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Clinical Commissioning

(Pencil Beam Scanning System)

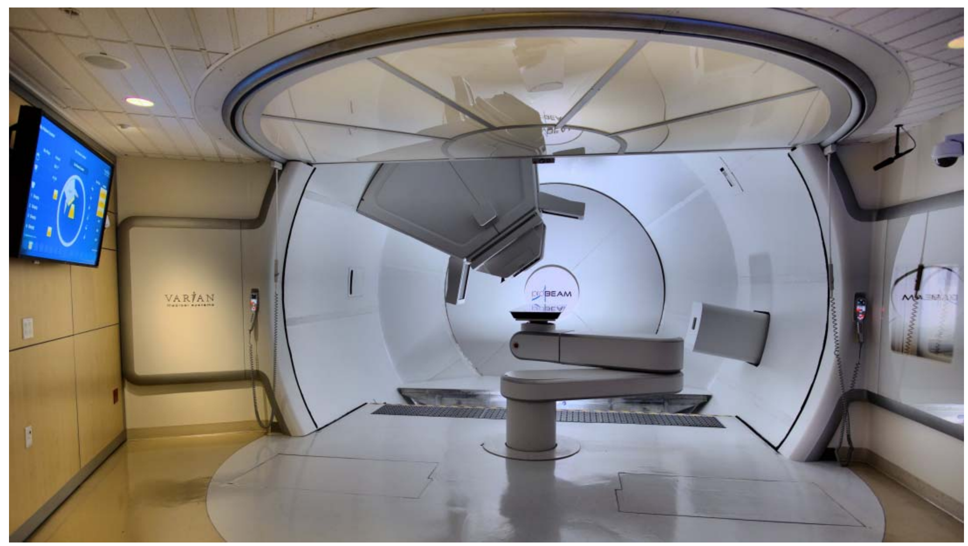
Lei Dong, Ph.D.

Scripps Proton Therapy Center

San Diego, CA

Welcome to San Diego

- Scripps has ~14,000 employees, five hospitals and over 2000 affiliated physicians in San Diego area
- Scripps collaborates with UCSD and Rady Children's hospitals for the proton therapy program
- The home of Varian's first ProBeam™ system in US
- Scripps treated first patient on Feb. 12, 2014



Disclosure: Varian customer

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Clinical Commissioning

- **General definition of clinical commissioning**
  - **Preparation to treat the first patient**
    - **Workflow**
  - **Immediately after the acceptance test and possession of beam time**
- **General task categories**
  - **Establish clinical protocols**
    - **immobilization, simulation, planning, evaluation, imaging, documentation etc.**
  - **Beam calibration protocol**
  - ***TPS commissioning**
  - **Risk assessment and machine QA**

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Commissioning Goals

- **Commissioning is time sensitive and financially liable**
  - **Save money on salaries and bank loans**
- **Prepare for clinical operation**
  - **HR**
  - **Regulation**
  - **Business contracts and licensing agreements**
  - **Marketing**
  - **IT**
  - **Equipment commissioning**
  - **Training**

Timeline

- **Prior to room handover**
  - Any preparation that does not need beam time
  - Negotiate beam time for commissioning
- **After room handover**
  - Beam calibration*
  - External peer review
  - Beam data acquisition
  - TPS validation measurements
  - End-to-end tests
  - User training

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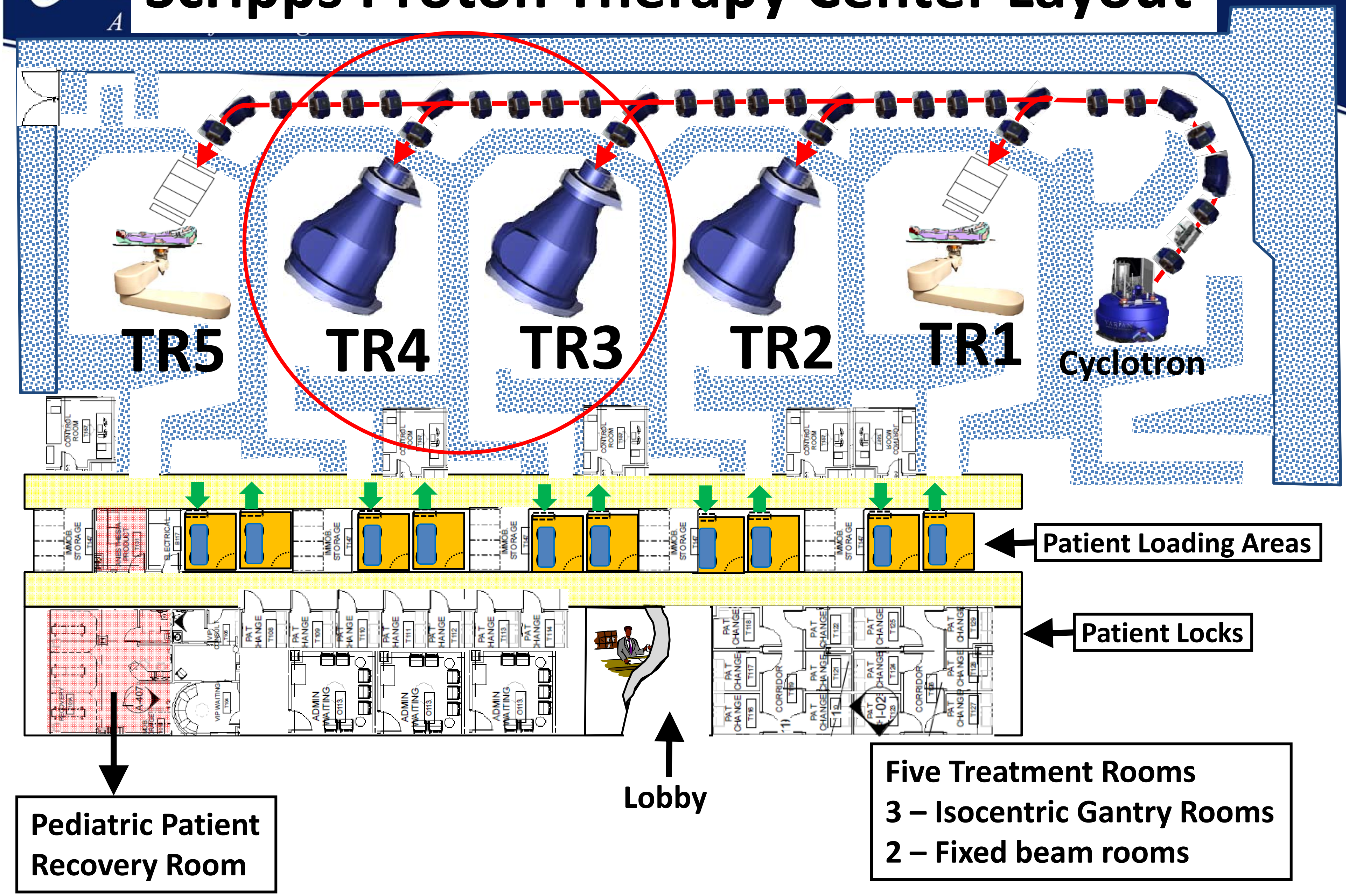
Learn about your machine and environment!

Vendor training required

Scripps Proton Therapy Center Layout



Five Treatment Rooms
3 – Isocentric Gantry Rooms
2 – Fixed beam rooms

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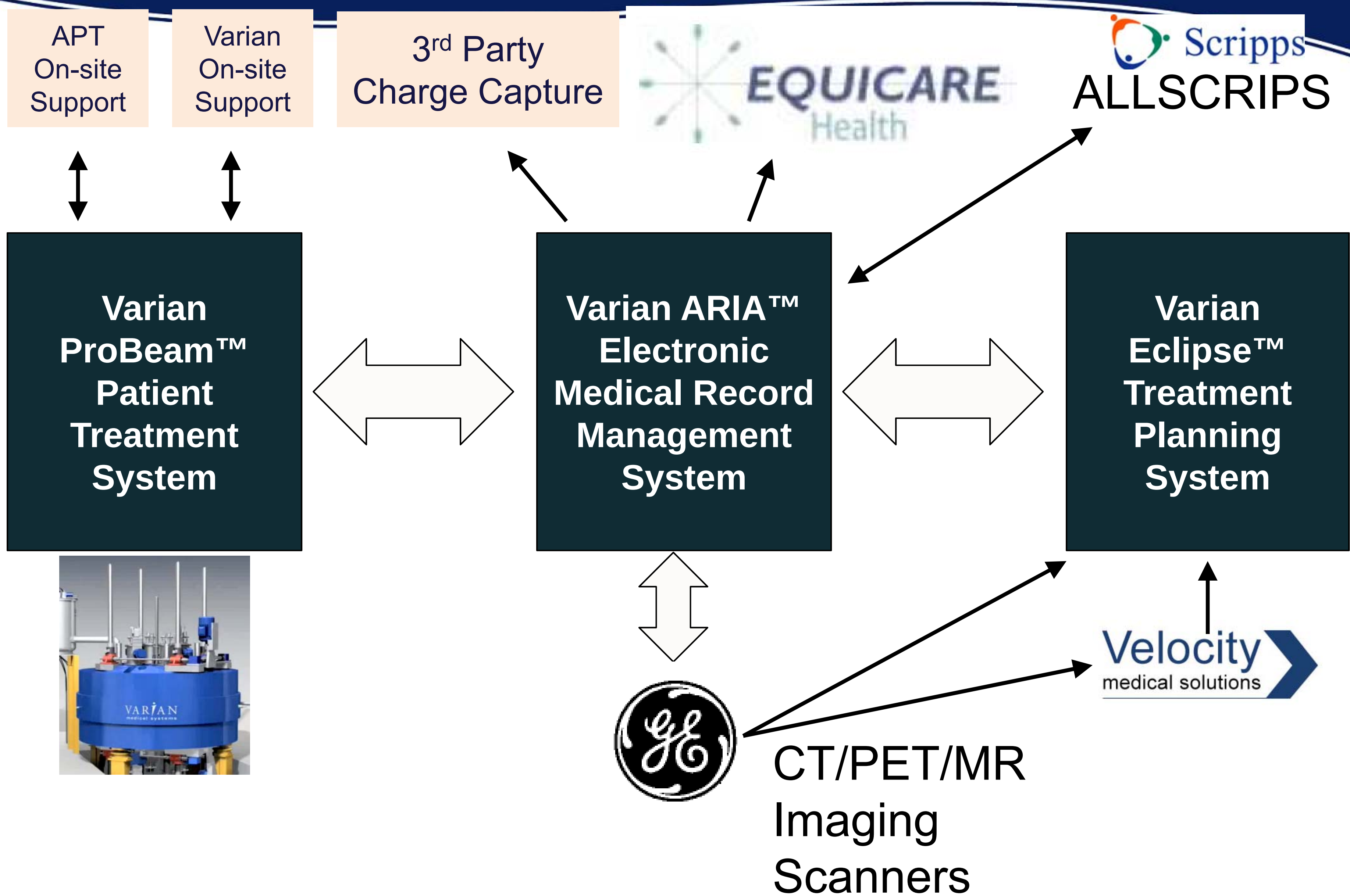
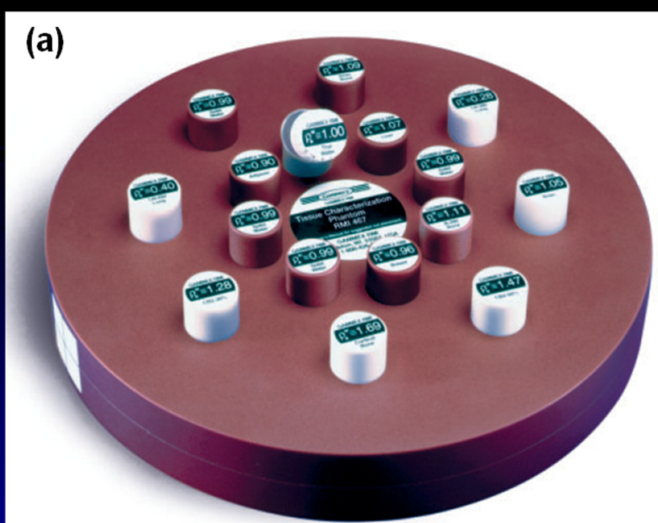
SPTC Site-Configuration



CT HU Calibration

Phantom Composition is Different from Human Tissue!



