Region of Interest Imaging in CBCT for Radiation Therapy

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Motivation

Proposition:

There are cone beam CT (CBCT) imaging tasks in Radiation Oncology in which full SNR information is not required for the entire image volume.

Hypothesis:

We can take advantage of this concept to reduce scattered radiation and dose to the patient by selectively weighting the intensity of the x-ray beam.

Significance

"Imaging dose can be concentrated at the skin or distributed throughout the anatomical volume of interest. Given these circumstances it is no longer safe to consider the dose from only one imaging procedure at a time or to assume that the cumulative imaging dose is negligible compared to the therapeutic dose."

"It can also be achieved in both axial and cone-beam CT by restricting the field of view in the slice direction by collimating down the fan angle to the volume of interest, but the resulting truncation of the projection data produces artifacts from filtered backprojection, necessitating a more sophisticated reconstruction process."

- Report of the AAPM Task Group 75

Outline

- Theory
  - Reconstruction Overview
  - Intensity Weighting
- Experimental Methods
- Results
  - Reconstructed Images
  - Dose Reduction Measurements
- Conclusions
- Future Work

Reconstruction Overview - FDK

- Essentially filtered back-projection for CBCT
- Standard method
- Susceptible to truncation artifacts
- Noise propagation is local

$$f_{\mathrm{FDK}}(x,y,z) = \frac{1}{2}\int d\lambda \frac{1}{U^2}\int du_d \frac{R}{\sqrt{S^2+u_d^2+v_d^2}} P(u_d,v_d,\lambda) h(u_d' - u_d)$$

