Some recent dosimetry studies with EGSnrc

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P_{repl}: PhD work of Lilie L W Wang

"Study of the replacement correction factors for ionization chamber dosimetry by Monte Carlo simulation"

Carleton University,

April 2009

Nominated for a Senate Medal

Many slides are from his work

See http://www.physics.carleton.ca/~drogers/pubs/theses

and 7 publications referenced therein (on line same site)

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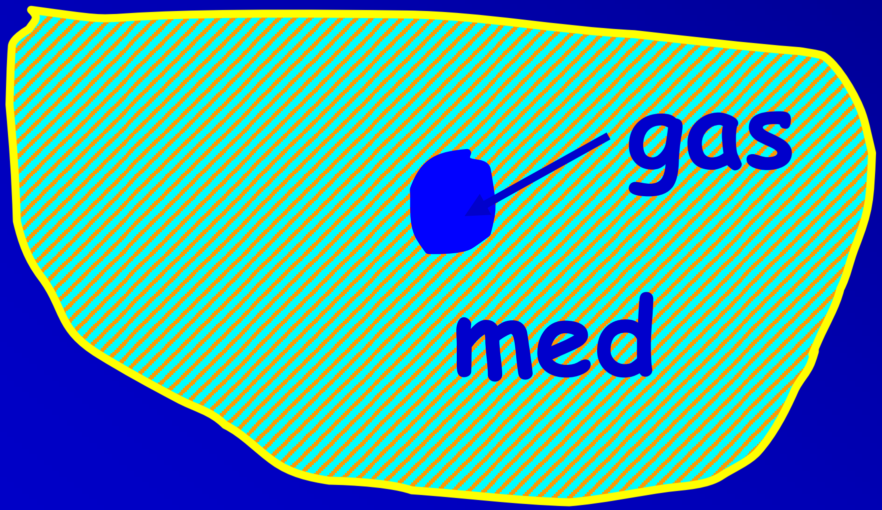
Cavity theory: stopping-power ratios

Relates dose in cavity to dose in medium.



sprs are fundamental to

-dosimetry protocols

-primary standards

$$D_{med} = D_{gas} \left(\overline{L}/\rho\right)^{med}_{gas}$$

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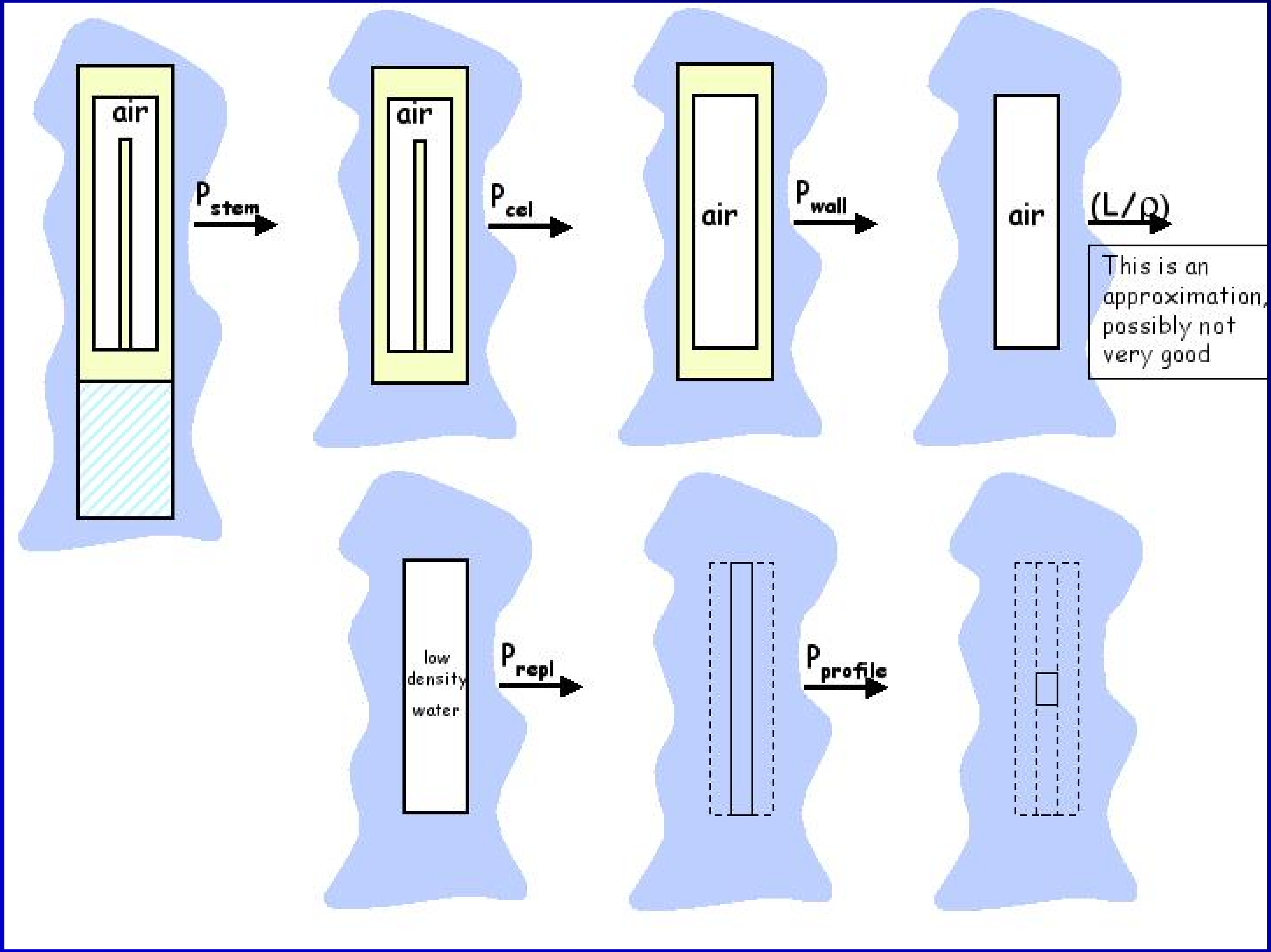
Dosimetry in a water tank with realistic ion chamber



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Dosimetry in a water tank

$$D_{\rm med} = D_{\rm gas} \left(\frac{L}{\rho}\right)^{\rm med}_{\rm air} P_{\rm wall} P_{gr} P_{fl} P_{\rm cel}$$

$$P_{\rm repl} = P_{gr} P_{fl} = p_{\rm dis} p_{\rm cav}$$

for complete definitions of $P_{\rm wall}$ etc see
http://www.physics.carleton.ca/~drogers/pubs/papers/ss96.pdf

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P_{repl} in dosimetry protocols

Electron beams

- "well-guarded" plane-parallel chambers: $P_{repl} = 1$
- cylindrical chambers: measured P_{repl} at d_{max}($= P_{fl}$)

Photon beams

- plane-parallel chambers: $P_{repl} = 1$
- cylindrical chambers: measured $P_{repl} = P_{gr}$

TRS-398: the uncertainty in value of P_{repl} in photon beams "is one of the major contributions to the final uncertainty in k_Q"

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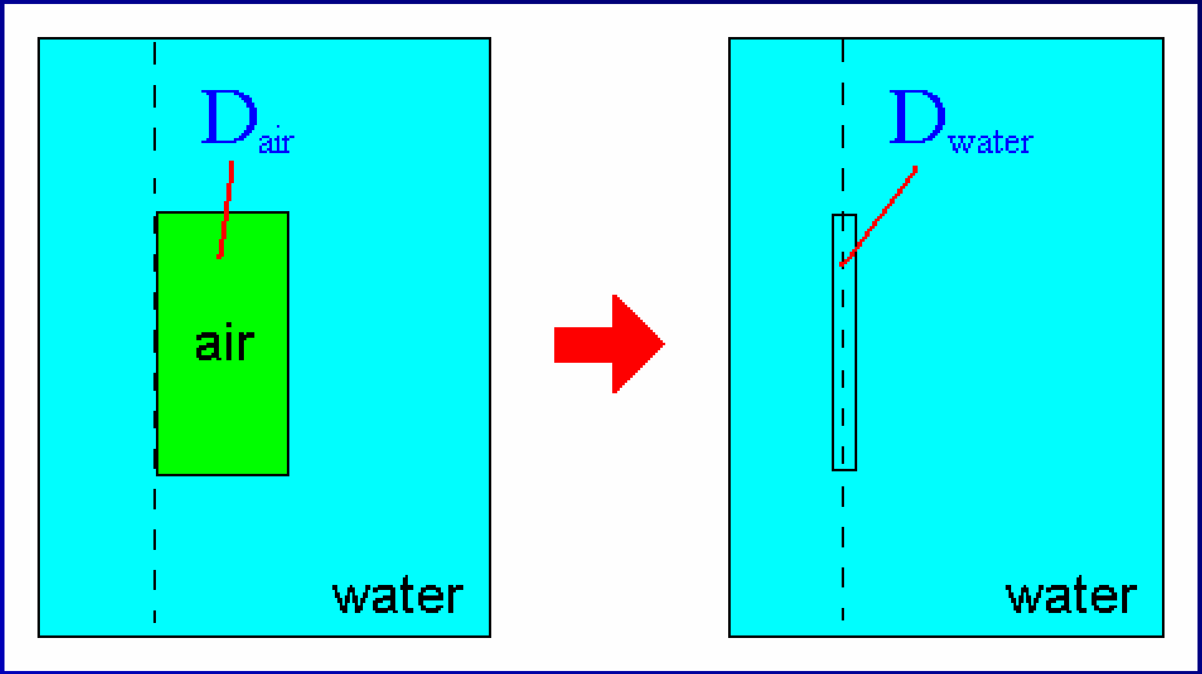
P_{repl} calculation methods (I)

SPR method



$$P_{\text{repl}} = \frac{D_{\text{water}}}{D_{\text{air}}} \Big/ \left(\frac{\overline{L_\Delta}}{\rho}\right)^{\text{water}}_{\text{air}}$$

Need a separate stopping-power ratio calculation.
This is "traditional" technique - residual effect.

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P_{repl} calculation methods (II)

FLU method

If electron fluence spectrum in air cavity differs from that in water only by a constant, i.e. $\Phi_{water}(E)$ = const x $\Phi_{air}(E)$, then

$$P_{\mathrm{repl}} = \frac{\Phi_{\mathrm{Total,water}}}{\Phi_{\mathrm{Total,air}}}$$

P_{repl} value depends on the above assumption

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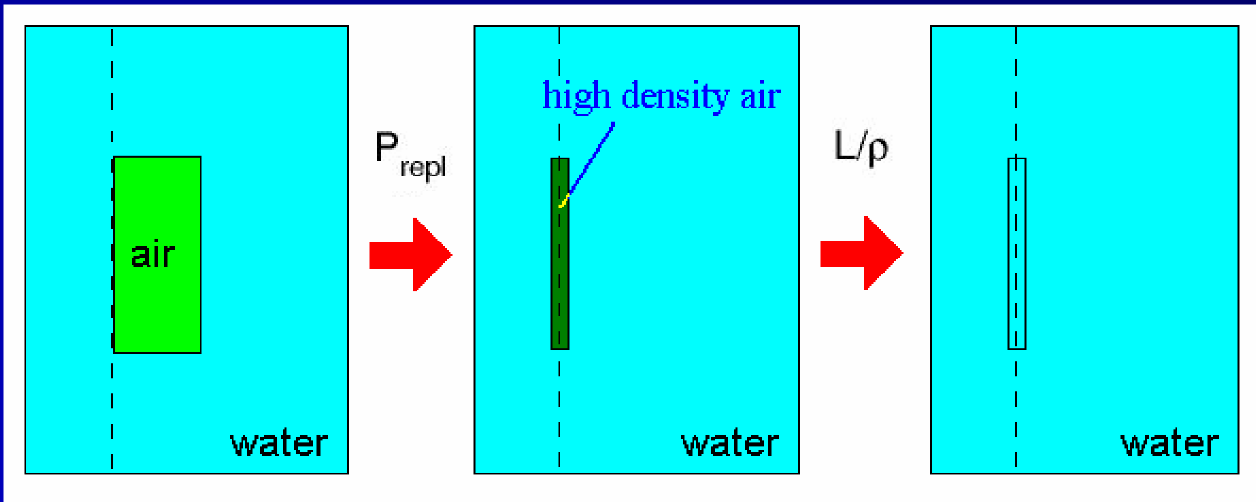
P_{repl} calculation methods (III)

HDA method (direct method)

$$P_{\rm repl} = \frac{D_{\rm HDA}}{D_{\rm air}} \Big/ \left(\frac{\bar{L}_\Delta}{\rho}\right)^{\rm air}_{\rm air}$$

$$P_{\rm repl} = \frac{D_{\rm HDA}}{D_{\rm air}}$$



Replace thin slab of water with thin slab of high density air (HDA) which is same as normal-density air except with water density.

