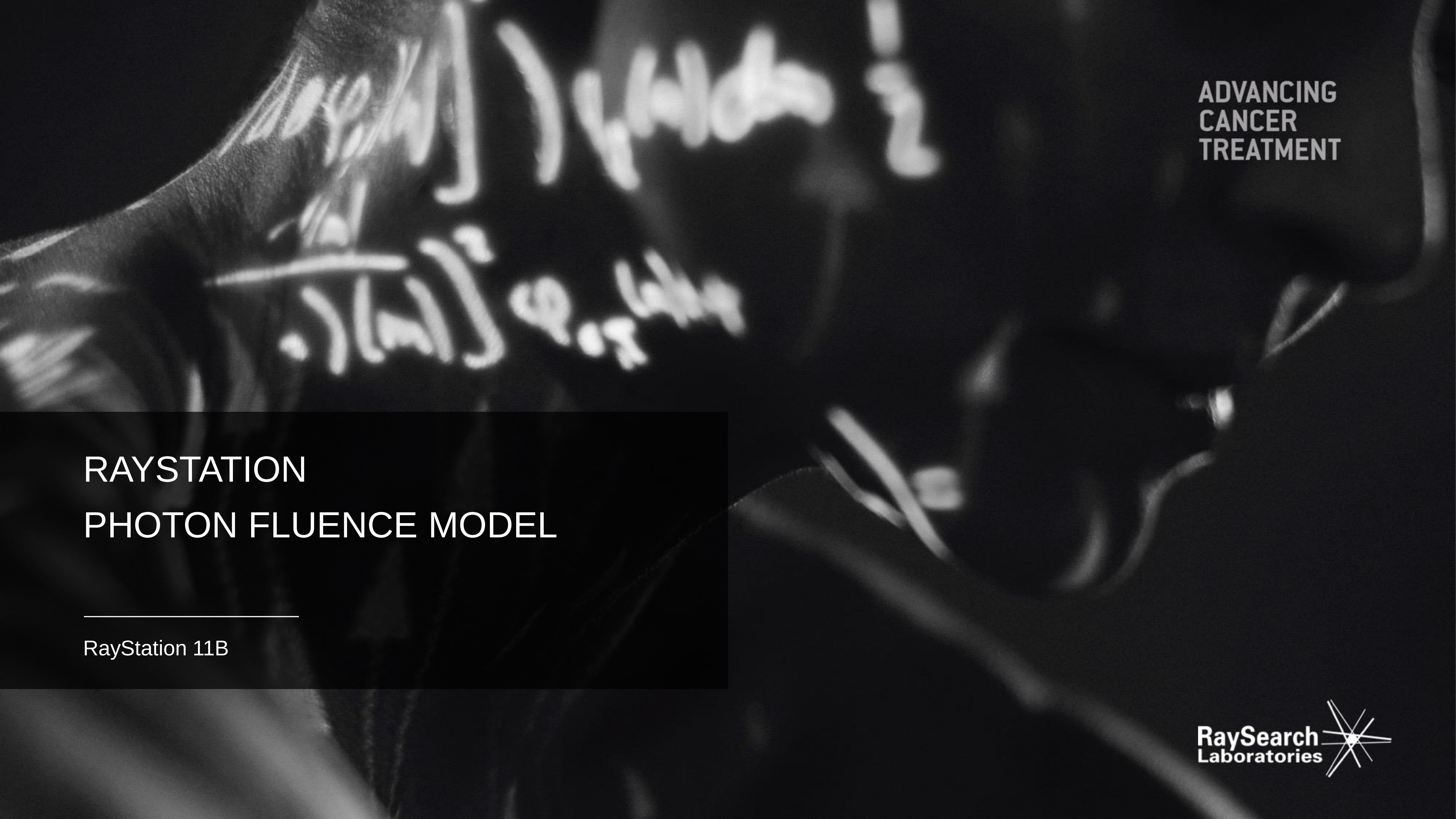


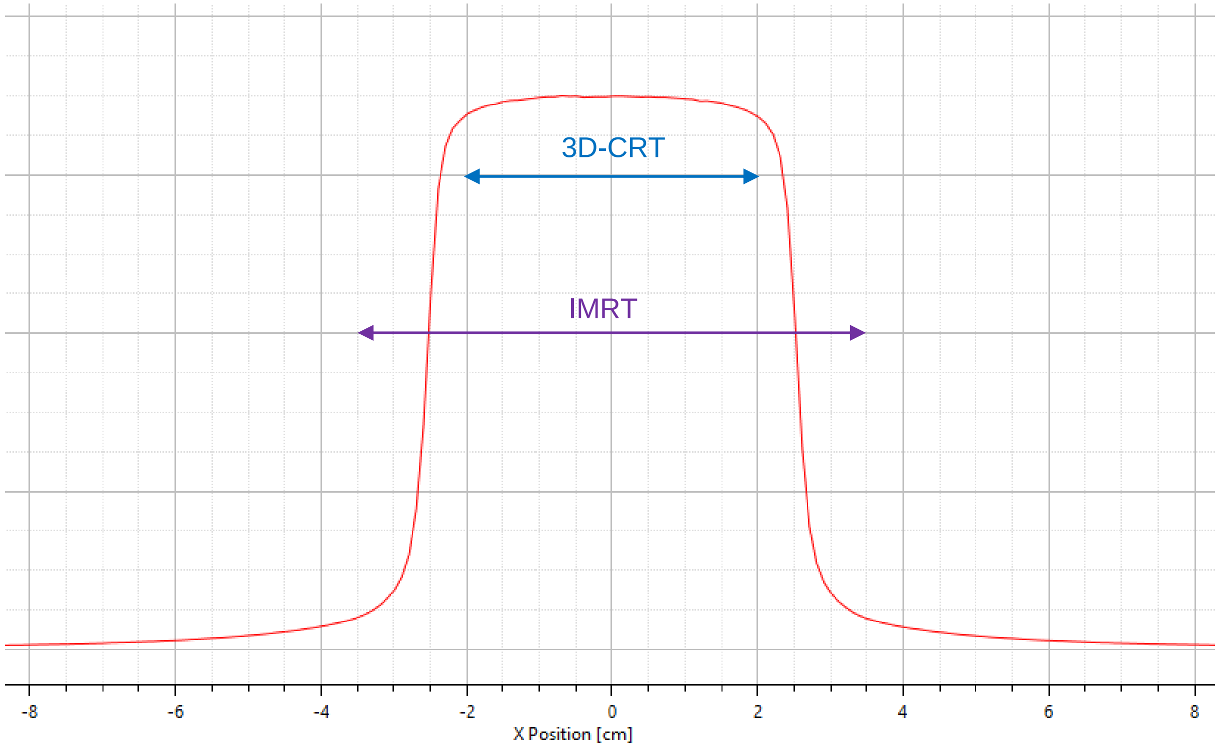
ADVANCING
CANCER
TREATMENT

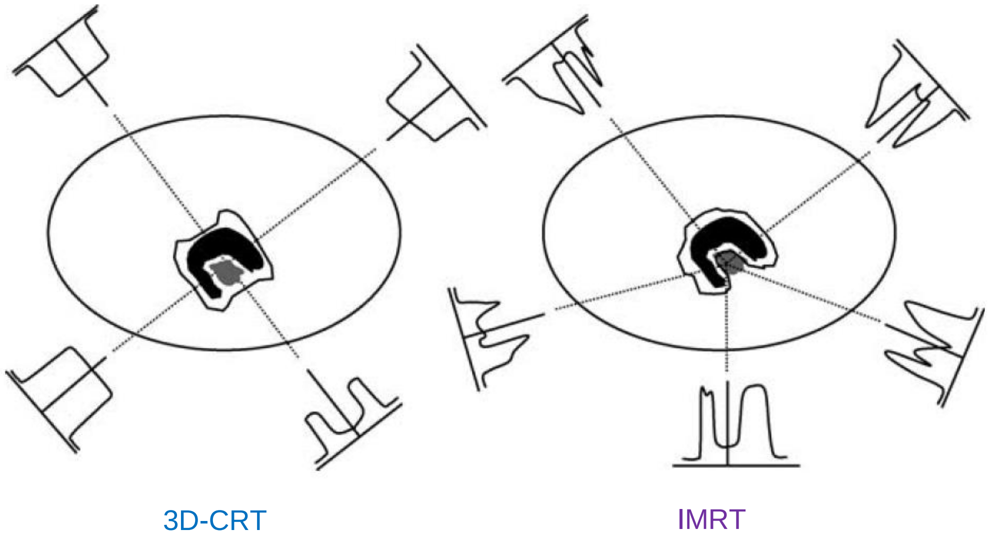
RAYSTATION
PHOTON FLUENCE MODEL

RayStation 11B

RaySearch Laboratories

MULTI-SOURCE MODELLING OF ENERGY FLUENCE

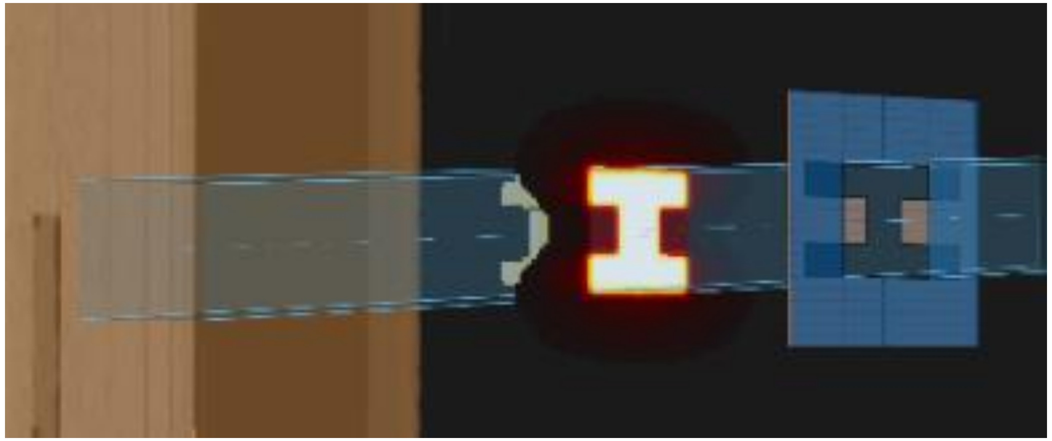




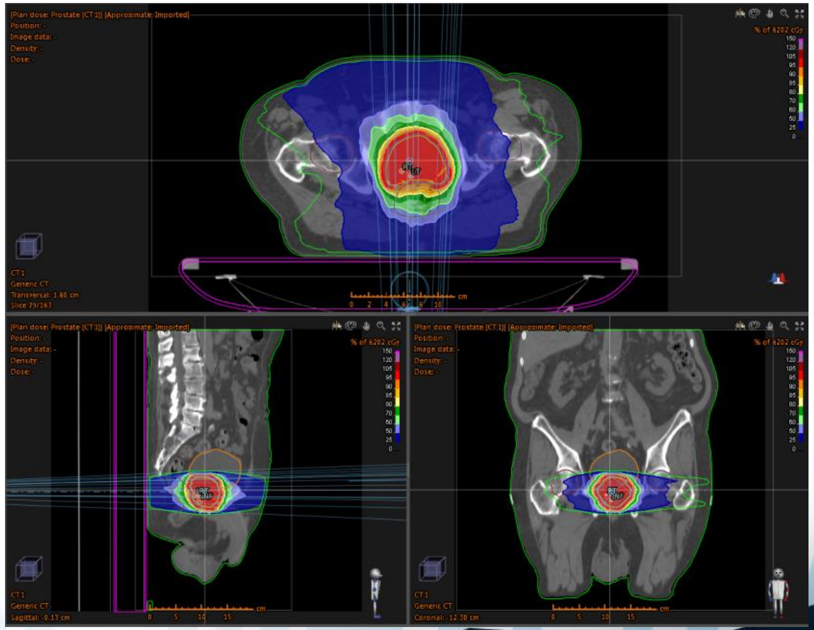
ICRU Report 83 Vol 10 No 1 (2010)

