Neutrino Factory / Muon Collider Collaboration Meeting
March 17-19, 2008, FNAL, Batavia, IL

Target Simulations

Roman Samulyak

Department of Applied Mathematics and Statistics
Stony Brook University
and
Brookhaven National Laboratory
U.S. Department of Energy, rosamu@bnl.gov

Collaborators: **Jian Du, Wurigen Bo**

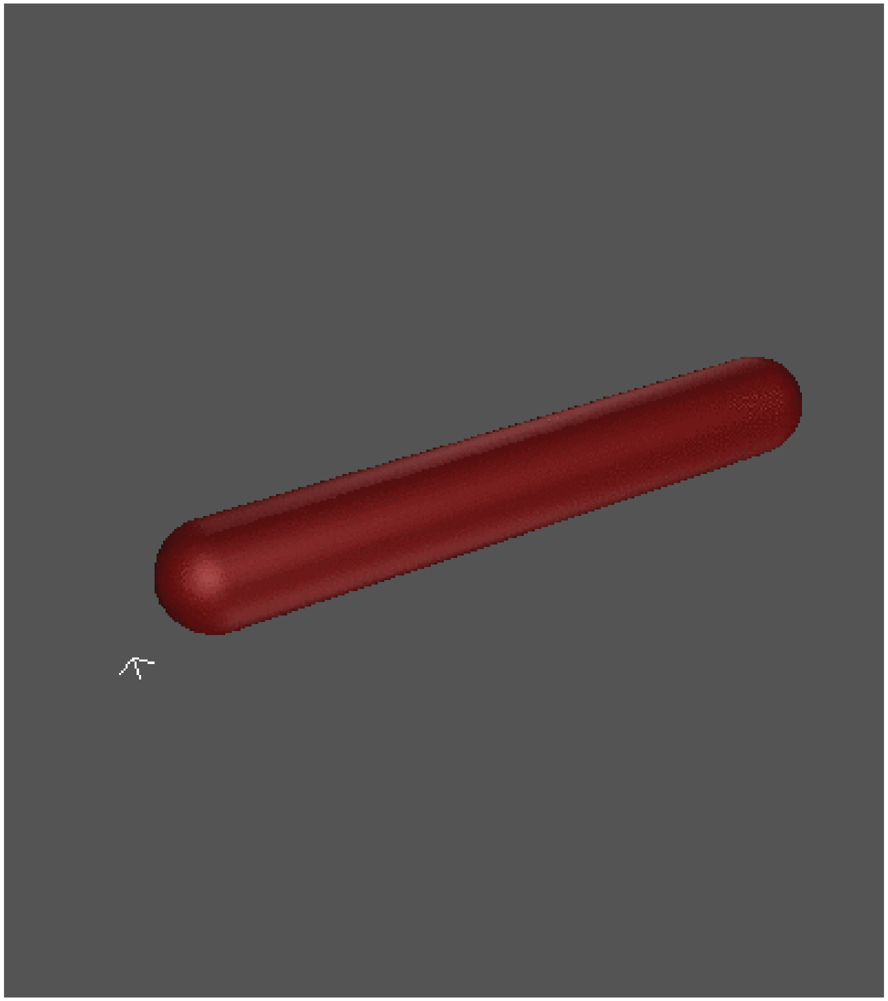
Talk Outline

- Distortion of the mercury jet entering magnetic field
- Simulation of the mercury jet – proton pulse interaction.
- Conclusions and future plans

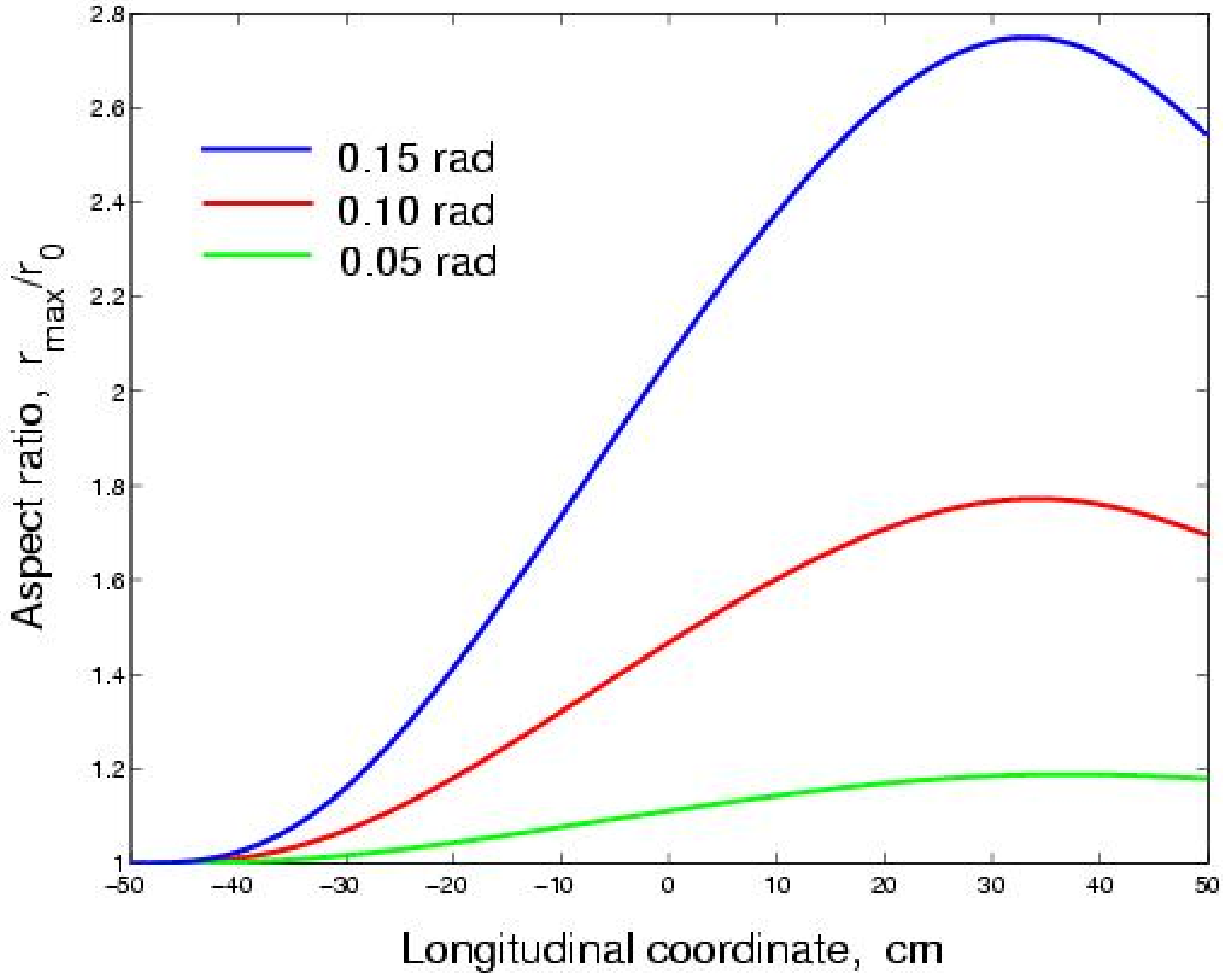
Jet entering 15 T solenoid

FronTier code:

- Explicitly tracked material interfaces
- Multiphase models
- MHD in low magnetic Reynolds number approximation

