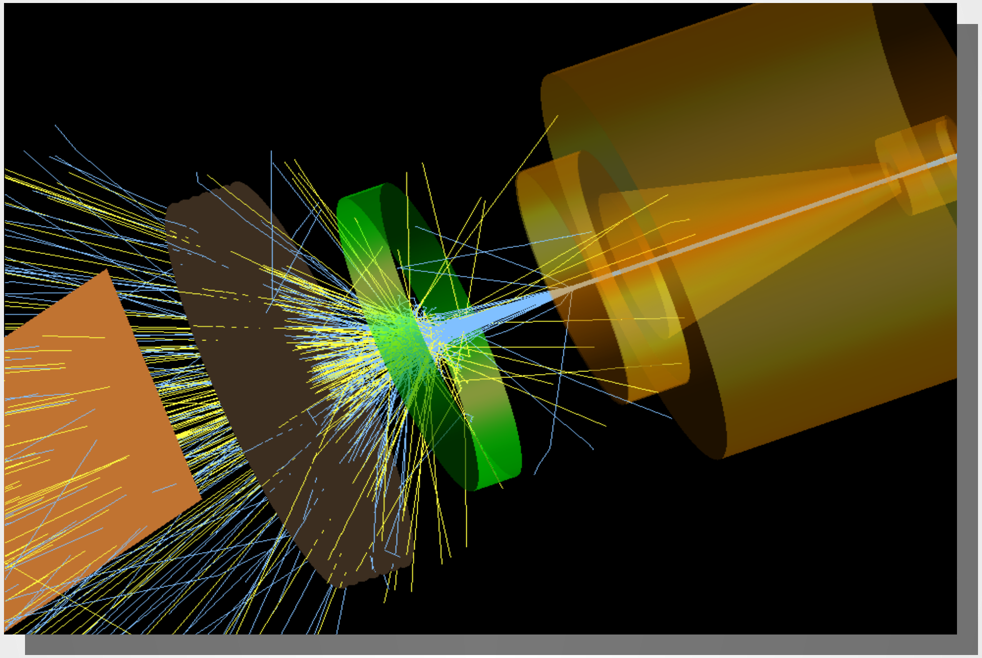
INVESTIGATION OF NESTED VOLUME-OF-INTEREST CONE-BEAM CT IMAGING WITH A LOW ATOMIC NUMBER LINEAR ACCELERATOR TARGET



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AAPM Rocky Mountain Chapter Meeting May 20, 2016

College of Veterinary Medicine & Biomedical Sciences

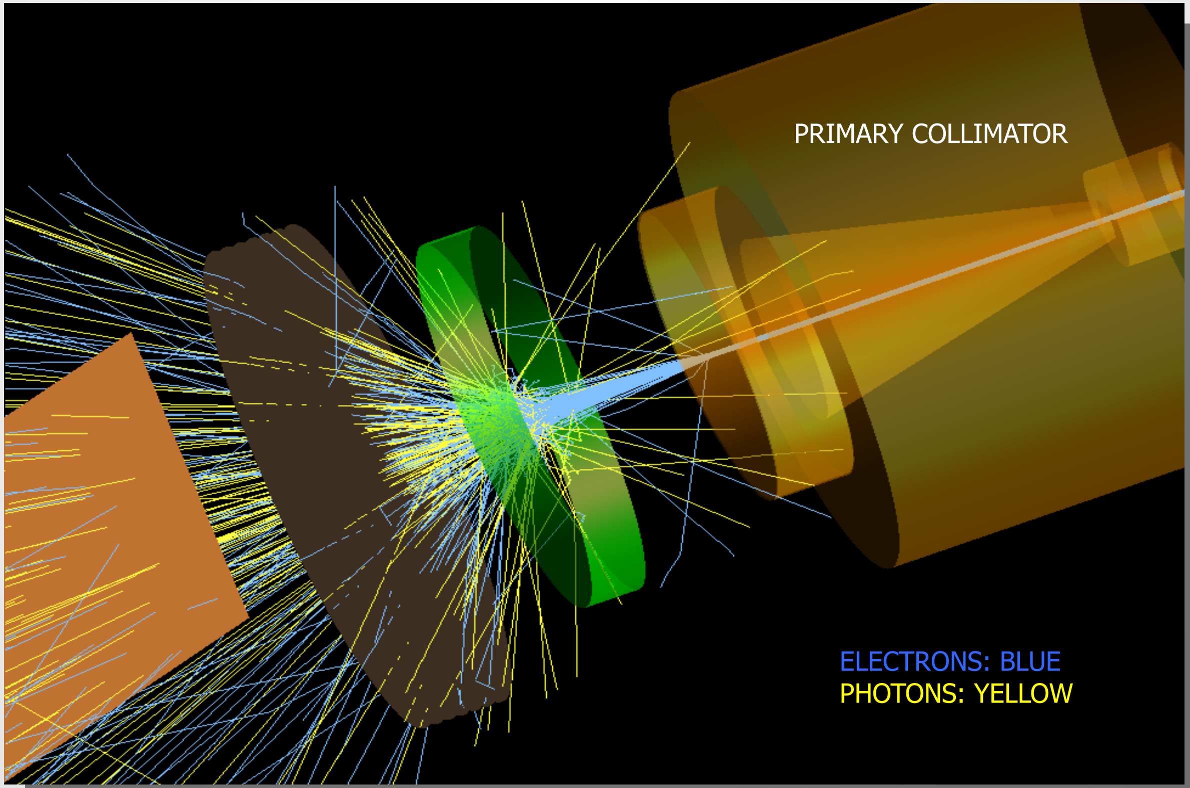
Colorado State University

Outline

- Low Z target
- VOI
- Workflow and Utility (multiple and nested VOIs)
- Normalization and dosimetry
- Applications and future work

Low-Z target CBCT

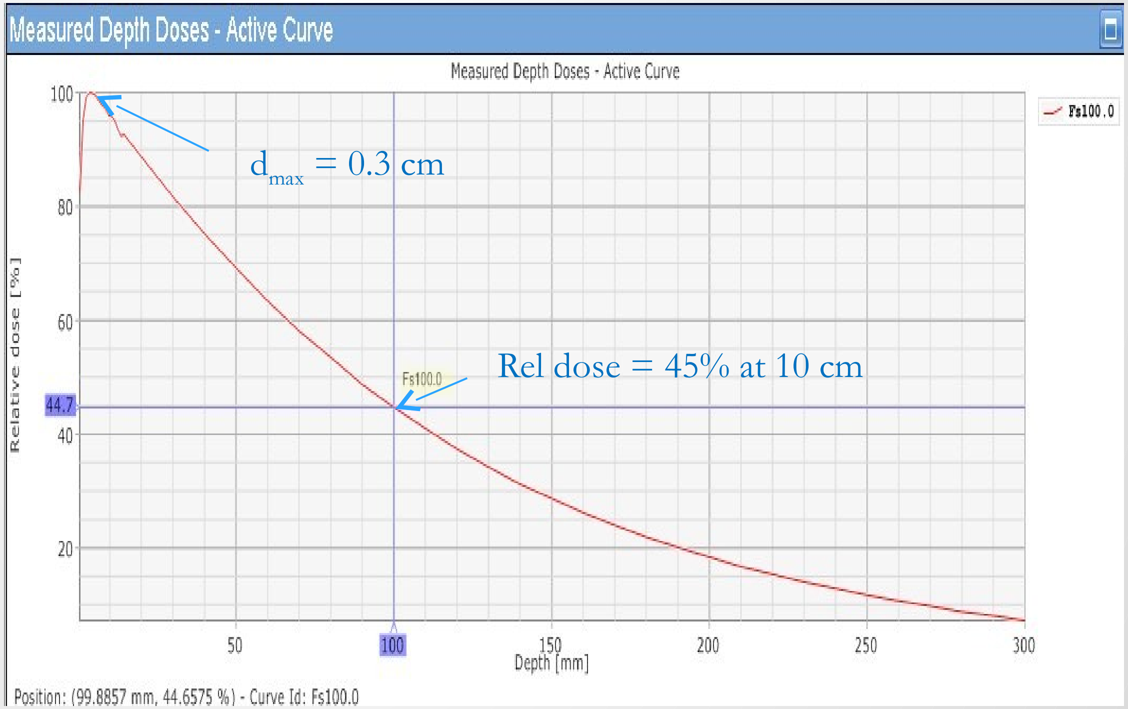
- **Carbon, beryllium or aluminum target** in linac beam line
- Replaces flattening filtration
- Allows improvement of CNR by **2-5x**



