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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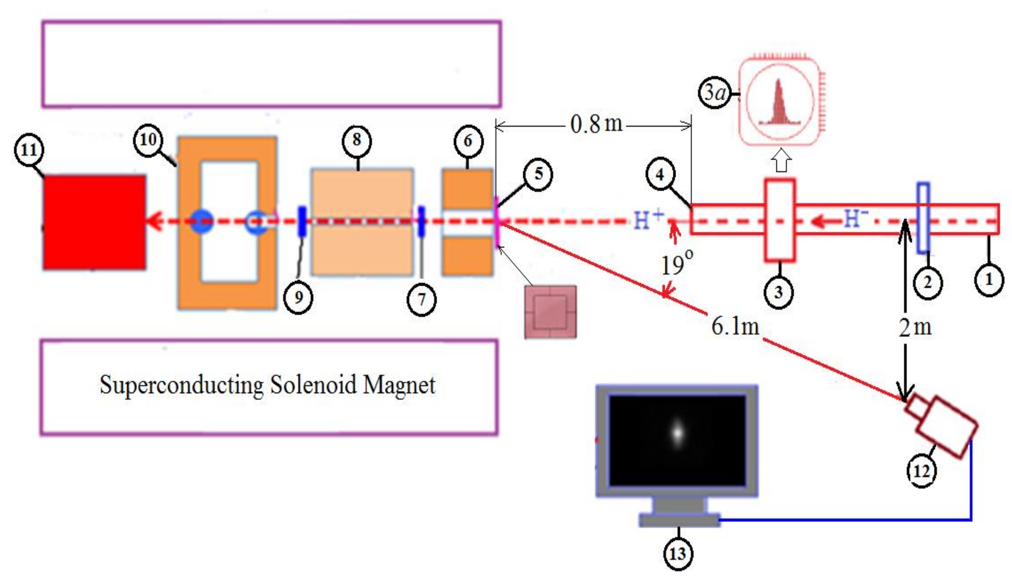
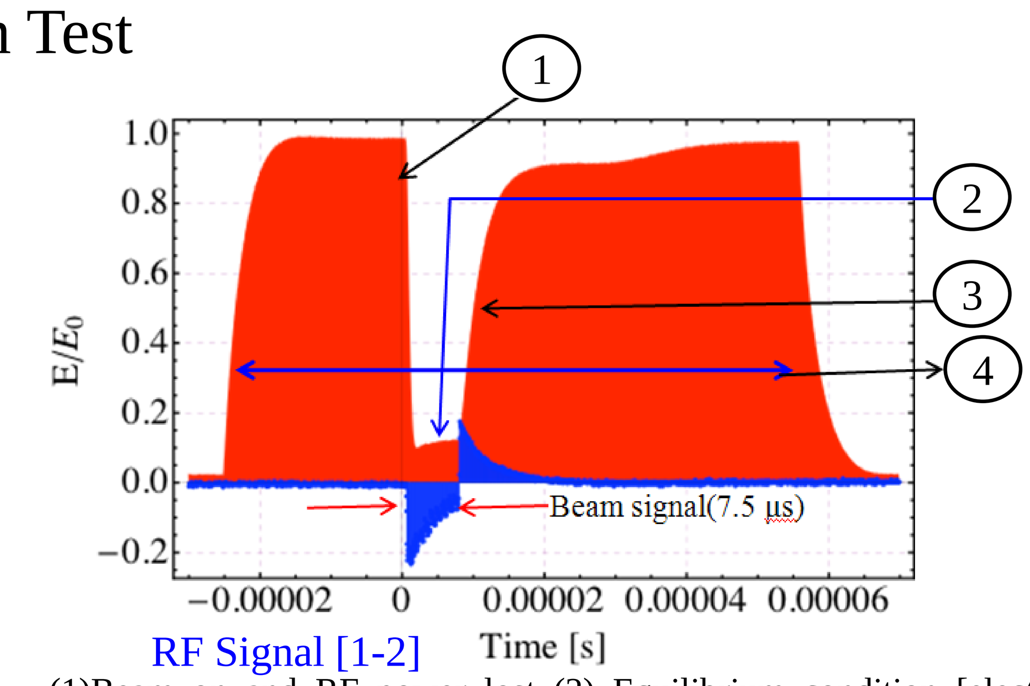
Objective