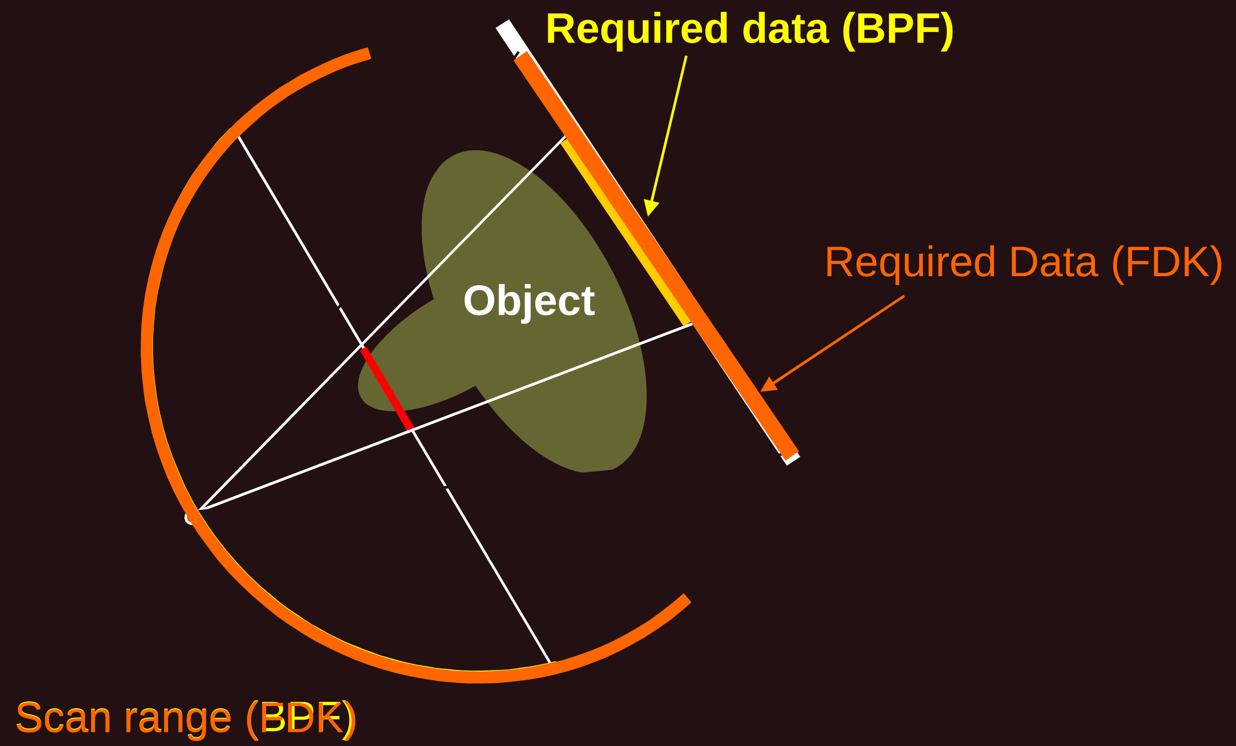
Reconstruction Overview - Chords

- Using chord based BPF (c-BPF)
- Filtering only requires complete data along reconstruction chords
  - Robust against some forms of truncation
  - This allows for some types of ROI image reconstruction
- Noise propagation is local

$$\mathrm{f}_\pi(x_\pi,\lambda_1,\lambda_2,z_0)=\frac{1}{2\pi^2}\frac{1}{\sqrt{(x_{\pi\lambda 2}-x_\pi)(x_\pi-x_{\pi\lambda 1})}}\times\Big[\int_{x_{\pi\lambda 1}}^{x_{\pi\lambda 2}}dx'_\pi\frac{\sqrt{(x_{\pi\lambda 2}-x'_\pi)(x'_\pi-x_{\pi\lambda 1})}}{(x_\pi-x'_\pi)}\times g_\pi(x'_\pi,\lambda_1,\lambda_2,z_0)+2\pi P_0\Big]$$

$$\mathrm{g}_\pi(x'_\pi,\lambda_1,\lambda_2,z_0)=\int_{\lambda_1}^{\lambda_2}\frac{d\lambda}{|\vec{r}'-\vec{r}_c(\lambda)|}\frac{d}{d\lambda}P(u'_d,v'_d,\lambda)\Big|_{\hat{\beta}'}$$

Comparison of FDK and c-BPF



Theory of Intensity Weighting

- CBCT reconstruction is approximation of inverse 3D x-ray transform

$$\mathrm{f(x,y,z)}=\mathrm{H}^{-1}P(u_d, v_d, \lambda)$$

- Projection data

$$\mathrm{P}(\mathrm{u}_d, v_d, \lambda) = \ln(\frac{I_0}{I})$$

- Image intensity and structure invariant to intensity modulation

$$\ln(\frac{m(u_d, v_d) I_0}{m(u_d, v_d) I}) = \ln(\frac{I_0}{I})$$

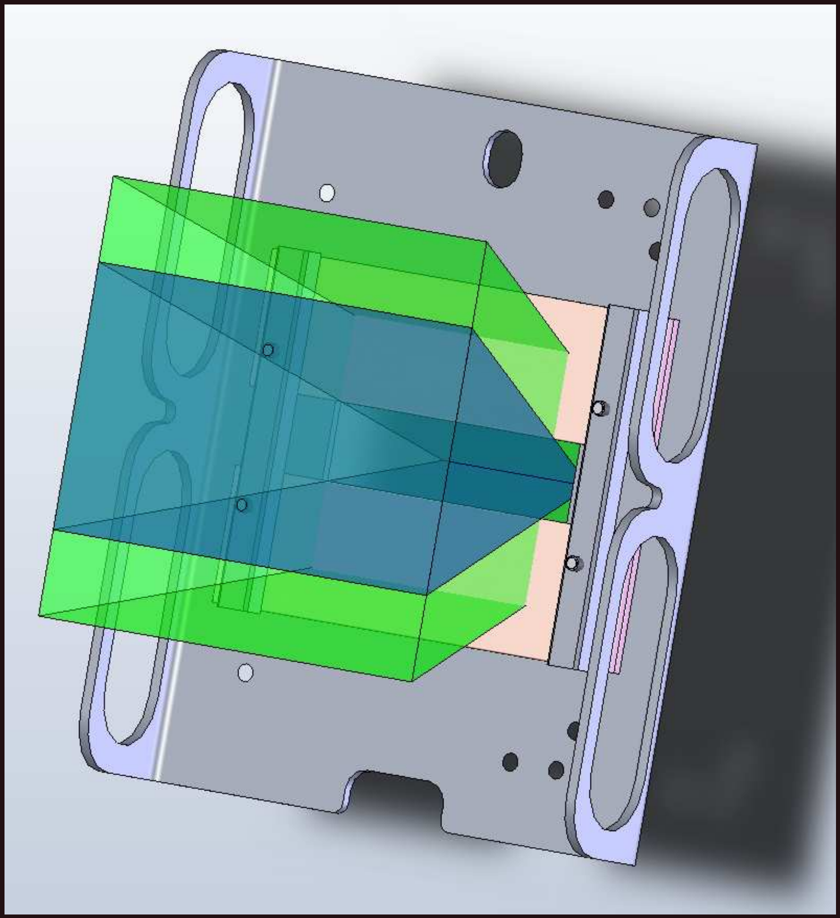
- Noise Properties are not but we have found they are roughly local to corresponding projcetion data

