Mini-Beam Collimator Transferability Study

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Basic Radiation Oncology

- Ionizing radiation causes DNA strand breaks, which can be leveraged for therapeutic benefit in cancer treatment
- Most modern external beam radiotherapy is delivered using medical linear accelerators, or "linacs"

Figure 1: Varian 21EX linear accelerator

Micro-Beam Radiotherapy

- Micro-beam radiotherapy uses a synchrotron-generated array of parallel micro-planar beams
  - Typical ~200kV
  - Array
    - Typical <100 µm FWHM
    - Typical <400 µm spacing
  - However, micro-beams have low penetration, and can only be produced at synchrotron facilities

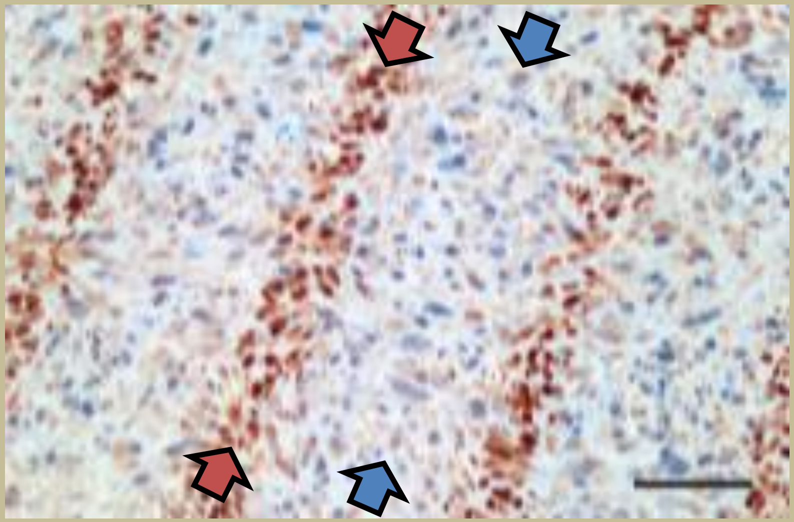

Figure 2: EMT-6.5 tumour cells 4 hours after micro-beam irradiation (bar is 100 µm) [Crosbie *et al*. 2010]

- Dilmanian *et al.* 2002
- Laissue *et al.* 1998
  - Both studies showed promise for the use of micro-beam radiation in the treatment of brain lesions in rats.

High-Energy Mini-Beam Collimation

- A mini-beam collimator for use with Varian iX medical linear accelerator

- Mini-beams are parallel planar beams
  - 6 MV photon energy
  - Projected at isocenter
    - 1 mm peak FWHM
    - 2 mm peak to peak separation

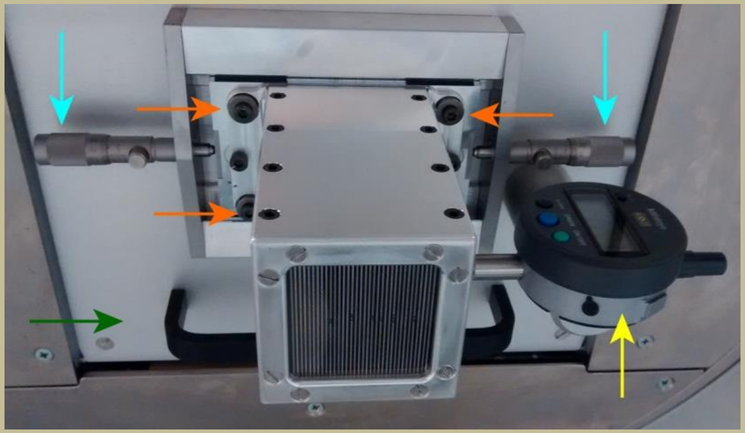

Figure 3: Mini-beam collimator [Cranmer-Sargison *et al*. 2015]

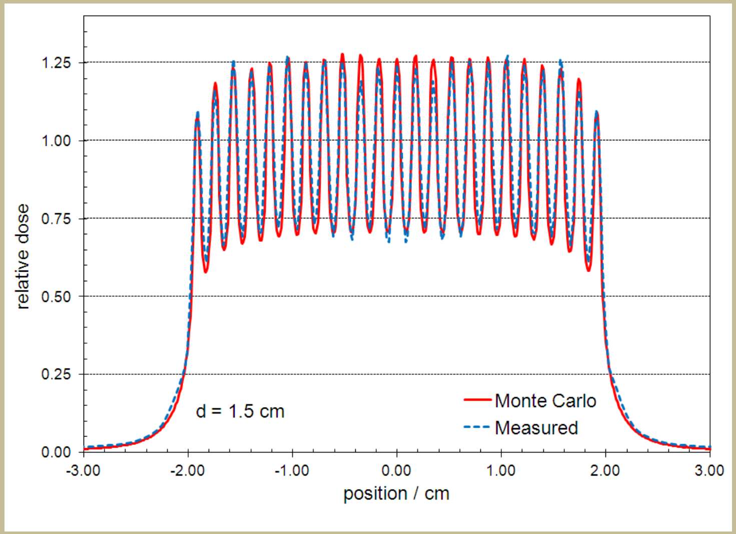

Figure 4: Commisioning dose profile [Cranmer-Sargison *et al.* 2015]

