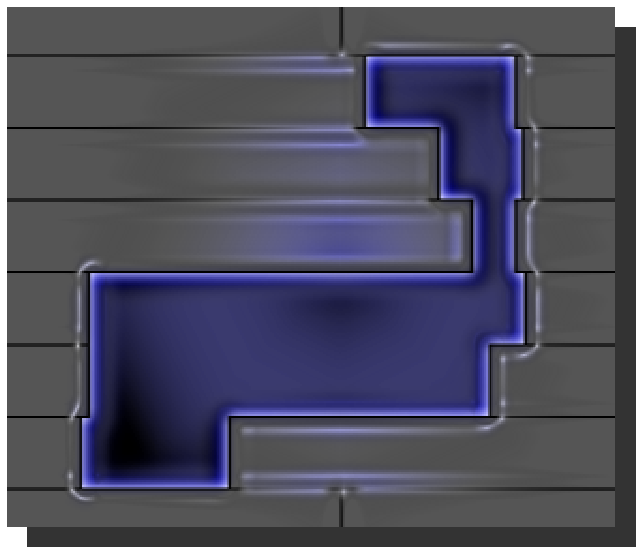
Planning Constraints for Paraspinal Volumetric Modulated Arc Therapy



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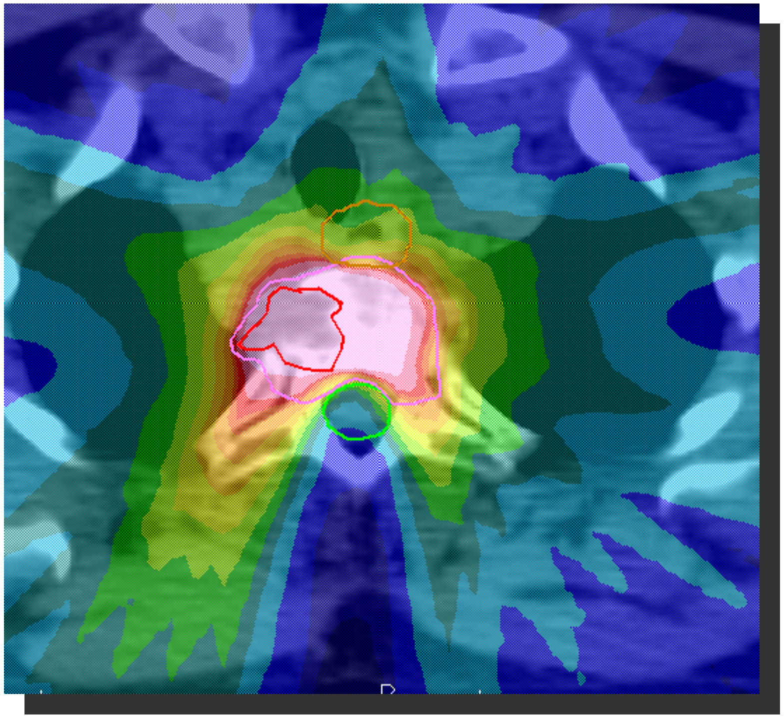
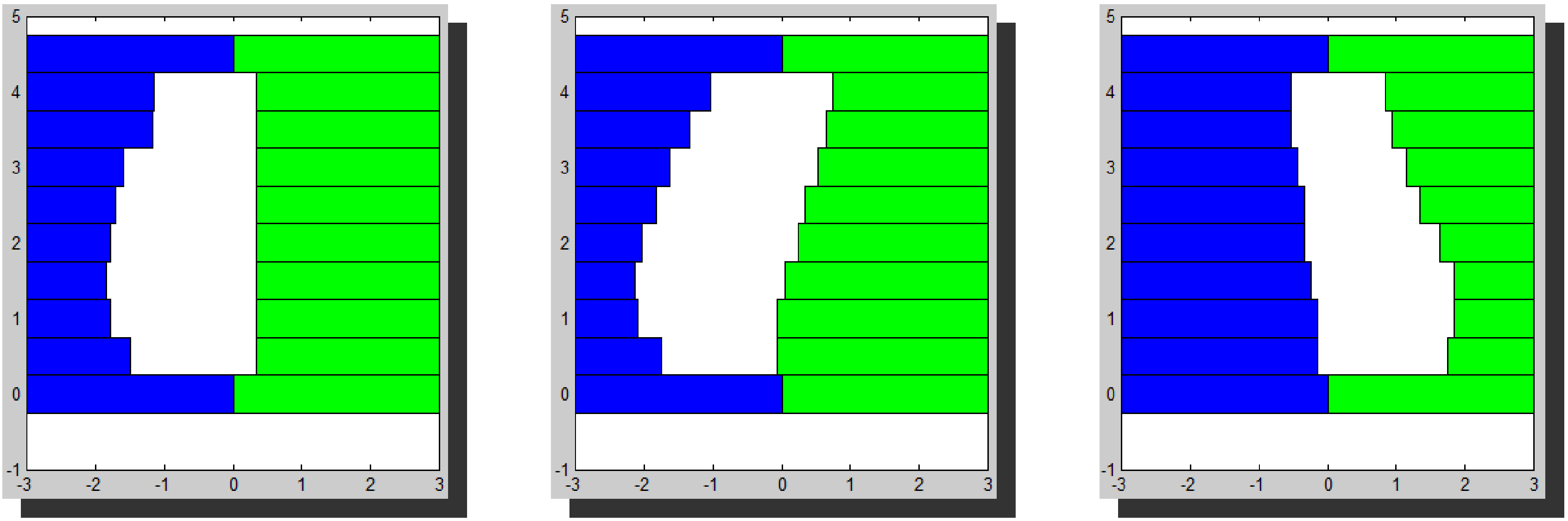
Paraspinal VMAT Overview

- Treatment delivery with simultaneous gantry rotation
- VMAT is an intuitive treatment option for paraspinal cases
- Gives comparable dose distributions in a significantly reduced treatment time
- Small target volumes can lead to irregular apertures with dosimetric uncertainty
- Must ensure dosimetric deliverability



Aperture comparison: 3DRT

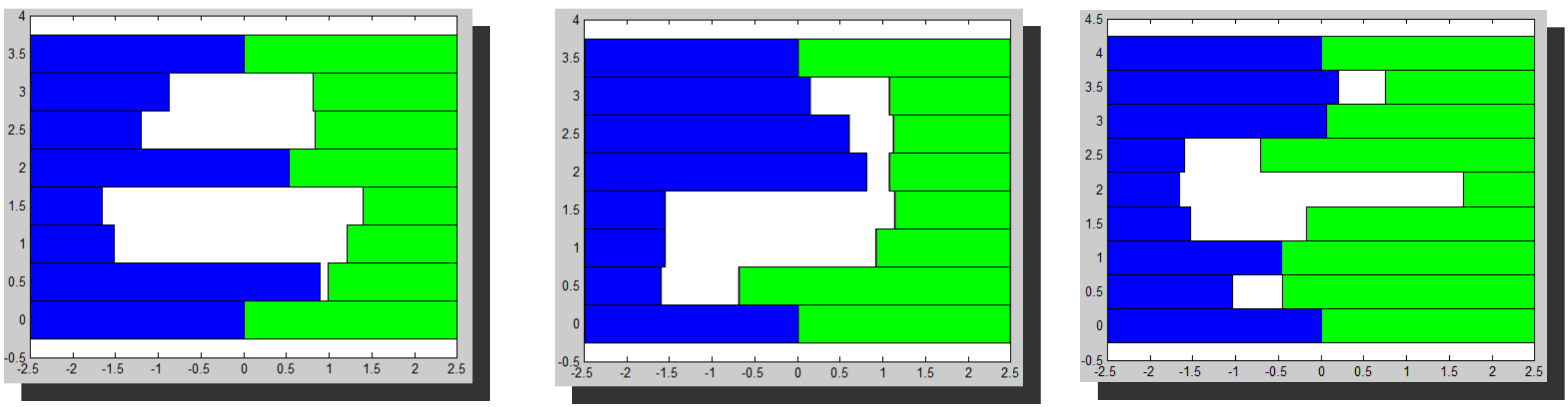
- 3D conformal treatment plan with regularly shaped beam apertures



