BEAMnrc: a code to simulate radiotherapy external beam sources

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Disclosure

I used to work for, and still receive some royalty income from the National Research Council of Canada which has licensing agreements re Monte Carlo software with:

Elekta Philips/ADAC NAS/NOMOS
Nucletron Varian

The following companies have provided support for my group at Carleton University:

Nucletron Canada TomoTherapy Inc Philips/ADAC
MDS Nordion Varian

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BEAM code

- general purpose code to simulate radiotherapy beams
  - accelerators -electrons & photons
    - ^{60}Co units
    - x-ray units

- originally part of the OMEGA project done in collaboration with Rock Mackie's group in Madison (1990-1996)

- **O**ttawa **M**adison **E**lectron **G**amma **A**lgorithm

- many grad students, RAs and TOs involved

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BEAM developers

Dave Rogers
Iwan Kawrakow
Bruce Faddegon
Geoff Zhang
Michel Proulx
Joanne Treurniet
Blake Walters
Charlie Ma
George Ding
Jiansu Wei
Daryoush Sheikh-Bagheri

EGS4: Ralph Nelson and Alex Bielajew

EGSnrc: Iwan Kawrakow

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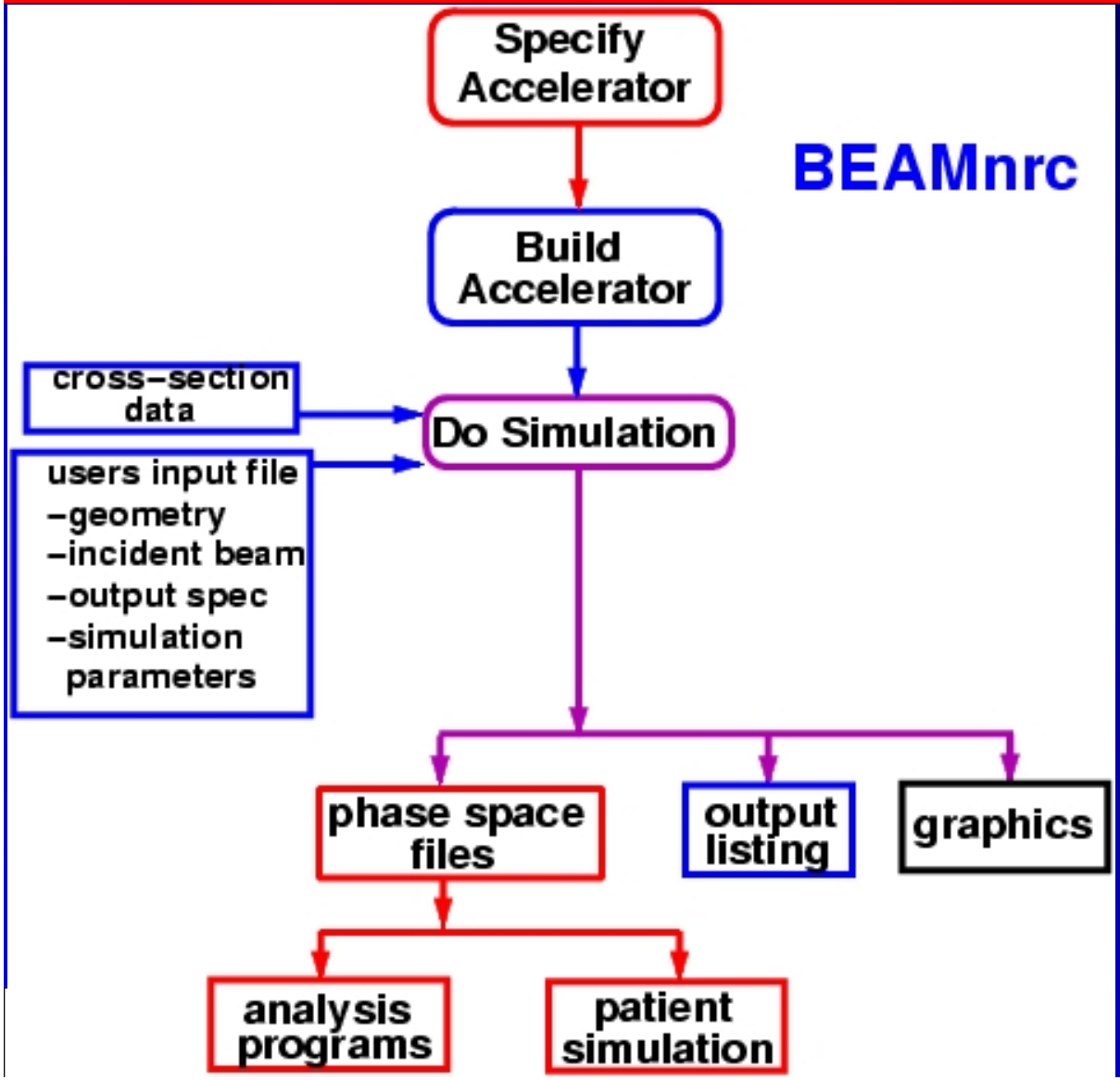
BEAM design features

- **C**omponent **M**odules (CMs)
  - between parallel planes
  - can combine in arbitrary order
  - builds in flexibility and extensibility
- Not restricted to cylindrical symmetry (all prior models had been cylindrical)
- variance reduction built in for accelerator modelling
- detailed testing
- expert user friendly (only need be expert to use it well)

