OncoRay – National Center for
Radiation Research in Oncology, Dresden

First clinical application of a prompt-gamma-ray based proton range verification system

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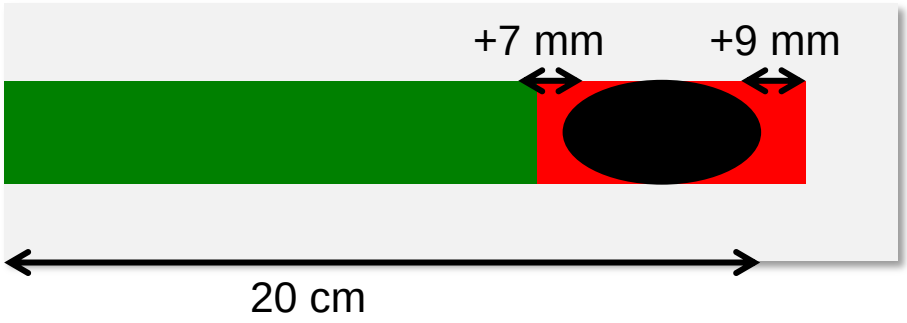
Range uncertainties and *in vivo* verification

- **The good thing: Protons stop.**
  The bad thing: We do not know where exactly.
- Range uncertainty: 3.5 % + 2 mm



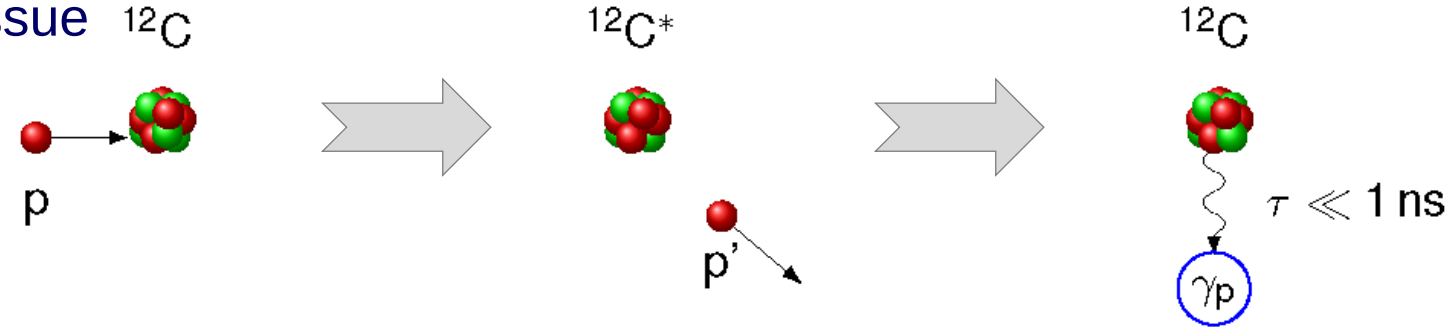
→ Dose distribution vulnerable to range uncertainties

→ Sub-optimal plans have to be chosen

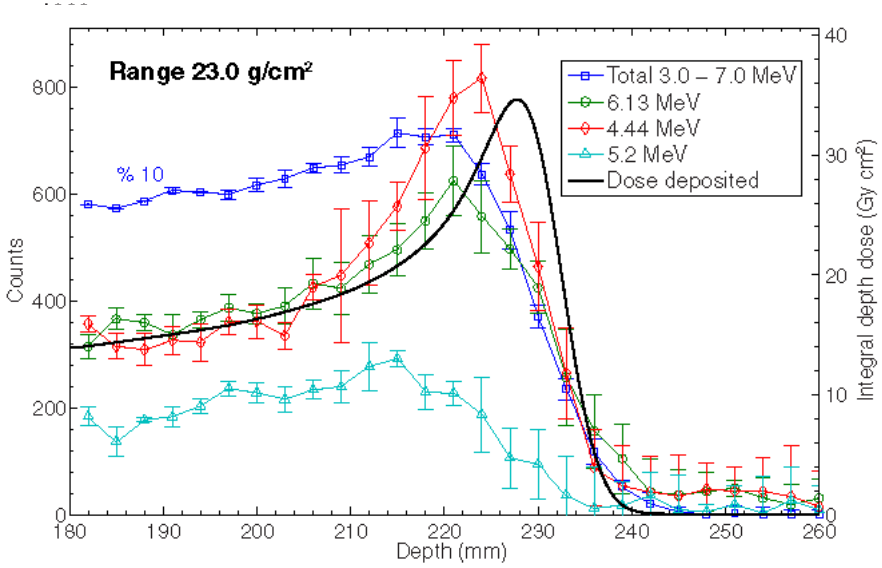
- Real-time information
- Accuracy significantly below range uncertainty

Prompt gamma emission

- Prompt gammas: Resulting from nuclear interactions of beam particles with tissue



- Emitted directly after the interaction (prompt)
- Energy spectrum: E ≤ 8 MeV
- Strong spatial correlation of gamma emissions with dose deposition



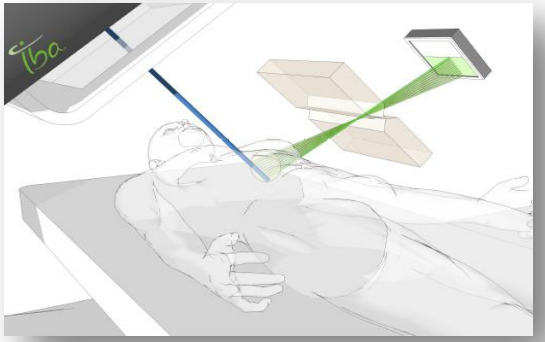
The PGI slit camera project

Background:

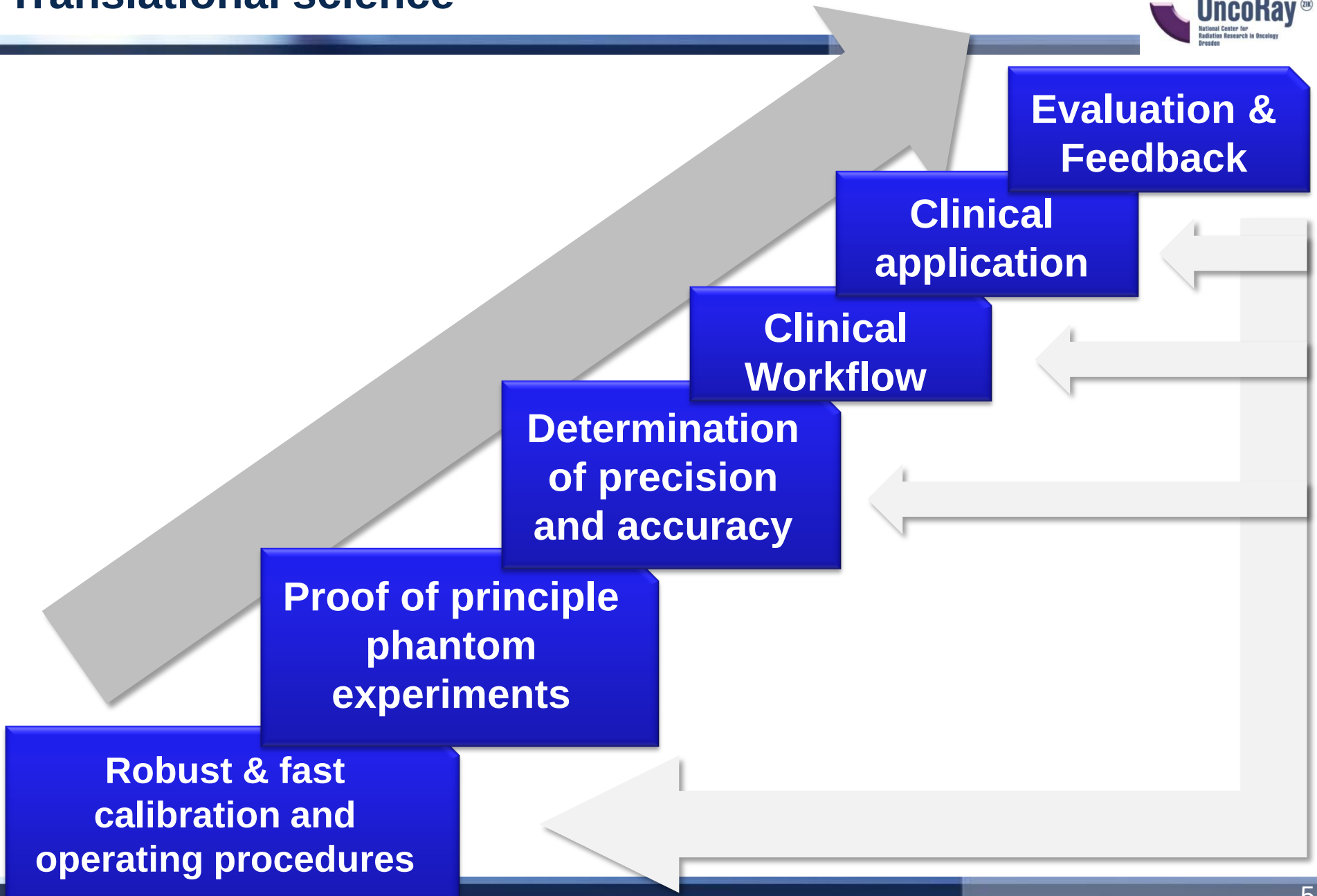
- Developed by IBA within ENVISION project
- 1st prototype in Dresden since 10/2014
- Close cooperation between OncoRay, HZDR, IBA

Goals:

- Evaluation of the benefit under clinical conditions
- **Final Goal:** Reduction of range uncertainties and irradiation of normal tissues

