Photon collimator design and ILC target studies

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- ILC target unit (Ti wheel and collimator stages)
- Parameter table with different collimator settings (250GeV – 500 GeV)
- Collimator cooling design (high lumi)
- Dynamic stress and temperature evolution in a test target (high lumi)
- Velocity and stress calculations in the SLAC target
- Conclusion

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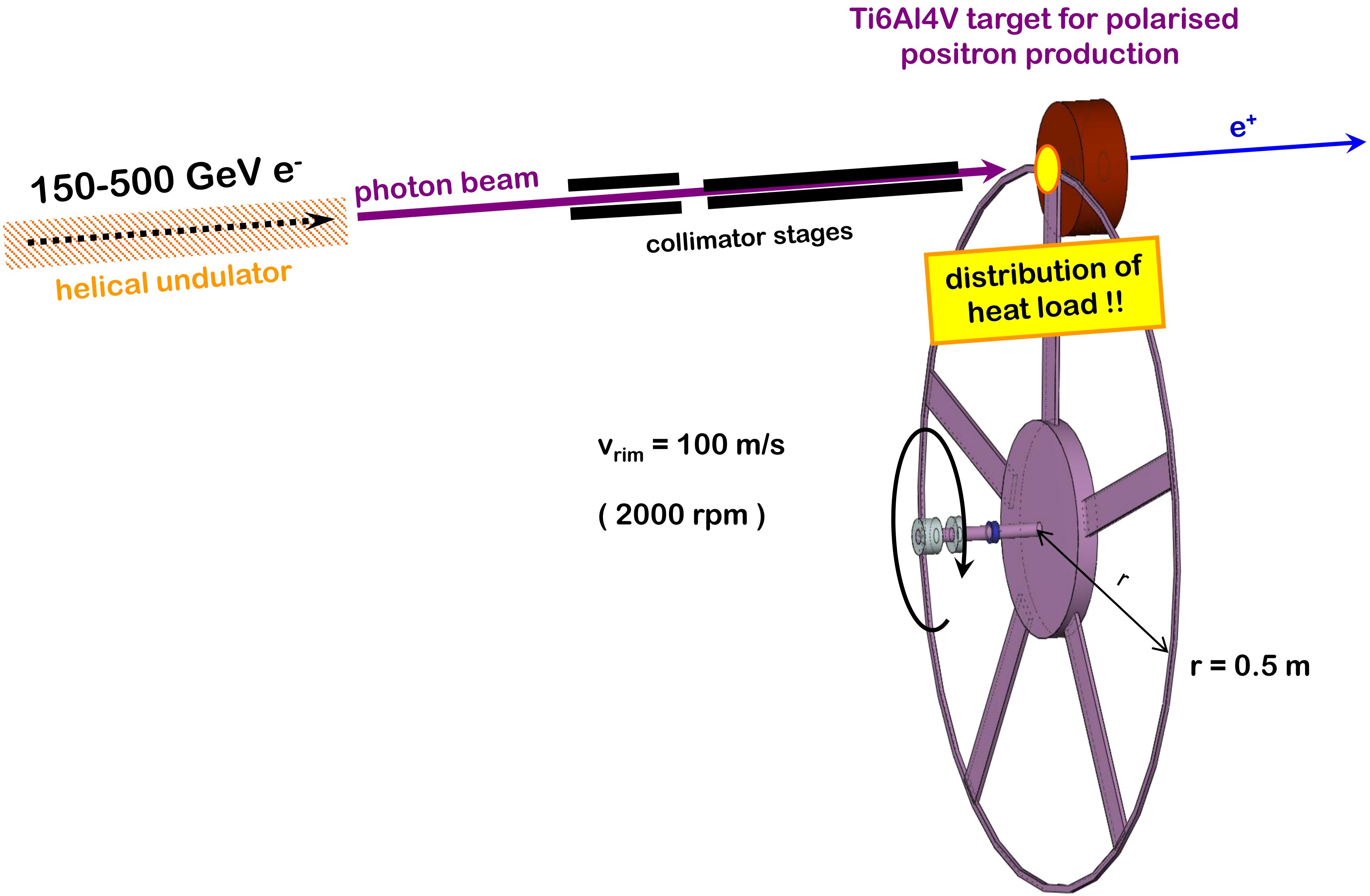
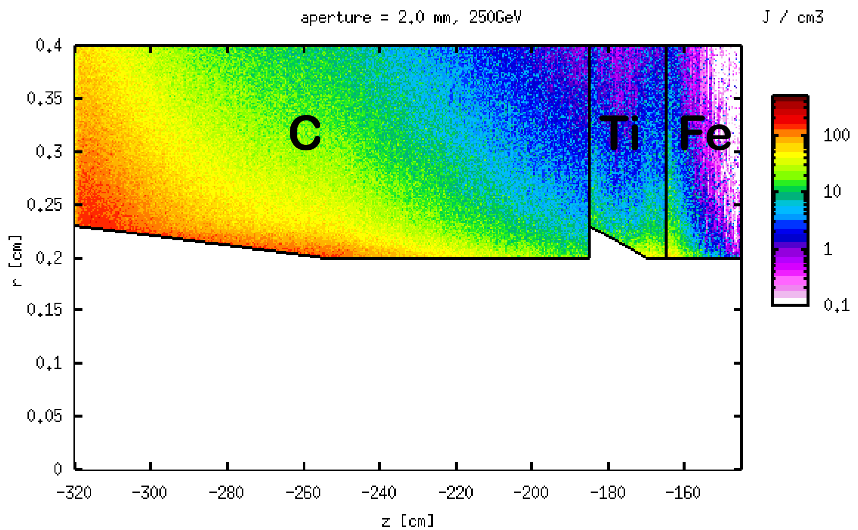
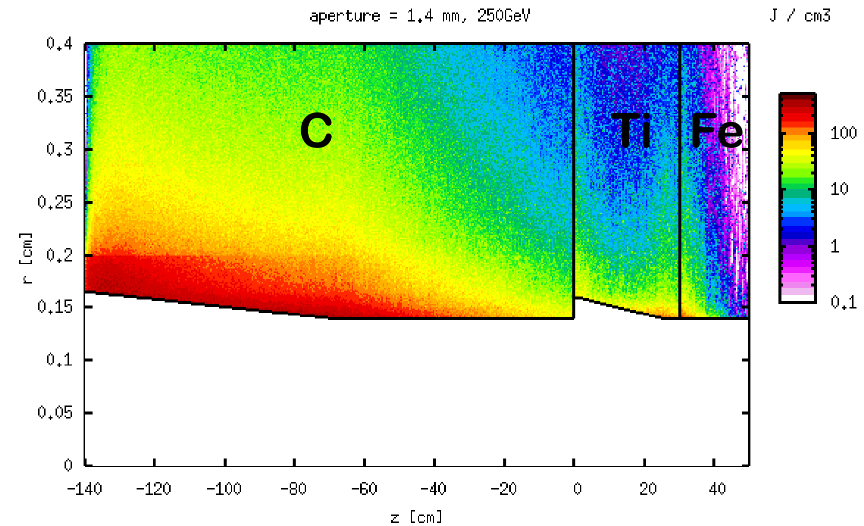
DESY

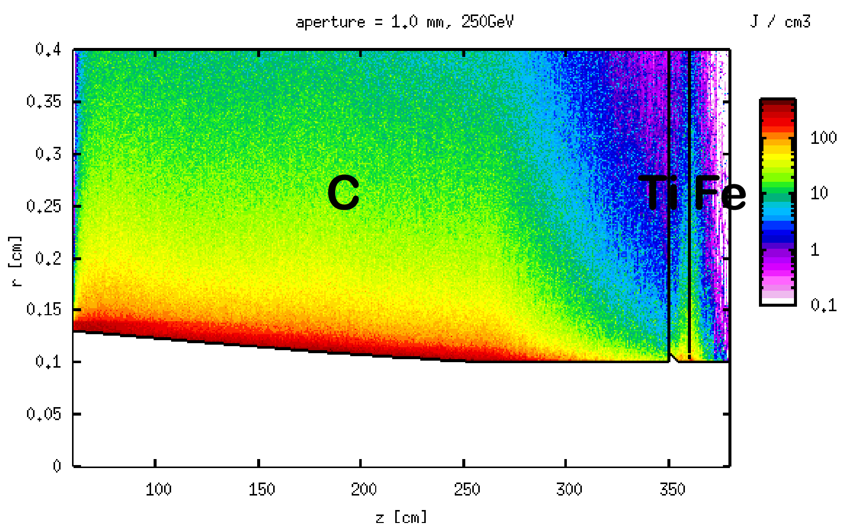
ILC target unit (Ti wheel and collimator stages)



