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Utilizing CBCT data for dose calculation in adaptive IMPT

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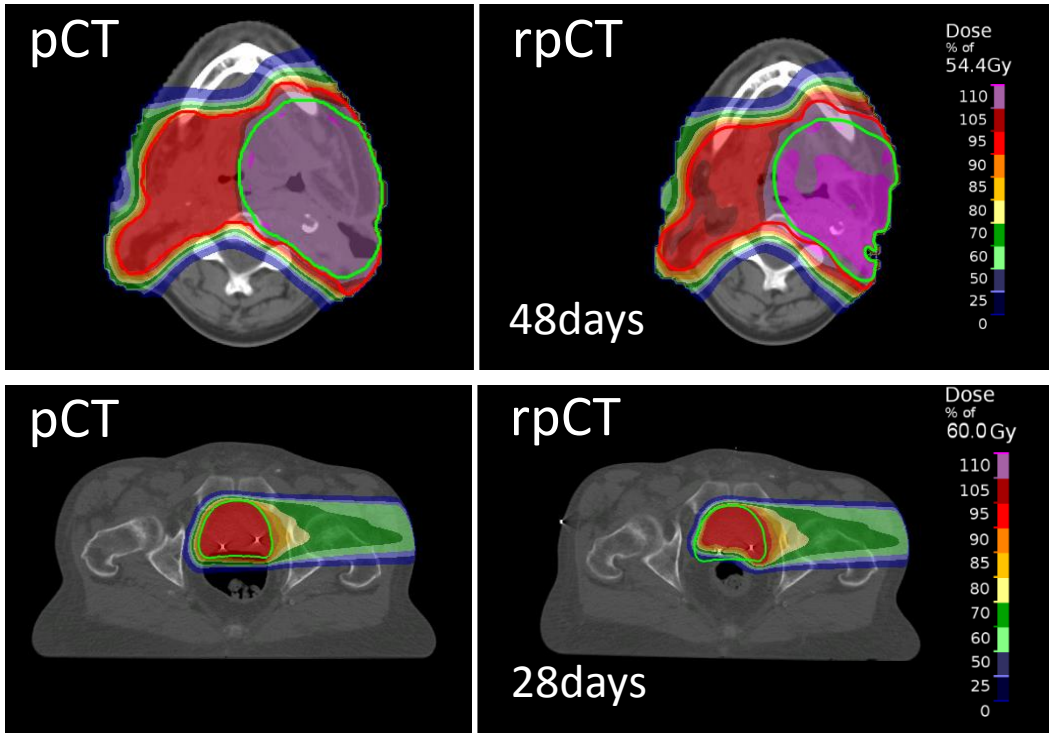
Motivation

- **IMPT plan quality** might be compromised due to **anatomical changes**



Head and neck:
Timescale: days/weeks

Prostate:
Timescale: minutes/hours

- May be restored by **plan adaptation**
- Requires **frequent** imaging and accurate **up to date 3D dose** calculation

Material and Methods

- **CBCT imaging** entering clinical routine for patient **positioning** in IMPT

- **CBCT** imaging provides:
  - **Bony anatomy** position
  - Gross **volume changes**
  - **Treatment** position

- **CBCT** imaging **does not** provide:
  - High soft tissue contrast
  - Reliable **electron densities**

→ **Utilization of CBCT images in IMPT requires intensity correction**

→ **Investigate two recently proposed methods**

→ **Cohort of 3 H&N and 3 prostate cancer patients**

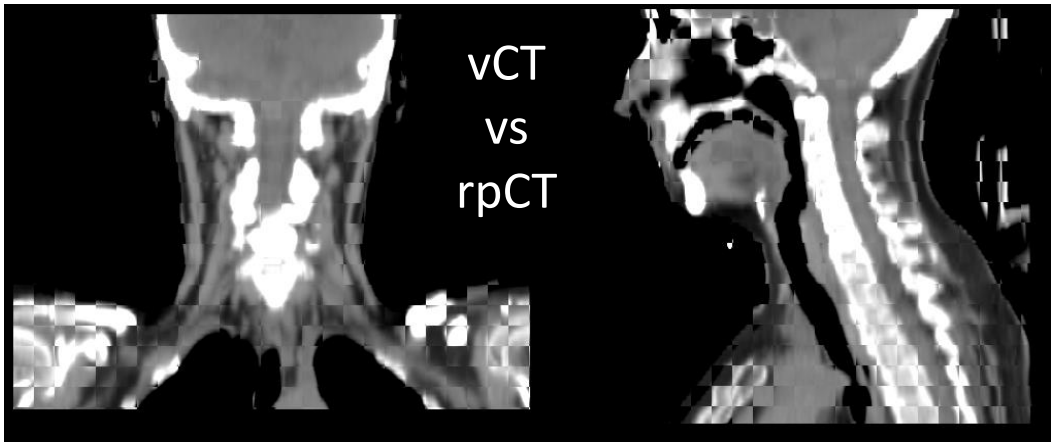
→ **Investigate SFUD proton range and delineation accuracy**

