ADVANCING
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TREATMENT

PHOTON BEAM COMMISSIONING - MEASUREMENTS

RayStation 11B

RaySearch Laboratories

CONTENTS

- Introduction to Photon Beam Commissioning
- Measurements

INTRODUCTION TO PHOTON BEAM COMMISSIONING

BEAM COMMISSIONING WORKFLOW

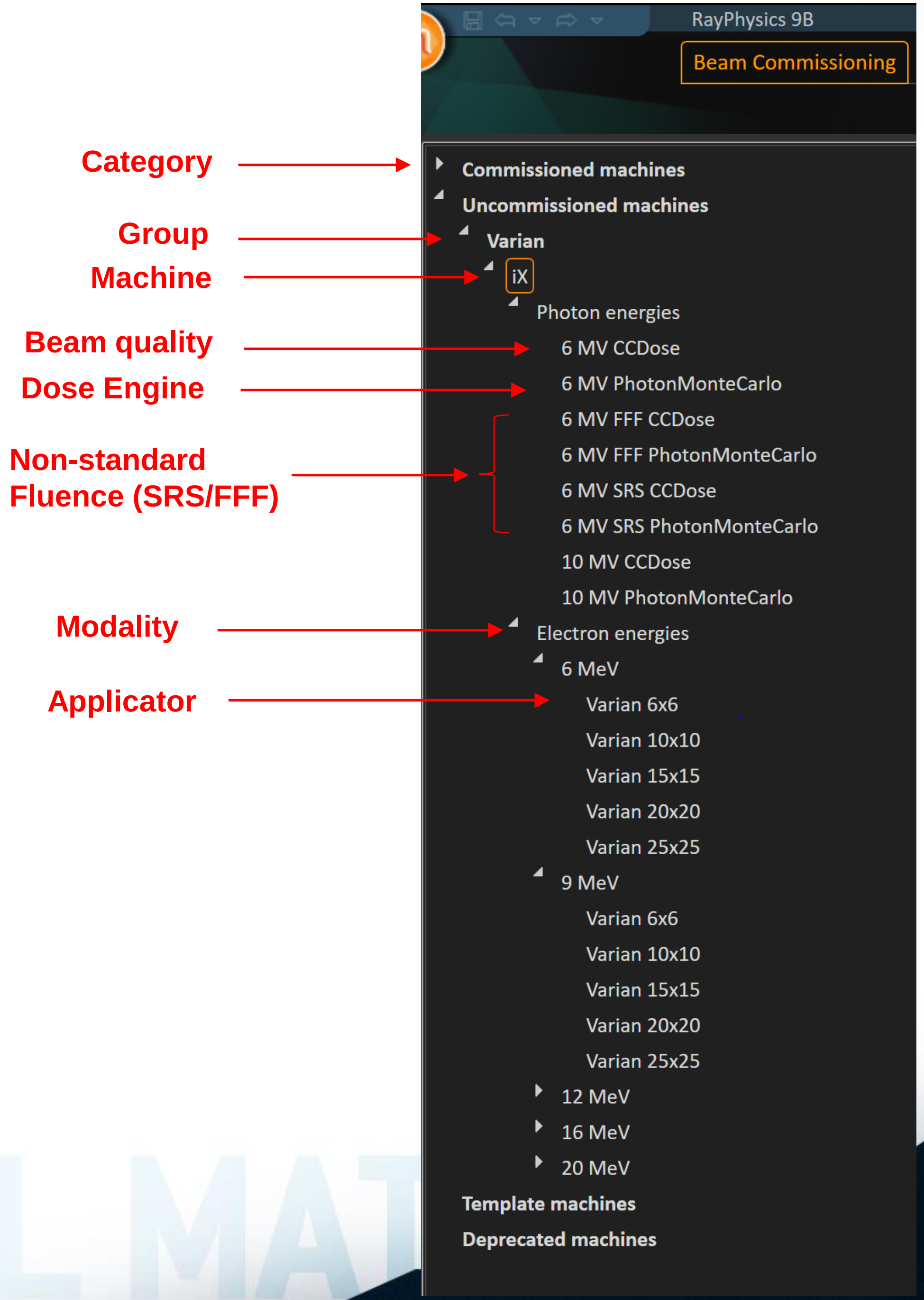
1. **Copy a machine** — A similar machine, MLC, manufacturer.
2. **Remove dose curves (if present)** — Dose curves must be from your machine.
3. **Change machine geometry and constraints** — To LINAC specifications.
4. **Import measured data** — If there are problems – contact support.
5. **Work on beam model until computed match measured** — Manual and automodeling. Requires thinking and knowledge.
6. **Commission the machine** — Review by physicist at clinic.
7. **Machine model available for planning and dose computation** — 3D-validation of more complicated fields

MACHINE TREE VIEW

4 categories:

- ***Commissioned***
- ***Uncommissioned***
- ***Template***
- ***Deprecated***

- A machine must be commissioned to be available for treatment planning in RayStation!
- Templates are only suggestions, always verify all properties
- Name maximum 16 characters (DICOM)
- Unique names, unique commissioning date
- Groups (uncommissioned only)
- Each machine must have at least 1 photon beam quality. Electron beam quality optional.



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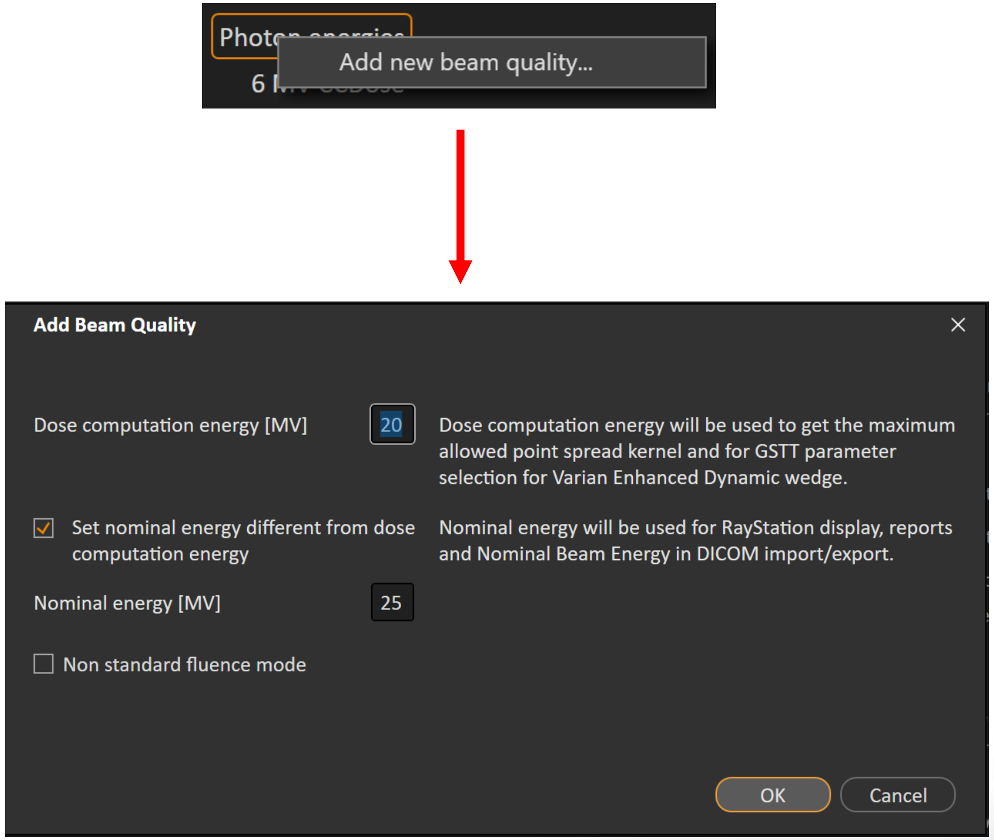
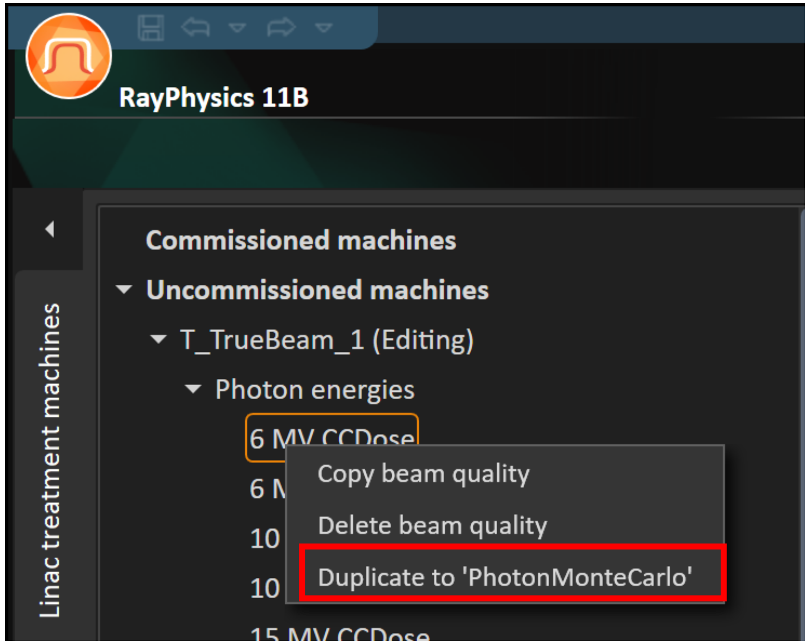
PHOTON BEAM QUALITY – NOMINAL ENERGY

- Nominal energy will be displayed in RayStation user interface, used in reports and as DICOM nominal beam energy in both DICOM import and export
  - Nominal energies between 4MV and 25MV are supported
- Dose computation energy used to get maximum allowed energy bins in photon energy spectrum
  - Dose computation energies between 4MV and 20MV are supported



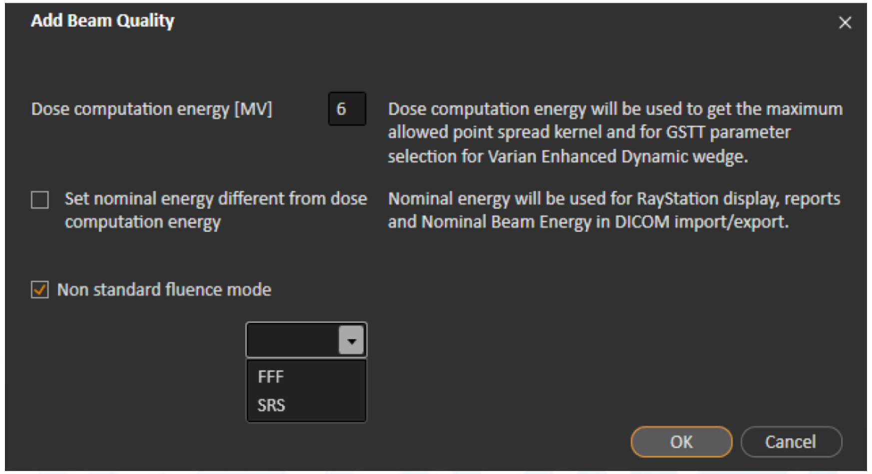
PHOTON BEAM QUALITY – DOSE ENGINE

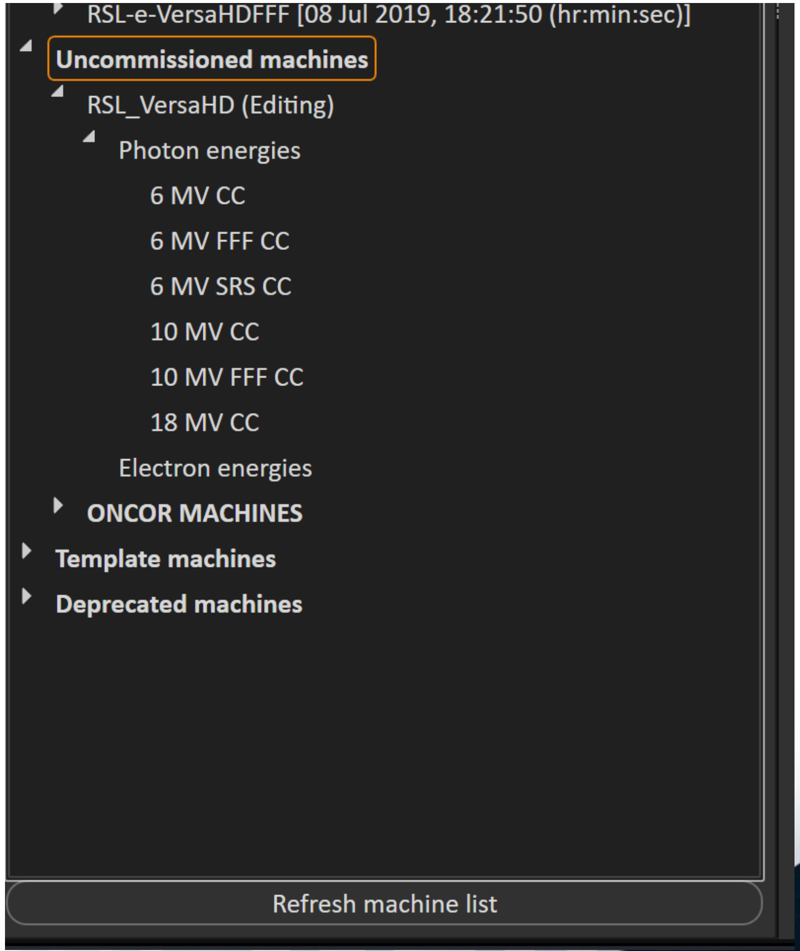
- It is possible to commission machines with both Collapsed Cone and Photon Monte Carlo dose engines in the same model.
- If one beam model exists, the beam quality will be duplicated to the dose engine that does not already exist on the beam quality
  - Right click on the beam quality for an uncommissioned machine
  - To remove either dose engine, right click on the beam quality and select Remove CCDose or Remove PhotonMonteCarlo



PHOTON BEAM QUALITY – NON-STANDARD FLUENCE MODE

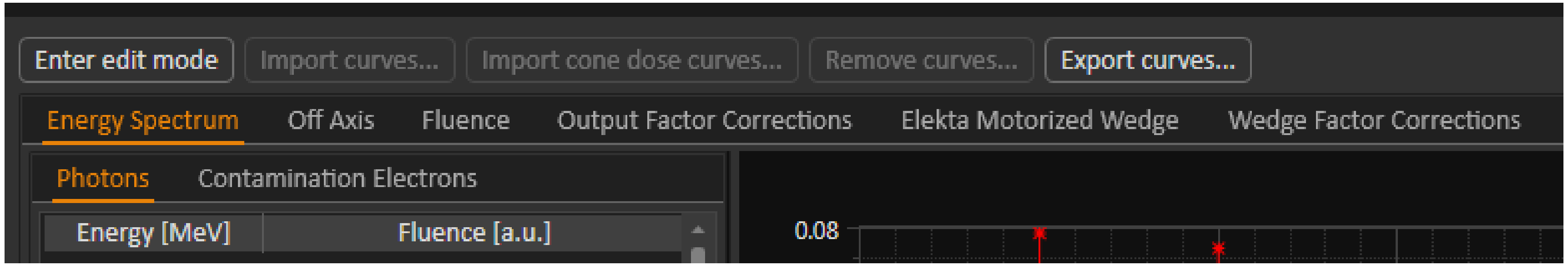
- It is possible to select a beam quality with non-standard fluence modes
  - Flattening Filter Free (FFF)
  - Stereotactic Radiosurgery (SRS)
- This ensures that during DICOM export, information about non-standard fluence mode is included in RTPlan.



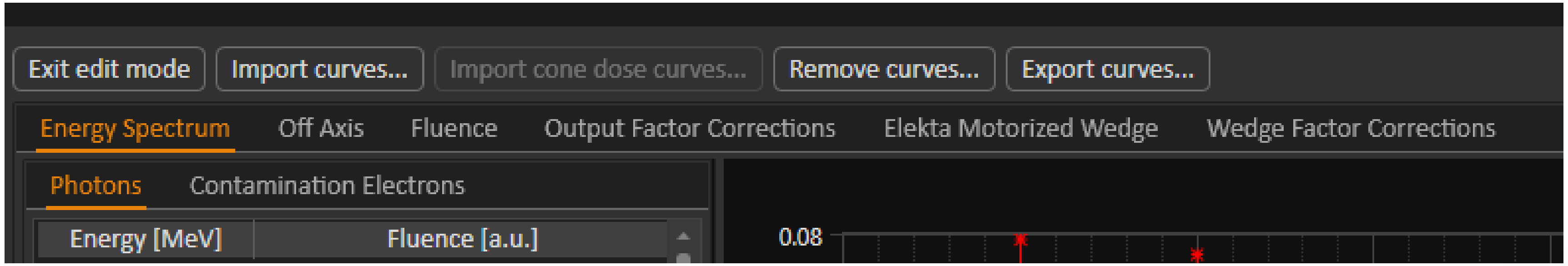


EDIT MODE AND CURVE IMPORT & EXPORT

- Edit Mode and Curve Import & Export



- Measured curves can be imported, removed and exported.
- Computed curves can be exported (.csv format)