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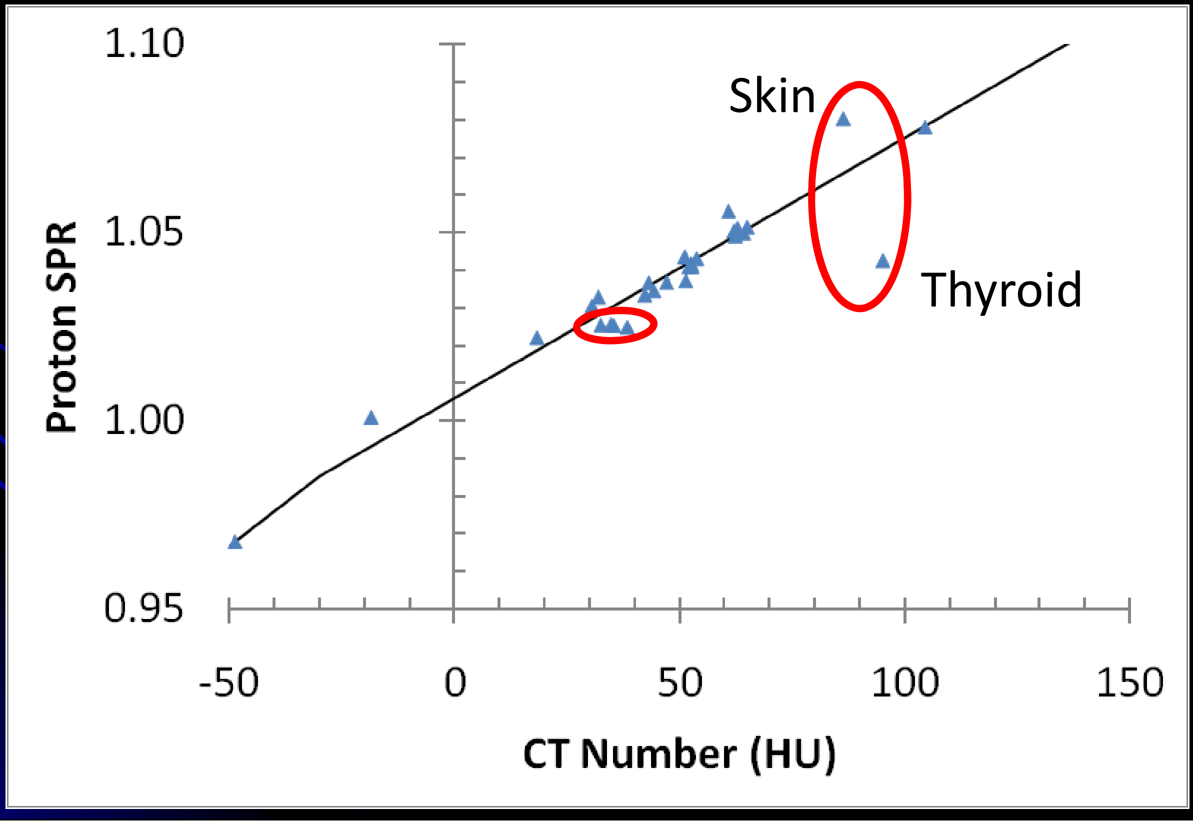
Dong

CT number to Proton Stopping Power

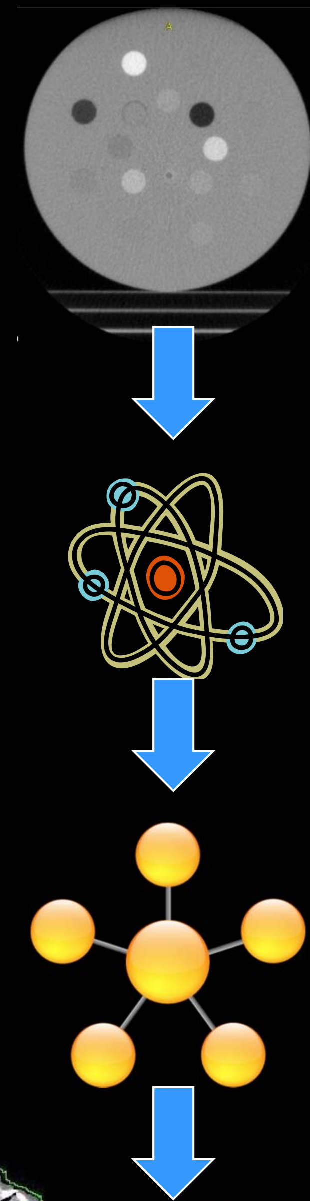
- Degeneracy problem
  - HU (ρ_1, Z_1) = HU (ρ_2, Z_2)
  - SPR$(\rho_1, Z_1) \neq$ SPR(ρ_2, Z_2)

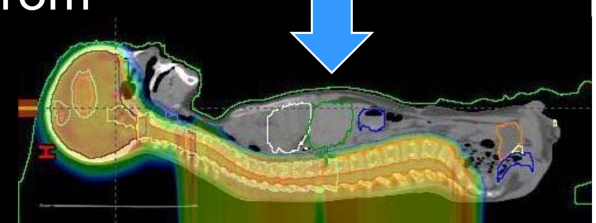


Dong

Stoichiometric Tissue Model

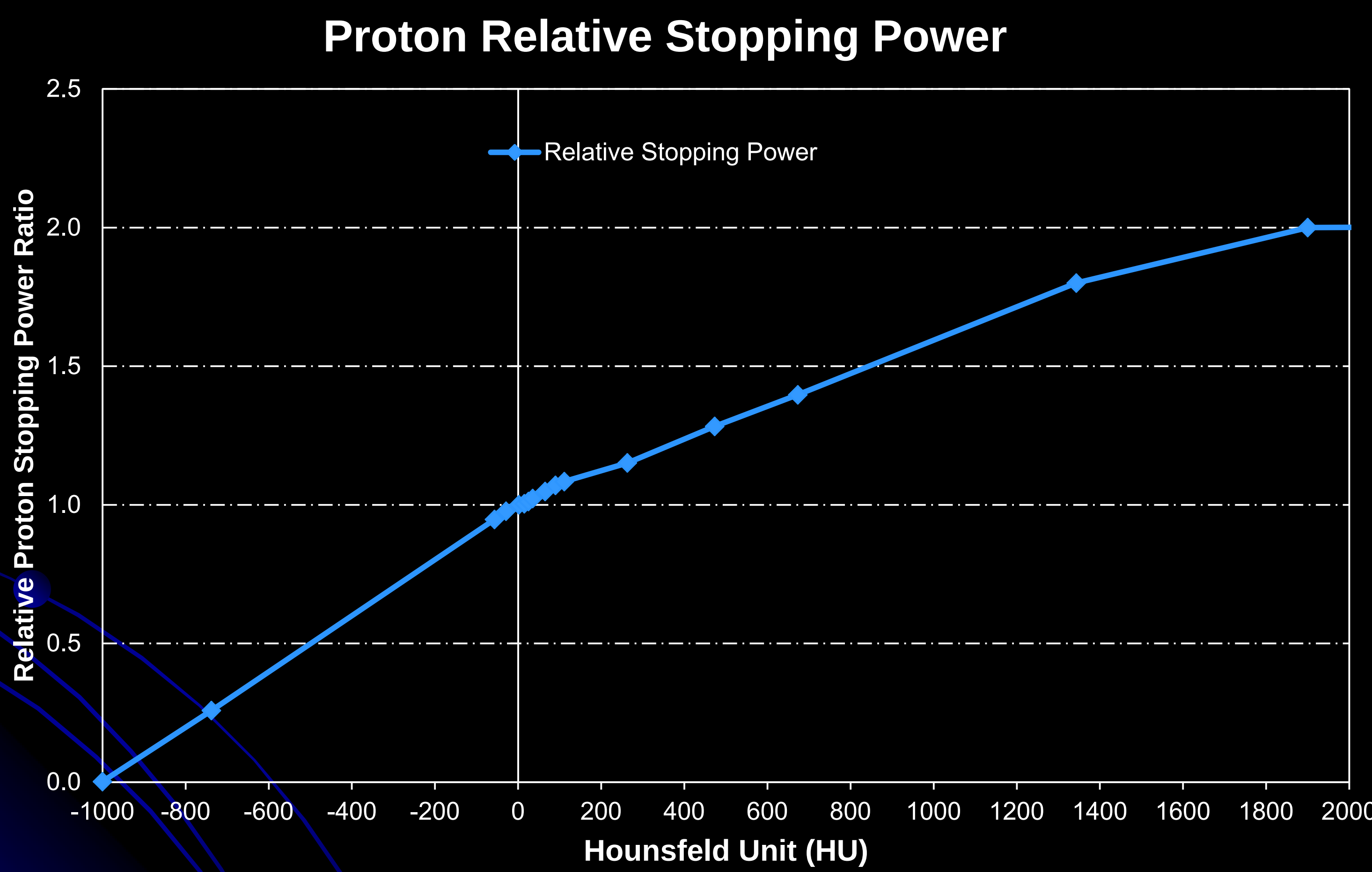
- The calibration curve is determined based on calculated CT# and SPR of human body tissues
  - **CT#**: CT scanner specific parameters determined after scanning a few tissue substitutes
  - SPR: calculated based on the Bethe-Bloch equation
  - Both calculations need human tissue compositions information
    - Based on the population average values from ICRP 23, ICRU 44, etc.





Schneider, U., E. Pedroni, and A. Lomax, Physics in Medicine and Biology, 1996. 41(1): p. 111-124.

HU to Stopping Power Ratio



GE Optima CT580/Scripps

Additional Considerations

- **Extended CT range**
  - Allow visualization of high density materials
  - Allow density override
  - Allow importing of other CT studies from different institutions
- **Special material table**
  - Known materials and their SPRs
  - Dealing with metal artifacts
- Documentation of CT recon parameters

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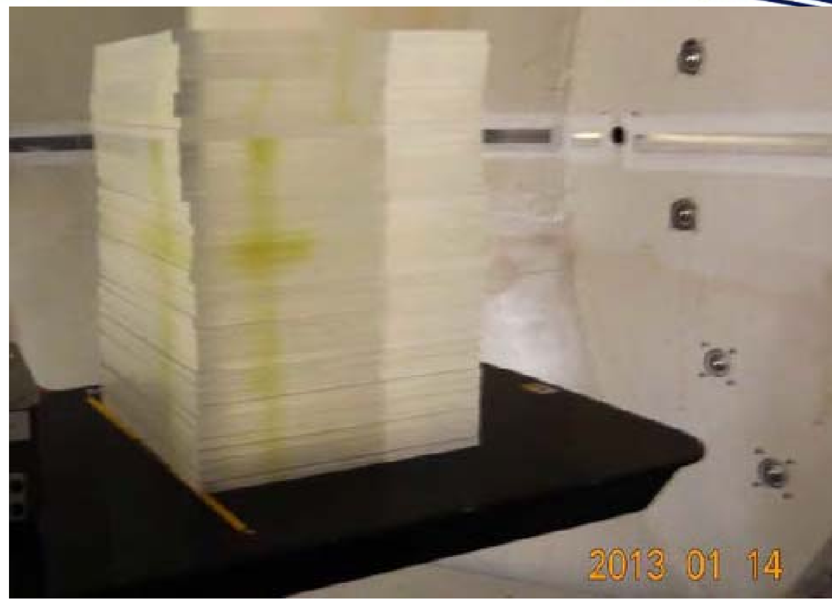
VARIAN PT SC Cyclotron Key Data
(Engineering Goals)

2nd Workshop on Hadron Beam Therapy of Cancer
Erice, Sicily, May 2011

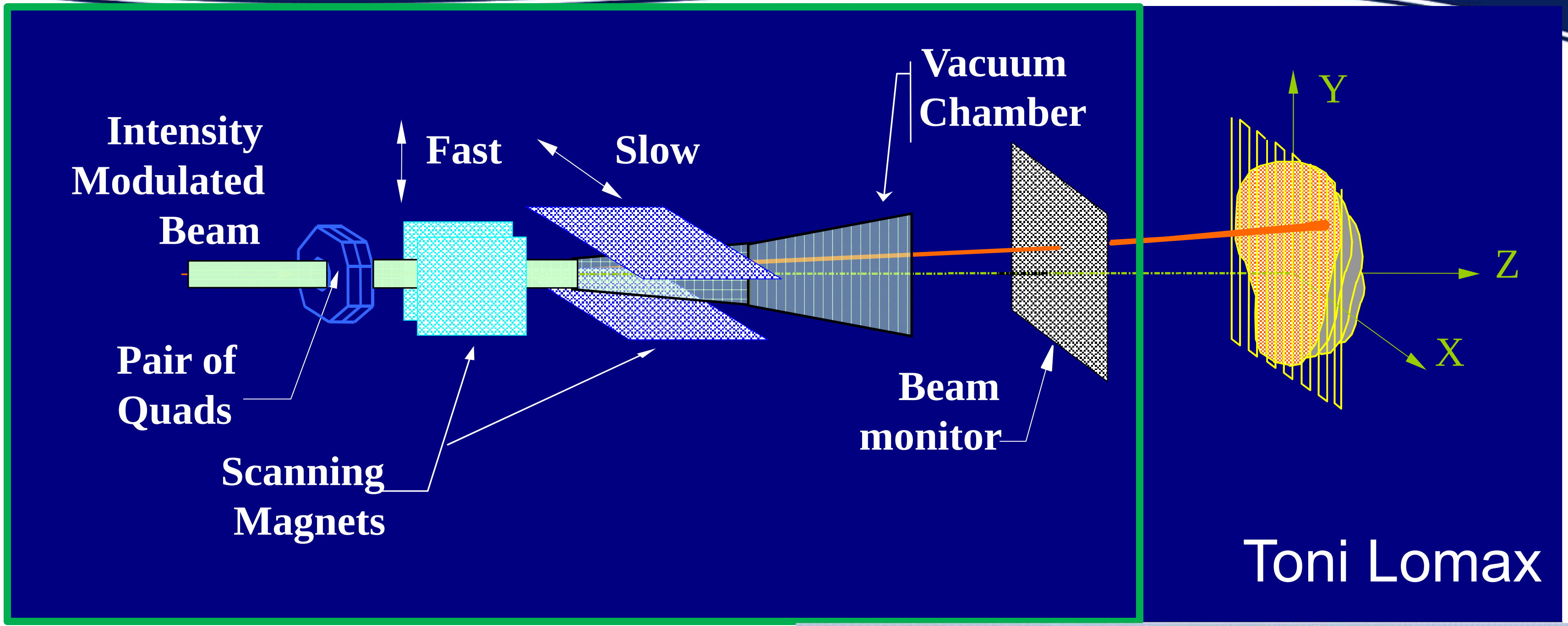
➢ Beam	- Energy	250 MeV
	- Extracted current (max)	800 nA
	- Emittance of extracted beam	< 3 / 5 π mm mrad (2σ)
	- Momentum spread $\Delta p/p$	±0.04% (i.e. 200keV @ 250MeV)
	- Number of turns	650
	- Extraction efficiency (multi-turn extraction mode)	~80%
	- Dynamic range for intensity modulation	1:800
	- Fast intensity modulation	via electrostatic deflector, >10% in 100 µs
➢ Iron Yoke	- Outer diameter	3.1 m
	- Height	1.6 m
	- Weight	<90 t
➢ SC Magnet	- Stored energy	2.5 MJ
	- Central field	2.4 T
	- Max. field at the coil	<4 T
	- Operating current	160 A
	- Rated power of cryocoolers	40 kW
➢ RF System	- Frequency	72.8 MHz (2nd harmonic)
	- Voltage source to puller / @ extraction radius	80 kV / 130 kV
	- RF power	≤115 kW