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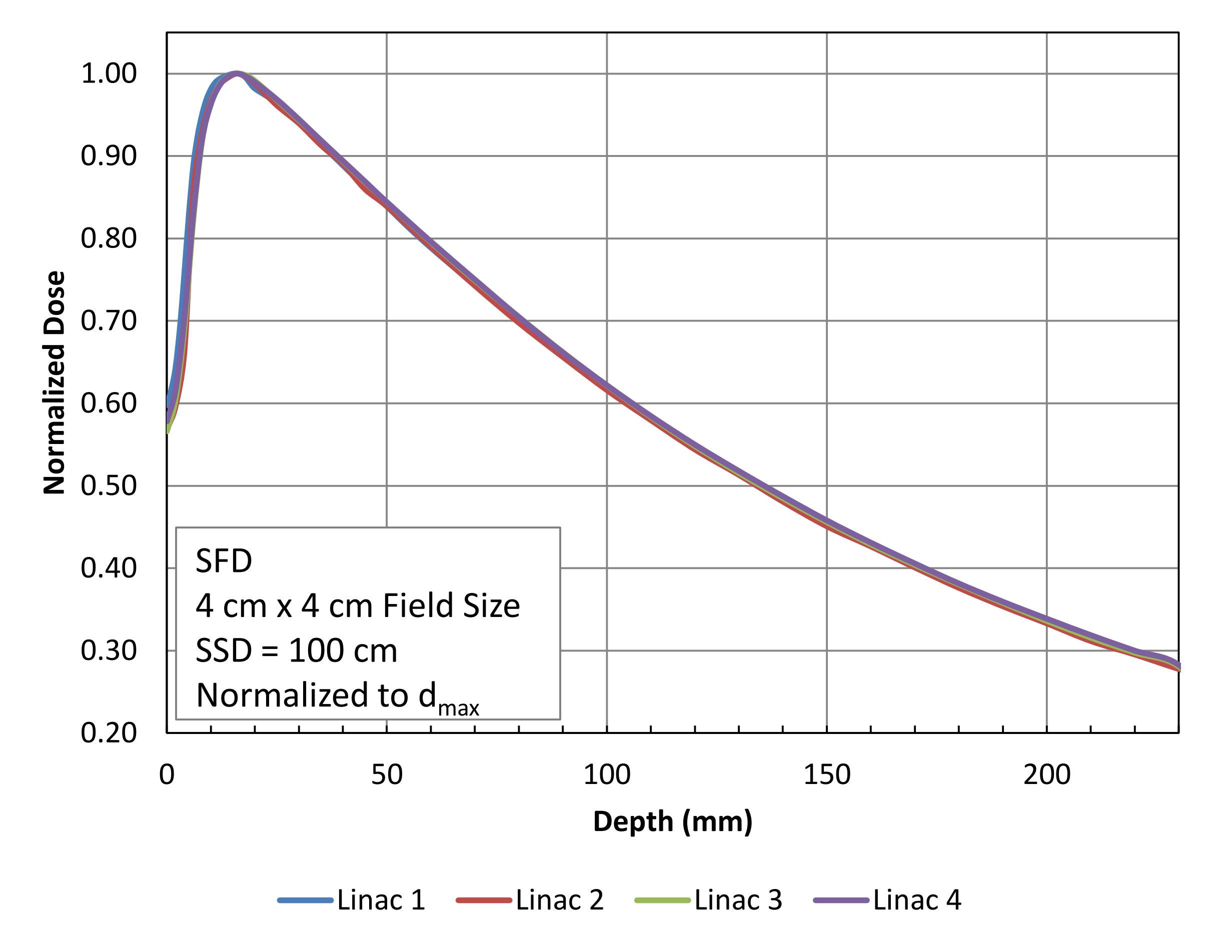
Characterization on Multiple Linacs

Figure 5: Experimental Setup

- Measurements of mini-beam collimated fields on multiple clinically beam-matched linacs

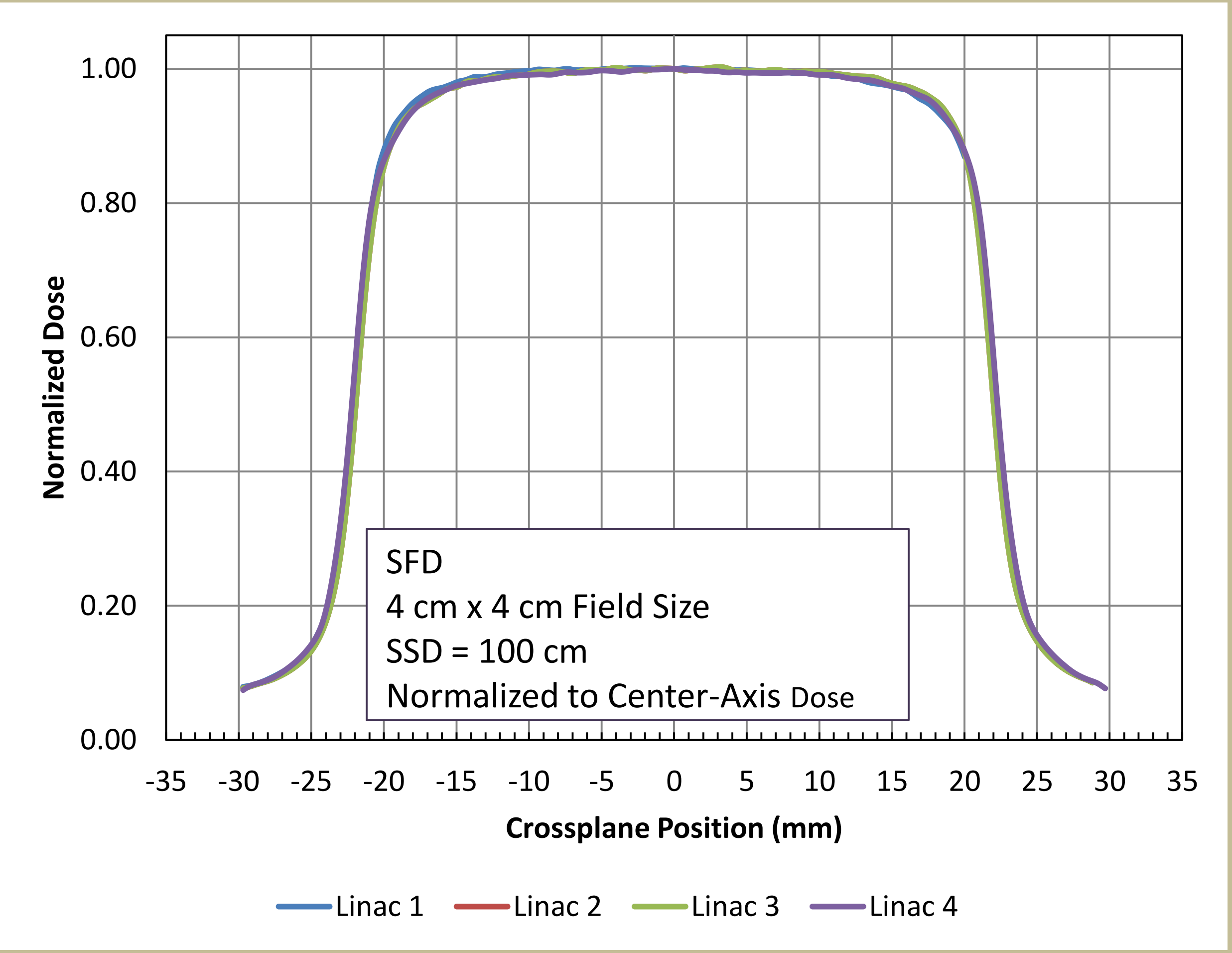
- Materials
  - Four Varian 21EX accelerators
    - 6 MV nominal beam energy
  - Two unshielded diodes
    - TN60017 (PTWe)
    - Stereotactic Field Diode (SFD)
  - MP3 water tank
    - 0.1 mm positional resolution
    - ± 0.1 mm positional uncertainty