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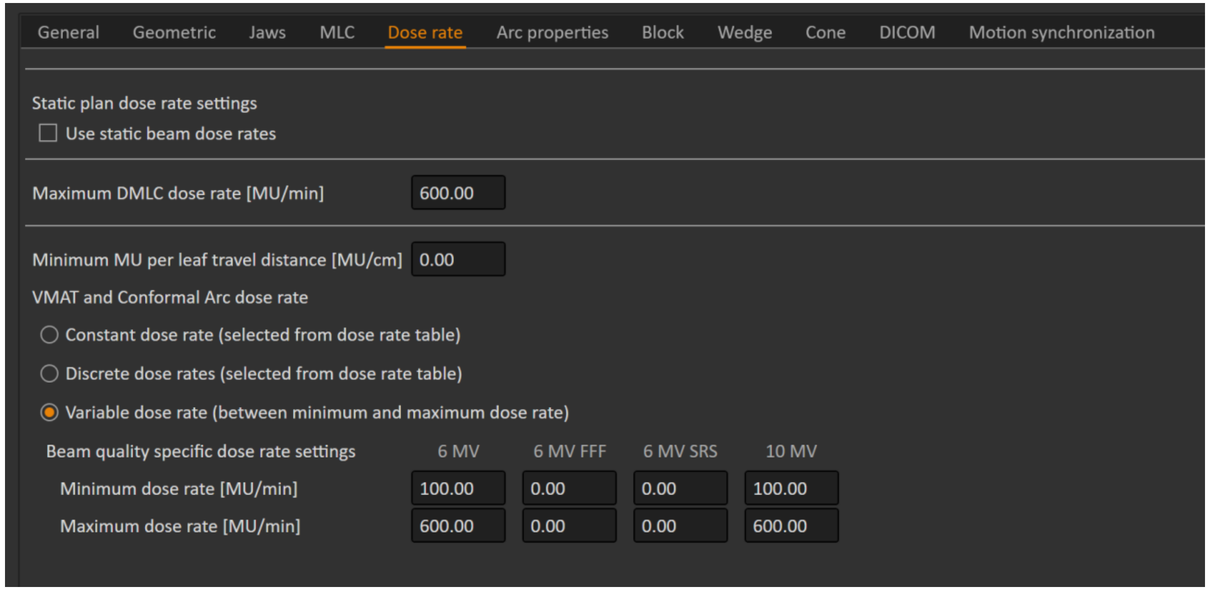
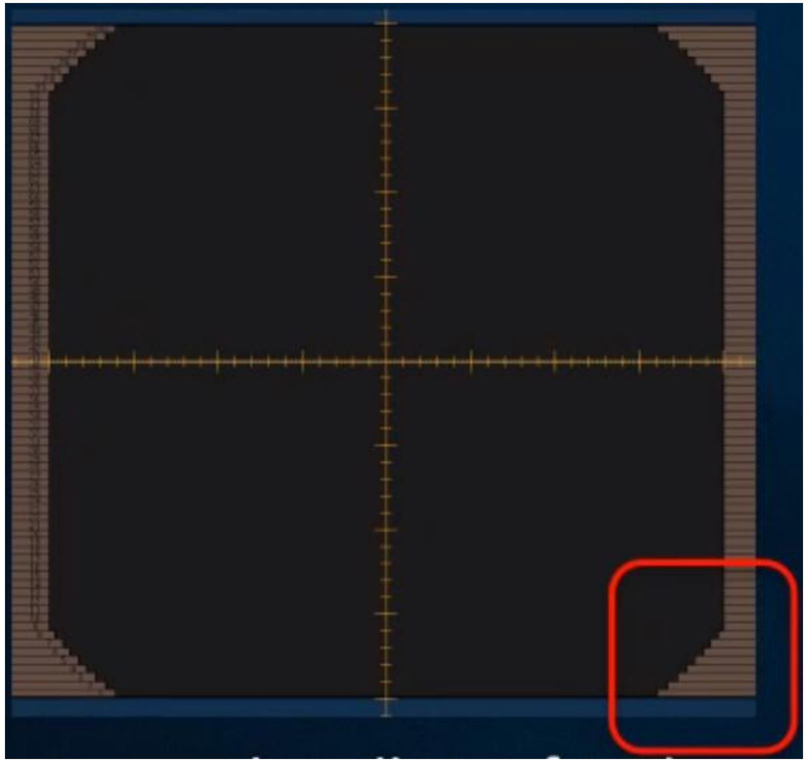
MACHINE GEOMETRY AND CONSTRAINTS

- Machine-specific tabs
- Enter values from LINAC-specifications.
- Constraints can be hard physical limits, recommended limits in LINAC or R&V (Record and Verify system), or limits with a margin to be sure to have deliverability.
- Some influence dose curve computation (SAD, MLC geometry)
- Some are used to create deliverable plans (motion properties).
- Some properties are per energy level.
- Enable and configure support for export of motion synchronization techniques
  - This setting is now done per machine in RayPhysics and no longer in Clinic Settings



MIN/MAX TIP POSITION PER MLC LEAF



	Leaf center position [cm]	Width [cm]	Minimum tip position [cm]	Maximum tip position [cm]
1	-19.75000	0.5000	-15.00	16.10
2	-19.25000	0.5000	-15.00	16.70
3	-18.75000	0.5000	-15.00	17.30
4	-18.25000	0.5000	-15.00	17.80
5	-17.75000	0.5000	-15.00	18.30
6	-17.25000	0.5000	-15.00	18.80
7	-16.75000	0.5000	-15.00	19.20
8	-16.25000	0.5000	-15.00	19.70
9	-15.75000	0.5000	-15.00	20.00
10	-15.25000	0.5000	-15.00	20.00
11	-14.75000	0.5000	-15.00	20.00

- Correct handling of Agility corners

MIN/MAX MU FOR WEDGED BEAMS

- Possible to define minimum and maximum MU allowed for beams that use wedges
- Specified per wedge

Beam quality 6 MV | Beam quality 10 MV

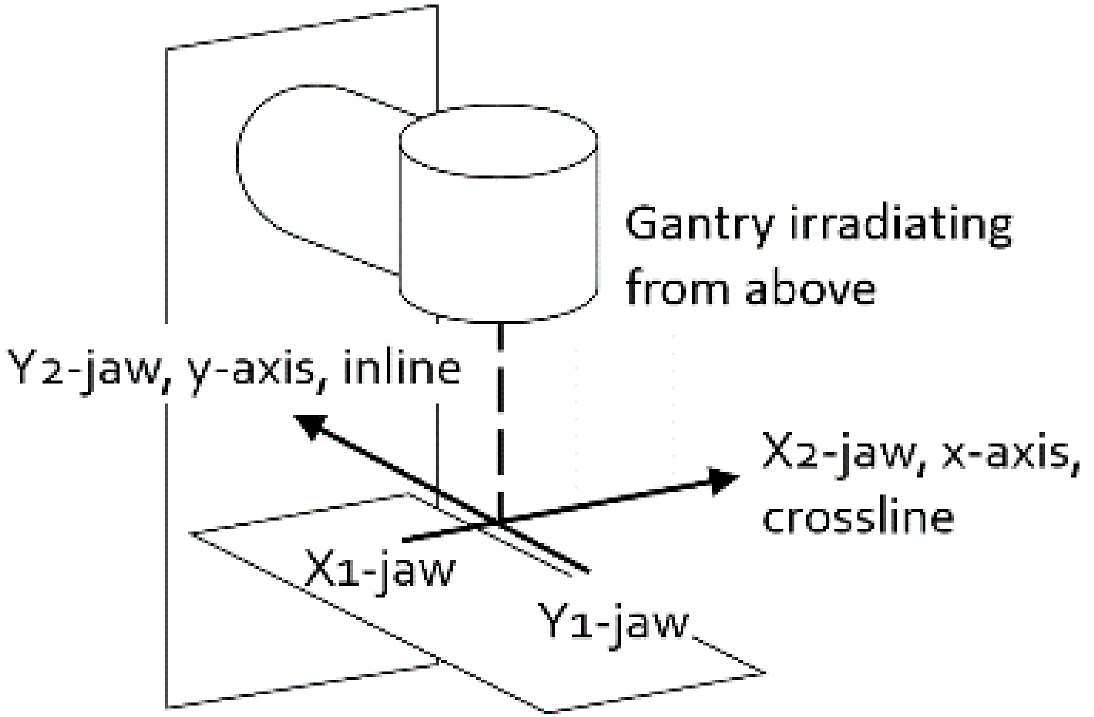
Angle [deg]	Wedges 0°	Wedge ID	180°	Wedge ID	Field size limits [cm] Min X	Max X	Min Y	Max	Min MU	Max MU
10	☑	EDW10IN	☑	EDW10OUT	-20.00	20.00	-15.00	15.00	0.00	-
15	☑	EDW15IN	☑	EDW15OUT	-20.00	20.00	-15.00	15.00	0.00	-
20	☑	EDW20IN	☑	EDW20OUT	-20.00	20.00	-15.00	15.00	0.00	-
25	☑	EDW25IN	☑	EDW25OUT	-20.00	20.00	-15.00	15.00	0.00	-
30	☑	EDW30IN	☑	EDW30OUT	-20.00	20.00	-15.00	15.00	0.00	-
45	☑	EDW45IN	☑	EDW45OUT	-20.00	20.00	-15.00	15.00	0.00	-
60	☑	EDW60IN	☑	EDW60OUT	-20.00	20.00	-15.00	15.00	0.00	-

- The functionality is mainly intended for Siemens Virtual Wedge and Varian Enhanced Dynamic Wedges, but it is possible to define minimum and maximum MU for all wedge types. For Elekta motorized wedge, the minimum/maximum MU will apply to the total MU per fraction and not the wedge in MU

COORDINATE SYSTEM INTERDEPENDENCIES

- Beam model parameter coordinate system (in RayPhysics, IEC-61217) is independent of coordinate system chosen for the machine

- Properties in the machine constraints tabs are affected by the choice of coordinate system for the machine



MEASUREMENTS

GENERAL MEASUREMENT INSTRUCTIONS

- Measure open or wedged fields (one wedge orientation)
- With flattening filter or flattening filter free
- Use water tank
- ***<u>Same SSD for all measurements!</u>***

- **Required data:**
- Depth dose curves on CAX
- Profiles in X, Y and diagonal
- Absolute dose calibration
- Output factors and Wedge output factors*

- Details in *Beam commissioning data specification* and *RayPhysics Manual*

** N.B.: Wedge output factors definition is different from other TPS*
- See the following for further explanation -

CROSSLINE & INLINE PROFILES

- Profiles must have corresponding PDD to allow import
- Profiles at several depths, e.g. D_{max} or d_{ref}, 5 cm, 10 cm and 20 cm.
- Cover clinically relevant fields (Reference field size must be included, 10x10 or close, if 10x10 cannot be used.)
- Field requirements for profiles:
  - Rectangular
  - Centered (by < 1 cm)
  - Crossline (x) or Inline (y)

Generally [cm]

2x2

3x3

5x5

5x20

10x10

15x15

20x5

20x20

30x30

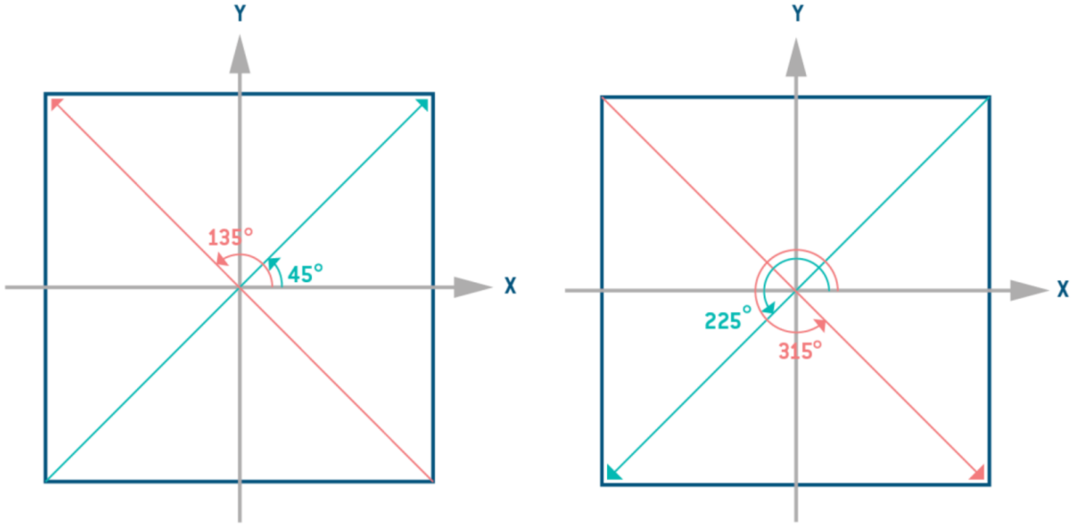
40x40

DIAGONAL PROFILES

- It is strongly recommended to import at least one diagonal profile for the largest supported field size to correctly model the corners
- Profiles at several depths can be imported, recommended to use a depth well below build-up region
- Place the phantom so that a scan can be made all the way past the corner along a diagonal
- Profiles may have an arbitrary angle
  - Not possible to import diagonal profiles in *.xmcdat format
  - Only diagonal profiles that cross the CAX are supported
- Detailed information on the import of diagonal profiles for the different dose curve formats can be found in the RayPhysics manual Appendix B – Dose Curve Format

DIAGONAL PROFILES - .CSV FORMAT

- The orientation of a diagonal curve is given by DiagonalAngle tag, which can have angles between 0° and 360°. The diagonal angle is defined according to:



Example: Diagonal profile with diagonal angle 45 degrees

```
energy[MV]:; 6
SSD[mm]:; 1000
Fieldsize[mm]:; -200; -200; -200; -200;
CurveType:; Diagonal
RadiationType:; Photon
DiagonalAngle[deg]:; 45
Quantity:; RelativeDose
StartPoint[mm]:; -14.48; -14.48; 15
-20.48; 3.3209
-17.92; 3.3196
-15.36; 3.3031
-12.80; 3.2959
```

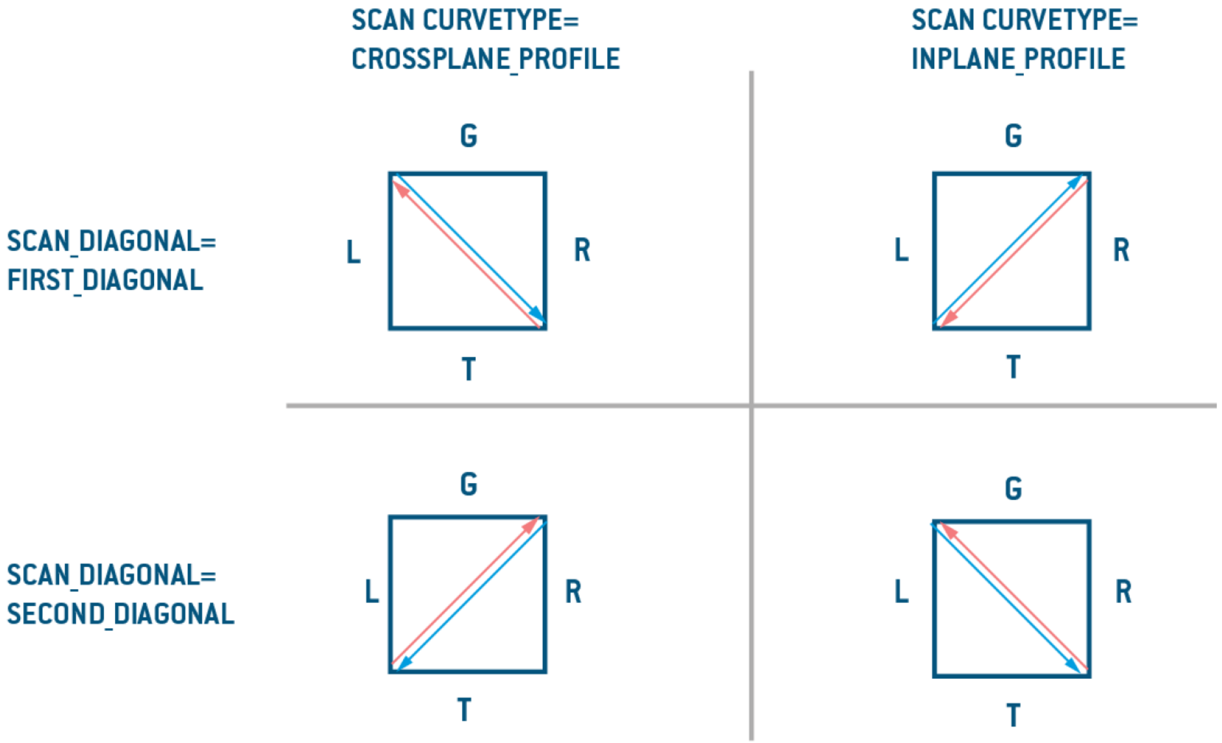
DIAGONAL PROFILES - .MCC FORMAT

- There are two ways to define diagonal profiles:
  1. SCAN_DIAGONAL=FIRST_DIAGONAL or SECOND_DIAGONAL and SCAN_ANGLE=0
  2. SCAN_DIAGONAL=NOT_DIAGONAL and SCAN_ANGLE is non zero

DIAGONAL PROFILES - .MCC FORMAT

Diagonal profiles with SCAN_ANGLE=0

Different directions that the measuring positions are stored in are shown by the arrow directions for the different combinations.



CROSSPLANE_AXIS_DIR=LEFT_RIGHT ("normal")
CROSSPLANE_AXIS_DIR=RIGHT_LEFT ("inverse")

INPLANE_AXIS_DIR=TARGET_GUN ("normal")
INPLANE_AXIS_DIR=GUN_TARGET ("inverse")

SCAN_CURVETYPE=CROSSPLANE_PROFILE,
SCAN_DIAGONAL=FIRST_DIAGONAL,
CROSSPLANE_AXIS_DIR=LEFT_RIGHT.

$$x = y = \frac{radius}{\sqrt{2}}$$

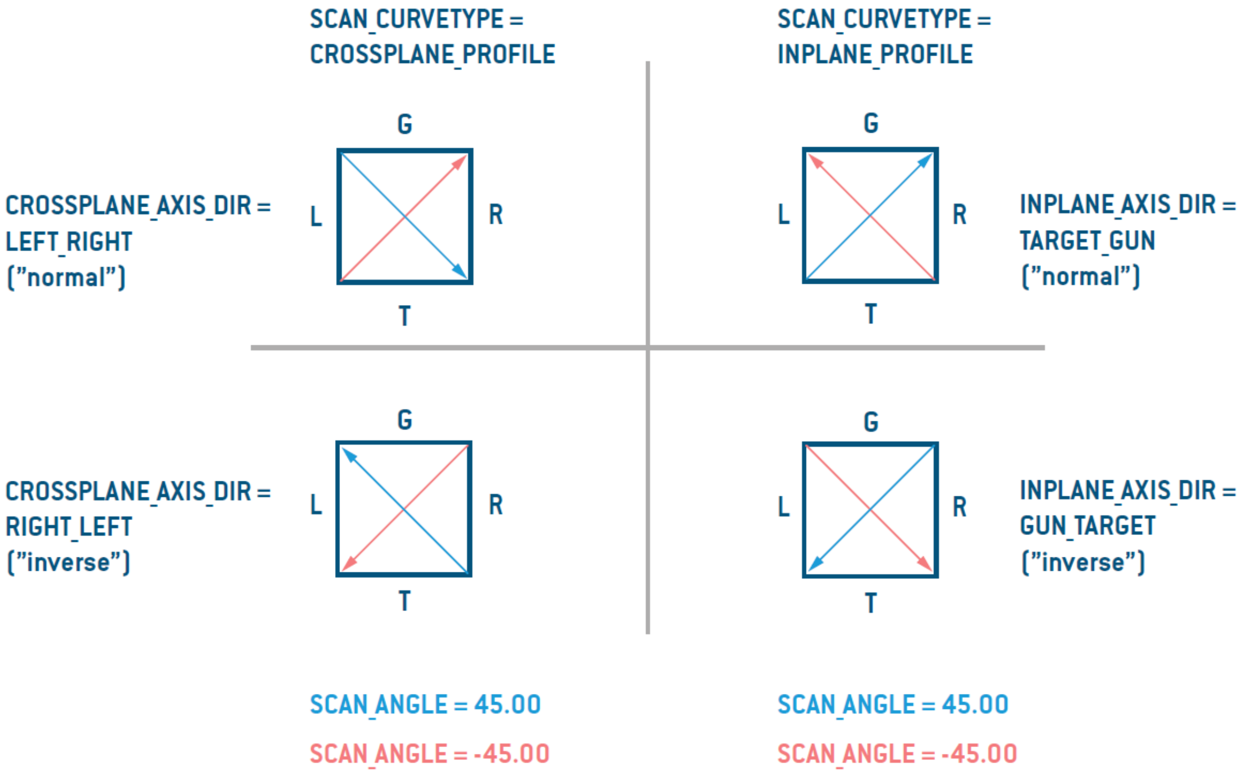
Measuring position/radius	RayPhysics x-coordinate	RayPhysics y-coordinate
-10.0	-7.07	7.07
-5.0	-3.54	3.54
0.0	0.0	0.0
2.0	1.41	-1.41
4.0	2.83	-2.83
8.0	5.66	-5.66

- Note that CROSSPLANE_AXIS_DIR only is relevant for SCAN_CURVETYPE = CROSSPLANE_PROFILE

DIAGONAL PROFILES - .MCC FORMAT

Diagonal profiles with SCAN_ANGLE=non-zero

The description “normal” refers to an axis direction that follows the positive x- and y-axes of the dose curve coordinate system



SCAN_CURVETYPE=CROSSPLANE_PROFILE,

SCAN_ANGLE=30.00,

CROSSPLANE_AXIS_DIR=LEFT_RIGHT.

$$x = radius \times \cos\theta$$

$$y = radius \times \sin\theta$$

Measuring position/radius	RayPhysics x-coordinate	RayPhysics y-coordinate
-10.0	-8.66	5.0
-5.0	-4.33	2.5
0.0	0.0	0.0
2.0	1.73	-1.0
4.0	3.46	-2.0
8.0	6.93	-4.0

- Note that CROSSPLANE_AXIS_DIR only is relevant for SCAN_CURVETYPE = CROSSPLANE_PROFILE

For a measurement to be accepted as a diagonal profile, coordinates have to change along both x- and y-axes.