pCT vs rpCT CBCT vs rpCT

Virtual CT

Virtual CT (vCT)

- **Deformable** image registration of **pCT** to daily **CBCT → vCT**
- Use **Morphons algorithm** (REGGUI package*)
- Yields **up-to-date contours**
- **Validated** and found **accurate** for **H&N** [1], **here** extended to **prostate**



*REGGUI kindly shared and developed at ICTEAM/UCL, Belgium

[1] G Landry et al, 2015. Investigating CT to CBCT image registration for head and neck proton therapy as tool for daily dose recalculation. Med. Phys. **42**(3)

$CBCT_{cor}$

Scatter corrected CBCT ($CBCT_{cor}$)

- **vCT** as **prior**: **Forward projection** of **vCT** according to CBCT geometry

  I_{vCT}

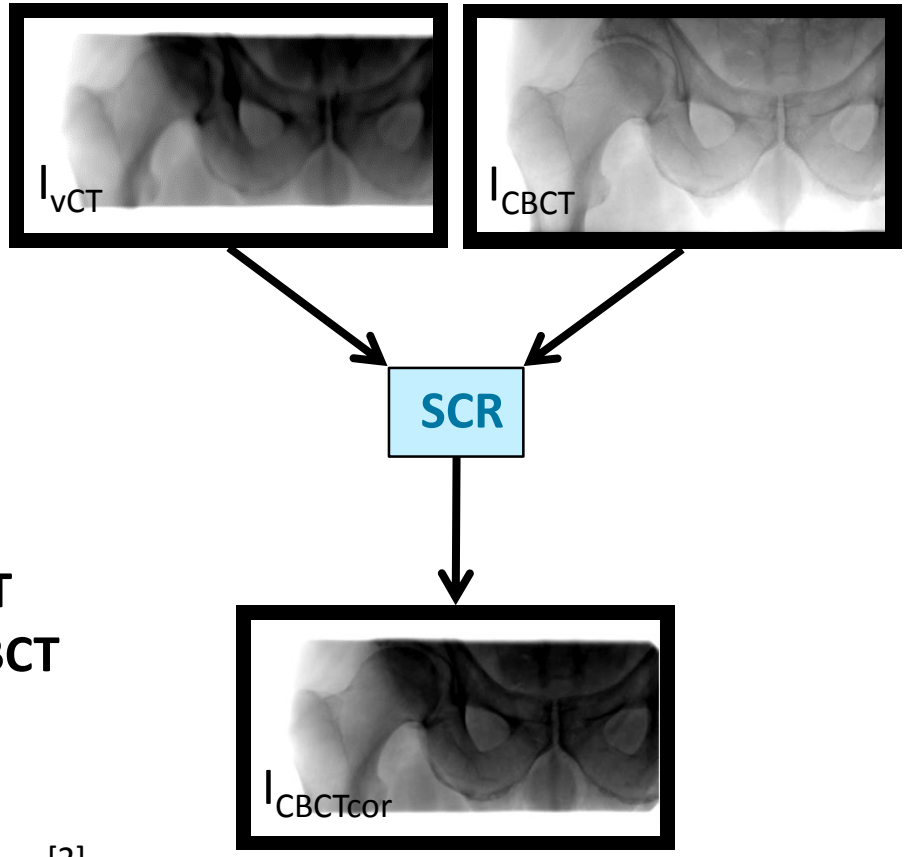
- **Scatter estimate by subtracting I_{vCT}** from scaled **daily CBCT projections I_{CBCT}** and smoothing

  $SCR=f(CF \times I_{CBCT} - I_{vCT})$

- **Subtract scatter map** from **daily CBCT** projections, **reconstruct** corrected **CBCT**

