MASSACHUSETTS GENERAL HOSPITAL

RADIATION ONCOLOGY

The MGH Experience with a Single Room Proton Therapy System

Modern Single Room Proton Therapy Installations: Challenges and Opportunities for the Medical Physicist

Marc Bussière, MSc DABR, Director of Stereotactic Physics (photons and protons)
on behalf of the MGH proton therapy team with special thanks to Ben Clasie

AAPM Annual Meeting, July 2022

OBJECTIVES

Overview of MGH experience prior to introducing the single room system

Motivation for single room system

Introduction to MGH-Protom system

Process and effort required from install to 1st delivery

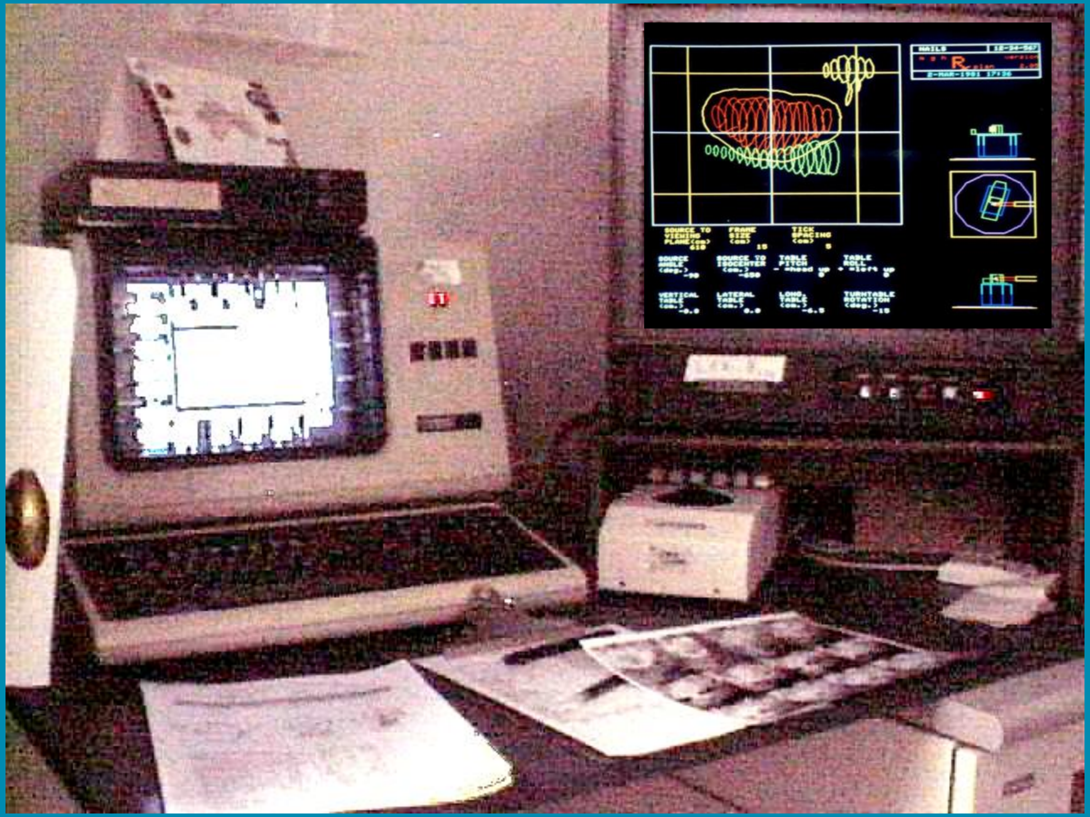
Ongoing QA

Challenges and opportunities for physicists

MY EXPERIENCE: 30 YEARS WORKING WITH PROTONS

HARVARD CYCLOTRON LABORATORY / MGH (95” cyclotron, 3 horizontal fixed passive-scattering beamlines)

- 95” cyclotron 160 MeV
- 3 horizontal fixed passive scattering beamlines
- accelerator maintenance by HCL staff
- discrete number of large modulation wheels
- custom apertures and range compensators
- in-house TPS (X/P)
  - flat SOBP
  - pasted distal and lateral fall-off
- each field’s range and output measured



MGH 1811

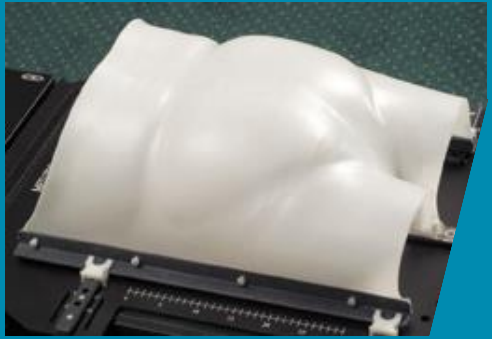
MY EXPERIENCE: 30 YEARS WORKING WITH PROTONS

HARVARD CYCLOTRON LABORATORY / MGH

1 Fractionated Fixed Beamline (double scattering, maximum WET: 16.3 cm)

- Linac treatments 1 day per week

- supine, pitch/roll ± 10° (R, L, R/L coronal obliques), conventional CT
    - cranial, H&N, body
    - “conventional” immobilization



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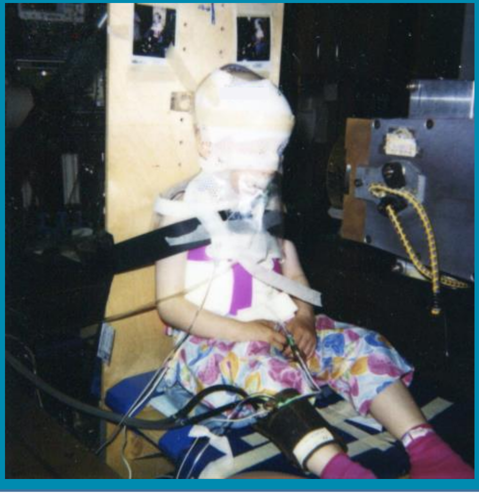
- seated (A, P, R, L, axial obliques), <u>vertically mounted CT</u>
  - cranial, H&N, body
  - complex immobilization incl. orthopedic casts and modifiable supports



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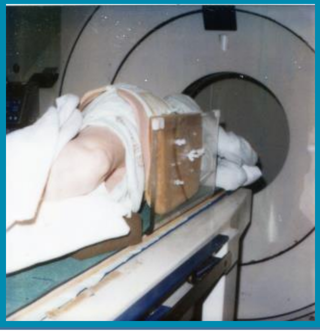
    - body
    - orthopedic body cast attached to plywood frame with door hinges



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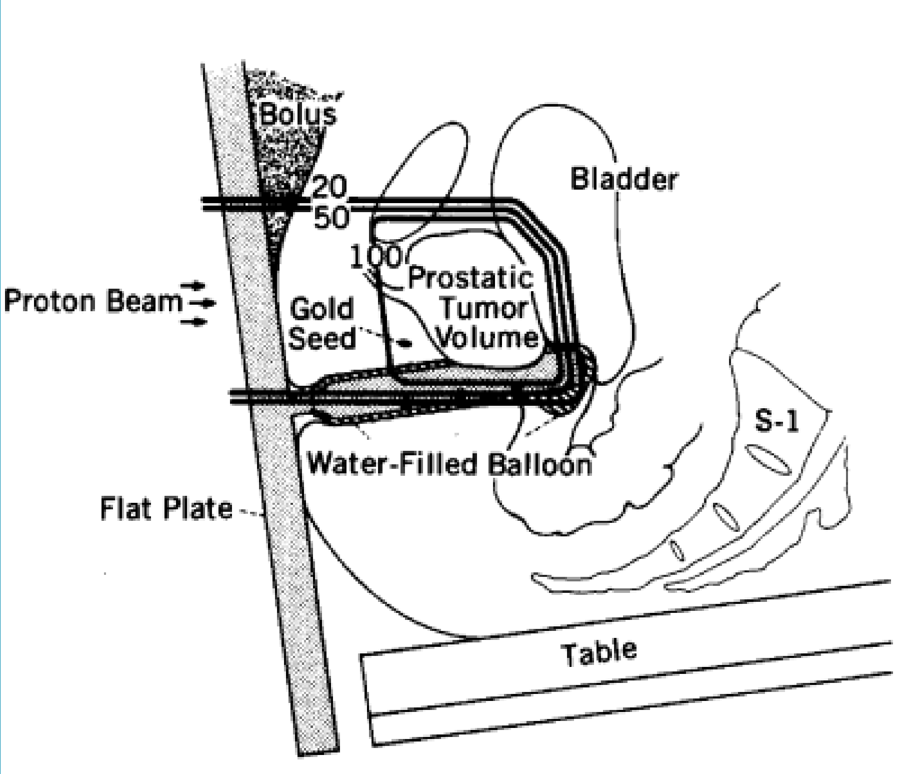
  - prostate, stirrups with rectal probe and balloon



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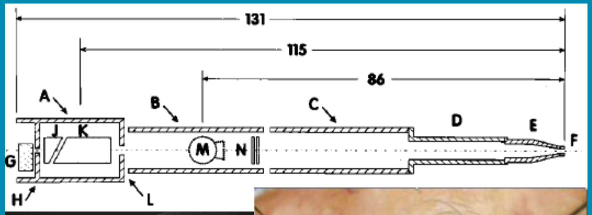
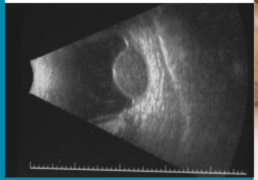
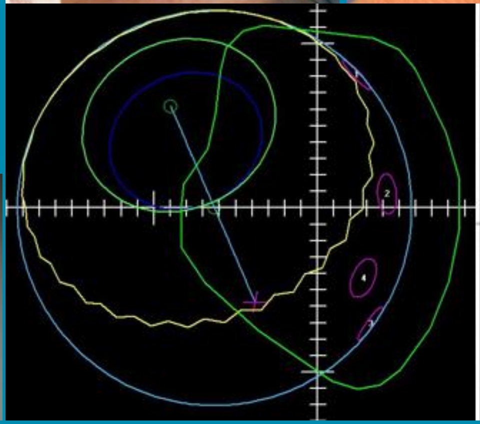
- lithotomy (inferior), conventional CT
  - prostate, stirrups with rectal probe and balloon

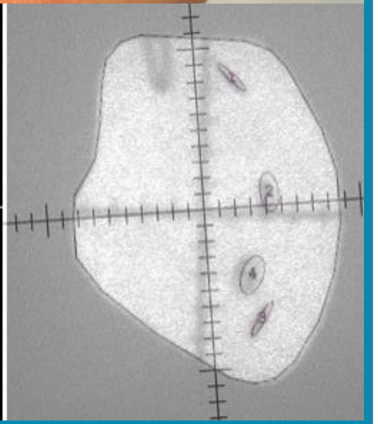
2 Ocular Beamline (single scattering, maximum WET: 4.0 cm)

- seated in barber’s chair with eyelid retractors, no CT
- apertures and modulation wheels
- tantalum surgical clips or clinical light field setup









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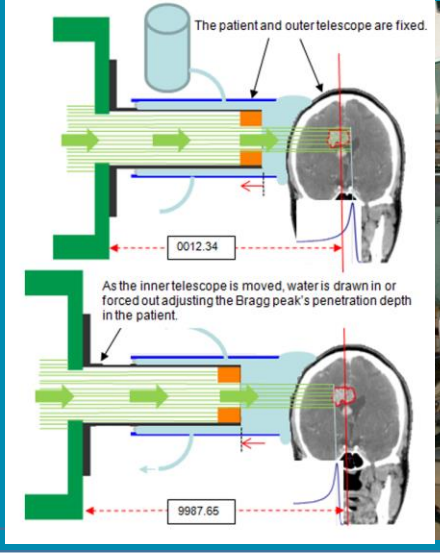
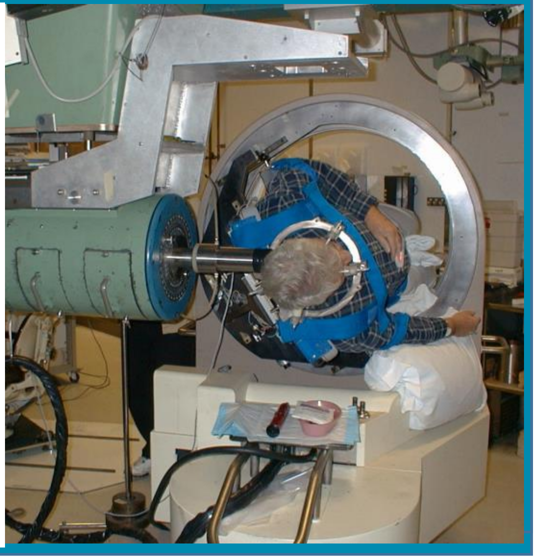
3 SRS (single scattering, maximum WET: 14.2 cm)

- conventional CT with α- cradle mold
- 4π isocentric treatment geometry
- invasive fixation
- custom apertures
- water bolus conforms to external body
- water column range pullback to create SOBP





MY EXPERIENCE: 30 YEARS WORKING WITH PROTONS

MGH Northeast Proton Therapy Center / Francis H. Burr Proton Center

IBA Proton Therapy System: Proteus PLUS 235 isochronous cyclotron
1st clinical release

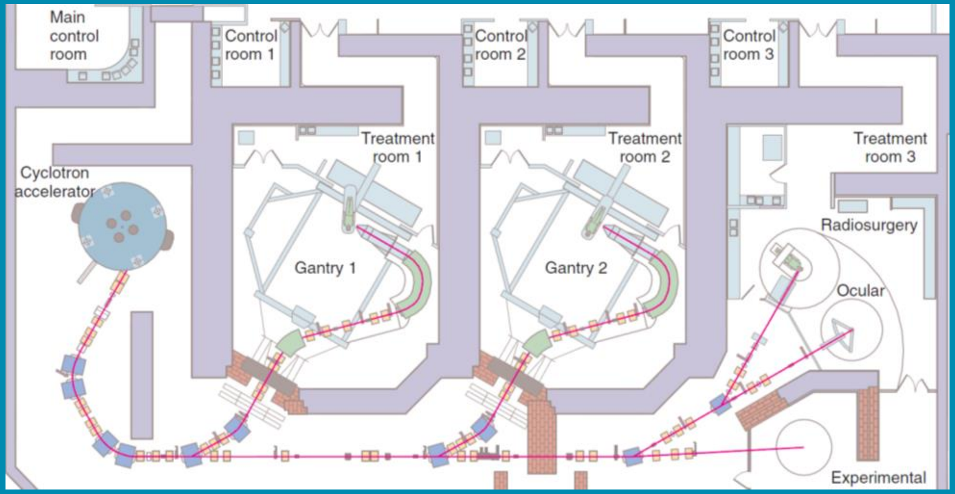
2 gantries, 2D/3D imaging (Double Scattering → PBS 2008/2011/2015 & 2020)

