Source Modeling for Monte Carlo Treatment Planning

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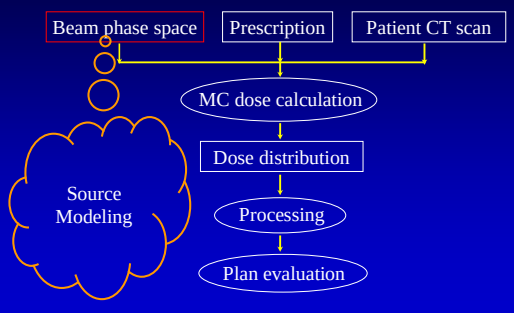
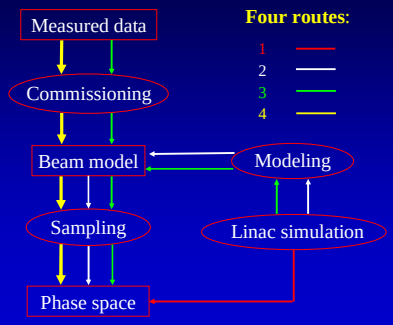
Outline

- 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



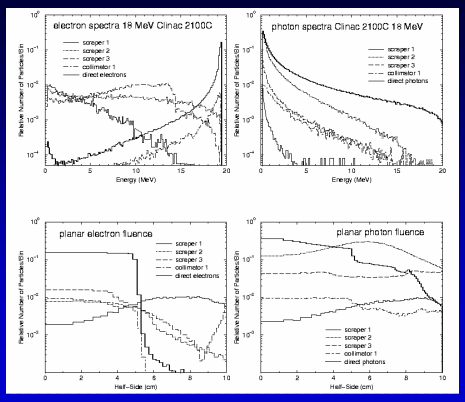
Beam Models vs Phase Space

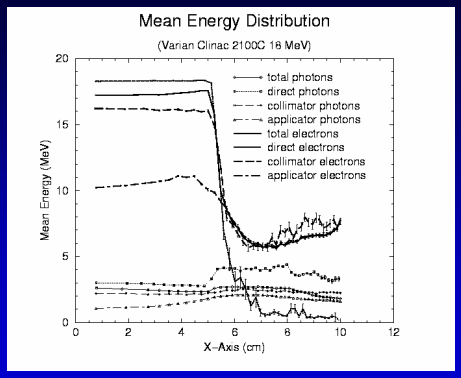
- **Beam models are based on good understanding of phase space representation and reconstruction**
- **Beam models can be more computationally efficient**
- **Beam models require less storage space**
- **Beam models are easier to commission and implement clinically**

A Multiple Source Model

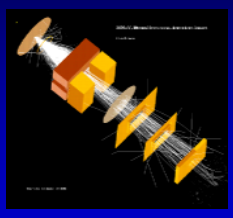
- Individual linac components are considered as sub-sources
- Each sub-source has its own energy and fluence distributions
- Angular correlation is retained

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





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*.

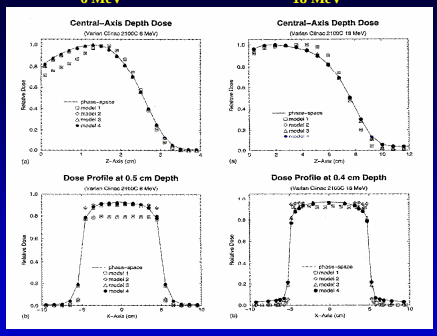
How many sources are enough?

- 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

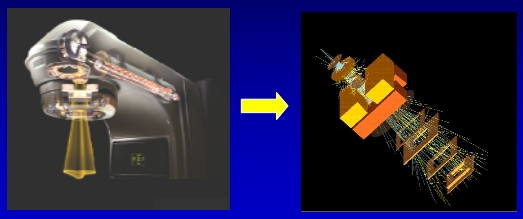
CM Ma, BA Faddegon, DWO Rogers and TR Mackie 1997 *Med. Phys.* 47(3):401-416

