

# Radiation Levels in Target Area of Undulator-Based Positron Source

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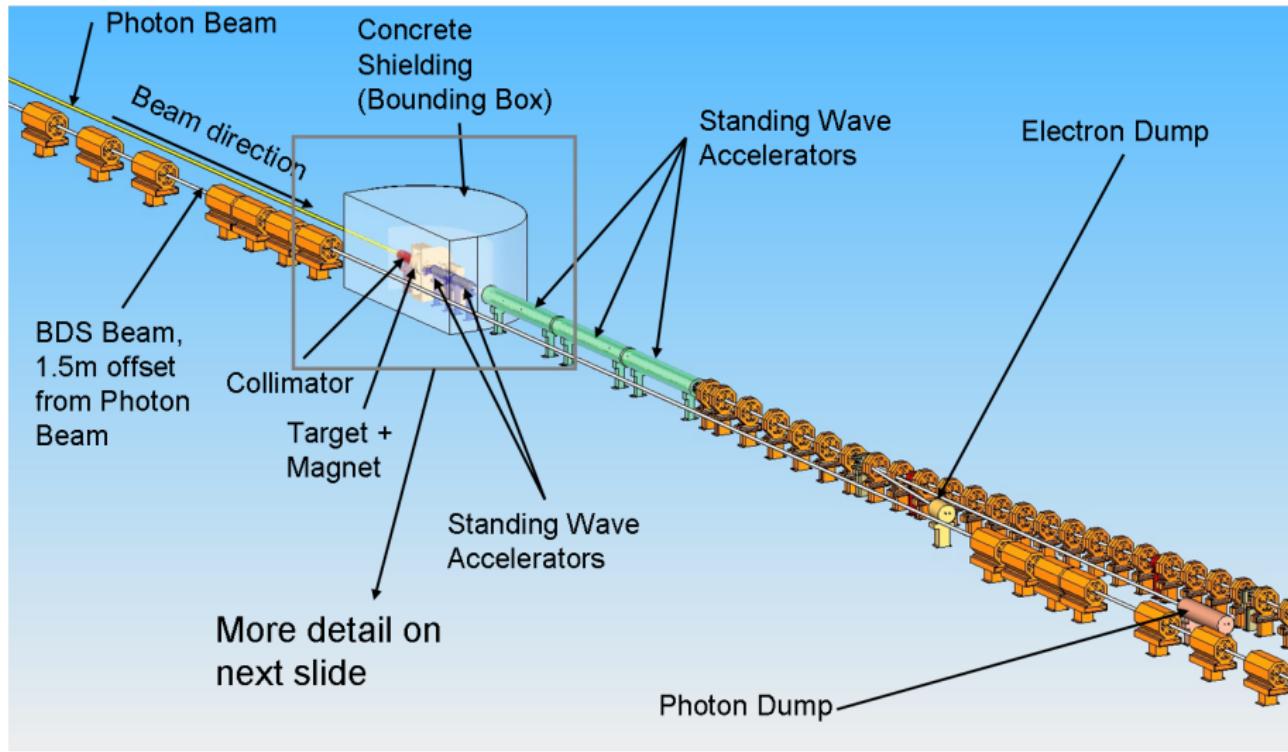
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Linear Collider Workshop 2015