Facility Room Shielding Survey

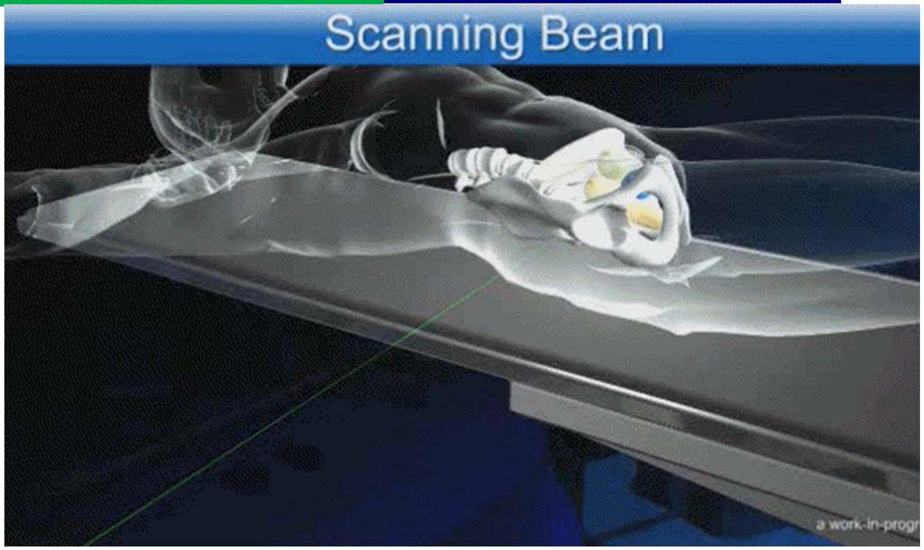
- Very high dose rate!



Pencil beam scanning nozzle



- No patient specific hardware
- Variable intensity and energy for each ray line
- Large treatment field (40x30) cm^2
- Inverse planning



Commissioning PBS system for Eclipse

- Measurements
  - Single pencil beam IDD in water (all energies)
  - Single pencil beam in-air fluence profiles at a few distances (at least three)
  - Normalization factor (output) at a fixed depth (all energies)
  - Single pencil beam in-air fluence for each range shifter

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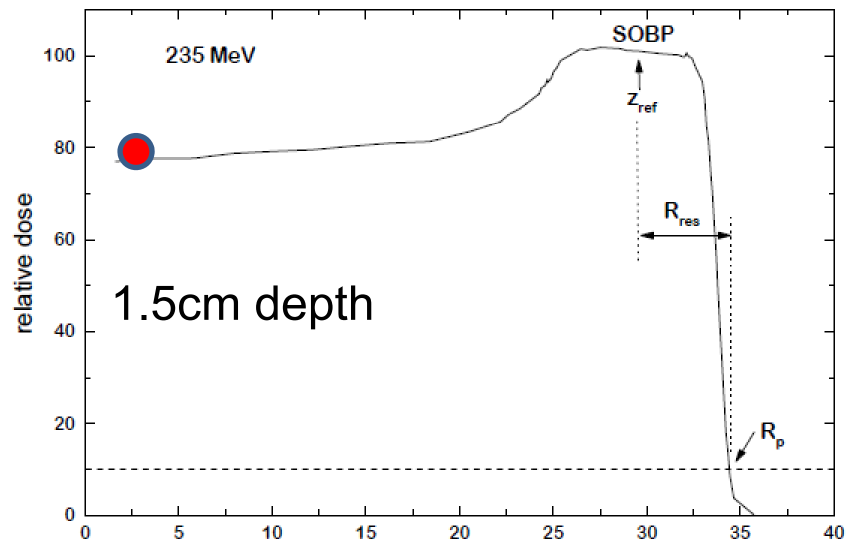
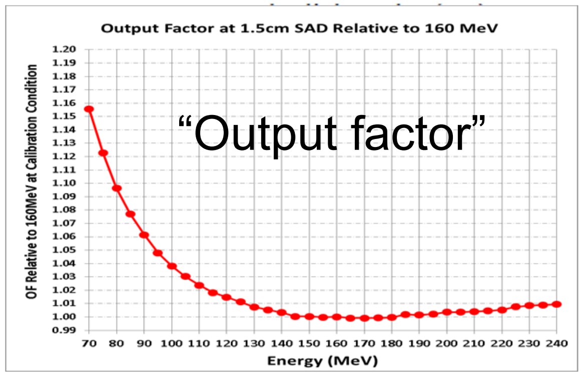
Dose Calibration for PBS

Calibrating the PBS system

- Goal: establish the dose-MU relationship
  - IAEA TRS 398 protocol
    - Plateau region
      - Less uncertainties Dwq
      - 160 MeV
      - Uniform spot pattern
  - Energy Output Factors
  - Normalized IDD Curves
- Cross-verify at SOBP





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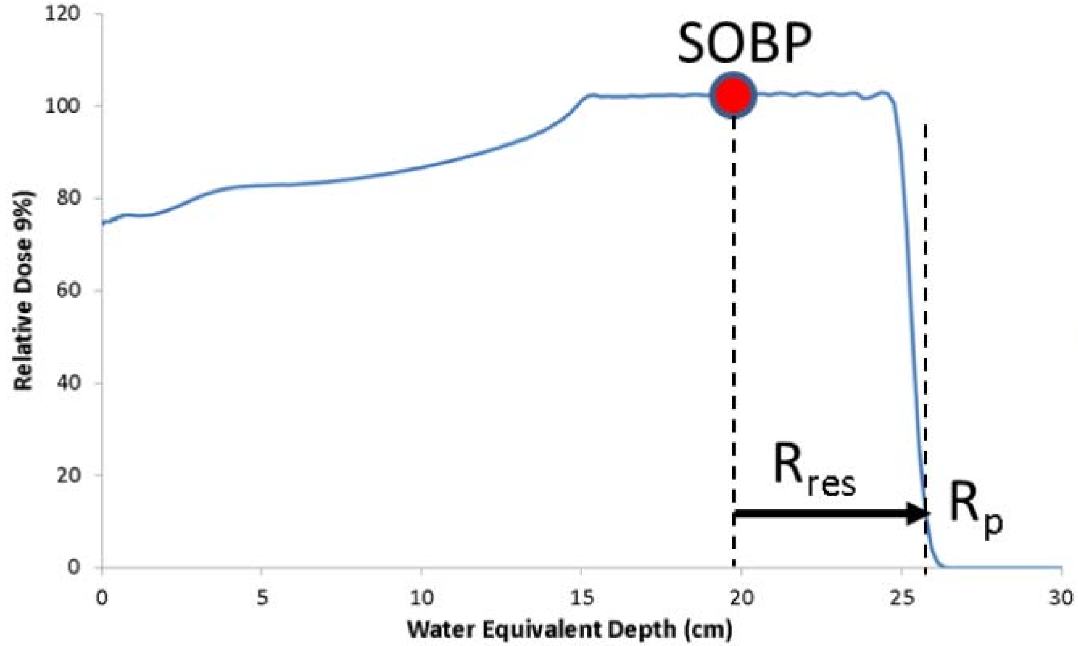
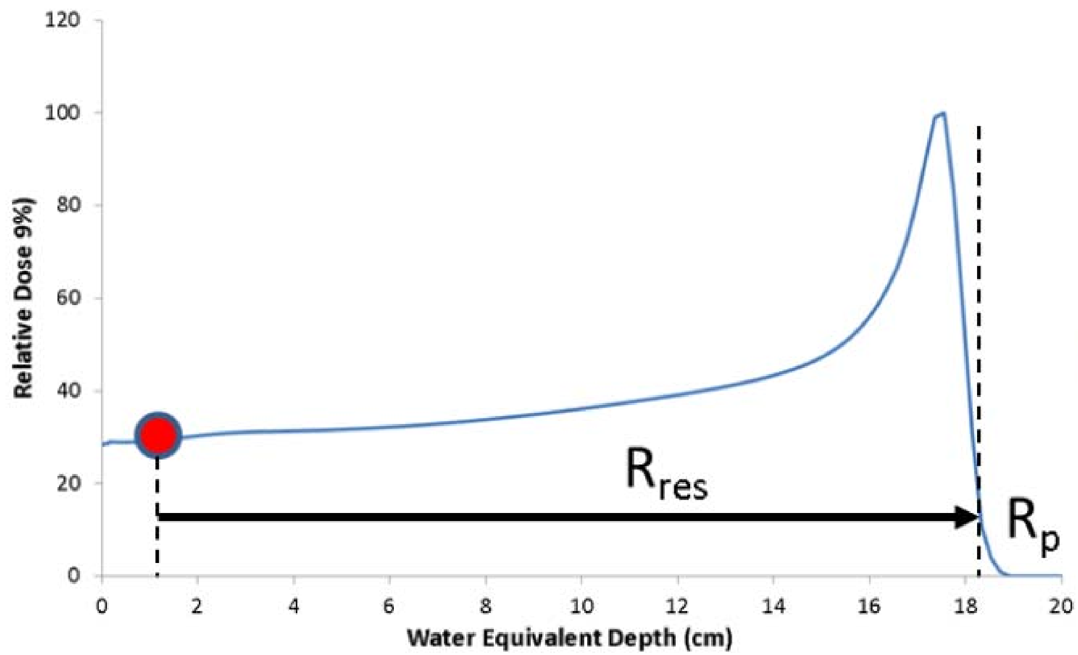
(a) Calibration at Mid SOBP (good for machines with built-in SOBP capabilities)



(a)

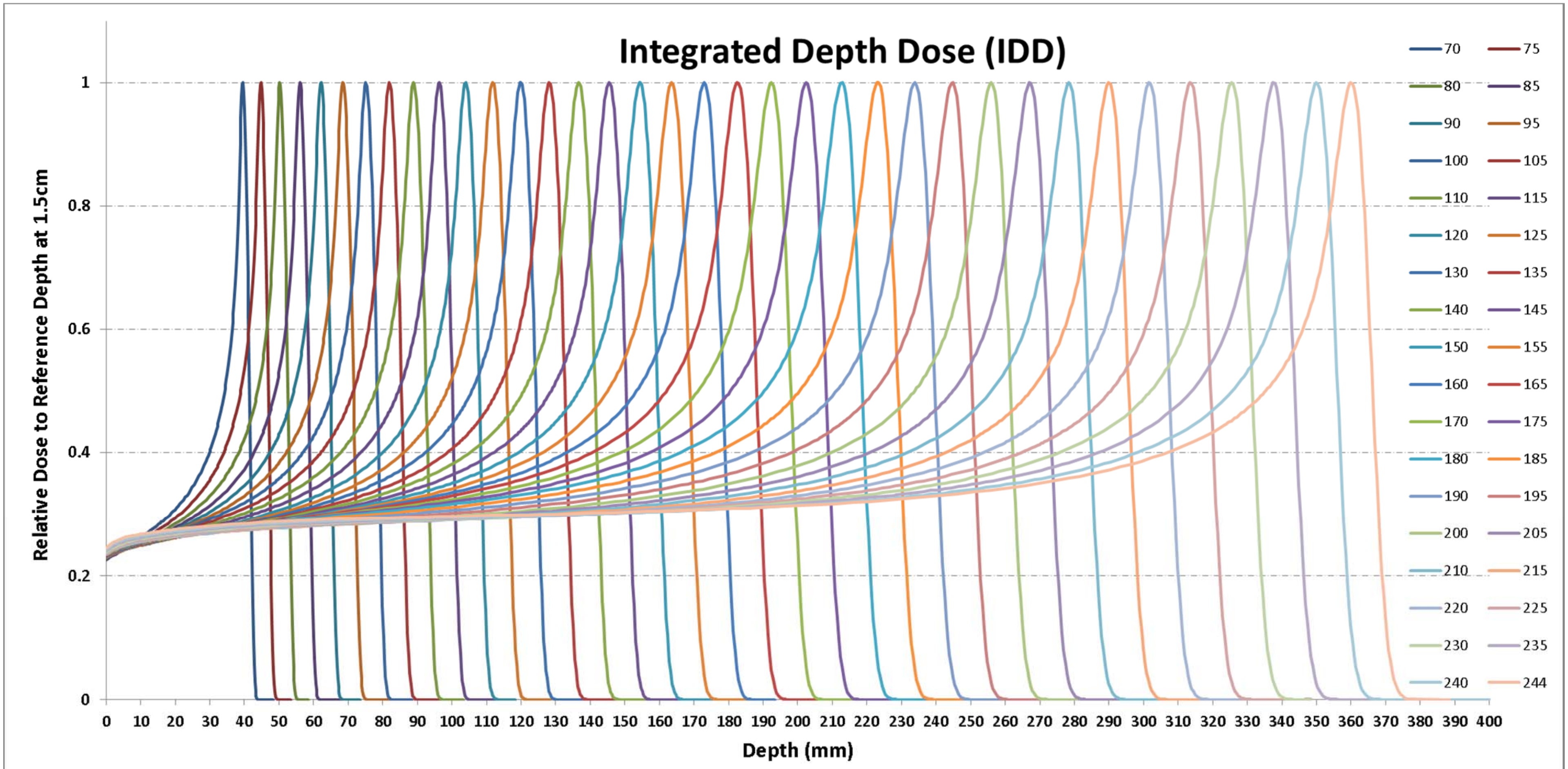
(b) Calibration at entrance region

For single energy planar irradiation (PBS)



(b)

What is the depth to calibrate?



