HiRadMat Beryllium Thermal-Shock Test

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CERN's HiRadMat Facility

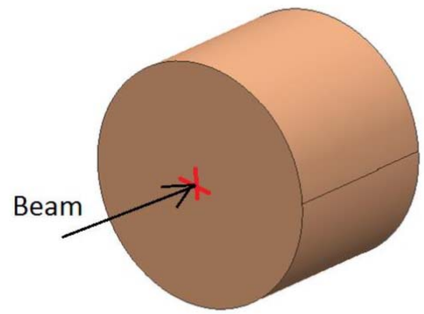
- Provides high-intensity pulsed beam where material samples can be tested (4.9e13 ppp)
- Short pulse lengths suited for thermal shock tests (7.2 μs)

Objectives

- Collaboration with RAL HPTG
- Fracture Beryllium with one or multiple beam pulses
- Experimentally deduce the onset of plastic deformation
- Benchmark numerical simulations currently based on scarce literature data
- Potential post irradiation analysis

Conceptual test design

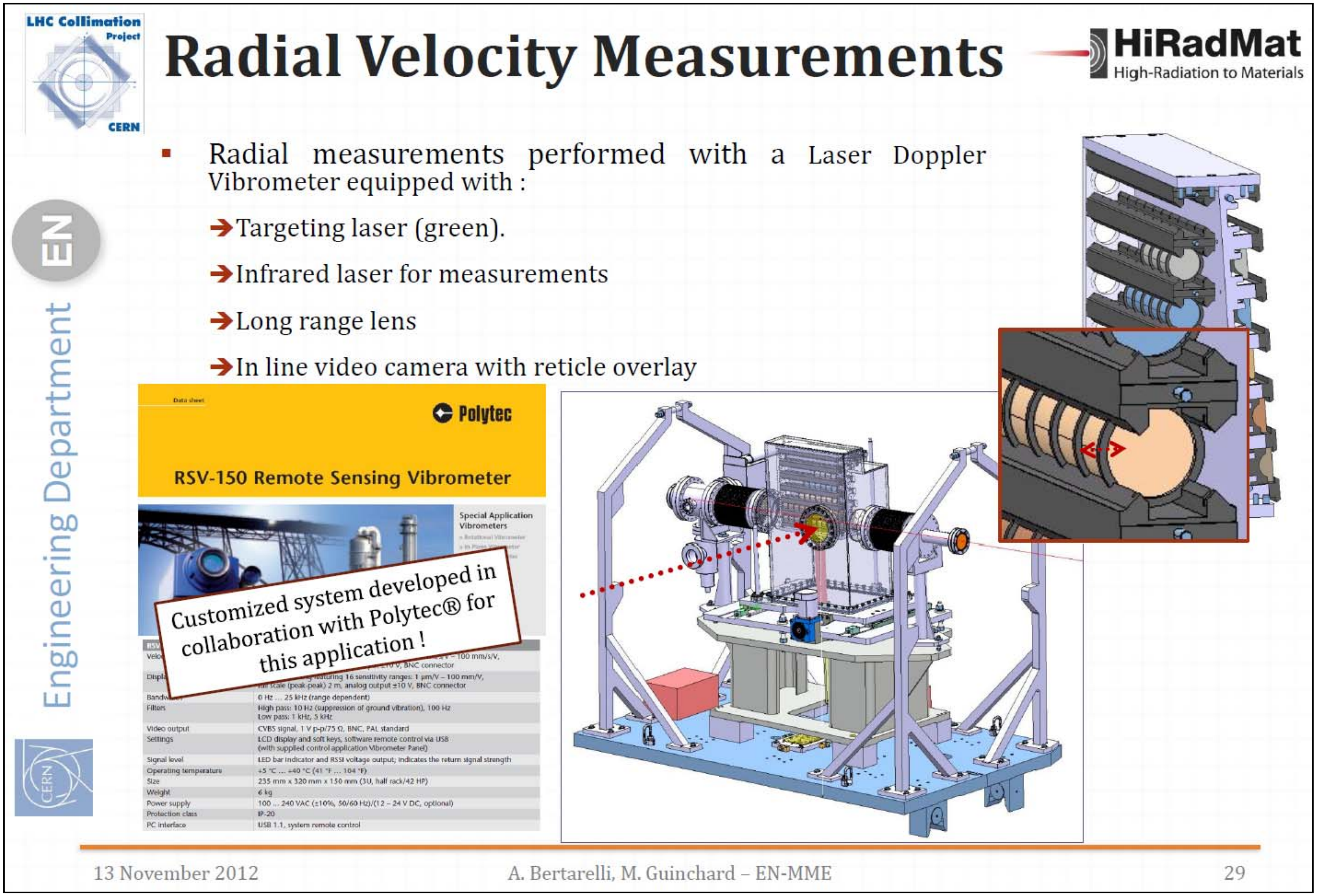
Fall 2014?



- Thick/thin Be specimens
- Incident beam at different radial locations
- One or multiple beam pulses per specimen

