

Neutrino Factory / Muon Collider Collaboration Meeting
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Target Simulations

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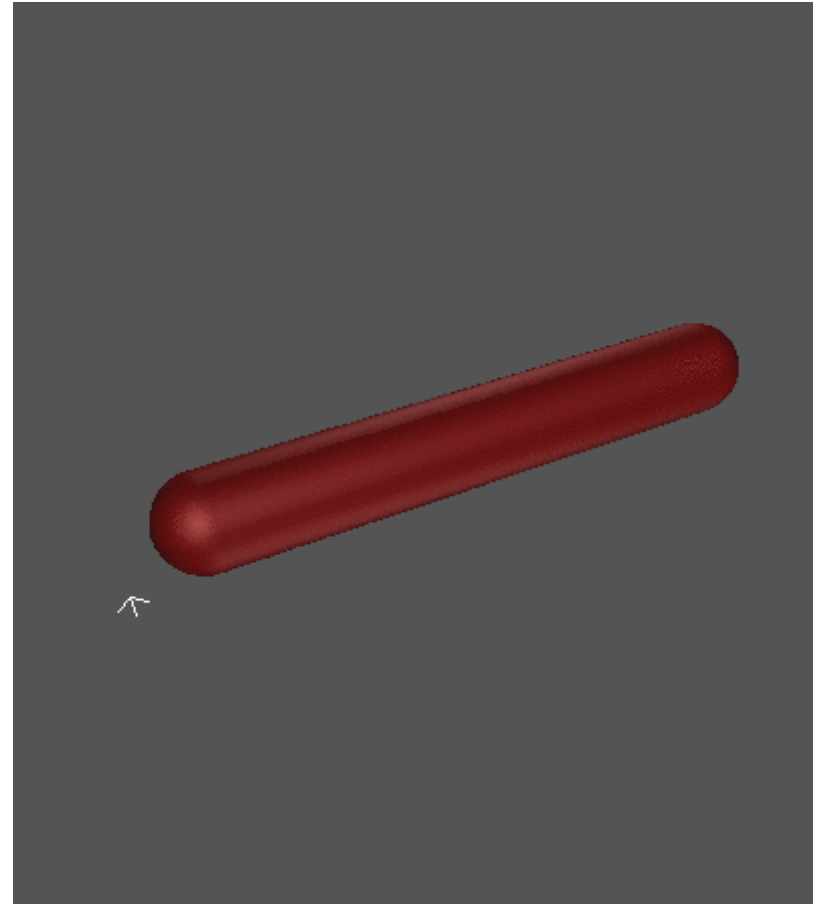
Talk Outline

- 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

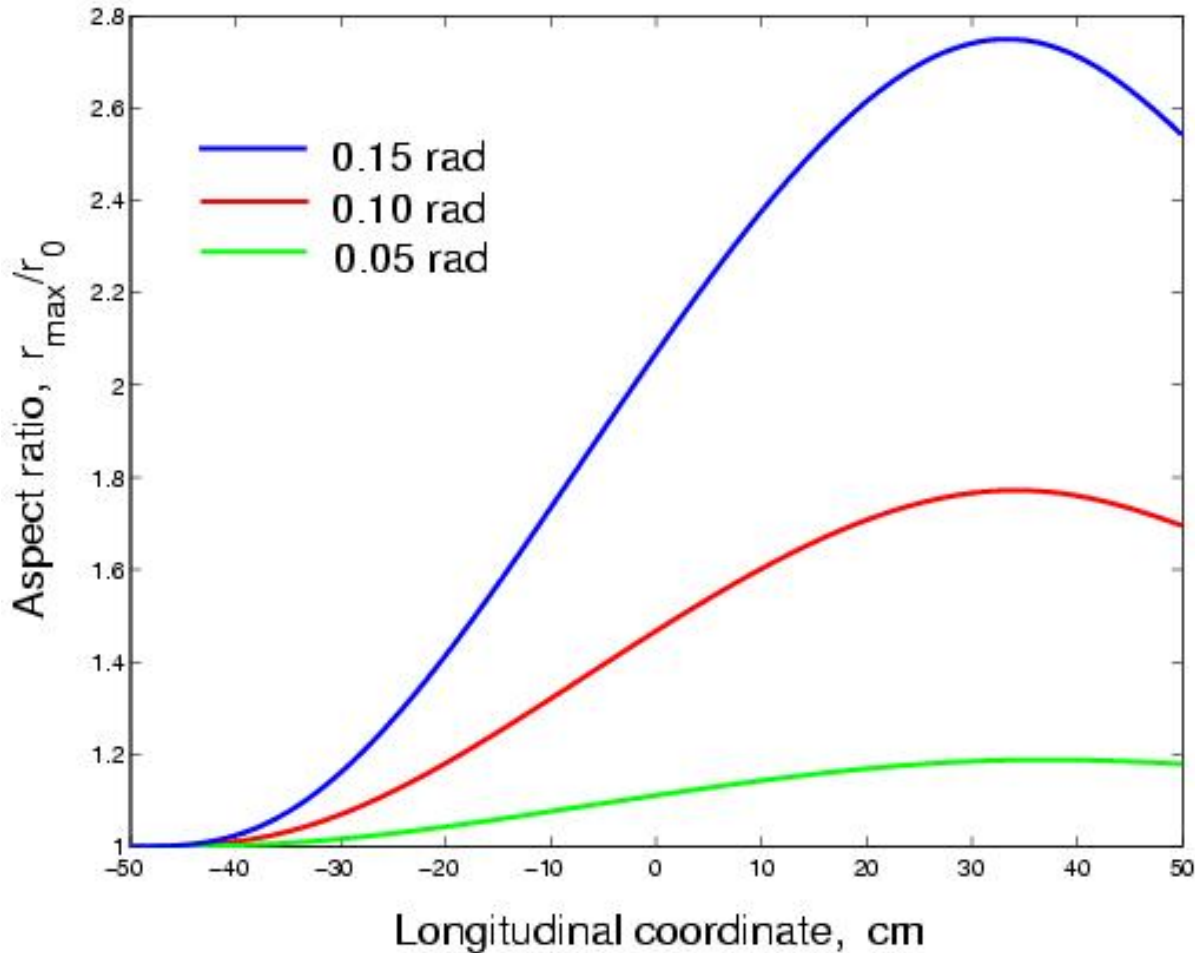
FrontTier code:

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



Previous Results (2005)

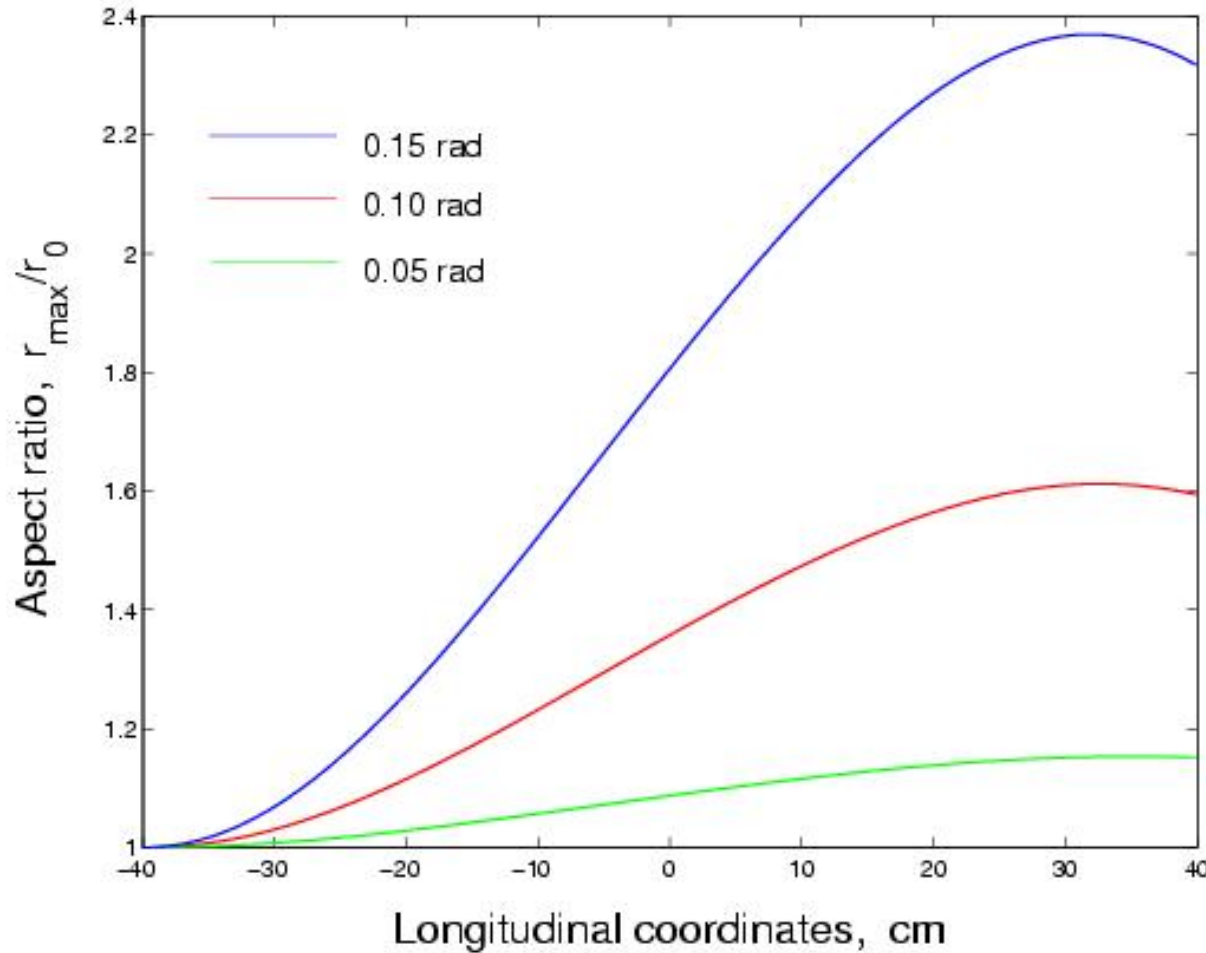
Aspect ratio of the jet cross-section. I



$B = 15 \text{ T}$
 $V_0 = 25 \text{ m/s}$

Previous Results (2005)

