From radiotherapy dose monitoring to low-dose morphologic imaging with scanned megavoltage X-rays

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FCT Fundação para a Ciência e a Tecnologia
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QREN Quadro de Referência Estratégico Nacional Portugal 2007.2013

Ciência Inovação 2010 Programa Operacional Ciência e Inovação 2010
Ministério da Ciência, Tecnologia e Ensino Superior

União Europeia
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Outline

0. Summary

1 **Purpose:** To investigate whether orthogonal ray imaging, a new technique that consists in detecting radiation dispersed in the patient and emitted at right angles in respect to the beam axis, is capable of assisting external photon beam radiotherapy by providing images correlated with the effective dose distribution, and by enabling in parallel low-dose morphologic imaging, mainly on-board tumor/patient imaging.

2 **Materials/methods:** Monte Carlo simulations were carried out with the anthropomorphic phantom NCAT adapted to Geant4, together with experimental proof-of-principle measurements collected with a heterogeneous phantom made of acrylic/air and irradiated with a clinical linac. The Monte Carlo simulations comprise an intensity modulated radiation therapy-like treatment in the region of the pituitary gland, together with the irradiation of a tumor with a diameter of 30 mm located in the lung. The lung tumor irradiation was considered in four possible scenarios: original (normal) irradiation, tumor shift of 9.36 mm to caudal, a tumor diameter shrinkage of 9.36 mm, and tumor diameter enlarged by two times the initial value.

3 **Results:** The simulated results show that, despite the subtherapeutic, very-low dose simulated (ca 1 mGy), a good visual agreement between the planned dose distribution and the orthogonal ray simulated images is obtained. It is also shown that the filling of the nasal cavity of the patient may account for a dose reduction of up to 10%, which may be detected with an orthogonal ray imaging system. In the case of the irradiation of the lung, images allow a tumor shrinkage or dislocation of 9.36 mm to be clearly discernible. The experimental results show that scanned pulse height spectra acquired with a collimated detector allowed for a profile correlation of 0.9911 to be obtained between the measured data and the dose simulated inside the acrylic/air heterogeneous phantom. In addition, a 2-mm phantom displacement was clearly distinguishable by simulation and experiment.

4 **Conclusions:** Orthogonal ray imaging is a new imaging concept for assisting external photon beam radiotherapy that shows a good potential for image-guided radiotherapy, adaptive radiotherapy, and low-dose on-board patient imaging.

1. Motivation

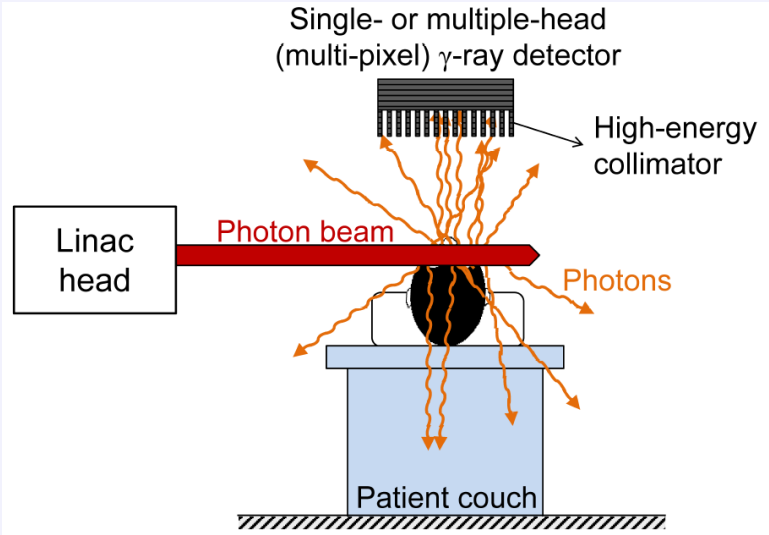
Need for image guided radiotherapy (IGRT), adaptive radiotherapy (ART), and (real-time, in-vivo) dose monitoring techniques:

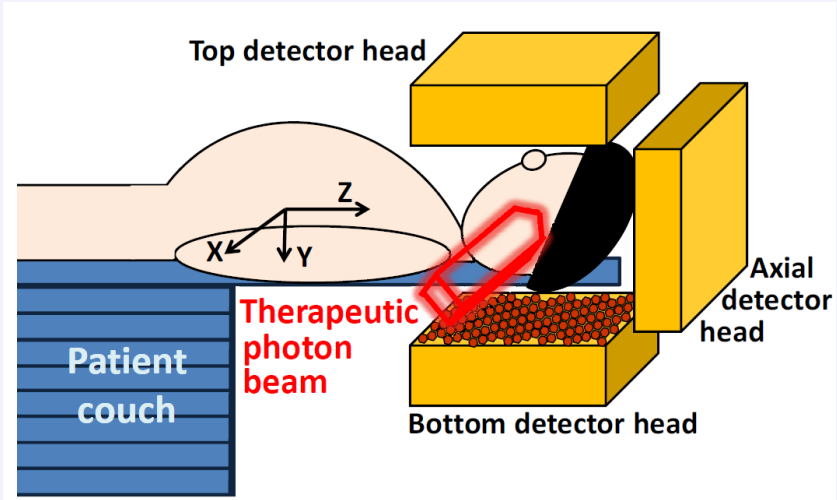
- Modern RT allows for increasingly higher conformality
- Such conformality aims at maximizing radiation dose in the tumor and minimizing side effects in healthy tissue
- Challenges of higher conformality:
  - Patient repositioning
    - Difference(s) between planning CT and first fraction
    - Differences between fractions
  - Anatomical changes
    - Patient repositioning
    - Cardiorespiratory movements
    - Bowel movements
    - Tumor or healthy tissue shrinkage/swelling/growth

2. RTmonitor: dose monitoring in RT

2.1 Concept

- Detection of photons at approximately right angles
- Determination of positional deviations from the planning
- Real-time dose monitoring*
- Allows for potential intervention whenever needed, without additional dosage to the patient



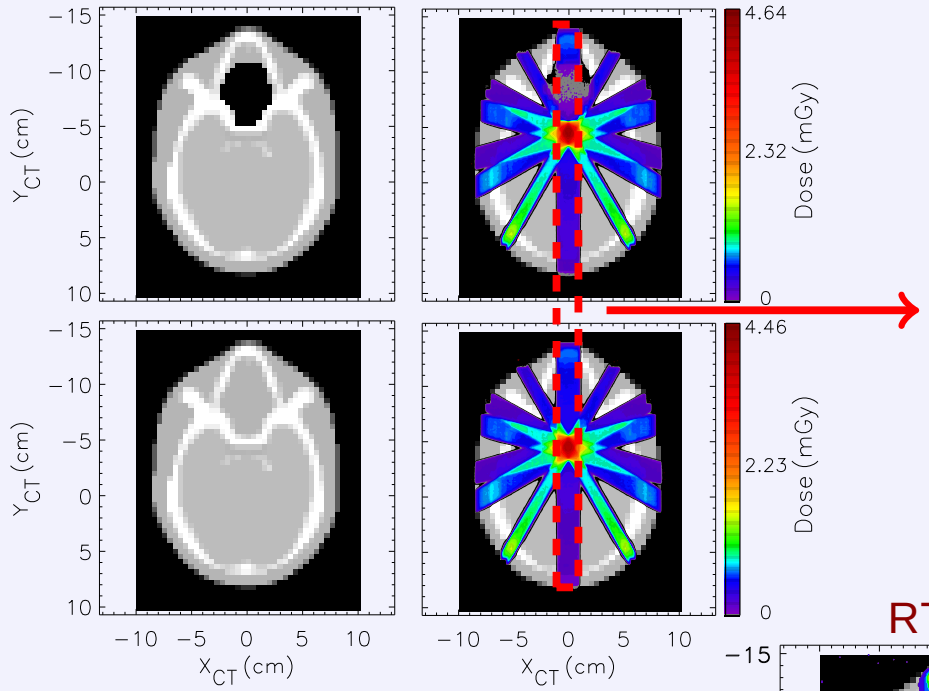


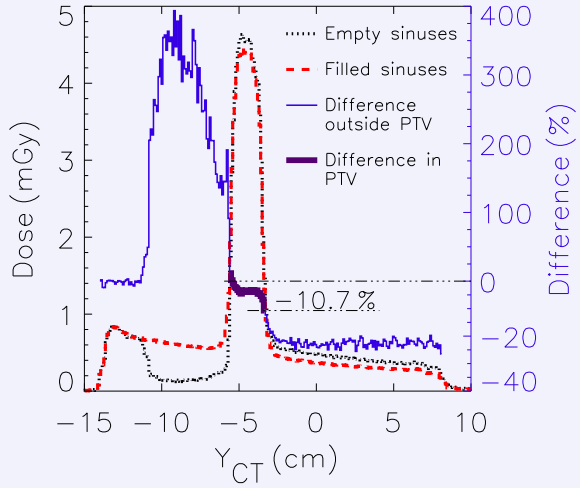
* Cunha et al (2013) IEEE TNS
* Simões et al (2013) IEEE TNS
* Battaglia et al (2012) IEEE NSS & MIC