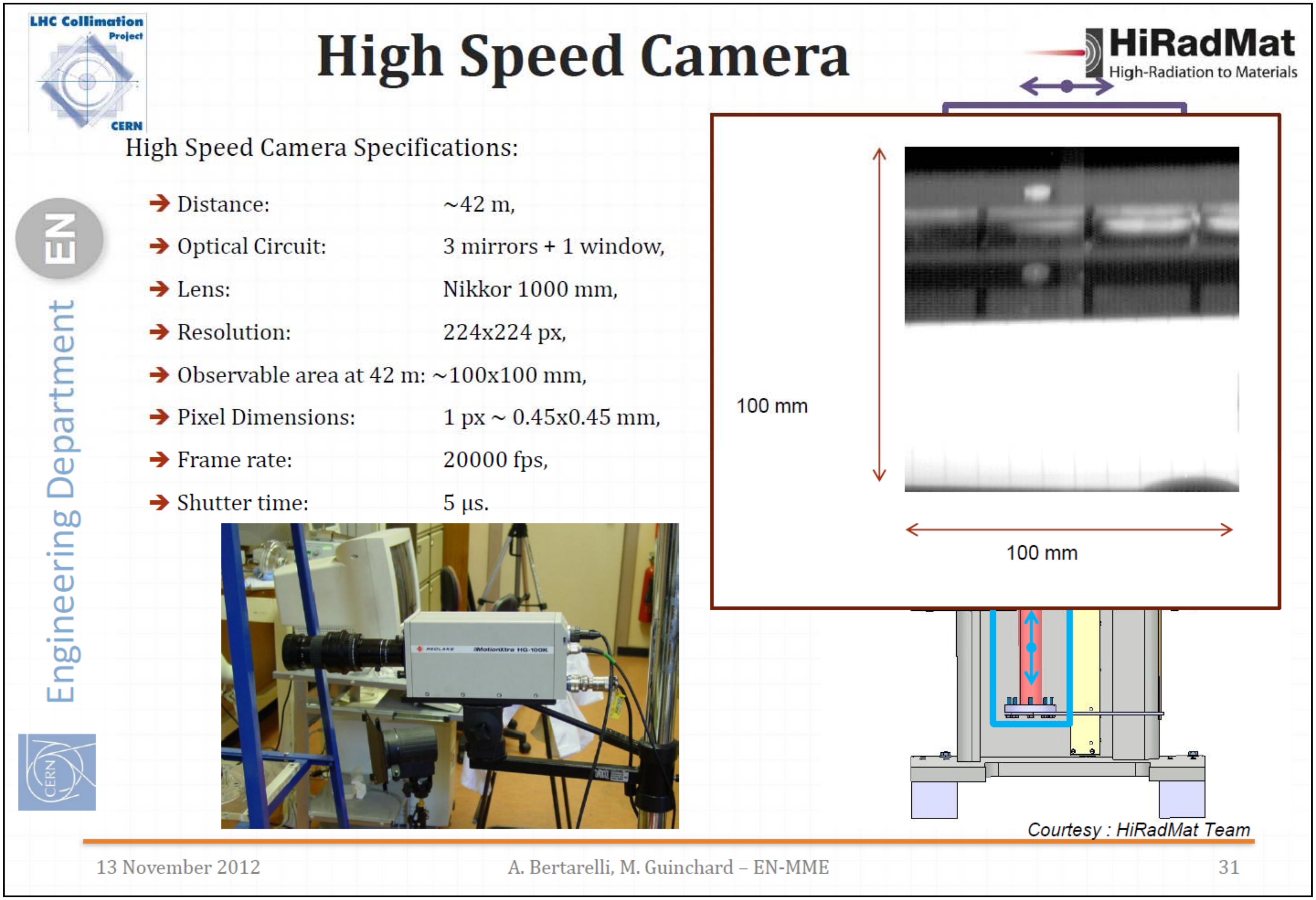
- Measurements
  - Radial vibrations - Laser Doppler Vibrometer (LDV)
  - Image fracture – High speed camera

HRMT-14 experiment



Bertarelli, A and Guinchard, M., 'An overview of HiRadMat experiment on collimator materials', CERN Engineering Department Technical Meeting (ENTM), 13 Nov 2012.

HRMT-14 experiment



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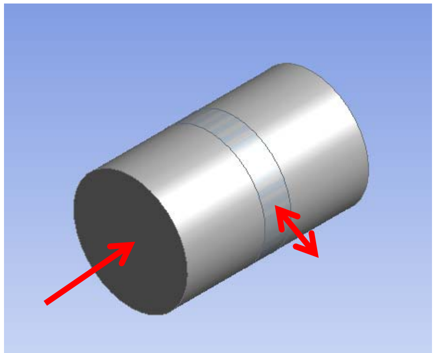
ANSYS numerical simulations

HiRadMat maximum intensity beam parameters:

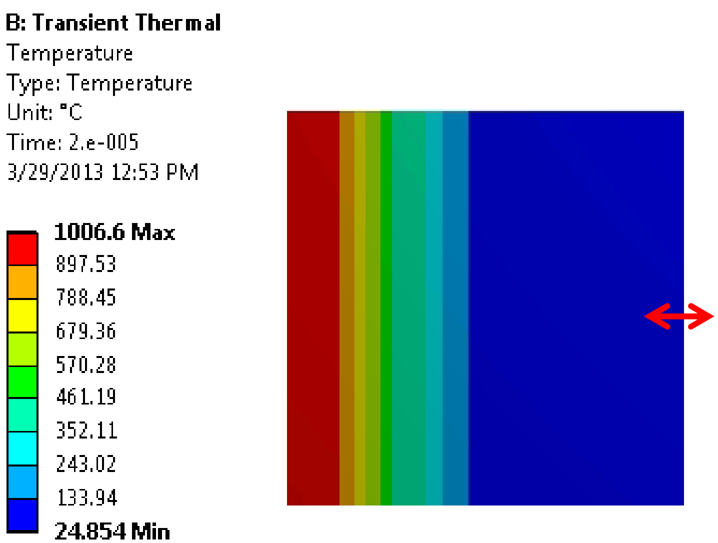
- Beam energy: 440 GeV
- Bunch intensity: 1.7e11 protons
- Number of bunches: 288
- Maximum pulse intensity: 4.9e13 protons
- Pulse length: 7.2 µs
- σ_{rms}= 1 mm

- Scaled MARS energy deposition up to 10 times to obtain peak temperatures close to melting (~ 1100 °C)