Aspect ratio of the jet cross-section. II

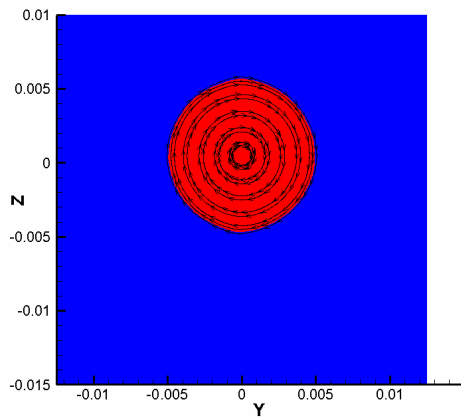


B = 15 T
V₀ = 25 m/s

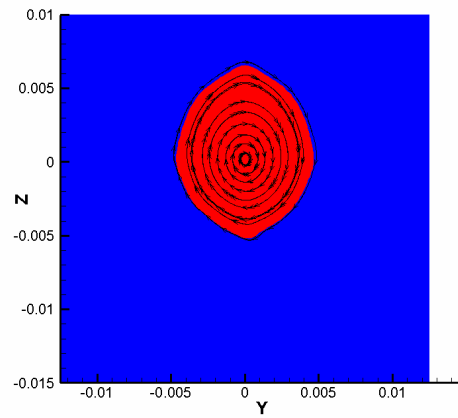
0.10 rad, z = 0:
Aspect ratio = 1.4

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

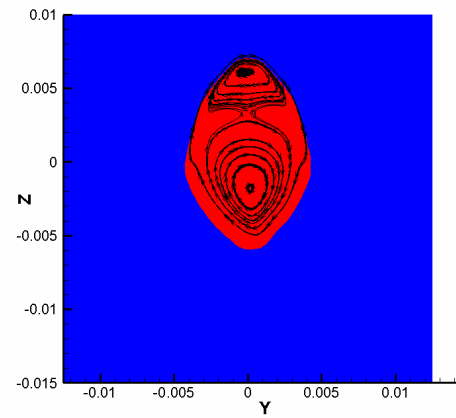
100 mrad tilt angle



$z = 0$ cm



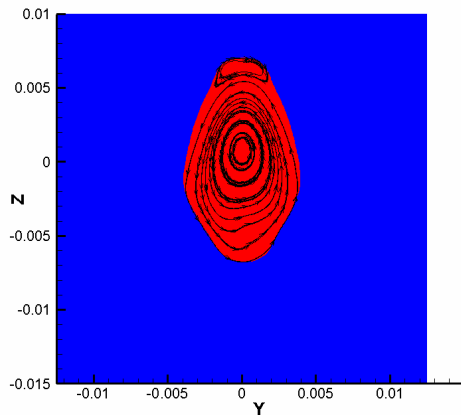
$z = 20$ cm



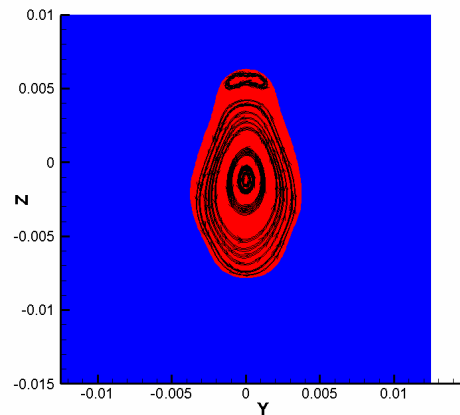
$z = 30$ cm

