IMRT/VMAT
Quality Assurance and Pre-Treatment Verification

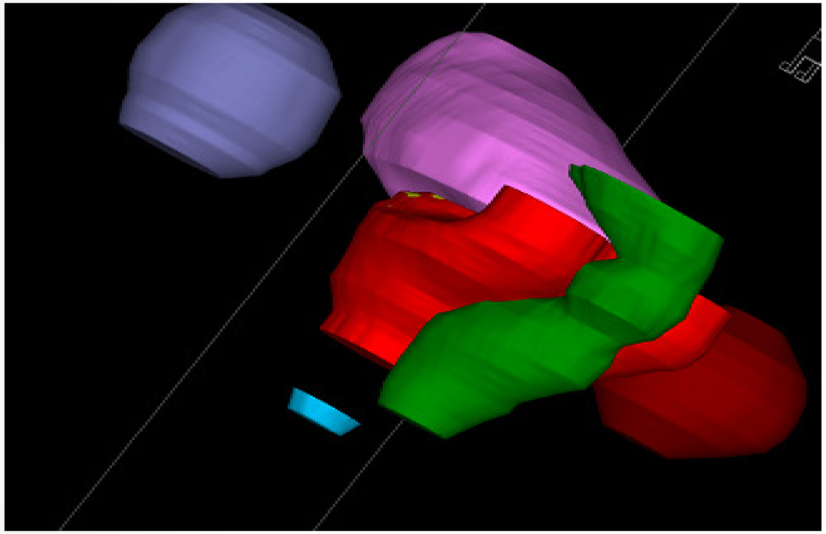
Prof. Dr. Golam Abu Zakaria

Department of Medical Radiation Physics, Gummersbach Hospital/ Klinikum Oberberg, Academic Teaching Hospital of the University of Cologne, Germany
&
Department of Biomedical Engineering
Faculty of Electrical. Mechanical and Industrial Engineering
Anhalt University of Applied Sciences, Germany

Background

- Complex Target Volumes
- Safety and quality of radiation therapy
- IMRT (Intensity Modulated Radiation Therapy)
- VMAT (Volumetric Modulated Arc Therapy)
- Machine specific QA
- Patient specific QA
- References

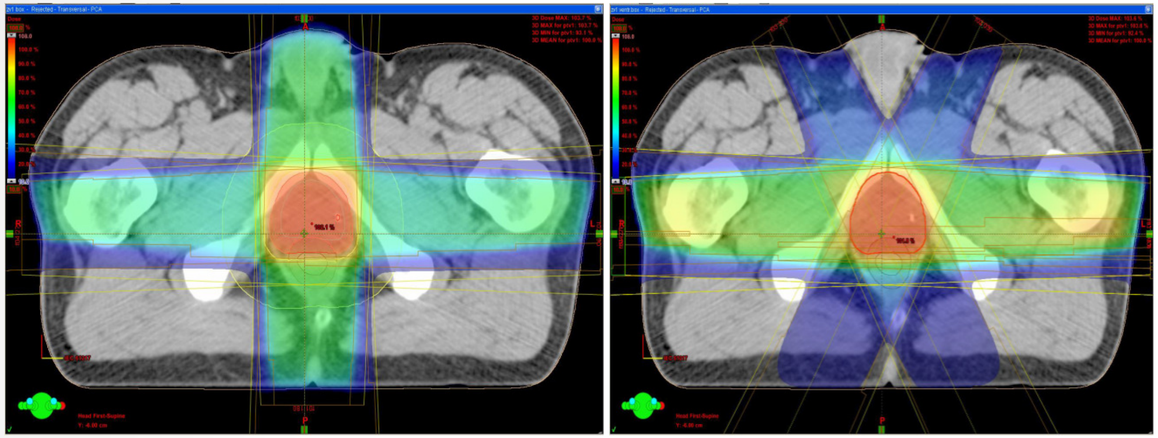
Complex Target Volumes



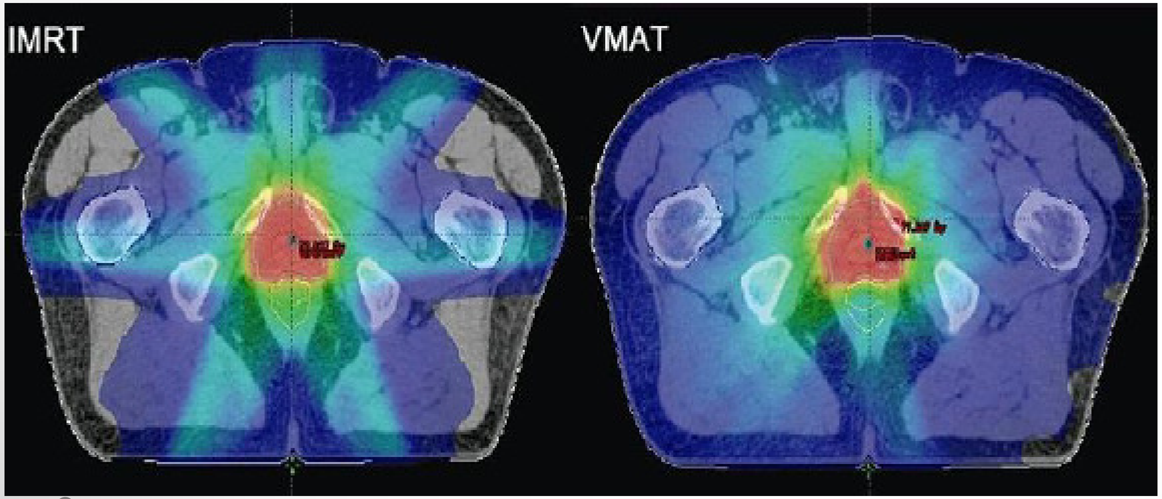
- Tumor in red (Prostate) surrounded by many organs at risk (Hips, bladder, rectum, bulbus, ...) and Tolerance dose must be maintained => Problem for 3D conventional planning

Serial tissue	Volume (mL)	Volume max (Gy)	Max point dose (Gy)	Endpoint (≥grade 3)
Single-fraction treatment				
Brain	5–10	12[a]		Necrosis (<20%)
Optic pathway	<0.2	8	10 12	Neuritis Neuritis (<10%)
Cochlea			12 ≤14[a]	Hearing loss Hearing loss (<25%)
Brainstem	<1	10	15 <12.5[a]	Cranial neuropathy Cranial neuropathy (<5%)
Spinal cord	<0.25 <1.2	10 7	14 13[a]	Myelitis Myelitis (<1%)
Cauda equina	<5	14	16	Neuritis
Sacral Plexus	<3	14.4	16	Neuropathy
Esophagus	<5	14.5	19	Stenosis/fistula
Ipsilateral brachial plexus	<3	14.4	16	Neuropathy
Heart/pericardium	<15	16	22	Pericarditis
Great vessels	<10	31	37	Aneurysm
Trachea and ipsilateral bronchus	<4	8.8	22	Stenosis/fistula
Skin	<10	14.4	16	Ulceration
Stomach	<10	13	16	Ulceration/fistula
Duodenum	<5	8.8	16	Ulceration
Jejunum/ileum	<5	9.8	19	Enteritis/obstruction
Colon	<20	11	22	Colitis/fistula
Rectum	<20	11	22	Proctitis/fistula
Bladder wall	<15	8.7	22	Cystitis/fistula
Penile bulb	<3	14	34	Impotence
Femoral heads (right and left)	<10	14		Necrosis
Renal hilum/vascular trunk	<2/3 volume	10.6		Malignant hypertension
Parallel tissue	Critical volume (mL)	Critical volume dose max (Gy)		Endpoint (≥grade 3)
Lung (right and left)	1,500	7		Basic lung function
Lung (right and left)	1,000	7.4		Pneumonitis
Liver	700	9.1		Basic liver function
Renal cortex (right and left)	200	8.4		Basic renal function
Three-fraction treatment				
Optic pathway	<0.2	15 (5 Gy/fx)	19.5 (6.5 Gy/fx)	Neuritis
Cochlea			20 (6.67 Gy/fx)	Hearing loss
Brainstem	<1	18 (6 Gy/fx)	23 (7.67 Gy/fx)	Cranial neuropathy
Spinal cord	<0.25 <1.2	18 (6 Gy/fx) 11.1 (3.7 Gy/fx)	23 (7.67 Gy/fx)	Myelitis
Cauda equine	<5	21.9 (7.3 Gy/fx)	24 (8 Gy/fx)	Neuritis
Sacral Plexus	<3	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Esophagus	<5	21 (7 Gy/fx)	27 (9 Gy/fx)	Stenosis/fistula
Ipsilateral brachial plexus	<3	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Heart/pericardium	<15	24 (8 Gy/fx)	30 (10 Gy/fx)	Pericarditis
Great vessels	<10	39 (13 Gy/fx)	45 (15 Gy/fx)	Aneurysm
Trachea and ipsilateral bronchus	<4	15 (5 Gy/fx)	30 (10 Gy/fx)	Stenosis/fistula
Skin	<10	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Ulceration
Stomach	<10	21 (7 Gy/fx)	24 (8 Gy/fx)	Ulceration/fistula
Duodenum	<5	15 (5 Gy/fx)	24 (8 Gy/fx)	Ulceration
Jejunum/ileum	<5	16.2 (5.4 Gy/fx)	27 (9 Gy/fx)	Enteritis/obstruction
Colon	<20	20.4 (6.8 Gy/fx)	30 (10 Gy/fx)	Colitis/fistula
Rectum	<20	20.4 (6.8 Gy/fx)	30 (10 Gy/fx)	Proctitis/fistula
Bladder wall	<15	15 (5 Gy/fx)	30 (10 Gy/fx)	Cystitis/fistula
Penile bulb	<3	21.9 (7.3 Gy/fx)	42 (14 Gy/fx)	Impotence
Femoral heads (right and left)	<10	21.9 (7.3 Gy/fx)		Necrosis
Renal hilum/vascular trunk	<2/3 volume	18.6 (6.2 Gy/fx)		Malignant hypertension
Parallel tissue	Critical volume (mL)	Critical volume dose max (Gy)		Endpoint (≥grade 3)
Lung (right and left)	1,500	10.5 (3.5 Gy/fx)		Basic lung function
Lung (right and left)	1,000	11.4 (3.8 Gy/fx)		Pneumonitis
Liver	700	17.1 (5.7 Gy/fx)		Basic liver function
Renal cortex (right and left)	200	14.4 (4.8 Gy/fx)		Basic renal function

Safety and quality of radiation therapy

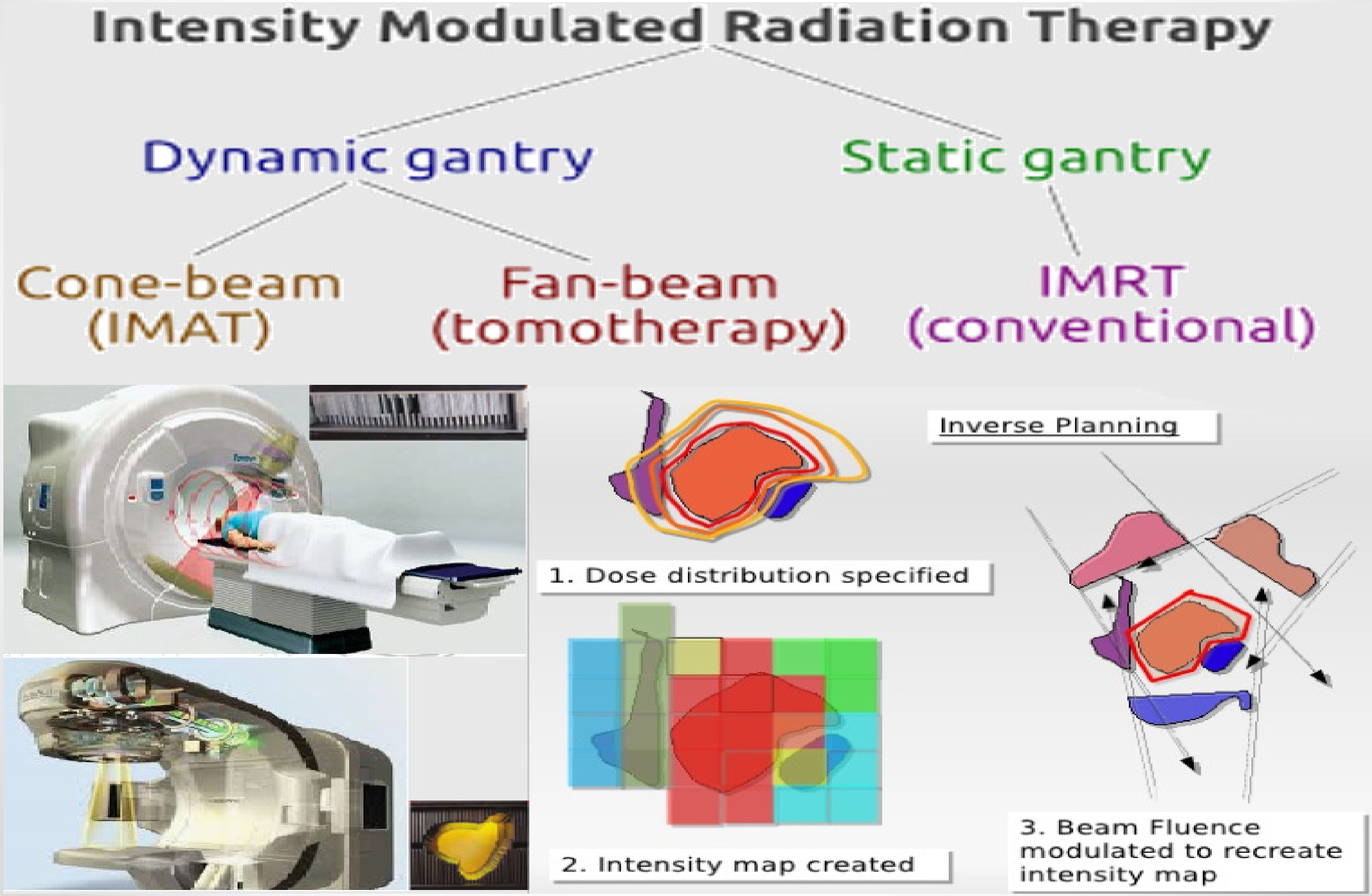


Conventional treatment => Prescribed Dose is limited => more Risk for the neighbour organs



