Simulation of Muon Collider Target Experiments

Yarema Prykarpatskyy

Center for Data Intensive Computing

Brookhaven National Laboratory

U.S. Department of Energy

yarpry@bnl.gov

Muon Collaboration

BROOKHAVEN NATIONAL LABORATORY

Talk outline

- Numerical methods for the hyperbolic subsystem.
  The *FronTier Code*
- Numerical simulation of the interaction of a free mercury jet with a proton pulse
- MHD simulations: stabilizing effect of the magnetic field
- Numerical simulation of the interaction of mercury with a proton pulse in a thimble (BNL AGS and CERN ISOLDE experiments)
- Conclusions
- Remarks on the future research plans

Muon Collaboration

BROOKHAVEN
NATIONAL LABORATORY

Numerical methods for the hyperbolic subsystem.

- We used FronTier code with free interface support
- FronTier uses method of front tracking
- FronTier has large collection of Riemann solvers:

MUSCLE (Monotonic Upstream Centered Difference Scheme for Conservation Laws)

exact Riemann Solver

Colella-Glaz approximate Riemann solver

Gamma low fit

Dukowicz Riemann solver

- For material modeling we use realistic models of the equation of state:

polytropic EOS

stiffened polytropic EOS

two phase EOS for cavitating liquid

SESAME EOS library

Isentropic two phase EOS model for cavitating liquid

- Approach: connect thermodynamically consistently different models for different phases
- Pure liquid is described by the stiffened polytropic EOS model (SPEOS)
- Pure vapor is described by the polytropic EOS model (PEOS)
- An analytic model is used for the mixed phase
- SPEOS and PEOS reduced to an isentrope and connected by the model for liquid-vapor mixture
- All thermodynamic functions depend only on density

The EOS

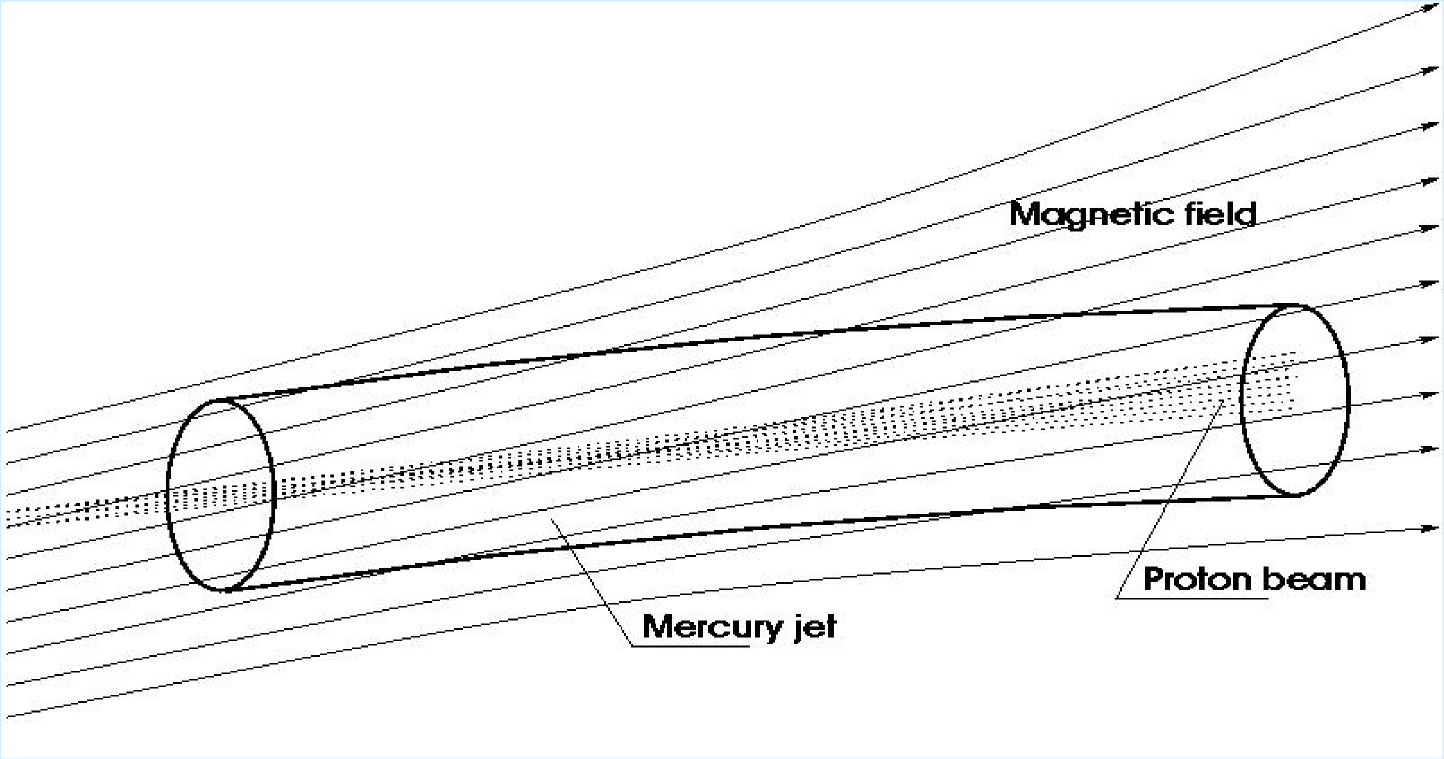
- does not take into account drag forces, viscous and surface tension forces
- does not have full thermodynamics

