LINAX TECHNOLOGIES
VIRTUAL RADIATION SYSTEMS

TRAINING COURSE

Matching out of tolerance to QA results to linac adjustments and dose prediction

QA Profile interpretation for service and clinical interpretation.

Marco Carlone

30 minutes

Agenda

01 A digital representation of a real linac – why?

02 Beam symmetry effect

03 Steering dose effects

04 Energy – flatness dose effects

05 Summary – all effects combined

BY THE END OF THIS MODULE

Learning objectives

01

Introduce linac simulation

A digital linac concept is introduced.

02

Review symmetry cause and effect

Physical cause of asymmetry and an example.

03

Review flatness cause and effect

Physical cause of flatness and an example.

04

Interpret tolerance effect on dose dose distribution

Interpretation of out of tolerance errors on the dose distribution

01

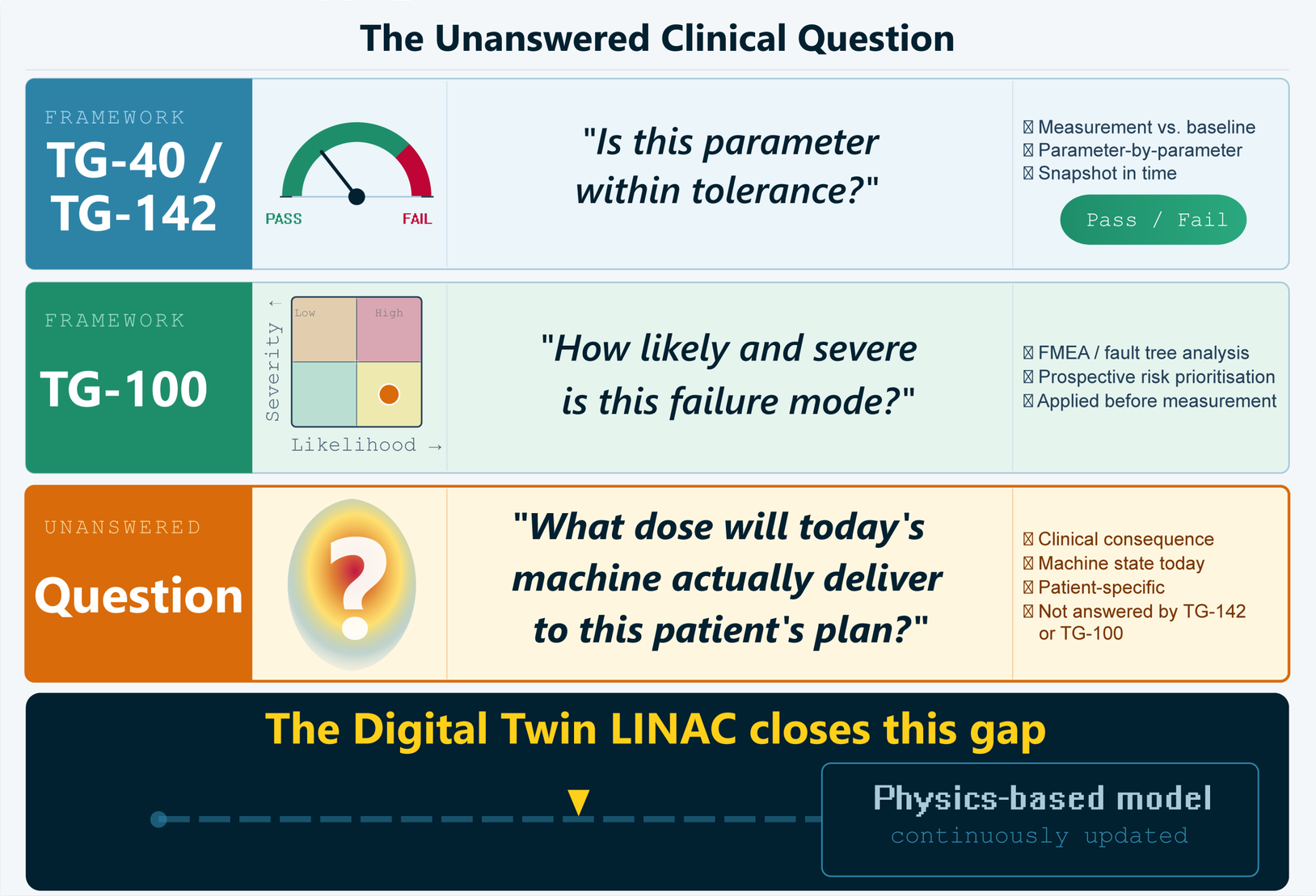
A digital representation of a real linac – why?

Physical models for the linac to help interpret results.

THE PROBLEM

Two Frameworks. One Missing Question.

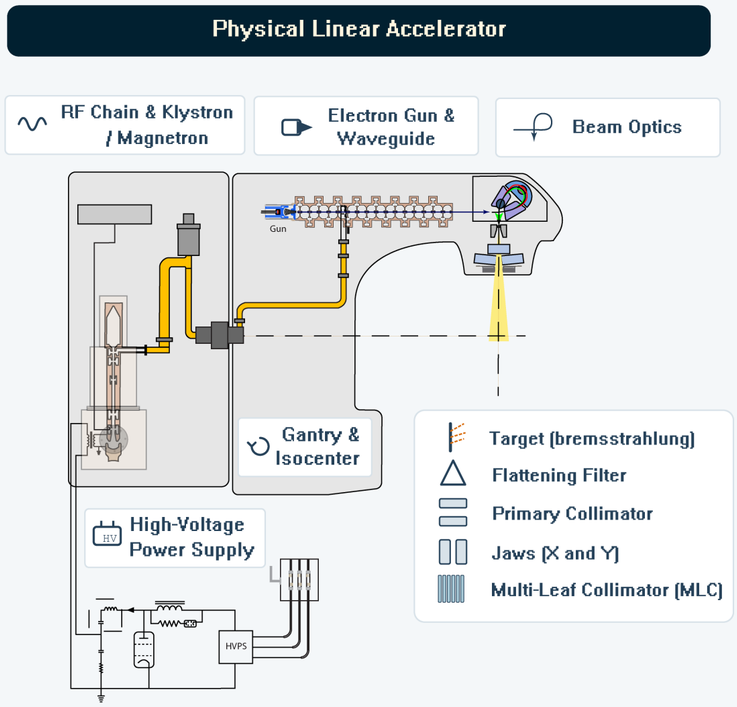
- **TG-40 / TG-142 asks:** is this parameter within tolerance? — a parameter-by-parameter snapshot against a fixed baseline.
- **TG-100 asks:** how likely and severe is this failure mode? — a prospective judgment made before any measurement is taken.
- **Neither asks:** what dose will today's machine actually deliver to a real patient's plan, given everything measured right now?

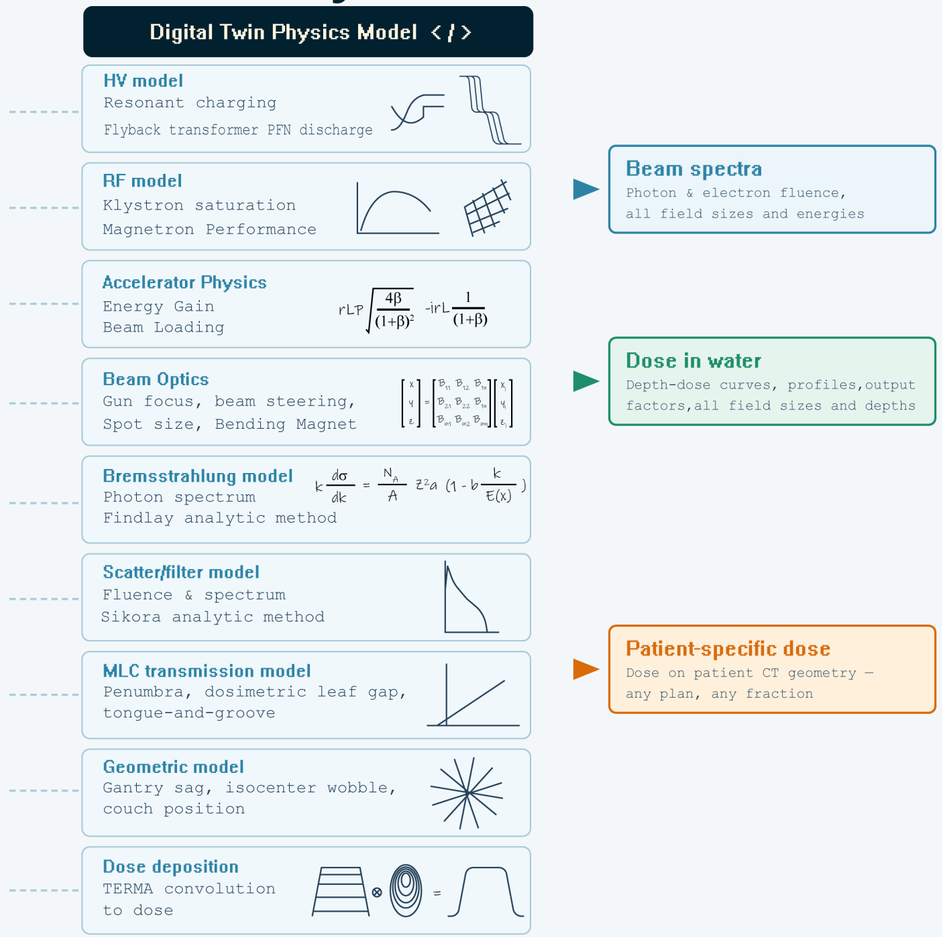


Digital Twin → *Physical Model + QA Data + Dose Calculation*

- **Built from physics, not curve-fits:** first-principles models of the HV supply, RF chain, target, flattening filter, jaws/MLC, gantry, and dose-calculation chain.
- **Extrapolates safely:** a physical model stays valid at field sizes and geometries never directly measured at commissioning.
- **Updated from data you already collect:** routine QA measurements refit the model — no new Monte Carlo runs, no full water-tank recommissioning.

Digital Twin Architecture: From Subsystems to Dose





Model parameters are fit to commissioning measurements at installation and updated continuously from routine QA data.

