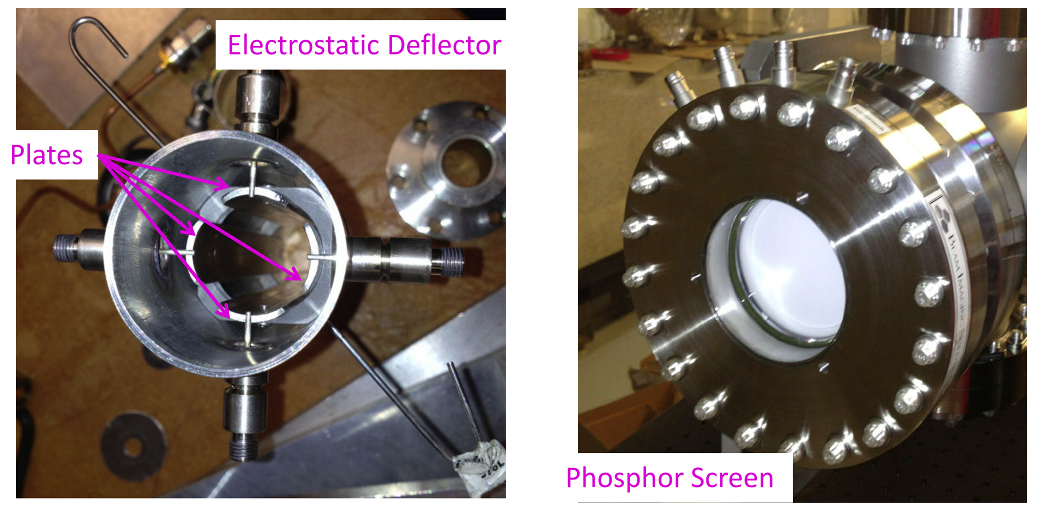
$$\boxed{\theta(b) = \mathrm{erf}(b)}$$

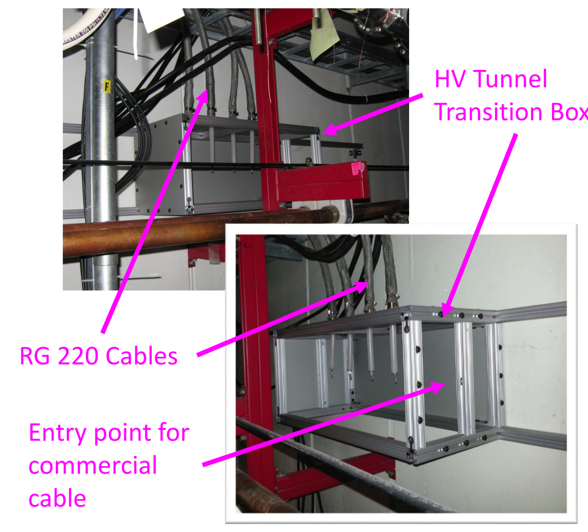
Device

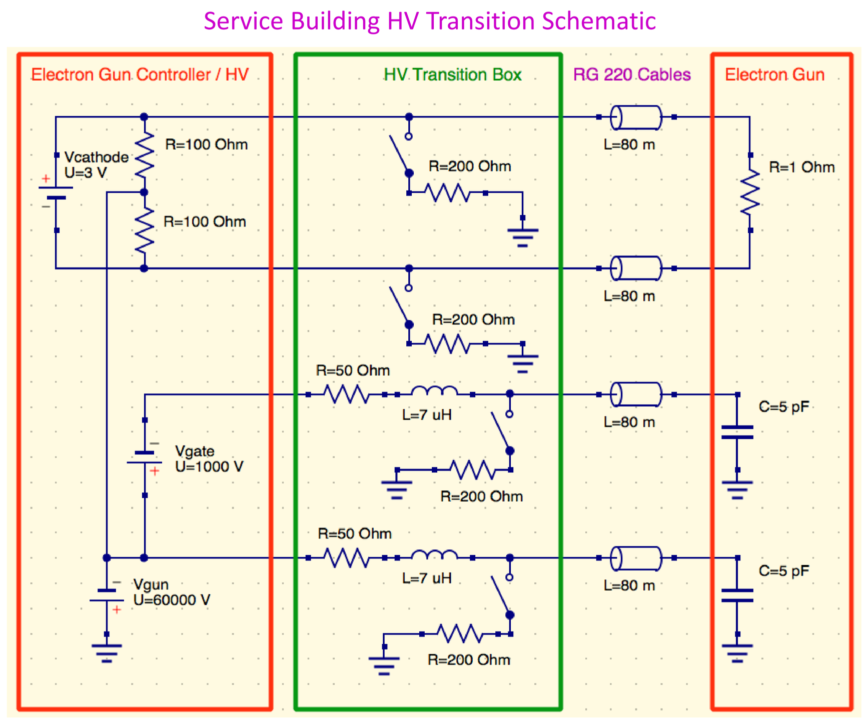










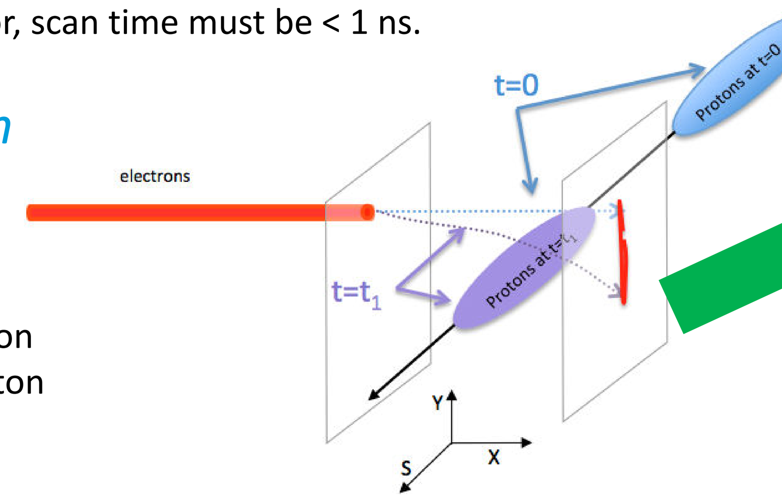


Experimental Techniques

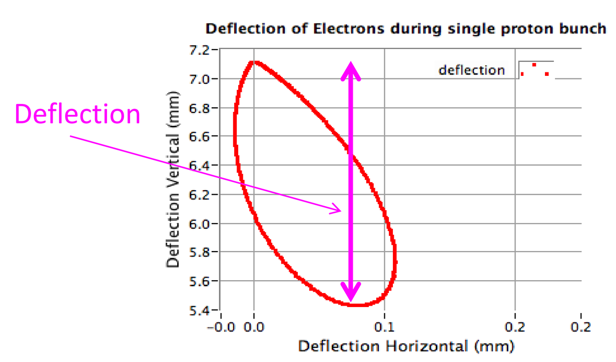
Fast Scan

Electron beam scanned diagonally through single proton bunch. Requires fast deflector. For Main Injector, scan time must be < 1 ns.

Slow Scan

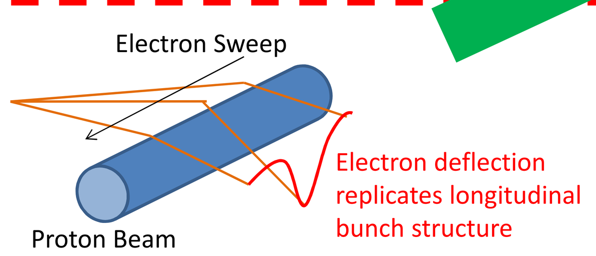


Deflection of a stationary electron beam as the proton bunch passes by. There is some deflection along the proton beam direction due to the magnetic field of the proton beam, but it is much smaller than the deflection transverse to the proton beam.



