Radiation Levels and Activation at the ILC Positron Source

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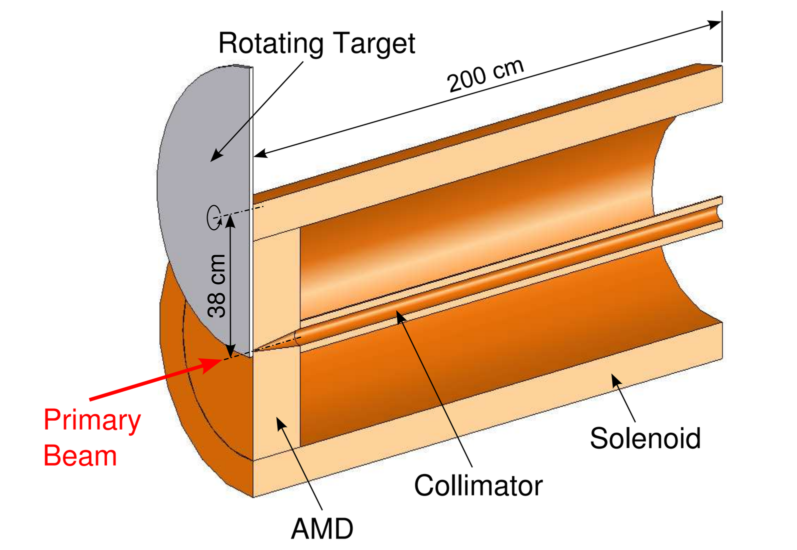
Positron Source Model

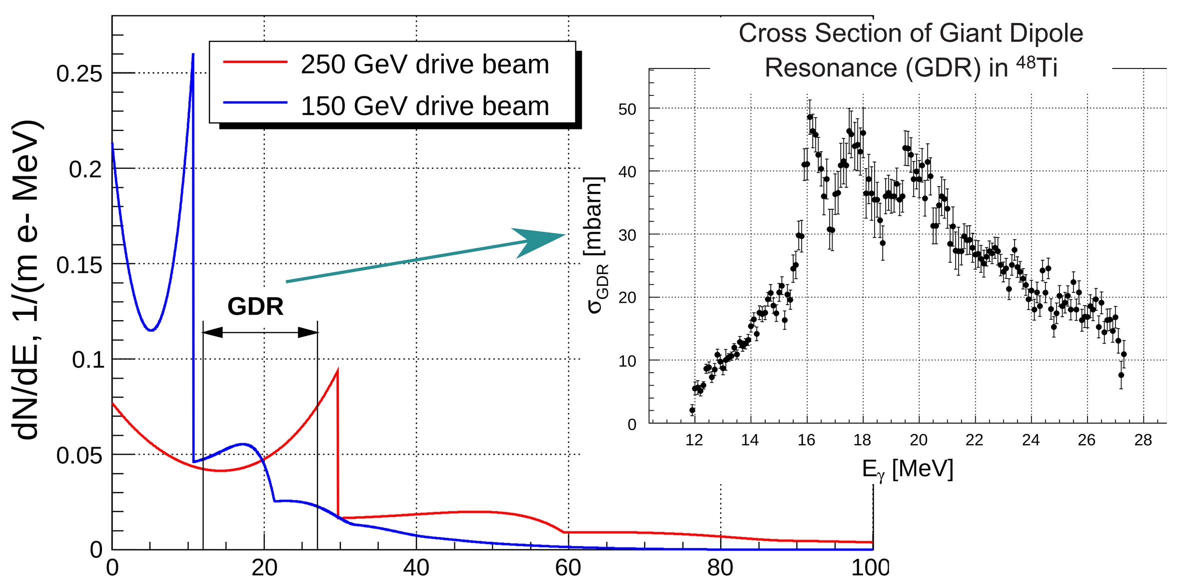


	Undul.	Conv.
Electron Drive Beam Energy, GeV	150 (250)	6.2
Beam Radius, mm	0.35	
Beam Divergence, mrad	0	
Target Compounds	Ti-6Al-4V, Ti-5Al-2.5Sn	W-25Re
Target Thickness, X_0	0.4	4.5
Material of Capture Section	Cu	