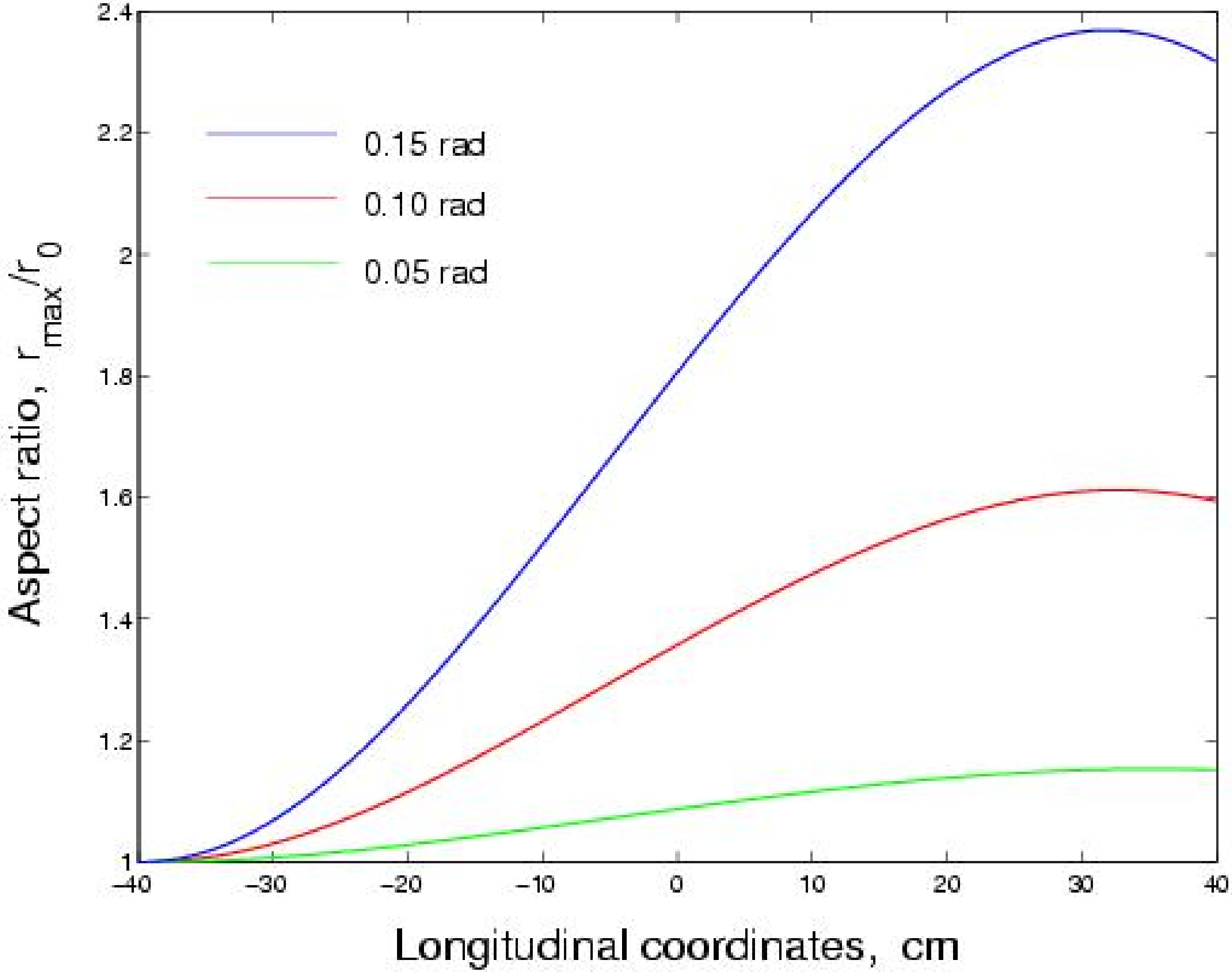


Previous Results (2005)
Aspect ratio of the jet cross-section. I



B = 15 T
V0 = 25 m/s

Previous Results (2005)
Aspect ratio of the jet cross-section. II

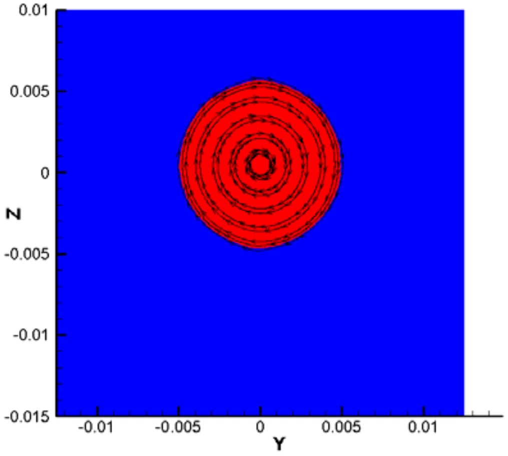


B = 15 T
V0 = 25 m/s

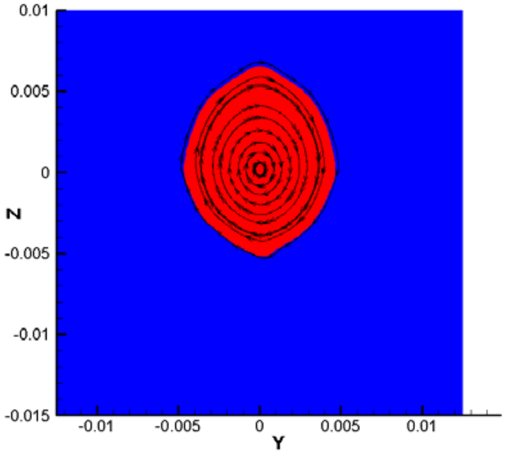
0.10 rad, z = 0:
Aspect ratio = 1.4

Confirmation: Independent studies by Neil Morley, UCLA, HiMAG code

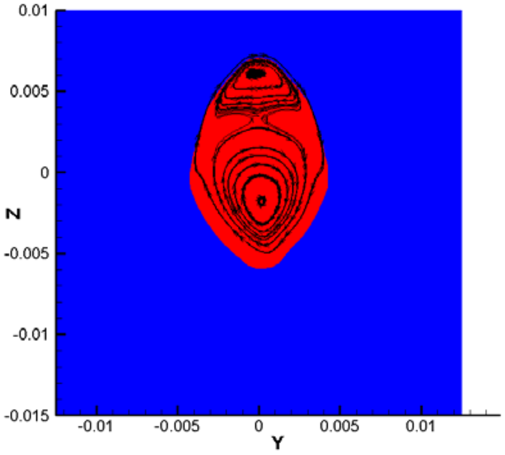
100 mrad tilt angle



z = 0 cm



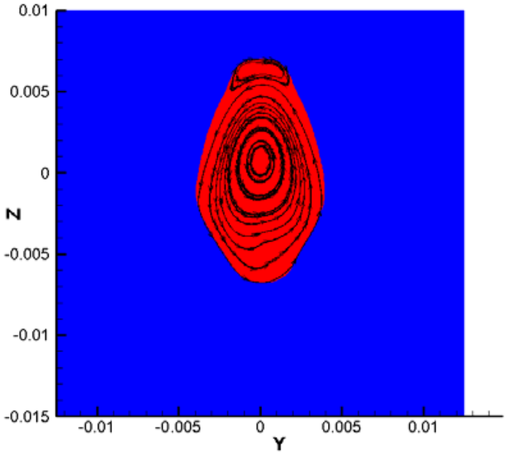
