Performance Simulations/Heat Stress/Shockwave, etc.

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ILC Technical Baseline Review

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Outline

- Positron source parameters
- Simulation results
  - Temperature and stress in rotated target after one pulse
  - Time evolution of target deformation, equivalent stress etc.
- Outlook

Source Parameters (EDMS)

- Fixed Undulator Field, QWT Capture Device, 2625 Bunches/Train, 100 m/s rot. speed

Center-of-mass energy [GeV]	200	250	350	500	1000
Pulse repetition rate [Hz]	10		5		4
Required undulator length [m]	231		150	75	?
Average photon beam power on target [kW]	279*	328*	168	164	?
Energy deposition per bunch [J]	1.17		0.92	0.61	?
Photon opening angle [μrad]	3.4		2.9	2.0	?
Peak energy density in target [J/g]	126		124	126.4	?
Peak thermal stress in target	?	?	?	**?**	?

- Fixed Undulator Length Scenario (Field and K-factor are “free”)
- Pulsed Flux Concentrator, Li-Lens
- Electron Bunch Separation

Center-of-mass energy [GeV]	200	250	350	500	1000
KCS	554 ns				366 ns
DRFS	732 ns				366 ns

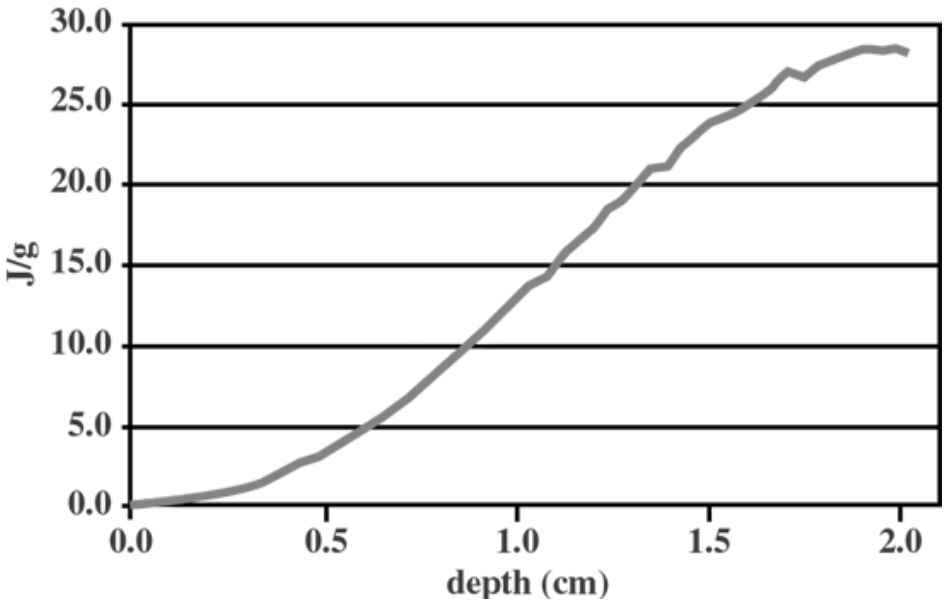
- Photon Collimator with Different Apertures

SLC Target

- $4 \cdot 10^{10}$ e^-/bunch at 33 GeV
- 0.8 mm spot size
- 6 X_0 W25Re target

"For a tensile strength of 1.1e+9 Pa (160 ksi) (at **348 C**), the calculated peak Von Mises stress of **5.7e+8 Pa** (83 ksi) is at **52%** of the tensile stress."
[W. Stein et al. PAC2001]

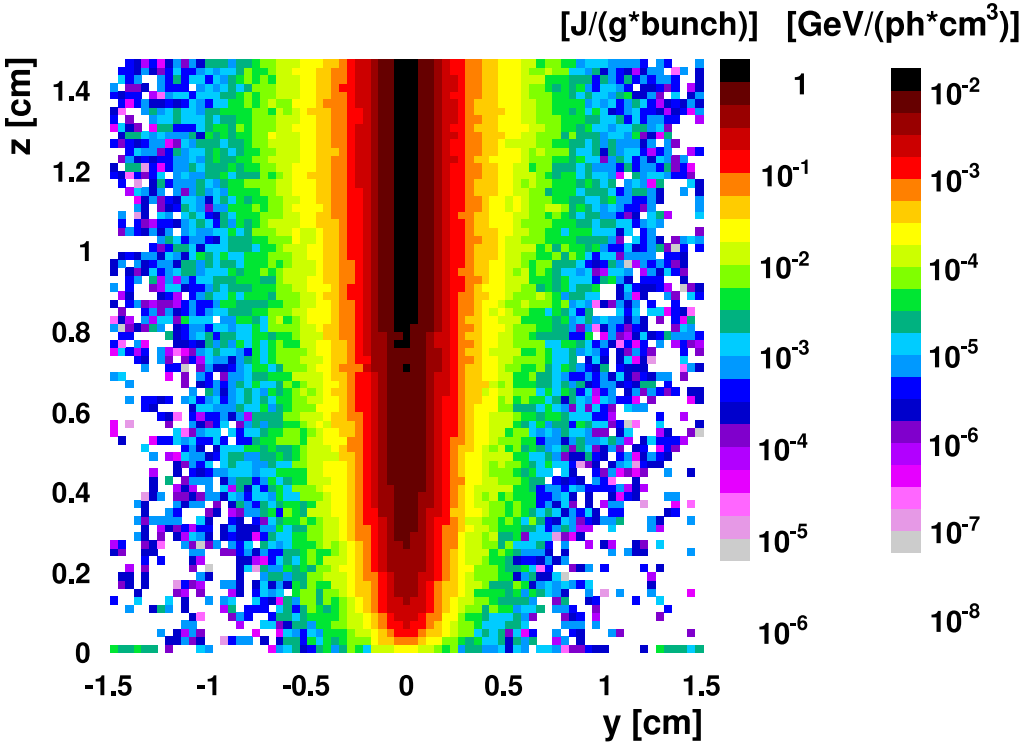
Calculated Energy Deposition along Beam Centerline [W. Stein et al. PAC2001]



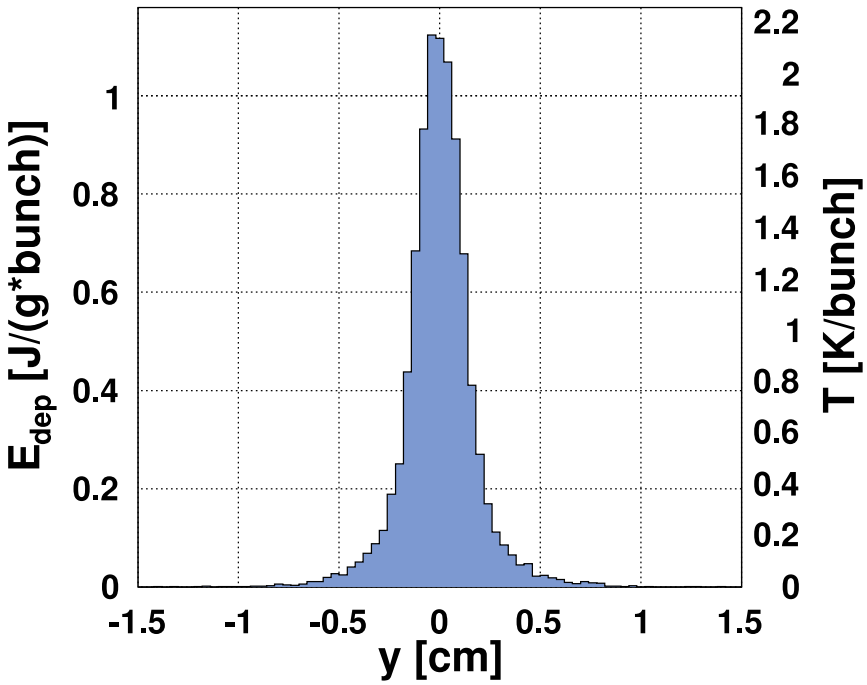
Deposited Energy and Temperature Rise per Bunch