An undulator-based positron source is recommended as base design for the International Linear Collider (ILC). Photons generated by electrons passing an undulator hit a rotating target and create electron-positron pairs. The positrons emerging from the target are collected and accelerated in a capture section. The capture section consists of the adiabatic matching device (AMD) and an accelerating RF structure embedded in a focusing solenoid. The accelerating structure is modelled as an "effective" collimator with an aperture corresponding to the size of iris of the accelerating structure. The AMD is a tapered solenoid starting with an initial magnetic field of 6 T which is reduced adiabatically down to the constant field of 0.5 T. The undulator based sources with an electron drive beam energy of 150 GeV (U150) and 250 GeV (U250) are compared with the conventional positron source with an electron beam energy of 6.2 GeV. The influence of the target compound (Ti-6Al-4V and Ti-5Al-2.5Sn) on positron yield and radiation levels has been studied.

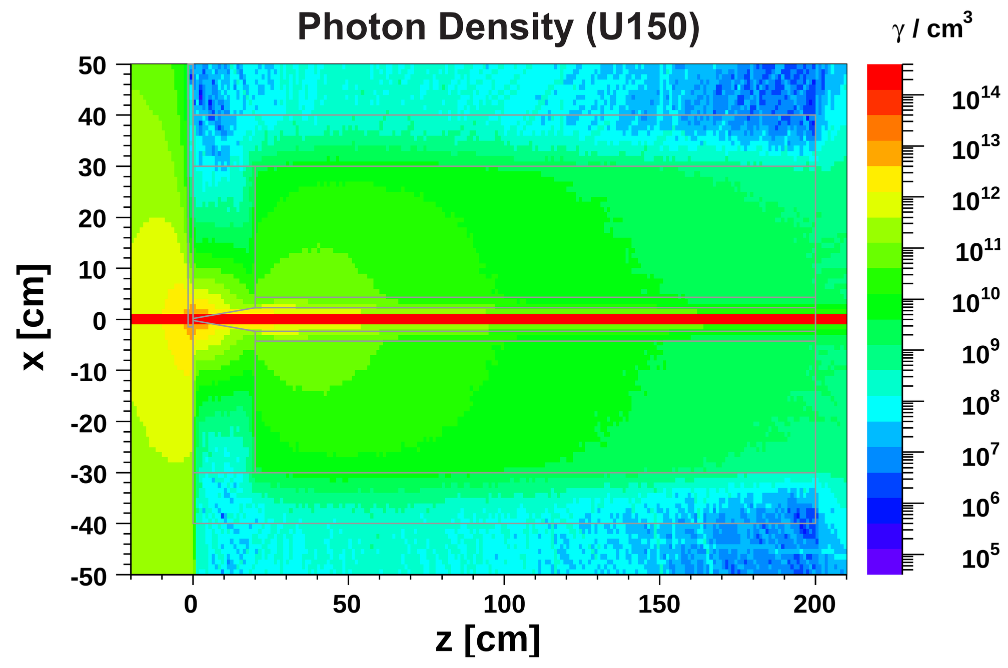
Energy Distribution of Photons
(produced by one electron per one meter of undulator)

