Optical Diagnostic Results of MERIT Experiment and Post-Simulation

H. Park[1], H. Kirk[2], K. McDonald[3]

[2] Brookhaven National Laboratory
[3] Princeton University
[1] Stonybrook University

January 26, 2009

Neutrino Factory And Muon Collider Collaboration Meeting
Lawrence Berkeley National Laboratory, CA

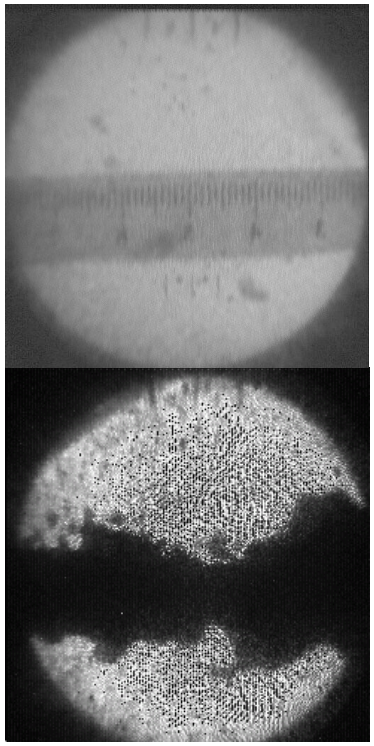
Talk Outline & Introduction

- Introduction : Aim of work
  - Understand the optical diagnostic results from experiment.
  - Do post-simulation with the experimentally observed results.
  - Investigate the characteristics of mercury jet flow through the comparison of theoretical calculated results with experimental results.

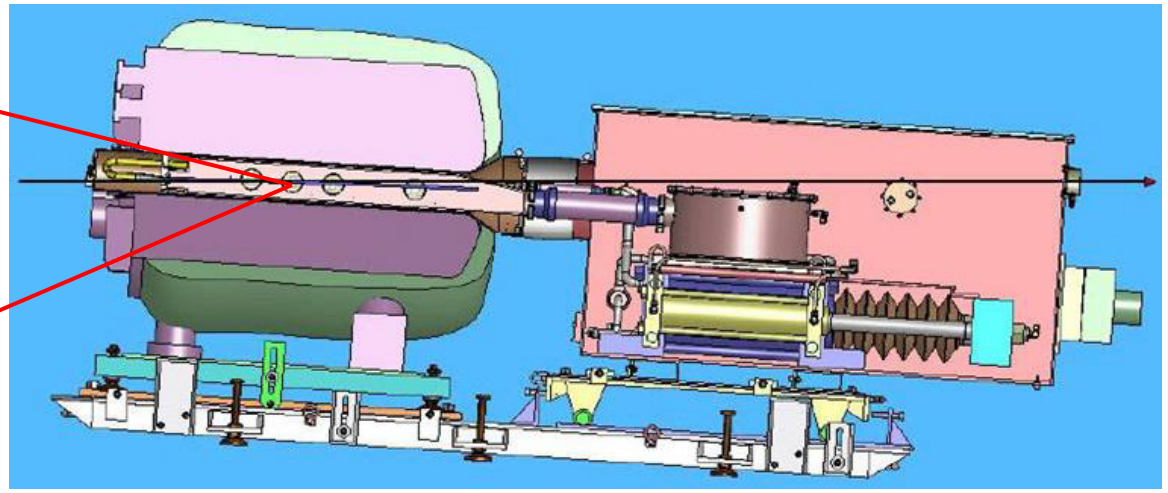
- Experimental Results
  - Optical diagnostic observation of jet flow using short laser pulsed retro-back shadow-photography.
  - Behavior of mercury jet in magnetic fields: stabilization, destabilization, flow velocity, drop/filaments velocity.
  - Proton beam structures. (CERN, G. Skoro)
  - Disruption of mercury jet by interaction of mercury jet with an intense proton beam in magnetic fields.

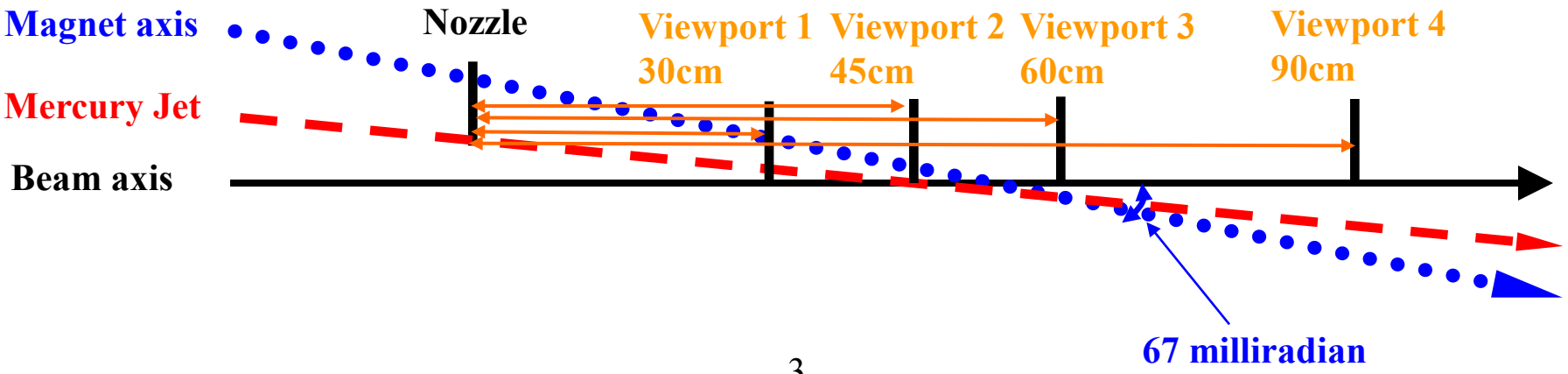
- Post-Simulation Results
  - Calculation of energy deposition density by an intense proton beam. (FNAL, S. Striganov)
  - Calculation of mercury drop velocity by the deposited energy presssurization.

Mercury Intense Target Experiment : October 22, 2007 ~ November 11, 2007

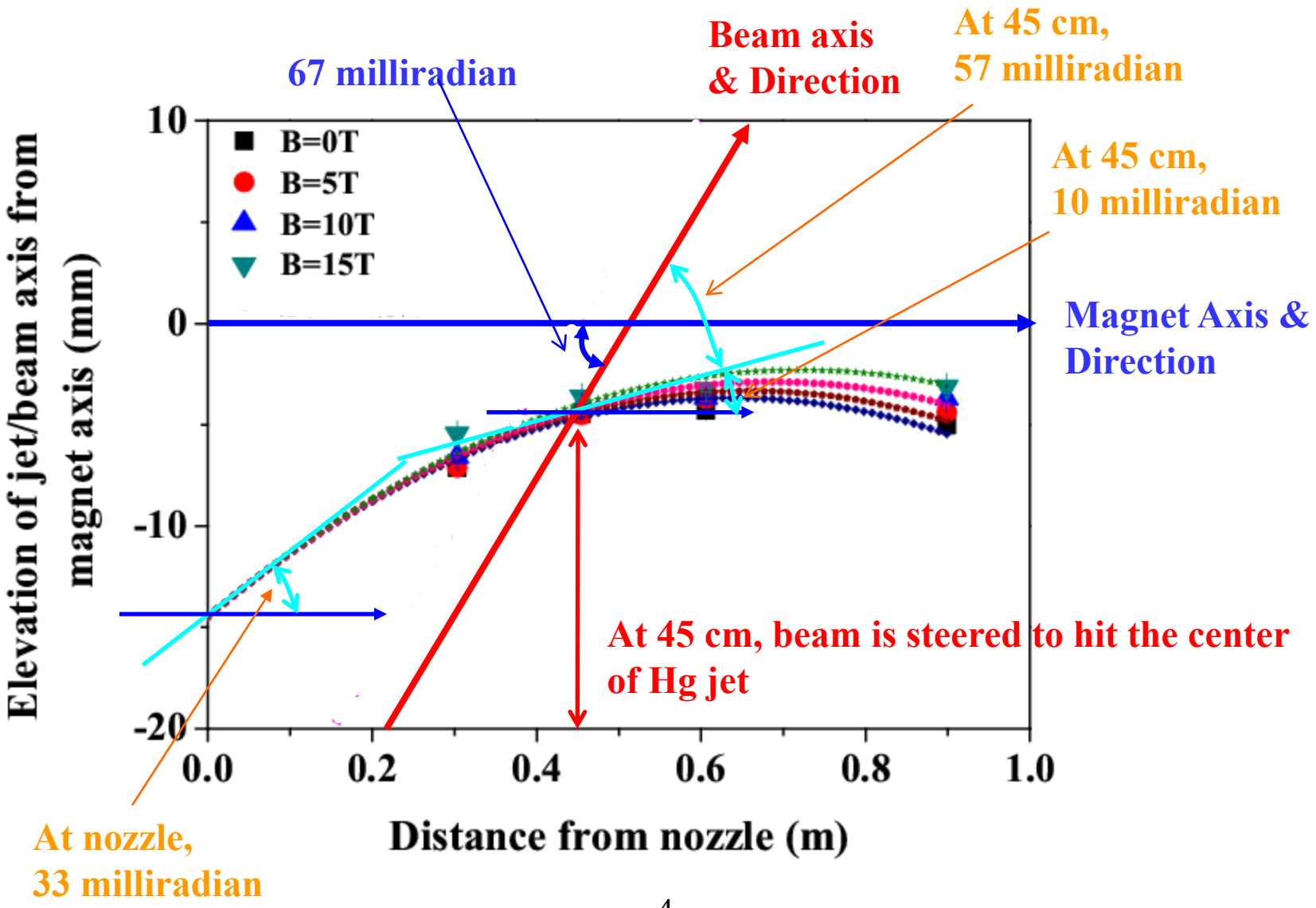


Setup of key components for MERIT experiment



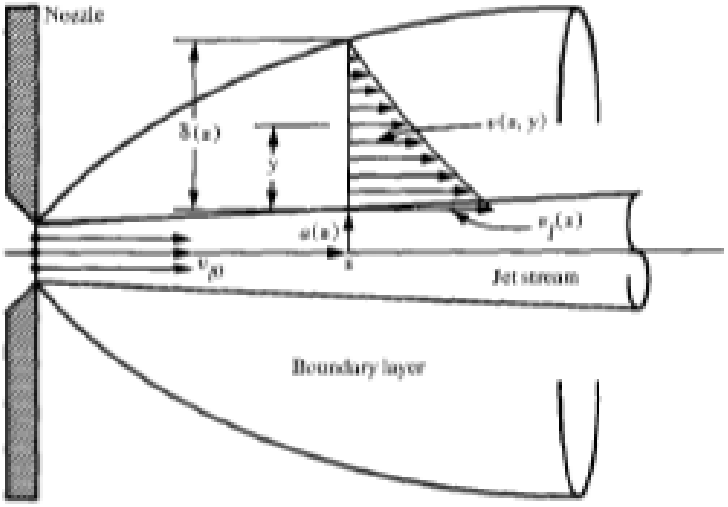


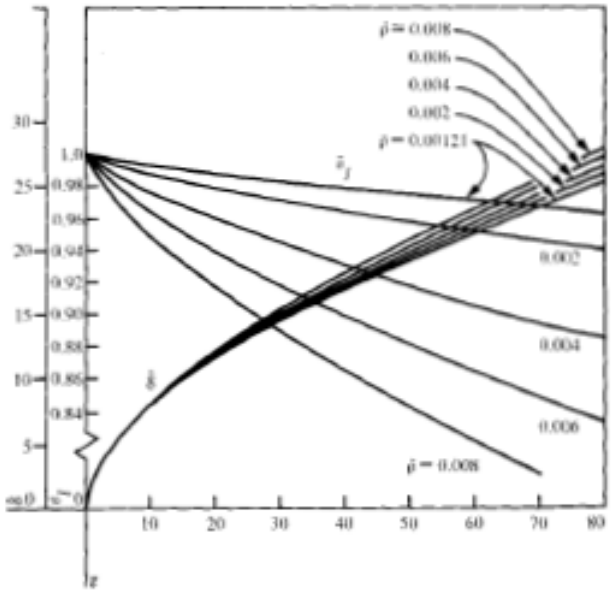
Influence of Magnetic Field and Gravity to Jet Trajectory

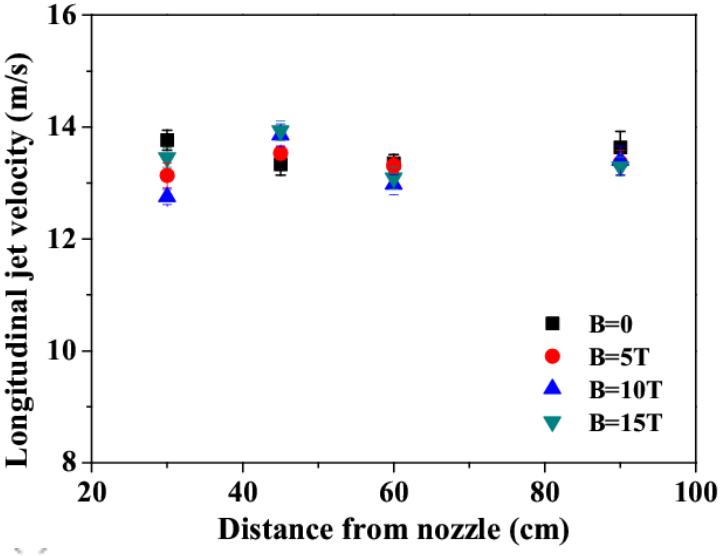


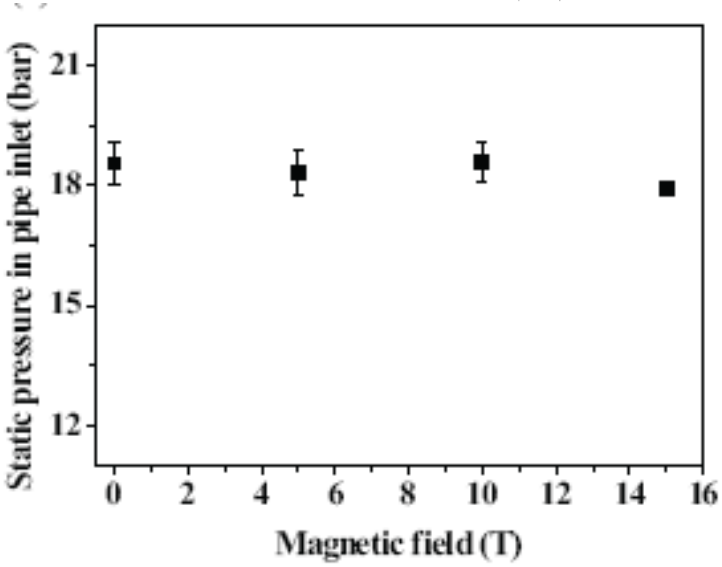
Longitudinal Hg Jet Stream Velocity along Distance from Nozzle