BRIEF OVERVIEW OF THE DOSE COMPUTATION

Beam model
Parameters*
+
Treatment plan
→
Energy Fluence

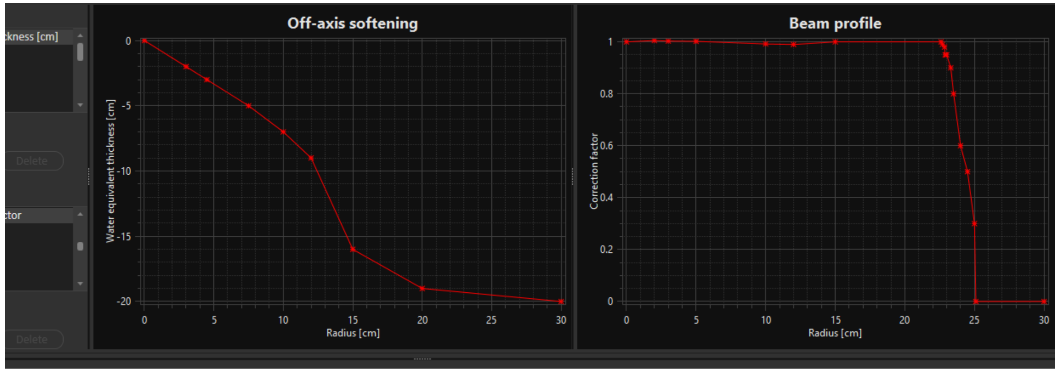


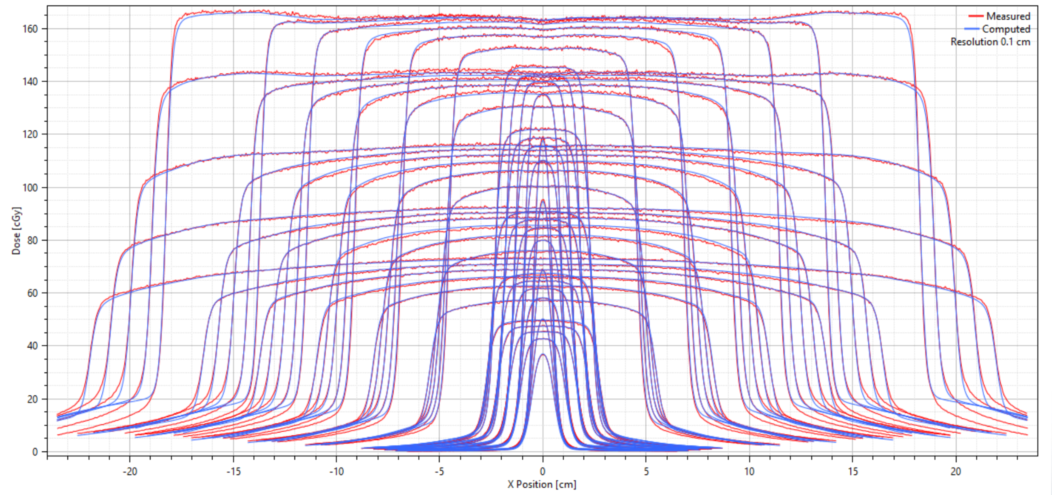
Energy Fluence
+
Beam model parameters**
+
Patient
+
CC dose engine
or MC dose engine
→
Dose



THE MULTI-SOURCE BEAM MODEL PARAMETERS

- Number of parameters set by the user at the beam commissioning stage to give best description of a specific LINAC
- Some actual physical quantities
- Some adapted to provide the best fit possible with measurements





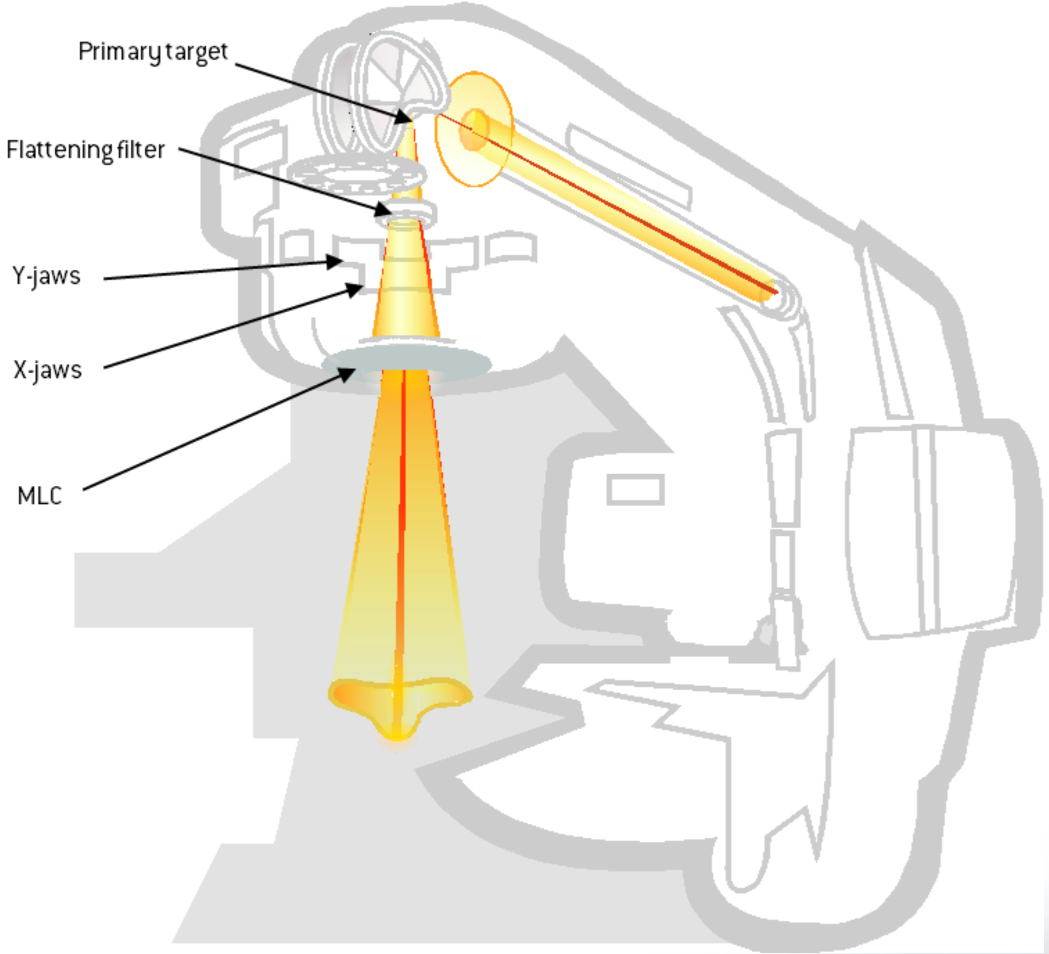
MULTI-SOURCE MODELLING OF ENERGY FLUENCE

Photon sources:

- Primary photon source
  - σ_P = 0 - 2 mm (elliptical, NOT rotated with the collimator)
- Flattening filter (FF) photon source
  - σ_{FF} = 1 - 3 cm (circular)
- Wedge scatter source (if present)

Contamination electron sources:

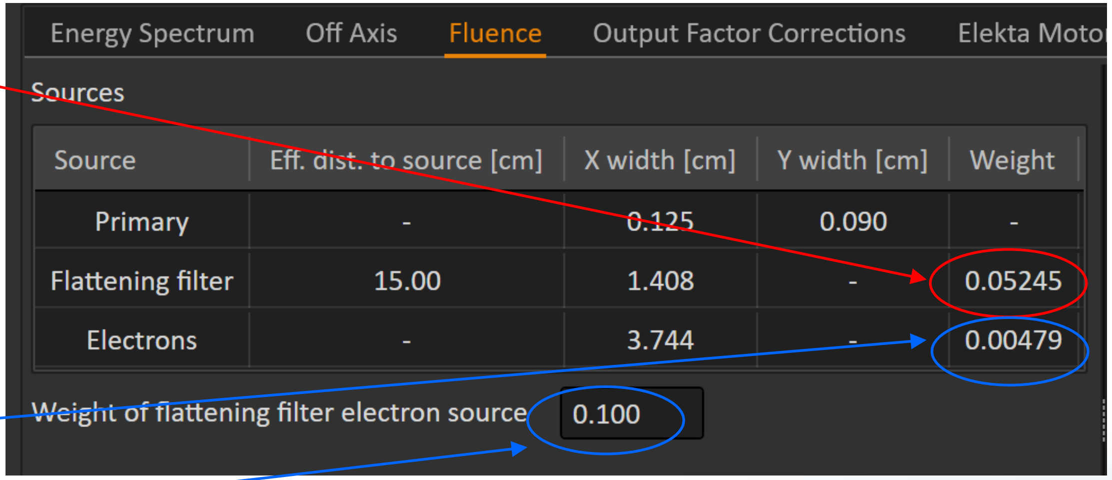
- Primary electron source
  - σ = 4 - 15 cm (circular)
- Flattening filter electron source
  - $\sigma = \sigma_{FF}$



MULTI-SOURCE MODELLING OF ENERGY FLUENCE

- Total photon (X-ray) source weight:
  - $w_X = w_p + w_{FF} + w_{wedge} = 1$
  - w_p = primary source weight
  - w_{FF} = FF source weight
  - w_{wedge} = wedge scatter source weight

- Total electron source weight:
  - $w_e = w_{e,p} + w_{e,FF}$
  - w_e = total electron source weight
  - $w_{e,FF}$ = FF electron source weight



Source	Eff. dist. to source [cm]	X width [cm]	Y width [cm]	Weight
Primary	-	0.125	0.090	-
Flattening filter	15.00	1.408	-	0.05245
Electrons	-	3.744	-	0.00479

