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Small Field Dosimetry: Beam and dose modelling in TPS

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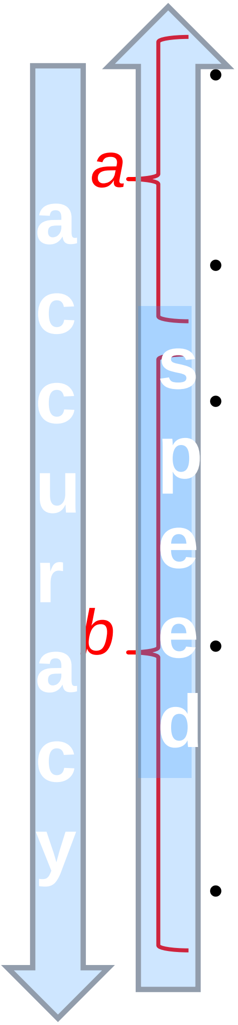
Dose models



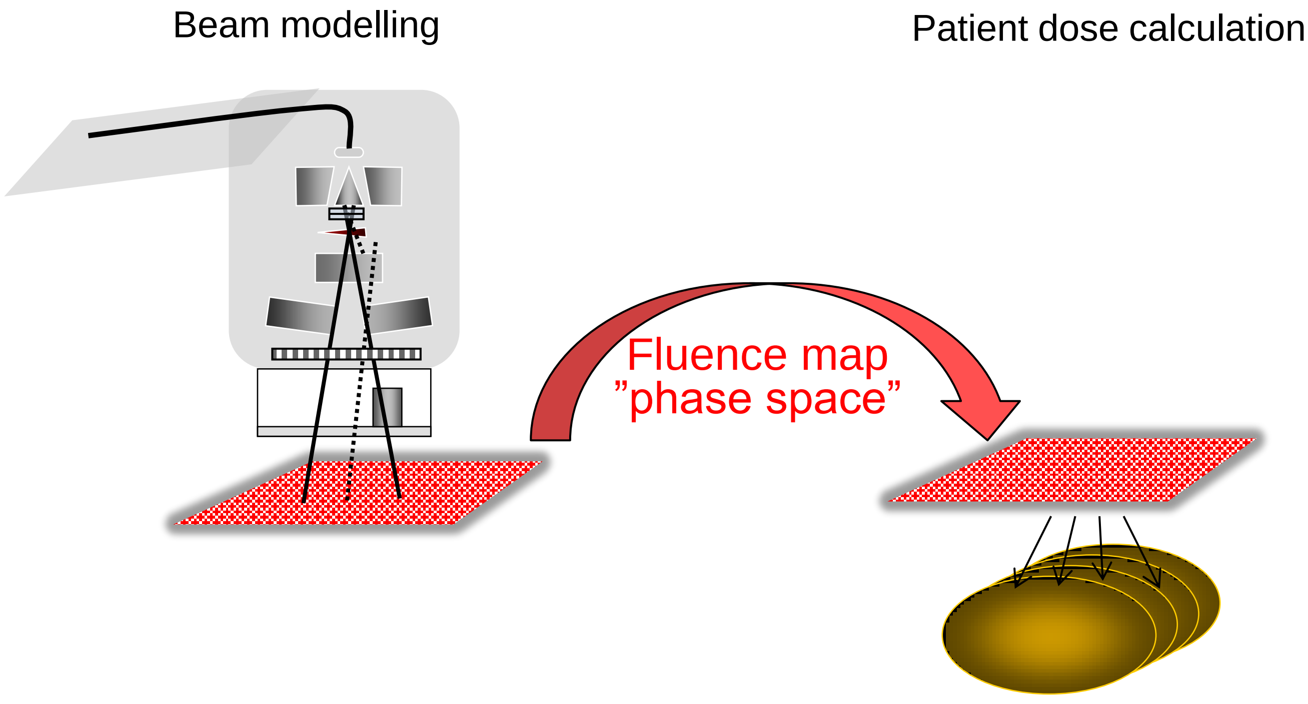
- **Factor based** methods reconstructs measured dose by interpolating profiles and depth doses. Limited to fields for which data exist.
- **Pencil kernel** methods superpose predetermined dose distributions from narrow “pencils” of radiation in water.
- **Point kernel** methods. Ray traces in detail primary photon energy transfers. Dose modeled by means of (precalculated, heterogeneity scaled) point kernels. Traded as “Collapsed Cone” or ”Convolution/Superposition” methods.
- **Grid based Boltzmann solvers.** Ray traces in detail primary photon energy transfers to secondary particles which fluencies are determined by numerical solution of particle balance differential equations.
- **Monte Carlo particle transport** simulates the fate of individual particles by using random numbers.

Model based

Knöös et al 2006 Phys. Med. Biol. 51

Model based dose calculations

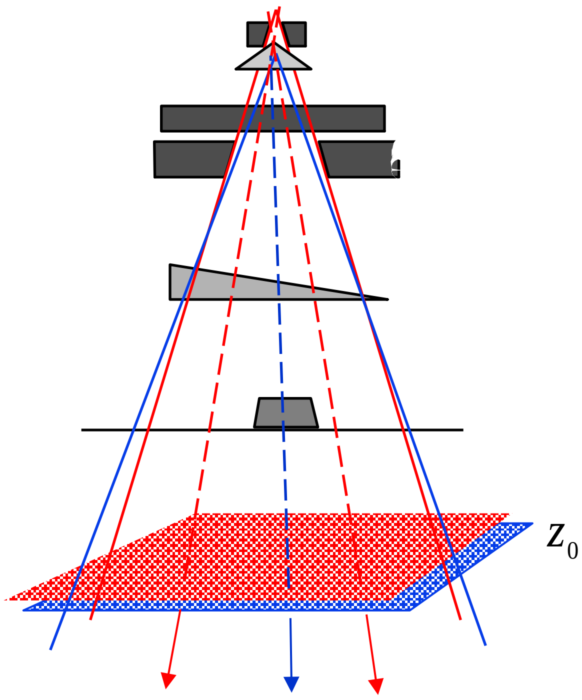
1. Beam commissioning – setting/adjusting parameter values that describes the beam such as source size, spectral shape, open beam lateral fluence, etc.
2. Dose calculations is a two step procedure:
   - for the optimized beam setup, calculate fluence maps (patient independent!)
   - calculate dose based on the fluence maps



