OncoRay – National Center for
Radiation Research in Oncology, Dresden

# Prompt-gamma based range verification with a slit camera:

# Sensitivity and first clinical experiences

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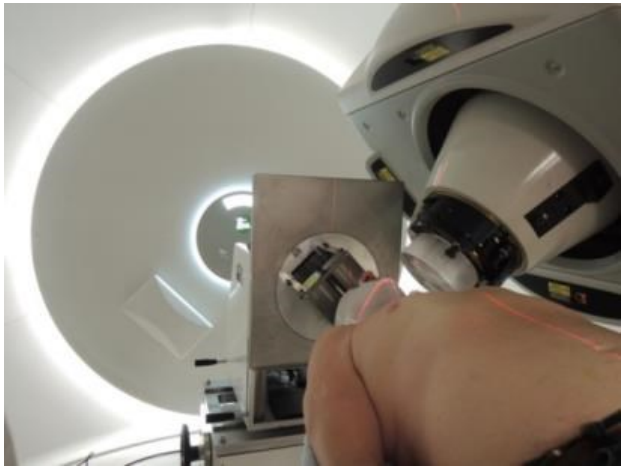
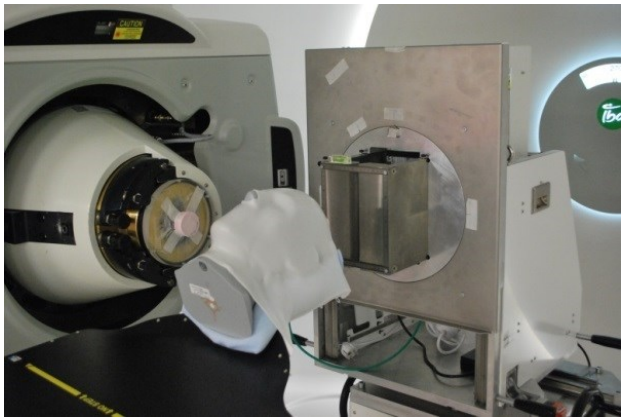
# Outline

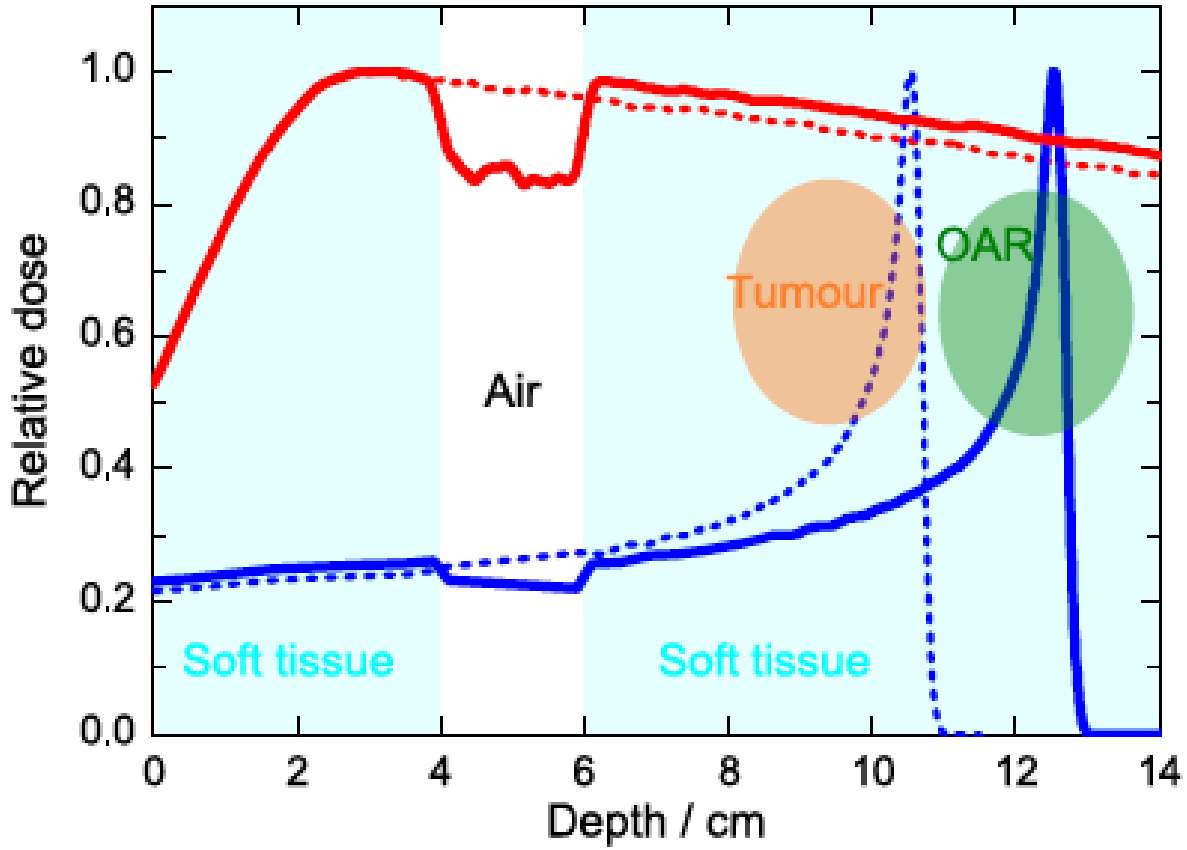
1. First clinical application in double scattered PT



2. Shift detection sensitivity in a clinical scenario



# Range uncertainties in particle therapy




**Dose distribution very vulnerable to range uncertainties**

**→ Sub-optimal plans have to be chosen**

Image: Annika Jakobi

# Range uncertainties in particle therapy


3.5 % + 2 mm

MDACC, Loma Linda

Dresden

MGH, Boston

University of Florida

Aim

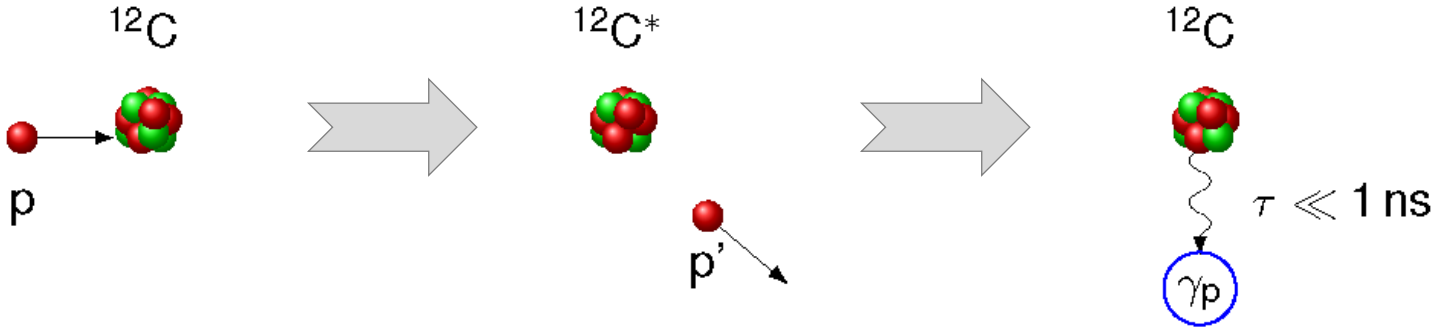
Range in mm added to the prescribed range

Prescribed range in cm

# Range uncertainties in particle therapy

# Prompt gamma-based range verification

**Prompt gammas:** Resulting from nuclear interactions of beam with tissue




## Properties

- Strong spatial correlation of gamma emissions with dose
- Emission spectrum depends on the proton energy (penetration depth)
- Detection time of prompt-gammas decodes penetration depth

## Options for range verification

- Prompt gamma imaging (PGI)
- Prompt gamma spectroscopy (PGS)
- Prompt gamma timing (PGT)

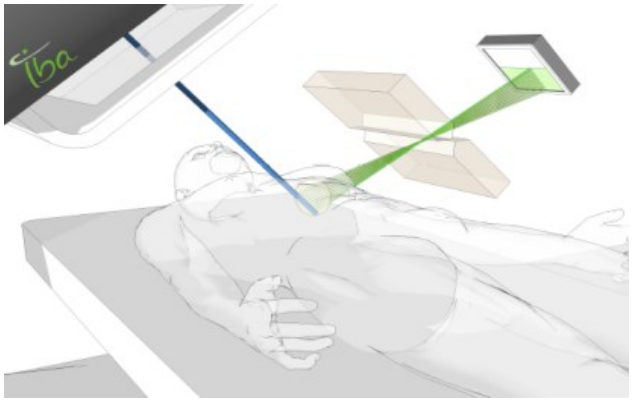
# The PGI slit camera project

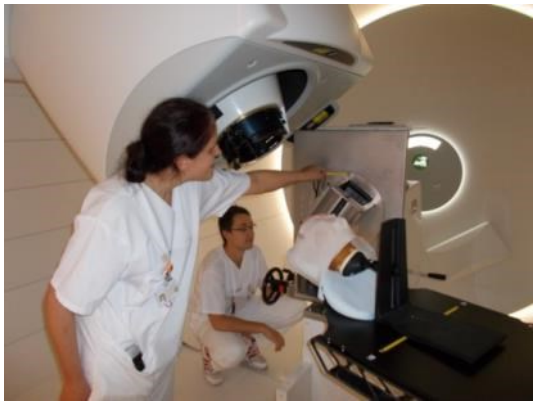
## Background:

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

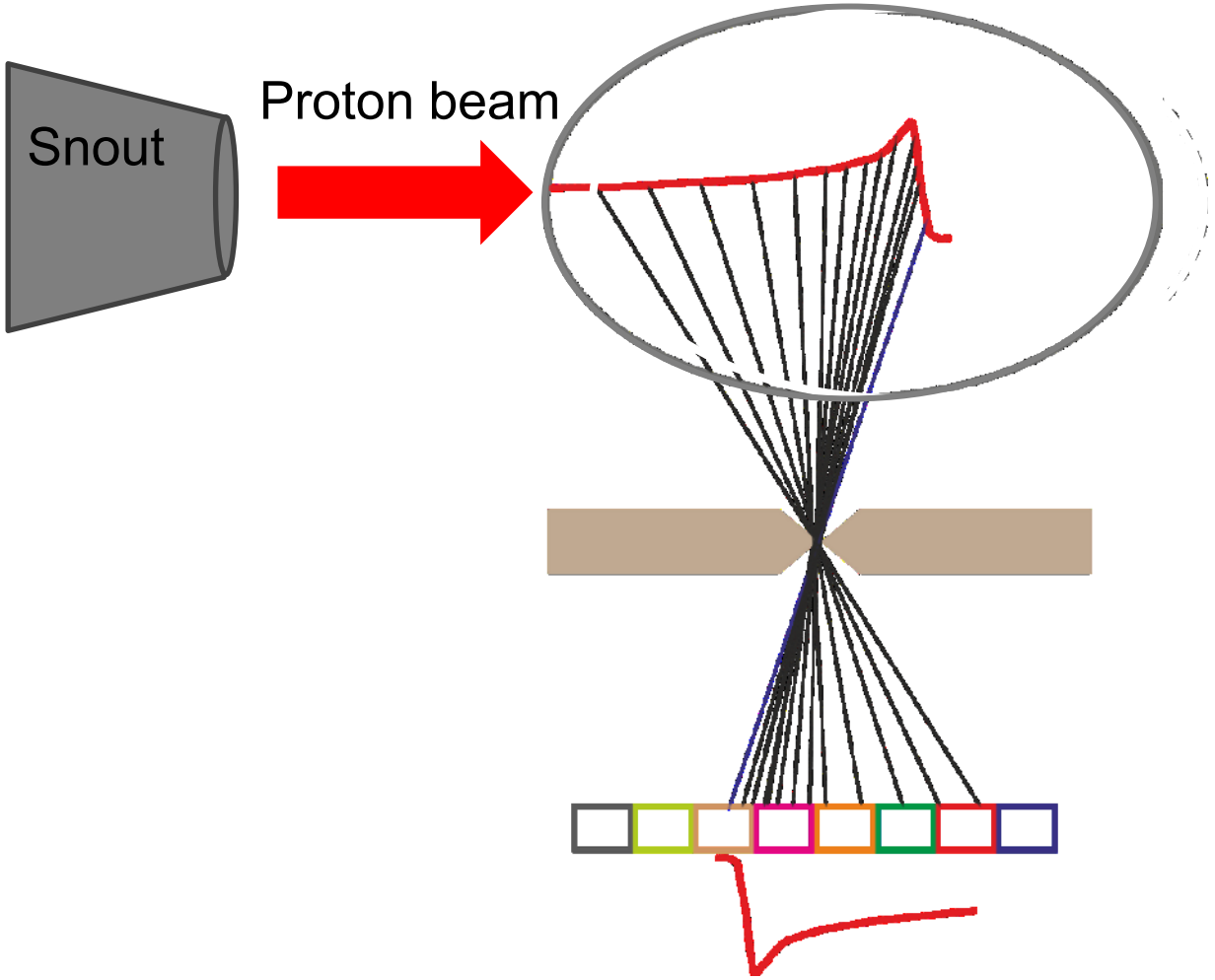
## Goals:

- Evaluation of the benefit under clinical conditions

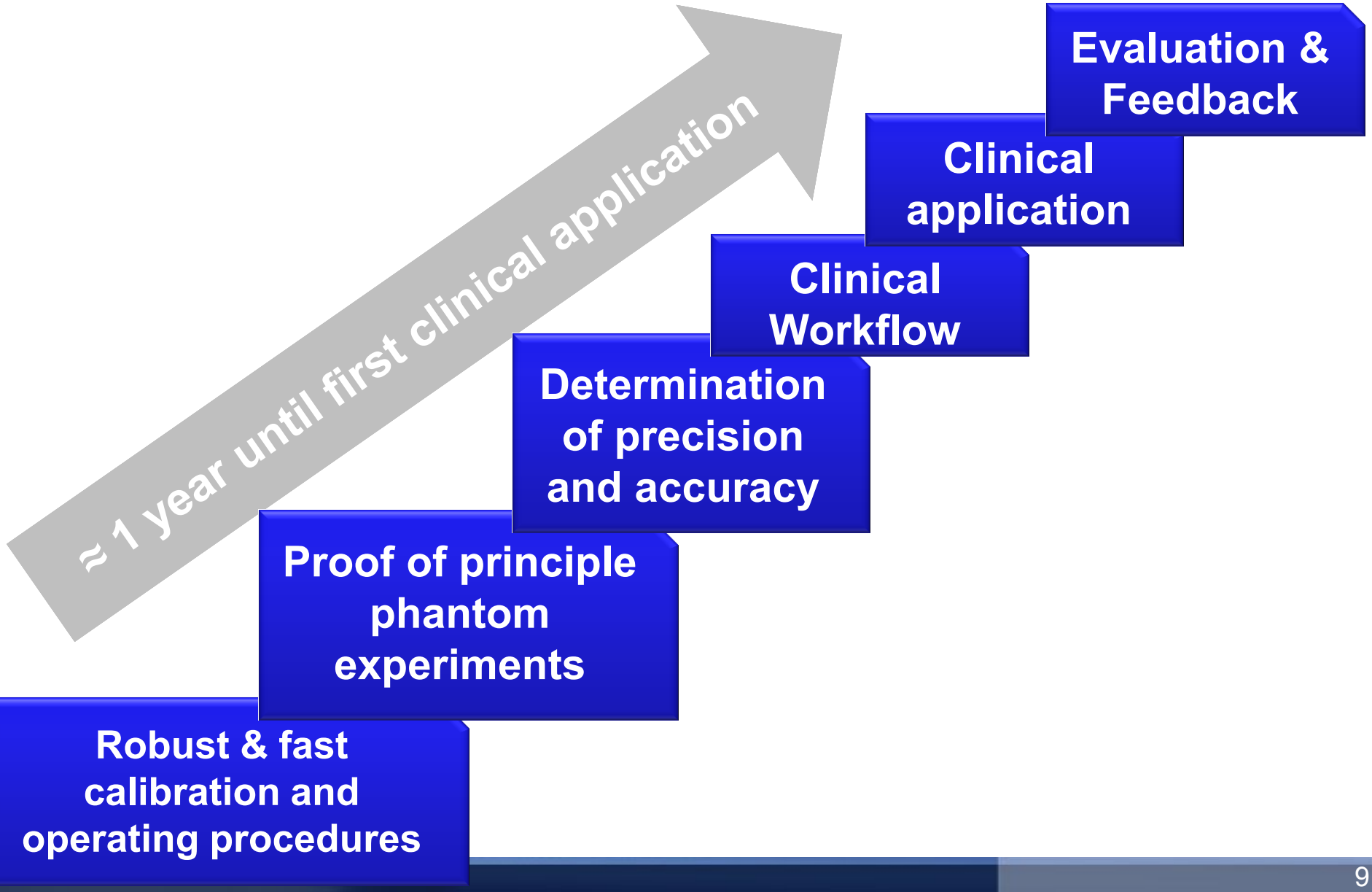




# Principle of the PGI slit-camera

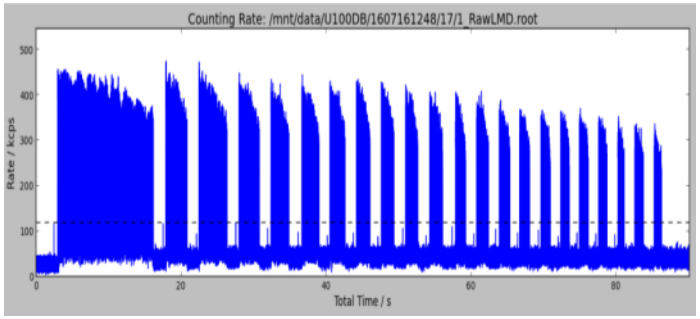


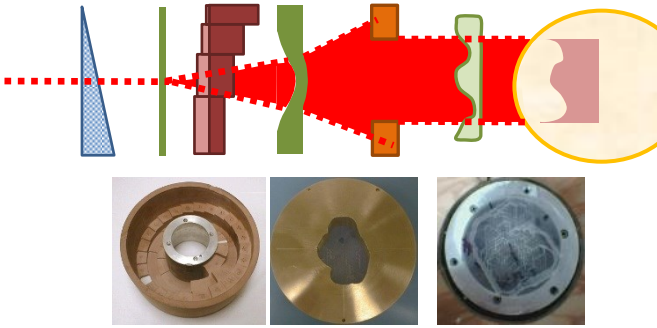
# Translational research



# Comparison of PBS and DS application

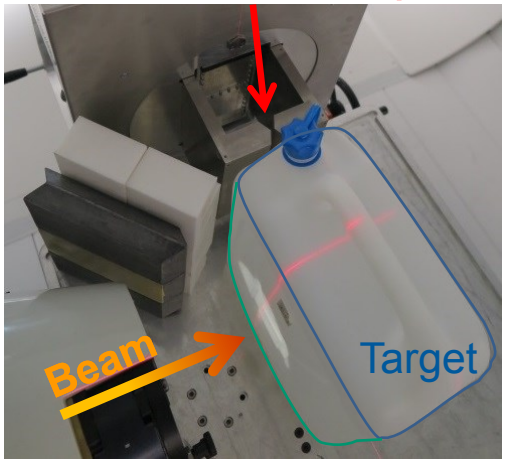
| | Application in PBS | Application in DS |
|---|---|---|
| Absolute range analysis (via simulation) | ☺ | ☹ (not yet available) |
| Inter-fractional range deviation analysis | ☺ | ☺ |
| Information per | Spot | Whole field or iso-energy layers |
| Challenges | | Increased neutron background → Background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