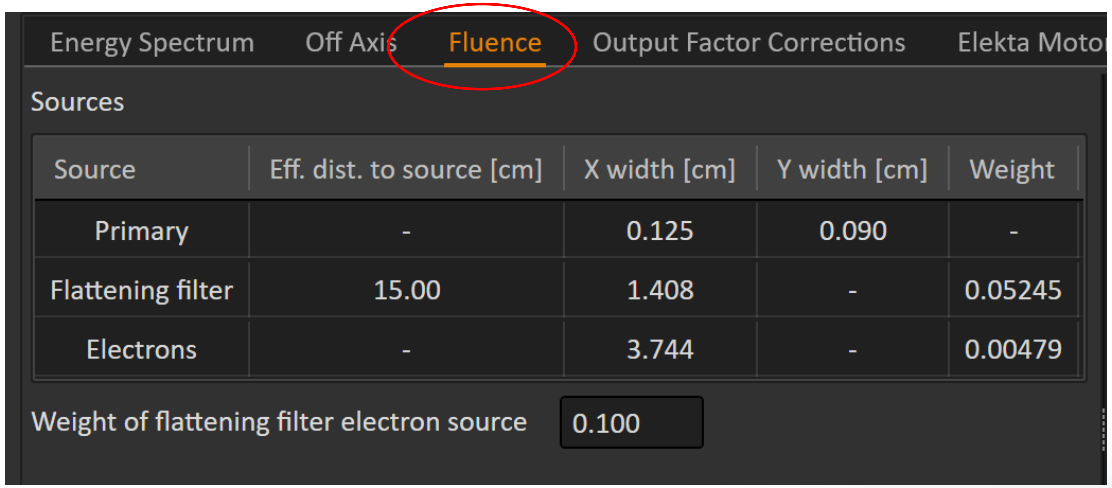
Weight of flattening filter electron source 0.100

MULTI-SOURCE MODELLING OF ENERGY FLUENCE

- Total photon (X-ray) source weight:
  - $w_X = w_p + w_{FF} + w_{wedge} = 1$
  - w_p = primary source weight
  - w_{FF} = FF source weight
  - w_{wedge} = wedge scatter source weight

- Total electron source weight:
  - $w_e = w_{e,p} + w_{e,FF}$
  - w_e = total electron source weight
  - $w_{e,FF}$ = FF electron source weight

Energy fluence = Photon or electron energy per area



Source	Eff. dist. to source [cm]	X width [cm]	Y width [cm]	Weight
Primary	-	0.125	0.090	-
Flattening filter	15.00	1.408	-	0.05245
Electrons	-	3.744	-	0.00479

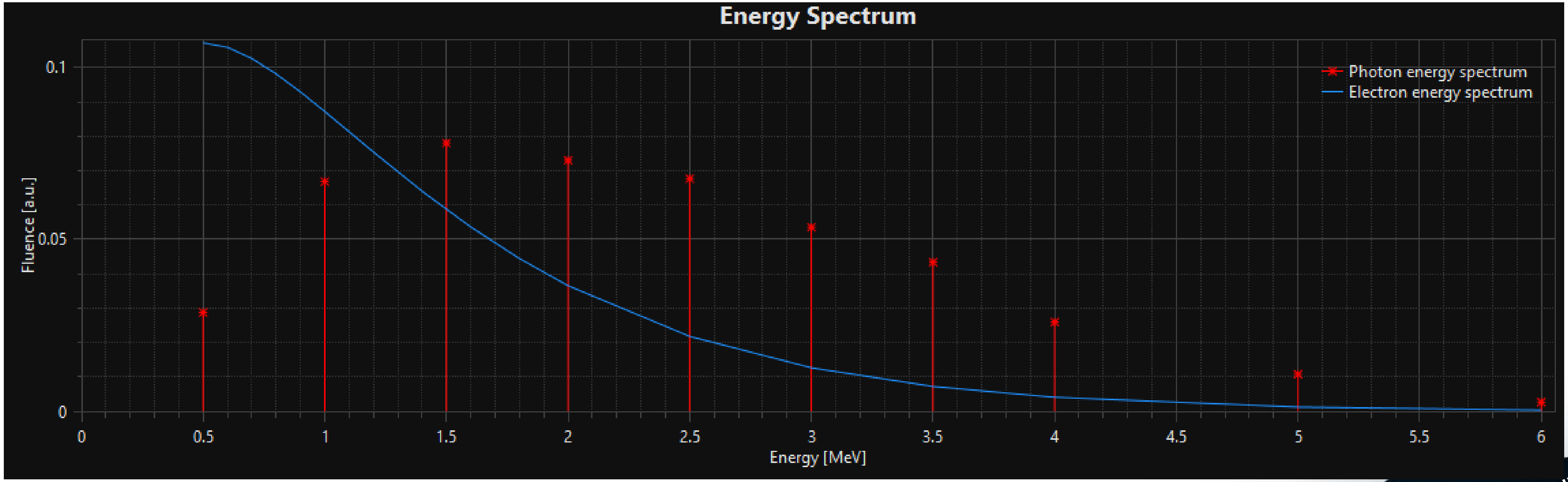
Weight of flattening filter electron source: 0.100

ENERGY SPECTRUM USED AT TERMA + PSK CALCULATION

Photon Energy spectrum

Electron Energy distribution

$$f(E) \propto E^c e^{-E/E_0}$$



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ENERGY SPECTRUM USED AT TERMA + PSK CALCULATION

Photon Energy spectrum

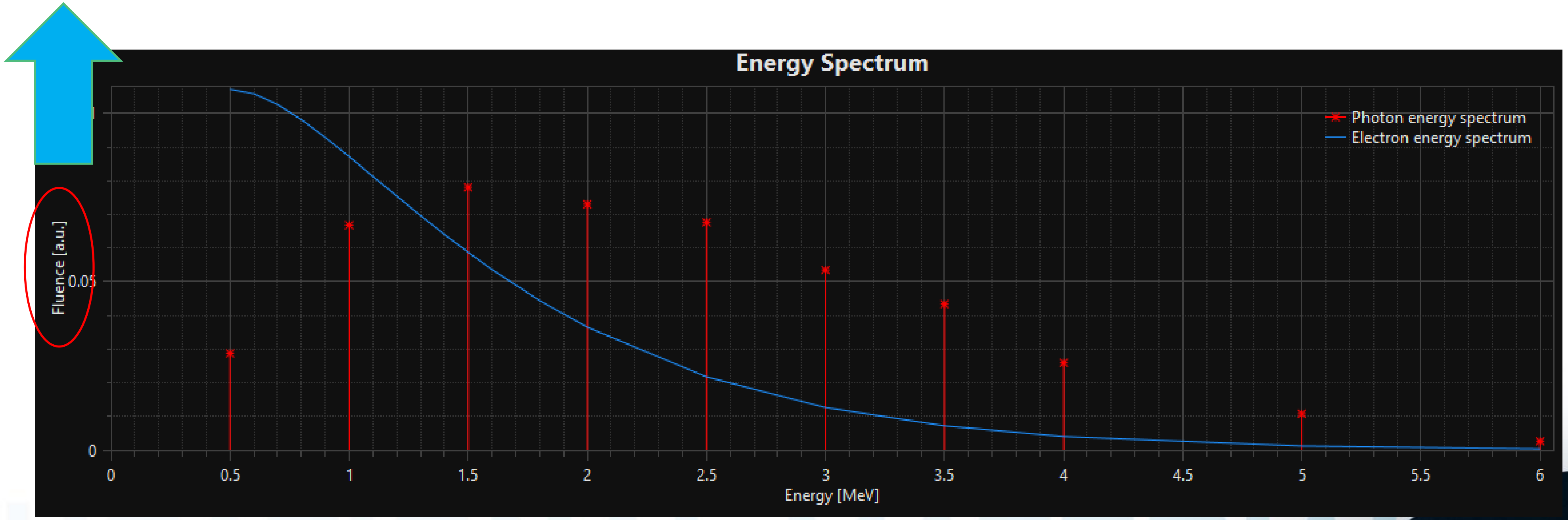
Electron Energy distribution

Fluence = **Particle Fluence** = Photon or electrons per area

Fluence means particle fluence only in the energy spectrum

In all other instances the word fluence is used for energy fluence

$$f(E) \propto E^c e^{-E/E_0}$$



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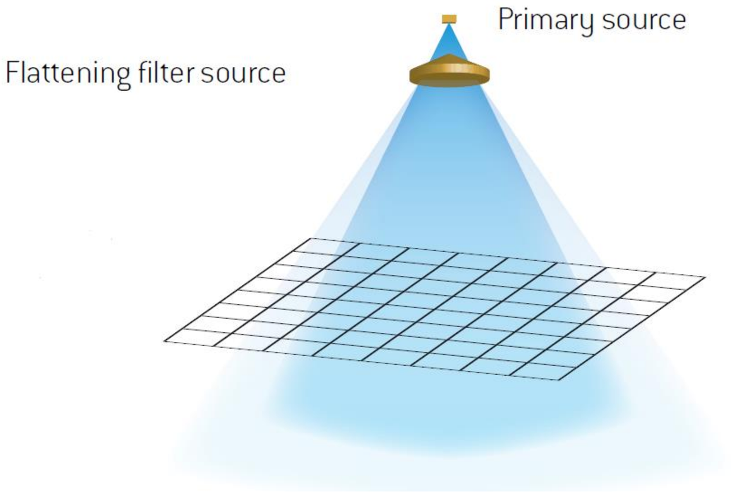
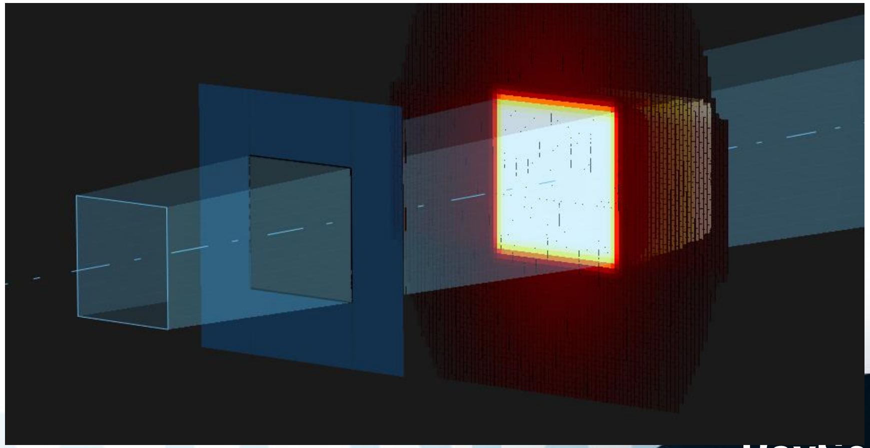
MULTI-SOURCE MODELLING OF ENERGY FLUENCE

- Energy fluence for photons and electrons is an intermediate step before dose calculation

- Accurate energy fluence engine is used for clinical dose calculation. The SVD (singular value decomposition) fluence is slightly different (optimization).
  - The SVD dose engine is based on the pencil beam convolution technique. Always non-clinical in RayStation





