Application of GEANT4-based Monte Carlo simulations in Medical Physics

2019.11.18

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국립암센터 NATIONAL CANCER CENTER 양성자치료센터 PROTON THERAPY CENTER

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Monte Carlo simulations for Medical Physics

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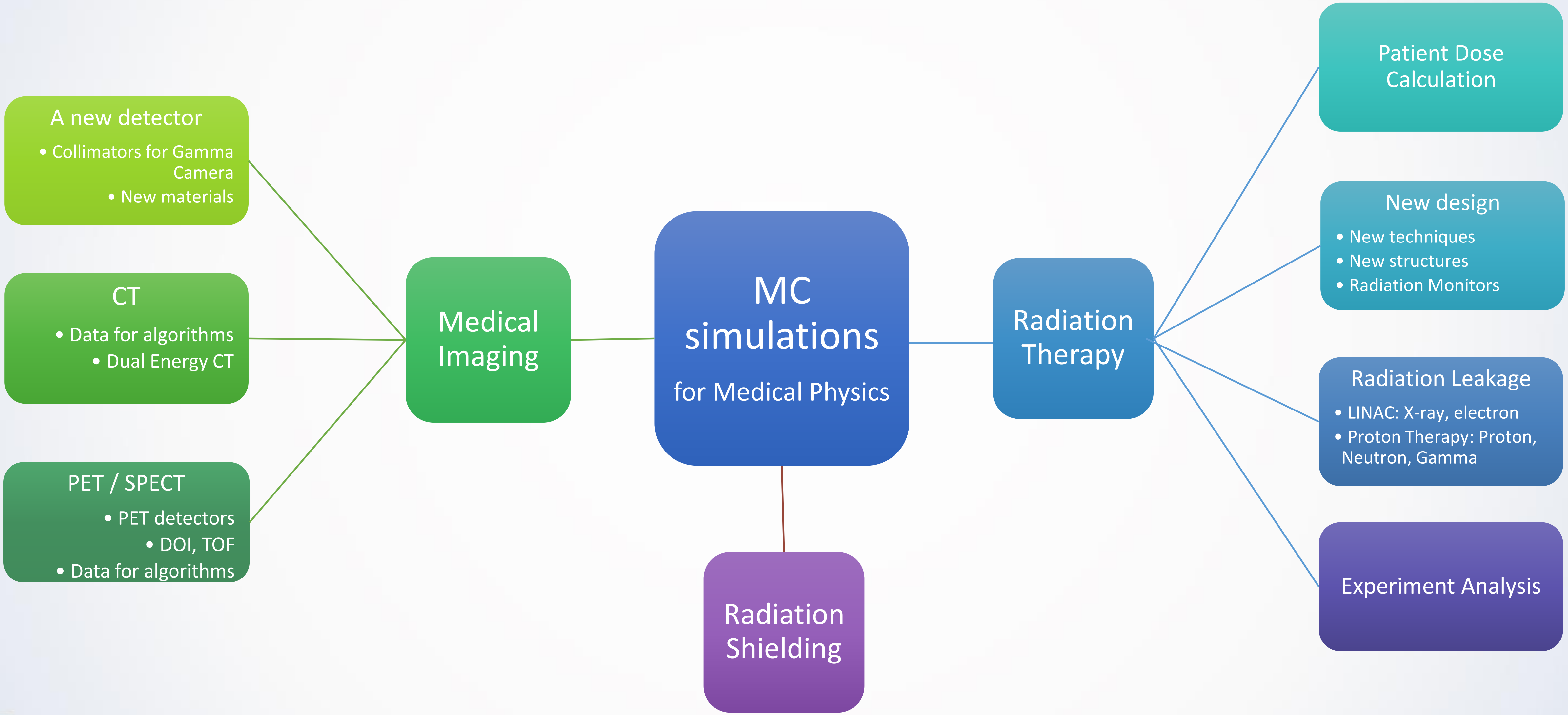

Monte Carlo simulations for Medical Physics

- GEANT4 (for GEometry and ANd Tracking, by CERN)
  > GATE (Medical Imaging)
  > TOPAS (Radiation Therapy)

- MCNP (a general Monte Carlo N-Particle transport code, by LANL)

- EGS4 (Electron Gamma Shower, originated at SLAC)
  > EGSnrc (by National Research Council of Canada)
  > EGS5 (by KEK, Japan)
- Fluka (FLUktuierende KAskade, by CERN, INFL, SLAC)

Monte Carlo simulations for Medical Physics

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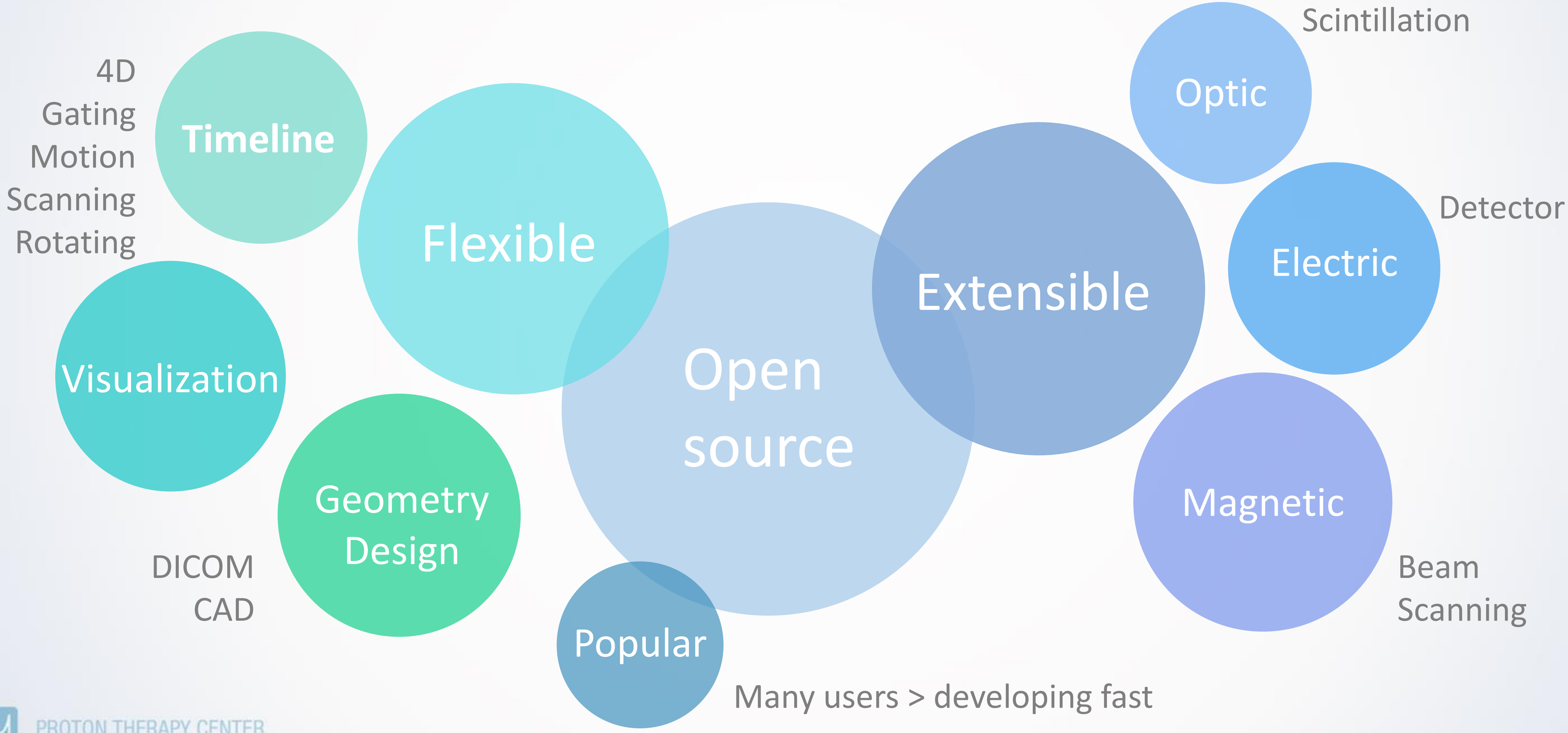
Tools	Language/ Input		Particles	Parallel Execution	Based	General Uses	Note
GEANT4	C++	Coding	68 (unlimited)	YES	Physical Model	High energy physics	
GATE		Macro		YES		Medical Imaging	PET, SPECT
TOPAS		Macro		Supported		Radiation Therapy	Proton Therapy
MCNP	Fortran	Macro	36 + all heavy ions	Supported	Data/ Model	Nuclear Engineering	
EGSnrc/ EGS5	Mortran3/ Fortran	Coding/ GUI	3 (photons, e+, e-)	YES	Model	Radiation Therapy	X-ray Therapy
Fluka	Fortran	Macro/ GUI	65	YES	Data/ Model	High energy physics	Carbon Therapy

Possible with all MC codes !