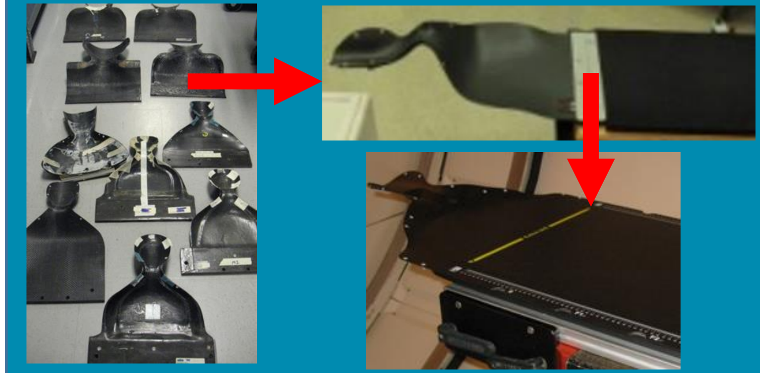
1st IBA site to deploy PBS; 3 yrs @ 100x 4pm-7am development/commissioning shifts/yr to 1st TX
Another 3 yrs of refinement and recommissioning to 2nd patient (DS+PBS) and another 2 yrs to PBS only

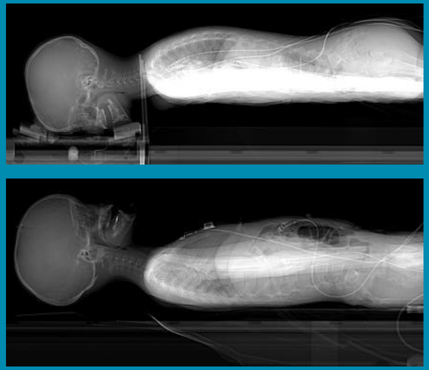
1 in-house dedicated SRS single-scattering beamline, non-invasive (2006-2018)

1 ocular beamline (same system as HCL, improved imaging)

improved technology, immobilization, workflow and automation…







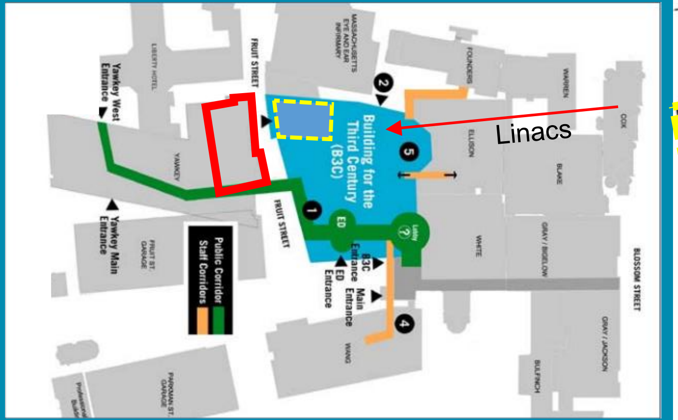
Consideration of a 2nd Proton Delivery System: Compact PBS Solution

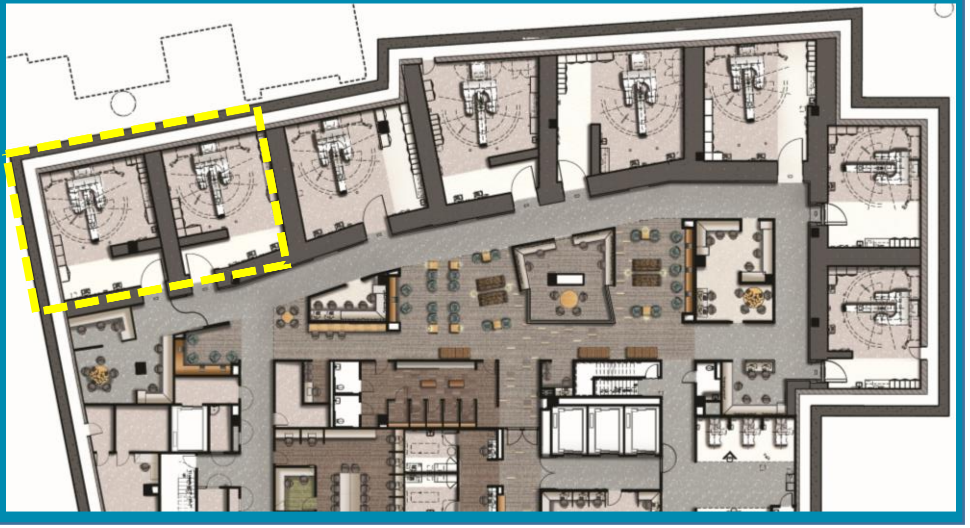
WHY?

increased capacity	5-7 week waiting list
improved technology	CBCT imaging smaller spot size safety systems improved integration
proton treatment redundancy	minor repairs and unanticipated down time major planned events, e.g., IBA cyclotron down 3 months + ramp up/down to replace main coils

WHERE?

"new" on-campus, hospital building
lower floor designed for Linacs





WHEN?

2007-2008 demo 3 existing buildings
2009-2011 construction of 530,000 sf building
2011 Linac based treatments start

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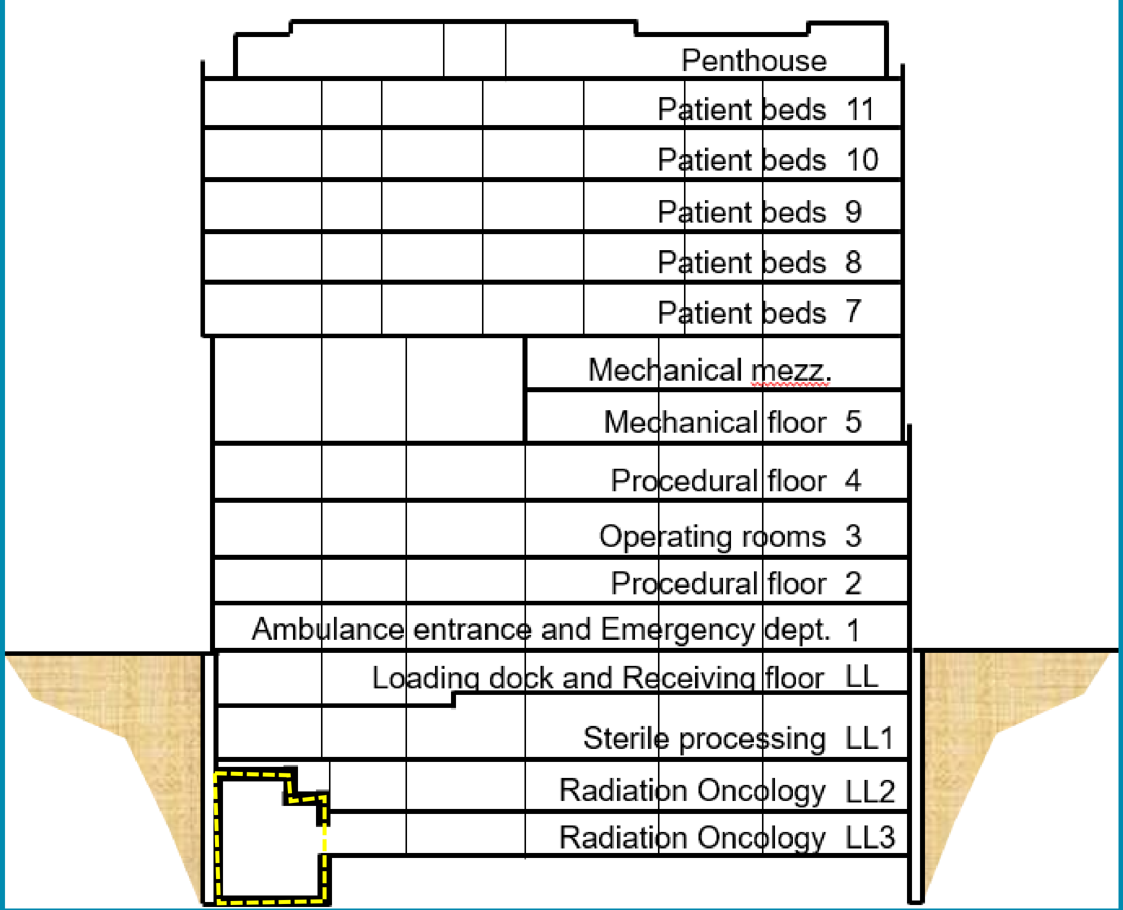
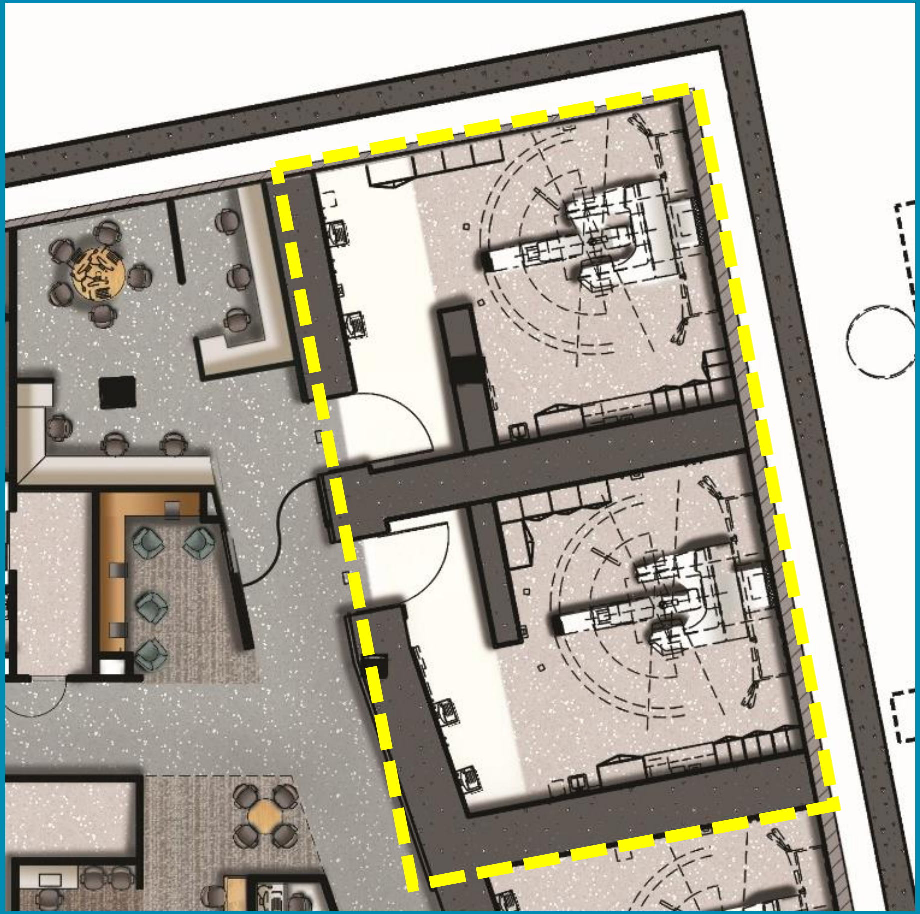
Consideration of a 2nd Proton Delivery System: Compact Solution

WHERE \ WHEN?

2007 concept

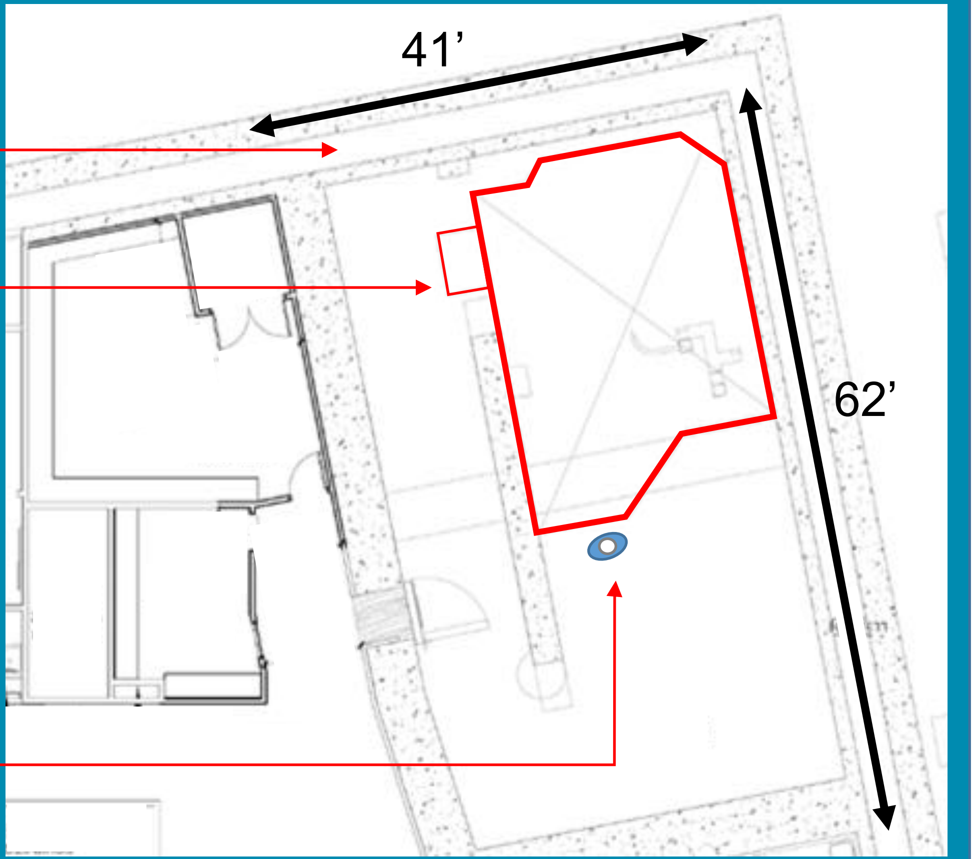




2nd Proton Delivery System: Compact Solution (no vendor selected)

WHERE \ WHEN?

