Inelastic nuclear interactions in MC simulations for clinical proton beams

H Palmans, D Shipley, R Nutbrown & F Verhaegen

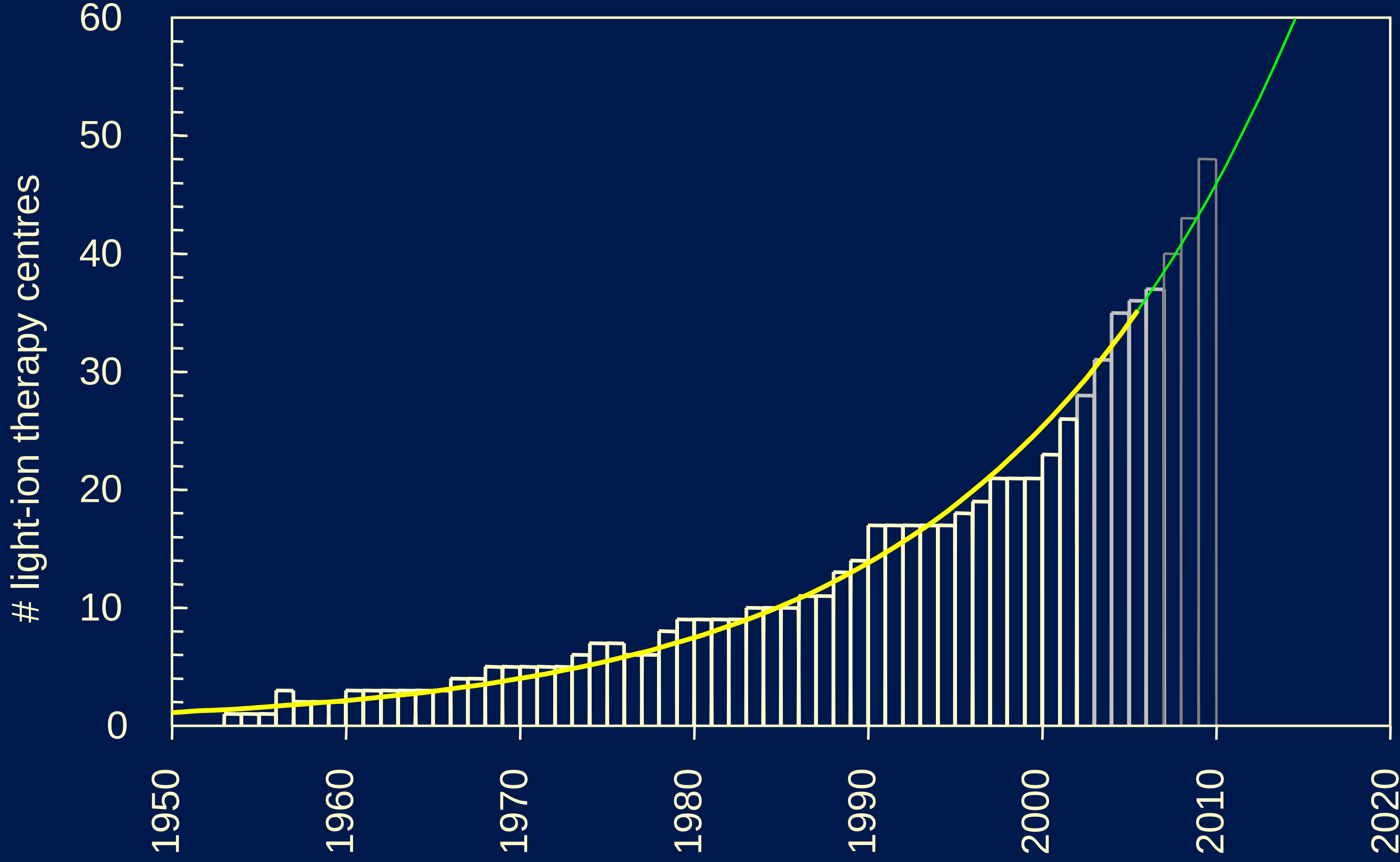
Centre for Acoustics & Ionising Radiation, NPL, UK

Medical Physics Unit, McGill University, Montreal, Quebec, Canada

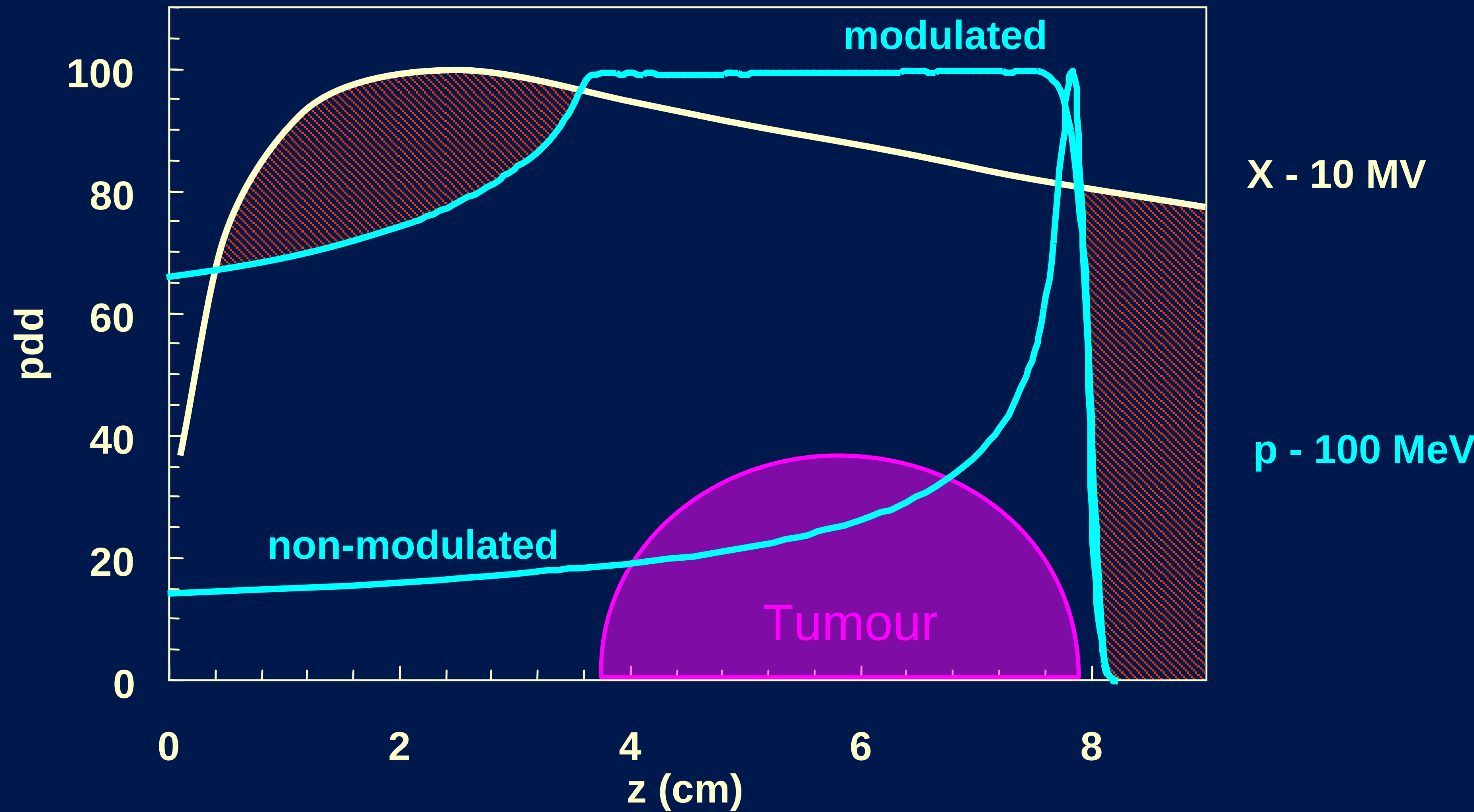
Overview

1. Proton therapy beams
2. Inelastic nuclear versus Coulomb interactions
3. Monte Carlo calculations
4. Ionisation chambers
5. Fluence correction factors
6. Water equivalence of graphite (graphite calorimetry)
7. Clinical dose calculations

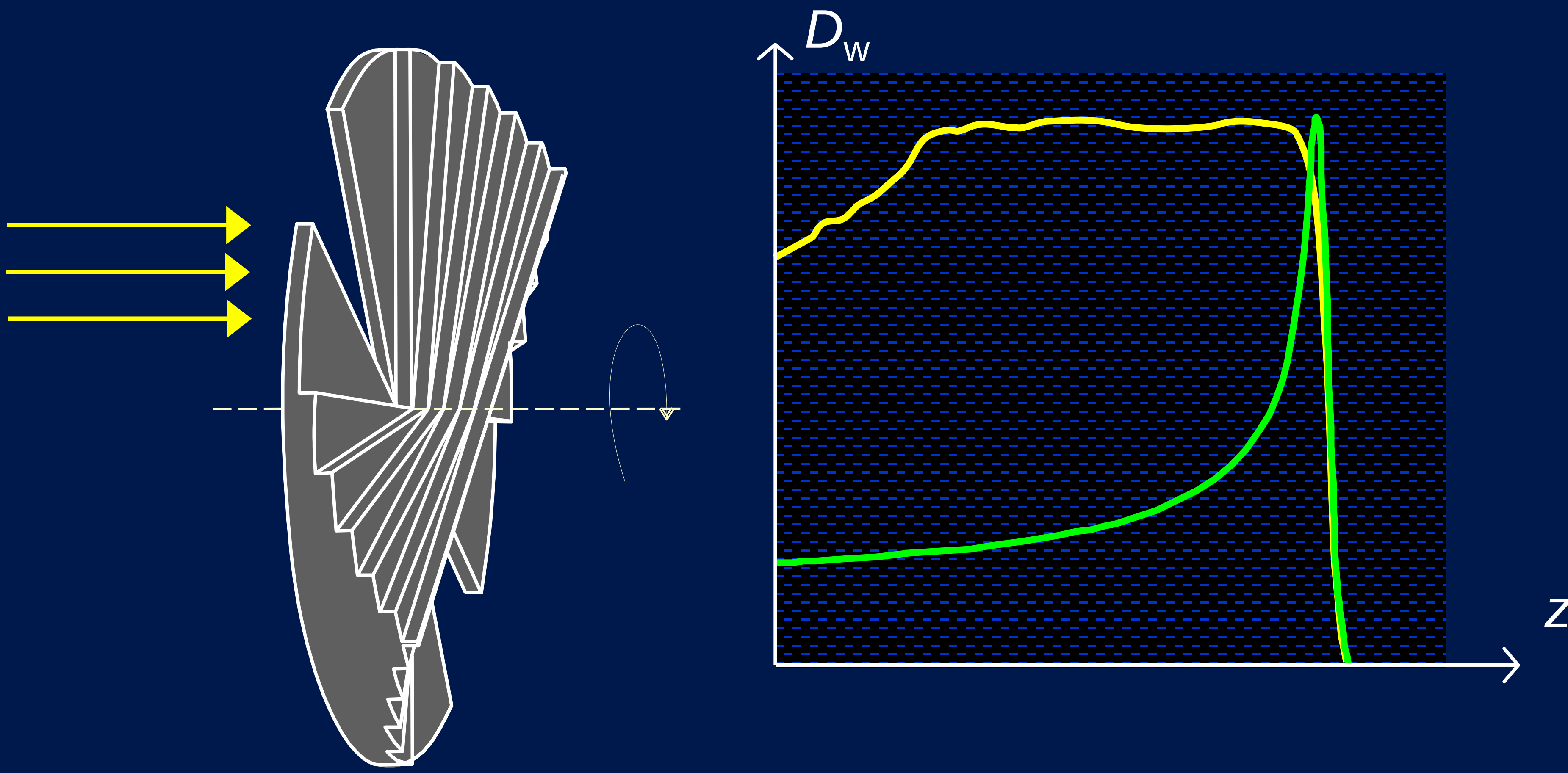
1. Proton (and ^{12}C) therapy beams worldwide