Monte Carlo simulations for Medical Physics

- Advantages of GEANT4 simulations in Medical Physics



Monte Carlo simulations for Medical Physics

- Basic structure of MC simulations in Medical Physics

I. World
- World
- Elements
- Materials
- Physics
- Threads
- …

II. Source (Beam)
- Particle
- Type
- Position
- Energy
- NPS
- …

III. Geometry
- Shape
- Material Composition
- …

IV. Tally (Scoring)
- Quantity for Scoring
- Scoring pos
- Physical Filters
- …

Monte Carlo simulations for Medical Physics

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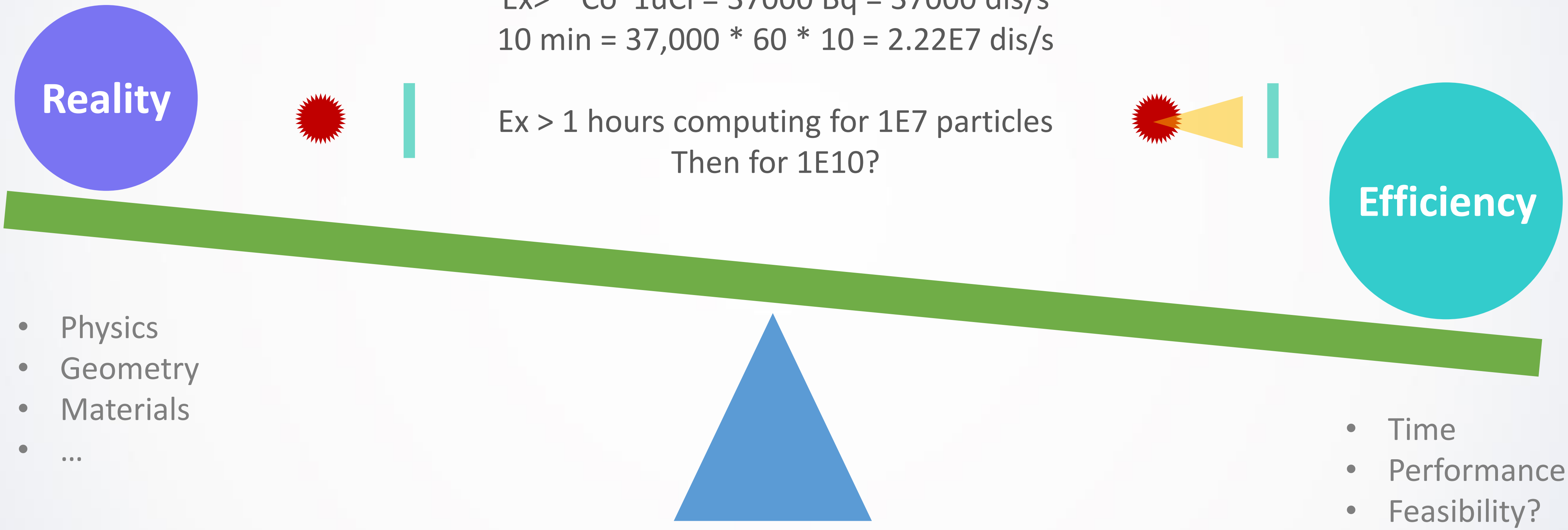
- The perfectly realistic MC simulation?

Ex> ^{60}Co 1uCi = 37000 Bq = 37000 dis/s
10 min = 37,000 * 60 * 10 = 2.22E7 dis/s

Ex > 1 hours computing for 1E7 particles
Then for 1E10?



- Physics
- Geometry
- Materials
- …

- Time
- Performance
- Feasibility?

Reasonable approximation + Techniques are essential !

Studies based on GEANT4 simulations in Medical Physics

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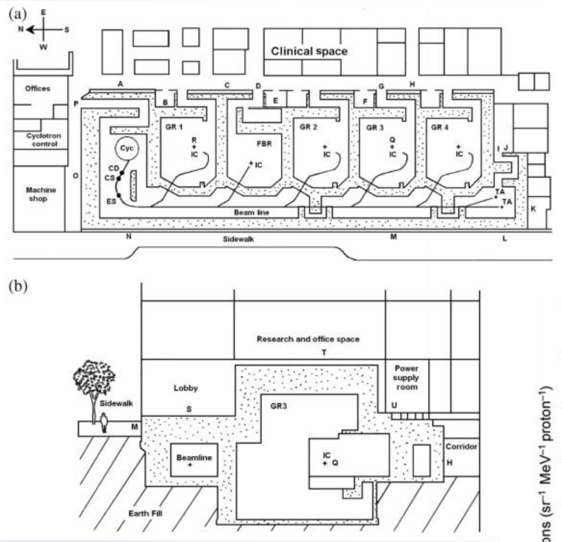
- Radiation shielding of the facility

2016, Physica Medica

Radiation Protection Dosimetry (2008), Vol. 131, No. 2, pp. 167–179
Advance Access publication 16 May 2008
doi:10.1093/rpd/ncn136

ANALYTICAL SHIELDING CALCULATIONS FOR A PROTON THERAPY FACILITY

Stephen Avery*, Chris Ainsley, Richard Maughan and James McDonough
Hospital of the University of Pennsylvania, 3400 Spruce St., 2 Donner, Philadelphia, PA 19104, USA



ANALYTICAL SHIELDING CALCULATIONS

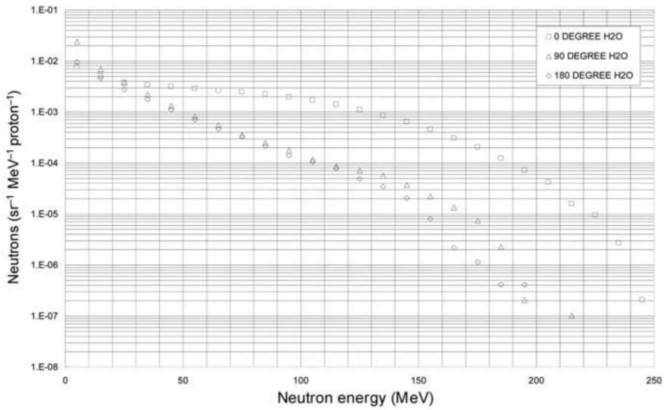


Figure 1. Spectra of neutrons produced by a 250-MeV proton beam incident on a water target. The spectra are calculated at neutron scattering angles of 0°, 90° and 180° using the GEANT4 Monte Carlo code.

Original paper

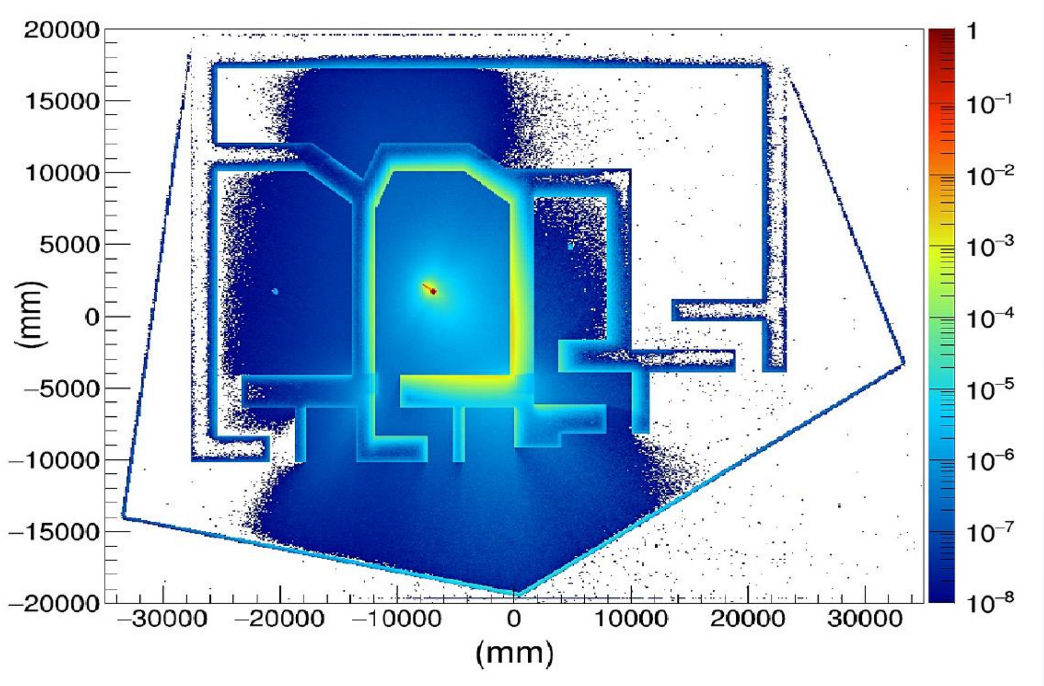
Neutron shielding for a new projected proton therapy facility: A Geant4 simulation study

