Trento Institute for Fundamental Physics and Applications

Istituto Nazionale di Fisica Nucleare SEZIONE DI FIRENZE

Azienda Provinciale per i Servizi Sanitari Provincia Autonoma di Trento

The proton radiography experiment

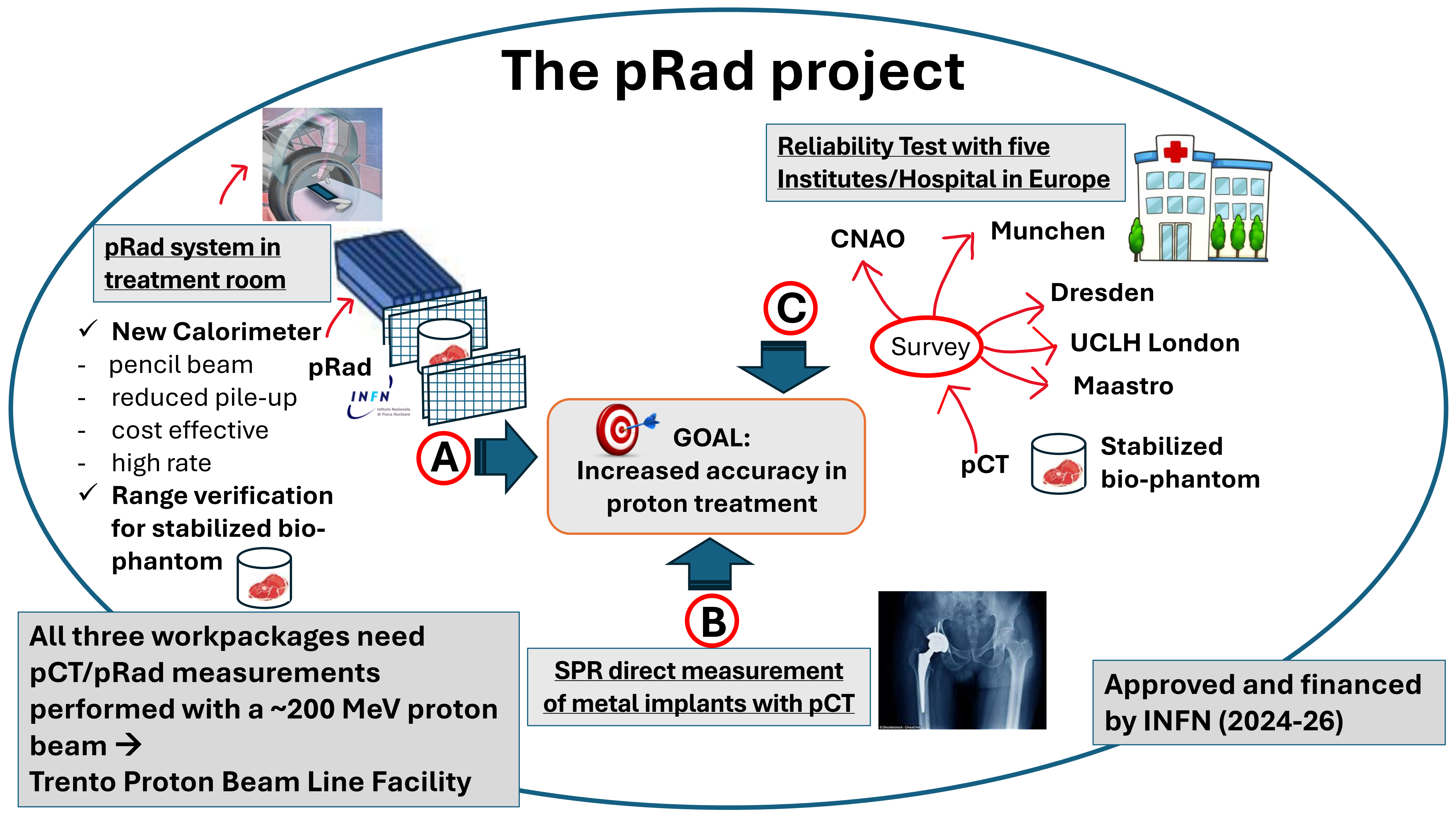
Carlo Civinini

INFN-Firenze

PRAD-Collaboration

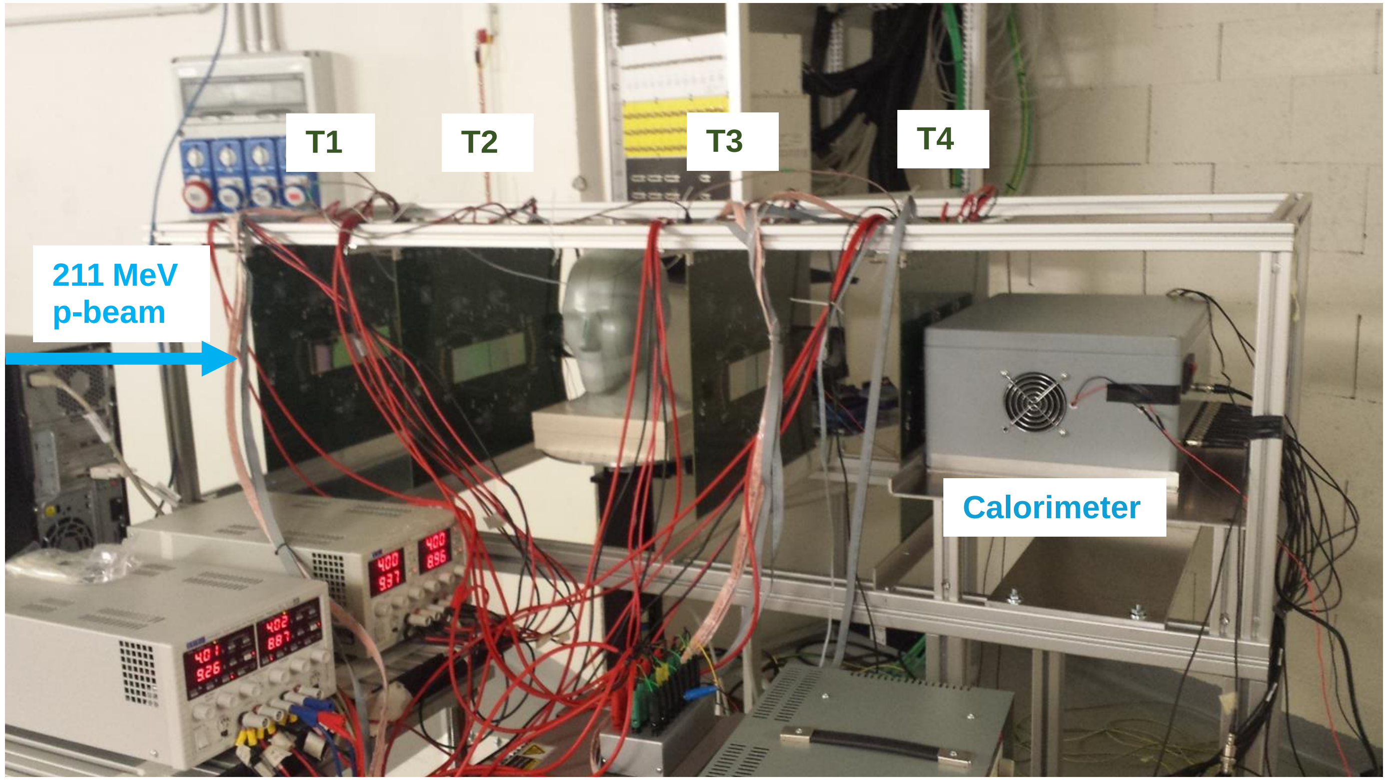
Trento proton beam line facility – 2nd Workshop

June 17-18 2024



The pRad project
pRad system in treatment room
✓ New Calorimeter
- pencil beam
- reduced pile-up
- cost effective
- high rate
