

Developing a Modern, High-Quality Proton Therapy Medical Device with a Compact Superconducting Synchrocyclotron

T. Zwart, J. Cooley, K. Franzen, K. Milkowski, M. Jones, M. Wagner, S. Rosenthal.



“Our Mission: Drive down the cost, size and complexity of proton therapy systems and make this therapy readily available to the pediatric and adult cancer patients who may benefit from this advanced form of radiation treatment.”

**Transformative Proton Therapy.
Superior Performance.
Proven Results.**



Conventional Proton Therapy Challenges

- **Too Big**

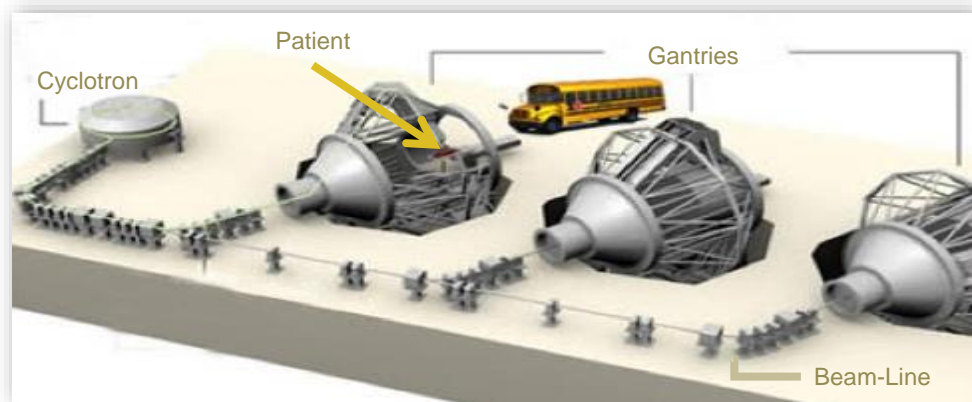
- Typically 3 or More Rooms
- Up to 100,000 Ft.2 for 5 Rooms

- **Too Costly**

- > \$200 MM for Recent Facility
- > \$1 MM Annual Energy Costs
- > 100 Staff for 5 Rooms

- **Too Complex**

- Multiple Rooms Depend on One Accelerator
- Complex Beam Transport Requiring Many Steering Magnets & Power Supplies and Large Gantries
- Daily Maintenance Required
- Beam Switching & Queuing Complicate Patient Setup
- Historic Lack of Integrated Imaging & Oncology Info-System Connectivity

