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Muon Beam Monitoring Using Luminophore Foils

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1 Introduction

The Paul Scherrer Institut will host two next generation charged lepton flavor violation experiments, MEG II and Mu3e, utilizing the world's highest intensity continuous muon beams at more than 10^8 μ^+/s. A novel technique using a 5 µm luminophore layer of CsI(Tl) deposited on PET/MYLAR foils and directly imaged using a CCD is presented. Results using 28 MeV/c muons show luminophore foils provide a fast measurement of beam quality with negligible impact.

2 Setup

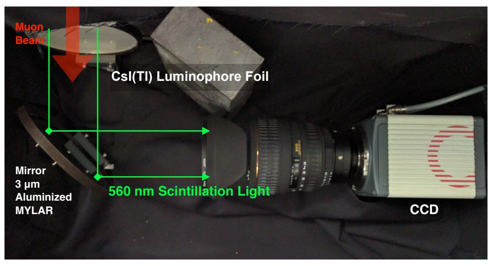


Fig. 1. The muon beam enters the light tight box in the upper left corner through a 20 µm aluminum window. Just downstream is the CsI(Tl) Luminophore foil, which the muons will pass through depositing a few keV. Further downstream an aluminized MYLAR mirror of 3 µm is oriented at 45 degrees to the lumuinophore foil, redirecting scintillation light to the CCD.

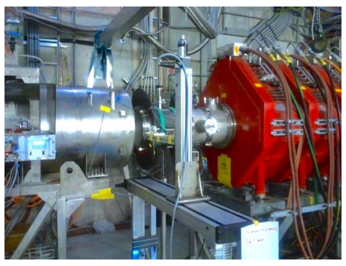
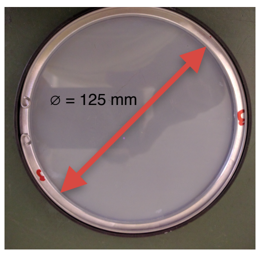
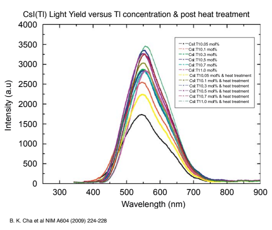
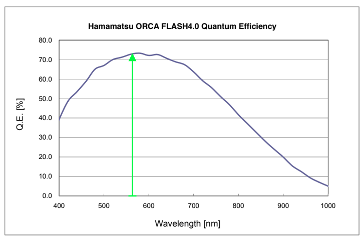


Fig. 2 Standard beam measurement system, consisting of a mini PMT+scintillator on x/y scanner system. The scanner is place between beamline elements.

- Four foils constructed using 3 µm LAVSAN (MYLAR equivalent)
  - produced by MEG Novosibirsk colleagues from BINP
  - Thin CsI(Tl) layer deposited via chemical vapor deposition
  - Varying layer thickness (3 - 5.2 µm)
- Hamamatsu ORCA FLASH4.0 C11440-22C
  - 2048 × 2048 pixels → 4.19 MPix
  - 16 bit depth (high contrast)
  - Peltier + water cooling to -30 °C
  - Peak QE near 560 nm
- 2D XY Scanner system
  - PMT Hamamatsu R9880U-110
  - ⌀ = 2 mm scintillator NE102A
  - Auto-scanning software
  - online fit of beam profile
  - 2D raster scan





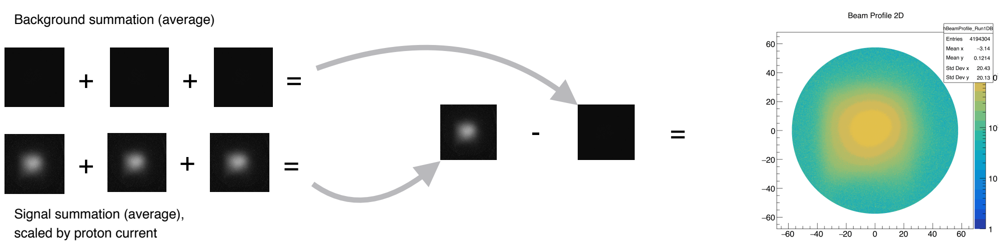


- High light yield > 50k ph / MeV deposited
- Peak emission ~ 560 nm, suitable for visible/CCD
- $\rho = 4.51$ g/cm³
- $\tau_{fast} = 0.6$ µs, $\tau_{slow} = 3.5$ µs
- Light yield/temp ≅ constant

3 Analysis

The capture of the beam profile consists of an individual exposure of 10 seconds, repeated several times. An equivalent exposure of the background is also taken, with the beam shutter closed, capturing any stray ambient light and inherent thermal noise of the sensor. Each individual image is then normalized by the total proton current during the exposure period. This is achieved by an external trigger that simultaneously begins the exposure and the proton scalar.

All signal and background images are separately summed and averaged to generate a calibrated signal image, which is then cut down to an ROI excluding the foil frame and support structure. This image is then fitted using a 2D correlated gauss function to obtain the beam position and widths in x/y as well as an correlations.



4 Results

Spatial Resolution

The spatial resolution intrinsic to the muon beam foil measurements was estimated using an aluminum grid placed just upstream of the foil to modulate the beam profile intensity. The resolution was estimated by fitting a step function convoluted with a gaussian to the profiles.