Muon Collaboration

BROOKHAVEN NATIONAL LABORATORY

Applications: Muon Collider Target

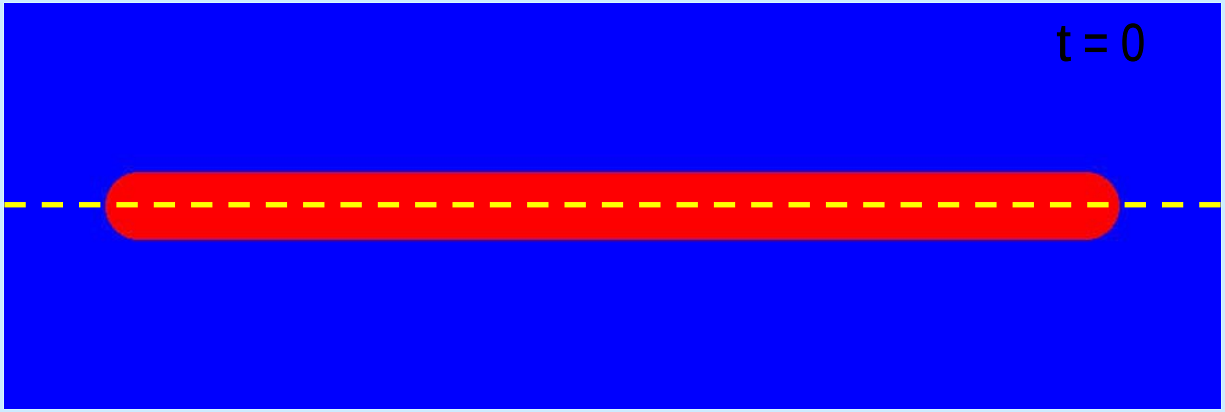
Numerical simulation of the interaction of a free mercury jet with high energy proton pulses in a 20 T magnetic field

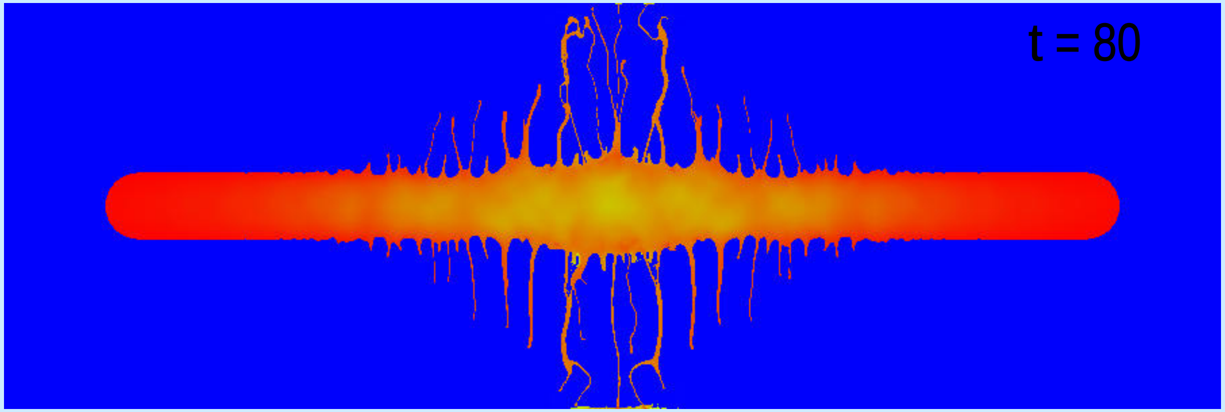


Muon Collaboration

BROOKHAVEN
NATIONAL LABORATORY

Simulation of the Muon Collider target. The evolution of the mercury jet due to the proton energy deposition is shown.
No magnetic field





