Photon collimator design studies

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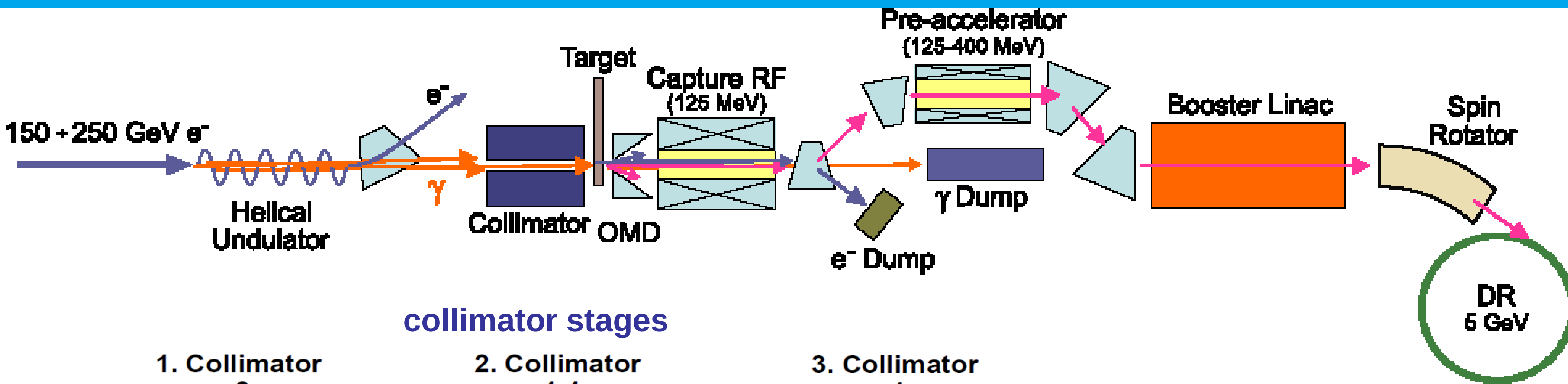
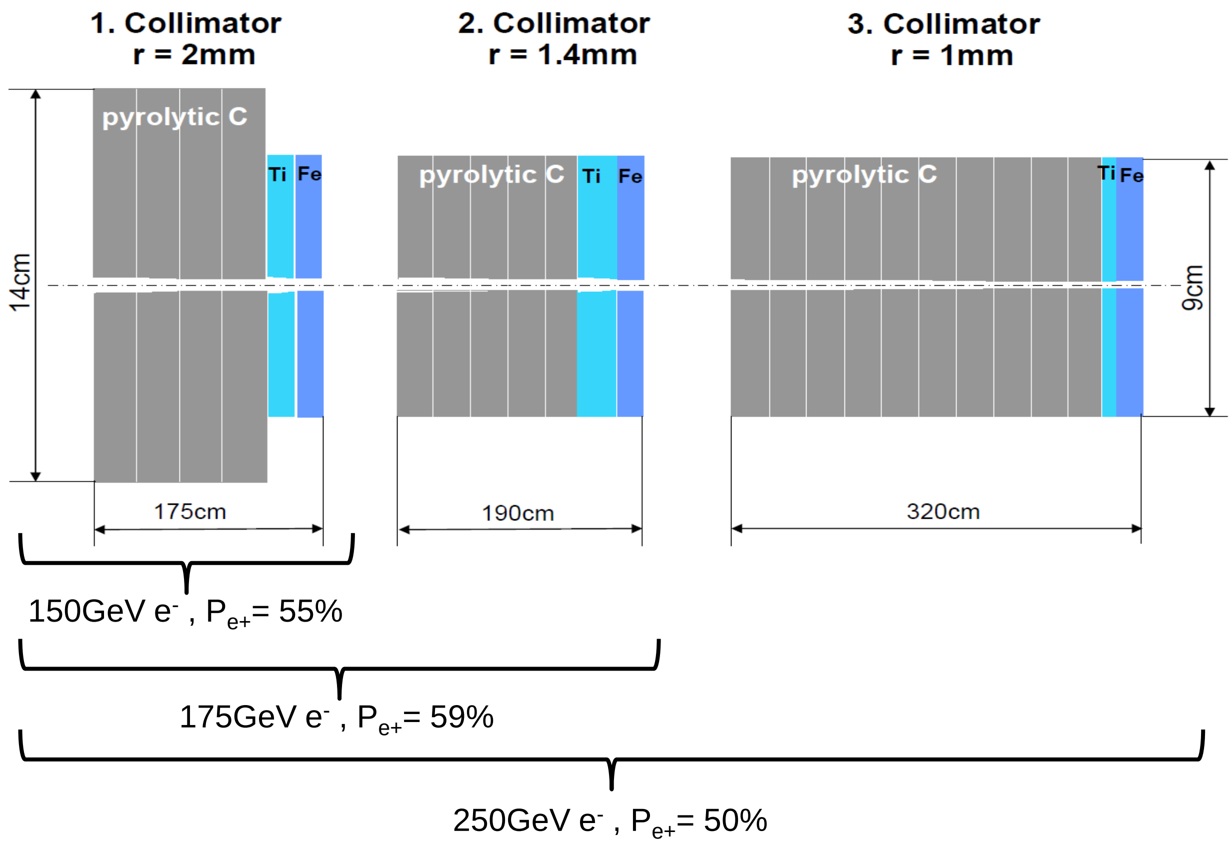
- ILC positron source unit
- Energy deposition in the collimators
- TDR parameter table with different collimator settings
- Dynamic evolution in the collimator
- Collimator cooling (average temperature)
- Conclusion

