High-power photon collimators

Lei Zang

Cockcroft Institute/University of Liverpool

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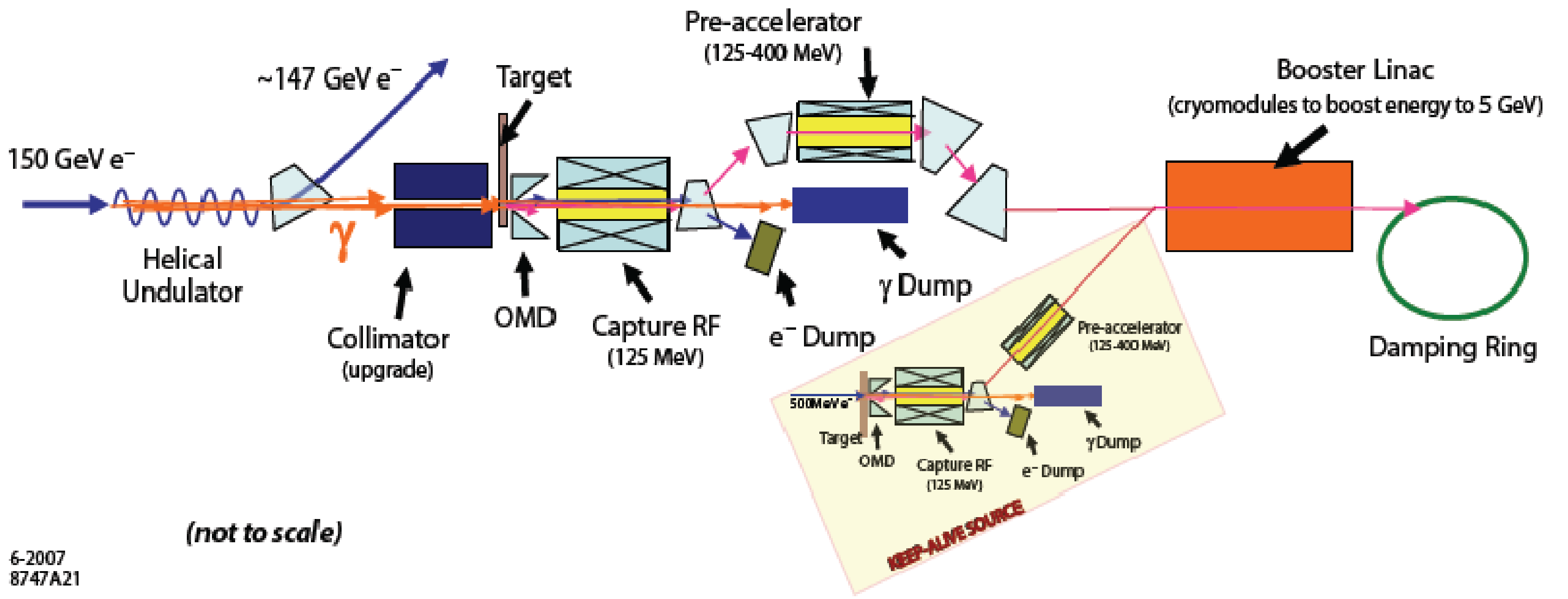
Overview

- Undulator-based positron source scheme
- Motivation for a photon collimator
- Proposed Models
- Thermal consideration
- Activation studies
- Comparison of designs
- Conclusion