Flow of the process

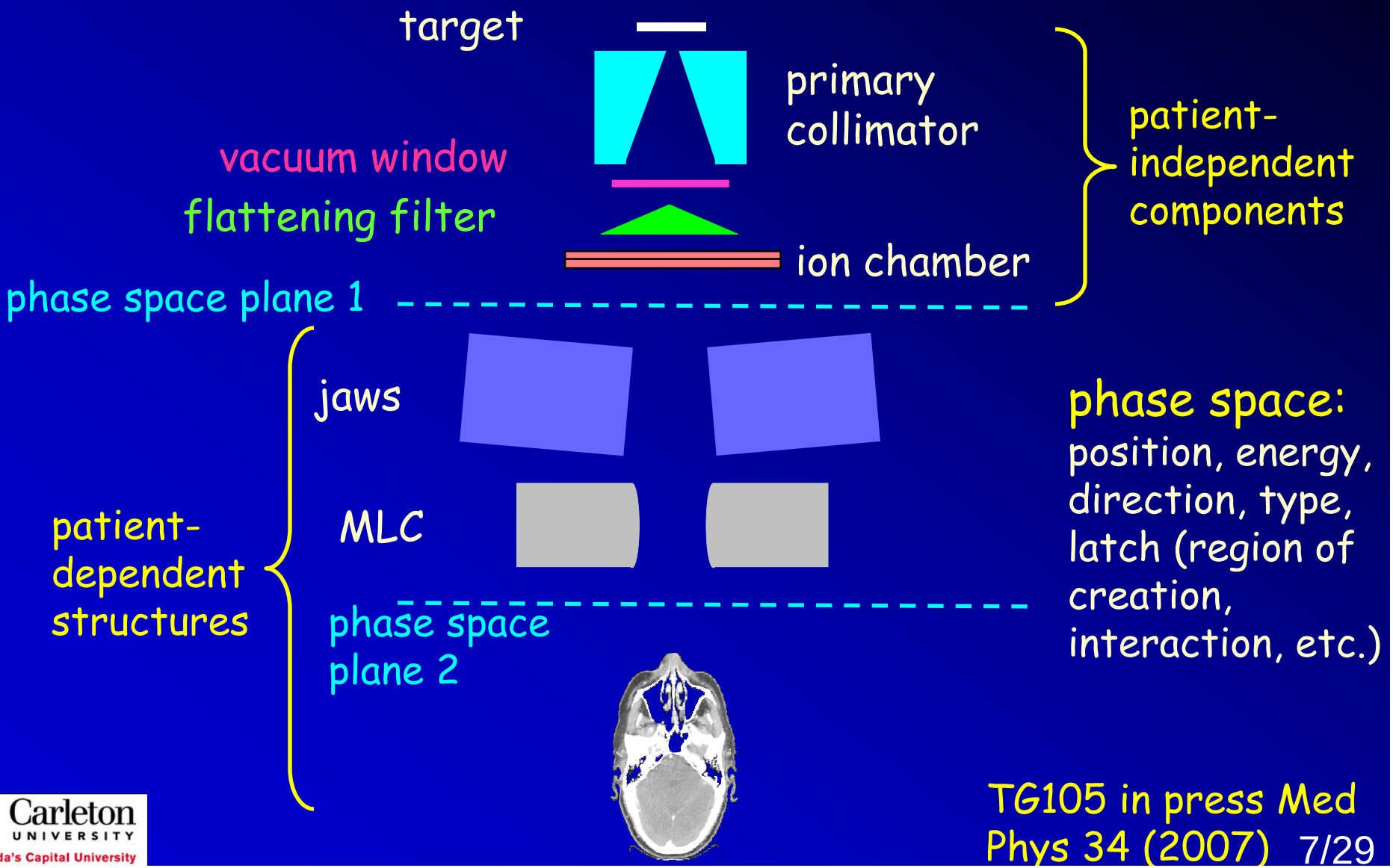


defines a class of accelerators
-ordered list of CMs

pulls together source code & compiles it

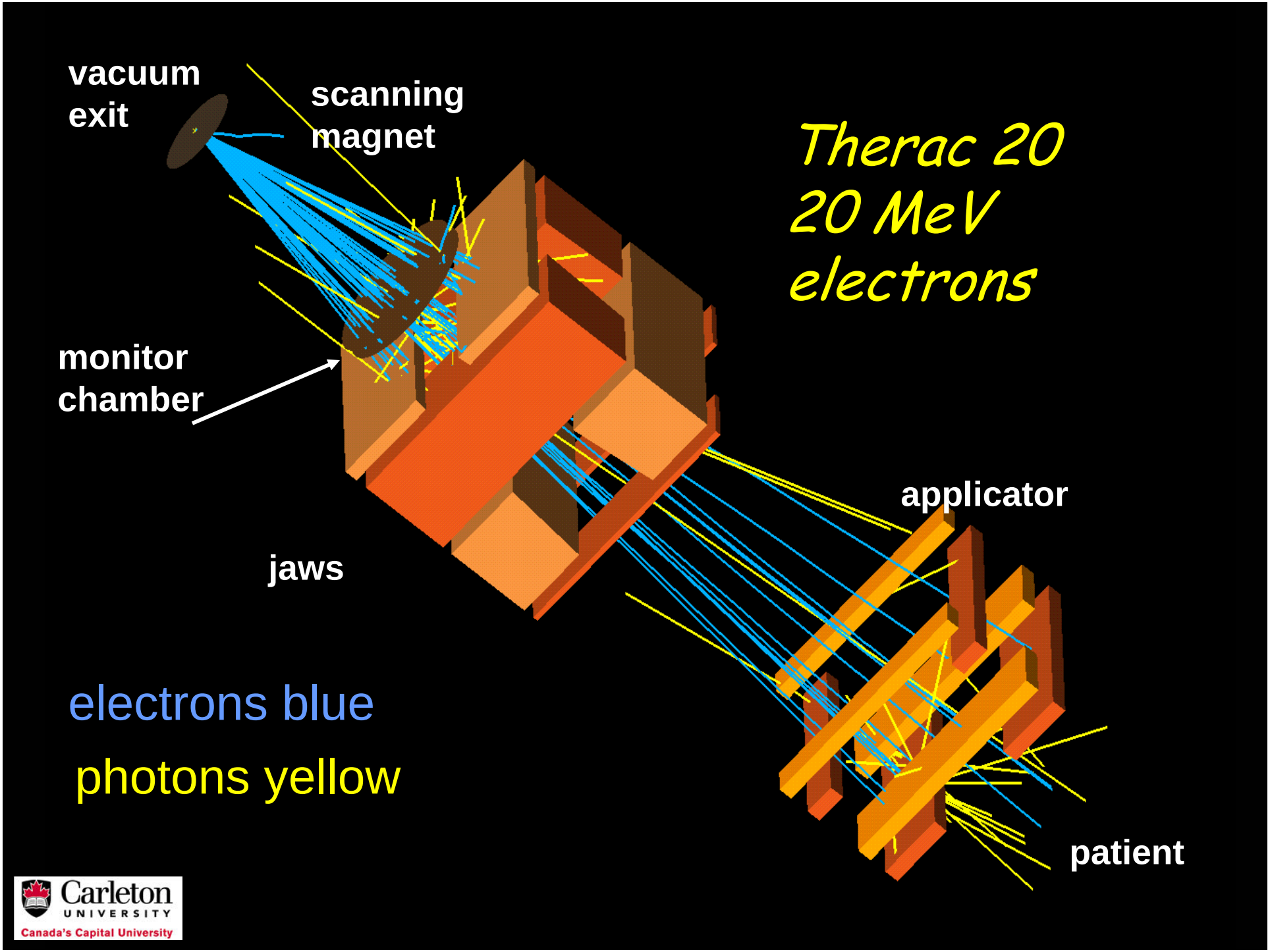
input file defines specifics of one accelerator & this run's parameters

Overview of the entire process



IAEA recommended phase space variables (Capote et al. 2006).

Variable	Meaning	Type of variable returned
X	Position in X direction in cm	Real*4
Y	Position in Y direction in cm	Real*4
Z	Position in Z direction in cm	Real*4
U	Direction cosine along X	Real*4
V	Direction cosine along Y	Real*4
E	Kinetic energy in MeV	Real*4
Statistical_ weight	Particle statistical weight	Real*4
Particle_type	Type of the particle	Integer*2
Sign_of_W	Sign of W (direction cosine in Z)	Logical*1
Is_new_history	Signifies if particle belongs to new history	Logical*1
Integer_extra	Extra storage space for variables (e.g., EGS LATCH, incremental history number, PENELOPE ILB, etc.)	n*(Integer*4) ($n \geq 0$)
Float_extra	Extra storage space for variables (e.g., EGS ZLAST)	m*(Real*4) ($m \geq 0$)


vacuum exit
scanning magnet
Therac 20
20 MeV
electrons
monitor chamber
applicator
jaws
electrons blue
photons yellow
patient
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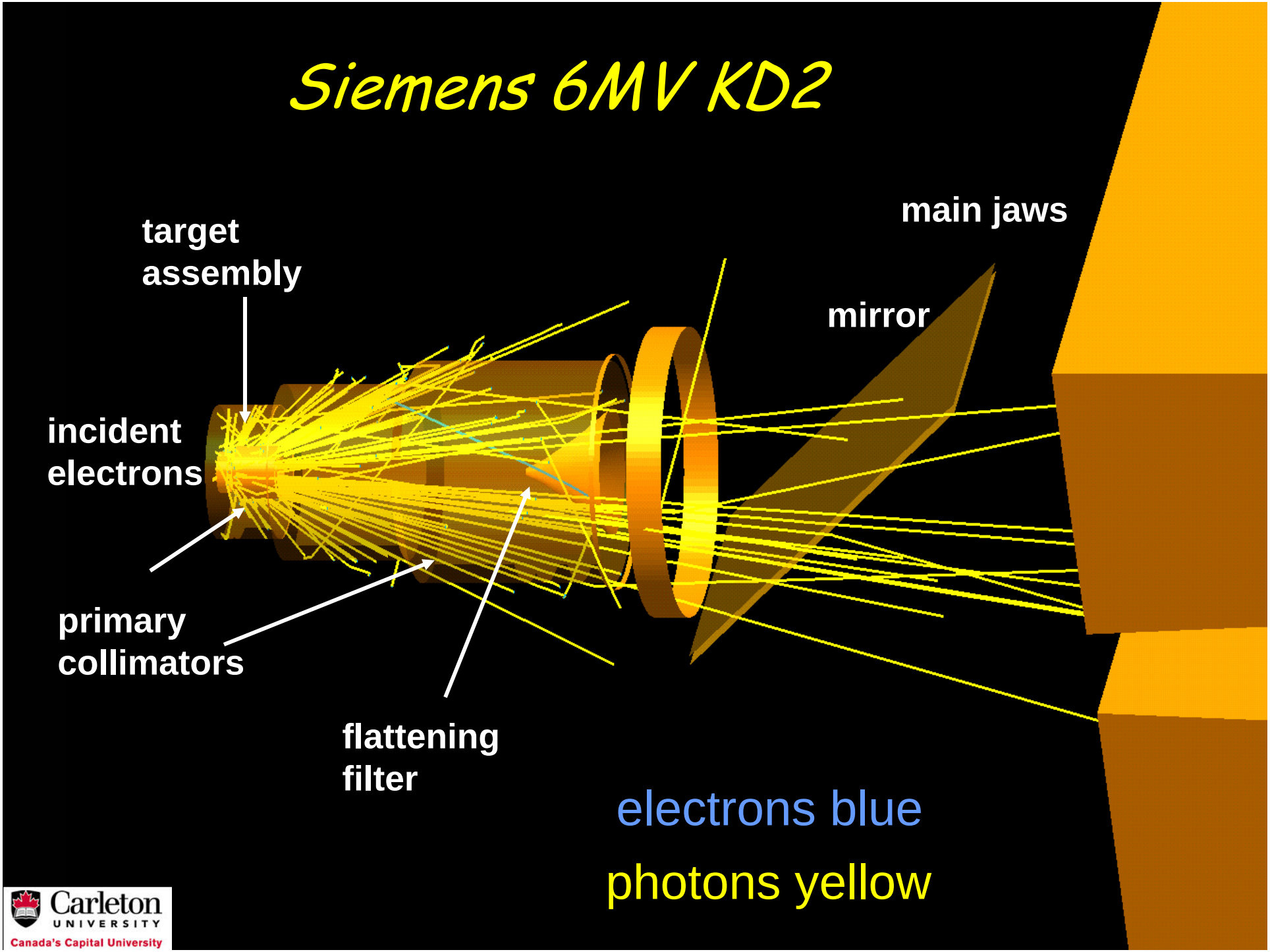
Siemens 6MV KD2