  $CBCT_{cor}=FBP(CF \times I_{CBCT} - SCR)$

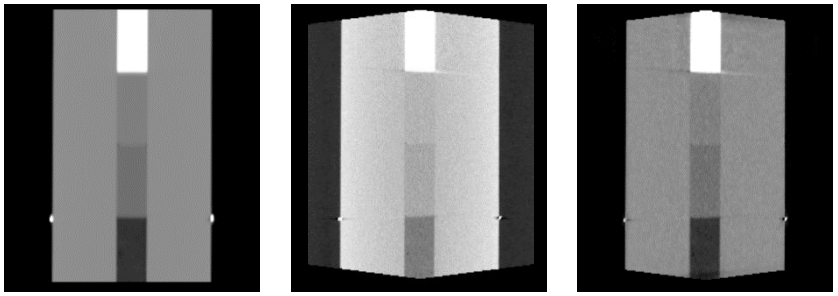
- **Validated** for **H&N** and **abdominal** sites[2]



[2] Y K Park et al, 2015. Proton dose calculation on scatter-corrected CBCT image: Feasibility study for adaptive proton therapy. Med. Phys. **42**(8)

$CBCT_{cor}$ validation

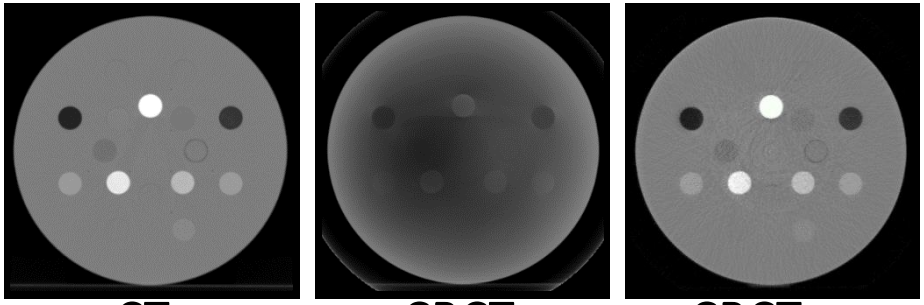
- **$CBCT_{cor}$ validated** for **LMU** on-board CBCT using **phantom data**
- H&N gammex phantom



CT CBCT $CBCT_{COR}$

Insert	CT HU	$CBCT_{cor}$ HU
Lung	-588±18	-585±36
Adipose tiss.	-114±3	-104±31
Solide water	4±3	15±32
Cort. bone	1517±12	1481±94

- Gammex phantom



CT CBCT $CBCT_{COR}$

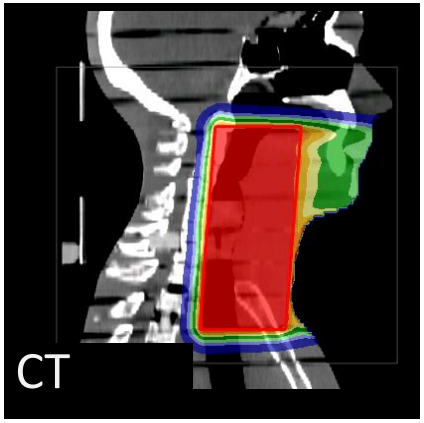
Insert	CT HU	$CBCT_{cor}$ HU
Lung	-562±19	-571±34
Adipose tiss.	-101±16	-93±50
Solide water	-9±16	0±42
Cort. bone	1249±17	1317±96

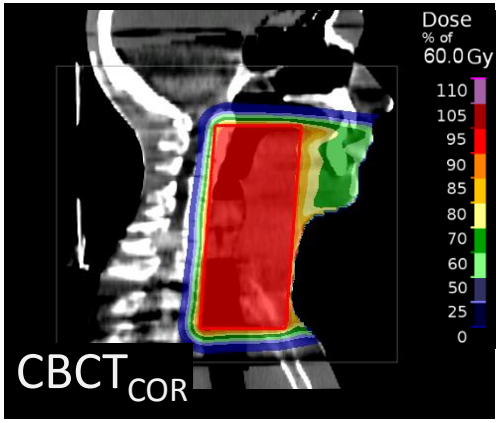
$CBCT_{cor}$ validation

- **$CBCT_{cor}$ validated** in terms of **proton range** using **phantom data**
- H&N Alderson

