CE- Head Scatter

Output factor in air and its impact on MU calculations

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Educational Objectives

- To examine the impact of output factor in air on MU calculations.
- To review influence of miniphantom on the measurement results.
- To review various components that contribute to the output variation of a clinical accelerator.

Educational Objectives

- To understand various approaches to parameterize the head-scatter sources.
- To examine S_c for offset fields, irregular field shaped by MLC, as well as off-axis points and EDW.
- To propose QA methods for output factor in air.

Definition and Terminology

- Output factor in air (*OF*, 13) is also called collimator scatter factor (S_c, *8*), head-scatter factor (*H*, *18*), or output ratio in air (*OR*, *3*).
- It is defined as a ratio of doses measured in a miniphantom between different collimator settings and a reference collimator setting (usually 10×10 cm^2).

Physical meaning

- The initial reason for introducing output factor in air is for the determination of phantom scatter factor (S_p).
- The recent renewed interest in this quantity is due to the fact that it may be used to measure *primary* kerma ratios in water at a point free in-air (ICRU 60, 1998), which can be useful for MC-based TPS.

Physical meaning

- "In-air" means a point in free air, without any influence of surrounding medium.
- Measurements with a miniphantom are said to be *in-air equivalent* if dose ratios measured in it equal primary kerma ratios in water: $D_1/D_2 = K_{p,1}/K_{p,2} = \mu \cdot \Phi_p / \mu \cdot \Phi_p$
- Easy to establish *in-air equivalence* for output factor in air measurement. (Johnsson et al, PMB 44, 2445-50, 1999).

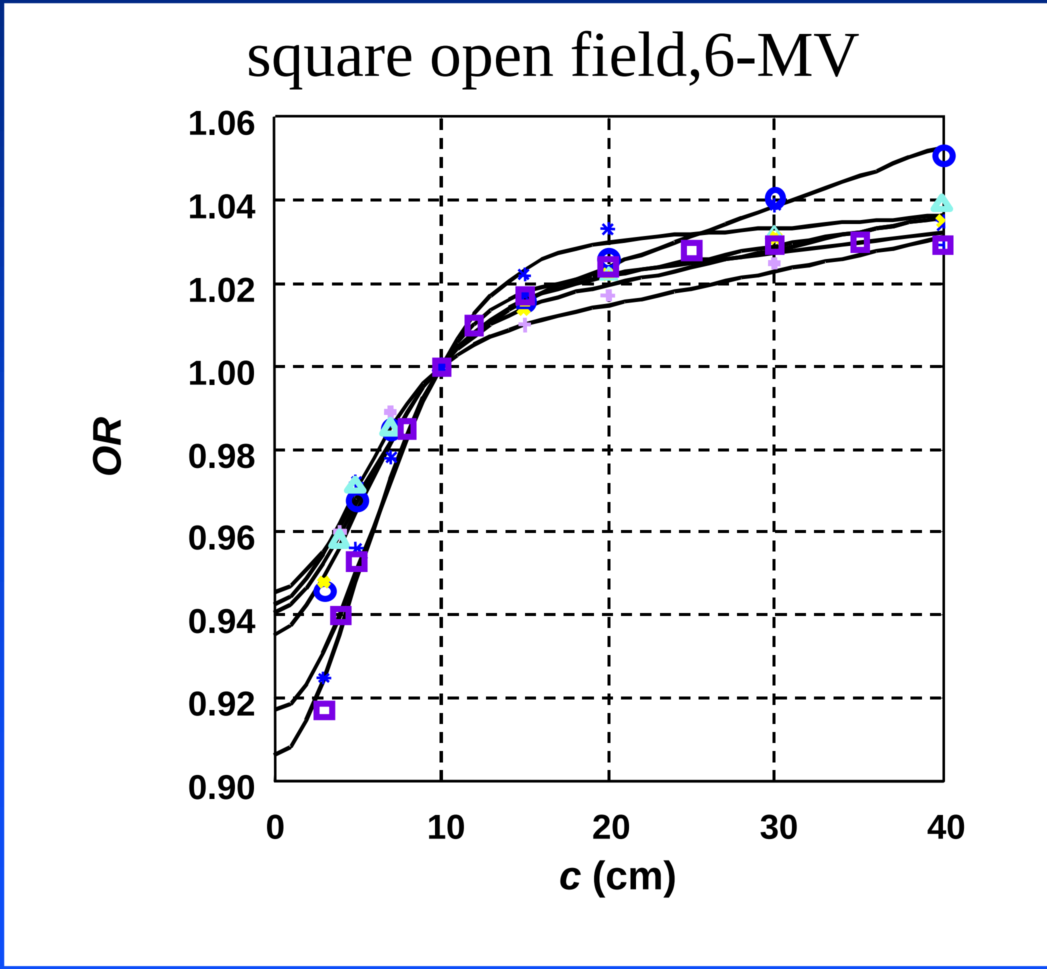
Basic characteristics of S_c

- S_c is almost independent of SSD.
- S_c does not depend on miniphantom depth, provided d_{meas} is beyond the contaminant electrons.
- S_c is only a function of collimator setting *c*.
- $S_p=S_{c,p}/S_c$ is only a function of nominal energy, while S_c is also a function of photon beam. Van Gasteren et al, Radiother Onc, 20, 250 (1991).

Impact of output factor in air on MU calculation

- Output factor in air varies by up to 12% for open beams.