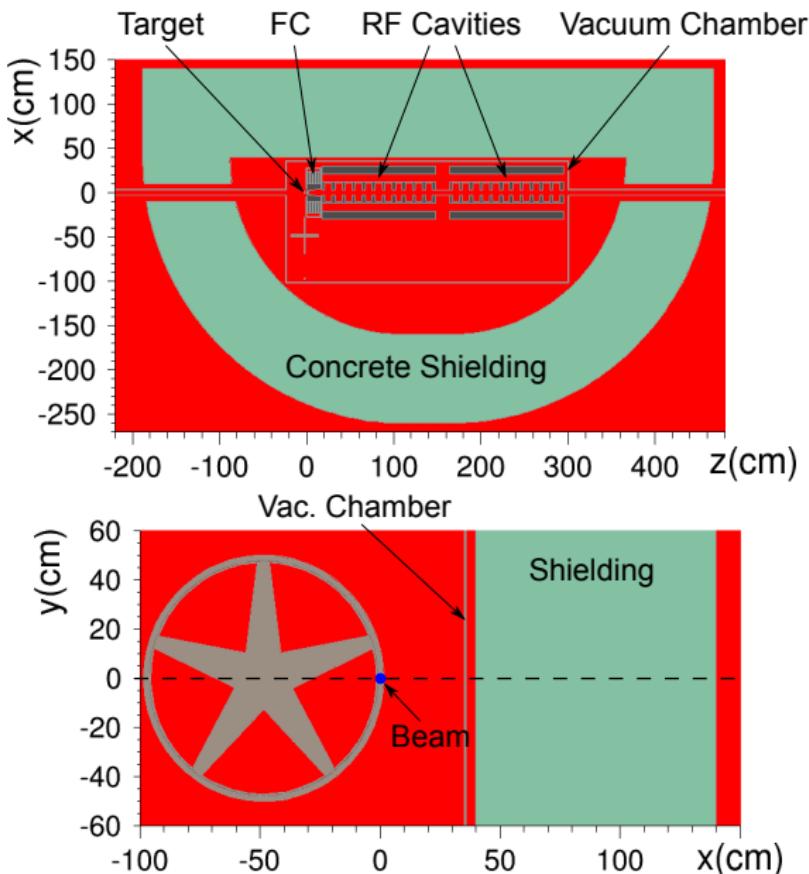
5 November 2015  
Whistler, Canada

# Provisional Sketch of Target Area

Norbert Collomb, STFC, 2009



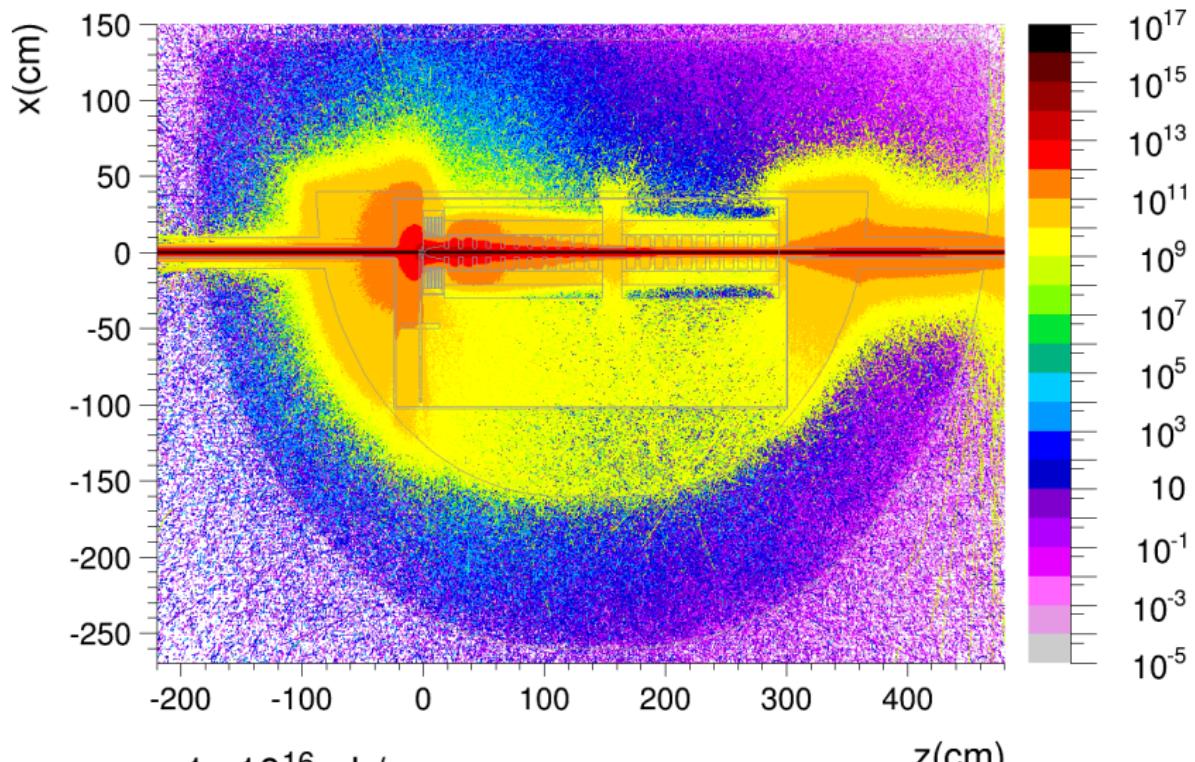
# Simplified Model for Simulations



# Undulator Source Parameters at 500 GeV

Number $e^-$ per Bunch	$2 \cdot 10^{10}$
Number of Bunches per Pulse	1312
Pulse Repetition Rate [Hz]	5
Undulator Field [T] (Undulator K value)	0.42 (0.45)
Photon Energy (1st harmonic) [MeV]	42.9
Average Photon Energy [MeV]	26.8
Required Undulator Length [m]	147
Undulator Photon Yield [ph/( $e^-$ m)]	0.52
Number of Photons per Second	$1 \cdot 10^{16}$
Average Photon Power [kW]	43
Thickness of Ti6Al4V Target $X_0$	0.4
Max. Field of Flux Concentrator [T]	3.2
Background B-Field in 1.3 GHz 11 Cells RF Structures [T]	0.5
E-Field of RF Structures [MeV/m]	14.5 (0!)

