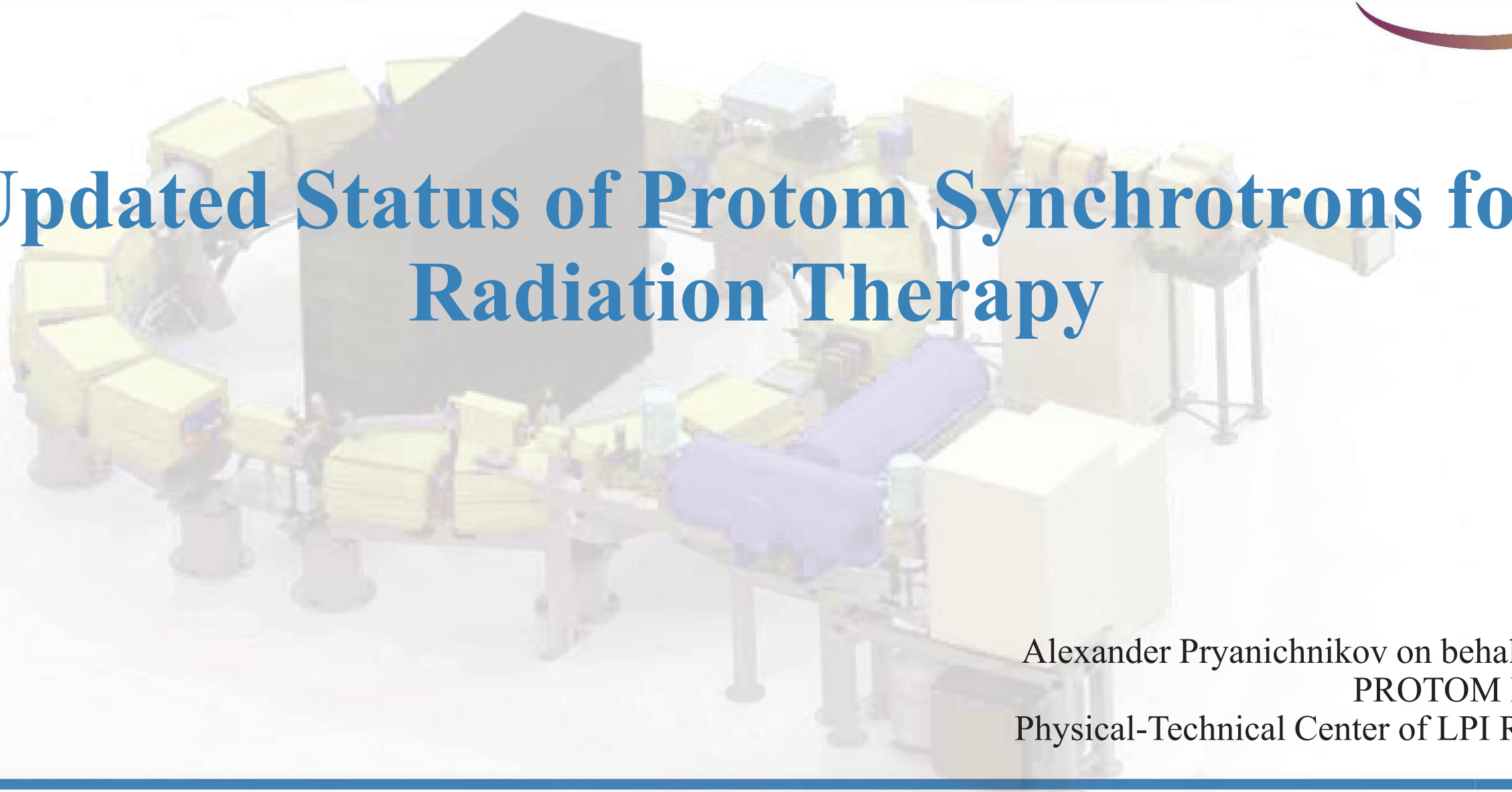
Updated Status of Protom Synchrotrons for Radiation Therapy



Alexander Pryanichnikov on behalf of
PROTOM Ltd.
Physical-Technical Center of LPI RAS

Agenda

1. Protom Synchrotron Timeline
2. Proton Therapy Solutions Overview
3. Accelerator Facility Components
4. Key Upgrades
5. Protom Medical Part

Protom Synchrotron Timeline

Technical runs	Start of treatment	Patients irradiated worldwide
• 2003 – The 1st Protom Synchrotron • 2010 – Protvino City Hospital, Protvino, Russia • 2010 - Central Military Hospital, Ruzhomberok, Slovakia • 2011 – McLaren Hospital, Flint, MI, USA • 2015 - MRRC, Obninsk, Russia • 2016 – MGH, Boston, MA, USA	• 2015 – Protvino City Hospital, Protvino, Russia • 2016 – MRRC, Obninsk, Russia	• 2017 – 100th patient **RuPAC'2018**
• 2019 – P-Cure, Shilat, Israel • 2021 – MIT Bates, USA (for Australian Bragg Center for PT)	• 2018 – McLaren Hospital, Flint, MI, USA. • 2020 – MGH, Boston, MA, USA	• 2020 – 500th patient • 2021 – 1000th patient **RuPAC'2021**

Protom Synchrotron Geography

* Under Constriction

Agenda

1. Protom Synchrotron Timeline
2. Proton Therapy Solutions Overview
   - “Prometheus”
   - “Radiance 330”
   - P-Cure PT Solution
3. Accelerator Facility Components
4. Key Upgrades
5. Protom Medical Part