250 GeV energy deposition (high lumi)







parameter table with different collimator settings

Photon Collimator Parameters

						L upgrade			E_{cm} upgrade	
			Centre-of-mass energy Ecm (GeV)							
Parameter			**250**	**350**	**500**		**500**		**1000**	
Pulse repetition rate		Hz		5,0			5,0		4,0	
Number of bunches	n_b			1312,0			2625,0		2450,0	
Positron bunch populatio	N_+	$\times 10^{10}$		2,0			2,0		1,7	
undulator period length	λu	cm		1,2			1,2		4,3	
Effective undulator field	B_{und}	T		0,9		0,4	0,9	0,9	0,6	0,8
				K=0.92		K=0.45	K=0.92	K=0.92	K=2.5	K=3.0
Photon Yield per electron	n_{ph} / e-			2,0		0,5	2,0		1,6	1,8
Active undulator length	L_{und}		231,0	196,0	70,0	147,0	70,0	143,5	176,0	176,0
Photons per bunch train	n_{ph} / train	$\times 10^{15}$	11,8	10,0	3,6	4,0	7,2	14,6	12,2	13,3
Average photon power	P_{photon}	kW	98,5	113,8	83,0	88,0	166,0	346,2	115,1	93,3
Abs.ph. power in collim.	$P_{collimator}$	%	48,8	60,4	52,3	-	52,3	70,1	45,6	42,8
Collimator radius	r	mm	2,0	1,4	1,0	-	1,0	0,7	1,0	1,2
Positron Polarization	P_+	%	55,3	58.5	50,3	28,8	50,3	58,7	51,1	52,2
collimator r=2.0 / Pyr. C	E_{max}	J/g	177	144	36		72			
collimator r=2.0 / Pyr. C	P	kW	44,8	36,3	7,9		15,8			
collimator r=2.0 / Ti	E_{max}	J/g	16	18	6		11			
collimator r=2.0 / Ti	P	kW	0,8	0,8	0,2		0,4			
collimator r=2.0 / Fe	E_{max}	J/g	13	13	5		10			
collimator r=2.0 / Fe	P	kW	0,2	0,3	0,1		0,2			
cooling / Cu	P	kW	2,3	1,9	0,4		0,8			
collimator r=1.4 / Pyr. C	E_{max}	J/g		183	73		146			
collimator r=1.4 / Pyr. C	P	kW		25,9	12,9		25,8			
collimator r=1.4 / Ti	E_{max}	J/g		22	30		30			
collimator r=1.4 / Ti	P	kW		0,9	0,6		1,2			
collimator r=1.4 / Fe	E_{max}	J/g		13	11		22			
collimator r=1.4 / Fe	P	kW		0,2	0,1		0,2			
cooling / Cu	P	kW		2,4	1,2		2,4			
collimator r=1.0 / Pyr. C	E_{max}	J/g			82		163			
collimator r=1.0 / Pyr. C	P	kW			17,9		35,8			
collimator r=1.0 / Ti	E_{max}	J/g			13		26			
collimator r=1.0 / Ti	P	kW			0,2		0,4			
collimator r=1.0 / Fe	E_{max}	J/g			9		19			
collimator r=1.0 / Fe	P	kW			0,1		0,2			
cooling / Cu	P	kW			1,8		3,6			

Parameter / length of / (r_{out})	Unit	1.colli. (r=2mm)	2.colli. (r=1.4mm)	3.colli. (r=1mm)
pyrolytic C	cm	135 (7.0)	140 (4.5)	290 (4.5)
Titanium	cm	20 (4.5)	30 (4.5)	10 (4.5)
Iron	cm	20 (4.5)	20 (4.5)	20 (4.5)
total length	cm	175	190	320

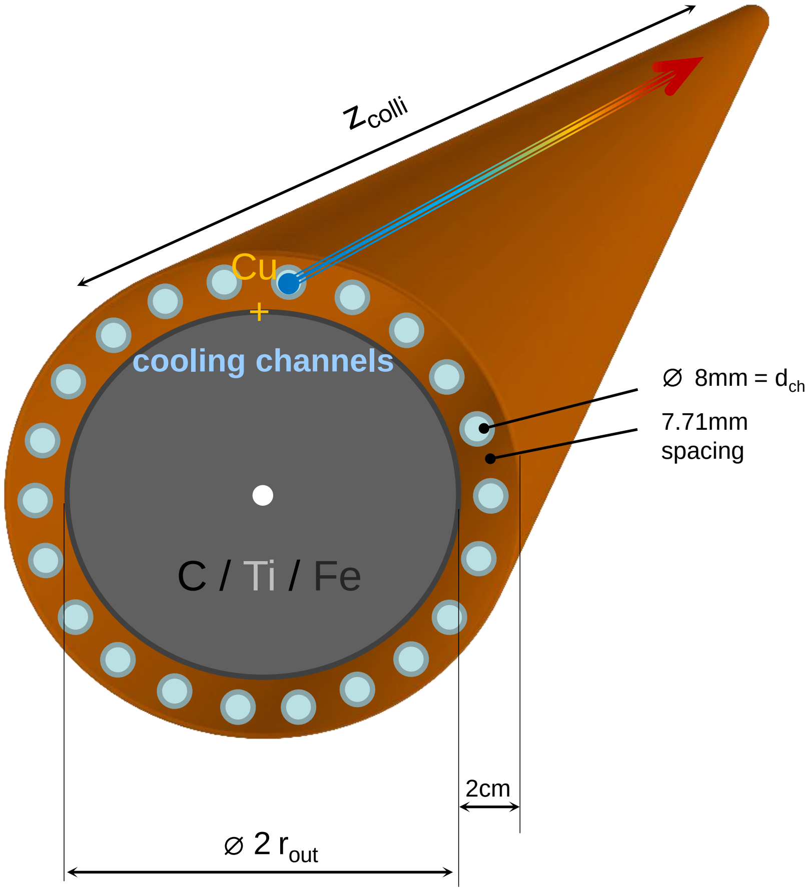
		Pyr. C	Ti	Fe (ST70)	W (annealed)	W26Re (hardened)
Fatique Temperature : (Ansys) T	°C	900	600	130	185	500
Fatique Energy : (Ansys) $E_{fatique}$	J/g	753	314	58	24	64
Fatique Yield Strength : (Ansys) $P_{fatique}$	M Pa	40	340	280	440	600
Exp. Fatique Yield Strength : 0.4 R_{max}	M Pa	36	356	280	440	600
Exp. Yield Strength : R_{max} / $R_{elastic}$	M Pa	90	890 / 820	700 / 340	1100 / 800	1500 / 1200

$$\xrightarrow{\text{cyl.}} Q = \frac{\lambda\, 2\pi\, z_{colli}\, \Delta T}{\ln\left({}^{r_{out}}/_{r_{in}}\right)}$$

$$\mathbf{Q}_{cool}/\mathbf{chan.} \approx \mathbf{0.3}\ \mathbf{kW}/\mathbf{m^2}\,K \quad \Leftrightarrow \quad \bar{v}_{water} = 2\ {}^{m}/_{s} \xRightarrow{d_{ch}=8mm} \mathbf{0.1}\ {}^{l}/_{s}$$