Aspect ratio = 1.4 in the solenoid center

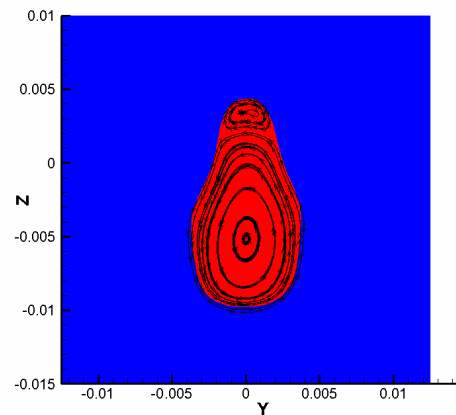
$z = 40$ cm



$z = 50$ cm

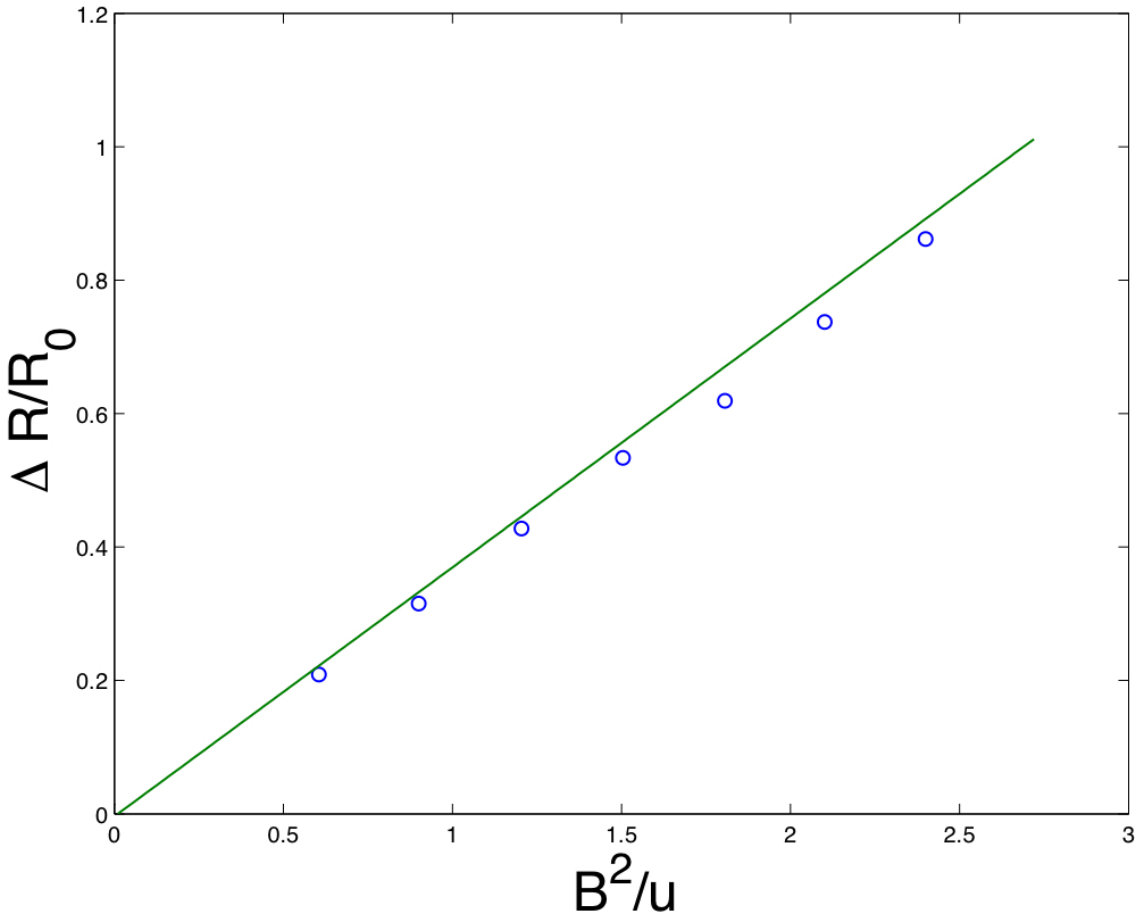


$z = 60$ cm



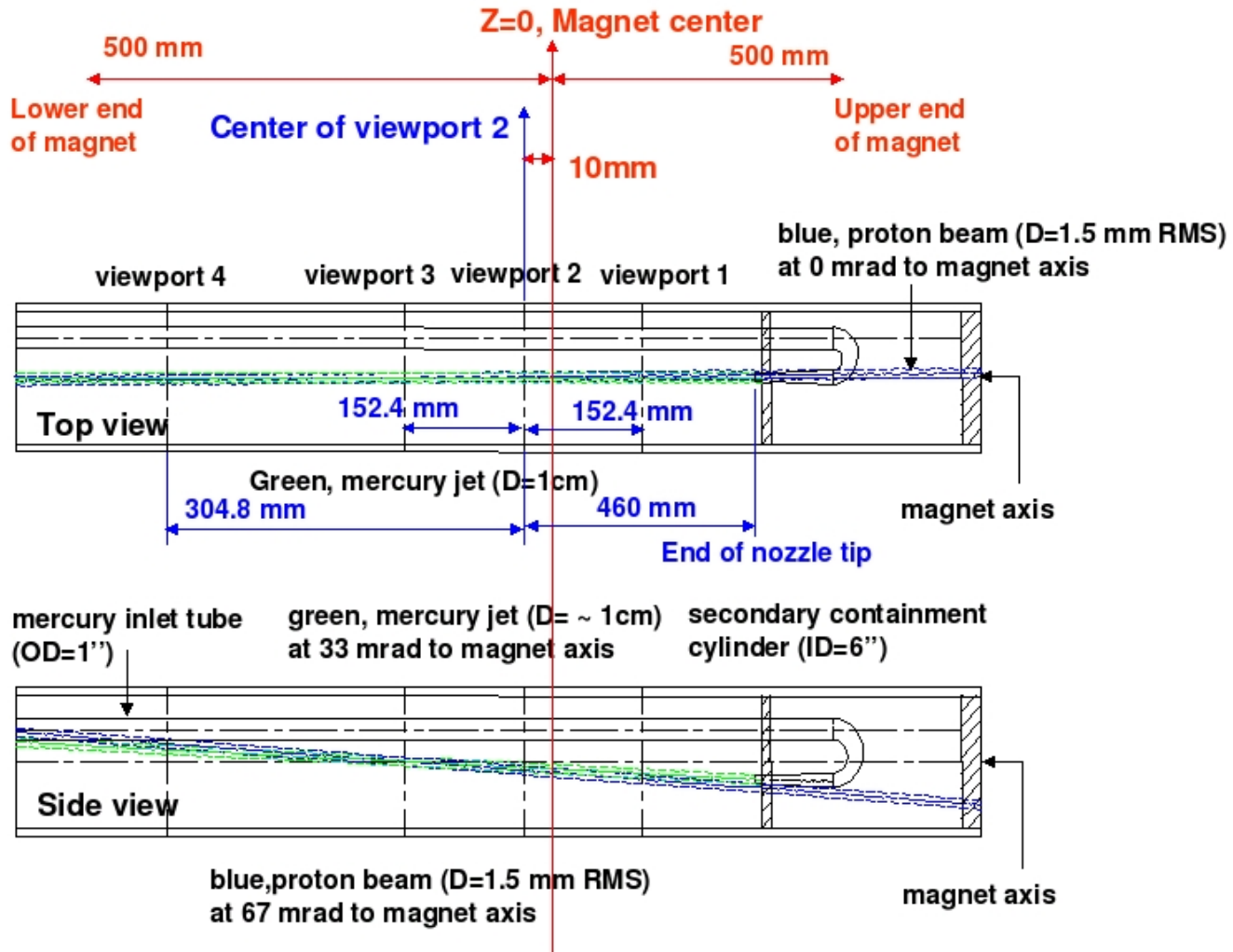
Comparison with the theory

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

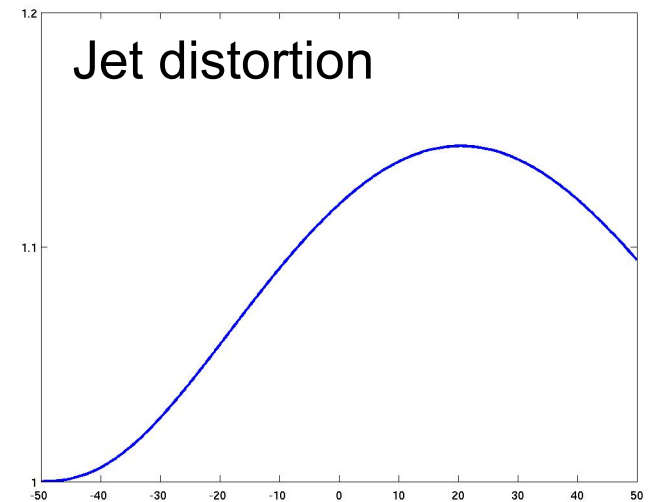
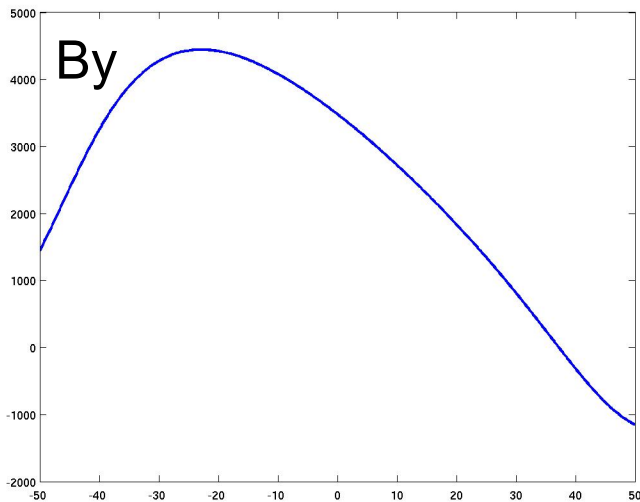
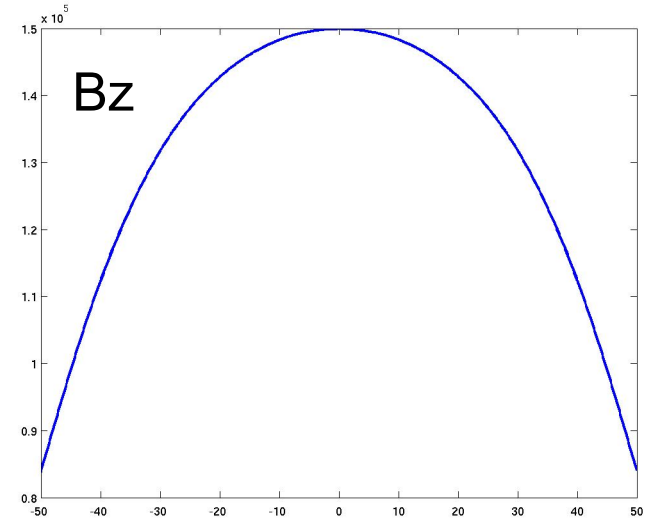
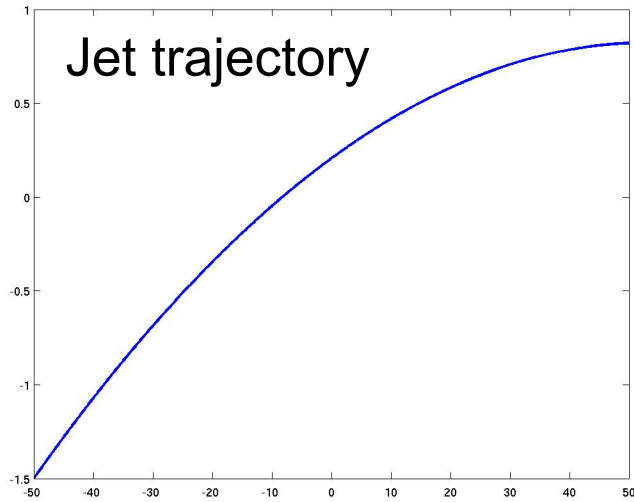