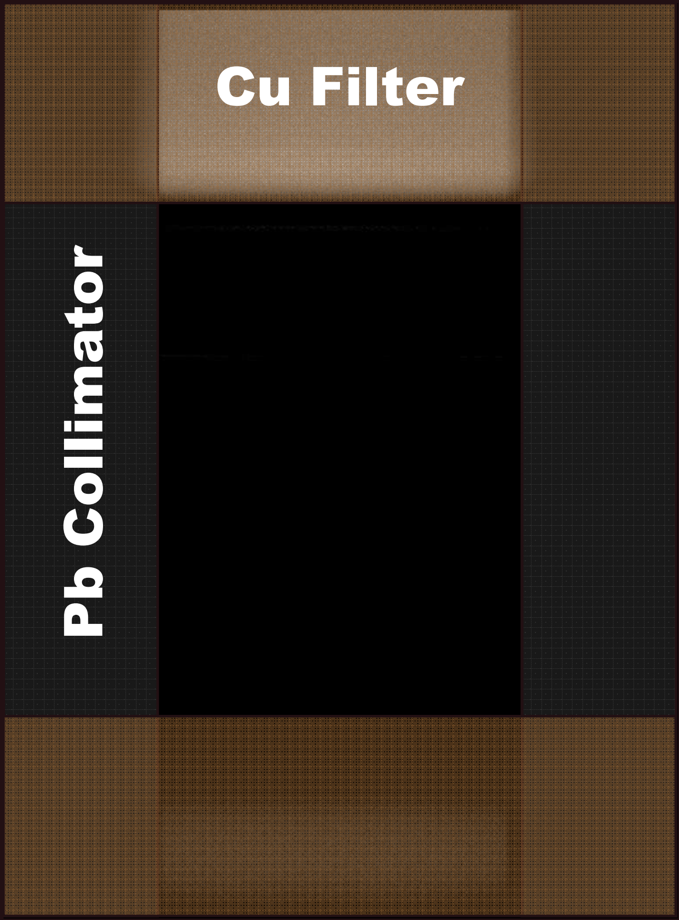
$$\mathrm{var}\{\mathrm{f(x,y,z)}\} \sim \mathrm{var}\{P(u_d, v_d, \lambda)\}$$

What does it mean?