- $2 \cdot 10^{10}$ e^-/bunch at 250 GeV
- 70 m RDR undulator
- 500 m middle of undulator to target distance

Energy Deposition in Ti6Al4V Target



E_{dep} and T Profile Near Back Side of Target

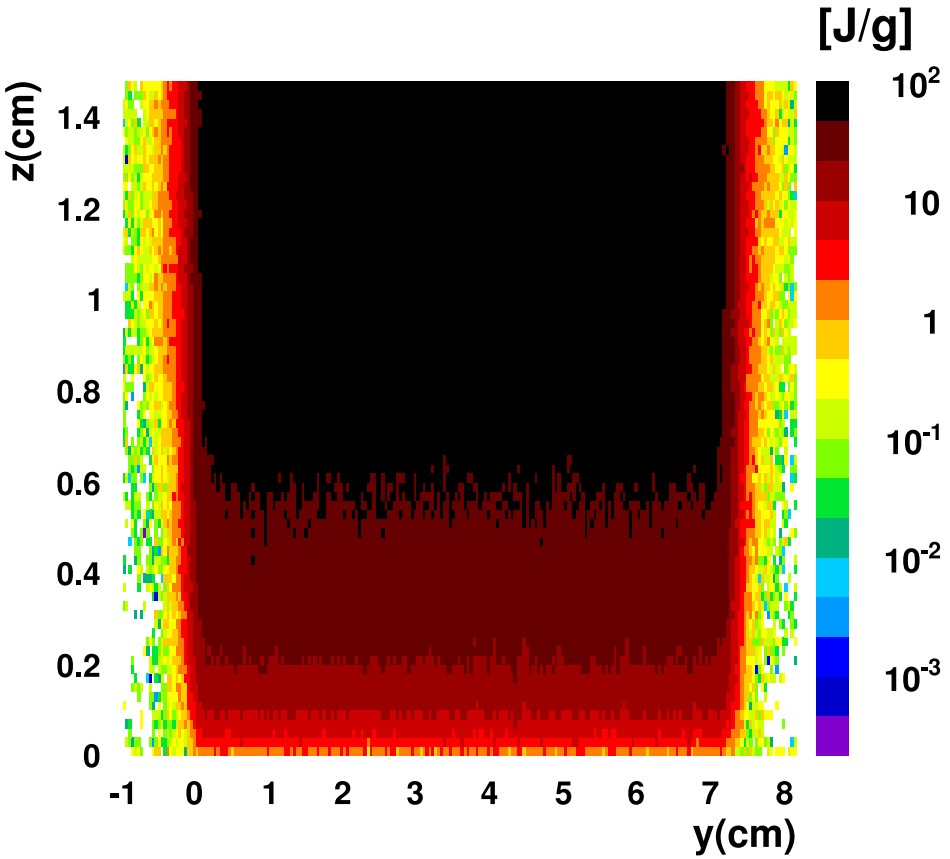


$$\delta T[\mathrm{K}] = E[\mathrm{GeV/(ph \cdot cm^3)}] \cdot 1.6 \cdot 10^{-10}[\mathrm{J/GeV}] \cdot 2 \cdot 10^{10}[\mathrm{e\text{-}/bunch}] \cdot 1.94[\mathrm{ph/(e\text{-}\ m)}] \cdot 70[\mathrm{m}] / / 4.49[\mathrm{g/cm^3}] / 0.523[\mathrm{J/(g\ K)}]$$

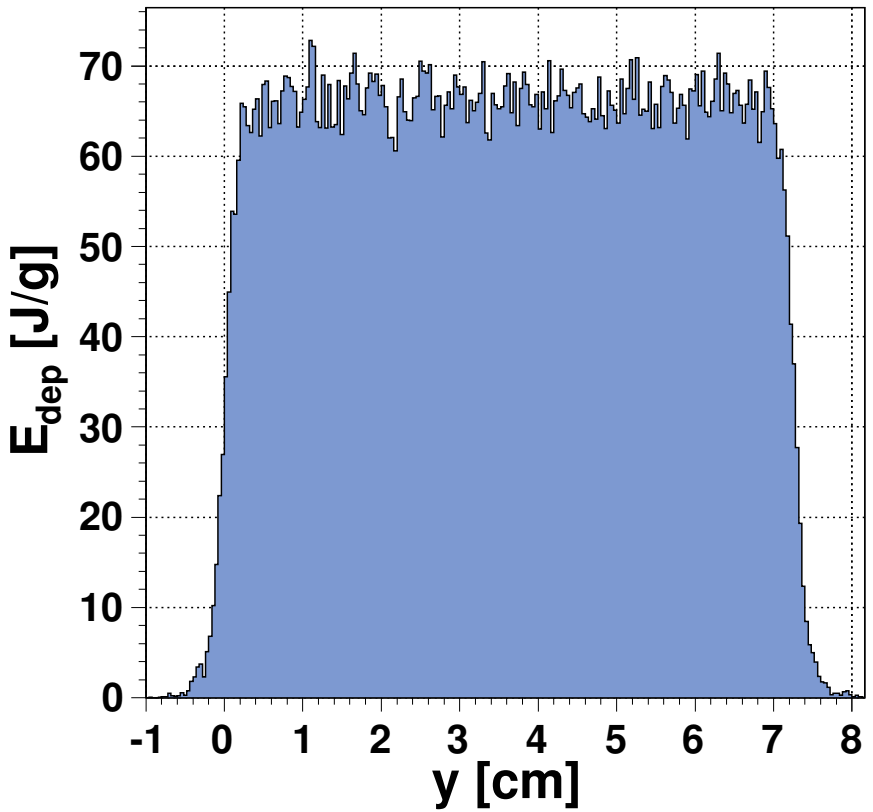
Energy Deposition per Pulse

- 1312 bunches/train, 554 ns bunch separation, 100 m/s

Energy Deposition Map



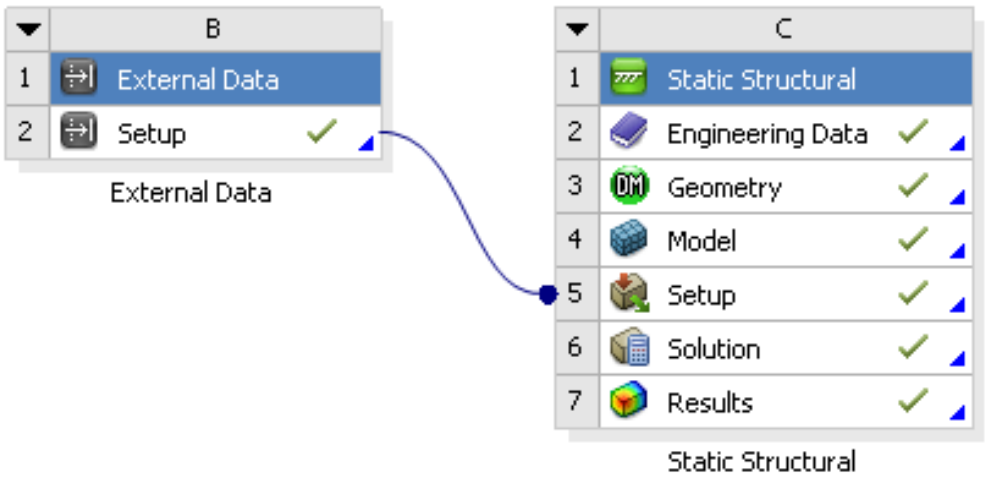
Deposited Energy Near Back Side of Target