Boundary layer induced by a jet emerging from a nozzle

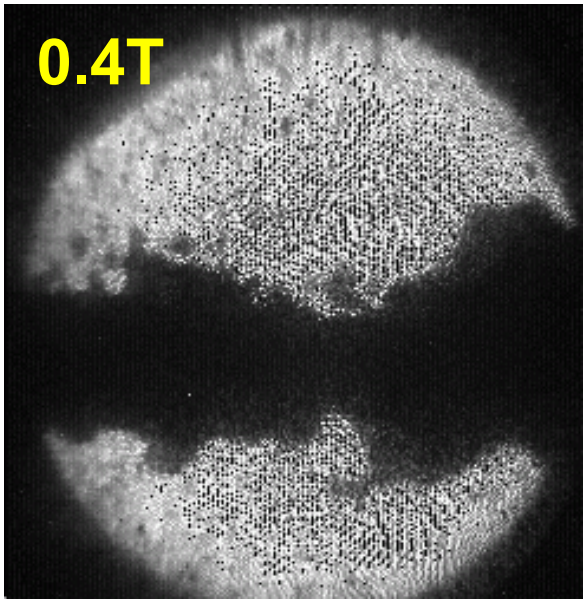


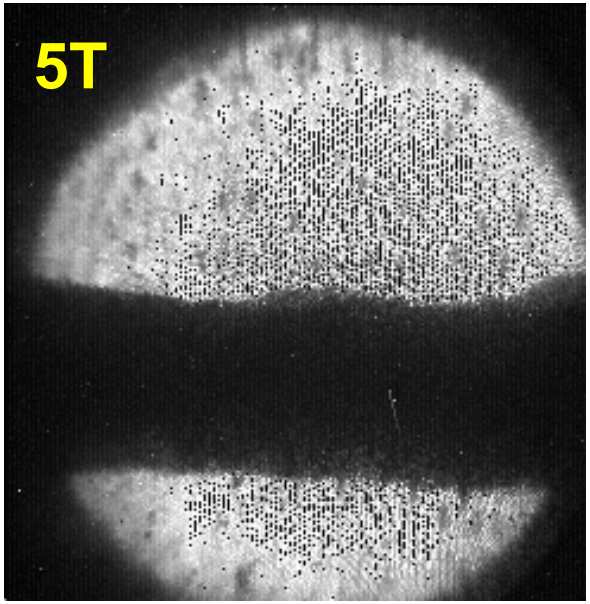


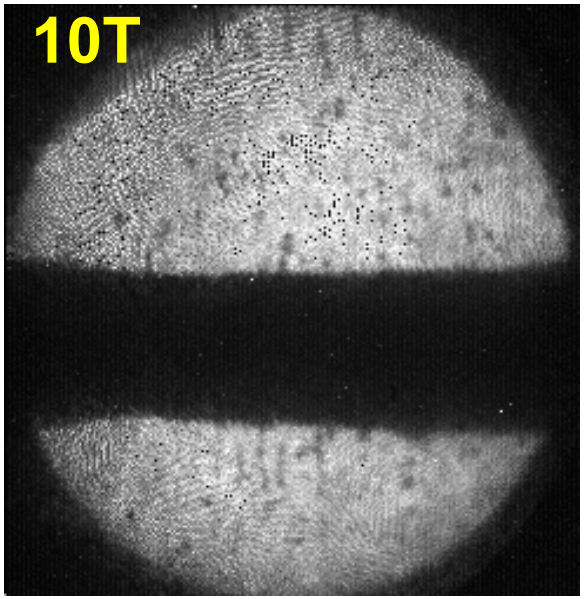


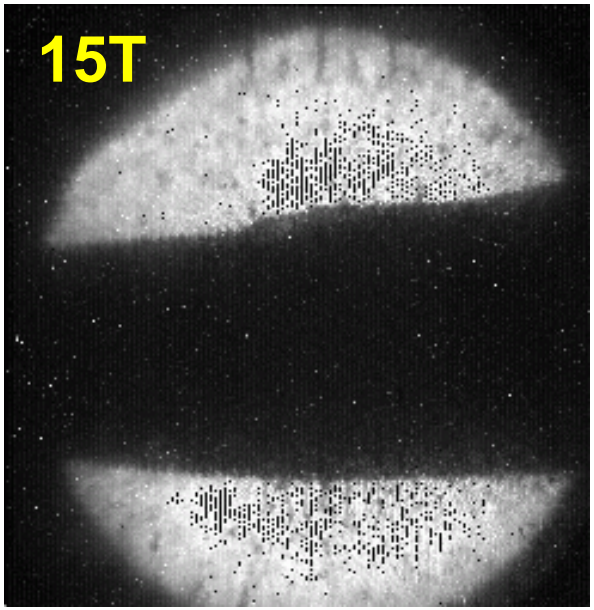


Stabilization of Jet Surface by Magnetic Field



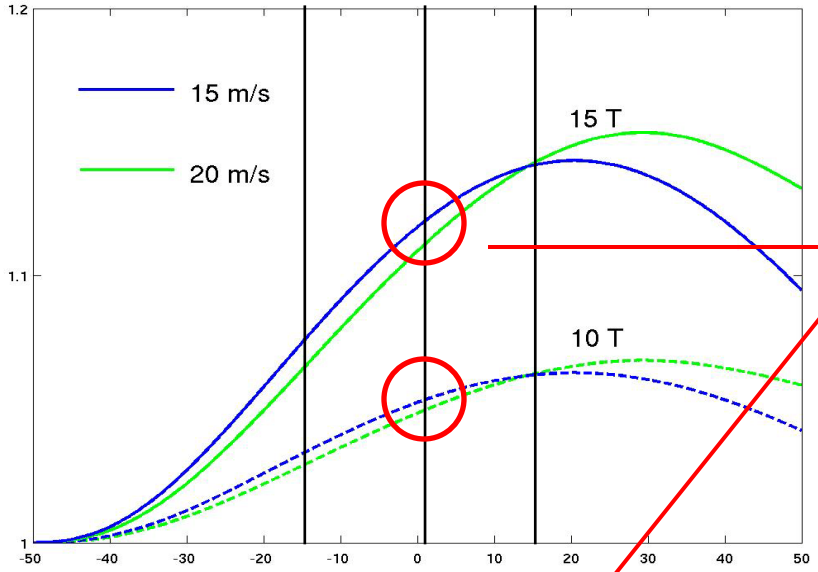


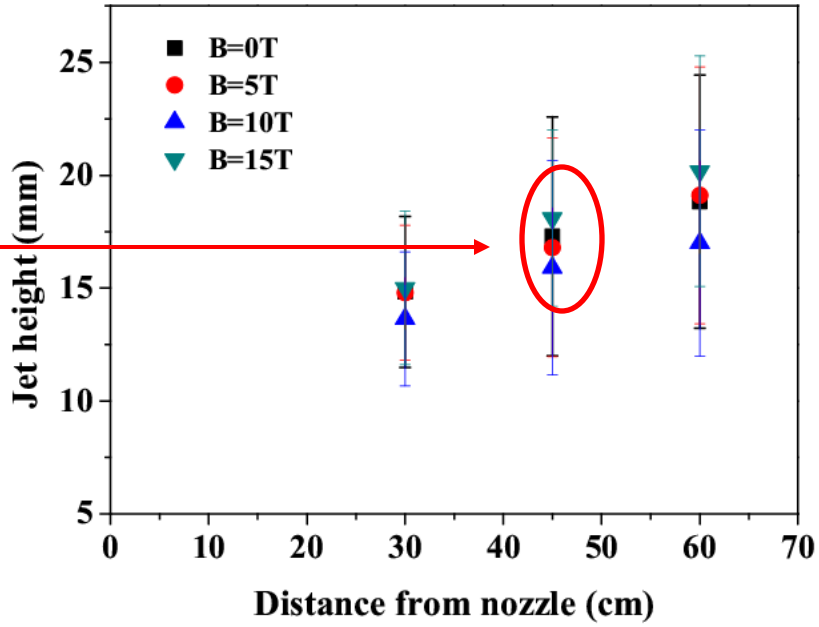


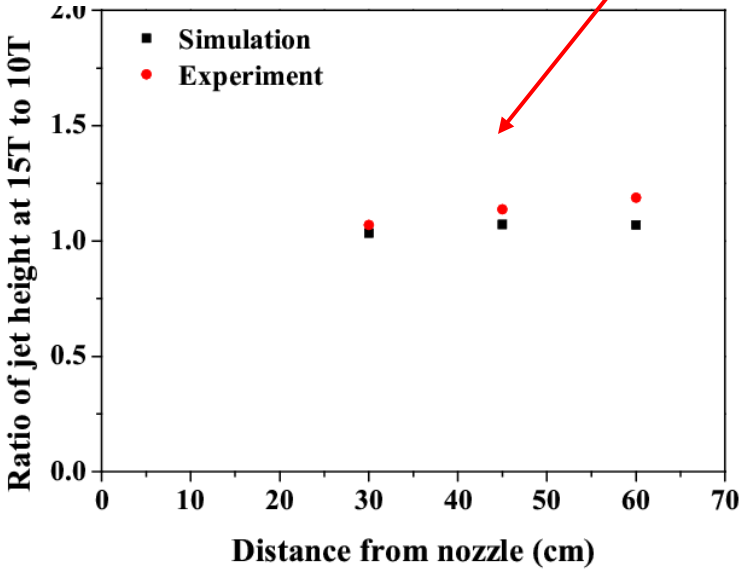


Hg Jet Height vs. Magnetic Field and Distance from Nozzle

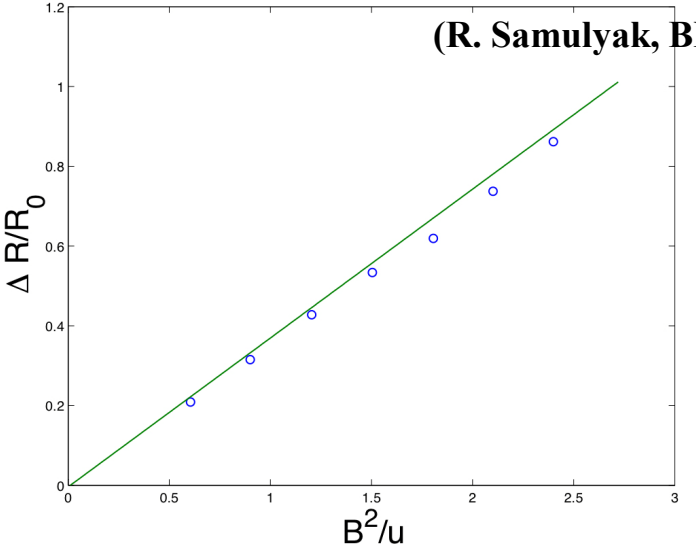
Jet distortion vp1 vp2 vp3 (R. Samulyak, BNL, 2008)



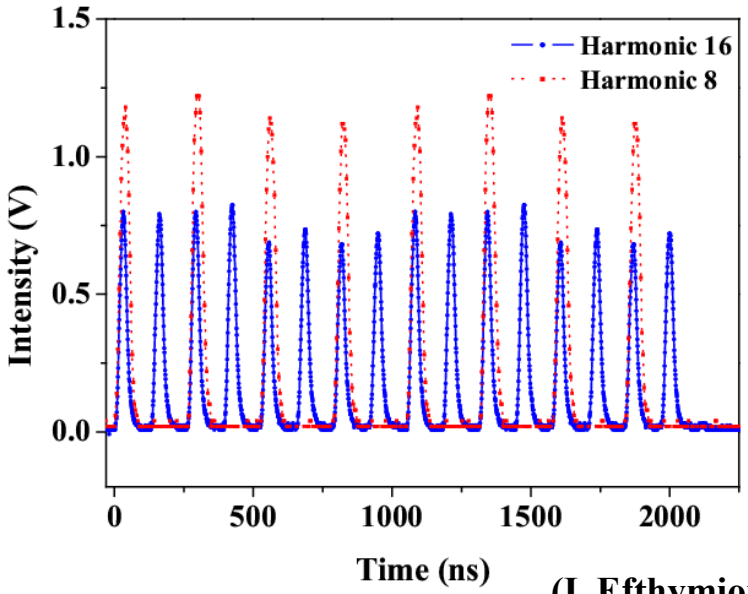




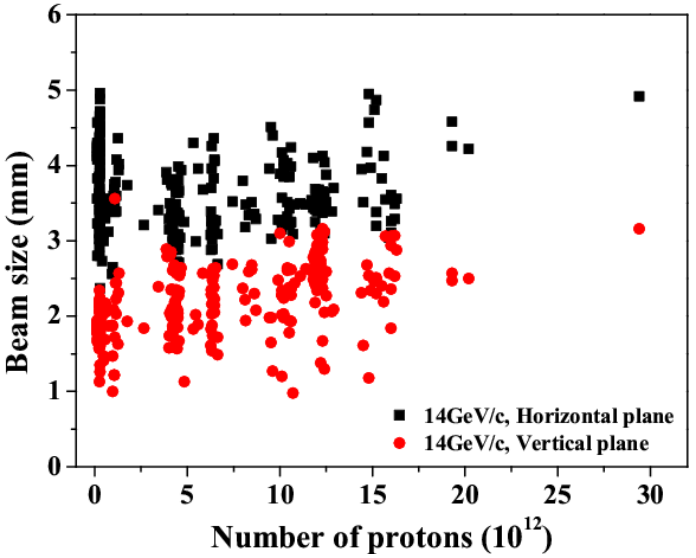
(R. Samulyak, BNL, 2008)



