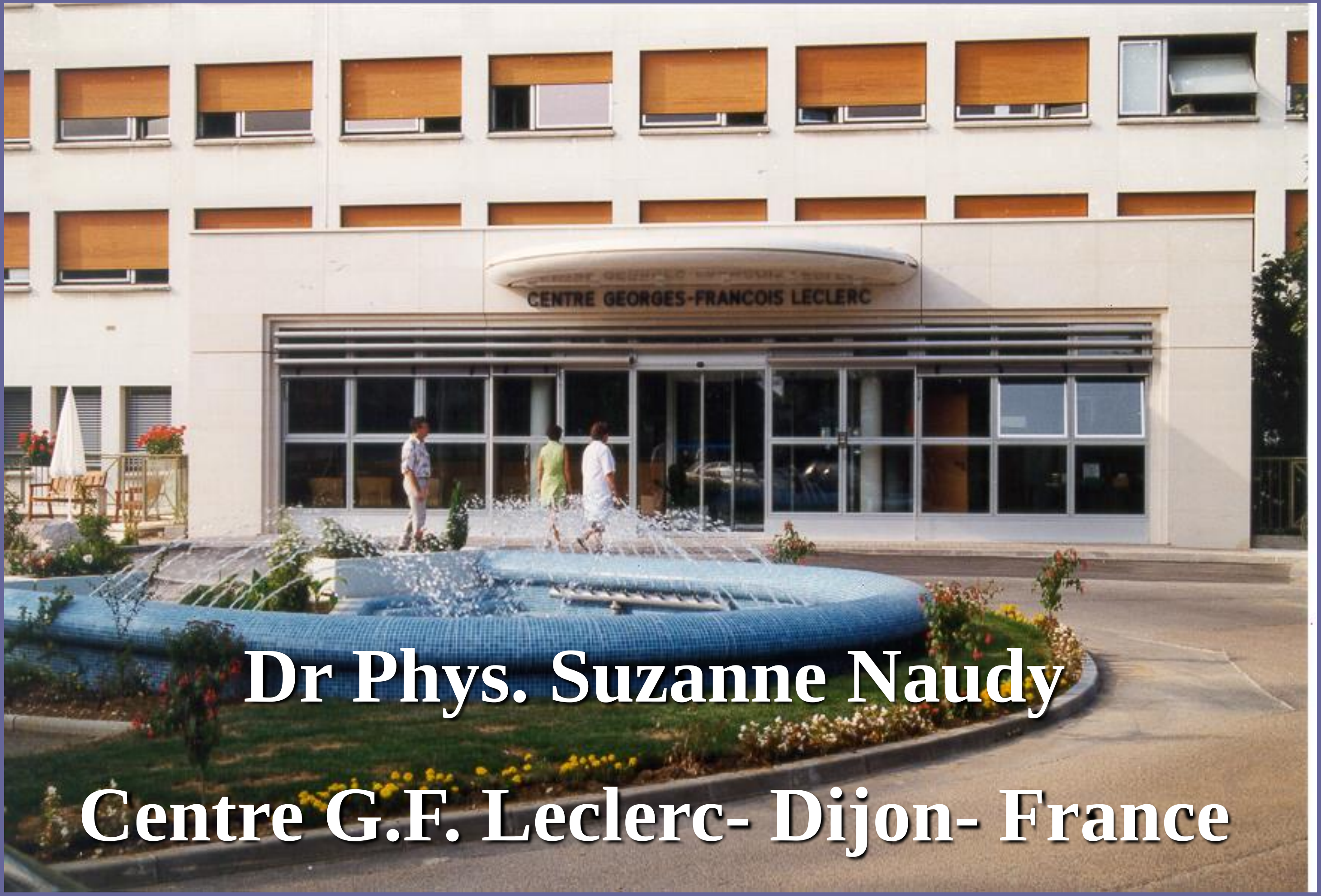
Quality Assurance for Intensity Modulated Radiation Therapy



Dr Phys. Suzanne Naudy

Centre G.F. Leclerc- Dijon- France

- Part 1: Equipment related QA

Content:

- IMRT relevant concepts
- QA questions , answers
- Implementation

Plan to implement IMRT?

What do I need?

- Inverse treatment planning based on dose volume constraints to target and organs at risk

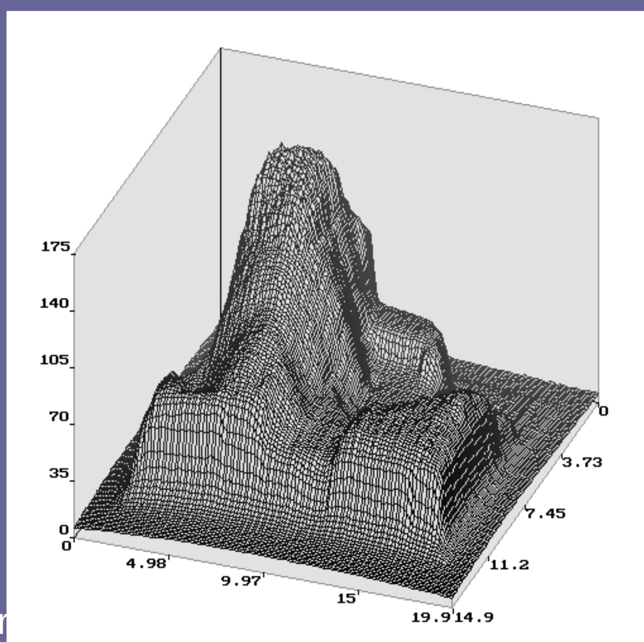
- **Possibility for fluence modulation**

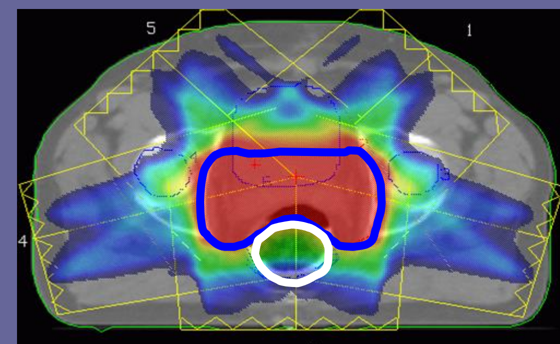
This talk focuses on

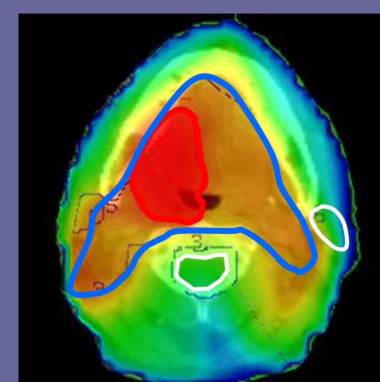
Lateral modulation with MLC

Photons beams

Multiple entries

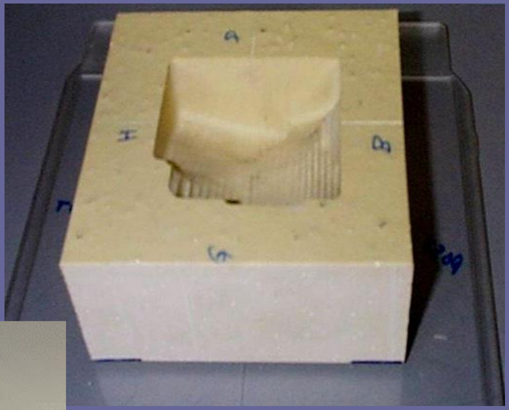


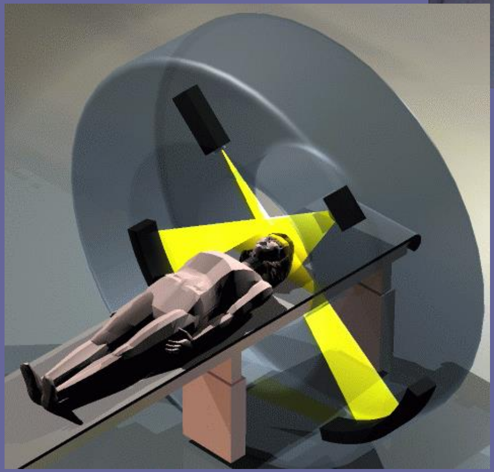




Other possibilities for fluence modulation

Wedges , Compensators

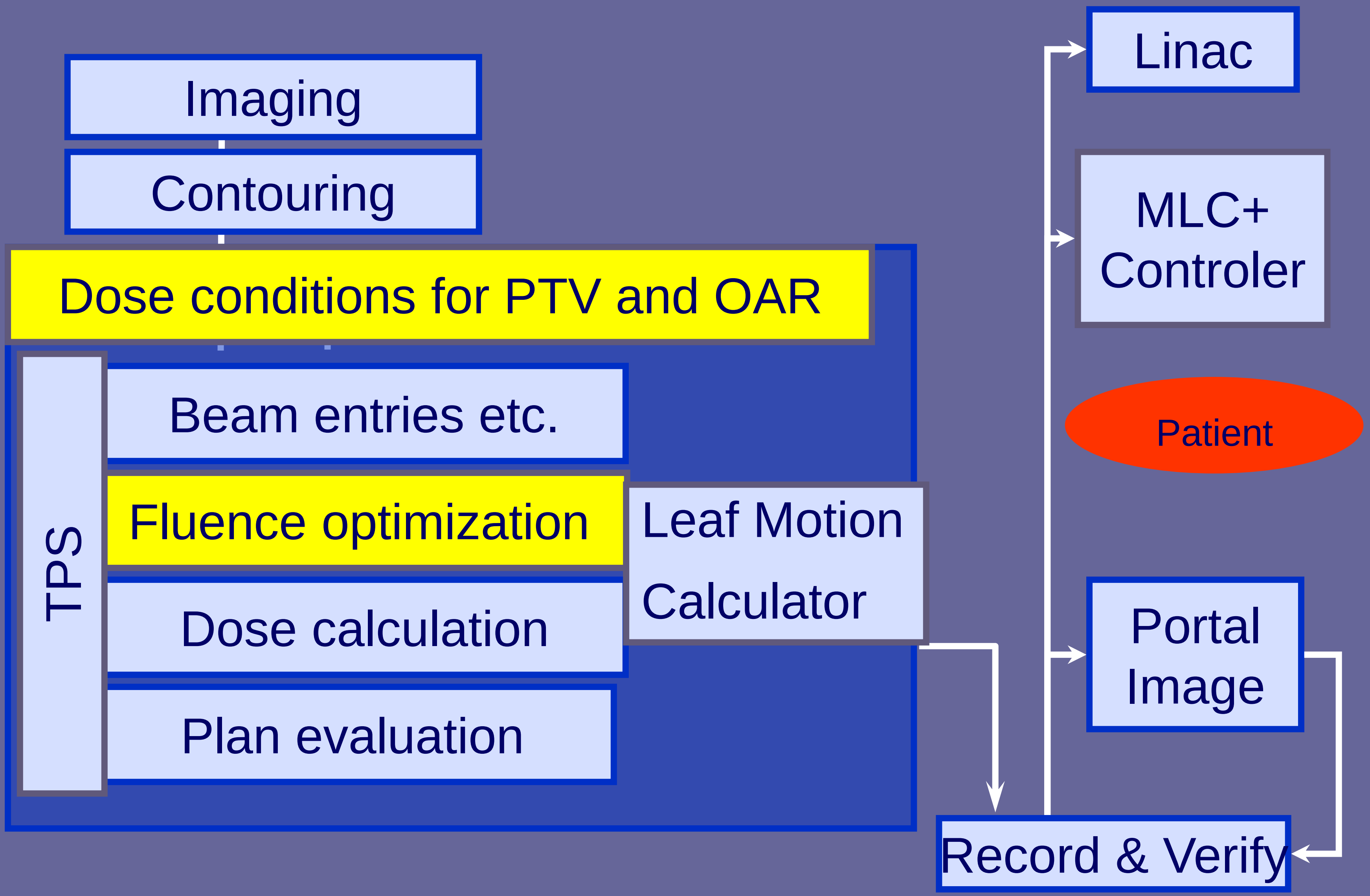




Modulated arctherapie
Tomotherapie

Heavy ions

The IMRT Process using Linac + MLC



Plan to implement IMRT?