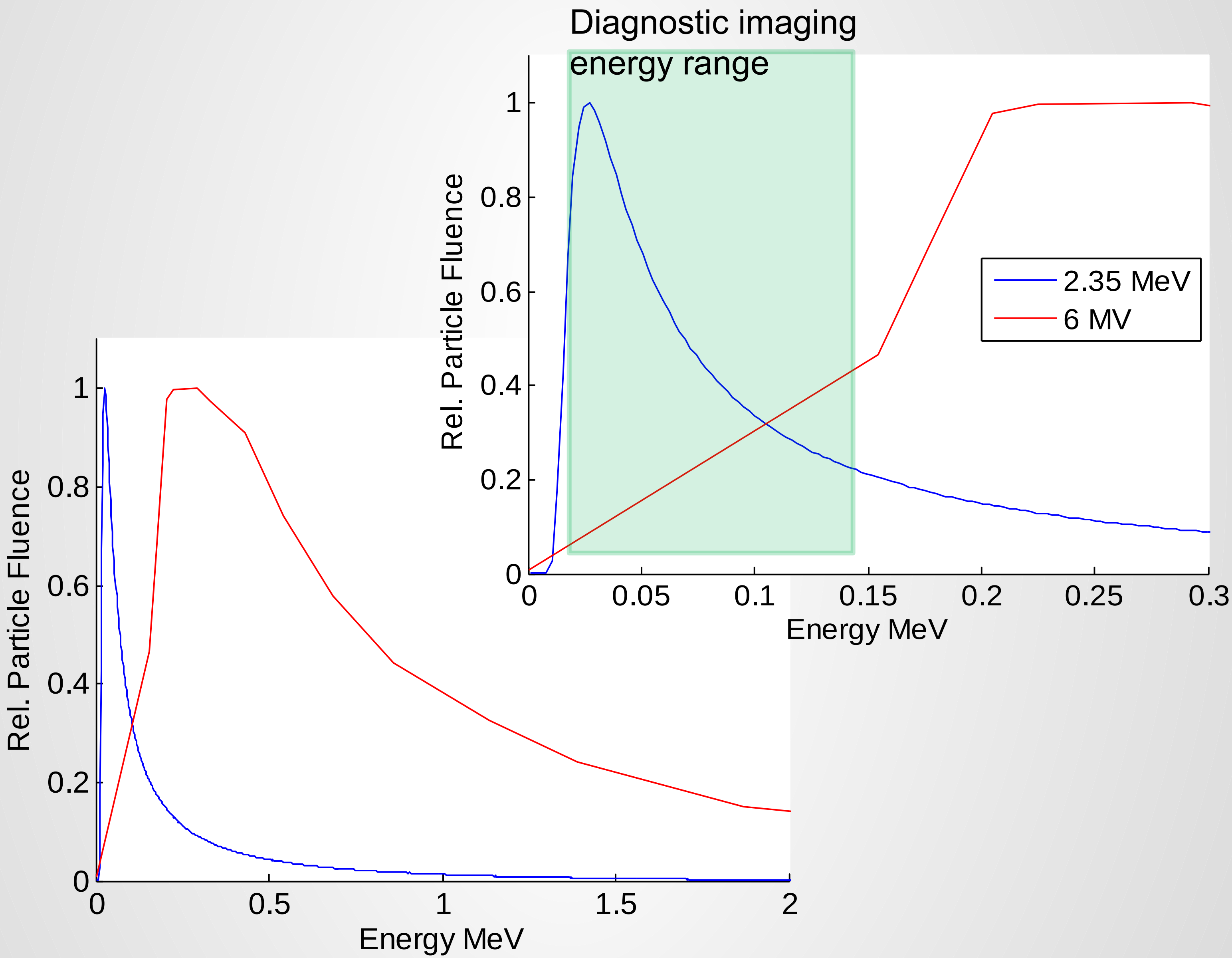
PDD

6 MV

2.35 MV



Compare energy spectra

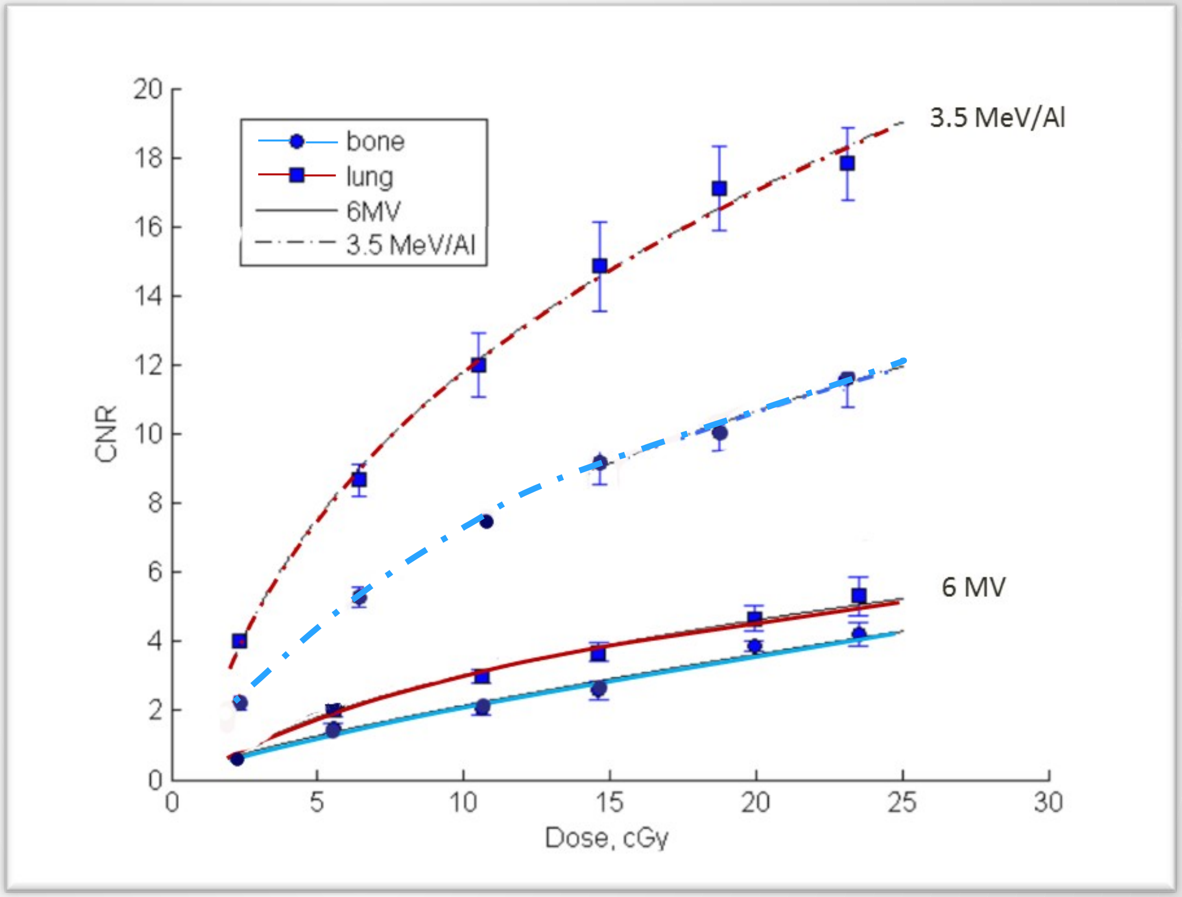


Low-Z CBCT: Contrast-to-noise

3.5 MeV/Al

6 MV

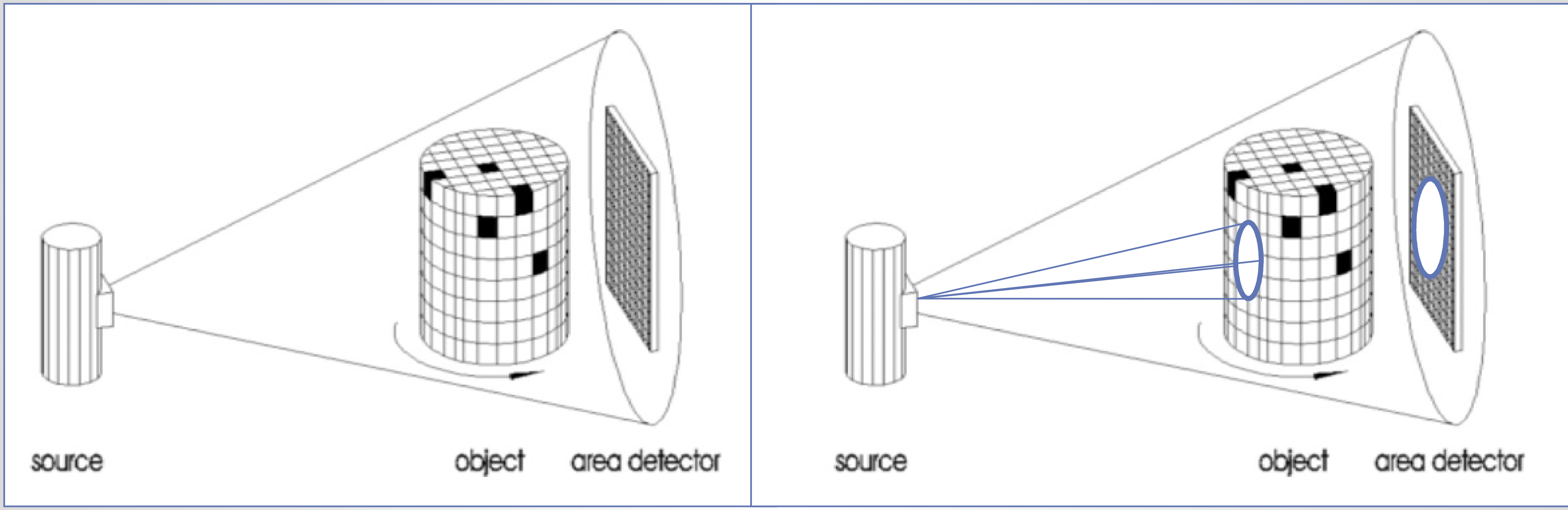
Robar et al. Med. Phys. 36, pp.3955



Decrease of dose with 3.5 MeV/Al beam compared to 6MV by a factor of ~5–8 depending on tissue and CNR

CBCT versus VOI CBCT

Full-Field (FF) | Volume-of-Interest (VOI)



Costs:

1. Imaging dose to entire volume of patient
2. Reduction of image quality due to scatter

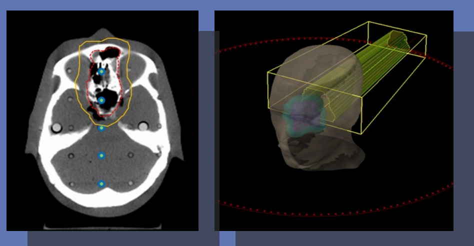
Benefits:

1. Localization of imaging dose to VOI
2. Improved scatter-to-primary characteristics

Low-Z VOI CBCT workflow

1

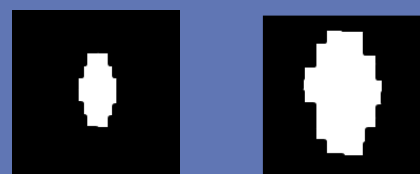
- Delineate VOI for imaging on planning CT
- Define CBCT arc geometry and beam shaping – export MLC sequence file