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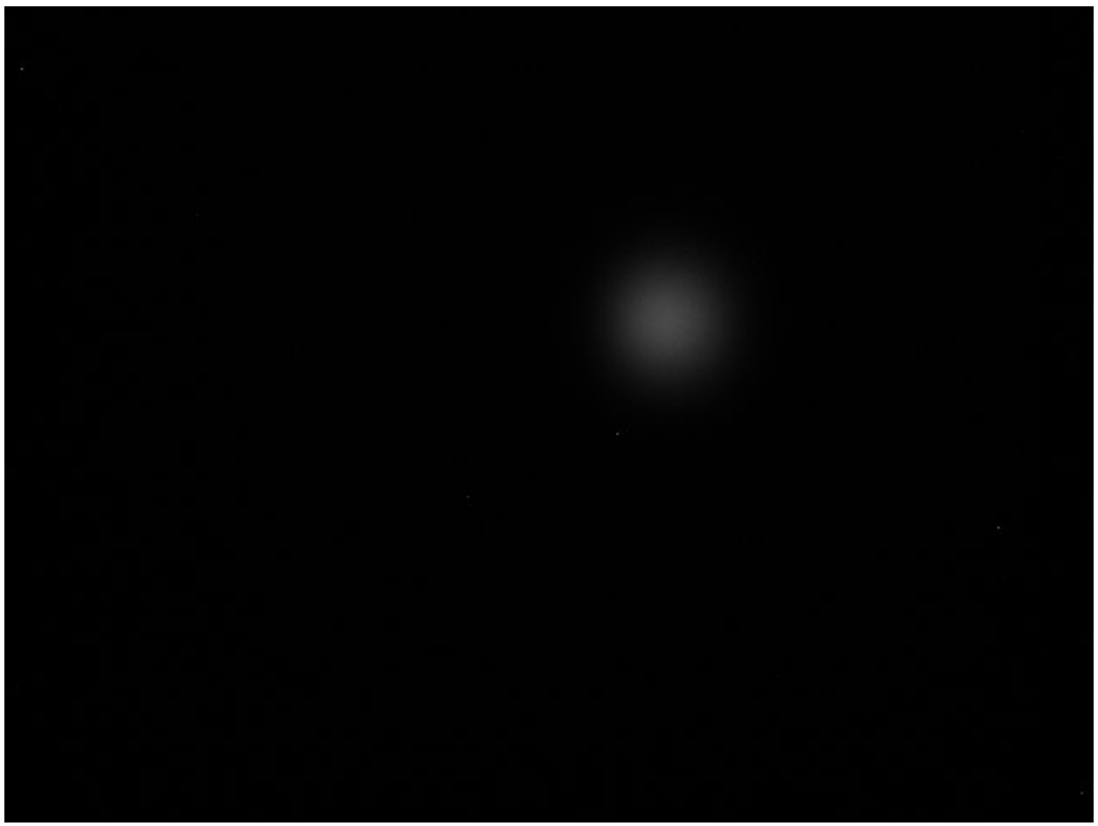
PBS Calibration Pattern

Single Energy: 160 MeV

Depth: 1.5cm SAD



Correction for recombination:
Pulsed scanned?
Pulsed?
Continuous?

"Avg Dose Rate"
60k MU/min

Instantaneous DR
~ 10Gy/s

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Peer Review

- External review by a physicist
  - Bring independent chamber and electrometer
- IROC TLD measurements (at center of SOBP)
  - TR4: 1.00
  - TR3: 0.99
  - TR2: 1.00

Institution:	Scripps Proton Therapy Center, S
RTF Number:	4813
Person irradiating dosimeters:	Anthony E. Mascia
Radiation Machine:	IBA Cyclotron - Scattered (TR4)
Distance from source to reference point:	227.0 cm

Major Measurement Equipment

- 3D Water Phantom - thin window (PTW)
  - Commissioning

- 2D imaging system
  - Commissioning & Monthly QA
  - (spot profile and position)

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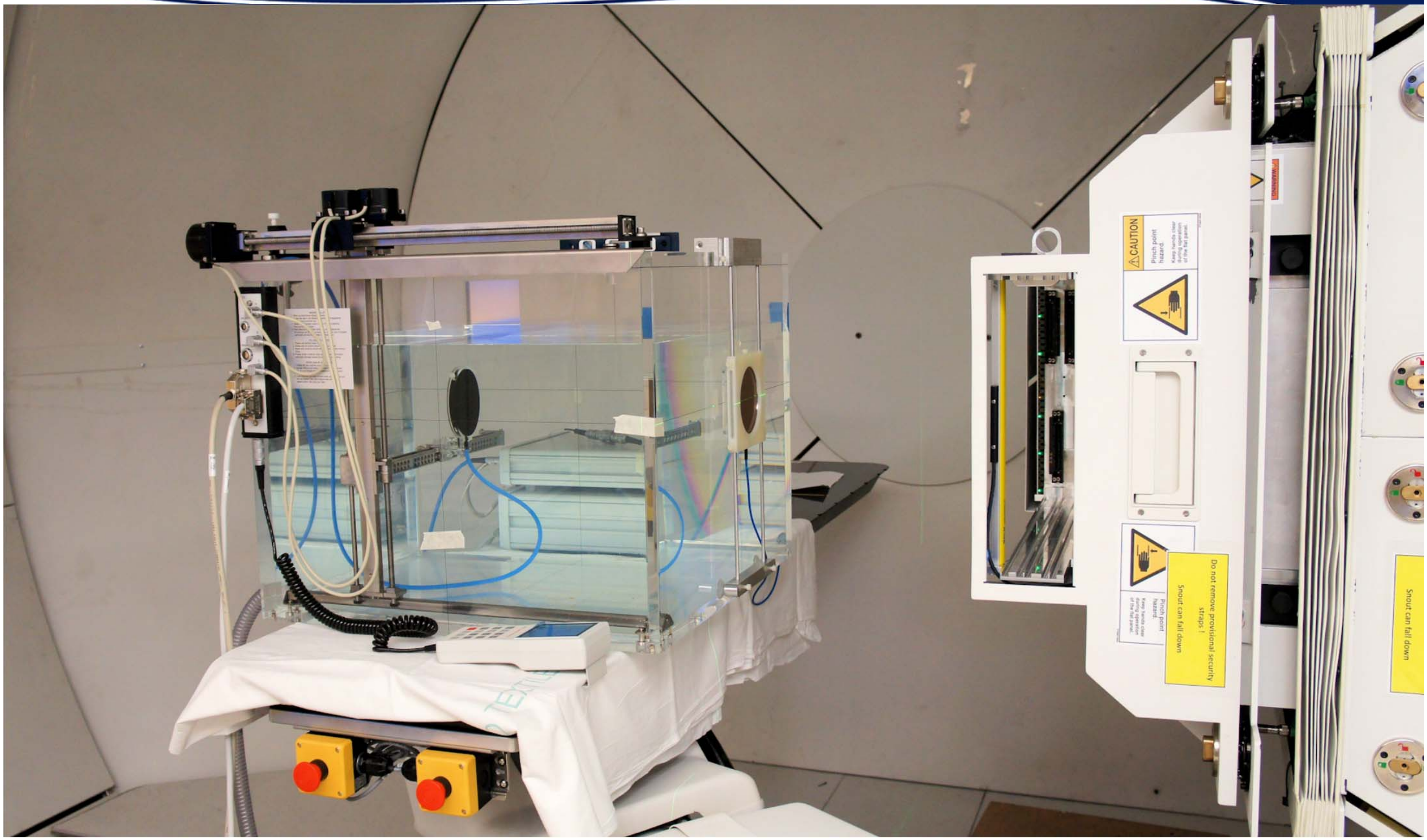
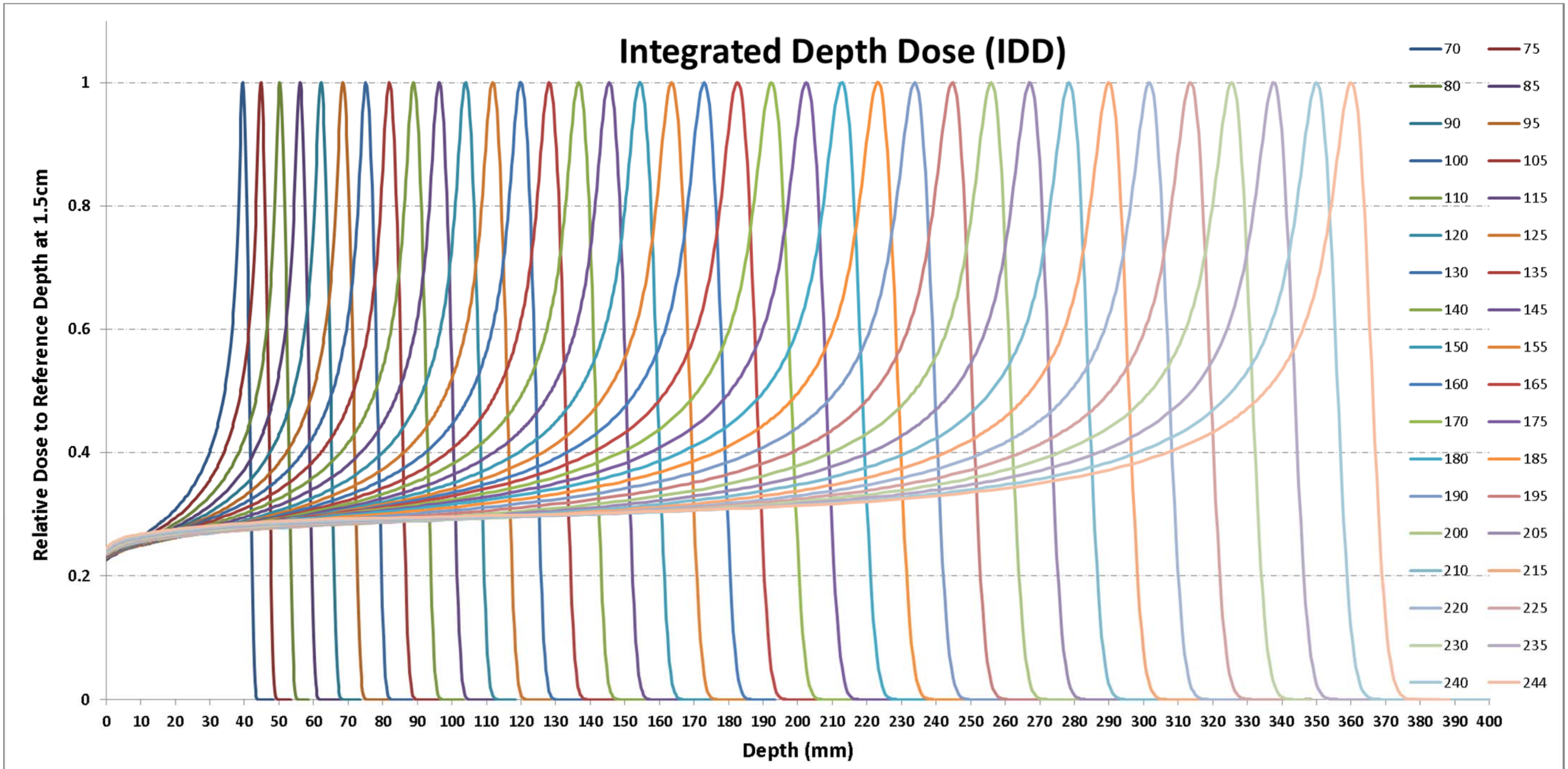
Integrated Depth Dose Measurement using BraggPeak Chamber