ILC positron source unit

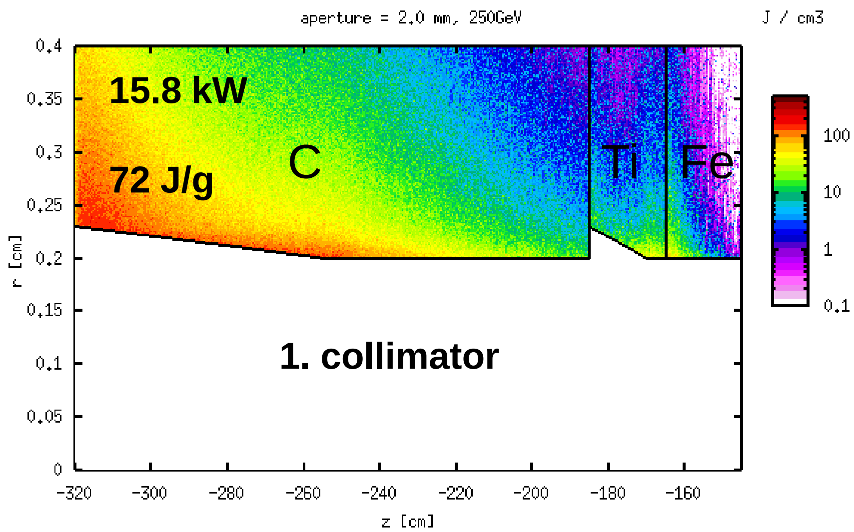


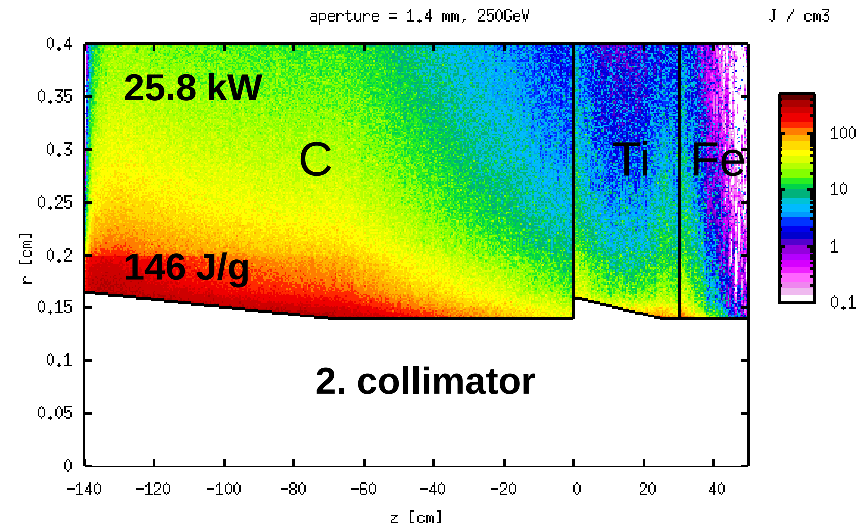
collimator stages

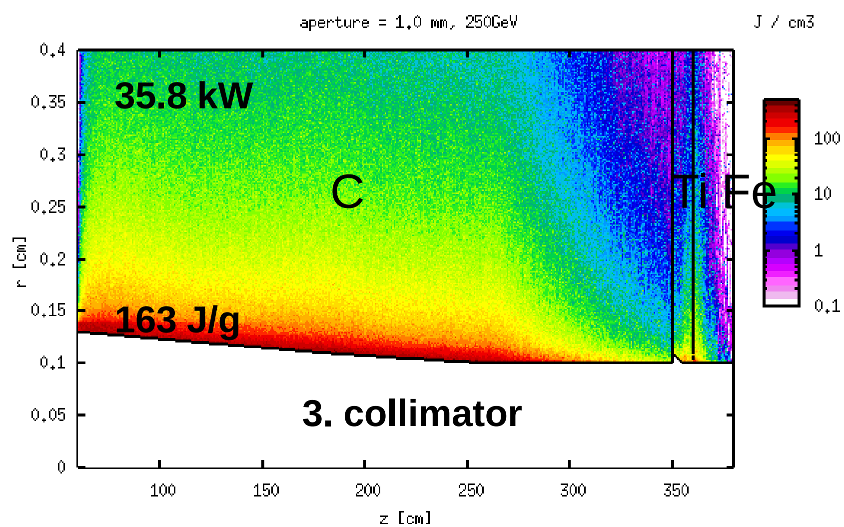


Energy deposition in the collimators (high lumi)

drive beam 250GeV e^- , P_{e+}= 50%







Energy deposition scored with FLUKA [J/cm^3]

TDR parameter table with different collimator settings

Photon Collimator Parameters

Parameter			e- drive beam energy (GeV)			L upgrade
			150	175	250	250
Effective undulator field	B_{und}	T	0,86 K=0.92			0,86 K=0.92
Active undulator length	L_{und}	m	231,0	196,0	70,0	70,0
Photons per bunch train	n_{ph} / train	$\times 10^{15}$	11,8	10,0	3,6	7,2
Average photon power	P_{photon}	kW	98,5	113,8	83,1	166,2
Abs.ph. power in collim.	$P_{collimator}$	kW	48,1	68,7	43,7	87,3