$$\mathrm{Re} = \frac{\bar{v}_{water}\, d_{ch}}{\nu(T = 30°C)_{kin\ vis}} = \frac{\bar{v}_{water}\, d_{ch}\, \rho}{\eta(T = 30°C)_{dyn\ vis}} \approx 2000 < 2300 = \mathrm{Re}_{krit,\ laminar}$$

$$r_{out} = \begin{cases} 7.5\text{cm} \Rightarrow Q_{cool}(34\text{ ch}) \approx 10.2\ \text{kW}/\text{m}^2\,\text{K} \\ 4.0\text{cm} \Rightarrow Q_{cool}(20\text{ ch}) \approx 6.0\ \text{kW}/\text{m}^2\,\text{K} \\ 3.0\text{cm} \Rightarrow Q_{cool}(16\text{ ch}) \approx 4.8\ \text{kW}/\text{m}^2\,\text{K} \end{cases}$$



$$\Delta T = T_{in} - T_{out}(20°C) = \frac{Q_0 \ln\left({}^{r_{out}}/_{r_{in}}\right)}{\lambda\, 2\pi\, z_{colli}}$$

$$\xRightarrow{+\ cooling} T_{in} = \frac{Q_0 \ln\left({}^{r_{out}}/_{r_{in}}\right)}{\lambda\, 2\pi\, z_{colli}} + \text{Tout}(20°C) + \underbrace{\frac{Q_{0\ norm}}{Q_{cool}}}_{\text{cooling}}$$

$$Q_{0\ norm} = \frac{Q_0}{2\pi\, r_{out}\, z_{colli}}\ \text{kW}/\text{m}_2$$

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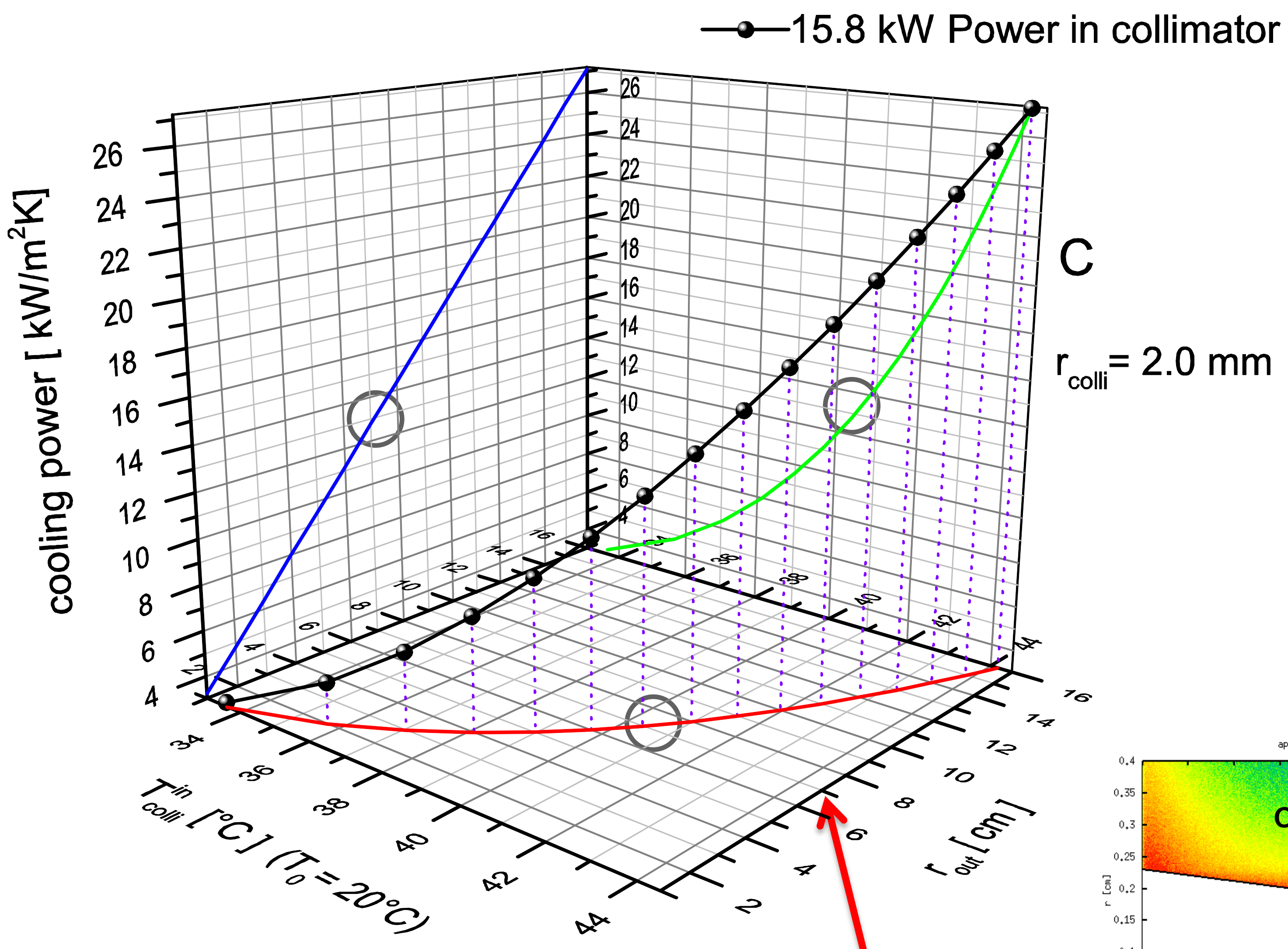
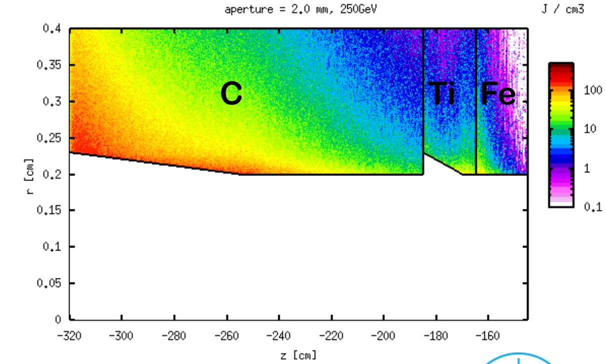
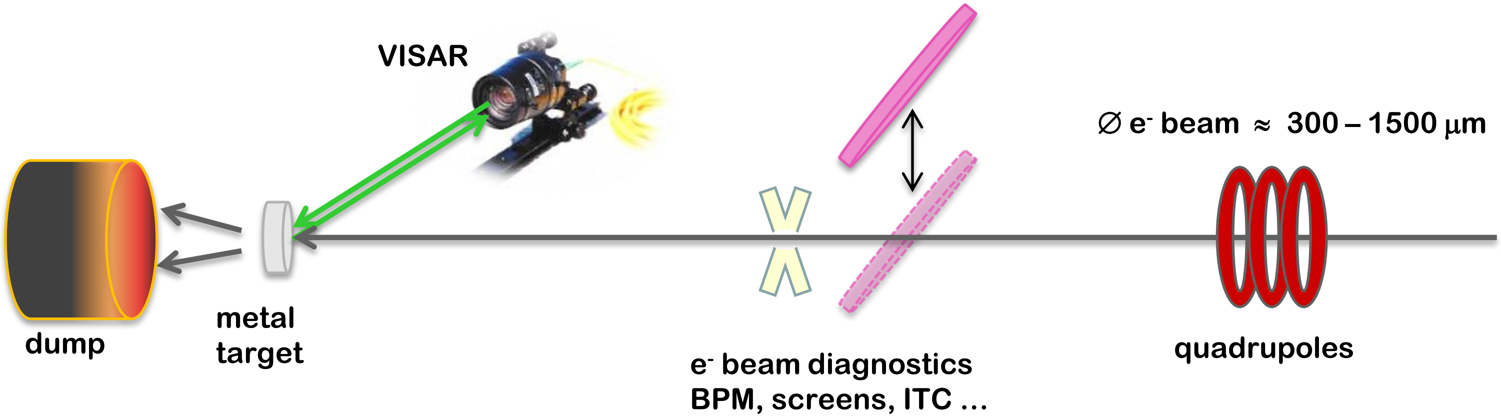
DESY