Eclipse 10.0

2

- Processing of MLC files using Matlab



Matlab

3

- Acquire 2.35 MV / Carbon target VOI CBCT

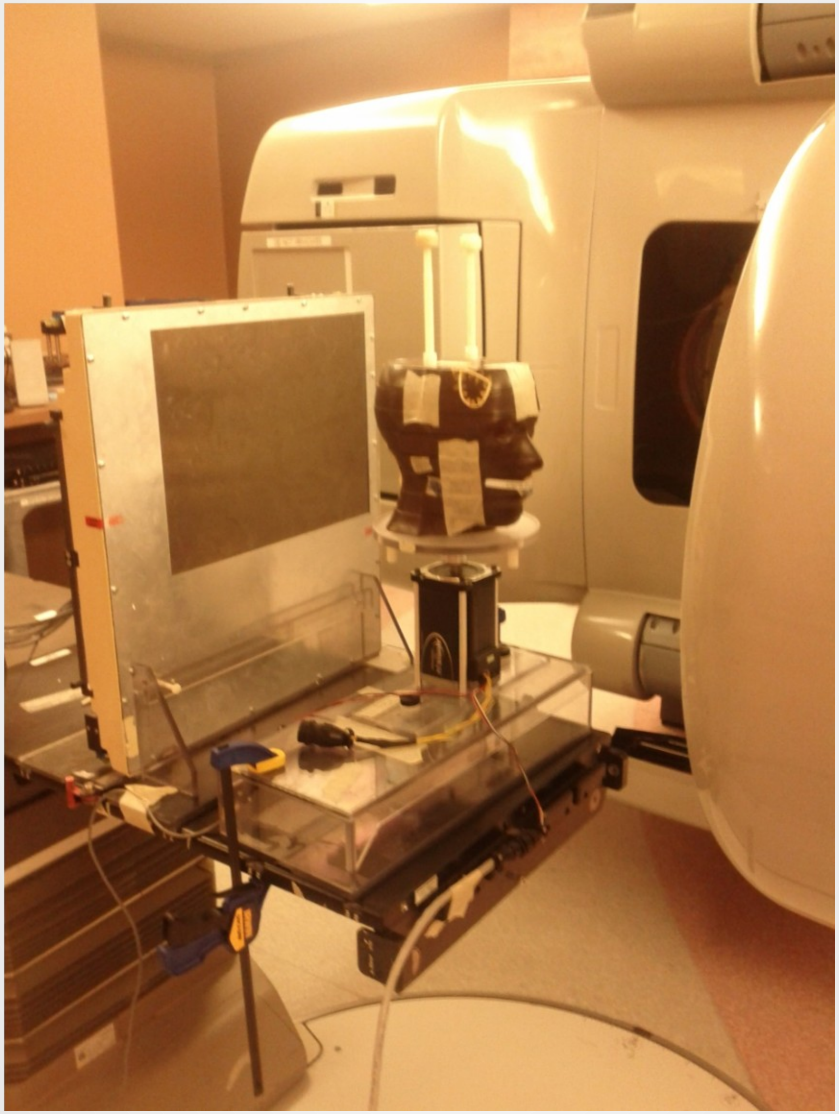
Clinac with carbon target

4

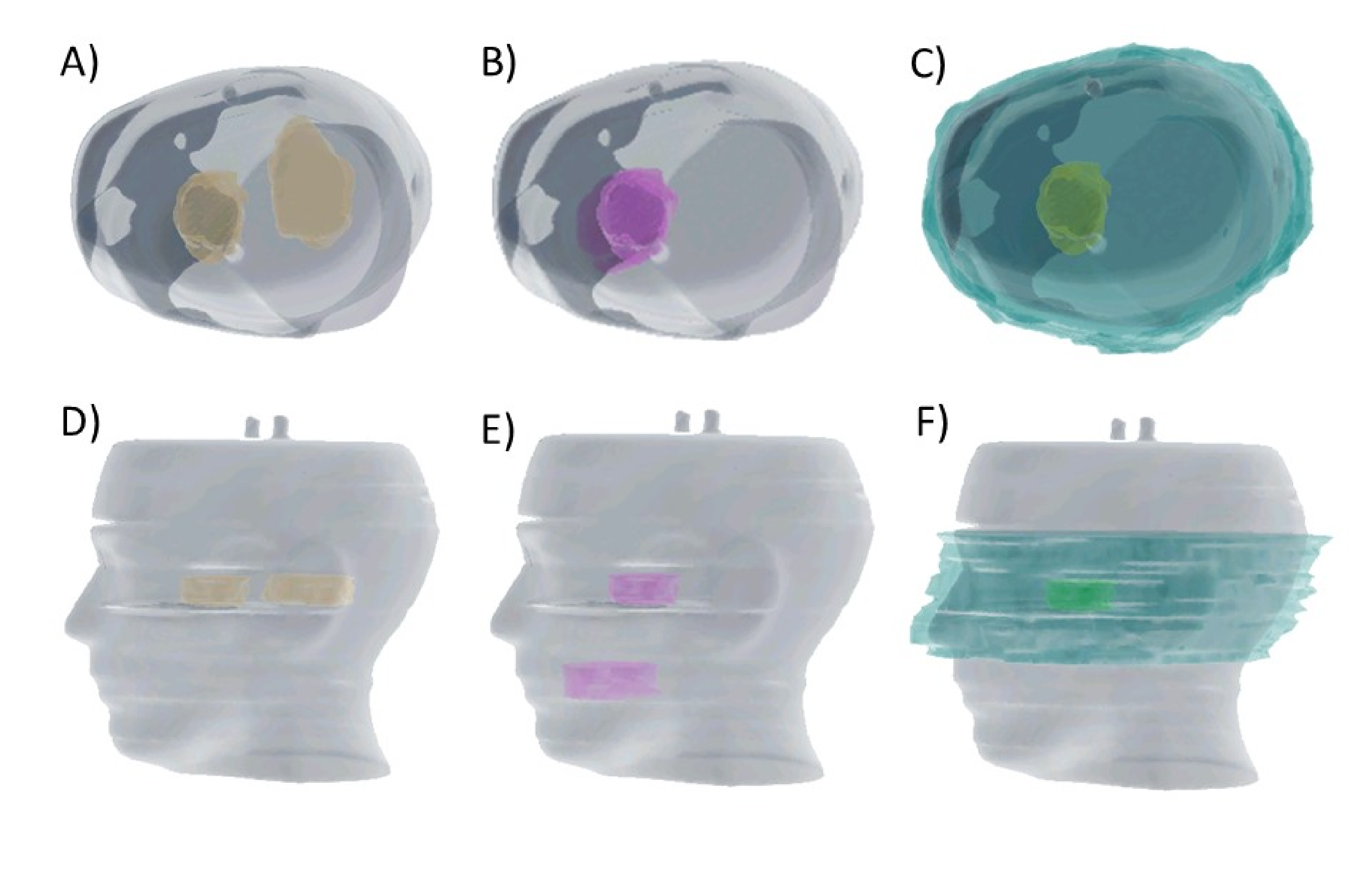
- FDK reconstruction
- Normalization

Reconstruction

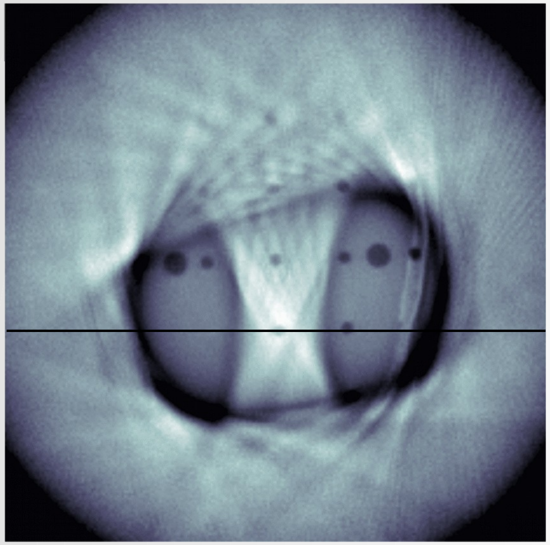
Apparatus

