Limitations and benchmarks of EGSnrc

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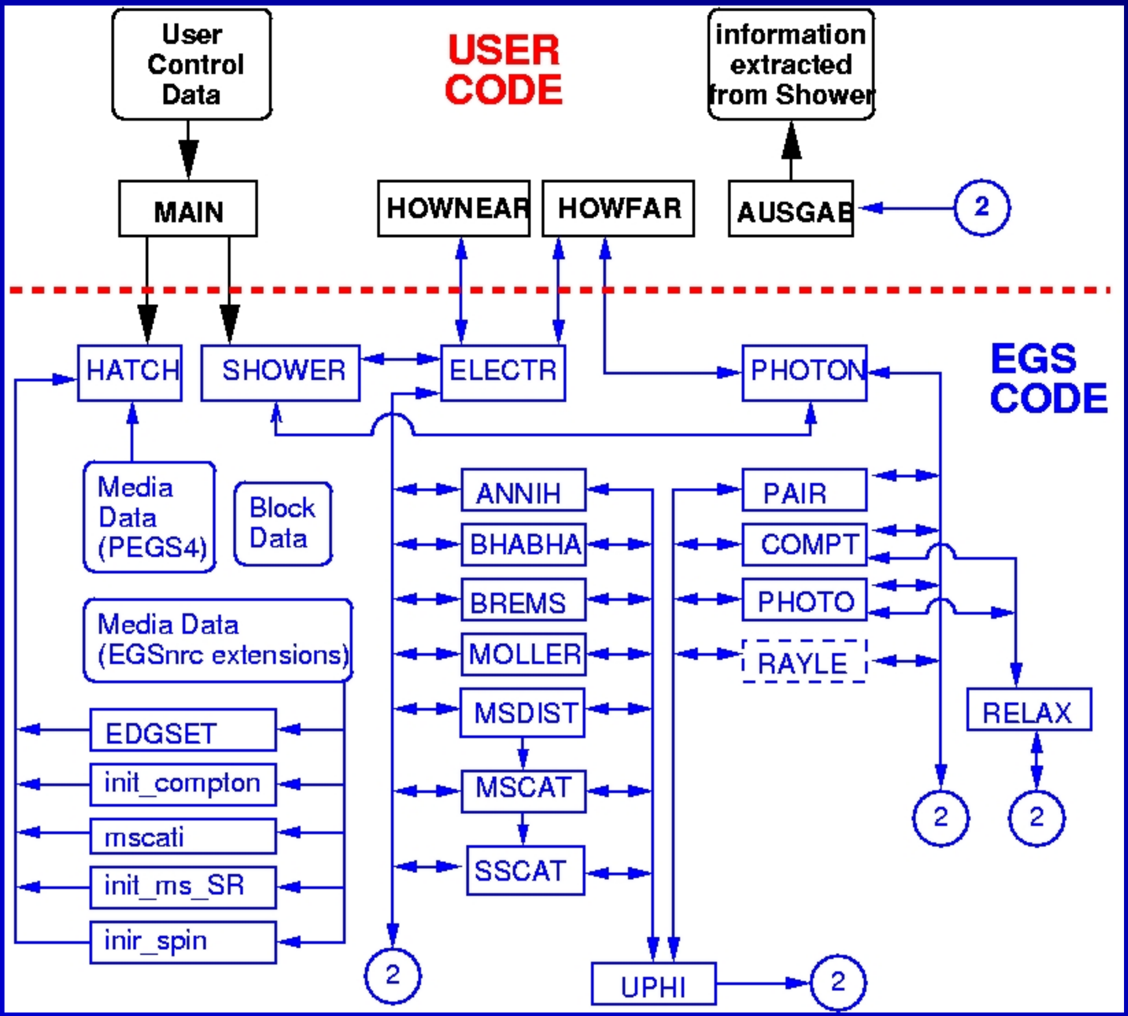
Components of EGSnrc



Things to consider

- -energy range
- -accuracy of models
  - -x-ray fluorescence
  - -brem production
  - -multiple scattering
  - -transport models
- -geometry limits
- -calculation efficiency

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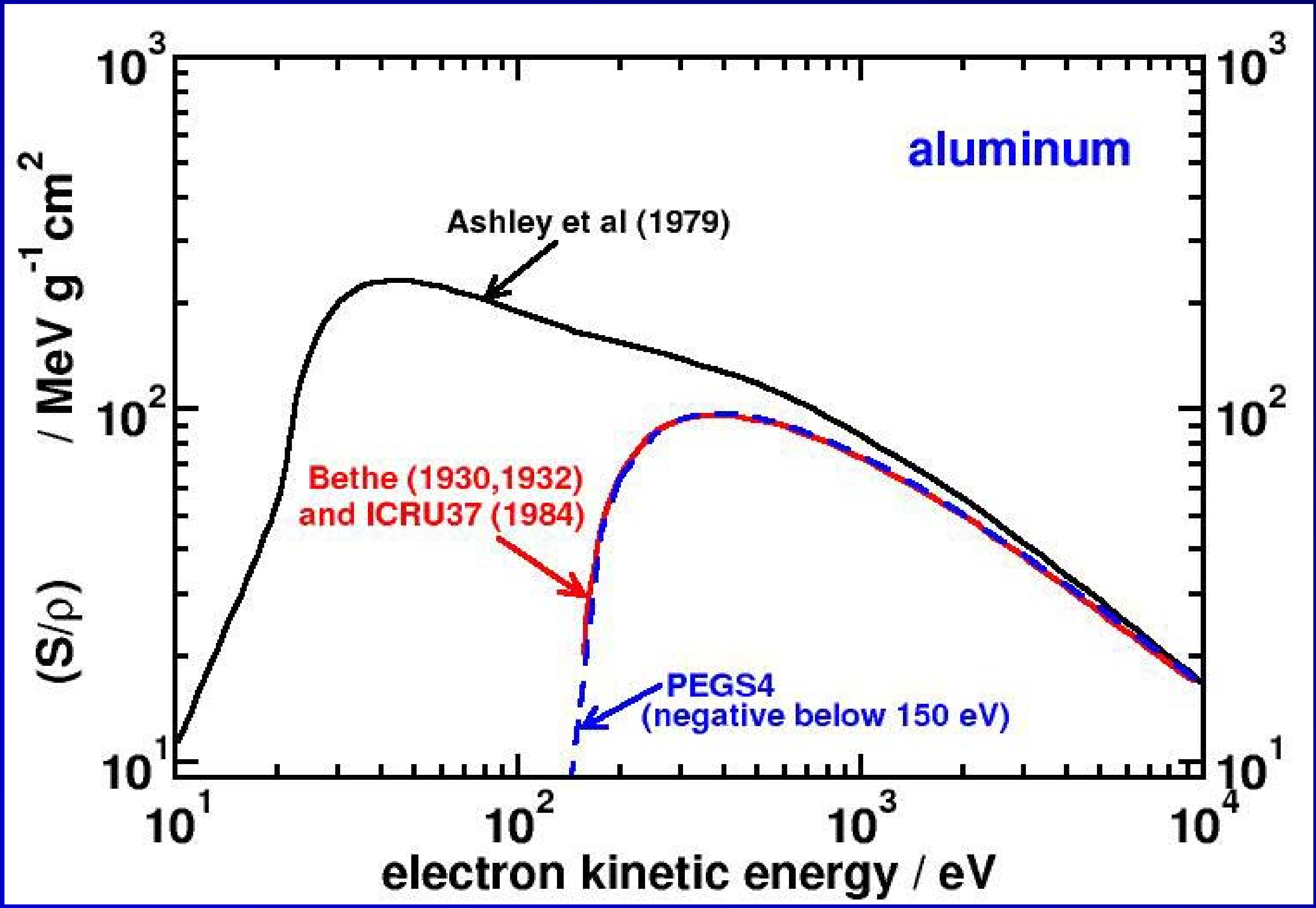
Low-energy limitations

Photon cross sections included down to 1 keV

K,L,M shell fluorescence included
(some approx above k shell)

Beth-Block stopping power calculations
-assumes unbound electrons
-obviously not true for high-Z materials at energies low compared to binding energy

Low-energy electron stopping powers



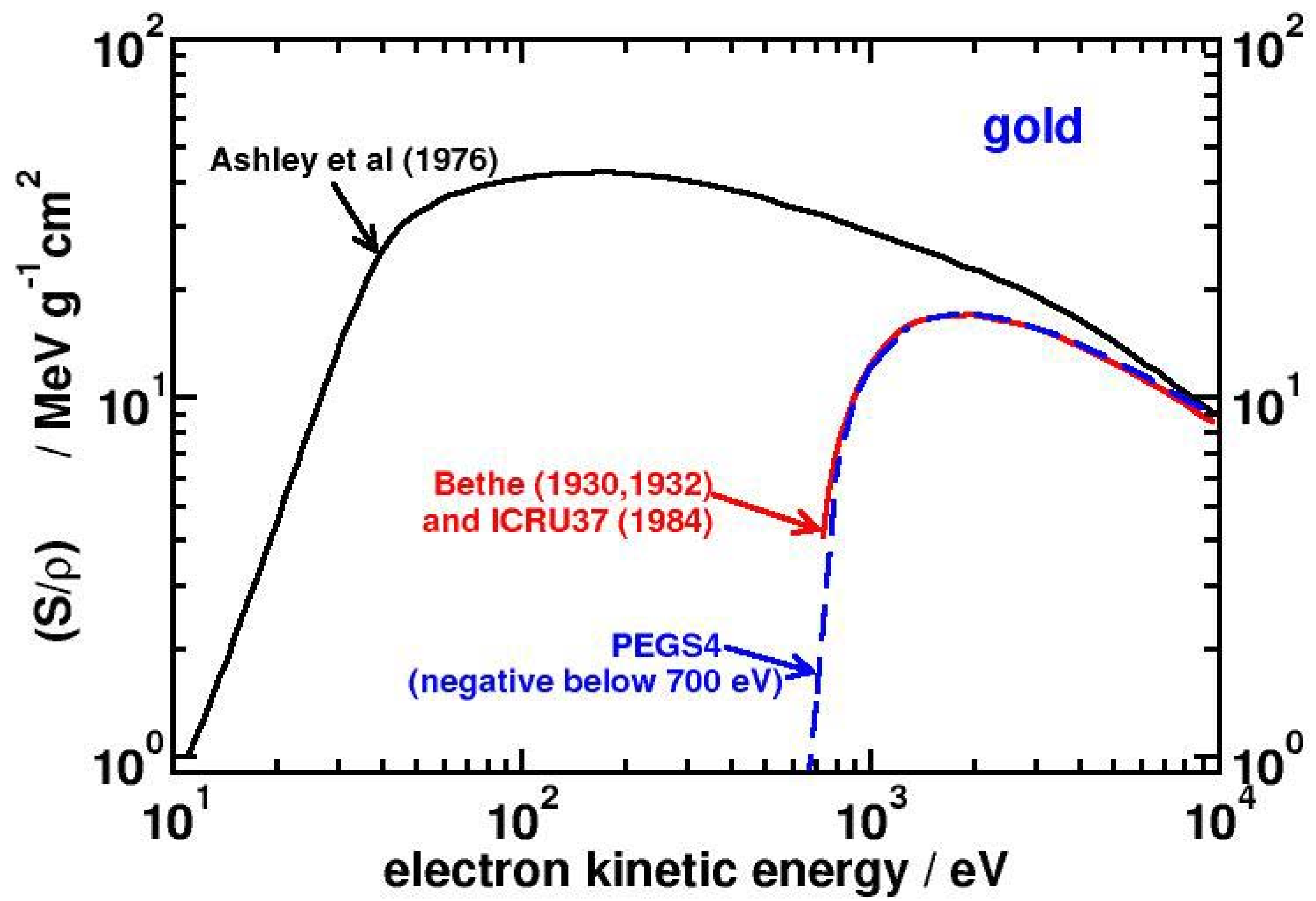
from E S M Ali

Low-energy electron stopping powers

Does it matter?

Only if transport of < 10 keV electrons matters

(when is that?)



from E S M Ali

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Fluorescent x-rays

EGSnrc uses K and L shell individual binding energies but uses averaged values for the M and L shells.

Tungsten

K	L_1	L_2	L_3	<M>	<N>
69.5	12.1	11.5	10.2	2.27	0.301

$$< M_k >= \frac{\sum \nu_{KM_j} E_{M_j}}{\sum \nu_j}$$

ν_{KM_j} is probability of an M_j to K transition

If used L-M_j probabilities <M> = 1.88 keV

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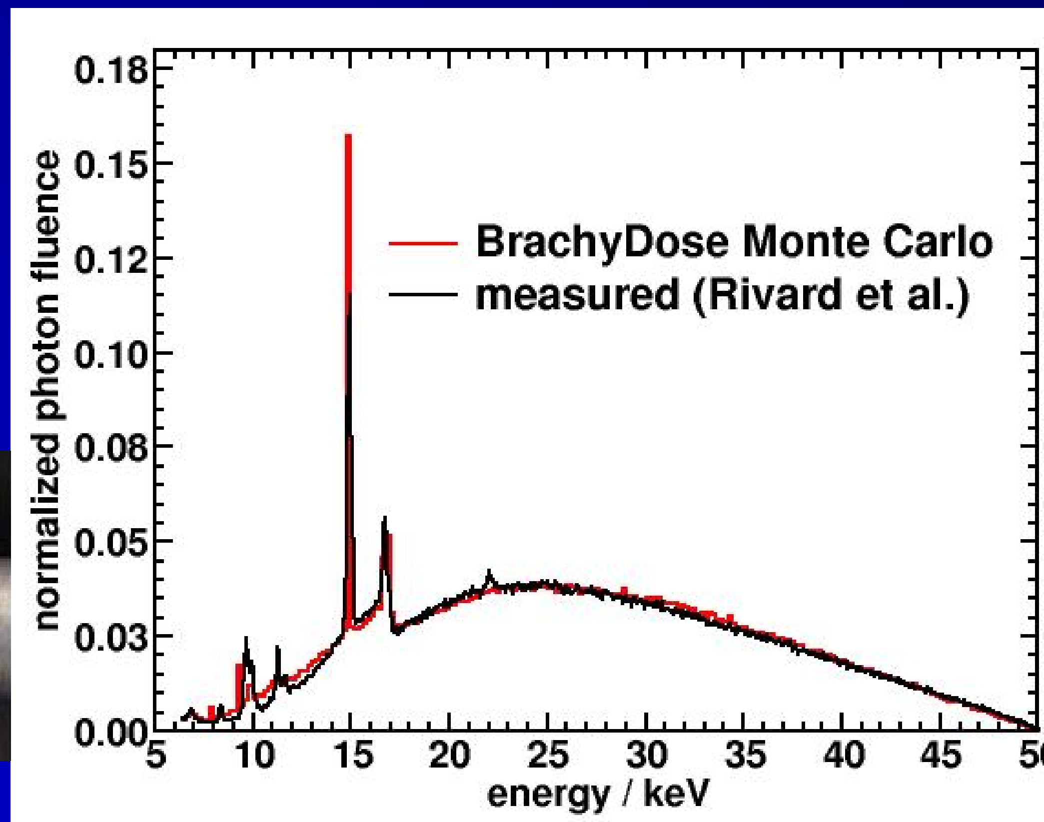
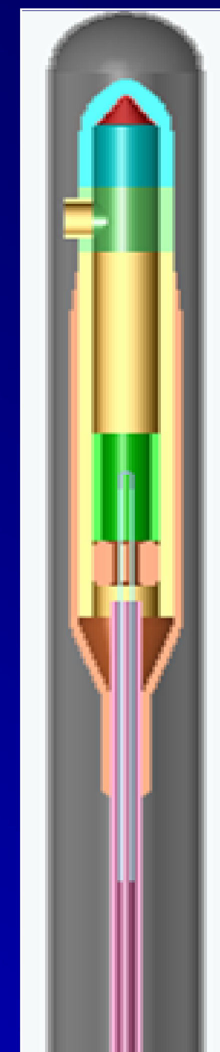
Xoft: 50 kV brachytherapy source





