Monte Carlo simulation of ionisation chambers with Penelope

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Outline

- The struggle of MC codes to accurately simulate ICs:
  Interface effects in condensed history algorithms

- Stability test: the Fano theorem
  (or “How to choose safe transport parameters”)

- Results for a real-life IC

Electron simulation strategies

- Detailed simulation, i.e. interaction-by-interaction

  → Highest accuracy, but VERY slow. Feasible only at low *E*'s.

- Condensed history technique (M J Berger 1963)

  → Multiple interactions along *s* (step length) simulated collectively in a single computational step.

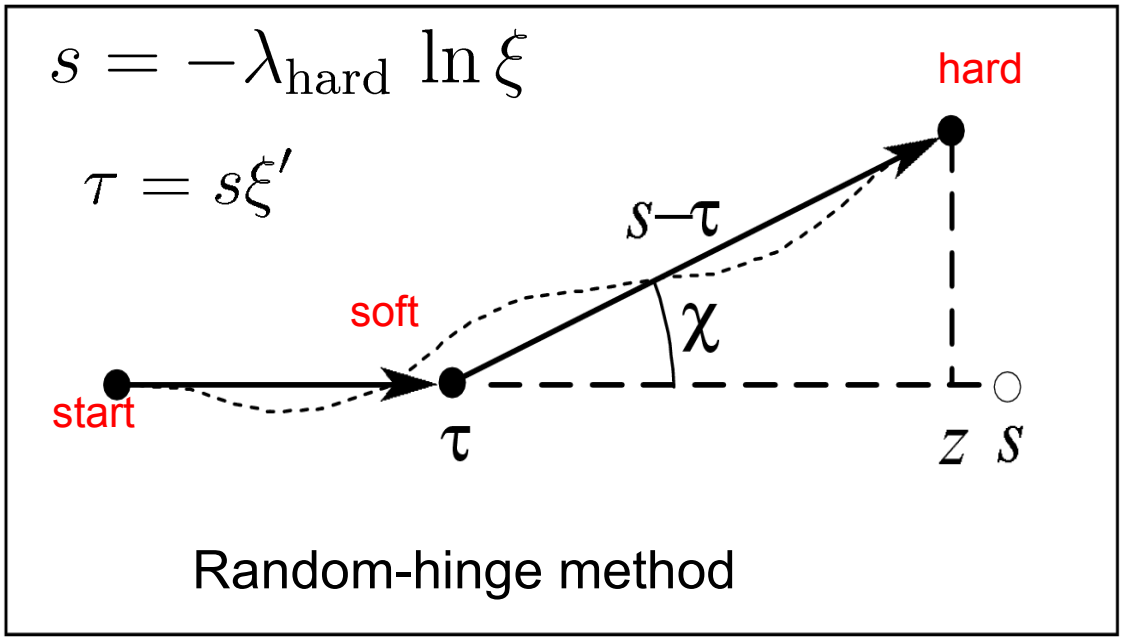
  → Based on multiple scattering theories, which characterise PDFs (e.g. angular deflection, penetration depth) after a given *s*.

  → In general, larger steps *s* produce faster simulations but may reduce the accuracy.

  → CH should reproduce detailed simulation when $s \rightarrow 0$ (but this is not always the case).

Two modalities: purely condensed (class I) or mixed (class II)

Penelope's mixed simulation scheme



F Salvat *et al*
NEA-6222, 2006
(Penelope manual)

Hard ($\theta > \theta_c$, $W > W_c$)
Soft (the rest)

