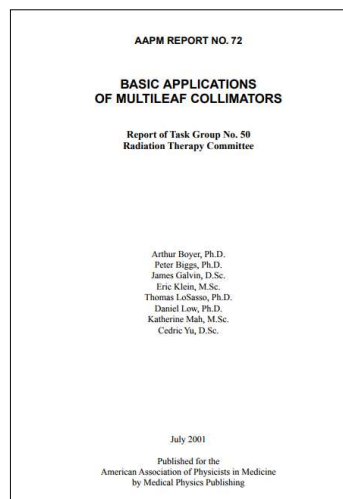


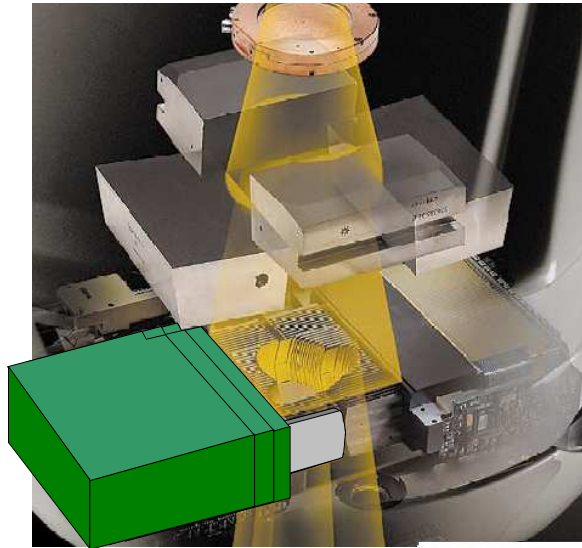
# Multileaf Collimator QA

## Static MLC QA


- Multileaf collimators (*MLC*) are devices that are used to shape the radiation beam using movable leaves
  - The rationale for using MLCs in conventional radiation therapy is to improve the efficiency of delivery
  - The rationale for using MLCs in intensity modulated radiation therapy (*IMRT*) is to shape the radiation dose
- The purpose of this lecture is focus on the conventional design and application of MLC
- AAPM Task Group 50 focuses on this topic and was published in 2001



## Varian MLC Design



THOMPSON CANCER  
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## Varian MLC Design

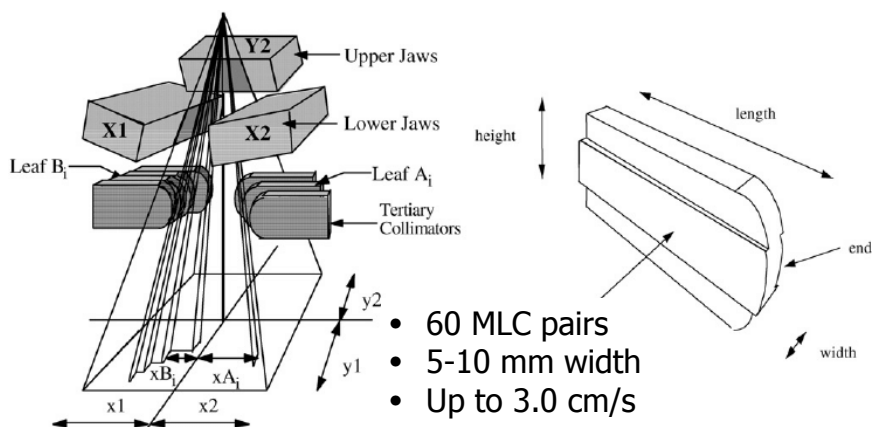


- Varian 120 leaf MLC systems use Maxon Motor 12 V leaf motors
- The motors consist of a magnetic encoder for positional and speed information, a permanent magnet motor, and a gearbox

THOMPSON CANCER  
SURVIVAL CENTER

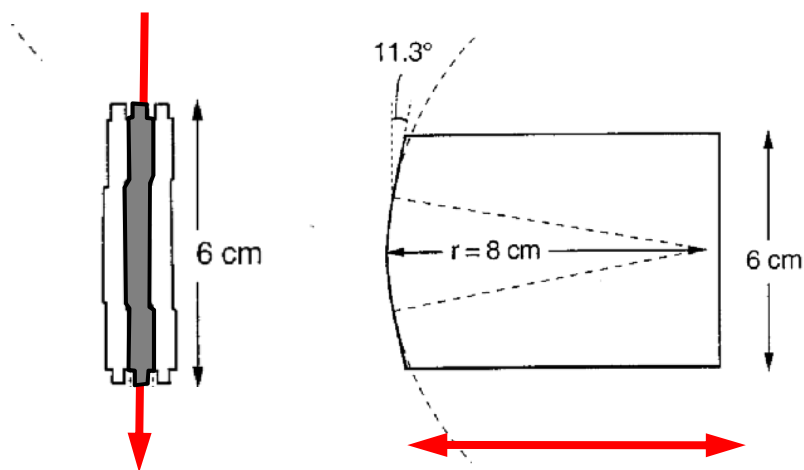
THE UNIVERSITY of TENNESSEE 

## Varian MLC Design



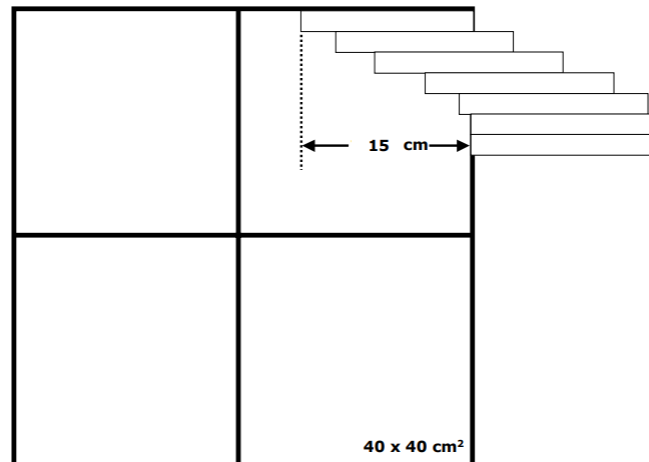
### Varian Tertiary MLC (2000)

## Varian MLC Design

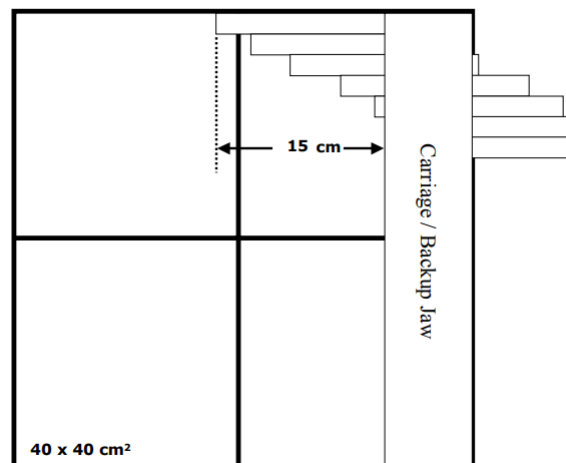


LoSasso *et al*/  
Med. Phys. 25: 1919

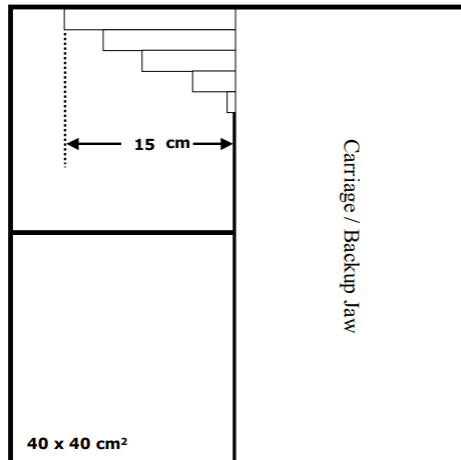
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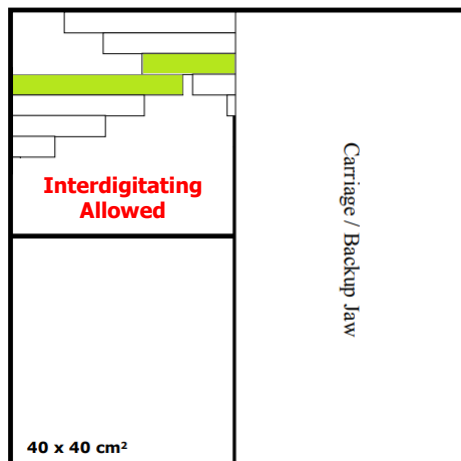
## Varian MLC Design



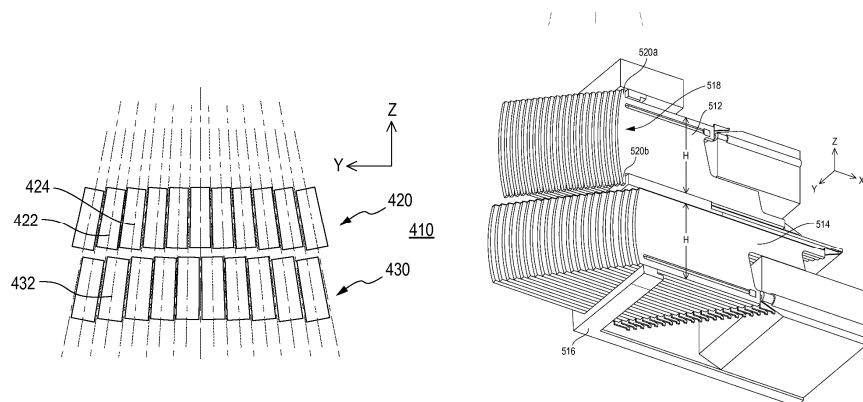
## Varian MLC Design



## Varian MLC Design

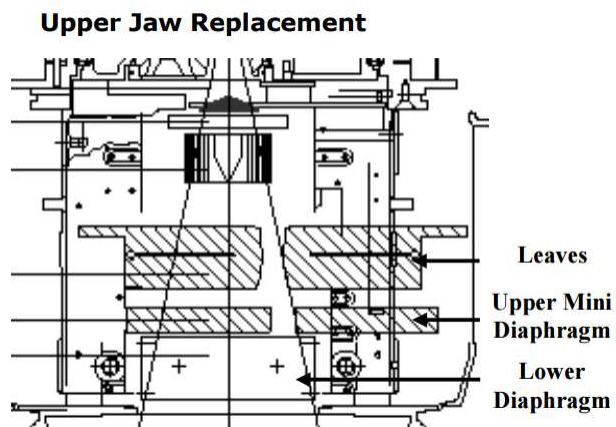


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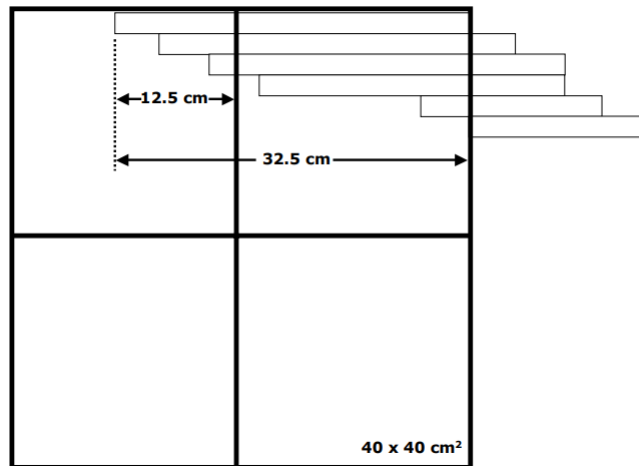
### Varian Dual Layer MLC (2017)

## Elekta MLCi Design

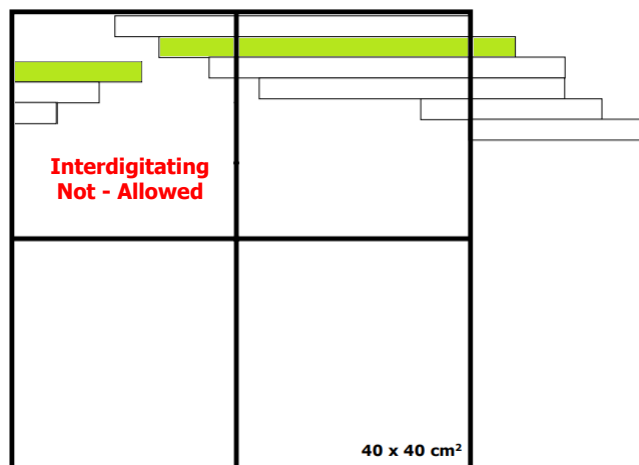


### Elekta Upper MLCi (1998)

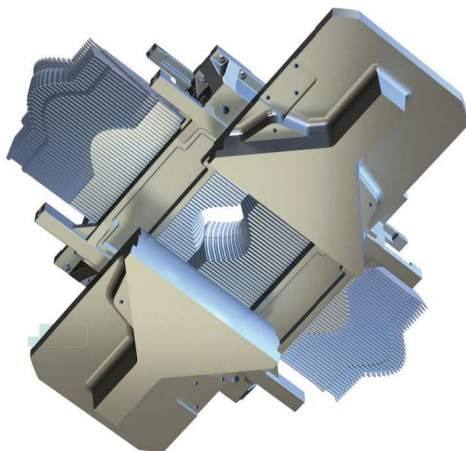
## Elekta MLCi Design



## Elekta MLCi Design



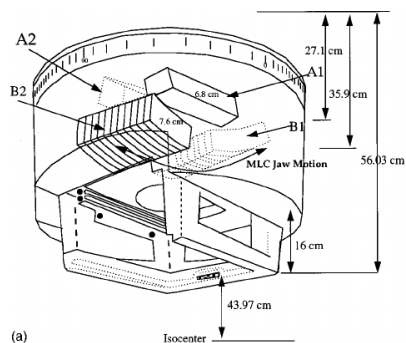
## Elekta Agility MLC Design



- 80 MLC pairs
- 5mm width
- Up to 6.5 cm/s

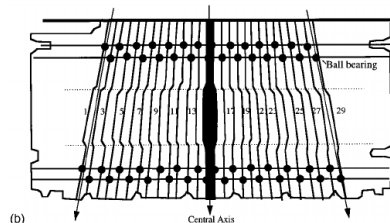
### Elekta Agility Upper Replacement MLC (2012)

## Siemens MLC Design



(a)

*Das et al*  
Med. Phys. 25 :1676



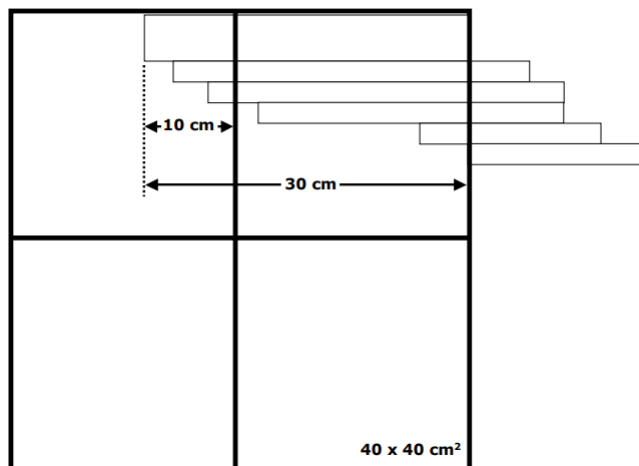
(b)

