Thermo-structural analysis on the UHV gate valve between PSB and ISOLDE (accidental case)

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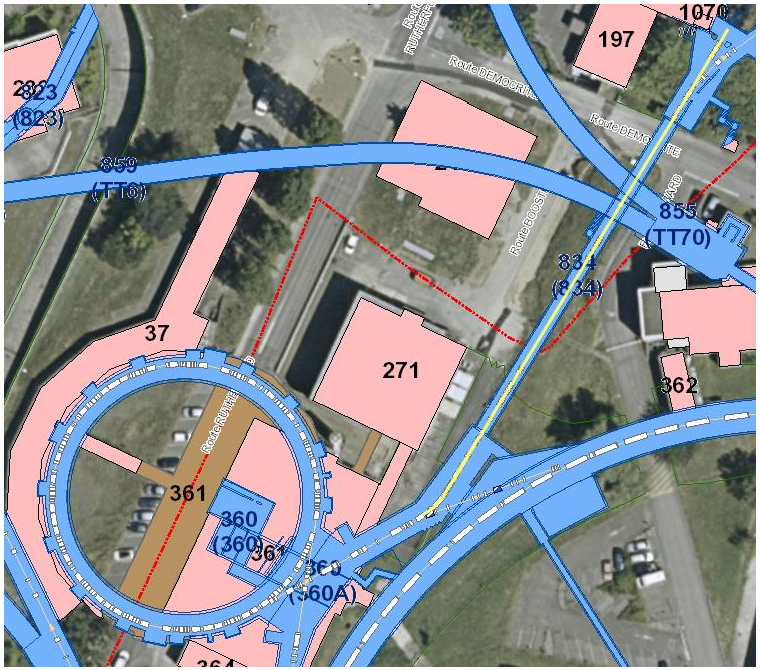
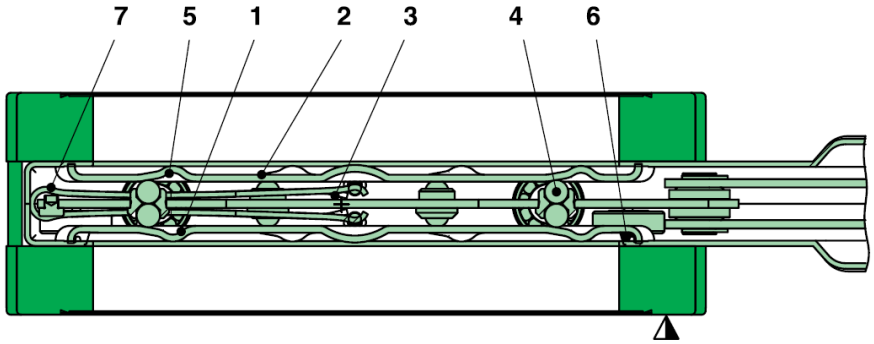
0. Valve type / position

- UHV gate valve with pneumatic actuator
- Series 10.8, DN 63 - 200 (2½" - 8"), VAT Vakuumventile
- Housing / mechanism material: AISI 304 (1.4301)

- They are used to separate 7 vacuum sectors:
  - 4 sectors from the PSB extraction to BTY
  - 3 in the BTY line



