CLINICAL ASPECTS OF COMPACT GANTRY DESIGNS

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New gantry developments

Viewpoint from user and vendor perspective

what is important for the customer?

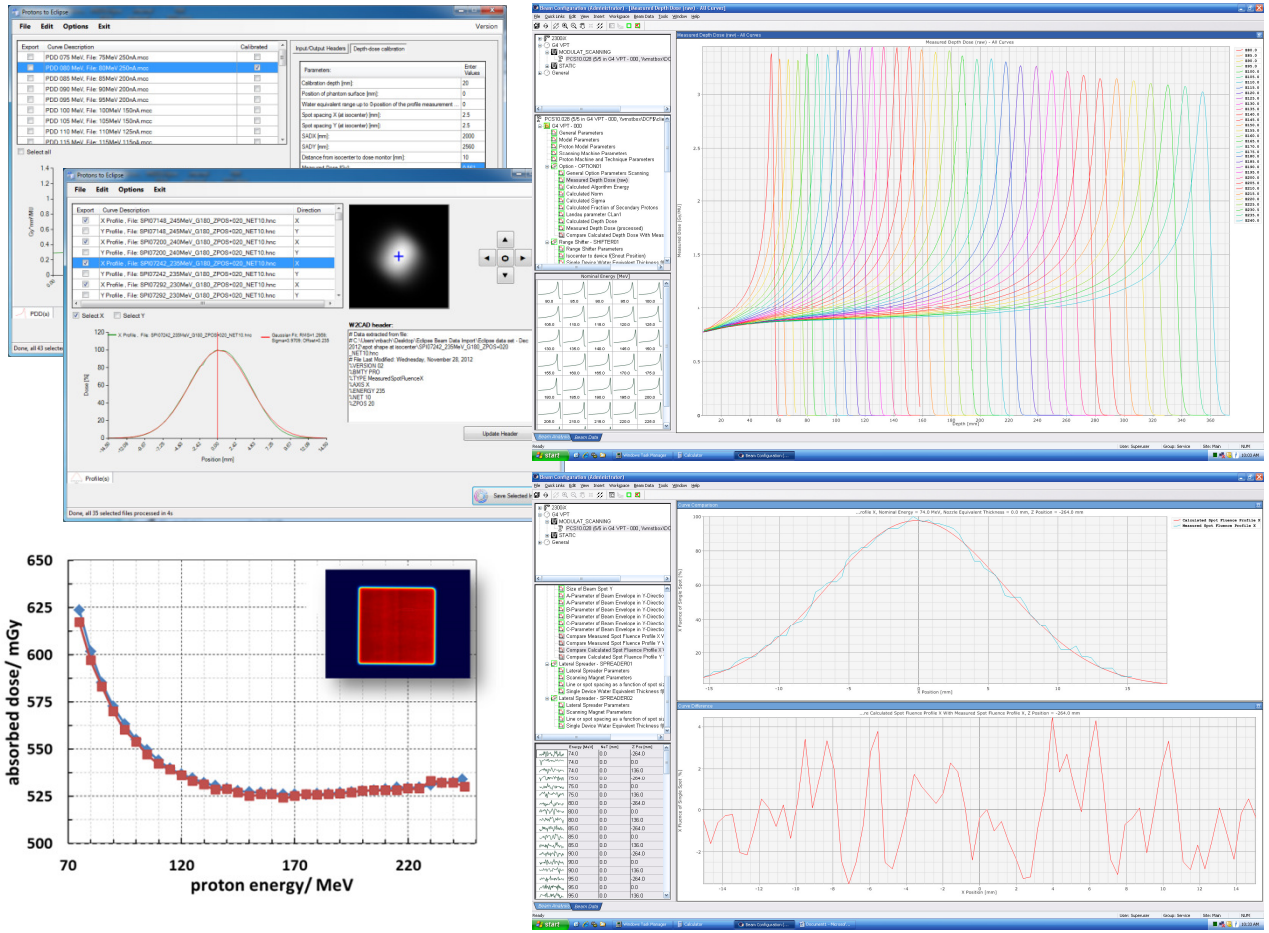
- precise dosimetry system
  - minimum corrections
- simple and time efficient measurements to set up the clinical system
  - short clinical commissioning time

Clinical aspects of compact Gantry designs

Agenda (focus on modulated scanning only)

- TPS setup for modulated scanning
  - required measurements
- Spot positions
- Spot shapes
- SAD
- Upstream scanning
- Achromatic optics