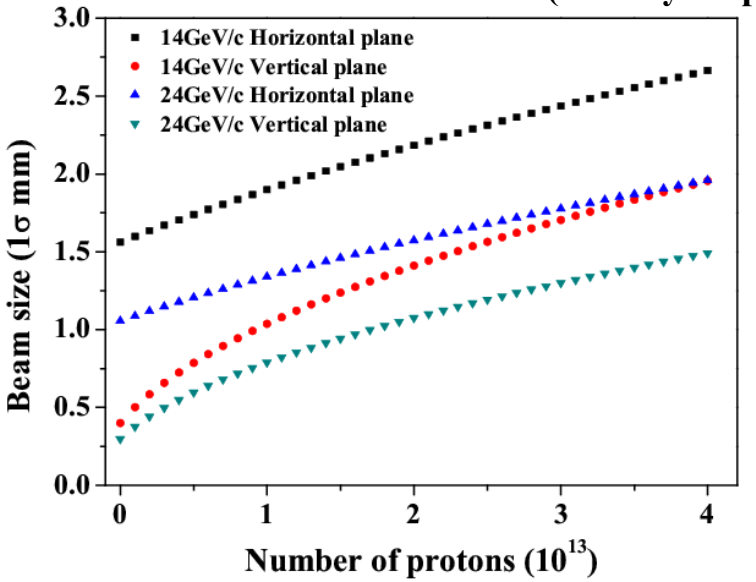
Beam Pulse Structure and Beam Size from Beam Optics and Camera Screen



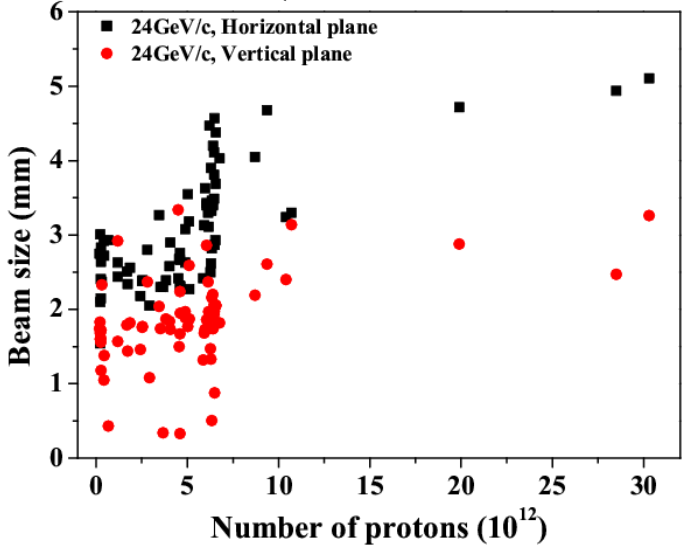
(G. Skoro, U. Sheffield, 2008)



(I. Efthymiopoulos, CERN, 2008)



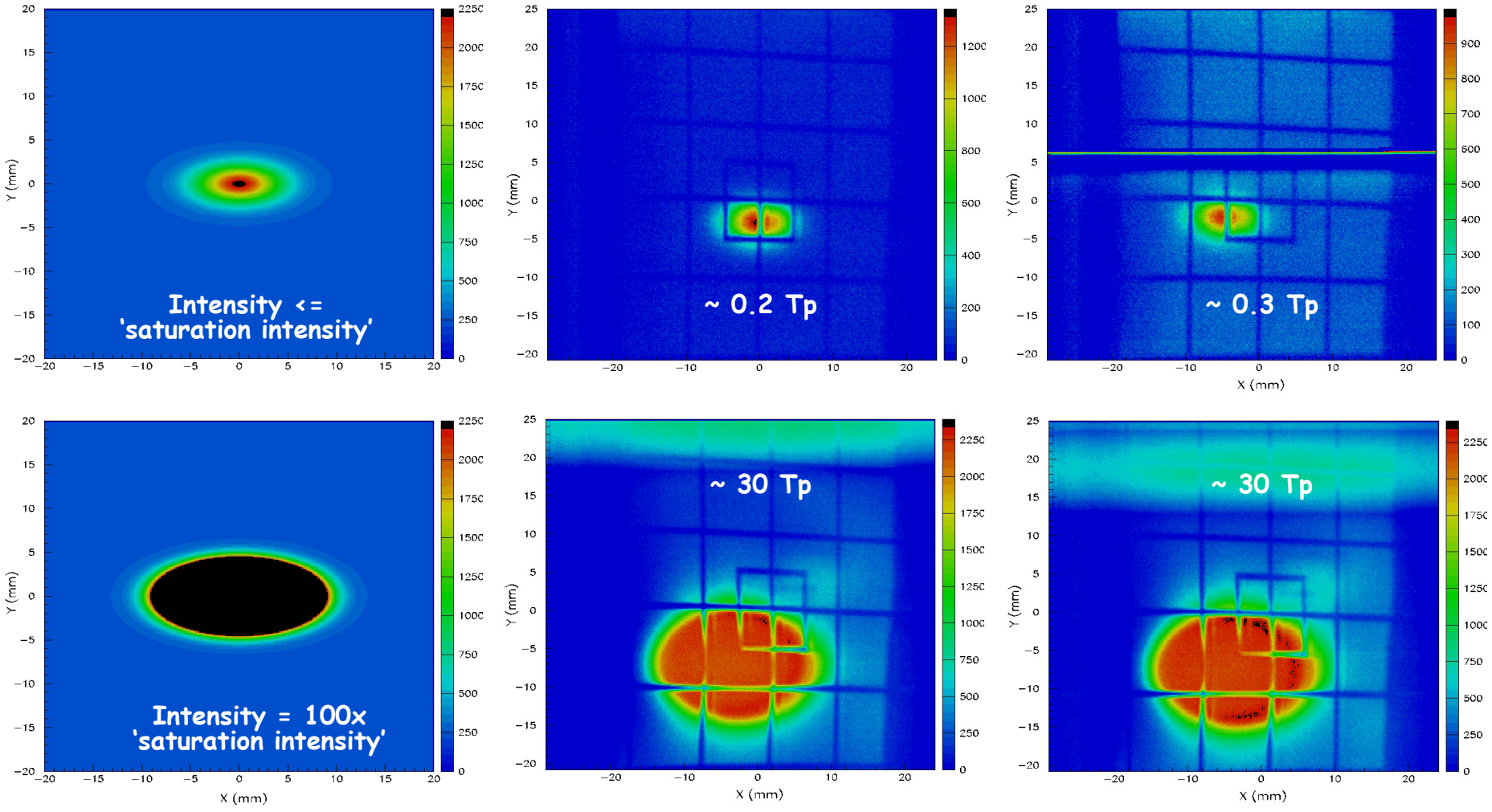
(G. Skoro, U. Sheffield, 2008)



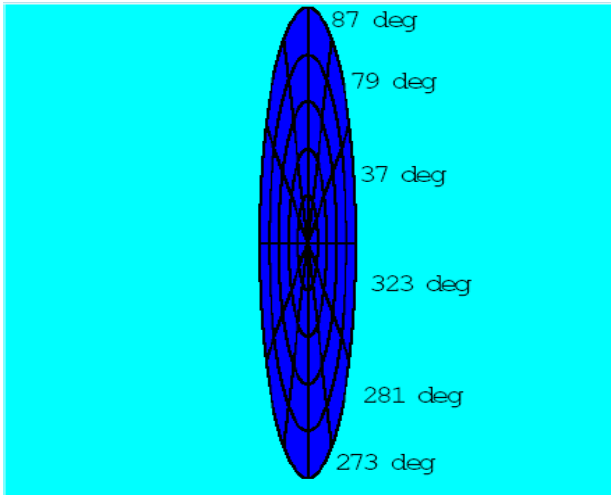
Beam Shape from Screen Shots

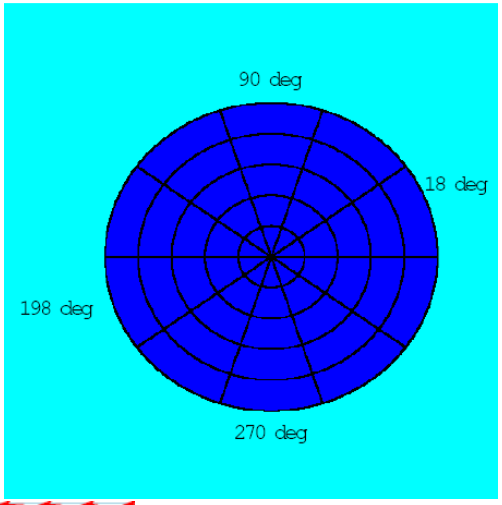
(G. Skoro, U. Sheffield, 2008)

Simulations **Experiment**



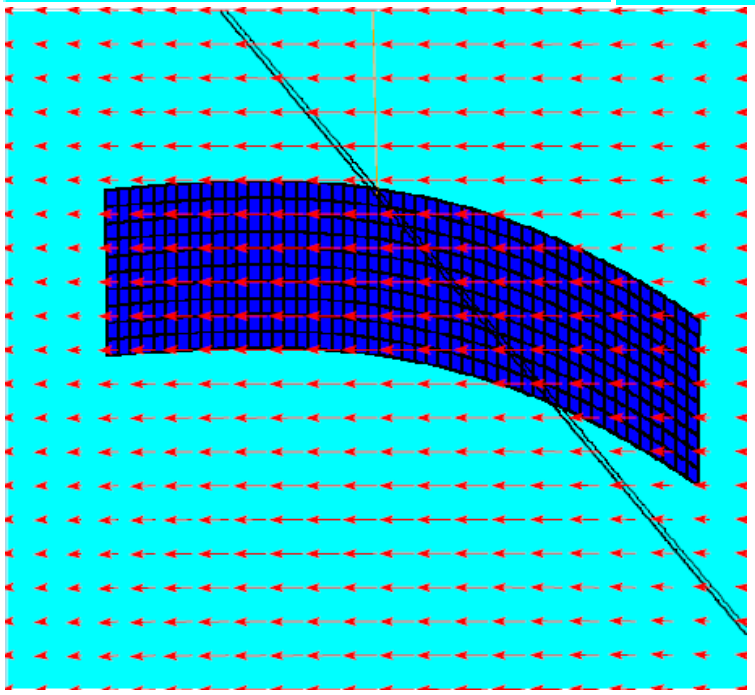
Beam Jet Interaction Model in MARS Code





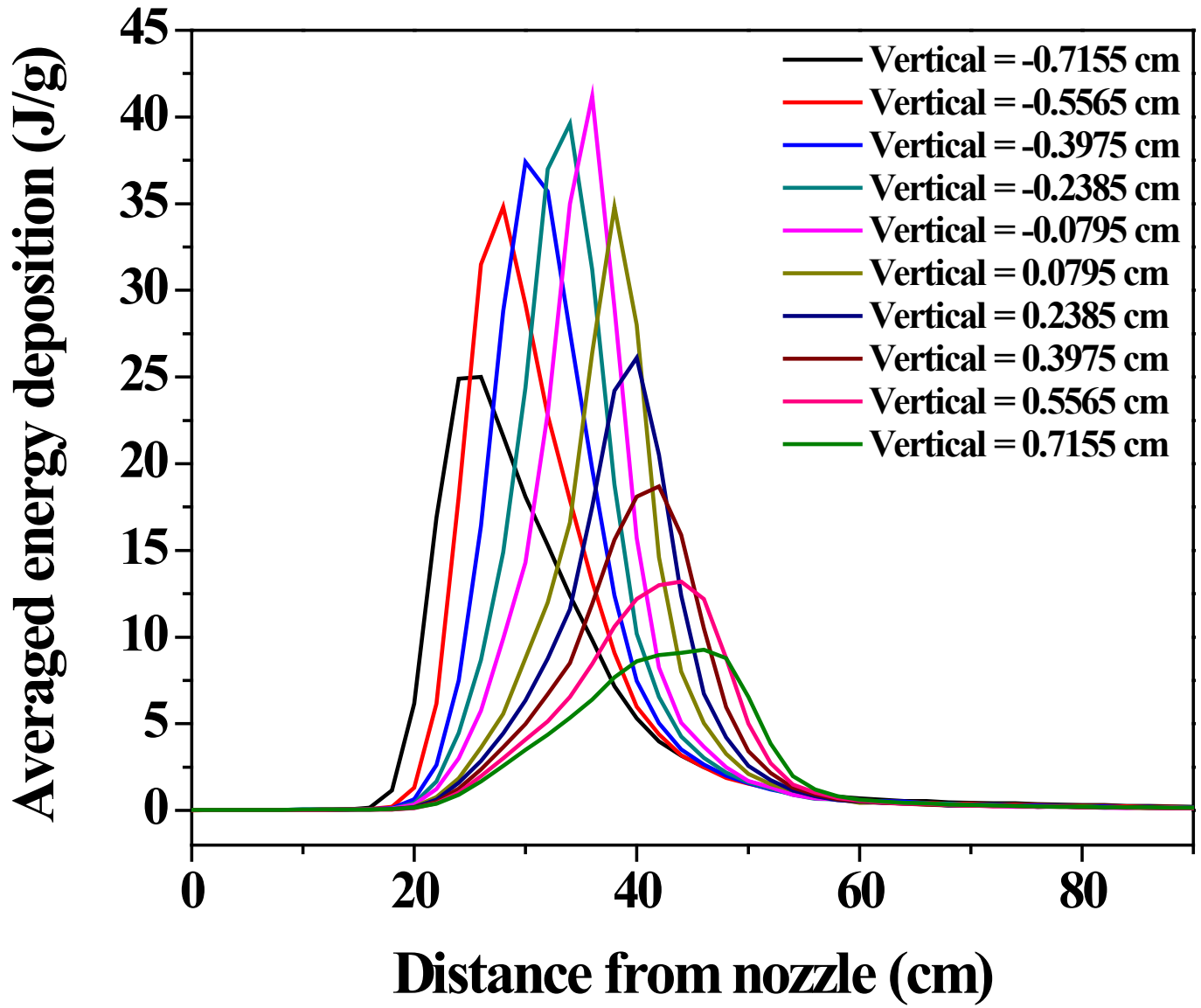
(S. Striganov, FNAL, 2009)

(Beam spot size: CERN calculated, G. Skoro measured)

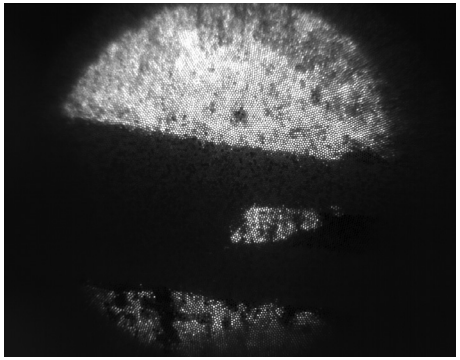


Input Parameters	
Beam spot size(cm) by beam intensity	1Tp, 3Tp, 10Tp, 30Tp
Jet size(cm)	-
Magnetic field strength(T)	0, 5, 10
Jet trajectory(cm)	-
Beam momentum(GeV/c)	24
Hg density(g/cm^3)	13.546
Output Results	
Energy deposition density (GeV/g/proton)	
Volumes(cm^3)	