Variation of output factor in air for open beams



o – Varian 2300CD,

x – Clinac 6/100,

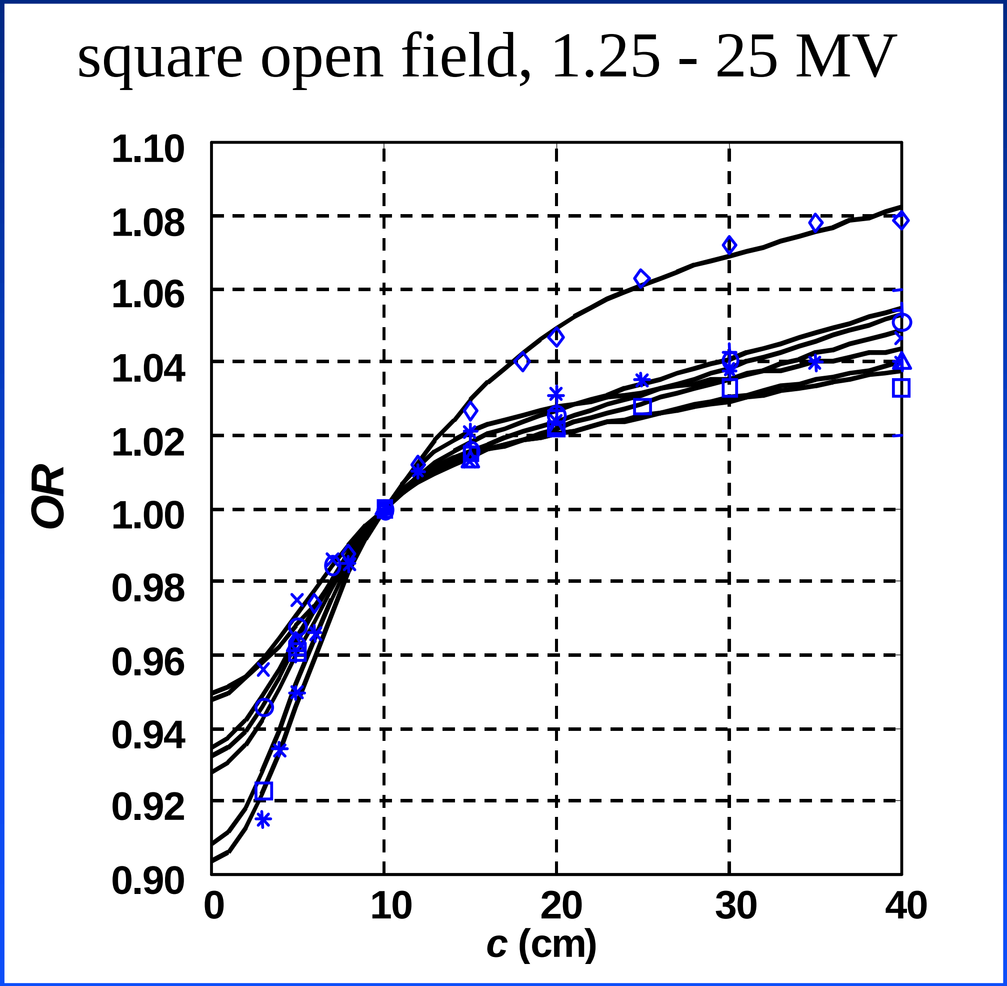
+ – Elekta SL75/5,

Δ – Elekta SL25,

* – Siemens Primus,

– Siemens MXE

Variation of output factor in air for open beams



o – Varian 2300CD, 6 MV,

× – 2300CD, 15 MV,

+ – 2100CS, 10MV,

Δ – Clinac 1800, 18 MV,

* – Elekta SL20, 20 MV,

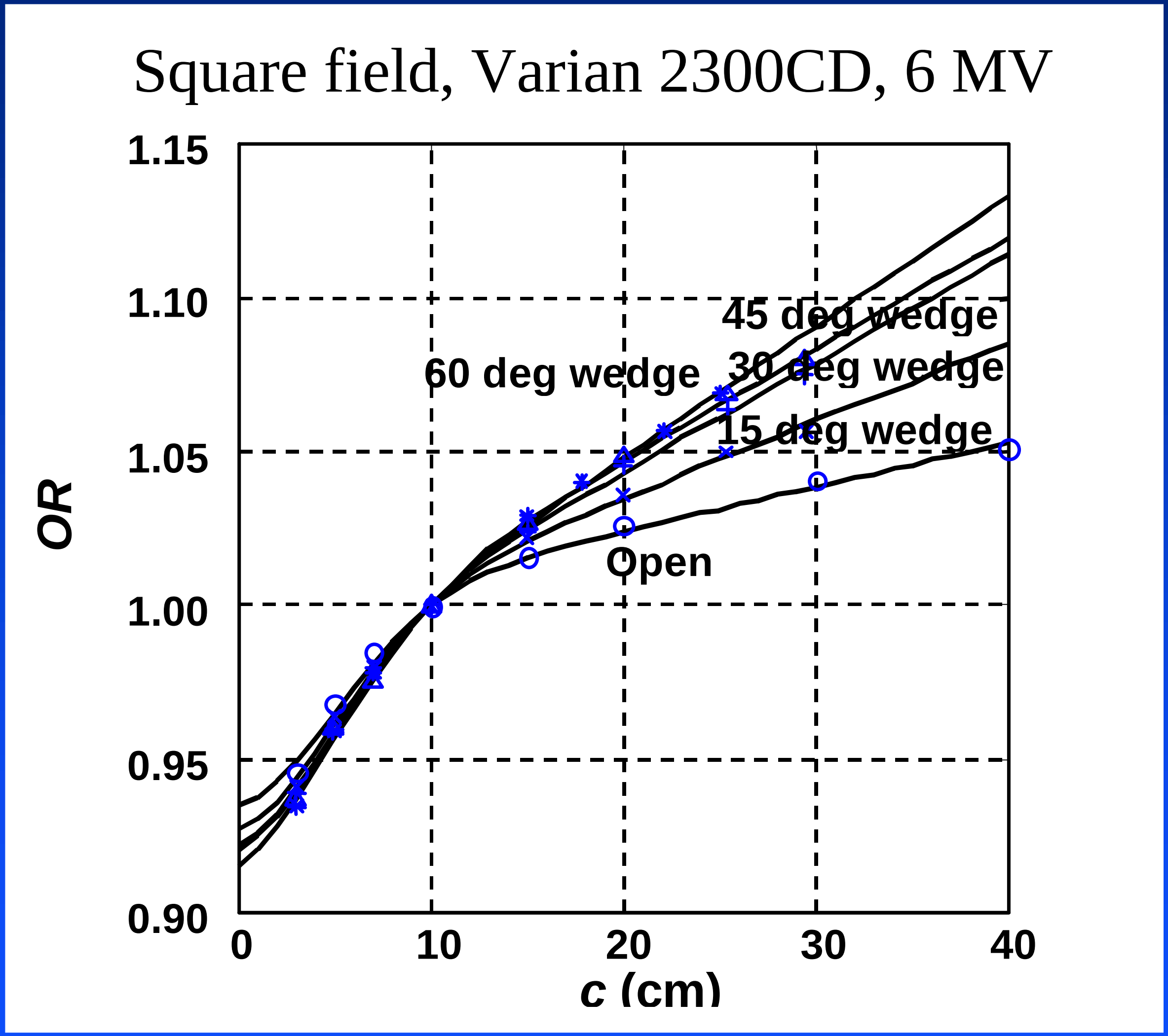
– SL25, 25 MV,

◊ – Theratronics T1000, Cobalt-60

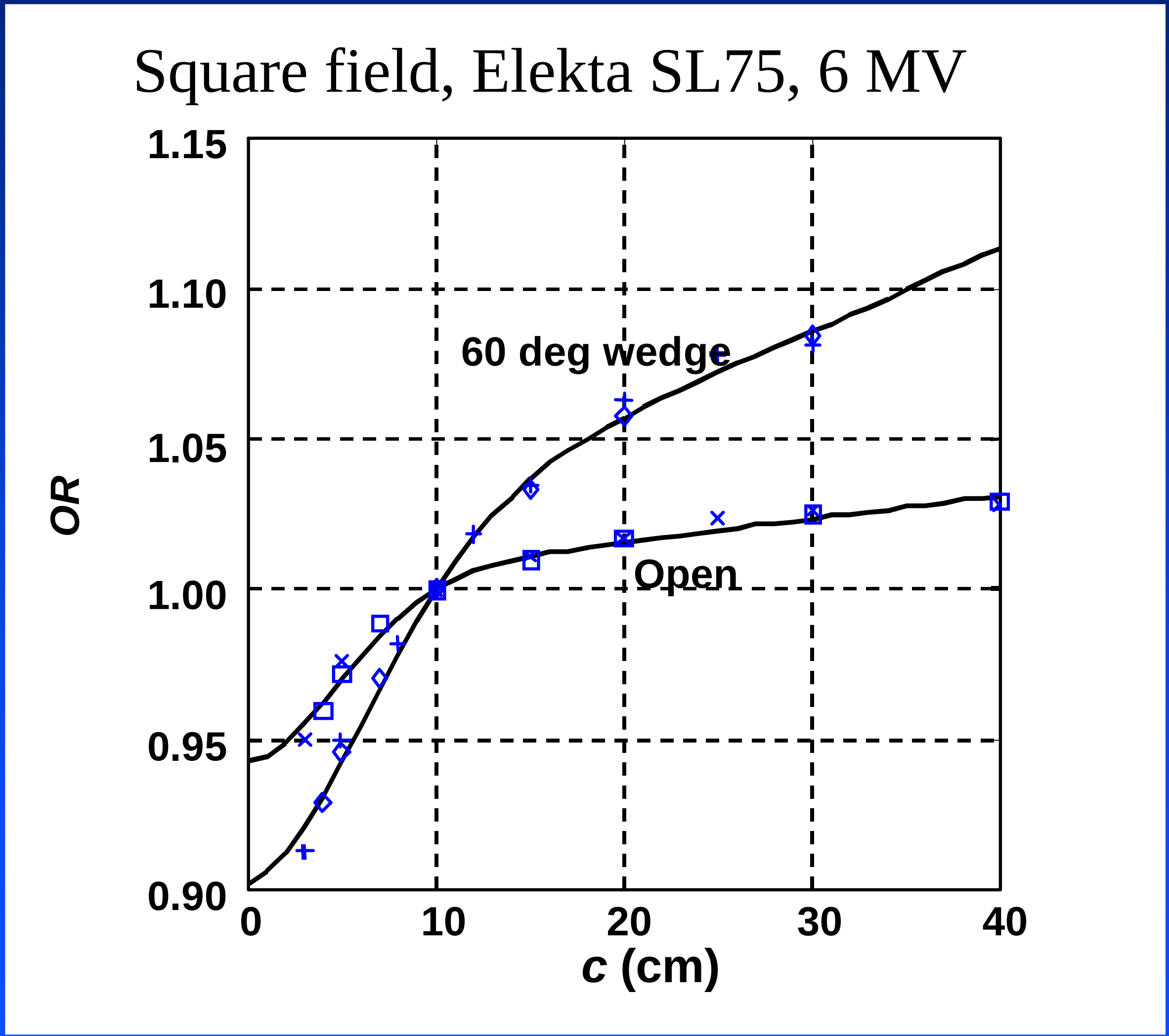
Impact of output factor in air on MU calculation

- Output factor in air varies an extra 5 - 13% for wedge beams depending on the wedge angle and location.

Variation of output factor in air for wedge beams



Variation of output factor in air for wedge beams



Impact of S_c on MU calculation

- The separation of S_c and S_p has proven to be a useful concept that improves the accuracy of MU calculation in cases where collimator defined field size does not correspond with the field size projected on the patient.
  - Blocked fields
  - SSD ≠ SAD

Impact of S_c on MU calculation

- For conventional MU calculations on the central-axis, ignoring the separation between S_c and S_p may produce errors up to 4% for open beams.
- Failure to account for difference of S_c between open and wedge fields (or the field size dependence of WF) may produce errors up to 8% for wedge beams.

Impact of S_c on MU calculation

- Using S_c measured on the central-axis for S_c at the center of offset fields may introduce up to 2% errors for open beams.
- S_c for irregular fields shaped by MLC fields may introduce 5% errors if output factor is estimated by the encompassing rectangular field. (Palta *et al*, Med Phys, 23:1219-24 (1996))

Methods to determine S_c

- Direct measurement using a detector in a miniphantom
  - Pro: Applicable to wider range (only method to study detailed features of S_c), more accurate.
  - Con: Miniphantom material/shape may affect results
- In phantom determination (Lam *et al* Med Phys 23:1207 (1993))
  - Pro: No need for miniphatom
  - Con: Require complete knowledge of S_p.

Influence of miniphantom on S_c

- Van Gasteren et al (Radiother Oncol 20, 250 (1991)) established definitive specification of the miniphantom to obtain consistent result
  - Low Z material (polystyrene)
  - minimum lateral dimension 4 cm diameter
  - thickness of miniphantom (5 or 10 cm) > range of electron contamination.