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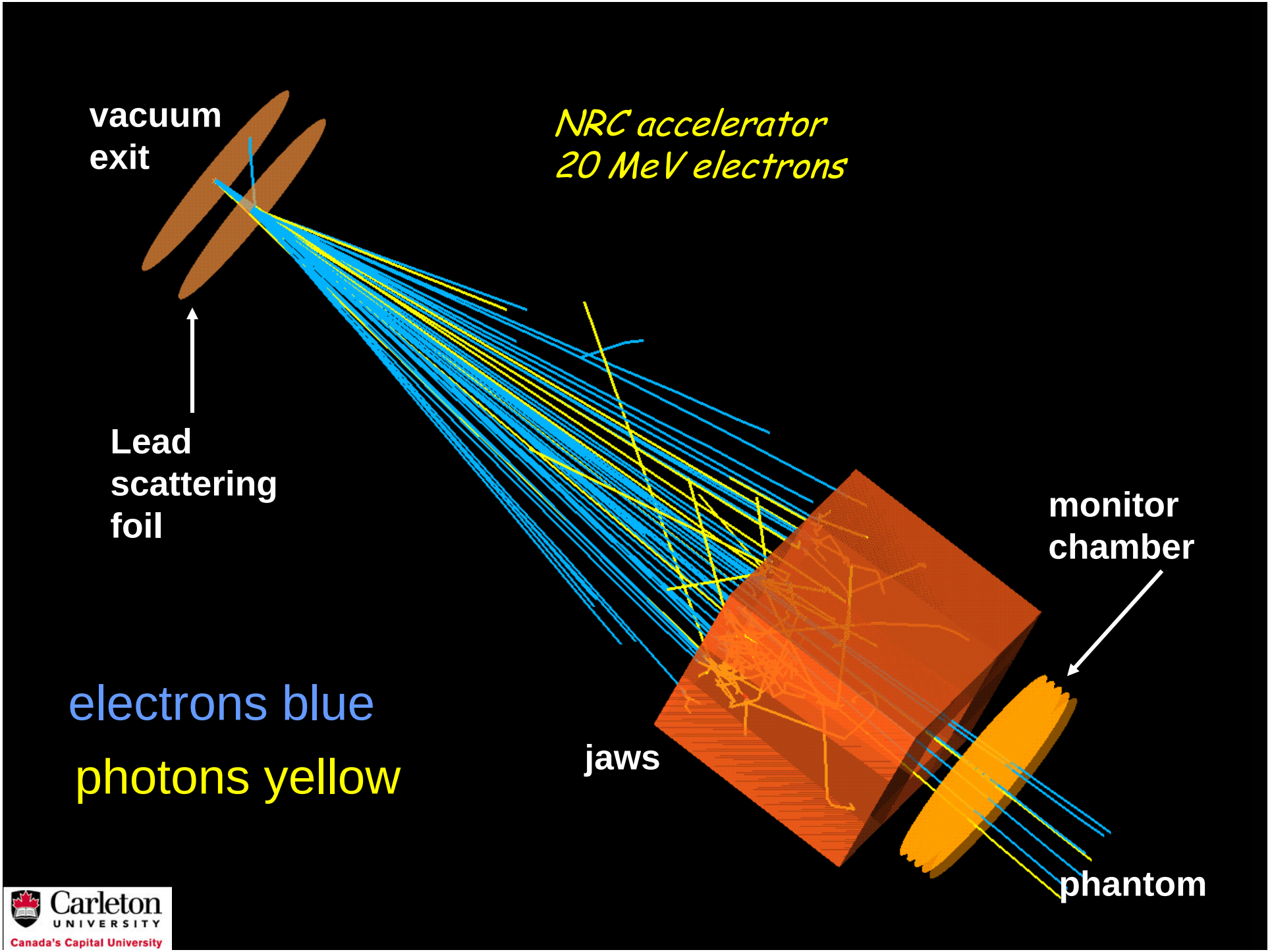

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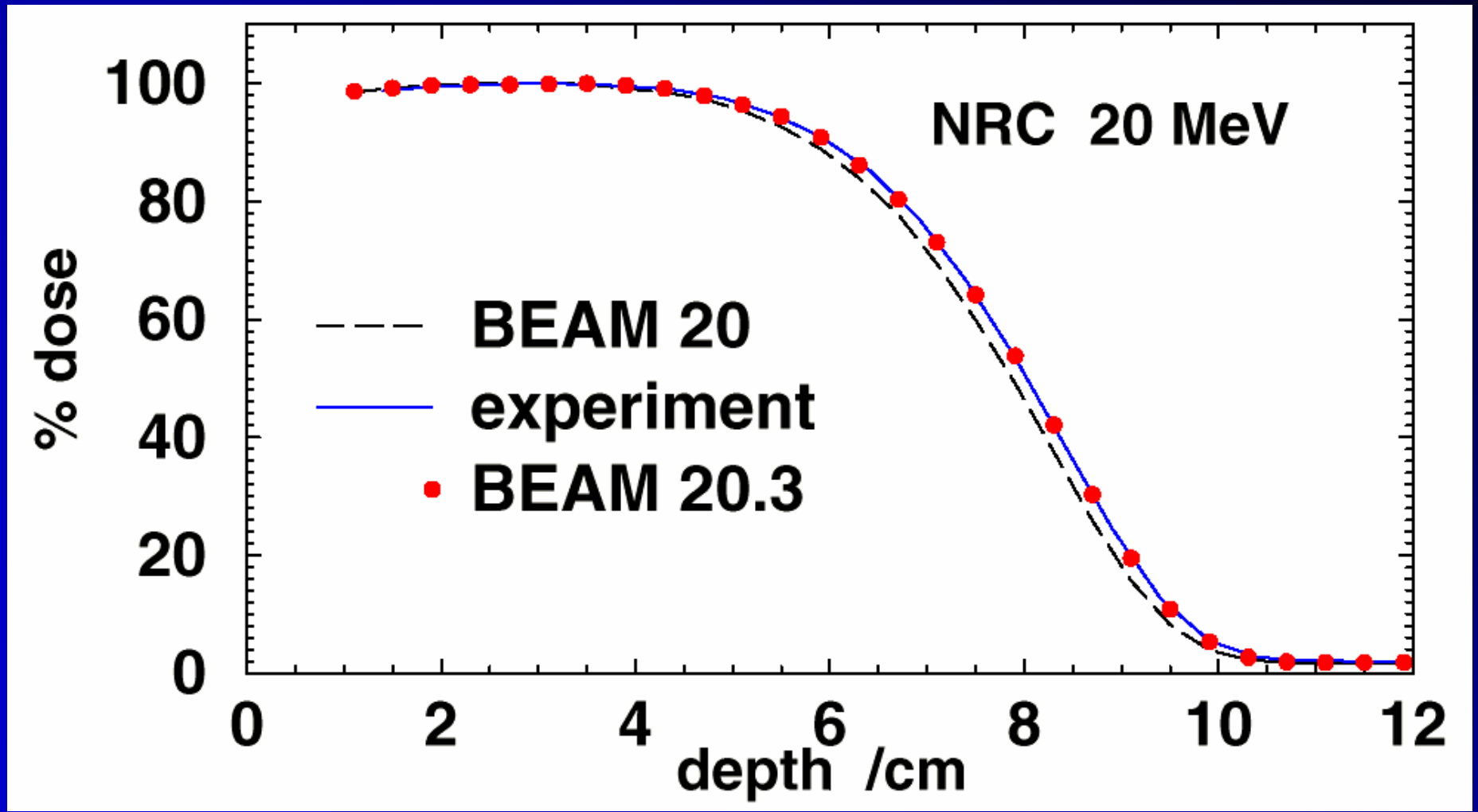
20 MeV NRC depth-dose