Integrated Depth Dose Curves



Spot Size Correction in IDD Measurements

- 8-cm Effective Size for the Bragg Peak Chamber (PTW)
  - No tailed outside the measurement area
    - Single profile measurement with small chamber
    - Profile measurement with the Bragg peak chamber

A procedure to determine the planar integral spot dose values of proton pencil beam spots[b)]

Aman Anand,[a)] Narayan Sahoo, X. Ronald Zhu, Gabriel O. Sawakuchi,[c)]
Falk Poenisch, Richard A. Amos, George Ciangaru, Uwe Titt, Kazumichi Suzuki,
Radhe Mohan, and Michael T. Gillin
Department of Radiation Physics, University of Texas M. D. Anderson Cancer Center,
1515 Holcombe Boulevard, Box 1150, Houston, Texas 77030

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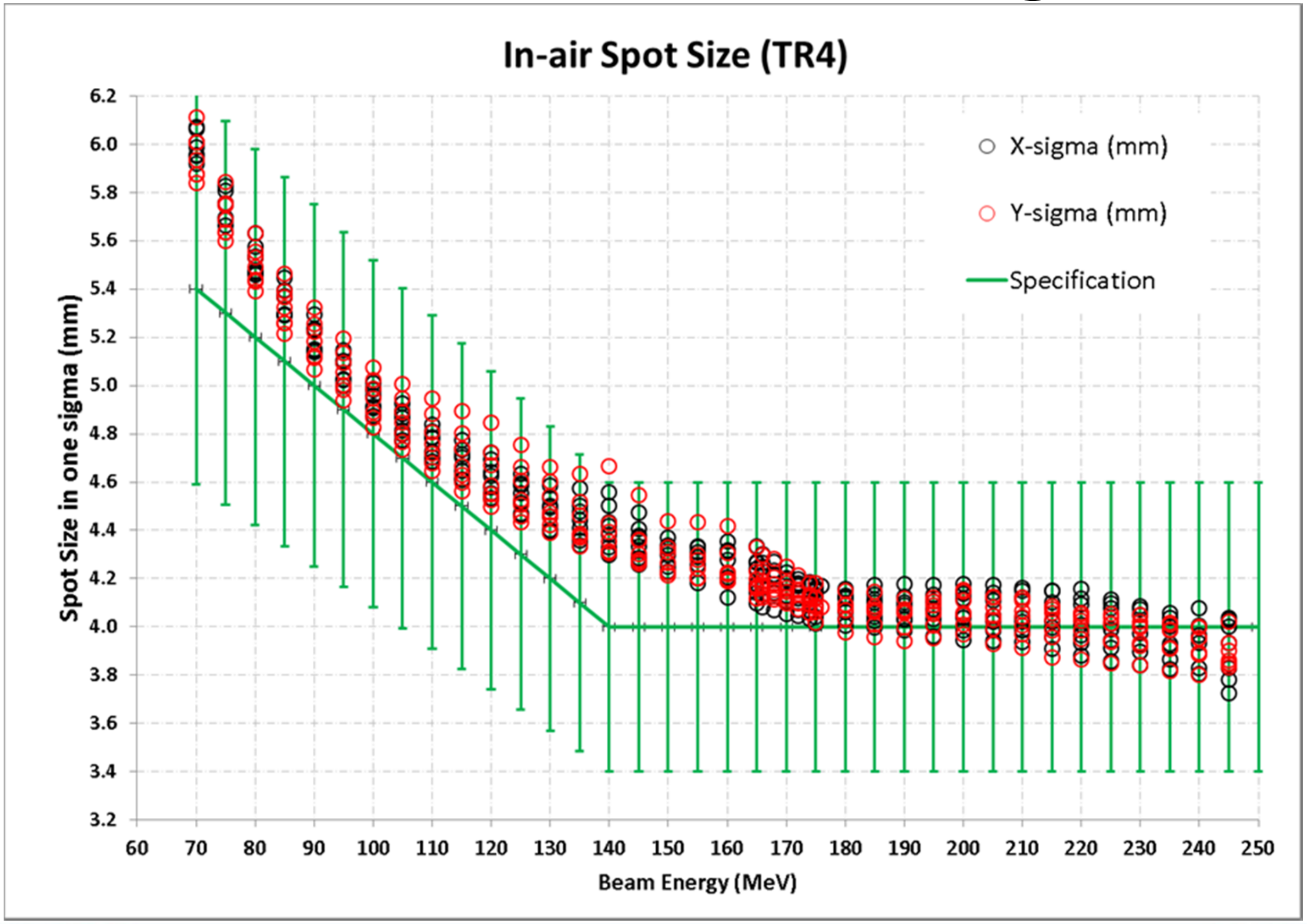
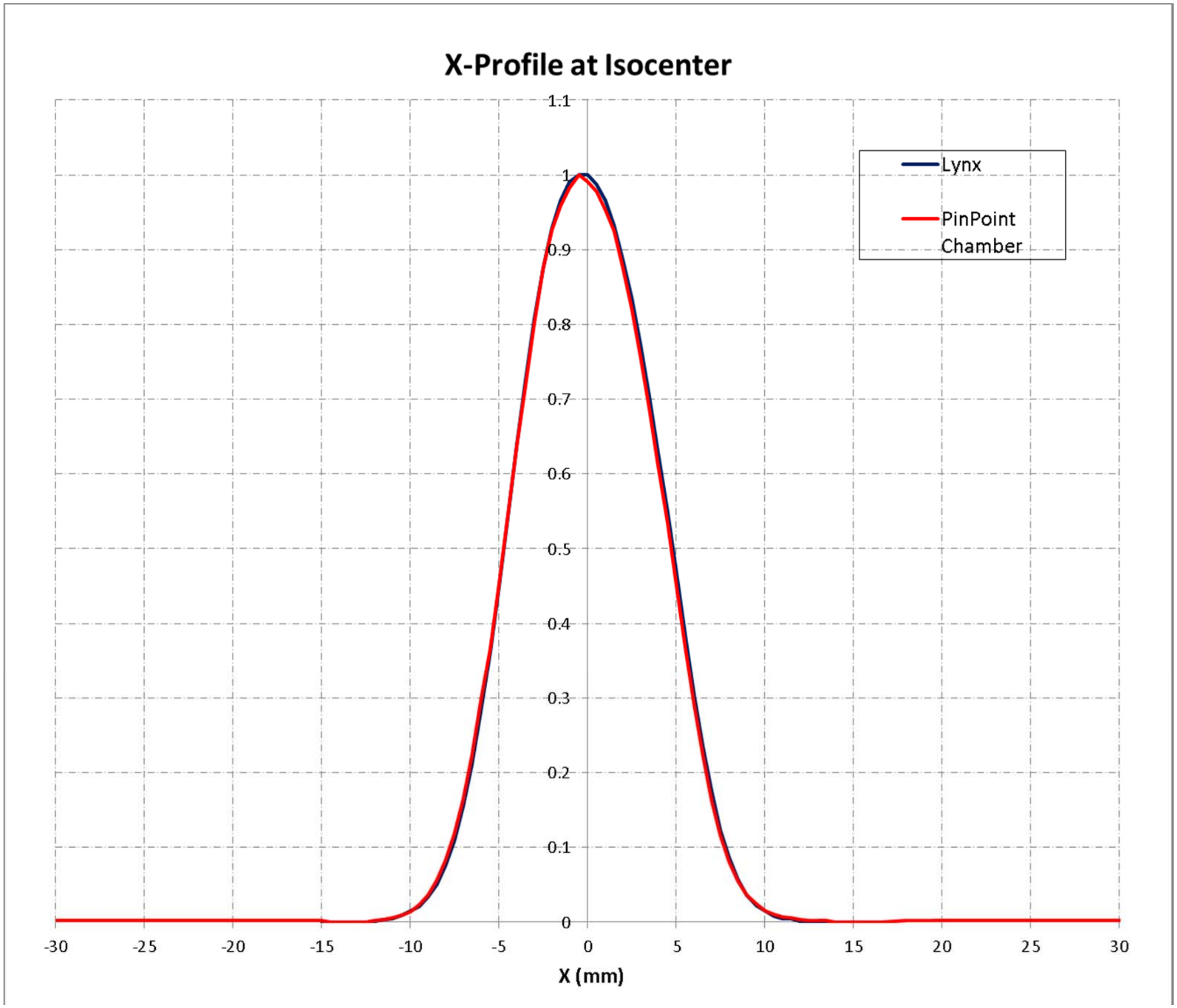
In-Air Spot Size Specification for Beam Matching



CCD vs. PinPoint Ion Chamber



Luis Perles

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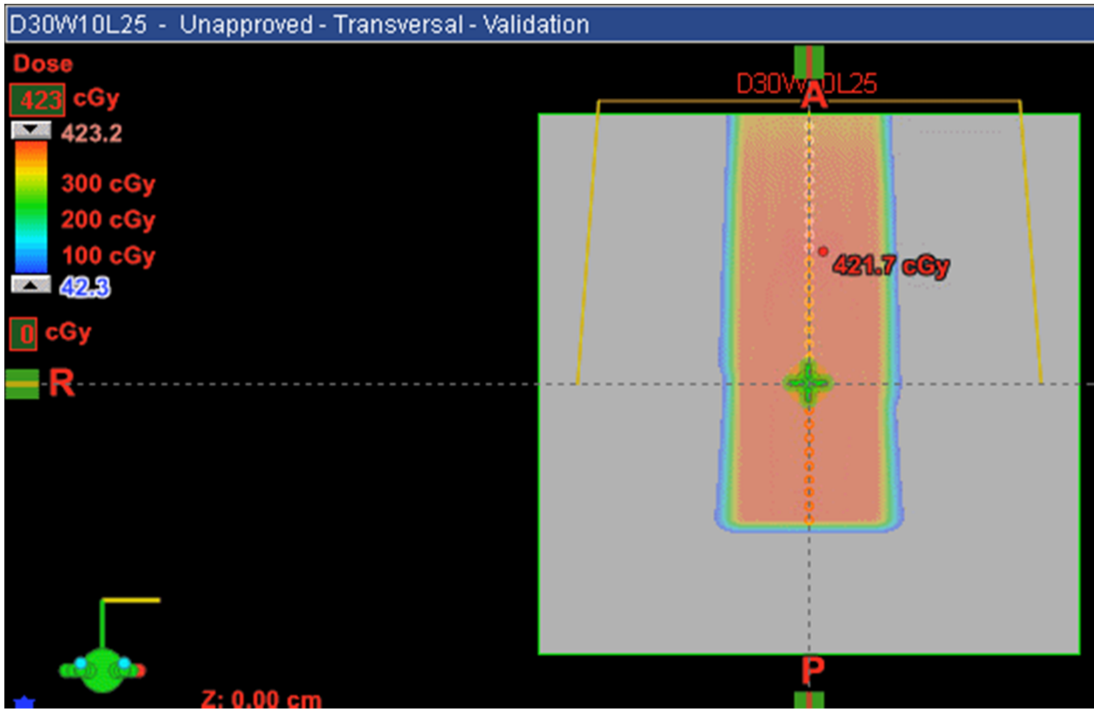
The First Week!

- Make sure you test your equipment and perform some important measurements
  - To avoid finding measurement errors too late in the commissioning process
  - Examples
    - Electrometer and ion chamber evaluation (leakage; linearity; end-effect; ion collection efficiency etc.)
    - Dose calibration
    - Water tank and scanning hardware and software tests
    - Detector tests for measuring beam profiles
    - Gantry angle dependence
    - Testing the accessory holders (range shifter, QA holder etc.)