Organ at Risks are more spared => escalation of the prescribed dose is possible => Reduction of Recurrence

Inverse Planning



Advantage of the inverse planning

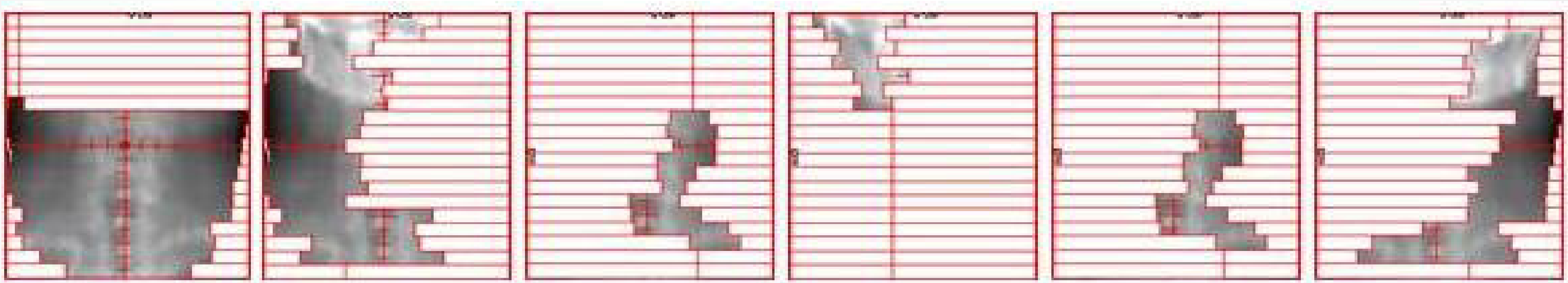
Main Advantage are:

- Conformal treatment
- Better protection for the organs at Risk
- Possible reduction of the margin

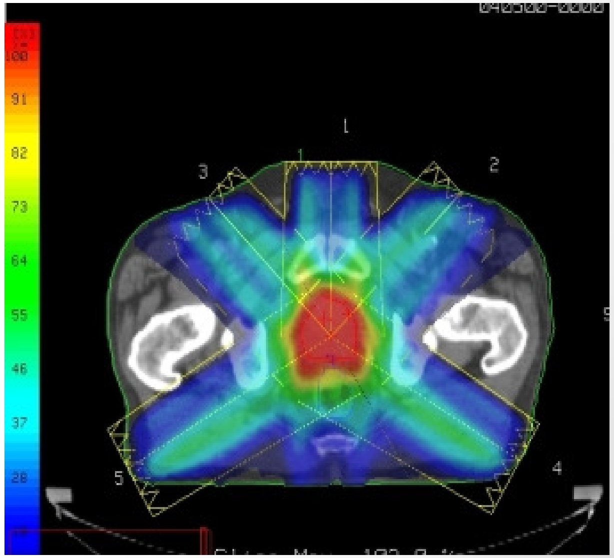
However precaution are to be taken into account

- Scattering radiation are higher then in conventional treatment
- Possible recurrence on margin border if motion is not well considered

IMRT technique



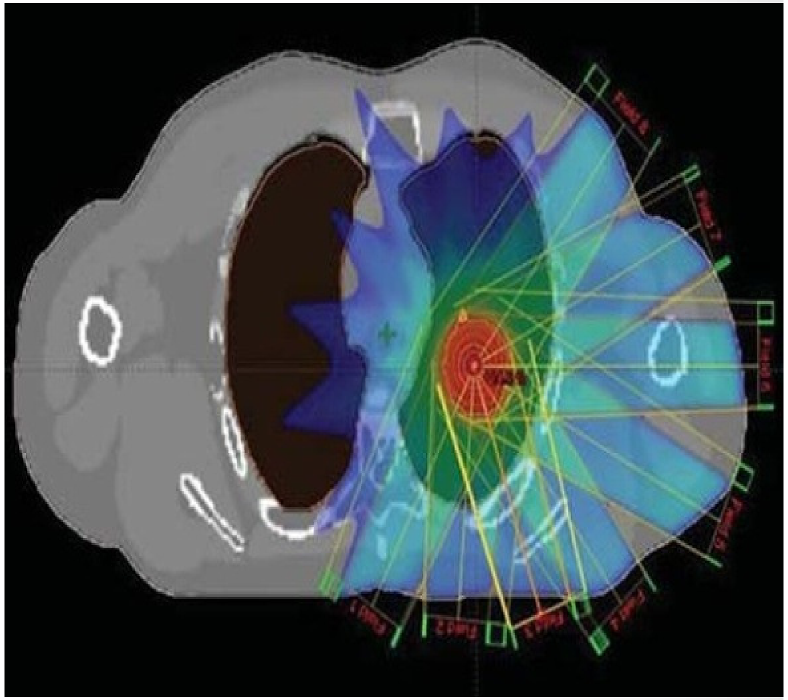
- Fixed gantry angle
- Multileaf collimator (MLC) leaves move during the treatment (Sliding window)
- Multileaf collimator (MLC) leaves move before each sub field delivery (Step and Shoot)
- Non-uniform beam intensity



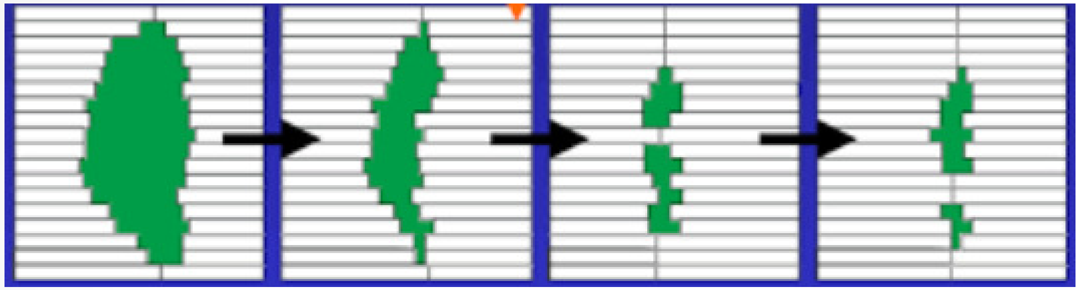
IMRT technique

Step and shoot technique:

- The MLC are not moving during Irradiation
- All sub fields within a beam angle are consecutively delivered to the target volume
- During gantry rotation the beam is off



IMRT technique

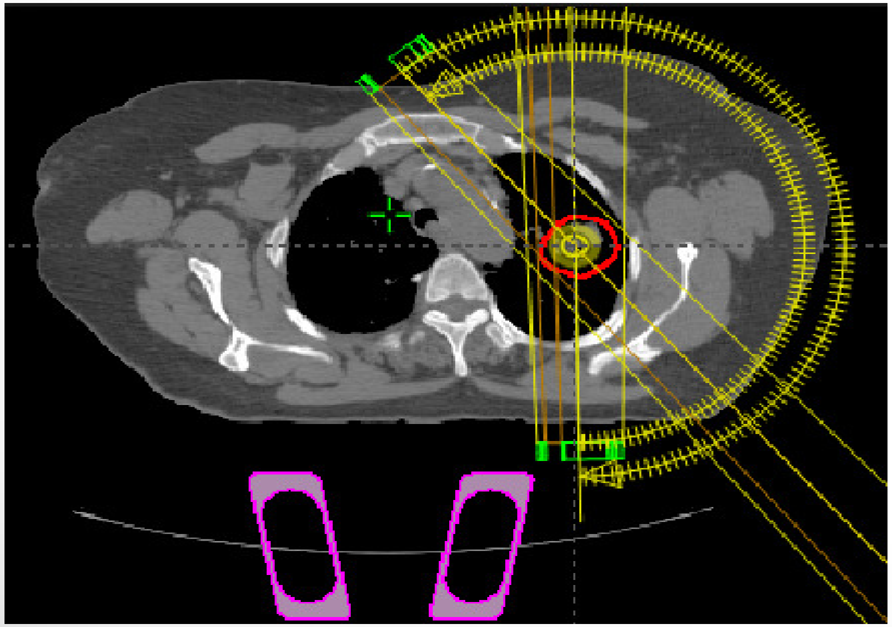


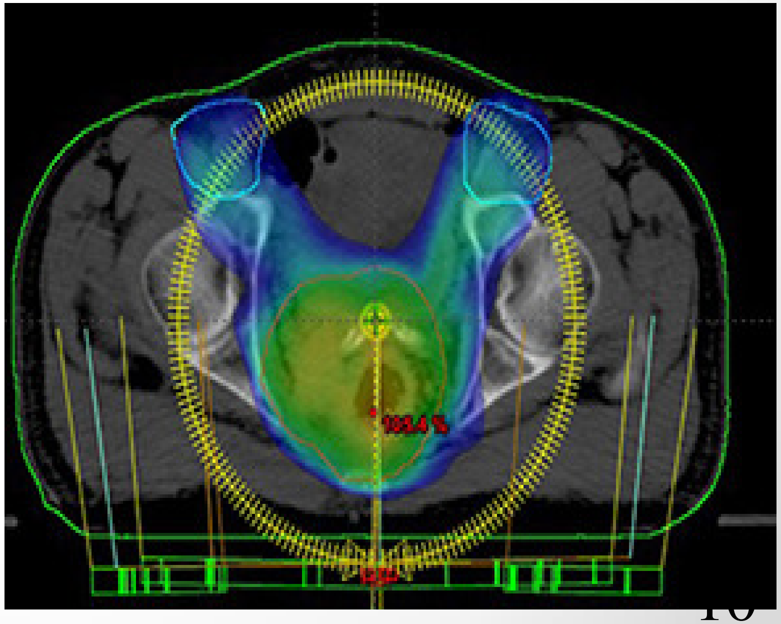
Sliding Window Technique

- During irradiation the MLC are moving and forming different opening in the field which lead to an achieving fluence
- Dose rate variable
- During gantry rotation the beam is off

VMAT technique

- During irradiation the MLC are moving and forming different opening in the field which lead to an achieving fluence
- Dose rate variable
- During gantry rotation the beam is On





IMRT/VMAT -QA

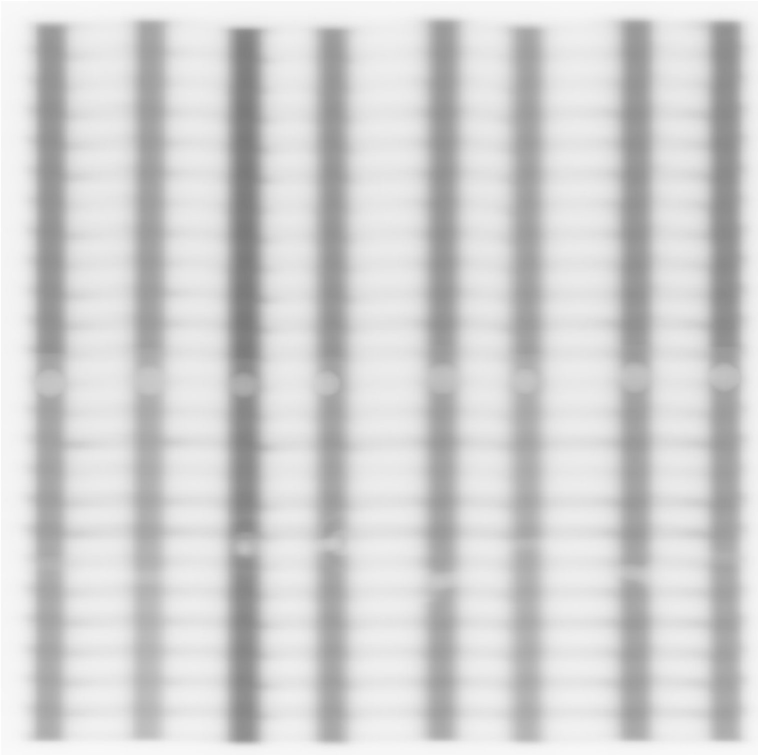
- The IMRT/VMAT treatment plans are not plausible and they can not be simply checked with a calculator.