z = 20 cm



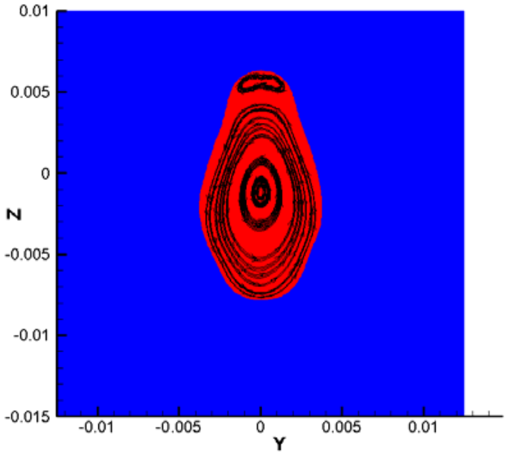
z = 30 cm

Aspect ratio = 1.4 in the solenoid center

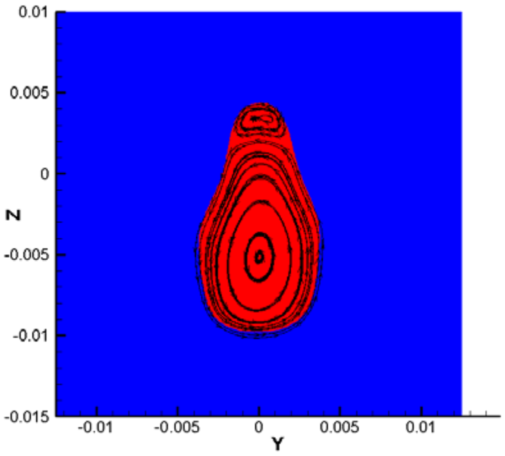
z = 40 cm



z = 50 cm

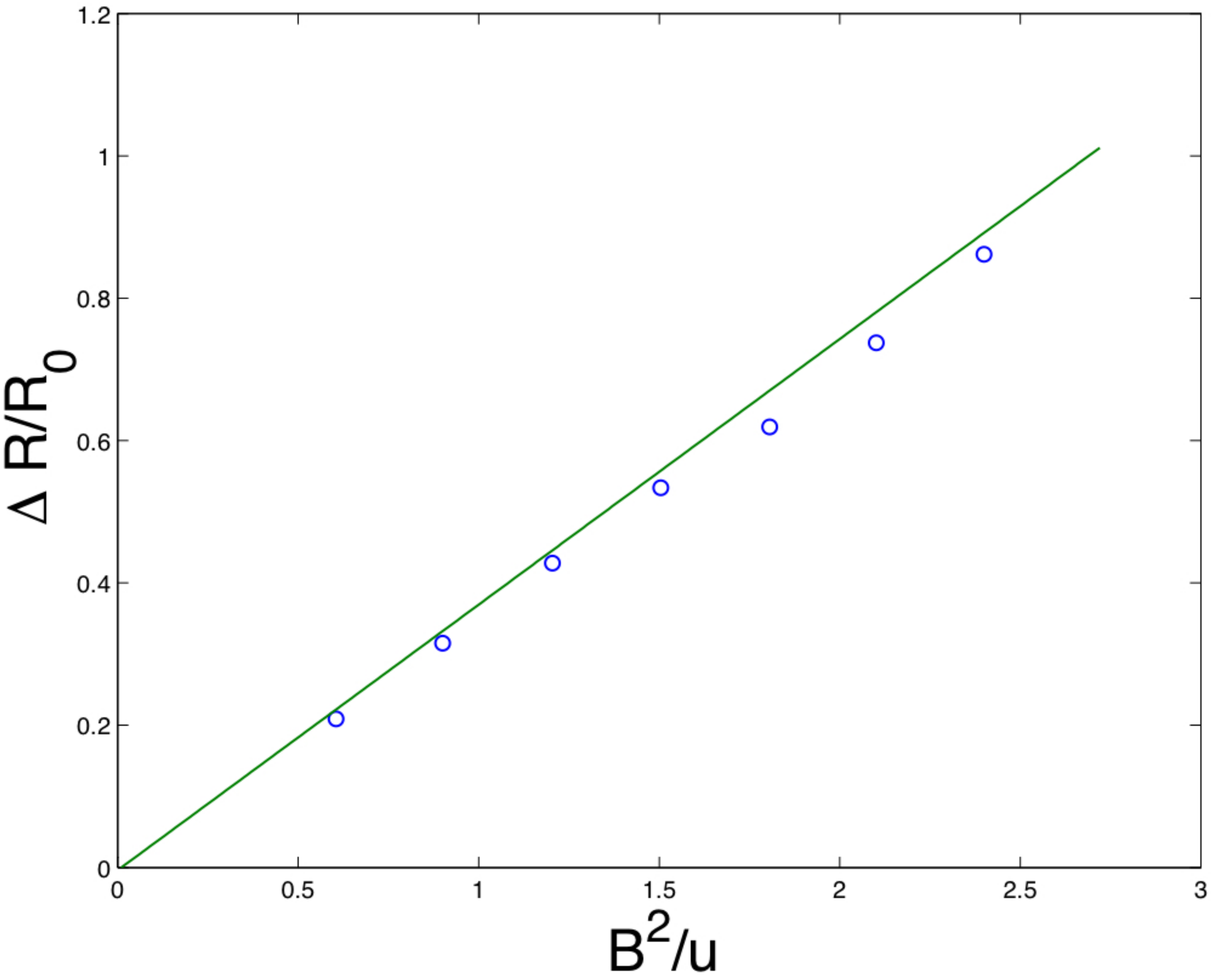


z = 60 cm



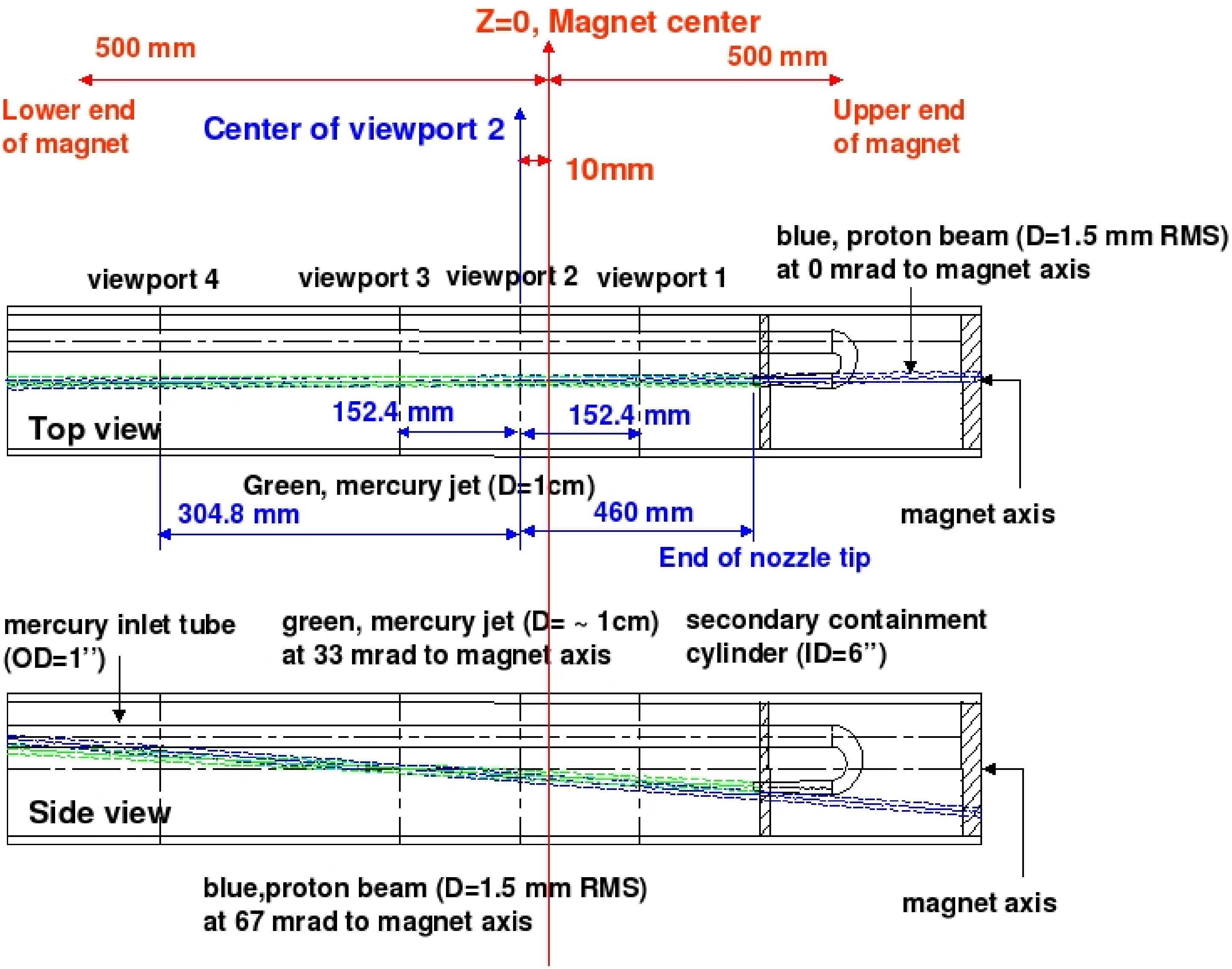
Comparison with the theory

R. Samulyak et. al, Journal of Computational Physics, 226 (2007), 1532 - 1549.



MERIT setup

Geometry of Hg system in Magnet



Z=0, Magnet center

500 mm

500 mm

Lower end of magnet

Center of viewport 2

10mm

Upper end of magnet