✓ Range verification for stabilized bio-phantom
pRad
INFN
A
GOAL: Increased accuracy in proton treatment
C
B
SPR direct measurement of metal implants with pCT
Reliability Test with five Institutes/Hospital in Europe
Survey
CNAO
Munchen
Dresden
UCLH London
Maastro
pCT
Stabilized bio-phantom
All three workpackages need pCT/pRad measurements performed with a ~200 MeV proton beam →
Trento Proton Beam Line Facility
Approved and financed by INFN (2024-26)

Starting point: the pCT system



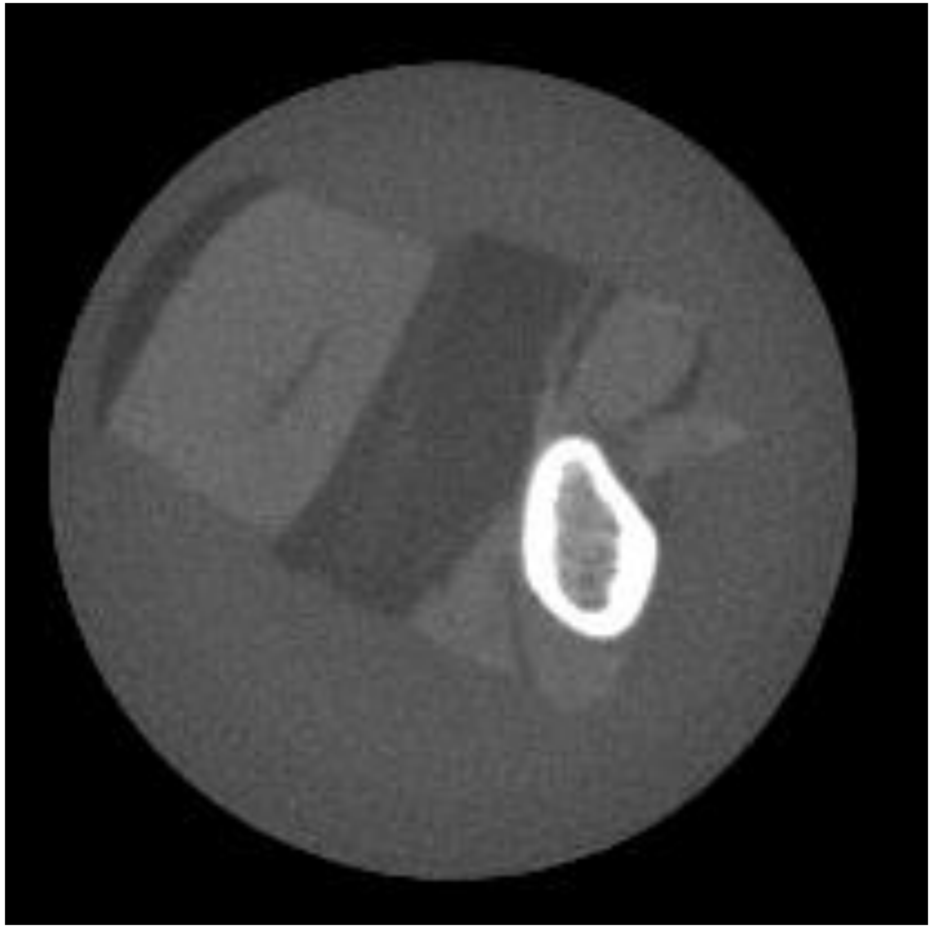
Build by Florence and Catania group [1] (2014-2017)