Distances in cm

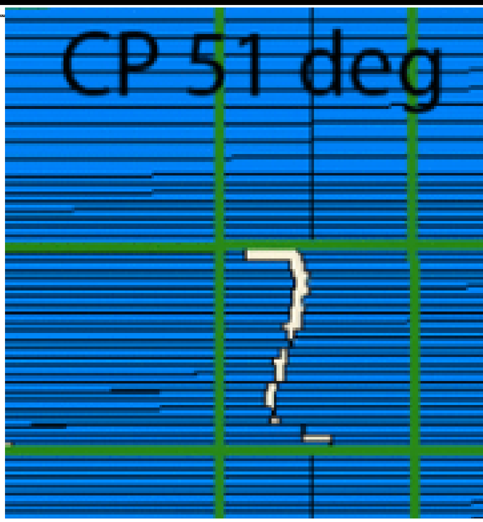
Aperture comparison: VMAT

- VMAT optimized beam apertures can be very irregular
  - Optimizer only concerned with cost of cost functions
  - Narrow openings, non-contiguous regions

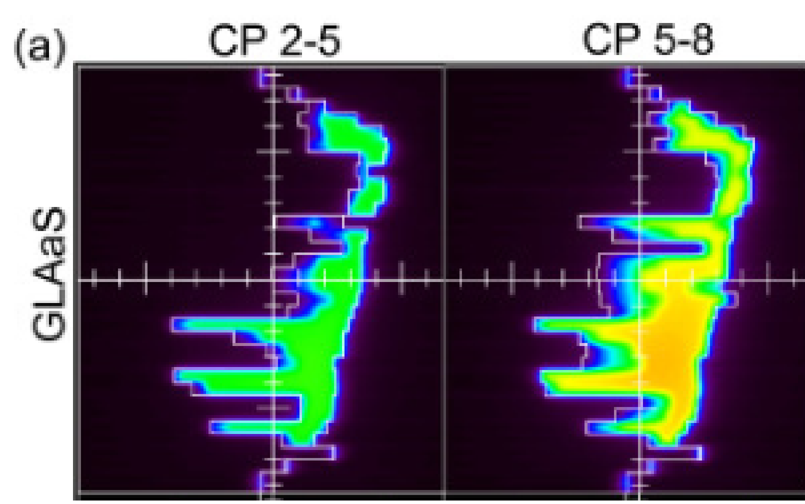


Distances in cm

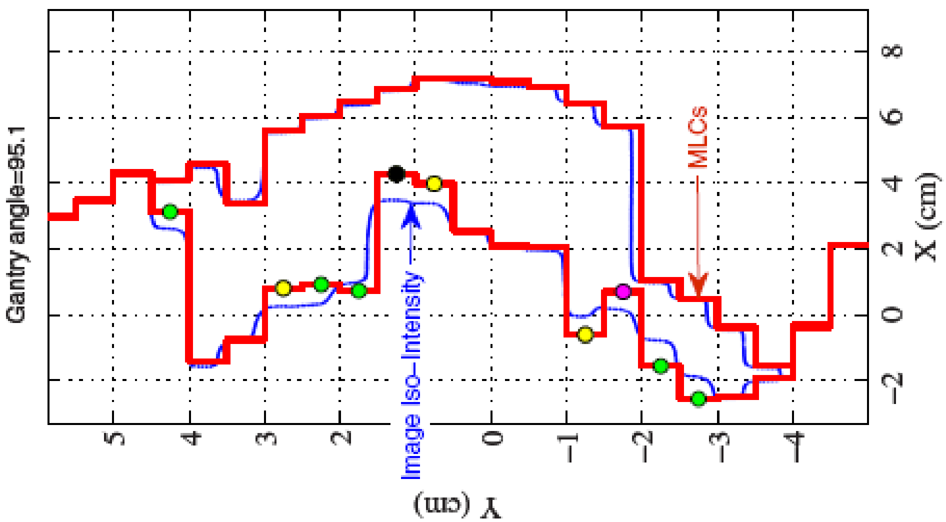
Other VMAT Apertures



Feygelman et al. *JACMP* **11 (2009).**



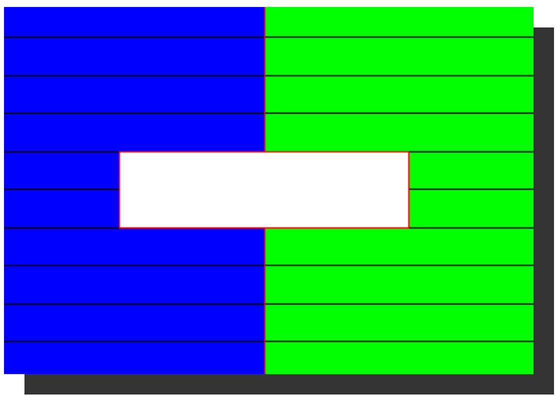
Nicolini et al., *Radiation Oncology* **3** (2008).

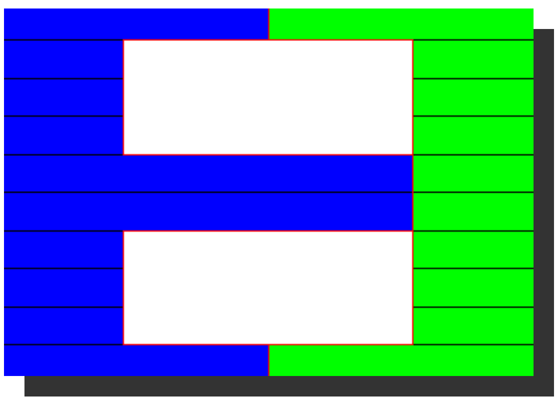


Bakhtiari et al, *Med. Phys.* **38** (2011).