Energy Deposition vs. Vertical Length in Jet Section and Distance from Nozzle, B=10T, N=10Tp

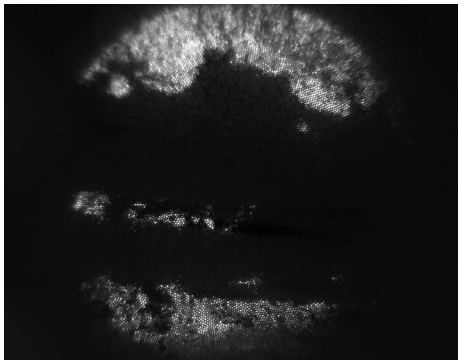


Images of Jet Flow at Viewport 3, B=10T, N=10Tp, L=17cm, 2ms/frame



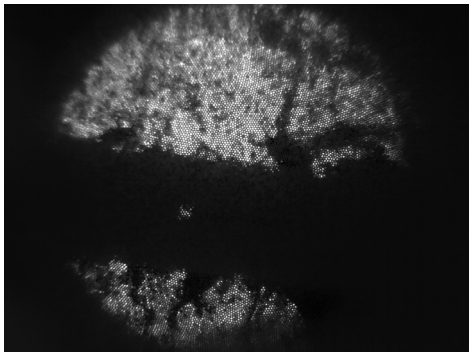
t = 20 ms

t = 18 ms

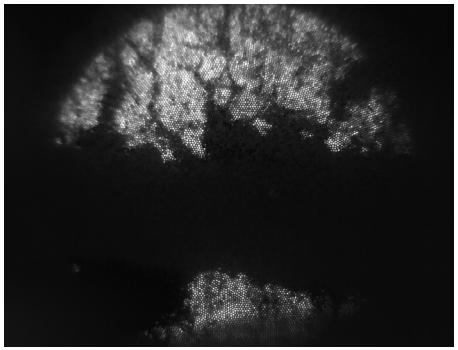


t = 16 ms

t = 14 ms

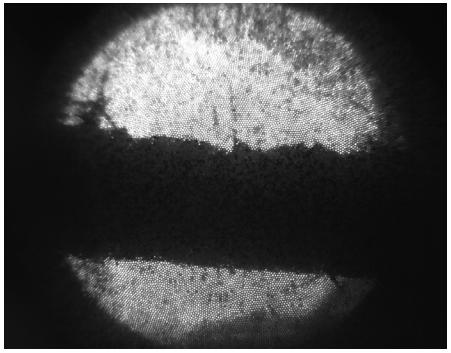


t = 12 ms



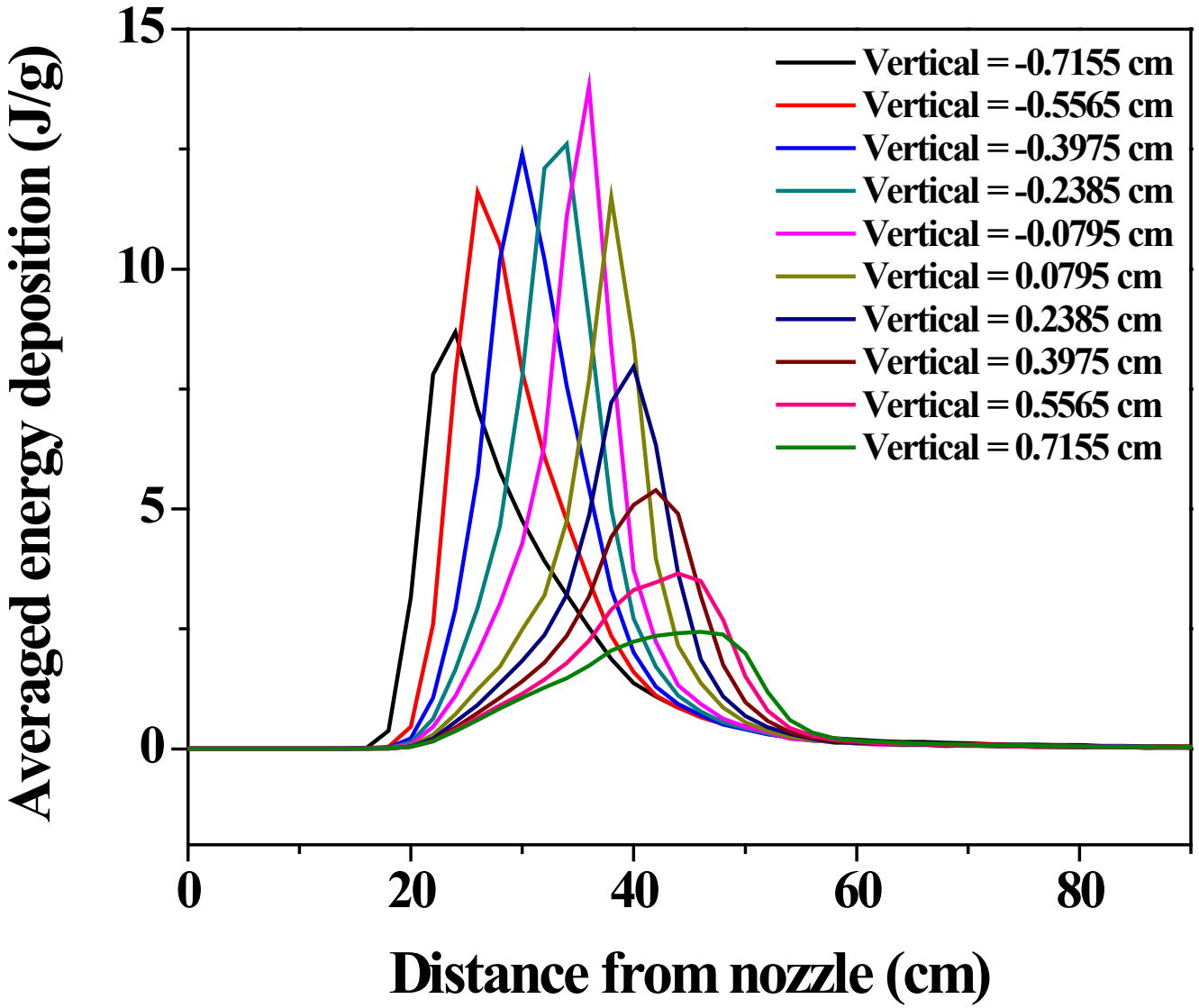
t = 10 ms

t = 8 ms

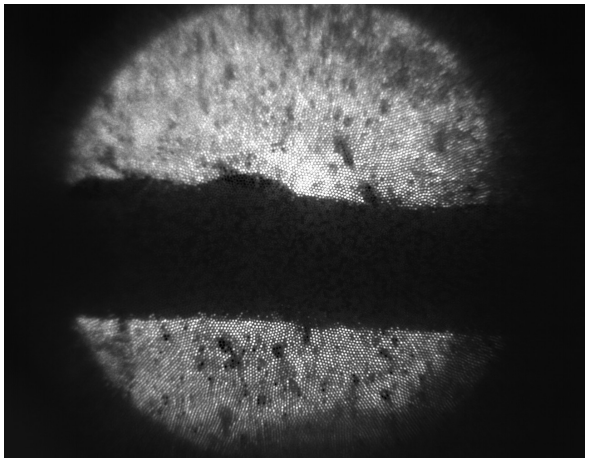


t = 6 ms

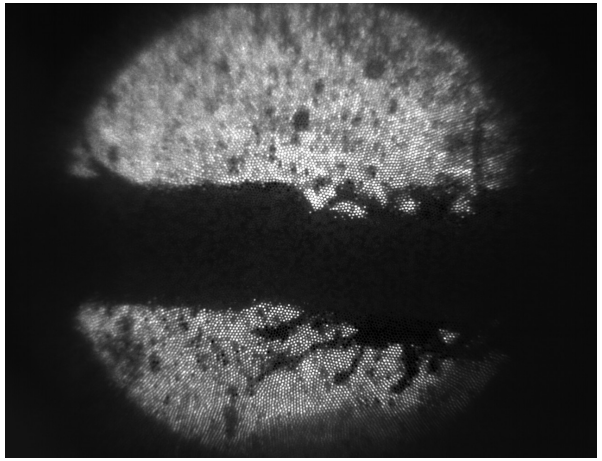
Energy Deposition vs. Vertical Length in Jet Section and Distance from Nozzle, B=5T, N=3Tp



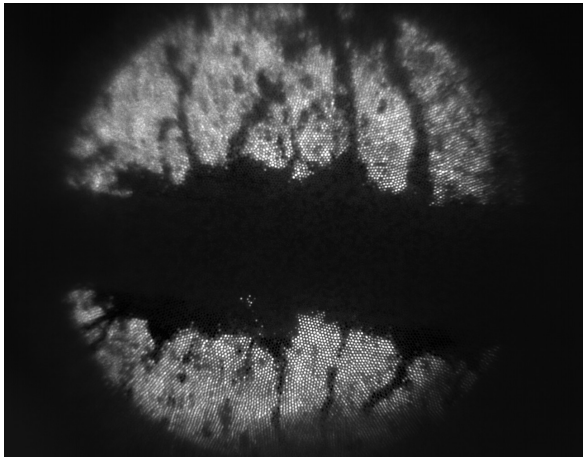
Images of Jet Flow at Viewport 3, B=5T, N=3Tp, L=11cm, 2ms/frame