[1] C. Civinini et al., 'Relative stopping power measurements and prosthesis artifacts reduction in proton CT', 2020 Phys. Med. Biol. 65 225012

[2] M. Scaringella et al., 'The INFN proton computed tomography system for relative stopping power measurements: calibration and verification', 2023 Phys. Med. Biol. in press, https://doi.org/10.1088/1361-6560/ace2a8

[3] E. Fogazzi et al., 'Characterization of the INFN proton CT scanner for cross-calibration of x-ray CT', 2023 Phys. Med. Biol. 68 124001

Our images are the '**state of the art**' of the proton Tomography (pCT) technique [1,2,3].



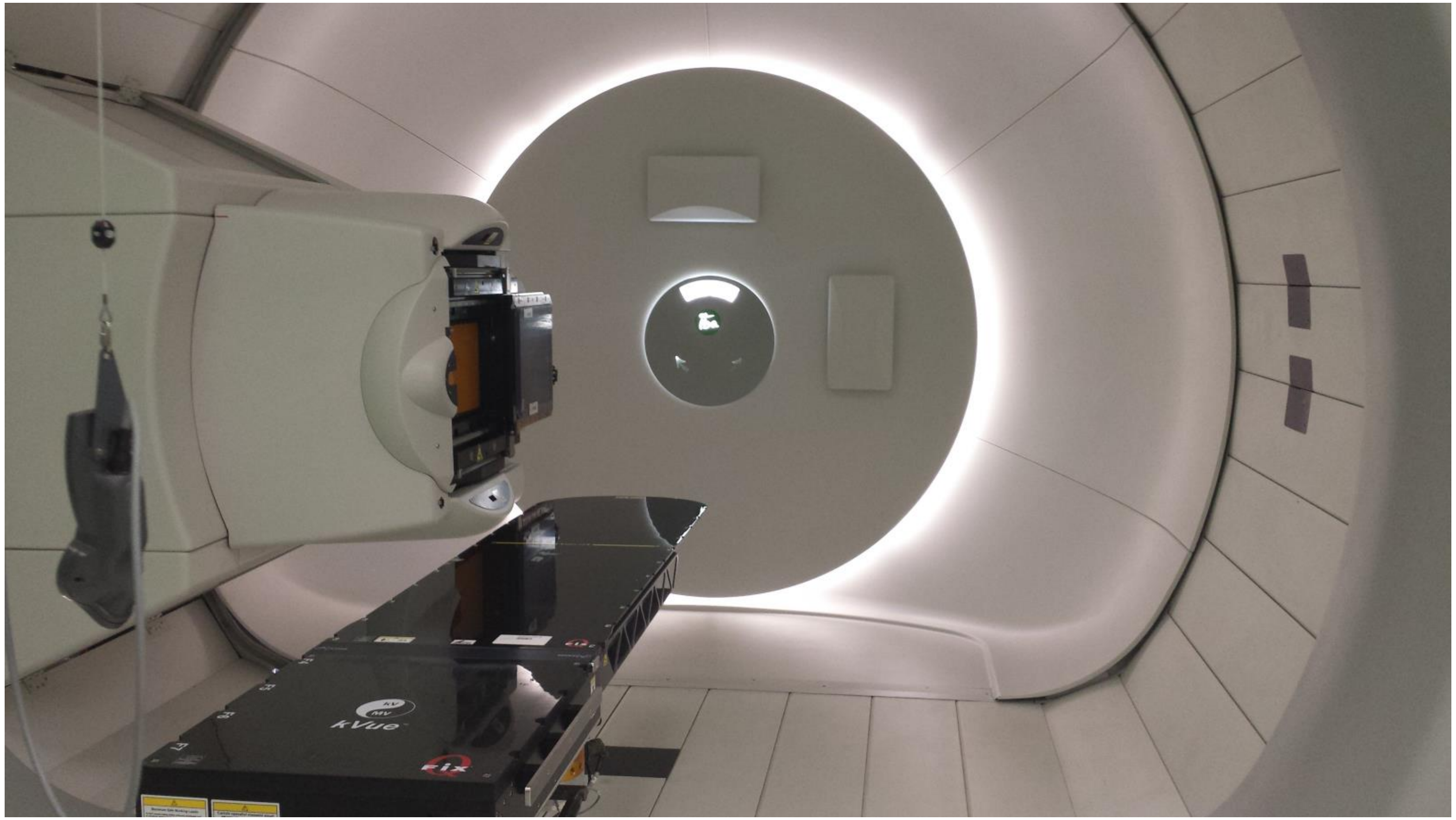
Axial view (Stopping Power Relative to Water - SPR) of a **proton tomography of a stabilized bovine sample**: bone, bone marrow, fat and muscle embedded into an agar-agar matrix

Pixel size: 0.6x0.6x2.75 mm^3, $\phi \approx 108\ mm$.