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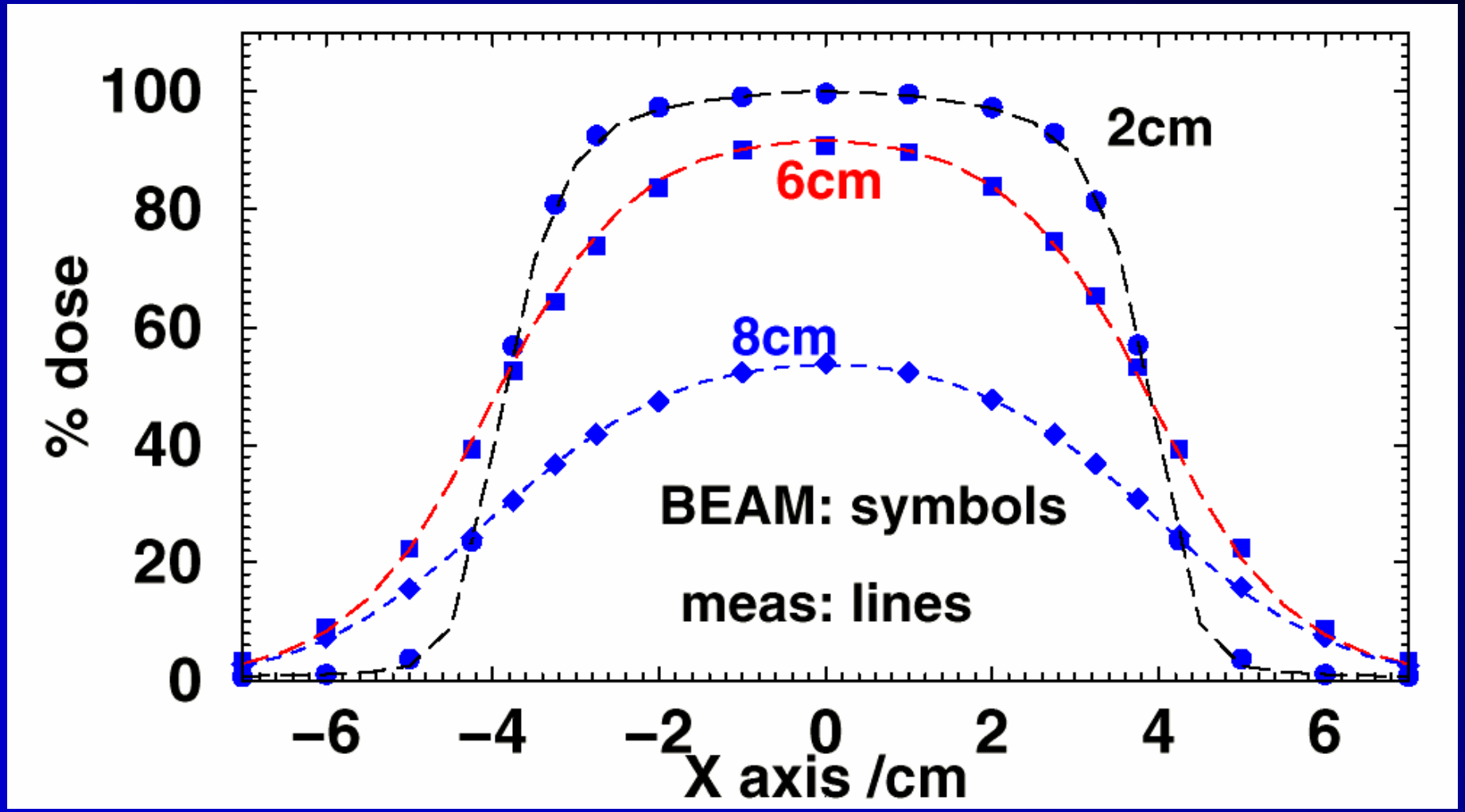
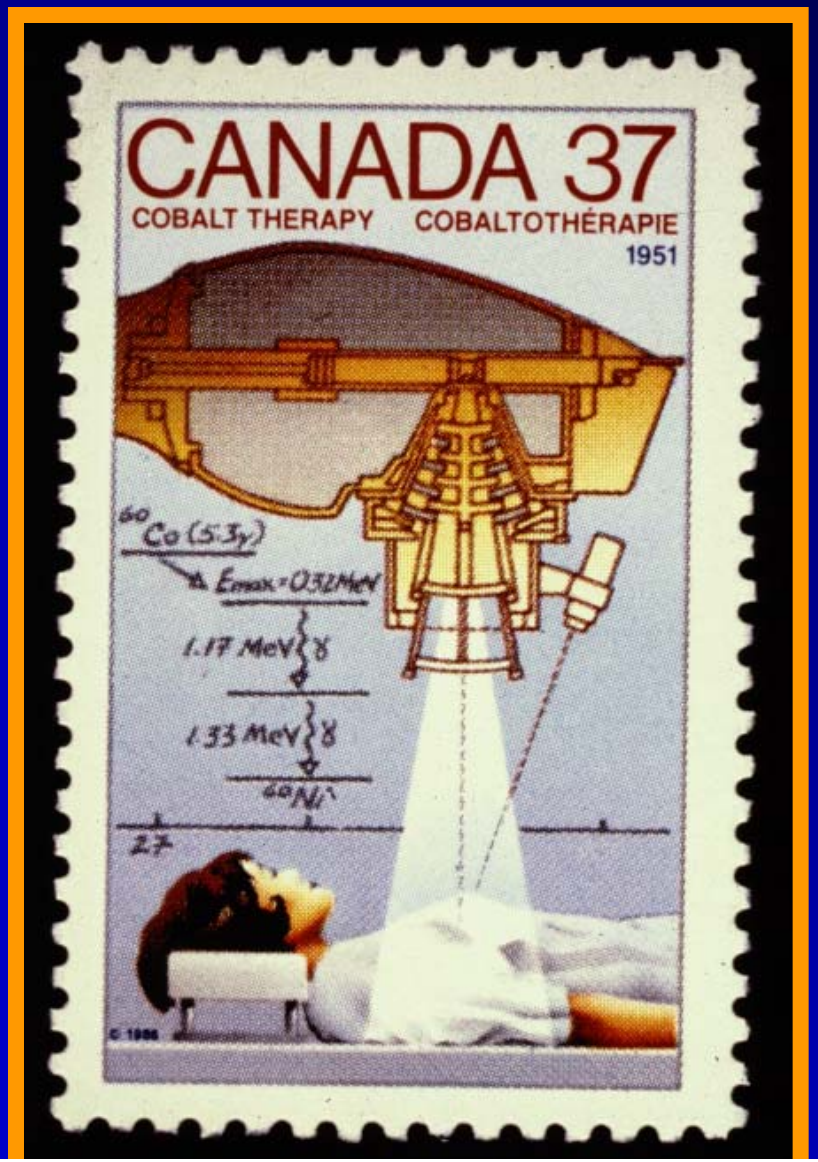
BEAM paper Med Phys 22(1995) 503-524

