Beam Diagnostic Instrumentation at MTA using Chromox-6 Scintillation Screen

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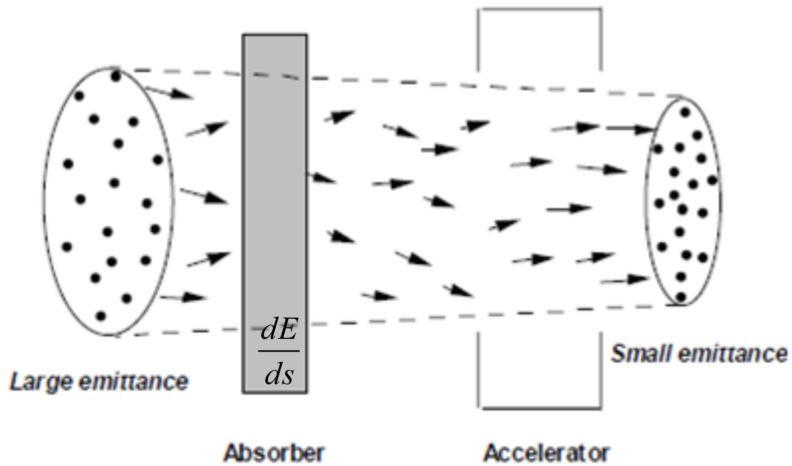
Outline of the Talk

- Introduction
- Beam Instrumentation
- Results of beam transmission through collimator
- Conclusions

Acknowledgement

M. Chung, B. Freemire, P. Hanlet, M. Leonova, A. Moretti, M. Palmer, T. Schwarz, A. Tollestrup, Y. Torun, K. Yonehara, Beam Division, Accelerator Division, Control Group and MCR Staff

Muon Ionization Cooling

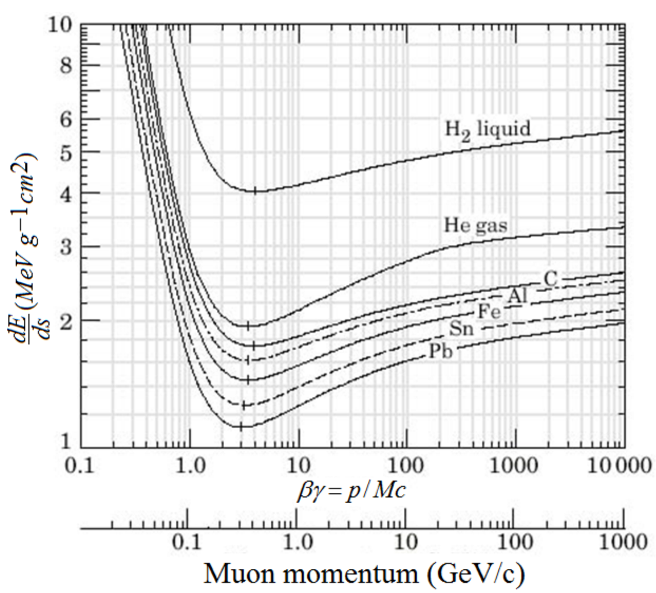


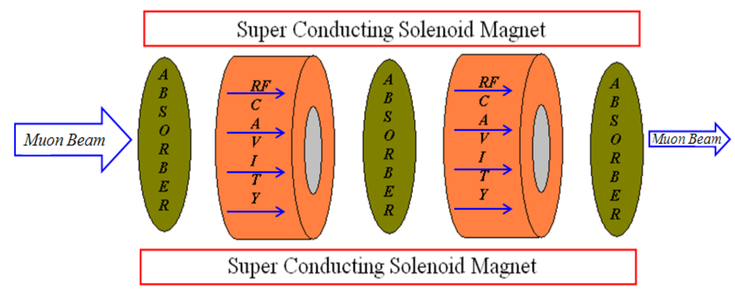
Change of normalized emittance per unit path length

$$\frac{d\varepsilon_n}{ds} = -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\varepsilon_n}{E_\mu} + \frac{1}{\beta^3}\frac{\beta_\perp (0.014\,GeV)^2}{2\,E_\mu\,m_\mu\,L_R}$$

Cooling
(Ionization energy loss)

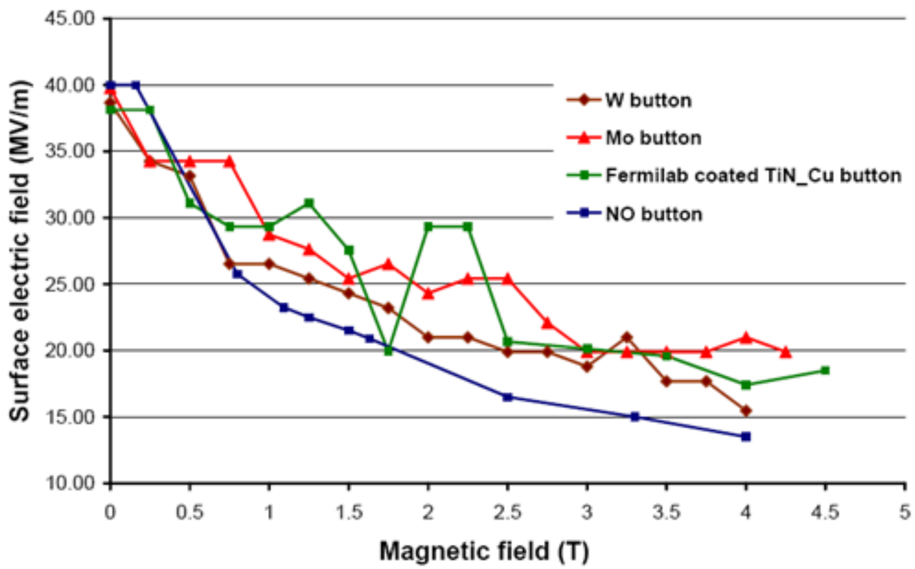
Heating
(Increase beam divergence due to multiple Coulomb scattering)

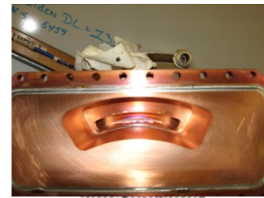


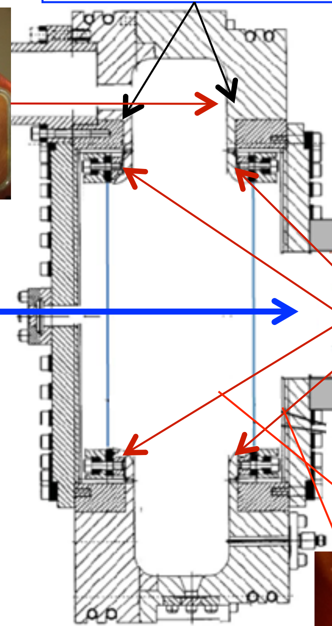


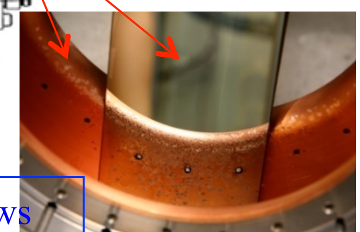
- •Energy absorbing medium (low Z e.g. H)
- • Minimize transverse position spread in absorber by using strong focusing magnetic field (Typically using SC Solenoid Magnet, B ~ 5 T)
- • RF cavity for longitudinal acceleration (E-field gradient ~ 20 MV/m)

Pill Box Cavity Experiment









In LBL Pillbox cavity after 250 $\times 10^6$ pulses, serious spark damage was observed at RF coupling iris and button . These are due to the high field gradients at sharp edges (small radii)

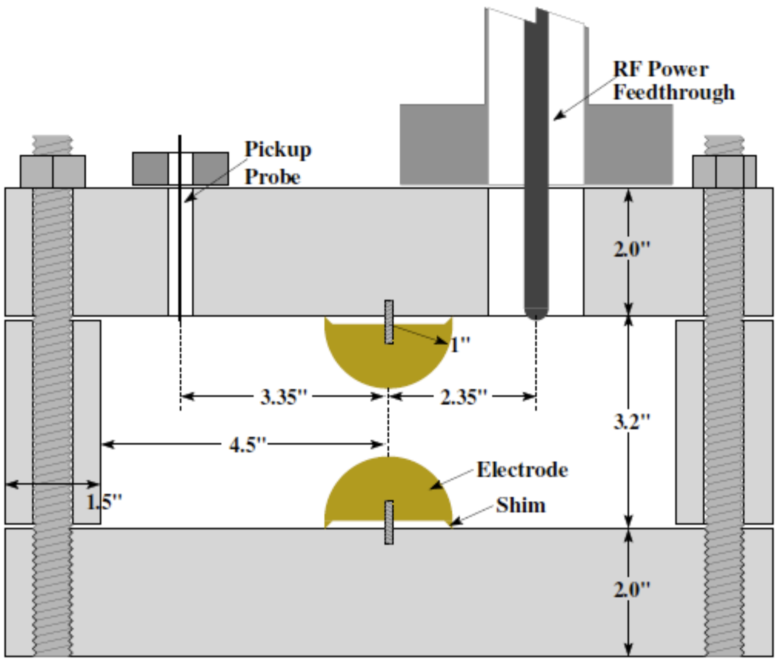
- Sharp edges / corners at RF windows
- E parallel B
- Electron current / arcs focused by B

Surface Field Enhancement Initiates the event & B focuses the e-current which causes damage

