31.Aug.2019

TPS transition of dose calculation method and state of the art of Planning System

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Medical Physicist
National Cancer Center Hospital East, Japan

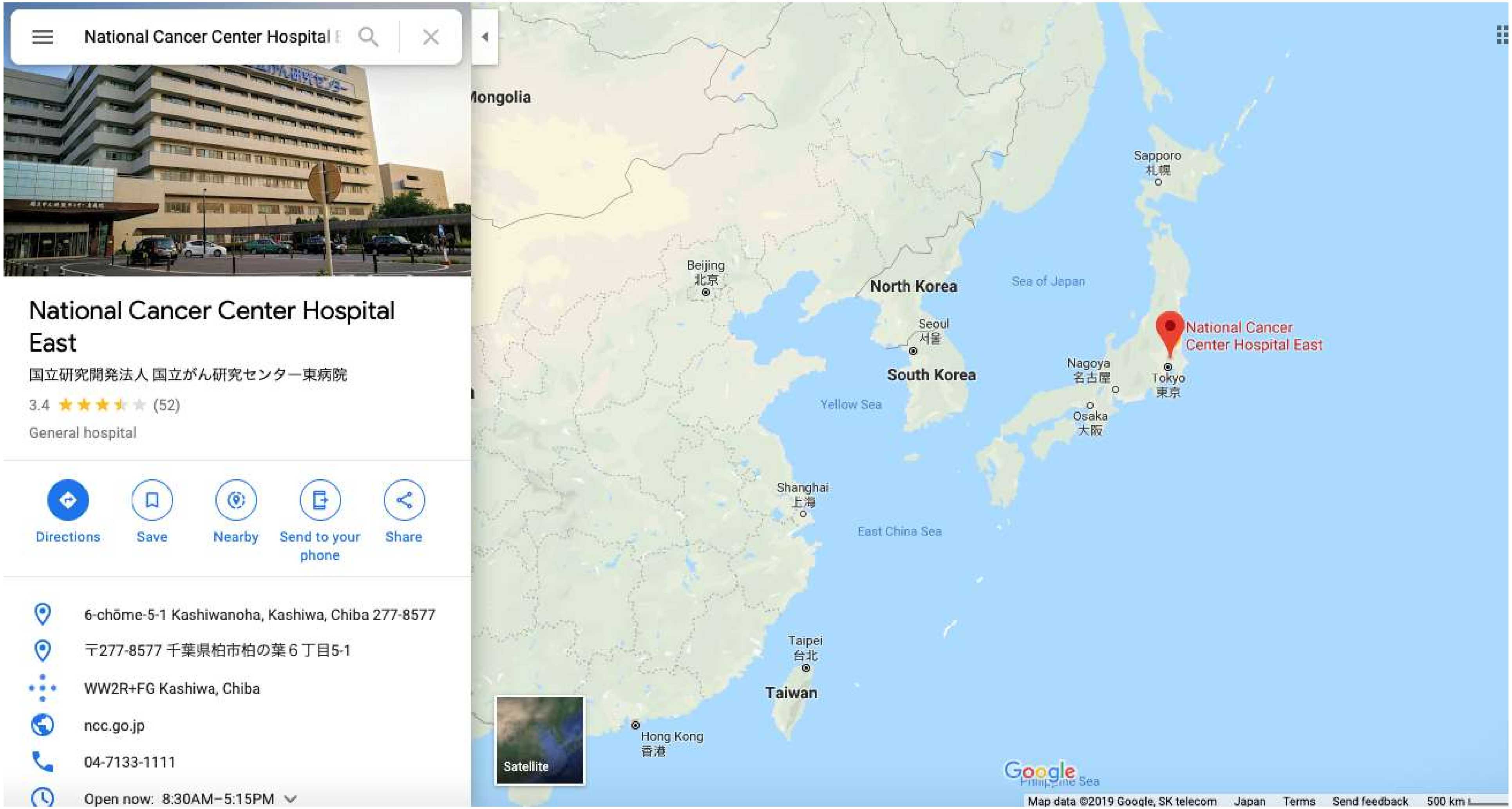
Outlines

- About National Cancer Center Hospital East
- About TPS: State of the Art

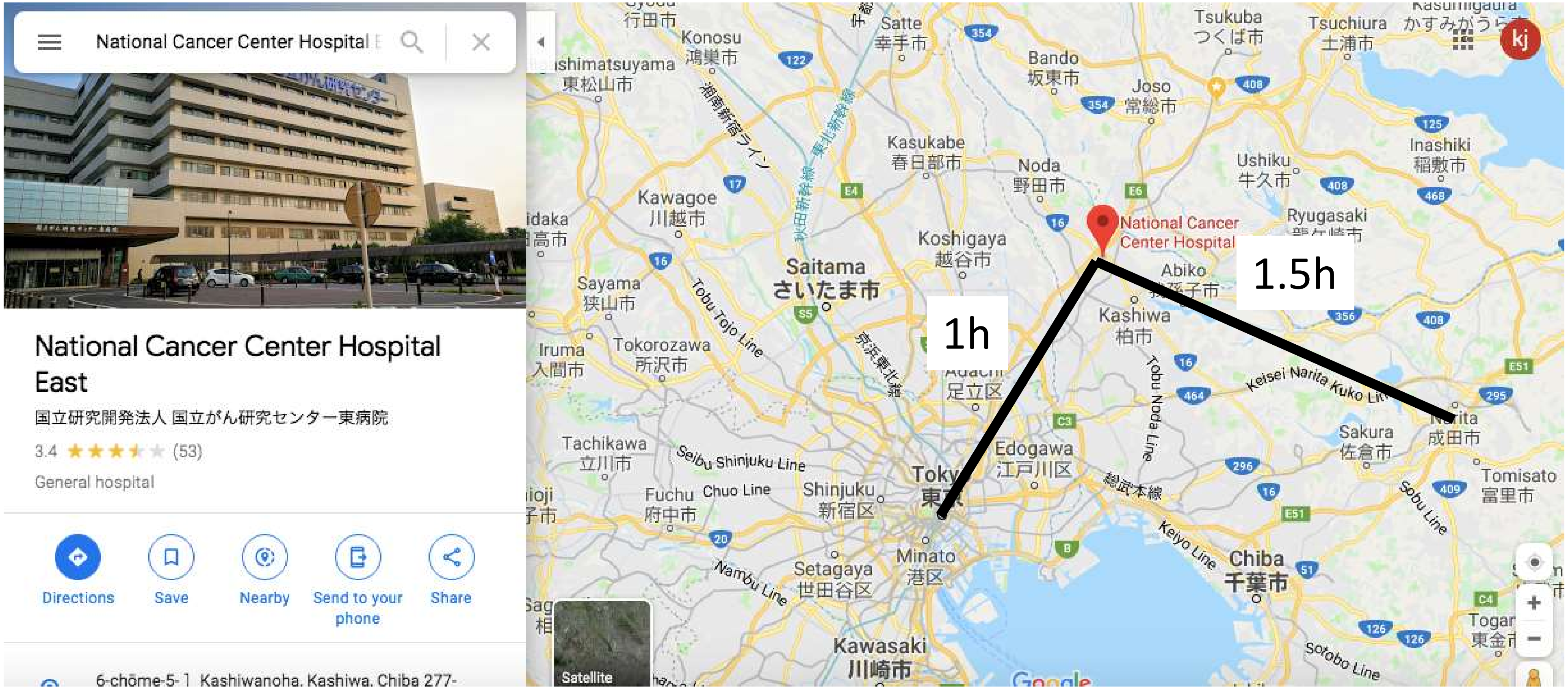
Introduction of Our Proton TPS

- Simplified Monte Carlo for Broad Beam
- Independent Dose Calculation for Patient QA

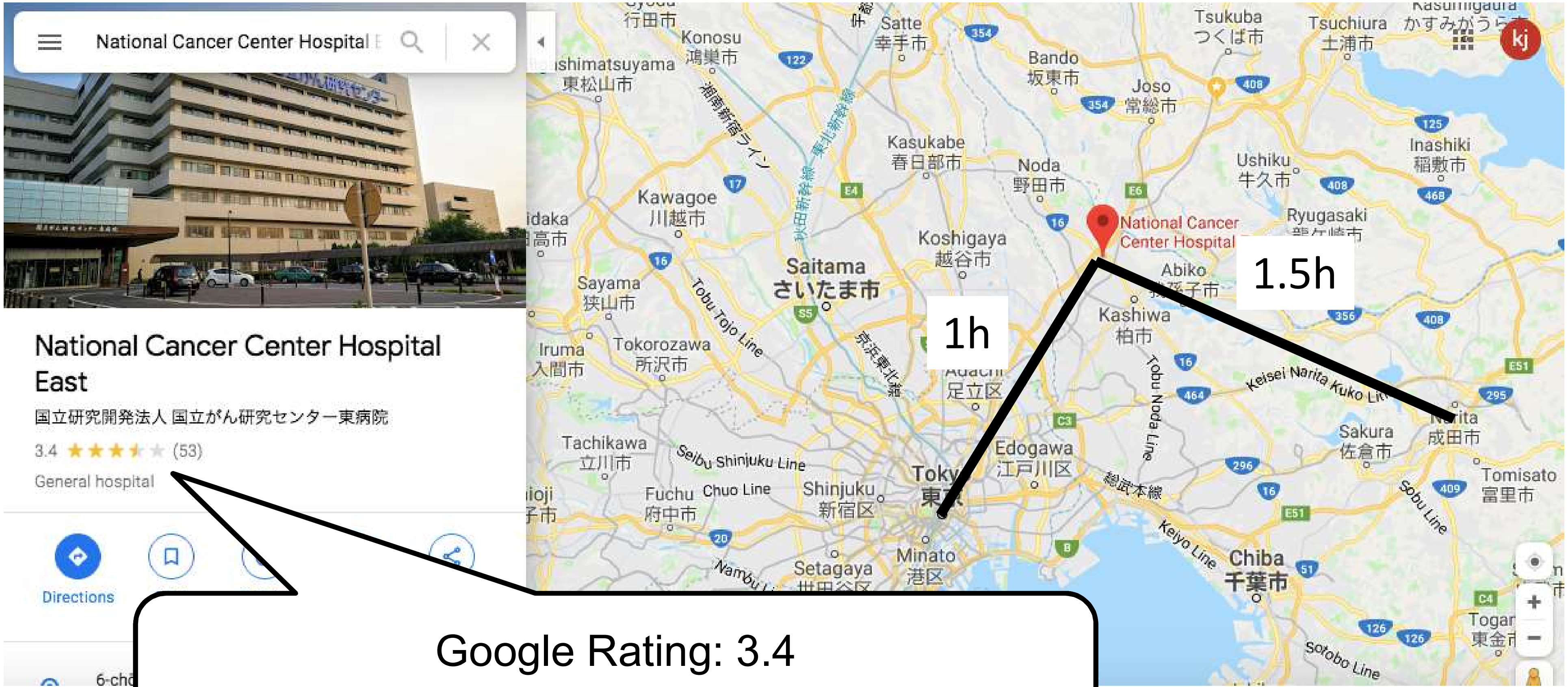
National Cancer Center Hospital East



National Cancer Center Hospital East



National Cancer Center Hospital East



Google Rating: 3.4

≒Average value of hospitals in Japan

Machines

4 Lineacs

- ONCOR (Siemens)
- Clinac-iX (Varian)
- TrueBeam (Varian)
- Halcyon (Varian)

2 Proton Gantries

- Proton G1 (Sumitomo)
- Proton G2 (Sumitomo)

No Brachytherapy

Once Closed, Restart in 2020

TPS

- RayStation (ReySearch):X
- Eclipse (Varian):X,P
- PTPLAN (in-house):P
- ~~XiO(Electa)~~

Support System

- MIM maestro (MIM software)

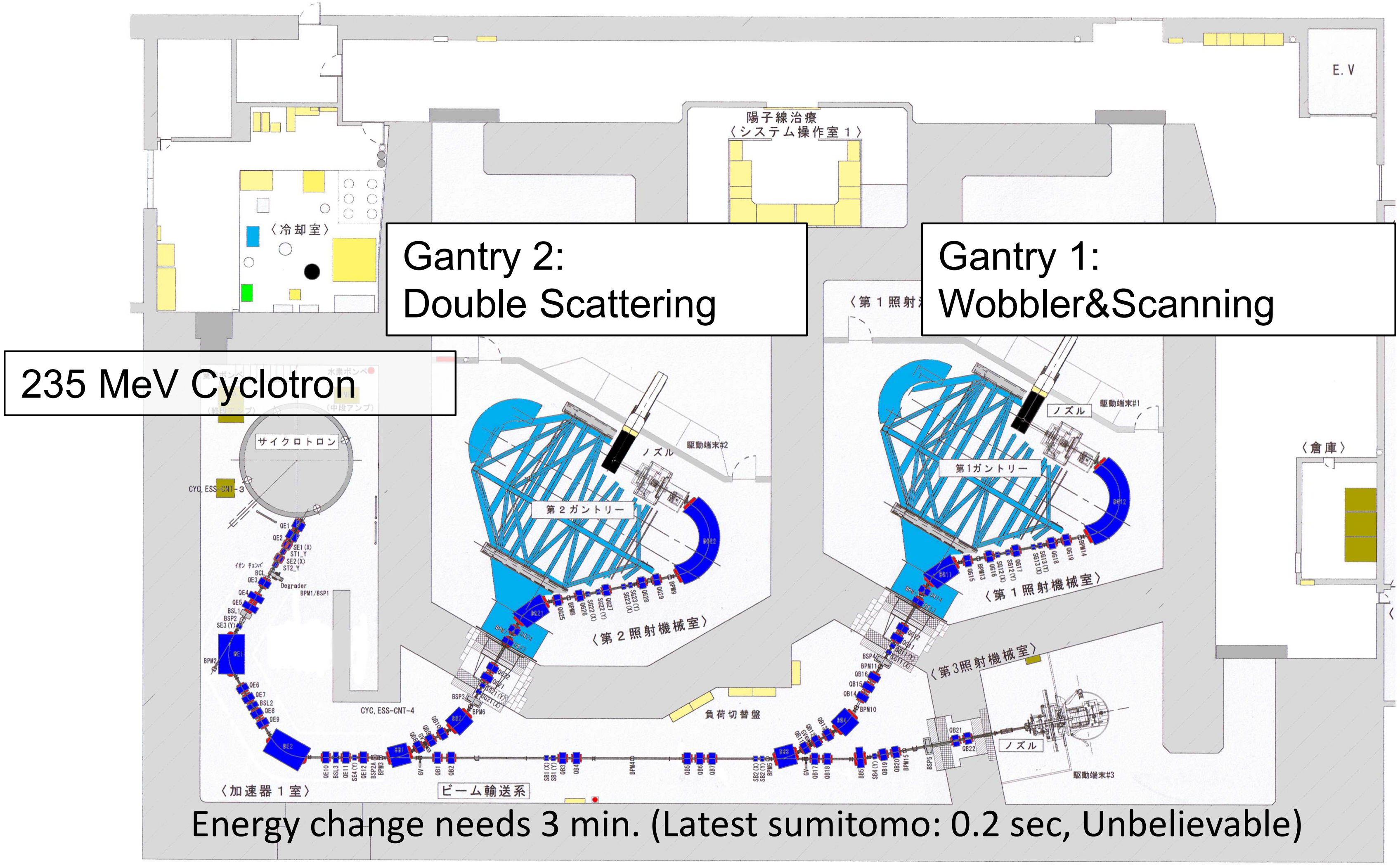
CT

- Aquillion One (Canon)

Staff (Photon + Proton)