Modulated Scanning
Commissioning of Treatment Planning System



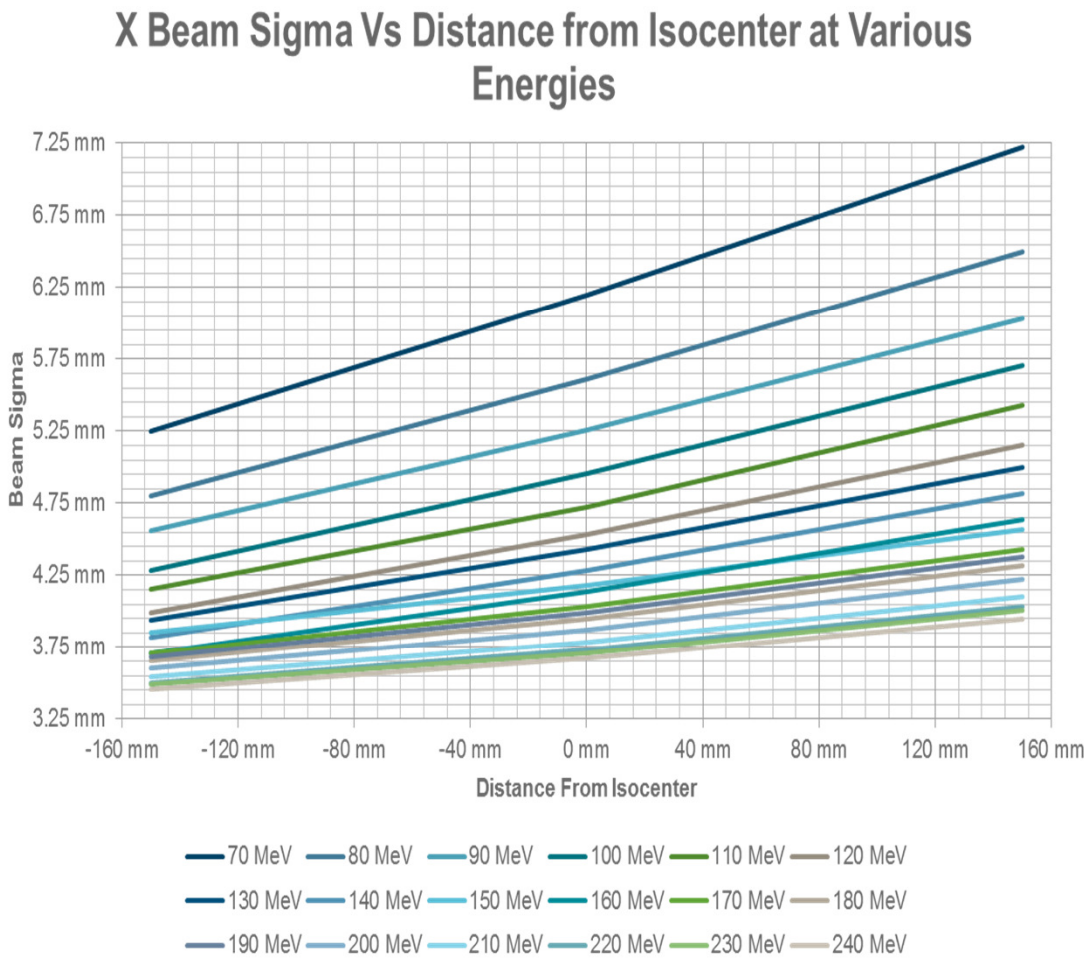
PENCIL BEAM SCANNING ALGORITHM

- RELATIVE INTEGRATED DEPTH DOSE
- CALIBRATION OF DEPTH DOSE CURVES
- DOSE OUTPUT
- 2D SPOT SHAPES AT DIFFERENT DISTANCES
  - Gaussian spots required
- VIRTUAL SAD; FOR SCANNING SAD-X AND SAD-Y REQUIRED IF DIFFERENT

VARIAN medical systems | proBEAM

Divergence

Evolution of beam size around isocenter

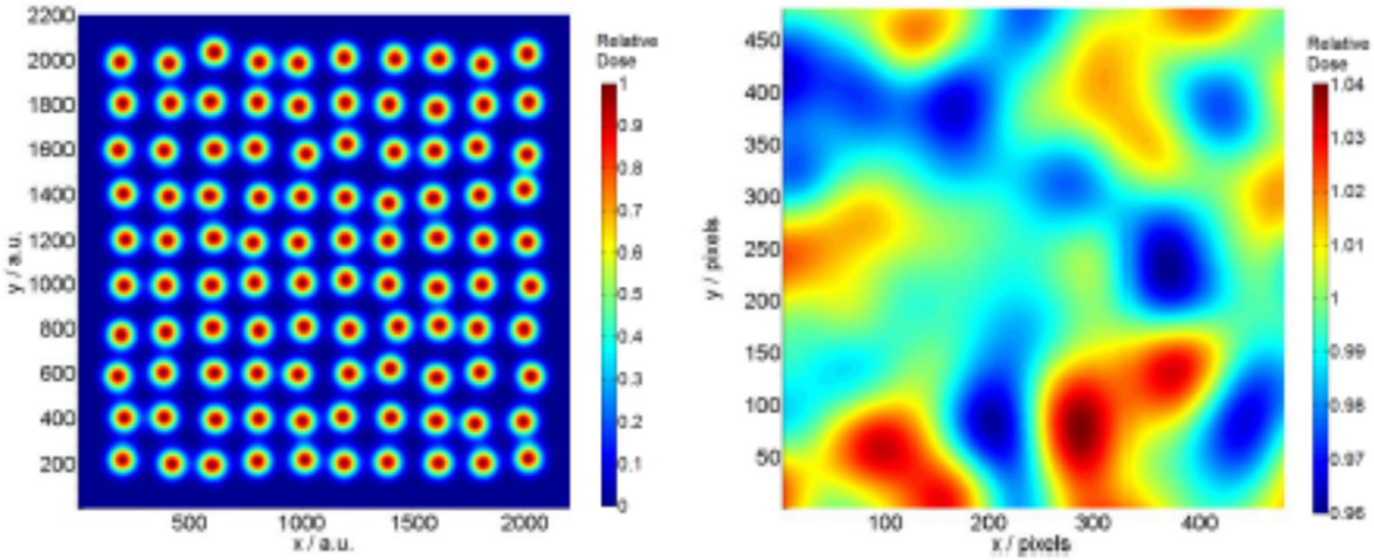


Linear increase of sigma with distance from nozzle

Parametrized in treatment planning (linear/quadratic)

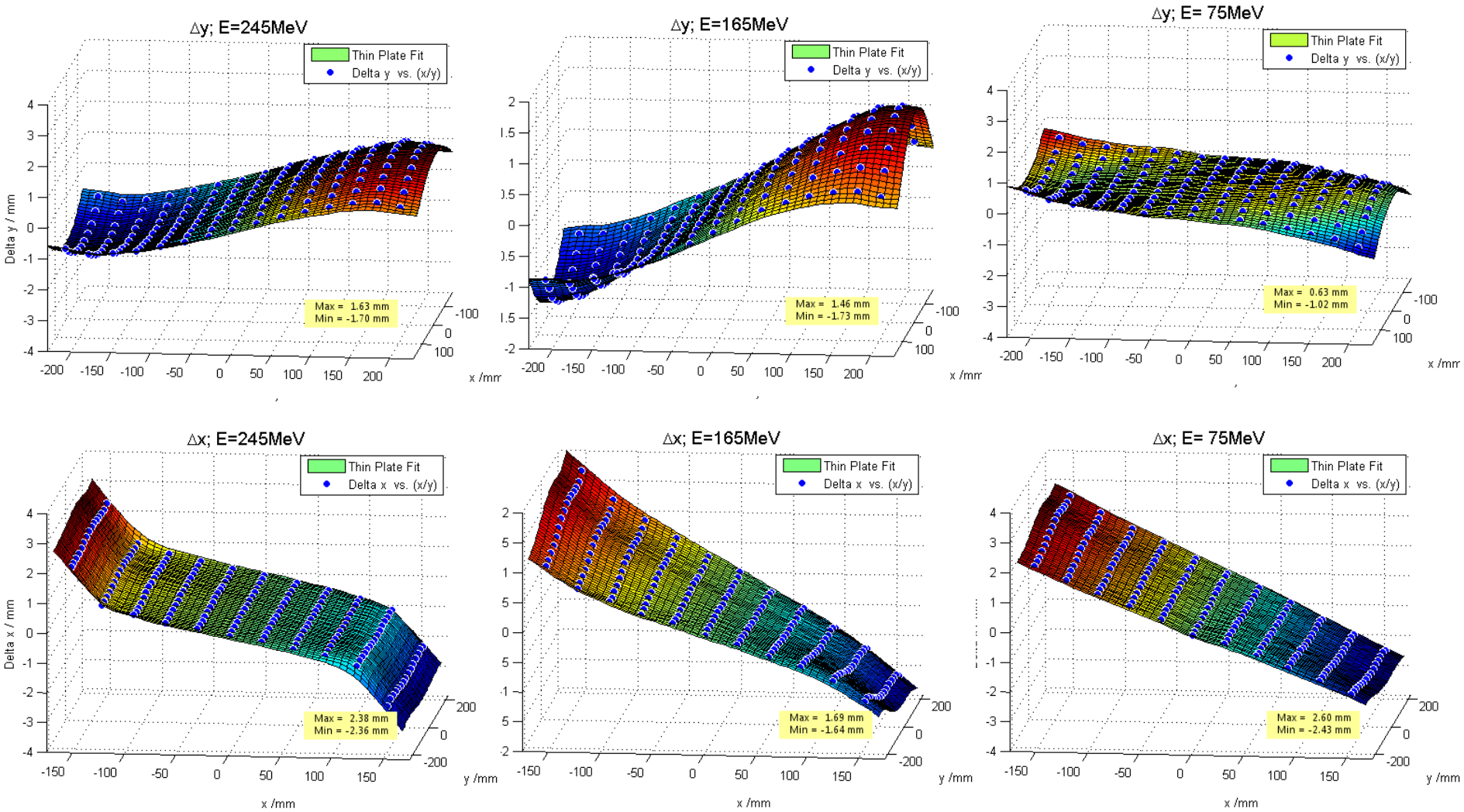
Spot position accuracy

- Significant deviations between planned and delivered spot position will cause dose inhomogeneities
- Scanning correction required