ILC RDR Positron Source Design

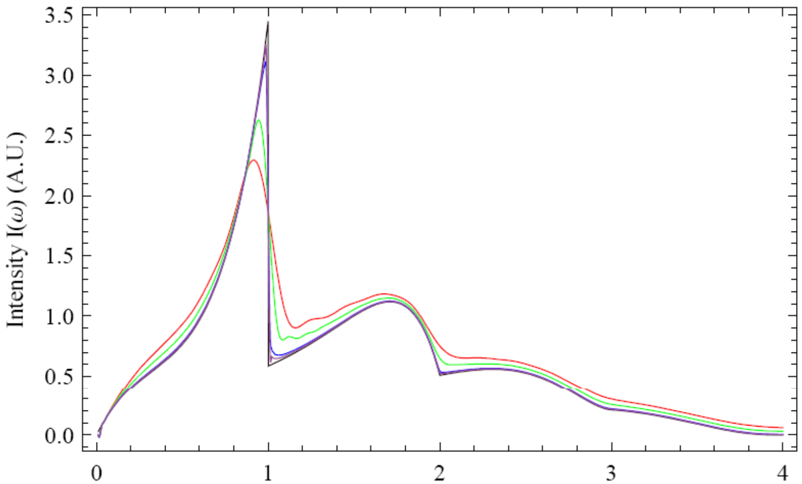


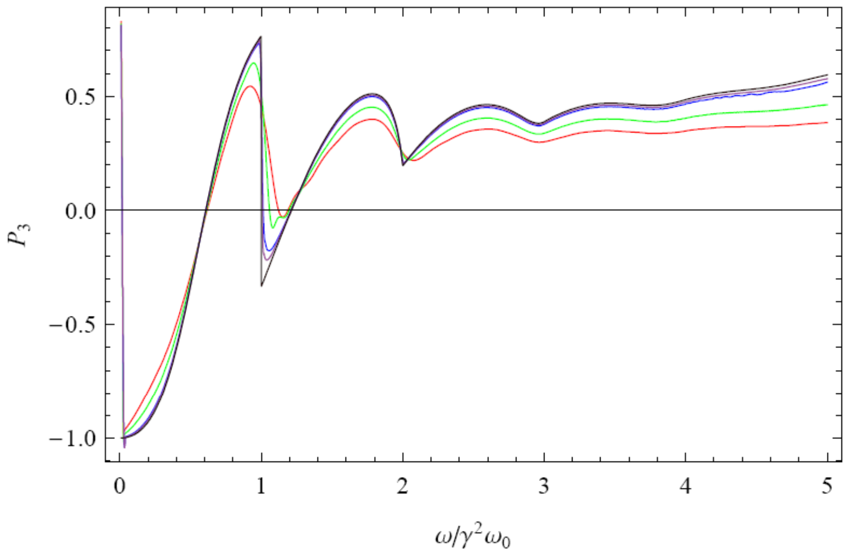
- Active (K=0.92, period=1.15 cm, B0=0.86T) undulator: 147 m
  - Photon beam power: 131 kW
  - ~300γ/e
  - Photon energy: ~10 MeV (First harmonic)
  - Net positron polarisation ~30%

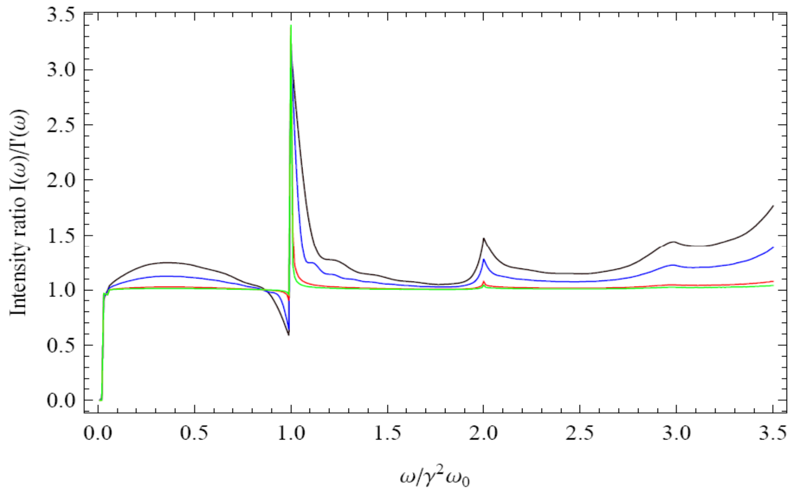
ILC nominal positron source parameters

e^- drive beam energy, GeV	150
e^+ per bunch at the end of pre-accelerator	$3 \cdot 10^{10}$
Bunches per pulse	2625
Pulse repetition rate, Hz	5
e^+ polarization	30 (60)

Photon Distributions







- Intensity spectrum and polarisation for helical undulator with K=1 and N=5, 10, 50, 100.

- The shape approaches the large *N* limit for *N* = 100, the large *N* limit can be used without significant loss of accuracy: at the first harmonic peak, for example, the large N approximation differs from a more exact calculation for *N* = 100 by 4.3%.

Photon Collimator --- Motivation

- Since the polarisation of photons in the beam is dependent on the angle of the photons with respect to the undulator axis, the collimator may also, in principle, be used to control the polarisation.

- Optimisation of the positron source will involve finding a balance between polarisation and intensity

- Photon collimator is an important component to scrape the photon beam to limit the extraneous halo

- Because the capture device has certain energy window and angular acceptance, it is equivalent to an angular cut on gamma spectrum.

Photon Collimator --- Models

Model 1

- Copper is used as an absorber because of high thermal conductivity (~401W/m/K) and high melting point (T_{melt}~1357.77K)

- Titanium (melting point ~1941K) is used as spoilers whose length is 1cm (0.28 radiation length).