86% profiles within 2mm

Median RD 0.3mm

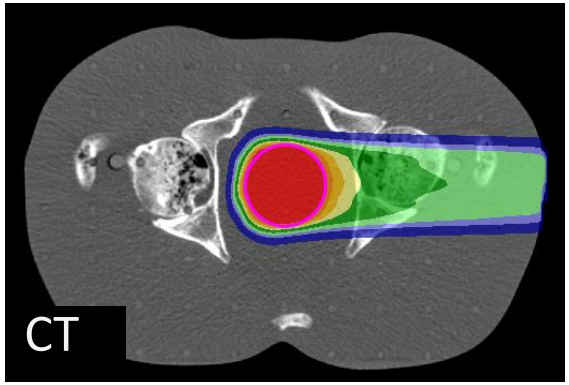


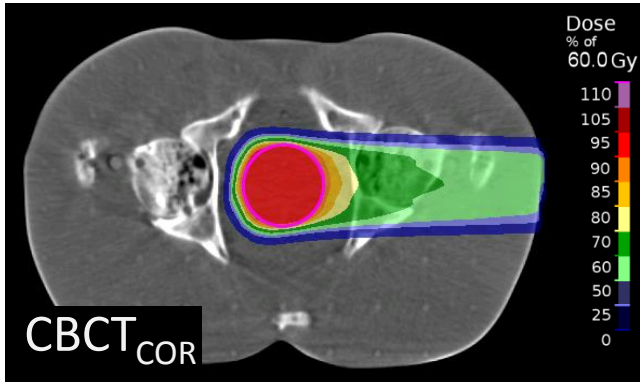


- Pelvis Alderson

100% profiles within 2mm

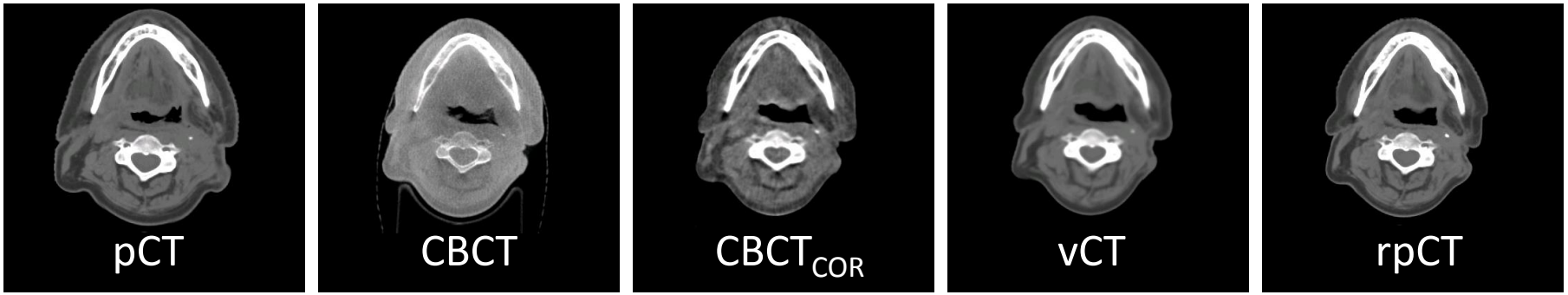
Median RD -0.4mm



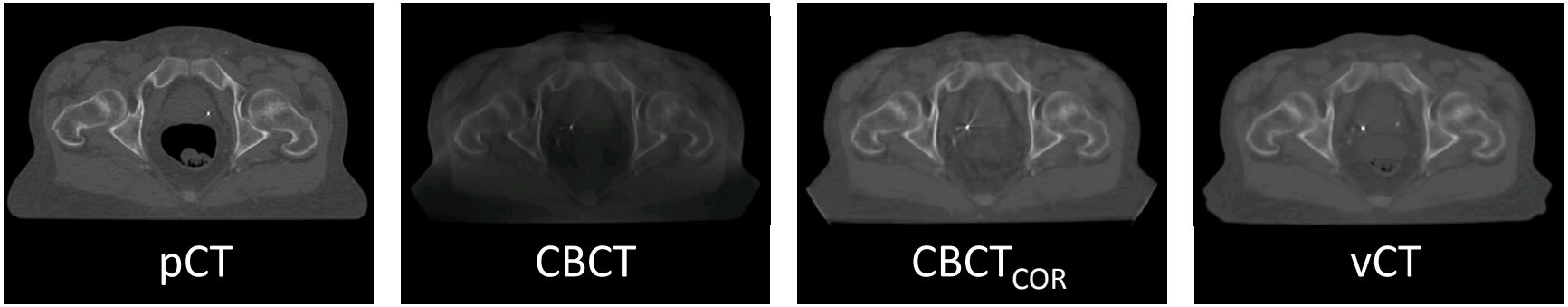


$CBCT_{cor}$ and vCT

- **$CBCT_{cor}$** implementation for **prostate** and **H&N patient data**
- H&N

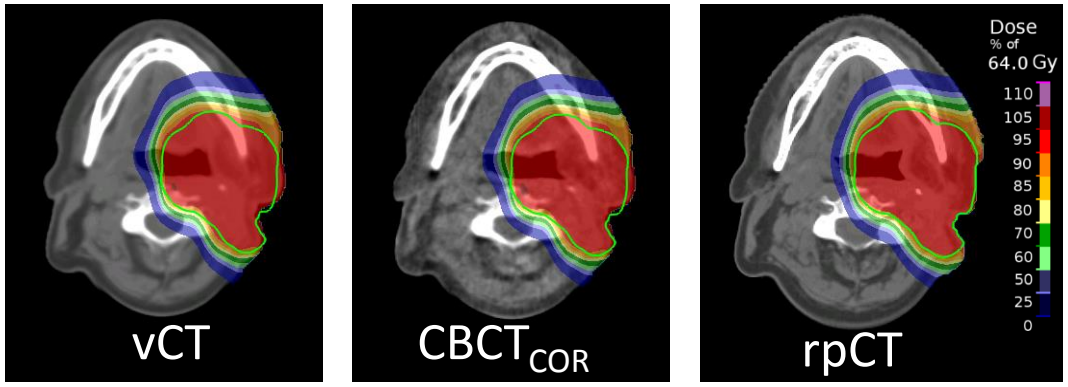


