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Current and future of independent dose calculation using Monte Carlo in Nagoya Proton Therapy Center

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Outline

- Introduction
- Development of MC system
- Independent dose calculation
- Speeding up by GPU

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PBA vs. MC

TPS (TPS): Pencil beam algorithm (PBA)

Large uncertainty in inhomogeneous structure

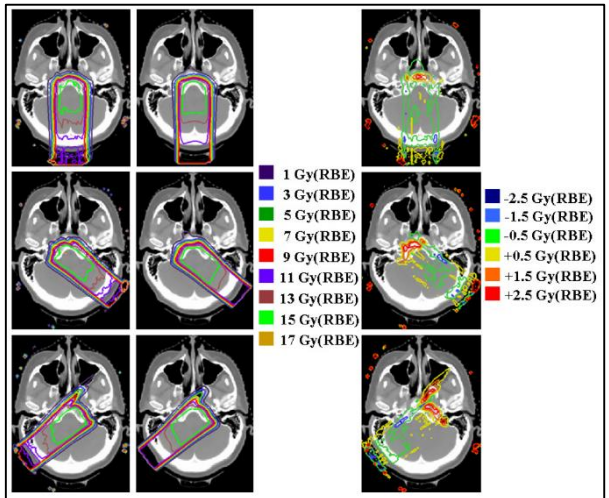


Figure 9. Axial views of three proton therapy treatment fields as planned for a para-spinal tumor. The calculated dose distributions using the Monte Carlo system are shown in the left column. The treatment plan was executed using XiO (middle column). The right column shows the dose difference (Monte Carlo minus XiO).

Paganetti PMB 53 4825 2008

MGH, US

Range uncertainty

Dose to OAR

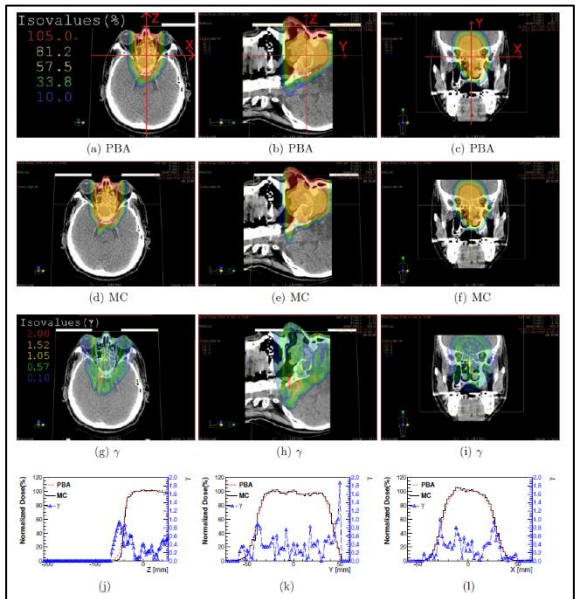
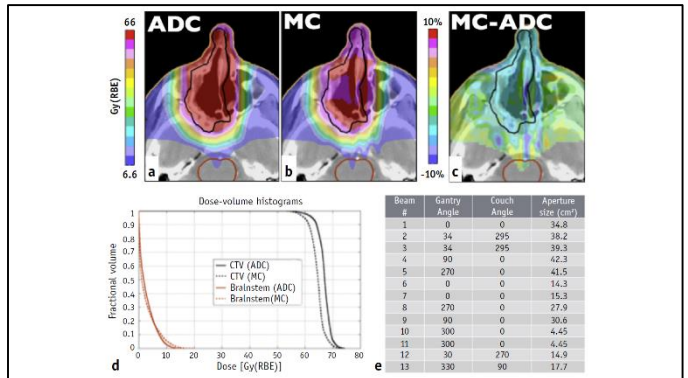


Figure 2. Comparison of dose distribution in the example of head1/field1. (a)–(c) Dose distribution on the iso-center calculated by PBA, and (d)–(f) by MC. PTV is represented as the area shaded in yellow around the origin. (g)–(i) γ distribution between two calculation methods. (j)–(l) Comparison along the x-, y- and z-axes, where the z-axis is set along the beam axis with positive to beam upstream and the x-axis perpendicular to z-axis on the transverse plane, while the y-axis is set to cranial. Dose distribution by MC (pencil beam) is represented by the black histogram (red dashed spaced line). γ distribution is represented by the blue dashed line with triangles.

Yamashita PMB 57 7673 2012

HIBMC, Japan



Beam #	Gantry Angle	Couch Angle	Aperture size (cm²)
1	0	0	34.8
2	34	295	38.2
3	34	295	39.3
4	90	0	42.3
5	270	0	41.5
6	0	0	14.3
7	0	0	15.3
8	270	0	27.9
9	90	0	30.6
10	300	0	4.45
11	300	0	4.45
12	30	270	14.9
13	330	90	17.7

Fig. 3. Head and neck patient with the lowest γ-index passing rate. The prescription dose for the clinical target volume was 66 Gy(RBE). (a, b) Dose distributions for ADC and MC, respectively. (c) Difference (MC−ADC). (d) Dose-volume histograms for the clinical target volume (CTV) and the selected organs at risk. (e) Beam angles and aperture sizes for each treatment field. ADC = analytical dose calculation; MC = Monte Carlo simulation.

Schuemann IJROBP 92 1157 2015

MGH, US

Max. error in dose to target: 5%

TCP: 11%

- "The most accurate, and hence desirable, dose-estimation algorithm are Monte Carlo models."
  - ICRU 78, 2007

NPTC -Nagoya Proton Therapy Center

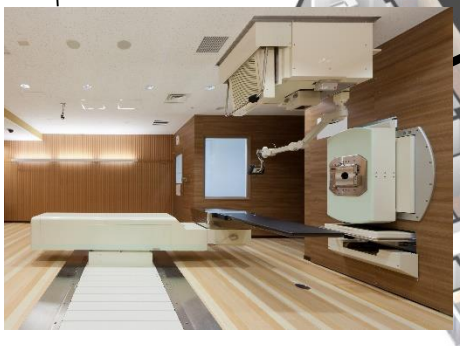
Spot scanning

Gantry 1
for head and neck, etc.