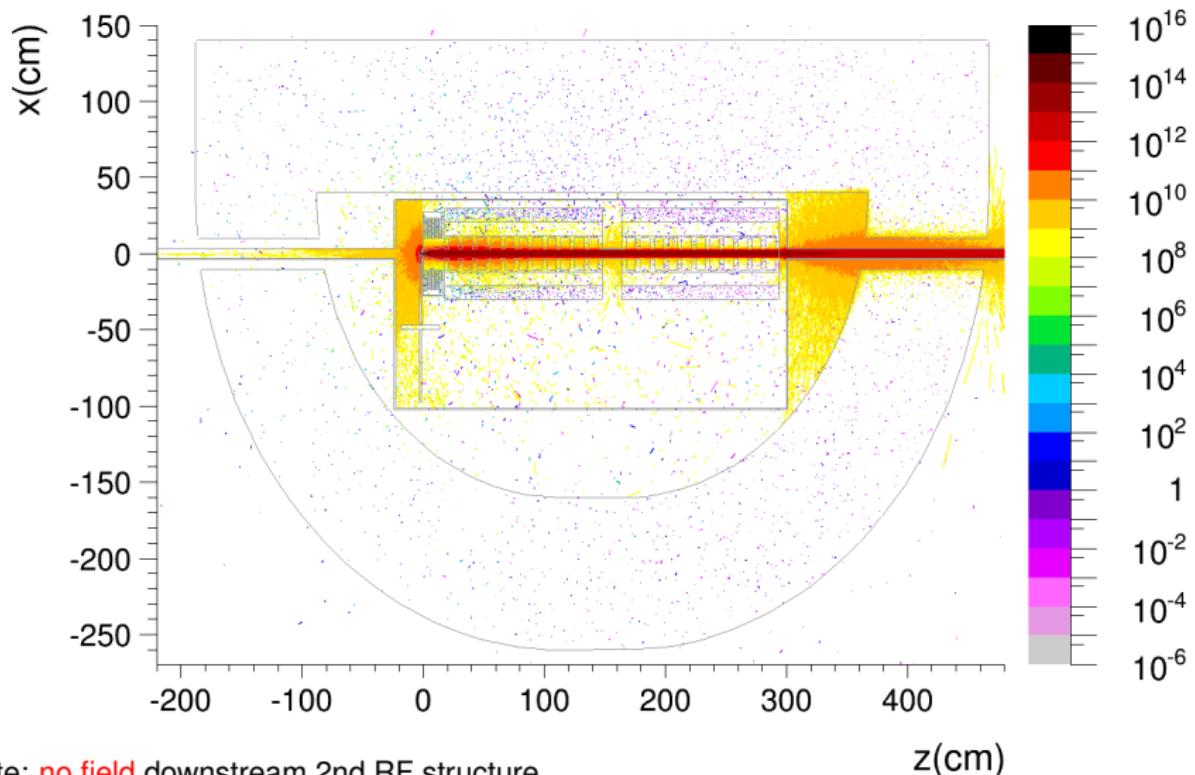
# Photon Distribution [ph/(s cm<sup>3</sup>)]