Model 1

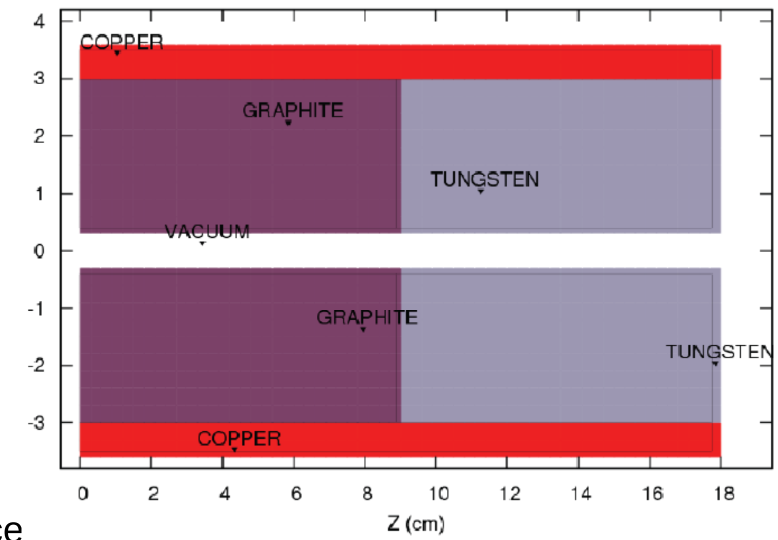
- Absorber Length is 90 cm (64.3 radiation length). And between spoilers there are 6 cm gaps.

Model 2

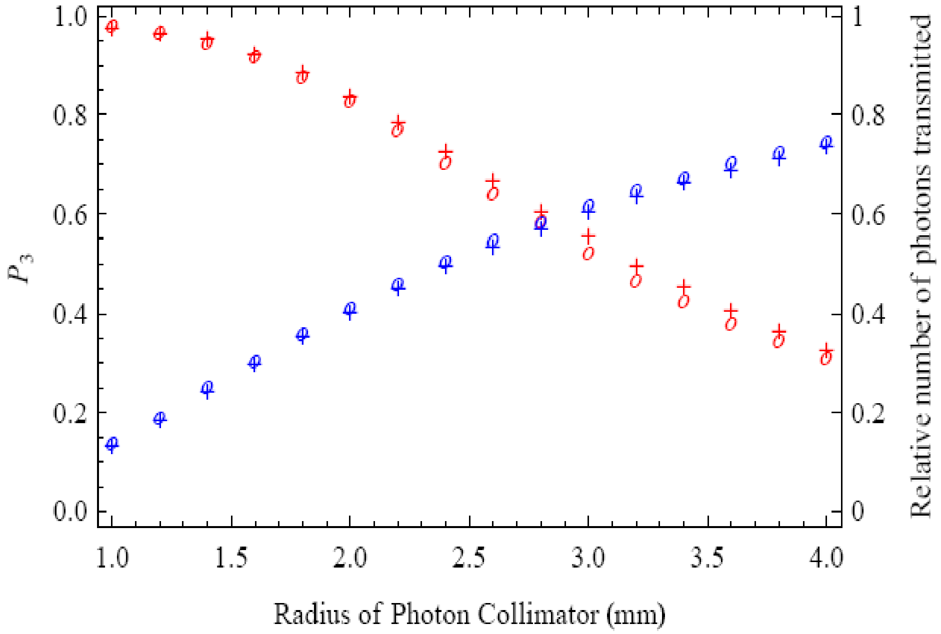
- Cylinder shape collimator consisting of Graphite and Tungsten as a spoiler and absorber respectively.

- Both Graphite (T_{melt}~4000) and Tungsten (T_{melt}~3695) have very high melting points.

Model 2 (A. Mikhailichenko, EPAC'06)



Collimation Effect

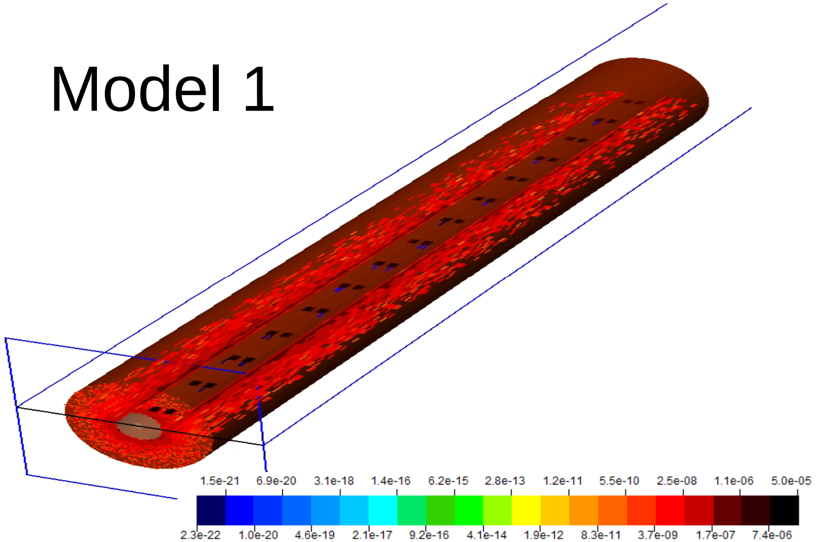


Polarisation (red) and number of **photons transmitted (blue)** as a function of collimator aperture. The number of photons transmitted is normalised to the uncollimated beam. **Analytical results** (circles) are compared with **Fluka simulation** (crosses).

