

Stress simulation in the ILC positron target with ANSYS

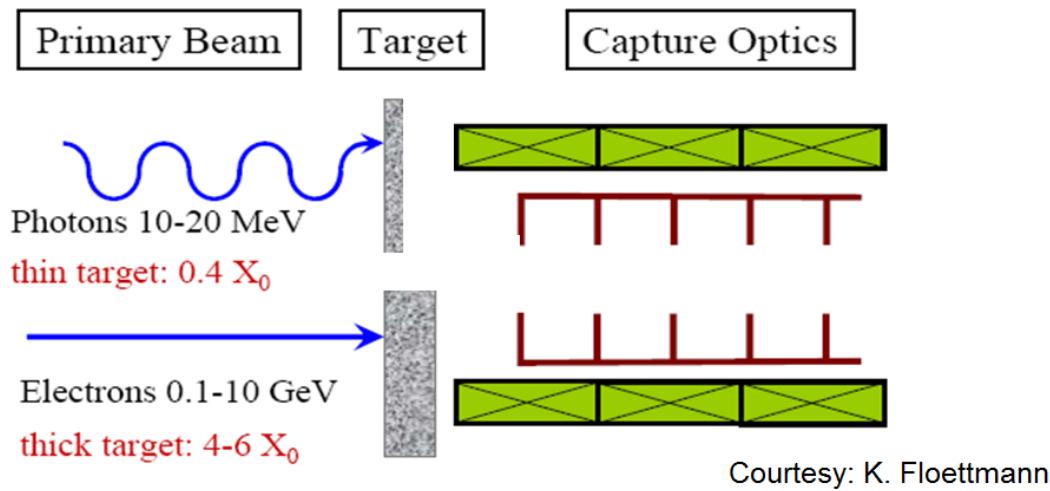
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Outline

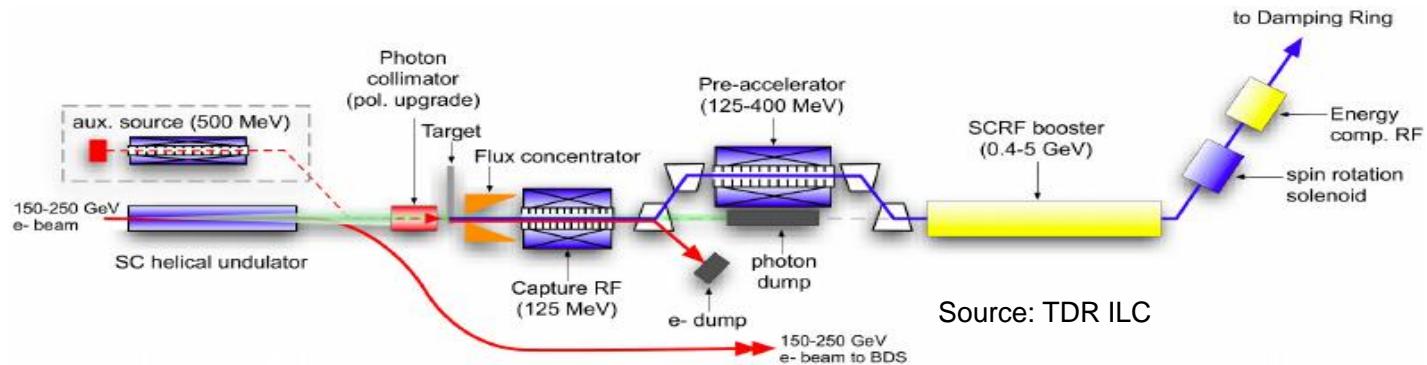
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Introduction

- High energy particles interact with target material
- pair production → e^+ and e^-
- e^- are dumped
- e^+ are accelerated
- Interaction with the target → heat load



ILC – Positron source



> Photon production:

- Helical undulator, $\lambda_{\text{und}} = 11.5\text{mm}$, $K = 0.92$, ($L_{\text{und}} \leq 147\text{m}$)
- Drive beam energy $\geq 150\text{ GeV}$