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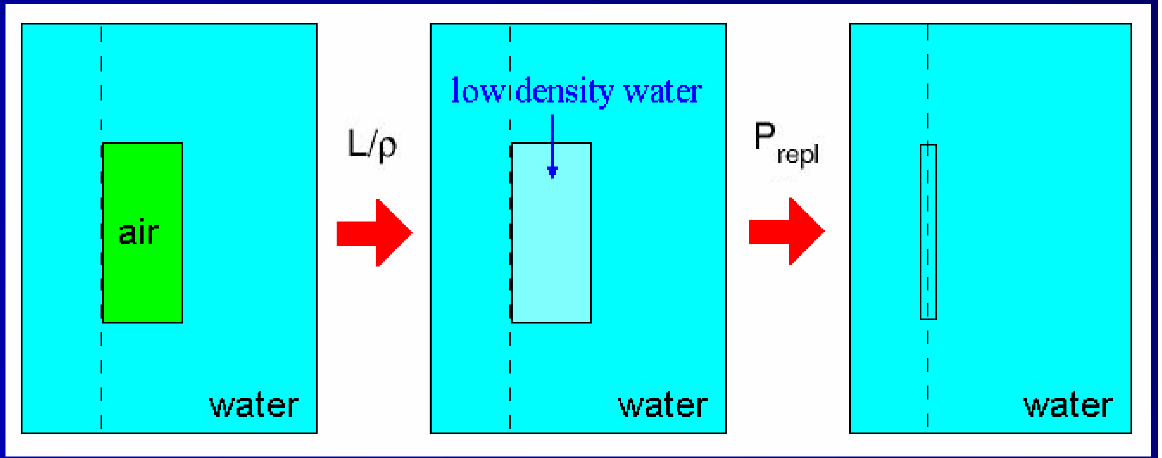
P_{repl} calculation methods (IV)

LDW method (direct method)

$$P_{\mathrm{repl}} = \frac{D_{\mathrm{water}}}{D_{\mathrm{LDW}}} \Big/ \left(\frac{\overline{L_\Delta}}{\rho}\right)^{\mathrm{water}}_{\mathrm{water}}$$



$$P_{\mathrm{repl}} = \frac{D_{\mathrm{water}}}{D_{\mathrm{LDW}}}$$

Replace air in cavity with low density water (LDW) which is same as normal-density water except with air's density

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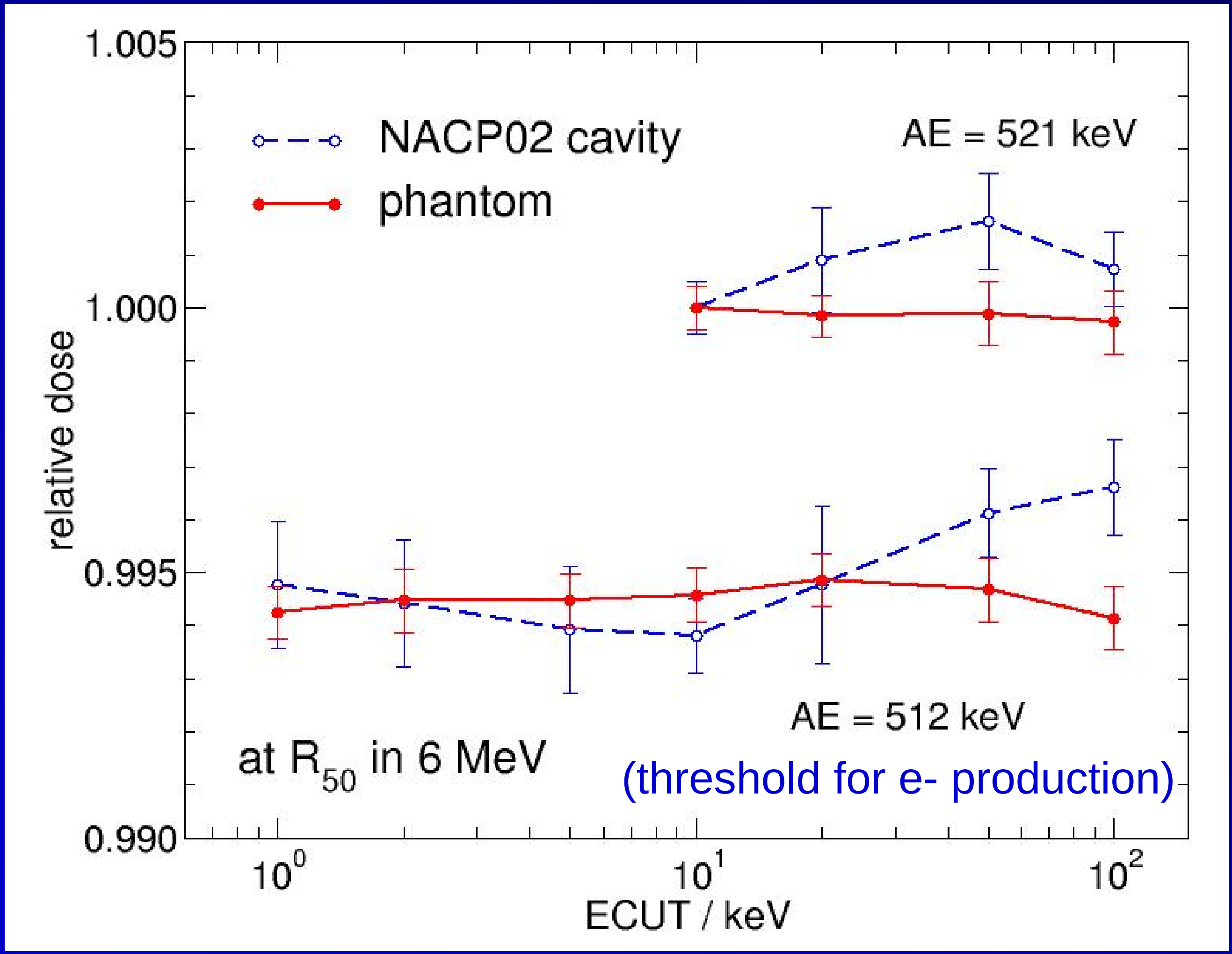
Dose in water & NACP02 cavity vs cutoff energy at R_{50} in 6 MeV electron beam

- *difference due to energy-loss straggling effects on depth-dose*
- *but ratio independent of AE or ECUT at 0.1% stats*
- *AE 512 3-5 times slower*



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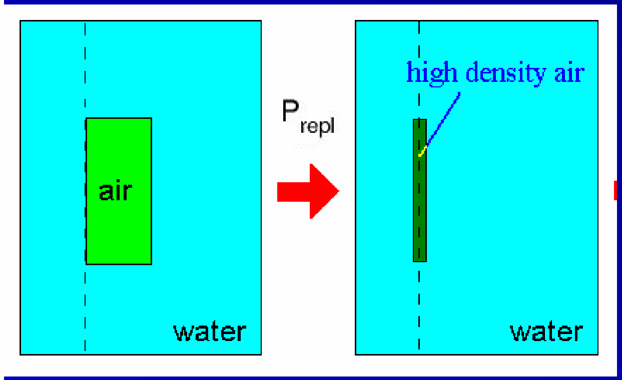
normalized separately at AE & ECUT=10 keV

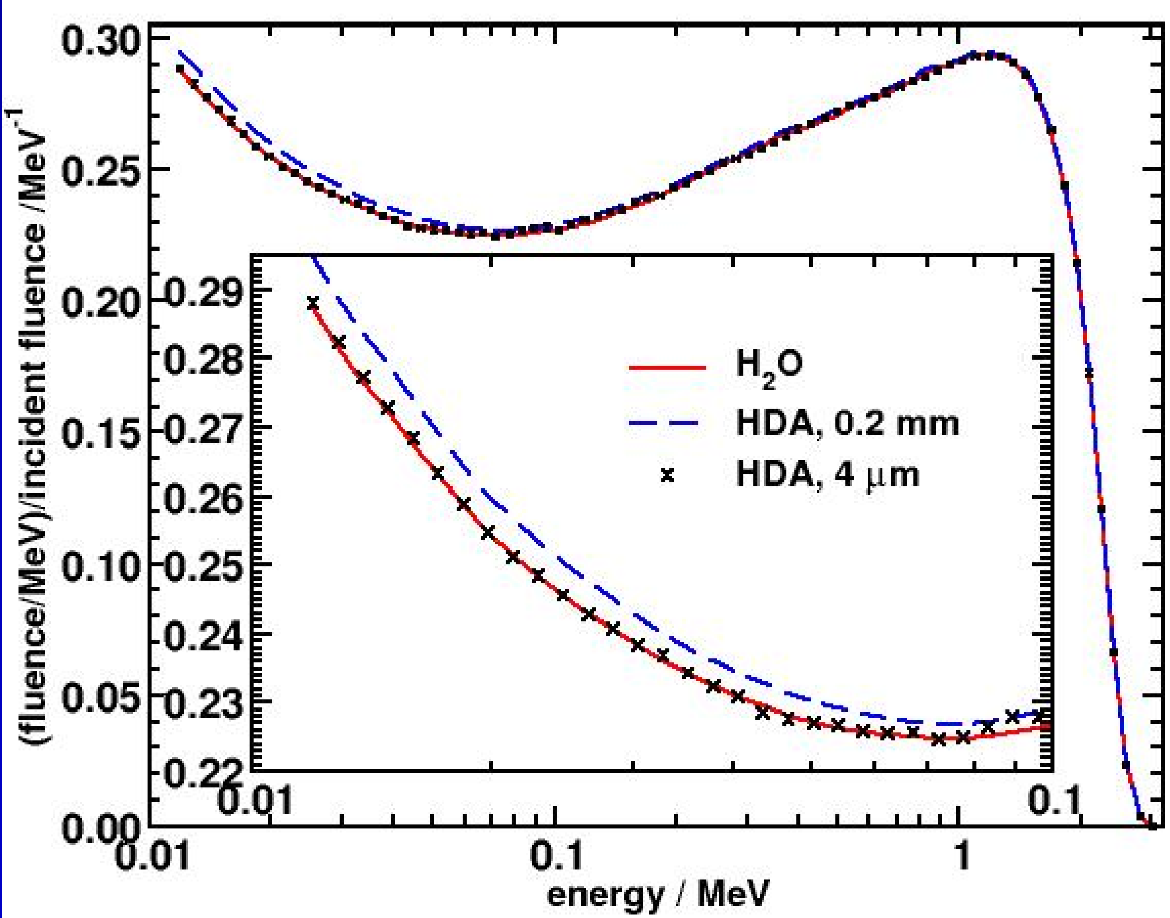
HDA method: uncertainties



$$P_{\mathrm{repl}} = \frac{D_{\mathrm{HDA}}}{D_{\mathrm{air}}}$$

Assumption is that spectra in HDA and water are the same

-if slab sufficiently thin.



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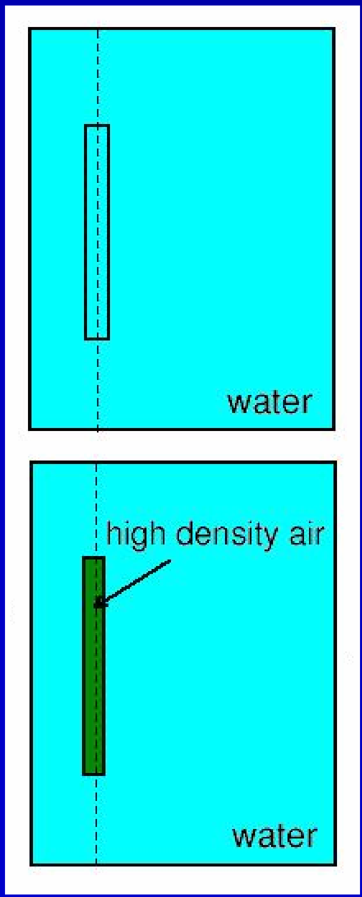
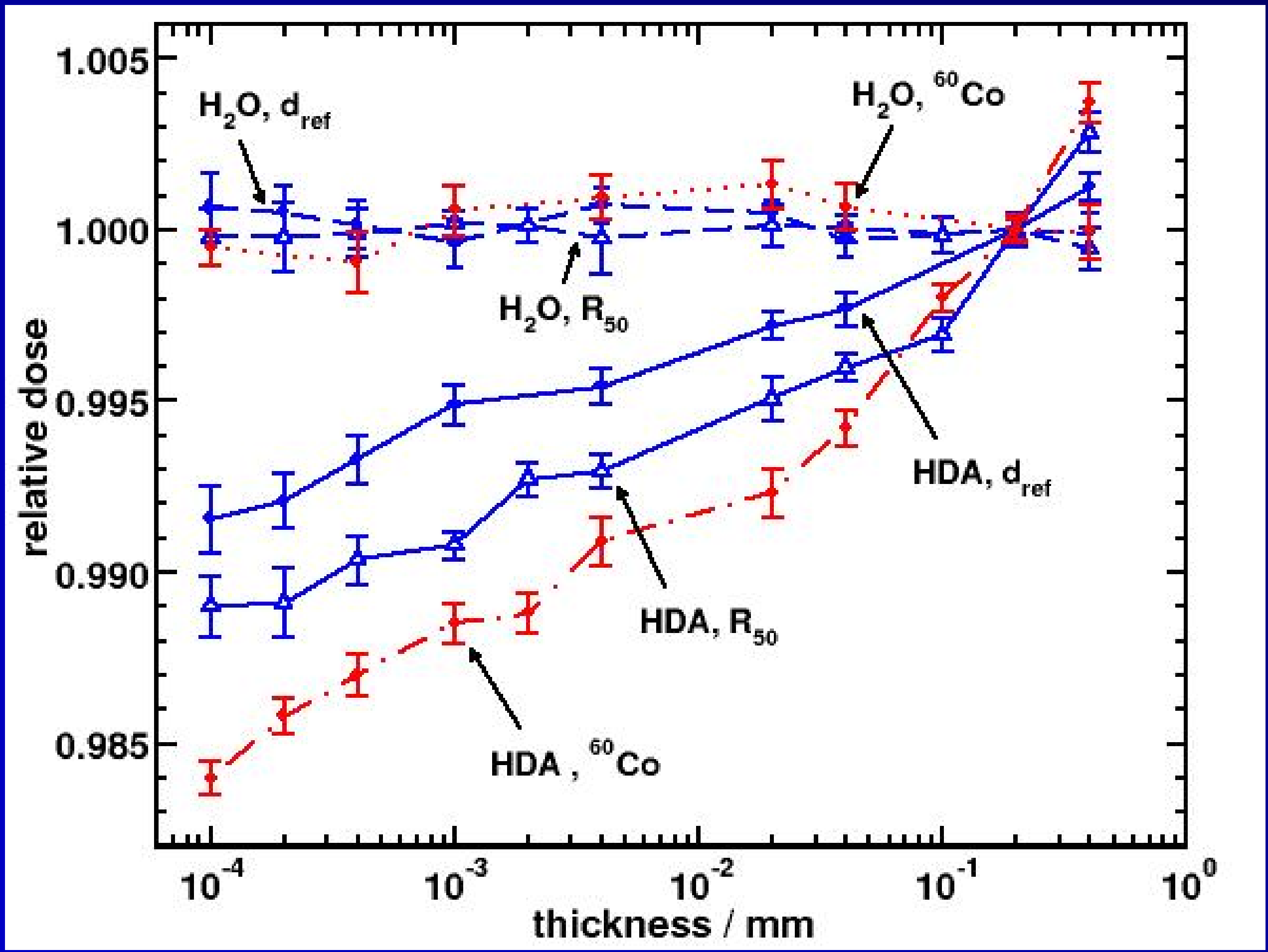
HDA method: slab thickness





Is the variation due to fluence perturbation or ?

