SEM Grid Profile Monitors for MegaWatt Proton Beams

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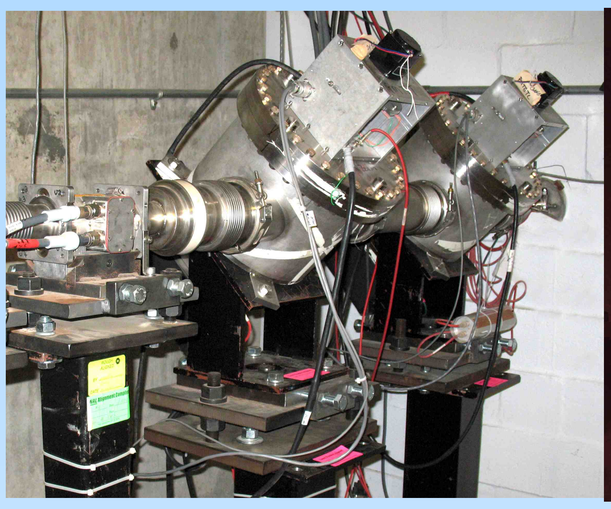
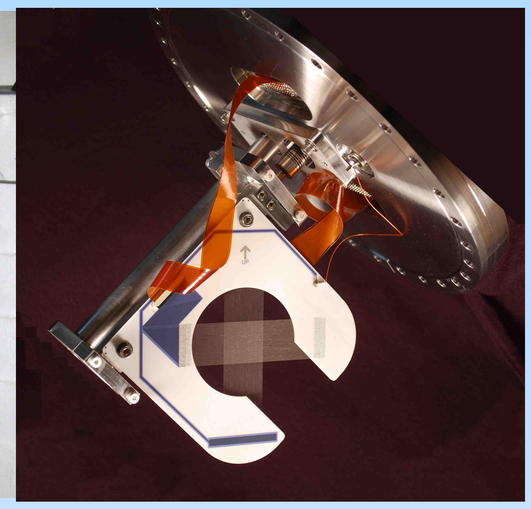
ABSTRACT - Monitors providing precision measurement of beam profile distributions are essential for transport and targeting of high intensity proton beams. We describe here the SEM grid monitors developed for the 0.4 – 0.7 MegaWatt NuMI proton beam. We also provide details of their utilization in the NuMI beam, along with performance results. Finally, we provide design and performance details to date for monitors which should work well in 2+ MegaWatt proton beams.

NuMI Profile Monitor Usage:

- Profile monitors have a dual use application in the 0.4 – 0.7 MW 120 GeV NuMI/NOvA primary proton line. An essential requirement has been to be able to use them readily at operational beam power.
  - Determination of beam size and shape along the transport and for targeting. This provides the primary diagnostic for emittance and optics understanding.
  - Continuing precision calibration for the BPM's and BLM's. This imposes additional requirements for profile monitor position reproducibility < BPM accuracy.
- A robust solution for moving profile monitors in or out of the intense beam seamlessly has been implemented, utilizing the combination of:
  - Vacuum can mounted at 45 deg.
  - Slotted ceramic C-frame wire mount also at 45 deg.

  resulting in horizontal and vertical beam profile measurements.
- Monitors are automatically moved into the beam on a once per shift basis.