- Irregular apertures occur even for large target volumes
- Side-effect of inverse planning

Small aperture dosimetric uncertainty





- Fog et al. showed that open apertures defined by two MLC leaves (0.25 mm width each) underestimated maximum dose by over 20%
- Penumbra width (10-90% width) overestimated by ~100%
- Similar results in two leaves covering the center of a field

Fog et al., *Phys. Med. Biol.* **56** (2011)

Purpose

- Goal: Improve deliverability of plans by preventing the optimizer from generating fields known to result in unacceptable error
  - Develop metrics to predict error based on aperture shape
  - Incorporate metrics in a cost function that penalizes undesirable aperture shapes

Methods: Treatment Planning

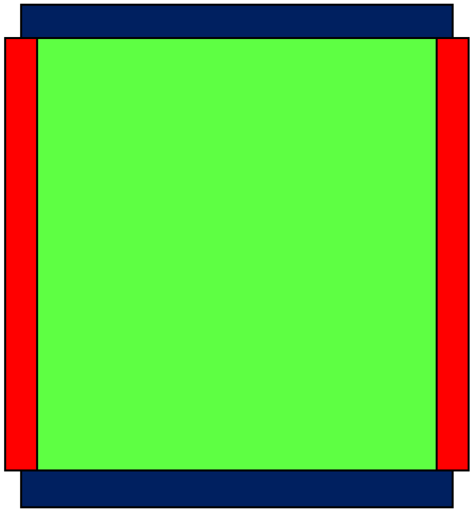
- Treatment Planning
  - UMPlan
    - Direct Aperture Optimization and field weight optimization
    - New Edge algorithm, 1 mm grid size
    - 2 paraspinal VMAT plans for each of 5 patient cases

Methods: Dosimetry

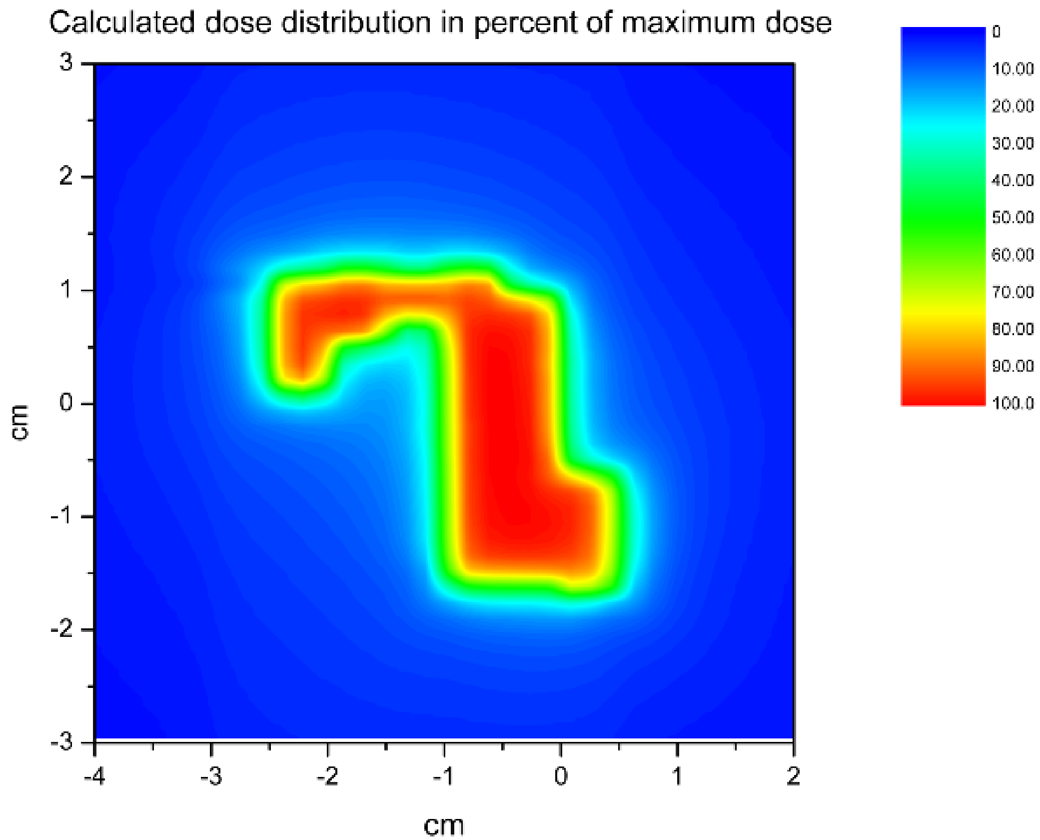
- Measurements
  - Measured dose for 23 apertures from one example case
  - Measured 15 rectangular apertures of varying area and aspect ratio
- Dosimetry
  - Kodak EDR film planar measurements in solid water
  - Verification of film measurements for 15 rectangular fields by measuring dose profiles with scanning stereotactic diode in Wellhofer Blue Phantom water tank

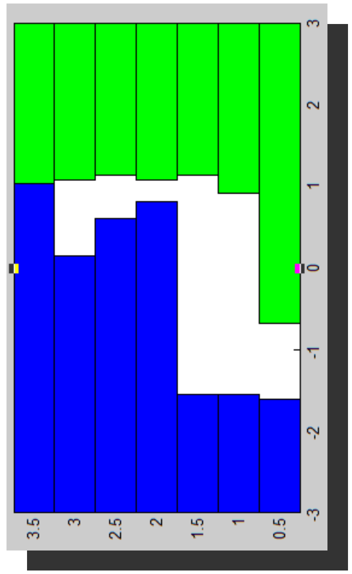
Methods: Dose comparison

- Dose Comparison
  - Image registration to maximize agreement
  - Pixels with at least 5% of maximum dose analyzed
  - $\% \text{ deviation} = \dfrac{\text{Calculation} - \text{Measurement}}{\text{Max Dose}}$
  - Dosimetric error quantified by % of pixels with greater than 5% deviation
- Correlation methods
  - Aperture area
  - Perimeter/aspect ratio
  - Edge erosion technique