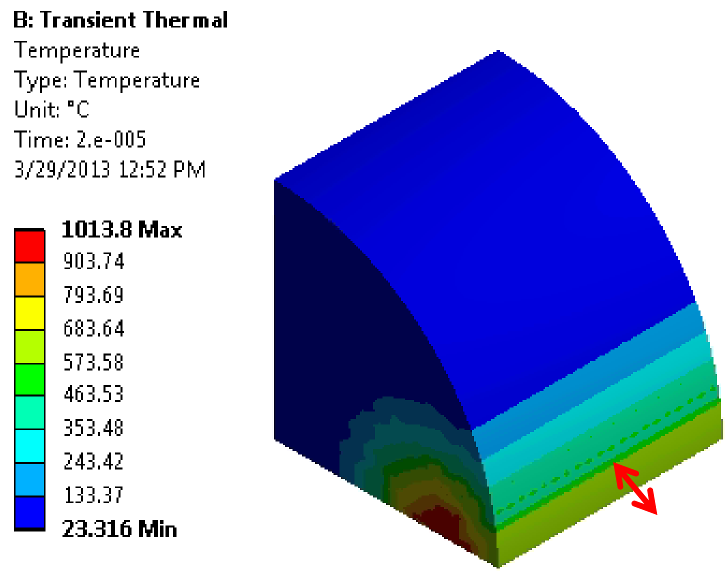


- Radial displacements resulting from 1 beam pulse
- Radius: 5 mm
- Elastic and bilinear kinematic plastic material model

- Axisymmetric model
- Incident beam at r/R = 0

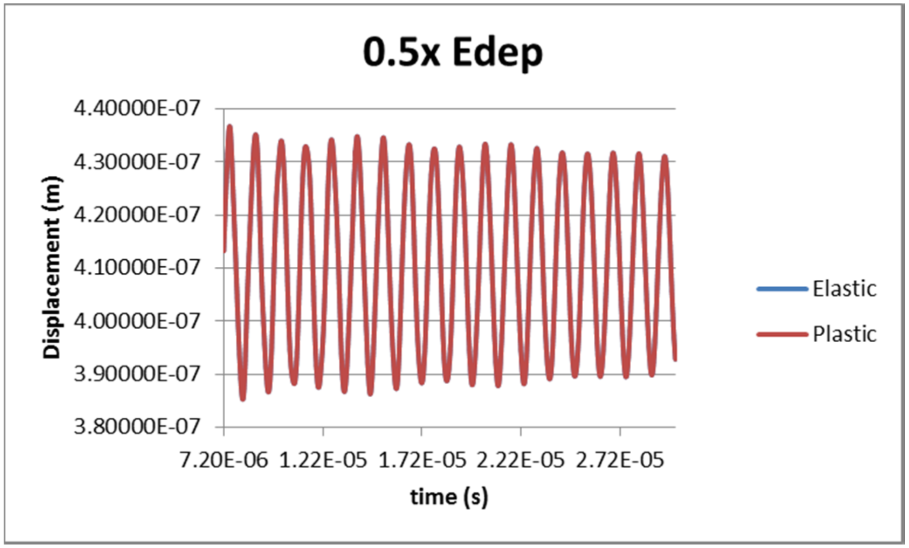


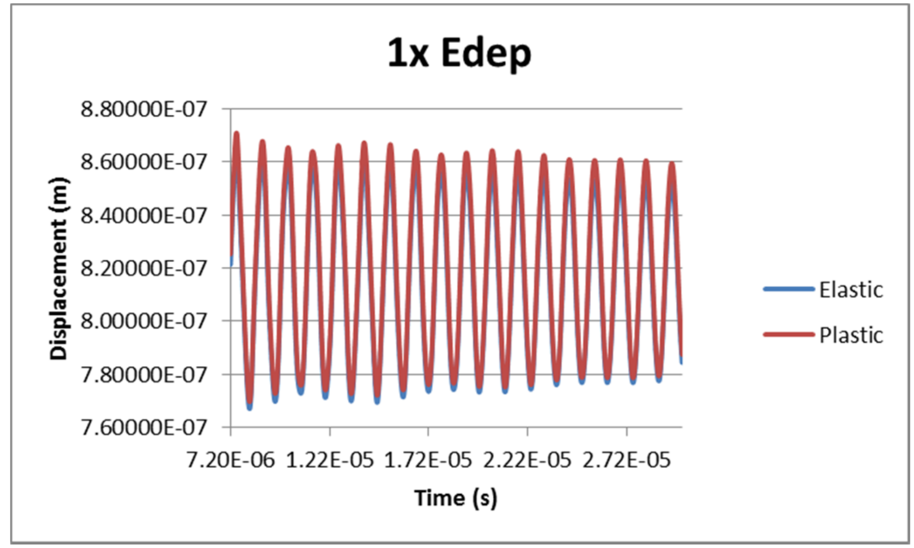
- 3D model
- Incident beam at r/R = 0.5 & 0.75