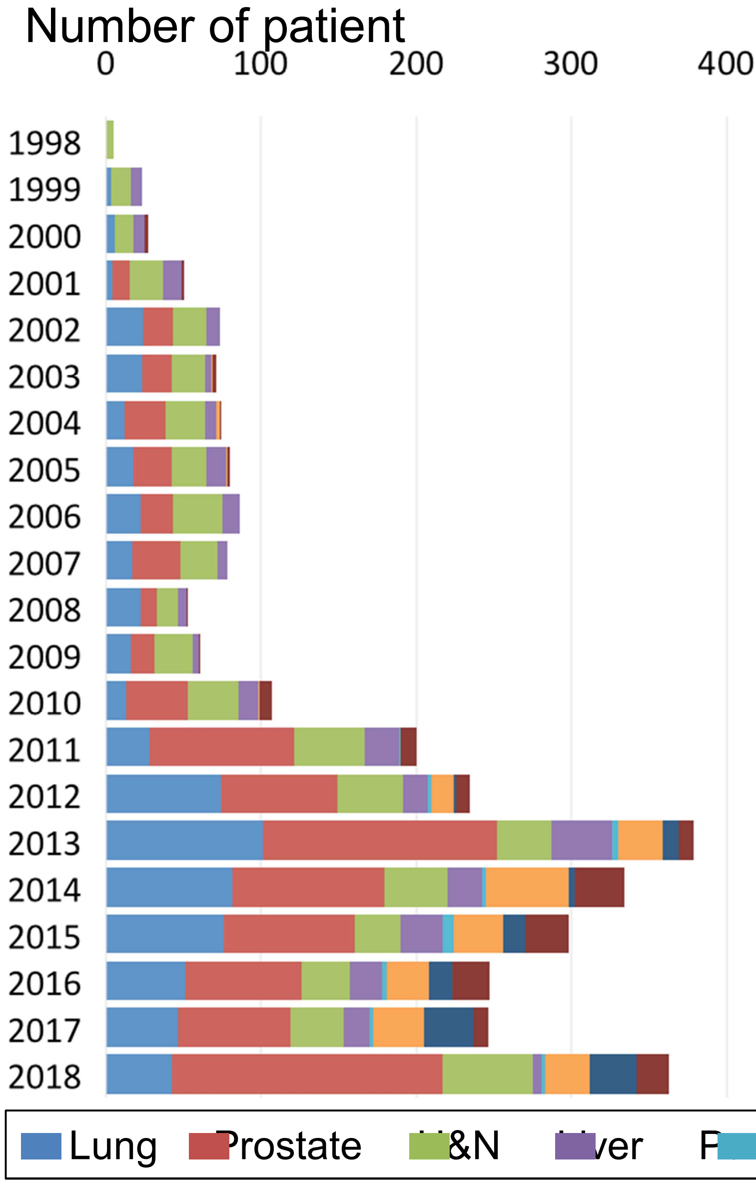
- Physician： 7 (＋2 Part-time)
- Therapist: 18
- Medical Physicist：5(＋4 Part-time)
- Nurse: 3

Proton Therapy System



Energy change needs 3 min. (Latest sumitomo: 0.2 sec, Unbelievable)

Proton therapy



- 1998. First Treatment

Customizing for Scanning

- 2014.10. First Scanning Treatment (Only Prostate)
- 2018.09. Using Eclipse for scanning
- 2018.10. IMPT(Head and Neck)

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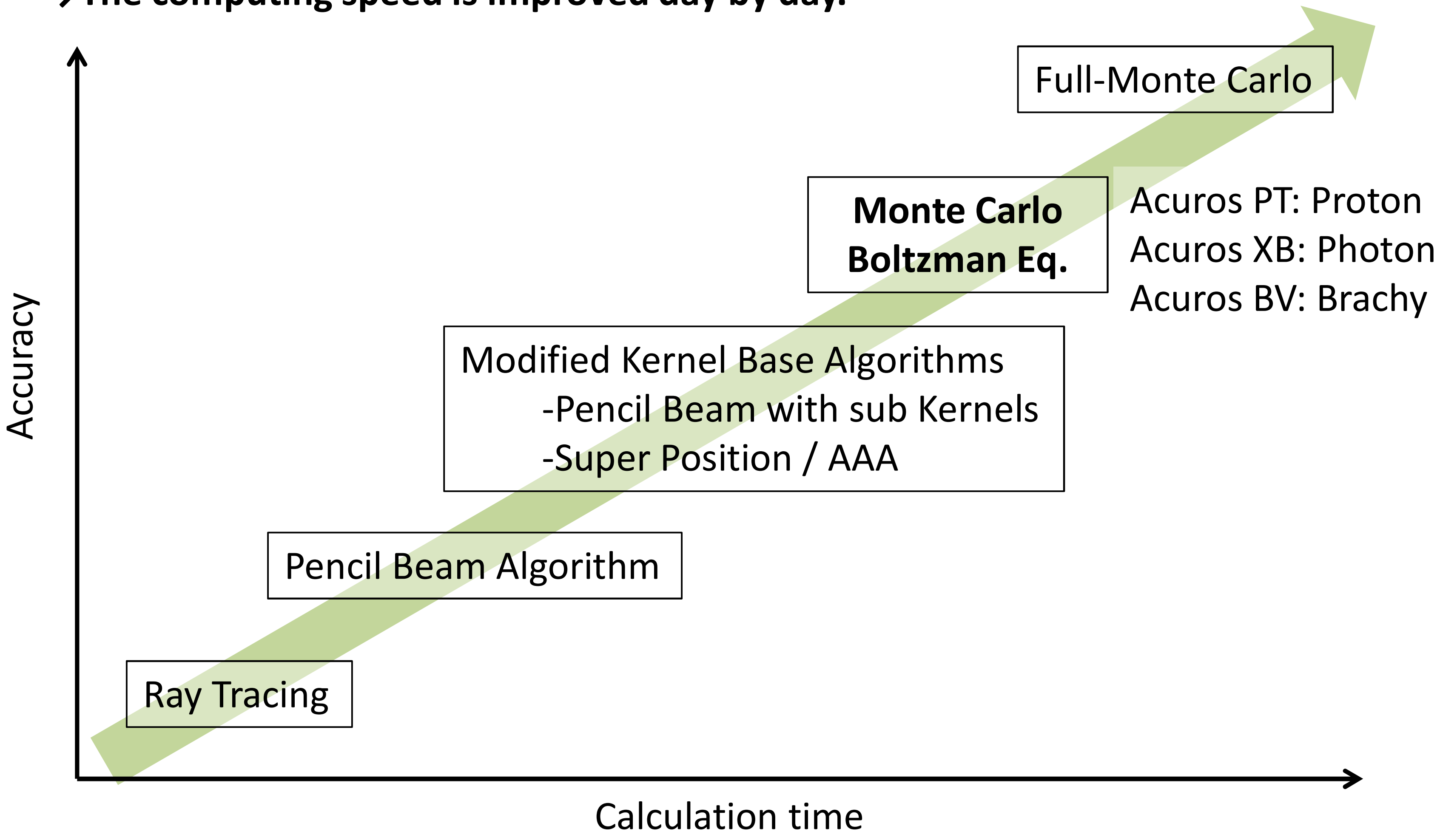
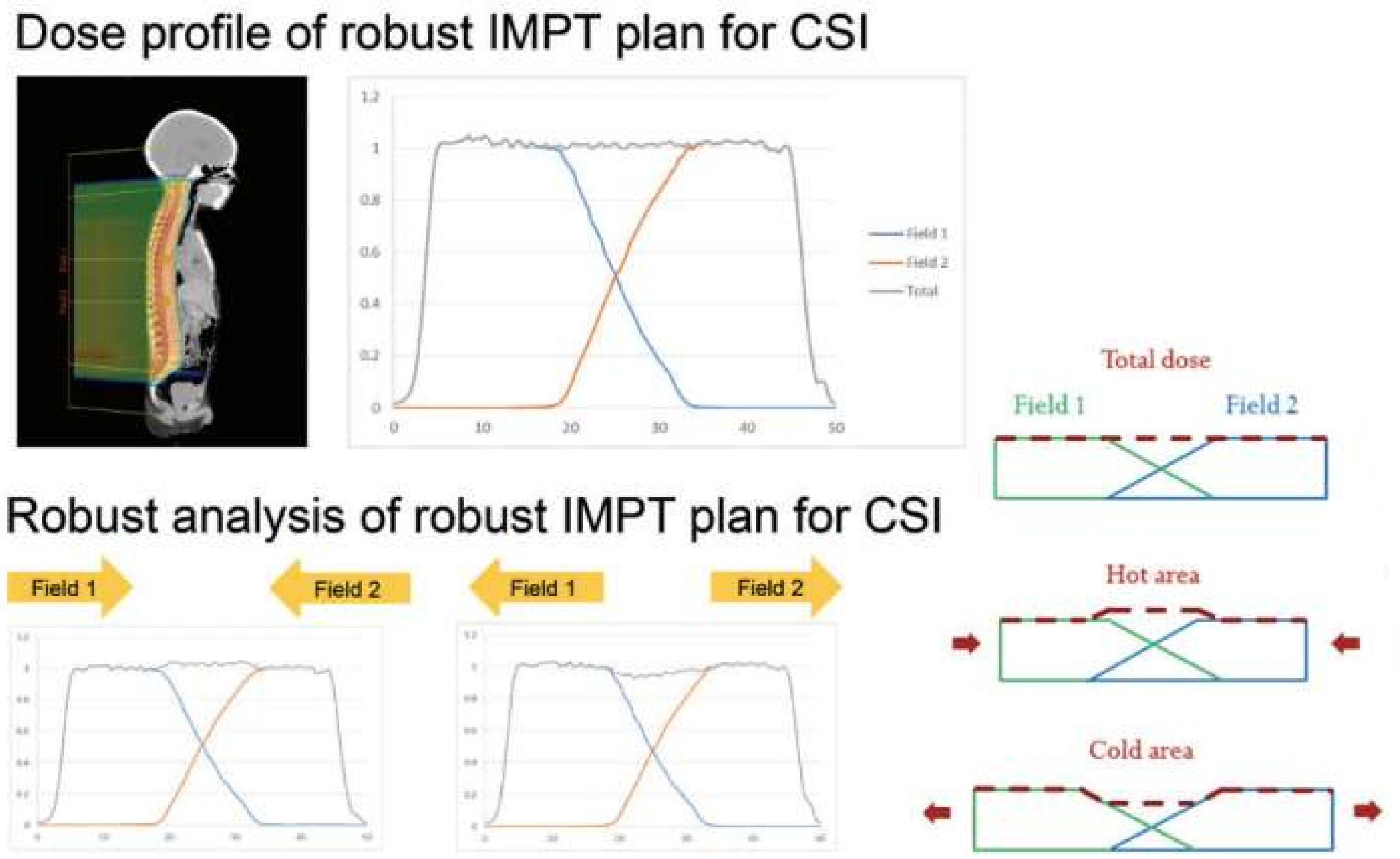
Evolution of Calculation Algorithm

Accurate algorithm needs LONG calculation time
→The computing speed is improved day by day.



Robust Optimization



The impact of robust junctions on a plan with two beams and two isocenters (image courtesy of: MD Anderson Cancer Center)

Automation

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

Improving Health Through Medical Physics

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AAPM

AAPM VIRTUAL LIBRARY

2016 AAPM Annual Meeting - Session: An Introduction to Research and Clinical Development Using Treatment Planning System APIs

- Session about TPS APIs (Application Programming Interface)
Some codes are uploaded on git-hub.

- Machine learning for Auto Planning

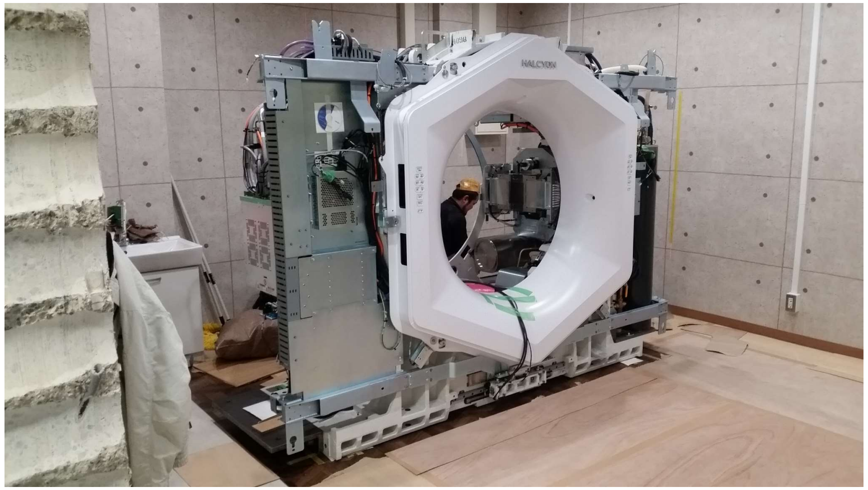
Golden Beam Data

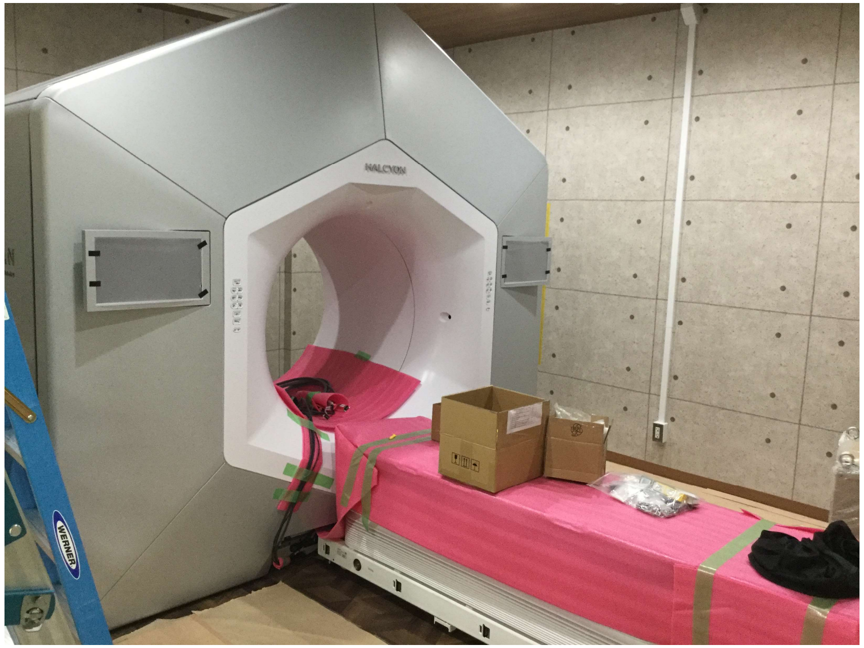
- Varian has been provides
  GOLDEN BEAM DATA
  (Averaged beam data)

→User can start RT without
  measuring beam data.

- Halcyon: User **can't**
  touch the beam data.

Varian certifies the beam data.





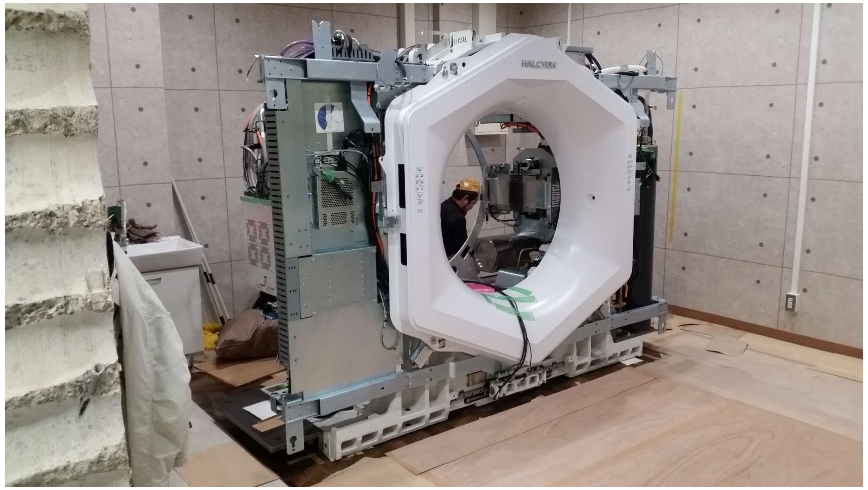
Machines

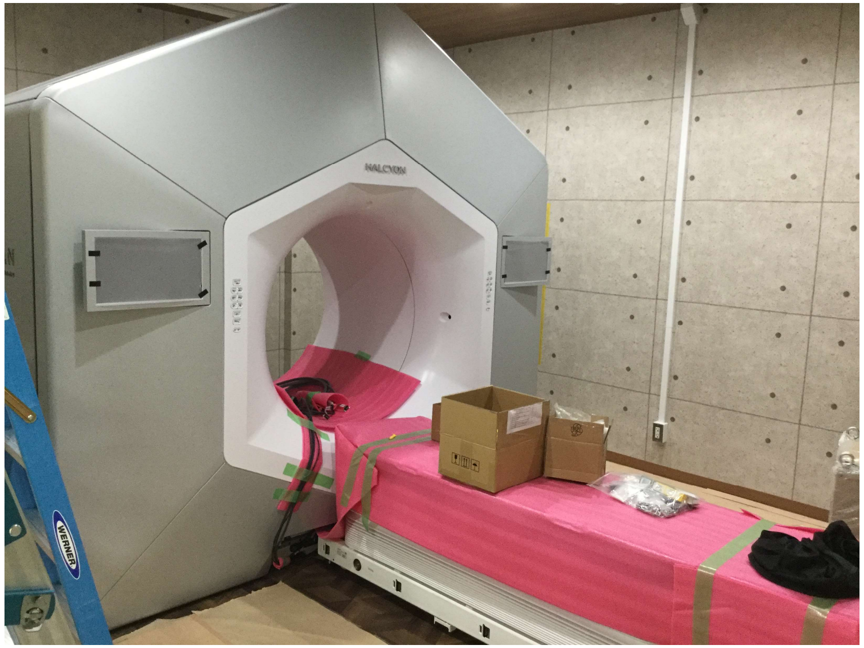
There is 3% dose output error.