Proton Therapy Solutions Overview

Complex Name	Prometheus	Radiance 330	P-Cure Proton Therapy Solution
Main Manufacturers	**Protom Ltd.**	**Protom International** Protom Ltd. Pyramid Technical Consultants AccSys Technology Oy International Electric Co.	**P-Cure** Protom Ltd.
Permissions to Treat	Russian local granted CE is ongoing	FDA proved CFDA is ongoing	FDA is ongoing Israel local is ongoing CFDA is ongoing
Locations	Obninsk, Russia Protvino, Russia Ruzhomberok, Slovakia	Flint, MI, USA Boston, MA, USA Middleton, MA, USA Adelaide, Australia*	Shilat, Israel Weifang, China*

Proton Therapy Solutions Overview

Prometheus	Radiance 330	P-Cure PT Solution
		
PCH, Protvino, Russia, 2010	McLaren, Flint, USA, 2011	P-Cure, Shilat, Israel, 2019
		
MRRC, Obninsk, Russia, 2016	MGH, Boston, USA, 2017	

Protom Production Line

Up to 5 full magnetic system assemblies

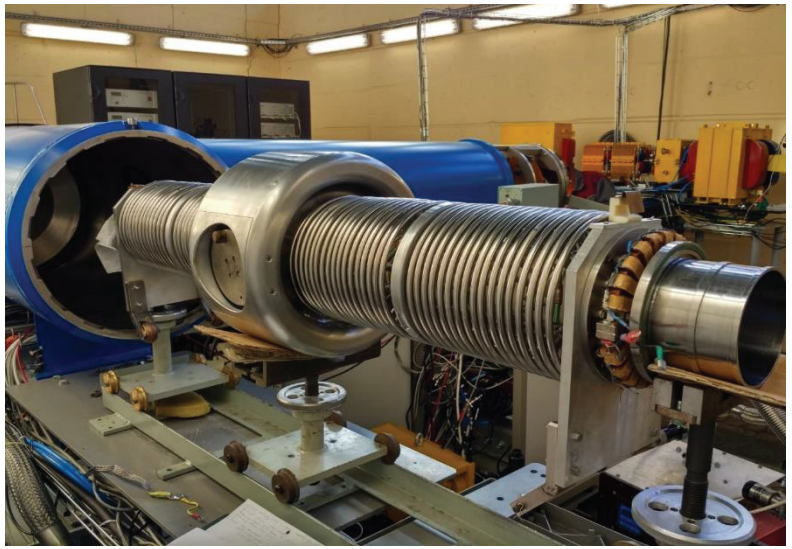
3 bunkers for proton accelerators

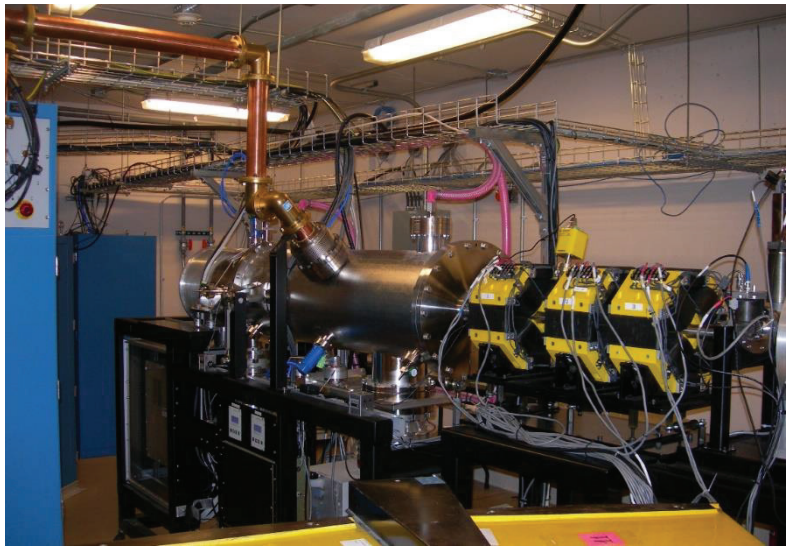
1 bunker for ion accelerator complex

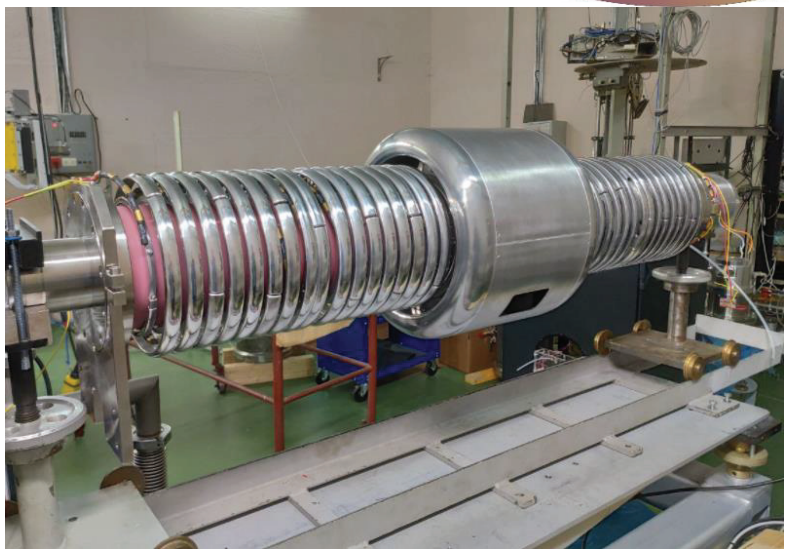
Agenda

1. Protom Synchrotron Timeline
2. Proton Therapy Solutions Overview
3. Accelerator Facility Components
    - Injector
    - Synchrotron
    - Extraction System
4. Key Upgrades
5. Protom Medical Part