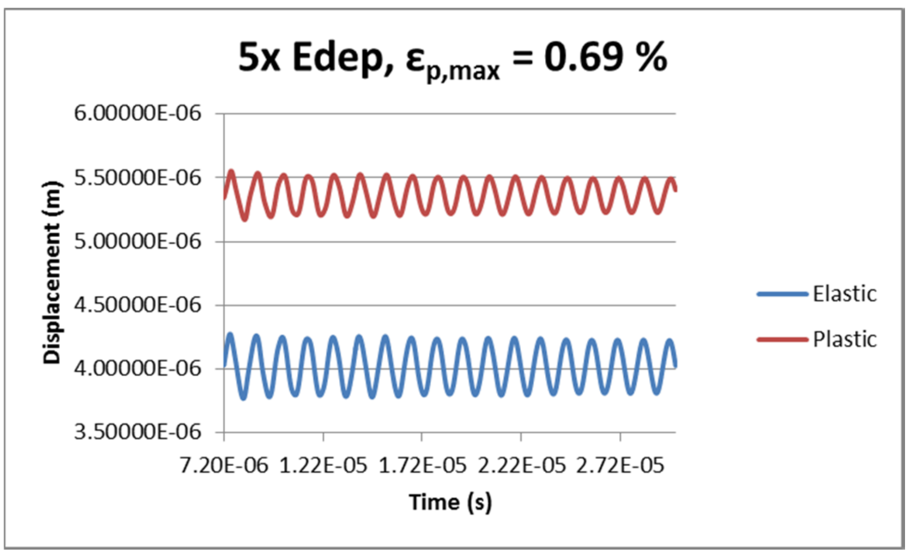


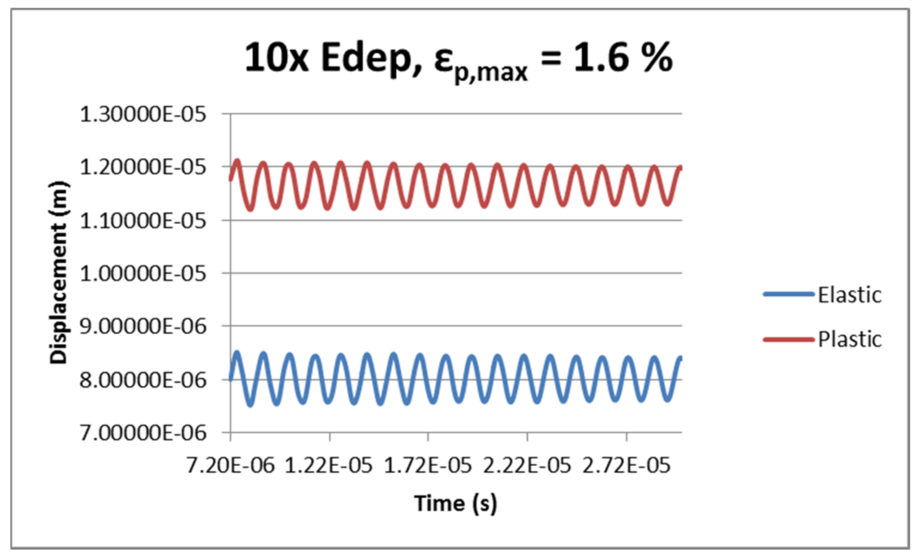
- Radial displacements at window edge

Displacements - beam at r/R = 0



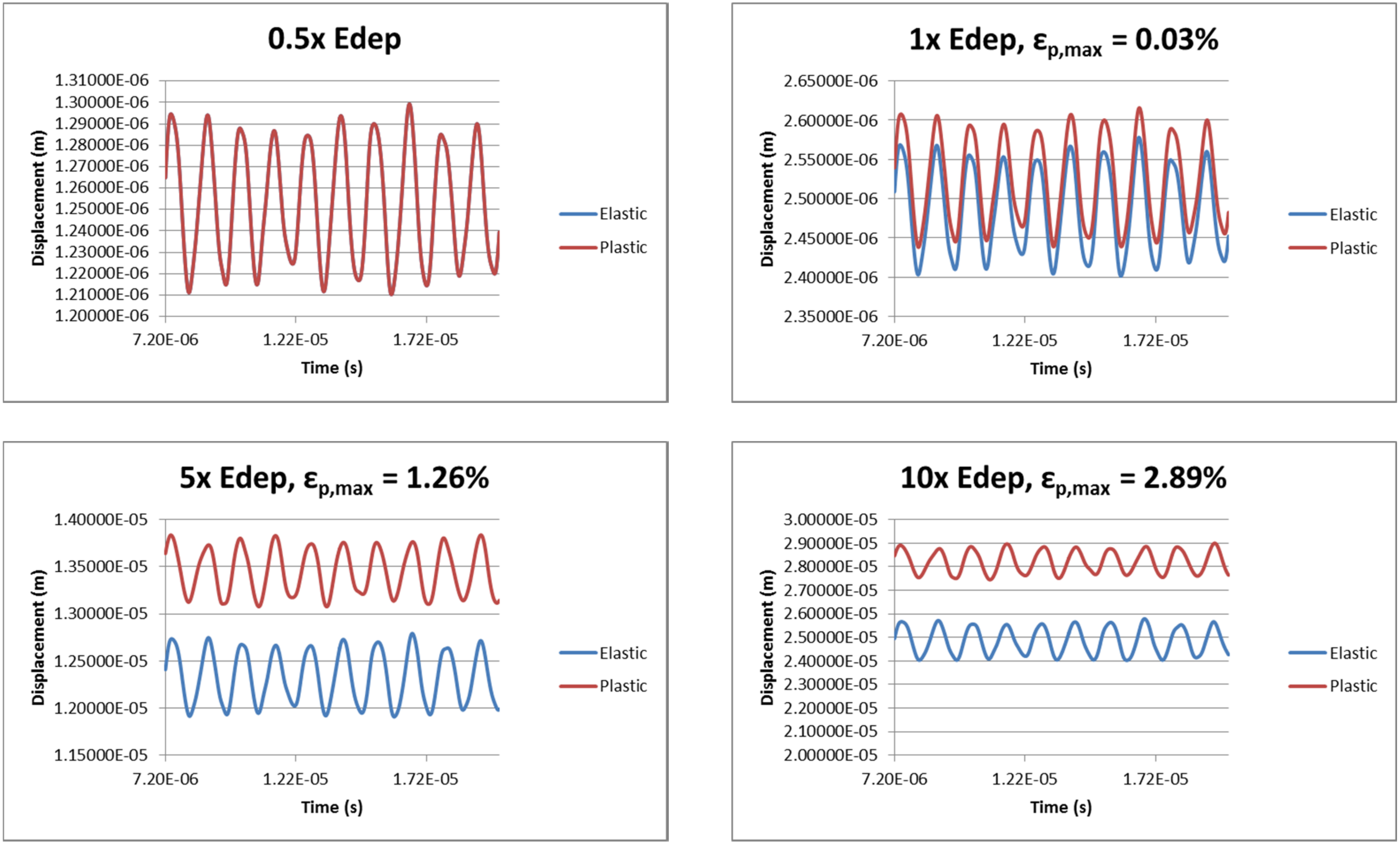






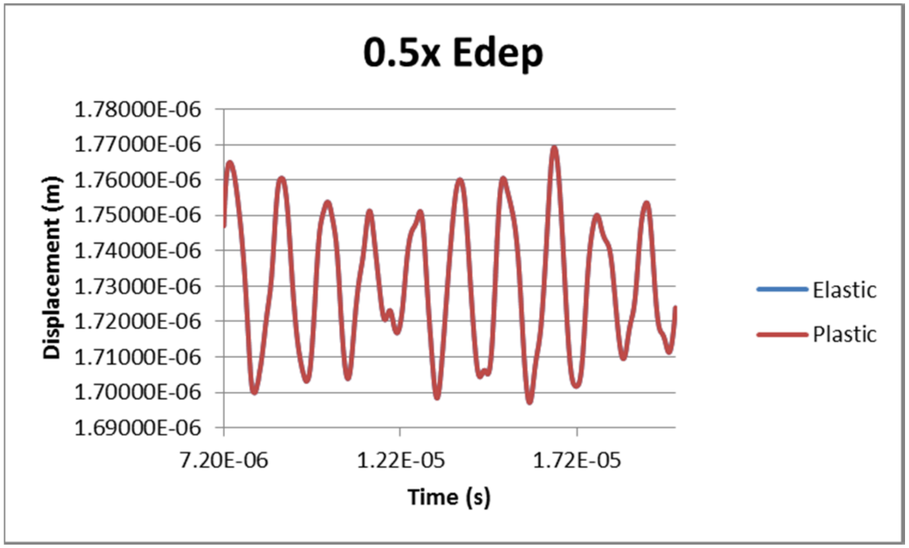