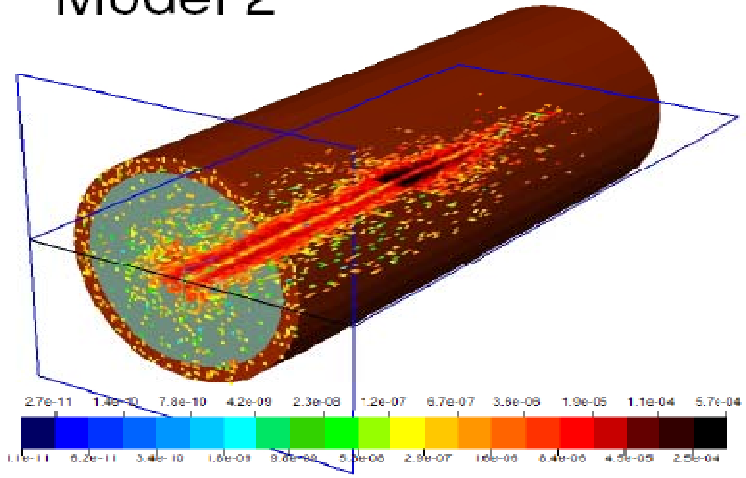
	Model 1		**Model 2**	
Inner Radius [mm]	Photon transmitted	Polarisation	Photon transmitted	Polarisation
2	41.50%	84.37%	41.20%	83.62%
3	60.80%	56.22%	61.10%	55.48%
4	74.10%	33.49%	74.10%	33.70%