2. RTmonitor: dose monitoring in RT

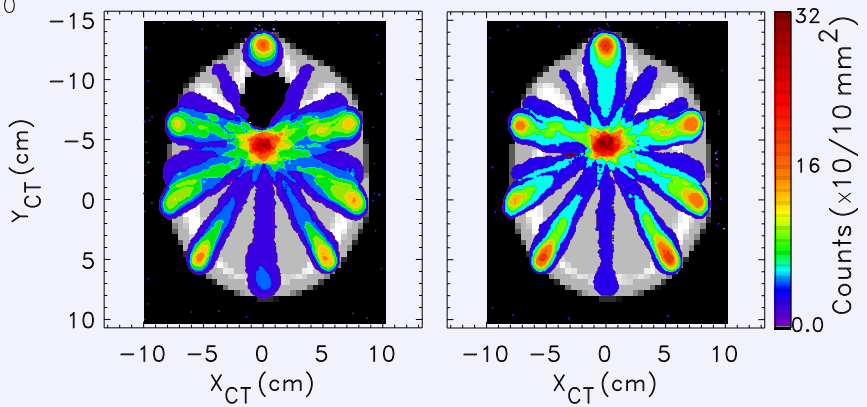
2.2 Simulated results: head (preliminary)

- Filling of nasal sinuses





RTMONITOR IMAGES

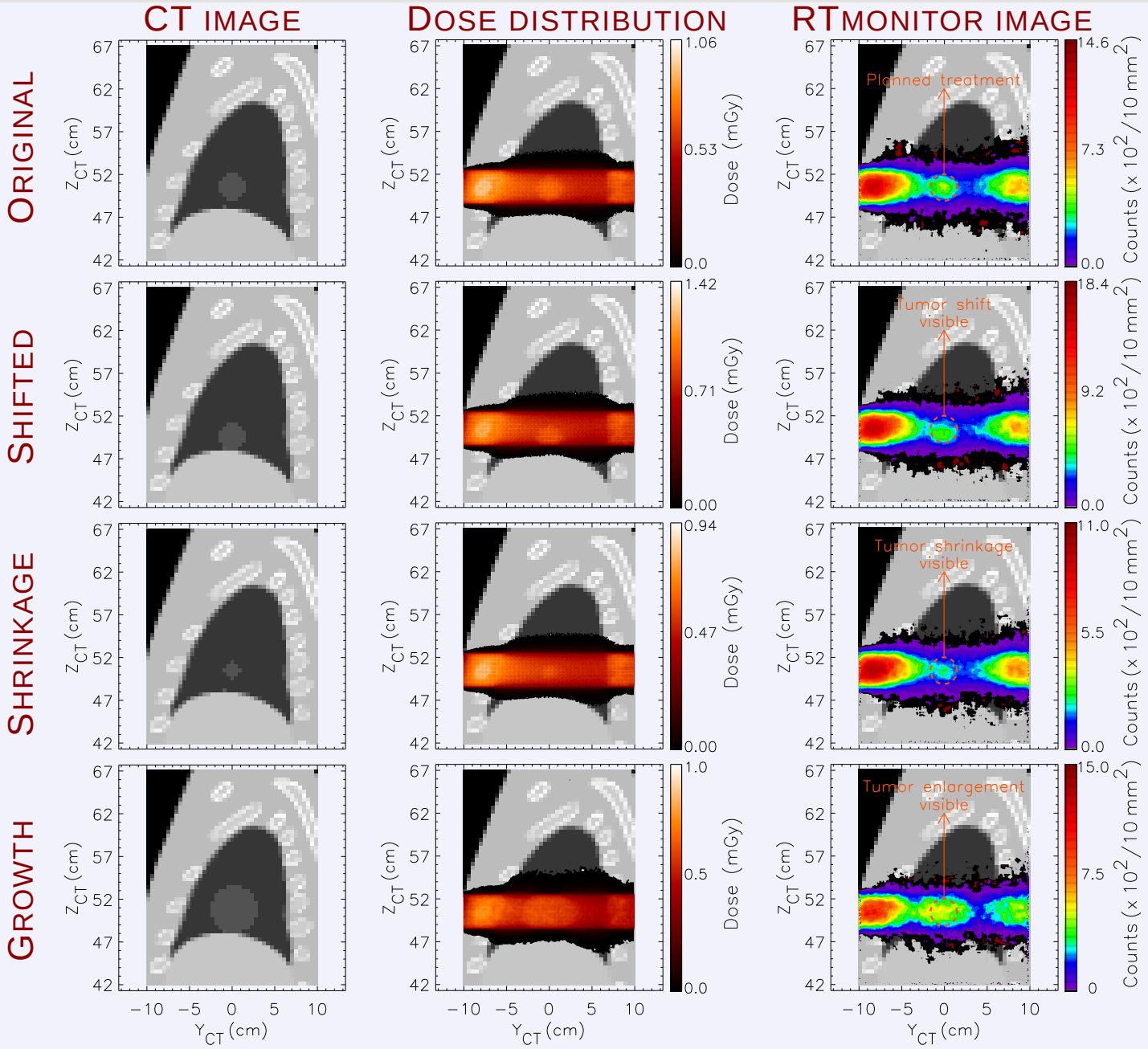