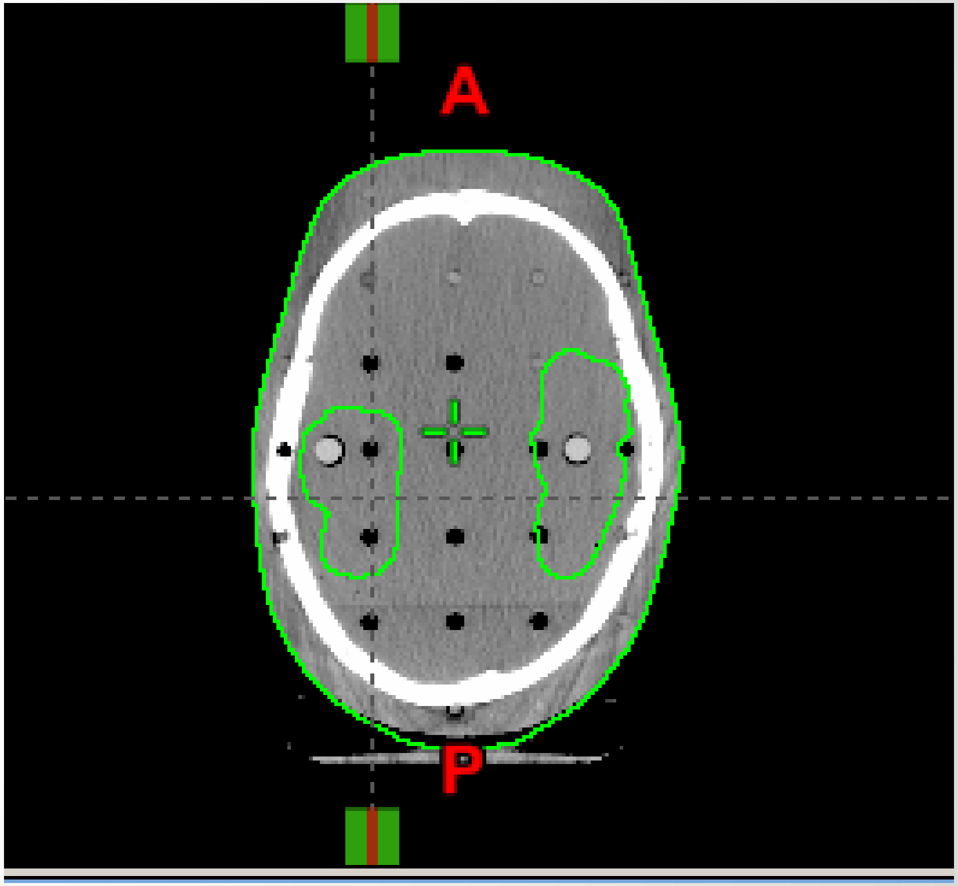


Example VOI configurations

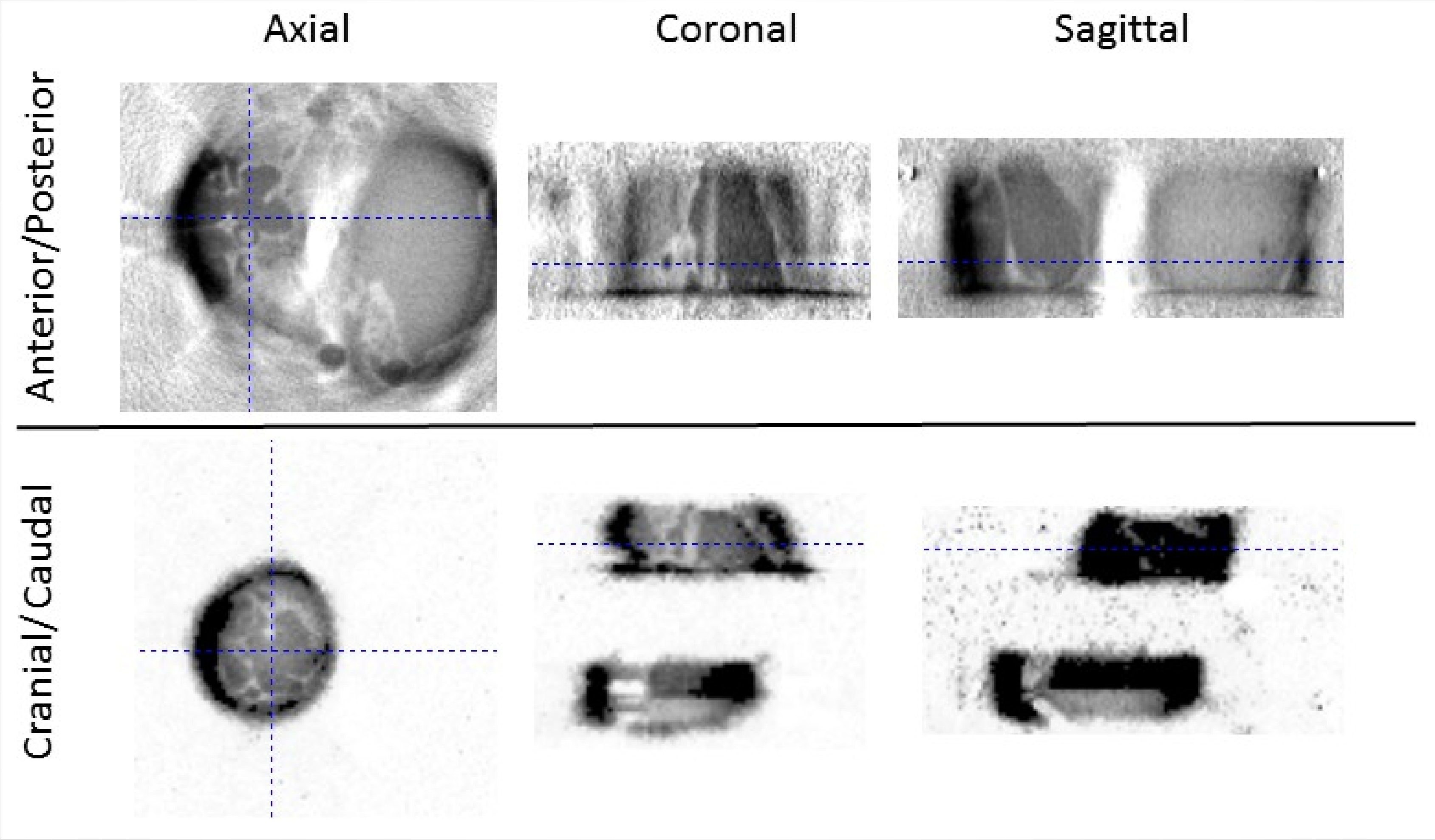


Multiple VOIs





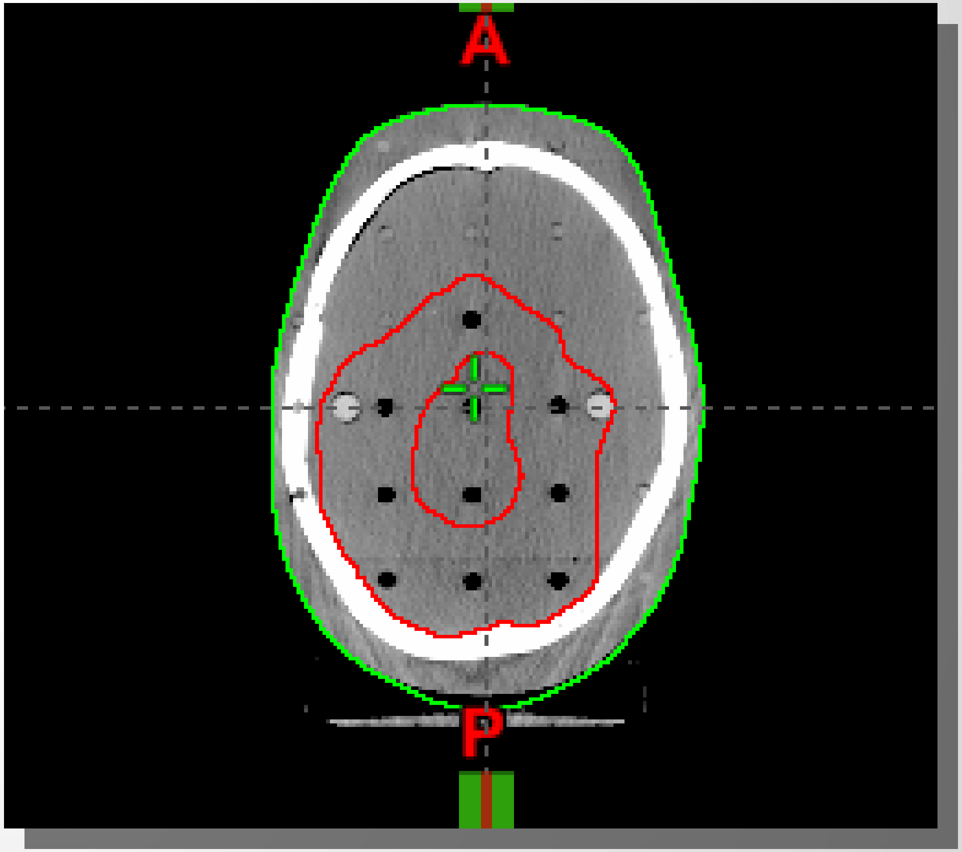
Multiple VOIs

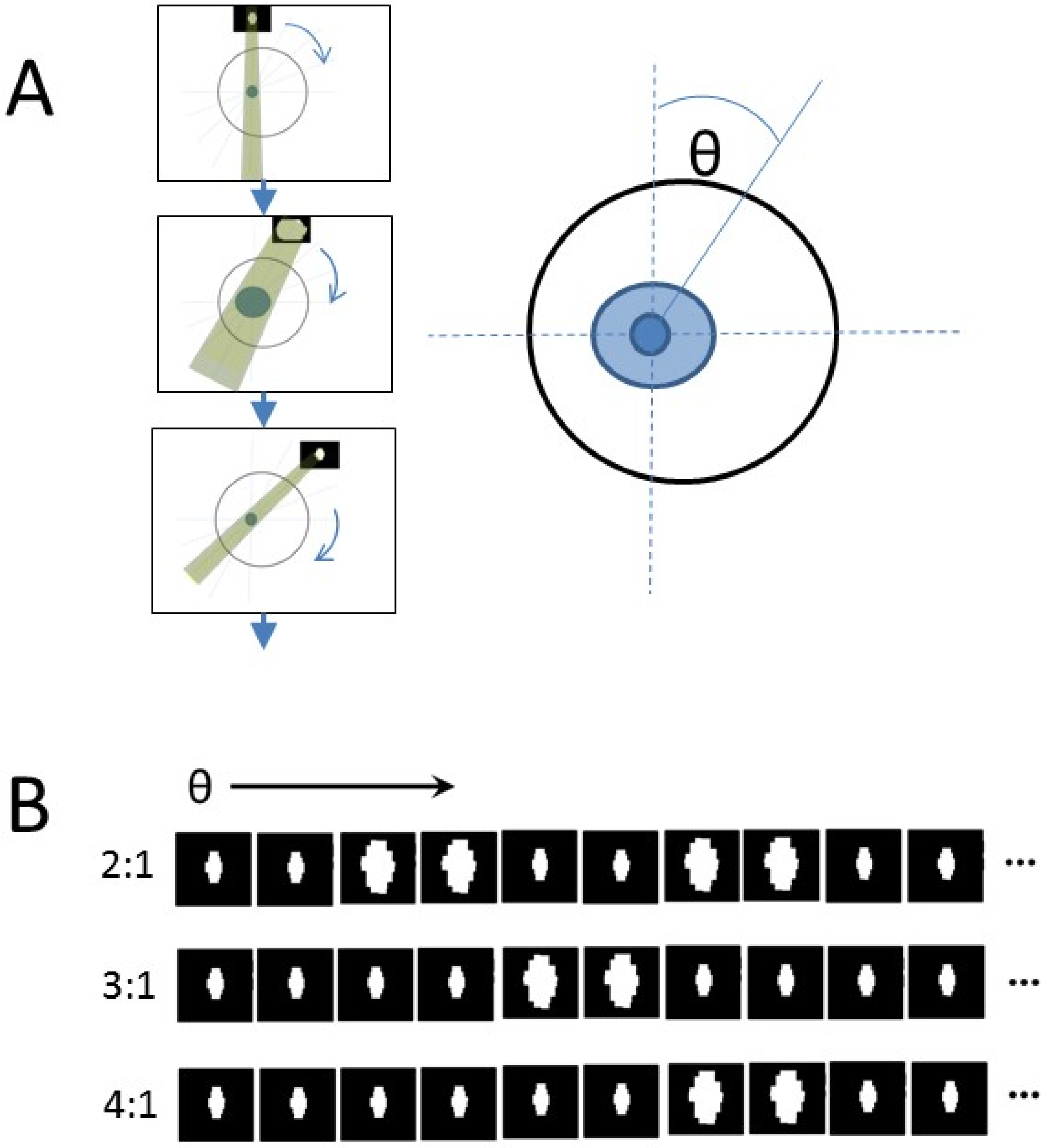


Nested VOIs

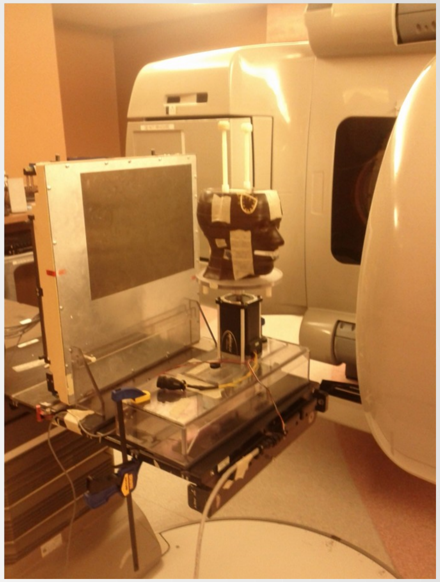
Two separate MLC sequences merged together