R Taylor MSc thesis, Carleton U, 2006

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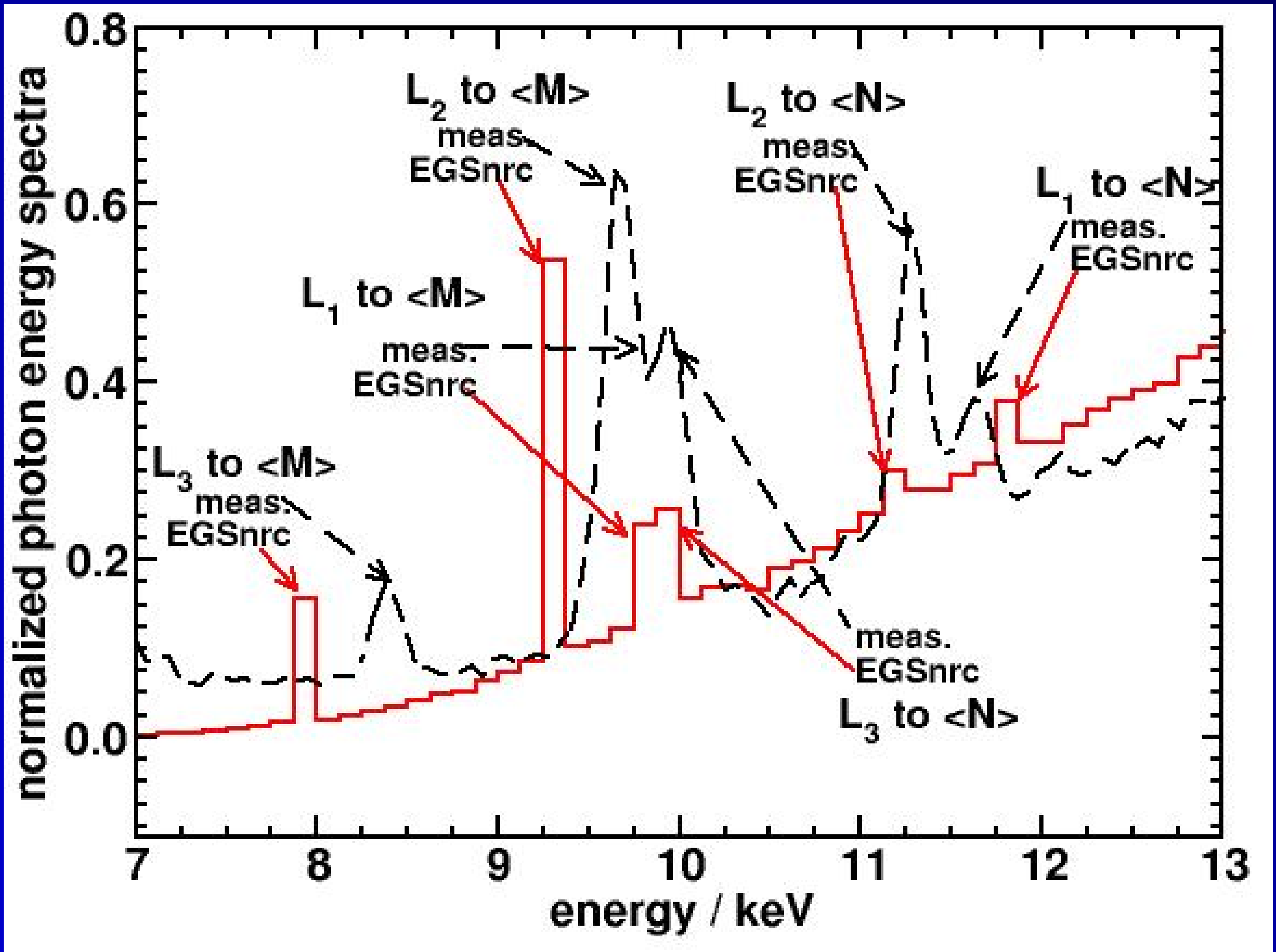
Xoft: 50 kV brachytherapy source



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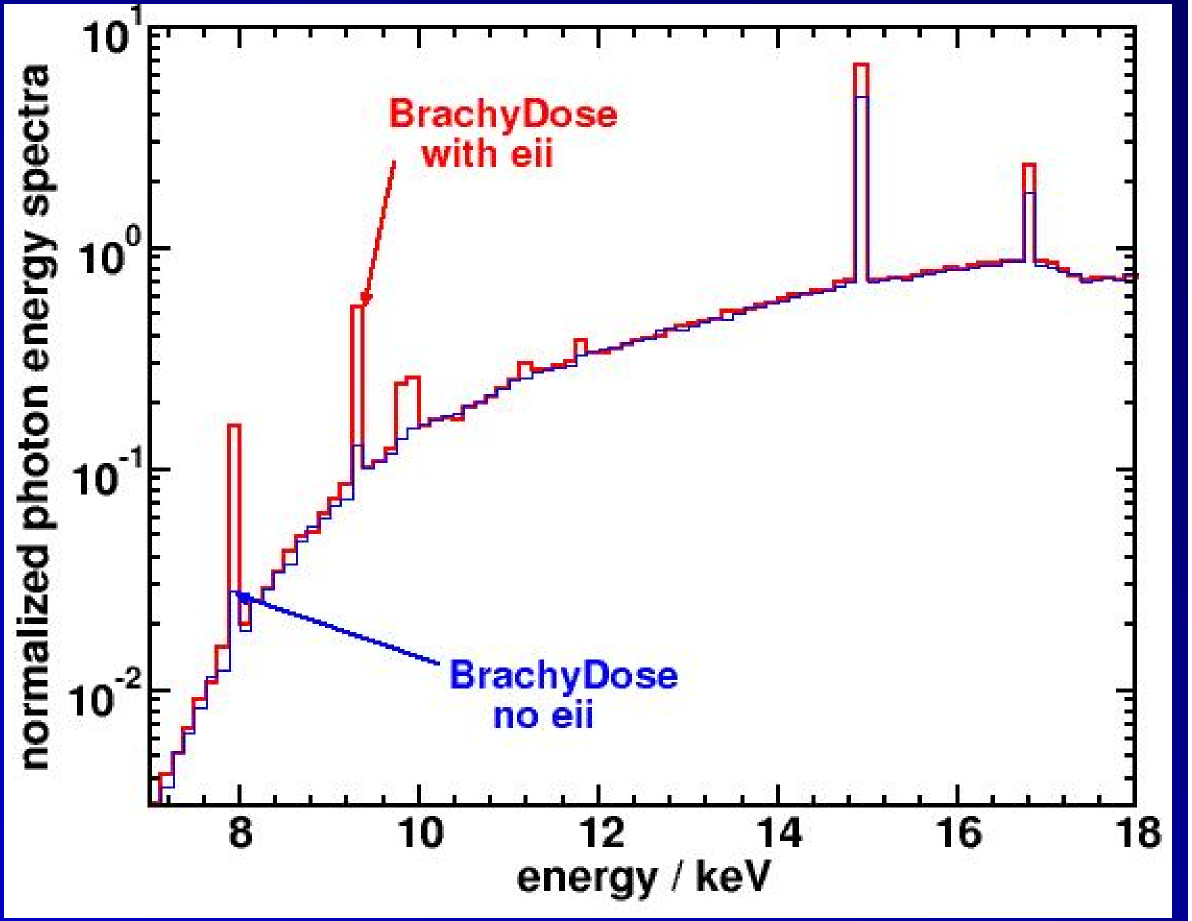
R Taylor MSc thesis, Carleton U, 2006

electron impact ionization

-creation of a vacancy in the atom directly by electrons (brem + photo-electric)

-available in EGSnrc based on a new theory by Kawrakow
-unpublished results improve agreement

with experiment



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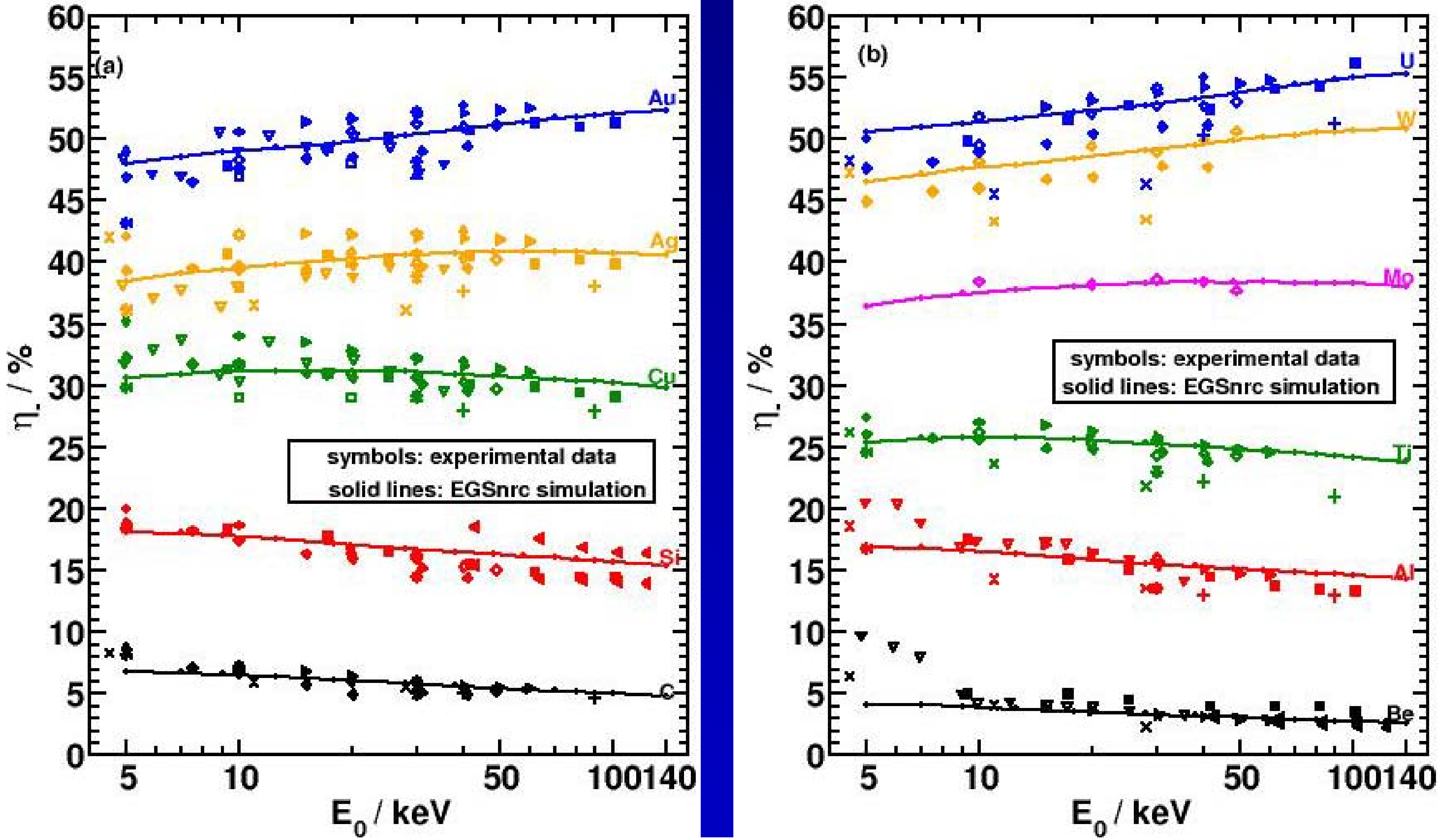
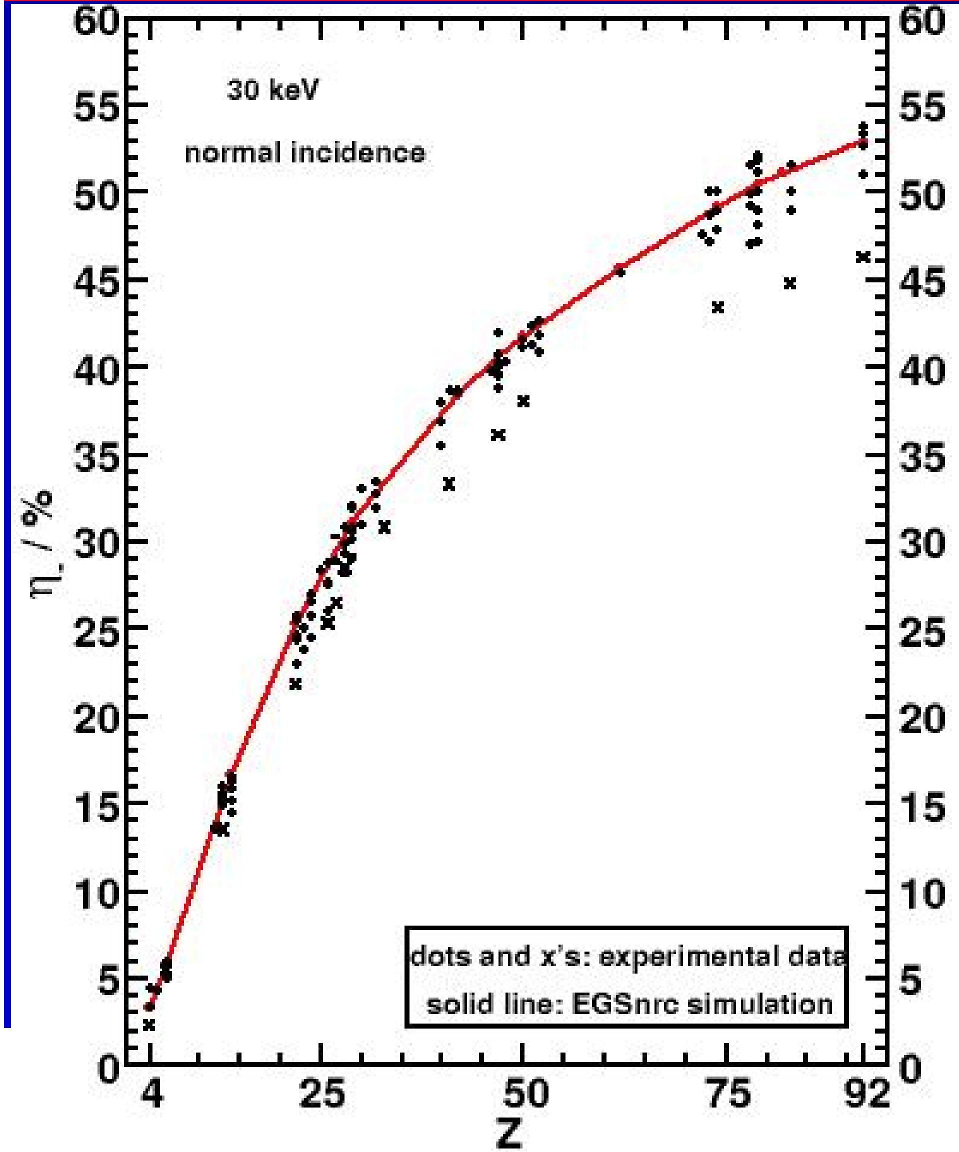
R Taylor MSc thesis, Carleton U, 2006

