Beryllium Material Tests
HiRadMat windows and NOvA fins

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Motivation

Beryllium is currently widely used in various accelerator beam lines and target facilities as material for beam windows and to a lesser extent, particle production targets. With plans to increase beam intensities in future accelerator facilities, it is essential to understand the response and potential limits of beryllium in such extreme environments. It is important to experimentally identify the dynamic limits and failure mechanisms of beryllium in order to avoid compromising particle production efficiency by limiting beam parameters. Current plans include two in-beam beryllium material tests at CERN's HiRadMat test facility and at Fermilab by using the NOvA medium energy target.

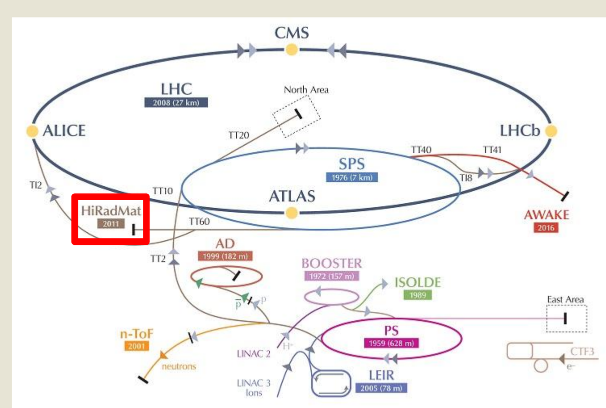
HiRadMat Beryllium Window Test

Objectives

- Explore the onset of failure modes of various Be grades/forms under controlled conditions at very high localized strain rates and temperatures
- Identify and quantify any potential thermal shock limits
- Compare measurements to highly non-linear failure simulations for validation of material models

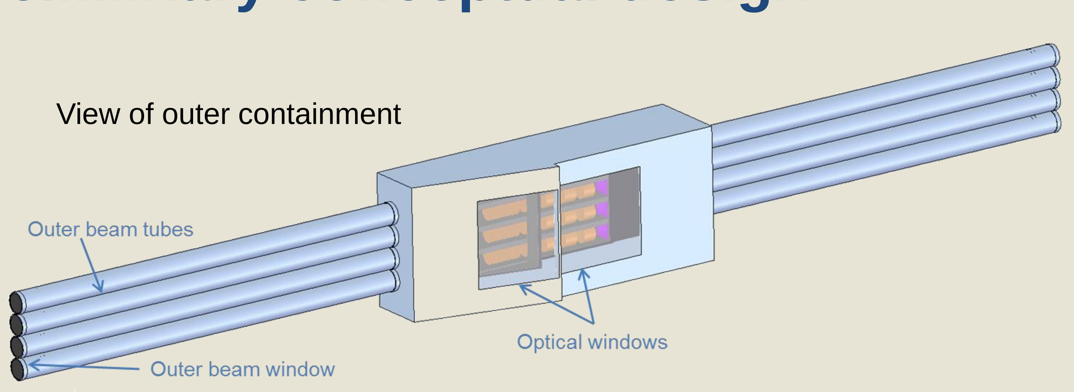
HiRadMat test facility

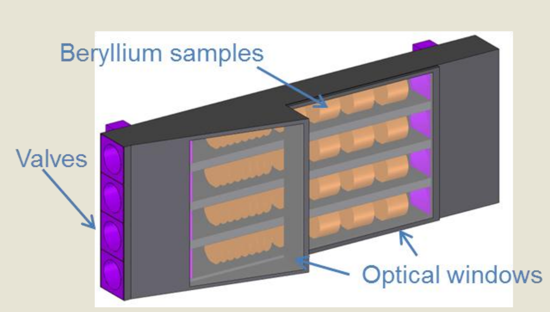
- 440 GeV protons
- Maximum bunch intensity: 1.7 x 10^{11}
- Maximum bunches: 288/pulse
- Pulse length: 7.2 µs
- Minimum beam sigma: 0.1 mm