# Slit camera in DS: Background subtraction

Collimator slit open

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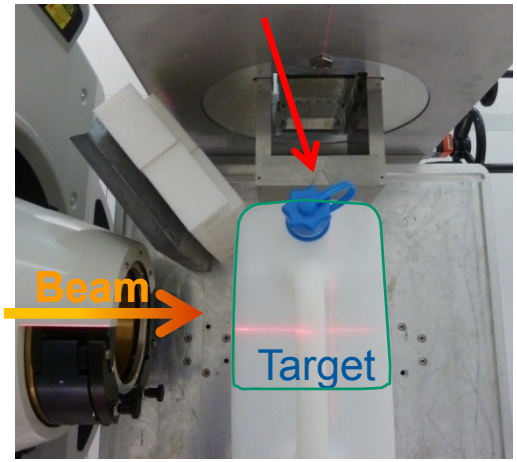
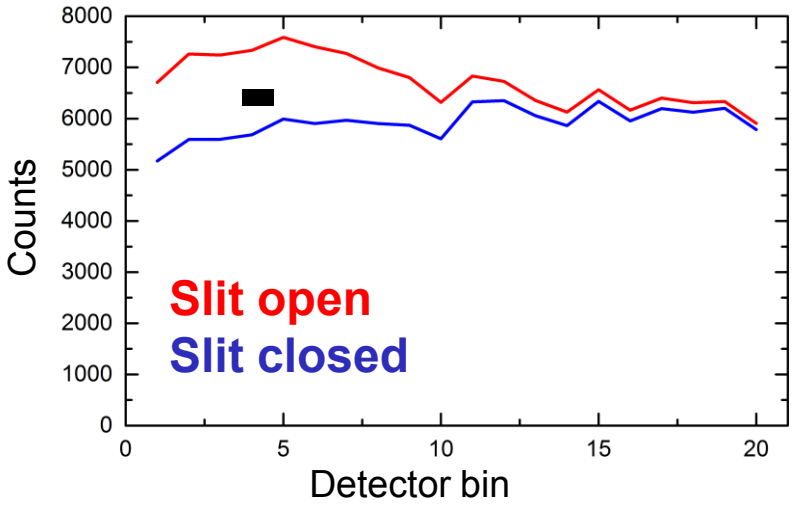
Collimator slit closed

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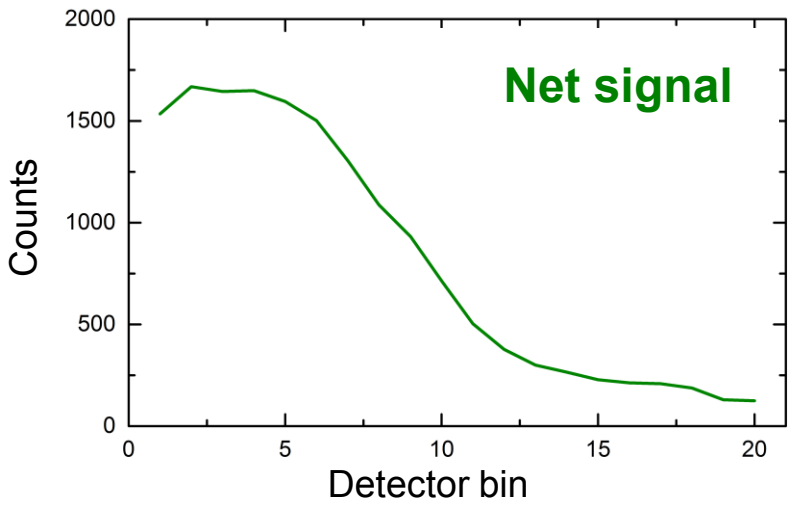
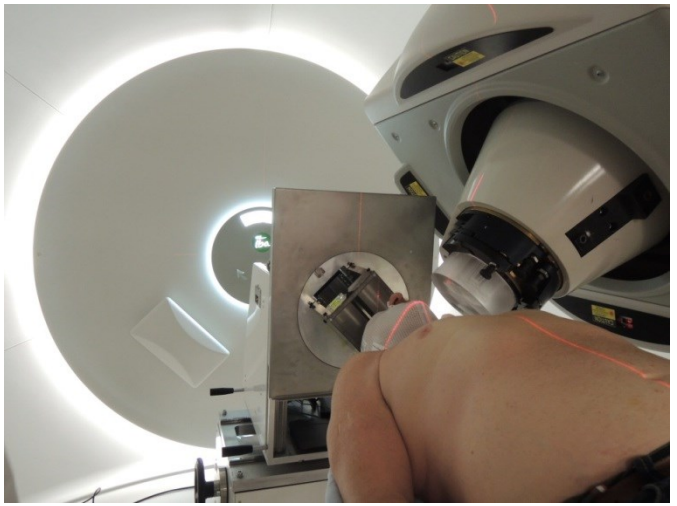
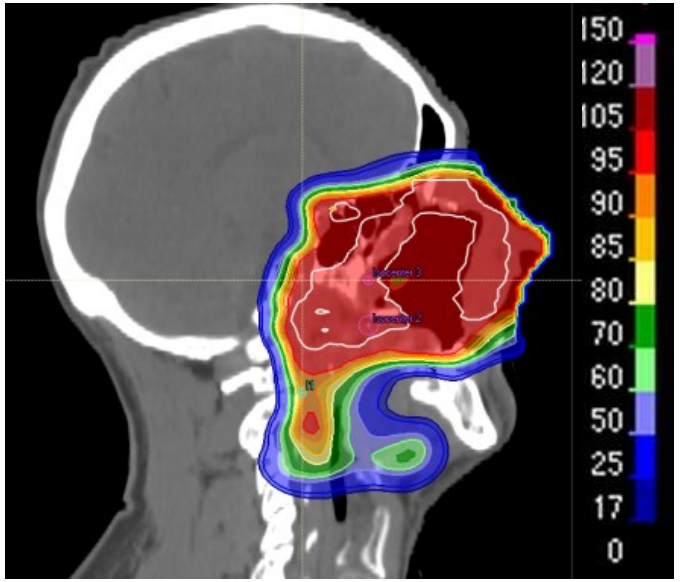