PEDD Ti target	E_{max}	J/g	61	61	31	63
Abs.ph. power in Ti target	P_{target}	kW	4,3	3,2	1,9	3,7
Collimator radius	r	mm	2,0	1,4	1,0	1,0
Positron Polarization	P_+	%	55,3	58.5	50,3	50,3
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	0,7
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	32
collimator r=1.4 / Ti	P	kW		0,9	0,6	1,2
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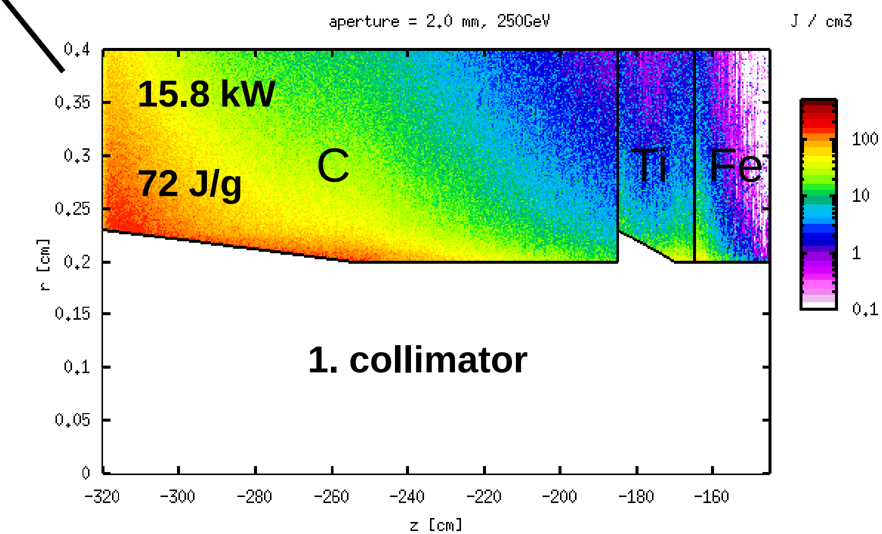
cooling / Cu	P	kW		2,4	1,2	2,4
collimator r=1.0 / Pyr. C	E_{max}	J/g			82	163
collimator r=1.0 / Pyr. C	P	kW			17,9	35,8
collimator r=1.0 / Ti	E_{max}	J/g			13	26
collimator r=1.0 / Ti	P	kW			0,2	0,4
collimator r=1.0 / Fe	E_{max}	J/g			9	19
collimator r=1.0 / Fe	P	kW			0,1	0,2
cooling / Cu	P	kW			1,8	3,6