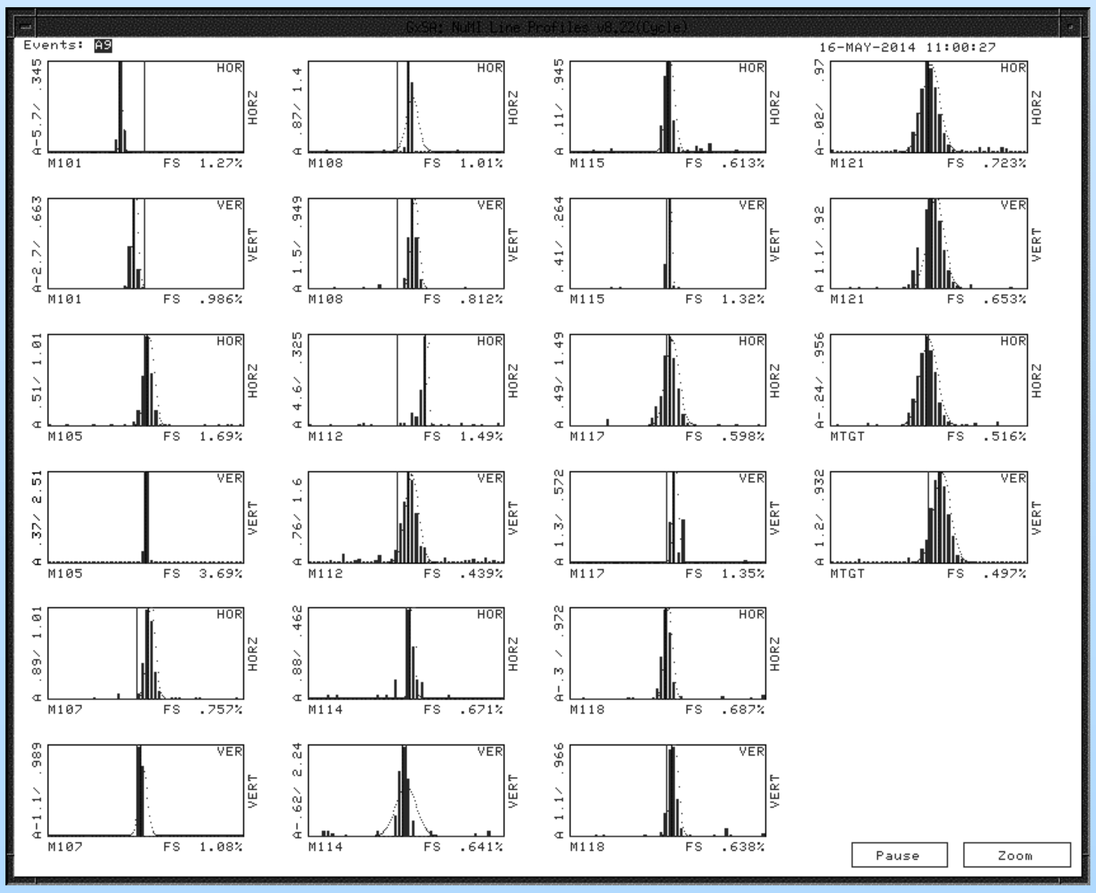
700 KW Key Requirements	Specification Details
Robust to sustained high intensity beam exposure.	Must withstand beam heating by the 700 kW beam, and radiation dose of ~ 1E20 protons/cm^2. Secondary emission properties should not age significantly in the NOvA beam.
Material thickness restrictions to maintain acceptable beam loss.	Required fractional beam loss < 2.5 x10^{-6} for beam transport and targeting monitors.
Movable into or out of the beam without interruption of beam operations.	No material should be exposed to the beam during monitor movement other than the SEM signal strips.
Robust precision capability for insertion into the beam.	Accuracy for placement of monitors into the beam should be < 20 µm, for a lifetime total of 20,000 insertions. (life tested to 500,000 insertions)
Robust operation with an ion pumped vacuum system at 1x10^{-8} Torr.	Gas load after 100 deg. C bake-out of < 3x10^{-7} Torr liters/sec. All gaskets/seals should be metal.

List of Detectors in NuMI Primary Beam

Name	Material/Dimension	Wire pitch (mm)	Comment
PM-101	25µ Dia. Ti wire	1 .0	
PM-105	5µ thick Ti foil	1 .0	Ti Foil[1]
PM-107	33µ C filament	1 .0	
PM-108	25µ Dia. Ti wire	1 .0	
PM-112	20µ Dia. Ti wire	1 .0	Grade 5*
PM-114	20µ Dia. Ti wire	1 .0	Grade 5
PM-115	33µ C filament	1 .0	
PM-117	33µ C filament	1 .0	
PM-118	33µ C filament	1 .0	
PM-121	20µ Dia. Ti wire	1 .0	
PM-TGT	20µ Dia Ti wire	0.5	Grade 5
PM-TGTL	75µ Dia. Ti wire	0.5	

*Ti Grade 5 high performance alloy which contains 6% Al and 4% V. It was selected because it can be manufactured to smaller wire diameters.

Beamline Profiles at 120 GeV @ 2 x 10^{13} Protons Per Pulse



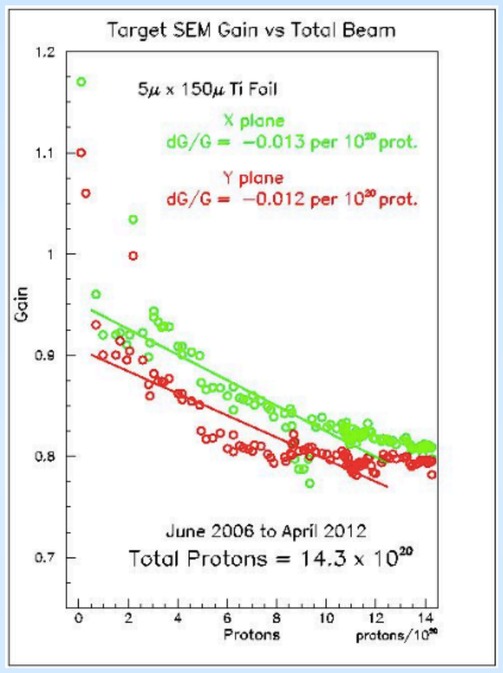
Wire Heating: Simulations of temperature rise for various materials and thickness were done both at UTA[1] and Fermilab. The simulations show that the 25 µ Ti wires and 5 µ thick Ti foils will survive at a beam power of over 700 KW. For beam of > 1 MW we have developed monitors with carbon monofilament SEM grids, which are operational.

