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Monte Carlo Simulation of CBCT on-board imager using EGSnrc/BEAMnrc/DOSXYZnrc codes

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1. Background-Aim

- ❖ Image-guided radiation therapy (IGRT) has been extensively utilized in clinical practice, significantly improving the precision of radiation treatments. Among its techniques, Cone Beam Computed Tomography (CBCT) plays a crucial role by producing high-resolution, volumetric images of patients directly on the treatment table, thereby enabling accurate alignment and verification of the target area.
- ❖ The primary objective of this study is to simulate Cone Beam Computed Tomography (CBCT) using the Varian On-Board Imager (OBI) system. By developing a detailed simulation of the CBCT process, this research aims to enhance the understanding of imaging doses and improve dose calculation methodologies, ultimately contributing to safer and more effective radiation treatment planning.

2. Materials & Methods

→ The gold standard for modelling particle in a wide range of imaging applications is Monte Carlo Simulation

- EGSnrc/BEAMnrc/DOSXYZnrc Monte Carlo was used for the study

BEAMnrc

- ✓ Tube Housing
- ✓ Pre-collimator
- ✓ Blades
- ✓ Bowties (additional filters for enhancing image quality)

DOSXYZnrc

- ✓ Water Tank
- ✓ Patients

2. Materials & Methods

BEAMnrc

Monte Carlo Simulation Characteristics

- 1. Tube Model:** G242 Varian (rotating anode)
- 2. Operating Voltage:** 125 kV
- 3. Simulation Scale:** 2×10^9 particle histories
- 4. Bowtie Filters:**
 - No Bowtie
 - Half Bowtie
 - Full Bowtie
- 5. Variance Reduction Techniques:** Implemented to reduce computational time while maintaining accuracy in simulation results
- 6. Pegs4 data:** Cross sections data from 1KeV
- 7. Phase Space Files:** Generated at a 100 cm distance from the X-ray tube for each of the three bowtie configurations

These characteristics define the framework of the Monte Carlo simulation, providing the basis for precise dose calculations and improving the efficiency of modeling CBCT imaging doses.

The image displays the BEAMnrc graphical user interface (GUI) with several windows open. The 'EGSnrc Parameters' window is the central focus, showing a grid of settings for various simulation parameters. The 'Selected components' window lists available components like XTUBE, SLABS, and PYRAMIDS. The main 'BEAMnrc GUI' window shows the title bar, menu options (File, Preview, Execute, Help, About), and a logo for NRC-CARC. The main area contains a list of simulation parameters such as Title, Medium, IWATCH Output, RNG Seed Options, Run option, Output Options, Store Data Arrays, LATCH option, Score Last Z, Number of histories, Initial RNG seed 1, Initial RNG seed 2, Maximum CPU hours allowed, Bremsstrahlung Splitting, Brems cross-section enhancement, Split electrons or photons at CM, Incident particle, Source number, Global electron cutoff energy - ECUT (MeV), Global photon cutoff energy - PCUT (MeV), Electron range rejection, Global electron cutoff (ESAVE_GLOBAL, range rejection, MeV), Photon forcing, Number of scoring planes, Dose calculation, and Z of front of 1st CM to reference plane (cm). Buttons for 'Define Media', 'Edit EGSnrc Parameters', and 'Close' are visible at the bottom.

Parameter	Value	Parameter	Value
Maximum step size (cm)	5	Bound Compton scattering	On
Max. fractional energy loss/step	0.25	Compton cross sections	default
Xlmax	0.5	Pair angular sampling	Simple
Boundary crossing algorithm	EXACT	Pair cross sections	BH
Skin depth for BCA	0	Photoelectron angular sampling	On
Electron-step algorithm	PRESTA-II	Rayleigh scattering	On
Spin effects	On	Atomic relaxations	On
Electron impact ionization	On	Photon cross-sections	xcom
Brems angular sampling	KM	Photon cross-sections output	Off
Brems cross sections	NIST		

Component	Value	Action
XTUBE	xube	Edit...
SLABS	vac_slab	Edit...
SLABS	nbewind	Edit...
SLABS	add_fit	Edit...
PYRAMIDS	precoll	Edit...
JAWS	blades	Edit...
SLABS	Glass	Edit...
PYRAMIDS	bowtie	Edit...
SLABS	air_slab	Edit...