> Positron production target: spinning wheel

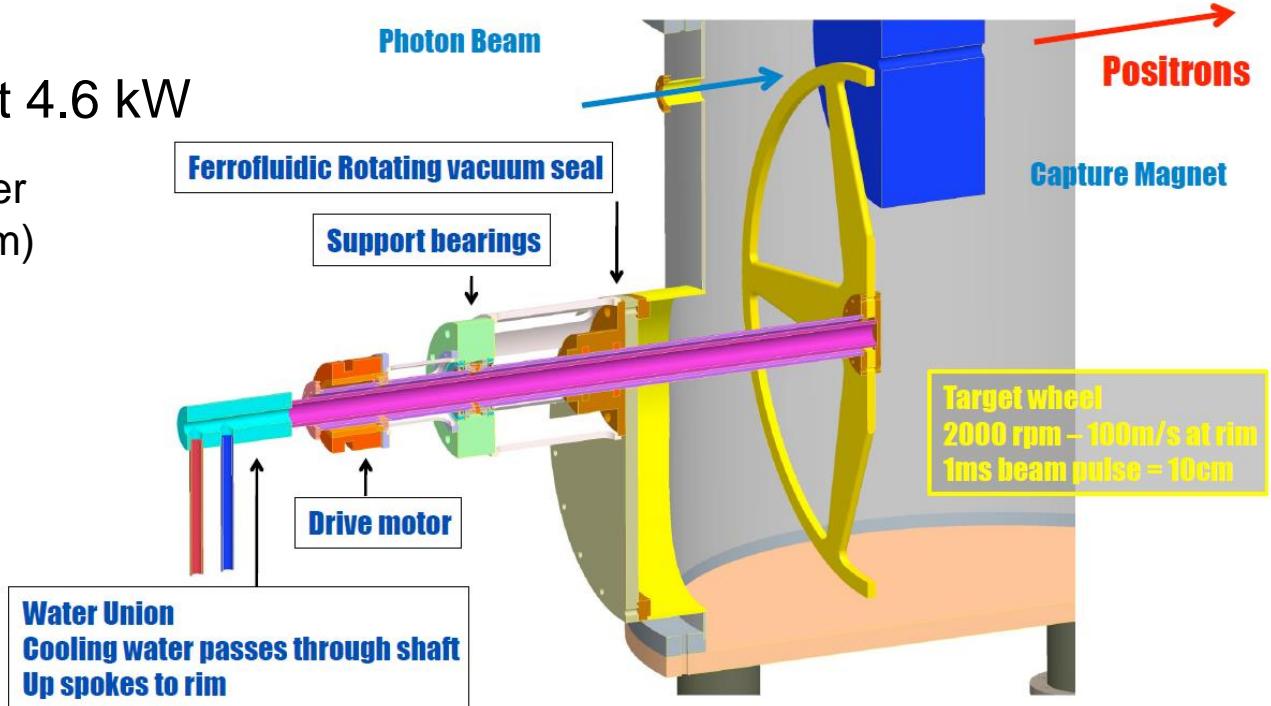
- Ti-Alloy (Ti6Al4V)
- Thickness $t = 0.4 \times 0$ (1.4cm)
- Diameter $d=1\text{m}$
- 100m/s at rim $\Leftrightarrow 2000\text{rpm}$

e^+ Source load parameters

> Drive beam energy 250 GeV, 30% e^+ polarization \rightarrow 95.1 kW photon beam

> Deposition in target 4.6 kW

- Temperature rise per bunch train(2000rpm)
 $\Delta T = 119K$

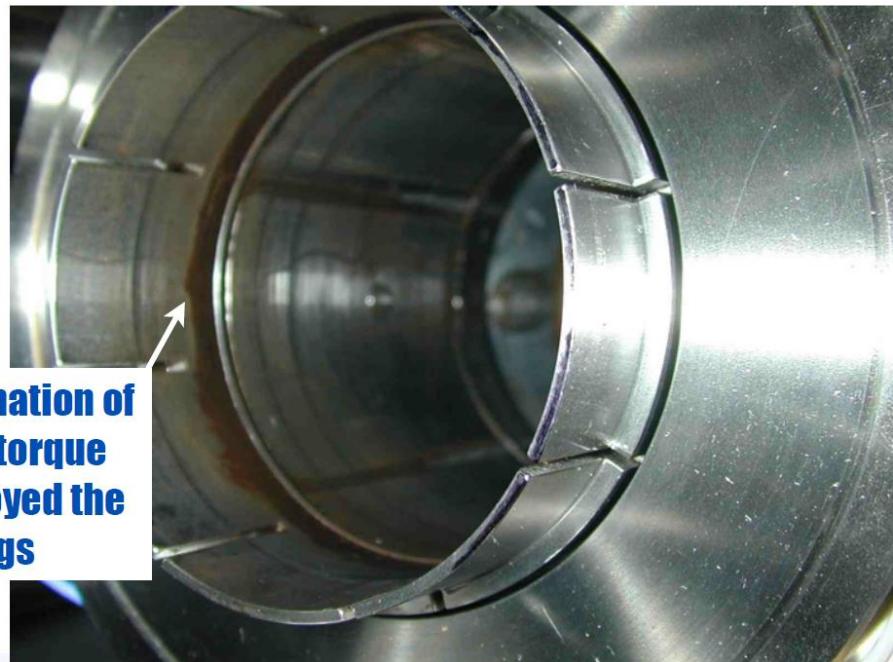


> Resulting stress $\approx 173\text{MPa}$

> Should work but prototype must demonstrate the feasibility to build target wheel spinning in vacuum and operate it at least one year