WP-A. New pRad calorimeter

Resp. Monica Scaringella
INFN-FI

- Goal: **<u>'single event' proton radiographies in treatment room of biological phantoms</u>**
- Advantage: **<u>proton range control</u>** with respect to the TPS (Treatment Planning System) predictions
- The tracker will be the same of the present pCT system(Si-microstrip)
- **<u>New calorimeter:</u>** plastic scintillators
- Treatment room: operation with magnetic beam and pencil beam
- Acquisition rate ~MHz → proton radiography time ~**<u>seconds</u>**
- **<u>Dose $\sim 20\mu Gy$</u>**



Treatment room of the 'Proton therapy center' APSS Trento

WP-A. New pRad calorimeter

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- **<u>Dose $\sim 20\mu Gy$</u>**

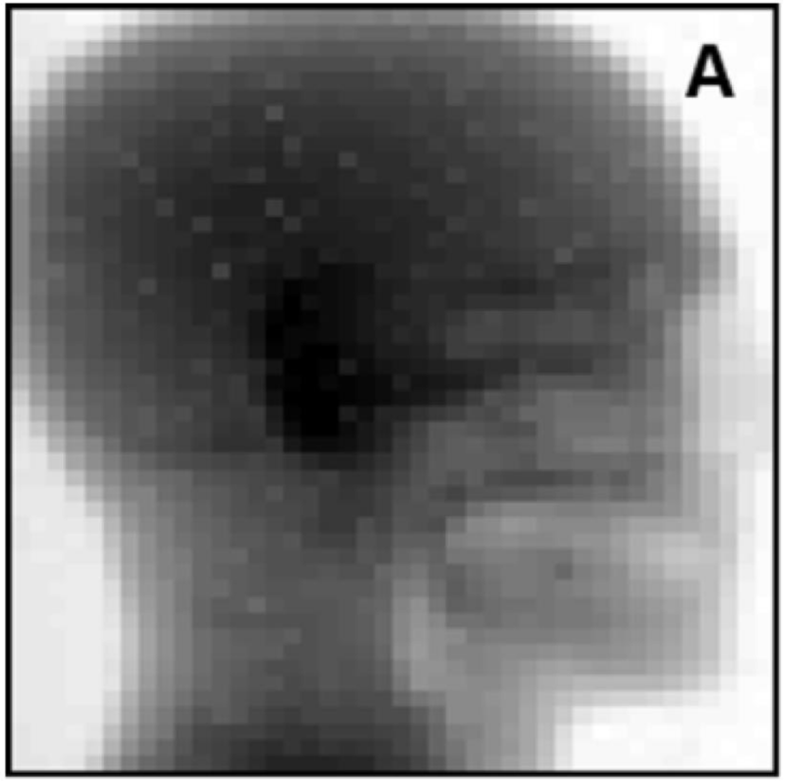
'Single proton' radiography of an anthropomorphic phantom (CIRS 731-HN): Event-by-event reconstruction.

Proton radiography taken by the pCT-INFN [1]: **dose < 0.01 cGyE**

[1] INFN PRIMA-RDH-IRPT collaboration
C. Civinini et al., 2017 IEEE-MIC Symposium DOI: 10.1109/NSSMIC.2016.8069620

Anthropomorphic phantom (CIRS 731-HN)

‘Integration mode’ radiography



Qualitative visualization of a proton radiography acquired by a MLIC (Multi Layer Ionization Chamber) IBA Giraffe[1]:

Mean dose < 1cGyE

[1] P. Farace et. al., Med. Phys. 43 (12), December 2016

< 1cGyE

Dose

< 0.01 cGyE

‘Single proton’ radiography

Proton radiography acquired by the pCT-INFN [2]:

Mean dose < 0.01 cGyE

[2] INFN PRIMA-RDH-IRPT collaboration

C. Civinini et al., 2017 IEEE-MIC Symposium DOI: 10.1109/NSSMIC.2016.8069620

Anthropomorphic phantom (CIRS 731-HN)

‘Integration mode’ radiography

‘Single proton’ radiography

< 50-60cGyE

Dose

< 0.01 cGyE

Qualitative visualization of a proton radiography acquired by a ‘Flat Panel’ Phoenix, (Amorphous silicon), IBA Dosimetry [2]:

Mean dose 50-60 cGyE

[2] C. Seller Oria et al., Med Phys. 2023;50:1756–1765.

Proton radiography acquired by the pCT-INFN [2]:

Mean dose < 0.01 cGyE

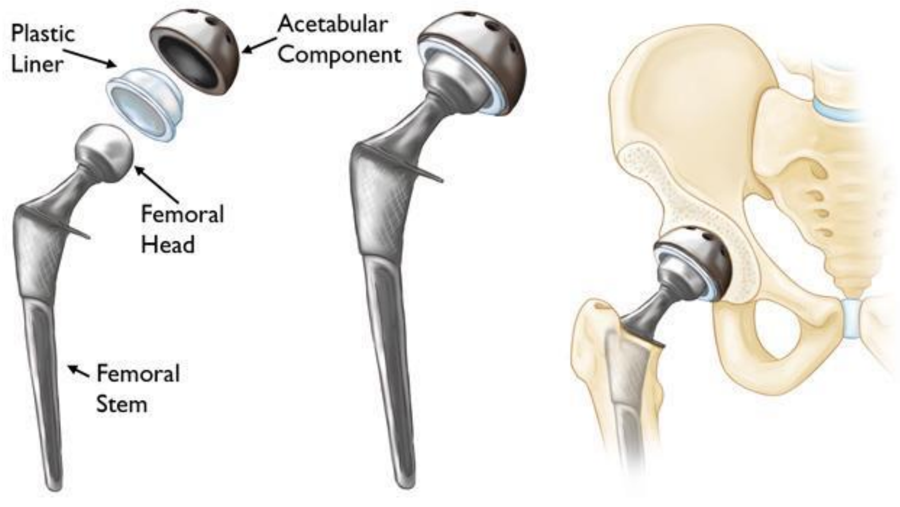
[2] INFN PRIMA-RDH-IRPT collaboration

C. Civinini et al., 2017 IEEE-MIC Symposium DOI: 10.1109/NSSMIC.2016.8069620

Resp. Mara Bruzzi
Florence Univ. and INFN-FI

WP-B. SPR measurements on prosthesis

- If the patient has **implanted prosthesis** close to the tumor, the TPS defines 'avoidance regions' to limitate the SPR uncertanties due to these materials.
- This makes treatment plans **more complex** and also **less efficient**.
- The **direct measurement of the SPR**, of the different materials and their spatial distribution, performed on a prosthesis identical to the implanted one, can lead to **greater flexibility** in defining irradiation directions and, consequently, to a **better overall quality of the treatment**.
- **Goal: build a library of pCT images of the most common prosthesis**: spinal implants, vertebral corpectomy prosthesis, femoral implants, ecc.
- Potentially **the clinical application of the pCT** in this field is very close.

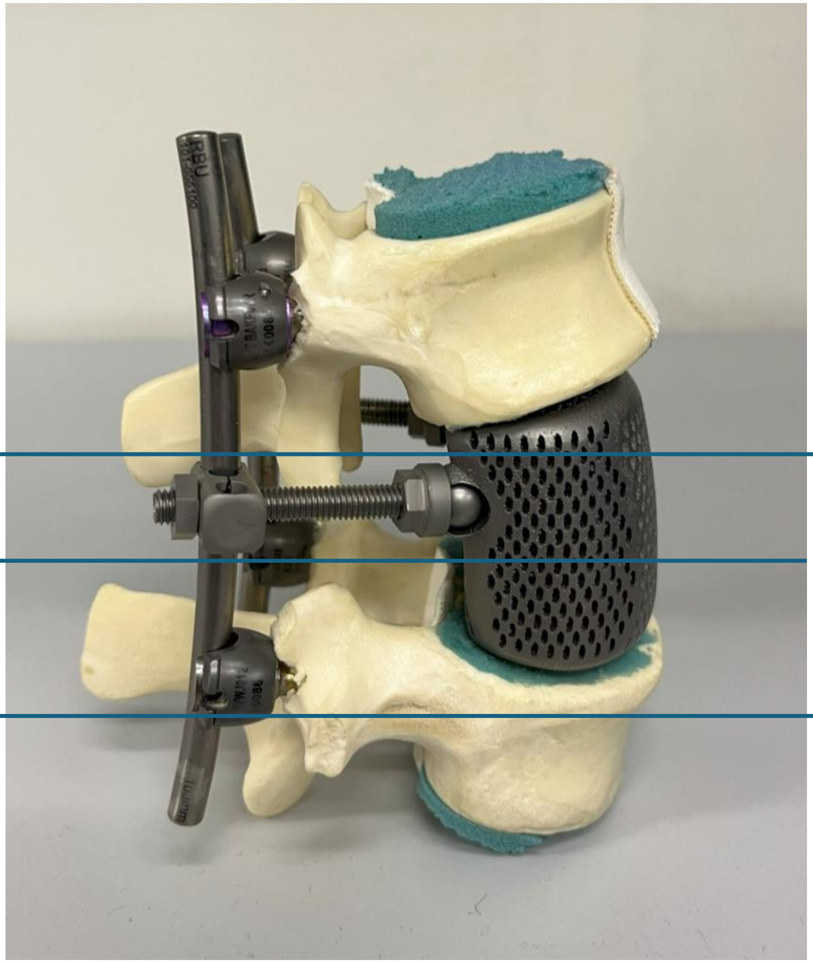


Due to the complex geometry of the prosthesis it is impossible to measure the SPR of the materials using a proton beam and an MLIC.
A pCT apparatus can measure the SPR values and their distribution in the prosthesis with a single tomography.

WP-B. Prosthesys phantom

- Spinal prosthesys in a demineralized water cylinder (115 mm)

Field-of-view
$\sim 45\ mm$



Axial slice shown in the next slide

WP-B. Tomography of the titanium prosthesis

- Voxel size: 0.39x0.39x1.5 mm^3
- FDK-like reconstruction modified to use the proton MLP
  - S. Rit et al., Med. Phys. 40 (3), March 2013
- No filter