Injector







Tandem v.1	AccSys Technologies RFQ	Tandem v.2
Injection energy 0.9 MeV	Injection energy 1.6 MeV	Injection energy 1.1 MeV
Film recharge (Carbon)	Oper frequency 425 MHz	Gas recharge (Nitrogen)
“Prometheus” 1st gen	“Radiance 330”	P-Cure PT Solution “Prometheus” 2nd gen

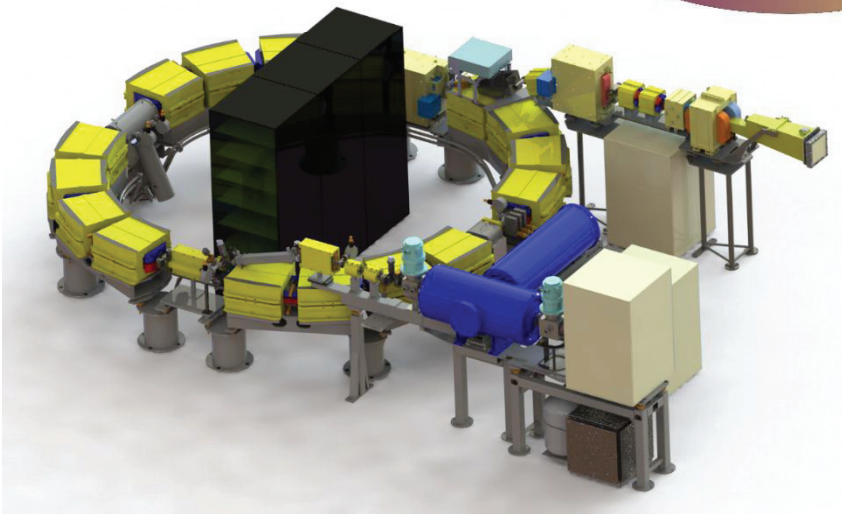
Synchrotron

Synchrotron Main Parameters

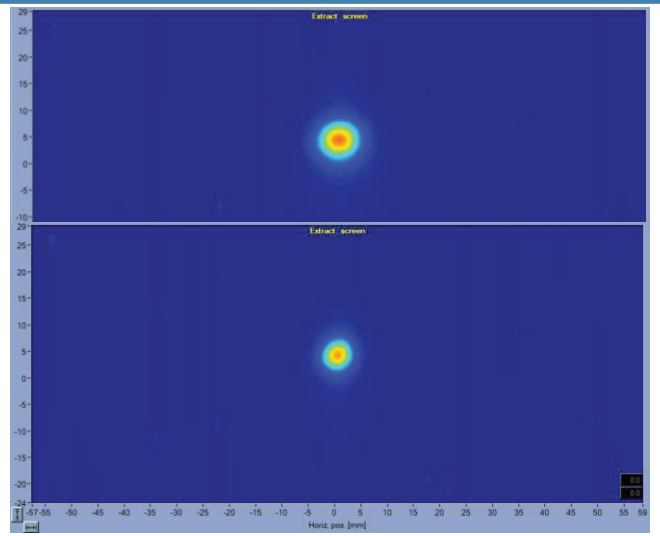
Range of accelerated proton energies, MeV	30 - 330
Range of energies for treatment, MeV	70 - 250
Acceleration time for 250 MeV, sec	0.9
Intensity of extracted beam, protons per cycle	up to 4×10^9
Outer diameter of the ring, m	5
Accelerator weight, tons	15
Average energy consumption during treatment, kW	30

Synchrotron Main Components

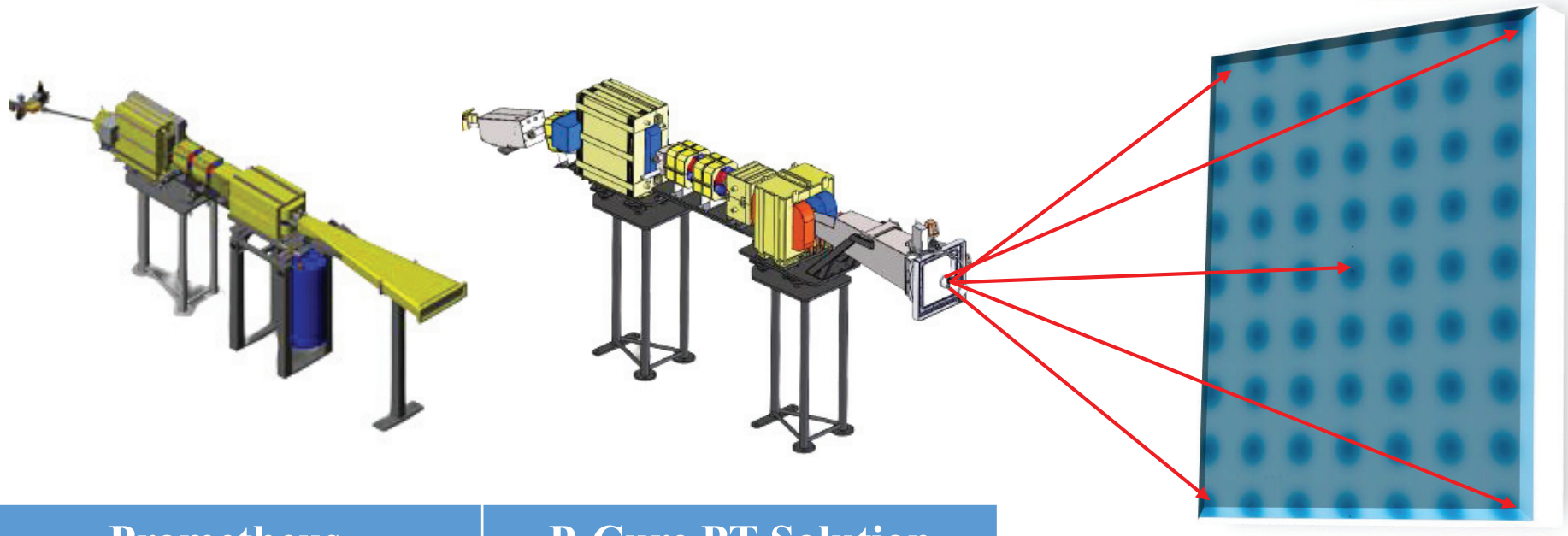
16 bending magnets up to 1.9 T
16 horizontal and 4 vertical electromagnetic correctors
4 right gaps
1 RF station up to 15 MHz
1 electrostatic deflector up to 100 kV
8 BPMs
1 beam current sensor and 4 luminophores