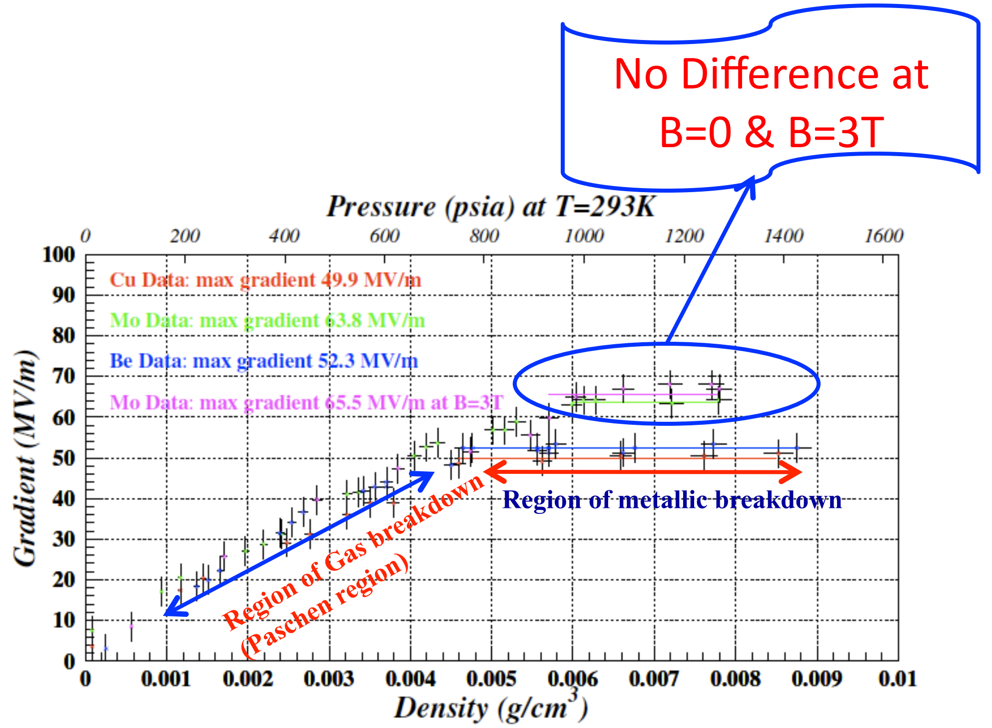
HPRF Cavity Experiment

Muons, Inc.

Past Experiment (without beam)



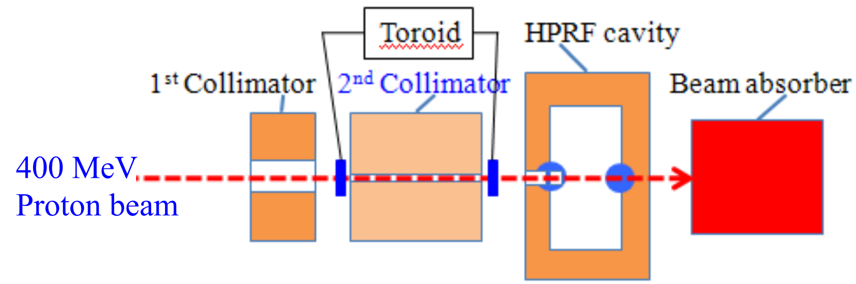
Schematic view of HPRF cavity



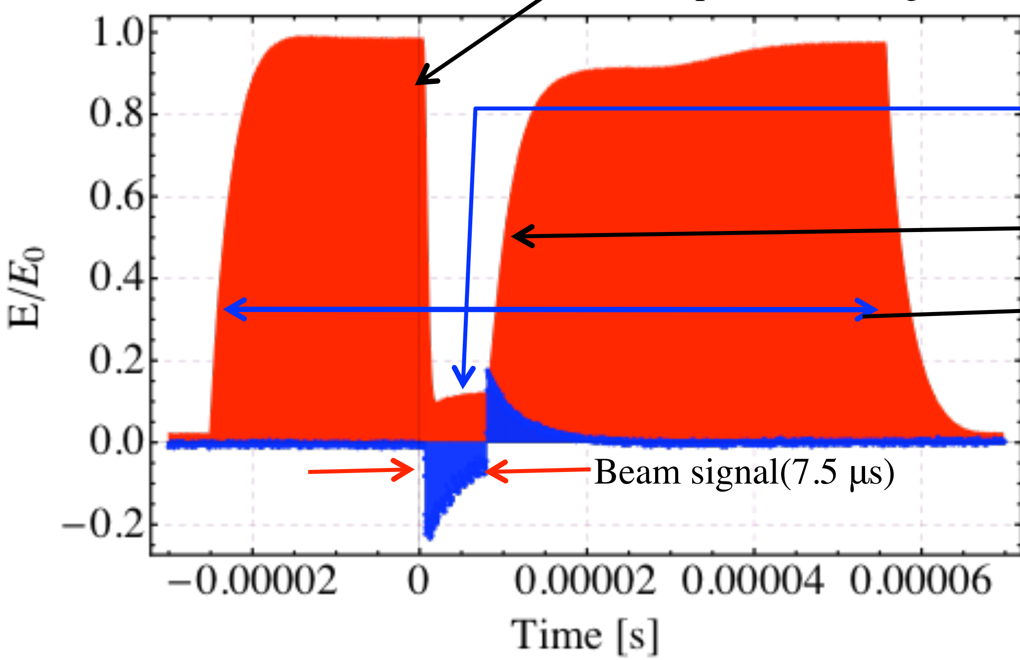
Ref: P. Hanlet *et al.*, Proceedings of EPAC 2006

HPRF Cavity Experiment with 400 MeV proton beam

ν= 802 MHz, Gas pressure = 950 psi, E_o=20 MV/m
Beam intensity = 2×10^8 ppp/bunch



Schematic of HPRF cavity beam test



Ionization process:
$p + H_2 \rightarrow p + H_2^+ + e^-$
1600 e^-/cm are generated by incident p @ E = 400 MeV

Ref: K. Yonehara, MAP Friday meeting, 9/23/11
M. Chung and A. Tollestrup et al

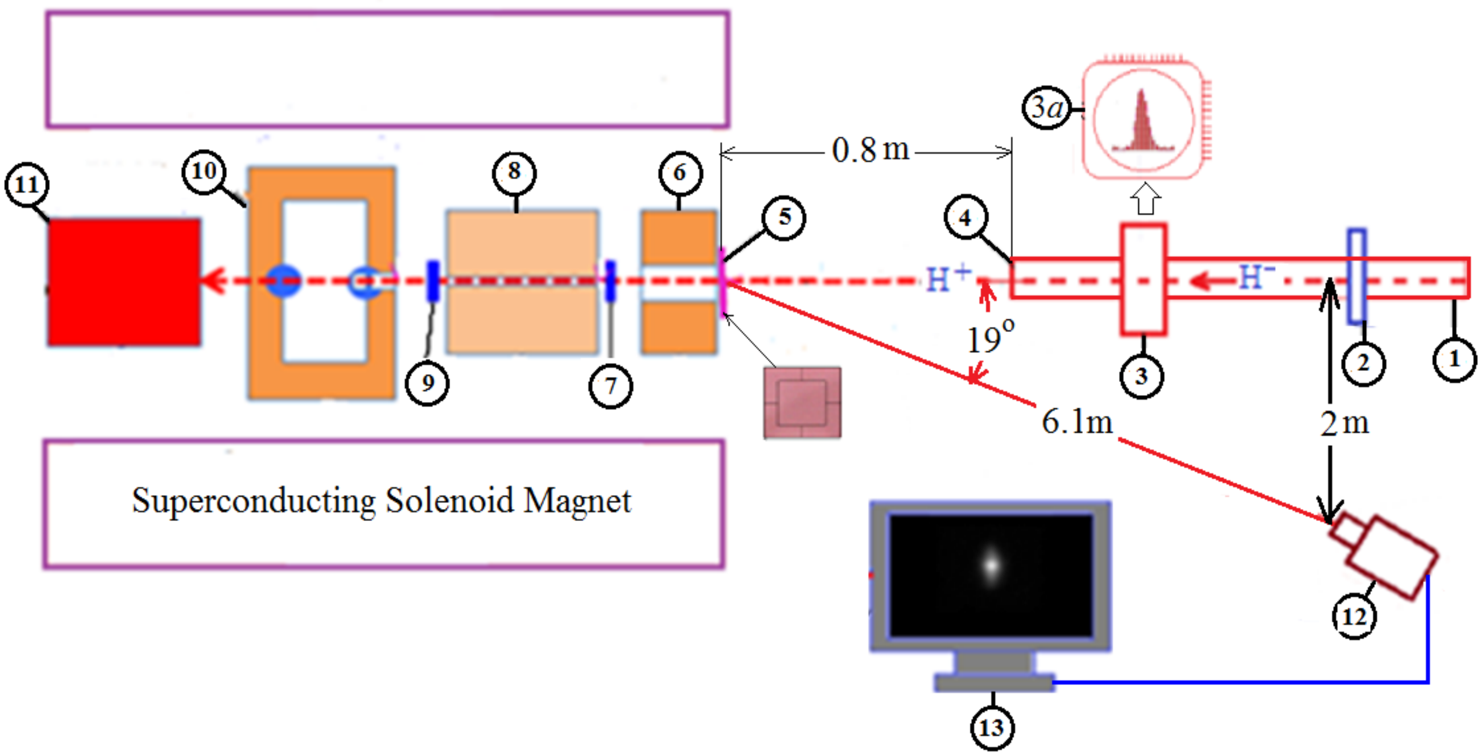
Requirements of HPRF Cavity Experiment

- Exact number of protons entering into HPRF cavity (Beam Transmission through collimator hole) is needed
- Current Transformer (Toroid) measured beam intensity does not work at B=3 T due to saturation of ferrite material
- MTA is flammable gas (H) hazard zone, due to safety reason within 15 feet no energized (active) beam monitor device can be used