MERIT setup

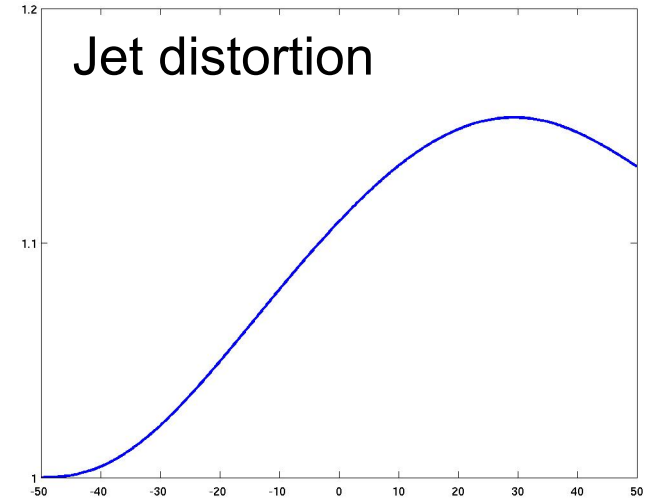
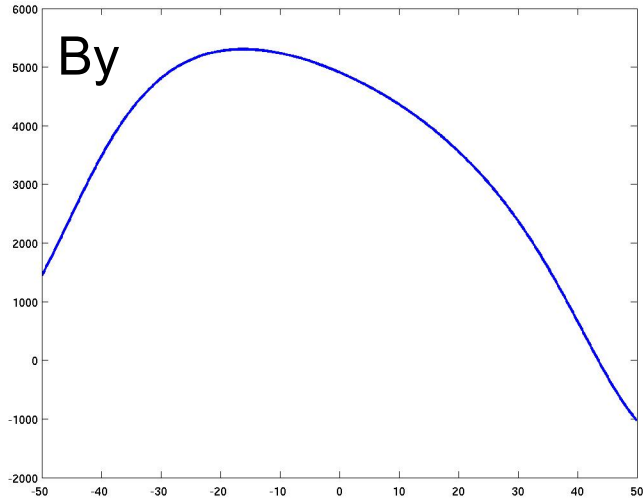
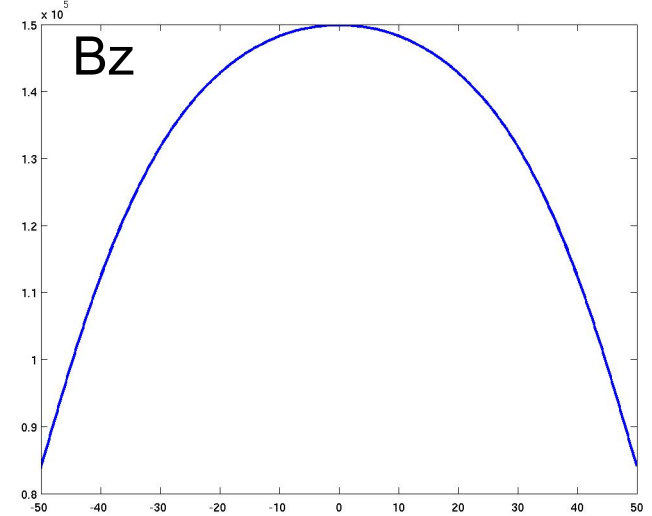
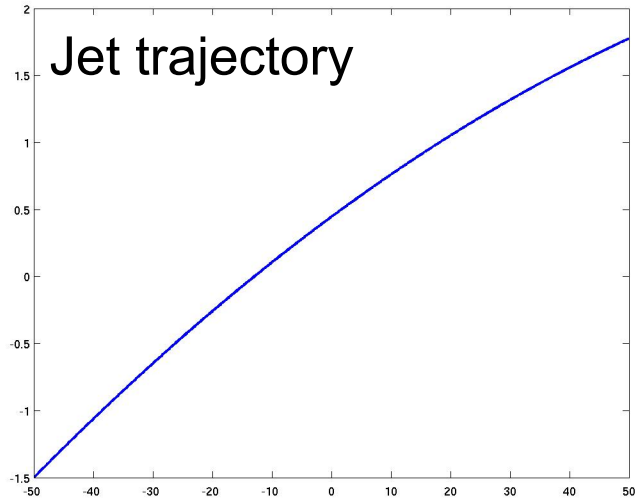
Geometry of Hg system in Magnet