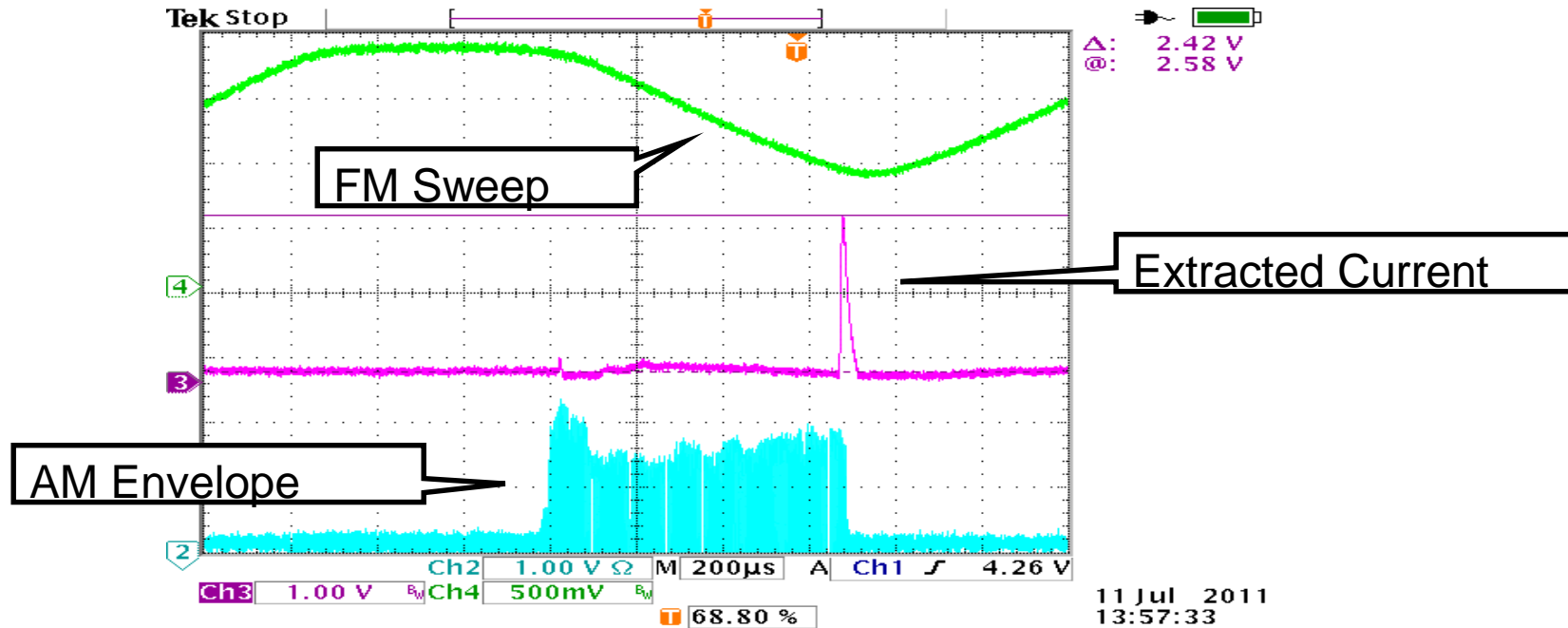


Enabling Technology – A Superconducting Synchrocyclotron



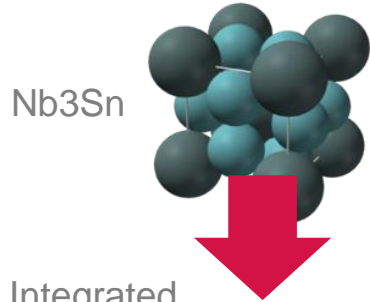
Founder Ken Gall with the MEVION S250 Cyclotron - 17 tons , 8.5 Tesla, 250 MeV

Synchrocyclotron Time Structure



Synchrocyclotron time structure similar to many x-ray therapy systems. Well matched to clinical needs