- 40 MLC pairs
- 10mm width
- Up to 2.0 cm/s

### Siemens Lower MLC Replacement (1998)



## Siemens MLC Design



## Design Summary (Circa 2001)

Table 2. Summary of MLC Configurations for Various Treatment Machines

| Source To                  | Varian<br>CL2100C | Elekta<br>(Philips)<br>SL | Scandatronix<br>Microtron | Siemens<br>Digital<br>Mevatron | General<br>Electric<br>Saturne 43* |
|----------------------------|-------------------|---------------------------|---------------------------|--------------------------------|------------------------------------|
| Bottom of upper jaw        | 35.7 cm           | 42.6 cm                   | 47.5 cm                   | 27.8 cm                        | 33.6 cm                            |
| Bottom of lower jaw        | 44.4 cm           | 50.9 cm                   | —                         | 35.9 cm                        | NA                                 |
| Leaf bottom                | 53.6 cm           | 37.3 cm                   | 67.5 cm                   | —                              | 45.7 cm                            |
| Block tray                 | 65.4 cm           | 67.2 cm                   | 70.6 cm                   | 56.0 cm                        | 61.0 cm                            |
| Compensating filter tray   | 69.2 cm           | N/A                       | N/A                       | N/A                            | 50.5 cm                            |
| Top of internal wedge      | N/A               | 18.6 cm                   | 22.0 cm (45°)             | N/A                            | 22.9 cm                            |
| Gantry housing             | 57.9 cm           | 52.9 cm                   | 71.0 cm                   | ***43.0 cm                     | 50.0 cm                            |
| Leaf thickness             | **5.53 cm         | 7.5 cm                    | 7.5 cm                    | 7.6 cm                         | 10.0 cm                            |
| Maximum height of blocks   | 7.6 cm            | 11.9 cm                   | —                         | 7.5 cm                         | 11.0 cm                            |
| Number of leaves           | 26 x 2            | 40 x 2                    | 32 x 2                    | 29 x 2                         | 32 x 2                             |
| Width of leaf at isocenter | 1.0 cm            | 1.0 cm                    | 1.25 cm                   | 1.0 cm                         | 1.25 cm                            |
| Shapable field (cm x cm)   | ***40 x 26 cm²    | —                         | 31 x 40 cm²               | —                              | 40 x 40 cm²                        |
| Leaf travel over isocenter | 16.0 cm           | 12.5 cm                   | 5.0 cm                    | 10.0 cm                        | 10.0 cm                            |

\*Sale of the GE accelerator has been discontinued since the production of this report.

\*\*The Varian leaf is made of denser tungsten than the Philips leaf.

\*\*\*Depending upon the field shape, the width may be limited to <40 cm.

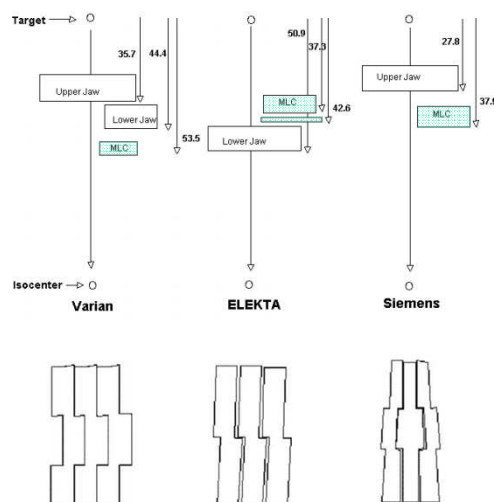
\*\*\*\*Accessory holder bolted in place.

### ADDENDUM

|                                | Varian MLC Options  |                                      |                       |                                      |   |
|--------------------------------|---------------------|--------------------------------------|-----------------------|--------------------------------------|---|
| (all dimensions in cm)         | Standard<br>52 leaf | Standard<br>80 leaf                  | Millennium<br>52 leaf | Millennium<br>80 leaf                | Millennium<br>120 leaf  |
| Number of leaves               | 52                  | 80                                   | 52                    | 80                                   | 120   |
| MLC Plan: Max Retract Position | 20.1                | 20.1                                 | 20.1                  | 20.1                                 | 20.1  |
| MLC Plan: Max Extend Position  | -16.0               | -16.0                                | -20.1                 | -20.1                                | -20.1   |
| Leaf span                      | 14.5                | 14.5                                 | 15.0                  | 15.0                                 | 15.0  |
| Leaf width                     | All pairs: 1.0      | Pairs 1 & 40: 1.5<br>All others: 1.0 | All pairs: 1.0        | Pairs 1 & 40: 1.4<br>All others: 1.0 | Pairs 1 & 40: 1.4<br>Pairs 2-10 & 51-59: 1.0<br>All others: 0.5 |
| Source to leaf bottom          | 53.6                | 53.6                                 | 53.8                  | 53.8                                 | 53.8  |
| Source to block tray           | 65.4                | 65.4                                 | 65.4                  | 65.4                                 | 65.4  |
| Source to gantry housing       | 57.9                | 57.9                                 | 57.9                  | 57.9                                 | 57.9  |
| Maximum height of blocks       | 7.6                 | 7.6                                  | 7.6                   | 7.6                                  | 7.6   |
| Maximum shapable field         | 26 x 40             | 40 x 40                              | 26 x 40               | 40 x 40                              | 40 x 40   |

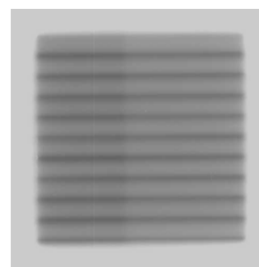
### AAPM TG-50

## MLC Intraleaf Leakage

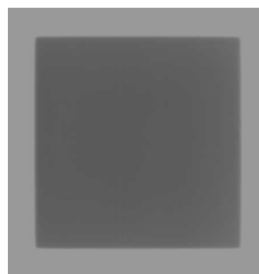


## MLC Intraleaf Leakage

- Intraleaf leakage is the radiation transmitted between adjacent MLC leaves
  - *Interleaf leakage is the transmission between opposed MLC leaves*
- Intraleaf leakage can be measured with radiochromic film or a high resolution detector array (*EPID imager*)
- Measurements are made with 1.) a closed field through the MLC leaves and 2.) an open field
- The open field is used to remove the off-axis component

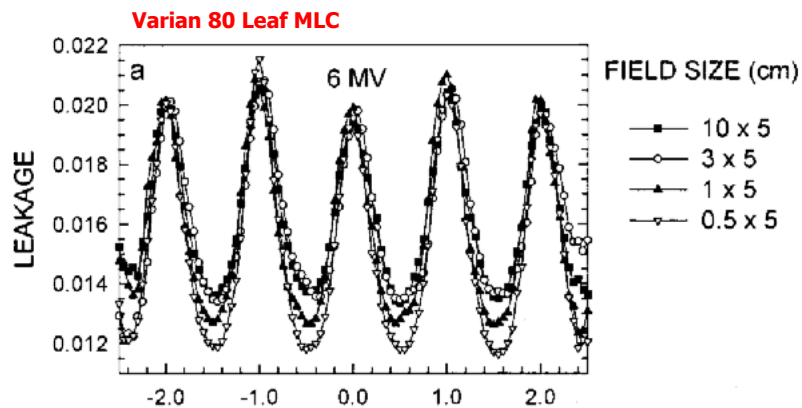


MLC  
Closed



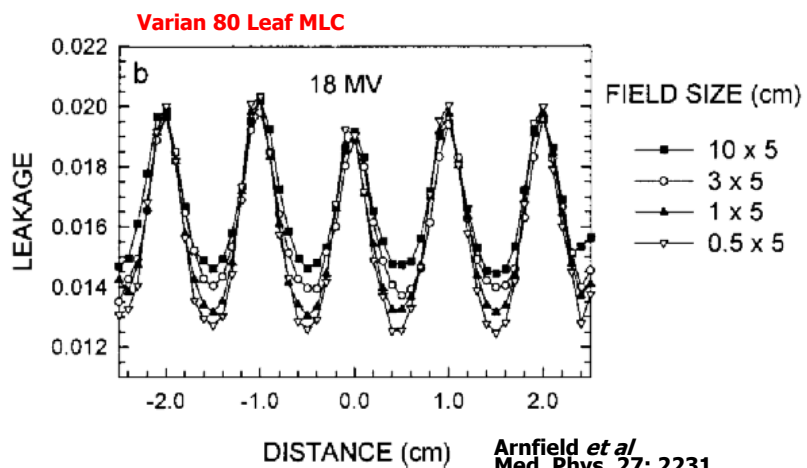
Open  
Field

## MLC Intraleaf Leakage



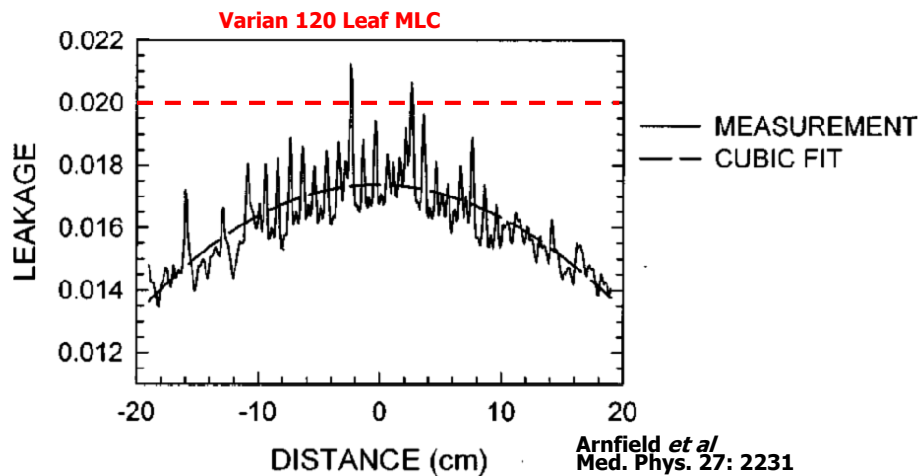
Arnfield *et al*  
Med. Phys. 27: 2231

## MLC Intraleaf Leakage

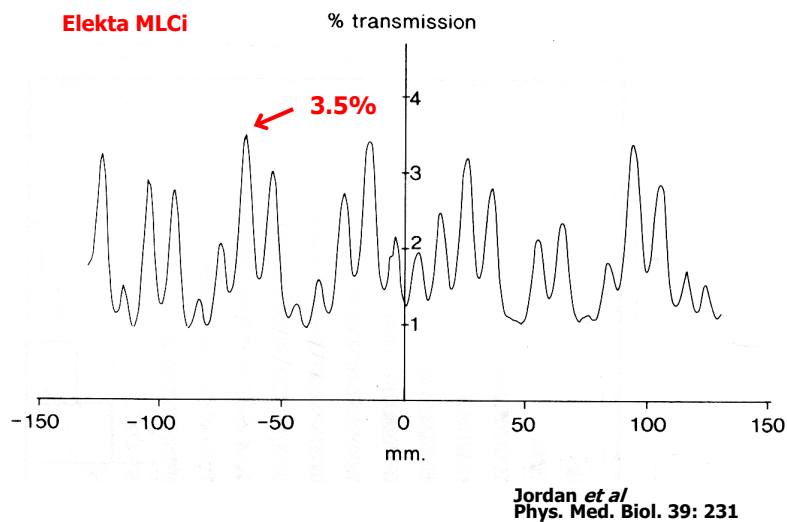


Arnfield *et al*  
Med. Phys. 27: 2231

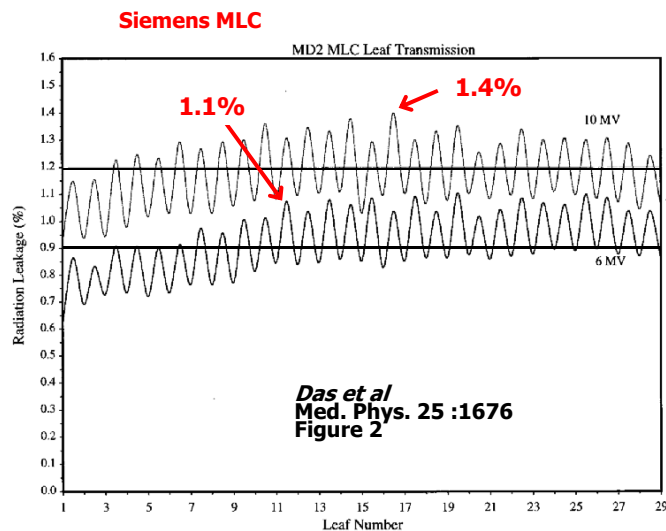
## MLC Intraleaf Leakage



## MLC Intraleaf Leakage



## MLC Intraleaf Leakage

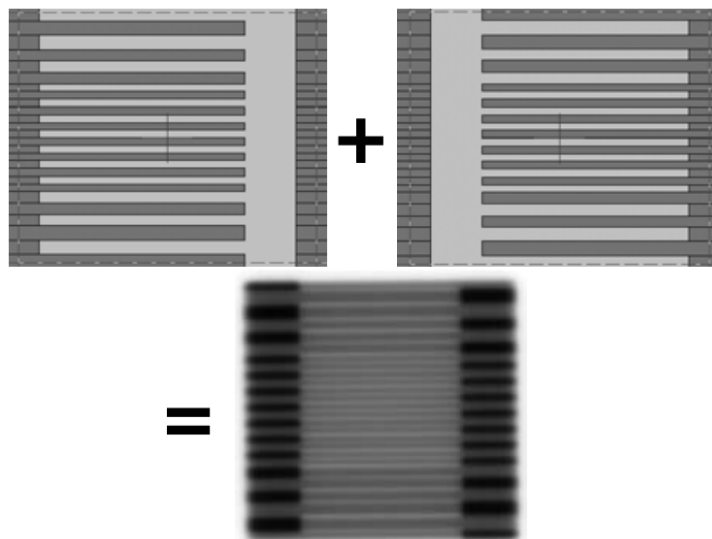


## TG-142 MLC Tests

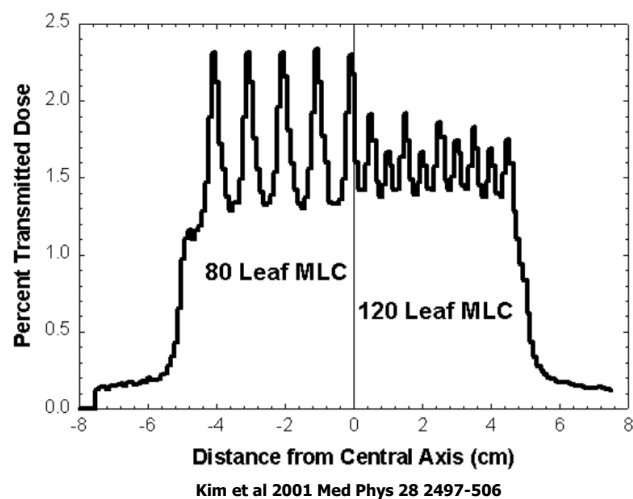
TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