Morphologic change detectable with RTmonitor imaging

2. RTmonitor: dose monitoring in RT

2.3 Simulated results: lung (preliminary)

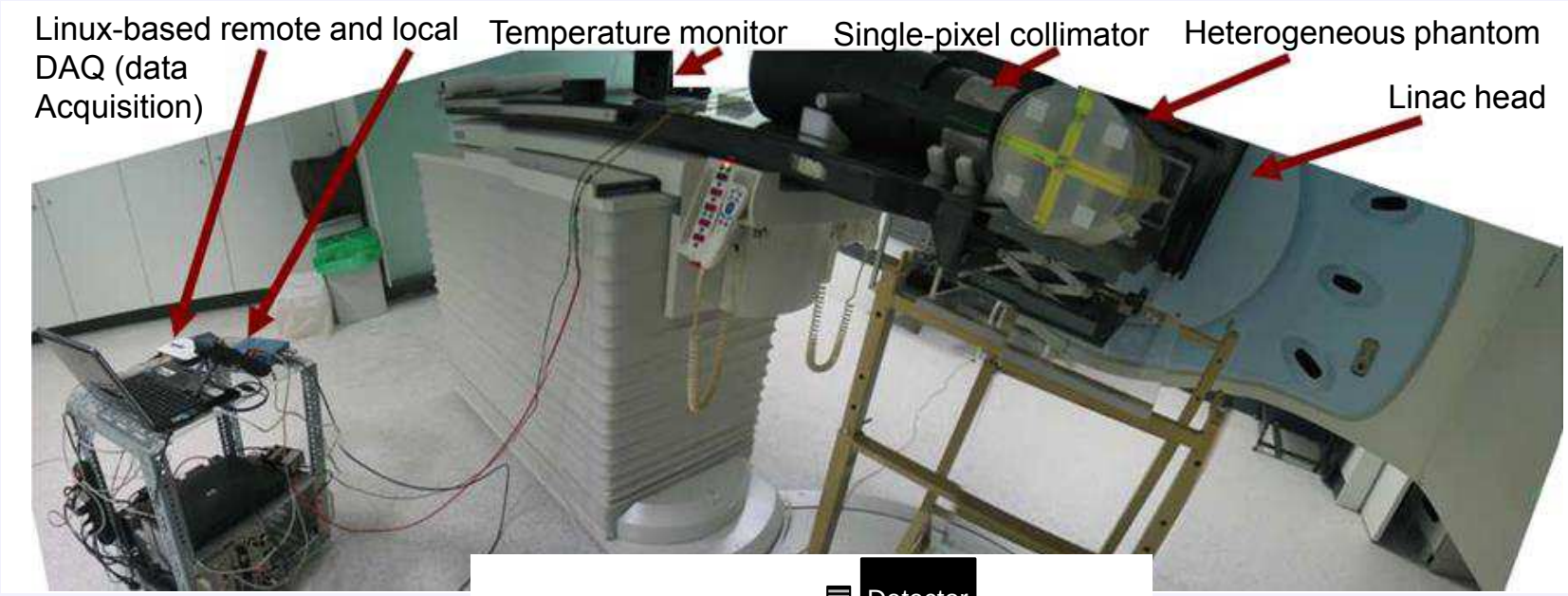
- Tumor movement or tumor shrinkage/growth

