# *MPM Workshop 2013*

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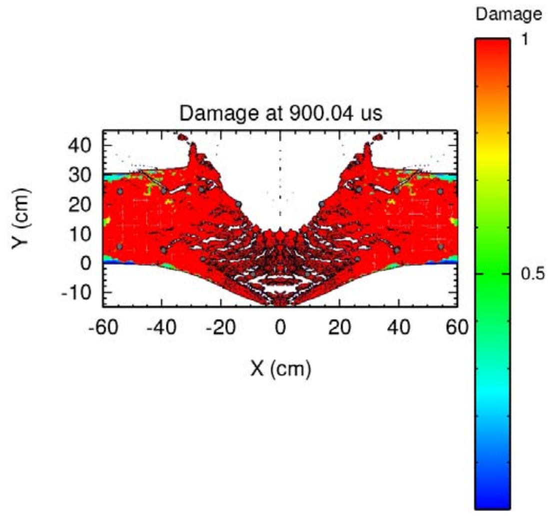
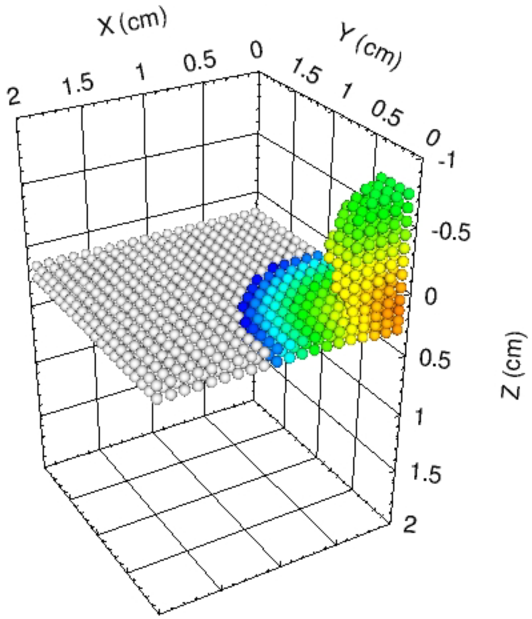
# *Project Goals*



- Add full Lagrangian capability into CTH
- Fully coupled fluid-structure interactions
  - Numerical method integrated into CTH
    - Common input between CTH and Lagrange method
  - Coupled to Adaptive Mesh Refinement (AMR)
    - Dynamic load balancing between CTH and Lagrange method
- Improve strength and failure mechanics
  - Lagrangian fracture mechanics
  - Reduce advection errors in damage and failure
- Fast, Robust and Easy to use

# *Challenges*

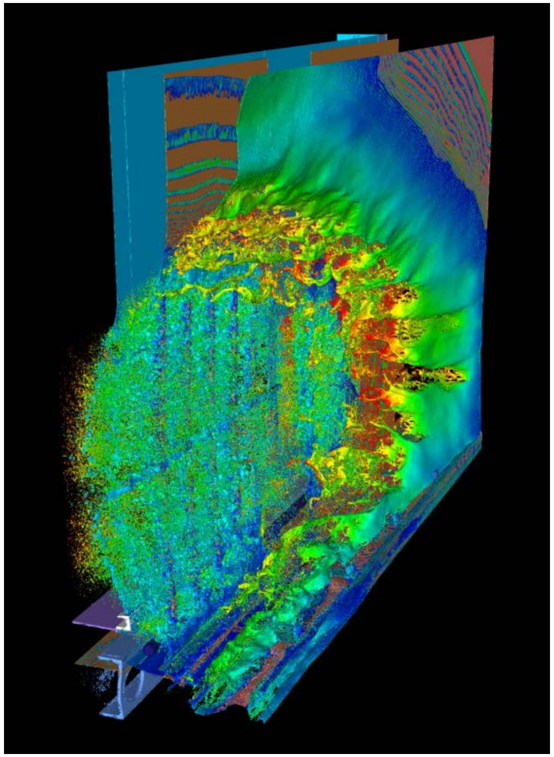
- Interface existing CTH data structure
  - Create new data structure for Lagrangian capabilities using Fortran 90
  - Interface new data structure to CTH
- Interface existing CTH models
  - EOS, strength and failure models
    - New material interface for Lagrangian materials
  - Lagrangian fracture coupled to CTH
    - Material switching and void insertion
- Visualization
  - Using Spymaster for on-the-fly and post visualization
  - Interface new data structure to Spymaster