250 GeV cooling and temperature (high lumi)





Experimental setup for material tests



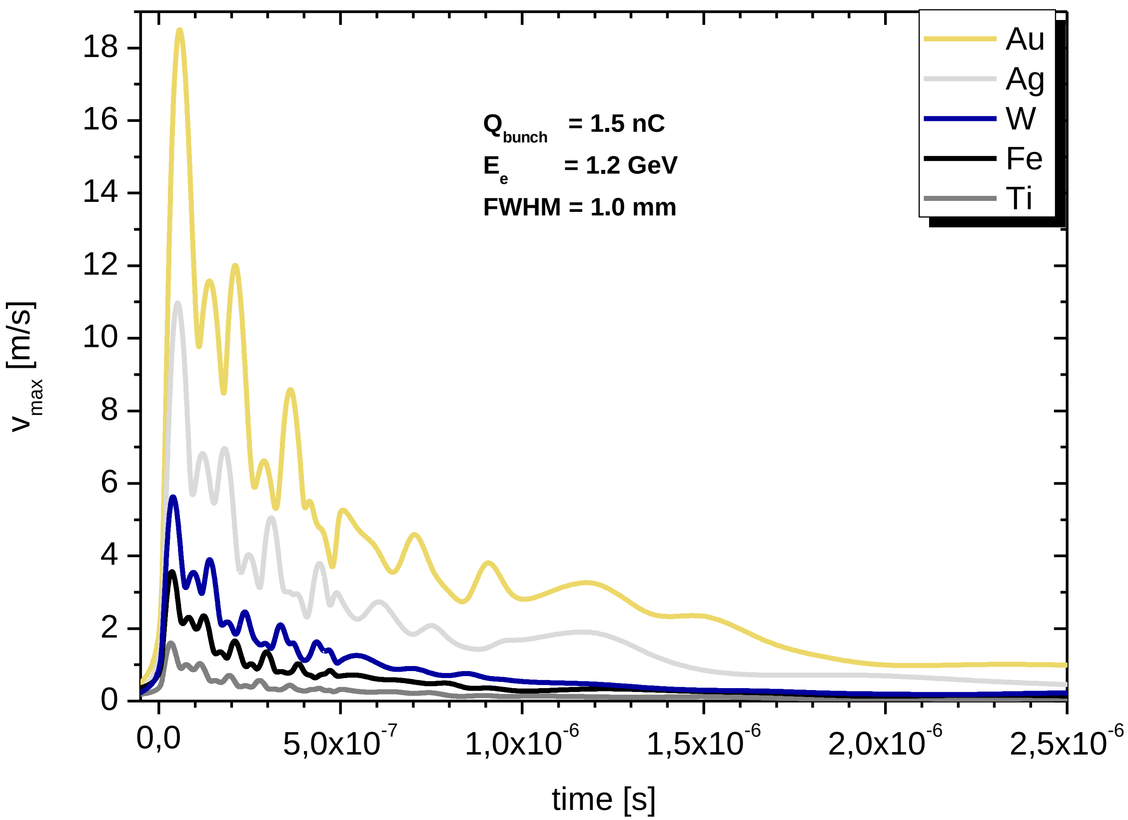
- Quadrupoles ⇔ focus beam to the test material (e.g. Ag, Brass, Fe, Ti)
- Radiation issues : disturpted beam has to be absorbed in the dump

Expected material dynamics

FLASH e⁻ beam

E_{e-} = 1.2 GeV (1 bunch, 1.5 nC)

beam ∅ = 1000 μm (FWHM)