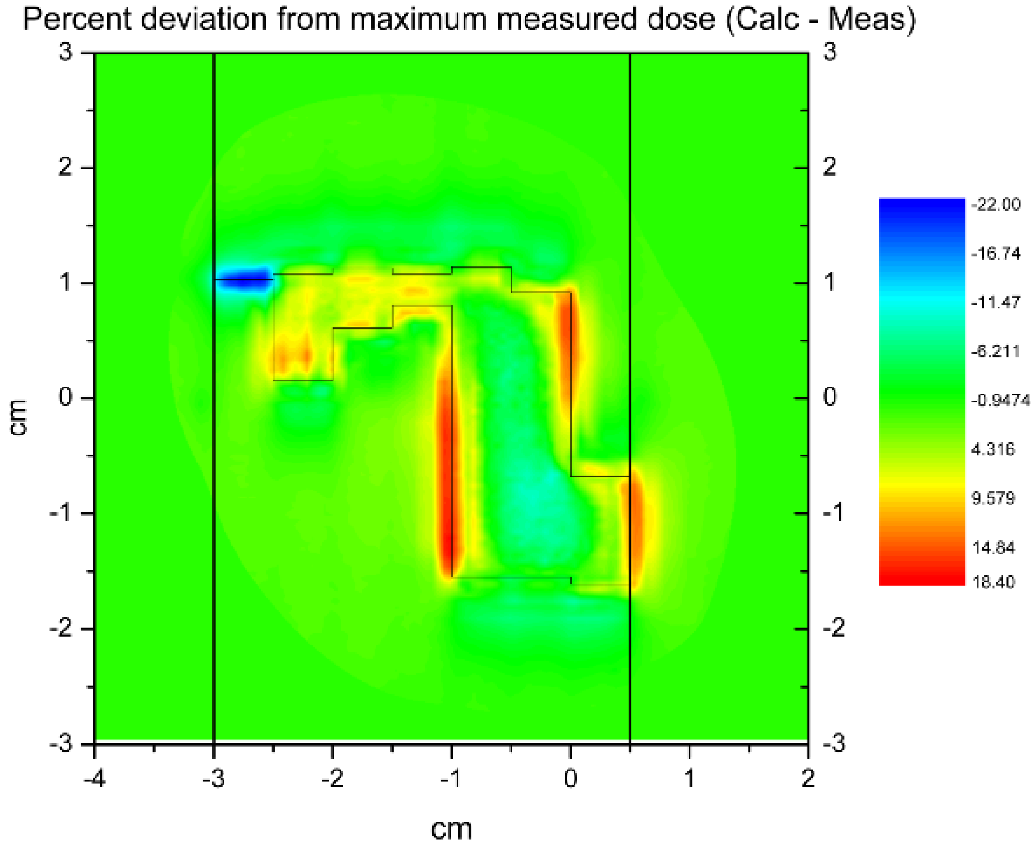
Example VMAT aperture dose

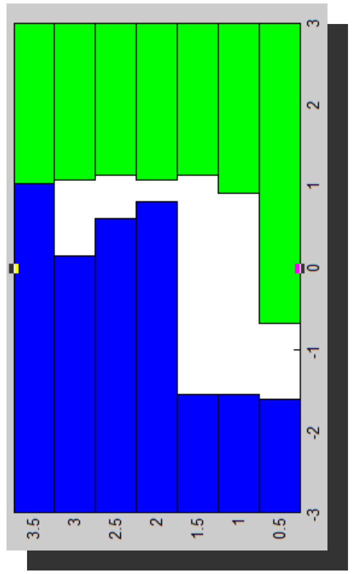




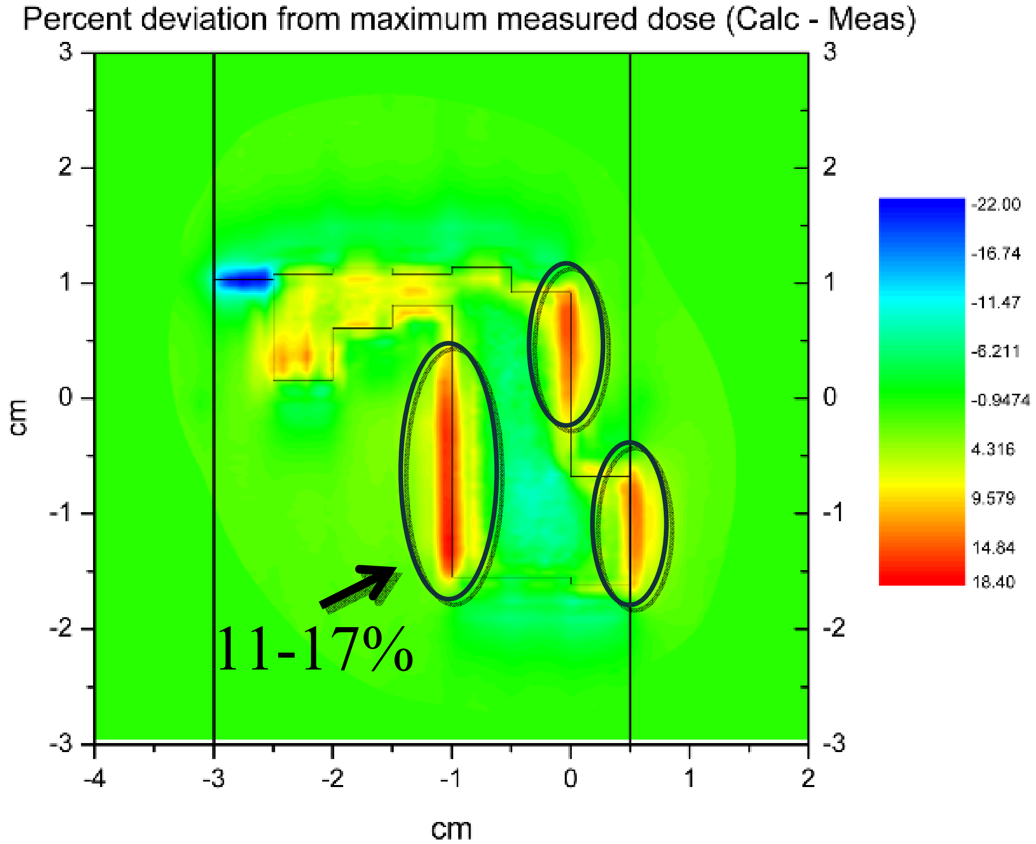
Maximum dose range for all apertures tested: 50 – 70 cGy