We have developed a passive beam diagnostic instrumentation using a combination of a Chromox-6 scintillation screen and CCD camera

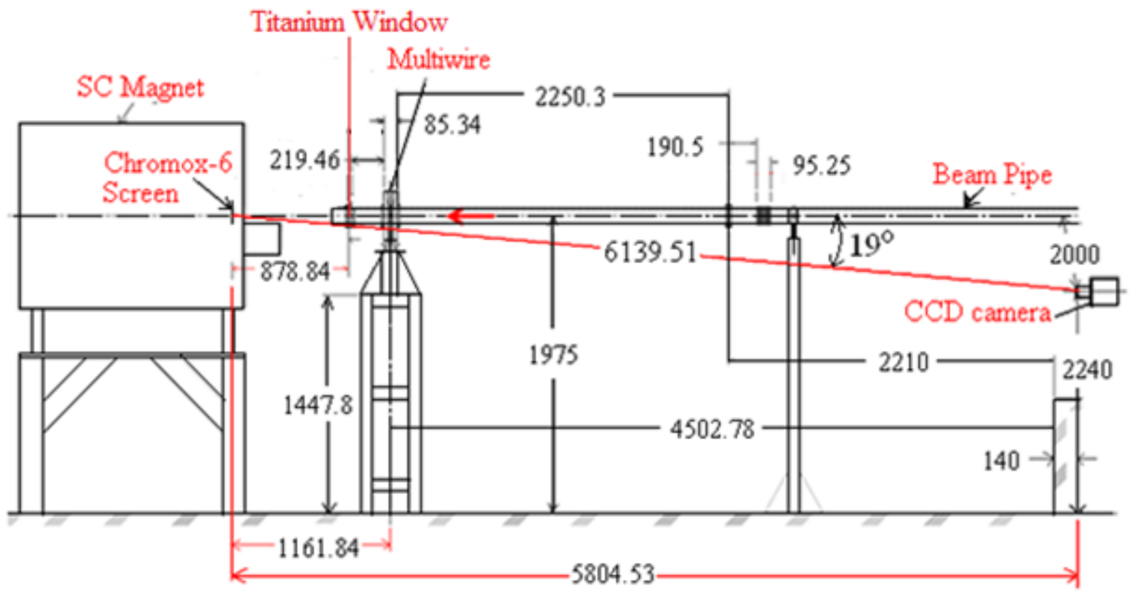
This is the main objective of this talk

Experimental Set Up of HPRF Beam Test

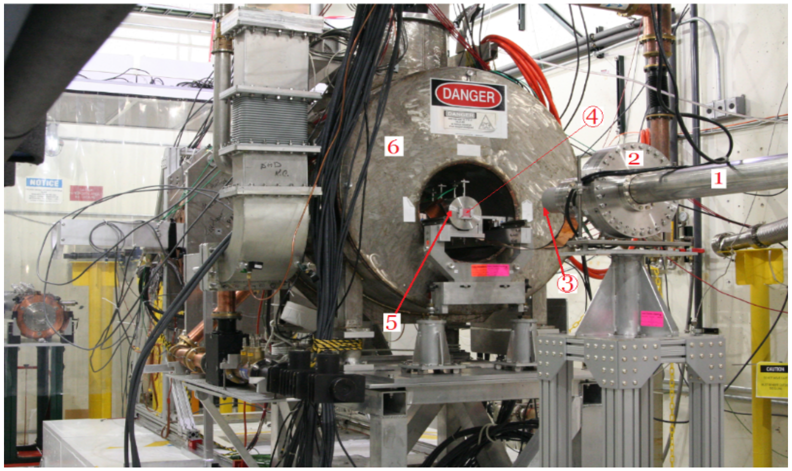


1: Beam pipe, 2: Linac Toroid (LT), 3: Multi-wire, 3(a): device (96 wires) inside flange, 4: Titanium window near end of beam pipe, 5: Chromox-6 scintillation screen, 6: First beam collimator (through hole diameter of 20 mm), 7: Up Stream (US) toroid, 8: Second beam collimator (through hole diameter of 4 mm), 9: Down Stream (DS) toroid, 10: HPRF cavity, 11: Beam absorber, 12: CCD camera, 13: sample CCD image on PC.