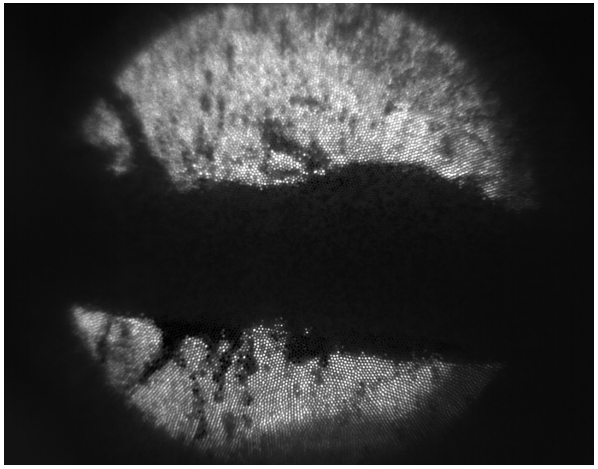
t = 18 ms



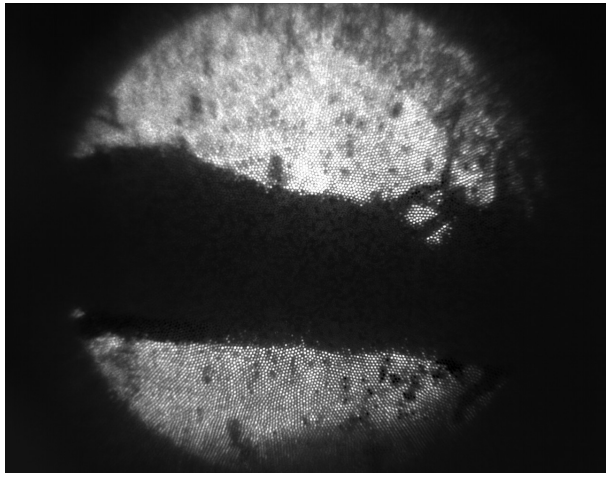
t = 16 ms



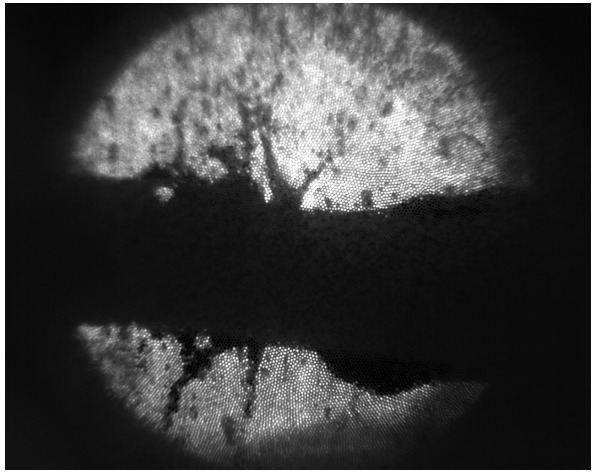
t = 14 ms



t = 12 ms

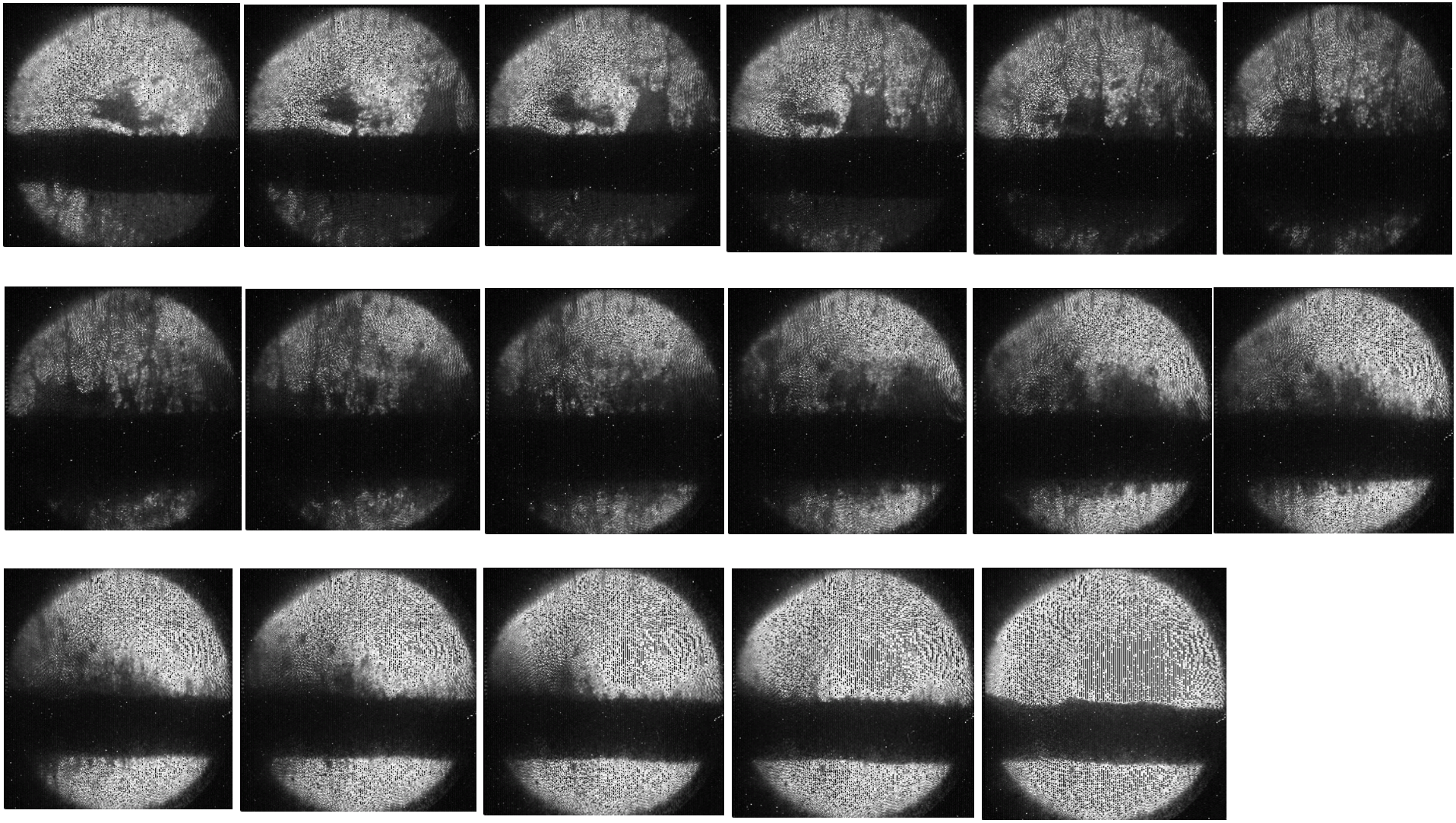


t = 10 ms



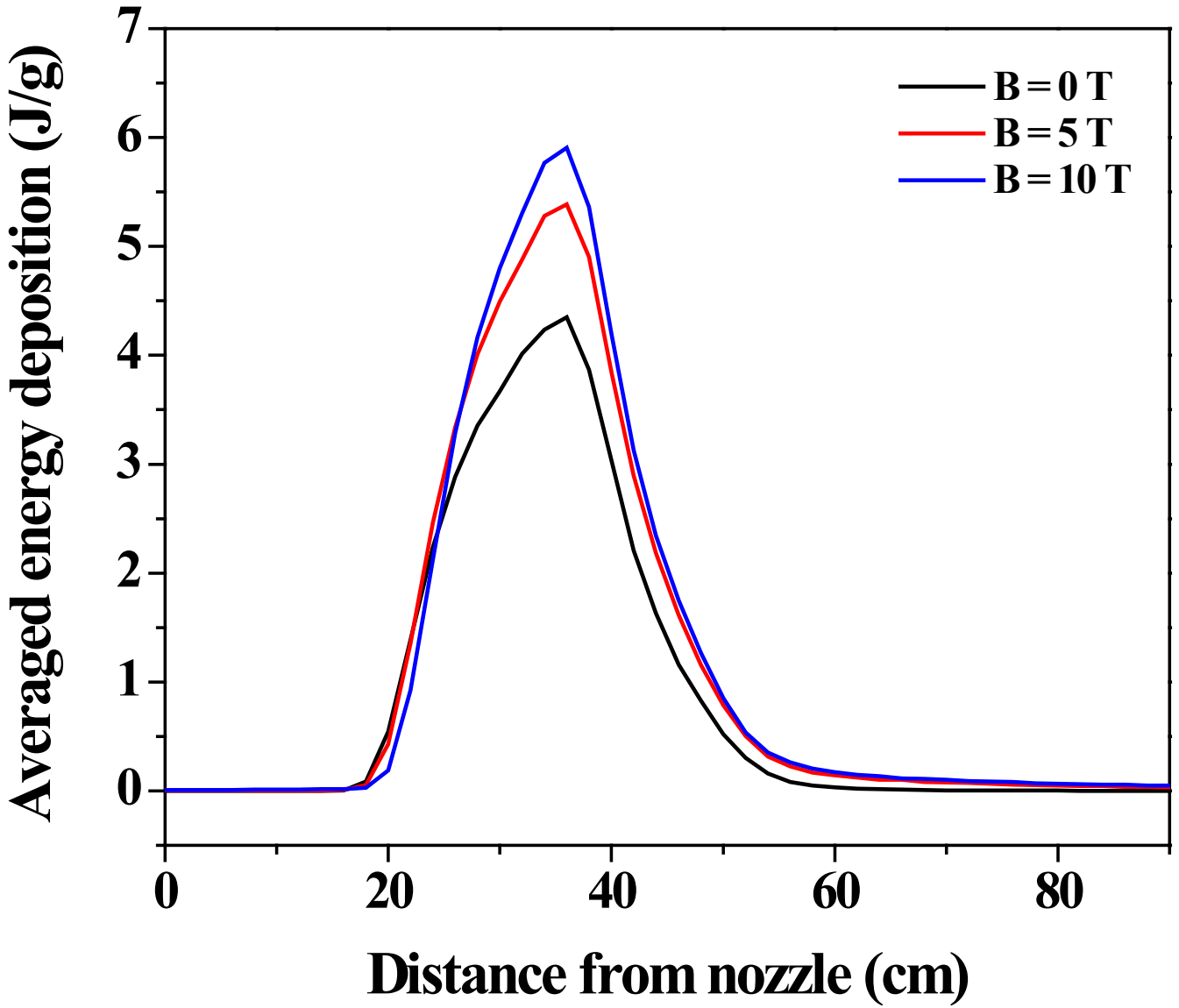
t = 8 ms

Images of Jet Flow at Viewport 2, B=7T, N=8Tp, L=11cm, 500μs/frame

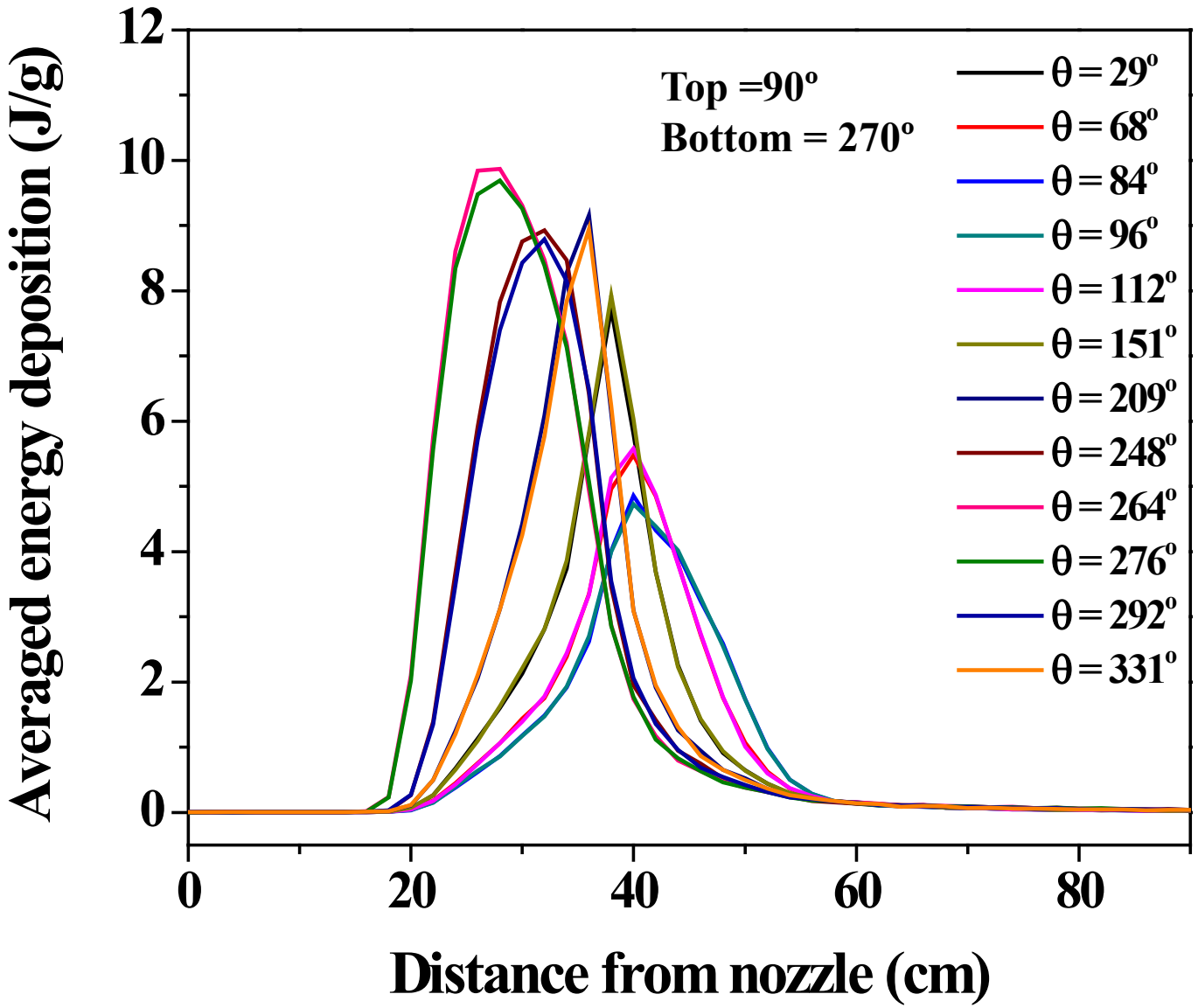


t = 0 μs

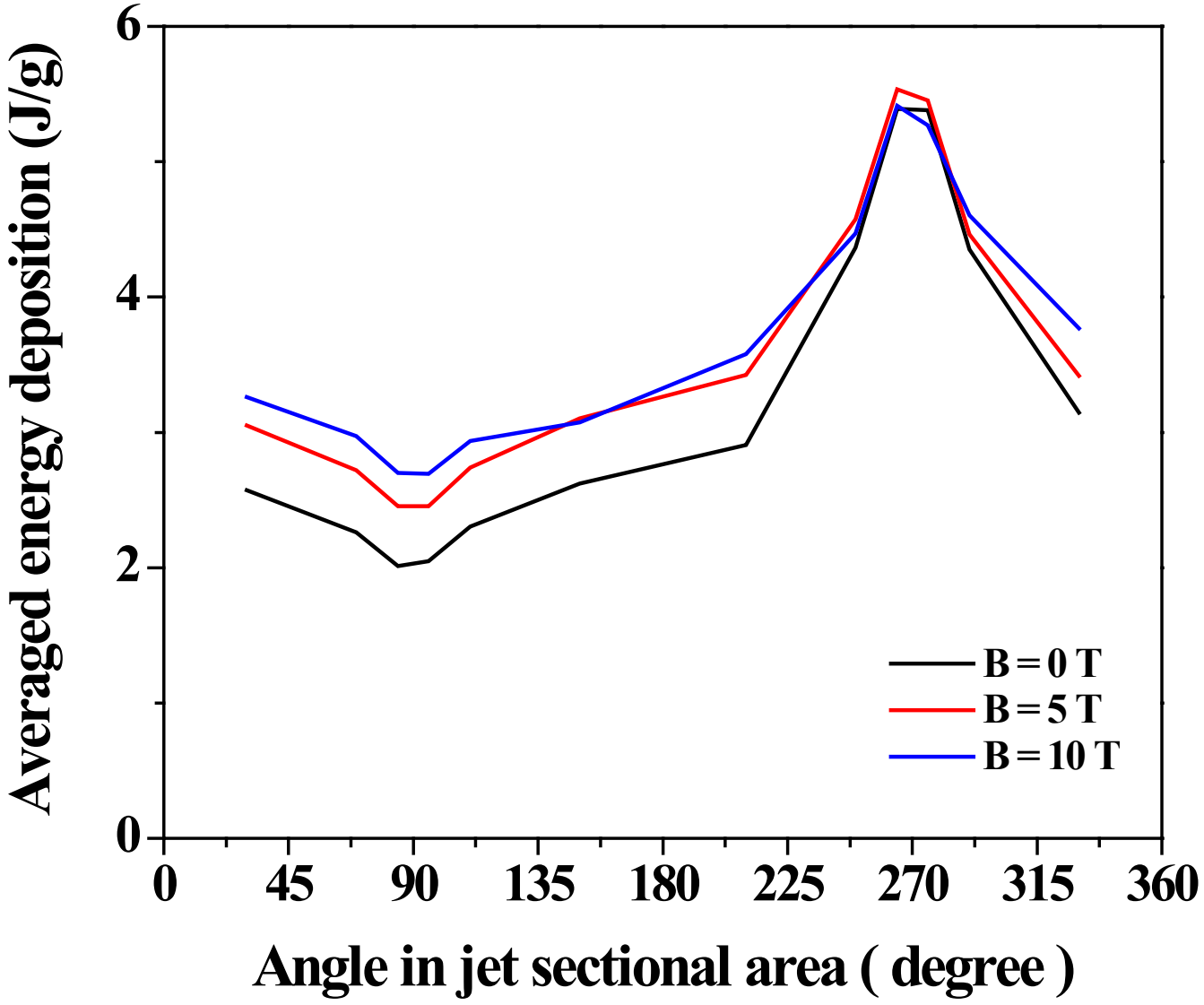
Energy Deposition vs. Magnetic Field and Distance from Nozzle, N=3Tp