- Frequency ~ 0.75 MHz

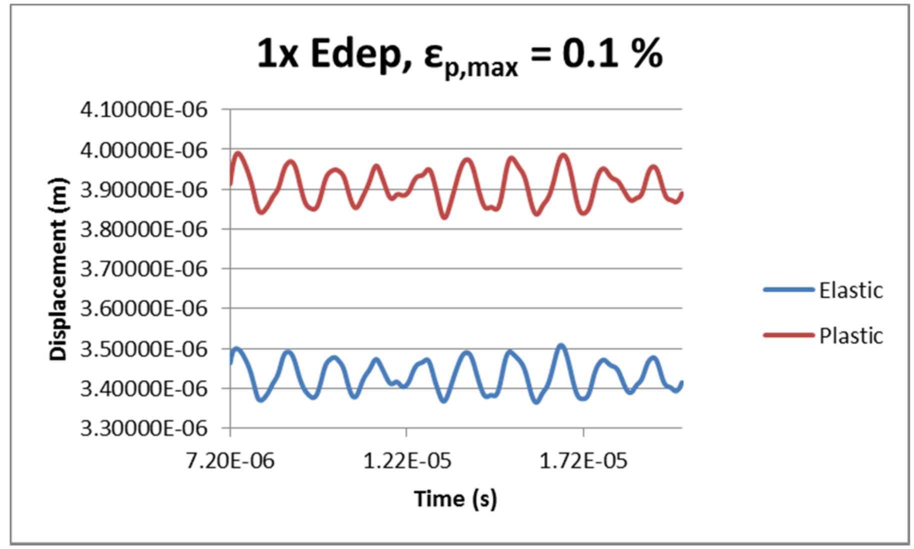
Displacements - beam at r/R = 0.5

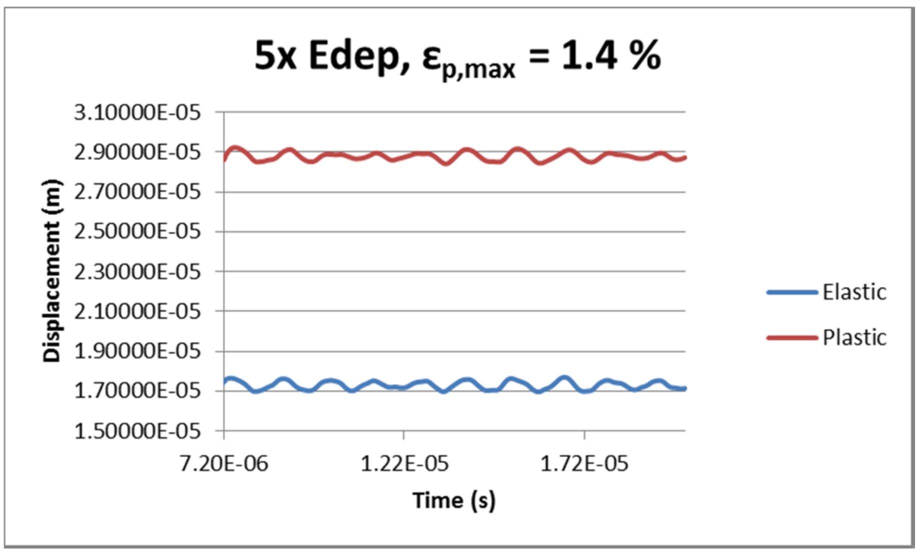


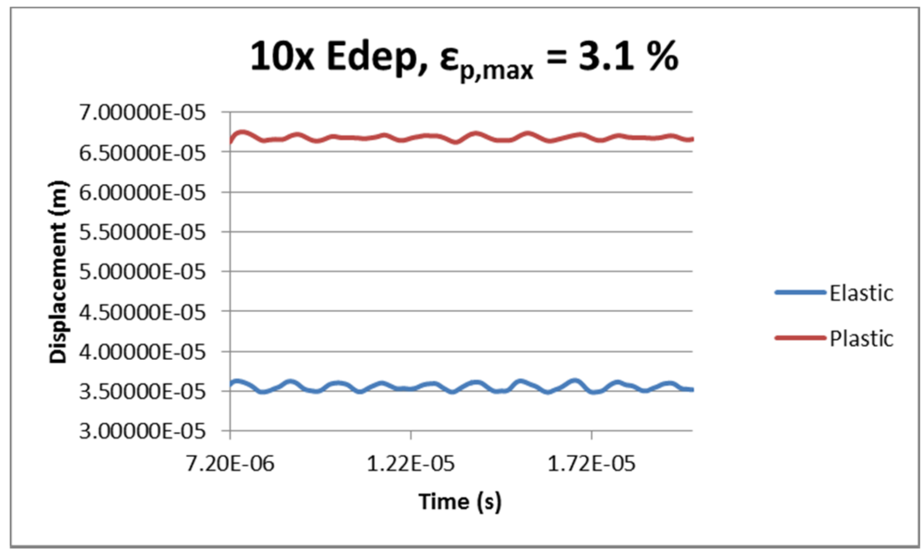
- Maximum plastic strain at window edge

