Orthogonal-ray imaging for radiotherapy and computed tomography

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[5] Was with Laboratório de Instrumentação e Física Experimental de Partículas – Coimbra

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Outline

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Acknowledgments

1. Motivation

Dose monitoring in radiotherapy

Cancer incidence in 2008

- 12.7 millions worldwide (*Jemal A, CA Cancer J Clin 2011*)
- 3.2 millions in Europe
- 2.4 millions in EU

(*Ferlay J, E J Cancer 2010*)

4800 new cases / year / million inhabitants

In the EU, about half of the cases have RT as therapeutic, in some stages of treatment; in 63% of the cases, RT is applied with curative intent (*Lopes MC, Gaz. Física 2007*).

- External beam radiation therapy (RT) is the use of radiation in order to treat solid tumors
- Modern RT allows for increasingly higher conformality
- Such conformality aims at maximizing radiation effects and minimizing side effects
- However high conformality requires high precision and accuracy in the monitoring techniques

1. Motivation

Dose monitoring in radiotherapy

Treatments uncertainties:

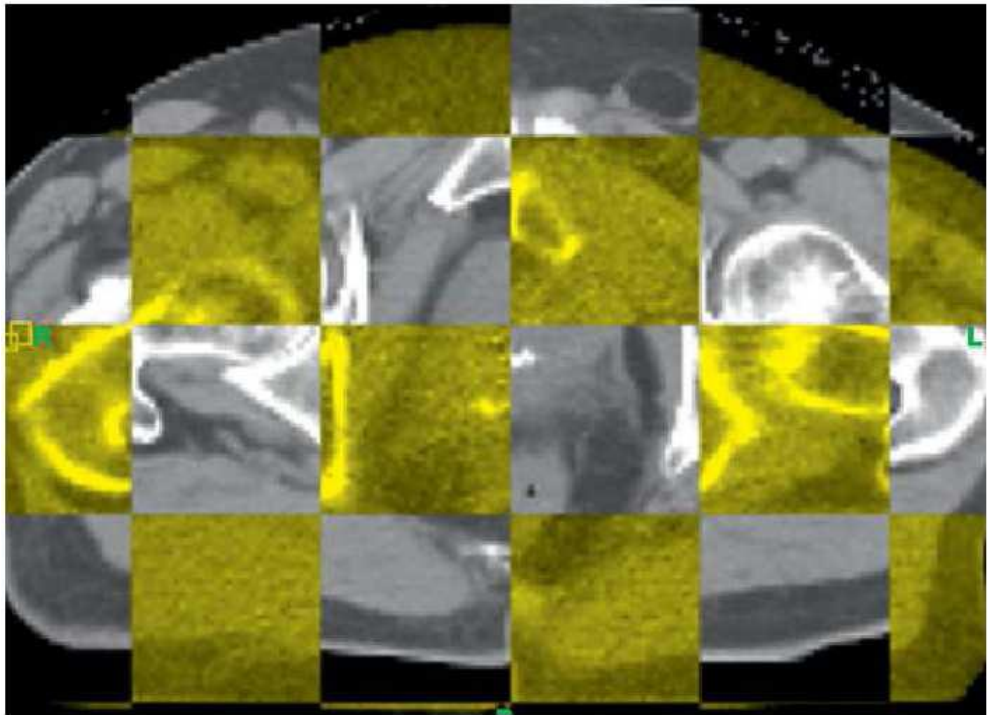
- Patient mispositioning
- Anatomical and/or morphological changes
- Beam-associated uncertainties
- Other

Potencial effects:

- Tumor underdosage
- Healthy-tissue overdosage
- Unknown effects

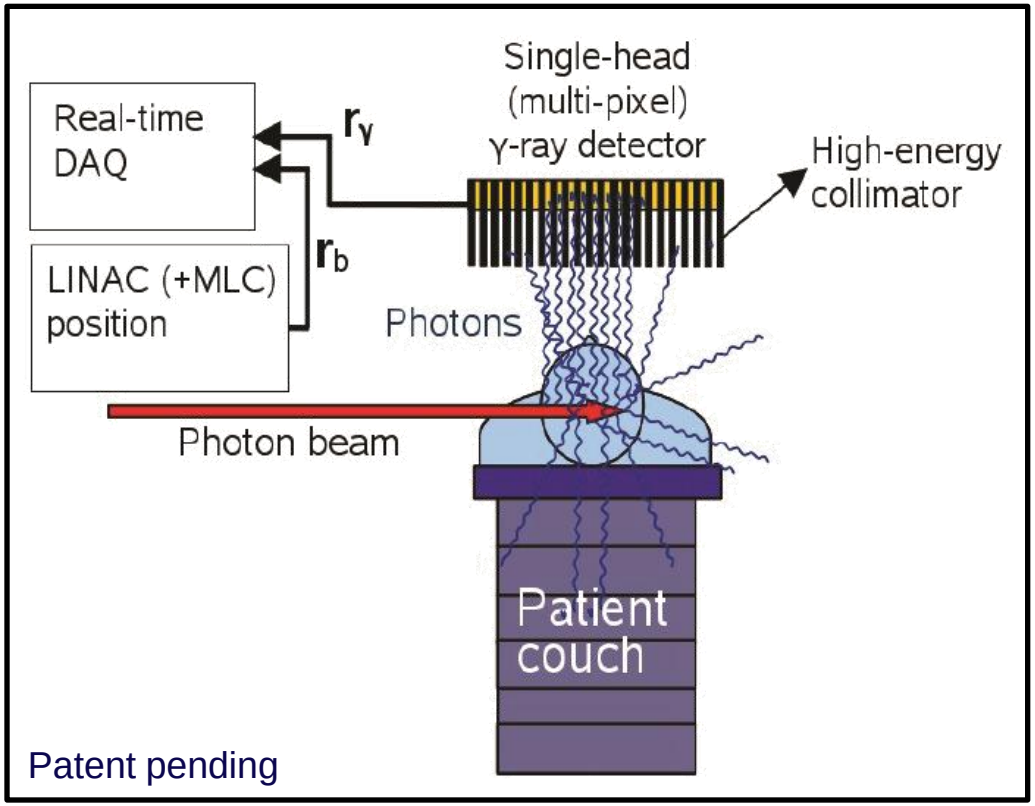
IGRT:

- The state-of-the-art solution for RT monitoring is image guided radiation therapy (IGRT)
- IGRT uses imaging, motion tracking, and/or localization systems in order to try monitoring dose delivery
- IGRT allows for adaptive radiation therapy (ART)



(Sterzing et al., Dtsch Arztebl Int. 2011)

2. Concept: RTmon

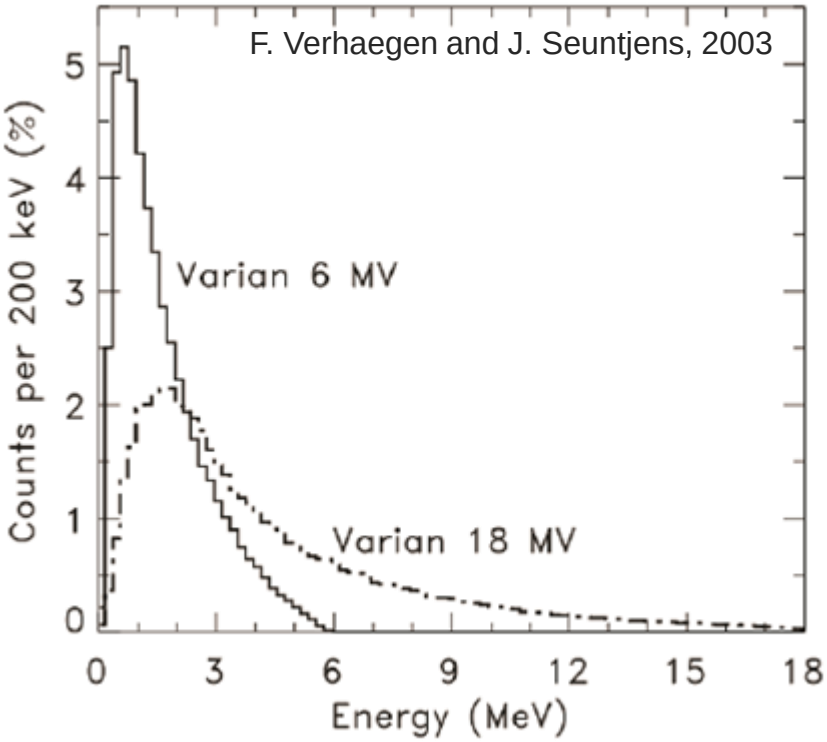


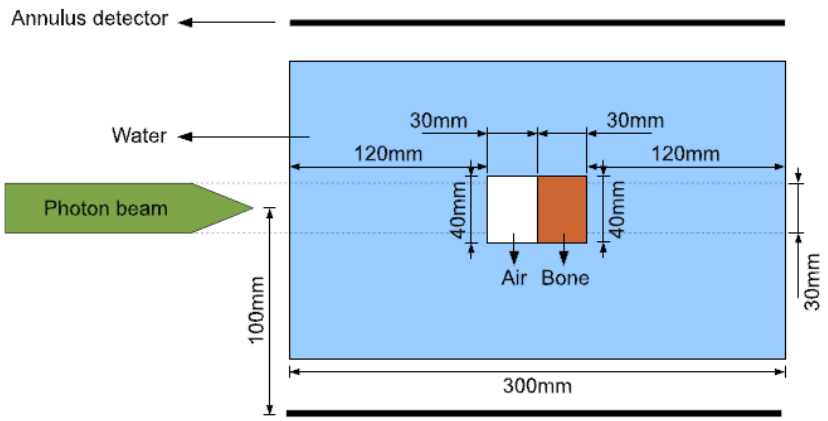
- Detection of photons at approximately right angles
- Spatial information obtained through the correlation between detected events and beam spatial location
- Determination of positional deviations from the planning
- Real-time dose monitoring
- Allows for potential intervention whenever needed (ART), without whatsoever additional dosage