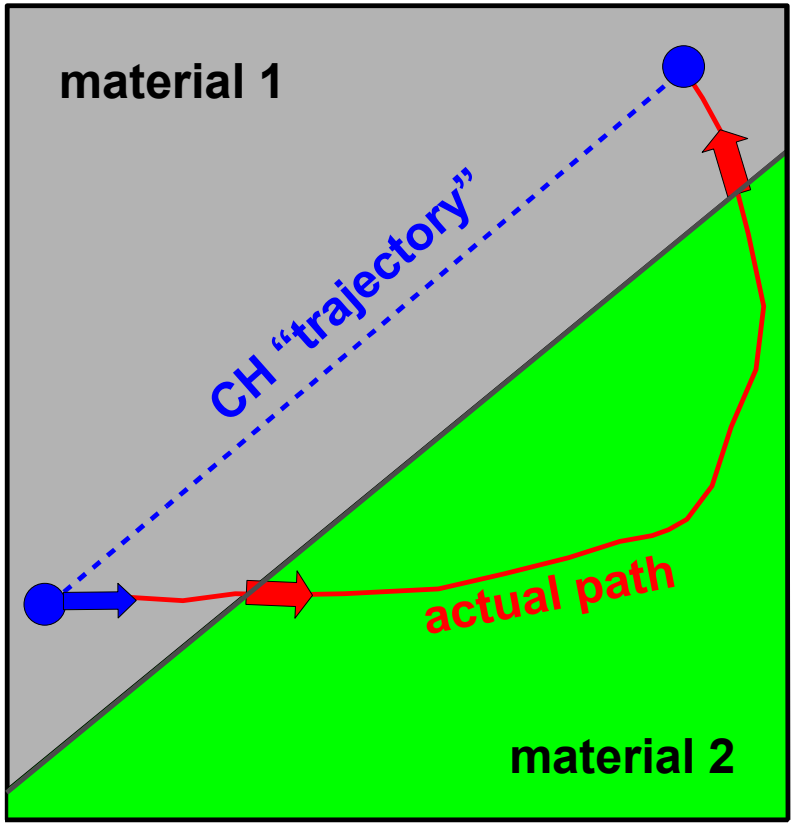
- $\theta_c = f(\mathrm{C1}, \mathrm{C2})$
- WCC , WCR
- $s \le \mathrm{DSMAX}$

Accomodates detailed sim.

$$\langle z \rangle_{\text{sim}} = \frac{s}{2} + \frac{s}{2}\langle \cos\chi \rangle = s\left[1 - \frac{1}{2}\left(\frac{s}{\lambda_1^{\text{soft}}}\right) + \frac{1}{4}\left(\frac{s}{\lambda_1^{\text{soft}}}\right)^2 - \ldots\right]$$

$$\langle z \rangle_{\text{Lewis}} = \lambda_1^{\text{soft}}\left[1 - \exp(-s/\lambda_1^{\text{soft}})\right] = s\left[1 - \frac{1}{2}\left(\frac{s}{\lambda_1^{\text{soft}}}\right) + \frac{1}{6}\left(\frac{s}{\lambda_1^{\text{soft}}}\right)^2 - \ldots\right]$$

Interface effects



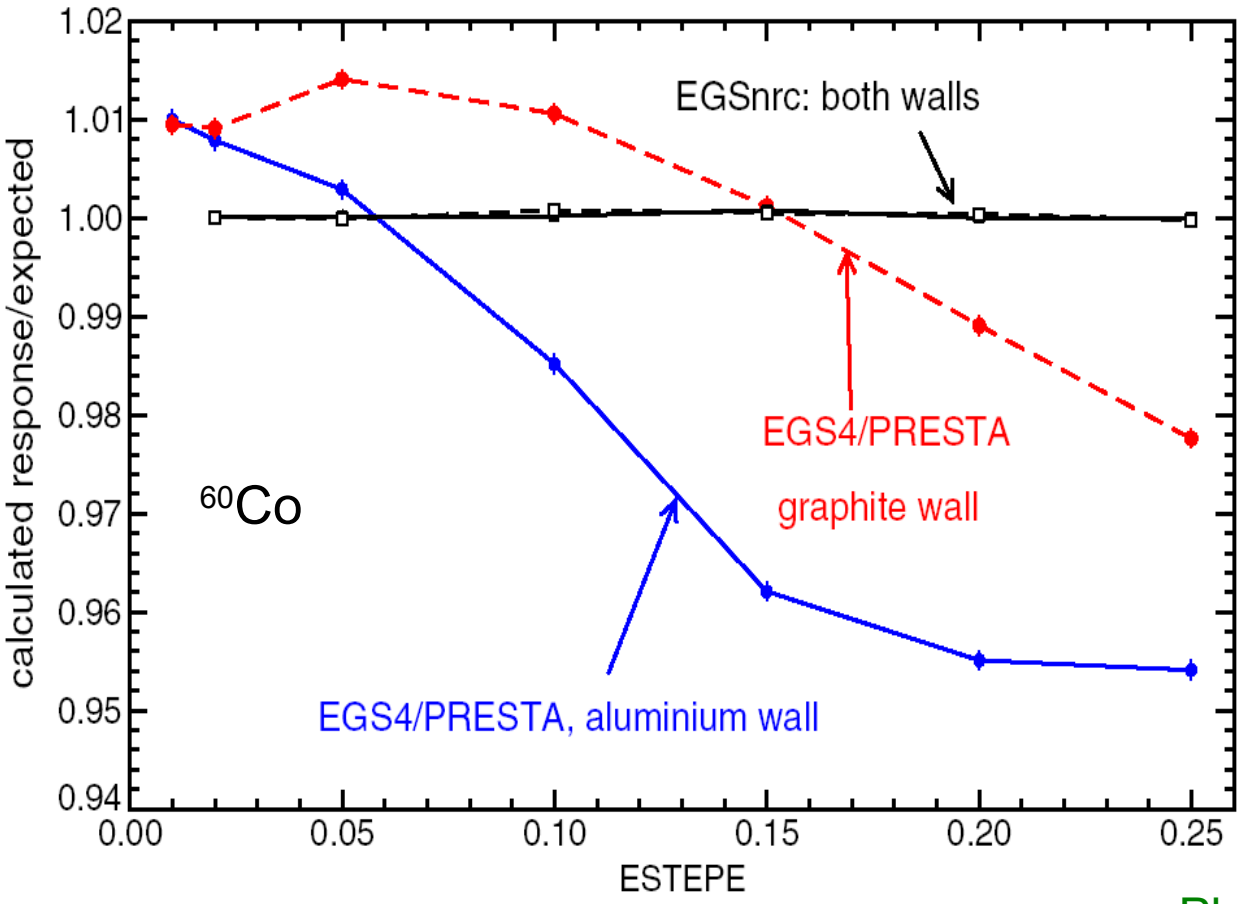
CH features:

- Approximate spatial moments
- Homogeneous medium assumed

Consequences:

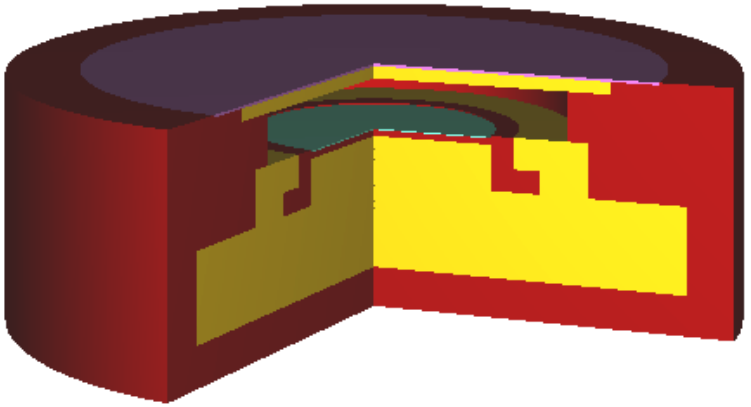
- Interface artefacts
- Results may depend on step size

Step size dependence



D W O Rogers
Phys. Med. Biol. 51 (2006)
(cover of the EGSnrc manual, Kawrakow and Rogers 2000)

Penelope configuration for ^{60}Co



IBA-Scanditronix NACP-02

Region	C1	C2	WCC (keV)	WCR (keV)
air	0	0	0	0
graphite (skin)	0	0	0	0
Rexolite (skin)	0	0	0	0
graphite (skin2)	0.02	0.02	2	0.2
Rexolite (skin2)	0.02	0.02	2	0.2
graphite (outer)	0.05	0.05	5	0.5
Rexolite (outer)	0.05	0.05	5	0.5
water	0.10	0.10	10	1

Testing CH algorithms

- The deviation of the ratio [D (s) / D_{detail}] from unity is a relevant measure of the quality of the electron transport algorithm.