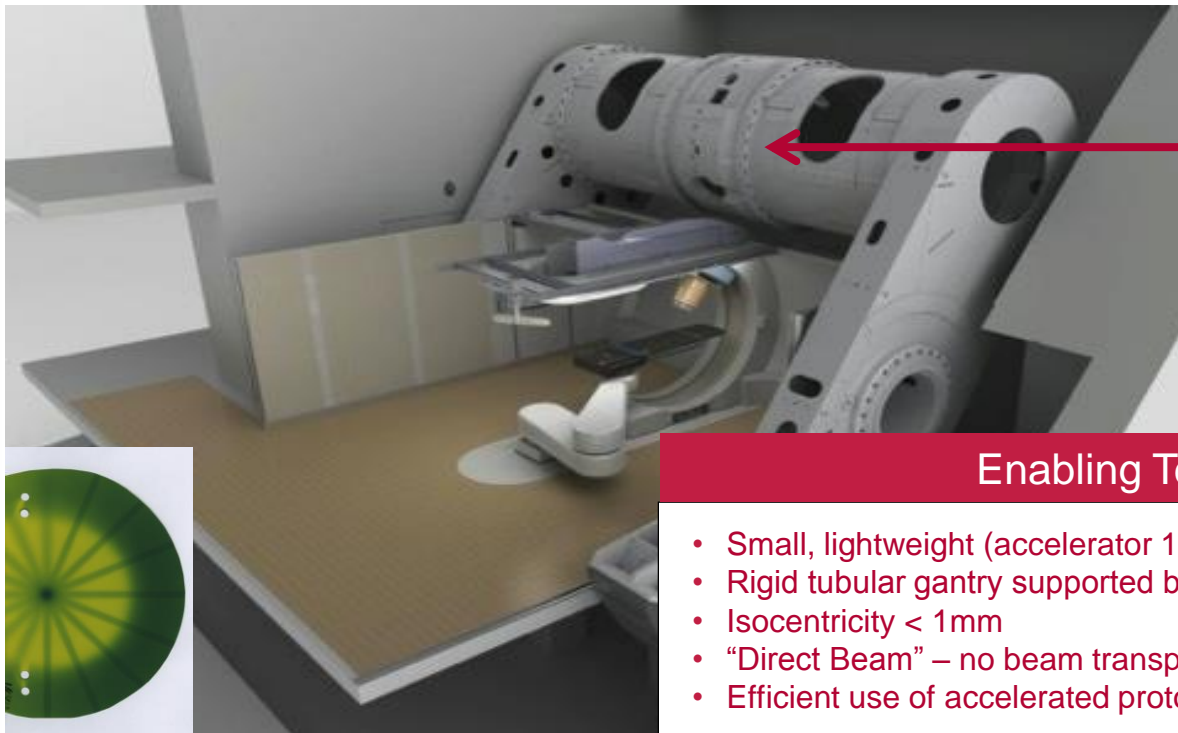
MEVION S250 Series — Nb₃Sn



Integrated
superconductor



Gantry-Mounted Cyclotron

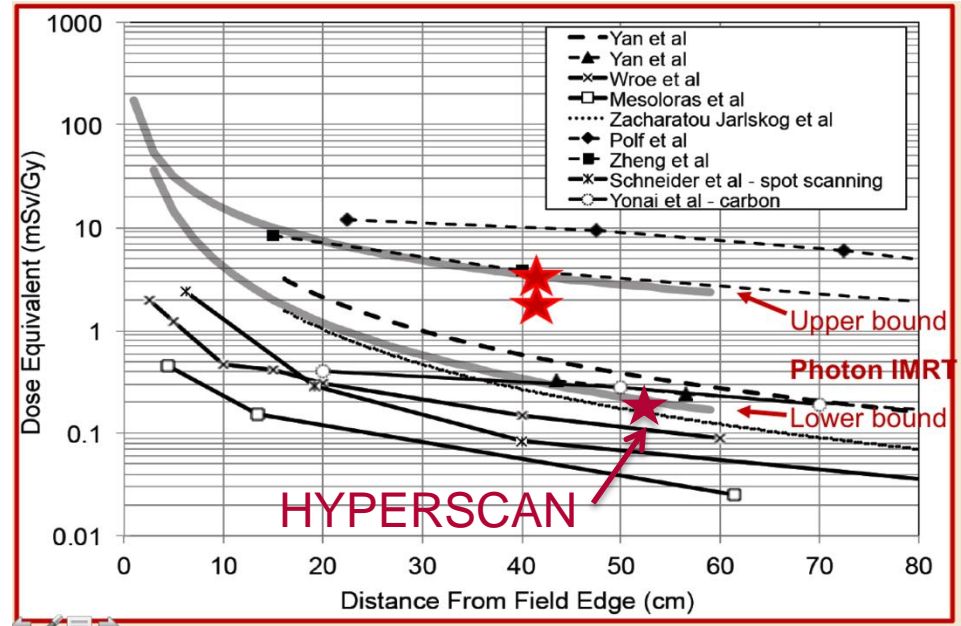


Enabling Technology

- Small, lightweight (accelerator 17 tons)
- Rigid tubular gantry supported by two “windmill” bearings
- Isocentricity < 1mm
- “Direct Beam” – no beam transport
- Efficient use of accelerated protons – low neutron dose

MEVION S250 Neutron Measurements

- Fewer protons accelerated**
~ 2 nA beam current required for 2 Gy/L/min
Less impact to patient
- No EES**
- No beam transport**
- Scanning is more efficient**
Loses fewer protons than scattering



Dr. Rebecca Howell – MD Anderson

Transformative Proton Therapy – The MEVION S250 Series



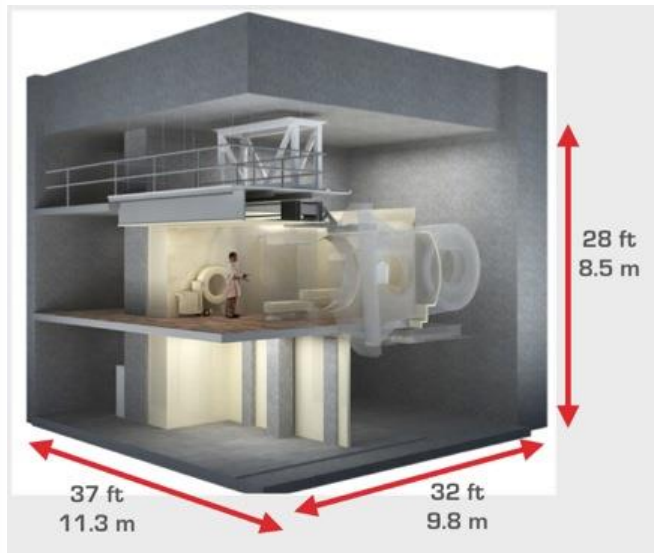
Core Technology:

- World's only gantry-mounted accelerator
- Direct beam technology

Results:

- Higher proton beam quality
- Lower complexity
- Higher reliability and throughput
- Lower capital and operating costs

Compact Proton Treatment Center



Ackerman Cancer Center

- Footprint of single room: 1,500 to 2,000 sq. ft. (140 - 180 m²) - include shielding
- Standard RT electrical requirements

HYPERSCAN Technology

Technology designed to deliver simultaneously conformal and robust IMPT treatments by overcoming the limitations of current pencil beam scanning systems

Challenges of PBS

- **Complicated**
 - Remote ESS
 - Dual Scanning magnets
 - Gantry dependence of beam spot size and shape
 - Beamline, many magnets for single spot delivery
- **Treatment uncertainties**
 - Poorly suited for moving tumors
 - Slow energy/layer switching, slow volumetric delivery
 - High QA time
 - Poor lateral penumbra w/o apertures

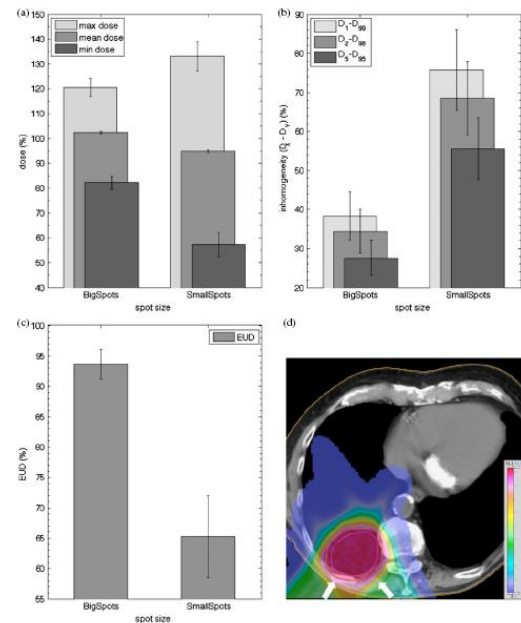


Figure 1. Average of the various interplay metrics for a single fraction for patient 1 for BigSpots and SmallSpots with a spot spacing of 0.7σ . The values are the averages of the results from the 36 combinations of τ_{es} , τ_{st} and phase. The error bars are ± 1 standard deviation. (a) shows the maximum (D_1), mean and minimum (D_{95}) doses, (b) shows the dose homogeneity: D_1-D_{95} , D_2-D_{98} and D_5-D_{95} . (c) shows the EUD and (d) shows the planned dose distribution for SmallSpots. The contours shown are the ICTV and the PTV, with the white arrows indicating the field directions and the color bar units in Gy(RBE).