Beam data are protected.

We fixed error by modifying
output factor calibration.

Negative image for Halcyon.

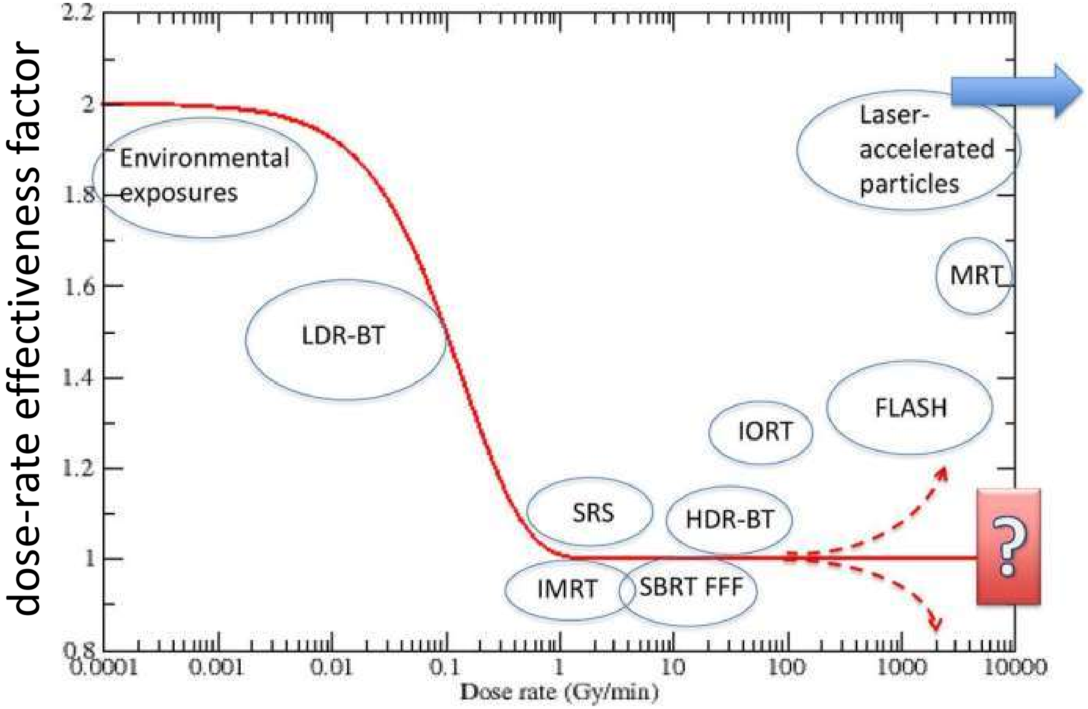




FLASH: ultra high dose rate RT

Science Translational Medicine 16 Jul 2014 Vol. 6, Issue 245, p245

- NTCP is degreased at dose rate > 30 Gy/sec.
- This phenomenon is only occurred *in vivo*, not *in vitro*.
- It is hard to believe, but there is dream in the result.



FLASH: ultra high dose rate RT

Proton therapy / 11.06.2019

Successful Ultra High Dose Rate delivered at Isocenter in IBA's compact proton therapy solution

Louvain-la-Neuve, Belgium, 11 June 2019 – IBA (Ion Beam Applications SA), the world's leading provider of proton therapy solutions, is pleased to announce the first Flash irradiation in an IBA Proteus®ONE compact gantry treatment room at the Rutherford Cancer Cent
represents a
their work to

Varian Forms FlashForward Consortium to Study Ultra-high Dose Rate Cancer Treatments with Protons

October 20, 2018

PALO ALTO, Calif., Oct. 20, 2018 /PRNewswire/ -- To expand the encoura...g preclinical and translational research already conducted by Varian ... its clinical partners, Maryland Proton Treatment Cent... on Therapy Center, on the value of ultra-high ... cancer, the company has formed the FlashForw... initial thirteen members, the consortium is focused on preclinical research, ... implementation and advocacy efforts of Flash therapy. The initial FlashForward Consortium members are:

Commercial purpose?

FLASH: ultra high dose rate RT

Dr. Montay-Gruel P, Radiother Oncol. 2018 Dec;129(3):582-588
X-rays can trigger the FLASH effect: Ultra-high dose-rate synchrotron light source prevents **normal brain injury after whole brain irradiation** in mice.

Whole Brain irradiation is needed for
- Small cell lung cancer
- **Pediatric** neuroblastoma.

Side effect: Decrease learning ability.

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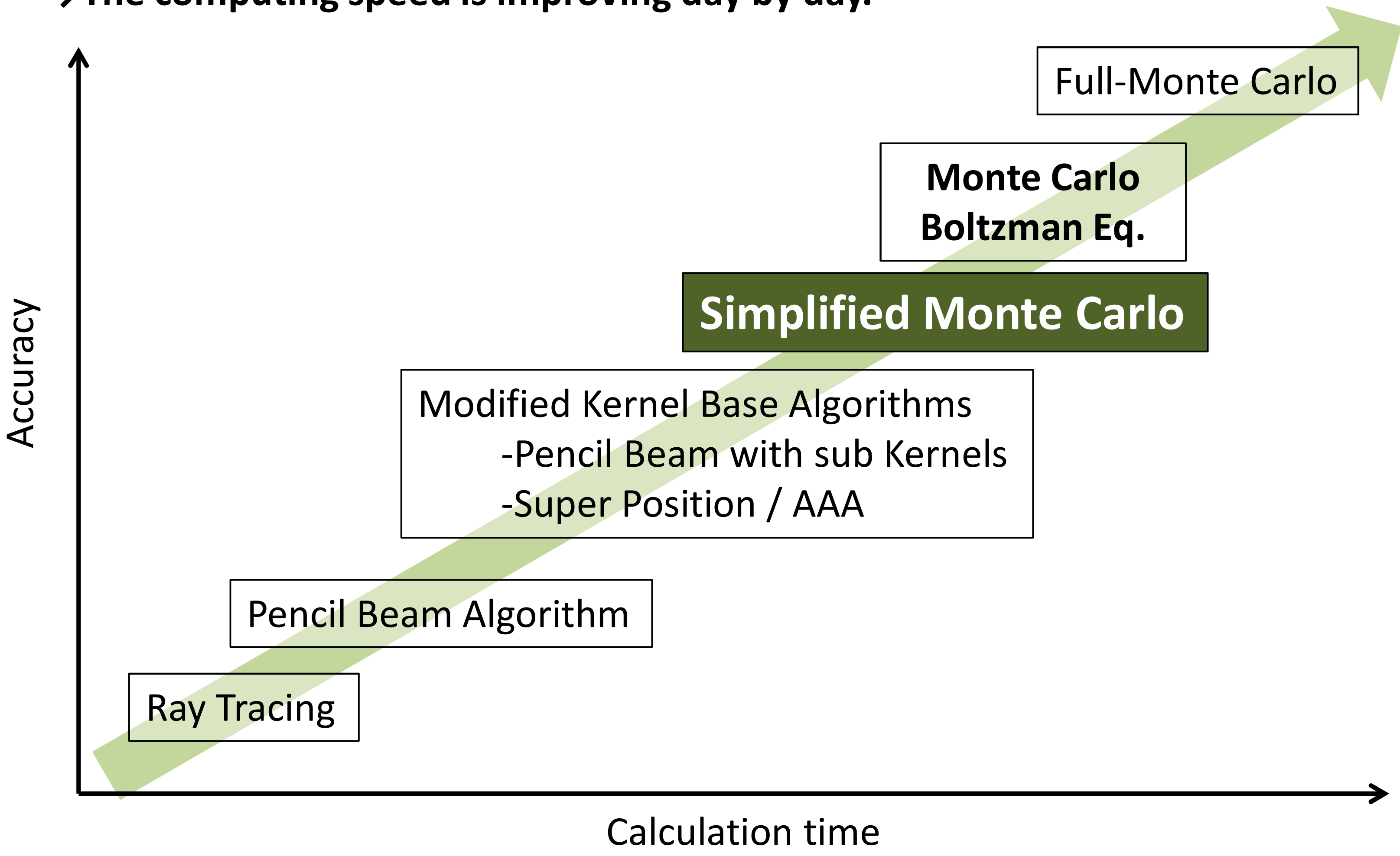
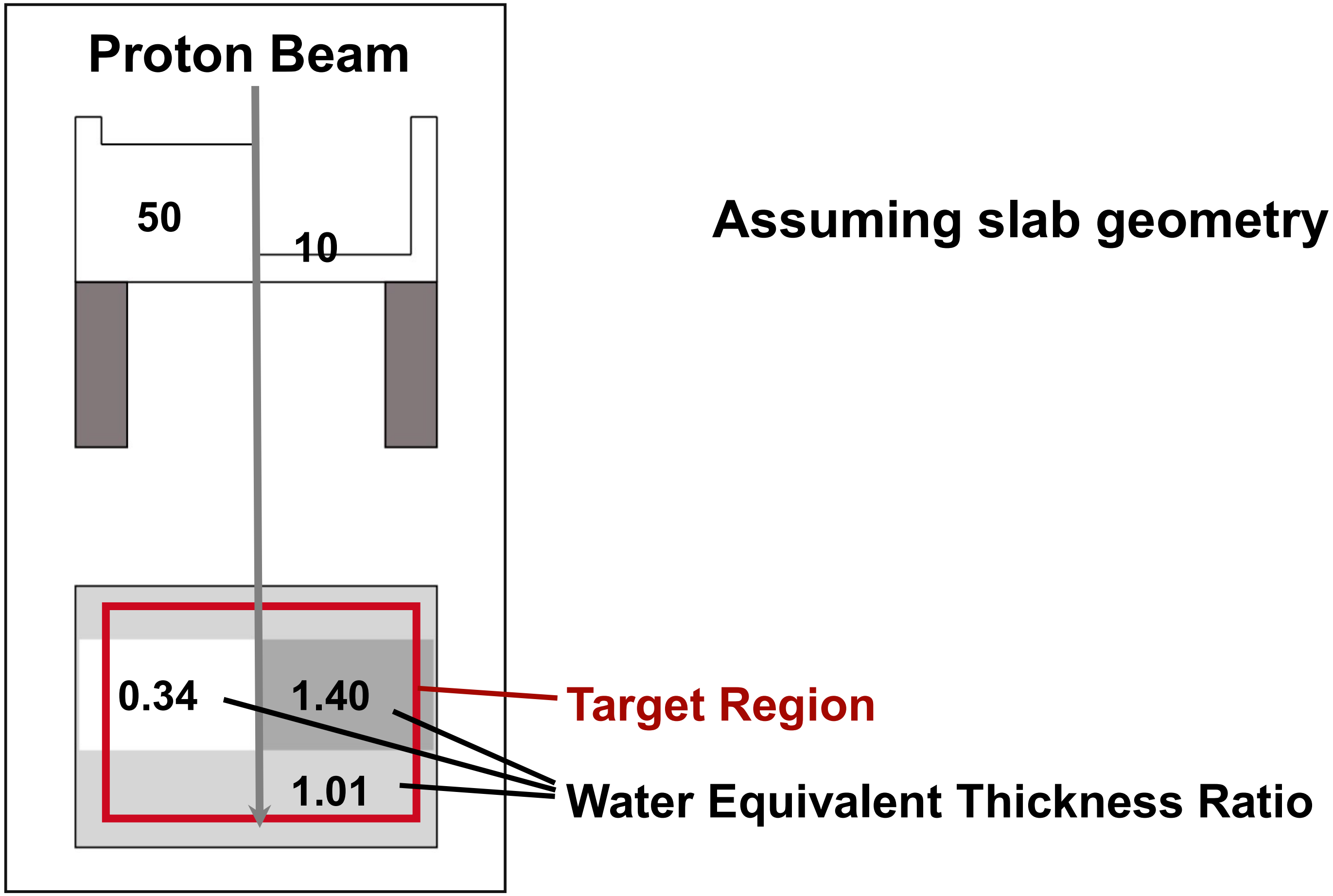
Simplified Monte Carlo

Accurate algorithm needs long calculation time
→The computing speed is improving day by day.

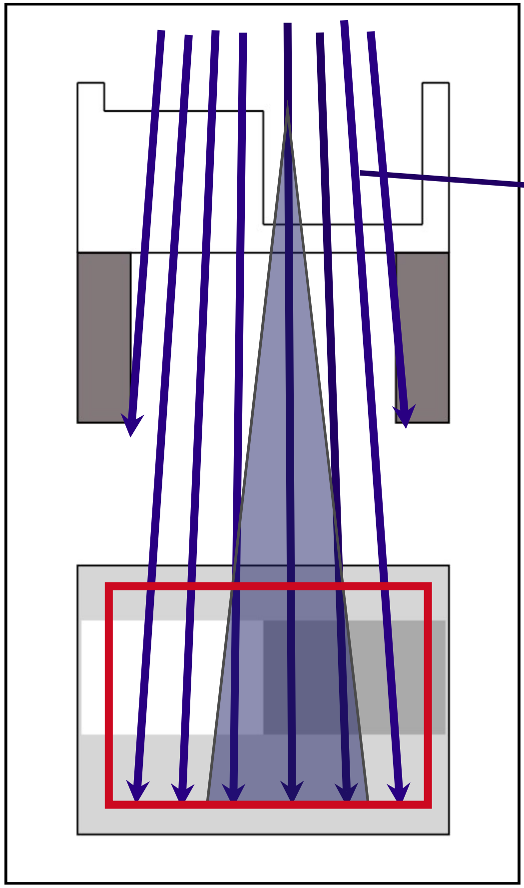


Why does PBA failed the calculation?



Assuming slab geometry

Why does PBA failed the calculation?



PBA

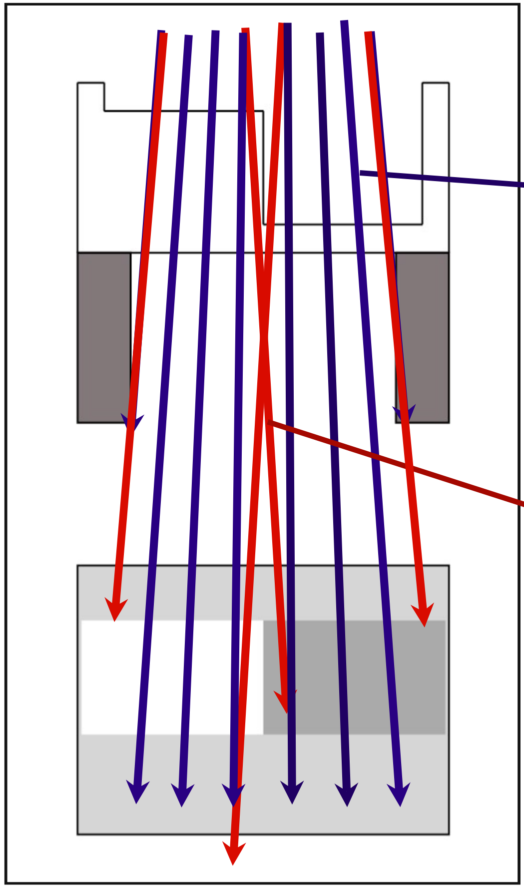
The Central Axes of Pencil Beam kernels

- ☐ Straight Lines from the Beam Source
- ☐ Vanish in the collimator

- ☐ Initial Parameter : Effective Source Model
- ☐ Lateral Scattering : Highland's eq.
- ☐ Energy Loss : Water Equivalent Model
- ☐ Dose Deposit : Measured Depth Dose

L. Hong et al; Phys. Med. Biol. **41** (1996)

Why does PBA failed the calculation?