$$N_{\text{primary ph}} = 1 \cdot 10^{16} \text{ ph/s}$$

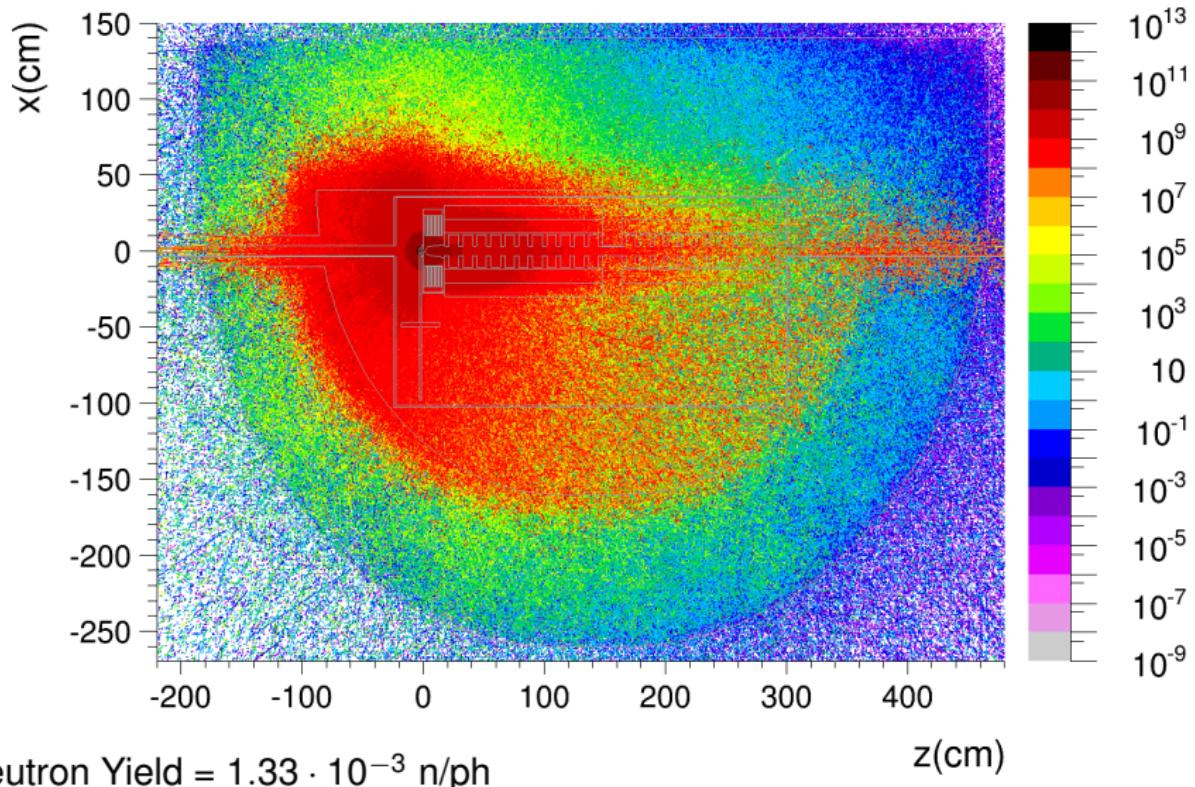
$z(\text{cm})$

# Positron Distribution [ $e^+/(s\ cm^3)$ ]

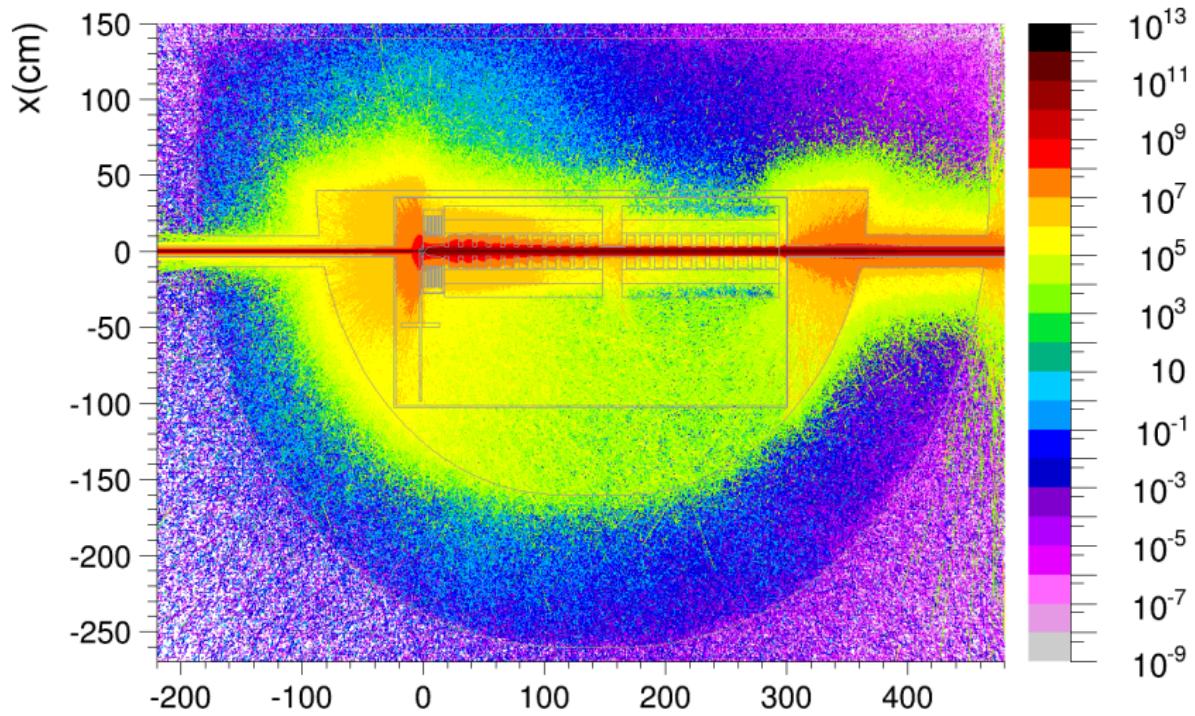


Note: no field downstream 2nd RF structure

# Neutron Distribution [n/(s cm<sup>3</sup>)]



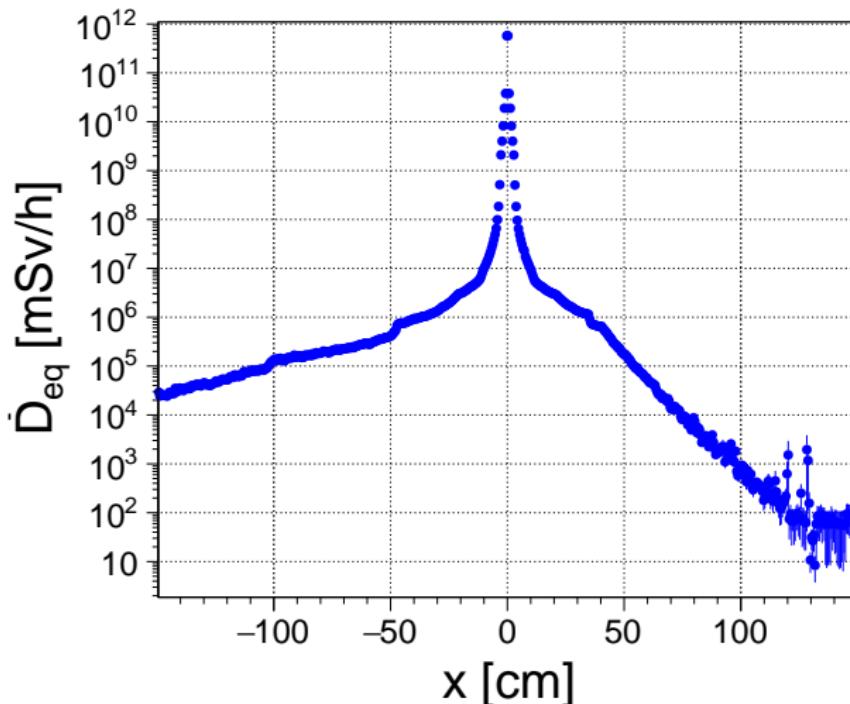
# Distribution of Equivalent Dose Rate ( $\dot{D}_{eq}$ ) [mSv/h]