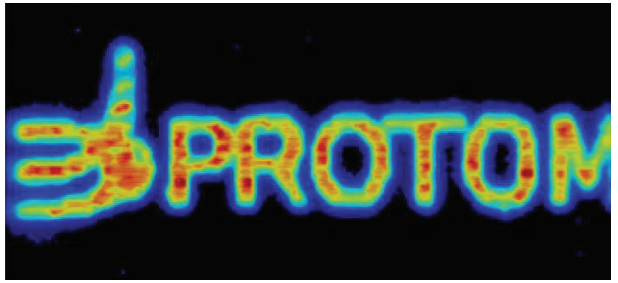
Extraction Channel and Nozzle



Beam Size at the Nozzle
(100 and 250 MeV)



	Prometheus 1st gen	P-Cure PT Solution Prometheus 2nd gen
Horizontal field size, mm	700	400
Vertical field size, mm	90	400
Horizontal speed, A/s	1500	2000
Vertical speed, A/s	500	1000



Examples of Pencil Beam
Scanning System

Agenda

1. Protom Synchrotron Timeline
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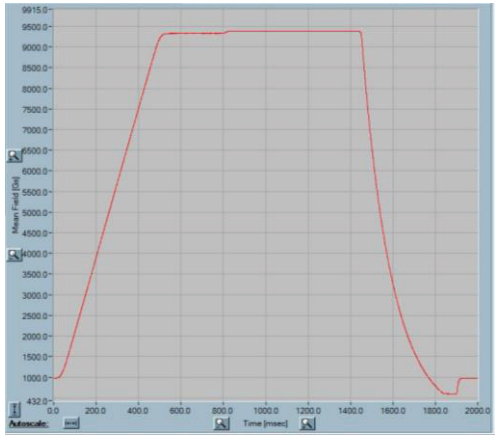
3. Accelerator Facility Components
4. Key Upgrades
   - Treatment Time
   - Precise Dose Control and Delivery
5. Protom Medical Part

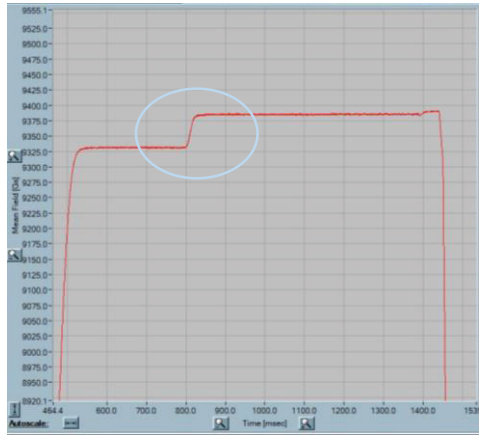
Decreasing Treatment Time

Increasing Injected Beam Intensity

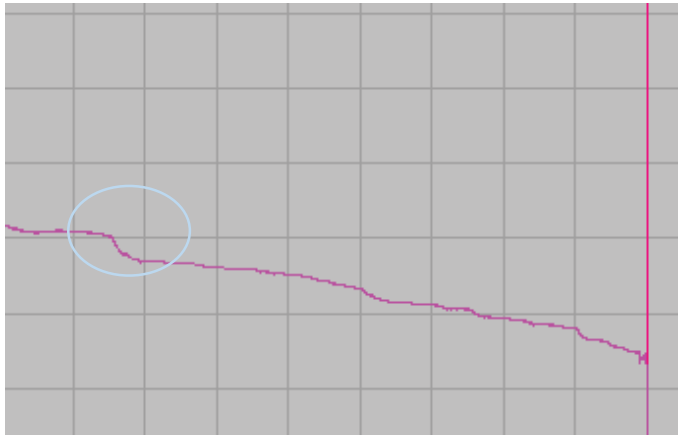
Complex Name	Prometheus 1st gen	Radiance 330	P-Cure PT Solution	Prometheus 2nd gen
Injector Type	Protom Tandem v.1	AccSys RFQ	Protom Tandem v.2	Protom Tandem v.2
Extraction intensity, protons per cycle (for full treatment energy range)	1×10^9	4×10^9	2×10^9	2×10^9

Double energy extraction (experimental mode only)