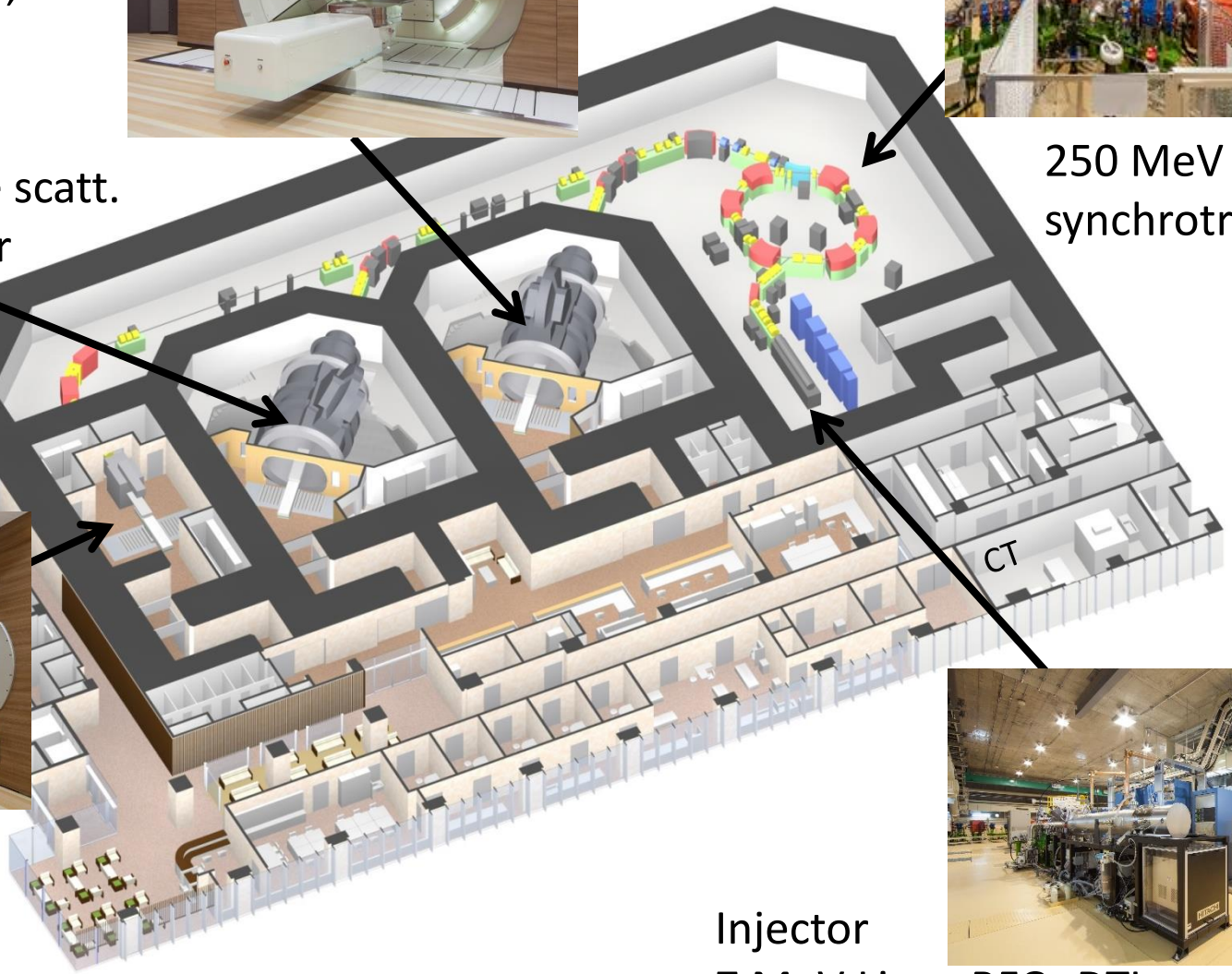
250 MeV
synchrotron

Broad-beam

Gantry 2 Double scatt.
for lung and liver



Fixed Beam
Double scatt.
for prostate

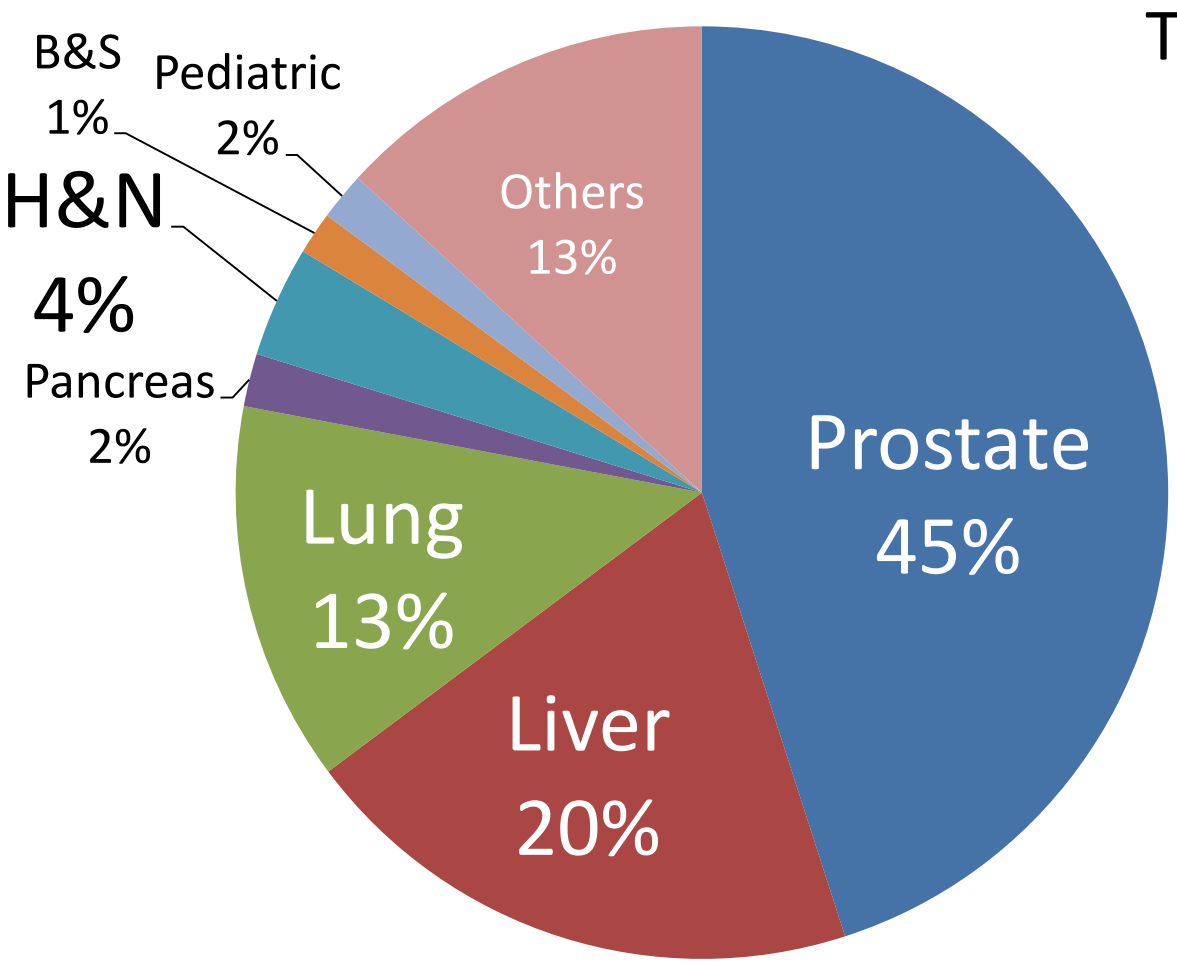


Injector
7 MeV Linac RFQ+DTL

Patients

2013-May 31, 2019

Total 2778



- Introduction
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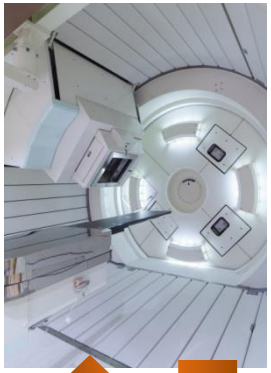
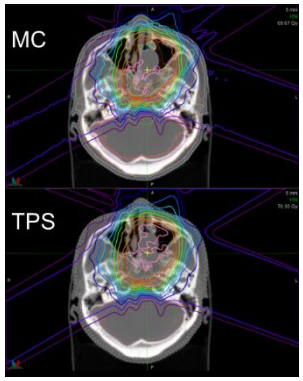
Data flow