Displacements - beam at r/R = 0.75





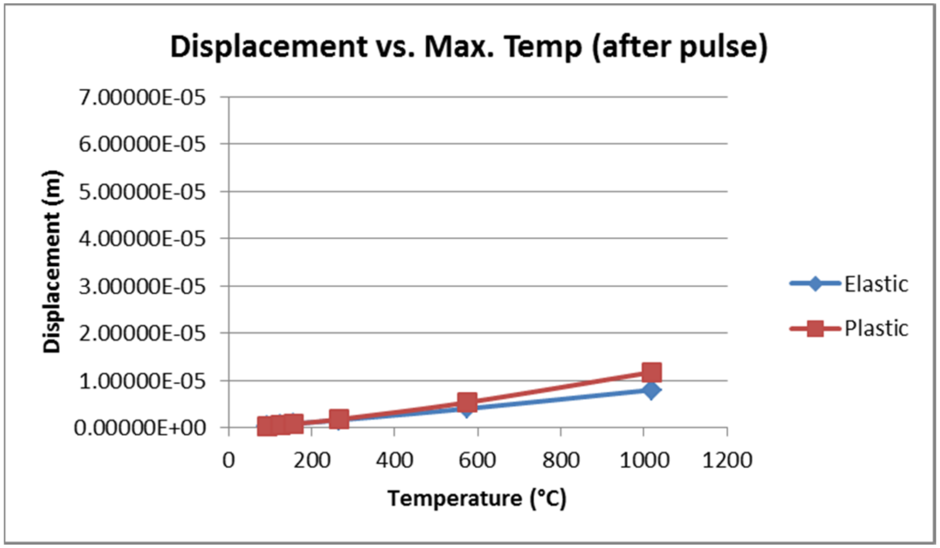




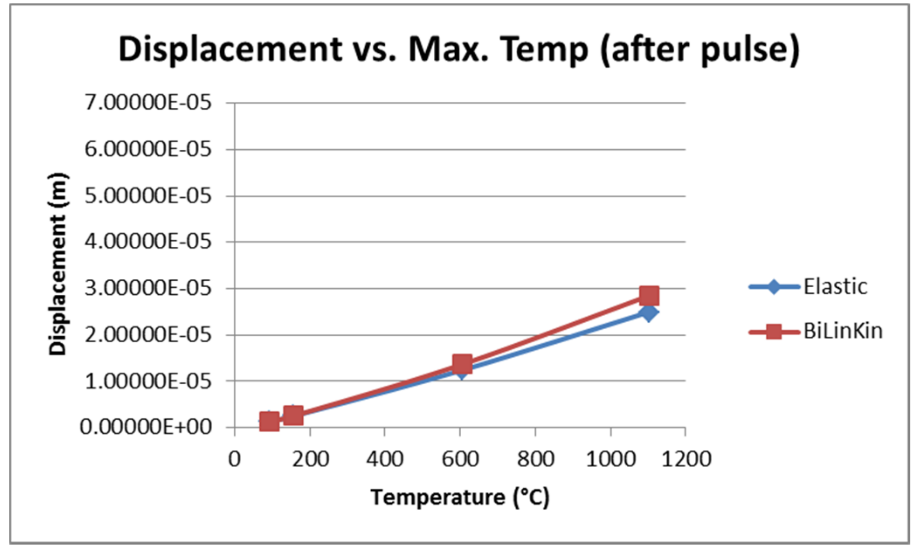
- Maximum plastic strain at window edge

Maximum displacement as a function of Edep (Tmax)