CrossMark

Francesco Cadini [a,b,*], David Bolst [b], Susanna Guatelli [b,c], Chris Beltran [d], Michael Jackson [e], Anatoly B. Rosenfeld [b,c]

[a] Politecnico di Milano, Dipartimento di Energia, Via La Masa 34, I-20156 Milano, Italy
[b] Centre for Medical Radiation Physics, University of Wollongong, NSW, Australia
[c] Illawarra Health Medical Research Institute, University of Wollongong, NSW, Australia
[d] Mayo Clinic, Rochester, MN, USA
[e] Department of Radiation Oncology, Prince of Wales Hospital, Randwick, Australia

NEW facility, CAD



Studies based on GEANT4 simulations in Medical Physics

- Medical Imaging

866 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 3, JUNE 2004

Conceptual Design of a Proton Computed Tomography System for Applications in Proton Radiation Therapy

Reinhard Schulte, Vladimir Bashkirov, Tianfang Li, Zhengrong Liang, Klaus Mueller, Jason Heimann, Leah R. Johnson, Brian Keeney, Hartmut F.-W. Sadrozinski, Abraham Seiden, David C. Williams, Lan Zhang, Zhang Li, Steven Peggs, Todd Satogata, and Craig Woody

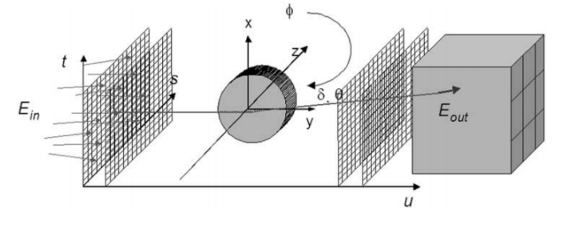


Fig. 1. Schematic of the proposed approach to pCT. Protons with known entry energy E_{in} are recorded one by one in the detector reference system (s, t, u) as they traverse the image object from many different projection angles ϕ. The recorded data include entry and exit positions and entry and exit angles as well as exit energy E_{out} in the energy detector.

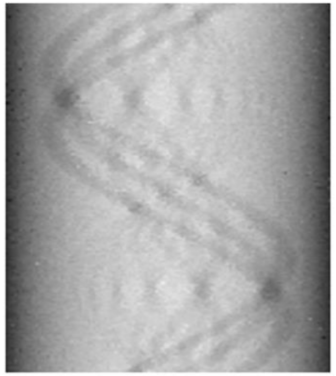


Fig. 5. Sinogram constructed by interpolation of virtual projection rays.

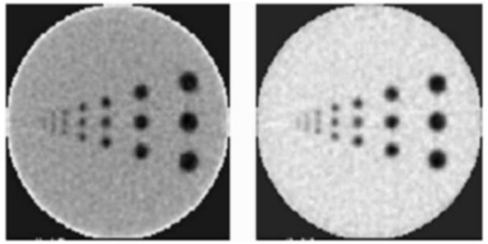


Fig. 7. Reconstructed image using paths L (left) and path L' (right) for image reconstruction. Although the spatial resolution of both images is similar, some density distortion is present in the left image at the object boundary, which is not seen in the right image.

Validation of GATE Monte Carlo simulations of the GE Advance/Discovery LS PET scanners

C. Ross Schmidtlein,[a] Assen S. Kirov, Sadek A. Nehmeh, Yusuf E. Erdi, John L. Humm, and Howard I. Amols
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Department of Imaging Physics, The University of Texas M.D. Anderson Cancer Center, 1515 Holcombe Blvd., Houston, Texas 77230-1439

Alex Ganin, Charles W. Stearns, and David L. McDaniel
GE Healthcare Technologies, 3000 N. Grandview Blvd., Waukesha, Wisconsin 53188

Klaus A. Hamacher
Weill Medical College of Cornell University, 525 East 68th Street, New York, New York 10021

(Received 17 February 2005; revised 29 August 2005; accepted for publication 1 September 2005; published 28 December 2005)

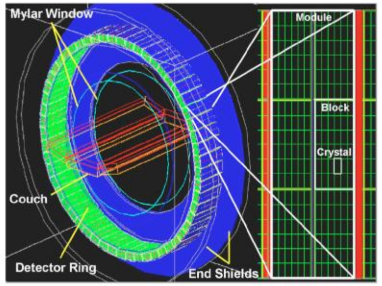


FIG. 1. GATE simulation model of the GE Advance/Discovery LS PET scanner. The proximal end shield, the couch, and the Mylar cover are depicted via wire-frame lines. In addition, an expanded view of the detector module, block, and crystal arrangement is shown.

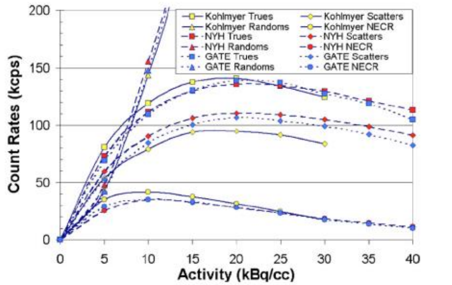
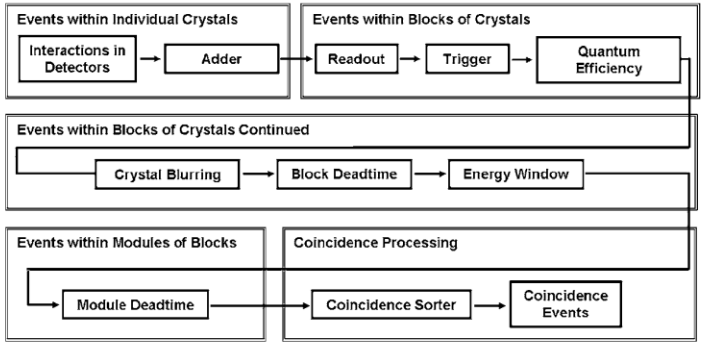


FIG. 5. 3D mode count rate response showing both simulated (GATE, dotted lines) and experimental data (Kohlmyer *et al.*,[41] solid lines, and NYH DLS, dashed lines).



Studies based on GEANT4 simulations in Medical Physics

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- Radiation Therapy

Modeling the TrueBeam linac using a CAD to Geant4 geometry implementation: Dose and IAEA-compliant phase space calculations

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Paul J. Keall
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(Received 16 June 2010; revised 17 May 2011; accepted for publication 19 May 2011; published 20 June 2011)

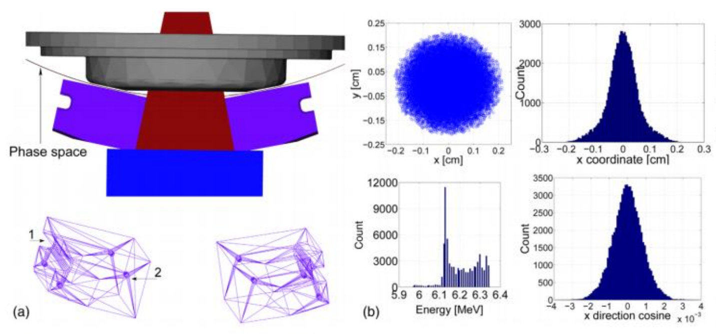
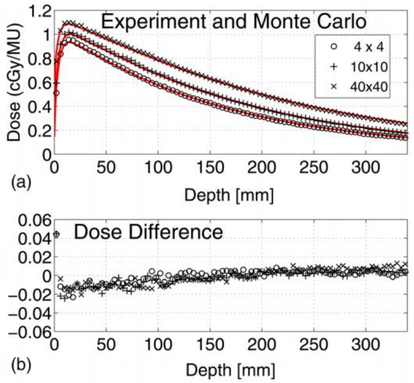


FIG. 1. (a) Part of the TrueBeam treatment head showing the shielding collimator, the cylindrical phase space surface, the upper jaws and the lower jaw block. The middle trapezoid tangent to the jaws is the x-ray field for a 40 × 40 cm² open field (at isocenter). The tessellated representation of the movable upper jaws is displayed. Labels one and two point to the bar canal and the mounting holes of the jaws. (b) Phase space of the input Parmela electrons (using 71 712 primary electrons). The plots of the y coordinate and y direction cosine are not displayed due to their similarity with the x correspondent.