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DIAGONAL PROFILES - .SNC FORMAT

- Scan Type: Profile at Angle is only supported for photons
- Diagonal profiles must cross CAX

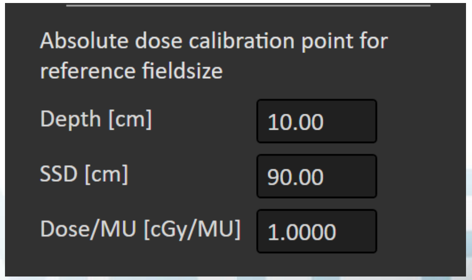
Summary Scan Type	Type of scan (Inline, Crossline, Depth Scan, Profile at Angle, Point Measurement, Point to Point, Ray Trace)

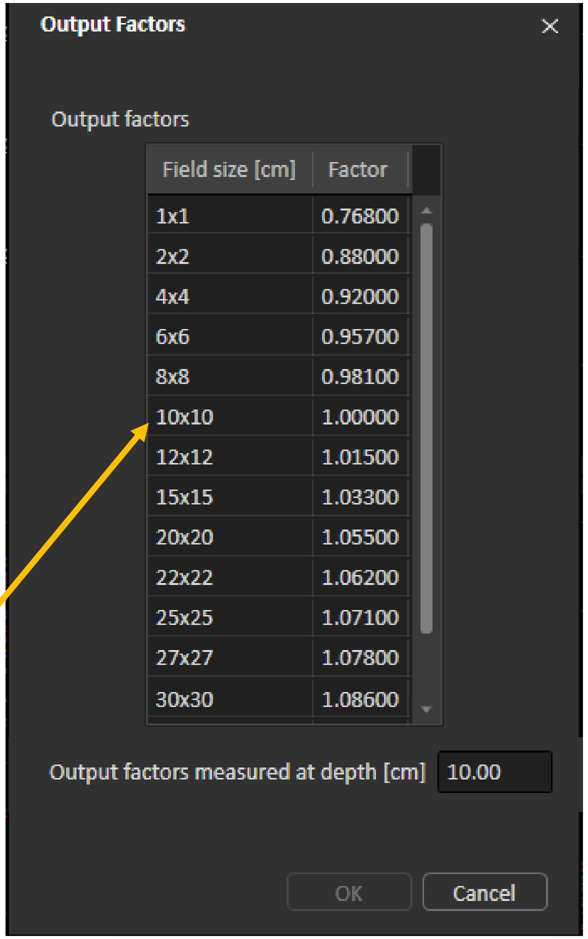
ARBITRARY FIELDS

- Arbitrary fields may be useful to help model parameters such as MLC parameters, which are difficult to see the effect of with only rectangular fields
- Supported for 3D-CRT, SMLC and DMLC photon beams, with gantry/couch angles 0°
  - Blocks, wedge or cones not supported
- Possible to import profile curves without corresponding depth dose curves
- All dose curves belonging to a specific arbitrary field must be measured with the same SSD
  - SSD not required to match the SSD of rectangular fields
  - Dose curves belonging to different arbitrary fields can have different SSDs
- More information on importing and modeling with arbitrary fields can be found in the MLC modeling presentation.

ABSOLUTE DOSE CALIBRATION

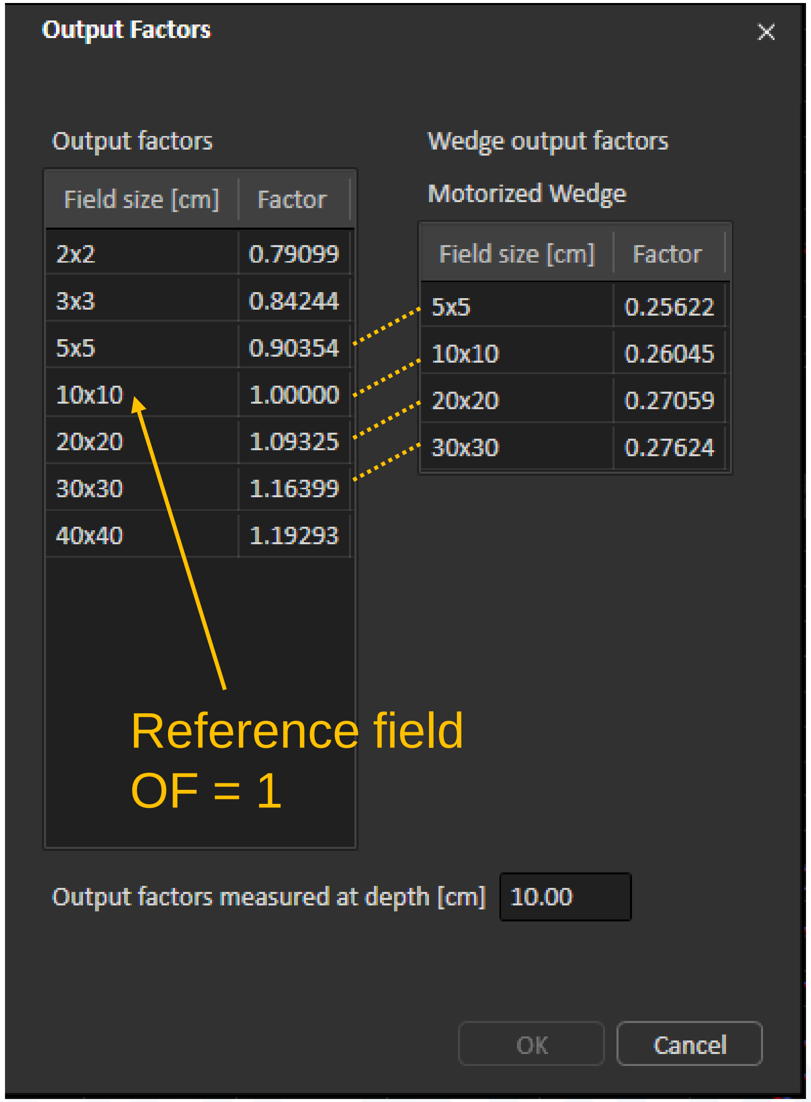
- Measured at reference point for the reference field size
  - Using same SSD
  - Recommended to measure absolute dose for calibration below electron contamination (at 5 cm – 10 cm depth)
- Measured dose curves give relative doses
- Absolute dose calibration needed for reference field size
- Depth dose curve for reference field size normalized in absolute dose calibration point.
- Depth dose curves for other field sizes normalized using output factors and wedge output factors.
- Profiles normalized with the depth dose curve.





Field size [cm]	Factor
1x1	0.76800
2x2	0.88000
4x4	0.92000
6x6	0.95700
8x8	0.98100
10x10	1.00000
12x12	1.01500
15x15	1.03300
20x20	1.05500
22x22	1.06200
25x25	1.07100
27x27	1.07800
30x30	1.08600

OUTPUT FACTORS AND WEDGE OUTPUT FACTORS

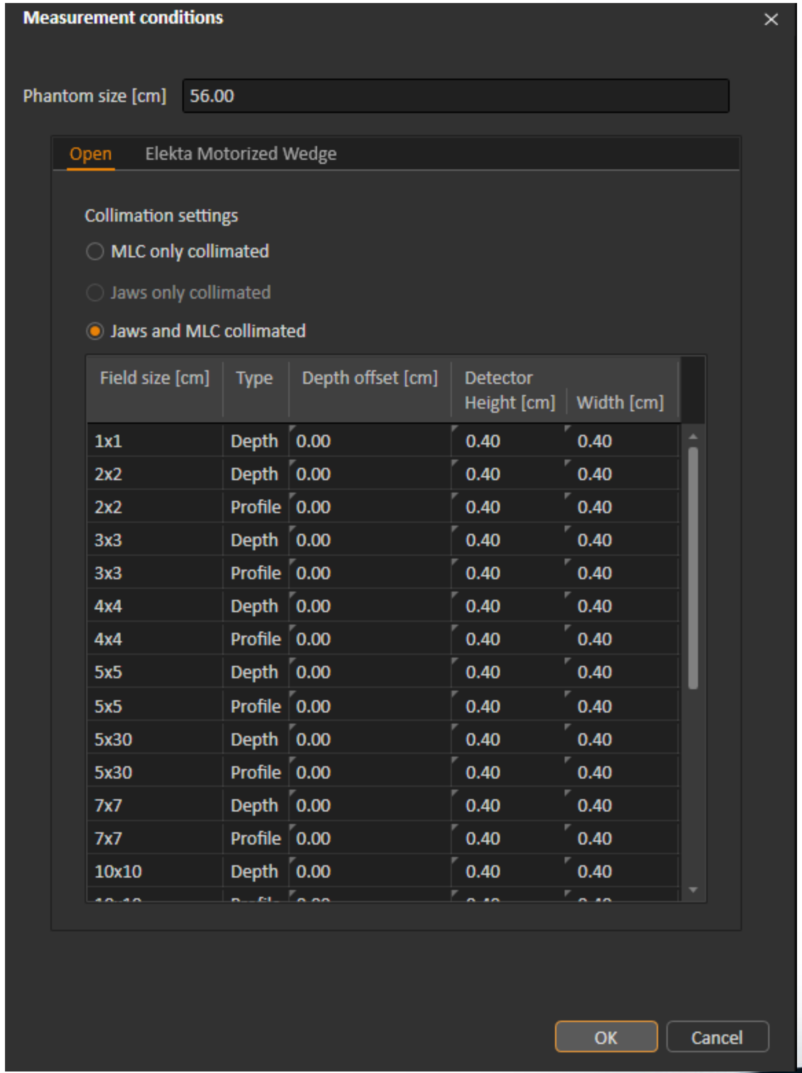


- ***Output factors***: ratio of measured dose at the reference point for any field size and the dose at the same point for the reference field size (typically 10 x10).
- ***Wedge output factors***: dose for the wedged field divided by the dose for the same size open field at the same depth with the same SSD
  - All field sizes in wedge list must have an output factor also for open field even if no open field curves are included.
- Entered at import (can be changed later)
- Not part of the beam model/dose calculation, only used for normalization.
- Recommended to measure OFs and wedge OFs below electron contamination (at 5 - 10 cm depth)

MEASUREMENT CONDITIONS

- ***Phantom size***
- ***Collimation settings***
- ***Depth offset***
- ***Detector height and width***

- Only used in BC dose curve calculation, not for dose calculations in patients.
- Used to make the conditions of the calculated curves mimic the conditions of the dose curve measurements.
- Separate conditions for open and wedged fields.



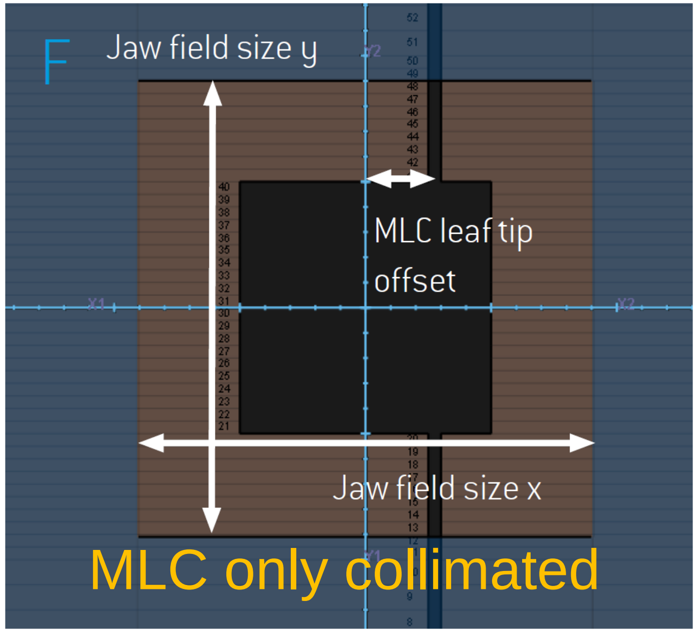
MEASUREMENT CONDITIONS – PHANTOM SIZE

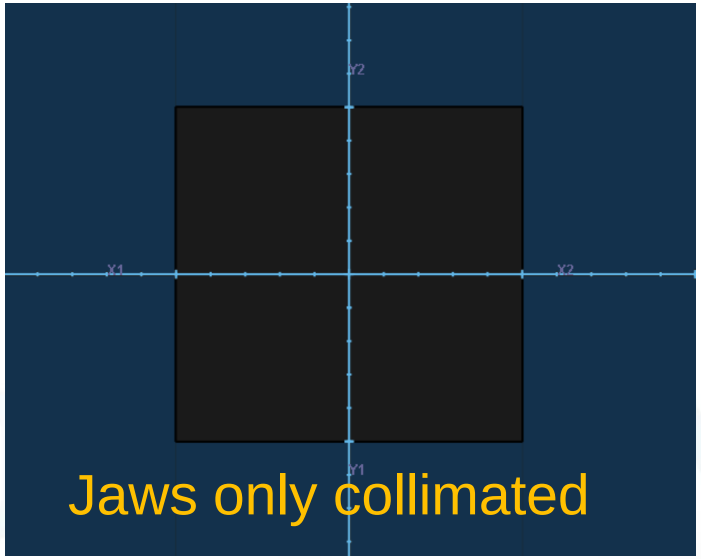
- One value only for the *Phantom size* – use some kind of average side length if phantom is a non-square cuboid

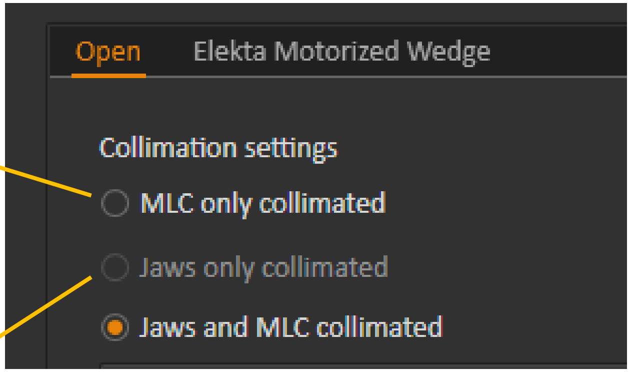
MEASUREMENT CONDITIONS IN RAYPHYSICS – ALLOWED COLLIMATION SETTINGS

- All measurements per beam quality must be collimated the same way
- Is it important that the field setup used when measuring dose curves matches the field setup used in beam commissioning.
  - To visualize how MLC and Jaws will be positioned for a specific machine, a Rectangular field can be created in Beam 3D Modeling in RayPhysics.
- If some fields are measured for different conditions than others, a separate machine must be created to properly model these.
  - Eg: For a machine with MLCs below the Jaws (Varian), we can use:
    - Jaws only collimation as a main model
    - MLC only collimation to fine tune the collimator calibration parameters