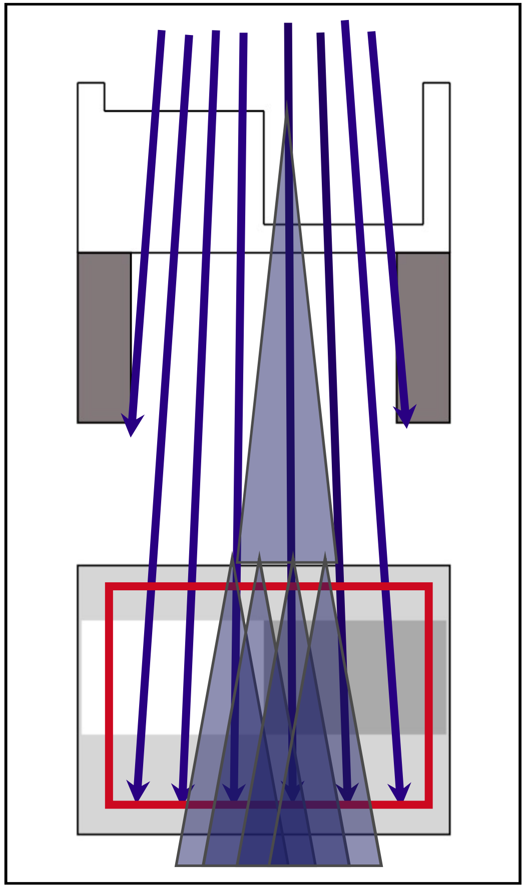
The Central Axes of Pencil Beam kernels

- ☐ Straight Lines from the Beam Source
- ☐ Vanish in the collimator

PBA missed these Paths

→forms Higher/Lower Dose Regions

Why does PBA failed the calculation?



To avoid ignored path…

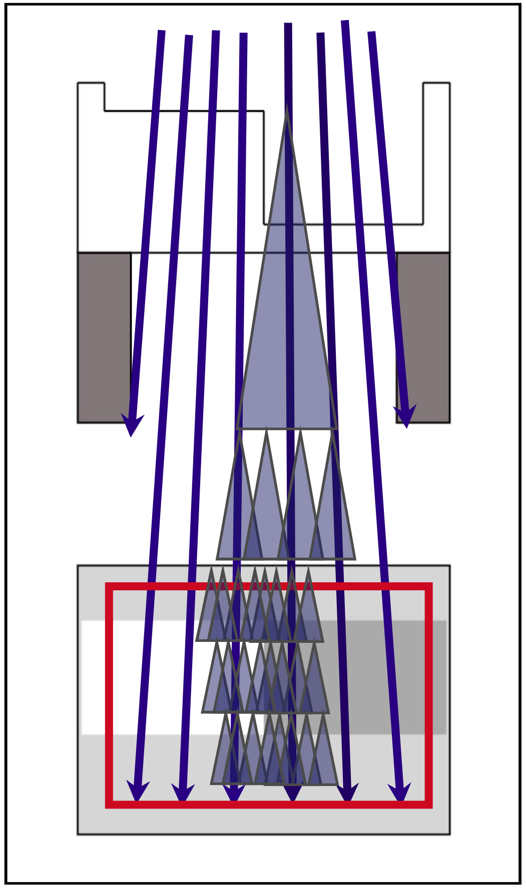
Modified PBA

Divide kernels into sub-kernels.

→ Installed in Eclipse

Schaffner B, Phys. Med. Biol. 44; p27 (1999)

Why does PBA failed the calculation?



To avoid ignored path…

Divide kernels more multiply

↓

Calculate Multiple Integrals

↓

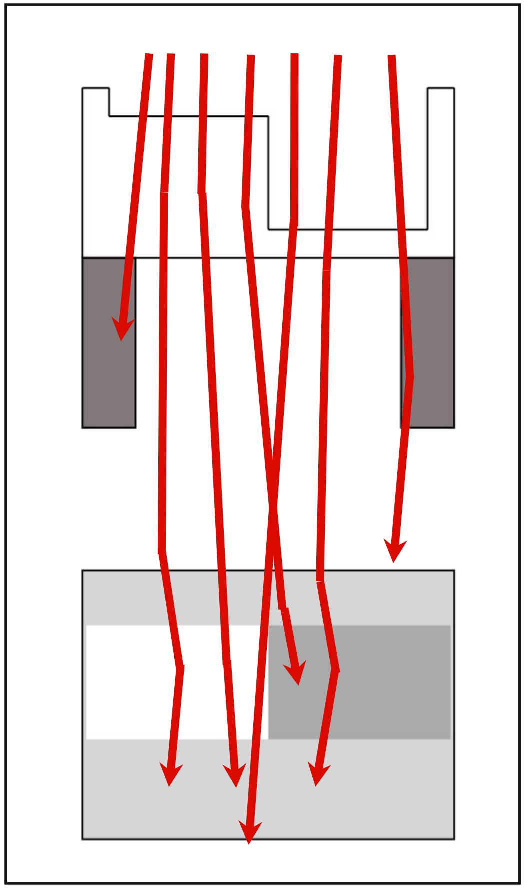
Increase the Calculation time

Calculate the multiple integrals

in realistic time

= Primitive Aim of Monte Carlo

Simplified Monte Carlo



The SMC traces individual proton path

☐ Initial Parameter : Effective Source Model

☐ Lateral Scattering : Highland's eq.

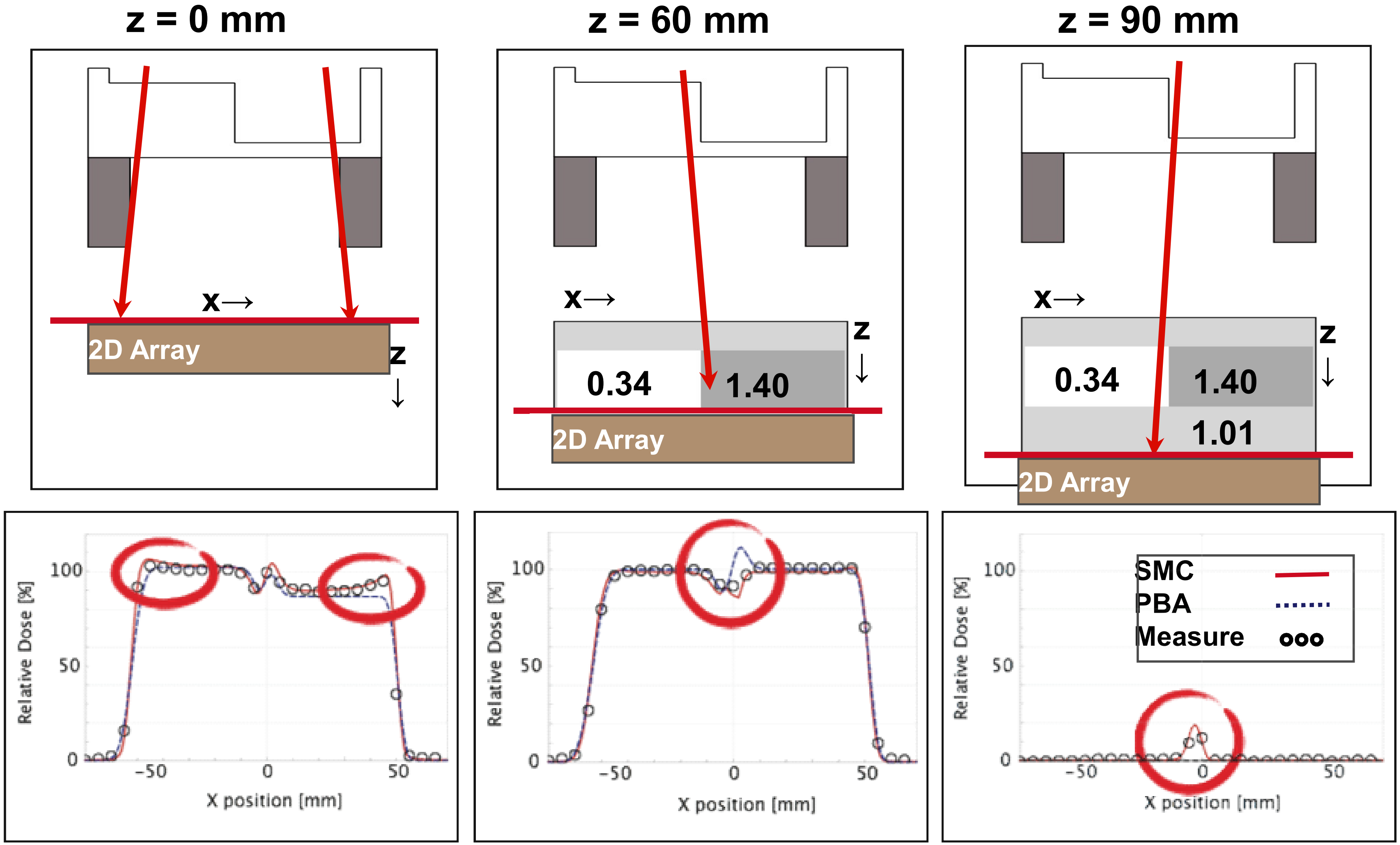
☐ Energy Loss : Water Equivalent Model

☐ Dose Deposit : Measured Depth Dose

Hotta K, Phys. Med. Biol. 55; p3545-3556 (2010)

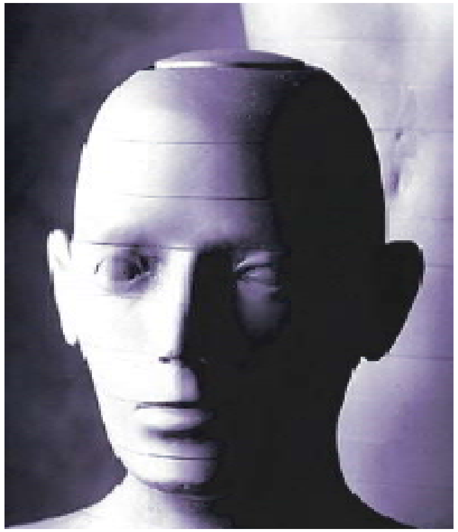
Verification in slab phantom

Detector : PTW Octavius

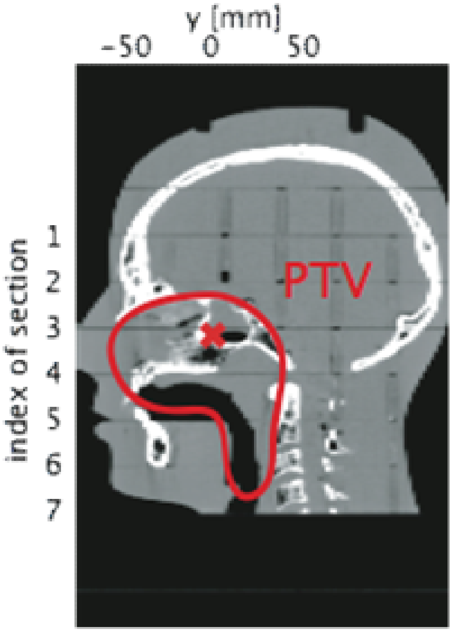


Verification in RANDO phantom

Proton Beam
↓ ↓ ↓ ↓ ↓



Picture



CT

235 MeV

SOBP width 80 mm

PTW 2D Array Seven29

27 x 27 Matrix (10 mm pitch)

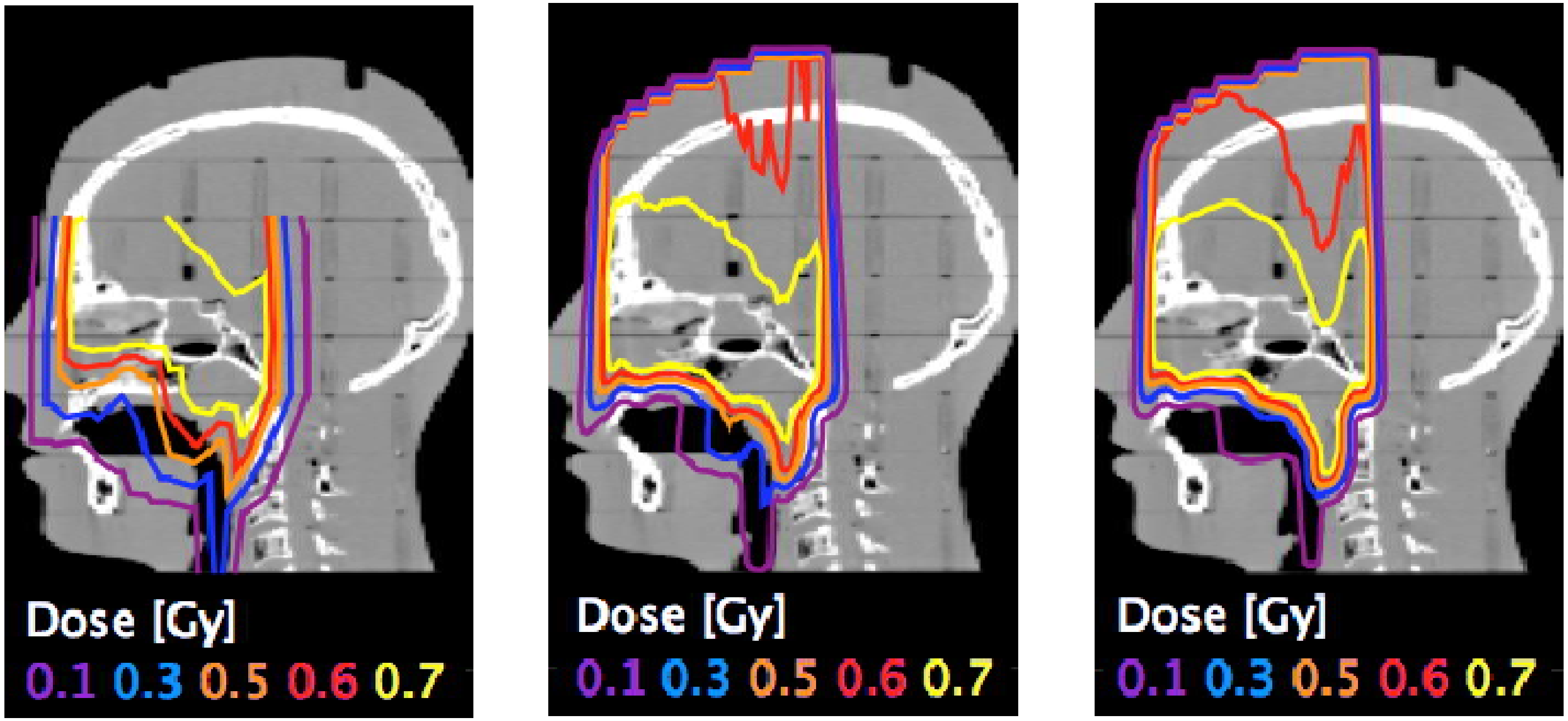
RANDO Phantom (Head)

made by Phantom Laboratory Ltd.

with section in 25 mm pitch

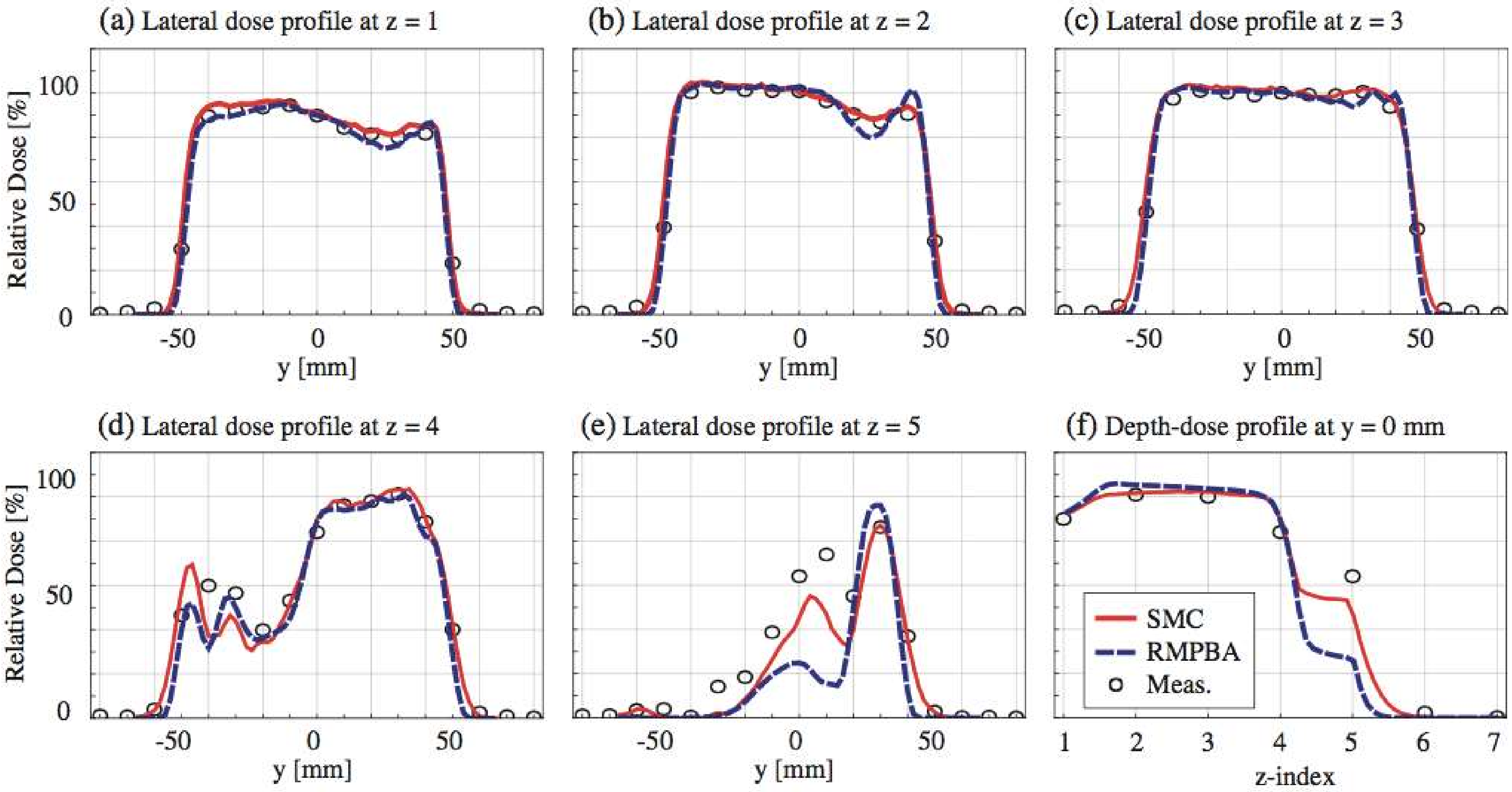
Verification in RANDO phantom

Measurement **SMC (30 min)** **PBA (2 min)**



Iso-dose distribution (calculated volume = 2.0 liter)