		Pyr. C	Ti	Fe (ST70)	W (annealed)	W26Re (hardened)
Fatique Temperature : (Ansys) T	°C	900	600	130	185	500
Fatique Energy : (Ansys) $E_{fatigue}$	J/g	753	314	58	24	64
Fatique Yield Strength : (Ansys) $P_{fatigue}$	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

$$\Delta T = E_{max} * c_v^{-1}$$

$$c_v^{-1}{}_{Carbon} \approx 1.2\ [g*K/J]$$

$$c_v^{-1}{}_{Ti,Fe} \approx 2.0\ [g*K/J]$$



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Abs.ph. power in Ti target	P_{target}	kW	4,3	3,2	1,9	3,7
Collimator radius	r	mm	2,0	1,4	1,0	1,0
Positron Polarization	P_{+}	%	55,3	58.5	50,3	50,3
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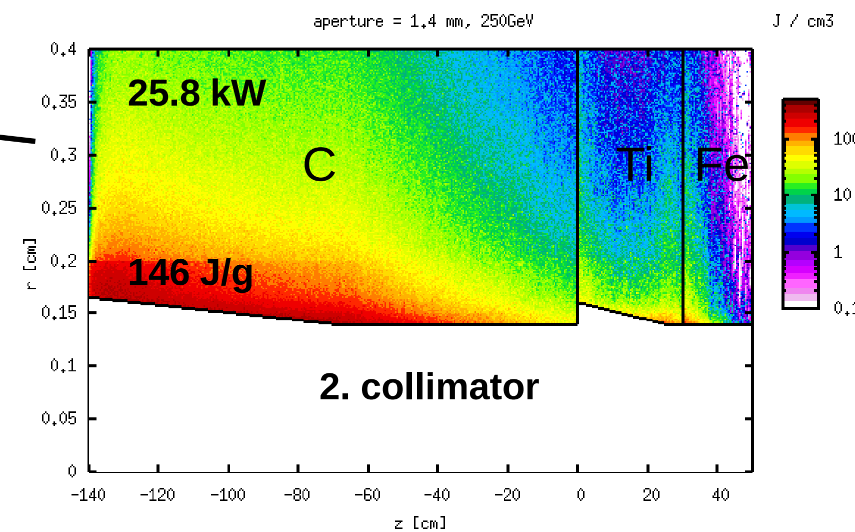

