A Monte Carlo dose estimation method using a voxelized phantom for pediatric CBCT

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Goal

- To establish a voxel Monte Carlo (MC) model for radiation dose estimation from pediatric CBCT
  - Build a CBCT x-ray tube model
  - Build a voxelized anthropomorphic phantom for dose calculation
- To validate the MC model with physical measurements

Goal

- To estimate absorbed doses and effective dose from pediatric CBCT using the MC model and physical measurements

Monte Carlo

- MC techniques are those which simulate the random trajectories of individual particles by using machine-generated (pseudo-) random numbers to sample from the probability distributions governing the physical processes involved

Varian On-Board Imager

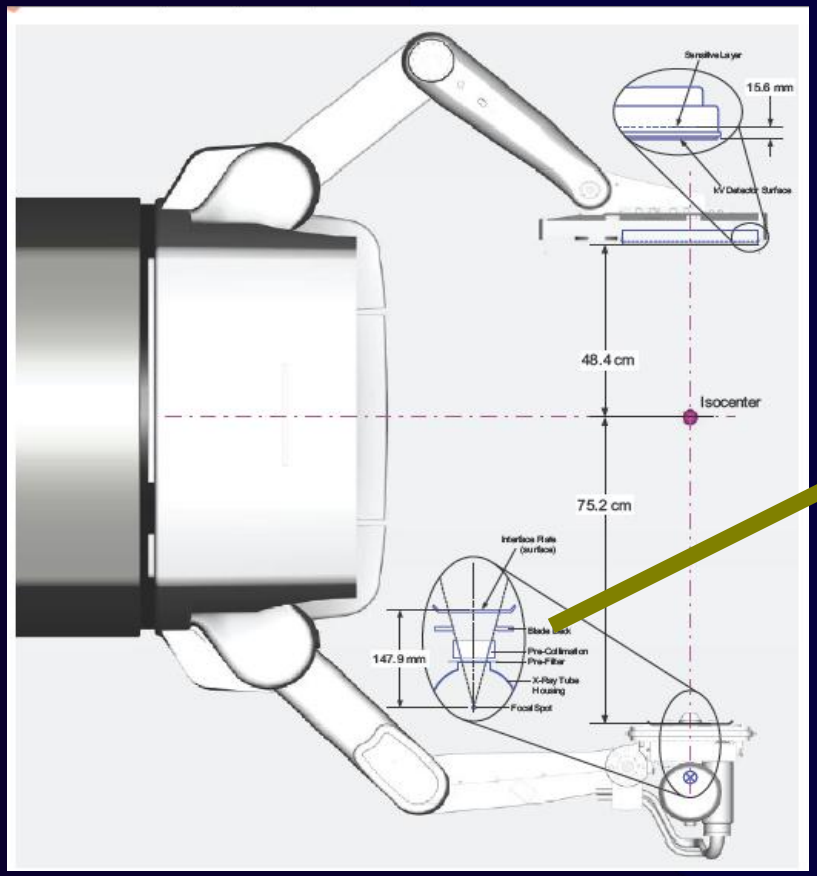
- KV x-ray system mounted on a Linac
- Used for Image Guided Radiation Therapy (IGRT)
  - To localize the patient setup
  - 3D CBCT or 2D fluoroscopic images