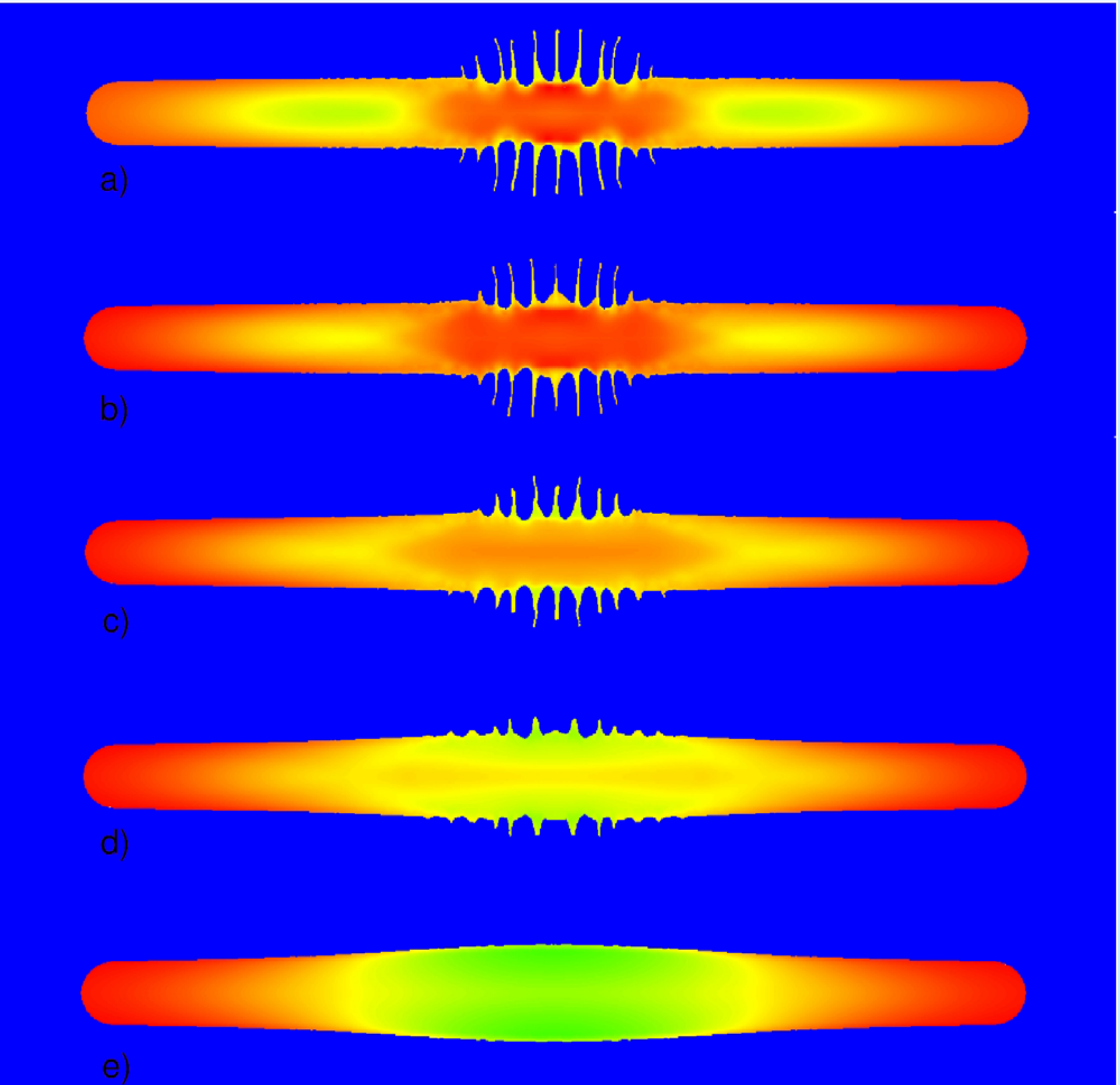
fact Muon Collaboration

BROOKHAVEN NATIONAL LABORATORY

Jet in a uniform magnetic field

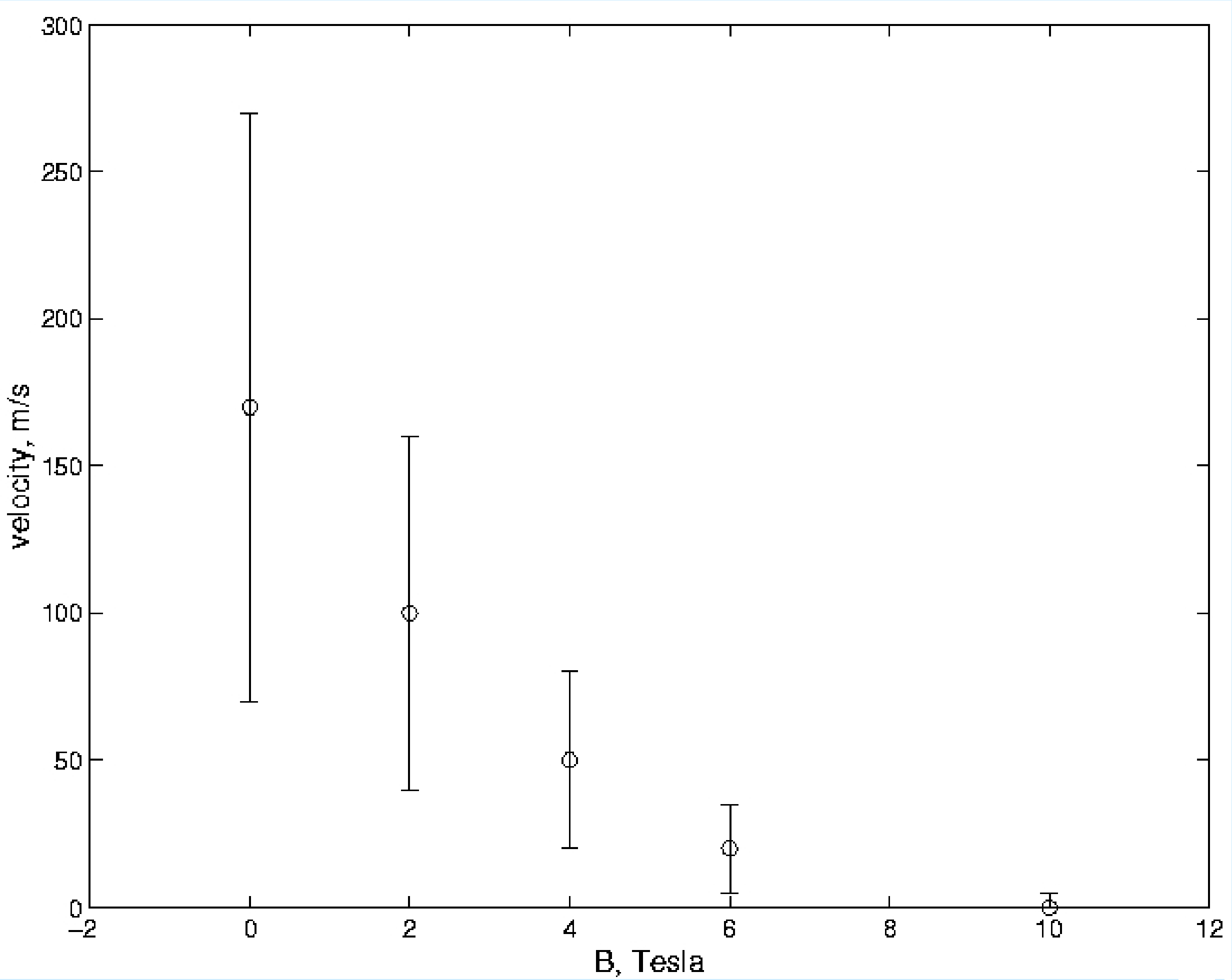
- Stiffened polytropic EOS was used to model the mercury jet
- A uniform magnetic field was applied to the mercury jet along the axis. The Lorentz force due to induced currents reduced both the shock wave speed in the liquid and the velocity of surface instabilities

