Quality and Safety Issues Associated with Proton Beam Therapy

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Name Change (2011)

Midwest Proton Radiotherapy Institute (MPRI)

Indiana University Health Proton Therapy Center (IUHPTC)

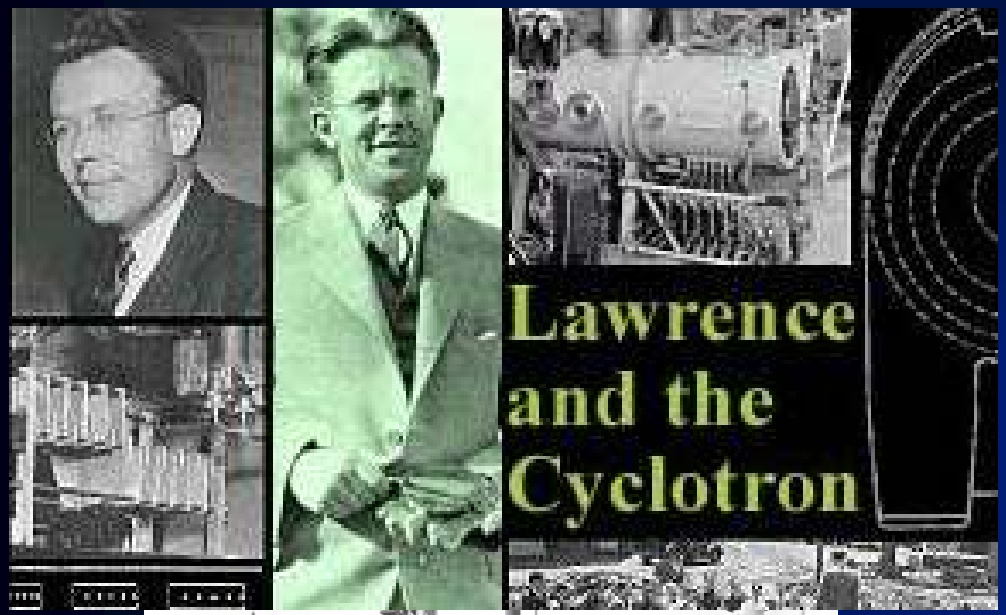
Same location, Same people, same machines

Safety & Quality Issues

- Machine (Cyclotron, Synchrotron)
- Beam line
- Bending magnets
- Energy Selector
  - At production: synchrotron
  - In beam line
  - In Nozzle: range shifter
- Nozzle
- Treatment table
- Patient specific devices

Ernest Lawrence

Nobel Prize winner in Physics 1939



60-inch Cyclotron

Radiation Lab in Berkeley

Types of Machines: Variable Design (Specific QA and Safety)

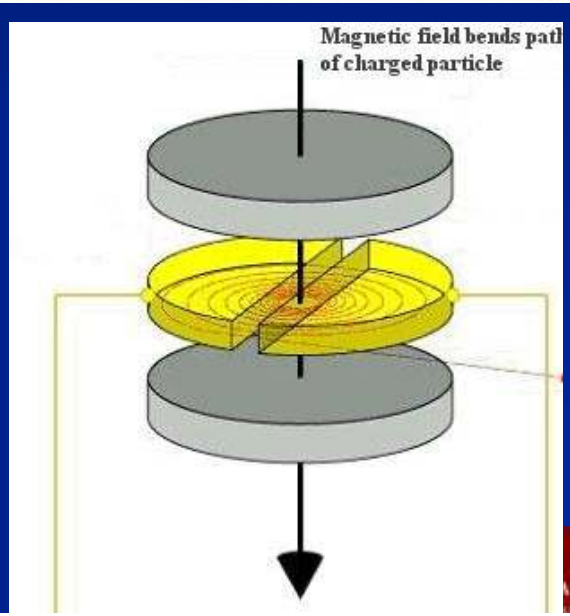
- Home grown (Cyclotron)
  - Harvard Cyclotron
  - Indiana university
- Loma Linda (only one of its kind): (Synchrotron)
- IBA (Cyclotron)
- Hitachi (Synchrotron)
- Mitsubishi (Synchrotron)
- Sumitomo (Cyclotron)
- ProTom (Compact Synchrotron)
- Mevion (Superconducting Synchrocyclotron)

Machine: Cyclotron

IUCO cyclotron

Excel, Varian

IBA

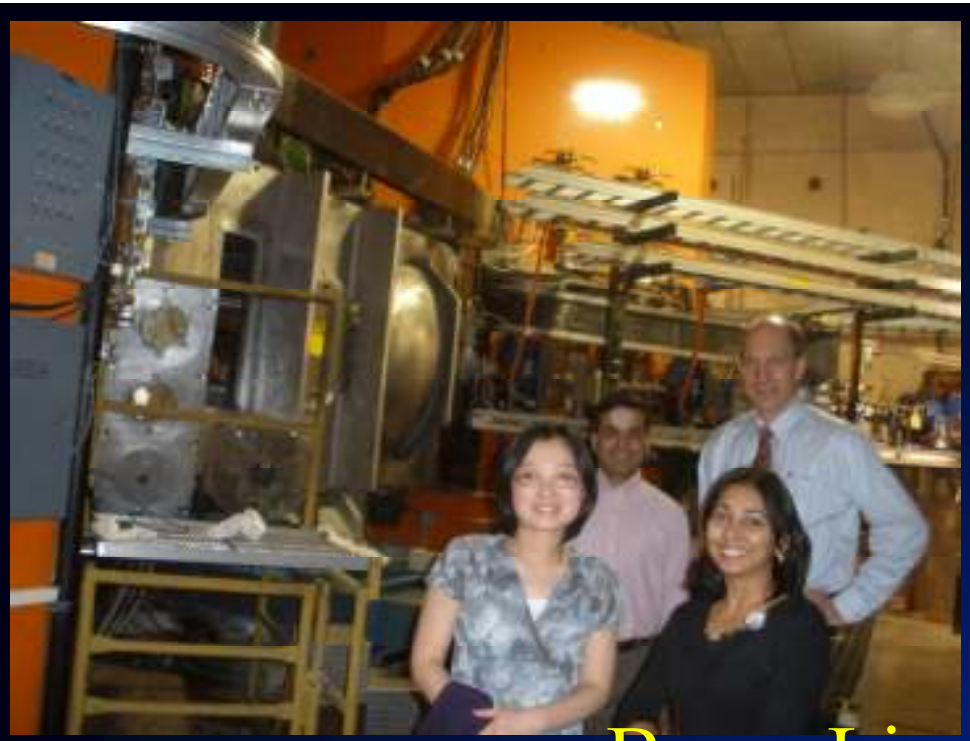




Synchrotron: Ion beam (H^{+}, He^{2+}, C^{6+}, O^{8+})

Heidelberg, Germany (120 m)

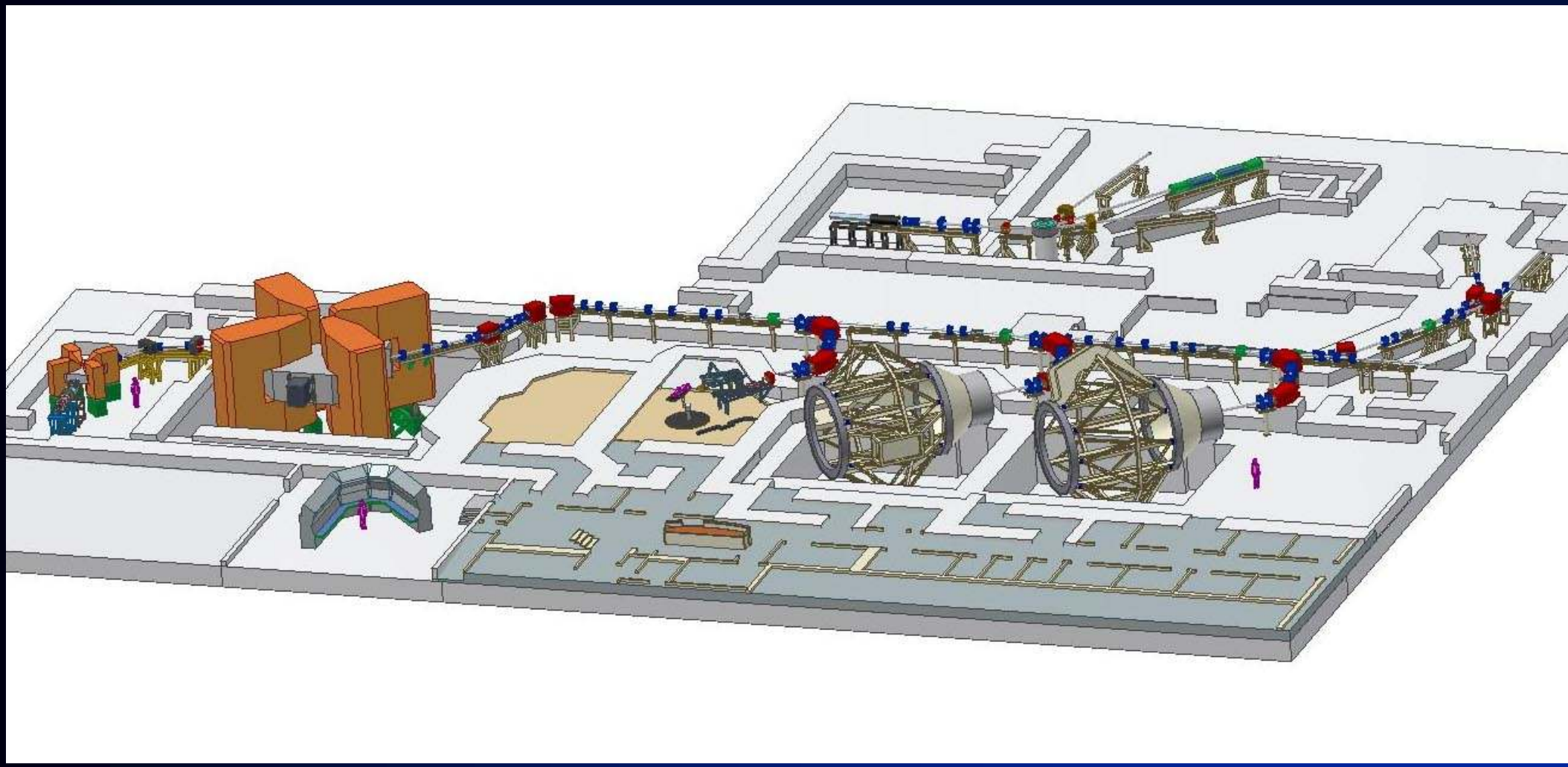




Beam Line Components (IUHPTC)

Ramping & support integrity

IUCF/IUH Proton Therapy System



Double Scattering in Fixed Beam Line (TR1); Under Upgrade

Rudimentary, needs periodic QA of every component

Types of Beams

- Passive scattering
  - Single
  - Double
- Uniform scanning
  - Compact magnet: 2 plane sweeping (IUCO)
  - 2 plane magnet: single plane sweeping (IBA)
- Pencil beam Scanning
- Spot scanning