$$\dot{D}_{eq}(z \approx 0, x \approx 145 \text{ cm}) \approx 60 \text{ mSv/h}$$

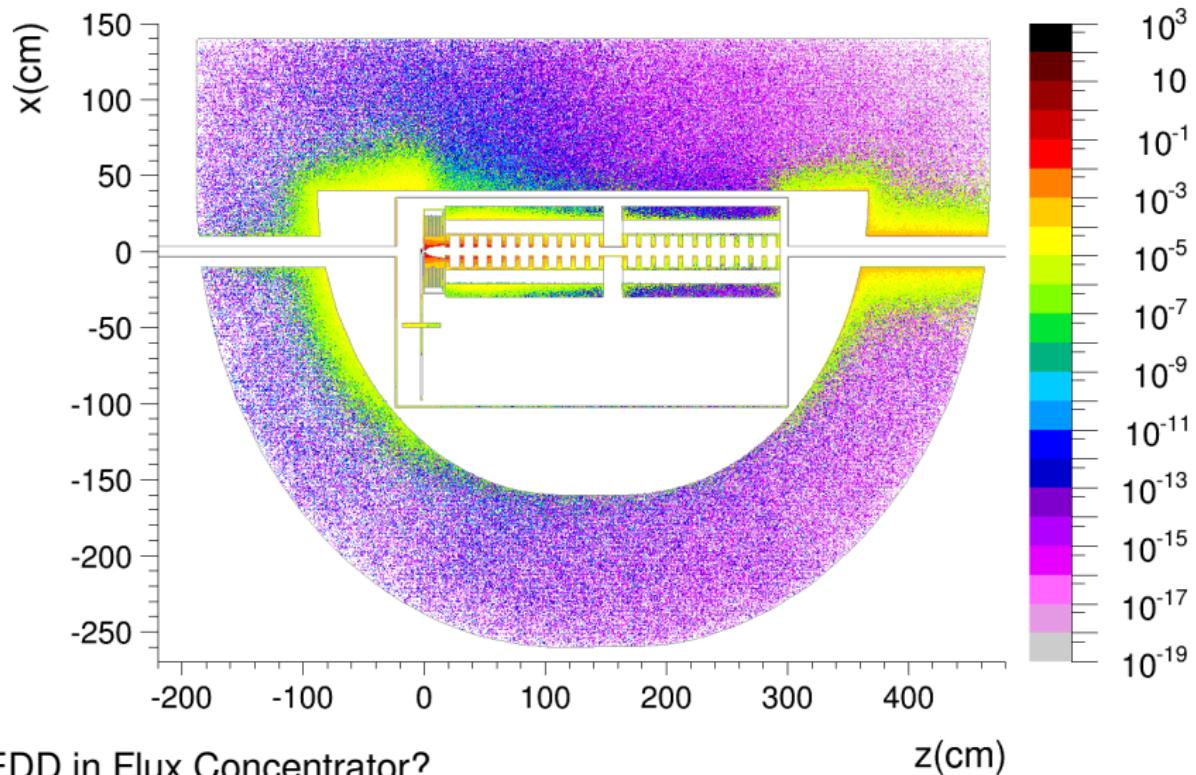
$z(\text{cm})$

# Radial Profile of Equivalent Dose Rate



Dose rate reduction by 1 m ordinary concrete ( $\rho = 2.3 \text{ g/cm}^3$ )  
is approx.  $10^5$  times

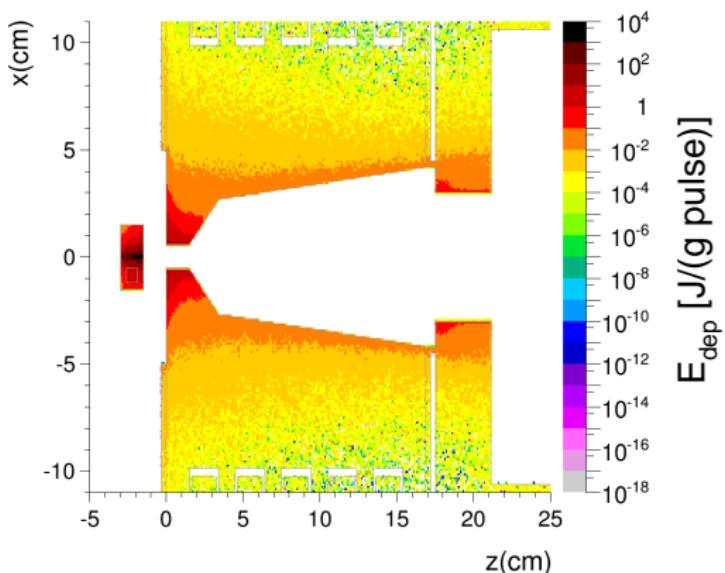
# Distribution of Energy Deposition [J/(g pulse)]



