Overview of Quality Assurance in Proton Therapy

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ProCure Proton Therapy Center

Learning Objectives

- Understand proton beam dosimetry characteristics and compare them to photon beams
- Familiarize with proton dosimetry QA tools
- Understand challenges in proton therapy QA

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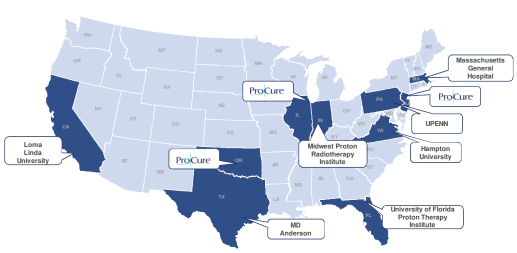
Clinically operating proton therapy facilities



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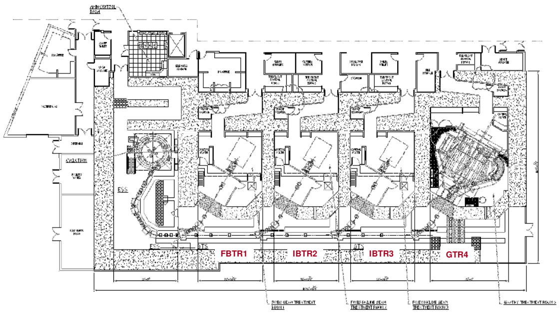
Multi-room Facilities



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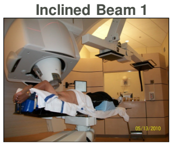
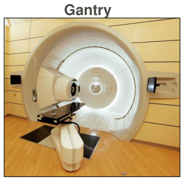
In-room Design

Inclined Beam 1

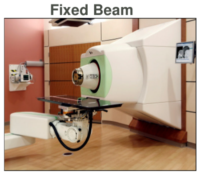


Inclined Beam 2

Gantry



Fixed Beam



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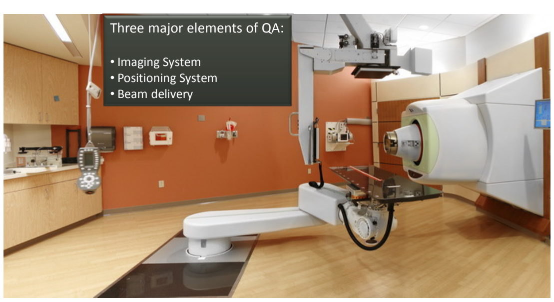
Inside Treatment Room



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Beam Delivery Techniques

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Beam Spreading Techniques

Passive Scattering ← vs → **Active Scanning**

- Passive Scattering
  - Single Scattering
  - Double Scattering (DS)
- Active Scanning
  - Uniform Scanning (US)
  - Pencil Beam Scanning (PB)

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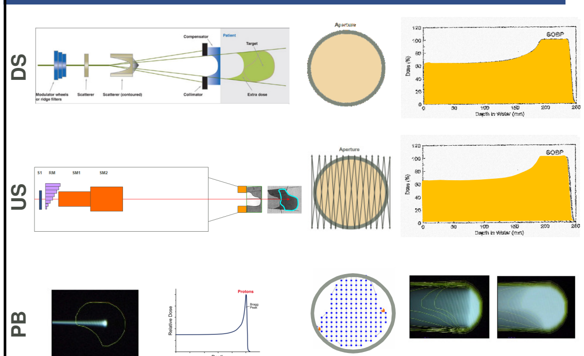
Beam Delivery Techniques



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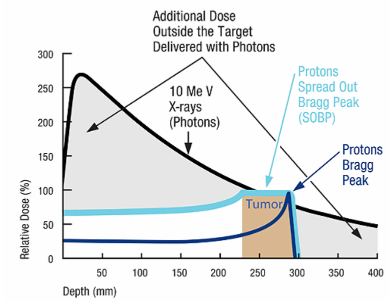
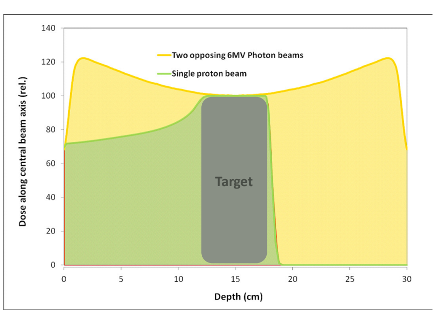
Beam Characteristics at Depth