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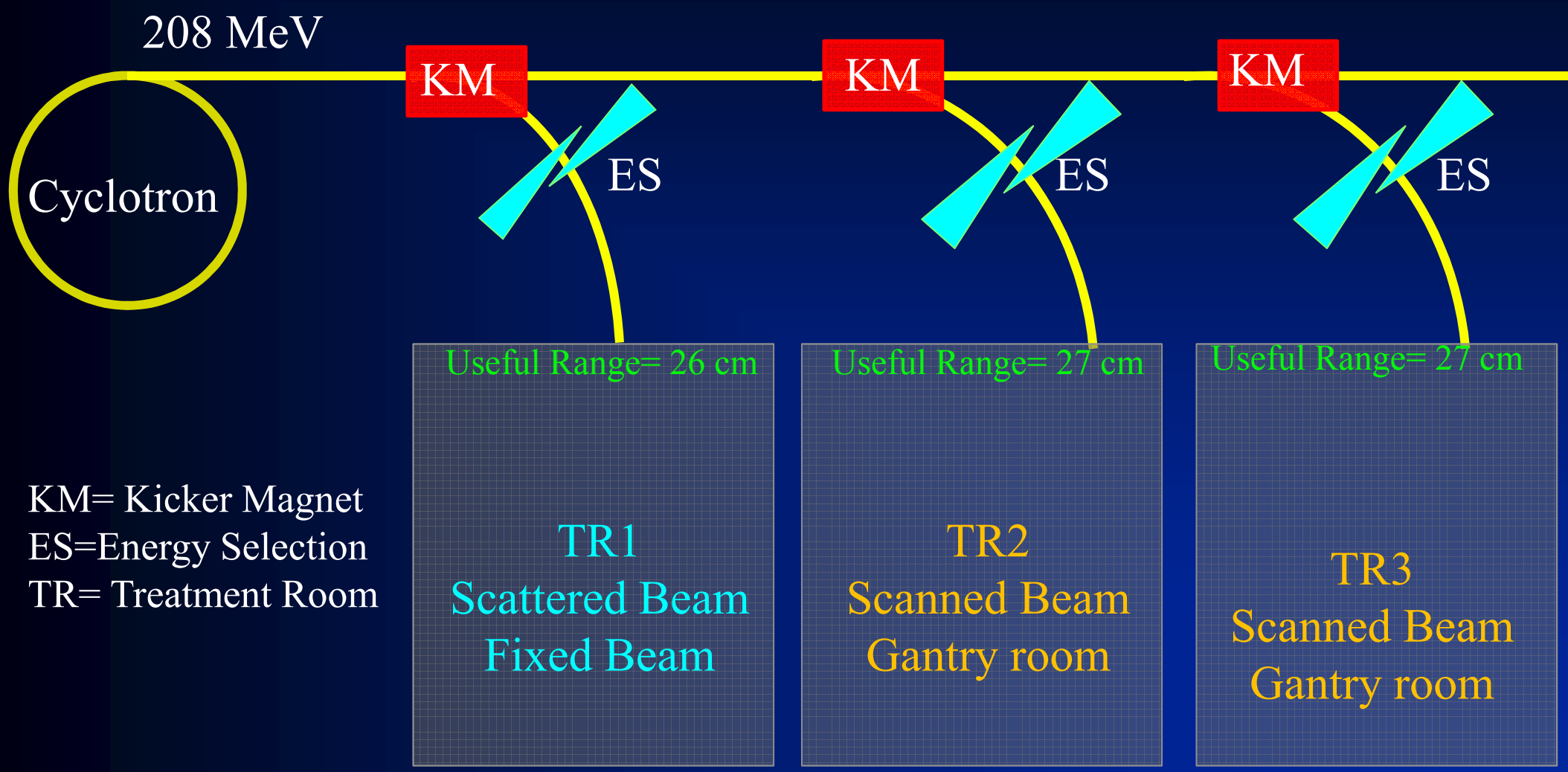
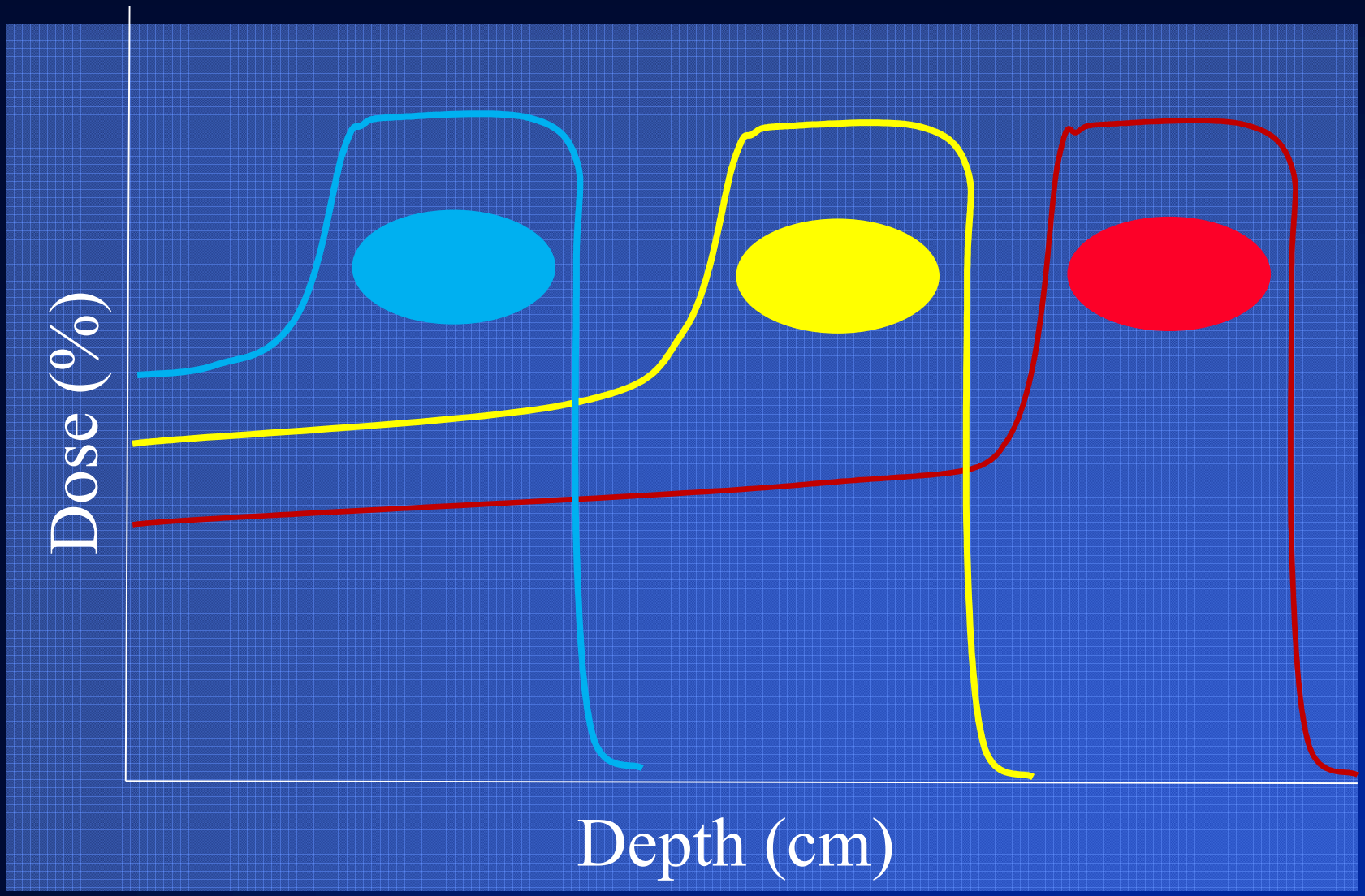
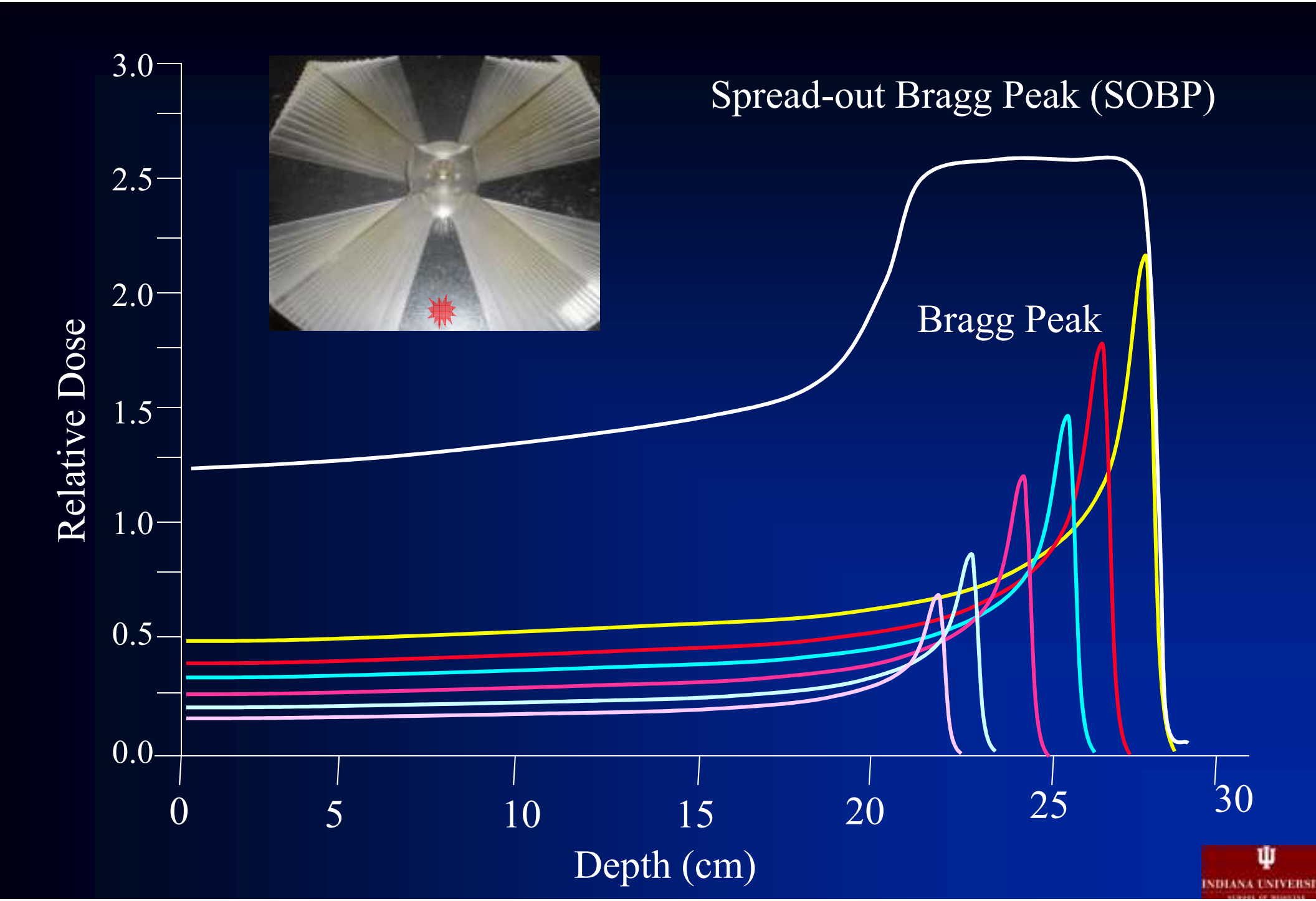
IUH PTC Beam Line



KM= Kicker Magnet
ES=Energy Selection
TR= Treatment Room

SOBP Redistribution



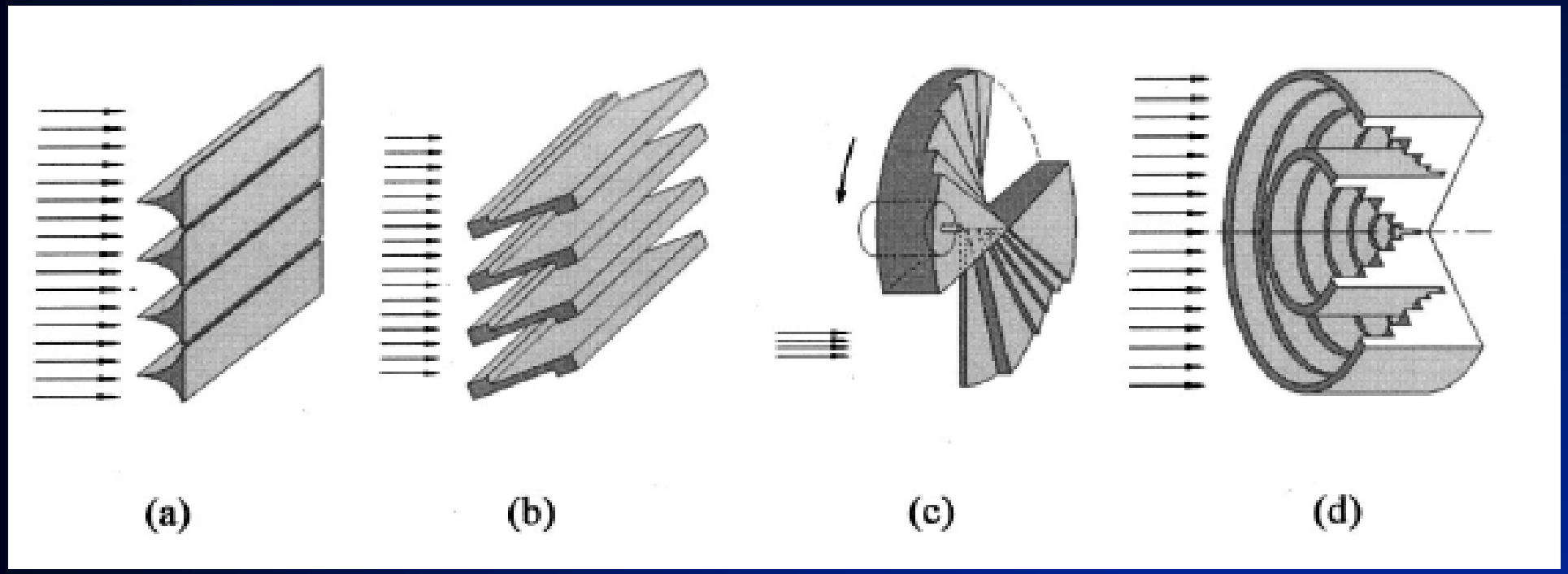

Spread-out Bragg Peak (SOBP)
Bragg Peak
Relative Dose
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
Depth (cm)

Samples of Propeller Wheel Modulator

SOBP wheel range from 2.3-16 cm

QA issues with wheel

Ridge Filters for SOBP



Grating Ridge Filter

Propeller wheel modulator Ridge Filter

Spiral Ridge filter

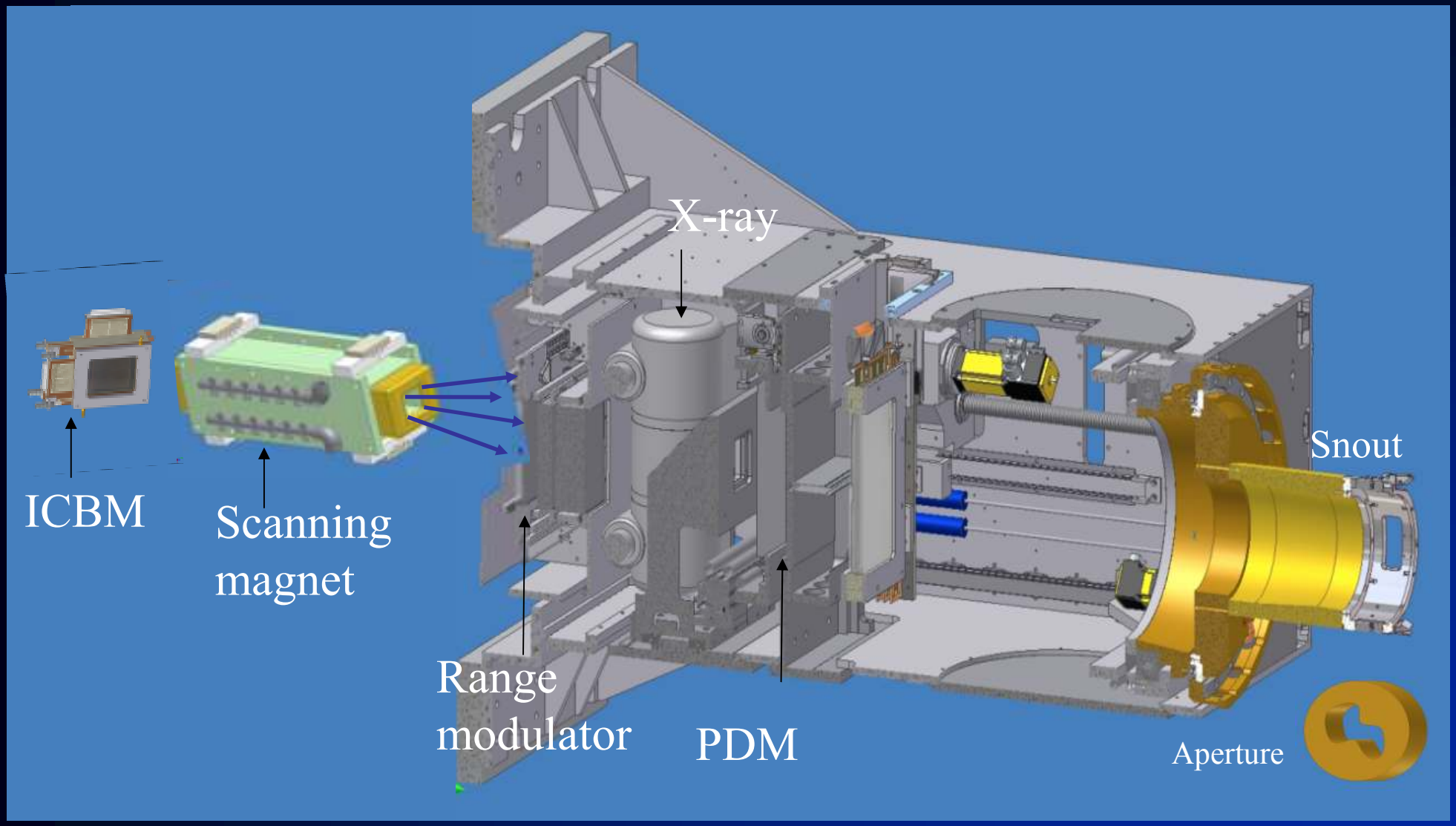
Kostjuchenko, Nichiporov, Luckjashin; Med Phy, 28, 1427, 2001

IU Health Proton Therapy Center, Proton Gantry

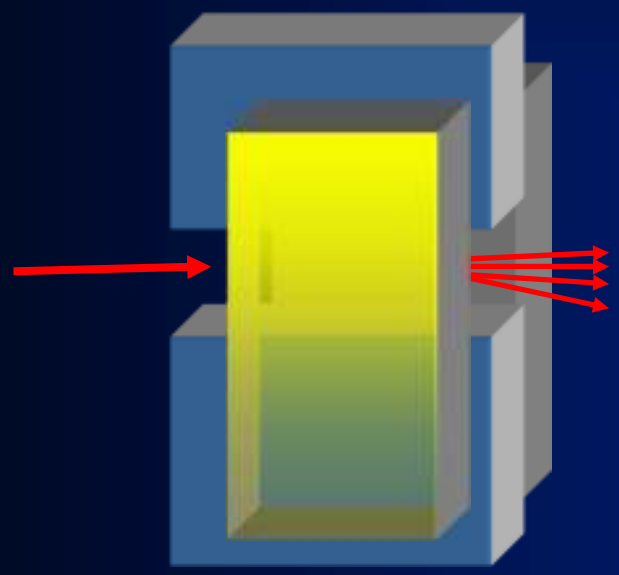
1 RPM

Braking system within 1 deg

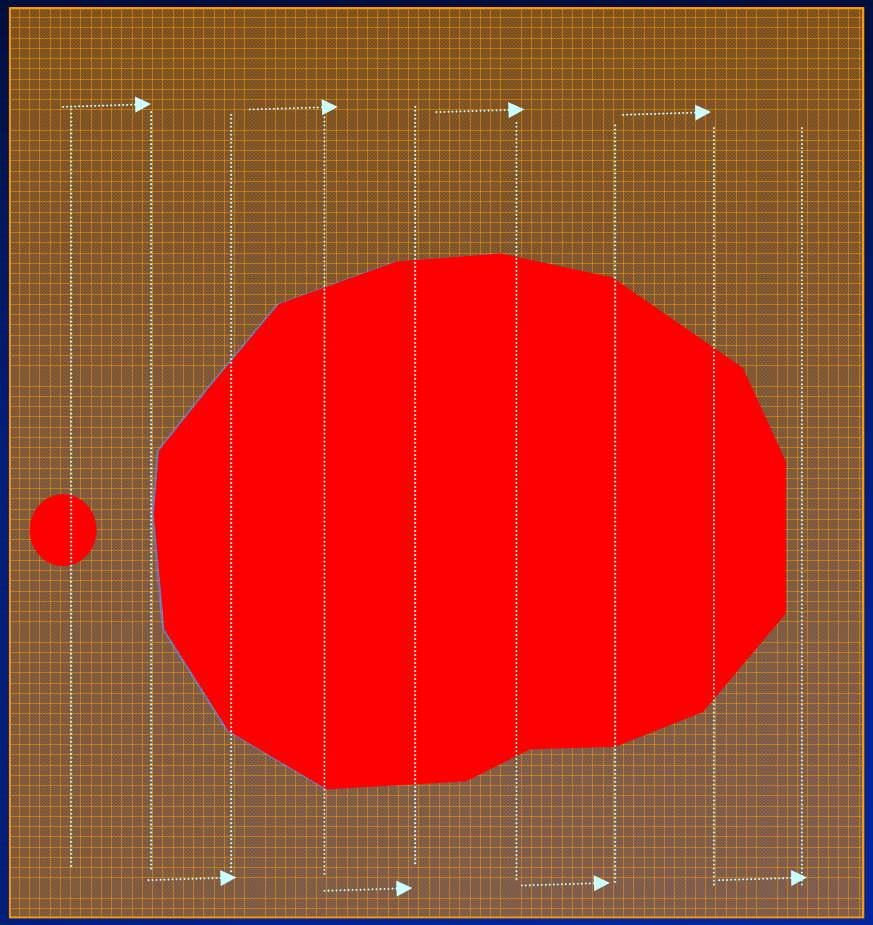
Nozzle with a Scanning Magnet at IUHPTC



Uniform Scanning (IUHPTC)