- Therefore extensive checks need to be done in order to avoid accidents and severe damage to the patient

Machine specific QA

- Regular checks according to e.g. DIN, IAEA, AAPM
- Frequency: daily, half-monthly, quarterly, half-yearly, annually
- Include mechanical and dosimetric tests
- Include tests for 3D techniques and IMRT/VMAT

Tools for the Machine specific QA



Gafchromic-Film Allows quick and precise verification of MLC leaf positions (Possible also with portal imaging system)

Tools for the Machine specific QA

Mostly used:

- Ionisation chambers
- Ionisation detectors pin point chamber (diode, diamond, ...) for small fields measurements

Tools for the Machine specific QA

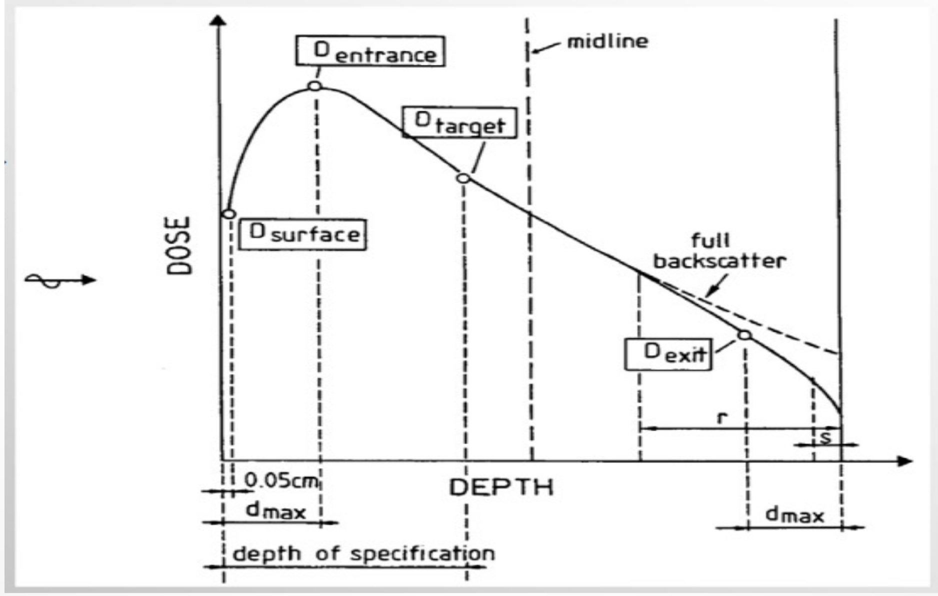
Water phantom (ex: IBA Blue Phantom)

Tools for the Machine specific QA

(Measurements in the Water Phantom)

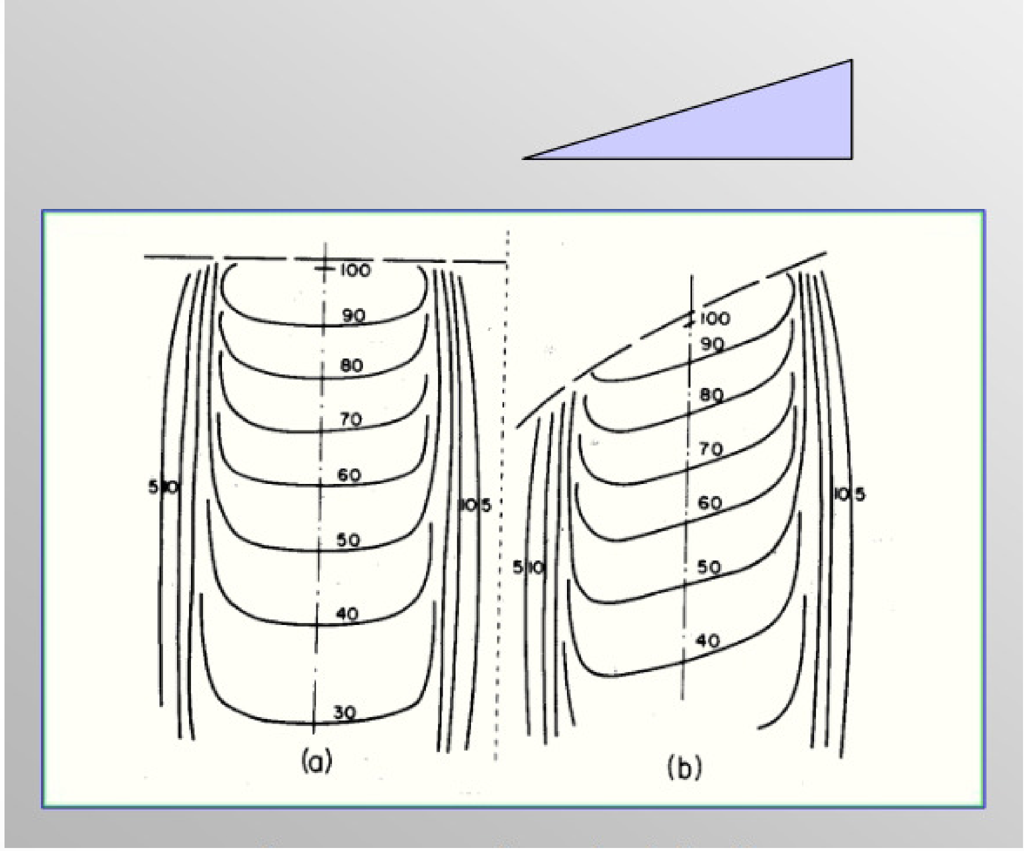
Depth dose distribution measured in the Water Phantom

- Dose distribution along the axis of the radiation beam (PDD = Percentage Depth Dose)
- Depending on density, atomic number of the medium, beam quality and energy



Tools for the Machine specific QA

(Measurements in the Water Phantom)



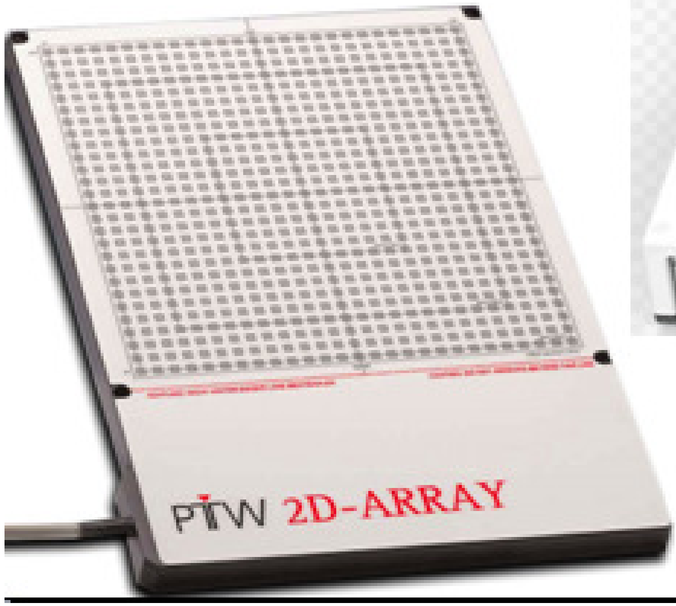
Without and with wedge

- Beam profiles measured in the Water Phantom

Tools for the Machine and Patient specific QA

Mostly used:

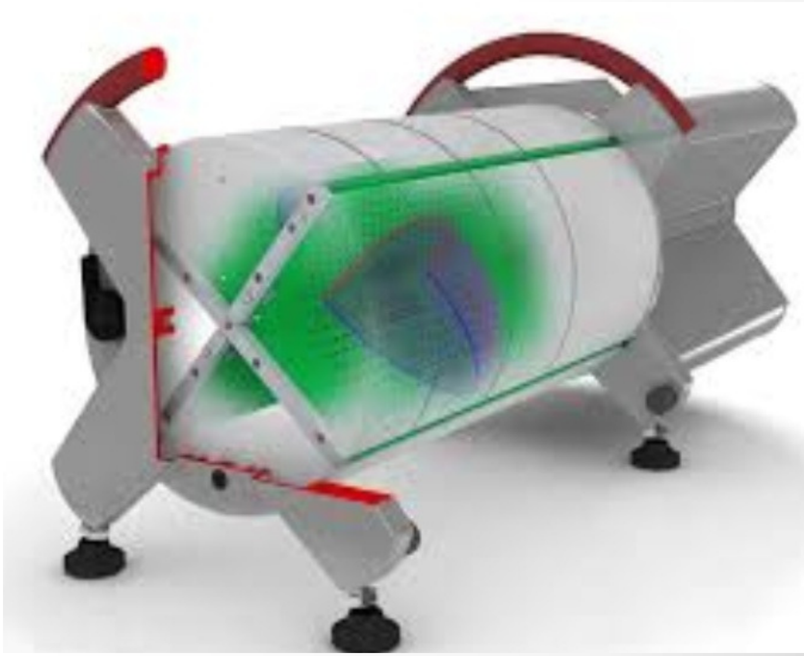
- 2D-Array in RW3 phantom: Matrixx, PTWseven29, ...



Tools for the Machine and Patient specific QA

Mostly used:

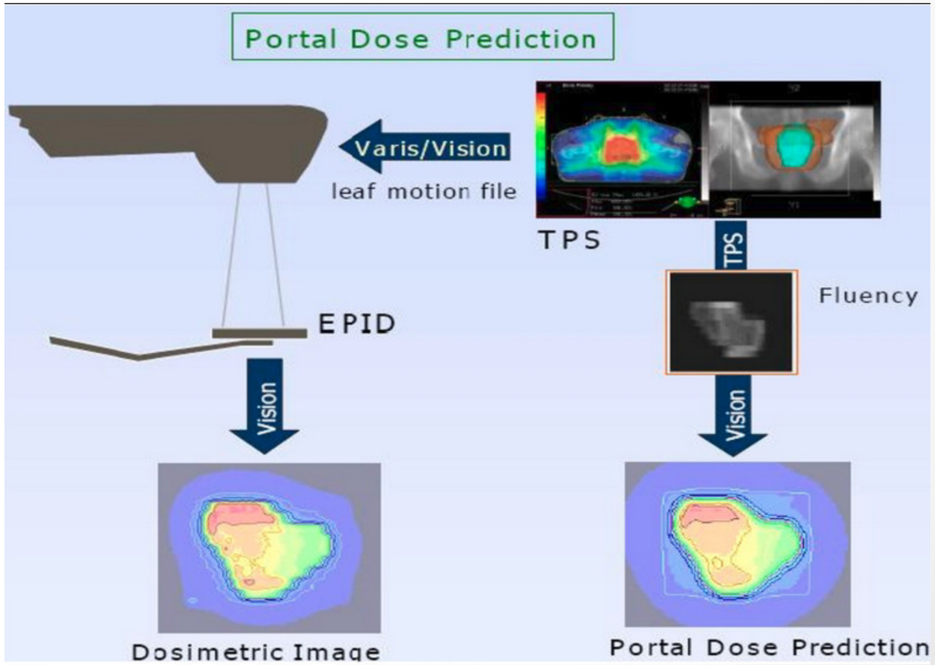
- Octavius4D, Delta4, ...



Tools for the Machine and Patient specific QA

Mostly used:

- Portal Imaging Detector



IMRT/VMAT-QA

Machine dependency tests:

- Gantry position/ angle verification
- Static vs. arc dosimetry
- Linearity/ proportionality of the dose monitor at small Monitor Units
- Dose profile/ depth dose curve at small MU
- Dependency of the Dose with respect to the field size
- Geometric field size/ dosimetric field size
- Transmission constancy (middle between opposite leafs-DLG)
- DMLC dosimetry
- Leaf speed vs. Dose rate and gantry angle
- Change of the leaf speed
- Detection if intentional errors during rapid Arc

IMRT/VMAT-QA

Machine dependency tests:

Gantry position/angle verification with display indicators

- 0, 90, 180 and 270° gantry angle,
- Tolerance 0.5°

Gantry angle (rotation)	0°	90°	180°	270°
Gantry angle (display)	0°	90°	180°	270°
Difference	0°	0°	0°	0°

IMRT/VMAT-QA

Machine dependency tests:

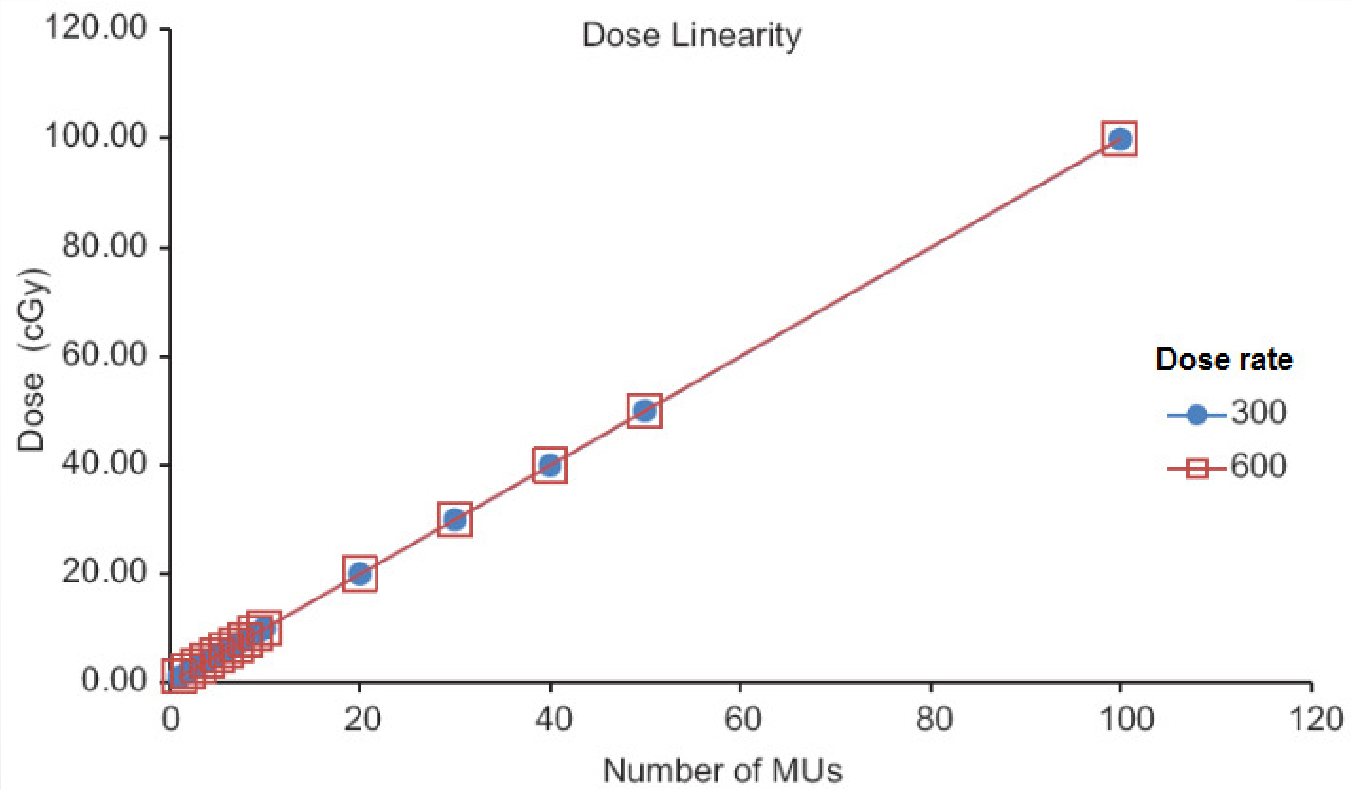
Methodology: *Static Vs Arc Dosimetry*

- To verify consistency and stability of beam output for arc beams, dose output measurements are done at isocenter using an ion chamber with build-up cap for:
  - Two static fields,
    - Field 1: 180° gantry angle, 72MU
    - Field 2: 180° angle, 900MU
  - Two Arc fields,
    - Arc 1: 0-180° arc (half), 72MU
    - Arc 2: 179-181° arc (full), 900MU
- % difference between corresponding static and Arc fields is calculated, acceptable tolerance is 2%