Verification in RANDO phantom



Evaluation by gamma index

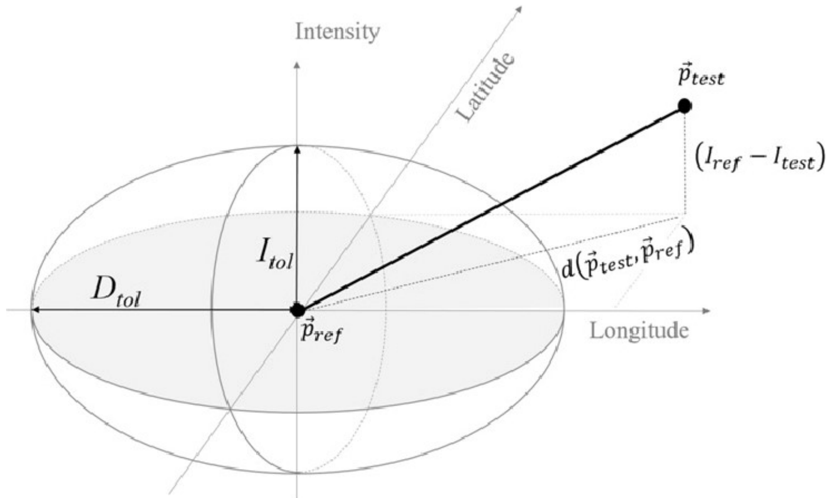
[5] D. A. Low et al; Med. Phys. **25** (1998)

$$\gamma_{\pm}(\mathbf{r}_m) = min\{|\Gamma(\mathbf{r}_m, \mathbf{r}_c)|\} \; \forall\{\mathbf{r}_c\}$$

$$\Gamma(\mathbf{r}_m, \mathbf{r}_c) = \sqrt{\frac{|\mathbf{r}_m - \mathbf{r}_c|^2}{\Delta d_M^2} + \frac{(D_m(\mathbf{r}_m) - D_c(\mathbf{r}_c))^2}{\Delta D_M^2}}$$

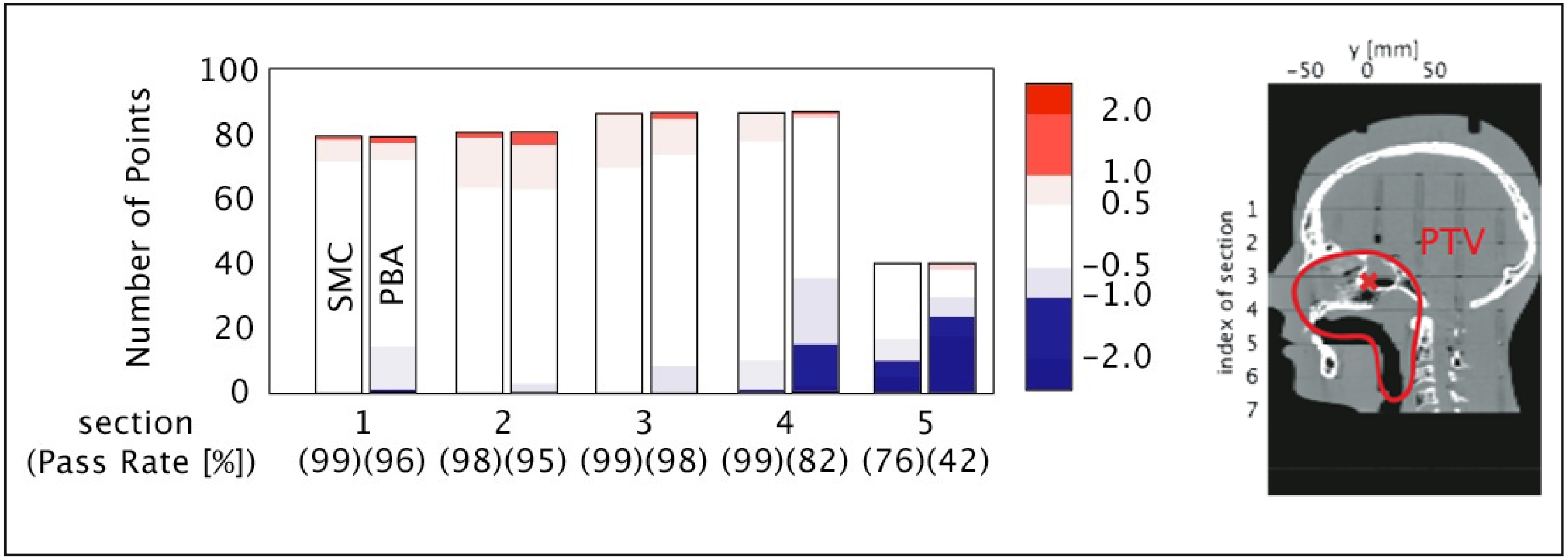
Δd_M =3 mm, ΔD_M =3%

Position error **Dose error**



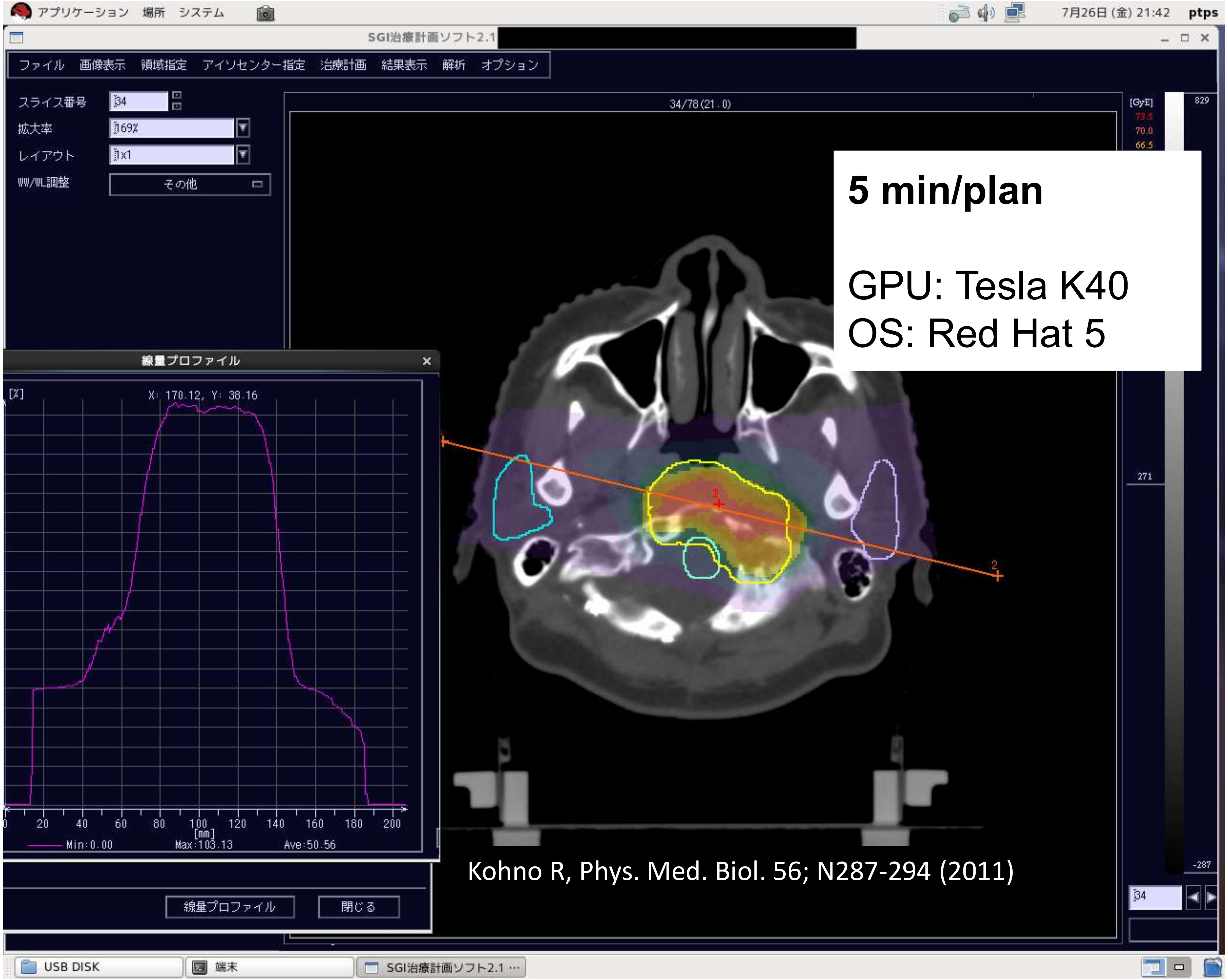
D_c : calculated dose
D_m : measured dose
D_M : Tolerance dose error
d_M : Tolerance position error

Evaluation by gamma index



Stacked Bar Chart of γ± histogram

To control the statistical error:
Particle numbers per pixel
アプリケーション 場所 システム
7月26日 (金) 21:40 ptps
SGI治療計画ソフト2.1 [redacted]
ファイル 画像表示 領域指定 アイソセンター指定 治療計画 結果表示 解析 オプション
治療室 第2照射室
総線量(処方線量) 70 GyE
一回線量 2 GyE
CT値水等価厚変換テーブル
1F-ONE-M.cvt
切削ドリル径 9
呼吸同期フラグ OFF
パッチ照射フラグ OFF
門番号 照射回数 寝台角度 ガントリー角度 アイソセンター番号
1 13 0 280 1
2 12 0 80 1
3 5 0 315 2
4 5 0 45 2
門の追加 門の削除 照射条件追加
34/78(21.0)
門番号
エネルギー
照射タイプ
照射回数
照射総線量
寝台角度
アイソセンター番号
スノート位置 -220 mm
側方マージン 0 mm
深さマージン 4 mm
コリメータの種類 個人用
ボーラスの種類 個人用
スノート干渉チェック
治療部位 頭頸部 体幹部
ICと寝台の距離 0.0 mm
ICと寝台境界距離 (S-I方向) 0.0 mm
手上げ台サイズ (A-P方向) 0.0 mm
線量計算
計算デバイス
CPU GPU
線量計算手法
NCC-PBA
SMC
SMC_THEO
PBA
粒子数
ボーラス内散乱 ON OFF
ndose・線量計算共通オプション
計算範囲
全スライス
範囲指定
ndoseオプション
ログ取得設定
取得する
取得しない
USB DISK
端末
SGI治療計画ソフト2.1 ...