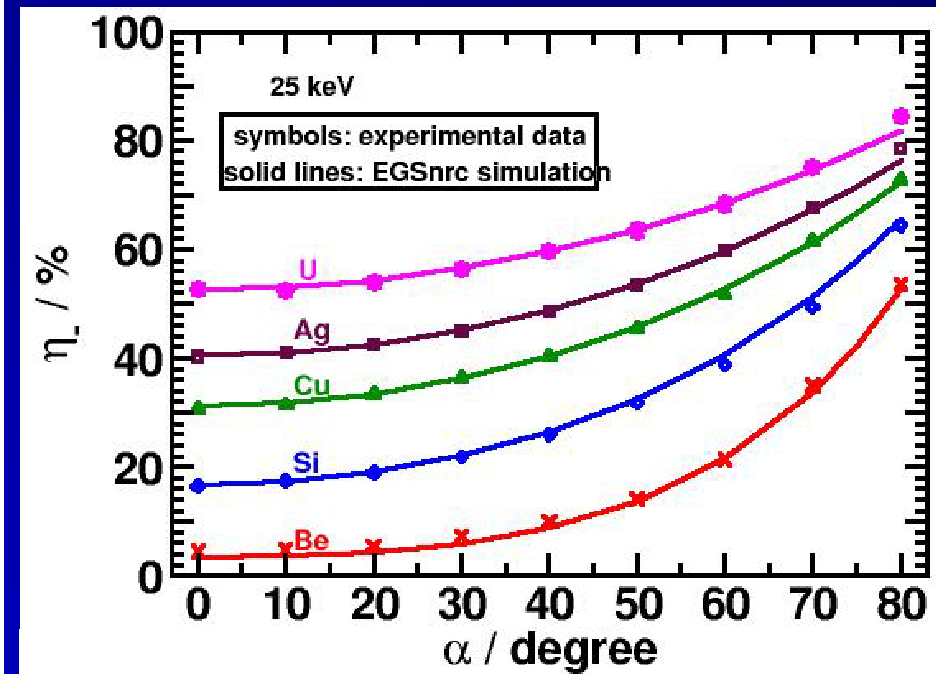
Backscatter - a tough test: kilovolts

Ali & Rogers PMB 53(2008) 1527-1543



Backscatter - a tough test: kilovolts

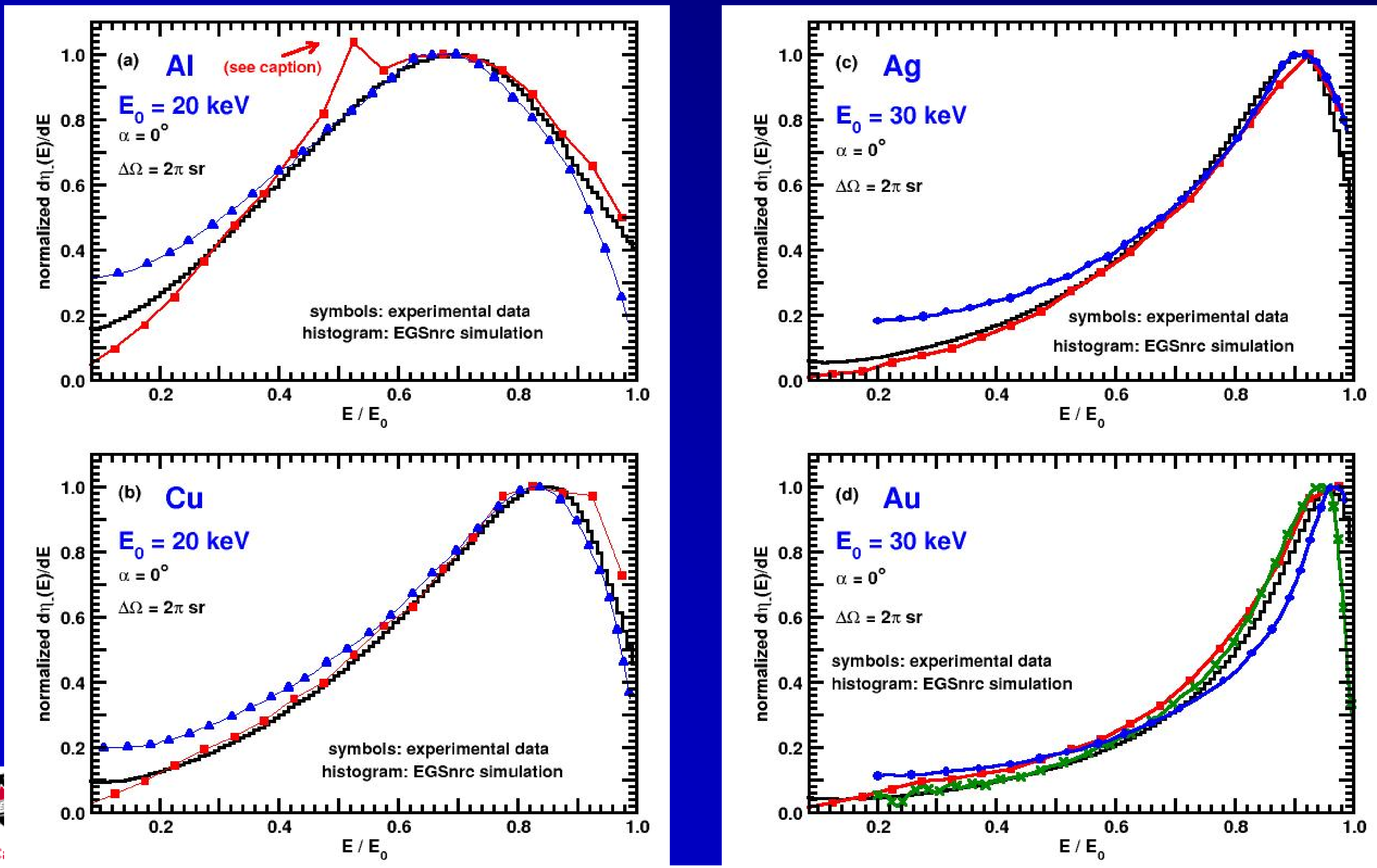




PMB 53(2008) 1527-1543

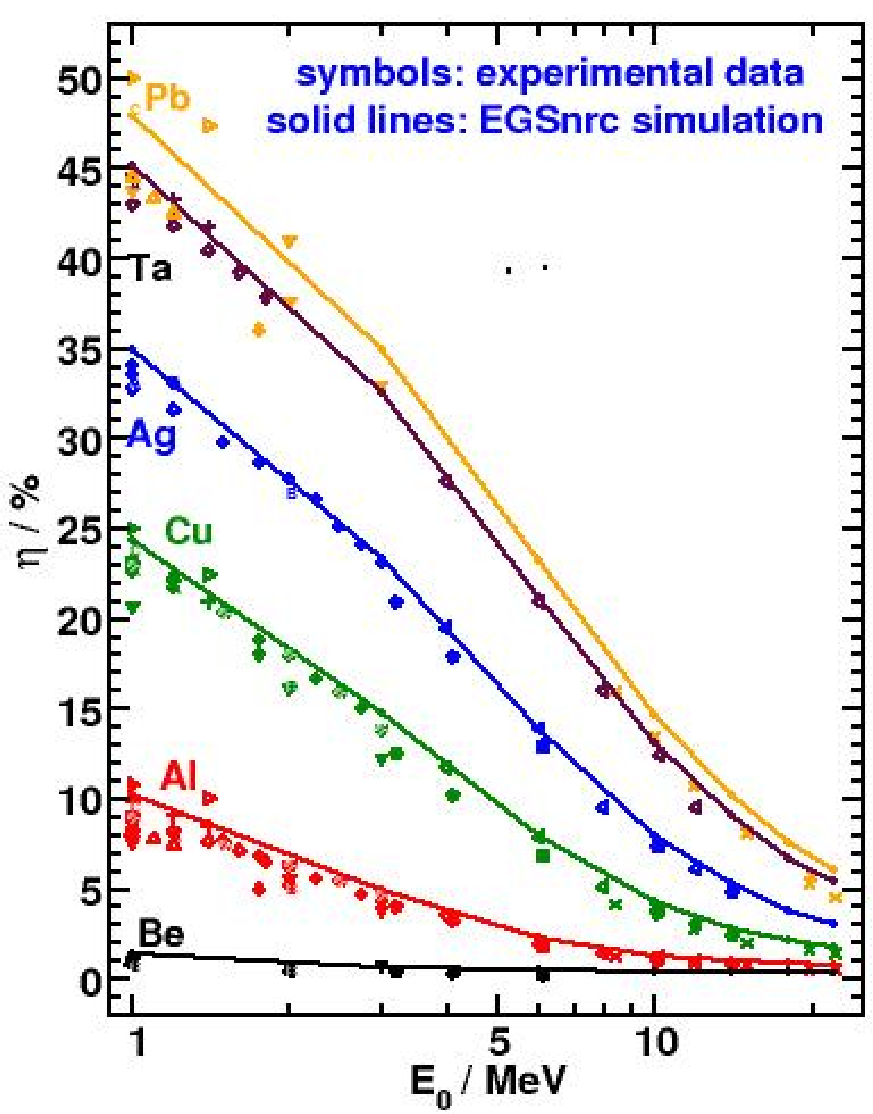
Backscatter - spectra

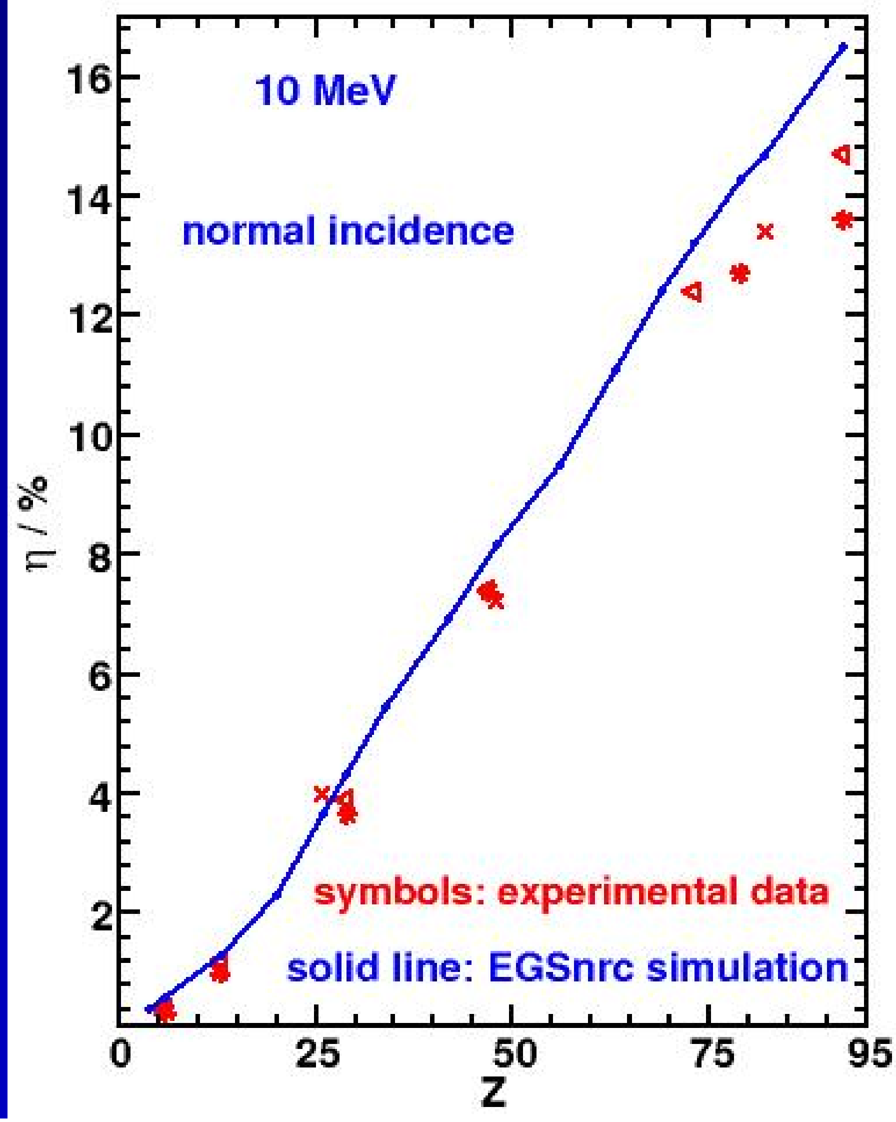
Ali & Rogers J Phys D: App Phys 41 (2008)055505



Backscatter: megavolts

Ali et al, in preparation





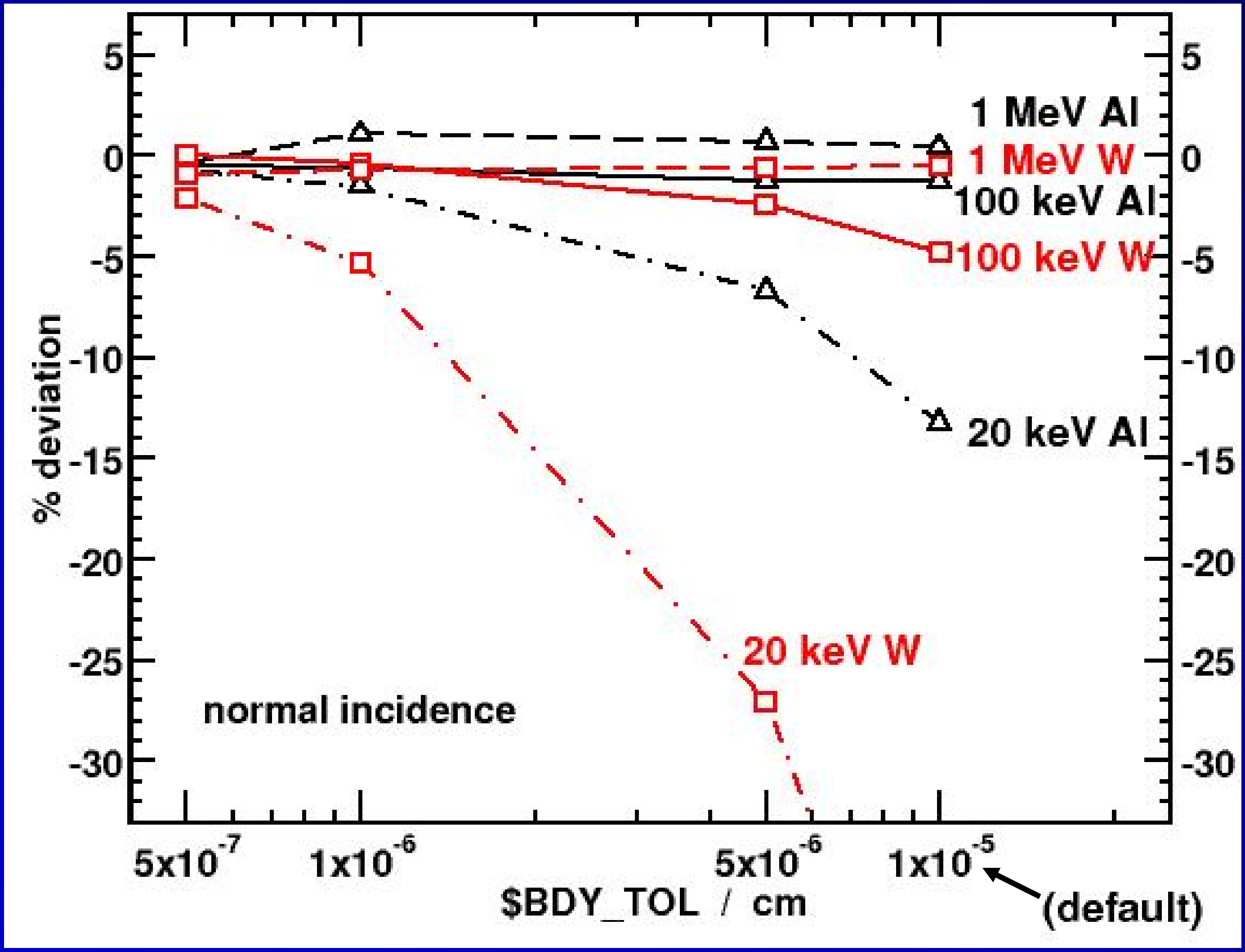
Geometry issues in BEAMnrc

$BDY_TOL

parameter re: boundary crossing

-default fine in accelerator simulations

-not OK for kilovoltage backscatter



PMB 53(2008) 1527-1543

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Accuracy of multiple scattering

Multiple scattering is a dominant physical effect with electrons.

EGSnrc uses a multiple scattering theory developed by Kawrakow (NIMB 134 (1998) 325-336)

It has the advantage of seamlessly converting into a single scattering theory for very short steps.

