

# PENCIL BEAM SCANNING WITH HYPERSCAN AND ADAPTIVE APERTURE

## ANDREAS SCHULTE

23-25 February 2017 - Molecular Biotechnology Center, Torino  
*Workshop on Innovative Delivery Systems in Particle Therapy*



# 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.”

# Conventional Proton Therapy Challenges

- **Too Big**

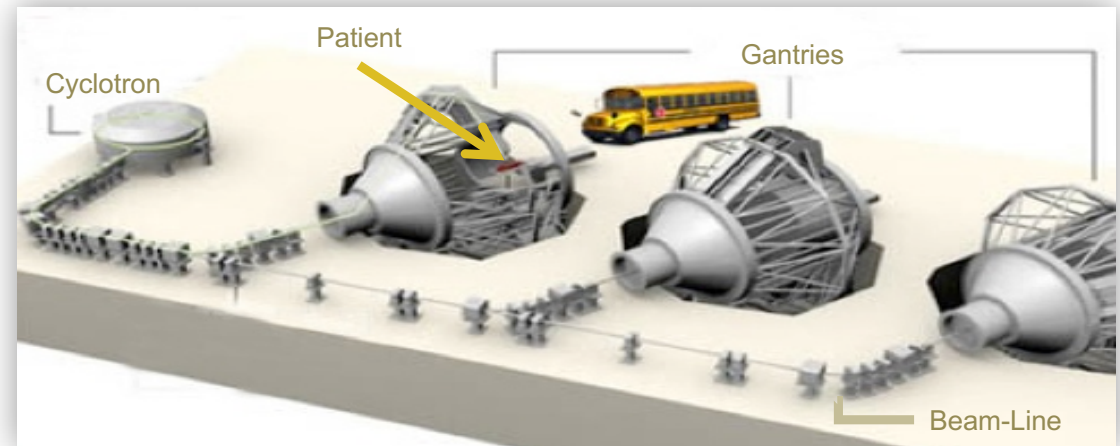
- Typically 3 or More Rooms
- Up to 100,000 Ft.2 for 5 Rooms

- **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



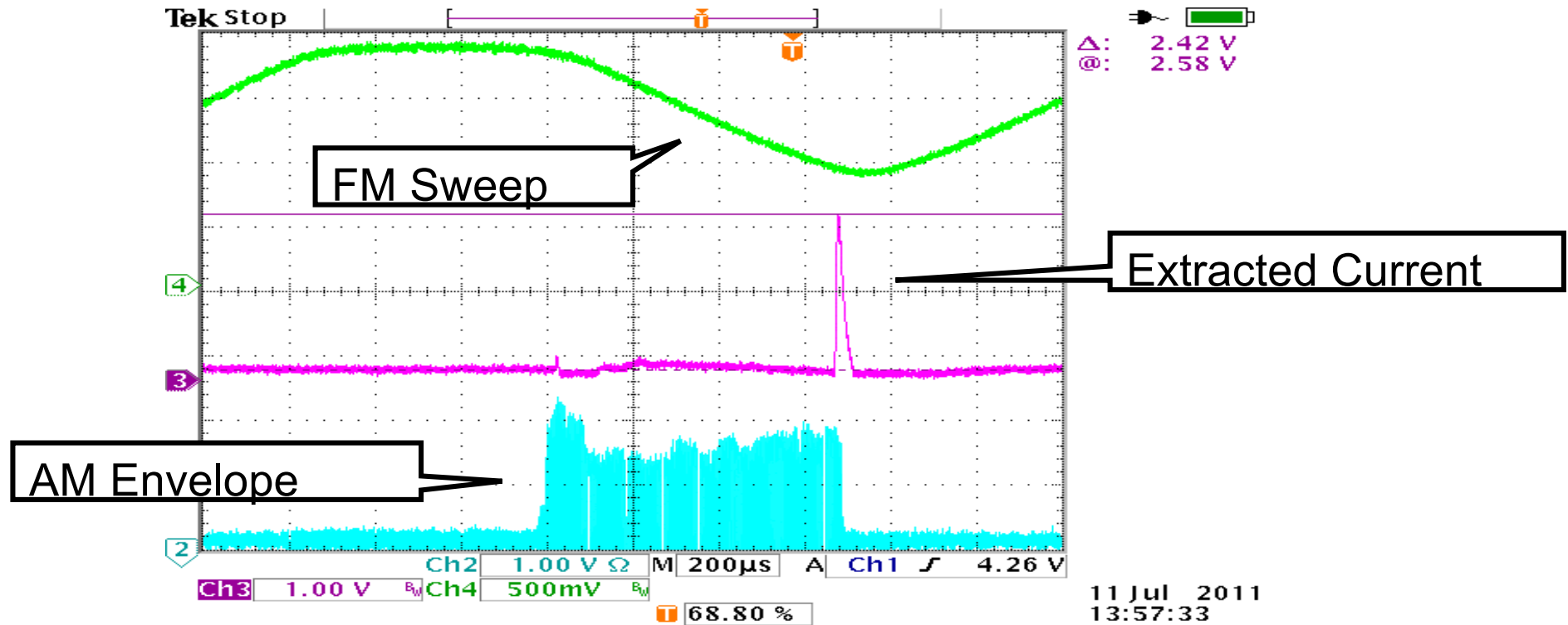
# Enabling Technology – A Superconducting Synchrocyclotron



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

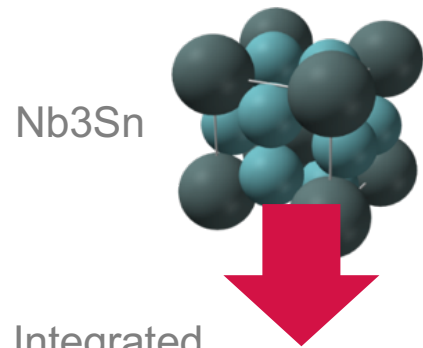


# Synchrocyclotron Time Structure

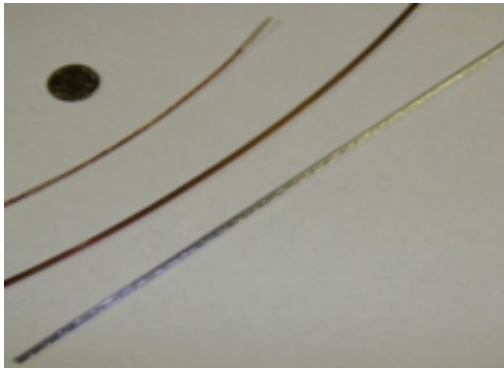


Synchrocyclotron time structure similar to many x-ray therapy systems. Well matched to clinical needs