Dosimetric Advantage of PT

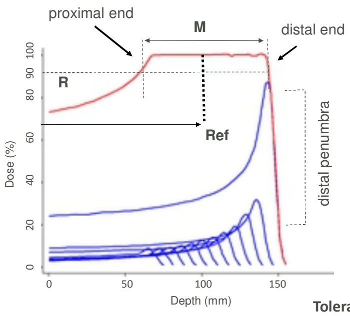


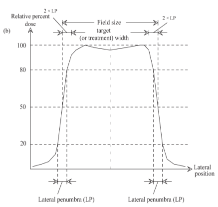
Coverage at depth: Protons vs Photons



Y. Zheng

Anatomy of a Spread-Out Bragg Peak (SOBP)

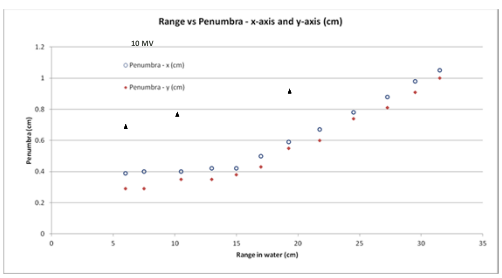




Tolerances
- Flatness within **5%**
- Symmetry within **3%**
- Range within **1.5 mm**
- Modulation within **5 mm**

ICRU 78

Lateral penumbra at depth



Uniform Scanning beam data, ProCure - OKC

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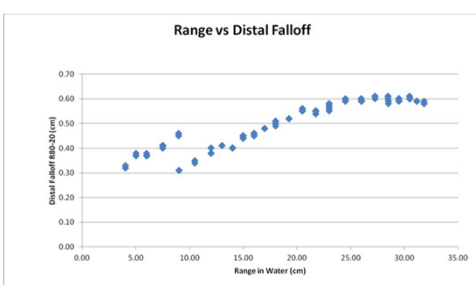
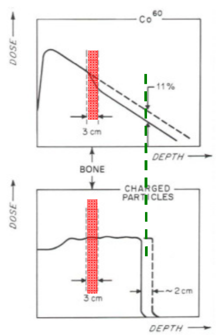
Distal penumbra at depth



Uniform Scanning beam data – ProCure -OKC

Proton vs. Photon PDDs in presence of heterogenieties



Photons → Loss in Fluence (attenuation)
SAME ENERGY

Protons → Loss in Range (Energy) (degradation)
SAME FLUENCE

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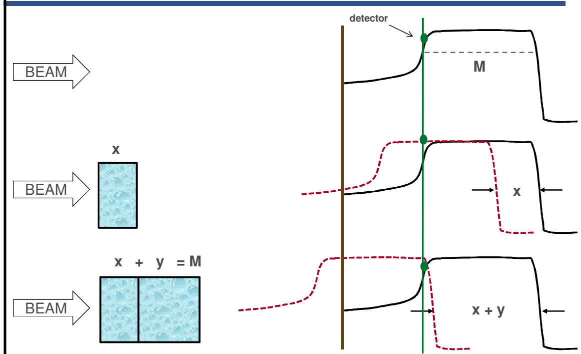
How to manipulate the SOBP beam?



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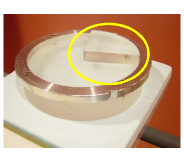
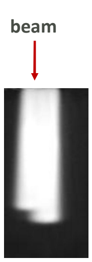
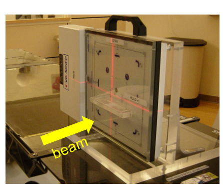
What can you get from a **SINGLE** delivery?