Recently there have been some high quality measurements done by my ex-colleagues at NRC to test the theory as implemented in EGSnrc

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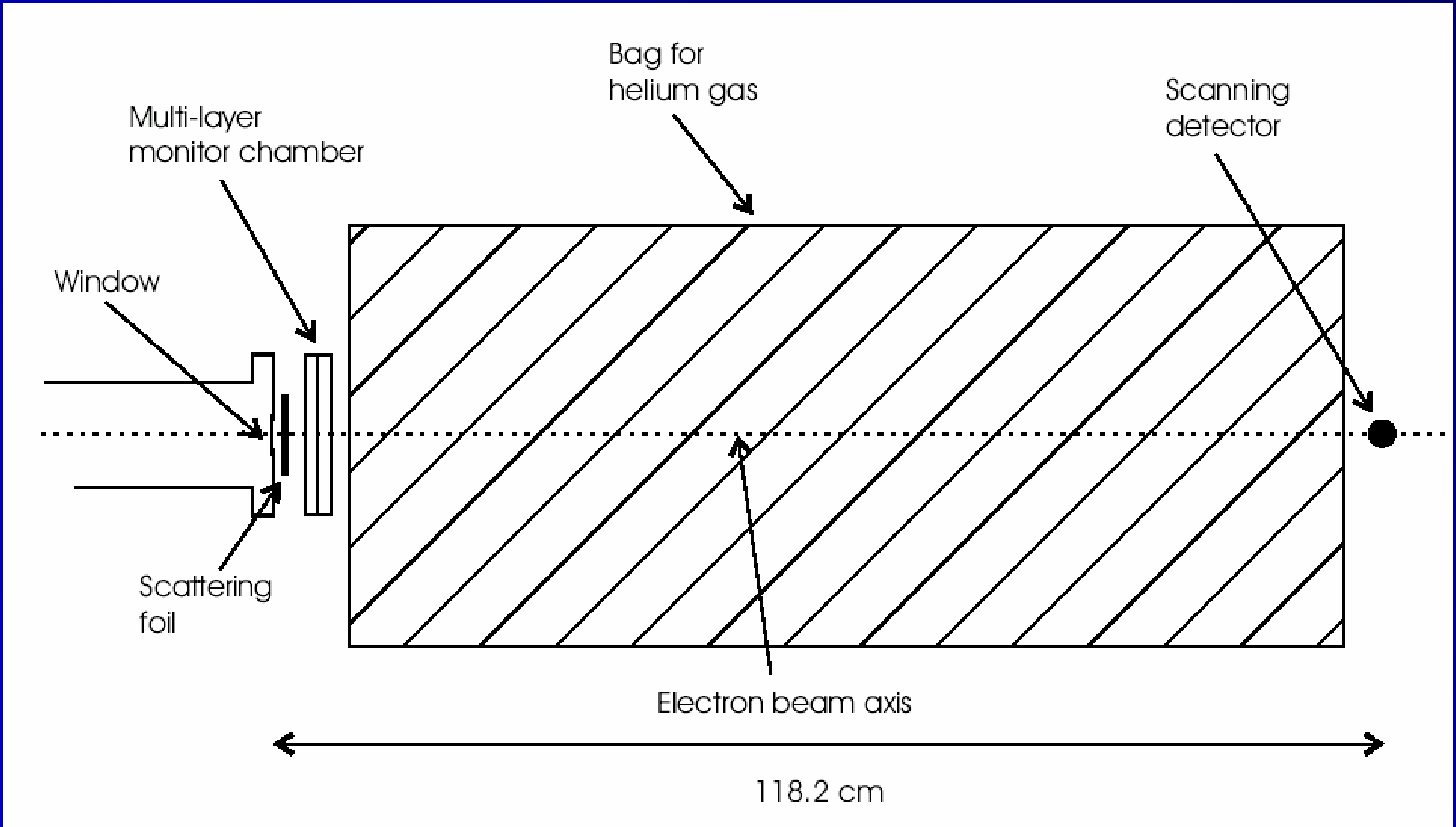
Ross et al, Med Phys 35 (2008)4121 - 4131

NRC experimental setup



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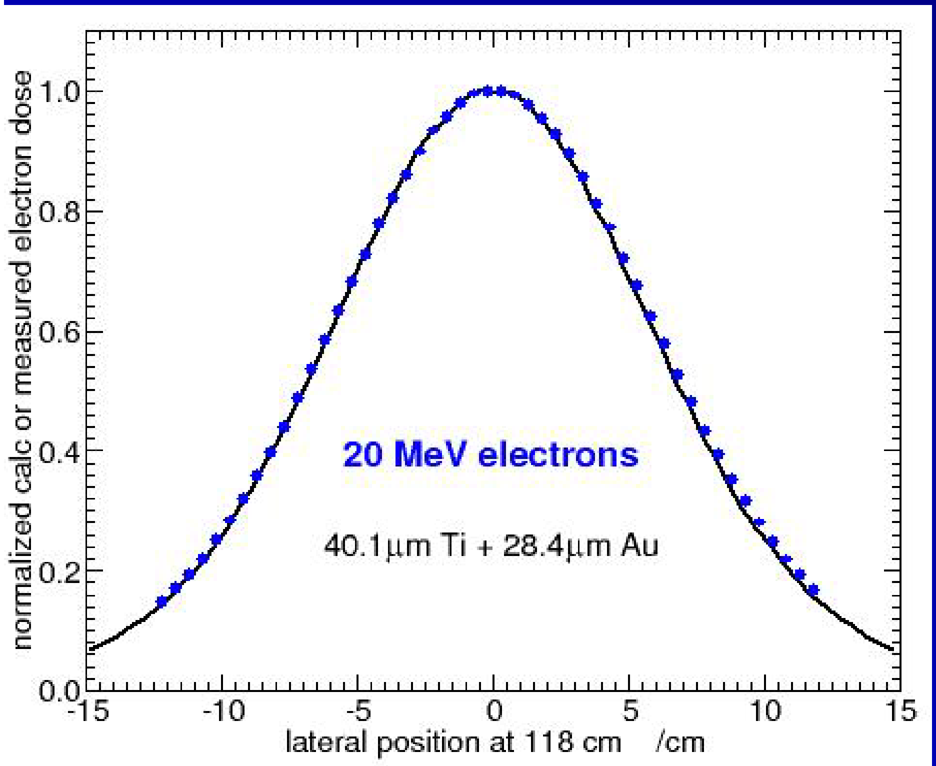
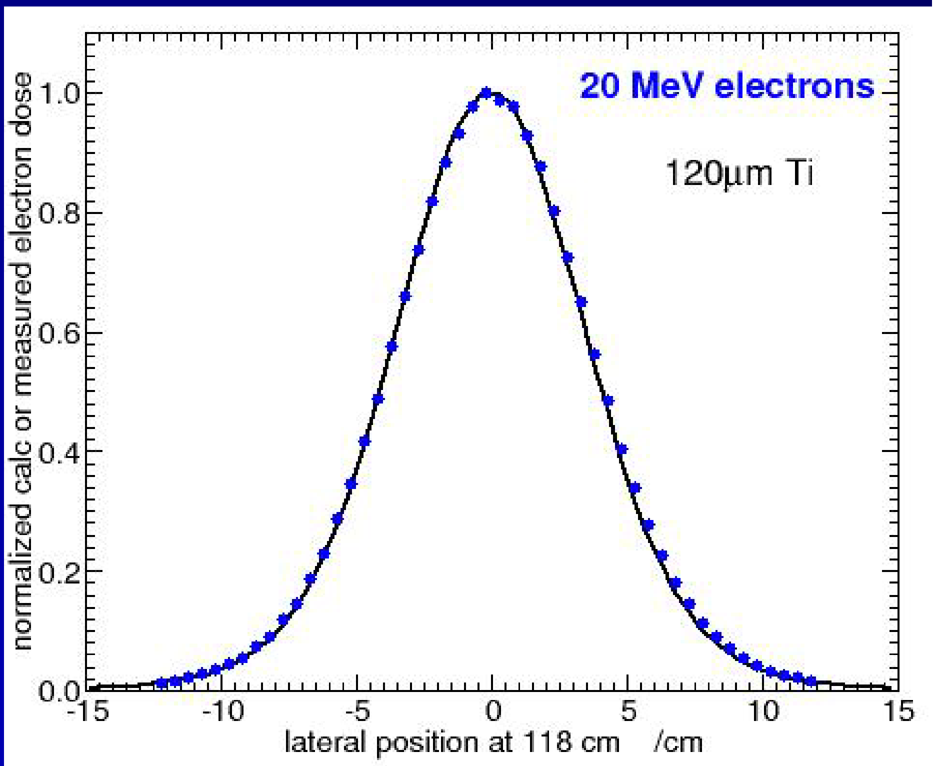
Med Phys 35 (2008)4121 - 4131

NRC's results





Note the experiment is slightly wider than calculations

Thanks to Malcolm McEwen for the raw data

Med Phys 35 (2008) 4121 - 4131

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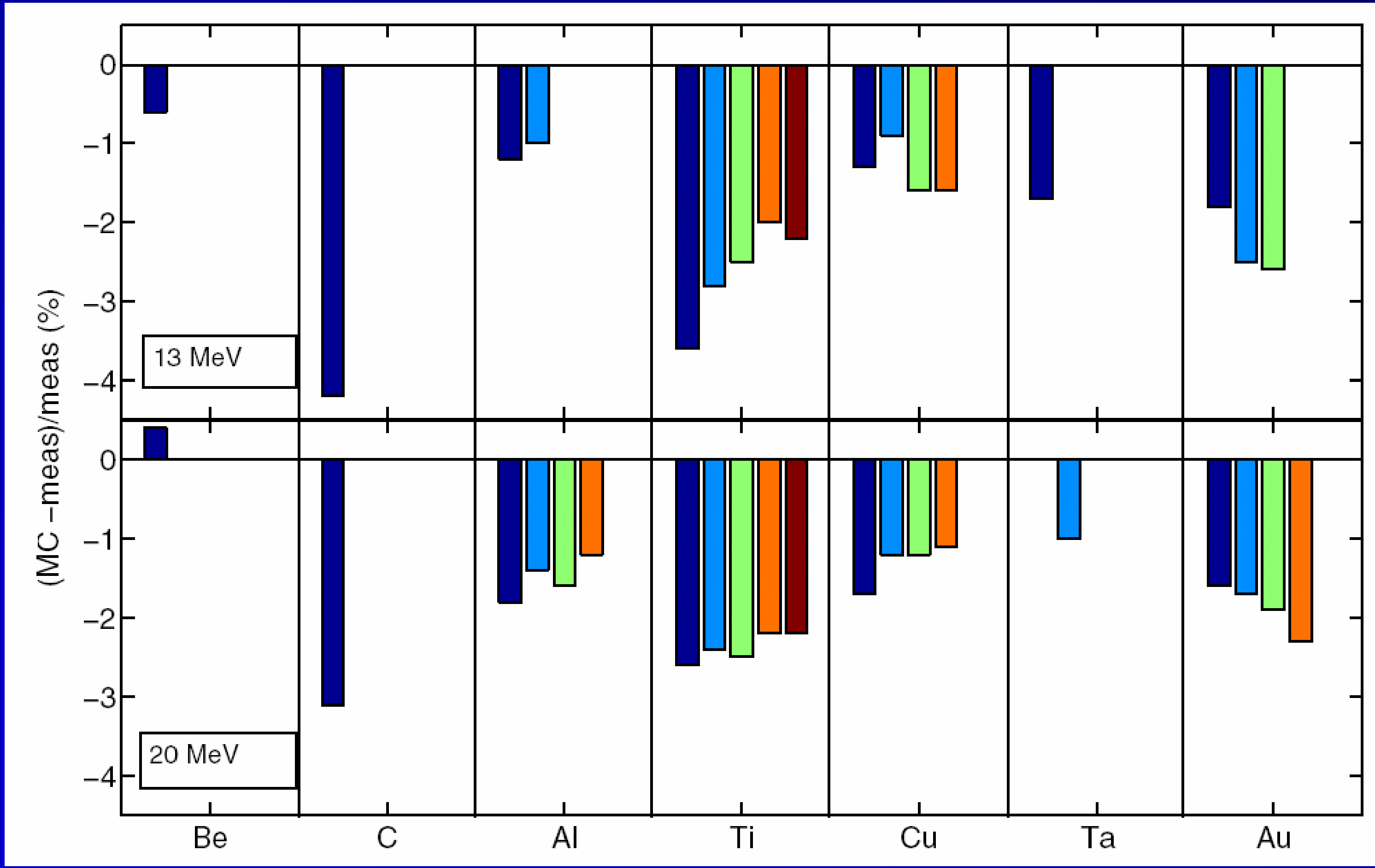
NRC's results for $\theta_{1/e}$ widths

Experimental uncertainty

about 1 %.



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Med Phys 35 (2008) 4121 - 4131

How accurately can we calculate ion chamber response? The Fano test

Fano's theorem

Under conditions of charged particle equilibrium the electron fluence in a medium is independent of the density.

Fano cavity chamber,

- full build up wall
- cavity either: gas of wall material or wall material
- perfect CPE => no attenuation or scattered photons

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Fano test (cont)

Consider the case with cavity of wall material

$$(K_{col})_{\mathrm{wall}} \overset{CPE}{=} D_{\mathrm{wall}}$$

but since, by Fano's theorem the electron fluence is unchanged => $D_{\mathrm{gas}} \overset{CPE}{=} D_{\mathrm{wall}}$

and hence:

$$(K_{col})_{\mathrm{wall}} = E\phi \left(\frac{\mu_{en}}{\rho}\right)_{\mathrm{wall}} = D_{\mathrm{gas}} = D'_{gas} K_{\mathrm{wall}}$$

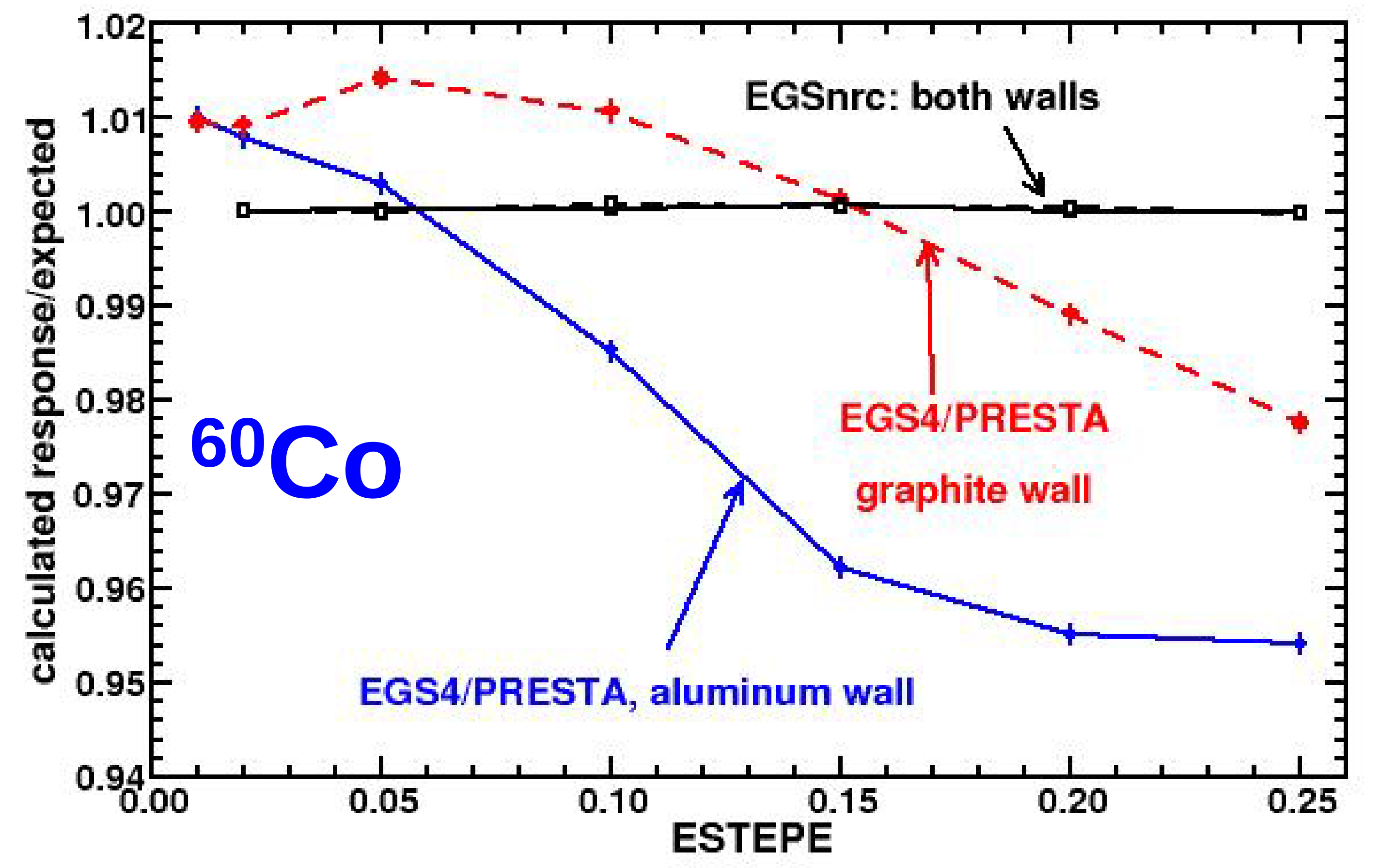
where D_{gas} is the dose to the gas without any attenuation and scatter (so there is CPE) and D'_{gas} is the dose calculated with attenuation and scatter and then corrected by the wall correction factor, i.e. K_{wall} (not another kerma!)