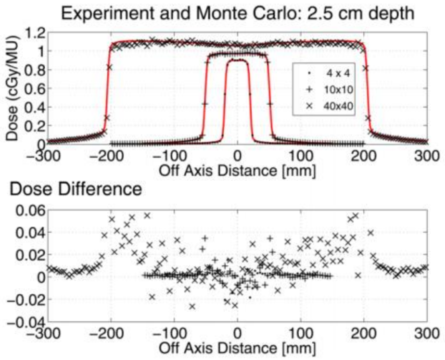


FIG. 3 Experimental (lines) and GEANT4 (points) calculated dose profiles for 2.5 cm depth. The Monte Carlo dose was averaged over three voxels with a total length of 1.2 cm. The dose differences (i.e., experiment—Monte Carlo) are shown in the bottom panel.

Nuclear Instruments and Methods in Physics Research B 396 (2017) 18–25

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journal homepage: www.elsevier.com/locate/nimb

ELSEVIER

Monte Carlo simulation for calculation of fragments produced by 400 MeV/u carbon ion beam in water

CrossMark

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[a] Physical Science and Technology College, Zhengzhou University, Zhengzhou 450001, China
[b] College of Science, Henan University of Technology, Zhengzhou 450001, China

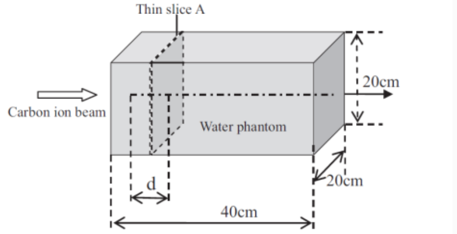


Fig. 1. Schematic diagram of carbon ion beam incident on water phantom.

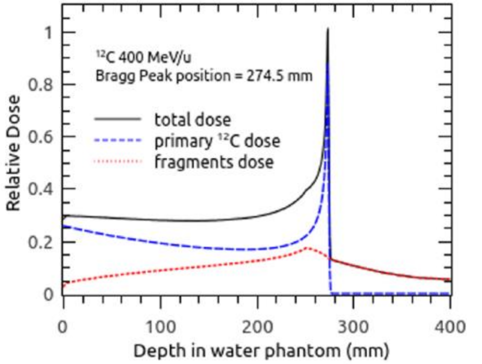


Fig. 2. Relative dose distributions of carbon ion beam, primary ^{12}C ion and fragments in water phantom (with the Bragg peak value of total dose as normalization factor).

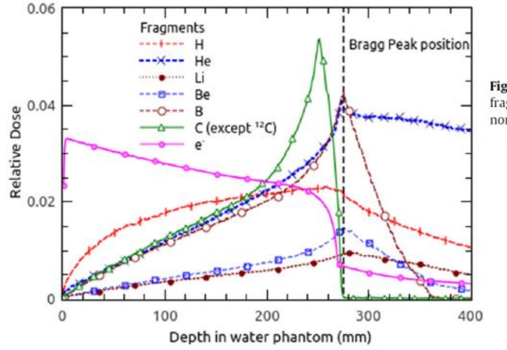
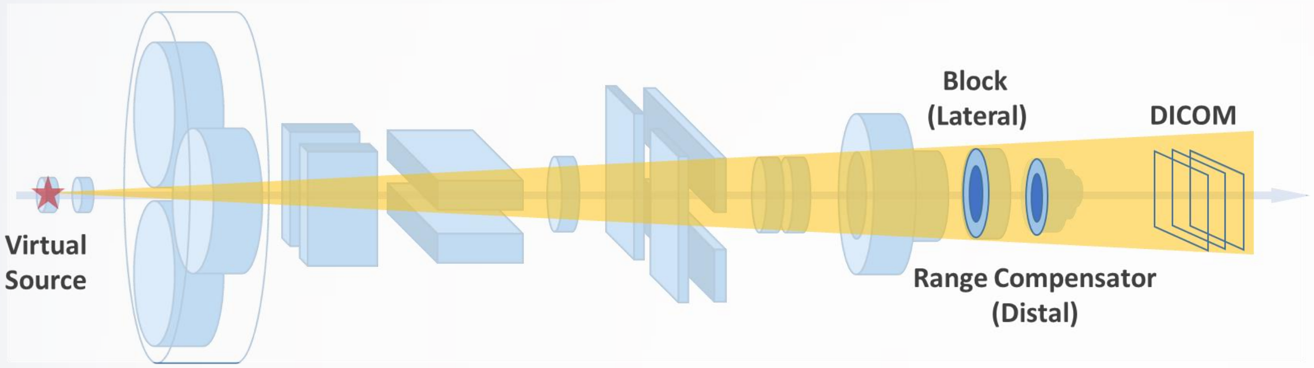


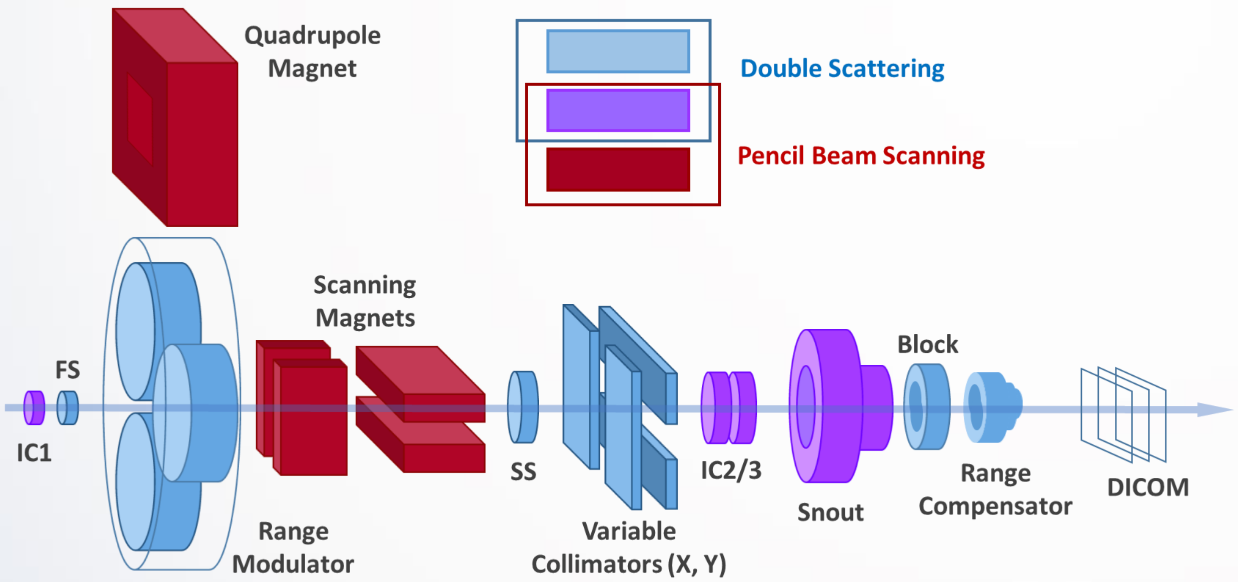
Fig. 3. Dose distributions of H, He, Li, Be, B, C (except ^{12}C), e^- in water phantom (with the Bragg peak value of total dose as normalization factor).