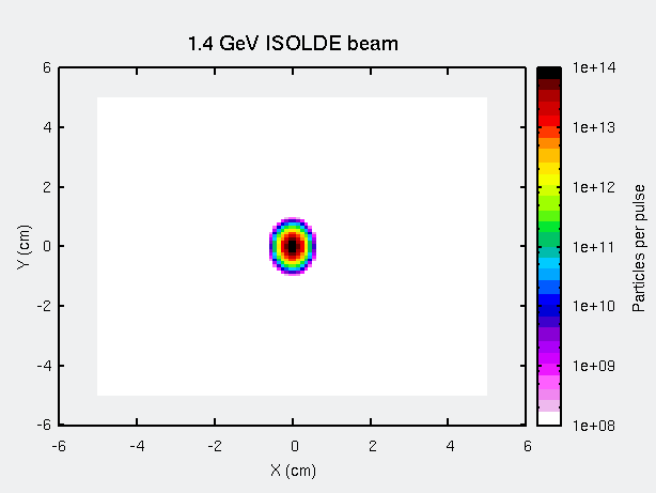


1 Gate
2 Counter-plate
3 Leaf springs
4 Ball pairs
5 Ball detents
6 Gate seal
7 Spring stop
▼ Valve seat side

1. Simulation properties

- Beam kinetic energy: 1.4 and 2.0 GeV (ISOLDE beam)
- Gaussian beam shape with

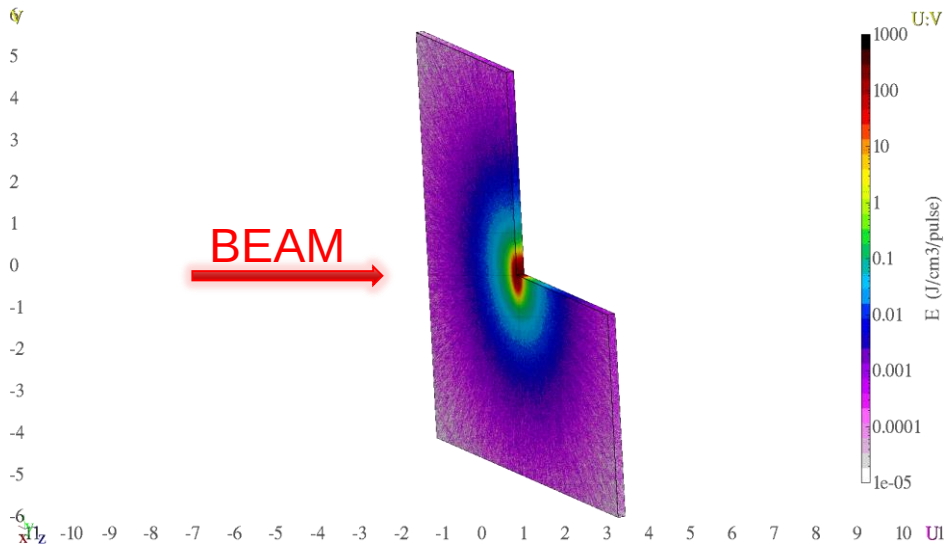
  σ_x = 1.2 mm, σ_y=1.9 mm

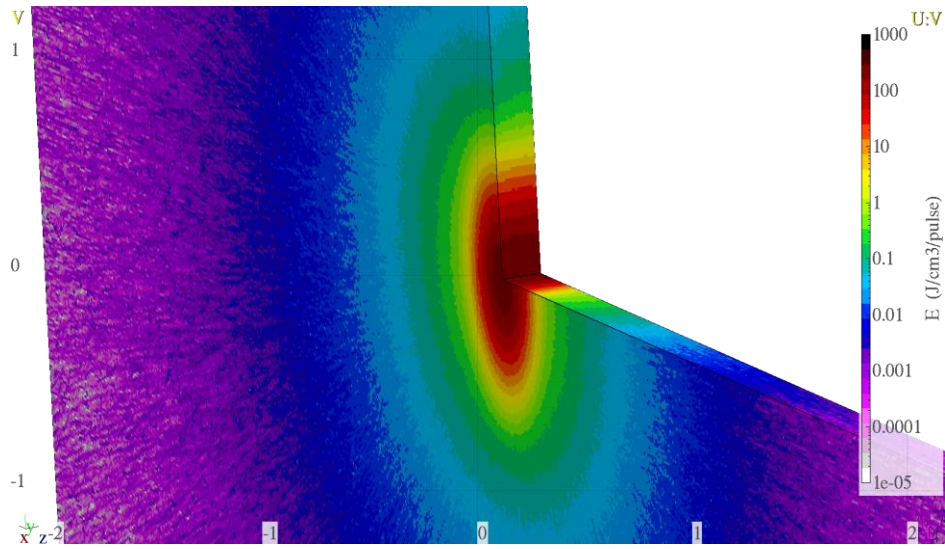


- Beam intensity: 1.6 x 10^{13} protons

- 10 cm x 10 cm x 2 mm target. SS304L material (ρ=8.02 g/cm^3)

