Source Modeling for Monte Carlo Treatment Planning

C-M Charlie Ma, Ph.D.

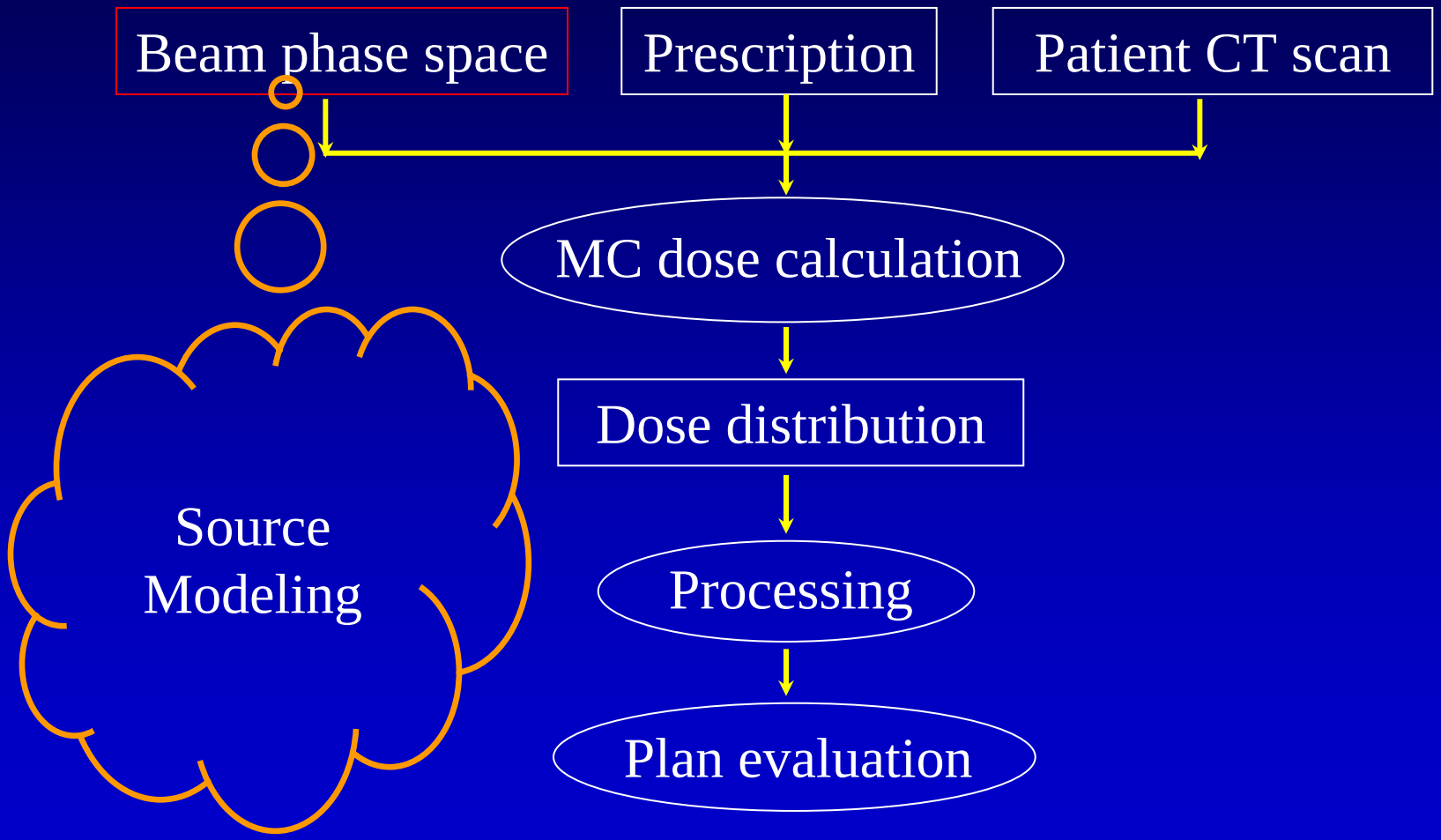
Department of Radiation Oncology

Philadelphia, PA 19111, USA

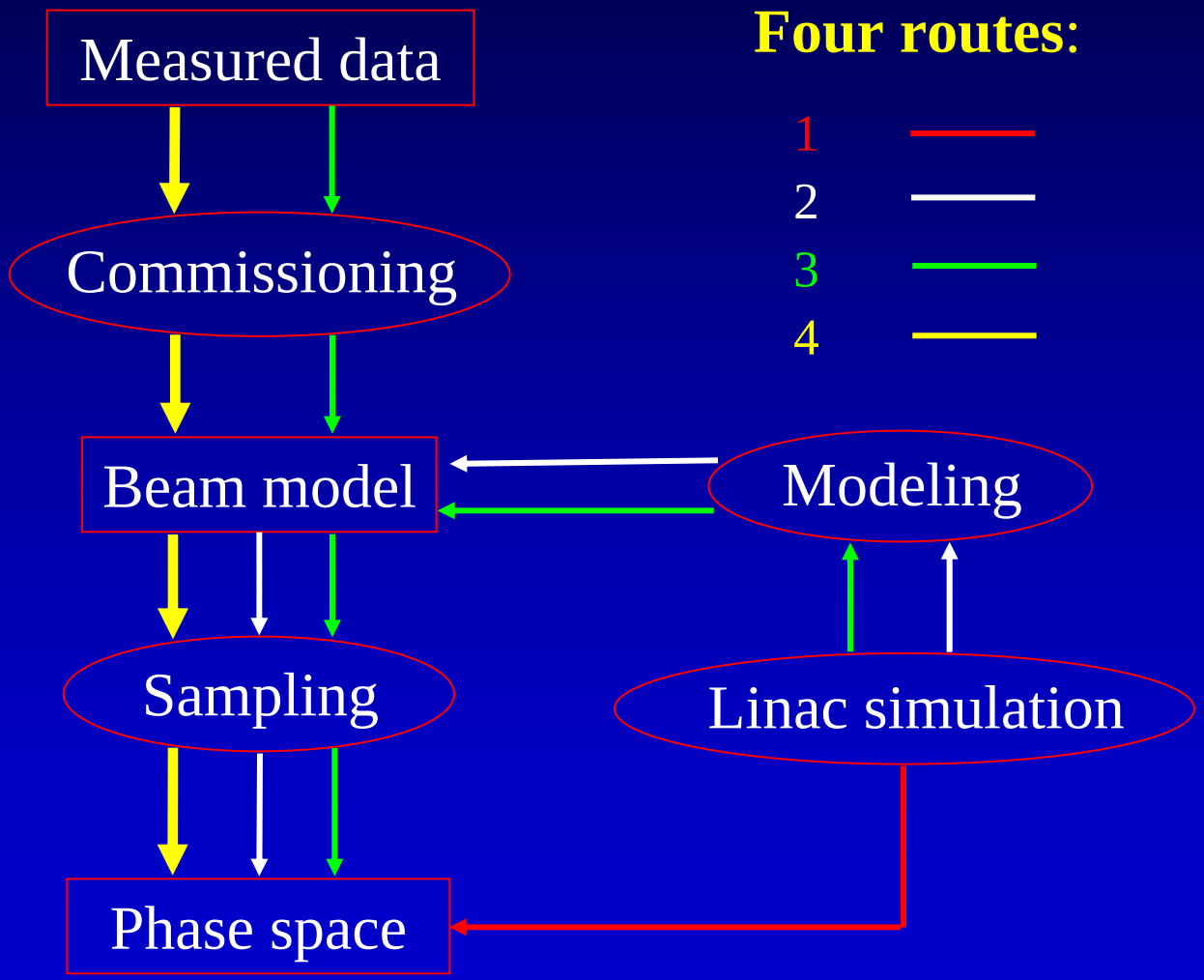
Outline

- Why source modeling for MCTP
- A multiple source model
- Electron beam modeling and commissioning
- Photon beam modeling commissioning