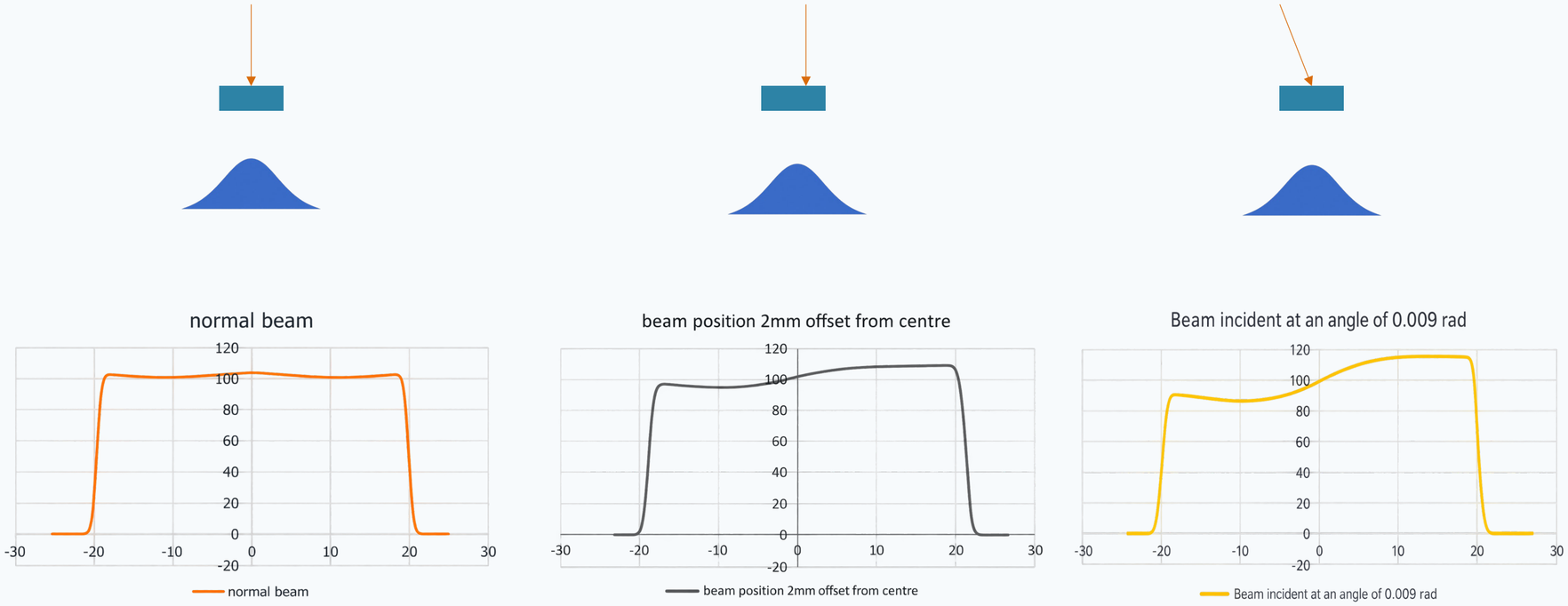
02

Beam symmetry effect

Modelling beam symmetry, and propagating to a dose distribution.

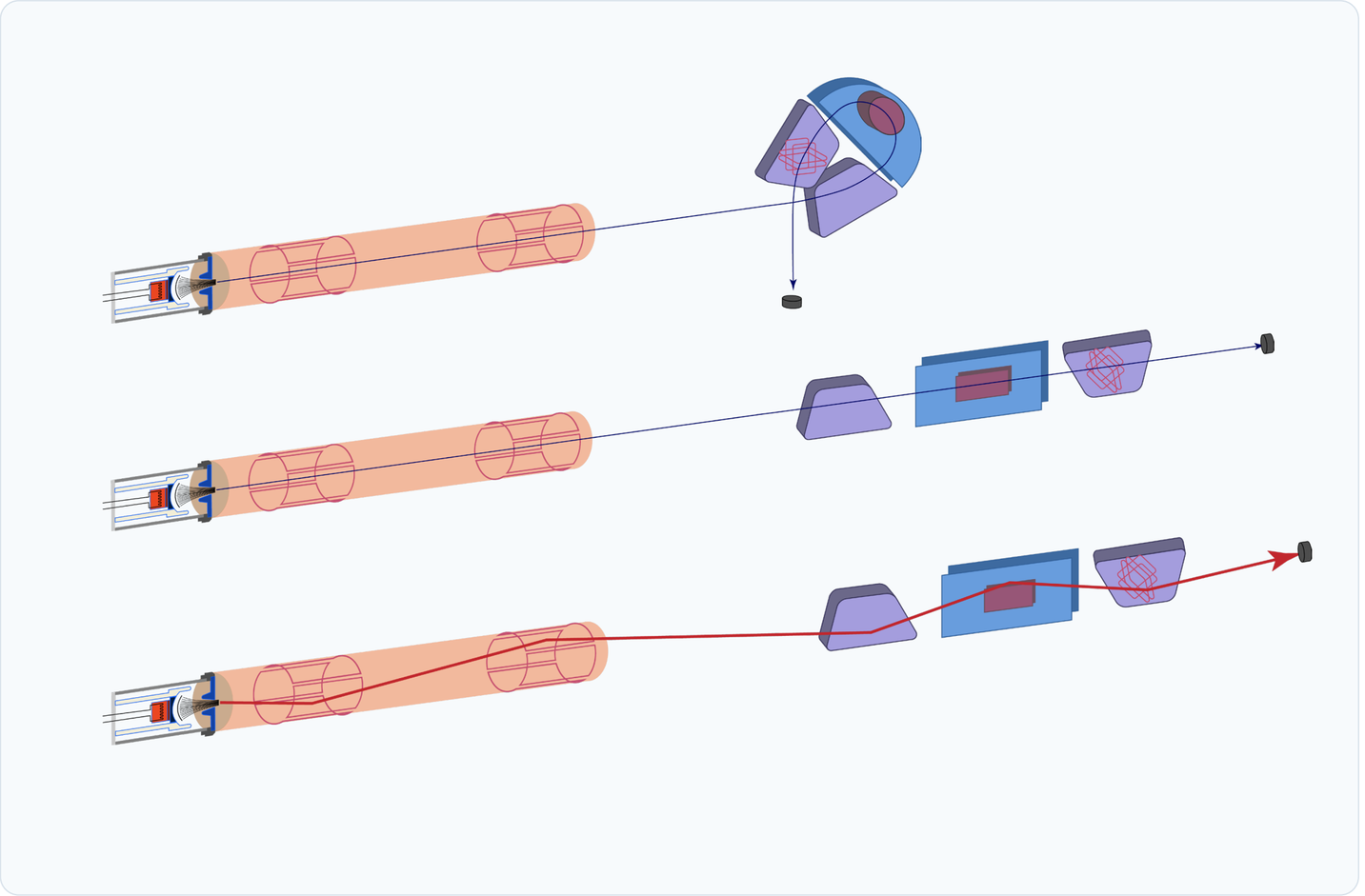
Beam symmetry

- Asymmetry is a result of a misalignment between electron beam/target/flattenig n filter
- Many reasons for asymmetry
  - Unstable emission position
  - Deflections from earth's magnetic field
  - Component shifts
- To correct an asymmetry, the steering system is used to reposition the electron beam.



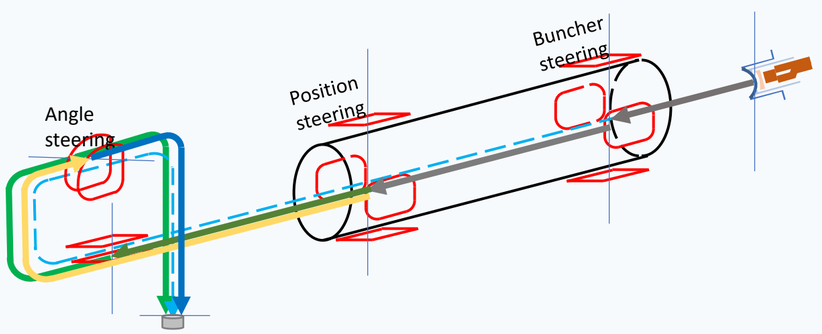
Steering model - Varian

- Varian beamline is illustrated at the top.
- In the middle figure, the beamline is unfolded so that it goes straight.
- The bending magnet elements are not in line.
- The deflections from each steering coil or bending magnet element are illustrated.
- The beam position and angle if incidence of the beam on the target can be estimated.



Steering model

- The steering model consists of the positions of the elements that affect beam deflection in the beam path.
- Each element will generate a deflection.
- The longer the path from the deflection to the target, the greater the effect on symmetry.
- **Varian: buncher coil has the greatest effect**
- **Elekta: 1 coil has the greatest effect.**



d_{GB} = distance gun to buncher coil

d_{BP} = distance buncher to position coil

d_{PA_trans} = distance position to angle coil transverse direction

d_{AT_trans} = distance angle coil transverse direction to target

d_{PA_radial} = distance position to angle coil radial direction

d_{AT_radial} = distance angle coil radial direction to target

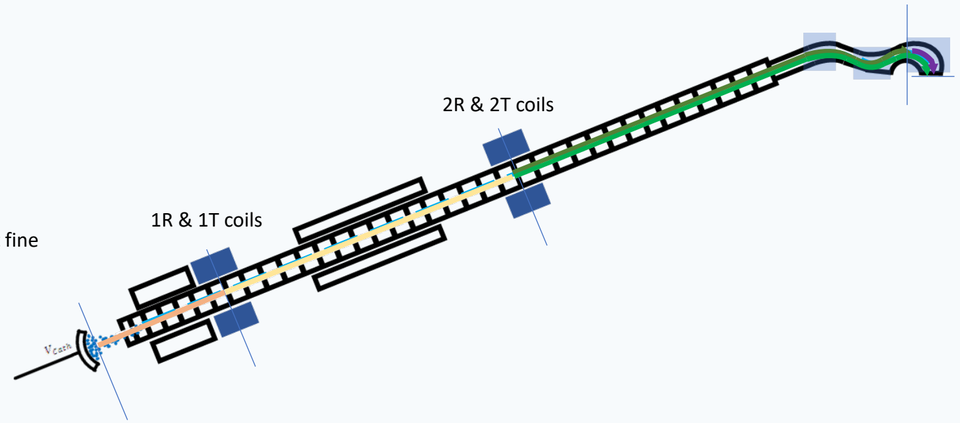
d_{GC1} = distance gun to coil 1

d_{C12} = distance coil 1 to coil 2

d_{C2BMF} = distance coil 2 to bending magnet fine

d_{C2T} = distance coil 2 to target

d_{BMFT} = bending magnet fine to target



03

Steering dose effects

How asymmetric beams affect the patient dose distribution.