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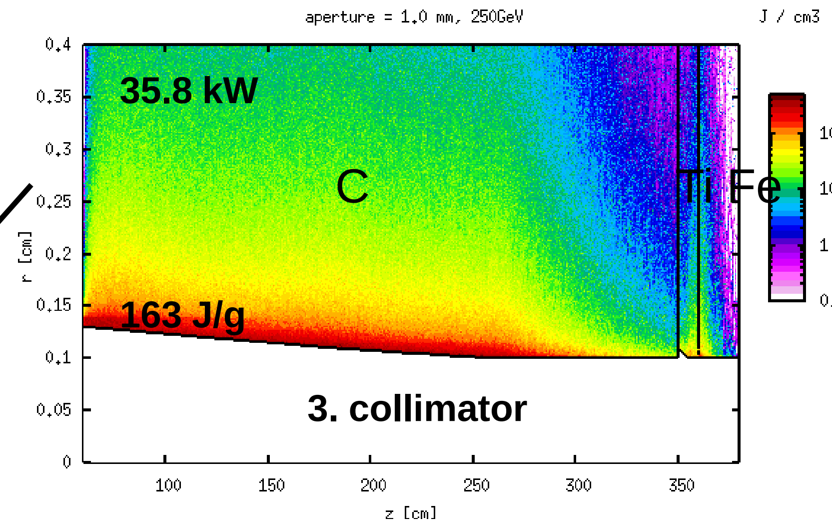
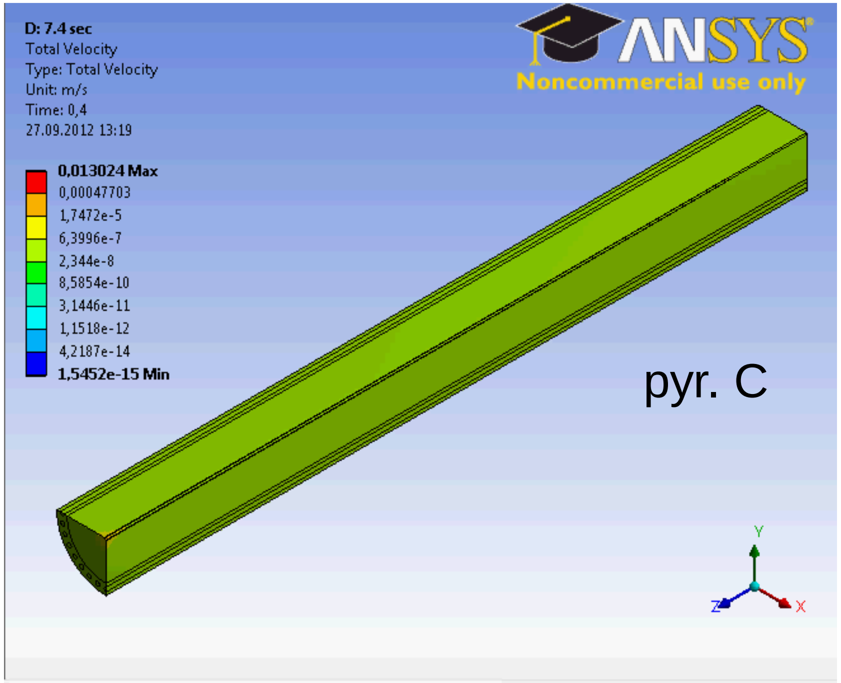
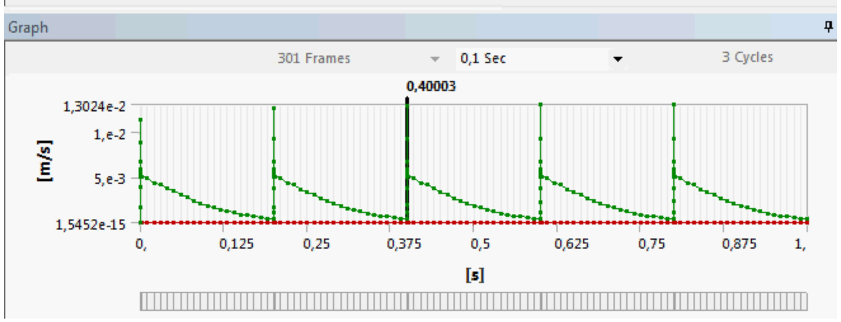
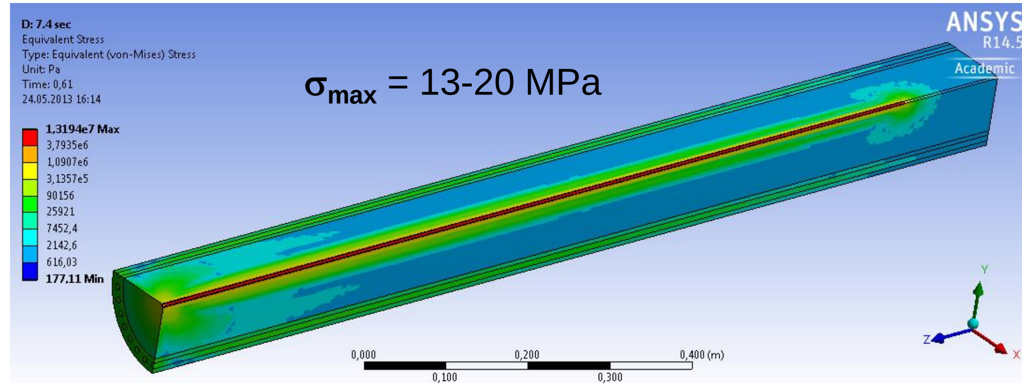