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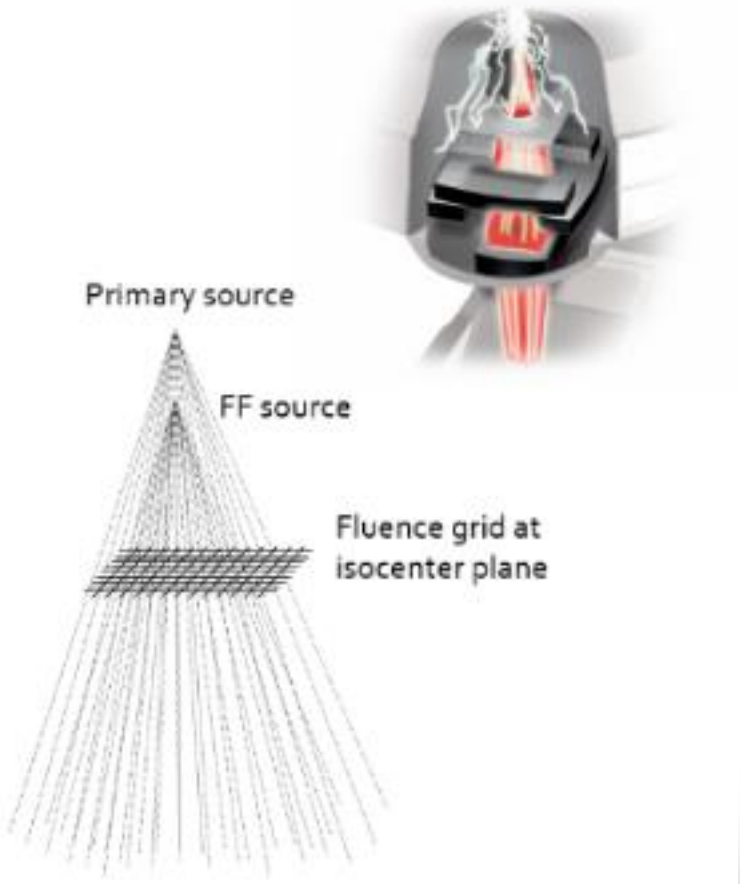
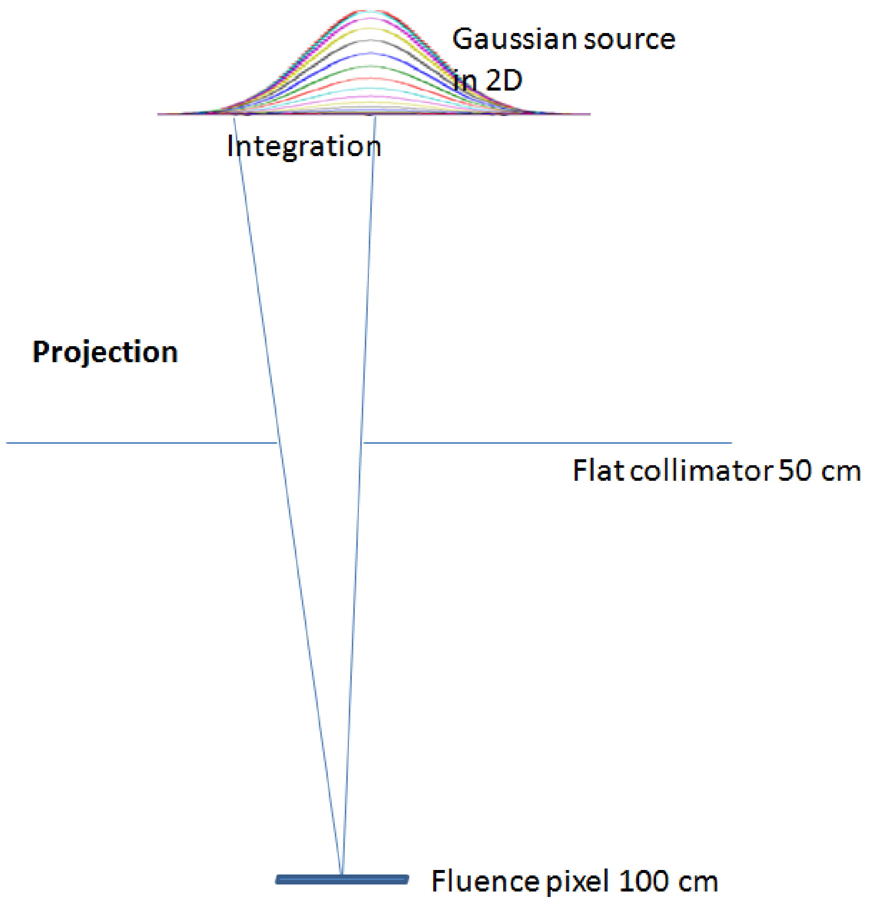
MULTI-SOURCE BEAM MODEL – SOURCE PROJECTION

- Energy fluence calculated from the beam model by projecting each source through the collimators on the fluence plane (isocenter) without the patient
- Projection through:
  - Open areas
  - Jaws
  - MLC leaves (closed leaves, leaf tips, Tongue and Groove)
- Divergence from source point
- Collimators assumed to be flat (in reality rounded, targetpointing or skewed)



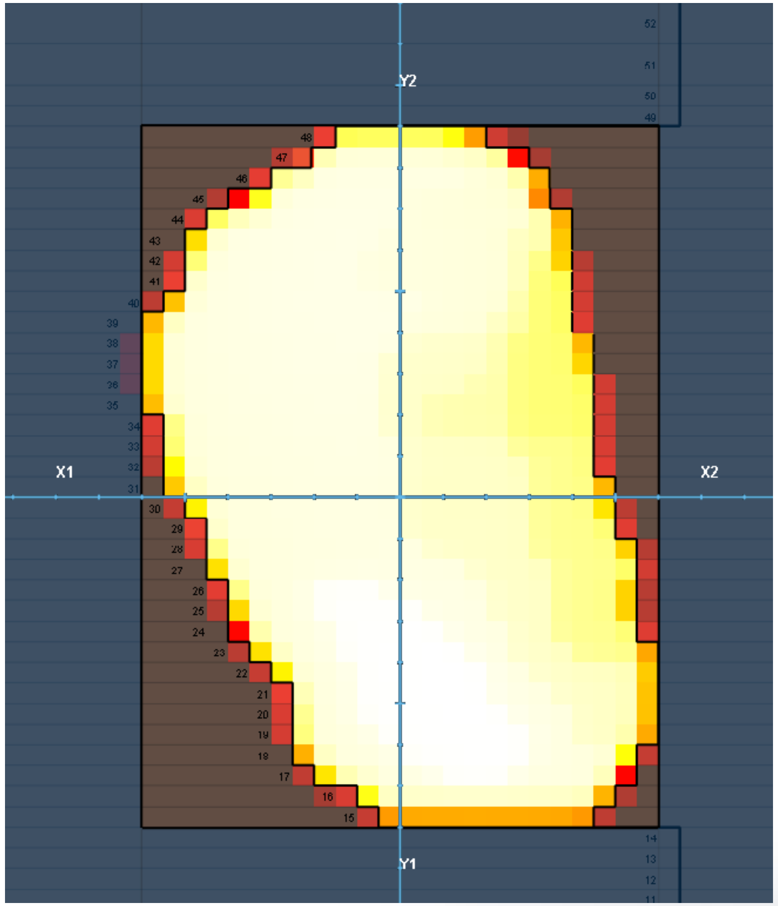
MULTI-SOURCE BEAM MODEL – SOURCE PROJECTION

- Back projection: For each central pixel point in the fluence plane, integration over the visible part of the source.
- The collimator Z position specified in RayPhysics is used
- For the primary source (small source) : integration over the pixel size as well
- Fluence grid resolution:
  - 1 mm x 1 mm for primary source
  - 3 mm x 3 mm for other sources (resampled to 1 mm x 1 mm before TERMA computation)



ENERGY FLUENCE - FLUENCE MAP

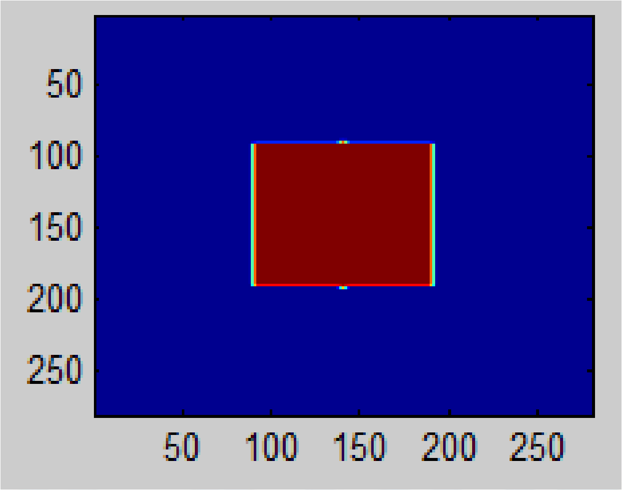
- A fluence map is created after projection.
- Projection separately for each source:
  - Primary photon source (projected through all regions)
  - Flattening filter photon source (not projected through T&G and leaf tip regions)
  - Wedge scatter source (if present, not projected through T&G and leaf tip regions)
  - Electron sources (no electron transmission through any MLC region)



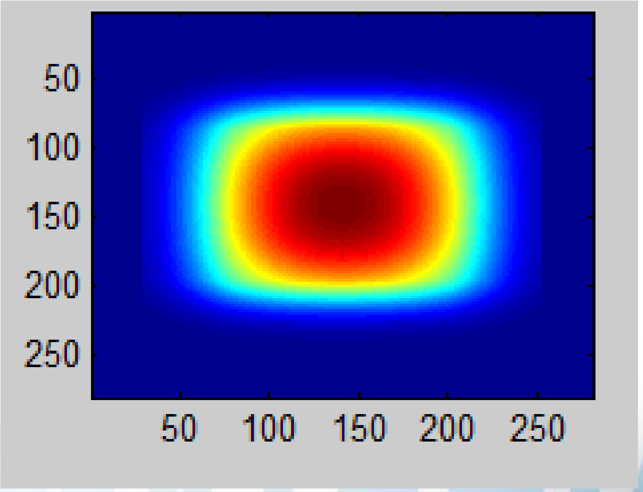
FLUENCES – PRIMARY vs FF PHOTON SOURCES

- When projecting the small, almost point like, primary source, the resulting fluence gets sharp edges.
- Projection of the extended sources (wedge and FF) gives a more blurred fluence.