Monte Carlo treatment planning



How to Obtain Beam Phase Space



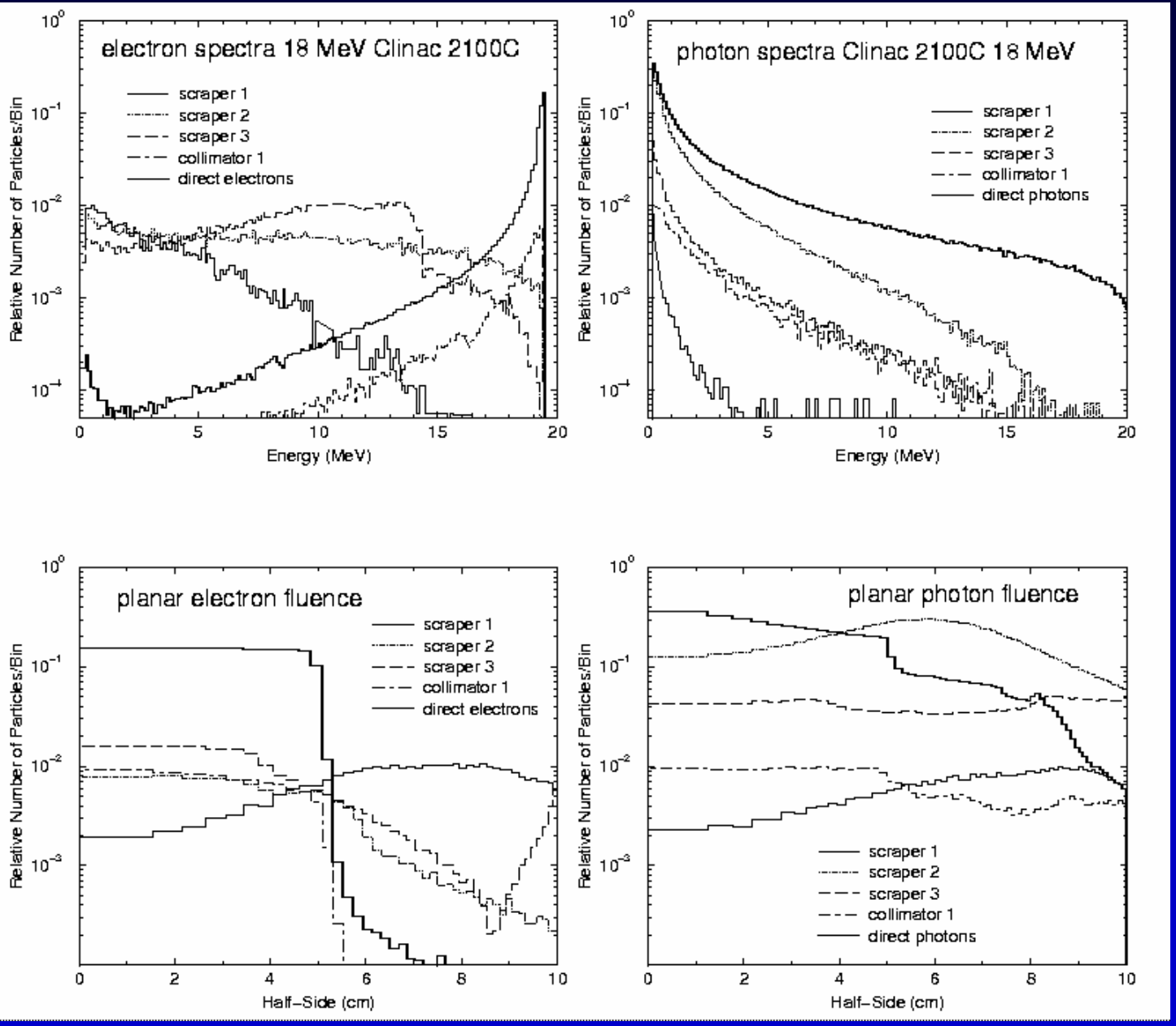
Beam Models vs Phase Space

- Beam models are based on good understanding of phase space representation and reconstruction
- Beam models can be more computationally efficient
- Beam models require less storage space
- Beam models are easier to commission and implement clinically

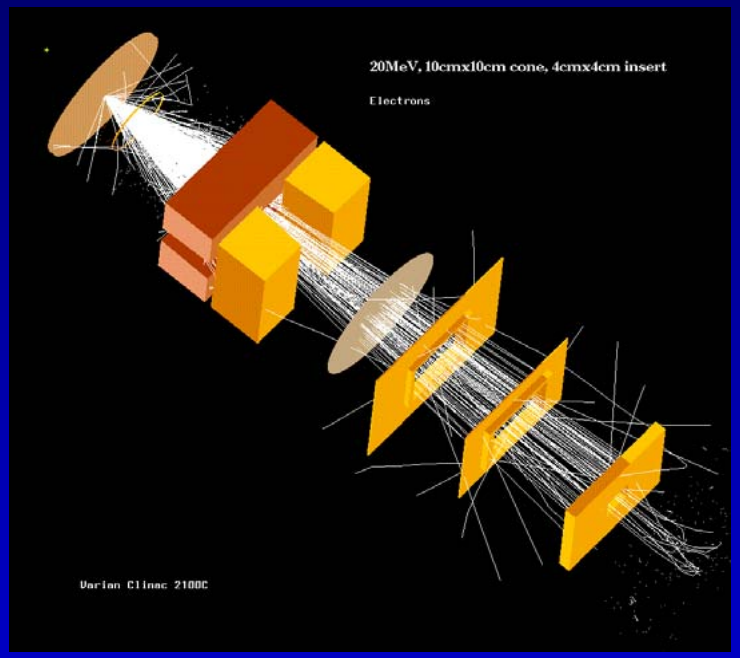
A Multiple Source Model

- Individual linac components are considered as sub-sources
- Each sub-source has its own energy and fluence distributions
- Angular correlation is retained

Ma et al *Med Phys* (1993,1994); Ma et al *NRCC/PIRS-0509C* (1995); Ma (1998)


electron spectra 18 MeV Clinac 2100C
scraper 1
scraper 2
scraper 3
collimator 1
direct electrons
Relative Number of Particles/Bin
Energy (MeV)
photon spectra Clinac 2100C 18 MeV
scraper 1
scraper 2
scraper 3
collimator 1
direct photons
Relative Number of Particles/Bin
Energy (MeV)
planar electron fluence
scraper 1
scraper 2
scraper 3
collimator 1
direct electrons
Relative Number of Particles/Bin
Half–Side (cm)
planar photon fluence
scraper 1
scraper 2
scraper 3
collimator 1
direct photons
Relative Number of Particles/Bin
Half–Side (cm)

Sub-source types



- Virtual point source
- Rings/cones for primary collimator
- Parallel bars for secondary collimator
- Rectangular sources for applicator
- Plane sources for mirror, monitor chamber, *etc*.

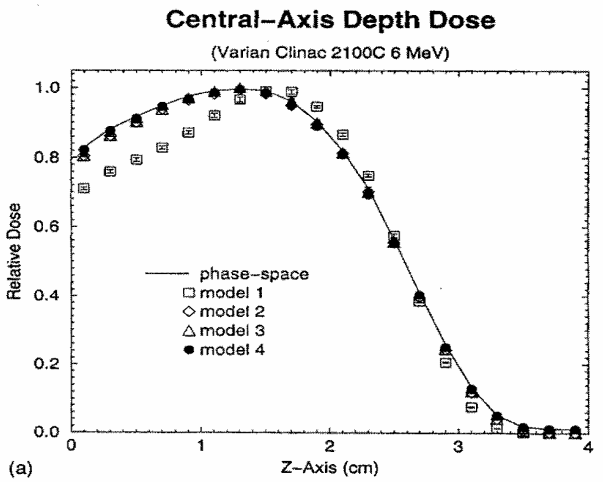
How many sources are enough?

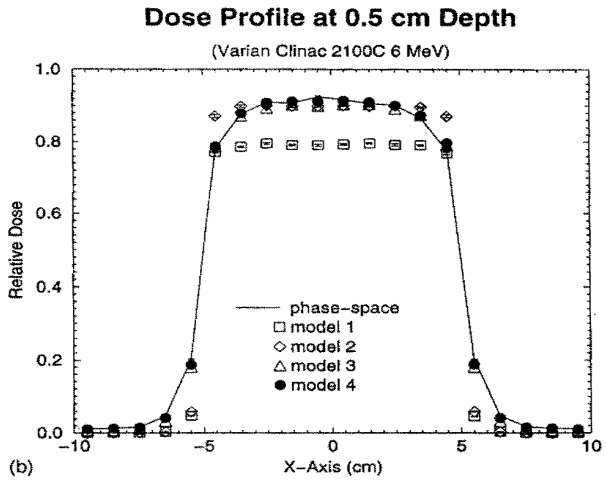
- an example: a 2100C electron beam

- model 1: a monoenergetic electron point source
- model 2: electron point source + energy spectrum
- model 3: electron point source + energy spectrum
  + beam profile
- model 4: a multiple source model

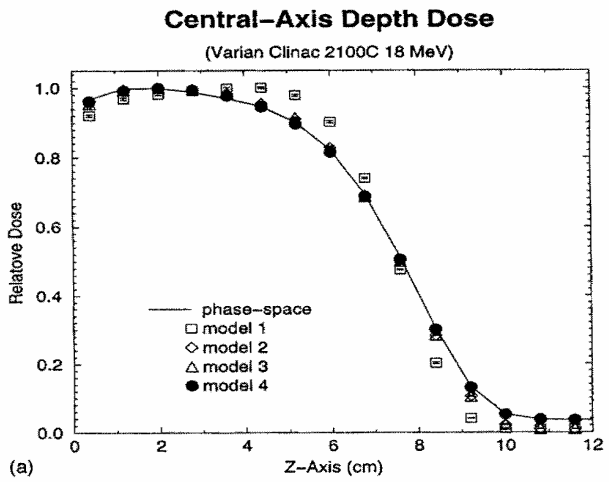
CM Ma, BA Faddegon, DWO Rogers and TR Mackie 1997 *Med. Phys.* 47(3):401-416