MHD simulations: stabilizing effect of the magnetic field.

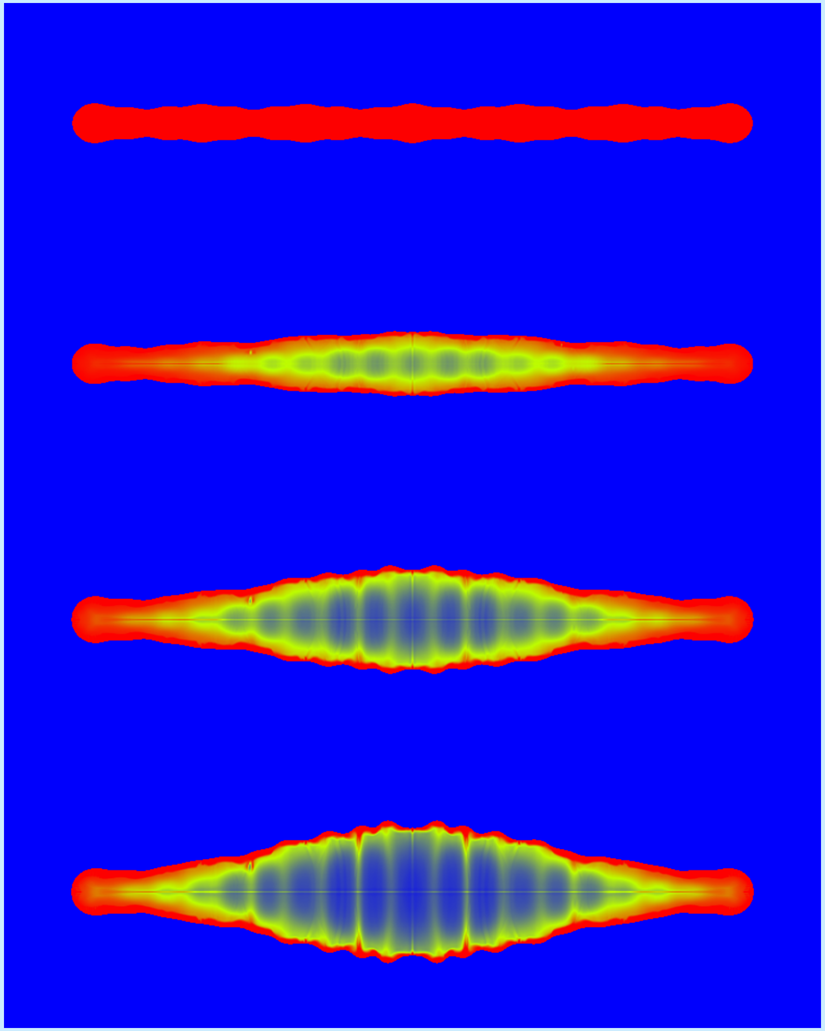


- B = 0
- B = 2T
- B = 4T
- B = 6T
- B = 10T

Velocity of jet surface instabilities in the magnetic field

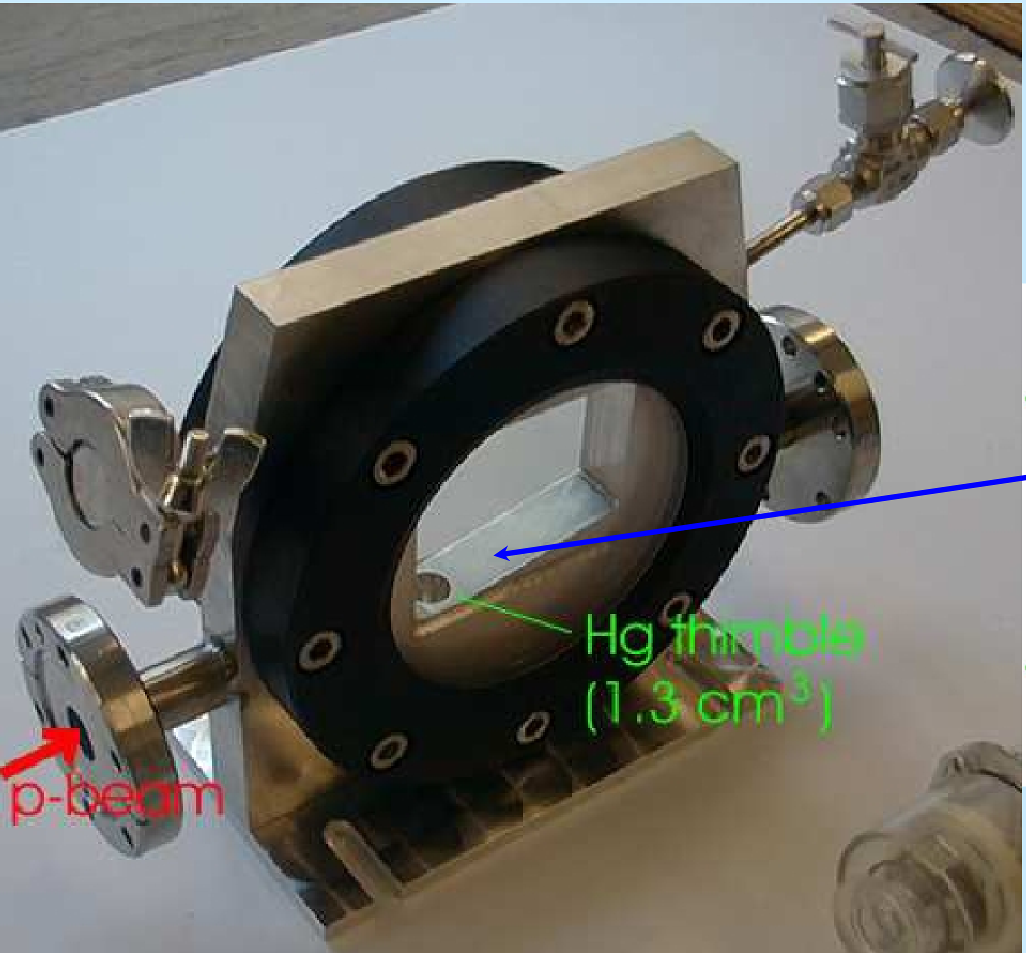


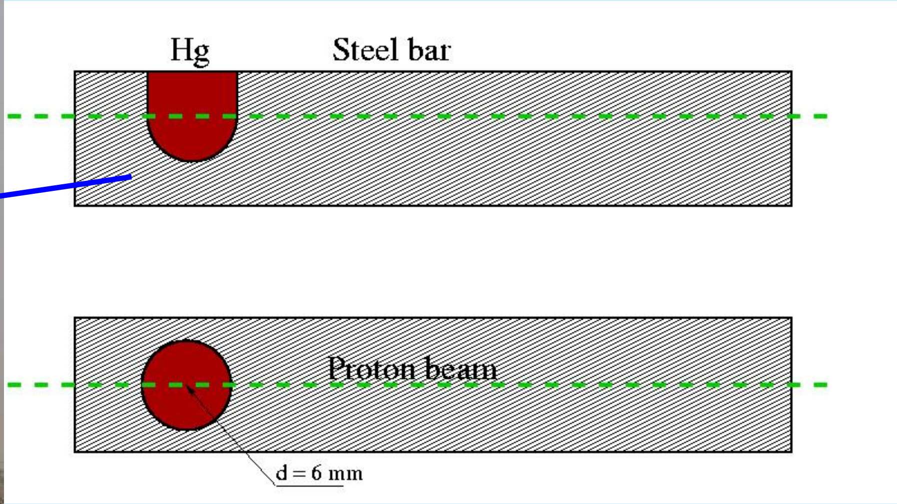
Numerical simulation of the interaction of a free mercury jet with high energy proton pulses using two phase EOS



