

PAUL SCHERRER INSTITUT

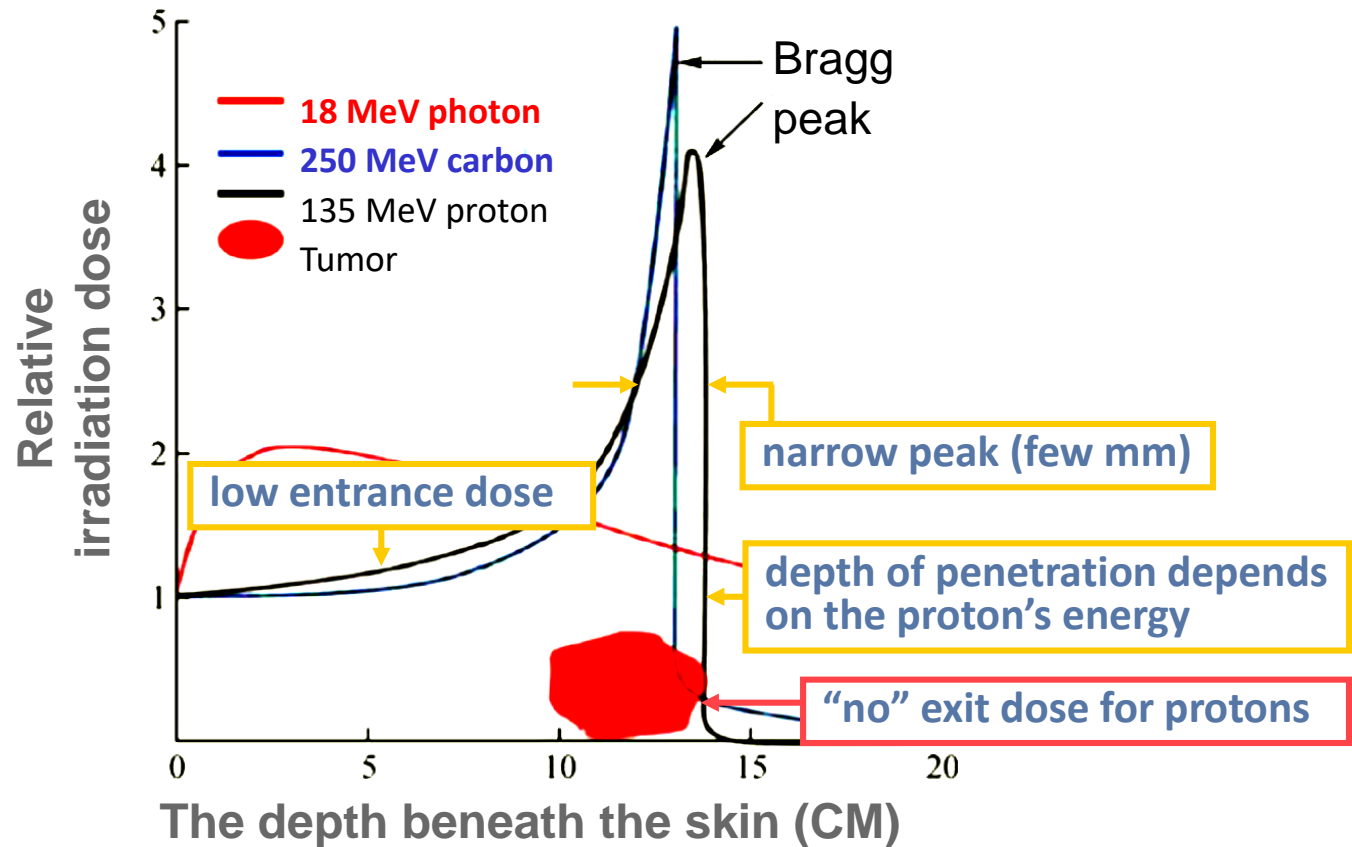


Oxana Actis :: Beam Technology Development :: Centre for Proton therapy :: PSI

Particle Therapy with Protons, Status and Plans at PSI

Workshop on Ions for Cancer Therapy, Space Research and Material Science
26-30 August 2017, Chania, Crete, Greece

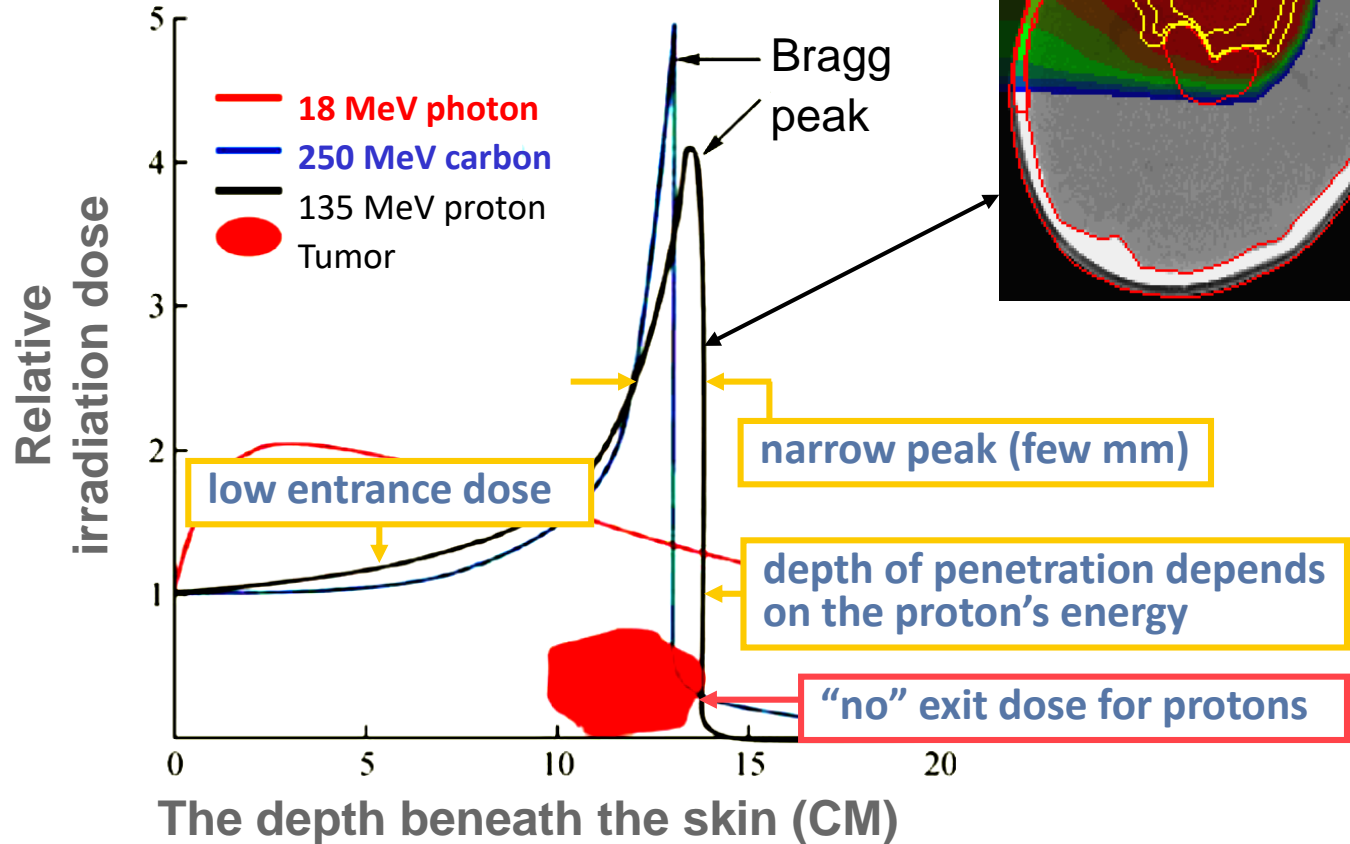
Particle therapy



Particle therapy

SFUD: can be delivered with a fixed beam line

Optimized treatment would require a gantry



Gantries in Particle Therapy

Allow us:

- To be flexible
- To deliver multiple, angularly spaced fields
- To improve dose homogeneity and conformity, plan robustness, delivery accuracy

BUT...

Add additional (substantial) cost to the facility...

which can partially be reduced by

- design optimization
- design using CS magnets

Gantries in Particle Therapy

Allow us:

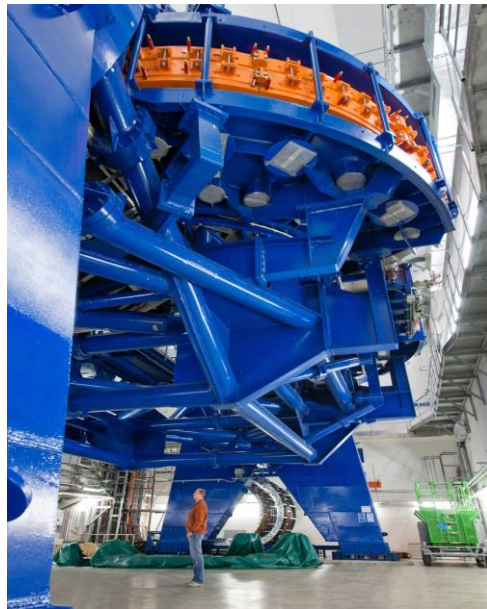
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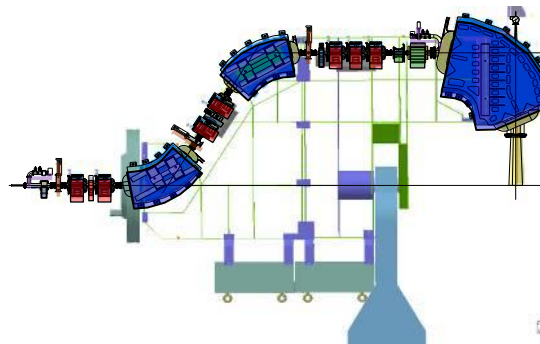
- design optimization
- Design using CS magnets