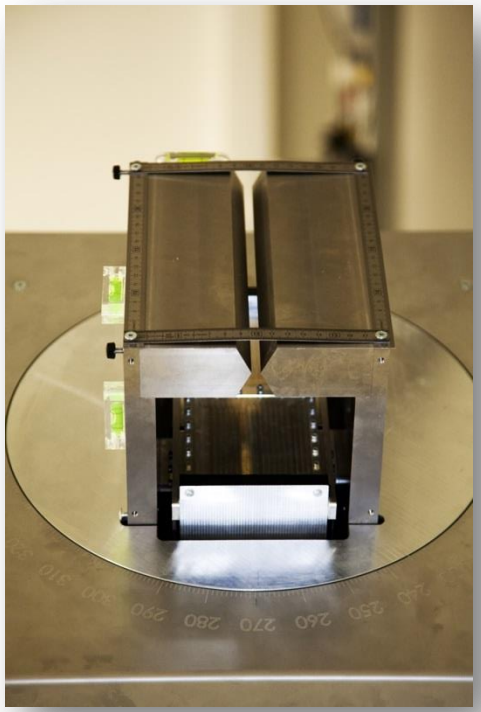


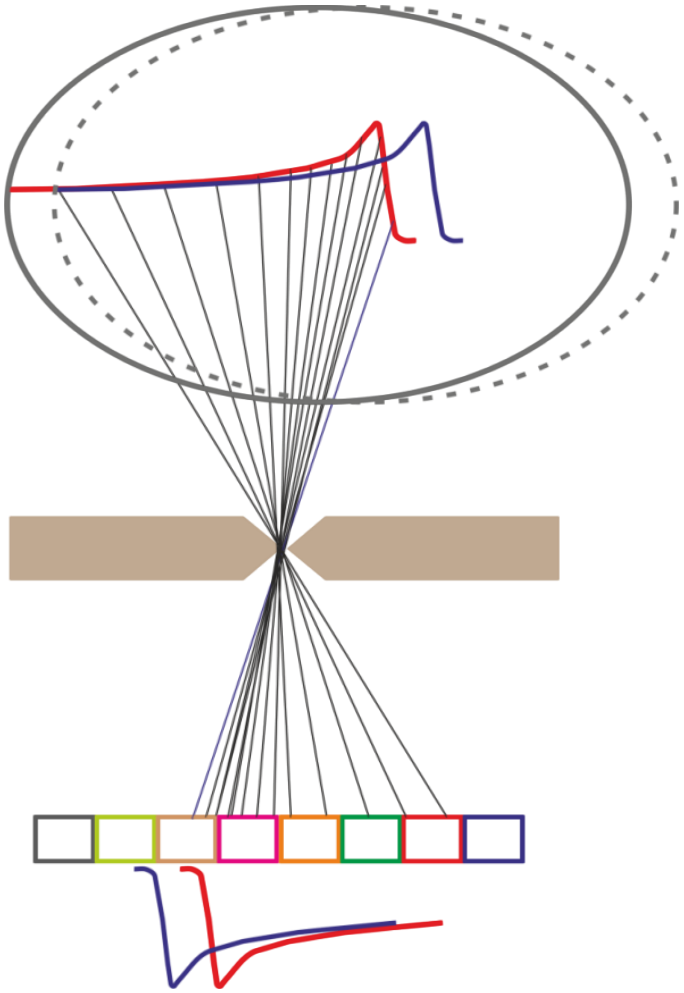
Translational science



PGI slit camera: Principle

Proton beam



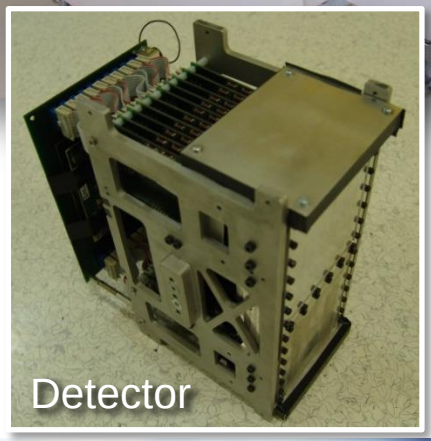


Irradiated Volume

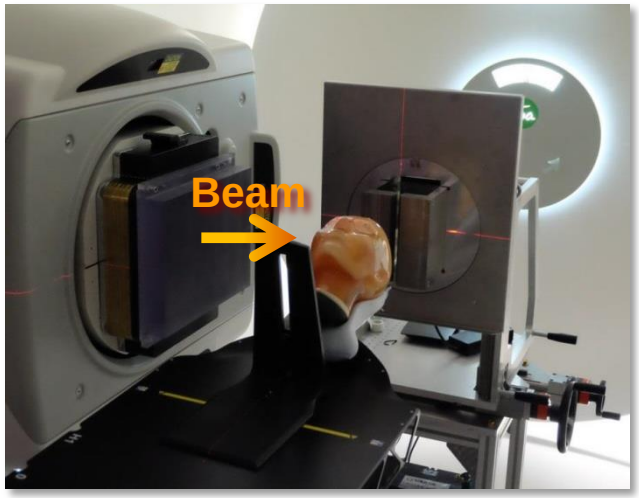
Tungsten collimator

Segmented detector

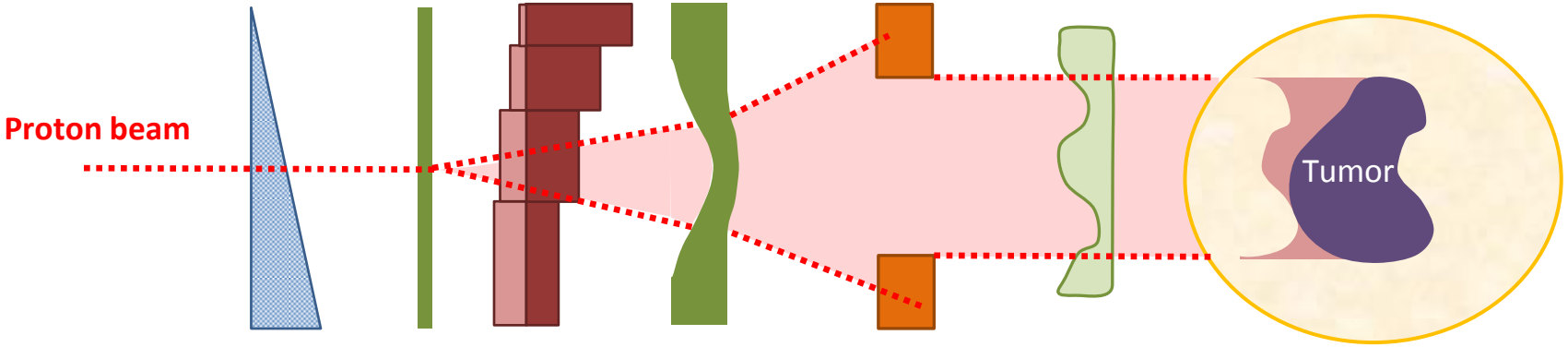
The PGI slit cam prototype



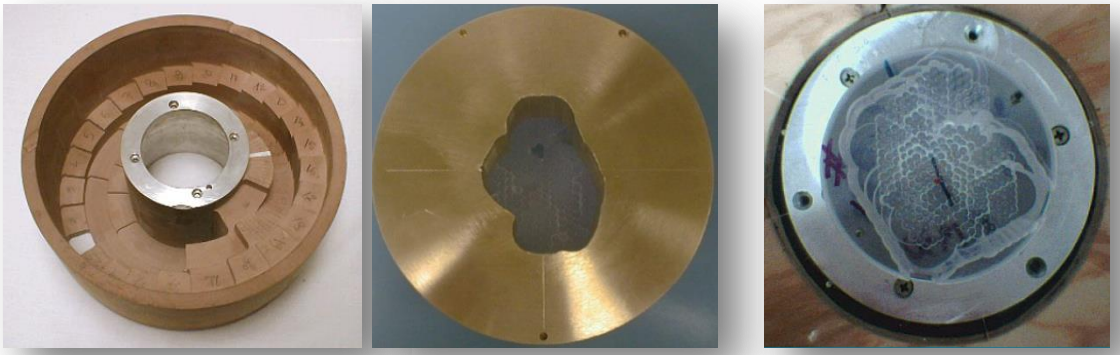
- Mobile trolley with collimator and support for the detector
- Wireless -> Easy to use
- 4 cm thick tungsten collimator
- Slit collimator 360° rotatable
- Setup: Slit perpendicular to beam



Application in DS treatments

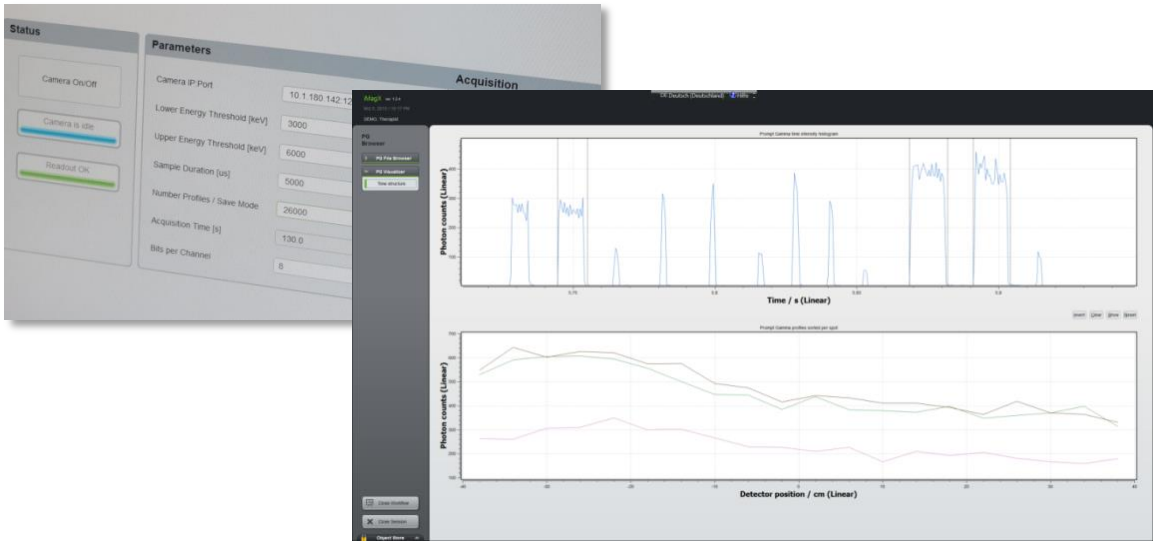


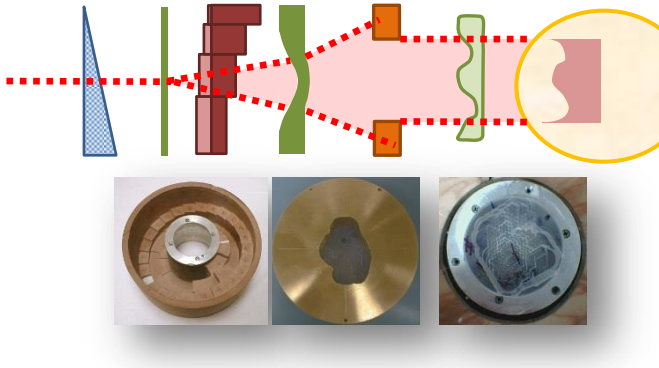
Degrader | First Scatterer | Modulator Wheel | Second Scatterer | Collimator | Range Compensator