Experimental Set Up at MTA



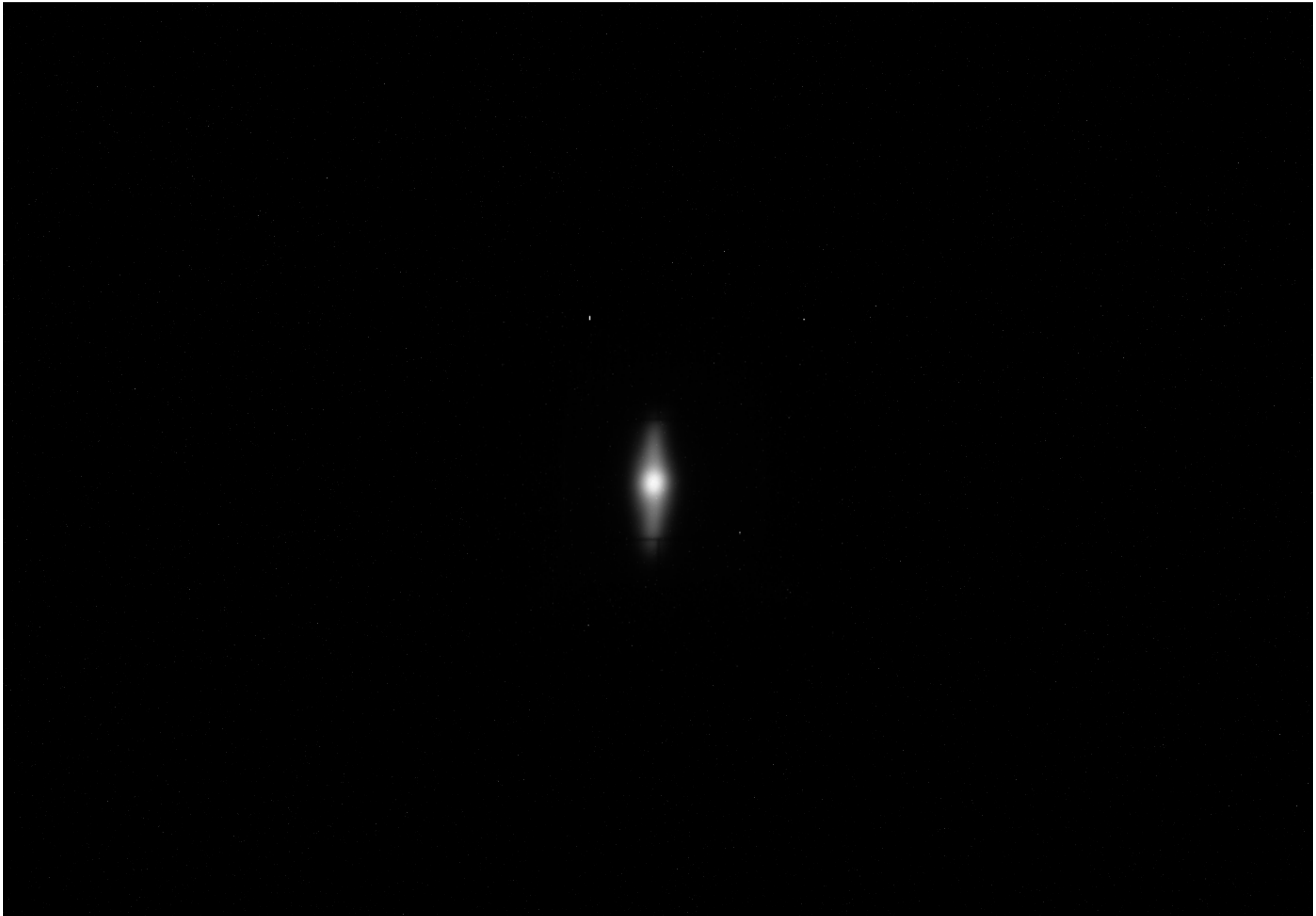
Dimensions (mm) of Expt. Set up



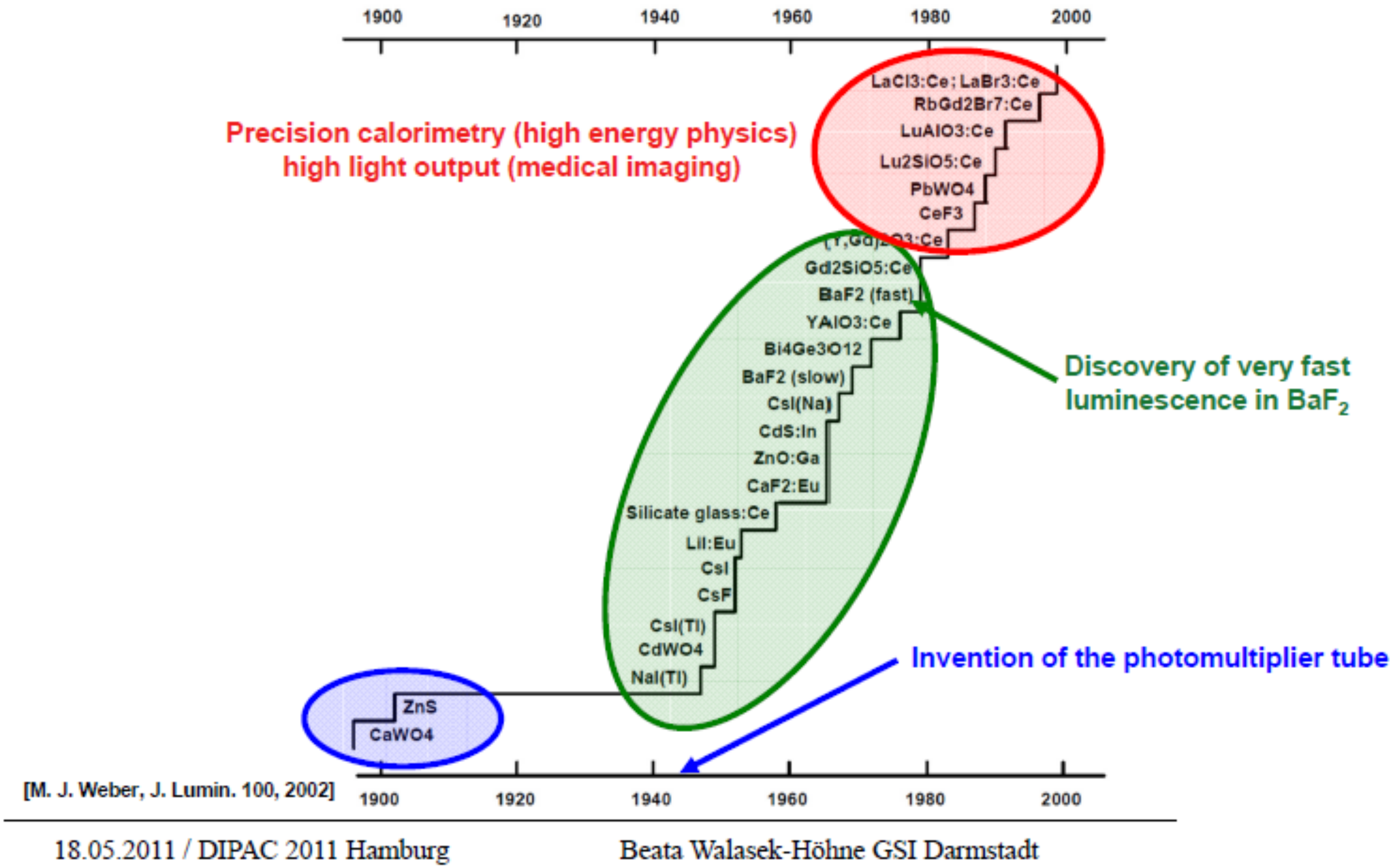
Photograph of Expt. Set up at MTA

MTA Beam Parameters

Beam Parameters	Value
Energy	400 MeV
Average beam current	36 mA
Species	H^-/H^+
Macro bunch length	10 μs
Micro bunch length	5 ns (200 MHz)
No. of Micro Bunch (10μs/5ns)	2000
Particle per Macro Bunch (Particles Per Pulse)	$\sim 2 \times 10^{12}$
Particle per Micro Bunch (2×10^{12} /2000)	$\sim 1 \times 10^{9}$
Average charge	240 nC
Repetition rate	1 pulse per min
Emittance, $\varepsilon_{95\%}$ (Simulated)	10 mm-mrad



History of Scintillator



Choice of Scintillator

- *Conversion efficiency (Light Yield)*: Conversion of kinetic energy of the charged particles into detectable light with a high scintillation efficiency which is defined as the average number of photoelectrons produced per eV input
- *Emission Spectra*: Emission light is matched to the optical system of the CCD camera in visible wave length range (450 nm $< \lambda <$ 700 nm)
- *Luminescence decay time*: Fast decay time is required for the observation of a variation of beam size
- *Linearity*: This means light output is proportional to the incident particle flux over as wide a range as possible.
- *High radiation hardness to prevent permanent damage*
- *Good mechanical properties*

Commonly used Inorganic Scintillators

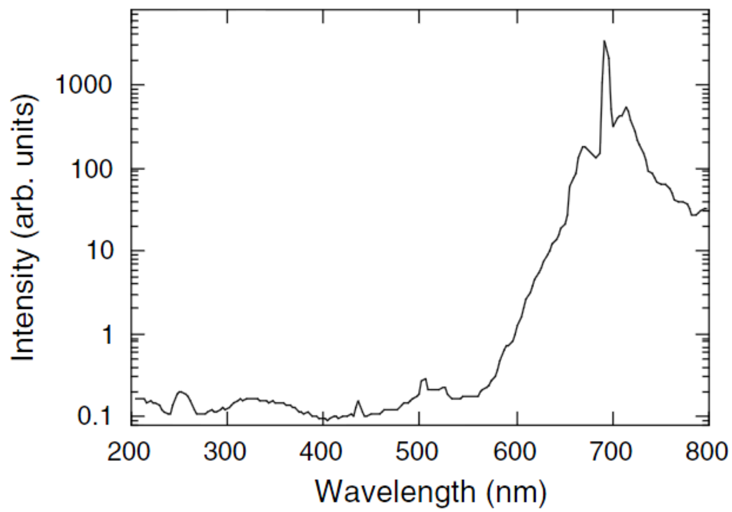
Material	Activator	Wavelength (nm)	Decay time	Light Yield (Photons/MeV)
CsI	*Tl*	*550*	$1\ \mu s$	6.5×10^4
Al_2O_3:Cr^+ (Chromox-6)	*0.5% Cr*	*700*	$3.4 - 100\ ms$	4.94×10^4
Glass	*Ce*	*400*	$0.1\ \mu s$	5×10^3
Yttarium Aluminium Garnet (YAG) $Y_3Al_5O_{12}$	*Ce*	*530*	$0.3\ \mu s$	1.7×10^4

We have selected Chromox-6 scintillator

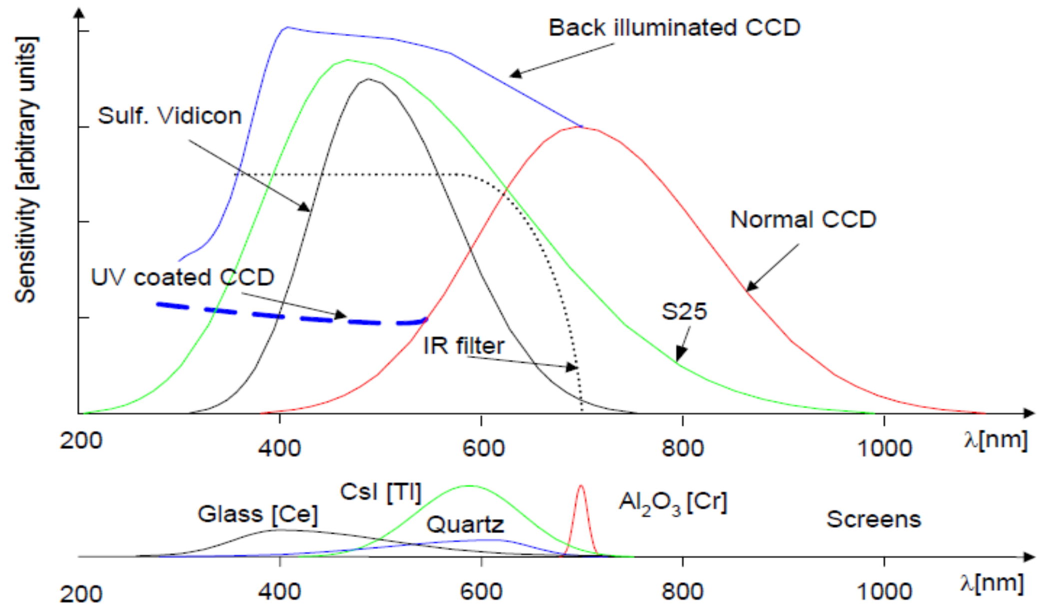
Properties of Chromox-6 Scintillator

Parameters	Value
Material: Al_2O_3	99.4%
Cr_2O_3	0.5%
Color	Pink
Wavelength of luminescent light (nm) (when impacted by electron or protons)	691 – 694
Bulk density (g/cc)	3.85
Grain size (µm)	10 – 15
Specific heat, C_p (J/kg K) @ 20 ^oC	900
Thermal conductivity (W/m K) @ 100 ^oC	30
Melting point (^oC)	2000
Max. Operating Temperature (^oC)	1600
Resistivity (Ω-cm) @ 400 ^oC	10^{12}
Attenuation co-efficient , α (mm^{-1}) @ 694 nm	0.8 ± 0.1
Starting Sensitivity (viewed by CCD camera)	$10^7 – 10^8$ protons
Ionization loss (for ultra-relativistic protons) (MeV/mm)	~ 1