Irradiation machine





MIM Maestro
contouring
dose evaluation

VQA (Hitachi)
TPS (PBA)

MOSAIQ (Elekta)
OIS

pTSIM GEANT4
Monte Carlo

Linux PC cluster
Intel Xeon 364 cores

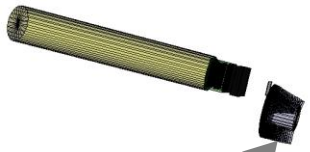
CT image, coordinate system,
Range shifter, energy absorber, aperture

Beam parameters
position(x_i,y_i), Energy$_i$, MU$_i$

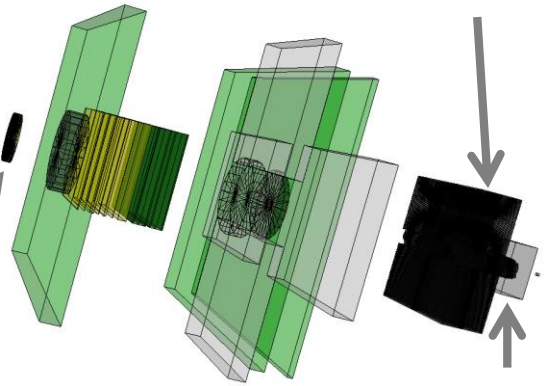
half a day for one patient
all patients for scanning 1.2×10^8 protons
some patients for double scatt.

Treatment Nozzles

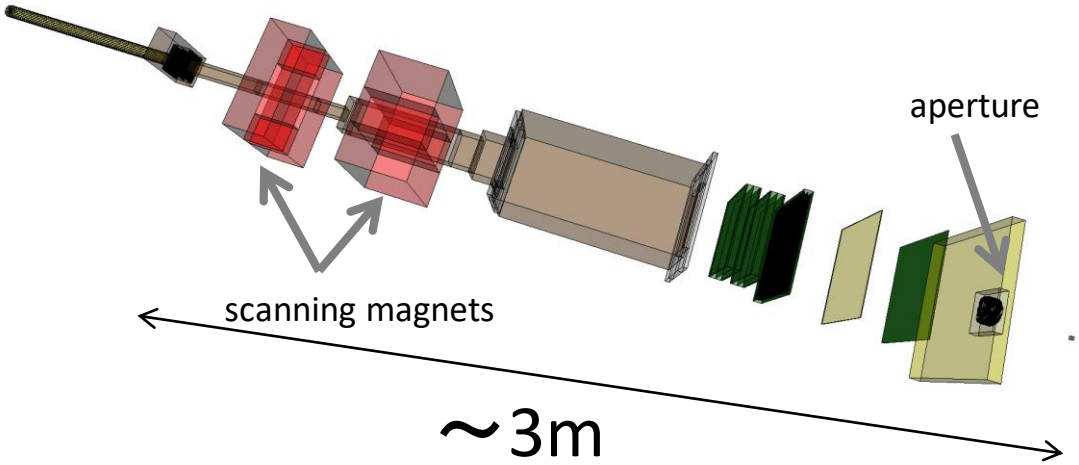
Broad-beam



Double scatt.



Spot scanning



Software development

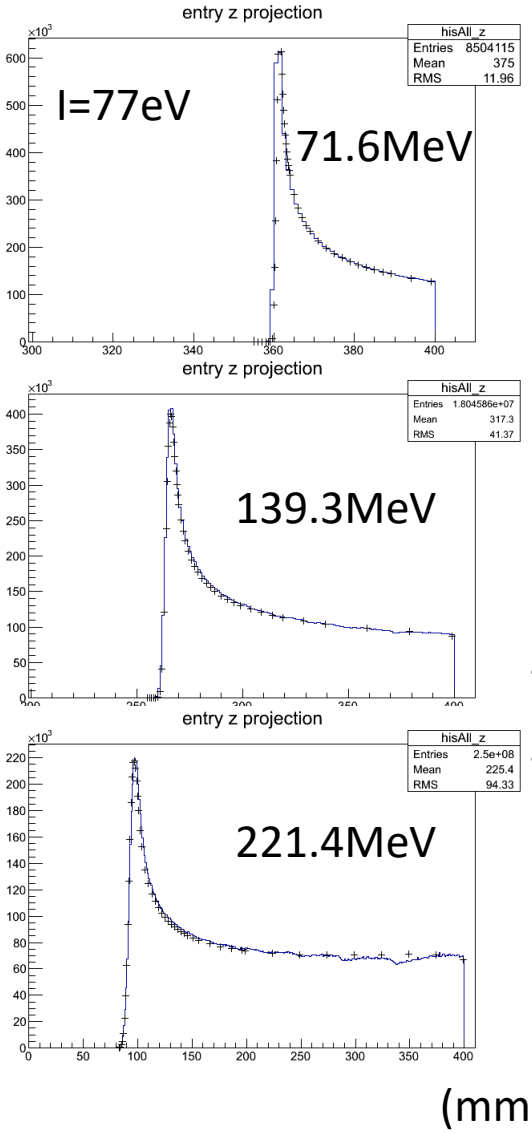
Geant4
1M lines
International collaboration 100 developers, 20 years

PTSIM
100k lines
10 developers mainly in Japan, since 2003

Dedicated for Nagoya Proton Therapy Center
10k lines
2 medical physicists, since 2012