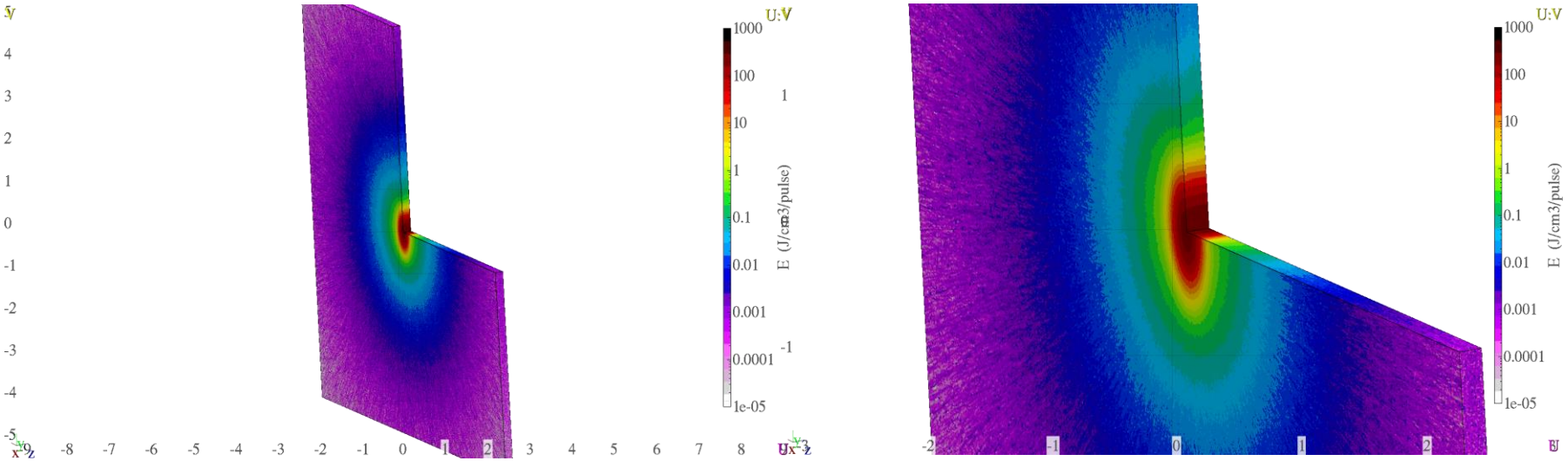
1.4 GeV proton beam deposition





98.7% of the beam energy scattered
1.3% intercepted
0.22% absorbed (3.16 MeV / proton)

2.0 GeV proton beam deposition



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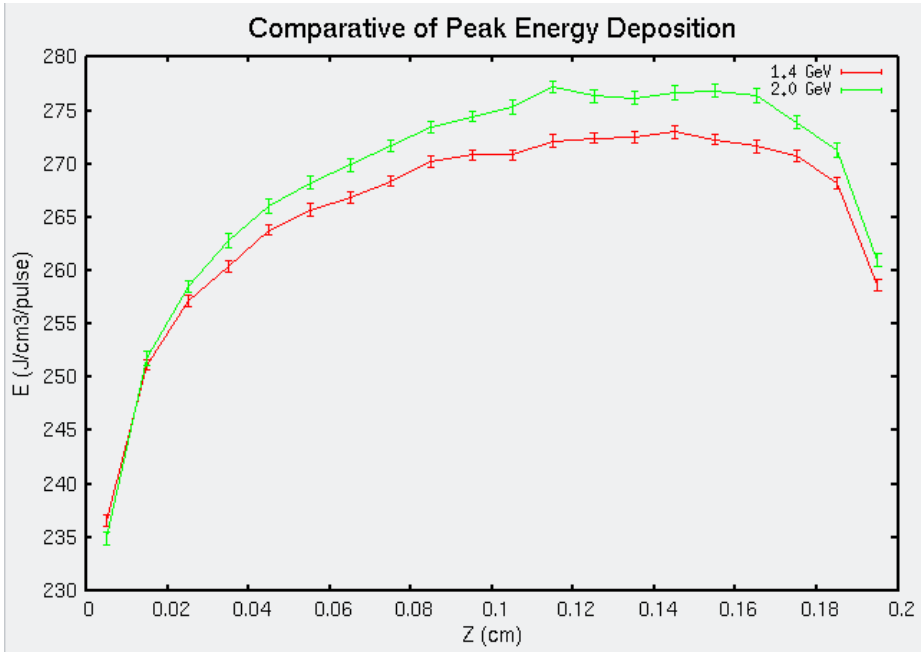
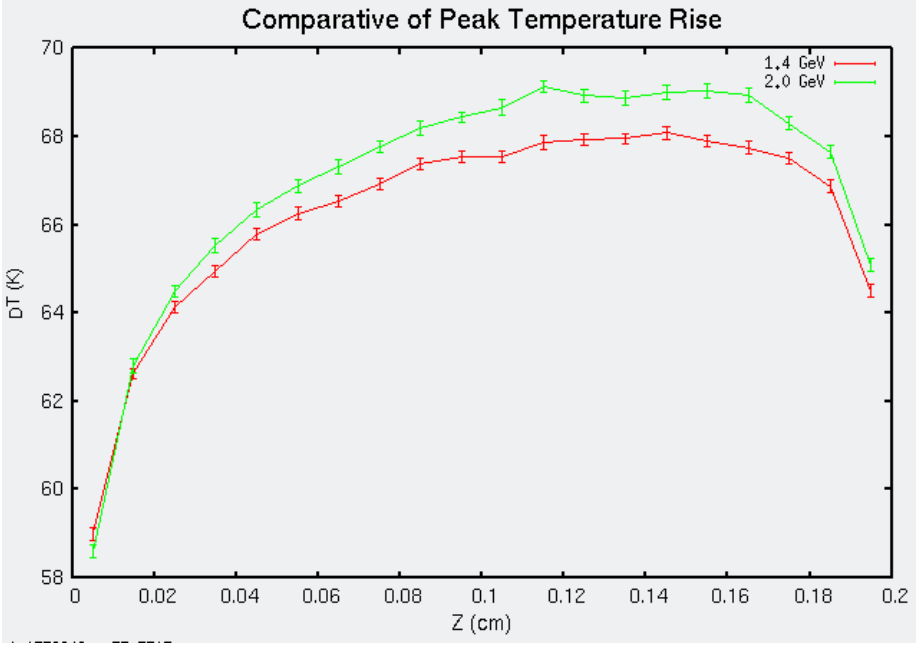
0.16% absorbed (3.22 MeV / proton)