- Imaging target is embedded within the ROI
- ROI can be subdivided into inner/outer ROIs
- Two regions are exposed to different beam intensity
- Image quality of the inner region can potentially be improved
- Imaging dose can be spared to the outer region

Practice of Intensity Weighting





Materials

- Varian Trilogy OBI
- Filters
  - 1/8” Copper
- Phantoms
  - Solid Water Slabs
  - Pelivic Phantom (Human bone in Lucite)
- Gafchromic EBT Film
- Epson Expression 10000 XL Flatbed Transparency Scanner

CBCT Scan Protocol

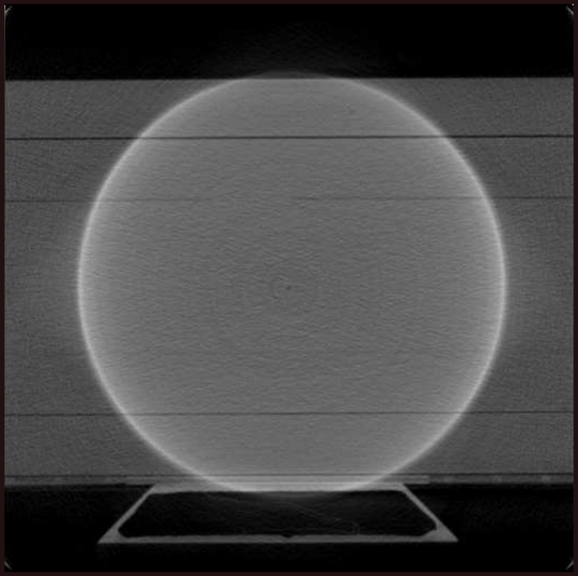
- Mount filters in place of bowtie
- Scan in CCW orientation
- Exposure Settings:
  - 125 kVp
  - 80 mA
  - 15 (13) ms

Film Scanning Protocol

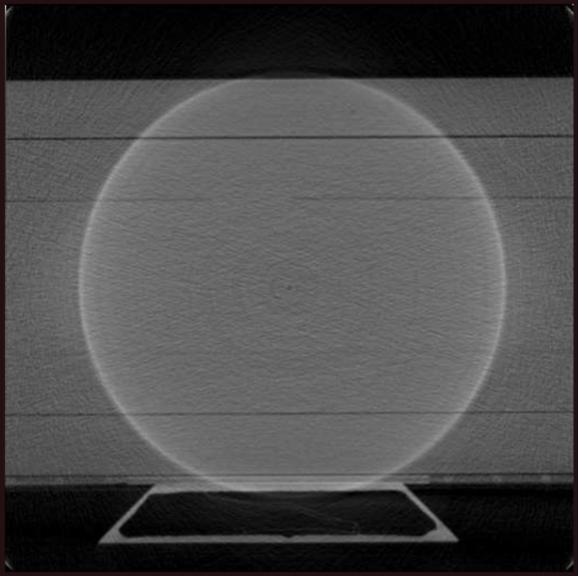
- Scan 5x to warm up light source
- 5x scan of glass
- 5x scan of unexposed film
- 5x scan dose measurement film
- Data for analysis is the average of the red channel intensity over the last 3 scans for each

- Calibration curve constructed using film irradiated by 6 MeV photons at known doses