blue, proton beam (D=1.5 mm RMS) at 0 mrad to magnet axis

viewport 4

viewport 3

viewport 2

viewport 1

Top view

152.4 mm

152.4 mm

Green, mercury jet (D=1cm)

304.8 mm

460 mm

magnet axis

End of nozzle tip

mercury inlet tube (OD=1'')

green, mercury jet (D= ~ 1cm) at 33 mrad to magnet axis

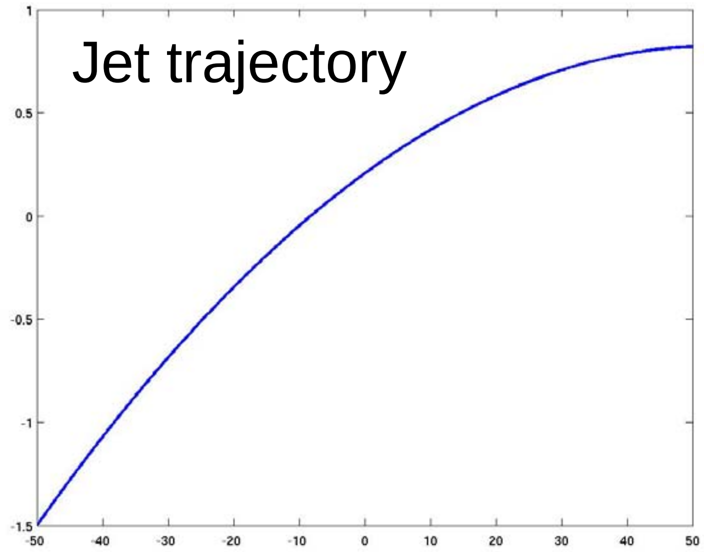
secondary containment cylinder (ID=6'')

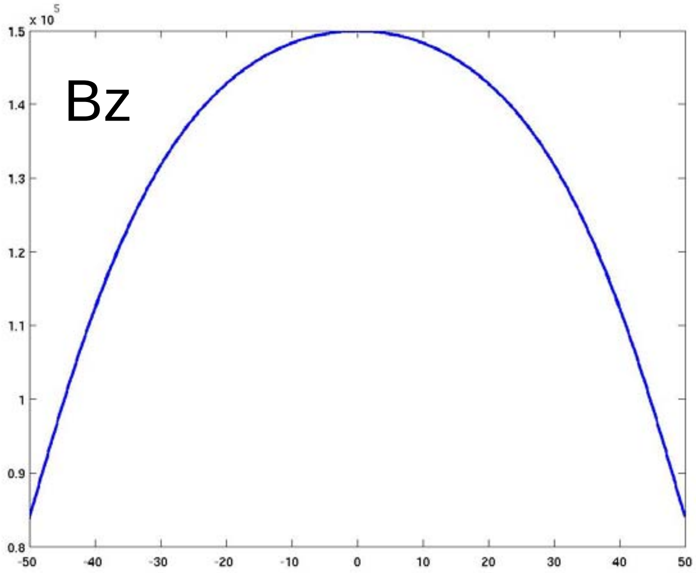
Side view

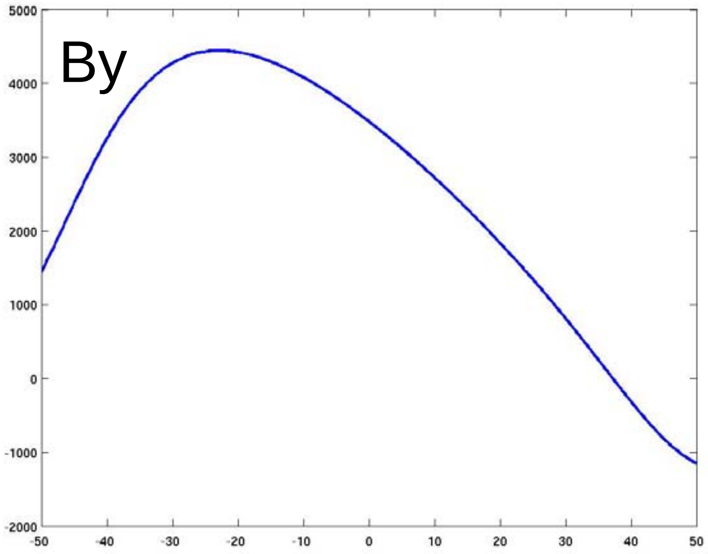
blue,proton beam (D=1.5 mm RMS) at 67 mrad to magnet axis

