# Instrumentation for Measurement of 400 MeV Proton Beam Intensity and Transmission Through Collimator of HPRF Cavity Experiment at Fermilab MuCool Test Area

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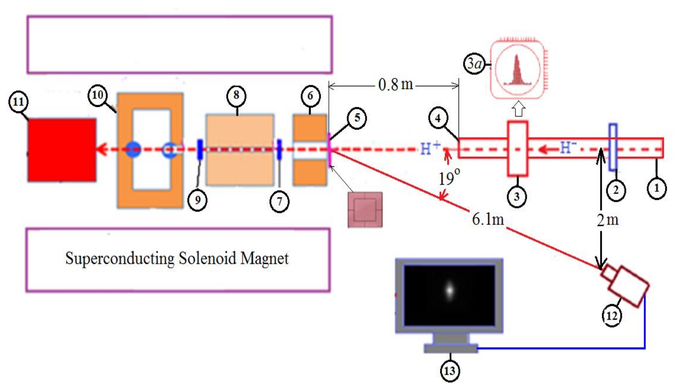
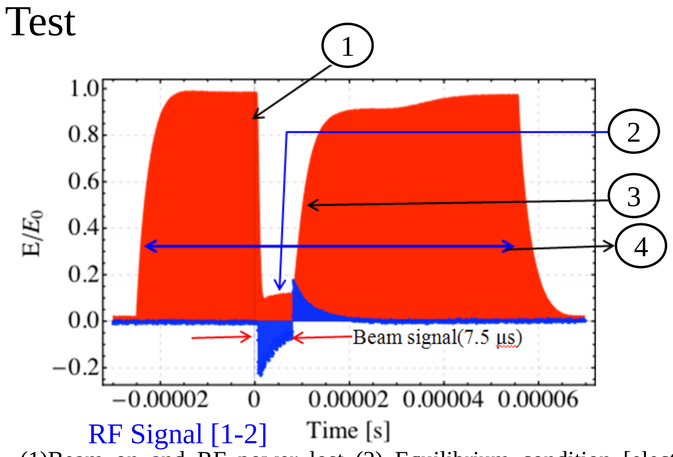
## Objective

- Muon Acceleration R&D (Ionization cooling): HPRF cavity (950 psi hydrogen gas)
- 1200 $e^-$/cm are generated by incident p @ E = 400 MeV [Ionization process: $p + H_2 \rightarrow p + H_2^+ + e^-$]
- No. of protons entering HPRF cavity need to be known
- MTA is hydrogen gas flammable area
- Current Transformer (Toroid) does not work in B= 3 T
- We need passive diagnostic system for beam position, profile and beam transmission measurement
- Chromox-6 screen and CCD camera is one of the option

## Expt. Set up for HPRF Beam Test



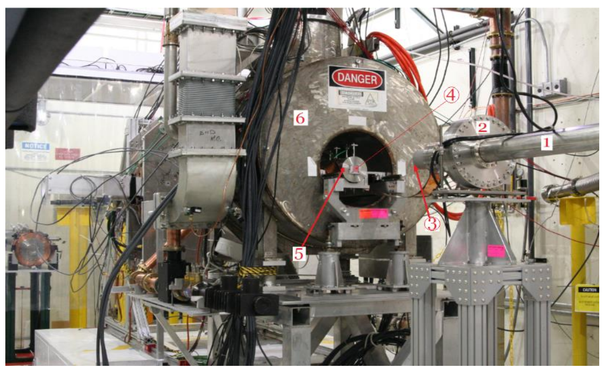

1: Beam pipe, 2: Linac Toroid (LT), 3: Multi-wire detector 4: Ti window, 5: Chromox-6, 6: 1st collimator, 7: US toroid, 8: 2nd collimator, 9: DS toroid, 10: HPRF cavity, 11: Beam absorber, 12: CCD camera, 13: CCD image on PC.