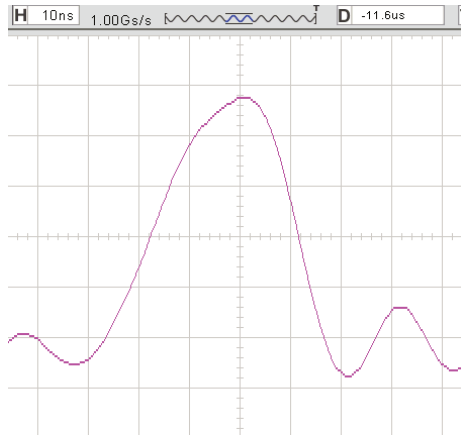




Time-field dependence



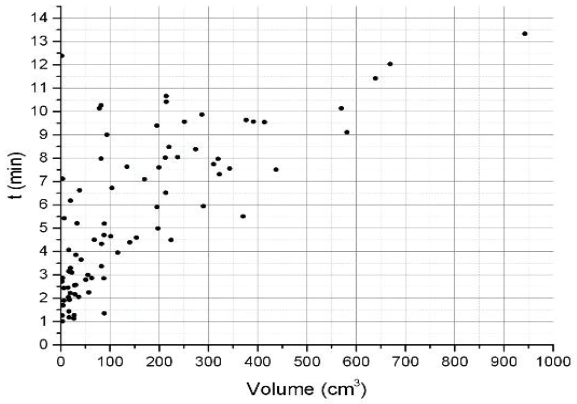
BPM Readings

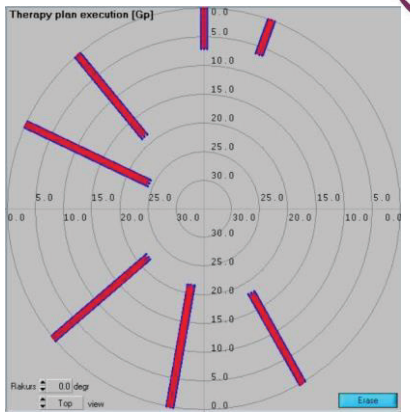


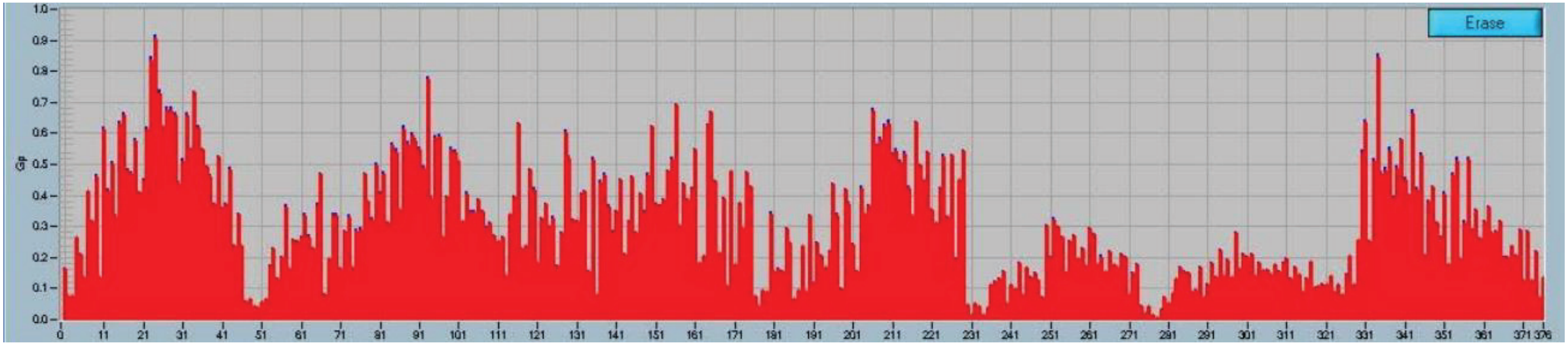
Beam Current

Example of Real Treatment Plan Execution 1

PTV:	897.06 cm^3
Dose:	2 Gy
Beam directions:	7
N of Energy Layers:	376
Number of protons:	$1{,}18\times10^{11}$





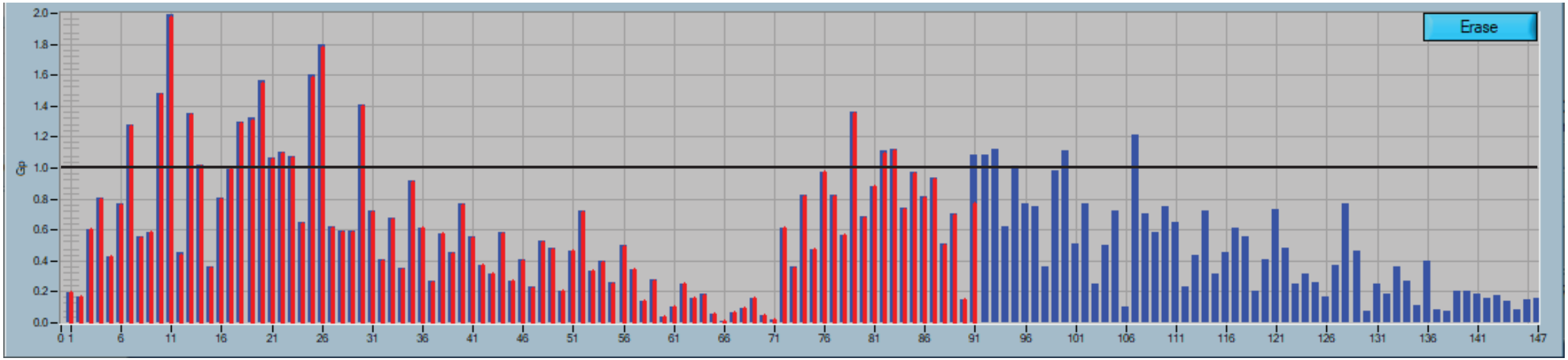


Each column is needed instensity for each energy layer
All energy layers needs less than 1×10^9 protons

Example of Real Treatment Plan Execution 2

PTV:	162.40 cm^3
Dose:	4 Gy
Beam directions:	2
N of Energy Layers:	147 (72-150 MeV)
Number of protons:	$4{,}20\times10^{10}$

Session Duration :	2 Gy	3m 11s
	4 Gy	4m 41s
	6 Gy	6m 18s



Each column is needed instensity for each energy layer
22 out of 147 energy layers needs more than 1×10^9 protons (only 15%)