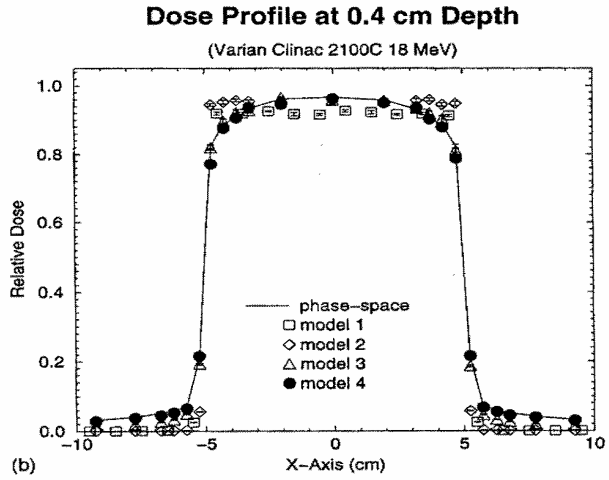
6 MeV





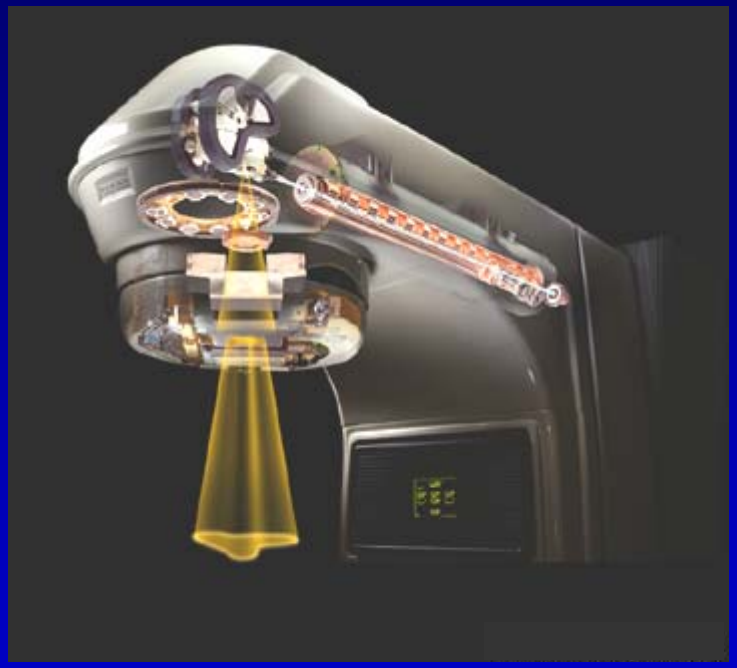
18 MeV

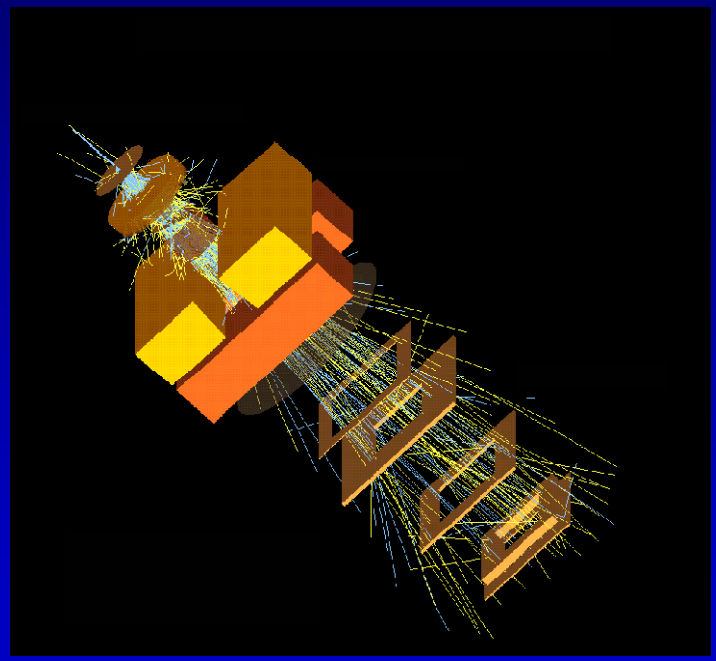




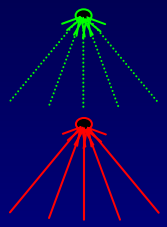
A point source + spectrum + profile ⇒ 2-5% accuracy

Electron Beam Modeling



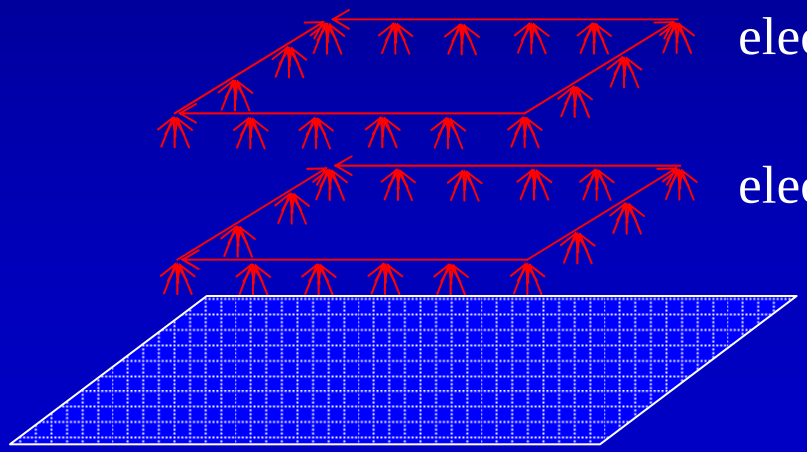


A four-source model for Varian 2100C



photon point source

electron point source

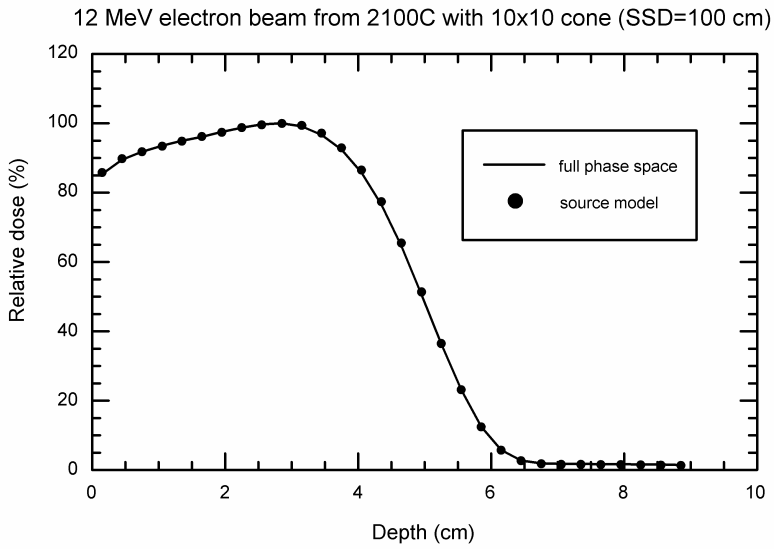


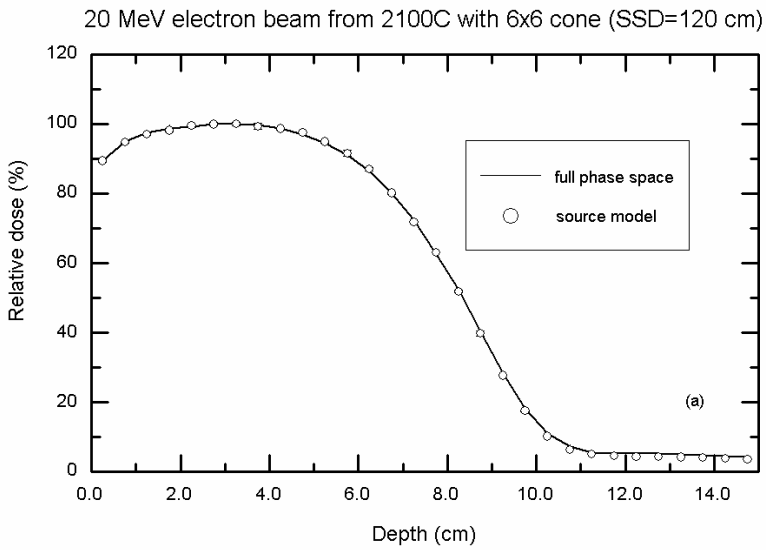
electron square ring source

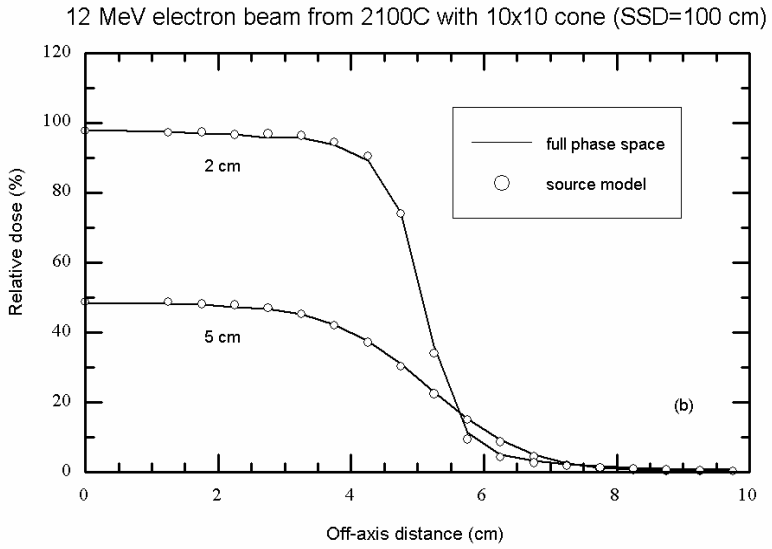
electron square ring source

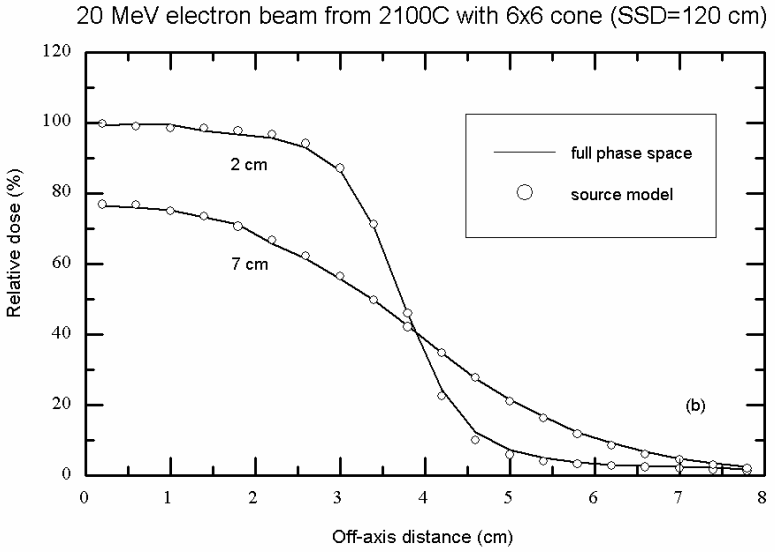
fluence scoring plane

Jiang et al *Med. Phys*.(1999) 27: 180-191; Deng et al *Proc. ICCR* (2000)