Undulator: λ_u = 1 cm, B = 1.07 T, K = 1

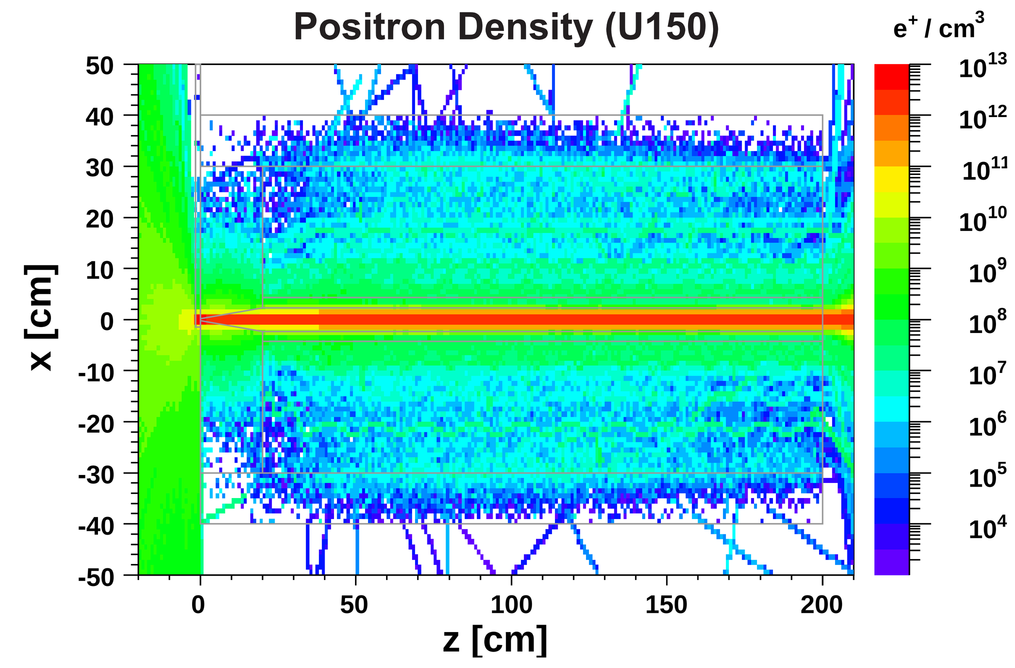


The simulation of the positron source has been done by the help of the particle transport code FLUKA.

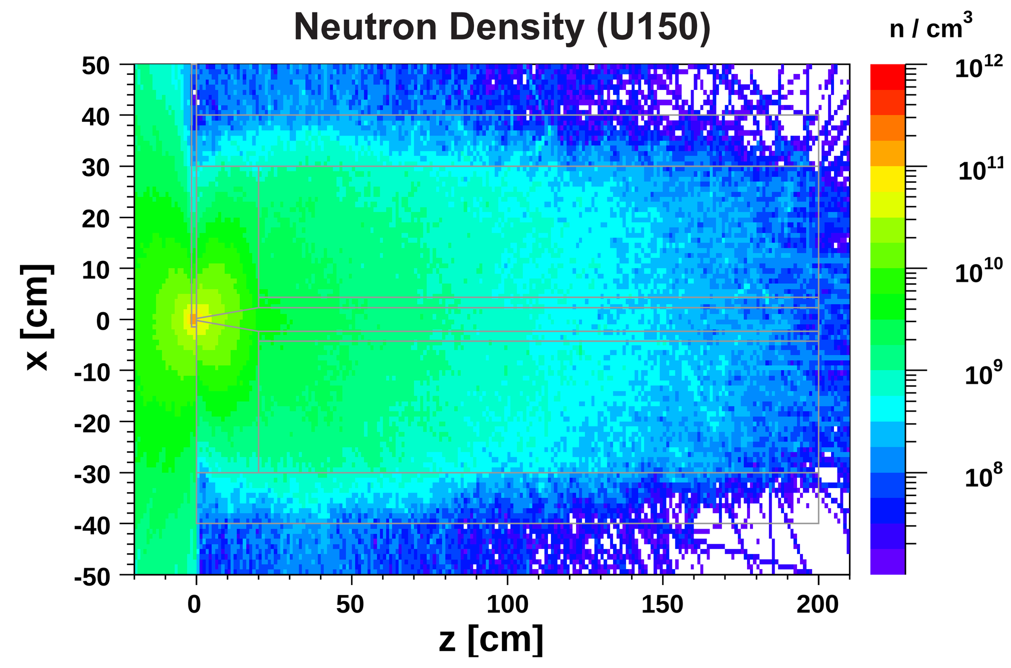
Photon Density (U150)



Positron Density (U150)



Neutron Density (U150)



Activation of Source Parts and Dose Rates

The saturation activity (A_{sat}) of the source parts and the activity after 5000 hours of operation (A_{5000h}) have been estimated.

The equivalent dose rates in soft tissue at a depth of 10 mm at a distance of 1 m from the source are shown after 5000 hours of operation ($\dot{D}_{5000h}$), and after 1 hour ($\dot{D}_{+1h}$), 1 day ($\dot{D}_{+1d}$), 1 week ($\dot{D}_{+1w}$) of shut down.