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| Setting vs radiation field for two patterns (non-IMRT)                      | 2 mm  |  |
| Backup diaphragm settings (Elekta only)                                     | 2 mm  |  |
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|   | Annually  |  |
| MLC transmission (average of leaf and interleaf transmission), all energies | ±0.5% from baseline   |  |
| Leaf position repeatability   | ±1.0 mm   |  |
| MLC spoke shot  | ≤1.0 mm radius  |  |
| Coincidence of light field and x-ray field (all energies)                   | ±2.0 mm   |  |
| Segmental IMRT (step and shoot) test  | <0.35 cm max. error RMS, 95% of error counts  |  |
|   | <0.35 cm  |  |
| Moving window IMRT (four cardinal gantry angles)                            | <0.35 cm max. error RMS, 95% of error counts  |  |
|   | <0.35 cm  |  |

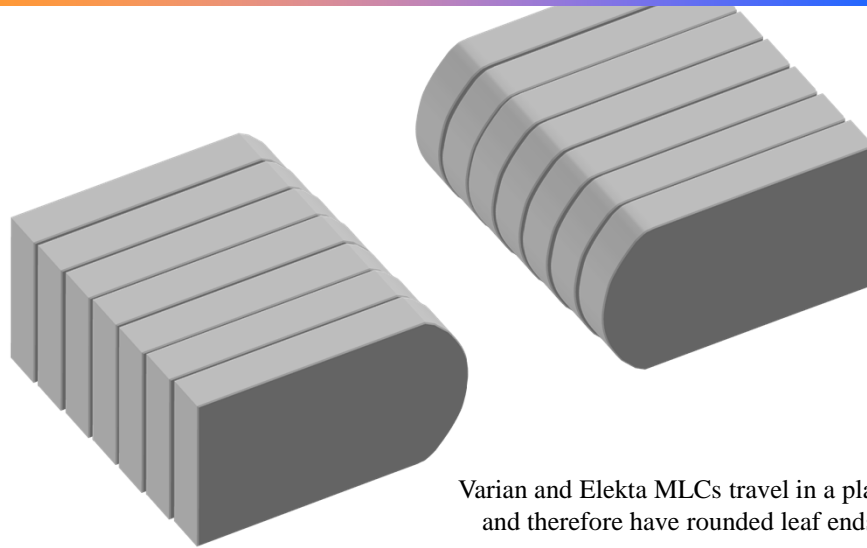
## MLC Tongue and Groove



## MLC Tongue and Groove

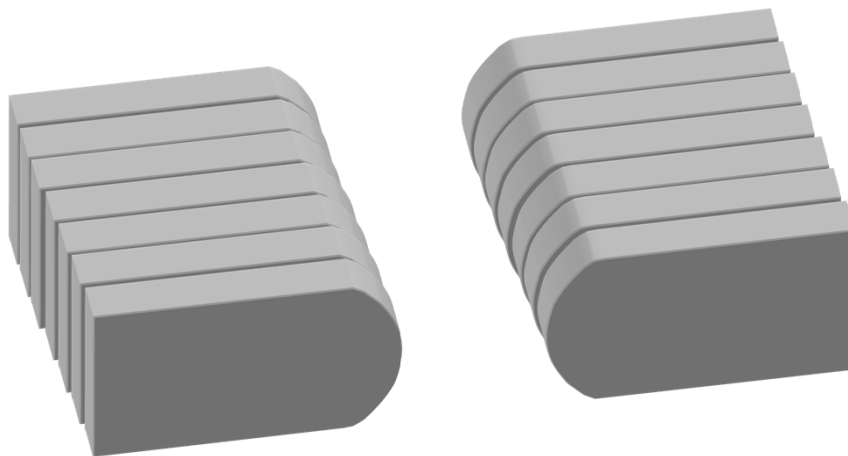


## MLC Leaf Ends



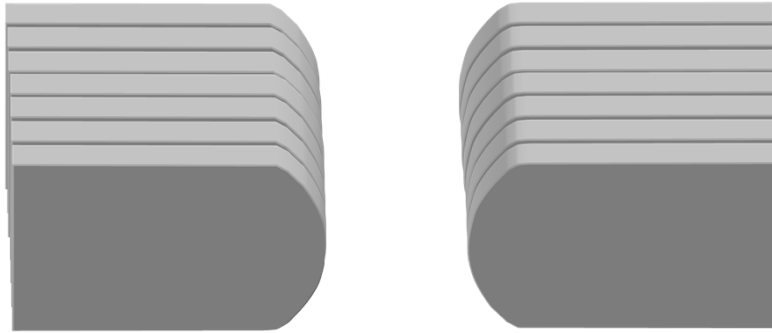
Varian and Elekta MLCs travel in a plane  
and therefore have rounded leaf ends

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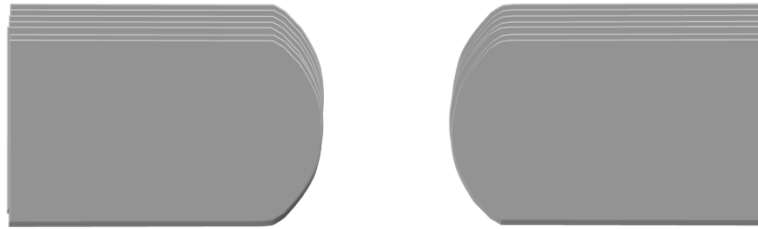
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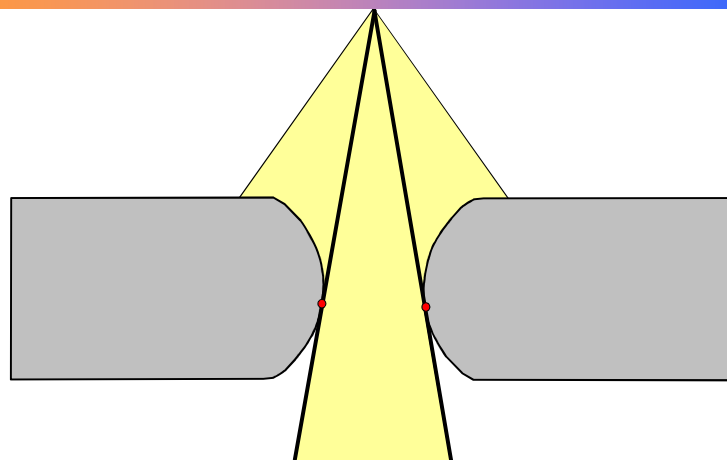


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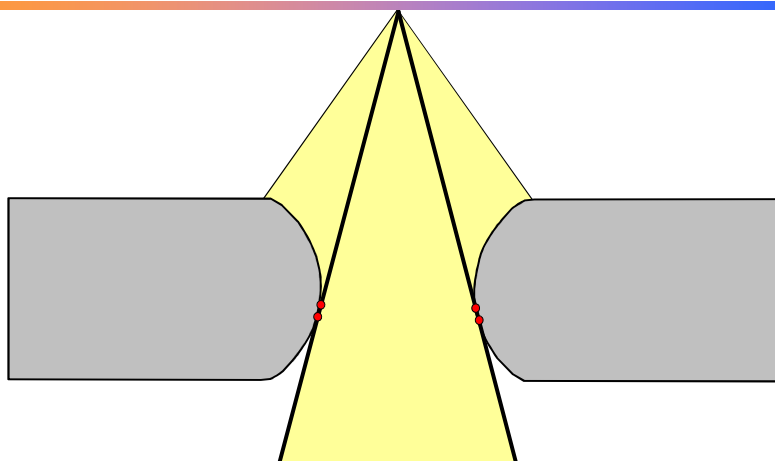
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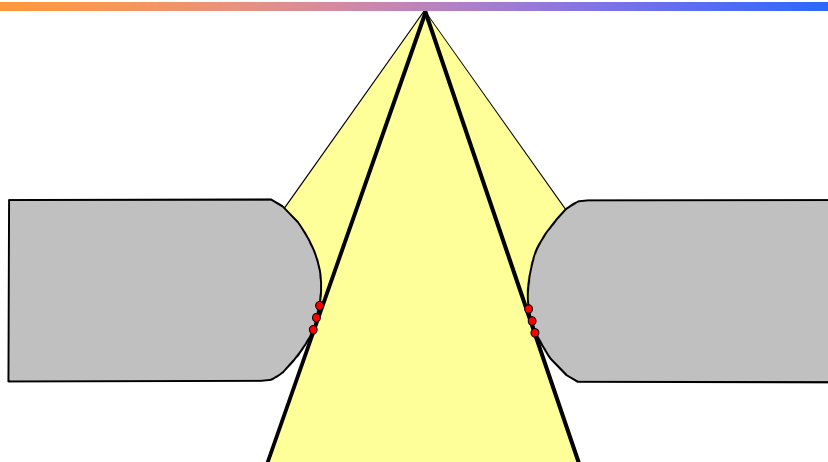
The Light-Field Edge is Defined by the  
Tangent Point on the MLC Leaf

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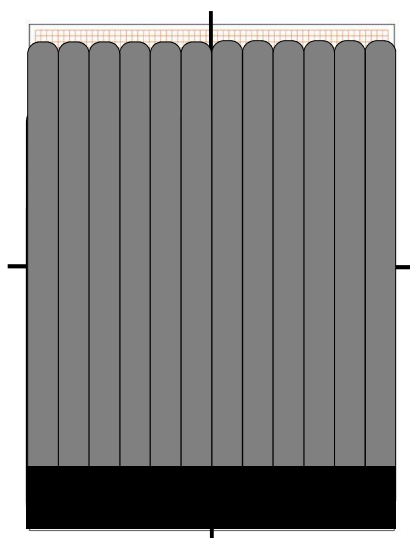
The Light-Field Edge is Defined by the  
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## TG-142 MLC Tests

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| Leaf position repeatability   | $\pm 1.0$ mm  |  |
| MLC spoke shot  | $\leq 1.0$ mm radius  |  |
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|   | <0.35 cm  |  |

## Light Field Edge



- The Light Field Edge is measured by moving the MLC leaves to known positions (-20, -16, -12, -8, -4, 0, +4, +8, +12, +16, +20 for each bank)
- Graph Paper placed at isocenter can be used as a course, but quick, visual assessment of the MLC to a precision of about 0.5-mm

## Light Field Edge



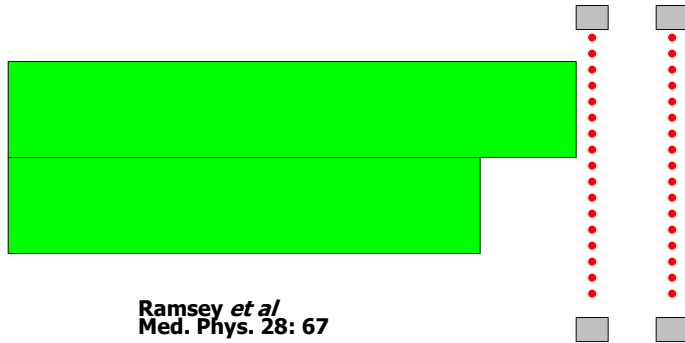
Ramsey *et al*  
Med. Phys. 28: 67

## Light Field Edge

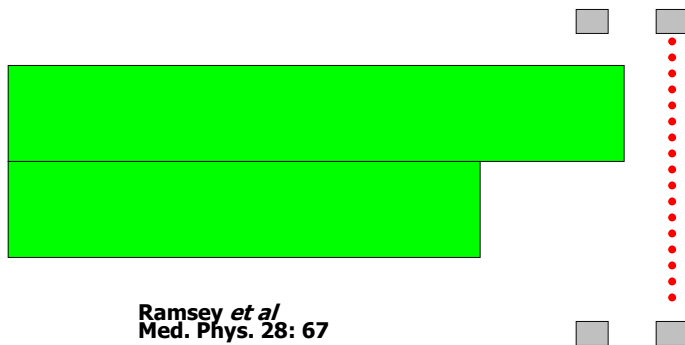


Ramsey *et al*  
Med. Phys. 28: 67

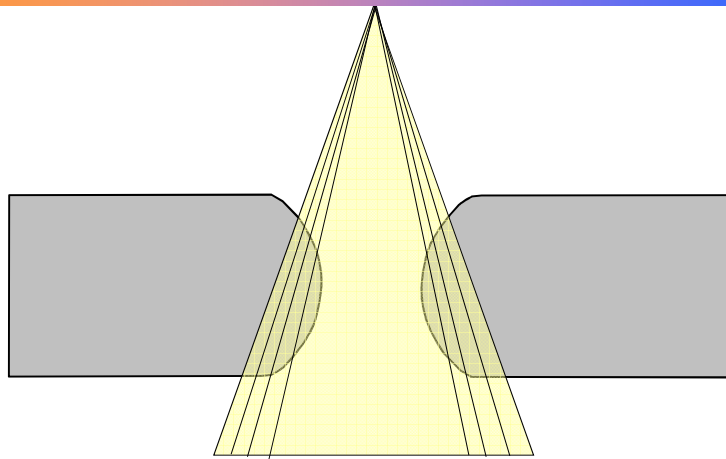
## Light Field Edge



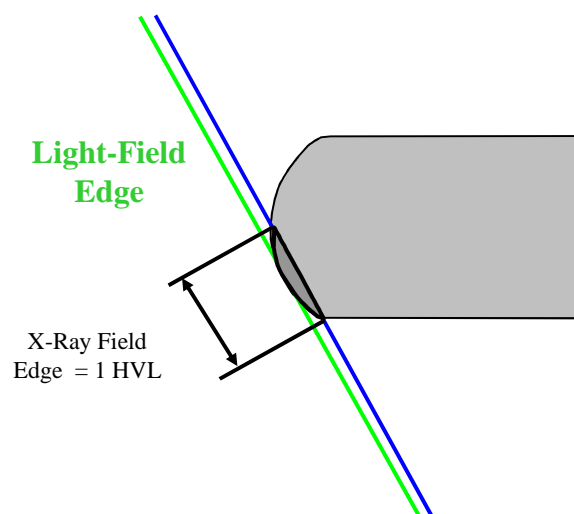
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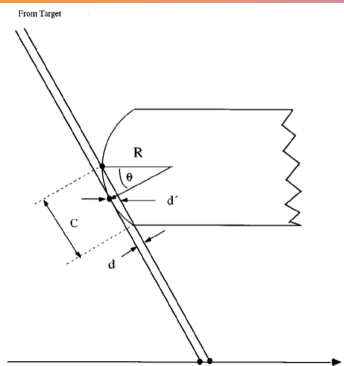
## X-Ray Field Edge