# Clinical study: First patient

- **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**





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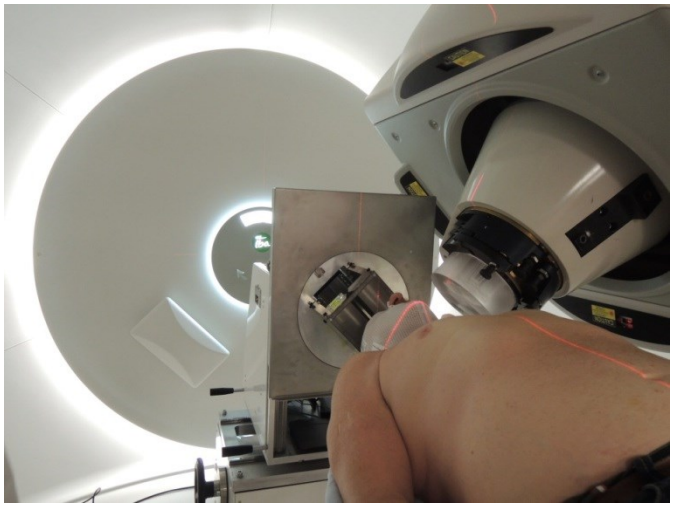
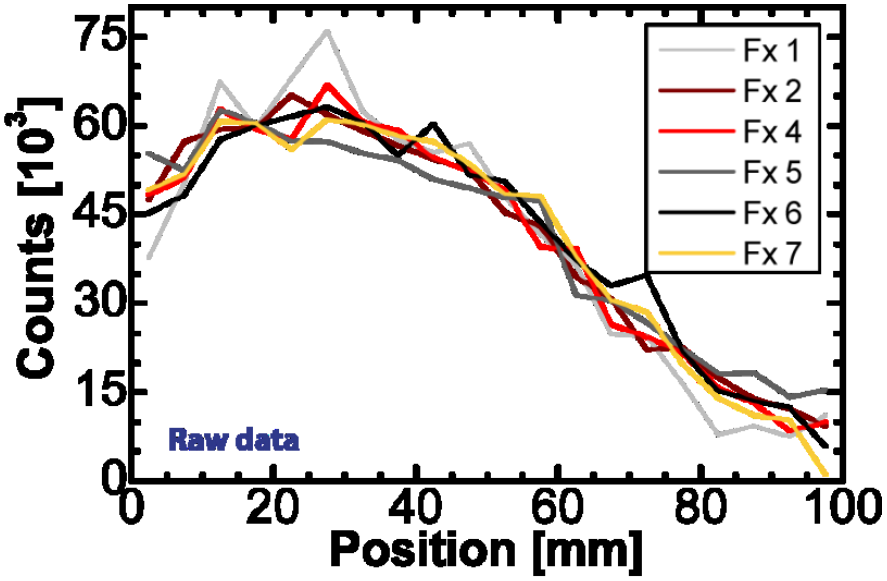
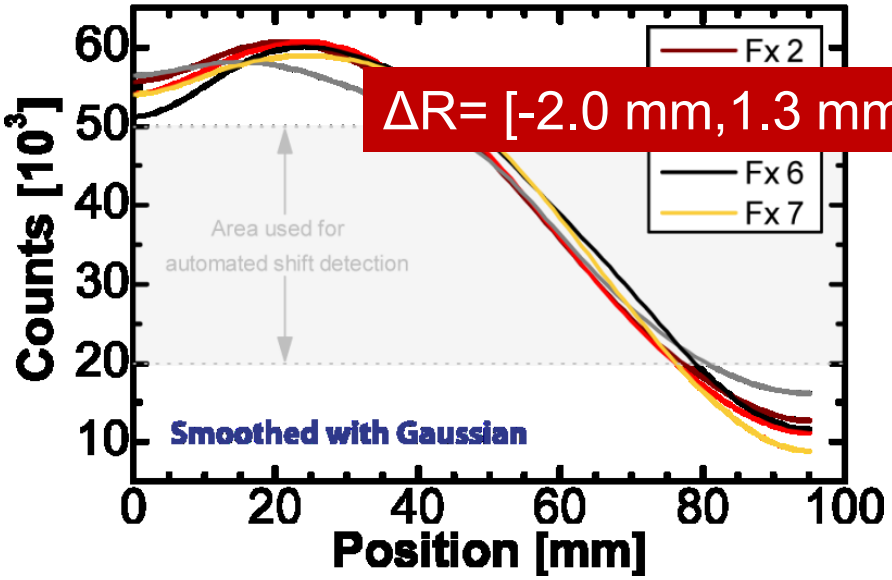
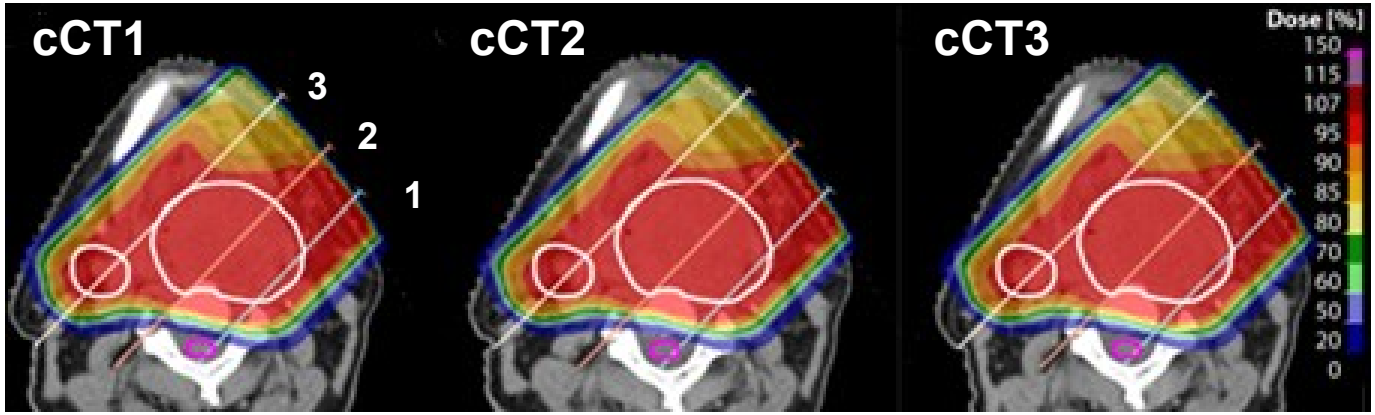
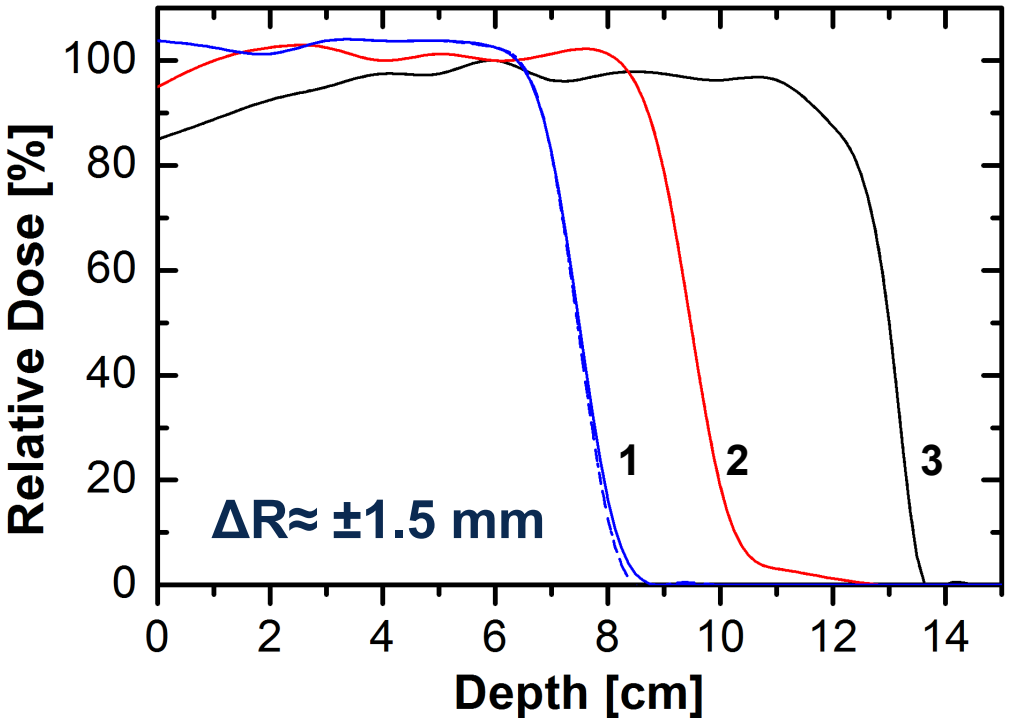




# First patient: Dose recalculation on control CT

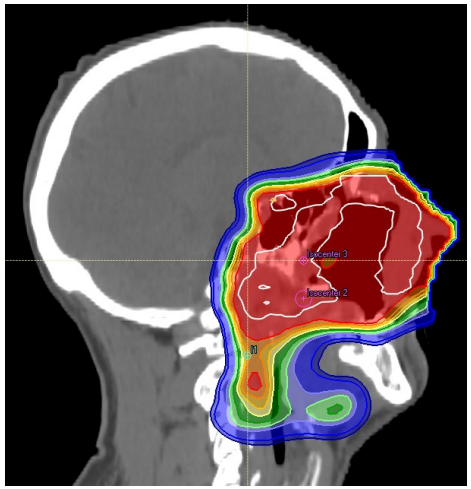


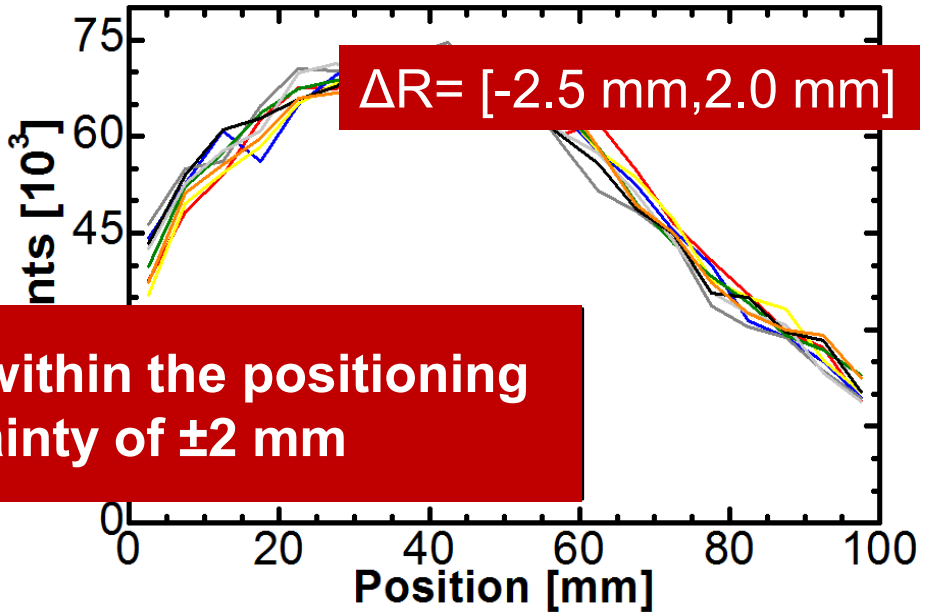

**Control-CT-based dose recalculation in agreement with PGI measurement**

# Clinical study: Patient #2 in DS

| | Pat. #1 | Pat #2 |
|---|---|---|
| Range + Modulation in cm | R =13.5<br>M =10.7 | R =10.2<br>M = 9.8 |
| Gantry angle | 45° | 60° |
| Monitored fractions | 6 | **8** |
| Monitoring time span | 1.5 weeks | **3 weeks** |
| Control CTs | 3 | **8** |