Undulator Based Source (150 GeV)

	A_{sat} GBq	A_{5000h} GBq	$\dot{D}_{5000h}$ mSv/h	$\dot{D}_{+1h}$ mSv/h	$\dot{D}_{+1d}$ mSv/h	$\dot{D}_{+1w}$ mSv/h
Target	5288	3421	437	397	213	164
AMD	3689	3566	81	14.0	3.6	0.1
Collimator	1090	1077	21	2.0	0.4	0.1
Solenoid	943	932	2.7	2.2	0.6	<0.1
	11011	8996	542	415	218	164

Influence of Target Compounds on Activation (U150)

	A_{5000h} [GBq]		$\dot{D}_{+1w}$ [mSv/h]	
	Ti-6Al-4V	Ti-5Al-2.5Sn	Ti-6Al-4V	Ti-5Al-2.5Sn
Target	3421	4017	164	171
AMD	3566	3533	0.1	0.1
Collimator	1077	1127	0.1	<0.1
Solenoid	932	958	<0.1	<0.1
	8996	9635	164	171

- ^{46}Sc with $T_{1/2}$ = 84 d makes 93% contribution in dose rate $\dot{D}_{+1w}$
- ^{46}Sc during decay radiates 1.1 MeV photons

Total Activation and Dose Rate

Source type	A_{5000h} GBq	$\dot{D}_{+1w}$ mSv/h
Undulator based source (150 GeV)	8996	164
Undulator based source (250 GeV)	10849	130
Conventional source	602850	4007

Comparison of the Sources

Positron Yield

Source type	Conv.	U150	U250
Primary electron beam energy, GeV	6.2	150	250
Required number of positrons at IP, e^+/s	$2.82 \cdot 10^{14}$ ($2 \cdot 10^{10}$ e^+/bunch)		
Required number of positrons at the entrance of damping ring, e^+/s	$4.23 \cdot 10^{14}$ (50% safety factor)		
Positron capture efficiency, %	11.5	35	
Conversion target positron yield *	14.42 e^+/e^-	0.0257 e^+/γ	0.0752 e^+/γ
Required primary e^--beam, e^-/s	$2.55 \cdot 10^{14}$	$2.82 \cdot 10^{14}$	
Number of photons, $\gamma/(e^-\ m)$	–	2.575	
Required undulator length, m	–	64.72	22.14

* The positron yields of the Ti-5Al-2.5Sn target for U150 and U250 are 0.0262 and 0.0755 correspondingly.

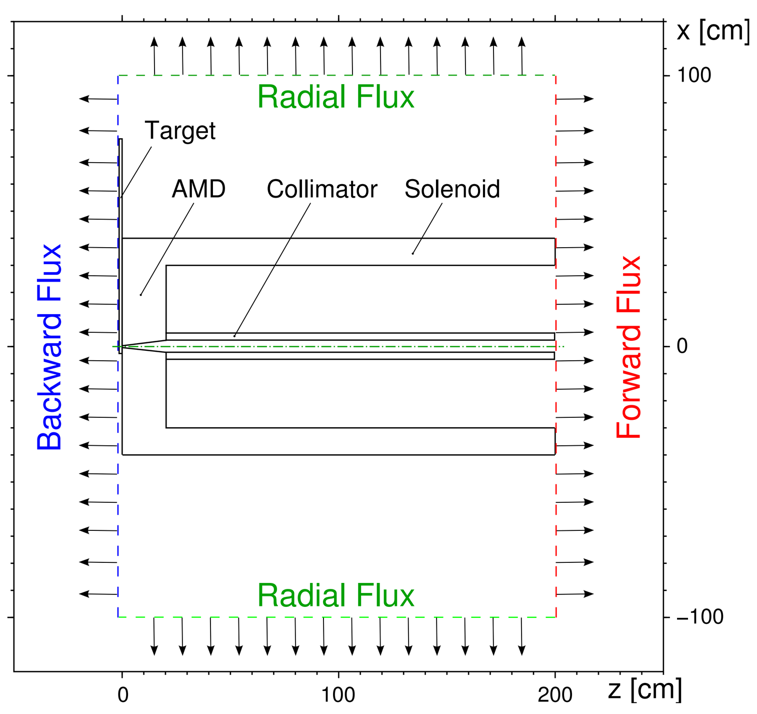
Beam Power and Deposited Energy

Source type	conv.	Ti-6Al-4V Target U150	Ti-6Al-4V Target U250	Ti-5Al-2.5Sn Target U150	Ti-5Al-2.5Sn Target U250
Primary beam power, kW	253.1	90.2	85.7	88.4	85.3
Photon beam power (forw.), %	17.40	82.06	80.45	82.91	81.00
Electron beam power (forw.), %	3.40	1.81	2.90	1.58	2.90
Positron beam power (forw.), %	3.16	1.10	2.34	0.93	2.35
Energy deposited in target, %	19.09	8.01	4.67	7.44	4.40
Energy deposited in AMD, %	19.40	5.70	5.97	5.68	5.80
Energy deposited in collimator, %	33.75	0.66	3.02	0.85	3.00
Energy deposited in solenoid, %	3.17	0.07	0.30	0.09	0.29
	99.38	99.41	99.66	99.48	99.74