Comparison of PBS and DS application

	Application in PBS	Application in DS
Absolute range analysis (via simulation)	☺	☹ (not yet available)
Inter-fractional range deviation analysis	☺	☺
Information per	Spot	Whole field or iso-energy layers
Challenges		Increased neutron background → Background subtraction

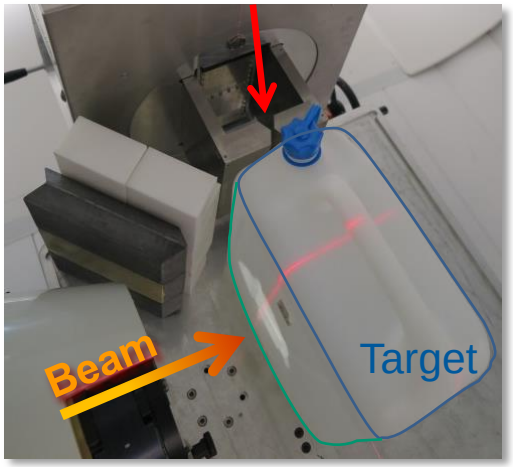




⇨ **Question: Is application in DS possible and useful?**

Slit camera in DS: Background subtraction

Collimator slit open



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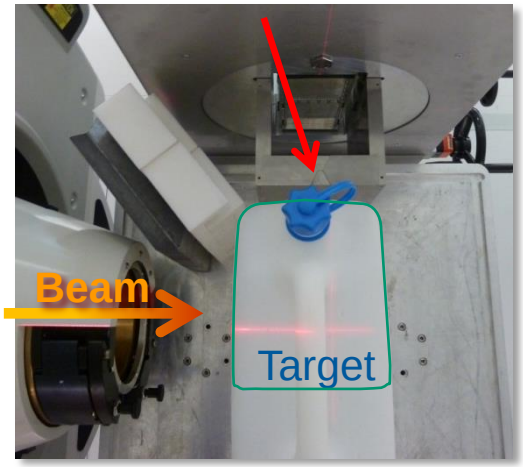
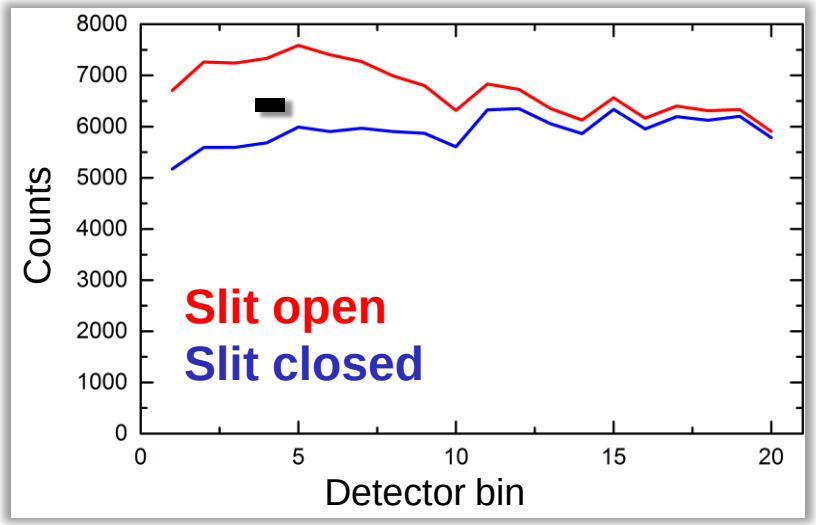
Collimator slit closed





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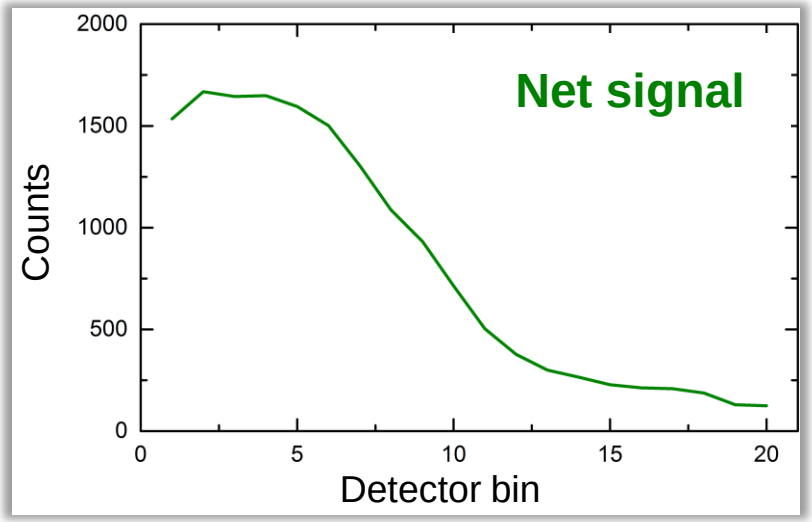
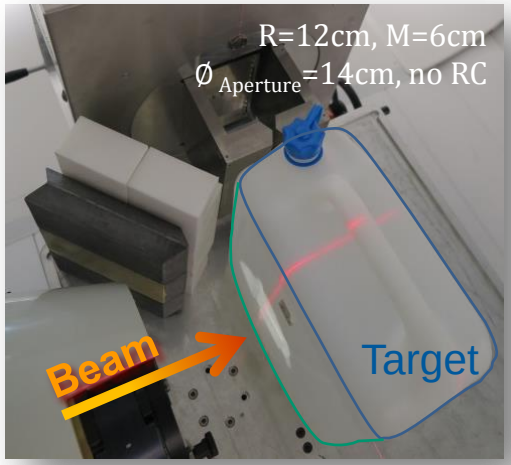
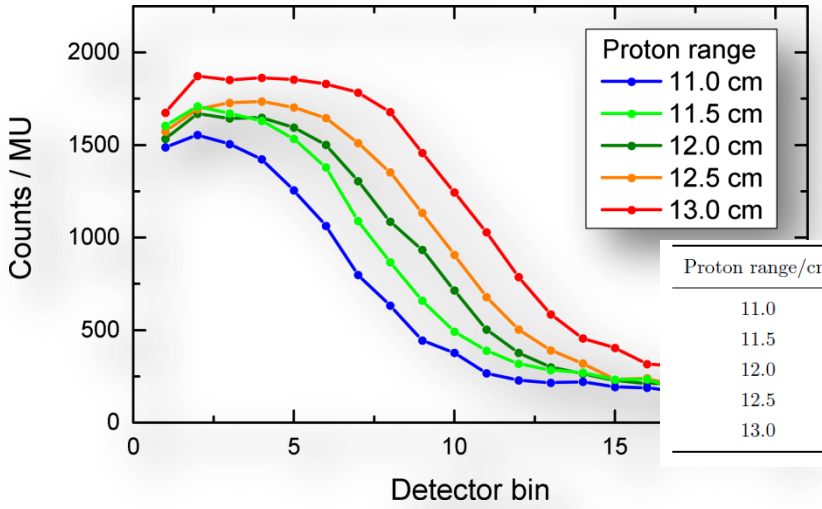
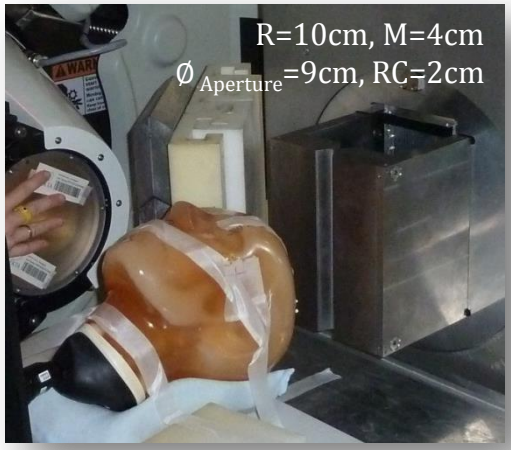