Dose Monitoring System

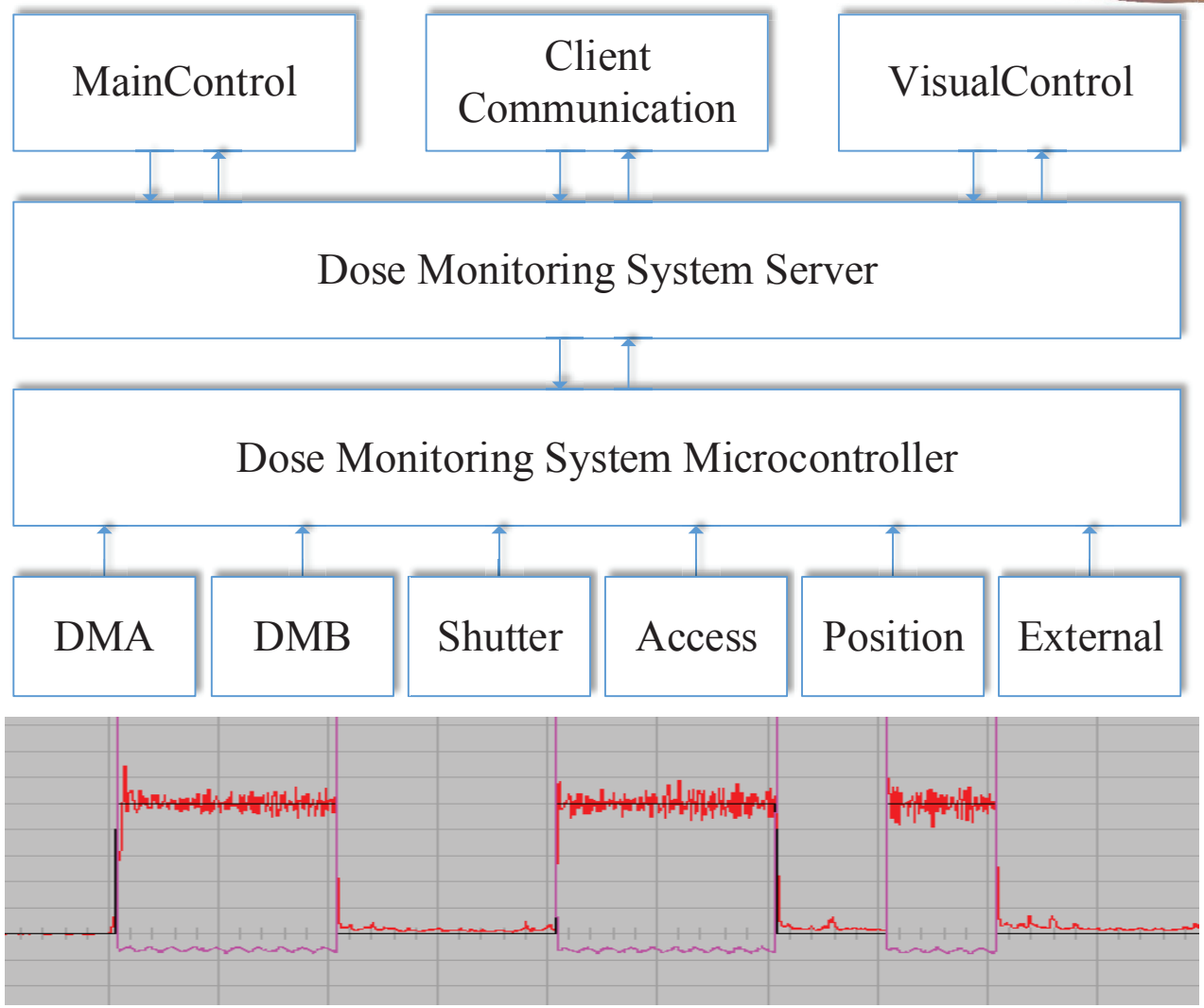
- Requirements:

Maximum error in additional absorbed dose should be less than 10% or 0.25 Gy

- Dose Monitoring Module “A”:
  - Luminophore screen at the nozzle
  - Additional PhotoMultiplier (extraction)
- Dose Monitoring Module “B”:
  - Pyramid Ionization Chamber
  - Control Scanning Magnets
- Energy Control (RF measurements)

Fast Electromagnetic Shutter (50 us)