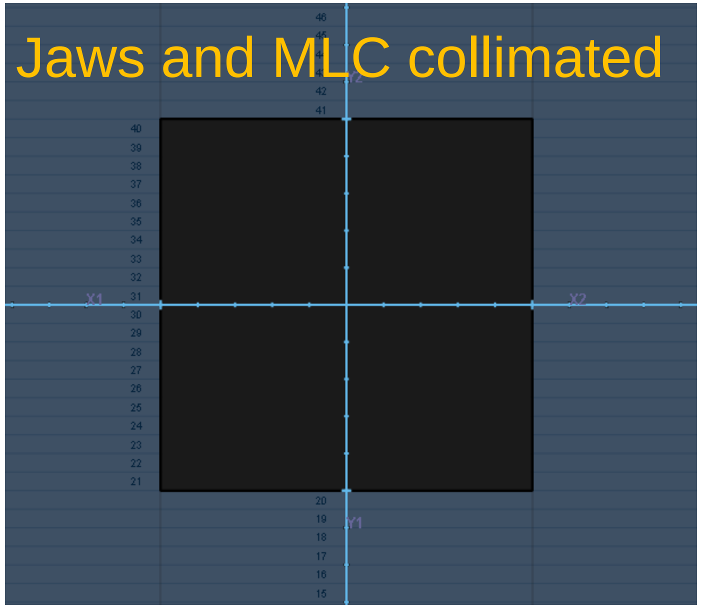
MEASUREMENT CONDITIONS – ALLOWED COLLIMATION SETTINGS

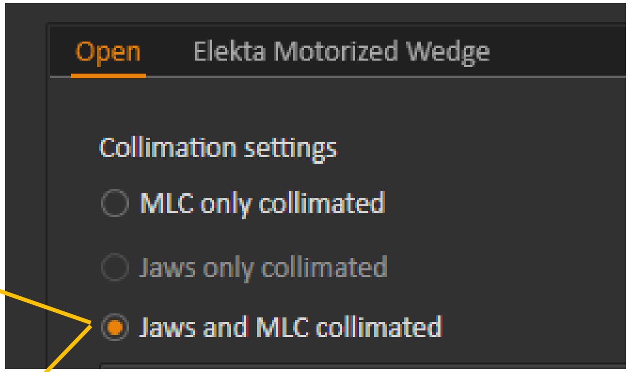


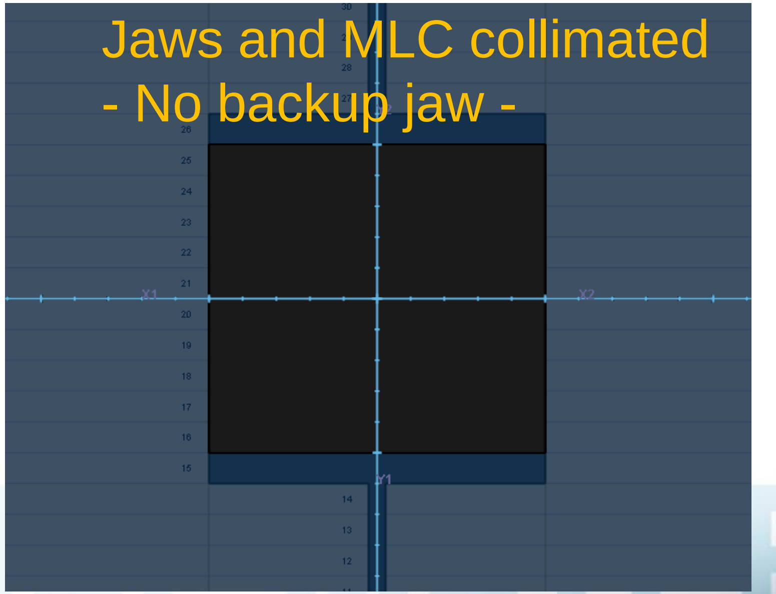




MEASUREMENT CONDITIONS – ALLOWED COLLIMATION SETTINGS

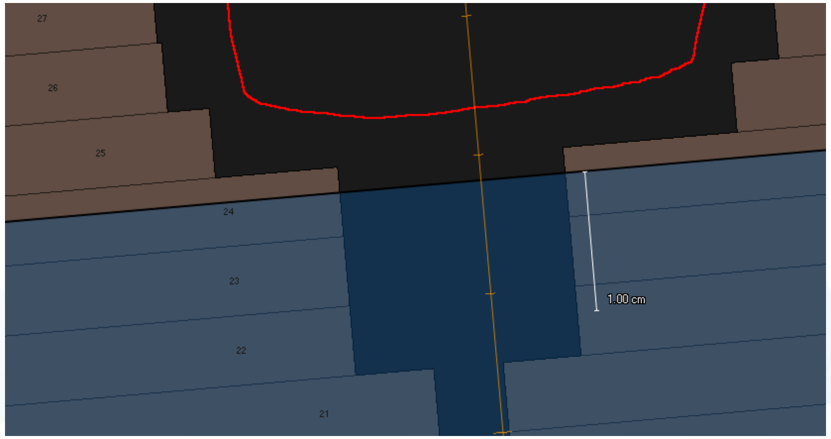






ELEKTA GUARD LEAVES

- Can be set in RayPhysics (MLC Tab)
- When set up, they are applied for the treatment techniques 3DCRT, SMLC, DMLC, Static Arc, Conformal Arc and VMAT
  - Not applied if segments are edited via scripting
  - Only used for plan creation, not part of the machine limitation checks when final dose is computed.
- ***Guard leaves distance [cm]:*** All leafpairs outside the aperture within Guard leaves distance from the y-jaw will be treated as guard leaves
  - Contact the suppliers of your R&V and/or TCS for more information
  - Example with Guard Leave distance set to 1cm:



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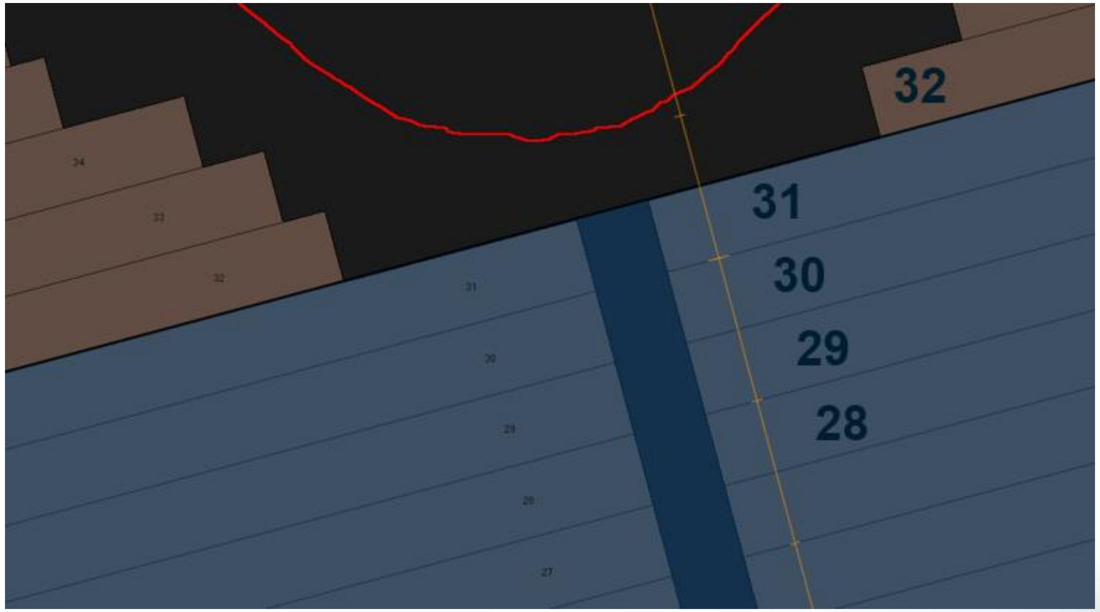
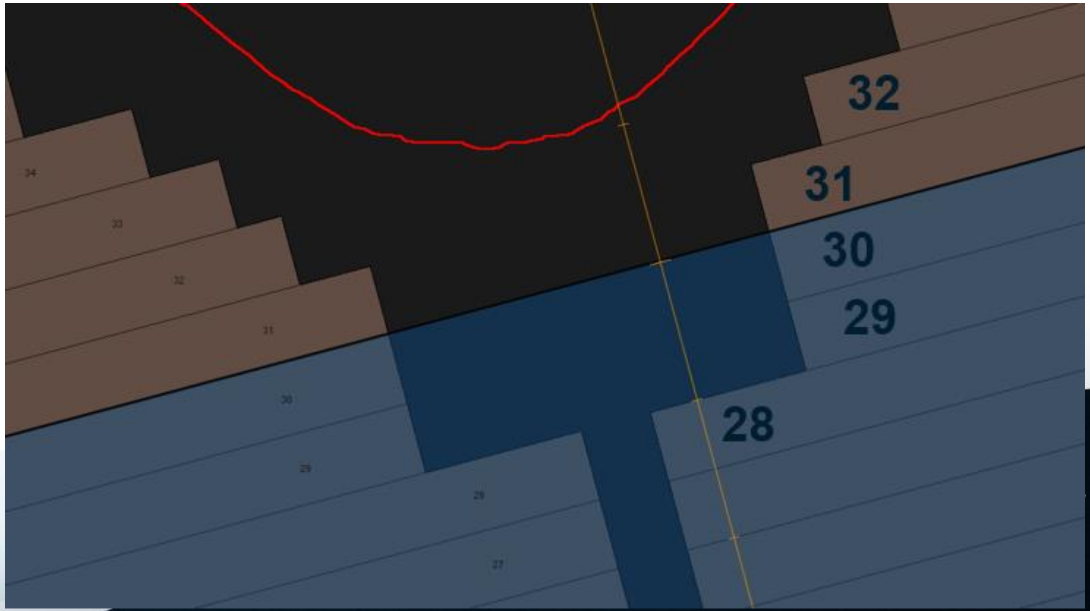
ELEKTA GUARD LEAVES – NEW IN 10B

- If the jaw movement rule is set to **Per segment** for the LINAC, the position of the y-jaws will typically vary for the different segments in a VMAT or Conformal Arc plan
  - Guard leaves (GL) are only applied when the outermost exposed leafpair (LP) of a segment is the same as the outermost exposed leaf across the beam
  - Example with GL distance set to 1cm and LP 31 being the outermost exposed LP across the beam:

Guard Leaves not applied (since segment only includes LP 32)



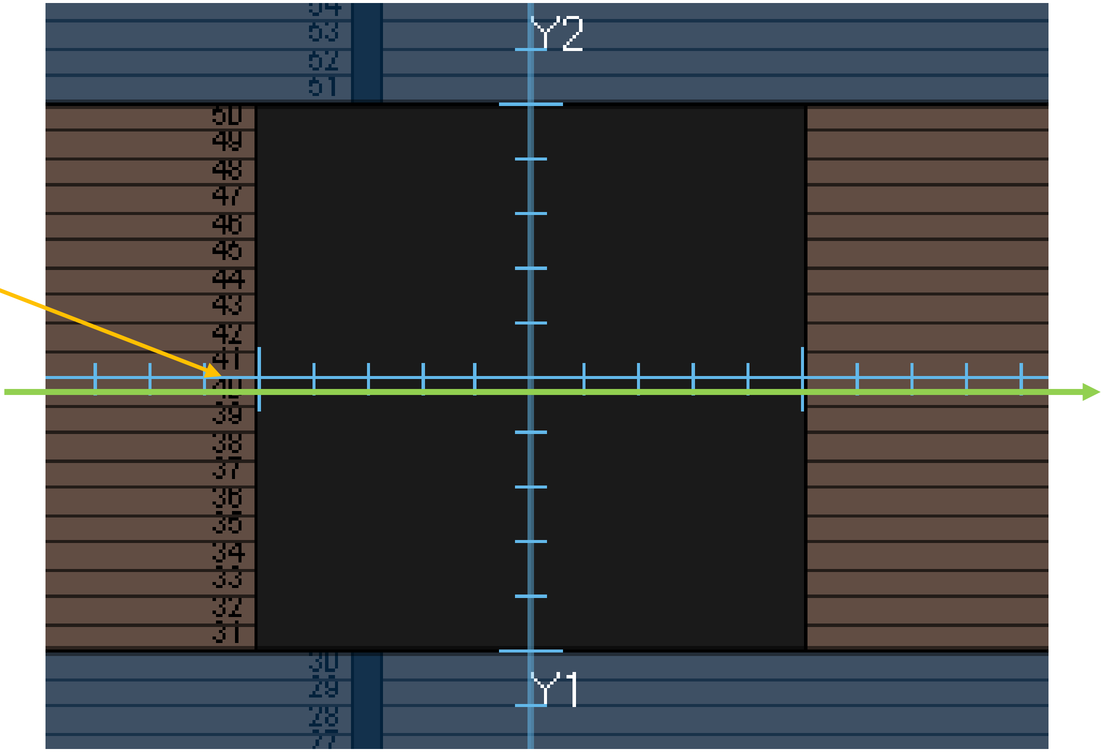
Guard Leaves applied to segment

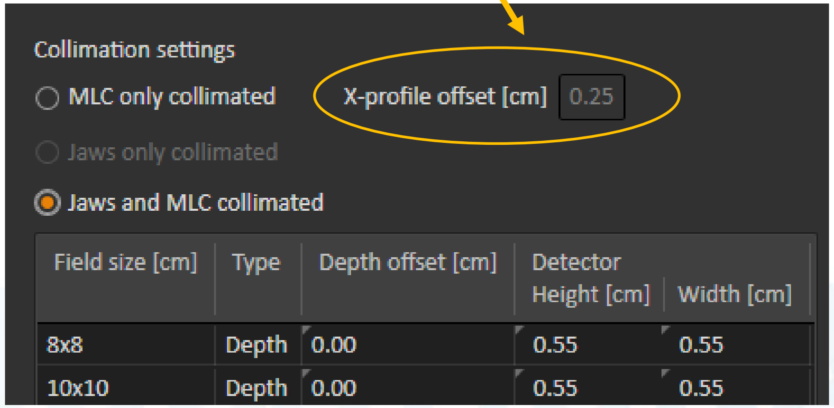


MEASUREMENT CONDITIONS IN RAYPHYSICS – JAWS AND MLC COLLIMATED

- **X-profiles** can be measured with a small offset for all field sizes in the y-direction for **“Jaws and MLC collimated” conditions**

- ***X-profile offset*** in y detected automatically at import and cannot be changed in RayPhysics





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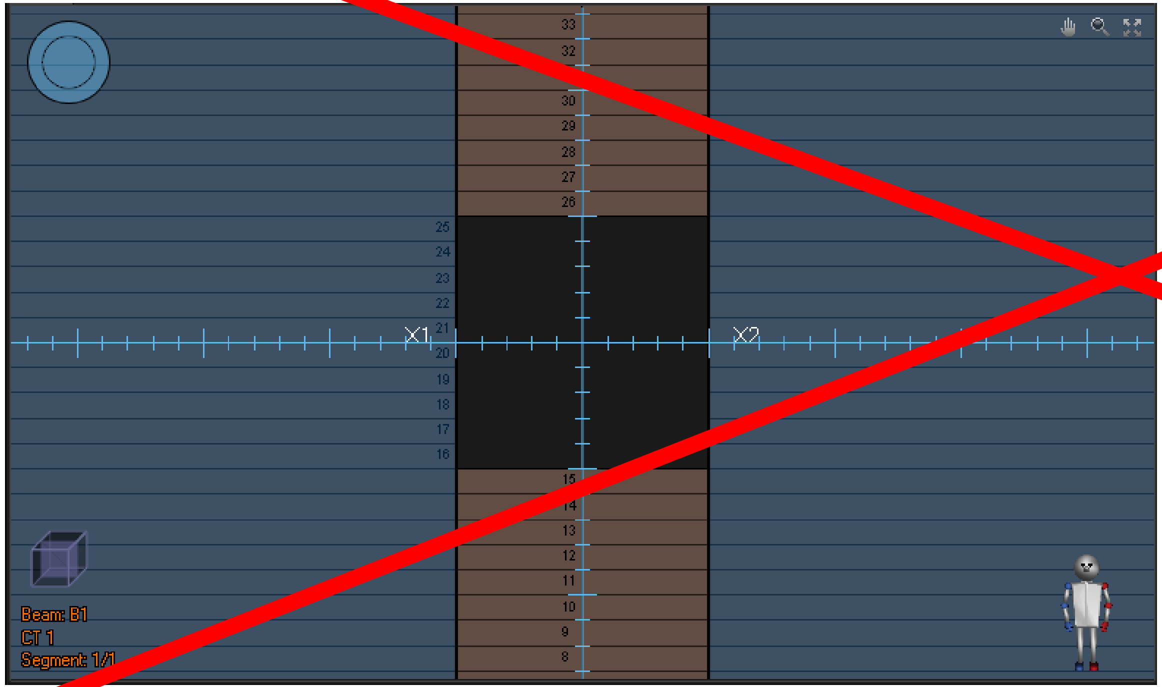
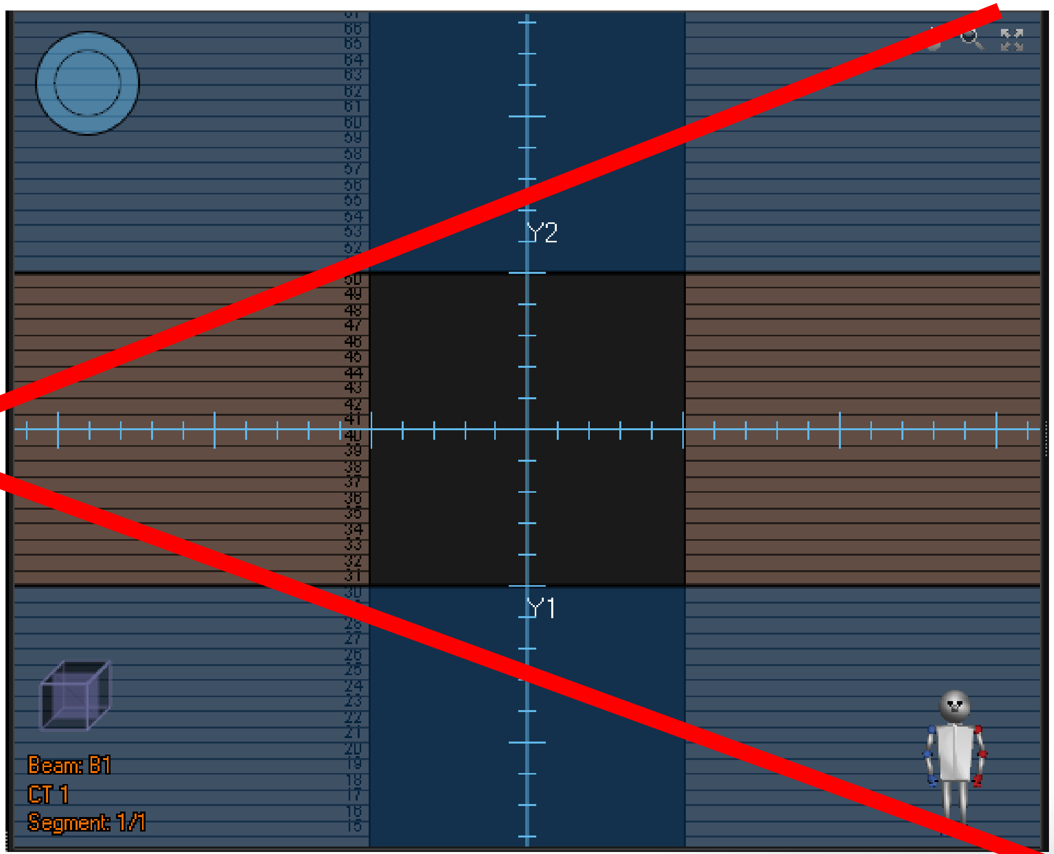
MEASUREMENT CONDITIONS – NOT ALLOWED COLLIMATION SETTINGS





MEASUREMENT CONDITIONS IN RAYPHYSICS – MLC ONLY EXTRA CONDITIONS

- Y-profiles must be measured without offset in x!

Instead use ***MLC leaf tip offset***.