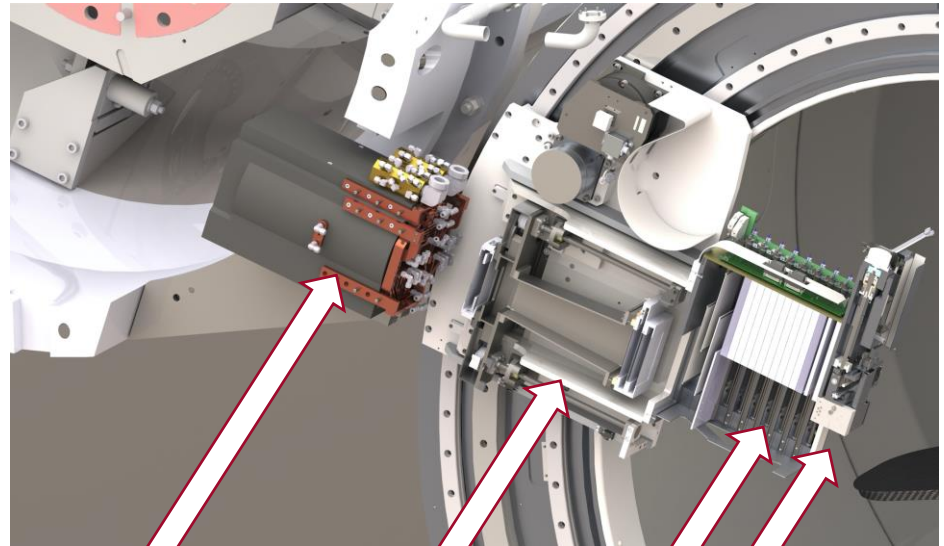
S Dowdell, CGrassberger, G C Sharp and H Paganetti 2013 *Phys Med Biol.* **58** 4137-4156.

The MEVION S250i with HYPERSCAN



- **Fast**
 - <6 sec to scan 1 liter volume
 - <50 msec energy switching time
- **Sharp**
 - Collimator always available
 - Sharp penumbra at all depths
- **Robust**
 - Optimal spot size, collimated where necessary
 - 10+ volumetric scans to 2Gy/1L
 - Spot size and Bragg Peak invariant with gantry angle

HYPERSCAN Topology



High Speed Scanning magnet

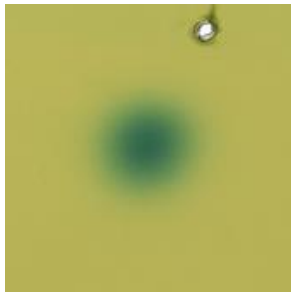
High Resolution Gated Dosimetry

Fast Energy modulation

Automated Patient collimation

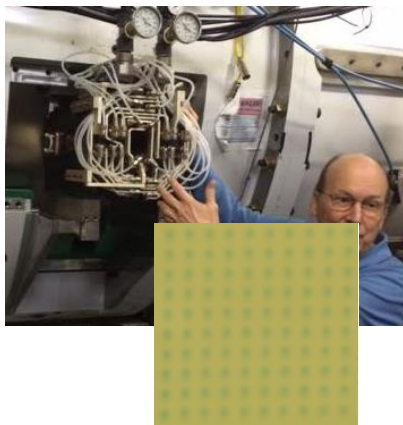
HYPERSCAN Elements

Cyclotron



- 3.1 mm x 3.7 mm spot size at isocenter
- 19 nA beam current
- Invariant with gantry angle

X/Y scanning magnet



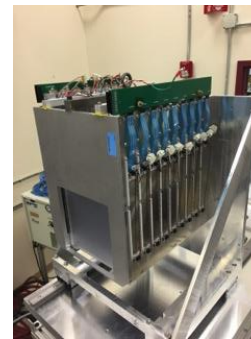
- Single focus dual direction
- Iron free design for high linearity and fast scan rates
- No run time limit