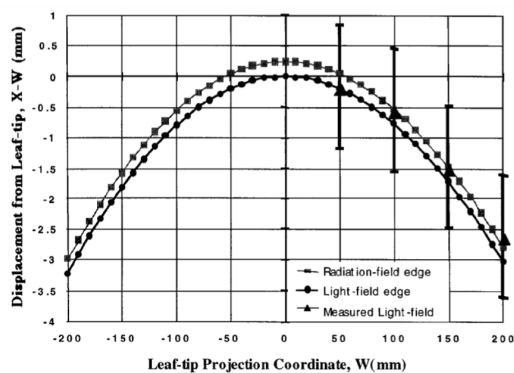
## X-Ray Field Edge



# X-Ray Field Edge



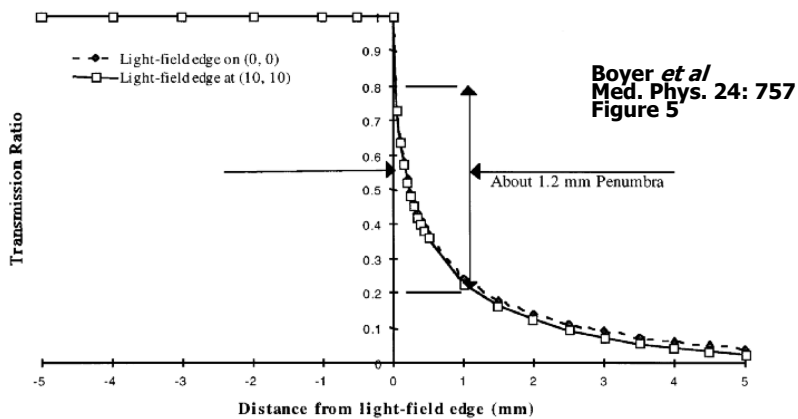
Boyer et al Geometric analysis of light-field position



$$d = R - \sqrt{R^2 - HVT^2/4}$$

$$d' = \frac{(R - \sqrt{R^2 - HVT^2/4}) \cdot \sqrt{SAD^2 + W_i^2}}{SAD}$$

# X-Ray Field Edge



## TG-142 MLC Tests

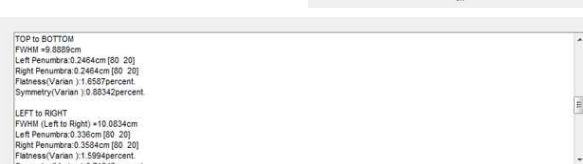
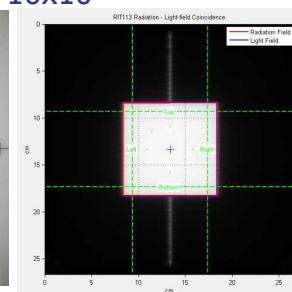
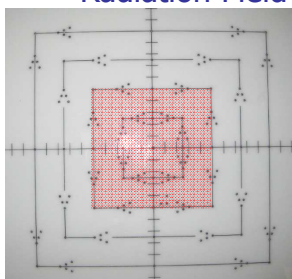
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## X-Ray Field Edge

- Set the Iso-Align (or equivalent device) at isocenter
- Using the MLC only (no x jaws or backup diaphragm) to make a 10x10-cm field
- Obtain an image and analyze to determine the x-ray field size

### Radiation Field 10x10

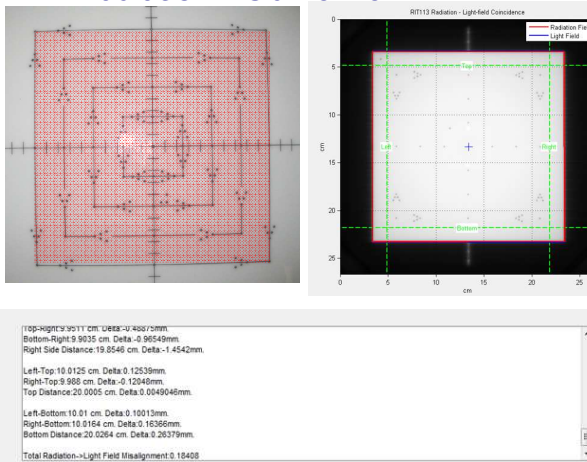




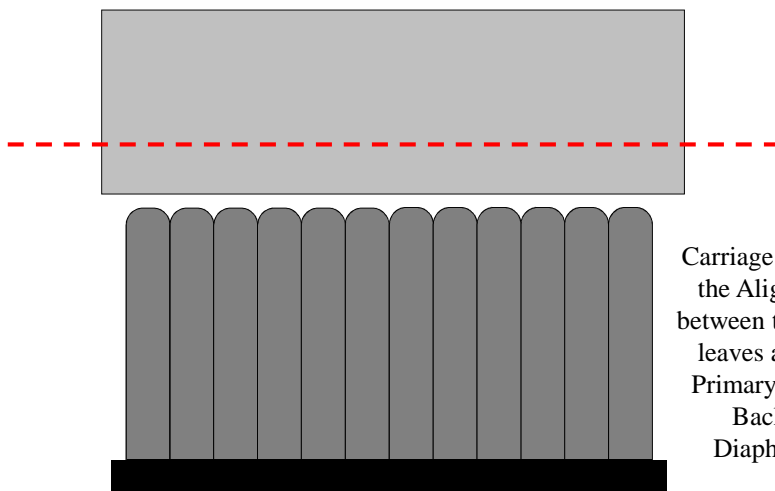
## X-Ray Field Edge

- Set the Iso-Align (*or equivalent device*) at isocenter
- Using the MLC only (*no x jaws or backup diaphragm*) to make a 20x20-cm field
- Obtain an image and analyze to determine the x-ray field size

Radiation Field 20x20

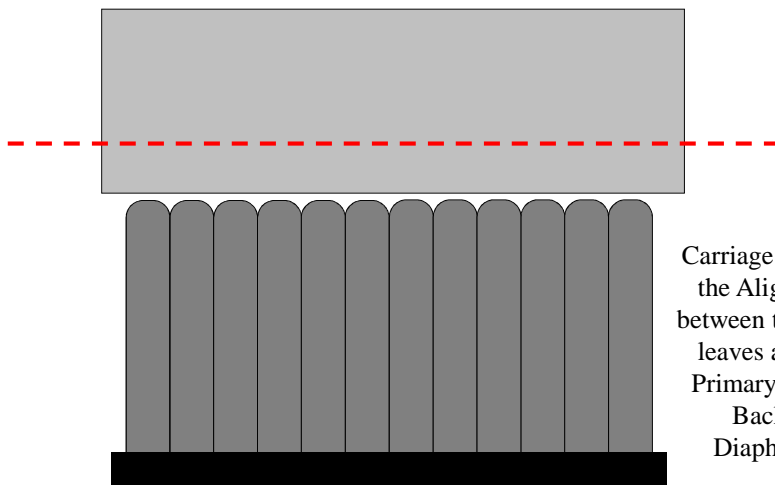


## Carriage Skew

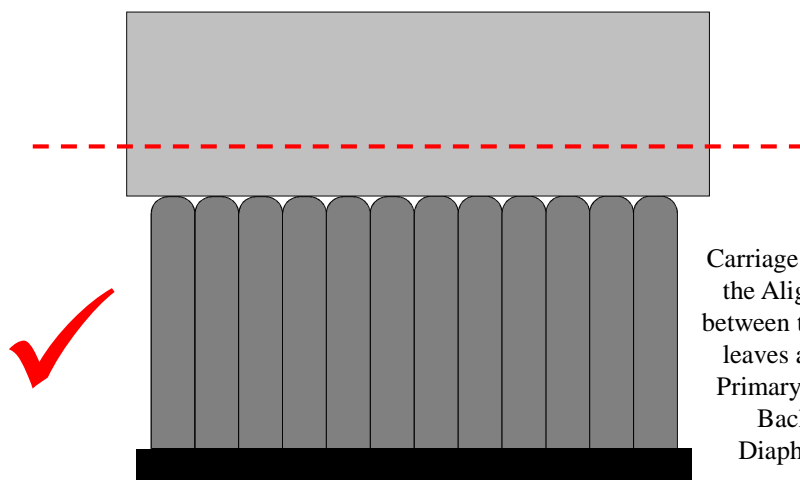


Carriage Skew is  
the Alignment  
between the MLC  
leaves and the  
Primary Jaw or  
Backup  
Diaphragm

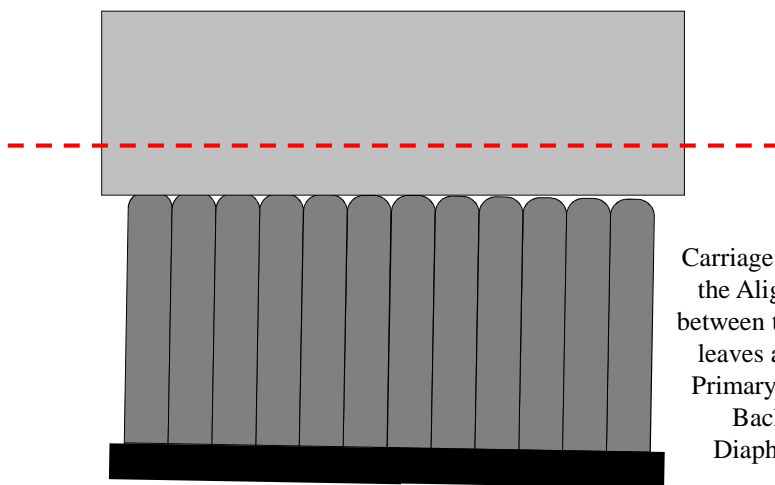
## Carriage Skew



## Carriage Skew

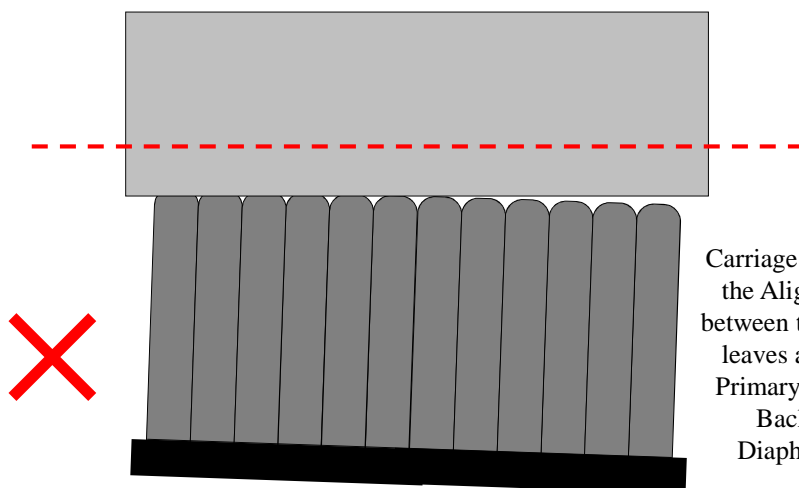


## Carriage Skew



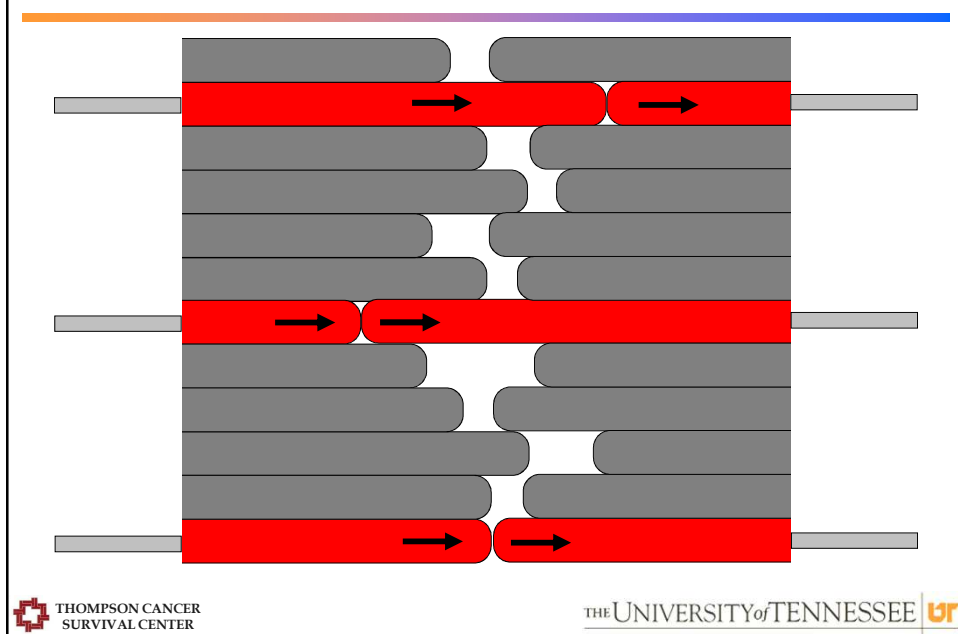
Carriage Skew is the Alignment between the MLC leaves and the Primary Jaw or Backup Diaphragm

## Carriage Skew

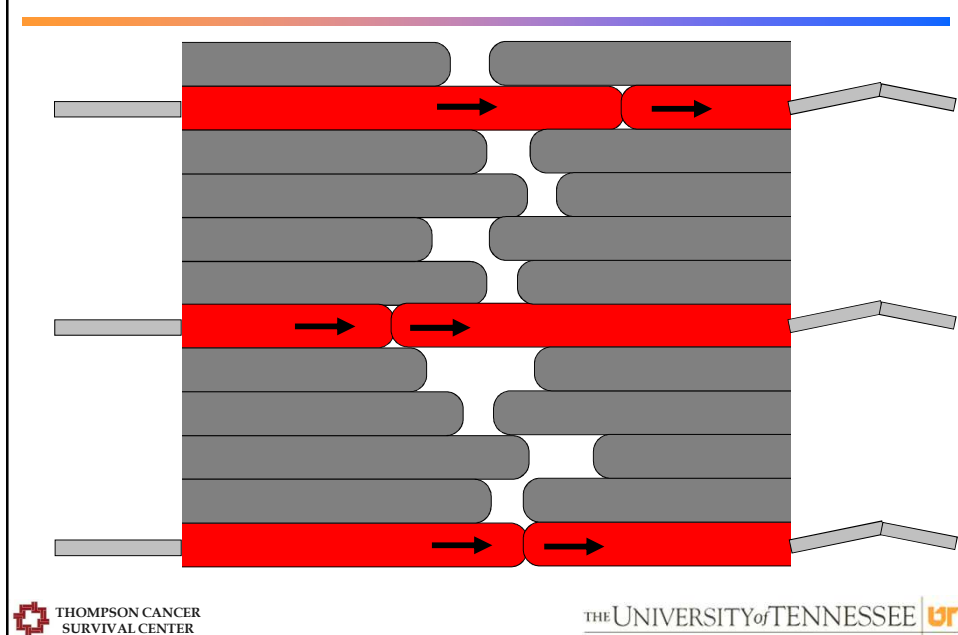


Carriage Skew is the Alignment between the MLC leaves and the Primary Jaw or Backup Diaphragm