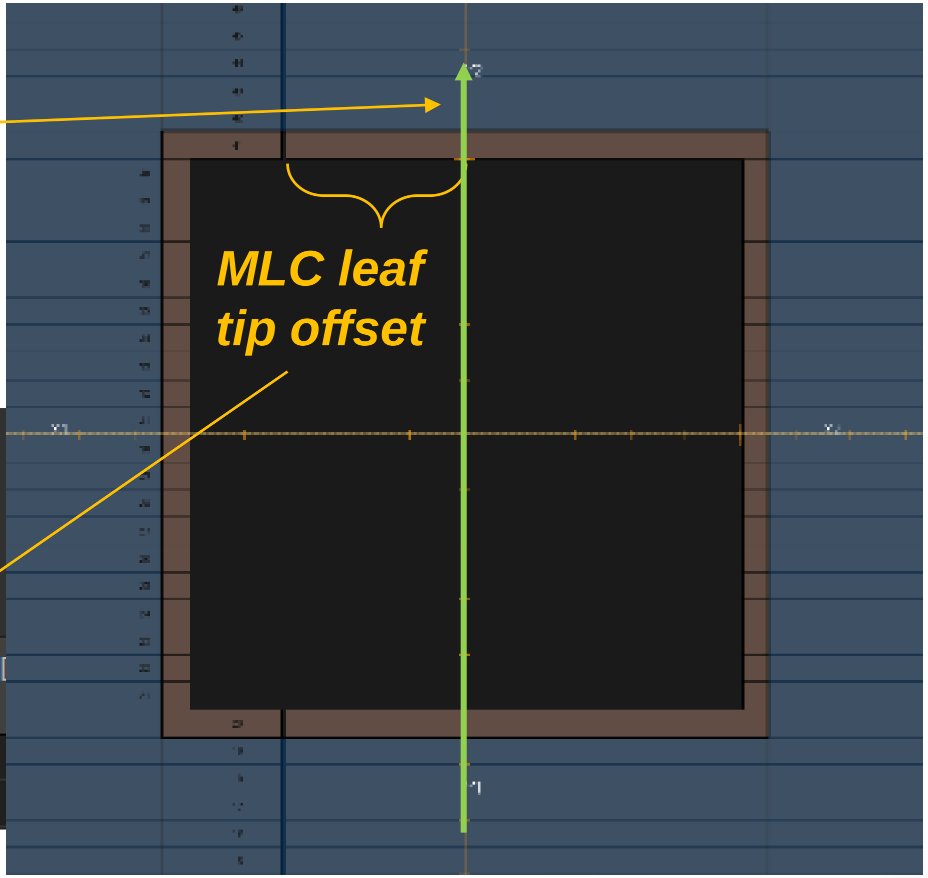
Collimation settings

MLC only collimated   X-profile offset [cm] 0.25

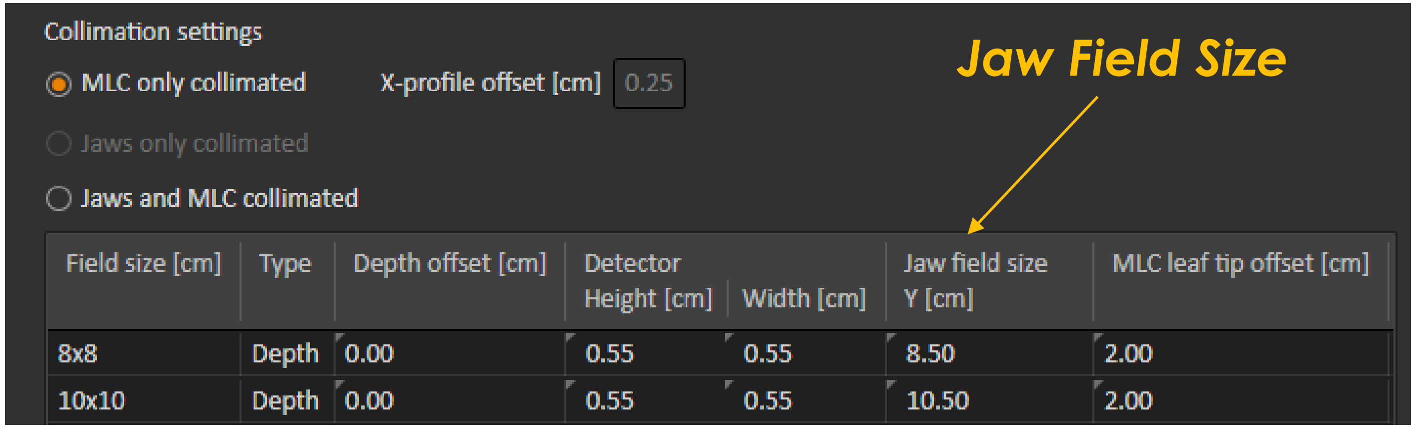
Jaws only collimated

Jaws and MLC collimated

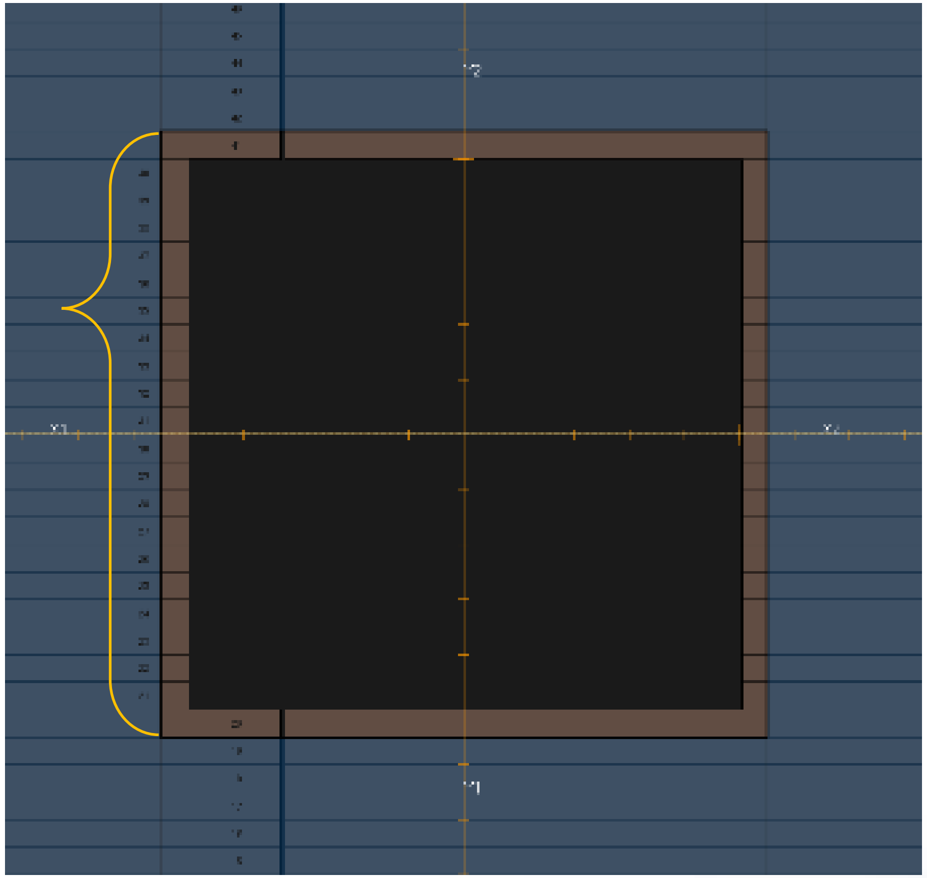
Field size [cm]	Type	Depth offset [cm]	Detector Height [cm]	Width [cm]	Jaw field size Y [cm]	MLC leaf tip offset [
8x8	Depth	0.00	0.55	0.55	8.50	2.00
10x10	Depth	0.00	0.55	0.55	10.50	2.00



MEASUREMENT CONDITIONS IN RAYPHYSICS – MLC ONLY EXTRA CONDITIONS



Field size [cm]	Type	Depth offset [cm]	Detector Height [cm]	Detector Width [cm]	Jaw field size Y [cm]	MLC leaf tip offset [cm]
8x8	Depth	0.00	0.55	0.55	8.50	2.00
10x10	Depth	0.00	0.55	0.55	10.50	2.00

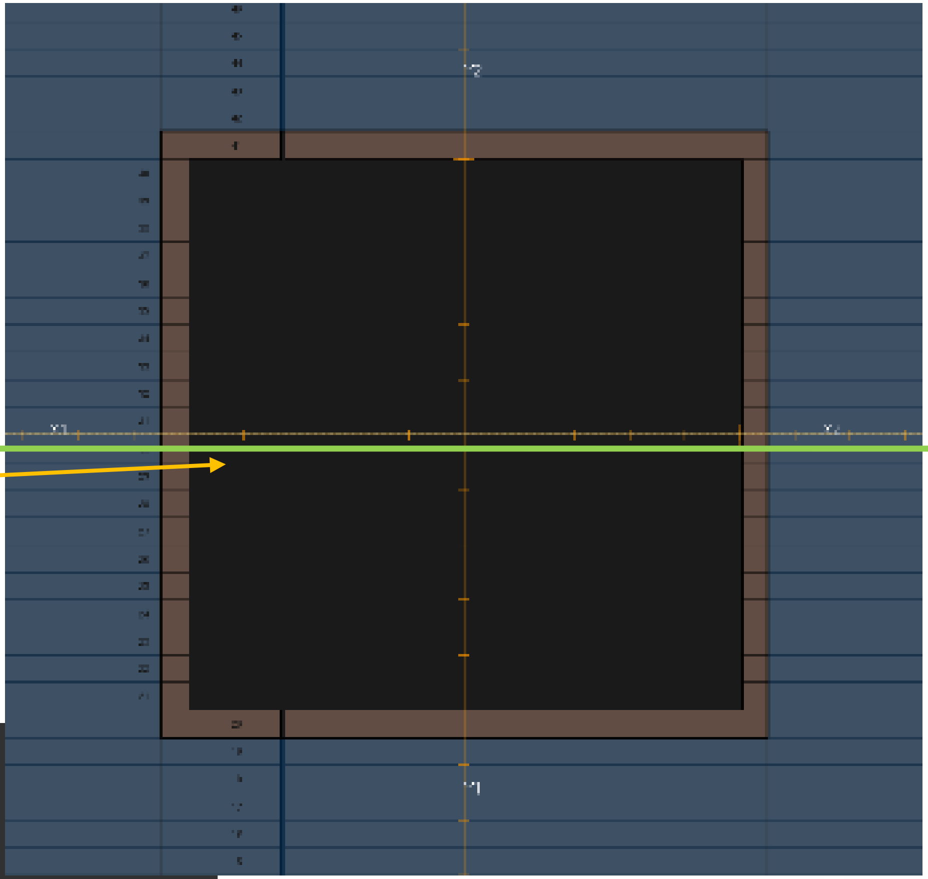


- MLC only option is used for a machine with both X and Y jaws and the jaws positioned above the MLC (ex. Varian machines):

- NOT position the jaws fully retracted
- NOT use the same jaw field size for all field sizes
- Position the jaws only at a slightly larger field size than the MLC, for example retracted **0.5-1 cm**

MEASUREMENT CONDITIONS IN RAYPHYSICS – MLC ONLY EXTRA CONDITIONS

- Y-profiles must be measured without offset in x!
- Instead use ***MLC leaf tip offset***.
- ***X-profile offset*** in y detected automatically at import and cannot be changed in RayPhysics.



Collimation settings

MLC only collimated — X-profile offset [cm] 0.25

Jaws only collimated

Jaws and MLC collimated

Field size [cm]	Type	Depth offset [cm]	Detector Height [cm]	Detector Width [cm]	Jaw field size Y [cm]	MLC leaf tip offset [cm]
8x8	Depth	0.00	0.55	0.55	8.50	2.00
10x10	Depth	0.00	0.55	0.55	10.50	2.00

RaySearch Laboratories

MEASUREMENT CONDITIONS – DETECTOR CHOICE

- Ionization chamber –> resolution effects
- Diode –> energy sensitive.
- Follow published dosimetric recommendations (AAPM TG51 addendum, IAEA TRS398 or similar)
- RayStation standard for curves:
  – Ionization chambers for large fields
  – Diodes or pinpoint chambers for small fields (< 4 cm)
  – If the gradient over the detector region is small use well guarded plane-parallel ionization chambers for depth dose curves.
- RayStation standard for absolute dose and output factors:
  – Use correction factors, not adjustments of effective point of measurement (as per AAPM TG51 and IAEA TRS398).
  – Daisy chaining to obtain better absolute dose measurements for small fields.

MEASUREMENT CONDITIONS – DEPTH OFFSET

- The center of the detector is not necessarily the effective point of measurement.
- By shifting the depth dose curve, the measured curve can be made to correspond better to the true depth dose curve in water, this is referred to as correcting for the effective point of measurement
- The sum of the shift applied before importing the depth dose curves into RayPhysics and the extra depth offset entered in RayPhysics shall be the correct shift.

Finding the surface position

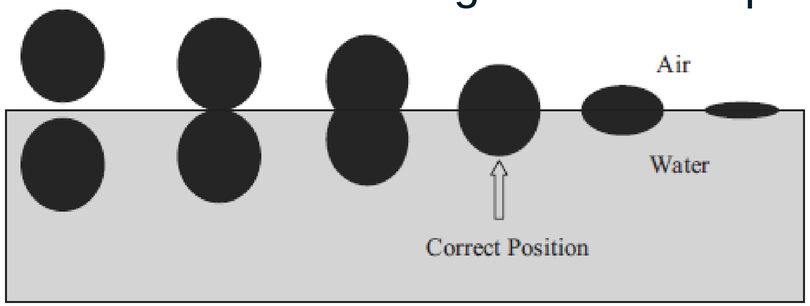
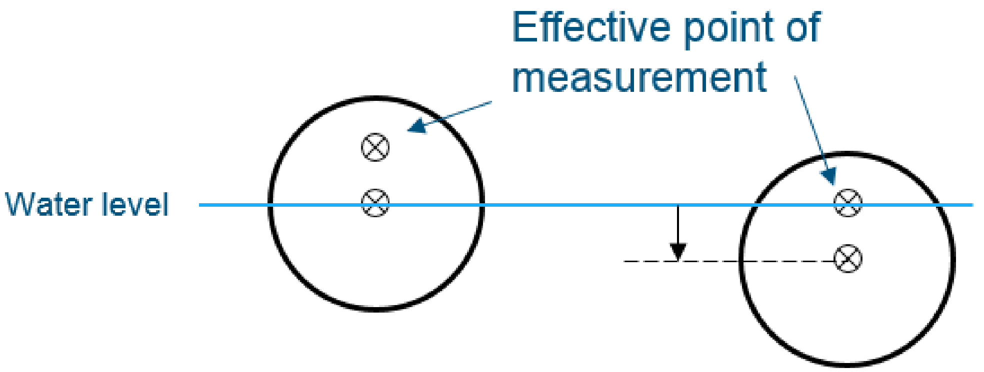


FIG. 6. Sequential appearance of chamber and its reflection in water viewed from tank side. The correct position is when both images form a perfect circle.

Das *et al.*: TG-106: Accelerator beam data commissioning

Med. Phys. 35 (9), September 2008

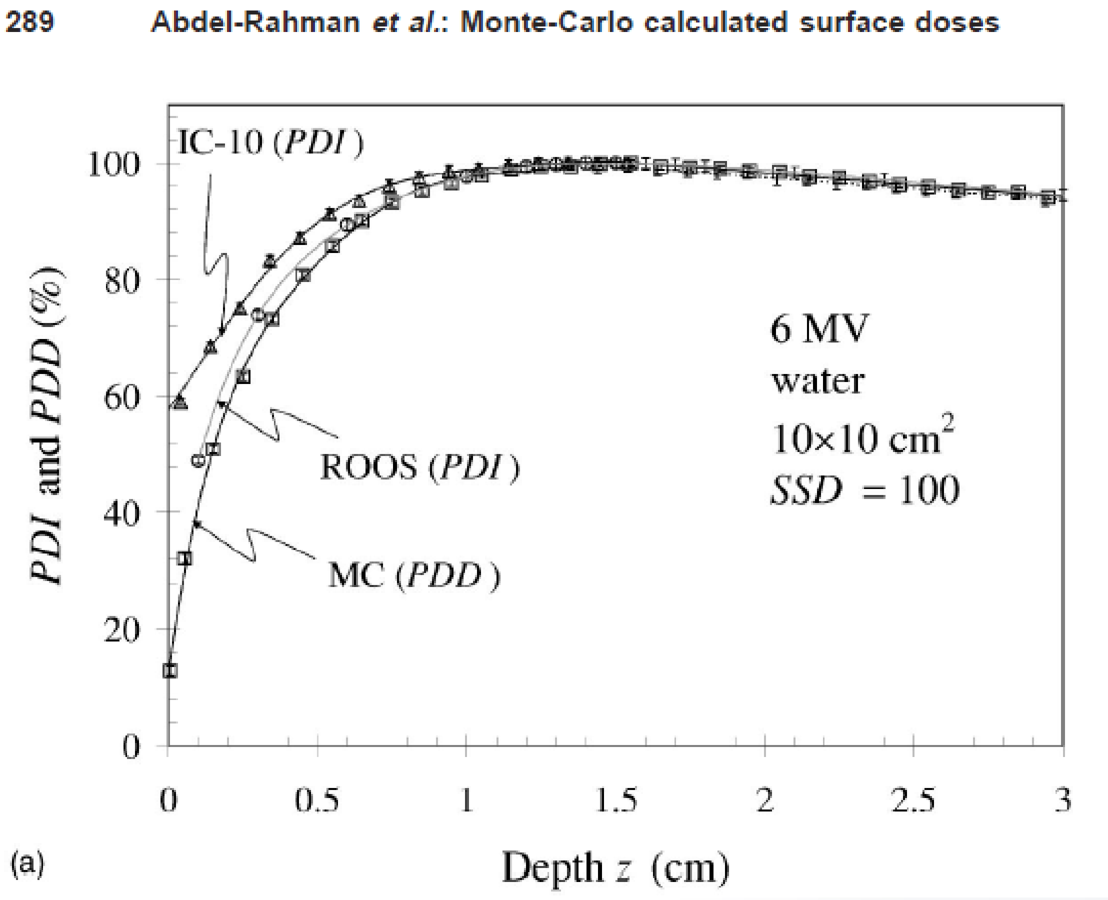
Field	Type	Depth offset [cm]	Detector Height [cm]	Width [cm]
2x2 cm	Depth	-0.03	0.00	0.20
2x2 cm	Profile	0.00	0.00	0.20
3x3 cm	Depth	-0.03	0.00	0.20
3x3 cm	Profile	0.00	0.00	0.20
4x4 cm	Depth	-0.06	0.00	0.40



BUILDUP

IC-10 curve shifted by -0.6 rcav

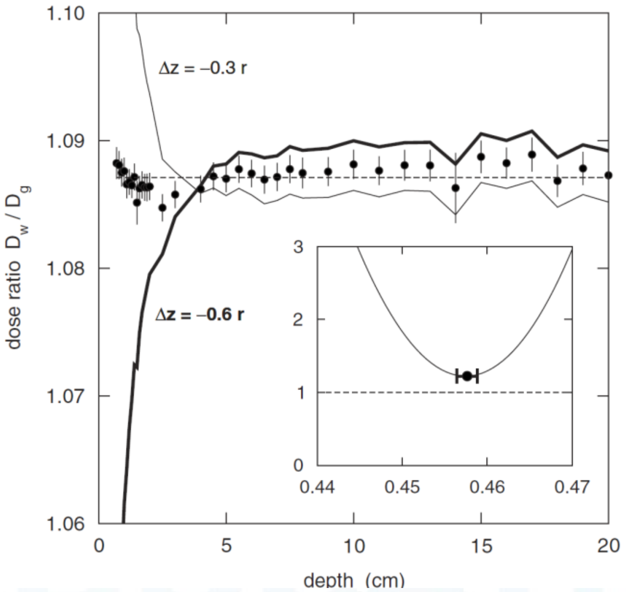
- IAEA TRS-398/AAPM TG-51.
  - Detector correction factors for point measurements
  - Extrapolation chambers or well guarded plane-parallell ionization chambers for PDDs.
- Old rule of thumb for cylindrical ionization chambers: shift depth dose curve towards surface by 0.6rcav (rcav = cavity radius).
  - Not bad after Dmax
  - Bad before Dmax for many detectors.
  - If this is done the measured percentage depth ionization is higher than real dose before Dmax.
  - The correct shift depends on many factors
    - Detector geometry and material, energy, field size