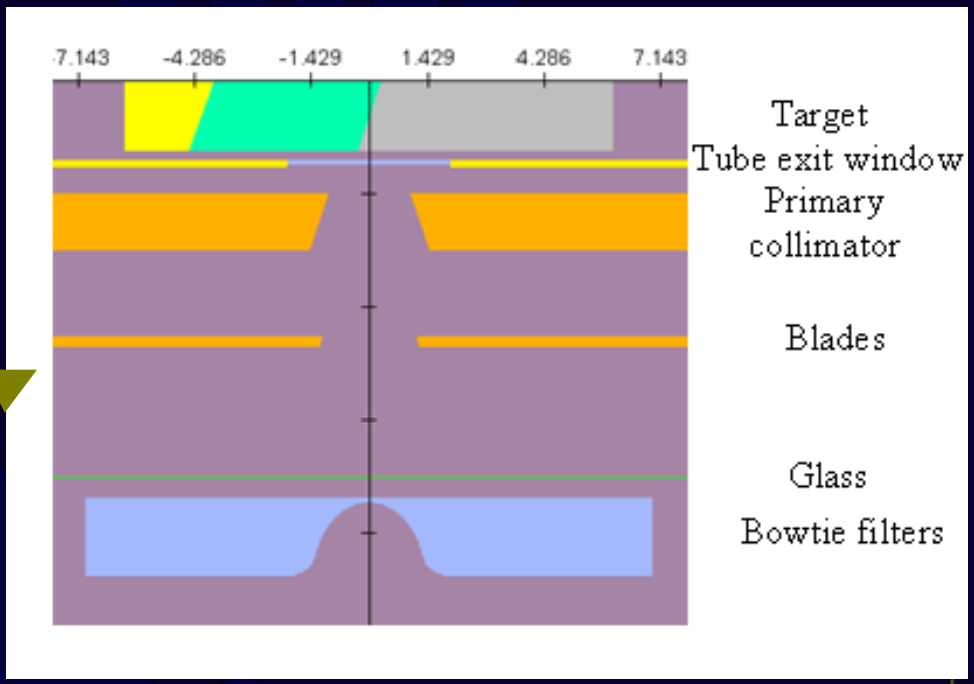
Source: http://www.youtube.com/watch?v=SJ2Unb-EwEE

BEAMnrc/EGSnrc code

- A MC system established for the purpose of linac head simulations
- Open to the public:
  - www.irs.inms.nrc.ca/EGSnrc/EGSnrc.html
  - www.irs.inms.nrc.ca/BEAM/beamhome.html
- Convenient GUI (tcl/tk scripts)
- Powerful variance reduction techniques
- Reliable radiation transport physics