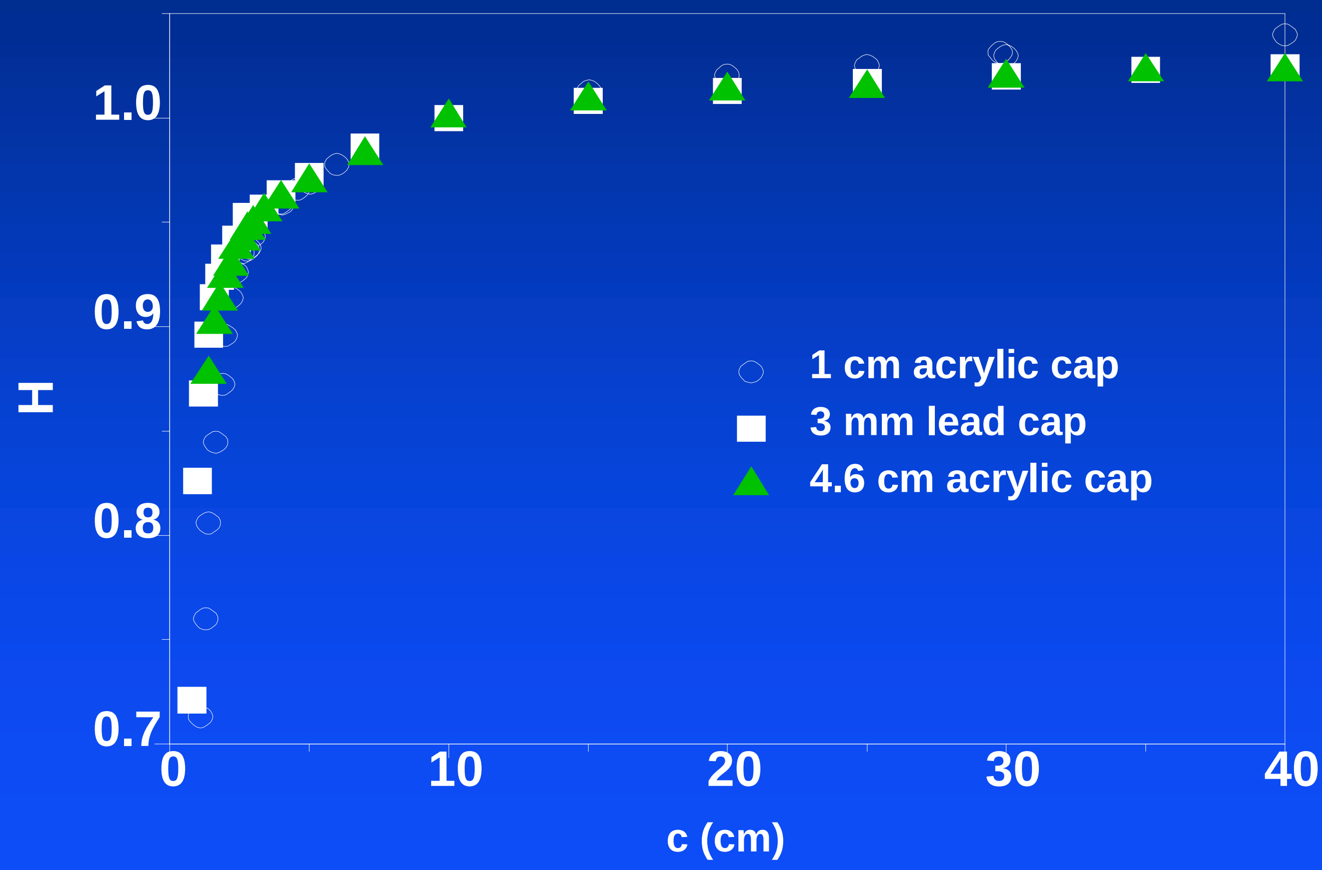
Influence of miniphantom on S_c

- Li *et al* (Med Phys 22, 1167 (1995)) studied the required lateral dimension of miniphantom to obtain consistent results using MC
  - minimum lateral dimension (4 cm diameter)
  - brass and low Z miniphantom gives consistent results.

Influence of miniphantom on S_c

- Lars Weber *et al* (PMB 42, 1875 (1997)) compared S_c measured by miniphantom with Z
  - Low Z materials give same results (polystyrene vs. graphite)
  - lead and brass produces less than 1% error for large fields at high photon energies.

S_c with different build-up caps for 6 MV photons



Influence of miniphantom on S_c

- Jursinic and Thomadsen (Med Phys 26, 512 (1999)) compared S_c measured by miniphantom for a wider range of Z
  - Low Z materials give same results (acrylic vs. mylar)
  - high Z materials (lead, tungsten, copper, aluminum) produce different S_c (up to 5%) than low Z material for 18 MV photons.

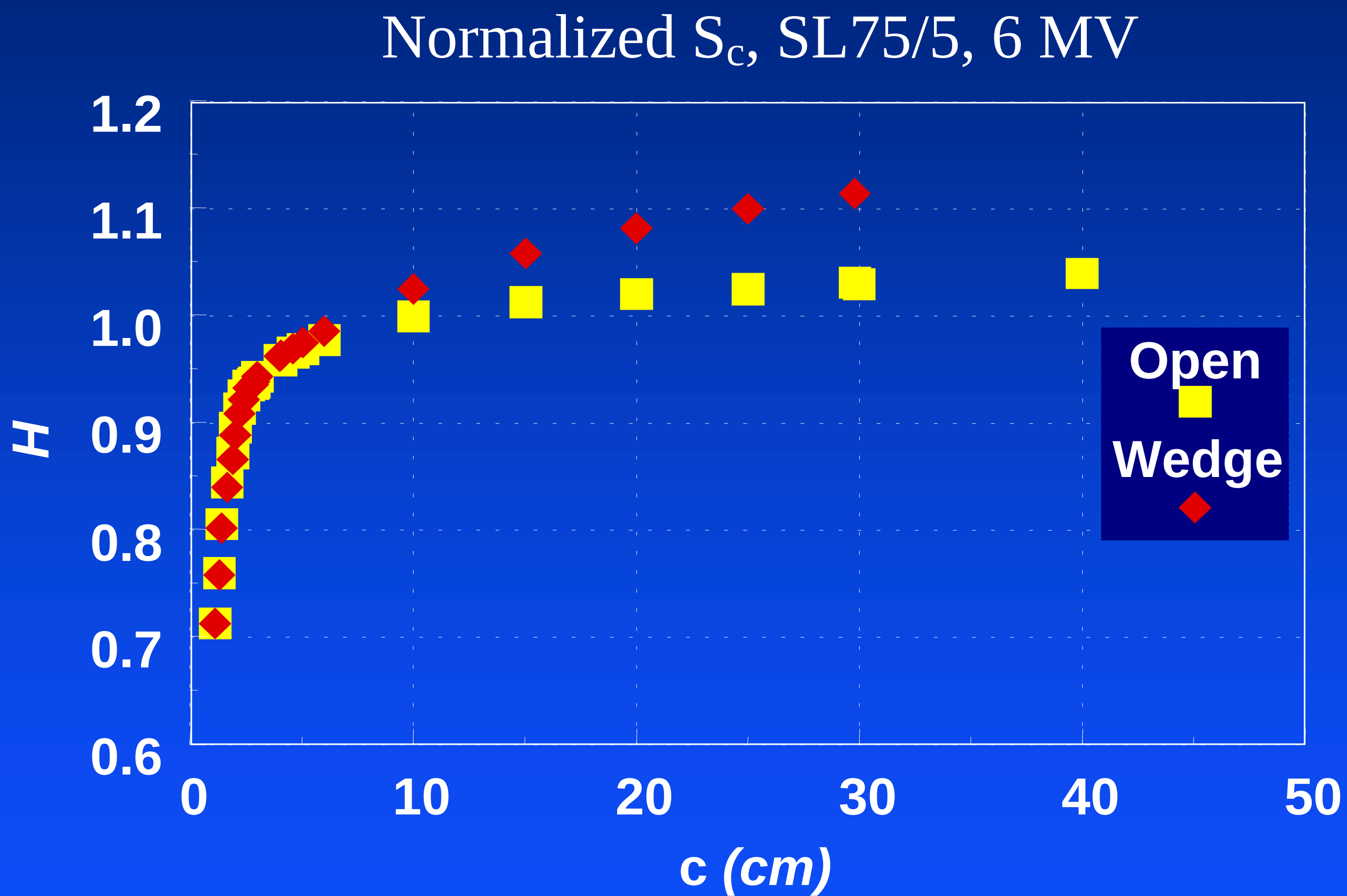
Influence of miniphantom on S_c

- ESTRO miniphantom gives consistent result for S_c (Dutreix et al ESTRO booklet 3, 1997)
  - PMMA or polystyrene miniphantom with 4 cm diameter lateral dimension and at depth of 10 cm.
- ESTRO miniphantom is not suitable for other “in-air” quantities, such as narrow beam transmission in water (Johnsson et al, PMB 44, 2445-50, 1999).

Component of S_c

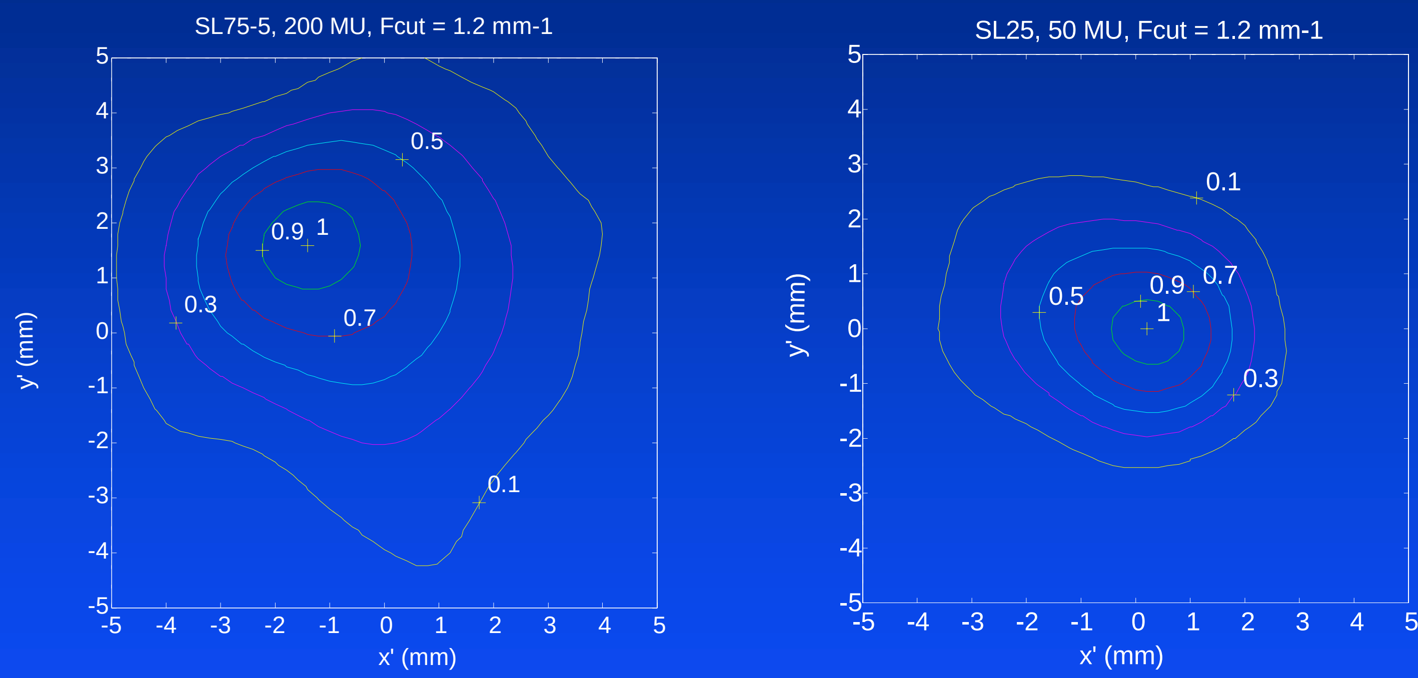
- Source-obscuring effect
- Head-scatter
- Monitor backscatter effect