What do I need?

- Information on functional performance characteristics and critical points
- Commissioning of the IMRT system
- A routine QA system

Critical points

Treatment Planning
(not adressed in this course)

OPTIMISATION,
FLUENCE CREATION
DOSE CALCULATION

MLC + Controler

ADJUSTEMENT

STABILITY

Leaf Motion Calculator

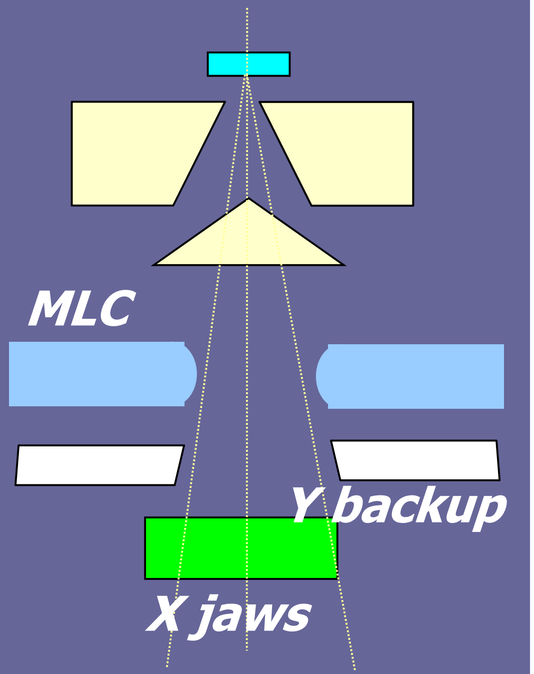
PARAMETERS

Beam

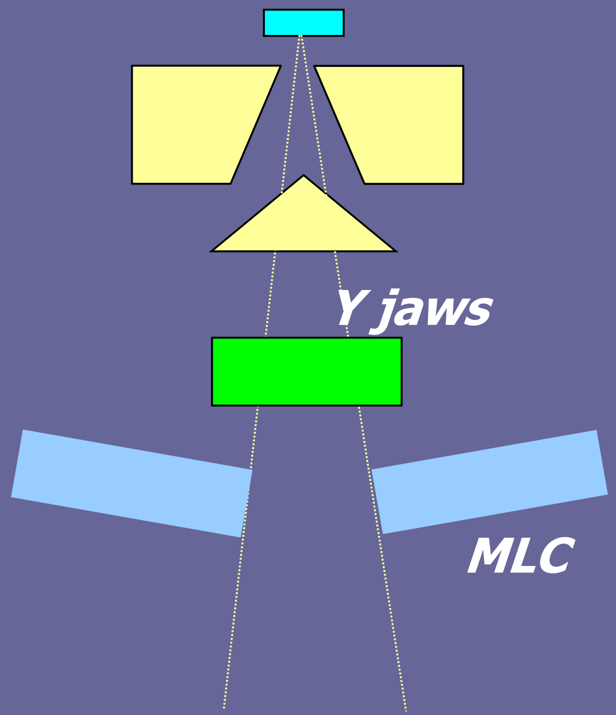
OUTPUT STABILITY

Critical point 1

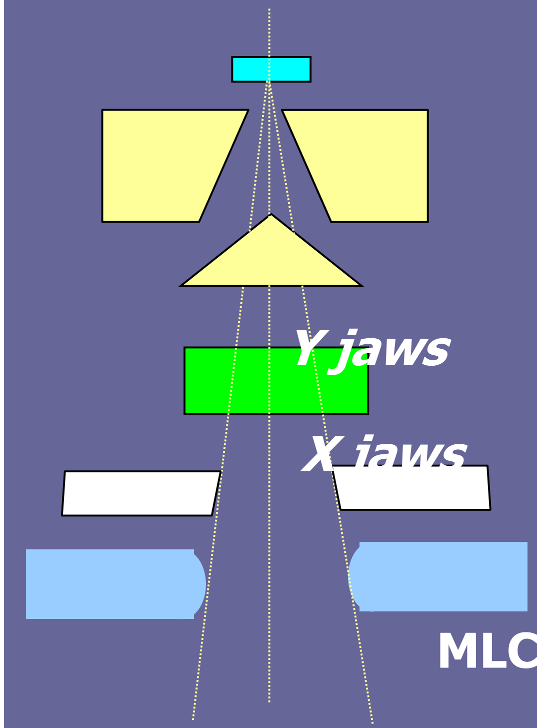
- **The multileaf collimator**



ELEKTA
MLC replaces
upper jaws



SIEMENS
MLC replaces
lower jaws
- Arc motion-



VARIAN
Tertiary Collimator

From C.Mubata, SFPH Tours 99)

MLC specifications (1)

	Elekta	Siemens	Varian
S-MLC Distance	**52.9**	**35.8**	**57.1**
Max size (cm x cm)	**40 x 40**	**40 x 40**	**40 x 40**
Leaves pairs number	**40**	**29 or 40**	**26, 40 or 60**
Width (cm)	**1**	**1**	**1 and 0.5**

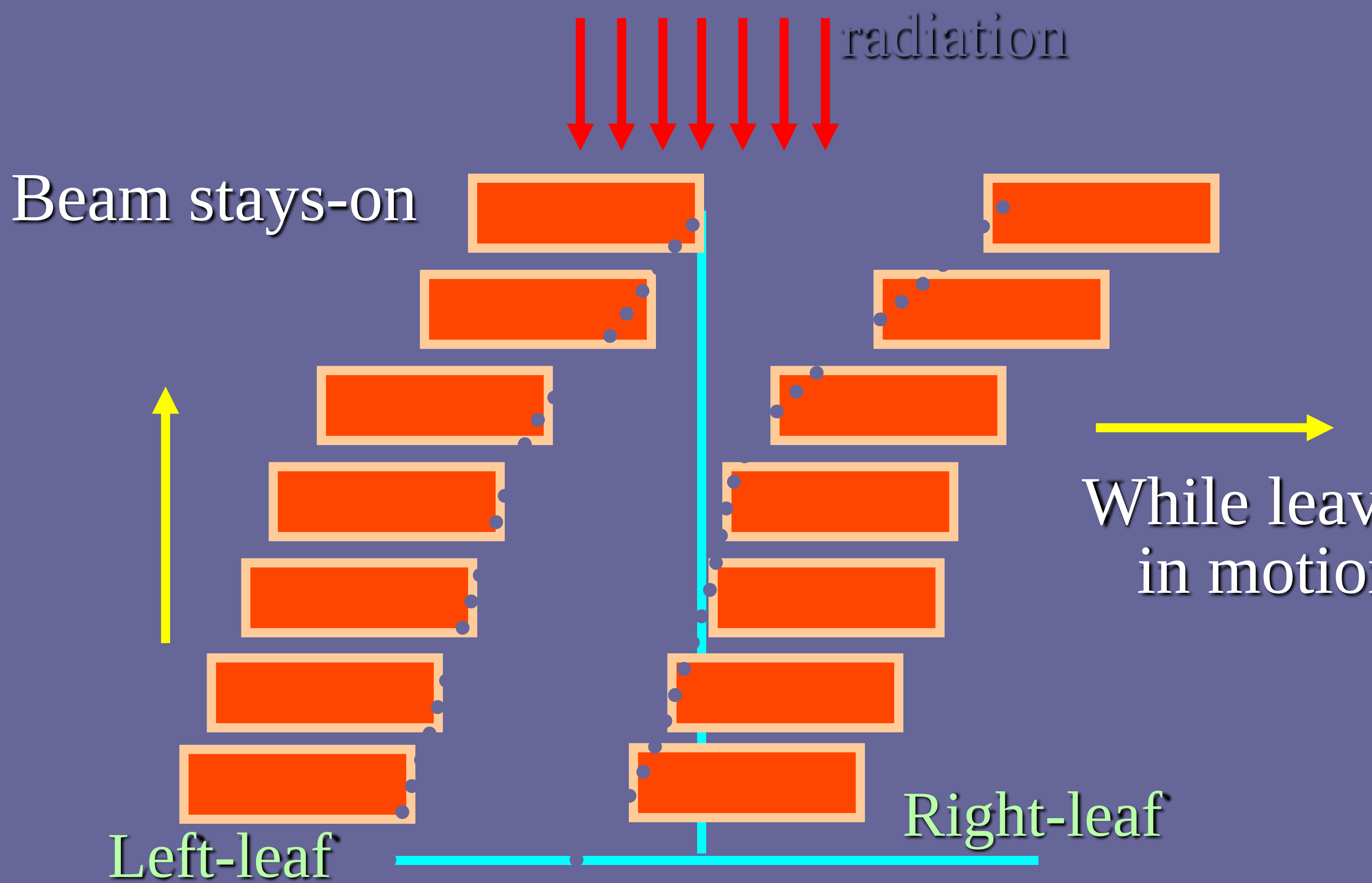
Delivery of IMRT

Two different ways

Sliding window

Step and shoot

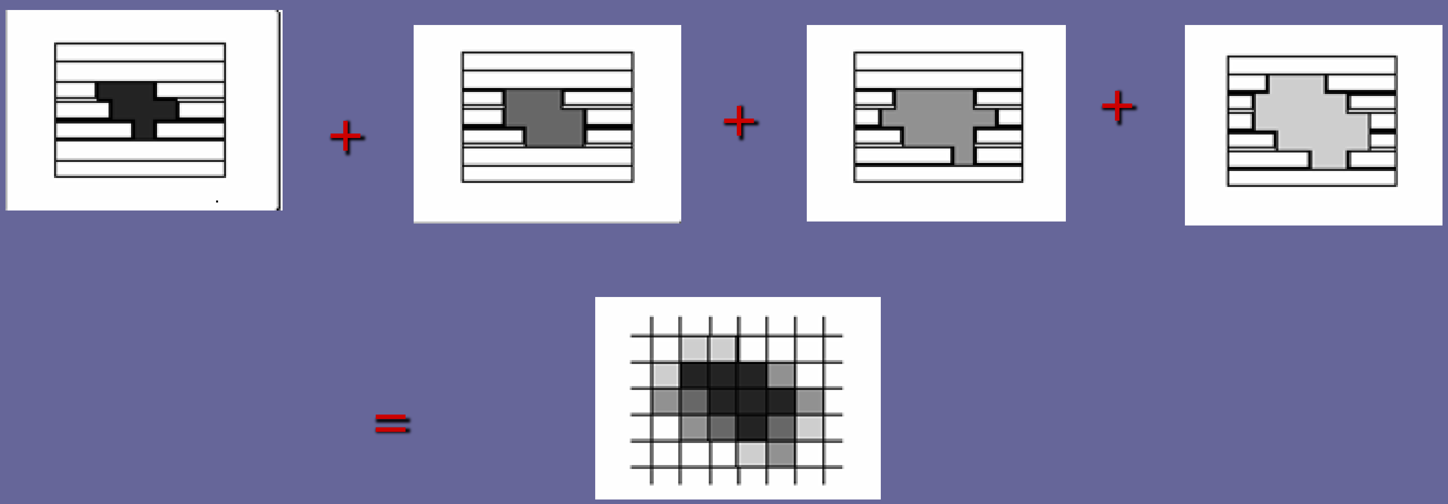
Delivery of IMRT (1)
sliding window method