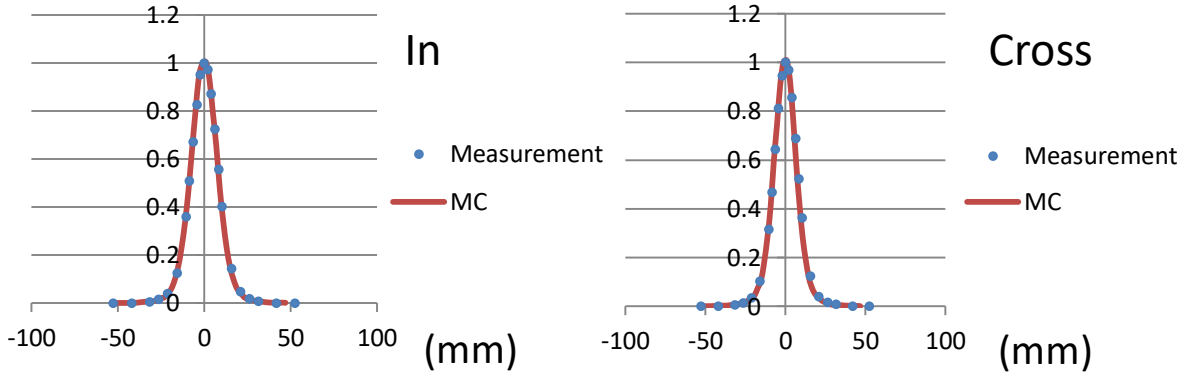
Verification

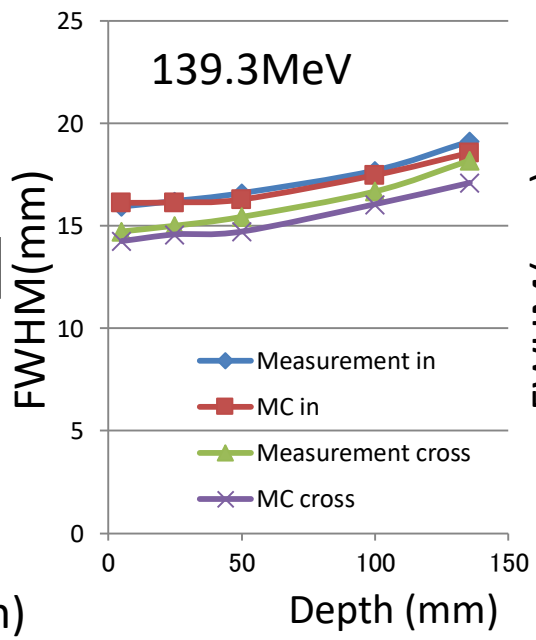
PDD in water

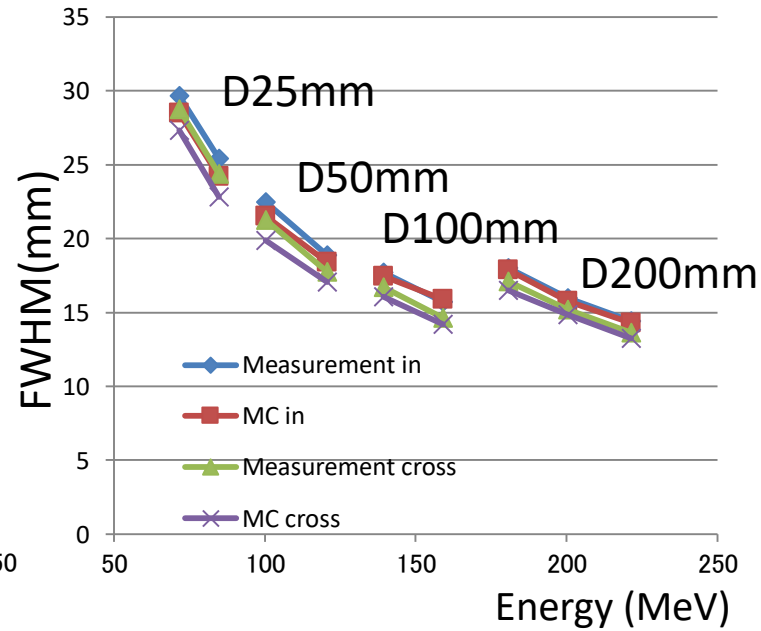


OCR for single spot in water

139.3MeV Depth: 100mm

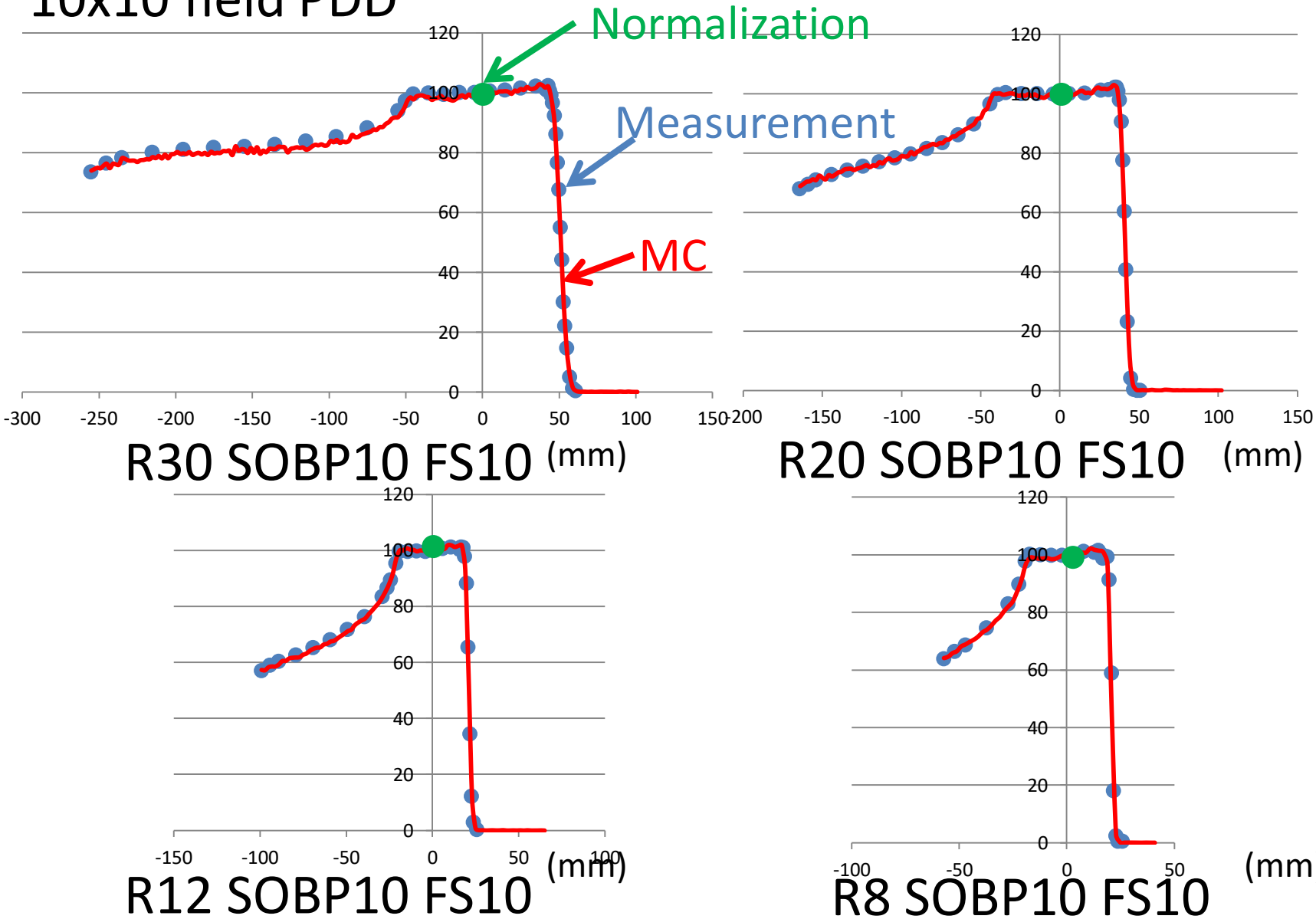






Verification and absolute dose normalization

10x10 field PDD



- Introduction
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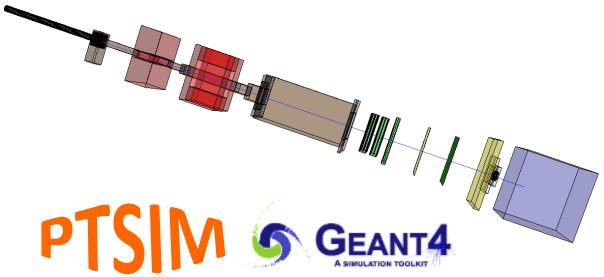
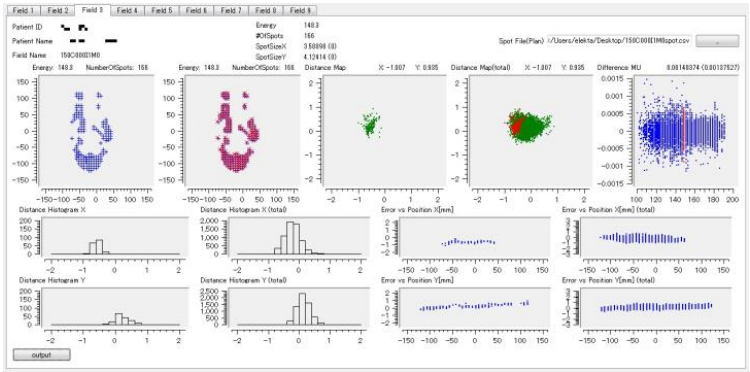