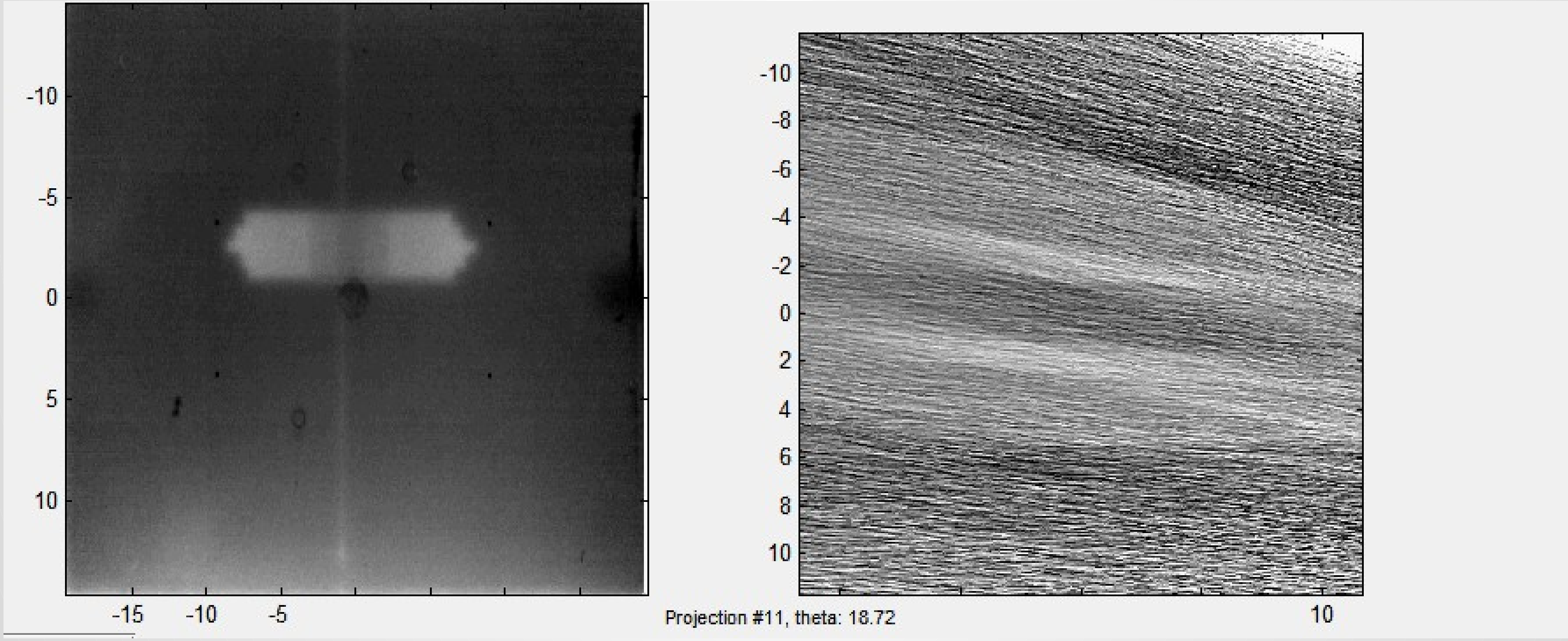
- Define inner VOI
    - e.g. PTV
- Define outer VOI
    - e.g. surrounding OARs or body contour
- Acquire inner VOI at higher dose and CNR



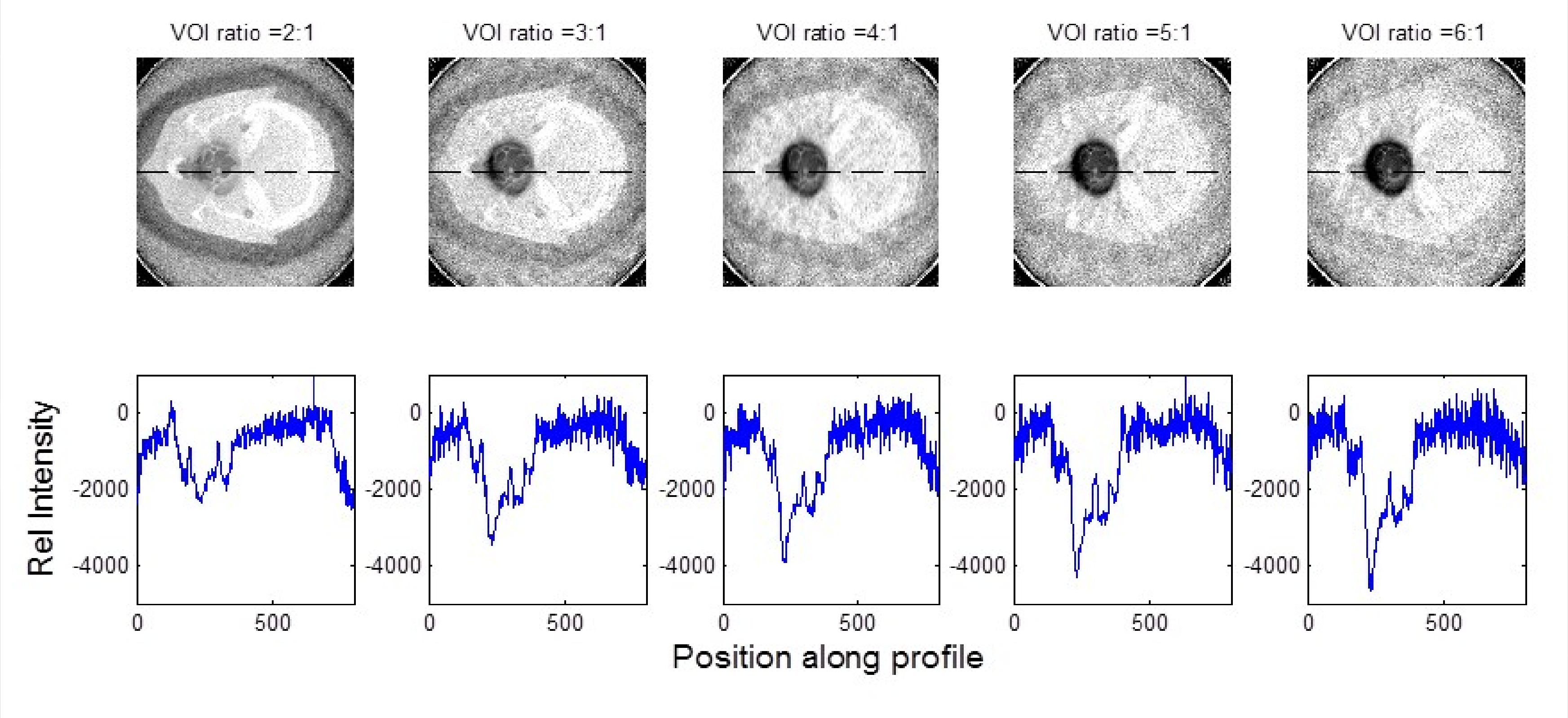

A
θ
B
θ
2:1
3:1
4:1
...
...
...

Nested VOIs



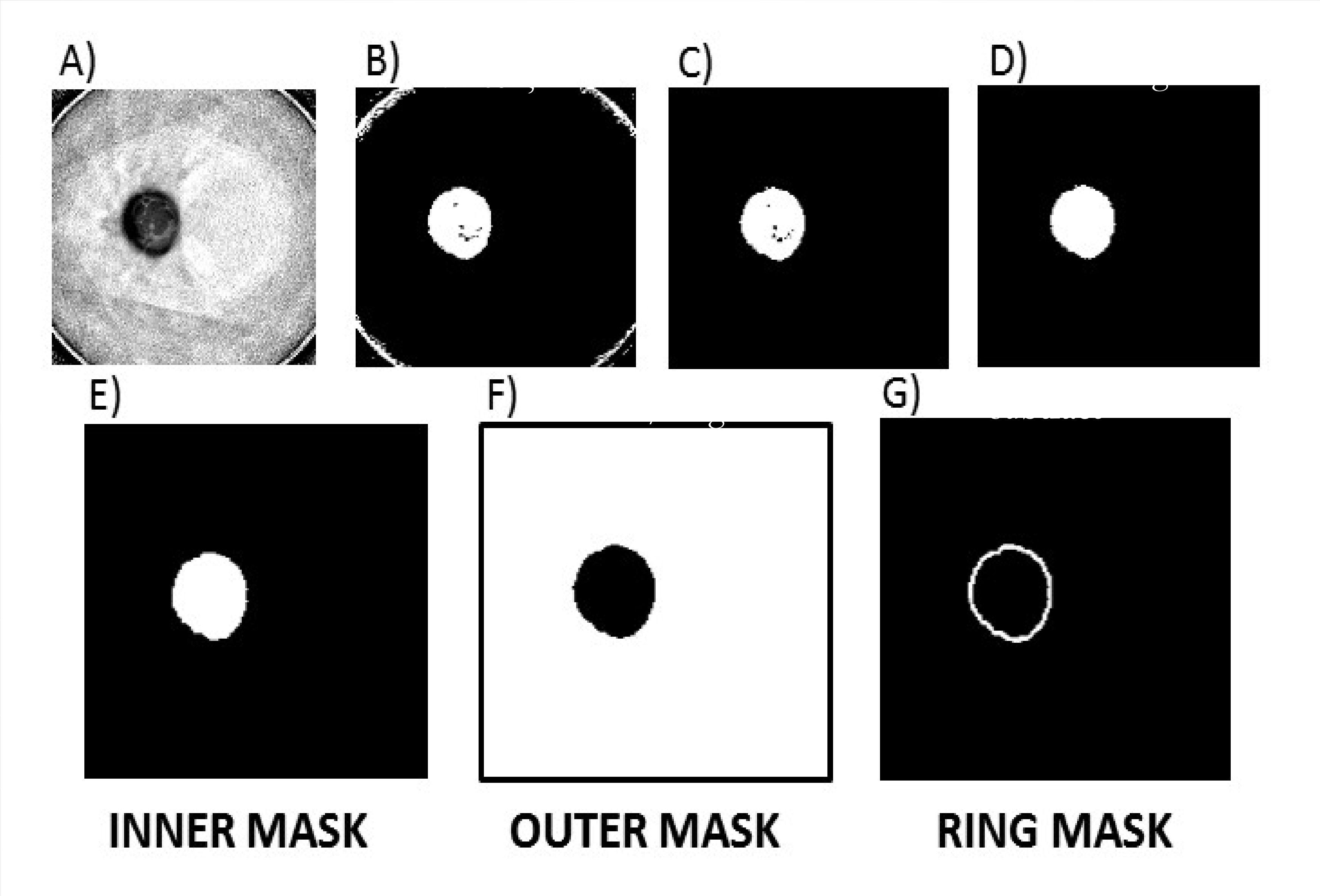


Raw reconstruction



- Pixel intensities between the two VOIs now have different relative radiodensities
- For this reason we normalize inner and outer VOI after the reconstruction that can later be converted into Hounsfield units.