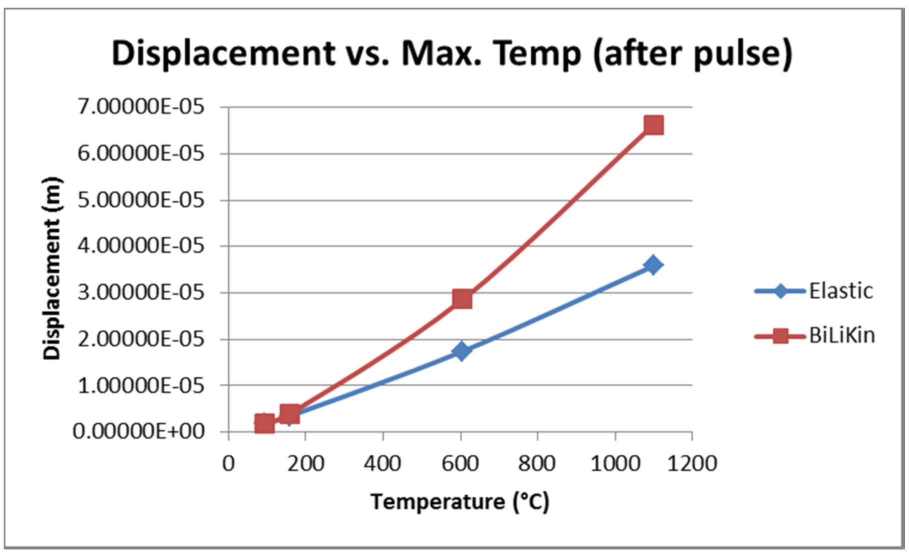
r/R = 0



r/R = 0.5



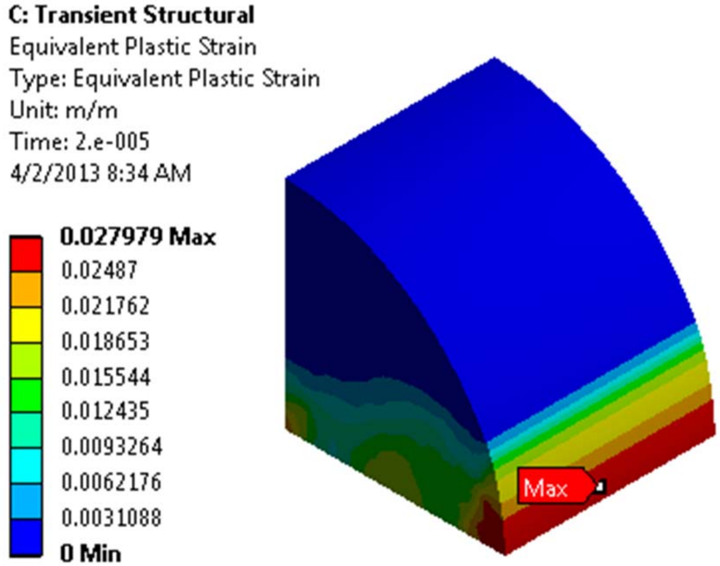
r/R = 0.75

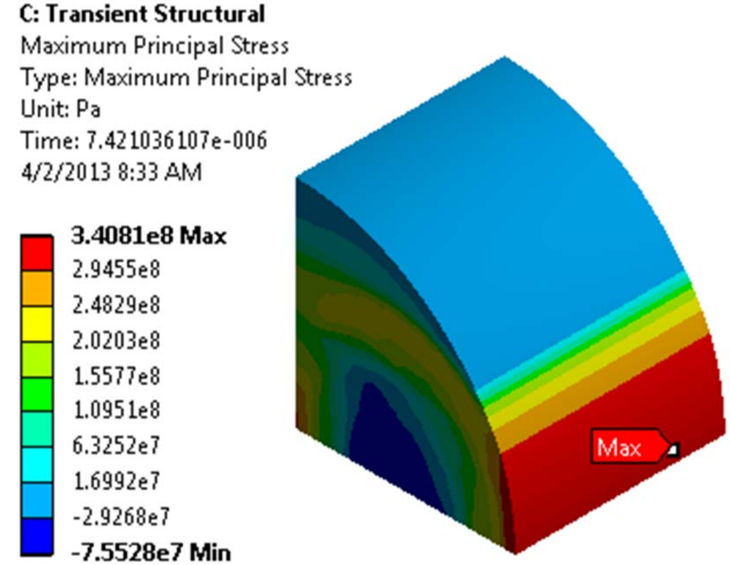


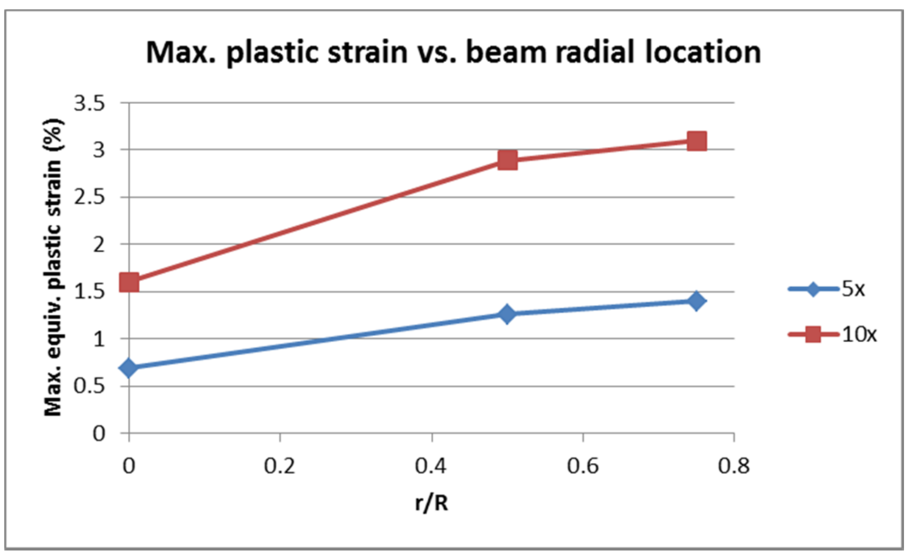
- Incident beam at r/R = 0.75 shows largest deviation in displacement for elastic and plastic behavior (~ 30 µm)

Ability to crack/fracture Be?

r/R = 0.5, 10x Edep, Edge T = 120 °C







- Large enough tensile stress at window edge may initiate cracks
- 3.1% plastic strain at RT may lead to fracture
- Dependent on temperature