Get creative with compensator design





Get creative with array housing

Ding *et al* 2012

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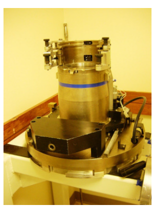
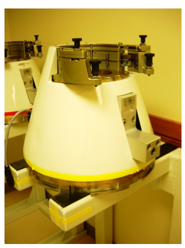
QA of Patient Devices

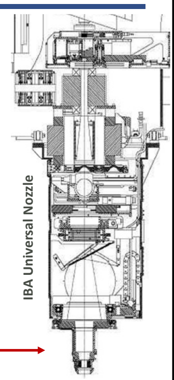
Nozzle & Snout Design



10 cm snout



18 cm snout



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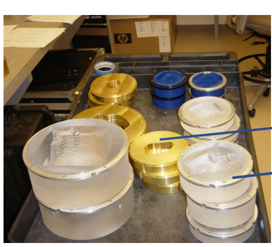
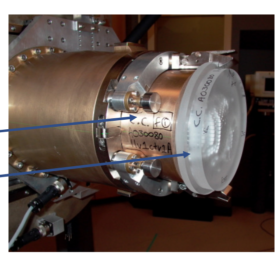
Patient Devices





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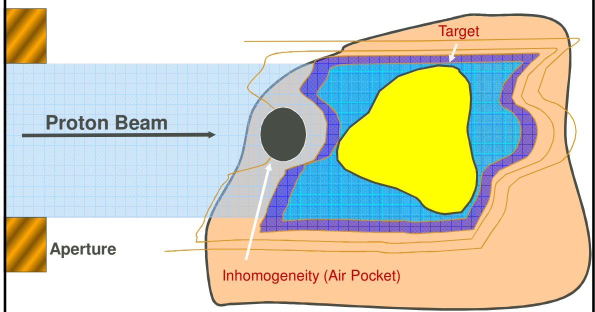
Distal end shaping - no compensator



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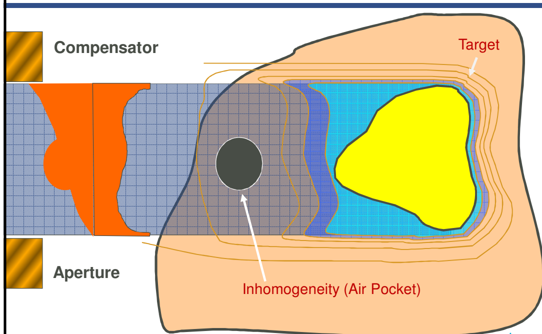
Distal end shaping – with compensator



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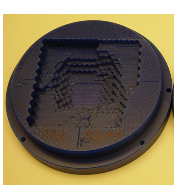
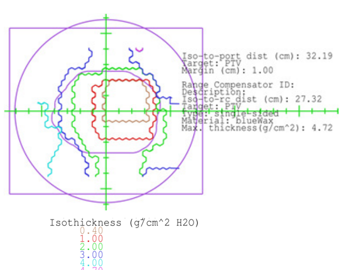
Patient Device QA



thick for tissue, thin for bone



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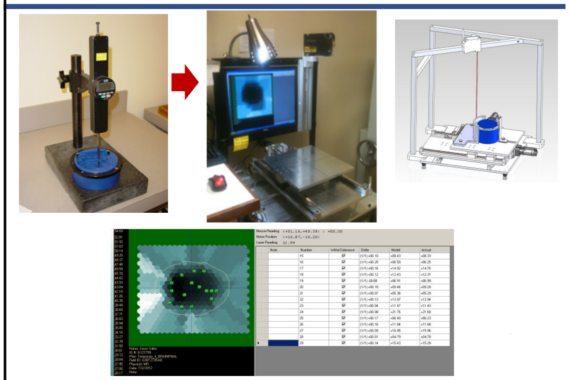
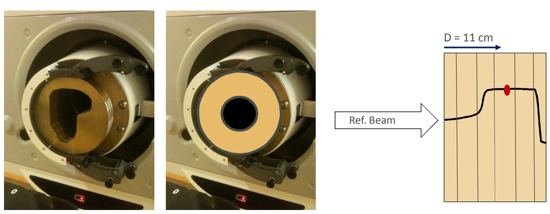
Improving QA equipment