Carbon Gantry @ Heidelberg

Size: 25 x 6.5 m

Weight: 600 t



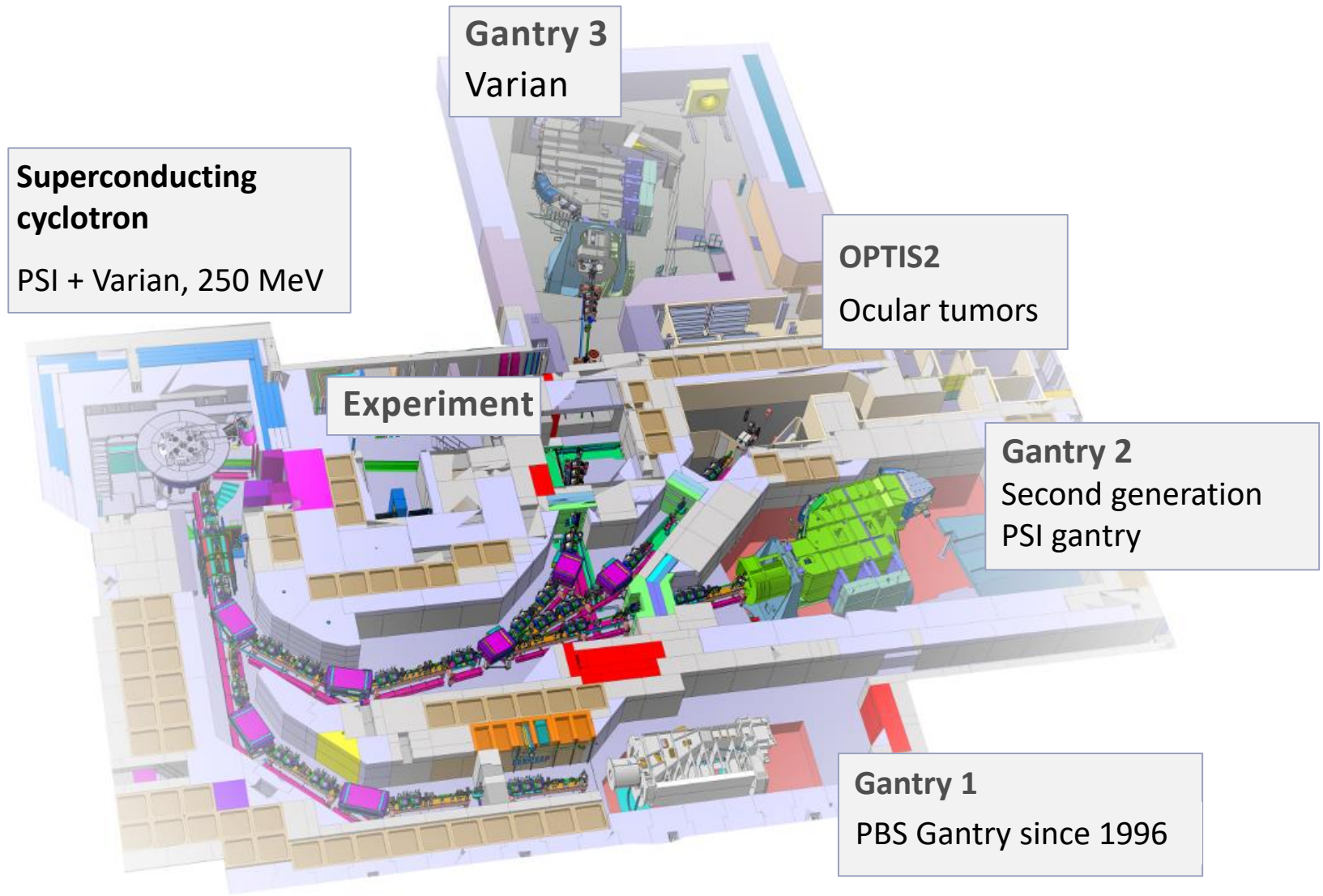
Proton Gantry 2 & PSI

Size: 3.2 m

Weight: 250 t

One of the reasons why protons are more popular...

PROSCAN at PSI (2017)



1984

1996

2006

2010

2013

2017



OPTIS 1:
eye melanoma
treatment since 1984

- Fixed beam line
- Mono-energetic beam + RM wheel
- Collimator (produced at PSI)

1984

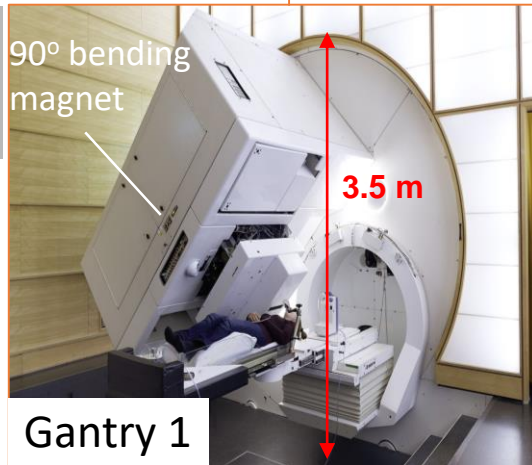
1996

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2017



- First PBS gantry worldwide & IMPT treatments
- Eccentric compact design to fit into existing facility
- +/- 180 degree rotation
- 3 energies after degrader + RS system
- Scanning:
 - 1st direction scanning magnet
 - 2nd direction table

OPTIS 1:
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PROSCAN timeline

1984

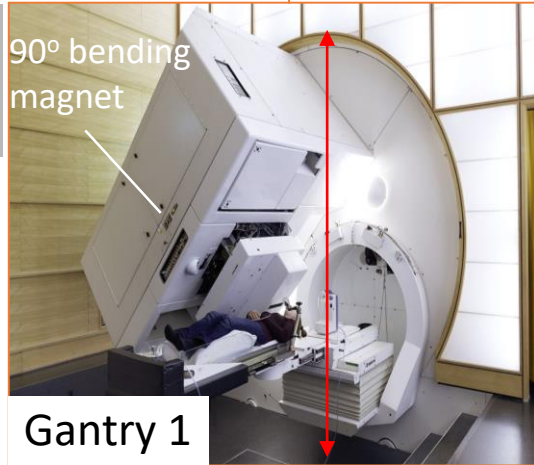
1996

2006

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2017



OPTIS 1:
eye melanoma
treatment since 1984



- Upgraded facility (OPTIS2) in operation since Feb 2010
- Typically 4-8 patients a day, ~220 a year
- > 6700 Patients treated
- Tumour control rate of 98%!

PROSCAN timeline

1984

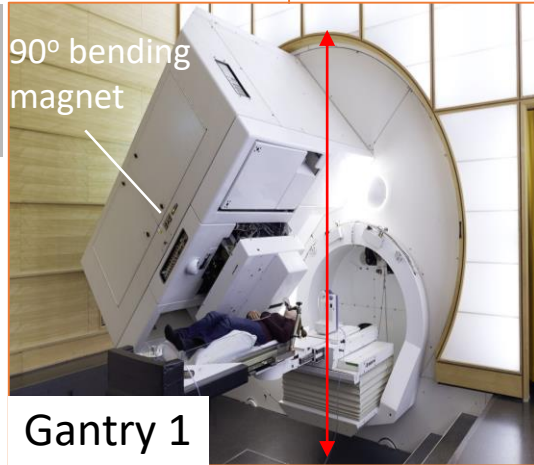
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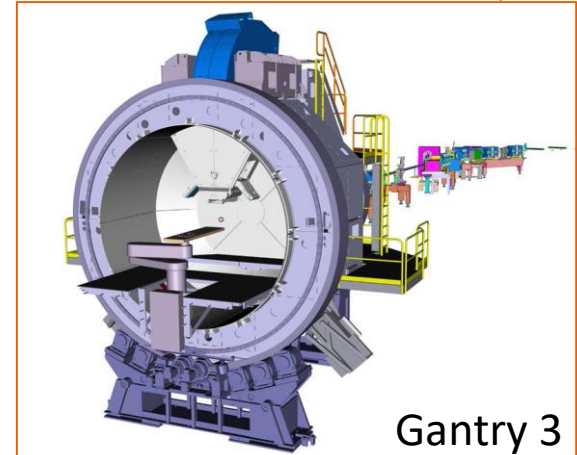
2010

2013

2017

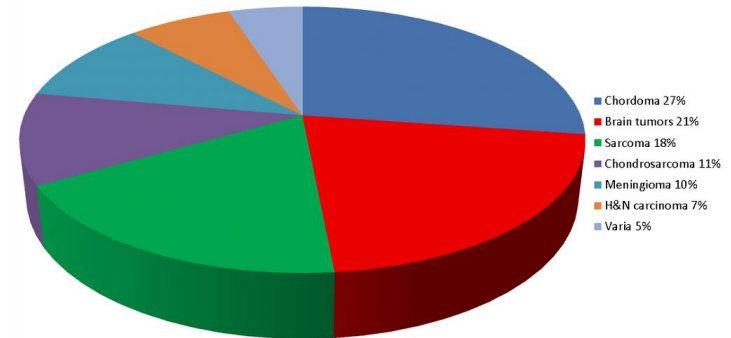


OPTIS 1:
eye melanoma
treatment since 1984



Treatment of deep seated tumours: brain, skull-base or spinal cord tumors, or sarcomas