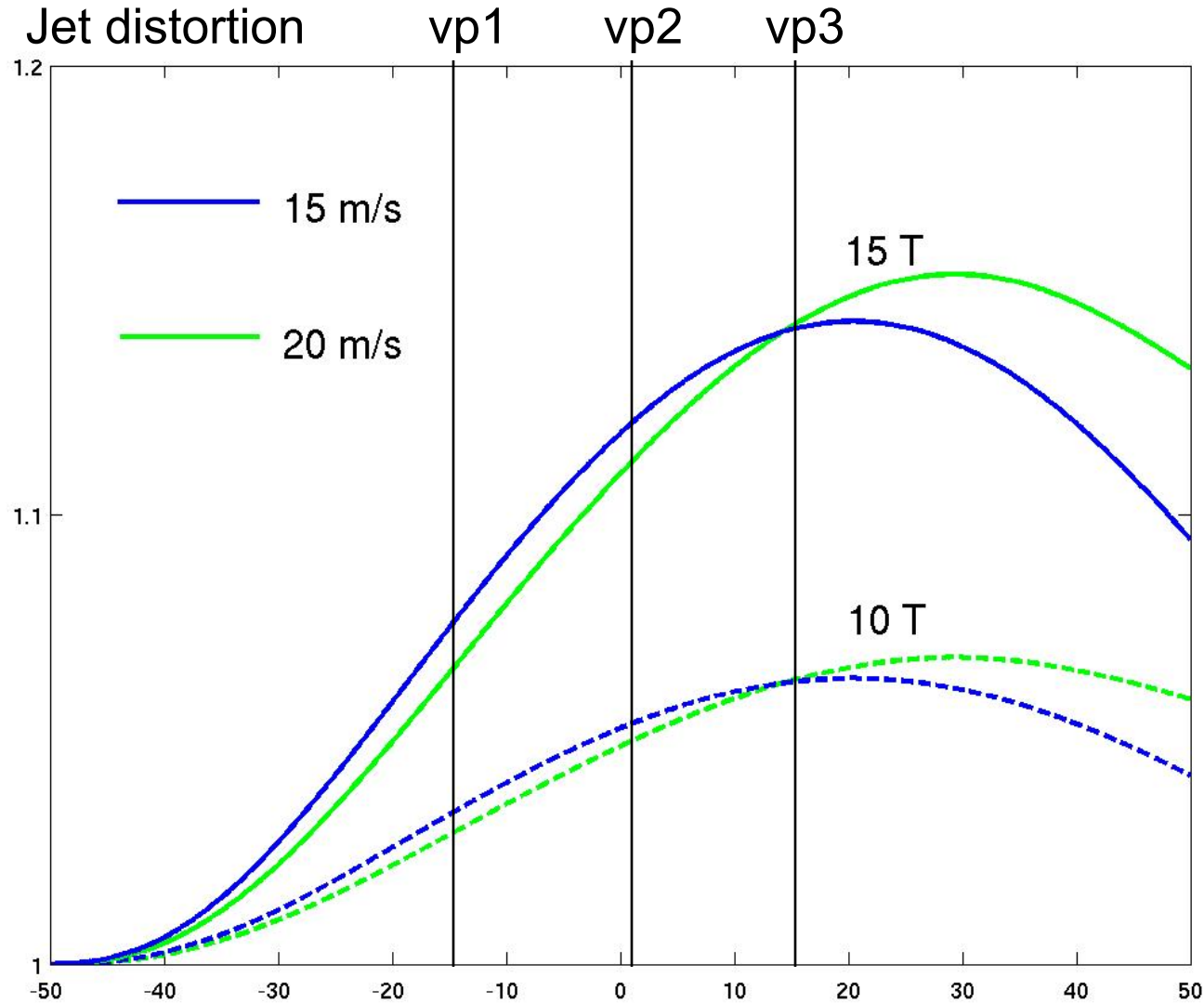
$V = 15 \text{ m/s}, B = 15 \text{ T}$



$V = 20 \text{ m/s}, B = 15 \text{ T}$



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.

B = 15T

QuickTime™ and a
TIFF (LZW) decompressor
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V = 20 m/s, B = 10T

QuickTime™ and a
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B = 15T

QuickTime™ and a
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are needed to see this picture.

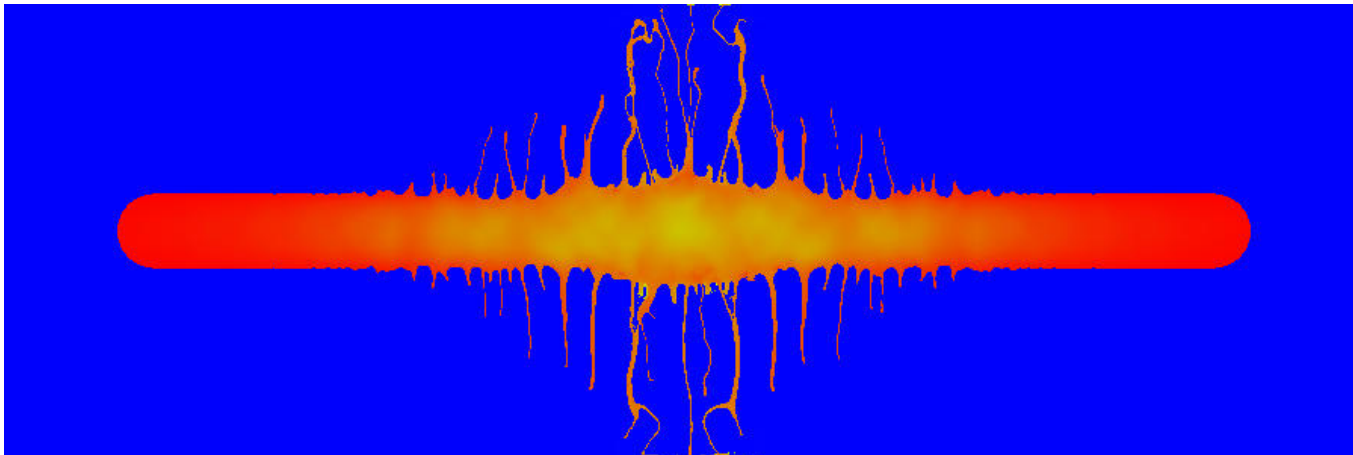
Simulations only qualitatively explain the width of the jet in different view ports.