Sensitivity and Emission spectra of various detectors and scintillation screen



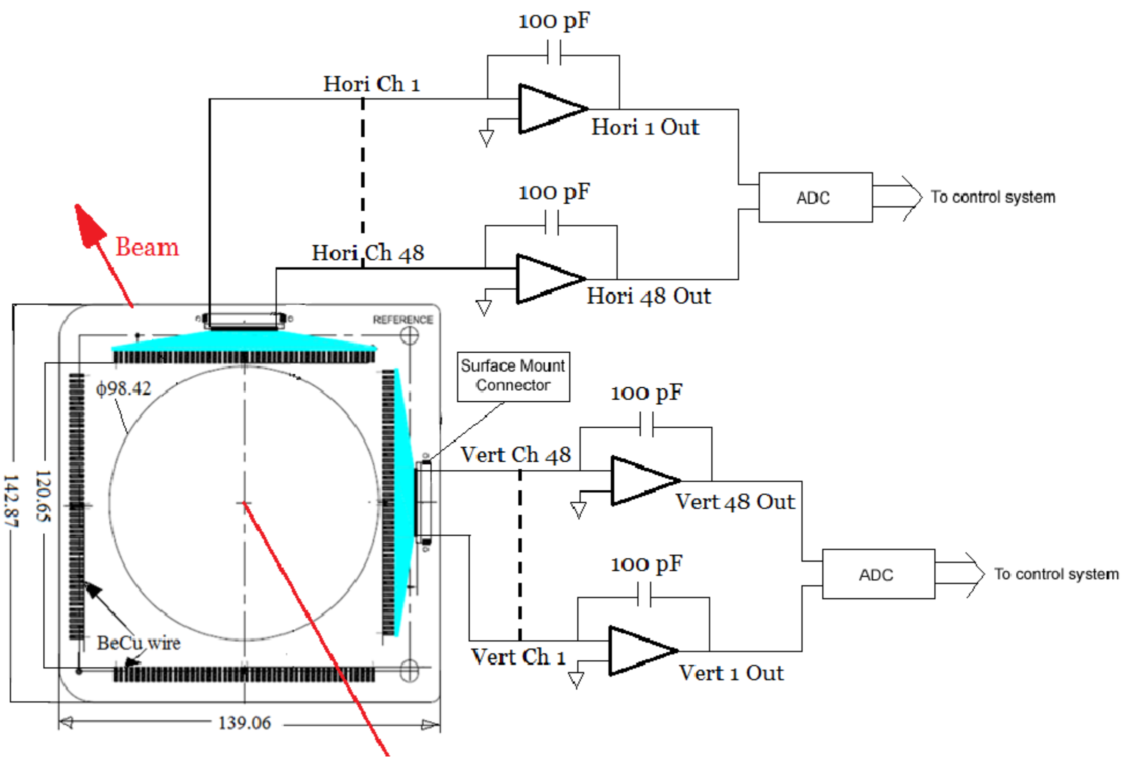
Emission spectrum of Chromox-6 scintillation screen [K. J. MacCarthy et al, J. Nucl. Materials 321 (2003) 78]



Sensitivity and emission spectra of various detectors and screens [R. Jung et al, DIPAC 2003, Mainz, Germany]

We have selected PixeLINK CCD camera (Model: PL-B955, USB 2.0) from Edmund Optics, USA

Multi-wires Detector



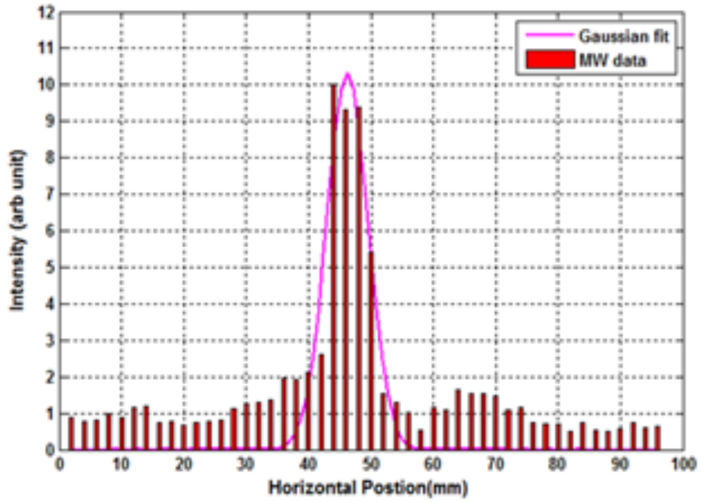
Parameters	Value
Diameter of the wire	50 μm
Spacing	2 mm
Length of the wires	120.65 mm
Number of wires in:	
Horizontal Plane	48
Vertical Plane	48
Material	BeCu
Tension	0.78 N
Signal wires	Kapton isolated
Insulation (frame)	Alumina 96
Vacuum performance	1.33×10^{-9} mbar
Maximum power deposited on a wire	0.34 $\mu W/mm^2$

Acknowledgement

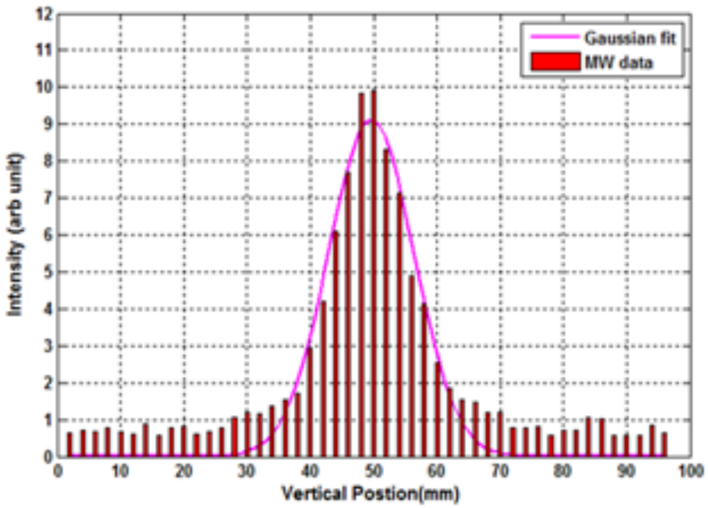
Fermilab Control Group

Results

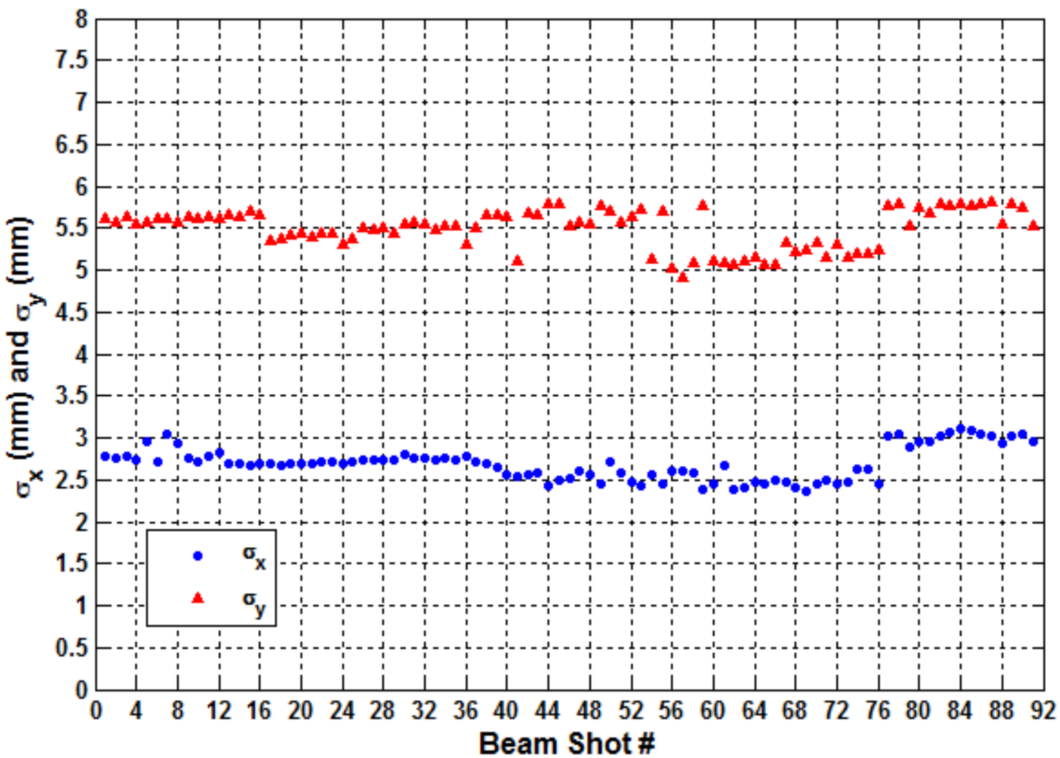
- Multi-wires (High Intensity)