# CTH Overview

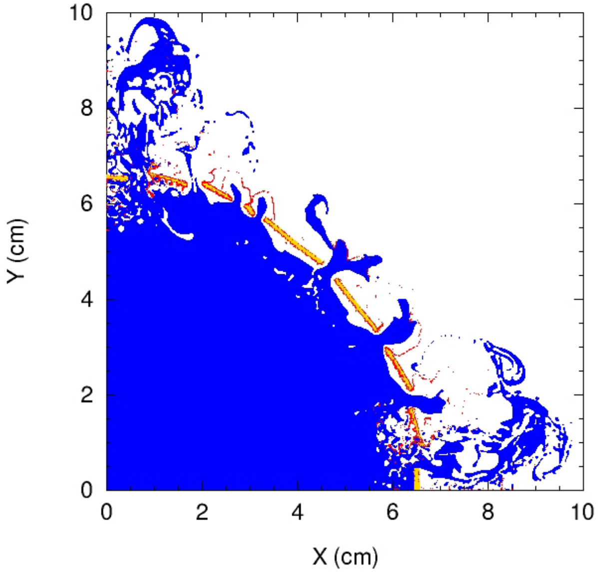
CTH is a massively-parallel shock-physics code.

- Eulerian shock wave physics computer code solving conservation equations of mass, momentum, and energy for up to 98 simultaneous materials including gases, fluids, solids, and reactive materials
  - Analytic & Tabular Equation-of-State representations
  - Advanced Strength & Fracture models
  - Adaptive Mesh Refinement
- Applications (partial list):
  - National Missile Defense (NMD), Nuclear Emergency Response (NEST), Weapon effects & vulnerability
  - Armor, Anti-Armor, Munitions Design, Blast Effects
  - Planetary Science, Asteroid Impact & Planetary Defense
- CTH licensed to hundreds of external DOE & DoD agencies and their subcontractors
  - 600+ users



32,000 processor Cielo calculation showing nearby blast on aluminum and steel structure

# *Fluid-Structure Interaction*



- Applications
  - Blast on target
  - Ballistics
  - Biomechanics
  - Damage and failure mechanics
- History
  - Charles S. Peskin
    - Immersed boundary method Heart valve modeling
  - Los Alamos National Lab (LANL)
    - Notables: F. Harlow, J.U. Brackbill, H.M. Ruppel, B.A. Kashiwa, R.M. Rauenzahn, M.W. Lewis and D. Zhang
  - Sandia National Laboratories (SNL)
    - Notables: S. W. Attaway, G. C. Bessette, D. A. Crawford, R. L. Bell

# *Lagrangian Numerical Method to Use?*

- Finite Element versus Particles
- Long history of both methods being used for Lagrangian Numerics
  - Los Alamos National Laboratories
    - Many projects over the past 50+ years looking at coupling methods
    - Finite element versus finite volume versus particles
  - Los Alamos National Laboratories – Particle-In-Cell (PIC)
  - Los Alamos National Laboratories – Fluid Implicit Particle (FLIP)
  - Sandia National Laboratories – Zapotec (1998)
  - Sandia National Laboratories – Fortissimo (2008)
  - Sandia National Laboratories – Zapotec II (2011)

    Eulerian/Lagrangian coupling using separate codes
  - NAVSEA - DYSMAS (DYNA-GEMINI)
  - Others, Material Point Method, Smooth Particle Hydrodynamics, etc.
- Mesh objects versus material insertion
- Adaptability to future numerical methods in Hydrodynamics

# Choice: Particles (Markers) Why?

- Material Point Method (MPM) and material tracking
  - MPM (Sulsky, D., Chen Z. and Schreyer, H. L.)
  - Both use structured background grid for gradient computations (no neighbor searching)
- History of working well in a finite volume shock hydrocode
  - Challenges in finite elements in a finite volume
  - Integration into a finite volume numerical framework by Bryan Kashiwa at Los Alamos National Laboratory
- Next generation failure mechanics
  - No element boundaries
  - Lagrangian fracture mechanics in a finite volume shock code
- No unstructured meshing
- Massively parallel
  - Dynamic load balancing based on marker count on processors
- Adaptive Mesh Refinement
  - Marker combining and splitting