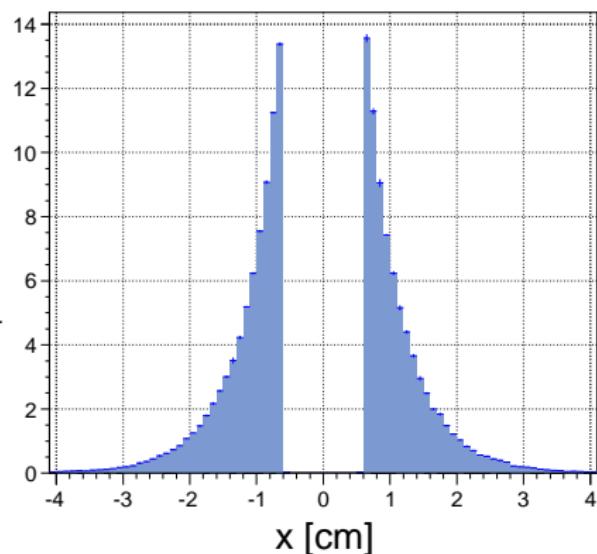
PEDD in Flux Concentrator?

# Peak Energy Deposition in FC and RF Cavity

2D Energy Distribution [J/(g pulse)]



Energy Profile at  $z = 0$



PEDD in 1st RF cavity is  $\sim 10^2$  less than PEDD<sub>FC</sub>

Note: target rotation was not taken into account

# Total Energy Deposition

Average Photon Power = 43 kW

Fraction of Photon Energy Deposited in Target, FC and etc.

Source Part	$E_{dep}/E_{ph}$ [%]
Target	5.4
FC	5.7
RF Structure #1	4.3*
RF Structure #2	0.1*
Shield	0.9
...	...
$\Sigma$	18.0

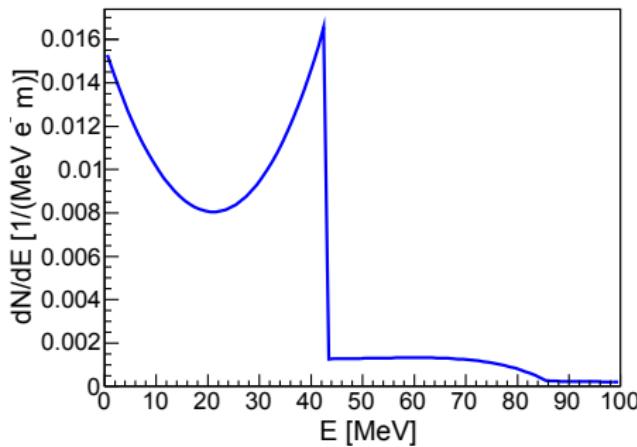
\* without acceleration

# Excitation of Atomic Nuclei by Photons

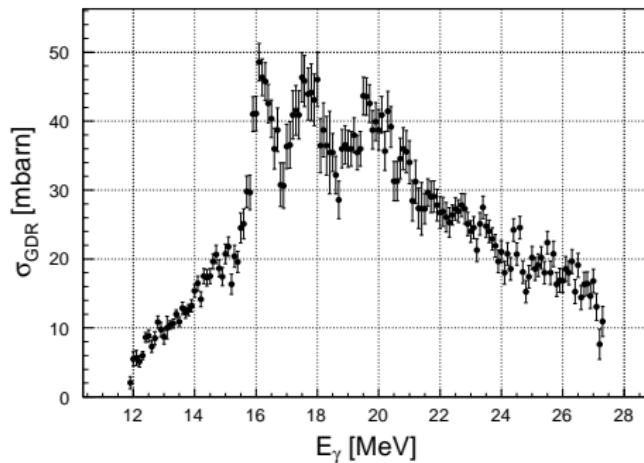
Giant Dipole Resonance (GDR)

Photon Energy Distribution

for 250 GeV  $e^-$ ,  $K = 0.45$



Cross-Section of Giant Resonance  
for photons in Ti target



De-excitation of nuclei results in a nuclear fission, neutron or gamma ray emission.