12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm)
Relative dose (%)
Depth (cm)
full phase space
source model


20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm)
Relative dose (%)
Depth (cm)
full phase space
source model
(a)


12 MeV electron beam from 2100C with 10x10 cone (SSD=100 cm)
Relative dose (%)
Off-axis distance (cm)
full phase space
source model
2 cm
5 cm
(b)

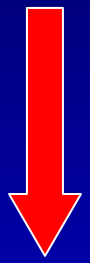

20 MeV electron beam from 2100C with 6x6 cone (SSD=120 cm)
Relative dose (%)
Off-axis distance (cm)
full phase space
source model
2 cm
7 cm
(b)

Linacs of the Same Model

Ma (1998); Jiang et al *Med. Phys.*(2000) 27: 180-191

A test of the commissioning approach

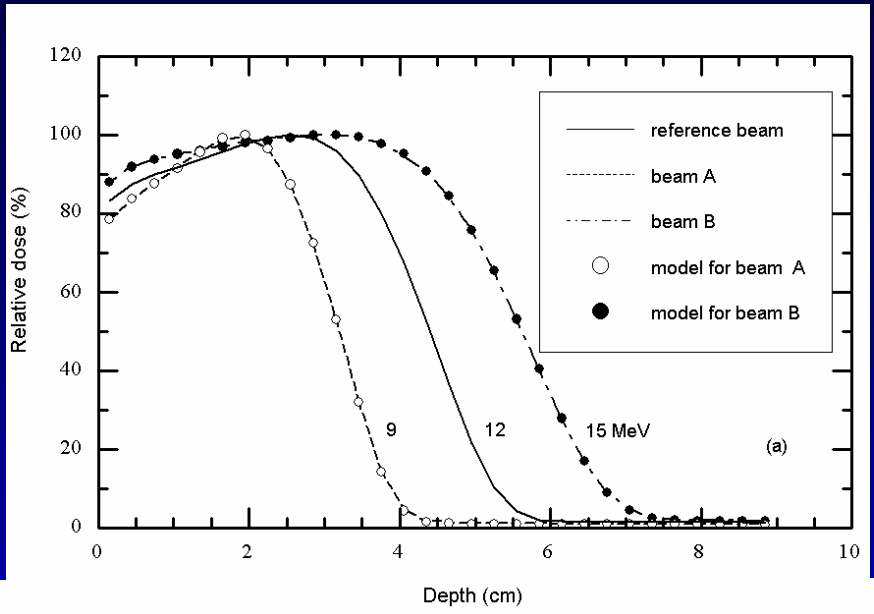
- Reference beam: Ein=12.0 MeV

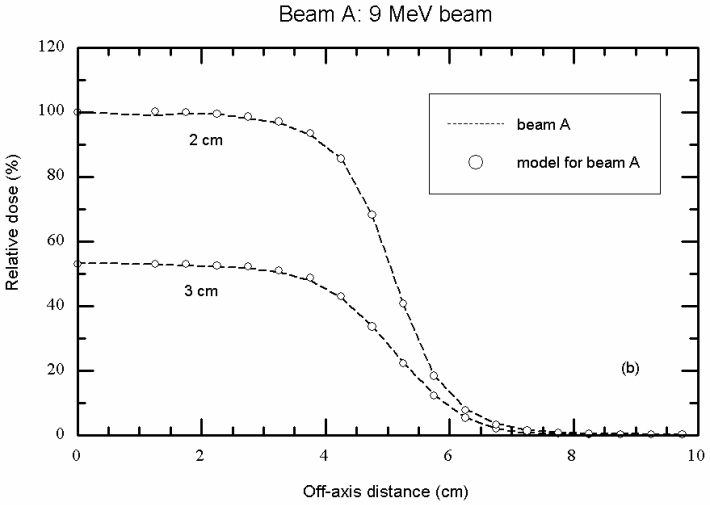


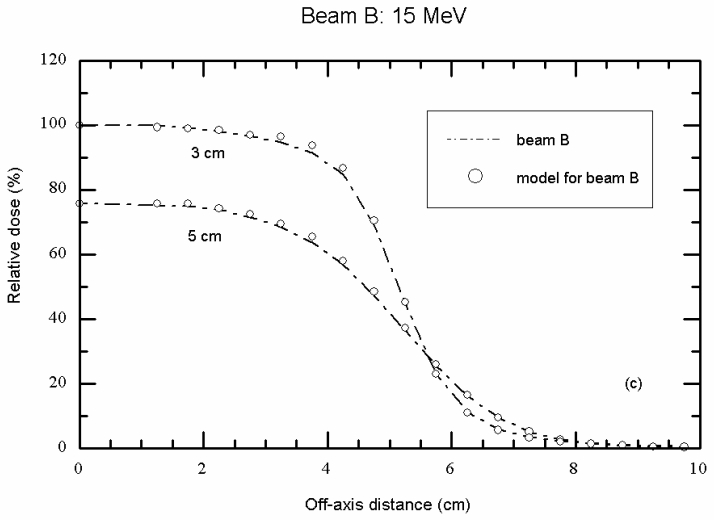
to match

- Beam A: Ein=9.0 MeV (simulated)
- Beam B: Ein=15.0 MeV (simulated)
- Beam C: published data (nominal 12 MeV?)