Output factor measurements



Patient Aperture | 10 cm Aperture | R16M10

$$OF_{pt} = \frac{RDG_{ref}}{MU_{ref}} / \frac{RDG_{pt}}{MU_{pt}}.$$

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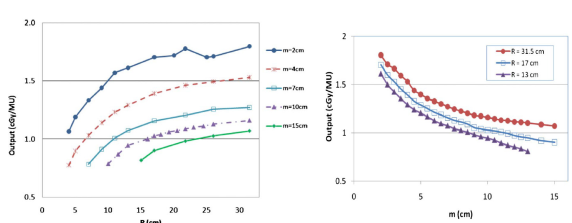
Output factor dependencies



Other factors:
Field size, snout position, phantom material, dose rate

Zheng *et al.*: Output factors for uniform scanning proton beams
Medical Physics, Vol. 38, No. 4, April 2011

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Beam QA with 1D Arrays

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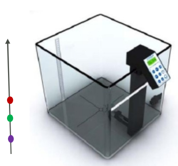
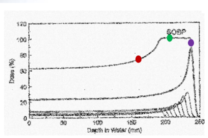
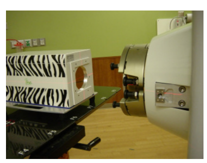
1D Arrays – How do they compare for PDD measurements?



vs





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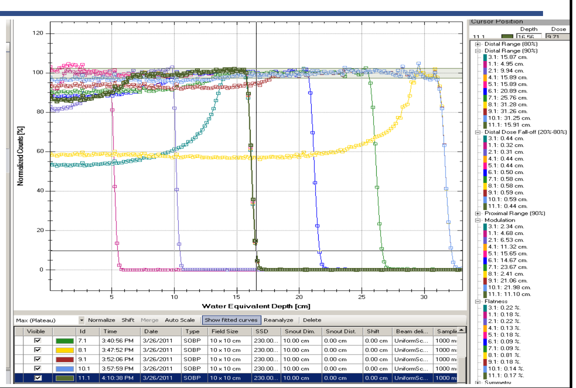
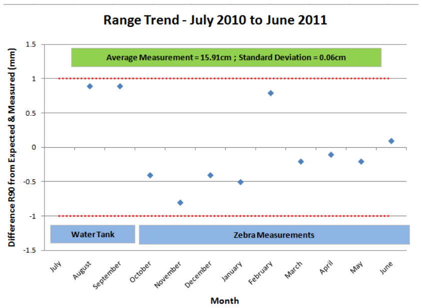
Zebra PDDs