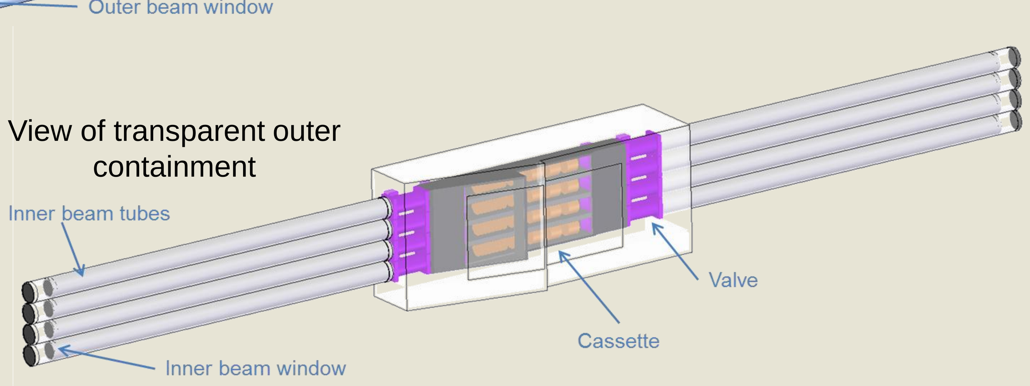


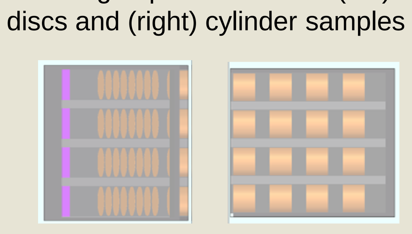
The HiRadMat test beam has the ability to impose both high strain rate and high temperature conditions, analogous to future target facilities.

Preliminary conceptual design



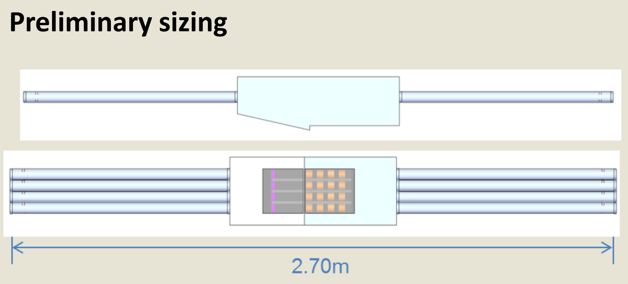




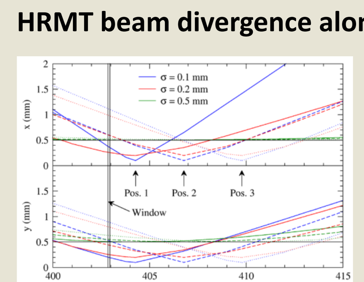


- Double containment for Be samples
- Dual valve system (shown in purple) allows cassette and outer containment to remain sealed during extraction
- Optical windows provide LDV access and high speed camera monitoring
- Aluminum containment vessel to minimize residual activity
- Tube extensions allow containment windows to be exposed to larger beam size
- Array positioning by external motorized positioning system