# Isotope Yield in Ti6Al4V Target

Nucl.	Yield [isotope/ph]	Err. [%]	$T_{1/2}$	Decay
$^{47}_{22}\text{Ti}$	$3.14 \cdot 10^{-4}$	0.1	$\infty$	
$^1_1\text{H}$	$1.94 \cdot 10^{-4}$	0.2	$\infty$	
$^{46}_{22}\text{Ti}$	$1.68 \cdot 10^{-4}$	0.4	$\infty$	
$^{48}_{22}\text{Ti}$	$8.16 \cdot 10^{-5}$	0.3	$\infty$	
$^4_2\text{He}$	$5.70 \cdot 10^{-5}$	0.7	$\infty$	
$^{45}_{21}\text{Sc}$	$4.90 \cdot 10^{-5}$	0.7	$\infty$	
$^{46}_{21}\text{Sc}$	$3.55 \cdot 10^{-5}$	0.5	<b>83.79d</b>	$\beta^-$
$^{45}_{22}\text{Ti}$	$3.50 \cdot 10^{-5}$	0.2	<b>184.8m</b>	$\varepsilon$
$^{49}_{22}\text{Ti}$	$3.15 \cdot 10^{-5}$	0.7	$\infty$	
$^{47}_{21}\text{Sc}$	$3.13 \cdot 10^{-5}$	0.4	<b>3.349d</b>	$\beta^-$
$^{50}_{23}\text{V}$	$2.08 \cdot 10^{-5}$	0.3	$\infty$	
$^{26}_{12}\text{Mg}$	$1.59 \cdot 10^{-5}$	0.6	$\infty$	
$^{42}_{20}\text{Ca}$	$1.41 \cdot 10^{-5}$	0.9	$\infty$	
$^{44}_{20}\text{Ca}$	$1.40 \cdot 10^{-5}$	1.1	$\infty$	
$^{46}_{21}\text{Sc}$	$1.39 \cdot 10^{-5}$	1.2	<b>3.97h</b>	$\varepsilon$
$^{26}_{13}\text{Al}$	$1.34 \cdot 10^{-5}$	0.5	$\infty$	
$^{25}_{12}\text{Mg}$	$1.25 \cdot 10^{-5}$	1.9	$\infty$	
$^{43}_{20}\text{Ca}$	$1.18 \cdot 10^{-5}$	0.1	$\infty$	

Nucl.	Yield [isotope/ph]	Err. [%]	$T_{1/2}$	Decay
$^{49}_{23}\text{V}$	$9.38 \cdot 10^{-6}$	1.9	<b>330d</b>	$\varepsilon$
$^2_1\text{H}$	$9.21 \cdot 10^{-6}$	1.5	$\infty$	
$^{23}_{11}\text{Na}$	$6.72 \cdot 10^{-6}$	1.9	$\infty$	
$^{41}_{20}\text{Ca}$	<b><math>4.67 \cdot 10^{-6}</math></b>	1.6	<b>1.02E+5y</b>	$\varepsilon$
$^{50}_{22}\text{Ti}$	$4.43 \cdot 10^{-6}$	1.5	$\infty$	
$^{44}_{22}\text{Ti}$	<b><math>4.35 \cdot 10^{-6}</math></b>	1.2	<b>60.0y</b>	$\varepsilon$
$^{27}_{13}\text{Al}$	$2.92 \cdot 10^{-6}$	1.0	$\infty$	
$^{48}_{21}\text{Sc}$	$2.69 \cdot 10^{-6}$	2.9	<b>43.67h</b>	$\beta^-$
$^{24}_{12}\text{Mg}$	$2.25 \cdot 10^{-6}$	1.7	$\infty$	
$^{22}_{10}\text{Ne}$	$2.14 \cdot 10^{-6}$	2.4	$\infty$	
$^{41}_{19}\text{K}$	$1.67 \cdot 10^{-6}$	3.2	$\infty$	
$^{40}_{19}\text{K}$	$1.65 \cdot 10^{-6}$	3.6	$\infty$	
$^{38}_{18}\text{Ar}$	$1.55 \cdot 10^{-6}$	5.0	$\infty$	
$^{45}_{20}\text{Ca}$	$1.44 \cdot 10^{-6}$	2.4	<b>162.61d</b>	$\beta^-$
$^{43}_{21}\text{Sc}$	$1.25 \cdot 10^{-6}$	3.4	<b>3.891h</b>	$\varepsilon$
$^{40}_{20}\text{Ca}$	$9.48 \cdot 10^{-7}$	2.2	$\infty$	
$^{48}_{23}\text{V}$	$8.70 \cdot 10^{-7}$	1.3	<b>15.9735d</b>	$\varepsilon$
$^3_1\text{H}$	$8.50 \cdot 10^{-7}$	2.6	<b>12.32y</b>	$\beta^-$