Common fluence map implementation concepts

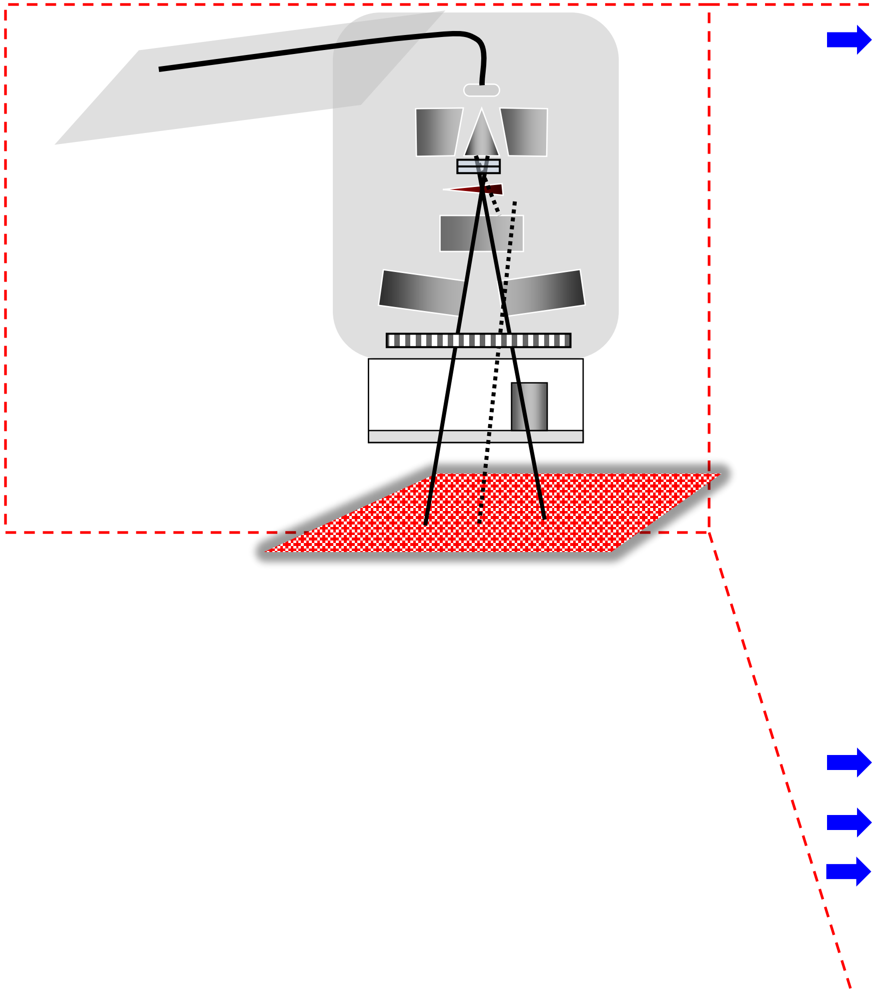
Fluence modelling give energy fluence maps for the direct beam and the head scattered beam. Particle characteristics to feed the dose engine are then deduced through:

- **Local fluence**– value of map element (which has to consider partial source blocking while being computed!)
- **Position** – element location
- **Direction** – as if the particles were coming directly from respective source to the matrix element, angular spread can be included
- **Energy** – given by a beam spectrum, off axis variations may be included
- **Extended sources** to model partial blocking



Modelling of fluence maps

Critical parts in beam commissioning for small field performance:

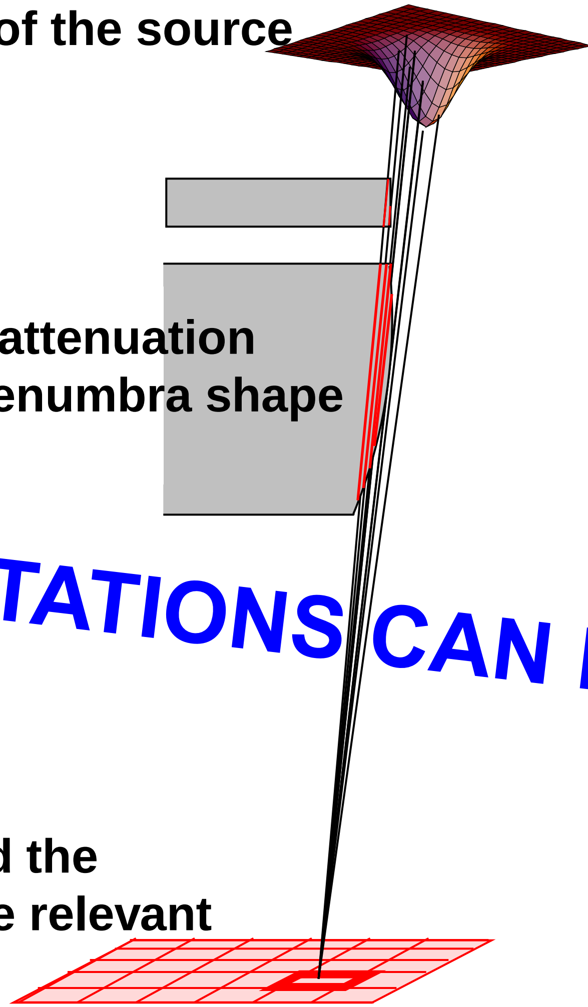


- **Direct beam source size**
- Open beam off axis distribution
- Fluence modulation
  - Step&shot
  - Dynamic
  - Wedges
- Head scatter sources
  - flattening filter
  - collimators
  - wedges
- Monitor back scatter
- Collimator leakage, including
  - MLC interleaf leakage
  - **shape of MLC leaf ends**
  - **MLC positioning**
- **Beam spectrum**
- Spectral changes
- Electron contamination

physics to include

Calculation of fluence map elements

The width and shape of the source

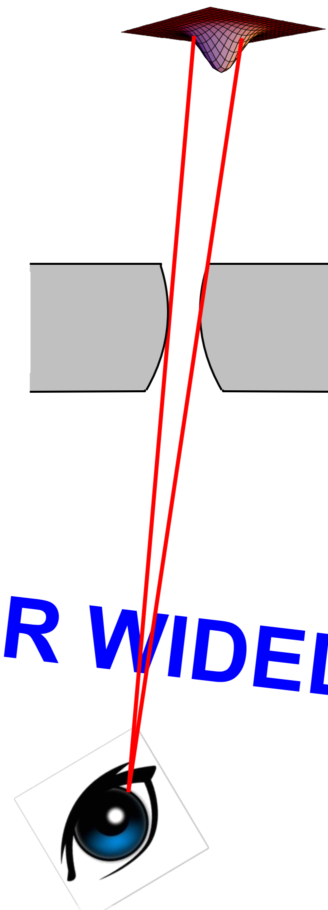


Raytrace to calculate attenuation or use approximate penumbra shape

For each element, find the contributions from the relevant sources

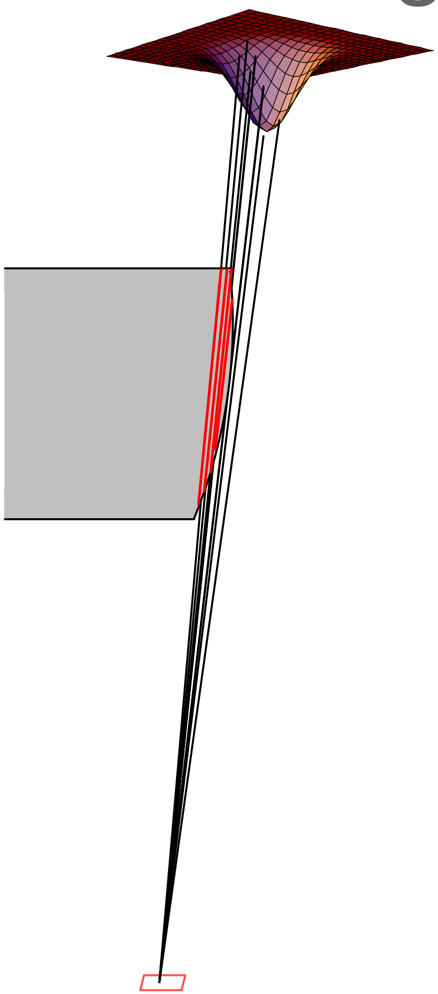
IMPLEMENTATIONS CAN DIFFER WIDELY!