Preliminary sizing



HRMT beam divergence along test area

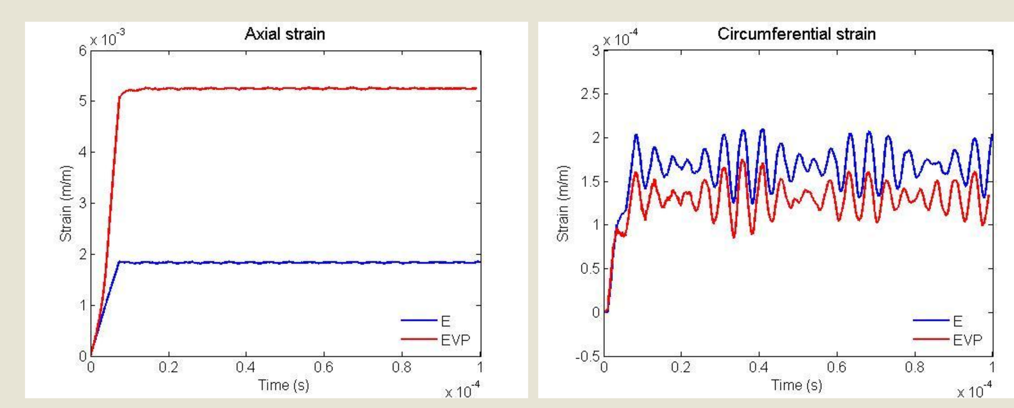


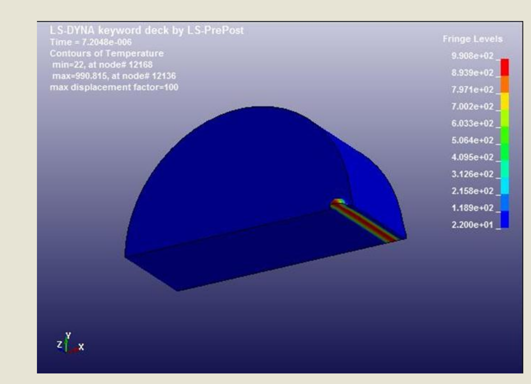
- Beam spot size on upstream HiRadMat primary beam window ≥ 0.5 mm

Simulations of beam induced stress/strain in Be samples

- Off center 0.3 mm beam on Be cylinder
- ΔT = 970 °C (288 bunches at max. intensity)
- Max. equivalent plastic strain ~ 2 %

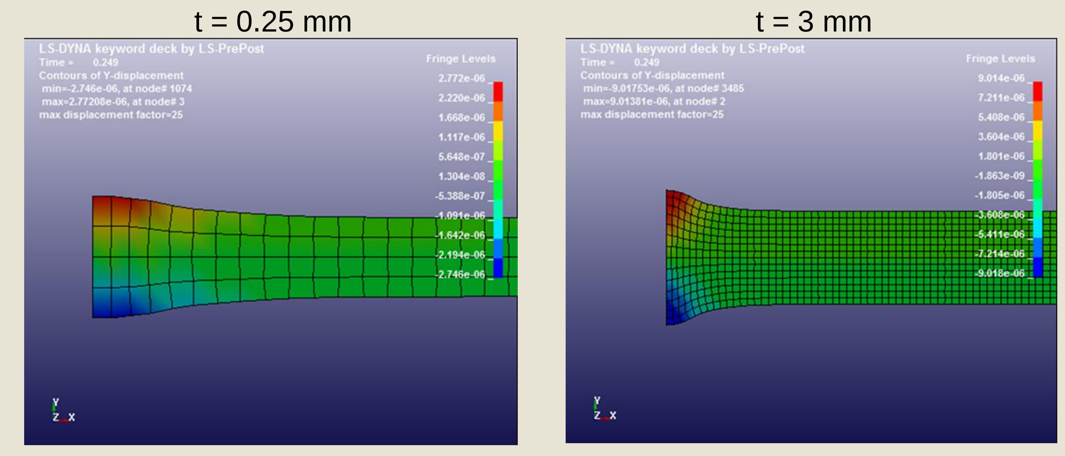
Dynamic response at cylinder edge





R = 20 mm, t = 30 mm
Beam location: r/R = 0.9

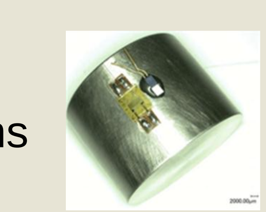
Permanent surface deformation after one pulse (thin discs)



- 2D axisymmetric model
- 0.3 mm beam sigma
- Max. beam intensity
- Out-of-plane surface displacement: 2-10 µm

Online instrumentation

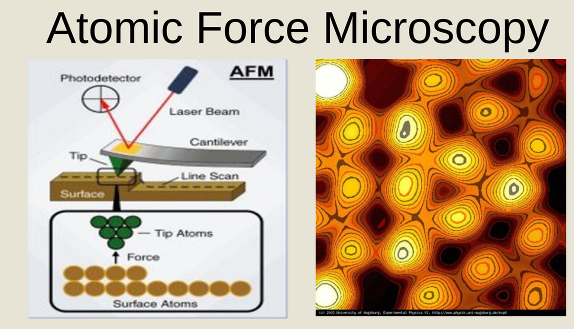
- Strain gages on Be cylinders to measure axial and hoop strains
- Laser Doppler Vibrometer to compare surface vibrations with simulations
- Optical pyrometer to measure peak temperature rise
- High speed camera to monitor experiment