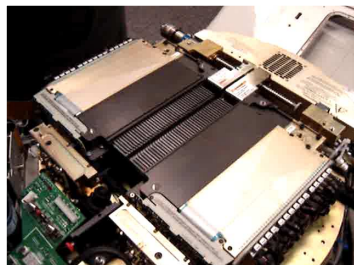
## Minimum Leaf Gap



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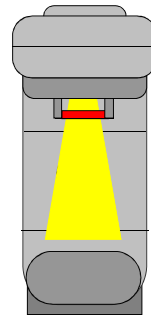
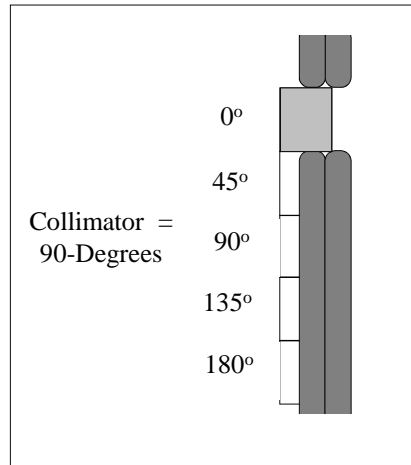
- A directly independent measurement of the mechanical gap can be made with a feeler gauge
- The opposed pair of MLC leaves are set to a 0-mm field at isocenter
- The gauge should read the demagnified value at the plane of the MLC
- Be aware that vendors have frequently changed the specification for this offset

## TG-142 MLC Tests

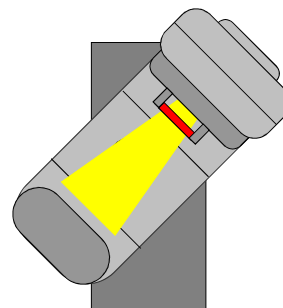
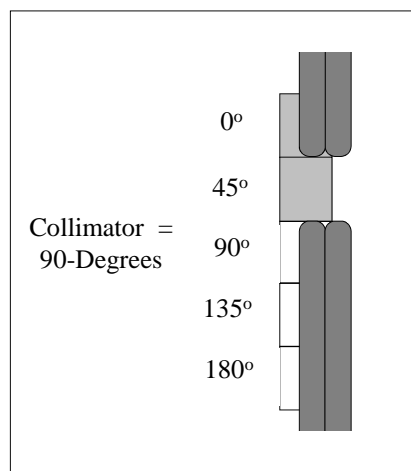
TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

| Procedure   | Tolerance   |  |
|---|---|--|
|   | Weekly (IMRT machines)  |  |
| Qualitative test (i.e., matched segments, aka "picket fence")               | Visual inspection for discernable deviations such as an increase in interleaf transmission  |  |
|   | Monthly   |  |
| Setting vs radiation field for two patterns (non-IMRT)                      | 2 mm  |  |
| Backup diaphragm settings (Elekta only)                                     | 2 mm  |  |
| Travel speed (IMRT)   | Loss of leaf speed >0.5 cm/s  |  |
| Leaf position accuracy (IMRT)   | 1 mm for leaf positions of an IMRT field for four cardinal gantry angles. ( <i>Picket fence</i> test may be used, test depends on clinical planning-segment size) |  |
|   | Annually  |  |
| MLC transmission (average of leaf and interleaf transmission), all energies | ±0.5% from baseline   |  |
| Leaf position repeatability   | ±1.0 mm   |  |
| MLC spoke shot  | ≤1.0 mm radius  |  |
| Coincidence of light field and x-ray field (all energies)                   | ±2.0 mm   |  |
| Segmental IMRT (step and shoot) test  | <0.35 cm max. error RMS, 95% of error counts  |  |
| Moving window IMRT (four cardinal gantry angles)                            | <0.35 cm max. error RMS, 95% of error counts  |  |

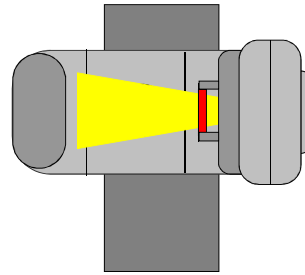
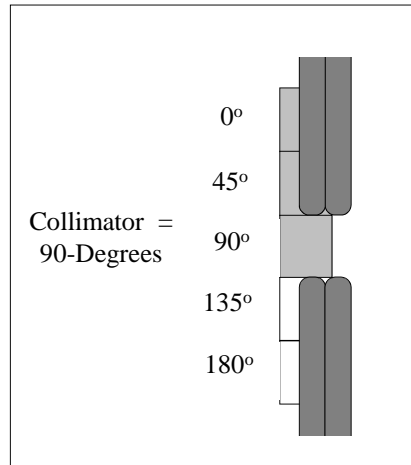
## Gravity Sag



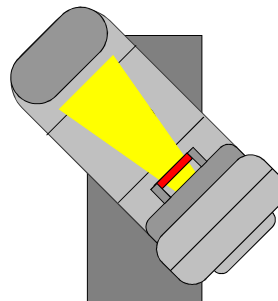
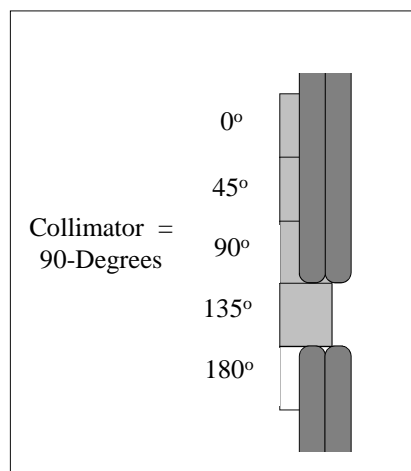
## Gravity Sag



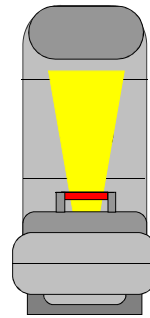
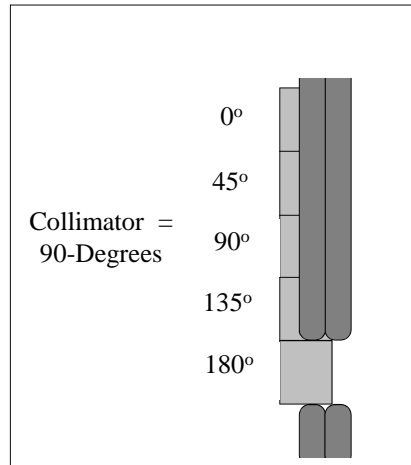
## Gravity Sag



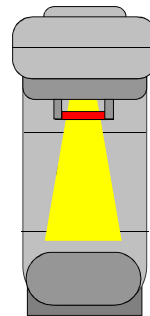
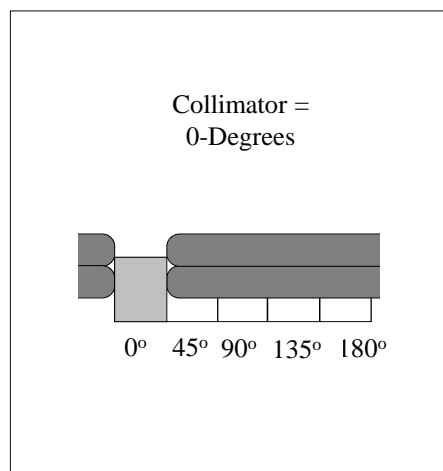
## Gravity Sag



## Gravity Sag



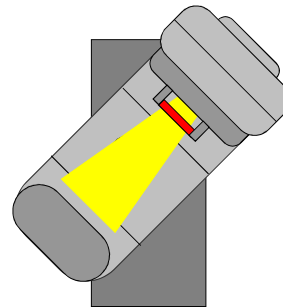
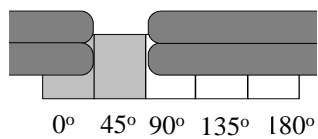
## Gravity Sag





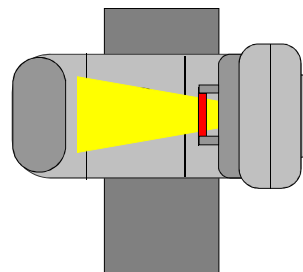
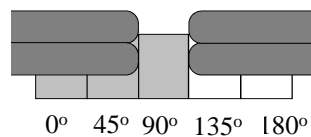
## Gravity Sag

Collimator =  
0-Degrees



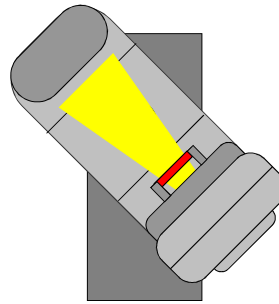
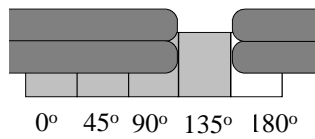
## Gravity Sag

Collimator =  
0-Degrees



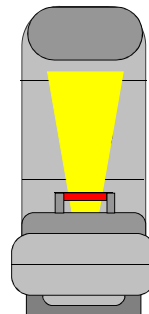
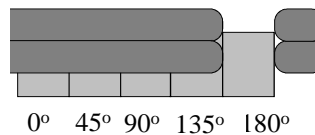
## Gravity Sag

Collimator =  
0-Degrees



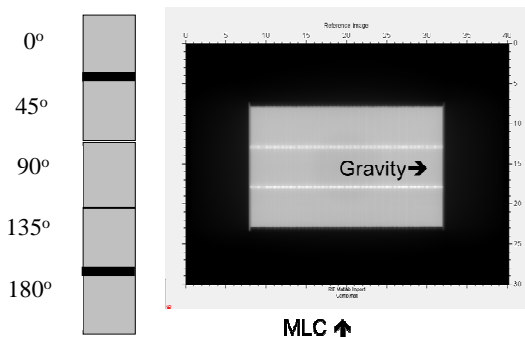
## Gravity Sag

Collimator =  
0-Degrees

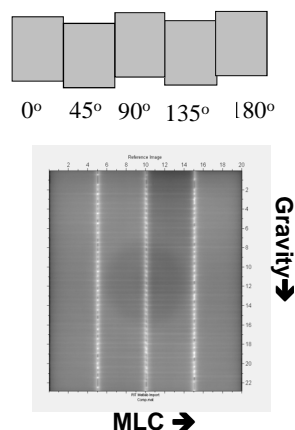


## Gravity Sag

MLC Sag

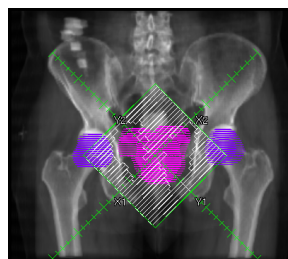
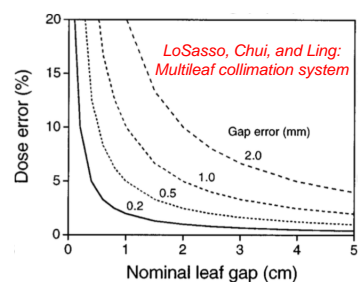


Carriage Sag

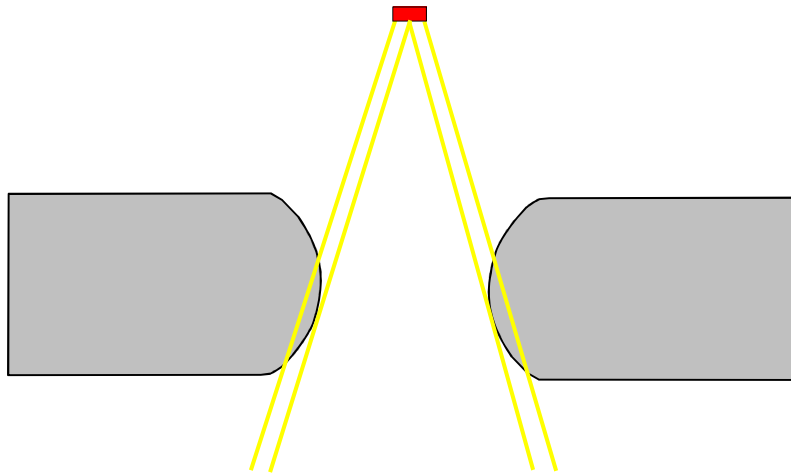


## Dynamic MLC QA

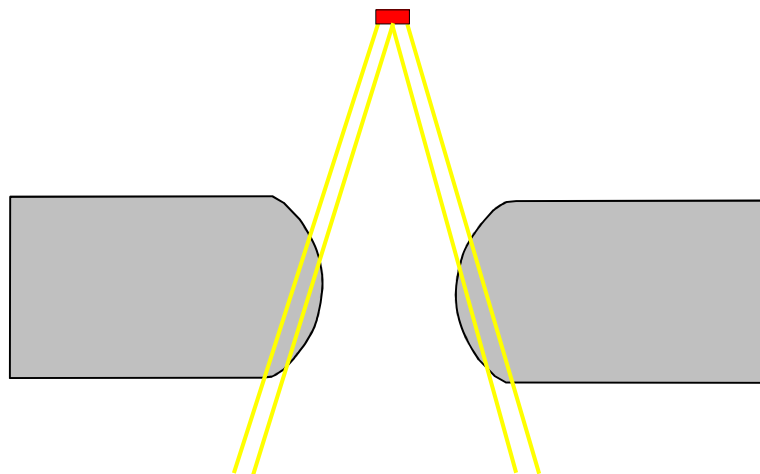
- For intensity modulated treatment delivery, there are additional MLC tests that must be performed
- All IMRT delivery types have leaf separations that are smaller than those used in conventional radiation therapy
- Sliding window and VMAT also have the added complexity of MLC leaves moving while the beam is on
- VMAT has the added complexity of variable gantry rotation speeds and variable dose rates



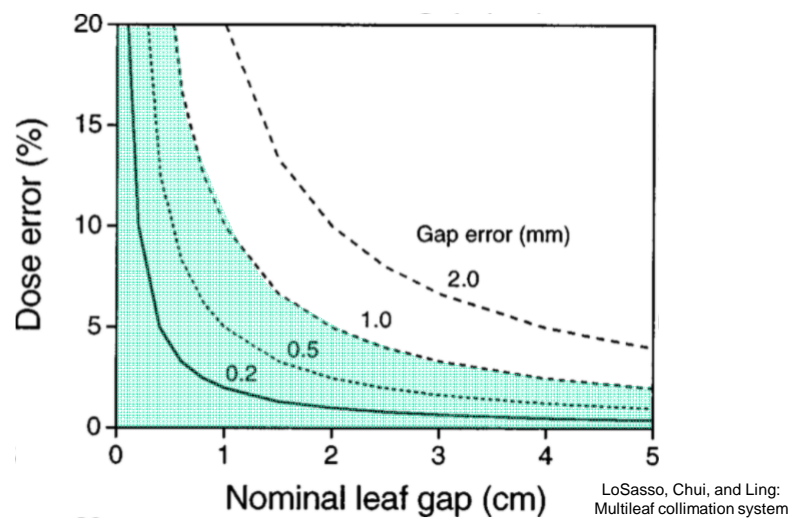
## Effective Leaf Shift



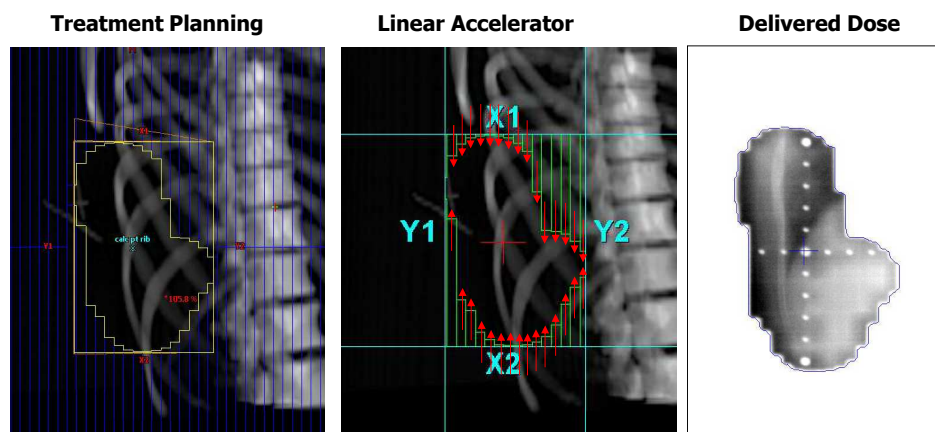
## Effective Leaf Shift



## Effective Leaf Shift

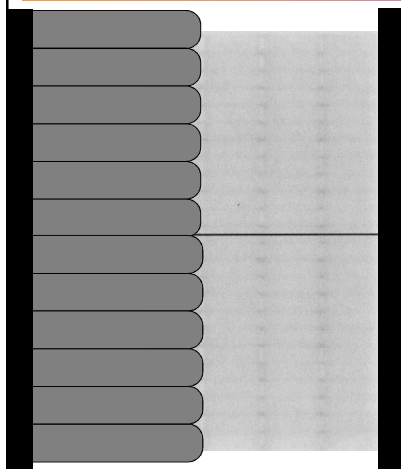


## Effective Leaf Shift



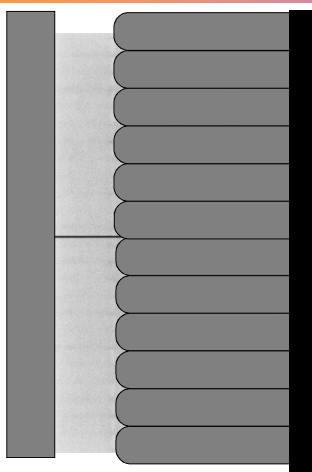
**MLC's are Modelled in Planning System**