Abdel-Rahman, Variation of Monte-Carlo calculated surface doses for megavoltage photon beams, Med. Phy. 32 (2005) 286

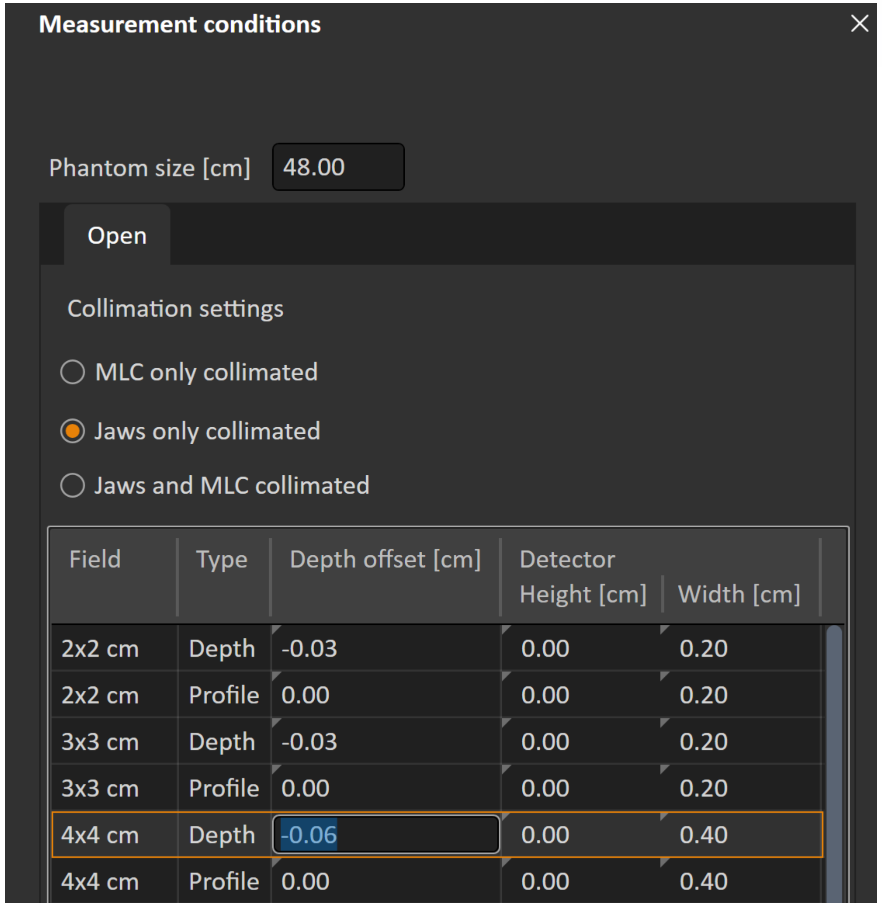
DEPTH OFFSET

- Monte Carlo or measurement based papers.
- Objective: Find shift that gives Dwater/Dchamber = constant.
- Too large shift gives PDI higher than PDD in buildup.
- Too small shift gives the opposite.
- Find sweet spot.
  - Per detector, per energy, per field size.

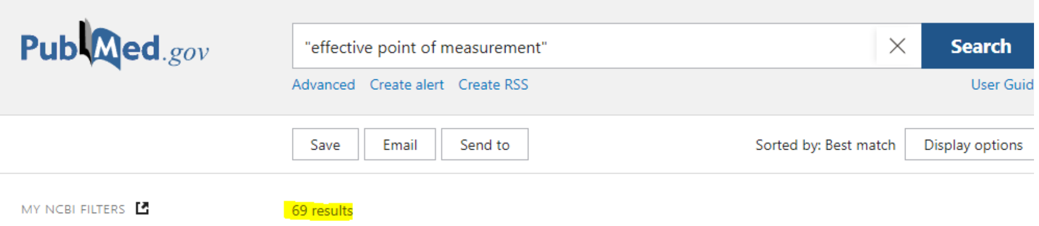


Tessier, Kawrakow, Effective point of measurement of thimble ion chambers in megavoltage photon beams, Med. Phys. 37 (2010)

From TG51 Addendum:
Result show in many cases, a shift significantly different from 0.6rcav was required to yield the 'true' depth-dose curve



SHIFTS FROM LITERATURE



Looe et al, Experimental detemination of the effective point of measurement for various detectors used in photon and electron dosimetry, Phys. Med. Biol. 56 (2911) 4267-4290.

Table 2. Positions of the reference point, measured values of the shift Δz of the effective point of measurement and test radiations for the detectors investigated in this paper.

Detector	Position of reference point	Δz	Test radiations
Radiochromic film	Central plane of the film	0	6 MV, 15 MV 6 MeV, 9 MeV
Roos chamber PTW 34001	Entrance surface of the air volume, 1.1 mm below the chamber's entrance surface	(0.4 ± 0.1) mm	6 MV, 15 MV 6 MeV, 9 MeV
Markus chamber PTW 23343	Entrance surface of the air volume, 1.3 mm below the surface of the protection cap	(0.4 ± 0.1) mm	6 MV, 15 MV 6 MeV, 9 MeV
PinPoint chamber PTW 31006	Symmetry axis. $r = 1.0$ mm	$-(0.30\pm 0.05)$ mm or $-(0.30 \pm 0.05)\ r$	6 MV, 15 MV
0.3 cm^3 Rigid-Stem chamber PTW 23332	Symmetry axis. $r = 2.5$ mm	$-(0.9 \pm 0.1)$ mm or $-(0.36 \pm 0.04)\ r$	6 MV, 15 MV
Semiflex chamber PTW 31013	Symmetry axis. $r = 2.75$ mm	$-(1.3 \pm 0.1)$ mm or $-(0.47 \pm 0.04)\ r$	6 MV, 15 MV
1.0 cm^3 Rigid-Stem chamber PTW 23331	Symmetry axis. $r = 3.95$ mm	$-(2.3 \pm 0.2)$ mm or $-(0.58 \pm 0.05)\ r$	6 MV, 15 MV
2D-Array PTW 10024	7.5 mm below the upper surface of the array	(0.5 ± 0.2) mm	6 MV, 15 MV
Si Diode PTW 60012	Plane at 0.6 mm below the tip	(0.6 ± 0.1) mm	6 MV, 15 MV

Table 3. Comparison of the Δz results from the literature (columns 1–5) for identical or similar chambers as those investigated in this study (columns 6 and 7).

Literature	Examined detector	Reference detector	Beam quality, literature	Δz value from literature	Beam quality, present study	Δz value from this study
Looe *et al* (2007)	Roos chamber	Radio-chromic film[a]	6 MeV, 6 MV	+0.5 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Bruggmoser *et al* (2007)	Roos chamber	TLD	4, 6, 8, 18 MeV	+0.4 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Zink and Wulff (2009)	Roos chamber	MC	6, 11, 21 MeV	+0.4 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Lacroix *et al* (2010)	Roos chamber	PSD	6, 12, 18 MeV	+0.12 mm to +0.9 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Roos *et al* (1998, 2000)	Markus chamber (with cap)	Roos chamber[b]	6, 12.5, 20 MeV	+0.5 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Looe *et al* (2007)	Markus chamber (with cap)	Roos chamber	6 MeV, 6 MV	+0.5 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Wang and Rogers (2009b)	Markus chamber (with cap)	MC	6, 22 MeV	+0.25 mm, +0.15 mm	6, 9 MeV; 6, 15 MV	+0.4 mm
Rubach *et al* 1986	Markus chamber (without cap)	Extrapol. chamber	Co-60, 10 MV	≈ +0.5 mm	6 MeV	+0.45 mm
Johansson *et al* (1978)	Cylindrical chamber, $r =$ 3.5 mm	Chambers with different radii	Co-60 and 5 to 42 MV	$-0.6\ r$	6, 15 MV	$-0.58\ r$

Table 3. (Continued.)

Literature	Examined detector	Reference detector	Beam quality, literature	Δz value from literature	Beam quality, present study	Δz value from this study
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	25 MV (10 cm × 10 cm)	$-0.41\ r$	15 MV	$-0.47\ r$
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	25 MV (30 cm × 30 cm)	$-0.35\ r$		
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	6 MV (10 cm × 10 cm)	$-0.49\ r$	6 MV	$-0.47\ r$
Kawrakow (2006)[c]	PTW 31010 ($r = 2.75$ mm)	MC	6 MV (30 cm × 30 cm)	$-0.43\ r$		
Huang *et al* (2010)	PTW 30006 ($r = 3.05$ mm)	Roos[d]	6, 15 MV	$-0.5\ r$ to $-0.65\ r$		
Huang *et al* (2010)	PTW 31002 ($r = 2.75$ mm)	Roos[d]	6, 15 MV	$-0.5\ r$ to $-0.6\ r$	6, 15 MV	$-0.47\ r$
Huang *et al* (2010)	PTW 31003 ($r = 2.75$ mm)	Roos[d]	6, 15 MV	$-0.5\ r$ to $-0.6\ r$	6,15 MV	$-0.47\ r$
Tessier (2010)	27 cylindrical chambers of various design	MC	6, 25 MV	$-0.15\ r$ to $-0.5\ r$	6, 15 MV	$-0.30\ r$ to $-0.58\ r$ $r = 1.0$ to 3.95 mm

[a] Taking 1.0 mm as the thickness of the Roos chamber window.
[b] With the front thicknesses of both chambers scaled according to electron densities.
[c] And the related papers by McEwen *et al* (2008) and by Tessier and Kawrakow (2010).
[d] Assuming that P_{eff} lies 1.50 mm below the surface of the Roos chamber.

SHIFTS FROM LITERATURE

TABLE II. Detailed EPOM analysis results. For each case (chamber model, nominal energy, and field size) we list (a) the EPOM shift relative to the chamber cavity radius, (b) the actual EPOM shift in millimeters, (c) the difference in millimeters between the EPOM and the recommended value of $-0.6r$, (d) the optimal value of the proportionality constant k [see Eq. (1)], (e) the goodness-of-fit estimator χ^2/d, (f) the relative rms deviation of the dose ratio with respect to k [see Eq. (4)], and (g) the same rms measure evaluated for a shift of $-0.6r$. Numbers in parentheses give the statistical uncertainty in the EPOM values in terms of the last two digits of the reported value, i.e., $-0.458(01)$ means -0.458 ± 0.001.

Ion chamber	Energy (MV)	Field size (cm^2)	(a) $\Delta z/r$	(b) Δz (mm)	(c) $\Delta z-(-0.6r)$ (mm)	(d) k	(e) χ^2/d	(f) s (%)	(g) $s_{(-0.6r)}$ (%)
Exradin A16	25	10×10	−0.190 (07)	−0.227 (08)	0.49	1.115	0.99	0.18	1.96
		40×40	−0.179 (15)	−0.214 (18)	0.50	1.115	2.26	0.36	1.12
	6	10×10	−0.240 (14)	−0.286 (17)	0.43	1.182	1.51	0.36	1.06
		40×40	–					1.10	1.11
Exradin A14SL	25	10×10	−0.144 (03)	−0.289 (07)	0.91	1.200	1.35	0.16	3.88
		40×40	−0.090 (07)	−0.181 (14)	1.02	1.207	0.77	0.20	2.33
	6	10×10	−0.173 (06)	−0.347 (13)	0.86	1.307	2.23	0.30	2.25
		40×40	–					0.52	1.25
Exradin A14	25	10×10	−0.206 (05)	−0.413 (10)	0.79	1.156	1.01	0.20	2.05
		40×40	−0.142 (13)	−0.286 (25)	0.92	1.162	0.94	0.22	1.30
	6	10×10	−0.234 (14)	−0.470 (28)	0.73	1.257	2.28	0.32	0.80
		40×40	–					0.54	0.59
Exradin A1SL	25	10×10	−0.139 (03)	−0.280 (06)	0.92	1.092	0.55	0.16	3.93
		40×40	−0.100 (05)	−0.201 (11)	1.00	1.097	0.81	0.14	2.20
	6	10×10	−0.145 (05)	−0.290 (09)	0.91	1.141	1.02	0.16	2.34
		40×40	−0.144 (11)	−0.289 (22)	0.91	1.142	1.41	0.24	1.31
Exradin A1	25	10×10	−0.184 (04)	−0.369 (08)	0.84	1.090	1.07	0.14	2.13
		40×40	−0.141 (08)	−0.283 (16)	0.92	1.094	0.79	0.12	1.23
	6	10×10	−0.199 (11)	−0.399 (22)	0.81	1.136	0.96	0.13	0.84
		40×40	−0.196 (29)	−0.393 (57)	0.81	1.136	1.83	0.28	0.51
Exradin A18	25	10×10	−0.234 (02)	−0.568 (04)	0.89	1.091	0.62	0.13	3.91
		40×40	−0.204 (03)	−0.495 (08)	0.96	1.094	0.97	0.14	2.23
	6	10×10	−0.252 (03)	−0.610 (07)	0.84	1.137	0.56	0.11	2.37
		40×40	−0.249 (06)	−0.605 (15)	0.85	1.138	2.05	0.25	1.35
Exradin A2	25	10×10	−0.309 (01)	−1.470 (04)	1.39	1.119	1.30	0.13	4.34
		40×40	−0.286 (02)	−1.362 (10)	1.50	1.124	0.98	0.11	2.51
	6	10×10	−0.377 (02)	−1.793 (10)	1.06	1.194	1.38	0.11	1.70
		40×40	−0.384 (06)	−1.831 (29)	1.03	1.195	2.43	0.21	0.93
Exradin A12S	25	10×10	−0.435 (02)	−1.322 (05)	0.50	1.109	0.76	0.08	1.46
		40×40	−0.388 (04)	−1.178 (11)	0.64	1.112	0.84	0.11	0.98
	6	10×10	−0.440 (04)	−1.336 (13)	0.48	1.167	1.45	0.15	0.64
		40×40	−0.432 (10)	−1.311 (30)	0.51	1.167	2.70	0.24	0.41
Exradin A12	25	10×10	−0.458 (01)	−1.389 (04)	0.43	1.087	1.22	0.08	1.27
		40×40	−0.421 (03)	−1.278 (10)	0.54	1.089	1.00	0.09	0.83
	6	10×10	−0.464 (03)	−1.407 (10)	0.41	1.133	1.88	0.12	0.56
		40×40	−0.477 (08)	−1.449 (25)	0.37	1.131	4.07	0.25	0.35
Exradin A19	25	10×10	−0.459 (01)	−1.375 (03)	0.42	1.086	1.56	0.11	1.75
		40×40	−0.420 (02)	−1.260 (06)	0.54	1.088	1.20	0.13	1.17
	6	10×10	−0.471 (02)	−1.413 (05)	0.39	1.132	1.57	0.11	0.95
		40×40	−0.474 (04)	−1.422 (12)	0.38	1.130	3.39	0.22	0.55
NE2571	25	10×10	−0.469 (01)	−1.466 (02)	0.41	1.071	3.74	0.16	2.15
		40×40	−0.427 (02)	−1.334 (06)	0.54	1.072	0.68	0.08	1.46
	6	10×10	−0.496 (01)	−1.550 (04)	0.32	1.110	5.61	0.20	1.22
		40×40	−0.494 (02)	−1.543 (08)	0.33	1.107	2.73	0.19	0.72
PTW30013	25	10×10	−0.483 (01)	−1.475 (02)	0.36	1.071	3.46	0.15	1.86
		40×40	−0.439 (02)	−1.339 (05)	0.49	1.072	0.67	0.09	1.32
	6	10×10	−0.517 (01)	−1.575 (03)	0.25	1.110	5.31	0.19	0.97
		40×40	−0.516 (02)	−1.574 (07)	0.26	1.107	4.10	0.28	0.59

Medical Physics, Vol. 37, No. 1, January 2010

McEwen et al, The effective point of measurement of ionization chamber and the build-up anomaly in MV x-ray beams, Med Phys. 35 (2008) 950.

Tessier, Kawrakow, Effective point of measurement of thimble ion chambers in megavoltage photon beams, Med. Phys. 37 (2010)

Wegener et al., The effective point of measurement for depth-dose measurements in small MV photon beams with different detectors, Med. Phys. 46 (2919) 5209.

TABLE II. Shifts from the central chamber axes for ionization chambers and from the top of the solid state detectors to the effective point of measurement averaged over three field sizes between 2 × 2 cm^2 and 10 × 10 cm^2, stated both in mm and as a function of detector inner radius, where applicable. Stated uncertainties represent one standard deviation of the mean. The last column shows the difference between 0.6r and Δz.

Detector	Shift Δz (mm)	Shift Δz/r	0.6r − Δz (mm)
FC65-G	1.51 ± 0.04	0.49 ± 0.01	0.35
FC23-C	1.41 ± 0.04	0.45 ± 0.01	0.45
CC13	1.19 ± 0.04	0.40 ± 0.01	0.61
CC04	0.72 ± 0.05	0.36 ± 0.03	0.48
CC01	0.36 ± 0.04	0.36 ± 0.04	0.24
CC003	0.30 ± 0.04	0.30 ± 0.04	0.30
RAZOR detector	−0.59 ± 0.07		
microDiamond 60019	−0.86 ± 0.04		

TABLE III. Shift in effective point of measurement relative to NE2571 reference chamber A positive shift indicates that the effective point of measurement must be moved downstream from its standard value of $-0.6r$ (i.e., towards the center of the chamber). Potentially relevant chamber data are also given. Other parameters (chamber cavity, wall material, etc.) can be found, for example, in IAEA TRS-398[6].

	Shift (mm)	Wall (g/cm^{-2})	Air gap (mm)	Cel[a] (mm)
NE2571	0	0.064	2.64	1
NE2581	0.18	0.040	1.64	3
PTW3001	0.20	0.045	2.55	1
PTW30013	0.10	0.056	2.55	1
Exradin A12	−0.06	0.088	2.55	1
Capintec PR-06G	0.23	0.050	2.70	1
NE2561/NE2611	0.33	0.090	2.70	2
PTW233642[b]	−0.02	0.078	2.25	1
Exradin A16	−0.02	0.088	1.05	1

[a]cel - central electrode diameter.
[b]now PTW31010.

TABLE IV. Shift of point of measurement from central axis to give correct depth-dose curve—comparision of experimental and MC-derived values with standard theory. A negative value indicates an upstream (to shallower depth) shift.