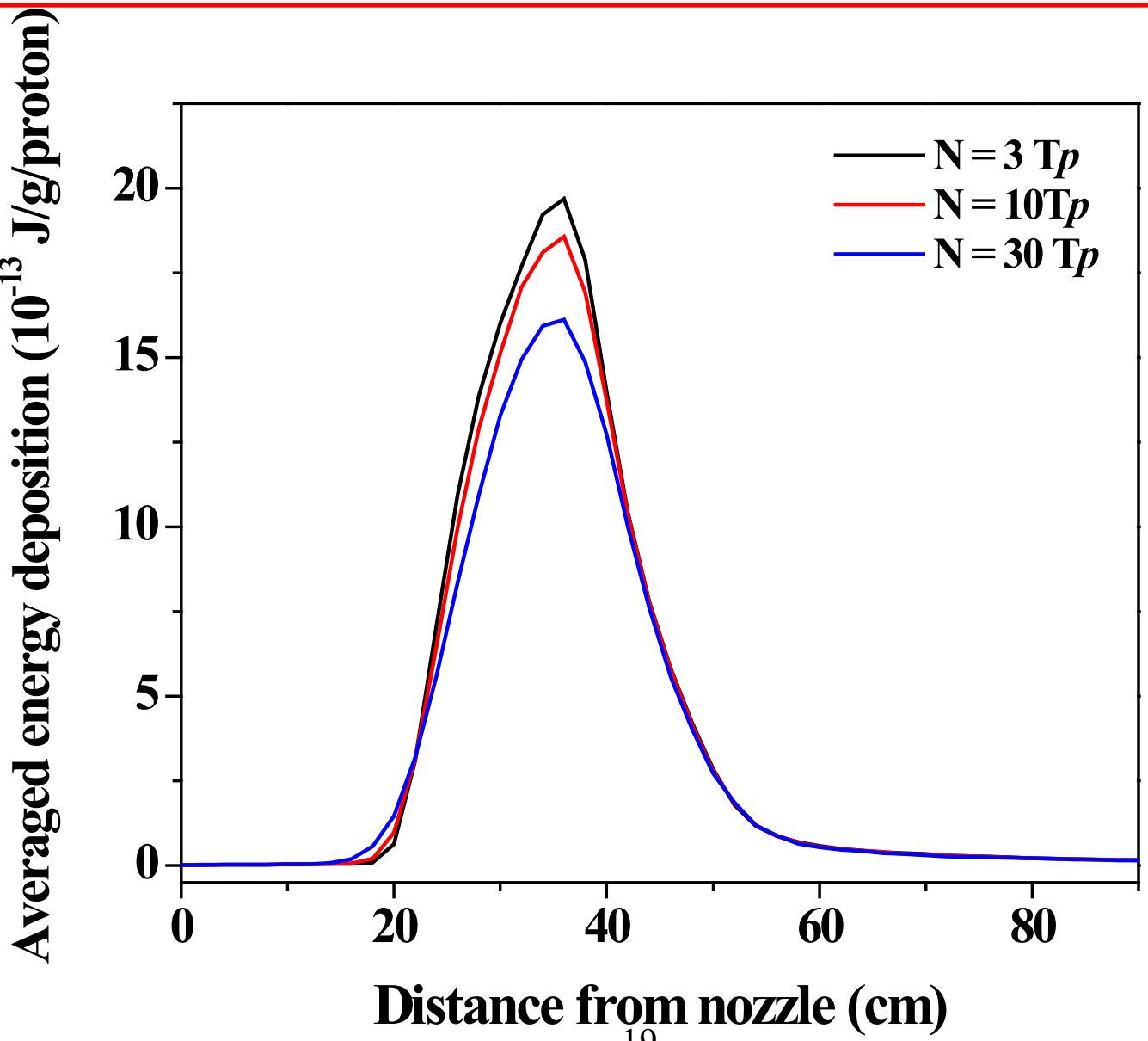
Energy Deposition vs. Angle in Jet Section and Distance from Nozzle, B=5T, N=3Tp



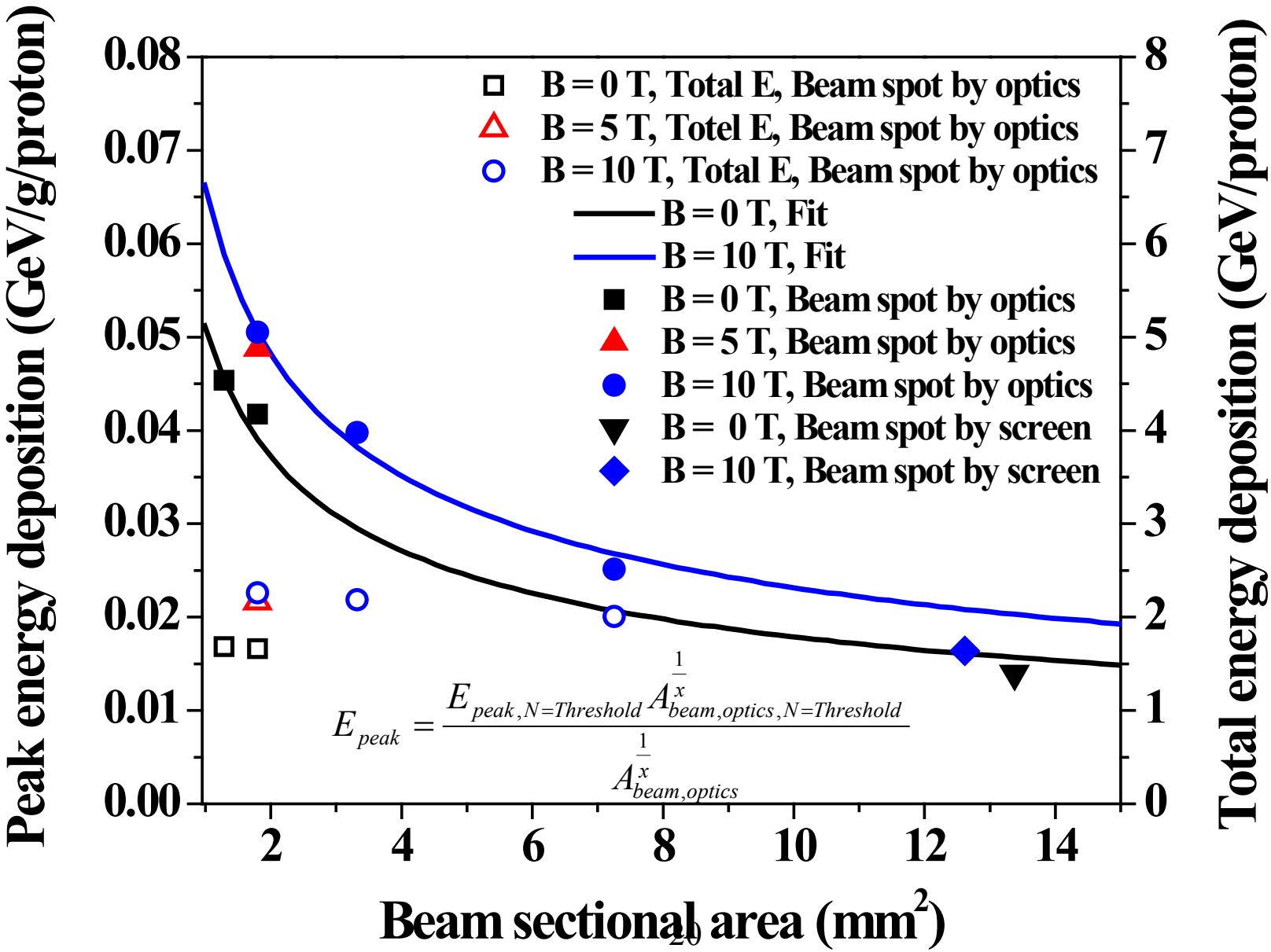
Energy Deposition vs. Magnetic Field and Angle in Jet Section, N=3Tp



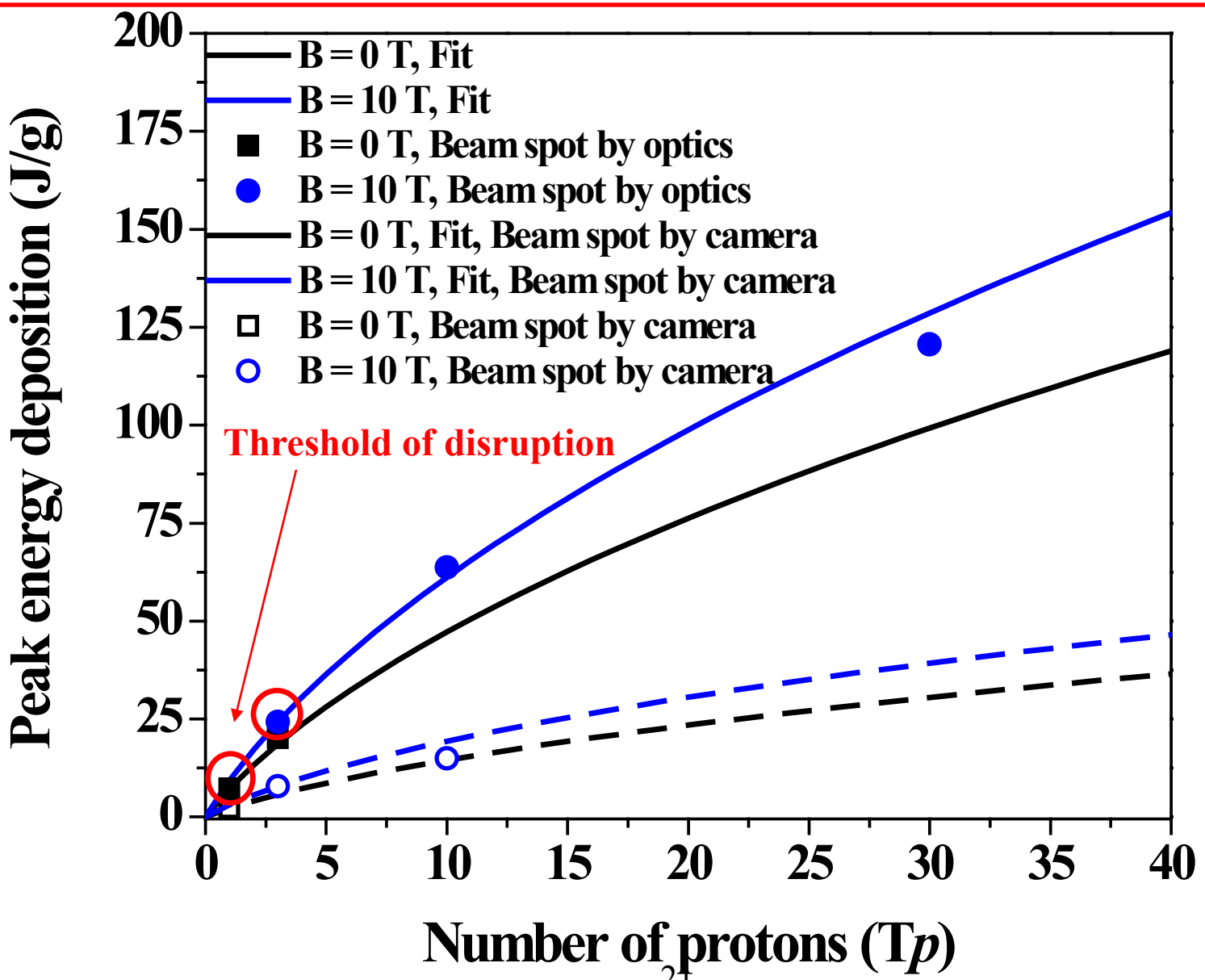
Energy Deposition vs. Number of Protons and Distance from Nozzle, B=10T



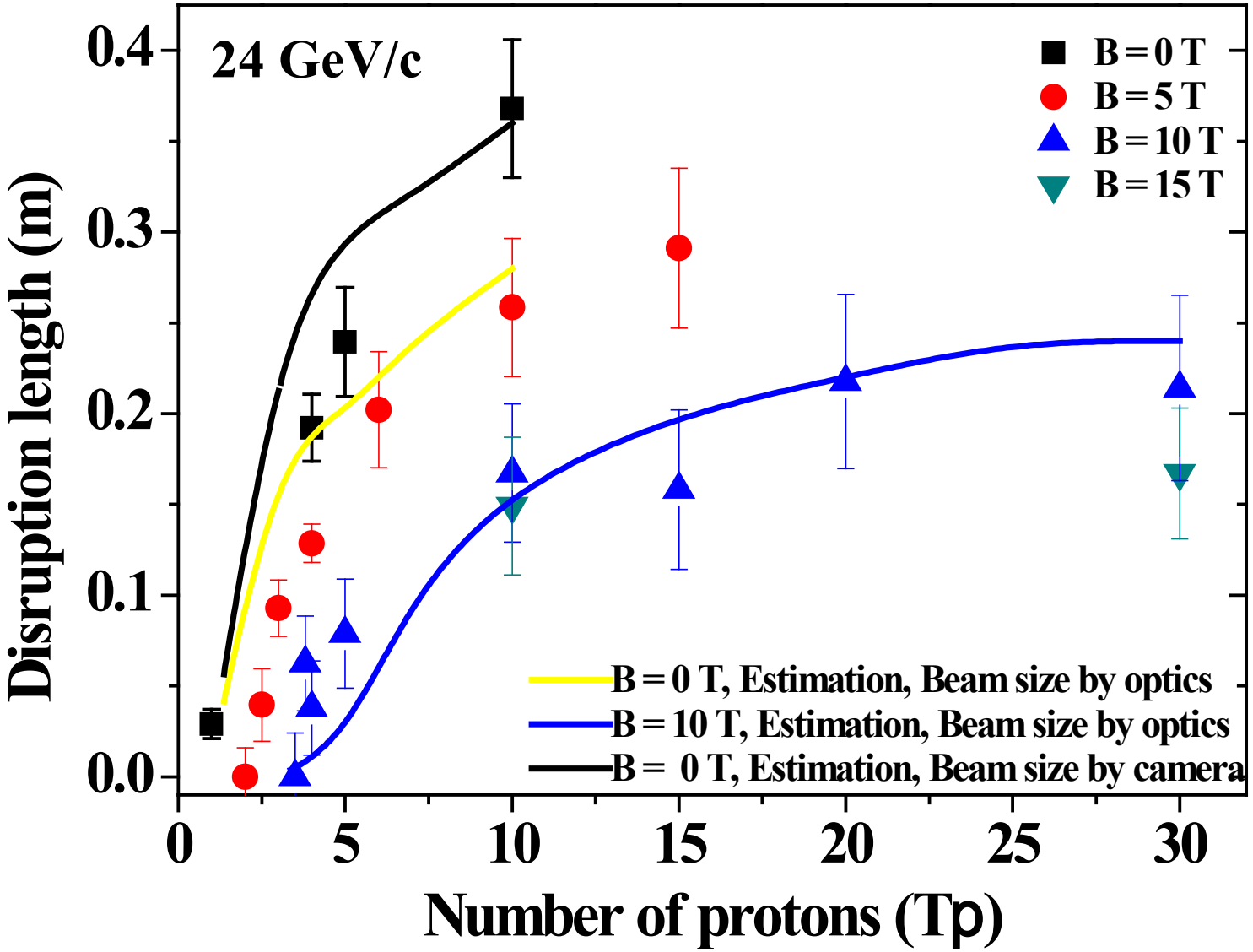
Peak Energy Deposition Density vs. Beam Sectional Area and Magnetic Fields