- 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



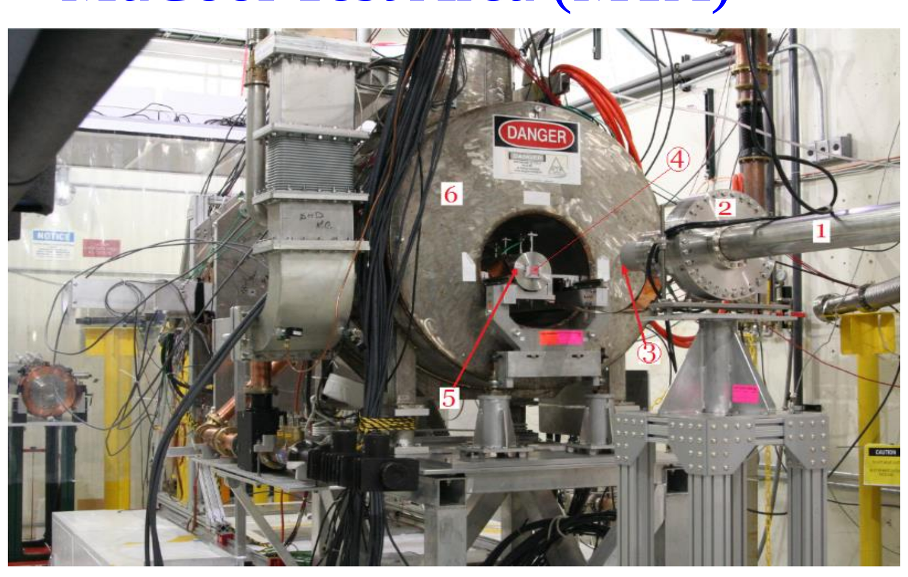
1: Beam pipe, 2: Linac Toroid (LT), 3: Multi-wire detector 4: Ti window, 5: Chromox-6, 6: 1st collimator, 7: US toroid, 8: 2nd collimator, 9: DS toroid, 10: HPRF cavity, 11: Beam absorber, 12: CCD camera, 13: CCD image on PC.



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 = 2×10^8 /bunch

MuCool Test Area (MTA)



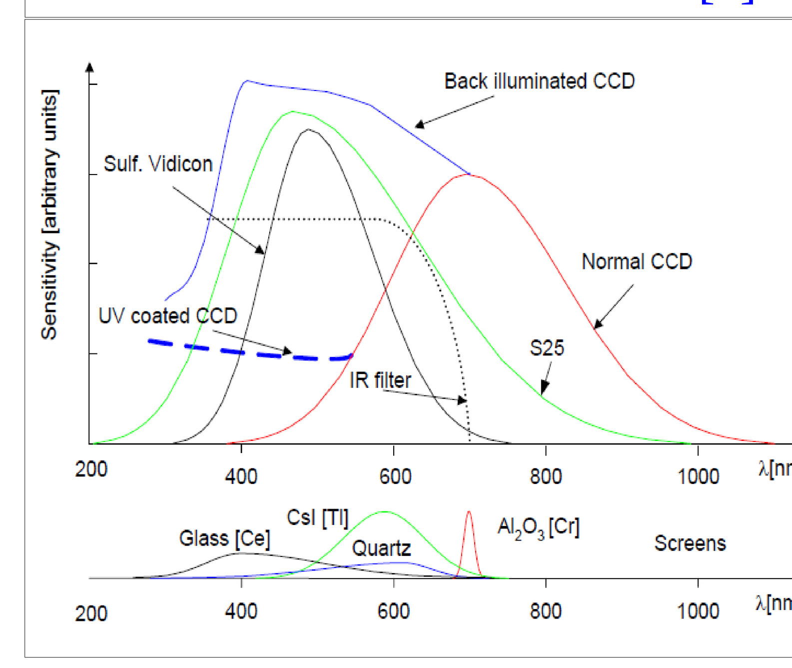
1: Beam pipe, 2: multi-wire detector, 3: Titanium window, 4: Chromox-6 scintillation screen, 5: First beam collimator, 6: Superconducting solenoid magnet.