Delivery of IMRT (2)

Step and shoot method

- Each leaf pair forms a window
- Dose given through the window as function of MU



- The final dose distribution is the summation from all "segments"

Marie Curie (Millenium MLC Varian 120 leaves)

Critical point 2

Leaf Motion Calculator

- **Converts the continuous optimized fluence distribution into a set of isodensity levels**

- **Generates the leaf motion instructions**

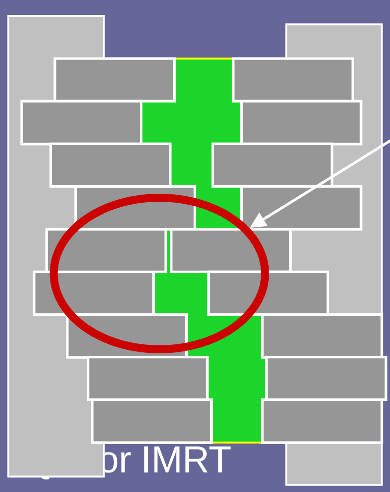
Leaf Motion Calculator

- Leaf motion instructions
- Step and shoot:
  - segment's shapes and MU/segment
- Sliding window:
  - leaves position versus time and leaves speed

Critical point 2

Leaf Motion Calculator

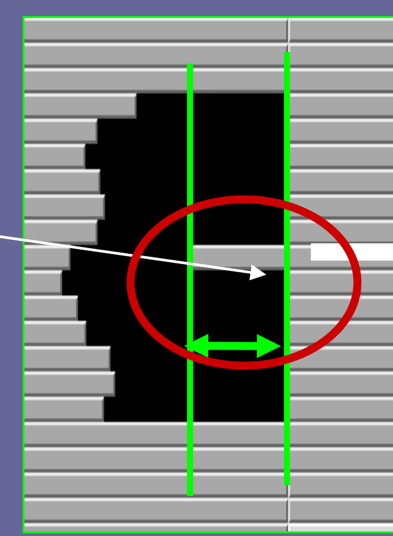
- Takes into account the mechanical limitations of the MLC



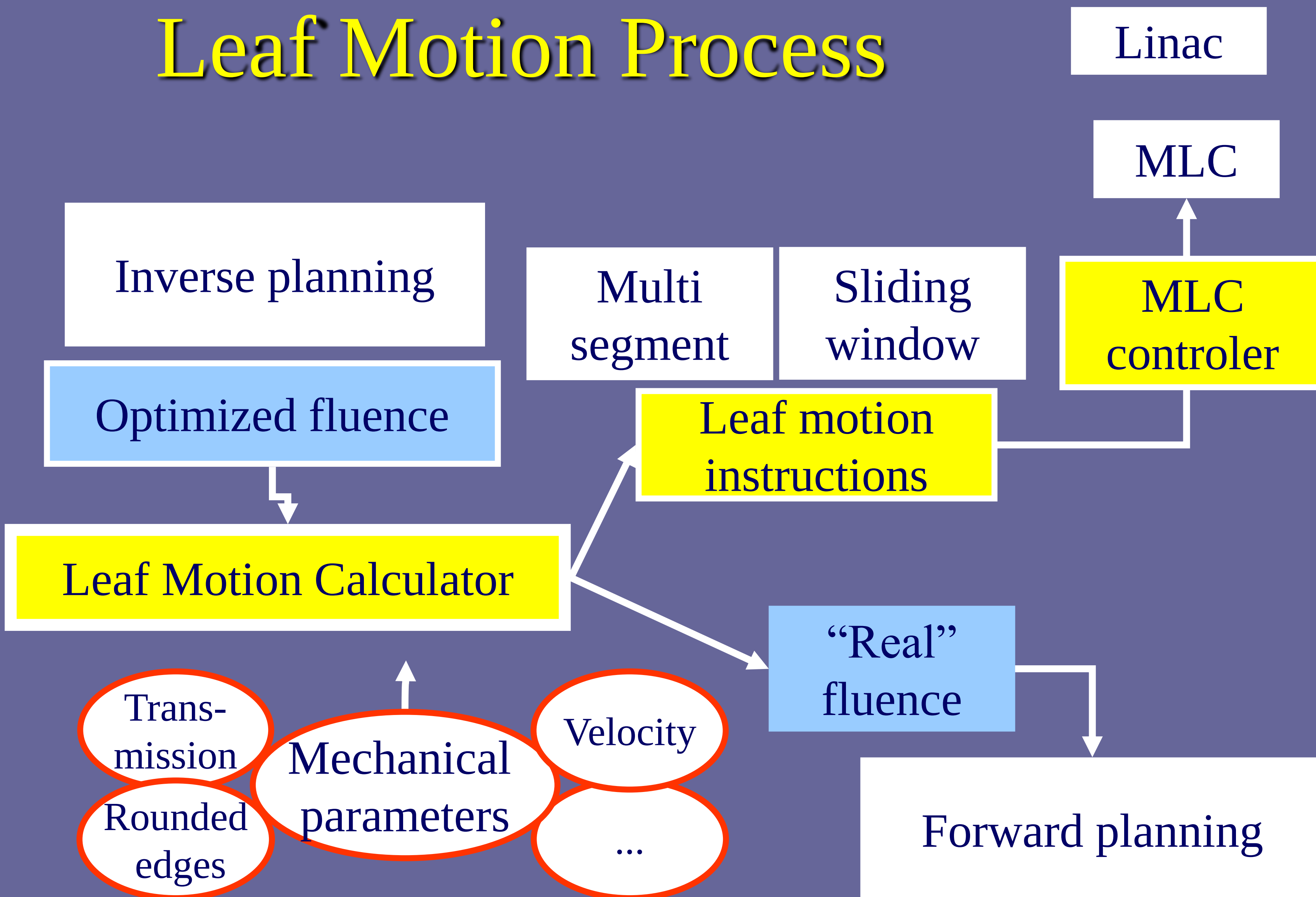
Interdigitation

Overtravel

Max. leaf speed



Leaf Motion Process



MLC specifications (2)

	Elekta	Siemens	Varian
Interdigitation	No	No	Yes
Min leaf gap	6 mm	0 mm	0.2 mm
Overtravel	12.5	10	14.5

MLC specifications (3)

	Elekta	Siemens	Varian
Leaf front	Round	Focalised	Round
Focalisation	Simple	Double	Simple
Thickness	75 mm	75 mm	59 mm

Critical point 3

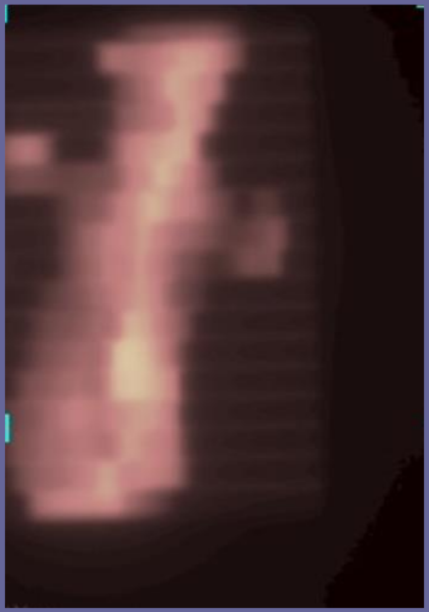
The leaf geometry

The leaf geometry influences the dose distribution

Thickness

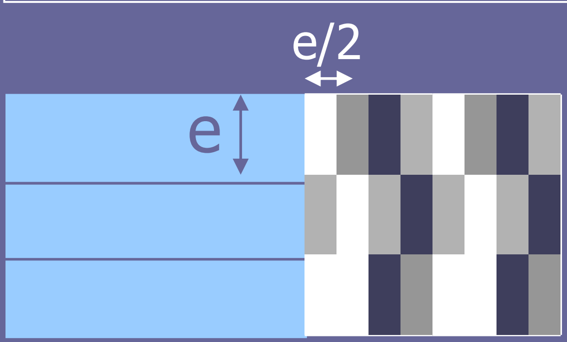
Leaf front geometry

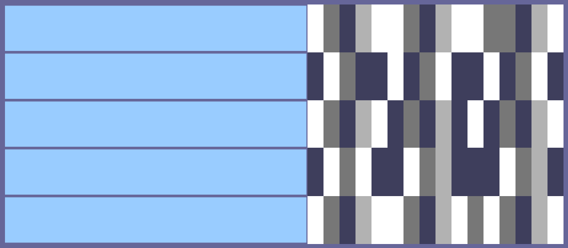
Dose transmission in and out of the field



Leaf width

Resolution of modulation





Leaf Transmission

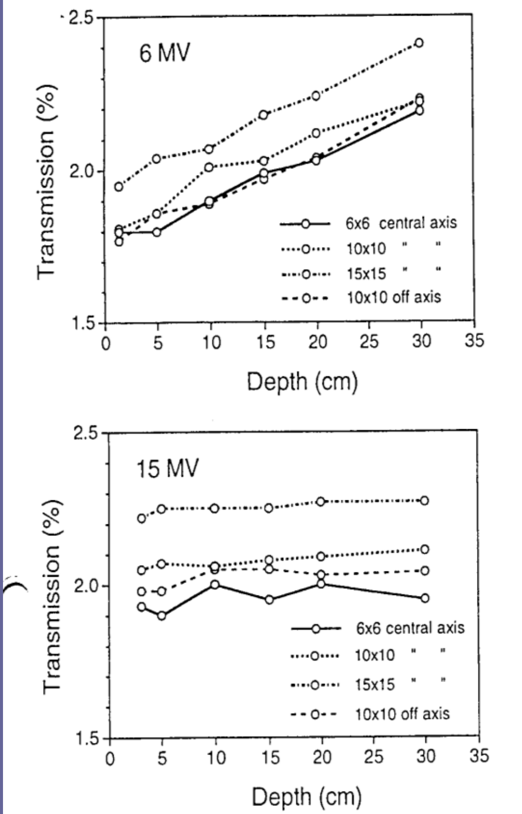


FIG. 3. The average of midleaf and interleaf transmissions measured at isocenter in phantom with a parallel plate ion chamber, 2.5 cm in diameter for (a) 6 MV x rays and (b) 15 MV x rays. The transmission is the ratio of the central axis dose for the MLC blocked field to the open field for the collimator settings and depths shown.