Figure 6: Open Field PDD



- Percent Depth Dose (PDD) curves show the relative dose as a function of depth in water
- PDD curves are the average of multiple measurements

Figure 7: Open Field Dose Profiles



- Dose Profiles show relative dose as a function of crossplane position at a depth of 10 cm in water
- Profiles are the average of multiple measurements
- SFD horizontally oriented for improved resolution

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Table 1: Output Factors

Linac	Field Size	PTWe	SFD
Linac 1	2 cm x 2 cm	0.88 ± 0.07%	0.87 ± 0.50%
Linac 2		0.88 ± 0.03%	0.87 ± 0.01%
Linac 3		0.88 ± 0.07%	0.87± 0.07%
Linac 4		0.88 ± 0.07%	0.87 ± 0.51%
Linac 1	3 cm x 3 cm	0.92 ± 0.12%	0.91 ± 0.07%
Linac 2		0.92 ± 0.06%	0.92 ± 0.02%
Linac 3		0.92 ± 0.05%	0.92 ± 0.07%
Linac 4		0.93 ± 0.13%	0.92 ± 0.09%
Linac 1	4 cm x 4 cm	0.96 ± 0.03%	0.96 ± 0.36%
Linac 2		0.96 ± 0.04%	0.96 ± 0.03%
Linac 3		0.96 ± 0.03%	0.96 ± 0.07%
Linac 4		0.96 ± 0.04%	0.96 ± 0.15%

- Output Factors (OF) are defined as the ratio of central axis point dose (D) such that,

$$\mathrm{OF}_{\mathrm{f_{clin}}}^{\mathrm{W}} = \frac{\mathrm{D}_{\mathrm{f_{clin}}}^{\mathrm{W}}}{\mathrm{D}_{f_{msr}}^{\mathrm{W}}}$$

- Where f_{clin} is the field size of interest and f_{msr} the machine specific reference field
- Reference field size of 5 cm x 5 cm
- SSD = 100 cm

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Mini-Beam Field Characterization

- Profile and PDD measurements
  - Same settings as for the open field measurements
- Collimator Factors (CF) are the ratio of point doses in a collimated field to that in an open field
  - Ratio of point doses at d = 10 cm along the beam center axis
  - Average of multiple measurements was taken as the measured CF

$$OF^{w}_{f_{mini}} = OF^{w}_{f_{clin}} \times CF^{w}_{f_{mini}}$$

$$CF^{w}_{f_{mini}} = \frac{D^{w}_{f_{mini}}}{D^{w}_{f_{clin}}} = \frac{D^{det}_{f_{mini}}}{D^{det}_{f_{clin}}} \times k^{det}_{f_{mini}}$$

$$k^{det}_{f_{mini}} = \frac{\left(\frac{D^{w}_{f_{mini}}}{D^{w}_{f_{clin}}}\right)}{\left(\frac{D^{det}_{f_{mini}}}{D^{det}_{f_{clin}}}\right)}$$