IMRT/VMAT-QA

Machine dependency tests:

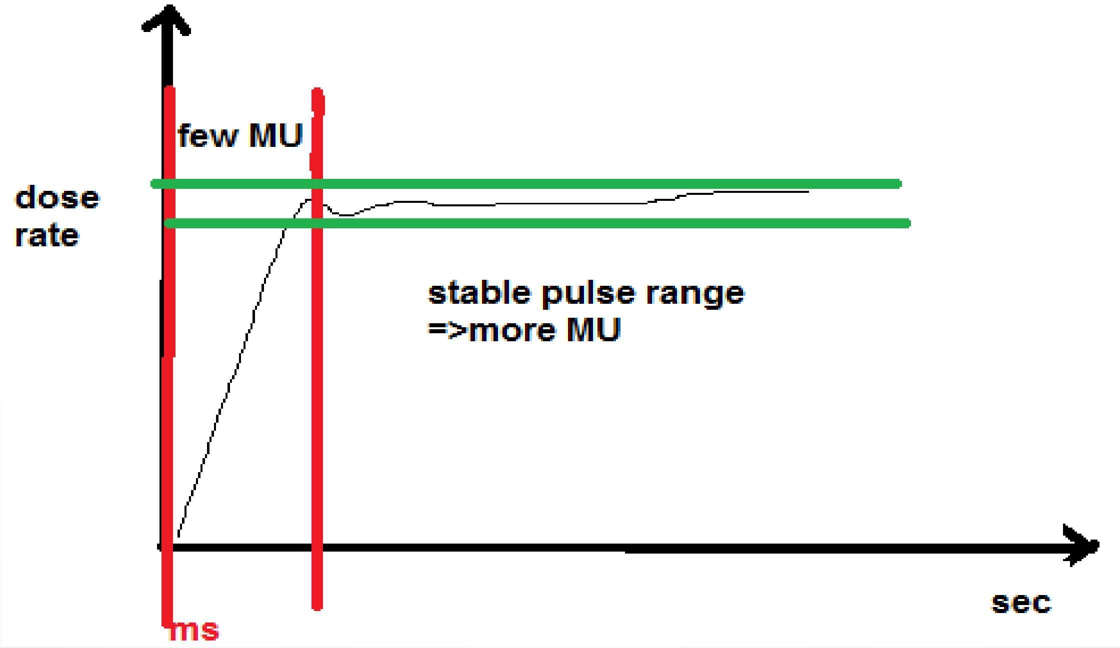
- Linearity/ proportionality of the dose monitor at small Monitor Units



IMRT/VMAT-QA

Machine dependency tests:

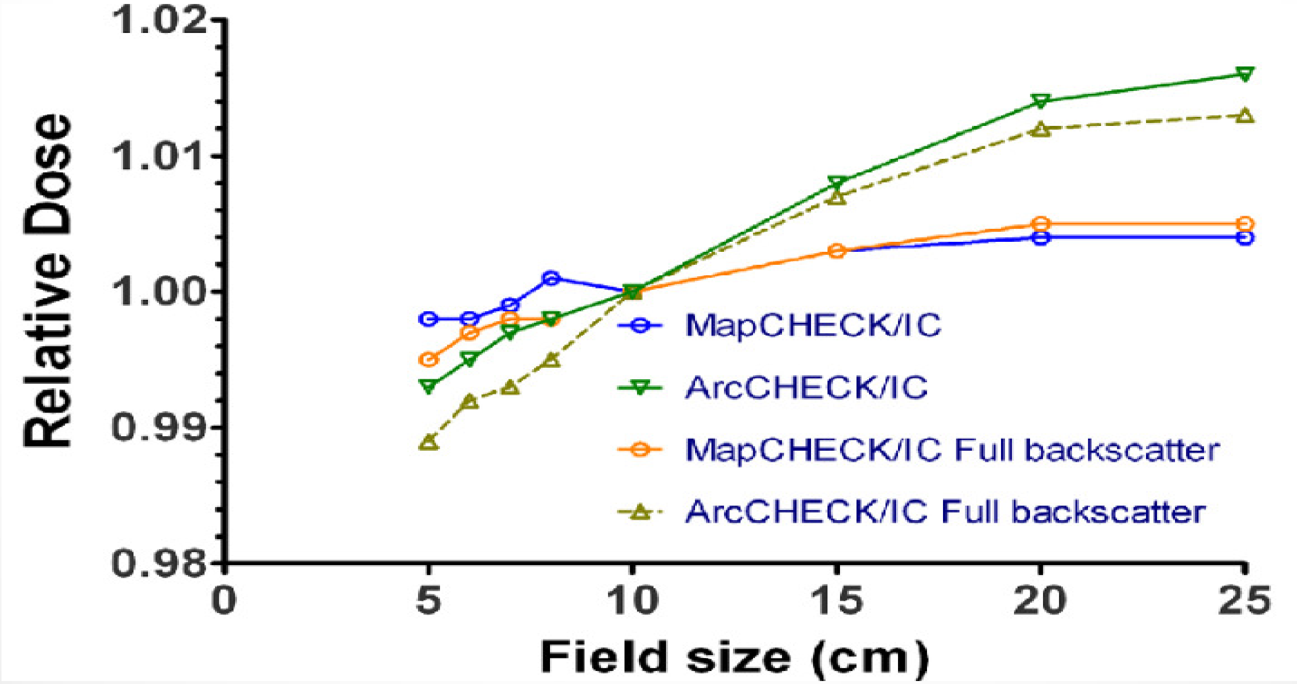
- Dose profile/ depth dose curve at small MU
- The reason is to identify the minimum possible MU that can be set in the optimisation: the machine need time to deliver a constant pulse



IMRT/VMAT-QA

Machine dependency tests:

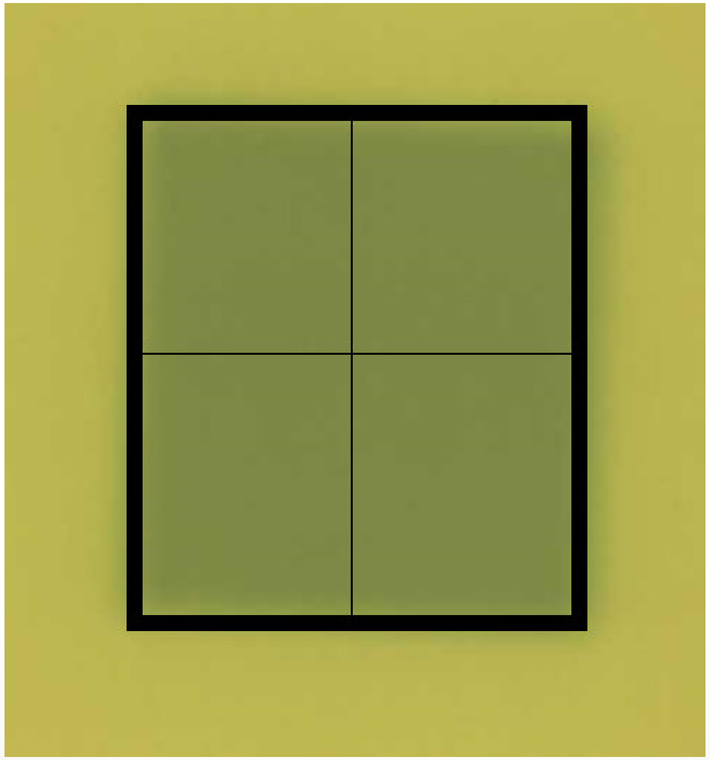
- Dependency of the Dose with respect to the field size (at small field size the choice of detector become critical !!!)



IMRT/VMAT-QA

Machine dependency tests:

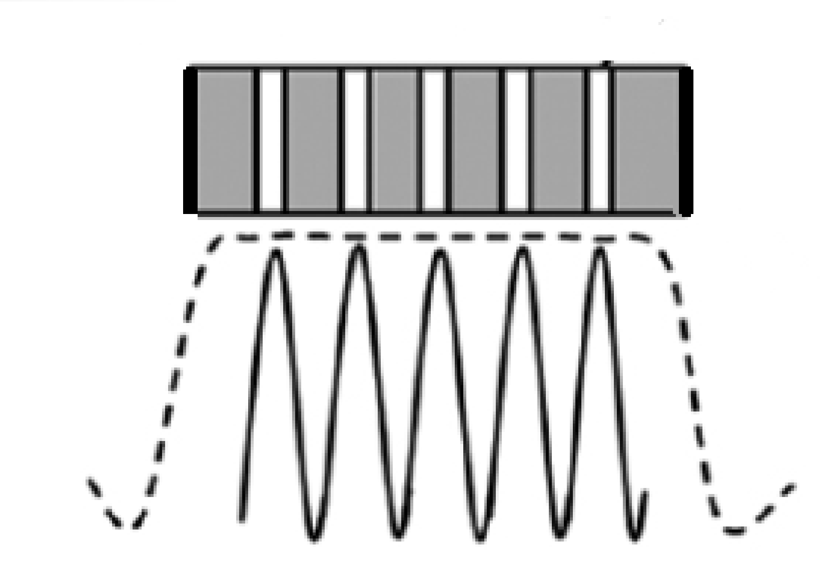
- Geometric field size/ dosimetric field size

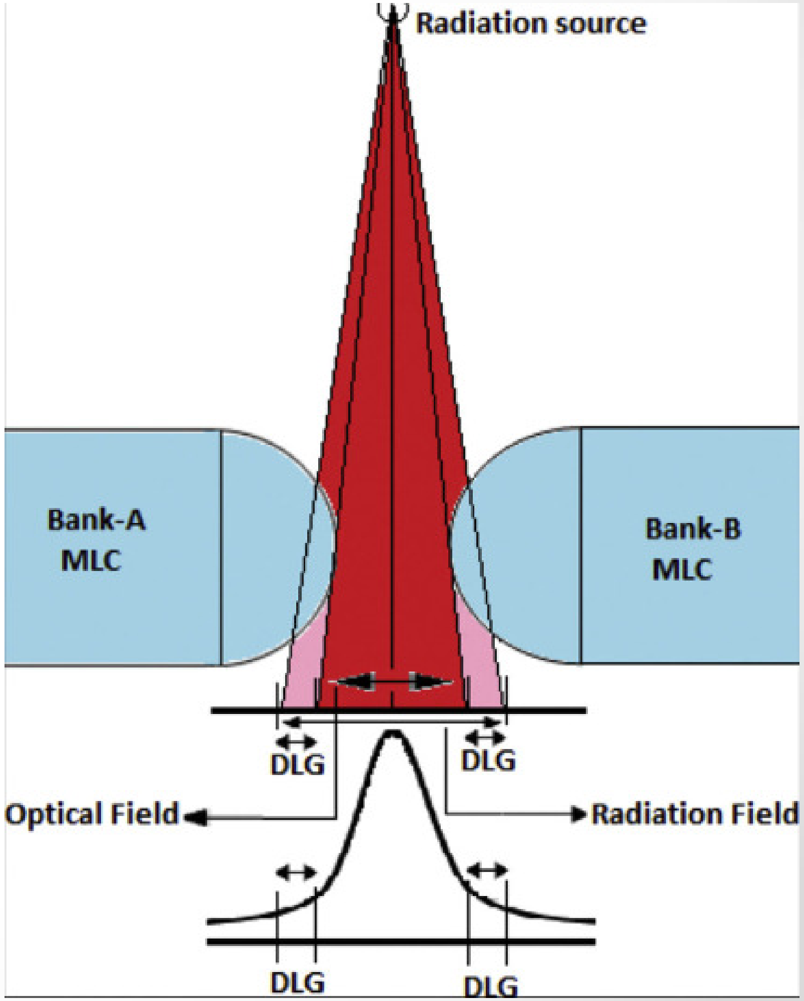


IMRT/VMAT-QA

Machine dependency tests:

- Transmission constancy
  (DLG = Dosimetric Leaf Gap)





•

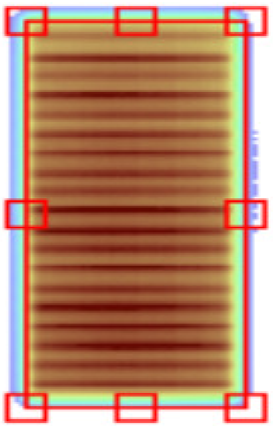
IMRT/VMAT-QA

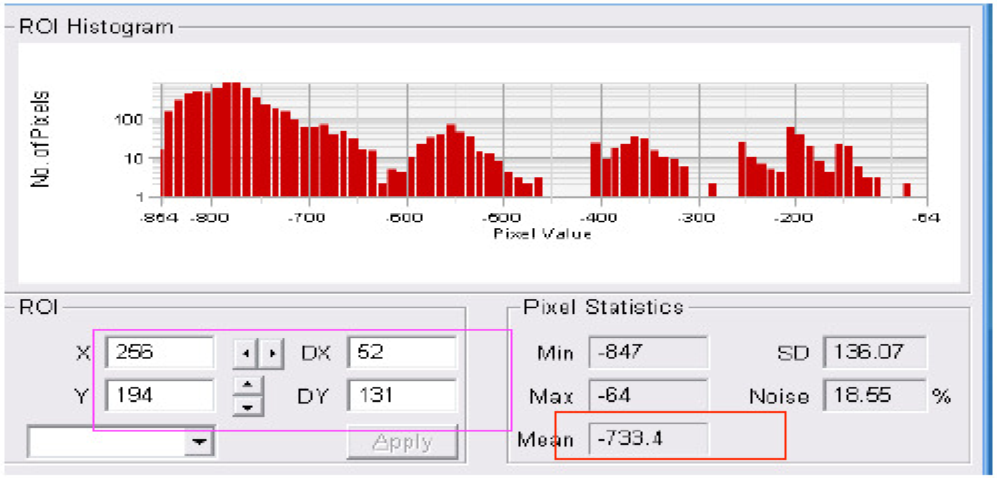
Machine dependency tests:

- dMLC position dosimetry

dMLC dosimetry

Gantry Angle	180	90	0	270
% Deviation from Ref value	0.58	0.21	0.24	0.16





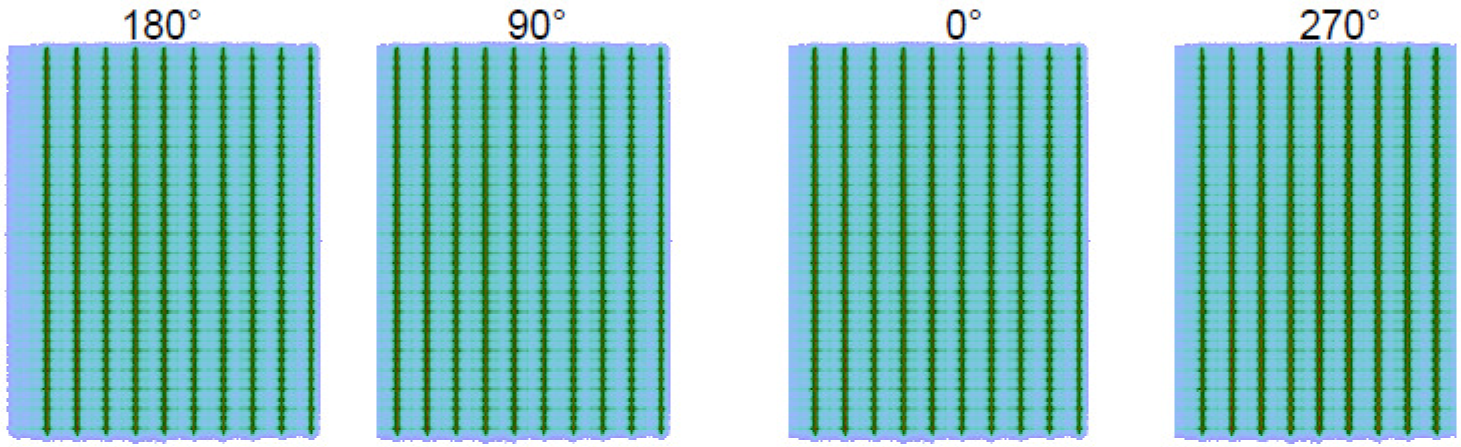
Dose delivery is consistent & stable in dMLC mode at different angles

IMRT/VMAT-QA

Machine dependency tests:

- Leaf accuracy position

Picket fence test vs. gantry angle

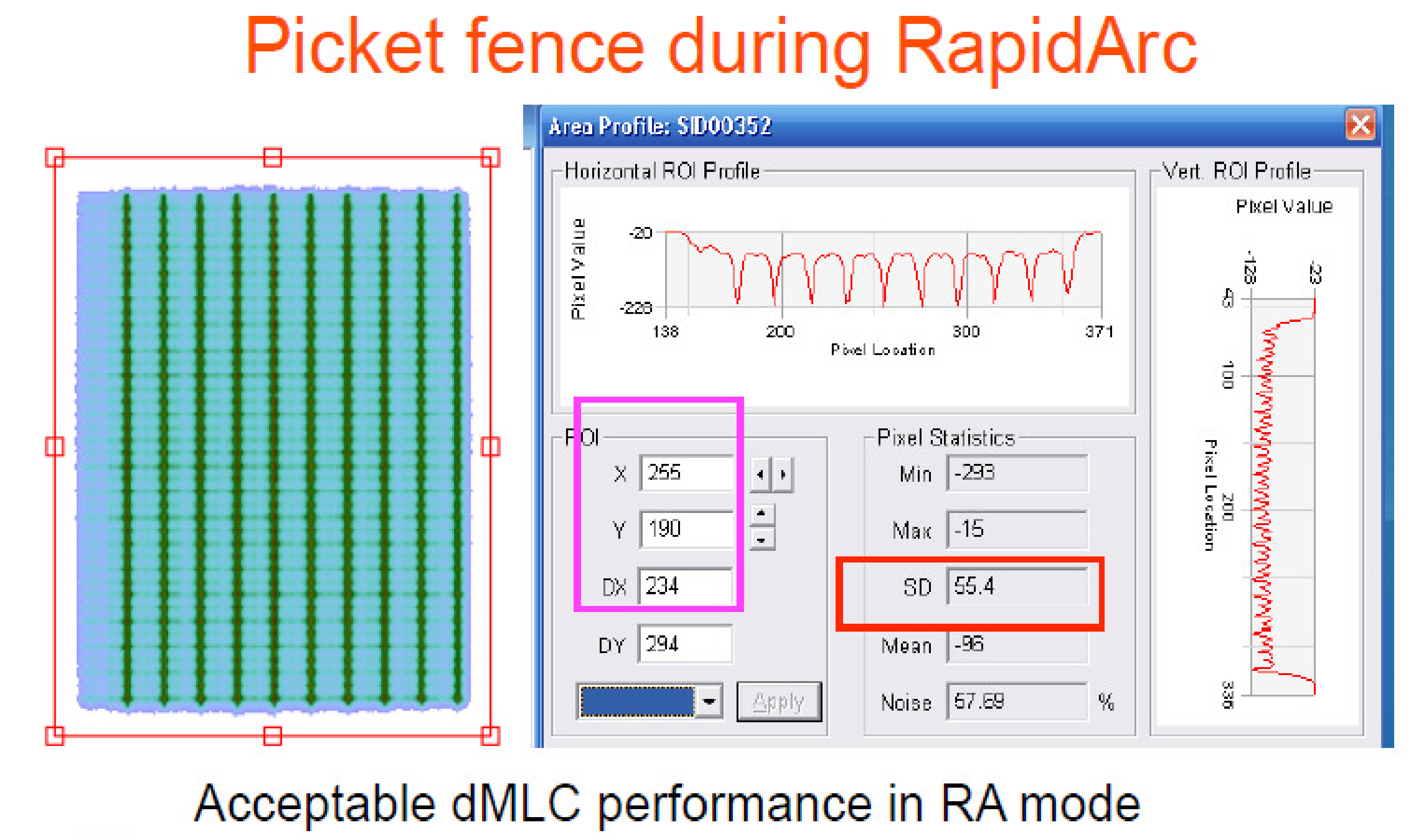


- Picket fences for all the gantry angles appear linear, uniform, well aligned & have consistent widths
- The dMLC performance is stable regardless of gantry angle

IMRT/VMAT-QA

Machine dependency tests:

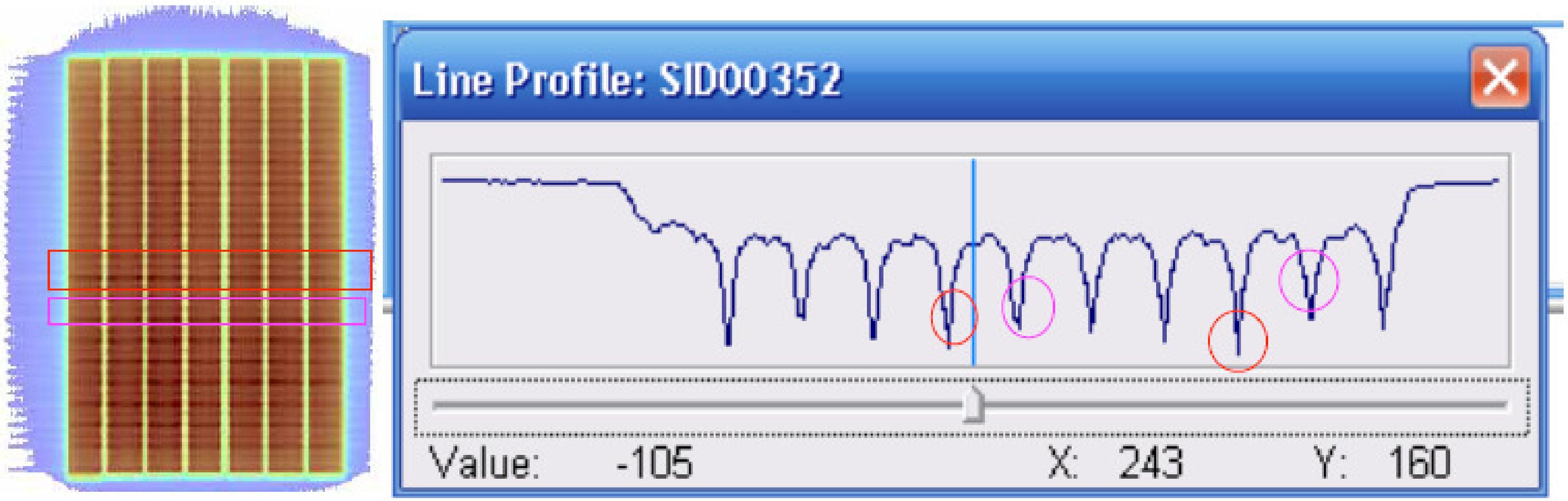
- Change of the leaf speed (VMAT)



IMRT/VMAT-QA

Machine dependency tests:

Picket fence test during RapidArc with intentional error

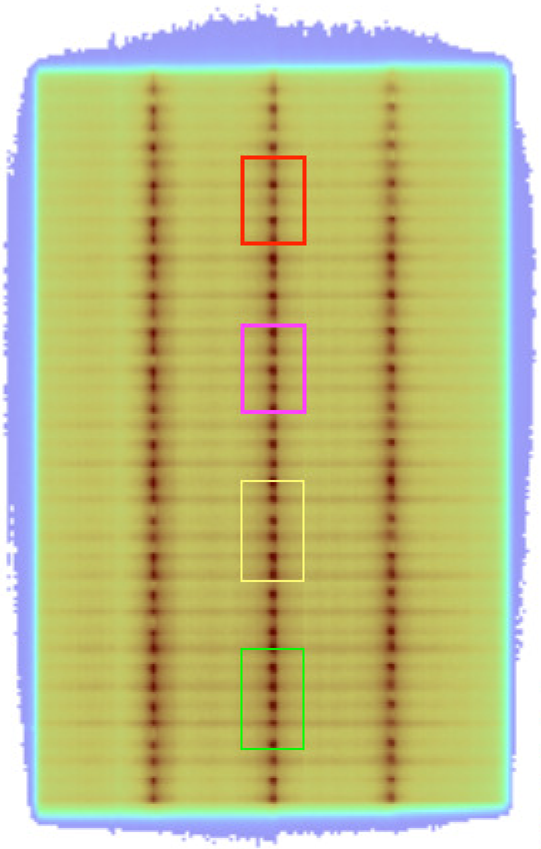


Test sensitivity acceptable

IMRT/VMAT-QA

Machine dependency tests:

Accurate control of leaf speed during RapidArc



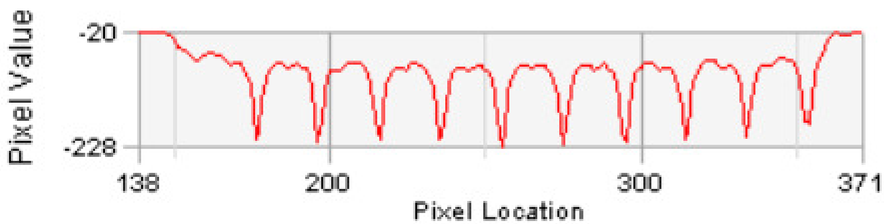
Deviation from ref value (%)

-1.22

-0.31

1.14

0.51



Dose output is consistent despite the use of different combinations of MLC speed & dose rate

Advantage/ Disadvantage

Machine dependency tests:

- Detection of any deviation or instability of the machine
- The test can be separately done at different time
- Risk management process (acceptable tolerance table)
- Not every plan of the patients is checked
- Spontaneous defect can not be checked

IMRT/VMAT-QA

Patient dependency QA:

- Due to the complexity of the IMRT/VMAT plans the treatment plan should be checked.
- An independent IMRT calculation for each field is necessary
- An independent VMAT calculation for each plan is necessary
- »end to end« Phantom-Verification of the fluence with a detector array
- Portal dosimetry
- Comparison of calculation with measurements at the same condition and same MU values.