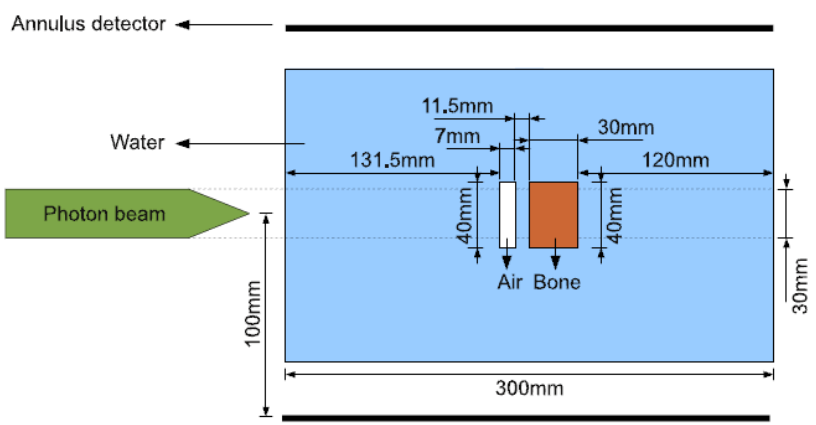
Cunha et al, 2011 IEEE NSS MIC, **MIC11-5**

3. Materials and methods

- Simulations: Geant4 version 9.4p01, emstandard_opt3 physics list
- Irradiation: 30-mm-diameter beam with no divergence
- Only perfect detectors used
- Irradiation with published 6-MV and 18-MV linac spectra (figure at right)
- Fully-collimated system
- "Normal" and morphologically-altered patient-like phantoms (figure below)

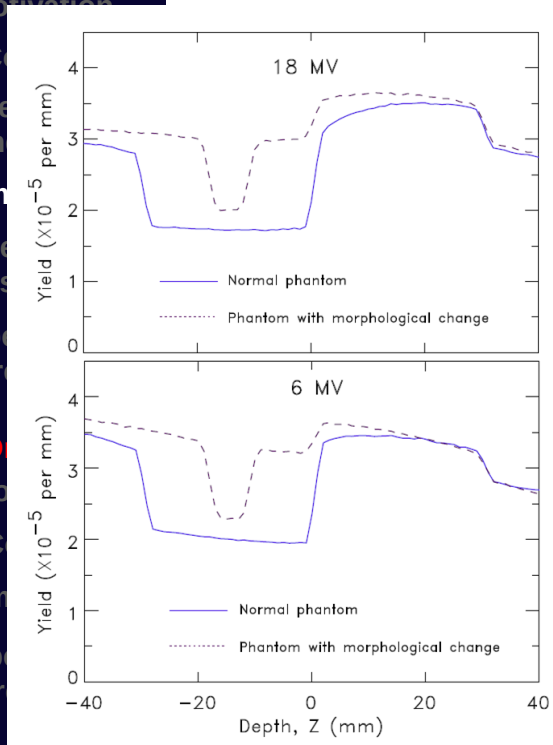


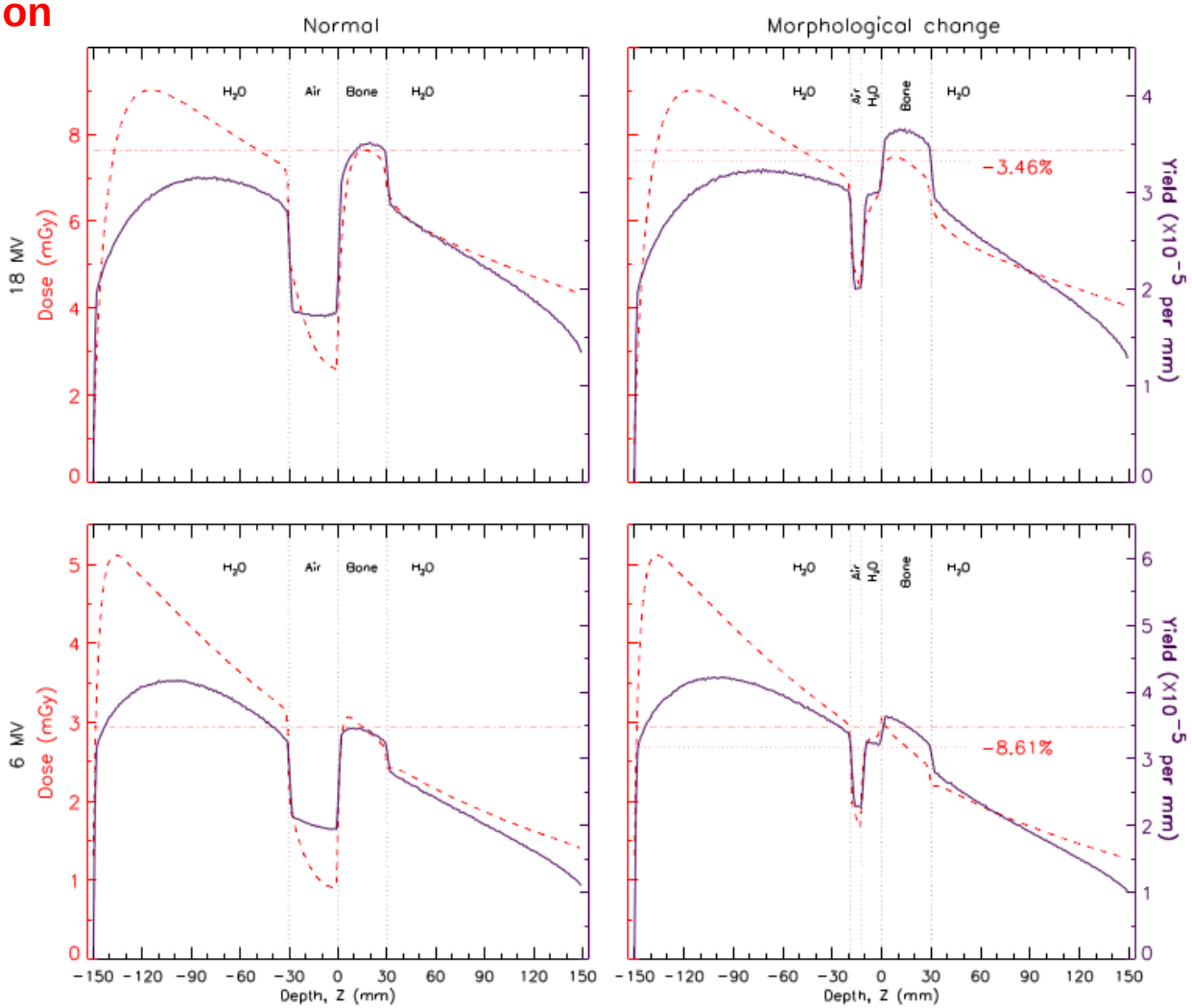




4. Simulated results with angle selection

Perfect collimation
90º ± 0.7º



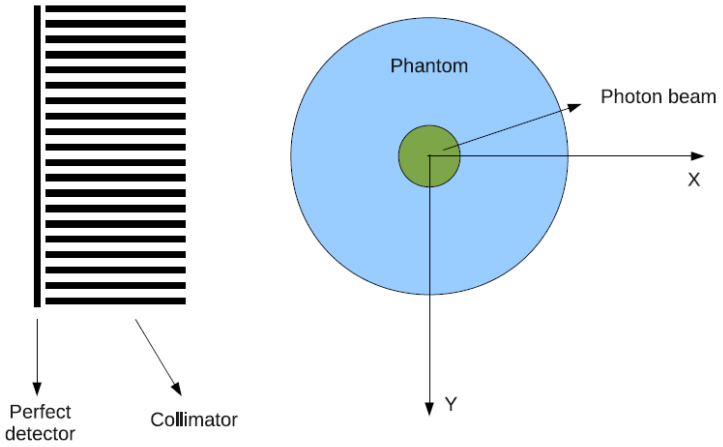


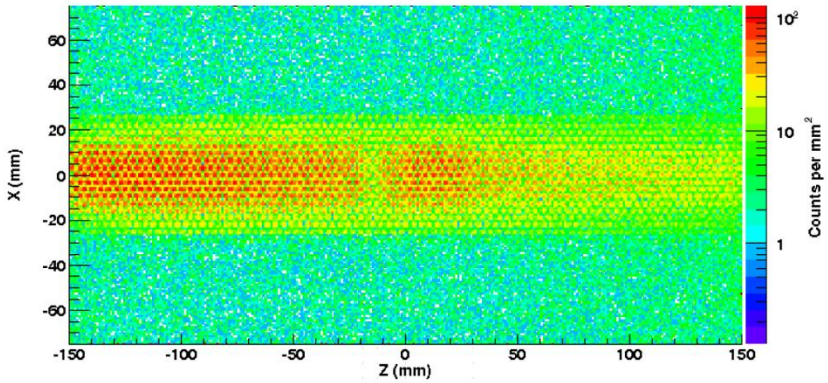
Comparison between collimated photon profiles and depth-dose profiles