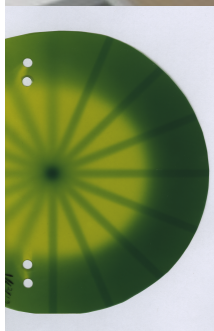
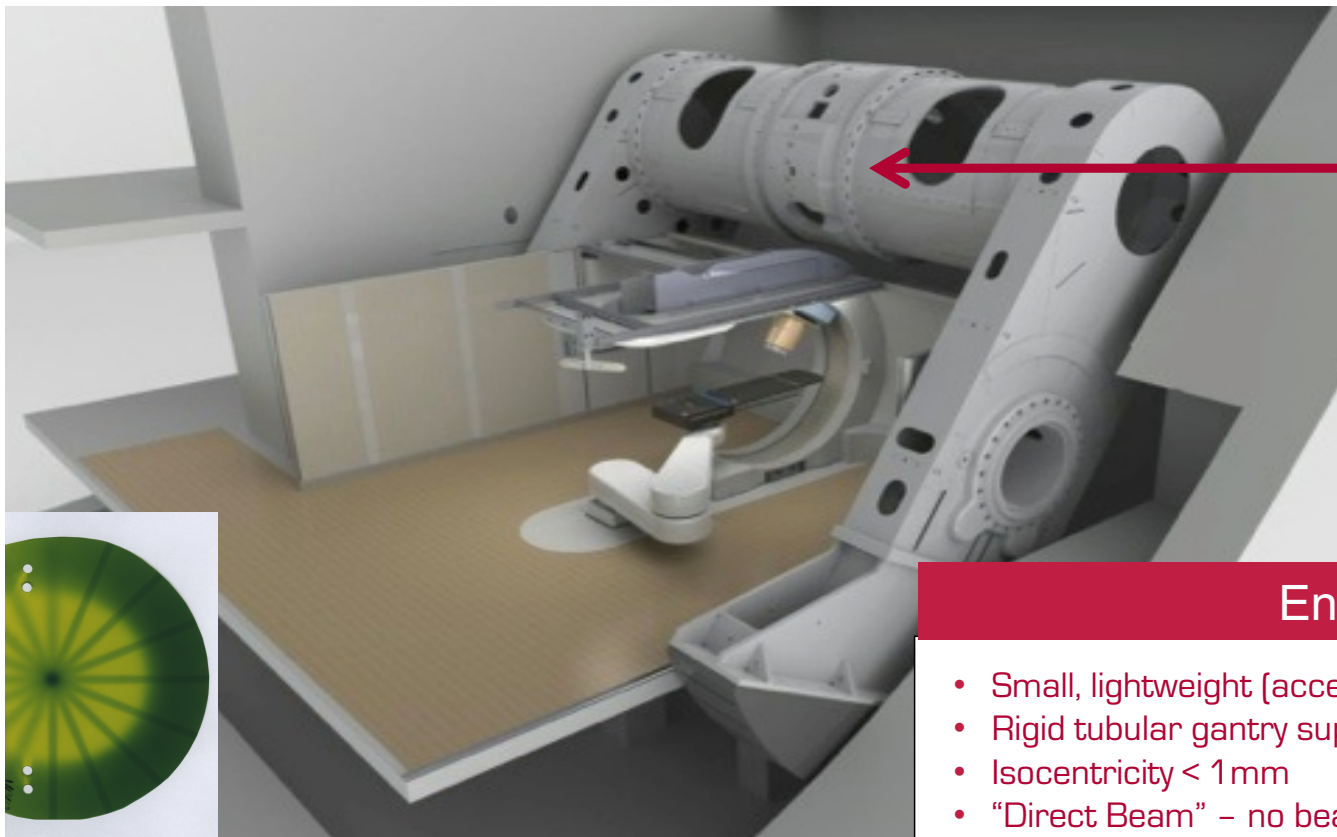
# MEVION S250 Series — Nb3Sn



Integrated  
superconductor



# Gantry-Mounted Cyclotron

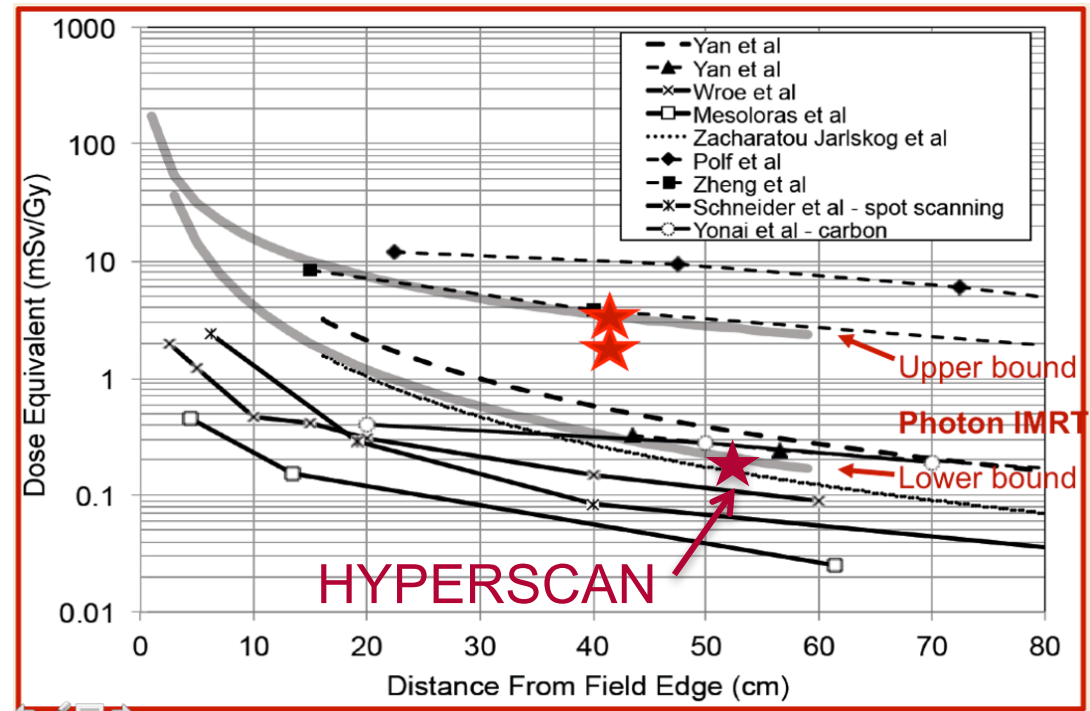


## Enabling Technology

- Small, lightweight (accelerator 17 tons)
- Rigid tubular gantry supported by two “windmill” bearings
- Isocentricity < 1 mm
- “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 ESS**
- 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:

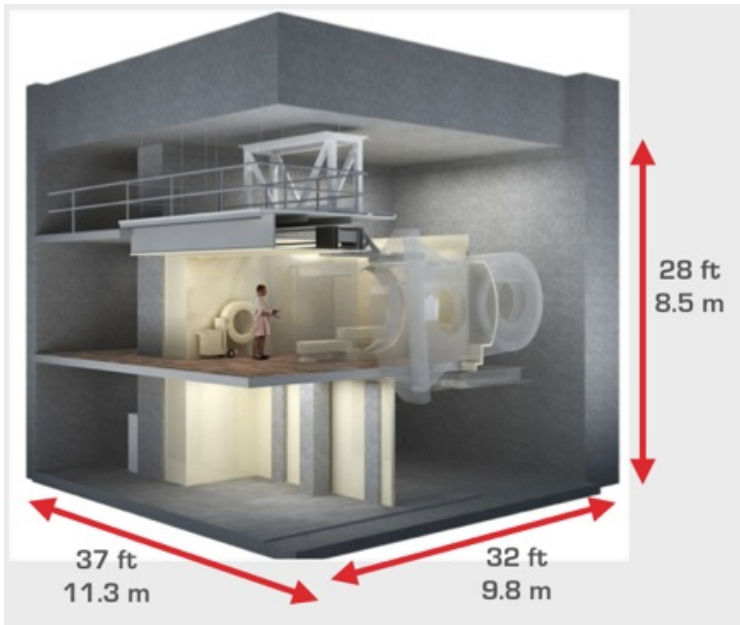
- World's only gantry-mounted accelerator
- Direct beam technology

## Results:

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



# Compact Proton Treatment Center



- Footprint of single room: 1,500 to 2,000 sq. ft. (140 - 180 m<sup>2</sup>) - 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

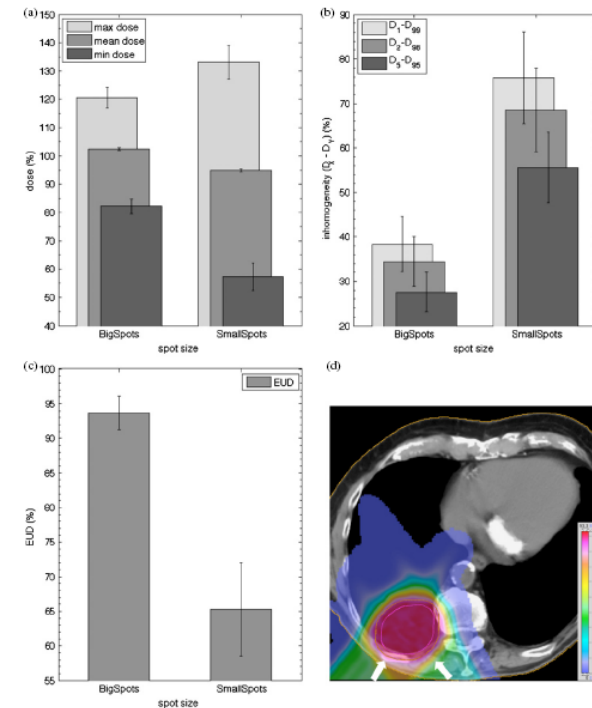


Figure 1. Average of the various interplay metrics for a single fraction for patient 1 for BigSpots and SmallSpots with a spot spacing of  $0.7\sigma$ . The values are the averages of the results from the 36 combinations of  $\tau_{\text{es}}$ ,  $\tau_{\text{st}}$  and phase. The error bars are  $\pm 1$  standard deviation. (a) shows the maximum ( $D_1$ ), mean and minimum ( $D_{99}$ ) doses, (b) shows the dose homogeneity:  $D_1$ - $D_{99}$ ,  $D_2$ - $D_{98}$  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).

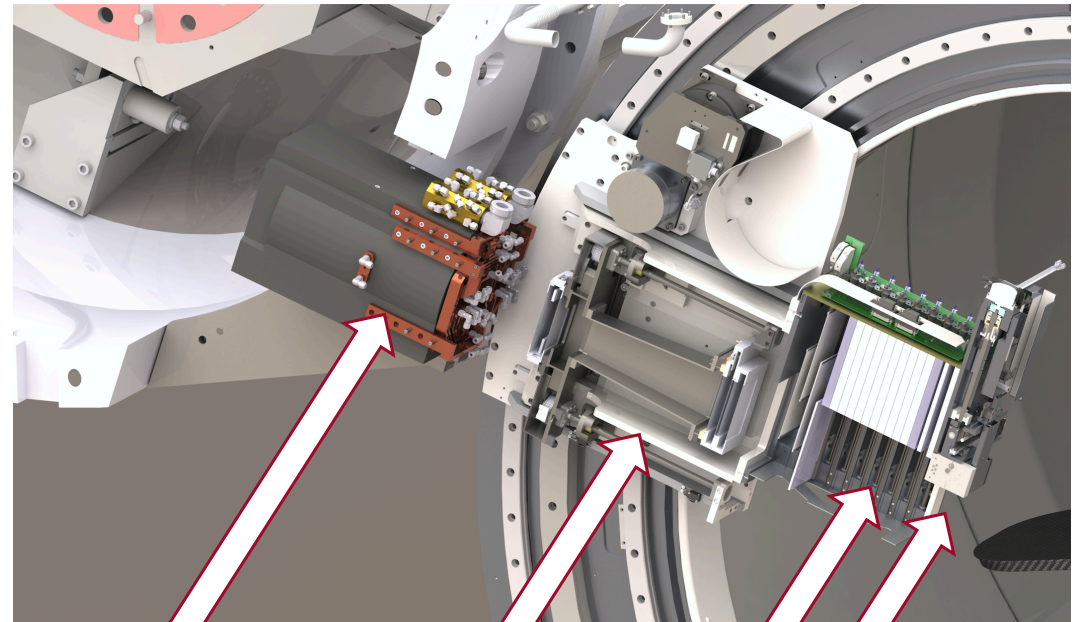
S Dowdell, CGrassberger, G C Sharp and H Paganetti 2013 *Phys Med Biol.* **58** 4137-4156.

# 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

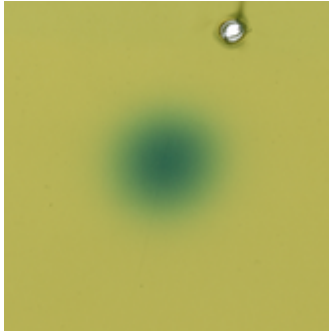
Fast Energy modulation

Automated Patient collimation



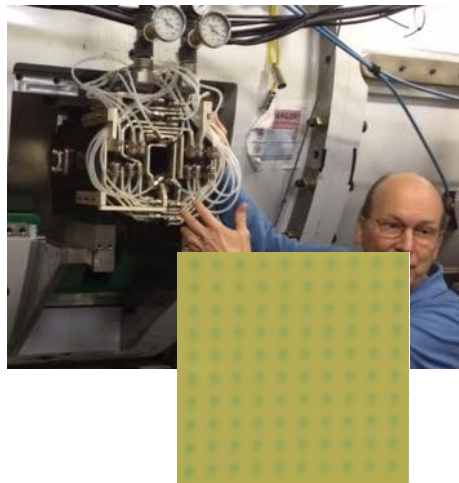
# HYPERSCAN Elements

## Cyclotron



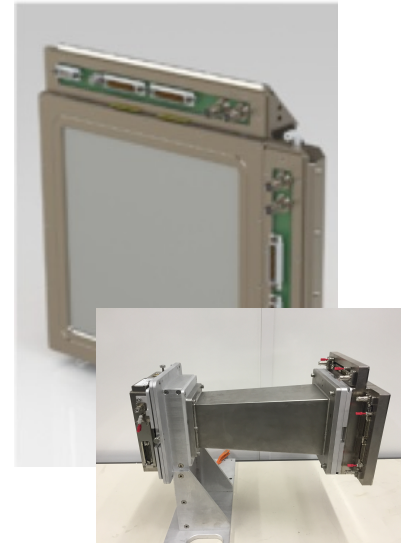
- 3.1 mm x 3.7 mm spot size at isocenter
- 19 nA beam current
- Invariant with gantry angle