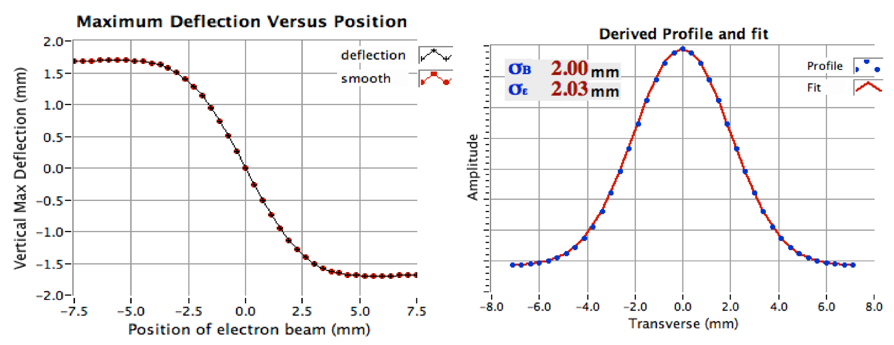
Fast and Slow

Electron beam scanned along single proton bunch. Repeated at different impact parameters.

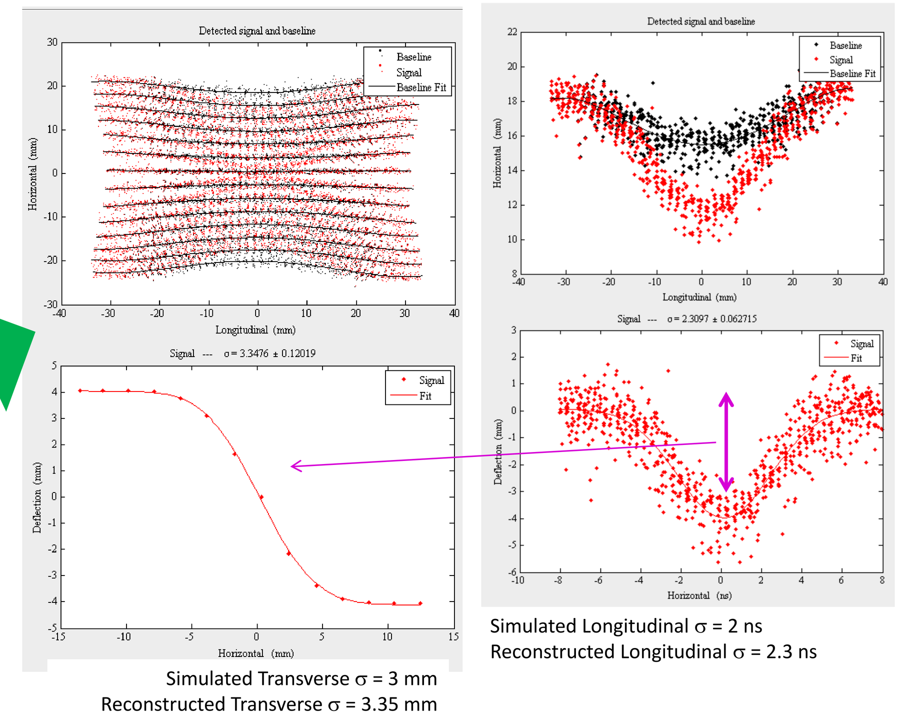


Simulations

Deflection plot of electron beam using slow scan method, and the derivative of it, showing agreement to better than 2%.