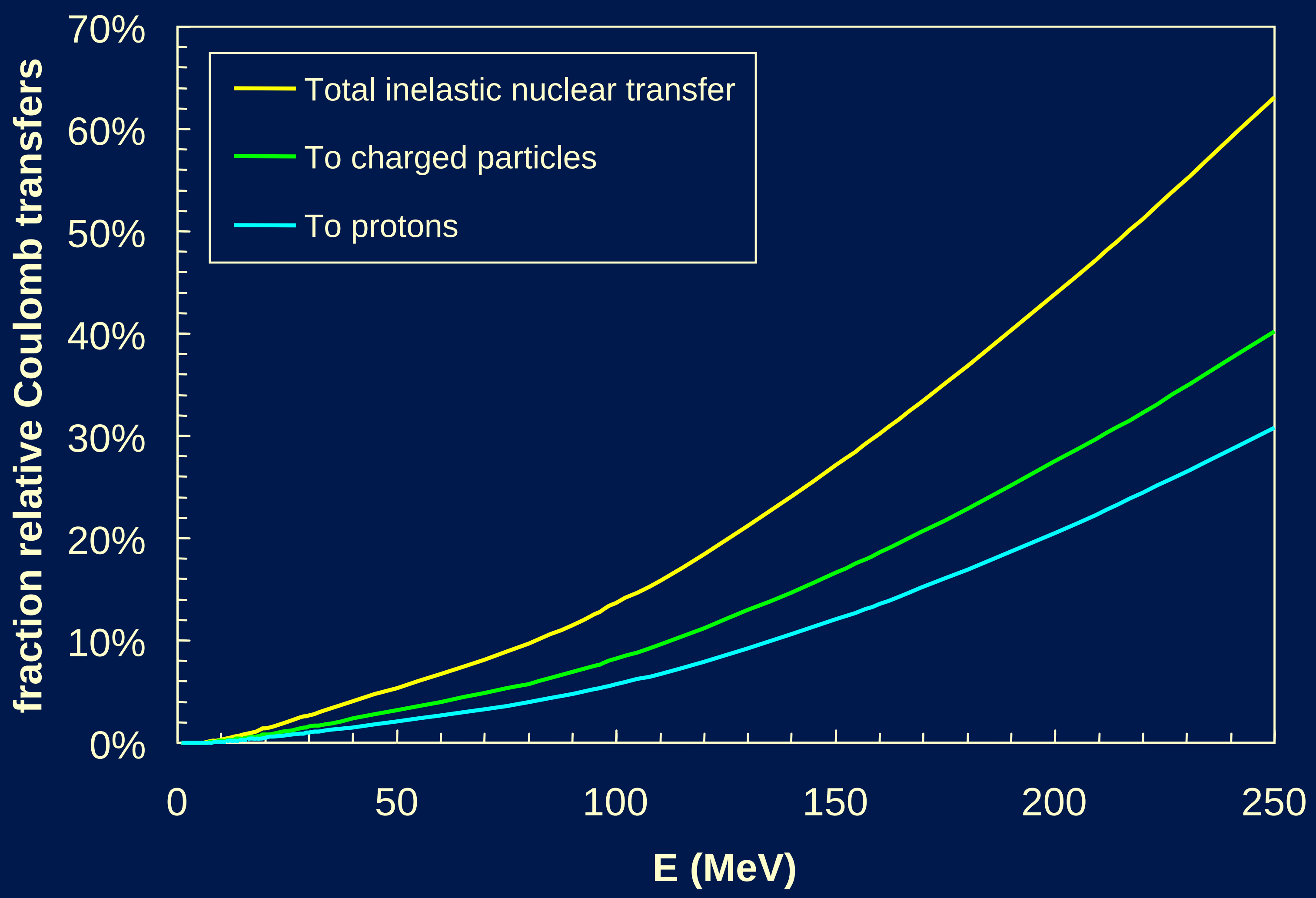
1. Proton therapy beams: depth dose characteristics