Energy Deposition

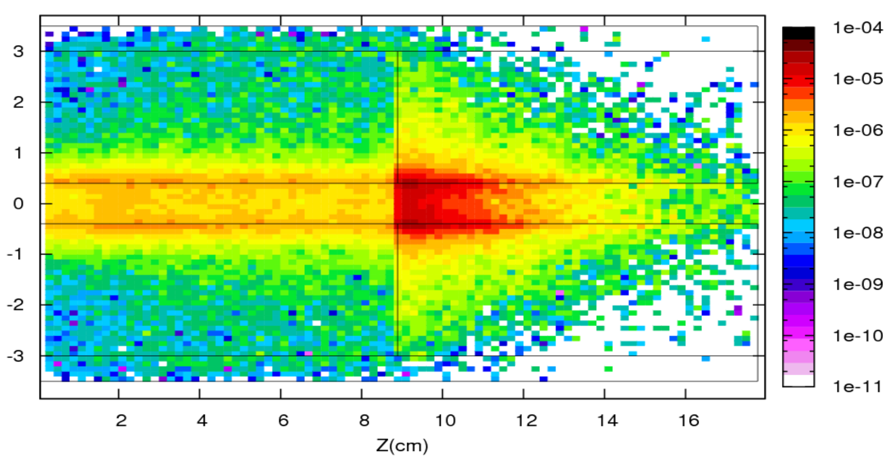
Model 1



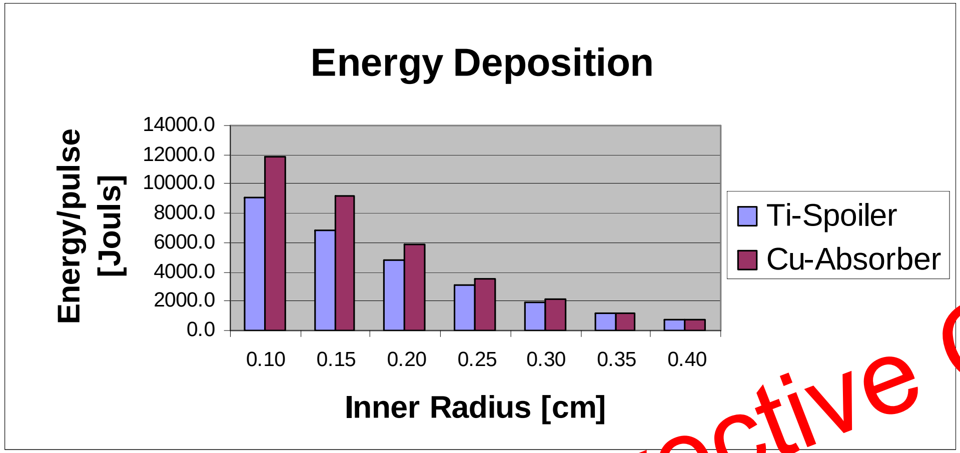
Model 2

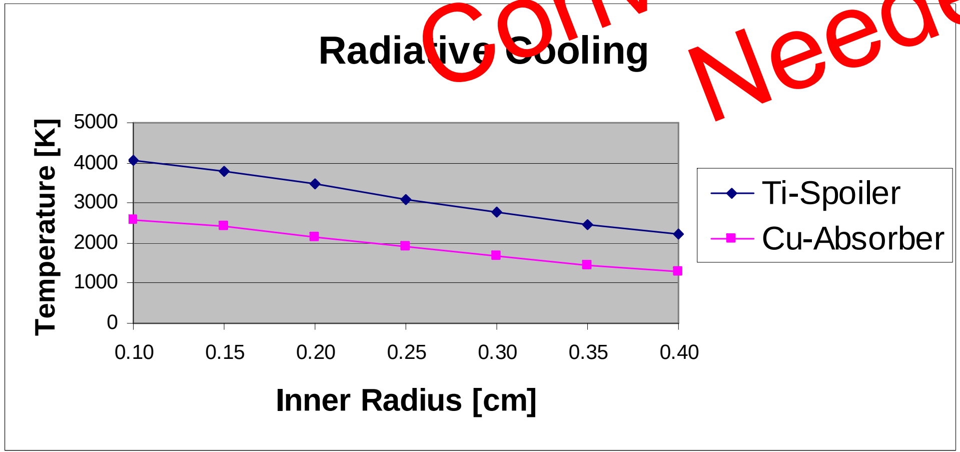


R_{col} [mm]	Model 1		Model 2		
	Deposited Energy [MeV/pr]				
	Ti	Cu	C	W	Cu
2	4.17 (34.7 %)		4.95 (41.1 %)		
	1.87	2.30	1.03	3.88	0.04
3	1.63 (13.6 %)		1.87 (15.6 %)		
	0.78	0.85	0.48	1.37	0.02
4	0.61 (5.1 %)		0.68 (5.7 %)		
	0.31	0.30	0.21	0.45	0.01



Thermal Consideration---Model 1



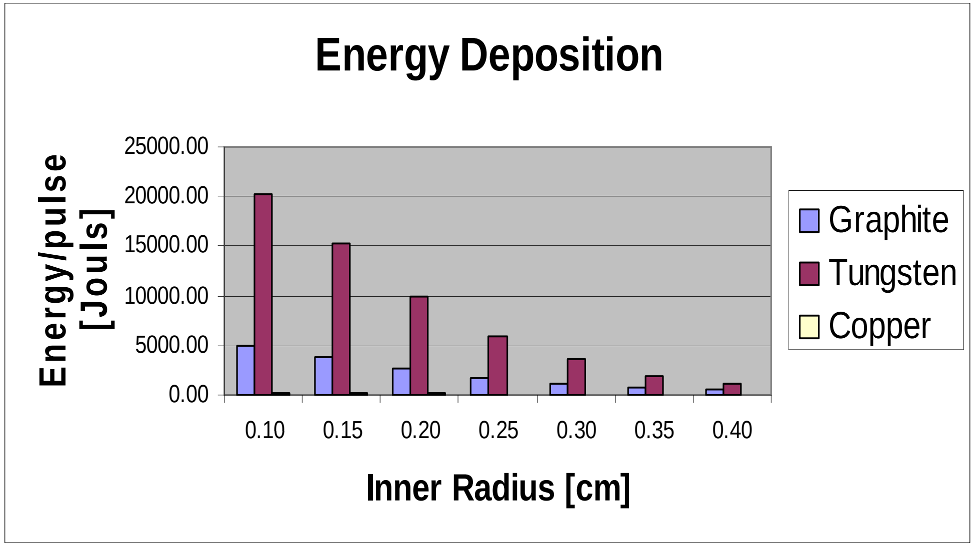


Convective Cooling Needed!!

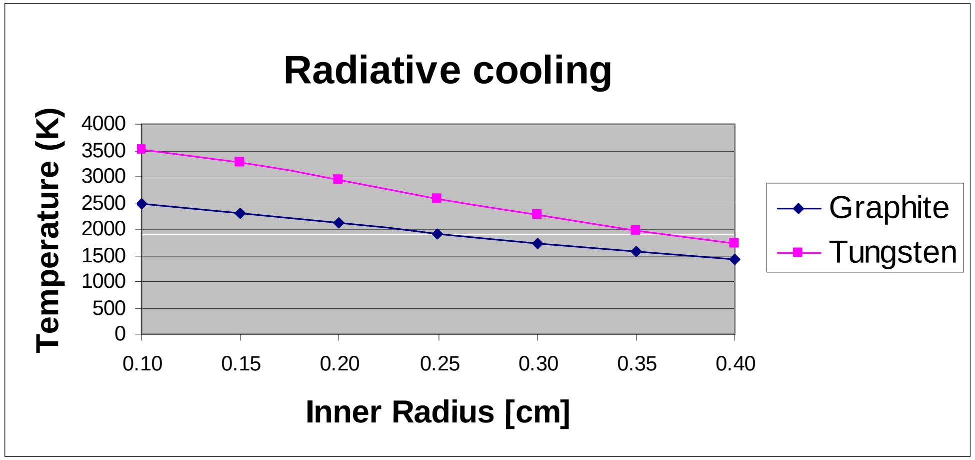
Inner Radius (cm)	Cu (K/pulse)	Ti (K/pulse)
0.10	0.379	79.607
0.15	0.294	61.440
0.20	0.189	43.489
0.25	0.112	28.339
0.30	0.069	18.891
0.35	0.039	12.213
0.40	0.025	8.239

More power deposited in spoiler, which will bring instantaneous heating. By considering the melting point of Titanium (T_{melt}=1941K), the spoiler will be melted if no cooling system.