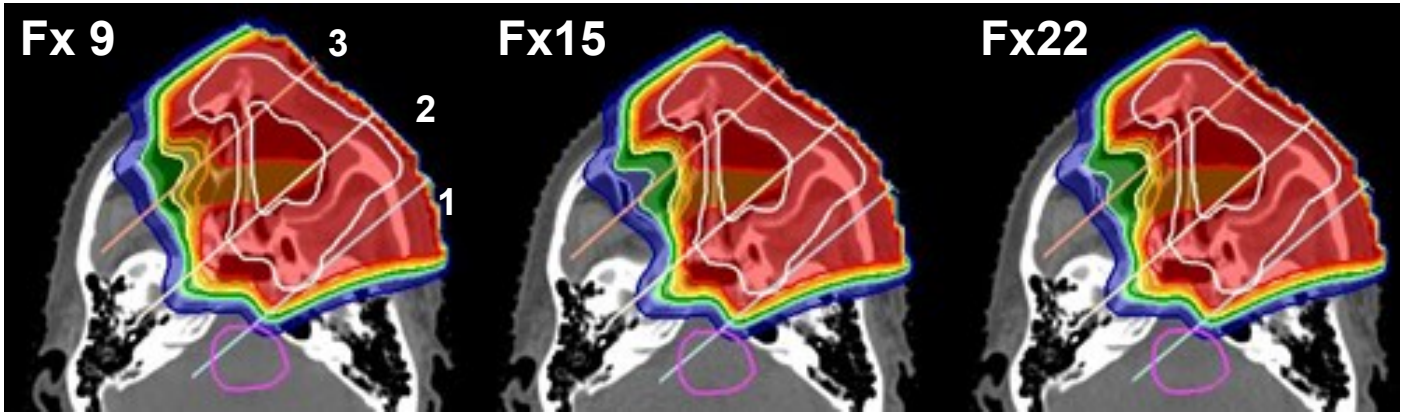


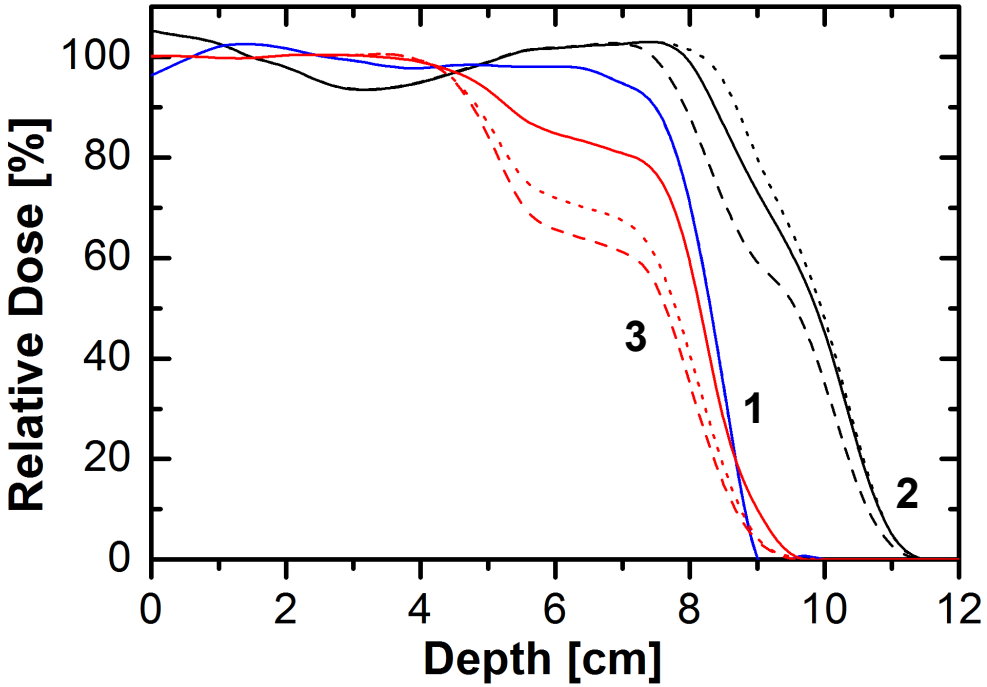
**Patient 2**




**Shifts mostly within the positioning uncertainty of ±2 mm**

# Clinical study: Patient #2 in DS




**Mix of over- and undershoot: Not detected with slit-camera**

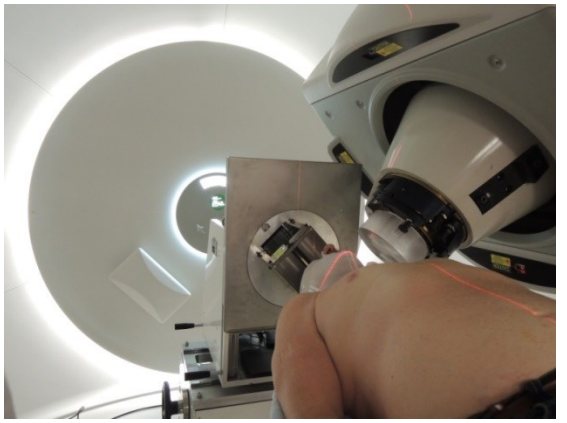
# Summary: PGI range verification in DS

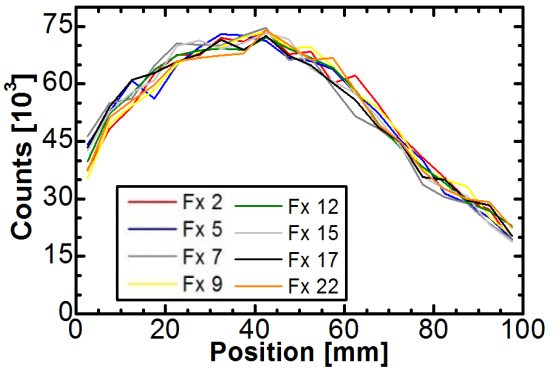
- **PGI-based range verification also possible in double-scattered proton therapy**
- Global and severe shifts can be detected
- Only interfractional comparison possible
- Local shifts can
  - Become indistinct in sum signal (washed out)
  - Compensate each other

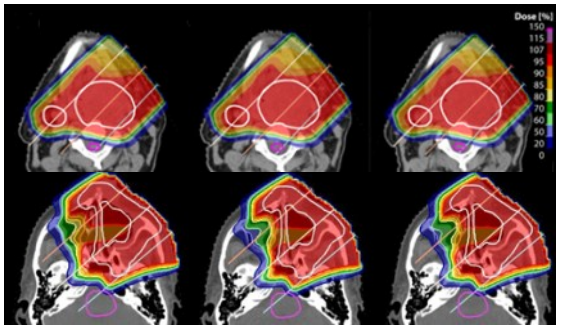
→ **Identification of severe treatment errors rather than localized anatomical changes**

- Decision to continue clinical PGI study with PBS when available in Dresden

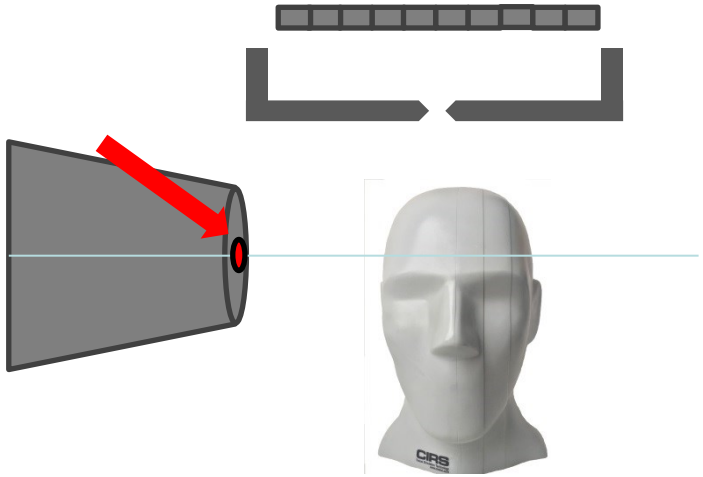
**Still missing:**
**Comprehensive evaluation of shift detection sensitivity**

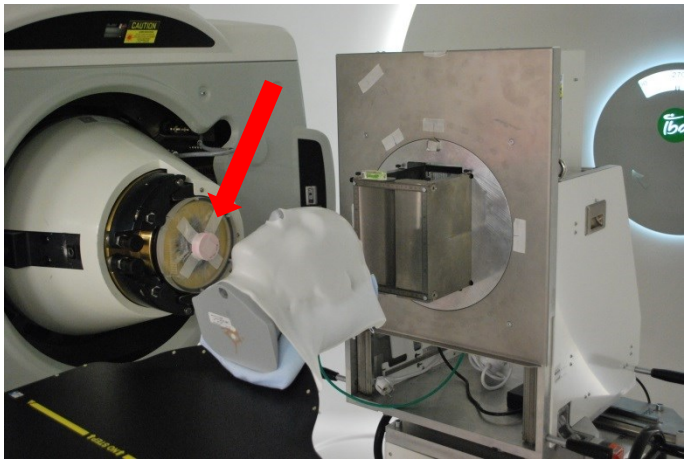


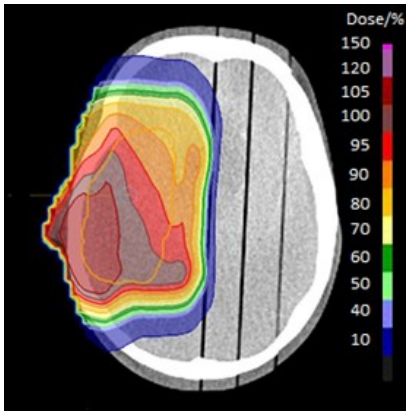


# Shift detection sensitivity: Experimental setup



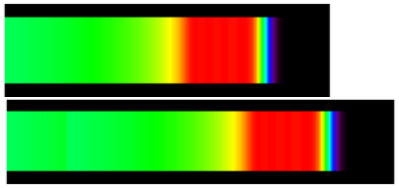





- Anthropomorphic head phantom (CIRS)
- Three treatment plans for same target volume:
  PBS-IMPT, PBS-SFUD, DS
- 2 Gy per plan → 1 Gy for monitored field
- **Introduced shifts:**

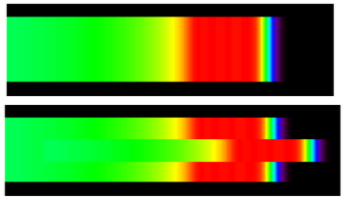
Calculated dose

**Global** range shift
(5mm, 7mm 10mm)



Calculated dose

**Local** range shift
(4 mm, 7mm, 10 mm)



# Shift detection sensitivity:Spotwise evaluation

Treatment plan

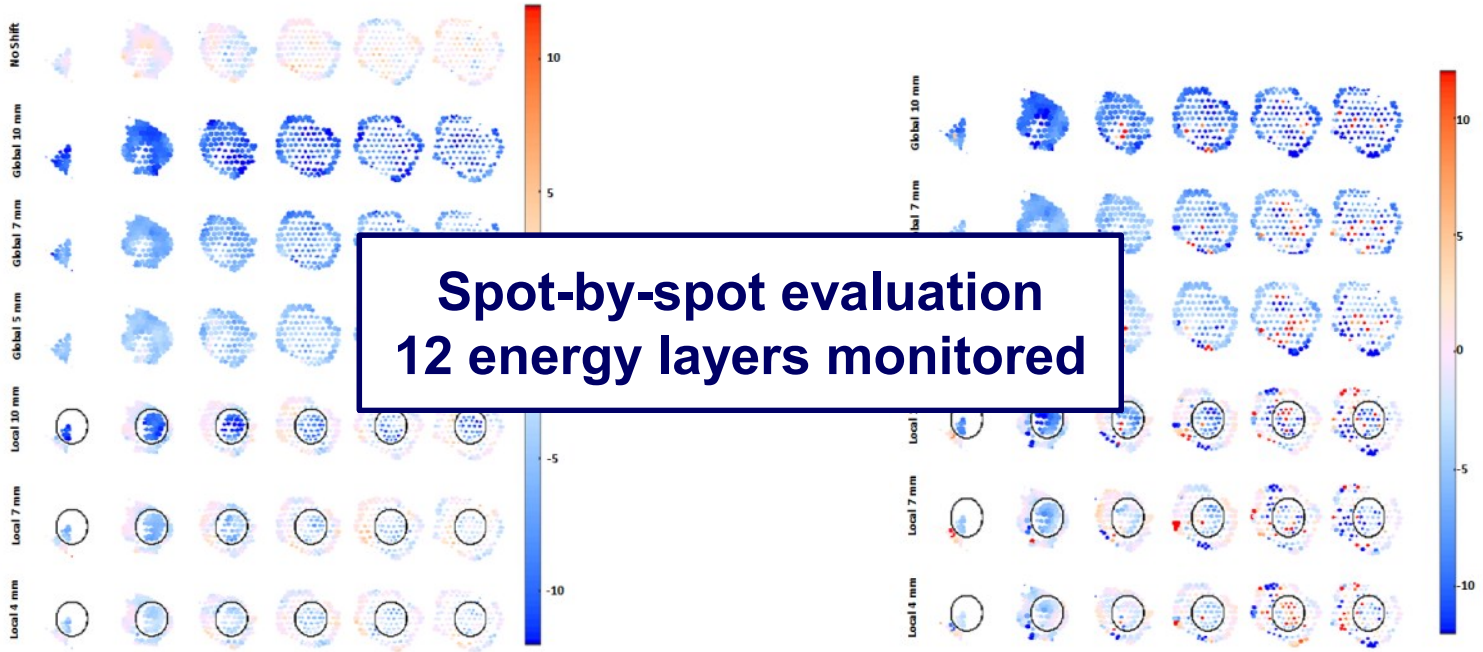
**Simulated** reference profile **without shift**