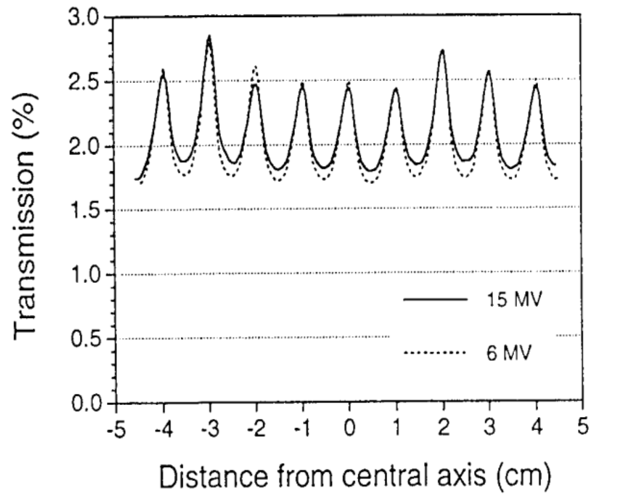


FIG. 4. The midleaf and interleaf transmissions measured at isocenter in phantom with radiographic film for 6 and 15 MV x rays. The transmission is the ratio of the MLC blocked field profile to the open field profile for a 10×10 cm^2 field defined by the jaws and a depth of 15 cm.

LoSasso et al., MedPhys 25, 1998

Average Leaf Transmission

	6MV	18 MV
Leaf Transmission	1.7%	1.9%

Step and shoot:

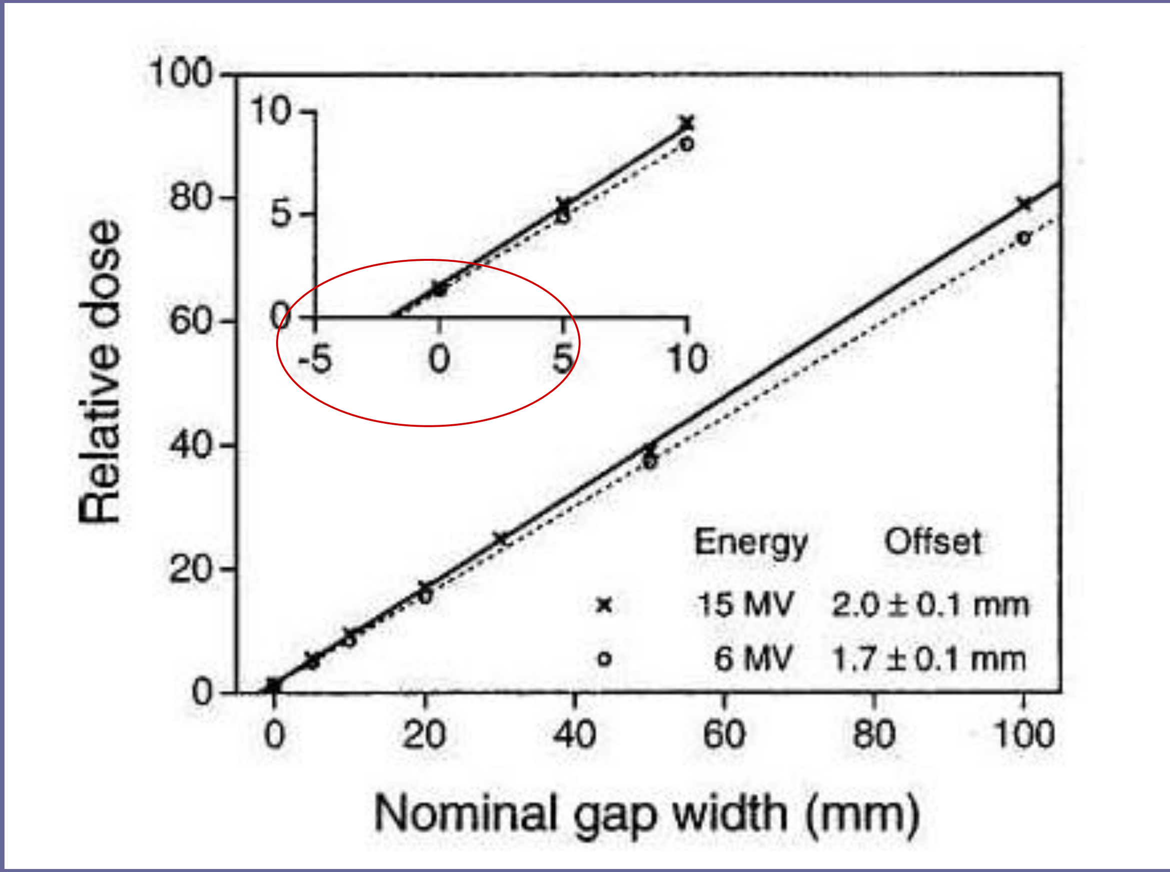
total transmitted dose =f (number of segments)

Sliding window:

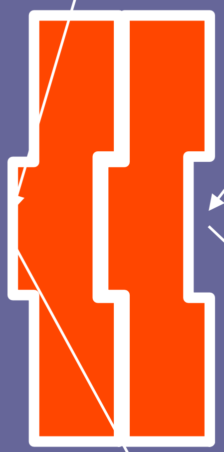
4 to 6% of total dose is transmitted dose

Modelling of rounded front in SW delivery

The rounded edge effect can be interpreted as a dosimetric leaf gap



Tongue and groove: Minimize radiation steaming along the sides of adjacent leaves

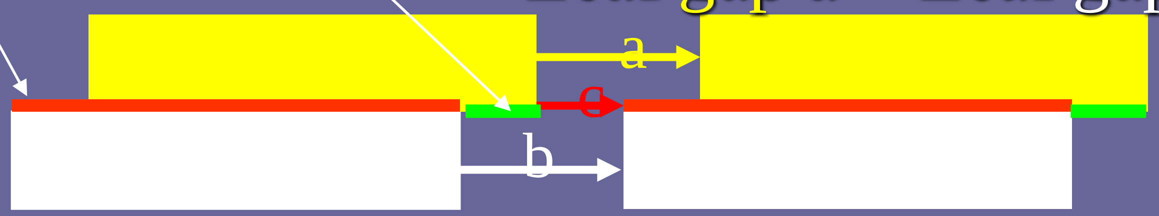


SW :Tongue and groove effect

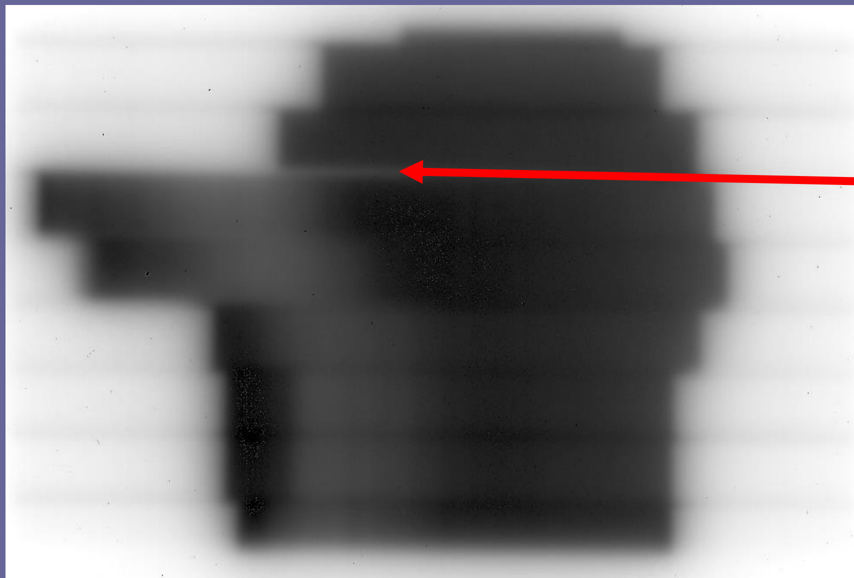
Left edge transmission ≠ right edge transmission

Adjacent leaf pairs with ≠ velocity

Leaf gap a = Leaf gap **b**



Leaf gap c < Leaf gap a



Tongue and groove effect

Narrow strip of low intensity

- **Up to 15 % for a single field**
- **<1.6% in multiple fields plans**

Synchronisation = smoothing

!

Optimisation

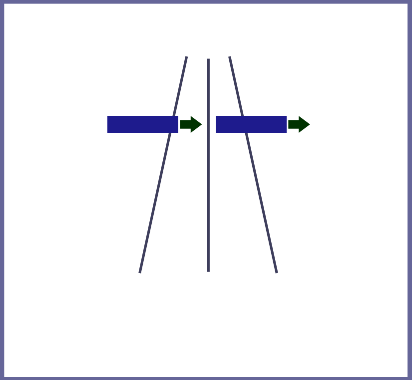
Critical point 4

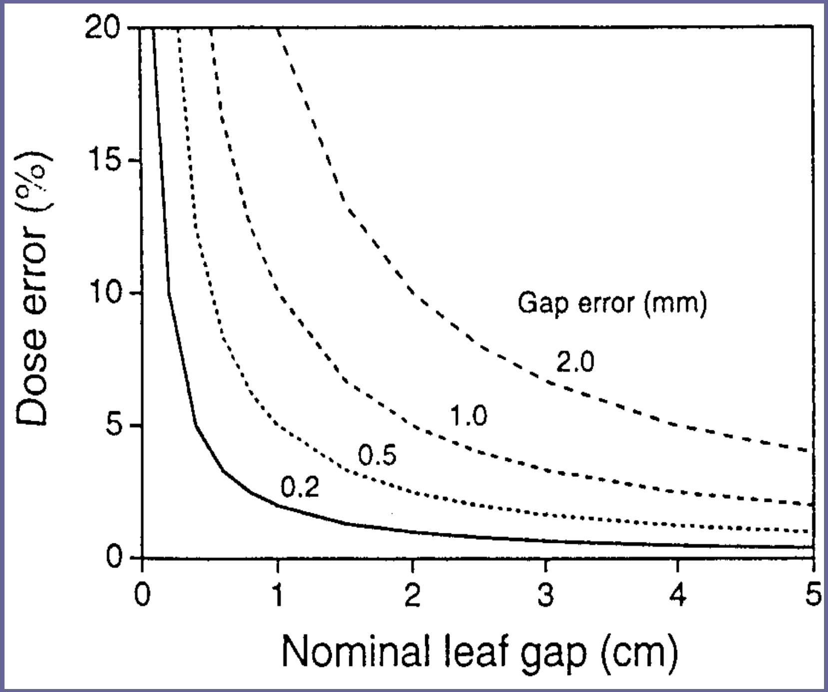
MLC calibration

The accuracy of leaves positionning affects the dose distribution

- Sliding window
  - Wrong position → Leaf gap error
  - Leaf speed instability → Leaf gap error