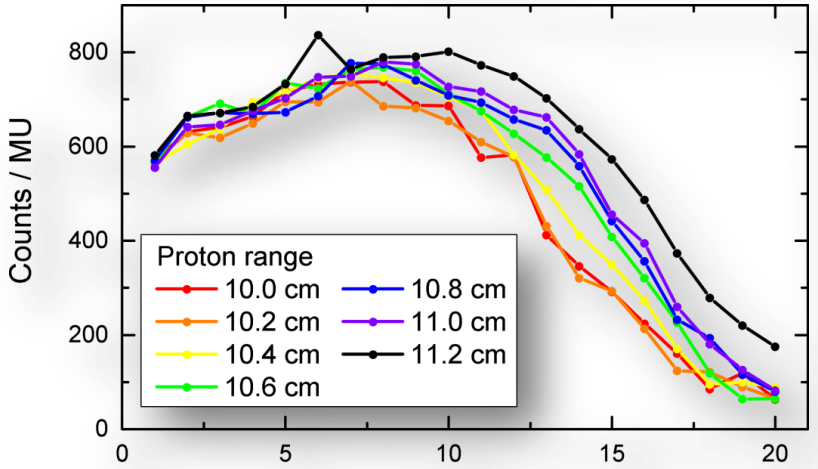
Slit camera in DS: Global range shifts





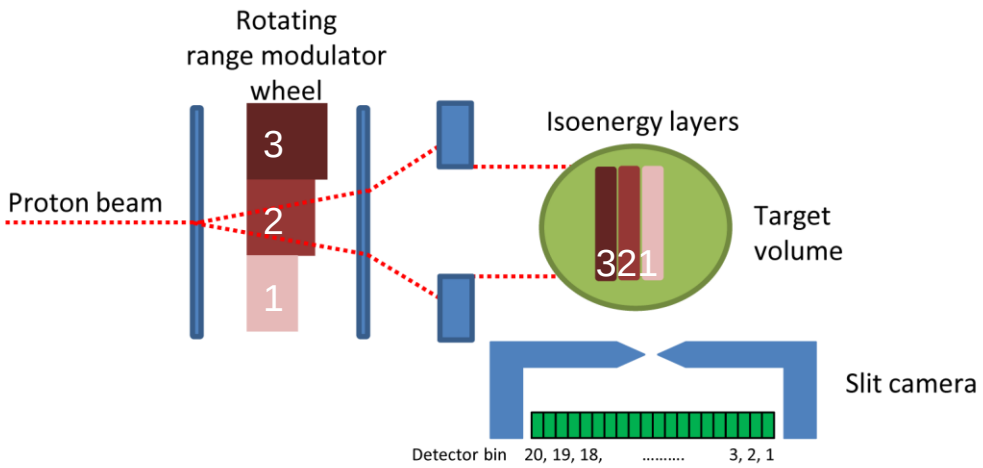
Proton range/cm	Expected shift/mm	Detected shift/mm
11.0	-10.0	-10.6
11.5	-5.0	-6.6
12.0	0.0	0.0
12.5	5.0	3.4
13.0	10.0	8.6

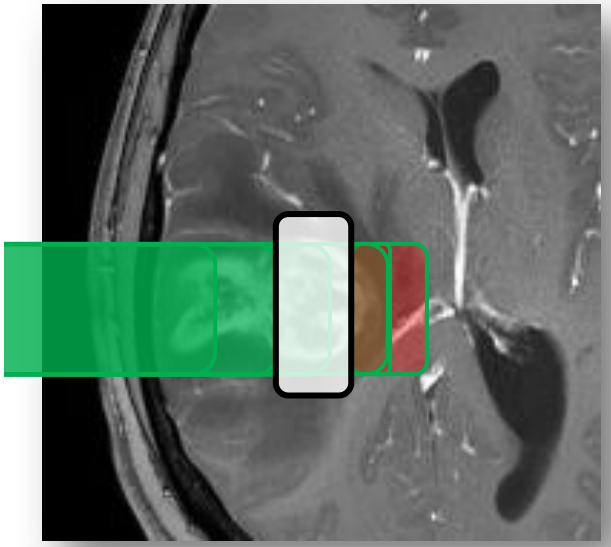




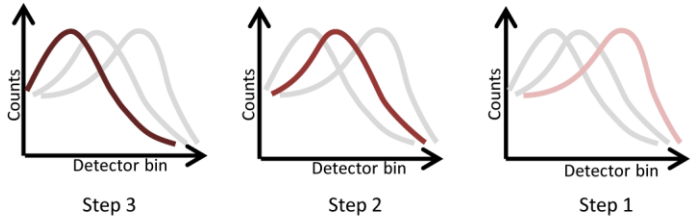
Detection of global range shift in sum profile

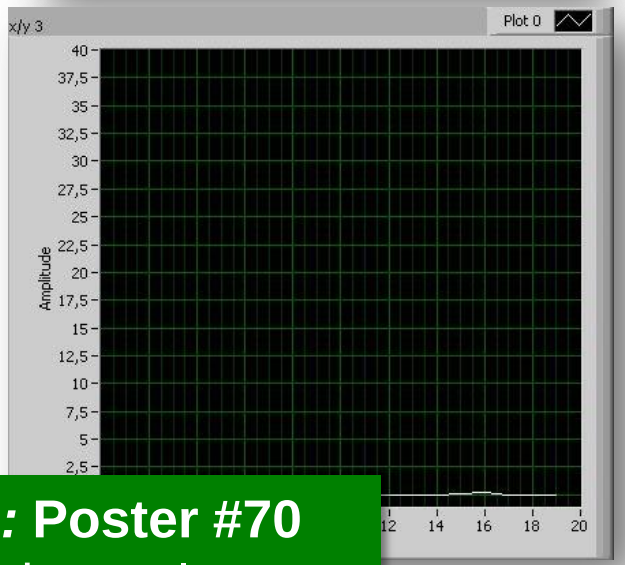
Slit camera in DS: Resolution of iso-energy layer