20 MeV NRC radial profile



BEAM paper Med Phys 22(1995) 503-524

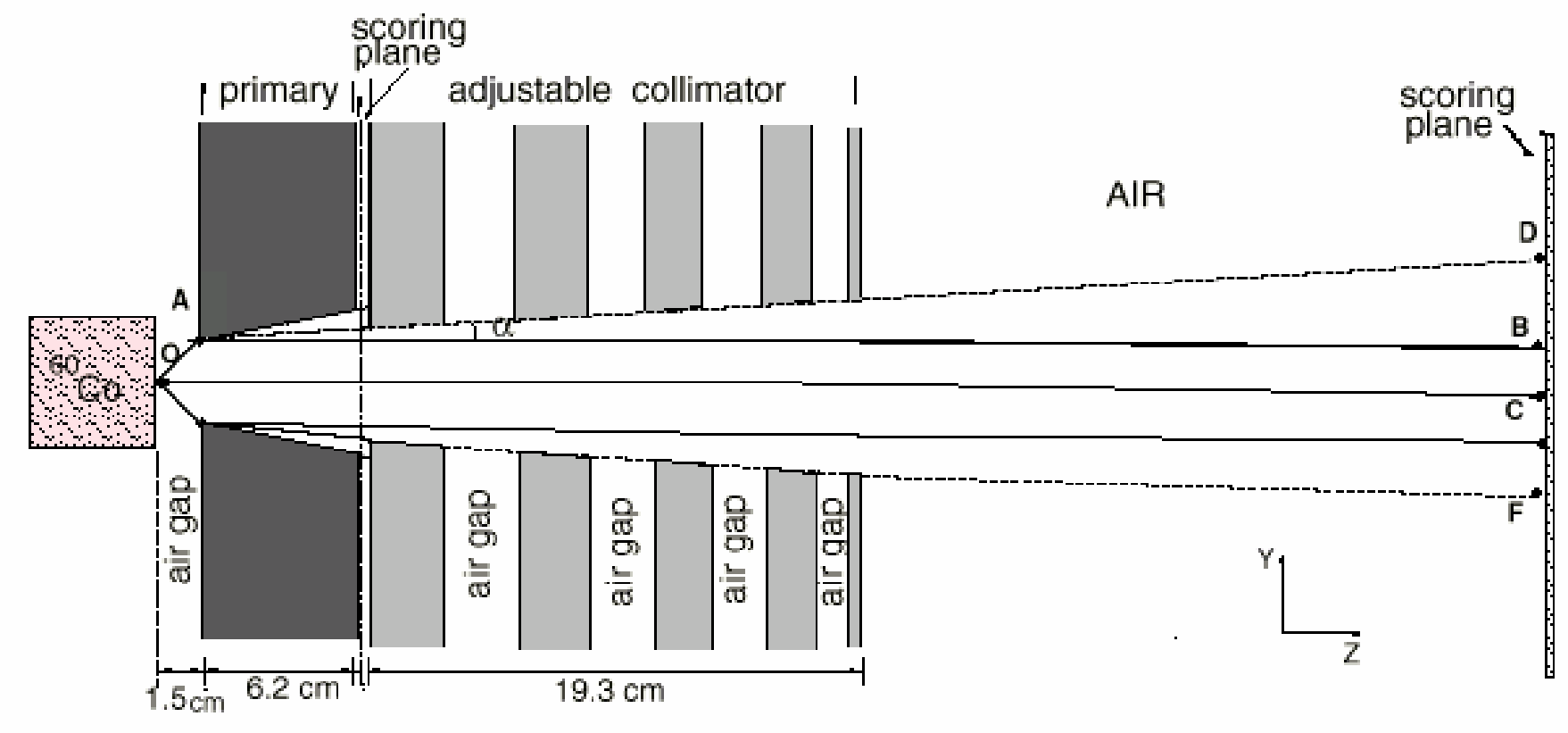
^{60}Co therapy unit



Issued
June 17,
1988

Thanks to
Jerry Battista

Simulating an Eldorado6



Mora et al Med Phys 26(1999) 2494

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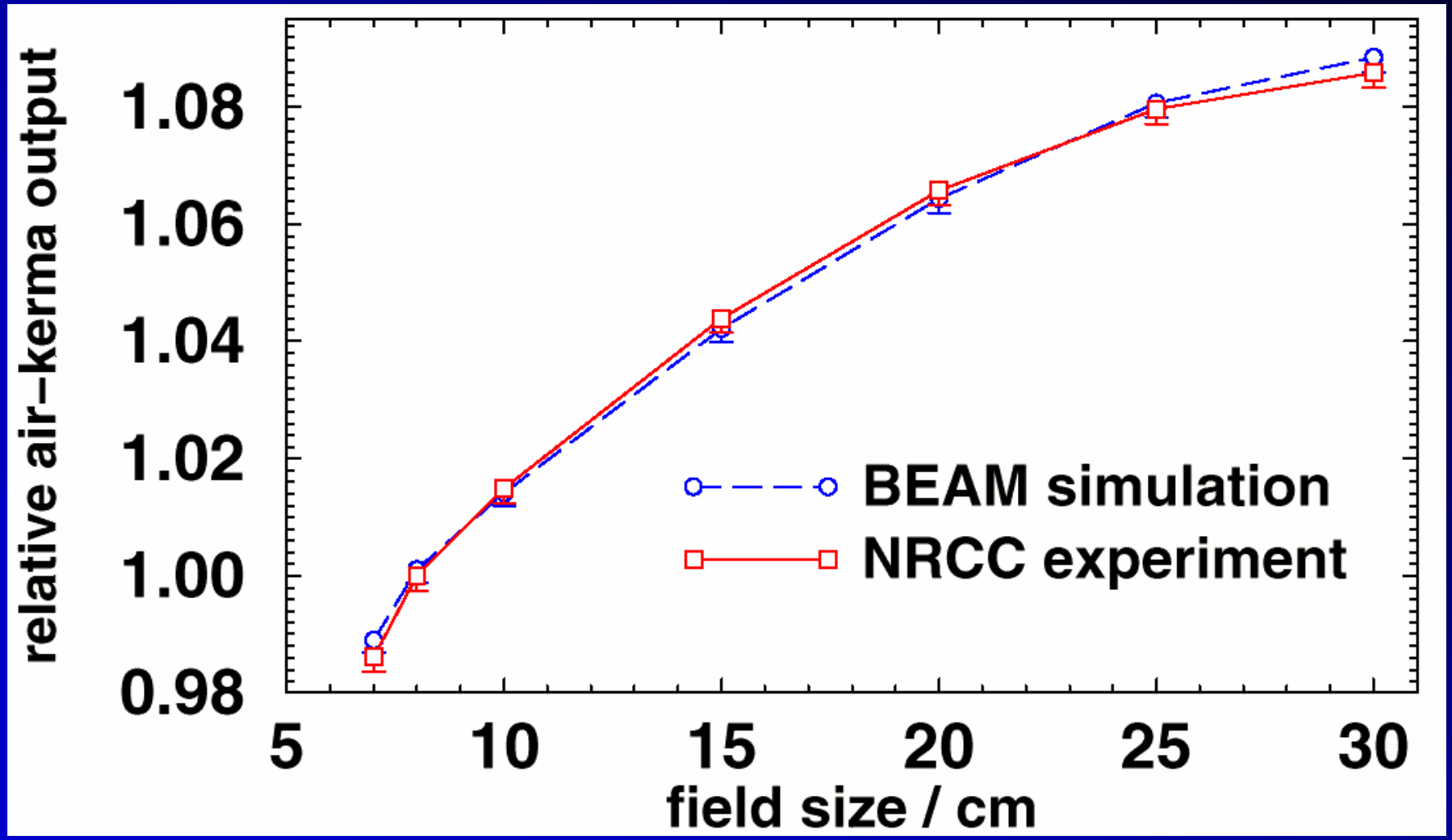
Output variation vs expt

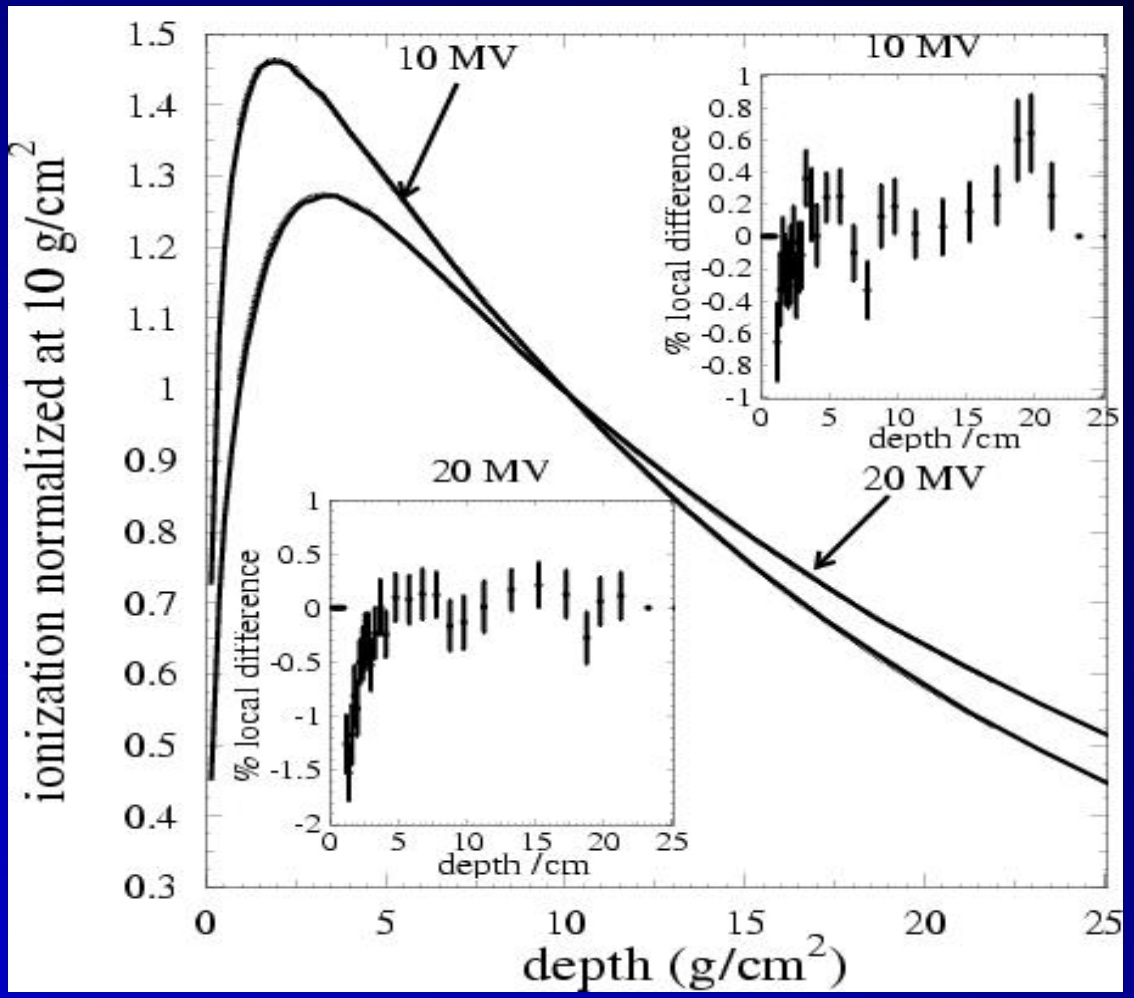


Mora et al Med Phys 26(1999) 2494

10 & 20 MV beams from NRC linac

NRC research accelerator, everything is known about it, including incident electron beam energy. Ion chamber measurements.