Nozzle with a Scanning Magnet



One Layer

Scan Parameters

- SAD 250 cm both x & y directions
- Spot size (FWHM) 12-15 mm circular diameter
- Frequency 5-16 Hz (horizontal), 144 Hz (vertical) and ratio changes 5-15
- Over scan is 3 cm for optimum uniformity

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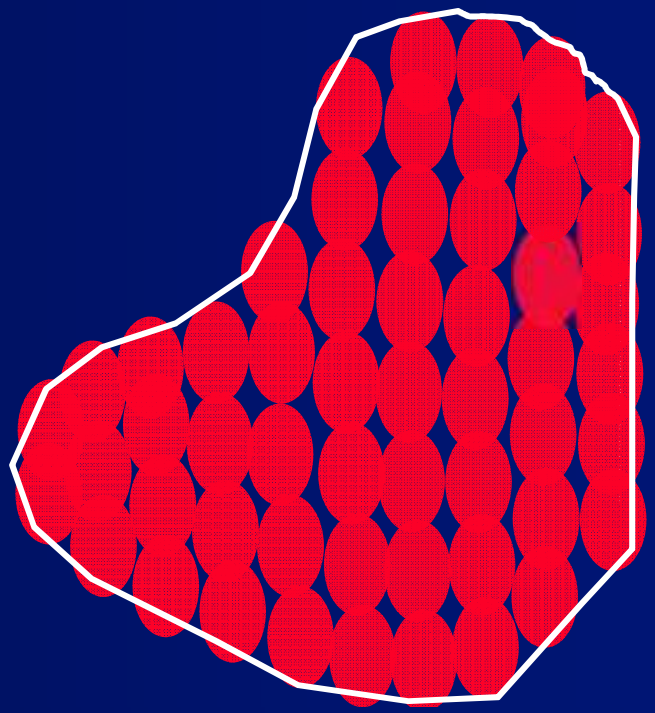
Uniform Scanning and Energy Stacking Method

Proton Pencil Beam



Target

Farr et al, Med Phys, 35, 4945, 2008

Binary Range Modulator

6 Plates

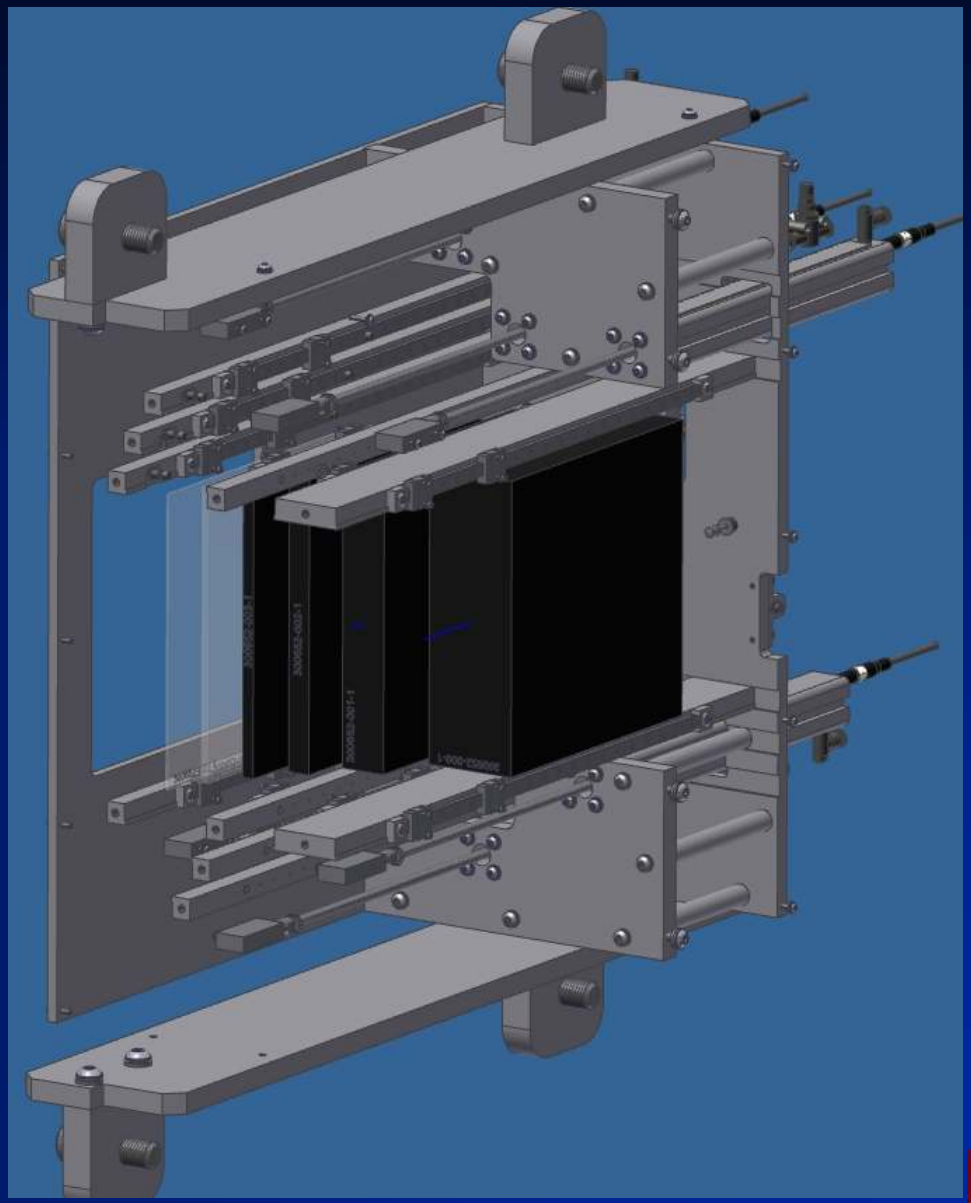
2 Lucite plates

4 Graphite Plates

Water equivalence

3, 6, 12, 24, 48 and 96 mm

Total range shift 18.6 cm

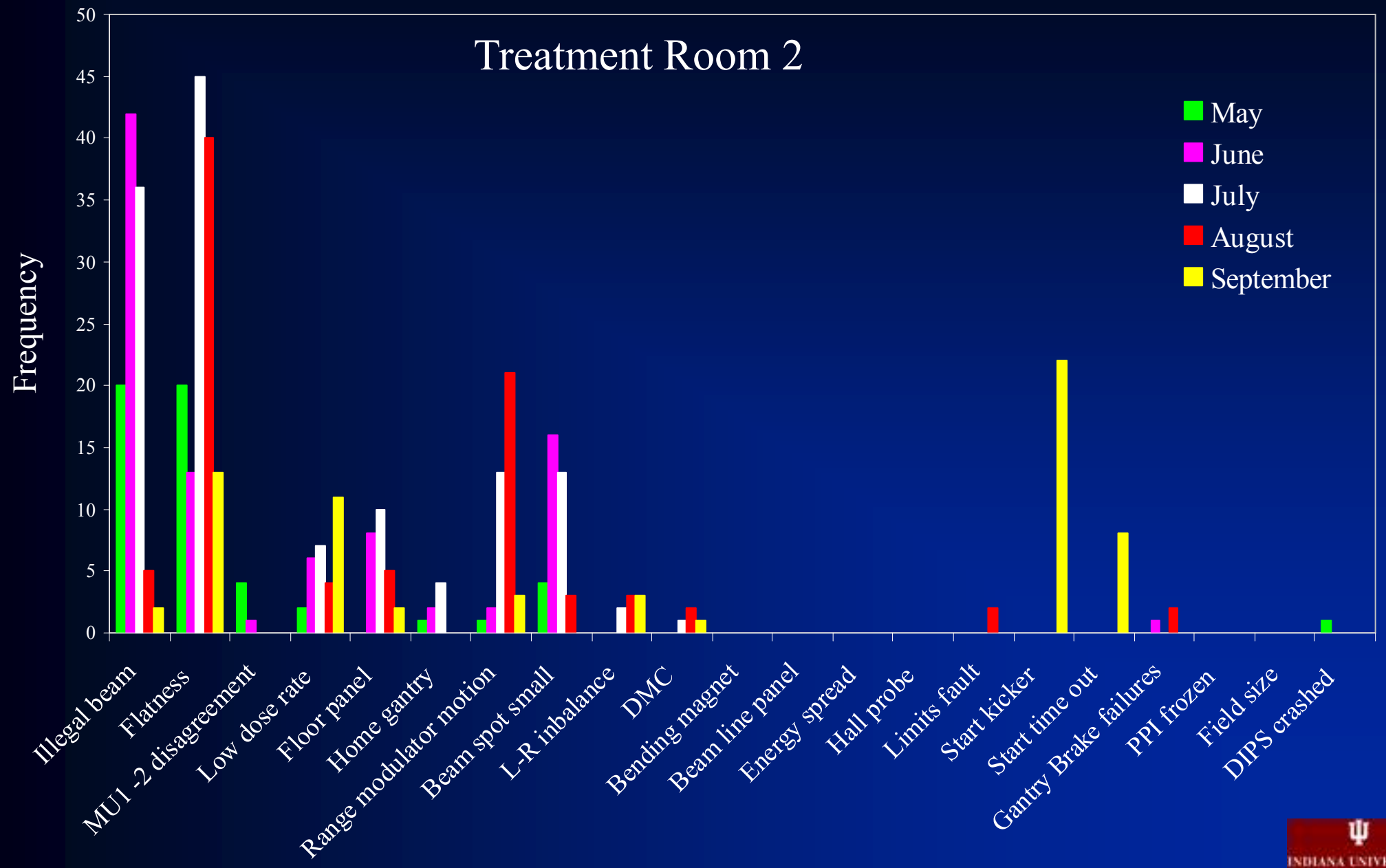


SOBP Creation Using Range Modulator

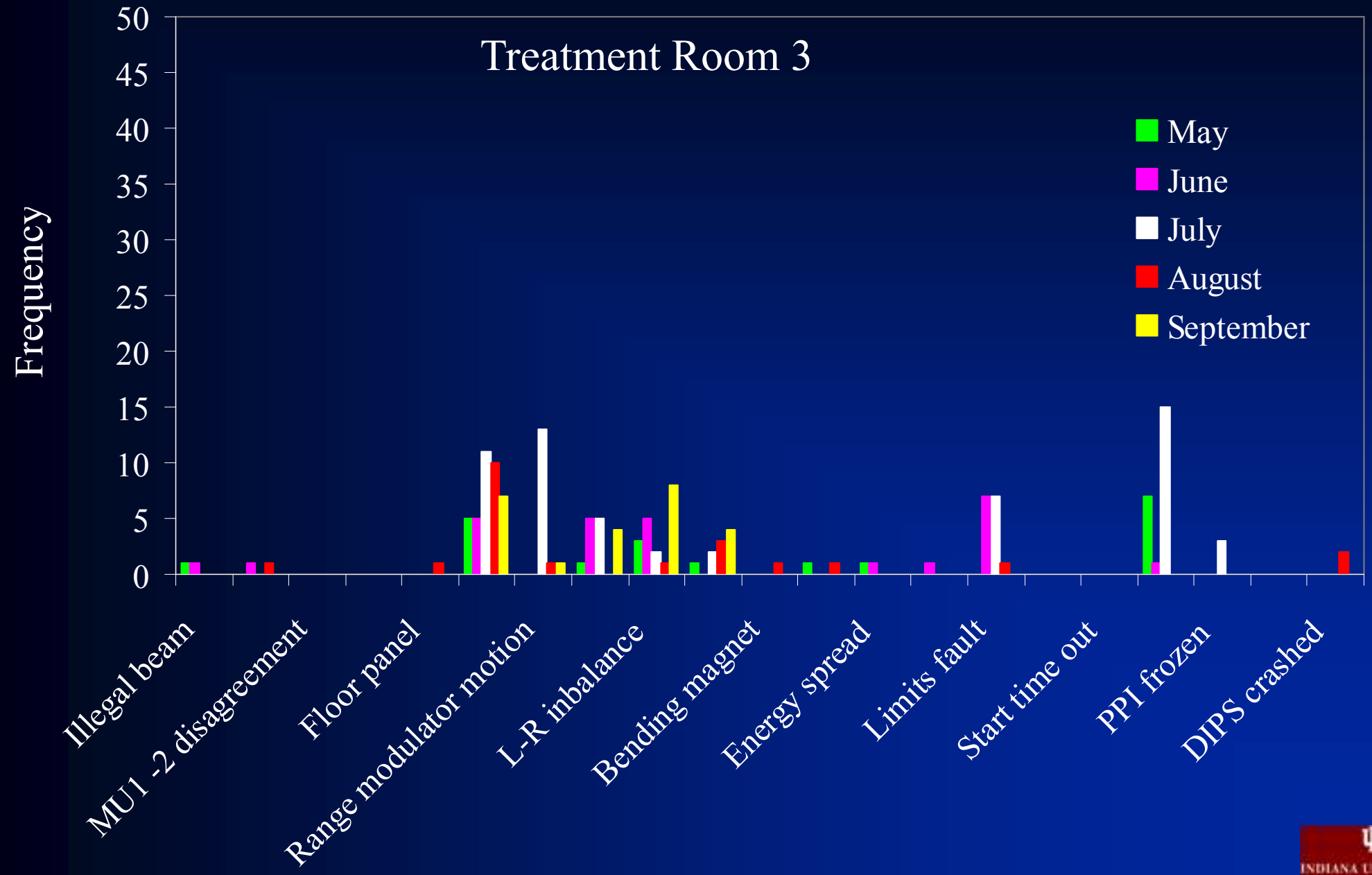
- SOBP files = Propellers
- Library 1 → 4-12 cm range in water
- Library 2→ 12-20 cm range in water
- Library 3 → 20-27 cm range in water