Monthly Range Trend



IBL3

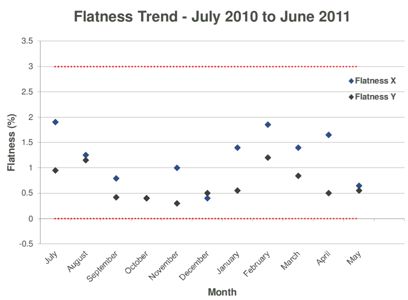
Beam QA with 2D Arrays

Measurements of Flatness & Symmetry

3. Flatness and Symmetry						
Tolerance:						
Flatness	5%	Symmetry	3%		Field size (cm)	0.5
Procedure:						
Use Sun Nuclear IC profiler, measure beams at gantry 90 and 30.						
Using Continuous mode (not pulsed beam).			Ctp=		1.03	
Snout10	@	18	AP diameter	10	RC thickness	10
		Gantry 90°			Gantry 30	
Beam	Item	Result	Pass/Fail		Result	Pass/Fail
R16M10D11			R16M10D11			
	Output (rel.)	553711.00			556952.00	Pass
	Y Flatness	2.5%	Pass		1.4%	Pass
	Y Symmetry	-0.2%	Pass		0.1%	Pass
	Y Field size (cm)	10.91	Pass		10.88	Pass
	X Flatness	1.8%	Pass		2.5%	Pass
	X Symmetry	1.2%	Pass		0.9%	Pass
	X Field size (cm)	10.73	Pass		10.70	Pass
R30M10D11			R5m4D4			
	Y Flatness	2.3%	Pass		3.7%	Pass
	Y Symmetry	0.0%	Pass		-0.1%	Pass
	Y Field size (cm)	10.95	Pass		10.89	Pass
	X Flatness	1.2%	Pass		2.1%	Pass
	X Symmetry	-0.3%	Pass		-0.1%	Pass
	X Field size (cm)	10.74	Pass		10.65	Pass

Monthly QA Sheet, IBL2 – Jan 2012

Monthly Flatness Trend – reference beam



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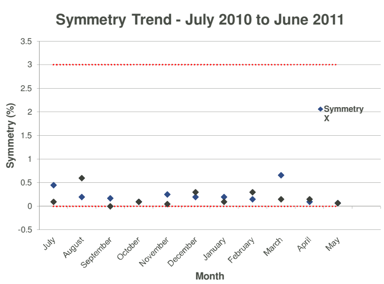
Monthly Symmetry Trend – reference beam



IBL3

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ProCure Morning QA Device

rf Daily QA3

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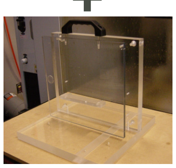
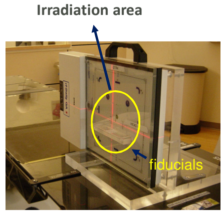


ProCure Machine Shop

Irradiation area



Xiaoning Ding, PhD

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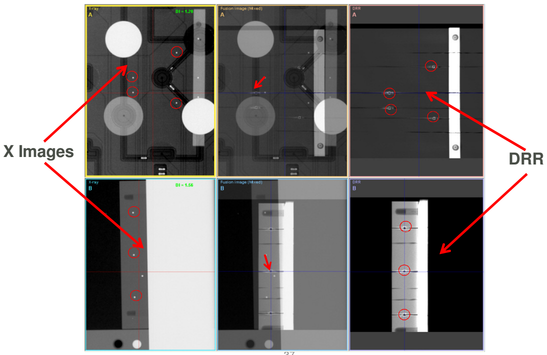
Imaging QA: Comparing DRR with X-ray Image



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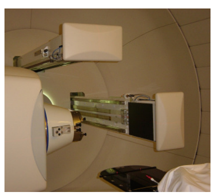
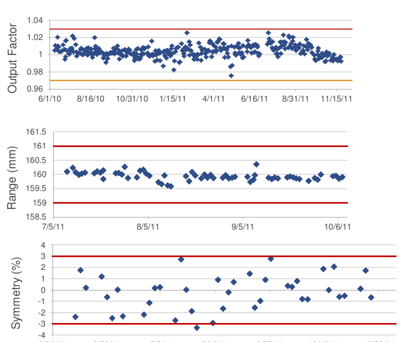
Morning QA Procedure

One setup, One device, One beam to get the following:

1. Output consistency check
2. Range consistency check
3. Symmetry consistency check
4. Imaging vs mechanical alignment check
5. In-room laser check



Morning QA Trends



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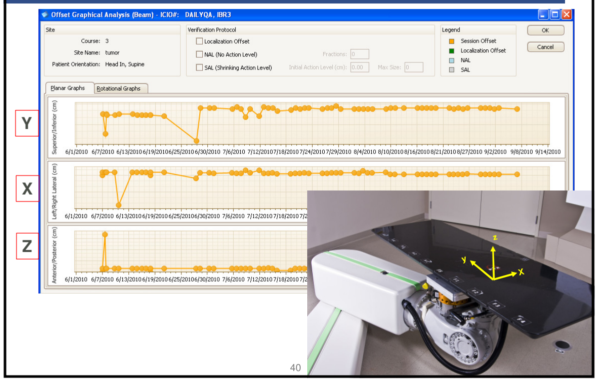
Temporal tracking of PPS correction vector