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	1.5×10^{12}
Particle per Micro Bunch	9.3×10^8
Average charge	240 nC
Repetition rate	1 macro-bunch /min
Emittance, $\varepsilon_{95\%}$ (Simulated)	10 mm-mrad

Chromox-6 Scintillation Screen

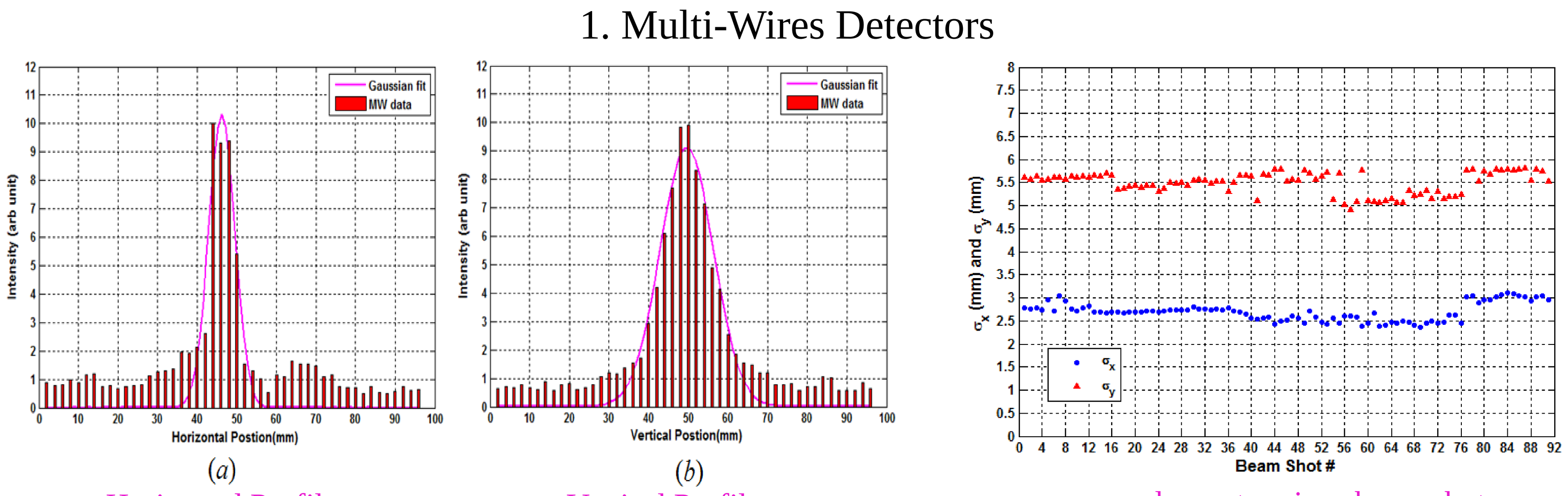
- Specialized Alumina (Al_2O_3 99.4%) doped with Cr_2O_3 (0.5%)
- Color: Pink , Bulk Density: 3.85 g/cc,
- Grain size: 10 – 15 µm
- λ for luminescent when impacted by electron or H^+ : 691-694 nm
- Melting point: 2000 °C
- Max. operating Temp: 1600 °C
- Resistivity @ 400 °C: 10^{12} Ω-cm
- UHV compatibility
- 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]



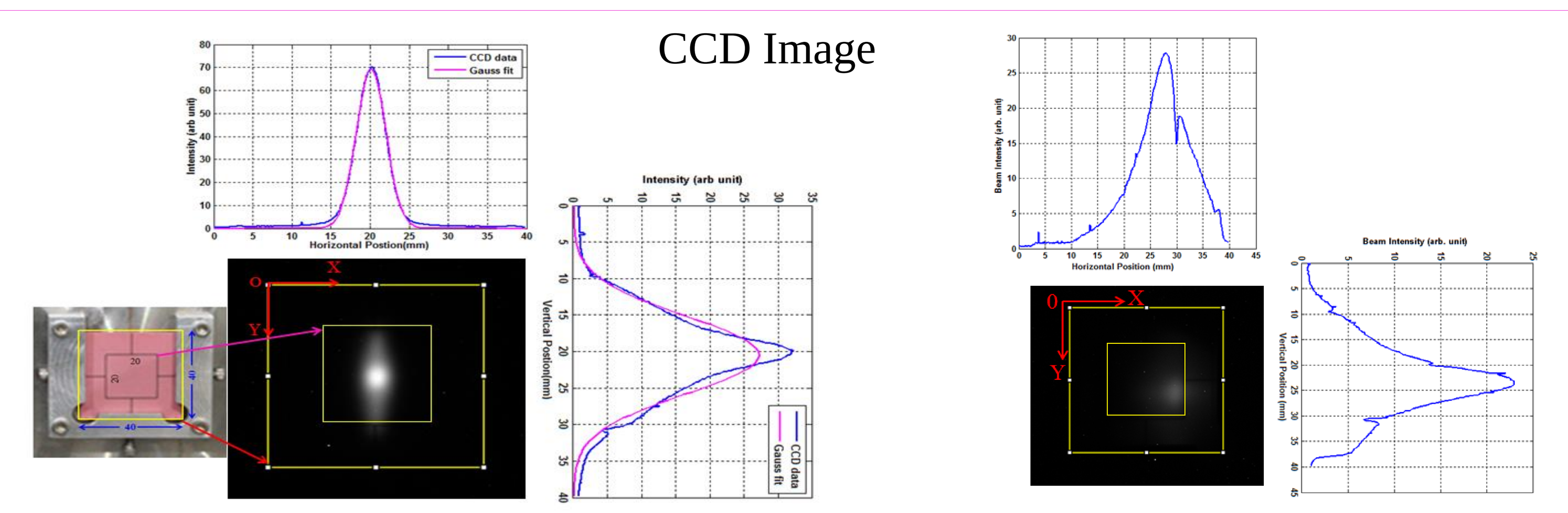
Results [4]