Neutron Fluxes in Different Directions

Direction	Area [cm²]	Neutron Flux [n/(s cm²)] U150	U250	Conv.
Backward	$3.14 \cdot 10^4$	$9.0 \cdot 10^8$	$5.9 \cdot 10^8$	$4.8 \cdot 10^9$
Radial	$1.27 \cdot 10^5$	$2.2 \cdot 10^7$	$3.1 \cdot 10^7$	$7.8 \cdot 10^8$
Forward	$3.14 \cdot 10^4$	$1.3 \cdot 10^7$	$1.9 \cdot 10^7$	$6.8 \cdot 10^8$

Definition of Calculated Fluxes

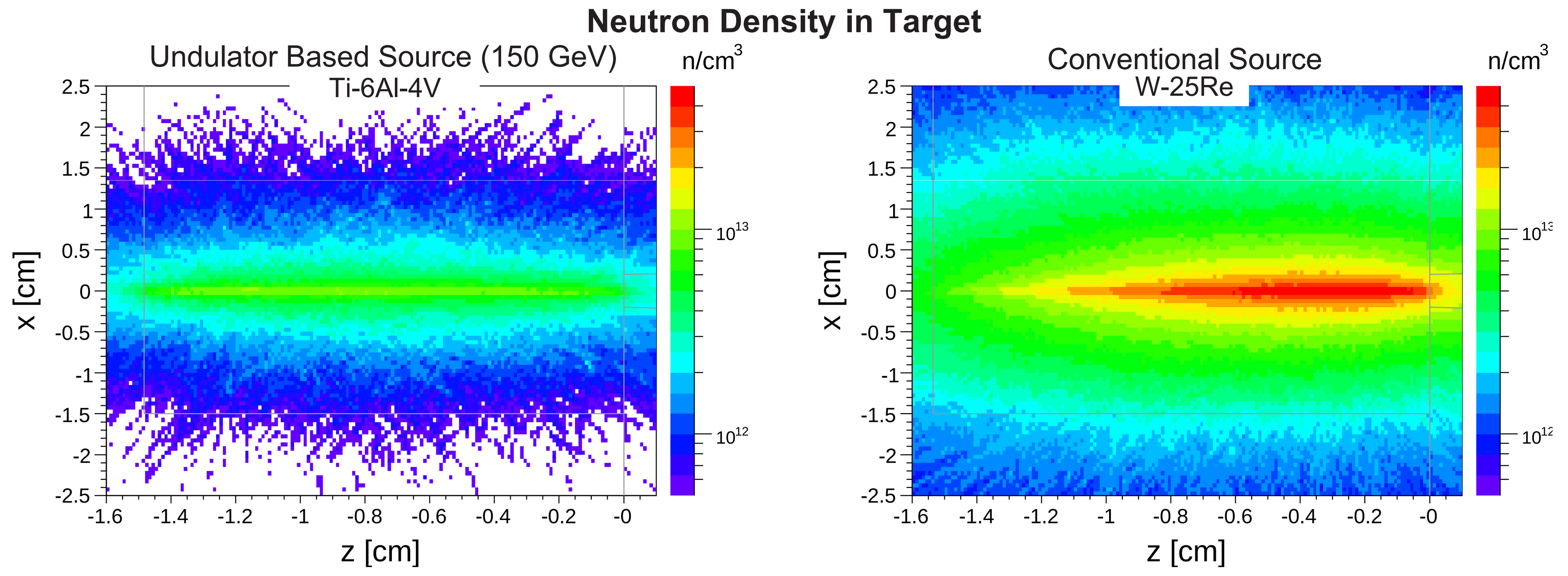


Total Number of Neutrons

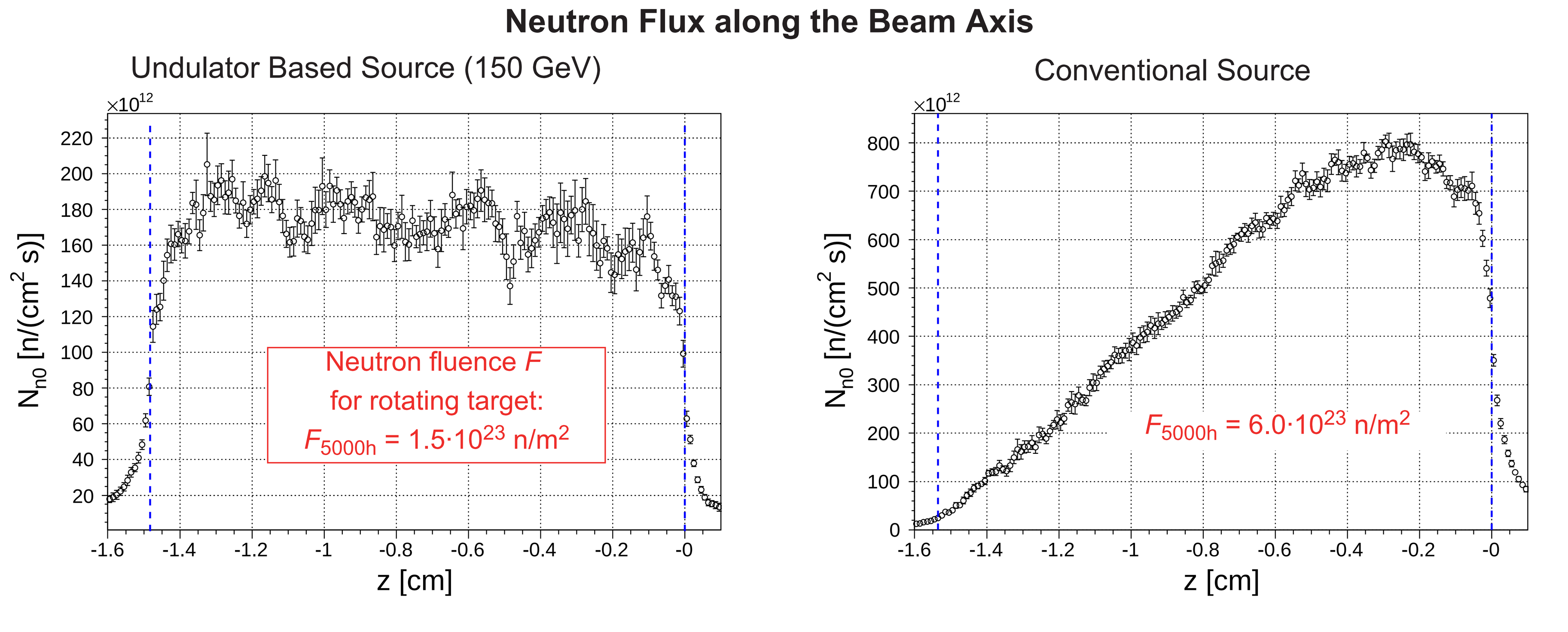
	Conv.	Ti-6Al-4V Target U150	Ti-6Al-4V Target U250	Ti-5Al-2.5Sn Target U150	Ti-5Al-2.5Sn Target U250
$N_{neutron\ total}$, n/s	$2.71 \cdot 10^{14}$	$3.15 \cdot 10^{13}$	$2.32 \cdot 10^{13}$	$3.02 \cdot 10^{13}$	$2.19 \cdot 10^{13}$

Neutron Irradiation Dose of the Target

Neutron Density in Target



Neutron Flux along the Beam Axis



Discussion of the Results

- FLUKA calculations for the undulator based and the conventional positron sources have been performed for the simplified model.
- Neutron fluxes, activation of source parts and dose rates have been studied.
- The dose rate of the conventional source is about 24 times higher than that of the undulator based source (150 GeV drive beam).
- 8.6 times more neutrons are generated in the conventional source in comparison to the undulator based source.
- The annual neutron irradiation dose of Ti-alloy target (used in the undulator based source) is about ten times smaller than the maximal acceptable neutron fluence. No significant changes of the mechanical properties of the target material are expected.

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