RF Signal [1-2]

(1)Beam on and RF power lost (2) Equilibrium condition [electron production rate = recombination rate], (3) Beam off and RF power is recovered, (4) RF pulse length: 80 μs; RF Frequency = 802 MHz; Gas pressure = 950 psi; $E_o$=20 MV/m, Beam intensity = $2\times10^8$ /bunch

## MuCool Test Area (MTA)



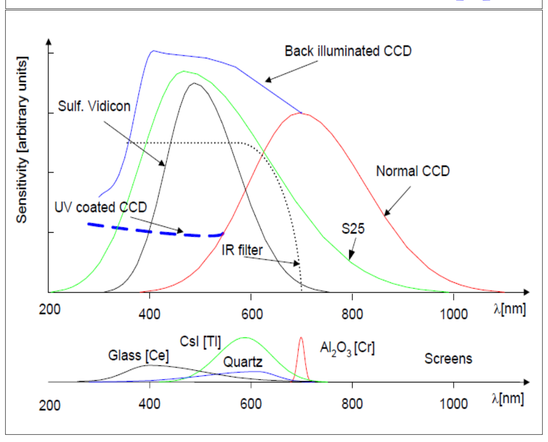

1: Beam pipe, 2: multi-wire detector, 3: Titanium window, 4: Chromox-6 scintillation screen, 5: First beam collimator, 6: Superconducting solenoid magnet.

| MTA Beam Parameters | Value |
|---|---|
| Energy | 400 MeV |
| Average beam Current | 32 – 50 mA |
| Species | $H^-/H^-$ |
| Macro bunch length | 10 μs |
| Micro bunch spacing | 5 ns (200 MHz) |
| No. of Micro Bunch (8μs/5ns) | 1600 |
| Particle per Macro Bunch | $1.5 \times 10^{12}$ |
| Particle per Micro Bunch | $9.3 \times 10^8$ |
| Average charge | 240 nC |
| Repetition rate | 1 macro-bunch /min |
| Emittance, $\varepsilon_{95\%}$ (Simulated) | 10 mm-mrad |

## Chromox-6 Scintillation Screen

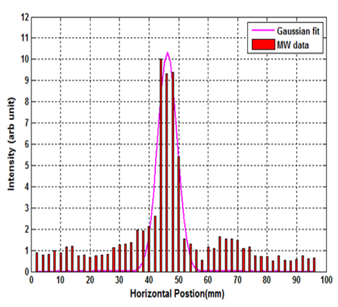
- Specialized Alumina ($Al_2O_3$ 99.4%) doped with $Cr_2O_3$ (0.5%)
- Color: Pink , Bulk Density: 3.85 g/cc,
- Grain size: 10 – 15 μm
- λ for luminescent when impacted by electron or $H^+$ : 691-694 nm
- Melting point: 2000 °C
- Max. operating Temp: 1600 °C
- Resistivity @ 400 °C: $10^{12}$ Ω-cm
- UHV compatibility
- Decay time: ~ 100 ms
- Attenuation co-efficient at 700 *nm*, α =0.8 ± 0.1 $mm^{-1}$