## Effective Leaf Shift



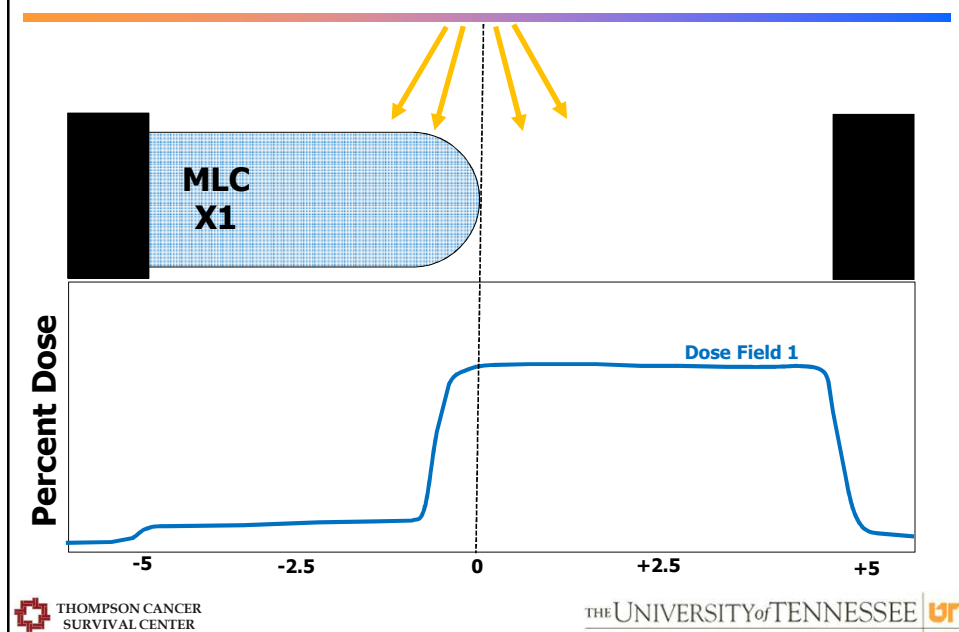
- The Effective Leaf Shift is measured using Multiple Static MLC fields
- The MLC leaves on one side move beyond the desired position by  $1/2$  the estimated gap width
- The opposing MLC leaves then move beyond the desired position by  $1/2$  the estimated gap width
- A double exposed image is used to measure the junction between the two fields

## Effective Leaf Shift

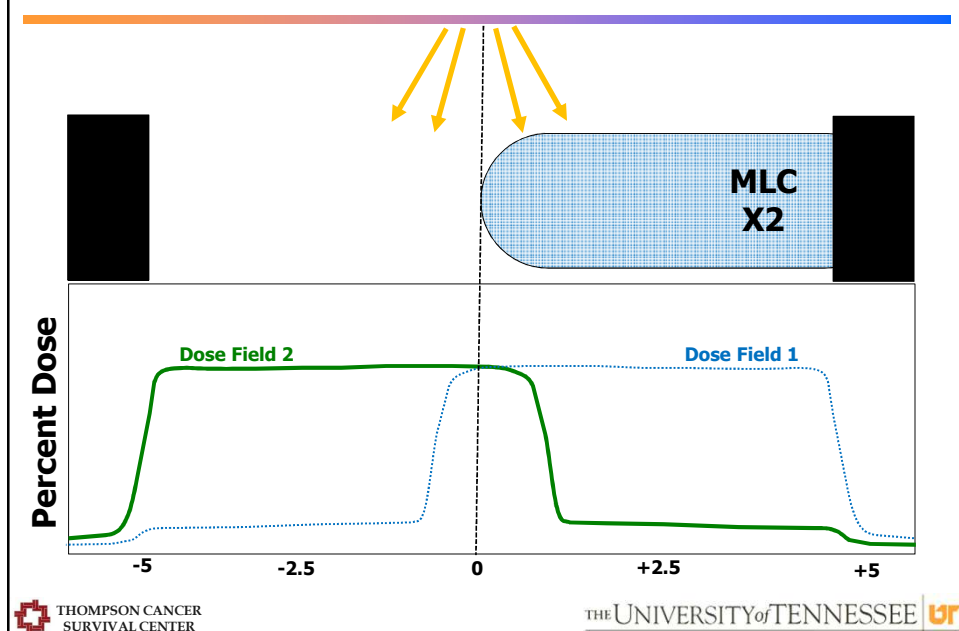


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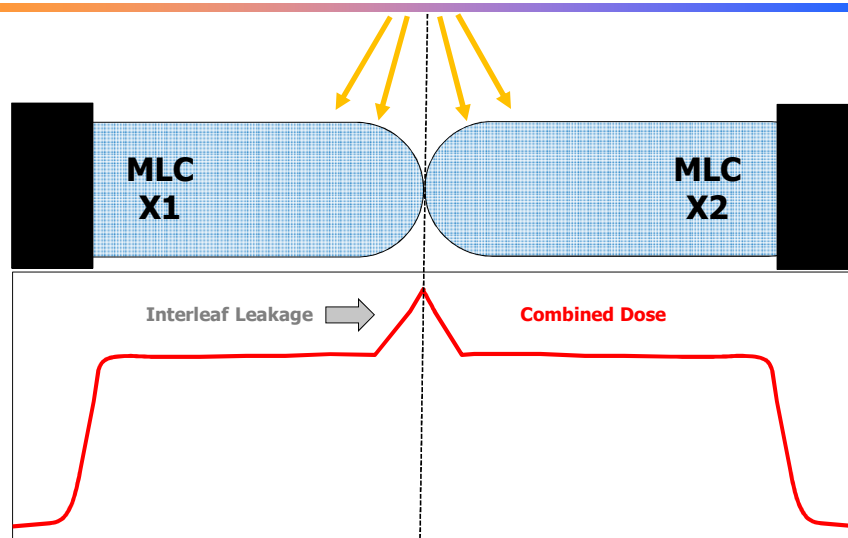
## Effective Leaf Shift