Horizontal Profile



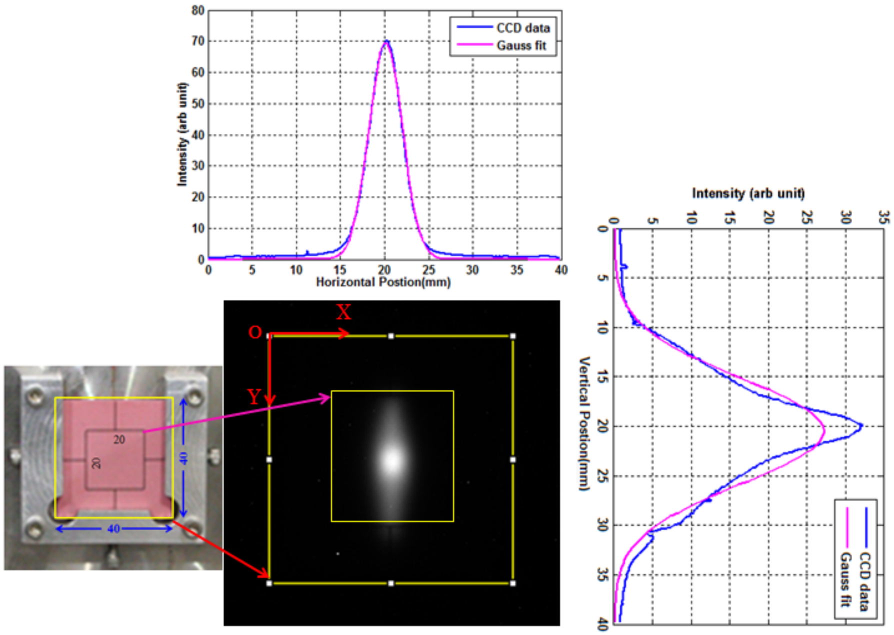
Vertical Profile

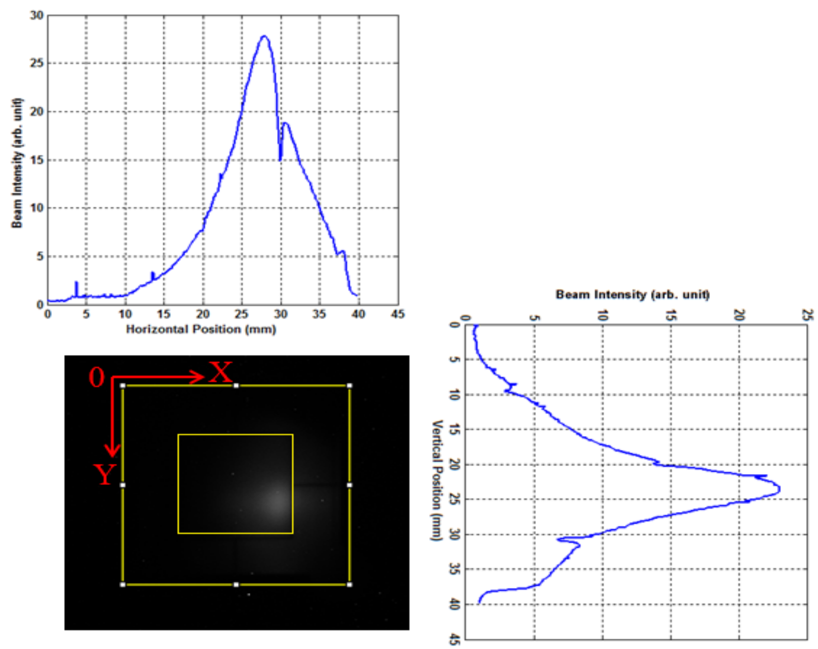


Average values
σ_x = 2.69±0.19 mm
σ_y = 5.49±0.23 mm

Results Cont…

CCD Image





High Intensity Beam

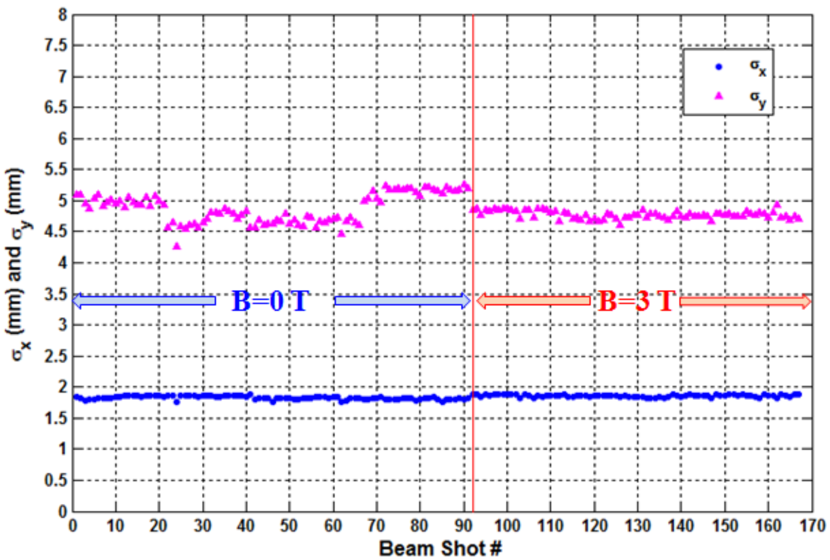
- Beam Center
- Beam size
- Beam Transmission

Low Intensity Beam

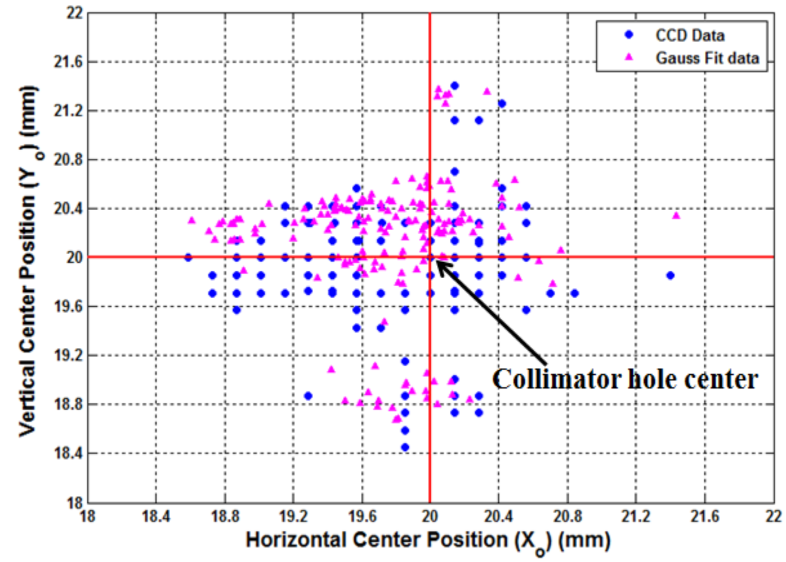
- Beam Transmission

Results Cont…

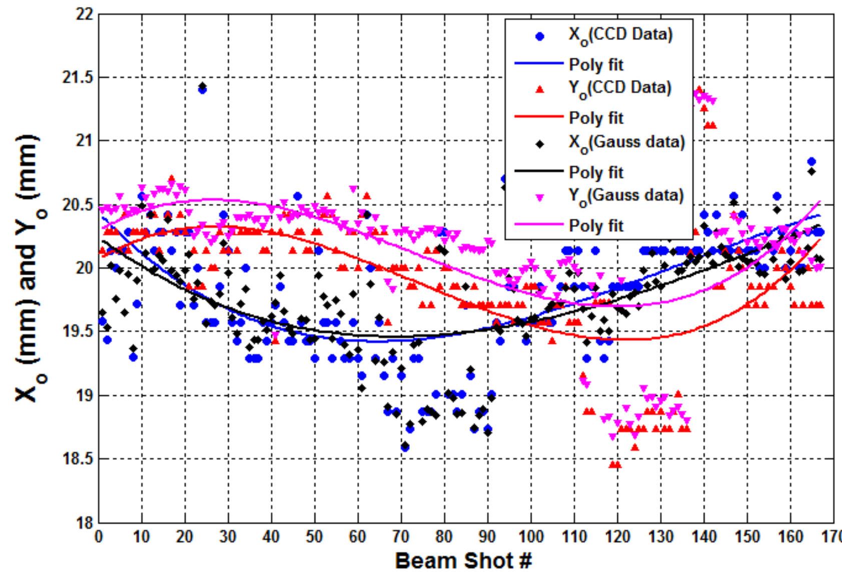
CCD Image (High Intensity)