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# *Marker Methods*

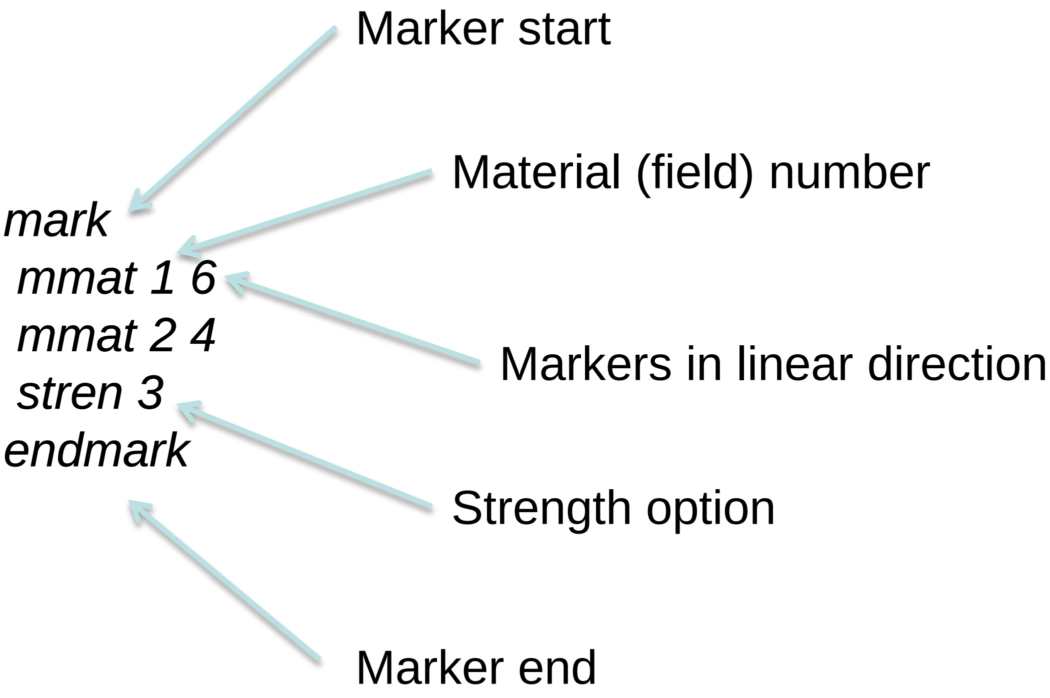
- 1D, 2D and 3D
- Interface into existing material insertion capability in CTH
  - Diatom insertion of marker fields
- Strength
  - Track material behavior through grid to marker differences (Material tracking)
  - Compute stress and accelerations on markers and update to grid (MPM)
- Boundary Conditions
  - Symmetric, outflow, inflow and outflow
- Failure
  - Material switch from shear supporting to hydrodynamic
  - Void insertion based on marker failure
  - No failure
- Massively parallel marker capability with/without AMR
  - Ghost markers
  - Combining and splitting
- All existing CTH material models have been integrated
  - All EOS models
  - Full stress tensor or deviatoric tensor options (except GEFFS and PSDAM)
  - All failure models

# *Marker Methods – cont.*

- Composite model integration with markers
  - Initializing marker with material direction using existing layering techniques
  - Separate strain rates for markers in layers
  - With multifield can track layer interaction for delamination and other failure processes
- Plate, shell and beam theories added to CTH
  - Implemented existing plate theory from Los Alamos National Laboratory
  - Working with Los Alamos National Laboratory to add new shell theory
- Discard
- New mass footprint of marker fields
  - Second order accurate and sharp object interfaces
- New material models
  - Full-stress tensor with MPM
  - Integration of deformation tensor
  - Hyperelastic Models
    - Mooney-Rivlin
    - Transverse-Isotopic Mooney Rivlin
  - Stochastic models
    - Research on stochastic energetic ignition models

# *Using Markers*

- Sample Input:



```
mark
 mmat 1 6
 mmat 2 4
 stren 3
endmark
```

Marker start

Material (field) number

Markers in linear direction

Strength option

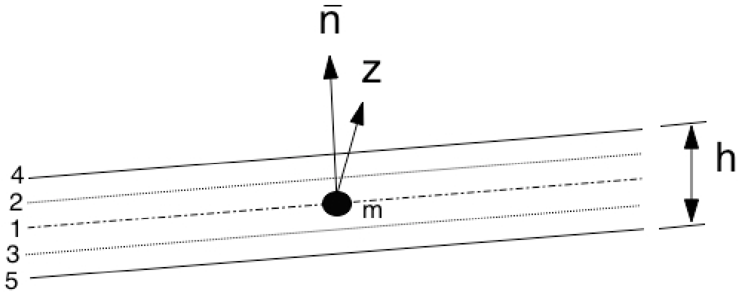
Marker end

# Using Markers
# Select Options

- Strength options
  - Material tracking (stren 1)
  - Material Point Method (MPM)  (stren 3)
- Energy options
  - Irreversible energy only (senrg 1)
    - Add only irreversible energy from stress power
  - Total energy, classical CTH, (senrg 2)
    - Total and irreversible energy from stress power
    - Controlled release of energy during fracture (reversible)
- Failure options
  - No failure (fail 10)
  - Reduce deviatoric stress (fail 2)
  - Field switching (fail 1)
    - Marker (fmat 0) or CTH type material (fmat 1)