6 MeV **18 MeV**

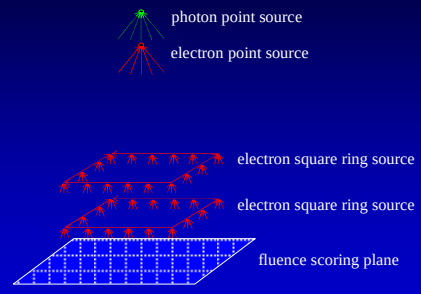


A point source + spectrum + profile ⇒ 2-5% accuracy

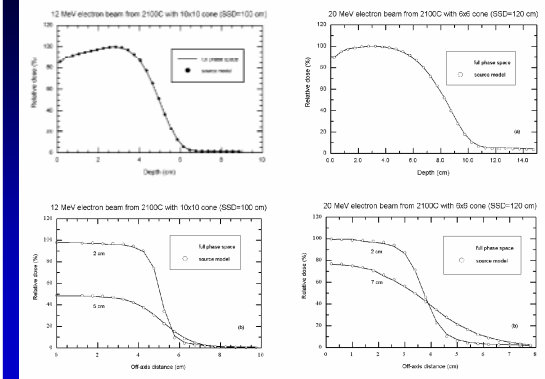
Electron Beam Modeling



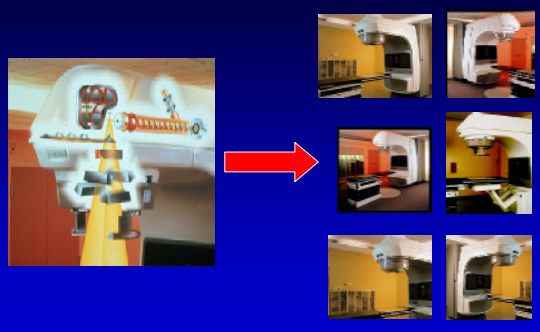
A four-source model for Varian 2100C



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



Linacs of the Same Model



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

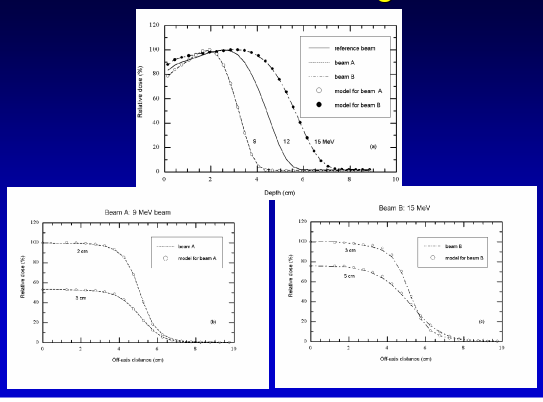
A test of the commissioning approach

- Reference beam: Ein=12.0 MeV

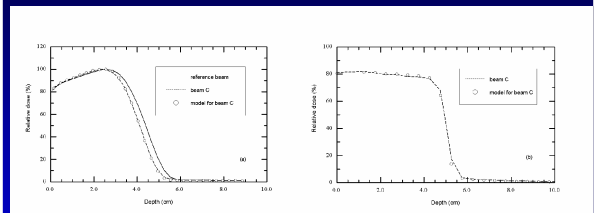
to match

- 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

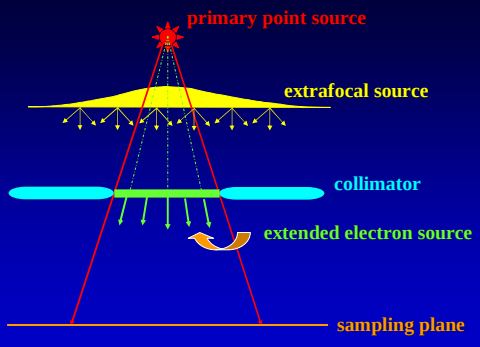
- Fluence dist. ensured by profile measurement
- Energy spectra ensured by depth dose measurement
- Angular dist. ensured by source geometry (model)
- Beam output ensured by direct measurement

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



Point/extended Source for Primary Photons

- position !
  - located at the target
- relative weight !
  - unity
- energy spectrum ?
  - off-axis softening effect
- planar fluence ?
  - horn effect

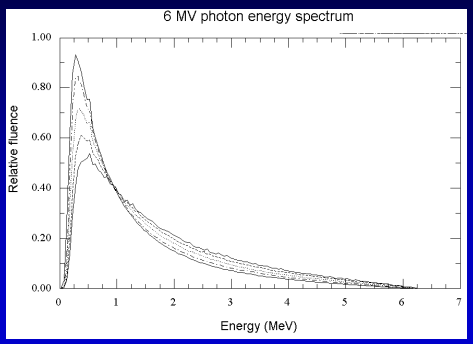
Extrafocal Source for Scattered Photons

- position !
  - located at the level of flattening filter
- relative weight ?
  - normalized to the point source
- source intensity distribution ?
- energy spectrum ?

Extended Source for Electrons

- position !
  - located at the level of photon jaws
- relative weight ?
  - normalize to the point source
- source intensity distribution !
  - uniform
- energy spectrum ?