The Fano test

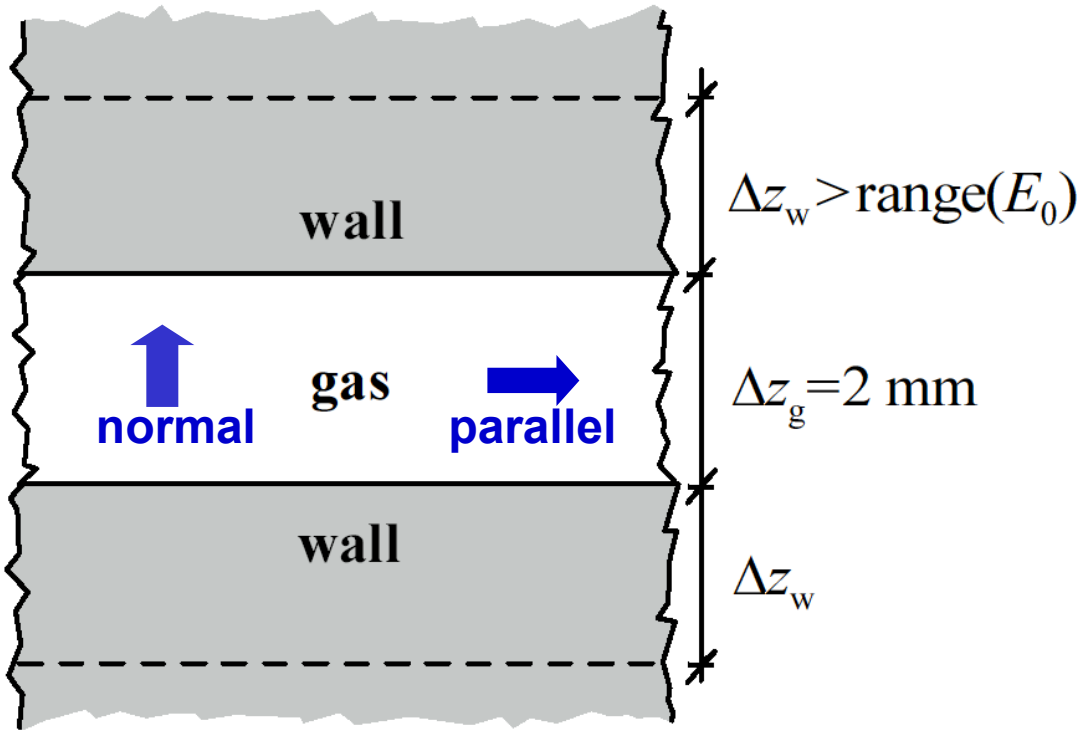
For a monoenergetic source energy conservation implies:

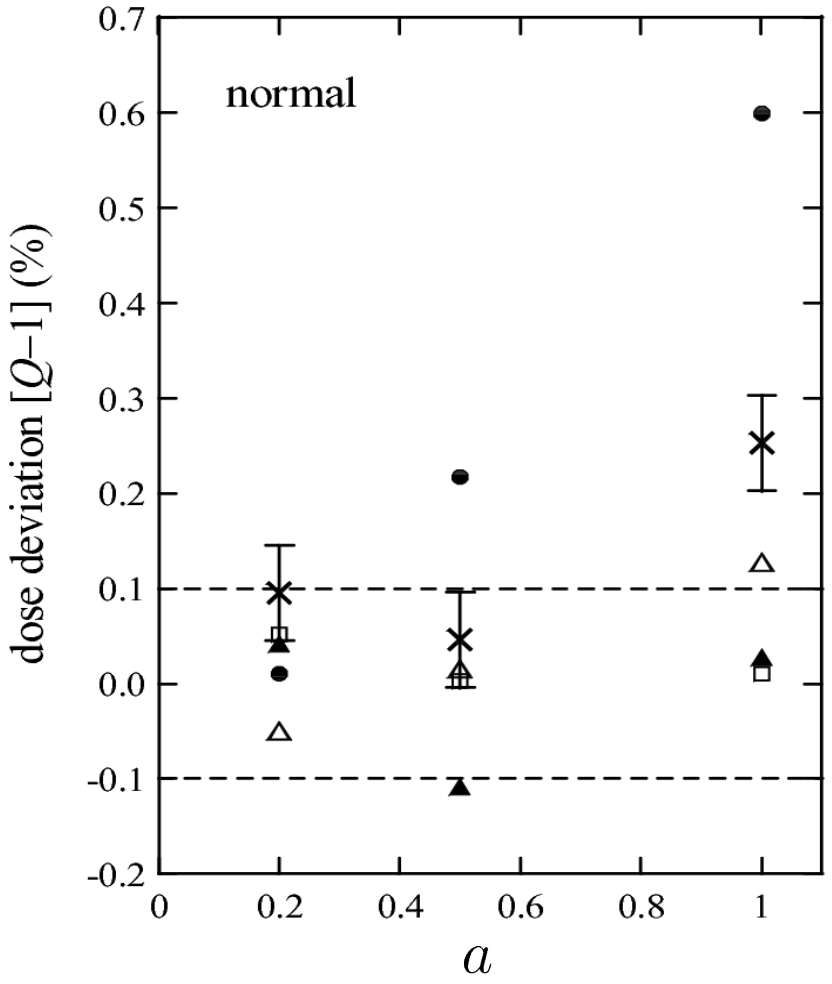
$$D = IE_0$$

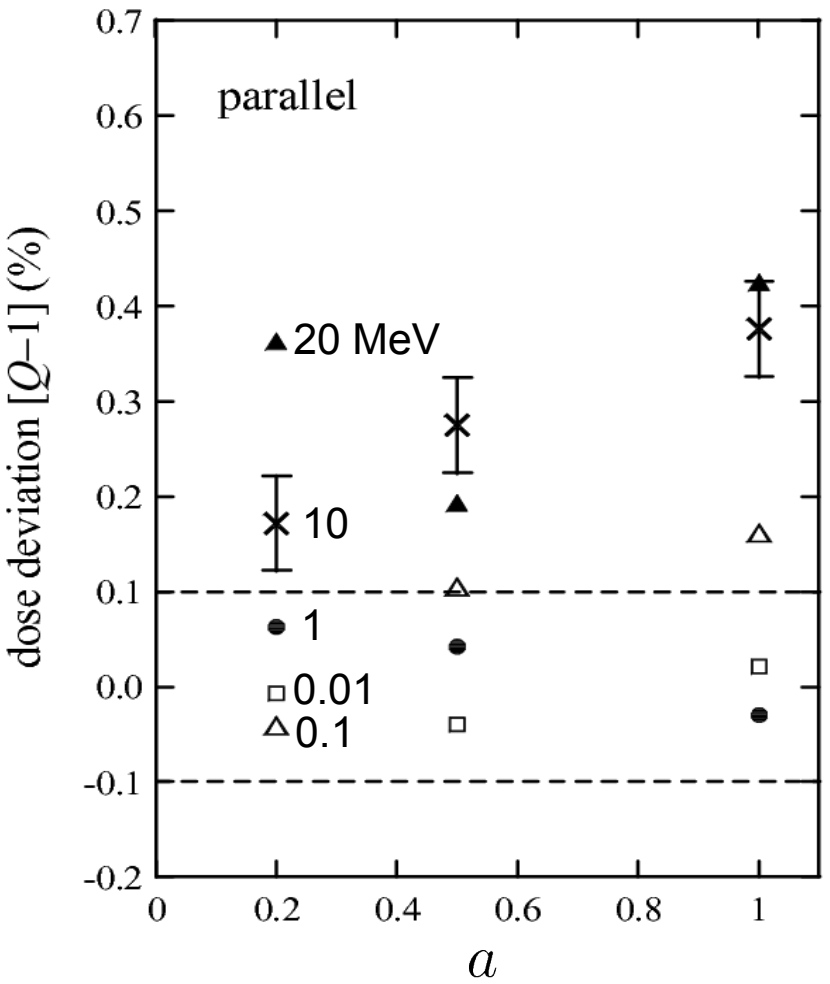
$$Q \equiv \frac{D}{IE_0} = \text{(reciprocity theorem)}$$

$$= \frac{E_{\mathrm{gas}}}{NE_0}\left(1 + \frac{2\rho_{\mathrm{w}}\Delta z_{\mathrm{w}}}{\rho_{\mathrm{g}}\Delta z_{\mathrm{g}}}\right)$$

(line source, infinite detector)