Chamber S/N	Characteristic	Standard shift (−0.6 r) (mm)	Experimental shift (mm)	MC shift (mm)
51151	"Standard" A2	−2.82	−1.47	−1.39
60613	1 mm C-552 electrode	−2.82	−2.02	−1.99
60612	Aluminum electrode	−2.82	−2.02	−1.96
60611	2 mm C-552 wall	−2.22	−0.92	−0.74

RaySearch Laboratories

MEASUREMENT CONDITIONS – DETECTOR HEIGHT

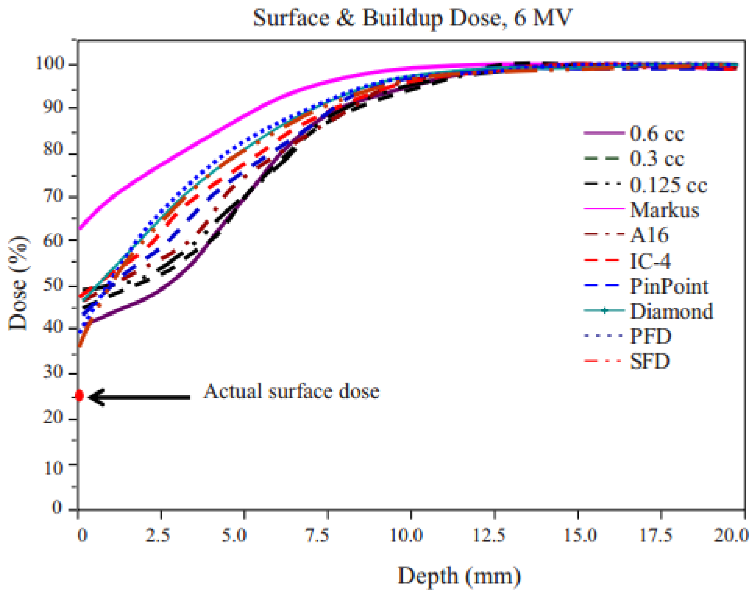


FIG. 10. Surface and buildup dose for 10×10 cm² field of a 6 MV beam with various detectors. The actual surface dose is also marked by the arrow.

- An alternative to depth offset is to use the detector height.
- Use detector height if curves are not shifted for EPOM before import and depth offset is not applied
- Do **not** use both
- Mimics dose reduction at surface for an unshifted depth dose curve
- ***Detector height*** mainly affects the buildup region of the depth dose curves.

Field	Type	Depth offset [cm]	Detector Height [cm]	Width [cm]
2x2 cm	Depth	0.00	0.20	0.20
2x2 cm	Profile	0.00	0.00	0.20
3x3 cm	Depth	0.00	0.20	0.20
3x3 cm	Profile	0.00	0.00	0.20
4x4 cm	Depth	0.00	0.40	0.40
4x4 cm	Profile	0.00	0.00	0.40

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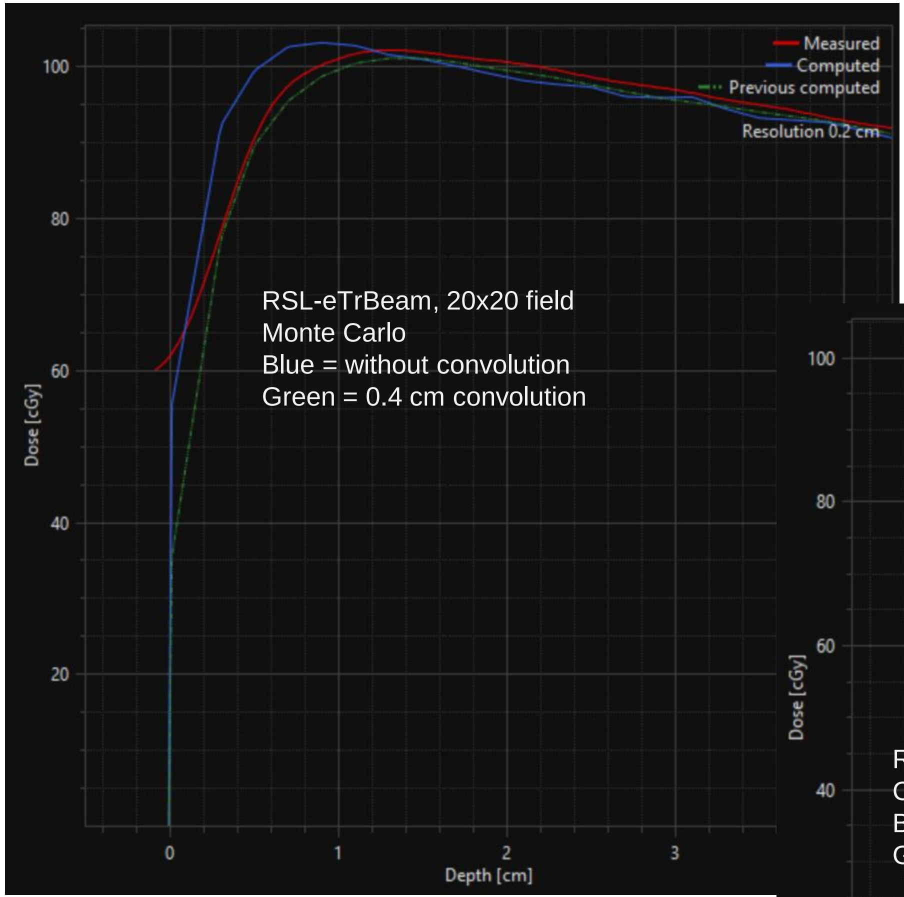
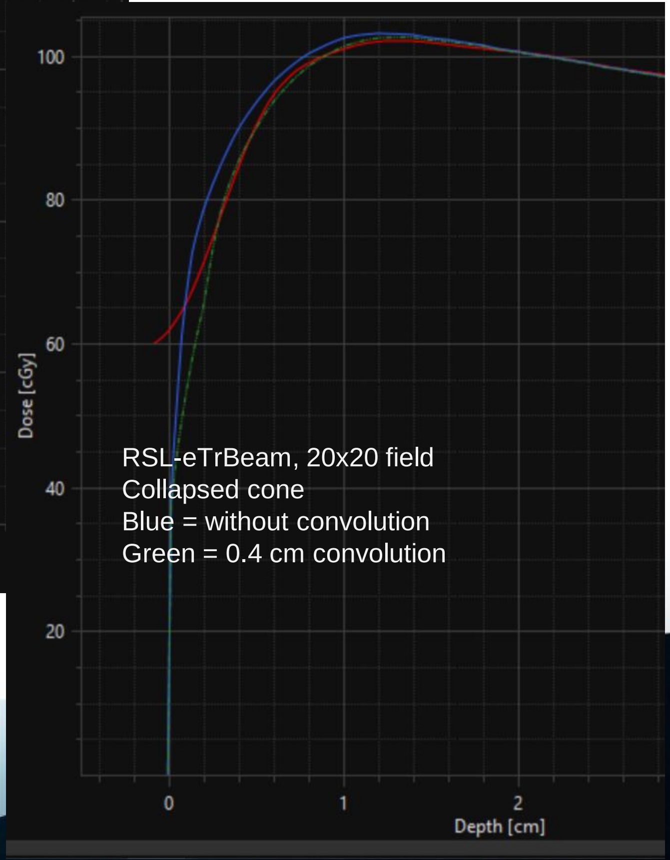
MEASUREMENT CONDITIONS - DETECTOR HEIGHT

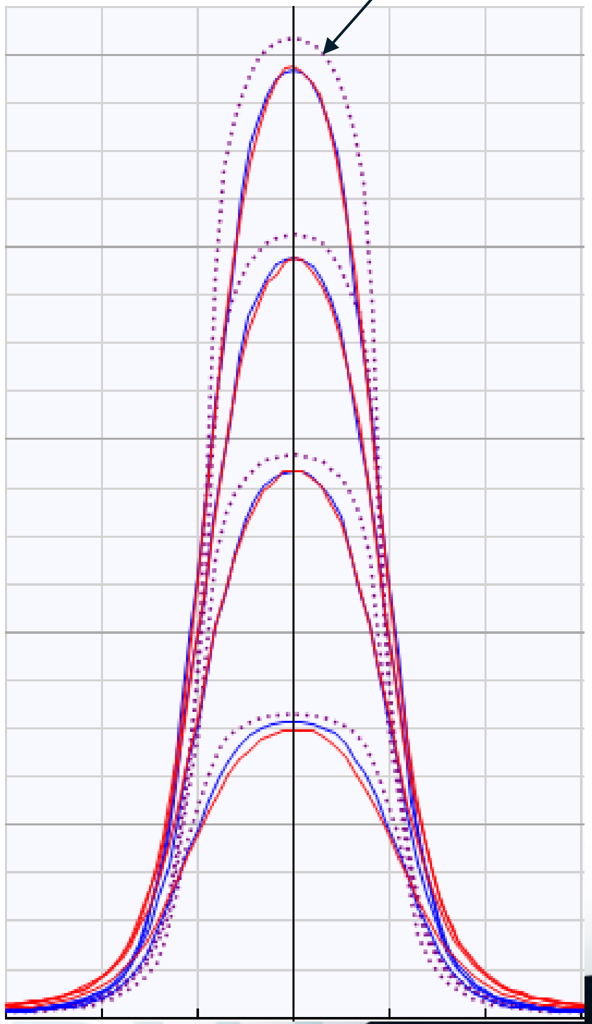
- Attempt to mimic the surface dose underestimation found for unshifted depth dose curves measured with circular detectors
  - Convolution of TERMA or Monte Carlo dose with zeroes above the surface.
  - Electron contamination only convolved up to the surface.
- Detector height decreases dose in the buildup for computed curves in RayPhysics
  - Do not use both depth offset and detector height, this gives dose overestimation in the buildup for patient dose.
- If the EPOM shift is done correctly, we do not need a detector height





MEASUREMENT CONDITIONS – DETECTOR WIDTH

- Penumbra broadening/detector volume effect
  - The ***detector width*** should be entered to RayPhysics during import.
  - Computed curves will then be convolved with a square well function to better match the measured curves.
  - The width shall be the convolution kernel of the detector. Examples can be found in literature, a first guess can be the active volume of the detector
  - The RayPhysics square well convolution will convolve TERMA for photons.
- If measured curves were deconvolved before import:
  - Set detector sizes to 0.
  - No convolution is then applied by RayPhysics.



MEASUREMENT CONDITIONS – DETECTOR WIDTH

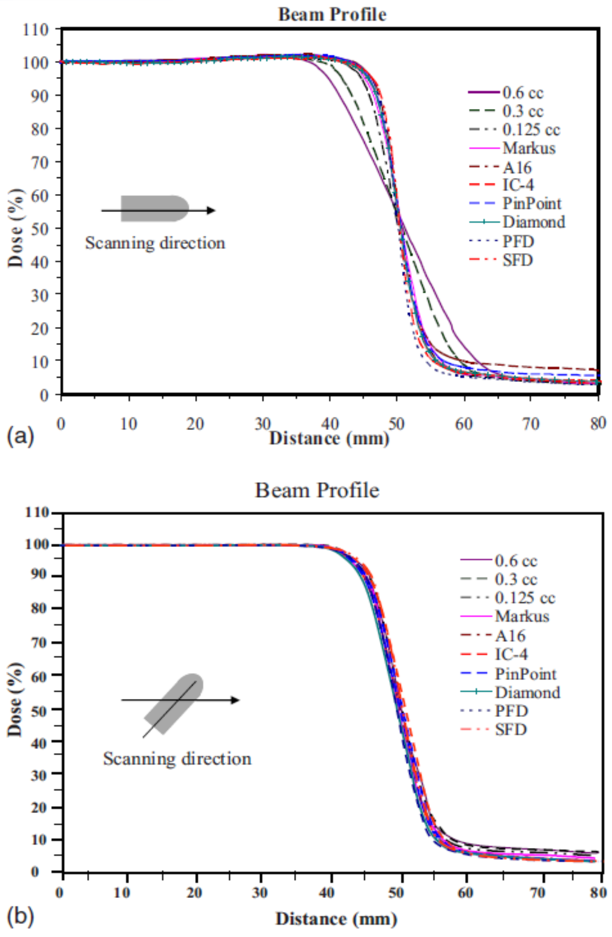
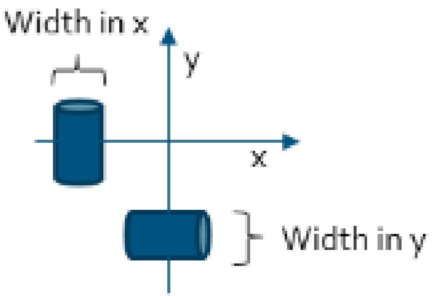


FIG. 11. Effect of chamber orientation on photon beam profiles for a 10 $\times$ 10 cm^2 fields: (a) long axis scan, (b) short axis scan with various size detectors. Only half scans are shown.

Das *et al.*: TG-106: Accelerator beam data commissioning
Med. Phys. 35 (9), September 2008

- ***Detector width*** affects penumbra steepness.
- Detector orientation determines the effective detector width in scanning direction.
- Be careful to use the same orientation in x and y!



- ***Detector width*** also affects output of small fields.

Field	Type	Depth offset [cm]	Detector Height [cm]	Width [cm]
2x2 cm	Depth	0.00	0.20	0.20
2x2 cm	Profile	0.00	0.00	0.20
3x3 cm	Depth	0.00	0.20	0.20
3x3 cm	Profile	0.00	0.00	0.20
4x4 cm	Depth	0.00	0.40	0.40
4x4 cm	Profile	0.00	0.00	0.40

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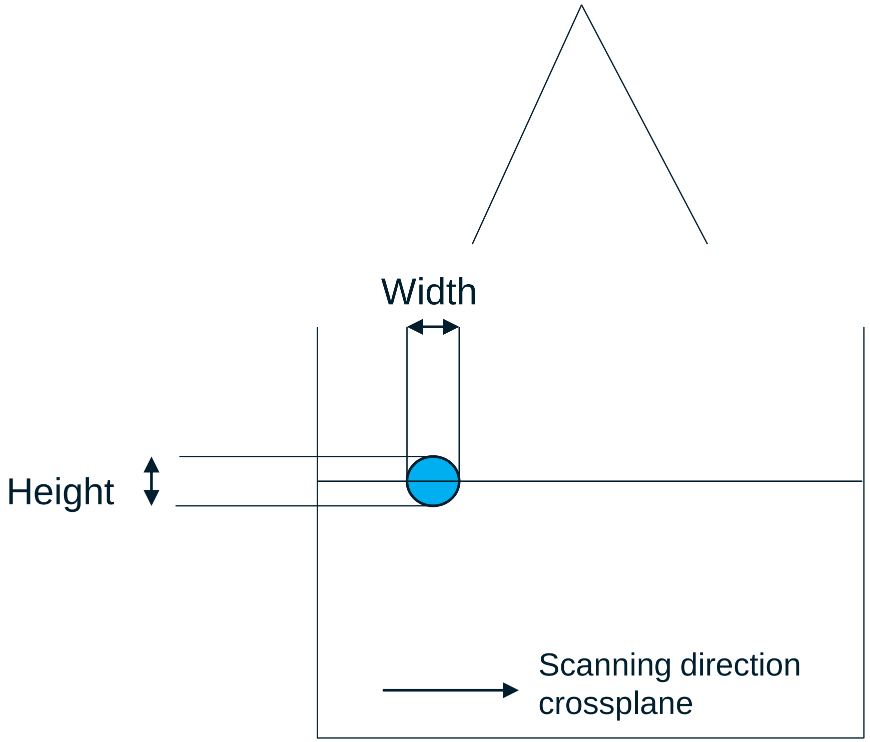
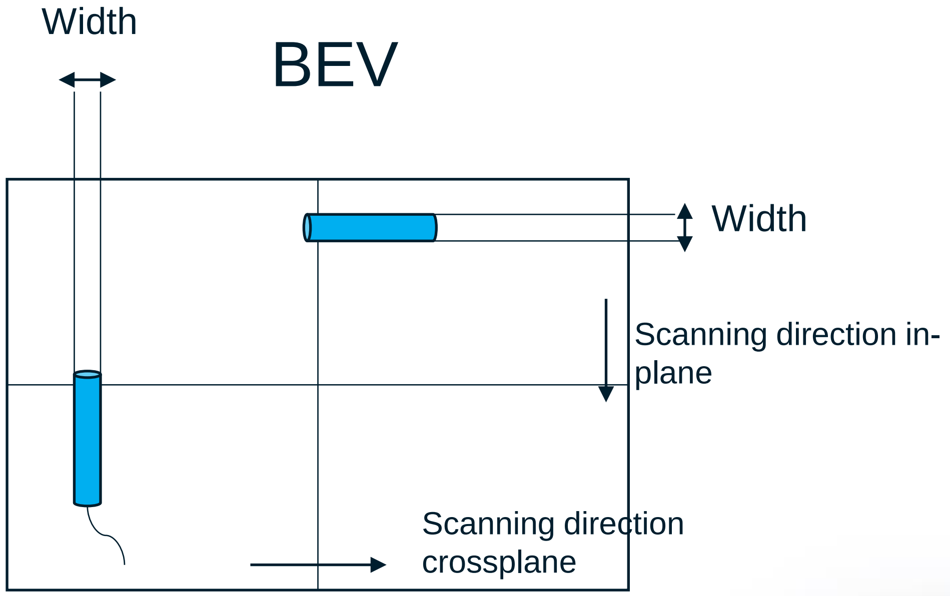
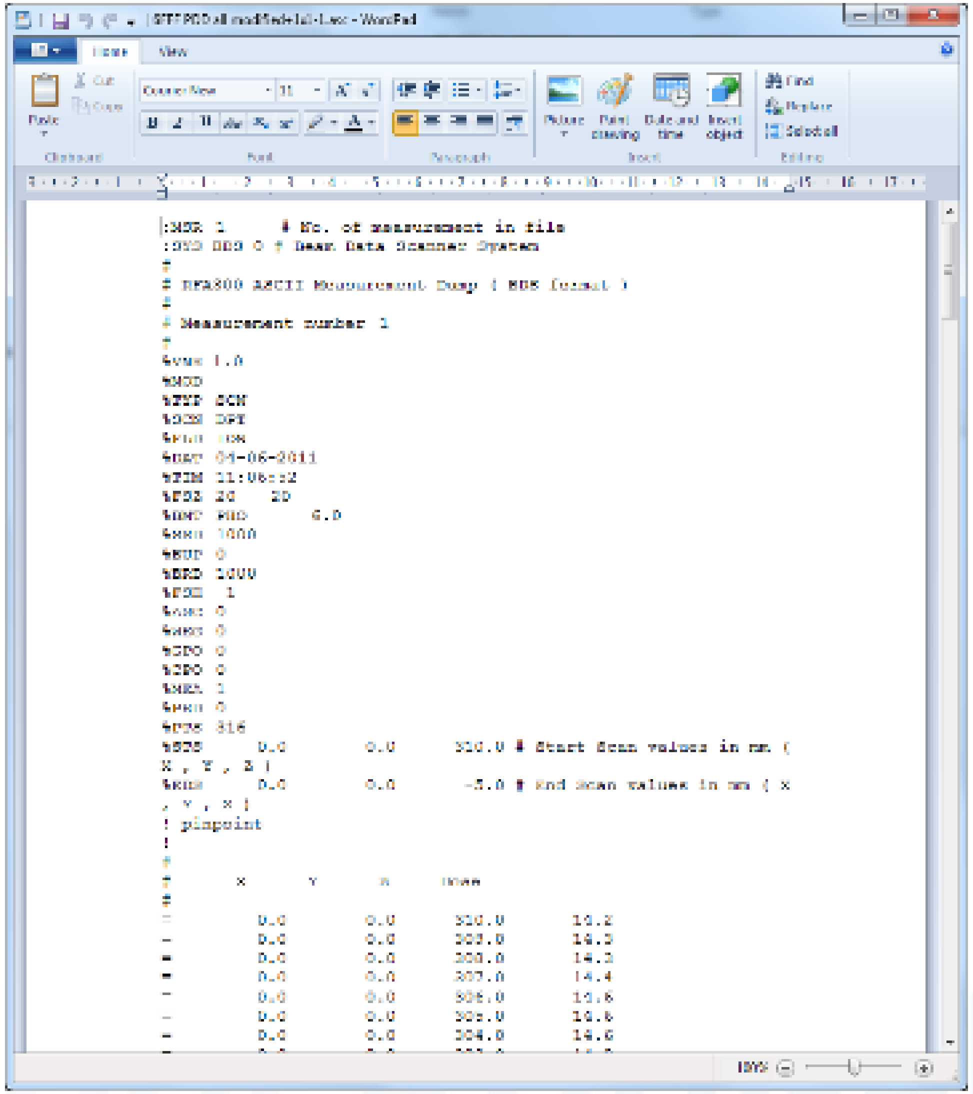
DETECTOR ORIENTATION – HOW TO INTERPRET DETECTOR HEIGHT AND WIDTH IN THE MEASUREMENT SETUP





SUPPORTED CURVE FORMATS



- All supported formats are simple text files with tags and values:
  - Comma-separated values (.csv)
  - RFA (.asc)
  - MEPHYSTO (.mcc)
  - SNC (.snctxt)
  - Brainlab MC (.xmcdat), photons only
- For further format requirements see *RayPhysics Manual Appendix B*.