Comparative for 2 beam energies



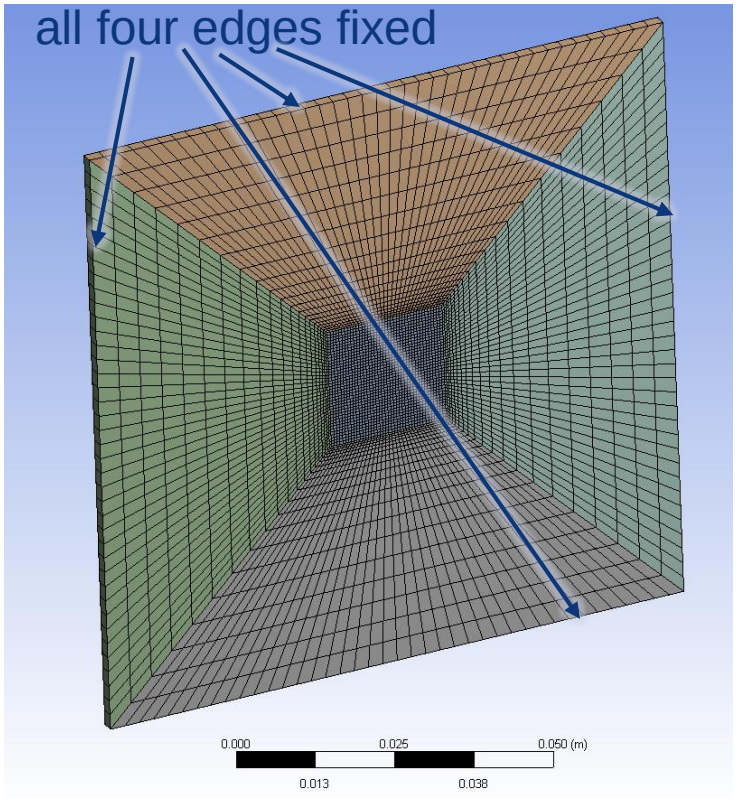


277 J/cm^3/pulse and ~69 K/pulse are peak values (obtained for 2 GeV)

For Adiabatic temperature rise: $\Delta T(\frac{\mathrm{K}}{\mathrm{pulse}}) = \frac{E(\frac{\frac{J}{cm^3}}{pulse})}{c\left(\frac{J}{g}/K\right) * \rho(\frac{g}{cm^3})}$ with c_{SS304L}= 0.5 J/(g x K)

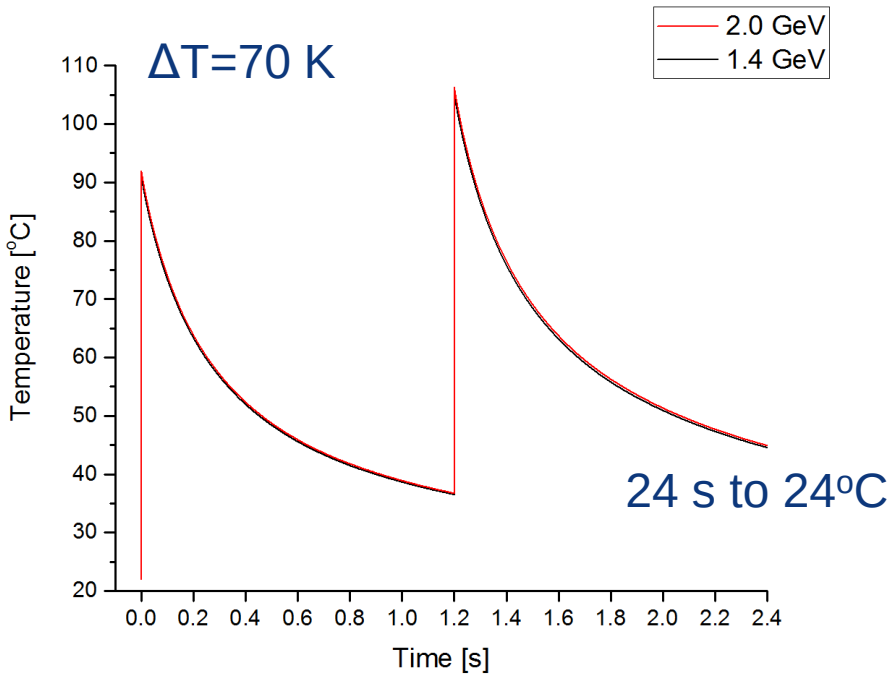
2. Thermal-structural analysis

- Two repeated beams
- Repetition rate: 1.2s
- Pulse length: 100 μs
- Initial temperature: 22^{o}C