2011 vault cavity construction complete
2012 DoN approval (MA DPH Determination of Need)
2013 system specifications defined for RFP (beamline, accessibility…)



SEQUENCE FOR OUR NEW PROTON FACILITY

- hospital building design, demo & construction (4 years)
- proton vault design based on knowledge of various single room vendor options available
  - no vendor selected at this time
  - integrated with building construction
- obtain Determination of Need (DoN) from state
- funding secured
- request for proposals
- vendor selection
  - Protom
  - first-generation system requiring substantial contract details

MGH PROTOM RADIANCE 330 OVERVIEW

- GE — CT
- MIM Software — Image management / contouring
- .decimal / astroid — TPS
- Whiteboard / ICT Netherlands — Workflow / OIS. R&V
- Elekta MOSAIQ — Dose Tracking / document management
- Epic — Medical Records

PROTOM proton therapy technologies

- Gantry
- Pyramid — Scanning & dose monitoring
- LEONI — Robotic 6dof PPS
- medPhoton — CBCT – *recently acquired by* BRAINLAB
- Optical trackers
- MEDCOM VERISUITE — 2D isocenter imaging, CBCT, 2.5D image registration/verification
- COSYLAB — Motion Control System (MCS), Treatment Delivery Control System (TDCS)
- Synchrotron

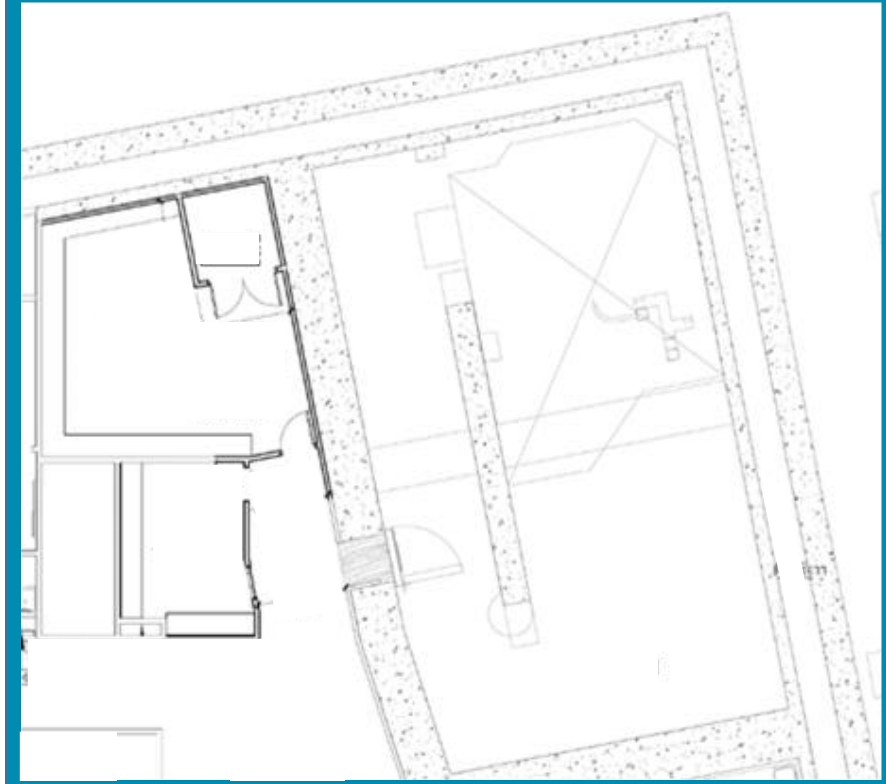
SEQUENCE FOR OUR NEW PROTON FACILITY

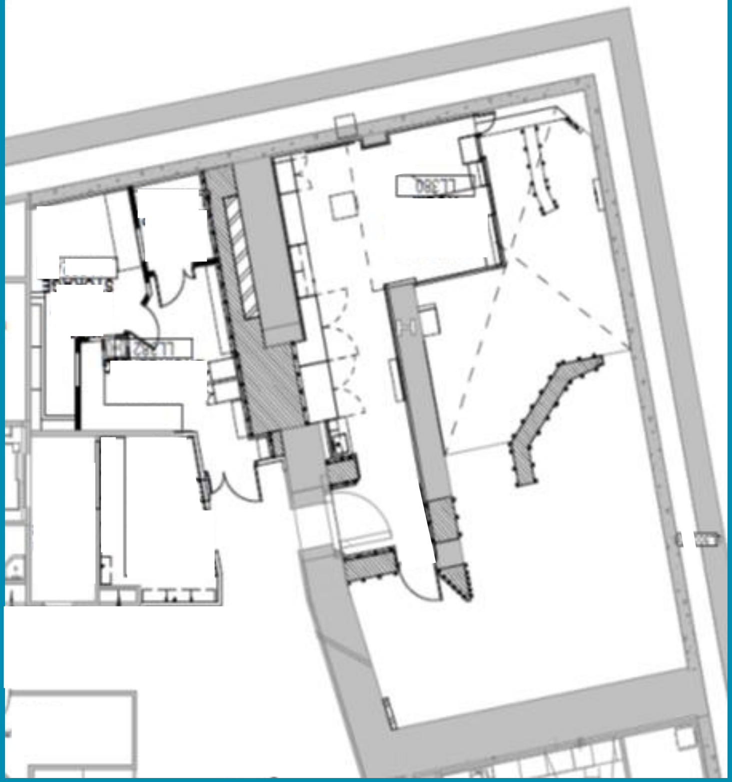
- Vendor specific facility design / construction by MGH (1 year)
- Installation (with vendor bankruptcy restructuring thrown into the mix, 3 years)
- Vendor pre-release testing
- Define QA / QC program / operations / clinical workflows
- Acceptance (1 year)
- Commissioning (6 weeks)
- FDA site clearance
- State licensing (7 months after initial walkthrough)
- Treatments

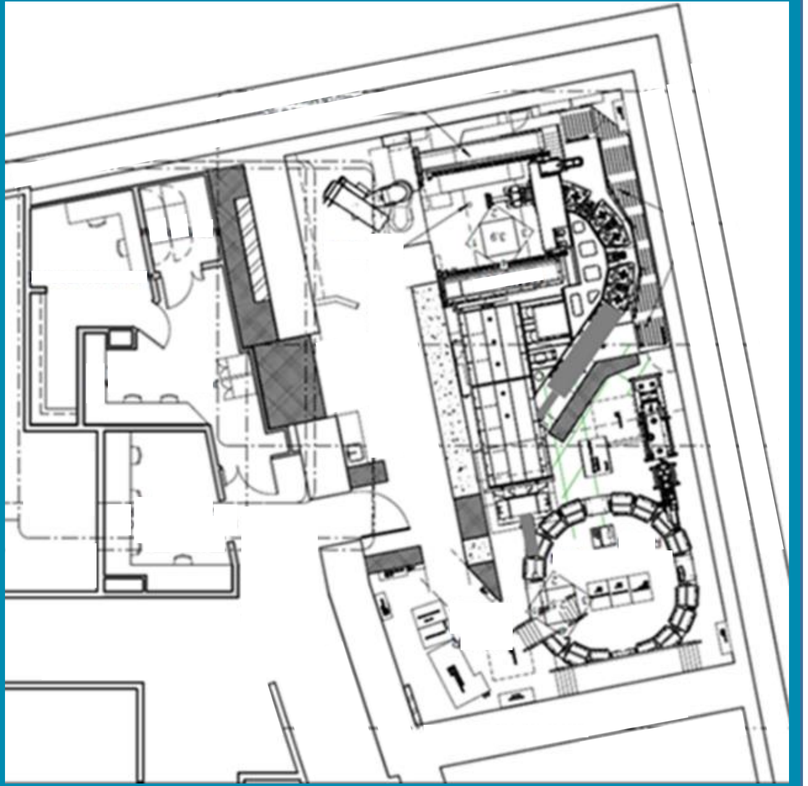
Lots and lots of planning, committees at every stage of the process…

PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

DESIGN

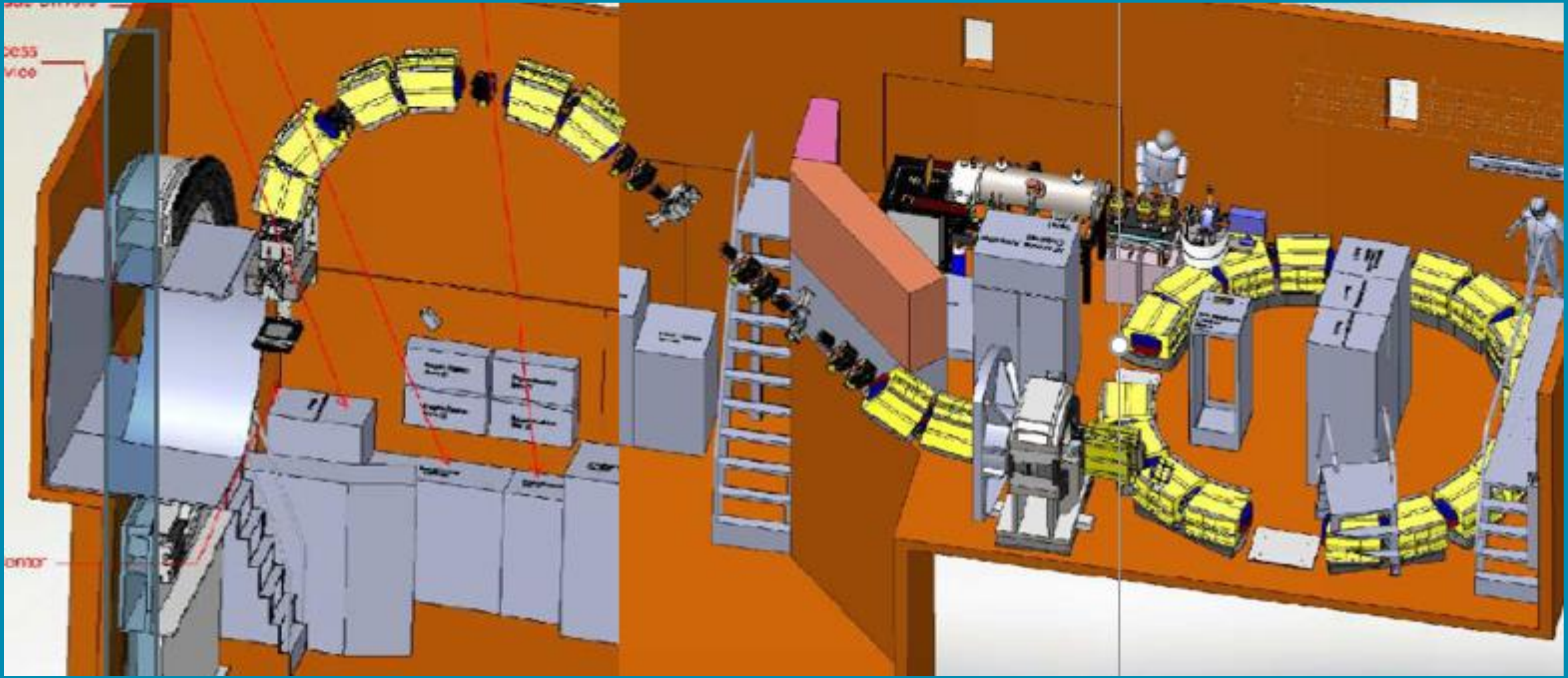






PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

DESIGN



PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

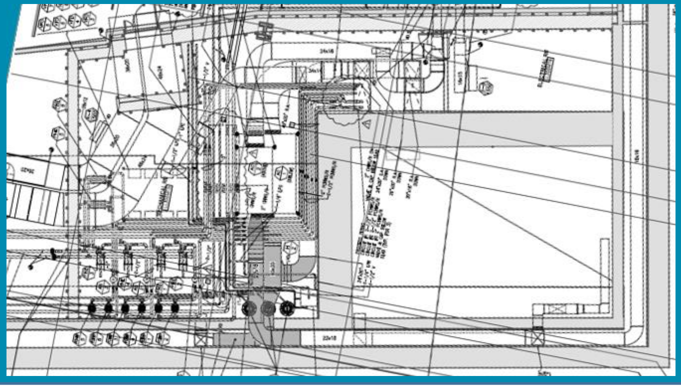
WHEN?

2014-16 significant design effort (this is the 2nd ProTom install, with significant changes from the original system)

- facility
- imaging system
- sub-system integration and interface
- treatment workflows…

infrastructure work

- essential additional shielding
- HVAC
- electrical
- deionized water system
- chilled water loops
- fire protection
- compressed air
- Medical gases
- …

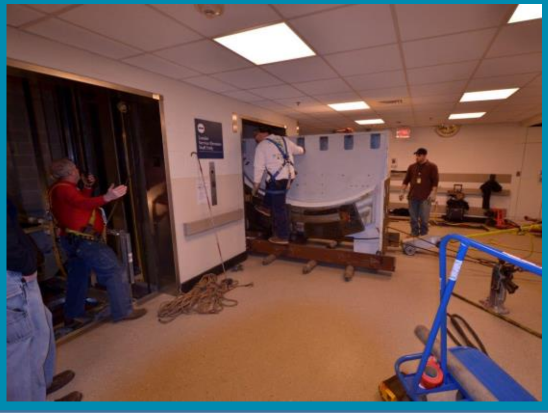


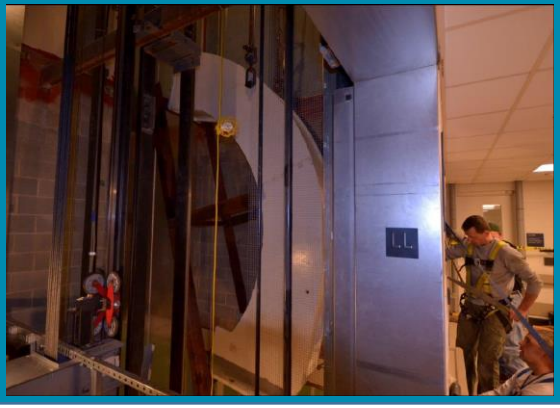
PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

GANTRY DELIVERY

2016 factory → MGH

…some individual components as heavy as 12 tons (24,000 lbs.)





PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

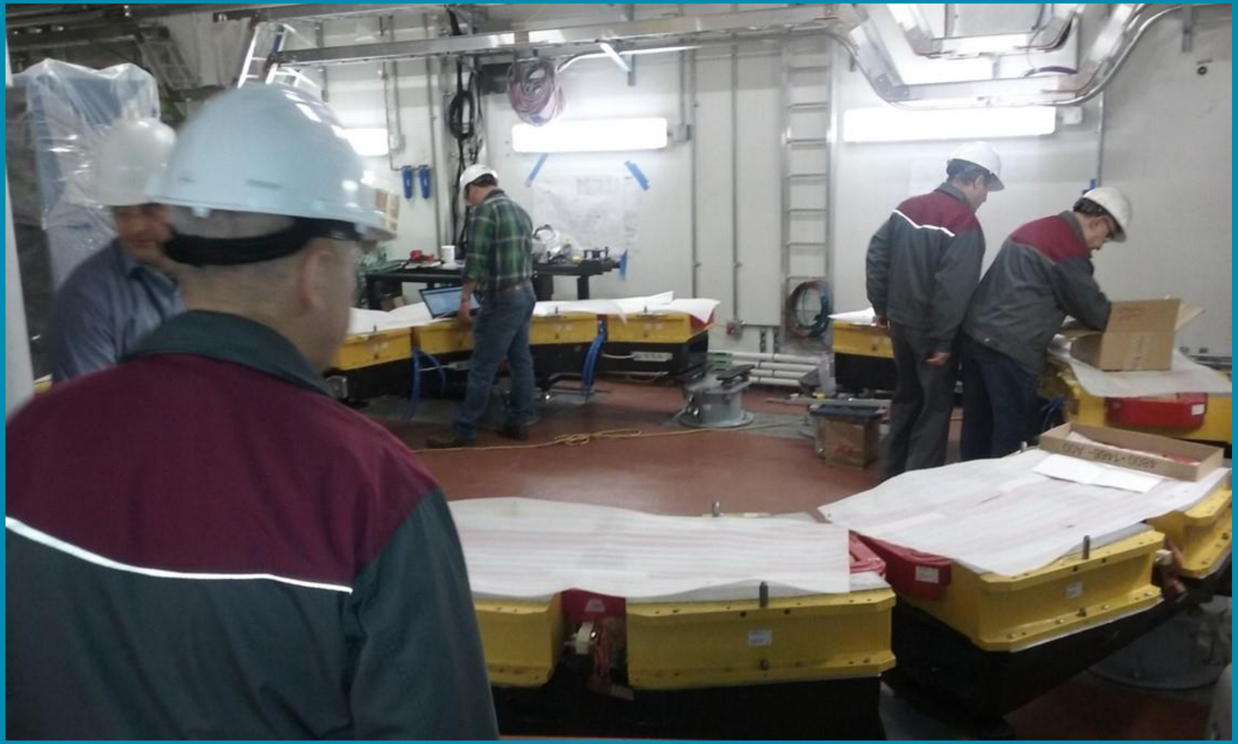
ASSEMBLED GANTRY (190°)

2016

PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

SYNCHROTRON DELIVERED / ASSEMBLED

2017



PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

WHEN?