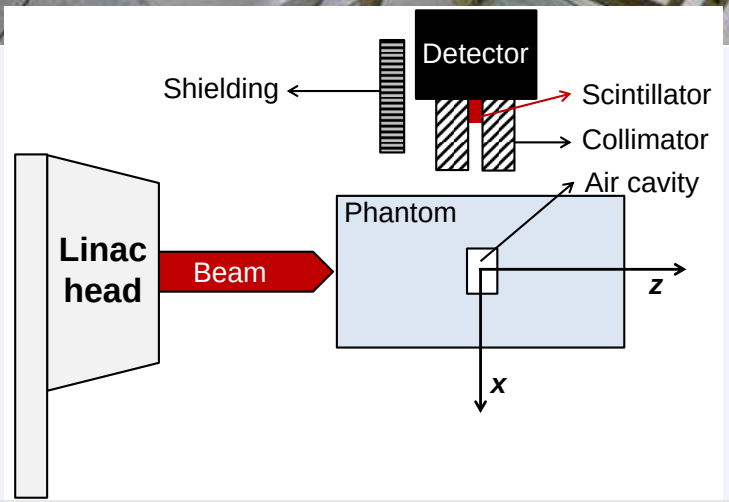


2. RTmonitor: dose monitoring in RT

2.4 Experimental results with a PMMA phantom

Setup implemented at IPOCFG, E.P.E. (IPO-Coimbra)

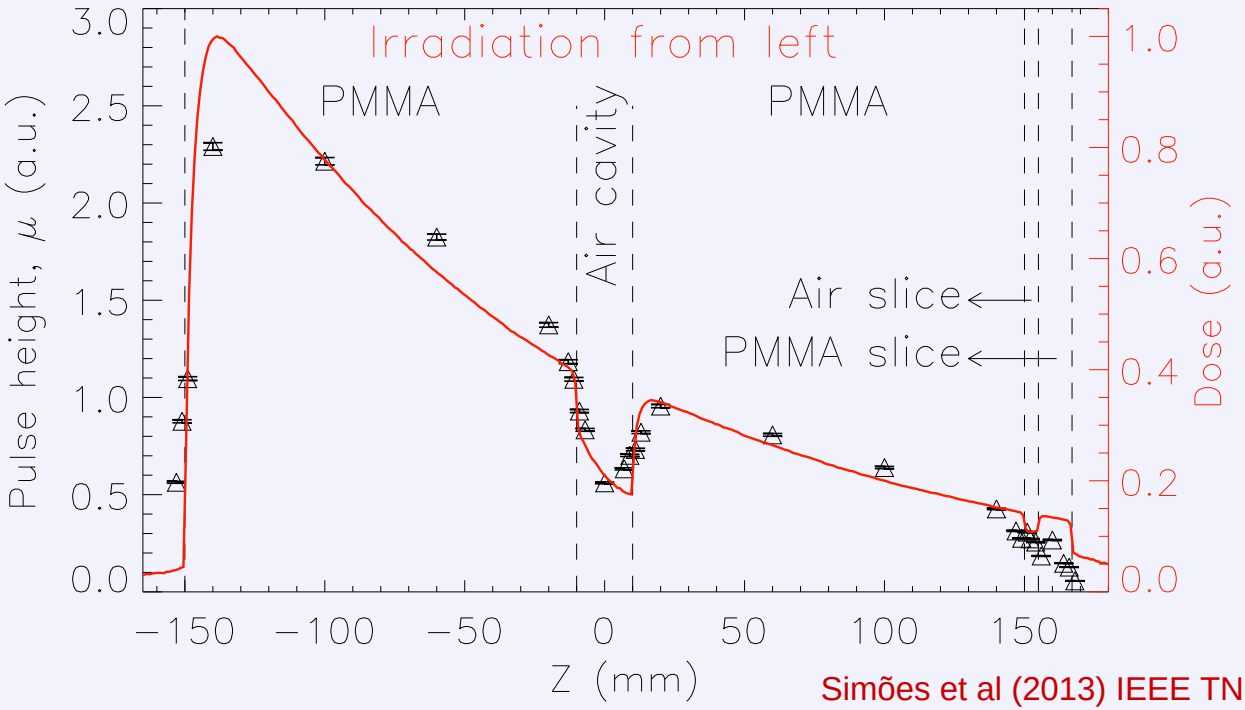




2. RTmonitor: dose monitoring in RT

2.4 Experimental results with a PMMA phantom

- Good visual correlation between measured data and simulated dose profile
- First-attempt data (detector with poor spatial resolution). Improved system ongoing.
- Two-millimeter phantom displacement clearly discernible (not shown).