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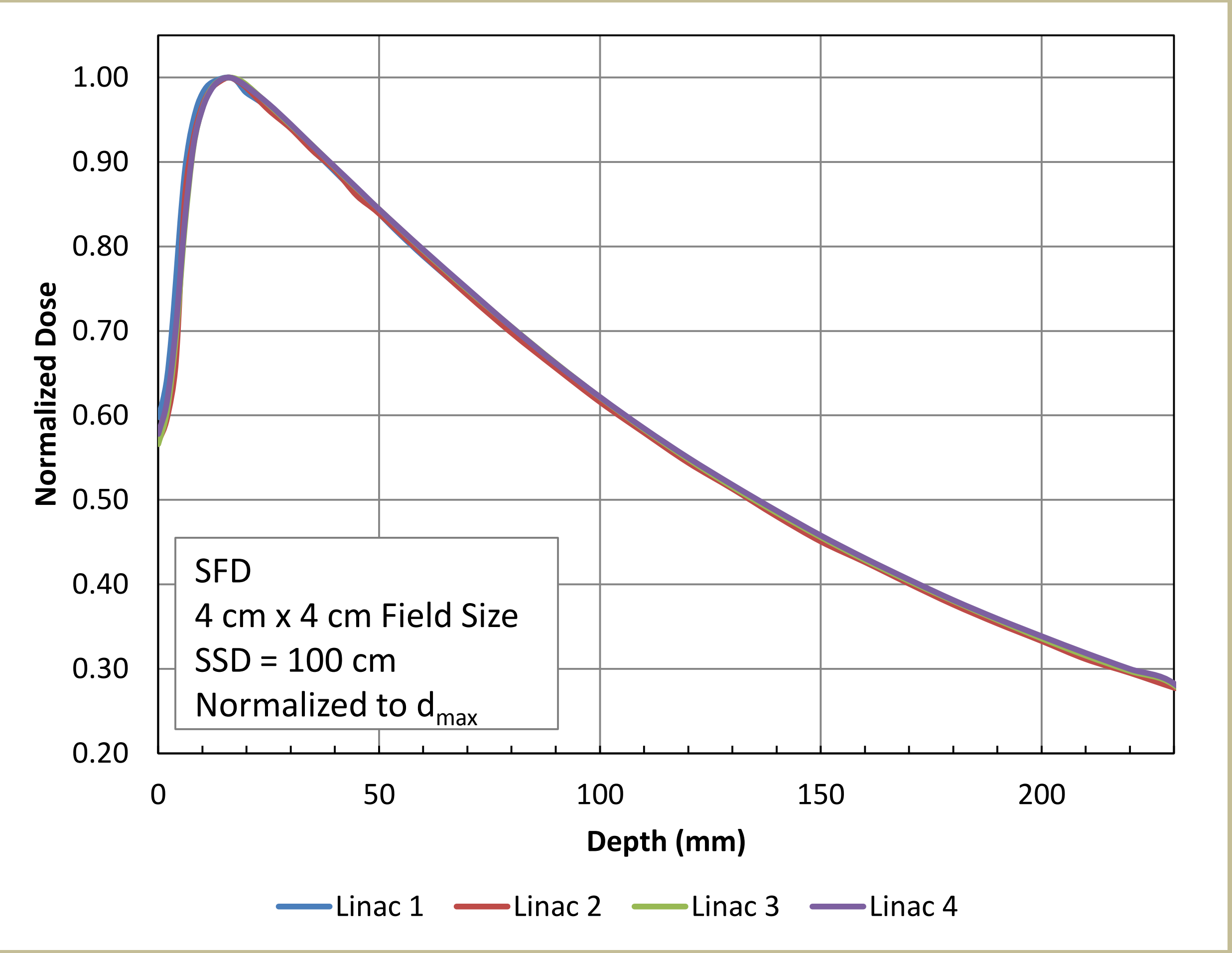
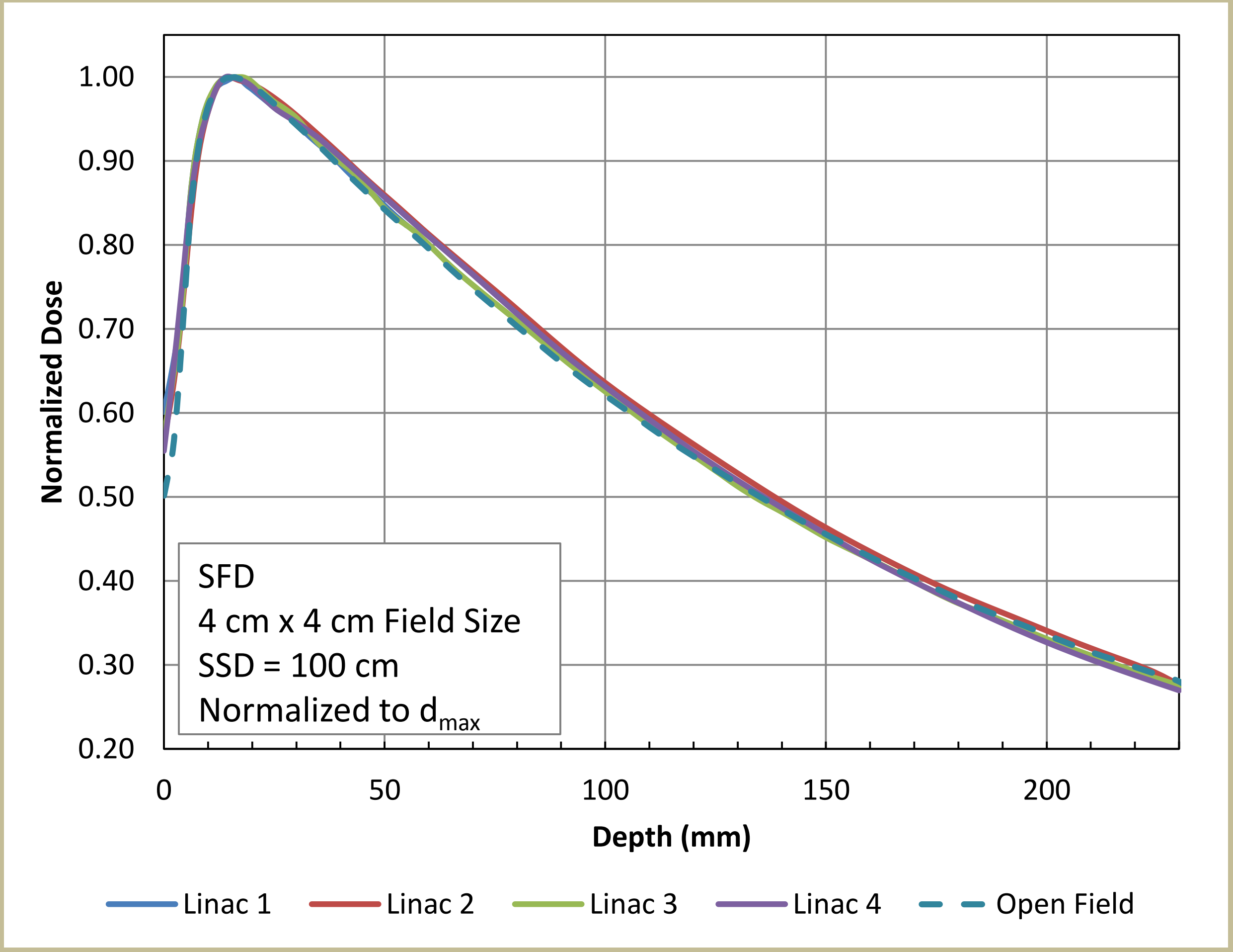
Figure 8: Mini-Beam PDD