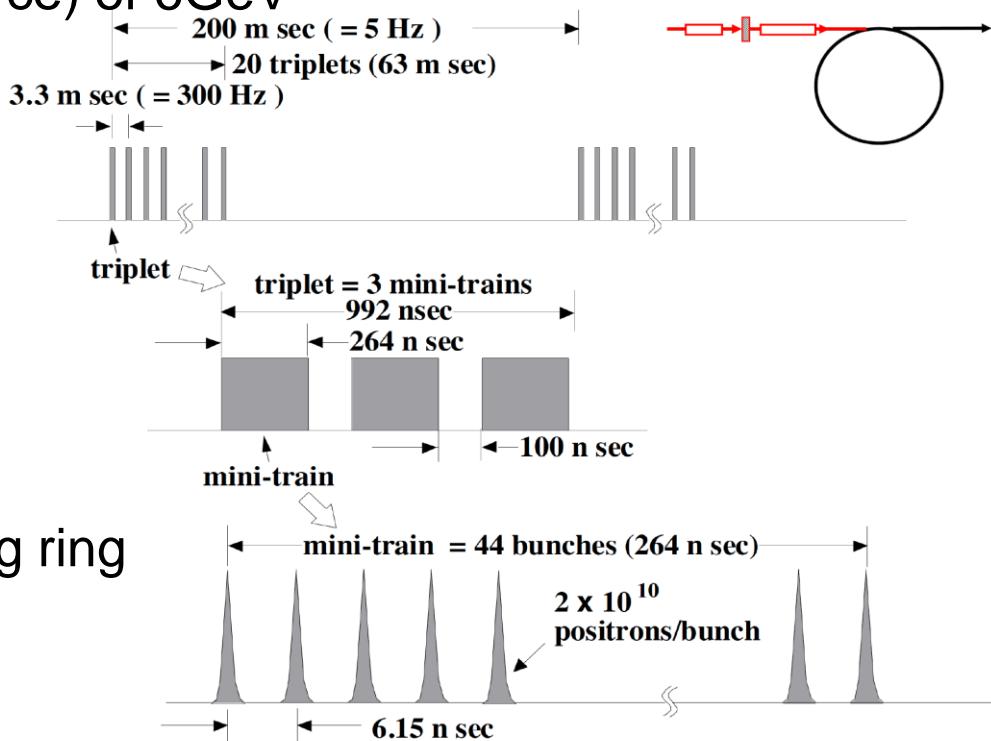
e⁺ Source load problems

- > Wheel rotates in vacuum, at 2000rpm, while being exposed to radiation and located close to a magnetic field → „a quite demanding challenge“
- > Prototype has been built and tested at LLNL
- > Vacuum seal not yet fully developed → first tests show vibrations in the seal and sometimes spikes in the vacuum
- > Further R&D work including prototyping is needed



Alternative source

- Suggested by T. Omori et al., see also NIMA672 (2012) 52
- Uses e^- beam (“conventional” source) of 6GeV
- Target: 4 X_0 Tungsten
- 300Hz scheme
 - Stretch ILC bunch train ($\sim 1\mu s$) to 63ms
→ lower peak heat load
 - Stacking of e^+ in the damping ring
- ILC time structure achieved by e^+ extraction scheme from damping ring
- Benchmark from SLC target: Peak Energy Deposition Density (PEDD) should not exceed 29J/g
- Electron beam parameters are selected accordingly



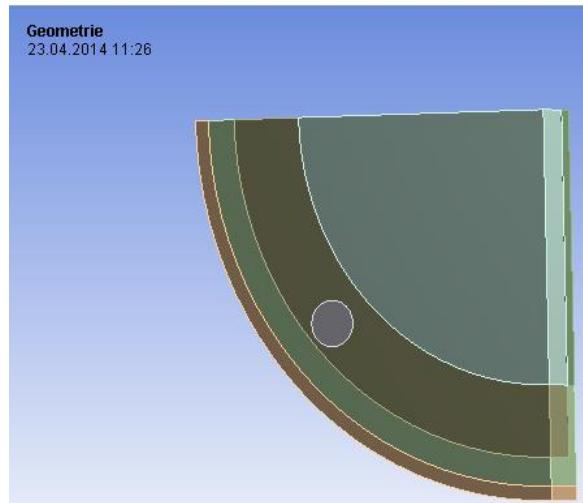
Goal of the studies

- > Beam parameters are given ($\Leftrightarrow \sim 29\text{J/g}$ peak energy deposition @ SLC)
- > How is the dynamic stress evolving in the target with 300Hz scheme in the tungsten target
- > Long-term change of material parameters and target lifetime depend on static and dynamic stress
 - Energy deposition within fraction of a nanosecond → instantaneous temperature rise
 - Reaction of material within milliseconds
 - Stress dynamics
- > Benchmark: SLC target
 - But SLC number of positrons per second was about 50 times lower than at ILC

Model

> Model 1– Modified SLC target

- Fe – ring & Ag – coat & W – core
- Beam spot radius = 0.8cm
- Radius for beam = 1.1cm



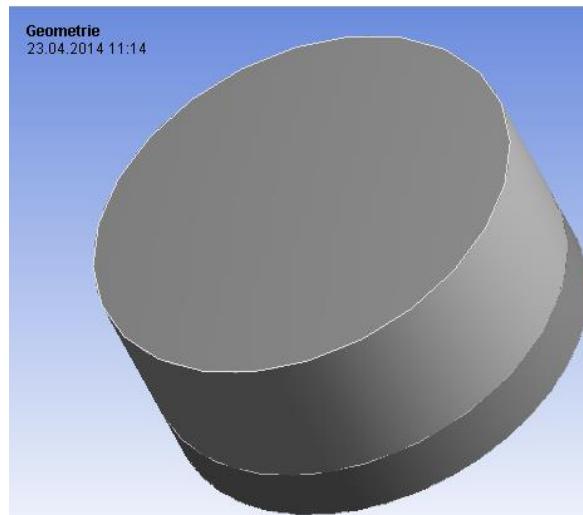
> Model 2– cylinder with diameter corresponding to beam spot size