2014-17 Design shielding through survey verification

- Primary barrier transmission B = Pd^2/WUT
- Shielding goal (P): ≤ 0.02 mSv / wk
- Workload (W): 40 hrs/wk, 155 TXs/wk @ 2 GyRBE/TX
  ~ 10^9 protons / Liter = 1-2 cGyRBE mostly dependent on depth **[x1.25 buffer]**
- Use (U): MGH historical trends, half-gantry G90° (horizontal) 5%, G0/180° (vertical) 22.5%, G±45° (oblique) 5% **[x1.25 buffer]**
- Occupancy (T): 20% hallways, 100% office and control rooms, 50% adjacent Linac vault

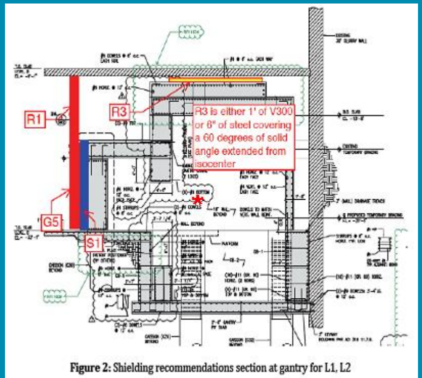


Figure 2: Shielding recommendations section at gantry for L1, L2

→ DEFINE SHIELDING REQUIREMENTS (1.5 months)
→ SHIELDING CONSULTANT / CONTRACTOR
→ RSO
→ DPH (1.5+ months)
→ SHIELDING VENDORS
→ CONSTRUCTION
→ SURVEYS

Wendi detector

bubble detector

OSL

survey meter

PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

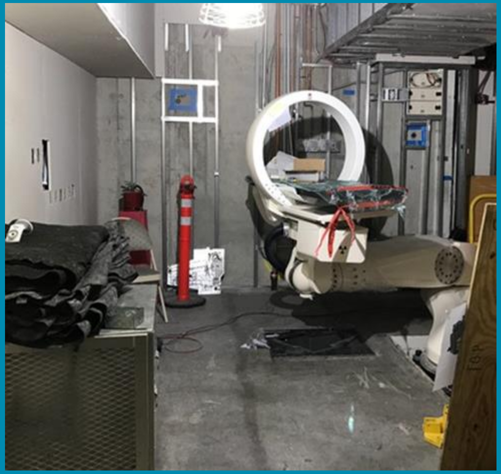
PATIENT POSITIONER 6 dof ROBOT DELIVERED / ASSEMBLED

2017

PPS Specifications

Maximum patient weight	200 kg
Load height	63.5 cm
Pitch and roll	+/- 15deg
Knuckle rotation	200 degrees
Combined PPS and gantry isocentricity	<1mm diameter sphere
Remastering (a calibration procedure)	1 hour
Optical tracking of couch position and automatic sag correction	YES
Automatic mini-pit cover	YES
Customized, indexed patient couch carrier/transfer plate	YES (can be removed within 3 min) “The Patient Positioning Subsystem shall be able to accept current commercially available proton therapy Couches (such as Q-Fix, Civco or Elekta). This requirement can be met by having the ability to dock different transfer plates (couch tops) to the carrier plate of medPhoton´s CBCT solution. “
Haptic controller	An option, still to be investigated
Distress buzzer	An option, MGH may supply a wireless device
Unload in the case of power failure	UPS power

May

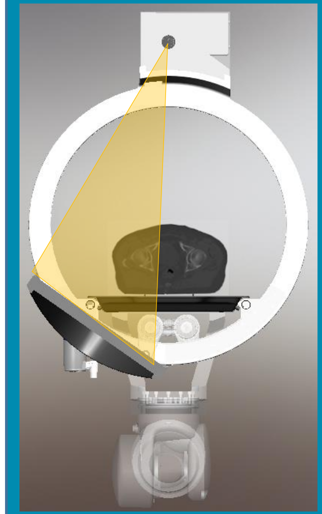


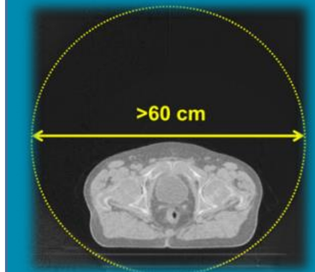
August

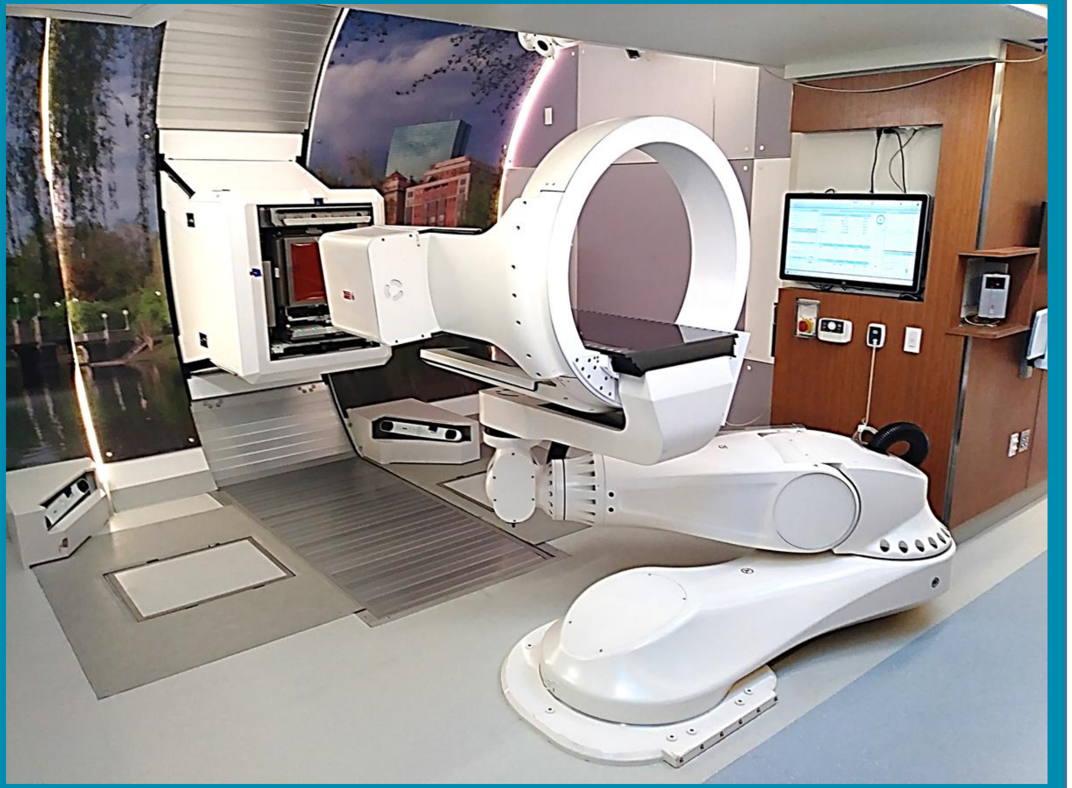
PROTOM SYNCHROTRON SYSTEM: **RADIANCE 330**

ON-BOARD IMAGING

2018 (January)





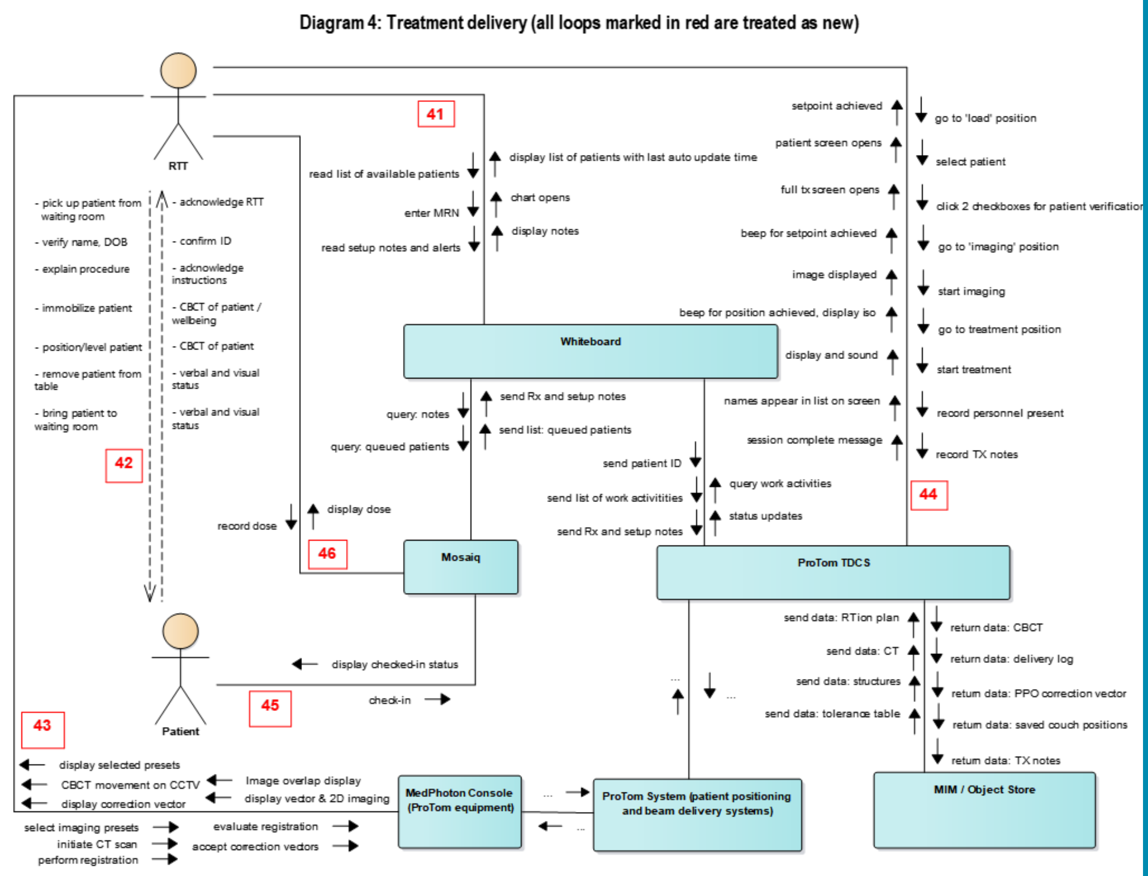


78 cm large bore, 40x40 cm fluoro-capable detector with 0.2 mm pixels, 4 rpm non-isocentric CBCT with 32 cm longitudinal x 60 cm axial FOV

PRE-ACCEPTANCE

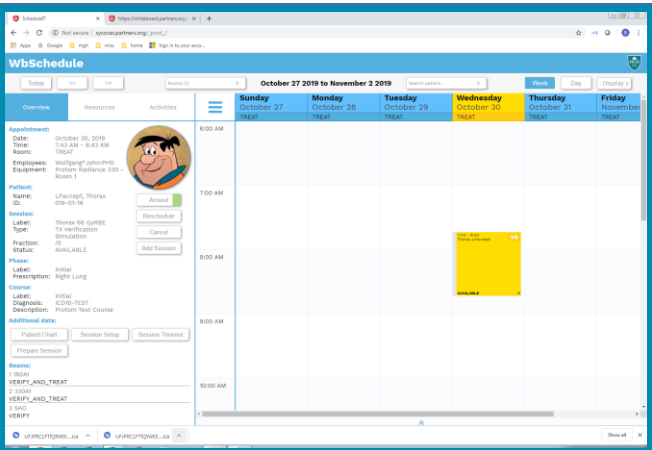
System Theoretic Process Analysis STPA (FMEA) – AAPM TG100

- ideal for new multi-system implementation
- does not require workflows to be rigidly defined
- analysis performed in-house generating 44-page report
- reviewed by external expert
- who / where / process input & output



Unsafe control action	Hazard	Causal scenario	#	Consequence	S	O	D	RPN	Mitigation	Mitigation	Notes/Conclus
Dosimetrist an ambiguous reference position in the patient CT when they do not know what to do	1	- Dosimetrist does not know which points in anatomy can be easily located on patient	27.13	- Treat through couch edge	3	2	2	12	1: QA	- Training mitigations - Physics plan check - Couch edge mitigations *** - Collision mitigations ****	

TREATMENT RELATED WORKFLOW



IMPORT "published" TPS DICOM CT/RTplan/RTst into OIS → IMAGING / TDCS

FIELD SPECIFIC QA

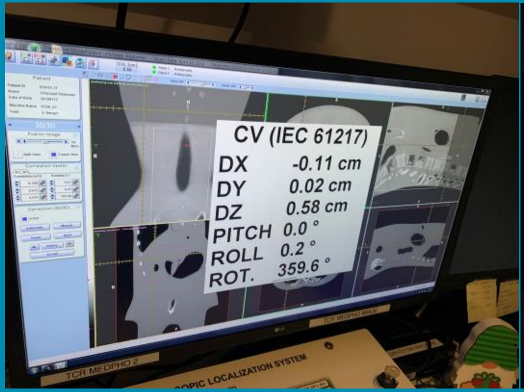
- 2D measurement at 2 depths delivered at 0° fixed angle
- delivery verified at treatment angle without measurement

VERIFICATION SIMULATION (couch edge interlocks tested \ added)

- CBCT (2,5D) defines expected treatment parameters & iso coordinates

TREATMENT (Gantry @ q10° initially, now q5°)

- CBCT and registration establishes plan isocenter(s) in room coordinates (virtual shifts)
- PPS robot translates/rotates patient to treatment position across the room
    - includes actual patient shifts + gantry sag correction
- 2.5D registration imaging at isocenter available
- Move patient to subsequent field
    - optical sensors independently confirm final PPS position
        - gantry must be 30° above horizontal before making any PPS motion
    - If imaging, move couch away from gantry for CBCT
    - can image and treat without going into the room



ACCEPTANCE

Typical time estimate for an established system with a knowledgeable team ~ 4-6 weeks

Our system is first generation with many “new” sub-vendor components being integrated (5/2018 – 5/2019 + 11/2019)