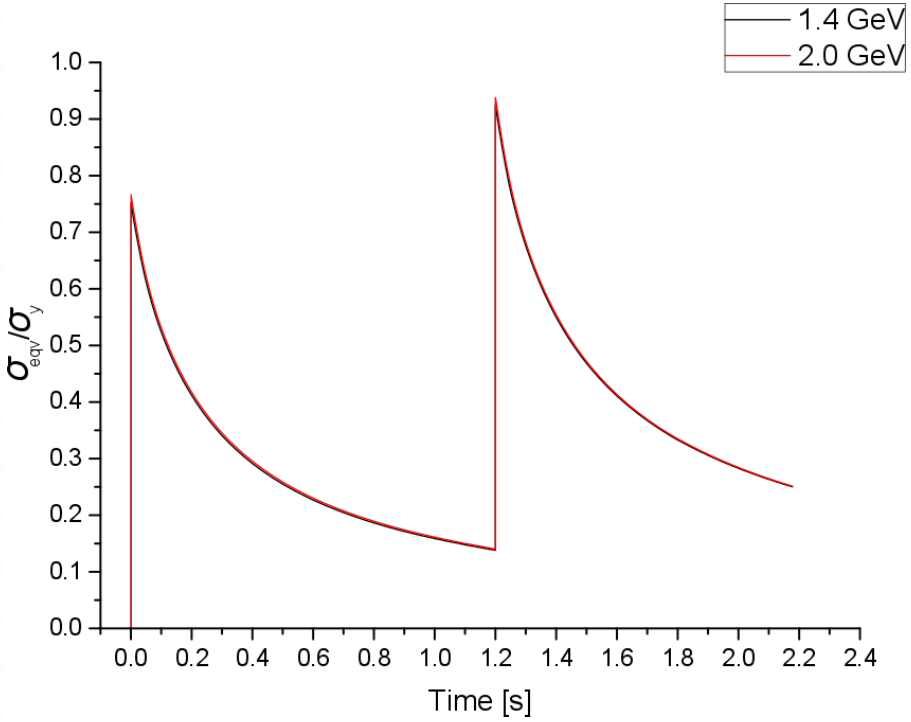


- FEM simulation (Ansys 17.1)
- SHELL131/181 layered elements
  - 20 layers (see EDMS 1610806)
- Boundary conditions:
  - Thermal: conduction through matter (neither convection nor radiation considered)
  - Mechanical: four edges fixed / bilinear isotropic hardening material model