- W – Layer & Ag – Layer
- Beam spot radius = $0.8\text{cm} = 2\sigma$

> Parameters

- Particle shower has been calculated with FLUKA
- $\Delta T(\text{per Bunch}) \approx 1.6K$
- Average energy deposition in the target:

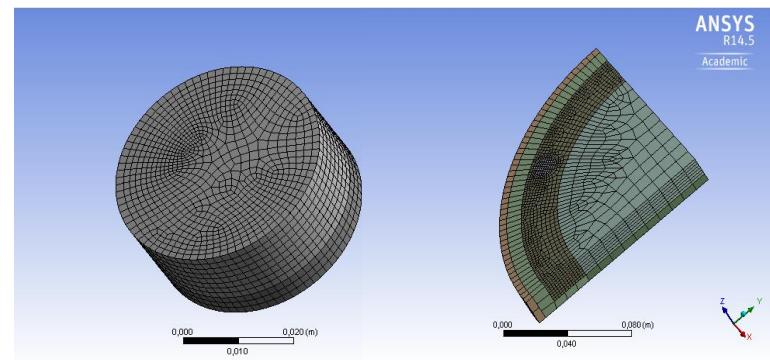
35kW without silver layer
49kW with silver layer



Implementation into ANSYS

> Mesh

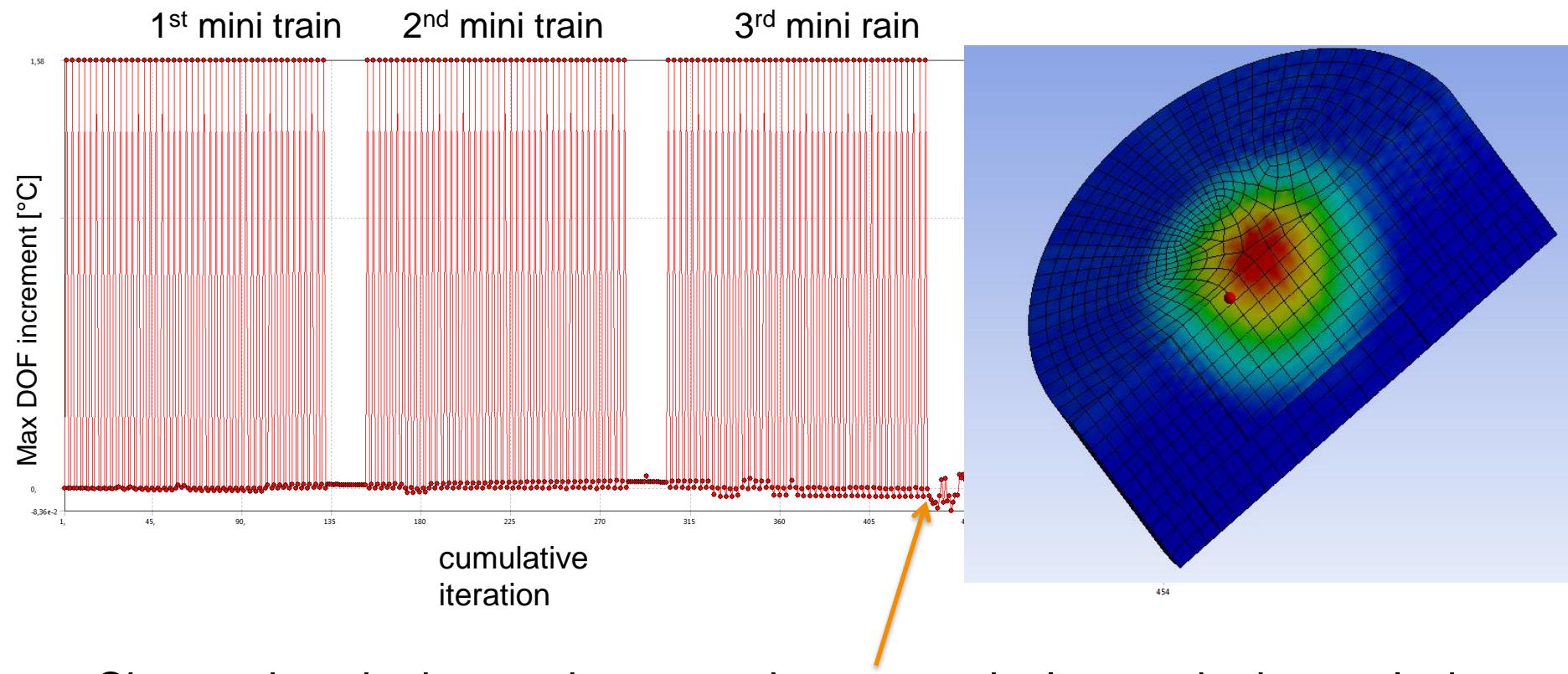
- Mesh size is related to time steps
- $\Delta t = \frac{l}{c_s} \rightarrow \Delta t$ is given $\rightarrow l \approx 1.5\mu m$
 c_s = velocity of sound = 5180 m/s
- Model 1 : 8152 elements
- Model 2 : 9419 elements
- Elements: Hexagonal elements