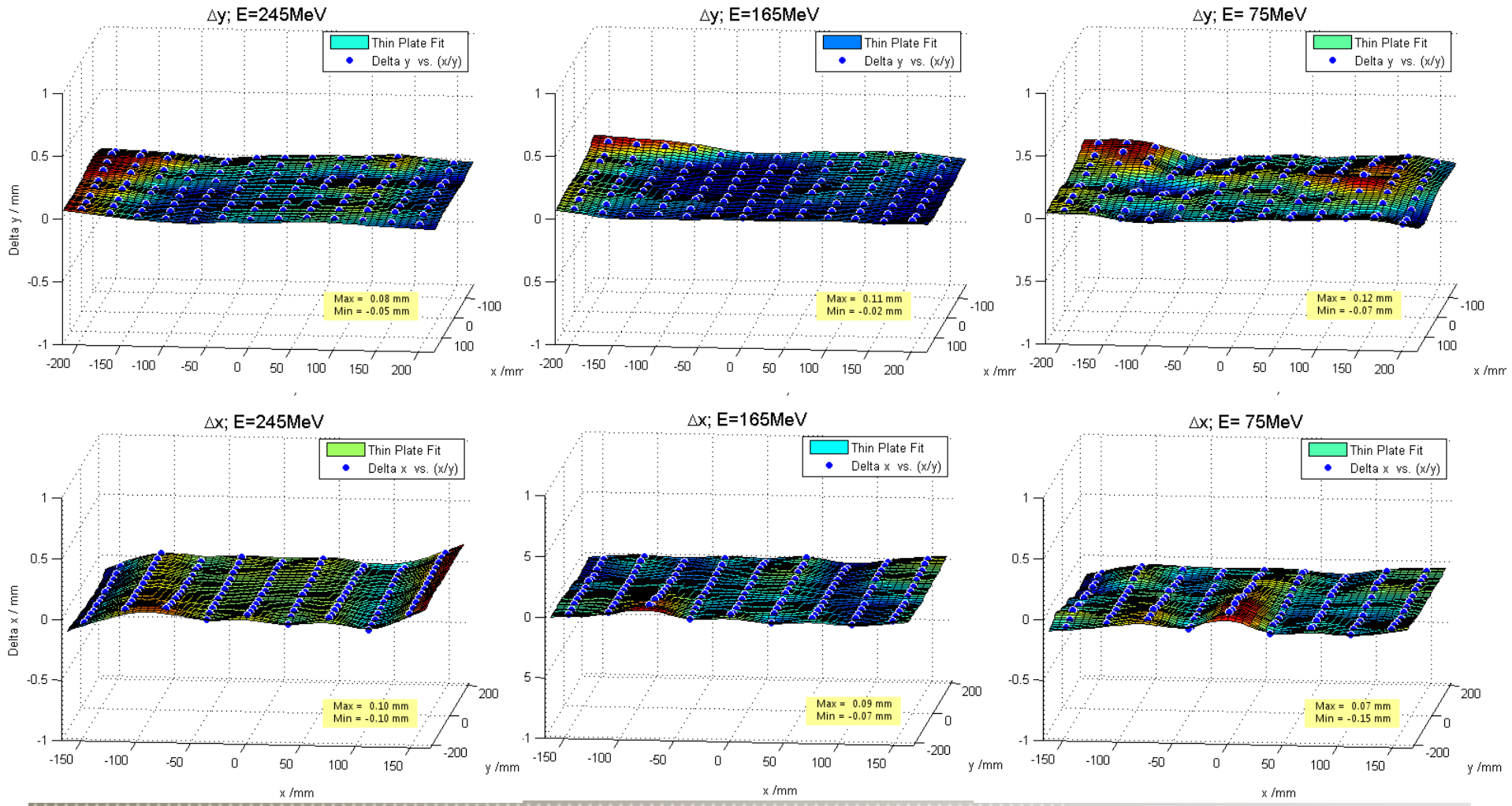


A. Huggins, master thesis

Before Scanning Magnet Calibration



After Scanning Magnet calibration



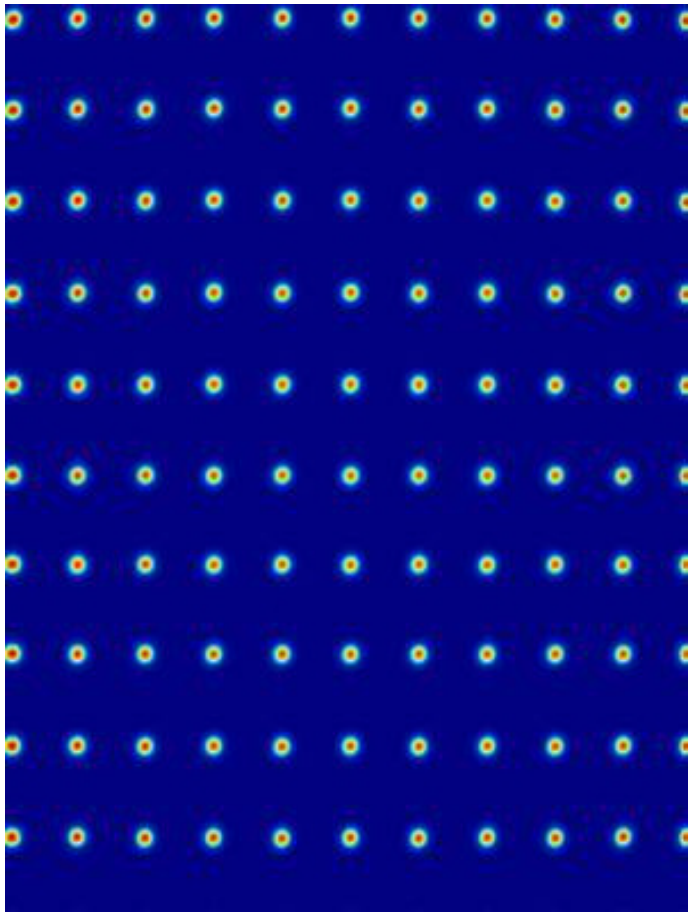
Spot positions
Conclusions

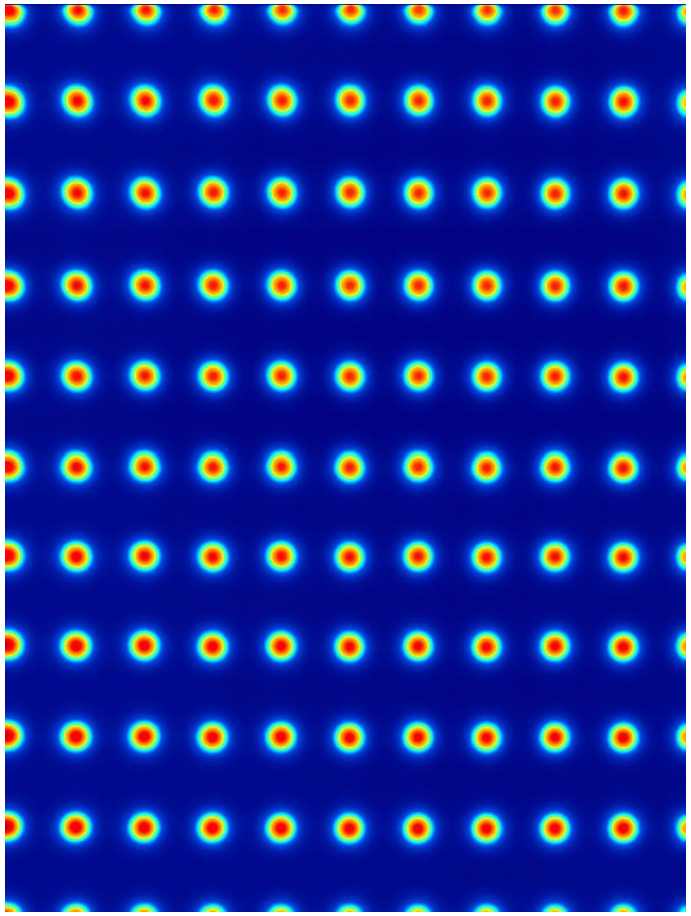
- After calibration, typically sub-mm accuracy of delivered vs planned spot positions can be achieved (at least in VARIAN systems)
- Not dependent on gantry angle
- Standard procedures exist to calibrate scanner magnets and derive corrections

Spot shapes

- currently, all commercial treatment planning systems assume gaussian spot shapes
- new gantry designs might imply deviations from gaussian shapes
- most commercial treatment planning systems do not expect variations of the spot shape over the scan area