Patient specific QA

- Radiation of patient plans
  - in a phantom (e.g. Octavius with a 2D-Array)
    - => Measurement of the dose distribution in the phantom
    - works with both 3D techniques and IMRT/VMAT
  - in air on an accelerator-specific portal imaging system without phantom
    - => Measurement of the fluence distribution
    - works with only IMRT / VMAT

- Comparison of the measured distribution with the calculated matrices (Phantom and portal-imaging-system)
  - The agreement is a measure of the reproducibility of the plans

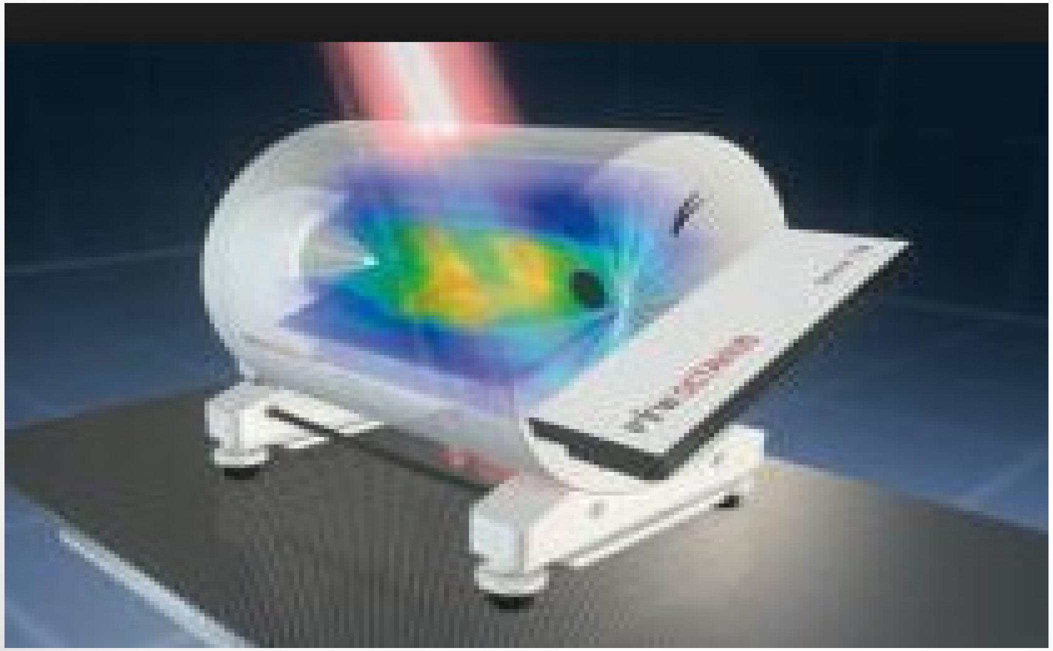
Patient specific QA

- Validation of patients QA with the portal imaging system by comparison with Phantom measurements
  - Review a sufficient number of patient plans using both the phantom system and the portal imaging system
  - If both systems meet the target (Gamma-Index-Method: 3%, 3mm) for the reviewed plans, patient QA can only be performed using the more convenient and faster portal imaging system
  - Furthermore, a regular check, e.g. every 10th patient plan with phantom measurement)

IMRT/VMAT-QA

Patient dependency QA:

- »end to end« Phantom-Verification of the fluence with a detector array

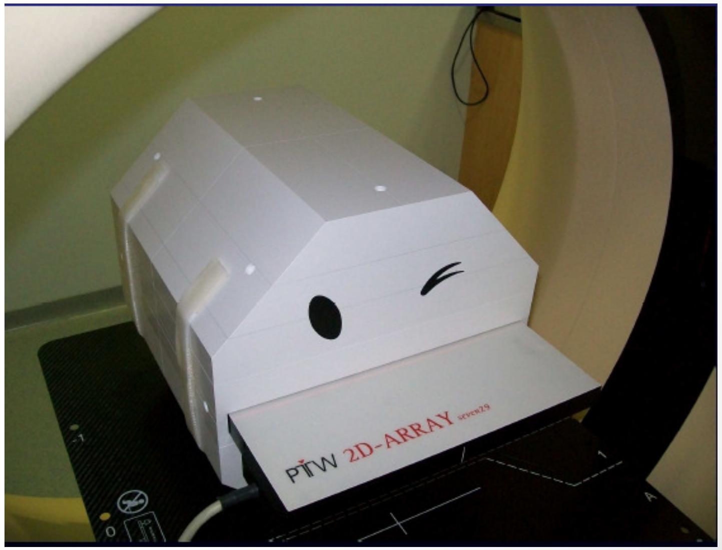


An independent calculation is necessary.
Gamma criteria: for example: 3% / 3 mm

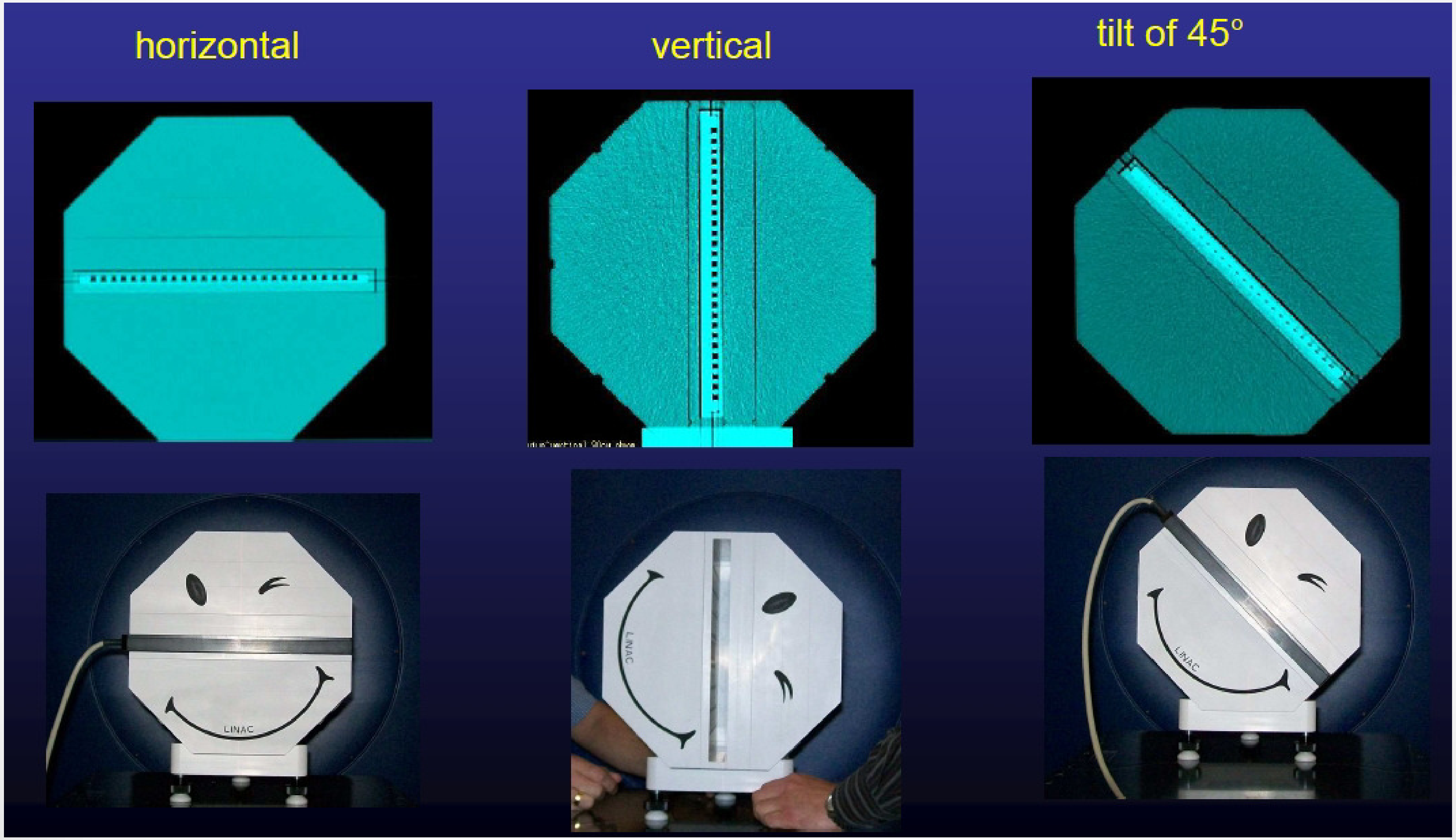
Patient specific QA

- Octaeder phantom (Octavius von PTW)
- 2D ionchamber-array (2D- ARRAY seven29,
  Matrix von 27x27=729 ionchamber,
  volume: 5x5x5 mm, 0,125cm^3)
- Evaluation with VeriSoft 4.0 (PTW)
  Gamma-index

OCTAVIUS® II



Patient specific QA



OCTAVIUS® II

Patient specific QA

- Recalc of the patient-plan in the phantom-CT

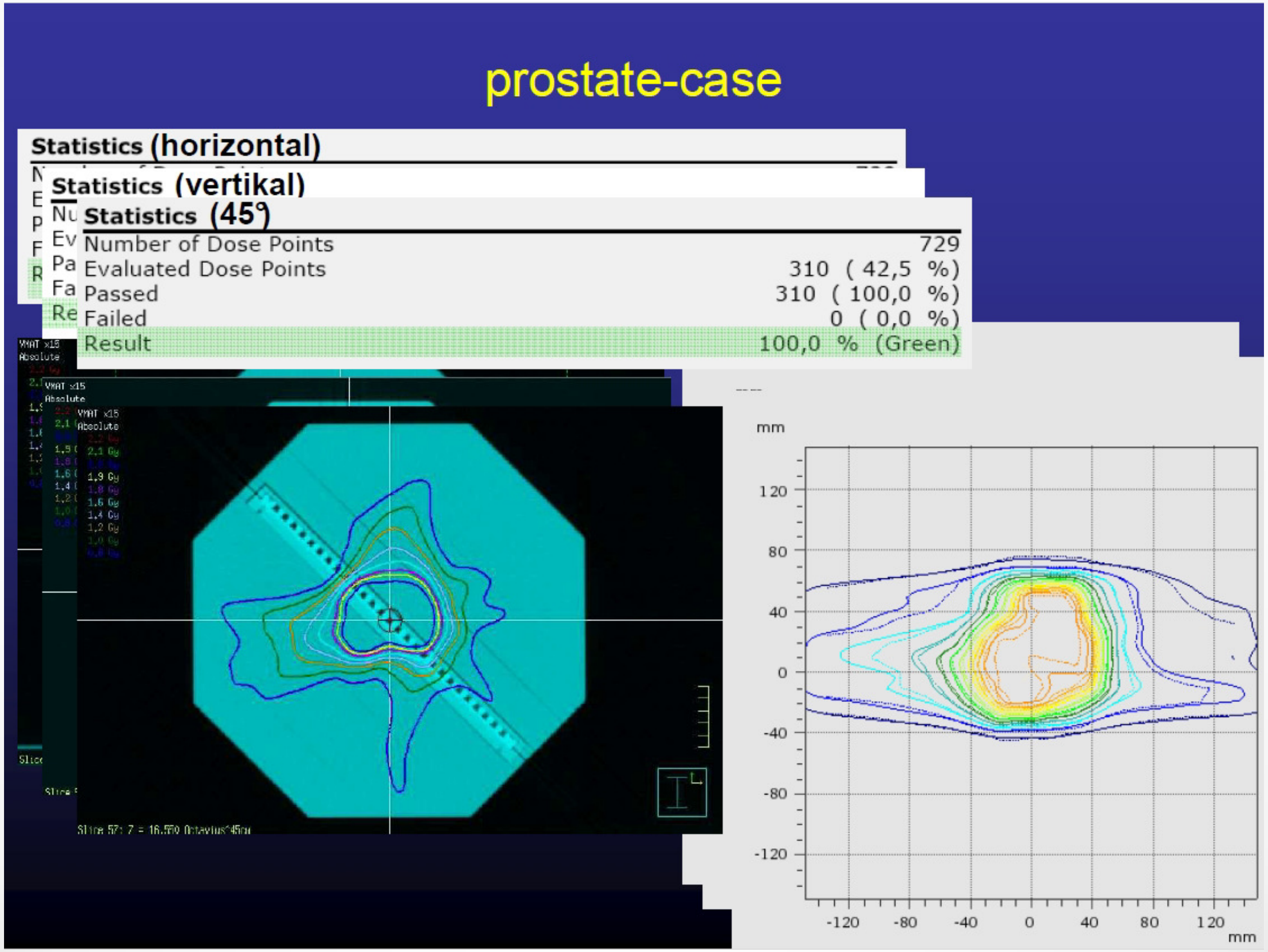
→ each plane one plan

- Treat the phantom (3x)
- Evaluation of abs.dose

Gamma 2D - Parameters
3,0 mm Distance- To- Agreement
3,0 % Dose Difference with ref. to Max. dose of measured data set
Suppress doses below 5,0 % of max. dose of measured data set

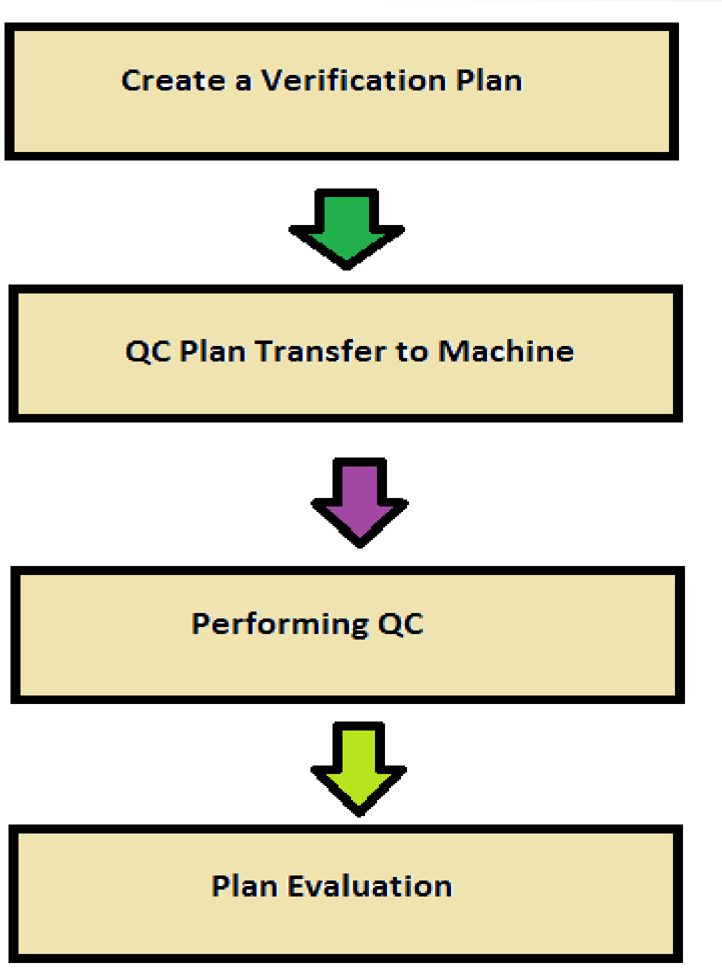
Settings	
Passing criteria	Gamma ≤ 1,0
Green	90,0 % to 100,0 %
Yellow	75,0 % to 90,0 %
Red	0,0 % to 75,0 %