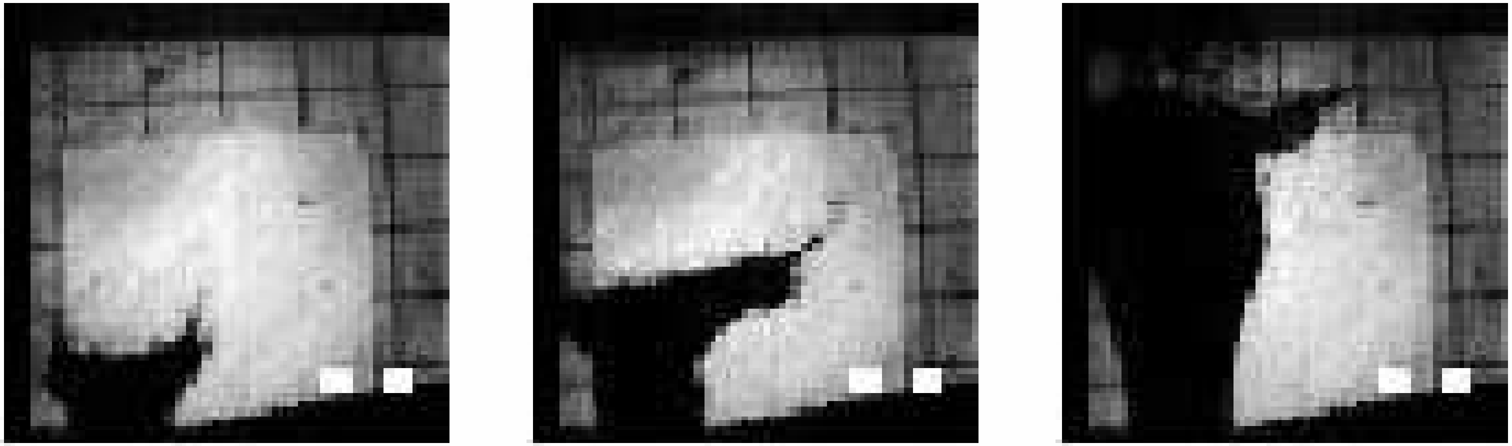
Evolution of the mercury jet after the interaction with a proton pulse

Mercury thimble experiment at AGS (BNL)
Left: picture of the experimental device
Right: schematic of the thimble in the steel bar