Experience with GEANT4-based simulations in NCC

- Monte Carlo modeling of proton therapy modes in NCC



- TPS (Treatment Planning System): Simplified beam model



- Passive scattering mode (2007 ~)
- Active scanning mode (2017 ~)

<u>**MC modeling and simulation**</u>

> Verification of the plan and measurement

Experience with GEANT4-based simulations in NCC

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- Monte Carlo modeling of a passive scattering proton therapy in NCC

Journal of the Korean Physical Society, Vol. 56, No. 1, January 2010, pp. 153~163

Monte Carlo Modeling and Simulation of a Passive Treatment Proton Beam Delivery System using a Modulation Wheel

Jungwook SHIN, Dongwook KIM, Young Kyung LIM, Sunghwan AHN, Dongho SHIN, Myong geun YOON, Sung-Yong PARK and Se Byeong LEE*
Proton Therapy Center, National Cancer Center, 111 Jungbalsan-ro, Ilsandong-gu, Goyang-si, Gyeonggi-do 410-769

Jungwon KWAK
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(Received 5 December 2009, in final form 24 November 2009)

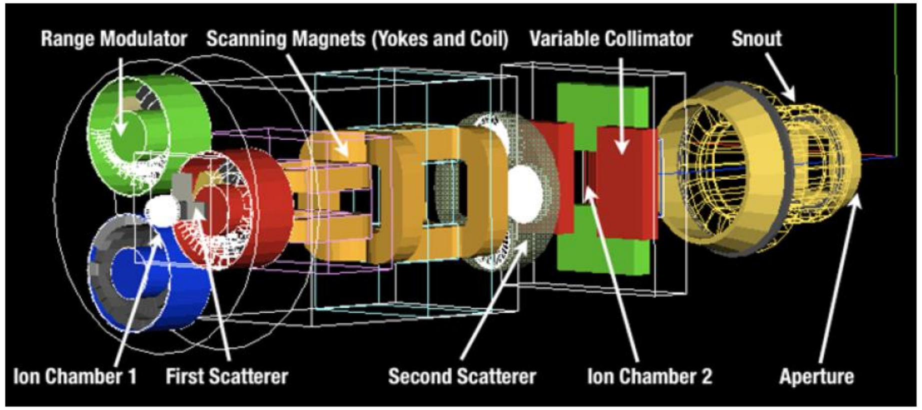


Fig. 1. (color online) Reconstructed NCC nozzle based onGEANT4 geometry packages.

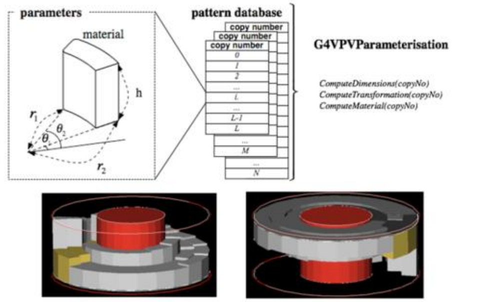


Fig. 4. (color online) Upper row: A schematic diagram of track construction in a range modulator. "Copy number" represents the segment index of a track. Bottom row: The designed small wheel. Three tracks are required on each side of the wheel.

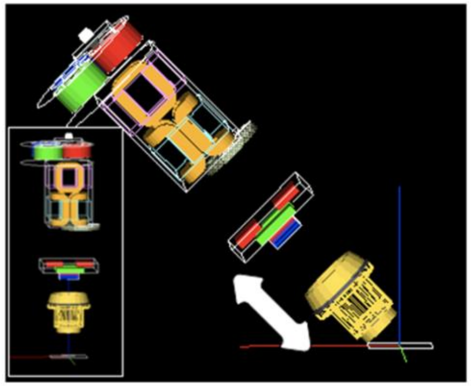


Fig. 7. (color online) Gantry rotation and result of snout retraction (small picture); before gantry rotation with snout extraction (inset)

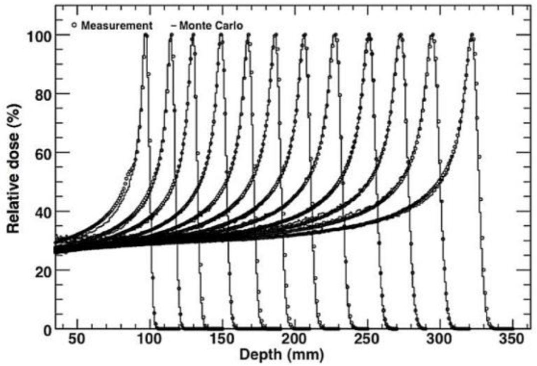
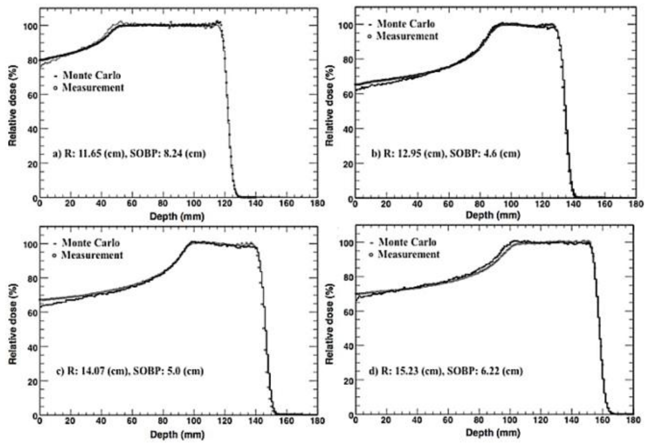


Fig. 12. Comparisons between the measurement and Monte Carlo dose profiles (each profile was normalized to the peak position) over the passive scattering treatment range.



Experience with GEANT4-based simulations in NCC

- Monte Carlo modeling of a passive scattering proton therapy in NCC

Journal of the Korean Physical Society, Vol. 61, No. 7, October 2012, pp. 1125∼1130

Monte Carlo Modeling and Validation of a Proton Treatment Nozzle by Using the Geant4 Toolkit

Dae-Hyun KIM

Department of Radiation Oncology, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul 137-701, Korea and Department of Biomedical Engineering and Research Institute of Biomedical Engineering, College of Medicine, The Catholic University of Korea, Seoul 137-701, Korea

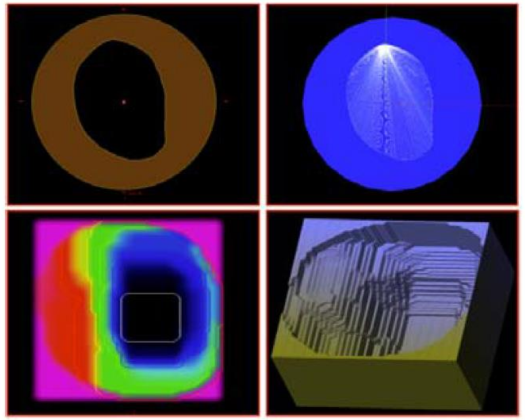


Fig. 3. (Color online) Comparison of the treatment planning system (TPS) and the Geant4 simulations of the aperture and the compensator. The modeled geometries used with the TPS and Geant4 are shown in the left and the right columns, respectively.

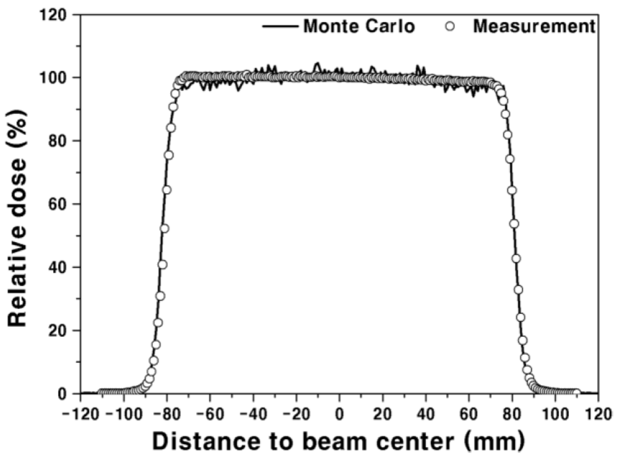


Fig. 5. Measured (open circles) and simulated (solid lines) dose profiles as a function of the cross-field distance (x) to the central axis. The field was produced for a 10-cm-range and 5-cm-modulated width in a water phantom at a depth of 7.5 cm with a 15 × 15 cm^2 collimator.