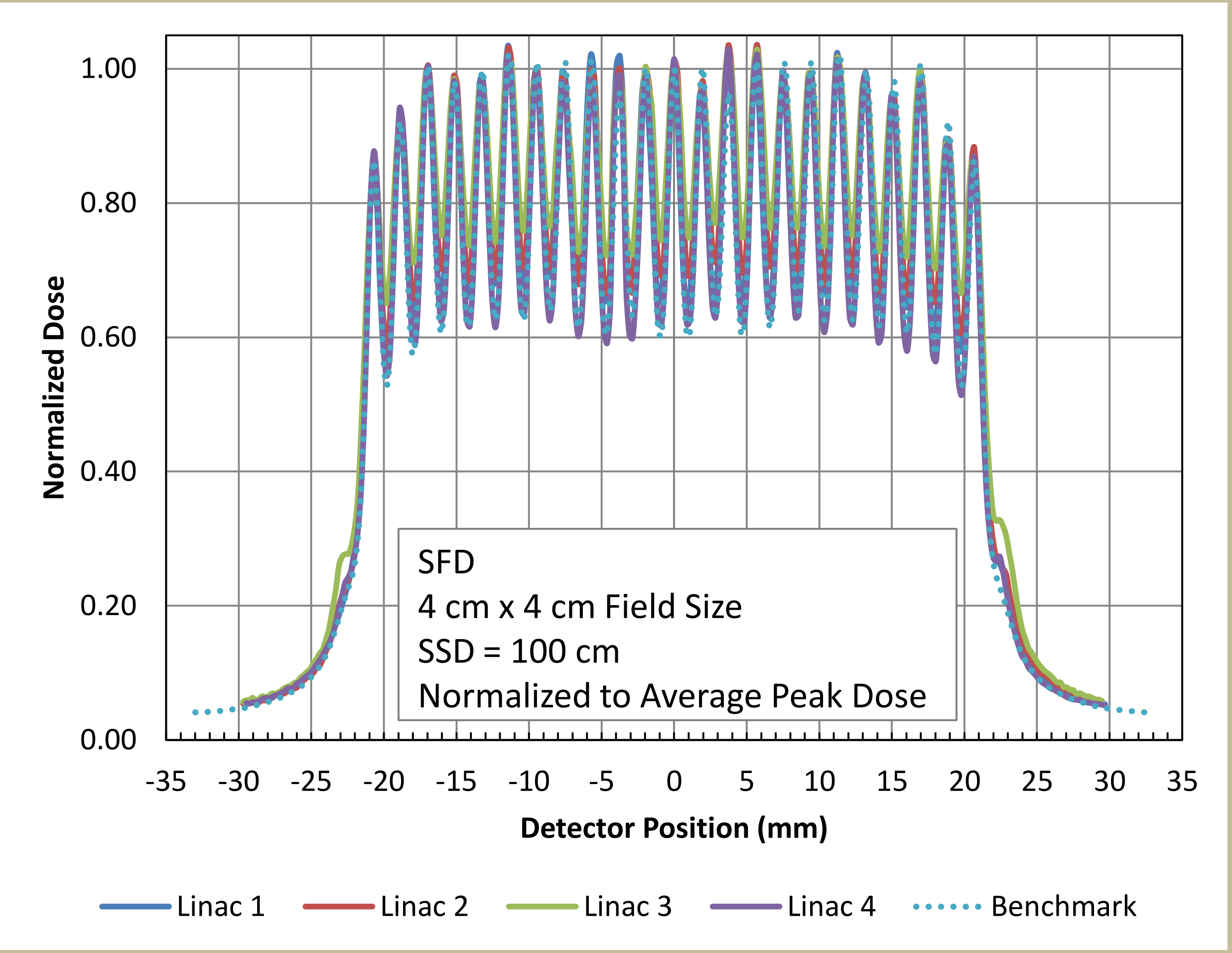
- PDD curves are the average of multiple measurements
- To ensure that the active volume was entirely in the peak, the SFD was horizontally oriented

Figure 9: PDD Comparison



- Average open field PDD is superimposed on the collimated PDD curves
- All PDD curves are similar, showing little variation in beam quality due to the collimator

Figure 10: Mini-Beam Dose Profiles



- Profiles are the average of multiple measurements
- SFD horizontally oriented for improved resolution
- Relative valley doses are not consistent across linacs