Primary energy fluence map



FF energy fluence map



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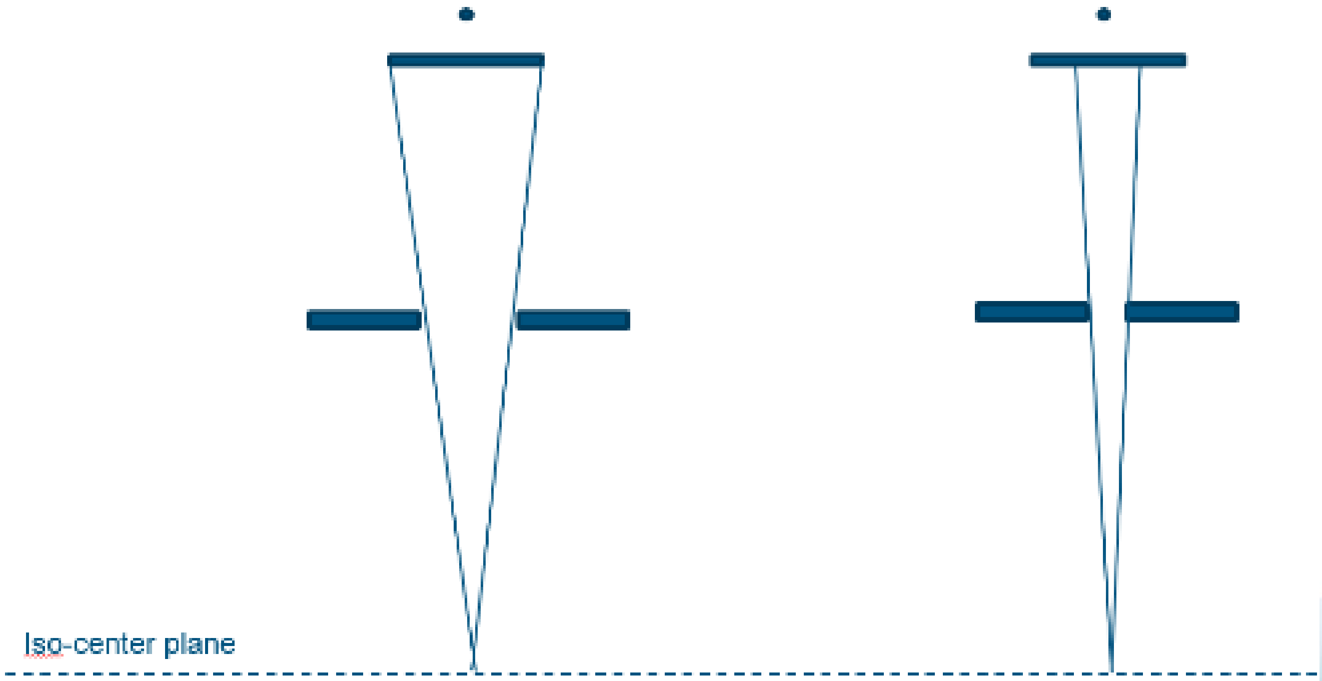
FLUENCES – PRIMARY vs FF PHOTON SOURCES

Larger part of FF included in back-projection for large fields ->

Large field penumbra more affected by FF source size and small field penumbra more affected by primary source size.



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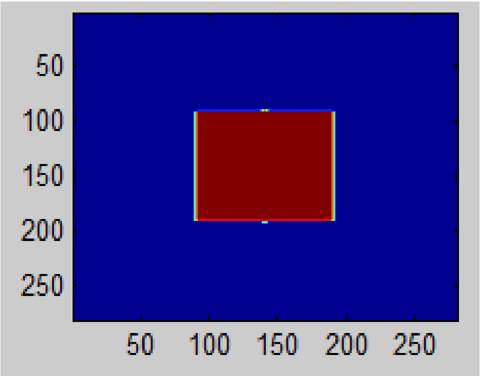
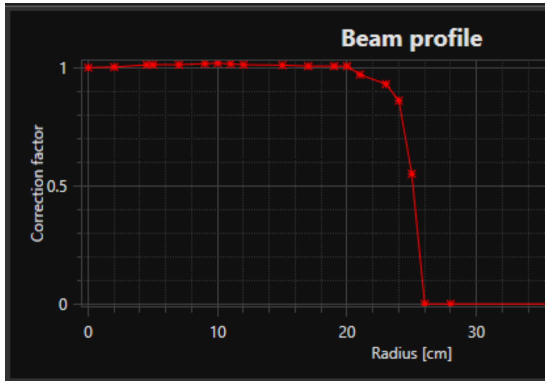
FLUENCES – TOTAL PHOTON ENERGY FLUENCE

Primary energy fluence map



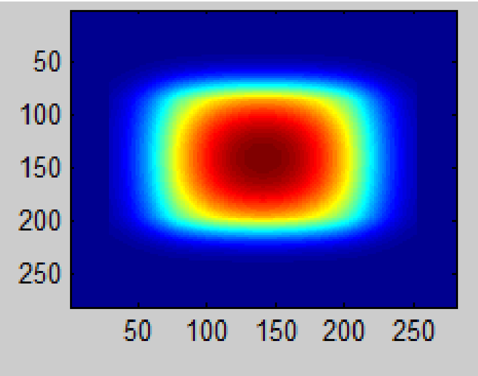
*

BPC(r)



+

FF energy fluence map



$$\Psi_{ph_{TOT}}(collimation) = \Psi_{ph_{primary}}(collimation, BPC = 1) * BPC(r) + \Psi_{ph_{secondary}}(collimation)$$

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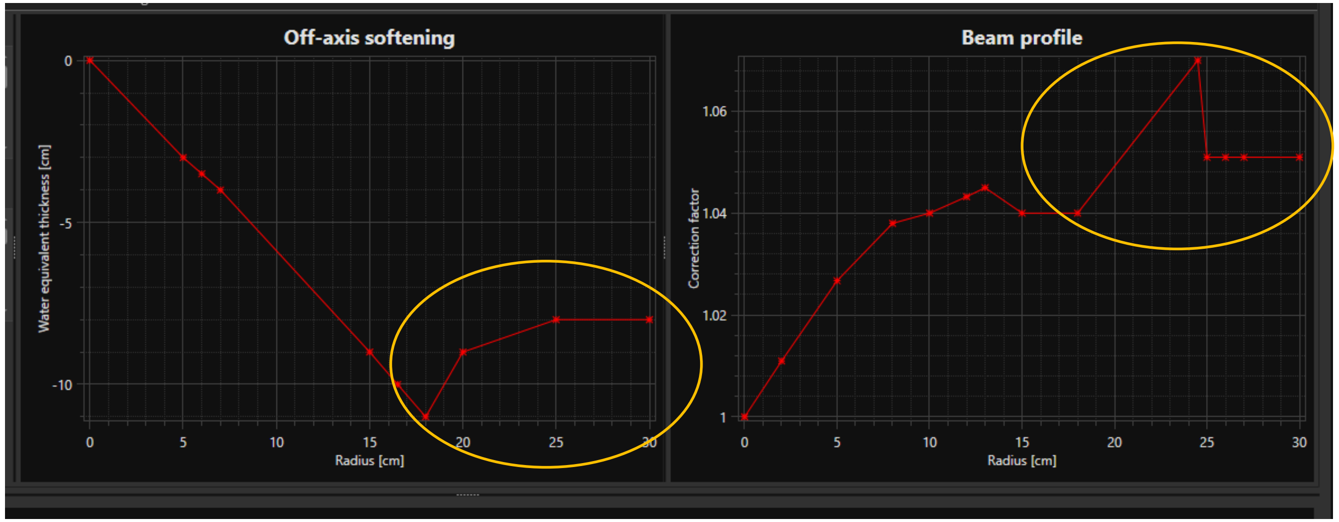
BEAM PROFILE CORRECTIONS AND OFF-AXIS SOFTENING FOR RADIUS > 20 CM

- **<u>From RayStation 8B:</u>** the auto-modeling does not change the values of OAS or BPC outside of the largest field anymore. See RayPhysics manual for details. Values are unchanged.
- **<u>From Raystation 9A</u>**: Beam Profile Corrections for radius > 20cm can be modeled in the “Beam Commissioning” tab by importing diagonal profiles of the largest field sizes at different depths



WARNING!

Beam profile correction and off-axis softening at large field radii. The photon beam model parameters *Beam profile correction* and *Off-axis softening* cannot be evaluated at large radii in the Beam commissioning module without having imported diagonal profiles which extend to the corners of the field. Special care must be taken when using auto-modeling for the *Beam profile correction* and *Off-axis softening* parameters if there are only x- and y-profile curves imported into the Beam commissioning module. Be aware that manual adjustments of these parameters at large radii will be necessary after using auto-modeling without diagonal curves. The Beam 3D modeling module can be used to check the calculated dose of the entire field, including corners, before commissioning a machine (not available for CyberKnife LINACs).

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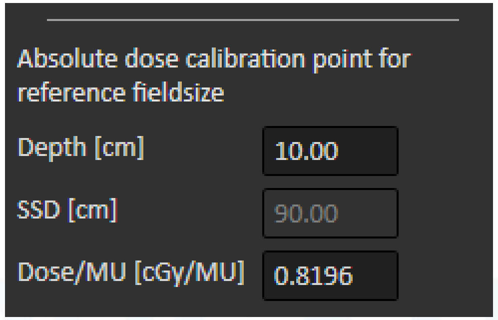
FLUENCE AND DOSE – CONTAMINATION ELECTRON SOURCES

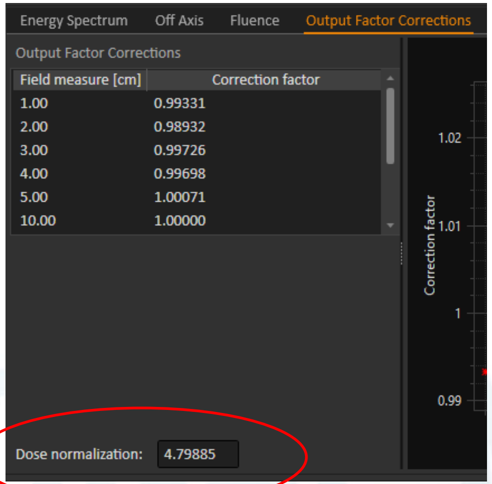
- Both projected though the collimators down to the fluence plane
- Electron contamination dose component computed separately and added to the photon dose

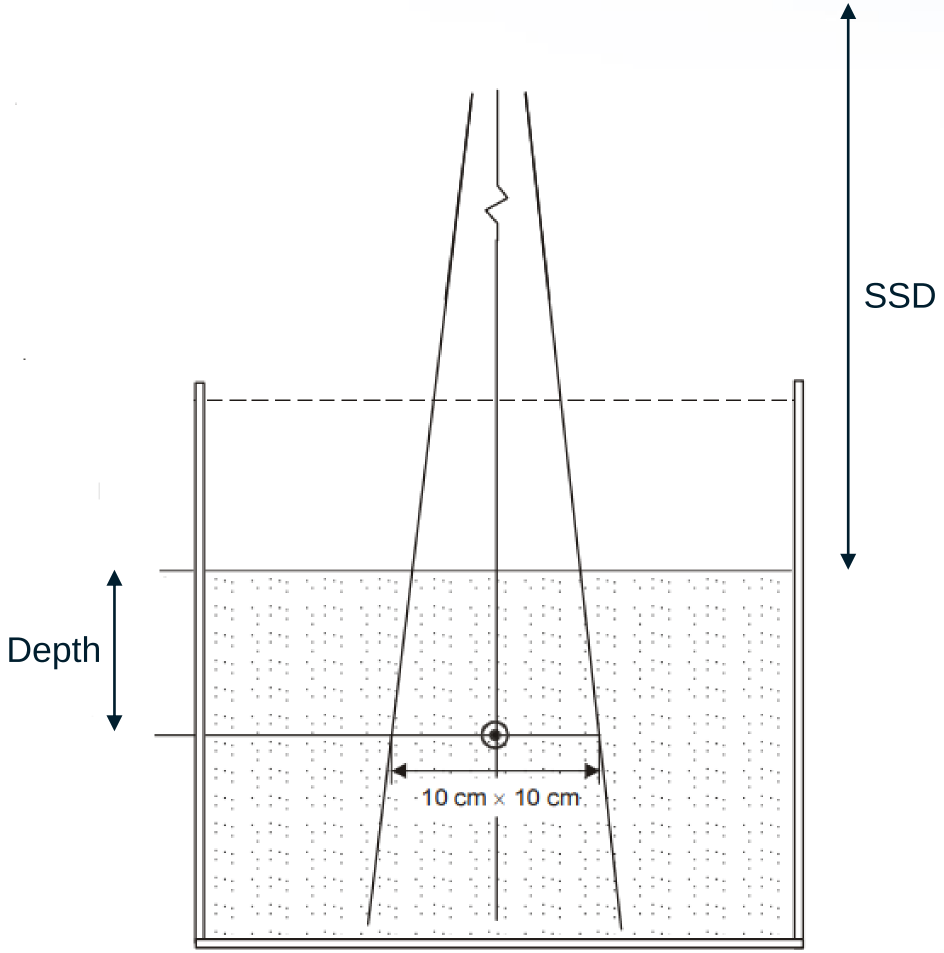
$$D(x,y,z) = D(x,y,z)_{photon} + D(x,y,z)_{contamination\ electrons}$$

DOSE NORMALIZATION

- Normalization of the measured curves refers to the dose in the Reference Point for the Reference Field Size for MU =1 → CALIBRATION DOSE
- All computed dose scaled with a computational dose normalization factor ***N*** to match the measured curves
- The relation between the calibration point dose and the normalization value depends on most of the beam model parameters.