- troubleshooting and testing the system with the vendor (> 124 tests)
- performed as components were installed and connected as others were added on

System	Tests
Equipment-building interface	Monthly power test, power failure, chilled water failure, HVAC failure
Gantry	Mechanical isocenter, range of motion, accuracy, speed
Patient positioning system	Mechanical isocenter, range of motion, sag, backlash, vibrations, accuracy, speed, buzzer
Imaging (2D and CBCT)	Limits, imaging dose, image quality, HVL, kVp, timer, scaling, FOV, registration and geometric accuracy, imaging and reconstruction time
Dose delivery	Proton range: min to max, accuracy, reproducibility, and energy spread Pencil beam: position, lateral spread, scanned distance, Gp Nozzle: SAD, range shifters Beam level: delivery time, field size, dose uniformity, gantry dependence, linearity, dose distribution
Lasers	Functionality and alignment
Integration	Origin alignment, treatment time, gating, test with MGH workflow and OIS, machine modes, hand pendant, log files, overhead displays, start-up time, continuations and other non-ideal conditions
Mock treatments	Superior cranial, H&N, Thoracic, Abdominal small, Abdominal large, CSI, orientation (patient, gantry, couch, imaging, CT ref, beam coordinates)
Safety	Shielding, nozzle leakage, door interlock, search zones, E-stop, warning lights, audible beam-on warning, collision mitigation

ACCEPTANCE

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
																						PTCOG										
May 2018		tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th
Burr	Early	BW	BW	ND	ND			AT	BW	SSJ	MB	ND			MB	SSJ	ND	BW	AT			ND	MB	SSJ	AT	KJ			H	BW	SSJ	MB
	Late	KJ	AT	MB	KJ			MB	JD	KJ	BW	KJ			AT	HML	JD	HML	JD			SSJ	SSJ	AT	MB	AT			H	JD	AT	HML
Lunder (7am-3pm)	*Lead*							BC	BW	BW	BC	BC	BC	GS	BW	BC	BC	BC	BW	BC	GS	BC	BW	BC	BC	BC	BC	GS	H	BC	BW	BC
	Sec. Lead							MB	BC	BC	AT	MB	KJ	BC	BC	MB	AT	MB	BC	GS	BC	MB	BC	DPG	MB	AT	GS	BC	H	GS	BC	MB
	Float							RES	RES	RES	JS	JS	JS	WS	JS	JS	JS	RES	RES	RES	WS	RES	RES	RES	JS	JS	JS	WS	H	RES	RES	JS
Lunder (3pm-11pm)	*Lead*							KJ	GS	ND	GS	GS			KJ	GS	GS	GS	ND			GS	KJ	GS	GS	GS			H	KJ	KJ	GS
	Sec. Lead							GS	SSJ	GS	ND	JD			GS	JD	SSJ	ND	KJ			BC	GS	KJ	SSJ	JD			H	GS	GS	SSJ
	Float							MC	MC	MC	MC	WS			MC	MC	MC	MC	WS			MC	MC	MC	MC	WS			H	MC	MC	MC

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Jun 2018		fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa
Burr	Early	AT			AT	ND	SSJ	SSJ	ND			AT	BW	SSJ	ND	MB			AT	MB	SSJ	SSJ	ND			BW	MB	ND	BW	KJ	
	Late	JD			BW	KJ	JD	MB	BW			AT	ND	JD	KJ	KJ			BW	HML	JD	KJ	KJ			KJ	MB	HML	HML	HML	
Lunder (7am-3pm)	*Lead*	BW	BC	GS	BC	BC	BC	BW	BC	BC	GS	BC	BC	BW	BC	BC	BC	BC	BC	BC	BC	BC	BW	BC	GS	BC	BC	BC	BC	BC	BC
	Sec. Lead	BC	GS	BC	MB	BW	AT	KJ	MB	GS	BC	BW	MB	BC	MB	AT	KJ	ND	MB	ND	AT	MB	BC	BW	ND	MB	ND	AT	MB	BW	GS
	Float	JS	JS	WS	RES	RES	RES	JS	JS	JS	WS	JS	JS	JS	RES	RES	RES	WS	RES	RES	RES	JS	JS	JS	WS	JS	JS	JS	RES	RES	RES
Lunder (3pm-11pm)	*Lead*	ND			GS	GS	KJ	GS	ND			GS	GS	GS	GS	KJ			KJ	GS	KJ	GS	GS			ND	GS	GS	KJ	KJ	
	Sec. Lead	GS			SSJ	JD	GS	ND	GS			JD	JD	ND	SSJ	ND			GS	SSJ	GS	HML	JD			GS	HML	SSJ	GS	JD	
	Float	MC			MC	MC	MC	MC	WS			MC	MC	MC	MC	WS			MC	MC	MC	MC	WS			MC	MC	MC	MC	WS	

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
																															AAPM	
Jul 2018		su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu	we	th	fr	sa	su	mo	tu
Burr	Early		MB	BW	H	MB	AT			AT	MB	MB	MB	KJ			AT	BW	ND	ND	KJ			AT	BW	ND	BW	AT			ND	MB
	Late		KJ	ND	H	JD	JD			KJ	HML	AT	BW	MB			JD	KJ	JD	HML	BW			JD	HML	JD	KJ	ND			JD	JD
Lunder (7am-3pm)	*Lead*	GS	BC	BC	H	BC	BC	KJ	BC	BC	BC	BW	BC	BC	BC	GS	BC	BC	ND	BW	BC	BC	GS	BC	BC	BW	BC	BC	BC	GS	BC	BC
	Sec. Lead	BC	BW	MB	H	AT	MB	BC	GS	MB	BW	BC	MB	AT	GS	BC	AT	BW	BC	BC	HML	GS	BC	HML	BW	BC	AT	HML	GS	BC	MB	ND
	Float	WS	RES	RES	H	JS	JS	JS	WS	JS	JS	JS	RES	RES	RES	WS	RES	RES	RES	JS	JS	JS	WS	JS	JS	JS	RES	RES	RES	WS	RES	RES
Lunder (3pm-11pm)	*Lead*		ND	ND	H	GS	GS			KJ	GS	GS	GS	KJ			KJ	ND	GS	GS	KJ			KJ	ND	GS	GS	KJ			KJ	GS
	Sec. Lead		GS	SSJ	H	ND	JD			GS	KJ	SSJ	HML	JD			GS	GS	SSJ	ND	JD			GS	GS	SSJ	ND	JD			GS	SSJ
	Float		MC	MC	H	MC	WS			MC	MC	MC	MC	WS			MC	MC	MC	MC	WS			MC	MC	MC	MC	WS			MC	MC

Shift lead	Prioritize procedures, answer questions about the measurement setup, sign forms, be familiar with the analysis framework, help to analyze data in real time, must be ABR certified
Secondary shift lead	Be a second set of eyes to check the results. Check on the shift from time to time. Discuss issues coming up in real time with the shift lead. Be at MGH and on call.
Float	Must be familiar with the measurement devices, set up detectors, acquire data and analyze data in real time

Actual shifts were intermittent and averaged closer to 1.5 per day

RETEST

- 20190819_MatriXX_UniformityTest
- 20191014_imaging
- 20191016_isocentricity
- 20191023_gantry_compensation
- 20191023_isocentricity
- 20191024_dose_control_calibration
- 20191024_dose_linearity
- 20191025_gamma_normalization
- 20191031_cbct
- 20191031_gamma
- 20191112_field_uniformity
- 20191112_max_field
- 20191112-gamma
- 20191115_lynx
- 20191119_isocentricity
- 20191211_lynx
- 20191212_gantry_rot
- 20191213_isocentricity
- 20191213_logs
- 20191216_lynx
- 20191218_isocentricity

COMMISSIONING, VALIDATION & TREATMENT PREP

IAEA Technical Report Series TRS-398	Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water
MGH Internal Commissioning Reports	Burr Proton Center
Massachusetts 105 CMR	120.437 Section (T)
AAPM Task Group Report 45	Code of Practice for Radiotherapy Accelerators
AAPM MPPG 5.a	Commissioning and QA of Treatment Planning Dose Calculations – Megavoltage Photon and Electron Beams
AAPM Virtual Library	2015 Summer School “Clinical Commissioning of Proton Beams”, Lei Dong.
Medical Physics 37 2010	Commissioning of the discrete spot scanning proton beam delivery system at MDACC Proton Therapy Center, Houston, M. Gillin
J. Appl. Clin. Med. Phys. 19 2018	Commissioning of the world’s first compact pencil-beam scanning proton therapy system, R. Pidkiti
AAPM Task Group Report 224	Comprehensive proton therapy machine quality assurance
AAPM Task Group Report 185	Clinical commissioning of intensity-modulated proton therapy systems

6 weeks (1. 6/2019 + 2. 12/2019 – 2/2020) followed by treatments within a few weeks

1. *Commissioning measurements that did not depend on certain systems such as TDCS, MCS, Robotics, imaging, and scanning nozzle*

COMMISSIONING

Calibrate delivery system following TRS-398 [uncommissioning TPS generated 12 x 12 cm^2 reference cube R23M6], dose uniformity ≤ ± 1.1%

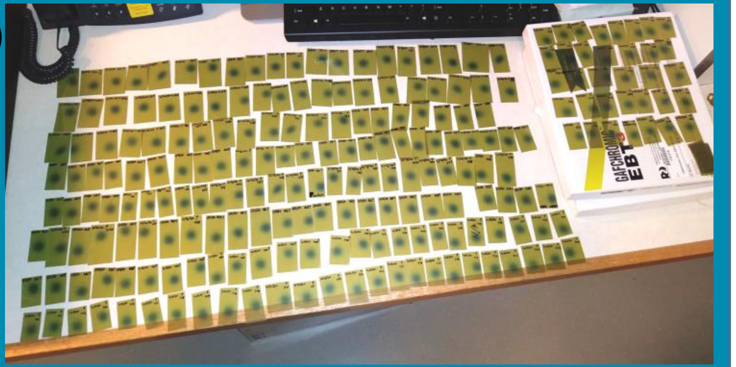
Define HU to RSP curve(s) for CT scanner(s) and various protocols ✓

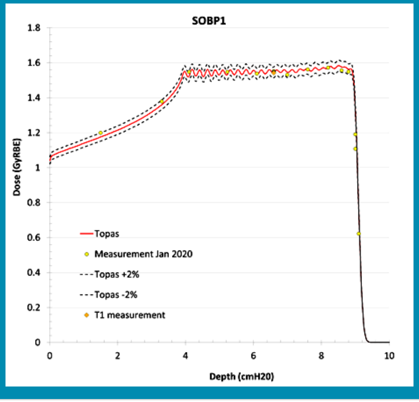
Collect TPS data for beam modeling and verification

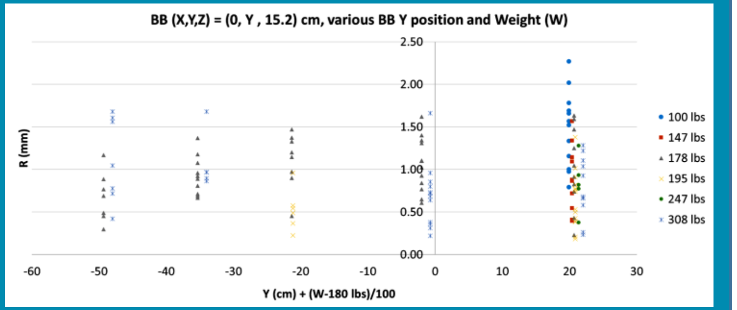
- cGyRBE/gp (cGy/MU)
- SOBP depth dose uniformity, distal/proximal fall-off
- SOBP cross-sectional dose uniformity, penumbra
- delivery settings v. TPS $R_{90water}$
- SAD
- pristine peaks depth dose profiles
- range vs RT_{ion} plan energy
- in-air σ_x, σ_y vs. Energy
- RS position (air gap) vs radiation isocenter
- couch, shifter and immobilization device WET
- interlock limits (plan input values, collision detection, motion, delivery, system failures…)
- radiation surveys including vault for activation (imaging and treatment)
- Winston Lutz imaging vs. radiation isocentricity
- robot motion and collision proximity
- laser alignment to isocenter
- monthly, daily QA procedure baselines
- imaging
- hidden targets ETE tests

COMMISSIONING

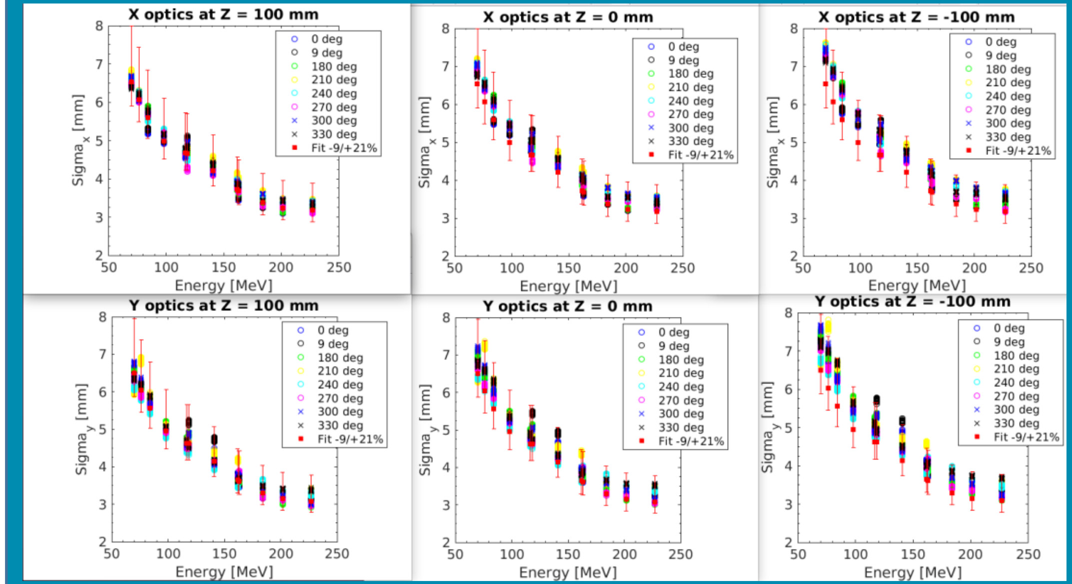
CBCT vs. 2D imaging vs. delivery vs. gantry vs. energy vs. air gap vs. current (on/off-axis)