A systematic problem near surface



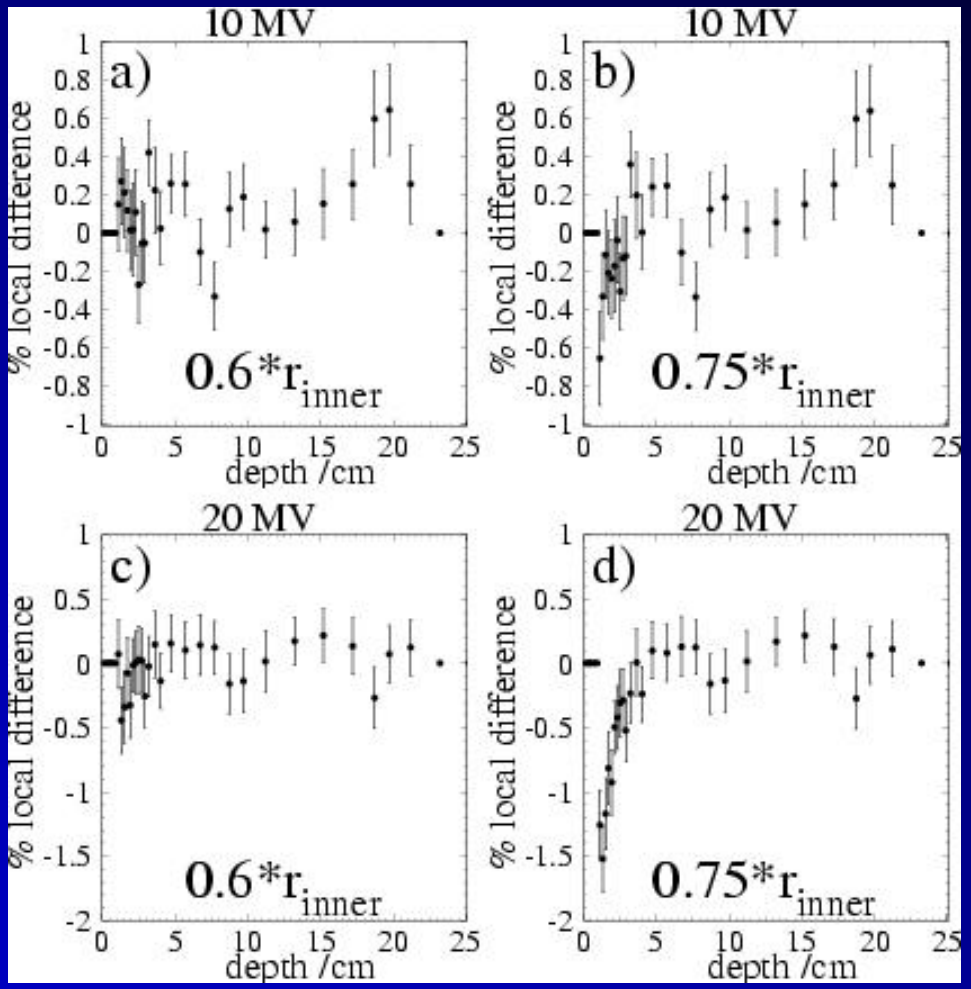
Sheikh-Bagheri et al Med Phys 27(2000) 2256-2266

The effective point of measurement

Varied the offset for effective point of measurement of ion chamber to establish best offset.

Agreement becomes almost perfect.

This offset is that used in TG51/TRS398



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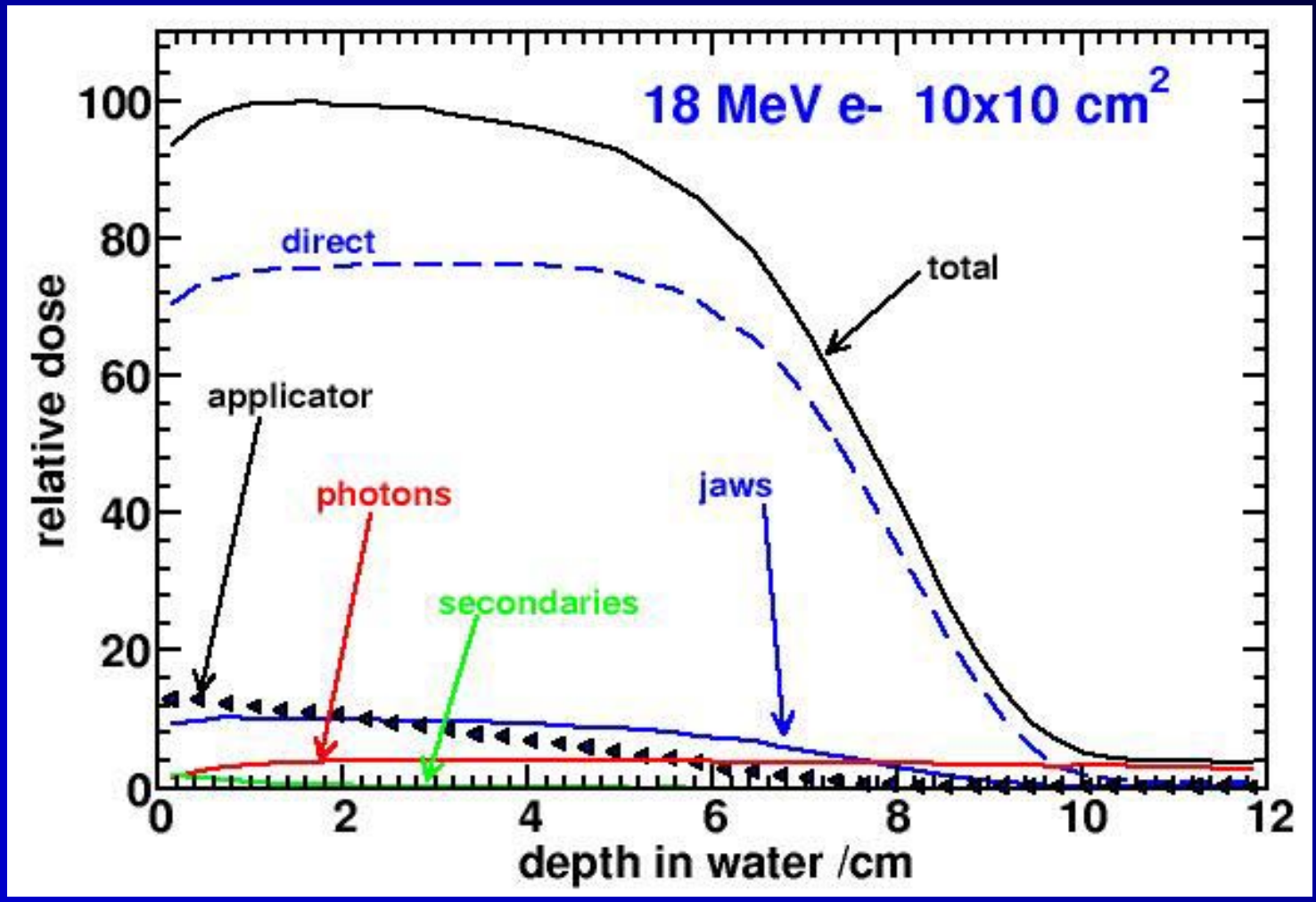
Sheikh-Bagheri et al Med Phys 27(2000) 2256-2266