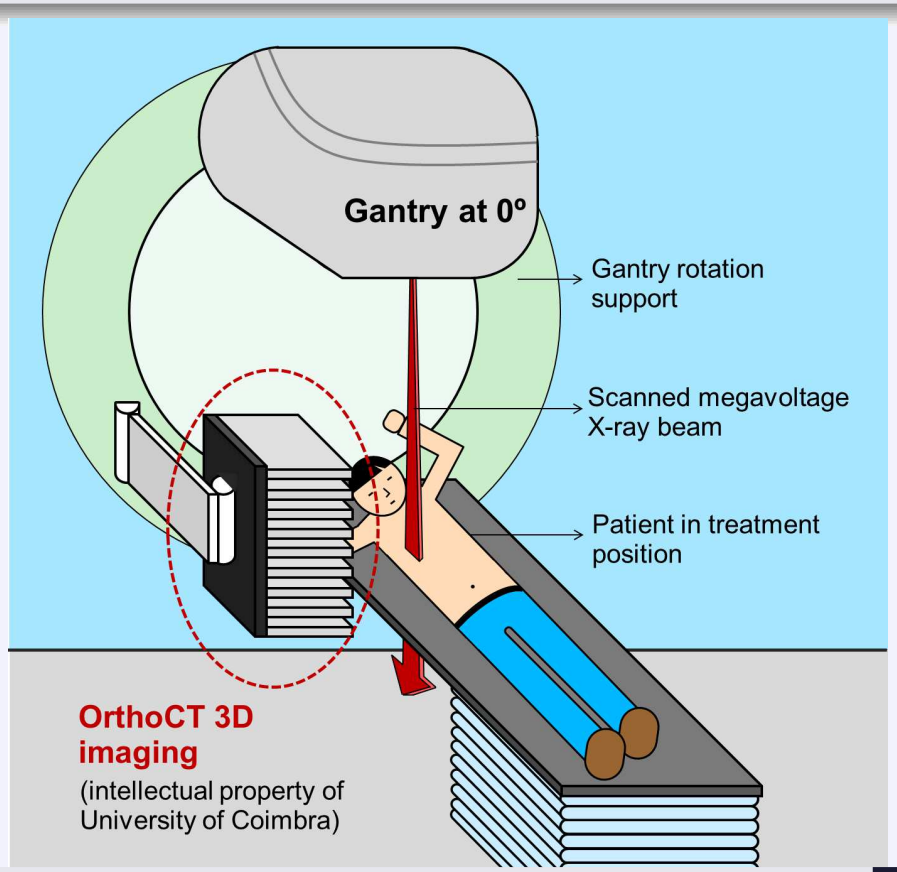
Simões et al (2013) IEEE TNS
Simões et al (2012) IEEE NSS&MIC

3. OrthoCT: low-dose morphologic imaging

3.1 Concept

- 3D imaging: a pencil-like photon beam traverses the patient at known coordinates (2D); the detector slice hit by an emerging photon yields the 3rd coordinate
- Scan area can be limited to the tumor only: organs at risk with minimal to null dose exposure
- Allows for targeted, on-board imaging with low dose