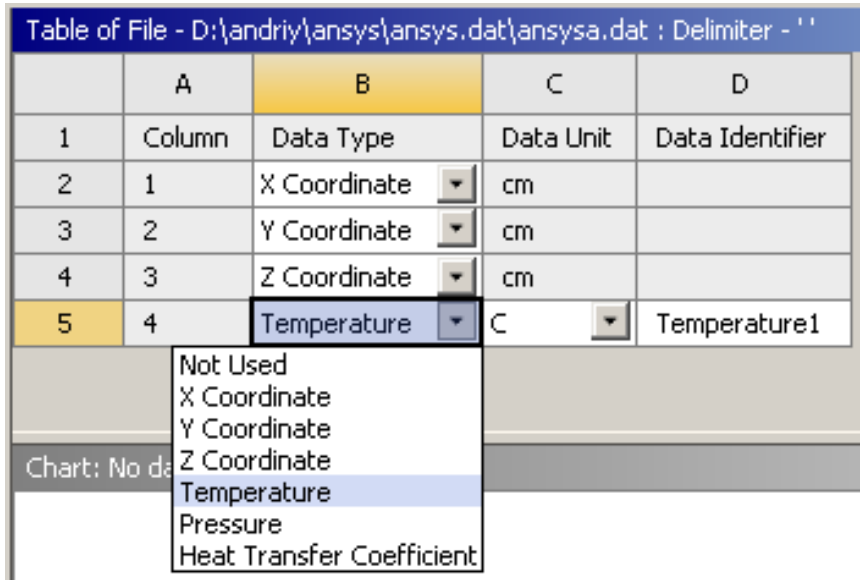
Bunch Overlapping Factor $\approx$ 66.34/1.12 = **59.1**

Import FLUKA Data into ANSYS Workbench

Structure of Project in ANSYS Workbench



Data Structure in External Data “Module”



Energy deposition per photon (original FLUKA data)

⇓ convert

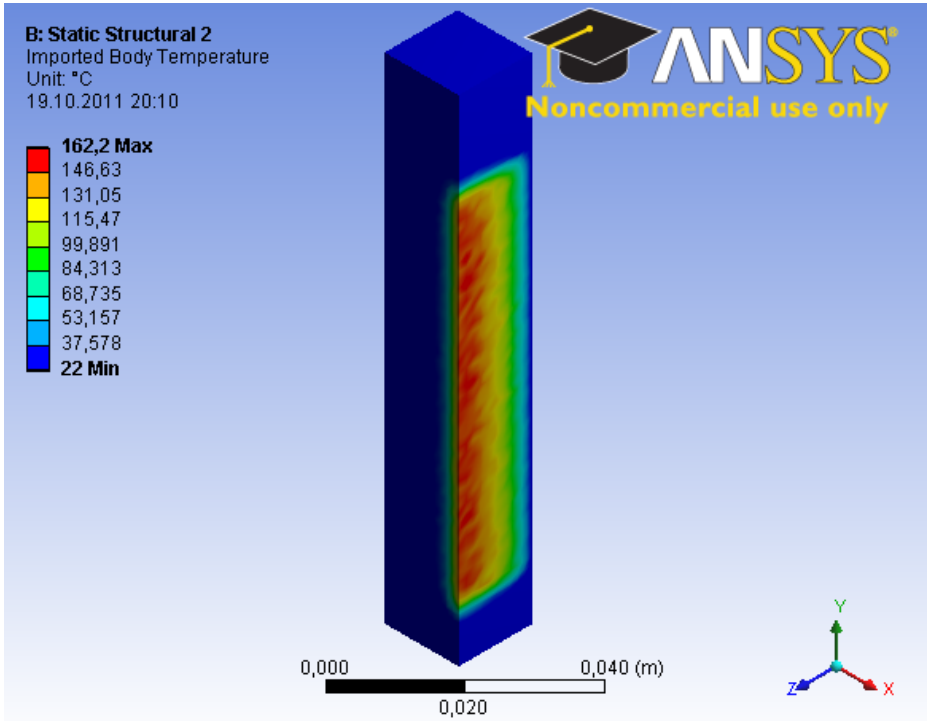
Spacial temperature distribution (after pulse or after “59.1” bunches)