- Gantry 1: 16-18 patients / day
- Gantry 2: 6-8 patients / day – to be increased
- Around 150 patients / year
- >1500 patients since 1996
- 5-8 weeks: 5/7 treatment, 1.8-2 Gy/day



More than 1/3 of the patients are children

Collaboration with anesthesiology Team of the Children's Hospital of Zurich



State-of-the-Art System

1984

1996

2006

2010

2013

2017



Gantry 1

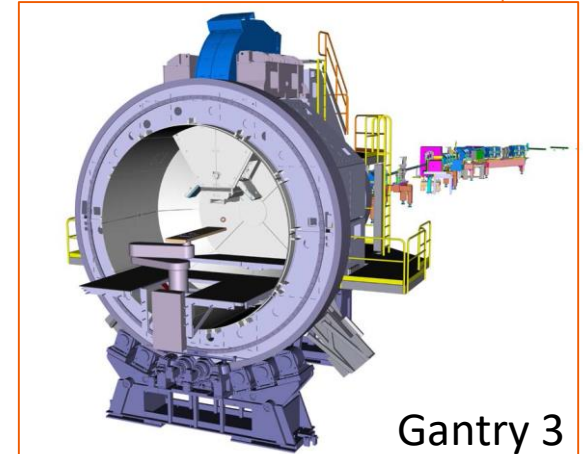


Gantry 2

OPTIS 1:
eye melanoma
treatment since 1984



OPTIS 2

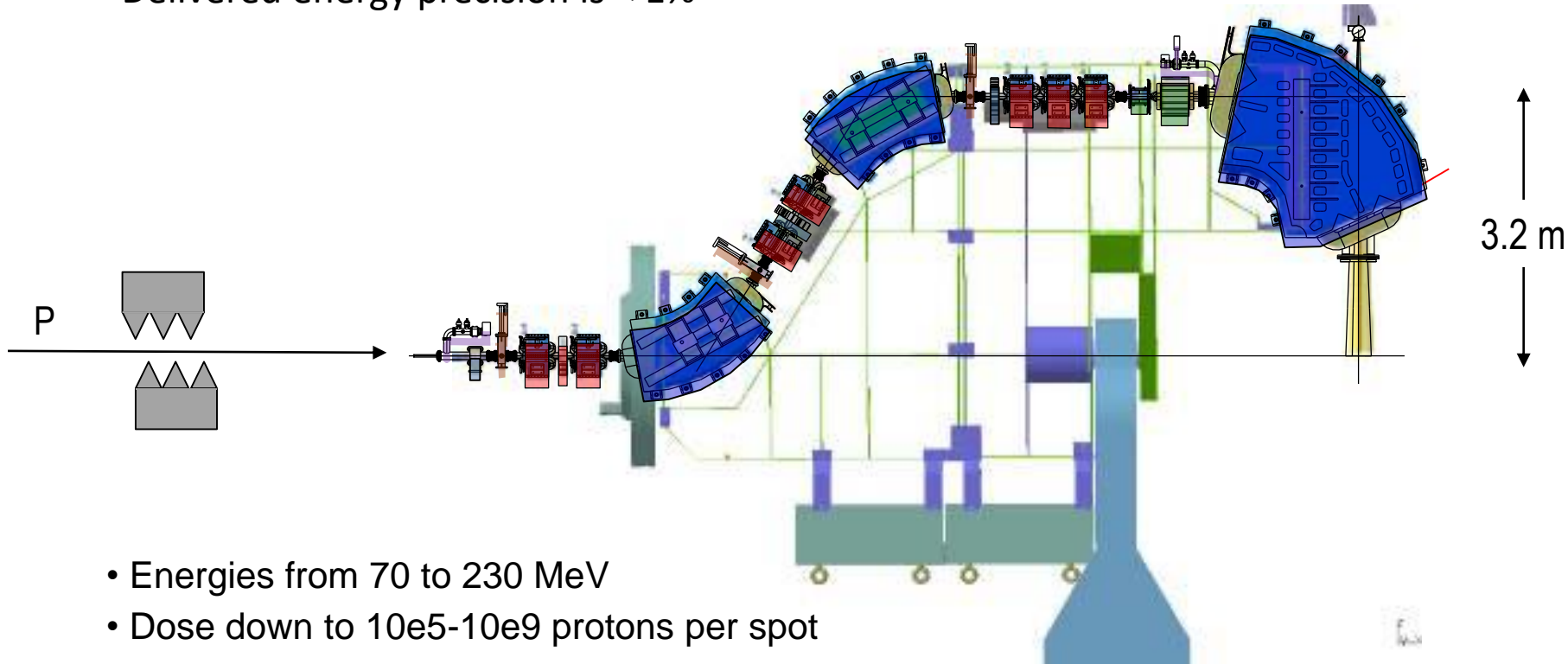


Gantry 3

Gantry 2: designed for fast 3D scanning

Fast Energy Change

- Degradator based energy change within **< 100 ms**
- Optimized magnet power supply & controller
- Delivered energy precision is **< 1%**



- Energies from 70 to 230 MeV
- Dose down to 10^5 - 10^9 protons per spot

Gantry 2: designed for fast 3D scanning

Fast Lateral Scanning

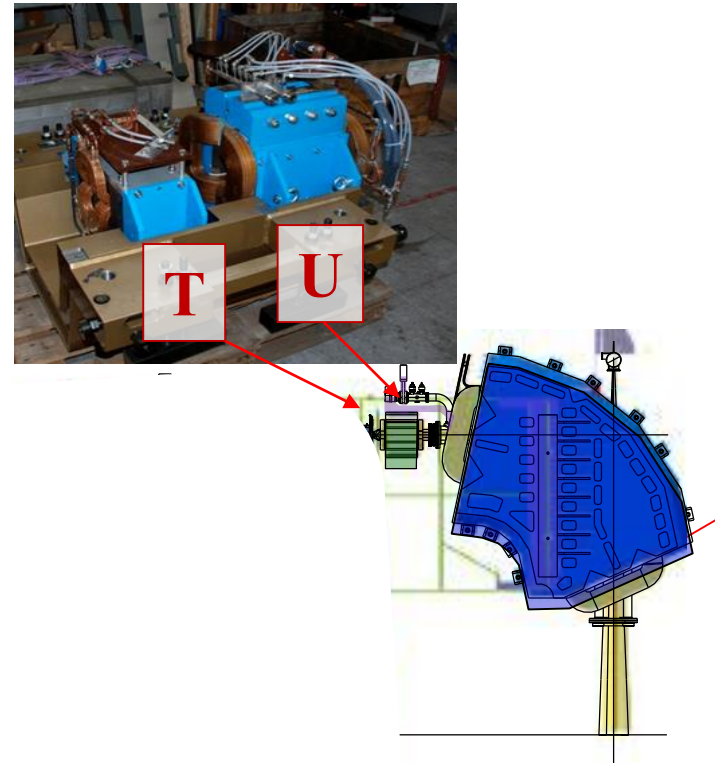
- T sweeper magnet 2 cm/ms
- U sweeper magnet 0.5 cm/ms

Parallel Scanning

- No source to target $\sim 1/d^2$ dosimetry effects
- Simplified QA
- Easy field patching for large fields
- Almost infinite SSD possible

Challenge – scan through the last bend

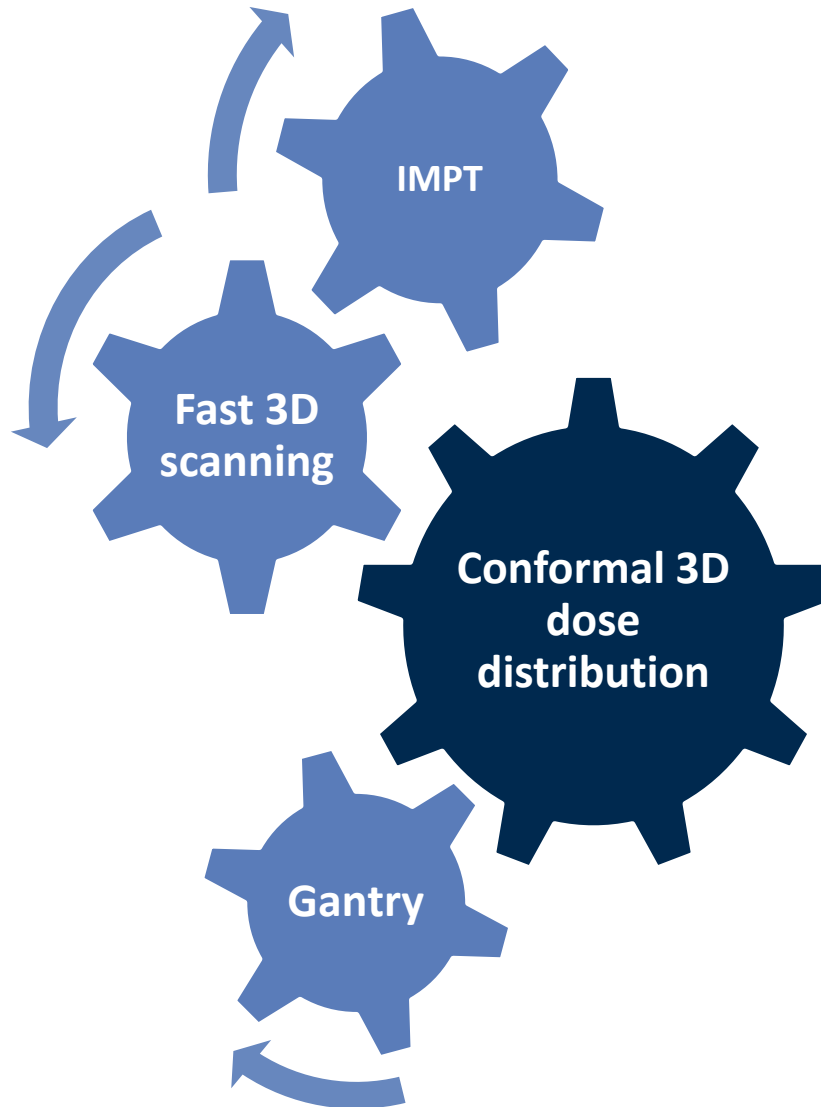
- Large aperture to accommodate deflected beam
- Scan area 20 x 12 cm
- Field patching for larger fields required
- Complex current -position calibration