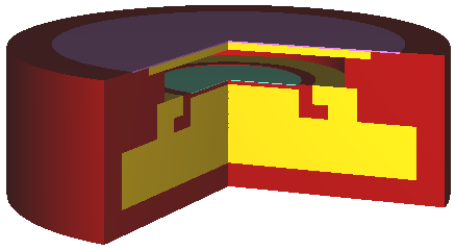
$\mathrm{C1} = \mathrm{C2} = a/10$

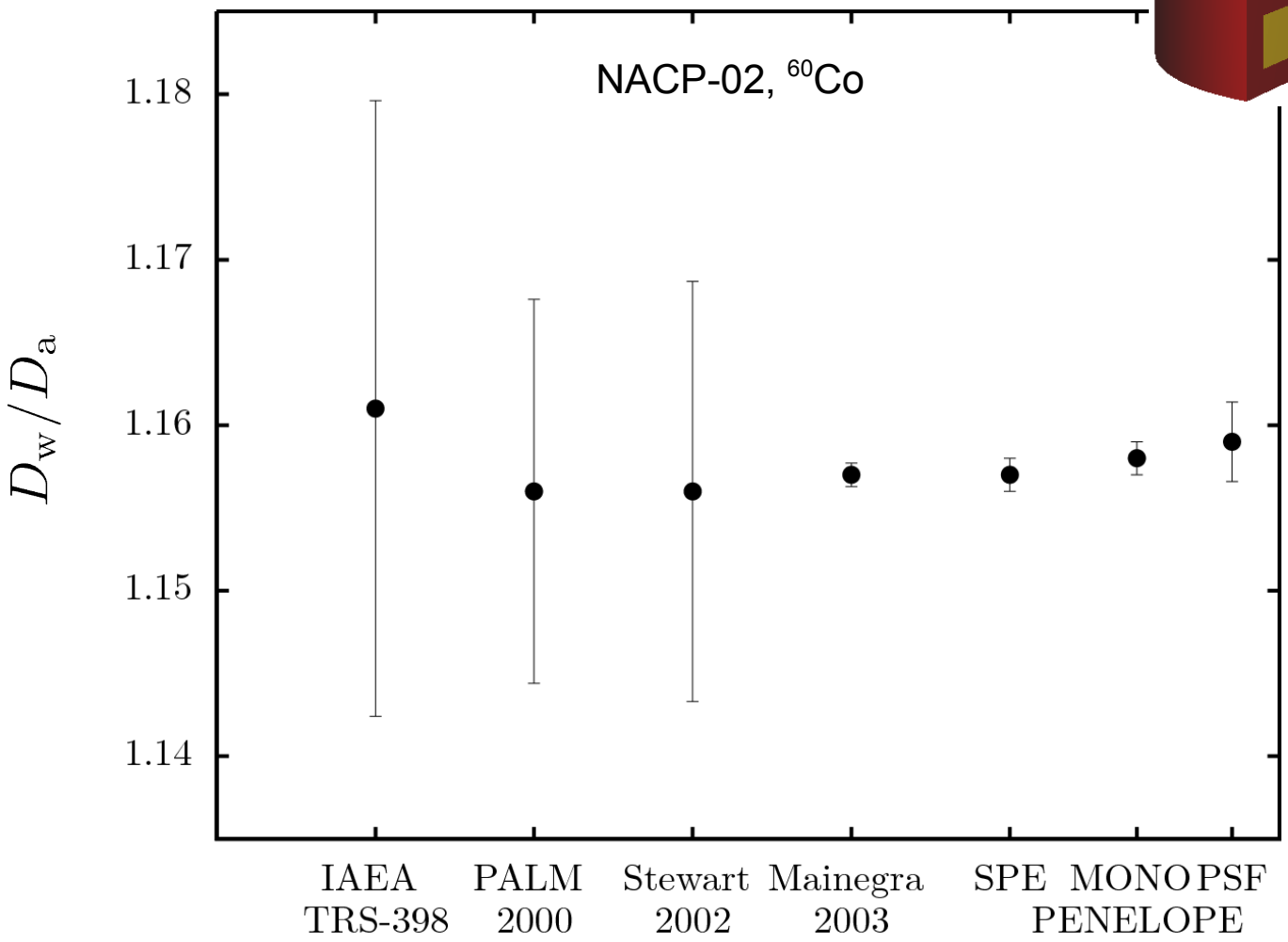
$\mathrm{WCC} = \min\{aE_0/100, 5\ \mathrm{keV}\}$

$\mathrm{WCR} = aE_0/1000$ (photon transport off)

J Sempau and P Andreo
Phys. Med. Biol. 51 (2006)

Results





V Panettieri *et al*, in preparation

(10×10 cm^2 field; reference conditions: SSD=100 cm, depth=5 cm)

Conclusion

- Penelope passes the Fano test at the ~ 0.1% level if the simulation parameters are set judiciously.
- ...this means that it will also reproduce IC response to a similar level of accuracy. **(?)**
- The possible effects of inaccuracies in the cross section models have not been comprehensively analysed.

  → The evaluation, under similar conditions, of ratios of absorbed doses tends to mitigate those effects. **(We hope.)**

At least we now know how to compute IC response in a **consistent** manner.

Acknowledgments

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Thank you.