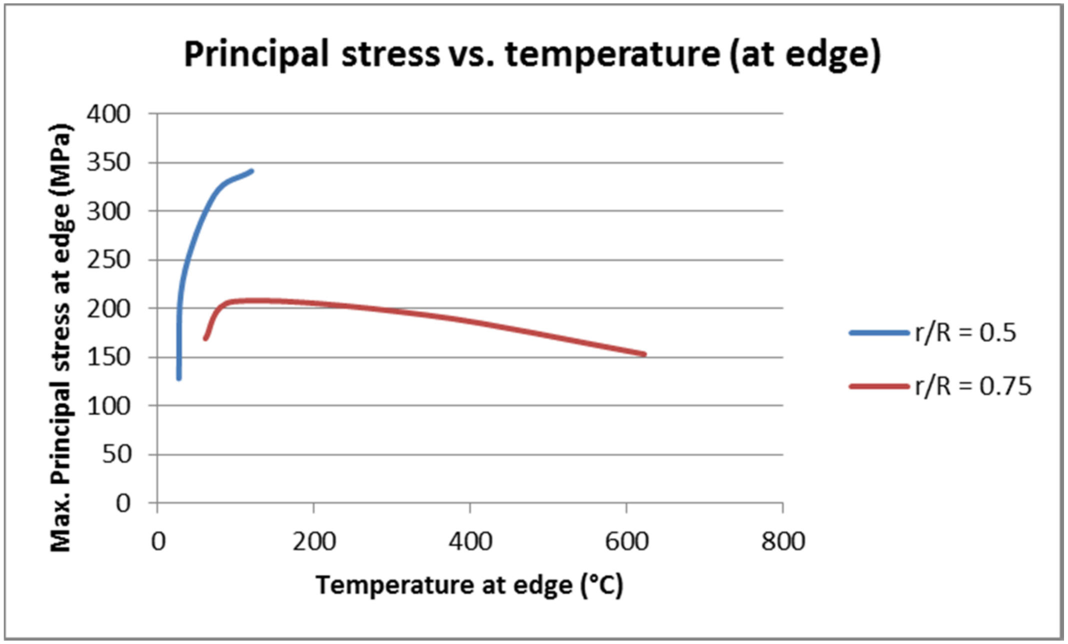
BUT…

Temperature of Be at max. equiv. plastic strain of 3.1% ~ 622 °C

$\varepsilon_{fracture}$ ~ 20 % at 600 °C

- Possibility of melting before any cracking occurs
  - Failure due to fatigue need to be investigated

Maximum principal stress at edge

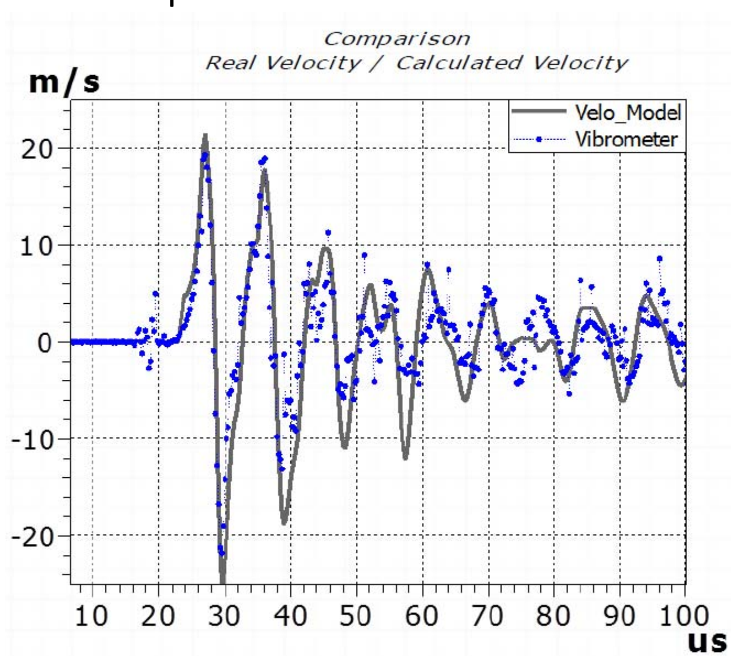


Further work

- More numerical simulations
  - Optimize specimen size and incident beam location
  - Multiple beam pulses
  - Other specimen geometries to induce larger plastic strain
- Be material properties
  - Strain rate dependency
  - Plasticity model for T > 600 °C
- Damage/fracture model using LS-DYNA/Autodyn
- Pre-cracked zone at edge of specimens?
- Further analysis for thin window tests

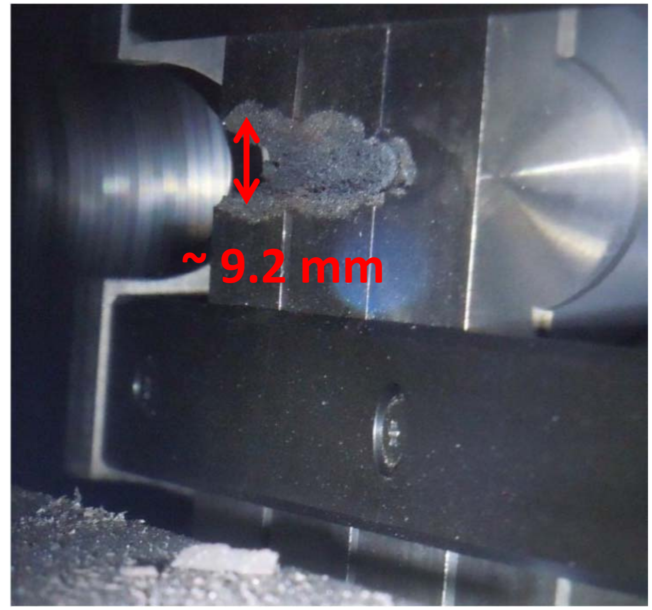
Some results from HRMT-14

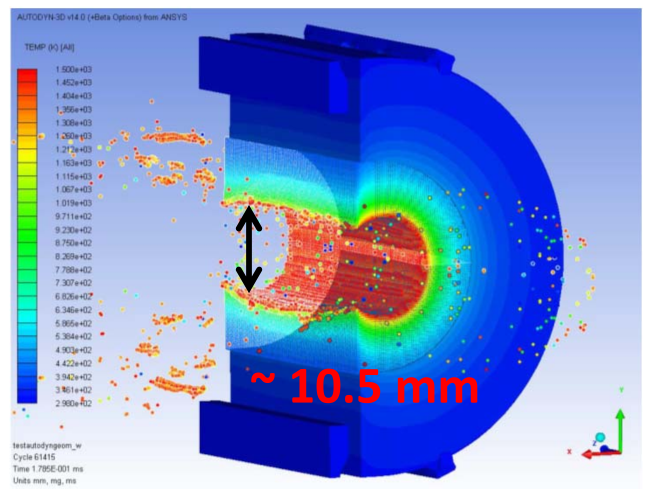
Glidcop



- LDV and high speed camera measurements fairly comparable with numerical simulations

- Goal: make similar comparisons for Beryllium





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Thank you