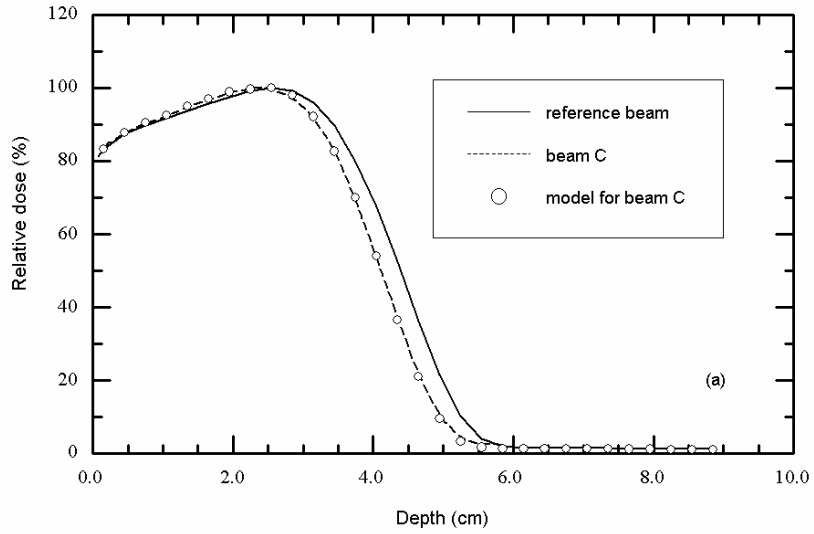
Match Different Energies

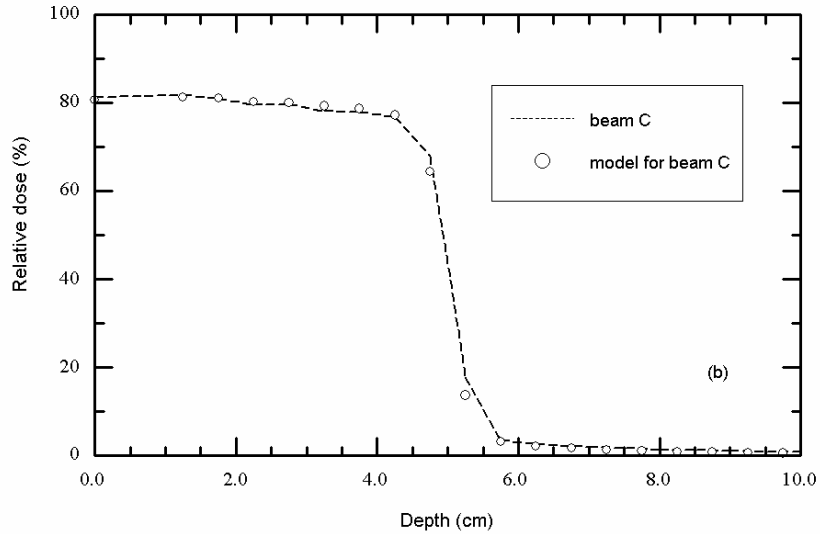






Match Unknown Dose Distributions





Advantages of Measurement-Based Source Modeling and Beam Commissioning

Less dependent on precise knowledge of linac geometry

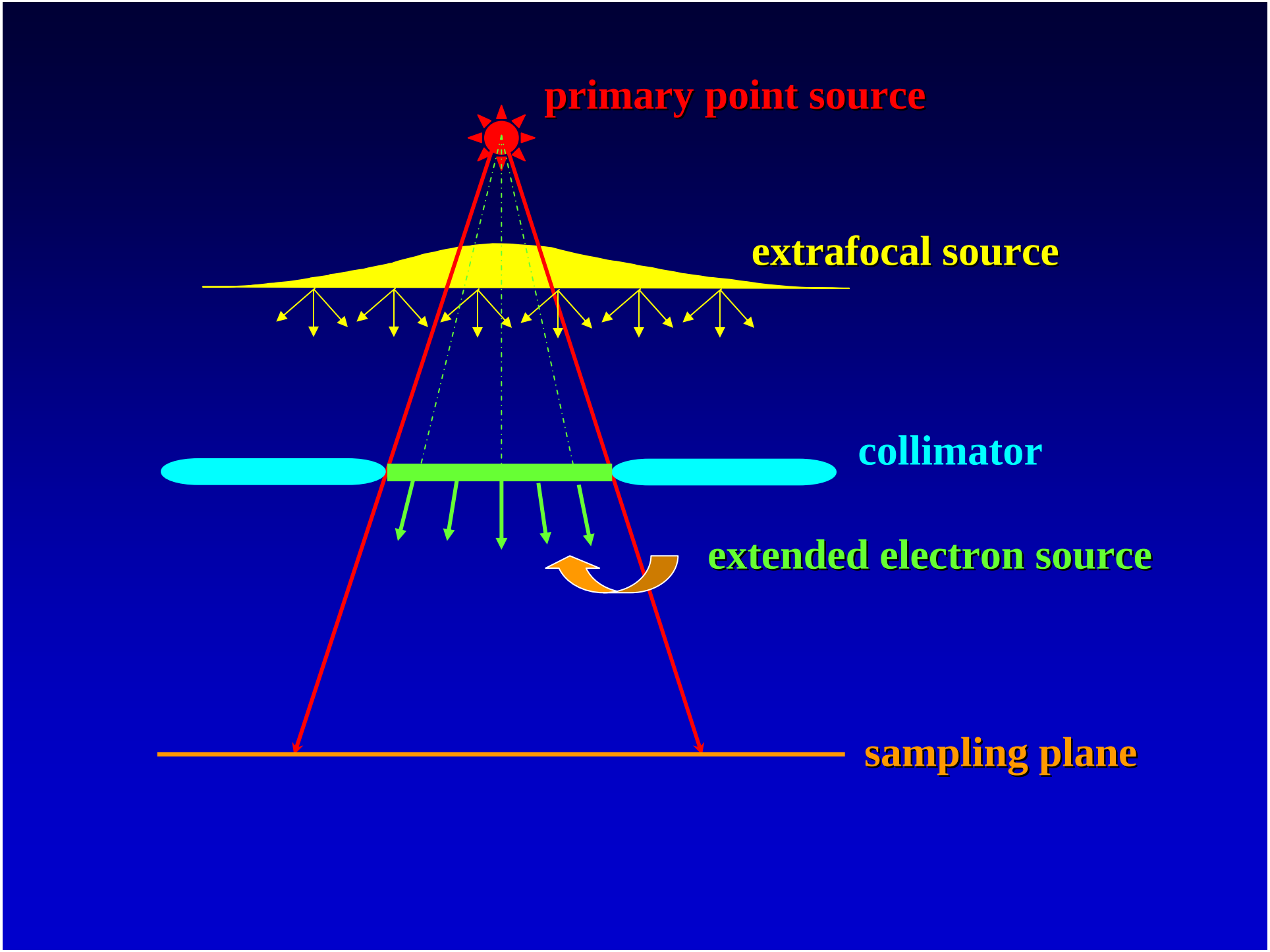
- Fluence dist. ensured by profile measurement
- Energy spectra ensured by depth dose measurement
- Angular dist. ensured by source geometry (model)
- Beam output ensured by direct measurement

Photon Beam Modeling and Commissioning

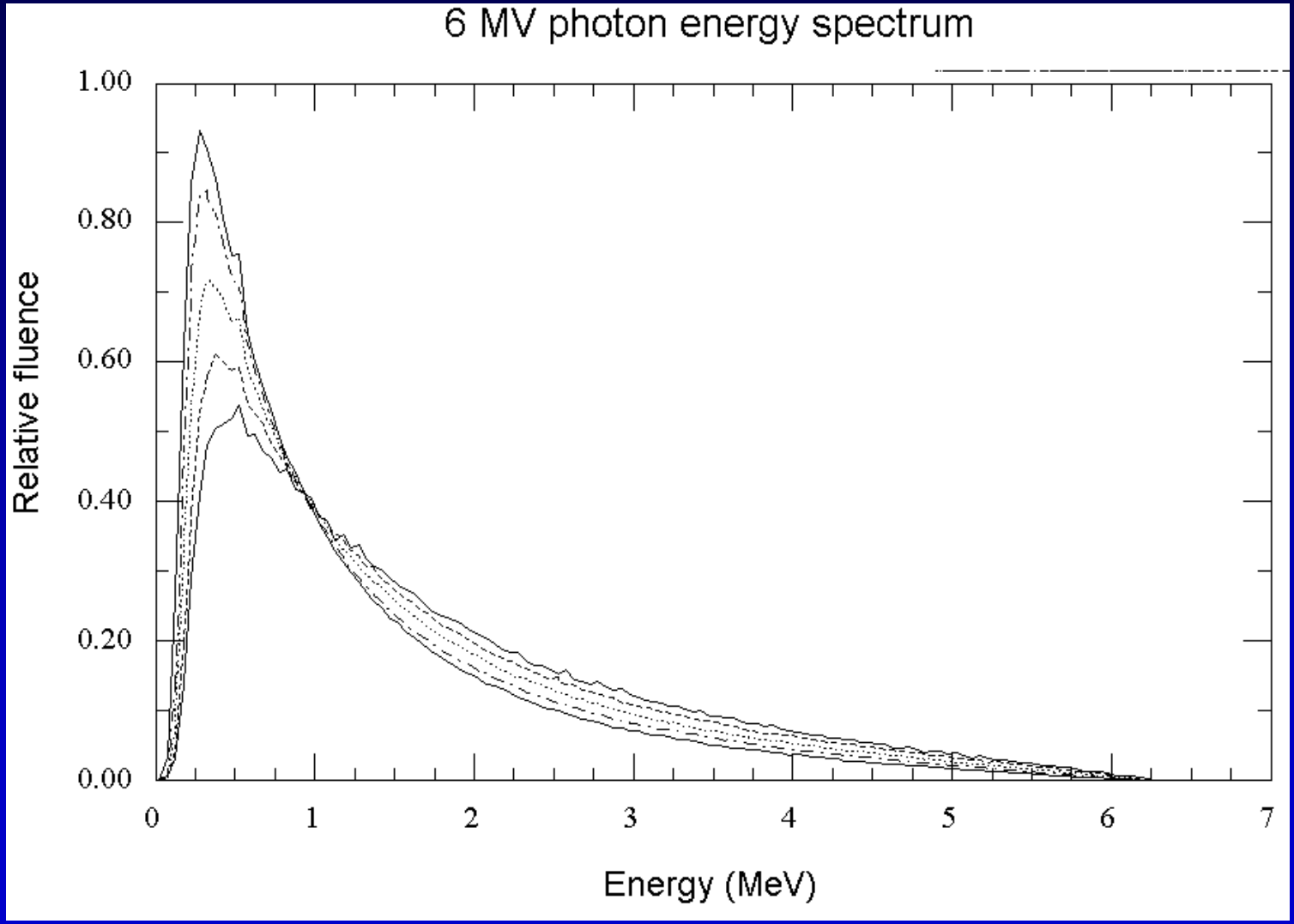
A Three-Source Model for Clinical Photon Beams

- Point/extended source for primary photons
- extrafocal source for scattered photons
- extended source for contaminant electrons

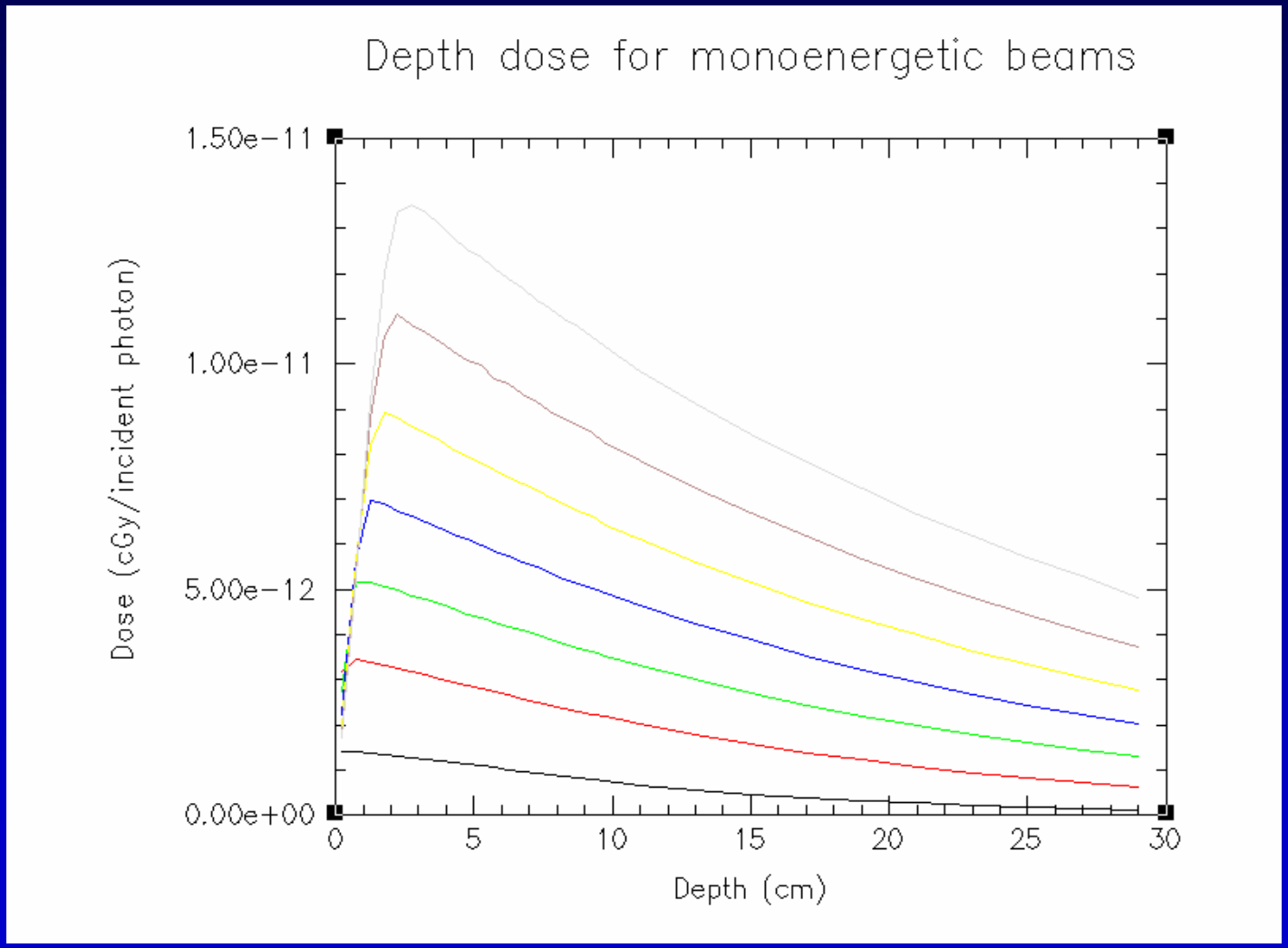
Jiang et al *Med. Phys.*(2001) 28: 55-66; Li et al (2002)