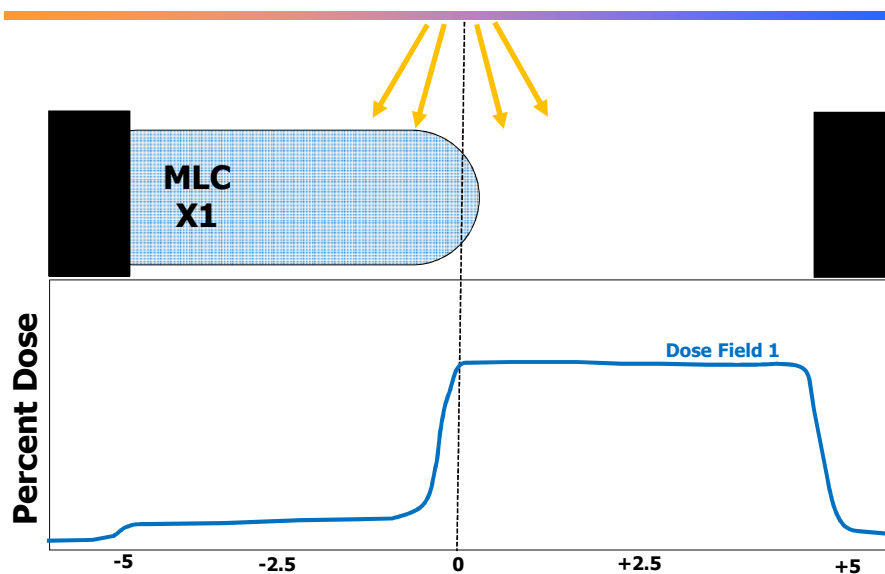
## Effective Leaf Shift



## Effective Leaf Shift

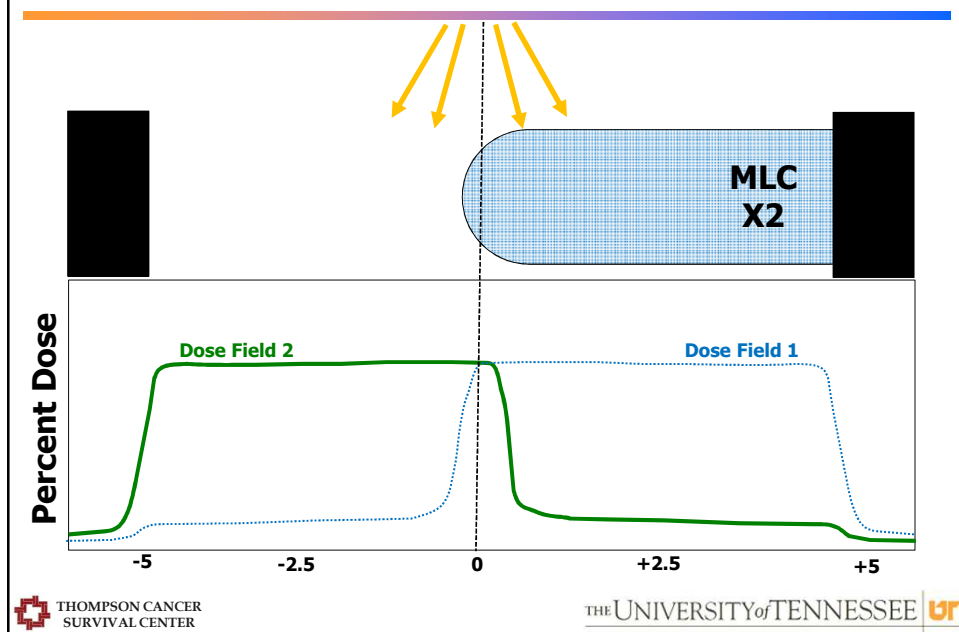


## Effective Leaf Shift

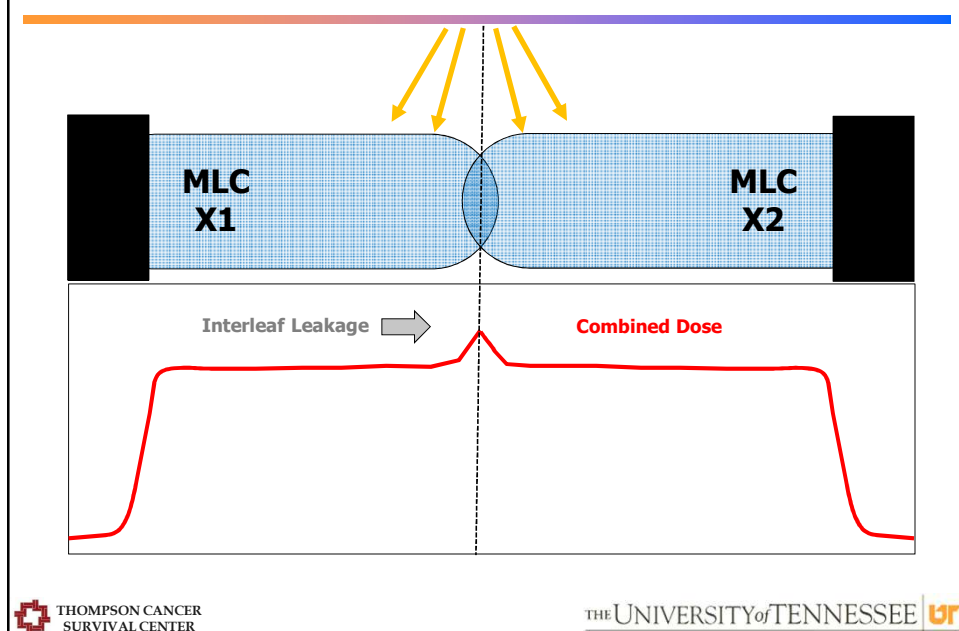




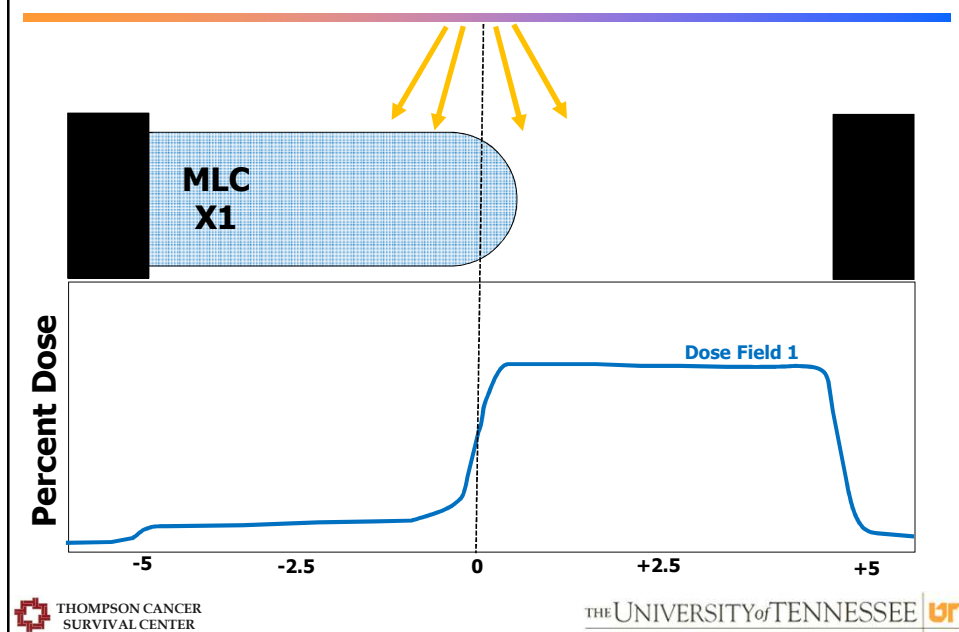
## Effective Leaf Shift



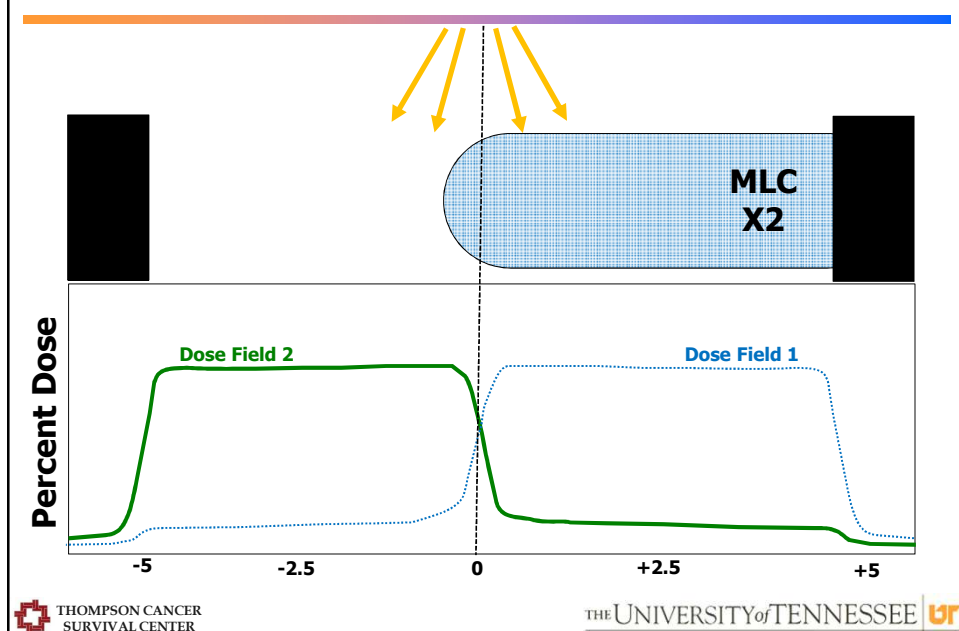
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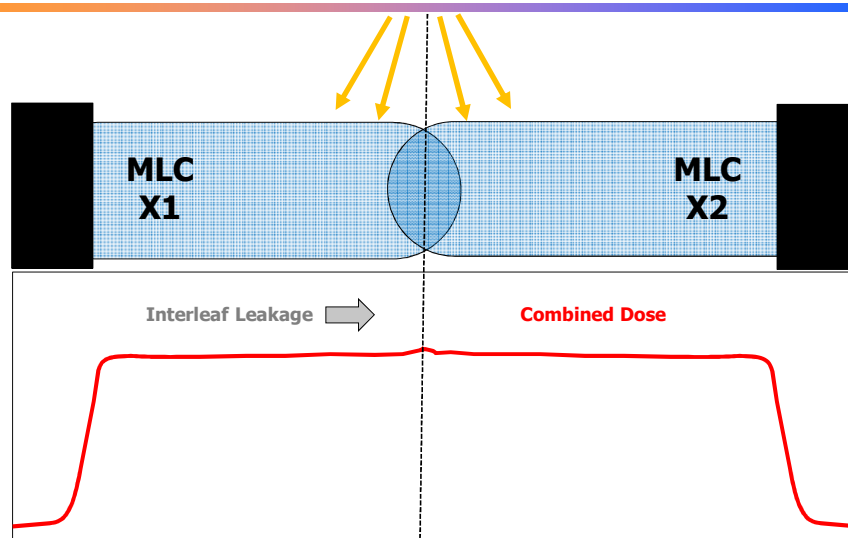
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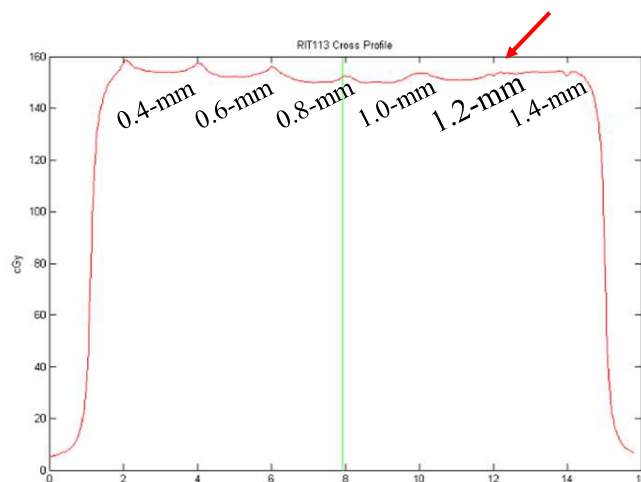
## Effective Leaf Shift



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## Effective Leaf Shift



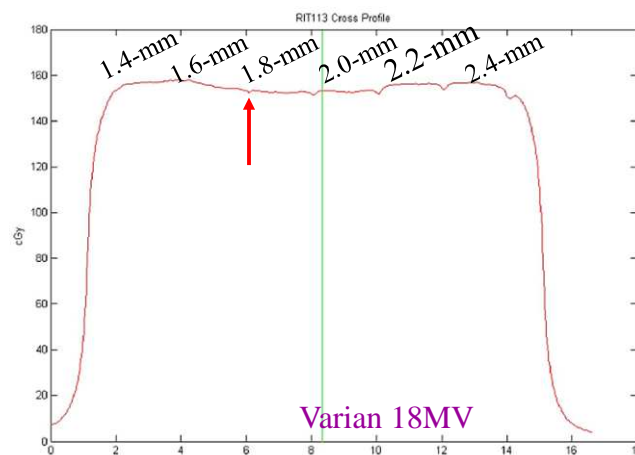
Example of 6MV Varian Effective Leaf Shift  
Measurements ranging from 0.4 to 1.4-mm



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## Effective Leaf Shift



Example of 18MV Varian Effective Leaf Shift Measurements ranging from 1.4 to 2.4-mm

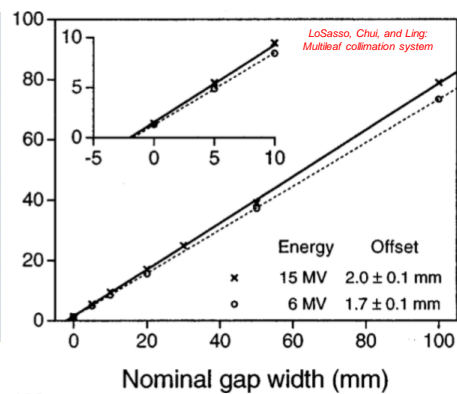
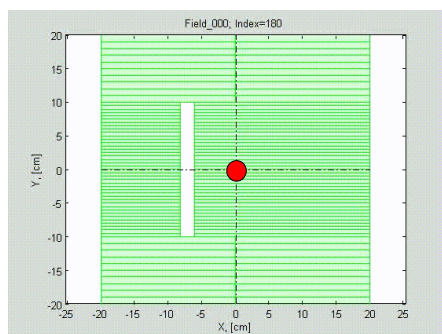


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## Effective Leaf Shift



- The Effective Leaf Shift can be measured using an ion chamber at isocenter
- Readings are taken for multiple sliding window gap widths
- Plot the readings and extrapolate to zero



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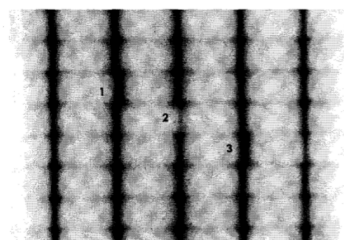
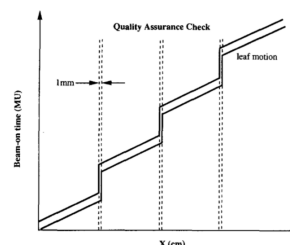
# TG-142 MLC Tests

TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

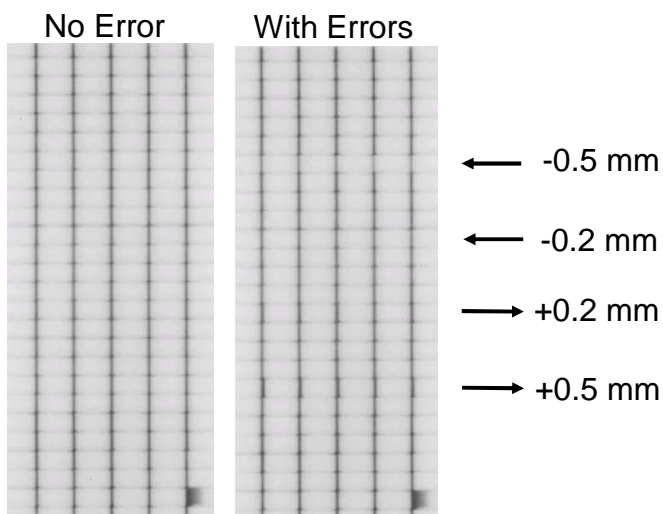
| Procedure   | Tolerance              |   |
|---|------------------------|---|
|   | Weekly (IMRT machines) |   |
| Qualitative test (i.e., matched segments, aka "picket fence")               |                        | Visual inspection for discernable deviations such as an increase in interleaf transmission  |
|   | Monthly                |   |
| Setting vs radiation field for two patterns (non-IMRT)                      |                        | 2 mm  |
| Backup diaphragm settings (Elekta only)                                     |                        | 2 mm  |
| Travel speed (IMRT)   |                        | Loss of leaf speed $>0.5$ cm/s  |
| Leaf position accuracy (IMRT)   |                        | 1 mm for leaf positions of an IMRT field for four cardinal gantry angles. ( <i>Picket fence</i> test may be used, test depends on clinical planning-segment size) |
|   | Annually               |   |
| MLC transmission (average of leaf and interleaf transmission), all energies |                        | $\pm 0.5\%$ from baseline   |
| Leaf position repeatability   |                        | $\pm 1.0$ mm  |
| MLC spoke shot  |                        | $\leq 1.0$ mm radius  |
| Coincidence of light field and x-ray field (all energies)                   |                        | $\pm 2.0$ mm  |
| Segmental IMRT (step and shoot) test  |                        | $<0.35$ cm max. error RMS, 95% of error counts  |
|   |                        | $<0.35$ cm  |
| Moving window IMRT (four cardinal gantry angles)                            |                        | $<0.35$ cm max. error RMS, 95% of error counts  |
|   |                        | $<0.35$ cm  |

## Picket Fence

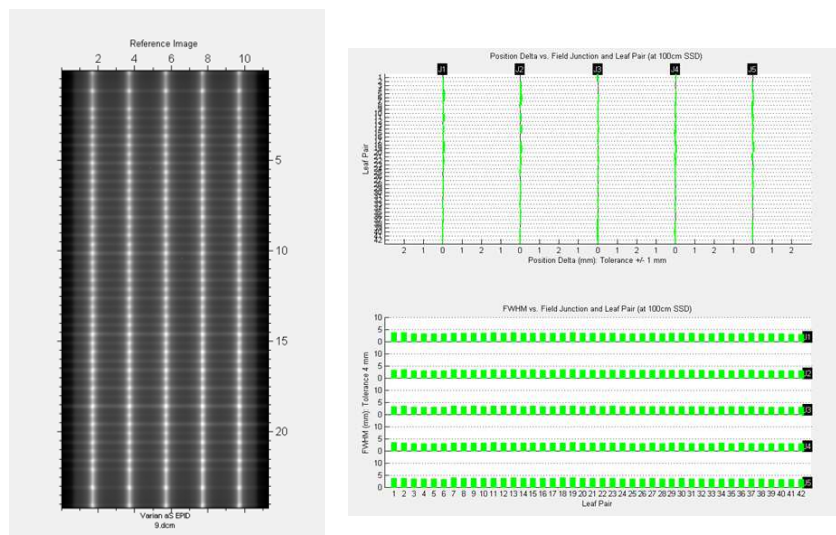
- The picket fence test is a two-dimensional check of MLC leaf position that uses either a step-and-shoot or a dynamic MLC pattern
  - Originally described by Chui, Spirou and LoSasso in 1996
- The MLC leaves move from left to right across the field with a fixed gap width between the opposed leaves
- The test is designed so that there are intentional hot spots at the junctions
- If the leaf positions are accurate, the dose pattern will show dark lines regularly spaced at equal distances over a light background



## Picket Fence



## Picket Fence



## TG-142 MLC Tests

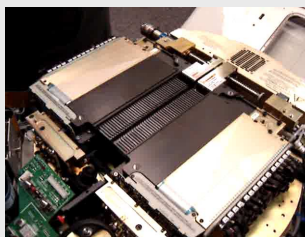
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|   | Annually               |   |
| MLC transmission (average of leaf and interleaf transmission), all energies |                        | $\pm 0.5\%$ from baseline   |
| Leaf position repeatability   |                        | $\pm 1.0$ mm  |
| MLC spoke shot  |                        | $\leq 1.0$ mm radius  |
| Coincidence of light field and x-ray field (all energies)                   |                        | $\pm 2.0$ mm  |
| Segmental IMRT (step and shoot) test  |                        | <0.35 cm max. error RMS, 95% of error counts<br><0.35 cm  |
| Moving window IMRT (four cardinal gantry angles)                            |                        | <0.35 cm max. error RMS, 95% of error counts<br><0.35 cm  |

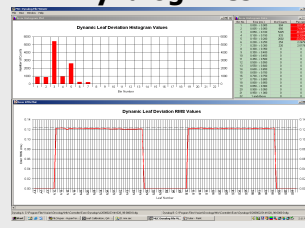
## Velocity Test – Log Files

- The performance of Varian 120-leaf MLCs can be tested using a series of dynamic test sequences
- MLC performance can be evaluated using EPID images and/or data from the MLC controller
  - The controller records actual and expected MLC positions for each leaf
  - Data is recorded every 50 msec and can be downloaded after treatment delivery

### 120 Multileaf Collimator



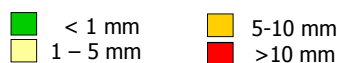
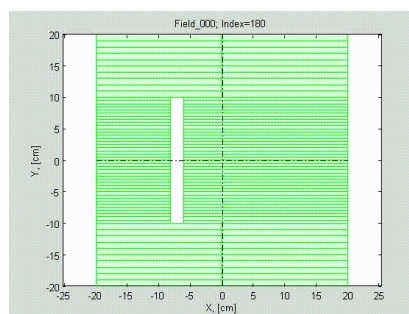
### Dynalog Files



## Velocity Test – Log Files

- In the first test, all 40 of the 5-mm leaves in the Varian “A” carriage move 14-cm in a forward direction extending out of the MLC carriage
- At the same time, all 40 of the 5-mm leaves in the Varian “B” carriage move in a backwards direction and are retracted 14-cm into the MLC Carriage
- In the second delivery sequence, the motion of the 5-mm MLC leaves is reversed with the “A” bank of leaves moving backward and the “B” leaves moving forward