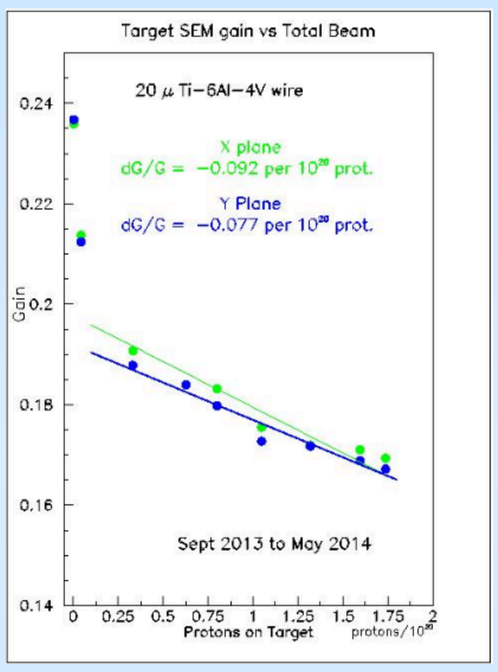
Target Detectors **0.5 mm wire pitch**

Signal Strength: Assuming a gaussian distribution the signal S (picoCoulombs) can be estimated using the formula S(pC) = SEE x N x e where:

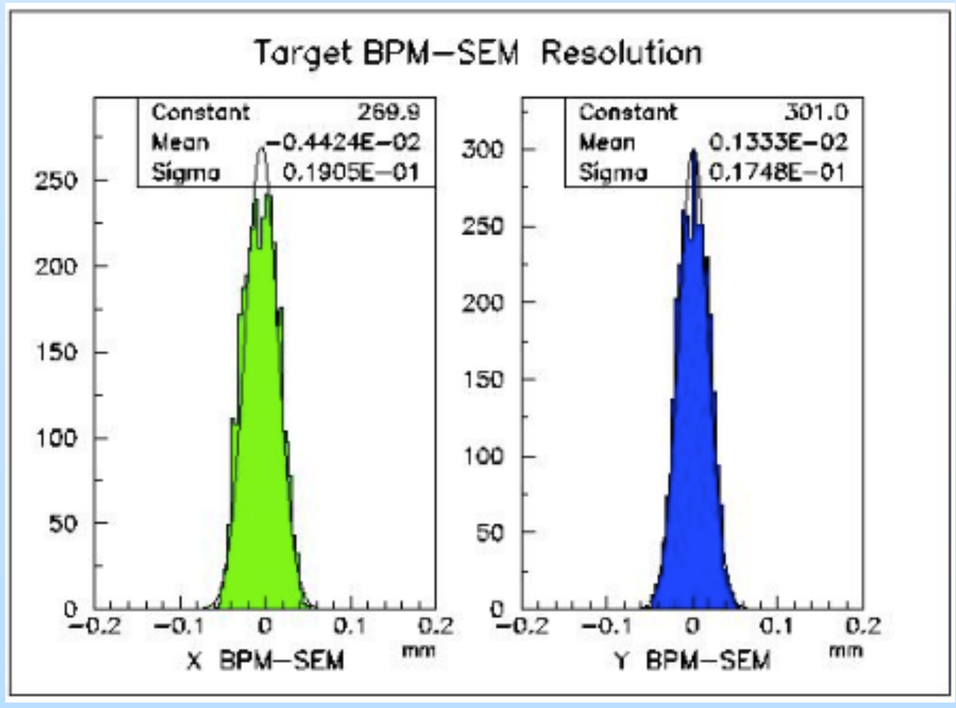
Secondary Emission Efficiency (SEE), depending on material, is about 3%
N is the number of protons through the wire
e is the electron charge, 1.6 x 10^{-19} Coulomb

So, for a 3 x 10^{13} particle beam with a wire Dia = 20 µ and a beam FWHM of 3 mm the signal on the center wire is about 900 pC. or about 100 times scanner noise level.





SEM Gain Stability for a Ti foil [1] target detector exposed to **1.43 x 10^{21} protons** and a Ti wire detector currently exposed **to 1.74 x 10^{20} protons**. The foil SEM grid was replaced by wires to achieve significantly less residual activity.



SEM-BPM Beam Resolution < 20 µm

ACKNOWLEDGMENTS: We would like to acknowledge the effort done by many people in Fermilab's groups too numerous to list.

Summary:

We have constructed and are successfully operating low mass SEM grid profile monitors which meet rigorous requirements for the 0.7 MW NuMI proton beam. Experimental carbon monofilament monitors are also in operation which should be robust for the 2+ MW beams. Continuing efforts are ongoing to optimize the selection of material and dimensions of wires/foils.

References:

[1] Kopp et al. DIPAC 2007, WECP27. 1University of Texas, Austin