Iso-energy layer
resolved PGI profiles



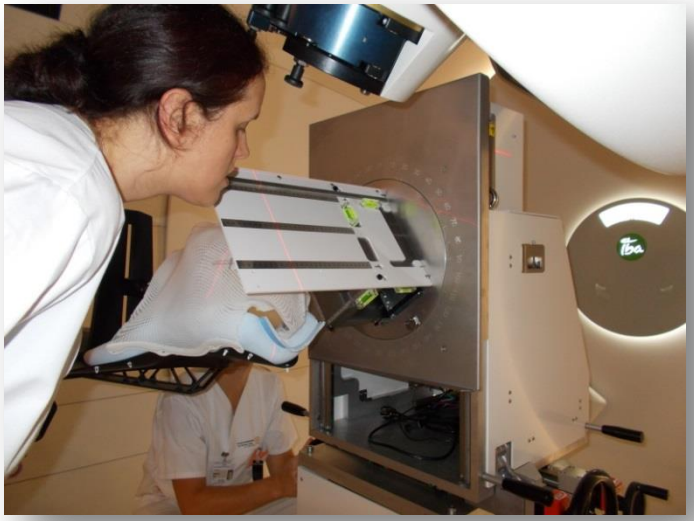


Resolution of iso-energy layers → Additional information

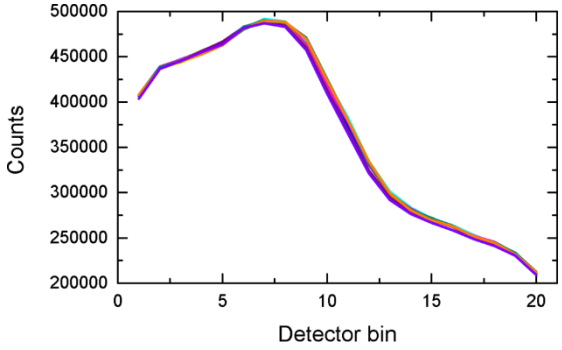
More details: **Poster #70**
Marlen Priegnitz et al.

Clinical study (PRIMA): Preparation

- **Intention:** Evaluate method, no influence for specific patients
- Workflow tests together with RTTs



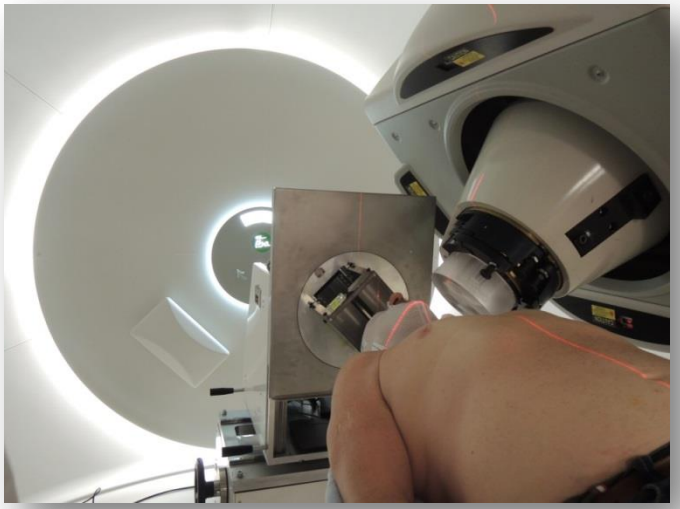
- Determination of positioning uncertainty:
  - Reproducibility: ≈ 1mm (2σ)
  - Absolute positioning relative to patient: ≈ 1mm



Clinical study: First patient

- **Worldwide first clinical application of PGI based range verification in August 2015**
- H&N patient, adenoid cystic carcinoma of left salivary gland
- DS, 3 fields, proton boost
- In-room control CT for dose recalculation

→ **Evaluation of inter-fractional changes**



	Fx 1	Fx 2	Fx 3	Fx 4	Fx 5	Fx 6	Fx 7
Slit open measurement during patient treatment	■	■		■	■	■	■
Background measurement during patient treatment (slit closed)			■				
Background measurement in water phantom (slit closed)		■	■	■	■	■	
Control CT + Dose reconstruction		cCT1		cCT2			cCT3