Patient specific QA



Patient QA Procedure with Portal Imager

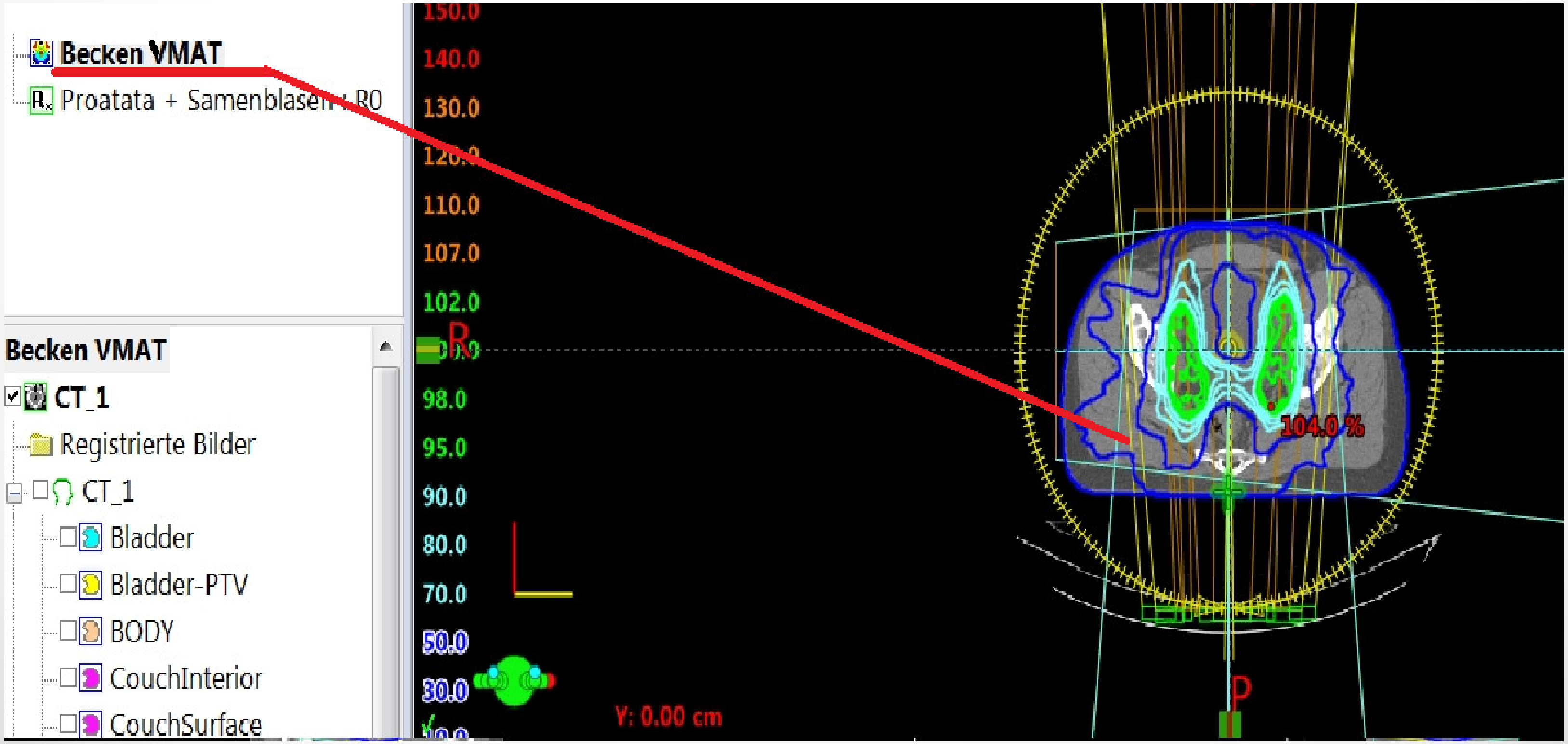
EPID can be widely used for patient specific QA for different cases but need to be cross checked with other external measuring tool to assure if EPID is providing correct results or not.



IMRT/VMAT-QA

Patient dependency QA with the Portal Dosimetry Procedure:

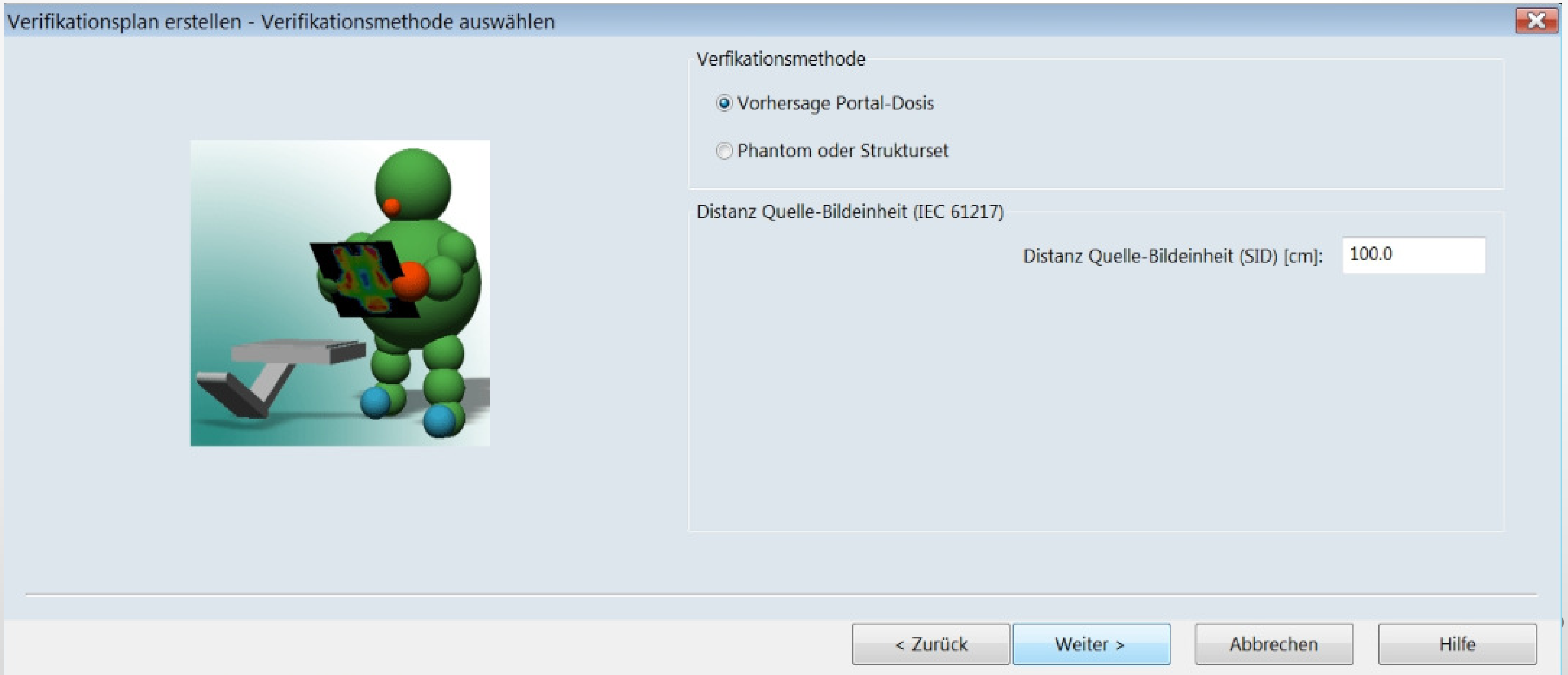
VMAT Plan example



IMRT/VMAT-QA

Patient dependency QA with the Portal Dosimetry Procedure:

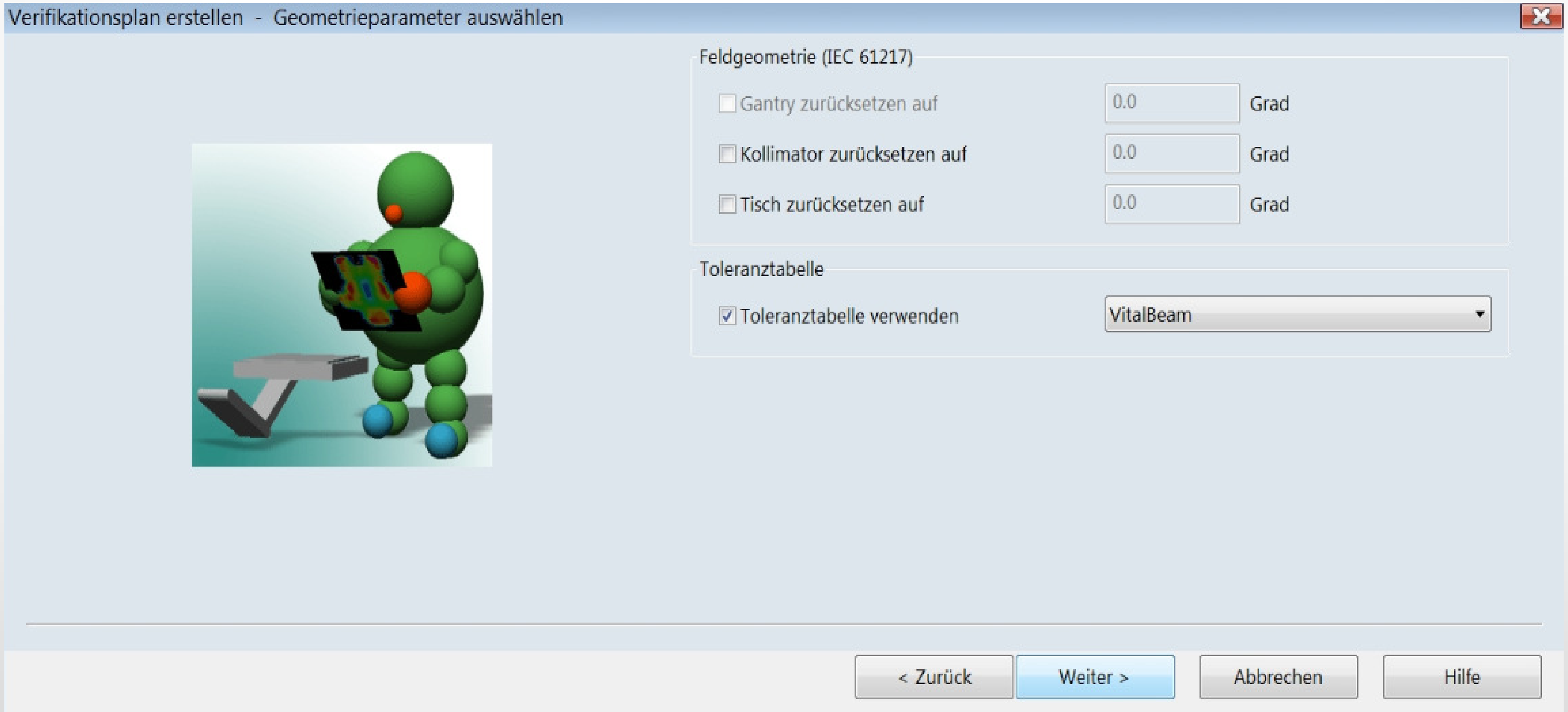
- The verification method can be either with a phantom or a predicted portal dose



IMRT/VMAT-QA

Patient dependency QA with the Portal Dosimetry Procedure:

- More option to choose whether all beamlet should be treated from one angle or as in the original plan

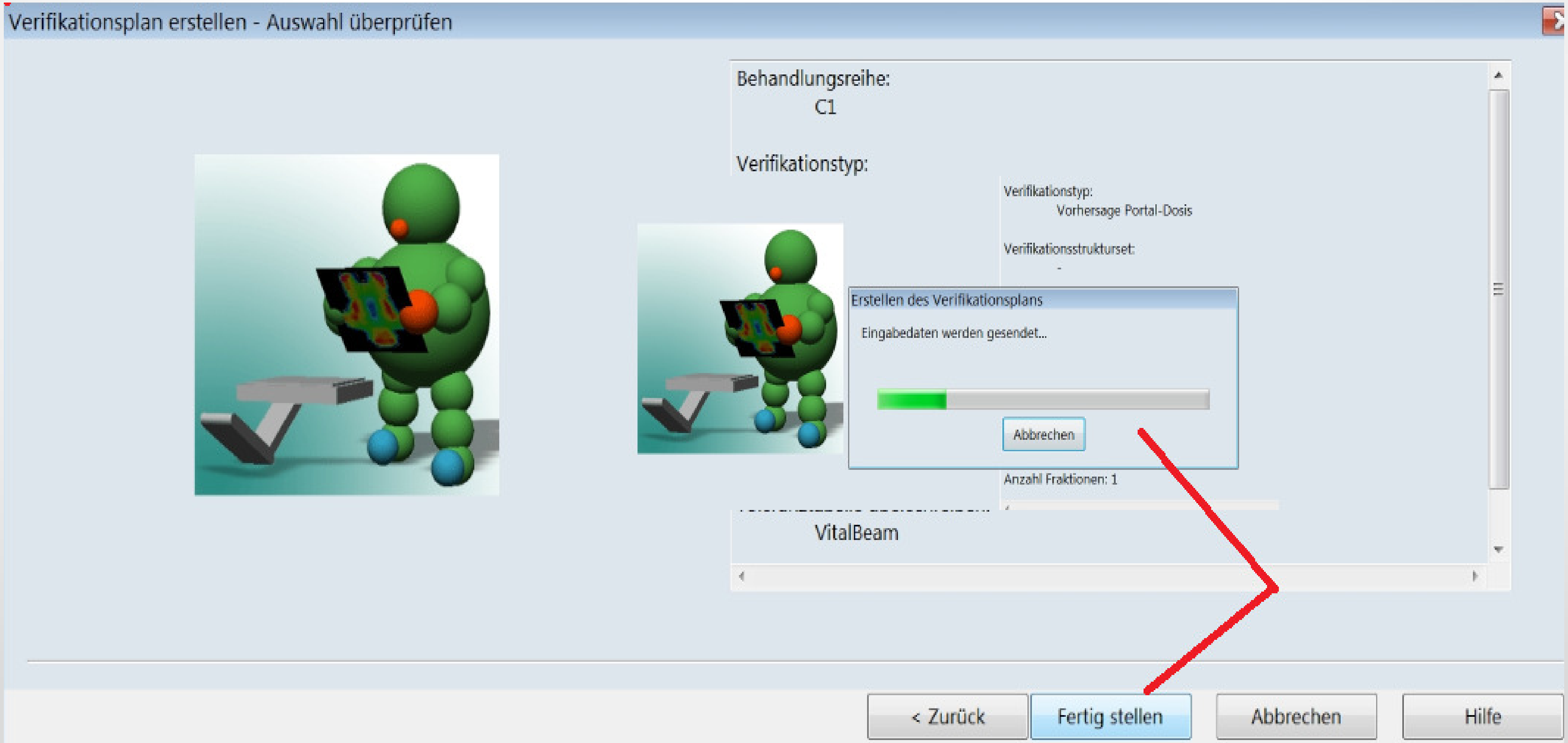


IMRT/VMAT-QA

More option for the plan generation: (for ex. in IMRT case for each angle a verification plan can be set