Results for two repeated pulses



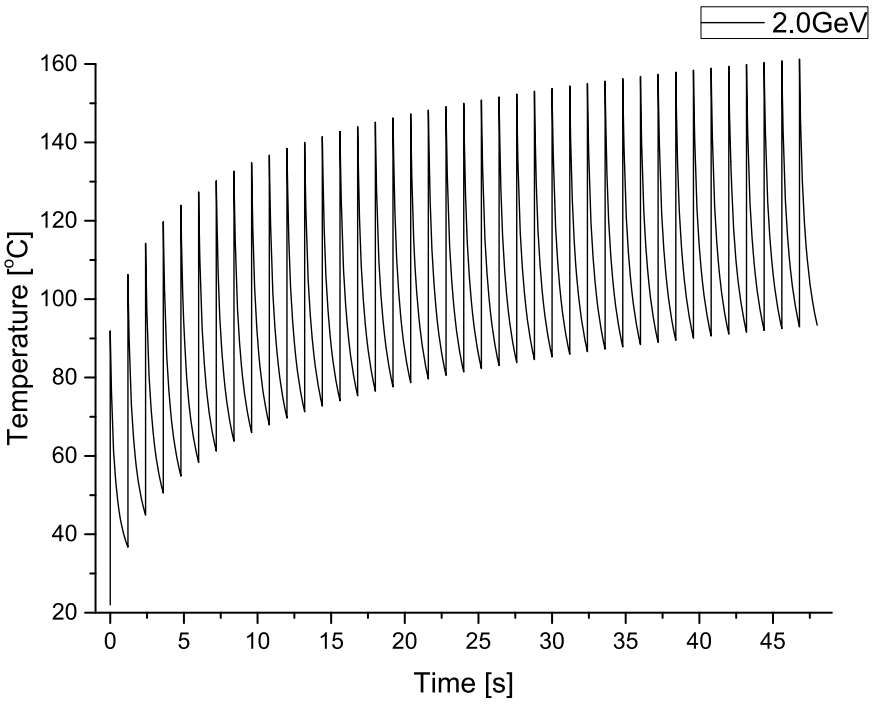
Maximum temperatures reached



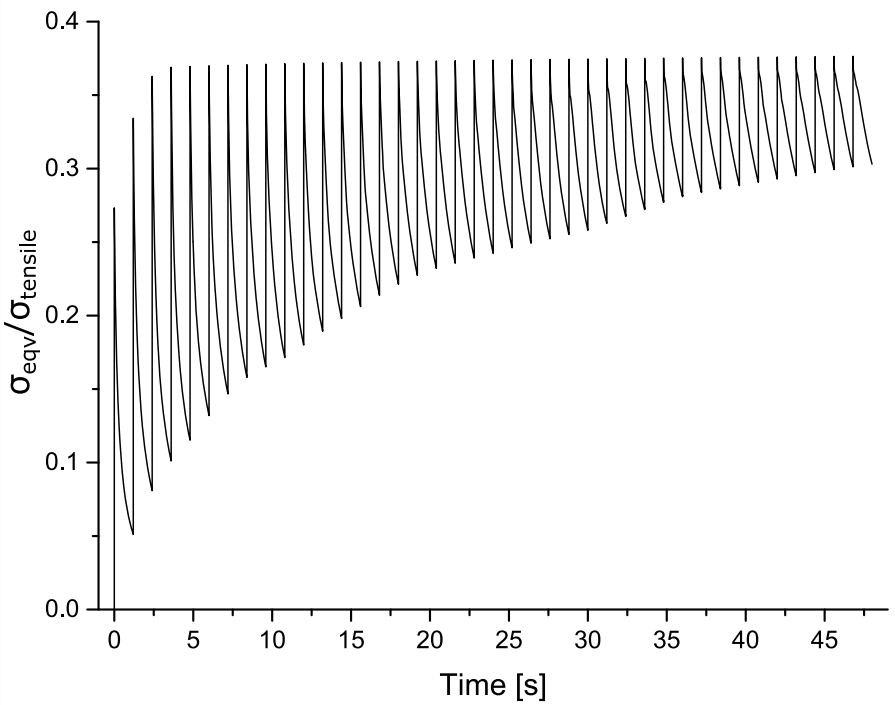
$\sigma_{eqv}/\sigma_{yield} < 1$: only elastic deformation

Multiple repeated pulses

- No necking for 40 repeated pulses ($\sigma_{eqv} < \sigma_{ultimate}$)