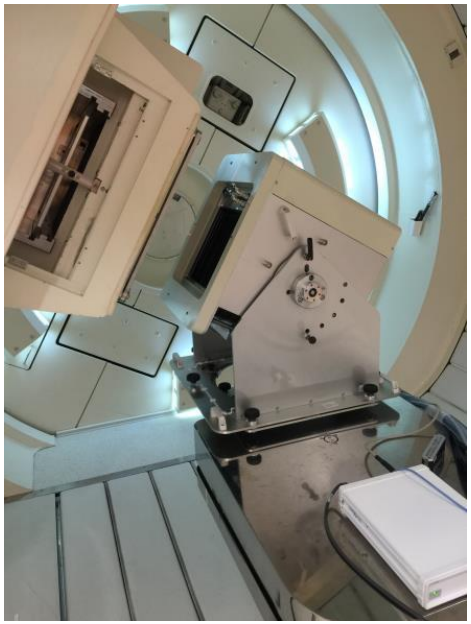
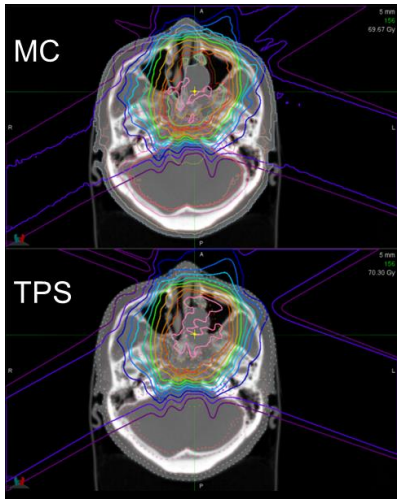
Work flow for patient-specific QA









Monte Carlo

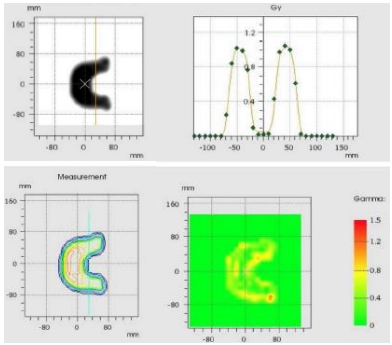
Log-file analysis

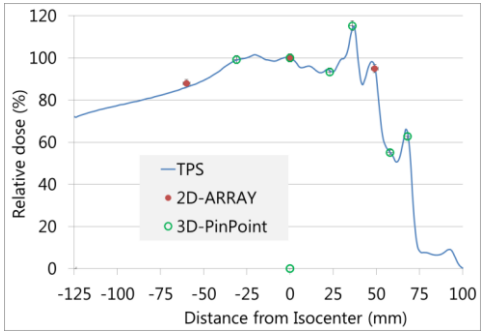
Log-file

TPS → OIS ↔ irradiation machine → Measurement → Comp.

DICOM-RT irradiation file

Comp.





We have carried out MC dose calculation as independent dose calculation in patient-specific QA for more than 400 patients since 2013.