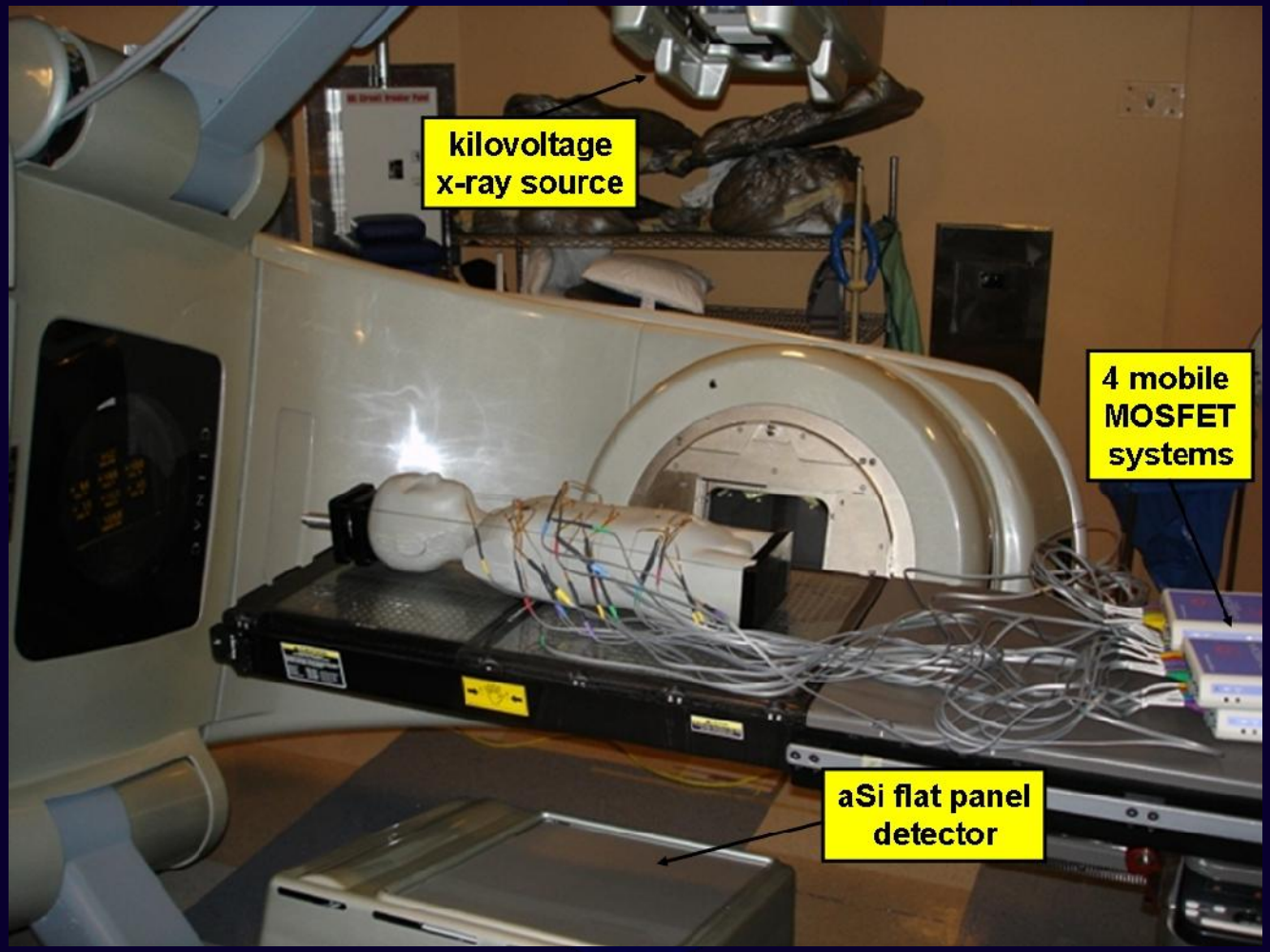
Varian G242 x-ray tube





Source: reference manual of Varian On-Board Imager

MOSFET experiment



CBCT parameters

Dose mode	Standard dose	Low dose
Fan type	Full-Fan	
Filter type	Full bowtie filter	
kilo-Voltage peak (kVp)	125	125
Current (mA)	80	40
Exposure time (pulsed, msec)	25	10
Focal spot (mm)	0.4-0.8	
Source to Isocenter Distance (SID, cm)	100	
Total number of projections	~660	
Milliampere second (mAs)	~1320	~264
Beam collimation (cm^2)	Lateral: 47.2, Axial: 20.6	