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DESY

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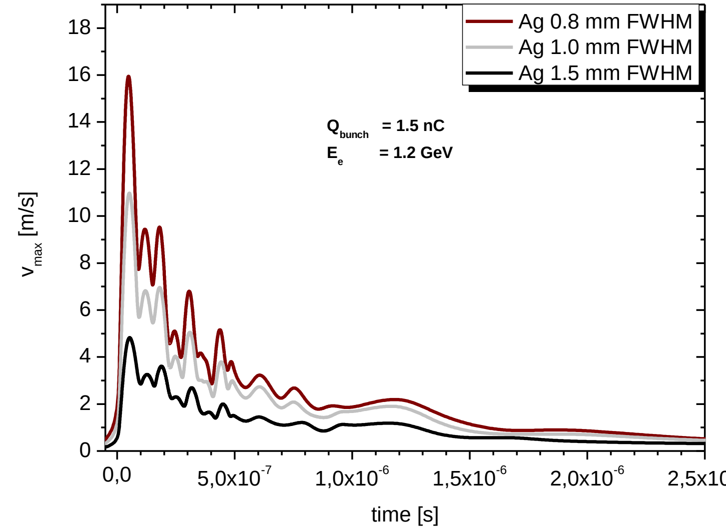
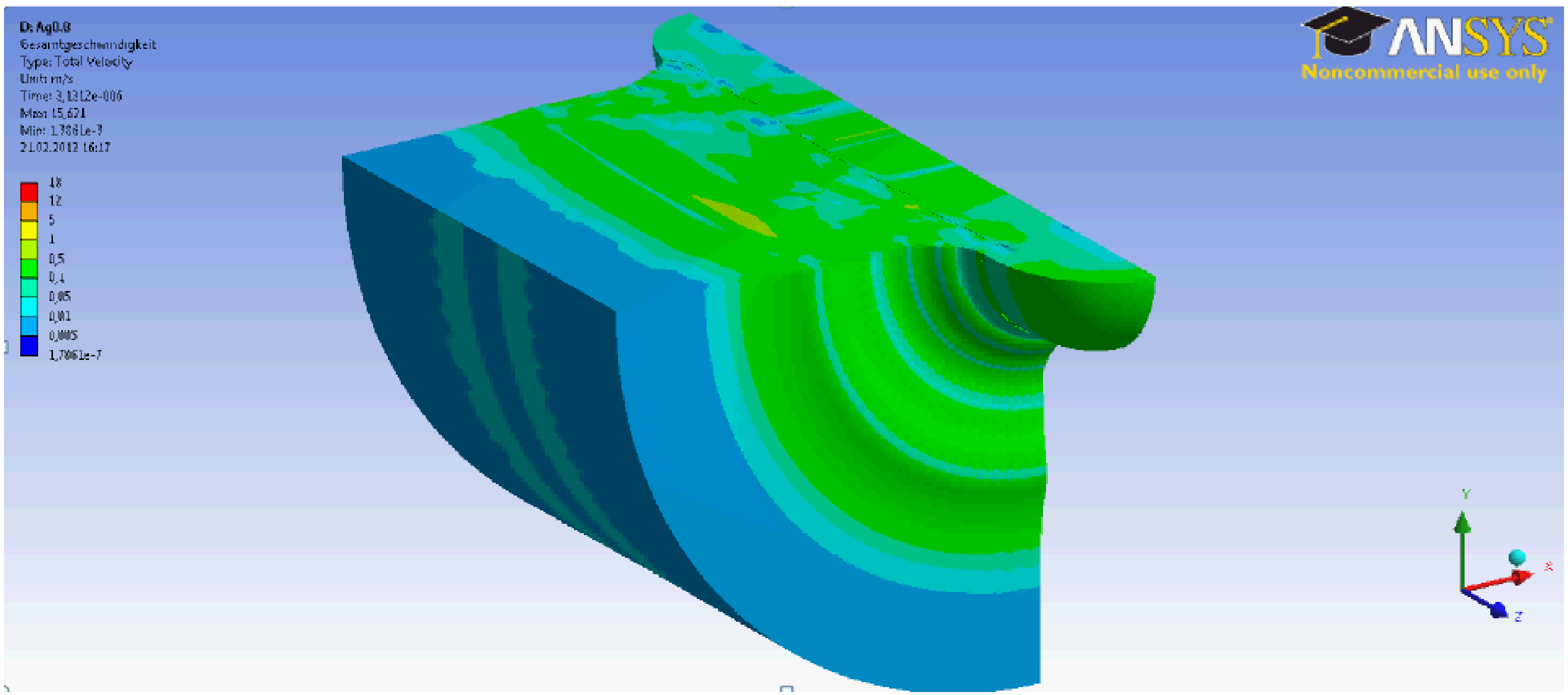
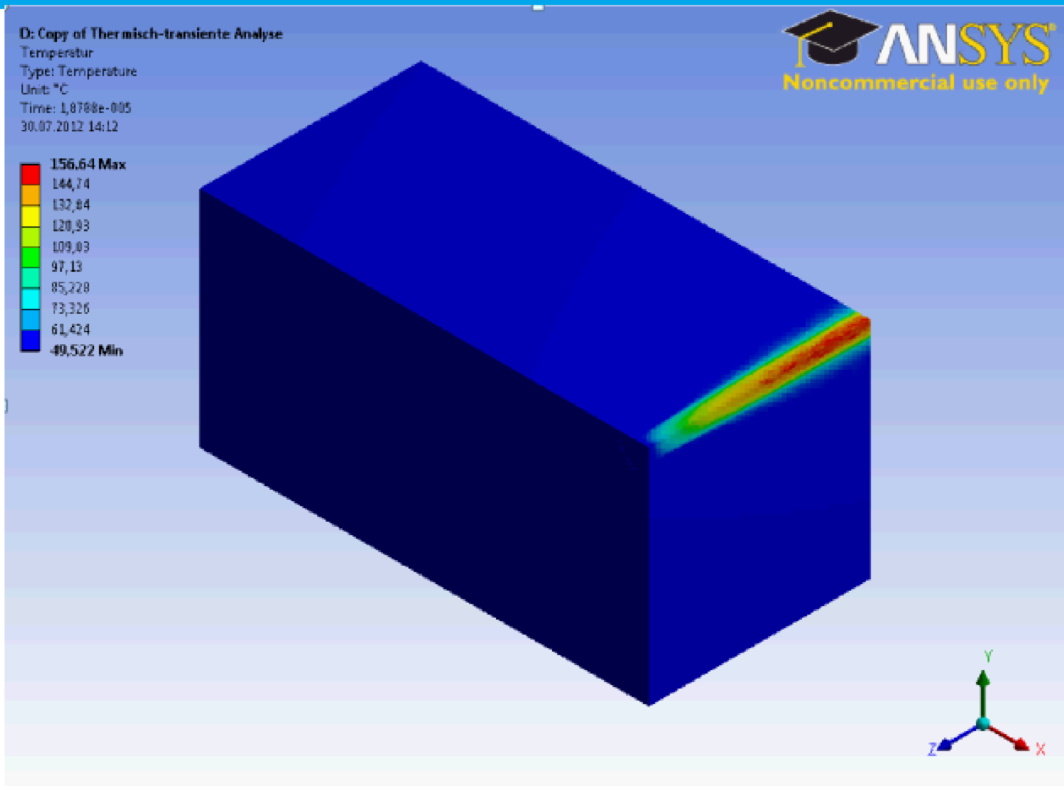
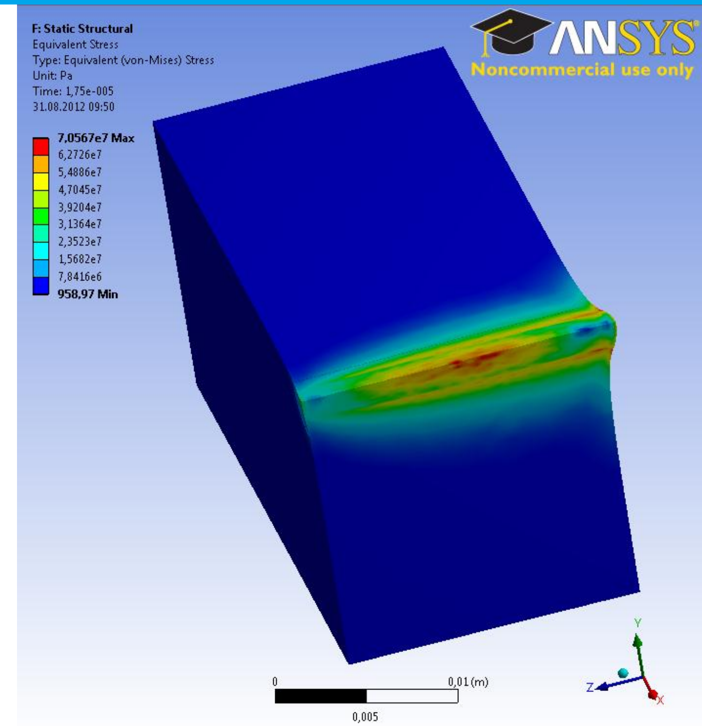
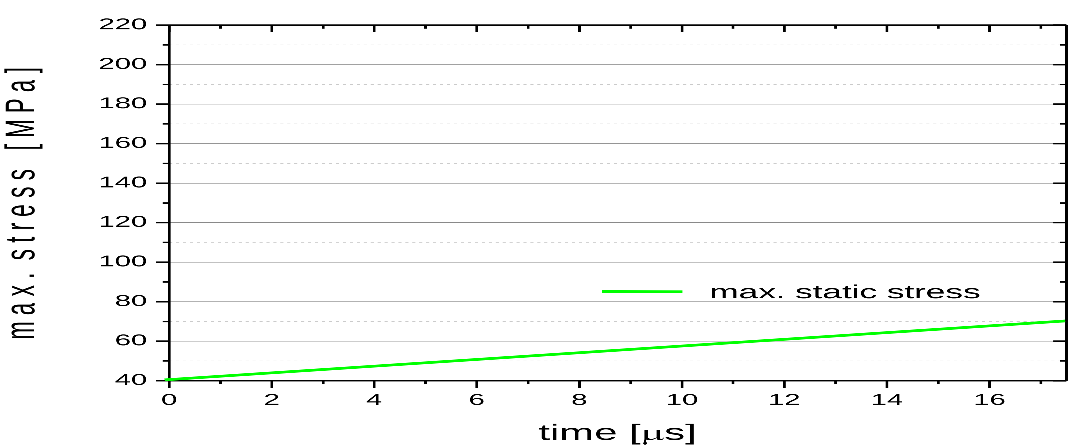




Dynamic stress and temperature evolution in a test target (high lumi)