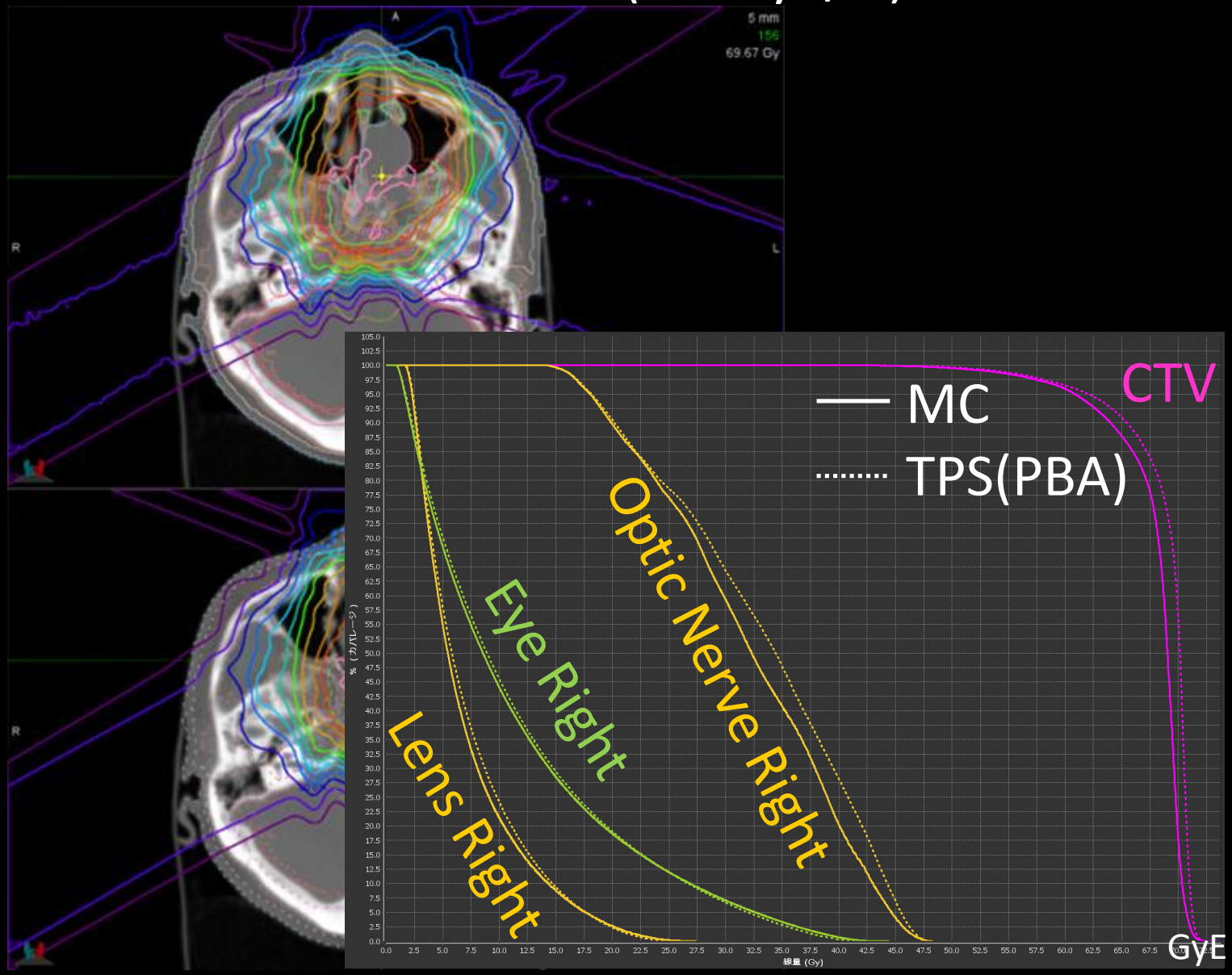
Clinical Case 1

70.2 GyE to the CTV in 26 fraction (2.7 GyE/fr)

MC

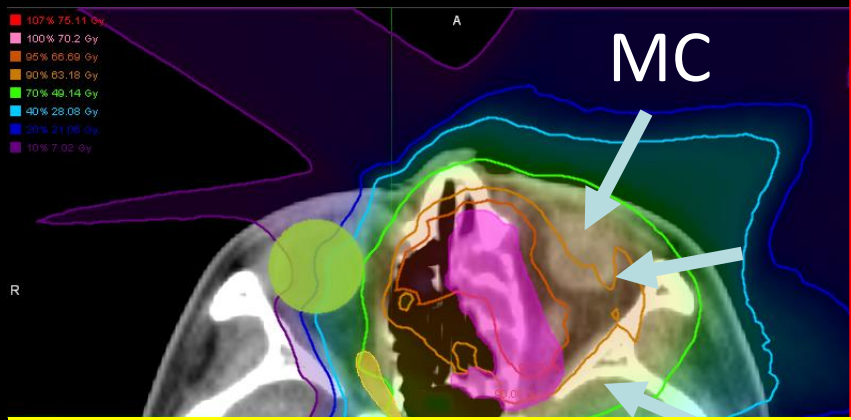
TPS (PBA)

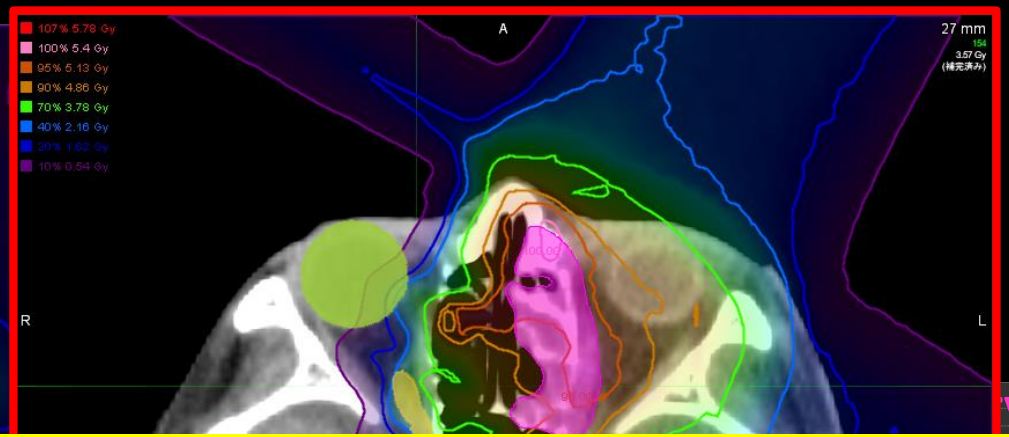
3 fields



Clinical case 2

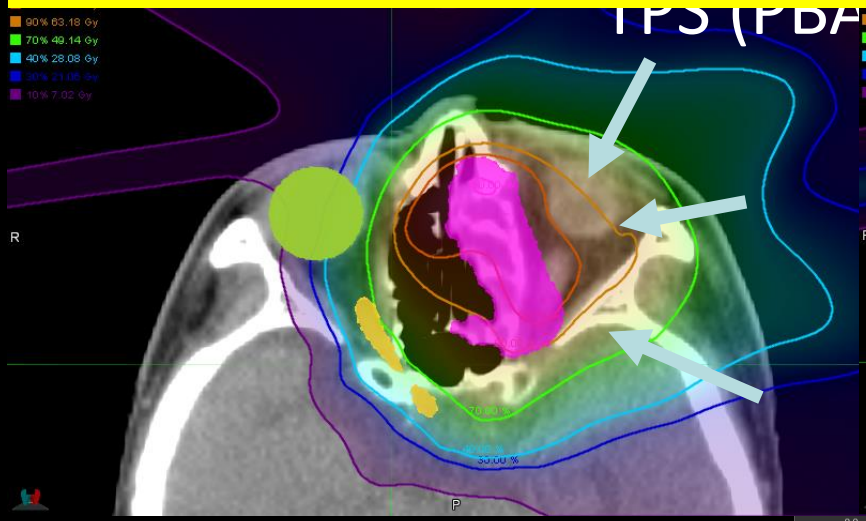
Paranasal sinus 70.2GyE/26frac SFUD
3 fields 30°,80°,120°