Dosimetry



- Commercial Dosimetry Units
- Two planes x,y strip detectors. Pitch 2 mm

Energy modulation



- Low neutrons
- Short layer switching time

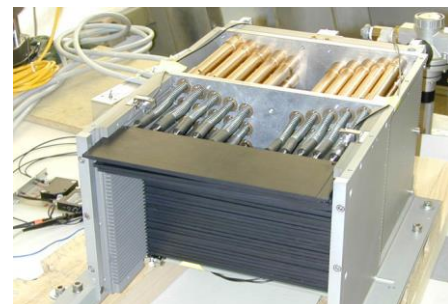
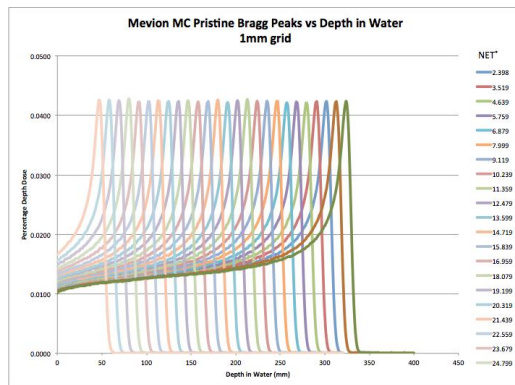
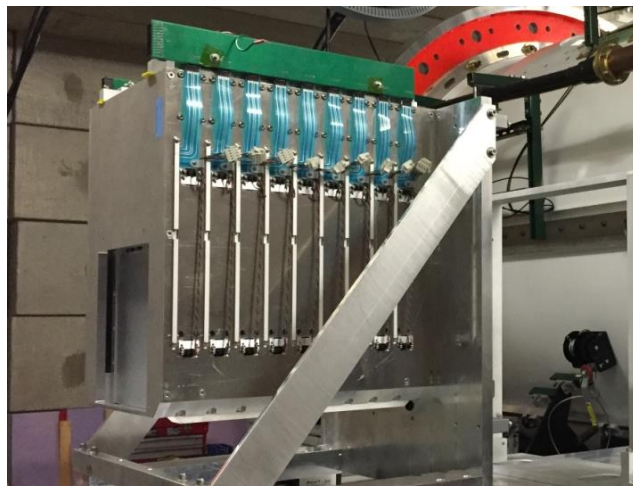
Automated collimation



- No patient-specific hardware
- Always available

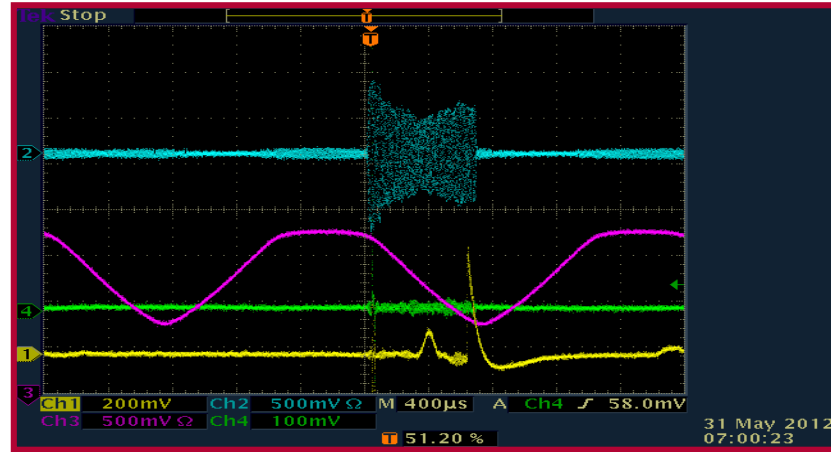
Energy Modulation

- Range shifting plates – 2 mm resolution
- Single Bragg peak
- Low Z: low neutrons, low scatter
- Low profile design to minimize air gap
- Rotary-linear actuator – simple & robust
- Scan-synchronous layer switching effectively eliminates layer switching time