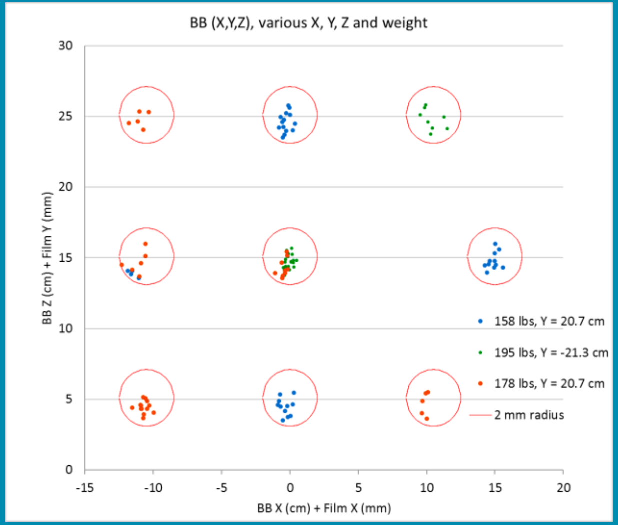


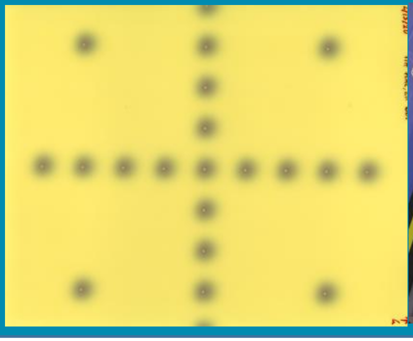


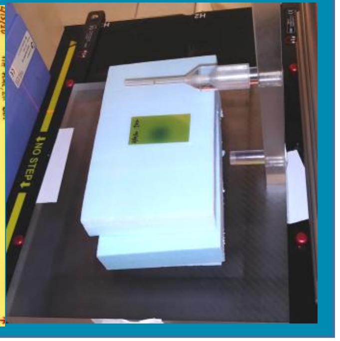


Beam optics









COMMISSIONING

Realized system uncertainties

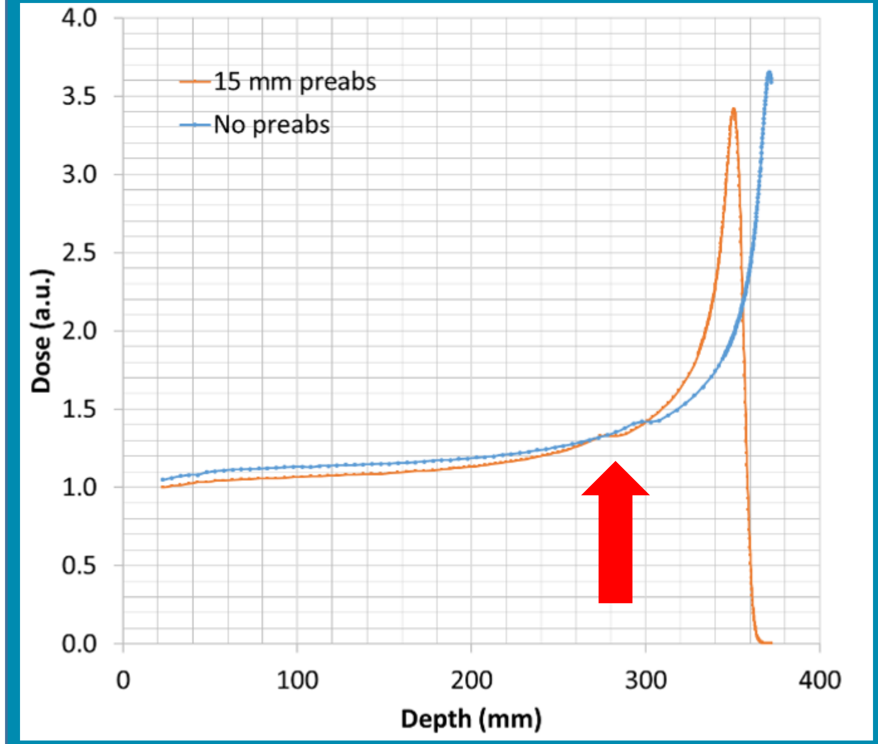
Interlocks Position Sigma Spot Gp Cumulative Gp Energy	 ± 1.5 mm ± 15% ± (1.0% + 0.003 Gp) ± (1.0% + 0.003 Gp) ± 0.25 MeV, not an explicit nozzle interlock but rather beam will not extract correctly and trigger other nozzle interlocks
MU chamber linearity and gantry dependence	± 1%
Gantry angle uncertainty	± 0.5°
Couch rotation movement accuracy	± 0.15°
Couch translation movement accuracy	± 0.5 mm
Gantry isocenter uncertainty (using couch PPCA position correction)	1.2 mm diameter
Couch isocentricity uncertainty	1.3 mm diameter
Beam to imaging isocenter alignment uncertainty	± 2 mm

Absolute dose	± 2% except for the entrance region ≤ 15 mm
Sigma	-9 to +21%
Range in room temperature water	± 1 mm
Position registration of soft tissue	± 1 to 1.5 mm
kVue extension thickness	± 0.3 mm H20
medPhoton carrier plate thickness	+0.5 to +1 mm (measurement is larger than CT)
Qfix2 couch thickness	Consistent with uncertainties in department boards
Range shifter thickness	± 1%
Uncertainties due to relative stopping power, inter-fraction motion, patient movement between registration and treatment, and patient weight loss during treatment are independent of the Lunder Proton machine but these uncertainties should be considered when making treatment margins	

COMMISSIONING

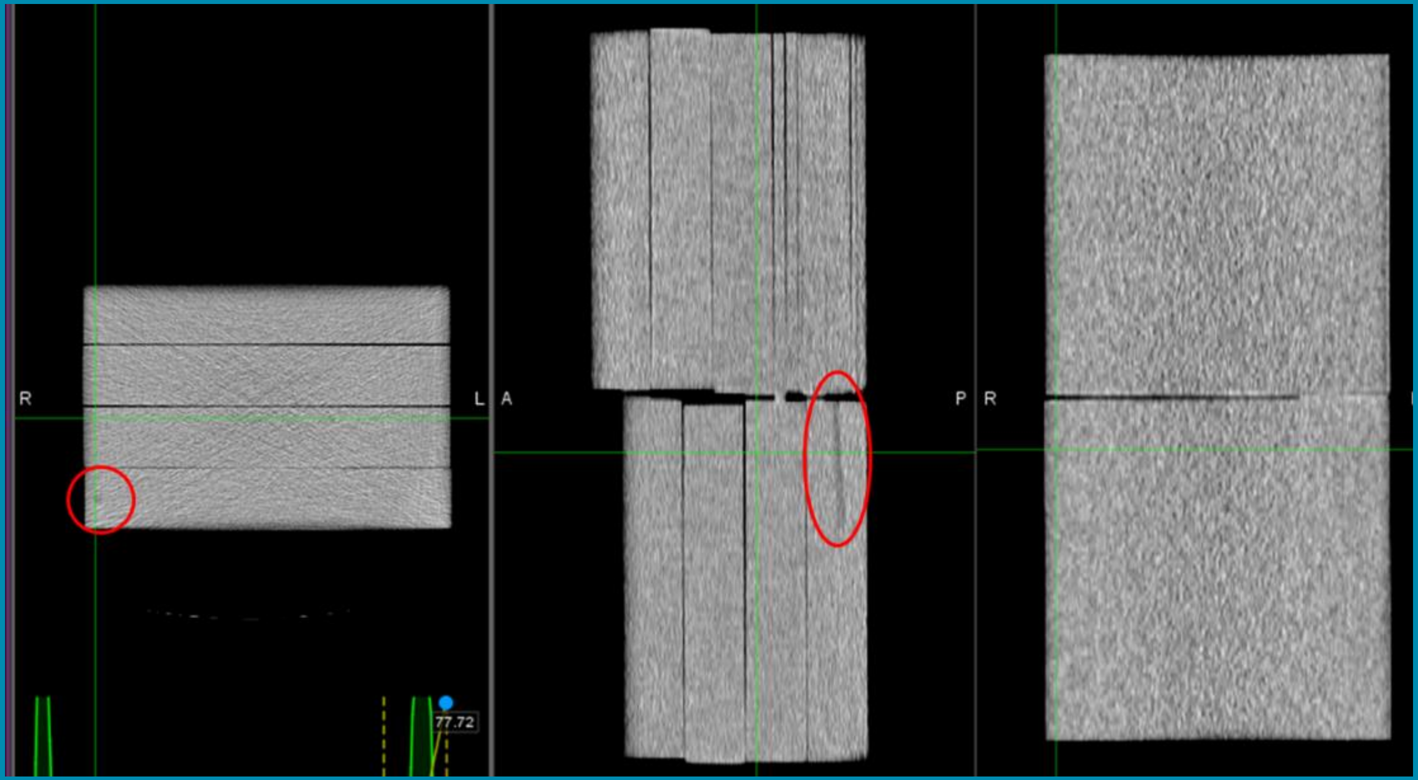
Beam scraping

Adjusting the last dipole + IC positions and current in the last beam steering magnet resolved the issue. ΔD_{0cm} 1%, ΔR_{80} 0.2 mm.



Defective Solid Water

Returned to manufacturer for replacement

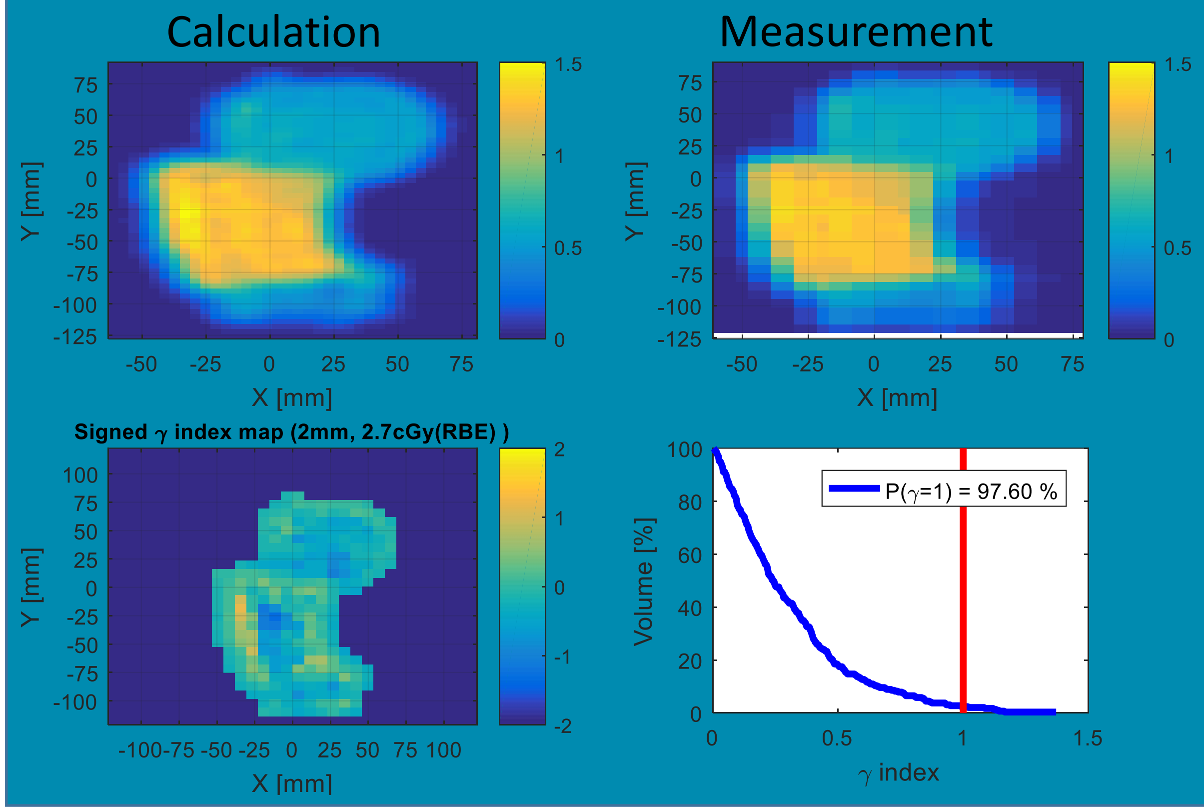


VALIDATION

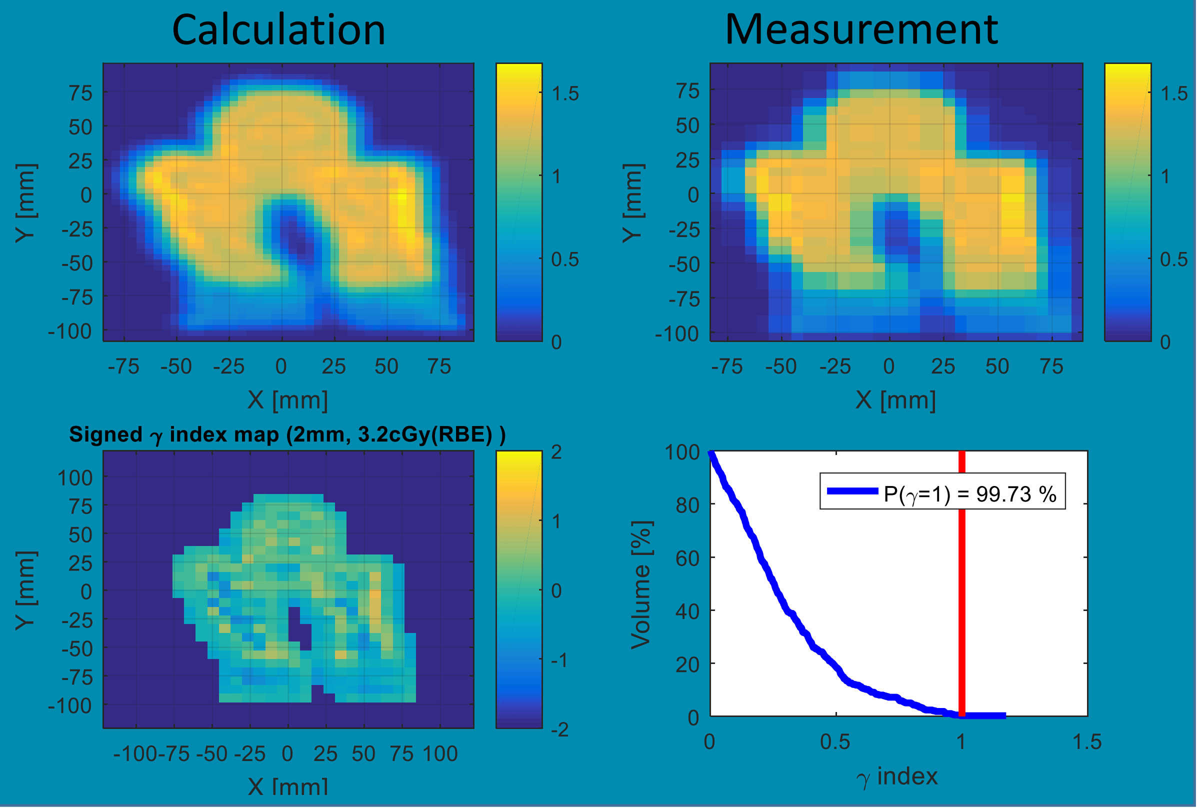
Head and Neck fields, γ(2mm,2%)

Feb 15, 2019

Beam 270A1



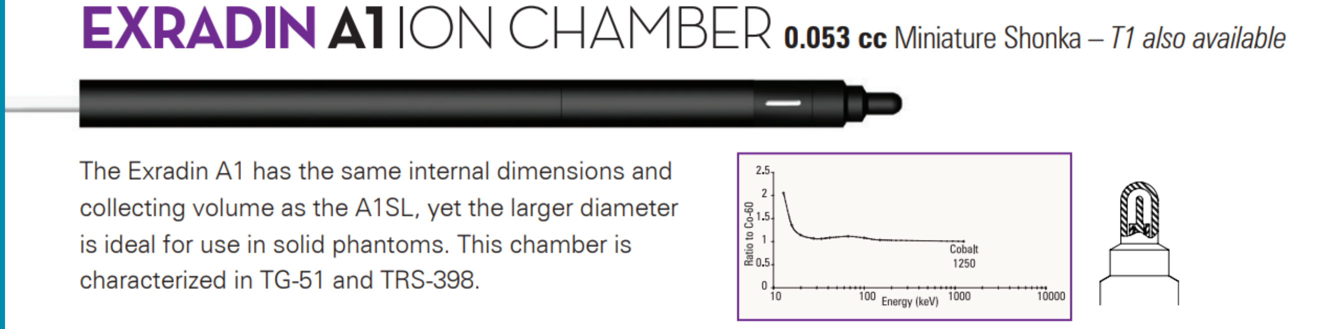
Beam 180A2



QA EQUIPMENT

IAEA Technical Report Series (TRS) No. 398 ABSORBED DOSE DETERMINATION IN EXPERIMENTAL RADIOTHERAPY, 2000
An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water

PTW MP-3P (entrance window: 5.93 mm)



QA EQUIPMENT

MatriXX PT (2mm electrode gap) and Evolution (5 mm gap) have the same detector array. In comparison with the MatriXX Evolution, a significant improvement absolute dose is observed with MatriXX PT. The MatriXX Evolution should not be used for QA of PBS for conditions in which ion recombination is not negligible.