Parameter	Value	Parameter	Value
Title	G242_Varian_Half_Bowtie	Bremsstrahlung Splitting	directional
Medium	AIR516ICRU	Brems cross-section enhancement	on
IWATCH Output	none	Split electrons or photons at CM	none
RNG Seed Options	store RNG at start of each batch	Incident particle	electron
Run option	first time	Source number	10 - Parallel circular beam incident from side
Output Options	phase space at each scoring plane	Global electron cutoff energy - ECUT (MeV)	0.516
Store Data Arrays	yes	Global photon cutoff energy - PCUT (MeV)	0.001
LATCH option	inherited latch - set by passage	Electron range rejection	on with set ECUTRR
Score Last Z	no	Global electron cutoff (ESAVE_GLOBAL, range rejection, MeV)	1
Number of histories	2000000000.0	Photon forcing	off
Initial RNG seed 1	33	Number of scoring planes	1
Initial RNG seed 2	97	Dose calculation	Only total dose
Maximum CPU hours allowed	500	Z of front of 1st CM to reference plane (cm)	0.0

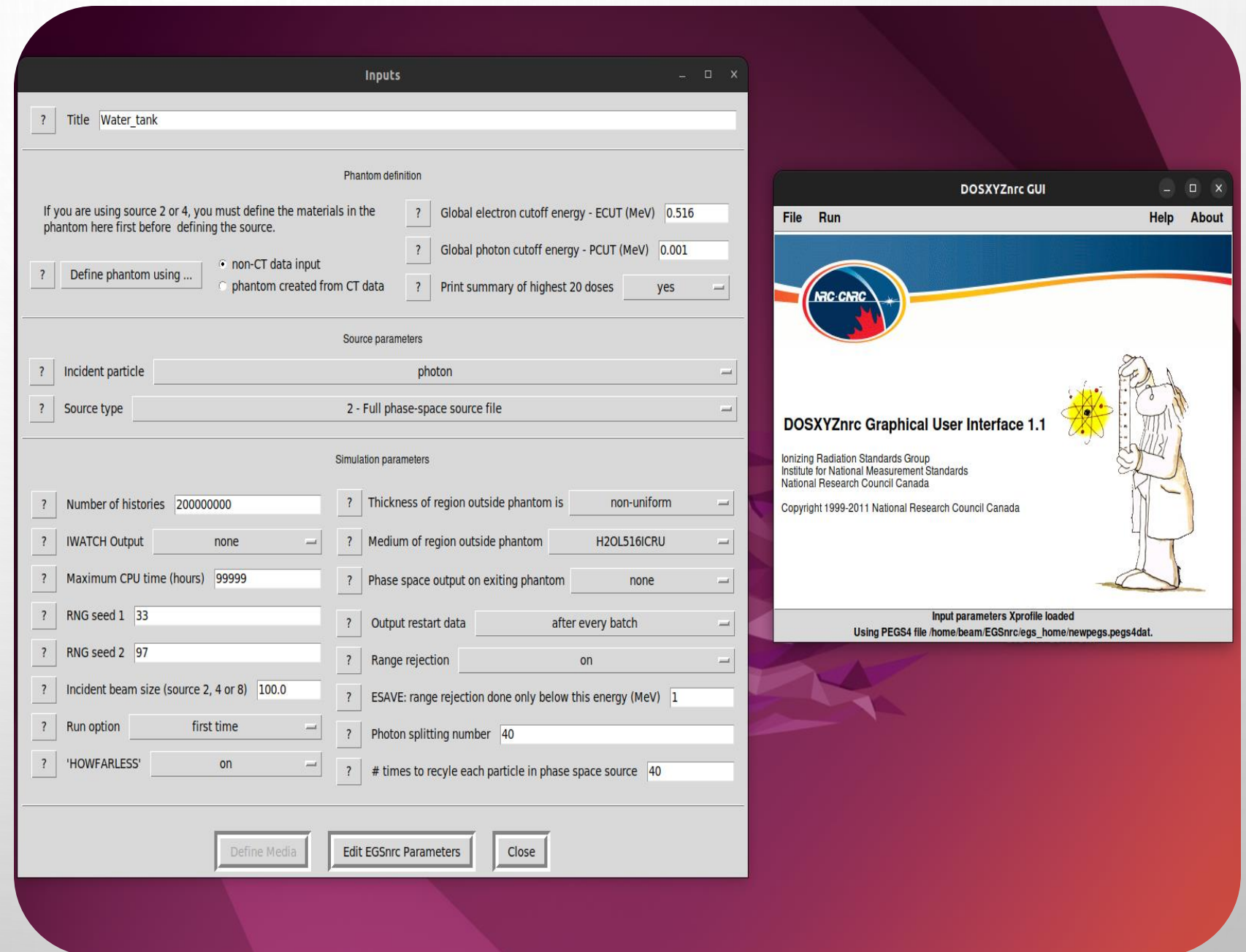
2. Materials & Methods

DOSXYZnrc

DOSXYZnrc Simulation Parameters

- 1. Water Tank Dimensions:** 64 cm x 64 cm x 52 cm
- 2. Simulation Scale:** 2×10^9 particle histories
- 3. Source Type:** Phase space files from BEAMnrc
- 4. Medium:** Water (homogeneous medium for dose calculation)
- 5. Output:** Dose distribution calculated in a 3D grid format

This configuration allows for detailed dosimetric analysis, ensuring accurate assessment of radiation dose delivery in a clinical setting.