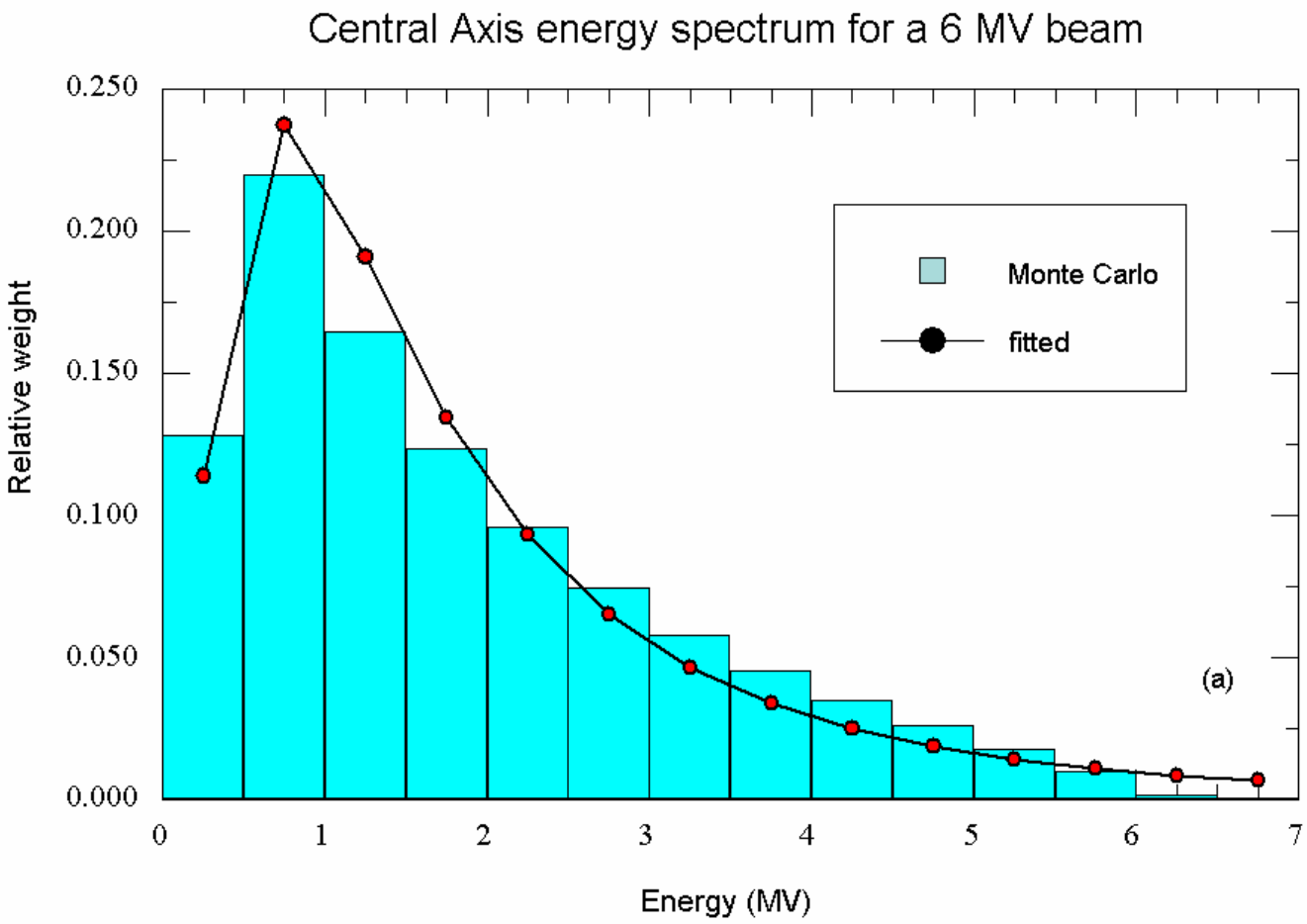

primary point source
extrafocal source
collimator
extended electron source
sampling plane