1. Proton therapy beams: Range modulation

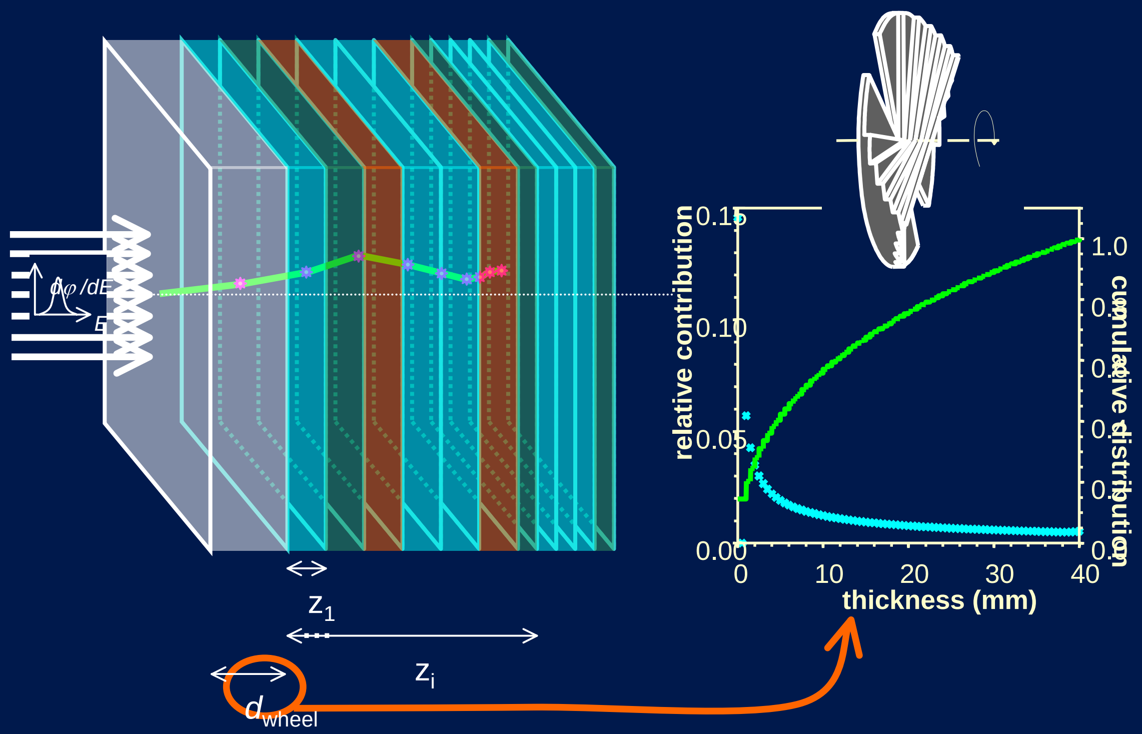


2. Inelastic nuclear versus Coulomb interactions (ICRU 49 & ICRU 63)



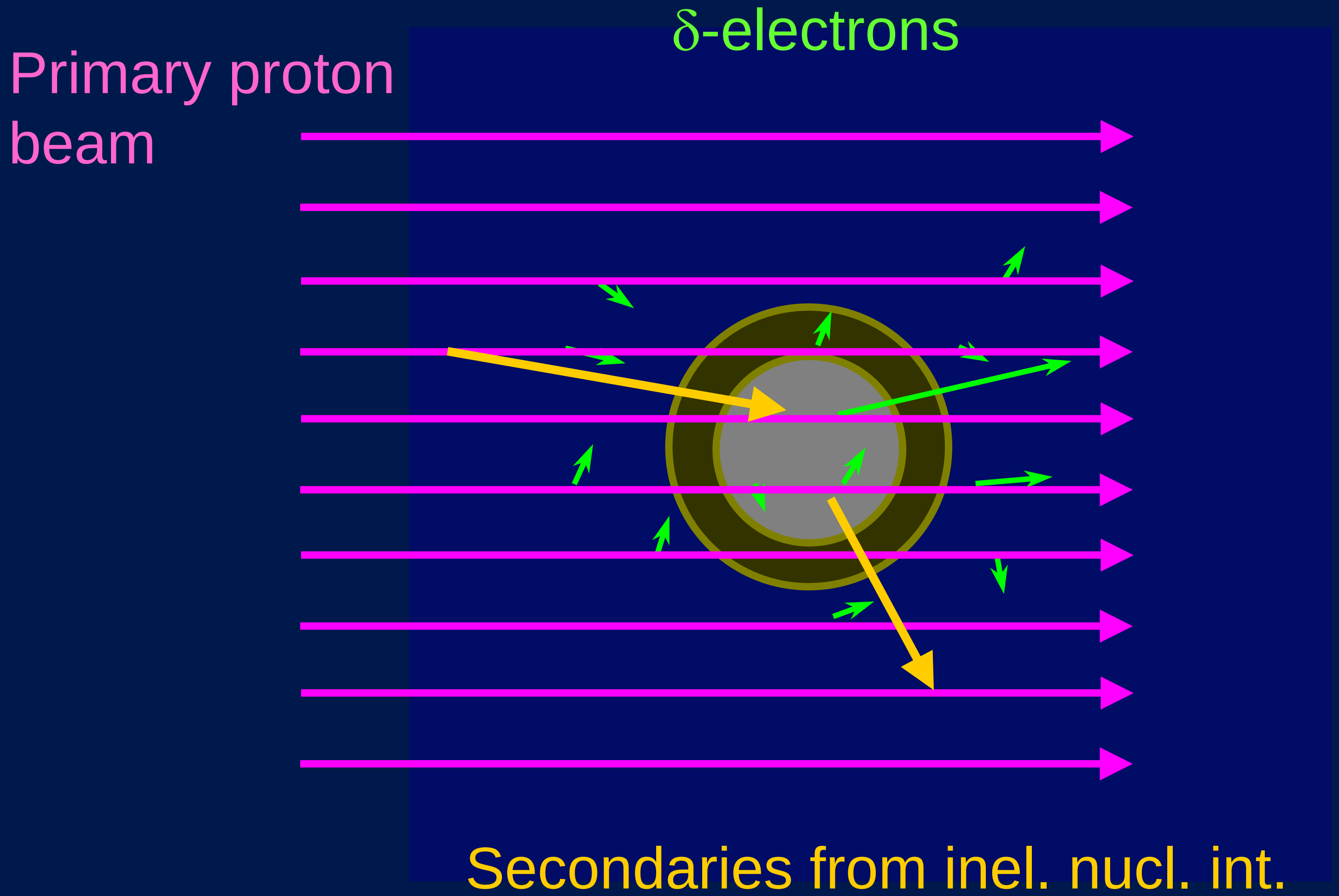
3. Monte Carlo calculations

- PTRAN_MEDIA (ICRU 49 + ICRU 63 data)



- MCNPX
- GEANT4

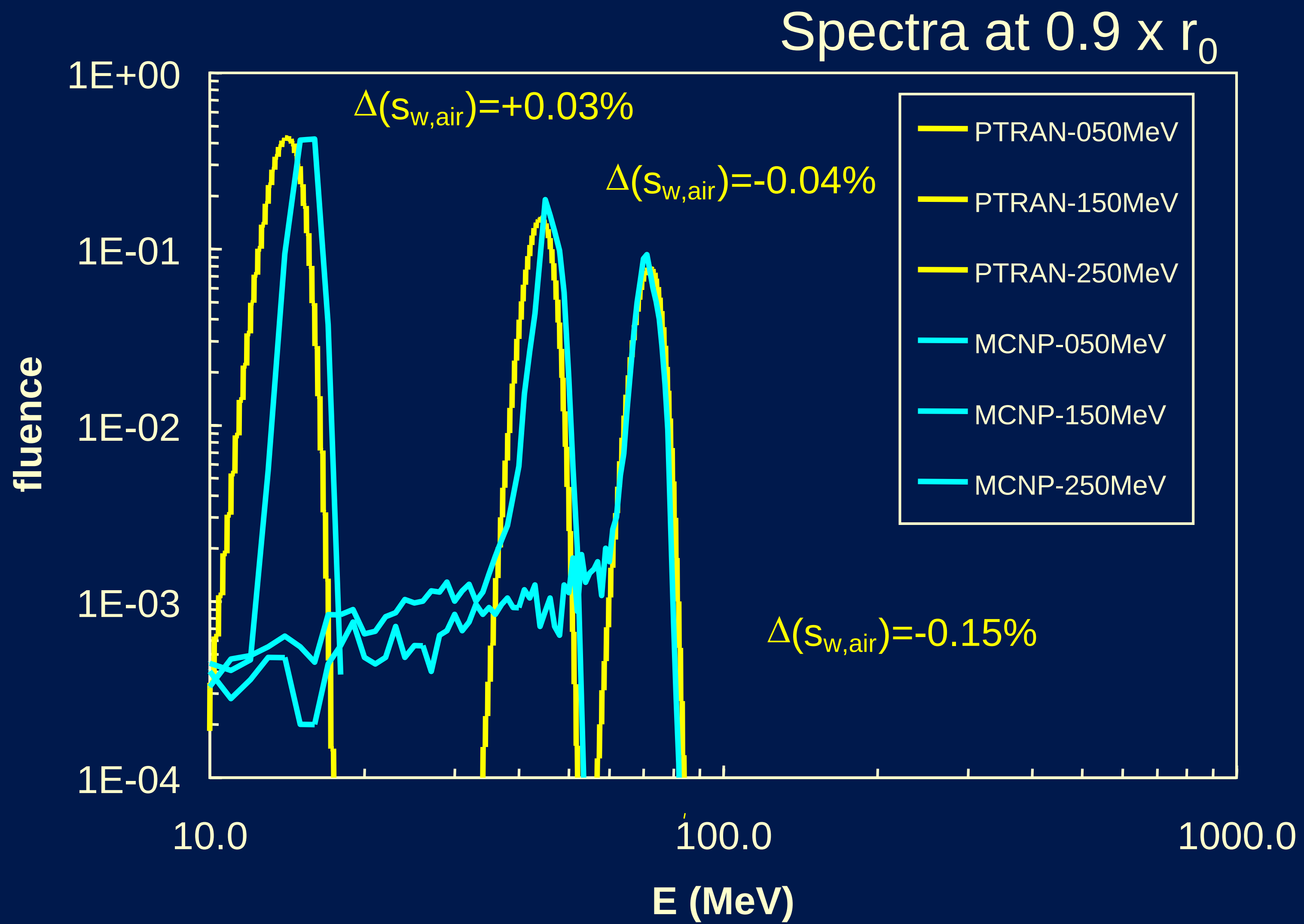
4. In ionisation chamber dosimetry



4. In ionisation chamber dosimetry

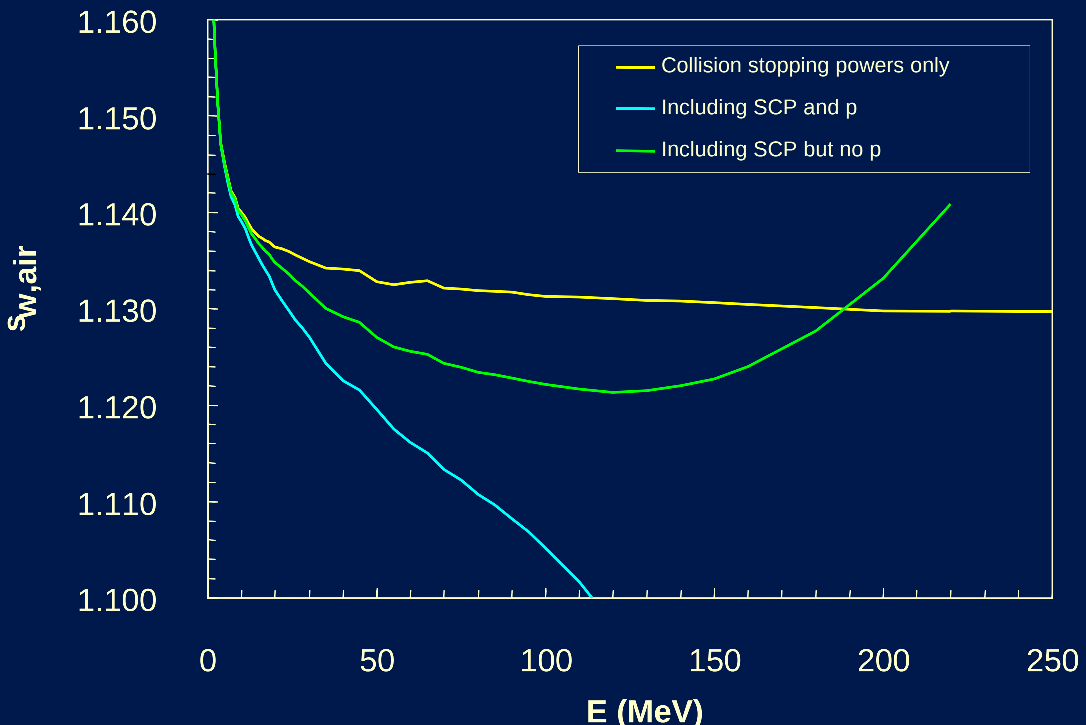
- Usually: only $s_{w,air}$
- IAEA TRS-398: Spencer-Attix $s_{w,air}$
- Secondary electron perturbations: 0-1%
  (Verhaegen and Palmans, Med. Phys. 28:2088-2095)
- Inelastic nuclear interactions:
  - Secondary charged particles (protons) in slowing down spectrum
  - Charged particles generated in cavity

4. In ionisation chamber dosimetry: secondary protons in Sl. D. S.



4. In ionisation chamber dosimetry: S. Ch. P. generated in cavity

- Under investigation
- Rough estimate:
  - Protons escape, other heavy charged particles not
  - Yields:



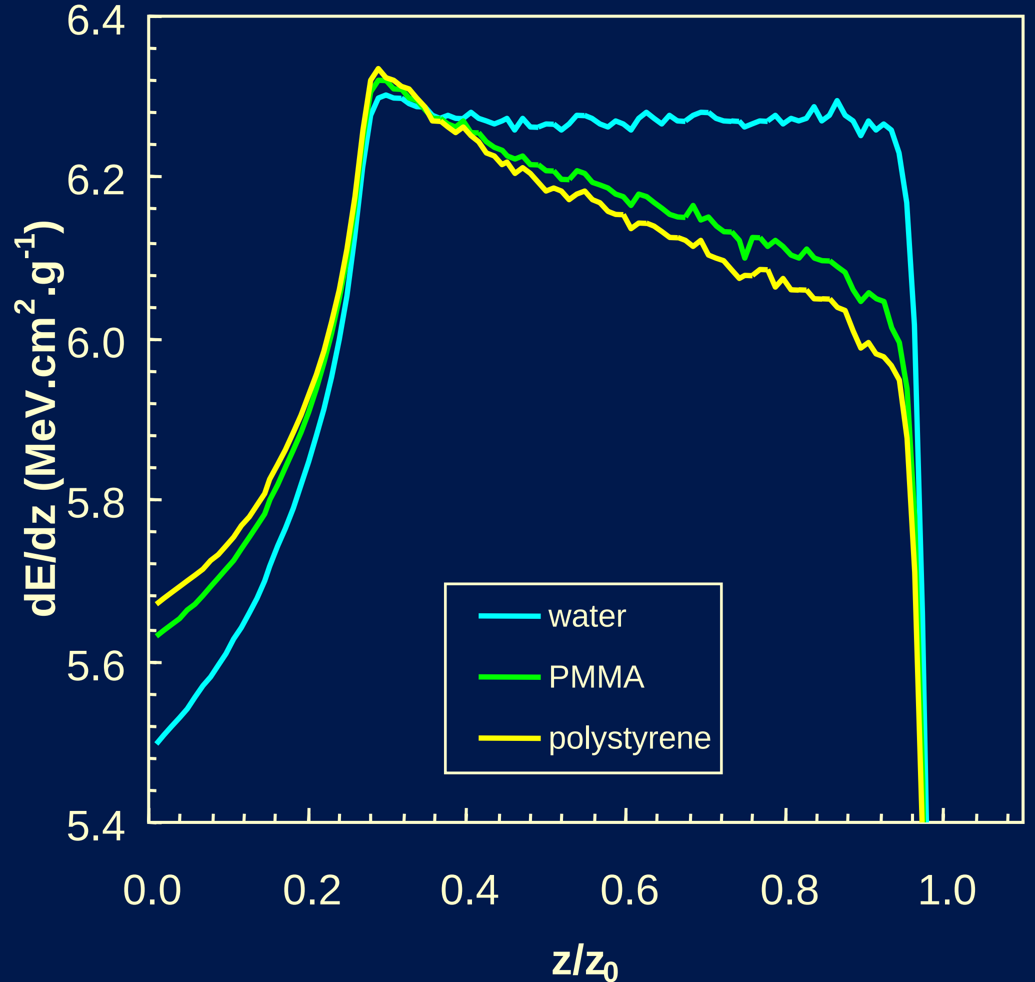
5. Fluence correction factors: definition (cfr. electron beams)

$$D_w(z_w) = D_{pl}(z_{pl}) \cdot s_{w,pl} \cdot \phi_{pl}^{w}$$

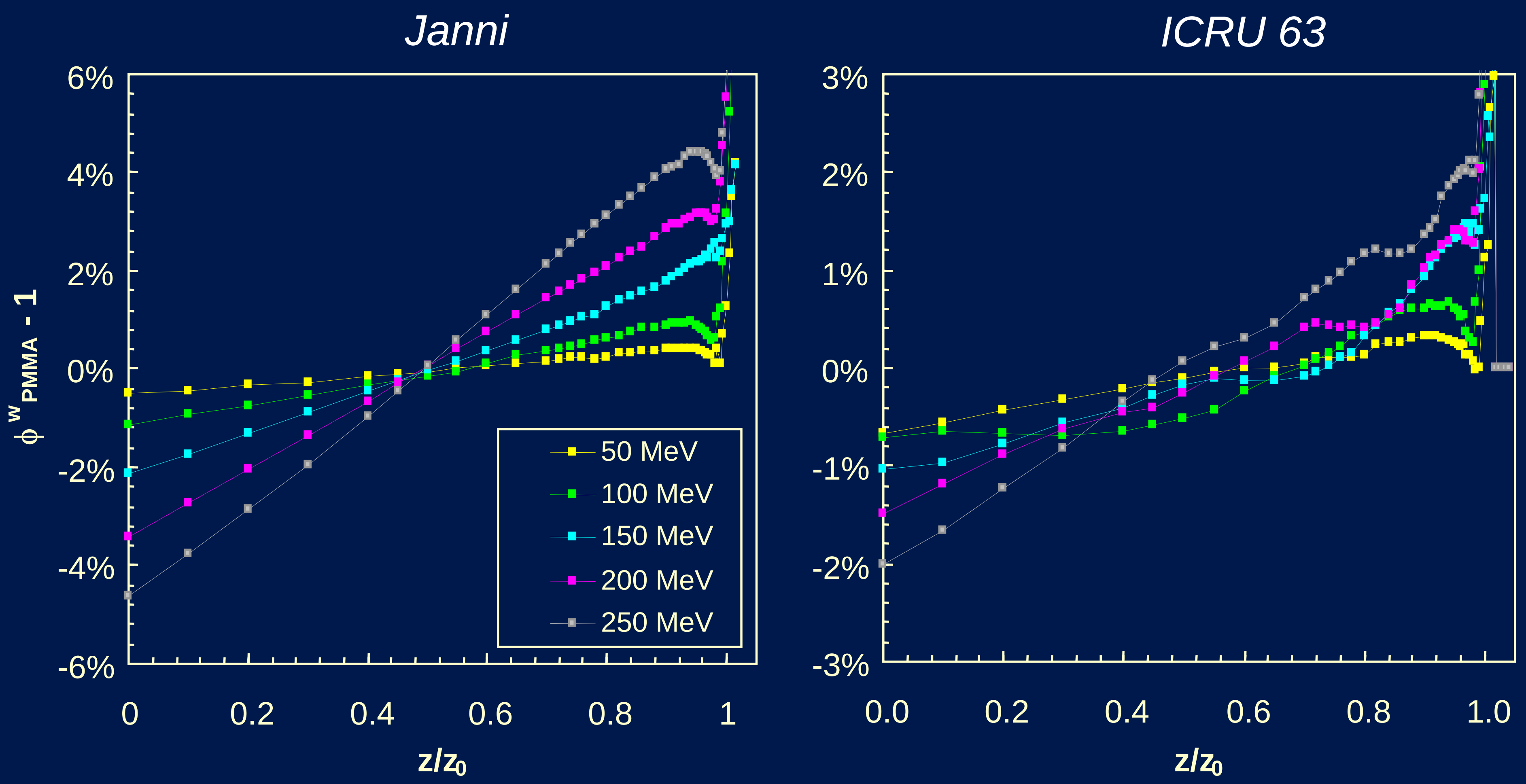
$$z_w = z_{pl} \cdot \frac{(z_0)_w}{(z_0)_{pl}}$$

$$h_{pl} = \frac{M^w}{M^{pl}}$$

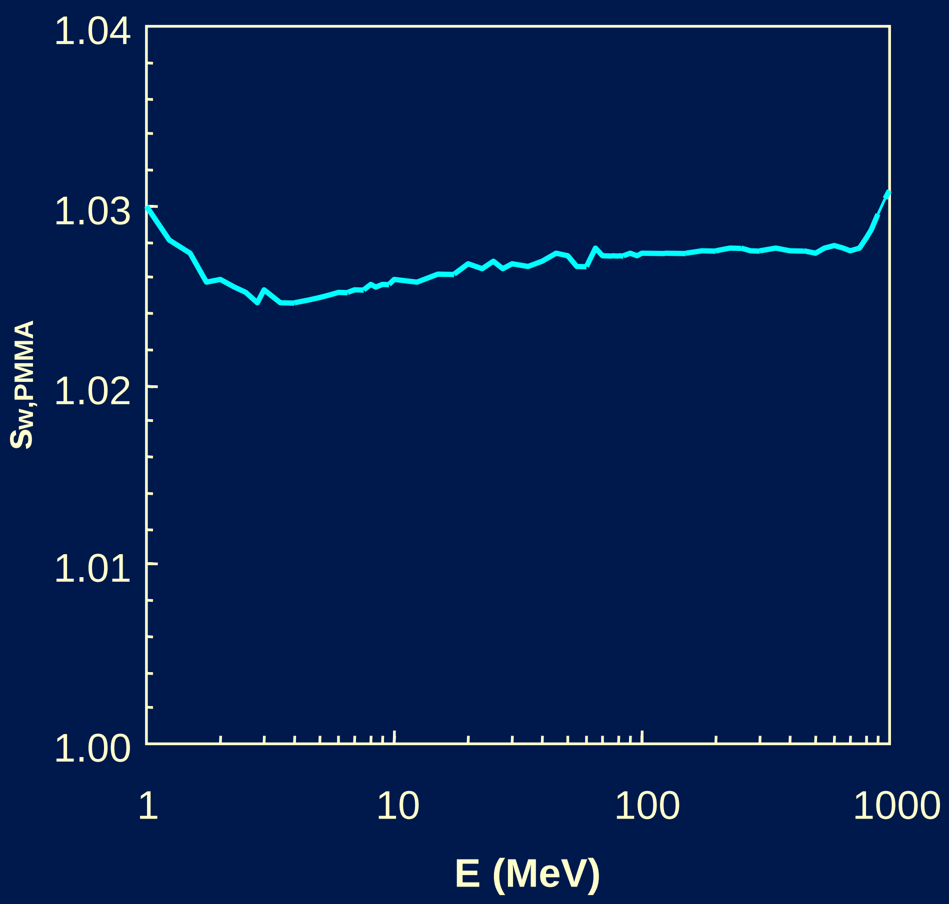
5. Fluence correction factors: calculated depth dose curves