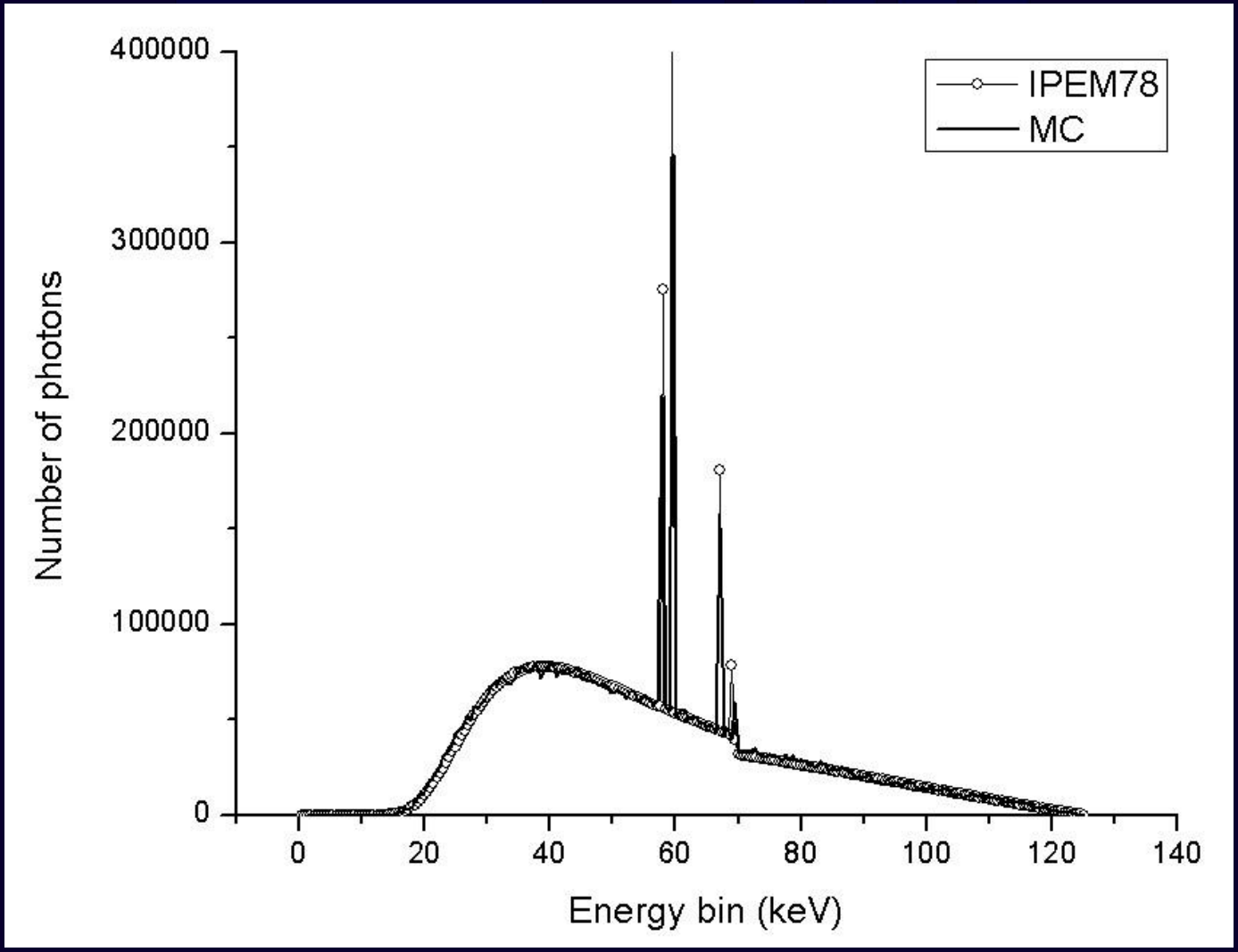
MC parameters

- # of histories : 2,000,000,000
- Incident electron energy : 125 keV

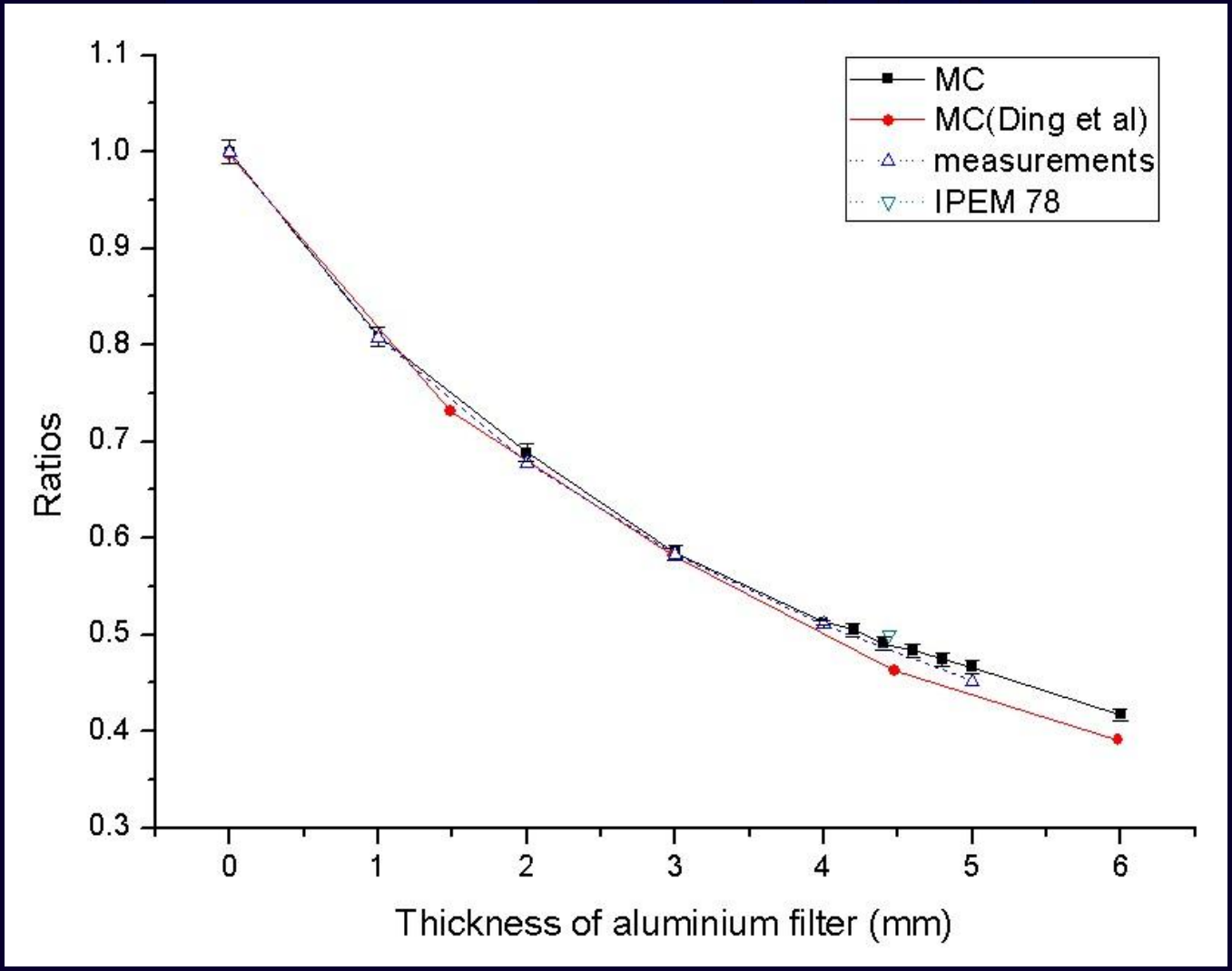
- ECUT: 512 keV
- PCUT: 1 keV

- Variance reduction techniques
  - Directional Bremsstrahlung Splitting (DBS)
    - Splitting field radius: 25 cm
    - Splitting field SSD: 80 cm
    - Splitting number in field: 10000
  - Electron range rejection: on with set ECUTRR
  - Global electron cutoff: 1 MeV
  - Photon forcing: off