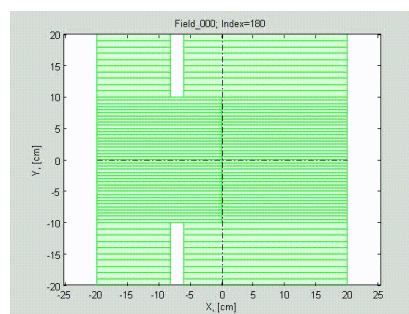
### Inner Leaf QA Test



## Velocity Test – Log Files

- In the third and fourth delivery sequences, the 5-mm MLC leaves are parked on do not move. In these tests, the 1-cm leaves are moved in and out of the carriage
- The 1-cm must be tested separately from the 5-mm leaves because they have different drive motors, and thus different dynamic MLC performance
- The desired MLC leaf velocities were adjusted by varying the total monitor units and the dose rate

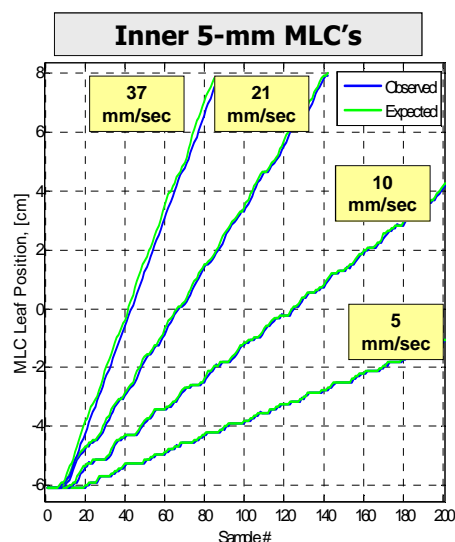
### Outer Leaf QA Test



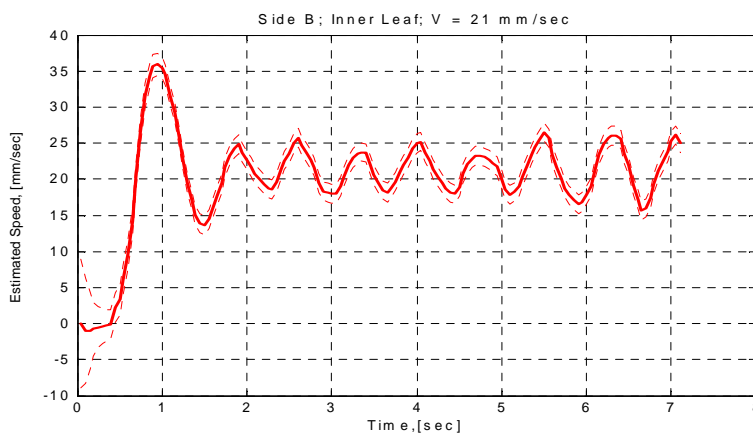


## Velocity Test – Log Files

- A total of 36 MLC test procedures were performed for 9 MLC velocities ranging from 5 to 37 mm per second
- This resulted in a total of 199,200 measurements of the actual versus expected MLC leaf positions
- For all MLC leaves and banks, the error in position during delivery increased with increasing leaf velocity

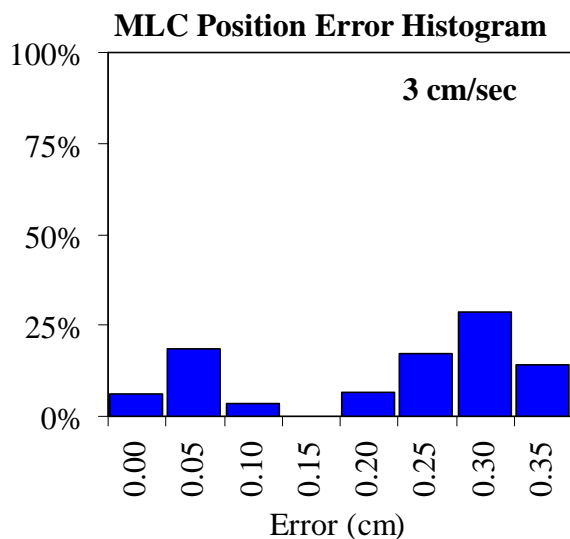


## Velocity Test – Log Files



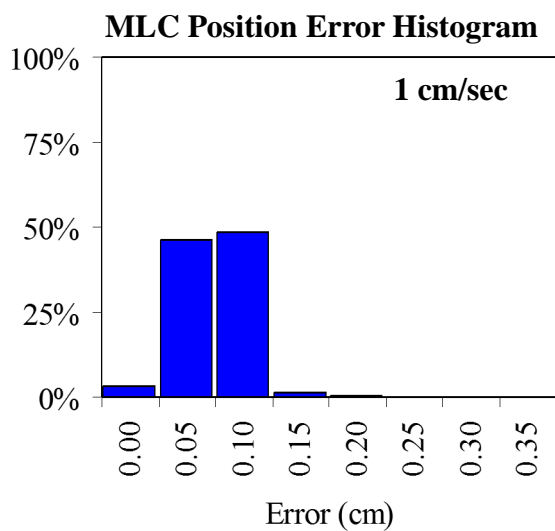
In this example, the position of an inner 5-mm leaf oscillates about the desired velocity of 2.1-cm per second

## Velocity Test – Log Files



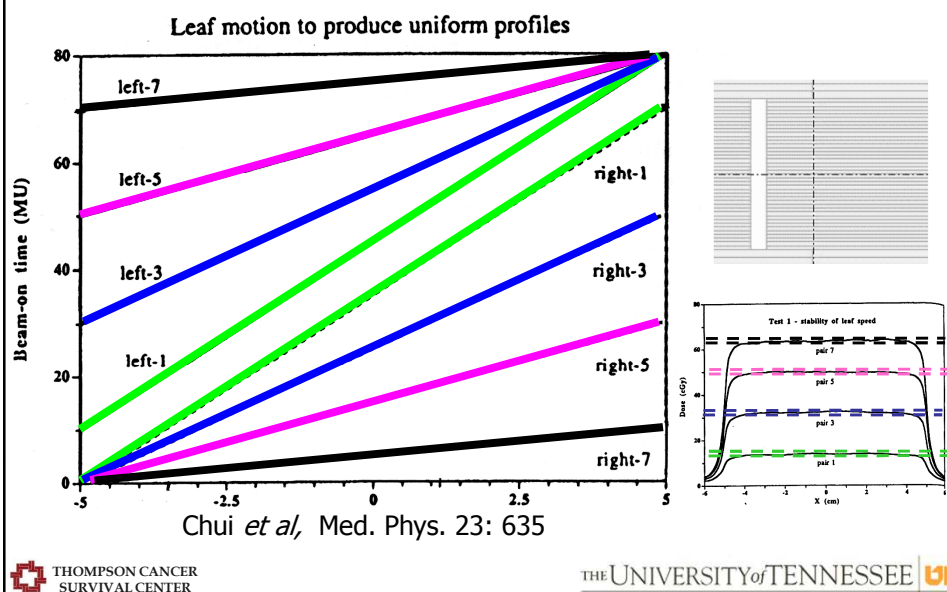
Ramsey *et al.*,  
Med. Phys. 28: 67

## Velocity Test – Log Files

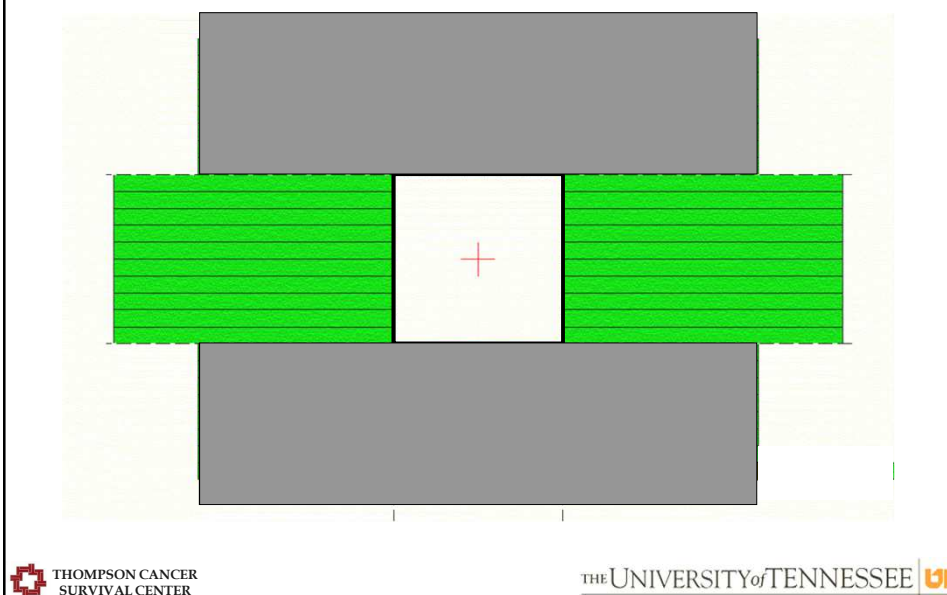


Ramsey *et al.*,  
Med. Phys. 28: 67

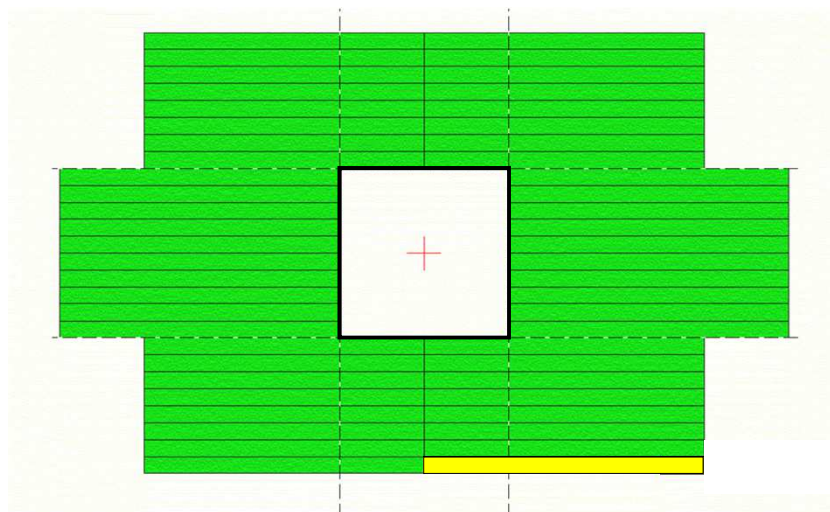
## Velocity Test – Imaging



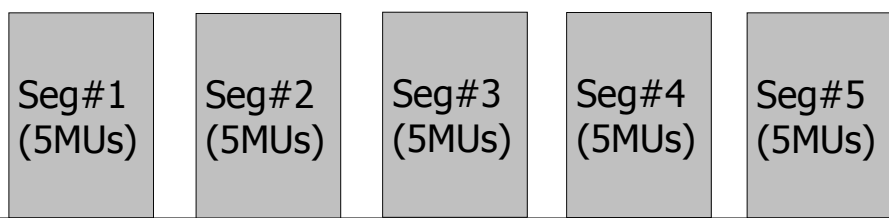
## Minimum Monitor Units



## Minimum Monitor Units

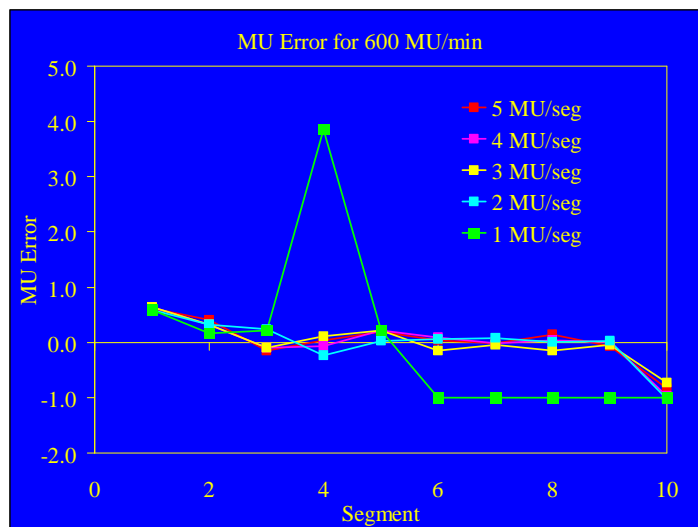


## Minimum Monitor Units

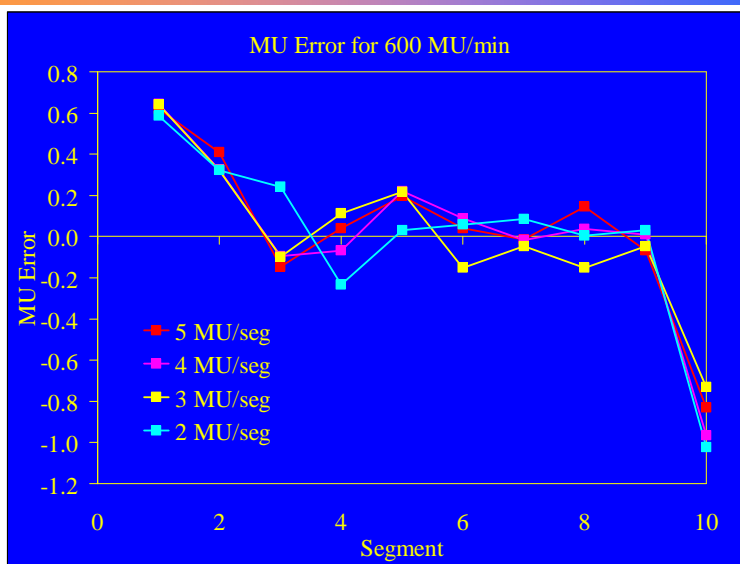


Dose #1 = Dose #2 = Dose #3 = Dose #4 = Dose #5

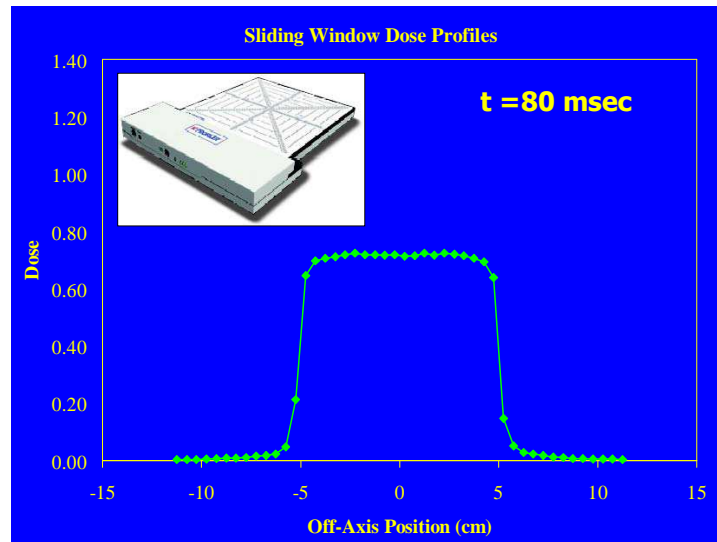
## Minimum Monitor Units



## Minimum Monitor Units



## Minimum Monitor Units



## Questions