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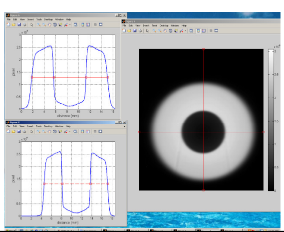
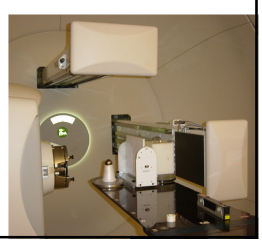
Colinearity Test

- Purpose: to check that imaging isocenter coincides with radiation isocenter to within 1 millimeter.

Imaging Iso = Proton Iso





Daily Checks Monthly Checks Annual Checks

- Imaging vs mechanical alignment
- Output
- Range
- Software Communication
- Proton-imaging isocentricity
- Flatness & Symmetry
- Ranges and Modulations
- Mechanical
- PPDs + Modulations
- Combinations of field sizes and gantry angles
- X-ray source & detector image characteristics
- Dose rate dependencies

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QA Challenges in PT

QA challenges in PT

- **Proton delivery modes & control systems are complex-**more things to check
- **Lack of methodology or forum to exchange ideas that improves QA processes** – very few clinical proton physicists
- **PT systems are not robust yet –** few years of operations, many bugs to resolve (software & hardware)
- **QA programs highly depend on vendor's system specs**

QA Challenges in PT – cont.

- **There are currently no task group recommendations for proton beam QA. Where relevant we follow guidelines from the following sources:**
  - IAEA TRS 398
  - ICRU 59
  - ICRU 78
  - TG 40
  - TG 142
  - Journal publications
- **Lack of dedicated commercial QA devices for PT** –adaptation of photon QA devices is necessary

QA Challenges in PT – cont.

- **It takes time to switch, tune, and deliver beam in every room**
  – QA tasks takes longer compared to linac systems
- **Current PT centers have 3-5 rooms with sequentially beam delivery –** beam sharing is necessary
- **Cost of proton specific QA equipment**
- **Multi vendor software/hardware –** lack of true integration

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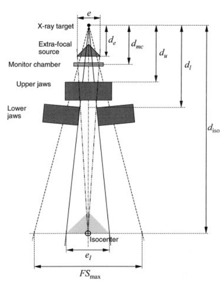
Anatomy of a linac head

- **Carousel (scatterers)**
- **Magnets**
- **Jaws (primary)**
- **Jaws (tertiary)**
- **Ion chamber**
- **MLCs**
- **Light field**

- **OUTPUT**
  - Electrons (4-6 energies)
  - Photons (1-3 energies)



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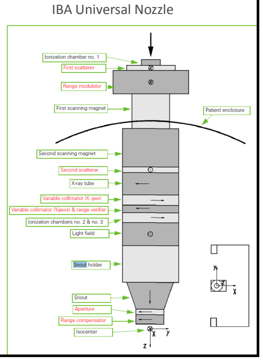
Anatomy of a Nozzle

- **Compensator**
- **Aperture(s)**
- **Snout with variable positions**
- **Lollipops**
- **Modulator wheels (multiple tracks)**
- **Multiple ion chambers**
- **Collimators (X-Y)**
- **X-Y magnets (3 scanning fields)**
- **Range verifier**
- **X-ray source**
- **Scatterers**
- **Light field**

- **OUTPUT**
  - Modulation (very large combinations)
  - Range (very large combination)

IBA Universal Nozzle



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Summary

- **Proton Therapy Systems are complex and requires specialized equipment to measure various beam parameters**
- **It is imperative to make use of commercially available 1D & 2D arrays and adapt them to PT to check routinely for**
  - Beam parameters (R,M, Symmetry, Flatness, Output)
  - Imaging System
  - Robotic positioning System
- **Standardization of QA procedures for PT is essential in establishing tolerance limits**

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Contributors

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Thank you

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