Each library contains SOBP files

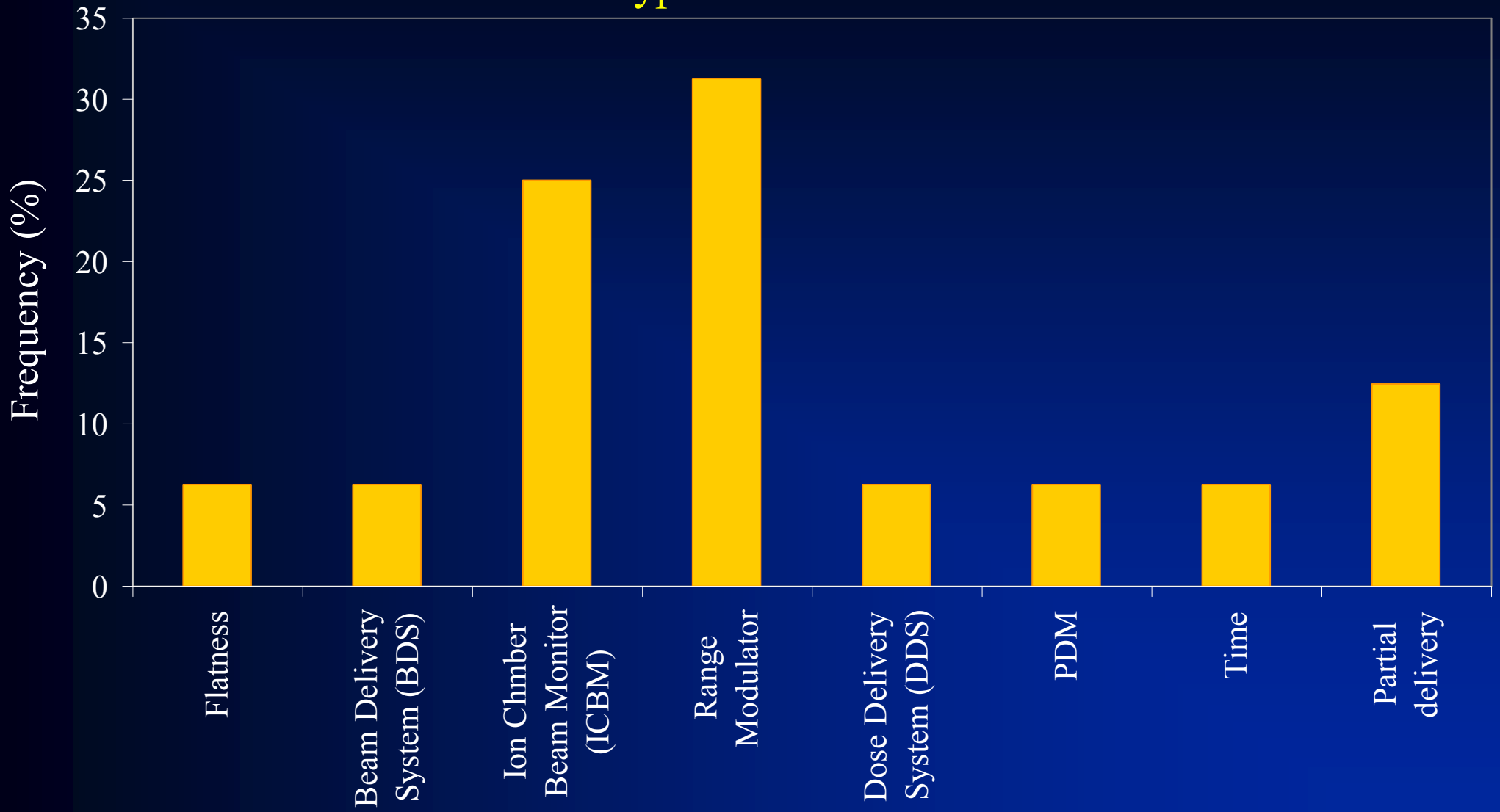
Frequency distribution of monthly faults at IUHPTC, 2009



Frequency distribution of monthly faults at IUHPTC, 2009



Typical Errors



Machine Specific QA (No guidelines)

Needs guidelines similar to TG-142

- Daily
  - Beam line
  - Flatness and Symmetry (Matrixx)
  - Absolute dose
  - Radiation Safety
- Monthly
  - Beam line
  - Flatness and Symmetry in 10, 20, 30 cm diameter snout
  - Absolute dose (water)
  - Range (Low, Medium and High) using MLIC
- Quarterly (optional of site dependent)
  - Mechanical
  - Selected QA, gantry and imaging system
  - Radiation Safety
- Annual
  - Comprehensive
  - Mechanical, Nozzle, DIPS
  - Dosimetry
  - Gantry angle dependence

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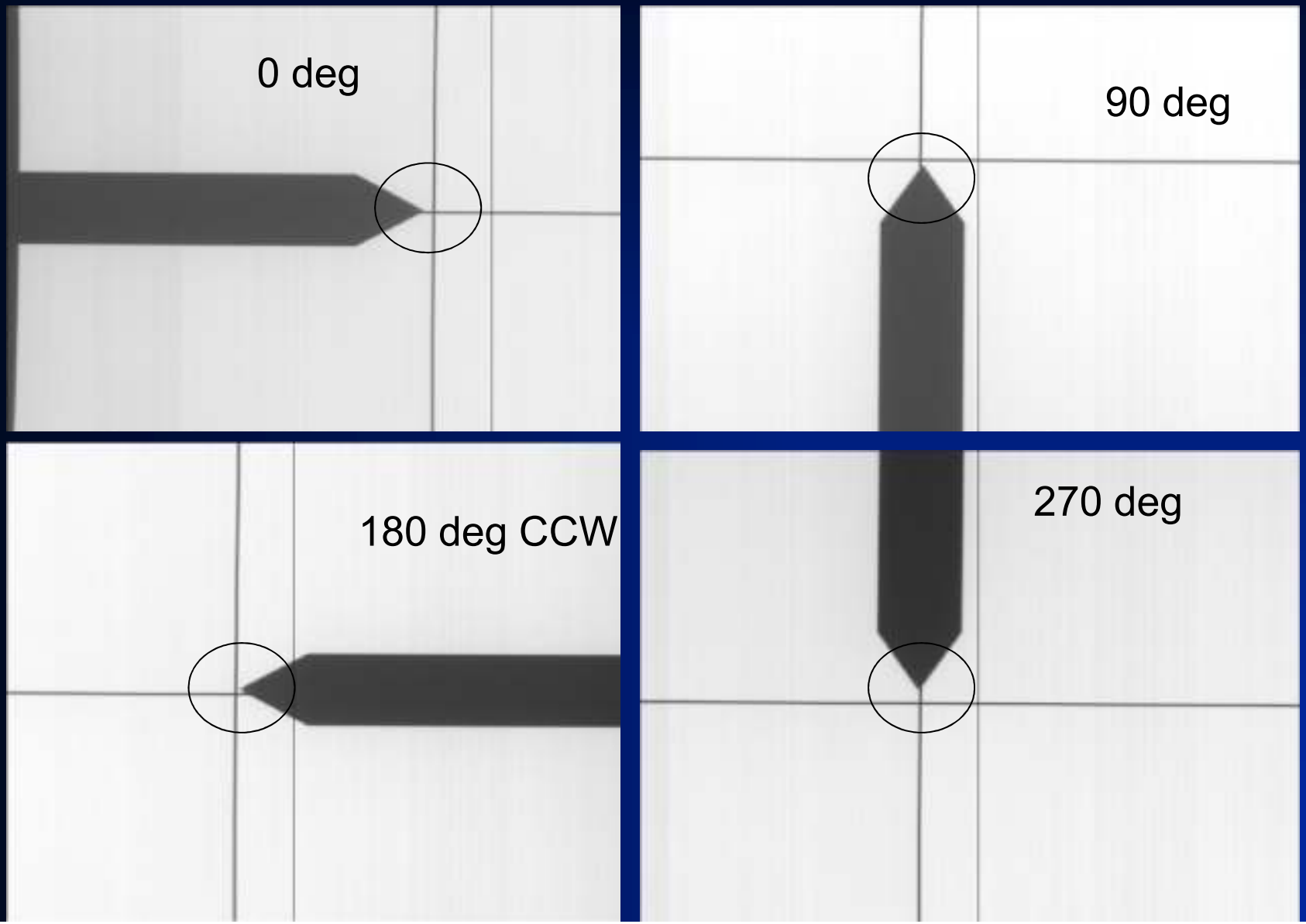
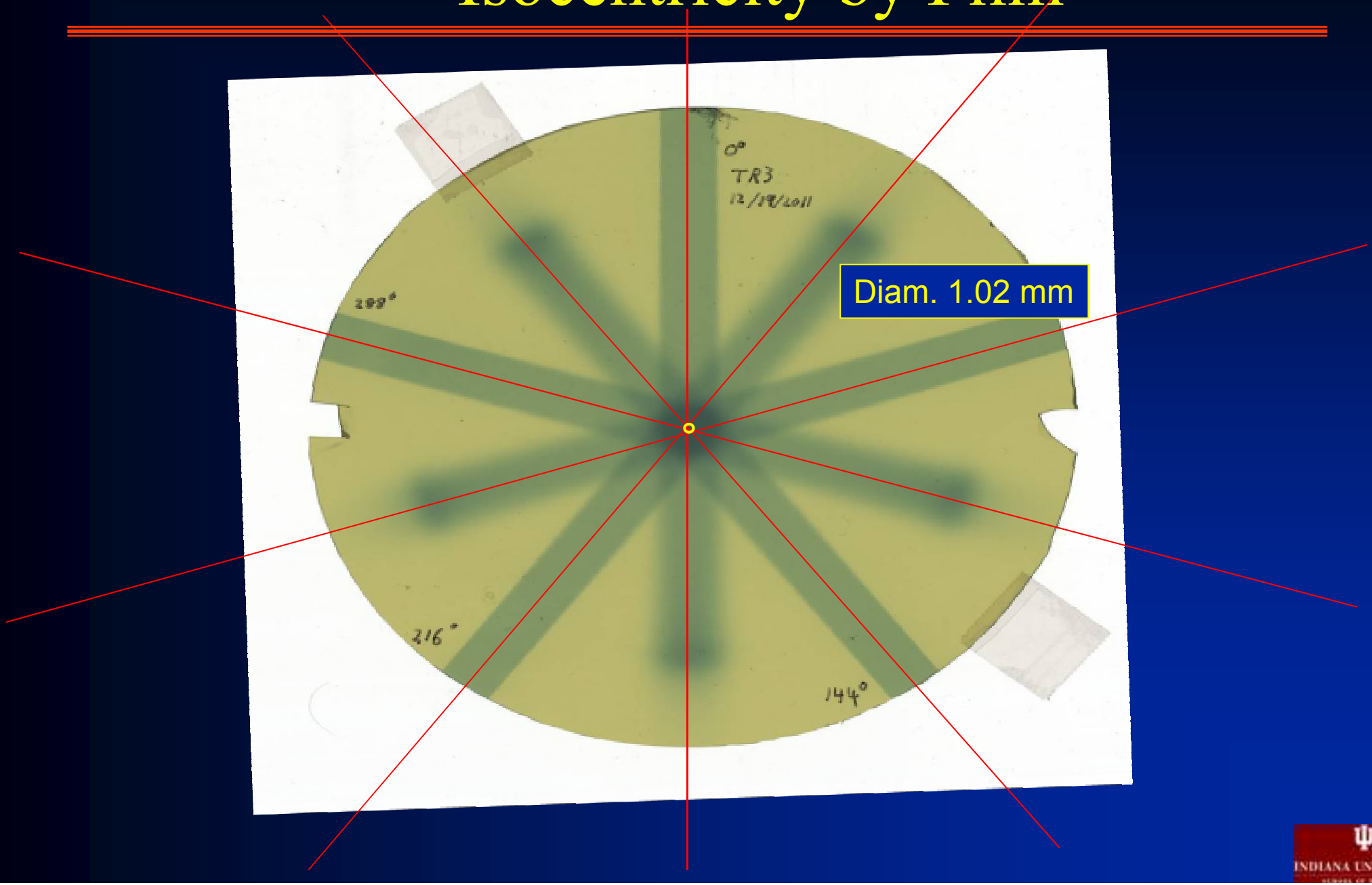
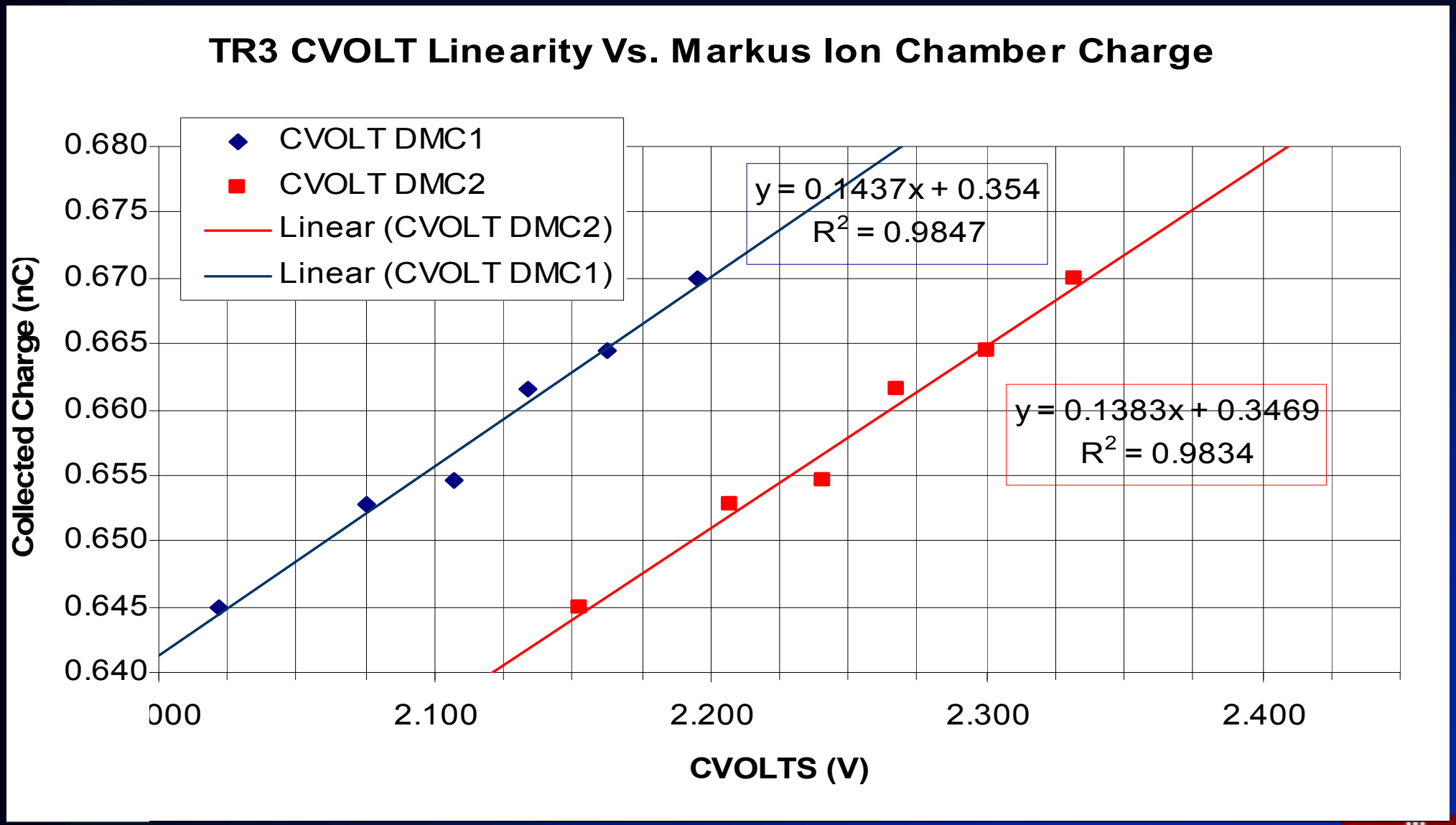
Mechanical Isocenter Check