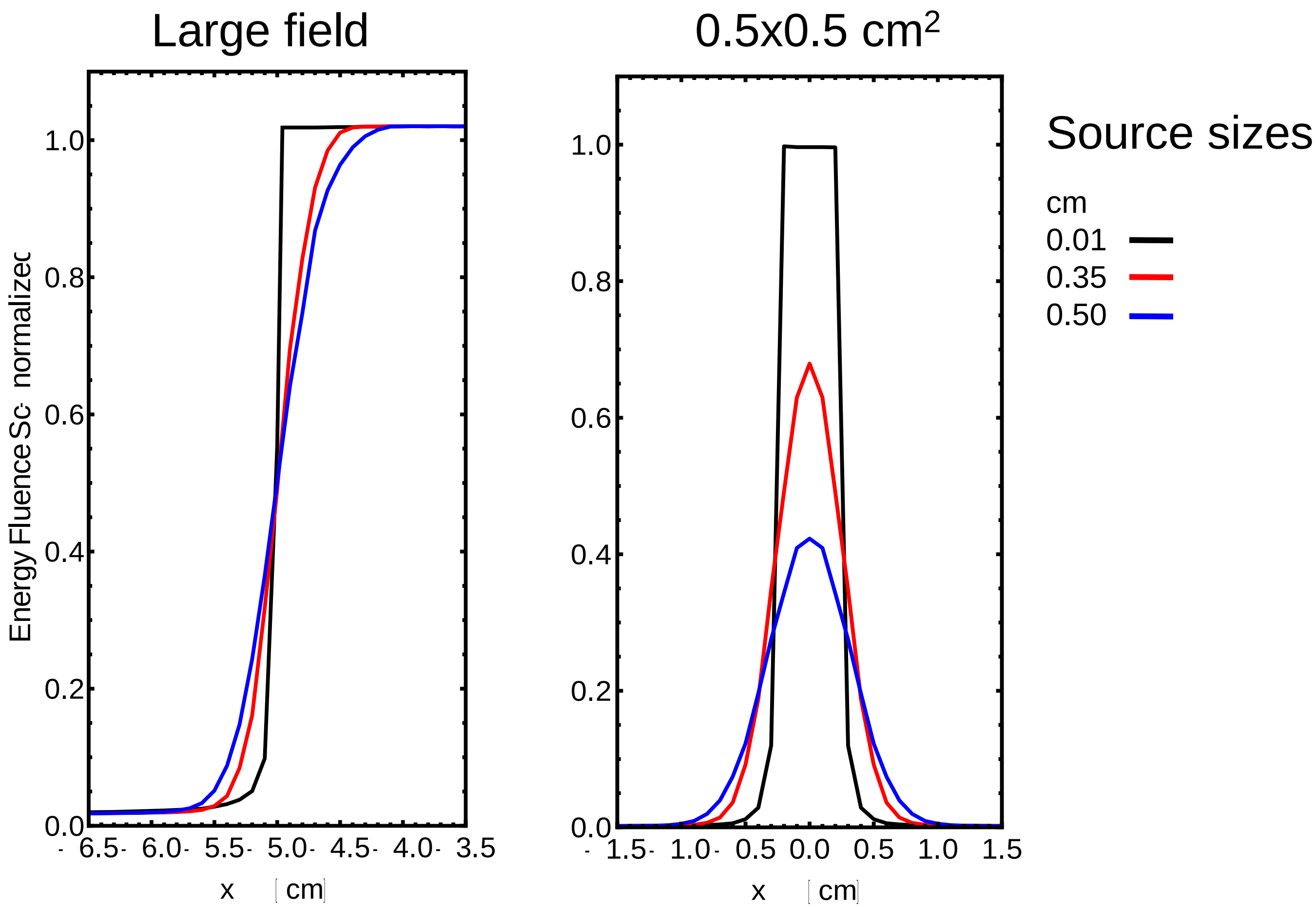
Dominating effect:



POI-eye-view of the source!