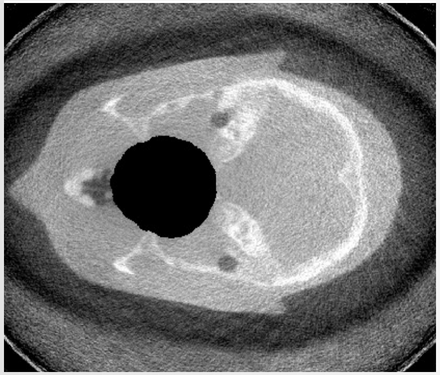
Normalize - masking

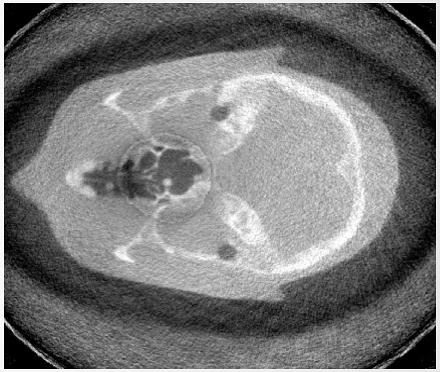


Normalize - masking

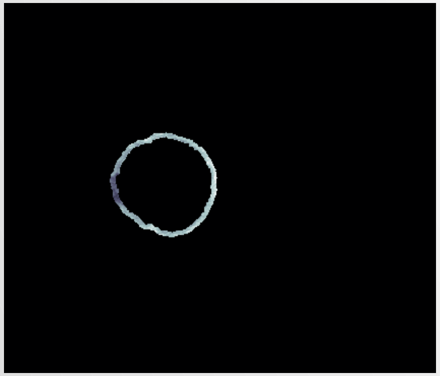
In

Out

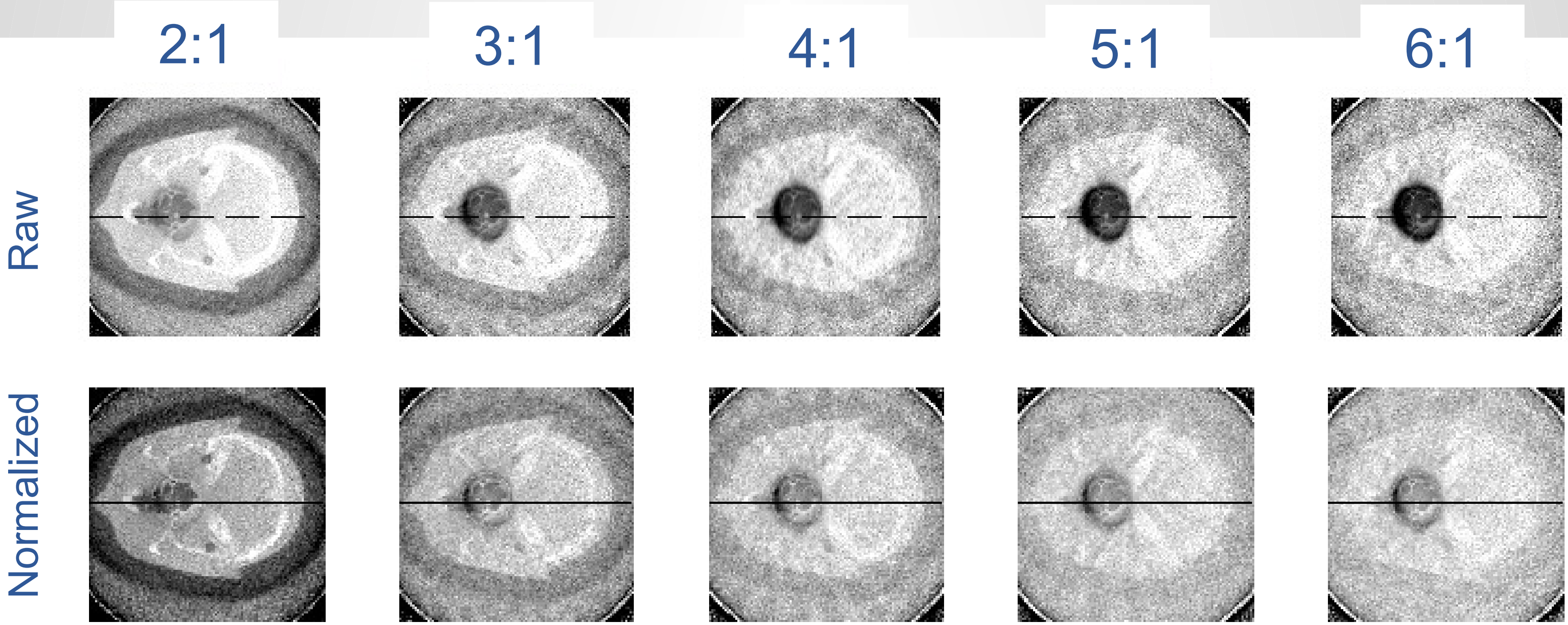




Ring

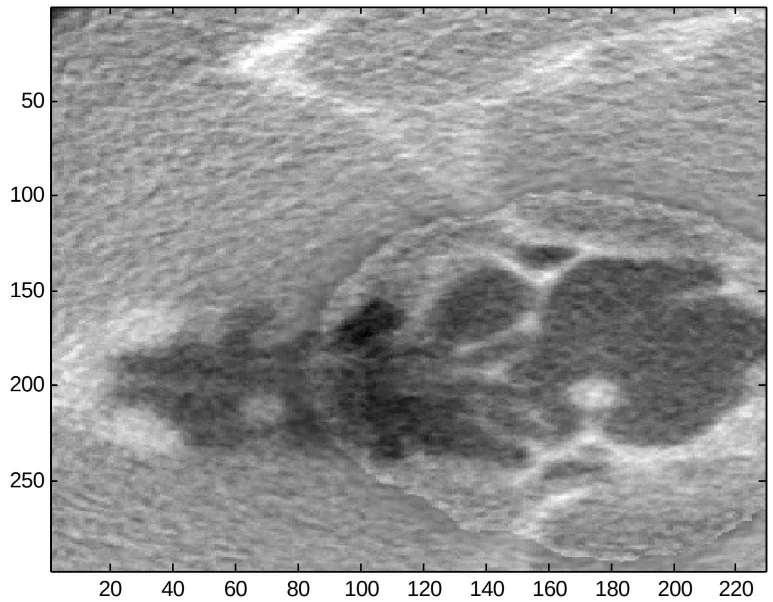


Normalized reconstruction

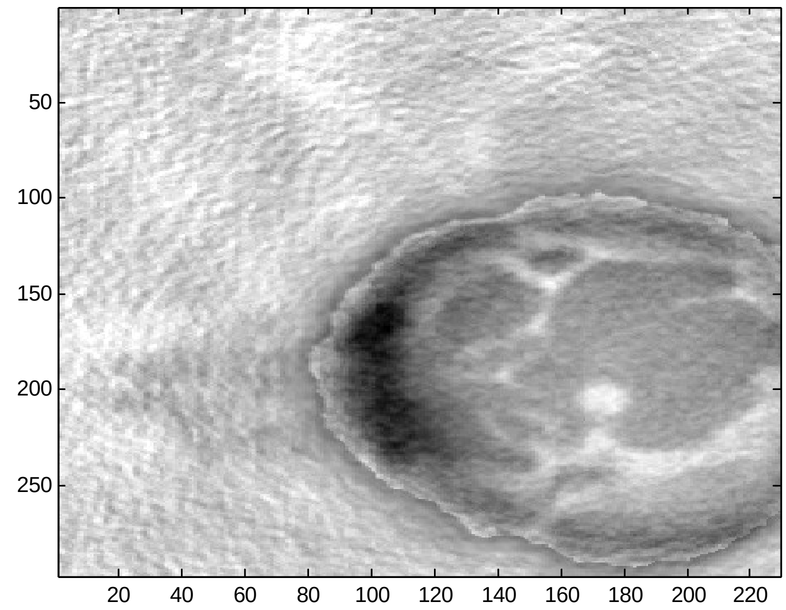


Zoomed images