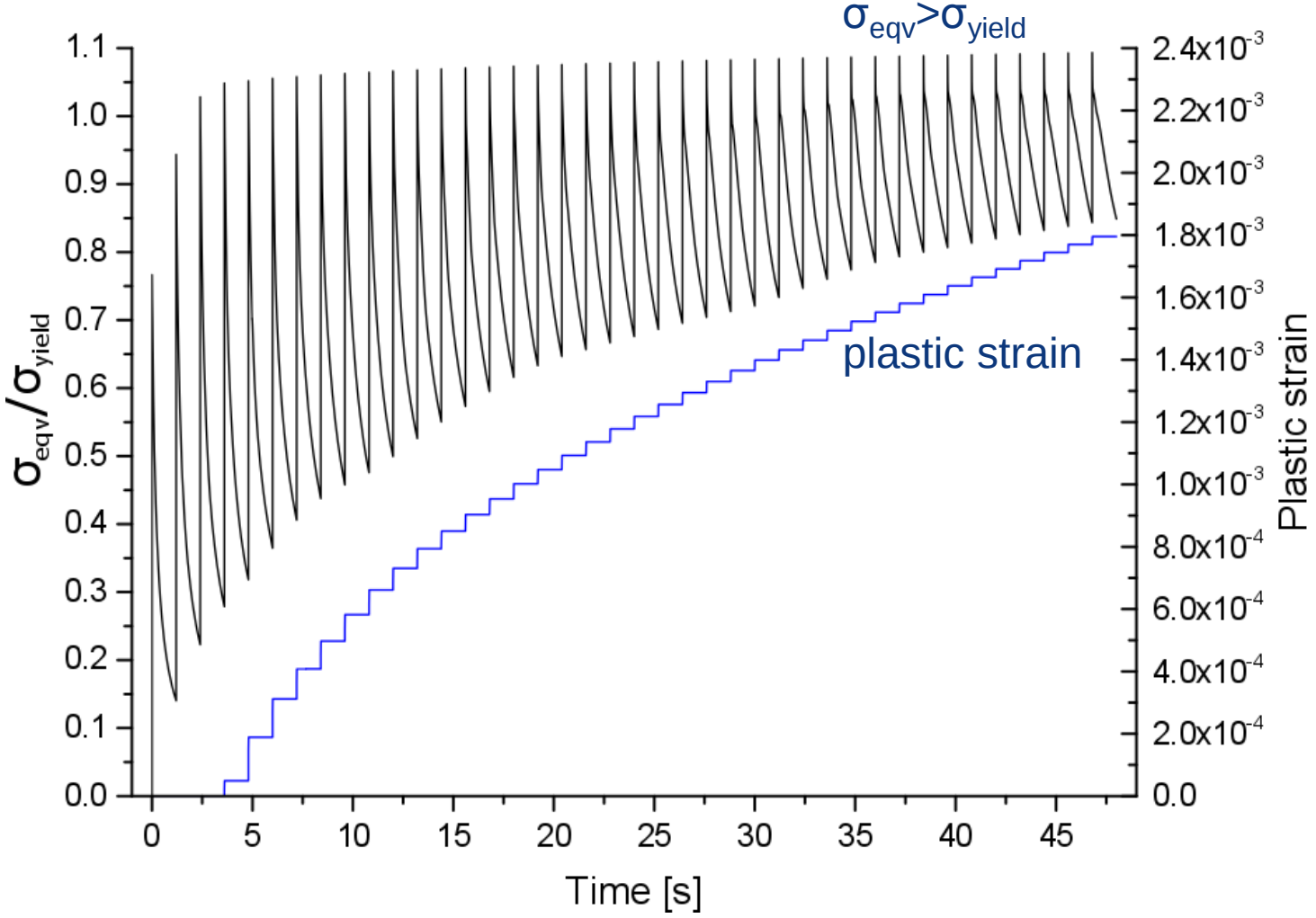


- Quasi-asymptotic behavior reached at ~160°C, due to thermal mass only



- Tensile strength is not reached after 40 repeated pulses ($\sigma_{eqv} < \sigma_{tensile}$)

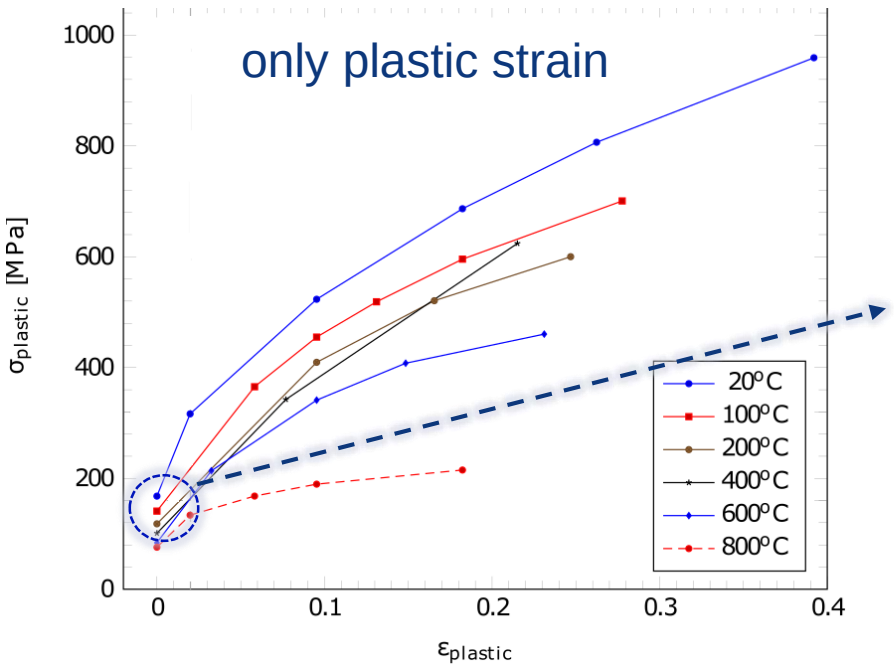
Plastic deformation



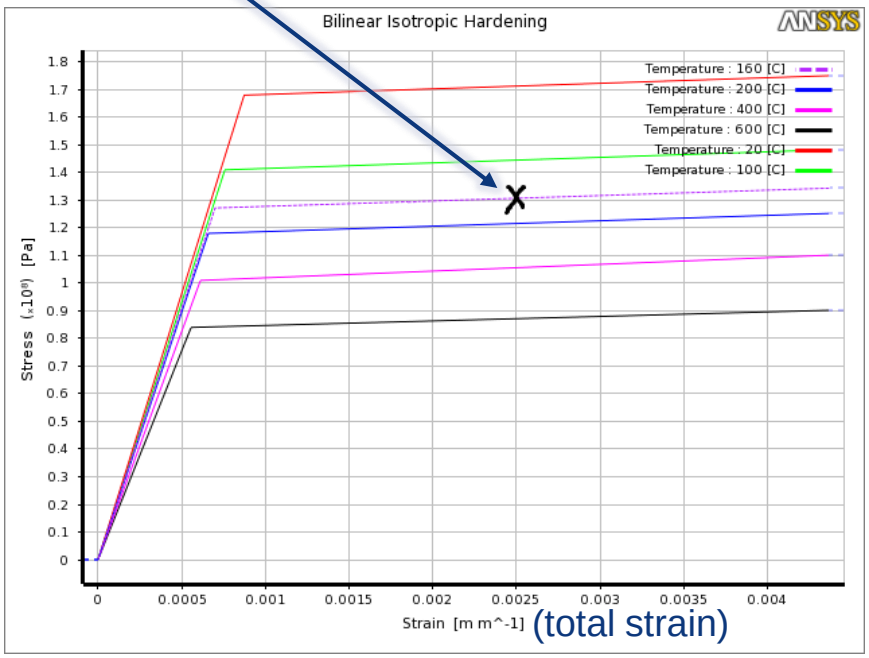
- $\varepsilon_{tensile}(150^{o}C) \sim 200x10^{-3}$ (no necking as $\varepsilon_{plastic,max}=1.8x10^{-3}$)
- $\varepsilon_{elastic,max} = 0.8x10^{-3}$