PSI - Energy Selector

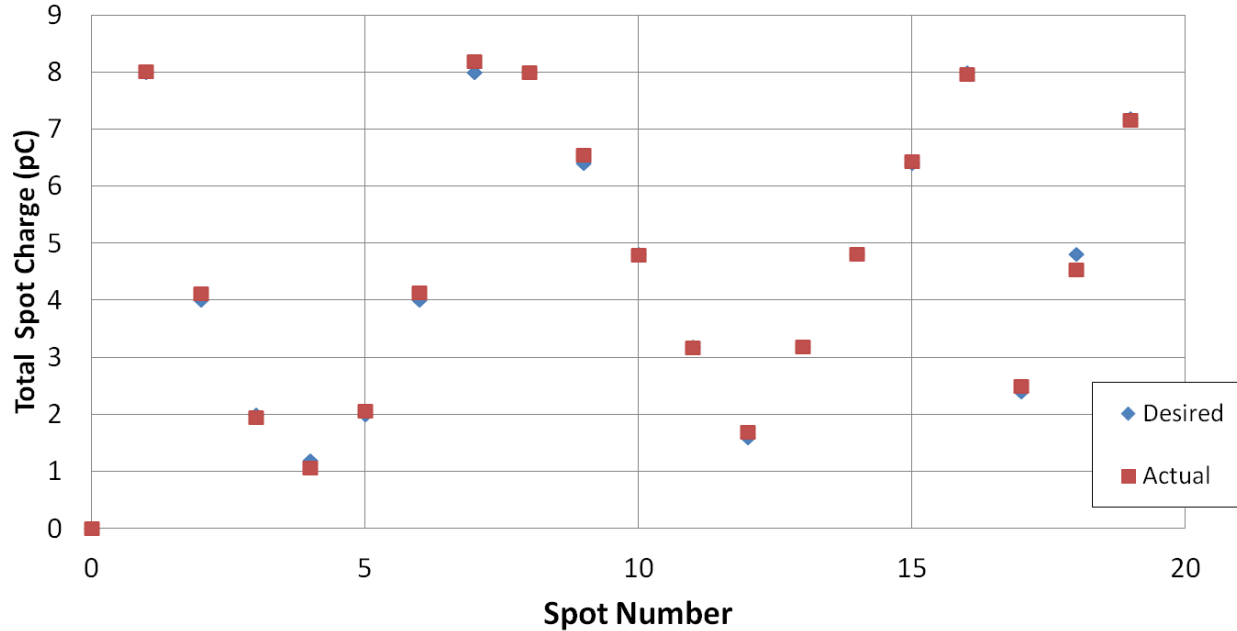
Dose Control



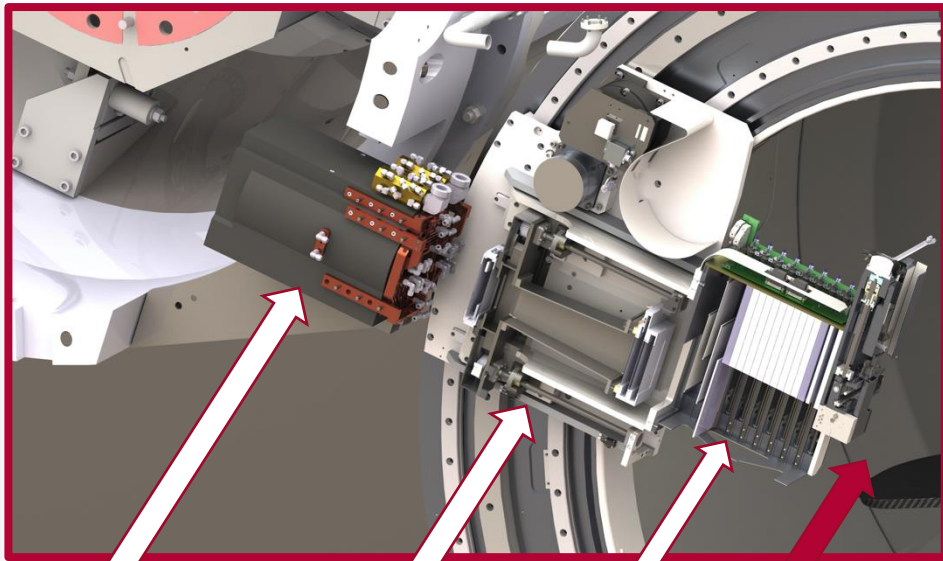
- Synchrocyclotron time structure is like that of a LINAC and well matched to spot scanning
- High frequency Accelerator: 30,000 pulses/min: Short packets (<20 us)
- Any individual pulse can be turned on or off with perfect contrast

Dose Control Performance

Spot to Spot Dose Control



HYPERSCAN Topology



High Speed
Scanning magnet

Dosimetry system

Fast Energy
modulation

Adaptive Aperture
Micro-MLC for PBS



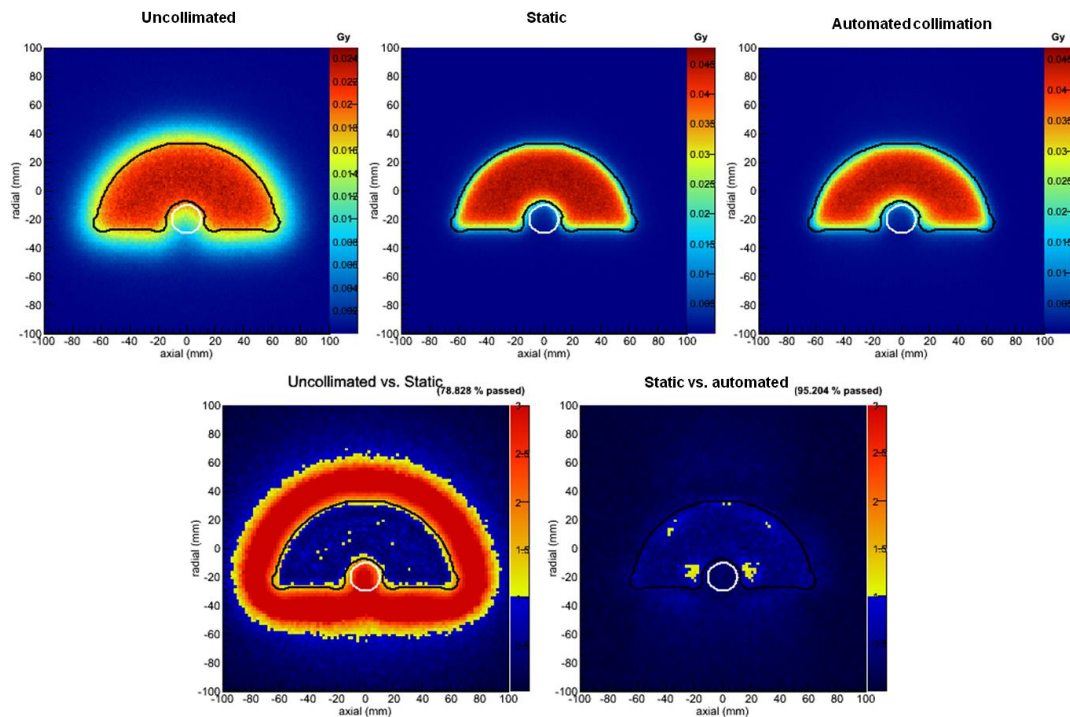
Transformative Proton Therapy.
Superior Performance.
Proven Results.

 **MEVION**
medical systems

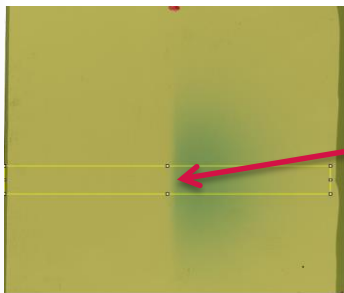
HYPERSCAN™ has not been cleared by the USFDA for clinical use.