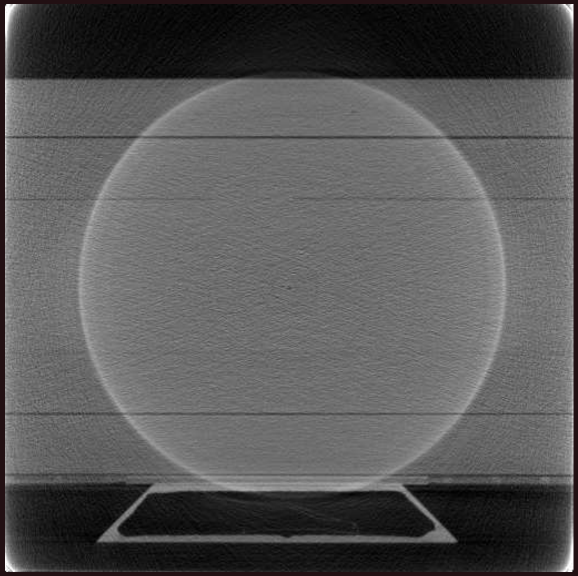
Results – Images – Solid Water



c-BPF w/o scatter correction

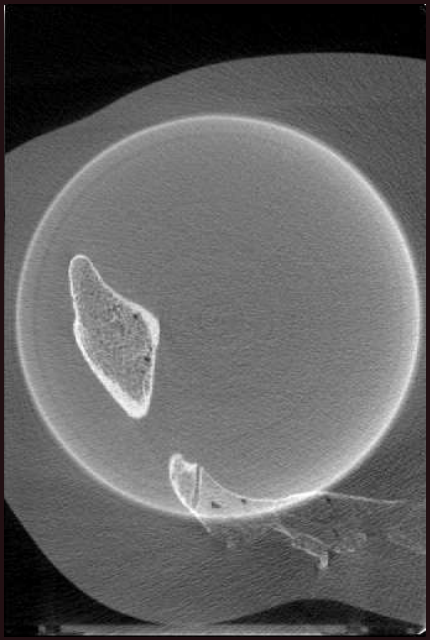


c-BPF w/ scatter correction

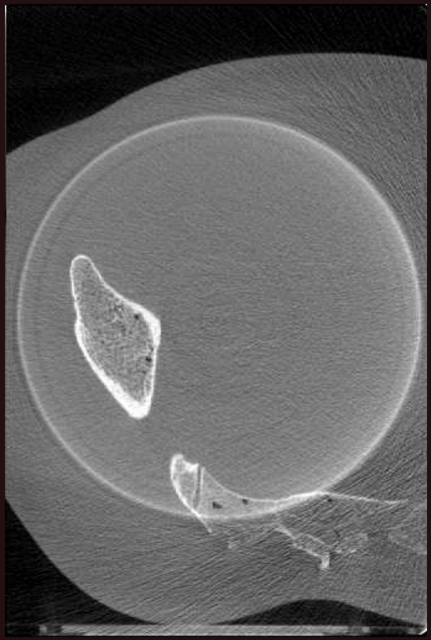


FDK w/ scatter correction

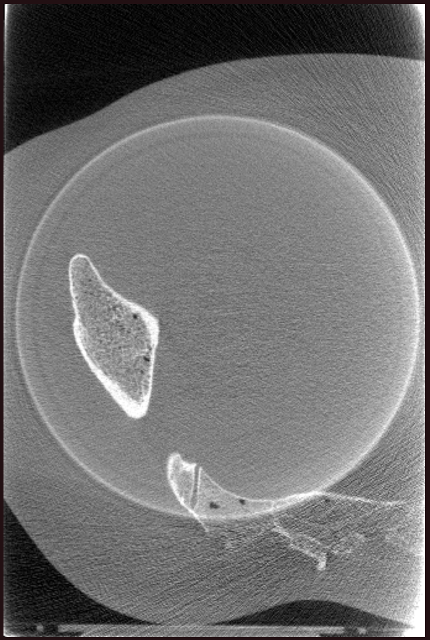