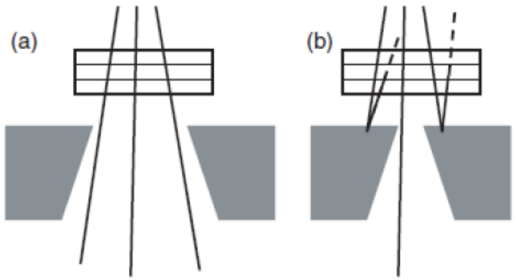
Reference Point - Adapted from IAEA TRS-398

LINAC OUTPUT FIELD SIZE DEPENDENCE

- Output factor (OF) = ratio of the dose at the reference point for the reference field size and the dose in the same point for a field size A.

$$OF = \frac{D_{FS_A}}{D_{ref}}$$

- Output factors are influenced by:
  - Phantom scatter
  - Head scatter
  - Monitor backscatter
- Smaller collimation → more backscatter → monitor chamber reaches sooner the calibration value
- → output in *cGy/MU* of a LINAC decreases while decreasing field size



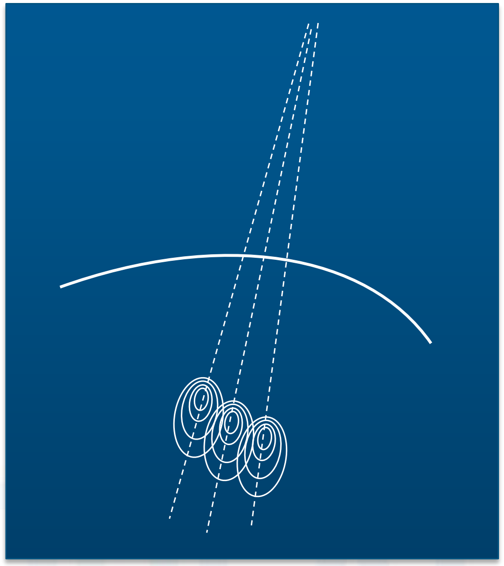
Verhaegen, Seuntjens 2003 Phys. Med. Biol. ***48***

LINAC OUTPUT FIELD SIZE DEPENDENCE

Phantom scatter

Most of the field size dependence comes from inscattering of dose.

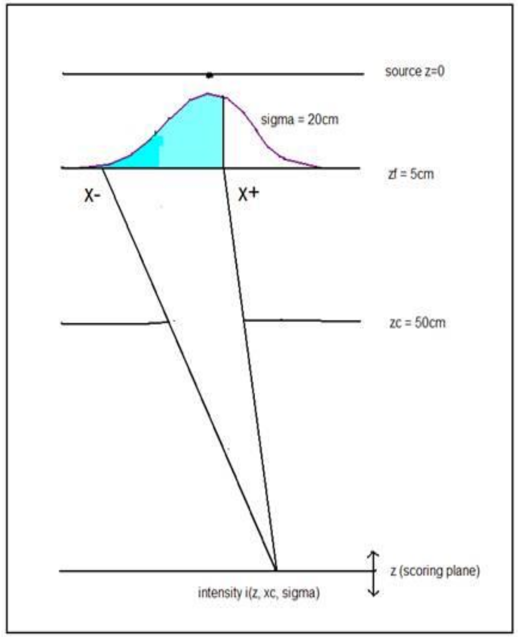
This is handled automatically by addition of point spread kernels in the CC dose engine



Head scatter

Some field size dependence comes from the projection of extended sources through the aperture.

Taken into account in the FF (and wedge) fluence projection.



Remaining FS dependence is assumed to be caused by Monitor Backscattering

This is taken into account in the model by the use of **Output Factor Corrections (*OFC*).**

The correction influences the theoretical model output and is not to be mixed up with the measured output factors which are not corrected!

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DOSE PER MU FORMALISM

- The Measured OF specify the scale of the dose measurements but they are not directly part of the dose computation. They influence the dose computation since we adjust the model parameters so that computed curves match the measured ones.

- How computed dose related to the measured calibration dose:

- Assuming that the calibration point is beyond the electron dose contamination region, we need only to take photon dose into account

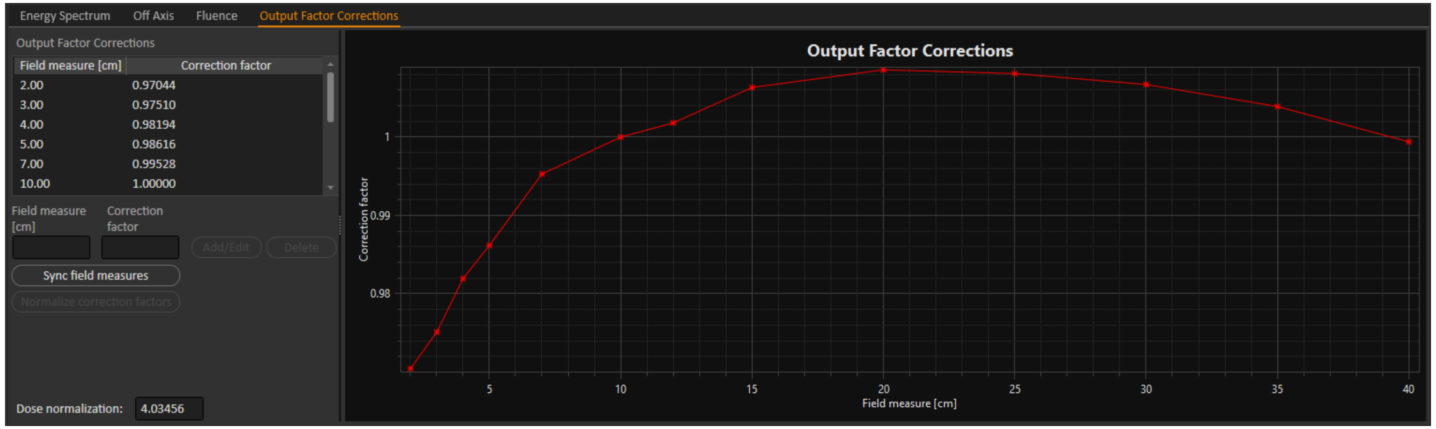
$$D(x,y,z) = MU * \frac{D_{ref}(d_{ref})_{MEAS}}{D_{ref}(d_{ref}, N=1, OFC=1)_{COMP}} * OFC\big(FM(Collimation)\big) * D(x,y,z,\Psi_{ph_{TOT}}(collimation, N=1, OFC=1, MU=1))$$

d_{ref} = reference depth

$OFC\big(FM(Collimation)\big)$ = OFC computed for the field measure of that specific collimation

D_{ref} = dose for the reference field

OFC AND FIELD MEASURE



- Field Measure (FM) is calculated from the jaw or MLC openings using an equivalent square formula
- Different FM calculations depending if the LINAC is equipped with back-up jaws or not
- FM automatically calculated in RayPhysics

- OFC → Constant extrapolation

Note: *The field measures of the output factor correction (smallest to largest) should cover the field sizes that the beam model is expected to calculate on. Extrapolation towards smaller or larger values than what is present in the table assumes a constant output factor, for smaller field the same as for the smallest field in the table, for larger fields the same as for the largest field in the table. To obtain a different behavior add extra points to the output factor correction table. Remember that auto-modeling using field measures that are smaller or larger than the measured curves is not possible. If extra field measures are added these should be verified by other measurements than the curves in beam commissioning.*

RayPhysics Manual

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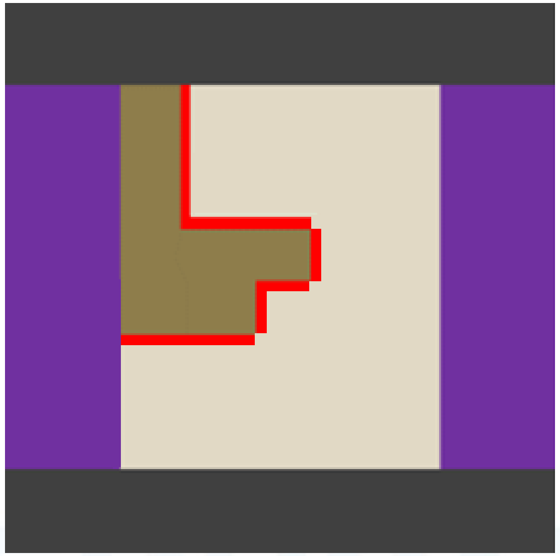
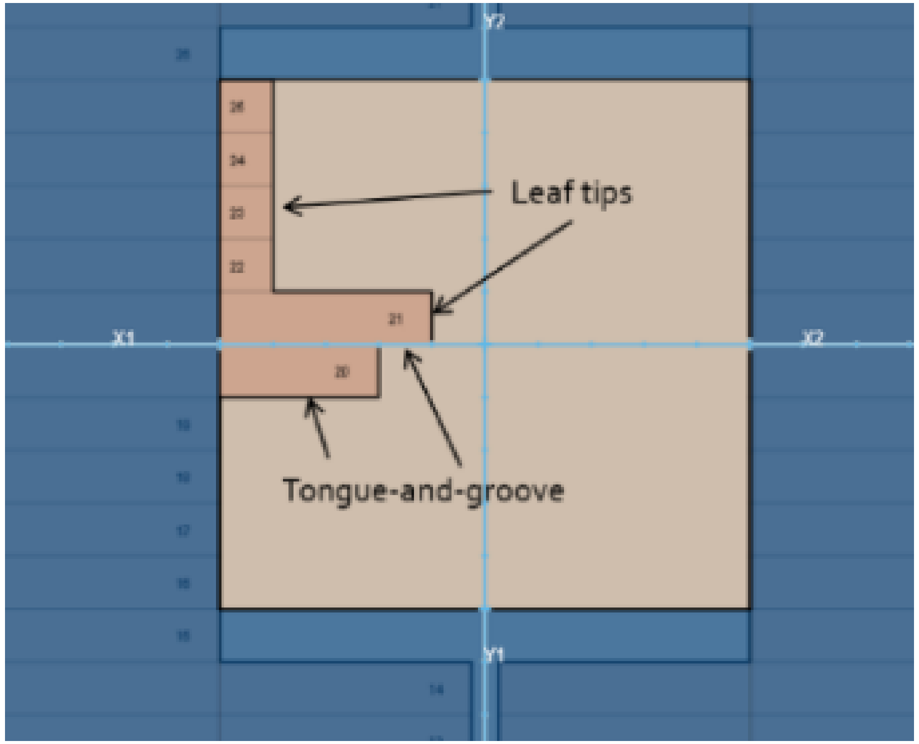
COLLIMATORS TRANSMISSION