- Prostate



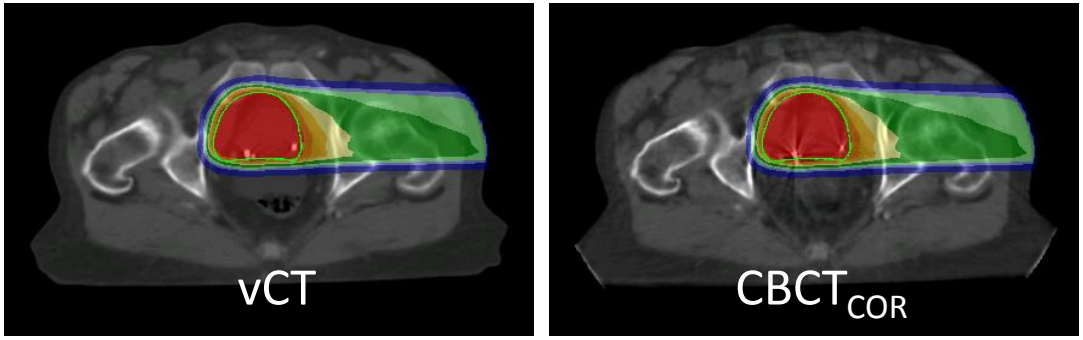
$CBCT_{cor}$ and vCT

- **$CBCT_{cor}$** and **vCT comparison** in terms of **proton SFUD range** difference
- H&N



Pat	RD<2mm	Med. RD
HN1	99%	0.1mm
HN2	91%	0.1mm
HN3	99%	0.3mm

- Prostate



Pat	RD<2mm	Med. RD
PR1	100%	0.2mm
PR2	100%	0.5mm
PR3	99%	0.1mm

$CBCT_{cor}$ and vCT

- **Comparison** of **contours** for **prostate** cases**:**

vCT (warped from **pCT**)