**Measured** prompt-γ profile **with** introduced **shift**

**Measured** reference profile **without shift**

„Absolute shift“

„Interfractional shift“




**Spot-by-spot evaluation**
**12 energy layers monitored**

# Absolute shift: Measurement vs. Simulation

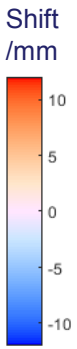
## Spot wise shift detection: One example energy layer

Measurement vs. simulation without shift



Global shift 10 mm

Local shift 10 mm




## Average shifts of all energy layers

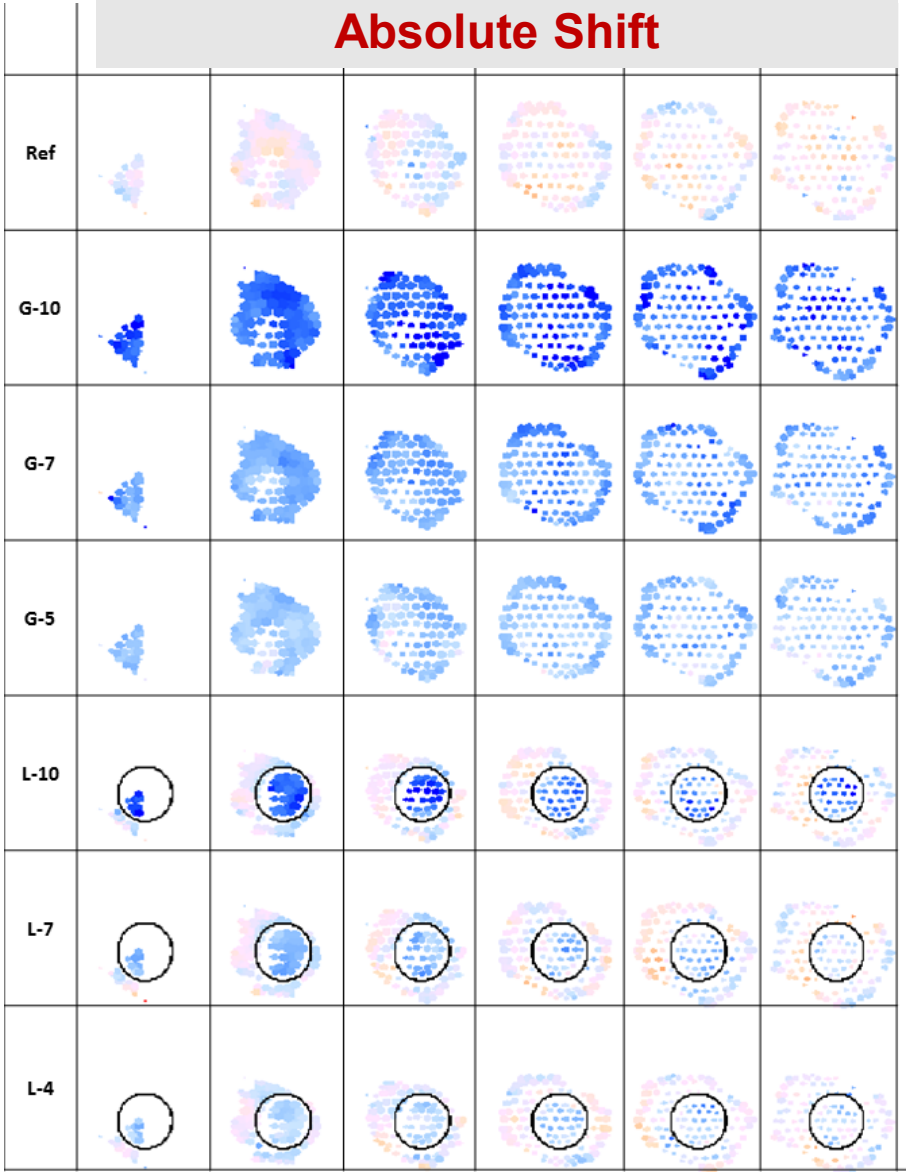
Simulation accuracy 1 mm

Shift accuracy ≤ 1 mm

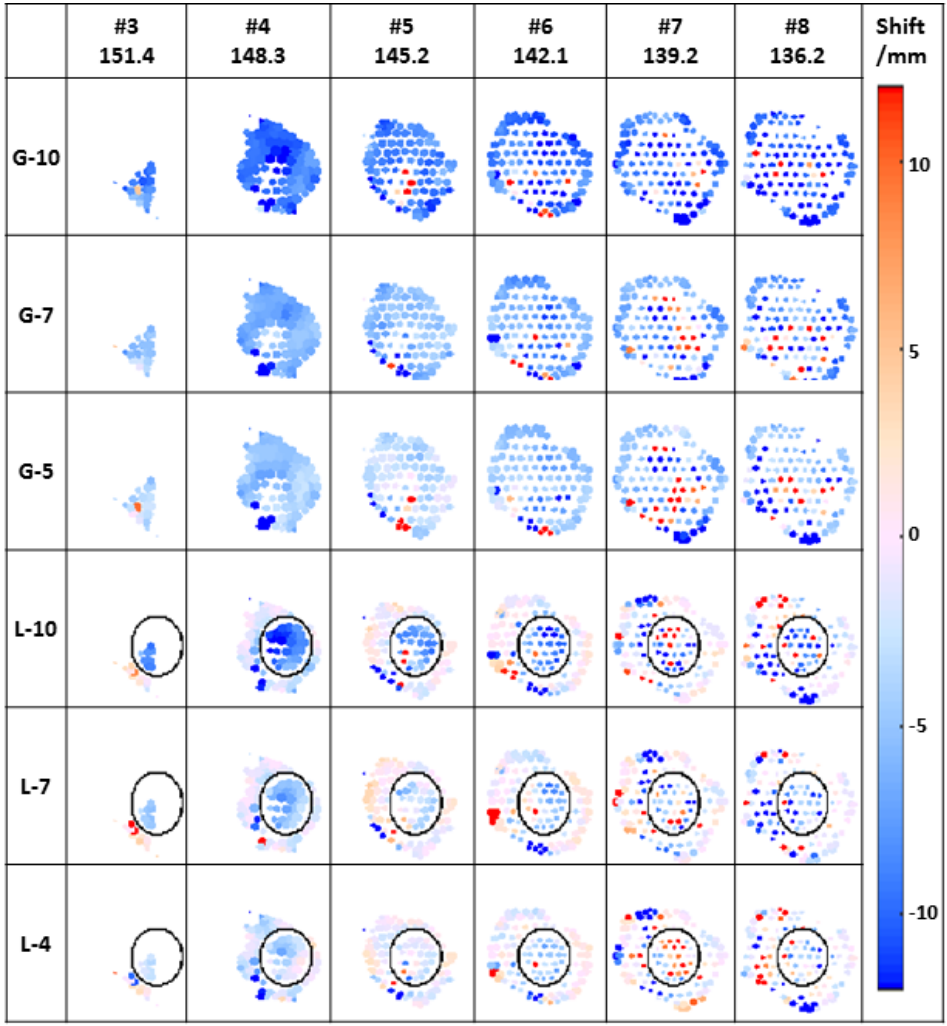
Shift accuracy ≤ 3 mm

# Absolute vs. interfractional shift

## Absolute Shift

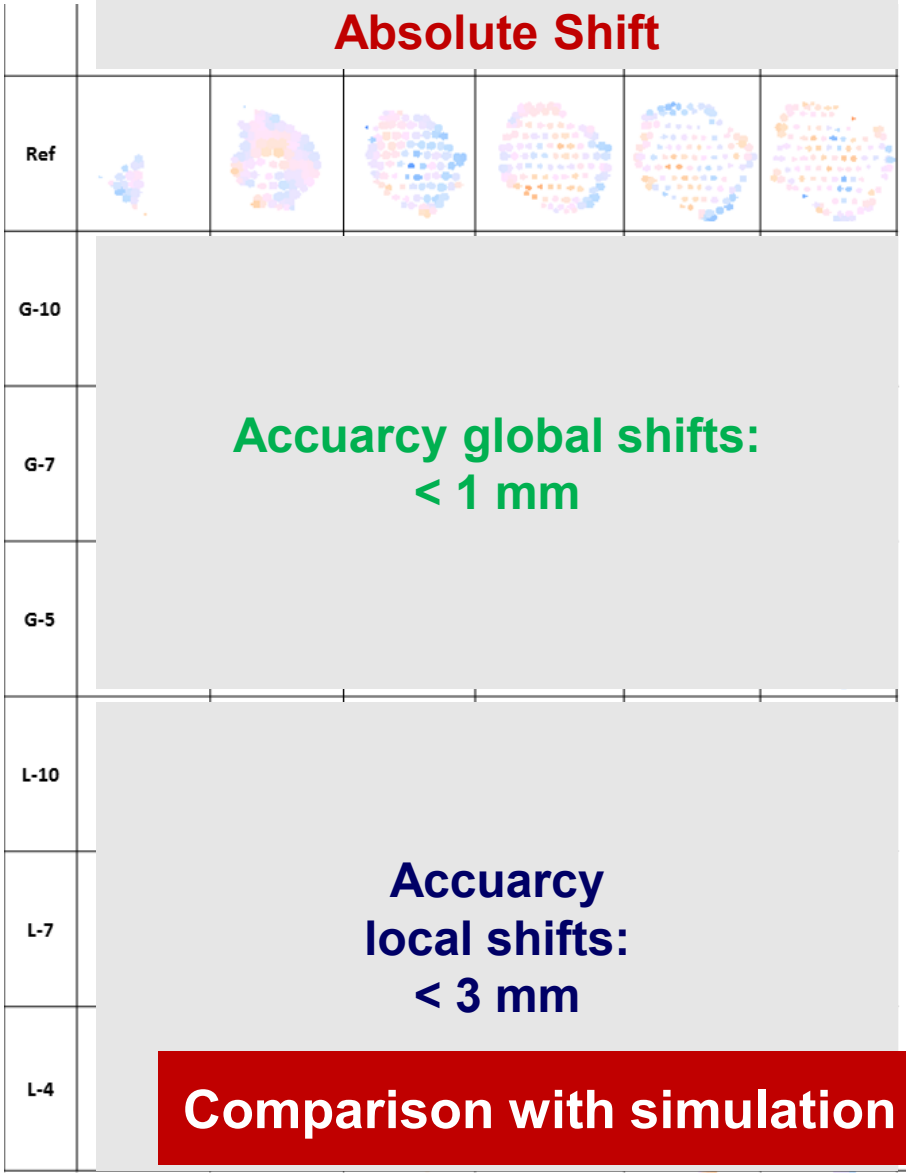



## Interfractional Shift



# Absolute vs. interfractional shift

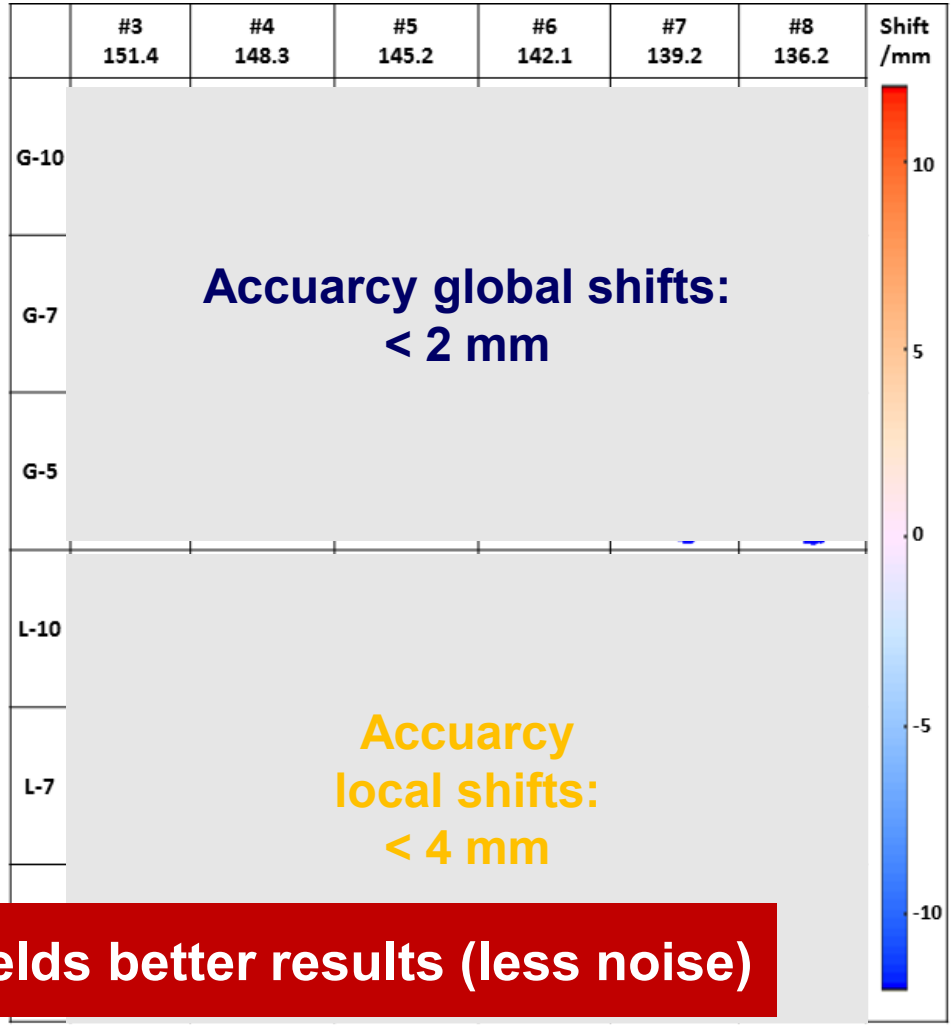