## X/Y scanning magnet



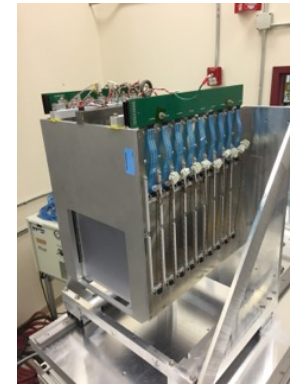
- Single focus dual direction
- Iron free design for high linearity and fast scan rates
- No run time limit

## Dosimetry



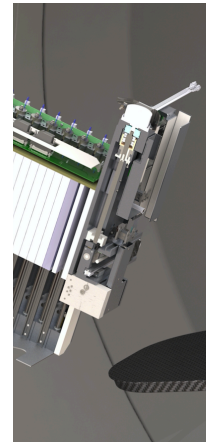
- Commercial Dosimetry Units
- Two planes x,y strip detectors. Pitch 2 mm

## Energy modulation



- Low neutrons
- Short layer switching time

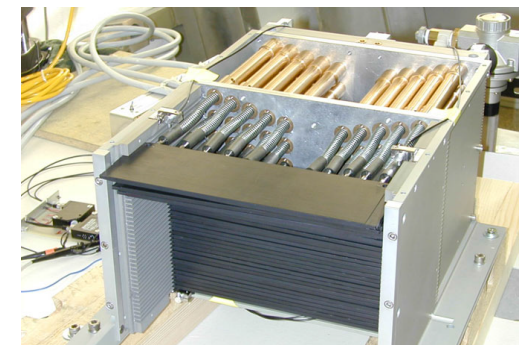
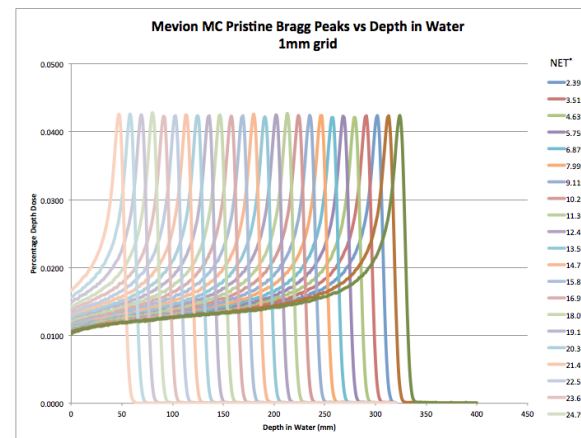
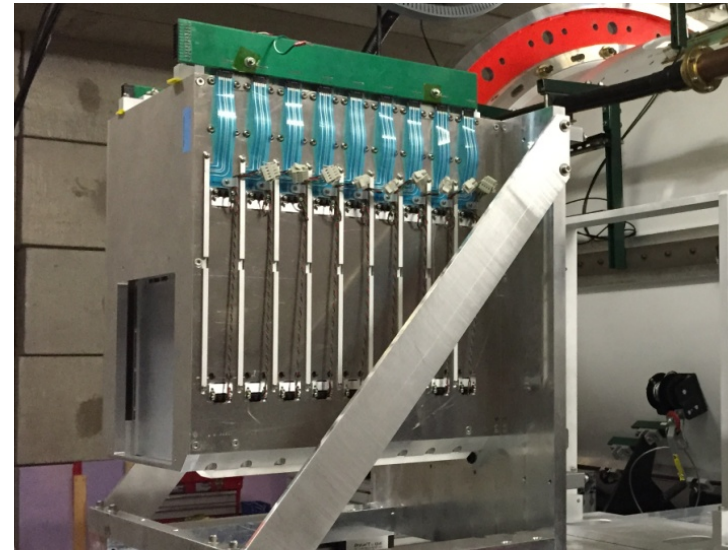
## Automated collimation