Validation Plans for TPS Commissioning and Parameter Tuning

- Systematic Plan Validation Approach
  - Width of SOBP
  - Length of SOBP
  - Depth of SOBP
    - With and without Range Shifter



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- Systematic Plan Validation Approach
  - Width of SOBP
  - Length of SOBP
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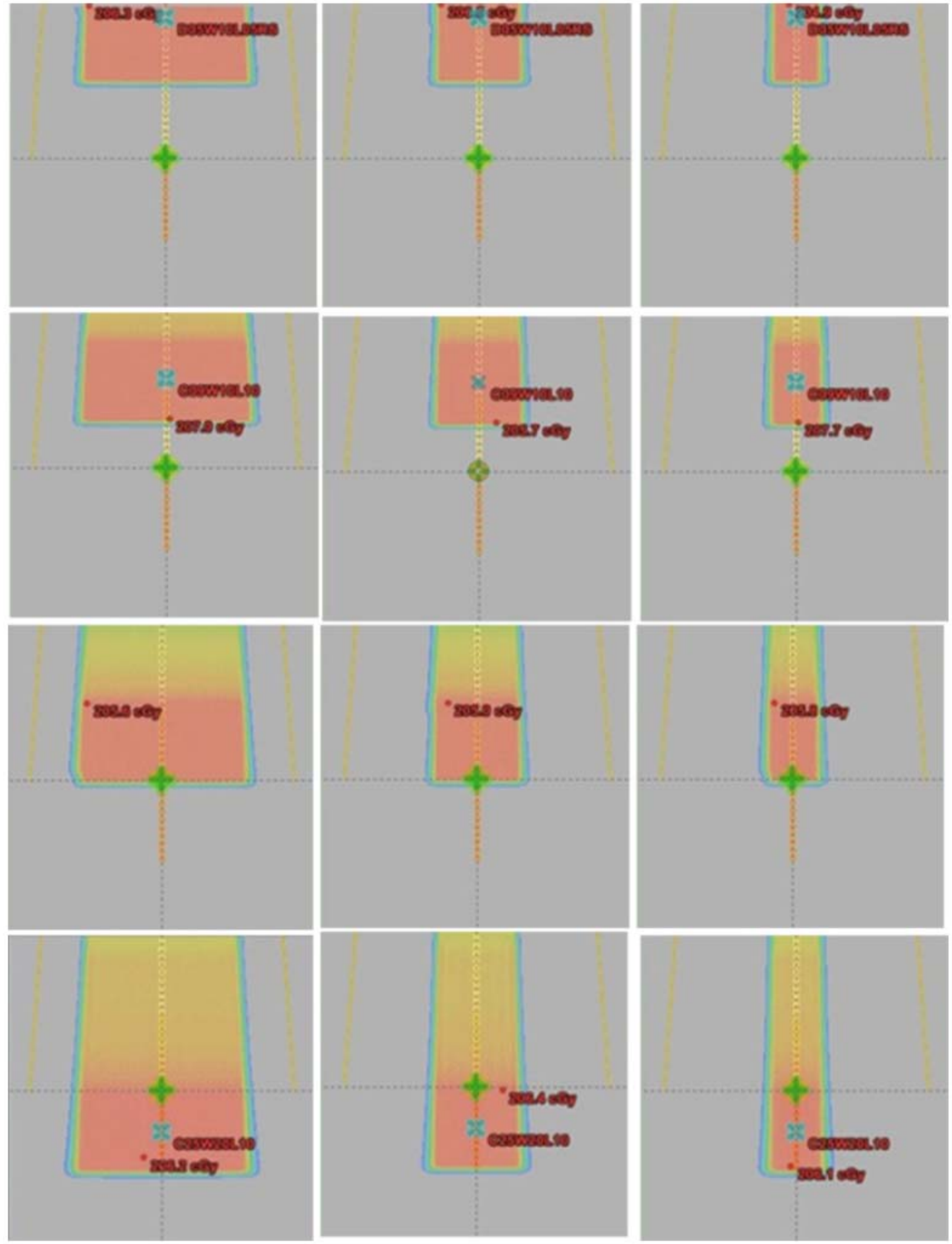
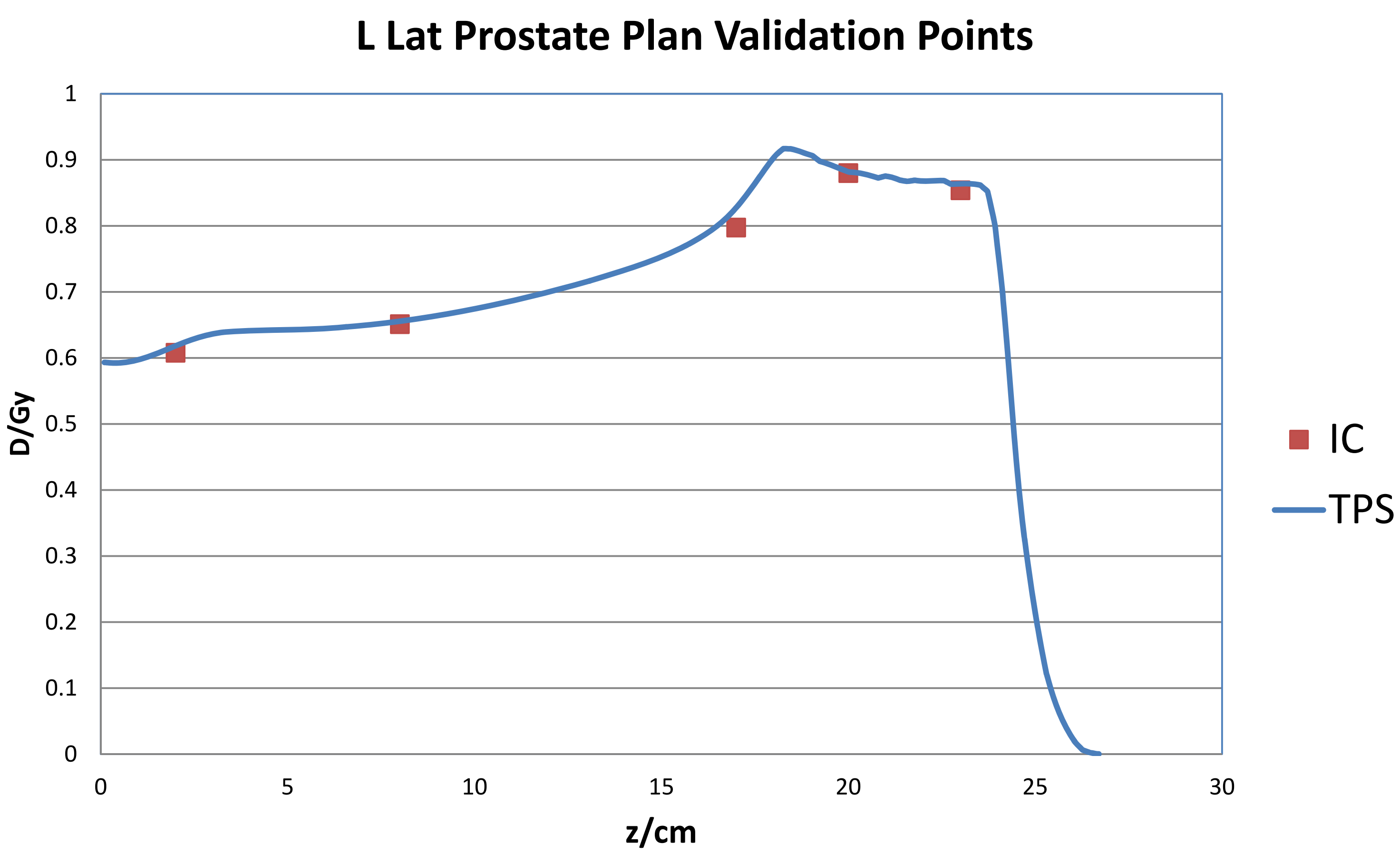
    - With and without Range Shifter




L Lat Prostate Plan Validation Points
D/Gy
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
z/cm
IC
TPS

Room Matching (TR4 vs. TR3 and TR2)

- In 91 ion chamber measurement of 21 SOBP plans
- Average difference: 0.1% +/- 1.1%

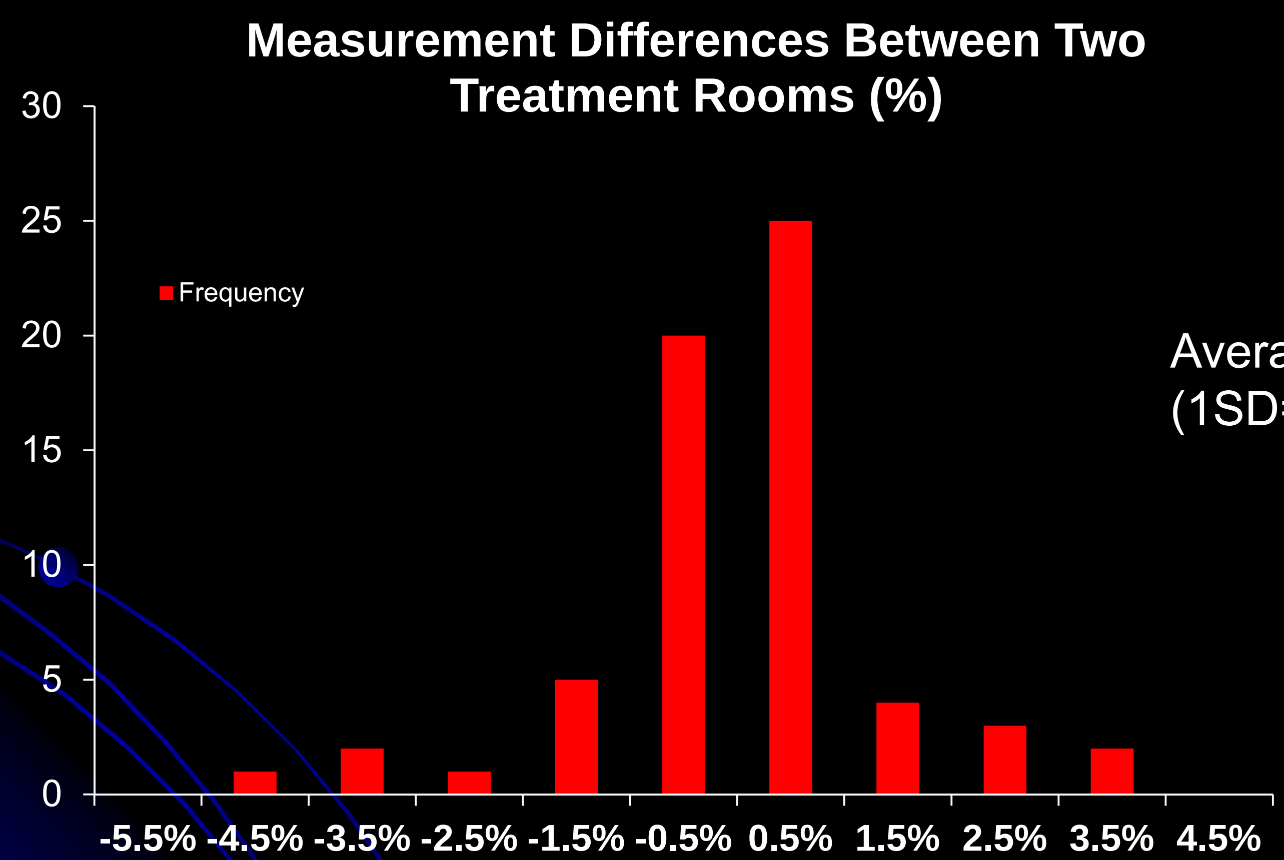
locations	Count	AVERAGE	STD
entrance	13	1.36%	1.14%
flat	2	1.89%	0.45%
gradient	9	0.38%	0.51%
proximal	14	-0.13%	1.56%
SOBP	55	-0.15%	0.40%
Overall	93	0.16%	0.99%

TR4 vs. TR3

locations	Count	AVERAGE	STD
entrance	13	1.70%	0.84%
flat	2	1.35%	0.33%
gradient	9	0.10%	1.02%
proximal	14	-0.73%	1.62%
SOBP	53	-0.27%	0.53%
Overall	91	0.01%	1.15%

TR4 vs. TR2

Room Matching (TR2/TR3/TR4)



Average = 0.06%
(1SD=1.4%)