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

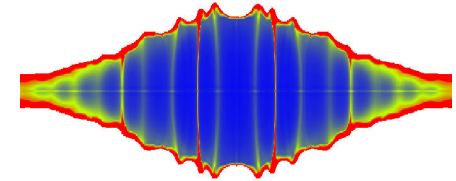
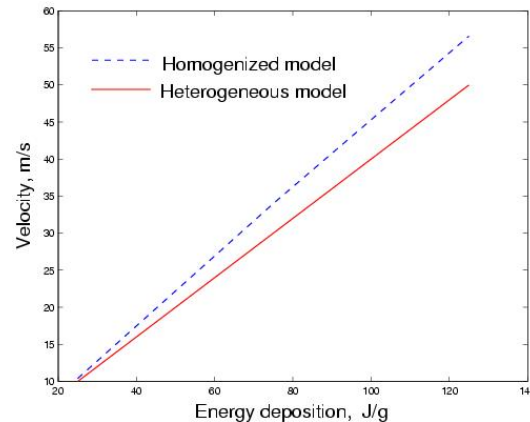
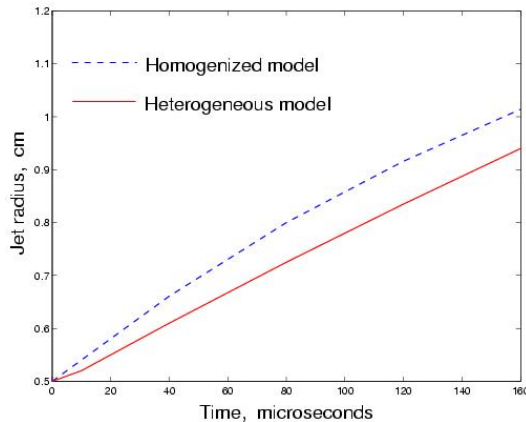
Jet surface instabilities



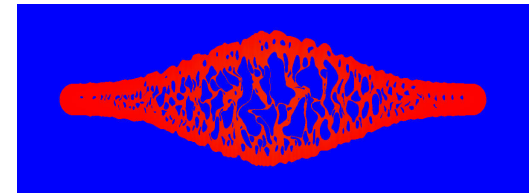
Jet - proton pulse interaction.

Phase II: Cavitation models

- We evaluated and compared homogeneous and heterogeneous cavitation models:

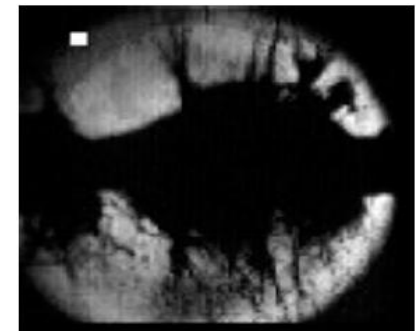
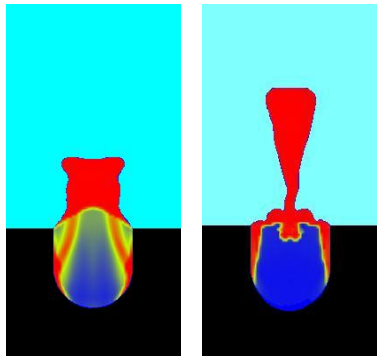


Homogeneous model



Heterogeneous model
(resolved cavitation
bubbles)

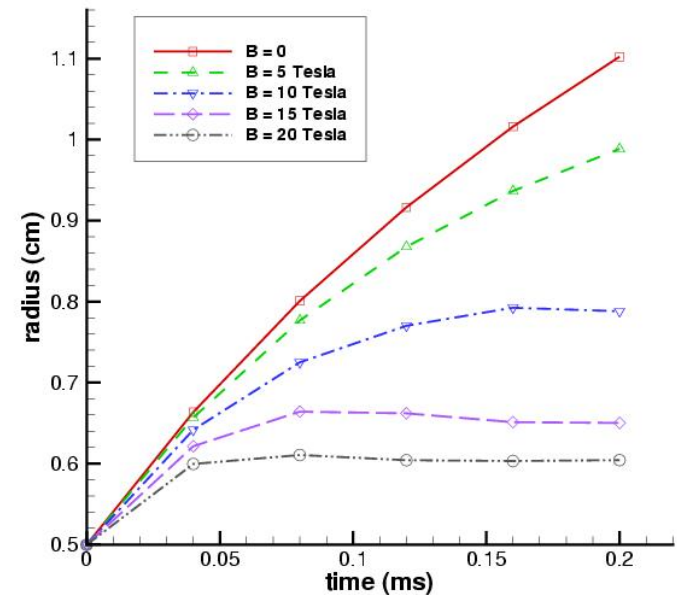
- Two models agree reasonably well
- Predict correct jet expansion velocity
- Surface instabilities and jet breakup not present in in simulations



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.