Dose discrepancy





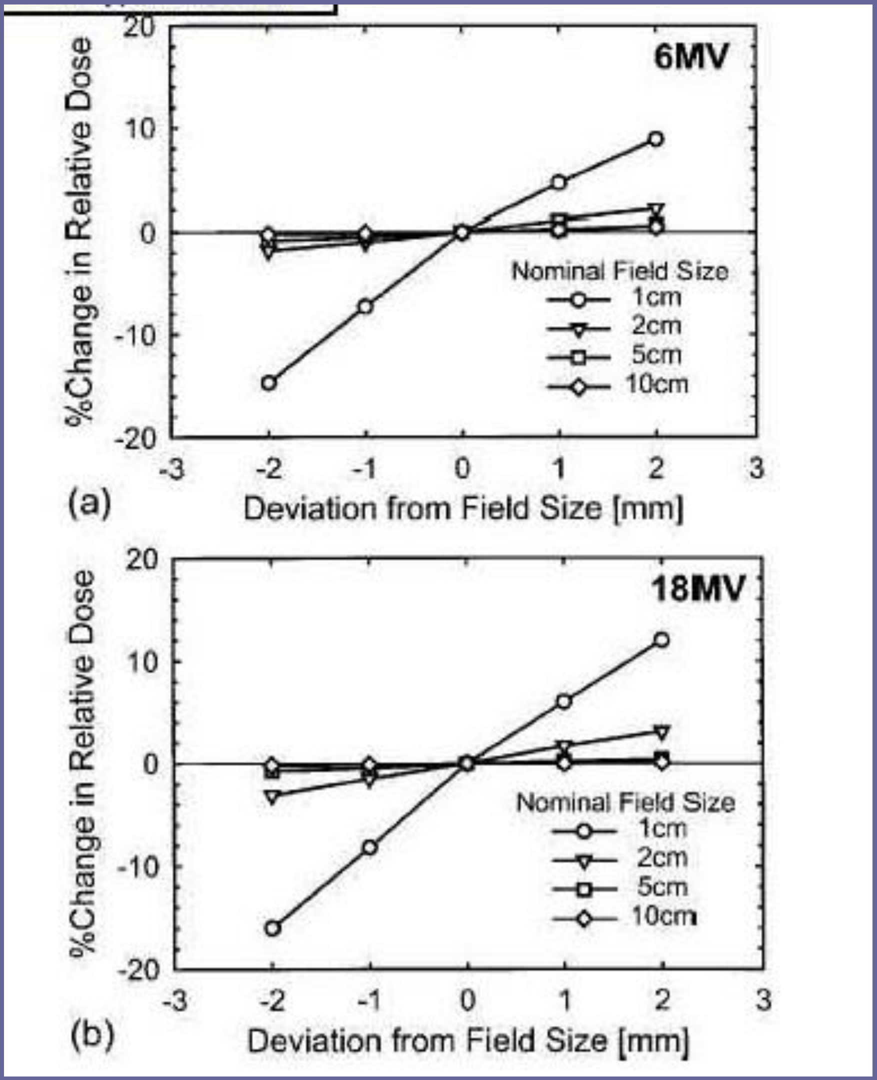
LoSasso et al., MedPhys. 25, 1998

Step and shoot:

Wrong position →

Wrong shape and Output factor

Dose discrepancy



Sharpe and alii

Med. Phys, 27(12)

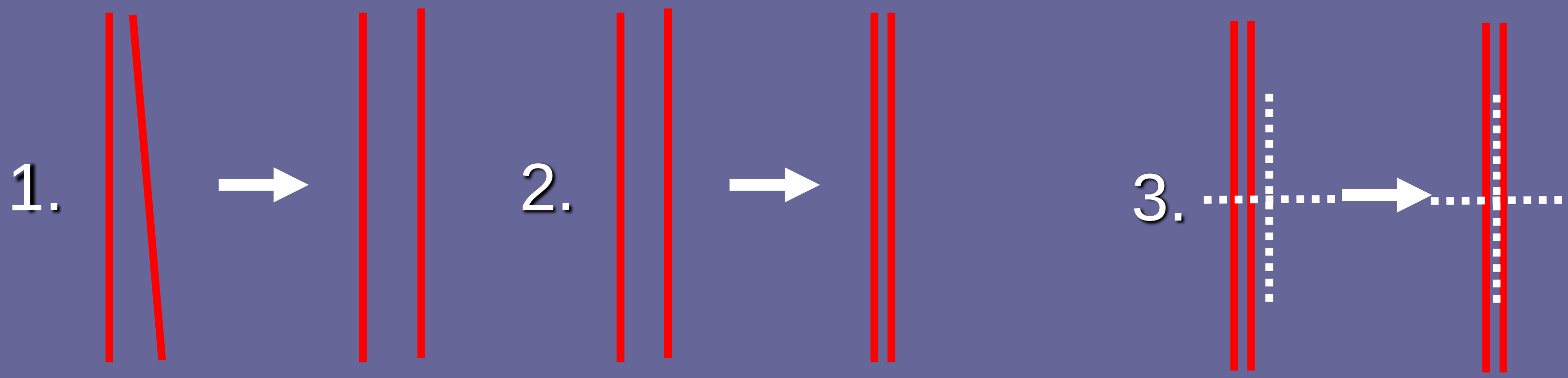
Adjustement
++

– leaf positioning calibration
– carriage calibration

Accuracy of position readout system

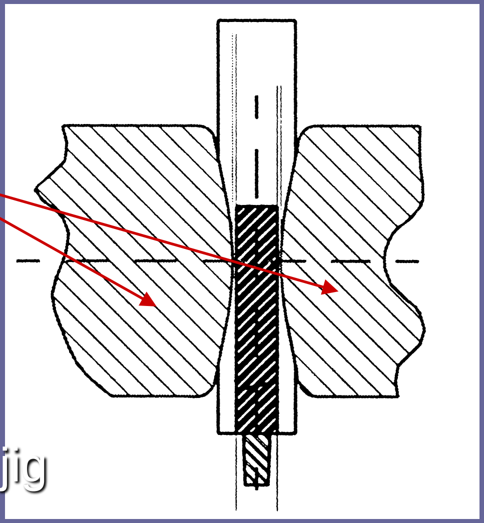
MLC Adjustment and Calibration in static mode:

Leaves parallel | **Minimum leaf gap** | **Centered**



Reference values in the MLC controler

Leaves



Varian calibration jig

Critical point 5

Leaf speed stability

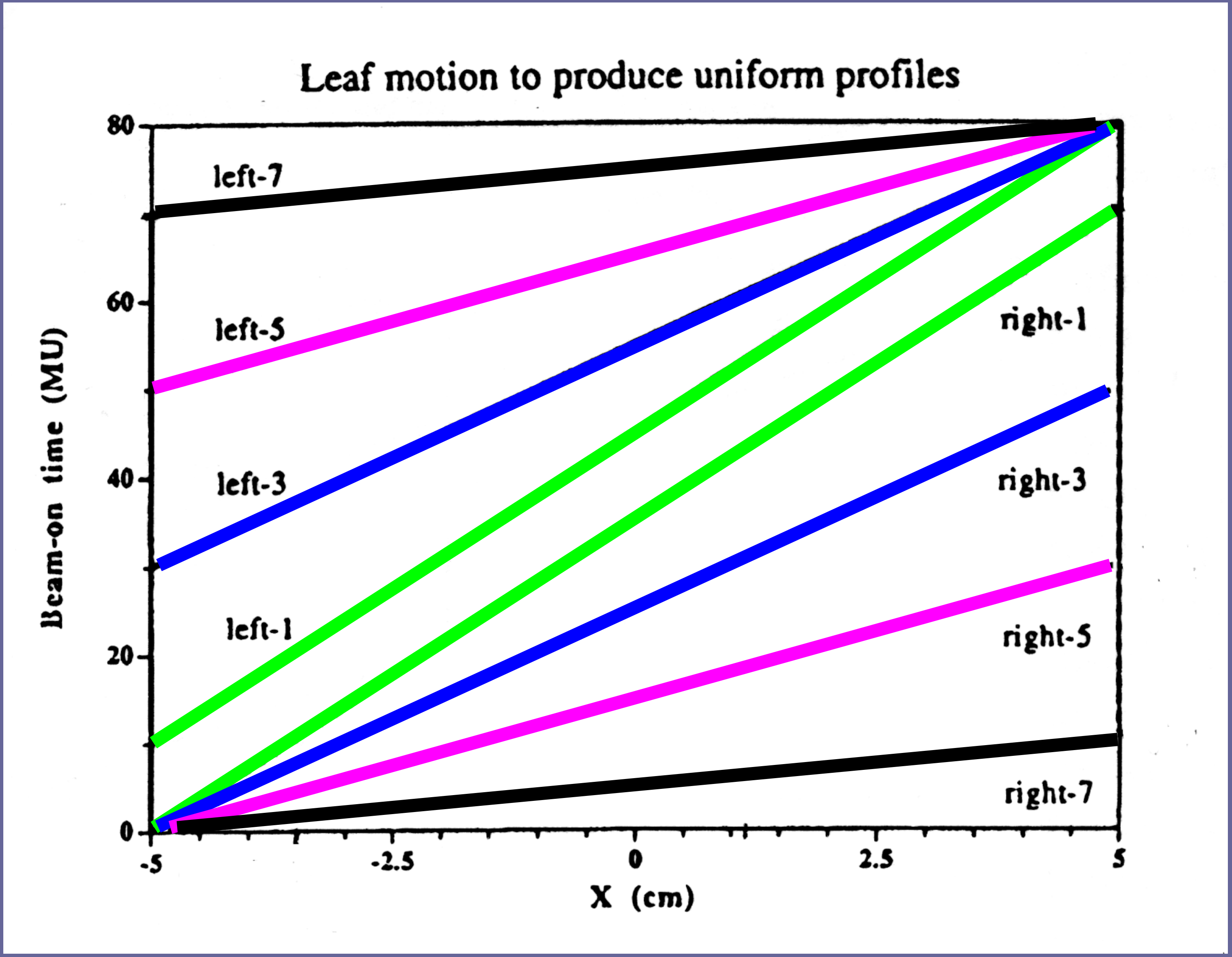
Important for sliding window delivery:

Different leaf speed
- **for different segments**
- **along the leaf trajectory**