Thermal Consideration---Model 2

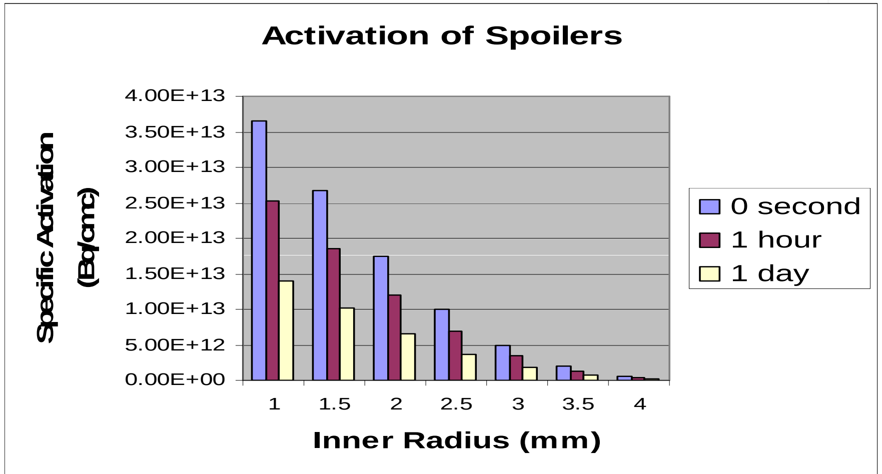


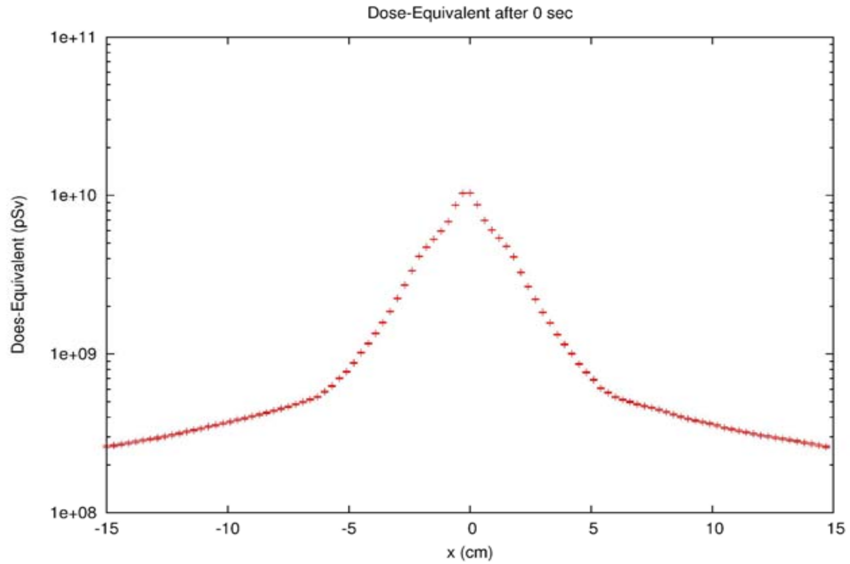
Inner Radius [cm]	Cu (K/pulse)	Graphite (K/pulse)	Tungsten (K/pulse)
0.1	0.27	12.62	31.11
0.15	0.22	9.60	23.64
0.2	0.16	6.70	15.26
0.25	0.12	4.52	9.17
0.3	0.10	2.99	5.49
0.35	0.07	2.05	3.07
0.4	0.06	1.40	1.80

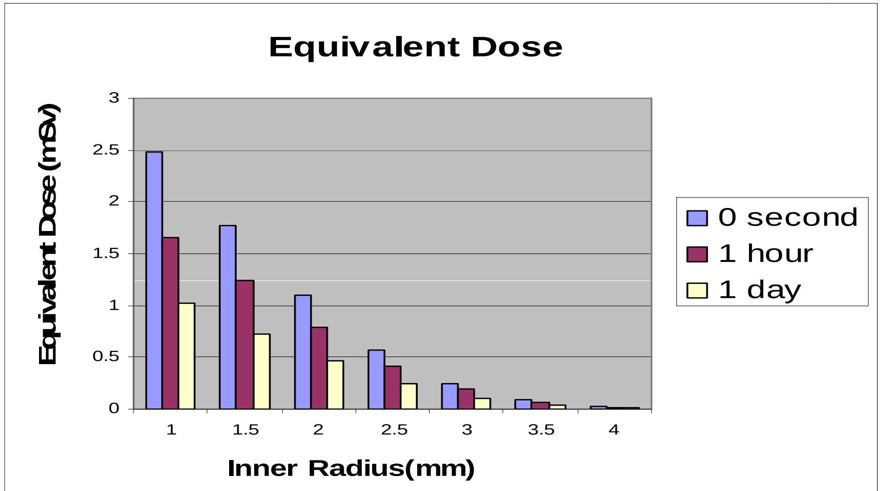


Both Graphite (T_{melt}~4000) and Tungsten (T_{melt}~3695) have very high melting point, which make them suitable candidate to survive the temperature increases generated by the impact of one or more bunches