## Sensitivity and Emission spectra of various detectors and screens [3]

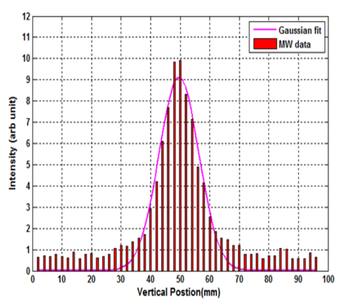



## Results [4]

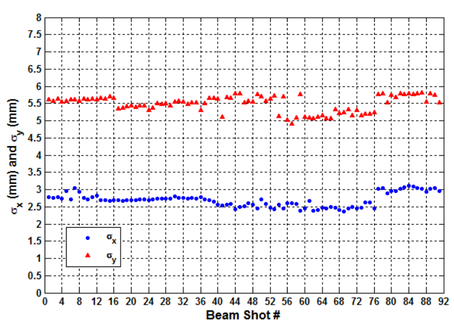
### 1. Multi-Wires Detectors




(a) Horizontal Profile

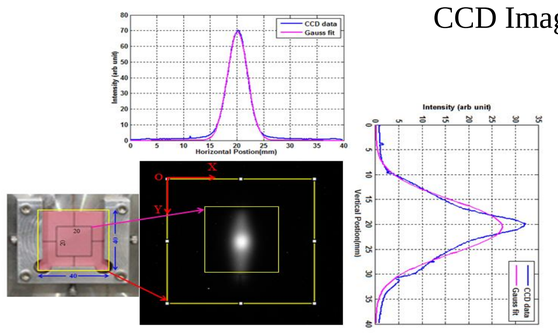



(b) Vertical Profile

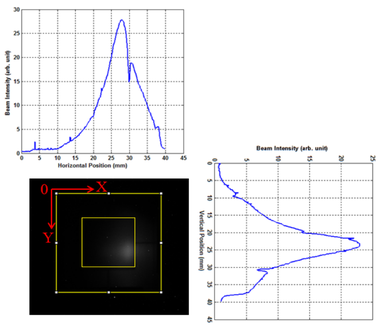



$\sigma_x$ and $\sigma_y$ at various beam shot

### CCD Image

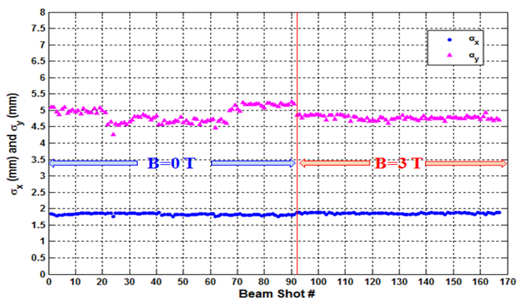



High Intensity Proton Beam

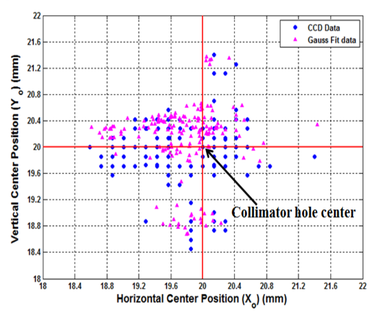



Low Intensity Proton Beam

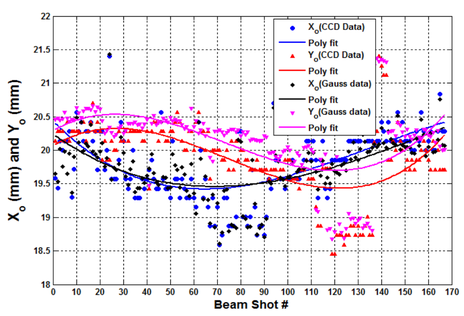
### 2. CCD Image Results for Beam Size and Position