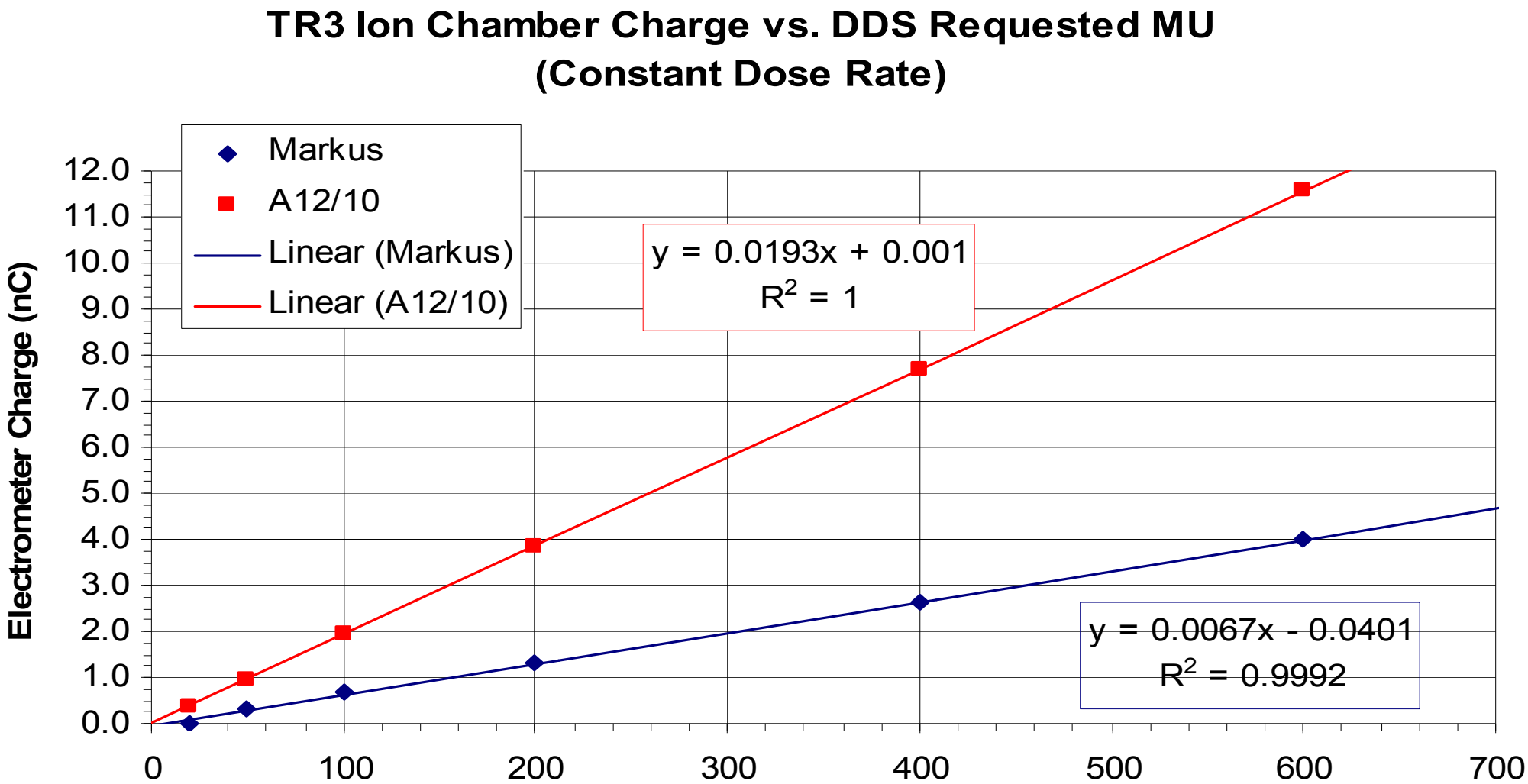
Isocentricity by Film



Linearity vs PDM Gain (Volt)

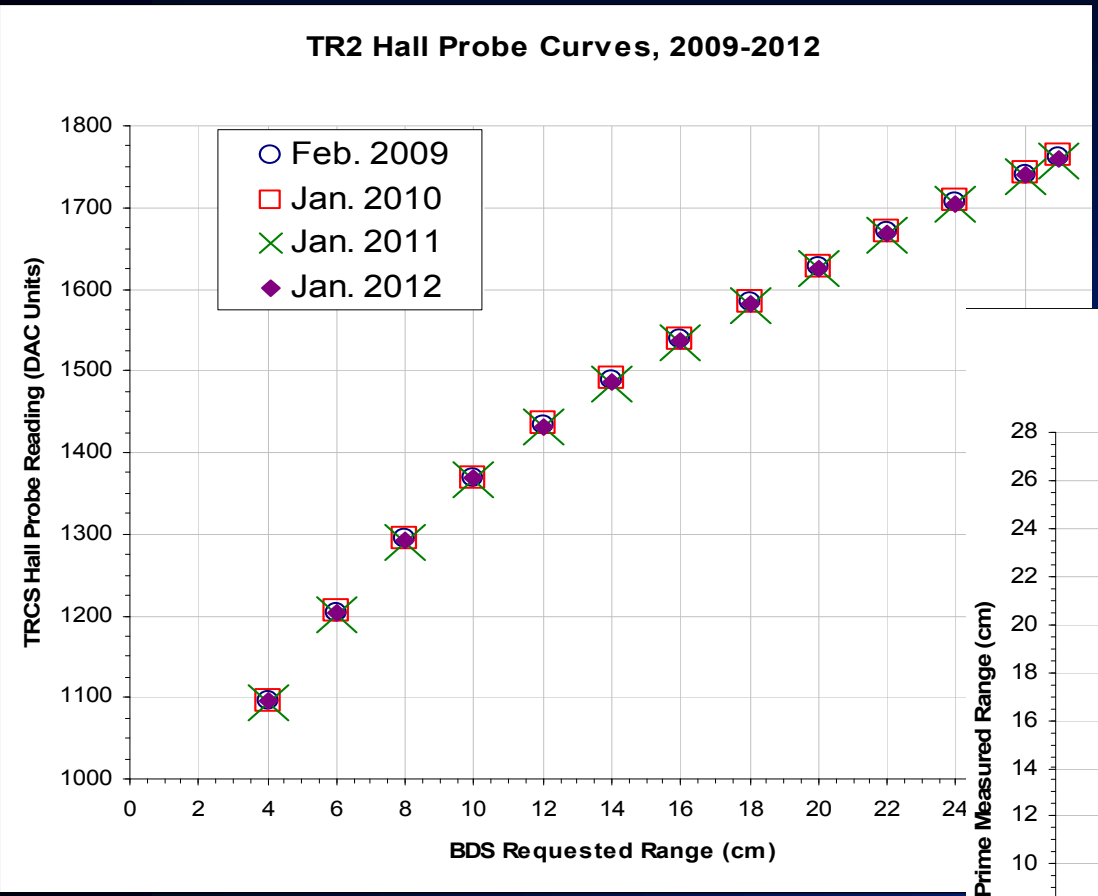


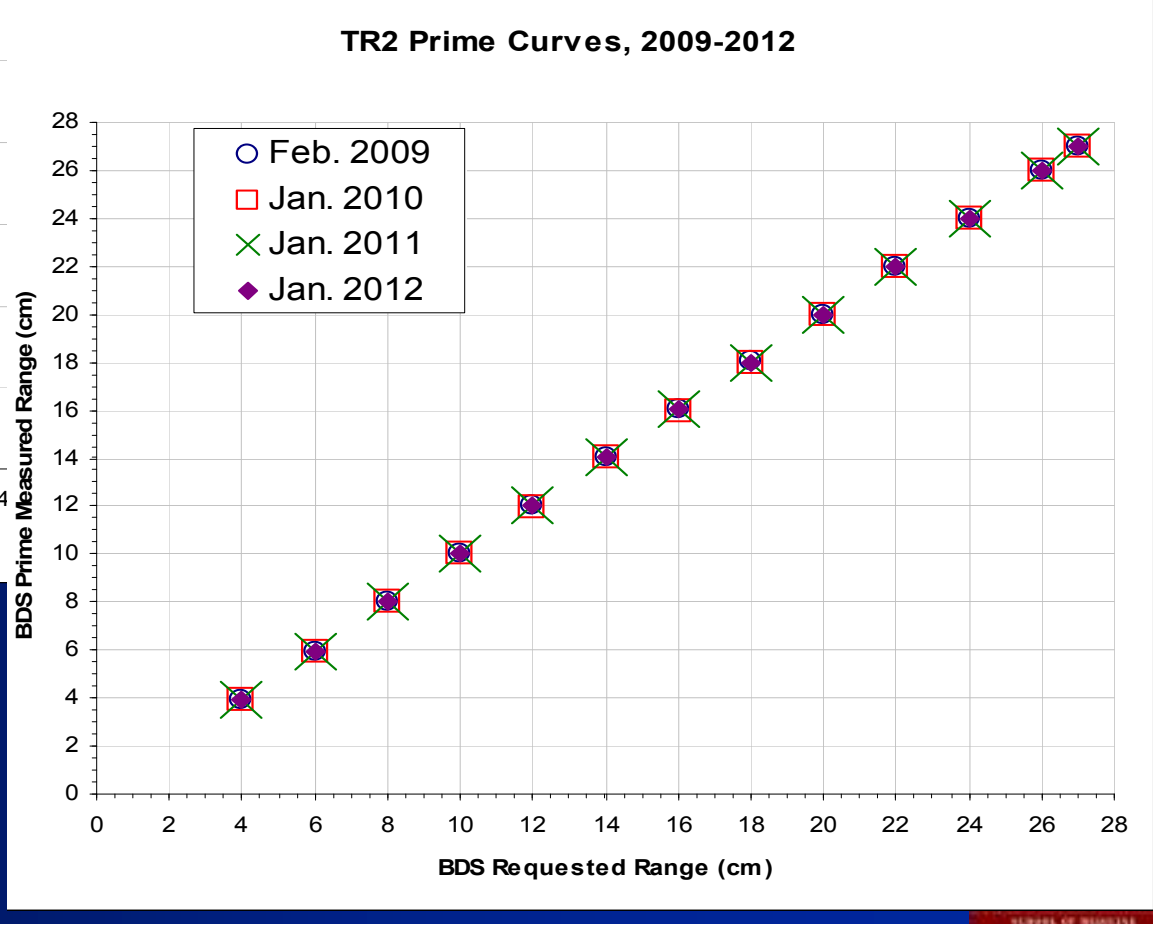
Dose Monitor Linearity



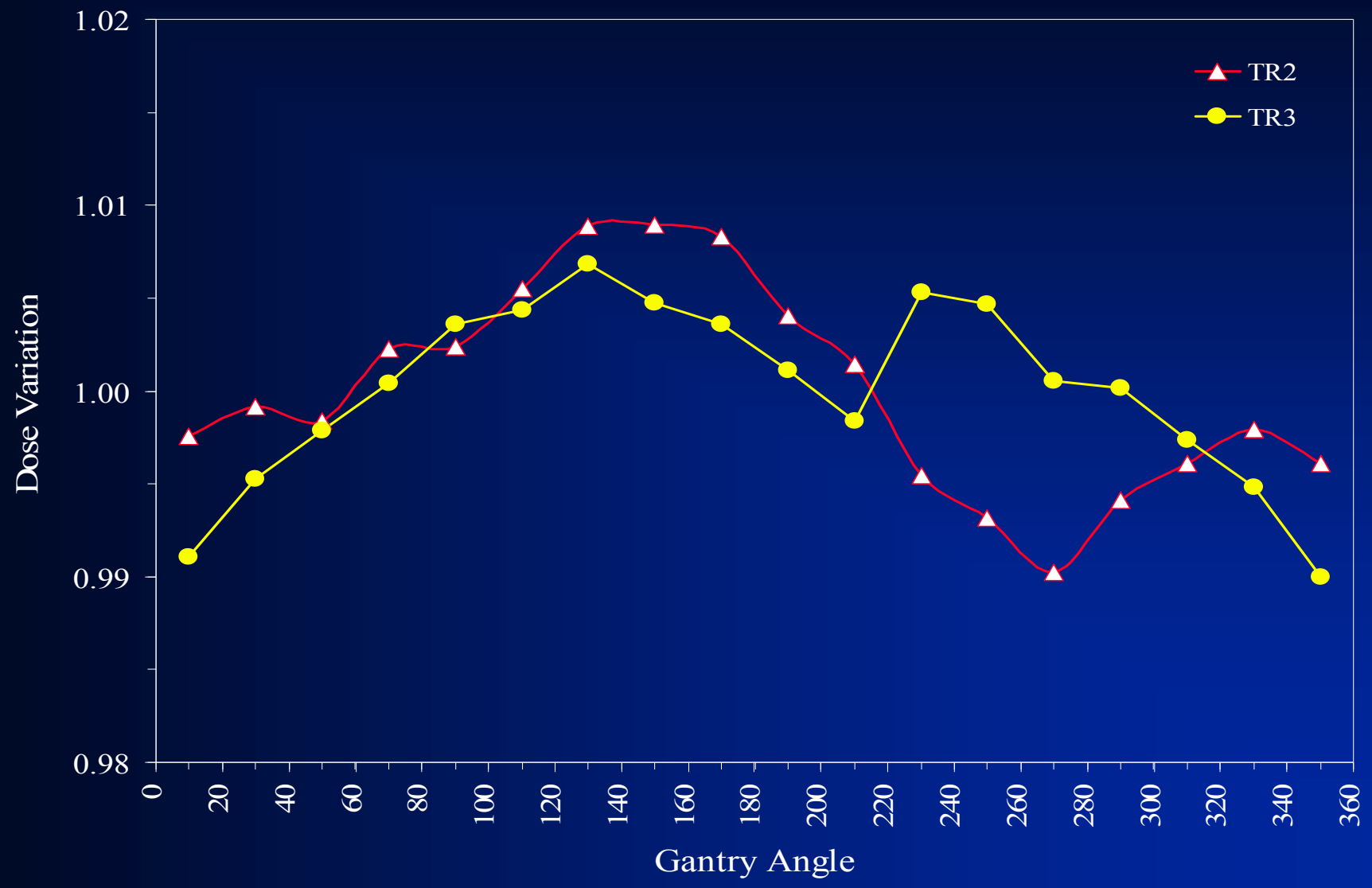
DDS requested MU

Parameter Reproducibility





Angular Dependence



Patient Support System

Treatment Table & Robotic systems QA

- Isocentricity
- Degree of freedom:
  (x, y, z), Pitch, roll, Yaw
- Motion accuracy
- Reproducibility
- Adoptability
- Compatibility
- Safety

Dose Delivery and Measurement

- Dose Monitoring Chamber
  - Pressure and temperatures dependence
  - Sensitivity to gantry orientation
  - High humidity: leakage current and ion recombination
    Dose and dose rate linearity
- Pencil beam scanning specific issues
  - Incomplete dose: Restarting error
  - Higher instantaneous beam intensities: Saturation and nonlinearity
  - On-off between each spot: should be very short to reduce error
  - Motion management is critical