⇓ transfer

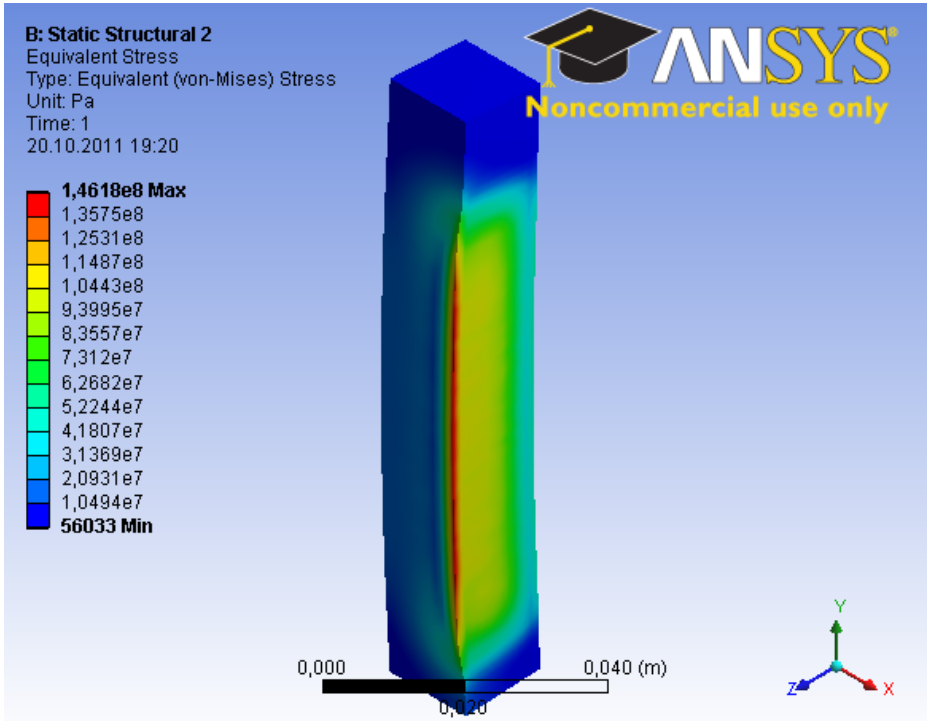
ANSYS Workbench

(*Static*) Temperature and Stress in Rotated Target

Temperature Distribution in Target



Equivalent Stress in Target



Maximal Static Equivalent Stress is about **146 MPa**

Tensile yield strength of Ti6Al4V is 880 MPa and ultimate strength is 950 MPa

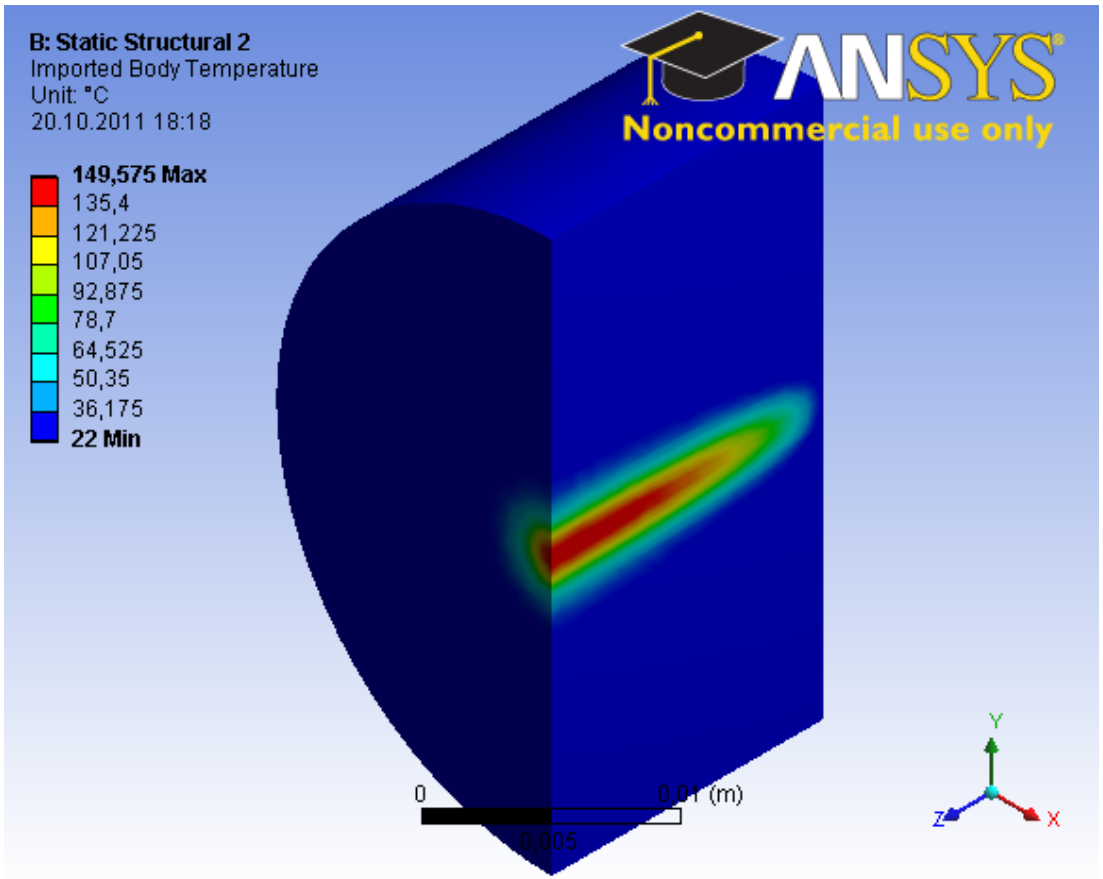
Considering the energy deposition in pulse (1312 $\times$ 554 ns = 0.727 ms) as instantaneous results in overestimation of deformation and stress in target

Second ANSYS Model. Temperature Distribution

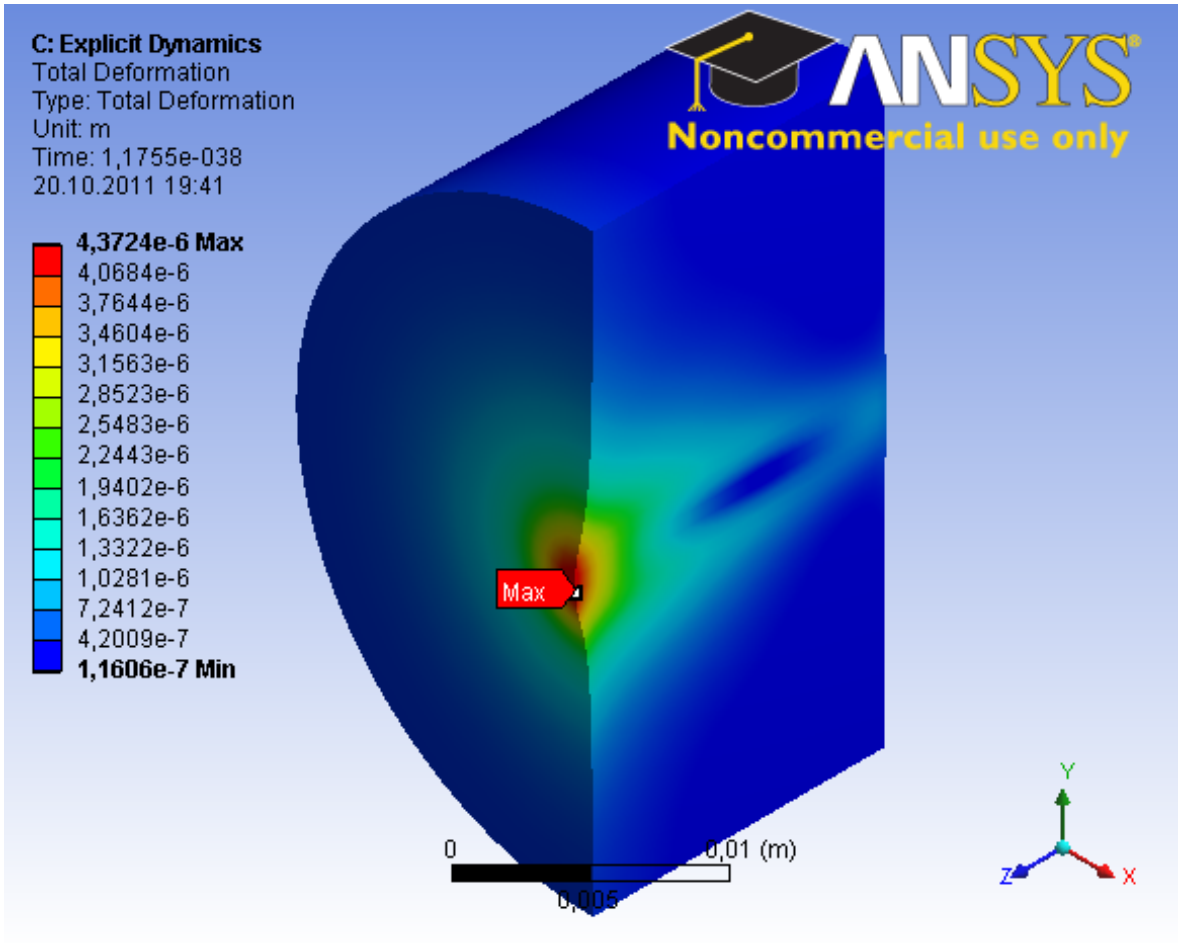
Second approach: 59 bunches crossing target at same place

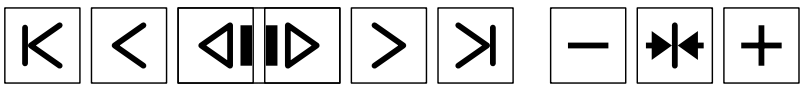
- Peak deposited energy is 66.3 J/g
- Smaller “hot” volume
- Higher gradients