Constant H_2O result => OK with very thin slabs

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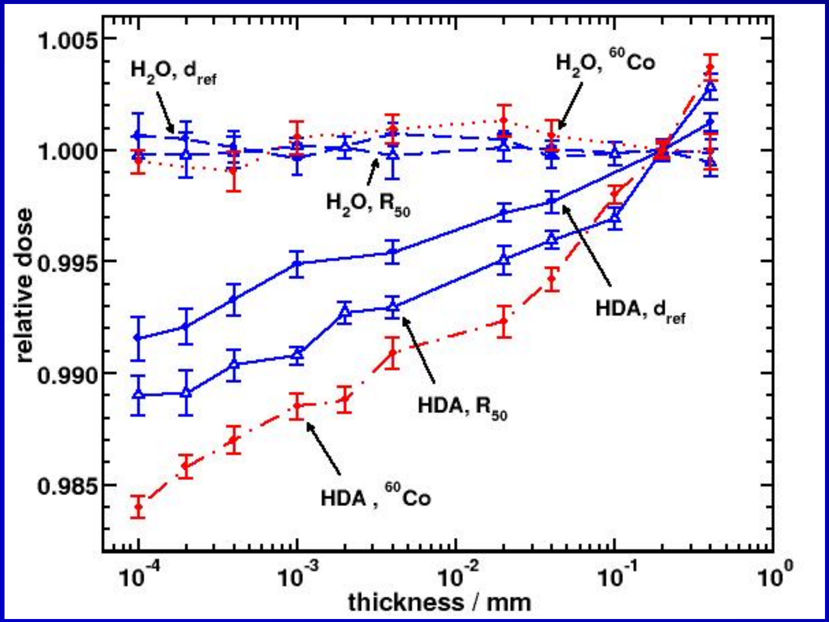
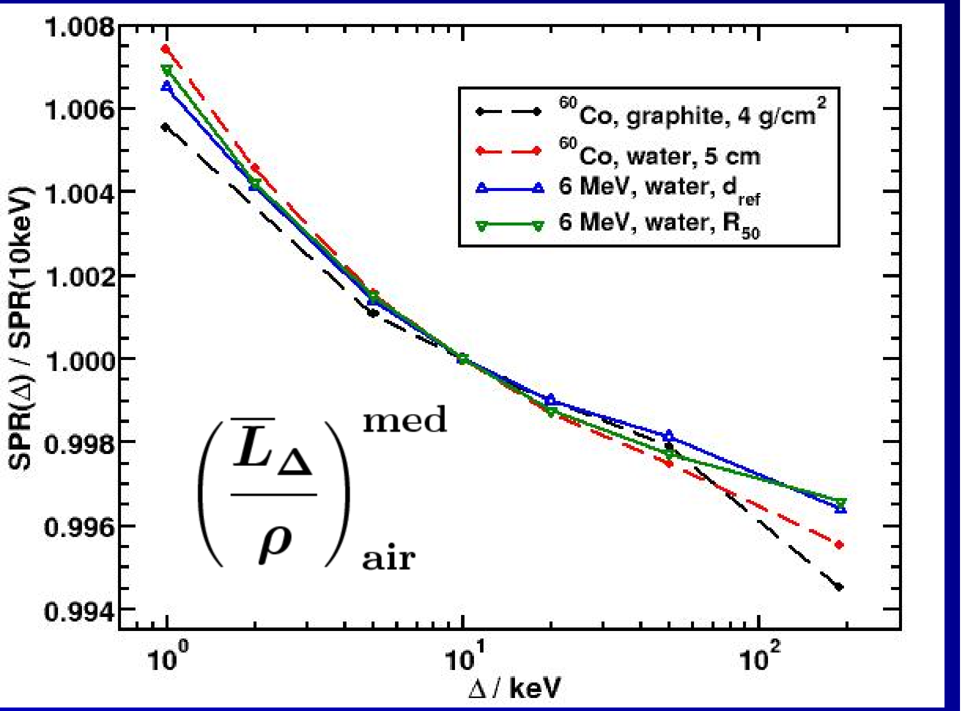
HDA method: slab thickness



$$\frac{D_{water}}{D_{HDA}} = \left(\frac{\bar{L}_\Delta}{\rho}\right)_{air}^{water}$$



At least part of the variation is due to variation in Δ which is related to thickness via range of e-

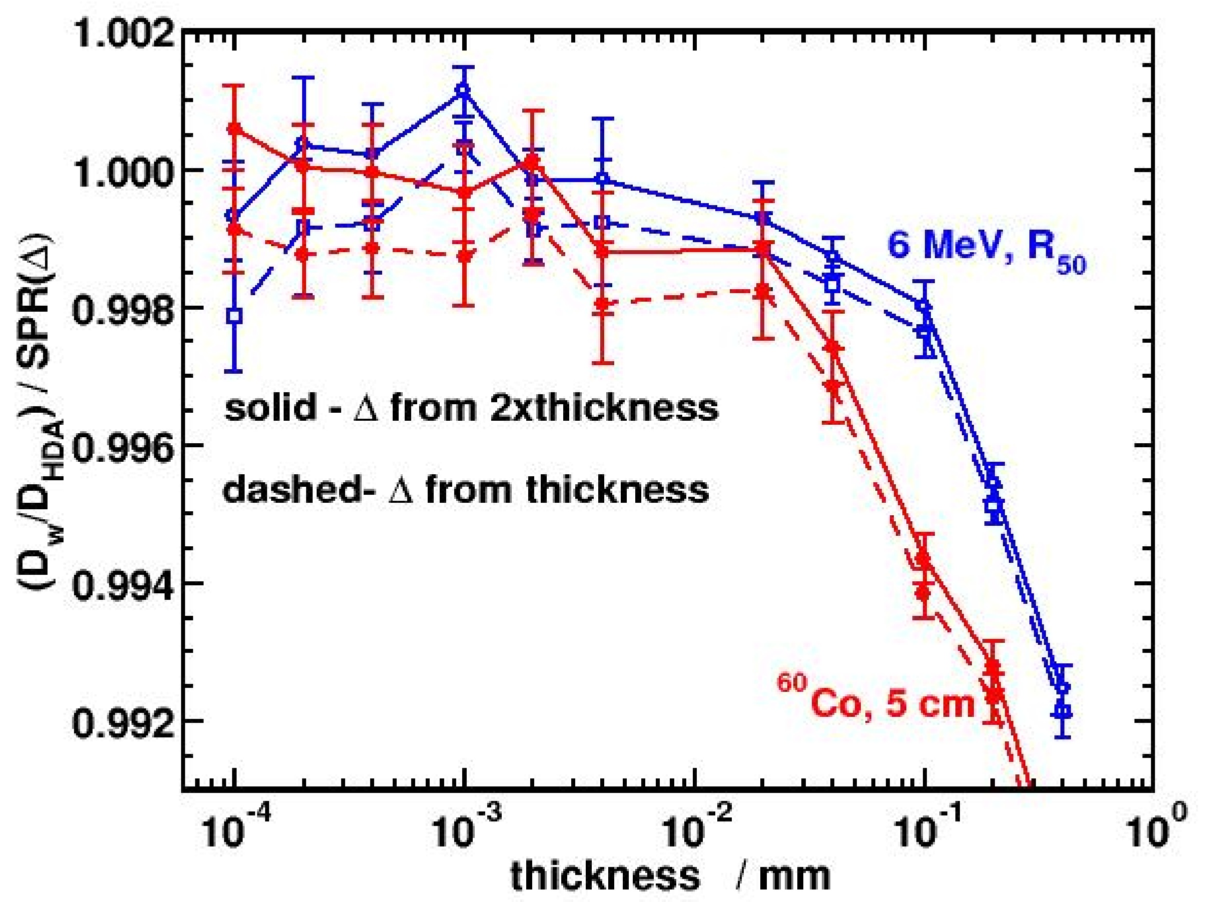
Select thickness corresponding to cavity average chord via L=4V/S = 2t, or just t

HDA: is there a perturbation?

If yes, then:

$$\frac{D_{\text{water}}}{D_{\text{HDA}}} = \left(\frac{\overline{L}_\Delta}{\rho}\right)_{\text{air}}^{\text{water}} P$$

Dose ratio/spr constant (=1)
=> no fluence perturbation.
For greater thickness there is (seen at 2 mm above).



2 possible algorithms for D, 2xthickness better
But difference less than 0.2%

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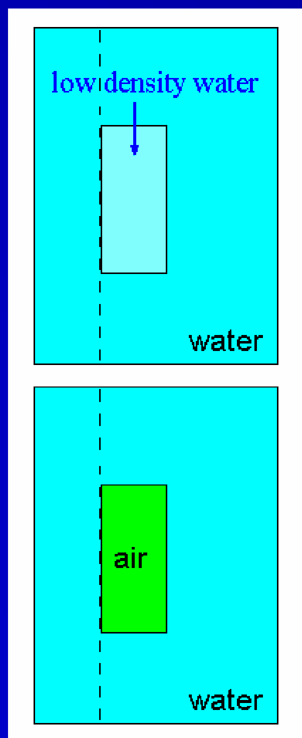
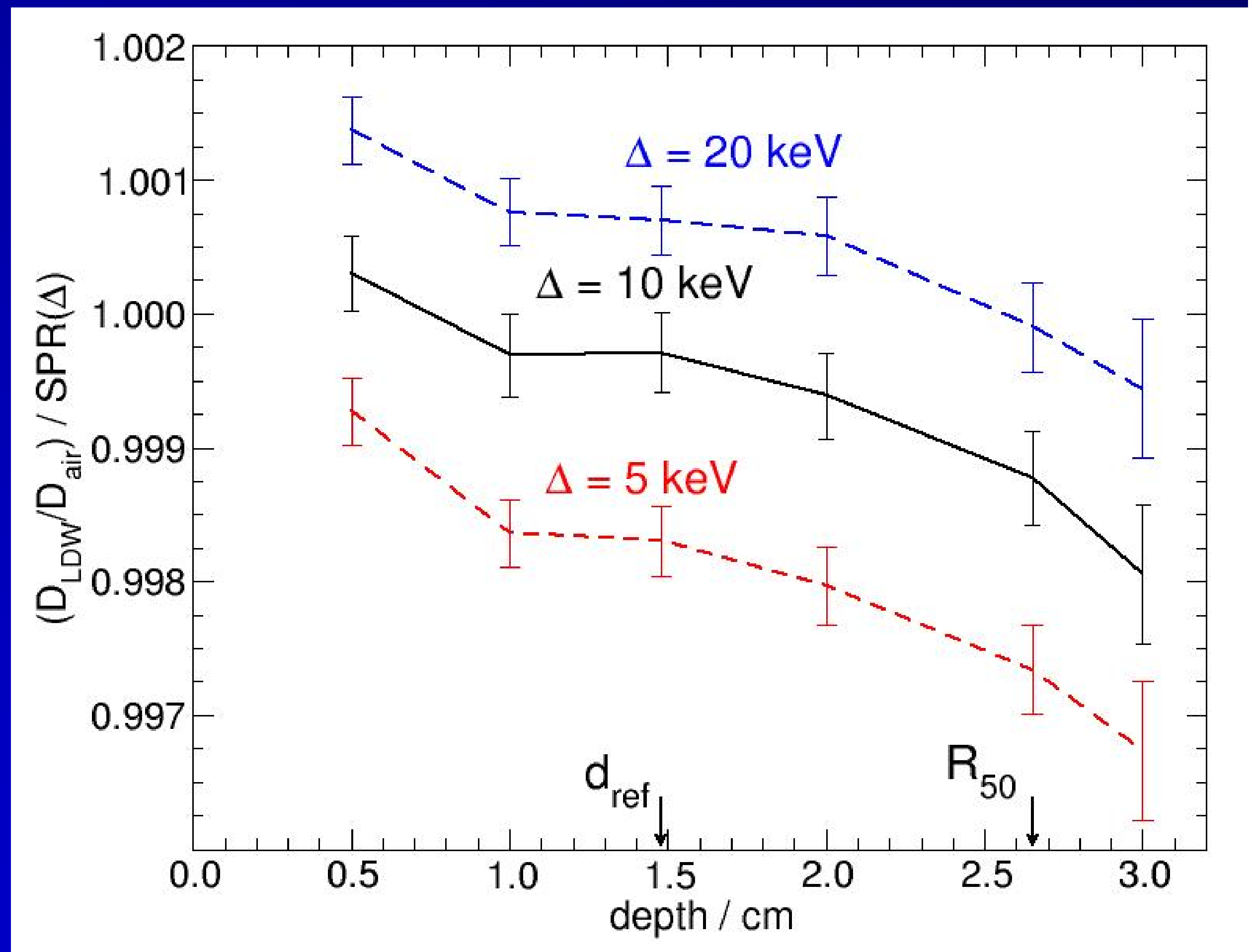
Uncertainty of P_{repl}: perturbation of electron fluence in LDW cavity

$$\frac{D_{\mathrm{LDW}}}{D_{\mathrm{air}}} = \left(\frac{\overline{L}_\Delta}{\rho}\right)^{\mathrm{LDW}}_{\mathrm{air}} P$$