Automated Collimation

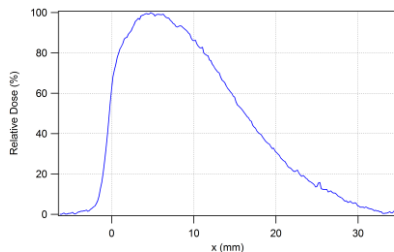
- No patient-specific hardware
- Close to patient w/o interference
- Compatible with TPS that supports static apertures
- Minimal impact on treatment time



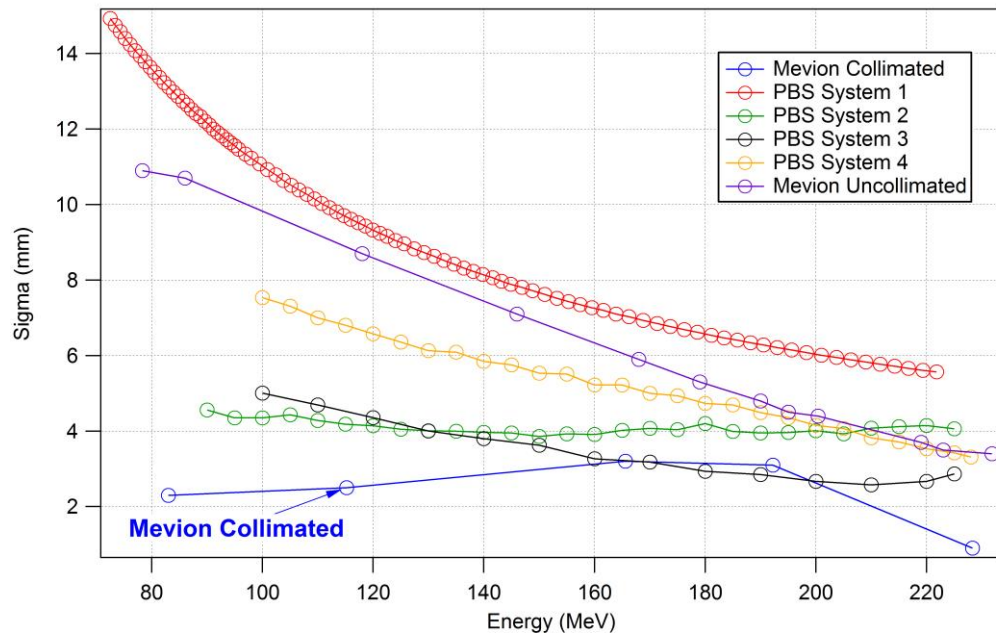
PBS with Sharp Penumbra



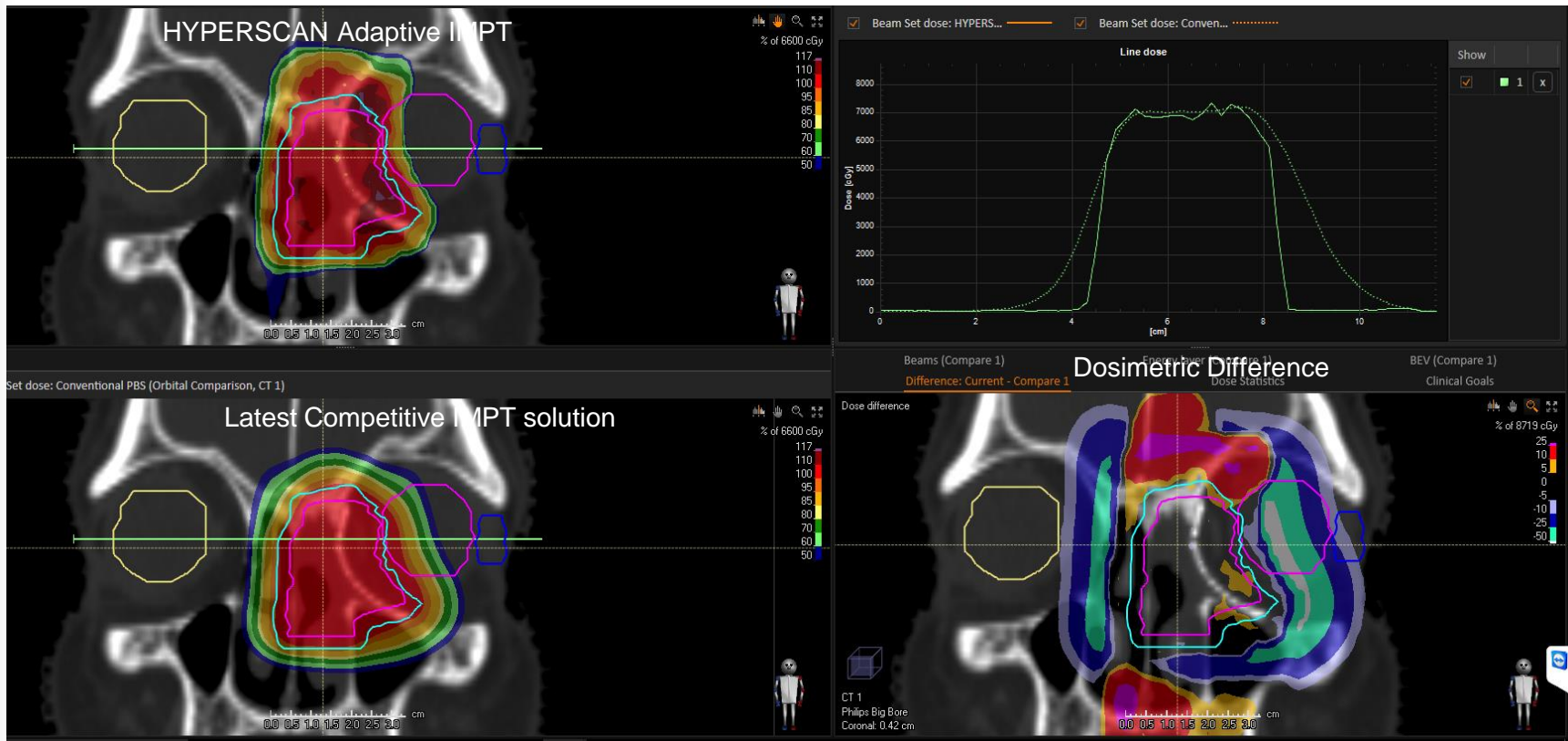
Central Axis



Film: Single spot in air with range 5 cm & nozzle at 5 cm with Hyperscan Penumbra Optimization



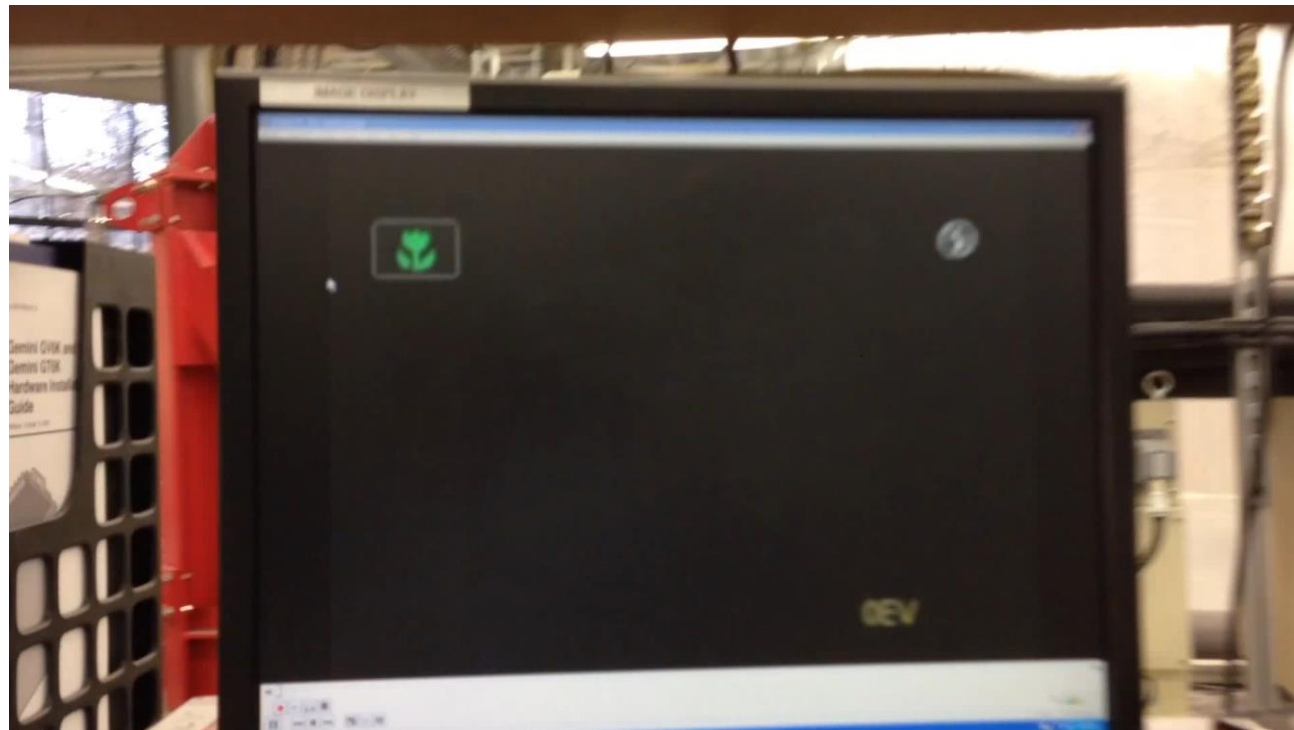
HYPERSCAN Treatment: Orbital Superior Gradient towards the Eyes and Lacrimal Gland



Transformative Proton Therapy.
Superior Performance.
Proven Results.

Fast volumetric delivery

- 1 liter cube
- Untrimmed
- ~6 sec once through



Conclusions

- The compact superconducting synchrocyclotron is well matched to needs of clinical proton therapy systems
- The gantry mounted “Direct Beam” provides essential and high quality performance
- Hyperscan with Adaptive Aperture adds essential and high quality IMPT to Mevion platform
- Therapeutic use of state of the art accelerator technology is professionally rewarding



- Thank you!