- If spots in air are non-gaussian, does multiple Coulomb scattering (MCS) help to reduce effects?

Spot shapes in current scanning system



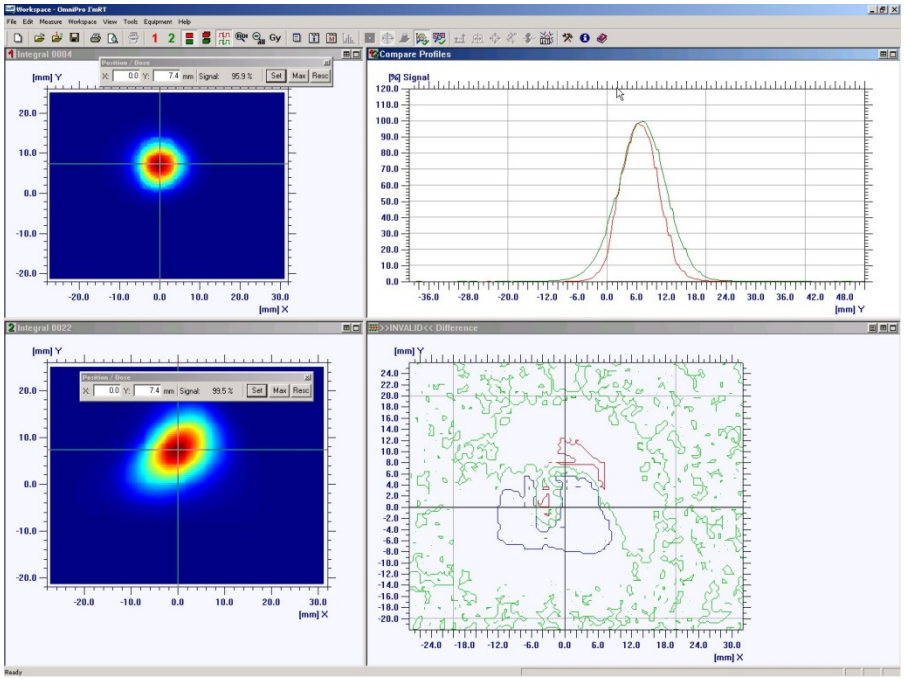


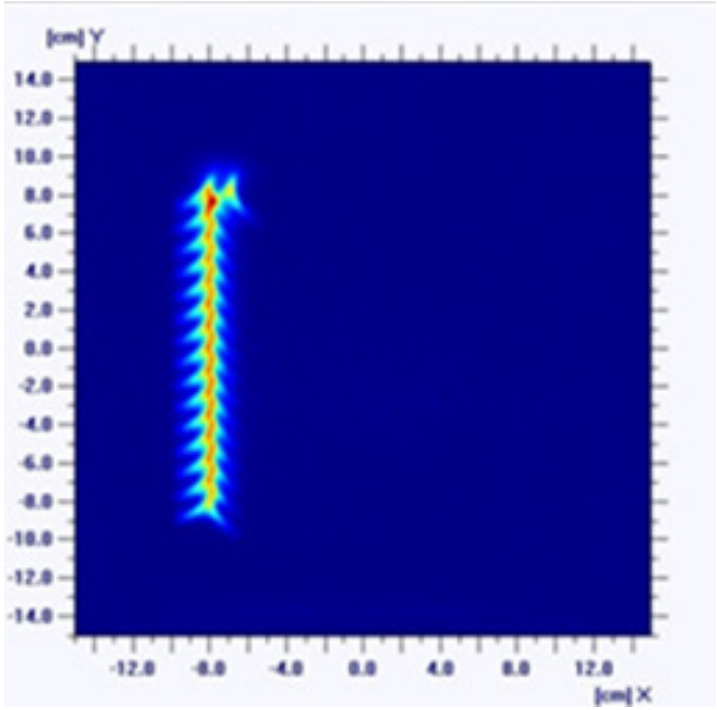
Circular spots over full field size of 30cm x 40cm from 245 to 70 MeV

Spot shape characterization for treatment planning:

- one measurement per energy interval on central axis at isocenter required
- data can be significantly reduced: 2D gaussian fits, extraction of sigma-x, sigma-y per energy point
- repeated at typically 3 distances from isocenter and multiple gantry angles

Spot shapes on future system
Where is the limit?