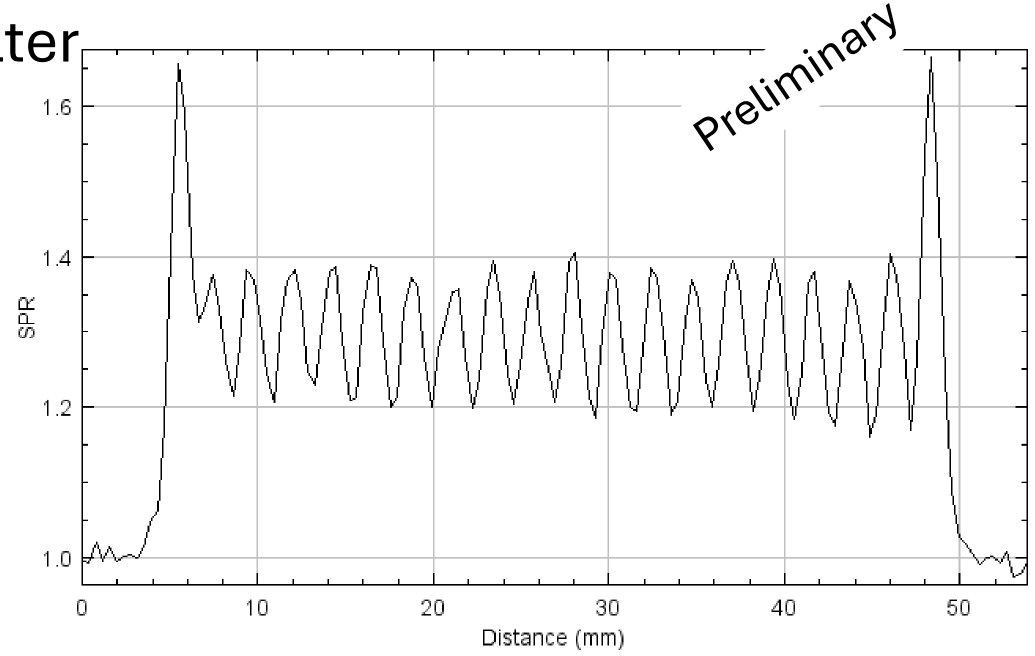
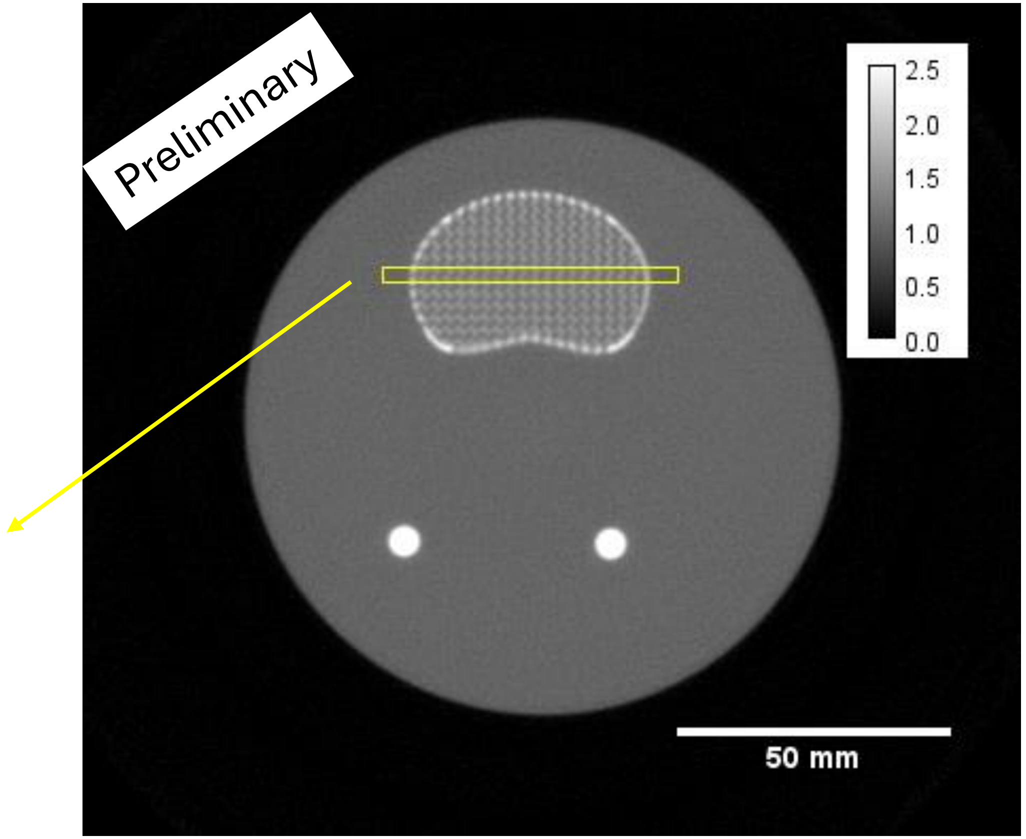


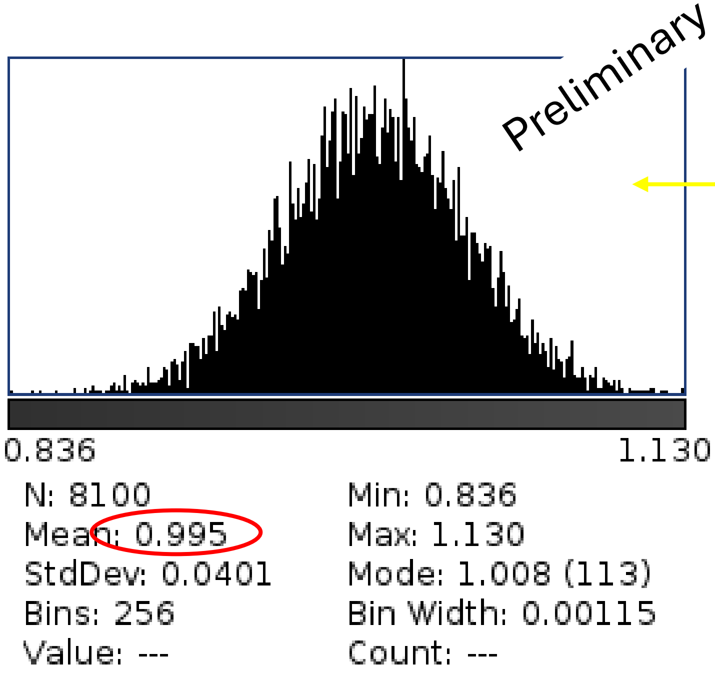
Image dose ~18.2 mGy



Trento proton beam line – Test January 2024

WP-B. Tomography of the titanium prosthesis

- Voxel size: 0.39x0.39x1.5 mm^3
- FDK-like reconstruction modified to use the proton MLP
  - S. Rit et al., Med. Phys. 40 (3), March 2013
- No filter
- Water RSP distribution in a ROI → cross-check of the pCT energy calibration validity