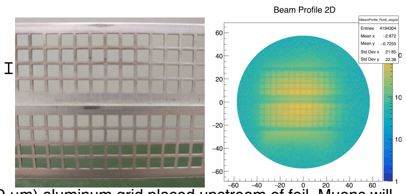
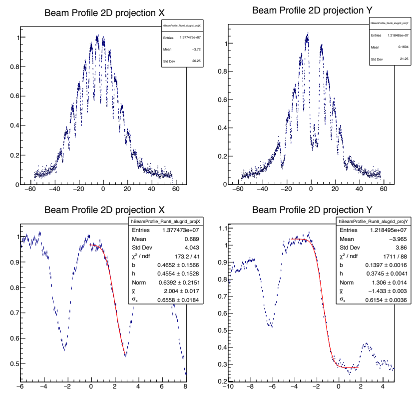


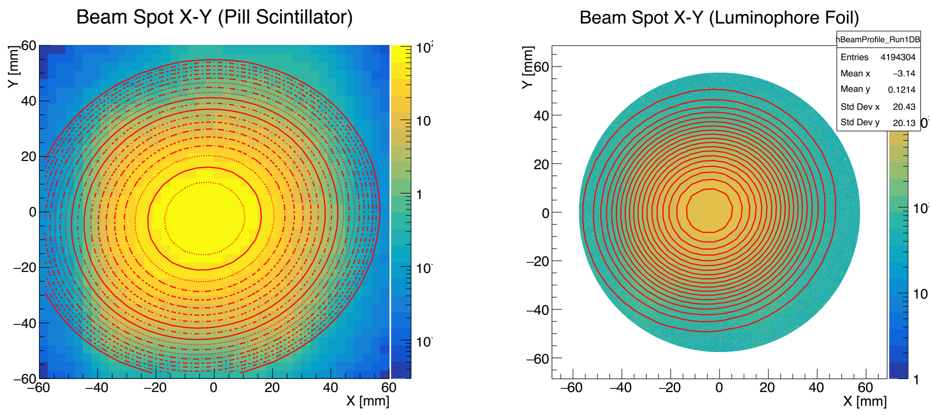
Fig. 2. Thin (750 µm) aluminum grid placed upstream of foil. Muons will stop in grid, but pass through gaps. The resolution is estimated from the step in intensity of the profile corresponding to muons stopped in the aluminum.



Upper limit on resolution $\sigma_x \cong \sigma_y \cong 650$ µm

Beam Spot Comparison 2D

Comparison of the pill scintillator raster scan and foil measurements using the 2D gauss fit of the full beam profile shows good agreement.



Pill Scintillator		Luminophore Foil	
$\bar{x} = -3.30$ mm	$\sigma_x = 16.62$ mm	$\bar{x} = -4.15$ mm	$\sigma_x = 16.35$ mm
$\bar{y} = -2.39$ mm	$\sigma_y = 15.85$ mm	$\bar{y} = 0.62$ mm	$\sigma_y = 15.71$ mm

Fig. 3. Comparison of the pill scintillator raster scan and foil measurements using the 2D gauss fit of the full beam profile shows good agreement.

Beam Rate Comparison

A slit system in the beam line can be operated symmetrically to modify the total beam intensity. The pill scintillator measurements are single rate measurements at a fixed location on the beam line axis (not a 2D scan). The rate is normalized to the proton current.

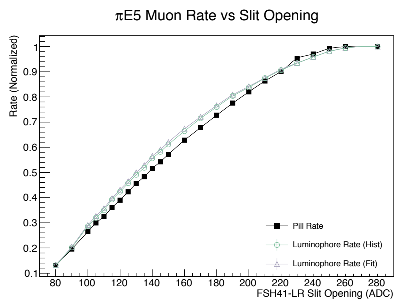


Fig. 4. Total pixel count and the integral from the 2D fit are plotted with the rates from the pill scintillator. Both systems show the same trend that the intensity increases nearly linearly across slit settings and reaches a plateau at ADC setting of 250.

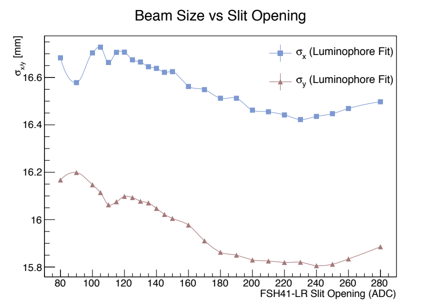


Fig. 5. The slight difference between pill scintillator and luminophore foil rates can be attributed to a changing beam spot size versus slit settings, whereby the beam spot becomes slightly smaller with increasing slit opening.

5 Conclusion

- CsI(Tl) Luminophore foils offer fast, in situ beam monitoring, with sub-millimeter resolution and negligible impact on beam parameters
- The foils coupled with a cooled camera system with sufficient resolution reproduces beam measurements done with the scanning pill scintillator
- Full beam measurement can be done approximately ten times faster while providing more information regarding beam profile
  - The system lacks pID but could possible be combined with upcoming technologies (MIXE)
- Online beam monitoring critical for cLFV physics programs
  - Continuous measurements of beam rates throughout a run period
  - Feedback on beam line centering and profiles