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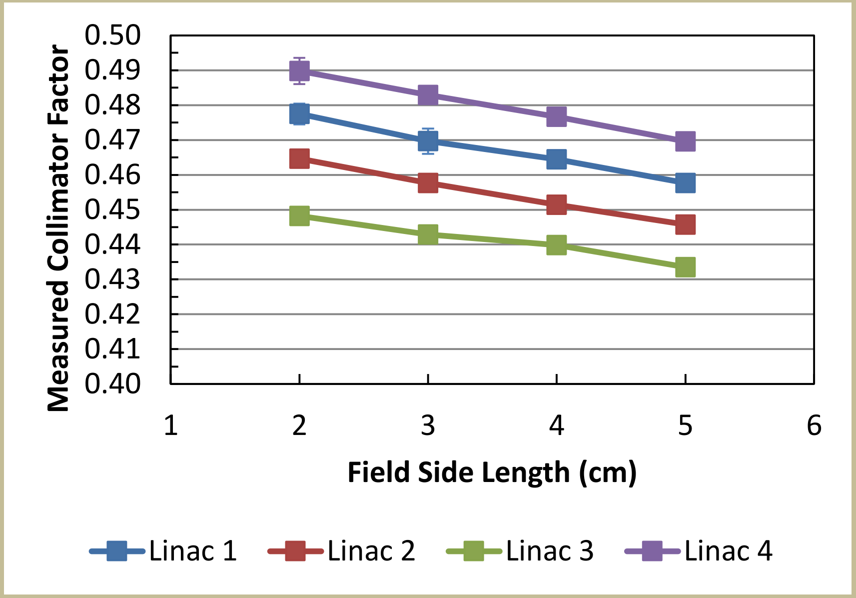
Table 2: Peak-to-Valley Dose Ratios

Linac	PVDR
1	1.59
2	1.53
3	1.41
4	1.71

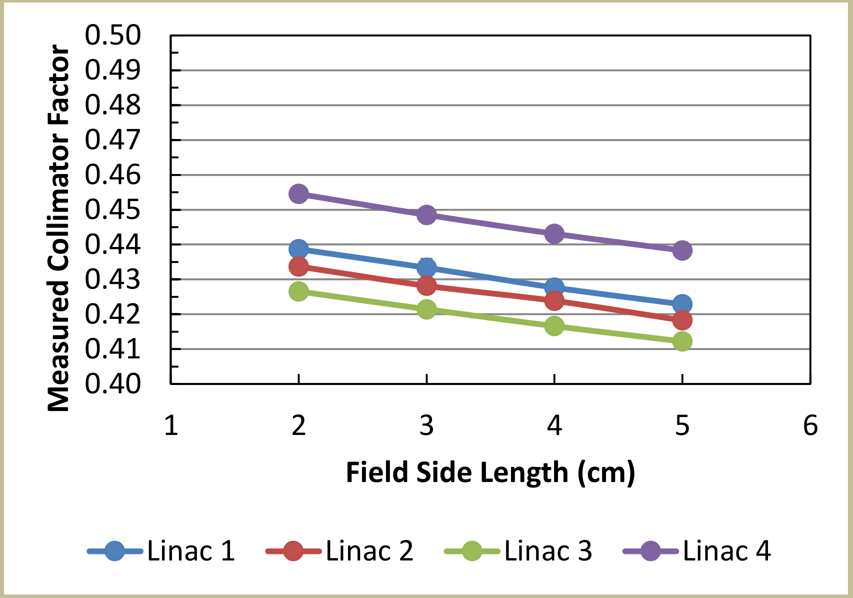
- Peak-to-Valley Dose Ratio (PVDR) is the ratio of the average peak dose to the average valley dose
- Used as a characterization metric for micro-beam dose distributions
- It can be seen that the resultant PVDR varies across the four linacs

Figure 11: Measured CF

SFD Measured Collimator Factors



PTWe Measured Collimator Factors



- Linear relation to the side length of the square field
- Increase in PVDR correlates to an increase in measured CF

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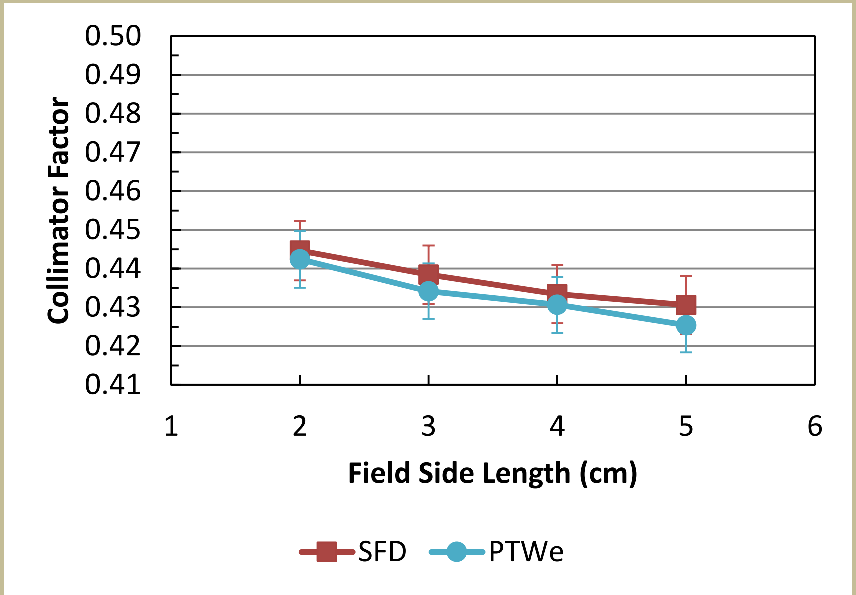
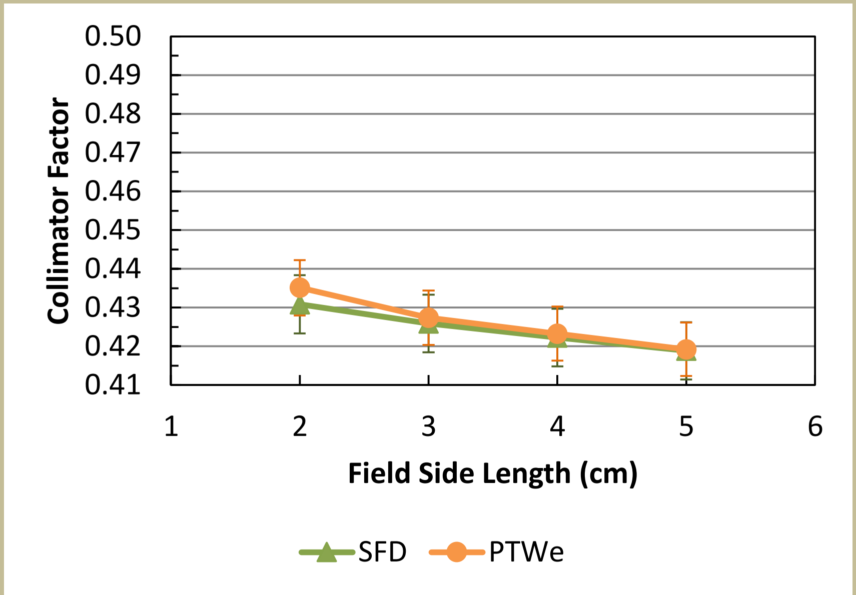
Figure 12: Corrected CF Part 1