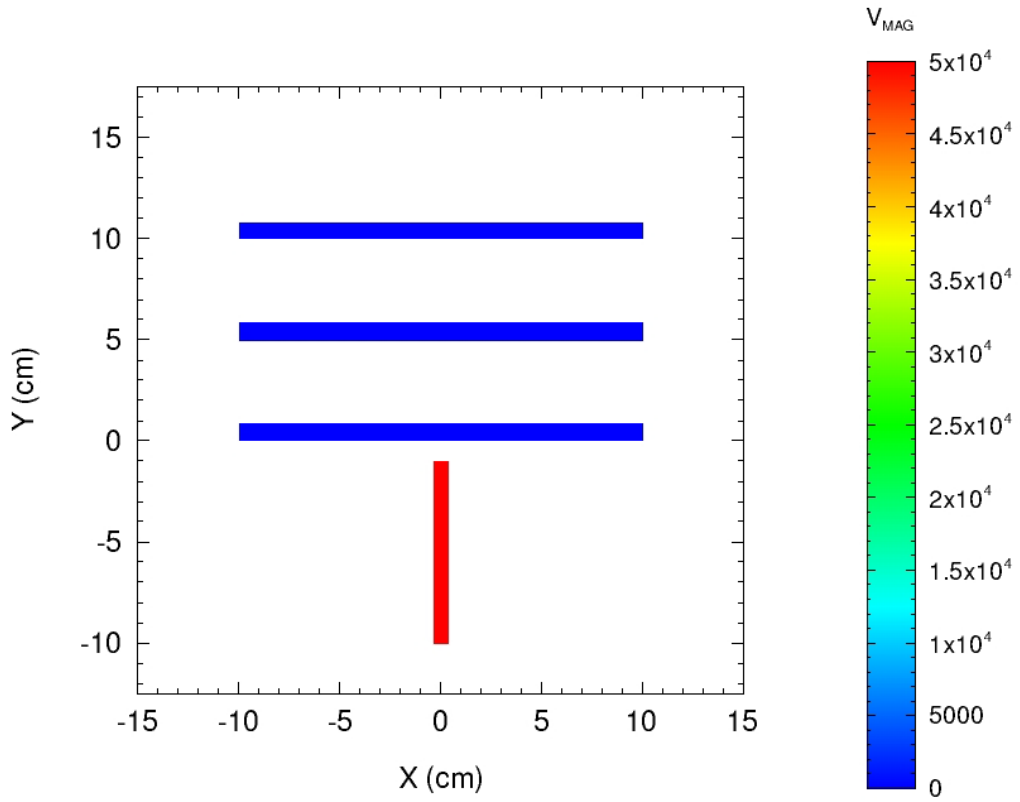
# *Using Markers*
# *Select Options cont.*

- Split and Combine
  - Momentum conserving techniques
  - AMR or non-AMR problems
  - Set limit number of markers in one cell to combine (mcomb #)
  - Set lower limit number of markers in one cell to split (msplit #)
- Plates, shells and beams
  - Plate option from LANL
  - Set by field (mplate “field #” “h” “integration”)
  - Shells and beams to be added in the future