If there is no perturbation, then ratio of doses/spr = 1.0

NACP02 cavity in a 6 MeV e- beam vs depth





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P_{repl} at 10 cm depth in water: ^{60}Co

Under Fano conditions (no attenuation or scatter), P_{repl} should be unity if the method is working.

cavity radius	0.5 mm	3 mm	5 mm
P_{repl} (normal)	0.9979(7)	0.9961(5)	0.9939(4)
P_{repl} (Fano)	0.9991(7)	0.9993(6)	0.9997(6)

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LDW method used

P_{repl}: Overall uncertainty

- statistics can be well less than 0.1%

-HDA technique, select thickness of HDA

corresponding to Δ appropriate for cavity.

1.3 to 3 μm typically.

-for low Z, => < 0.2% uncertainty

-for high Z => large uncertainty since variation

in D_{HDA} with thickness is much larger

-LDW method - uncertainty about same due to

inability to demonstrate the lack of fluence

perturbation between air and LDW

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P_{repl} for NACP02 chamber in electron beams and ^{60}Co beam

Calculation is done at d_{ref} for electron beams & at depth 5 cm for ^{60}Co beam

	SPR	FLU	HDA	LDW
6 MeV	0.9956 (0.06%)	0.9977 (0.10%)	0.9976 (0.08%)	0.9959 (0.06%)
18 MeV	1.0001 (0.06%)	1.0007 (0.06%)	1.0011 (0.07%)	1.0005 (0.05%)
^{60}Co	1.0059 (0.10%)	1.0063 (0.10%)	1.0062 (0.10%)	1.0065 (0.10%)

In all dosimetry protocols: $P_{repl} = 1$

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P_{repl} for Farmer chamber in ^{60}Co beam

Cavity diameter: 6 mm
Cavity length: 2 cm
Depth in water: 5 cm

SPR	FLU	HDA	LDW
0.9963 (0.08%)	0.9952 (0.08%)	0.9969 (0.09%)	0.9974 (0.07%)

P_{repl} value in dosimetry protocols:

AAPM 0.992
IAEA 0.988

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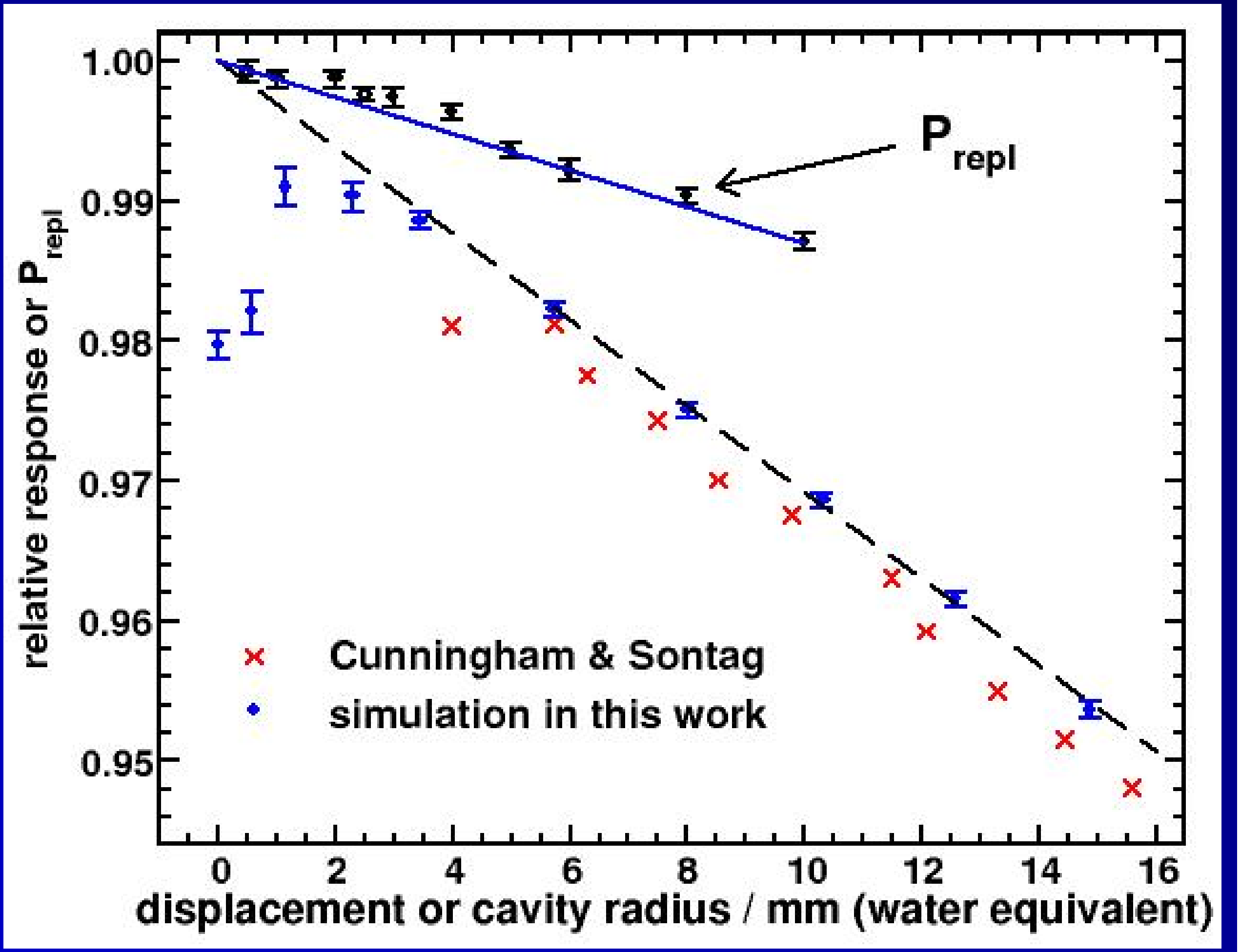
P_{repl} for photon beams (AAPM)

TG-21/TG-51 use values based on measurements by Cunningham and Sontag (1980)

The MC values differ considerably but duplicated the original measurements.

Conclusion:

Original interpretation of measurements in terms of P_{repl} was incorrect.



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LDW method used

P_{repl} for photon beams (IAEA)

IAEA uses values of Johansson et al (1977).

-values even farther from the Monte Carlo values

- problem was way in which the data were normalized between chambers with different radii
- using their normalization - Monte Carlo of the experiment matches their results
- using correct normalization - Monte Carlo of their experiment yields same result as Monte Carlo of P_{repl}

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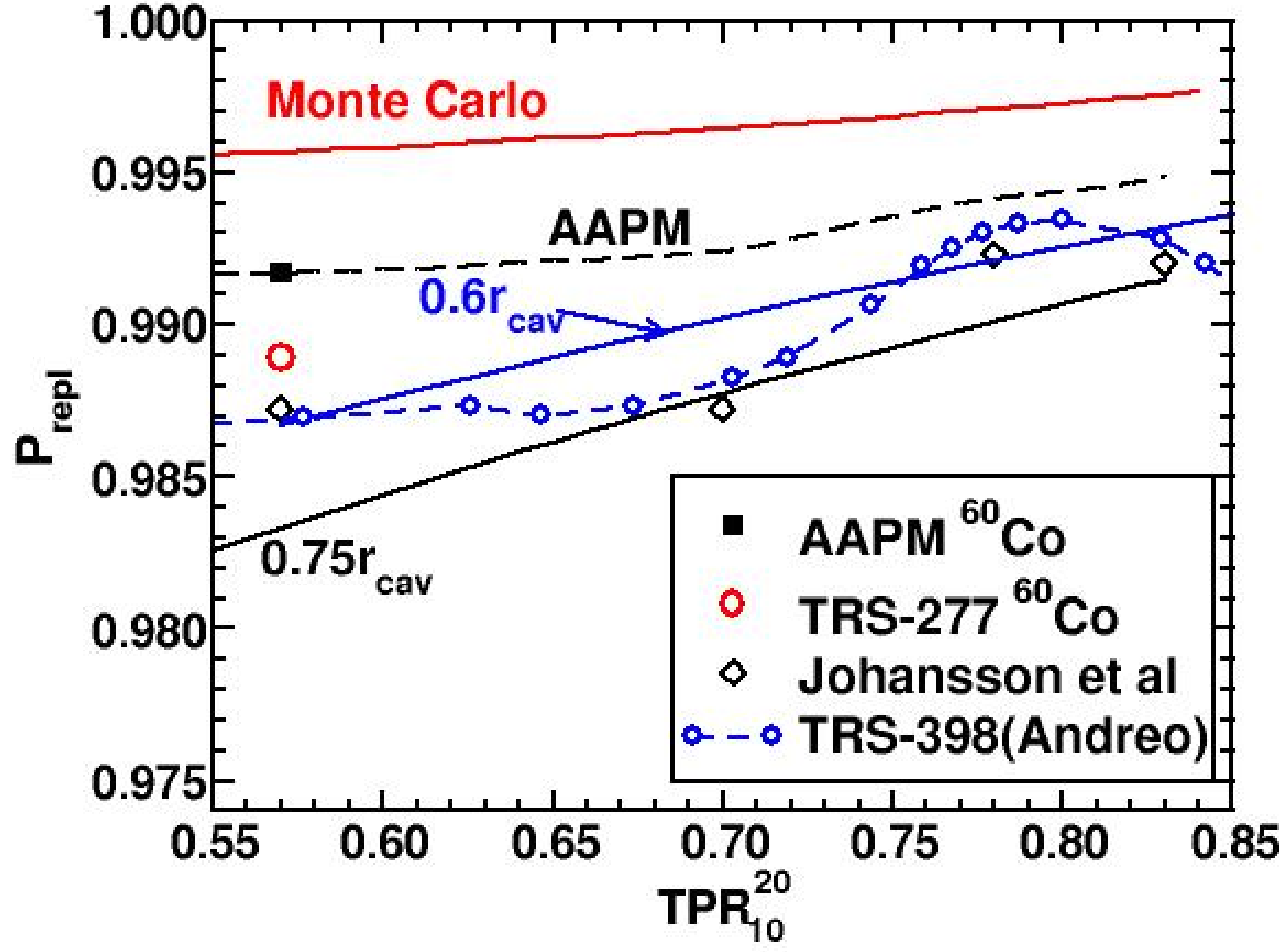
P_{repl} for Farmer chamber in photon beams