σ_x, σ_y vs beam shot plot



Beam center at different shot



X and Y position of Beam center at different shot

CCD Image

- B=0 T

$\sigma_x = 1.83 \pm 0.03$ mm

$\sigma_y = 4.88 \pm 0.23$ mm

- B = 3 T

$\sigma_x = 1.86 \pm 0.03$ mm

$\sigma_y = 4.78 \pm 0.06$ mm

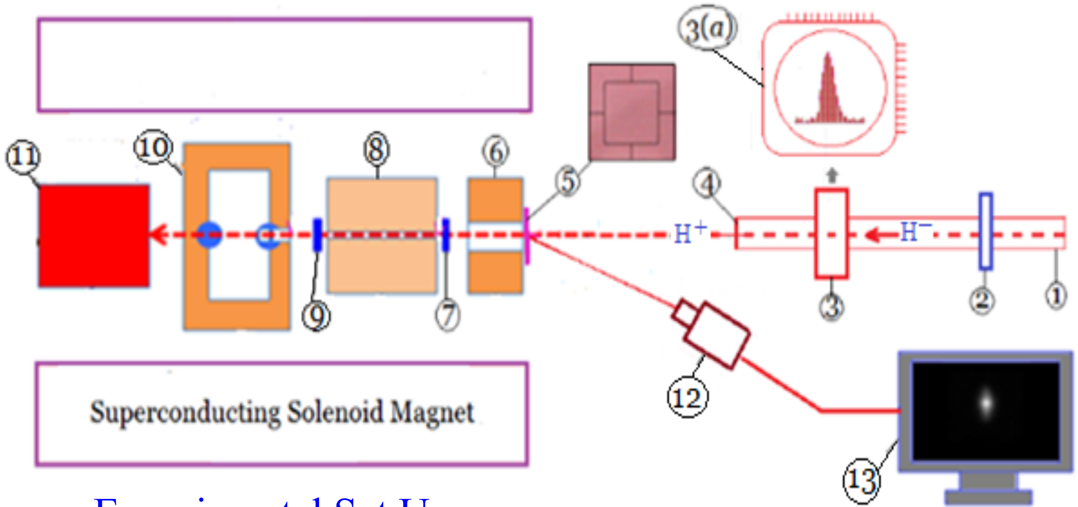
Multi-wires

- B = 0 T

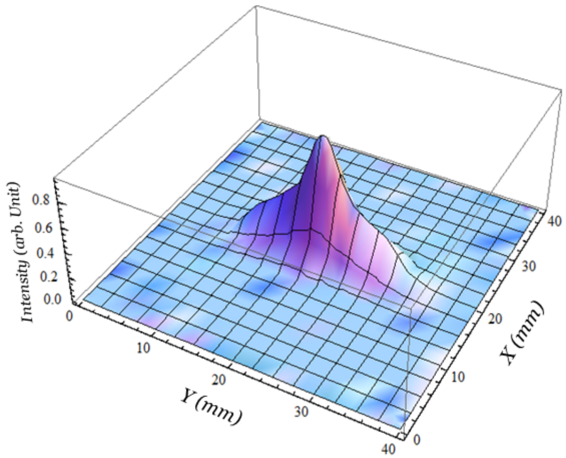
$\sigma_x = 2.69 \pm 0.19$ mm

$\sigma_y = 5.49 \pm 0.23$ mm

Beam Transmission Through Collimator Hole



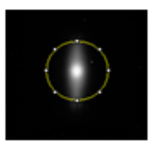
Experimental Set Up



3D plot of CCD image

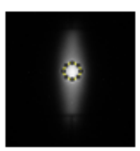
CCD Image

↓



Amount of beam passing through ϕ 20 mm first collimator hole (T_1) → $LT \times T_1$ and compare with US Toroid

↓



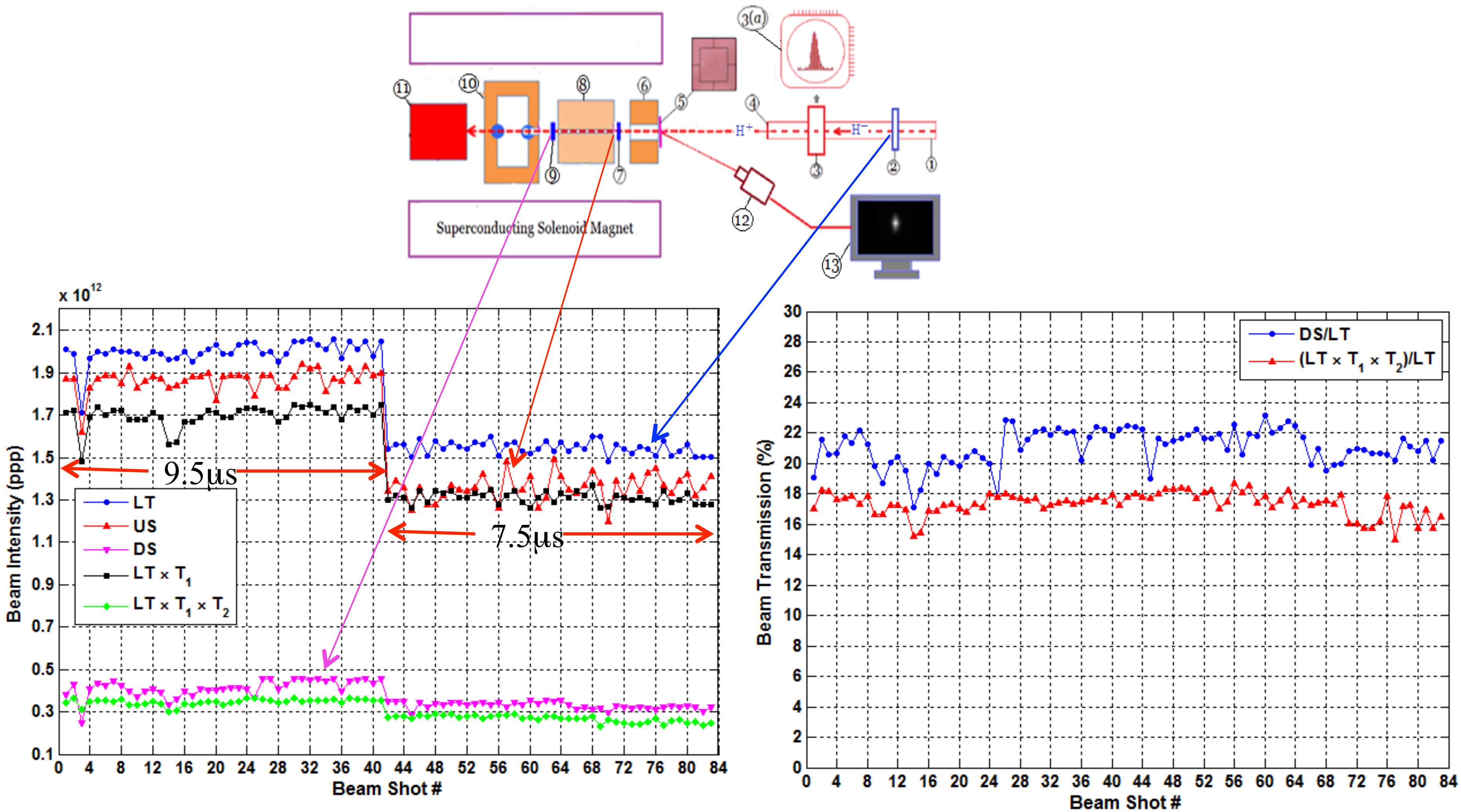
Amount of beam passing through ϕ 4 mm second collimator hole (T_2) → $LT \times T_1 \times T_2$ and compare with DS Toroid

↓

Plot of LT, US, DS, $LT \times T_1$, $LT \times T_1 \times T_2$

Flow chart of Beam Transmission calculation

Results (High Intensity beam and B=0 T)

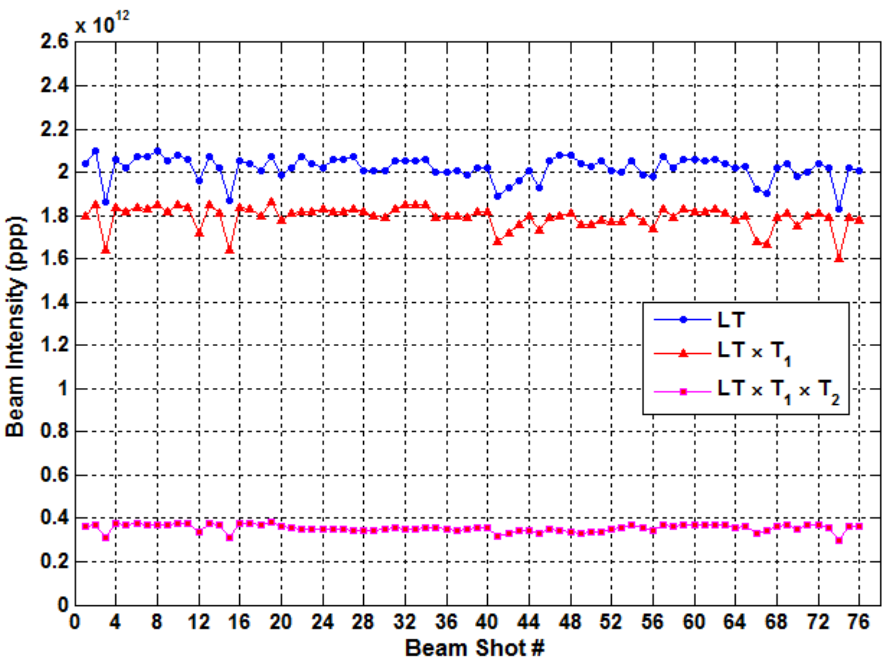


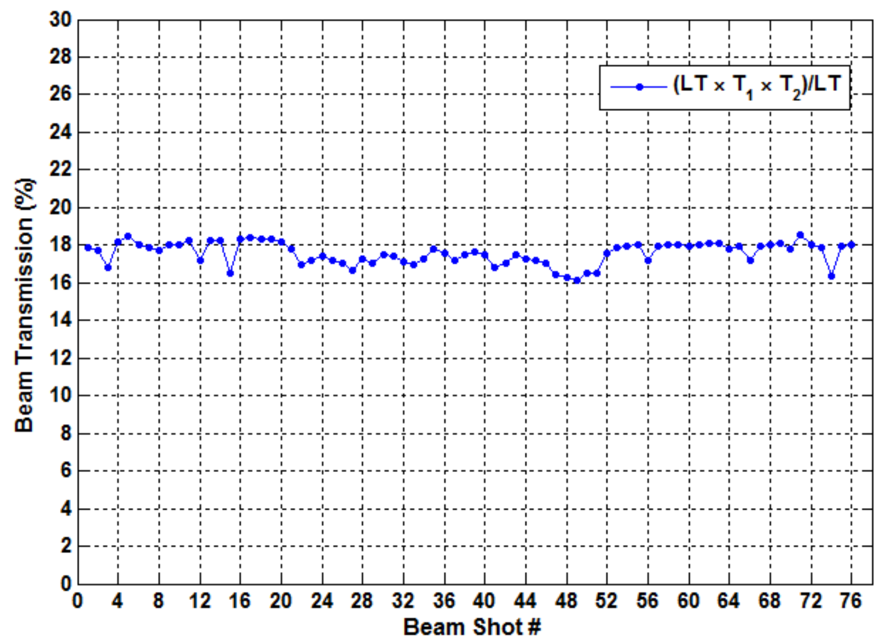
Beam Intensity measured by various device at B=0 T