Activation Studies---Model 1







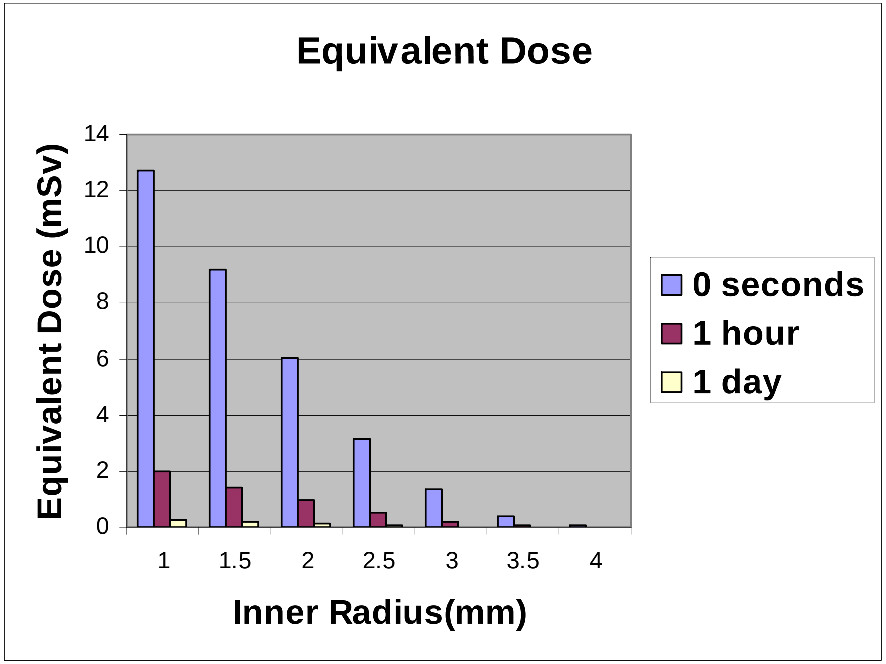
5000 hours operation with beam intensity of 8×10^{16} photons/sec

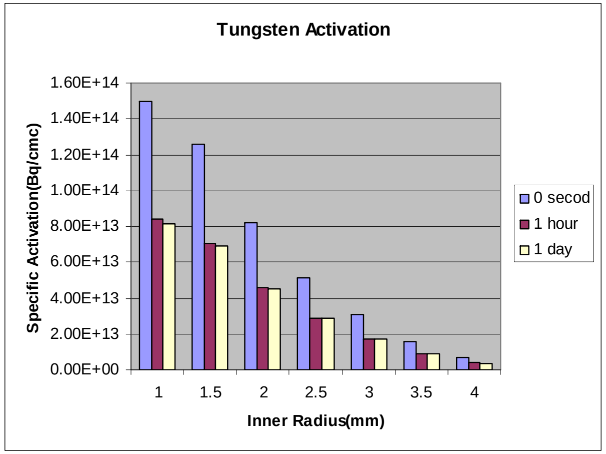
Left up: Activation of the Titanium Spoiler

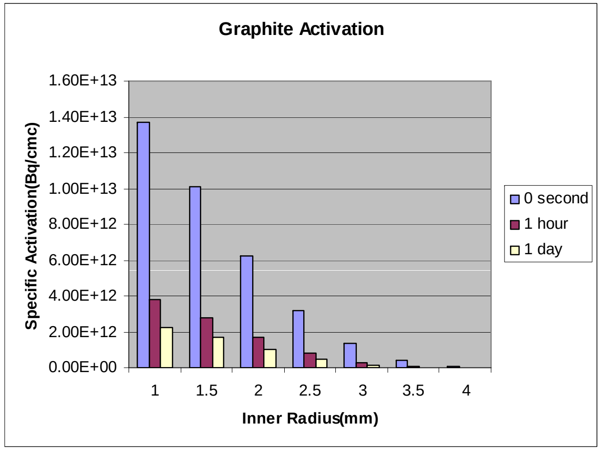
Right up: dose distribution.

Left down: Equivalent dose at the position 10 cm away from collimator.