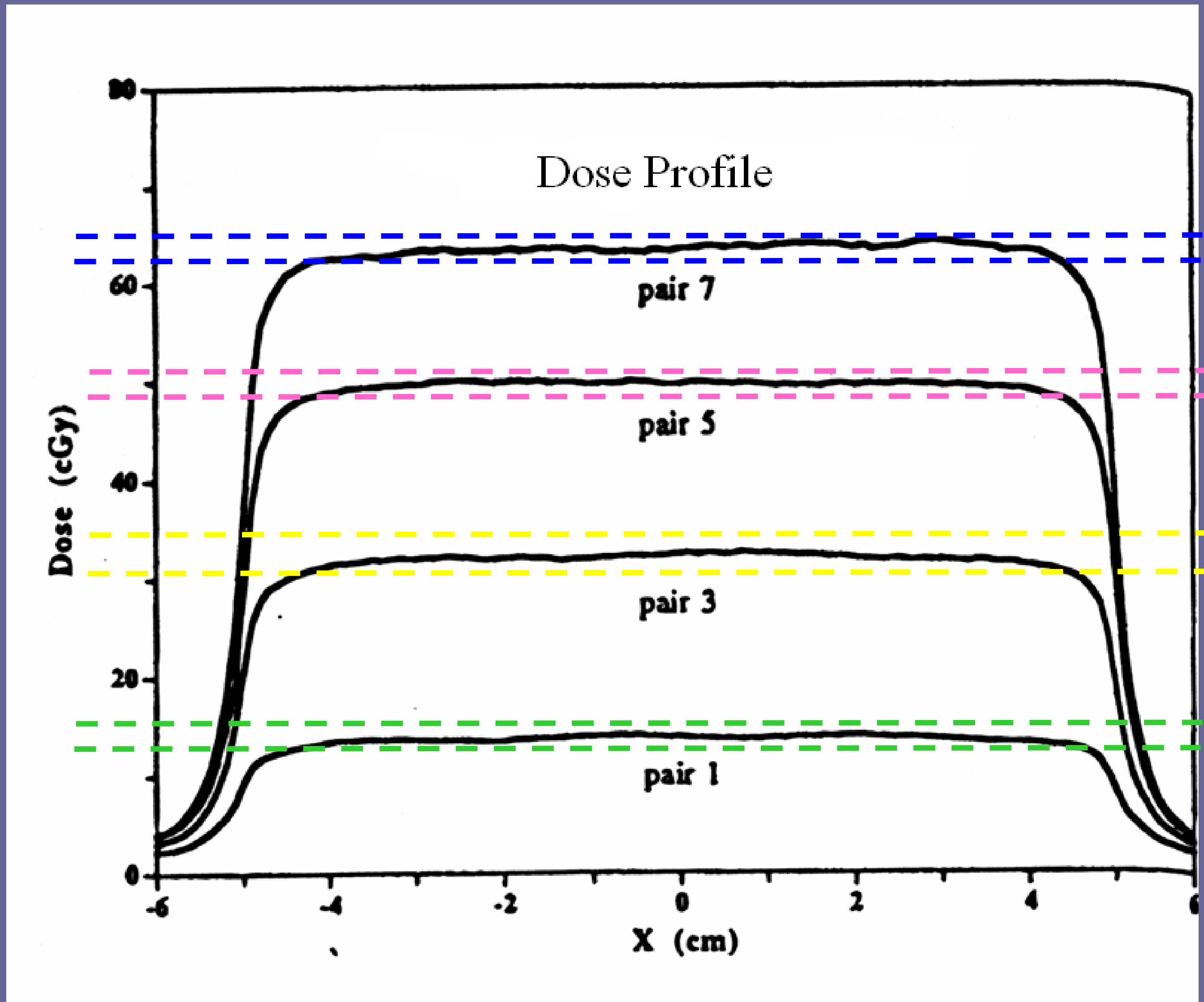
- **variation in the leaf speed may lead to the variation in the leaf gap**

↓ Dosimetric error

Stability of the leaf speed



Chui *et al*,Med. Phys. 23: 635



Chui *et al*,Med. Phys. 23: 635

MLC controler

Step&Shoot:

- Synchronisation of leaf position and MU

Sliding window:

- Synchronisation of dose rate and leaf speed

! May lead to beam hold off waiting for the leaves to reach the right position → machine unstable

Beam stability

Low MU per segment (muliple static segment)
Simultaneous start of beam and leaves motion (dynamic mode)

⇩

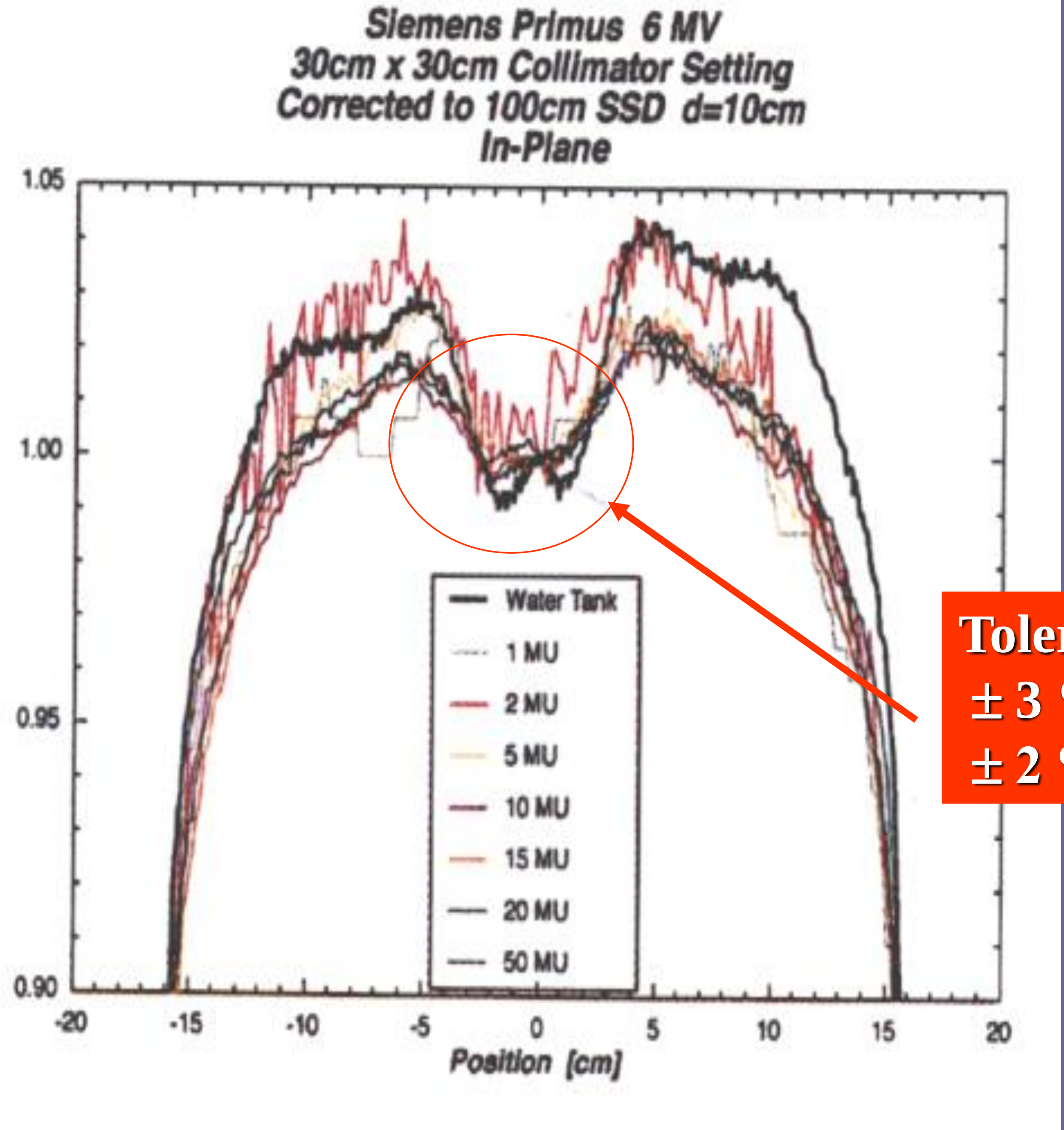
Beam characteristics should remain within tolerance

- **Homogeneity**
- **Symetry**
- **Nominal dose rate**

- Ex: Varian linacs

  - Homogeneity 1.9% (C. Ramsey)
  - Symmetry 0.8% (C. Ramsey)
  - Dose rate 0.8% (C. Ramsey, D.Kubo)
  - Energy <0.8% (C. Ramsey)

C. Ramsey et. all, Med.Phys. 26, 1999
Kubo,Wang, Med.Phys. 27, 2000



Homogeneity and symmetry

Tolerance:
± 3 % for 1 mu
± 2 % ≥ 2 UM.

St. Jude Children's research hospital

Output factor

The behavior of the dose monitor depends of the design and geometry of the whole collimation system

and should be assessed

for small fields and low MU

- **Dose monitor linearity (Siemens)**

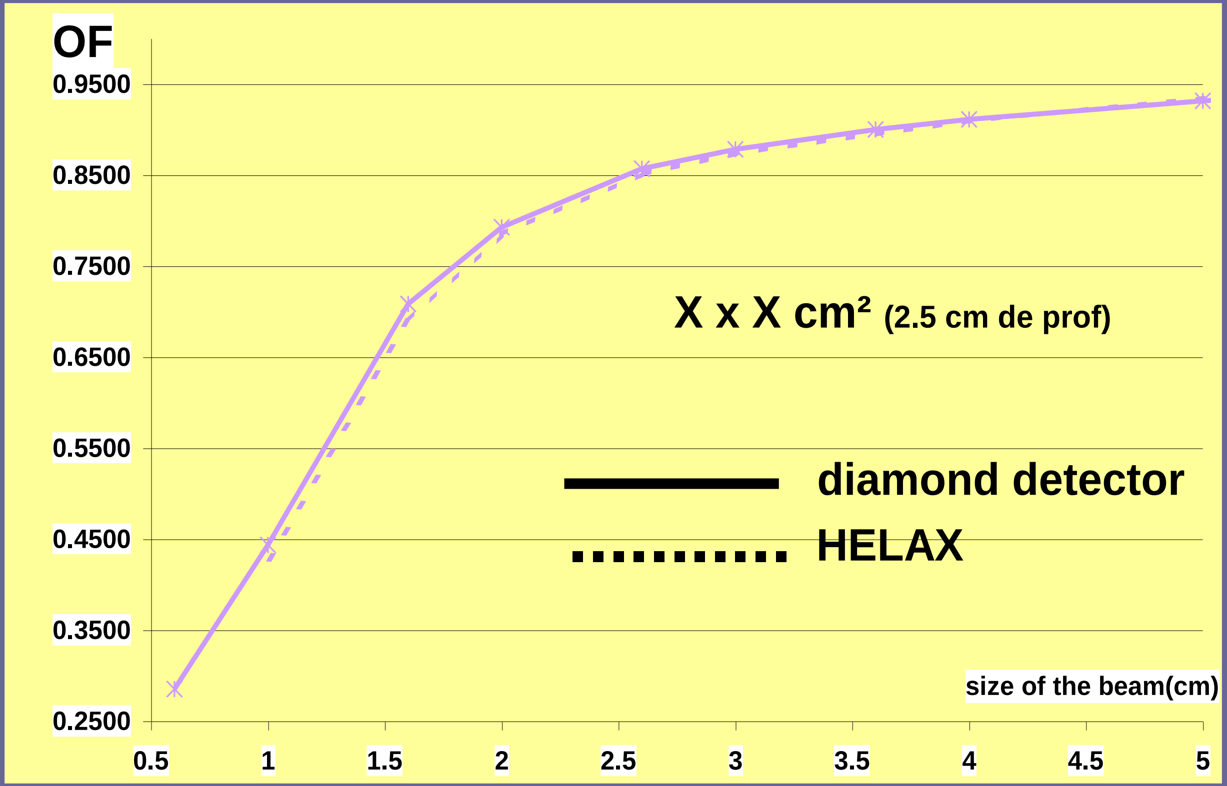
MU	linearity L
1	3,1%
2	3,2%
3	2,1%
4	1,9%
5	2,9%
6	2,4%
7	1,1%
8	0,9%
10	0,5%
15	0,3%
20	0,3%
30	0,1%
50	0,1%