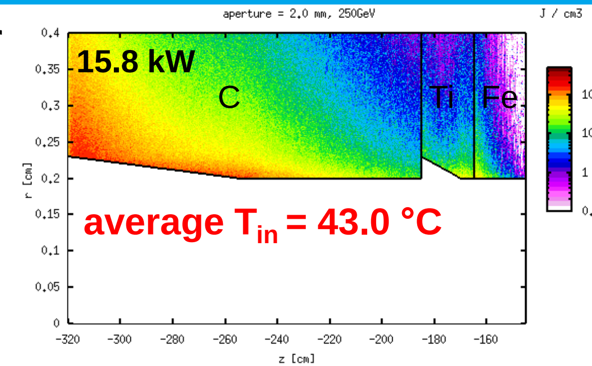


$\bar{\sigma}$ = 3 MPa

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

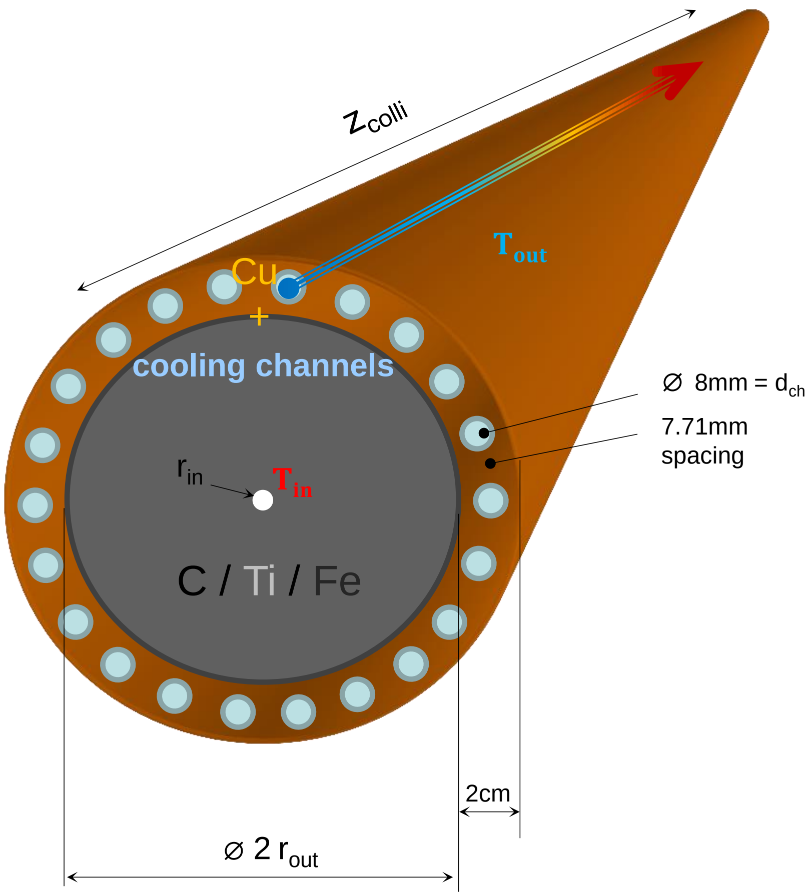
Collimator cooling (average temperature)

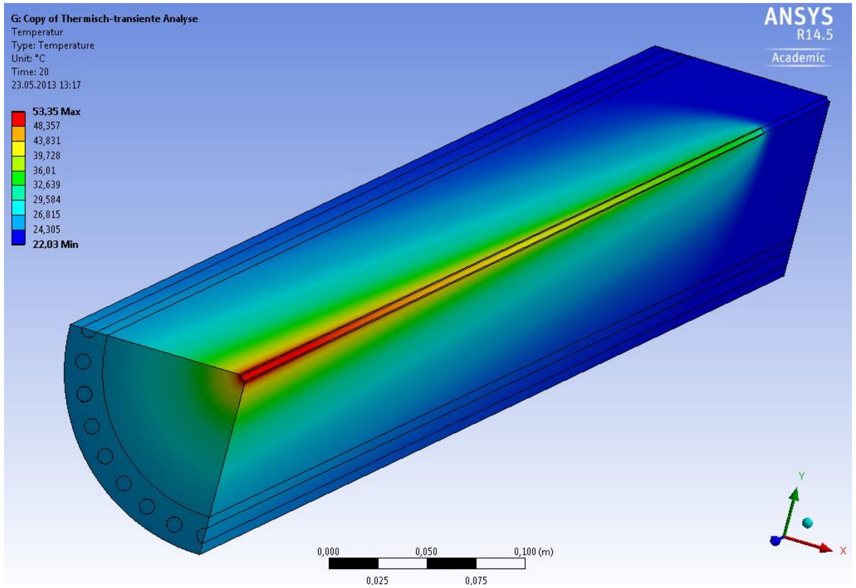
1.Collimator



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

radial heat flow





$$T_{in} = \frac{\dot{Q}_0 \ln(r_{out}/r_{in})}{\lambda\, 2\pi\, z_{colli}} + T_{water}\,(22°C) + \underbrace{\frac{\dot{Q}_{0\,norm}}{d\dot{Q}_{cool}/dT}}_{\Delta T_{water}} \cdot \frac{z}{z_{colli}}$$