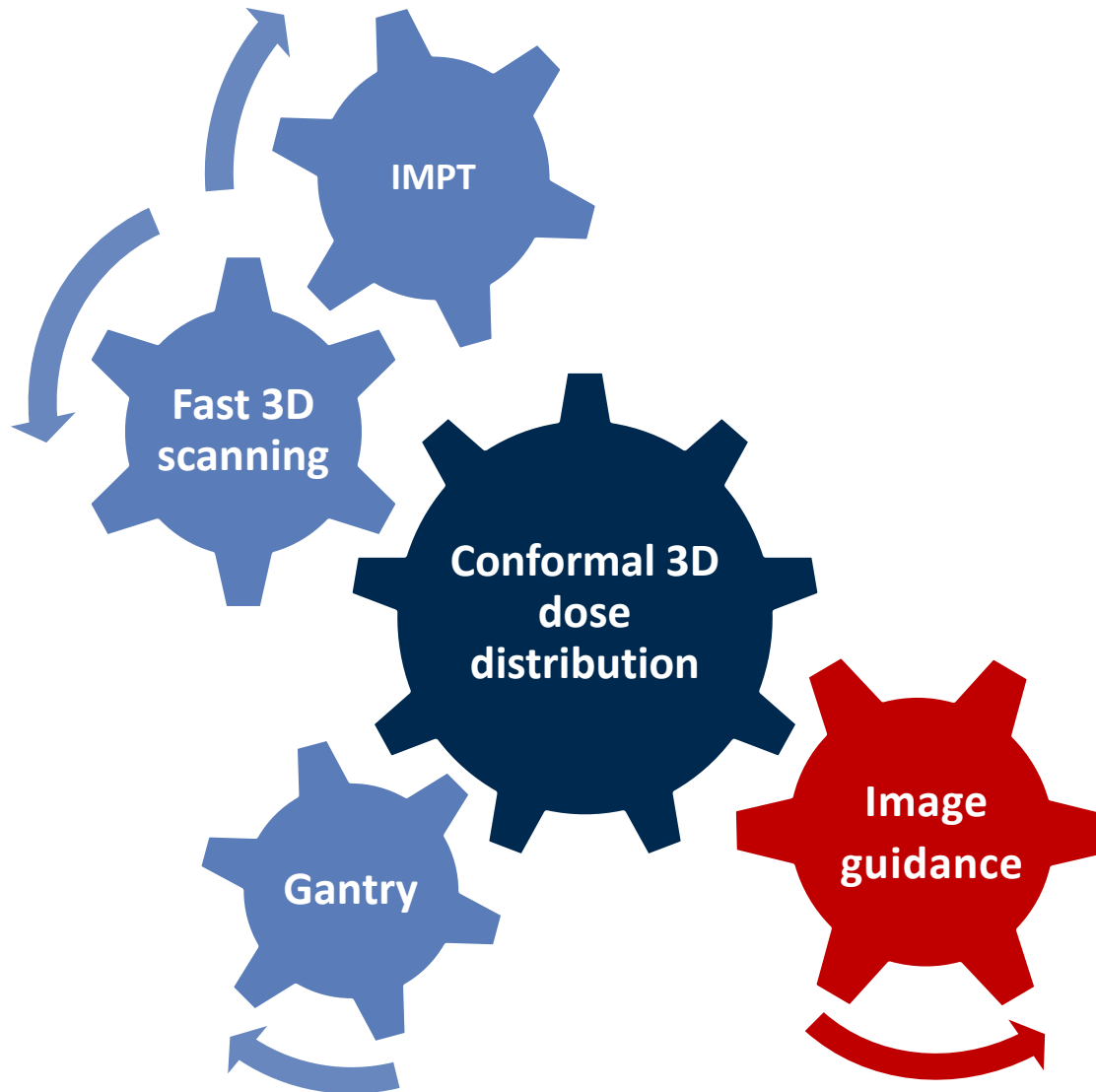


Lateral spot precision

< 0.5 mm +

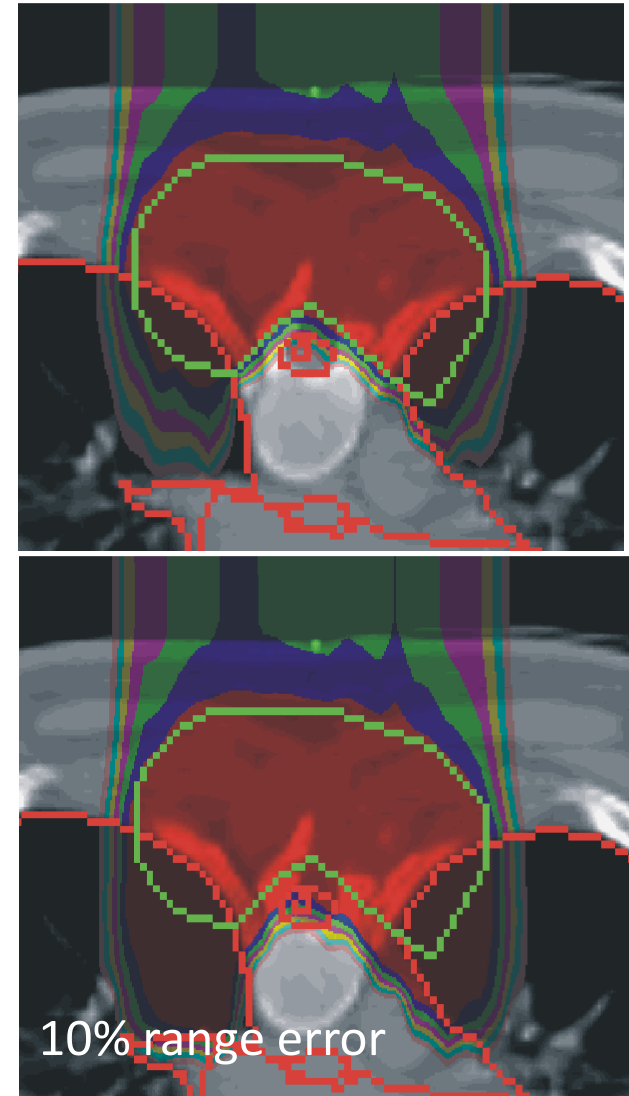
Range precision < 1%



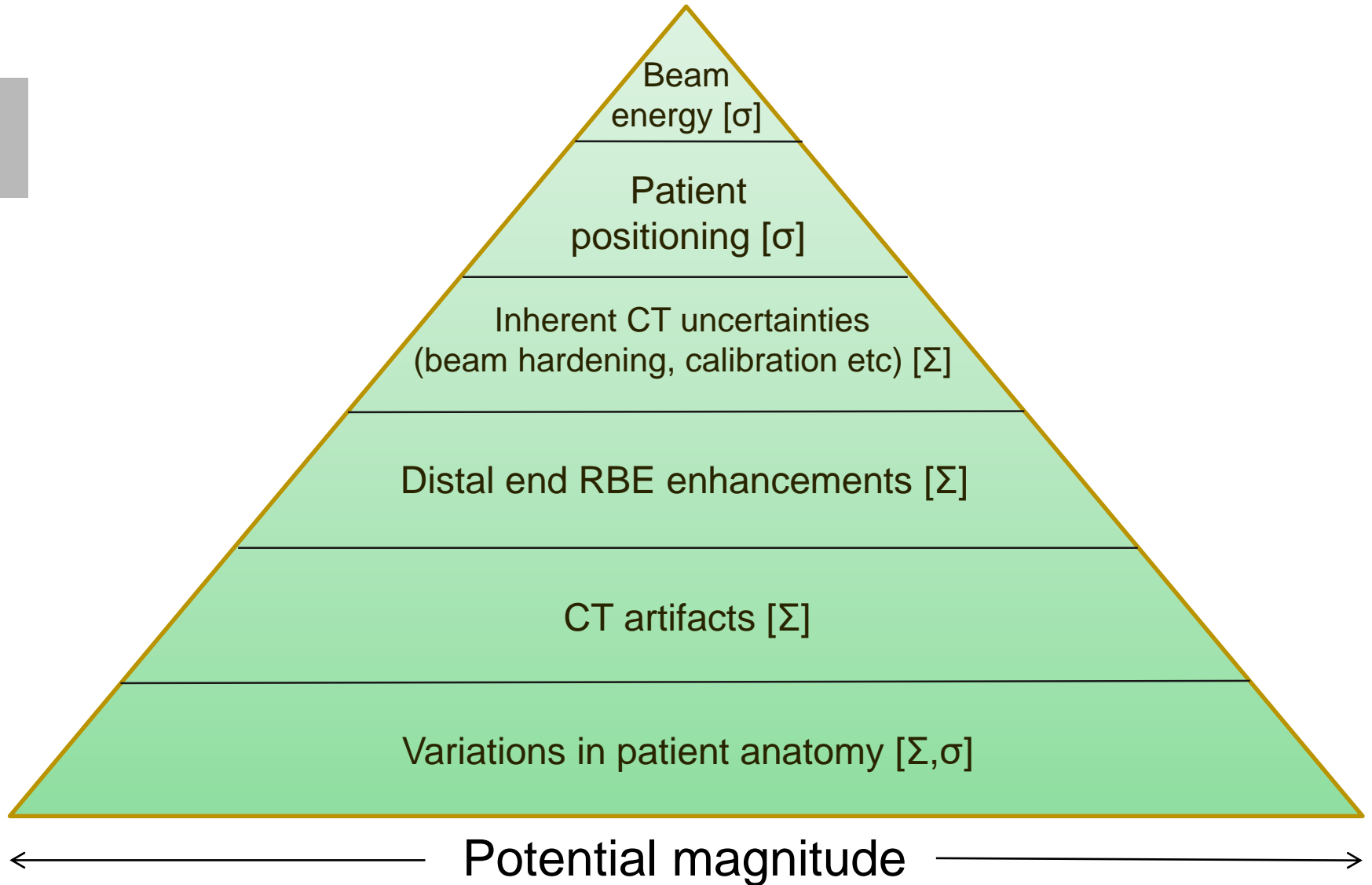


The advantage of protons is that they stop.