$$L = \frac{\text{Dose (x UM)/UM}}{\text{Dose (200 UM)/UM}}$$

Within tolerance from 1 MU

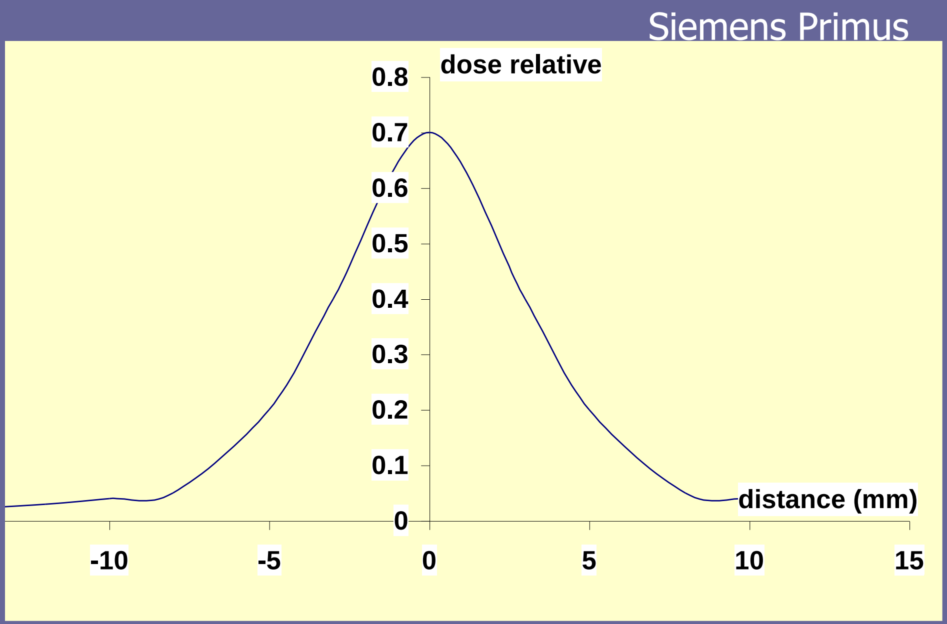
OUTPUT FACTOR SMALL FIEDS

Siemens Primus (10MV): **Collimator back scattering effect**



Output factor measurement: Beware!

Dose Profile : 1x 10 cm² field



- positioning of detector ++
- detector type (diamond, pin-point, …)

What about gravitation ?

- IMRT plans combine number of intensity modulated fields with various gantry angles

- Geometry may compromise

  – mechanical precision (leaves positioning)
  – performance of linear accelerator dosimetry system

Gravity test

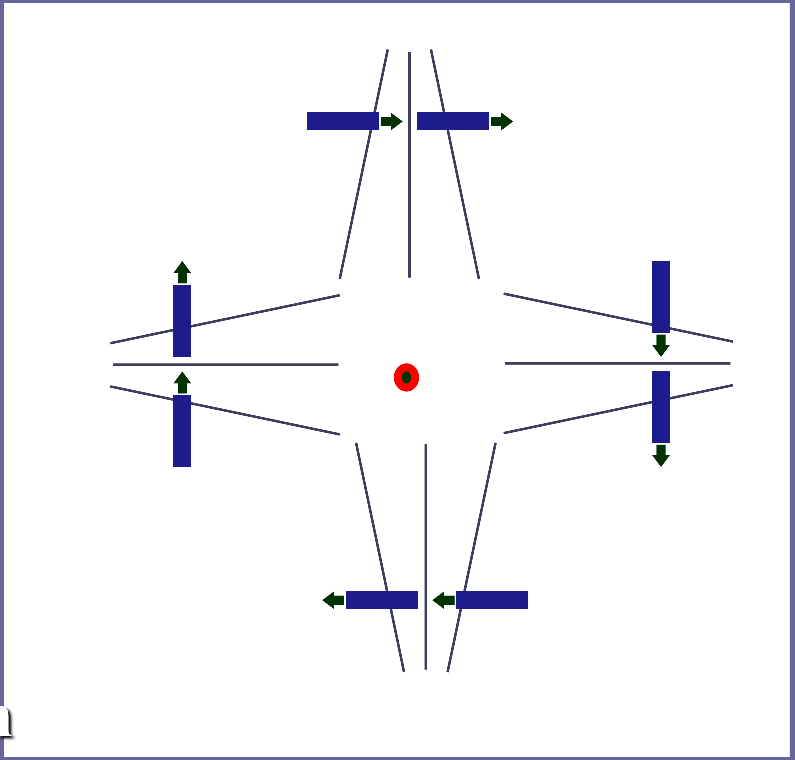
Principle

4 mm sliding window

Detector at the isocentre

Measurement in the 4 major gantry angles

Normalised to the static reference conditions térence



Sensibility:

Diff. 2.5% ↔ pos variation. 0.1 mm

!

Detector array: all leaves

Ionisation chamber : central leaf / carriage block

Specifications

Item	Tolerance
MLC Calibration	± 0. 2 mm
Positioning	± 0. 2 mm
Gravity test	± 0. 2 mm
Speed stability	H et S:± 2 %
Beam on/off	H et S:± 2 %
OF small fields	:± 2 %

- A routine QA system

QA of radiation therapy equipment is primarily an ongoing evaluation of functional performance characteristics”
(AAPM Report 46)

Tools

- **Small volume detector: pin point, diamond**
- **+**
- **Film dosimetry or**
- **Portal dosimetry or**
- **Detector array**

- **2D analysis software**

Positioning reproductibility test

1: Picket Fence : qualitative

! Dynamic:

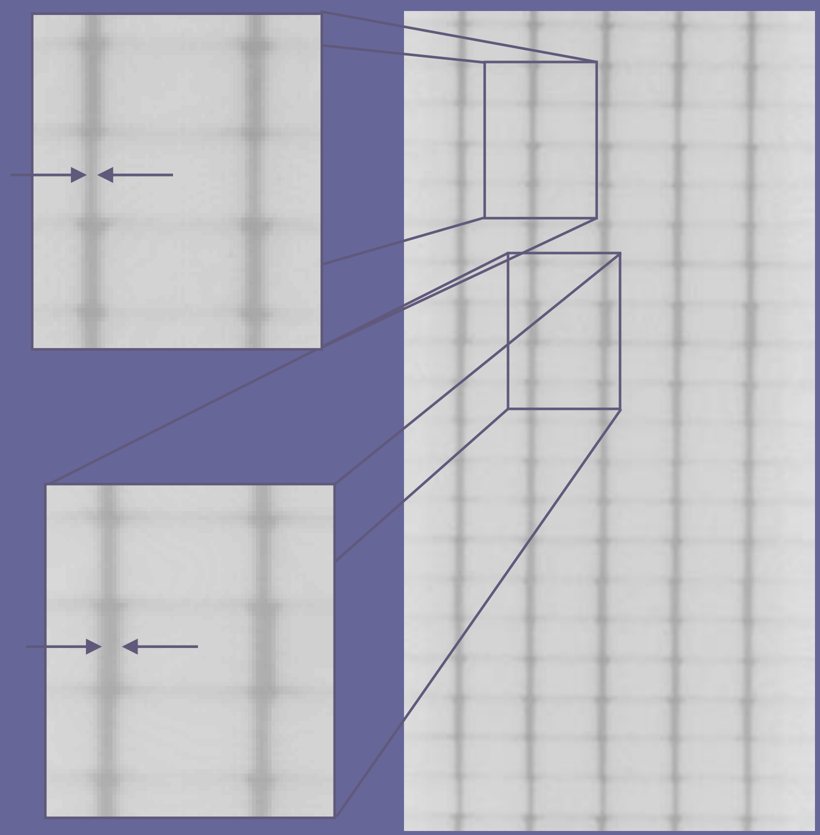
Sliding leaves

1mm gap changing speed every 2cm

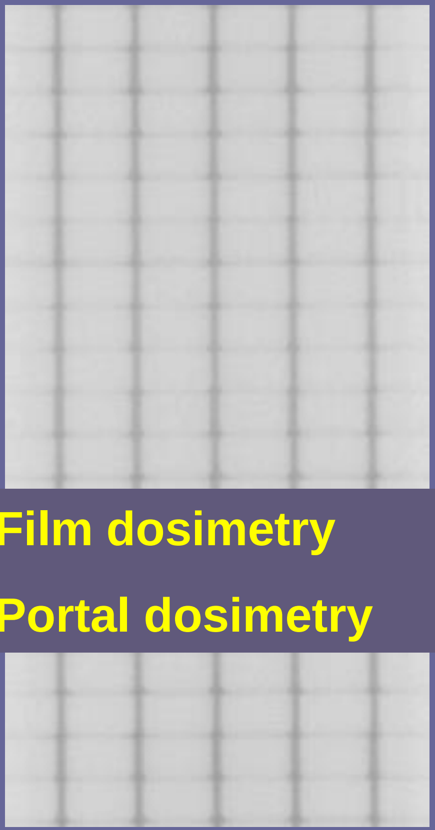
! Static:

1 mm segment every 2cm

errorrs±0.5mm



Correct adustement



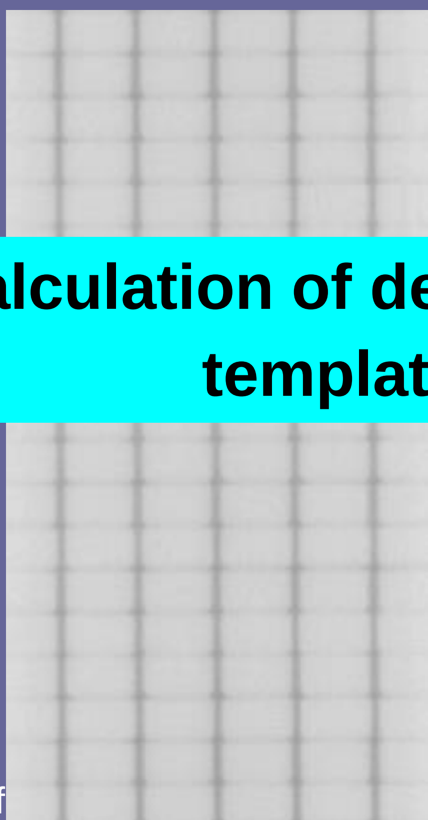
Film dosimetry

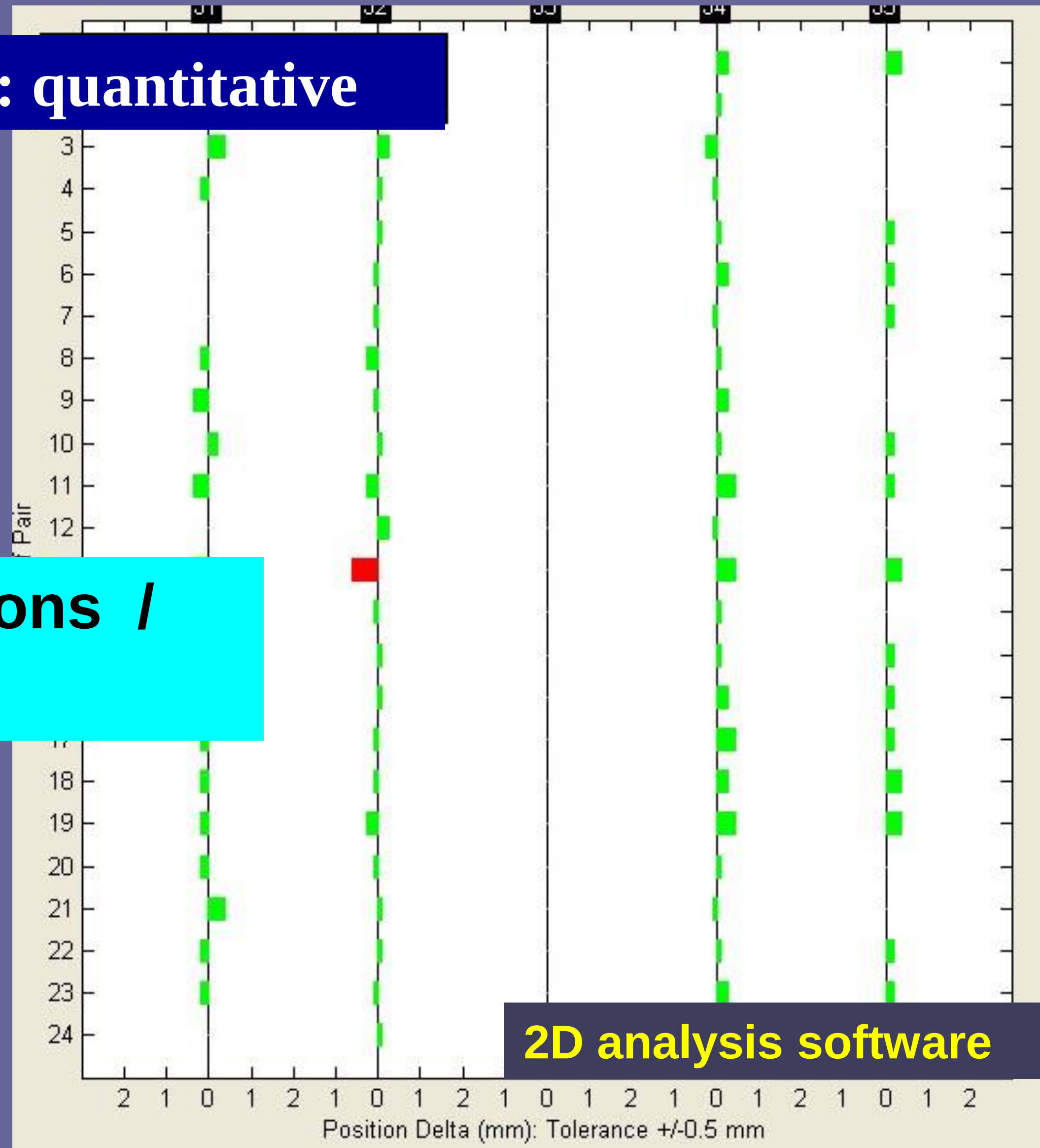
Portal dosimetry

Positioning reproductibility test

RIT 113

1: Picket Fence : quantitative





Calculation of deviations / template

2D analysis software

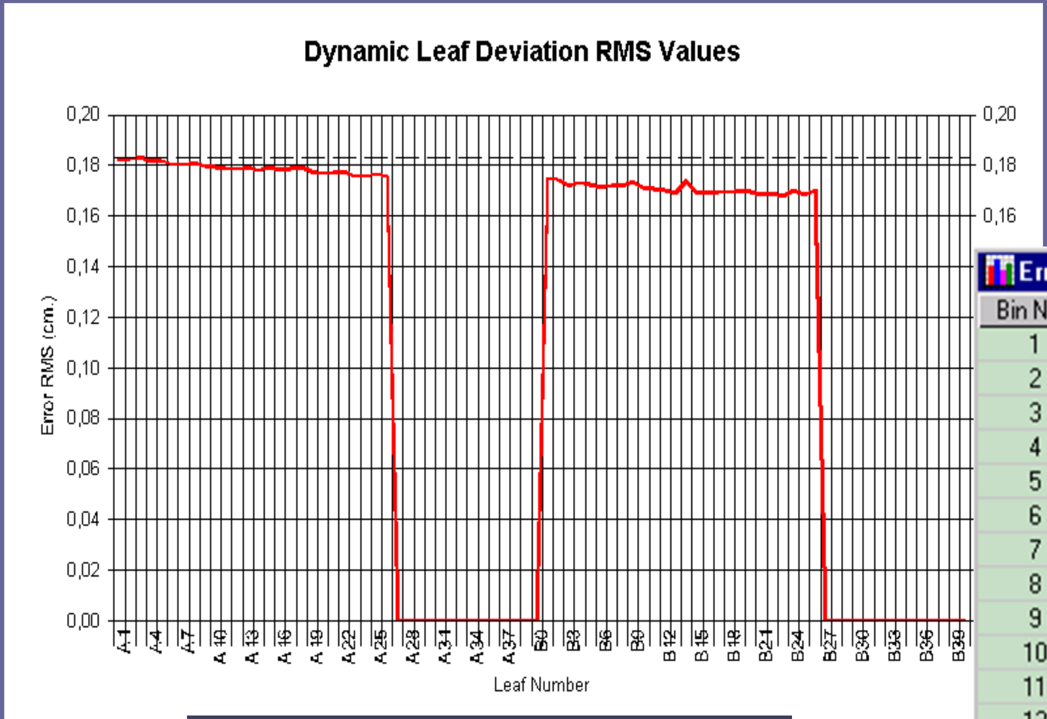
QA f

Positioning reproductibility test

Quantitative test (2)

- **Leaves moving at maximum speed**
- **Acquisition of positioning errors**
- **Statistical Analysis**

! Manufacturer tolerance
> IMRT relevant tolerance



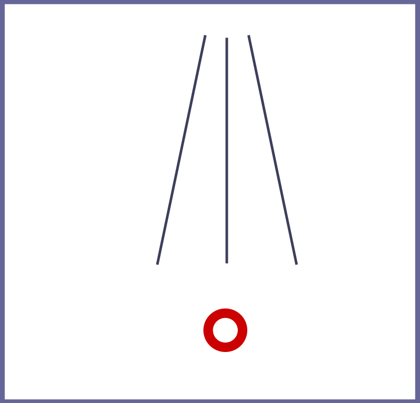
Shows motors failure and /or MLC untidiness

Error Histogram Data

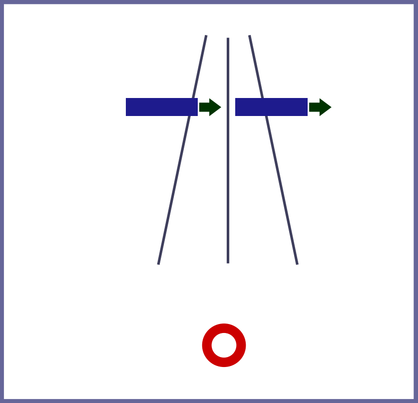
Bin No.	Error (cm.)	# of Count	Percent
1	0.000 - < 0.005	260	1.4706
2	.005 - < .05	0	0
3	.05 - < .1	104	.5882
4	.1 - < .15	130	.7353
5	.15 - < .2	17108	96.7647
6	.2 - < .25	78	.4412
7	.25 - < .3	0	0
8	.3 - < .35	0	0
9	.35 - < .4	0	0
10	.4 - < .45	0	0
11	.45 - < .5	0	0
12	.5 - < .55	0	0
13	.55 - < .6	0	0
14	.6 - < .65	0	0

Varian dynalog analysis

Dynamic dose reference value: Sweeping gap factor (SGF)



Dref



Dsg

static reference condition

4 mm sliding window

SG F= Dref/Dsg

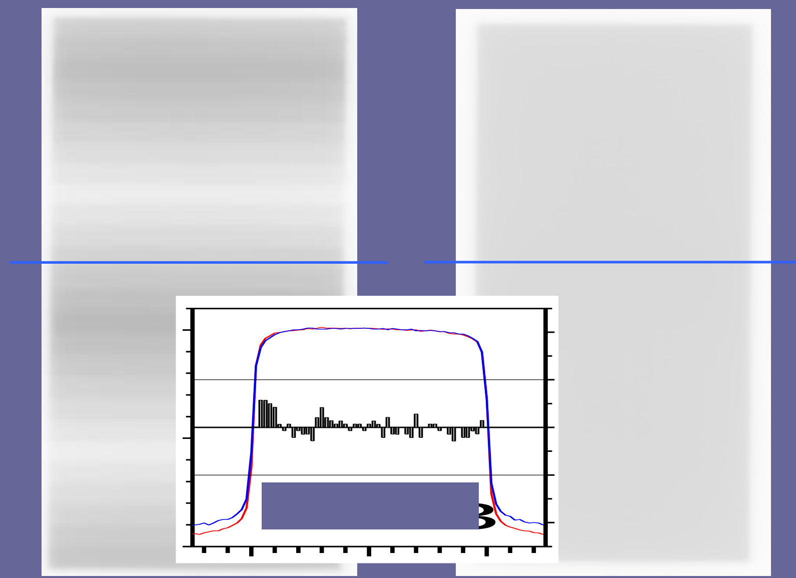
Ionisation chamber

Detector array

ΔSGF= 2.5 % → leaf gap error =0.1 mm

Speed stability test

- Each leaf pair cross the field at different velocity
- For each leaf pair, dose profile compared to static profile



Tolerance : 2%

Film dosimetry

Portal dosimetry

Detector array

IMRT test files

– **DMLC motion files based on the users' experience**
– **comparison of resulting pattern with the expected one**

Film dosimetry

Portal dosimetry

Routine QA

Test	Periodicity
MLC Calibration Gravity test	twice a year or after maintenance
Positioning	Daily qualitative
Sliding gap factor	Daily
Speed stability	twice a year or after maintenance
Beam on/off	yearly
OF small fields	yearly

Routine QA

Test	Machine time
MLC Calibration	60 min
Positioning	5 min
SGF and Gravity test	10 min
Speed stability	15 min
Beam on/off	1O min

Conclusion

With the right tools

And the right people

You can achieve it!

Thanks for your attention

and

See you later for the patient related QA in IMRT