ΔT = 19.5 K   22 °C   ΔT = 1.5 K

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Cooling and temperature (high lumi)

drive beam 250GeV e^- , P_{e+}= 50%

Carbon	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	43	86	72	750
2. collimator	54	174	146	
3. collimator	46	194	163	

Titanium	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	67	21	11	350
2. collimator	123	61	32	
3. collimator	132	50	26	

Iron (St70)	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	30	22	10	50
2. collimator	31	49	22	
3. collimator	32	42	19	

Cooling and temperature

drive beam 175GeV e^- , P_{e+}= 59%

Carbon	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	70	172	144	750
2. collimator	54	219	183	

Titanium	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	113	34	18	350
2. collimator	98	42	22	

Iron (St70)	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	34	29	13	50
2. collimator	32	29	13	

Cooling and temperature

drive beam 150GeV e^- , P_{e+}= 55%

Carbon	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	81	140	177	750

Titanium	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	113	31	16	350

Iron (St70)	average T [°C]	ΔT peak [K]	ΔE peak [J/g]	fatigue Energy [J/g]
1. collimator	30	29	13	50

Conclusion

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

- Dynamical calculations for the collimator shows not critical behavior

- Collimator cooling should be not difficult for this introduced design

to do: a material test experiment at a suitable accelerator have to be performed to verify (fatigue) stress limits with realistic beam conditions

Material data

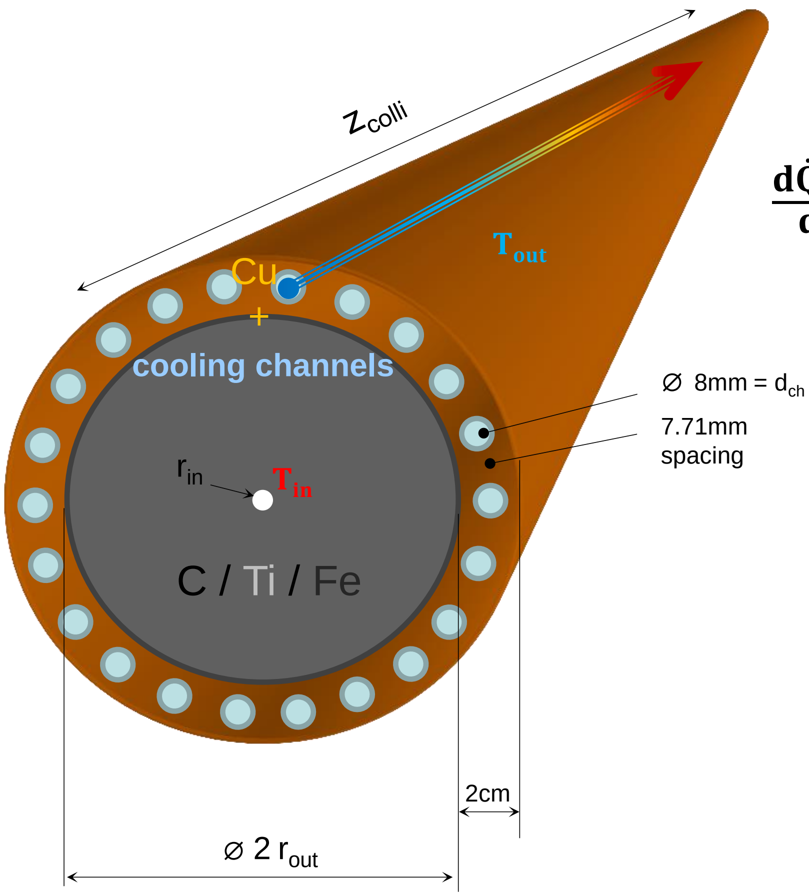
element $x_0[cm]$	E $[GPa]$	ν	ρ $\left[\frac{g}{cm^3}\right]$	α $\left[\frac{10^{-5}}{K}\right]$	c_v $\left[\frac{J}{kg\ K}\right]$	λ $\left[\frac{W}{m\ K}\right]$
Au **0.34**	81	0.42	19.3	1.43	128	320
Ag **0.85**	83	0.38	10.5	1.97	234	430
Cu **1.42**	117	0.34	8.3	1.65	385	400
W **0.35**	406	0.28	19.3	0.45	138	170
Fe **1.76**	196	0.30	7.9	1.22	449	80
Ti **3.59**	114	0.34	4.4	0.9	580	7-22
C **18.84**	20	0	2.2	0.05 - 0.6	837	350

Collimator cooling (average temperature)

Reynolds number

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

laminar flow of water !