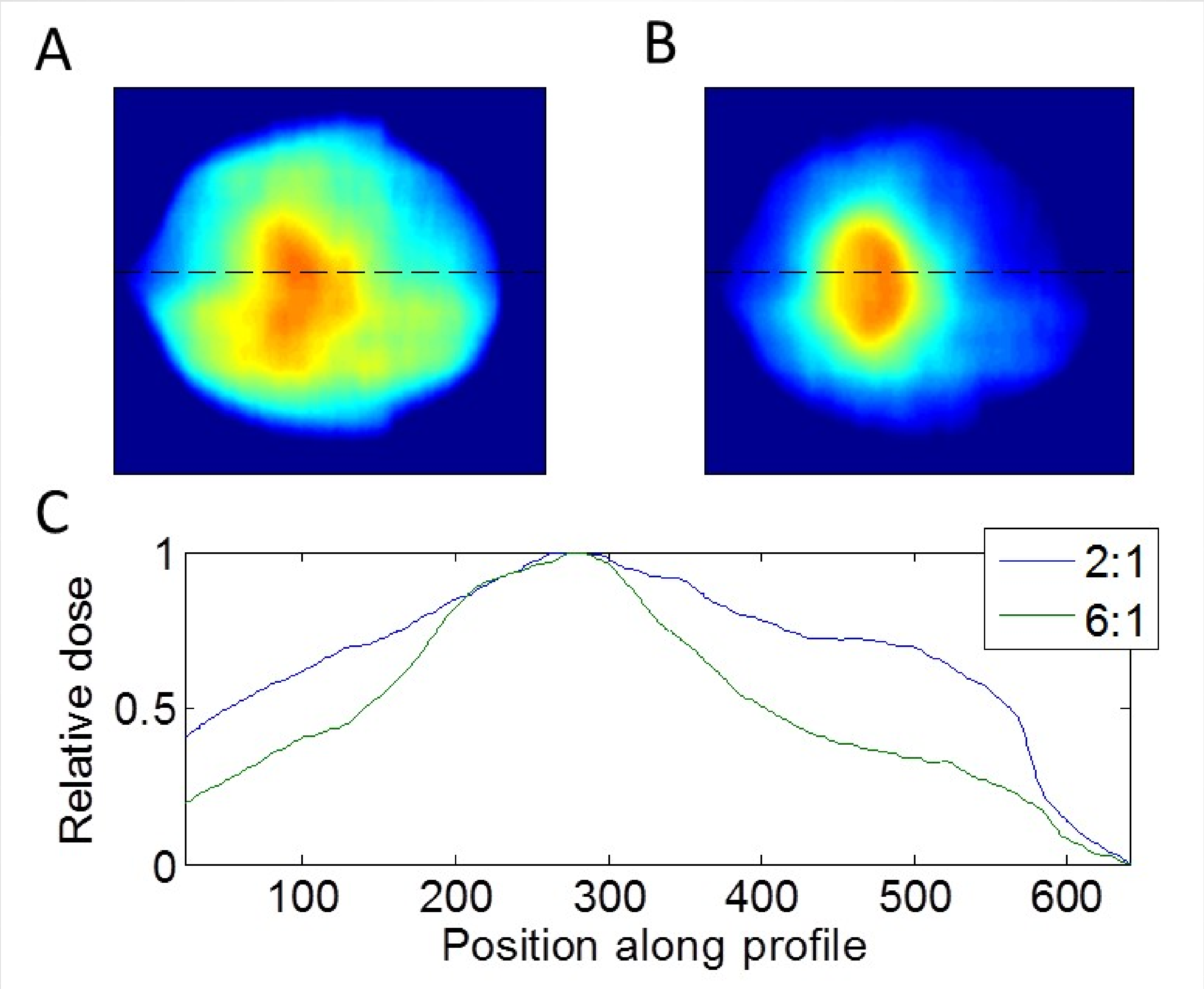
2:1



6:1

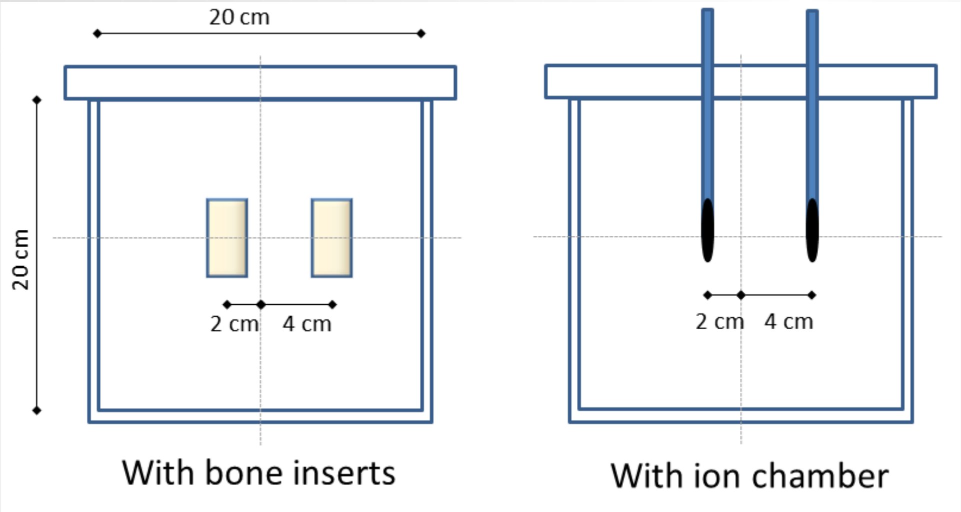


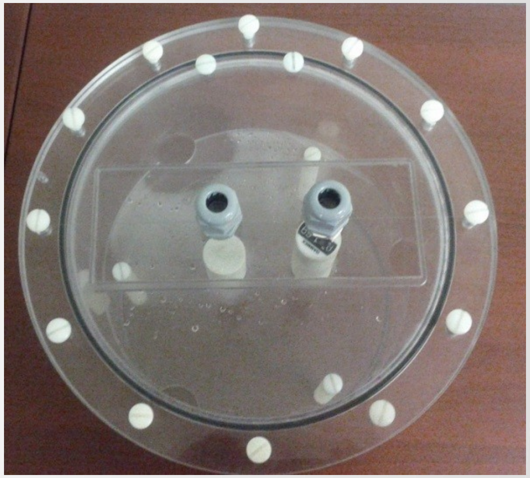
Radiochromic Film Dosimetry

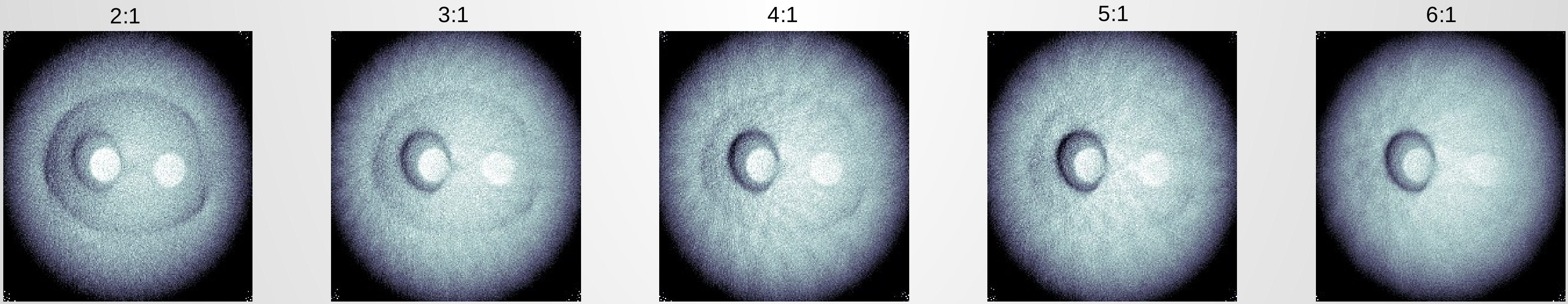


Find dose and CNR

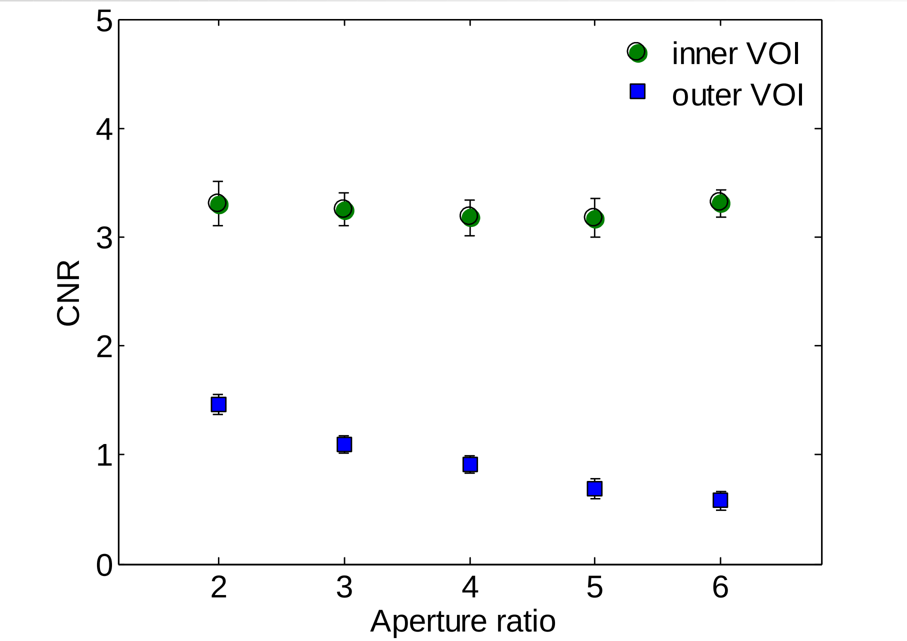
Repeat the VOI sequences on a water phantom with cortical bone ρ_e=1.69 contrast tissue