Lower two lines

Equivalent from effective point of measurement as labelled



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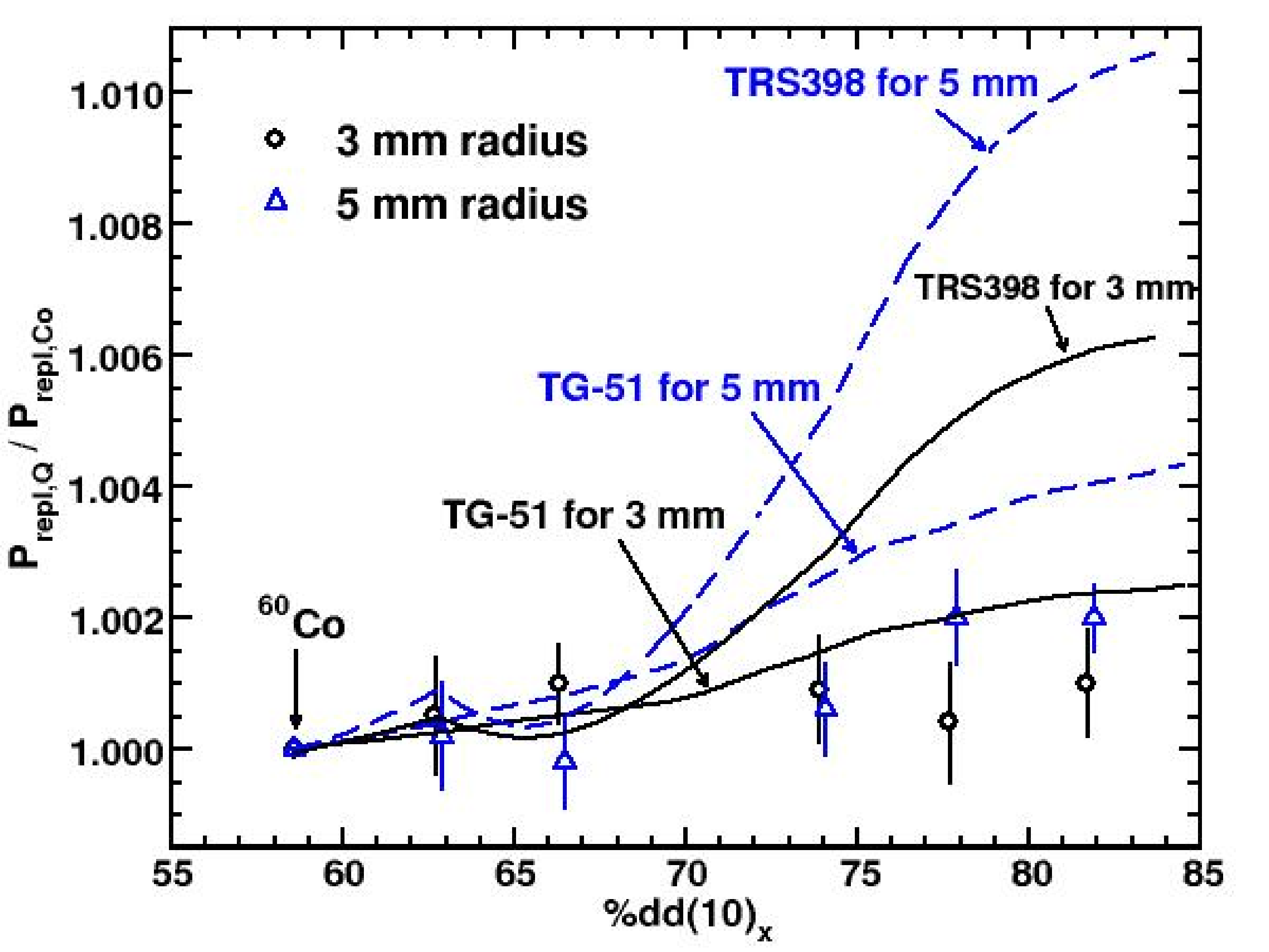
The ratio of P_{repl} in a photon beam to that in a ^{60}Co beam vs beam quality

Good news

It is only this ratio that matters in TG-51 & TRS-398

Difference not as much as absolute value



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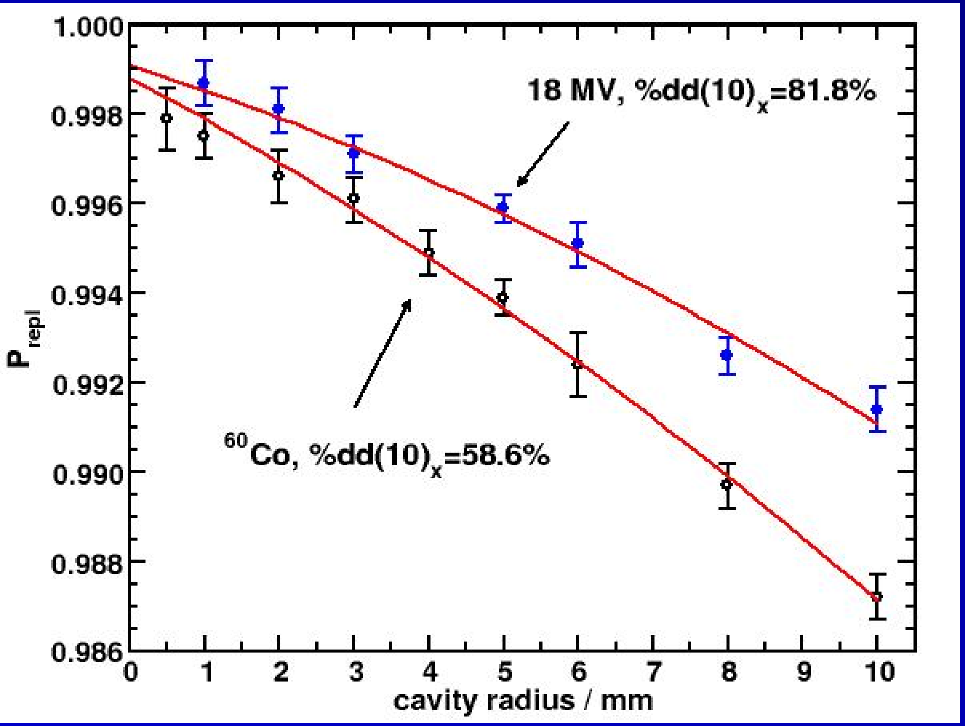
P_{repl} in photon beams

$$P_{repl} = 0.9974 - 0.00183\,r + 3.36 \times 10^{-5}\ \%dd(10)_x - 2.7 \times 10^{-5}\ r^2 - 1.6 \times 10^{-7}\ (\%dd(10)_x)^2 + 1.58 \times 10^{-5}\ r\ \%dd(10)_x,$$

$$P_{repl} = 1.0021 - 0.00188\,r - 0.0108\,TPR^{20}_{10} - 2.5 \times 10^{-5}\ r^2 + 0.009\ (TPR^{20}_{10})^2 + 0.00169\ r\ TPR^{20}_{10},$$



The Value of $(W/e)_{air}$

$(W/e)_{air}$ plays a central role in radiation dosimetry

It links the charge measured to the dose

$$D_{\mathrm{air}} = \left(\frac{W}{e}\right)_{\mathrm{air}} \frac{Q}{m_{\mathrm{air}}}$$

$$N_{\mathrm{gas}} = N_D = \frac{\left(\frac{W}{e}\right)_{\mathrm{air}}}{m_{\mathrm{air}}}$$

$(W/e)_{air}$ drops out of TG-51/TRS-398 on the assumption it is a constant.

BUT the world's air kerma standards are all directly proportional to its value

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Measuring $(W/e)_{air}$

In graphite determine D_{gr} using a calorimeter.

Then using a graphite-walled ion chamber, measure the absorbed dose using an ion chamber

$$D_{gr} = \frac{Q}{m_{\rm air}} \left(\frac{W}{e}\right)_{\rm air} \left(\frac{\overline{L_\Delta}}{\rho}\right)^{\rm gr}_{\rm air} P_{\rm repl}$$

Experiment actually extracts the product (W/e).spr

Result directly linked to P_{repl} value

Niatel et al, PMB 30(1985) 67-75

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Calculations of P_{repl}

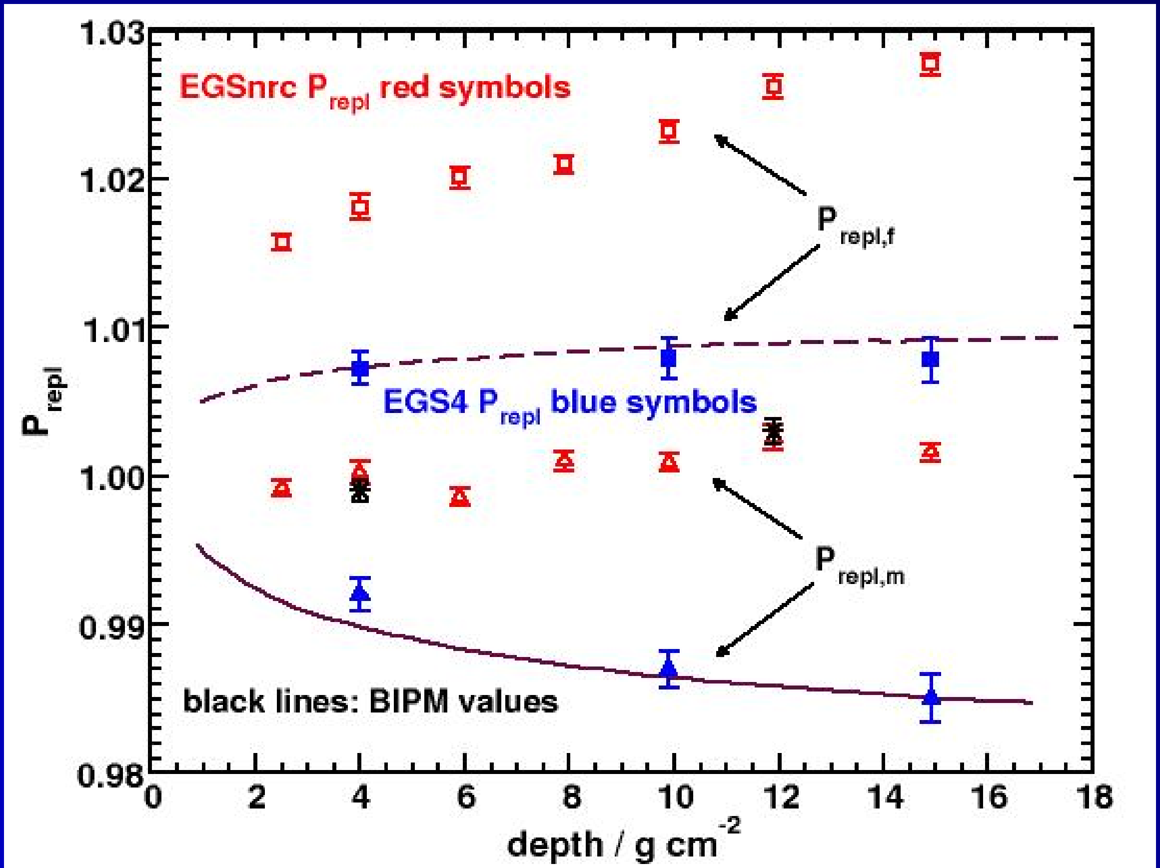
Two values

-point of measurement

-at front

-at mid-plane

EGS4
Ferreira et al
43 (1998) 2721



BIPM calns for K_{an} based on same techniques have been shown incorrect for K_{an}

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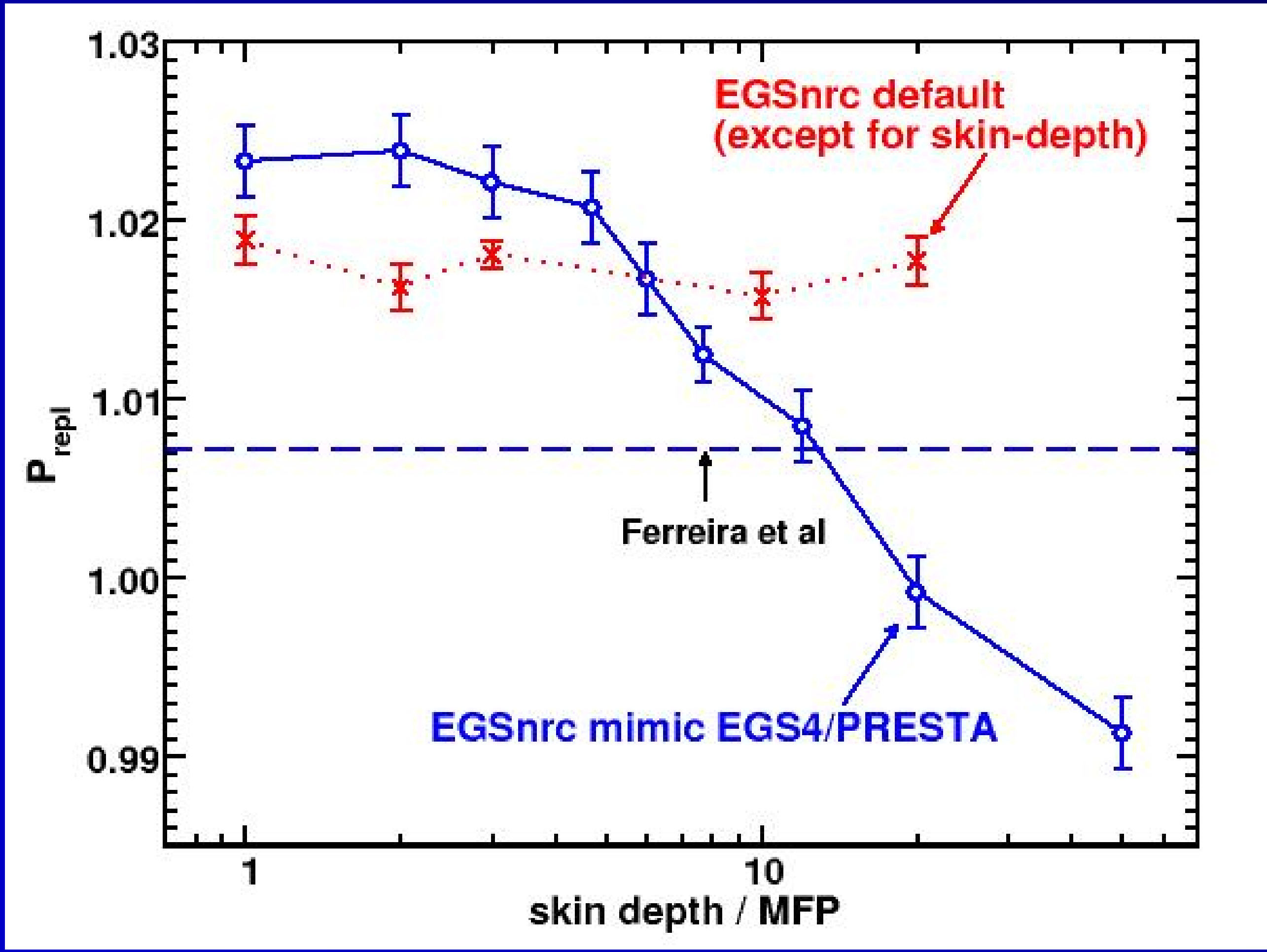
EGS4 vs EGSnrc calculations