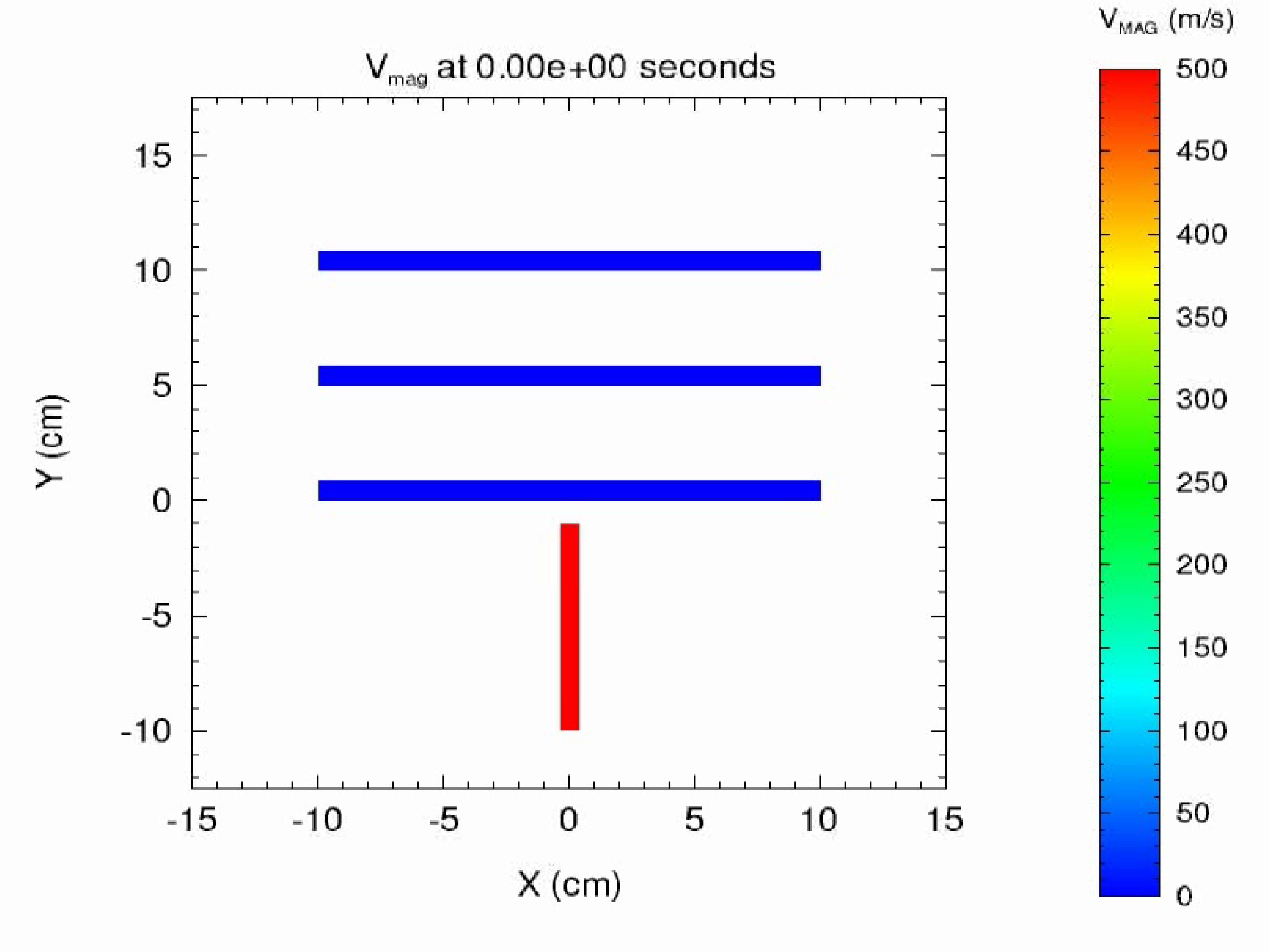


# *Triple Plate*

- Two-dimensional cylindrical
- Rod impacting flat plates
- Velocity is 500 m/s



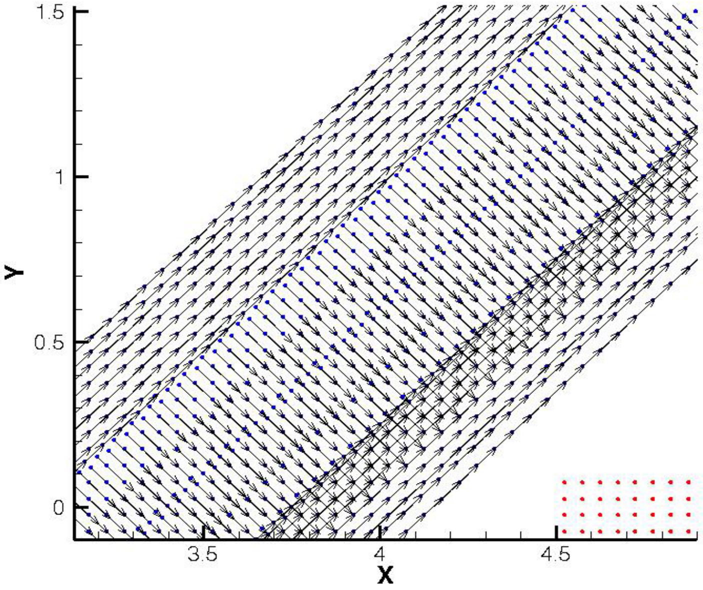