The disadvantage of protons is that we don't always know where...



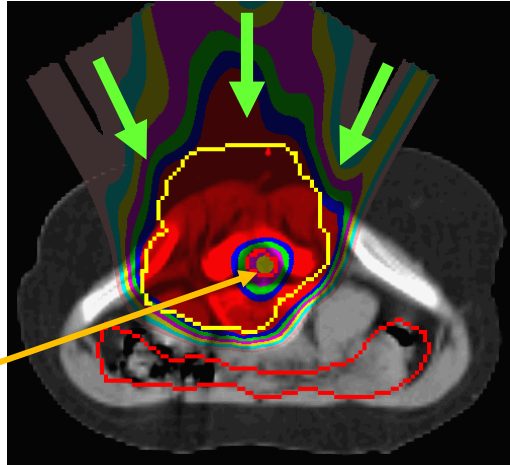
The 'Bermuda Triangle' of range uncertainties



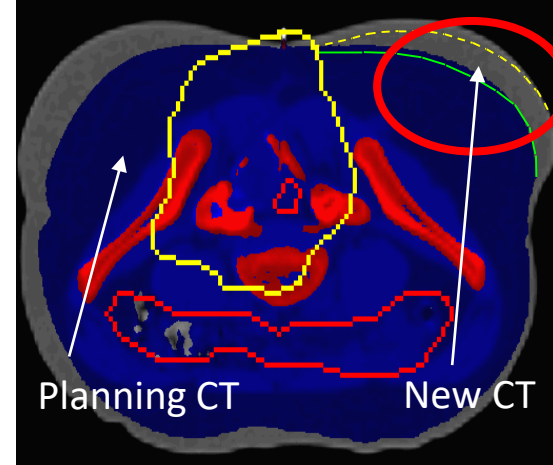
Examples of anatomic changes

3 field IMPT plan to an 8 y old boy

During treatment, 1.5kg weight gain



Note, sparing of spinal cord in middle of PTV

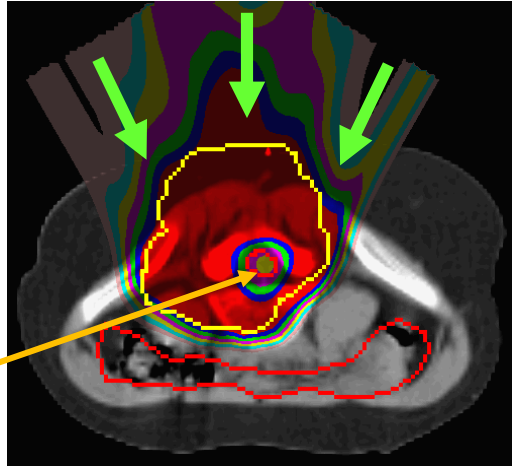


Max range differences:
SC 0.8cm
CTV 1.5cm

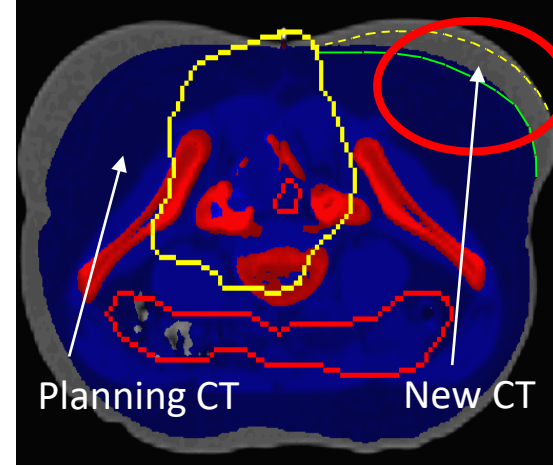
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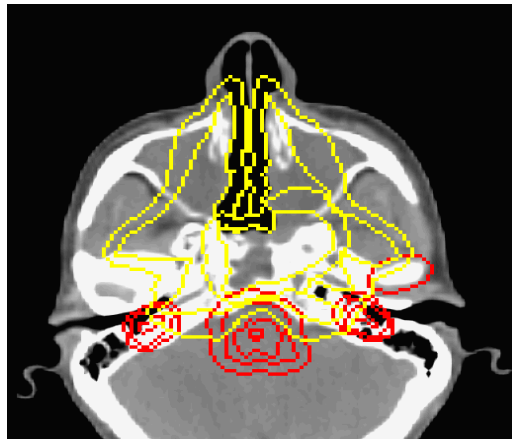
Note, sparing of spinal cord in middle of PTV



Max range differences:
SC 0.8cm
CTV 1.5cm

Francesca Albertini and Alessandra Boisi (PSI)