> Calculation & Results

- Model 1: at the contact regions between different materials and at regions with high temperature gradients mesh had low quality \rightarrow no useful results yet
- Model 2: works well, needs less computing time \rightarrow results presented for model 2

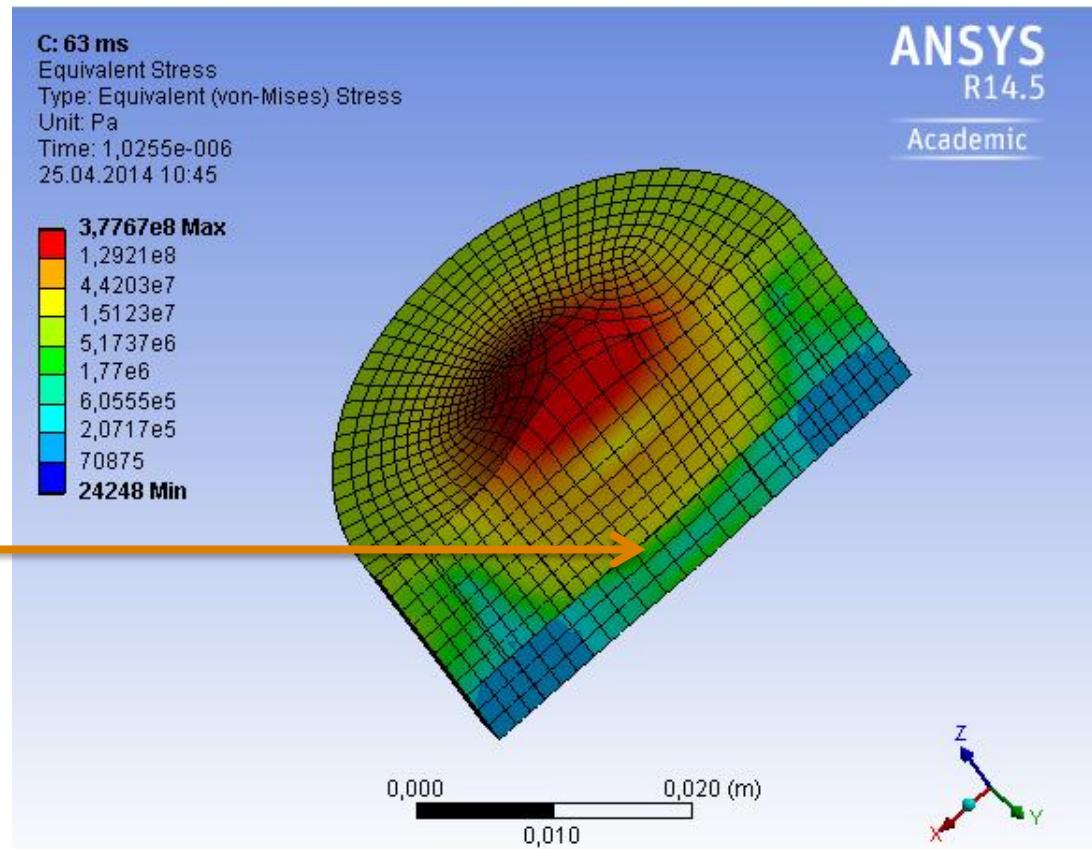
Temperature calculation



- Sharp edges in the mesh can produce numerical errors in the analysis procedure
- With good mesh, the temperature change resulting from energy deposition by each bunch shows regular behavior with negligible numerical errors