Source-obscuring effect



Med Phys 21, 65-8, 1994

Source-obscuring effect

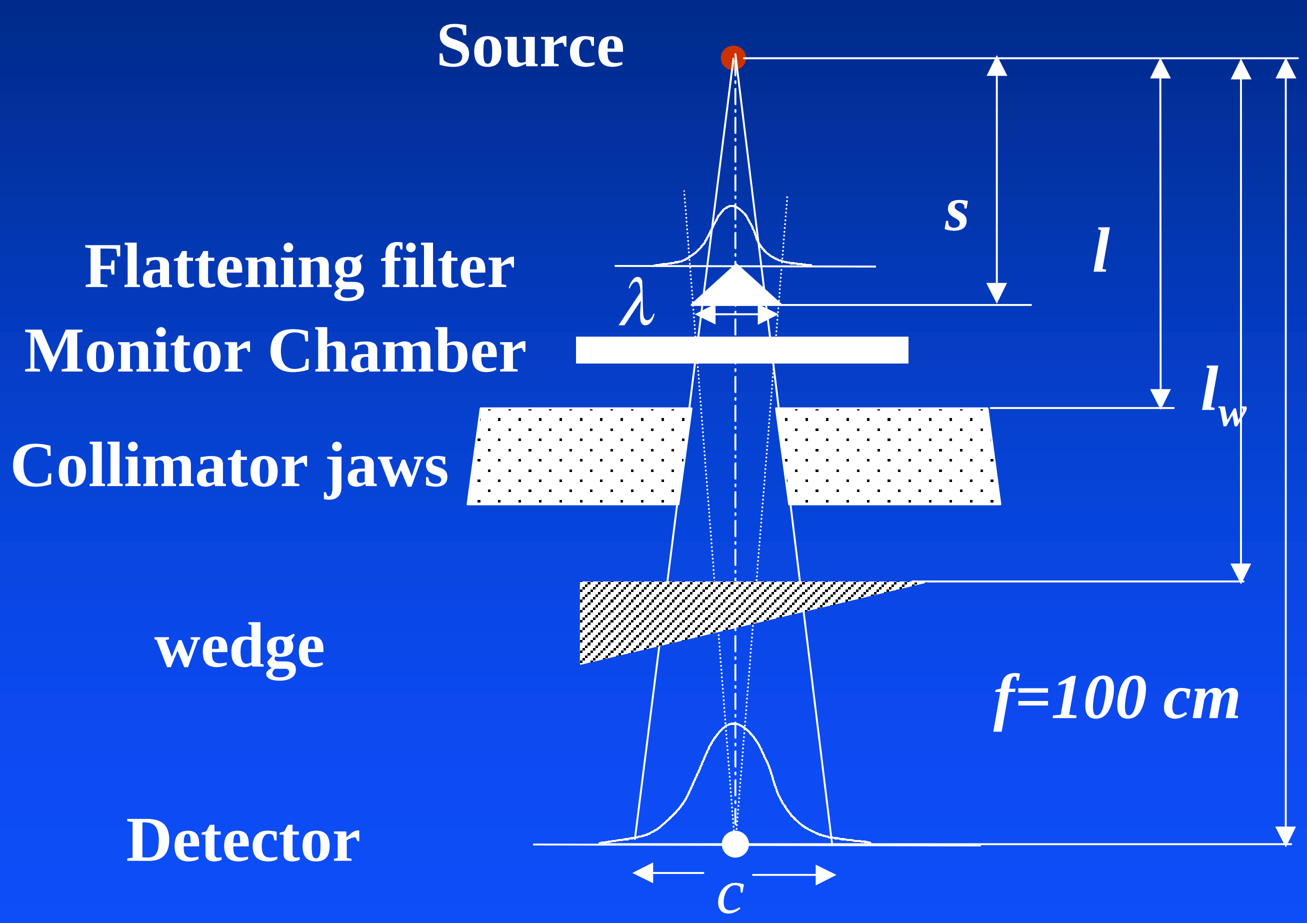


Proc. SPIE 2132:242-53, 1994

Source-obscuring effect

- Jaffray DA et al, Med Phys 20:1417-27 (1993)
- Sharpe MB et al, Med Phys 22: 2065-74 (1995)
- Zhu TC et al, Med Phys 22:793-8 (1995)