EGS4: Ferreira et al 43 (1998) 2721

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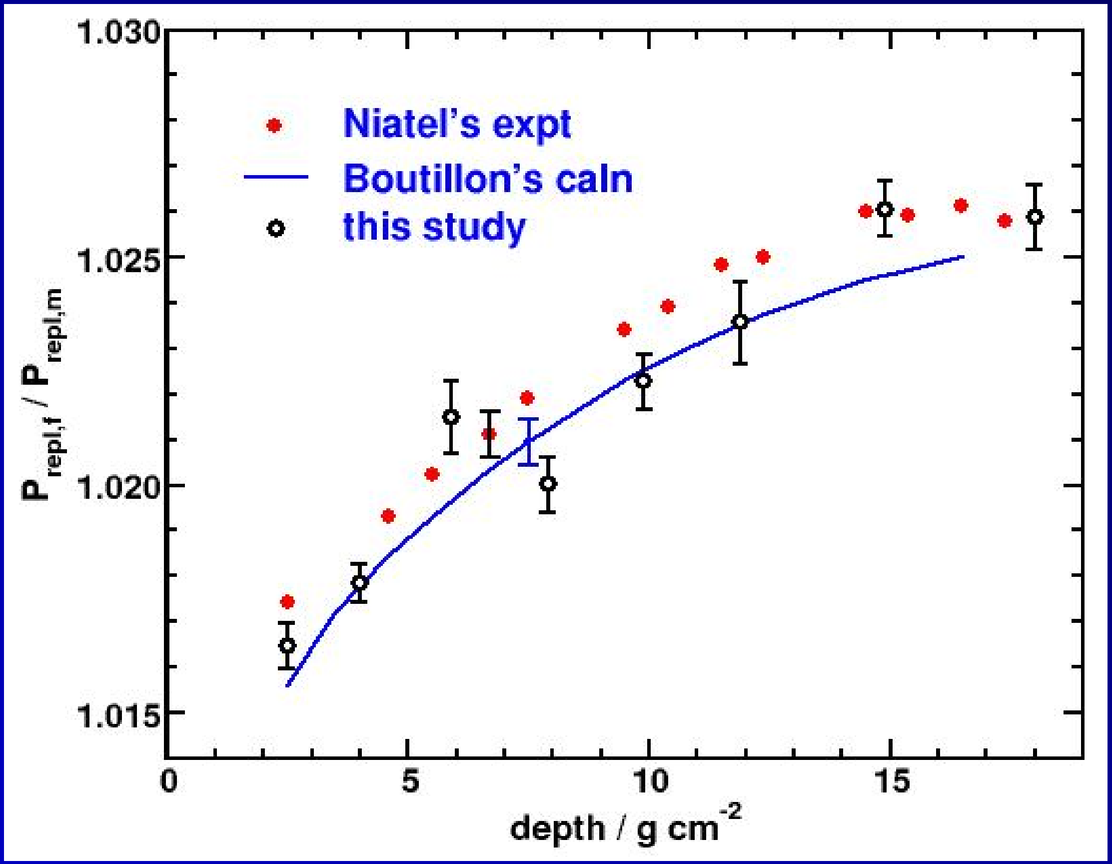
P_{repl} experimental verification

measured ratios for

front/mid-plane values vs depth

Both calculations agree.



Ferreira et al also measured ratio of P_{repl} for BIPM & IRD chambers vs depth and our calculated results agree with the measurements.

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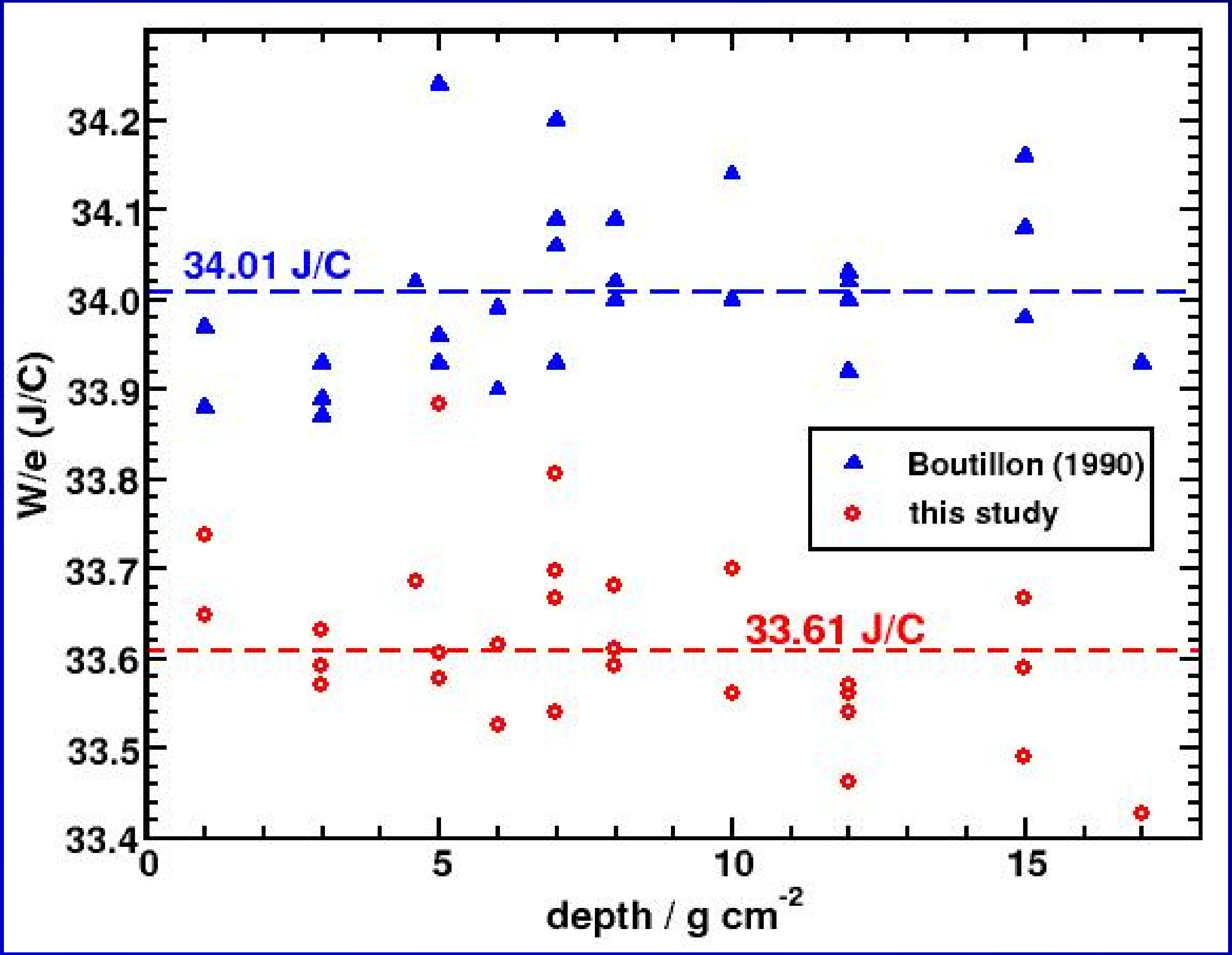
$(W/e)_{air}$ from multiple calorimeter

Change: 1.2%

- really measuring (W/e).spr

- W/e depends on spr used

(1.6%variation)



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W/e value: Niatel et al

Niatel et al used another method to measure

- using the measured activity they calculated the collision air kerma

- they took the measured exposure rate and divided by $(W/e)_{air}$ to get the collision air kerma

-solve resulting equations for $(W/e)_{air}$.spr

- $(W/e)_{air}$.spr is inversely proportional to exposure

- original 33.81 J/C +-0.42% becomes 33.61+-0.23%

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W/e value: Niatel et al

Calorimetric method: new P_{repl}

34.01 J/C --> 33.61 J/C

Exposure/activity method: new exposure standard

33.81 J/C --> 33.61 J/C

But really measuring product $(W/e)_{air}.spr$ and the spr $(L/\rho)_{gr,air}$ is uncertain

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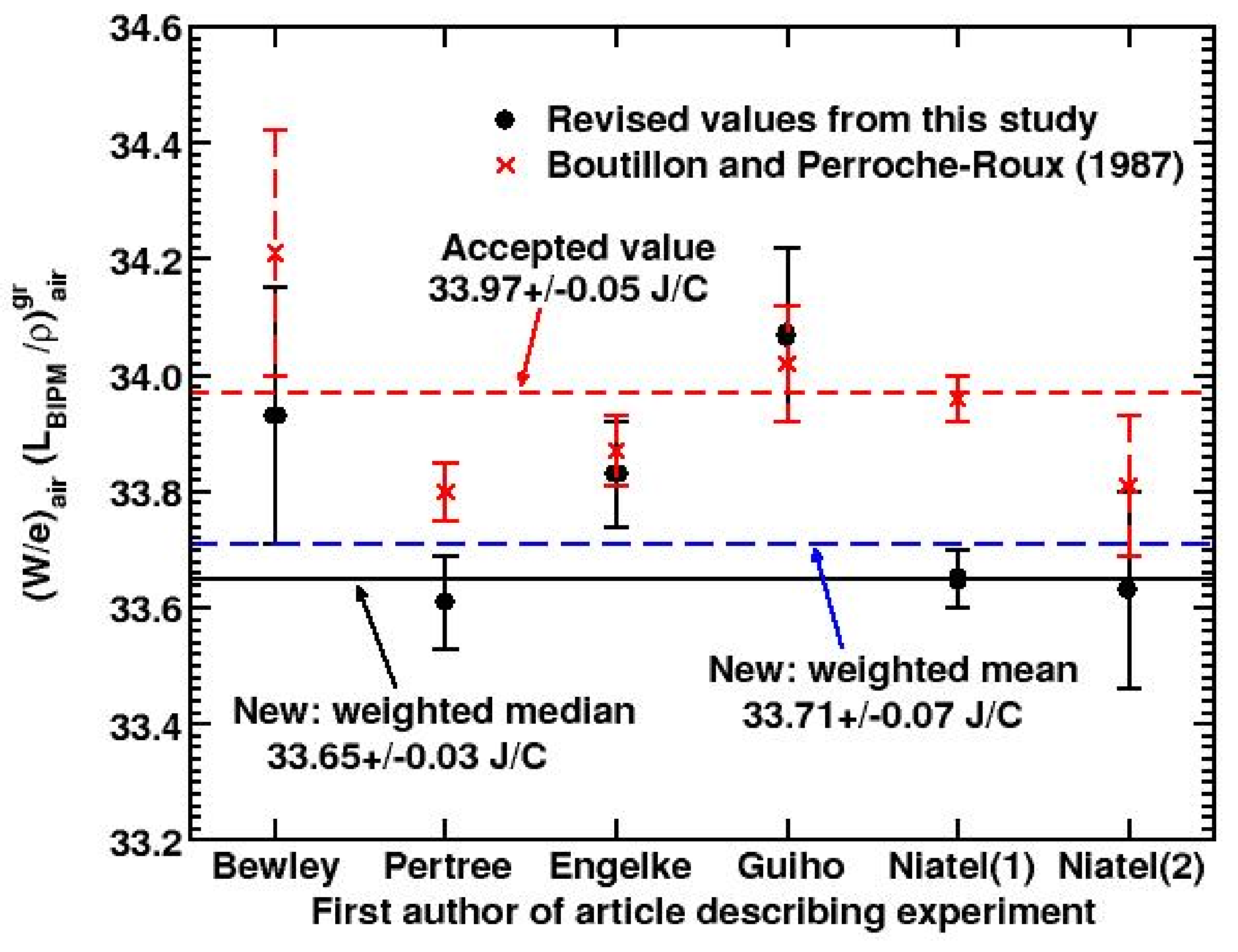
W/e.spr value: reanalysis

6 experiments contribute to the value of this product

Re-analyzed all

(not all used wrong value of P_{repl})



Rowan Thomson, in preparation

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W/e.spr value: reanalysis

33.97 (5) J/C --> 33.65 (3) J/C   0.95% change

from a value with stated uncertainty of 0.15%

Implies world's air kerma standards for ^{60}Co will need to be reduced by 0.95%.