# *Triple Plate*

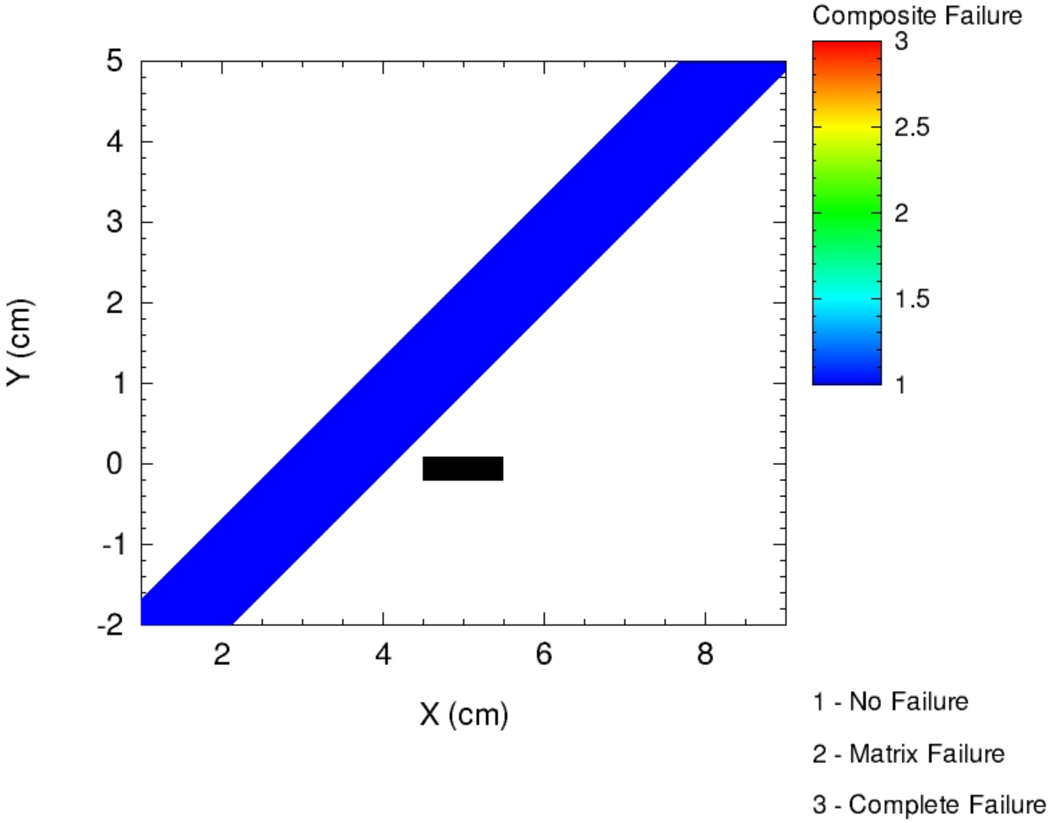


# *Oblique Composite Plate*

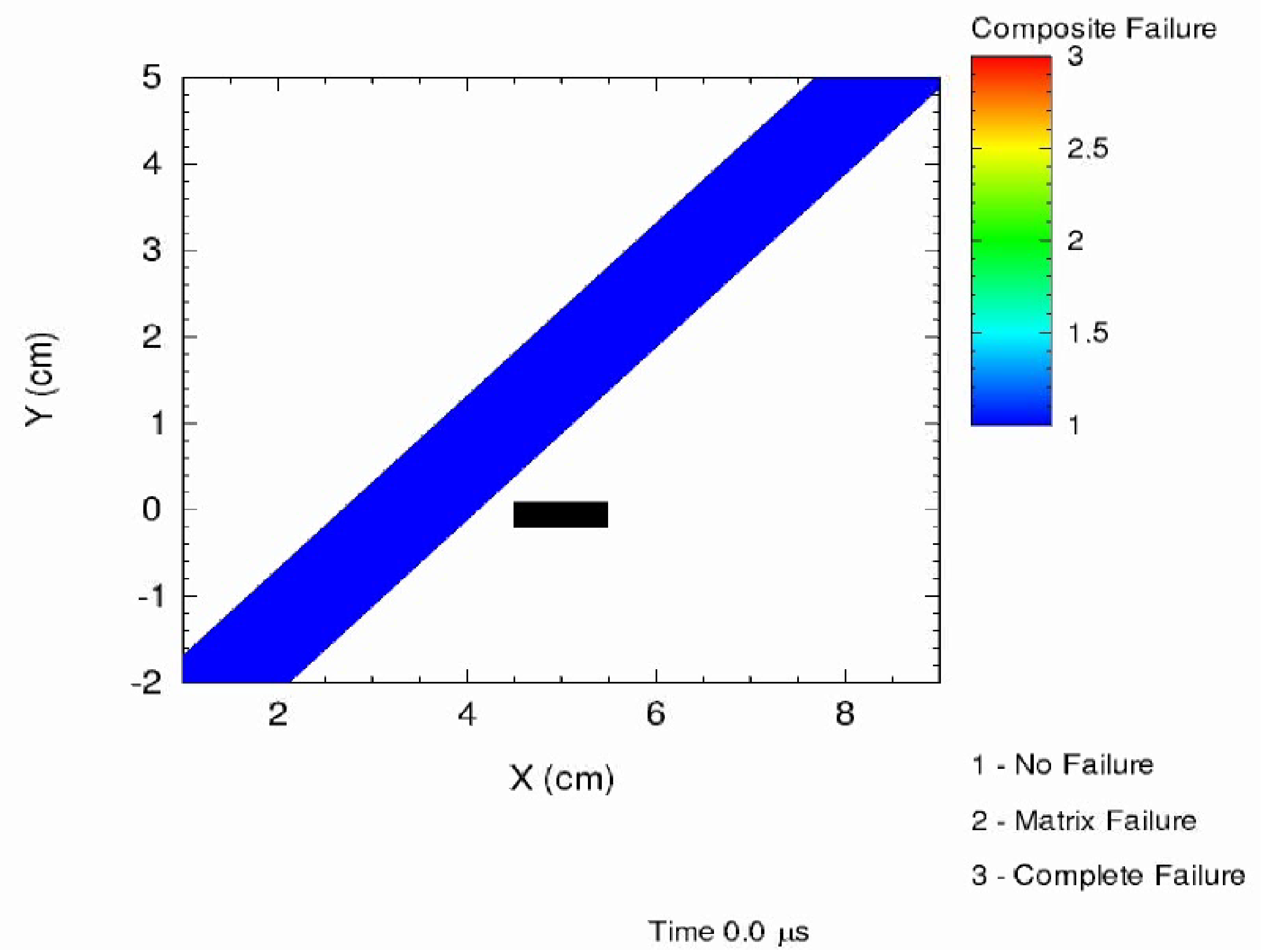
- Two dimensional rectangular
- Thin metal projectile
- Velocity of 100 m/s
- Composite
  - [0° ,90° ,90° ,0° ]