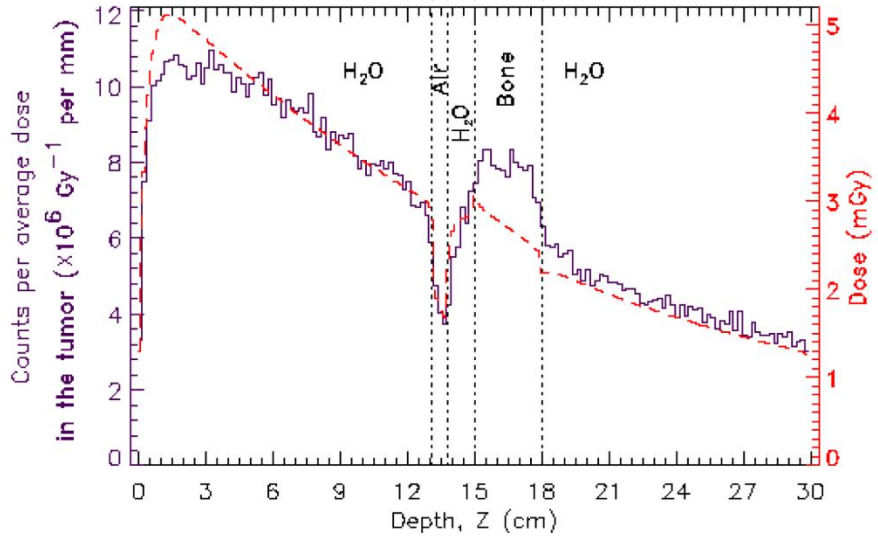
Cunha et al, 2011 IEEE NSS MIC, **MIC11-5**

5. Simulated results with a collimator

Hexagonal-hole lead collimator (300×150 mm^2)



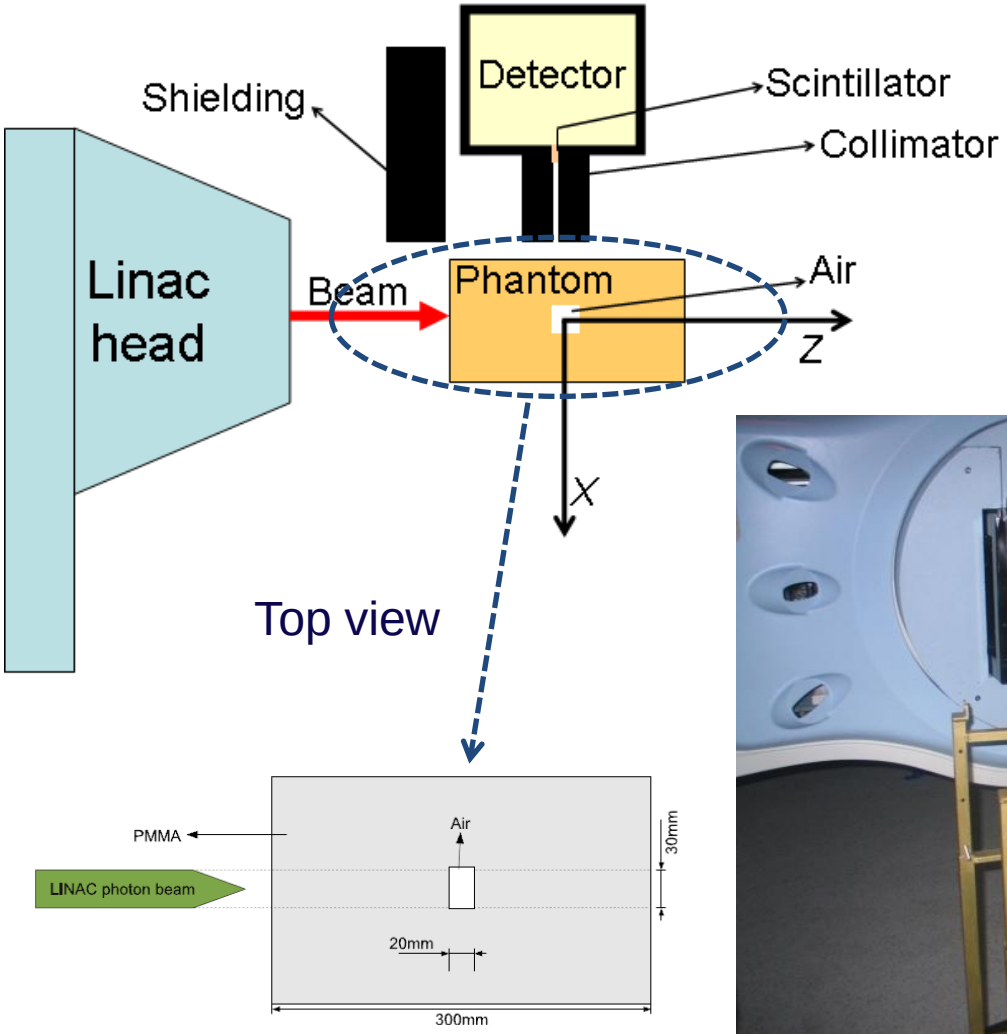




- **Top**: 2D hit count histogram
- **Bottom**: simulated dose profile and counts profile

Cunha et al, 2011 IEEE NSS MIC, **MIC11-5**

6. Experimental setup

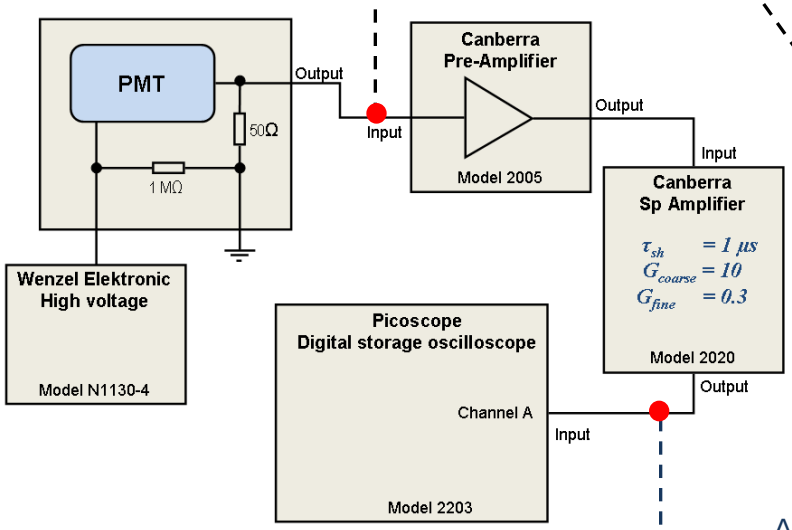


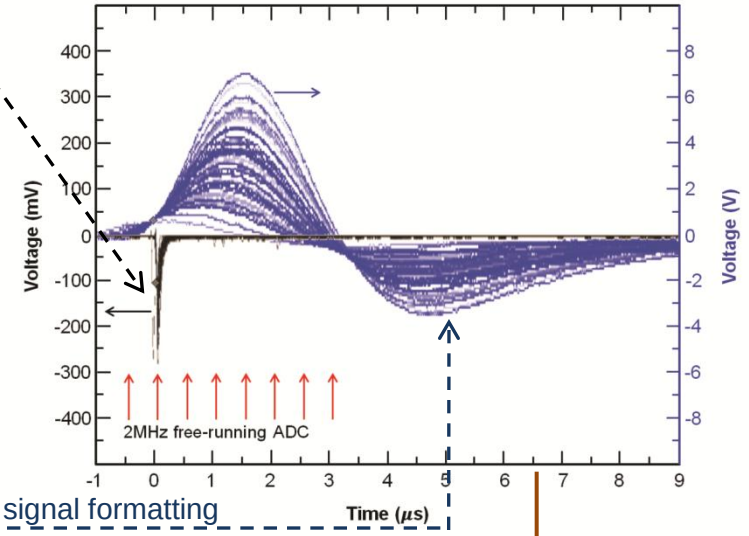
Side view

Simões et al, 2011 IEEE NSS MIC, **MIC21.S-258**

7. Data acquisition and processing

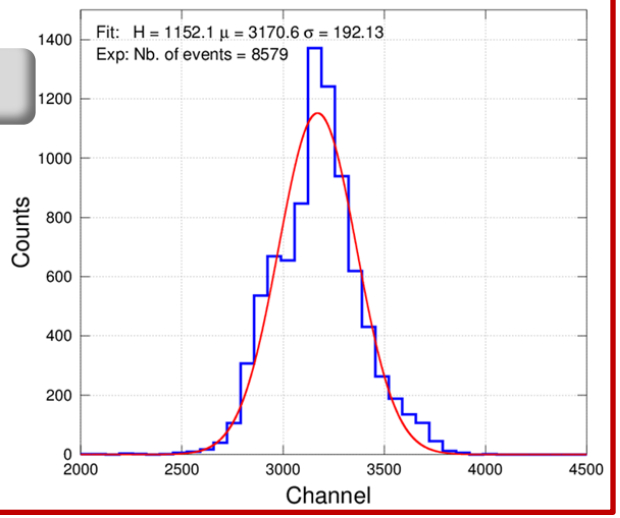
Time:

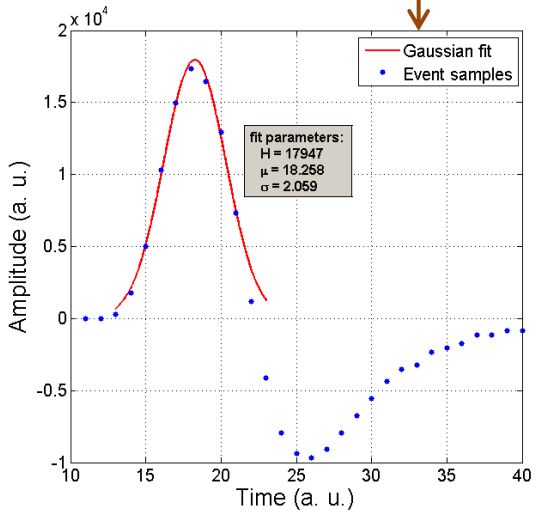




Energy:

Pulse height spectra





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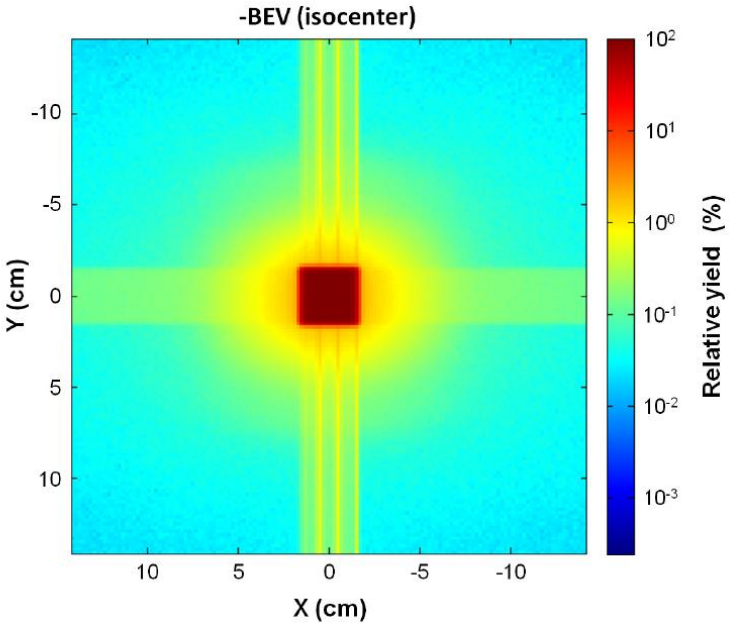
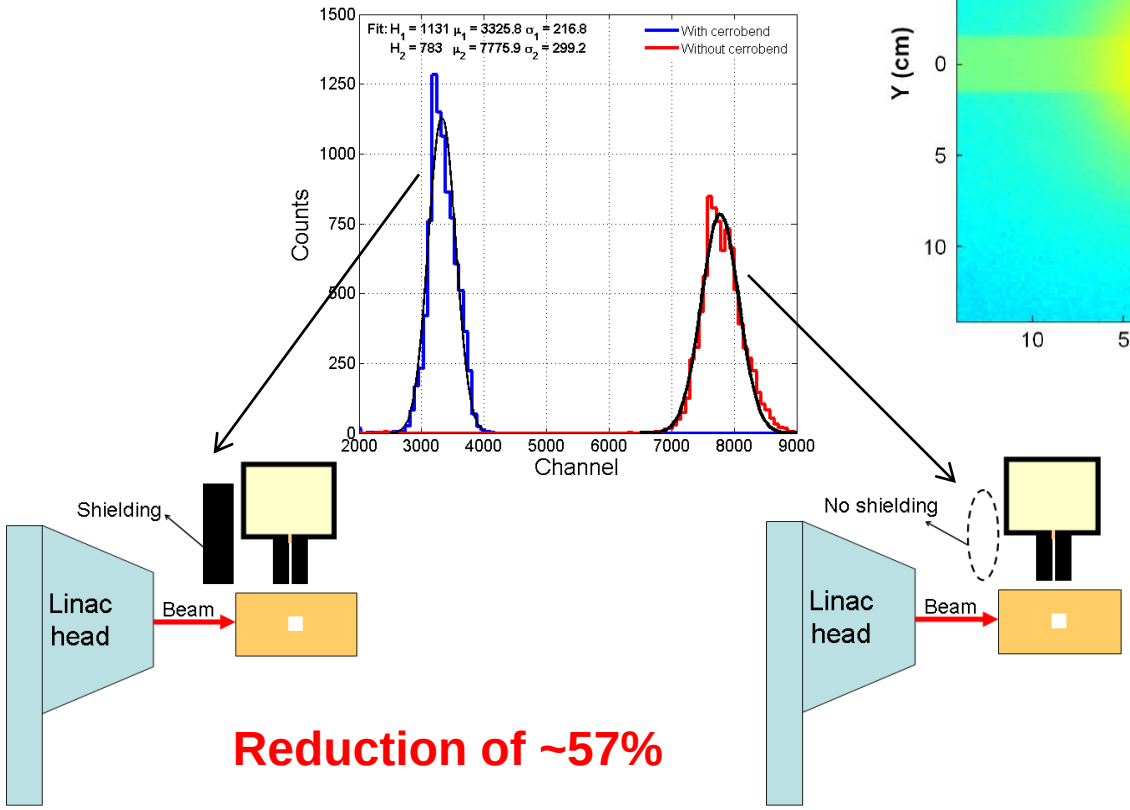
8. Experimental Results

Background from linac head

EGSnrc simulation of a 3x3 cm² field of a 6 MV photon beam (Siemens PRIMUS™)