Activation Studies---Model 2



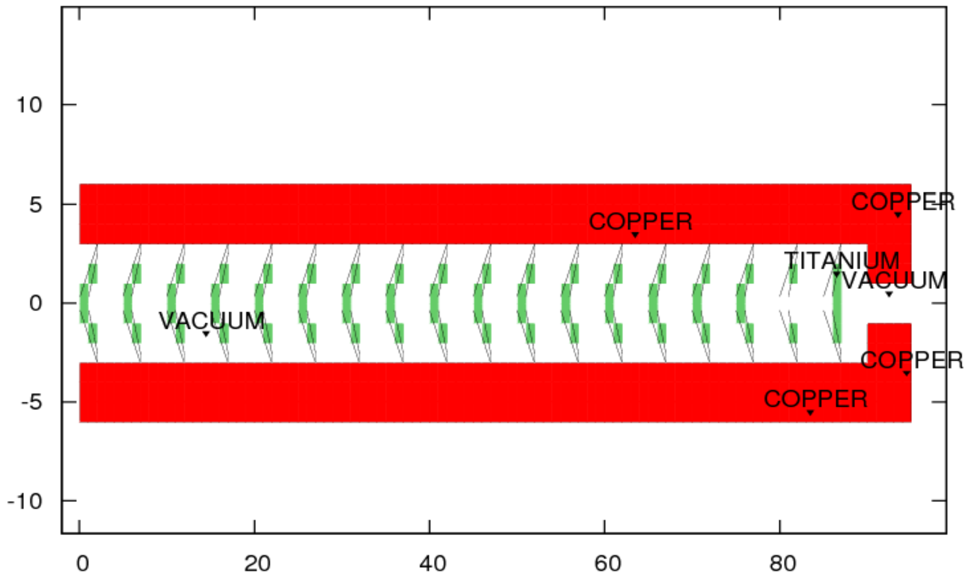




e^+ & e^- Striking Target Plane

Model 1		Events		Photons/sec			
		50000		8.00E+16			
Inner Radius(cm)		e-	Average energy of e- (MeV)	Power e-(W)	e+	Average energy of e+(MeV)	Power e+(W)
0.1		446	9.58	1.09E+03	249	12.4	7.90E+02
0.15		387	8.83	8.75E+02	181	12.8	5.93E+02
0.2		273	8.33	5.82E+02	118	10.3	3.11E+02
0.25		179	7.64	3.50E+02	74	8.97	1.70E+02
0.3		119	6.19	1.89E+02	41	8.28	8.69E+01
0.35		53	5.06	6.87E+01	19	4.99	2.43E+01
0.4		38	4.59	4.47E+01	8	5.5	1.13E+01
Model 2		Events		Photon/sec			
		50000		8.00E+16			
Inner Radius(cm)		e-	Average energy of e- (MeV)	Power e-(W)	e+	Average energy of e+(MeV)	Power e+(W)
0.1		13	3.62	1.20E+01	1	3.03	7.76E-01
0.15		26	10.9	7.26E+01	7	18.6	3.33E+01
0.2		31	10.5	8.33E+01	12	14.1	4.33E+01
0.25		21	7.47	4.02E+01	3	19.1	1.47E+01
0.3		29	8.55	6.35E+01	7	5.54	9.93E+00
0.35		17	6.63	2.89E+01	8	6.78	1.39E+01
0.4		17	7.41	3.22E+01	3	2.75	2.11E+00

A New Test Model



- **This test model mainly changed two things:**
  - **1) tilted spoiler sections**
  - **2) extra absorber at the end**

Results:

- **1) there are still large amount of energy deposit in spoiler which will damage the spoiler**
- **2) the number of electrons and positrons strike the target plane has been reduced**

Model 1		Events			Photon/sec				
		50000			8.00E+16				
Inner Radius(cm)		e-	New Model	Average energy of e-(MeV)	Power e-(W)	e+	New Model	Average energy of e+(MeV)	Power e+(W)
0.1		446	75	9.58	1.09E+03	249	40	12.4	7.90E+02
0.15		387	65	8.83	8.75E+02	181	21	12.8	5.93E+02
0.2		273	31	8.33	5.82E+02	118	24	10.3	3.11E+02
0.25		179	26	7.64	3.50E+02	74	19	8.97	1.70E+02
0.3		119	8	6.19	1.89E+02	41	2	8.28	8.69E+01
0.35		53	11	5.06	6.87E+01	19	2	4.99	2.43E+01
0.4		38	4	4.59	4.47E+01	8	1	5.5	1.13E+01

Conclusions

- Geometry: Model 2 is a shorter and smaller design which has similar effect of collimation.
- Thermal consideration: The spoilers in Model 1 may not survive without proper cooling system. Both Graphite spoiler and Tungsten absorber could be ok even without cooling system.
- e^- & e^+: Model 2 has a better absorption for secondary particles.
- High equivalent dose is a big concern. Need to evaluate the acceptable level and shielding need to be considered.
- So far the model 2 looks like a better design work for ILC positron source.