Material Vector Plot



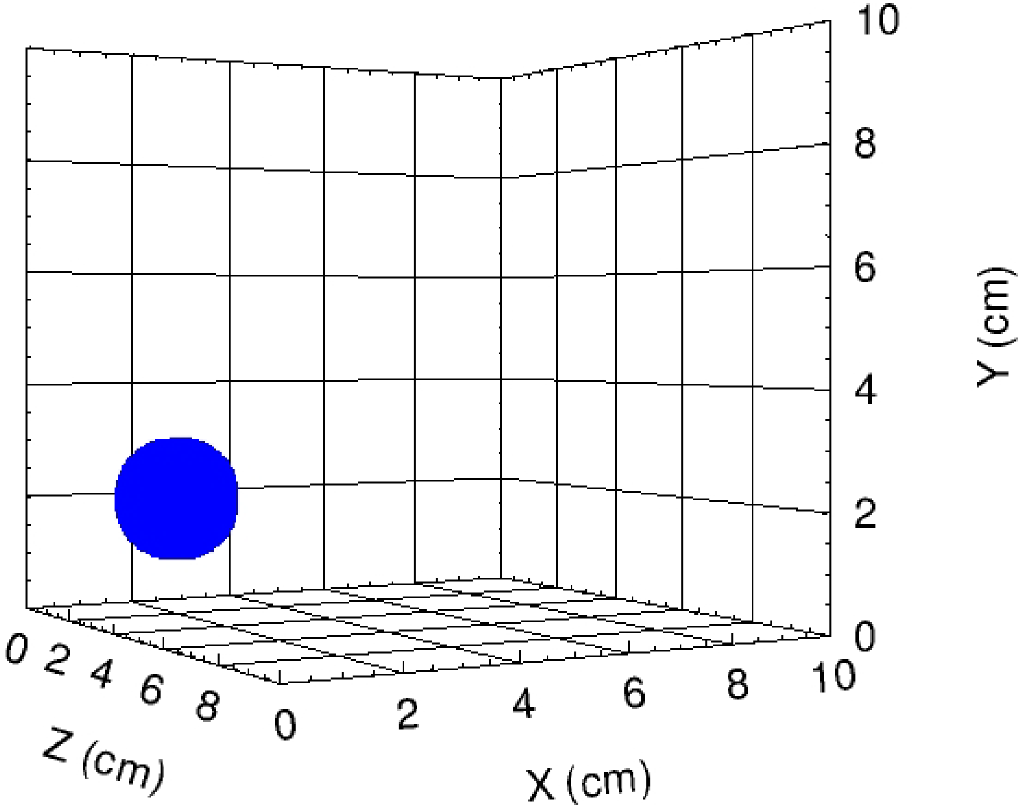


# *Oblique Composite Plate*

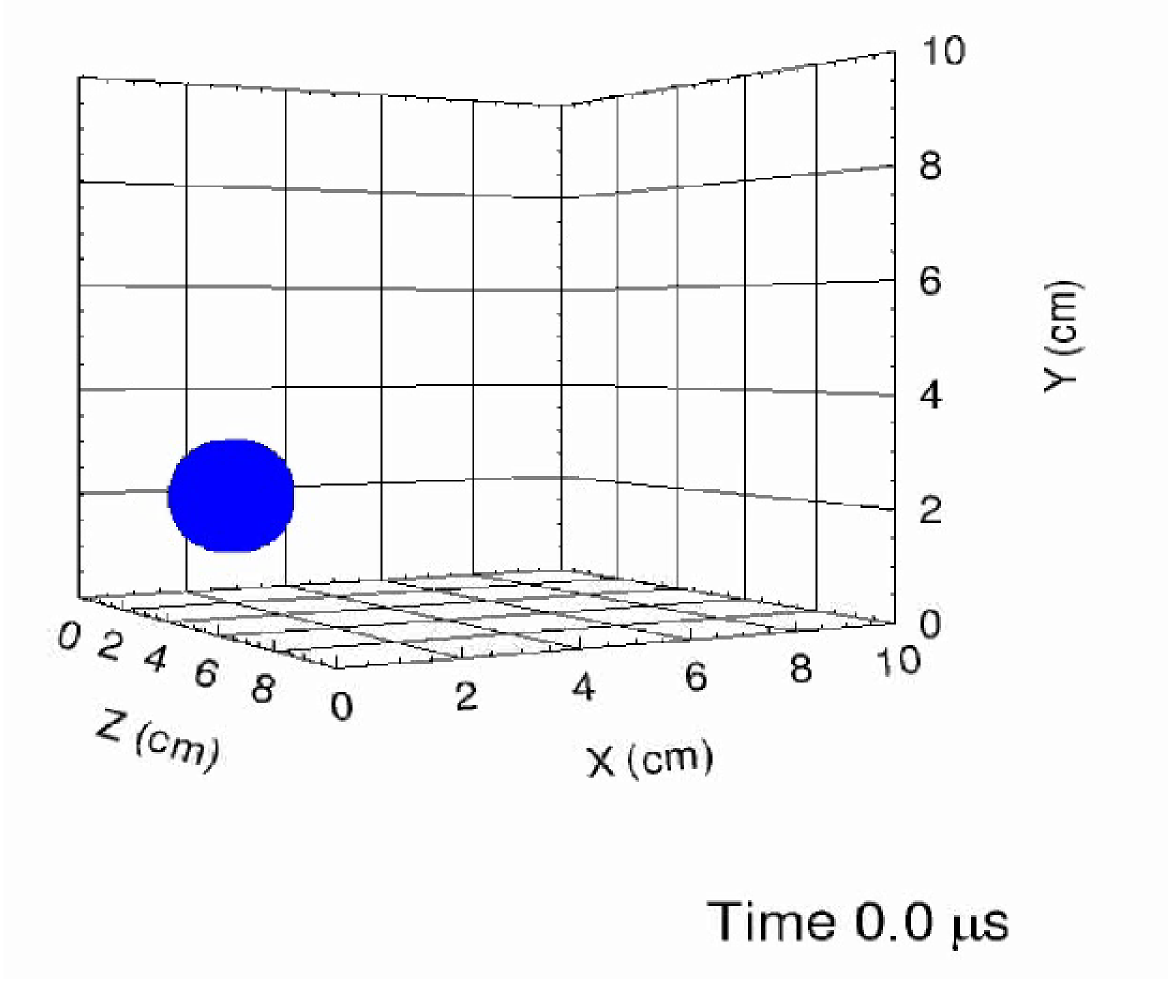


# *Elastic Ball*

- Three dimensional rectangular
- Elastic ball
- Velocity 500 m/s



# Elastic Ball

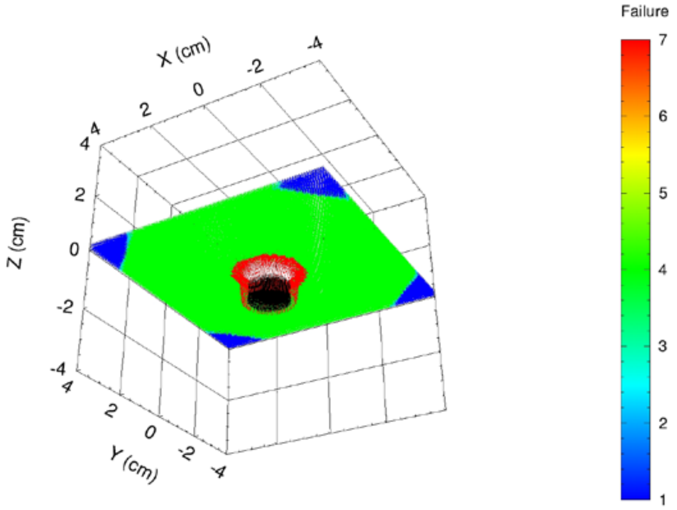


# *Future Directions*

- Thin structure mechanics
  - Shock support method for membranes/shells
- Integration of Convective Particle Domain Insertion (CPDI)
  - University of Utah collaboration
    - Summer student Michael Homel and Rebecca Brannon
  - Technique developed to expand a marker domain based on deformation
- Implicit Continuous Eulerian (ICE++)
- Multifield
  - Multiple velocities for each field (material) in a finite volume
  - Momentum, energy and mass interactions
- New material models
  - Fracture and failure
  - Non-linear elasticity in shock
  - Stochastic fields

# Conclusions

- Beta release of Markers in CTH version 11.0
  - March 2013
  - User manual
- Full Lagrangian method coupled into CTH
  - Reduce advection errors
  - Failure mechanics
  - Framework for new constitutive models
    - Hyperelastic constitutive models
- Marker options
  - Strength
  - Failure
  - Energy



Failure Plot at 15.1 μs

- Robust and easy to use technique for modeling fluid-structure interaction
  - No unstructured meshing
  - Fully coupled
  - Common “look and feel” input
  - Quick “total time-to-solution”

# *Questions?*