Dedicated TPS parametrization required:

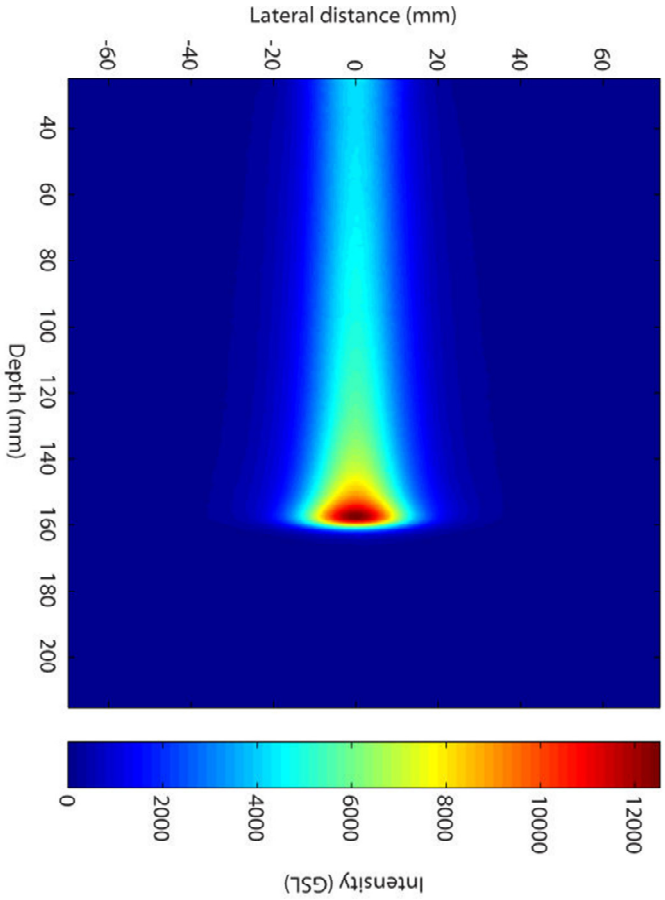
Could this spot shape be parametrized?

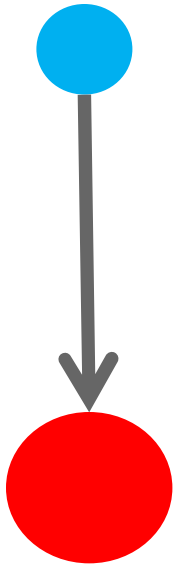
Elliptical spots (if gaussian):

- need sigma-max, sigma-min and ellipse angle
- All parameters required over full field size
- Smooth variations of parameters required

Multiple Coulomb Scattering

Effect on spot size





σ_0

surface

$$\sigma(Z) = \sqrt{\sigma_0^2 + \sigma_{MCS}^2(Z)}$$

35cm water

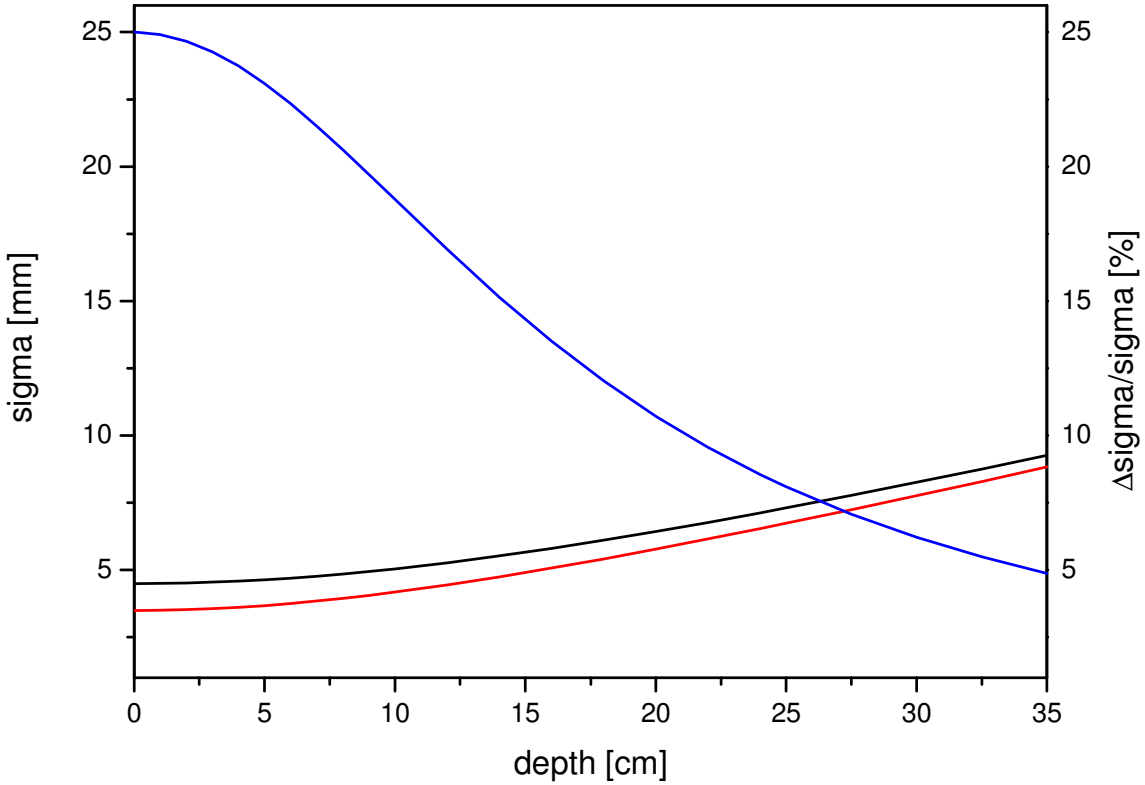
2mm 4mm

8mm 9mm

σ_{MCS}: additional contribution due to multiple Coulomb scattering in water (e.g. Hong et al PMB 1996)