Dose Components



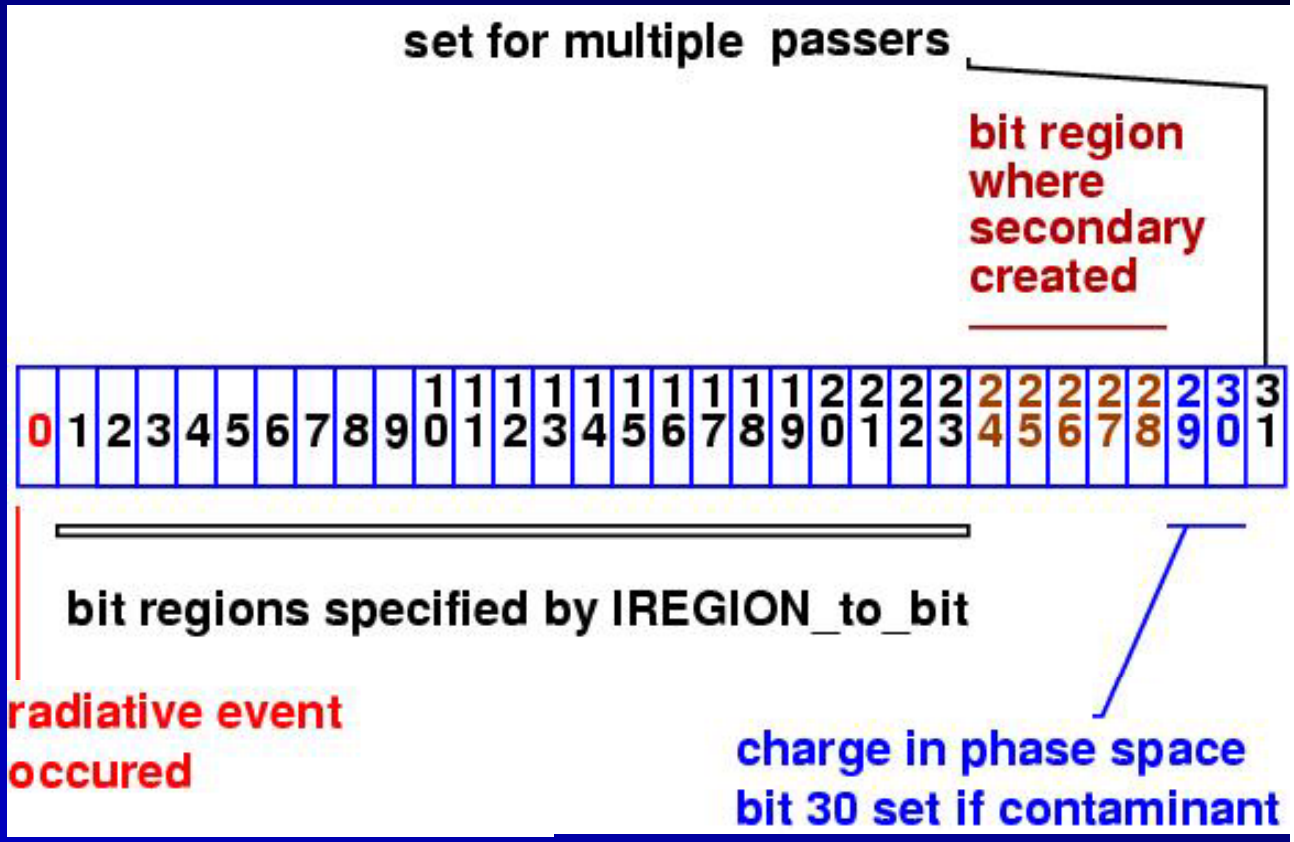
-makes use of LATCH

LATCH bits in BEAMnrc

BEAM associates regions or groups of regions with LATCH-bits(1->23)

Bits are set by particle interacting in these regions

LATCH is part of phase-space file



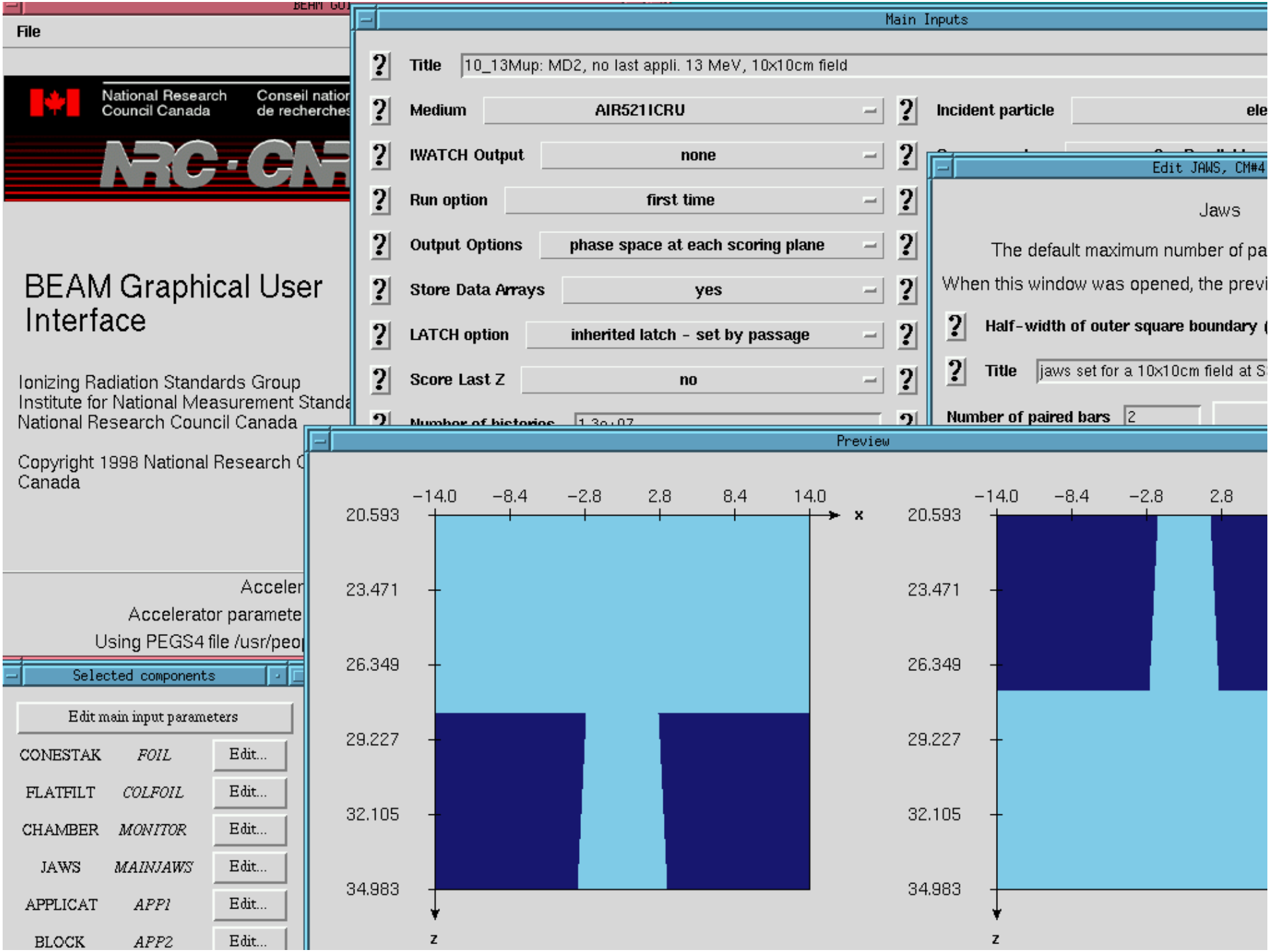
Allows a simple method of tracking a particle's history

Uses of BEAM

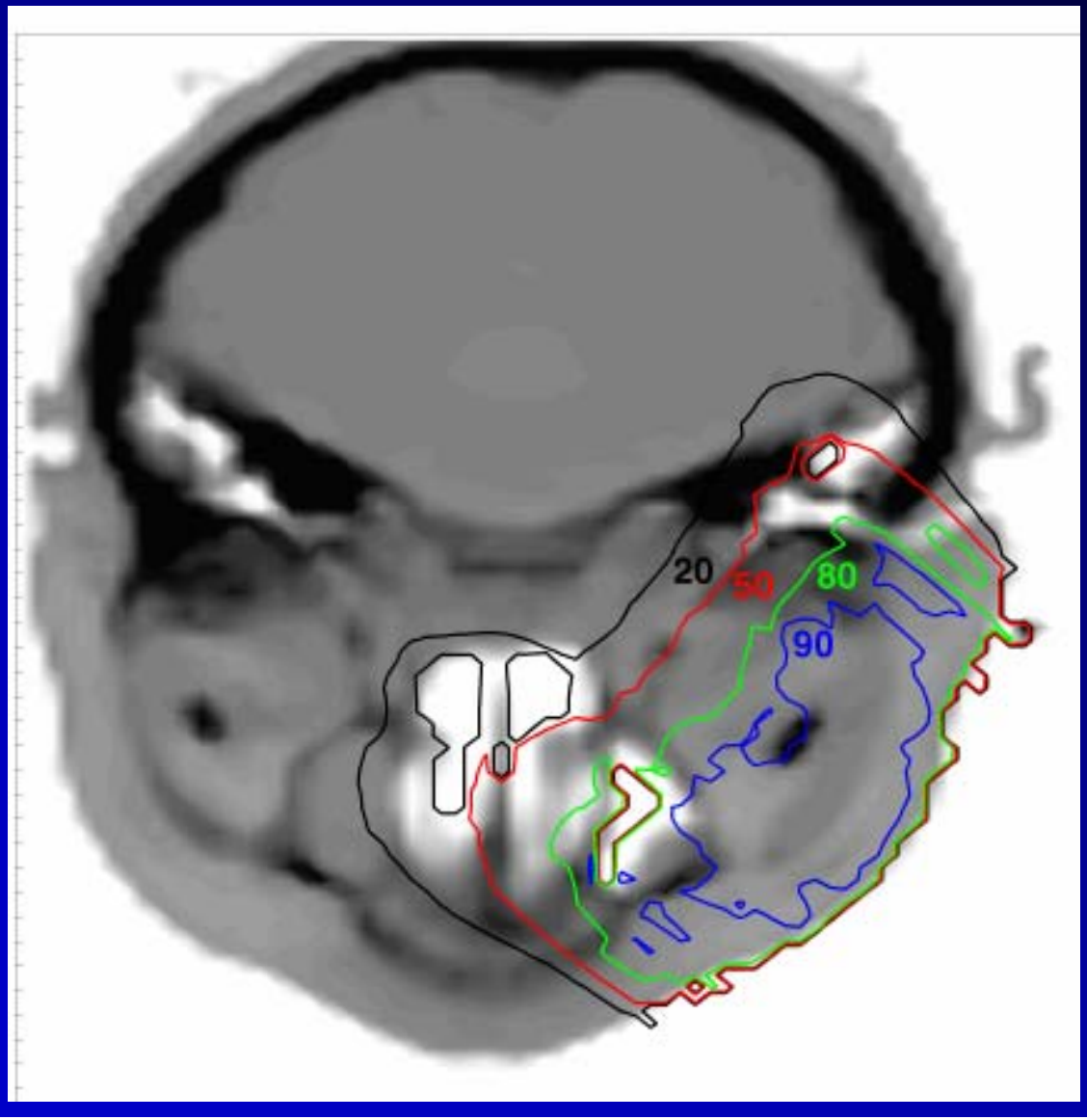
- accelerator design
- study physics of beams
- dosimetry studies
- beam characterization
  - 1st step to treatment planning
- commissioning accelerators