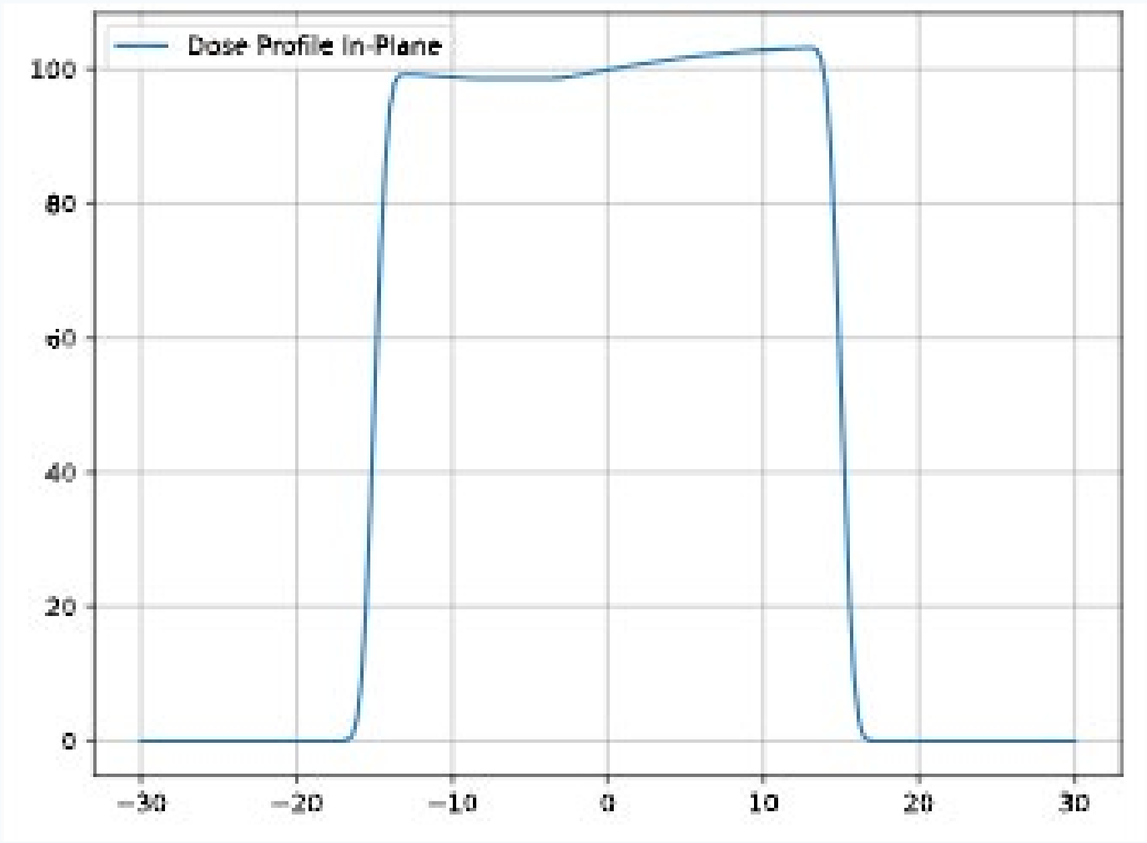
Symmetry fault simulation

Machine settings
- B Mag = 16.6 A
- PFN V = 7.768
- Grid = 112.1 V

Simulated gun error
- 0.5 mm

Profiles:
- Symmetry = 1.040
- PDD10 = 70.30

Beam
- FS = 30 x 30
- Open loop dose rate = 684 MU/min



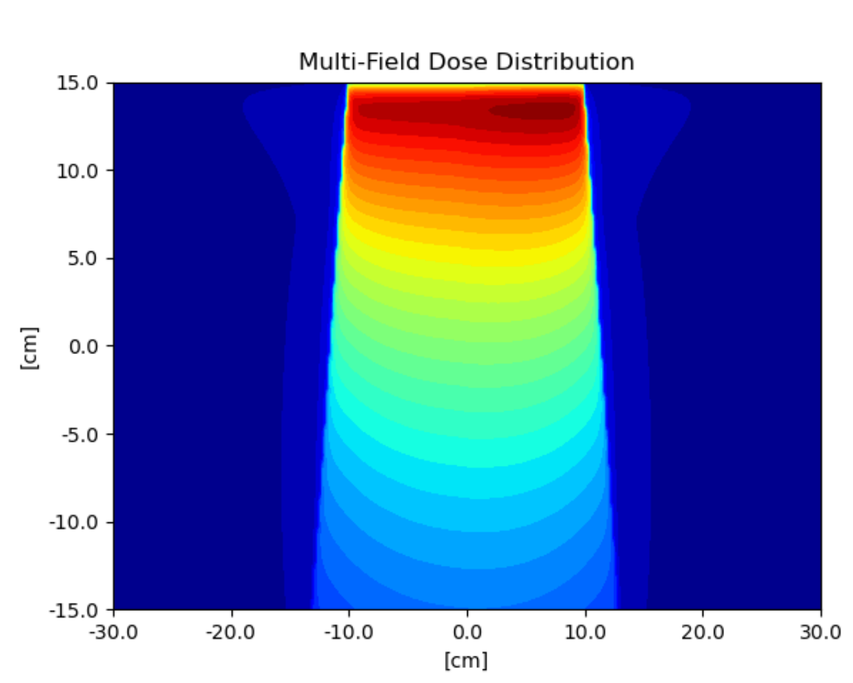
Symmetry fault simulation

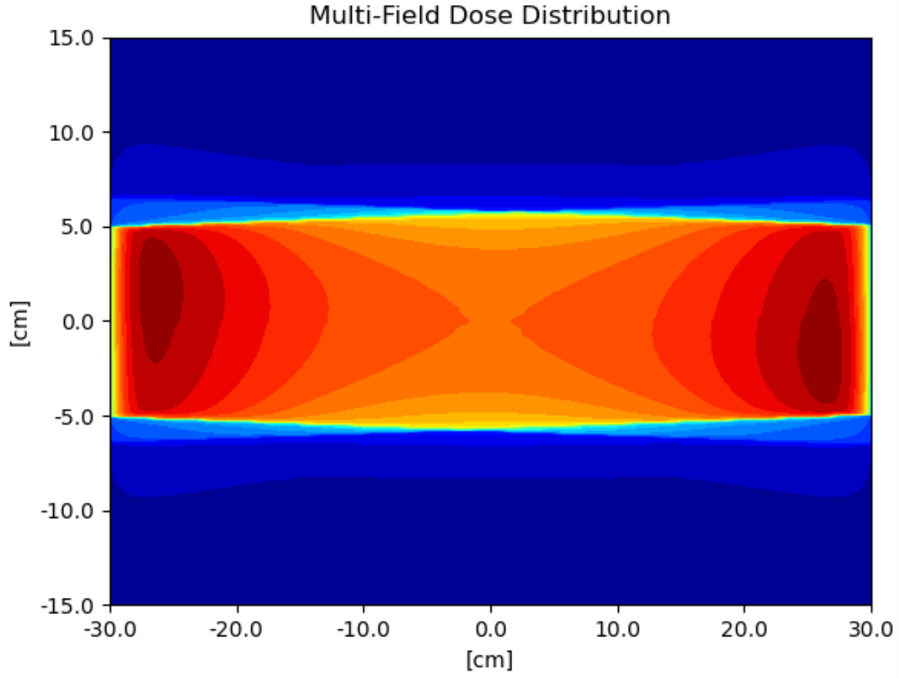
Machine settings
- B Mag = 16.6 A
- PFN V = 7.768
- Grid = 112.1 V

Simulated gun error
- 0.5 mm

Profiles:
- Symmetry = 1.040
- PDD10 = 70.30

Beam
- FS = 30 x 30
- Open loop dose rate = 684 MU/min





Symmetry fault simulation

Machine settings

- B Mag = 16.6 A
- PFN V = 7.768
- Grid = 112.1 V

Simulated gun error

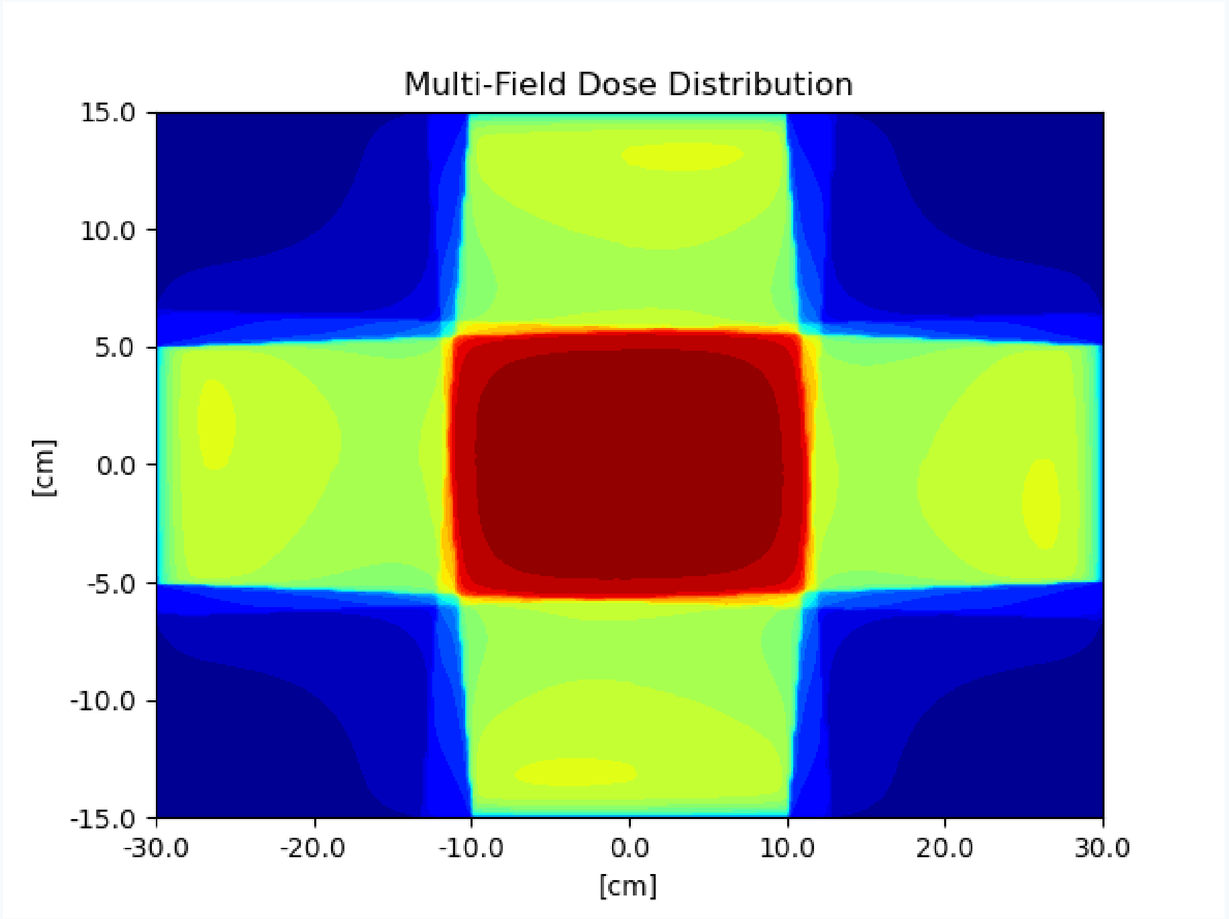
- 0.5 mm

Profiles:

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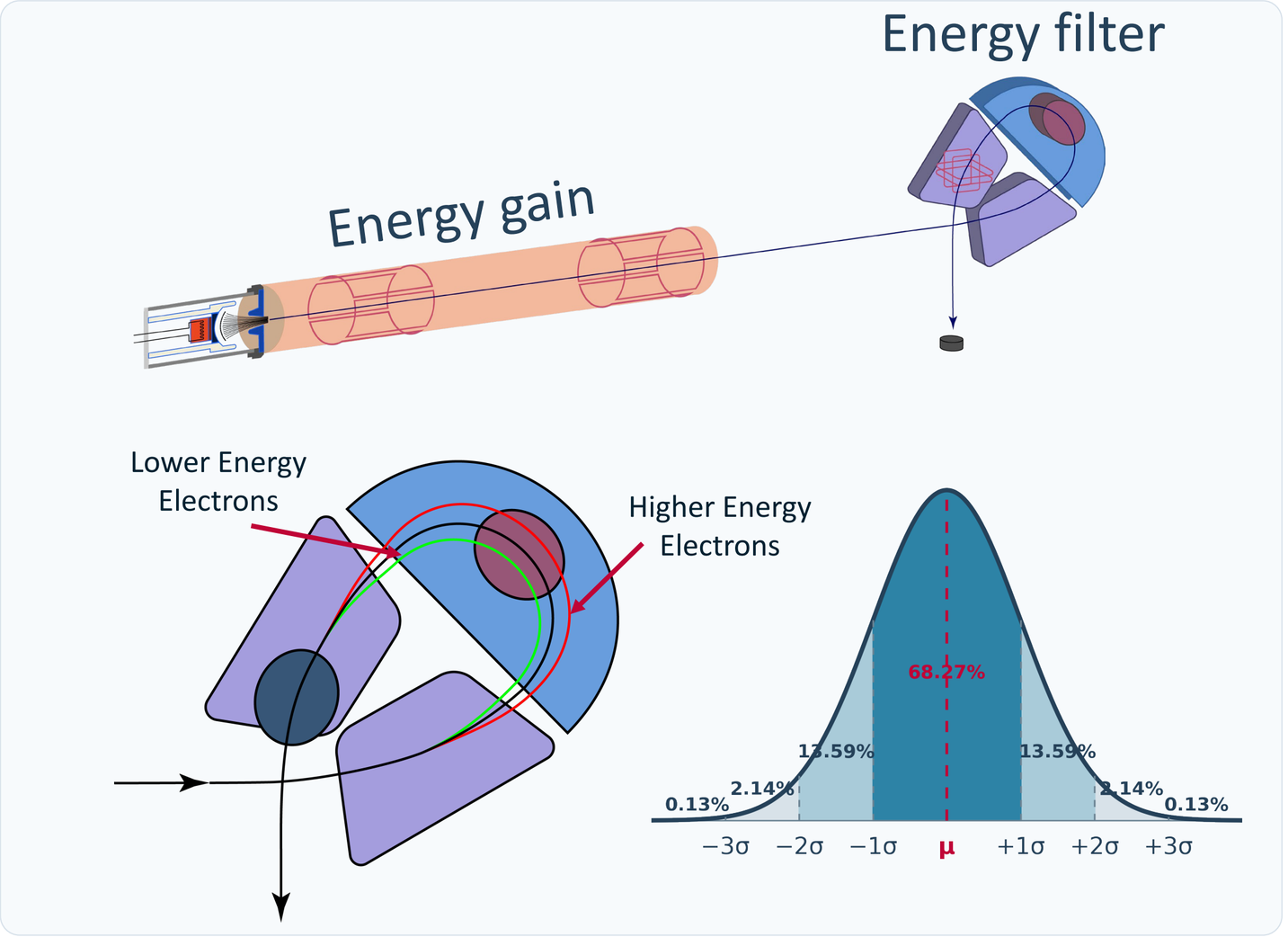
04

Energy – flatness dose effects

How beam energy affects flatness and dose distribution .

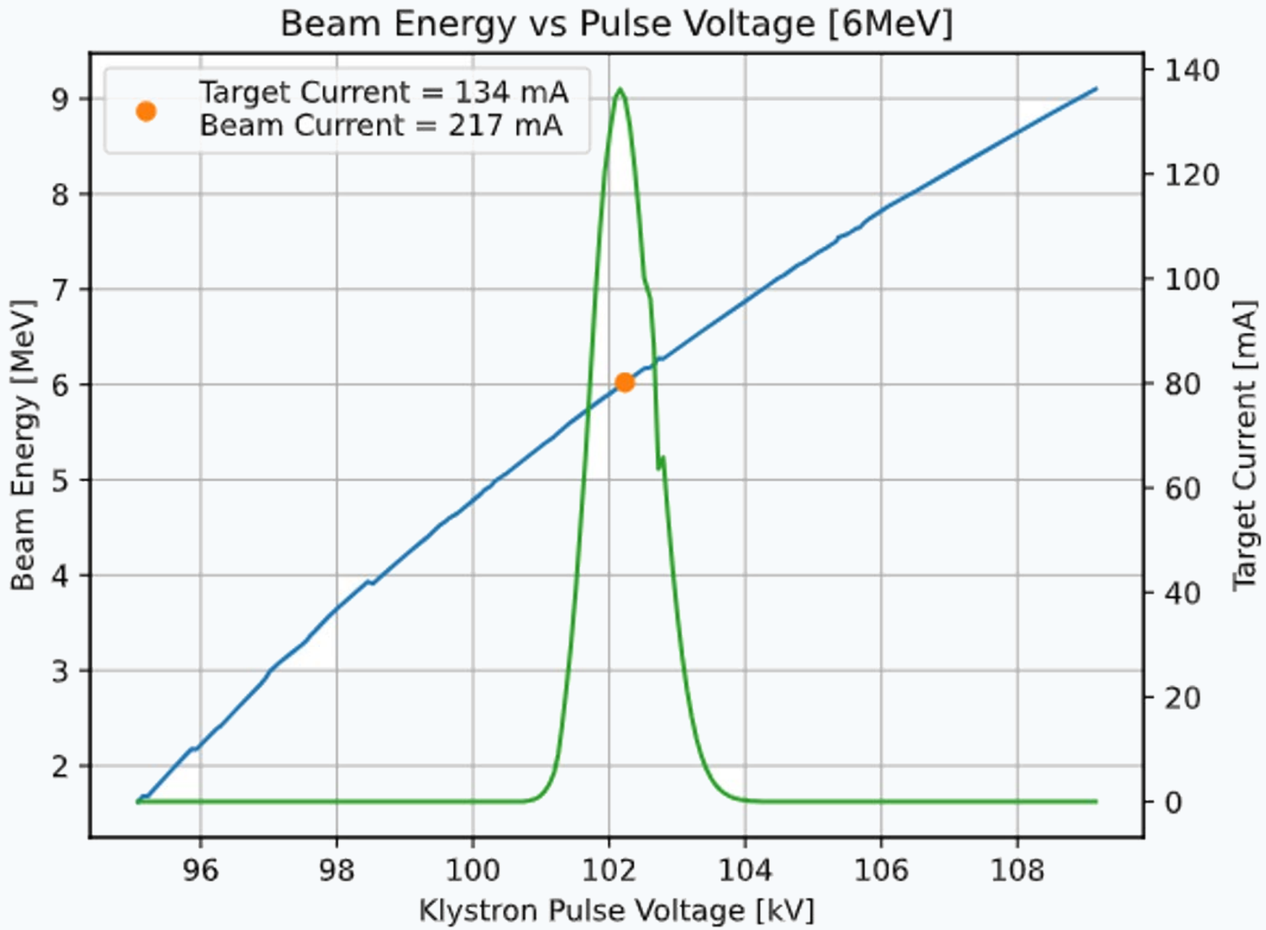
Energy balance in the beamline

- The accelerating waveguide accelerates the electron beam.
- The bending magnet acts as an energy filter.
- Only the correct electron beam energy gets through the bending magnet to the target,
- Electron beams with too high or too low an energy will be cutoff.
- The electron beam has a distribution of energies, so some will be cut off before making it to the target.



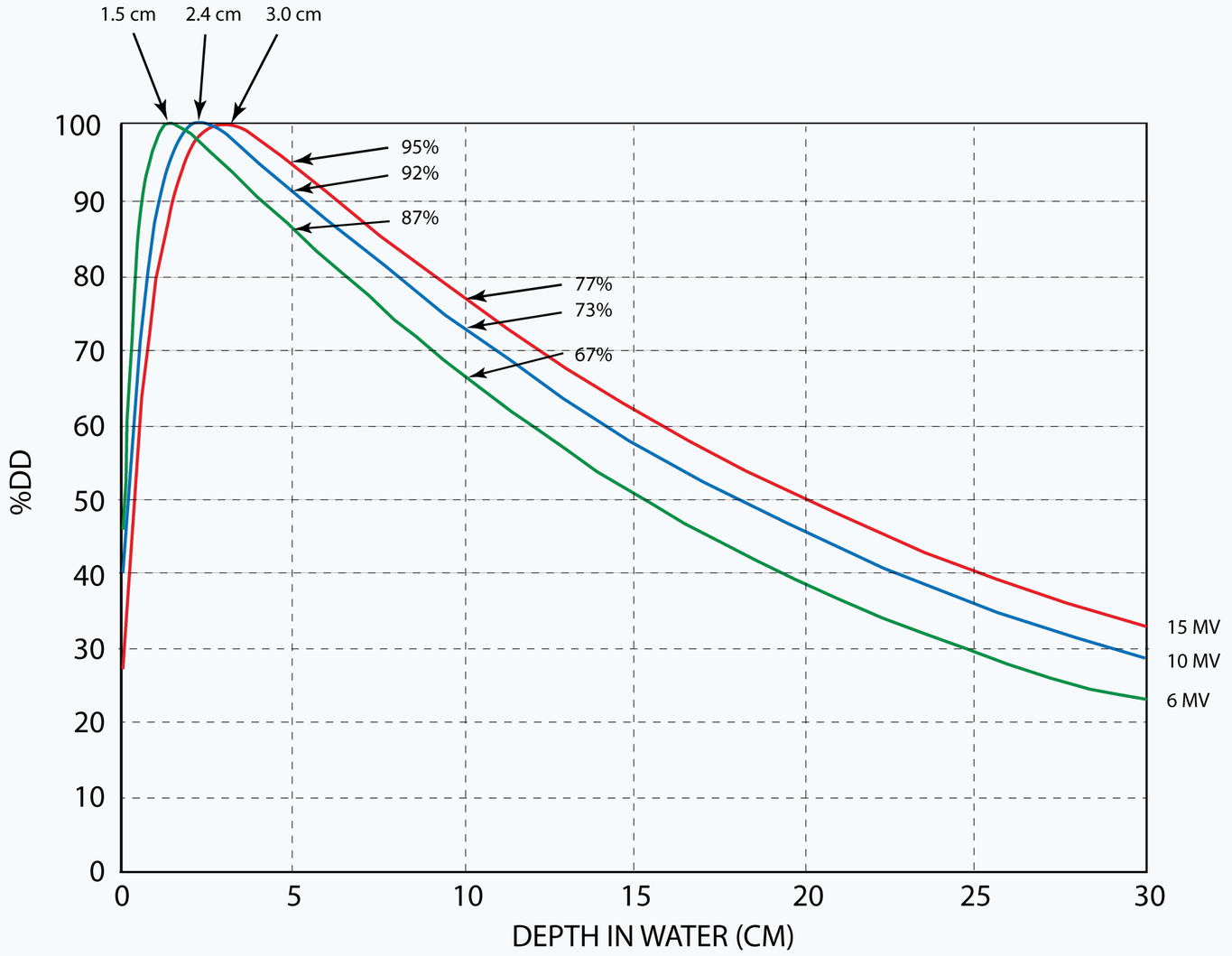
Beam (dose) peaking

- Illustration of a beam peaking procedure.
- The klystron pulse voltage is swept from a low value, 96 kV, to a high value, 108 kV.
- The accelerator beam energy is affected by the klystron mpulse voltage.
- The bending magnet is set to allow 6 MeV electron pass through.
- The beam is “peaked” or the dose rate maximized when the accelerator beam energy matches the bending magnet pass through energy.