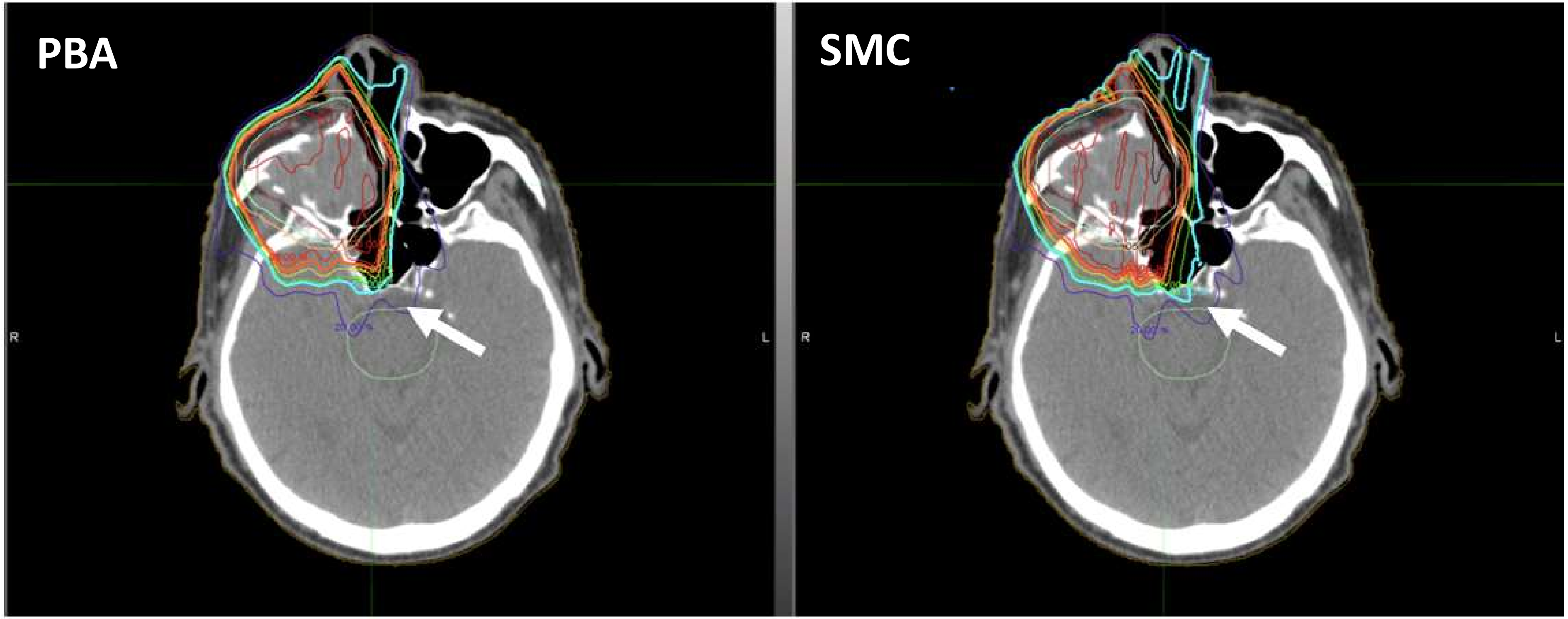


5 min/plan

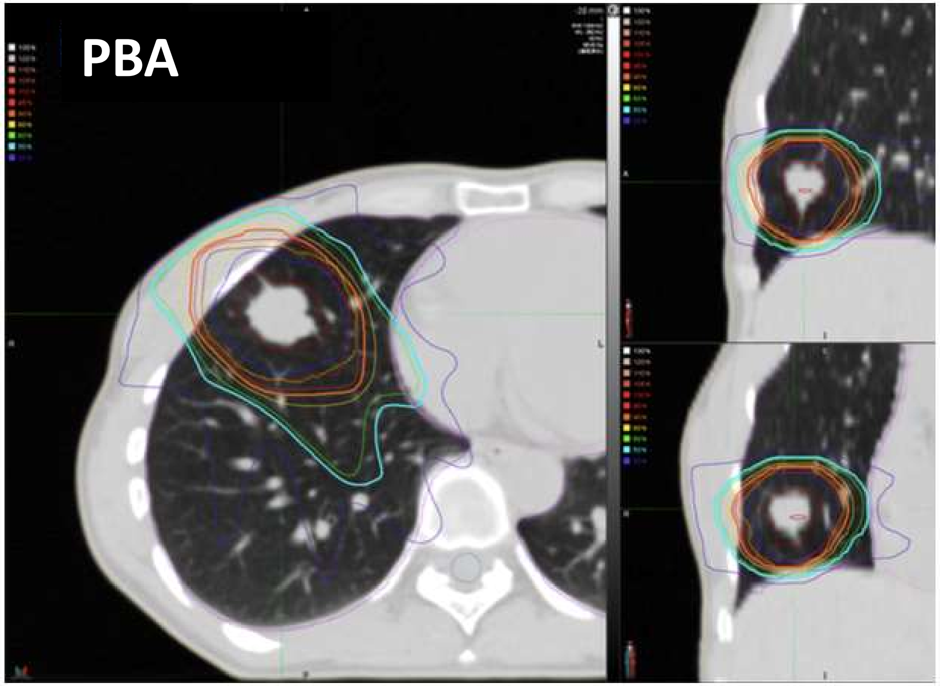
GPU: Tesla K40
OS: Red Hat 5

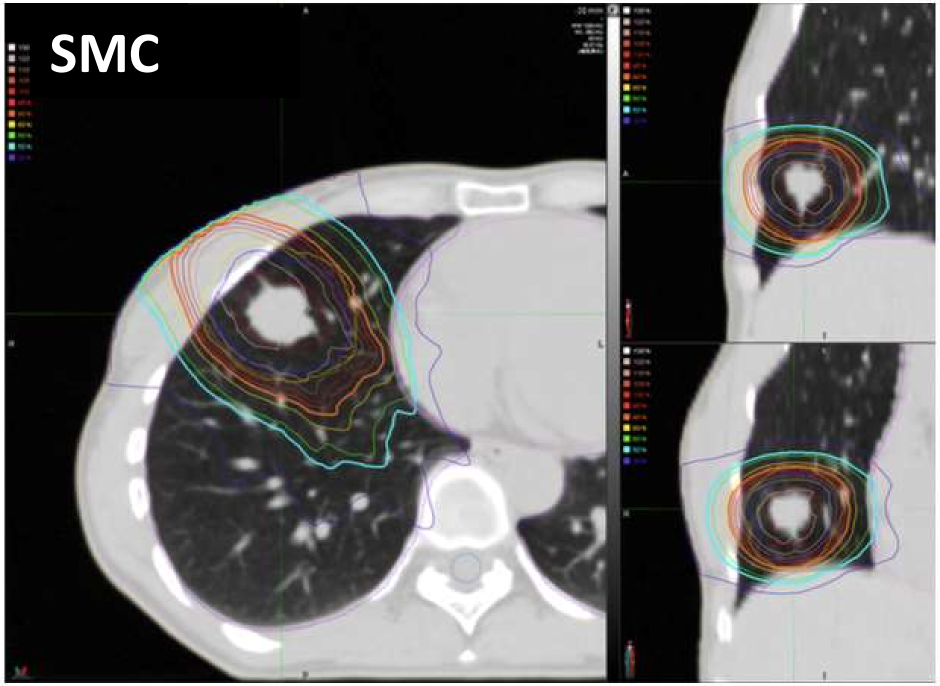
Kohno R, Phys. Med. Biol. 56; N287-294 (2011)

Change of Dose Distribution



Change of Dose Distribution





Discussion to change the TPS

- Dose distribution can be change

  Our protocol based on photon RT outcome.

- Absolute dose is not change. (decided by patient calb.)
- Old TPS is going to be broken.

→Now SMC is in clinical use.

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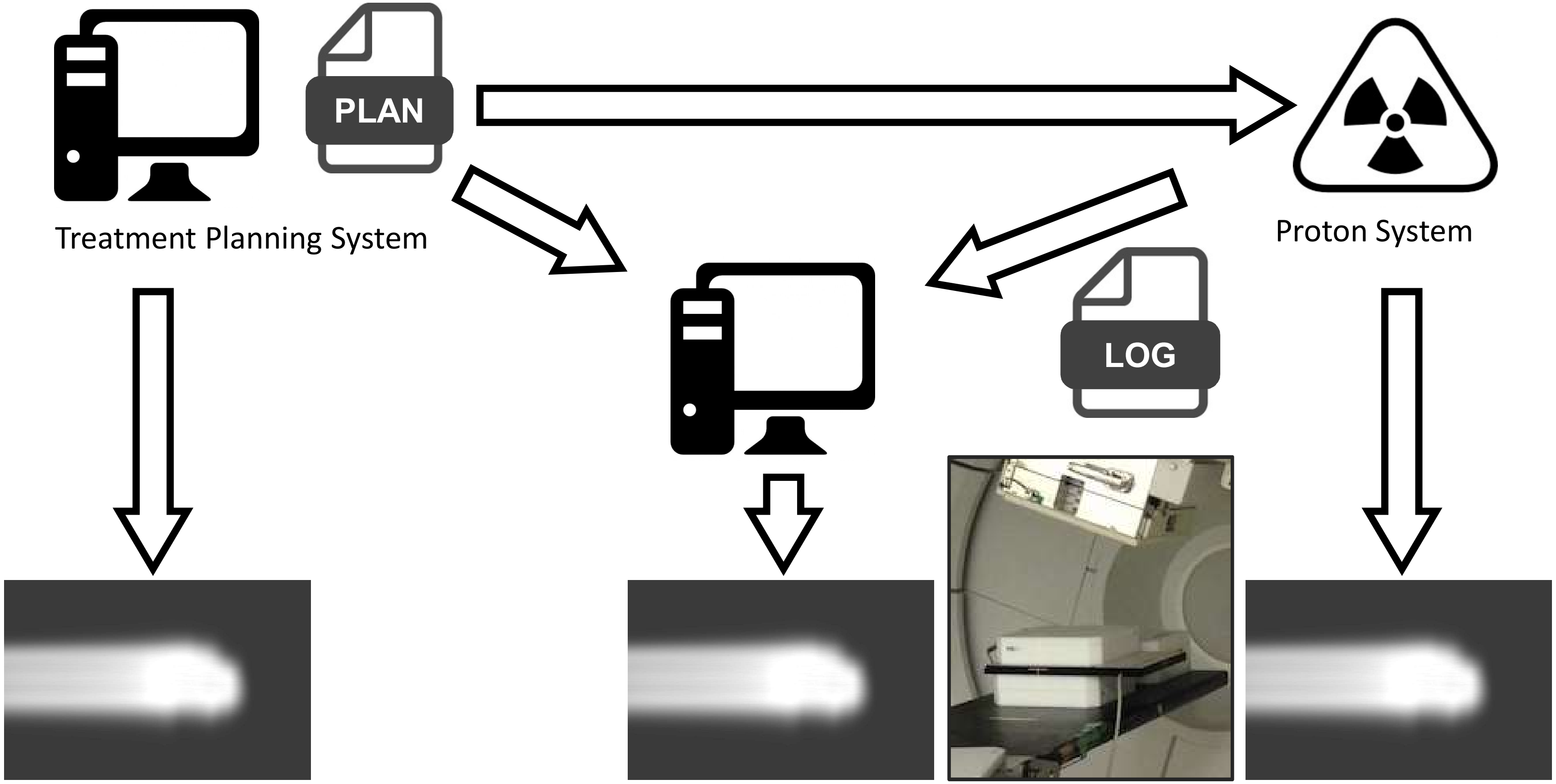
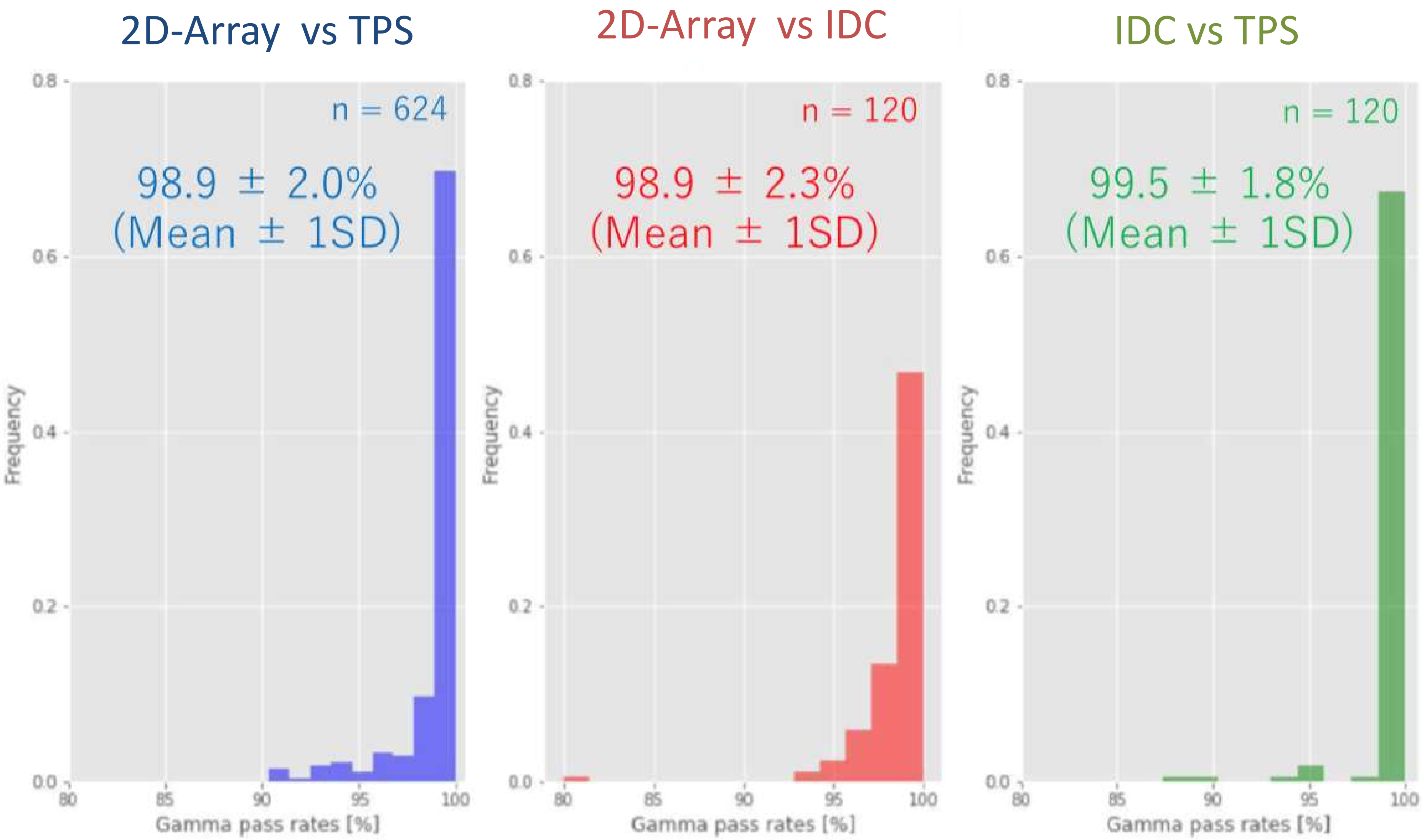
Independent Dose Calculation

IDC(Independent Dose Calculation system) :

construct the 3D dose distribution from stack of 2D log data



Independent Dose Calculation



Independent Dose Calculation (Prostate)

Point Dose @ Iso-center

Torrerance: 1%

Measure 3 depth

→

Point Dose @ Iso-center

Independent dose calculation

Compare with TPS dose
γ-pass rate≧96%

YES: Measure 1 depth

NO: Measure 3 depth

QA time: 1 hour → 30 min (/patient)

Summary

- I introduce hot topics around radiotherapy.
- Now our SMC is being in clinical use.
    - Calculation time is 5 min/plan using GPGPU tech.
    - SMC tends to calculate OAR dose higher than PBA.
- Independent Dose Calculation for Patient QA
    - Reduce the measurement time for Patient QA

Thank you for your attention.

FLASH: ultra high dose rate RT

Science Translational Medicine 16 Jul 2014 Vol. 6, Issue 245, p245

RESEARCH ARTICLE

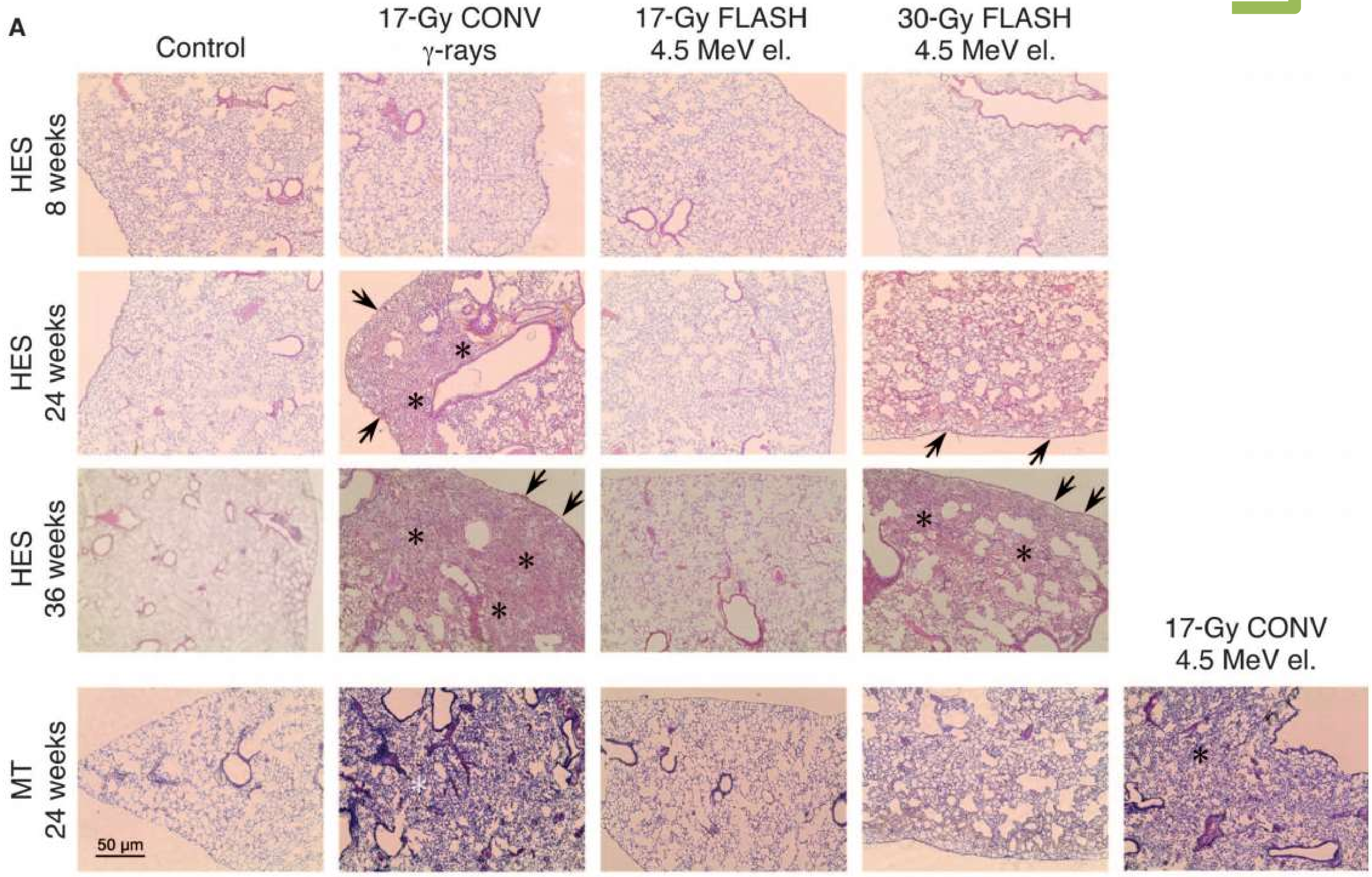
RADIATION TOXICITY

Ultrahigh dose-rate FLASH irradiation increases the differential response between normal and tumor tissue in mice