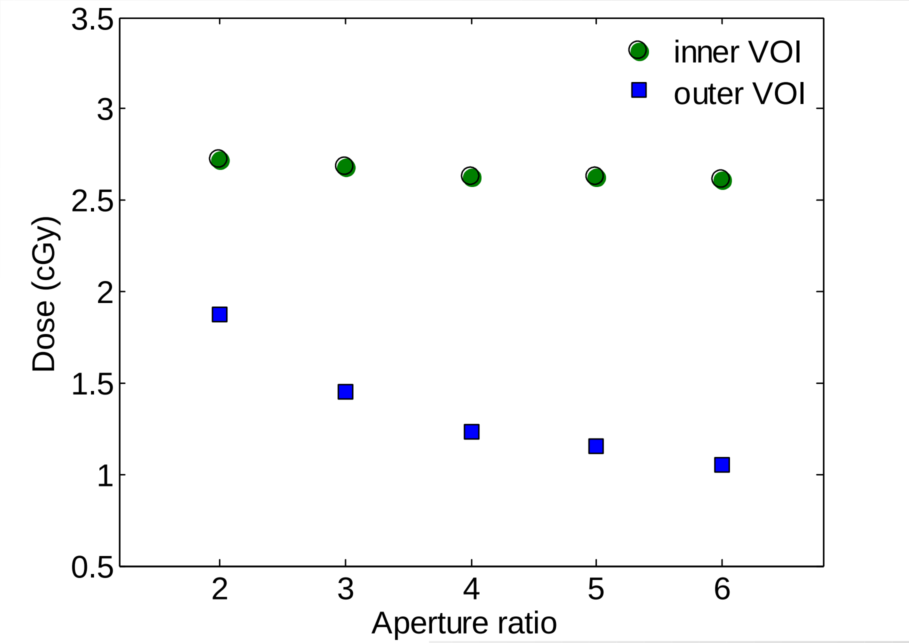


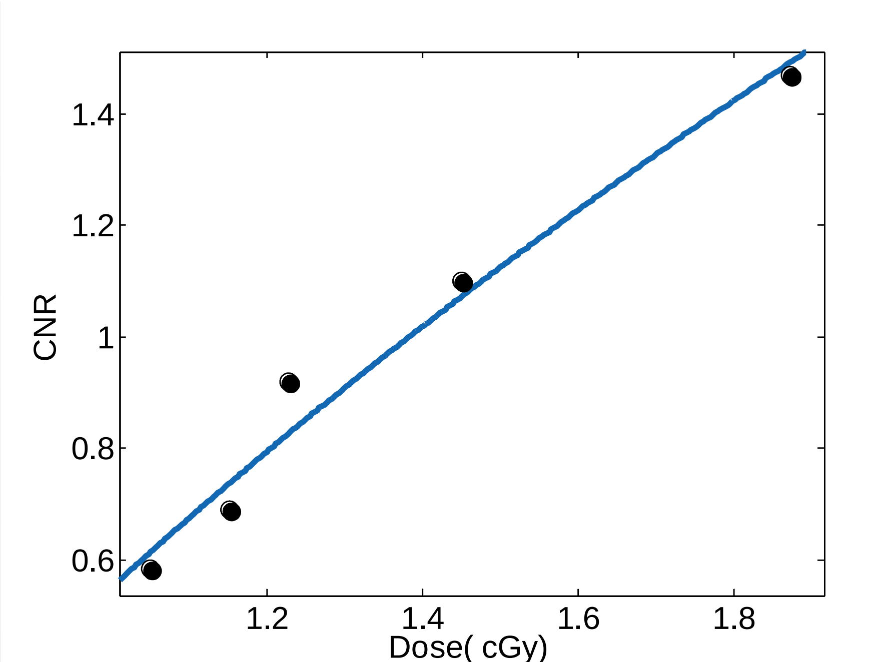




Control of dose and CNR in nested VOIs



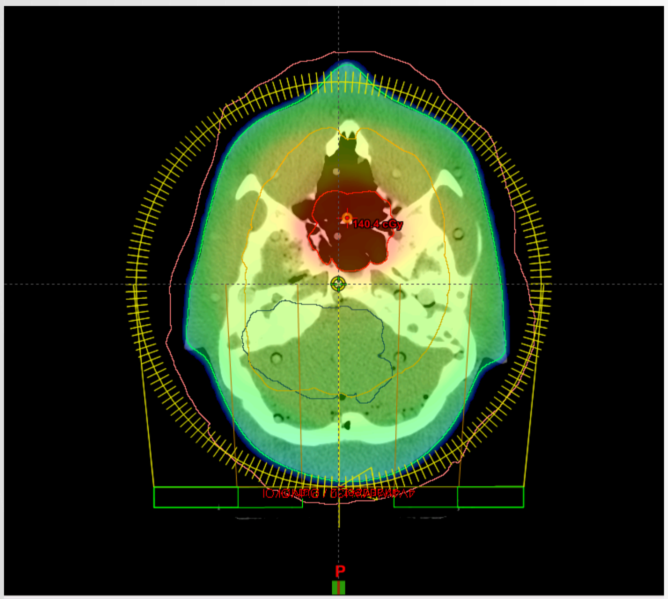




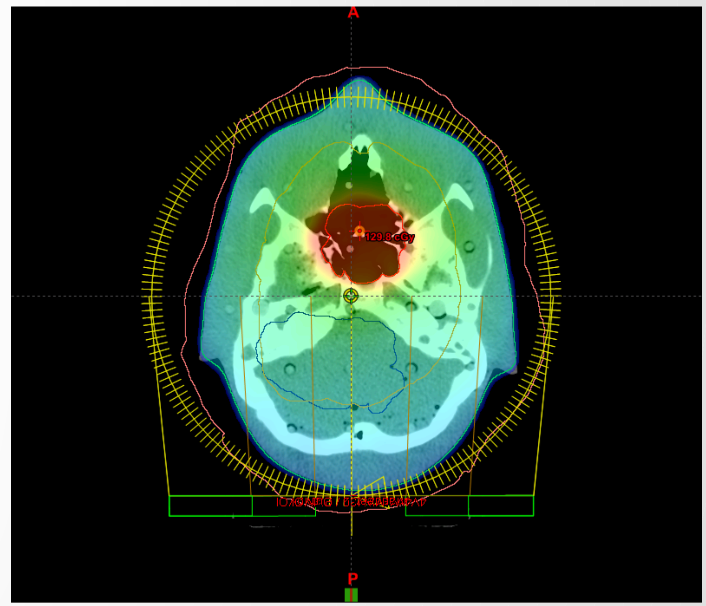
$$\mathrm{CNR} = \frac{|P_{\mathrm{bone}} - P_{\mathrm{water}}|}{\sqrt{\sigma^2_{\mathrm{bone}} + \sigma^2_{\mathrm{water}}}},$$

$$CNR \propto \sqrt{dose}$$

Low-Z CBCT dose AAA distributions

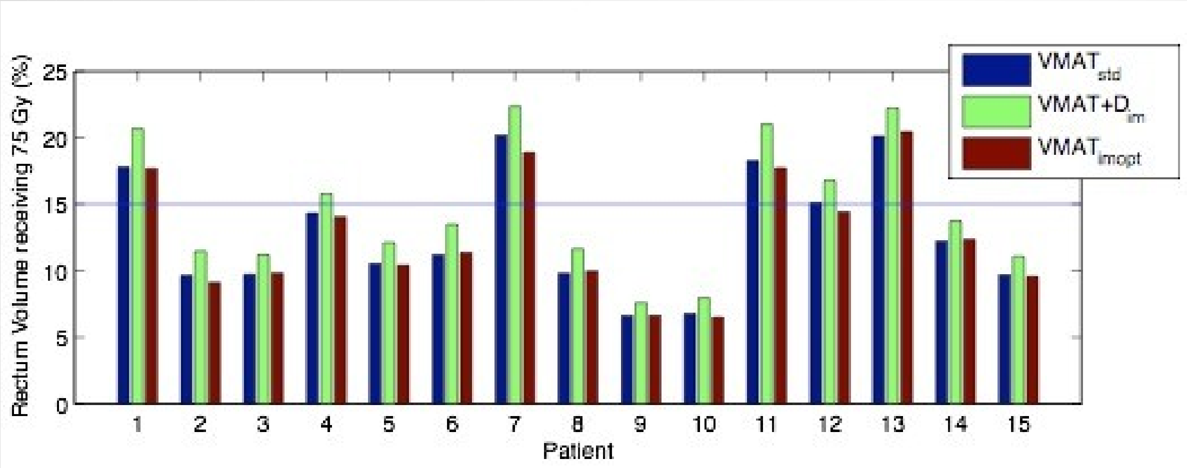


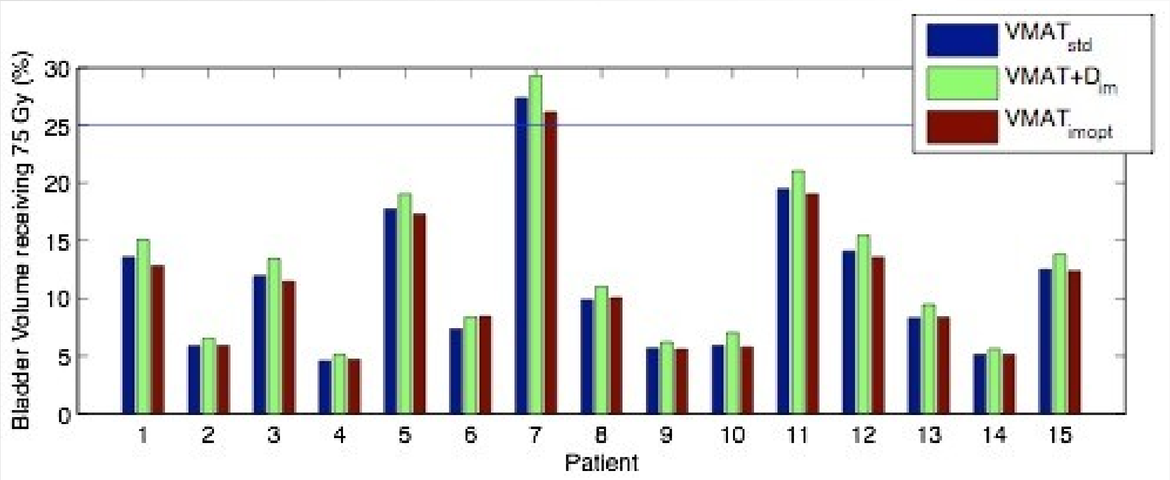
Nested VOI, 2:1



Nested VOI, 6:1

Case scenarios





Prostate cancer treatment

Based on QUANTEC review

For Rectum V75 < 15%

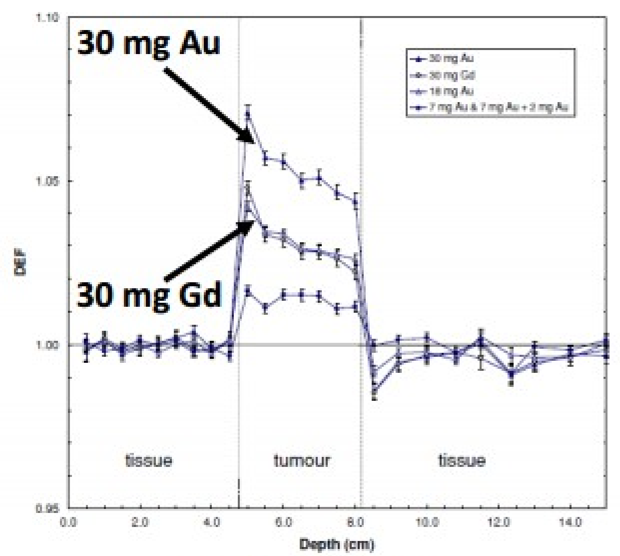
For Bladder V75 ≤ 25%

Summary

- Lowered dose and/or improved CNR by combining low-Z target beam with dose localization VOI approach
- Versatile MLC approach – multiple or nested VOIs possible as defined at planning step
- With VOI inner/outer ratio sequencing, dose reduction can be tuned to threshold CNR for outer VOI
- Dose can be calculated in Eclipse and subtracted from treatment dose

Future directions

Cho, S. (2005)
Based on the results of Hainfeld et al. (2004) simulated the dose enhancing using a modified phantom and tumor composition defined by ICRU to incorporate different concentrations of GNPs and compared 3 radiation sources.



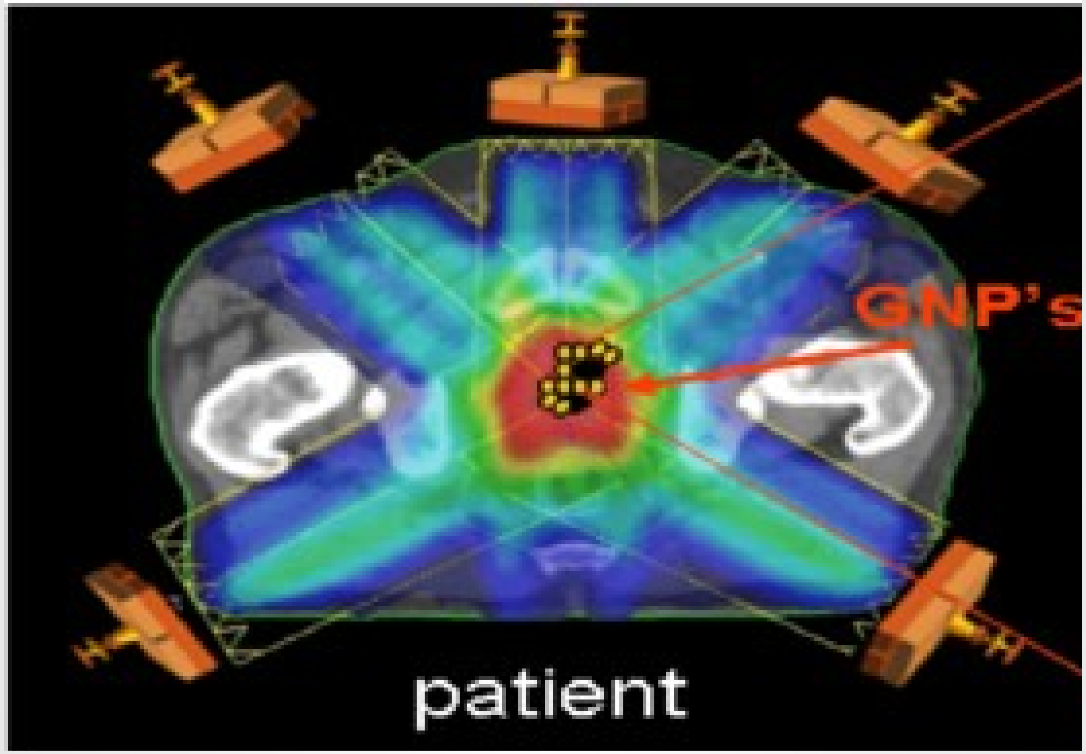
DEF for 6 MV NFF

Concentration (per gram of tumour)	140 kVp	6 MV FF	6 MV NFF	4 MV FF	4 MV NFF
7 mg Au	2.114	1.007	1.014	1.009	1.019
18 mg Au	3.811	1.015	1.032	1.019	1.044
30 mg Au	5.601	1.025	1.053	1.032	1.074

FF: flattening filter, NFF: no flattening filter.

Cho, S. H. Phys. Med. Biol. 2005,50: N163-N173

Future directions



Thank you!