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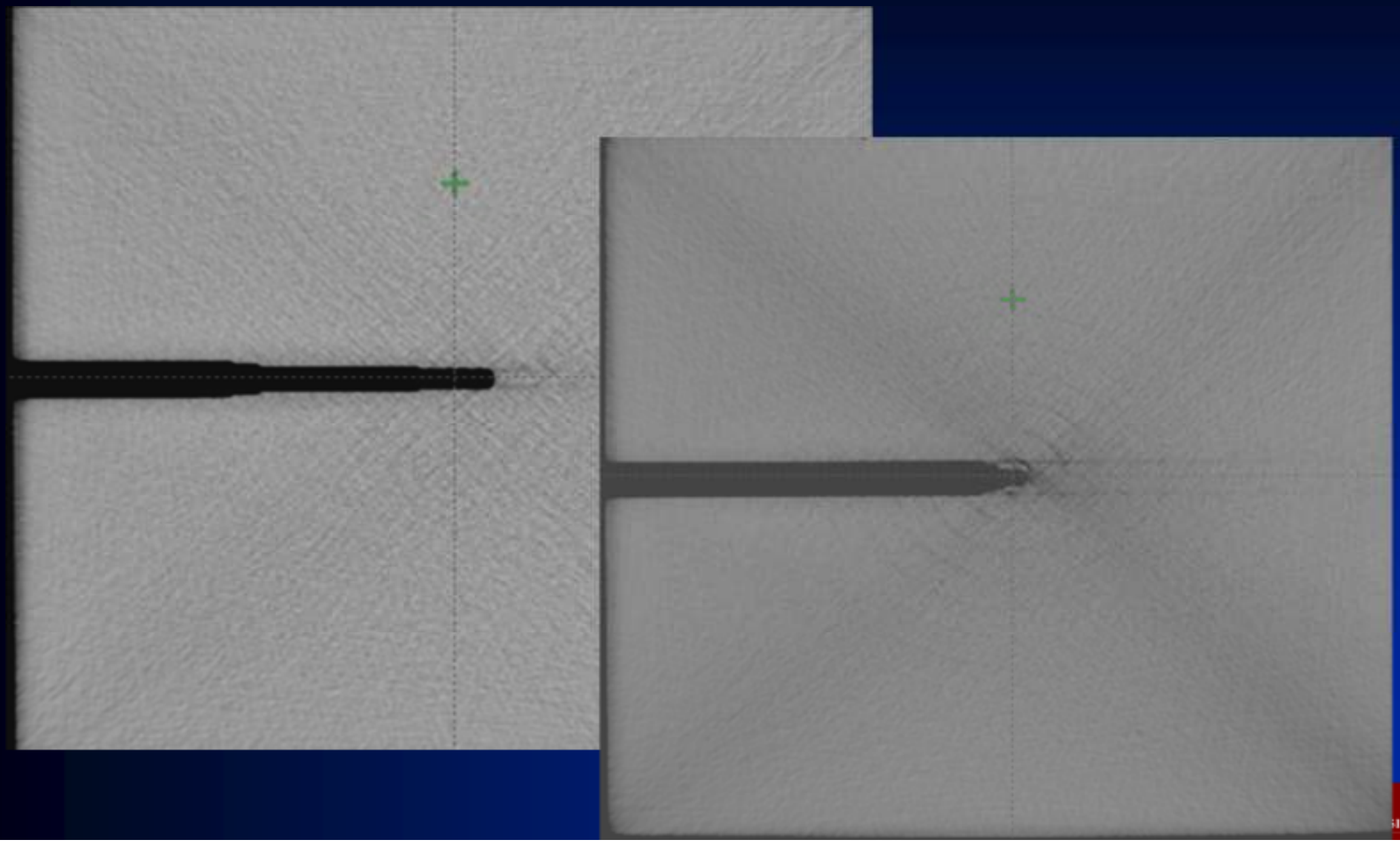
Error Associated with Solid water Phantom



Understand Detector, Connector & Cable

Srivastava et al, *Med Phys, 37(6), 3247, 2010*

Daily QA Parameters

Date: _____

Time: _____ Time Room Ready: _____

Alignment Checks	
1	Alignment of room las
2	Snout alignment
3	Snout position / PPIC
4	X-ray system alignme
5	Gantry alignment
6	Light field alignment
Safety Checks	
7	X-ray system acceler
8	Patient positioner acc
9	Beamline interlocks/s
10	Beamline xray
11	Floor panels
12	Barcode scanner
13	Patient distress butto
14	X-ray Collimators
15	Audio - Intercom
16	Camera and room mo
Beam Checks	
1	PPICS, DDS, BDS in
2	DDS motors and LCD
3	MIRS - Interlock and
21	Output Quality Assura
	Output = 0.99
	RCI1 = 2.17
	CV 1 = 2.07
	DDS: Pr = 9
22	Transverse Quali
	IP Flatness =
	CP Flatness =
Room Readiness	
23	Check RAF Box
	PP at Intm Position
	Gantry at 270degs
	Snout retracted
	Bed mech clamped lo
	Ap/Comp put away
	Deleted values in QA

Comments:

Alignment Checks

1	Alignment of room lasers at isocenter
2	Sn
3	Sn
4	X-
5	G
6	Li

Safety

7	X-
8	Pa
9	Be
10	Be
11	Fl
12	Ba
13	Pa
14	X-
15	Au
16	Ca

Beam Checks

1	PPICS, DDS, BDS in Dosimetry Mode; TRCS in Service Mode					
2	DDS motors and LCD backup counters working and recording					
3	MIRS - Interlock and radiation monitoring					
21	Output Quality Assurance					
	Output =	0.998	cGy / MU			
	RCI1 =	2.175	RCI2 =	2.417	ChamberID =	MatriXX
	CV 1 =	2.078	CV 2 =	2.315		
	DDS: Pr =	985.7	Tr =	20.4	Ctp =	1.0221
					Offs =	-0.0504
22	Transverse Quali					
	IP Flatness =	2.05%	IP Symmetry =	0.01%		
	CP Flatness =	2.28%	CP Symmetry =	0.31%		

Room Readiness

23	Check RAF Box		Reboot TRCS	
	PP at Intm Position		Pendant put away	
	Gantry at 270degs		MatriXX put away	
	Snout retracted		TRCS in Treat Mode	
	Bed mech clamped locked		DDS in Treat Mode	
	Ap/Comp put away		BDS in Treat Mode	
	Deleted values in QA sheet		PPICS in Treat Mode	

Dose Calibration

MPRI Proton Calibrations - TR1

Date: 01-Apr-09
Time: 06:21 AM

Ionization Chamber Number = 3

Ion Chamber Details

Chamber Name	Serial Number	Chamber Type	Last Calibrated	N_{DwQ} (Gy/C)	Nk [Gy/C]	A_{ion}	Awall
Markus	3997	Markus	14-Nov-07	5.615E+08	4.984E+08	1	1.003
Electrometer	**Electrometer Cal Fact**	K_Q	P_{ion}	P_{pol}	$\tau_{wall,d}$	$(\mu/\rho)_{air,wall}$	K_{hom}
INNOVISION 35040	1	1.002	1	0.999	1.102	0.925	0.997

Calibration Parameters

Monitor/Room (DDS) Temp =	20.3	°C
Ion Chamber Chamber temp =	19.2	°C
Room Pressure (mmHg) =	737.5	mmHg
Corrected Room pressure (mmHg) =	734.63	mmHg
Pressure (mBar) =	979.42	mBar
P_{Lp} =	1.025	
Field diameter =	10.00	cm
Air Gap (cm) =	5.00	cm
SOBP =	10.00	cm
Ref CVOLT1 =	6.132	
Ref CVOLT2 =	6.503	
REF CALIBRATION FACTOR	1.000	cGy/MU
Phantom Number =	1	
Selected Phantom =	Water Phantom	
Phantom Factor =	1	
R90% Range =	15.85	cm
Depth of Detector =	11.00	cm
Detector Position (IP;CP)	*CAX*	*cm*
Distal 10 % on BRAGG Peak =	16.350	cm

Measured Data

RESP. Q (nC)	DOSE A (MU)	DOSE B (MU)	MU - B Fraction	TIME (min)
0.8578	50			
0.8609	50			
	Average nC/MU_A		0.0172	nC/MU_A

OUTPUT

N_{DwQ} Based =	1.010	cGy/MU
Air Kerma Based =	1.001	cGy/MU
Average Dose Rate =	#DIV/0!	MU/min
TRS 398 =	*0.990*	*cGy/MU*
OUTPUT FACTOR =	*1.001*	
CVOLTS (Set on DMCs)	CVOLT1=	5.962
$P_{Lp\ DMC}$ = 1.029	CVOLT2=	6.322

COMMENTS

MORNING QA

Signed: RR/BA Date: _____ 01-Apr-09

updated 3/26/09 MW

C:\Documents and Settings\MPRI\Desktop\Master Cal Sheet Bar Correction V4.5 - TR1.xls4/1/2009

TRS-398 (New protocol)

Proton Calibrations -- TR2								
Calibration Data								
Ionization Chamber Number =	**3**							
Chamber	*PTW 23343*			**MEASURED RESPONSE**		**RATE (MU/mi**	100	
Serial Number	*3997*			**Q**	**DMC A**	**DMC B**	**DMC B**	**TIME**
Type	*Markus*			**(nC)**	**(MU)**	**(MU)**	**FRACTION**	**(min)**
Last Calibrated	*7-Nov-07*			1.729	100	99.8		1
				1.7267	100	99.8		1
NDwQ (Gy/)	*5.615E+08*							
k-Q	*1.002*							
k-ion (k-s)	*1.002*							
k-pol	*1.001*							
k-elec >> Verify for Electrometer <<	1.000							
Temperature at Barometer =	21.7	**˚C**						
Water Phantom Ion Chamber Temp =	19.5	**˚C**						
Barometer Pressure (mmHg) =	744.8	**mmHg**		**Average nC/MU A:**			*0.0172785*	
Corrected Barometer Pressure (mmHg	*741.7*	**mmHg**						
Pressure (mBar) =	*988.8*	**mBar**				**TRS 398**	*0.991*	**cGy/MU**
k-t,p (field chamber)=	*1.016*							
REF CALIBRATION FACTOR	1.000	**cGy/MU**			**OUTPUT FACTOR**		**0.991**	
Field diameter OR Name =	10	**cm**						
Air Gap (cm) =	5	**cm**						
SOBP =	10	**cm**						
R90% Range =	15.8	**cm**		**Ref CVOLTS**		**CVOLTS (Set on DMCs)**		
Depth of Isocenter	11	**cm**		**Ref RCI1 =**	2.044	**CVOLT1=**		
Depth of Detector =	11	**cm**		**Ref RCI2 =**	2.439	**CVOLT2=**		
Detector Position (IP;CP)	CAX	**(cm, cm)**						
COMMENTS				**Signed**		**Date**		

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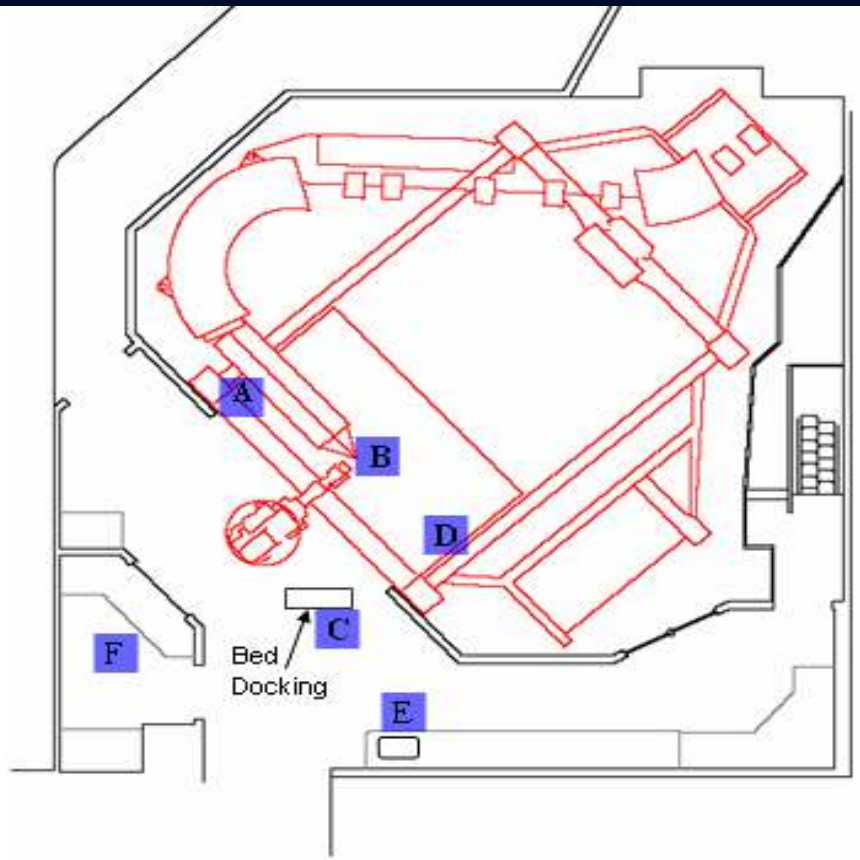
TR 2,3 Radiation Survey Map



Tolerances

Position A: < 100mRem/hr

Position B: < 10mRem/hr

Position C: < 5mRem/hr

Position D: < 5mRem/hr

Position E: < 2.5mRem/hr

Position F: < 2.5mRem/hr

Figure 1 - TR2 Radiation Testing Positions

Measured Exposure Rates:

Date: ____ / ____ / ____

Position A: = _____ mRem/hr

Position B: = _____ mRem/hr

Position C: = _____ mRem/hr

Position D: = _____ mRem/hr

Position E: = _____ mRem/hr

Position F: = _____ mRem/hr

Signed: _____

Neutron Safety

Facility	H_2O range (cm)	Field size	SOBP (cm)	Off axis distance (cm)	Neutron d (mSv/G
HIMBC wobbling (Yonai *et al.*, Ref. 28)	27	5×5 cm^2	6	50	**1.15**
HIMBC wobbling (Yonai *et al.*, Ref. 28)	16	5×5 cm^2	6	50	**0.5**
MPRI, U-scan (this experiment)	27	10 cm diam	10	40	**0.97**
MPRI, U-scan (this experiment)	16	5 cm diam	10	40	**0.5**
MPRI, DScatt (this experiment)	16	10 cm diam	10	40	**0.8**
Tsukuba, DScatt (Tayama *et al.*, Ref. 6)	15.5	11×11 cm^2	10	40	**1.0**
Harvard, DScatt (Yan *et al.*, Ref. 2)	16	5×5 cm^2	8.2	50	**4.8**
LomaLinda, DScatt (Moyers, Ref. 9)	30	14 cm diam	Pristine	55	**1.96**
PSI, spot scan (Schneider *et al.*, Ref. 16)	20.7	10×10 cm^2	10	50	**0.08**

Hecksel et al, Med Phy, 37, 1910-1917, 2010

Patient Specific QA

- Aperture
- Compensator
- Automatic precision measurements
- CMM at least 10% of the data
- Manual check at least 4 points
- Measure
  - The range with MLIC
  - Uniformity
  - Dose if needed or use mathematical model
  - Measure cGy/MU
  - Use proper correction

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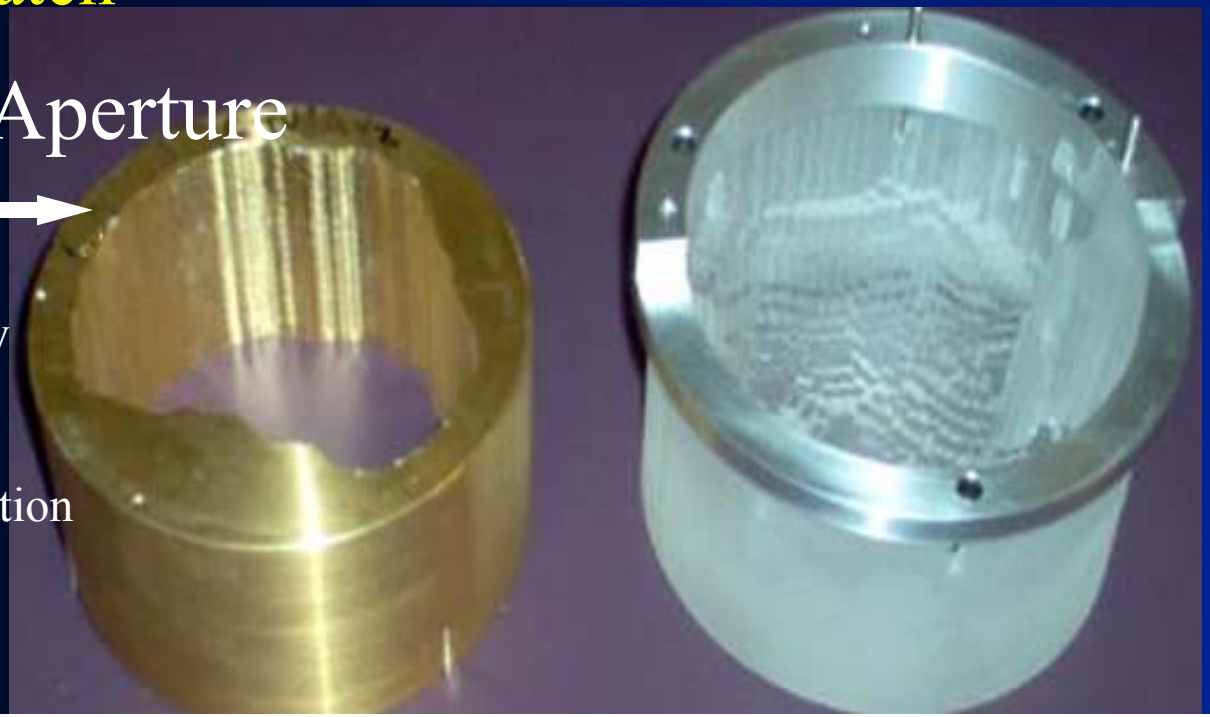
Proton Snout, sizes, 10, 20, 30 cm diameter