Mercury splash (thimble): experimental data

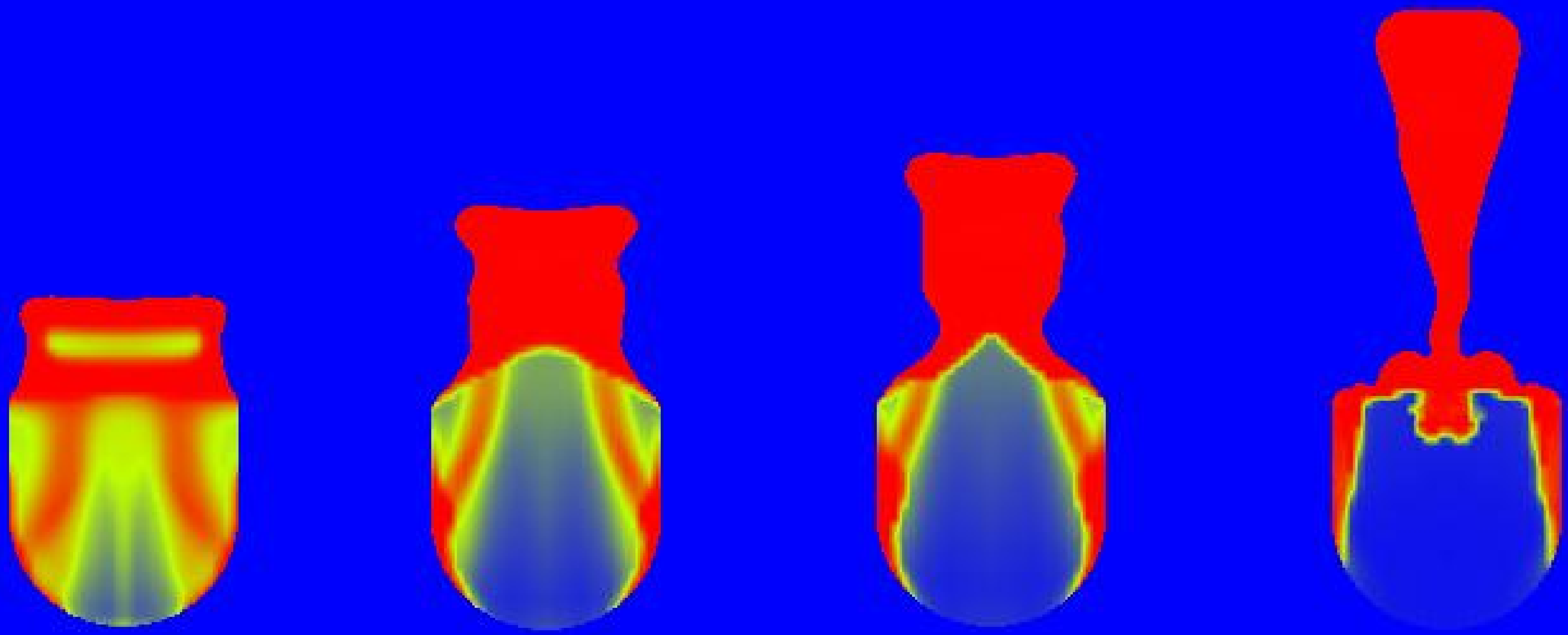


Mercury splash at t = 0.88, 1.25 and 7 ms after proton impact of 3.7 e12 protons

Mercury splash (thimble): numerical simulation