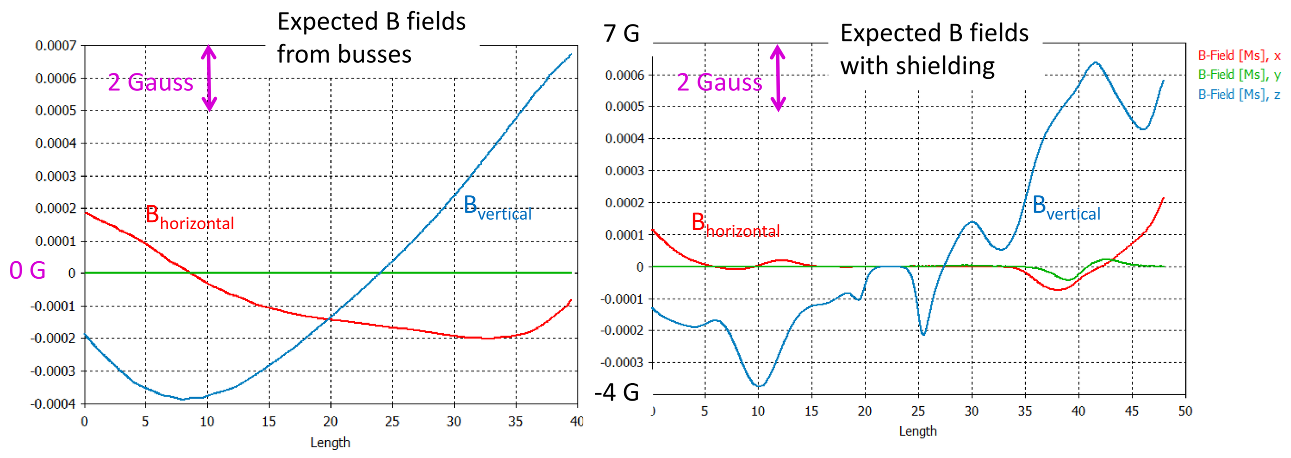


Simulated deflection data for varying impact parameters using the fast and slow method. The black points are baseline deflections with no beam. They result from the non-uniform deflector field. Each point represents a single electron with the random spread given by the measured emittance.