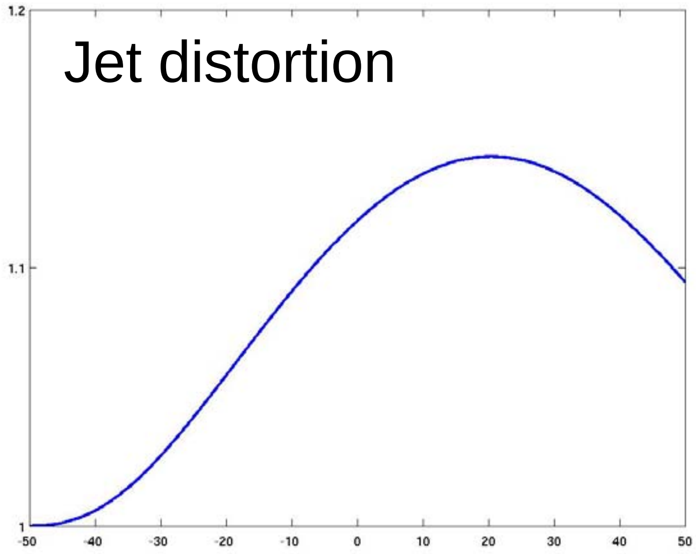
magnet axis

V = 15 m/s, B = 15 T

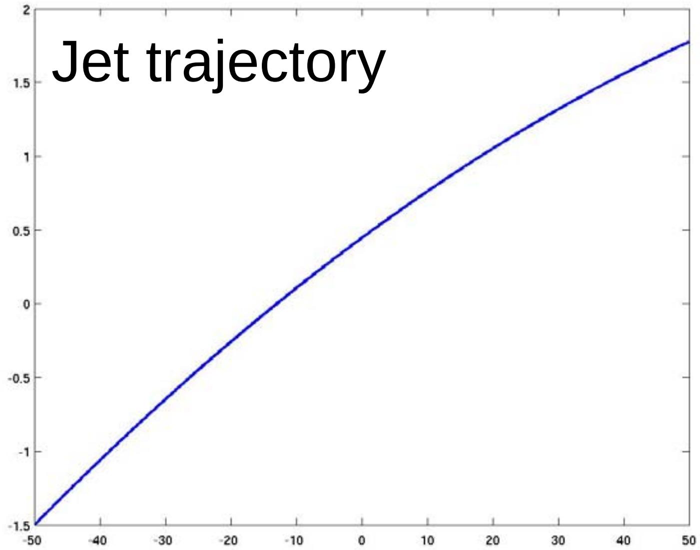

Jet trajectory
1
0.5
0
-0.5
-1
-1.5
-50
-40
-30
-20
-10
0
10
20
30
40
50

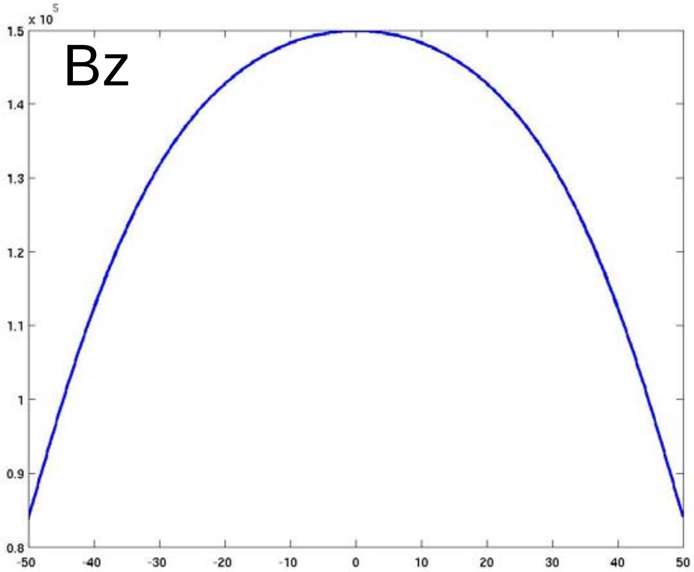

x 10^5
Bz
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
-50
-40
-30
-20
-10
0
10
20
30
40
50