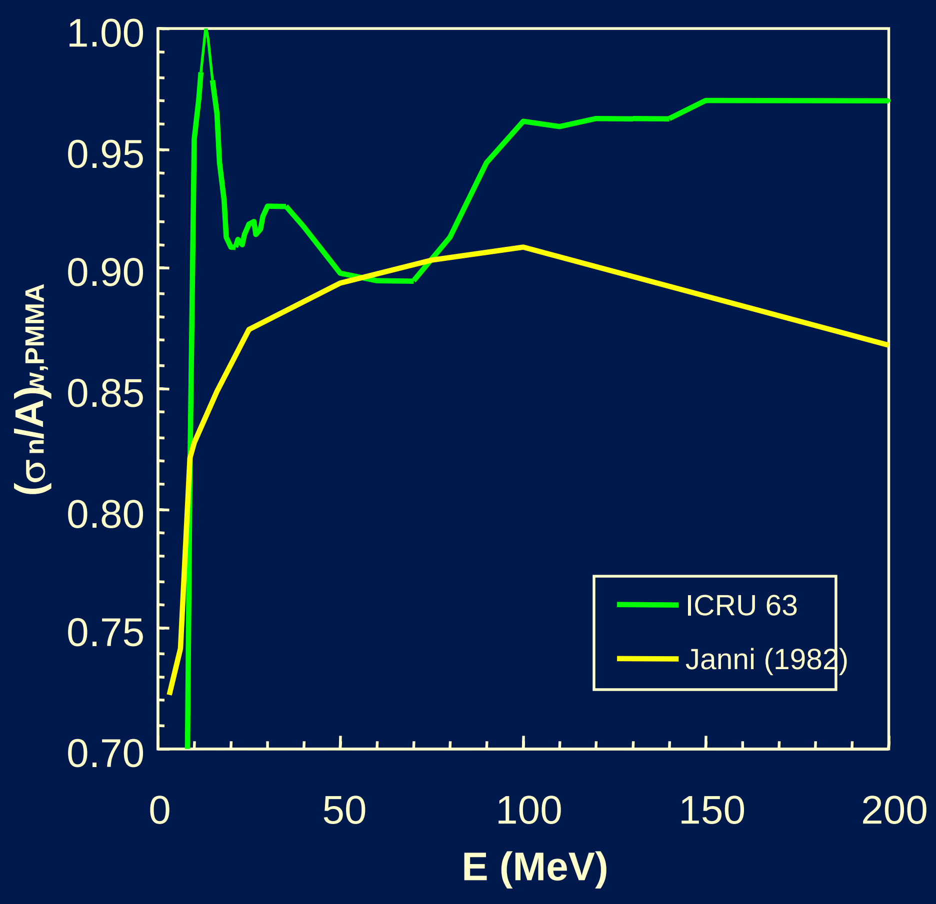


5. Fluence correction factors: calculated corrections



5. Discussion: stopping power data versus non-elastic nuclear cross sections



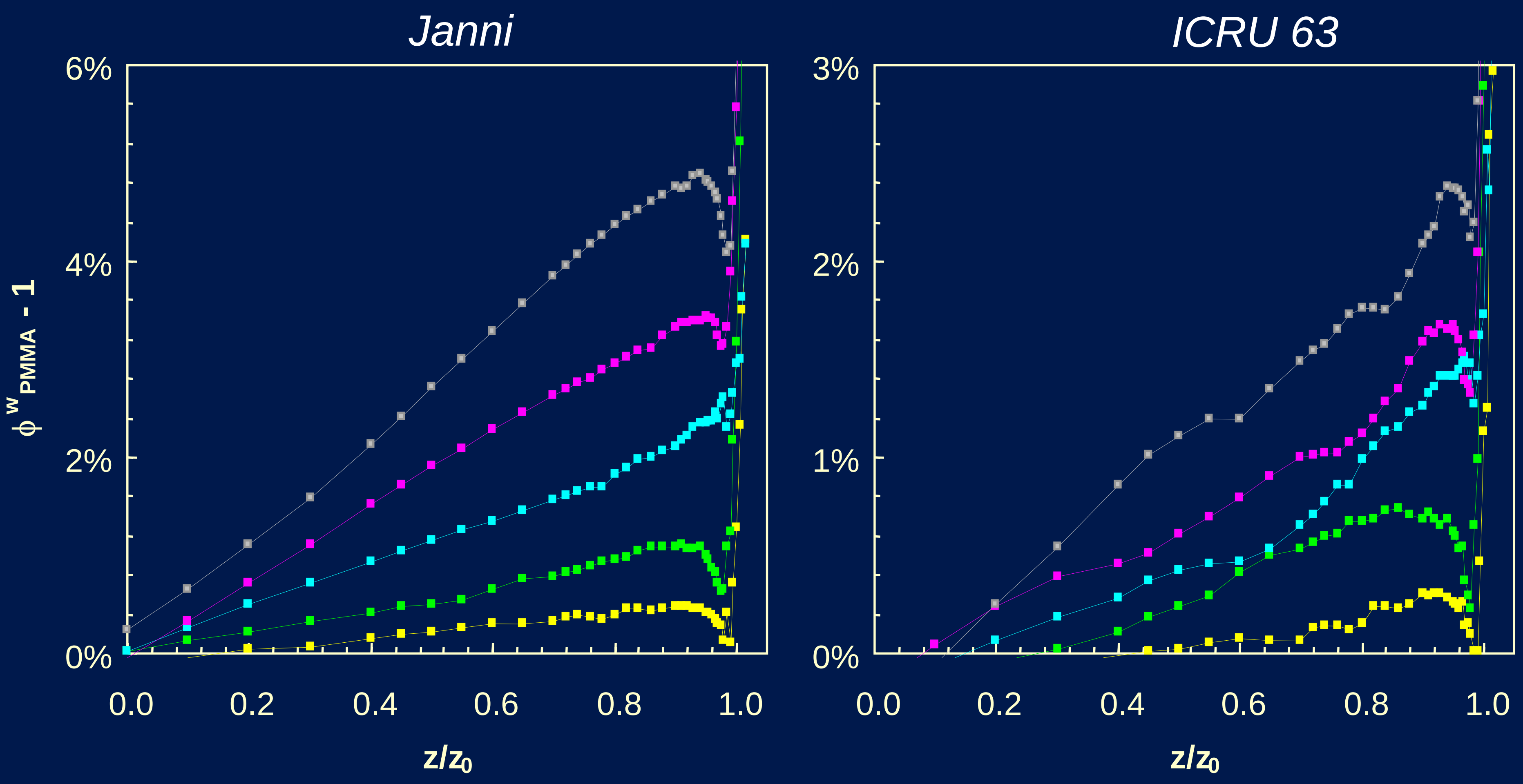


5. Fluence correction factors: correct dose conversion

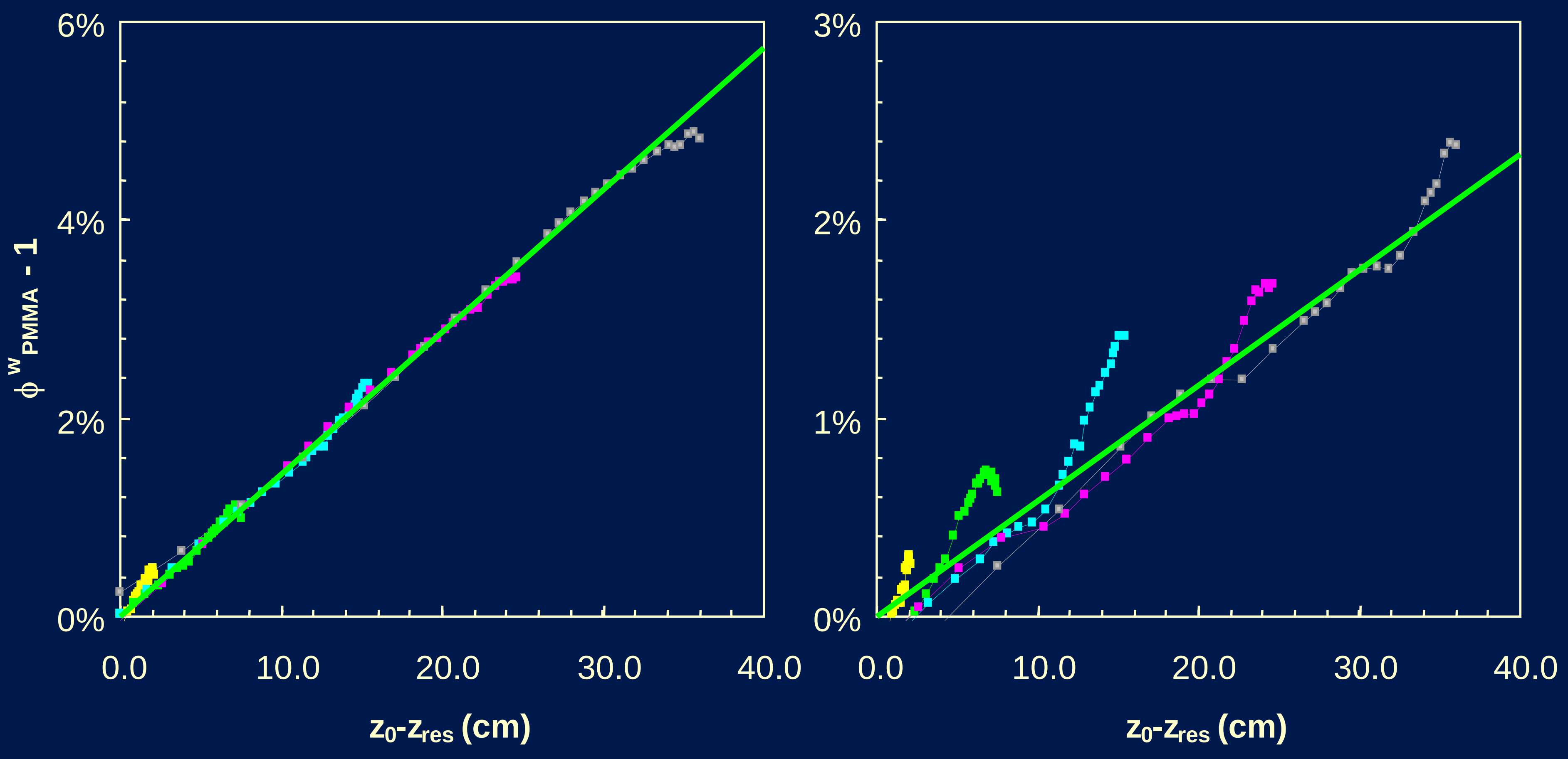
$$D_w(z_w) = \left[D_{pl,C}(z_{pl}).s_{w,pl} + D_{pl,N}(z_{pl}).\mathrm{E}.(\sigma_n/A)_{w,pl} \right] \phi_{pl}^{w}$$