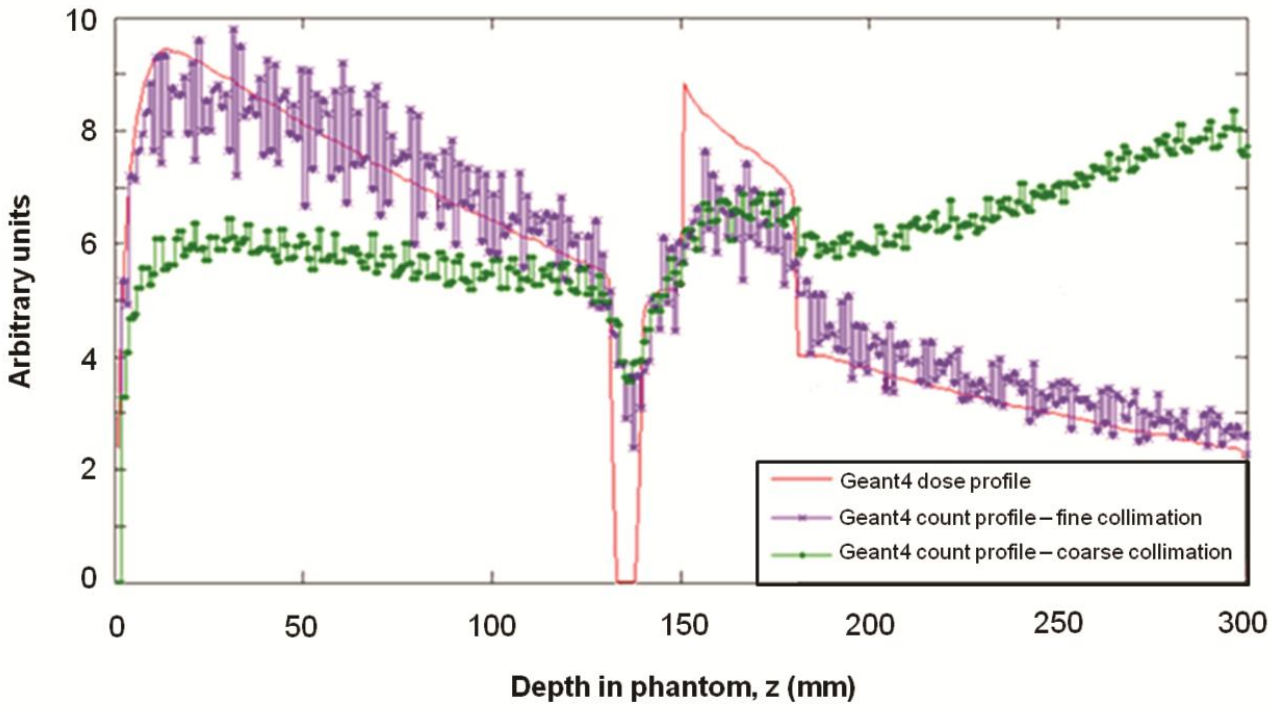


Reduction of ~57%

Simões et al, 2011 IEEE NSS MIC, **MIC21.S-258**

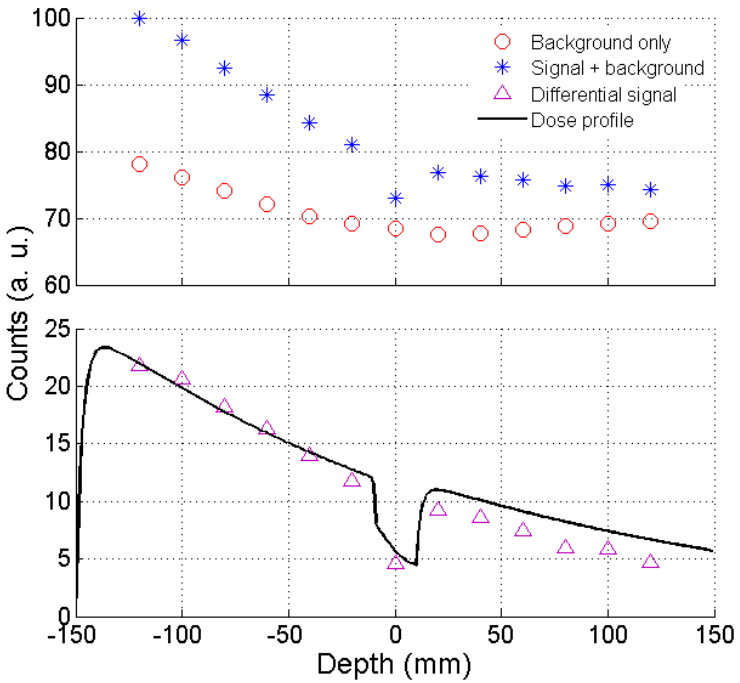
8. Experimental Results

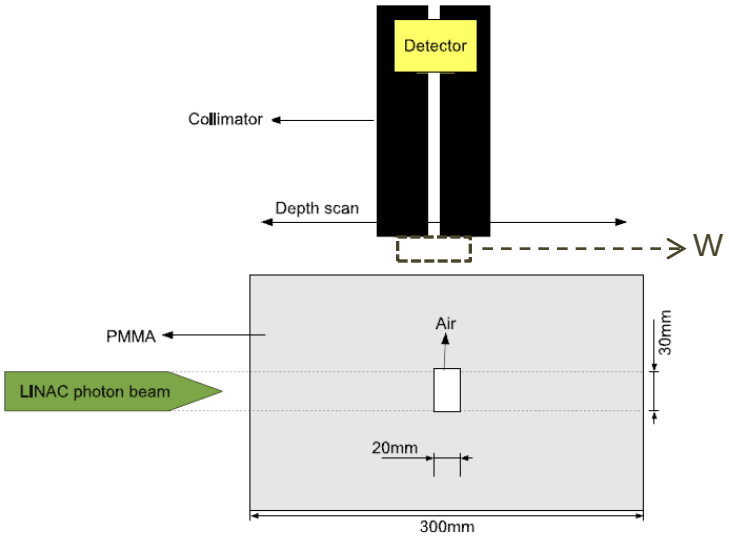
Background from linac head + influence of collimator

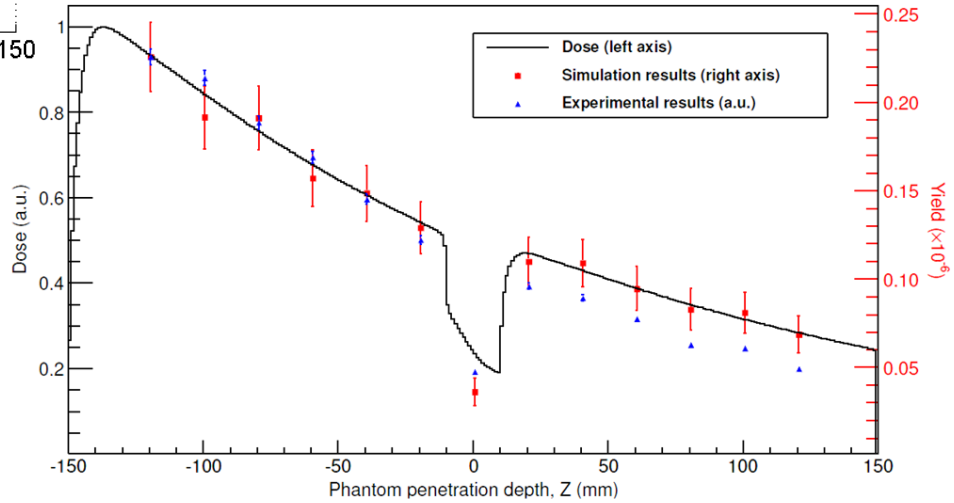


Influence of collimation: course collimation vs. fine collimation

8. Experimental Results



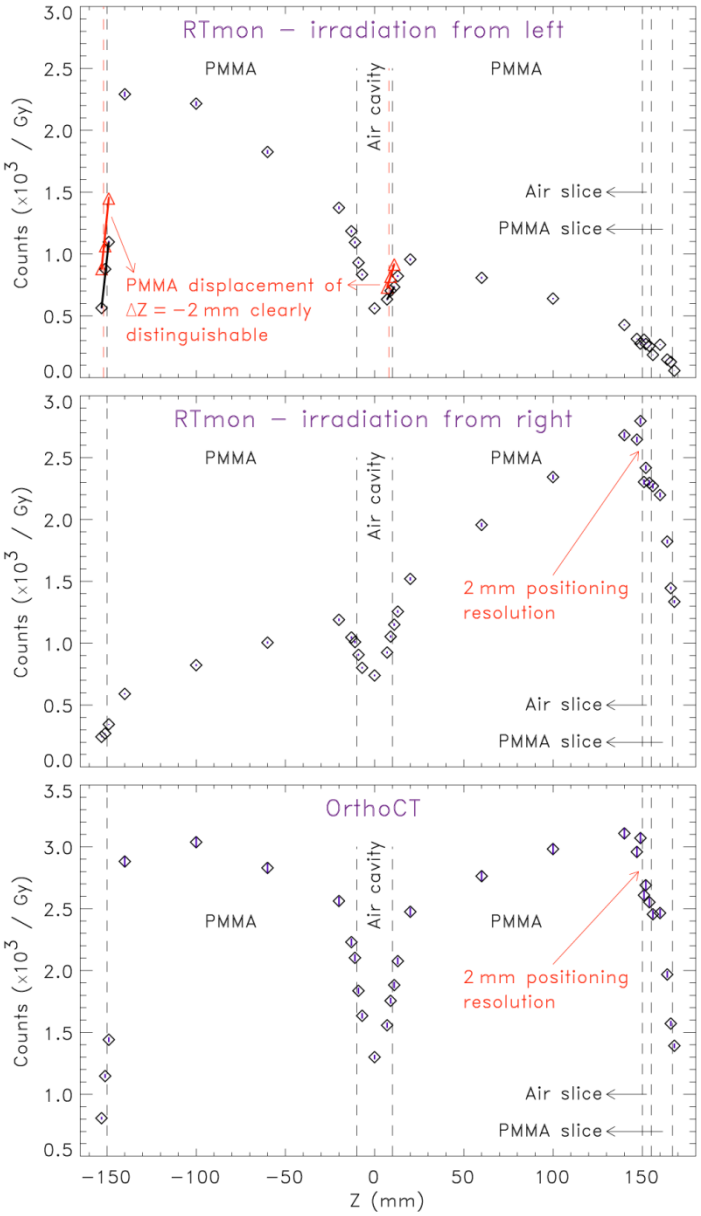




Good correlation between experimental and simulated results, and also with simulated dose.

Simões et al, 2011 IEEE NSS MIC, **MIC21.S-258**

What if two scans are performed in opposite directions?



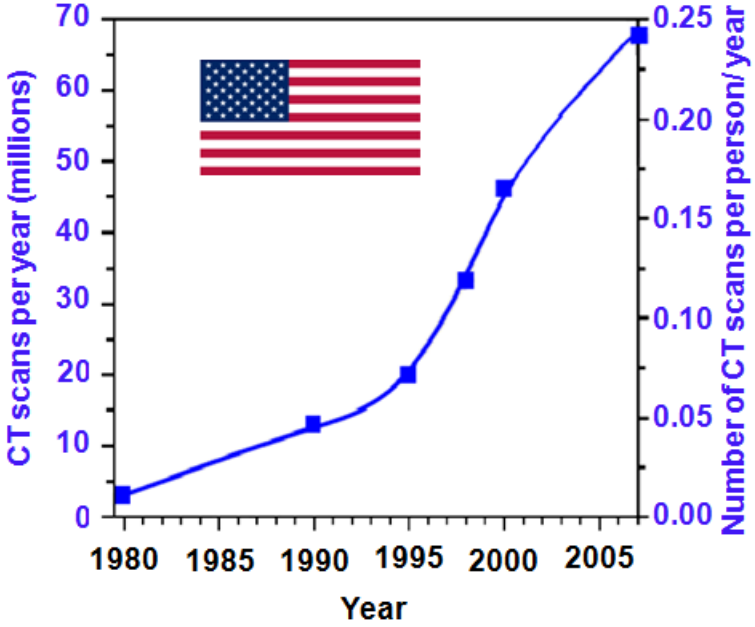
9. Motivation

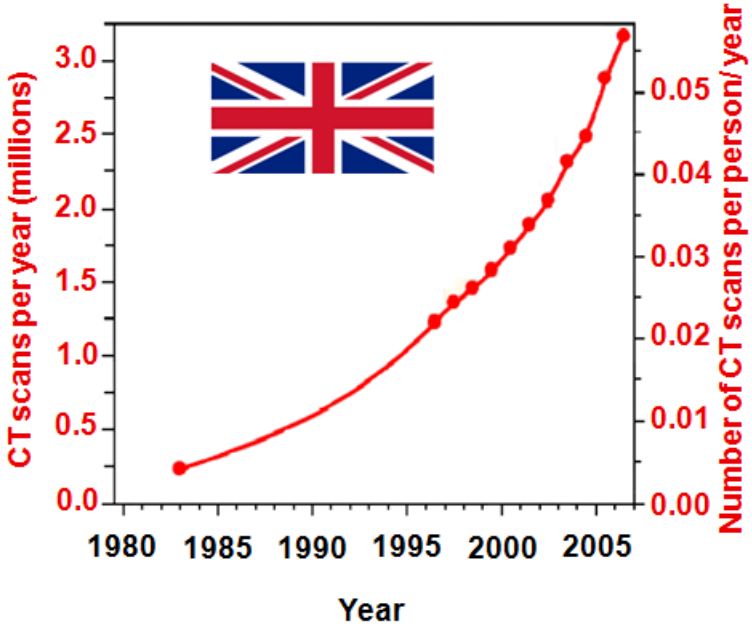
Side effects of dose from diagnostics and screening with CT

- CT scanning is a medical imaging procedure that uses X-rays to show cross-sectional images of the body.