- Open: transmission 1
- Under y-jaw: transmission 0
- Under MLC: transmission t_{MLC}
- Under MLC + x-jaw: $t_{\mathrm{MLC}} * t_{\mathrm{x\ jaw}}$
- Leaf tip or T&G: transmission $\sqrt{t_{MLC}}$

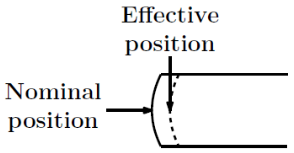




- For Dual Layer MLCs, it is possible to enter transmission for both MLCs, however, it is required that both layers have the same transmission

COLLIMATORS

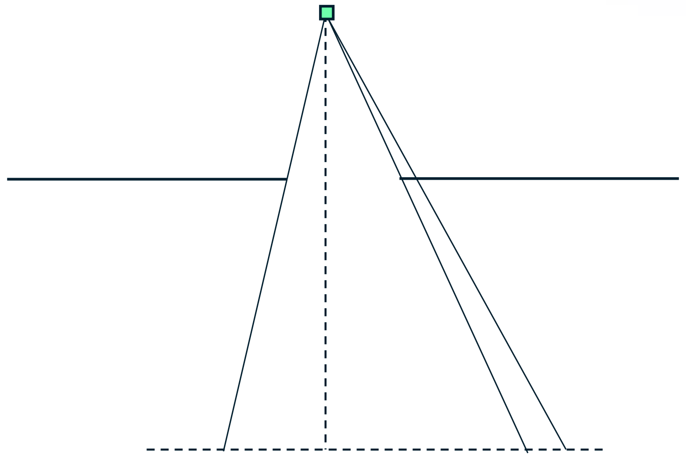
- Collimator assumed:
  - Flat
  - 2D
- Move the nominal position to correct the transmission
  - Correct 3D effect
  - Correct penumbra for the non-tilt approximation
- Both jaws and MLC leaves



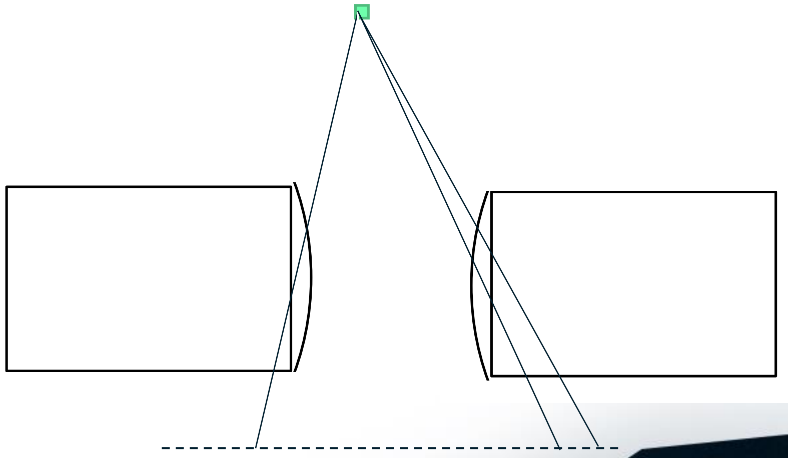
$$x_{effective} = x - offset + gain \cdot x - curvature \cdot x^2 \qquad left\ MLC\ bank$$

$$x_{effective} = x + offset + gain \cdot x + curvature \cdot x^2 \qquad right\ MLC\ bank$$

RayStation model



Reality (example)



TRANSMISSION THROUGH MLC LEAFS AND INTERLEAF LEAKAGE

- Interleaf leakage **NOT** separated from MLC leaf transmission in our model (use AVERAGE transmission).
- Measure MLC transmission using closed-leaf plans or use machine specs from manufacturer.

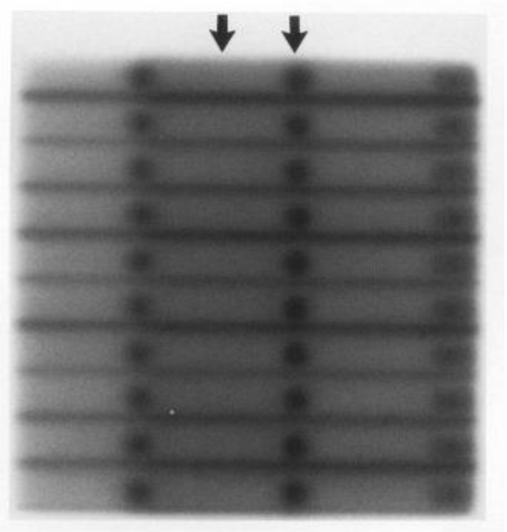
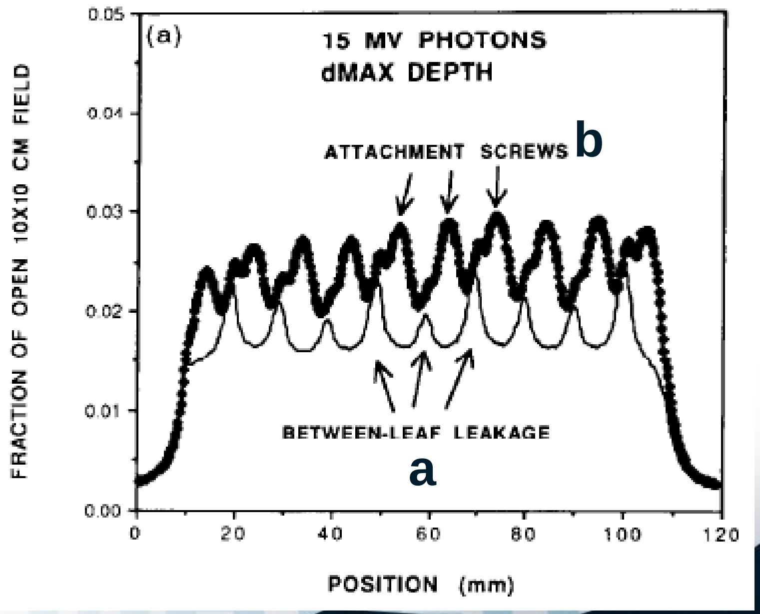


Fig. 9. Transmission radiograph of the leaves of the MLC system. The 15 MV beam was used to expose the film. Notice the position of the screws used to attach the individual leaves to the runners leading to the drive motors. The two arrows show the position of the profiles in the next two figures.

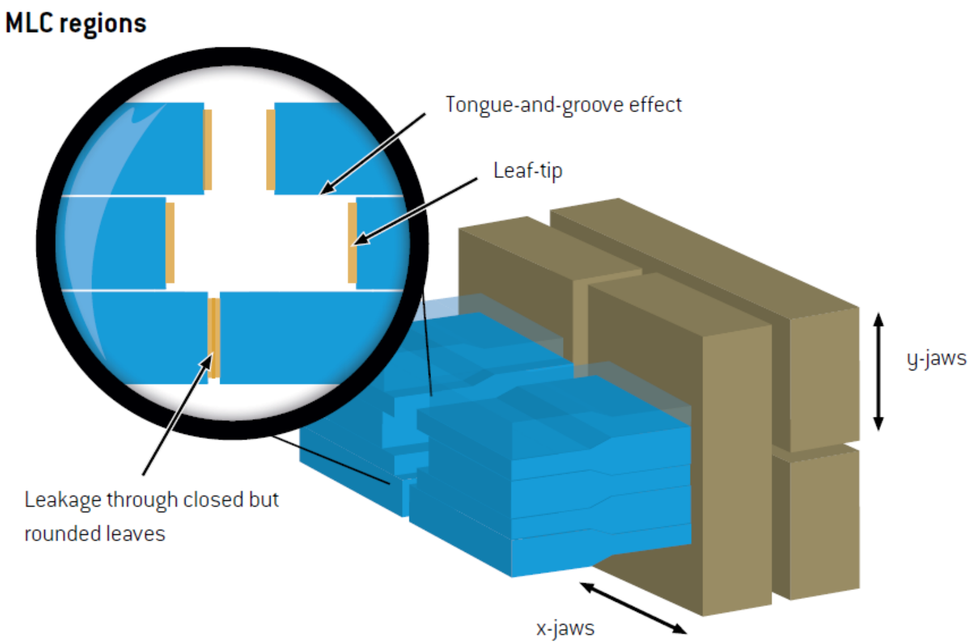
Galvin et al 1993, In. J. Radiation Oncology Biol. Phys. 55 181-192

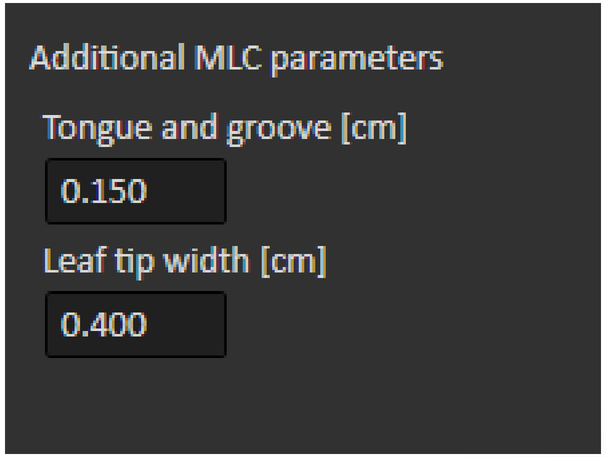
Profile across closed leaves:



MLC LEAF TIPS AND TONGUE&GROOVE

- Leaf tip and T&G
- Adjustable parameter in the beam model





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TRANSMISSION THROUGH LEAF TIPS

Radiograph of closed leaves:

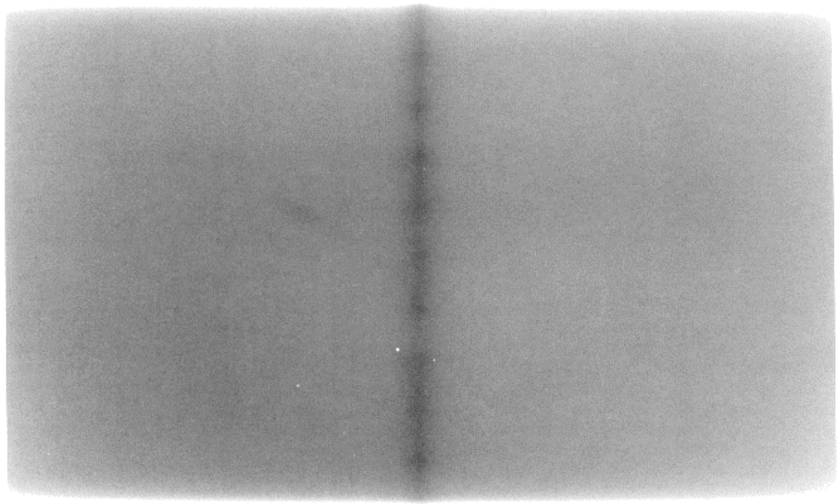
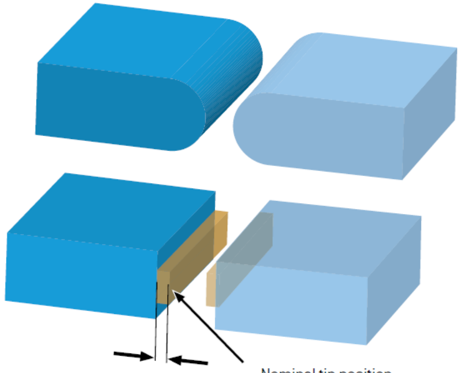
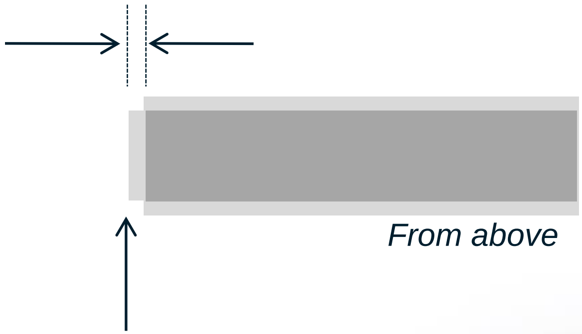


Fig. 11. Radiograph showing the high dose line that appears when a film is double exposed with the leaves abutted at the field midline. Notice also the diamond shaped pattern that results from the beveling at the front face of the leaves.