Dose difference: Calc - Meas



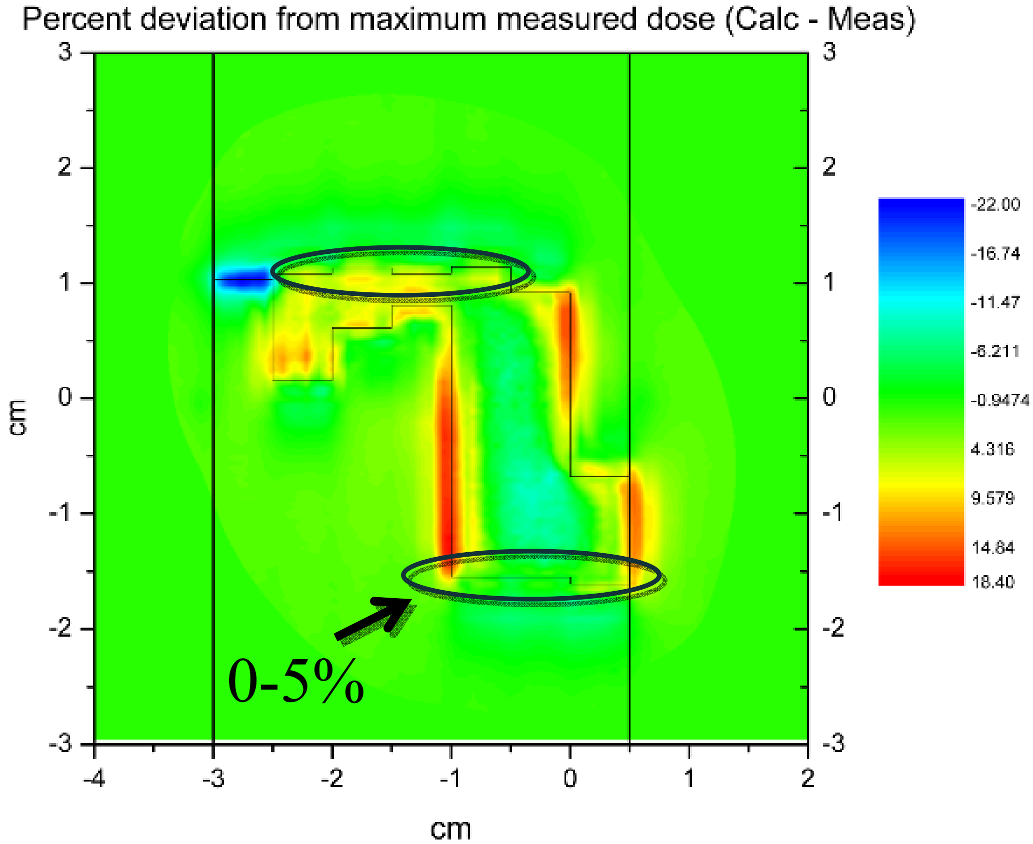


Dose calculation errors



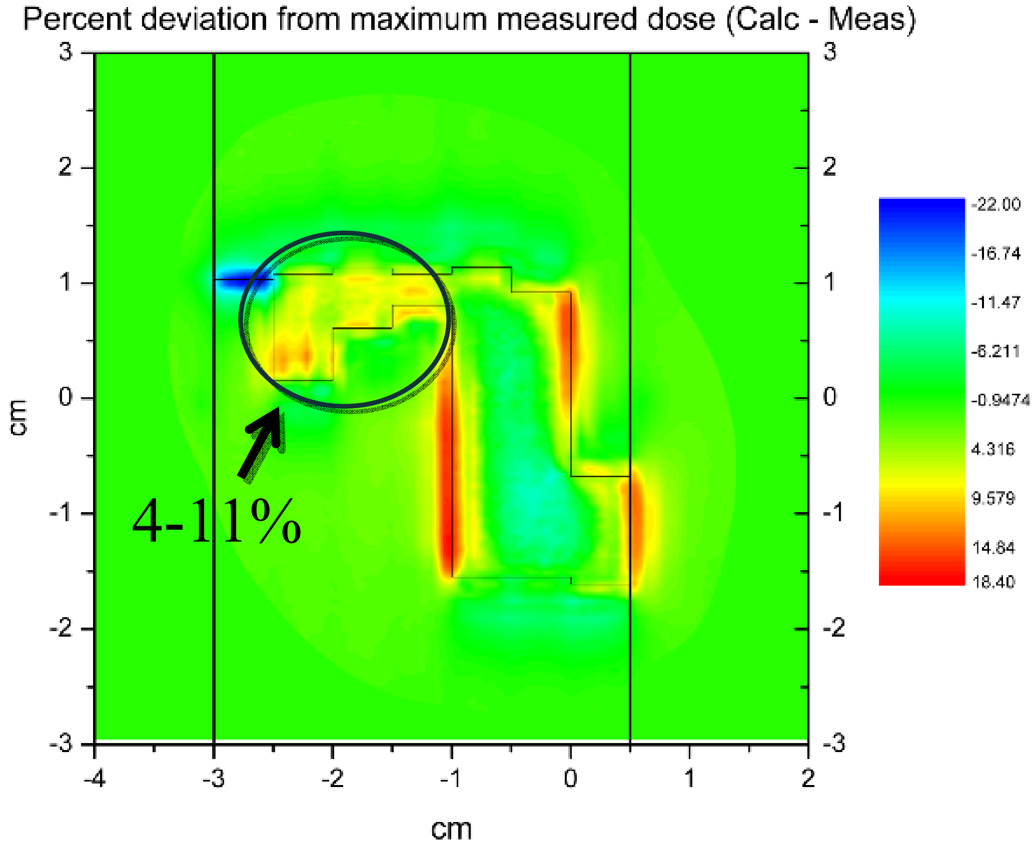
- Edge error on MLC leaf sides:
  - No compensation for tongue on MLC
  - 11-17% deviation as a percent of maximum dose

Dose calculation errors



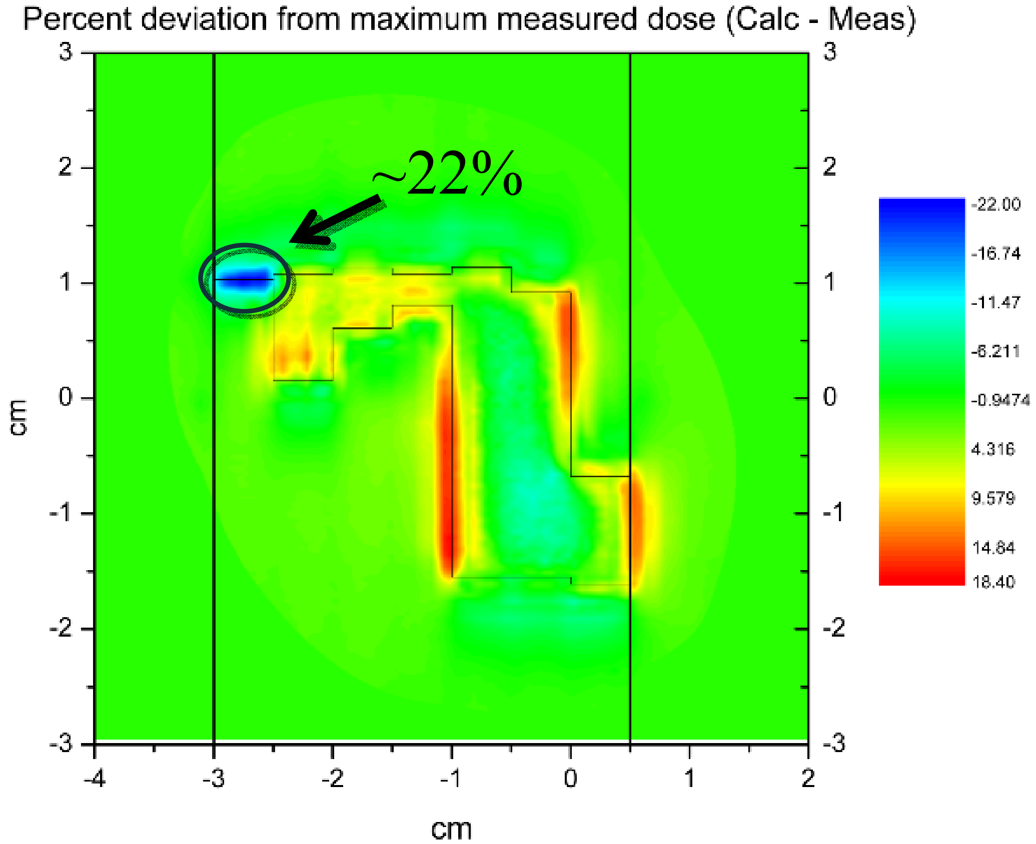
- Edge error on MLC leaf ends:
  - Rounded edge of leaf end is better modeled in the planning system
  - 0-5% deviation as a percent of maximum dose