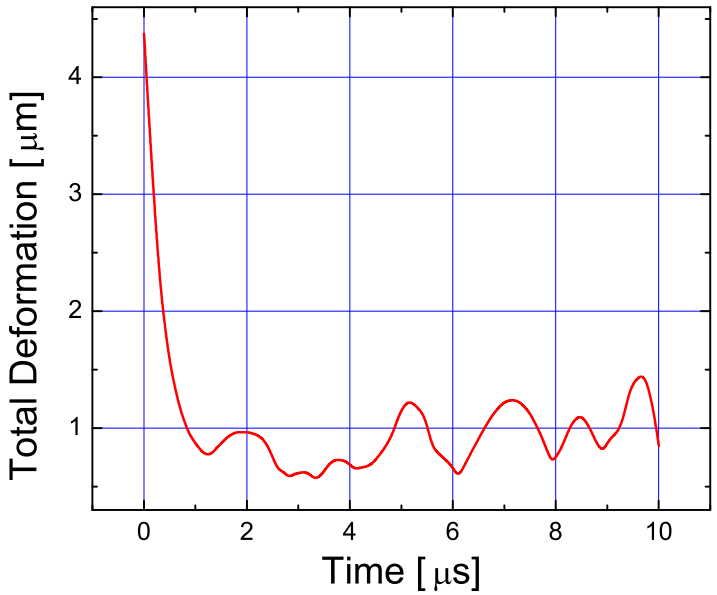
Temperature Distribution



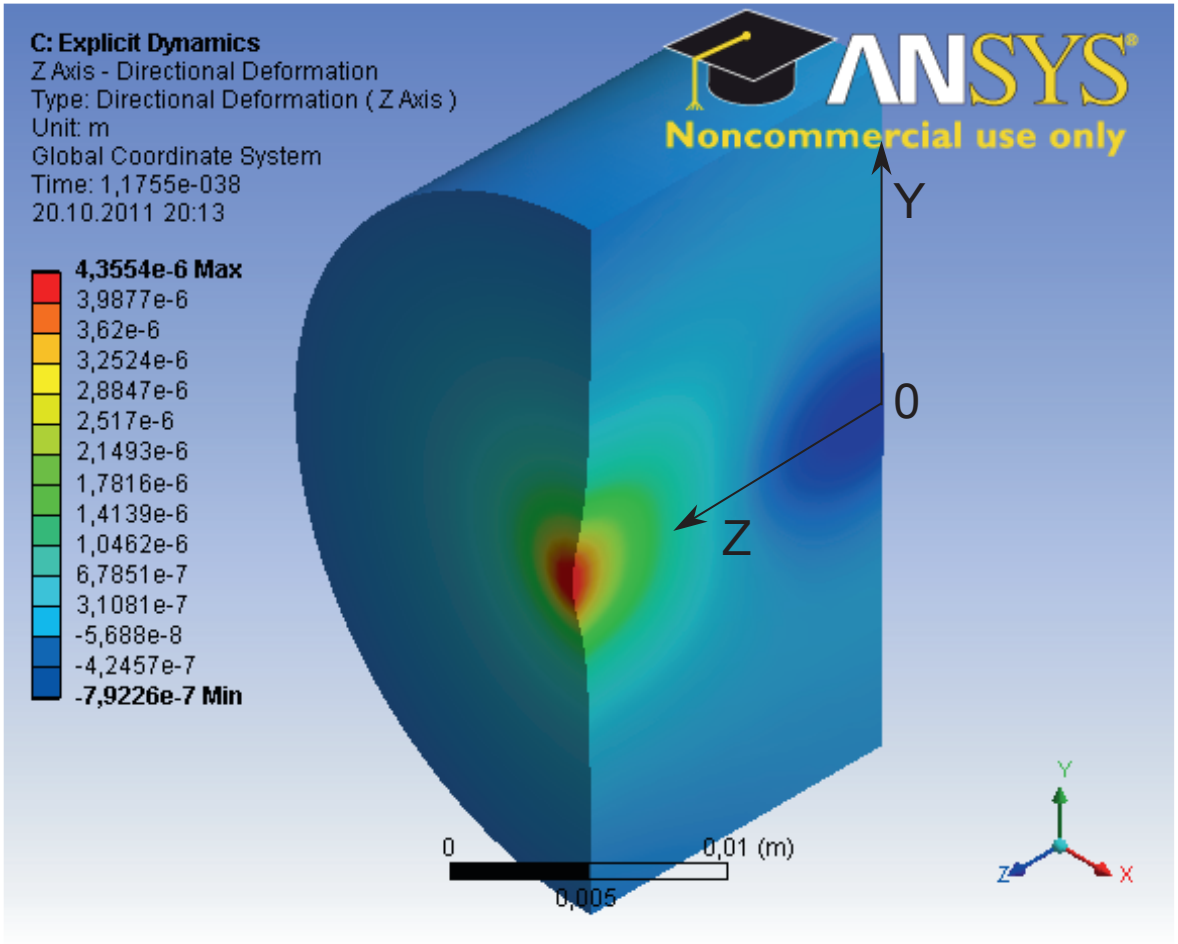
Total Deformation

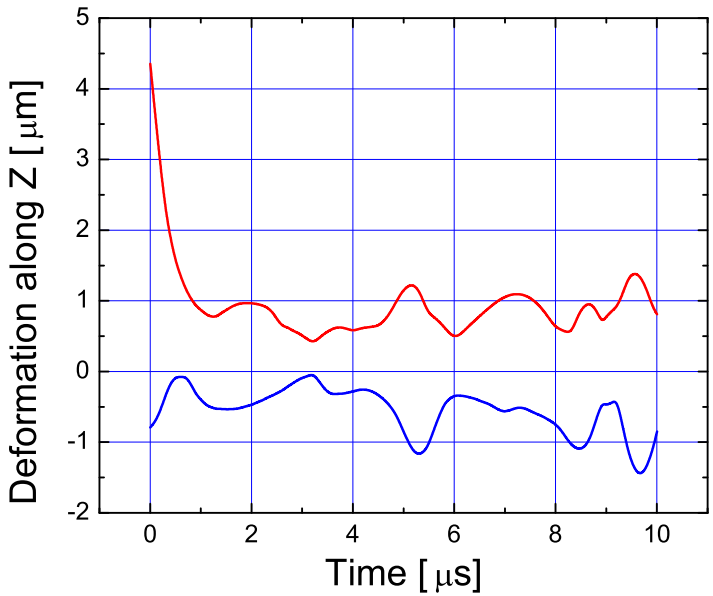




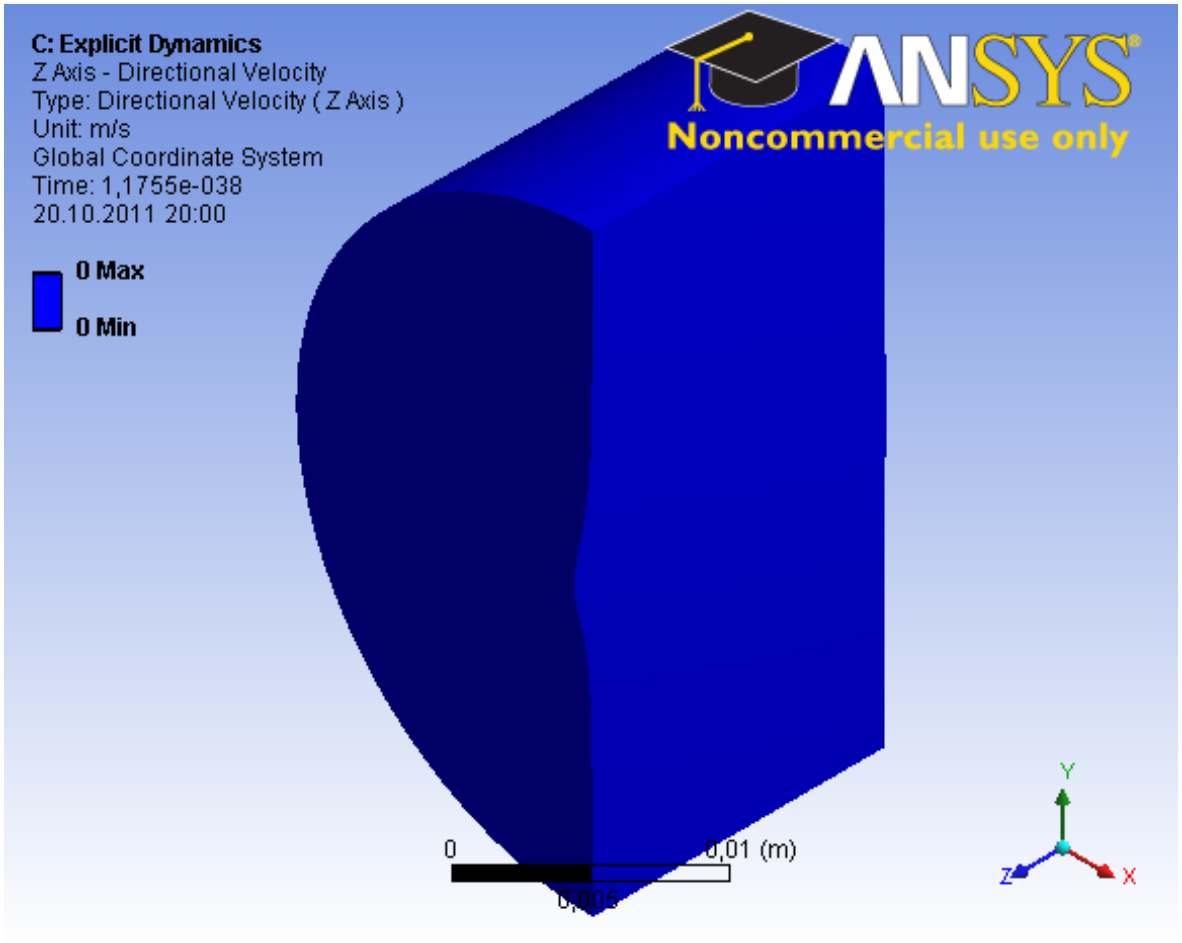