Results – Images – Pelvic Phantom



c-BPF w/o
scatter correction

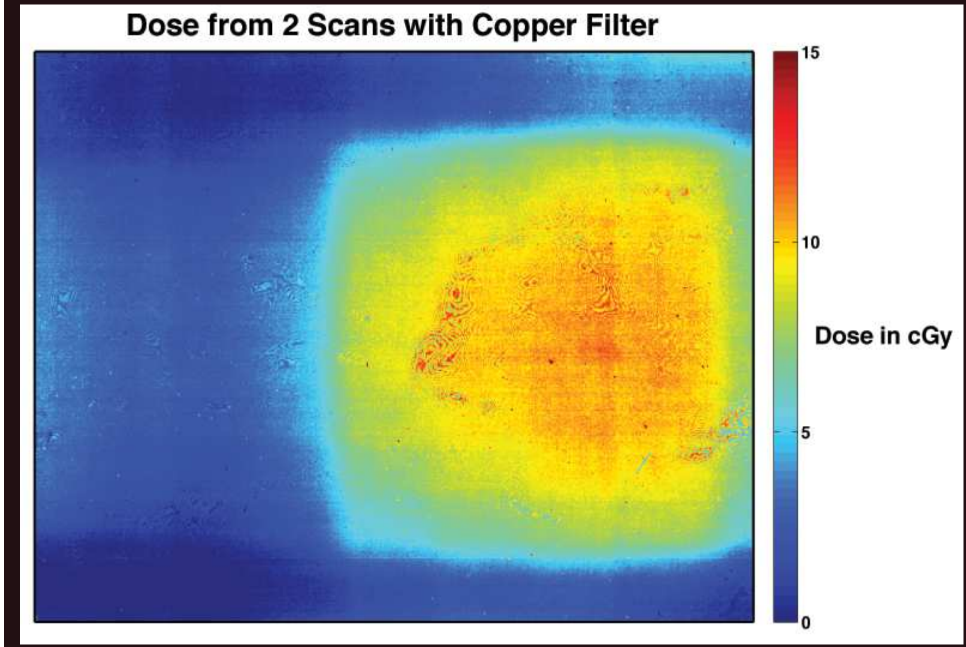


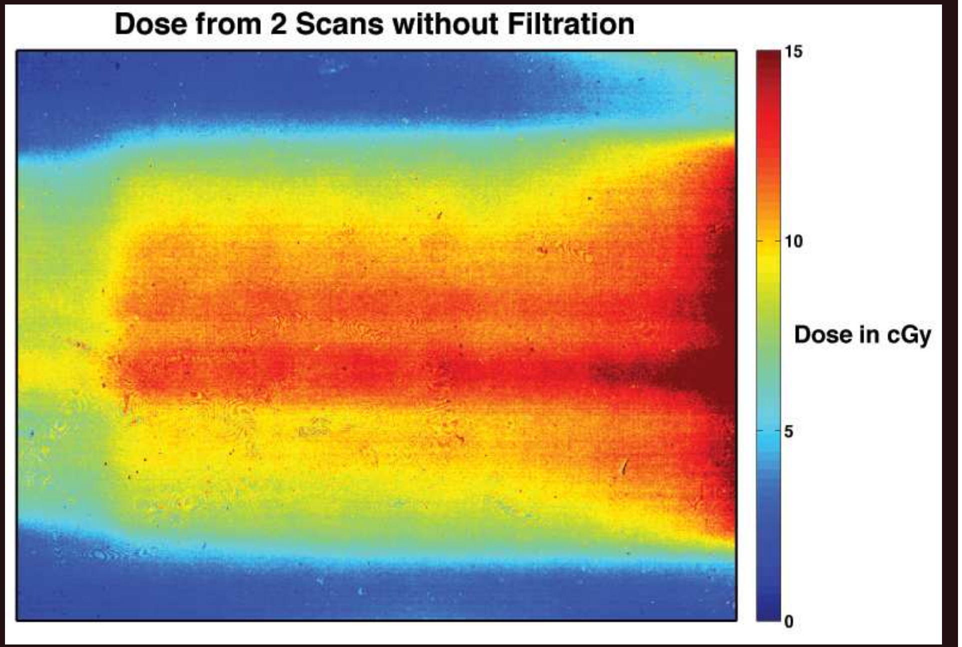
c-BPF w/ scatter
correction



FDK w/ scatter
correction

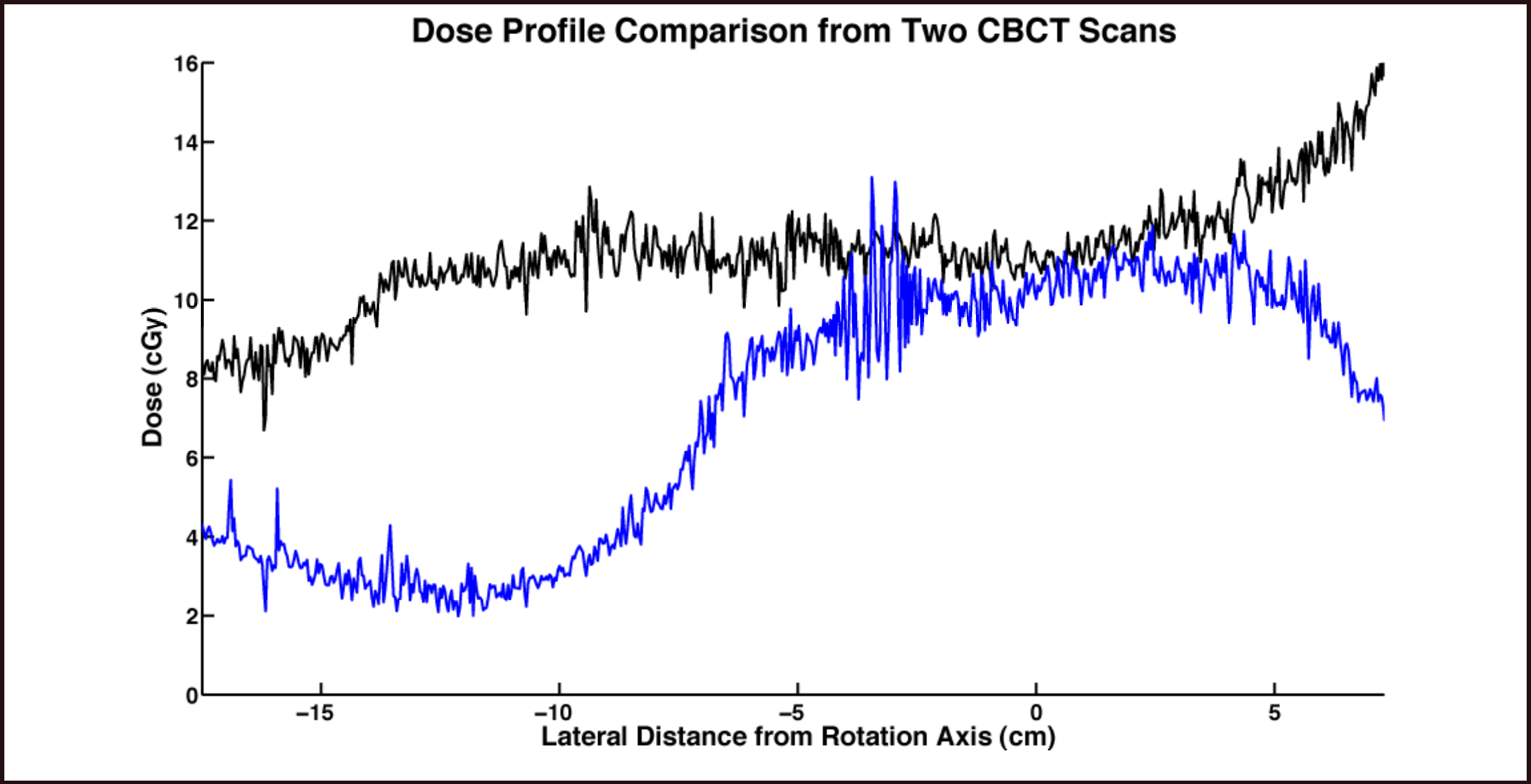
Results - Dose Reduction



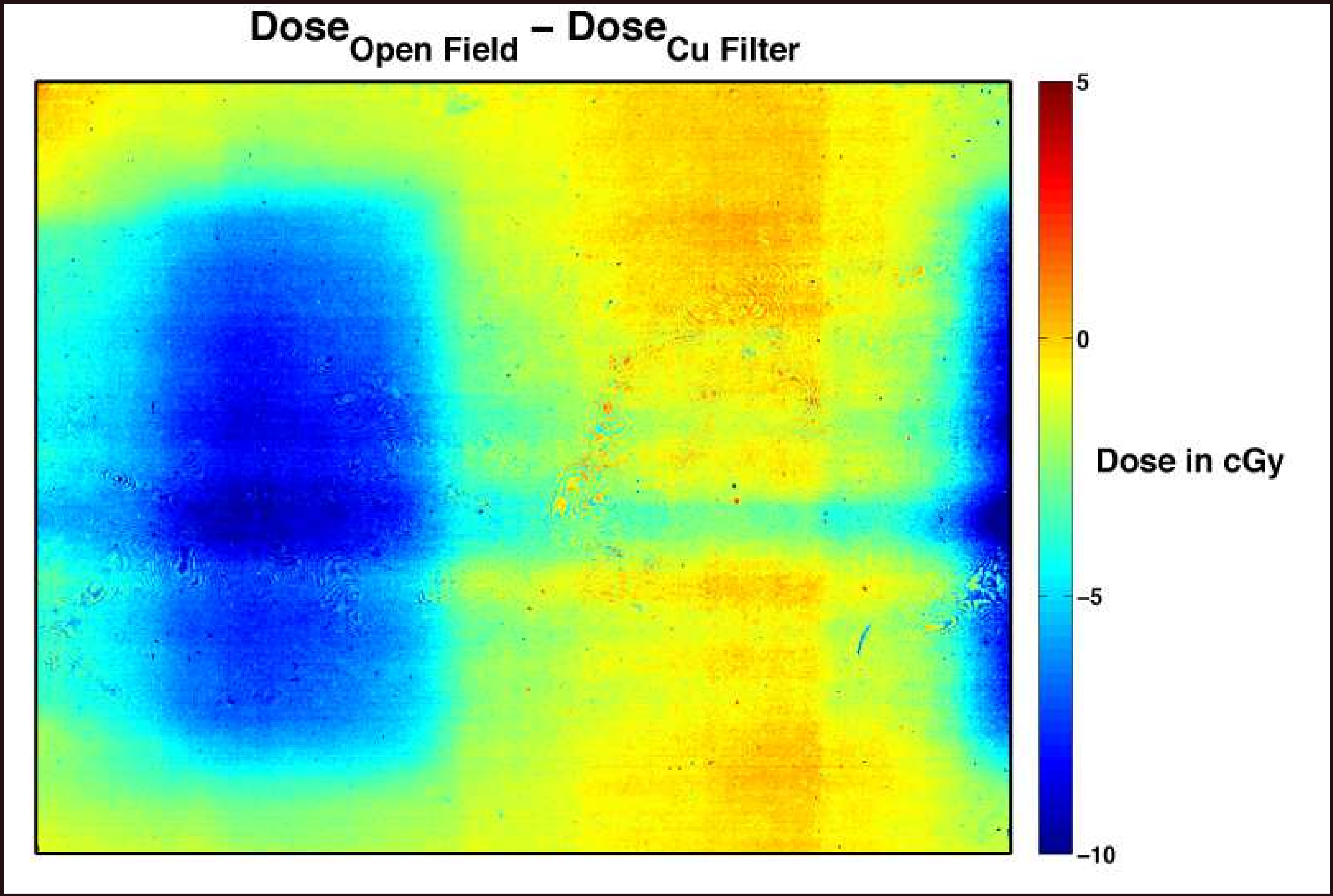


- 2 consecutive CCW scans
- 10 cm Solid water phantom at 5 cm depth
- Axis of rotation offset to right side
- Gafchromic EBT Film
- Expected error <10%

Results - Dose Reduction



Results - Dose Reduction



Conclusions

- Intensity weighted region of interest imaging performed with real data
- Significant dose reduction achieved
- Evidence of scatter reduction

Future Work

- Reduction of artifacts
- More thorough dose analysis
- Quantification of scatter reduction

- More complex fluence profiles via dynamic intensity weighting

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