30 actual patient QA plans measured by Ion Chamber

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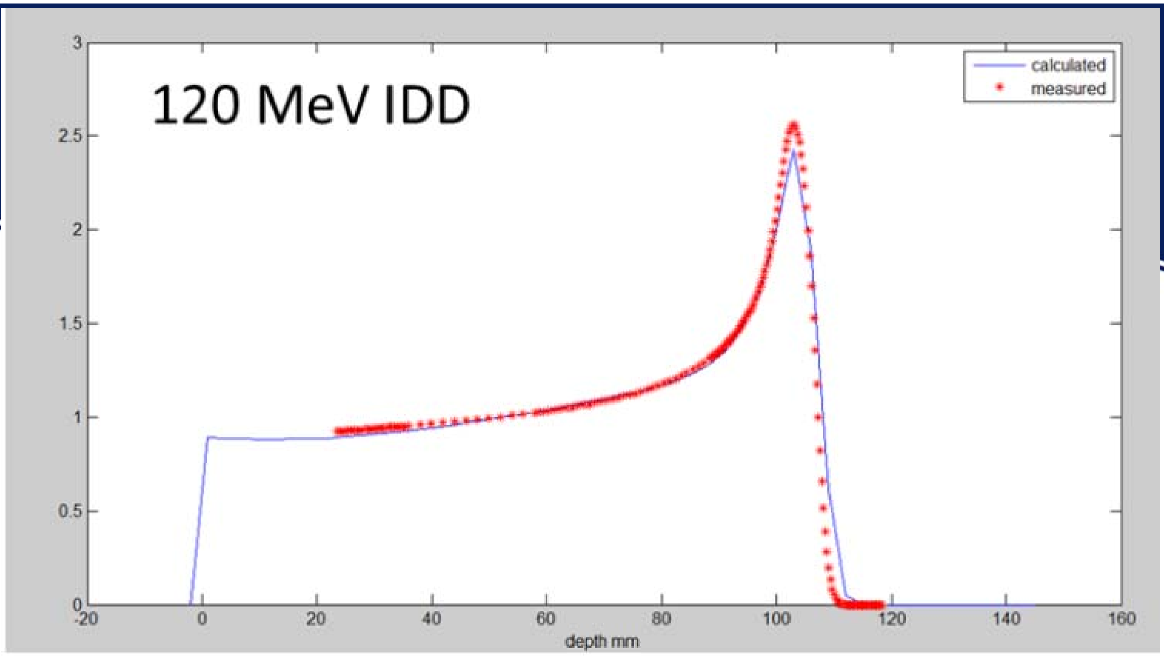
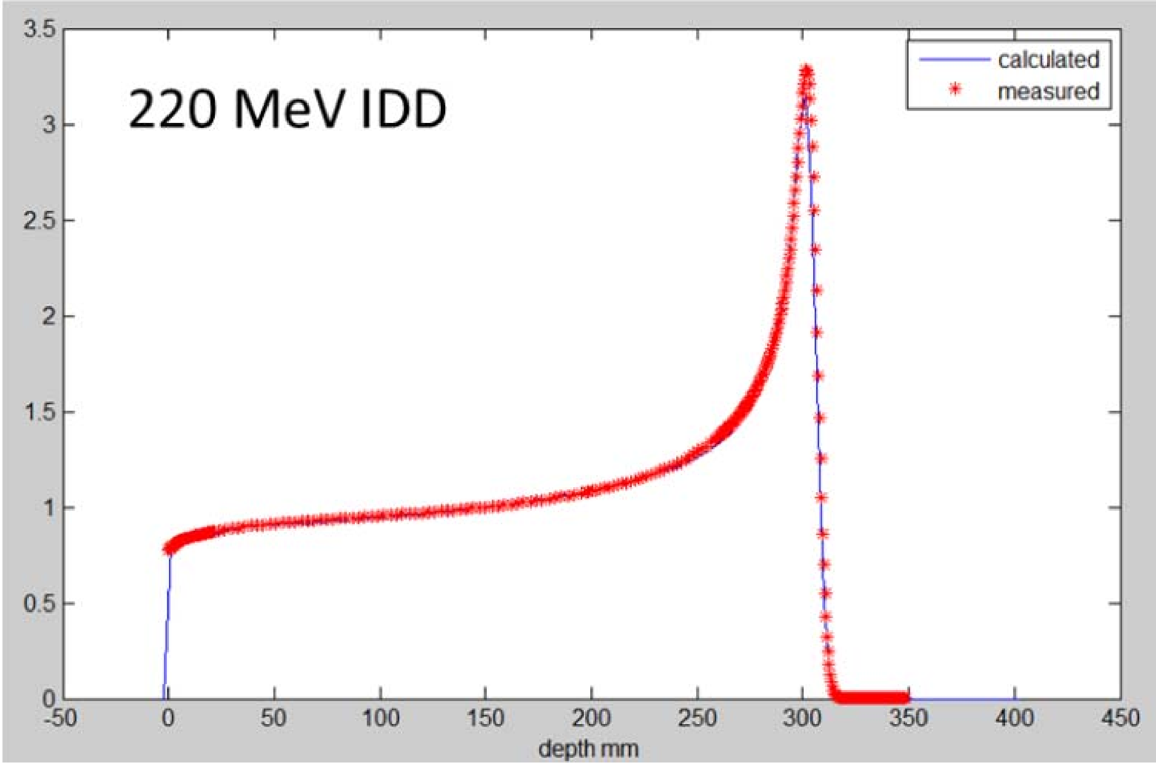
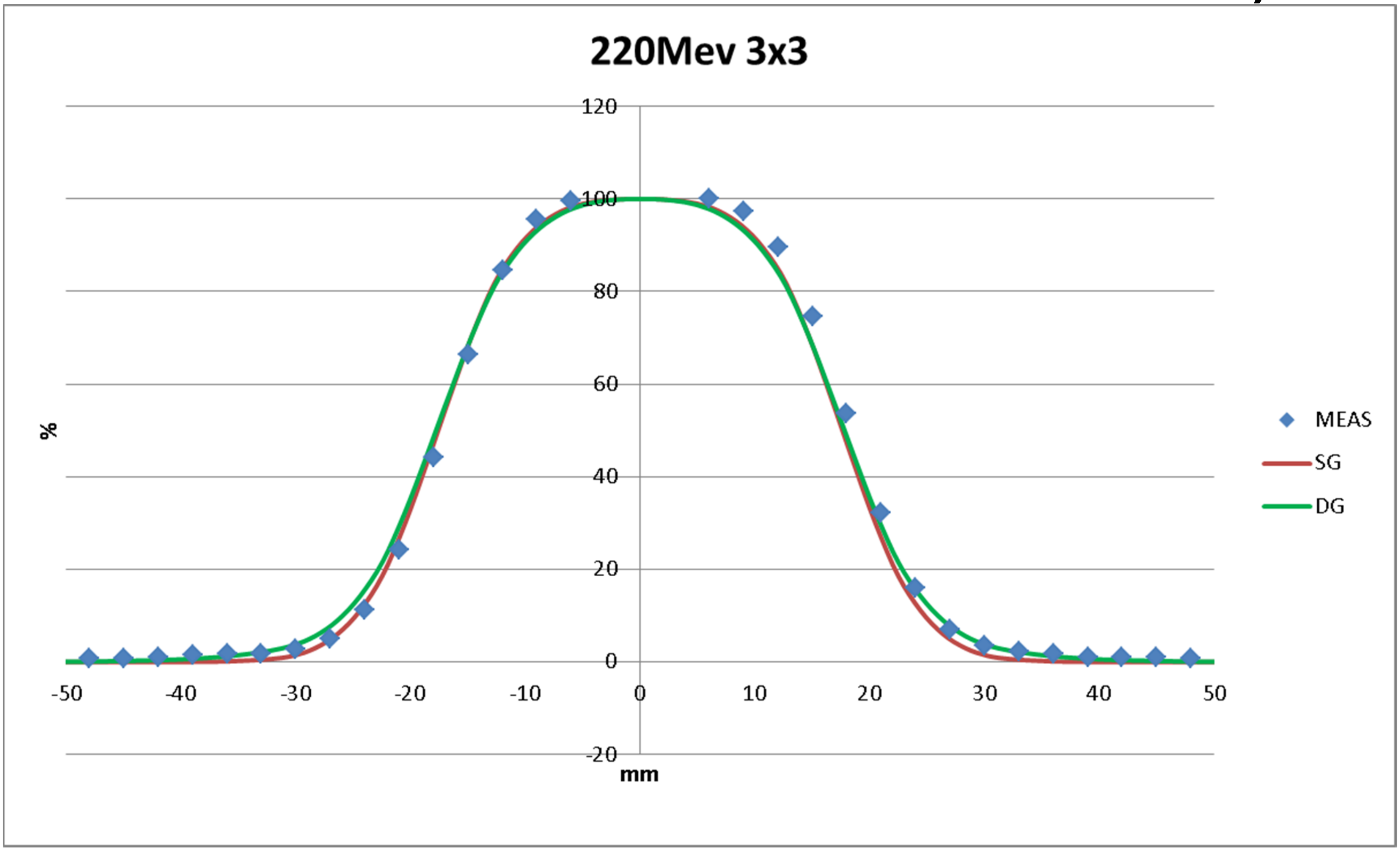
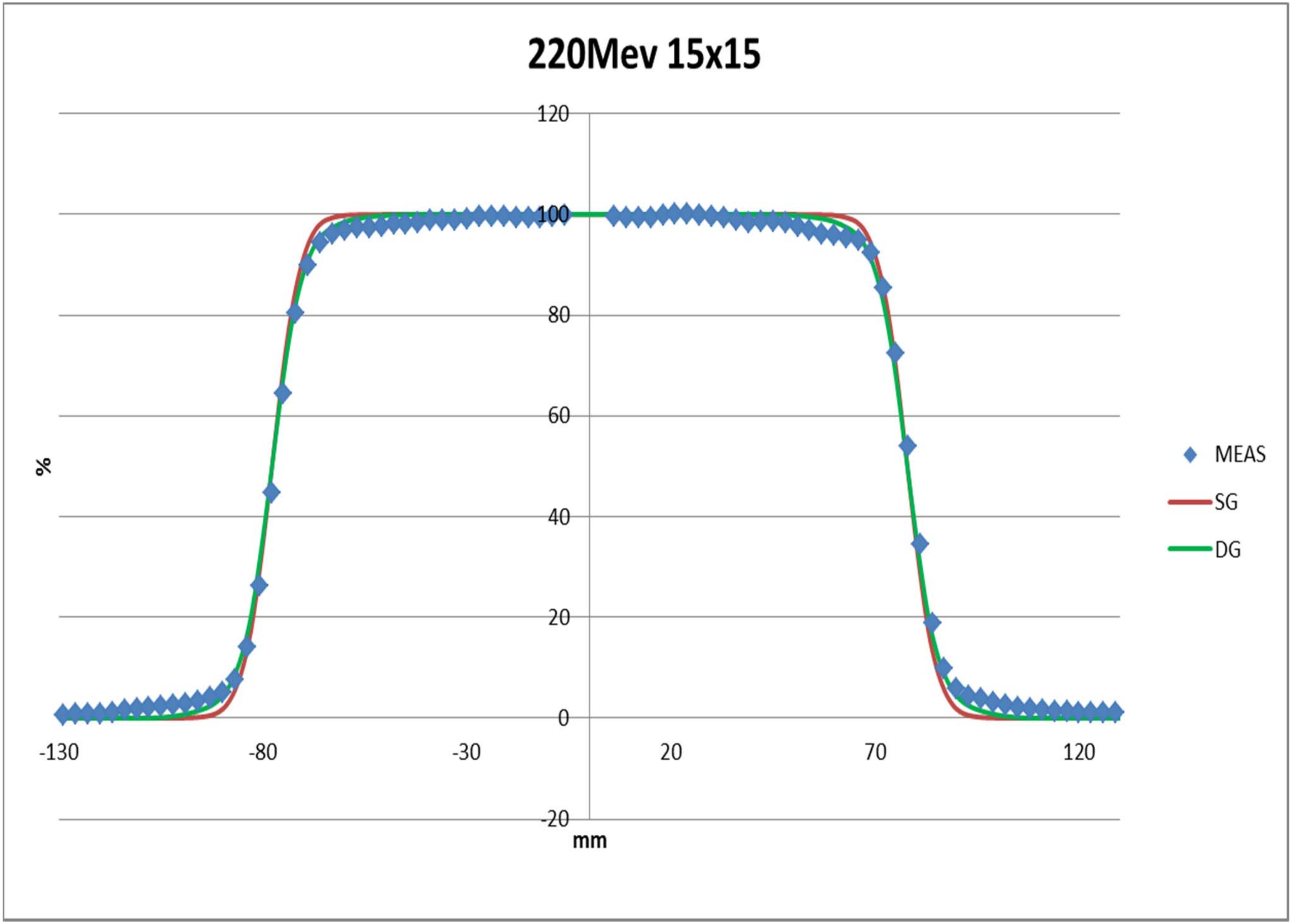
Validation of IDD calculation with raw measured data



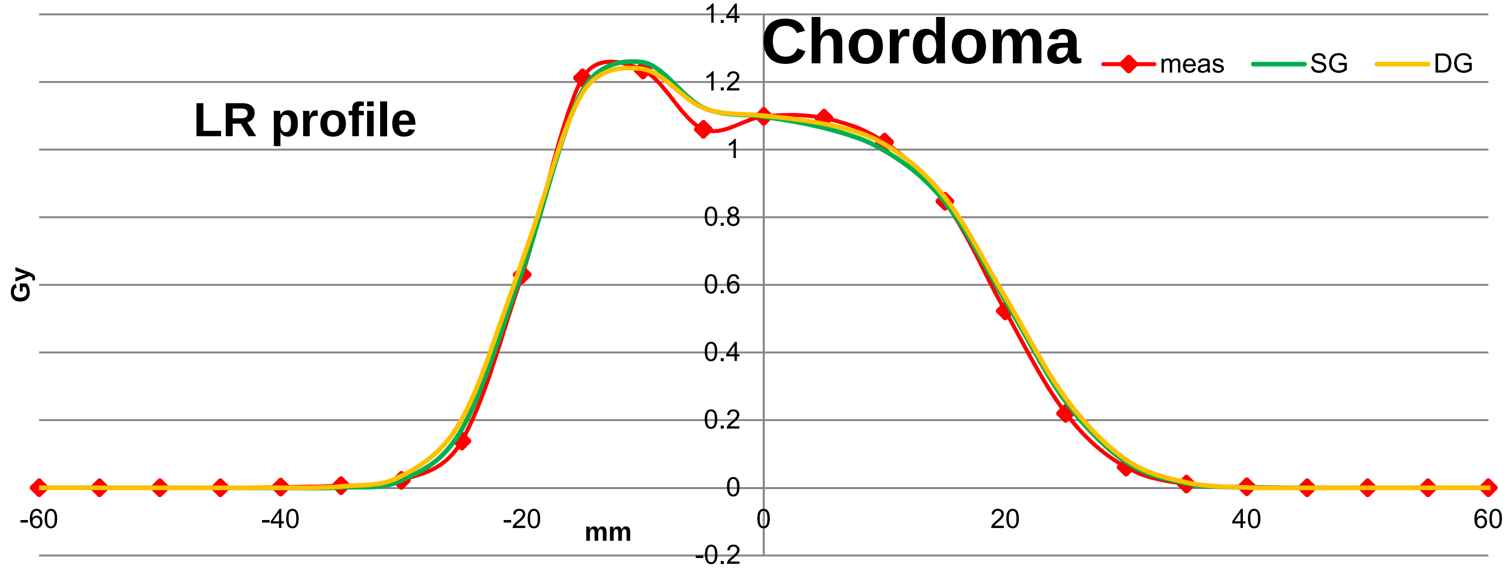


Testing Dose Models (Single-Gaussian vs. Double-Gaussian)