Fano test (cont)

-cover of EGSnrc manual

-against own cross sections

-ESTEPE is max fractional step size



This is the toughest test I know for any electron-photon Monte Carlo code

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Fano test (cont)

-has been applied to materials up to lead and EGSnrc passes it at 0.1 % level in ^{60}Co beams (La Russa, submitted to Med Phys). There is no need to adjust simulation parameters to get this accuracy.

-Sempau and Andreo (PMB, 51 (2006) 3533-3548) showed similar accuracy could be achieved with PENELOPE (using a different version of the Fano test) as did Yi et al (Med Phys 33 (2006) 1213) but in both cases adjustment of parameters was needed.

-Poon et al (PMB 50 (2005) 681 - 694) showed that GEANT4 failed the Fano test in ^{60}Co by as much as 39%.

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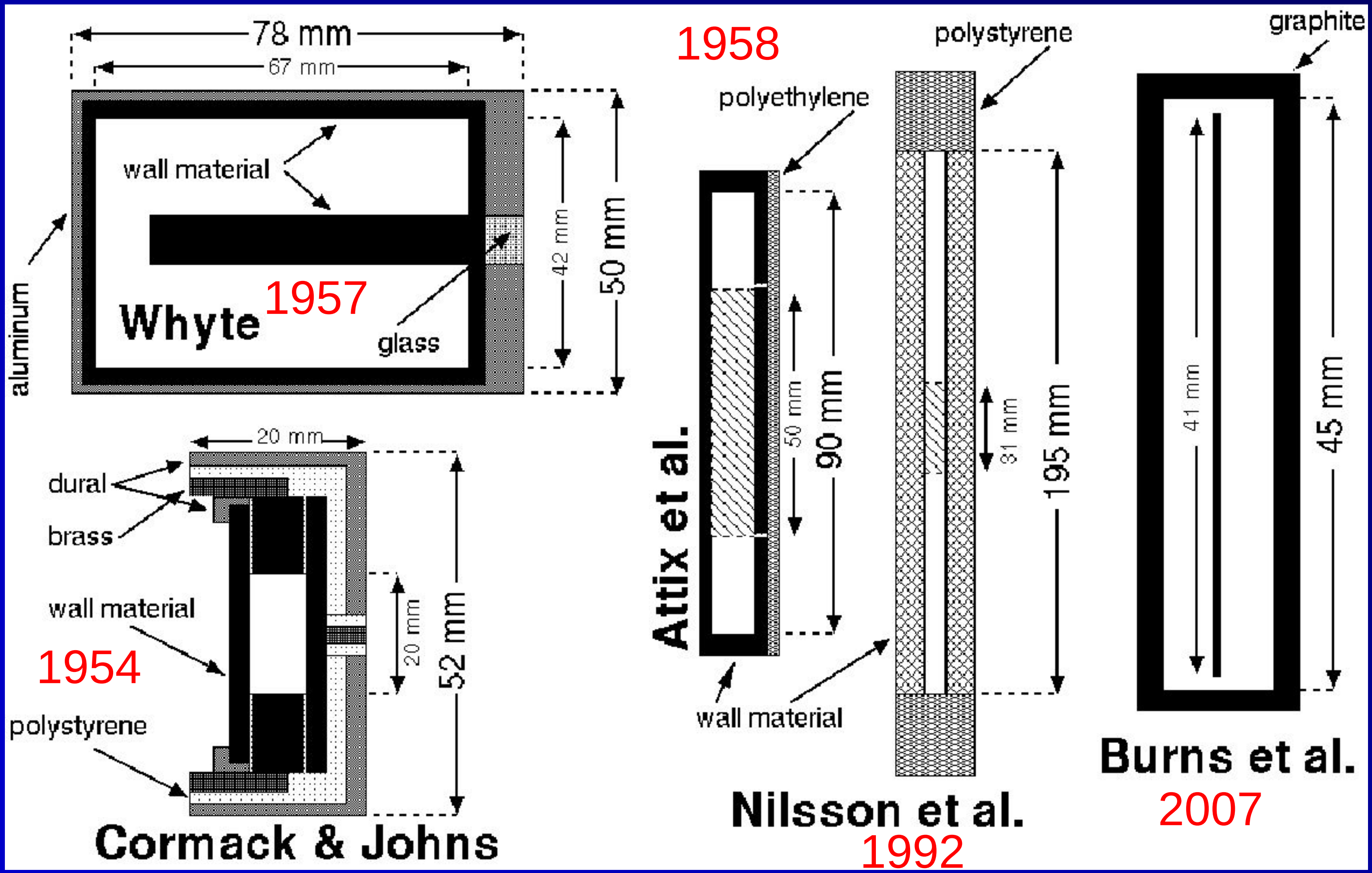
real chambers in ^{60}Co beams



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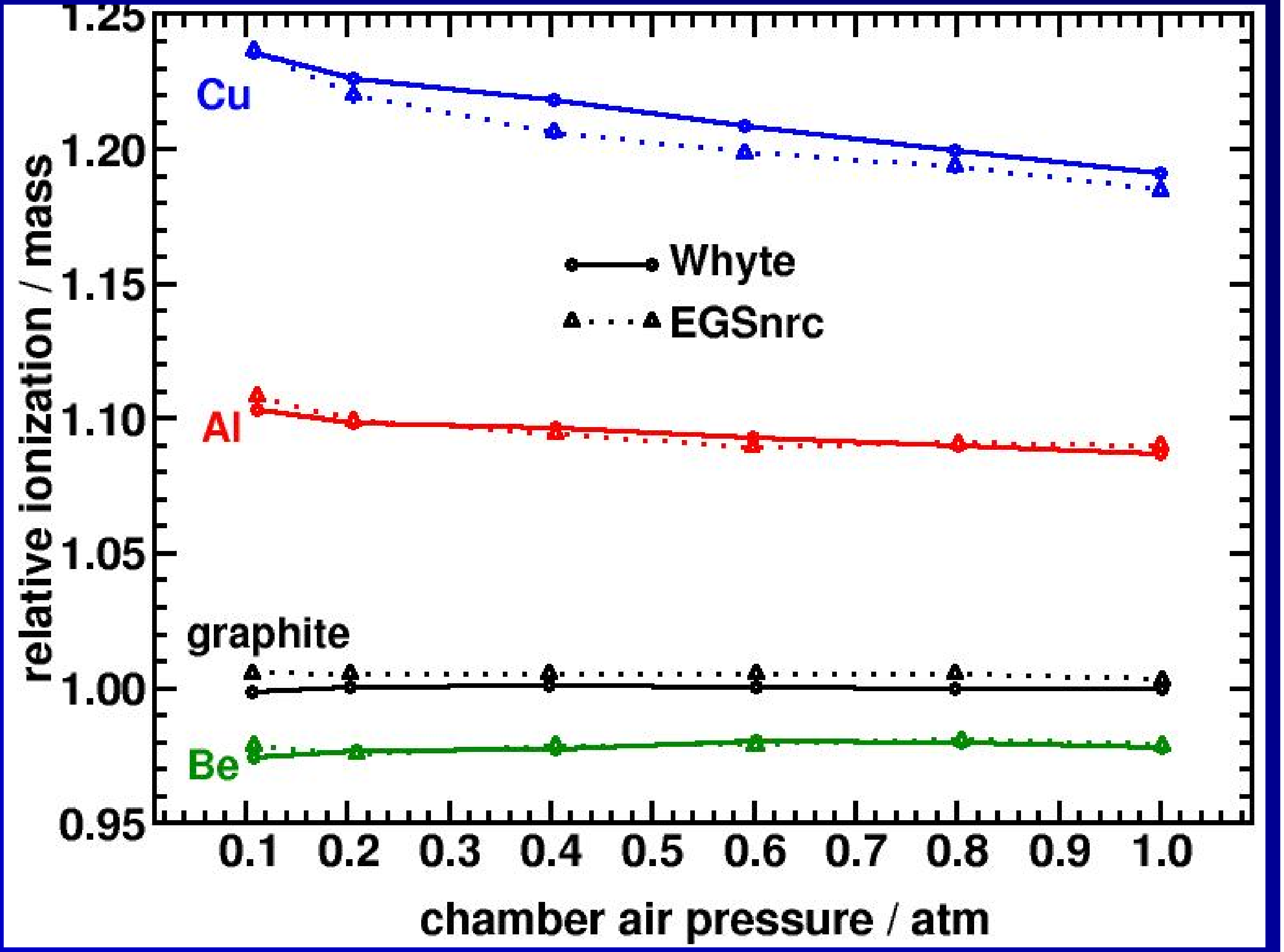
La Russa & Rogers Med Phys 35 (2008) 5629-5640

Whyte: variation of pressure/wal

- data normalized only once
  - i.e. relative values meaningful
  - depends on cross sections
- RMSD = 0.5%



Med Phys 35 (2008) 5629-5640

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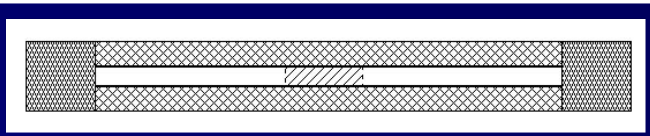
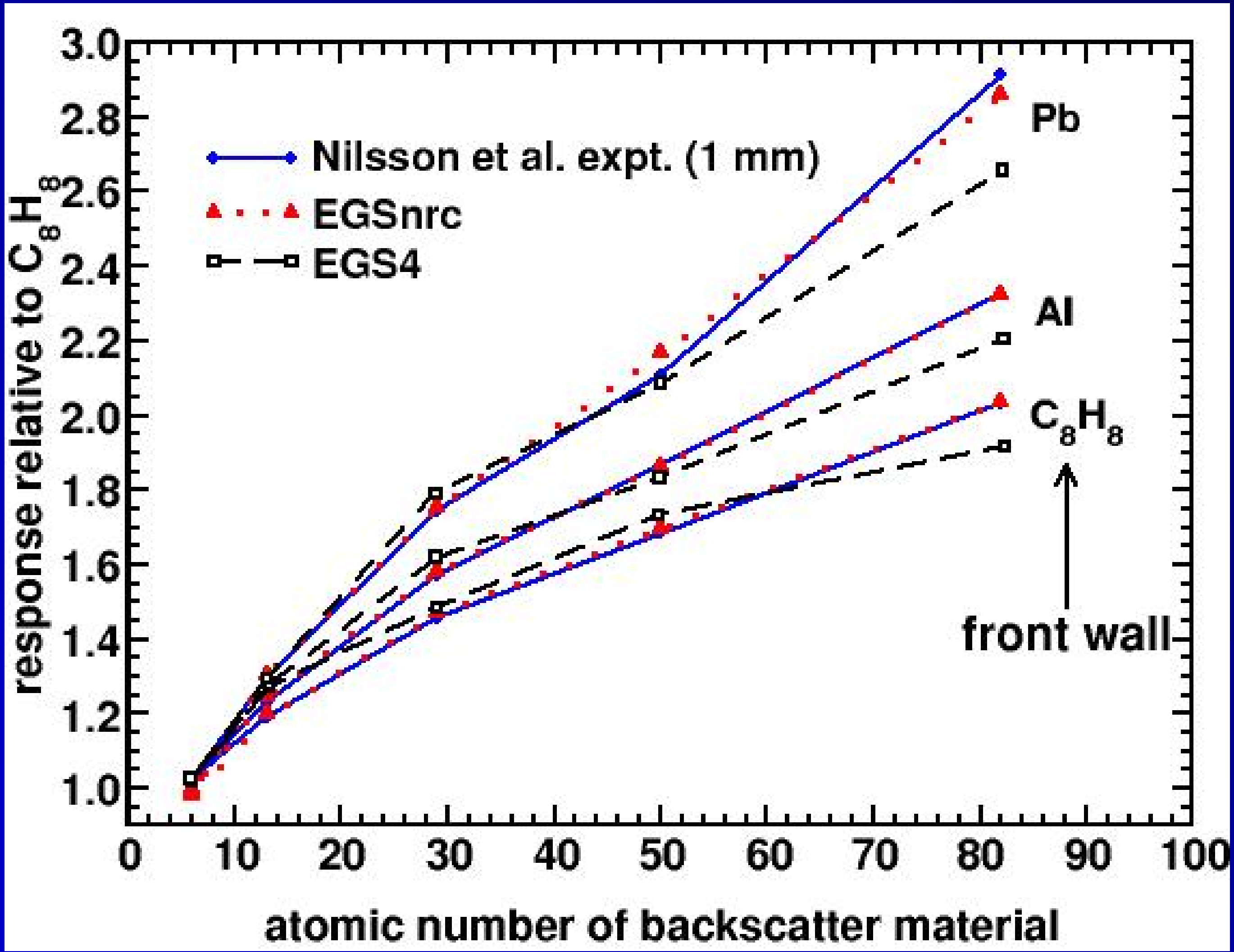


Nilsson et al: wall variations

- ^{60}Co
- normalized to polystyrene chamber
- RMSD=1.4% (EGSnrc/expt)
- depends on cross-sections

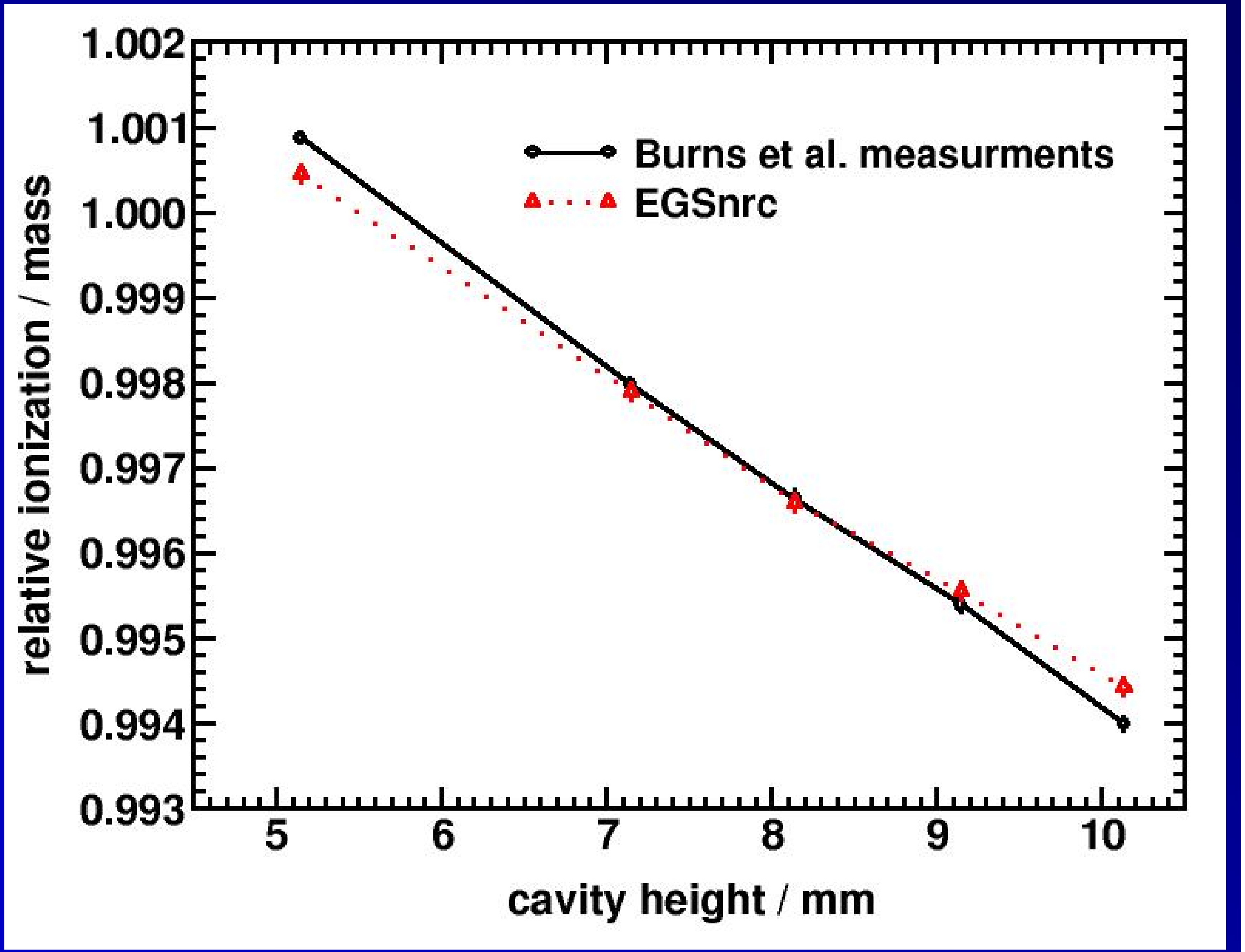


Med Phys 35 (2008) 5629-5640

Burns: variation of graphite chamber

- ^{60}Co

- RMSD = 0.03%
- (0.7% overall variation)