## Absolute Shift




**Accuarcy global shifts:**
**< 1 mm**

**Accuarcy**
**local shifts:**
**< 3 mm**

## Interfractional Shift

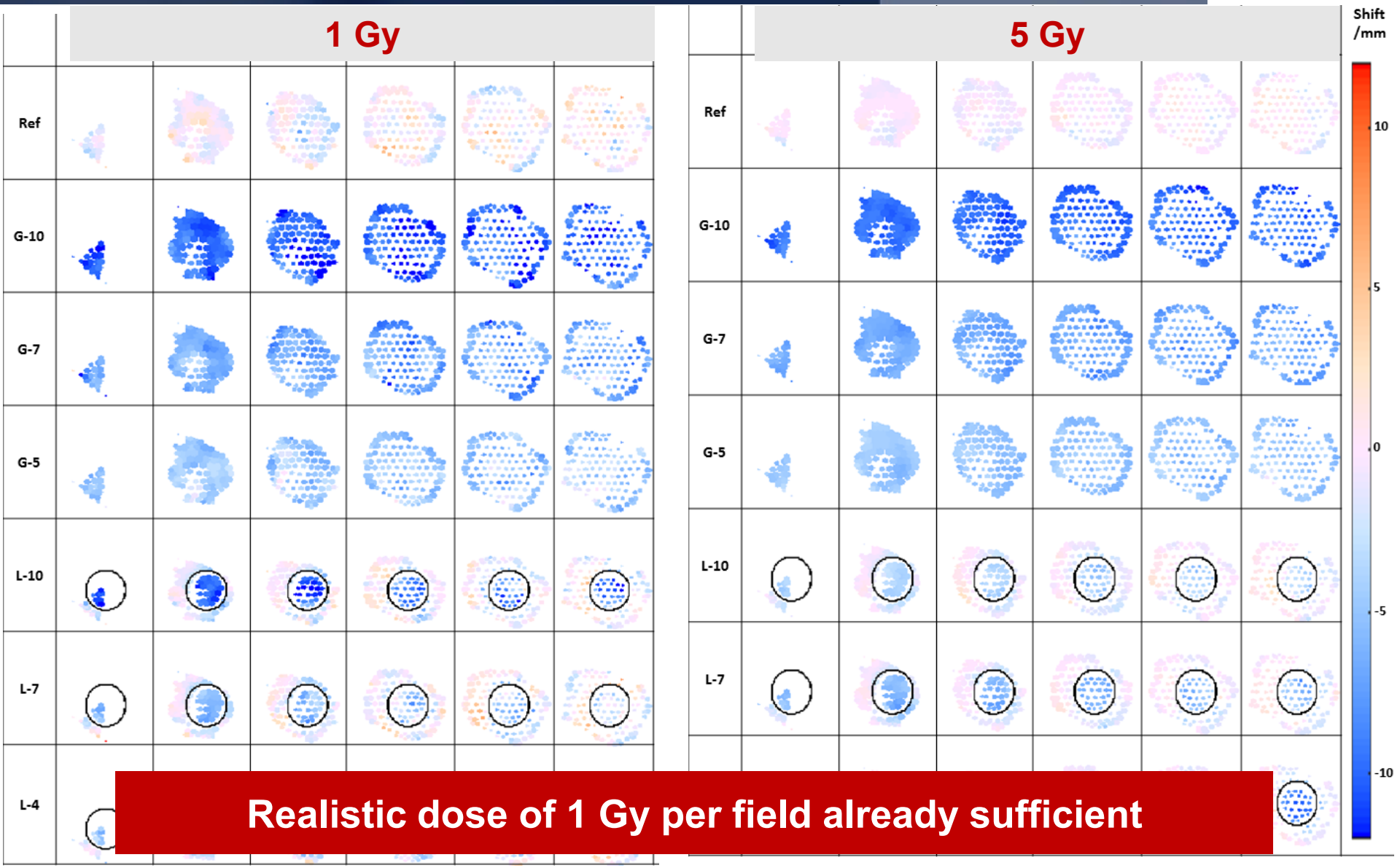



**Accuarcy global shifts:**
**< 2 mm**

**Accuarcy**
**local shifts:**
**< 4 mm**

**Comparison with simulation yields better results (less noise)**

# Dose per field: 1 Gy vs. 5 Gy




**Realistic dose of 1 Gy per field already sufficient**

# Shift detection sensitivity in PBS: Summary

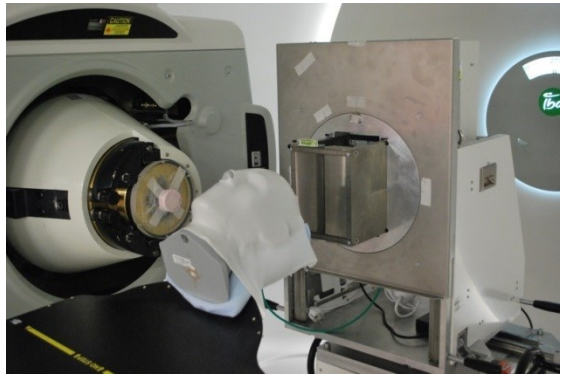
**Shift detection sensitivity in PBS:**

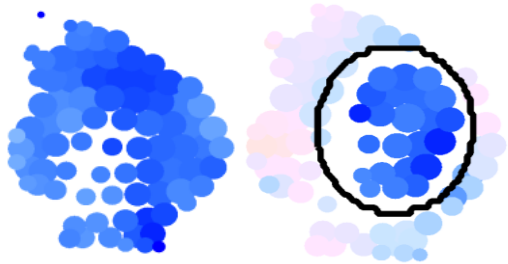
- **Shift detection of local and global shifts possible under realistic clinical conditions**
- Spot-by-spot evaluation
- Comparison against “treatment plan”