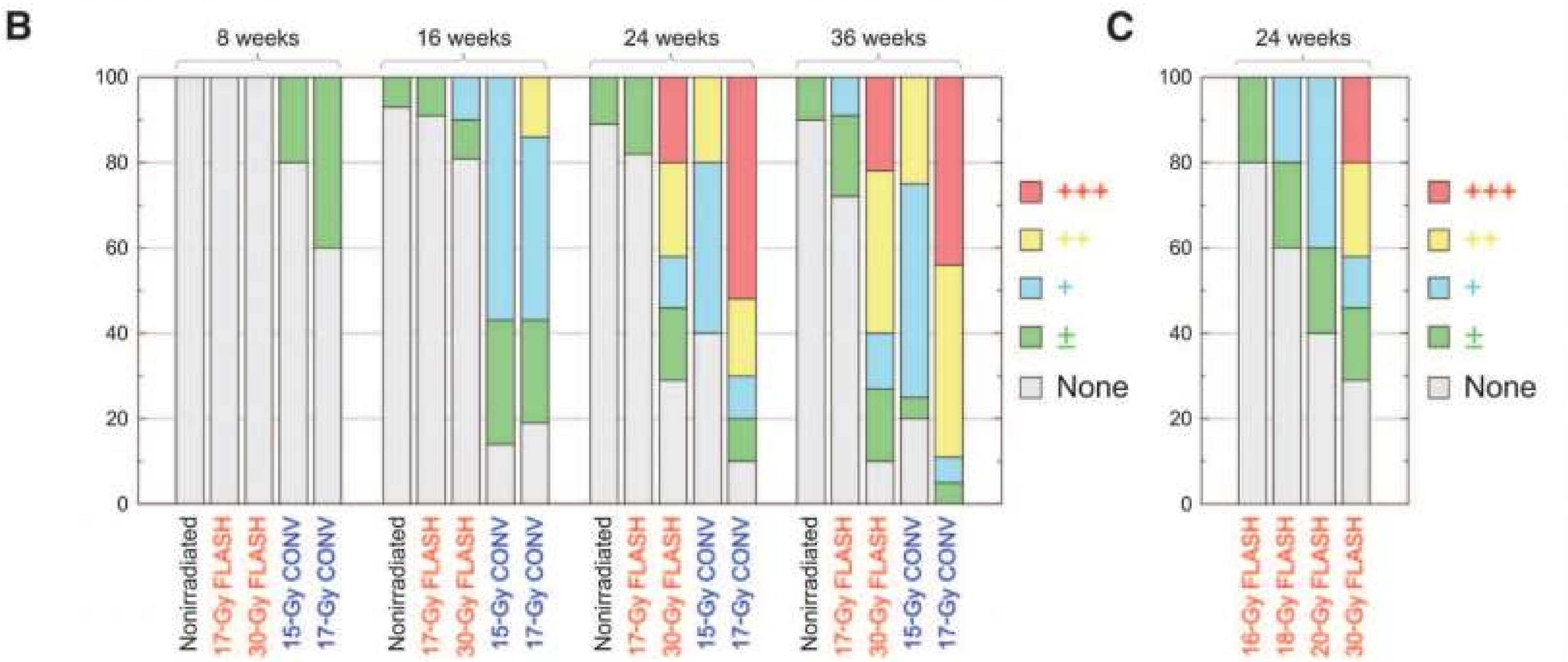
Vincent Favaudon,[1,2*] Laura Caplier,[3†] Virginie Monceau,[4,5‡] Frédéric Pouzoulet,[1,2§] Mano Sayarath,[1,2¶] Charles Fouillade,[1,2] Marie-France Poupon,[1,2‖] Isabel Brito,[6,7] Philippe Hupé,[6,7,8,9] Jean Bourhis,[4,5,10] Janet Hall,[1,2] Jean-Jacques Fontaine,[3] Marie-Catherine Vozenin[4,5,10,11]

In vitro studies suggested that sub-millisecond pulses of radiation elicit less genomic instability than continuous, protracted irradiation at the same total dose. To determine the potential of ultrahigh dose-rate irradiation in radiotherapy, we investigated lung fibrogenesis in C57BL/6J mice exposed either to short pulses (≤500 ms) of radiation delivered at ultrahigh dose rate (≥40 Gy/s, FLASH) or to conventional dose-rate irradiation (≤0.03 Gy/s, CONV) in single doses. The growth of human HBCx-12A and HEp-2 tumor xenografts in nude mice and syngeneic TC-1 Luc$^+$ orthotopic lung tumors in C57BL/6J mice was monitored under similar radiation conditions. CONV (15 Gy) triggered lung fibrosis associated with activation of the TGF-β (transforming growth factor–β) cascade, whereas no complications developed after doses of FLASH below 20 Gy for more than 36 weeks after irradiation. FLASH irradiation also spared normal smooth muscle and epithelial cells from acute radiation-induced apoptosis, which could be reinduced by administration of systemic TNF-α (tumor necrosis factor–α) before irradiation. In contrast, FLASH was as efficient as CONV in the repression of tumor growth. Together, these results suggest that FLASH radiotherapy might allow complete eradication of lung tumors and reduce the occurrence and severity of early and late complications affecting normal tissue.

FLASH: ultra high dose rate RT

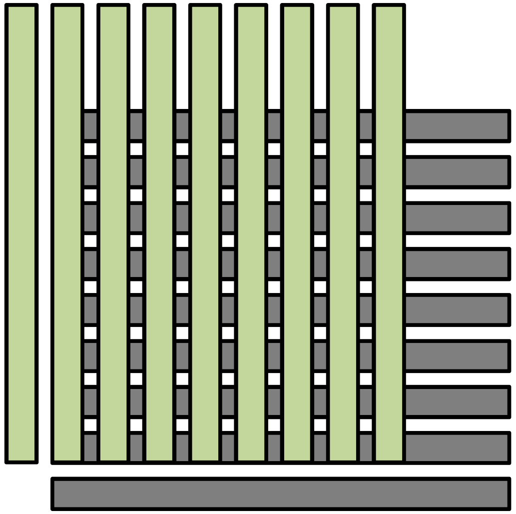


FLASH: ultra high dose rate RT



Lung fibrosis of irradiated mice.

Measure the beam data with Cross-mini



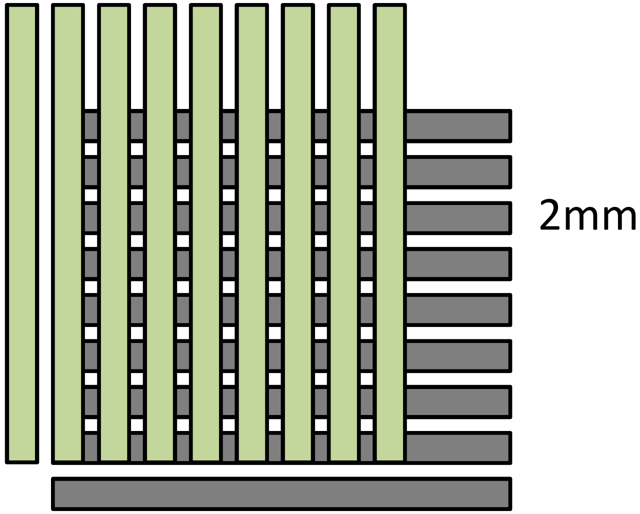
1-Dimension multi channel detector(101+101)

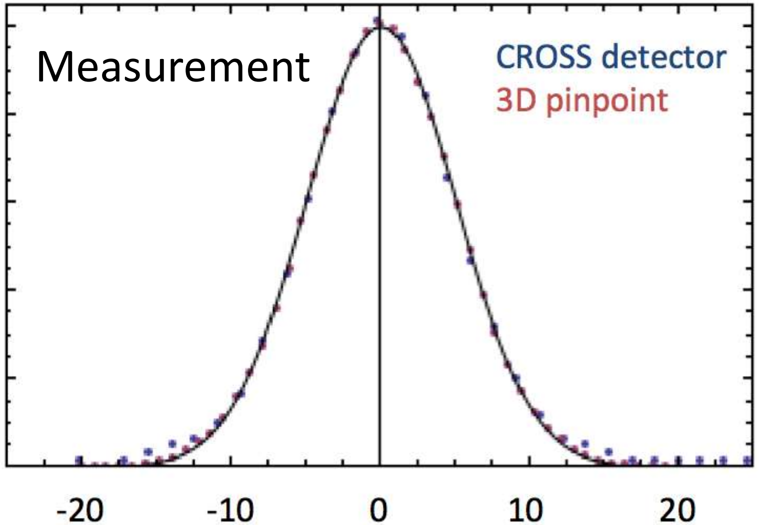
2 mm × 200 mm Parallel plate ionization chamber

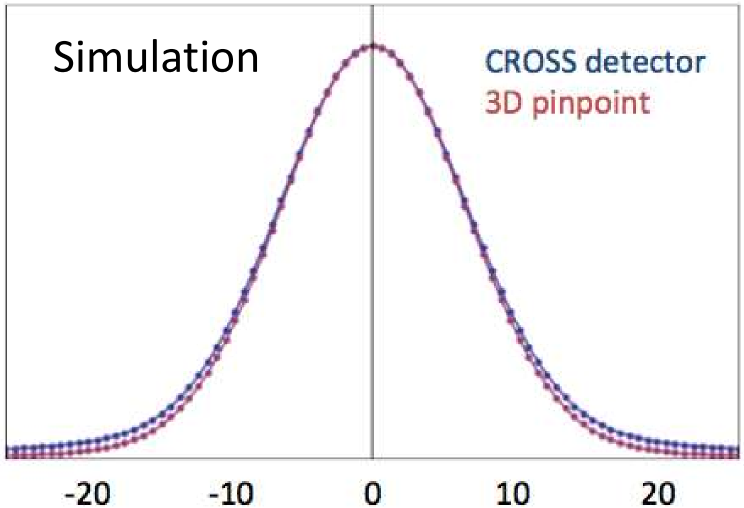
- Shorten the measurement time
- Robust to the beam positioning Error
- !!Need to Convert the measurement result

  (Because of the detector shape)

Measure the beam data with Cross-mini







Measure the beam data with Cross-mini

$$\phi(x,y) = (1-w)\left(\frac{1}{\sqrt{2\pi}\sigma_{1,x}}Exp[-2\sigma_{1,x}{}^2]\cdot\frac{1}{\sqrt{2\pi}\sigma_{1,y}}Exp[-2\sigma_{1,y}{}^2]\right) + w\left(\frac{1}{\sqrt{2\pi}\sigma_{2,x}}Exp[-2\sigma_{2,x}{}^2]\cdot\frac{1}{\sqrt{2\pi}\sigma_{2,y}}Exp[-2\sigma_{2,y}{}^2]\right)$$

$$\phi_{3DPP}(x) = \phi(x,y=0) = (1-w)\left(\frac{1}{\sqrt{2\pi}\sigma_{1,x}}Exp[-2\sigma_{1,x}{}^2]\cdot\frac{1}{\sqrt{2\pi}\sigma_{1,y}}\right) + w\left(\frac{1}{\sqrt{2\pi}\sigma_{2,x}}Exp[-2\sigma_{2,x}{}^2]\cdot\frac{1}{\sqrt{2\pi}\sigma_{2,y}}\right)$$

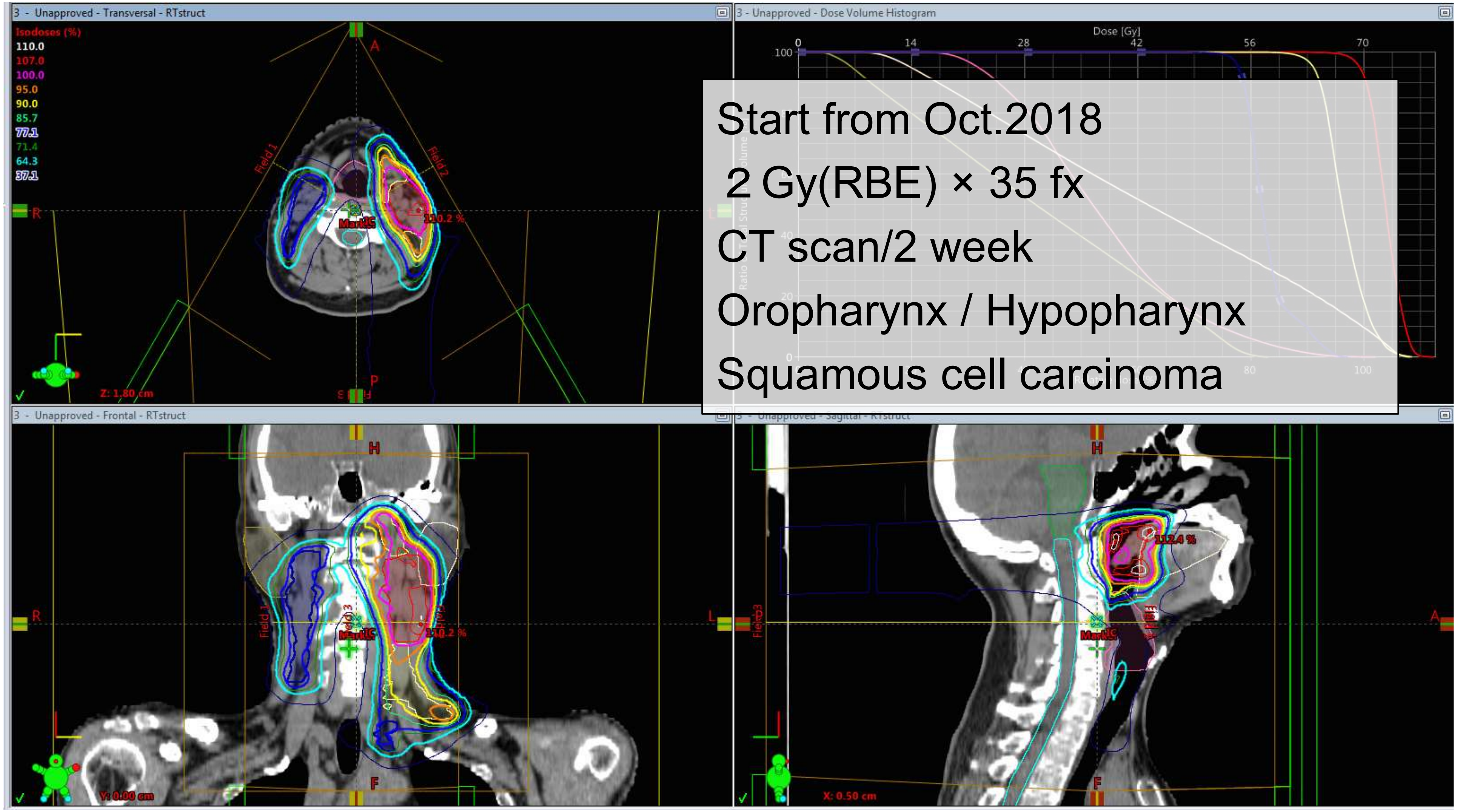
$$\phi_{Cross}(x) = \int\phi(x,y)dy = (1-w)\left(\frac{1}{\sqrt{2\pi}\sigma_{1,x}}Exp[-2\sigma_{1,x}{}^2]\right) + w\left(\frac{1}{\sqrt{2\pi}\sigma_{2,x}}Exp[-2\sigma_{2,x}{}^2]\right)$$

$$= \left((1-w)\left(\frac{1}{\sqrt{2\pi}\sigma_{1,x}}Exp[-2\sigma_{1,x}{}^2]\cdot\frac{1}{\sqrt{2\pi}\sigma_{1,y}}\right) + \boxed{\frac{\sqrt{2\pi}\sigma_{2,y}}{\sqrt{2\pi}\sigma_{1,y}}}w\left(\frac{1}{\sqrt{2\pi}\sigma_{2,x}}Exp[-2\sigma_{2,x}{}^2]\cdot\frac{1}{\sqrt{2\pi}\sigma_{2,y}}\right)\right)\sqrt{2\pi}\sigma_{1,y}$$

- Shorten the measurement time
- Robust to the beam positioning Error
- !!Need to Convert the measurement result

  (Because of the detector shape)