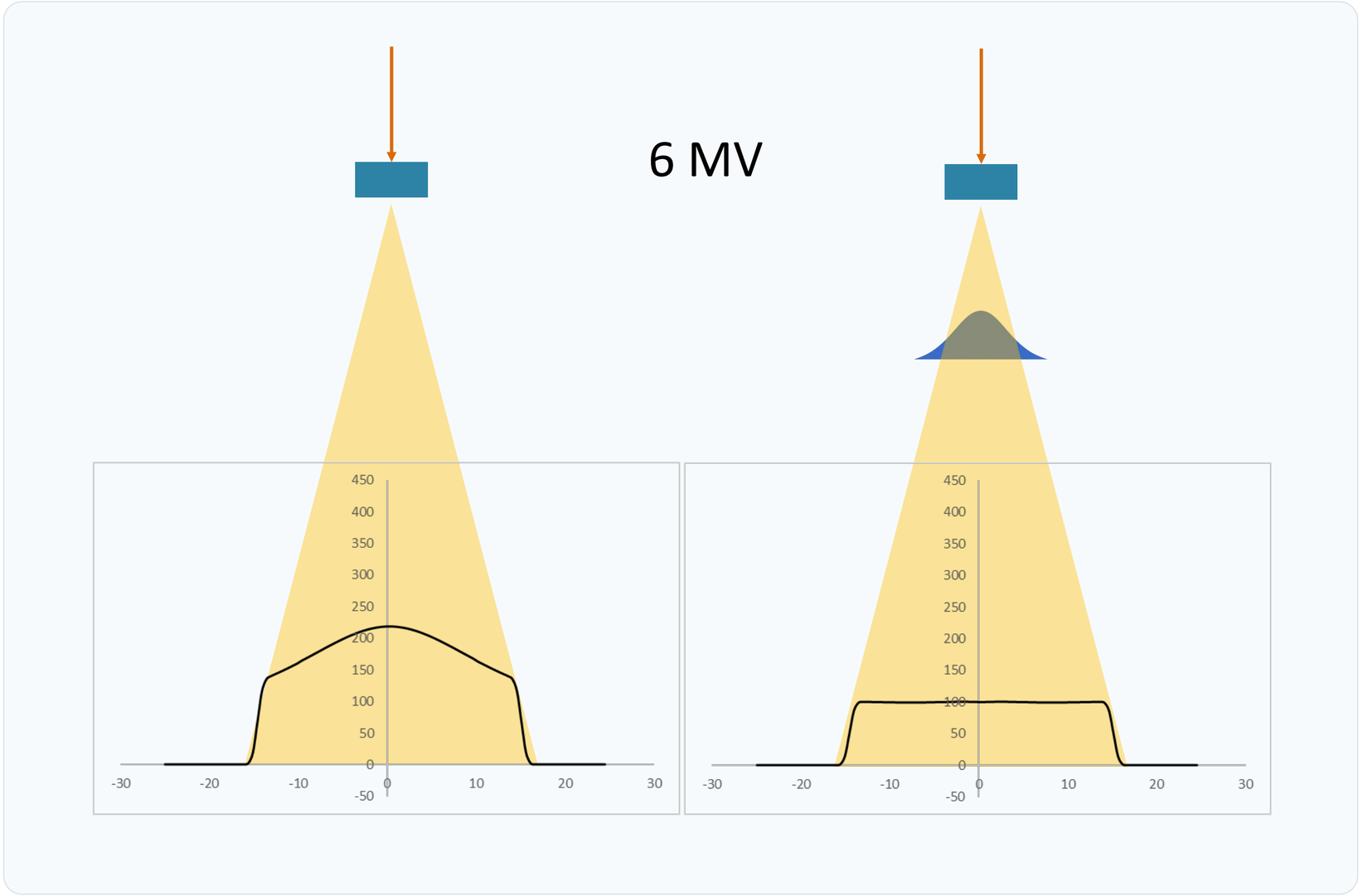
Energy measurement

- The PDD is the most common way of assessing photon beam energy.
- Higher energy beams penetrate further than lower energy beams.
- The plot translates well to clinical properties: i.e. patient dose at depth.
- It is not a real measure of beam energy
- It is a surrogate measurement.
- Beam flatness is also sensitive to beam energy.



Beam Flatness

- The radiation beam intensity profile is non-uniform.
- It is much more intense at the beam center.
- Flattening filters are used to produce a uniform intensity beam.
- The beam attenuation depends on both the beam energy and flattening filter shape.
- 6 MV example is shown

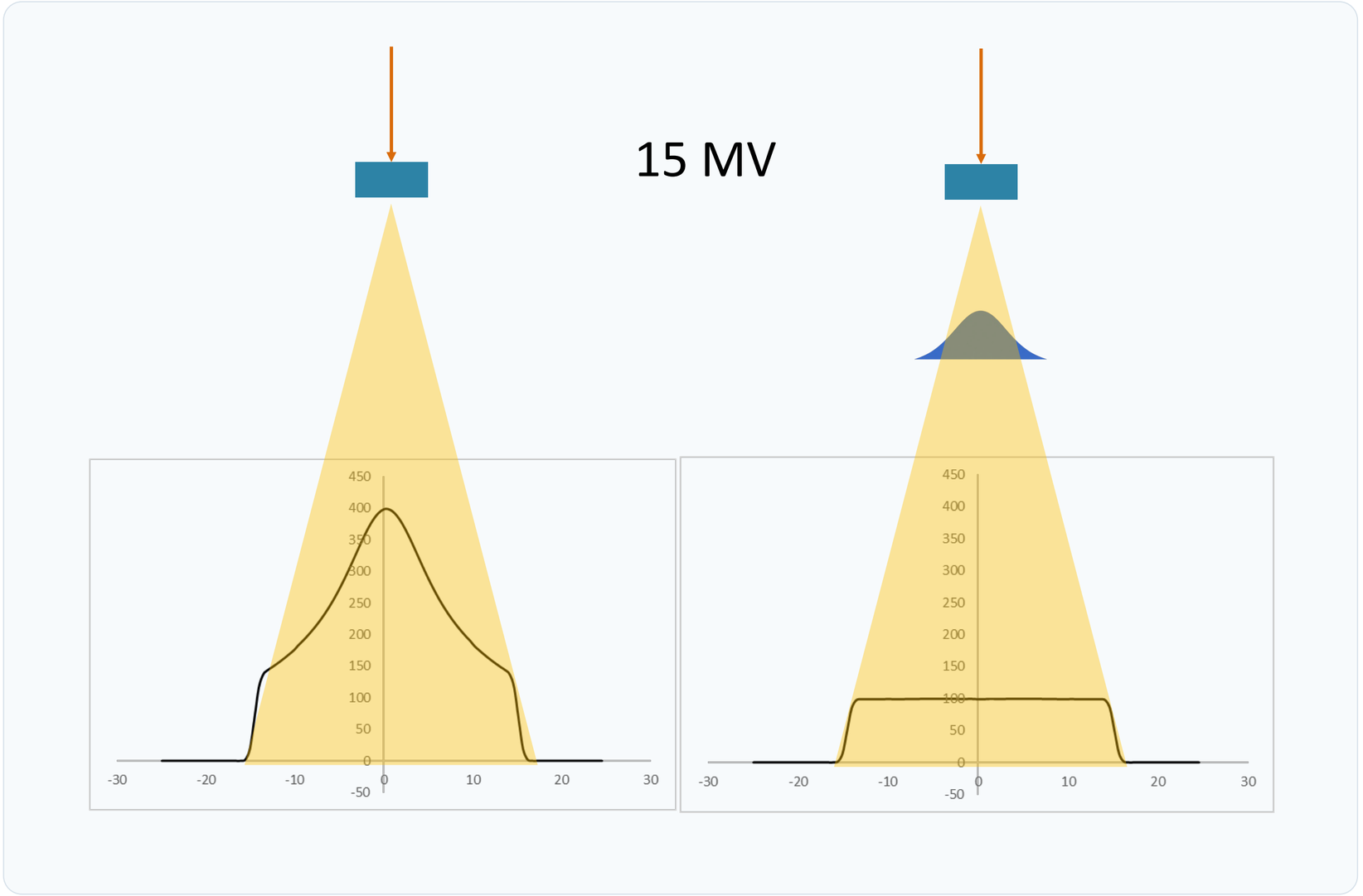


Un-flattened beam

Flattened beam

Beam Flatness

- 15 MV example is also shown.
- The beam is more forward directed than the 6 MV beam.
- The flatening filter must be taller to match the beam energy.