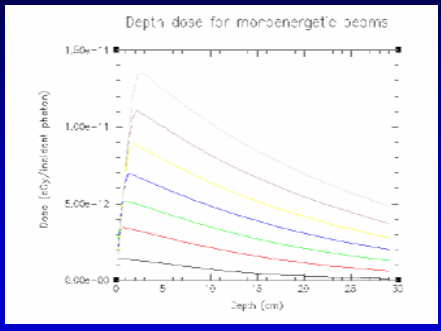
Photon energy spectra

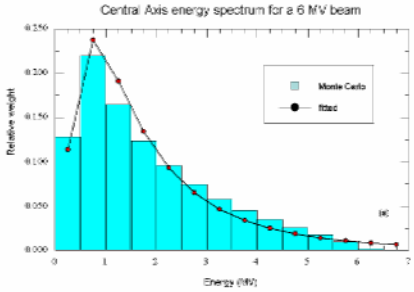


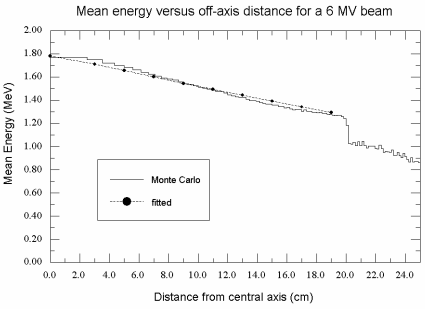
Determination of Photon Energy Spectra

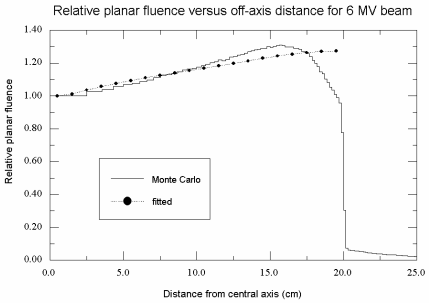
- CAX spectrum
  - fit measured CAX PDD
- off-axis spectra (r < 10 cm)
  - fit off-axis PDD every 1 cm interval
- off-axis spectra (r > 10 cm)
  - extrapolation

Pre-calculated Monoenergetic PDD



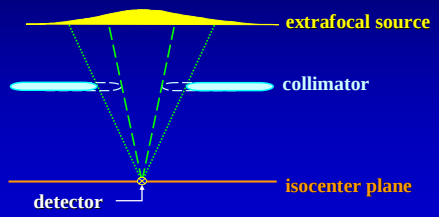


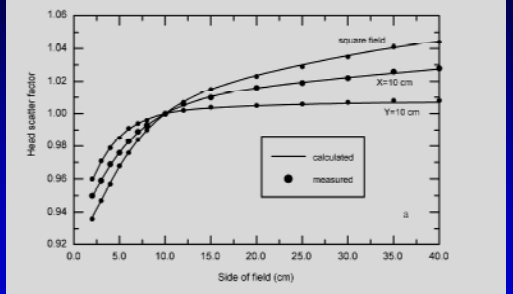




Assumptions for Extrafocal Source

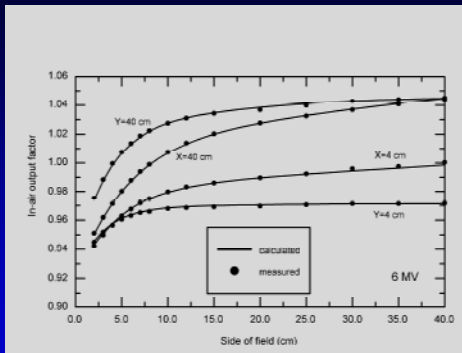
- The source plane emits photons isotropically over an angle.

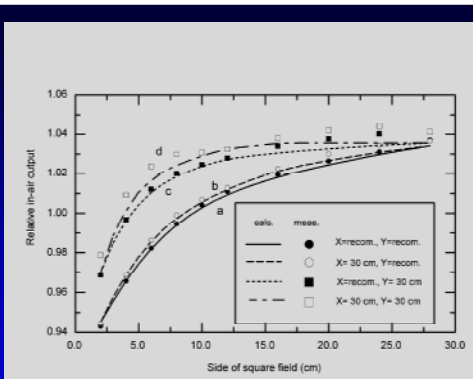




Variation of head scatter factor due to monitor chamber backscatter

- Results of this model
  - **1.2%** for 6 MV
  - **1.6%** for 15 MV
- Measured results from Yu *et al*
  (*Phys. Med. Biol.* 41(1996)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)

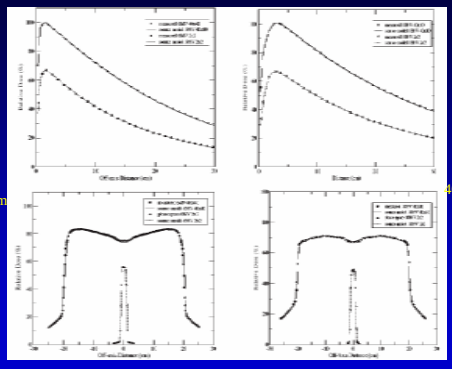
Reconstruction of Phase Space from the Source Model

Determine each particle's ...

- incident position
- incident direction
- incident energy
- weight

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

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The FCCC/Stanford Beam Characterization Team

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