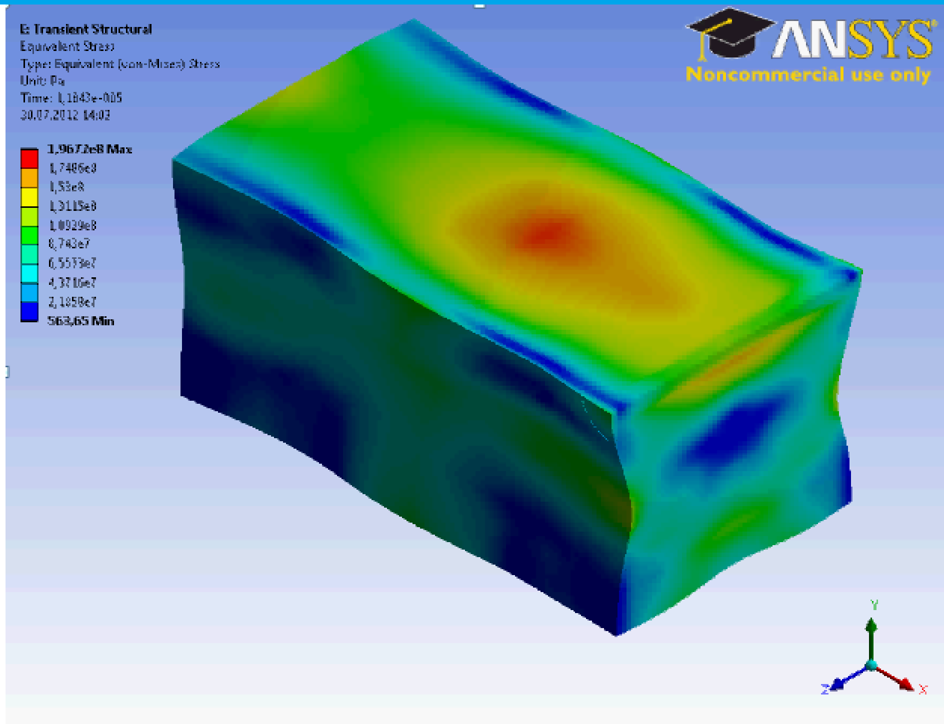


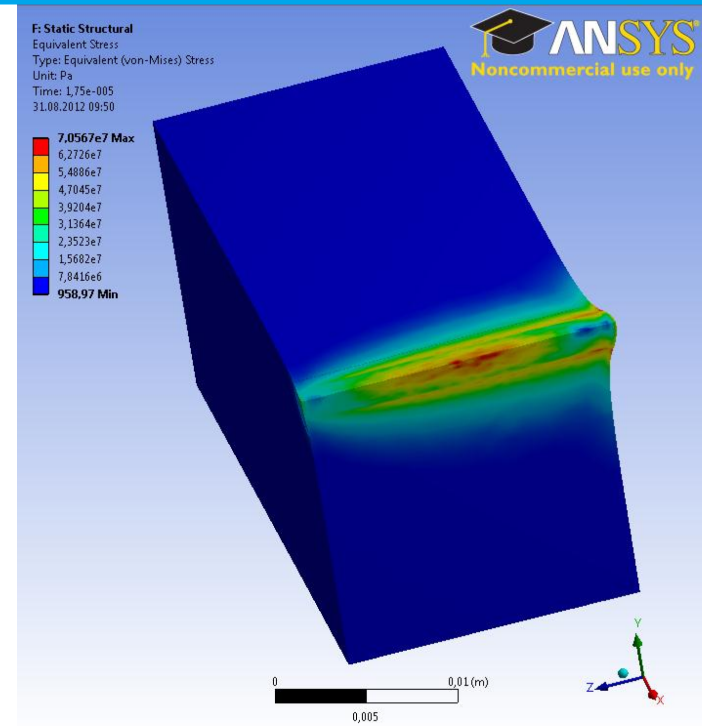


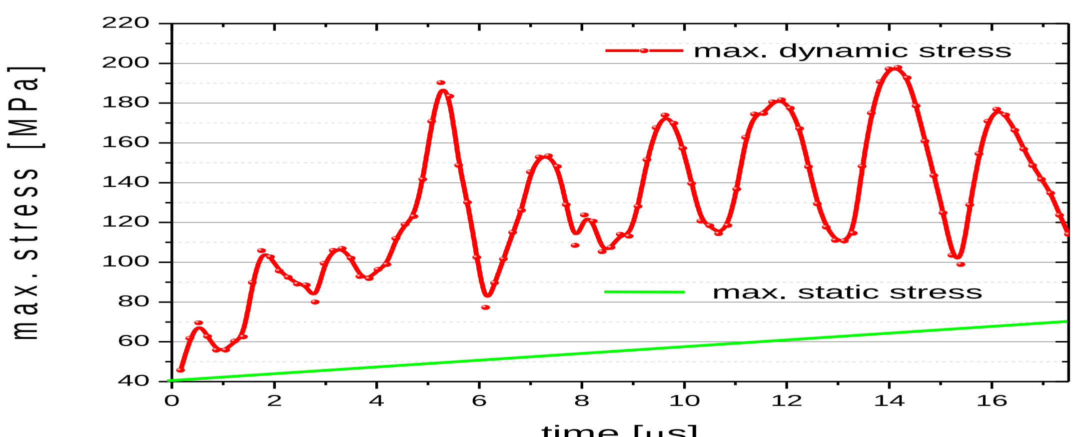


$2*10^{10}$ e^- / bunch
2625 bunch / train (0.97ms)
0.366μs bunch spacing
5 train / s

Dynamic stress and temperature evolution in a test target (high lumi)