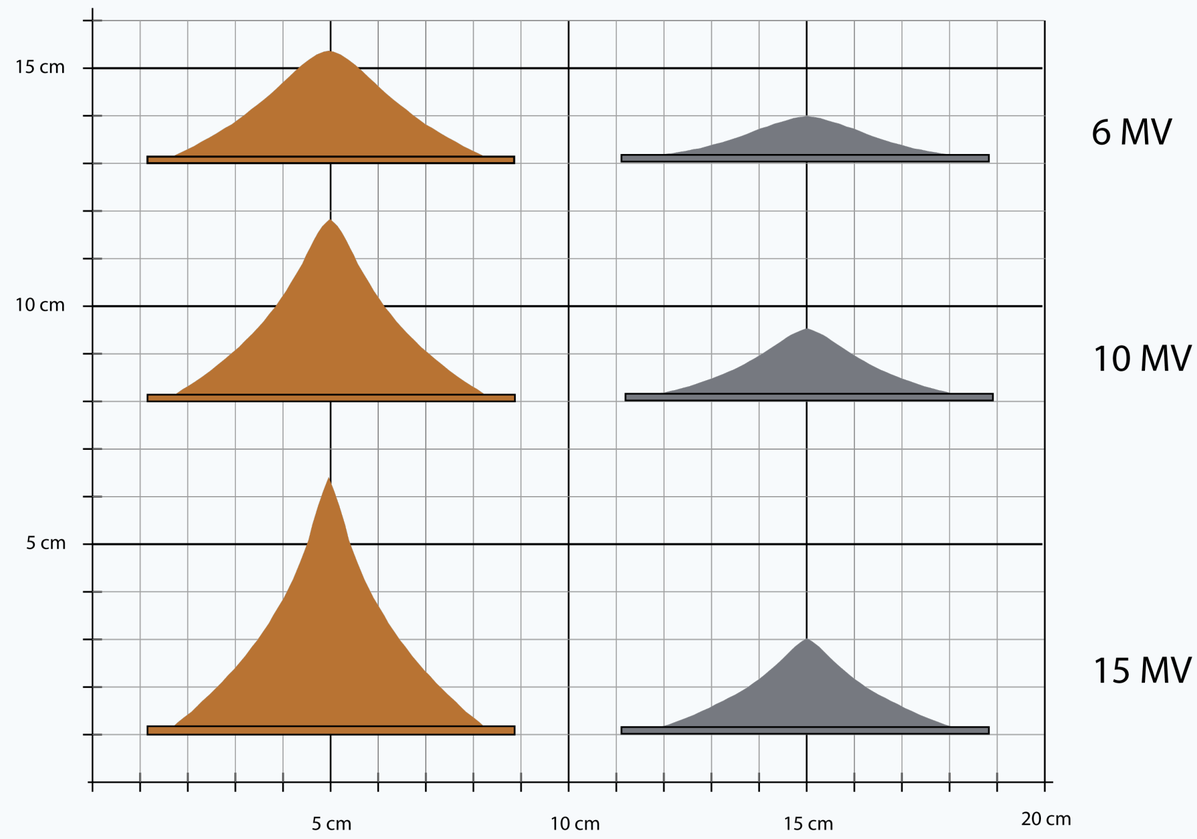


Un-flattened beam

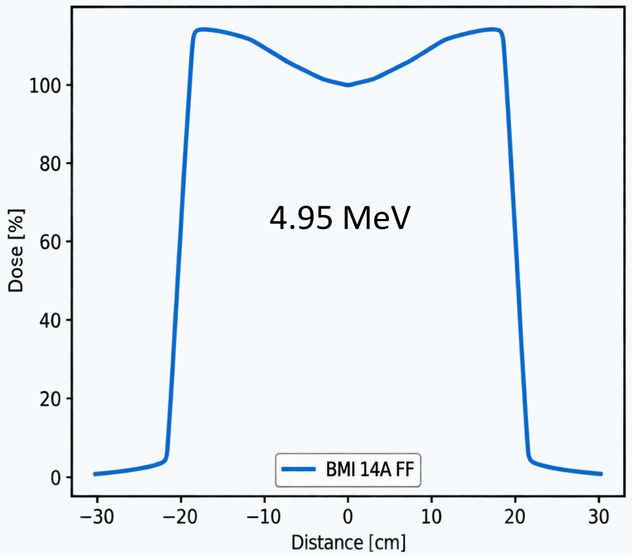
Flattened beam

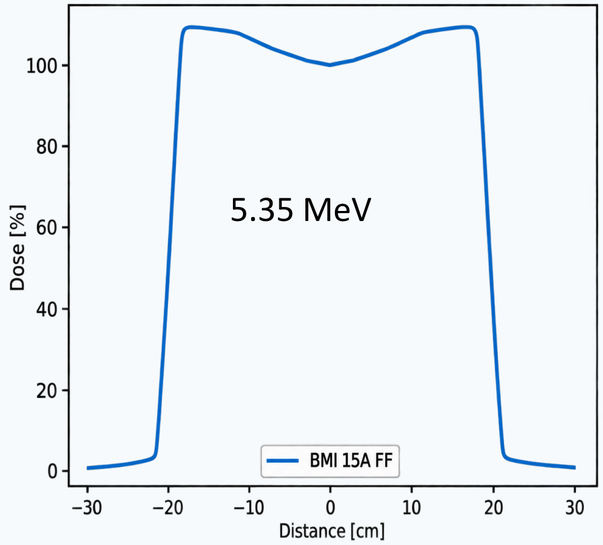
Example Flattening Filters

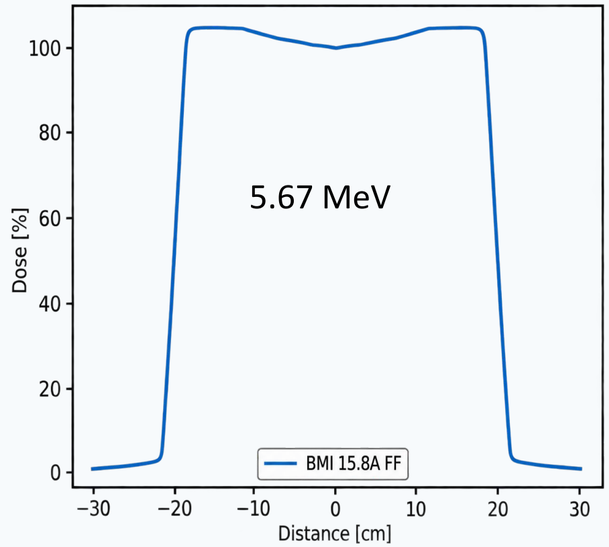
- Schematics of flattening filters for common beam energies
- Size is proportional to realistic flattening filter differences for different beam energies
- Filters on the left are made of Copper
- Filters on the right are made of Tungsten

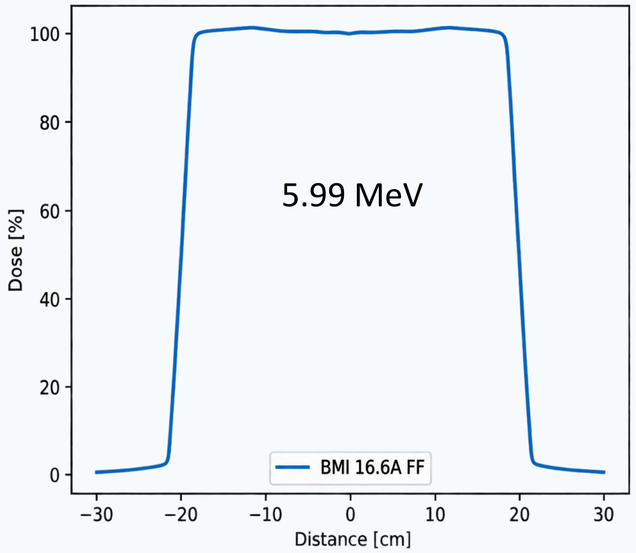


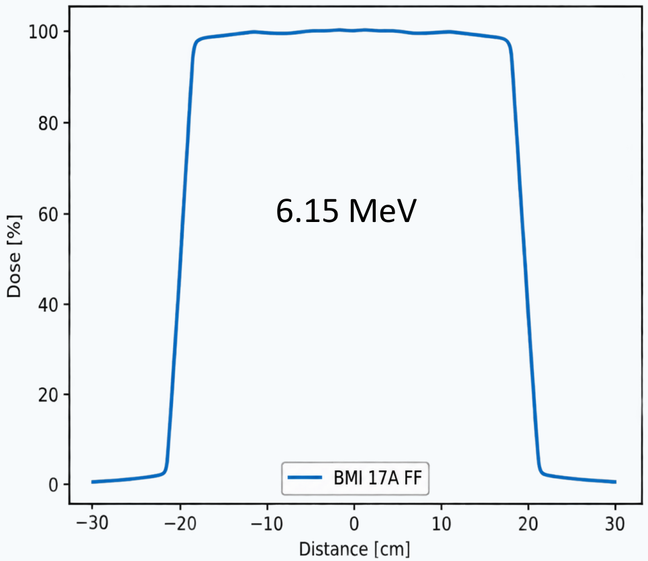
Profile flatness is a very good measure of energy

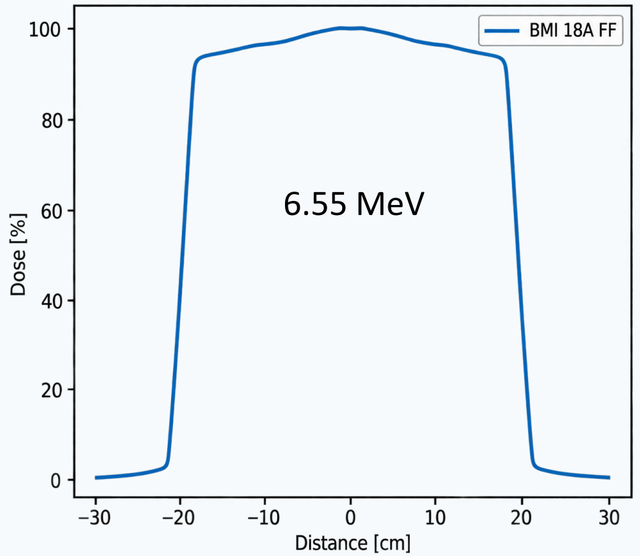












Energy fault simulation

Machine settings

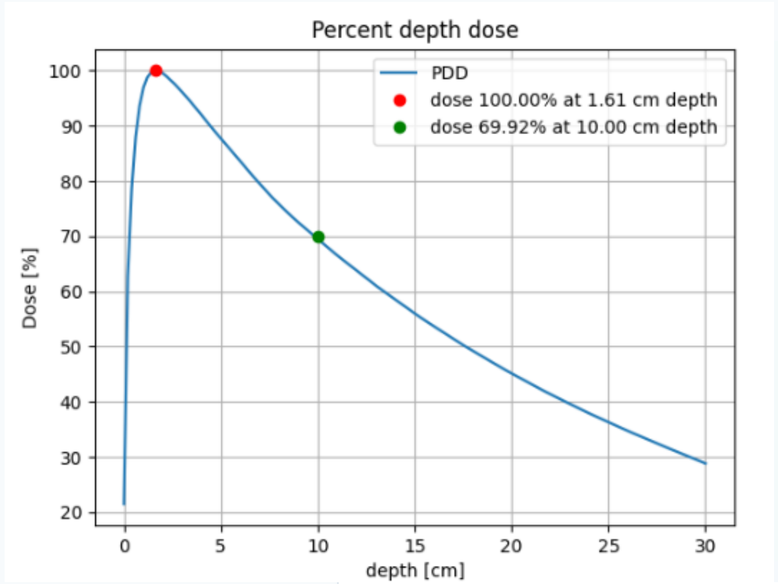
- B Mag = 16.0 A
- PFN V = 7.72
- Grid = 112.1 V
- Energy slit = 0.03