- Allows doctors to inspect inside the body in a non-invasive way (e.g. pinpointing tumours and helping in the planning of radiotherapy treatments).

- Whole-body CT systems were introduced in 1976 and became widespread since the 1980s.





http://www.oecd-nea.org/rp/vaulx_de_cernay09/presentations/Geard%20CONSENT%20OK.pdf

9. Motivation

Side effects of dose from diagnostics and screening with CT

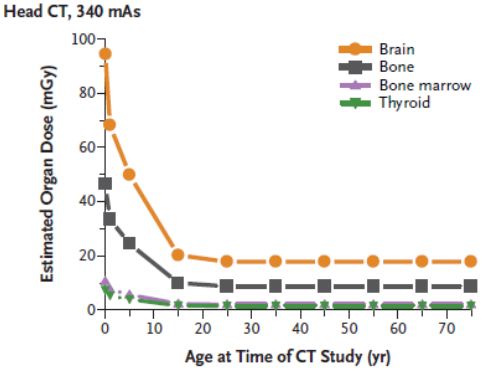
X-ray imaging constitutes the largest source of dose to the population at large due to artificial ionizing radiation. (Pedroso de Lima 2009, ISBN 978-989-8074-83-6)

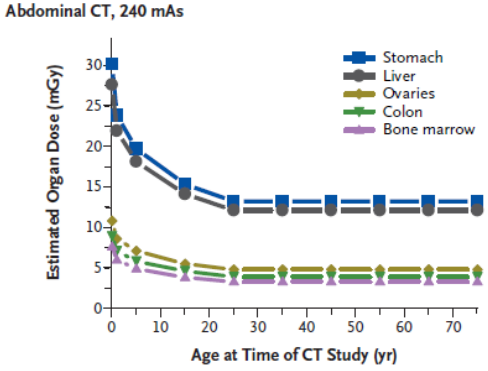
Diagnostic Procedure	Typical Effective Dose (mSv)	Equivalent No. of Single PA Chest Films
Conventional x-ray		
Chest (single PA film)	0.02	1
Pelvis	0.7	35
Abdomen	1.0	50
Computed tomography		
Head	2	100
Chest	8	400
Abdomen	10	500
Pelvis	10	500
PA = posteroanterior		

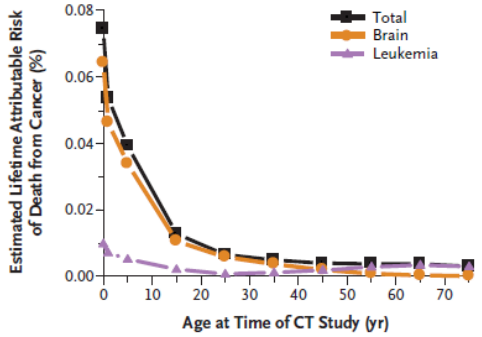
Fred H, *Texas Heart Institute Journal*, 31(4), 345-348, 2004

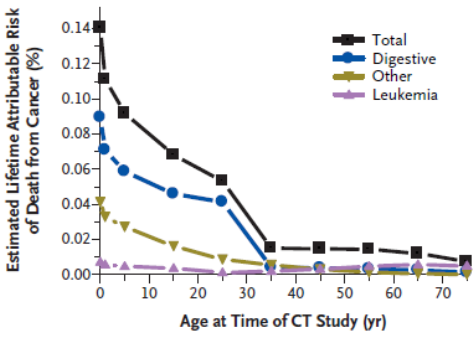
9. Motivation

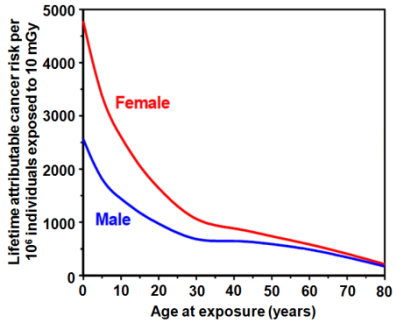
Side effects of dose from diagnostics and screening with CT

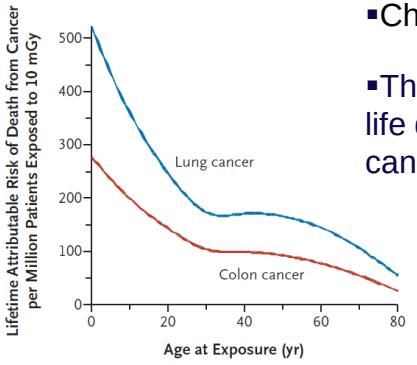








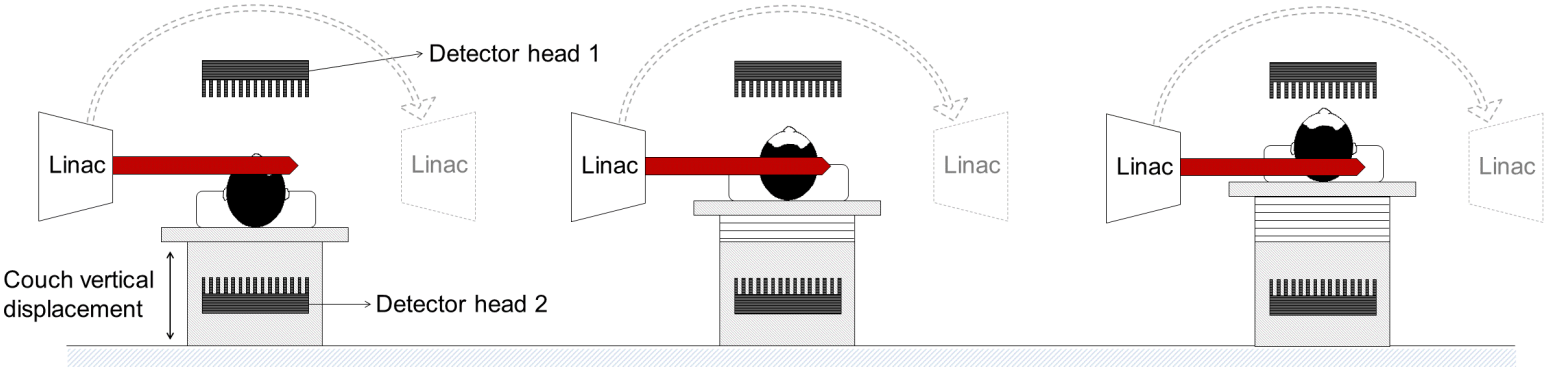


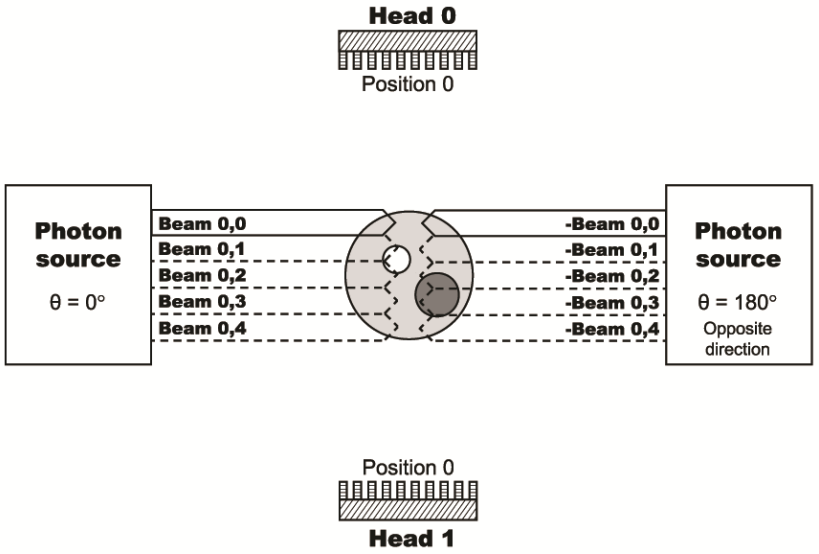


- Children are more radiosensitive
- They have more remaining years of life during which a radiation-induced cancer could develop

Brenner and Hall, N Engl J Med 357, 22, 2007

10. Concept: OrthoCT





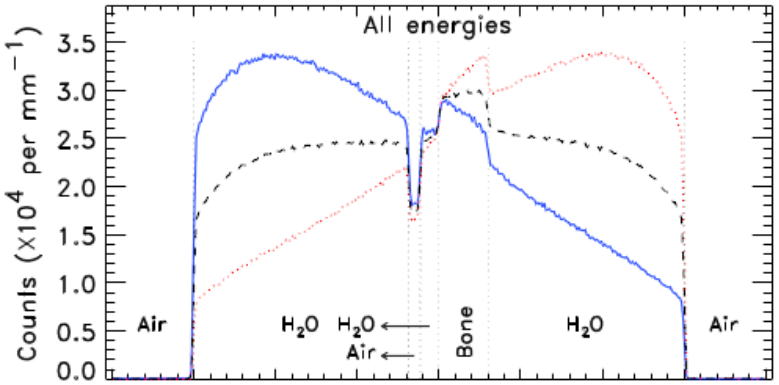
- Same principle as RTmon: detection of photons at approximately right angles
- But for each position, two scans in opposite directions are performed
- OrthoCT scan is obtained by combination of opposite scans
- Offers potentially rotation-free CT (faster scan? in-situ in radiotherapy?)