Med Phys 35 (2008) 5629-5640

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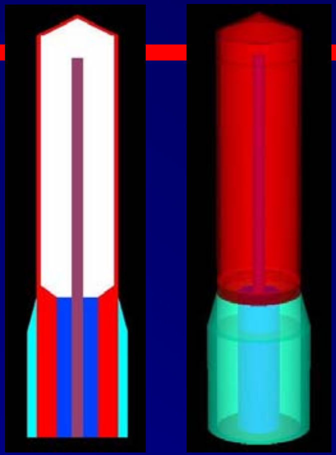
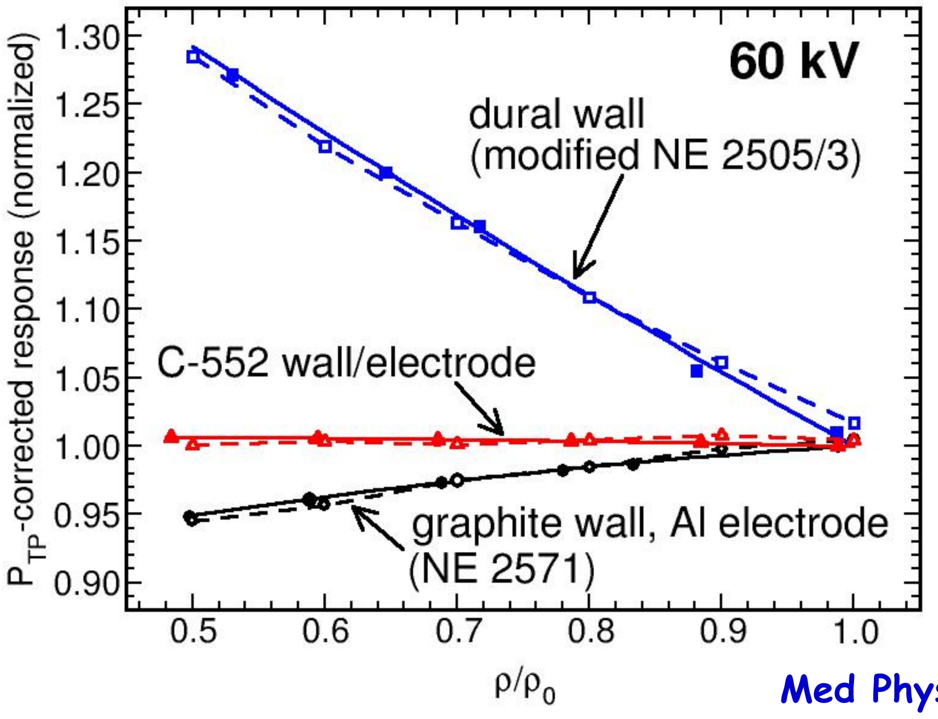
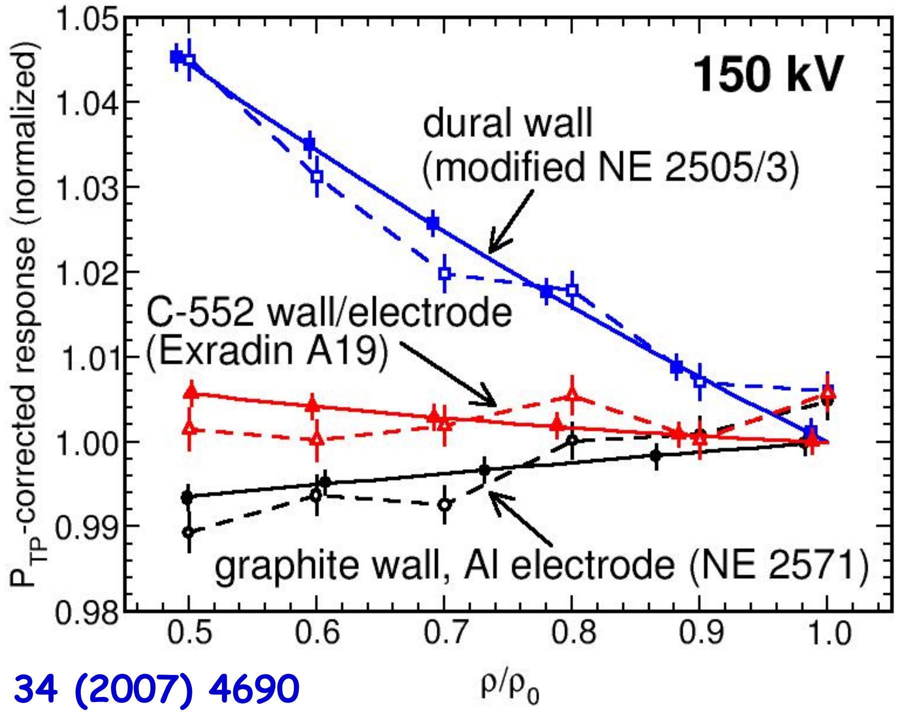
LaRussa et al: variation of pressure x-ray beams



- experiment = solid line
- EGSnrc = dashed line
- Calculated results generally within 0.5%.





Med Phys 34 (2007) 4690

brem yield from thick targets

Faddegon et al Med Phys 17 (1990) 773 and

Med Phys 18 (1991) 727

measured brem yield as a function of energy and angle for many different target materials and compared their results to EGS4 calculations.

Typical experimental uncertainty: 5%

Faddegon et al Med Phys 35(2008) 4308 compared same measured data to 3 Monte Carlo codes:

EGSnrc, GEANT4 and PENELOPE

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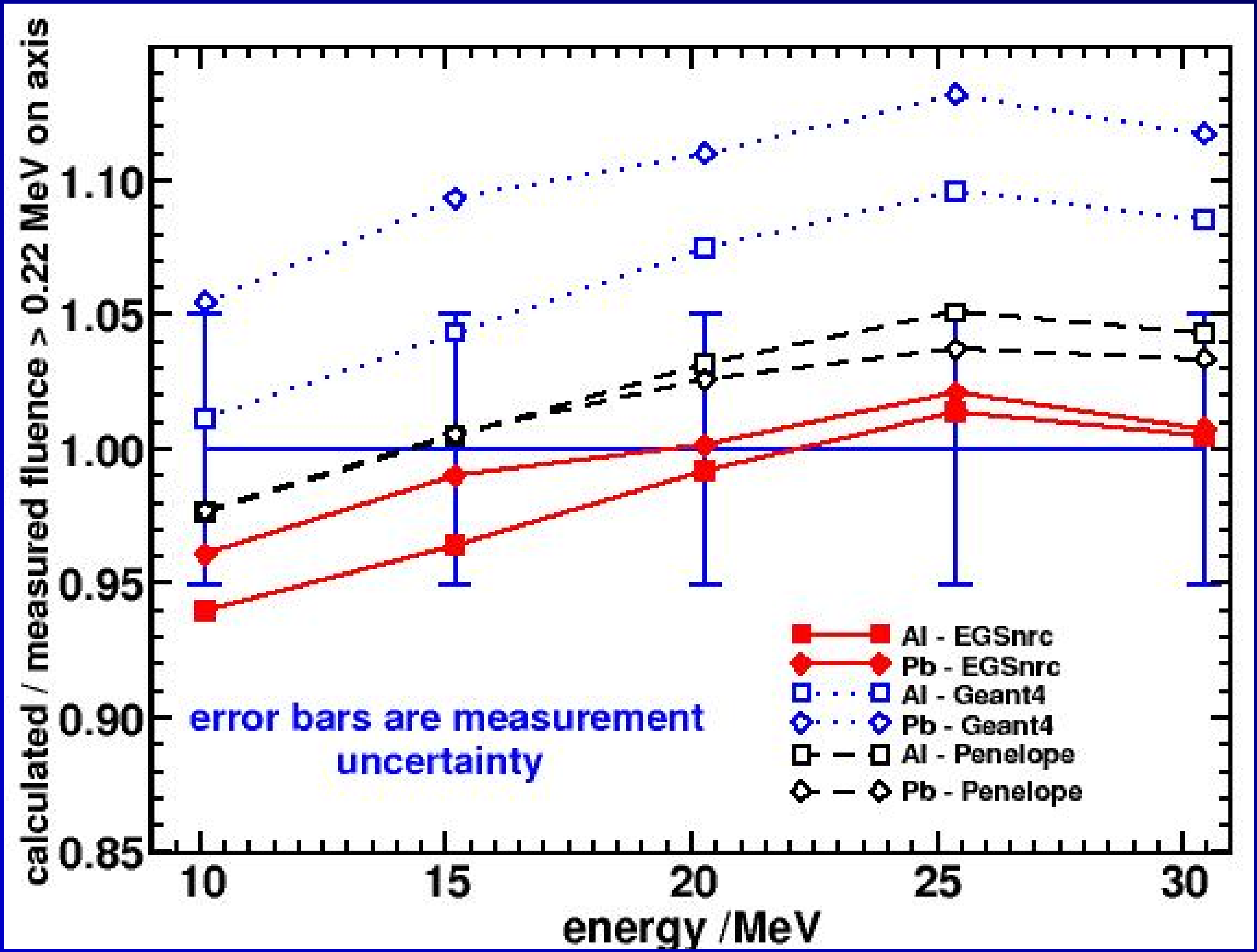
brem total yield vs incident energy

thick targets

5% uncertainty on measurements

photons

> 220 keV



Faddegon et al Med Phys 35 (2008) 4308

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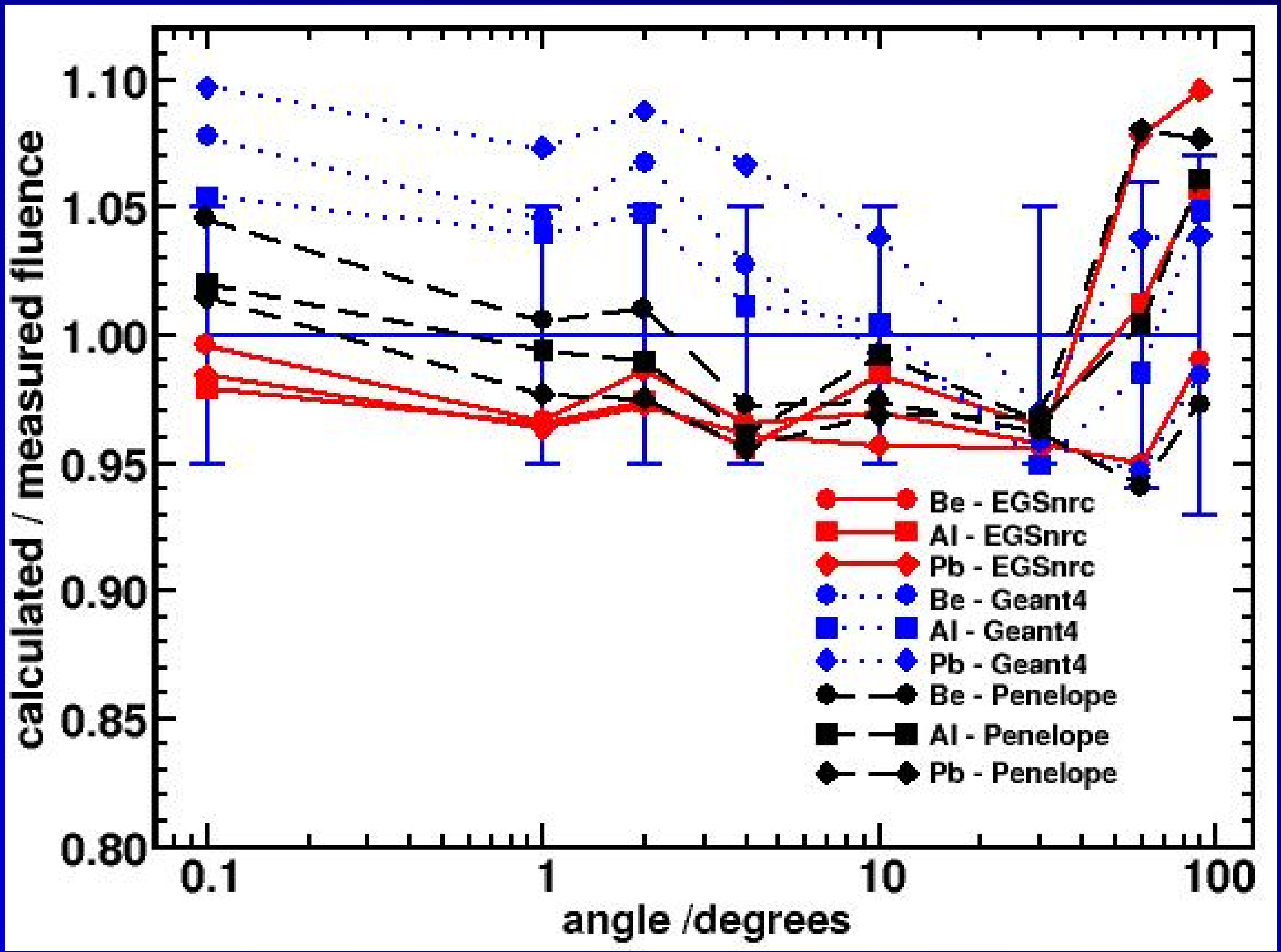
brem yield vs angle at 15 MV