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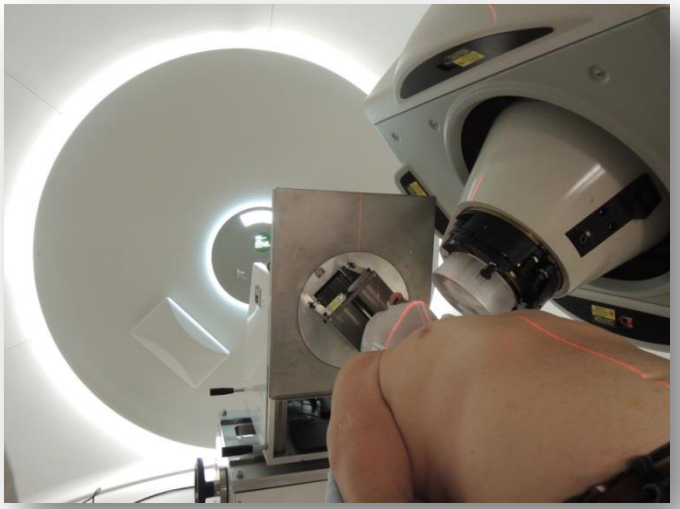
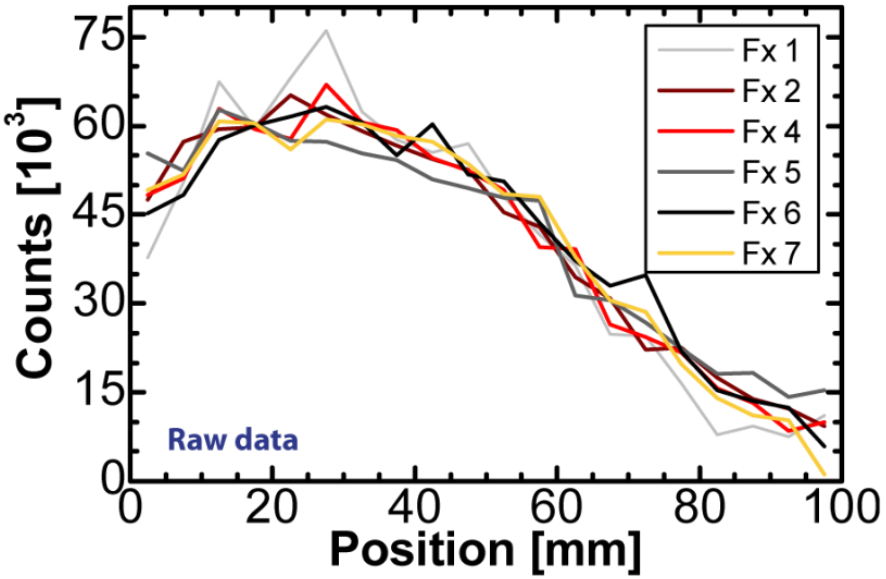
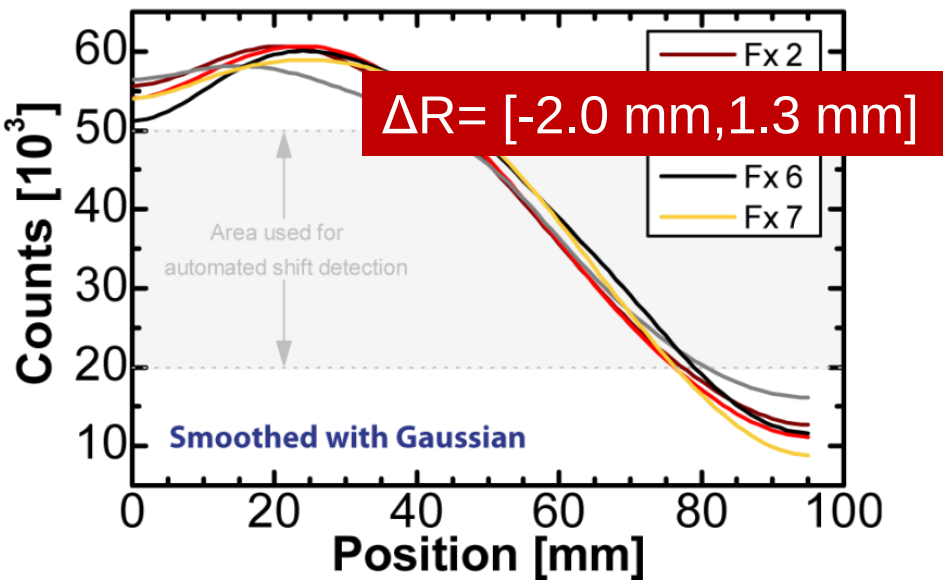
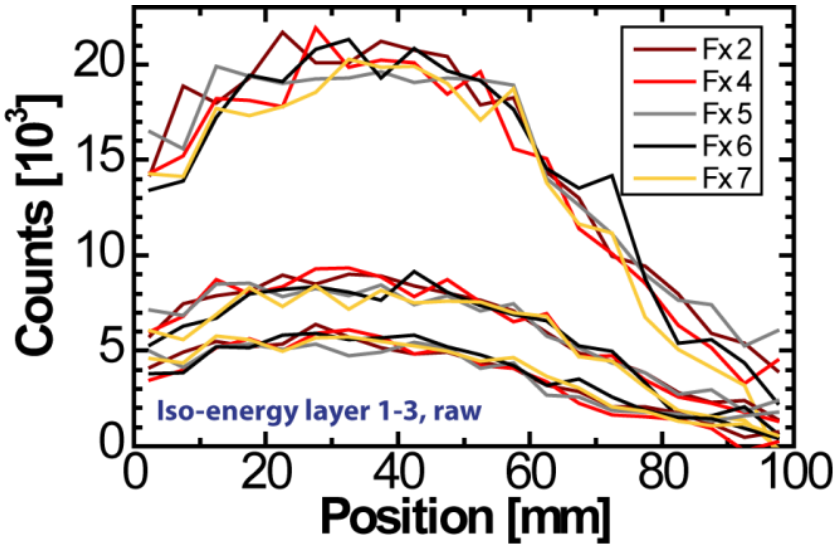
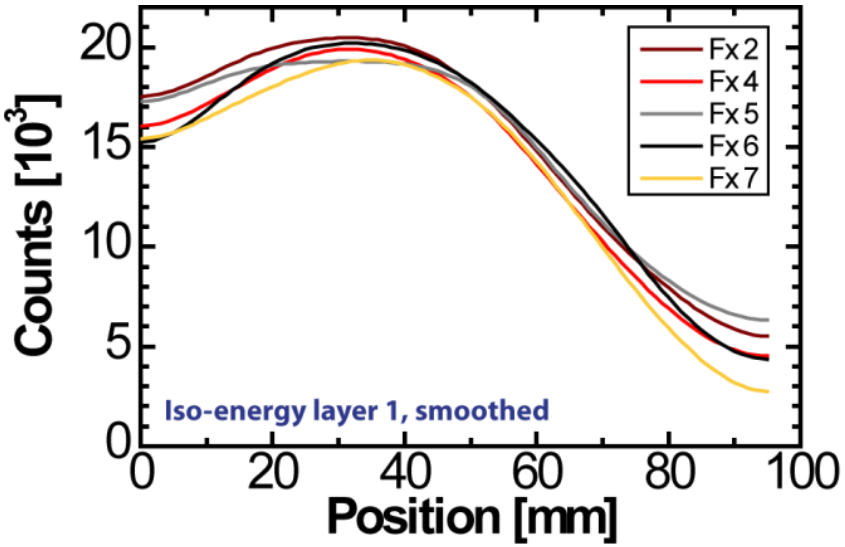