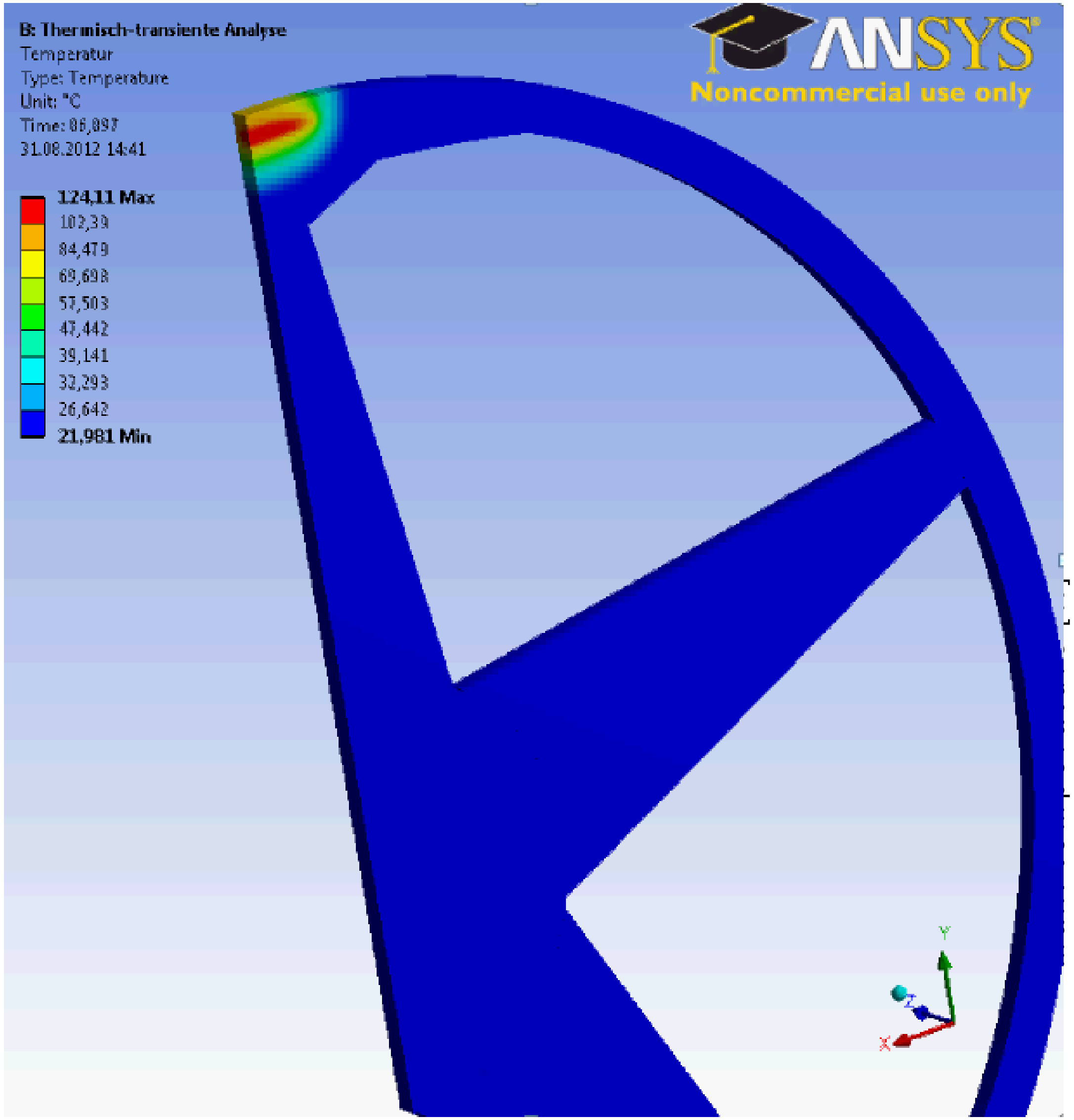






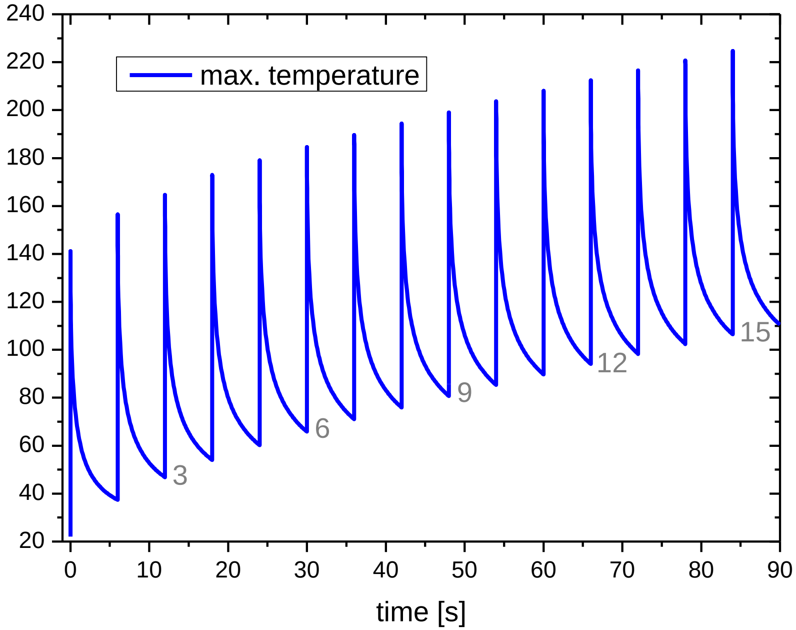
$2*10^{10}$ e^- / bunch
2625 bunch / train (0.97ms)
0.366µs bunch spacing
5 train / s

Temperature evolution in the ILC target wheel (high lumi)



temperature evolution without cooling

cooling system for the wheel have to be developed !



Temperature evolution in the SLAC target

SLAC-PUB-9437
August 2002

THERMAL SHOCK STRUCTURAL ANALYSES OF A POSITRON TARGET

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V.K. Bharadwaj, D.C. Schultz, J.C. Sheppard, SLAC,* Stanford, CA, USA

Abstract

In the positron source of the Stanford Linear Collider (SLC), the electron beam collides with a tungsten-rhenium target. As the beam passes into the material, thermal energy is created that heats the material to several hundred degrees centigrade on a time scale of nanoseconds. The heating of the material results in thermal stresses that may be large enough to cause material failure. The analyses calculate the thermal shock pressure and stress pulses as they move throughout the material due to the rapid energy deposition. Failure of the target occurred after three years of operation with an elevated power deposition toward the end of the three years. The calculations were made with the LLNL coupled heat transfer and dynamic solid mechanics analysis codes, TOPAZ3D and DYNA3D, and the thermal energy deposition was calculated with the SLAC Electron Gamma Shower (EGS) code simulating the electron-induced cascade. Material fatigue strength, experimentally measured properties for the non-irradiated and irradiated material, as well as the calculated stress state are evaluated in assessing the cause for the target failure.

1 INTRODUCTION

The SLC positron target was operated for several years with gradually increasing electron beam power. Inspection of the target showed considerable damage on the backside of the target in the region where the beam exits the target [1, 2]. The damage observed consisted of approximately one millimeter of missing material and cracks propagating in various directions into the target.

In an attempt to determine the cause of the material loss and cracks, a dynamic stress analysis was undertaken to model the pressure-induced stress waves in the material.

2 BACKGROUND

The SLC target consists of a hockey puck-shaped piece of Tungsten and 25% Rhenium (W25Re). Figure 1 shows the geometry of the target. The target consists of a 2.5-inch diameter disc of W25Re with a six-radiation length thickness of 0.81 inches. The target is cooled by

temperature before another electron bunch impinges [3]. During operation the target is rotated in a way that the impinging beam pulses strike a different part of the target after every pulse.

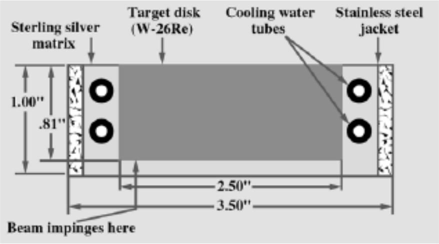


Figure 1: SLC target geometry.

2.1 Electron beam energy deposition

The electron beam of 4.0e+10 electrons/bunch at 33 Gev impinging on the target deposits 5 kW of power into the target at a frequency of 120 hertz. The beam has a Gaussian radial distribution with a spot size of 0.8 mm. The SLAC EGS code was used to calculate the energy deposition profile in the target. The energy deposition [4] is very low as the beam enters the target and increases to a maximum as the beam exits the back of the target (see Fig. 2).

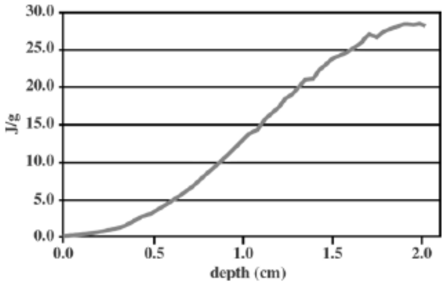
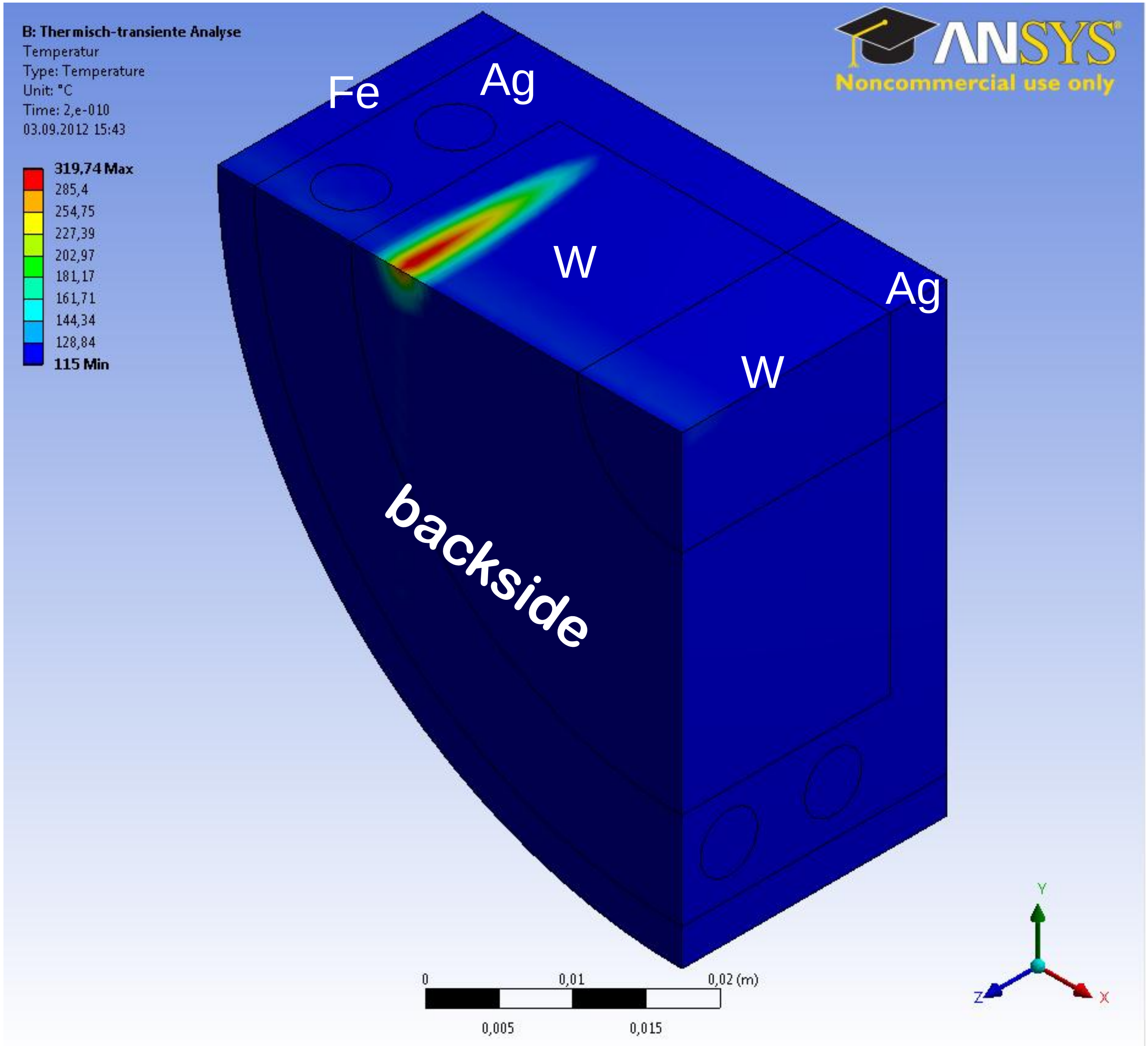


Figure 2: Beam centerline energy deposition, J/g, versus depth into target, cm.