$$z_w = z_{pl} \cdot \frac{(z_0)_w}{(z_0)_{pl}}$$

5. Fluence correction factors: calculated corrections



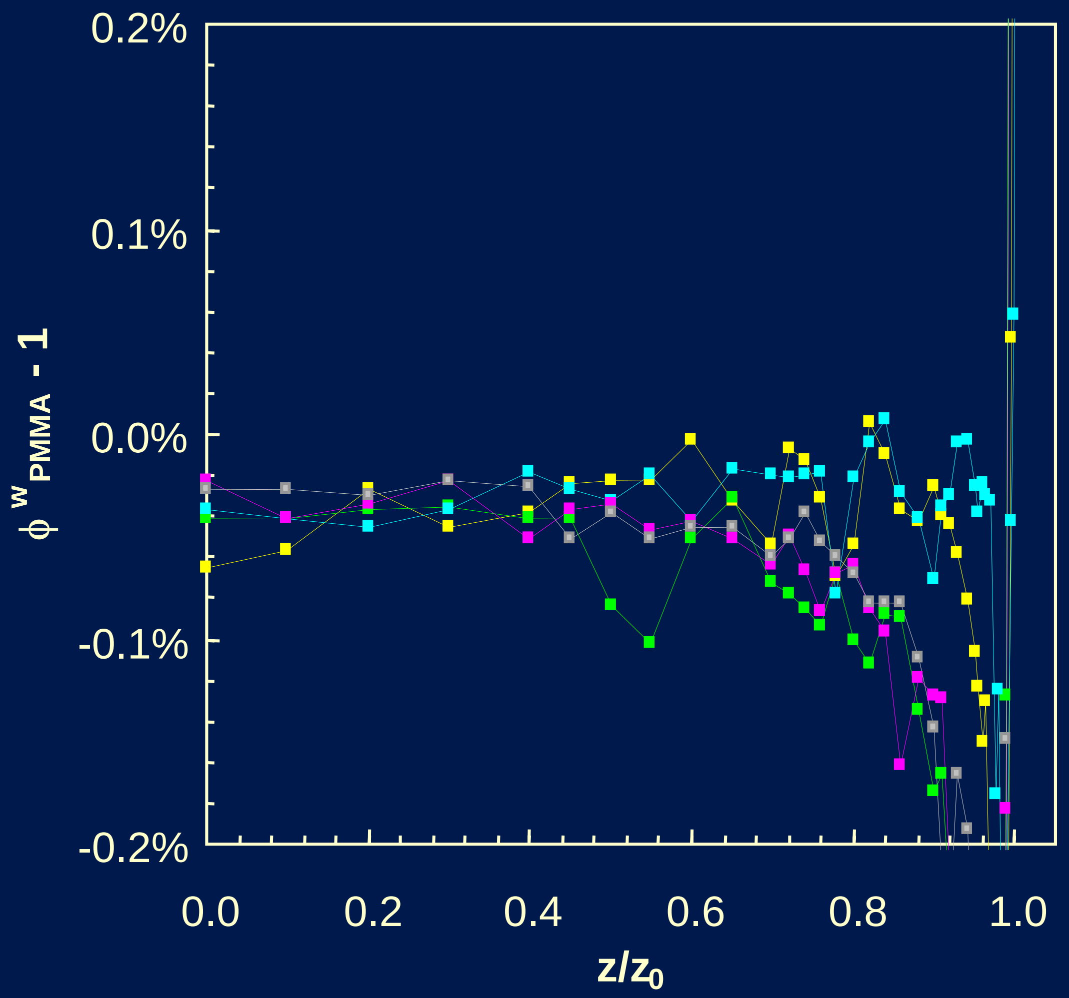
5. Fluence correction factors: correction versus penetration



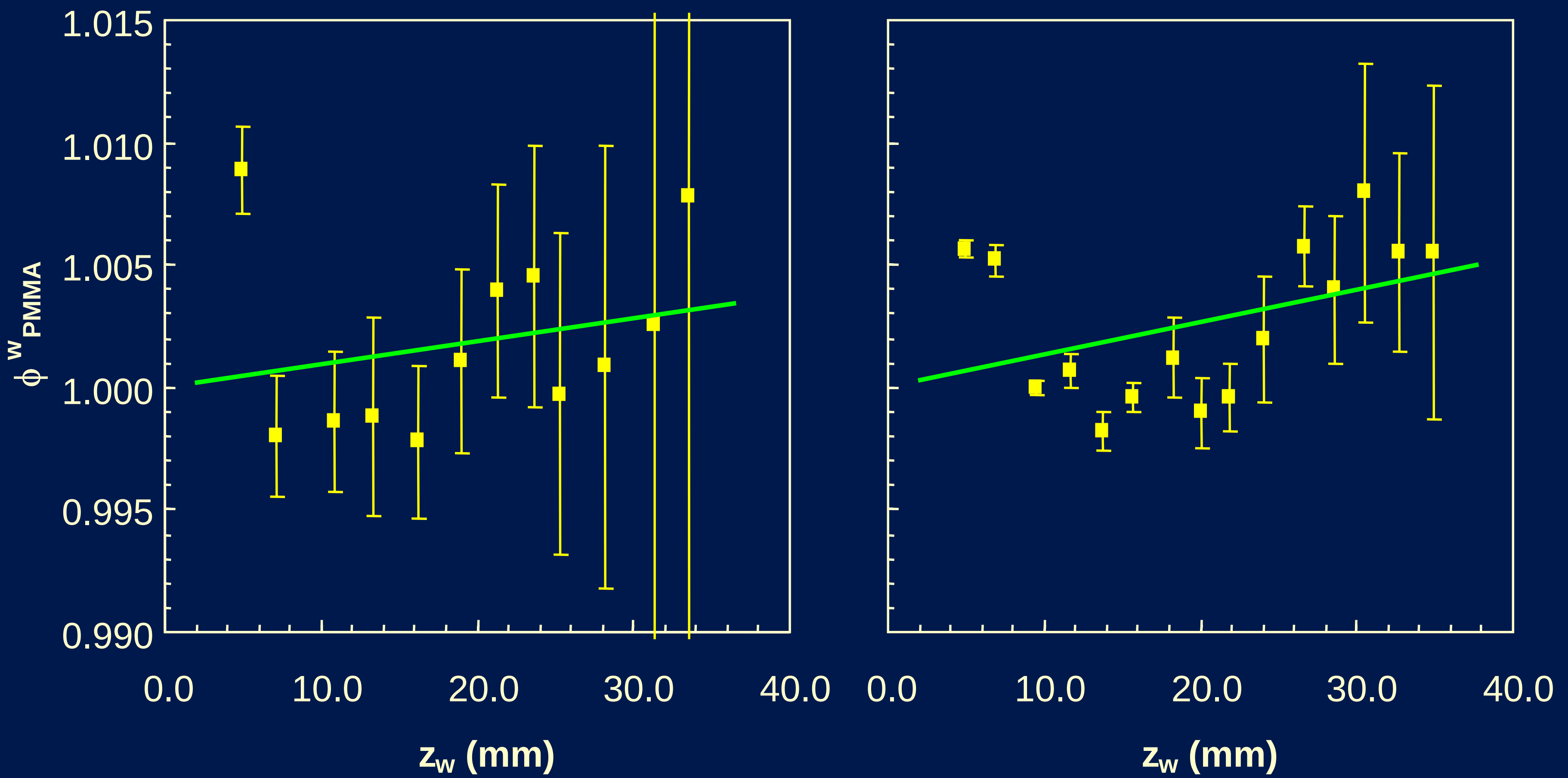
5. Fluence correction factors: correction per cm penetration

Phantom material	Janni (1982)		ICRU report 63
	Unmodulated beams	Modulated beams	Unmodulated beams
PMMA	0.14%/cm	0.15%/cm	0.058%/cm
polystyrene	0.19%/cm	0.20%/cm	0.064%/cm