Galvin et al 1993, In. J. Radiation Oncology Biol. Phys. 55, 181-192





TRANSMISSION THROUGH LEAF TIPS

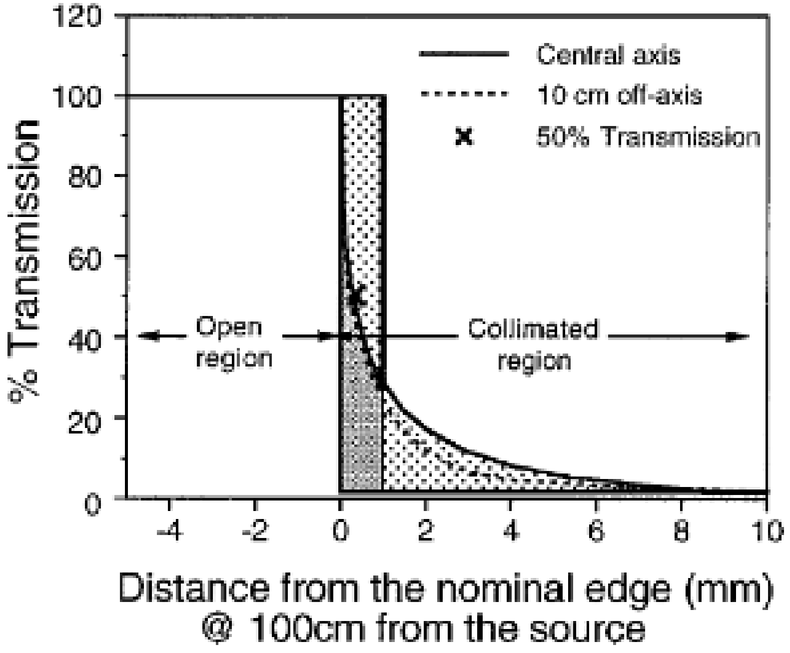
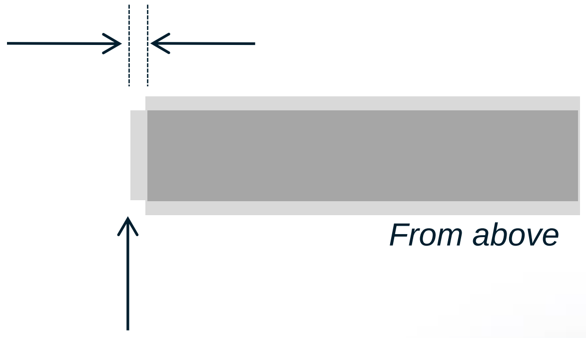


FIG. 6. Calculated primary beam transmission through the rounded leaf end. The central axis and off-axis transmissions are based upon the geometry of the leaf and the measured effective attenuation coefficient for the MLC. The area under the central axis transmission curve (less the 2% corresponding to the transmission for full leaf thickness) is equivalent to the rectangular area from 0 to 1 mm, indicating that the transmission due to the rounded leaf edges may be approximated in a dynamic treatment as an offset of the leaves by 1 mm.

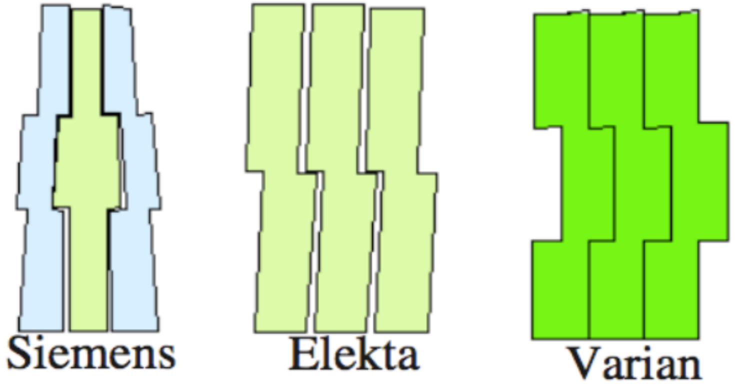
The **penumbra shape** can be modelled with the collimation position calibration (as in the left image) or combined with a low transmission part using the leaf tip width.

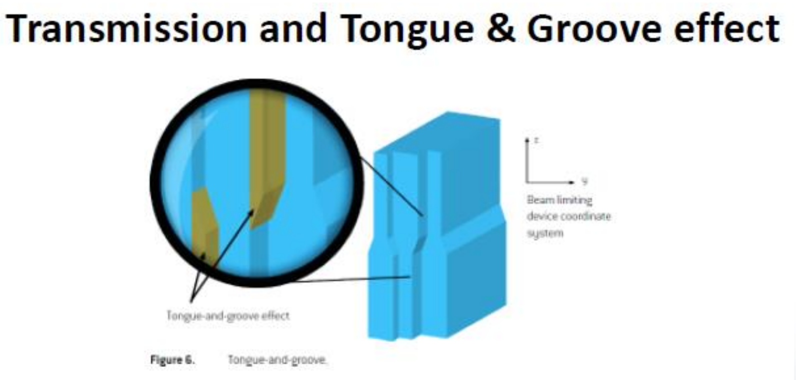
Making the leaf tip width larger should be balanced by making the offset slightly smaller to give the same integrated fluence for an IMRT field where out-of-field and penumbra regions add up to get an in-field dose.



TRANSMISSION THROUGH TONGUE-AND-GROOVE

- Centered on the leaf border
- In y-direction gain moves the nominal position to correct for reduced transmission.
- Only edge MLCs





From above

Nominal leaf-edge position

2 xTongue-and-groove width

RAYPHYSICS ENERGY FLUENCE INFLUENCING PARAMETERS

- A subset of the beam model parameters are used for Fluence calculation
  - Fluence tab parameters (sources, collimators, MLC parameters)
  - Beam profile corrections (only on primary photon fluence)
  - Output factor corrections and wedge factor corrections
  - Wedge scatter source and wedge scatter transmission

Energy Spectrum | Off Axis | Fluence | Output Factor Corrections | Elekta Motorized Wedge | Wedge Factor Corrections

Sources

Source	Eff. dist. to source [cm]	X width [cm]	Y width [cm]	Weight
Primary	-	0.125	0.090	-
Flattening filter	15.00	1.408	-	0.05245
Electrons	-	3.744	-	0.00479

Weight of flattening filter electron source: 0.100

Collimator position

Collimator	Eff. dist. to source [cm]	Transmission
Y-jaws	50.90	-
MLC	40.20	0.00500

Collimator calibration

Collimator	Offset [cm]	Gain	Curvature [1/cm]
Y-jaws	-0.010	-0.0020	0.00000
MLC x-position	0.010	-0.0030	0.00000
MLC y-position	-	0.0000	-

Additional MLC parameters

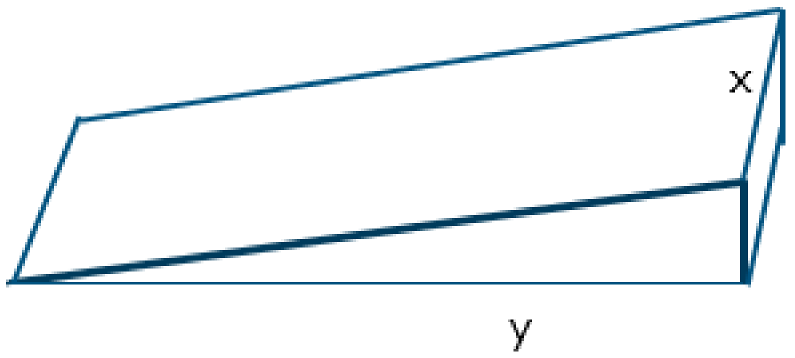
Tongue and groove [cm]: 0.050

Leaf tip width [cm]: 0.100

TRANSMISSION THROUGH WEDGES

- Transmission depends on wedge type
- **Virtual wedges:** Transmission determined by jaw transmission and motion. Fluence scaled by open time and depends on jaw offset, gain, curvature

- **Physical wedges (standard or motorized):** Transmission variations in both x and y is taken into account.
  - For standard wedges, transmission determined in discrete points at iso-center plane and by interpolation between these.
  - For Elekta motorized, transmission is parameterized.



VIRTUAL WEDGES

SIEMENS VIRTUAL WEDGE

$$MU_E(y) = MU_{cax} \cdot e^{-c \cdot \mu(E) \cdot y \cdot \tan(\alpha)}$$

WARNING!

Siemens virtual wedge. The Siemens virtual wedge parameters mean linear attenuation and calibration shall be adjusted from the default values to the proper values for your LINAC. Failure to do so may lead to error in the computed clinical dose.

[3180]

- Normalized to central axis
- Jaw calibration parameters (offset, gain and curvature) are taken into account
- MU_{cax} = MU on the central axis
- α = wedge angle at 10 cm depth
- c = calibration factor per beam quality
- μ(E) = mean linear attenuation factor per beam quality
- Wedge Output Factors should be close to 1
- Wedge curves import is optional but recommended before commissioning

Parameters from the machine vendor

VIRTUAL WEDGES

VARIAN ENHANCED DYNAMIC

$$Fluence\ scaling(y) = a - b \cdot \tan(\theta)[1 - c \cdot y - e^{d \cdot y}]$$

- *a, b, c, d* extracted from the "Golden segmented treatment table (GSTT)" (MU vs jaw position)
- Jaw calibration parameters (offset, gain and curvature) are taken into account
- Normalized to the toe side
- Y is positive on the toe side and negative on the heel side
- θ = wedge angle
- Parameters **NOT** adjustable in Beam Commissioning
- Wedge Factor Corrections are the only modelling parameters → They must be verified
- Supported **only** for 4, 6, 10, 15, 18, 20 MV
- Wedge curves import is optional but recommended before commissioning

THANK YOU!

RaySearch Laboratories