Snout latch

Brass Aperture



1. Accuracy
2. Weight
3. Composition

Lucite Compensator

1. QA on depth and fidelity of drilling
2. Minimum thickness of integrity
3. Quality of plastic (vendor variability)
4. Safety: Mechanical attachment issue

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MLIC: Multi-Layer Ion Chamber

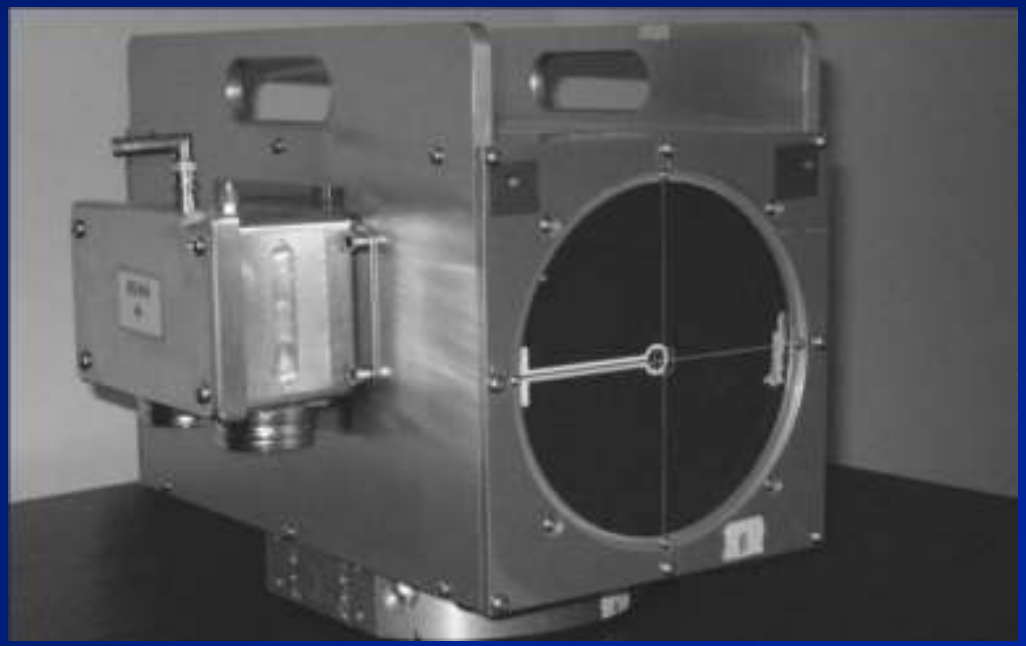
Multichannel detectors for profile measurements in clinical proton fields

Dmitri Nichiporov[a] and Keith Solberg
Indiana University Cyclotron Facility, 2401 Milo B. Sampson Lane, Bloomington, Indiana 47408

Wen Hsi, Mark Wolanski, Anthony Mascia, and Jonathan Farr
Midwest Proton Radiotherapy Institute, 2425 Milo B. Sampson Lane, Bloomington, Indiana 47408

Andries Schreuder
ProCure Treatment Centers, Inc., 115 North College Avenue, Suite 210, Bloomington, Indiana 47404

- Polystyrene plates with a 6 mm diameter signal spot
- Plates, 16 cm x16 cm, are separated with 1.0 mm air gaps
- 122-channel
- Total water-equivalent depth of the detector is about 220 mm
- Can be used with different gas



Nichiporov et al, Med Phys, 34, 2683, 2007

Dose Calculation & Modeling

- Patient specific measurements
  - Manpower
  - Accuracy limited to point selection
  - Open vs closed (with compensator)
- Model based
  - MGH: Kooy *et al. Phys Med Biol* 2005;50:5847-5856.
  - MDA: Sahoo *et al. Med Phys* 2008;35:5088-5097.
  - IU: Zhao *et al. Phys Med Biol* 2010;55:N87-95.
- TPS
  - Work in progress
- Monte Carlo
  - Work in progress

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Phys. Med. Biol. 55 (2010) N87–N95 doi:10.1088/0031-9155/55/3/N02

NOTE

A sector-integration method for dose/MU calculation in a uniform scanning proton beam

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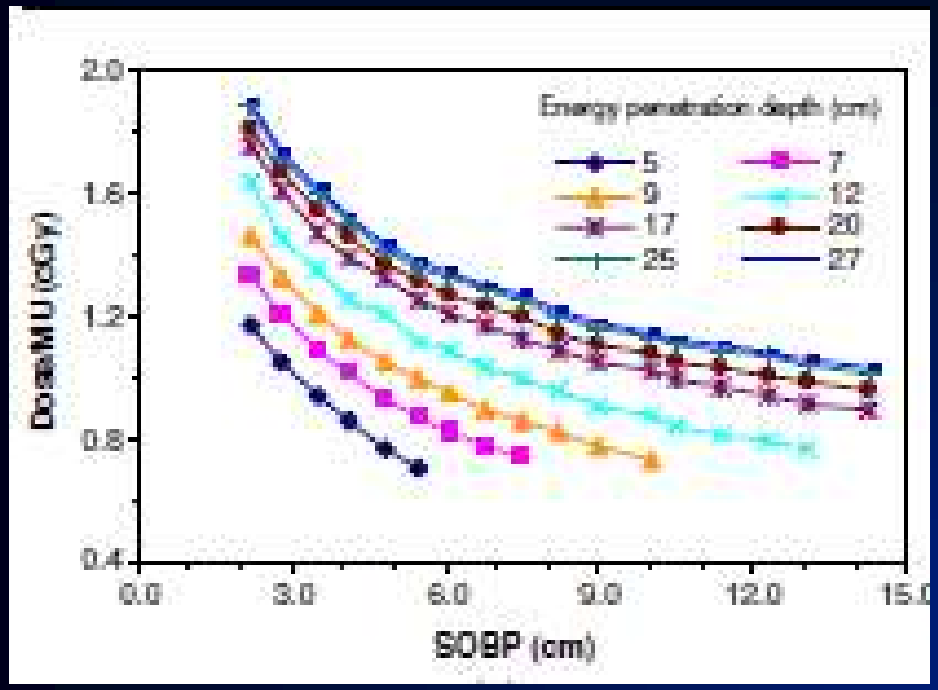
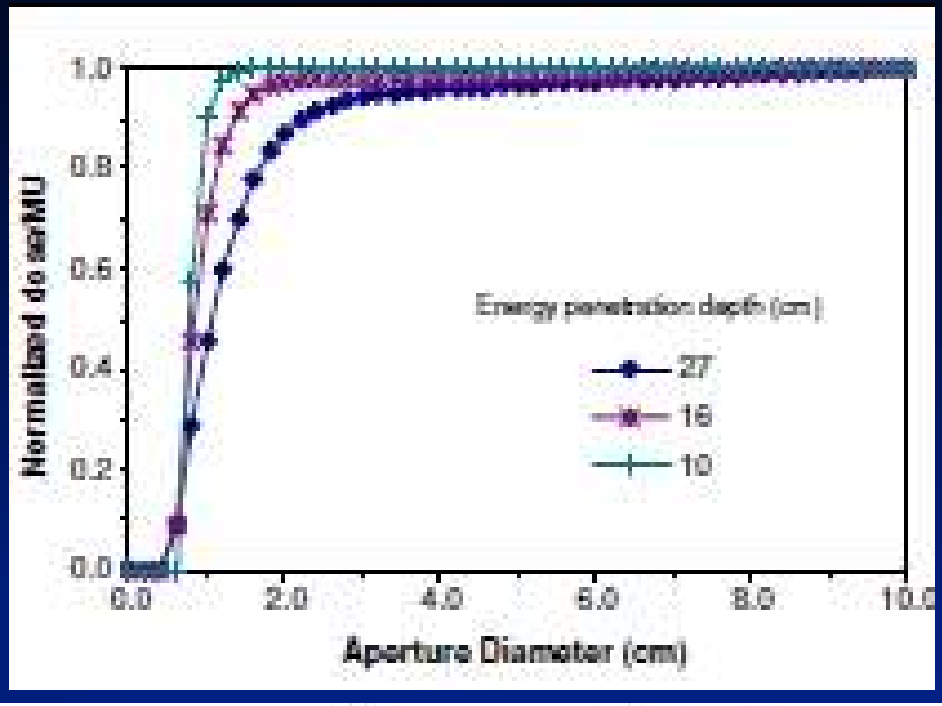
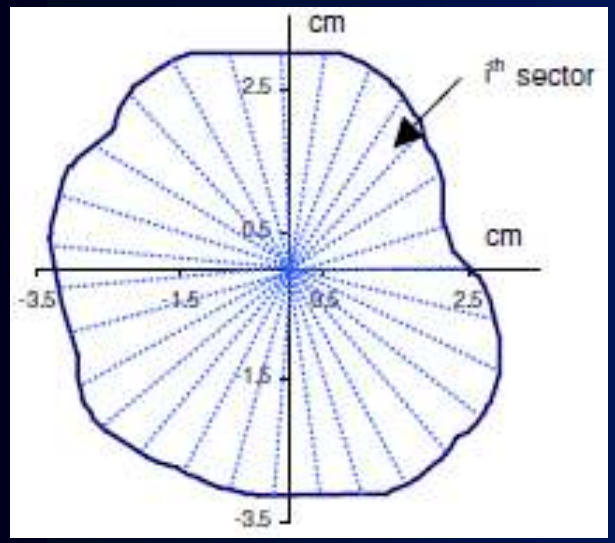
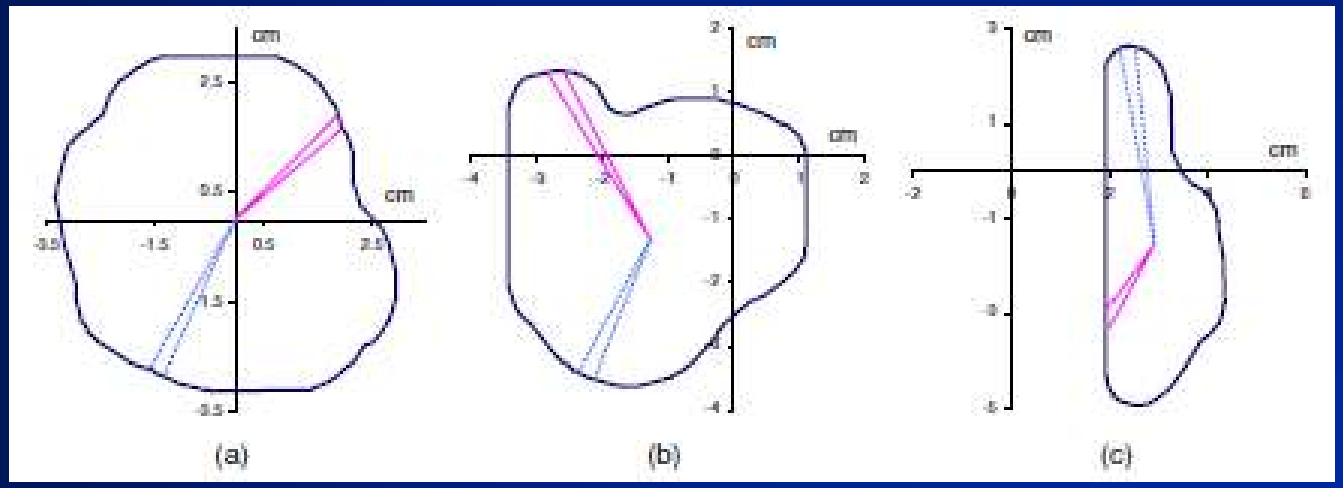
MU Calculation Model



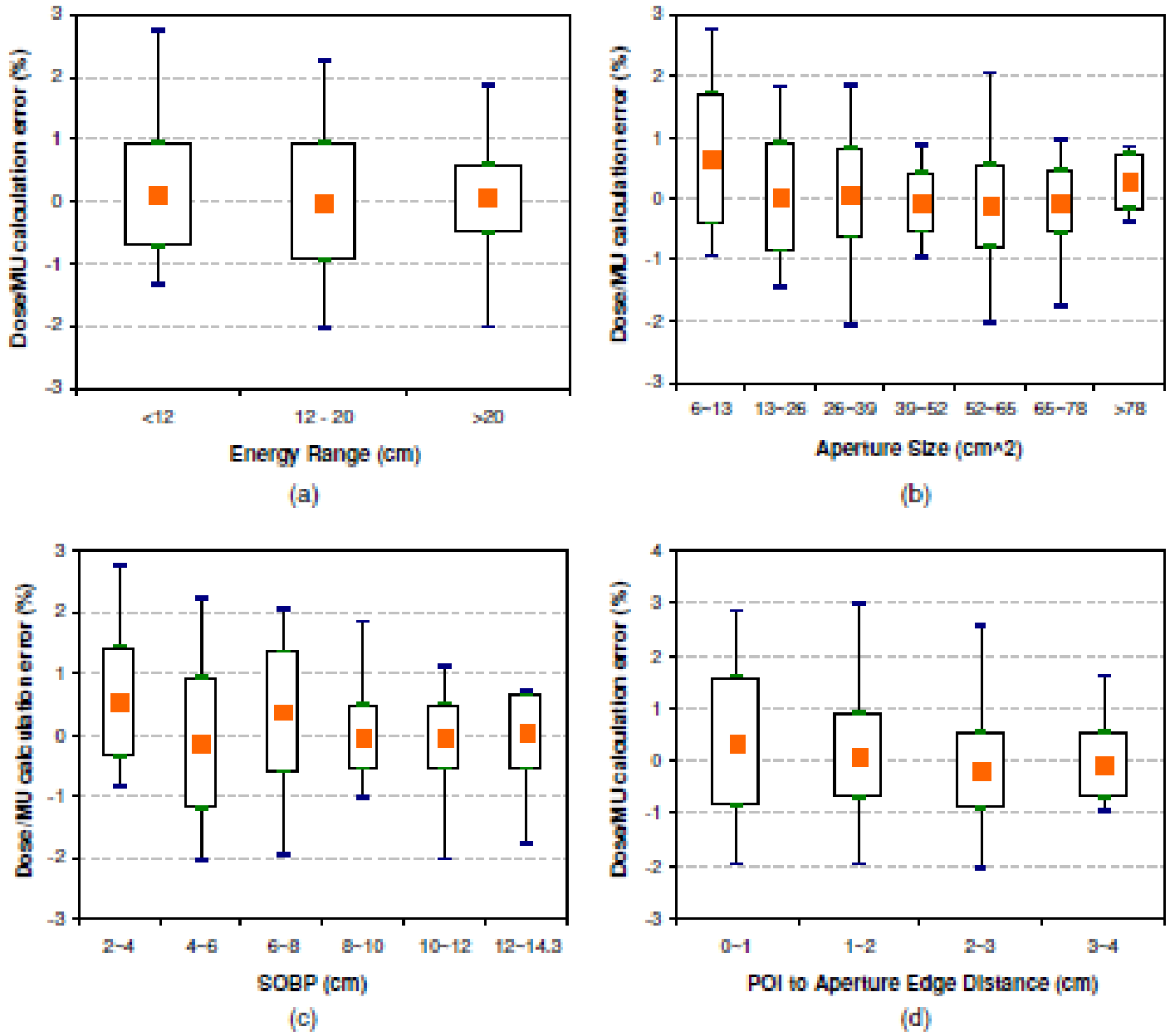






Zhao et al, Phys Med Biol,55, N87-95, 2010

Error Estimation in Model



Dose monitoring and output correction for the effects of scanning field changes with uniform scanning proton beam