5. Fluence correction factors: without inelastic nuclear interactions

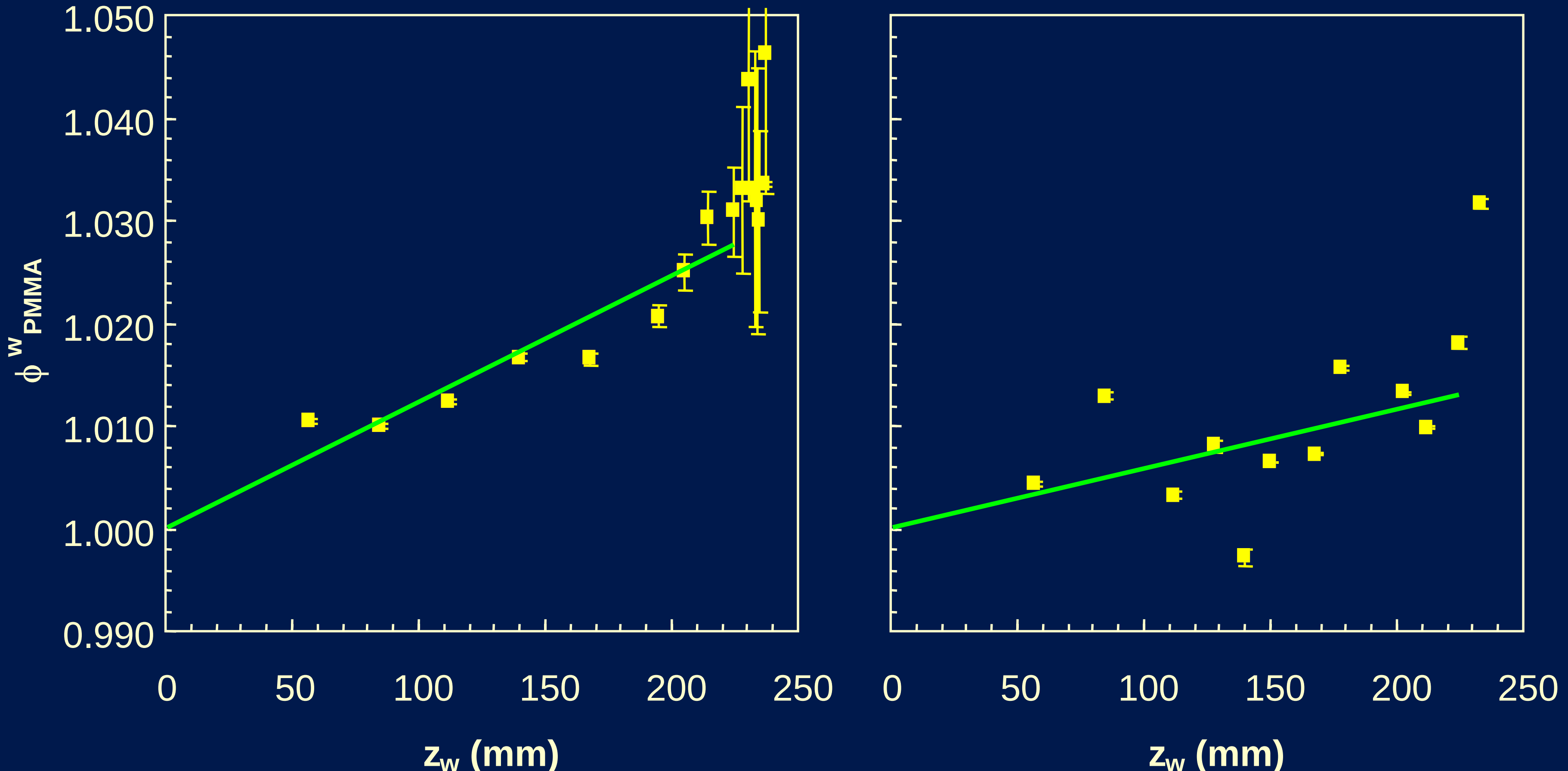


5. Fluence correction factors: experiment at LLN (75 MeV)



5. Fluence correction factors: experiment at NAC[*] (191 MeV)

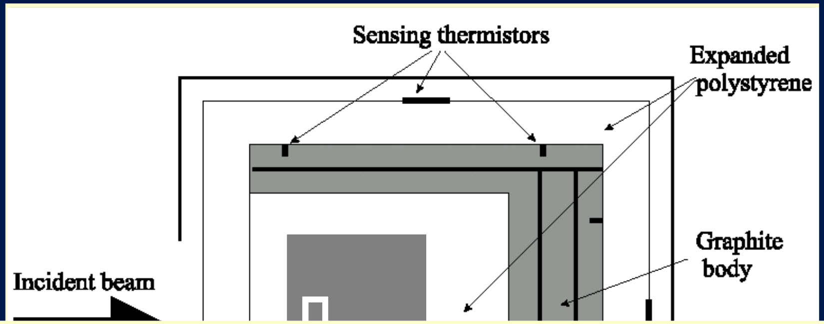
[*] Now iThemba Labs

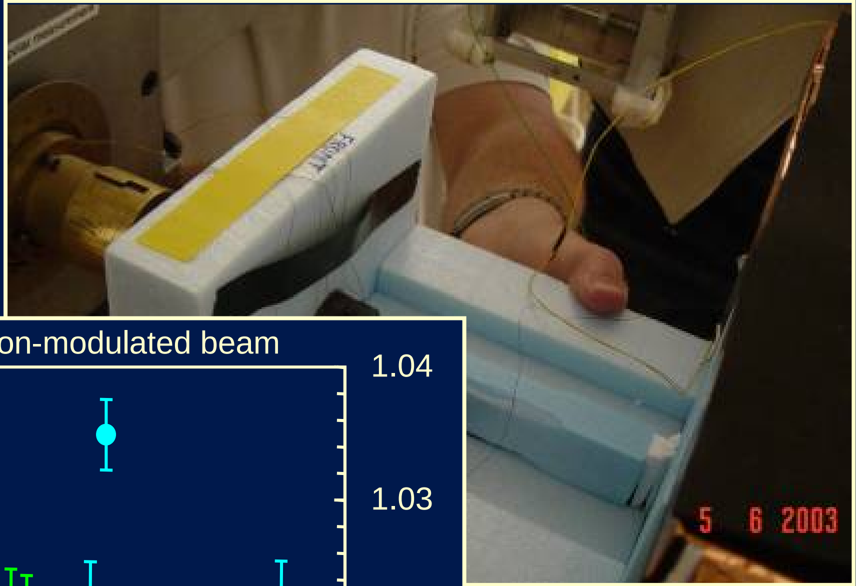


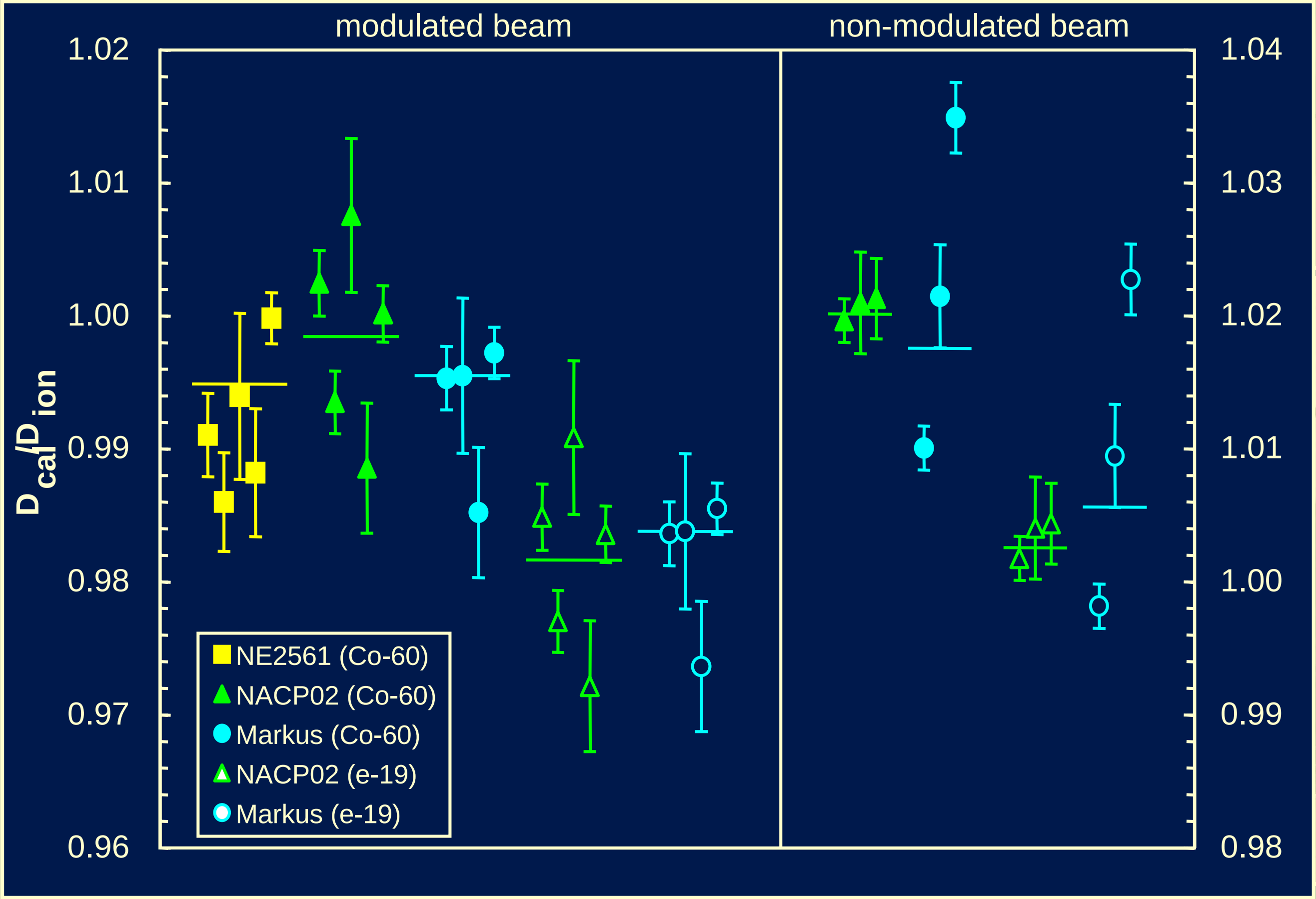
5. Fluence correction factors: very little experimental information

- Schneider et al. 2002 *Med. Phys. 29:2946-2951*
- Palmans et al. 2002 *Phys. Med. Biol. 47:3055-3071*
- Paganetti and Gottschalk 2003 *Med. Phys. 30:1926-1931*