Doing it with BEAMnrc an interactive demonstration

- use EX10MeVe accelerator model (comes with code)
- run beamnrc_gui
  - show a compilation
  - look at inputs for accelerator
    - note on-line help, LATCH dose components
    - show previews and how to run job
- look at .egsinp file, .egslst file
- beamdp_gui use to show spectrum, scatter plot
- demonstrate EGS_Windows, dosxyz_show


File
National Research Council Canada
Conseil nation de recherches
NRC·CN
BEAM Graphical User Interface
Ionizing Radiation Standards Group
Institute for National Measurement Standa
National Research Council Canada
Copyright 1998 National Research C
Canada
Acceler
Accelerator paramete
Using PEGS4 file /usr/peo
Main Inputs
Title
10_13Mup: MD2, no last appli. 13 MeV, 10x10cm field
Medium
AIR521ICRU
Incident particle
ele
IWATCH Output
none
Run option
first time
Output Options
phase space at each scoring plane
Store Data Arrays
yes
LATCH option
inherited latch - set by passage
Score Last Z
no
Edit JAWS, CM#4
Jaws
The default maximum number of pa
When this window was opened, the previ
Half-width of outer square boundary (
Title
jaws set for a 10x10cm field at S
Number of paired bars
2
Preview
−14.0
−8.4
−2.8
2.8
8.4
14.0
x
20.593
23.471
26.349
29.227
32.105
34.983
z
Selected components
Edit main input parameters
CONESTAK FOIL Edit...
FLATFILT COLFOIL Edit...
CHAMBER MONITOR Edit...
JAWS MAINJAWS Edit...
APPLICAT APP1 Edit...
BLOCK APP2 Edit...

CT Treatment Planning



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Parameter selection with BEAMnrc

- for electron beams, match measured R_{50}
  - little else matters (assuming symmetric energy)

- for photon beams,
  - determine the incident electron energy by matching the depth-dose curve in a narrow beam
  - determine the radius of the incident electron beam by matching an off-axis ratio or dose profile for a large beam (40x40)

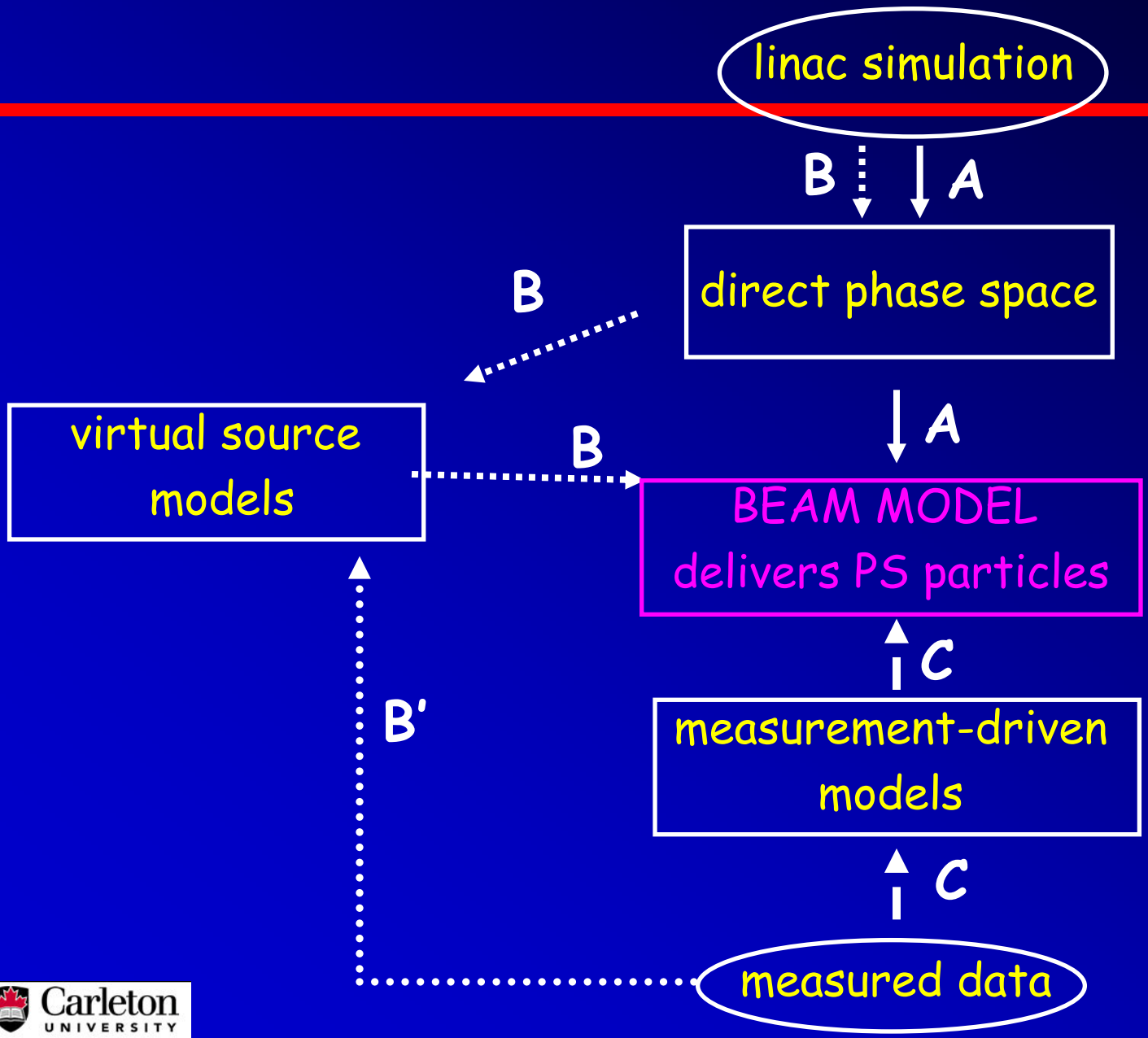
A summary of the findings of Sheikh-Bagheri and Rogers from Verhaegen and Seuntjens (PMB48(2003)R107)

Linac Characteristic	Effect on off-axis factors	Effect on depth dose
Primary electron energy	Linear decrease with primary electron energy: −0.105/MeV for a 6 MV Siemens beam. 0.2 MeV change has an observable effect	0.2 MeV change effects an observable effect
Gaussian width of electron energy distribution	No effect of Gaussian widening (0–20%) observed for a 6 MV beam. Asymmetrical energy distribution has small effect	Weak dependence on Gaussian energy spread at large depths. Asymmetrical energy dist'n affects dose in build-up region: up to 1.5% for 18 MV Siemens beam
Radial intensity distribution of electron beam	Quadratic decrease with radial spread: 6% for 0.15 cm FWHM increase for an 18 MV Varian beam	No effect
Divergence of the electron beam	Slight effect when changing beam divergence from 0–1° for 18 MV photon beam	No effect changing beam divergence from 0–5° for 18 MV photon beam
Upstream opening of primary collimator	Sensitive to a 0.01 cm change in lateral opening	No effect
Material / density of flattening filter	Large effect: 1 g cm^{-3} change of tungsten density causes 6% change in off-axis ratio for 15 MV	Not reported

Beam models

- a beam model, in this context, is any algorithm that delivers the location, direction and energy of particles to the patient dose-calculating algorithm.
- one type of beam model is a direct MC simulation of the accelerator head, but we refer to it as a beam simulation for clarity
- beam simulations can be done accurately if all the parameters are known - but they often are not

Possible ways to specify a beam model



TG105 in press
Med Phys 34

Acknowledgements

- The work described here has been done in conjunction with many colleagues, grad students and research associates. BEAM developers are listed on slide 4.

- I would particularly like to acknowledge that Iwan Kawrakow and Blake Walters have been the major developers of BEAMnrc for the last few years.

- Elsayed Ali is responsible for the BCSE work described.
- Support from the Canada Research Chairs program and

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Bibliography re BEAM/BEAMnrc

-BEAM: A Monte Carlo code to simulate radiotherapy units, Med Phys 22 (1995) 503-524.

pdf versions of this & related publications are available at:
http://www.physics.carleton.ca/~drogers/pubs/papers/

-BEAMnrc, DOSXYZnrc related manuals available via the BEAM home page
http://www.irs.inms.nrc.ca/BEAM/beamhome.html

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-Efficiency improvements of x-ray simulations in EGSnrc user-codes using bremsstrahlung cross section enhancement (BCSE), Med Phys 34 (2007) 2143-2154

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