→ **Valuable accuracy & high sensitivity**

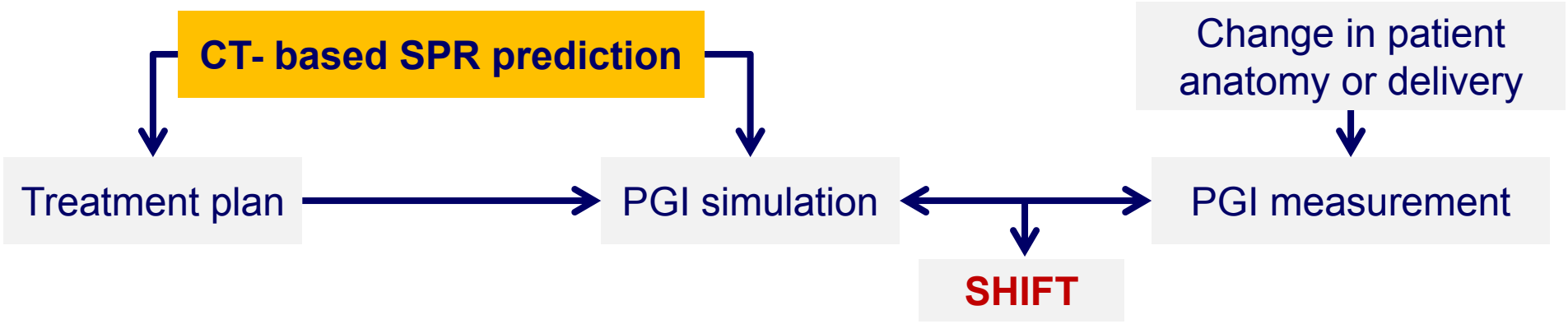
→ **Application promising**

- **Outlook:**
  - More sophisticated clustering method





# Range verification vs. Range prediction

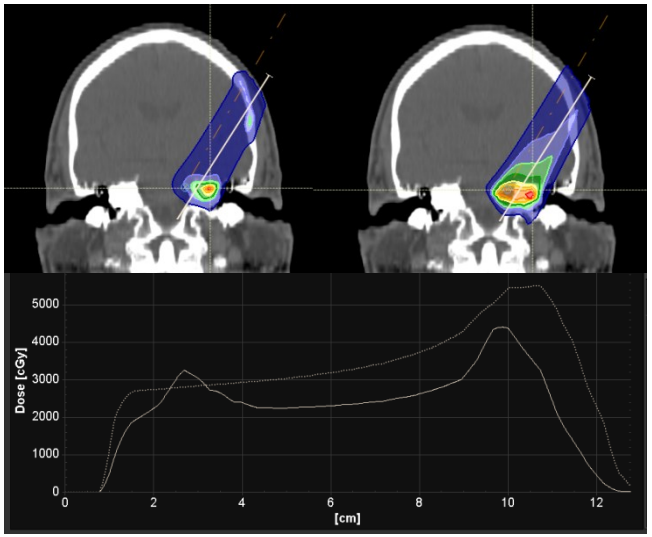



**CT-based SPR prediction important for PGI-based range prediction**

→ Consistent prediction for treatment plan and PGI simulation

→ High accuracy of SPR prediction

→ cf. Dual-energy CT




With courtesy of
M. Pinto, R. Nillson, E. Traneus, K. Parodi

**Both needed: Accurate range prediction + Range verification**

# Outlook: PGI range verification in Dresden

**Upgrade of PGI camera trolley**

- Absolute positioning to room isocenter, not relative to lasers or surface surrogates

→ **Overall increased accuracy of range verification**

**Systematic application in clinical PBS treatments**

- 10-20 patient per indication
- Comparison with independent control CT data

→ **Systematic assessment of clinical benefit**

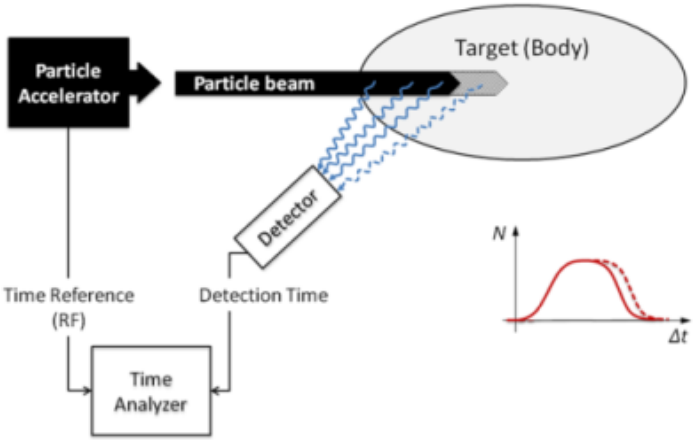
**Evaluation on detectability of range and setup uncertainties**

- Simulation study on clinical CT data
- Different “PGI signatures” for different error sources?

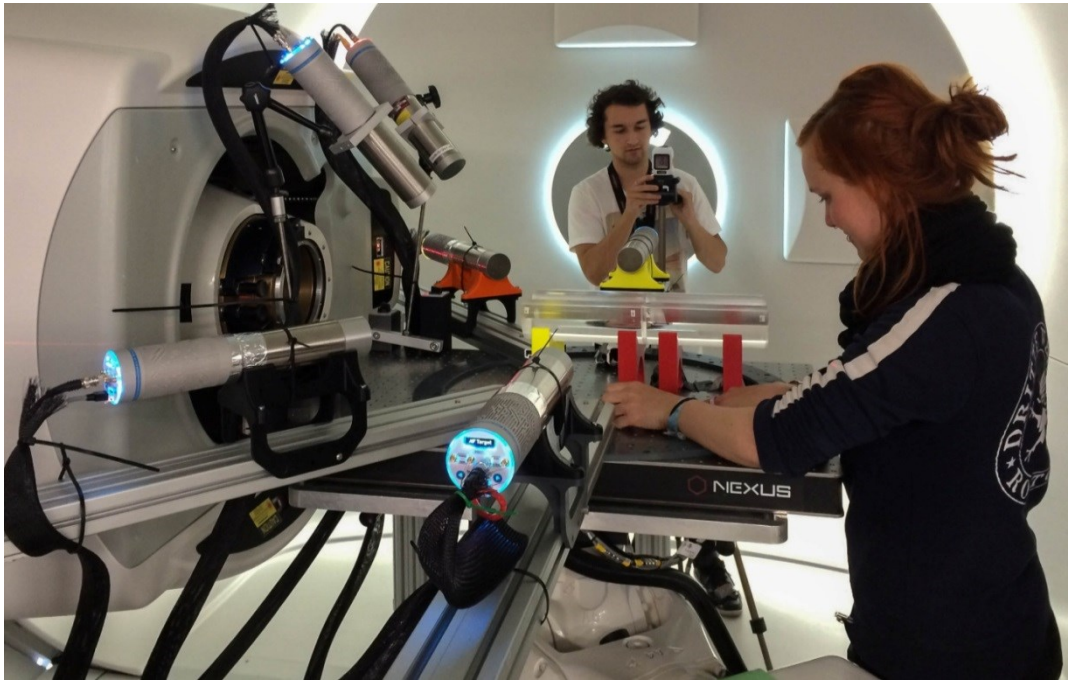
# Outlook: Prompt gamma ray timing (PGT)

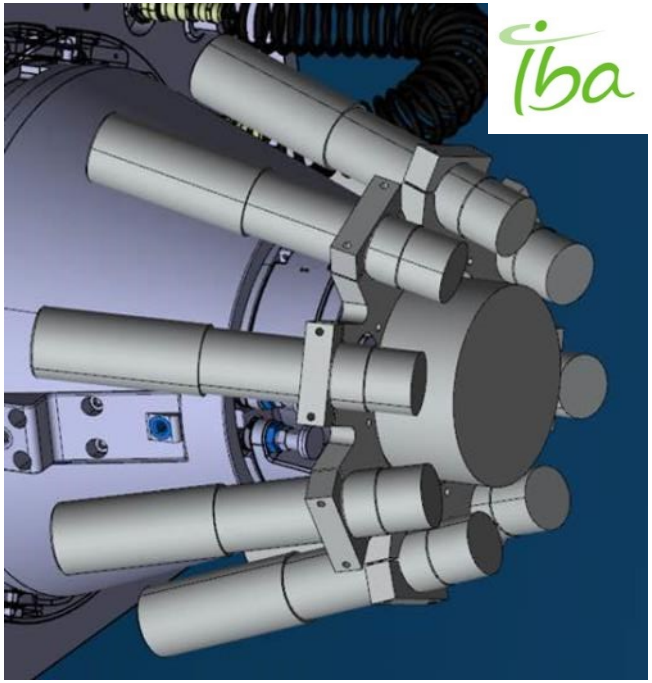
**Basic idea:**

Detection time of prompt-gammas decodes penetration depth




**Clinical implementation in preparation**




Images with courtesy of G.Pausch & IBA

# Interdisciplinary team

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Wolfgang Enghardt
Mechthild Krause
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**Julien Smeets**
**Johannes Petzoldt**
**Francois Vander Stappen**
**Lucian Hotoiu**
Guillaume Janssens
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