thick targets

photons

> 145 keV

Note: yield at 90° is very small



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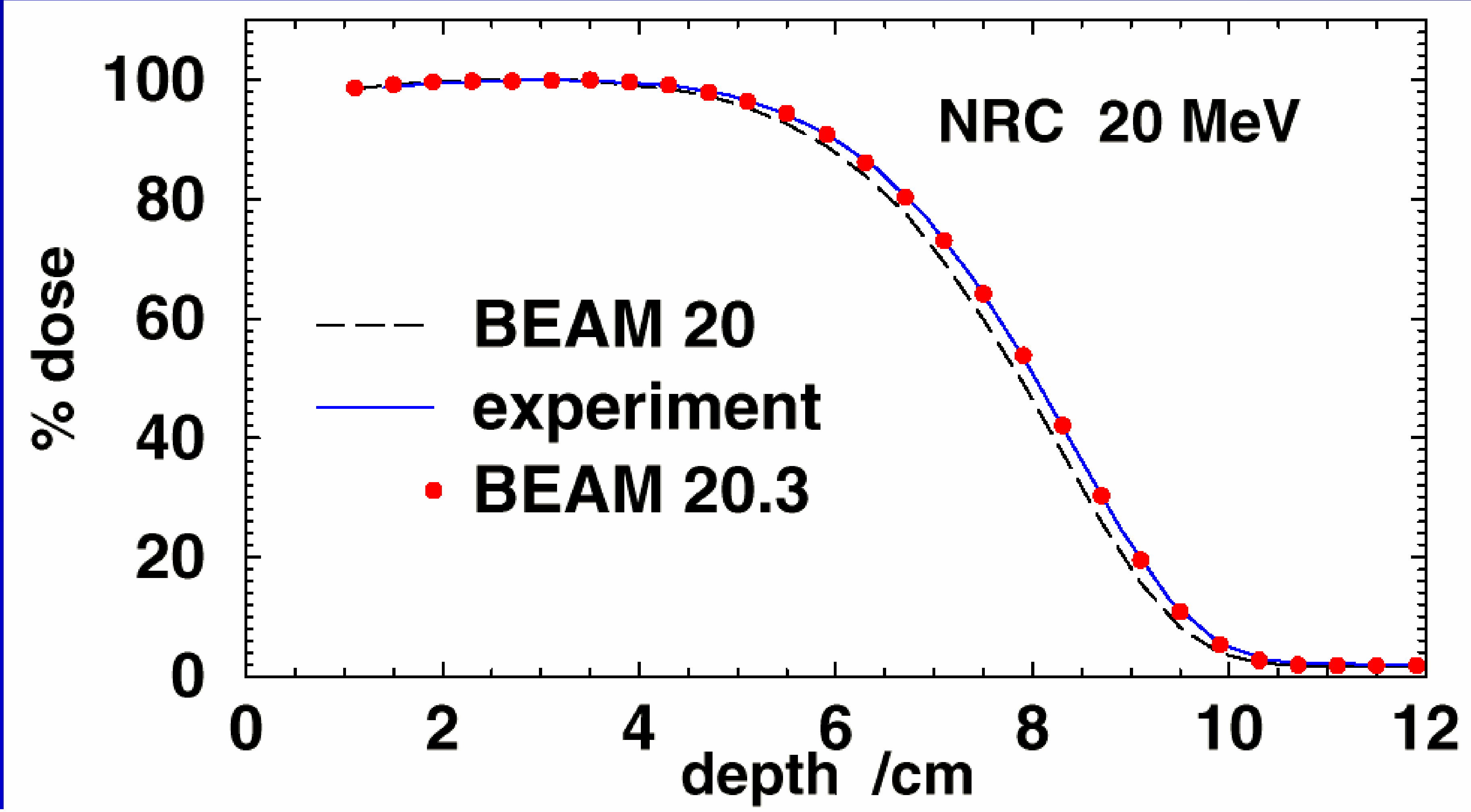
20 MeV NRC depth-dose



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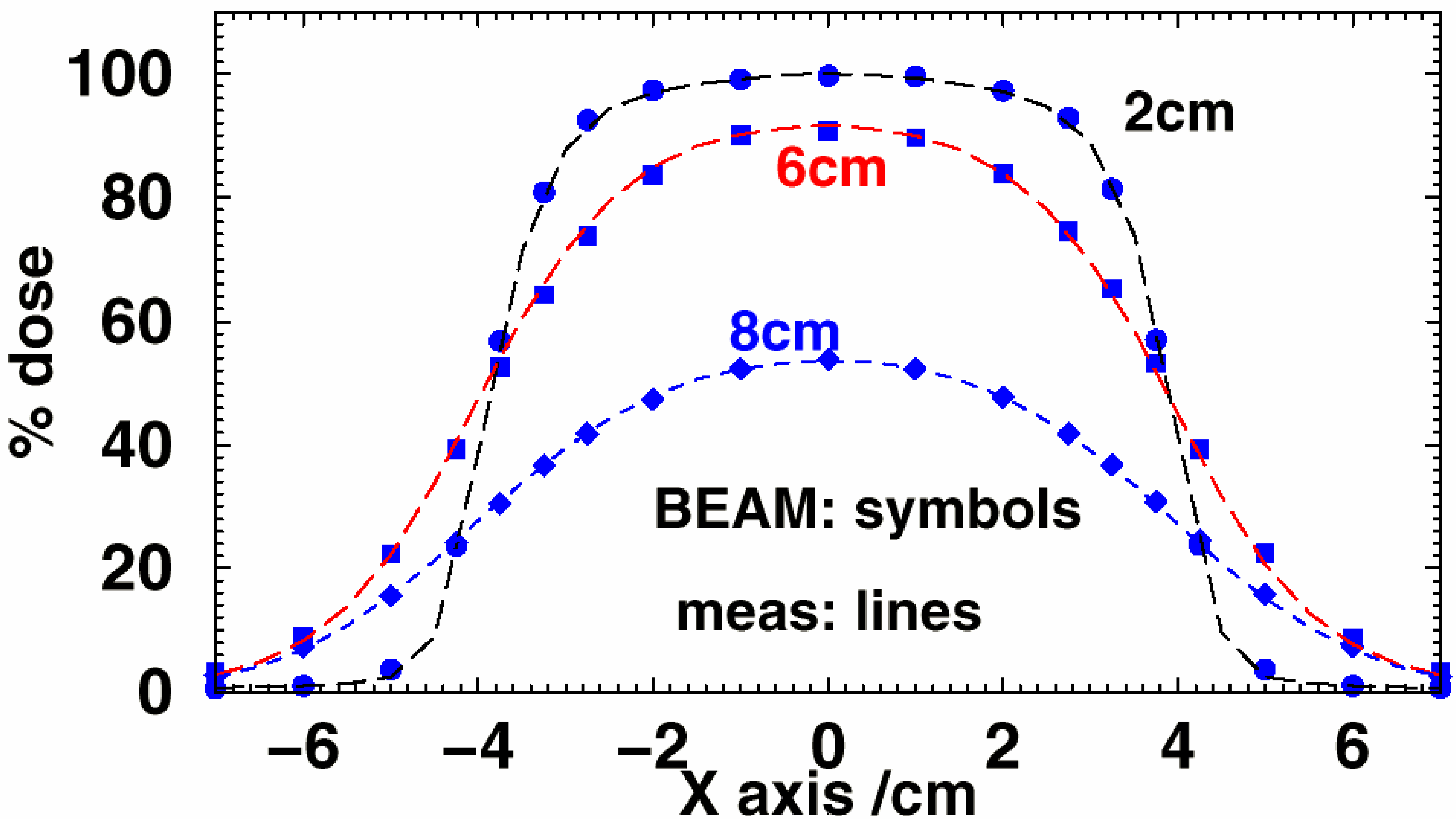
BEAM paper Med Phys 22(1995) 503-524

20 MeV NRC radial profile



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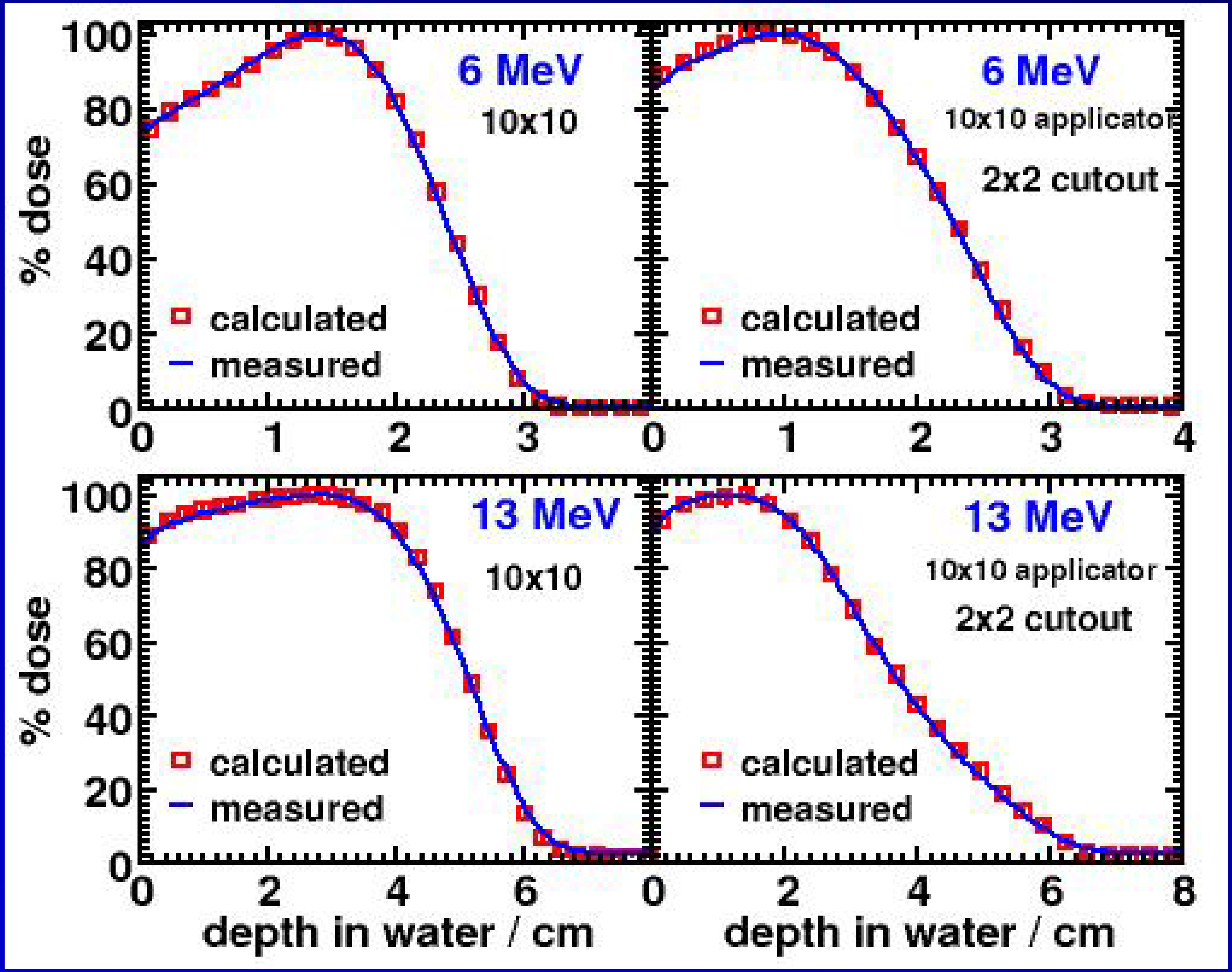
BEAM paper Med Phys 22(1995) 503-524

electron beam depth-dose curves

Siemens MD2

-diodes

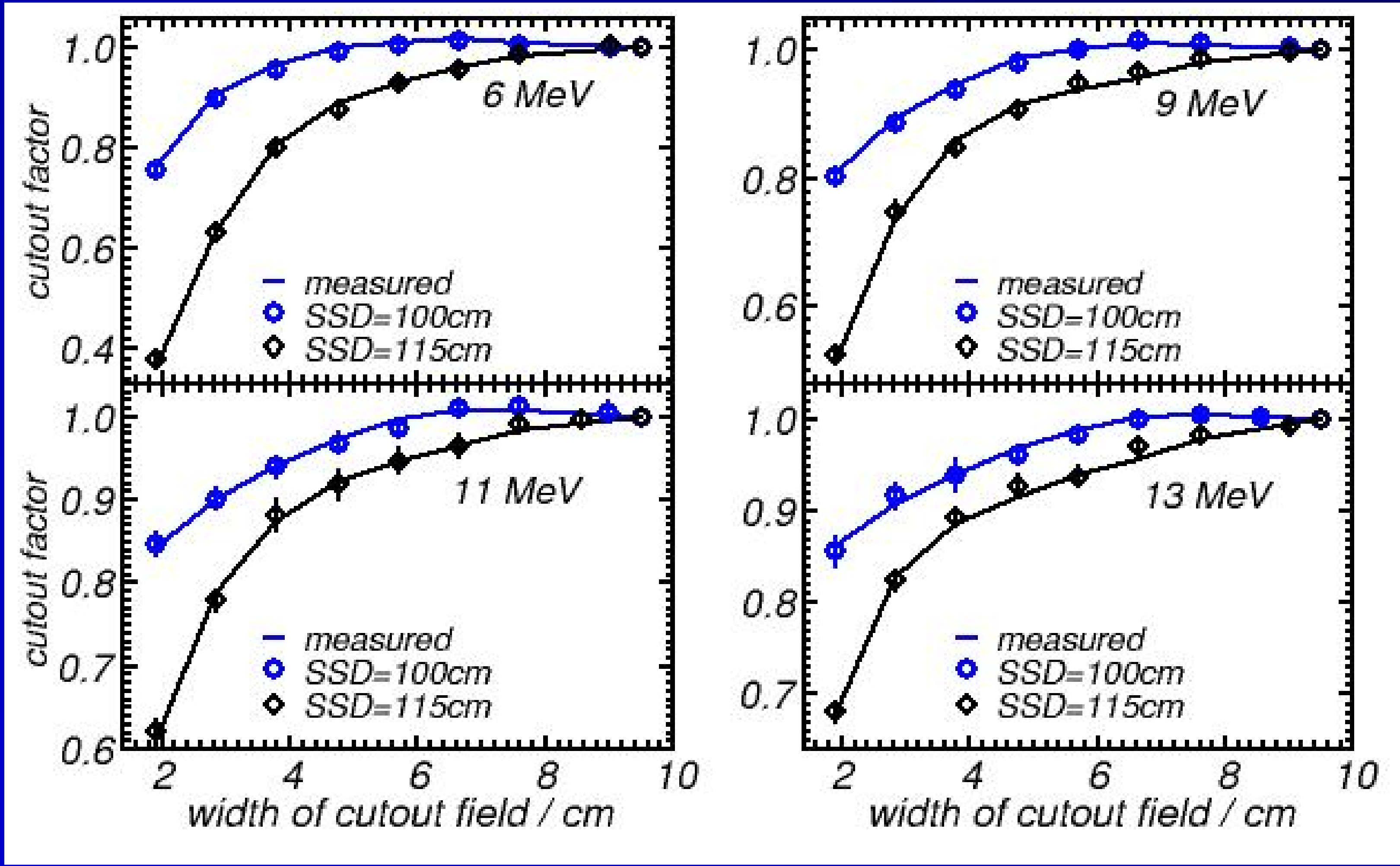


Zhang et al,. Med Phys 26 (1998) 743-750

electron beam cutout factors

Siemens MD2

-diodes



Med Phys 26 (1998) 743-750

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^{60}Co therapy unit

Issued June 17, 1988

Thanks to Jerry Battista

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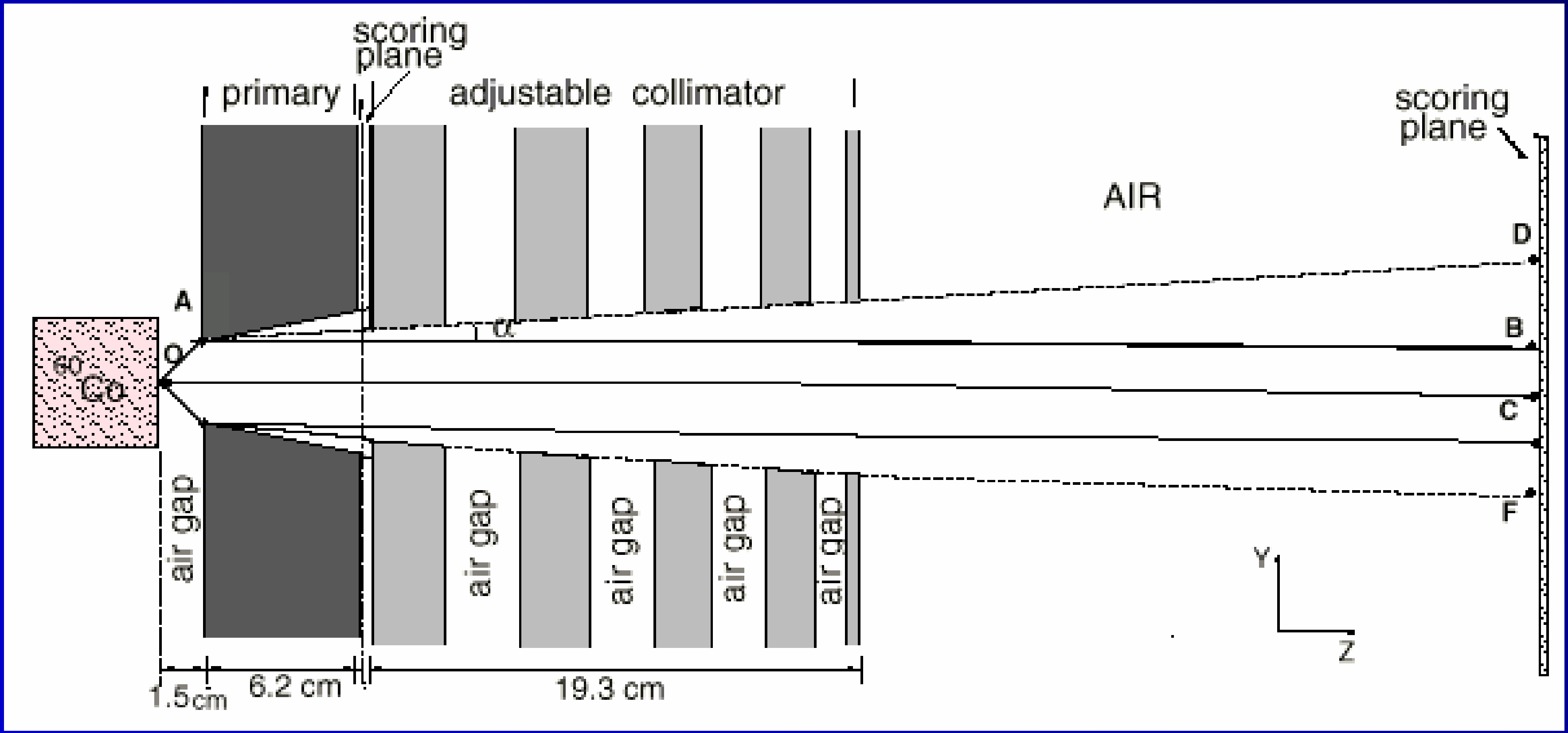
Simulating an Eldorado6