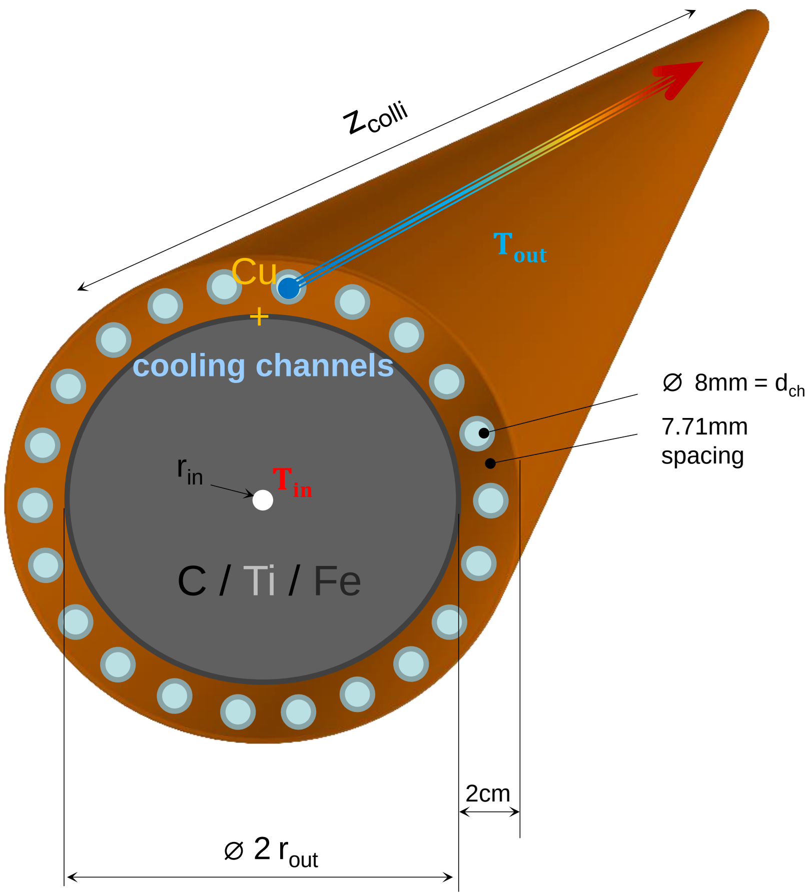
$$\left.\frac{d\dot{Q}_{cool}}{dT}\right/_{chan.} \approx 0.3\ {}^{kW}/_{m^2\,K} \Leftrightarrow \bar{v}_{water} = 2\ {}^{m}/_{s} \xrightarrow{d_{ch}=8mm} 0.1\ {}^{l}/_{s}$$

$$r_{out} = \begin{cases} 7.0cm \Rightarrow \frac{d\dot{Q}_{cool}}{dT}(32\ ch) \approx 9.6\ {}^{kW}/_{m^2\,K} \\ 4.5cm \Rightarrow \frac{d\dot{Q}_{cool}}{dT}(22\ ch) \approx 6.6\ {}^{kW}/_{m^2\,K} \end{cases}$$

Collimator cooling (average temperature)

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

radial heat flow



$$\Delta T = Tin - T_{out} = \frac{\dot{Q}_0 \ln\left({}^{r_{out}}/_{r_{in}}\right)}{\lambda\, 2\pi\, z_{colli}}$$

$$\overset{\text{cooling}}{\Longrightarrow} \quad T_{out}(z) = T_{water}(20°C) + \underbrace{\frac{\dot{Q}_{0\,norm}}{{}^{d\dot{Q}_{cool}}/_{dT}} \cdot \frac{z}{z_{colli}}}_{\Delta T_{water}}$$

$$\dot{Q}_{0\,norm} = \frac{\dot{Q}_0}{A_{cyl}} = \frac{\dot{Q}_0}{2\pi\, r_{out}\, z_{colli}} \left[{}^{kW}/_{m_2}\right]$$

$$\overset{\text{cooling}}{\Longrightarrow}$$

$$T_{in} = \frac{\dot{Q}_0 \ln\left({}^{r_{out}}/_{r_{in}}\right)}{\lambda\, 2\pi\, z_{colli}} + T_{water}(20°C) + \underbrace{\frac{\dot{Q}_{0\,norm}}{{}^{d\dot{Q}_{cool}}/_{dT}} \cdot \frac{z}{z_{colli}}}_{\Delta T_{water}}$$