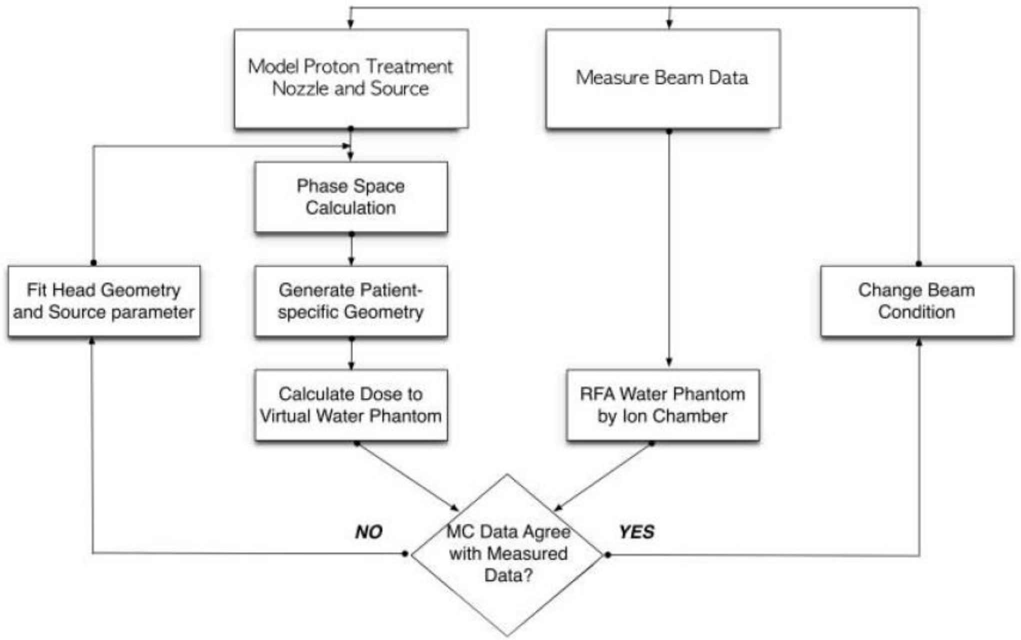


Fig. 1. Dose calculation flowchart for the NCC proton therapy simulation. In practice, several iterations may be required to obtain sufficient agreement between the measured and the simulated data.

Experience with GEANT4-based simulations in NCC

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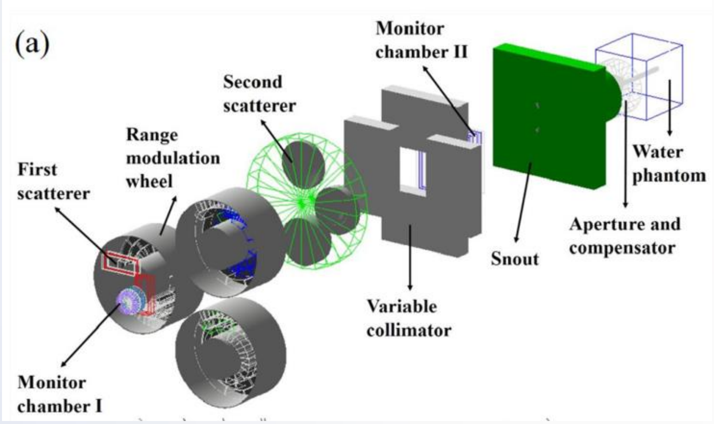
- Monte Carlo modeling of a passive scattering proton therapy in NCC

IOP Publishing | Institute of Physics and Engineering in Medicine Physics in Medicine & Biology
Phys. Med. Biol. 62 (2017) 7598–7616 https://doi.org/10.1088/1361-6560/aa8663

Independent dose verification system with Monte Carlo simulations using TOPAS for passive scattering proton therapy at the National Cancer Center in Korea

Wook-Geun Shin[1], Mauro Testa[2], Hak Soo Kim[3], Jong Hwi Jeong[3], Se Byeong Lee[3], Yeon-Joo Kim[3] and Chul Hee Min[1,4]

[1] Department of Radiation Convergence Engineering, Yonsei University, Wonju, Korea
[2] Institute of Nuclear Physics of Lyon, Villeurbanne, France
[3] Proton Therapy Center, National Cancer Center, Goyang, Korea



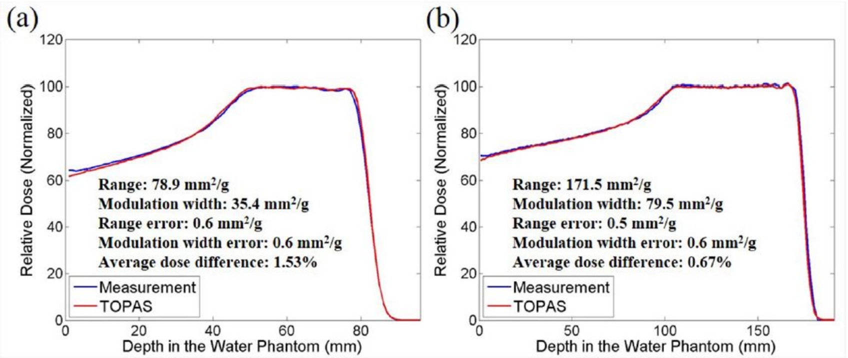
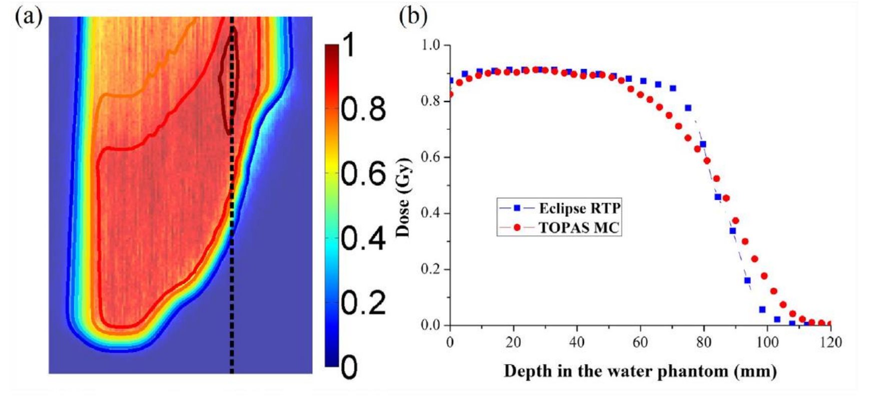


Figure 5. PDDs measured with a Markus ionization chamber (blue) and calculated with the TOPAS system (red), and the errors between them for the range and the modulation width of the B3 (a) and the B6 option (b).



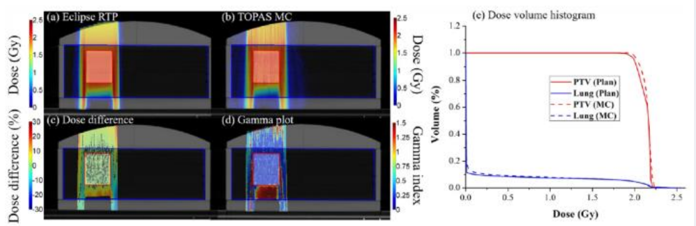


Figure 9. The results of the dose calculation in the lung phantom. The upper rows show the dose distribution calculated with Eclipse RTP (a) and TOPAS MC (b). The lower rows show the corresponding dose difference (c) and gamma plot (d). DVHs calculated using Eclipse RTP (solid line) and TOPAS MC (dashed line) (e). The red and blue contours and line indicate the acrylic PTV and the cork lung, respectively.

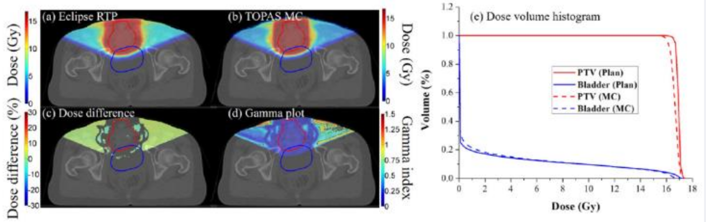


Figure 10. The results of the dose calculation in the ABD case. The upper rows show the dose distribution calculated with Eclipse RTP (a) and TOPAS MC (b). The lower rows show the corresponding dose difference (c) and gamma plot (d). DVHs calculated using Eclipse RTP (solid line) and TOPAS MC (dashed line) (e). The red and blue contours and line indicate the PTV and the bladder, respectively.