Lin et al., Use of a novel two-dimensional ionization chamber array for pencil beam scanning proton therapy beam quality assurance, JACMP 16(3), 2015.

Technical Information

MatriXX PT and MatriXX ONE

- 1020 air-vented ionization chambers
- Automated k[t, p] correction of the chamber signal
- Lightweight 10 kg
- 20 ms read-out time without dead time
- Active area of 24.4 × 24.4 cm^2
- Pixel spacing 7.6 mm

MatriXX PT

- Ideal for Cyclotron PBS beams
- Chamber volume: 32 mm^3
- Electrode gap: 2 mm

MatriXX ONE

- Ideal for high intensity Synchro-Cyclotron systems
- Chamber volume: 16 mm^3
- Electrode gap: 1 mm

The Zebra demonstrated better than 1% reproducibility and monitor unit linearity. The response of the Zebra is sensitive to radiation field sizes greater than 12.5 × 12.5 cm (not a problem for CAX scanned beams). Zebra and Bragg peak chamber range values demonstrated agreement of 0.0 ± 0.3 mm with a maximum deviation of 1.3 mm for PBS. The setup and measurement time using the Zebra is 3 and 20 times less compared to using a water tank.

Dhamesar et al., Quality assurance of proton beams using a multilayer ionization chamber system, Med. Phys. 40(9)

Technical specs

- Application: measurement of depth dose distribution in particle therapy
- Positioning: nozzle mount [holder optional] or patient table
- Range accuracy: ± 0.5 mm
- Measuring quantity: pristine and spread-out Bragg peak [SOBP]
- Energy range: 33 cm WET
- Dose rate range: 0.5 Gy/min to 15 Gy/min
- Signal to noise ratio: max. 0.2 % with 1 cGy integrated dose
- Dose linearity: max. 0.5 % from 10 cGy up to 5 Gy integral dose
- max. 1 % from 0.5 Gy/min up to 15 Gy/min dose rate
- Collecting electrode: 2.5 cm in diameter
- Spatial resolution: 2 mm detector spacing [native resolution]
- Chamber type: vented ionization chambers
- Typical sensitivity: 14.76 nC/Gy
- Electrometer: 4 TERA ASICs [each contains 64 independent electrometers]
- Channels: 180
- Charge resolution: 0.1 pC/count
- Sampling time: min. 10 ms
- Readout: parallel and synchronous with no dead time
- Weight: approx. 10 kg
- Dimensions: 43.9 cm [L] x 19.5 cm [H] x 17.5 cm [W]
- Power supply: 100-240 V, 50/60 Hz, power cord with US or German power plug included
- Interface to PC: point to point or network Ethernet connection

Bragg Peak® Chamber
Type 34070
Type 34080

Waterproof plane-parallel chamber for dosimetry in proton beams

Materials and measures	
Entrance window	3.35 mm PMMA 0.02 mm graphite 0.1 mm lacquer
Total window area density	411 mg/cm² vs. 205 mg/cm³
Water-equivalent window thickness	4 mm vs. 2 mm
Dimensions of sensitive volume	radius 40.8 mm depth 2 mm

We don’t have these detectors

Bragg Peak® 150
Type 34089

Very large area plane-parallel chamber for dosimetry in proton beams

Materials and measures	
Entrance window	0.29 mm PC foil 0.1 mm GFRP 2.47 mm CFRP 0.03 mm graphite
Total window area density	465 mg/cm²
Water-equivalent window thickness	4.65 mm
Dimensions of sensitive volume	radius 73.5 mm depth 2 mm

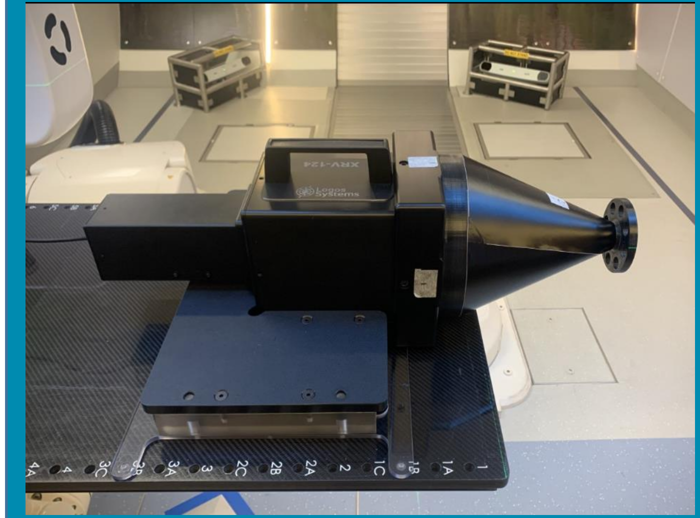
Technical specs

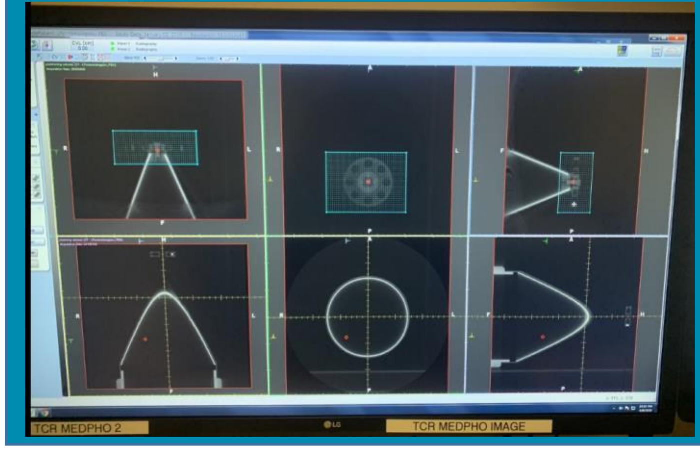
- Electrode diameter: 120.0 mm
- Electrode spacing: 1.0 mm
- Thickness of top electrode: 1.0 mm
- Thickness of housing cover: 2.0 mm
- Air gap between housing cover and top electrode: 0.8 mm
- Housing material: Top cover carbon; Back cover peek ELS

Markus parallel plate chamber
Electrode diameter 5 mm

QA EQUIPMENT

Logos XRV-124 (Winston Lutz)





Specifications:

Accuracy: [1]

XYZ Beam Center:	0.3 mm (hi-res)
Repeatability:	±0.03 mm (typical)
Vector Theta/Phi:	0.3 degree (hi-res)
Repeatability:	±0.1 degree (typical)

Optical System: [1]

Resolution:	1280 × 960 pixels or 640 × 480 pixels
Capture Rate:	1 - 30 frames/sec
Cone Angle:	45 degrees
Usable Cone Area:	140 mm over 360 deg. Width: 30 - 60 mm
Lens MTF:	Megapixel resolution
Camera Interface:	USB 3.0

Camera Shielding: [2]

Camera top and sides:	12.7 mm thick bismuth and polymer composite
CCD Lifetime:	~1,500 X-ray beam hours

Camera Module Physical:

H × W × D:	27 × 19 × 67 cm
Weight:	7.8 kg (17.2 lbs)
Enclosure Material:	Aluminum and Plastic

Lynx PT (spot positioning and size)

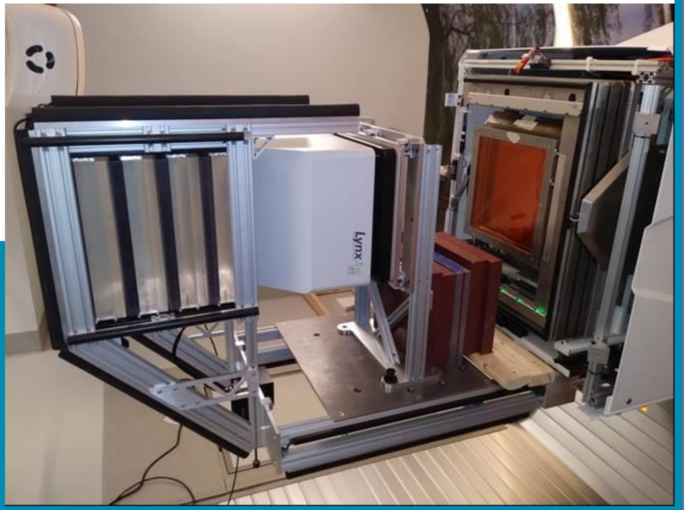
Technical specs

- Scintillation screen thickness: 0.4 mm
- Energy range: 60Co at 25 MV in photons /4 to 25 MeV in electrons/ 230 MeV Protons
- Active surface area: 300 x 300 mm² (600 x 600 pixels)
- Pixel size: 4.65 x 4.65 um²
- Effective spacial resolution: 0.5 mm
- Geometric distortion: ≤ 0.3 mm for the central zone of ≤ 280 x 280 mm²; ≤ 0.8 mm elsewhere
- Image acquisition: CCD camera
- Video camera: 1024 x 1024, 12-bit resolution
- Sampling time: 7 images / secondes
- Dose linearity within +/- 1.5%
- Spot sigma: Variation < 100 um

- Dimensions: 360 x 370 x 600 mm
- Weight: 11 kg

Auxiliaries

- Calibration plate for Lynx PDR1602



QA – DAILY (20-30 minutes)

performed by RTT (single device)

exercises all aspects of patient treatments, (imaging, registration, PPS, delivery)

includes safety checks (AV, door interlocks, beam ON indicator, beam pause)

measure and trend R80, W80, output, output/entrance, flatness, x, y, Δx, Δy σ_x, σ_y, dark current

M-1 Beam range – ±0.5 mm (O-2)

M-2 Depth-dose W_{80-80} – ±1.0 mm (O-2)

M-3 Dose constancy – ±1.5% (O-2, O-4)

M-4 Entrance dose relative to output – ±1.5% (O-2)

M-5 Spot position – ±1.2 mm (O-2)

M-6 Spot size (sigma) – ±10% (O-2)

M-7 Field flatness, (max-min)/(max+min) – ±2%(O-2)

M-8 Dose due to dark current – undetectable (O-2)

M-9 Dose monitoring accuracy (DCEU) – ±0.05 Gp (O-2)

M-10 Delivery of multilayer irradiation – functional (O-6)

M-11 Imaging and laser coincidence at setup position and isocenter – ±3 mm (O-8)

M-12 Patient positioning and imaging coordinate coincidence – ±1 mm (O-9)

M-13 Imaging and beam coordinate coincidence – ±1 mm (O-10, O-9)

M-14 Positioning/repositioning (i.e. constancy of registration correction vector when the phantom is not centered) – ±1 mm (O-10)

M-15 Door interlock stops beam – functional (O-11)

M-16 Door closing electric eye – functional (O-11)

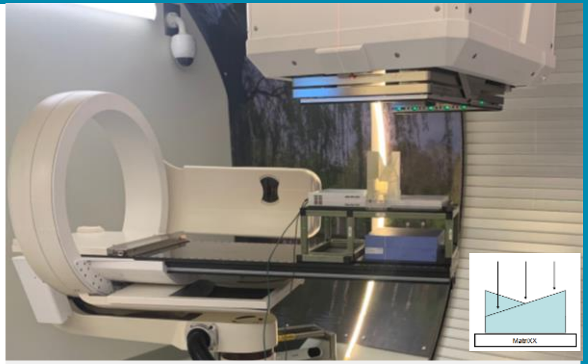
M-17 Patient distress buzzer – functional (O-11)

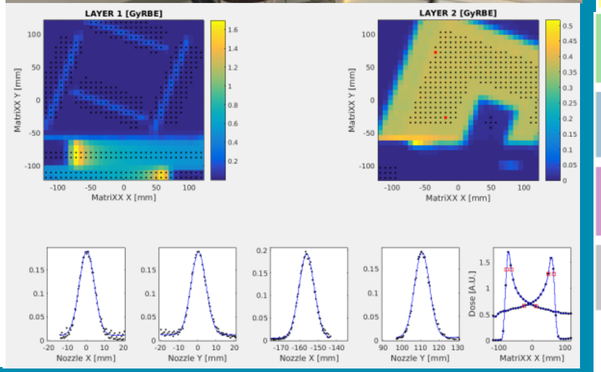
M-18 CCTV and audio monitors – functional (O-11)

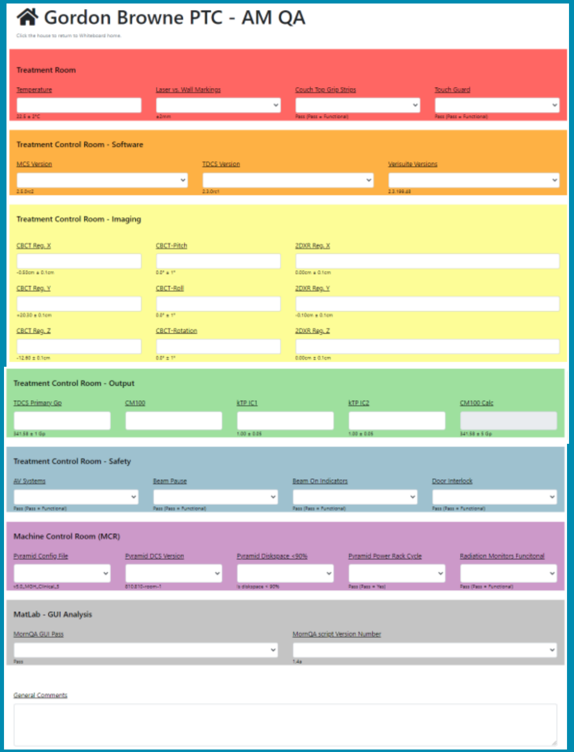
M-19 Radiation area monitors – functional (O-11)