X-ray spectra

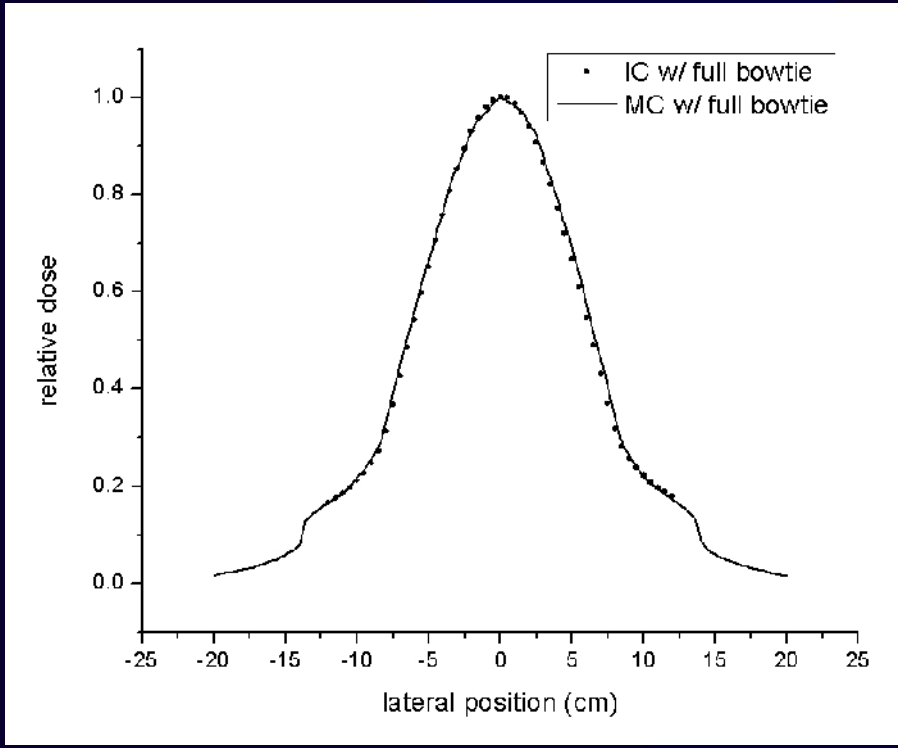


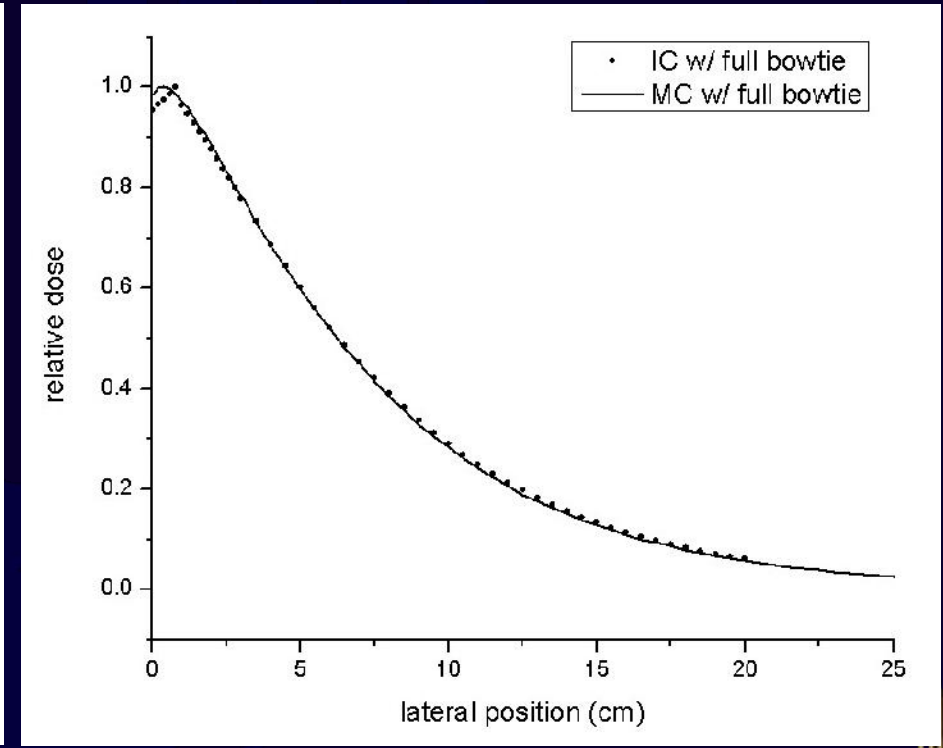
Half value layer (HVL)