IMPT for Head & Neck



Start from Oct.2018

2 Gy(RBE) × 35 fx

CT scan/2 week

Oropharynx / Hypopharynx

Squamous cell carcinoma

H&N IMPT：QA for multi-center study

Materials

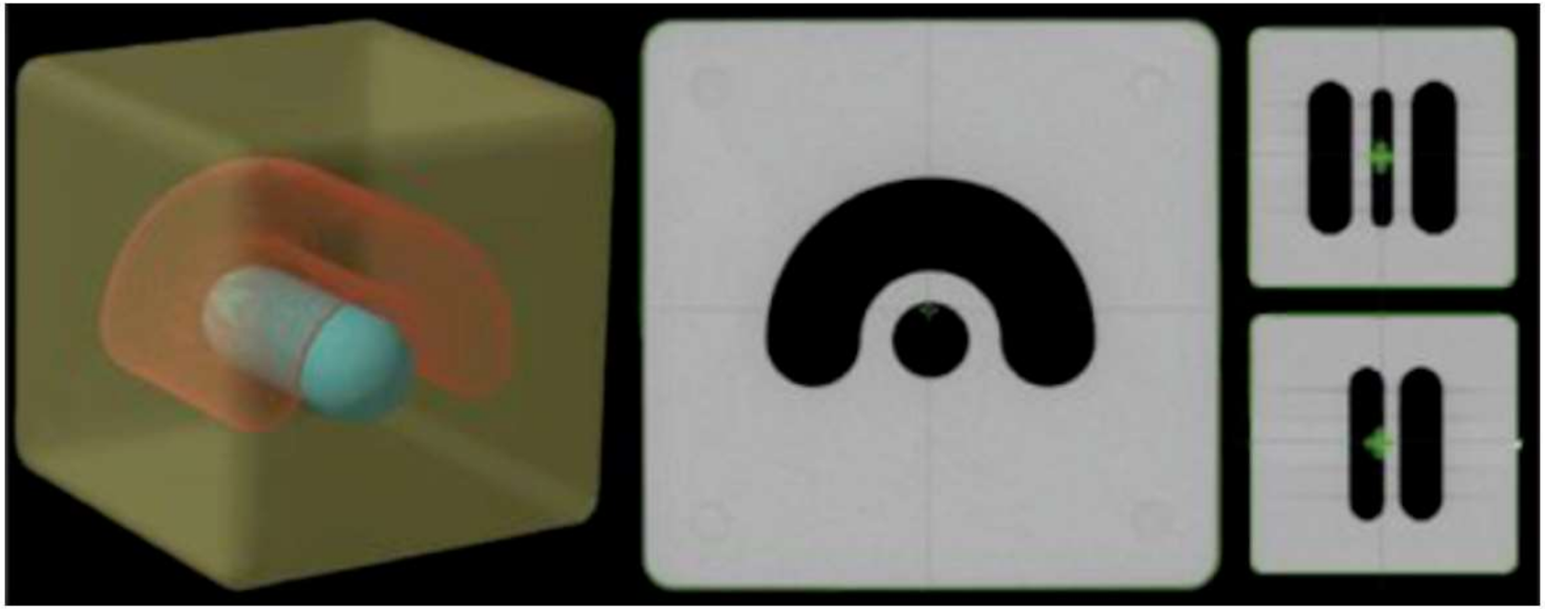
・IMRT Phantom of JCOG(Japan clinical oncology group)

・Film・・・Gafchromic Film(EBT3)

・Chamber・・・PTW30013

・Electrometer・・・UNIDOS webline Universal dosemeter

・Analyze software・・・Simple IMRT Analysis



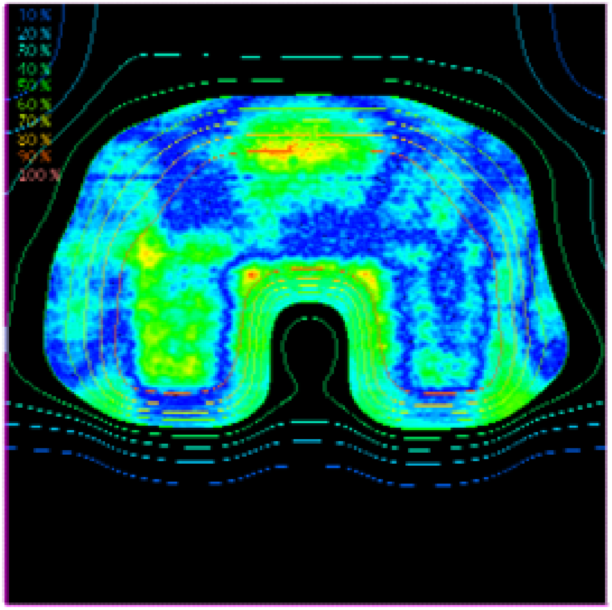
H&N IMPT：QA for multi-center study

Dose@Iso-center

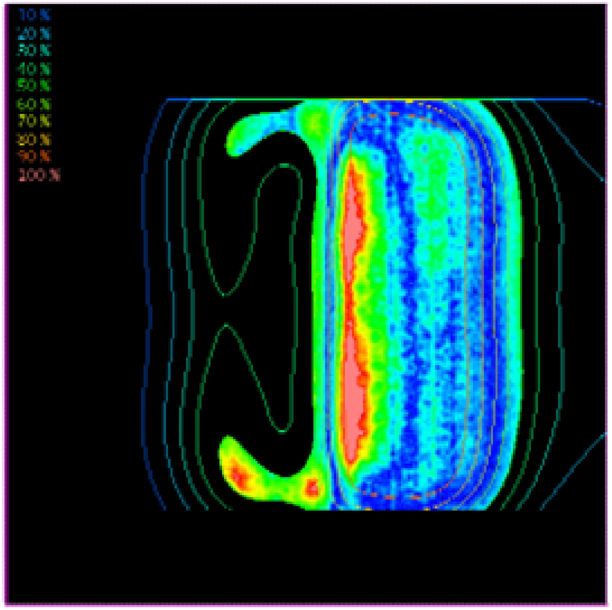
TPS: 1.875 Gy　Measure：1.887 Gy　Difference：0.7%

Dose Distribution γ-pass(3mm/5%)

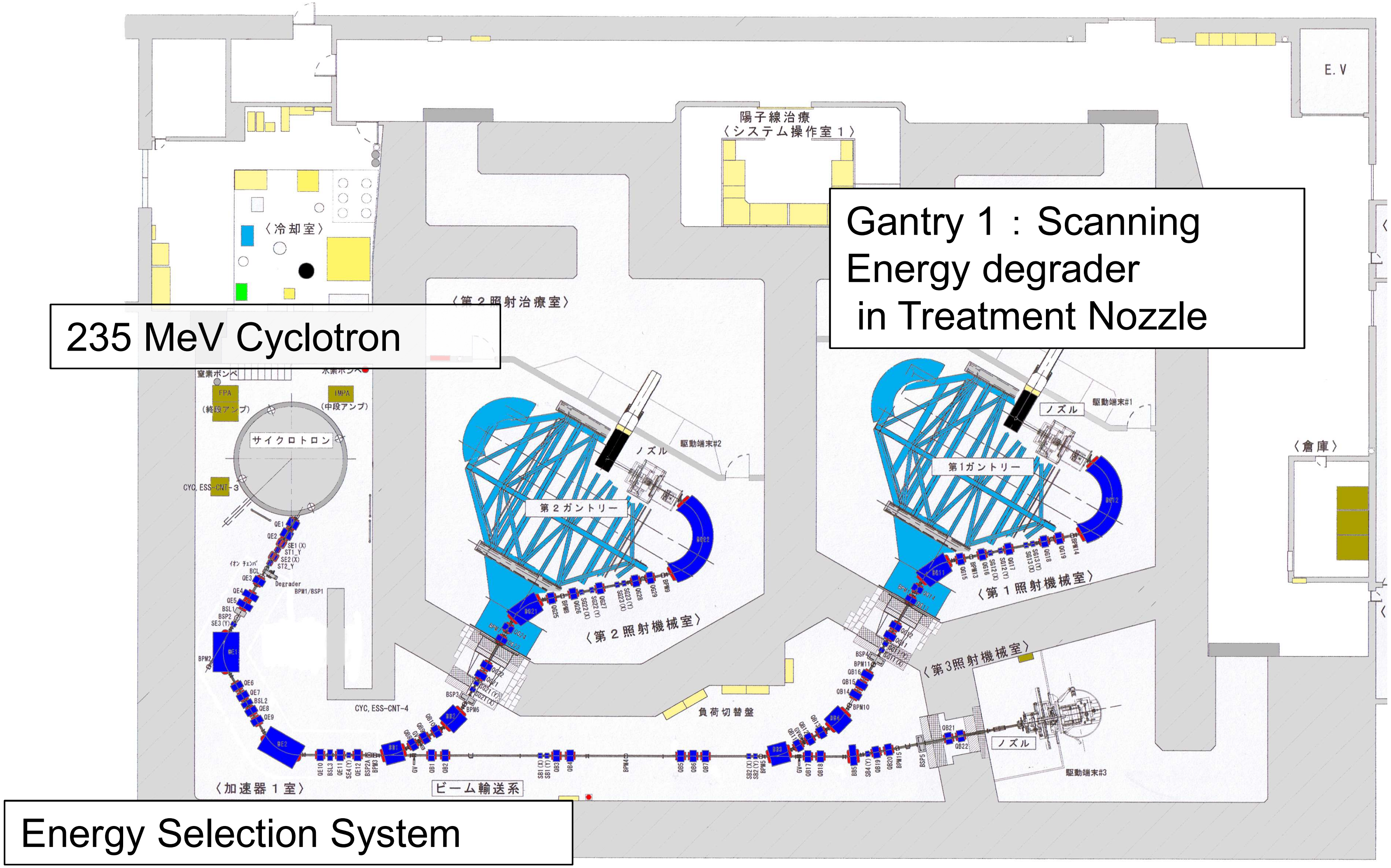
Axial：100%



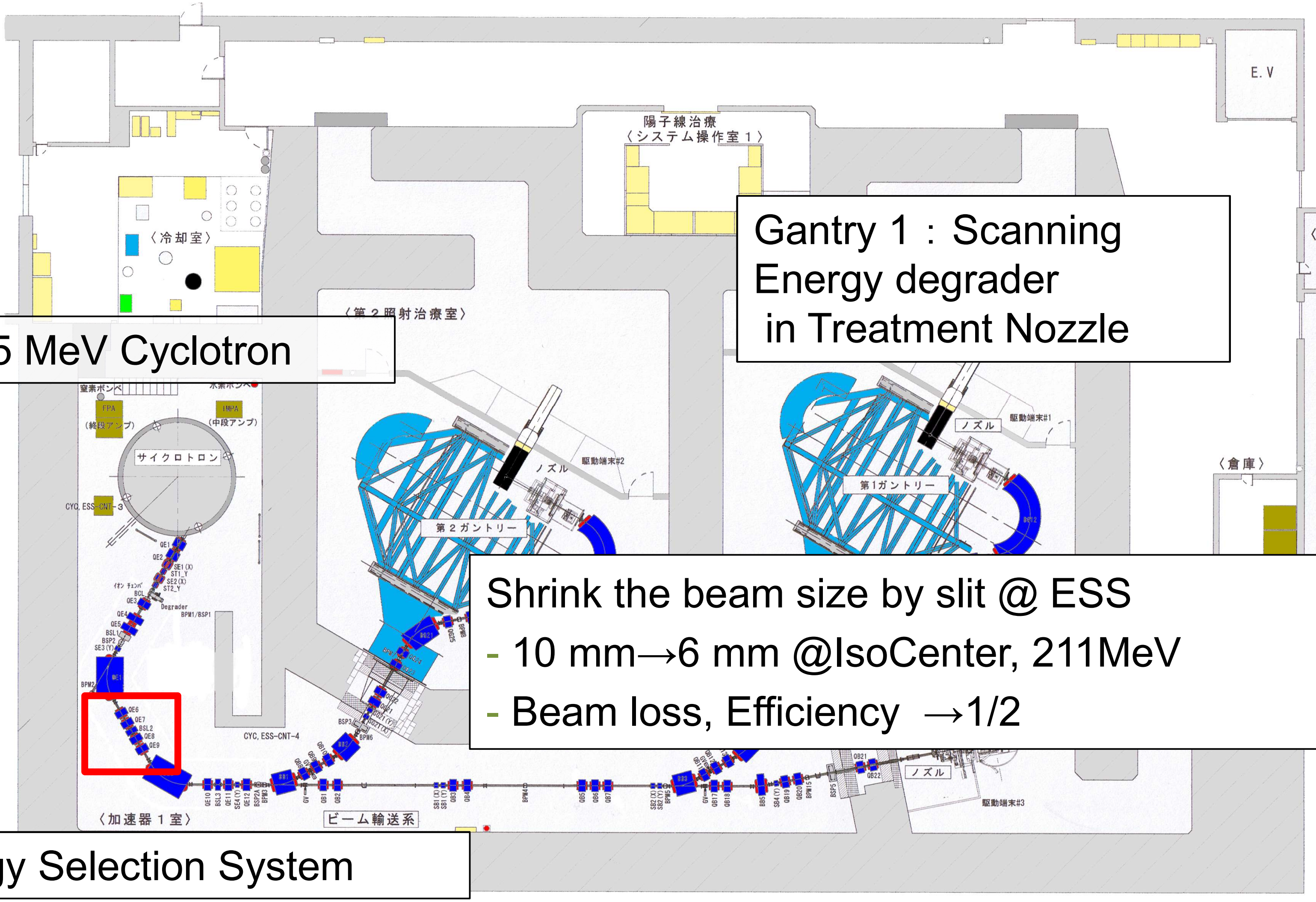
Sagital：96.9 %



Proton Therapy System (Scanning)



Shrink the beam size



235 MeV Cyclotron

Gantry 1 : Scanning
Energy degrader
in Treatment Nozzle

Shrink the beam size by slit @ ESS
- 10 mm→6 mm @IsoCenter, 211MeV
- Beam loss, Efficiency →1/2

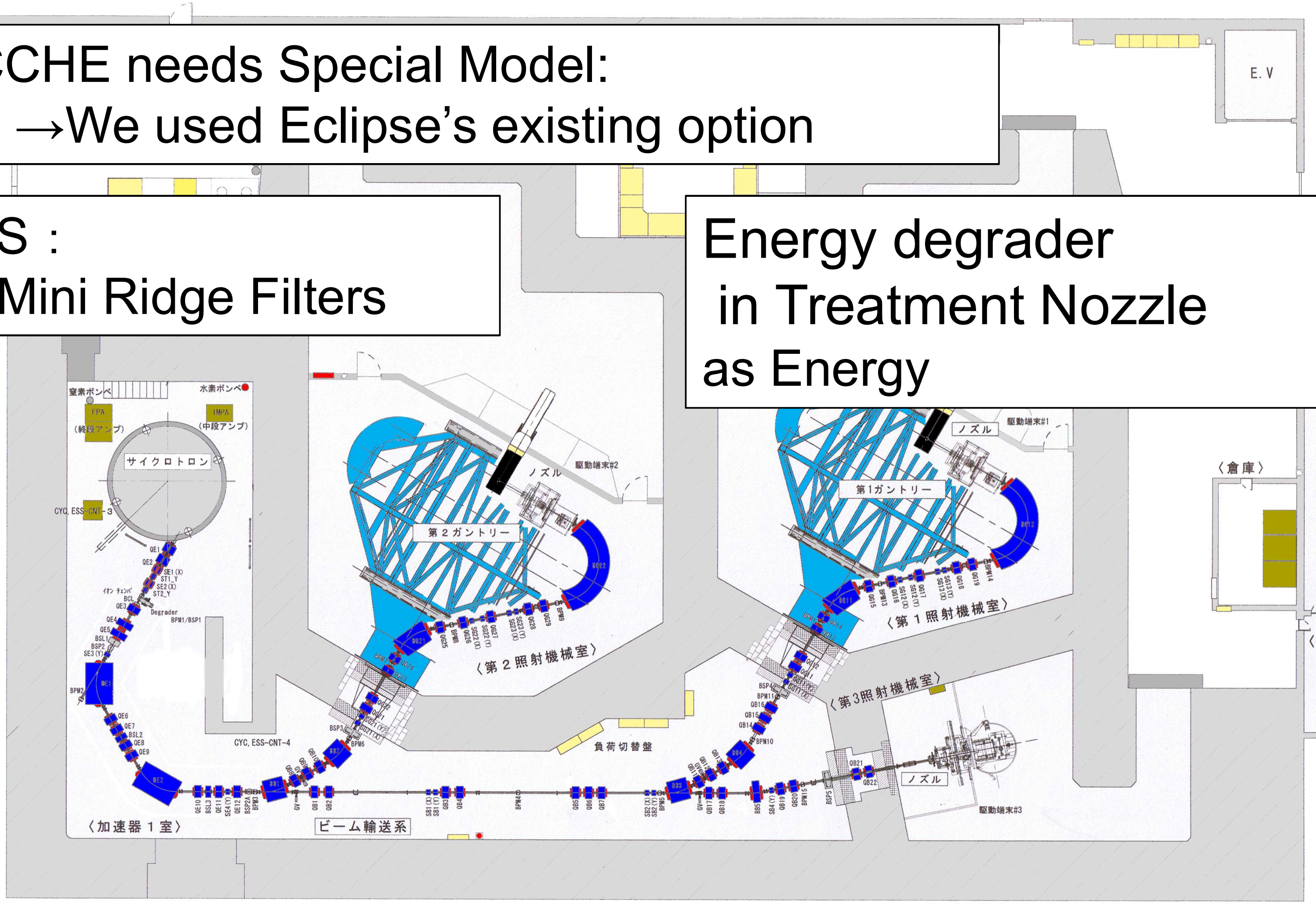
Energy Selection System

Change the TPS：Eclipse

NCCHE needs Special Model:
→We used Eclipse's existing option

ESS：
as Mini Ridge Filters

Energy degrader
in Treatment Nozzle
as Energy



Outlines

Introduction of Our Unique Approaches

- About National Cancer Center Hospital East
- Works to Realize Intensity Modulation Proton Therapy
- Use of Cross-mini: Chamber Array
- Independent Dose Calculation for Patient QA

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