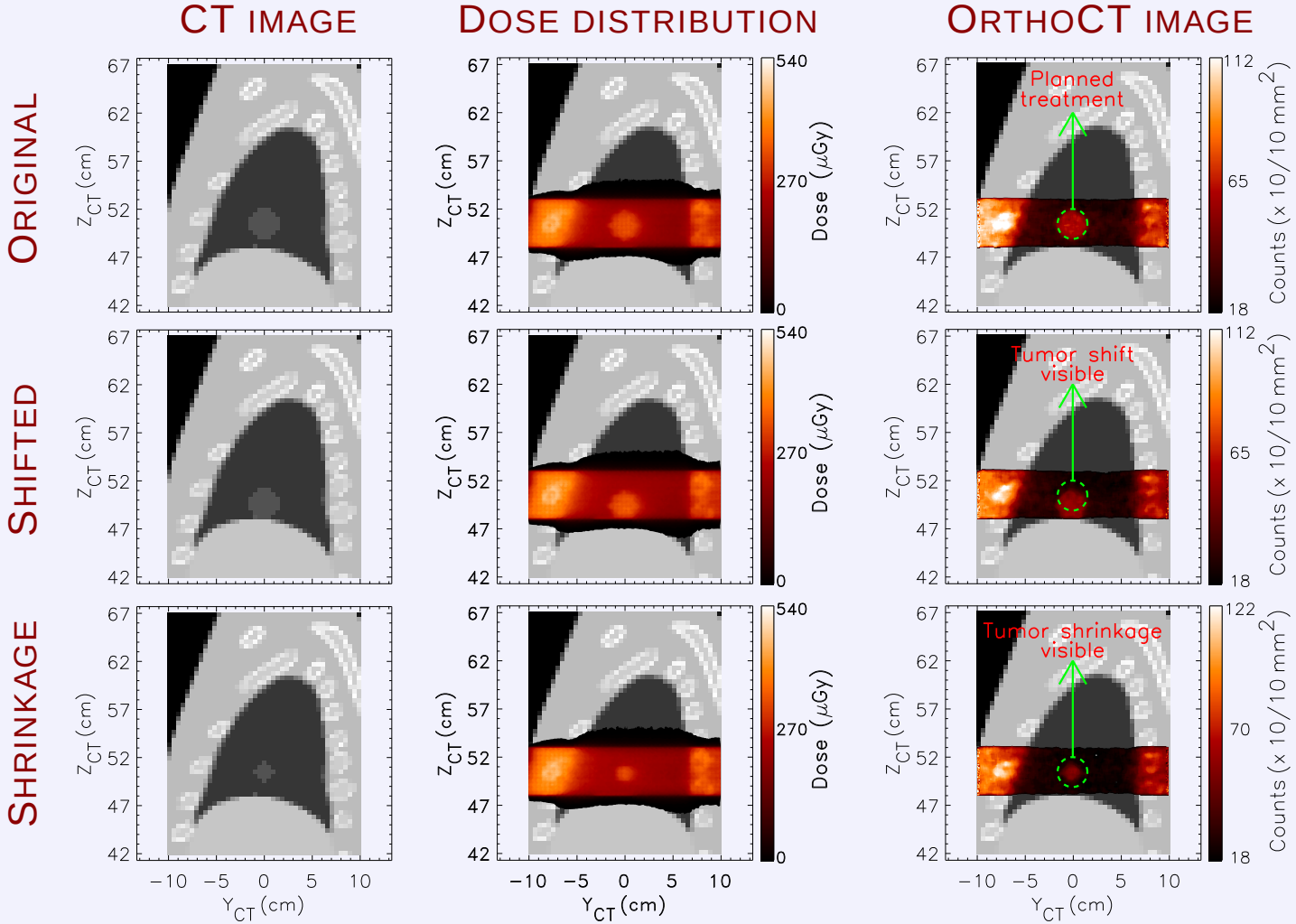
Simões et al (2012) IEEE NSS&MIC
Battaglia et al (2012) IEEE NSS&MIC



3. OrthoCT: low-dose morphologic imaging

3.2 Simulated results: lung (preliminary)

- Tumor movement or tumor shrinkage



4. Conclusions and ongoing work

Conclusions:

- RTmonitor images show high visual correlation with the prescribed dose and with patient structures, representing a high potential asset for IGRT, ART, and in-vivo dose verification.
- Even at very low doses, OrthoCT shows high visual correlation with (1) phantom anatomical structures and (2) tumor in lung region.
- The experimental results are promising; a good correlation between the experimental profile and the simulated dose has been obtained.
- Working only with experimental raw data, a phantom deviation of 2 mm has already been detected.

Ongoing work:

- Investigate the usefulness of orthogonal ray imaging (RTmonitor & OrthoCT) techniques to assist other cancer modalities (e.g. prostate, breast).
- Parameterize and build two small multi-pixel prototypes (RTmonitor & OrthoCT) and test them in RT environments.

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Thank you

for your attention