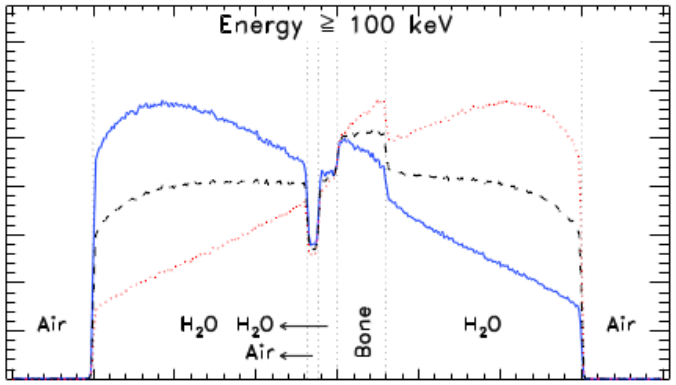
Provisional patent application

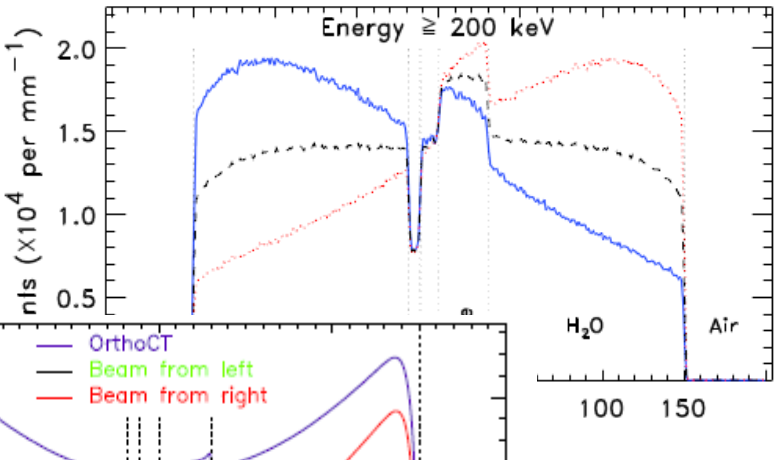
To be submitted

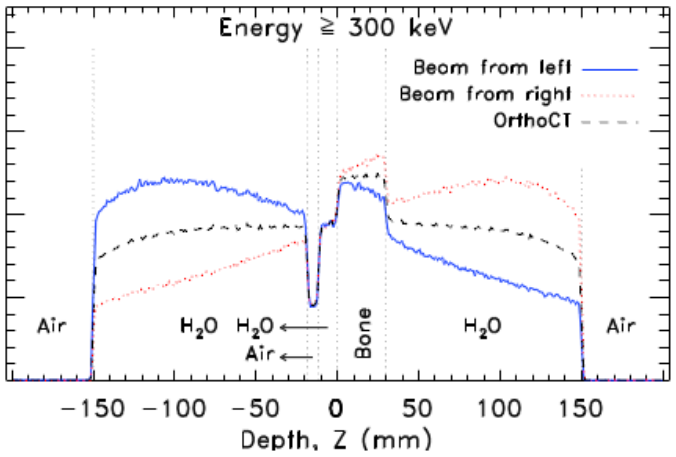
11. Simulated results with angle selection

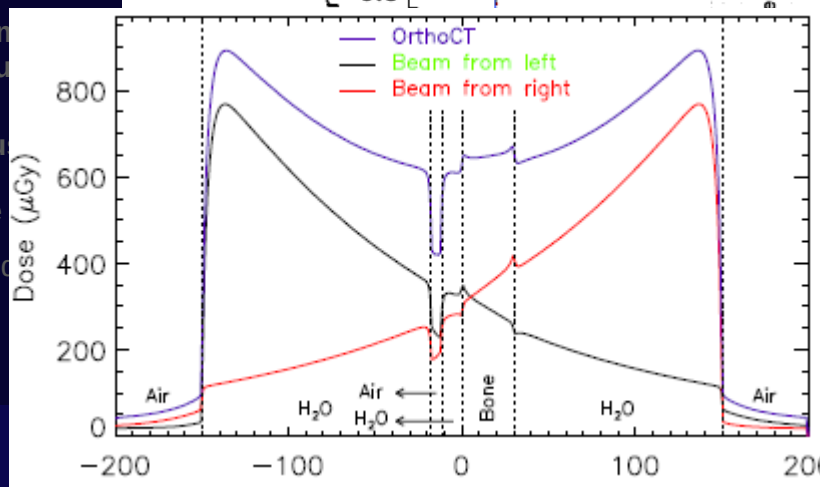
- **30 x 30 mm^2 (at isocentre) square beam WITH divergence (6-MV linac)**