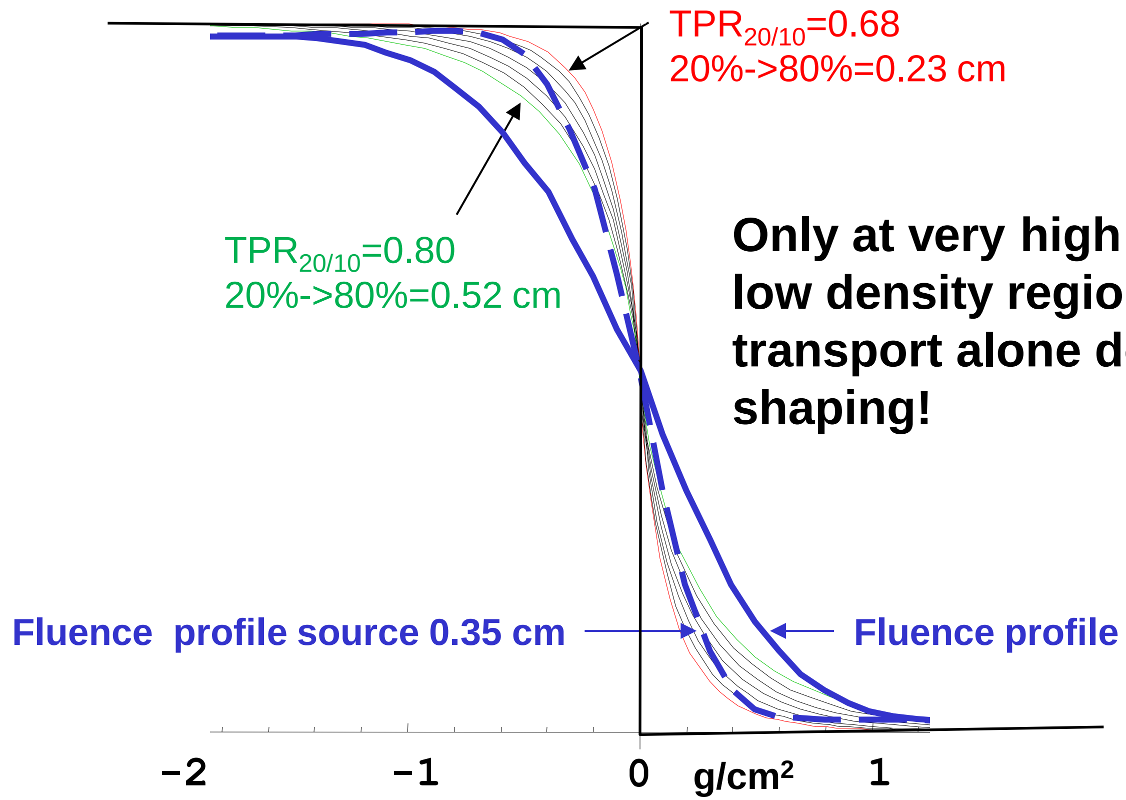
Energy fluence penumbra/output





Electron transport in dose penumbra formation

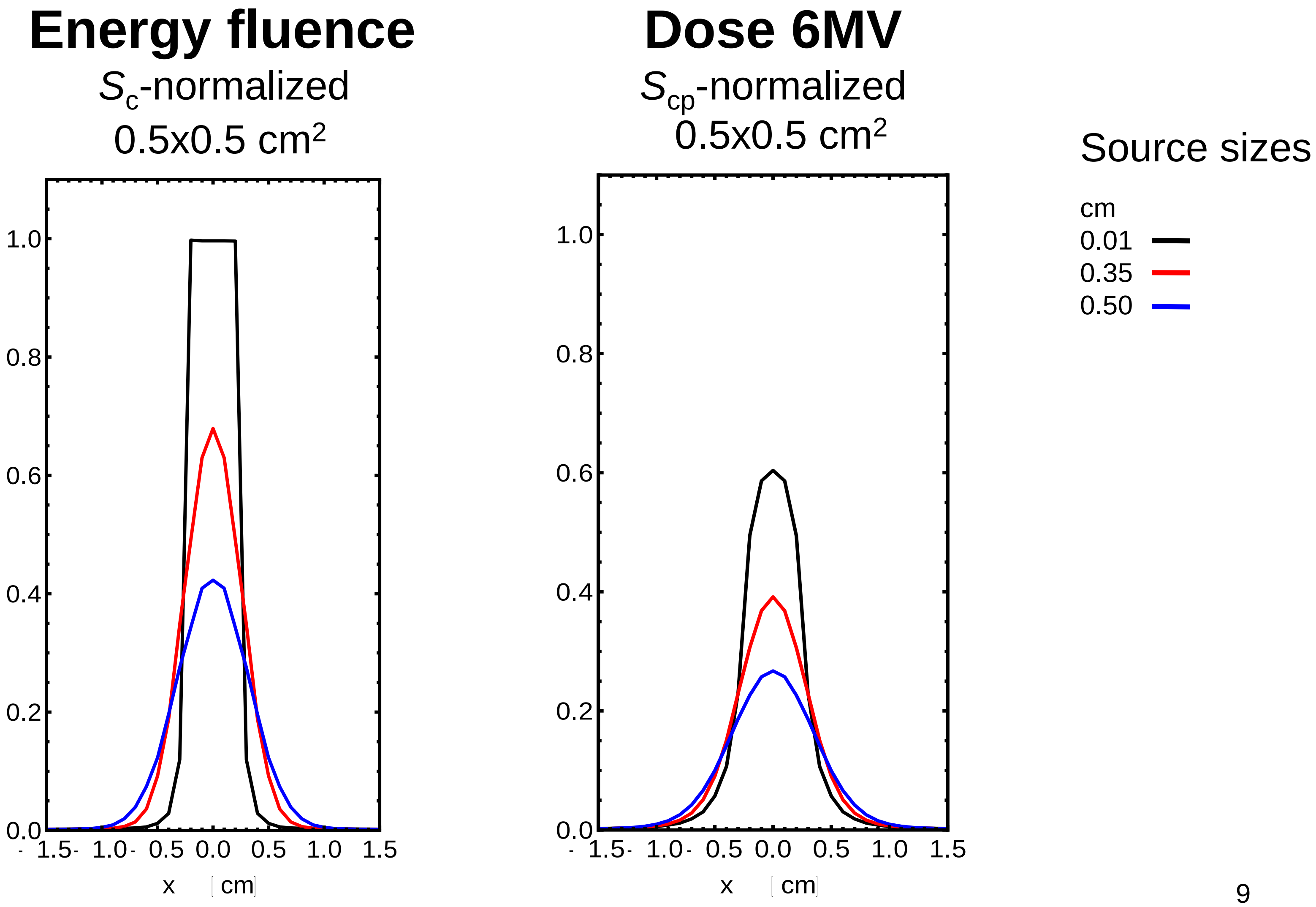
Primary dose penumbra - beam energy variations for ideal point source collimation



Only at very high beam energies (or in low density regions!) will the electron transport alone dominate penumbra shaping!

Calculated from Nyholm *et al* Rad. Onc. 78, pp 347-51 and PMB 51 pp 6245-62.

Fluence and dose profiles



Methods for beam source size determination

Model parameter fitting towards measured:

- in air profiles
- in air output S_c
- **water phantom large field dose profiles (most common)**
- **water phantom small field output S_{cp} (most effective)**

Deconvolution of lateral dose distribution:

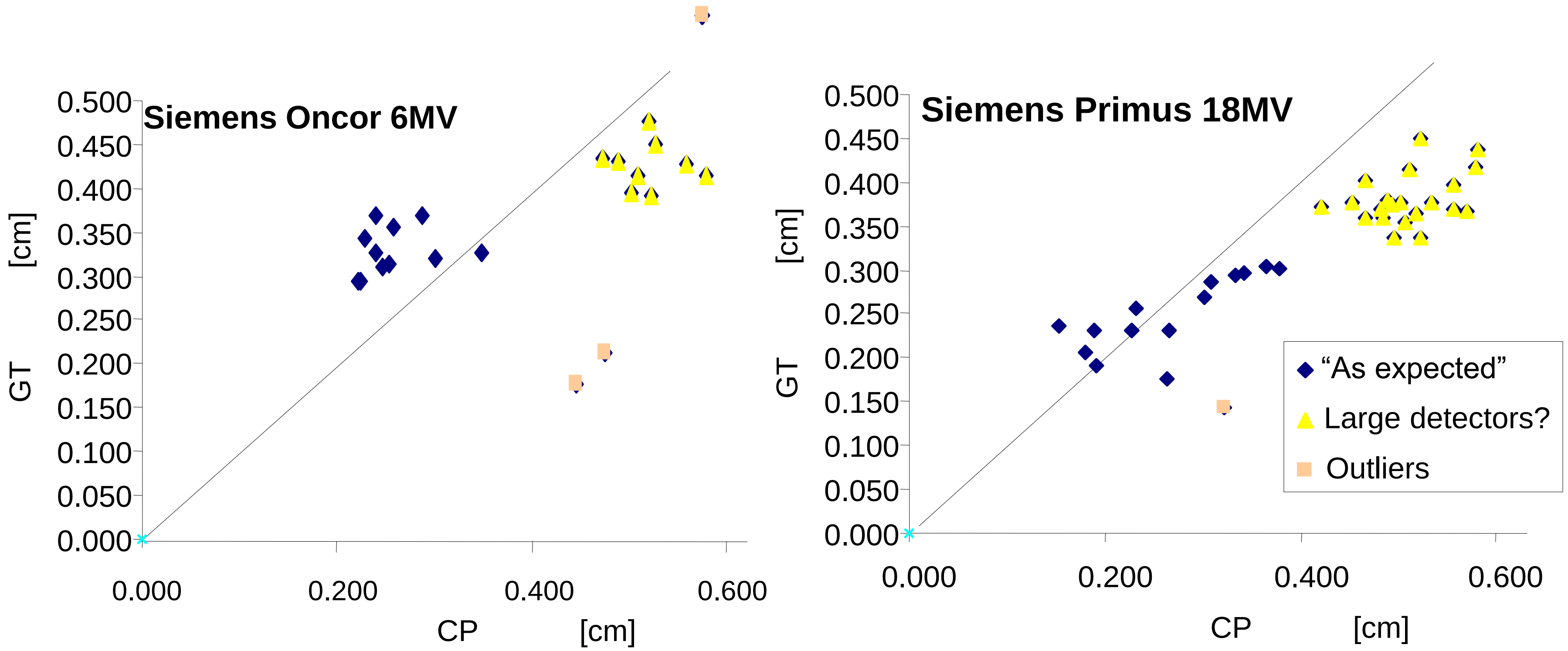
- water phantom dose profiles (Treuer etal, PMB 1993 pp 1895-1909)