3. Results

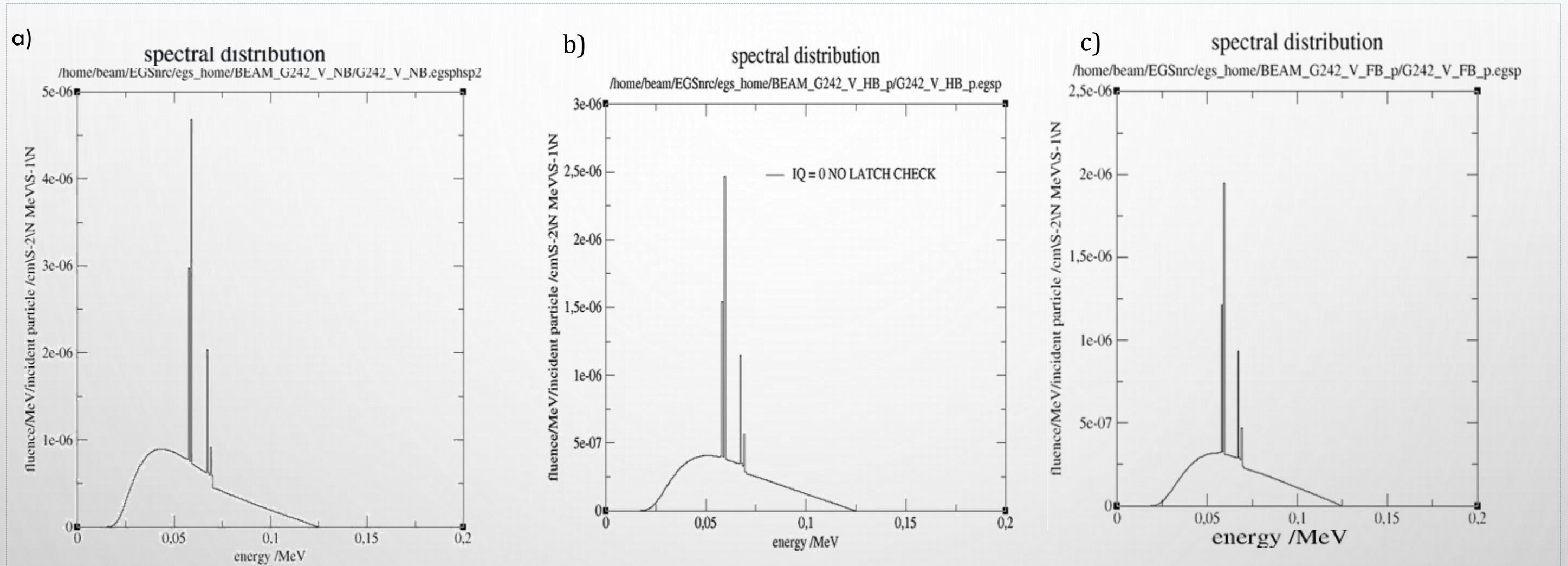


Figure 1a-c: 125kV spectrum for a) No bowtie, b) Half bowtie and c) Full bowtie

3. Results

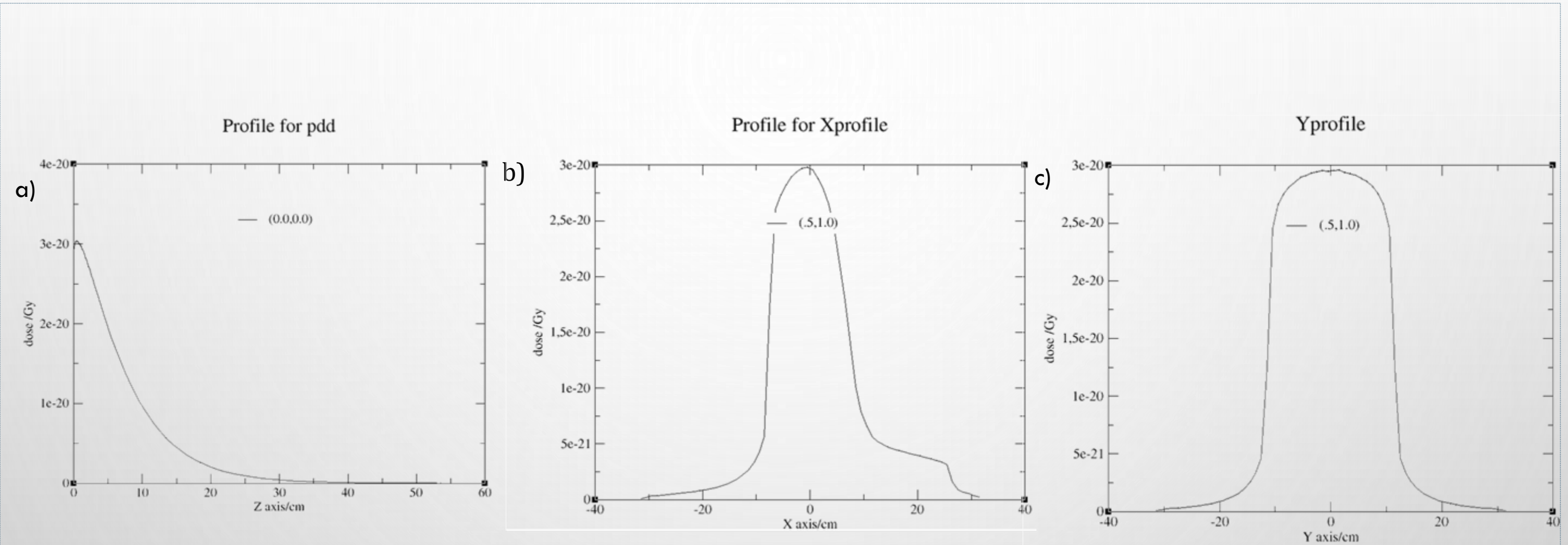


Figure 2a-c: a) PDD, b)X-profile and c) Y-profile for Half bowtie module

3. Results

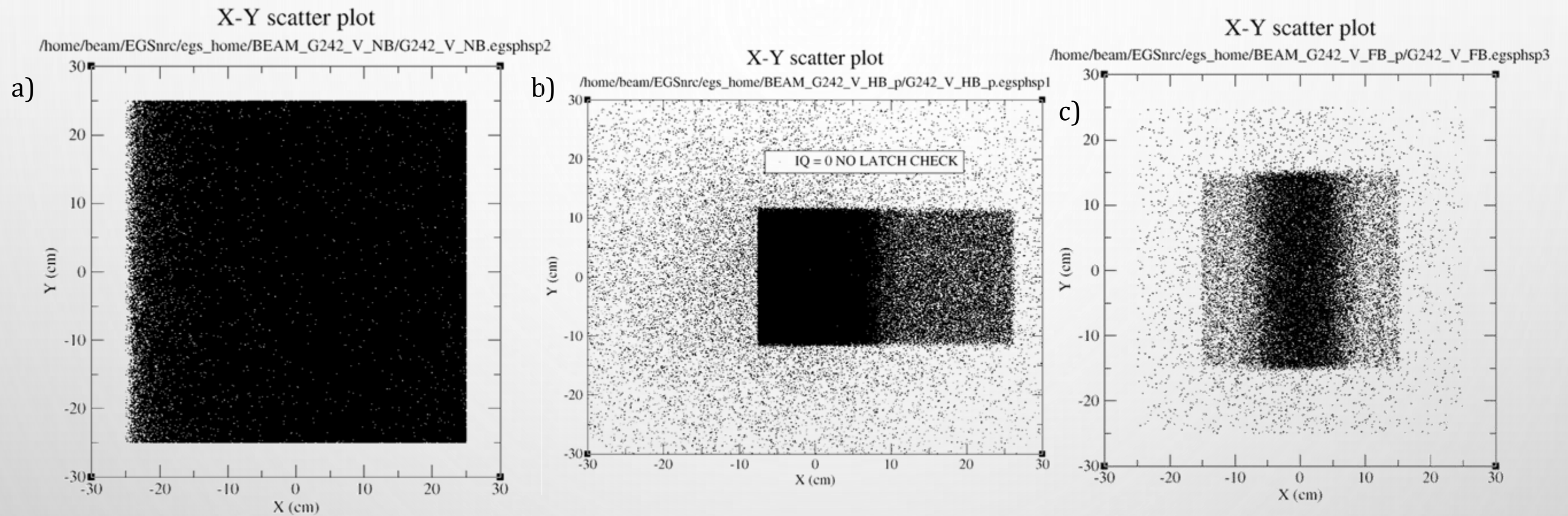


Figure 3a-c: Scatter Plots for a) No bowtie, b) Half Bowtie and c) Full bowtie module

4. Conclusions

- The modeled kV source has been validated against real measurements, making it an invaluable resource for Medical Physicists. This validation ensures the model's accuracy and reliability, providing a robust tool for precise dose calculations and treatment planning.
- This imaging dose can be factored into the total target dose as well as the cumulative dose delivered to Organs at Risk (OARs). By integrating this information, the overall treatment planning can be optimized, ensuring both treatment efficacy and minimizing potential harm to critical structures.
- In the future, utilizing advanced AI techniques, this model will be capable of predicting the dose from CBCT for each patient individually in real time. Consequently, it will be possible to determine the imaging dose for each session prior to treatment, enhancing precision and patient safety.