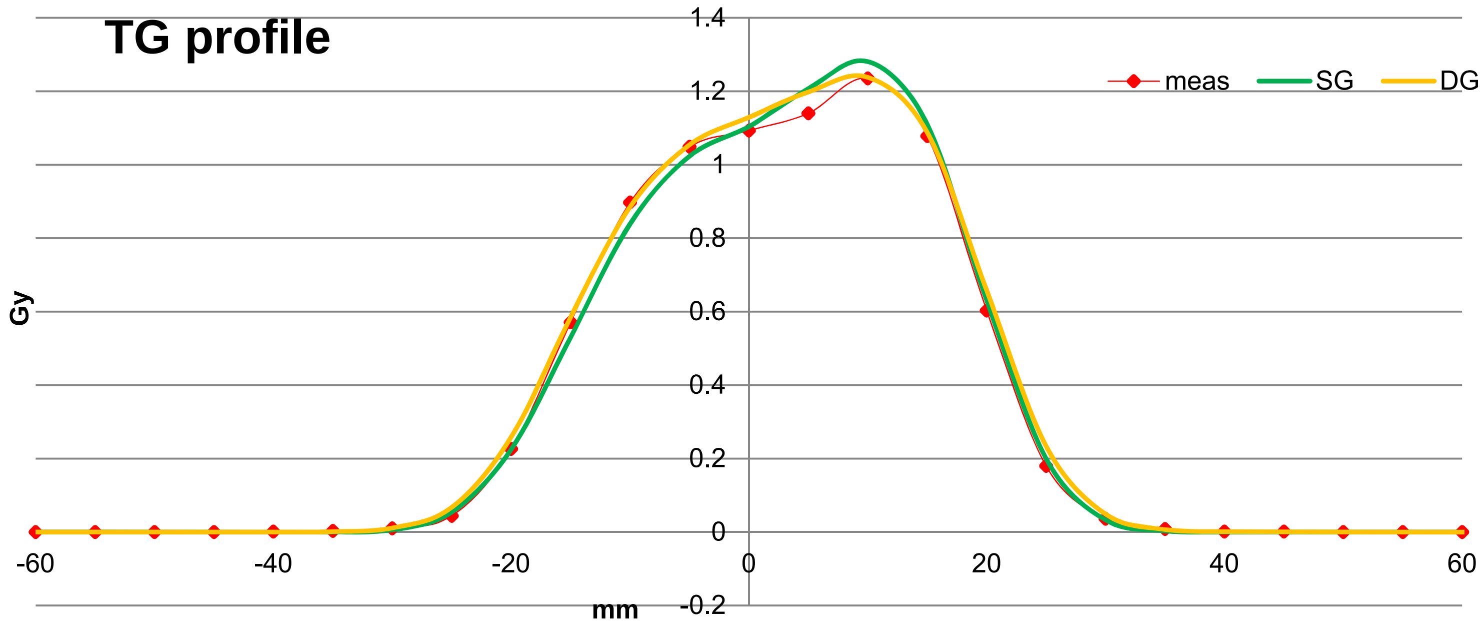



220Mev 15x15
120
100
80
60
40
20
0
-20
%
-130
-80
-30
20
70
120
mm
MEAS
SG
DG

Chordoma



LR profile
meas
SG
DG
Gy
mm
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-60
-40
-20
0
20
40
60



TG profile
meas
SG
DG
Gy
mm
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-60
-40
-20
0
20
40
60

Major Measurement Equipment

- TPS commissioning requirement
  - IDD (integrated depth dose curves
  - Chambers and electrometers
  - Spot profiles in air
- QA needs
  - Daily QA
  - Monthly QA
  - Patient QA

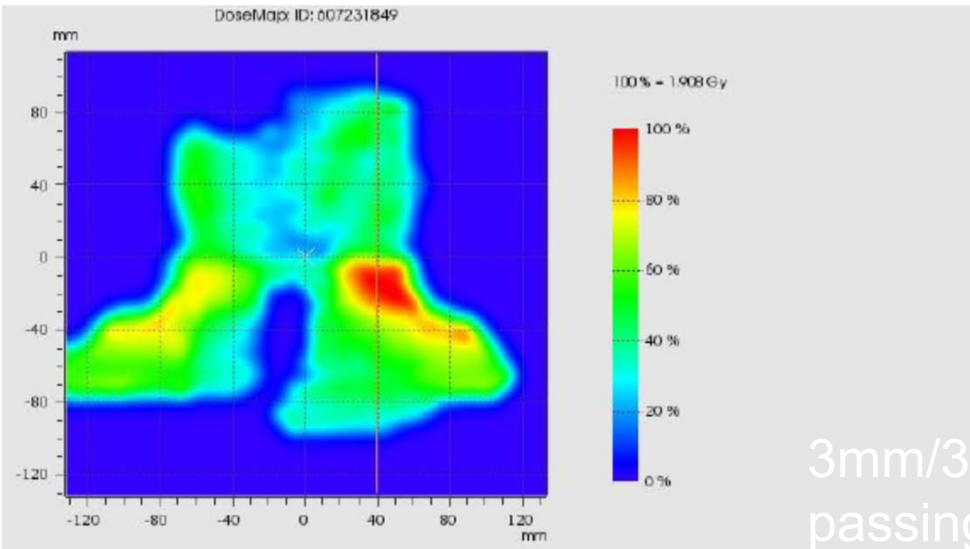
*Conditions

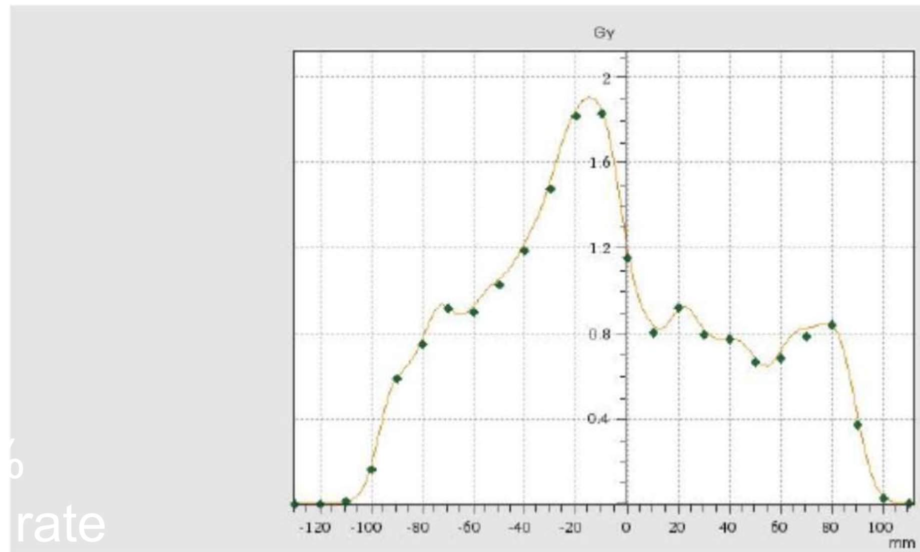




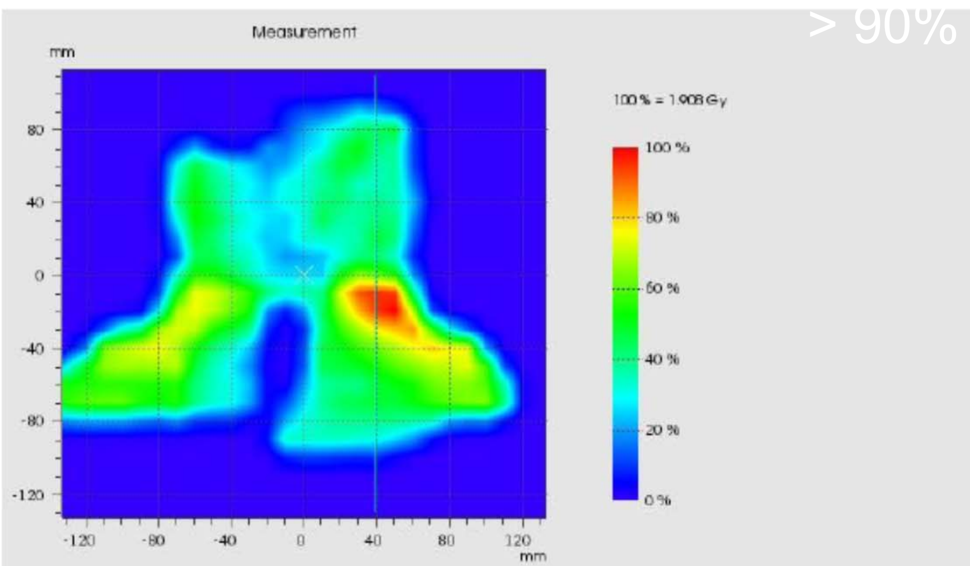


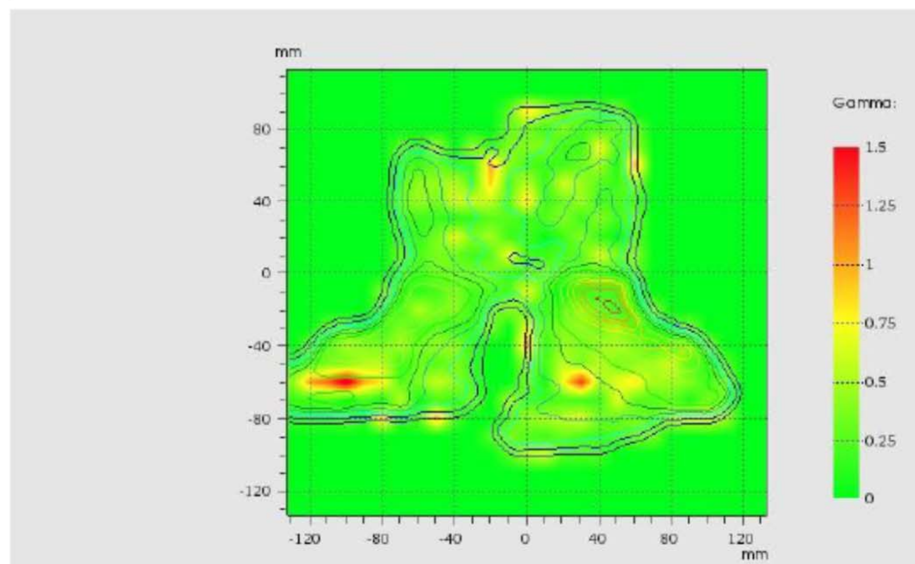

2D Array Measurement





3mm/3% passing rate > 90%





Comprehensive Patient QA Review

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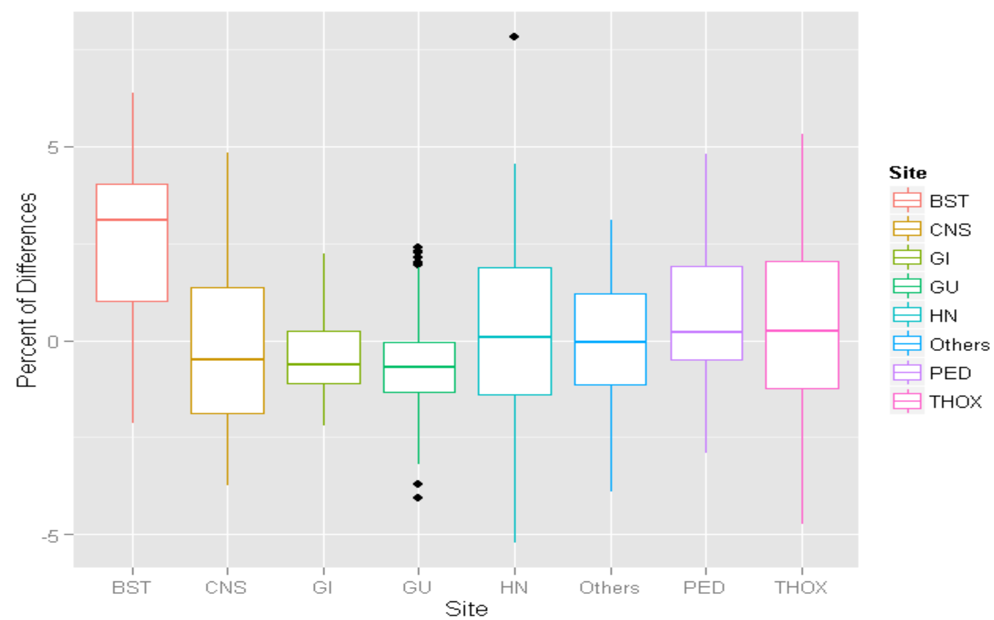
- 824 treatment fields were analyzed from 250 patients treated during first year's ramp-up
  - 72.8% used the single-field optimization (SFO) technique
  - 27.2%) used the multi-field optimization (MFO) technique
- The average of all QA results: -0.2% (1.8% 1SD)



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Summary of PBS Commissioning

- Much simplified data acquisition
  - ~Two weeks for beam data measurement
  - ~Four weeks for validation measurements
    - Oct. 8th, 2013: beam measurements
    - Nov. 2013 and Jan. 2014 for validation
    - Feb. 12: treated the first patient
- Important considerations
  - High dose rate: a measurement challenge, including finding appropriate commercial products
  - Beam spot QA requires new design
    - Intensity; position; energy; and shape
    - Gantry dependence
    - Room matching

Physics Team at Scripps PTC

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Thank you!