Direct measurements:

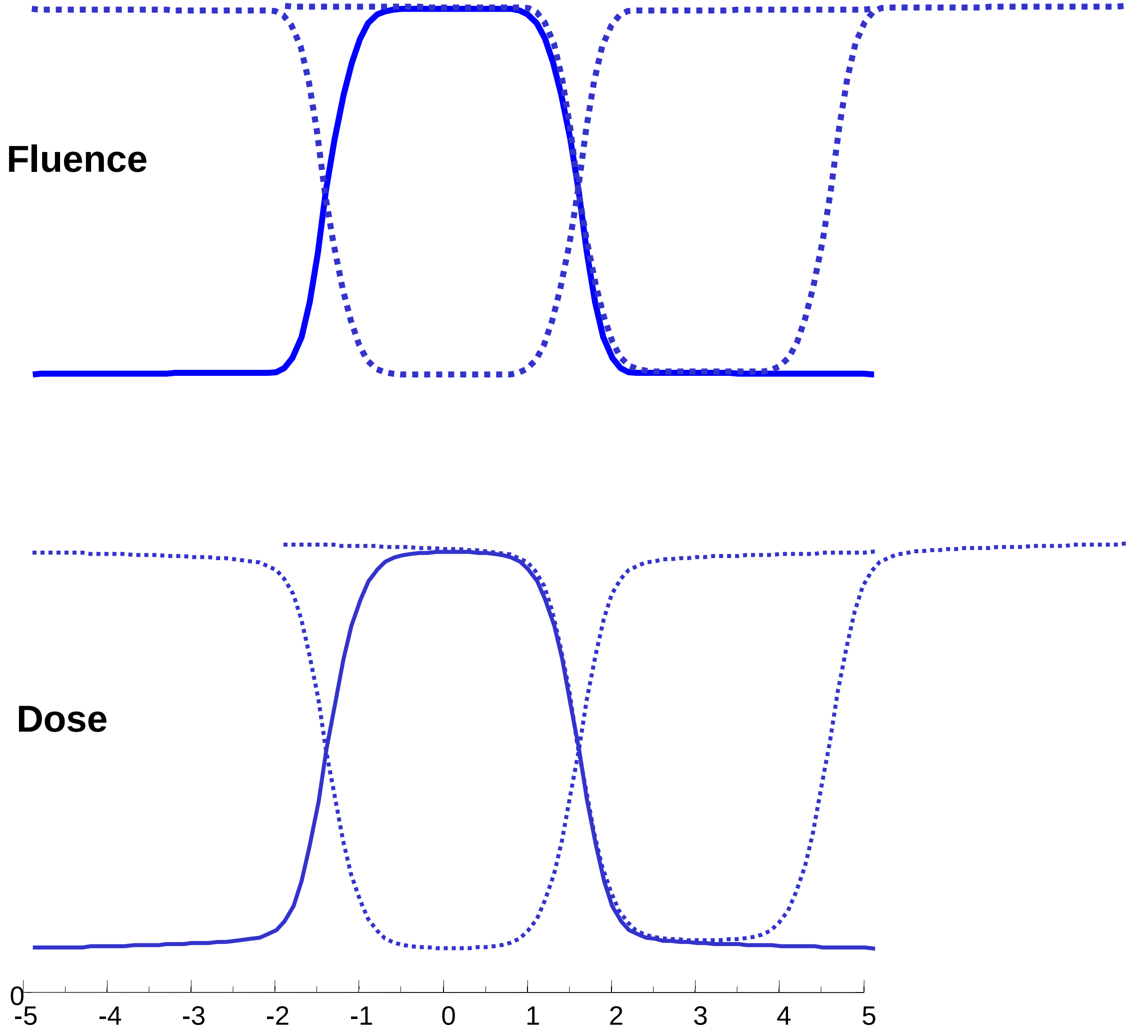
- Lutz camera (Lutz *et al*, Med.Phys. 1988, pp 614-7)
- Rotating slit image reconstruction (Munro & Rawlinson, Med. Phys. 1988, p517-24)

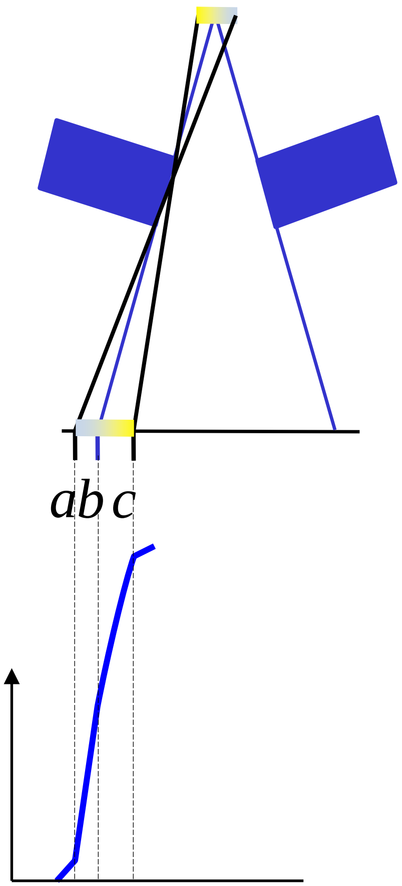
Source sizes from dose profile fitting for 10x10 cm^2 fields