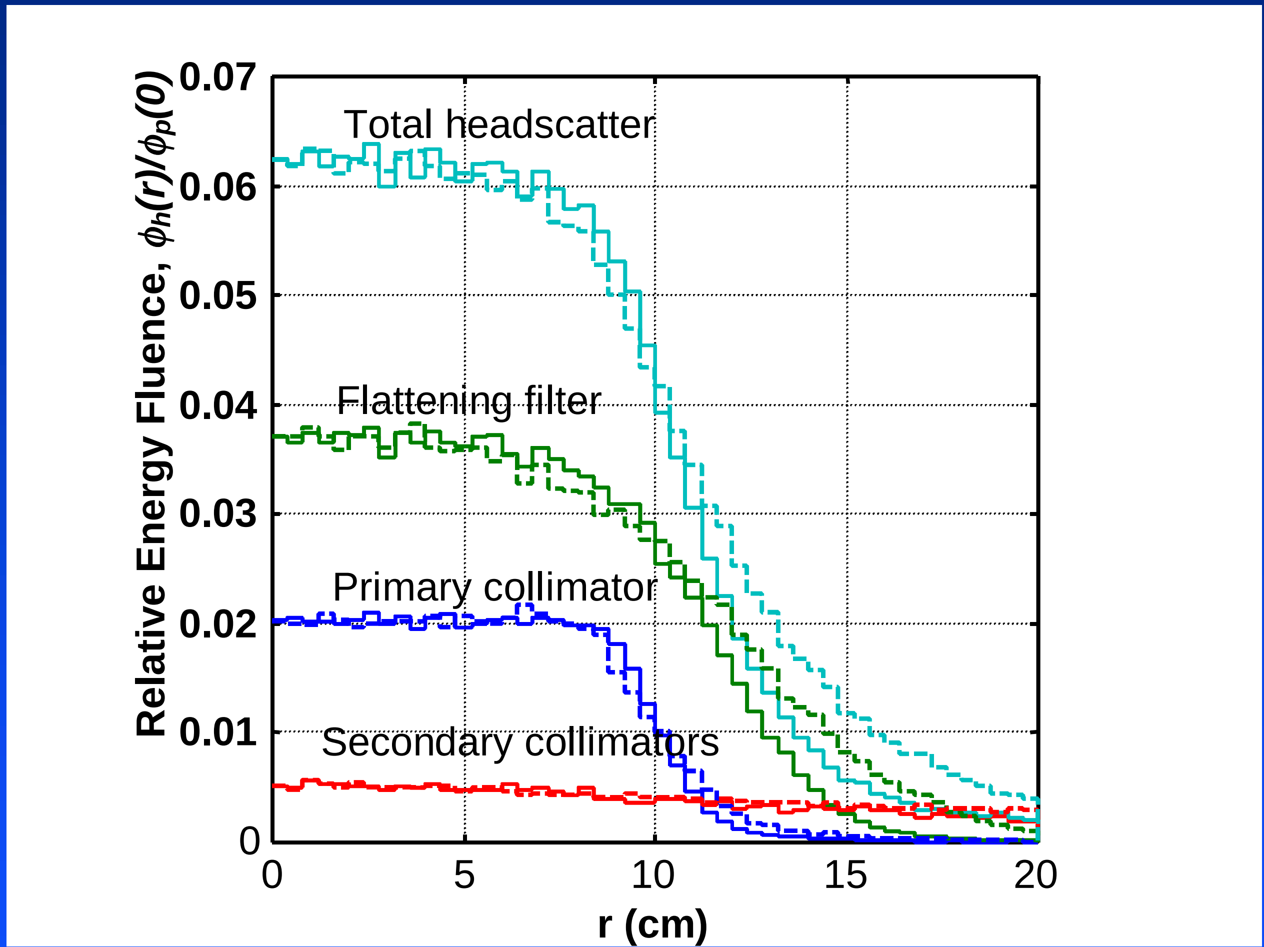
Headscatter sources



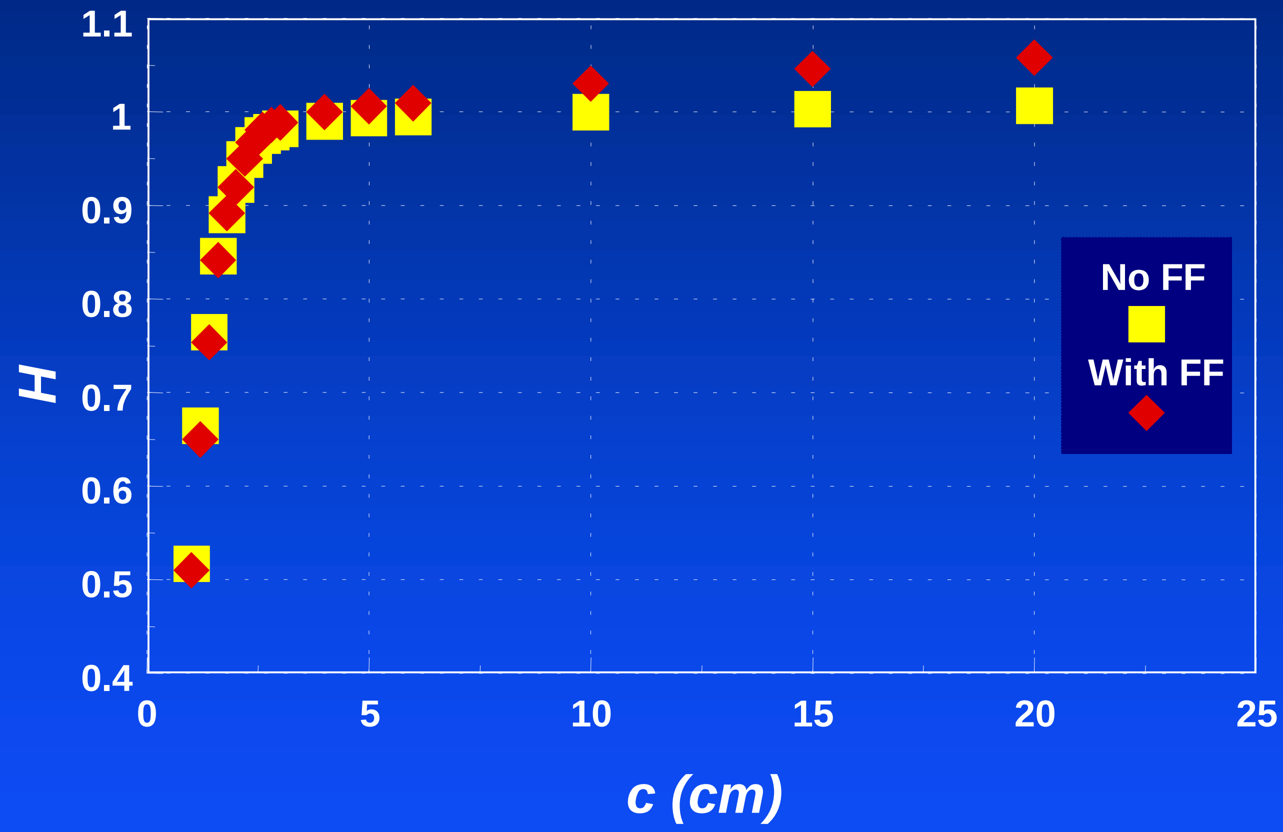
Headscatter

- For open beams, the majority of head-scatter is caused by the flattening filter.
- For wedge beams, the majority of head scatter is caused by both the flattening filter and wedge
- Monte-Carlo simulation is a useful tool to quantify relative magnitude of different components.

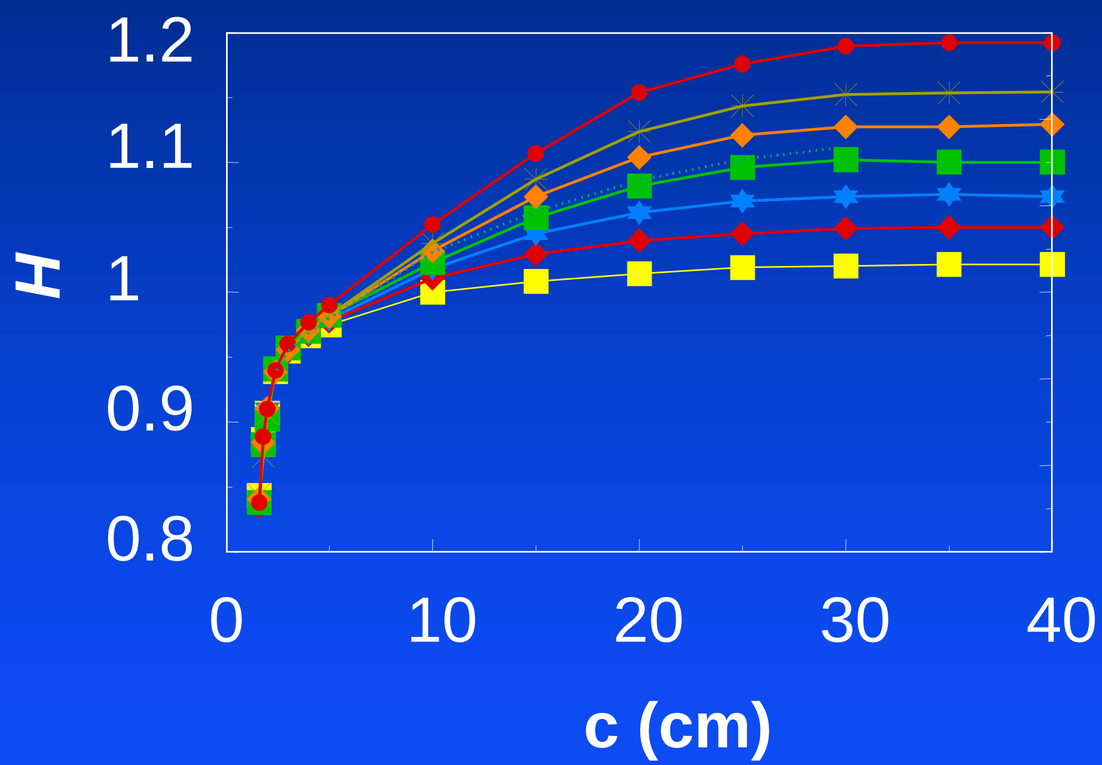
Headscatter - MC simulation



Normalized output factor in air, SL75-5, without flattening filter.



Normalized output factor in air with lead of various thickness

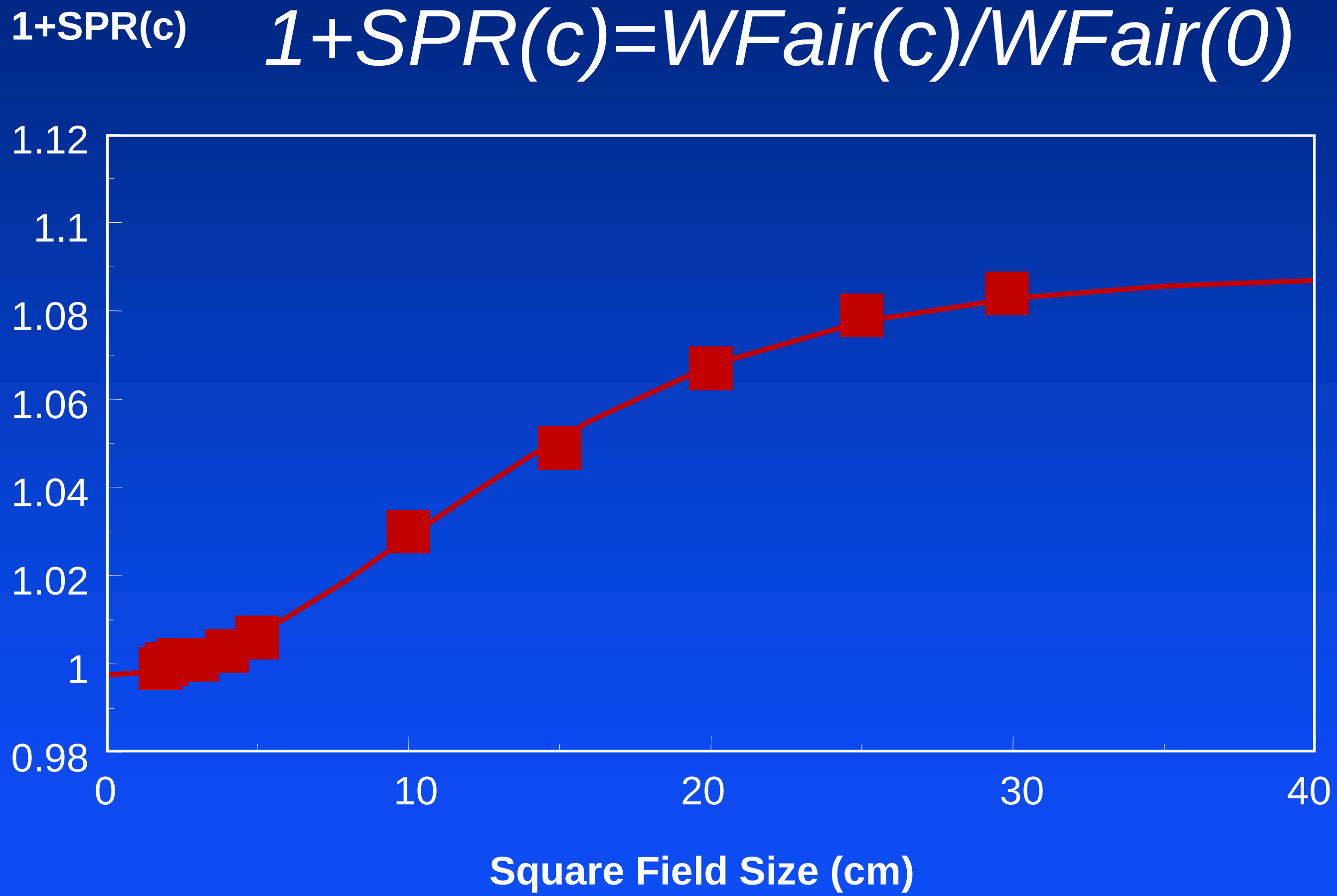


d = 0, 0.64, 1.27, 1.91, 2.54, 3.18, 3.81 cm

PMB 40: 1127-1134 (1995)