- No patient-specific hardware
- Always available

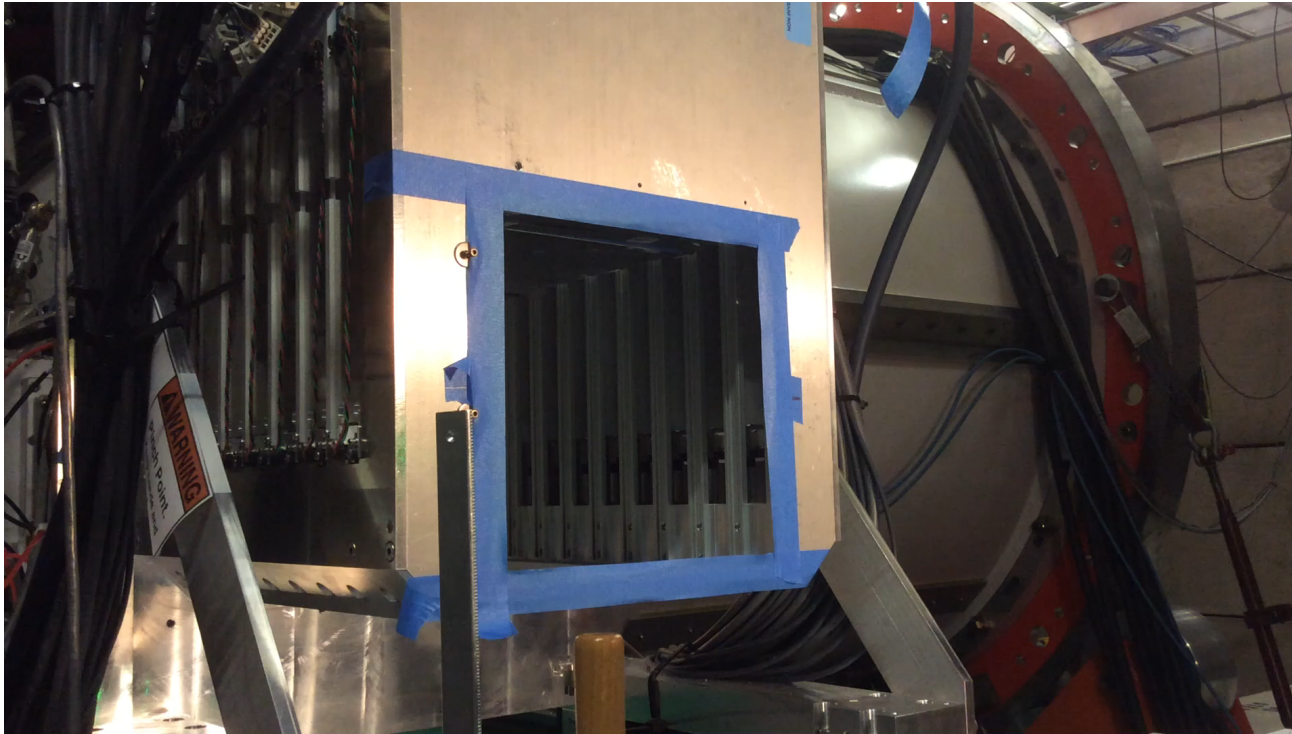
# Energy Modulation

- 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

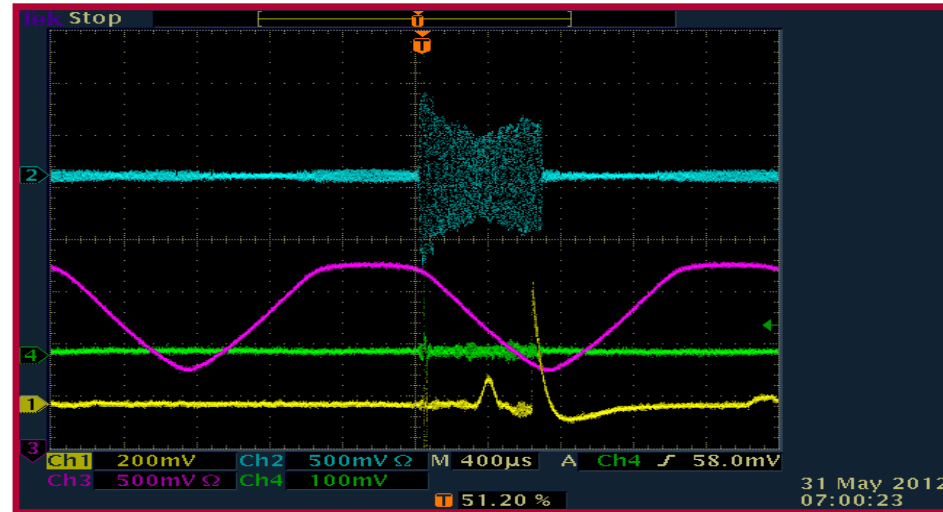
# Scan Synchronous Layer Switching



Transformative Proton Therapy  
Powerful Medicine. Smart Business.