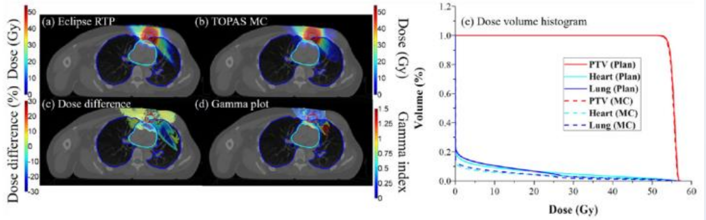


Figure 11. The results of the dose calculation in the IMN case. The upper rows show the dose distribution calculated with Eclipse RTP (a) and TOPAS MC (b). The lower rows show the corresponding dose difference (c) and gamma plot (d). DVHs calculated using Eclipse RTP (solid line) and TOPAS MC (dashed line) (e). The red, cyan, and blue contours and line indicate the PTV, heart, and lung, respectively.

- TOPAS (Tool for Particle simulation)
- DICOM, HU conversion

Experience with GEANT4-based simulations in NCC

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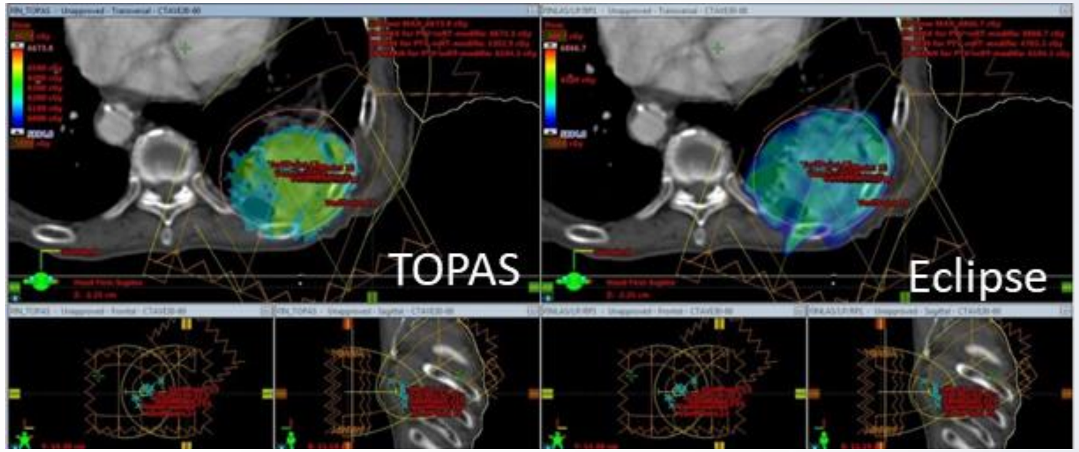
- Monte Carlo modeling of a passive scattering proton therapy in NCC

- Double Scattering Mode simulation Code (v5)
  - TOPAS 3.0 (Geant4 p10.2 based)
  - 신욱근 (연세대학교)
  - Patient CT , PLAN, DOSE importing > calculation (semi-auto)



Beam parameters (parameters.txt)

Patient's Data (DICOM) (Folder : Patient)

Generate TOPAS Inputs (makeinput.out)

DSF Calculation (CalculateDSF.sh)

DSF#.csv

Beam Simulation (RecordPhase.sh)

Phase#_Run.header
Phase#_Run.phsp

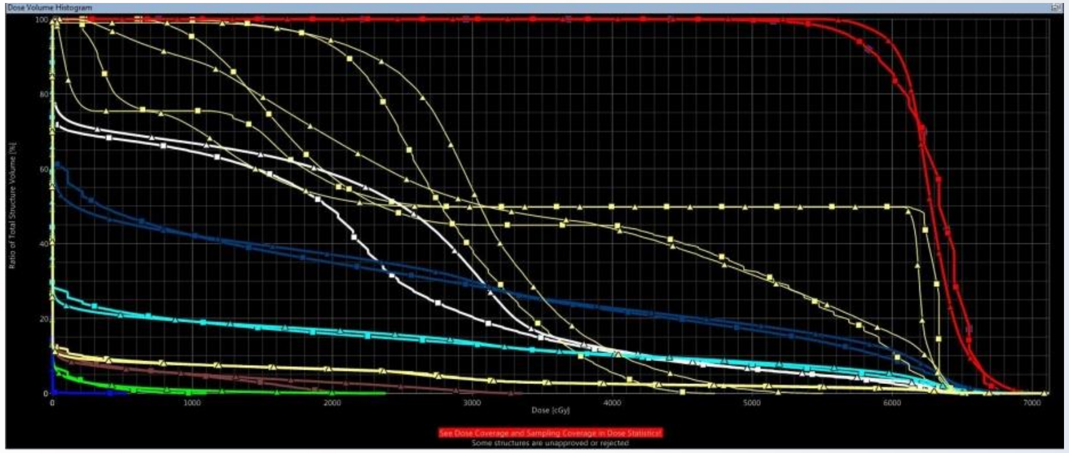
Patient Simulation (ReadPhase.sh)

DoseAtPhantom#.dcm

Weight factor

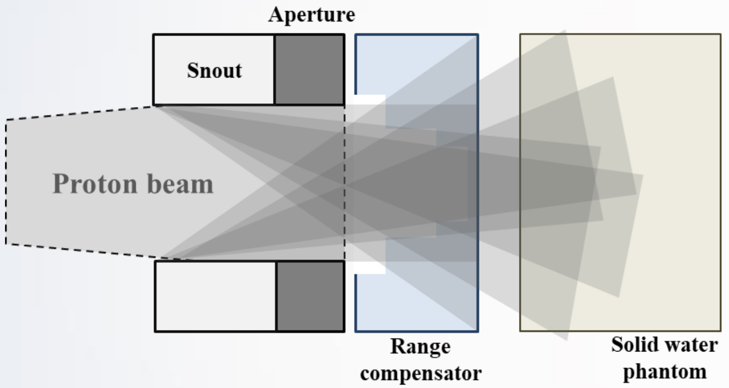
Result Reorganization (DICOM.out)

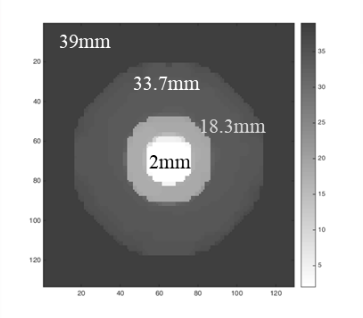
DICOM data

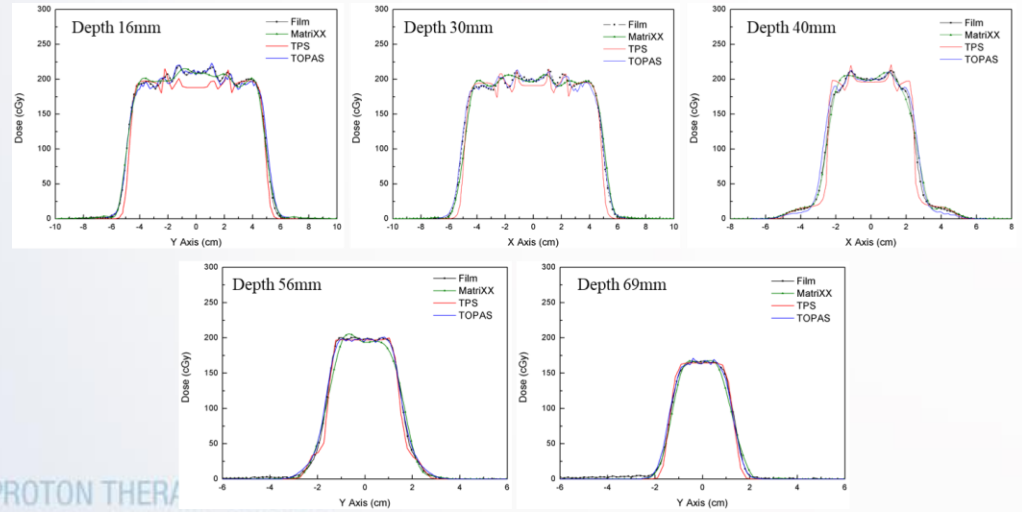


Experience with GEANT4-based simulations in NCC

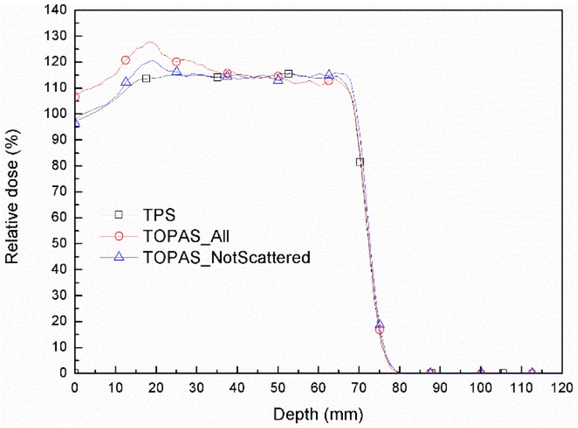
- Monte Carlo modeling of a passive scattering proton therapy in NCC
  - Study on the dosimetric effect of scattered protons (2018 ~)