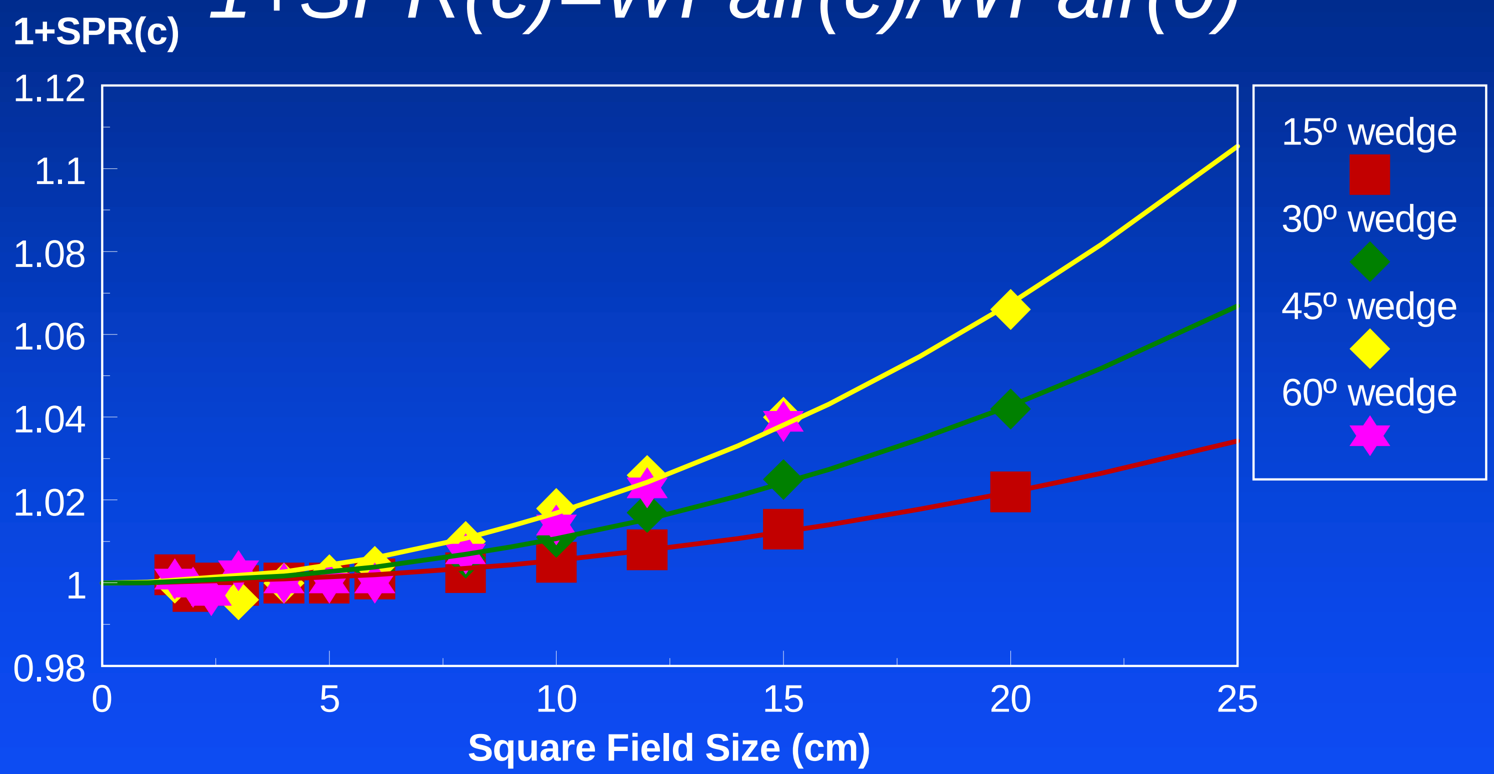
SL75, 6 MV, 30x30, internal wedge

$$1+SPR(c)=WFair(c)/WFair(0)$$



V2100C, 8 MV, 20x40 cm, external wedge

$$1+SPR(c)=WFair(c)/WFair(0)$$



Internal wedge, the Elekta SL75

External wedge, the Varian 2100 C/D

Monitor Backscatter effect

- Photons and electrons that are scattered from the collimator jaws back into the monitor chamber increase the ionization current to the monitor chamber for smaller collimator settings. Hence, the incident fluence per monitor unit (the “output”) increases with the collimator opening c.
- The effect is proportional to the collimator setting c, for square collimator settings, with a proportionality constant a_1.

Monitor backscatter effect - MC

- Electrons backscattered from the upper collimator jaws contribute to MB, thus it can be eliminated by a thin metal plate.
- The magnitude of MB is 2 - 3 % for Varian accelerators.
- References:
  - Liu HH, et al Med Phys 27:737-44 (2000).
  - Verhaegen et al PMB 45:3159-70 (2000).

Monitor backscatter effect - Exp

- The magnitude of MB is 3 - 5 % for Varian accelerators and negligible for Siemens and Elekta accelerators.
- Methods of measurements
  - Telescope method, Kubo Med Phys 16:295-8 (1989).
  - Dose rate without servo control, Huang et al Med Phys 14:268-9 (1987).
  - Target charge method, Lam et al Med Phys 25, 334-338 (1998).

Parameterization of S_c

- S_c for arbitrary collimator settings or irregular fields can be calculated by parameterizing HS and MB.
- All methods are empirical fit to determine model parameters. The models are used for
  - Analytical method.(Ahnesjo, Med Phys 21,1227 (1994))
  - Empirical methods (Dunscombe et al, Med Phys 19: 1441 (1992))
  - MC method (Liu H et al, Med Phys 24: 1960 (1997))

Parameterization of S_c

- Most methods assume that the dominant headscatter source is an extrafocal source located somewhere between the flattening filter and the primary collimator.
- Gaussian source shapes are most common but other source shapes are used
  - Yu et al Med Phys 23:973-84 (1996).
  - Ahnesjo Med Phys 21: 1227-35 (1994).
  - MO-517D-04, MO-517D-05 (2002)

Rectangular fields on central axis

- S_c is calculated according to

$$S_c(c) = (1 + a_1 \cdot c) \cdot (1 + a_2 \cdot erf(c/\lambda)^2) \cdot H_0,$$

where c is the equivalent square and

$$H_0 = 1/(1 + a_1 \cdot 10) \cdot (1 + a_2 \cdot erf(10/\lambda)^2)$$

- Three free parameters: a_1, a_2, λ

Rectangular fields - Equivalent square

- For a rectangular field shaped by X and Y collimator jaws, one can determine an equivalent square (Vadash *et al*, Med Phys 20, 733-4 (1993)):

$$c = (1+k)\cdot c_y \cdot c_x / (k \cdot c_x + c_y).$$

where

$$k = l_x \cdot (f - l_y) / l_y \cdot (f - l_x).$$

Kim *et al*, Med Phys 24, 1770-4 (1997)

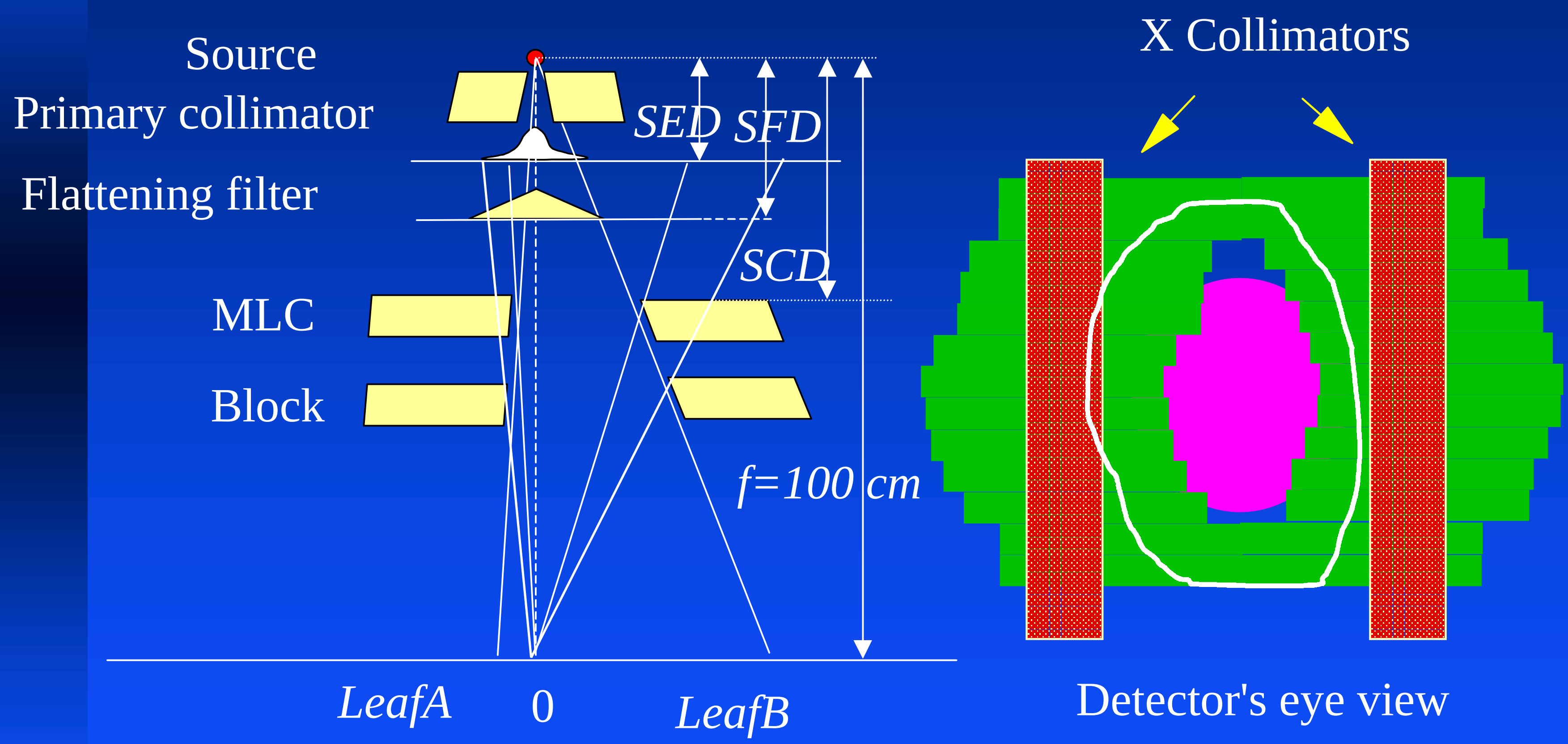
Parameterization of S_c

- For irregular fields, S_c can be determined by

$$S_c = (1 + a_1 \cdot c) \cdot (1 + a_2 \cdot \iint e^{-r^2/\lambda^2} dA) \cdot H_0$$

- Caution: Only true for some MLC, not for blocks.