Linac 2 Collimator Factors



Linac 3 Collimator Factors



- Both Linac 2 and Linac 3 show good agreement between the corrected diode measurements

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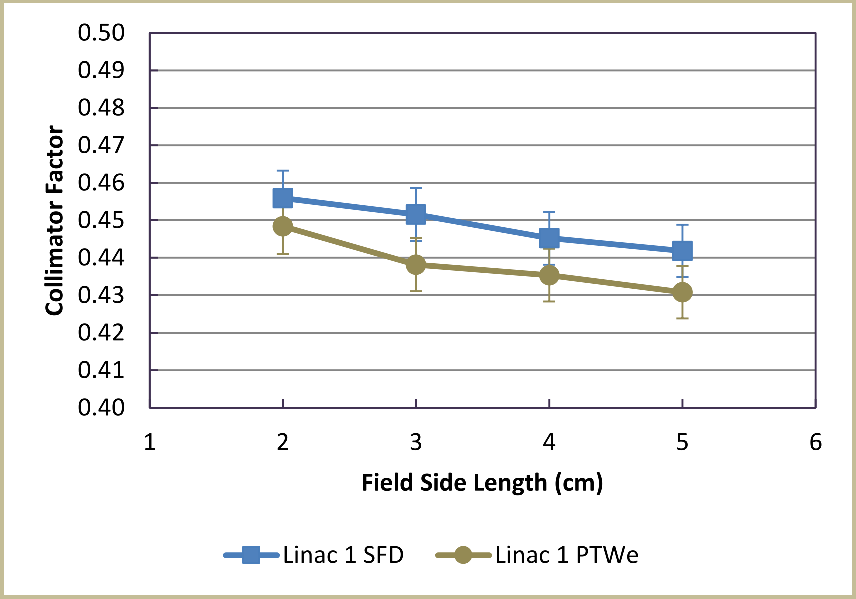
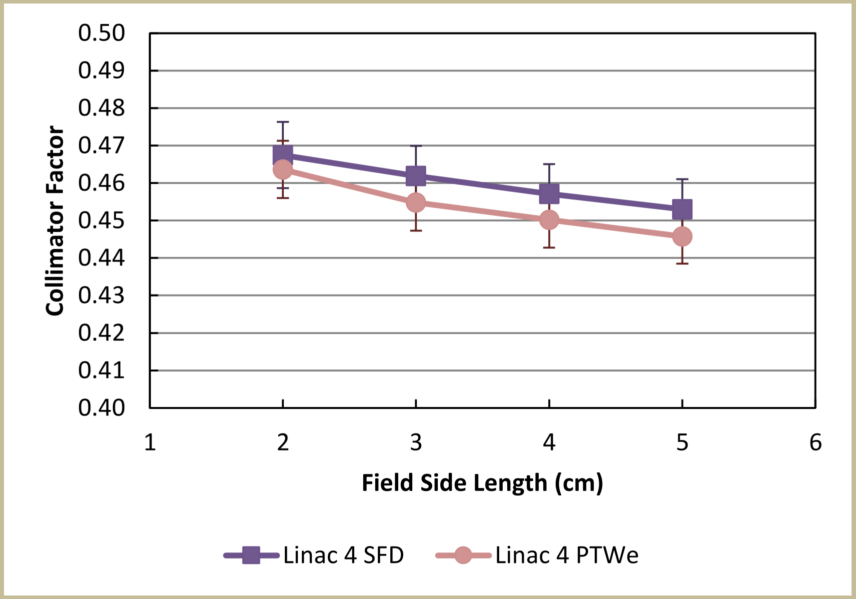
Figure 13: Corrected CF Part 2

Linac 1 Collimator Factors



Linac 4 Collimator Factors



- Linacs 1 and 4 show agreement within experimental uncertainty between the corrected diode measurements