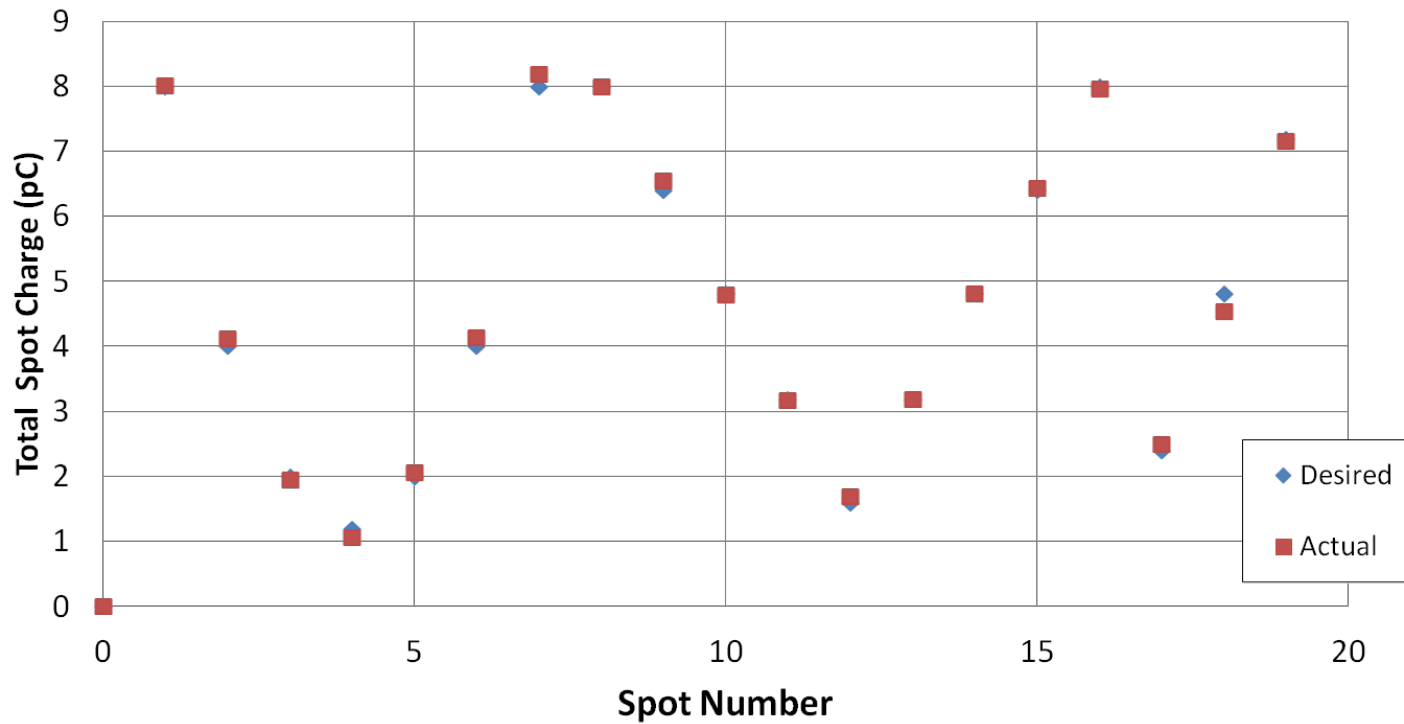
# Dose Control



- 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

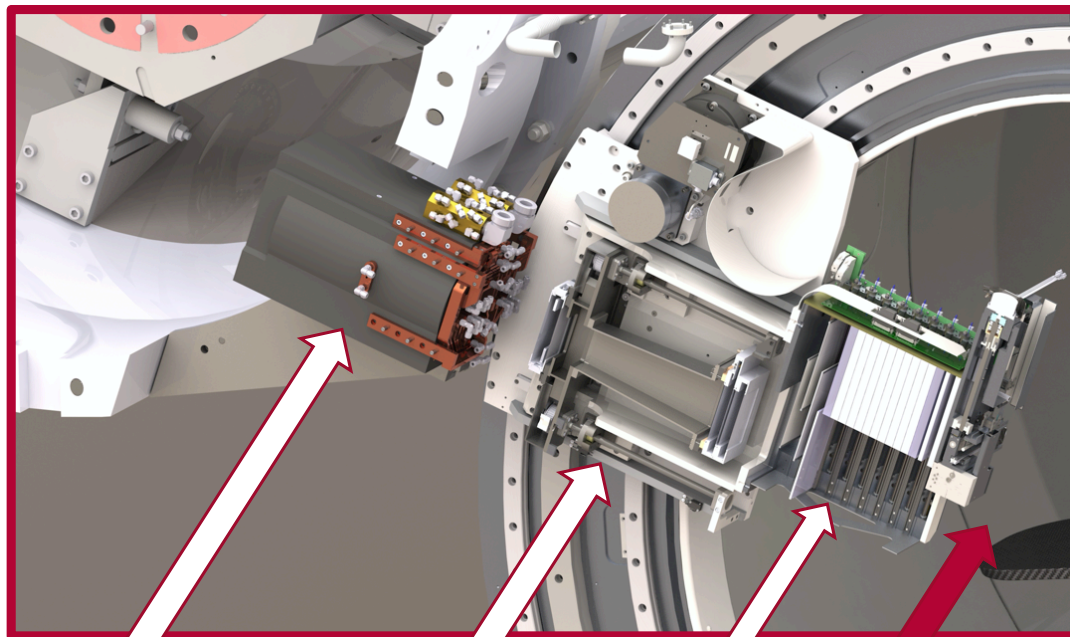
# Dose Control Performance

## Spot to Spot Dose Control





# HYPERSCAN Topology

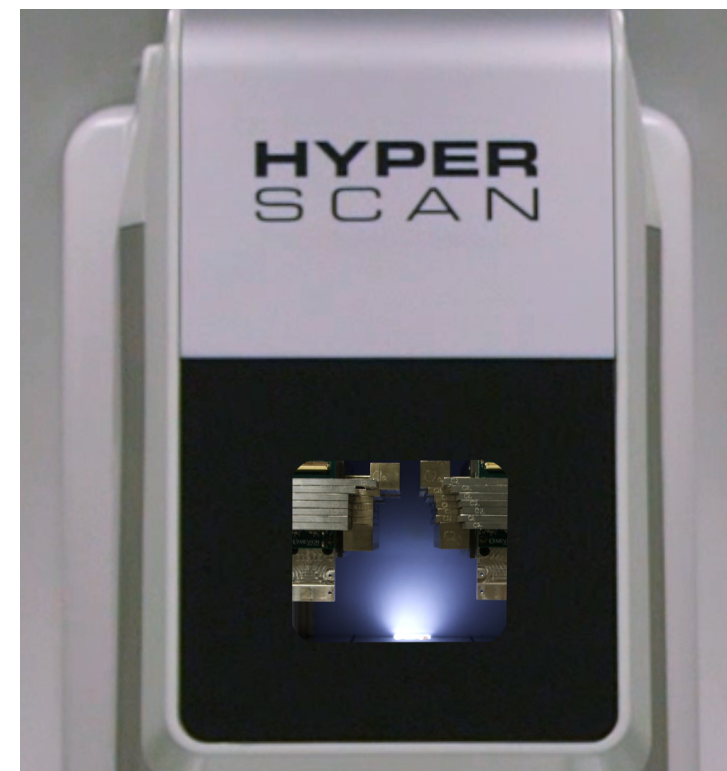


High Speed  
Scanning magnet

Dosimetry system

Fast Energy  
modulation

Adaptive Aperture  
Micro-MLC for PBS



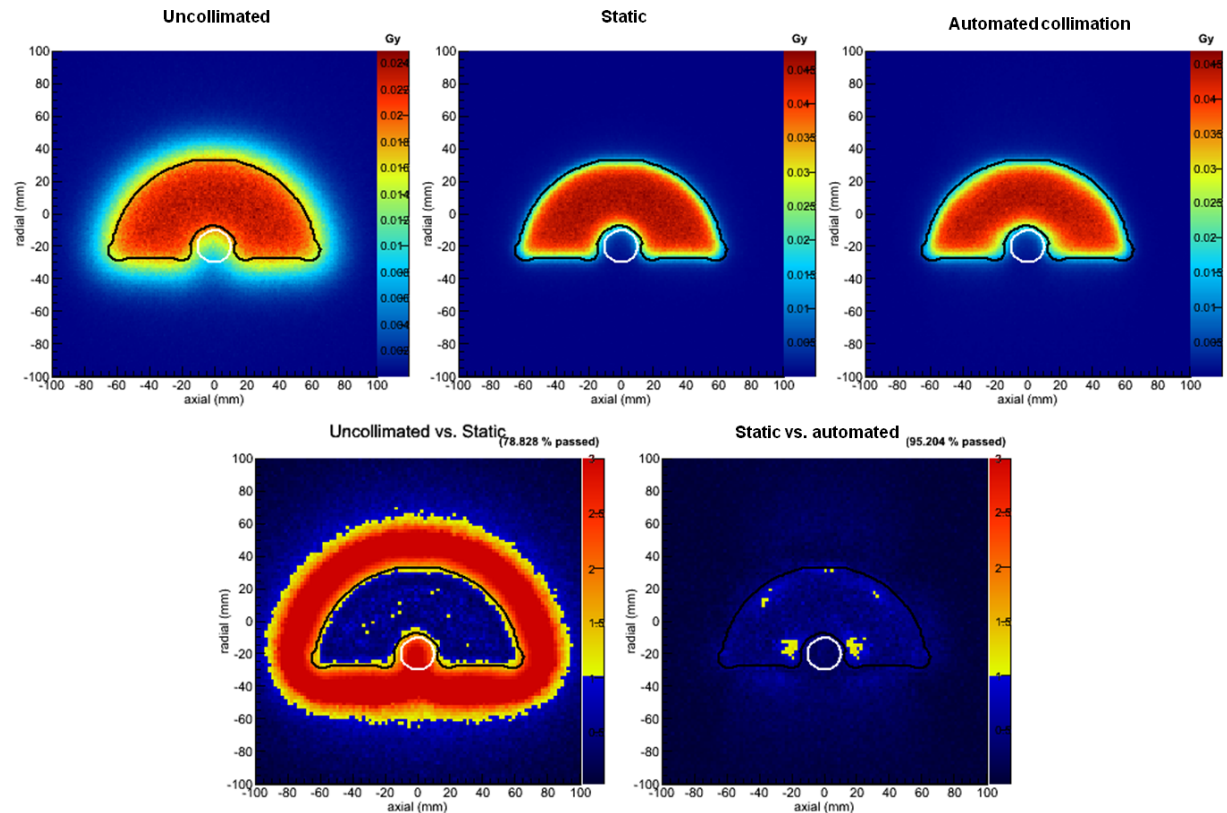
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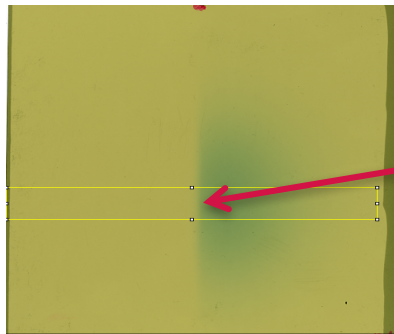
HYPERSCAN™ has not been cleared by the USFDA for clinical use.