COMMON ERROR/MESSAGES DURING IMPORT

SSD DOES NOT MATCH

Error message:

Error

SSD value (100 [cm]) does not match machine SSD (200 [cm]) for dose curve #0 in file C:\Users\muhhid\Desktop\RayPhysics Training\MNH\Dose curve data for BC exercises - Photons\Varian iX\6MV_Open.csv

OK

Solution: Change the SSD to the correct SSD used during measurement

Absolute dose calibration point for reference fieldsize

Depth [cm]	20.00
SSD [cm]	200.00
Dose/MU [cGy/MU]	2.0000

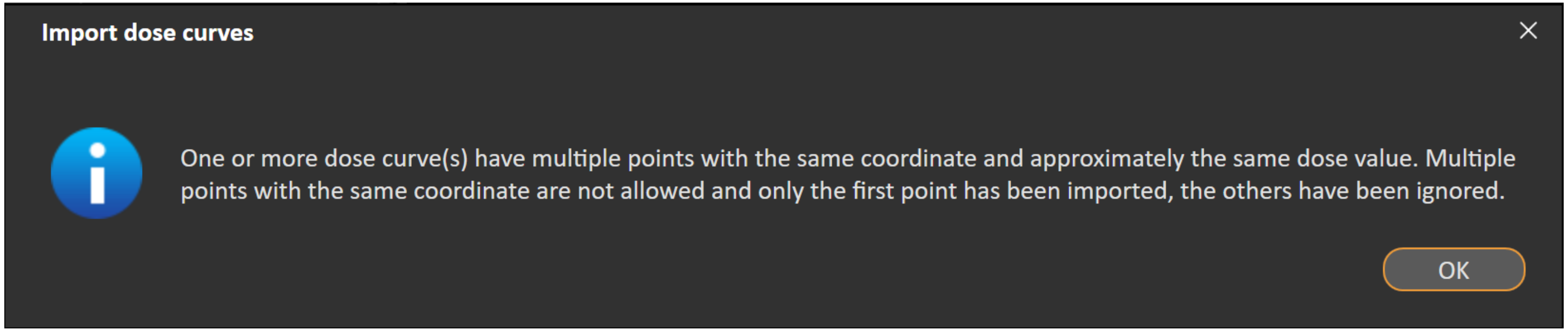
→

Absolute dose calibration point for reference fieldsize

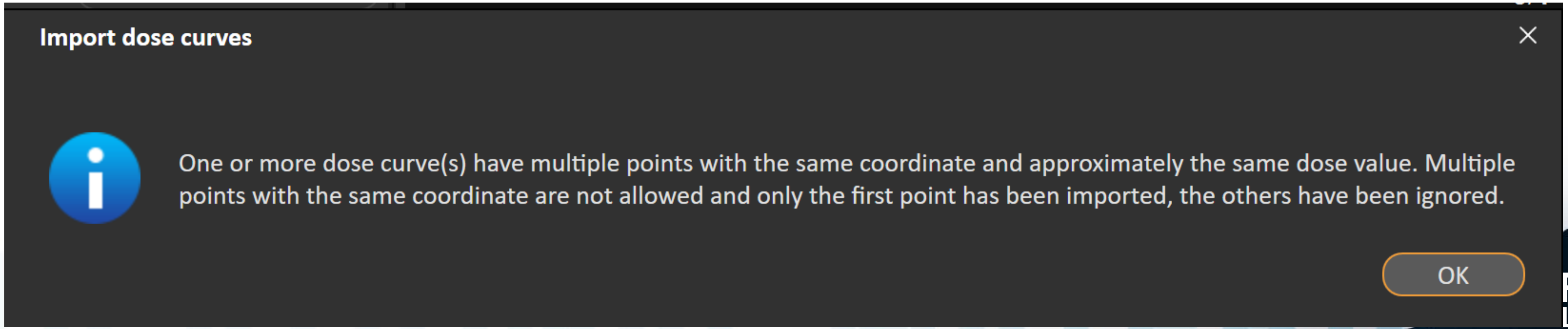
Depth [cm]	10.00
SSD [cm]	100.00
Dose/MU [cGy/MU]	1.0000

DUPLICATED POINTS WITH IDENTICAL DOSE VALUES

Message will appear (before 11B)



11B:



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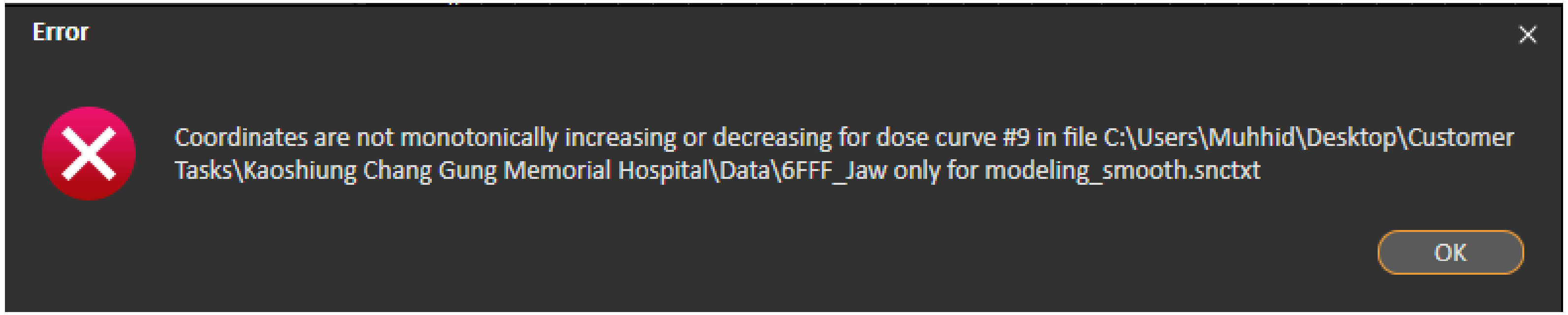
COORDINATES ARE NOT MONOTONICALLY INCREASING OR DECREASING

Error message:



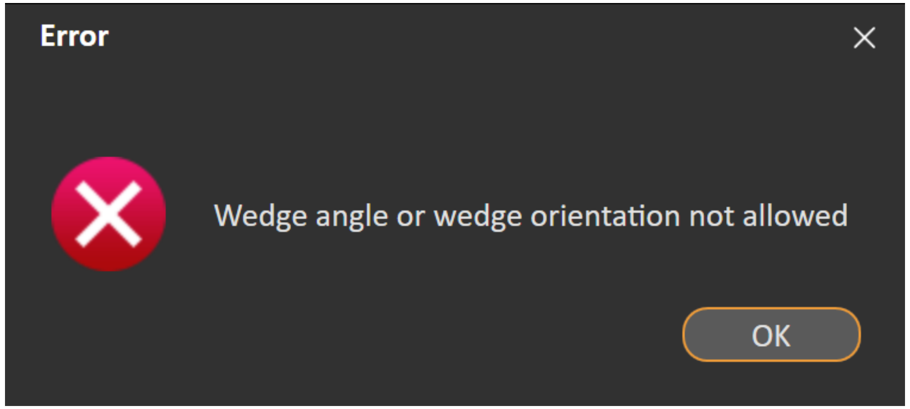
Solution: Remove the data that causes the error.

3510	0	0	29.588	15.2920995178746
3511	0	0	29.463	15.4015832026846
3512	0	0	29.3365	15.4811374234111
3513	0	0	29.3915	15.5172695149741
3514	0	0	29.3565	15.5215958531
3515	0	0	29.322	15.5860128908386

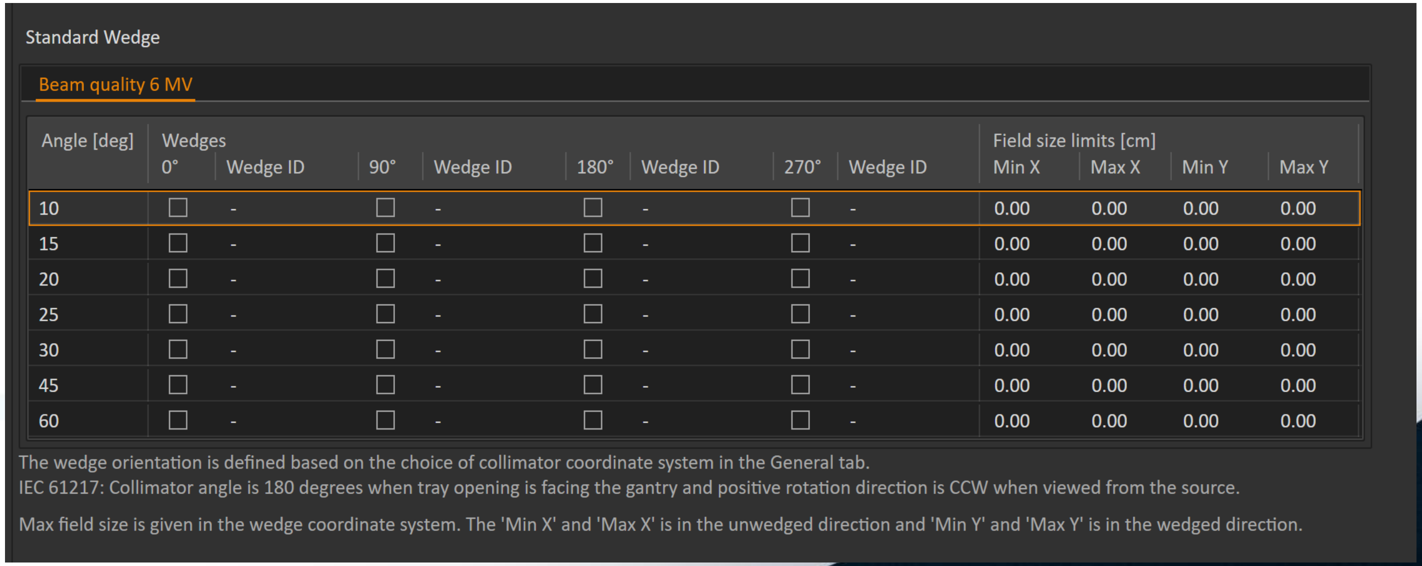
3509	0	0	29.7135	15.2016720241495
3510	0	0	29.588	15.2920995178746
3511	0	0	29.463	15.4015832026846
3512	0	0	29.3915	15.5172695149741
3513	0	0	29.3565	15.5215958531
3514	0	0	29.322	15.5860128908386

WEDGE IMPORT ORIENTATION ISSUE

Error message:



Solution: Check the correct wedge angle and orientation are checked



Standard Wedge

Beam quality 6 MV

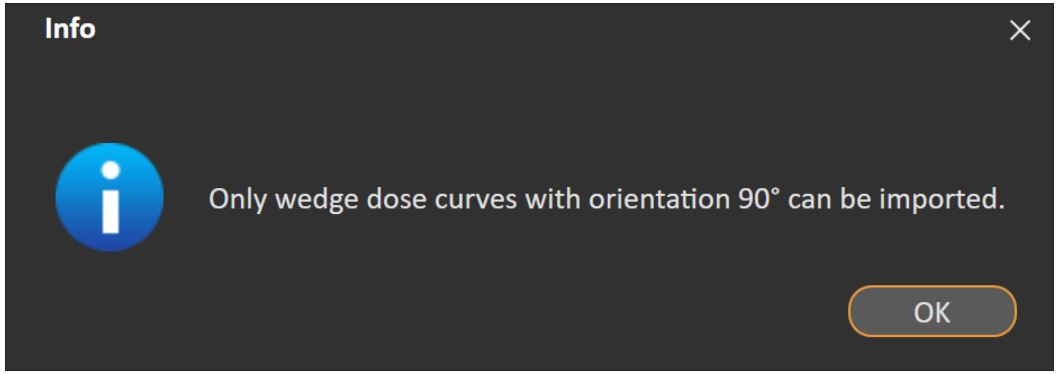
Angle [deg]	Wedges 0°	Wedge ID	90°	Wedge ID	180°	Wedge ID	270°	Wedge ID	Field size limits [cm] Min X	Max X	Min Y	Max Y
10	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00
15	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00
20	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00
25	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00
30	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00
45	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00
60	☐	-	☐	-	☐	-	☐	-	0.00	0.00	0.00	0.00

The wedge orientation is defined based on the choice of collimator coordinate system in the General tab.
IEC 61217: Collimator angle is 180 degrees when tray opening is facing the gantry and positive rotation direction is CCW when viewed from the source.

Max field size is given in the wedge coordinate system. The 'Min X' and 'Max X' is in the unwedged direction and 'Min Y' and 'Max Y' is in the wedged direction.

WEDGE IMPORT ORIENTATION ISSUE

Error message:

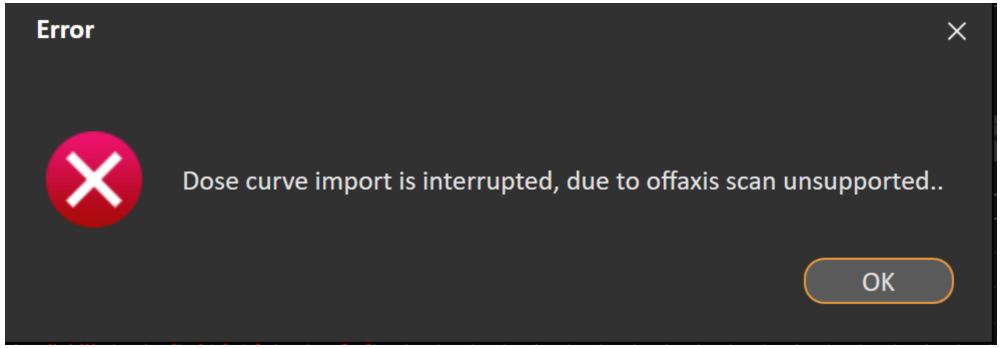


Message appears when trying to import the profile curves after successfully importing the depth dose curve.

Possible Solution: Combine the depth dose curve and profile curves into one file

DOSE PROFILE OFFSET FOR RS8A AND LATER

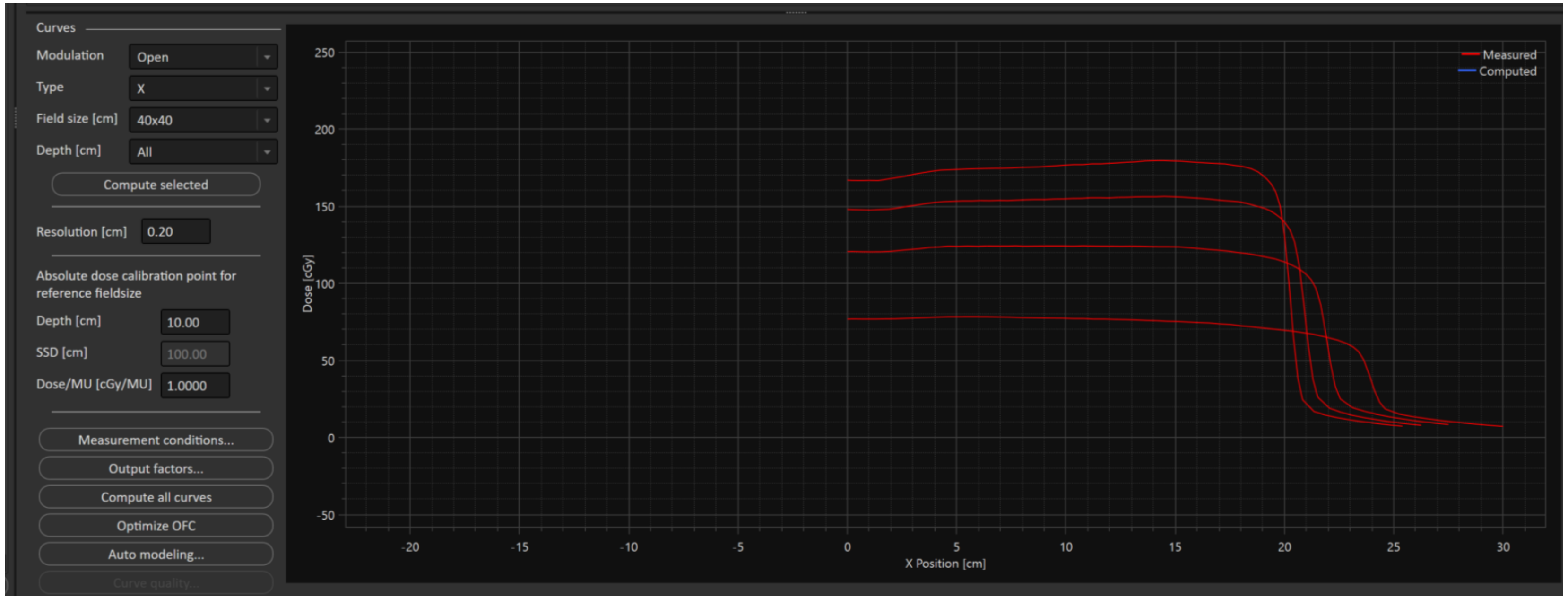
Error message:



Offset in dose profile not supported

Solution: For RSv8A and later, if crossplane profiles were acquired with an offset in the y-direction, then offset has to be the same for **all** field sizes.

PROFILES



Mirror the profile before importing into RayPhysics.