Dose calculation errors



- Error in small open areas:
  - 4-11% deviation as a percent of maximum dose

Dose calculation errors

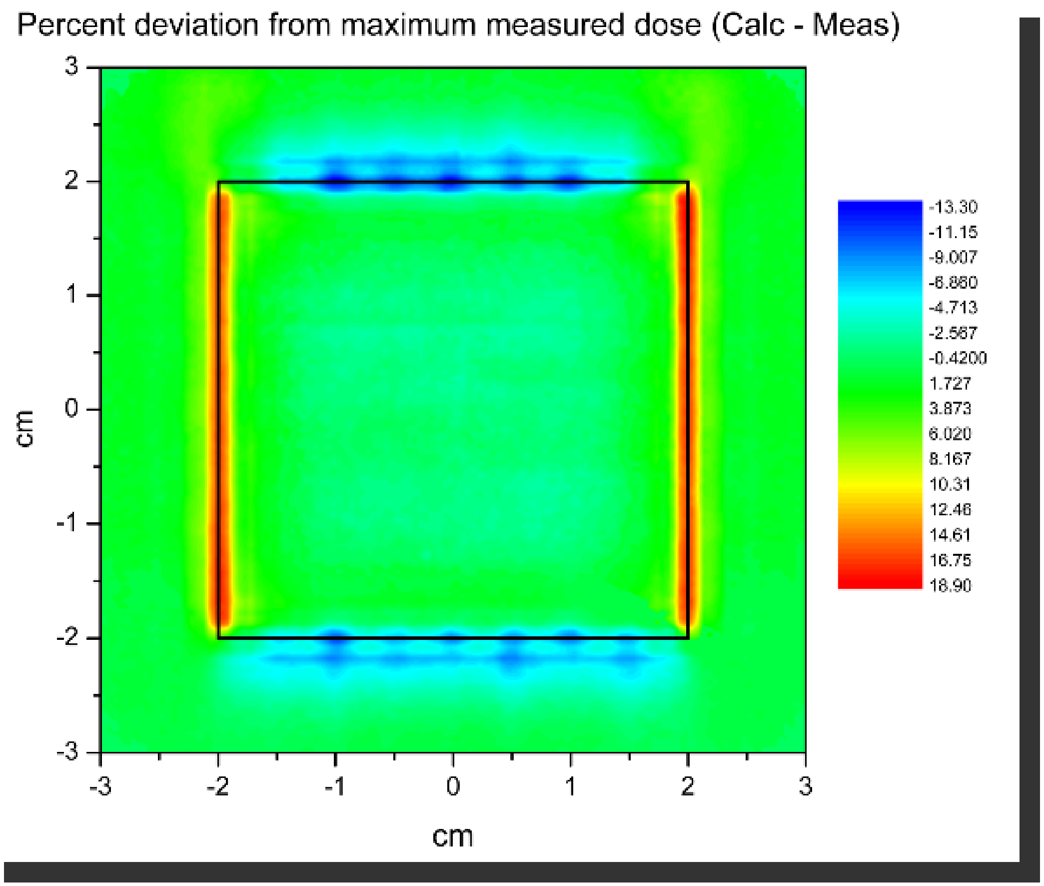


- Leakage between closed MLC leafs:
  - ~22% deviation as a percent of maximum dose

Assessment of dosimetric error

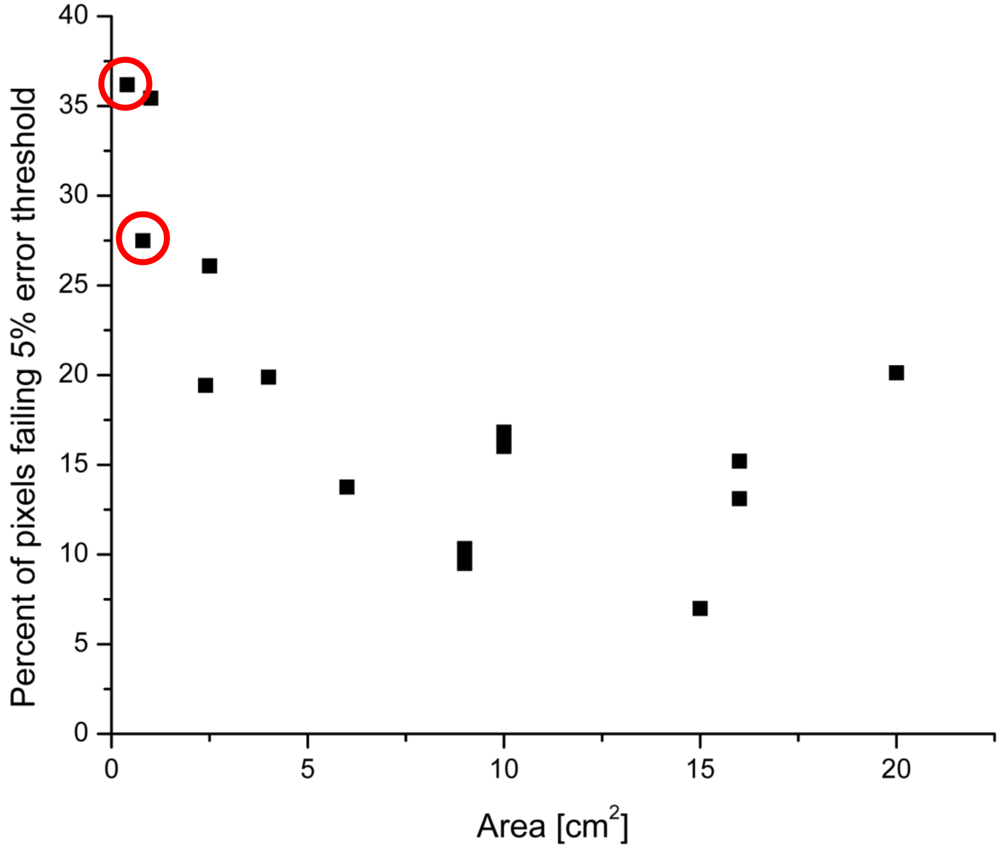
- Errors of small irregular fields occur because we cannot model all parameters of each field perfectly
- What can we learn from looking at these dose deviations?
  - Areas where dose calculation algorithm can be improved
  - Aperture shapes that should be avoided to ensure plans with optimal deliverability
  - Goal is to increase likelihood of accurate delivery

Assessment of Metrics



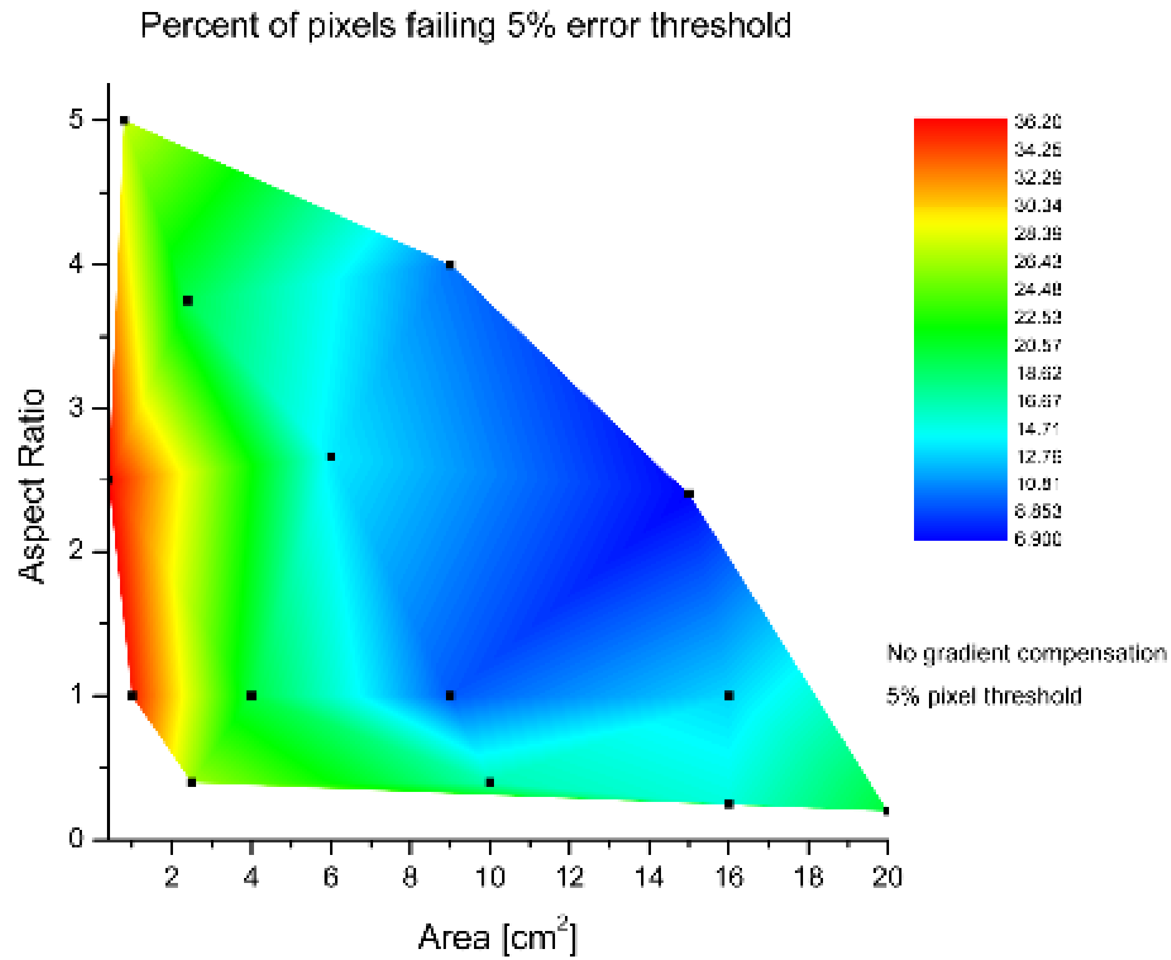
Percent of pixels with > 5% dose deviation: 7%