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?**

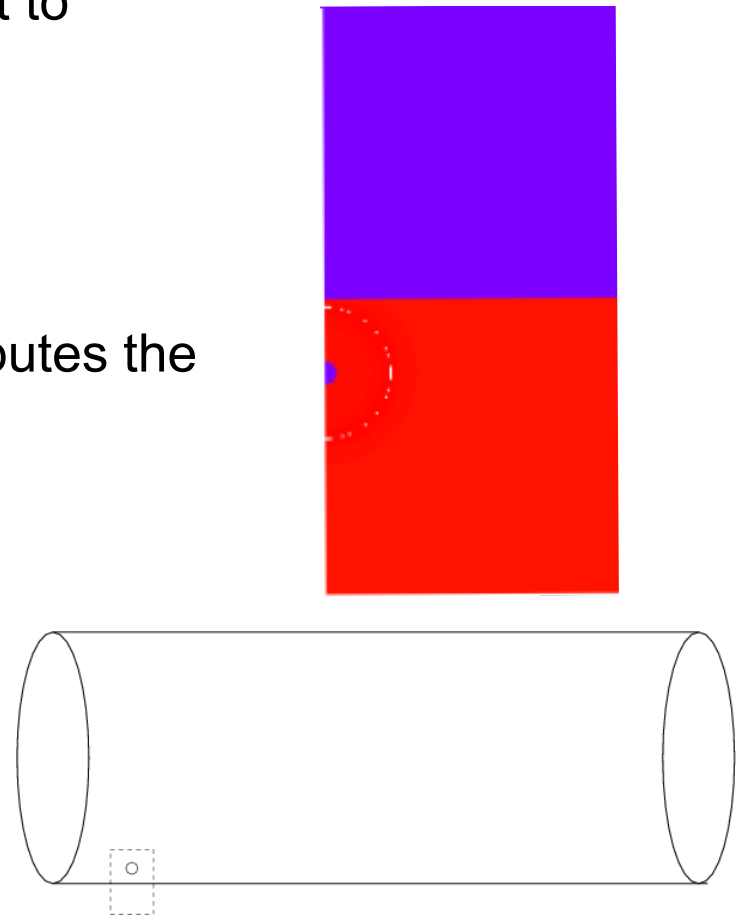
Multiscale approach to bubble collapse

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

Multiscale approach:

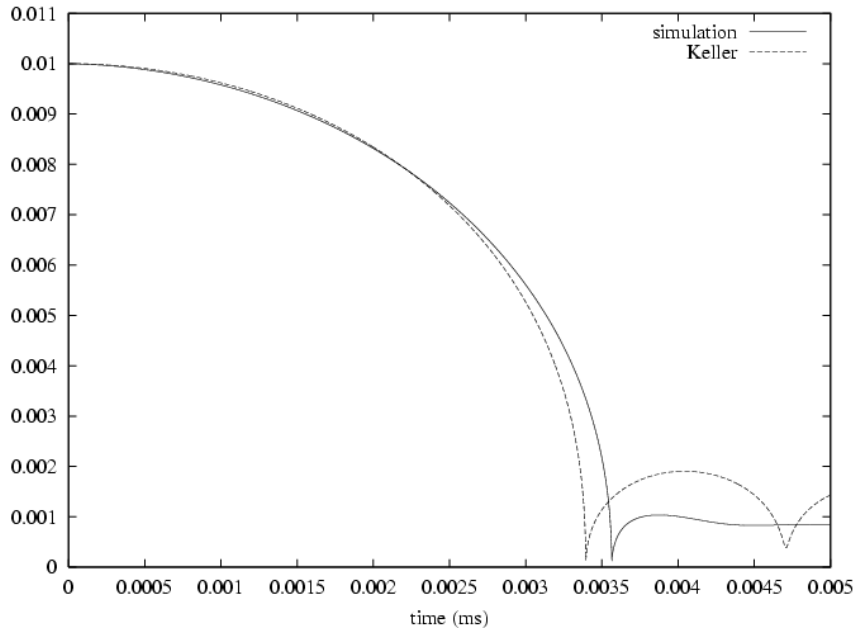
Step 1: Accurate local model precomputes the collapse pressure

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

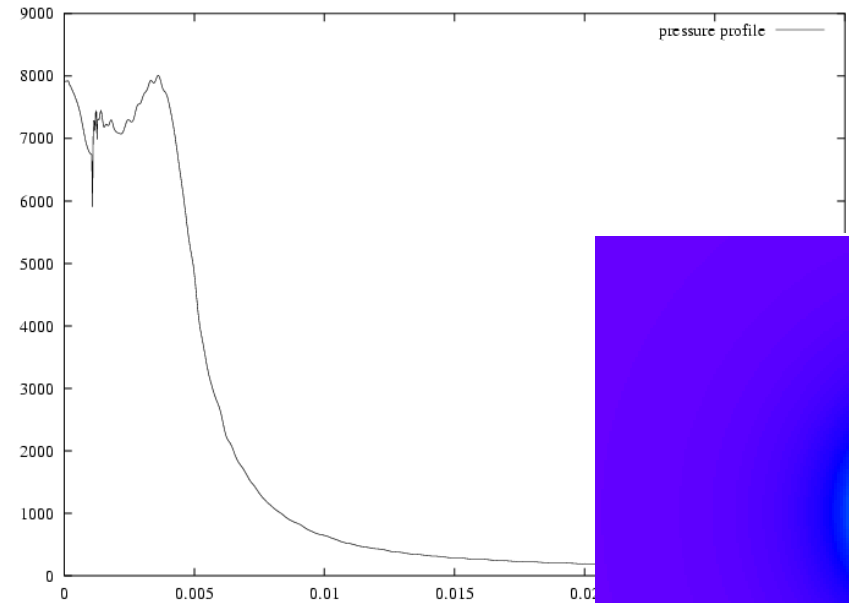


Step 1: 1D bubble collapse

Radius vs. Time



Pressure Profile at $t=0.0035$ ms



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

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t = 0

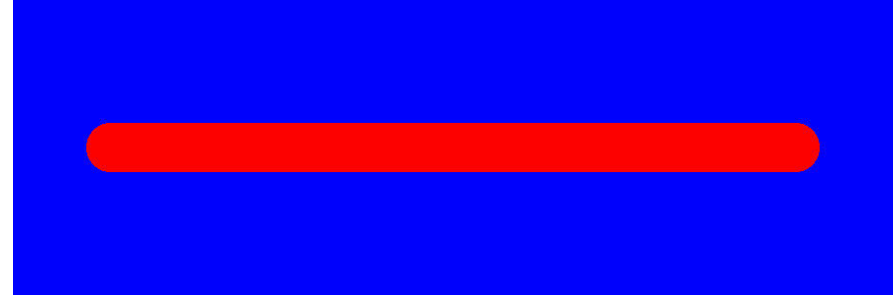
t = 0.0035 ms

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

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TIFF (LZW) decompressor
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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