Schematics of the detector's eye view



S_c for irregular field shaped by MLC

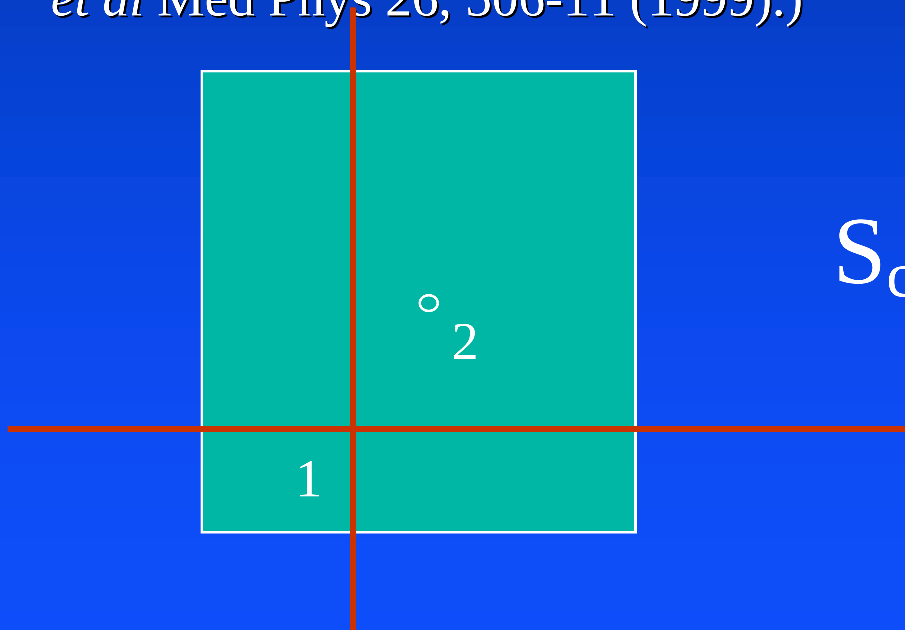
- The algorithm predicts S_c for MLC shaped irregular field to an accuracy of +/-1% for all three types of MLC (Varian, Siemens, and Elekta). (MO-D-517D-6)
- For Varian accelerator Sc can be well approximated by S_c for the secondary collimators for most clinic cases.

S_c for center of off-set fields

- The difference between S_c at center of off-set field and at isocenter for the same equivalent square c are within +/-1%, provided off-axis ratio is taking into account.(Shih *et al* Med Phys 26, 506-11 (1999).)
- More recent study showed a maximum 2% difference and provided a model to predict the result well (0.5%). (MO-D-517D-05)

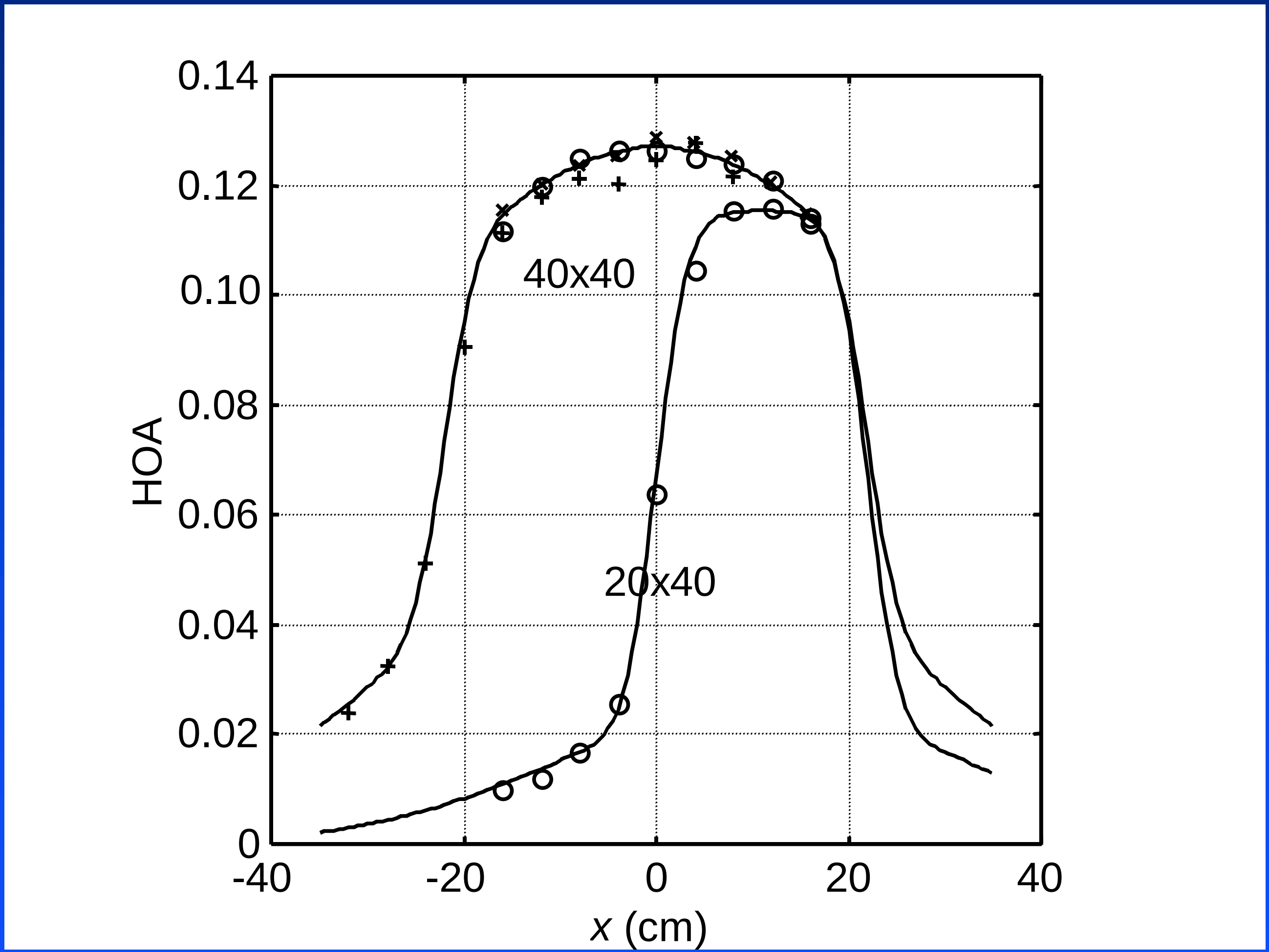
S_c for off-axis points

- The difference between S_c at center of off-set field and at isocenter for the same collimator setting are up to 4% different. (Shih *et al* Med Phys 26, 506-11 (1999).)