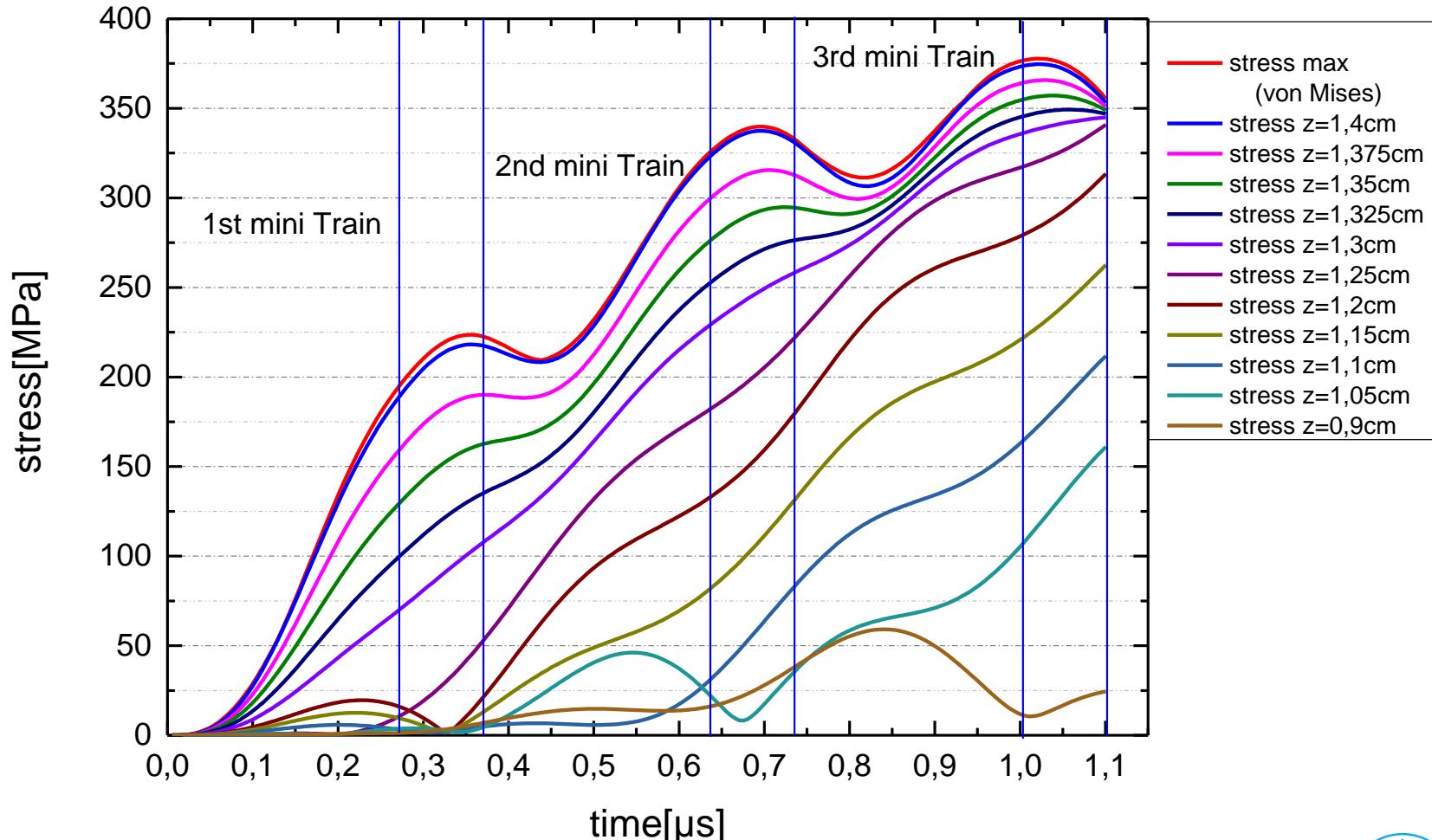
Results: Stress evolution

- > Highest stress after 1.0205 μ s
- > deformation is scaled by 730
- > Picture taken when the highest stress occurs
- > ANSYS results at contact regions have to be checked (solver problems → model must be improved)