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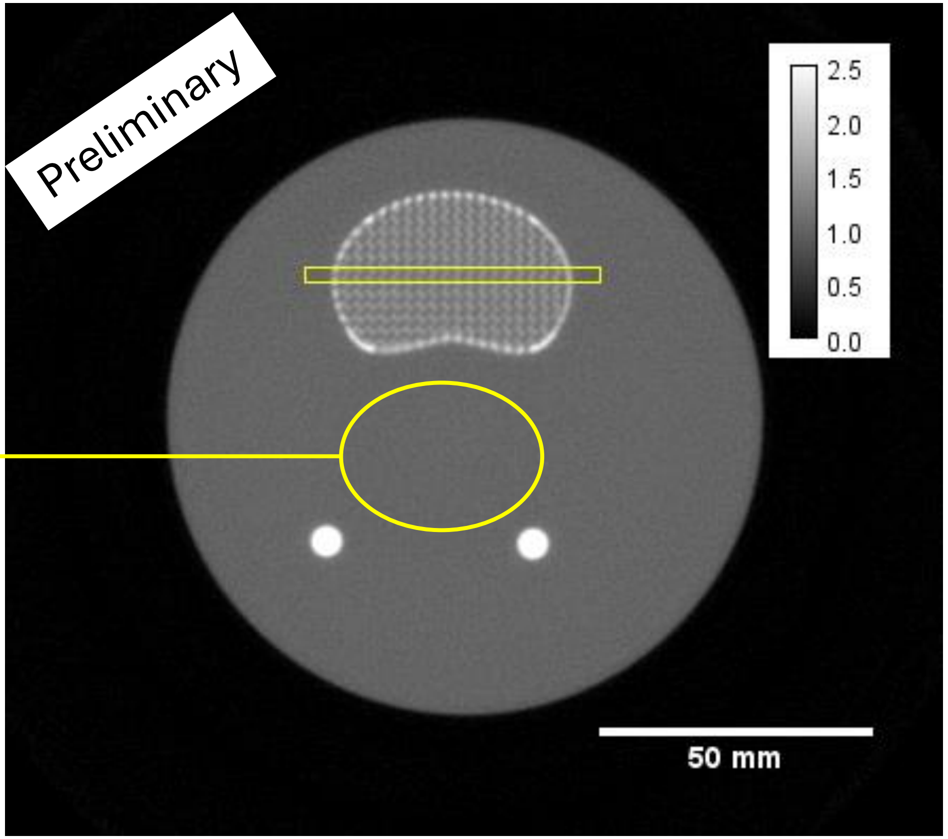


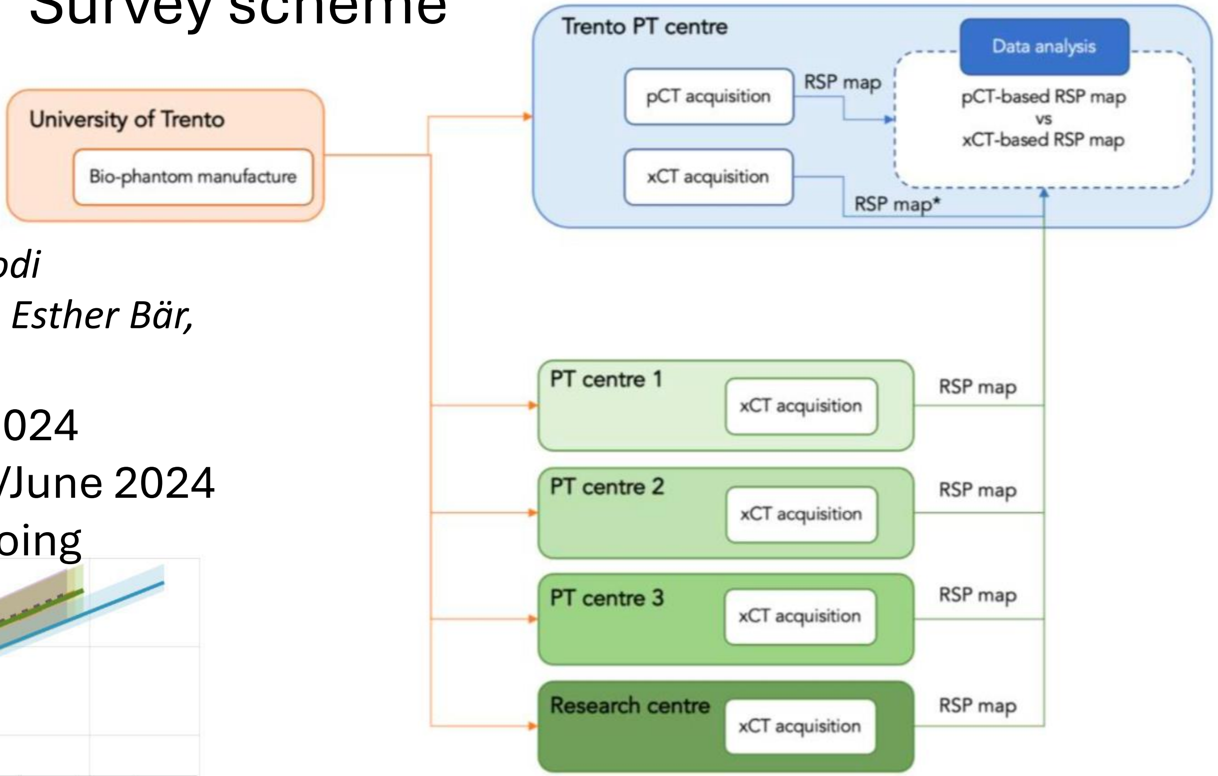
Trento proton beam line – Test January 2024