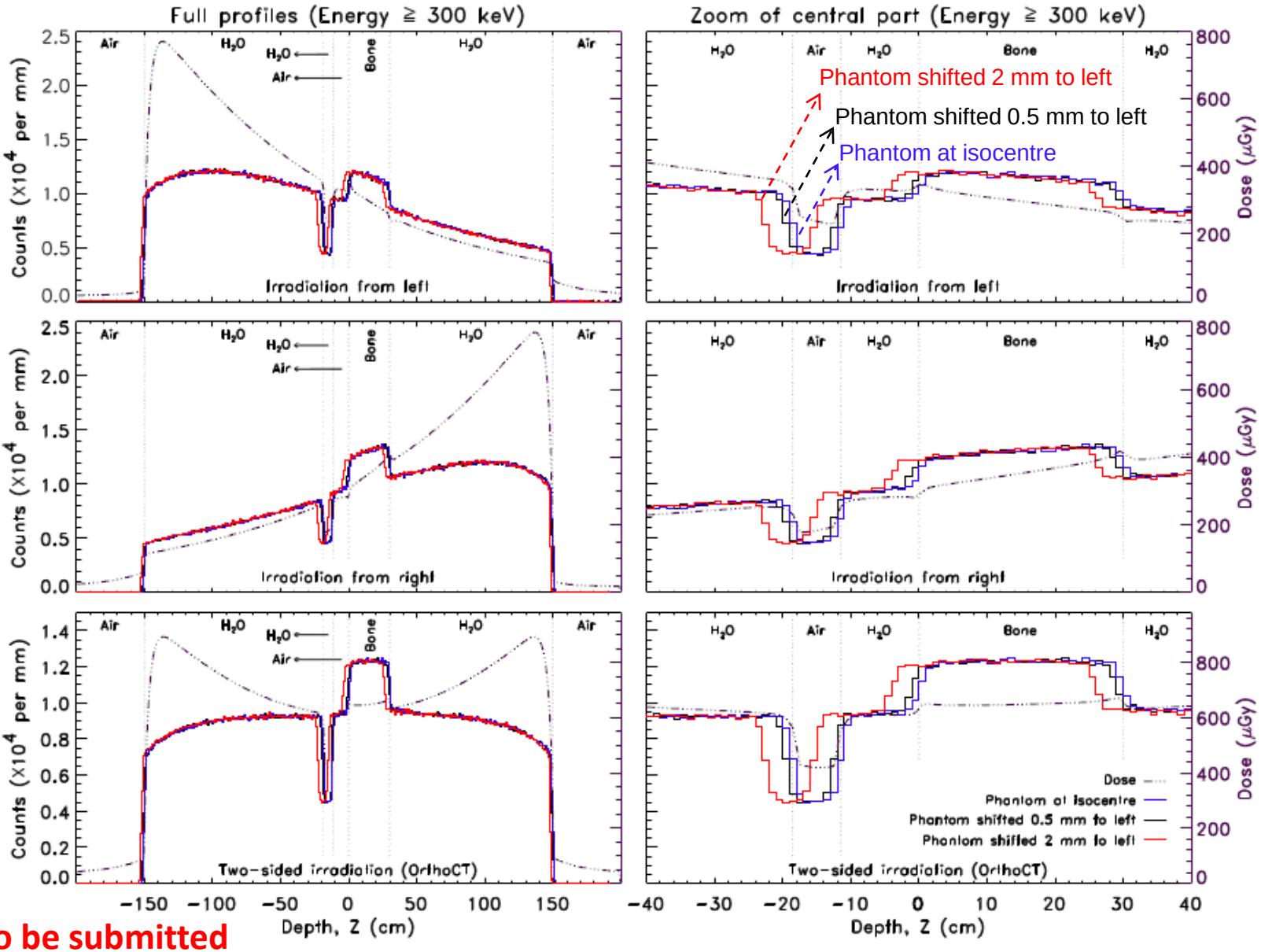




- Good contrast
- Ultra-low dose

To be submitted

11. Simulated results with angle selection

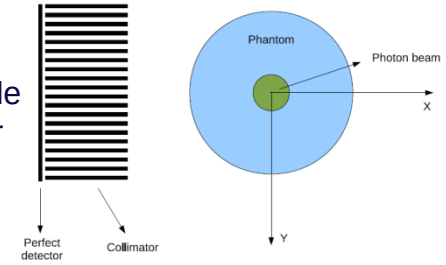


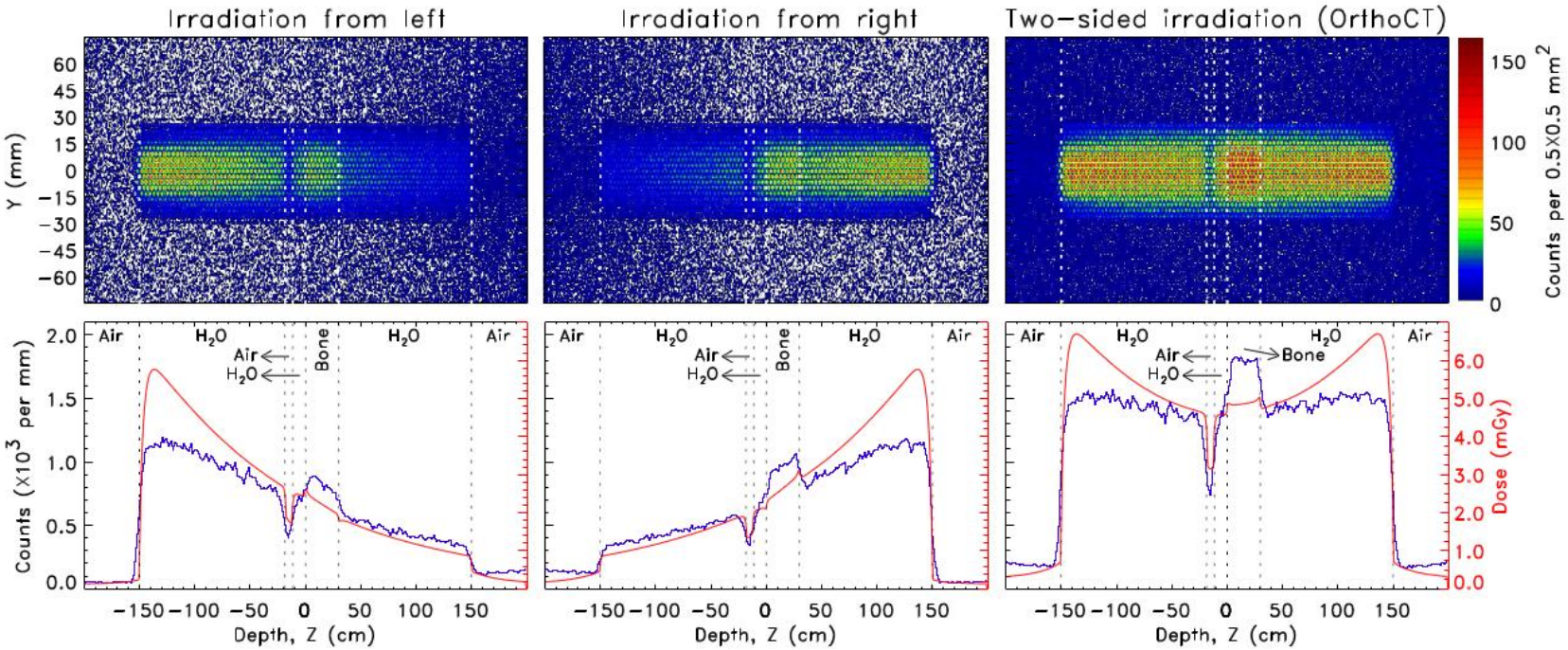
To be submitted

12. Simulated results with a collimator

- **Top**: 2D hit count histogram
- **Bottom**: simulated dose profile and counts profile

Hexagonal-hole lead collimator



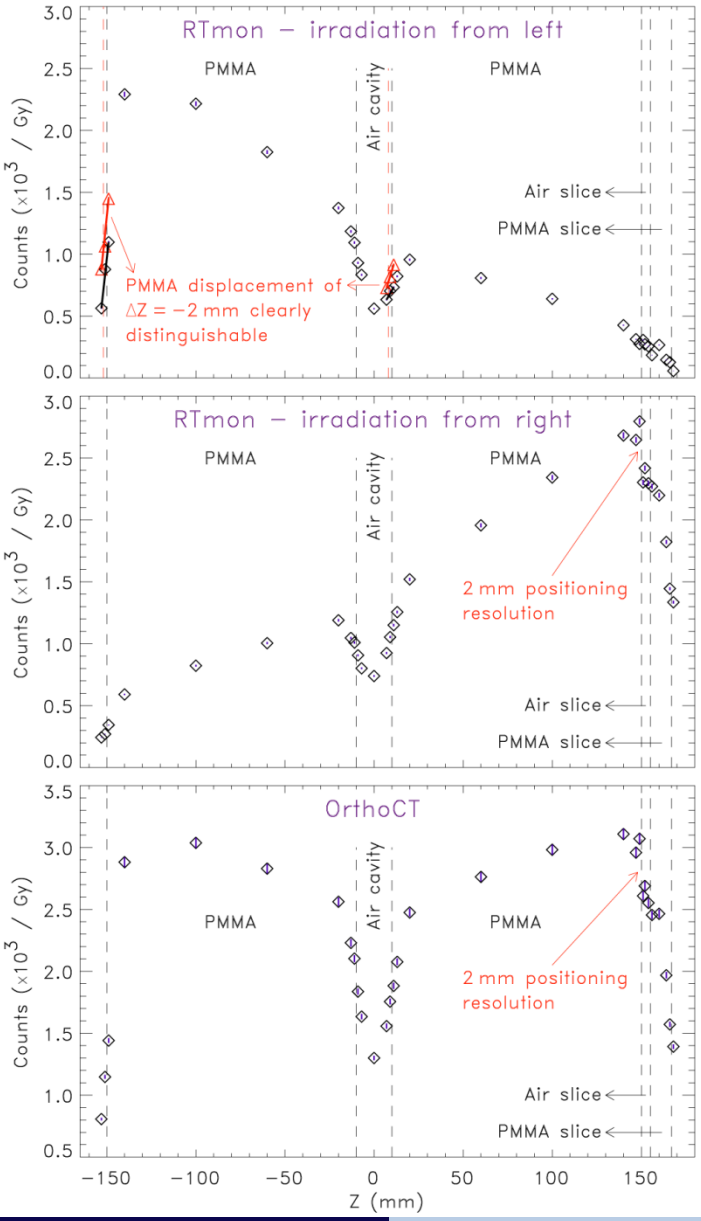


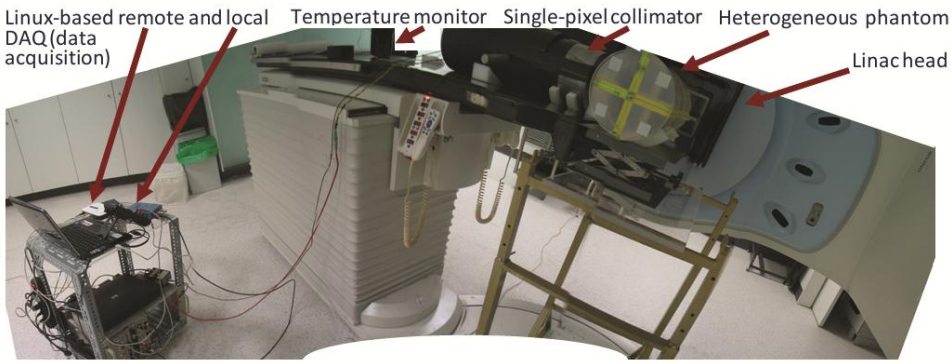
Promising results also with sub-mGy doses

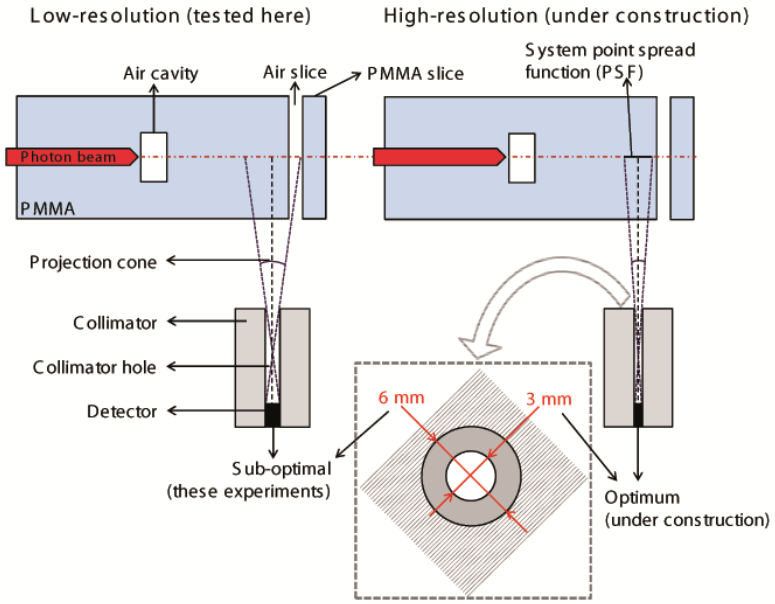
(work in progress)

To be submitted

13. Experimental Results







To be submitted

14. Conclusions

- **RTmon:**
  - Spatial correlation between simulated dose and collimated photons verified by simulation and experiment
  - Feasible without additional dose and potentially in real-time
  - Potential complement to state-of-the-art IGRT and ART techniques

- **OrthoCT:**
  - Simulation results indicate the capability of OrthoCT to provide contrast enhanced CT-like images even at low doses
  - Although in sub-optimal conditions, the experimental results are encouraging with regard to the resolution of OrthoCT

15. Future work

- **RTmon:**
  - Images with simulated patient instead of phantom (collaboration with IPOCFG, EPE and University of Catania)
- **OrthoCT:**
  - Simulation with two opposed detectors (face-to-face) with half pitch displacement for image improvement
- **Both:**
  - Fine-hole collimator for improved spatial resolution
  - Experimental determination of system point-spread-function and its parameterization for image improvement
  - Construction and test of multi-hole, multi-pixel detector for real 3D imaging

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- **Milipeia staff**: Pedro Almeida, Luís Pinto
- **The collaboration**: LIP, IPOCFG - EPE, HUC - EPE, Facultad de Medicina - Universidad de Sevilla
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Thank you for your attention