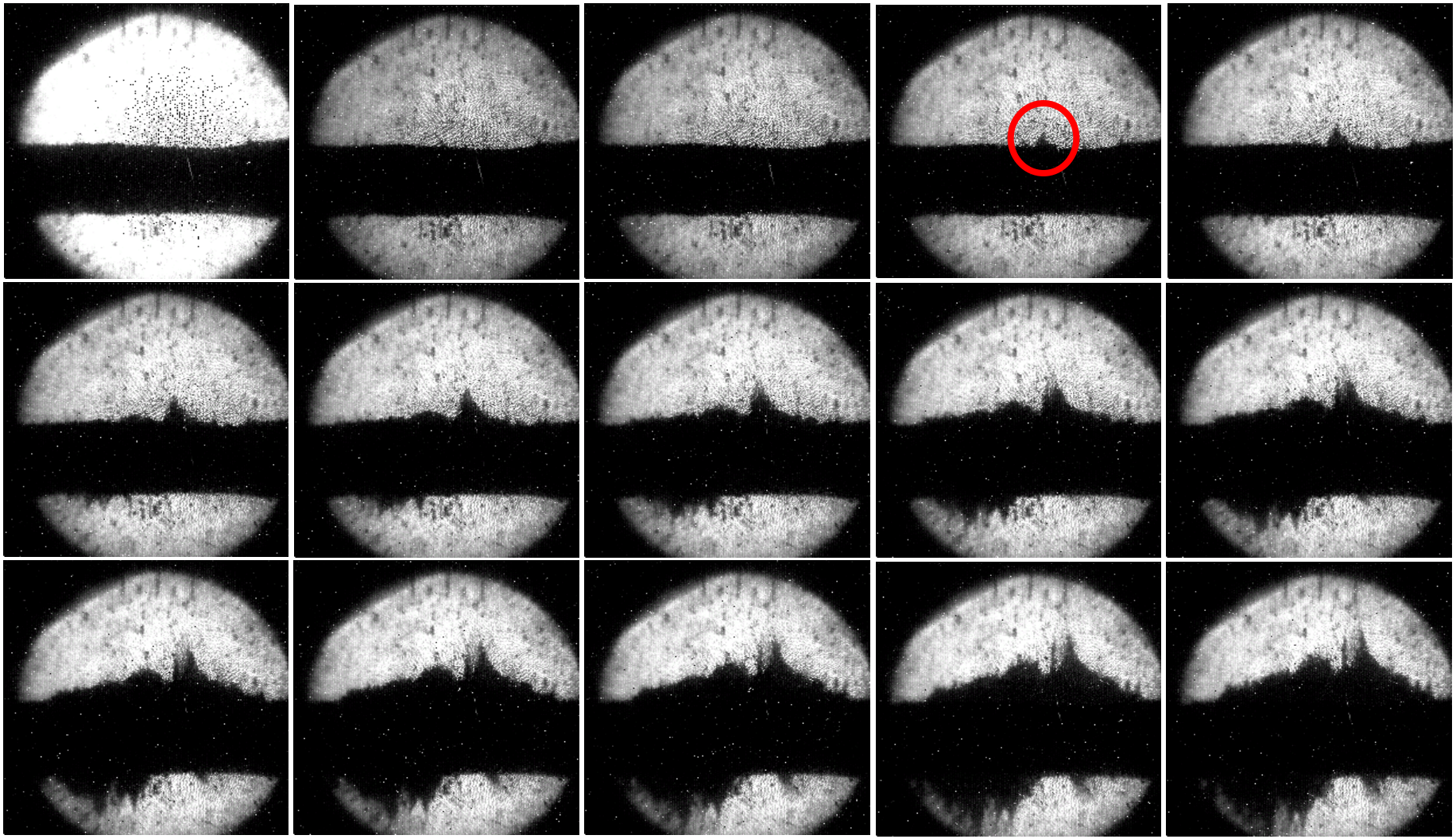
Peak Energy Deposition vs. Number of Protons and Magnetic Fields



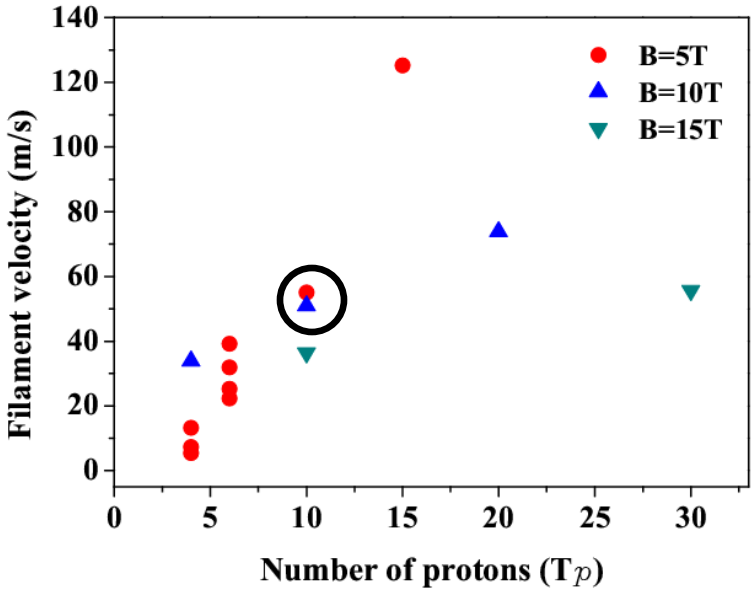
Disruption Length vs. Estimation

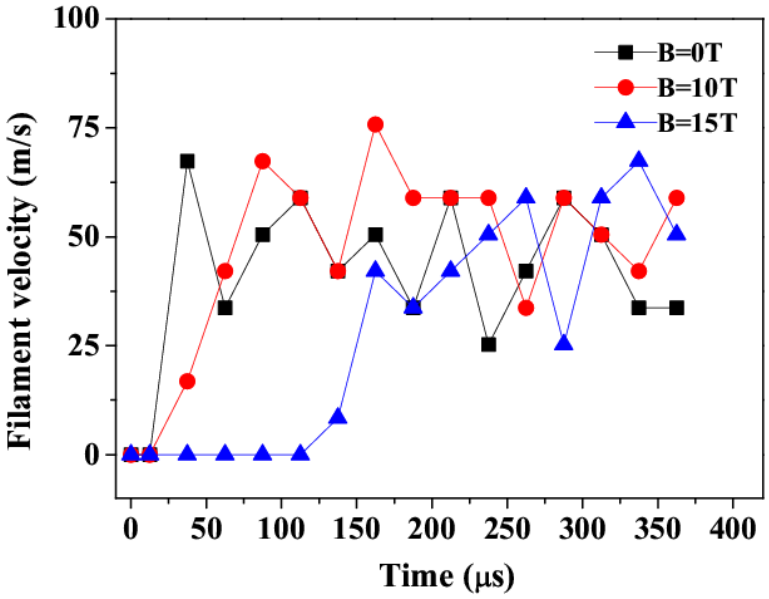


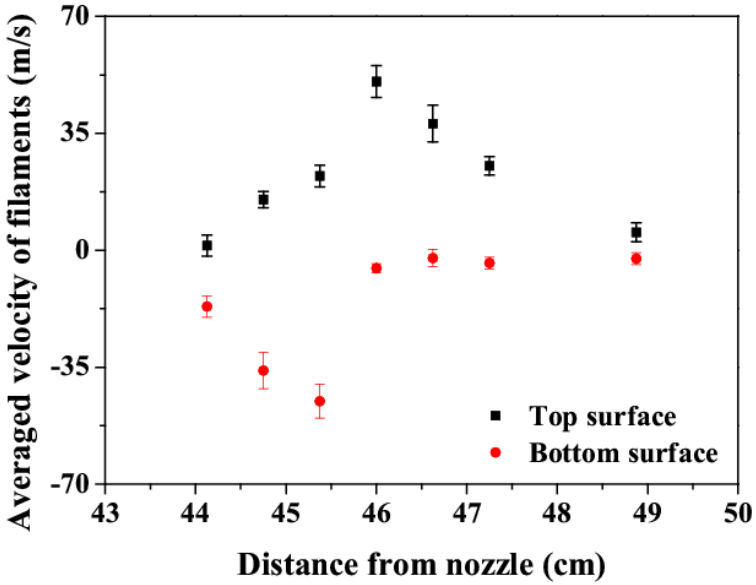
Investigation of Hg Jet Interacting with 24GeV 10Tp Beam in 10T Field, 25μ/frame