Stress-strain curve

stress/strain on the 40th pulse



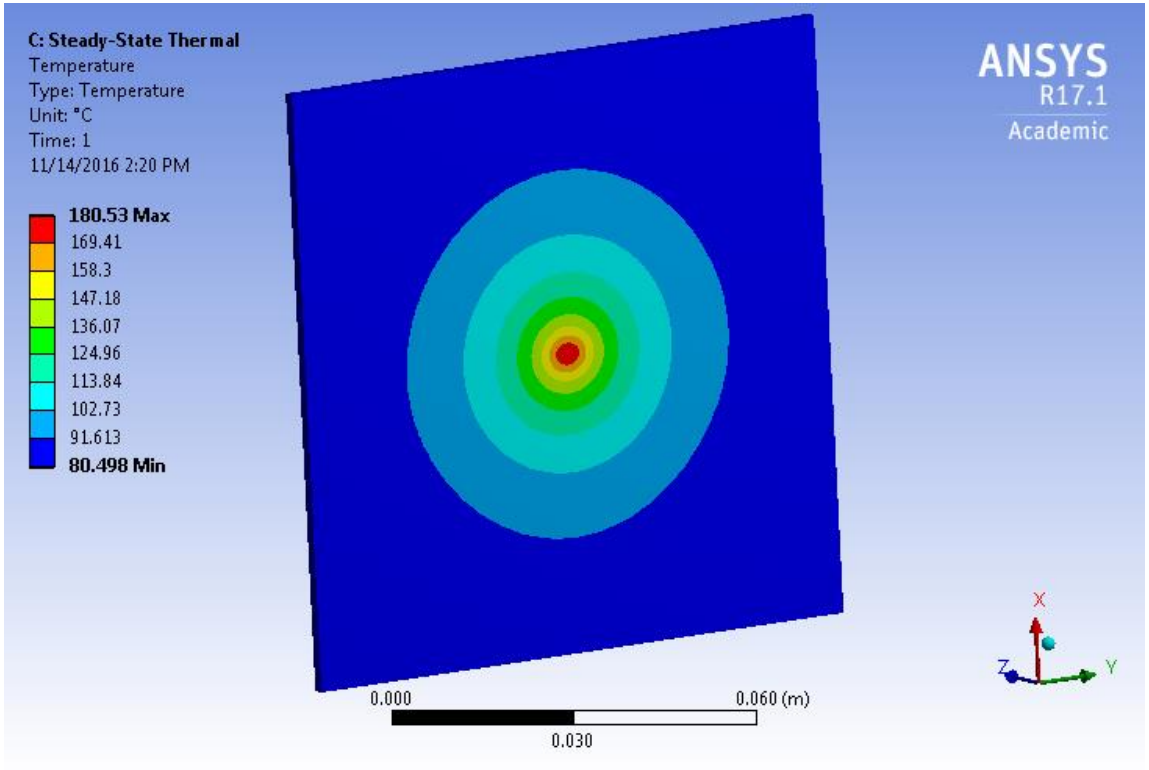
Multilinear model (before necking)



Bilinear model

Curves from: Dempsey, J. Franklin, et al. "Temperature dependent ductile material failure constitutive modeling with validation experiments." Challenges in Mechanics of Time-Dependent Materials and Processes in Conventional and Multifunctional Materials, Volume 2. Springer New York, 2013. 7-15.

Steady-state results



- Heat sink: radiation from the plate (ε=0.6 to the environment) only
  - No convection
- Maximum temperature: 180.5ºC (operational limit at T_{creep}=550ºC)

3. Conclusion

- Nearly the same energy deposition for 1.4 & 2GeV beams
- 2 repeated pulses :
  - T_{max}=106°C
  - No plastic deformation: σ_{max}= 135.7 MPa (equivalent von-Mises stress)
  - $\sigma_{limit}=\sigma_{yield}$= 141.4 MPa (yield strength at 106°C)
- A third repeated pulse causes plastic deformation
- Tensile strength is not reached after 40 repeated pulses
- T_{max}=160°C (transient, 40 repeated pulses)
- T_{max}=180.5°C (steady-state, constant beam impacts)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