1. Multi-Wires Detectors



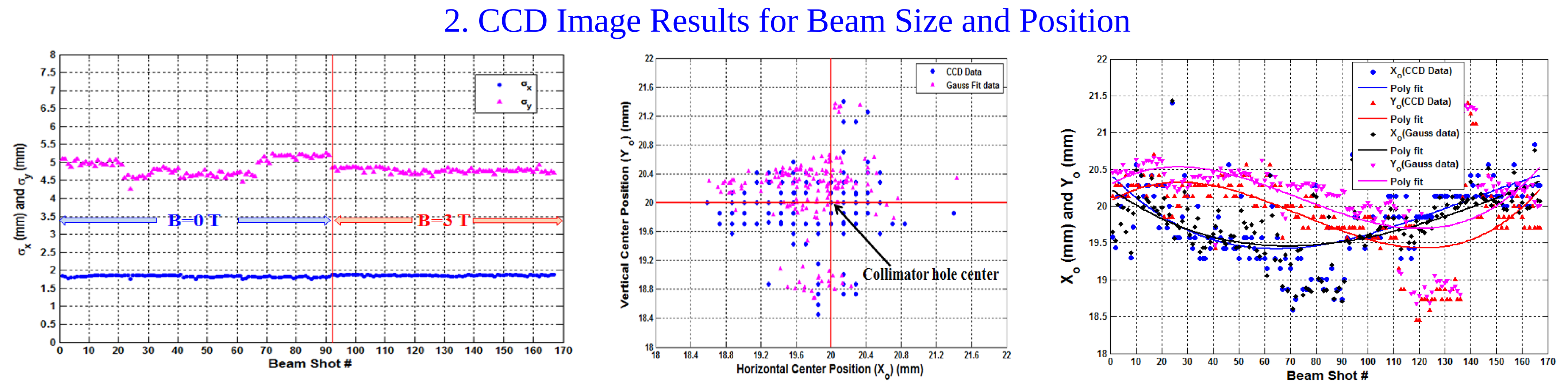
(a) Horizontal Profile (b) Vertical Profile σ_x and σ_y at various beam shot

CCD Image



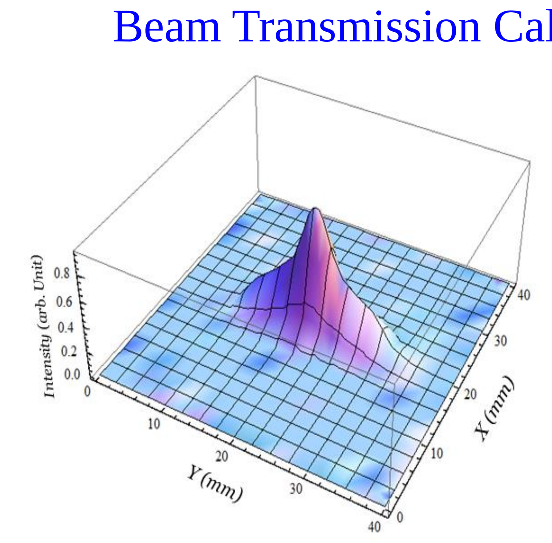
High Intensity Proton Beam Low Intensity Proton Beam