Effects of MCS

… no fast reduction of sigma differences

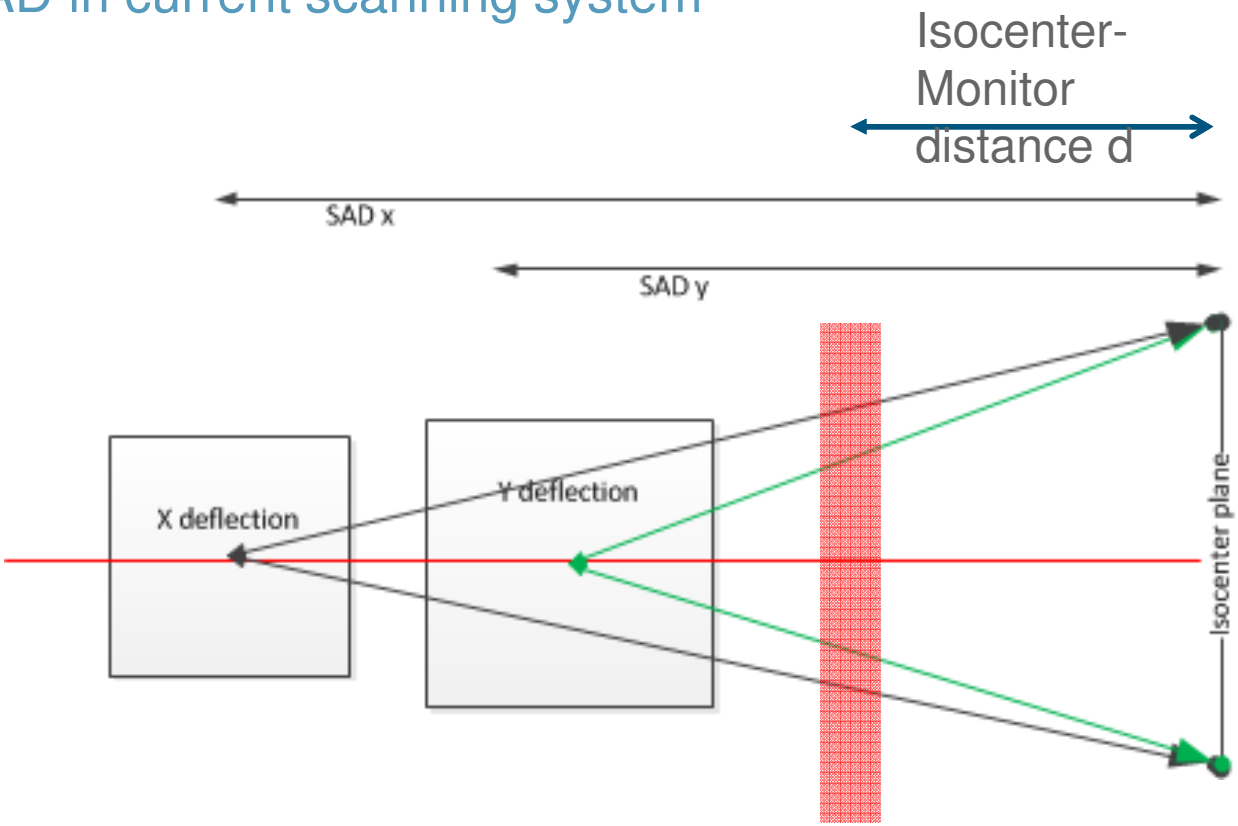


Spot shapes
conclusion

- Deviations of spot shapes from gaussian need parametrization in TPS
- The more gaussian, the better
- MCS may not be sufficient to smooth out deviations (ellipticities or non gaussian shapes)
- In case of large deviations from gaussian shapes, a robust algorithm to determine spot centroids for scanner corrections is required

SAD effects

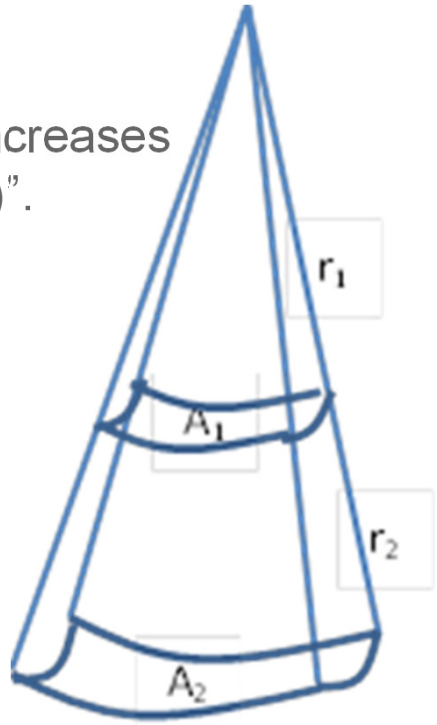
SAD in current scanning system



VARIAN medical systems

- is a large SAD required for modulated scanning?
  - skin dose limitations as a driver?

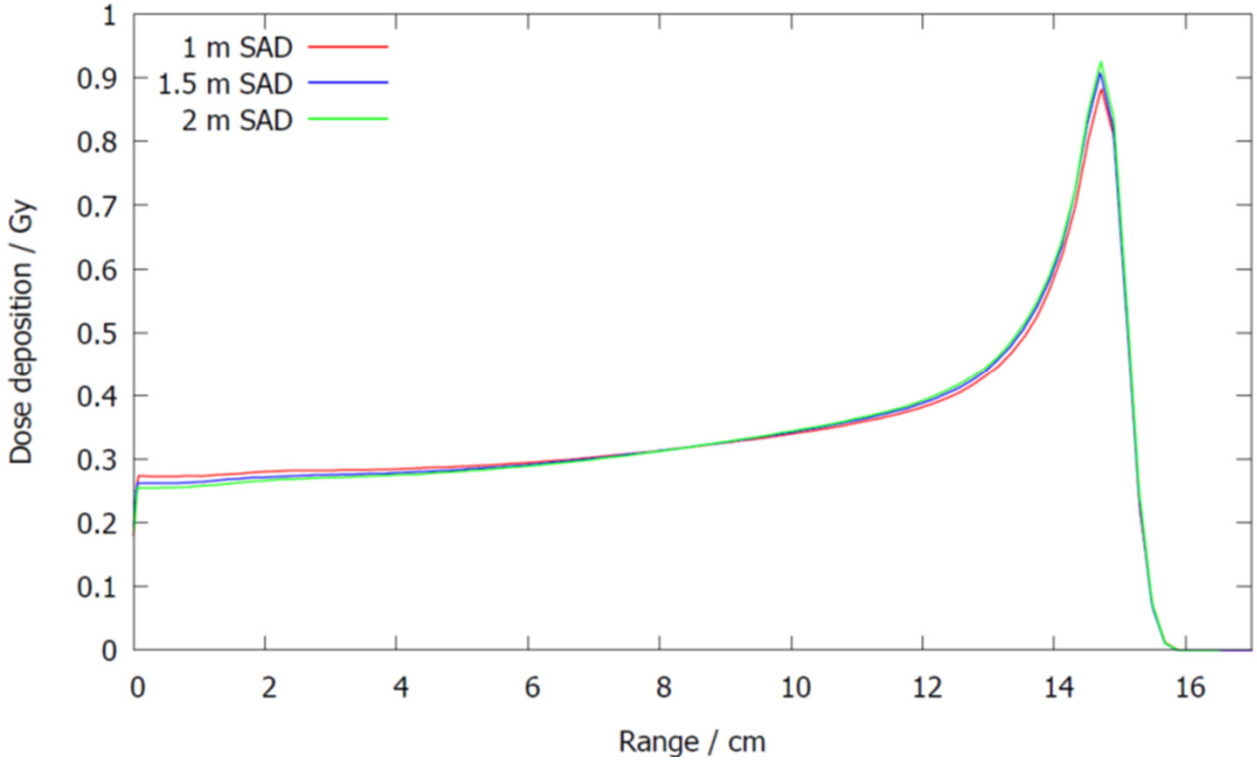
    "the dose to the skin relative to the dose in the SOBP increases with decreasing effective source-to-axis distance (SAD)".
    - correct statement, but significant effect?