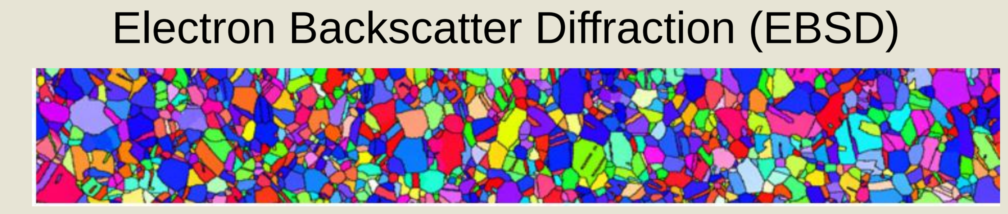
Example of how strain gages will be attached to Be cylinders

Offline material analysis

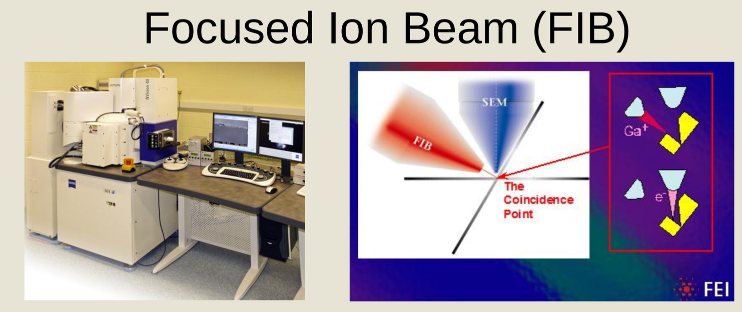
Atomic Force Microscopy



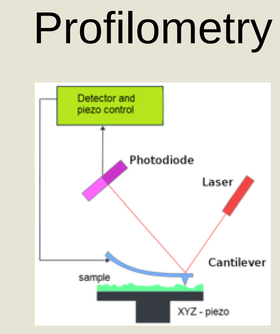
Electron Backscatter Diffraction (EBSD)



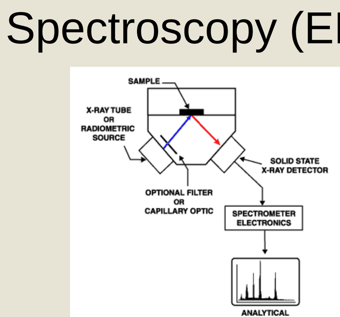
Focused Ion Beam (FIB)



Profilometry



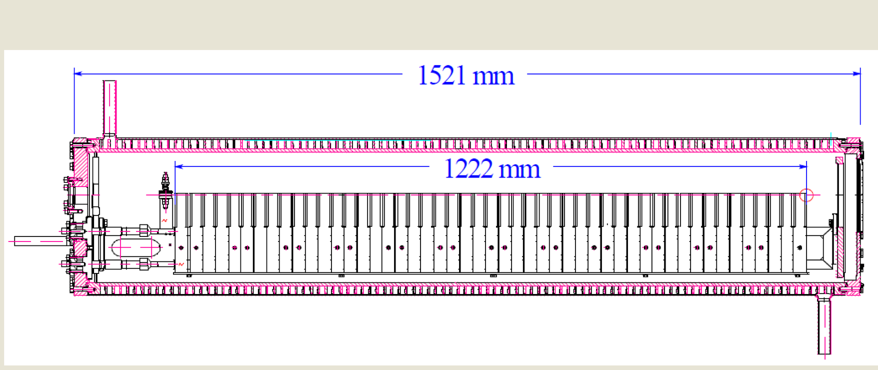
Energy Dispersive X-Ray Spectroscopy (EDS)