Skull base Chondrosarcoma



Planning CT



Repeat CT after 2 weeks

3/4D Imaging at PSI

Siemens Somatom CT-on-rails



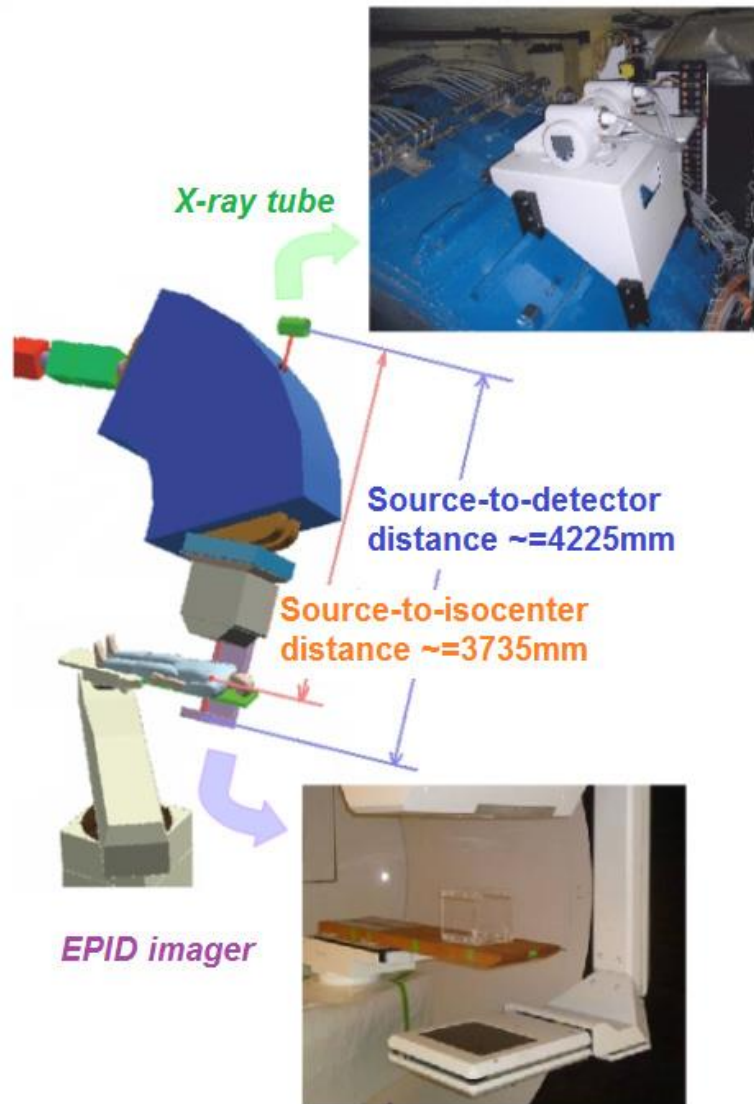
4D MRI Siemens Aera 1.5 T



Cone-beam CT on Gantry 3



2D/On-line imaging at Gantry 2



BEV imaging – equivalent to portal imaging with photons

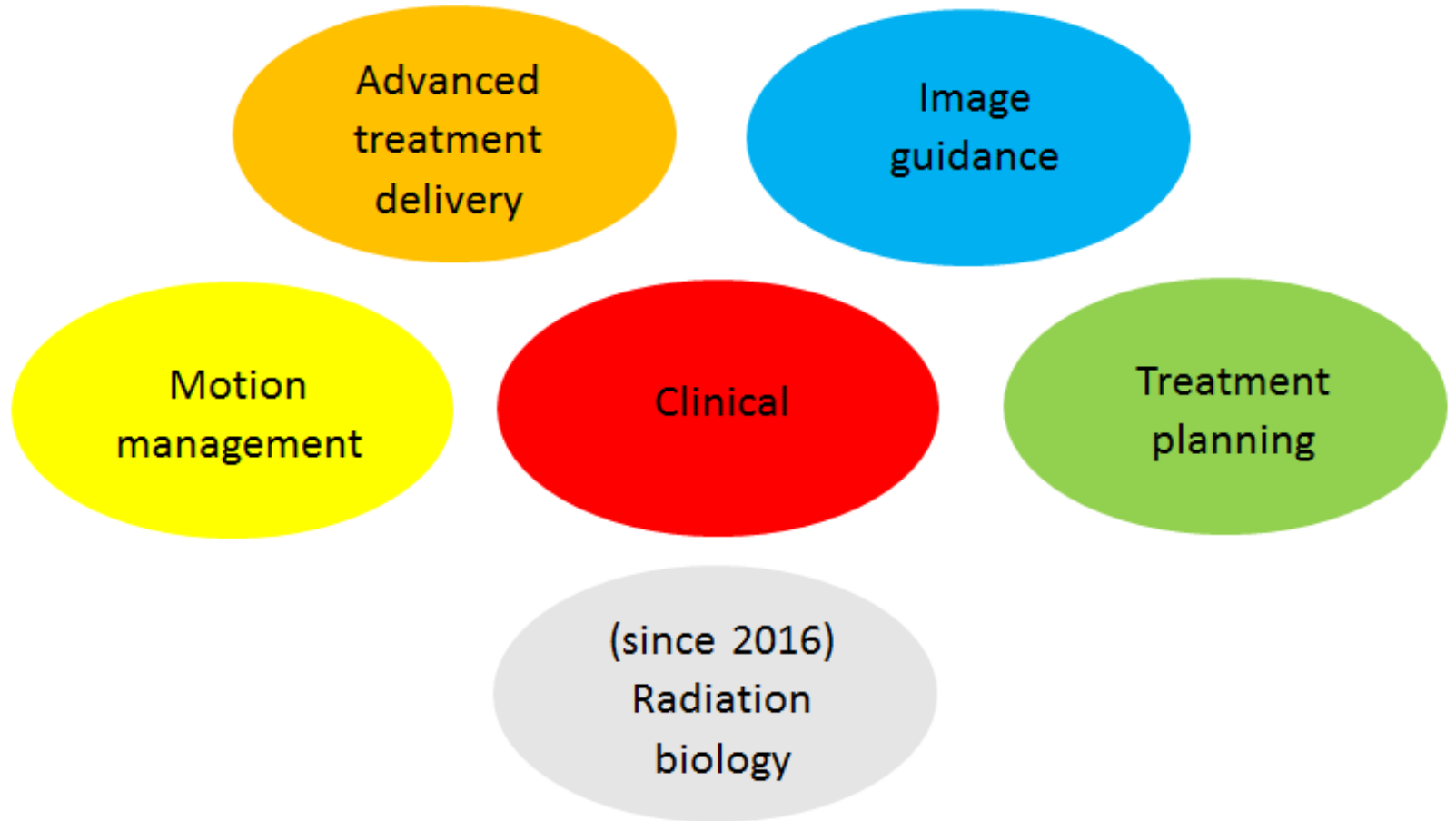
- Large field-of-view (26 cm x 16 cm)
- Not masked by equipment or collimators in the beam path

Scanning + pulsed X-rays

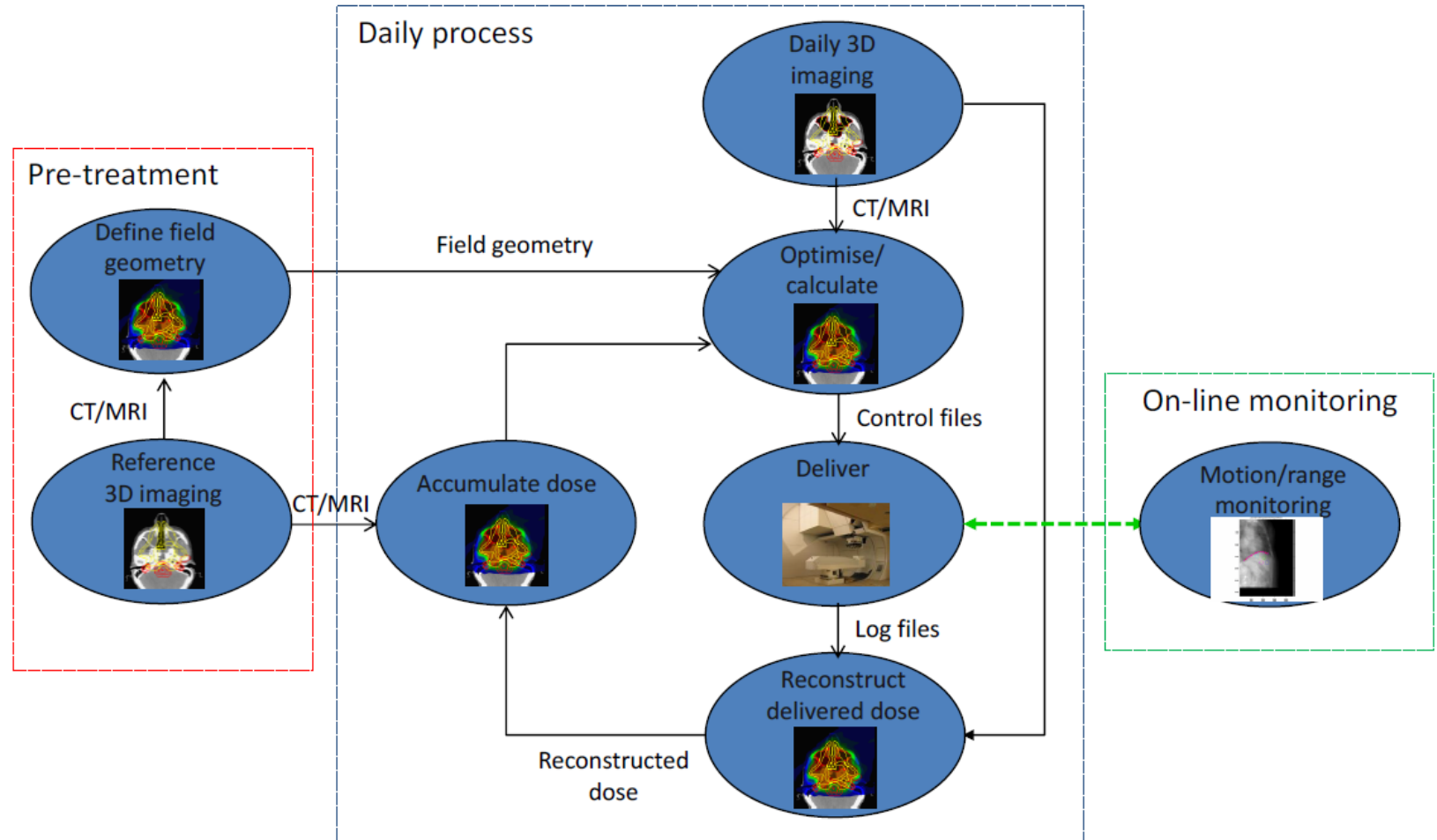
- QA control or patient positioning
- Gating and slow tracking