Results from 59 clinical Siemens machines in Nucletrons customer database

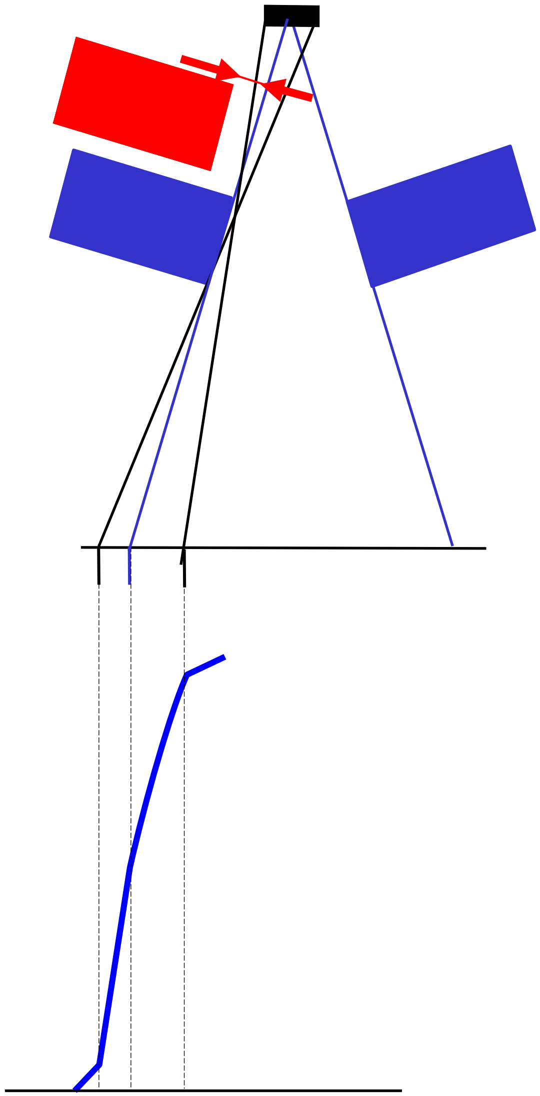


Slope variation due to collimating edge location



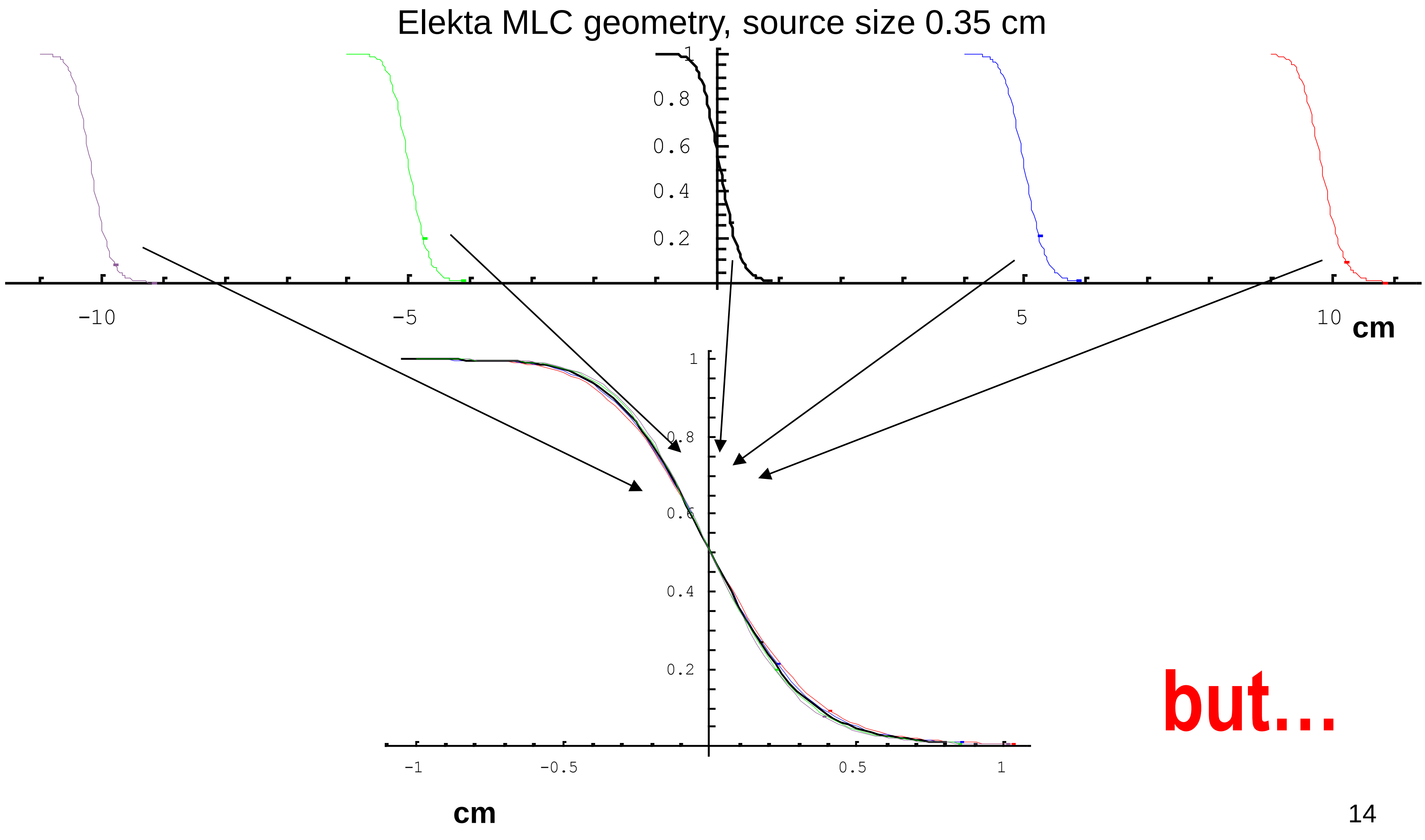


Alignments – potential issue for delivery robustness and consistent calculations



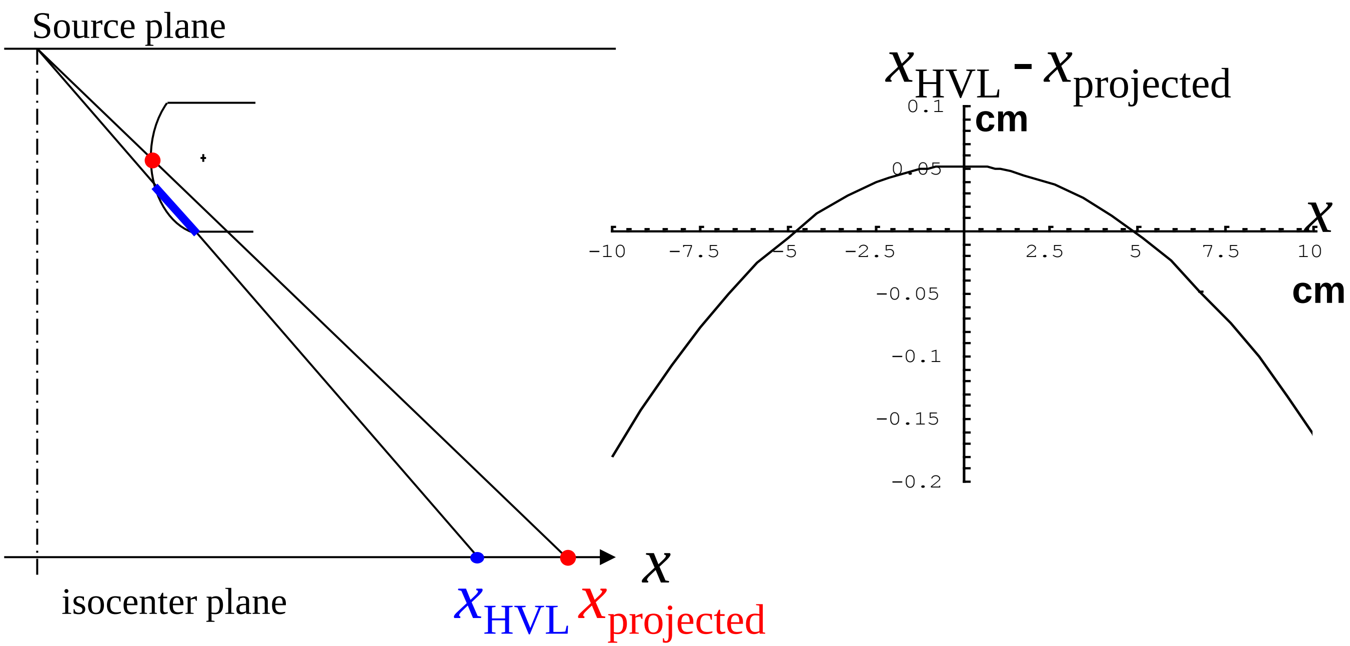
A margin for setting additional jaws make penumbra conditions more robust!

Rounded leaf penumbra almost invariant of position



but…