Temperature evolution in the SLAC target



SLAC

33 GeV e$^-$
4*10^{10} e$^-$/pulse
σ = 0.8mm
120 Hz ≈ 8 ms

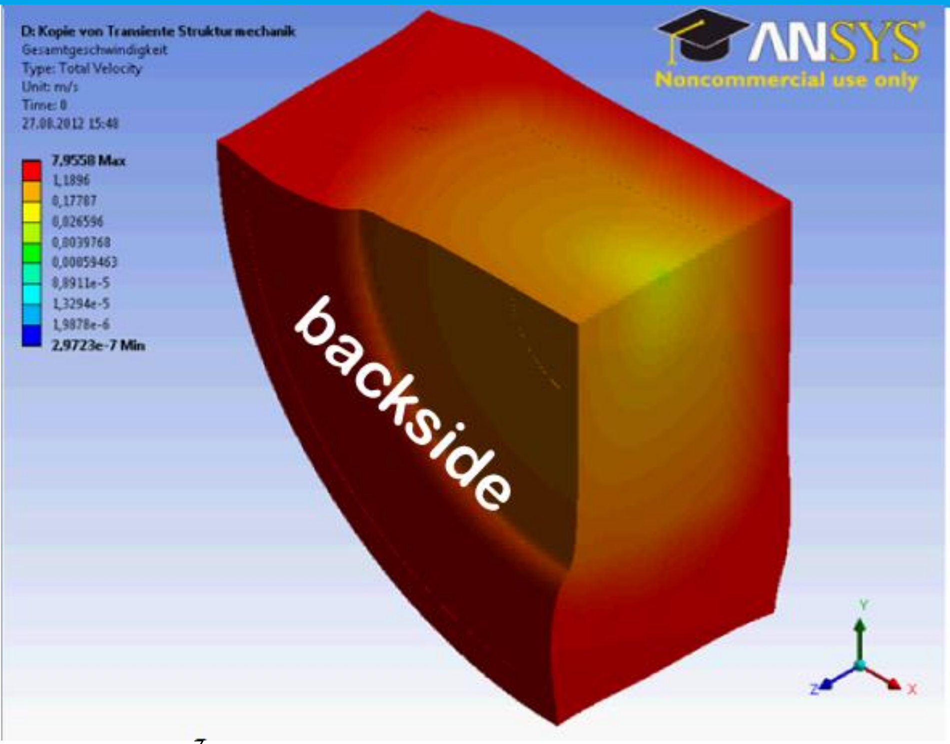
Figure 2a: Target - Beam Entry Face

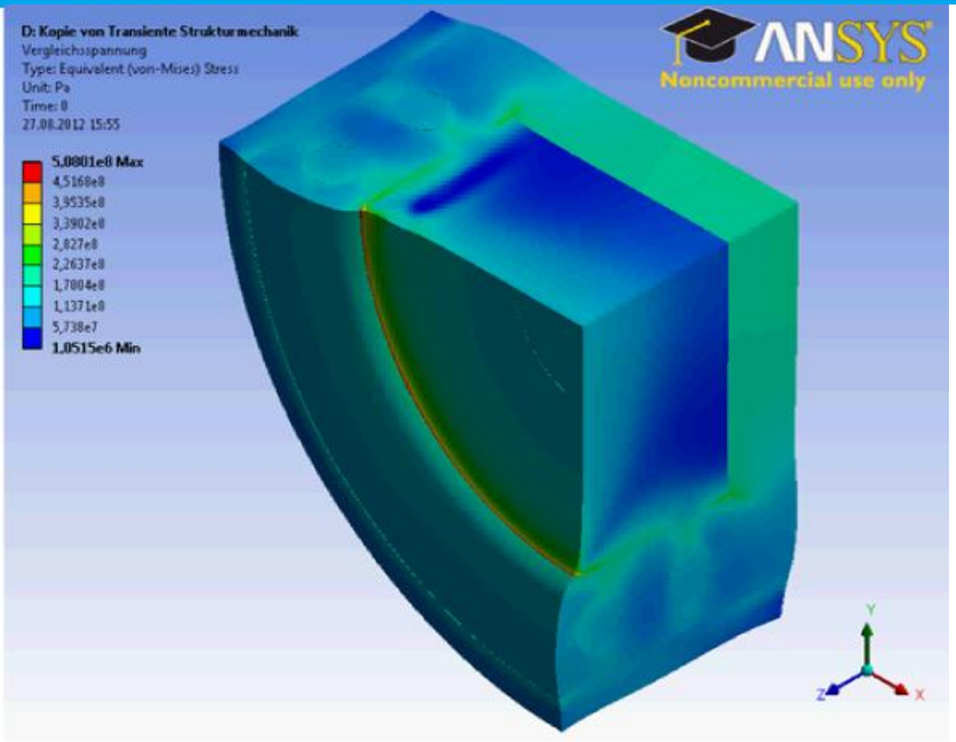
Figure 2b: Target - Beam Entry Face Detail

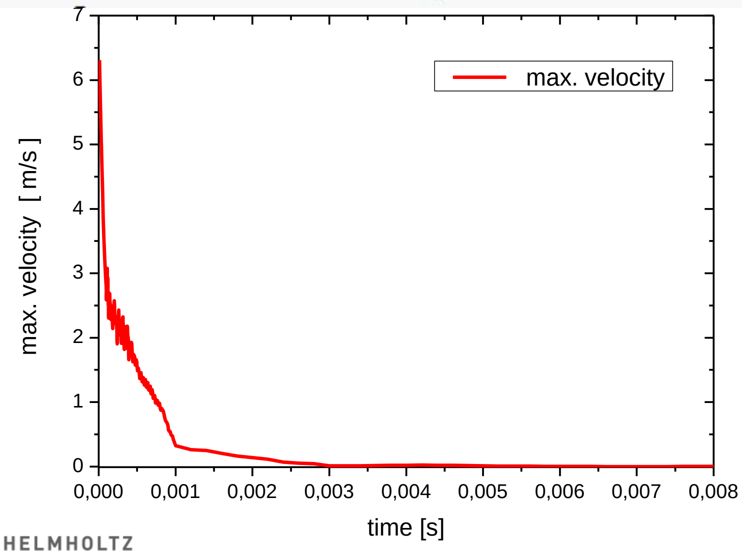
Figure 3a: Target - Beam Exit Face

Figure 3b: Target - Beam Exit Face Detail

Velocity and stress evolution in the SLAC target







SLAC

33 GeV e^-
$4*10^{10}$ e^-/pulse
σ = 0.8mm
120 Hz ≈ 8 ms

Conclusion

- The collimator design achieved in the static case the fatigue stress limits of the materials for the proposed parameter sets (including safety factors)

- Collimator cooling should be not difficult for this introduced design

- The dynamical calculations for the Ti6Al4V ILC target with ANSYS is ongoing
  - dynamical calculation for the collimator have to be done in the future

- The dynamical ANSYS calculations (life time) of the SLAC target should be consistence with the experience

to do: - a cooling channel design for the Ti-target wheel have to be developed
- a material test experiment at a suitable accelerator have to be performed