- does not consider
  - dose enhancement in Bragg peak
  - fluence modulation in modulated scanning
  - multiple fields
  - realistic tumor shapes and patient dimensions

Proximal dose effects for small SAD

central axis depth dose for a monoenergetic homogeneous field (Eclipse calculation with ProBeam beam model for different SADs)

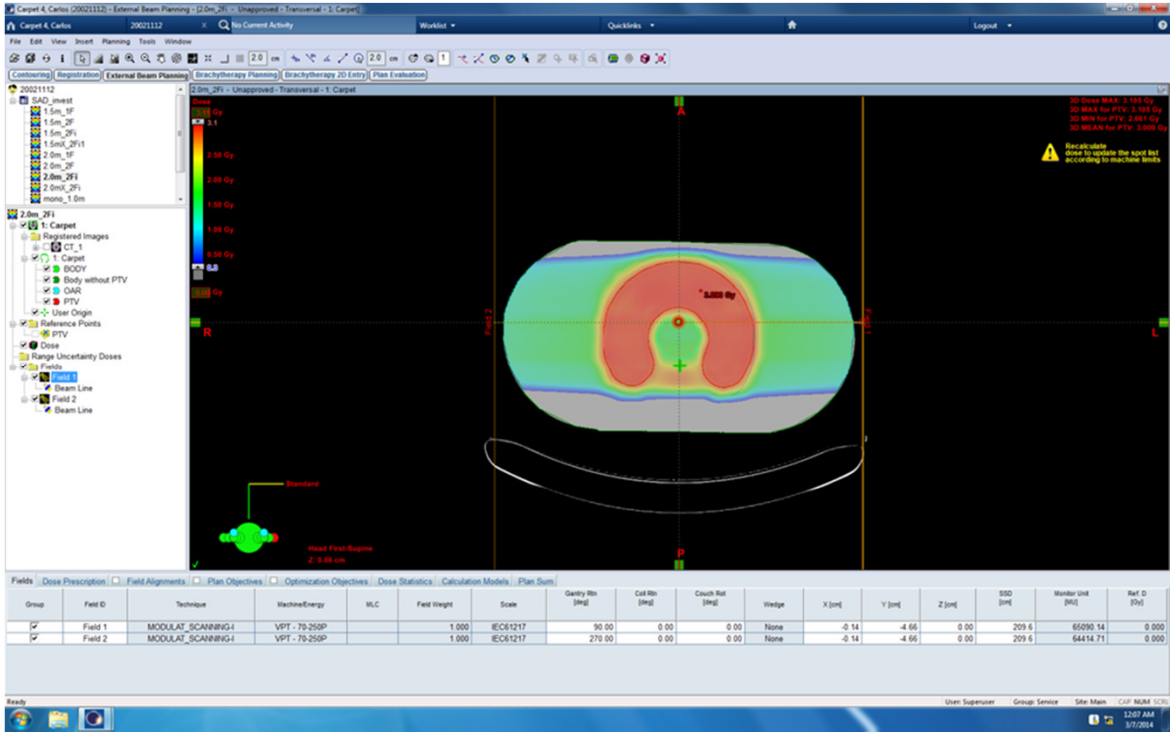


SAD	proximal dose /a.u.	peak dose / a.u.	norm prox. Dose / a.u.
1 m	0.273	0.882	0.310
1.5 m	0.262	0.906	0.290
2 m	0.254	0.924	0.275

13%

Effects for small SAD

Phantom study with Eclipse, two opposed SFUD /IMPT fields



Proximal dose enhancement of 1.5m vs 2m SAD relative to target dose

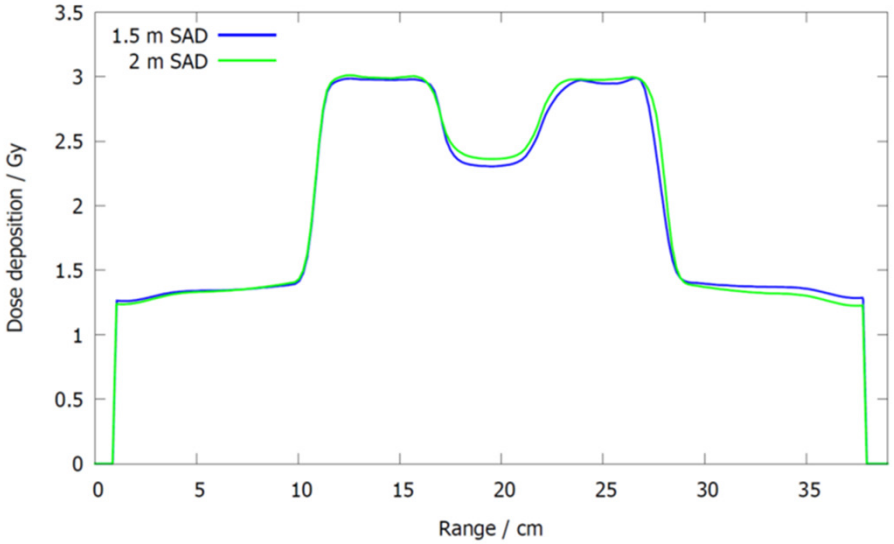
for SFUD optimization: 5.7%

for IMPT optimization: 1.9%

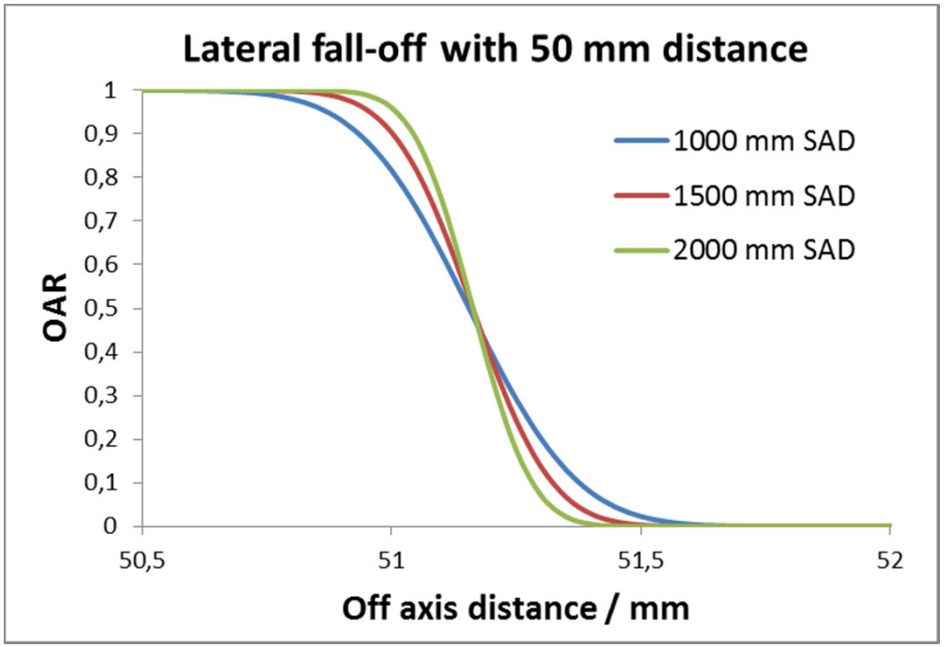
What are the SAD effects in treatment planning?