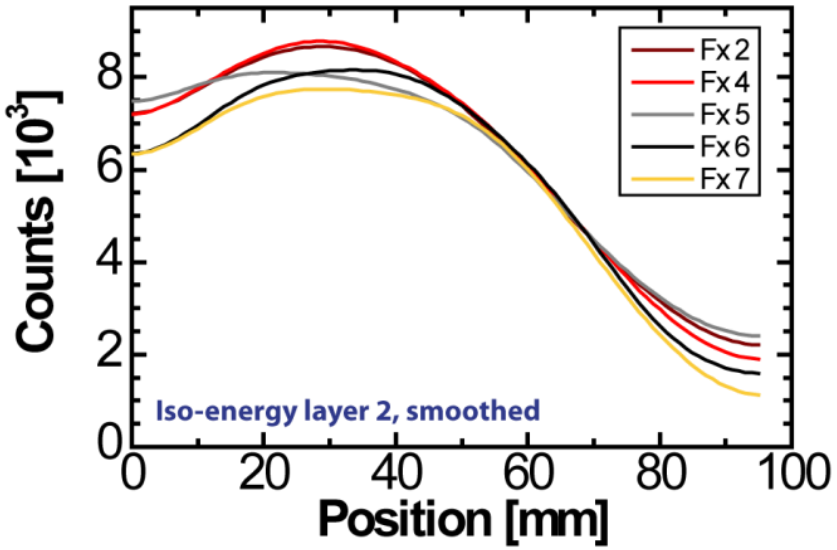


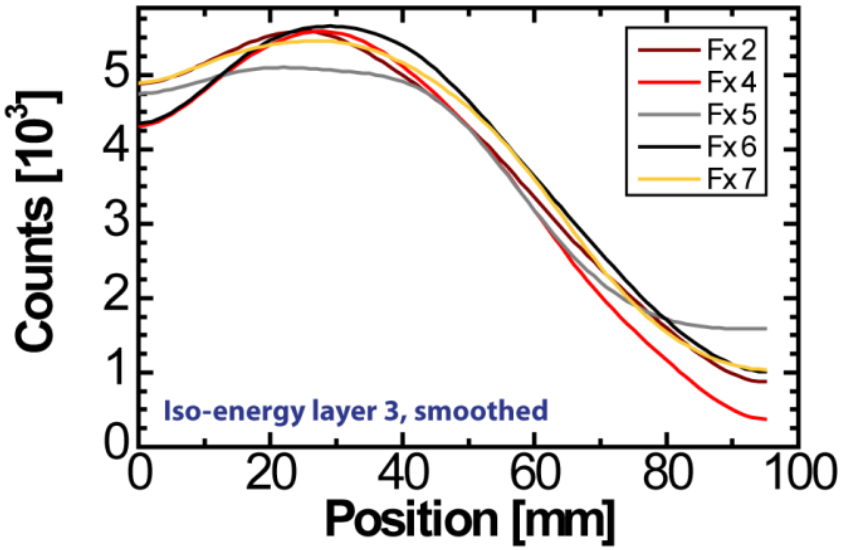


First patient: Iso-energy layers

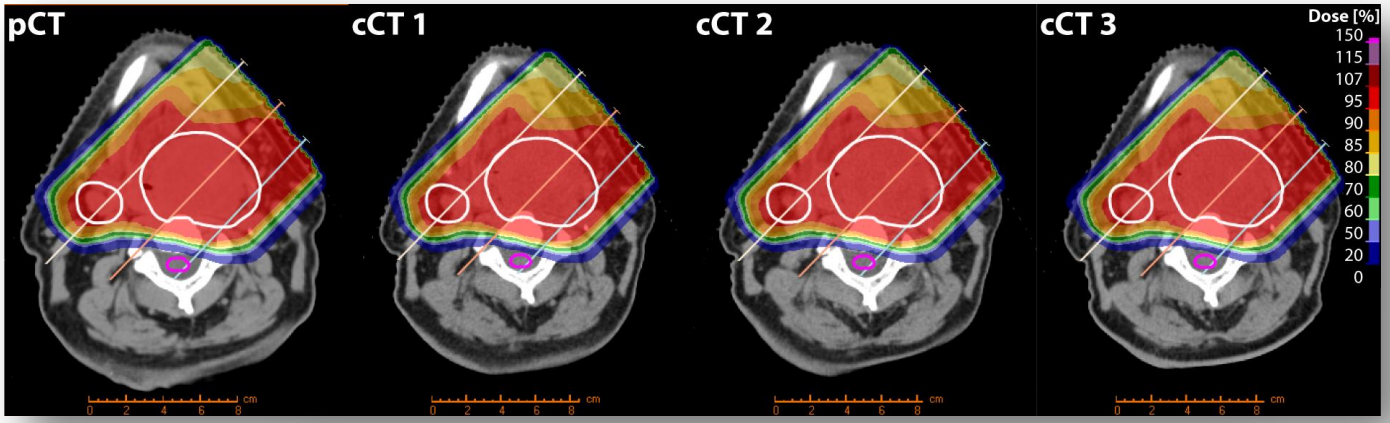


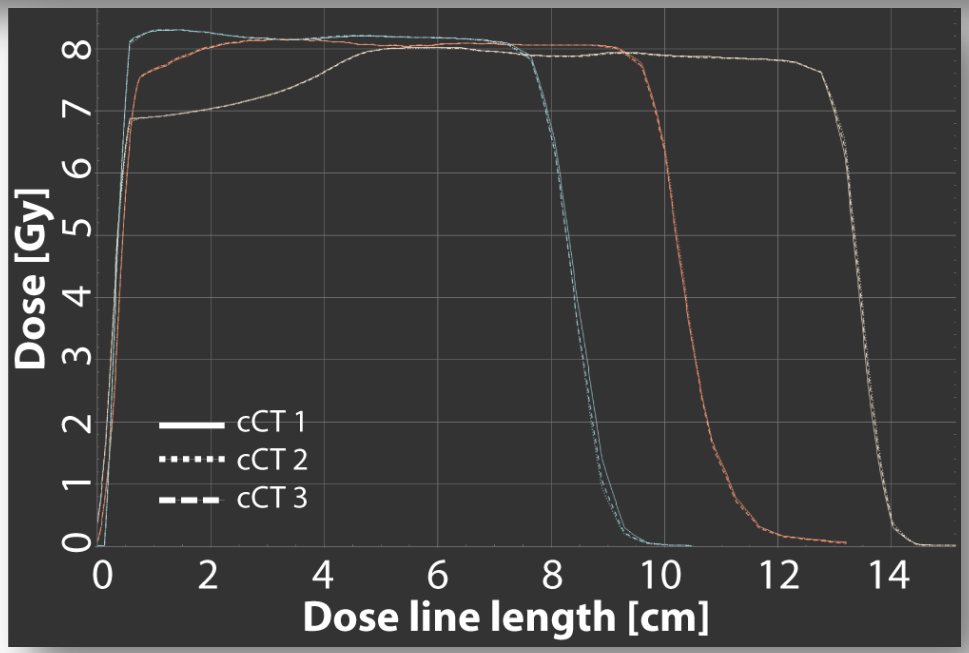






First patient: Control-CT based dose recalculation



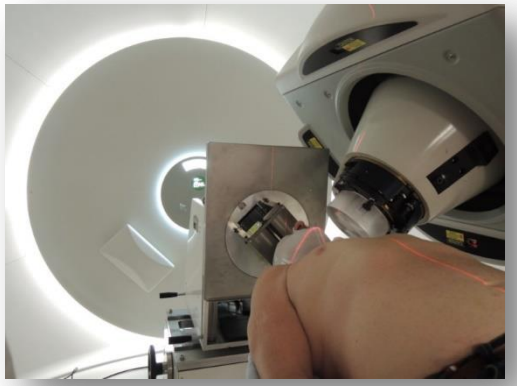


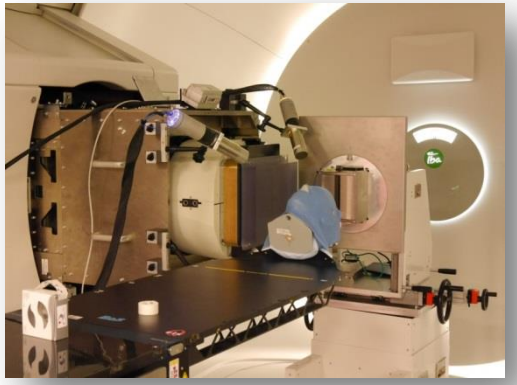
$\Delta R \approx \pm 1.5$ mm

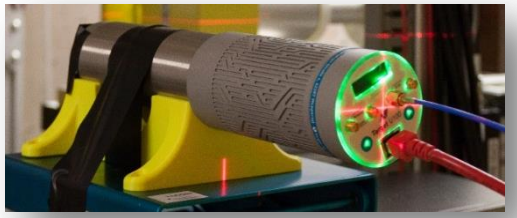
Control CT based dose recalculation in agreement with PGI measurement

Conclusion / Take Home

- **Worldwide first clinical application of a prompt gamma based range verification**
- **In Double Scattering:**
  - Application more challenging with limited local range information, but feasible
  - Global range shifts of a few millimeter detectable
  - Iso-energy layers can be resolved
- **In Pencil Beam Scanning:** Clinical application also possible, allowing absolute local range determination
- **Next Steps:**
  - Continuation of clinical study in DS+PBS
  - Phantom study comparing slit camera capability in PBS and DS mode
  - Clinical evaluation of prompt gamma timing (PGT)







Interdisciplinary team

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Guntram Pausch
Christian Golnik
Theresa Werner
Thomas Kormoll
Marc Berthel

See also Poster #70

Marlen Priegnitz

Julia Thiele et al.
Stefan Menkel
Wolfgang Enghardt
Mechthild Krause
Michael Baumann

Julien Smeets
Francois Vander Stappen
Lucian Hotoiu
Guillaume Janssens
Damien Prieels

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