Assessment of Metrics: Area



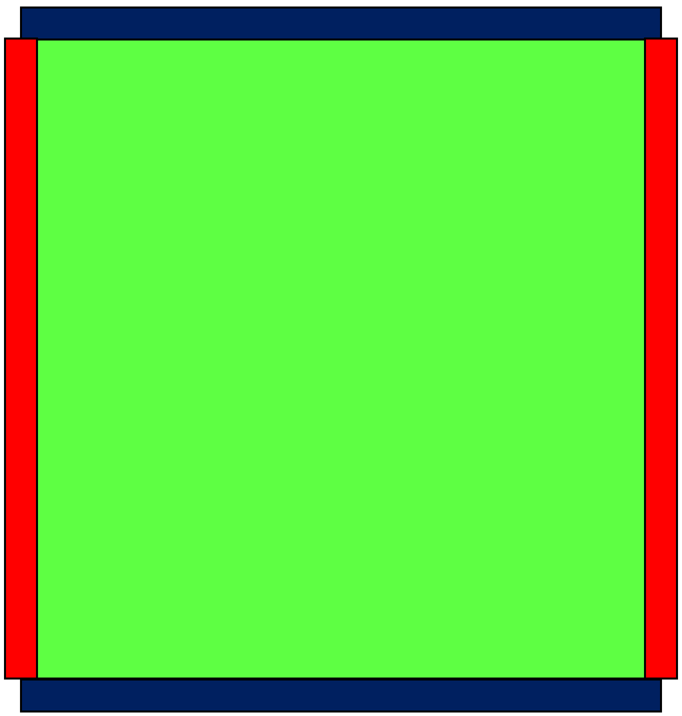
15 Rectangles: area → 0.4 cm^2 to 20 cm^2,
aspect ratio → 0.2 to 5

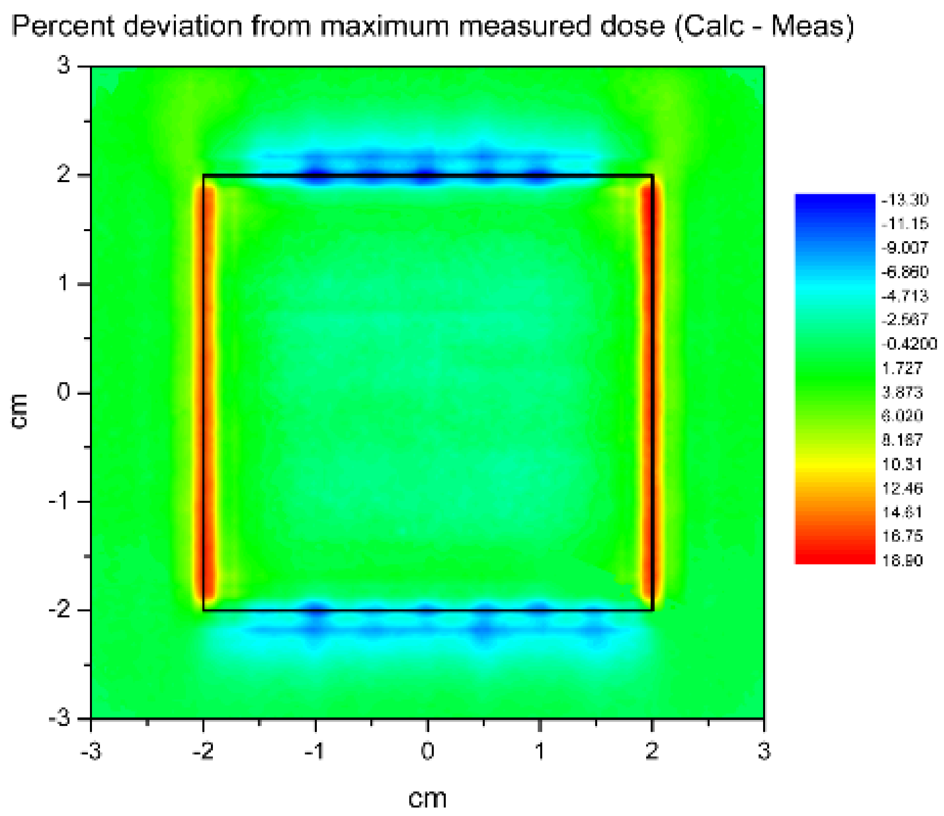
Assessment of Metrics: Aspect Ratio



15 Rectangles: area → 0.4 cm² to 20 cm², aspect ratio → 0.2 to 5

Assessment of Metrics: Erosion





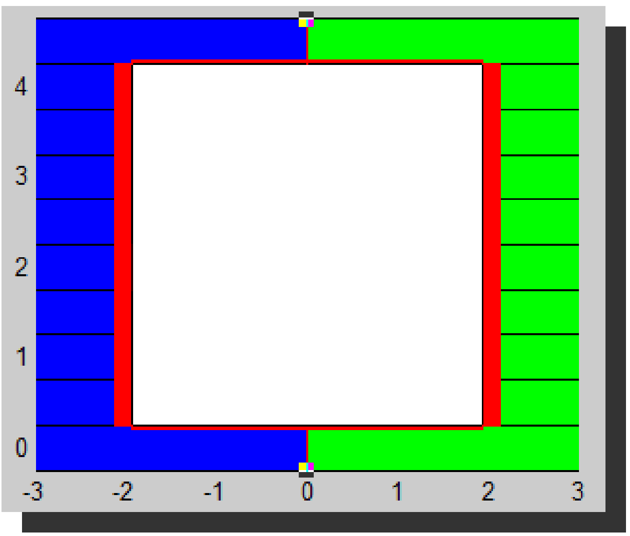
Eroded area % = (Expanded-Original)/Original

Correlation with eroded area

Parameters:

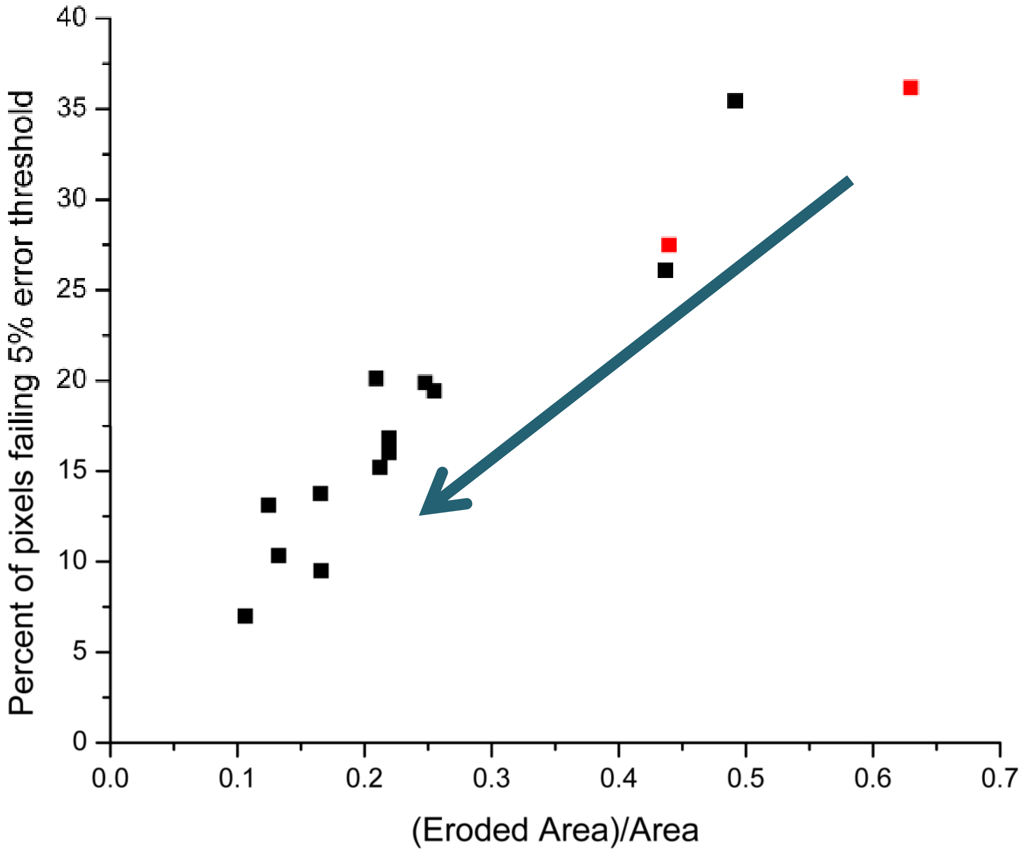
Expand 0.2 cm on leaf end

Expand 0.05 cm on leaf side



Example expanded area

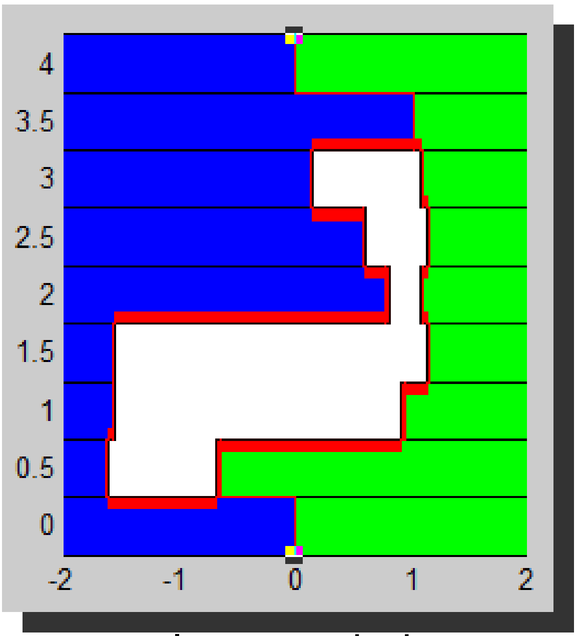
Rectangular Fields



Correlation with eroded area

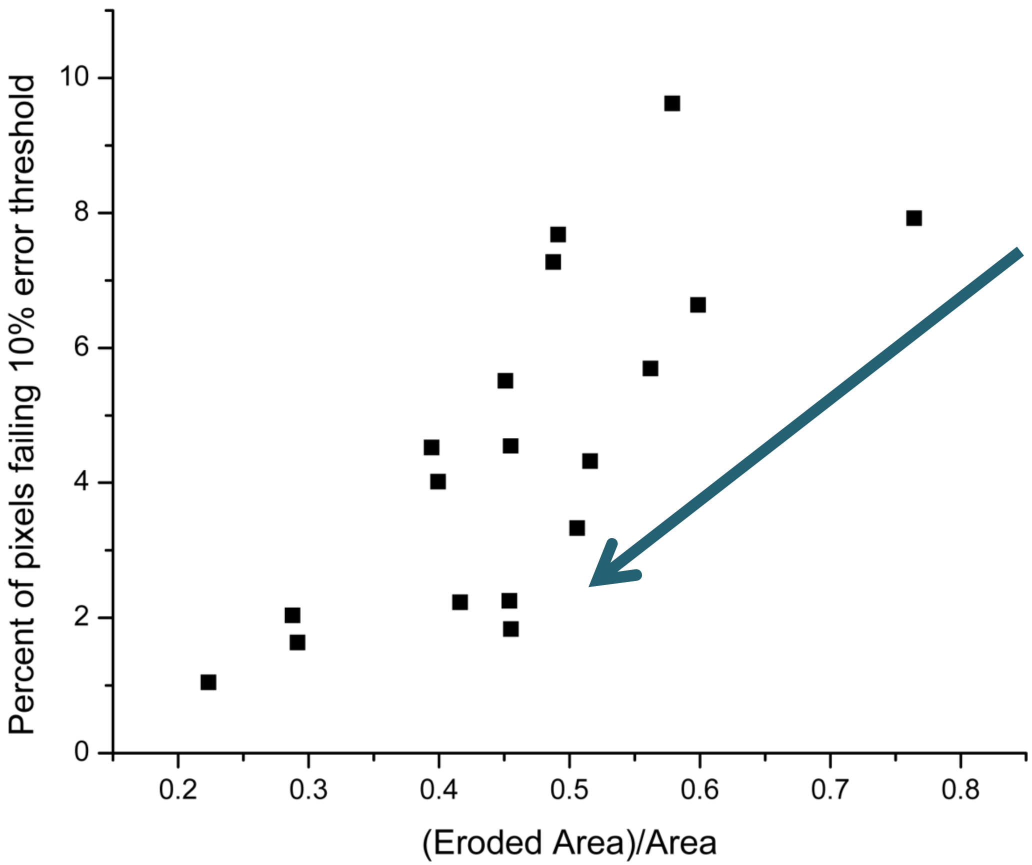
Parameters:

- Expand 0.025 cm on leaf end
- Contract 0.025 cm on leaf end
- Expand 0.1 cm on leaf side
- Contract 0.1 cm on leaf side



Example expanded area

VMAT Fields



Eroded area % = (Expanded – Contracted)/Original

Conclusions

- VMAT is a promising treatment technique, but the accuracy of plans with small, irregular apertures is questionable
  - These inaccuracies can be masked when using distance-to-agreement criteria
- Calculational errors can be better understood by analyzing dose differences
- Edge erosion is a promising metric for identifying undesirable apertures
  - Edge erosion can be used for different dose calculation algorithms if the unique erosion parameters are identified
- Adding a cost function based on aperture shape should help to minimize apertures that will lead to unacceptable error

Acknowledgements - Thanks

- UM Team VMAT
- Jean Moran
- James Balter
- Colleen Fox

Future directions

- Erosion parameters
  - Determine optimal parameters for erosion in x and y
  - Test with other dose calculation algorithms
- Add cost function to optimizer to penalize beams that may lead to large errors
- Compare plans with and without aperture shape cost functions