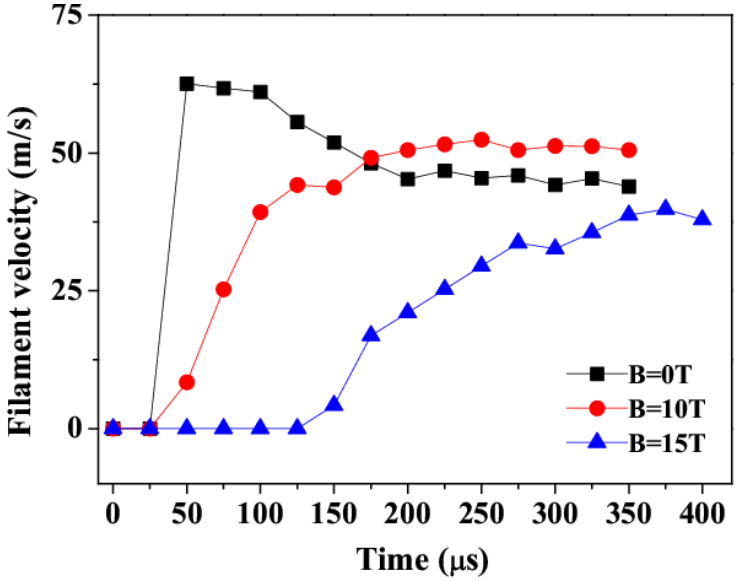


Velocity of Mercury Filament in Magnetic Fields

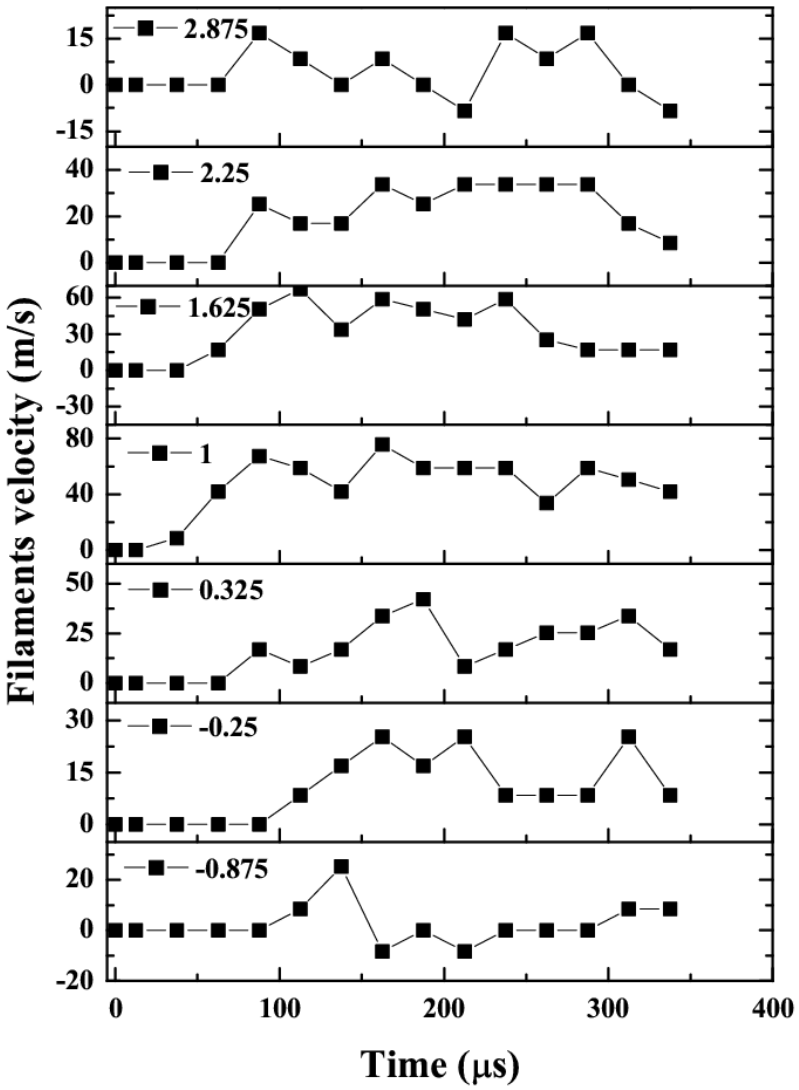


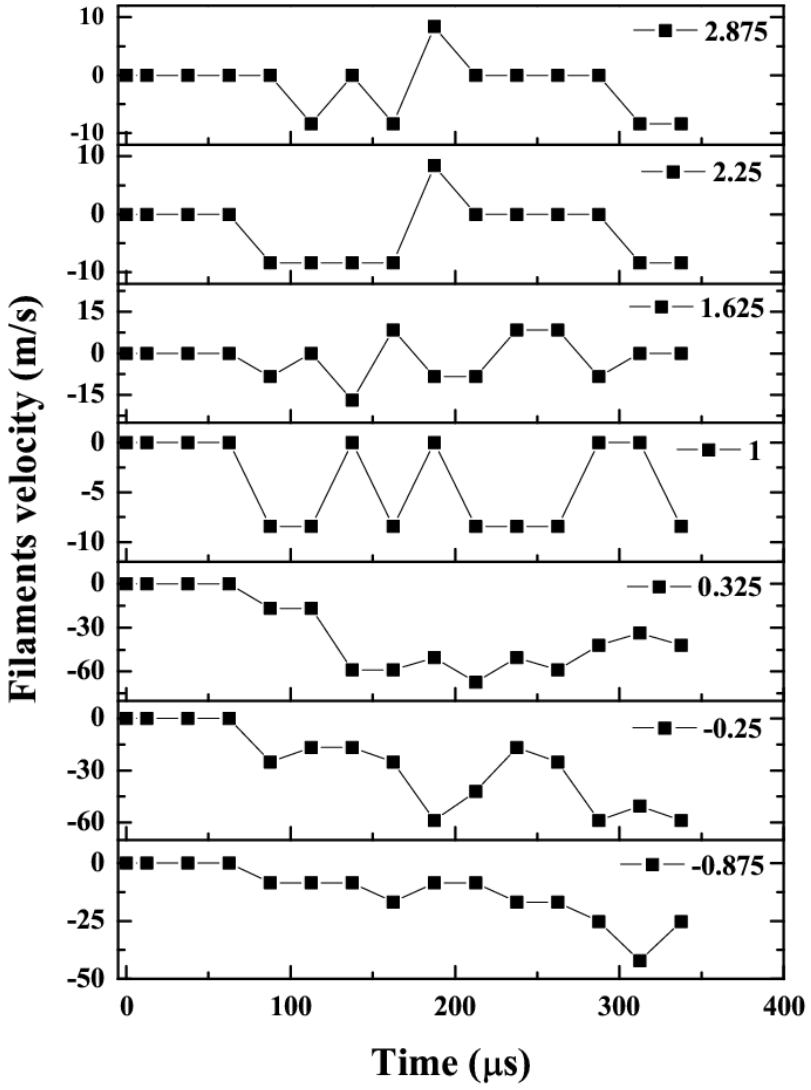






Time Response of Mercury Filament, B=10T, N=10Tp





Geometry of Viewing of Drops and Probabilistic Drop Velocity

1. **Uniform in θ**

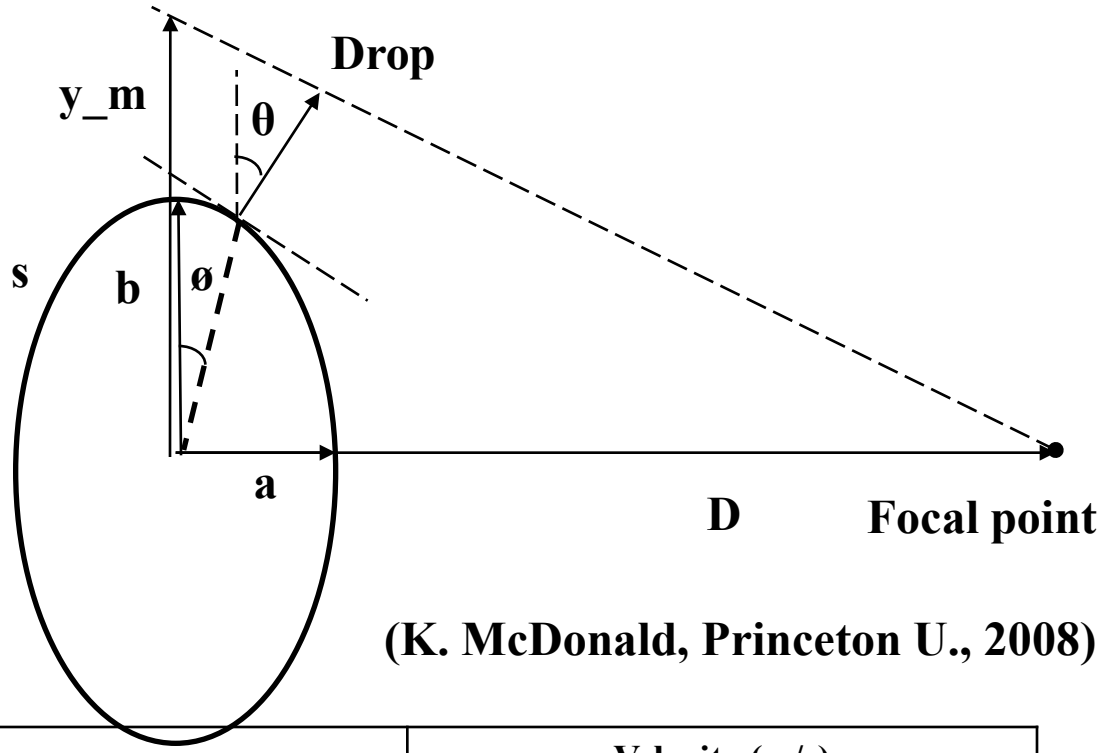
$$p(\theta)d\theta = \frac{1}{2\pi}d\theta$$

2. **Uniform in ø**

$$p(\theta)d\theta = \frac{1}{2\pi}d\phi$$

3. **Uniform in position s around the circumference C**

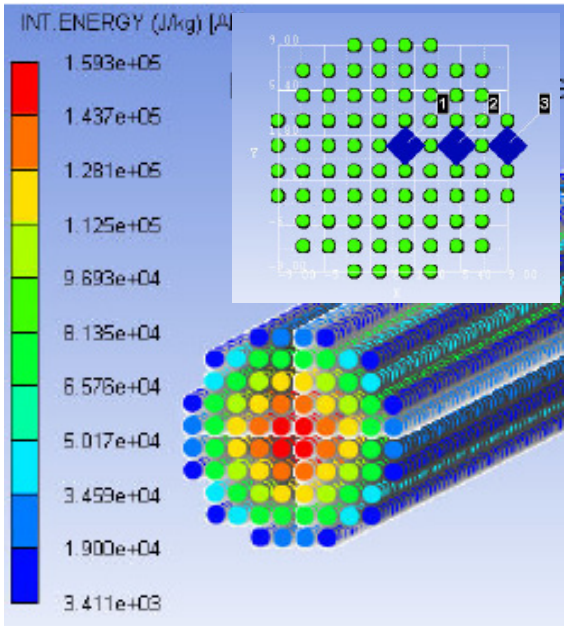
$$P(\theta)d\theta = \frac{1}{C}ds$$

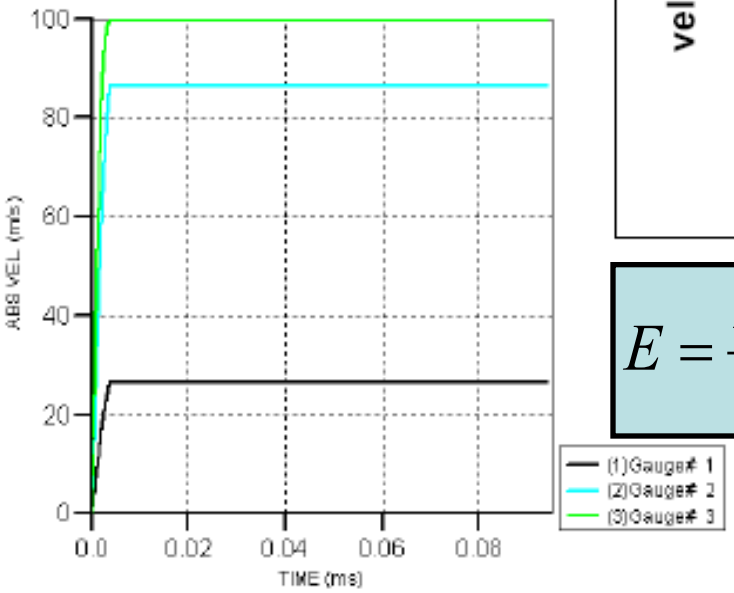


(K. McDonald, Princeton U., 2008)

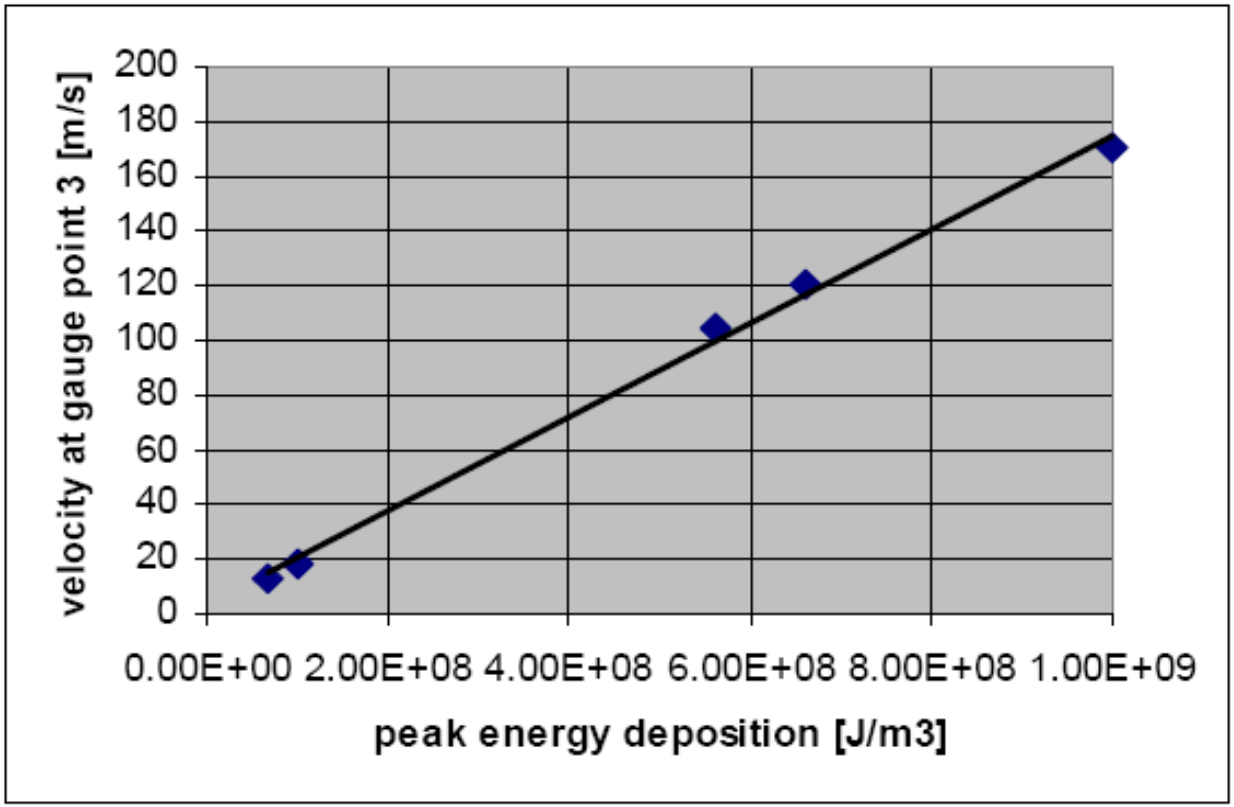
Jet shape	P(θ)	Velocity (m/s)	
		Mean	Sigma
Ellipse	Uniform in theta	38	13
	Uniform in phi	47	18
	Uniform in s	43	16
Circle	Uniform in theta	37	12
	Uniform in phi	38	13
	Uniform in s	38	13

Numerical Simulation of Sievers & Pugnat Result





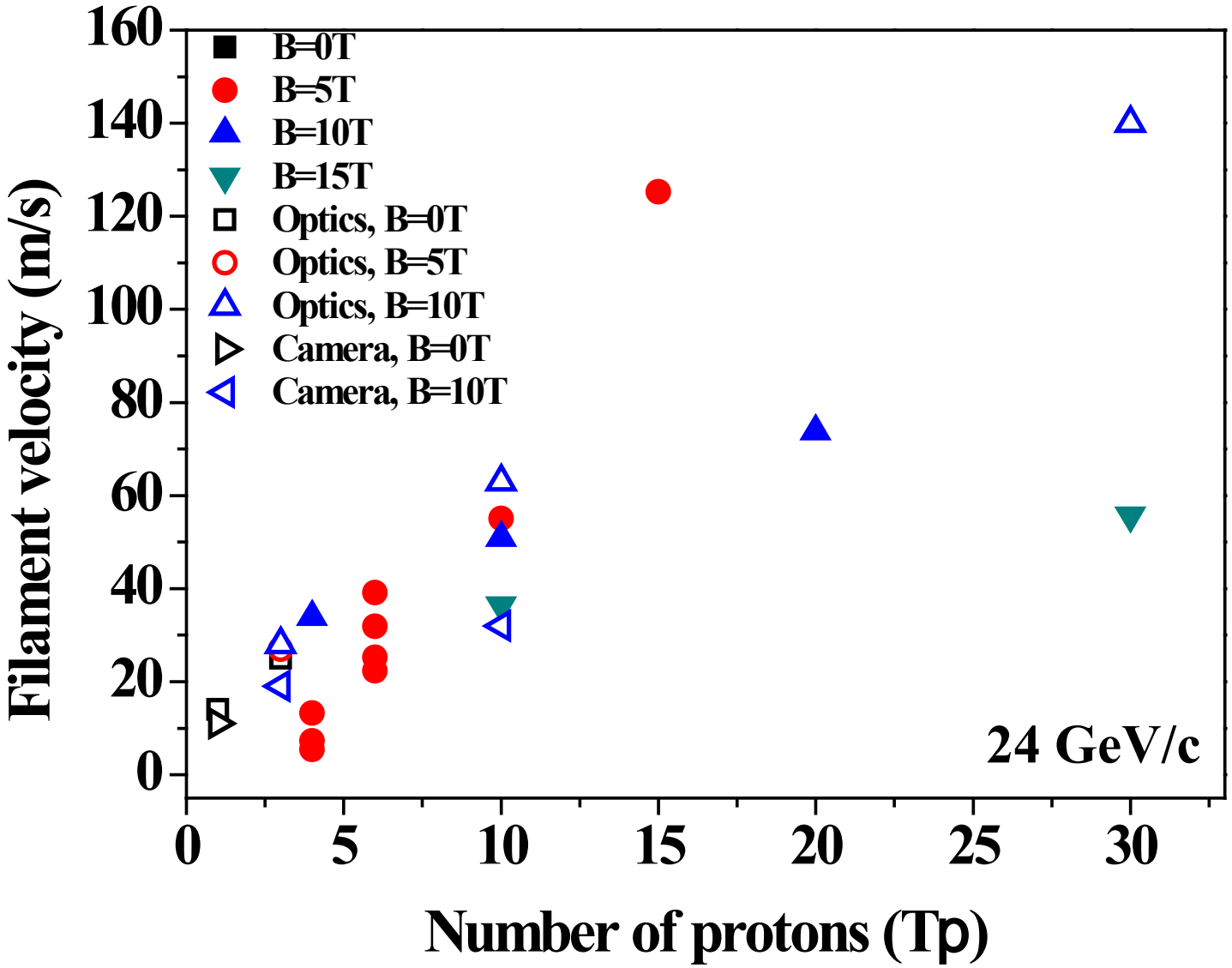
(T. Davenne, RAL, 2008)



$$E = \frac{K}{2}(\alpha \Delta T)^2 = \frac{1}{2}\rho V^2$$

Velocity response of 2cm diameter mercury jet. No magnetic Fields are employed.

Filament Velocity vs. Number of Protons and Magnetic Fields and Comparison with Estimated Numerical Simulation Results



Conclusions and Future Work

1. Mercury jet behaviors in magnetic fields were investigated experimentally and approximately compared with simulation/literatures.

2. Elliptic jet shape was approximated, but circular model with reduced density will be investigated and compared for review of validation.

3. Proton beam structures were investigated experimentally. (CERN, G.Skoro)

4. Energy deposition was calculated based on the experimental results and the distribution of energy deposition was investigated and well compared with optical diagnostic captured images. The energy deposition is varying with beam sectional area and magnetic fields and is dependent on the jet shape. (FNAL, S. Striganov)

5. The results from simulation was used for evaluation of experimental results. The comparison of disruption length implicitly shows the validation of beam spot size estimation and the comparison of filament velocity shows somewhat consistent relationship with energy deposition calculation, numerical velocity calculation, and experimental measurements.