IC measurements

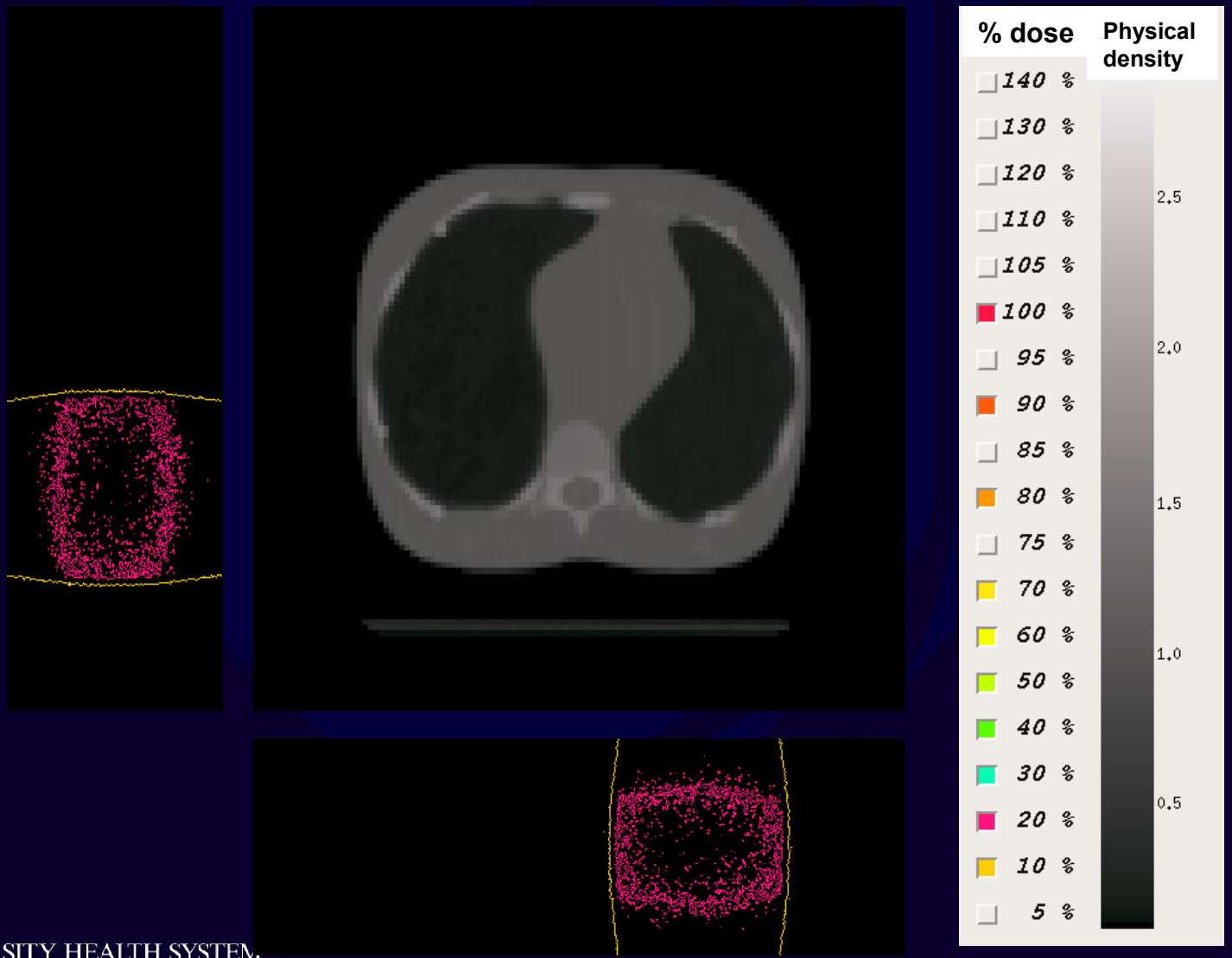
Lateral / depth dose profiles





3cm depth below the surface of water

3D dose distribution in phantom



Absorbed doses

Organs	Standard dose mode (cGy)			Low dose mode (cGy)		
	MOSFET	MC	% diff	MOSFET	MC	% diff
BM / Mandible	0.05±0.04	0.07	-40.00	0.02±0.03	0.02	0.00
Thyroid	0.15±0.08	0.12	20.00	0.05±0.01	0.03	40.00
Thymus	0.36±0.04	0.27	25.00	0.08±0.01	0.06	25.00
BM / Ribs	0.31±0.04	0.30	3.23	0.09±0.03	0.07	22.22
Breast (Left)	0.43±0.10	0.29	32.56	0.11±0.04	0.06	45.45
Lungs / Middle	0.86±0.02	0.64	25.58	0.17±0.01	0.14	17.65
Esophagus	1.28±0.10	1.21	5.47	0.25±0.02	0.26	-4.00
BM / Spine	2.01±0.07	2.46	-22.39	0.42±0.06	0.53	-26.19
Spleen	5.75±0.25	5.83	-1.39	1.28±0.09	1.26	1.56
Liver	6.17±0.18	6.26	-1.46	1.36±0.06	1.35	0.74
Kidney	5.68±0.20	5.95	-4.75	1.22±0.06	1.28	-4.92
Pancreas	5.57±0.16	5.92	-6.28	1.19±0.03	1.28	-7.56
Stomach	6.82±0.22	6.81	0.15	1.47±0.10	1.47	0.00
Intestine	6.18±0.24	6.21	-0.49	1.37±0.07	1.34	2.19
Ascending colon	6.95±0.37	6.51	6.33	1.53±0.12	1.40	8.50
BM / Pelvis	5.15±0.23	5.65	-9.71	1.12±0.09	1.22	-8.93
Ovaries (gonad)	5.37±0.29	4.96	7.64	1.13±0.02	1.07	5.31
Bladder	6.17±0.08	5.31	13.94	1.26±0.09	1.15	8.73
Descending colon	5.06±0.19	4.87	3.75	1.11±0.01	1.05	5.41
Skin	7.22±0.30	7.22	0.00	1.56±0.07	1.56	0.00

Results

- Highest absorbed doses were recorded for the skin, stomach and ascending colon
- Absorbed doses in MC
  - Standard dose mode: 0.07 ~ 7.22 cGy
  - Low dose mode: 0.02 ~ 1.56 cGy
- Absorbed doses in MOSFET
  - Standard dose mode: 0.05 ~ 7.22 cGy
  - Low dose mode: 0.02 ~ 1.56 cGy
- Dose differences between MOSFET and MC: 0 ~ 40 %
  - Dose differences for in-field organs were generally within 10 %
  - Differences for out-field organs marked from 20 to 40 %
- Effective doses
  - MC: 36.08 mSv (standard dose) and 7.78 mSv (low dose)
  - MOSFET: 37.80±0.71 mSv (standard dose) and 8.09±0.16 mSv (low dose)

Conclusion

- We have established a MC model for pediatric CBCT and validated the model by comparing the absorbed doses and ED with the MOSFET measurements
- We found that our MC model can successfully estimate the absorbed doses and the ED for the pediatric CBCT with the reasonable accuracy
- This MC model can be extended to multi-detector CT dosimetry for the future study

Thank you for your attention!