2. CCD Image Results for Beam Size and Position

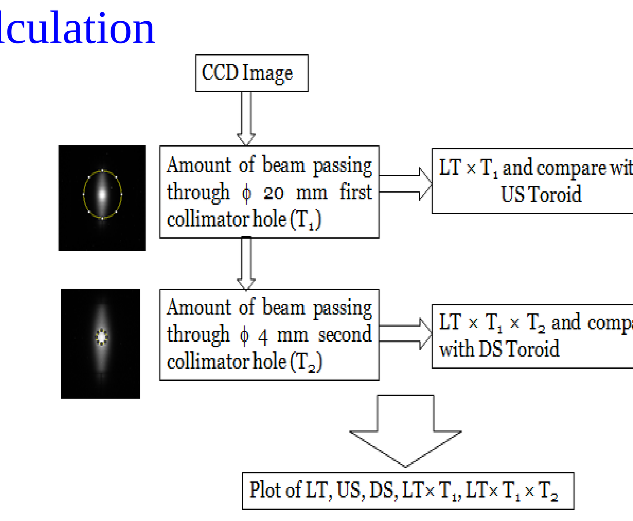


σ_x and σ_y vs beam shot # with B=0T and B=3T Foot print of beam center X_0 and Y_0 position of beam center vs Beam shot#

Beam Transmission Calculation

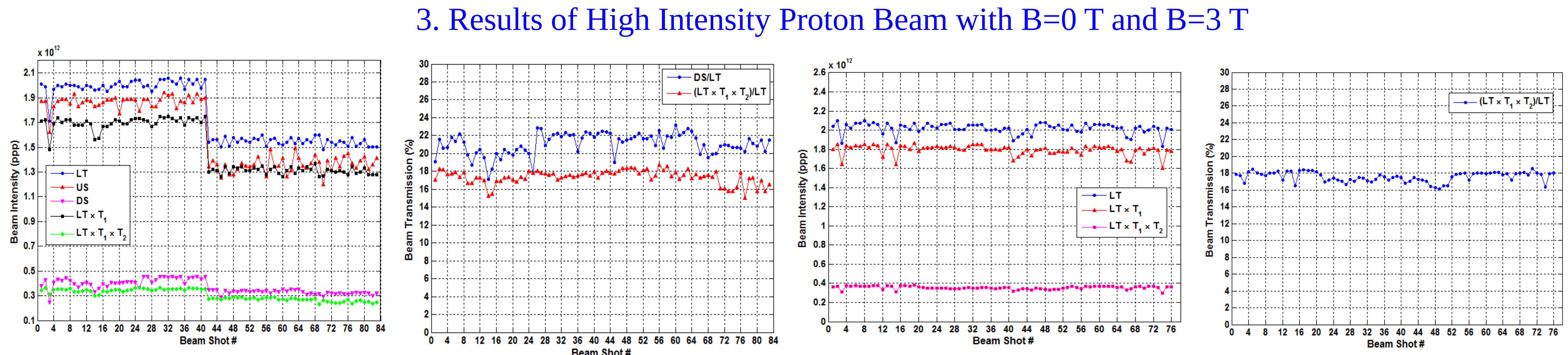


3D Plot of CCD Image



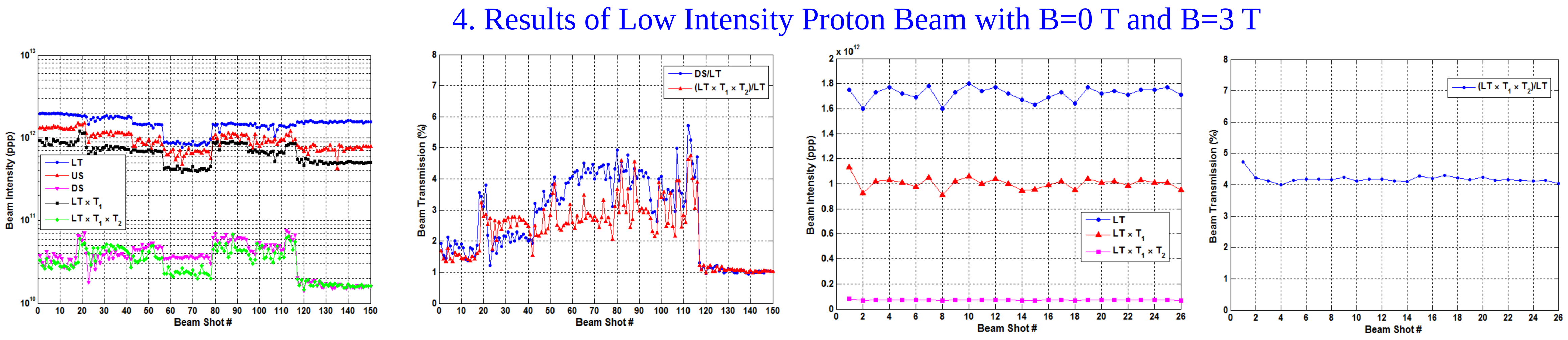
Floe chart for Beam Transmission calculation

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