Implications for W/e value (without spr) unclear until issue of the best value of $(L/\rho)_{gr,air}$ is resolved

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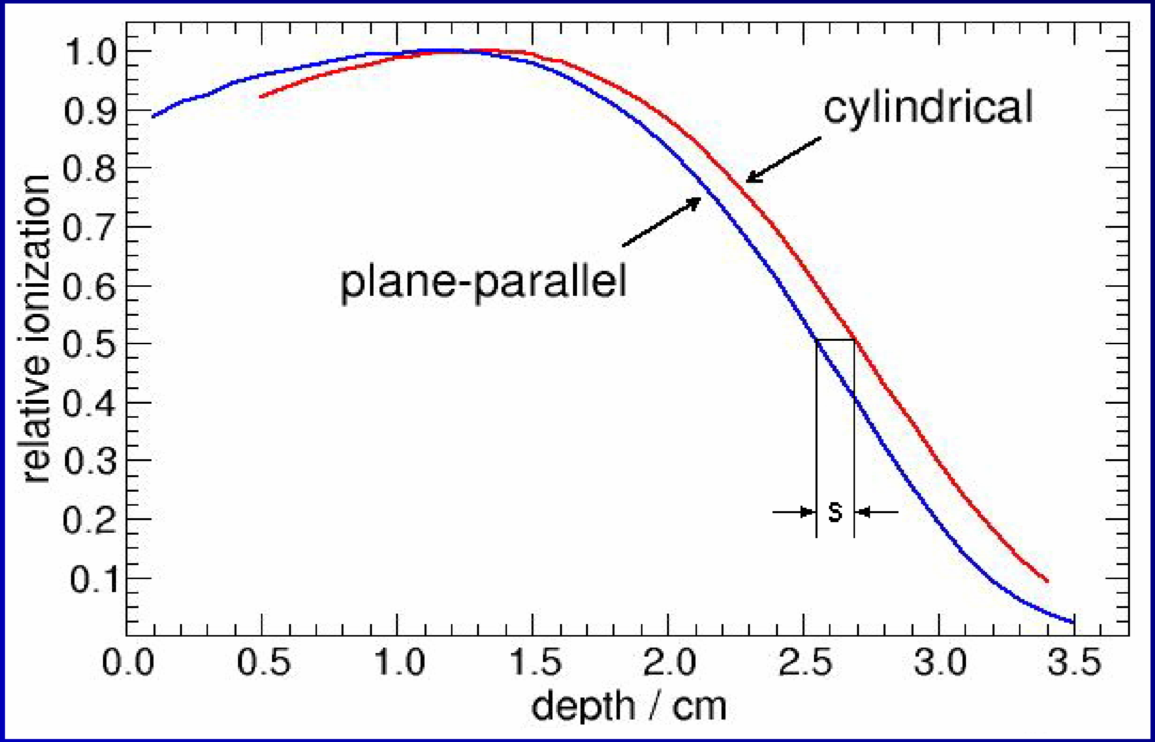
Determining effective point of measurement: matching depth-ionization curves

Use calculated depth-ionization curve

$$D_{\text{water}} = D_{\text{air}}^{\text{ideal}} \left(\frac{\overline{L}_\Delta}{\rho} \right)_{\text{air}}^{\text{water}}$$



Vary the offset s

$$z_i = z_{0,i} + s$$

to minimize d(s)

$$d(s) = \sqrt{\frac{\sum_i \left[D_{\text{air}}^{\text{ideal}}(z_i) - \alpha \cdot D_{\text{air}}(z_{0,i}) \right]^2}{N}}$$

D_{air} is dose to cavity gas

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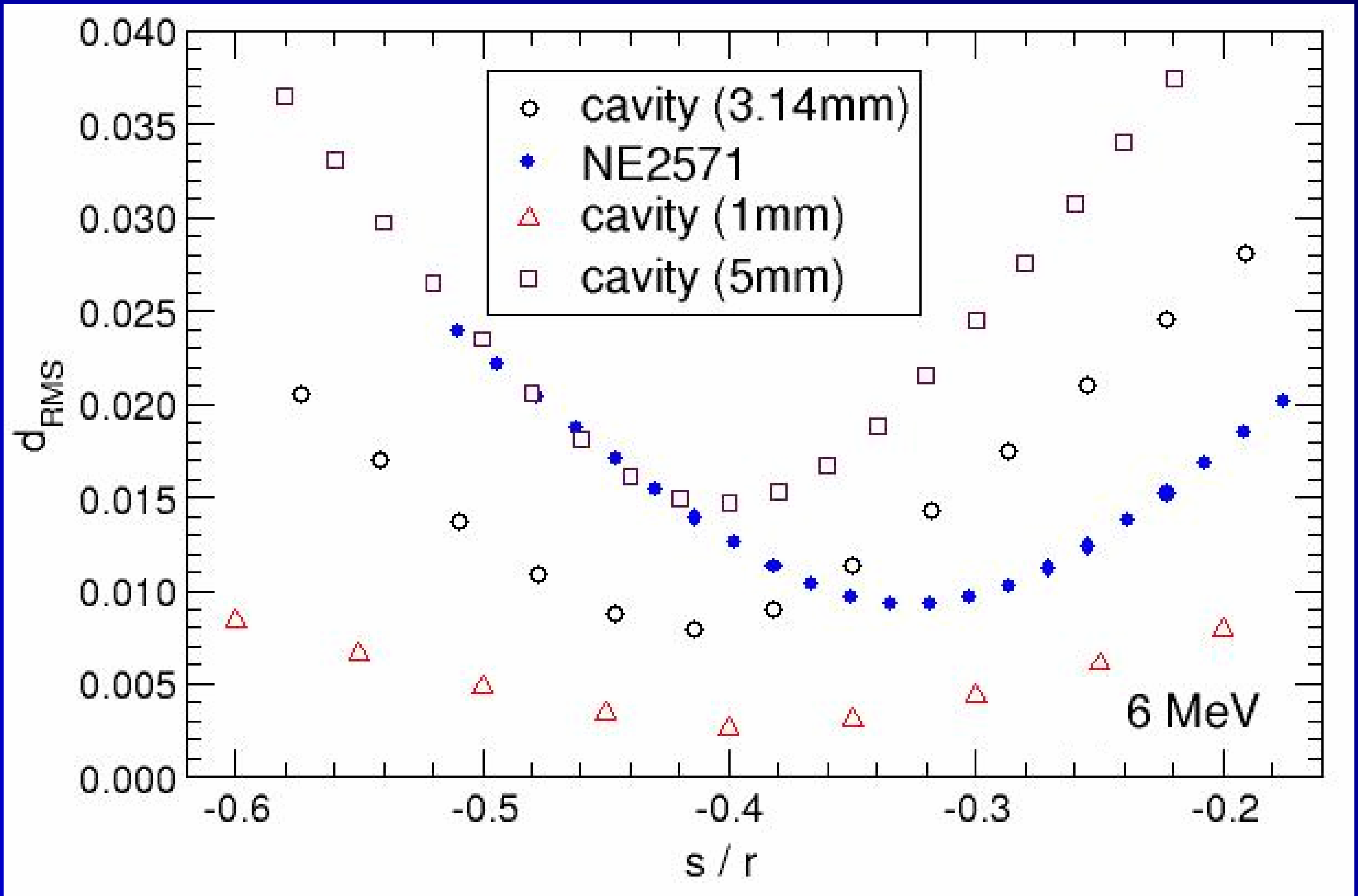
Shift for cylindrical chamber in 6 MeV electron beam



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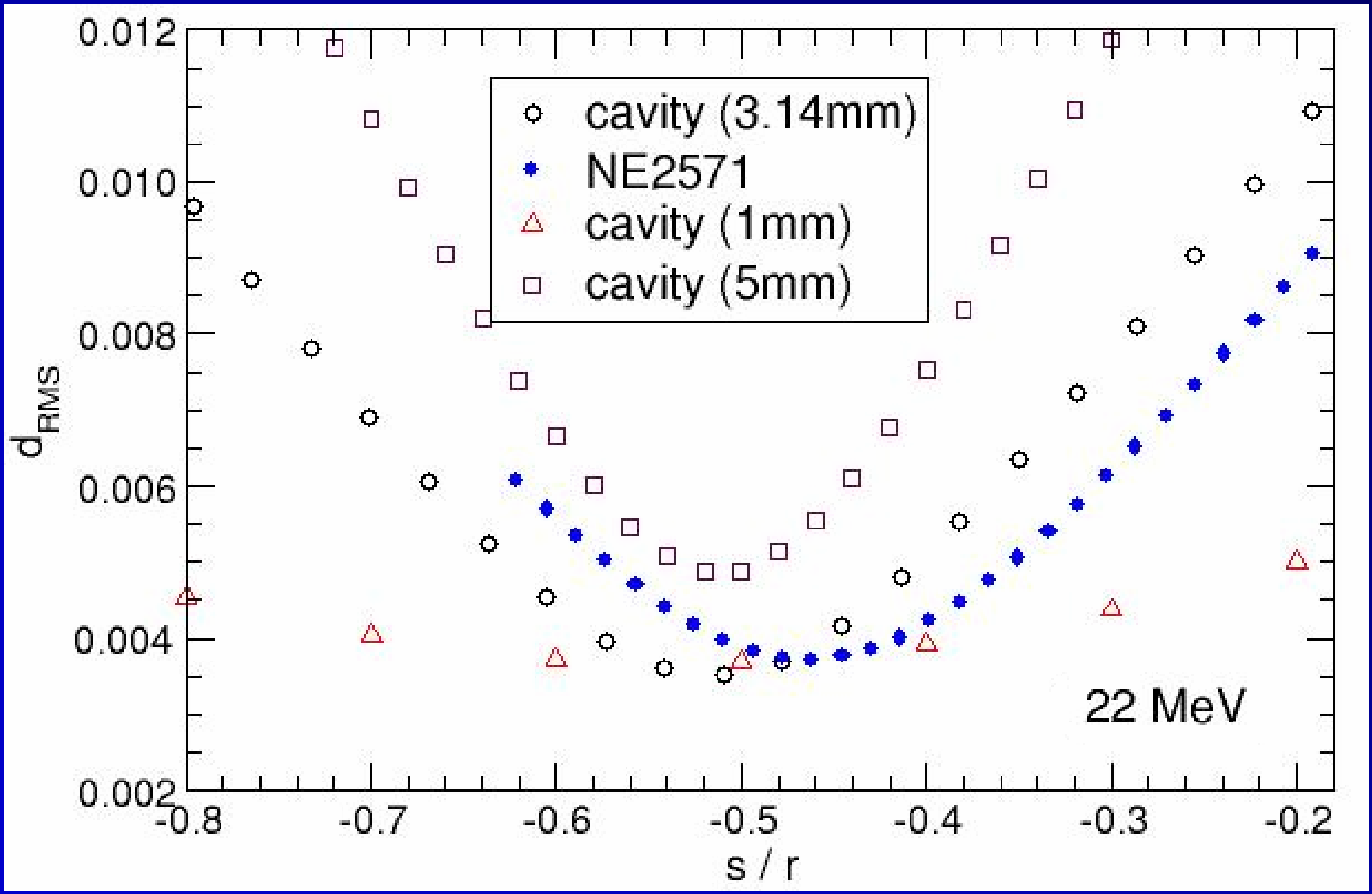
Shift for cylindrical chamber in 22 MeV electron beam



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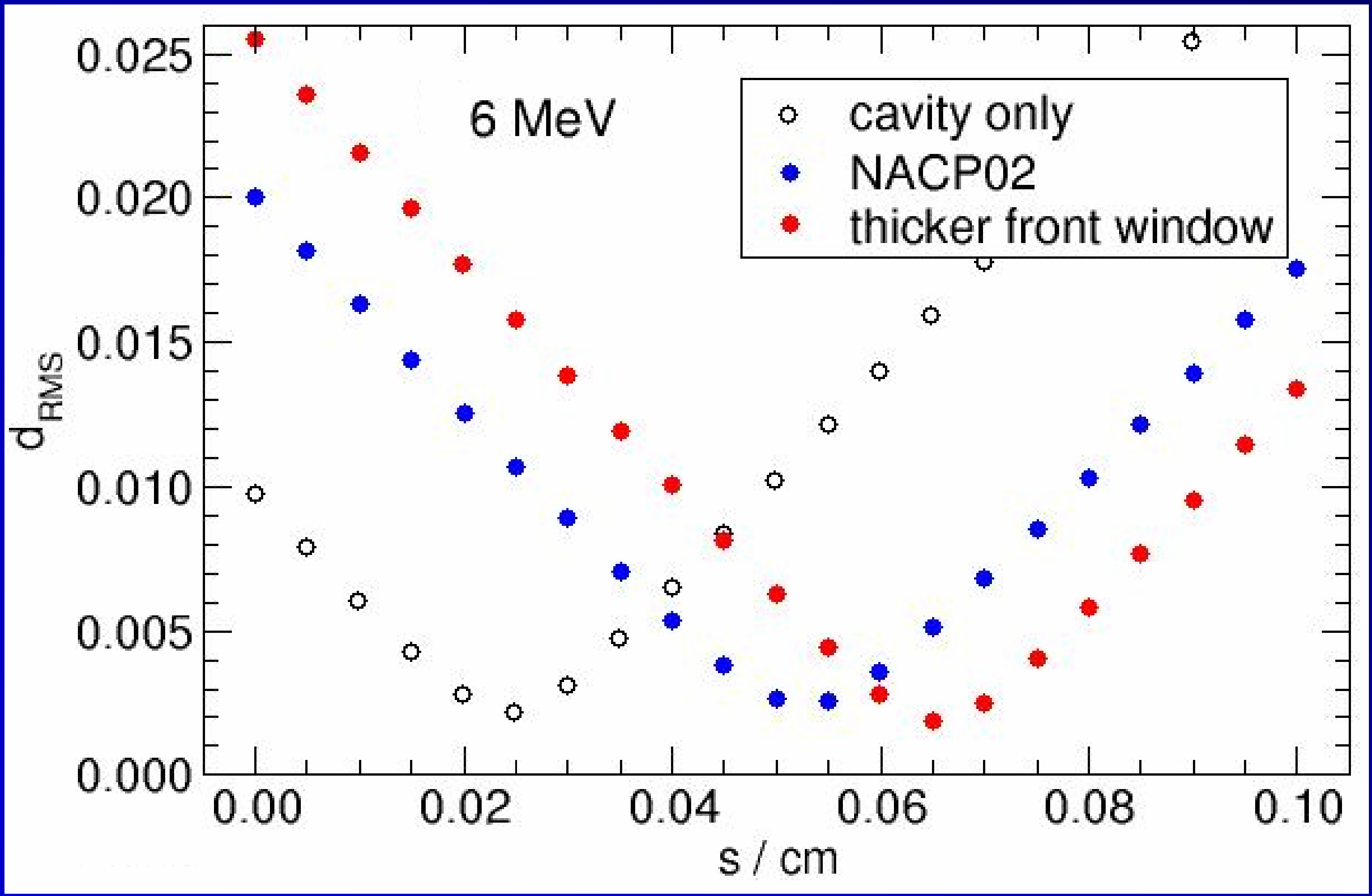
Shift for NACP02 chamber in 6 MeV electron beam