$$I = 3.7x10^{12}\ protons / pulse$$

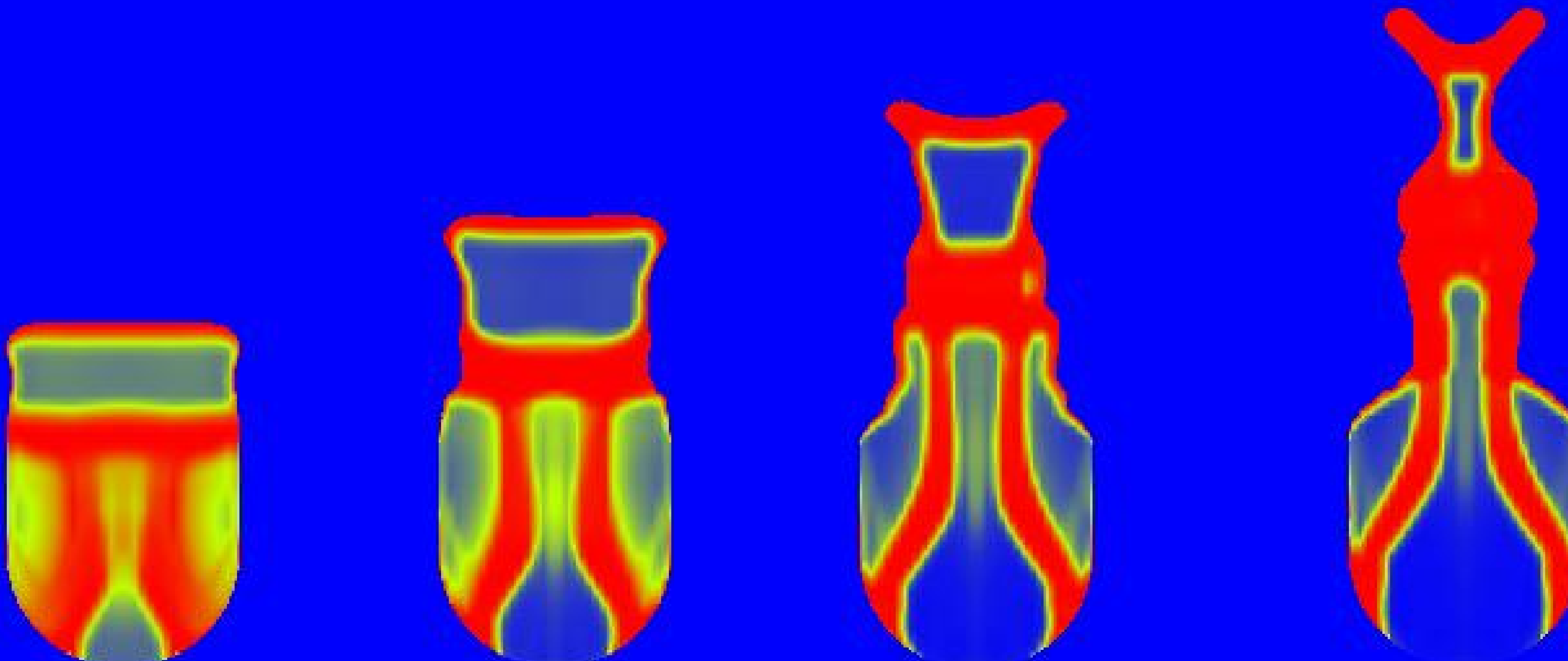
$t = 240\,\mu s$ $t = 480\,\mu s$ $t = 609\,\mu s$ $t = 1.014\,ms$



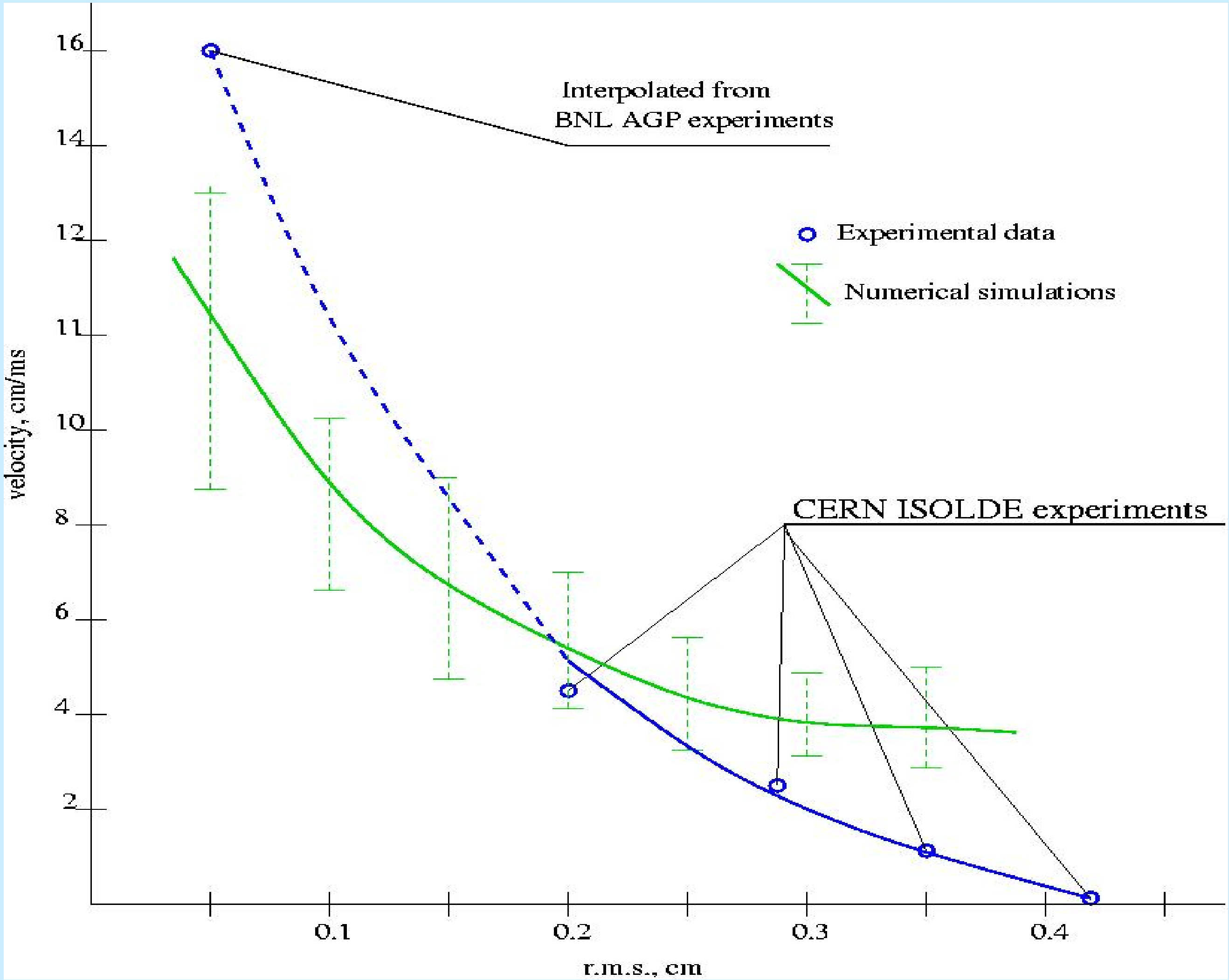
Mercury splash (thimble): numerical simulation