Result: Short time

➤ Stress in the center at different Z positions

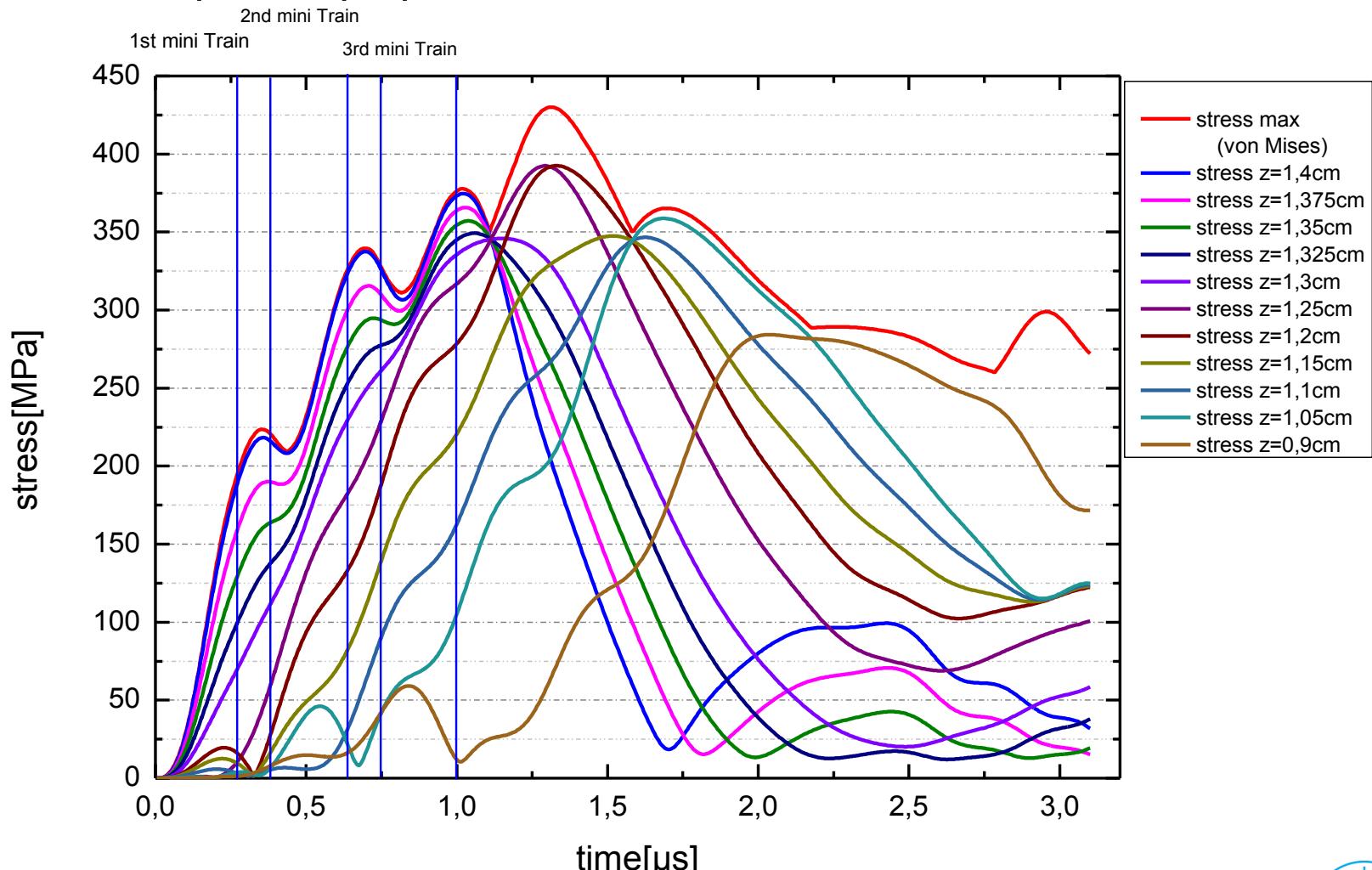


Result: conclusion

- > Max. temperature rise by one triplet is $T=230^{\circ}\text{C}$ within $\sim 1\mu\text{s}$
- > Heat dispersion into the target body within microseconds is negligible
→ temperature of the target body is 22°C
- > Max. stress after one triplet 377MPa
- > Every mini train adds a different stress load
 - First mini train $+225\text{MPa}$
 - Second mini train $+110\text{MPa}$
 - Third mini train $+37\text{MPa}$
- > Max. stress by one triplet is below fatigue stress limit $377\text{MPa} < 520\text{MPa}$