$\sigma_x$ and $\sigma_y$ vs beam shot # with B=0T and B=3T

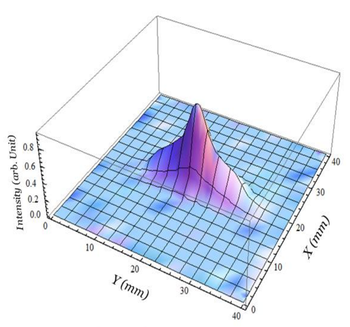



Foot print of beam center

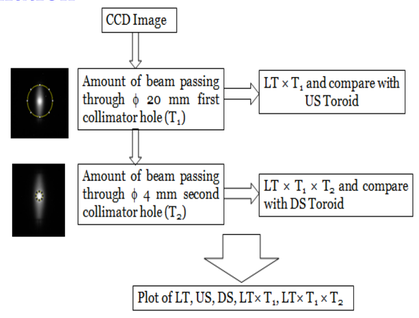



$X_0$ and $Y_0$ position of beam center vs Beam shot#

### Beam Transmission Calculation

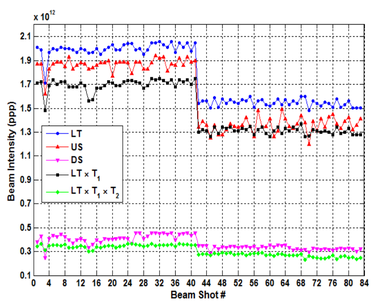



3D Plot of CCD Image

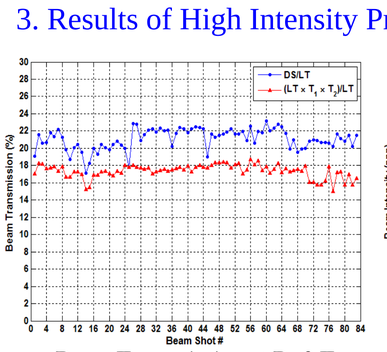



Floe chart for Beam Transmission calculation

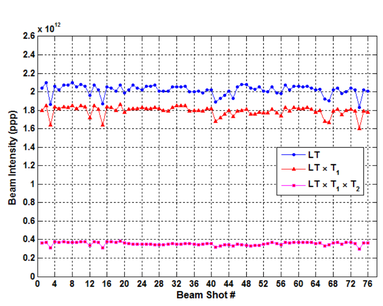
### 3. Results of High Intensity Proton Beam with B=0 T and B=3 T



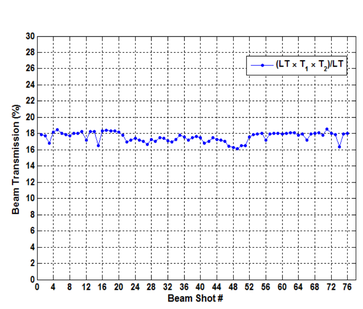

Beam Intensity at B=0 T




Beam Transmission at B=0 T

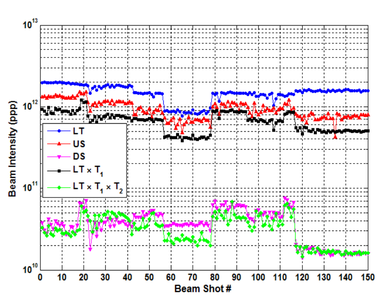



Beam Intensity at B=3 T

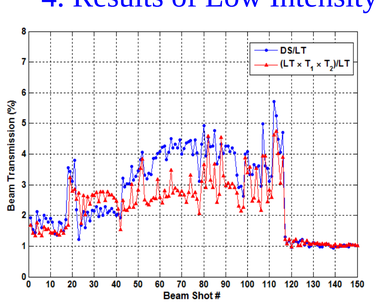



Beam Transmission at B=3 T

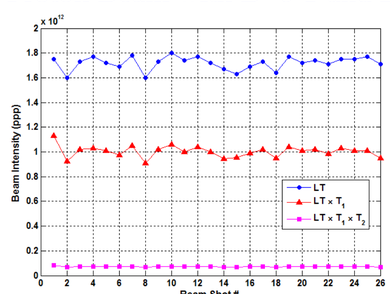
### 4. Results of Low Intensity Proton Beam with B=0 T and B=3 T



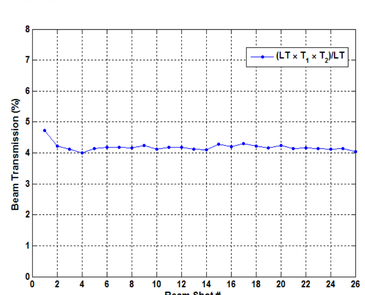

Beam Intensity at B=0 T




Beam Transmission at B=0 T




Beam Intensity at B=3 T




Beam Transmission at B=3 T

## Conclusions

- Combination of Chromox-6 scintillation screen (kept in air) and CCD camera works fine in B=3 T
- Transmission efficiency for high intensity proton beam
  Toroid measurement results: 21±1.4% (in B=0 T)
  CCD Image estimation: 17.3±0.8% (in B=0 T)
  CCD Image estimation: 17.6±0.6% 9in B=3 T)
- For low intensity and B=0 T
  Toroid measured max. Trans. efficiency: 4.13±0.3%
  and min. Trans. efficiency: 1.05±0.08%
  CCD Image estimated max. Trans. efficiency: 3.2 ±0.71%
  and min. Trans. efficiency: 1.07±0.06%
- For low intensity and B=3 T, CCD image estimated Trans. efficiency is 4.19±0.12%
- CCD results are reasonable agreement with simulation

## References

1. K. Yonehara, MAP Friday meeting, 9/23/11
2. M. Chung et al IPAC, Japan (2003) 3494
3. R. Jung et al, DIPAC 2003, Mainz, Germany
4. M. R. Jana et al, Rev. Scientific Instrum. 84 (2013) 063301

MAP 2013 Collaboration Meeting (MAP13) 19th – 22nd June 2013, Fermilab, USA