Beam Transmission efficiency at B=0 T

Results Cont.. (High Intensity beam and B=3 T)

UP and DS toroids stop working at B=3 T

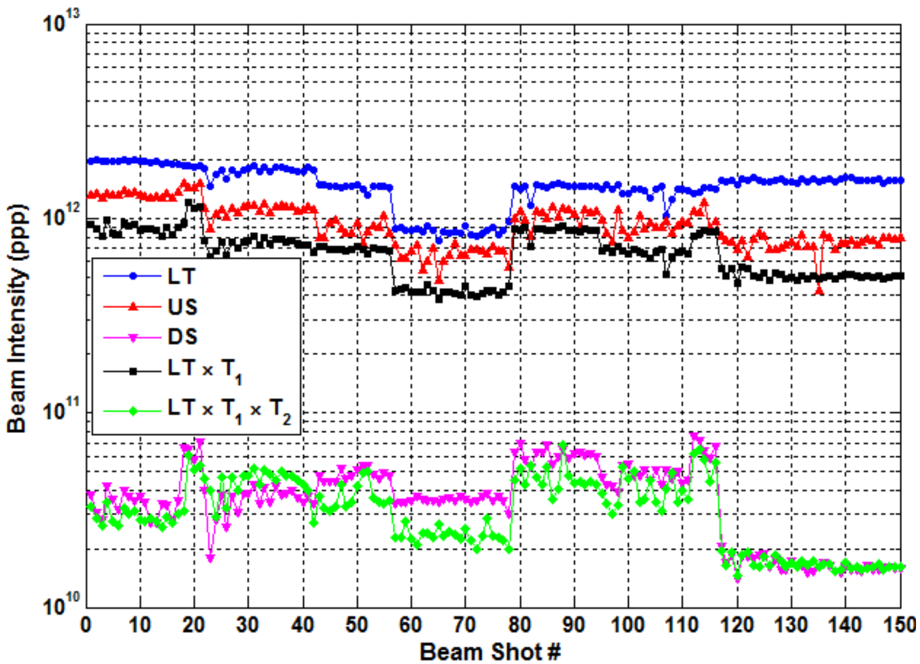




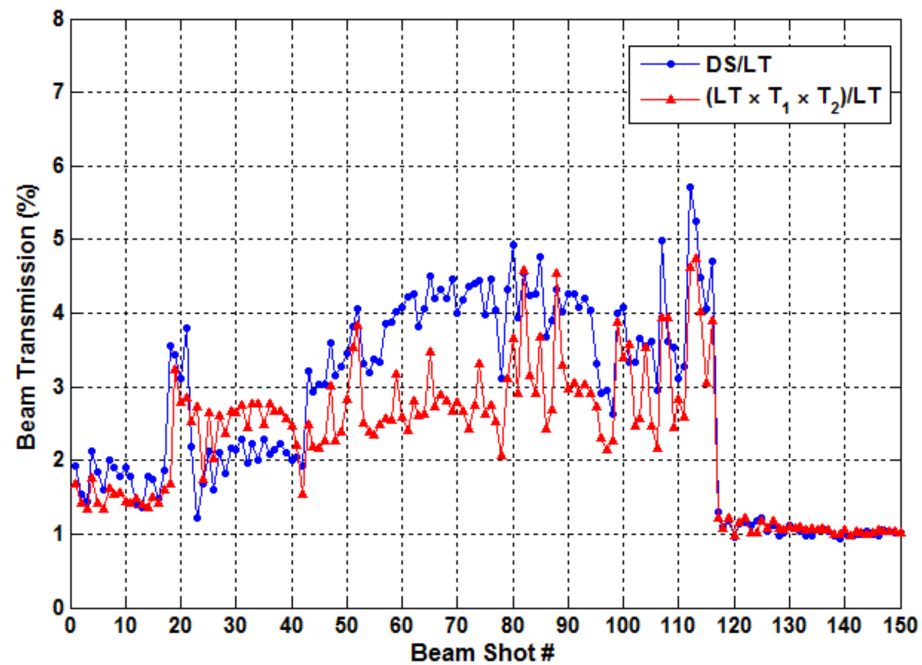
Beam Intensity estimated from CCD image at B=3 T

Beam Transmission efficiency at B=3 T

Results Conti.. (Low Intensity beam and B=0 T)



Beam Intensity measured by various device at B=0 T



Beam Transmission efficiency at B=0 T

Results Conti.. (Low Intensity beam and B=3 T)

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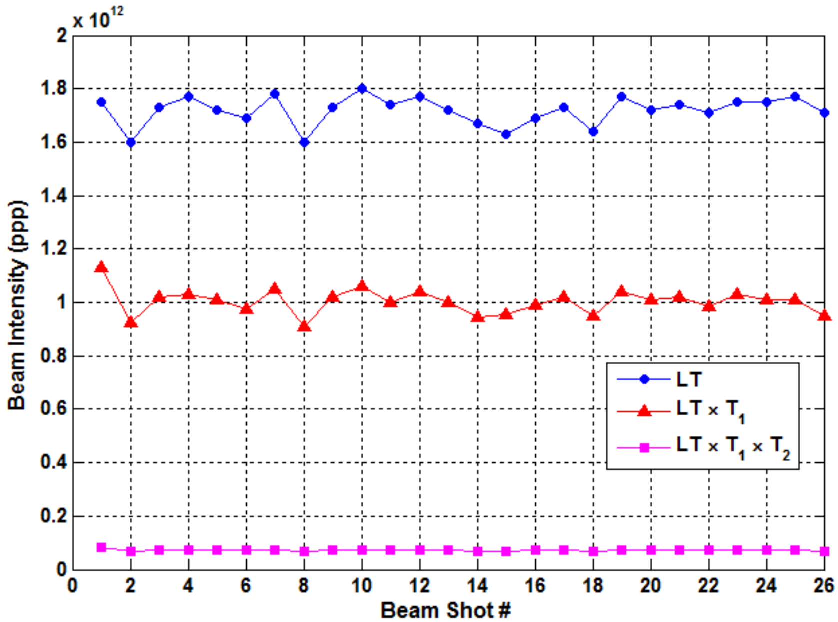

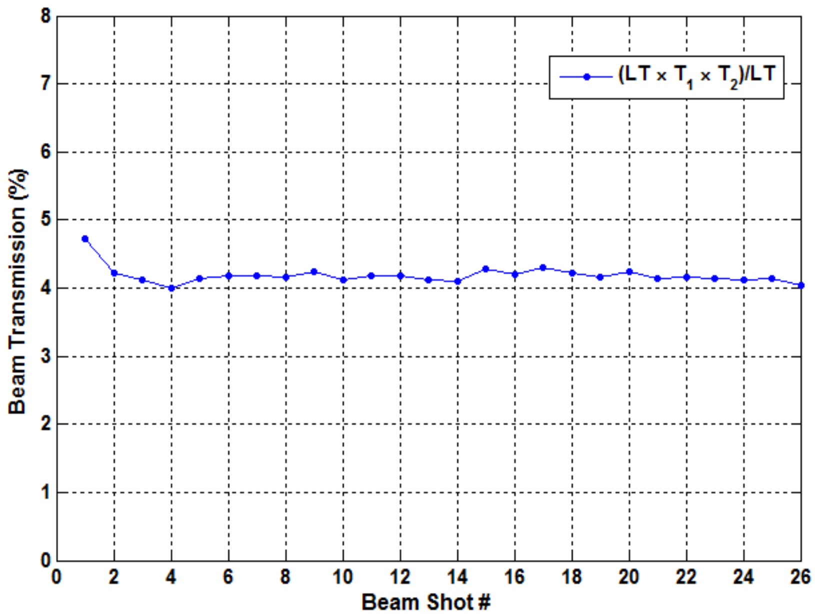

Beam Intensity measured by various device at B=3 T

Beam Transmission efficiency at B=3 T

Conclusions

- We have developed passive beam diagnostic instrumentation using a combination of a Chromox-6 scintillation screen and CCD camera for calculation of beam transmission efficiency through collimator. Results are consistent with toroid measurement.
- The technique works fine even in B=3 T where no other beam diagnostic instrumentation work.
- This technique is useful to MTA beam operator to tune the beam at MCR

➢ Screen is placed in air

➢ CCD camera is kept far away from screen and viewed with telephoto lens

➢ Beam image does not change with B=3 T

- A simulation calculation using G4beamline with a proton beam of σ_x = 1.67 mm and σ_y = 3.88 mm shows that the transmission efficiency through the 4 mm diameter collimator is 47%. Using these values of σ_x and σ_y in a Mathematica program developed for CCD image analysis we obtain a transmission efficiency of 55%. This bench mark calculation shows simulation and measurements are in reasonable agreement

Thank you very much for your kind Attention