Results: Long time

> First attempt → 2 μ s pause



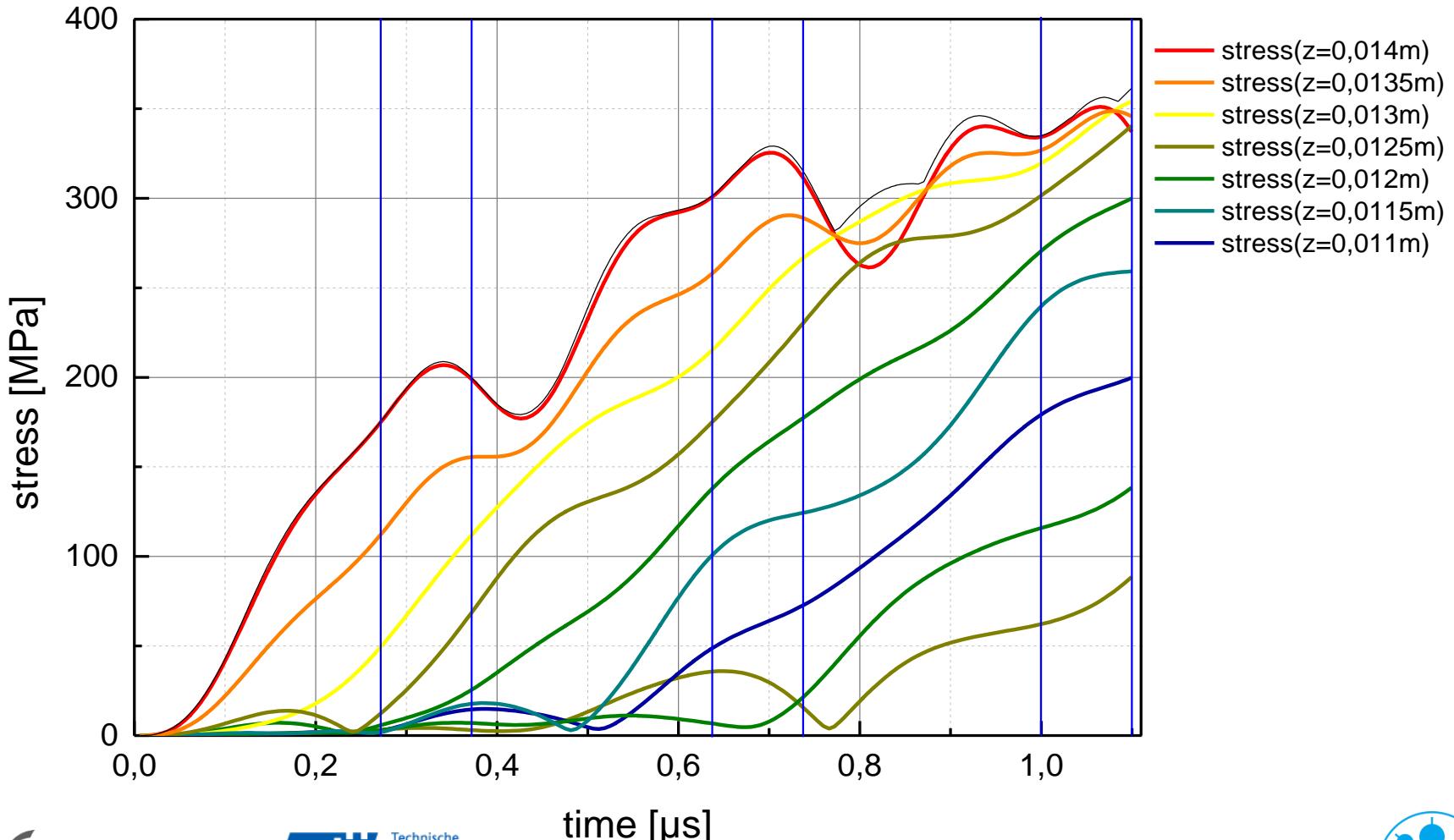
Summary

- > So far, reliable simulation results only for Model 2
- > Maximum dynamic stress per triplet is 377MPa (fatigue stress limit is 520MPa)
- > longer time → Stress could rise up to 425MPa (to be checked)
- > Load cycles per year: $20 * 3600 * 2000 * 5 \approx 75 * 10^7$ cycles
- > With target rotation the number of load cycles at the same beam spot volume can be kept below 10^7

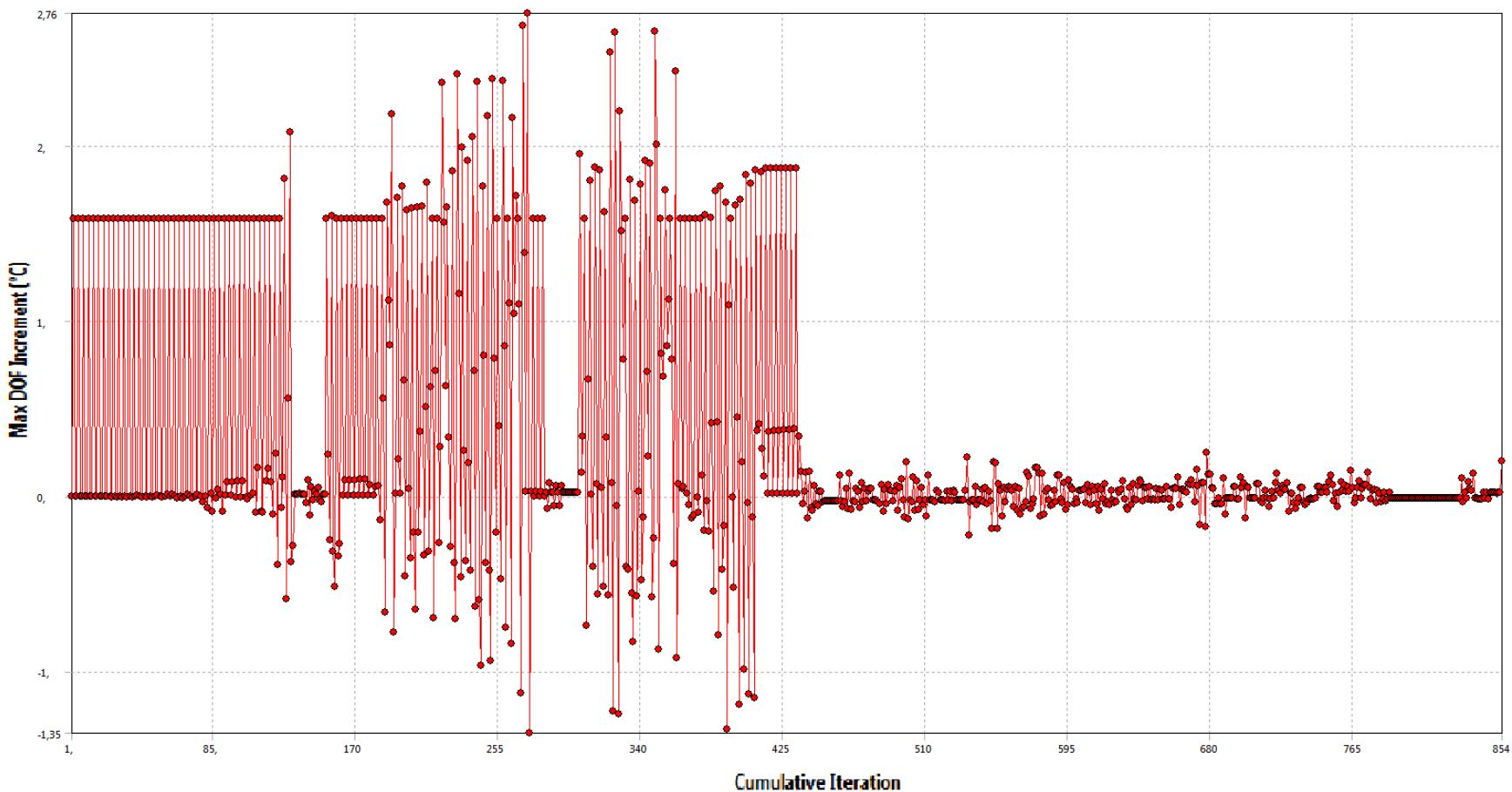
Next steps

- > Optimize the mesh of model 1 in ANSYS to perform simulation studies for the whole target
- > Simulations of a longer period:
 - Few triplets
 - Include target rotation
 - Check whether interferences of stress waves are possible
- > Degradation of material is expected due to irradiation
 - evaluation of dynamic load has to be repeated with modified parameters

Addition



Addition



Addition

stress[MPa]