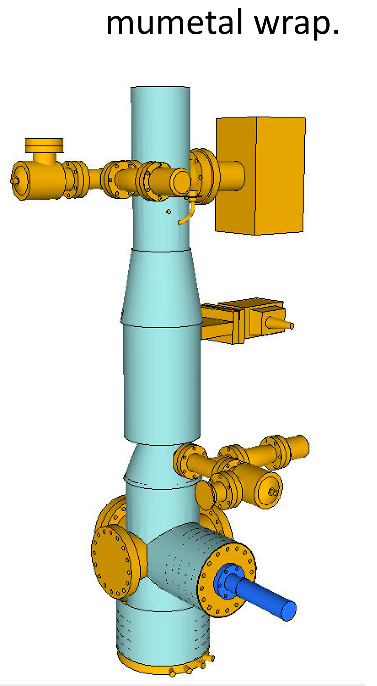


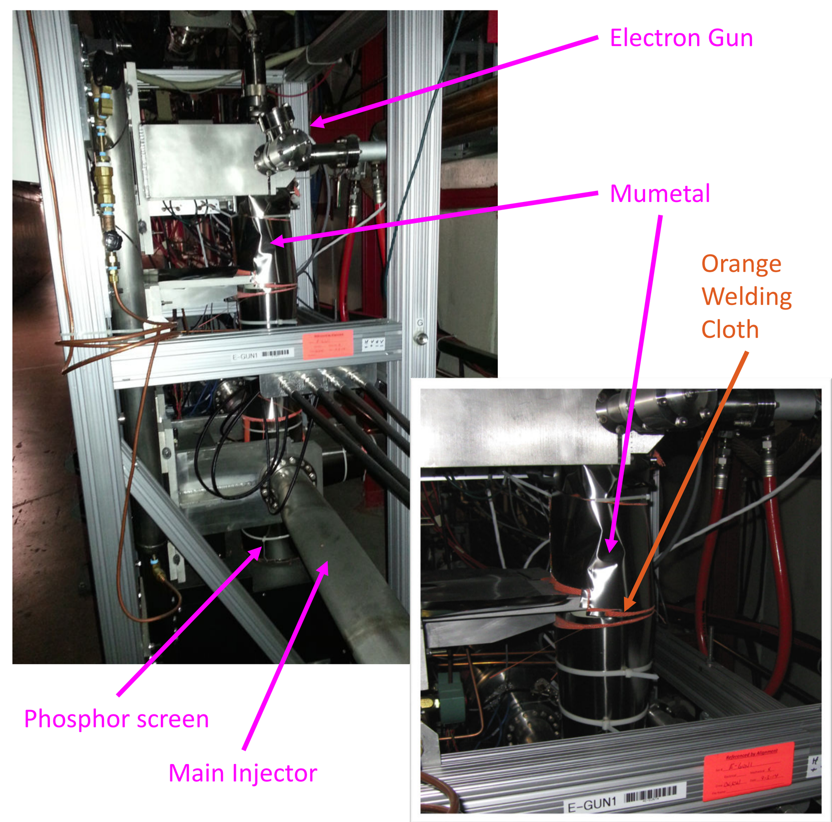
External Magnetic Fields

CST simulation of magnetic field from magnet busses along the line of the electron beam. The horizontal component is most important as the electron beam is vertical. The maximum horizontal field without shielding is 2 G (left). The majority of the field is removed with shielding.