Phantom study with Eclipse, two opposed SFUD /IMPT fields

Isodose effects



Influence on lateral penumbra with collimator



- field patching: can be handled by treatment planning independent of SAD
- spherical distal edge isodoses – no clinical impact

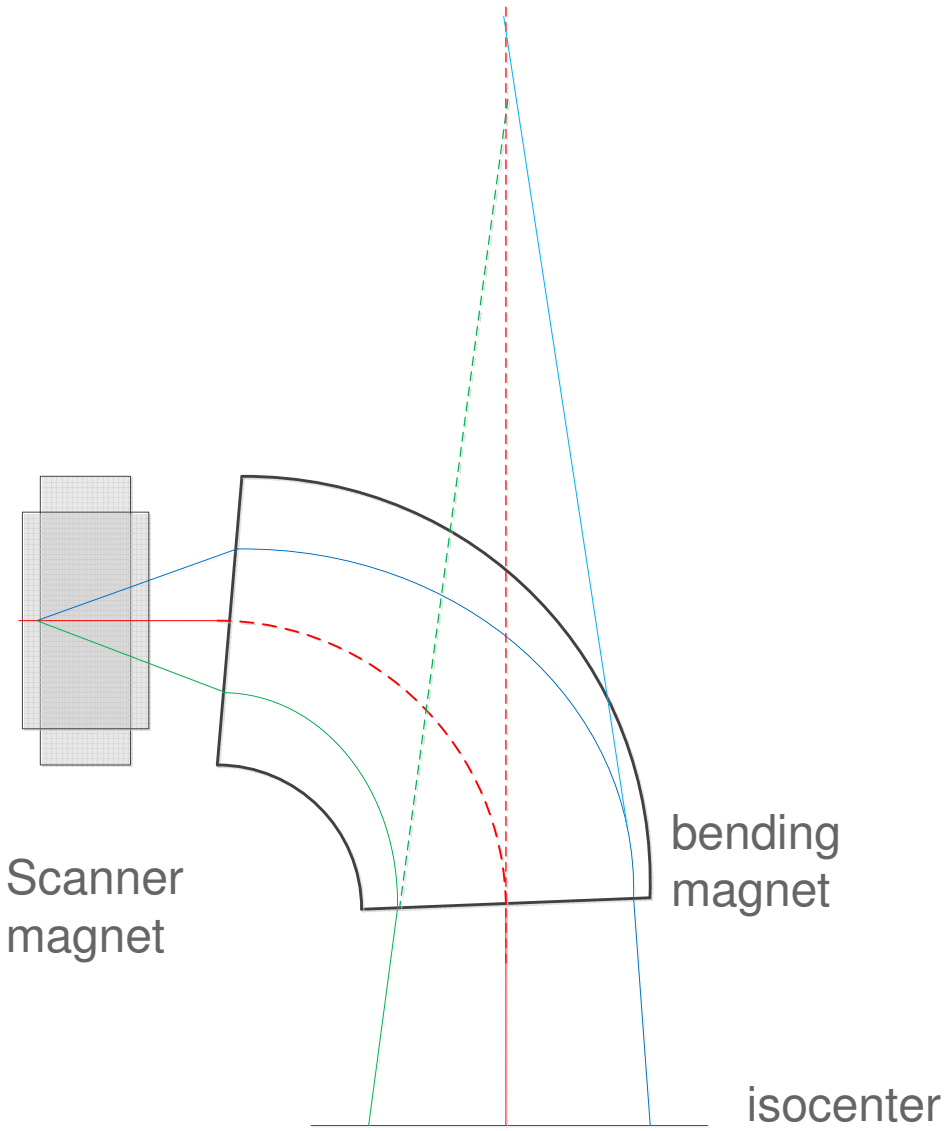
short SAD

Conclusion

- In the presented study no evidence for significant adverse effects of a short virtual SAD in modulated scanning down to 150cm has been identified

Upstream scanning
Variable virtual SAD

- Virtual SAD could be variable (dependent on scanning deflection in bending direction)
- Typically small impact on dosimetry due to large virtual SADs
- Variable SAD is typically not considered in treatment planning system
- Could have big impact in case of short virtual SADs



Large momentum acceptance bending magnets

Example:
Consider a modulated scanning treatment plan which requires one layer at 180 MeV

Case 1: E_{max} 200 MeV -> bending magnet field set to 200 MeV
Layer energy 180 MeV with magnet field setting of 200 MeV

Case 2 E_{max}=180 MeV-> bending magnet field set to 180 MeV
layer energy 180 MeV with magnet field setting of 180 MeV

- Case 1 and case 2 could be two examples to produce a layer energy of 180 MeV, but there are many more as E_{max} is variable

➢ leads to degeneracy of bending magnet current for a requested beam energy

Large momentum acceptance bending magnets

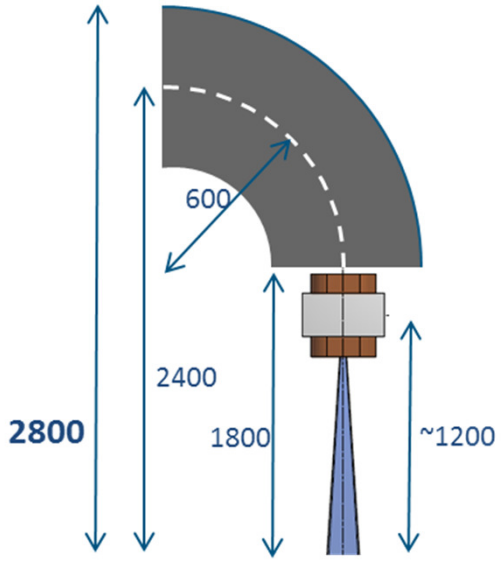
- trajectories in bending magnet and optics for one energy could be different due to different magnetic fields
- Could lead to degenerated 2D correction function (e.g. scanner magnet calibration)
- variable virtual SAD effects in y, also effects due to different trajectories in x?
- Energy/range verification required (IEC 60601-2-64)

Impact of additional corrections
Potential mitigations

- CORRECTION TABLES IN TREATMENT MACHINE
  - Additional commissioning work – cost driver
- CORRECTION TABLES BY USER
- Special knowlegde and training for user required
- Additional responsibility for user
- Additional measurements for user
- ADDITIONAL CORRECTIONS IN TREATMENT PLANNING SYSTEM
- Additional work for user

Summary

- SAD
  - A large SAD is not a key requirement for downstream modulated scanning
  - possible design could look like this:
    - Small bore superconducting bend (4T)
    - optimized downstream scanning, short SAD



- Upstream scanning
  - large virtual SAD is beneficial to minimize variable SAD-y
  - otherwise, TPS calculations or machine corrections have to be implemented
  - Spot shape variations to be evaluated
- Large momentum acceptance
  - Will have a more complicated impact. Solutions that work with minimum corrections have to be developed.

THANK YOU!

… questions?

VARIAN
medical systems