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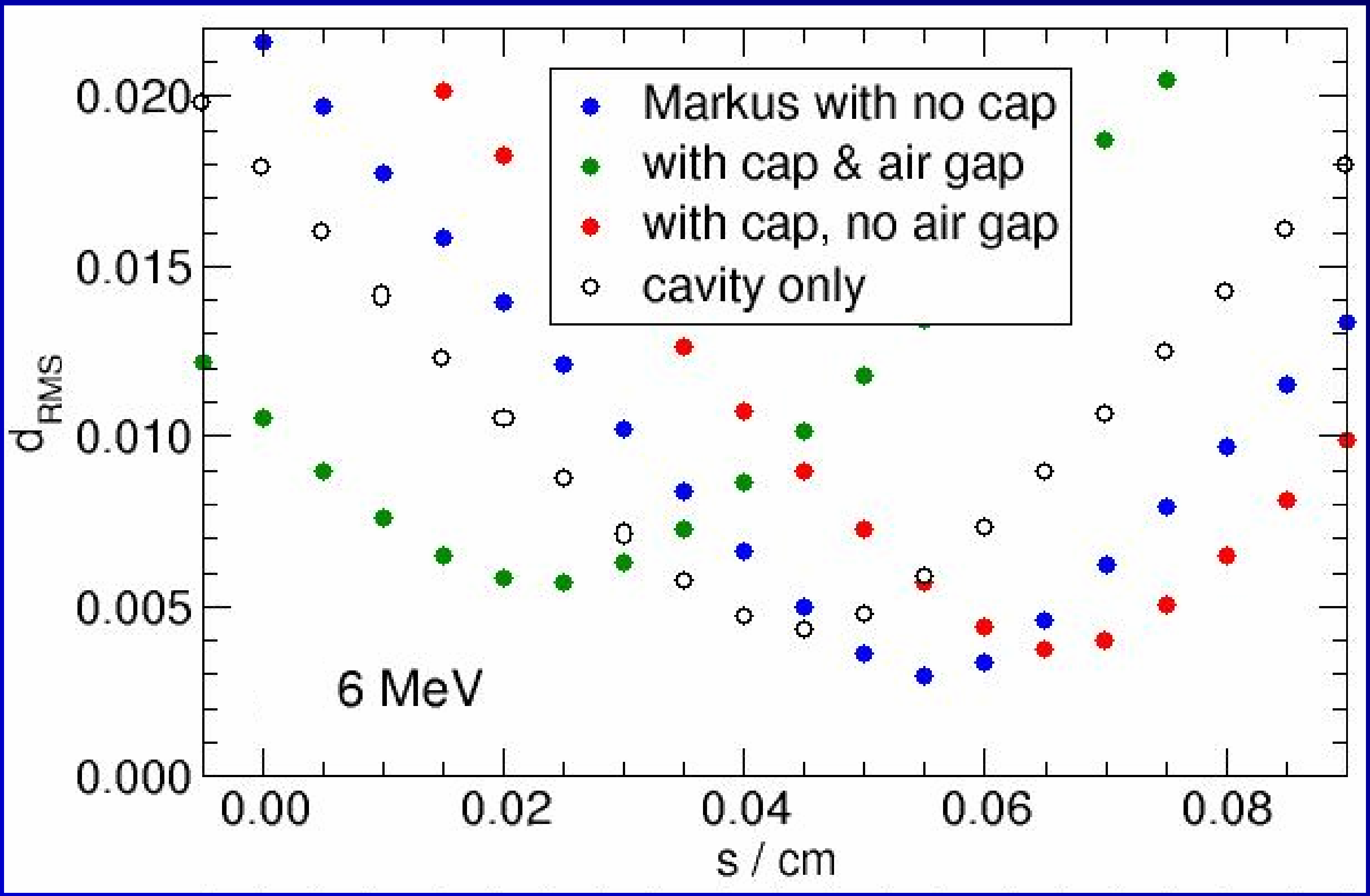
Shift for Markus chamber in 6 MeV electron beam



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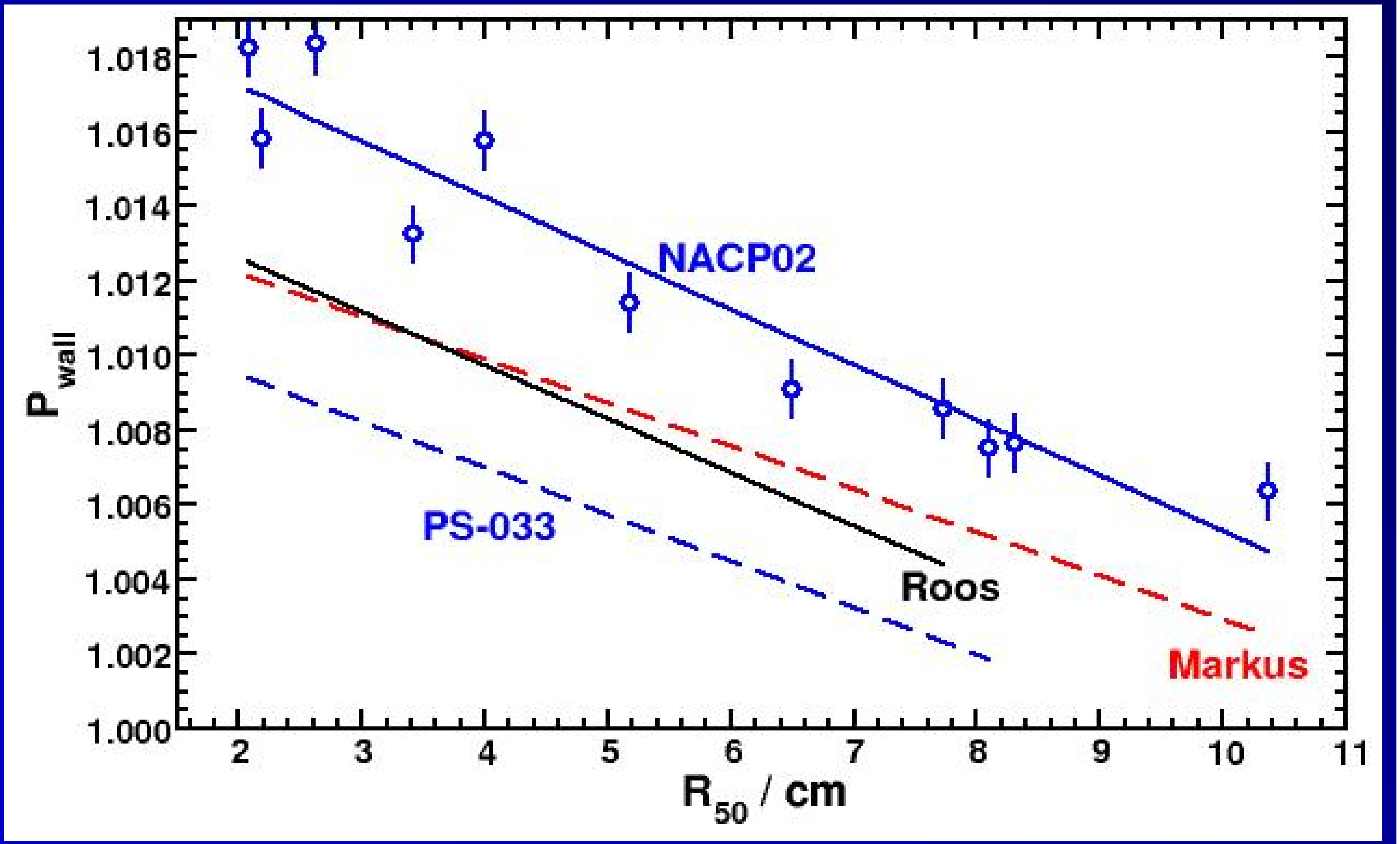
P_{wall} for plane-parallel chambers in electron beams

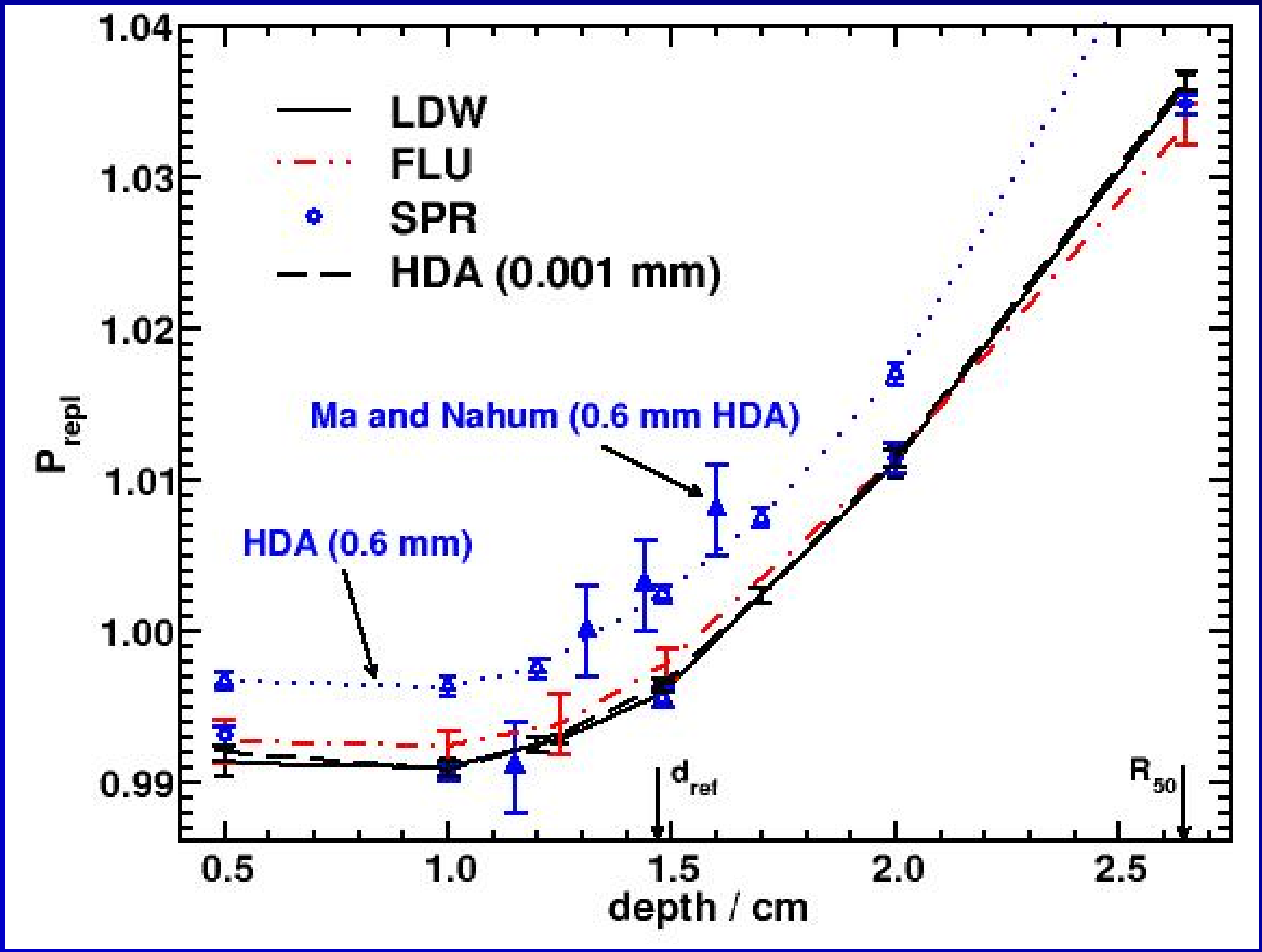
protocols currently all use *P_{wall}=1.0*

for all plane-parallel chambers



Buckley & Rogers, Med. Phys. 33(6), 1788 (2006)

P_{repl} vs depth for NACP02 chamber in 6 MeV electron beam



Conclusions

- Monte Carlo calculations can contribute to ion chamber dosimetry
- P_{repl} values for plane-parallel chambers are not unity in electron beams as assumed in protocols
- effective point of measurement is not exactly the front of the cavity for plane-parallel chambers in electron beams and is close to the centre of the cavity in photon beams
- values of $(W/e)_{air}$.spr need to be revised downwards by 6 times their stated uncertainty

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Acknowledgements

- the work reported on here is almost entirely from the PhD work of Lilie Wang
  http://www.physics.carleton.ca/~drogers/pubs/theses
- the work of Rowan Thomson and Lesley Buckley was also referred to.

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NSERC
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