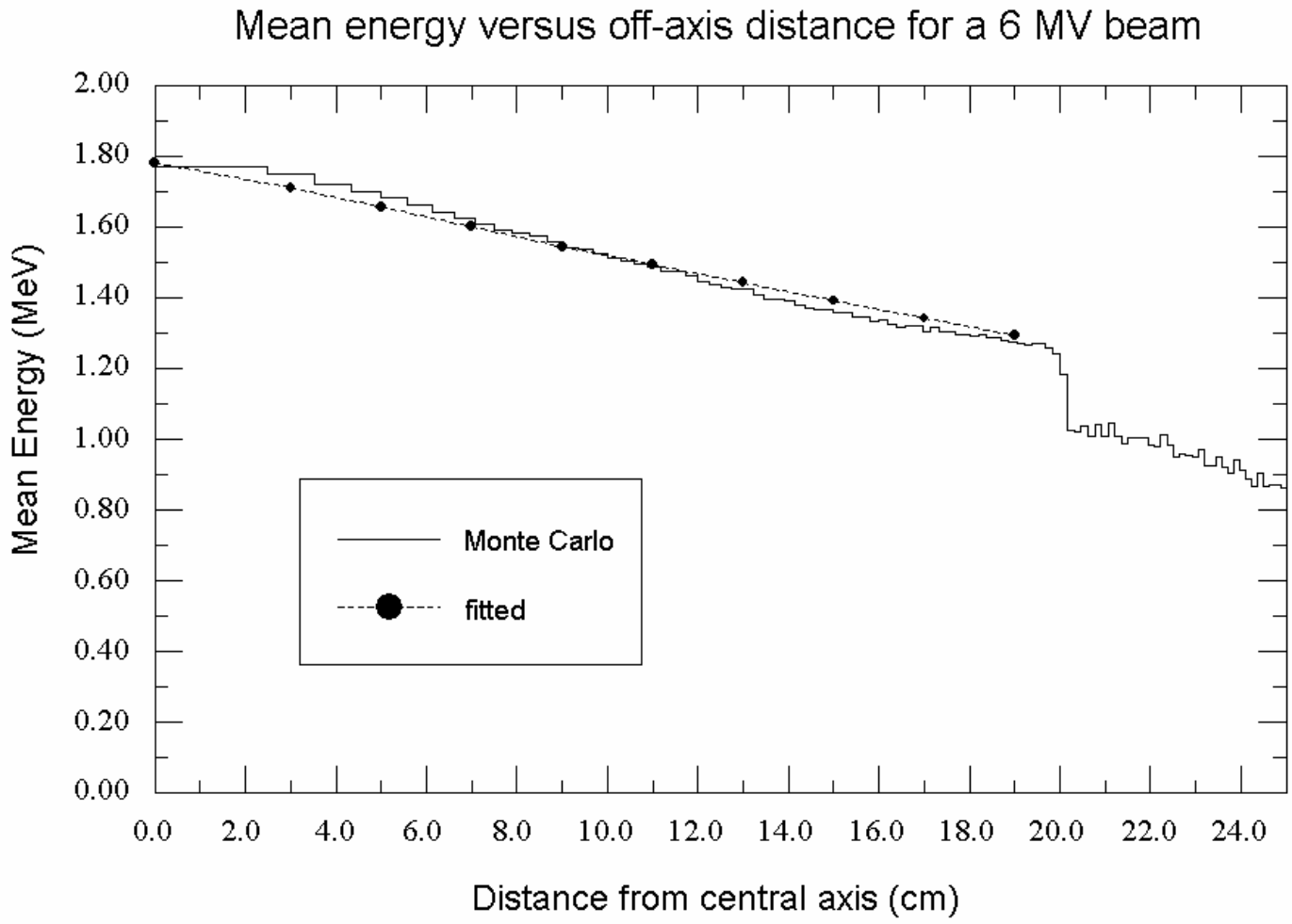
Photon energy spectra

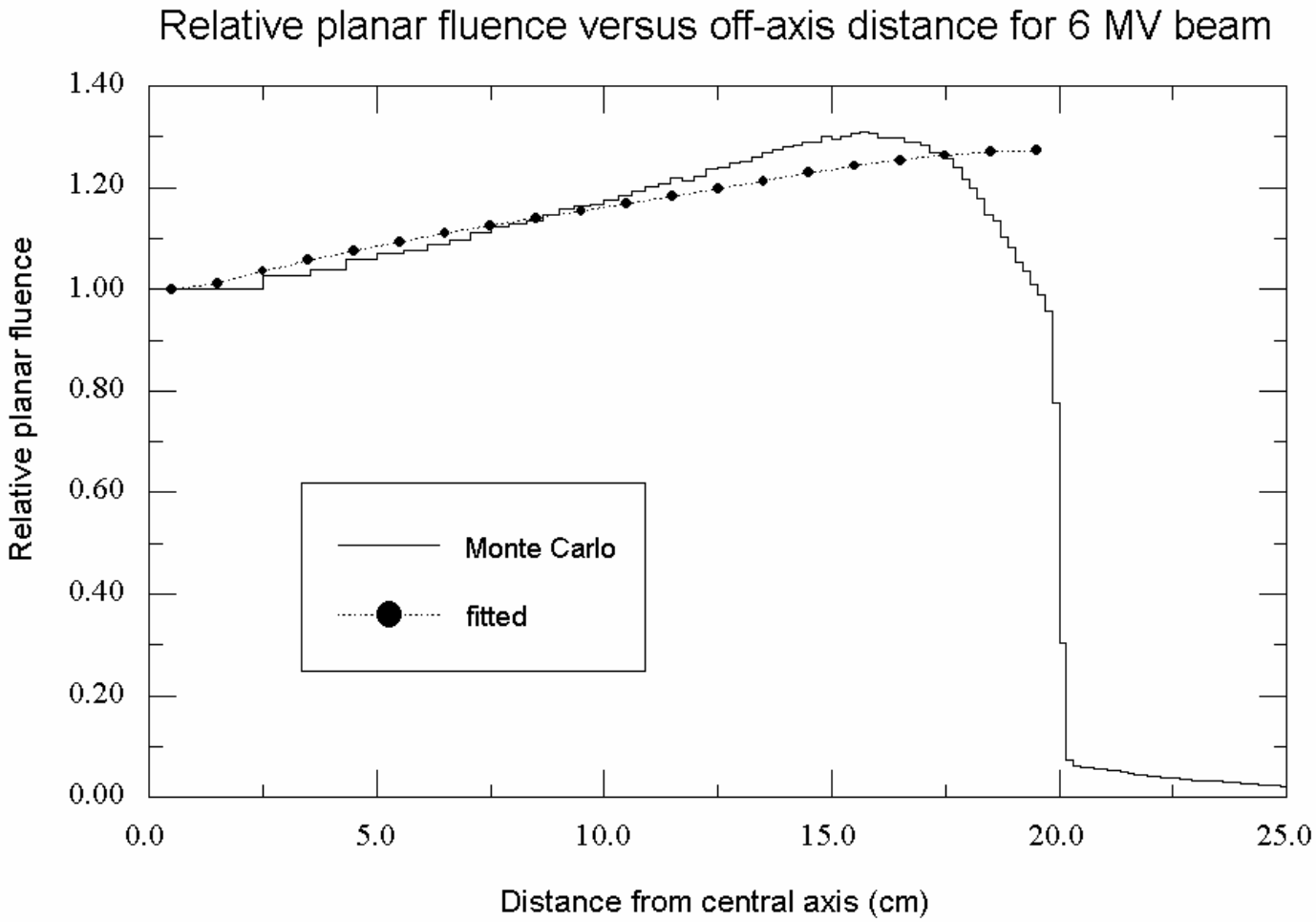


Pre-calculated Monoenergetic PDD



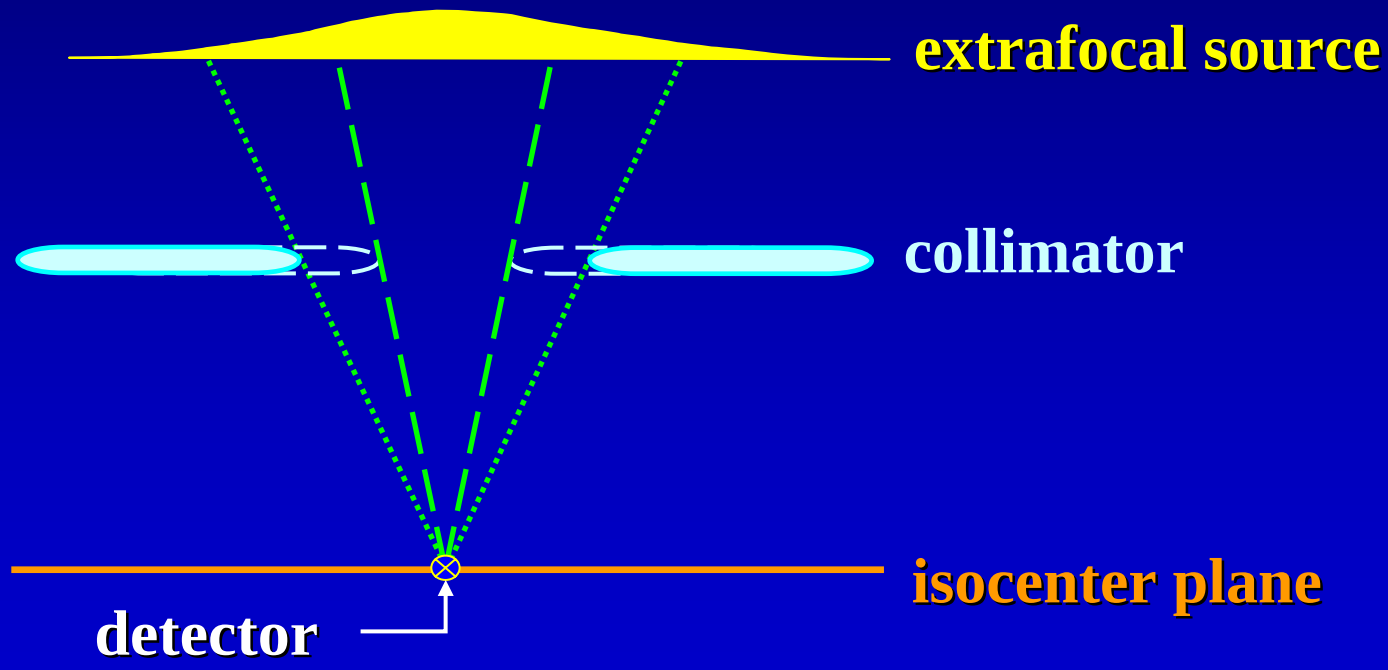

Central Axis energy spectrum for a 6 MV beam
Relative weight
0.250
0.200
0.150
0.100
0.050
0.000
0
1
2
3
4
5
6
7
Energy (MV)
Monte Carlo
fitted
(a)

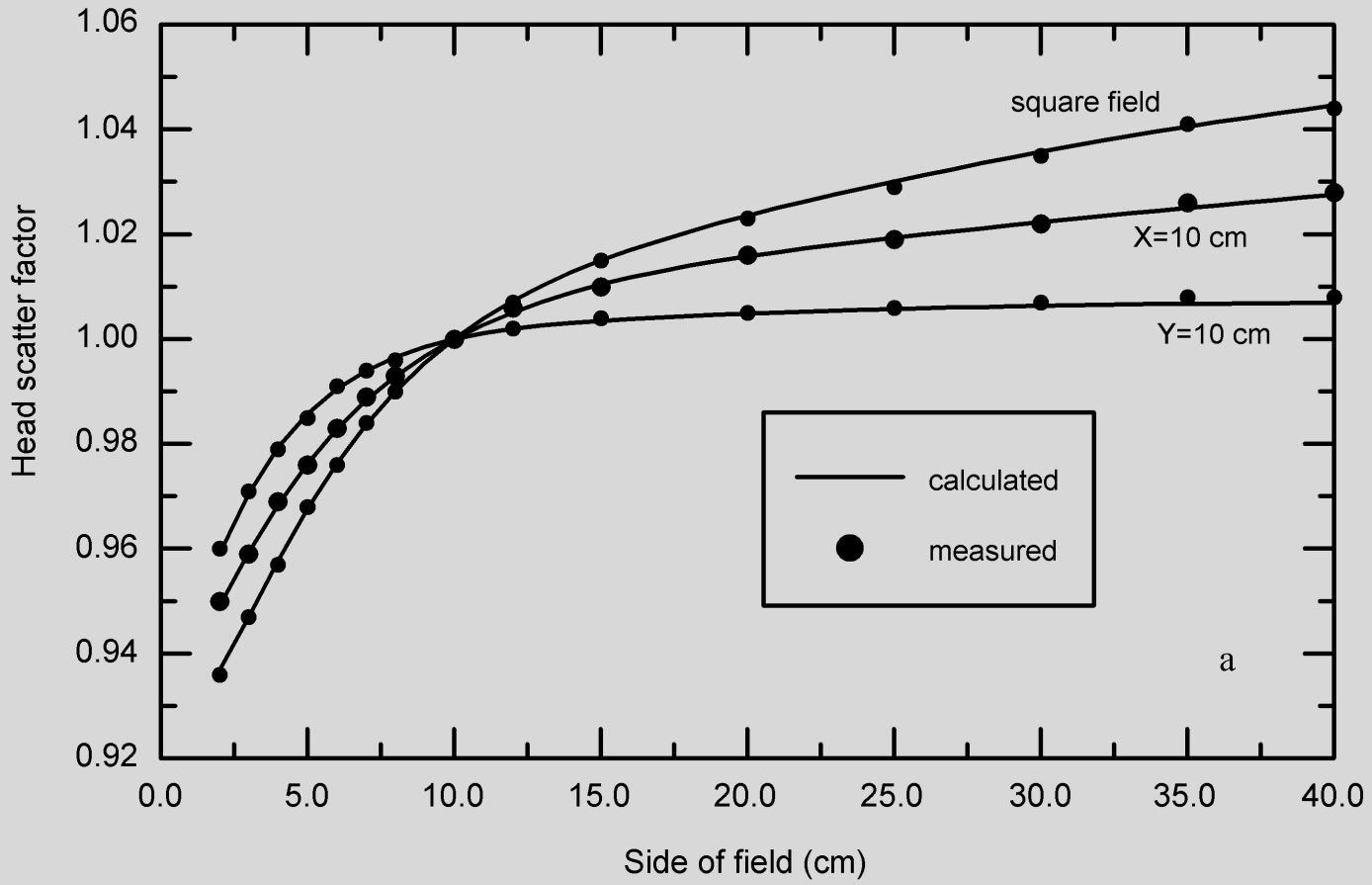

Mean energy versus off-axis distance for a 6 MV beam
Mean Energy (MeV)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
Distance from central axis (cm)
Monte Carlo
fitted