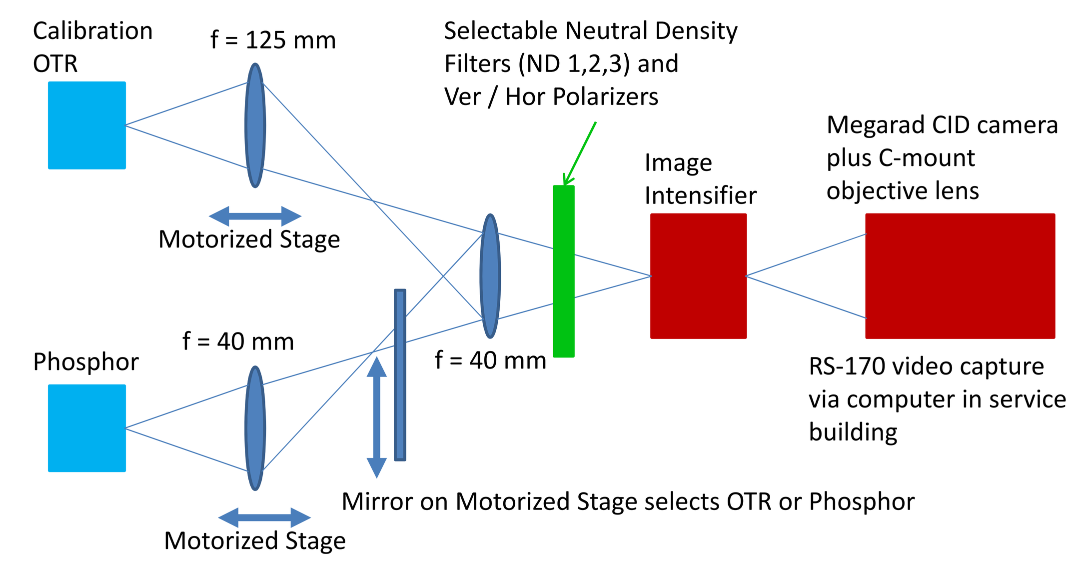


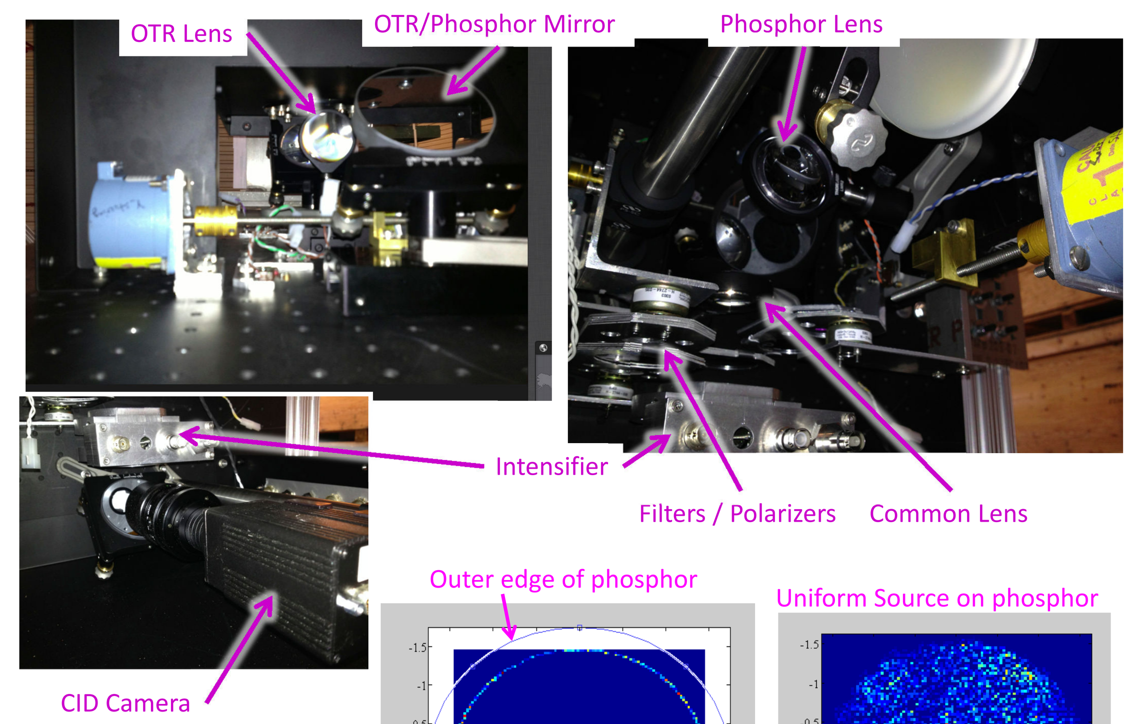
Model of mumetal wrap.