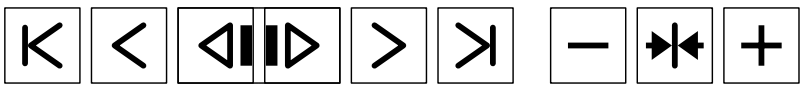
Directional Deformation (Z-Axis)

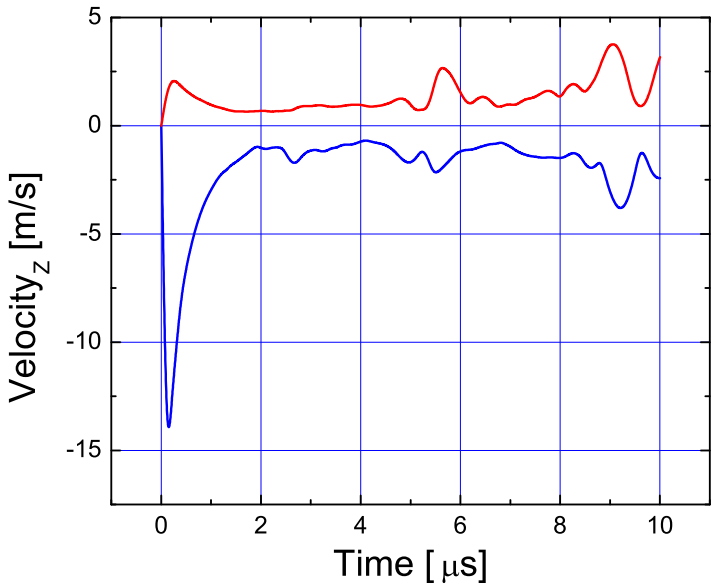




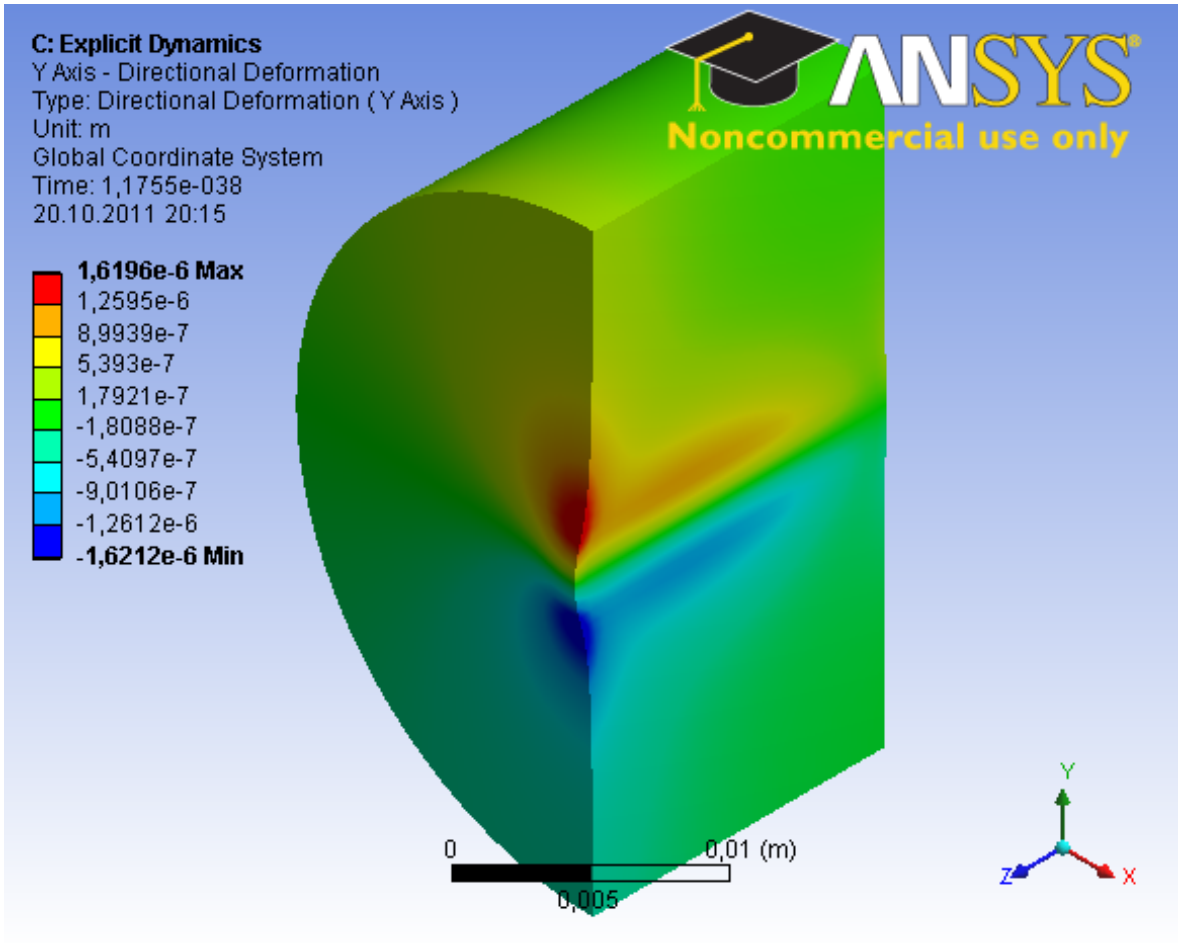
Directional Velocity (Z-Axis)