$$I = 17x10^{12}\ protons / pulse$$

$t = 200\,\mu s$ $t = 515\,\mu s$ $t = 810\,\mu s$ $t = 1.2\,ms$



Increasing the spot size of the proton beam results in a decrease of the splash velocities



Muon Collaboration

BROOKHAVEN NATIONAL LABORATORY

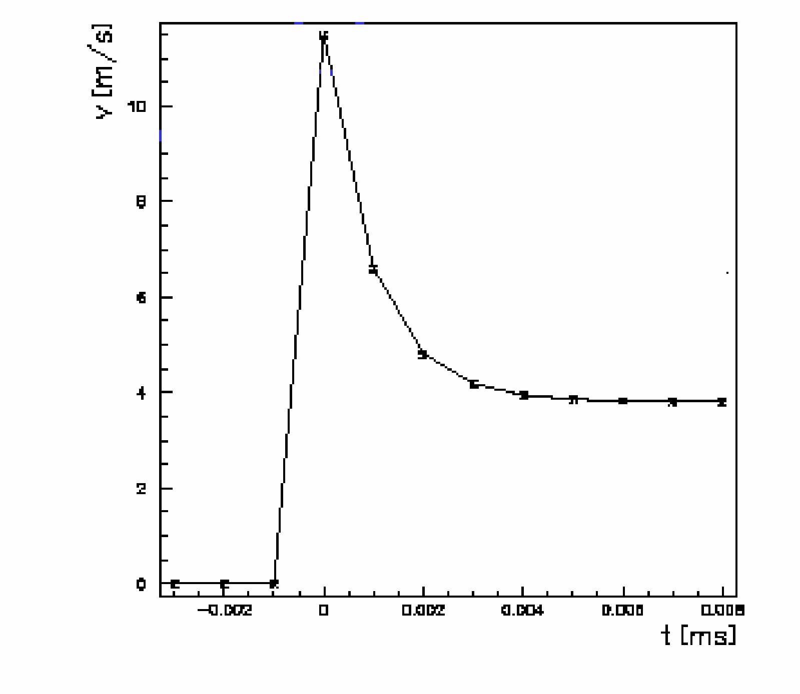
Conclusions: mercury jet simulations

- The one-phase stiffened polytropic EOS for liquid led to much shorter time scale dynamics and did not reproduce experimental results at low energies.
- The multiple reflections of shock/rarefaction waves from the jet surfaces and a series of Richtmyer-Meshkov type instabilities on the jet surface were obtained using of the stiffened polytropic equation of state for a one phase fluid
- Numerical experiments with the two phase EOS allowing a phase transition showed cavitation of the mercury due to strong rarefaction waves
- Application of different equations of state for modeling mercury jet in the strong magnetic field confirms stabilizing effect

Conclusions: mercury splash

• Numerical simulations show a good agreement with experimental data at early time.

• The lack of full thermodynamics in the EOS leads to some disagreements with experiments for the time evolution of the velocity during several microseconds. Can be corrected by the energy deposition.



Experimental data on the evolution of the explosion velocity (from Adrian Fabich's thesis)

• Equation of states needs additional physics (better mechanism of mass transfer, surface tension, viscosity etc.). Direct simulations and EOS based on the Rayleigh-Plesset equations will be used.

Muon Collaboration

BROOKHAVEN NATIONAL LABORATORY