IMRT/VMAT-QA

Once all parameters are set the TPS start to generate a verification plan

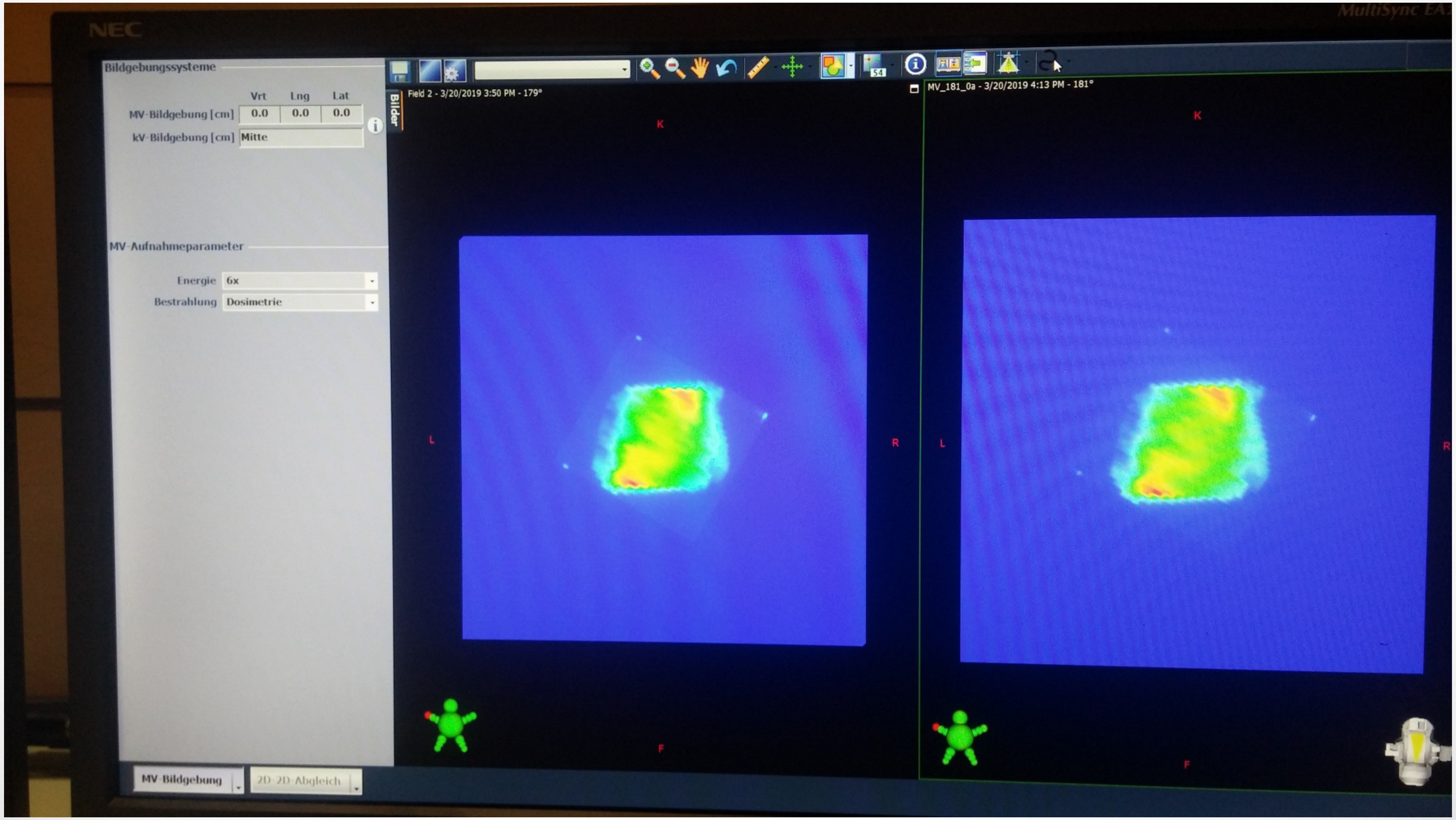


IMRT/VMAT-QA

Measurement (Portal Dosimetry)

IMRT/VMAT-QA

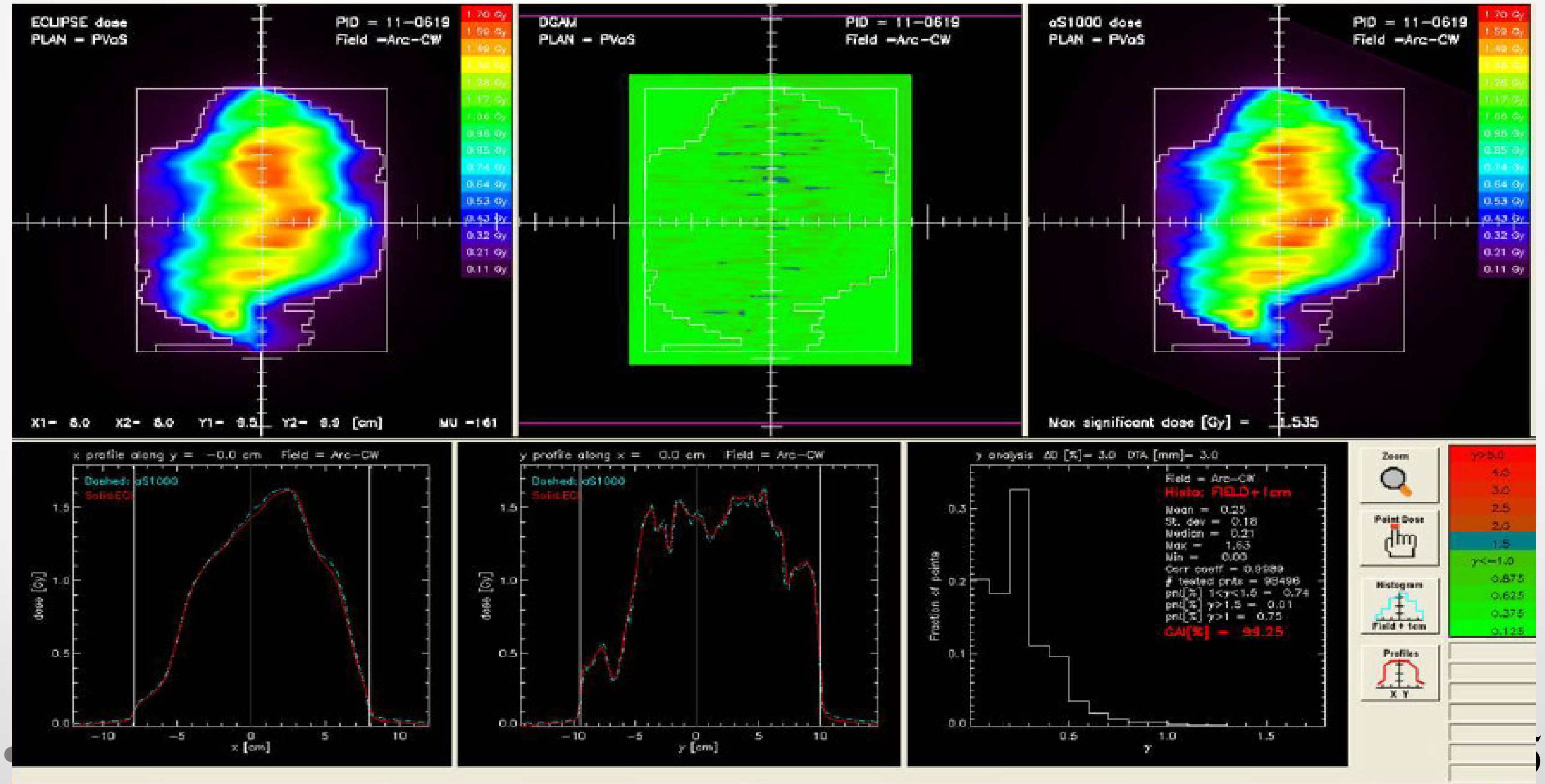
Measurement (Portal Dosimetry)
Comparision (left = Linac, right = TPS)



IMRT/VMAT-QA

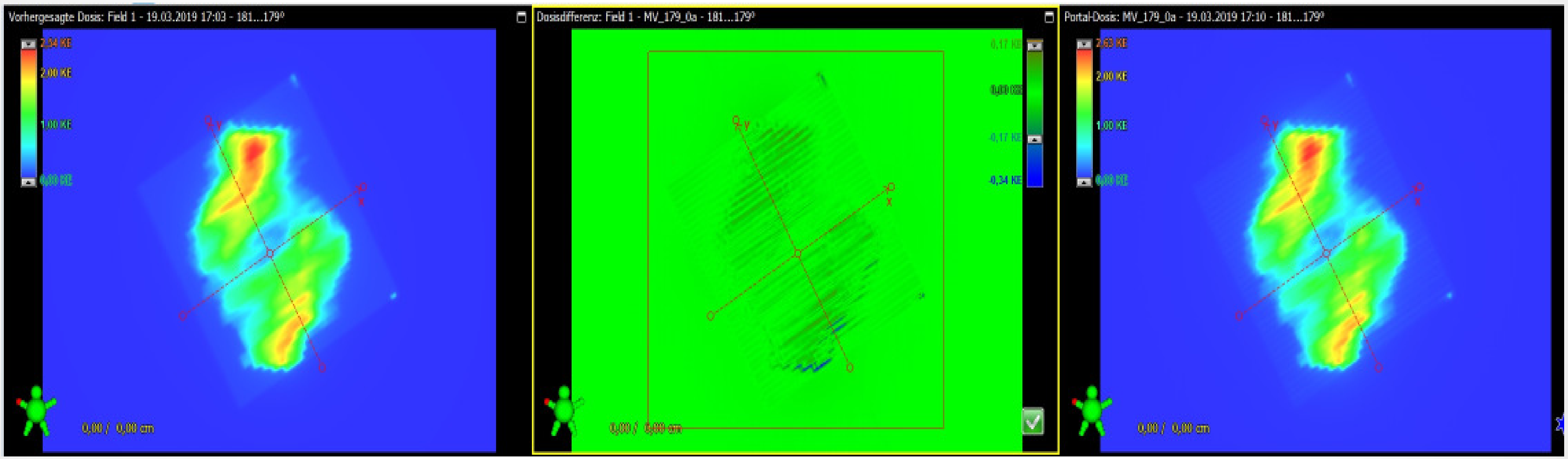
Patient dependency QA:

- Portal dosimetry   Gamma criteria: for example: 3% / 3 mm



Portal Imaging Evaluation

Portal Imaging tool:



- For each predicted Dose (left) a portal dose is measured (right)
- The dose difference (middle) is shown according to
- the gamma criteria

Advantage/ Disadvantage

Patient dependency tests:

Advantages:

- Real treatment of the plan is checked prior each delivery on the patient
- The quality of the plan can be directly identified
- Errors can be opposed and eliminated

Disadvantages:

- Machine QA must be in addition done
- Errors are difficult to track whether they come from the TPS, the machine itself of the QA Tools and method
- Time consuming
- The tests can not be separated to different time

Protocols

- DIN 6847-5: Medical electron accelerators - Part 5: Constancy tests of functional performance characteristics, 2013
- DIN 6875-3: Special radiotherapy equipments - Part 3: Intensity-modulated radiation therapy - Characteristics, test methods and rules for clinical application, 2008
- DGMP-Report 19: Leitlinie zur Strahlentherapie mit fluenzmodulierten Feldern (IMRT) (gemeinsam mit DEGRO), 2004
- AAPM Task Group 142 report: Quality assurance of medical accelerators, 2009
- AAPM Task Group 218 report: Tolerance limits and methodologies for IMRT measurement-based verification QA, 2018
- IAEA Technical Reports Series No.430: Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer, 2004

References

- Report from the feasibility testing of MatriXX device for RapidArc QA; Bocanek,J. 2008.
- Commissioning and QA of RapidArc delivery system, Ling et al, 2008
- QA of IMRT and RapidArc: An Overview; Fog, L.S. 2011
- Dosimetry validation of Volumetric Modulation Arc Therapy by using MatrixX in MultiCube Phantom, Yeh, C. 2008
- Varian RapidArc Manuals
- RapidArc Machine QA: http://epidos.eu/epiqa/artemis-for-rapidarc/machine-qarapid-arc/. Epidos, 2011
- Epiqa Rapid Arc Commissioning Tests
- Delta4 and MattrixX, OmniPro iMRT User Manuals
- PTW
- IBA
- Sunnuclear
- Sekai Shambira: RapidArc Quality Assurance at Addington Hospital
- Holger Wirtz: SmartArc + VMAT, Singen, Germany