profile versus leaf tip positions shifts with location…



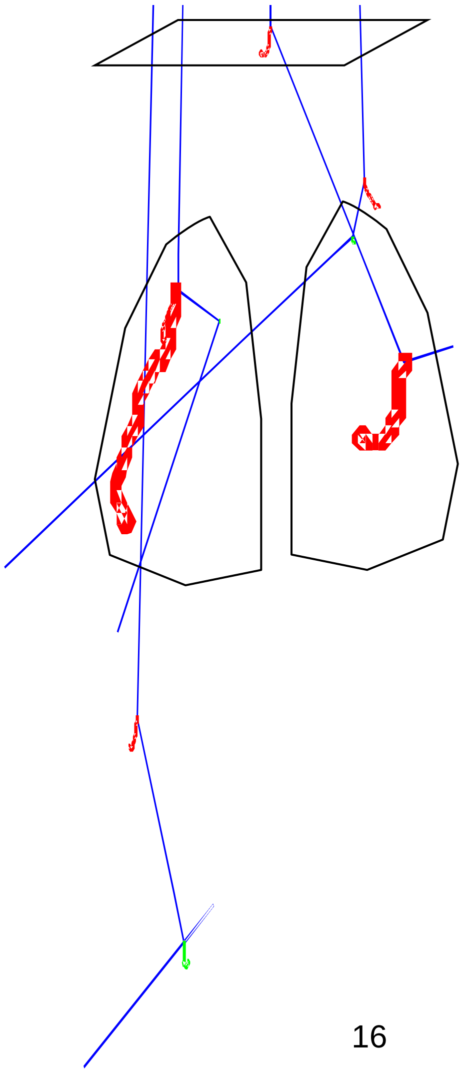
…potential inconsistency delivery ↔ dose calculations

Delivery: uses corrections, parameterized or from lookup tables
TPS: - “ - or direct calculation of 50% transmission

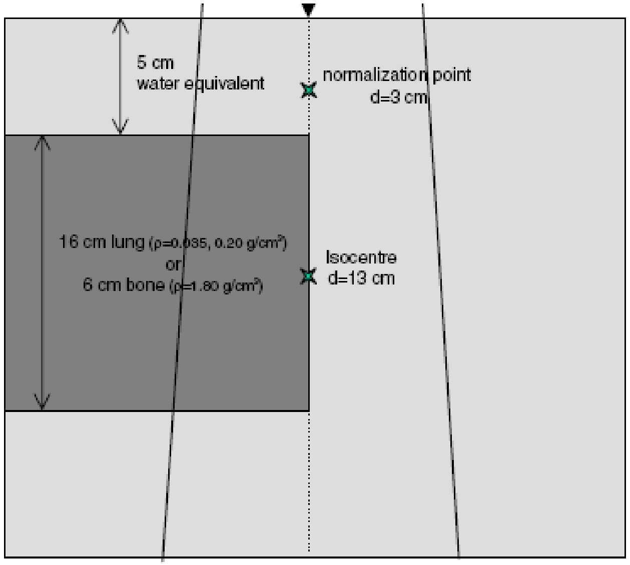
Lung dose issues

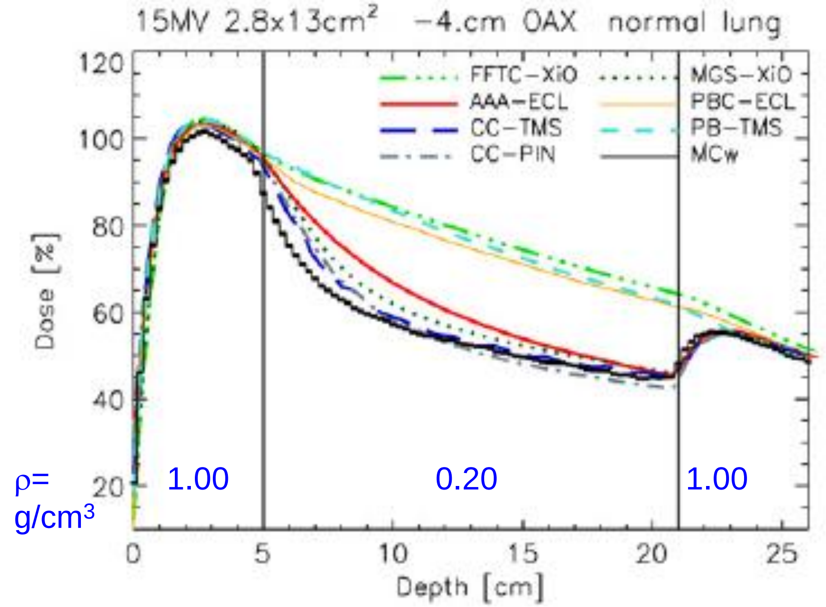
- For fields smaller than the lateral electron range, the dose **<u>varies strongly</u>** with local density variations and field size