All measurements each 200 us



Agenda

1. Protom Synchrotron Timeline
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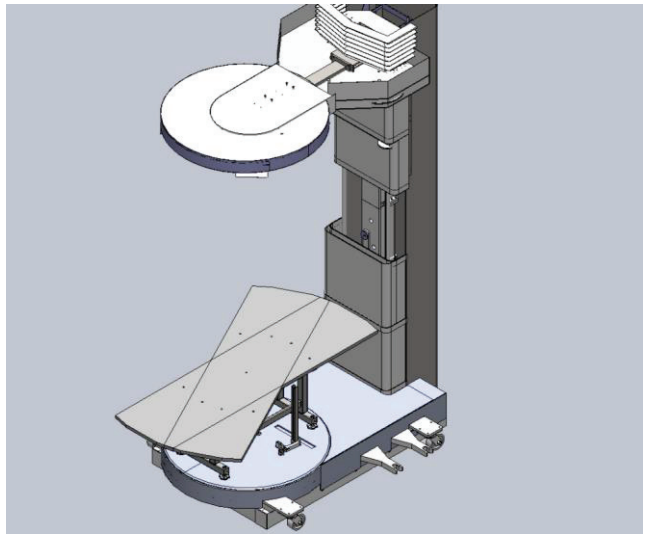
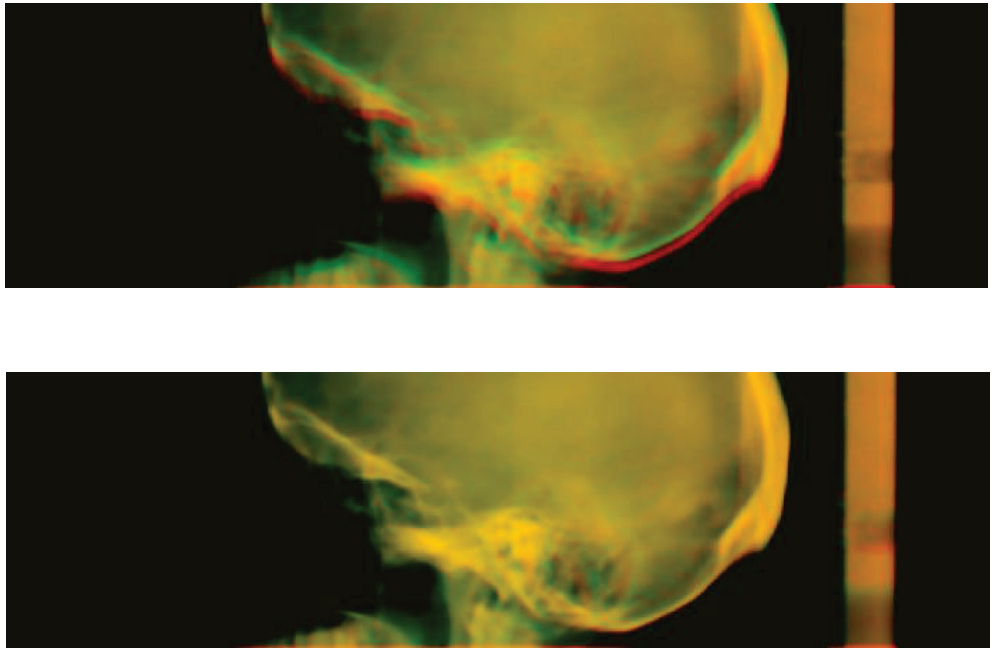
   - Patient Immobilization System
   - X-Ray Radiographic System
   - Treatment Planning System

Protom Patient Immobilization System



Dimensions (X, Y, Z), mm	1530, 3000, 1840
Angle of rotation	360°
Adjustment of patient's growth, mm	500
Max. patient weight, kg	135
Max. power consumption, W	600
Control opportunities	direct (wired) remote (wireless - Bluetooth) remote (LAN)