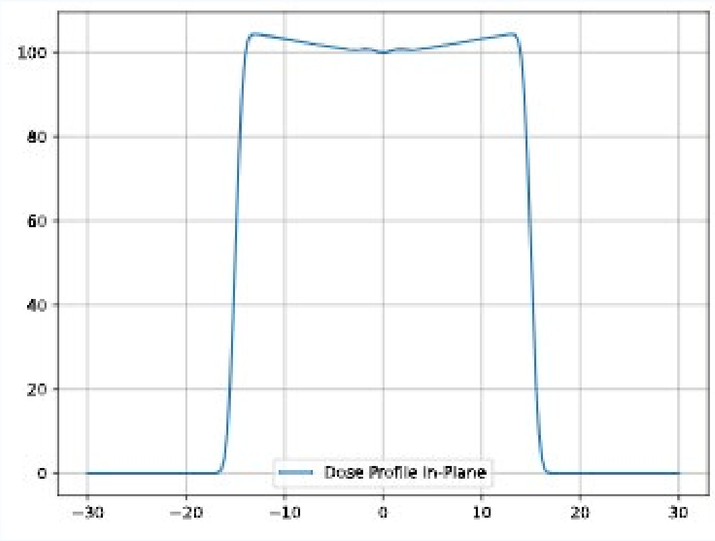
Profiles:

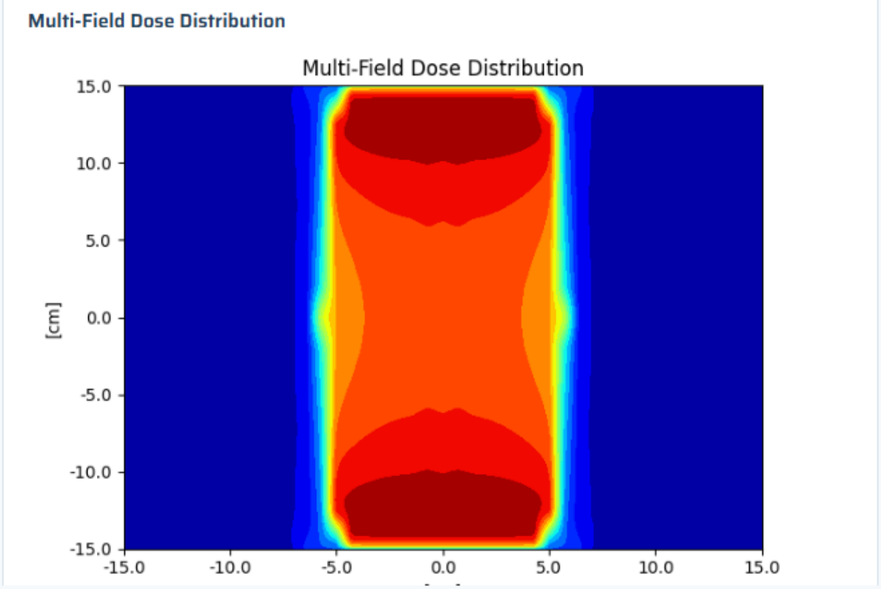
- Flatness = 1.021
- PDD10 = 69.92
- Electron Beam Energy = 5.73 MeV

Beam

- FS = 30 x 30
- Open loop dose rate = 645 MU/min







Energy fault simulation

Machine settings

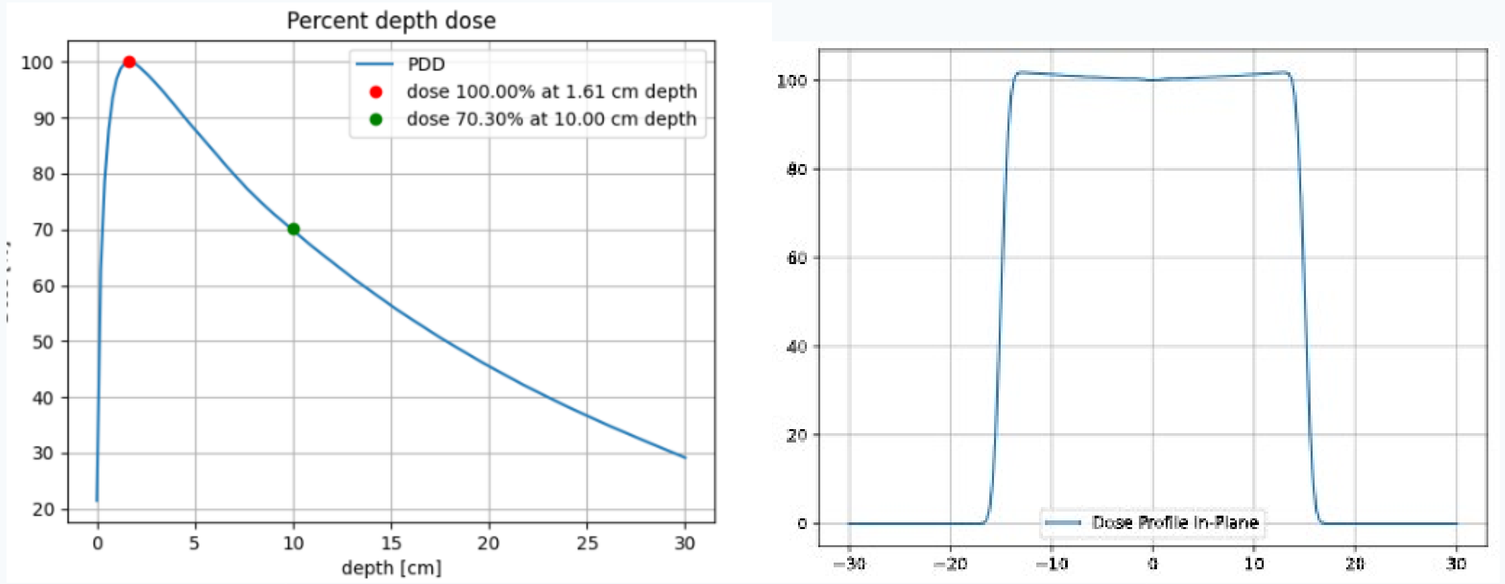
- B Mag = 16.6 A
- PFN V = 7.768
- Grid = 112.1 V
- Energy slit = 0.03

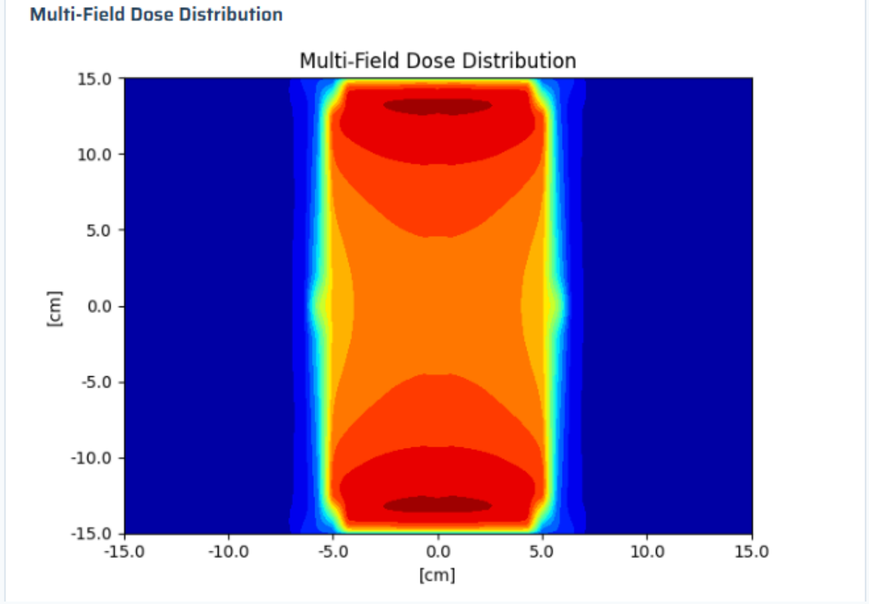
Profiles:

- Flatness = 1.008
- PDD10 = 70.30
- Electron Beam Energy = 6.00 MeV

Beam

- FS = 30 x 30
- Open loop dose rate = 684 MU/min





Energy fault simulation

Machine settings

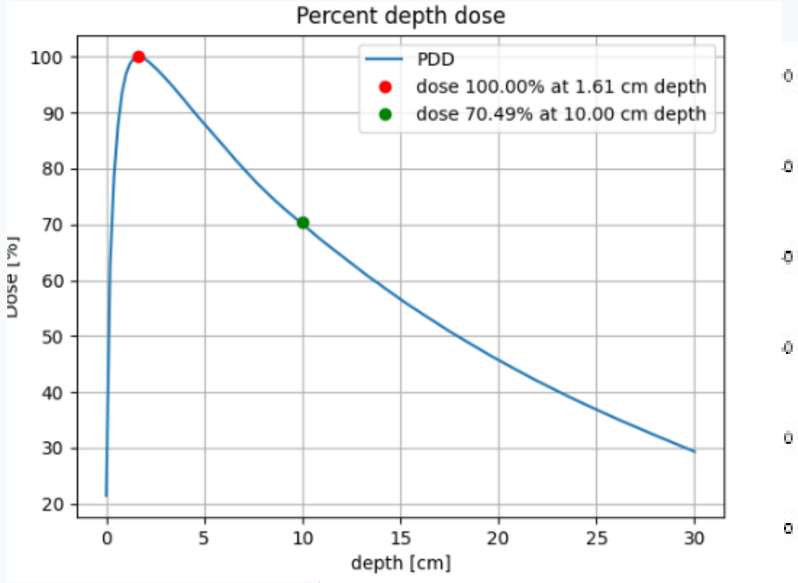
- B Mag = 17 A
- PFN V = 7.81
- Grid = 112.1 V
- Energy slit = 0.03