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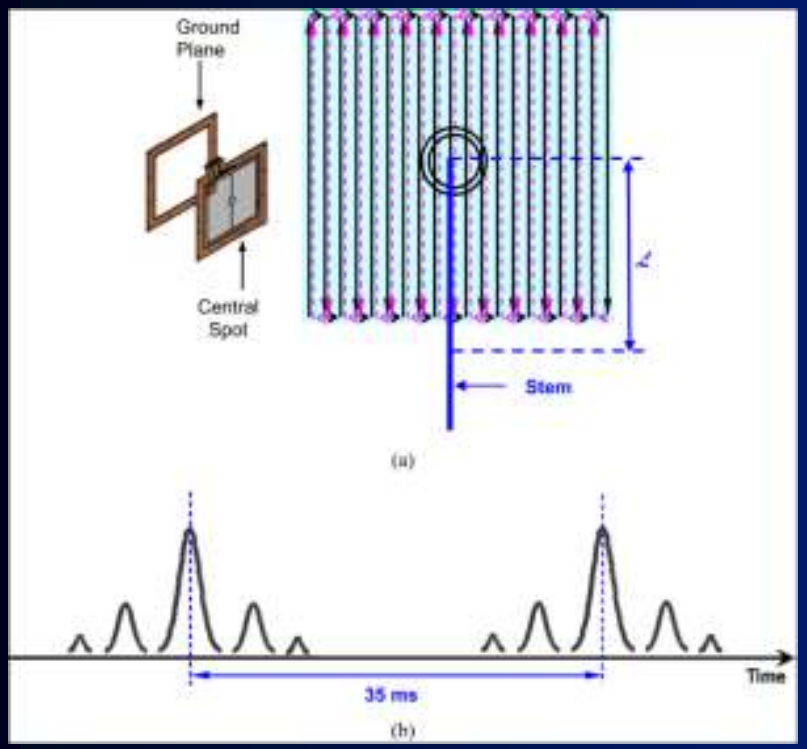
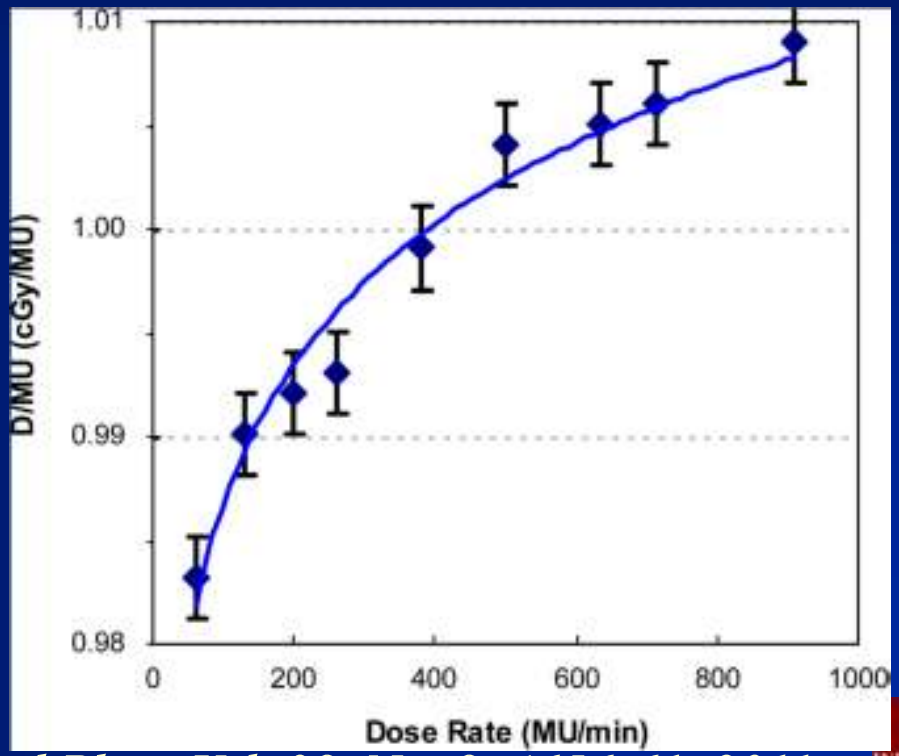
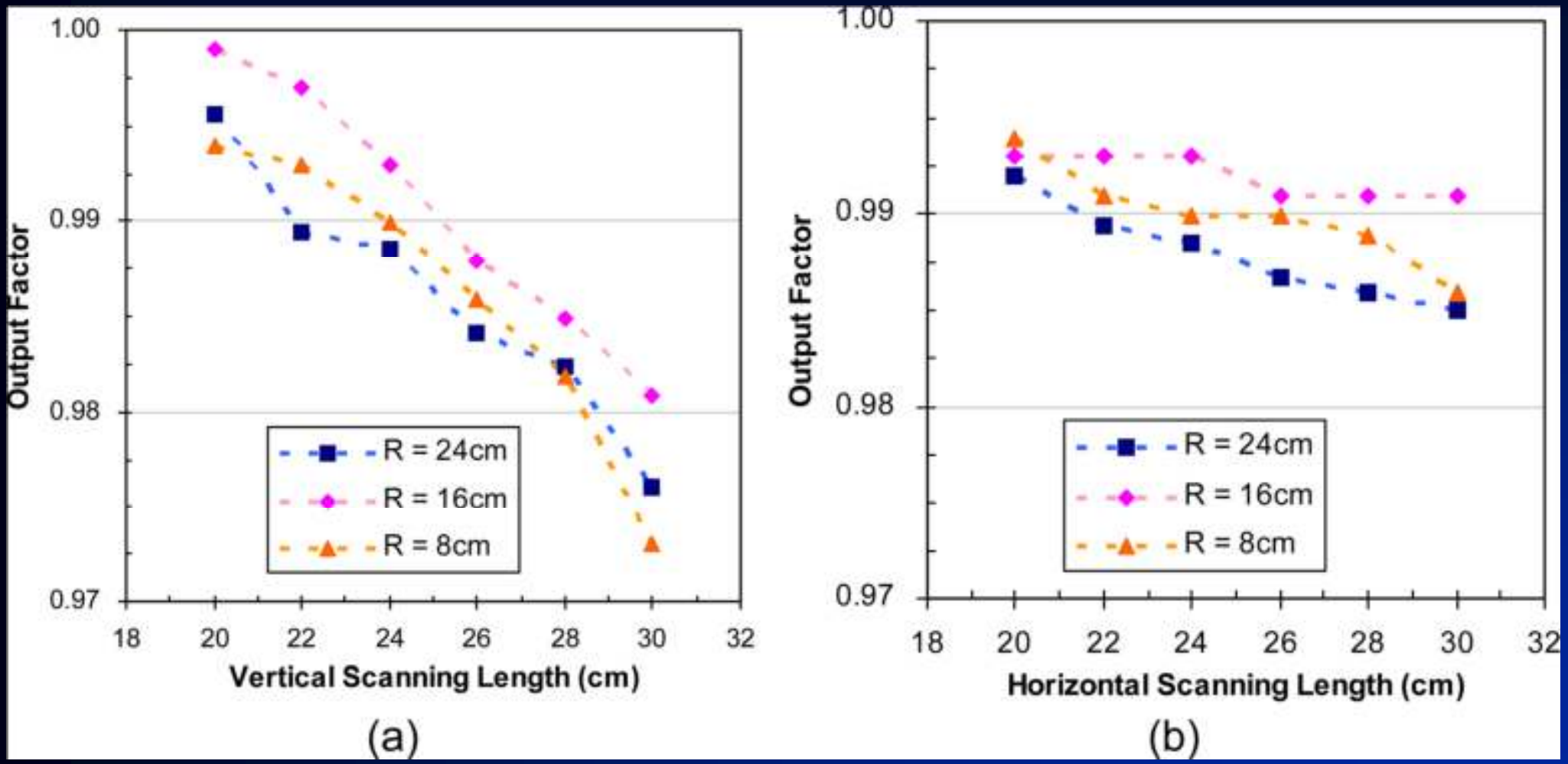




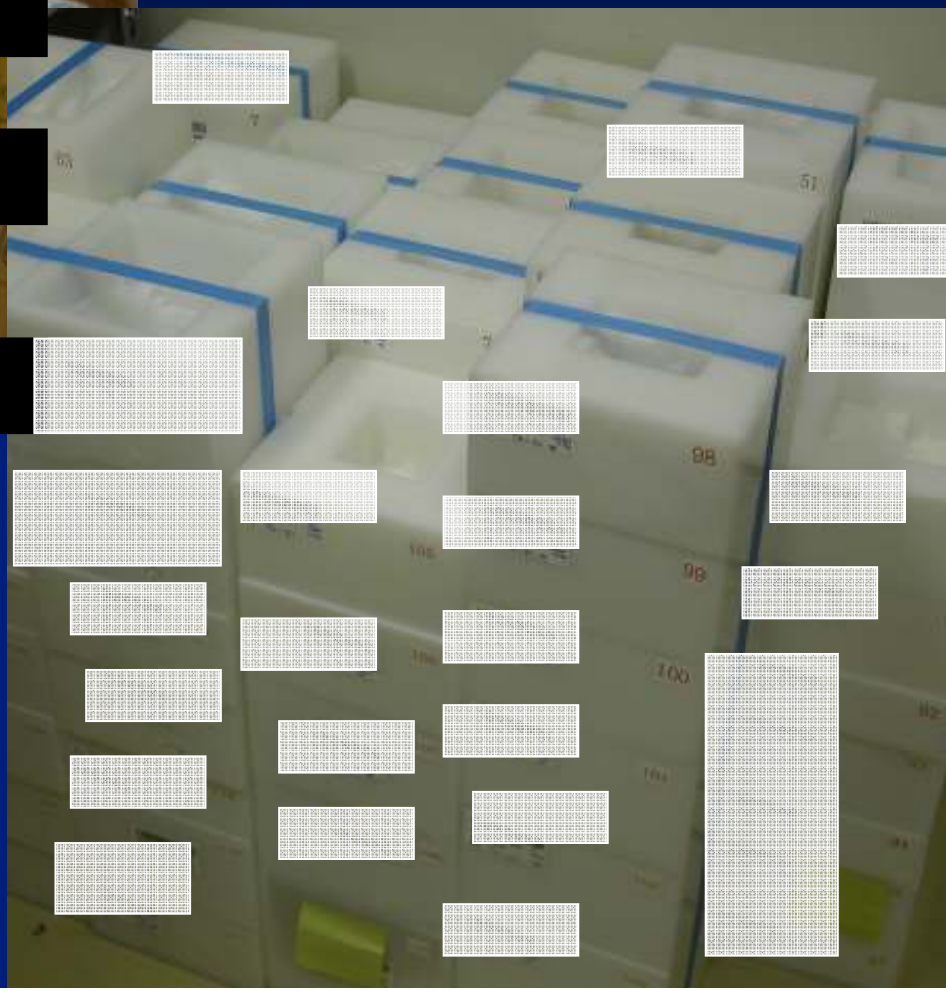
Zhao et al. Med Phys. Vol. 38, No. 8, 4656-61, 2011

Extracameral Effect in Scan Dose Monitoring



Zhao et al, Med Phys, Vol. 38, No. 8, 4656-61, 2011

Waste (Radioactive)



Radioactive storage issue

Radiation exposure

Neutron dose to patient

MLC

- Das I, Akagi T, Kagawa K, et al. Geometric and dosimetric characteristics of a proton beam multileaf collimator (MLC). Med Phys 2004;31:1797 (abs)
- Diffenderfer ES, Ainsley CG, Kirk ML, *et al.* Comparison of secondary neutron dose in proton therapy resulting from the use of a tungsten alloy MLC or a brass collimator system. *Med Phys* 2011;38:6248-6256.
- Moskvin V, Cheng CW, Das IJ. Pitfalls of tungsten multileaf collimator in proton beam therapy. *Med Phys* 2011;38:6395-6406.

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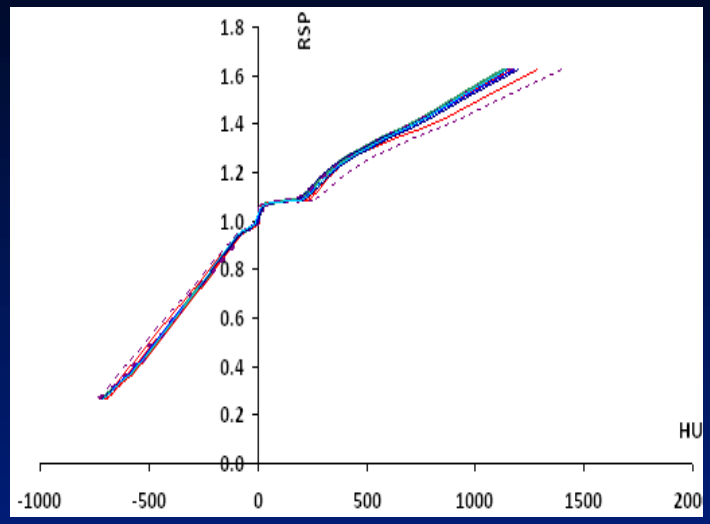
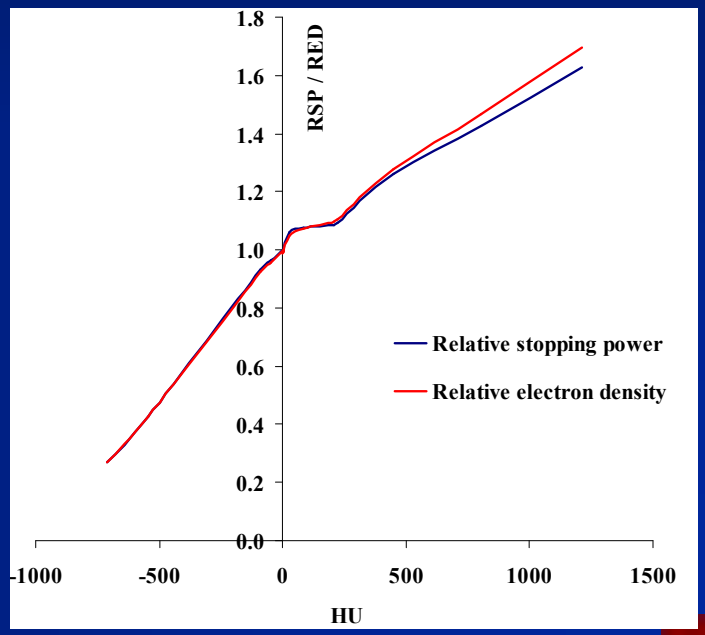
Views of Mitsubishi MLC

Das et al. Med. Phys., 31(6), 1797, 2004

Safety & Quality Issues in Rx

- Treatment processes
  - Immobilization
  - CT-scan (CT-RED and RSP)
  - Planning (algorithms)
  - PSD fabrication
- Treatment
  - Setup
  - Imaging (target localization)
    - DIPS
    - CBCT
    - CT on rail
    - PET
    - Other





Closing Note

- Beam parameters in scattering and scanned beam may be machine, vendor and treatment room specific that should be periodically checked
- Daily, Monthly, Quarterly and annual QA
- Patient specific QA include range, flatness, absolute dose and Dose/MU
- Changes in beam current and its implication in dosimetry should be evaluated including extra cameral effect Patient Specific QA along with model
- Safety, mechanical and radiation check at periodic interval
- Continuous quality check on PSD
- Interlock and warning signs must be respected

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http://iuhealthprotontherapy.org/about/staff/medical-physics-team/