# Automated Collimation

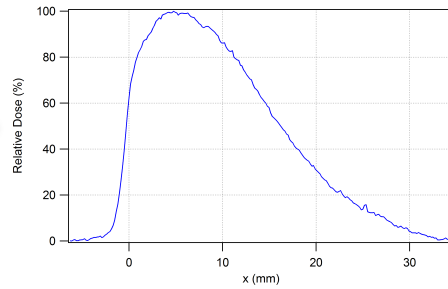
- No patient-specific hardware
- Close to patient w/o interference
- Compatible with TPS that supports static apertures
- Minimal impact on treatment time



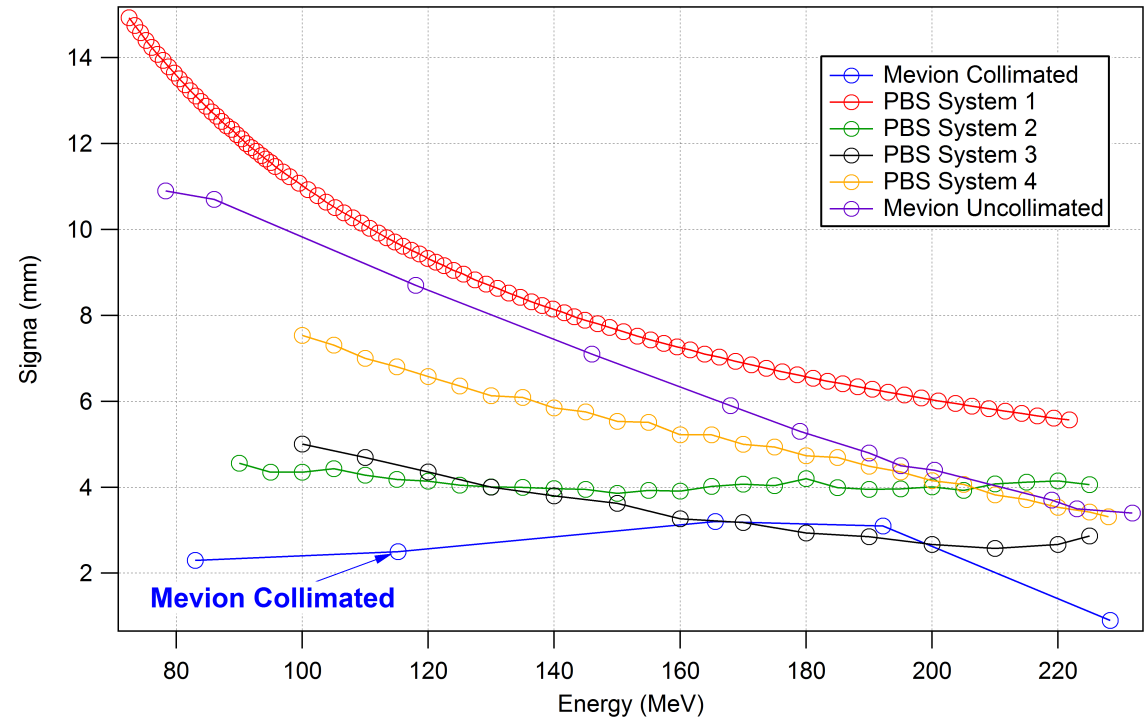
# PBS with Sharp Penumbra



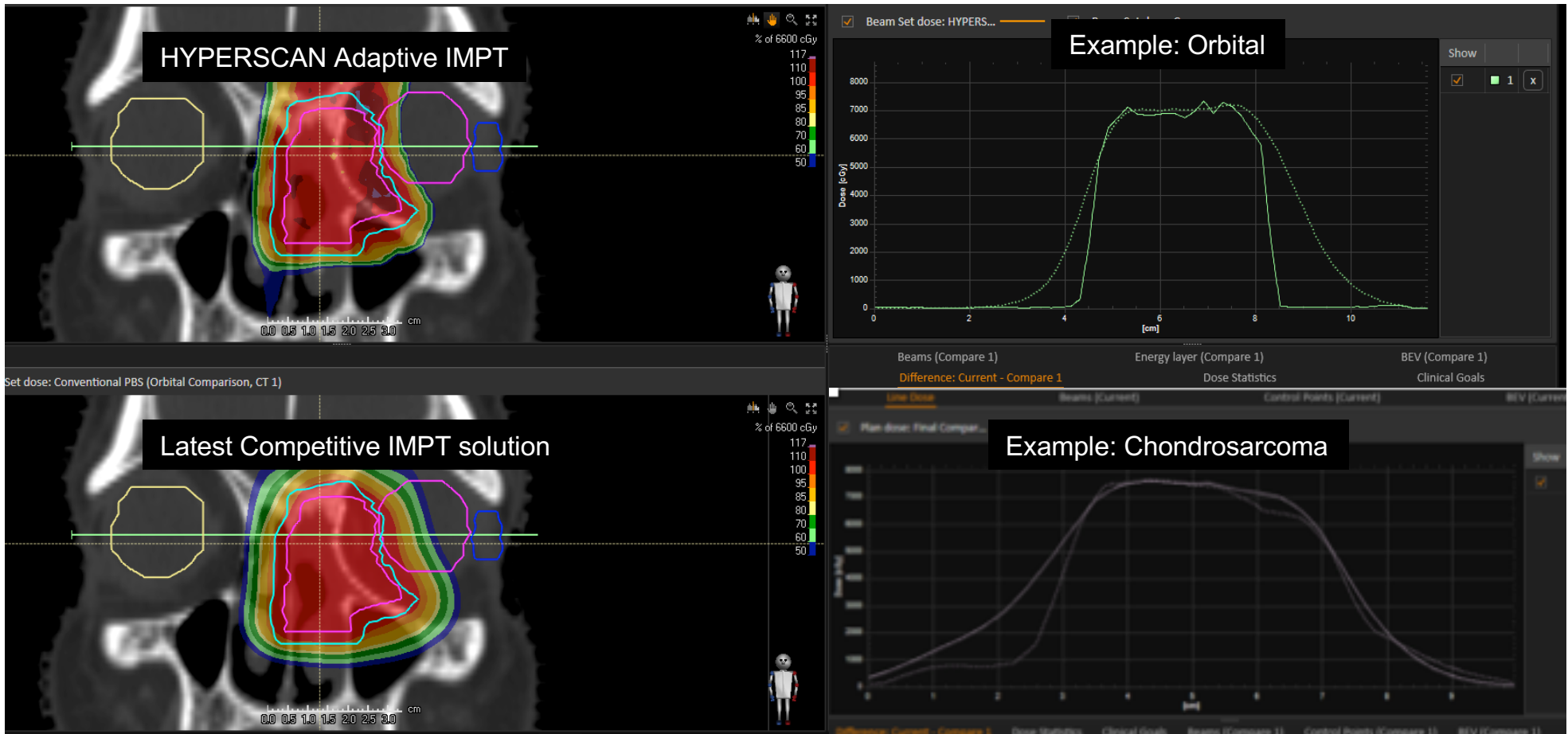
Central Axis



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