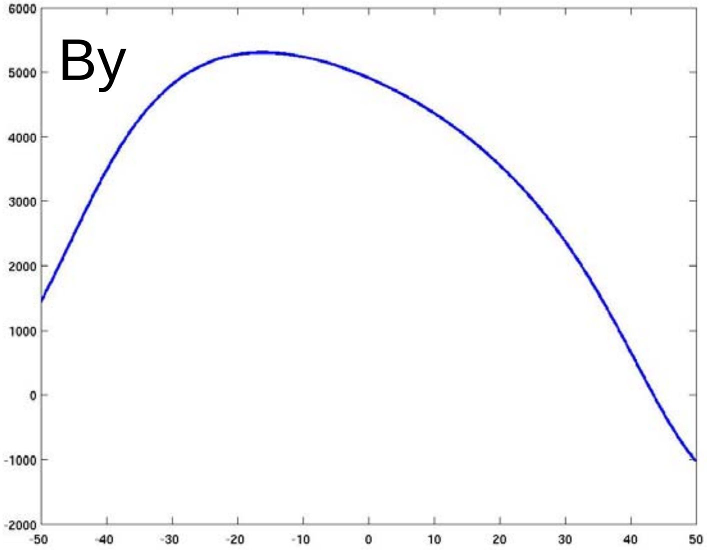

By
5000
4000
3000
2000
1000
0
-1000
-2000
-50
-40
-30
-20
-10
0
10
20
30
40
50

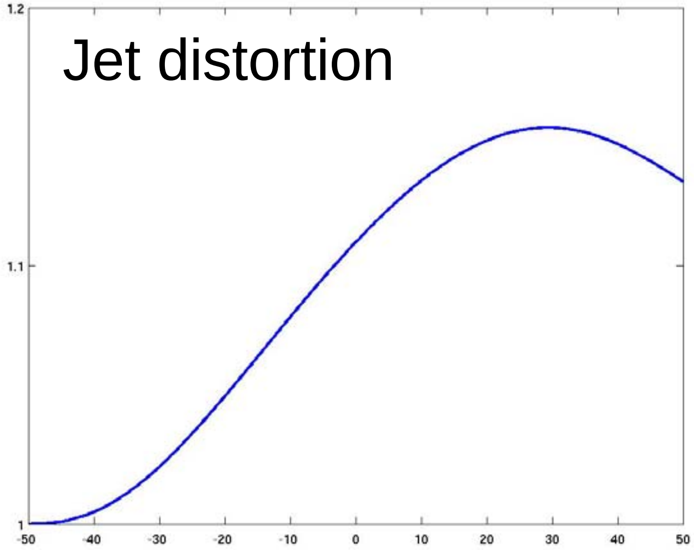

Jet distortion
1.2
1.1
1
-50
-40
-30
-20
-10
0
10
20
30
40
50

V = 20 m/s, B = 15 T

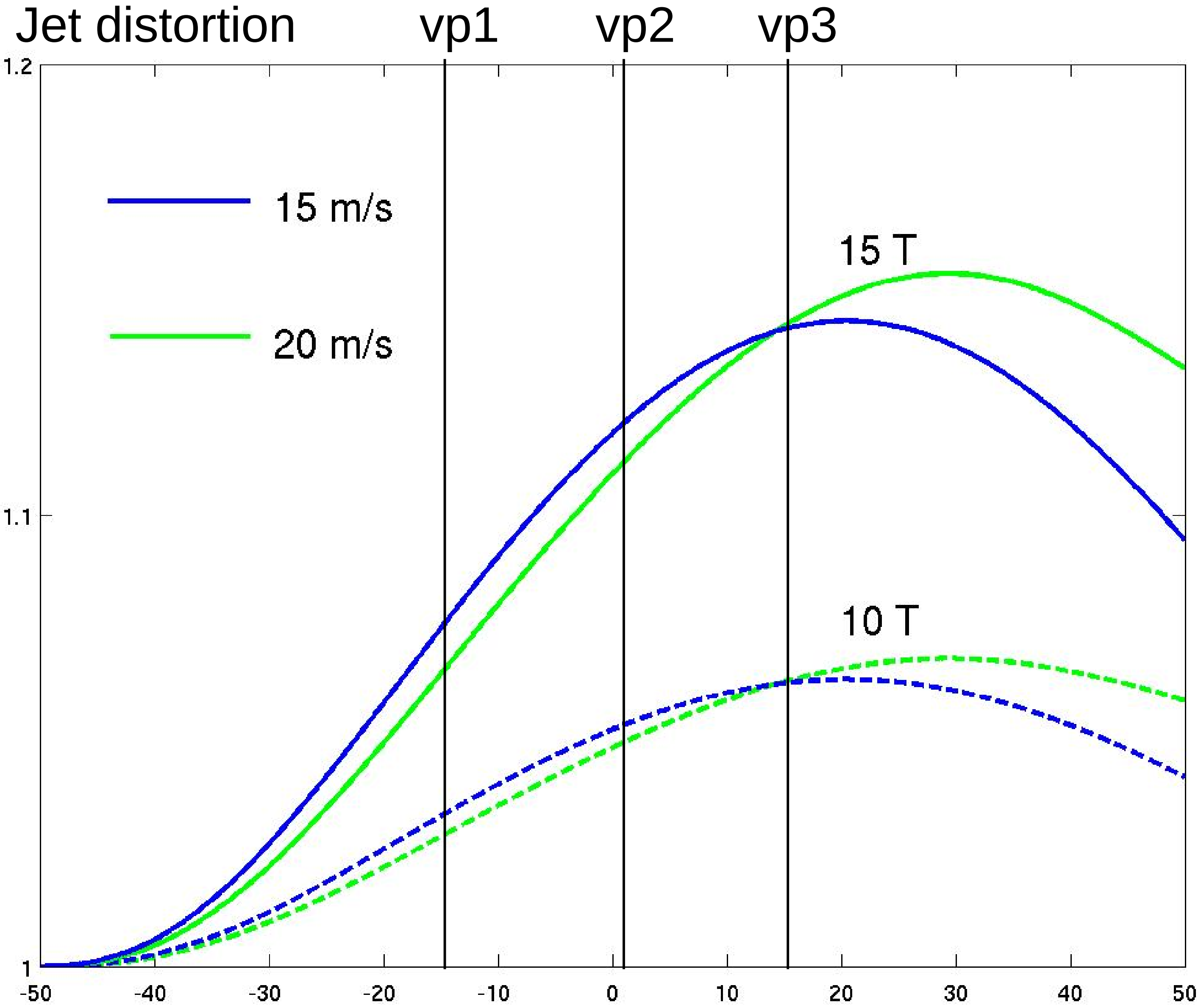

Jet trajectory
2
1.5
1
0.5
0
-0.5
-1
-1.5
-50
-40
-30
-20
-10
0
10
20
30
40
50


Bz
x 10^5
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
-50
-40
-30
-20
-10
0
10
20
30
40
50


By
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-50
-40
-30
-20
-10
0
10
20
30
40
50


Jet distortion
1.2
1.1
1
-50
-40
-30
-20
-10
0
10
20
30
40
50

Comparison: V = 15 and 20 m/s, B = 10 and 15 T



Experimental data

V = 15 m/s, B = 10T

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

V = 20 m/s, B = 10T

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

B = 15T

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

B = 15T

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

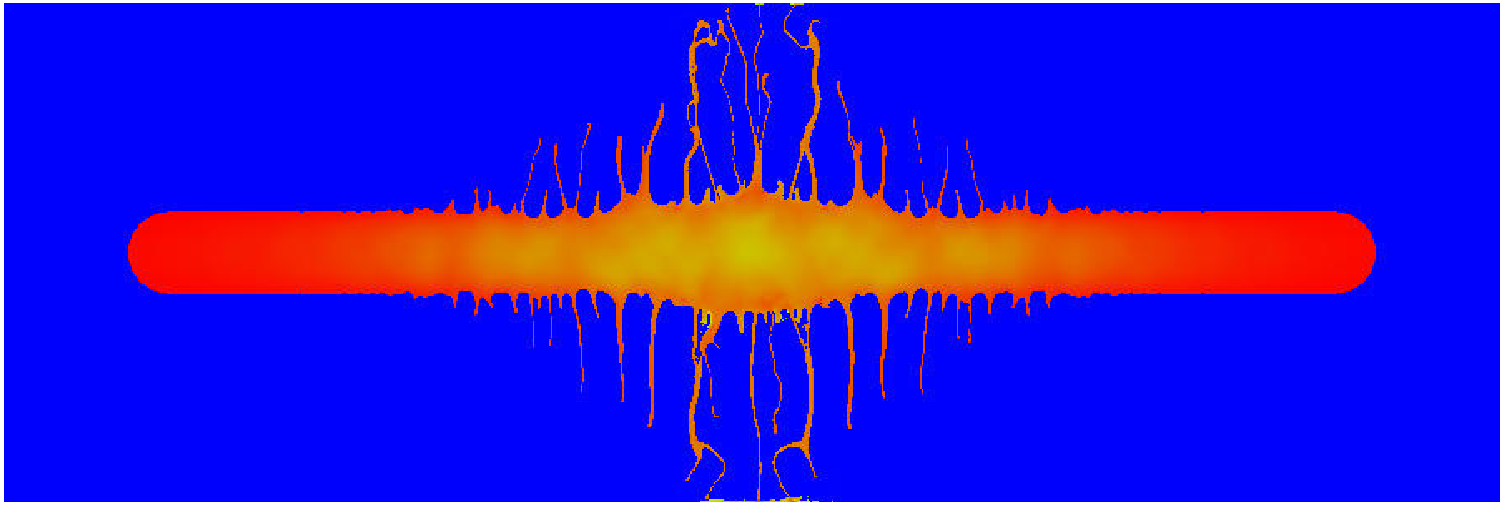
Simulations only qualitatively explain the width of the jet in different view ports.

Jet - proton pulse interaction. Evolution of models.
Phase I: Single phase mercury (no cavitation)

- Strong surface instabilities and jet breakup observed in simulations

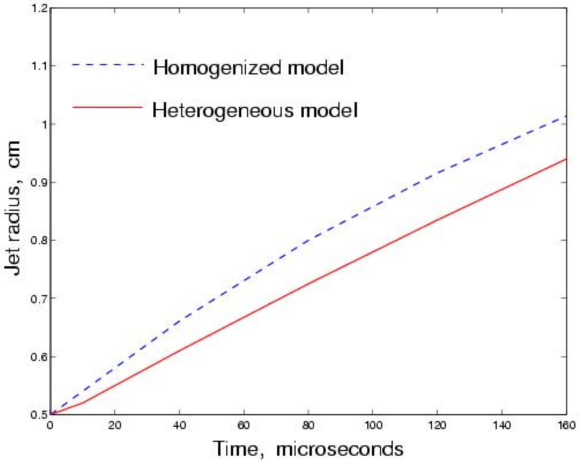
- Mercury is able to sustain very large tension
- Jet oscillates after the interaction and develops instabilities

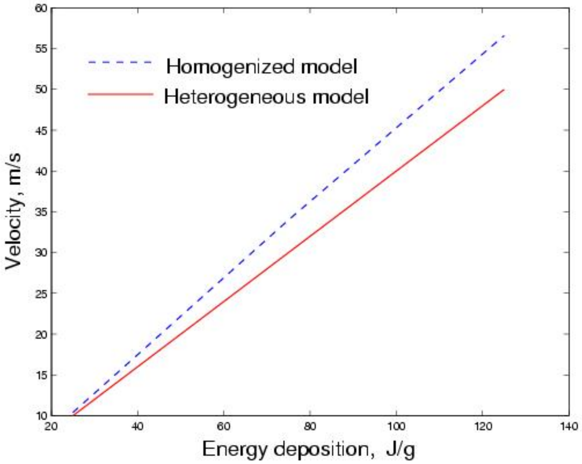
Jet surface instabilities

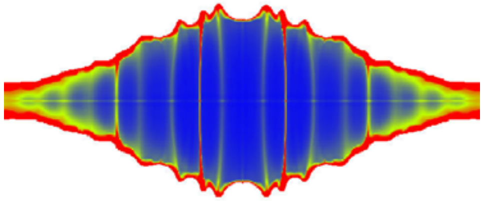


Jet - proton pulse interaction.
Phase II: Cavitation models

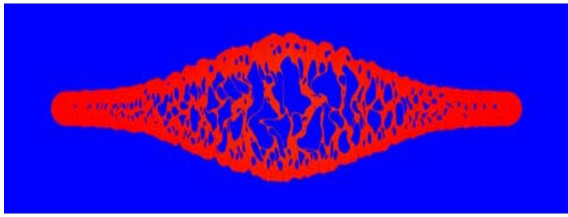
- We evaluated and compared homogeneous and heterogeneous cavitation models:





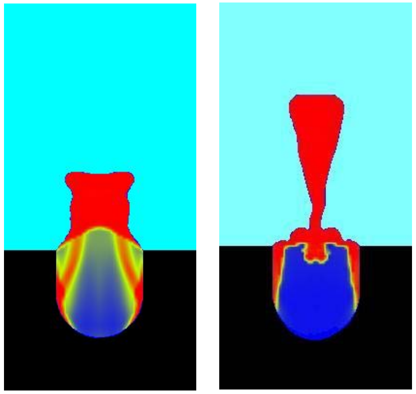


Homogeneous model



Heterogeneous model (resolved cavitation bubbles)

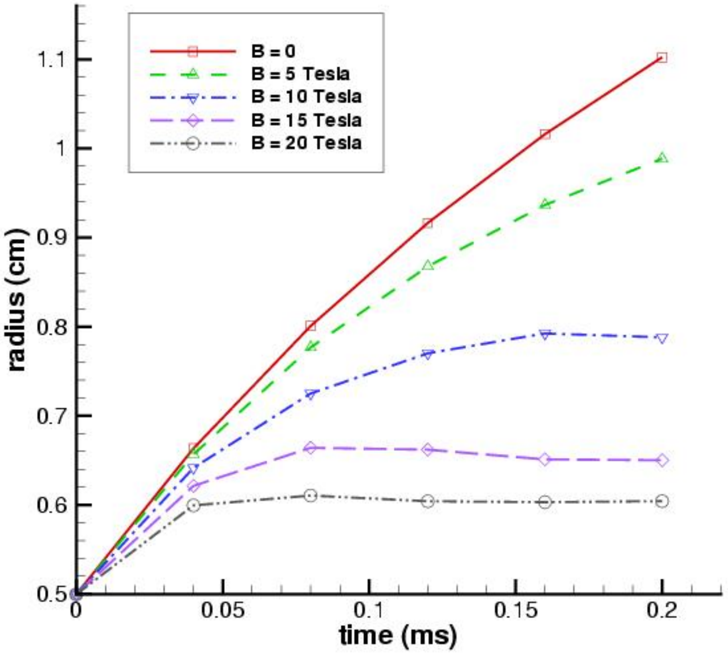
- Two models agree reasonably well
- Predict correct jet expansion velocity
- Surface instabilities and jet breakup not present in in simulations



Jet - proton pulse interaction
Phase II: Cavitation models in magnetic field

- The linear conductivity model predicts strong stabilizing effect of the magnetic field

- Stabilizing effect of the magnetic field is weaker if conductivity models with phase transitions are used (~ 20 % for Bruggeman’s model)



- If jet does not develop surface instabilities, the jet expansion is strongly damped in 15 T magnetic field (radial current are always present). Experimentally confirmed in MERIT.

Jet - proton pulse interaction
Phase III: Search of missing physics phenomena

Why surface instabilities and jet breakup are not observed in simulations with cavitation?

Possible Cause:

- **Turbulence nature of the jet**

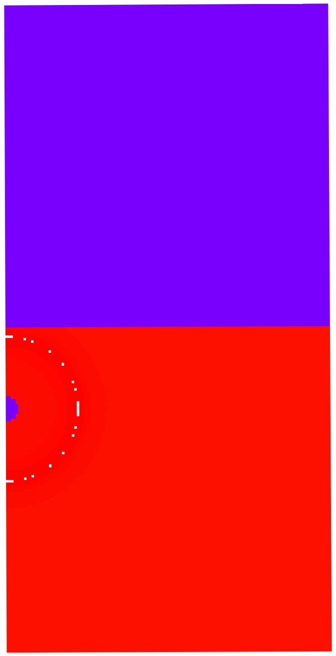
- **Microscopic mixture and strong sound speed reduction of the homogeneous model (separation of phases is important)**

- **Unresolved bubble collapse in the heterogeneous model**
  - **Bubble collapse is a singularity causing strong shock waves**

- **Other mechanisms?**

Multiscale approach to bubble collapse

- Bubble collapse (singularity) is difficult to resolve in global 3D model.



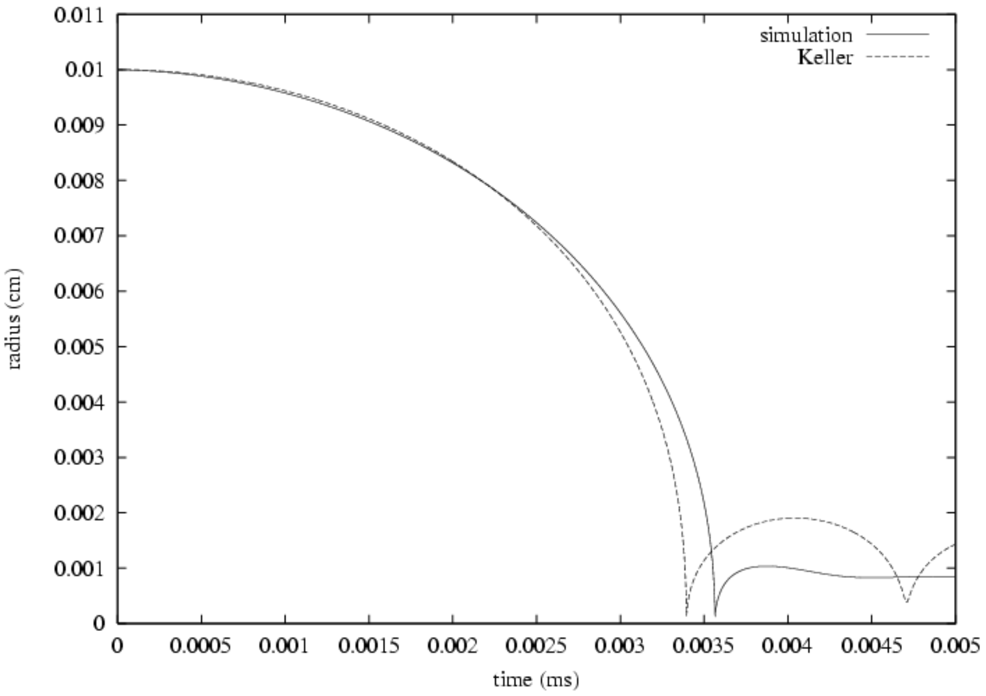
Multiscale approach:

Step 1: Accurate local model precomputes the collapse pressure

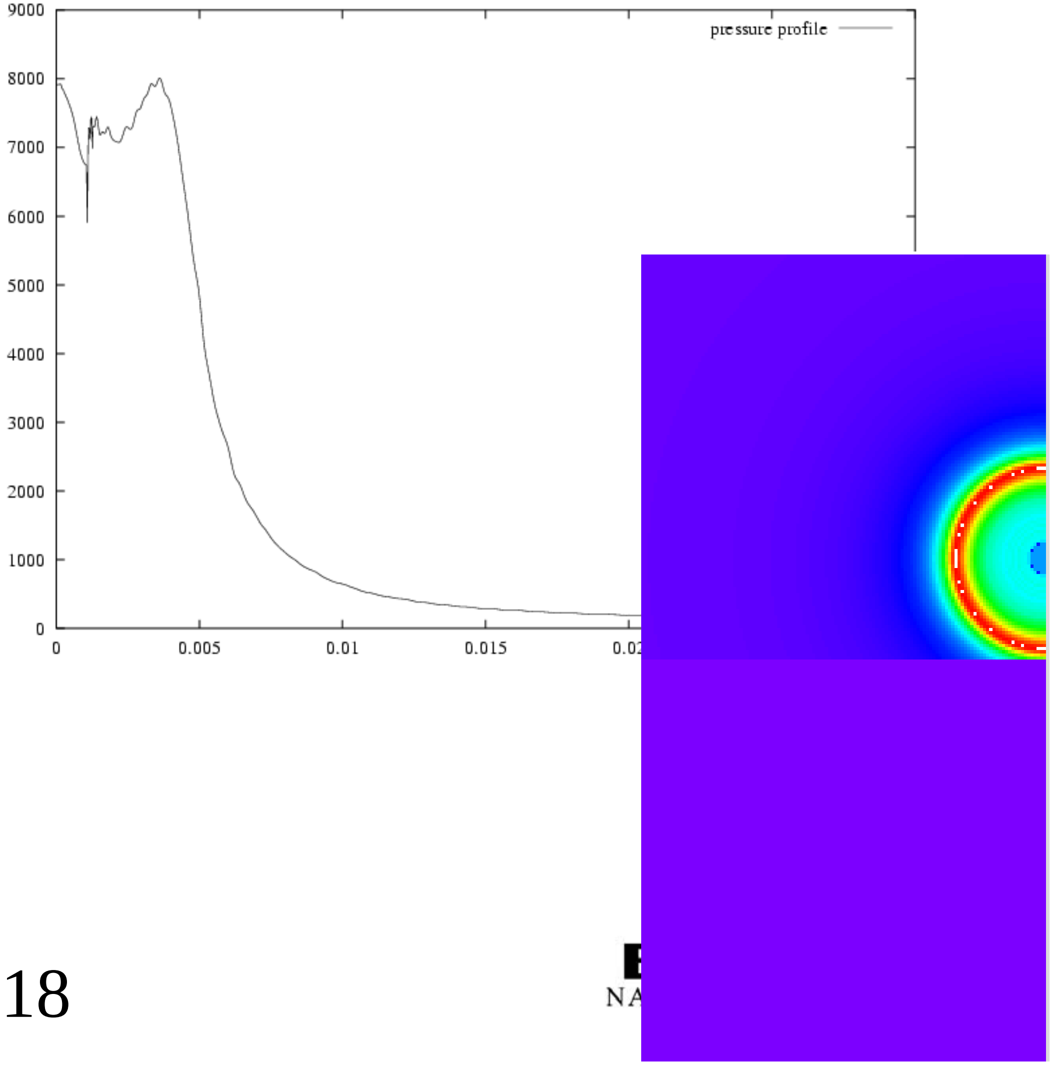
Step 2: Output of the local model serves as input to the global model

Step 1: 1D bubble collapse

Radius vs. Time



Pressure Profile at t =0.0035 ms



Step 2: 2D and 3D simulations of the collapse induced spike

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

t = 0

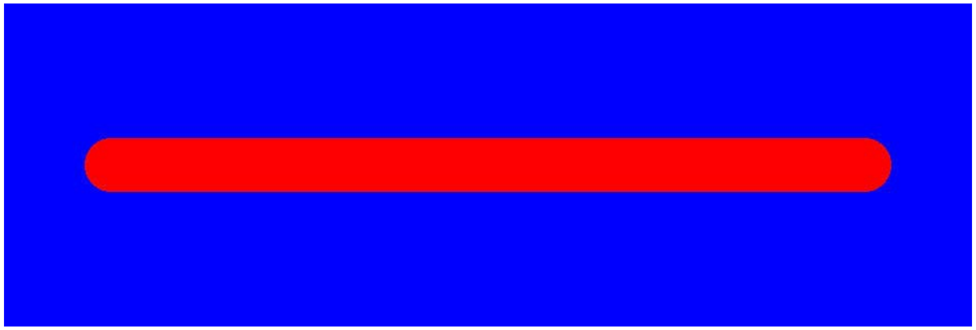
t = 0.0035 ms

t = 0.0070 ms

- Bubble collapse near the jet surface causes surface instability
- The growth of the spike is not stabilized by the magnetic field
- This is unlikely to be the only mechanism for surface instabilities

Initial instability (turbulence) of the jet

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

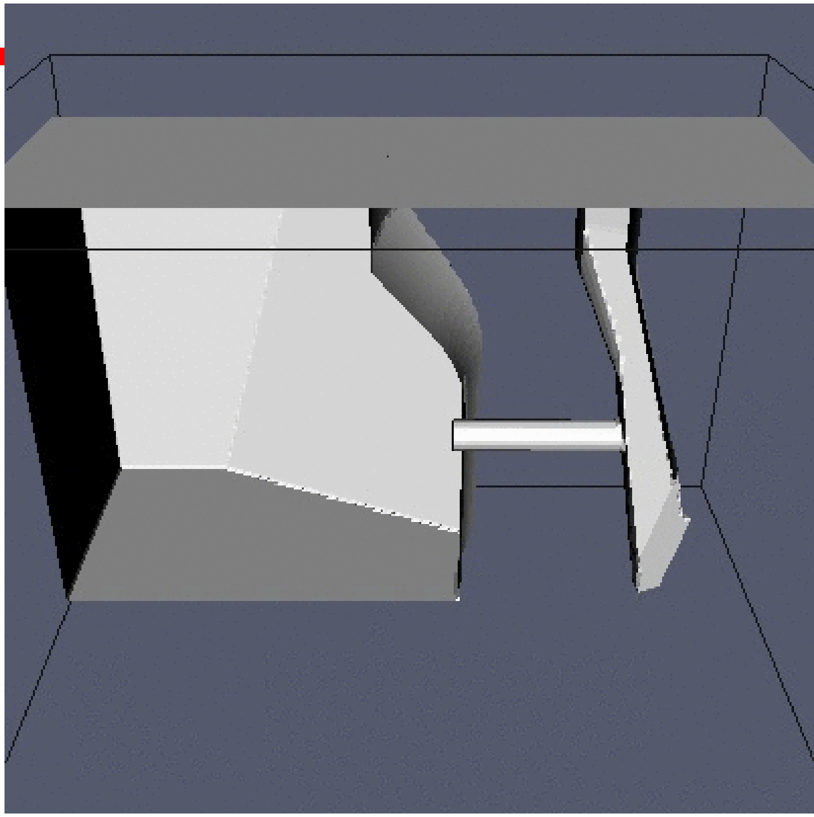


This was the real state of the jet before the interaction with protons

This was initial jet in previous numerical simulations (in 2D and 3D)

The obvious difference might be an important missing factor for both the jet flattening effect and interaction with the proton pulse.

3D jet naturally growing from the nozzle



- Major numerical development allowed us to obtain the state of the target before the interaction by “first principles”
- Simulation of the jet - proton pulse interaction is in progress