WP-C. Survey

Resp. Francesco Tommasino
Trento Univ. and INFN-TIFPA

1. CNAO (Pavia, Italy) *Contact: Mario Ciocca*
2. Maastro Clinic (Maastricht, Netherlands) *Contact: Ilaria Rinaldi*
3. OncoRay (Dresda, Germany) *Contact: Christian Richter*
4. LMU - Medical Physics dep. (Munich, Germany) *Contact: Katia Parodi*
5. University College London Hospitals NHS foundation trust *Contact: Esther Bär, Callum Gillies*

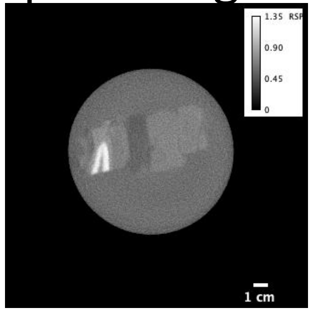
Survey scheme



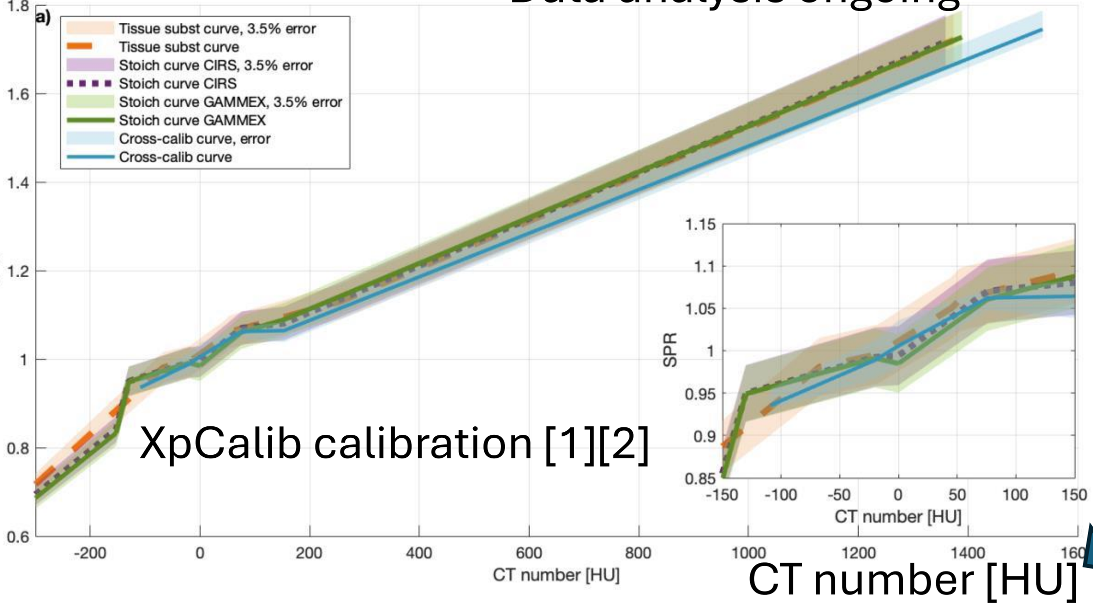
Biological stabilized phantom

pCT image: April 2024
xCTs images: May/June 2024
Data analysis ongoing

pCT image



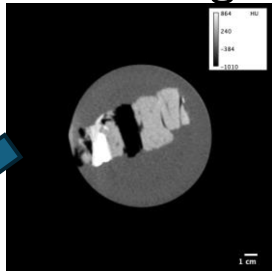
SPR



XpCalib calibration [1][2]

CT number [HU]

xCT image



[1] P. Farace et al., 'Technical Note: CT calibration for proton treatment planning by cross-calibration with proton CT data', Med Phys 48 (3), March 2021: 1349-1355
[2] E. Fogazzi et al., 'Proton CT on biological phantoms for X-ray CT calibration in proton treatment planning'
Phys. in Med. and Biol. Accepted for publication

Conclusions

- The **pRad experiment** aims to improve the precision of proton treatments by:
  1. A proton radiography apparatus with '**single event**' capability
  2. **Prosthesis SPR** measurements
  3. **SPR comparison** between different proton treatment/ research institutes and direct pCT measurements
- This programme need experimental measurements with the **pCT/pRad** systems on a 200 MeV proton beam

The Proton Radiography experiment

Mara Bruzzi[1,2], Carlo Cialdai[1], Carlo Civinini[1], Elvira D'Amato[3], Elena Fogazzi[3,4], Francesco Fracchiolla[4,5], Stefano Lorentini[4,5], Roberto Righetto[4,5], Monica Scaringella[1], Marina Scarpa[3,4], Francesco Tommasino[3,4], Enrico Verroi[4]

1 Italian National Institute of Nuclear Physics (INFN), Florence section, Via G. Sansone 1, Sesto Fiorentino (FI), Italy
2 Physics and Astronomy department, University of Florence, via G. Sansone 1, Sesto Fiorentino (FI), Italy
3 Physics department, University of Trento, via Sommarive 14, Povo (TN), Italy
4 Trento Institute for Fundamental Physics and Applications (TIFPA), Italian National Institute of Nuclear Physics (INFN), via Sommarive, 14, Povo (TN), Italy
5 Medical Physics Unit, Hospital of Trento, Azienda Provinciale per i Servizi Sanitari (APSS), Via Paolo Orsi 1, Trento, Italy