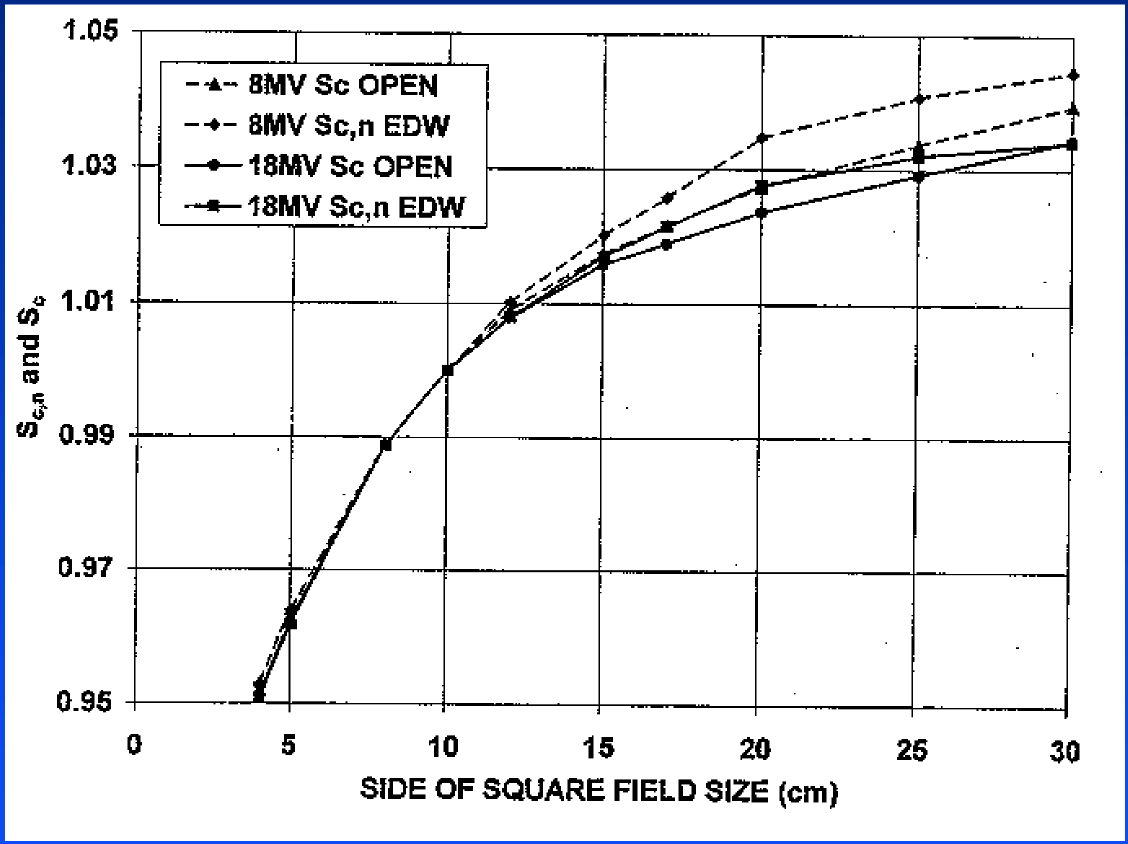


$S_c(2)/S_c(1)=1.04$

S_c for off-axis points



S_c for EDW - $S_c/N(Y)$

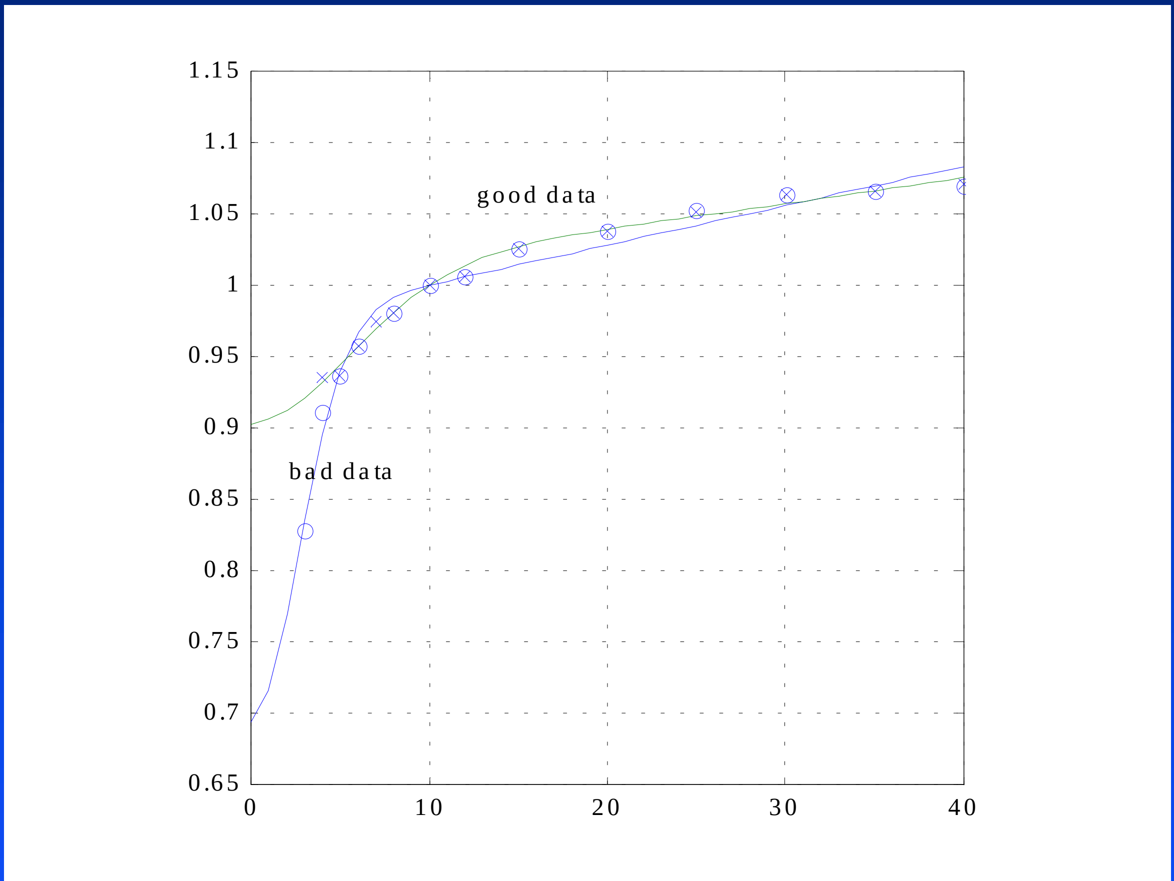


Liu C, Li Z, Plata JR Med Pays 25,64-67, 1998

QA of head-scatter factor-good data

Model	Energy (MeV)	a_1 (cm^{-1})	a_2	λ (cm)	Max error (%)	Std error (%)
Varian 2300CD	6	0.0015	0.064	8.12	0.4	0.3
	15	0.0014	0.050	8.45	0.4	0.2
Varian 2100CS	6	0.0012	0.066	8.99	0.1	0.1
	10	0.0014	0.076	8.47	0.2	0.1
Varian 2100CD	6	0.0013	0.067	8.06	0.4	0.2
	15	0.0012	0.051	7.47	0.3	0.2
Varian Clinac 1800	6	0.0009	0.072	7.96	0.1	0.1
	18	0.0010	0.074	8.11	0.2	0.1
Varian Clinac 6/100	6	0.0008	0.066	8.47	0.5	0.3
Varian Clinac 600C	6	0.0005	0.053	8.80	0.3	0.2
Elekta SL75/5	6	0.0007	0.061	7.81	0.6	0.4
Elekta SL20	6	0.0005	0.081	9.99	0.6	0.3
	20	0.0008	0.119	8.48	0.3	0.2
Elekta SL25/MLC	6	0.0003	0.069	10.8	0.6	0.4
	25	0.0007	0.104	7.64	0.8	0.5
Elekta SL25	6	0.0007	0.066	9.31	0.4	0.2
	25	0.0007	0.102	7.77	0.6	0.4
Siemens Primus	6	0.0004	0.099	9.15	0.5	0.3
	18	0.0006	0.115	7.95	0.9	0.4
Siemens KD2	6	0.0004	0.079	9.69	0.4	0.2
	15	0.0004	0.088	9.19	0.3	0.2
Siemens MXE	6	0.0005	0.117	8.21	0.8	0.3
Cobalt T-1000	1.25	0.0012	0.086	14.2	0.4	0.2

QA of head-scatter factor-bad data



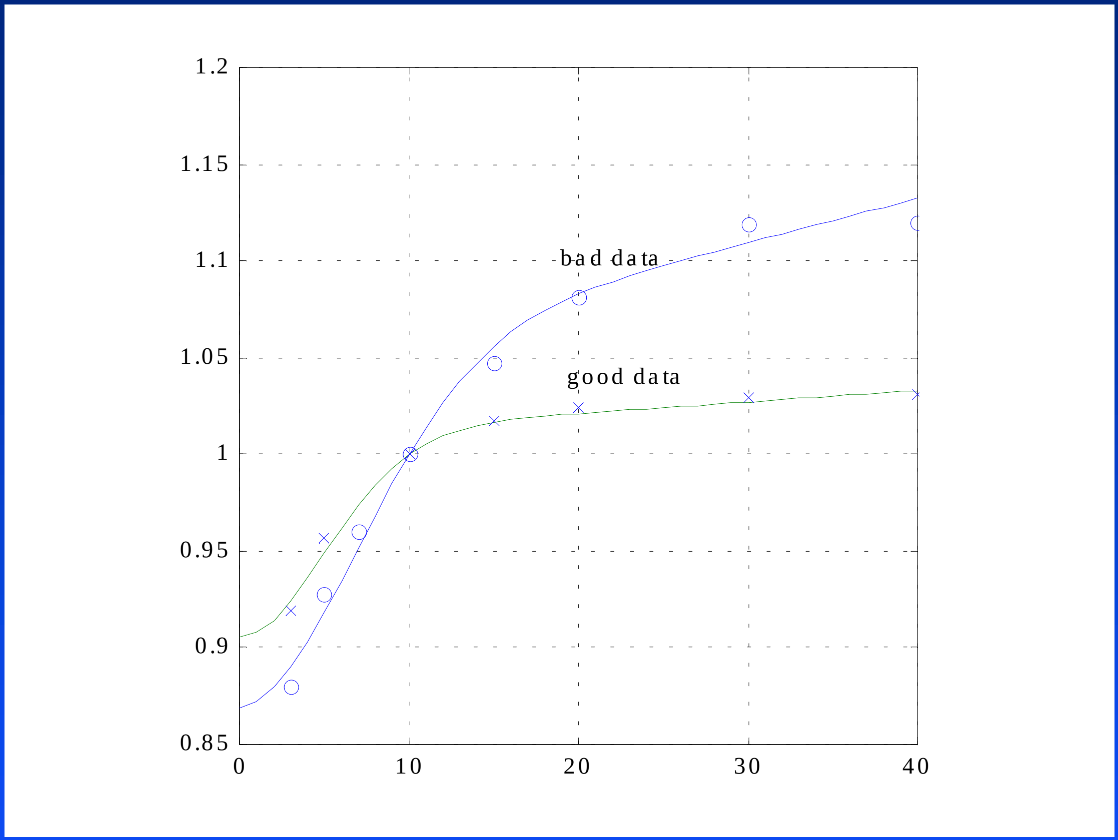
V2100
18 MV
Open

a_2, H_0 :

bad: 0.401, 0.695

good: 0.112, 0.903

QA of head-scatter factor - bad data



Siemens
Primus
18 MV
Open

a_2, H_0 :

bad: 0.198, 0.869

good: 0.115, 0.905

Summary

- A subset of miniphantom material and geometry can be defined to measure a consistent value of output factor in air, corresponding to primary kerma ratio in water in a point free in-air.
- There are three components of S_c: source-obscuring effect, headscatter, backscatter to monitor chamber.

Summary

- Monte-Carlo simulation has provided a useful tool to quantify magnitude of different component of S_c. Miniphantom measurements provide useful input data for Monte-Carlo based treatment planning.
- A great deal of progress has been made to parameterize headscatter photons and monitor backscatter effect for a wide range of linear accelerators and Co60 units.

Summary

- Progress has been made to characterize S_c at off-set points inside and outside beam collimation, which should improve dose calculation for IMRT.
- Sufficient information about S_c exists to develop QA methods for S_c.


Questions and comments are welcome !
Thanks