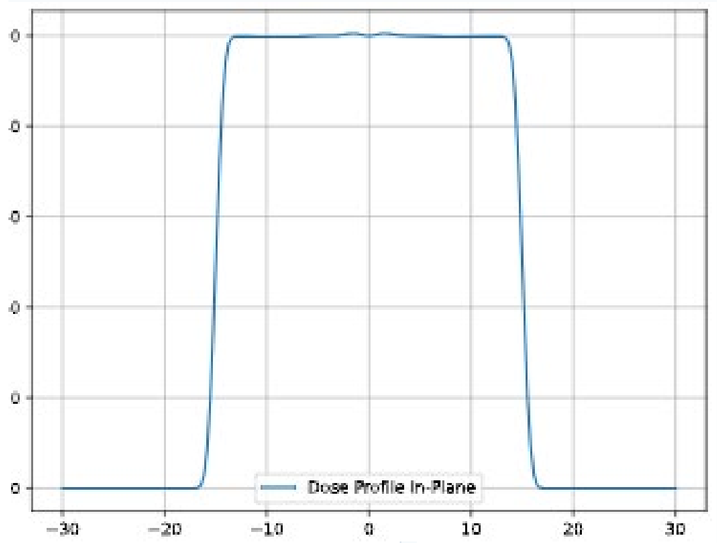
Profiles:

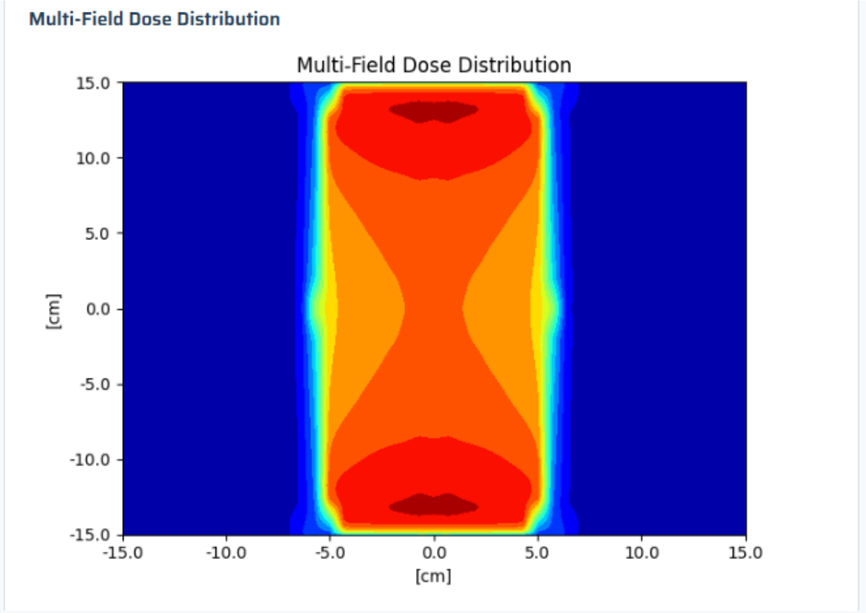
- Flatness = 1.005
- PDD10 = 70.49
- Electron Beam Energy = 6.24 MeV

Beam

- FS = 30 x 30
- Open loop dose rate = 679 MU/min



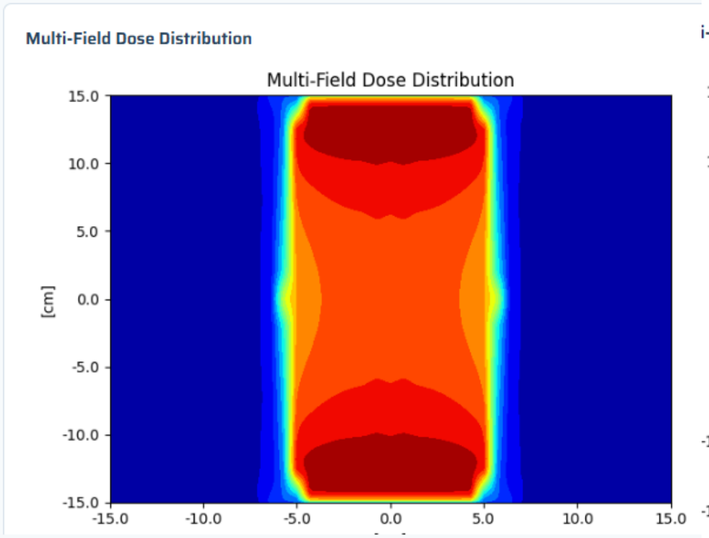


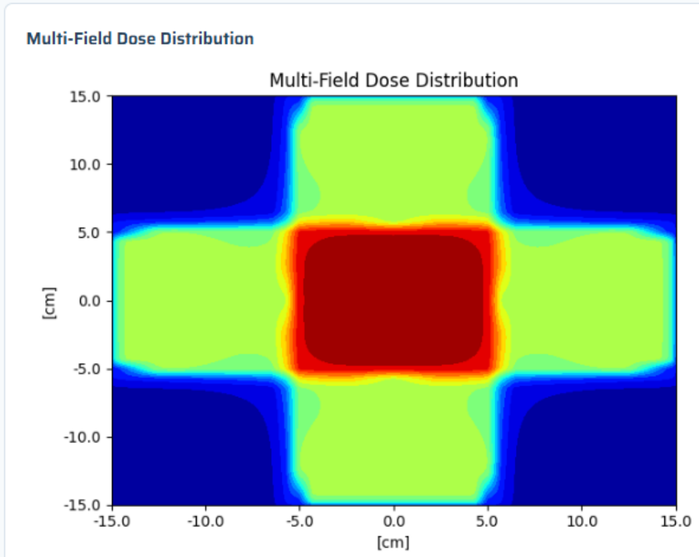


Measured values and tolerance

BMAG	PFN V	ENERGY	FLATNESS	PDD10
16 A	7.720	5.73 MeV	1.021	68.92
16.6 A	7.768	6.00 MeV	1.008	70.30
17 A	7.810	6.24 MeV	1.005	70.49

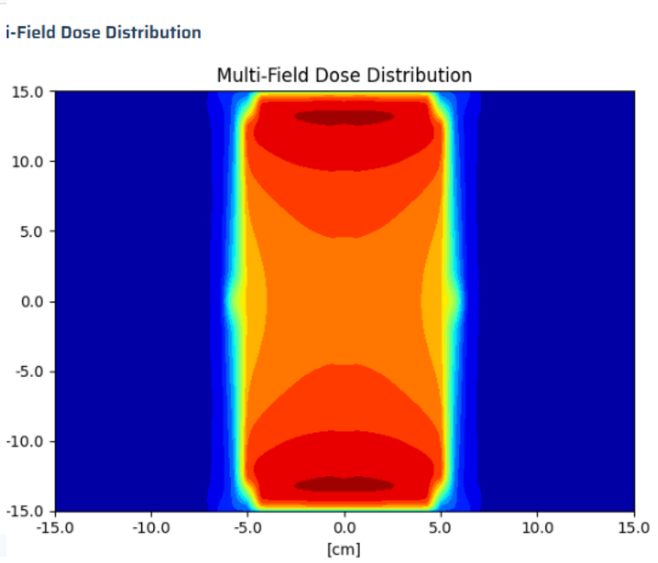
5.73 MeV

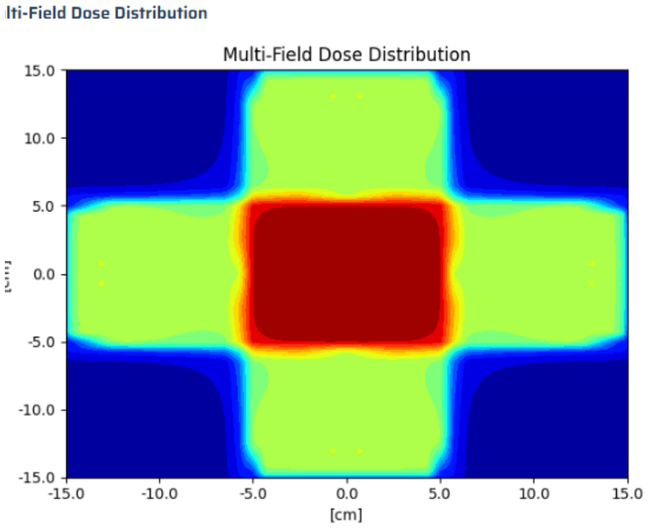




- B Mag = 16.0 A
- PFN V = 7.72

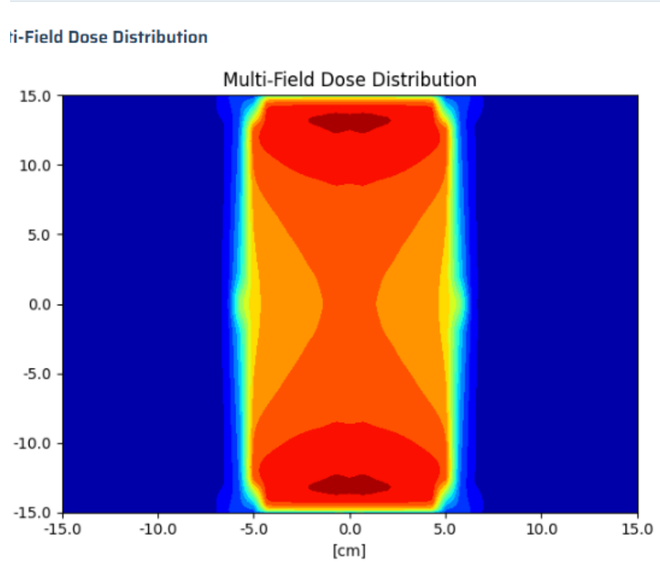
6 MeV

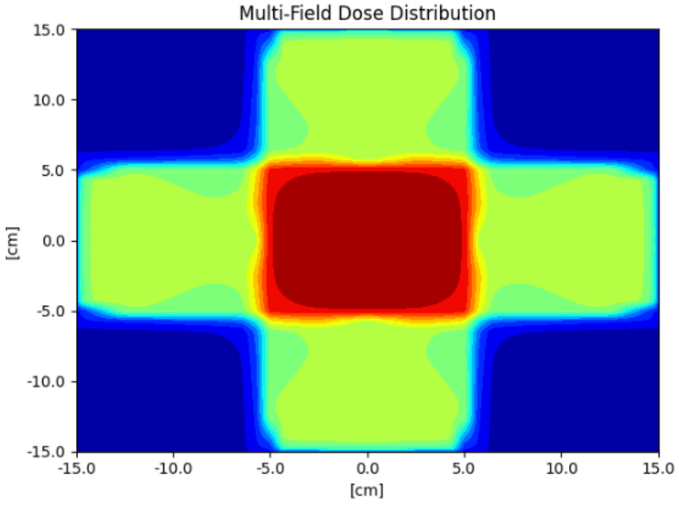




- B Mag = 16.6 A
- PFN V = 7.768

6.24 MeV





- B Mag = 17 A
- PFN V = 7.81

Key takeaways

01 A digital representation of a linear accelerator can help interpret machine tolerance faults.

02 Symmetry and flatness errors are difficult to interpret in terms of dose since they are not measured in dose.

03 Symmetry error appear to rotate the VMST dose distribution, flatness scales radially.

04 This is a preliminary investigation. More study is needed for definitive understanding.

Questions

LINAX TECHNOLOGIES
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