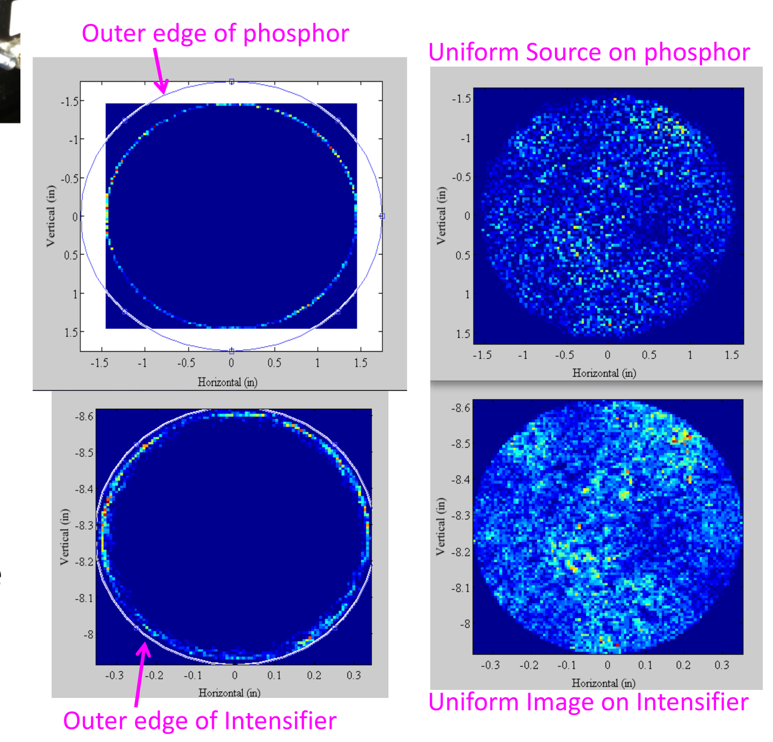




Optics

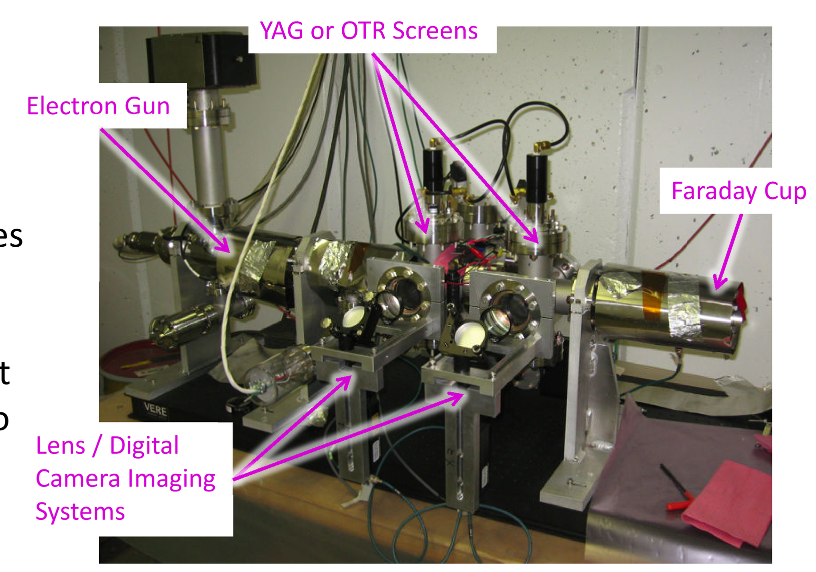




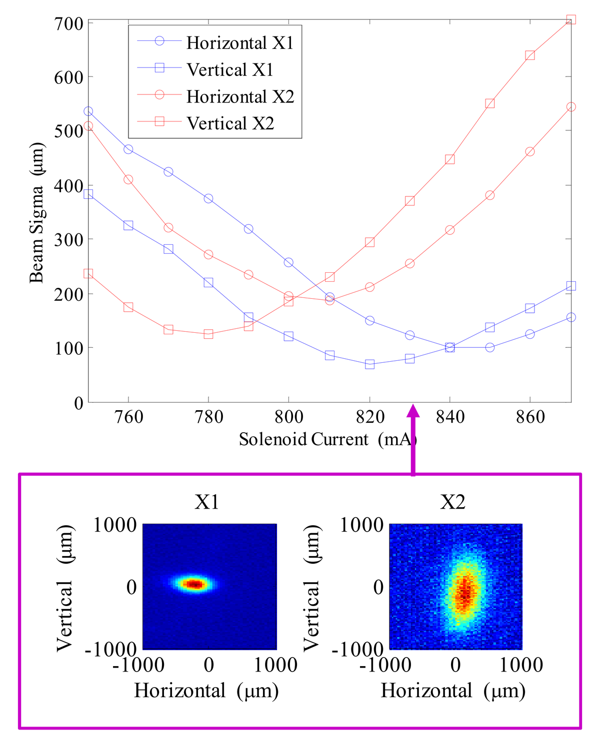


Ray tracing from source (top) to image planes (bottom) to determine aperture (left) and uniformity (right).

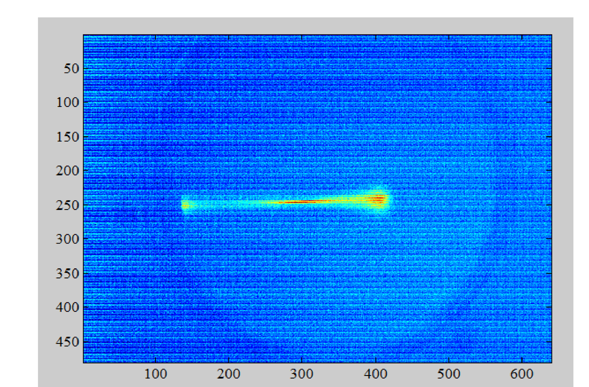
Test Stand



Horizontal and vertical rms beam sizes at the first (blue) and second (red) crosses in the test stand. The measurements are from OTR taken at ~50 keV and 1 mA beam current onto the stainless steel mirrors.



Trace of the electron beam on the phosphor screen for a deflecting voltage of ~±150 V. This image was taken with just a camera and objective lens.



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# keup@fnal.gov