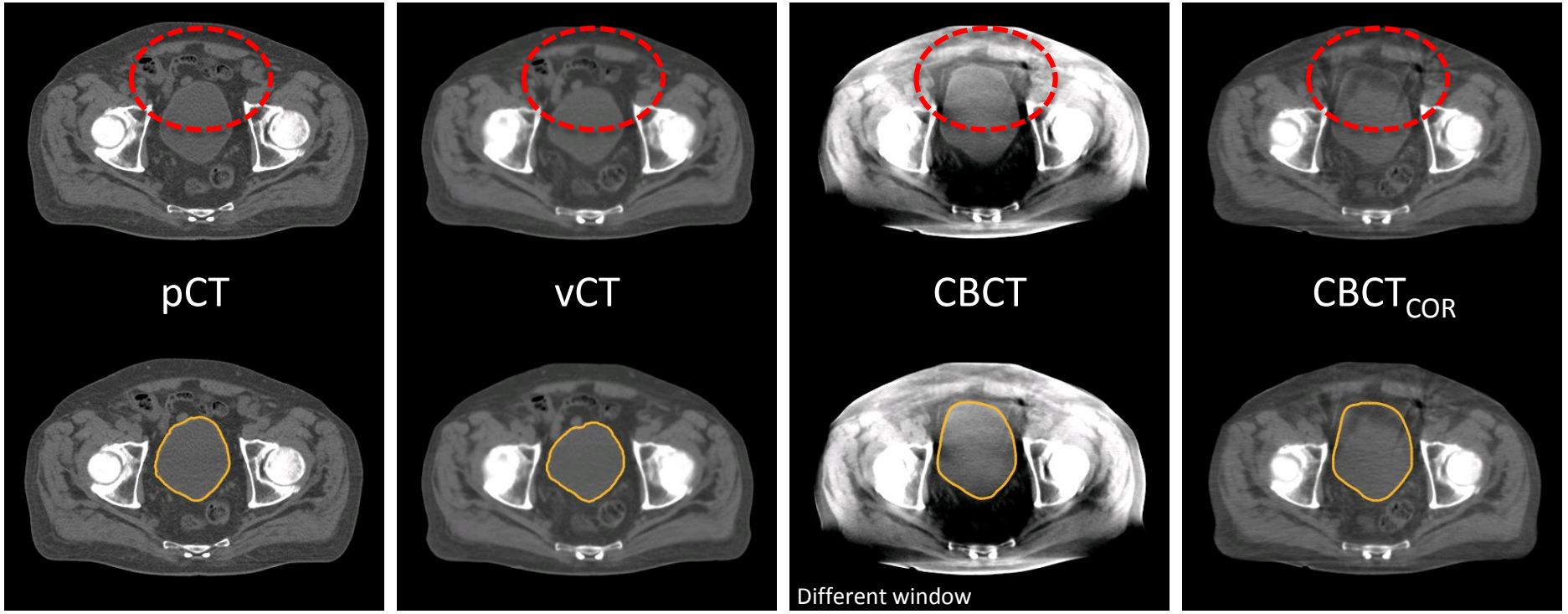
$CBCT_{COR}$ (physician)

} **vs.** original **CBCT** (physician)

Structure	CT set	DSC	Mean Hausdorff (mm)
PTV	**$CBCT_{COR}$**	0.92	1.7
	vCT	0.86	2.9
Bladder	**$CBCT_{COR}$**	0.95	1.0
	vCT	0.80	4.6
Rectum	**$CBCT_{COR}$**	0.90	1.2
	vCT	0.79	2.9

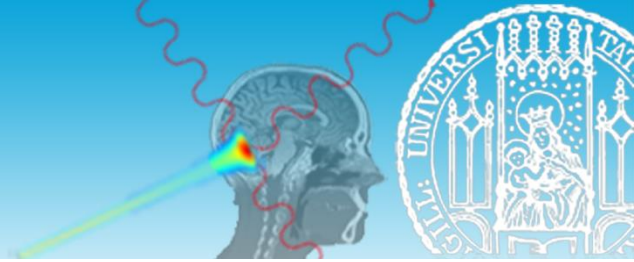
$CBCT_{cor}$ and vCT

- **Comparison** of **contours** for **prostate** cases**:**



- **Low CBCT contrast** and **strong** anatomical **changes** ⟶ **Limited DIR accuracy**

Conclusions



- A DIR and a scatter correction approach to enable CBCT-based IMPT dose calculation have been compared

- Similar results in head and neck cases
- Good agreement with reference rpCT

- Similar results in prostate cases in terms of proton range
- DIR insufficiently accurate in pelvic region
- $CBCT_{COR}$ can overcome DIR inaccuracies in vCT-prior

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