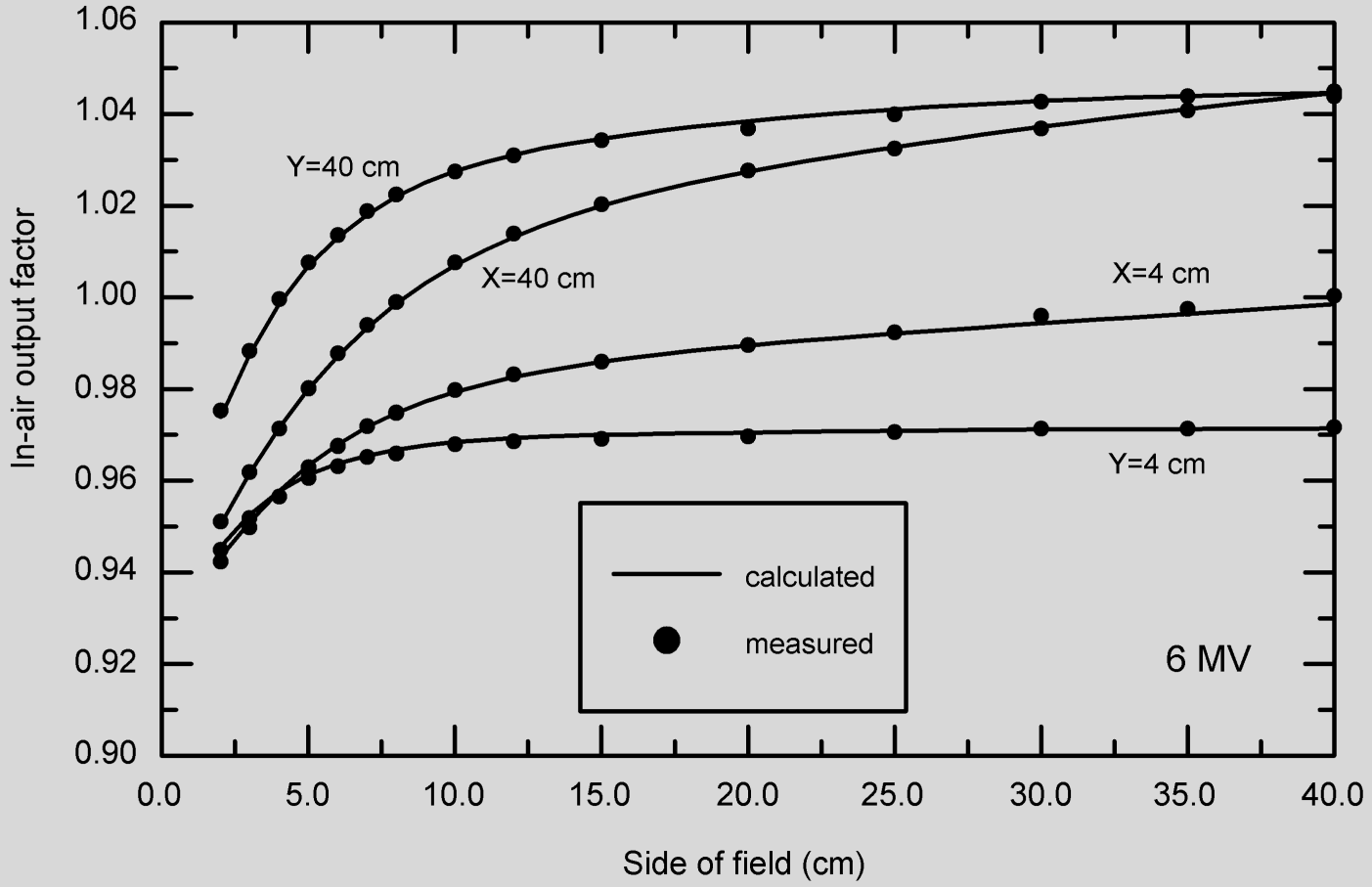

Relative planar fluence versus off-axis distance for 6 MV beam
Relative planar fluence
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.0
5.0
10.0
15.0
20.0
25.0
Distance from central axis (cm)
Monte Carlo
fitted

Assumptions for Extrafocal Source

- The source plane emits photons isotropically over an angle.




Head scatter factor
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Side of field (cm)
square field
X=10 cm
Y=10 cm
calculated
measured
a


1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
In-air output factor
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Side of field (cm)
Y=40 cm
X=40 cm
X=4 cm
Y=4 cm
calculated
measured
6 MV

Variation of head scatter factor due to monitor chamber backscatter

- Results of this model

  1.2% for 6 MV

  1.6% for 15 MV

- Measured results from Yu *et al*

  (*Phys. Med. Biol.* (1996) 41:1107-1117)

  1.2 ± 0.3% for 6 MV

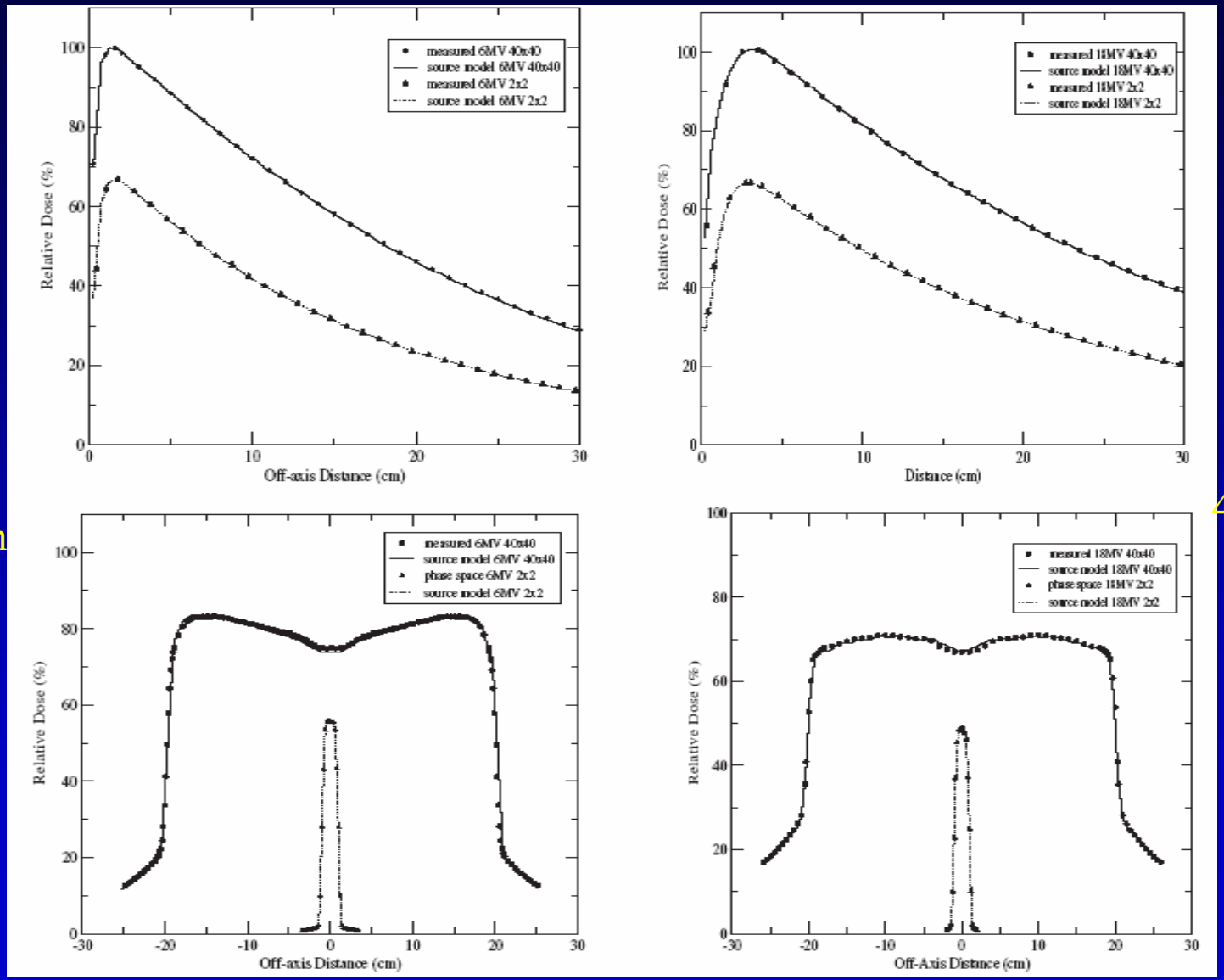
  1.8 ± 0.3% for 15 MV

Determination of Electron Energy Spectrum

- Calculate the CAX electron fluence as a function of field size using Fermi-Eyges theory
- Fit with the measured CAX electron surface dose
- Recent improvement for contaminant electrons by Yang et at (Phys Med Biol, 2004 49: 2657-73)

Measured vs MC Reconstructed Dose Distributions

6 MV
40cmx40cm



18 MV
40cmx40cm

Yang et al, *Phys Med Biol* (2004) 49: 2657-73

Summary

- An accurate source model can be built based on the simulated phase space data
- Measurement-based source modeling and beam commissioning is more suitable for widespread application
- The multiple source model has been proven to be accurate and practical for clinical implementation

References

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19. Yang et al, *Phys Med Biol* (2004) 49: 2657-73

Acknowledgments

The FCCC/Stanford Beam Characterization Team

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Jinsheng Li
Ajay Kapur
Grisel Mora
Omar Chibani
James Fan
Steve Jiang
Jun Deng
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Lihong Qin
Jie Yang