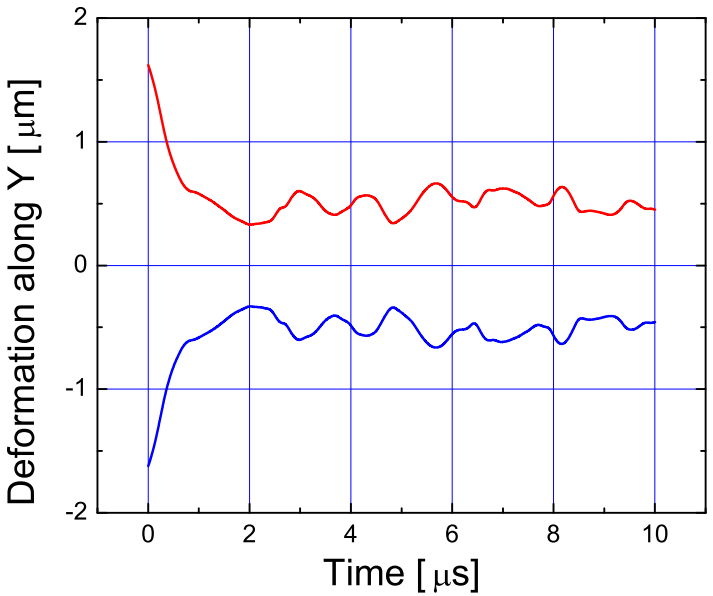




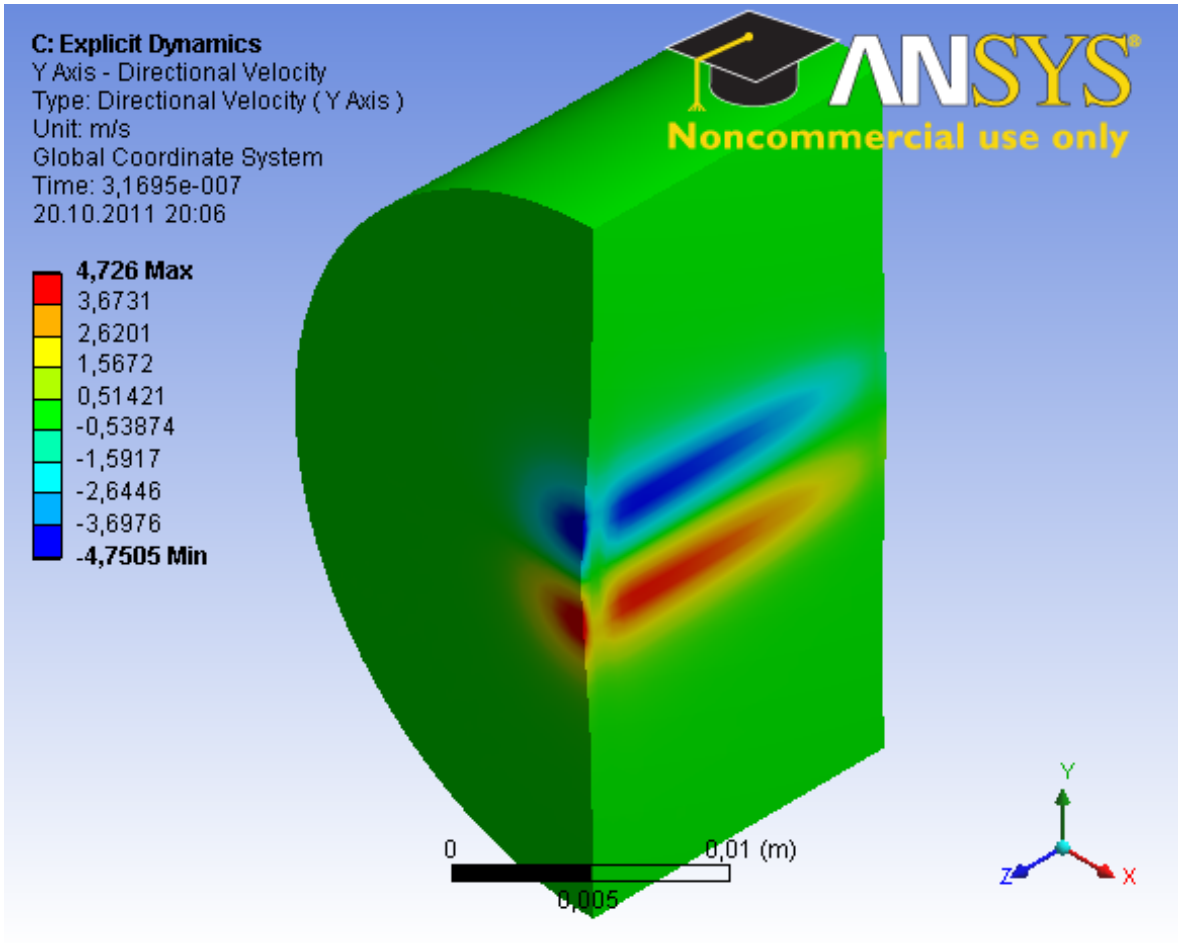


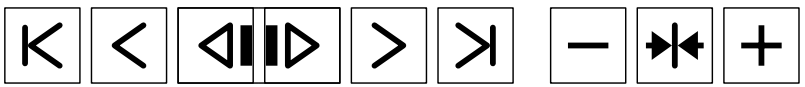
Directional Deformation (Y-Axis)

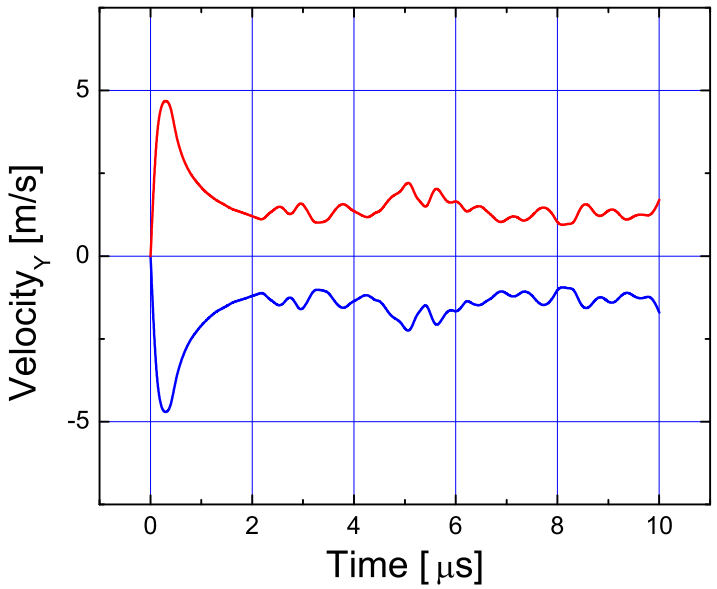




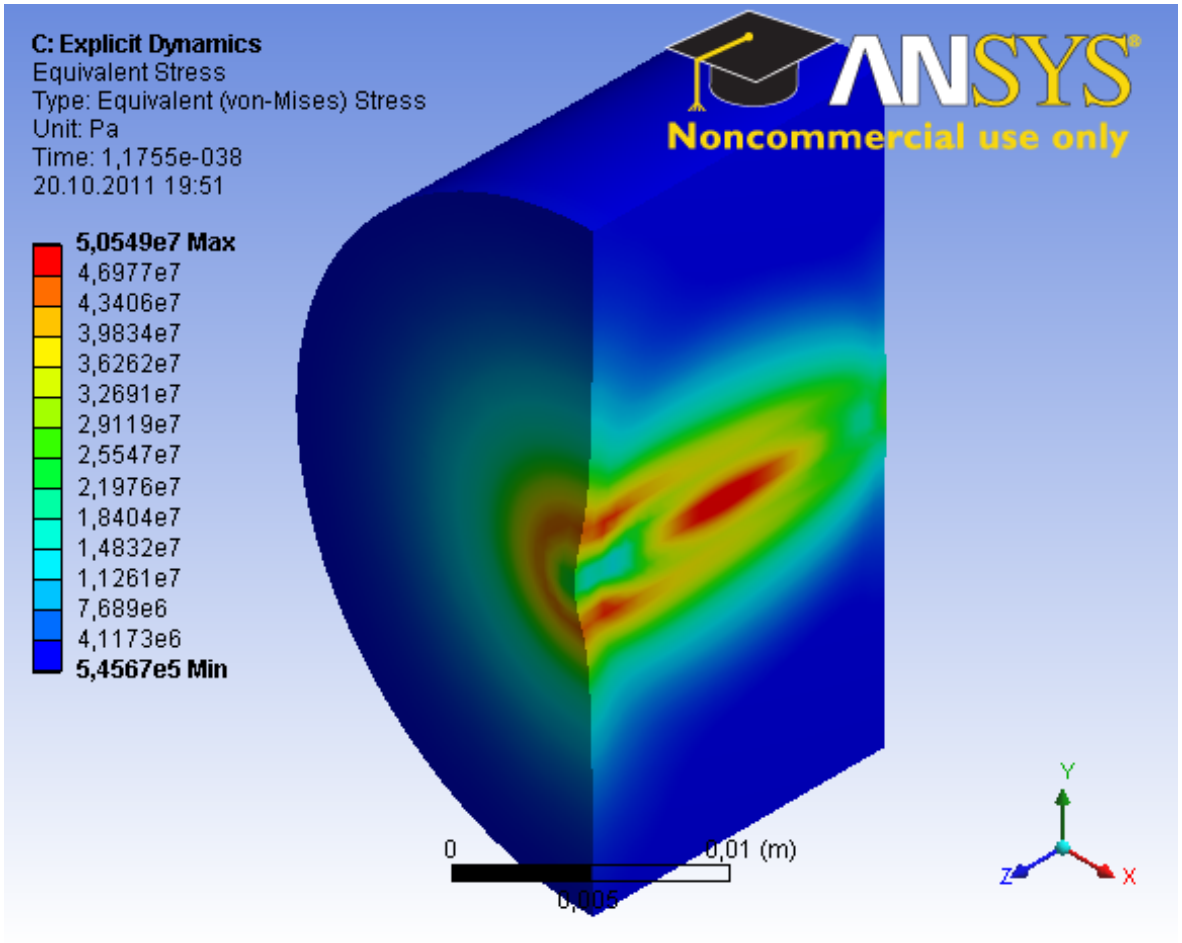
Directional Velocity (Y-Axis)