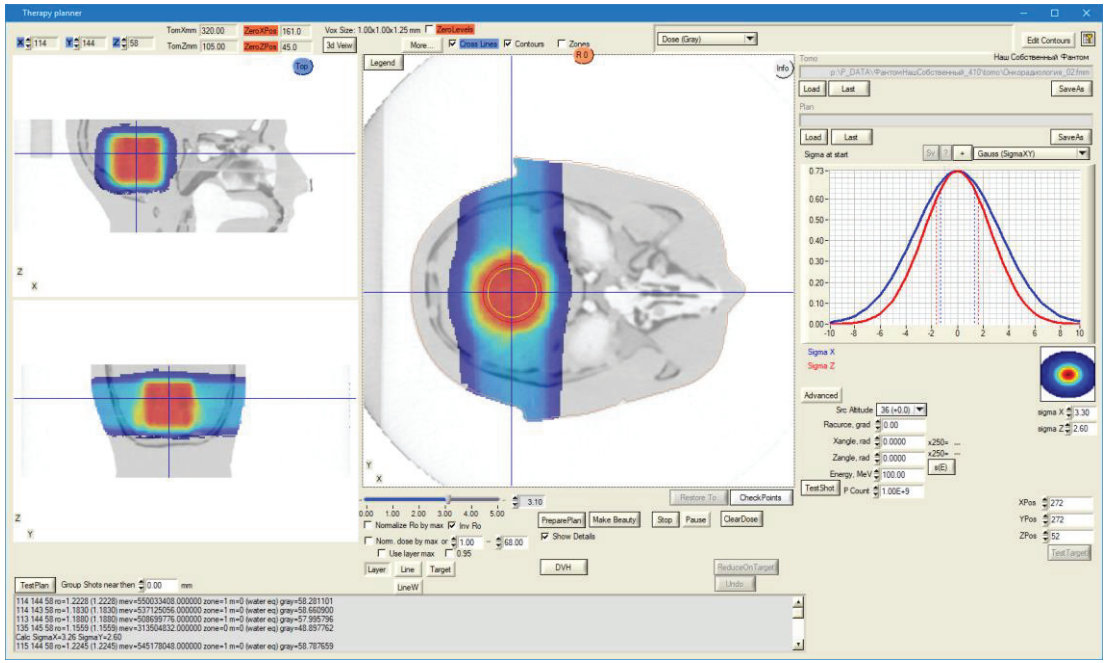
Protom X-Ray Radiographic System

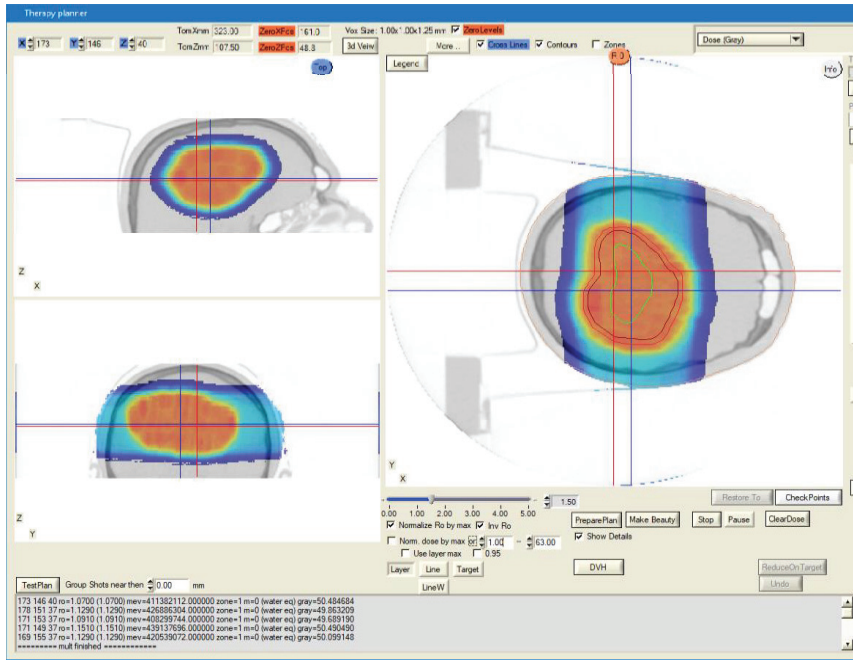


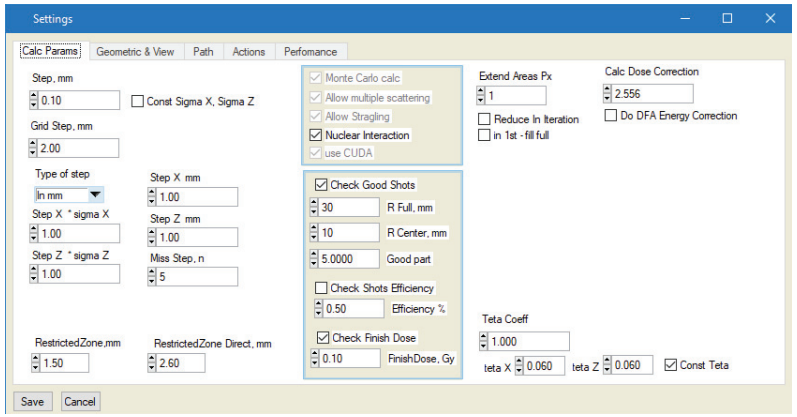
Patient position verification using X-ray CT

Radiographic system

Treatment Planning System



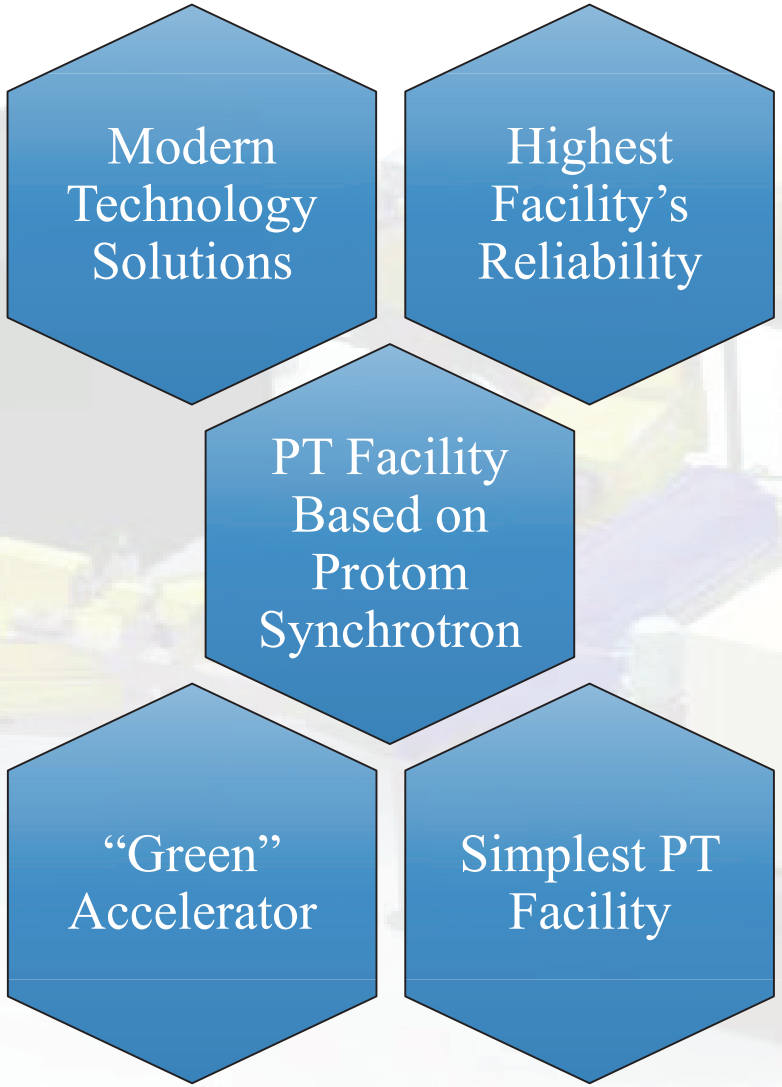




- Monte Carlo GPU based calculation
- Multiple Coulomb scattering
- Loss of protons for nuclear interactions

Summary

- Full IMPT with Extremely High Beam Delivery Accuracy
- Active Pencil Beam Scanning is a Native Technology
- Possibility for Proton Tomography



- 99.4% System Uptime
- 24/7 Remote Consultation
- Several Months of Customer Training
- Upgrade and Support

- No Radiation when Inactive
- Low Peak Power Consumption
- Low Average Power Consumption
- Standard Water Cooling System

- Low Cost Facility
- No Special Building Needed
- Low Operating Cost
- Significantly Less Staff
- Accelerator Installation Less Than 90 Days

Thank you for your attention!

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