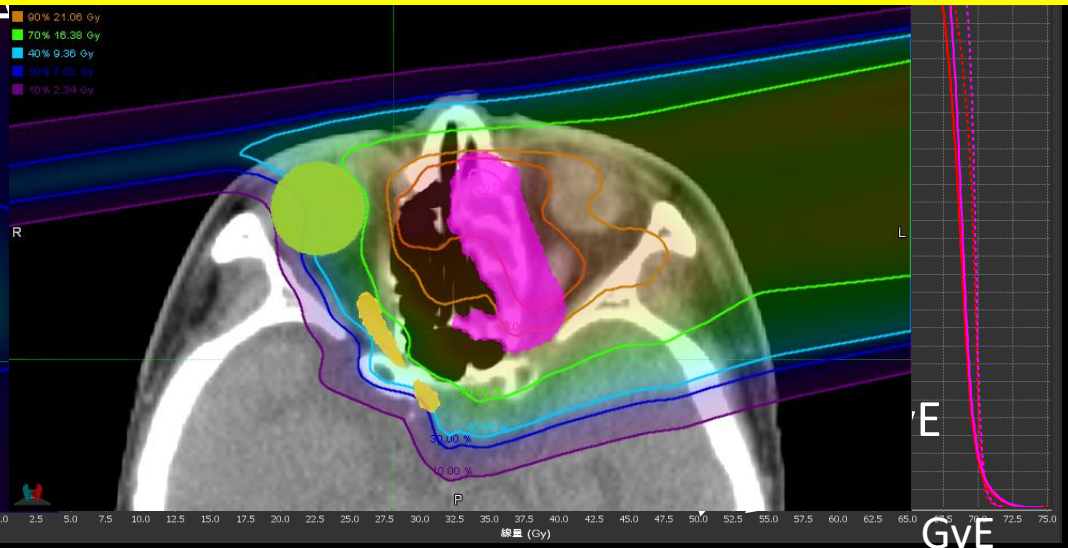




- Proton scanning for H&N: Overdose to optic nerve was revealed by MC in two cases out of 78 head and neck patients, and treatment plan was modified.

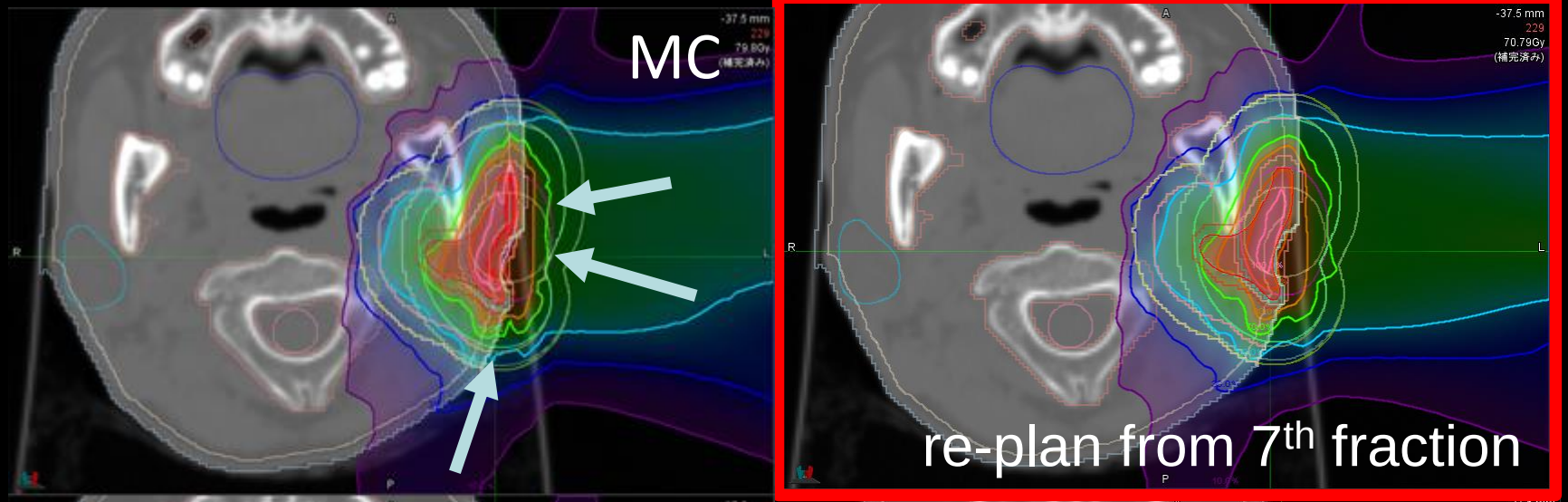
T. Toshito et al., The 30th Annual meeting of the Japanese Society for Radiation Oncology 2017





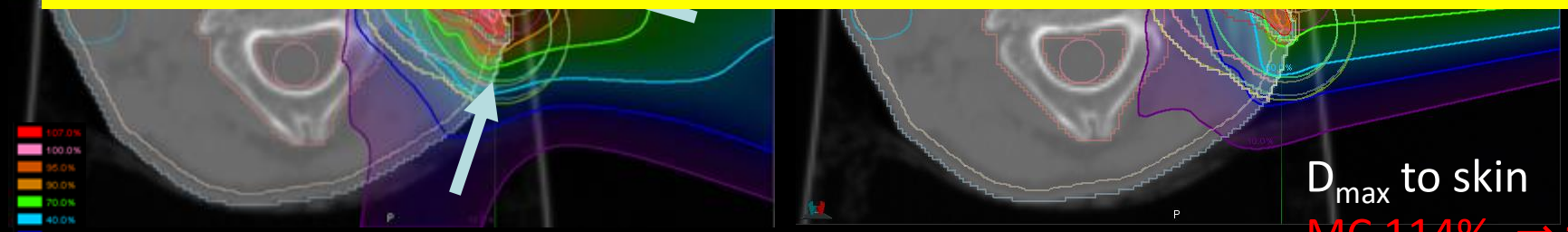
Clinical case 3

70.2 GyE/26frac IMPT
3 fields 195°,80°,110°



- IMPT for H&N: Intolerable dose to OAR was revealed by MC and treatment plan was modified in two cases out of 43 cases.