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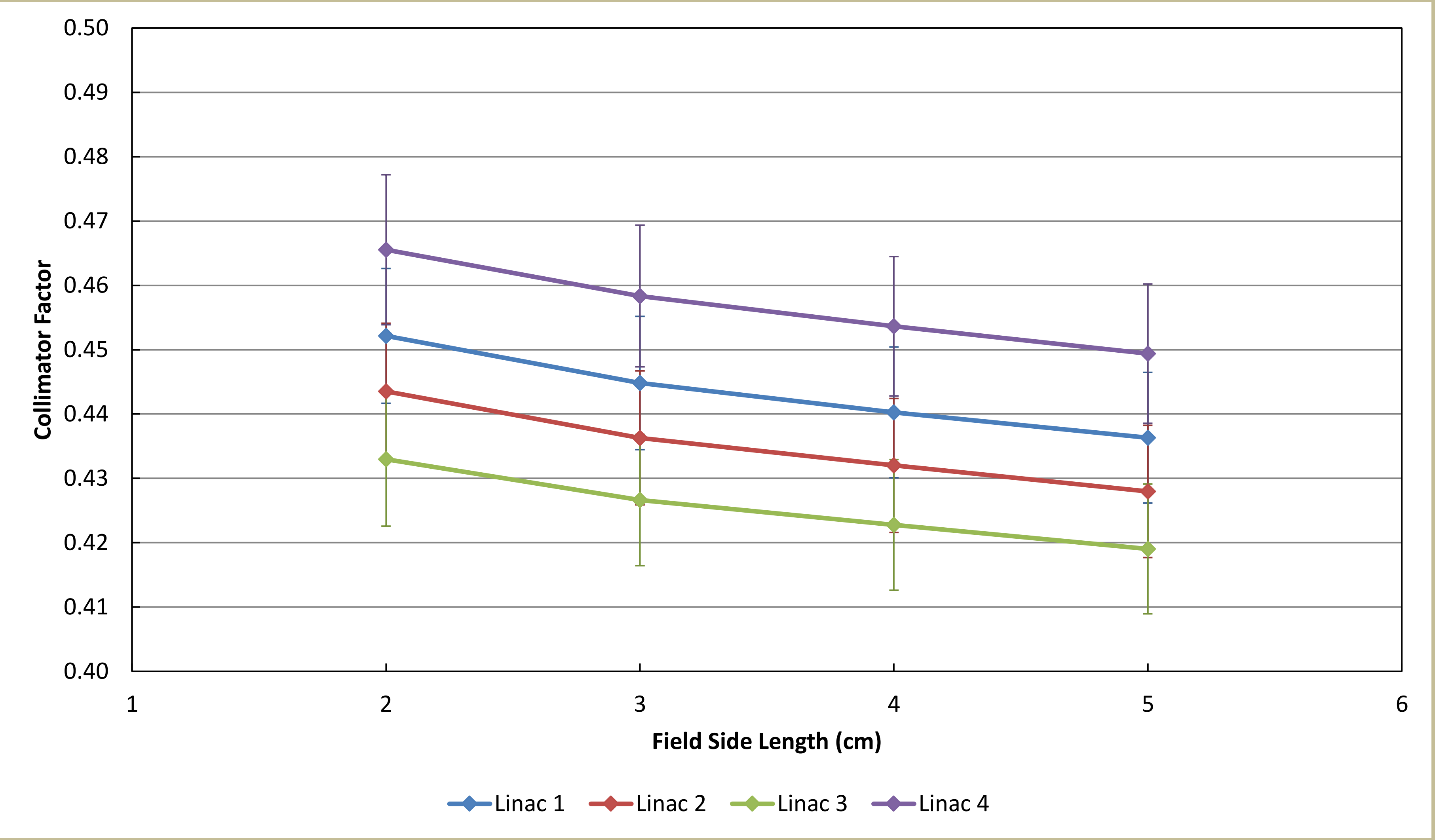
Figure 14: Corrected CF Part 3



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Example: Dose Calculation

- 5 x 5 cm^2 field, SSD = 100 cm, 6MV, 500 cGy at 5 cm depth
- Open Field:

$$\text{Open Field MU} = (\text{Dose}) * (\text{Output}) = (500\ \text{cGy}) * \left(1.25\,\frac{\text{MU}}{\text{cGy}}\right) = 625\ \text{MU}$$

- Linac 4 Collimated Field:

$$\text{Collimated Field MU} = \frac{(\text{Dose}) * (\text{Output})}{\text{CF}_{\text{f}_{\text{mini}}}^{\text{w}}} = \frac{(5\ \text{Gy}) * \left(125\,\frac{\text{MU}}{\text{Gy}}\right)}{0.449} = 1392\ \text{MU}$$

- Linac 3 Collimated Field

$$\text{Collimated Field MU} = \frac{(\text{Dose}) * (\text{Output})}{\text{CF}_{\text{f}_{\text{mini}}}^{\text{w}}} = \frac{(5\ \text{Gy}) * \left(125\,\frac{\text{MU}}{\text{Gy}}\right)}{0.419} = 1491\ \text{MU}$$

Differences

- The collimator is revealing a difference in the linacs
  - PVDR
  - Corrected Collimator Factor
- It is hypothesized that the electron beam width differs between the linacs
- This hypothesis is being tested via Monte Carlo simulation

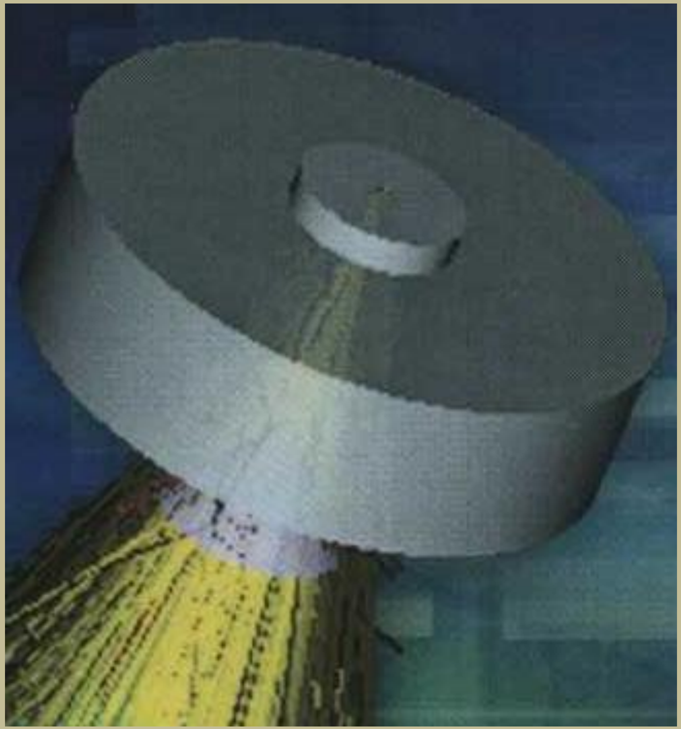

Figure 15: Simulated Bremsstrahlung Target [Seco and Verhaegen 2013]

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Questions?

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Citations

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