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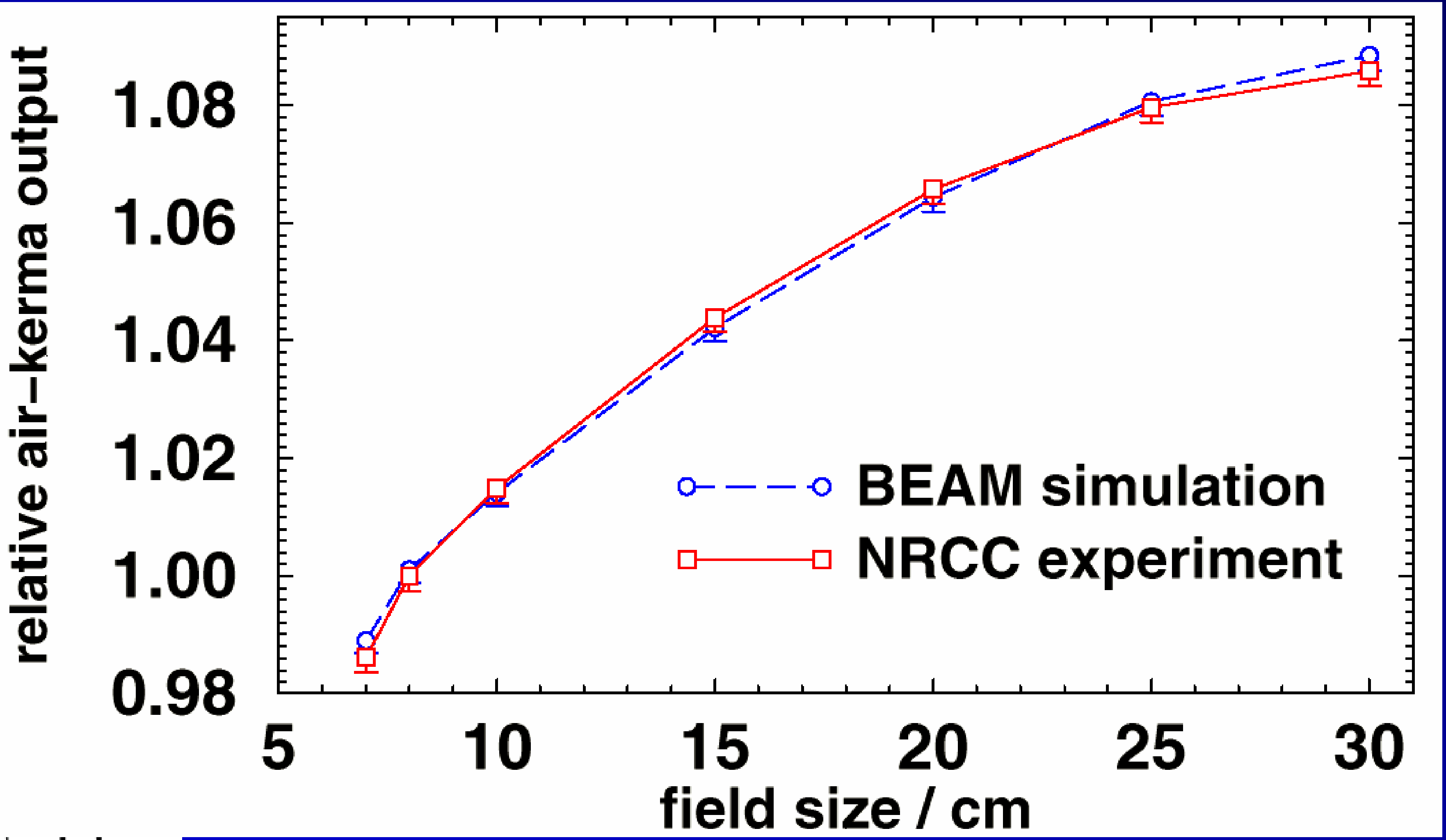
Mora et al Med Phys 26(1999) 2494

Output variation vs expt



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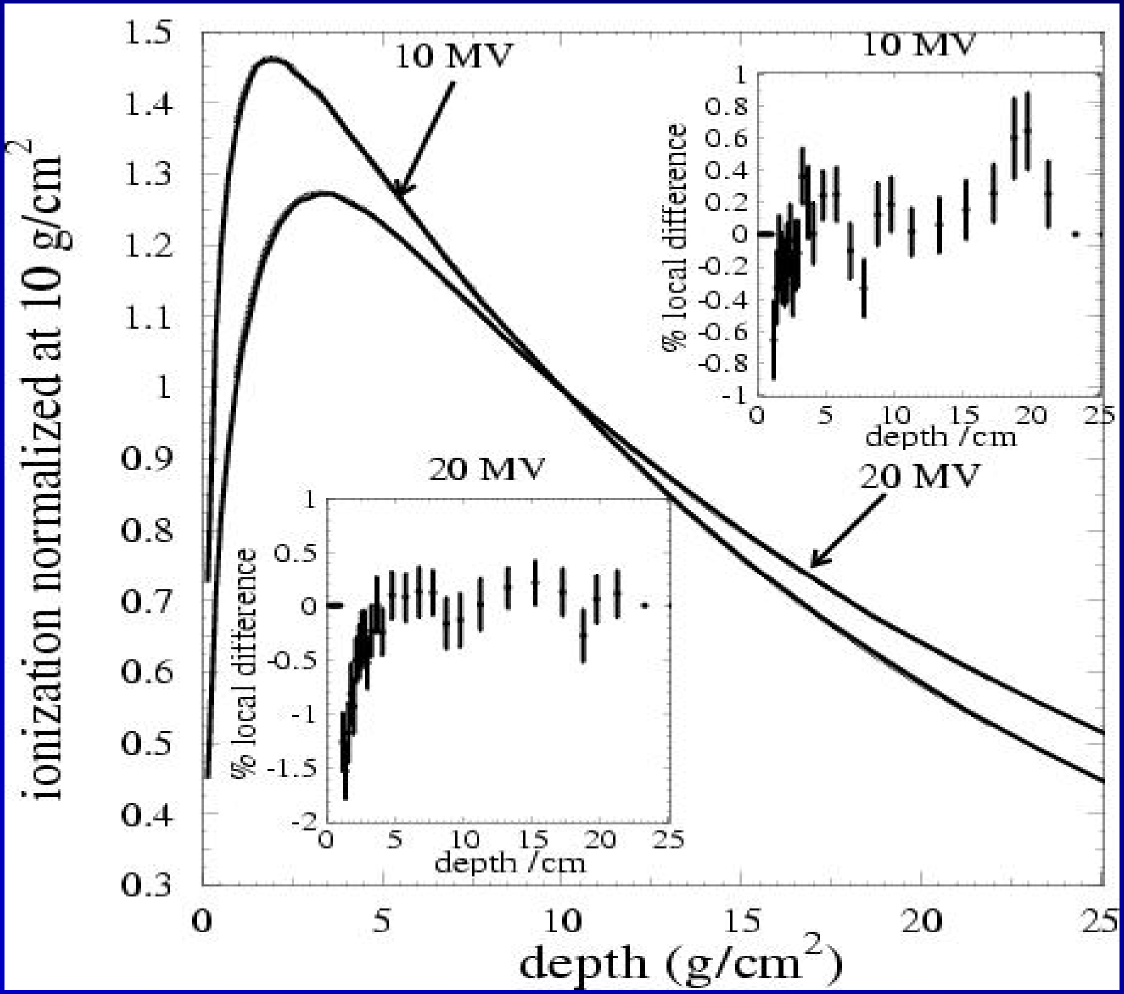
Med Phys 26(1999) 2494

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



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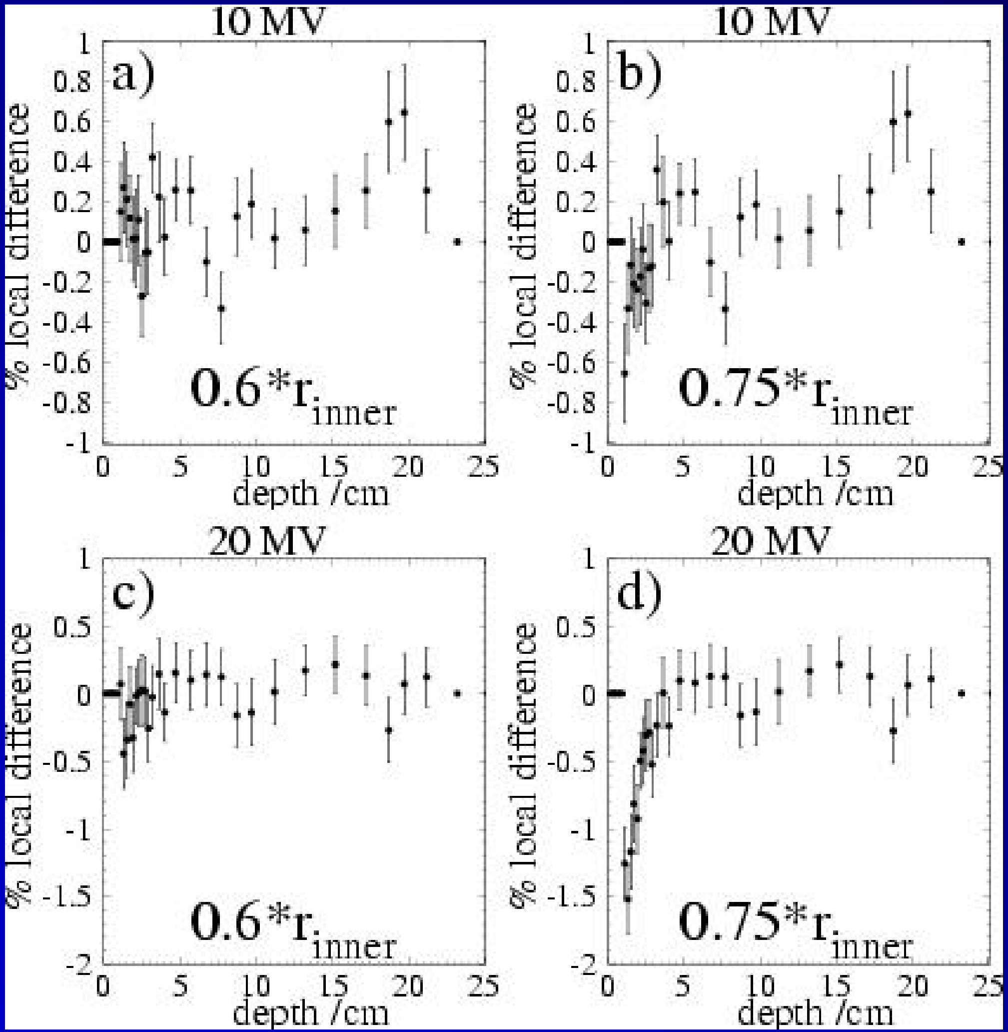
Sheikh-Bagheri et al Med Phys 27(2000) 2256-2266

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 used in TG51/TRS398



Med Phys 27(2000) 2256-2266

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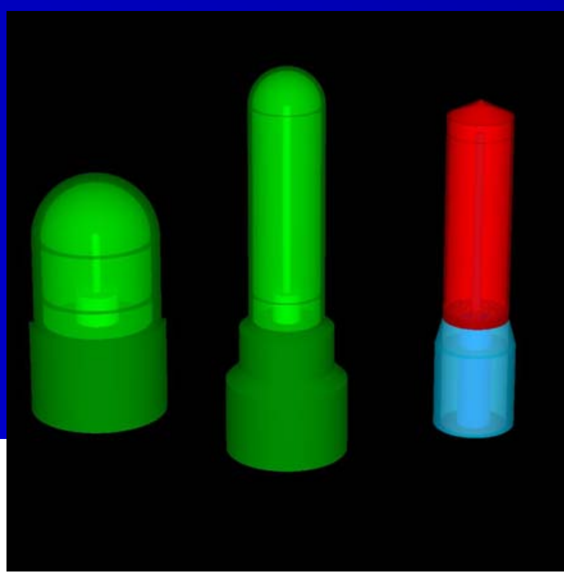
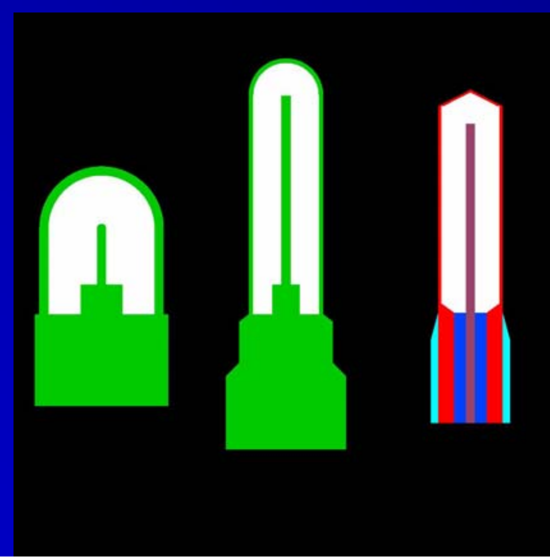
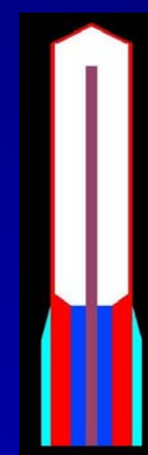
Geometry packages

- BEAMnrc for accelerators
- DOSRZnrc, CAVRZnrc,FLURZnrc for cylindrical geometry
- egs++ package of Kawrakow: a C++ general purpose interface with combinatorial geometry -very flexible
- worth effort to learn it (all my students have)



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Calculational efficiency

EGSnrc is much slower than VMC++ (only commercial)

EGSnrc timing is comparable to EGS4 which was comparable to ETRAN/ITS/MCNP for simple geometries

-but MCNP slows down considerably in complex geometries

EGSnrc is 3 to 5 times faster than PENELOPE ignoring variance reduction issues.

EGSnrc is much faster than GEANT4 (5 -10?)

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Acknowledgements

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- Geoff Zhang, Elsayed Ali, Dan La Russa, Waltraud Buchenberg, Daryoush Sheikh-Bagheri, and George Ding whose thesis work I have referred to.

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CRSNG