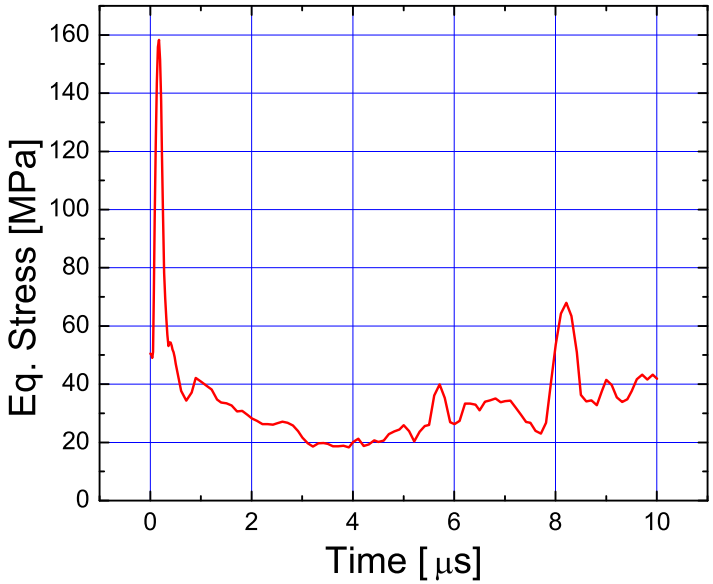






Equivalent Stress





PEDD and Eq. Stress in Target for Different Energies

PEDD and Stress for Different Bunch Separations and Energies

Bunch Separation [ns]	554			366		
e^- Energy [GeV]	150	175	250	150	175	250
Bunch Overlapping	90.6	82.1	59.1	137.1	124.2	89.4
PEDD[1] [J/g]	75.0	68.3	71.1	113.6	103.4	107.7
Peak Eq. Stress [MPa]	240	208	170	364	315.1	257

[1] PEDD for 0.4 mm mesh size

Center-of-mass energy [GeV]	200	250	350	500	1000
Pulse repetition rate [Hz]	10		5		4
Required undulator length [m]	231		150	75	?
Average photon beam power on target [kW]	279*	328*	168	164	?
Energy deposition per bunch [J]	1.17		0.92	0.61	?
Photon opening angle [μrad]	3.4		2.9	2.0	?
Peak energy density in target [J/g]	126		124	126.4	?
Peak eq. stress in target [MPa][2]	**404**		**378**	**302**	?

[2] Scaled stress for 366 ns bunch separation and given peak energy density

Summary and Outlook

- ANSYS simulations of thermal stress in target for different e^- energies have been performed
- Peak equivalent stress for 2625 bunches/train and QWT is in range between 300 MPa (500 GeV CM energy) and 400 MPa (300 GeV and below) that is about 32% and 42% of ultimate tensile stress

Next steps:

- Calculate stress in target for source with low K undulator, photon collimator
- Study temperature and stress evolution during the pulse
- Include change of target material properties
- Simulate real target geometry including cooling
- Further development of FlexPDE model (many thanks to Alexander Mikhailichenko for the help), especially to analyze negative pressure and acceleration of thin layer close to the backside of target at the end of bunch/pulse
- Material test experiment?

Backup Slides

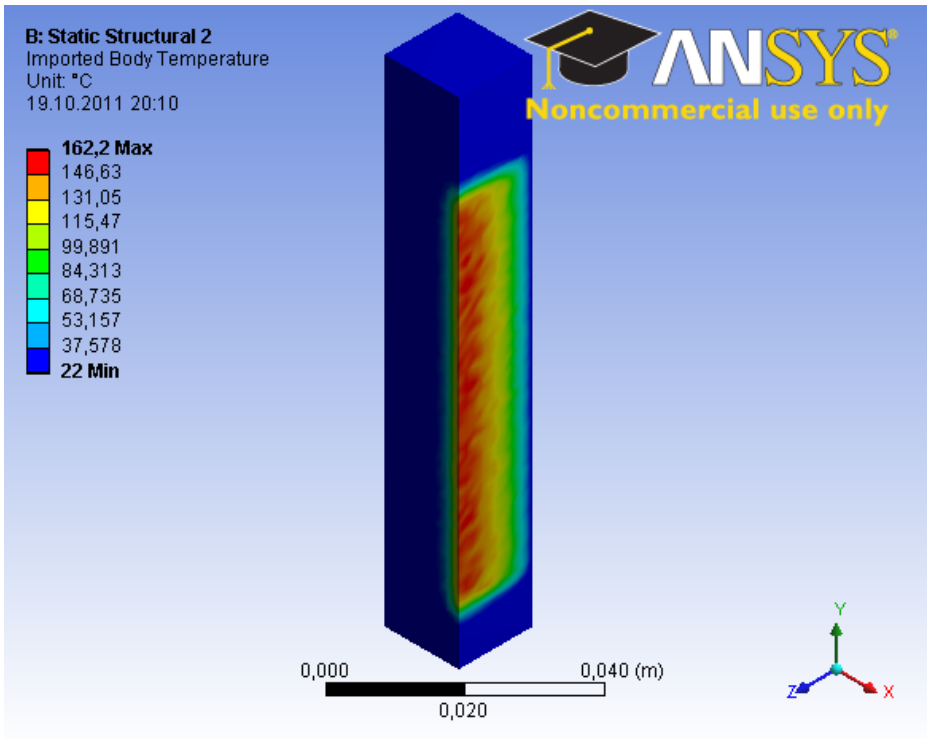
Material Properties

Properties of Outline Row 12: Titanium Alloy

	A	B	C
1	Property	Value	Unit
2	Density	4620	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	9,4E-06	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	9,6E+10	Pa
9	Poisson's Ratio	0,36	
10	Bulk Modulus	1,1429E+11	Pa
11	Shear Modulus	3,5294E+10	Pa
12	Tensile Yield Strength	9,3E+08	Pa
13	Compressive Yield Strength	9,3E+08	Pa
14	Tensile Ultimate Strength	1,07E+09	Pa
15	Compressive Ultimate Strength	0	Pa

(*Static*) Temperature and Deformation in Rotated Target

Temperature Distribution in Target



Total Deformation