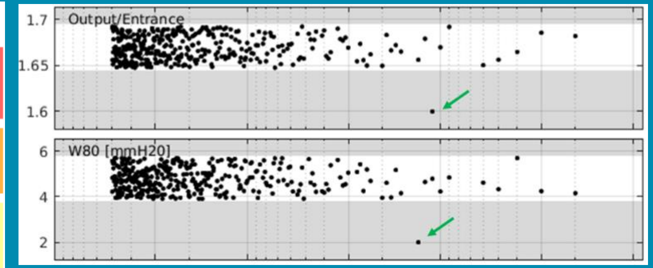
M-20 Beam on indicators inside and outside the treatment area – functional (O-11)

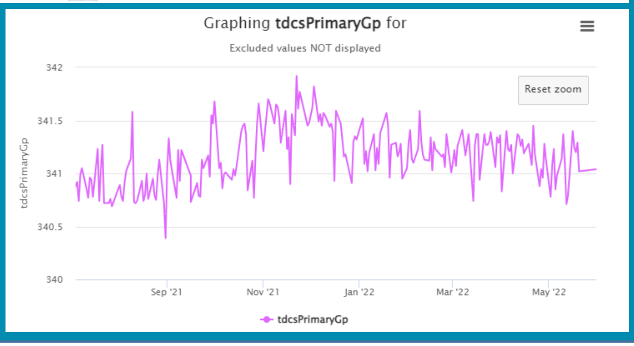
M-21 Collision interlocks – functional (O-11)







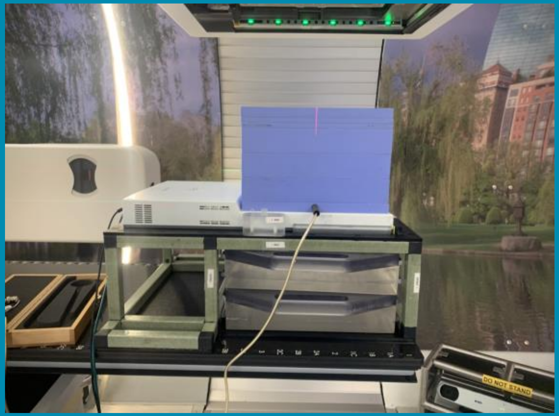


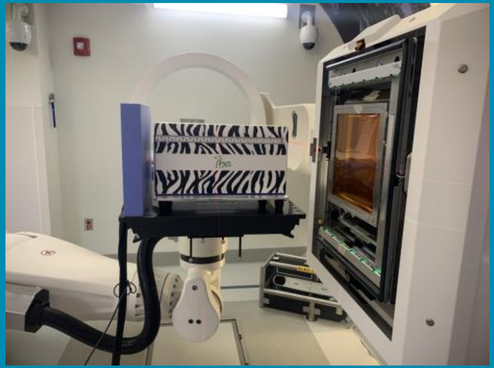


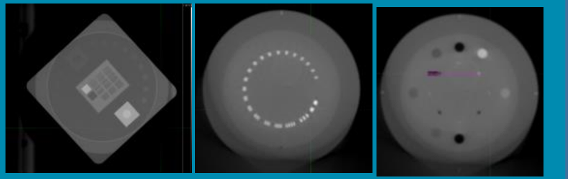
QA – MONTHLY (12-15 hours over 4 weeks, 8-10 hours in one session)

performed by MPA

- backup morning QA procedures
- Matrixx cross calibration (A1)
- dose uniformity (Matrixx)
- gamma consistency (Matrixx)
- range uniformity (Matrixx and SW)
- SOBP uniformity (Zebra)
- Winston-Lutz
- mechanical checks (translations, rotations)
- couch sag
- laser alignment
- image quality (Leeds & Cat phantoms)
  - HU, LP/mm, geometry
- safety checks
  - range shifter detection, emergency stops, door open, CBCT guard, wall laser guards, PPS and accessories

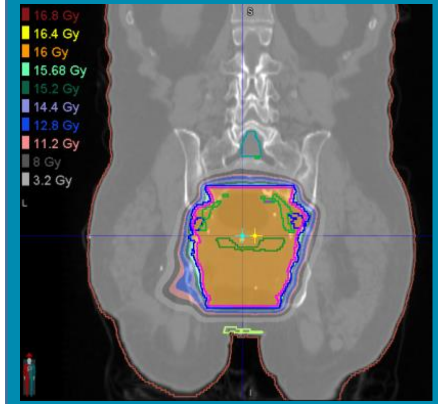


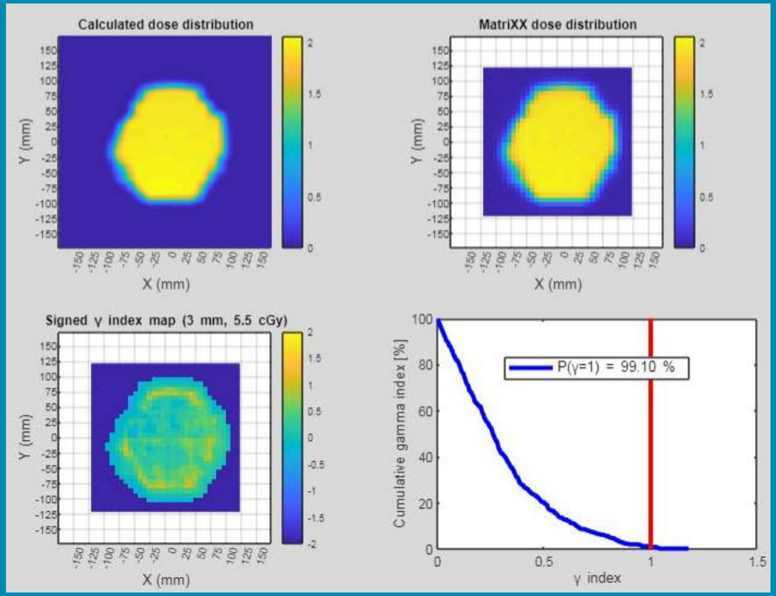




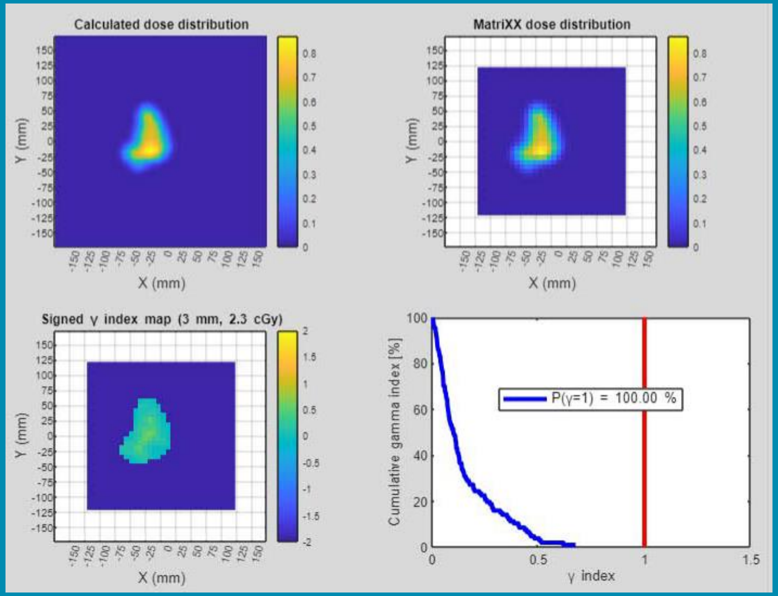
QA – FIELD SPECIFIC (10-20 minutes, 3 irradiations, $G_{0\text{-deep}}$, $G_{0\text{-shallow}}$, G_{TX})

performed by MPA

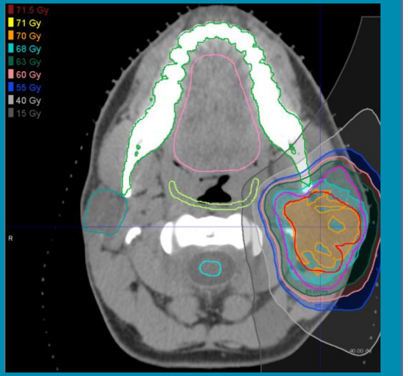


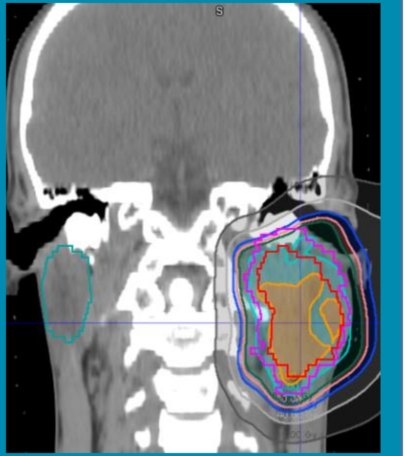


Iso depth: 50 mm
--------------------MEASUREMENT INFO--------------------
Measurement file name: 360A1c000_50mm.opg
Measurement type : Extended
Measurement depth: 50 mm
Gantry angle: 360 degrees
MatriXX orientation : 0 degrees
------------------------ANALYSIS INFO------------------------
Gamma criterion: 3 mm, 3 % of 1.821 Gy, with 10 % threshold
User dose shift : 0 %
User X shift: 0 mm
User Y shift: 0 mm
Room: Lunder



Iso depth: 50 mm
--------------------MEASUREMENT INFO--------------------
Measurement file name: 230A1c180_50mm.opg
Measurement type : Extended
Measurement depth: 50 mm
Gantry angle: 230 degrees
MatriXX orientation : 0 degrees
------------------------ANALYSIS INFO------------------------
Gamma criterion: 3 mm, 3 % of 0.761 Gy, with 10 % threshold
User dose shift : 0 %
User X shift: 0 mm
User Y shift: 0 mm
Room: Lunder





QA - ANNUAL

Performed by QMP

Dosimetry		
Standard output calibration	±2%	TRS 398 calibration
Range verification	±1 mm	Measured at 90% depth dose
SOBP width	-	Width between proximal and distal 90%[a] depth dose
Depth doses verification	±2%	Maximum difference at any depth
Lateral profile penumbra	±2 mm	80–20% for selected beams at different depths$dummy$and gantry angles
Range uniformity	±0.5 mm	Corresponding to depth of 90% dose at points off axis
Field symmetry	±1%	Measured at different gantry angles (relative to baseline)
Field flatness	±2%	Measured at different gantry angles (relative to baseline)
Spot position	1mm/0.5 mm	Absolute/relative
Spot size	±10%	At different gantry angles
Uniformity of spot shapes[c]	2% & 2 mm	Multiple gantry angles. Gamma: ≥ 90% of pixels passing
Inverse square correction	±1%	From effective source position
Monitor chambers:		
Linearity	±1%	
Reproducibility	±2%	
Minimum/Maximum dose/spot	Functional	Minimum and Maximum are determined by manufacturer
End effect	1 min MU	For PBS: minimum deliverable MU
SOBP factors	±2%	
Range shifter factors	±2%	
Relative output factors	±2%	
Verification of daily QA equipment	±1% and/or ± 1mm	Compared with ADCL calibrated equipment
Cross calibration of field chambers	±2%	Ionization chambers used for daily and monthly against standard ADCL chamber
~~MLC leakage~~		
~~Interleaf~~		~~Consistent with baseline~~
~~Leaf end~~		~~Consistent with baseline~~
~~Shielding support~~		~~Consistent with baseline~~
Mechanical (all delivery systems)		
Coincidence of proton and x-ray field		
Coincidence of proton and light field		If light field is used for setup
Gantry angle accuracy		
Gantry isocentricity		Diameter of a circle
Gantry x-ray isocentricty		Diameter of a circle
Couch sag		Weight limit and position as specified by manufacturer
Snout extension accuracy		
~~Snout rotational accuracy~~		
CBCT isocentricity		Diameter of a circle
Imaging System functionality		
Image system perormance and dose		TG-179 and TG-142
CBCT		TG-179, TG-142, and MPPG-2a
Standard annual x-ray system checks		State regulations

AAPM TG224

+ summarize monthly/daily QA reports
+ summarize ad hoc repair/upgrade validation reports
+ IROC TLD
+ optical tracker checks
+ couch edge interlock checks
+ laser guard checks
+ 2.5D imaging verification
+ immobilization and beam modifying device WET
+ n° activation, chilled water surveys and review badge readings
+ verify safety interlocks including redundant MU stops
+ TPS verification of stoichiometric HU → RSP
+ TPS end-to-ends tests
+ TG179 & 142 imaging

- we have not implemented gating, surface imaging, apertures so these are not currently checked as part of annuals

SYSTEM SUMMARY

	Burr (IBA multi-room circa 2001)	**Lunder Proton** (Protom single room)
Gantry rotation	0° to 360°	180° to 360° and 9° over-travel
Irradiation time, 1L 1.5 Gy	4 to 5 minutes	Same
Field size	30.5 x 28 cm	27 x 31 cm
Proton range	6.9 to 31.5 g/cm^2	3.9 to 31.5 g/cm^2 (later 37.5 g/cm^2)
Couch translation constraints	Nozzle cover and snout	Burr constraints plus: room walls, optical tracker volume, and couch joint
Beam size	8 to 15 mm	3.3 to 6.7 mm
Imaging	Gantry mounted 2D/2D Manual anatomic point-based registration Manual transfer of correction vector	Fixed 2D/2.5D, Couch mounted CBCT Automatic registration Automatic transfer of correction vector
Patient weight	400 lbs	310 lbs
Apertures	Yes	No*
Gating	Motion management strategy under evaluation. Gating capabilities available on both.	
Vision RT	Yes	Upgrade later

PROBLEM TRACKING

<u>CHALLENGES</u> AND OPPORTUNITIES

- vault built before vendor and product selection
- transport and delivery of very large gantry, accelerator… components
    - through a very active medical facility
    - limited space for transport and delivery
    - below ground level
- accelerator and treatment rooms
    - next to Linac vaults treating patients
    - very small, limiting system implementations options
        - couch mounted CBCT
        - need for secondary PPS tracking
- shielding (access to other departments, Linac radiation, supplemental in tight spaces)
- cutting of concrete with 13 floors above
- connection to building infrastructure while they are being used
- modular components requires significant installation sequencing coordination
- complex sub-system configuration and communication
- resource allocation with minimal increases
- **1st generation systems requires extensive resources to troubleshoot, maintain and upgrade…**

CHALLENGES AND OPPORTUNITIES

- achieve goals
  - providing backup redundancy for proton patients
  - increase capacity and patient access
- improve technology and safety
- customize workflows and system interaction
- work with vendors to solve challenges, improve workflows
- understand subtle differences between systems