Fluoroscopy mode

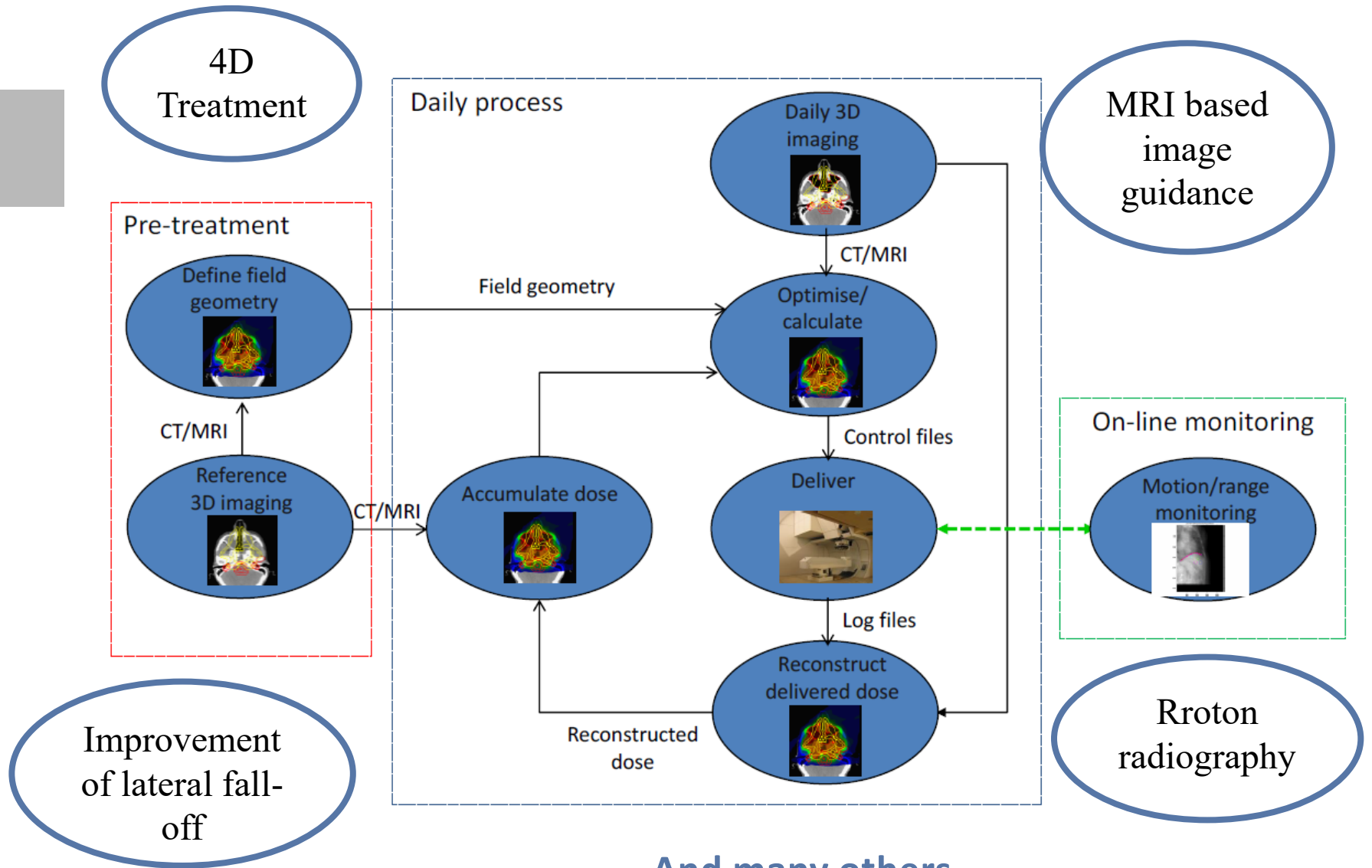
Research Areas



Daily Adaptive Proton Therapy

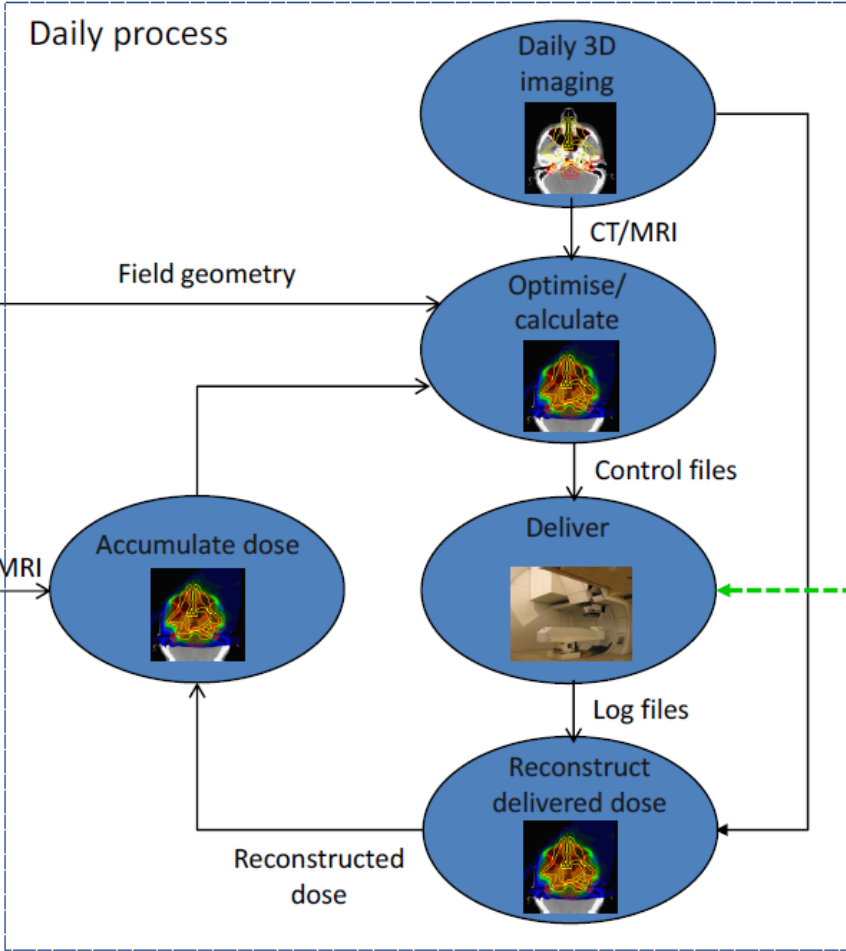
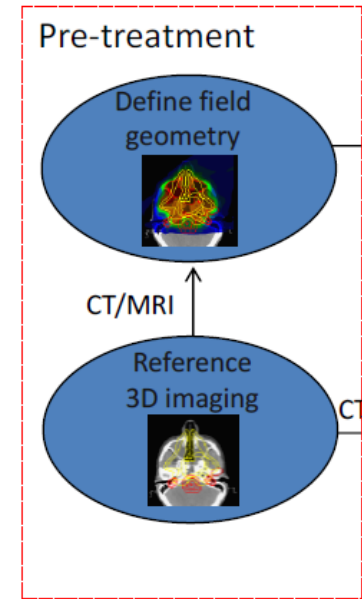


Daily Adaptive Proton Therapy & More

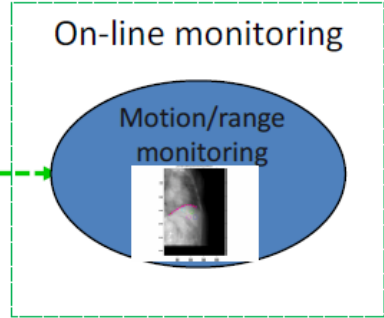


Daily Adaptive Proton Therapy & More

4D Treatment



MRI based image guidance



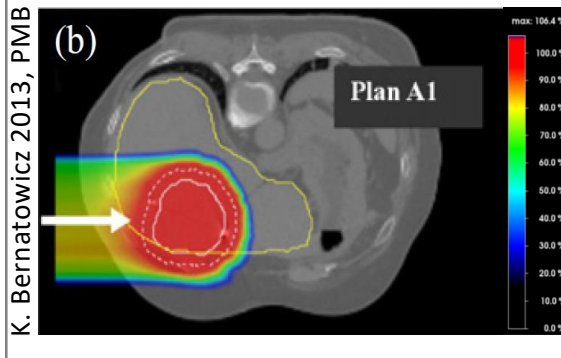
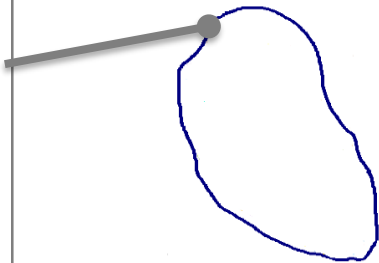
Improvement of lateral fall-off

Rron radiography

And many others...

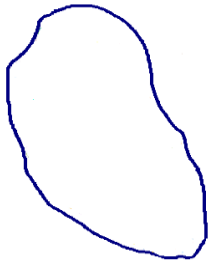
Static tumor

PBS has been proven to be one of the most effective methods for static tumor treatment



Static tumor

PBS has been proven to be one of the most effective methods for static tumor treatment



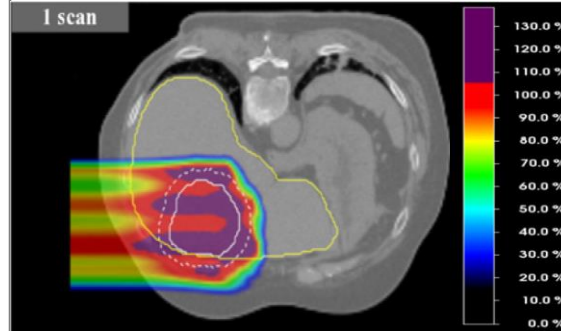
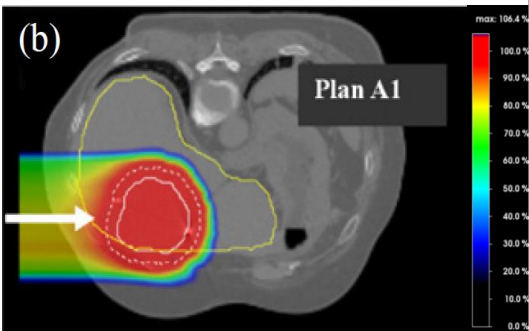
Moving target: single scan

- Irradiated volume blurring
- inhomogeneity within the target
- Cold and hot spots

Interplay effect

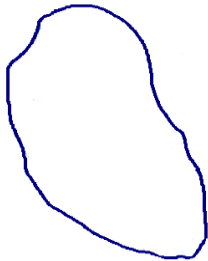


K. Bernatowicz 2013, PMB



Static tumor

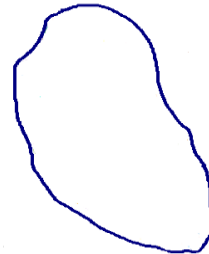
PBS has been proven to be one of the most effective methods for static tumor treatment



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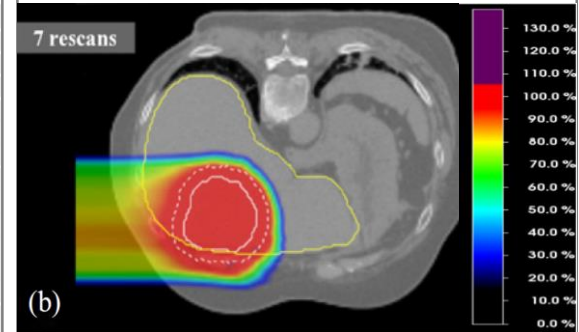
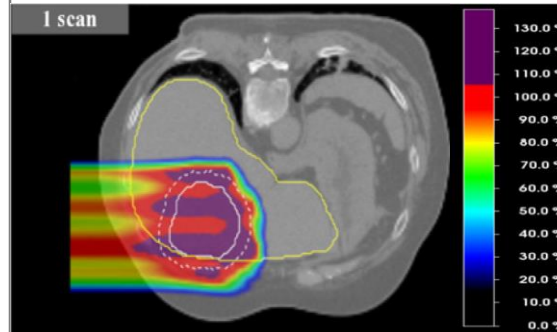
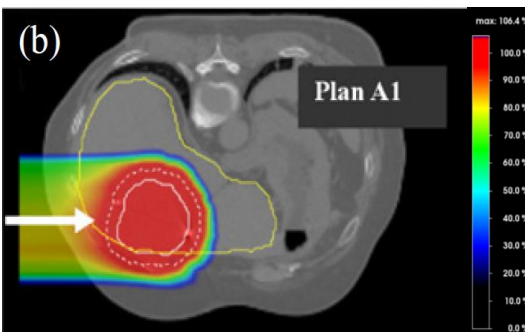
Moving target: options