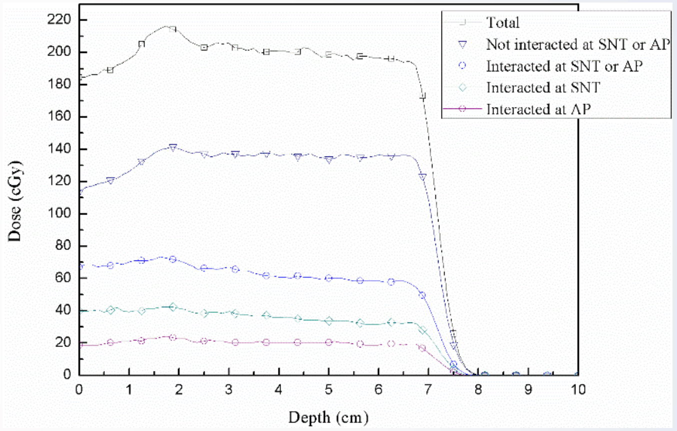




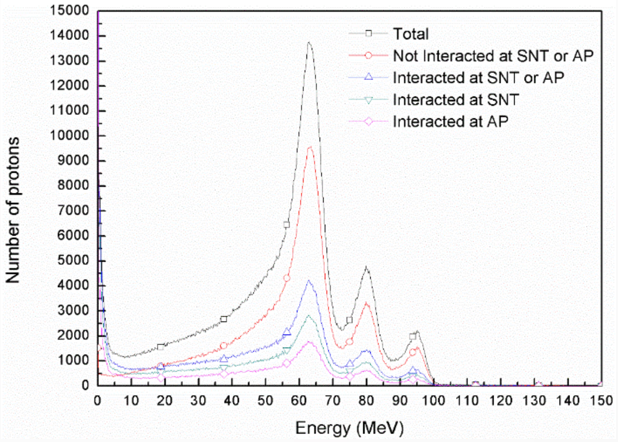


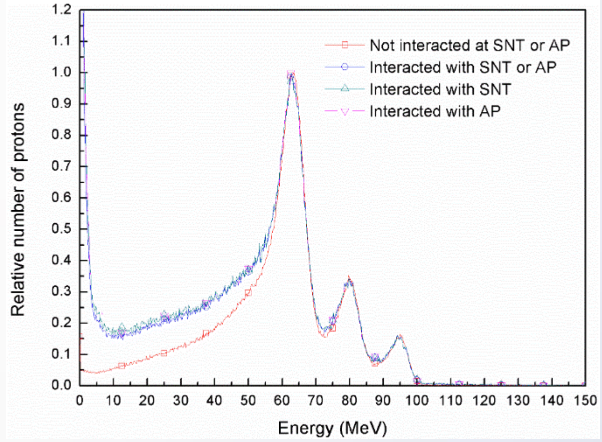
Application of physical filters





Energy histograms

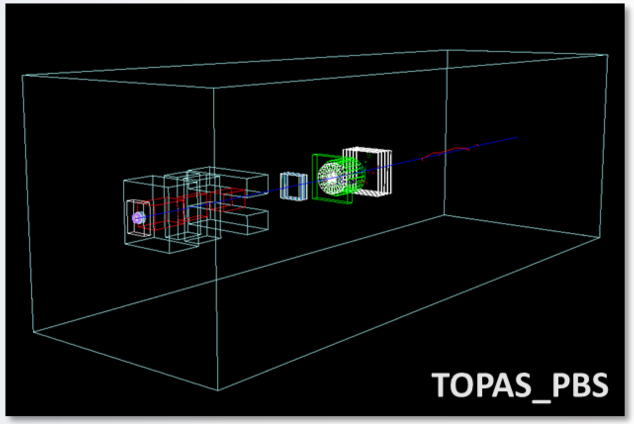


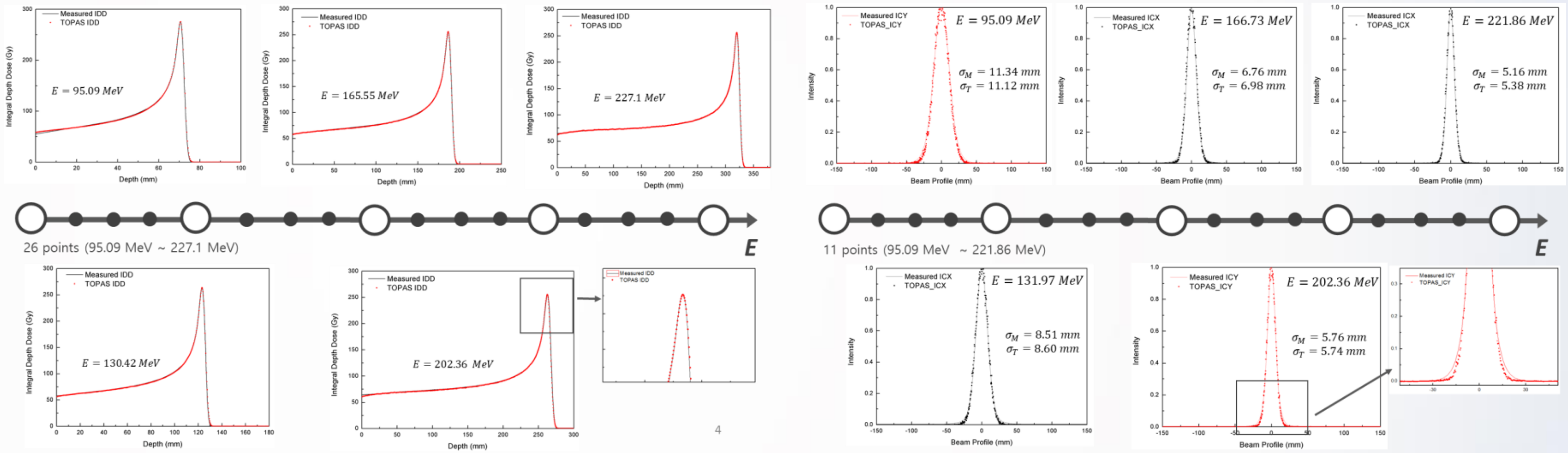


Experience with GEANT4-based simulations in NCC

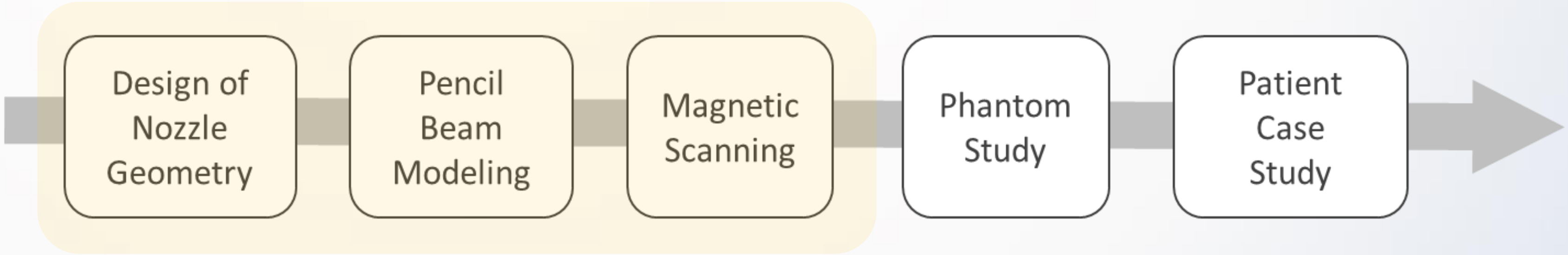
Monte Carlo modeling of a active scanning proton therapy in NCC

- Establishment of MC model of the pencil beam scanning mode in NCC (2016 ~ 2017)





- TOPAS
  (Tool for Particle simulation)



국립암센터
NATIONAL CANCER CENTER

THANKS FOR YOUR ATTENTION