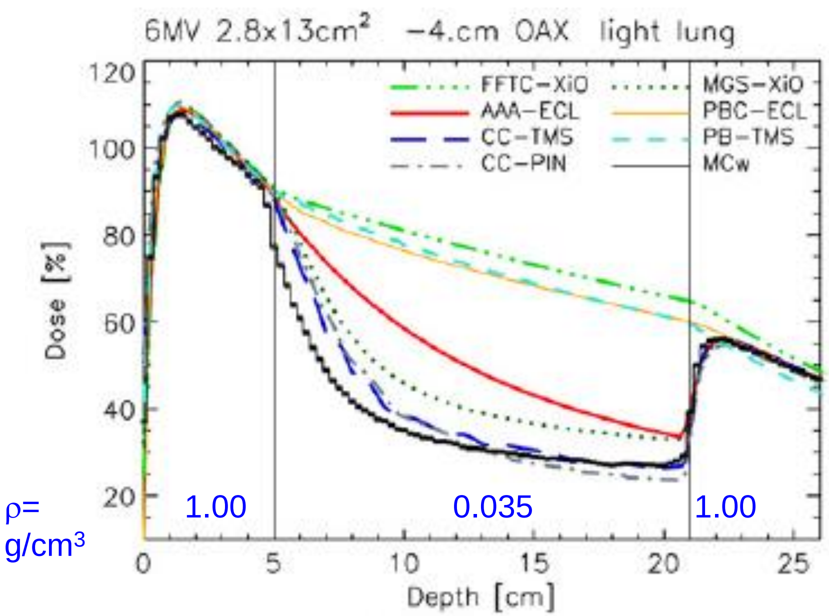
- For fields larger than the actual electron range, the dose varies less and is simpler to calculate

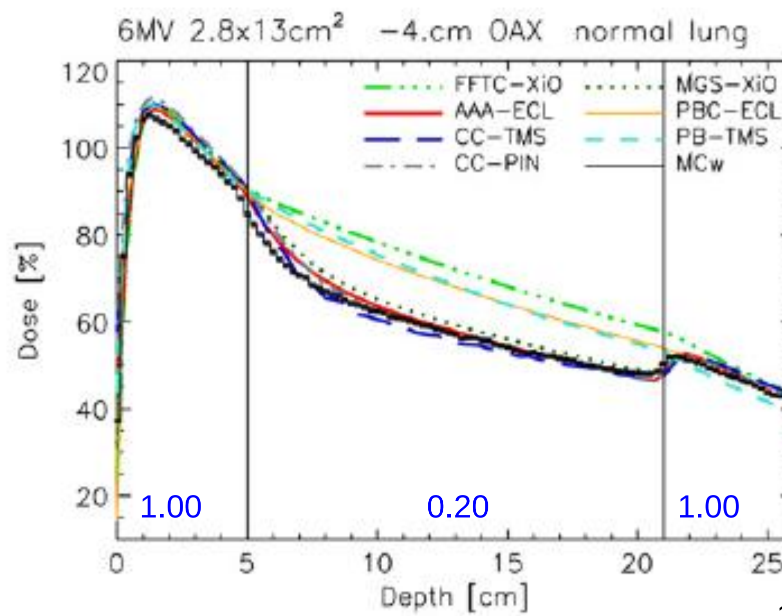


Fogliata *et al* PMB 52 (2007) p1363-85









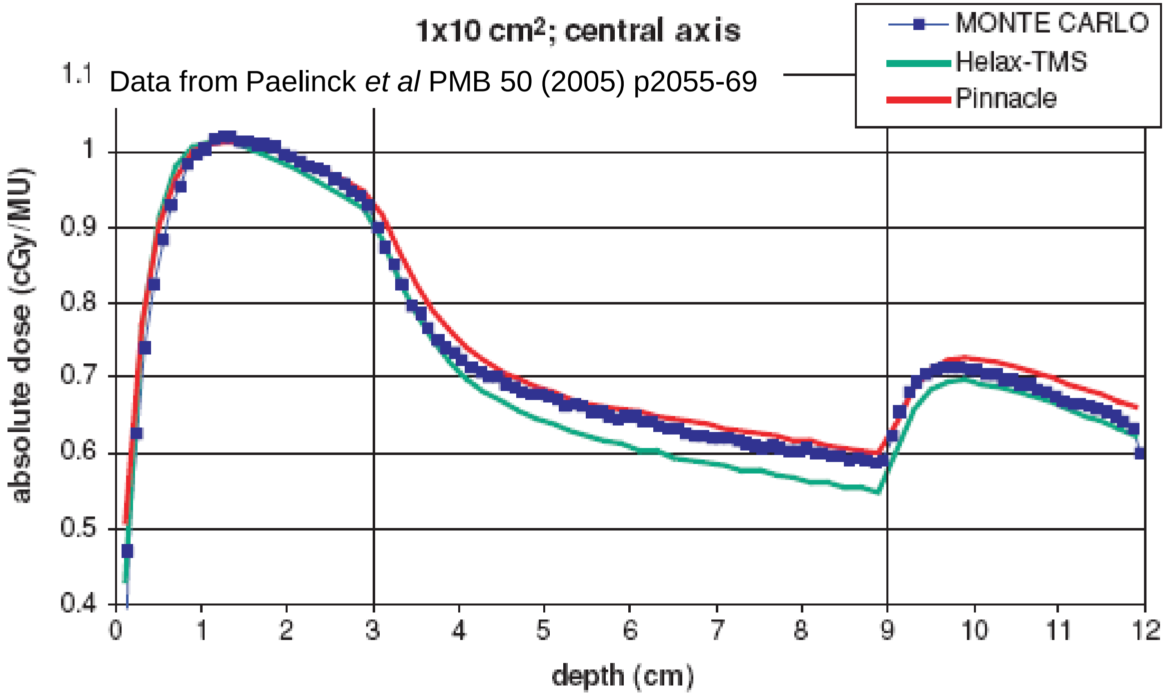
Algorithm performance for lateral electron transport in penumbra shaping

	Water phantom	Heterogeneous tissues
Factor based ”hand calc”	Limited applicability	
Pencil kernel	No problems	Not suited
Point kernel (conv/sup, ”CC”)	No problems	Well funded approximations
Monte Carlo	No problems	No problems

IMPLEMENTATIONS CAN DIFFER WIDELY!

”No problems” = the beam source modell determines the results!

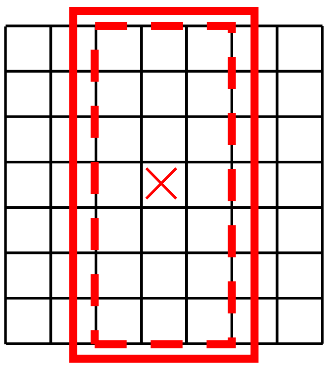
Example - discretization effects



(a)

Explanation:

Due to fluence elements of 2.5x2.5 mm², the field for Helax-TMS is likely effectively 7.5x97.5 mm² yielding the dose undershot. Corrected in later TPS versions.



Summary – TPS modelling for small fields

- Partial view modelling of the direct source most critical – results **VERY** sensitive to measurement/beam modelling errors
- Issues for consistency checks delivery-calculations:
  - treatment head geometry
  - MLC positions, field sizes
  - handling/positioning of block collimators
- Combining small and large segments requires MU calculations (”absolute dose”) involving:
  - full head scatter (flattening filter scatter, MU backscatter, etc)
  - collimator leakage