T. Toshito et al., The 116th Scientific meeting of the Japan Society of Medical Physics 2018

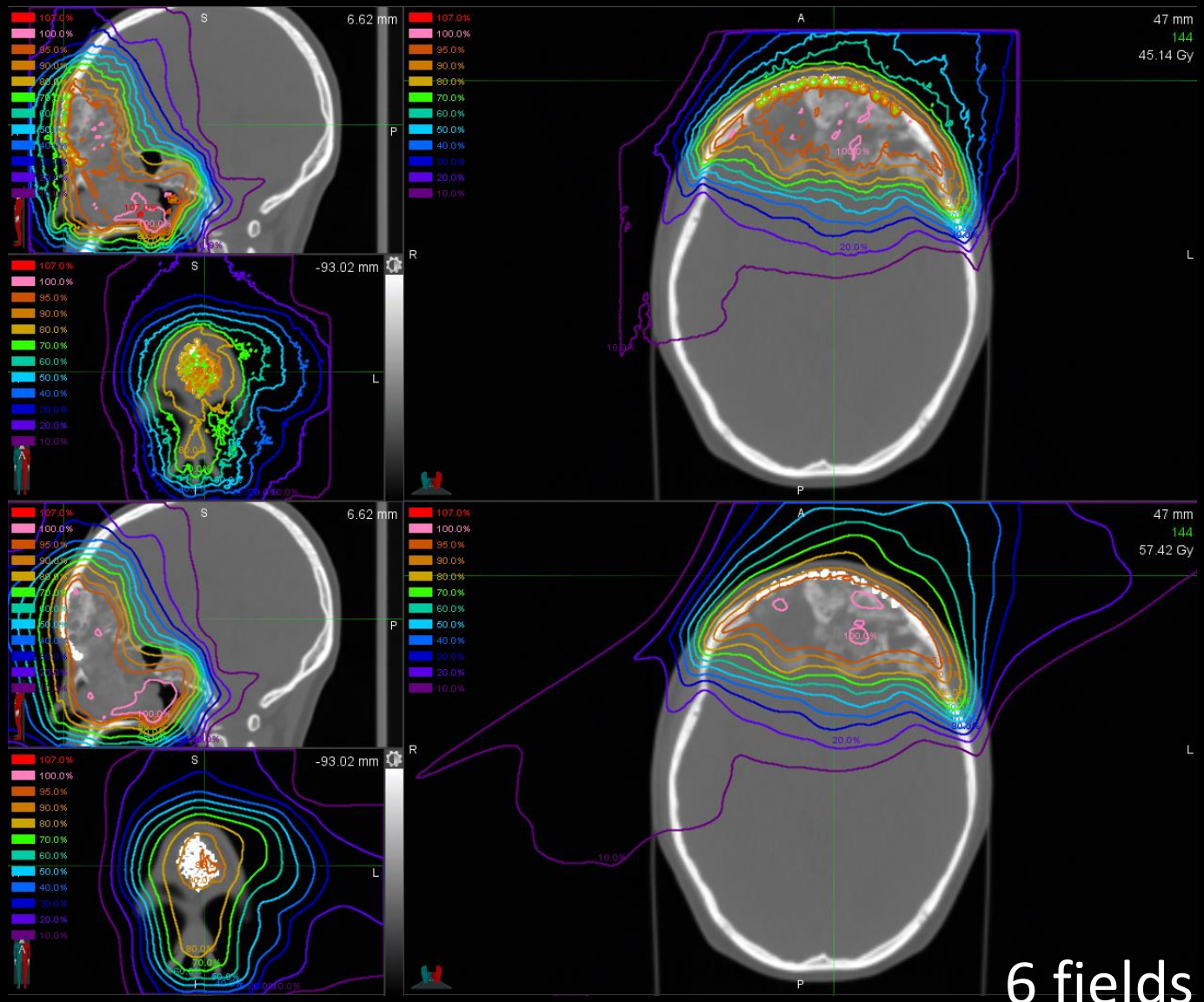


D_{max} to skin
MC 114% ⇒104%
PB 106%

Clinical case 4
Artificial bone made by titanium

MC

TPS (PBA)



6 fields

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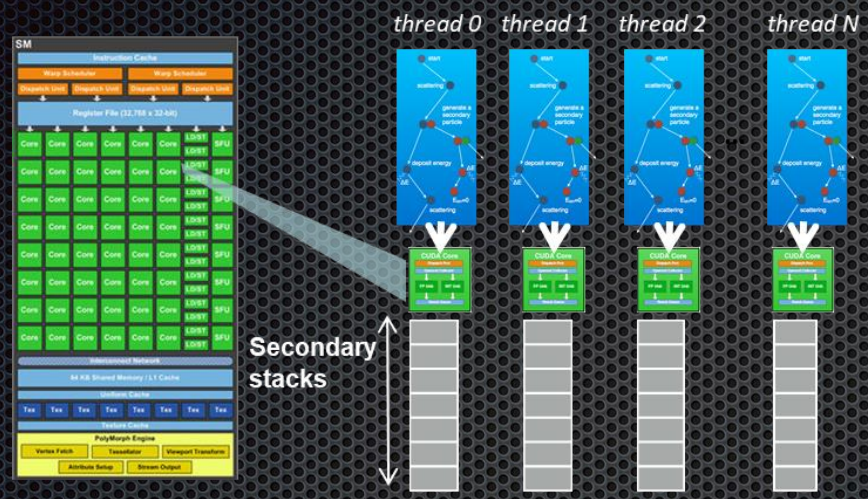
MPEXS [Massive Parallel Electro X-ray Simulator] :Geant4-based GPU Simulators

Developed in Stanford univ./SLAC/KEK https://wiki.kek.jp/display/mpexs/MPEXS+Project

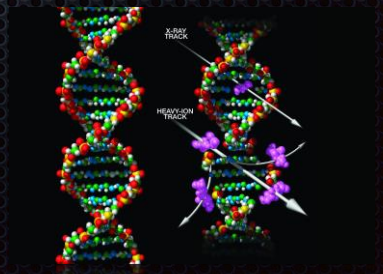
- **NVIDIA CUDA computing platform**

Parallel tracking



- GeForce GTX 1080Ti 1480 MHz 3584 CUDA cores
- Tesla K40 745 MHz 2880 CUDA cores

- ***MPEXS:*** *Massive Parallel Electro X-ray Simulator*
  - Geant4 EM on CUDA for medical application
  - Speedup factor : ~440
  - References
    - N. Henderon, et al. Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2013 (SNA + MIC 2013) DOI: https://dx.doi.org/10.1051/snamc/201404204
    - K. Murakami, et al. Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2013 DOI: 10.1109/NSSMIC.2013.6829452
- ***MPEXS-DNA***
  - Geant4-DNA on CUDA DNA-scale physics and chemical processes
  - Speedup factor : ~1000
  - References
    - S. Okada, et al. M&C + SNA + MC 2015 Proceedings CD-ROM: http://www.ans.org/store/item-700397/
    - S. Okada, et al. Innovation in Medicine and Healthcare 2015 DOI: https://doi.org/10.1007/978-3-319-23024-5_29



Migration from PTSIM to MPEXS-h

PTSIM GEANT4 A SIMULATION TOOLKIT

- CPU-based Particle Therapy MC Simulation framework using Geant4
- Versatile
  - Dose calculation
  - Machine design
  - Commissioning
  - Neutron dose
- Since 2003

MPEXS-h

- GPU-based MC for hadron on MPEXS platform
- Standard EM and Binary Cascade model in Geant4 are transplanted to CUDA
- Dedicated to dose calculation
- Since 2017

Conclusion

- In Nagoya Proton Therapy Center, in-house Monte Carlo dose calculation system was developed.
- It has been used for independent dose calculation for patient specific QA.
- Treatment planning was modified for a few percent of clinical cases according to Monte Carlo dose calculation.
- We demonstrated that Monte Carlo dose calculation was clinically useful.
- Migration to GPU-based system is conducted to speed-up calculation.