Rescanning – most studied solution for motion mitigation

Depending on system & motion parameters - combination with:

- **Gating**: scan target during part of the breathing cycle
- **Breath hold**: irradiate while patient is holding the breath

K. Bernatowicz 2013, PMB



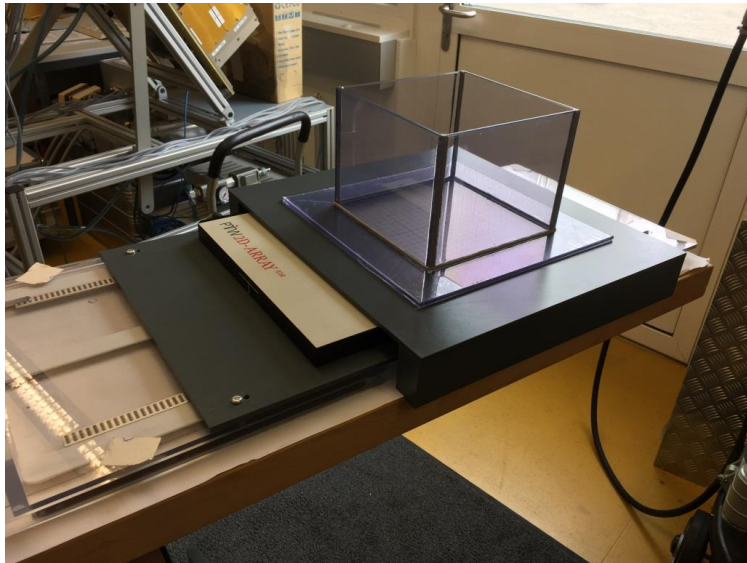
Commissioning of volumetric rescanning

4DCT dataset with primary motion below 8 mm

4D-dose calculation study: 4-8 rescans provide full and homogeneous target coverage

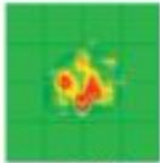
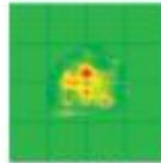

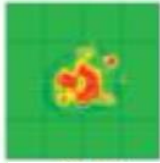

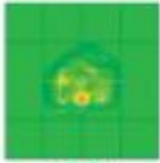

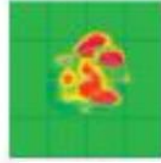
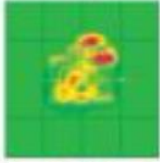
Dosimetric verification

- mid-SOBP and distal depth
- stationary 2D-chamber array



End-to-end testing performed with breathing anthropomorphic phantom

- nominal 8mm motion
- fluctuating motion
- scaled to exceed the clinical inclusion criteria (>10mm)

	1 scan	4 scans	8 scans
A = 5 mm T = 6.4 s	 86.7%	 89.4%	 100%
Random fluctuations	 72.7%	 87.0%	 97.8%
2x scaled	 39.5%	 70.8%	 82.4%

J. Hrbacek, PTCOG 56

1st patient has been treated at Gantry 2

Optical tracking of breathing motion for gated treatment with PBS is under commissioning

Polaris SPECTRA position sensor has been integrated in the Gantry 2 therapy control system

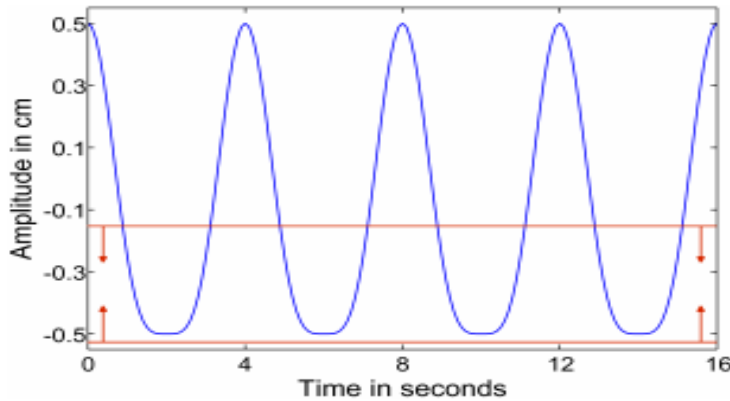


J. Fattori, Radiat. Onc. 2017

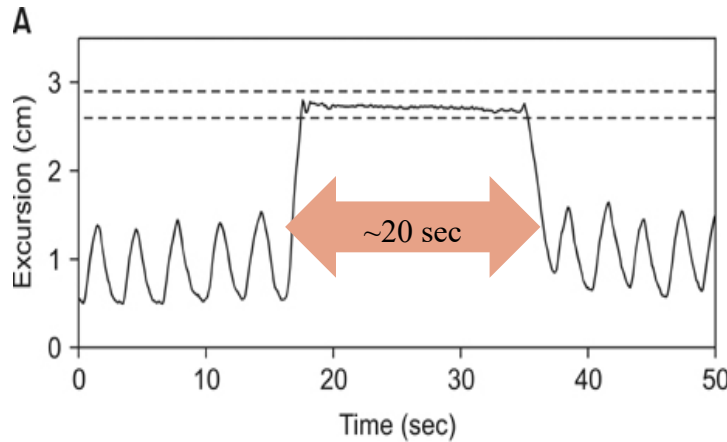
Possibility to treat moving targets with $A > 8$ mm

PBS for Static and Moving Targets

A. Schaetti, PSI



Radiat Oncol J. 2014 Jun;32(2):84-94



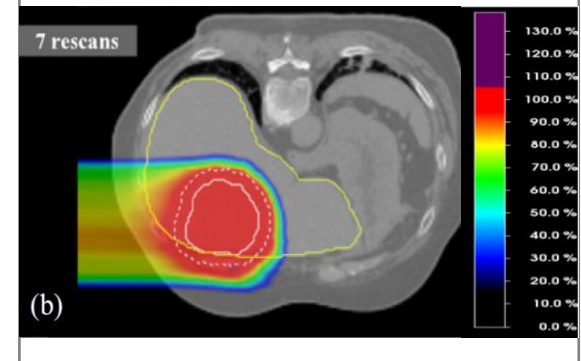
For all options/combinations scanning must be fast in all 3 dimensions

Moving target: options

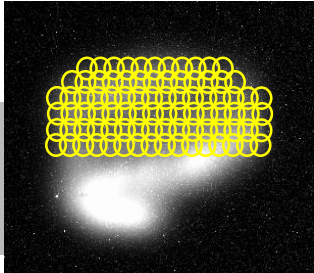
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Another way to optimize scanning performance



Discrete spot scanning

20412 spots, 28 energies

Beam-on time: 17s

Dead time: 80s

Total time: 97s

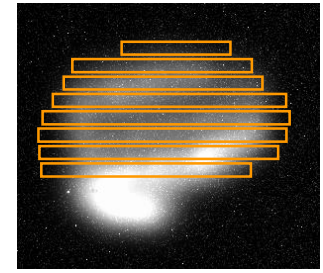
→ 5 re-scans: ~7min

Cubical target, $V = 1L$

Spot grid 4 mm

Dose: 0.6 Gy (typical 3 field
fraction dose)

Standard dose rate (<6 Gy/s)



Continuous line scanning

27 lines/energy, 28 energies

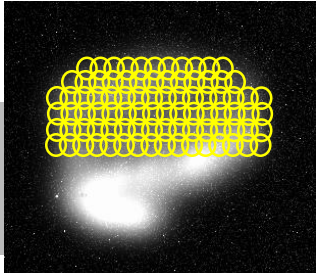
Beam-on time: 17s

Dead time: 3s

Total time: 20s

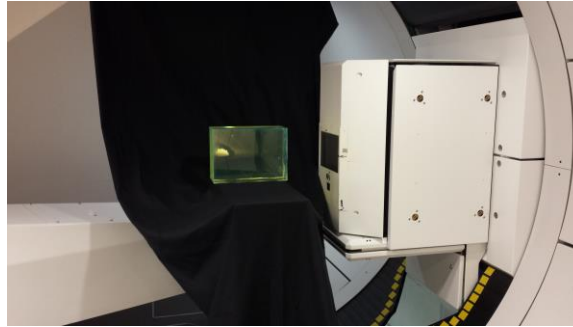
→ 5 re-scans: ~30s

Another way to optimize scanning performance

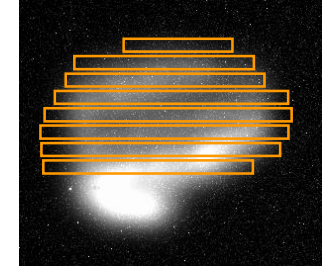


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A lot has been achieved since the beginning of clinical operation at PSI ...

And still a lot to do...



Thanks to the whole CPT team !!!