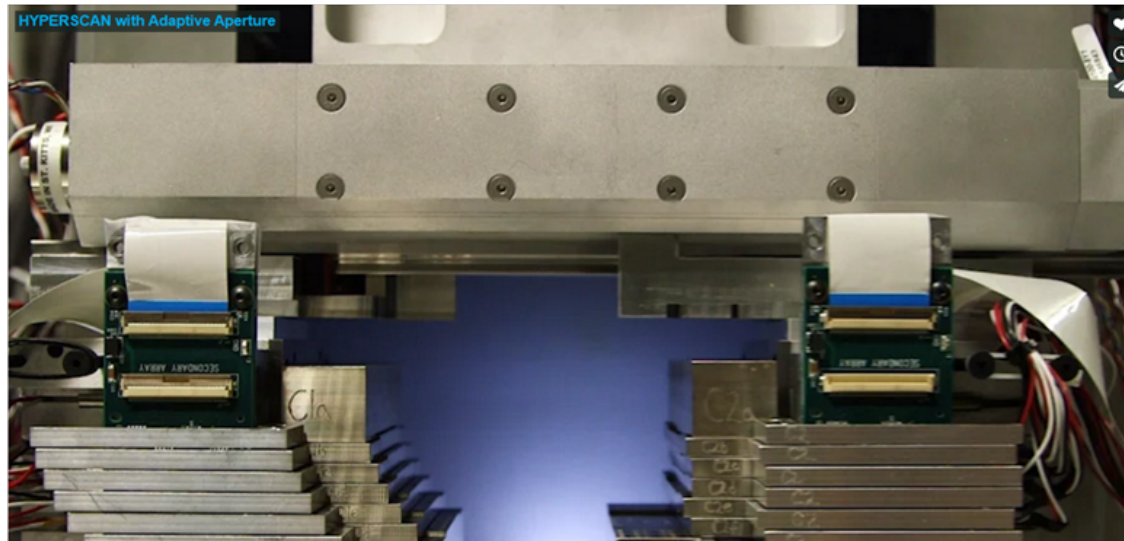
# HYPERSCAN Treatment: Orbital Superior Gradient towards the Eyes and Lacrimal Gland



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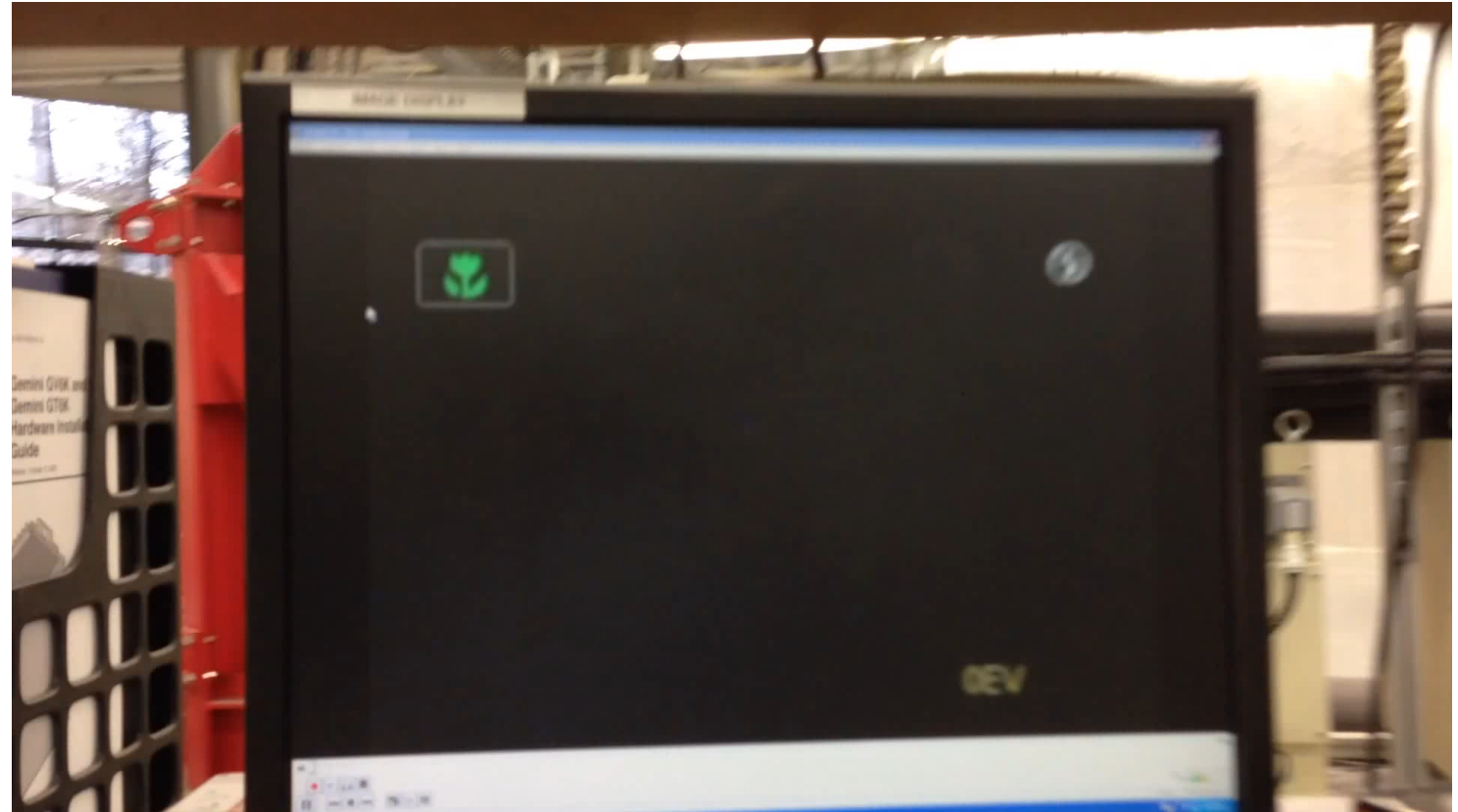
# Adaptive Aperture Implementation





# 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!

**Questions: [aschulte@mevion.com](mailto:aschulte@mevion.com)**