# Isotope Yield in Flux Concentrator (Copper)

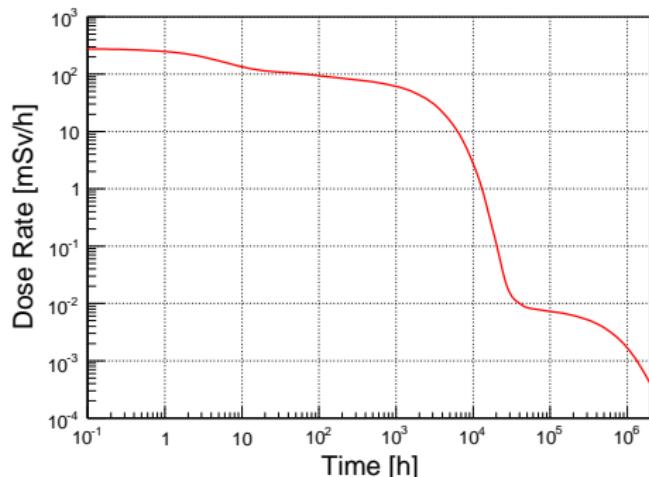
Nucl.	Yield [isotope/ph]	Err. [%]	T <sub>1/2</sub>	Decay
<sup>62</sup> Cu <sub>29</sub>	$1.16 \cdot 10^{-4}$	0.8	9.673m	$\varepsilon$
<sup>63</sup> Cu <sub>29</sub>	$8.48 \cdot 10^{-5}$	0.3	$\infty$	
<sup>64</sup> Cu <sub>29</sub>	$7.27 \cdot 10^{-5}$	0.5	12.701h	$\varepsilon: 61.5\%, \beta^- : 38.5\%$
<sup>1</sup> H <sub>1</sub>	$4.88 \cdot 10^{-5}$	1.1	$\infty$	
<sup>62</sup> Ni <sub>28</sub>	$3.36 \cdot 10^{-5}$	1.3	$\infty$	
<sup>65</sup> Cu <sub>29</sub>	$2.52 \cdot 10^{-5}$	0.6	2.5175h	$\beta^-$
<sup>4</sup> He <sub>2</sub>	$1.96 \cdot 10^{-5}$	1.4	$\infty$	
<sup>59</sup> Co <sub>27</sub>	$1.60 \cdot 10^{-5}$	1.4	$\infty$	
<sup>61</sup> Cu <sub>29</sub>	$1.02 \cdot 10^{-5}$	1.6	3.333h	$\varepsilon$
<sup>61</sup> Ni <sub>28</sub>	$9.76 \cdot 10^{-6}$	1.7	$\infty$	
<sup>66</sup> Cu <sub>29</sub>	$2.89 \cdot 10^{-6}$	0.5	5.12m	$\beta^-$
<sup>58</sup> Co <sub>27</sub>	$2.47 \cdot 10^{-6}$	3.1	70.86d	$\varepsilon^-$
<sup>64</sup> Ni <sub>28</sub>	$2.11 \cdot 10^{-6}$	3.2	$\infty$	
<sup>63</sup> Ni <sub>28</sub>	$1.98 \cdot 10^{-6}$	1.7	101.2y	$\beta^-$
<sup>60</sup> Ni <sub>28</sub>	$9.73 \cdot 10^{-7}$	3.9	$\infty$	
<sup>61</sup> Co <sub>27</sub>	$5.33 \cdot 10^{-7}$	6.8	1.65h	$\beta^-$
<sup>2</sup> H <sub>1</sub>	$2.90 \cdot 10^{-7}$	11.2	$\infty$	
<sup>60</sup> Co <sub>27</sub>	$2.53 \cdot 10^{-7}$	13.3	1925.28d	$\beta^-$

# Total Isotope Yields in Target, FC and RF Structures

	Yield [isotope/ph]
Target	$1.18 \cdot 10^{-3}$ $\pm 0.15\%$
Flux Concentrator	$4.15 \cdot 10^{-4}$ $\pm 0.18\%$
RF Structure #1	$4.49 \cdot 10^{-4}$ $\pm 0.57\%$
RF Structure #2	$1.23 \cdot 10^{-5}$ $\pm 1.35\%$

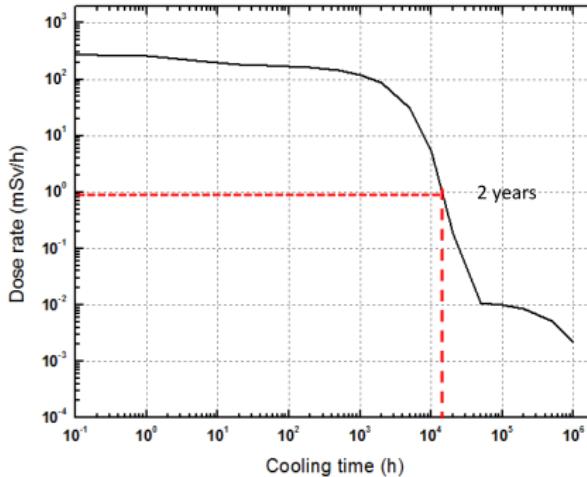
# Target Cooling

Equivalent Dose Rates vs Cooling Time after 1 Year Irradiation at 1 m from Target



A. Ushakov, ILC e<sup>+</sup> Source Collaboration Meeting,  
7 April 2008, Zeuthen, Germany

FLUKA code



Jia Xuejun (IHEP, China), KILC 12,  
24 April 2012, Daegu, Korea

MCNPX code

# Summary

- Radiation levels in target area have been estimated **during operation** of undulator based source at 500 GeV center-of-mass energy including spatial distributions of
  - photons,
  - positrons,
  - neutrons,
  - equivalent dose rate,
  - deposited energy.
- Radiation level in region of 2nd accelerating structure is not very high and, may be, it can be placed out of concrete shielding box.
- Space without fields has to be minimized as much as possible.
- Dose rates due to target activation have been estimated earlier. IHEP and DESY results based on different simulation tools are consistent.
- Acceleration of  $e^+$  and  $e^-$  has to be included in the future simulations.