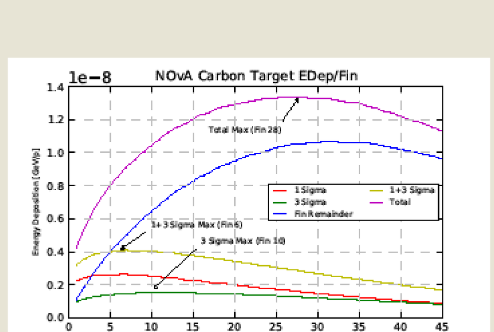
Be fins in NOvA target

Objectives

An in-beam test of beryllium is planned using the NOvA medium energy target MET-02. The main objective is to verify simulation results that show beryllium fin should survive in the NOvA ME target. At the end of the target's life, fins will be examined for signs of failure



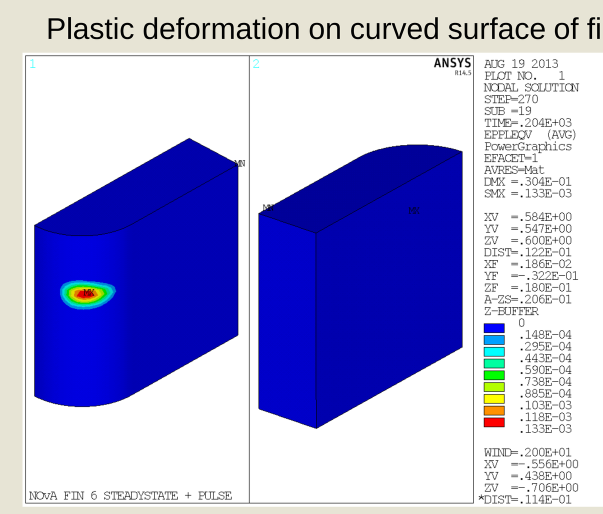
- Target comprised of an array of graphite fins extending from a water cooling block.
- Three of these fins could be replaced with beryllium with minimal impact to the physics.



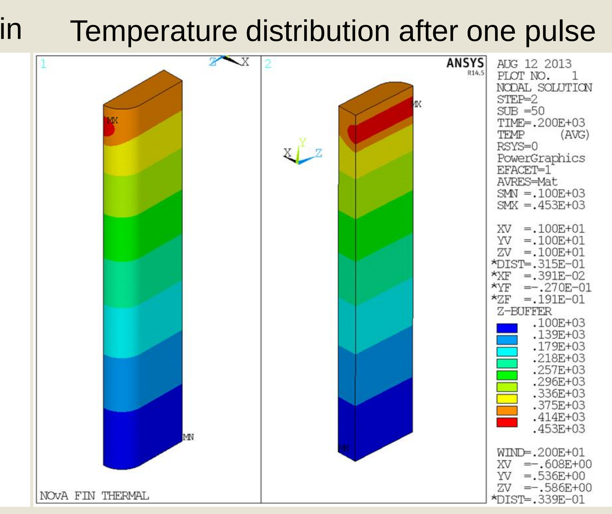
- MARS15 run was conducted to determine energy deposition profiles for each fin
- Fin 6 has the highest peak temperature and sharpest temperature gradient.

Thermo-mechanical analysis of fin 6

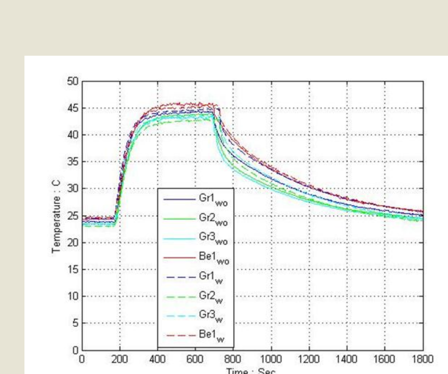
Plastic deformation on curved surface of fin



Temperature distribution after one pulse



- Single pulse analysis
- Multiple pulses after steady-state temperature ΔT/pulse = 75 °C T_{max} = 450 °C
- Dynamic effect of stress wave concentrations were minimal



Temperature vs. time of beryllium and graphite fins (with/without Grafoil)

- Test conducted to check thermal response of graphite and beryllium fins (M. McGee)
- Grafoil shims tested to improve thermal conduction

Assembled Be fin in final target