6. Graphite calorimetry



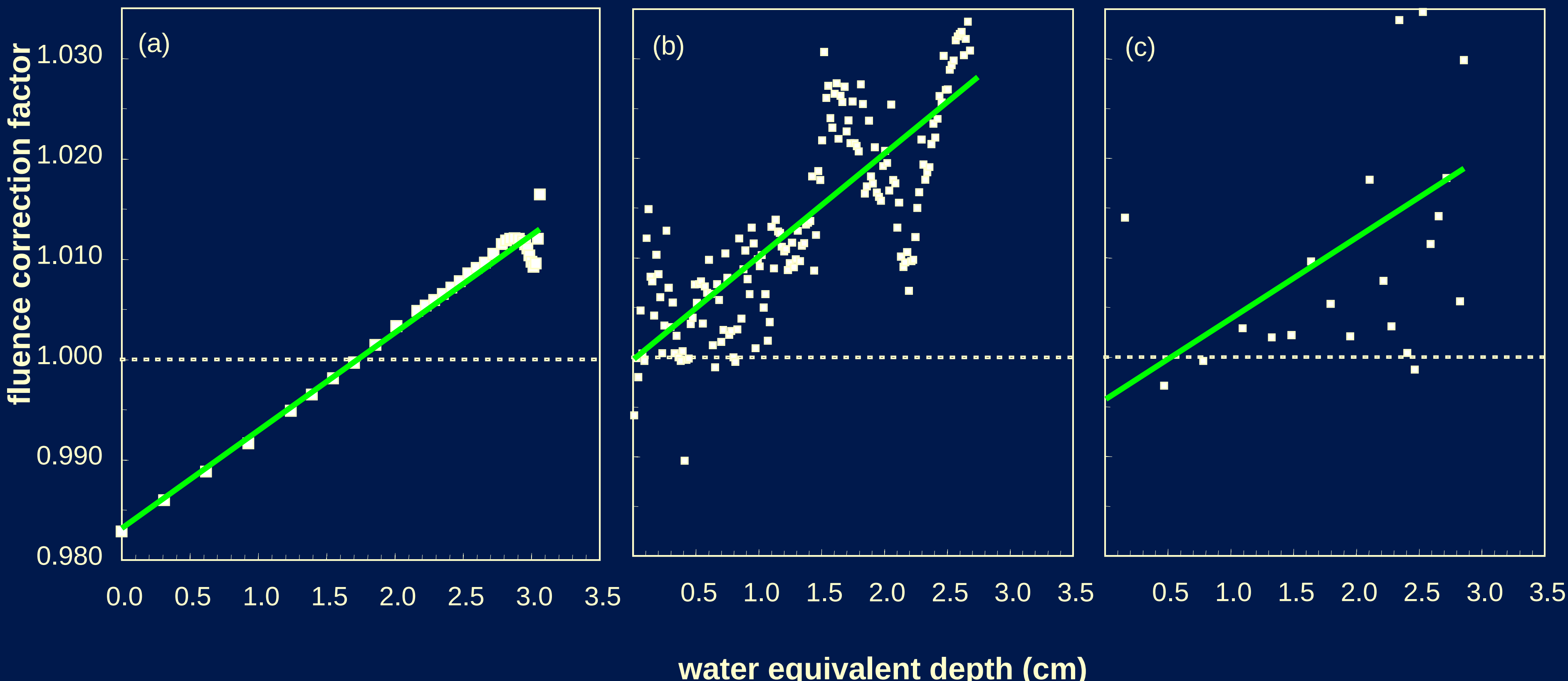




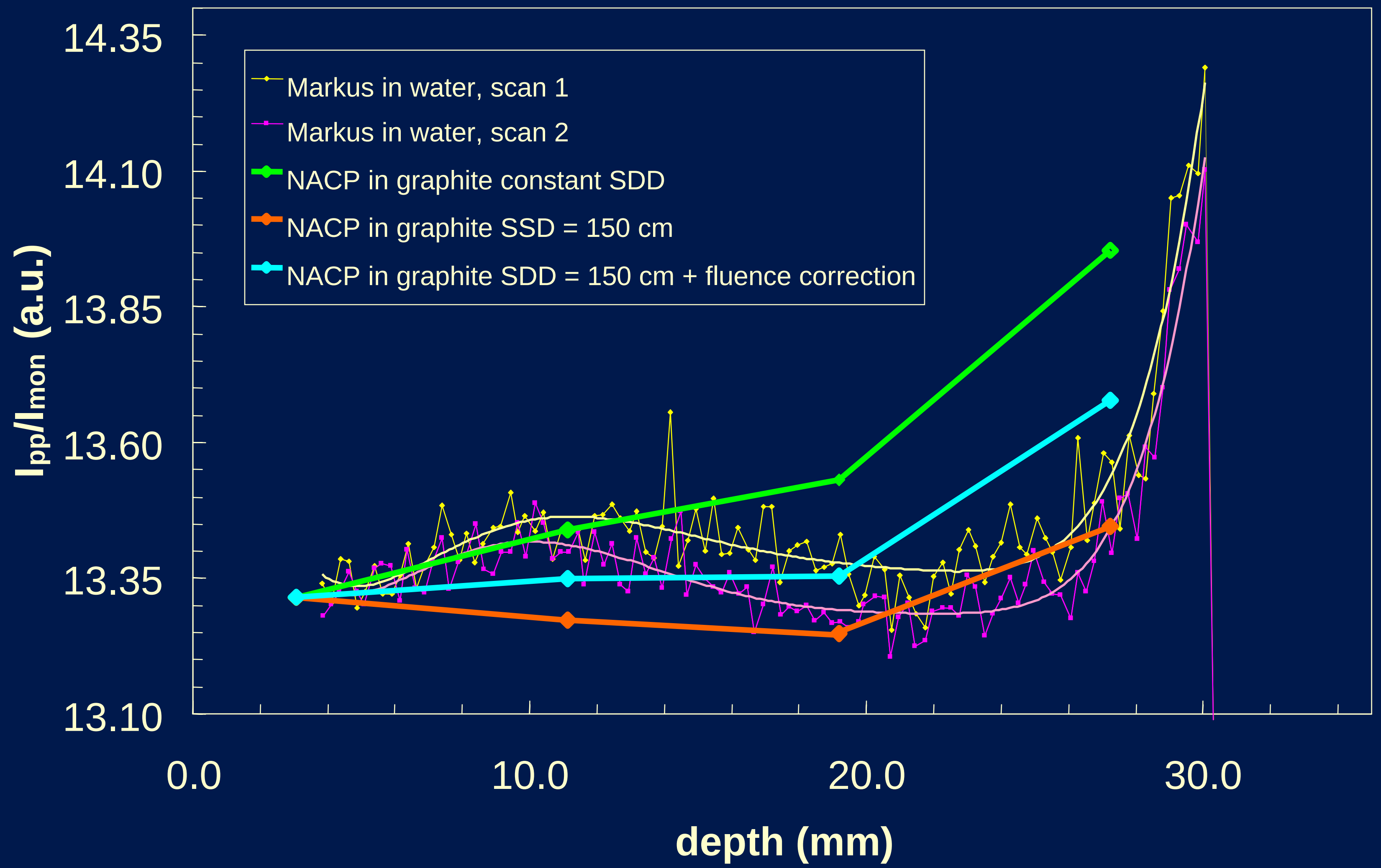
6. Graphite calorimetry

- Fluence corrections

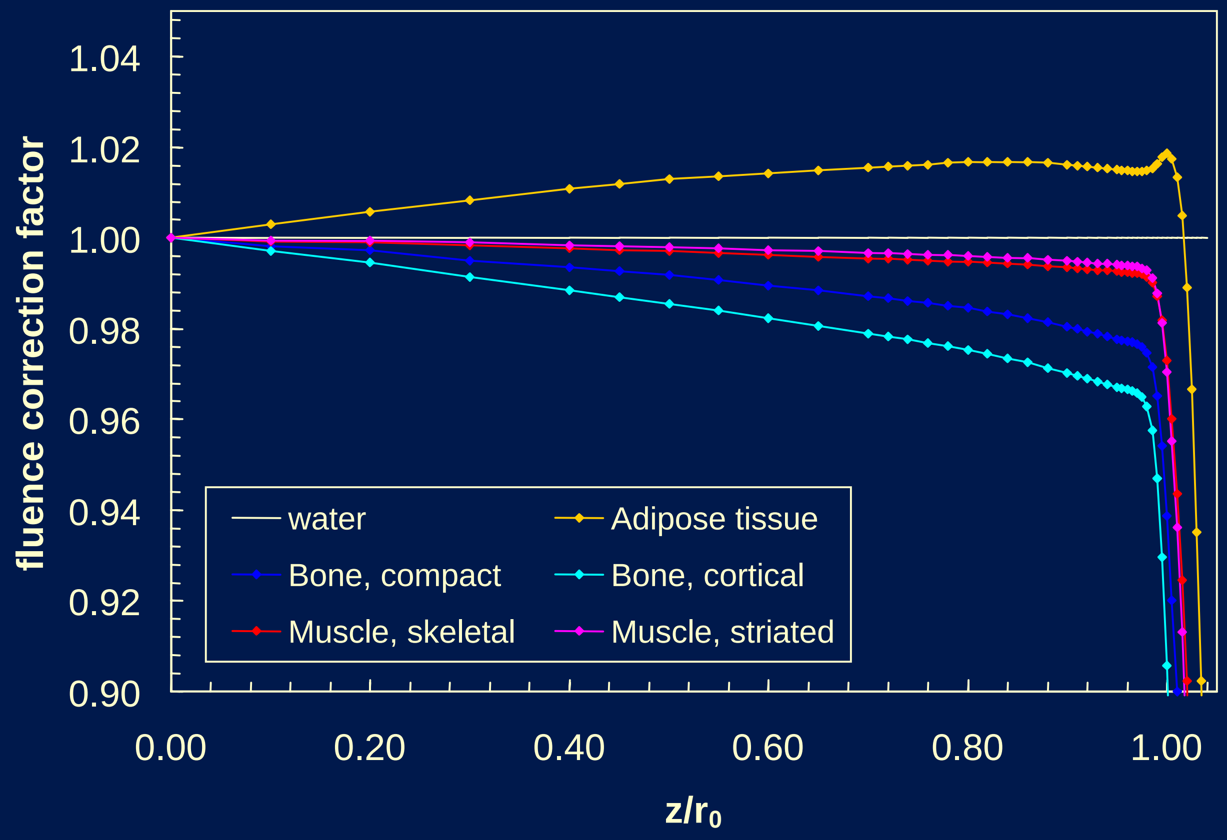
PTRAN GEANT4 MCNPX



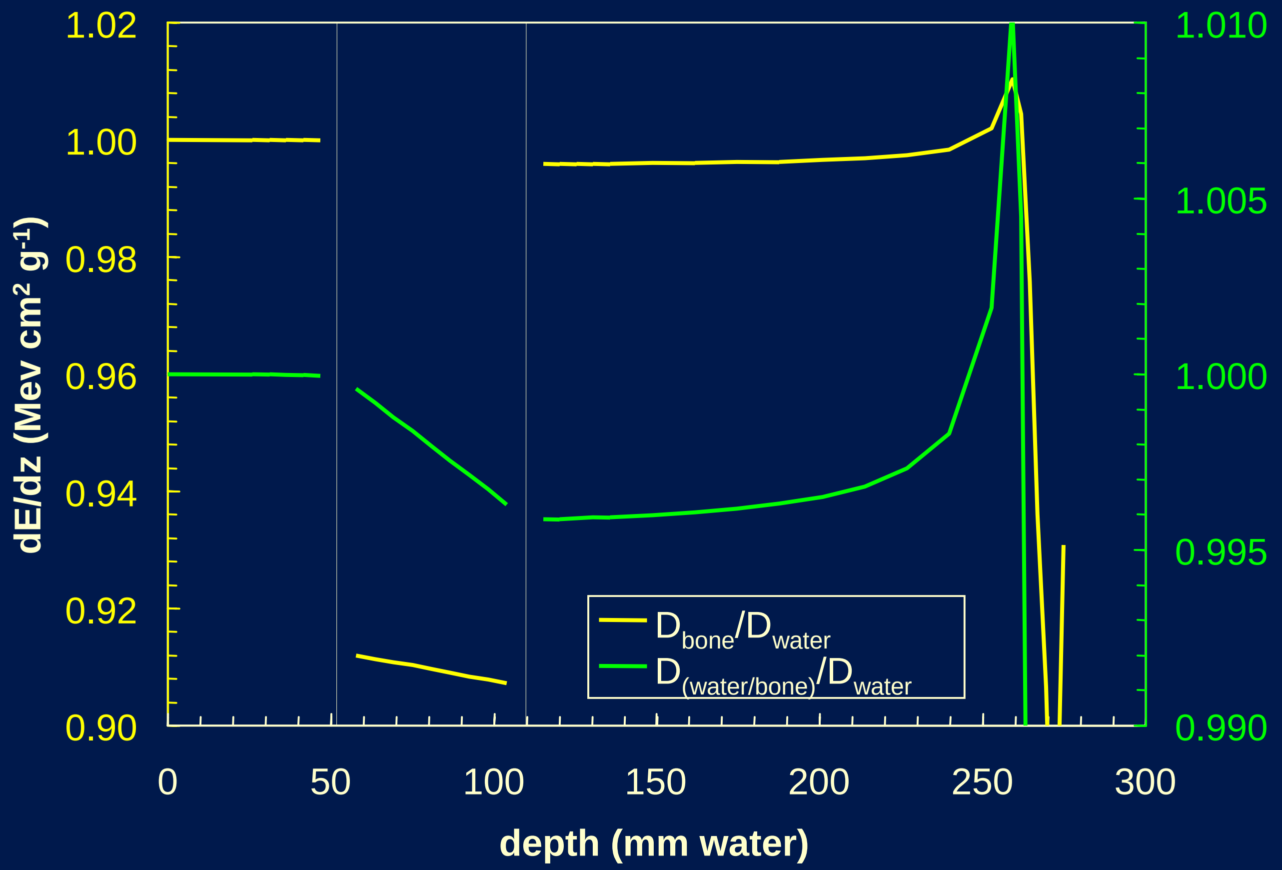
6. Graphite calorimetry: water equivalence – measured pdds



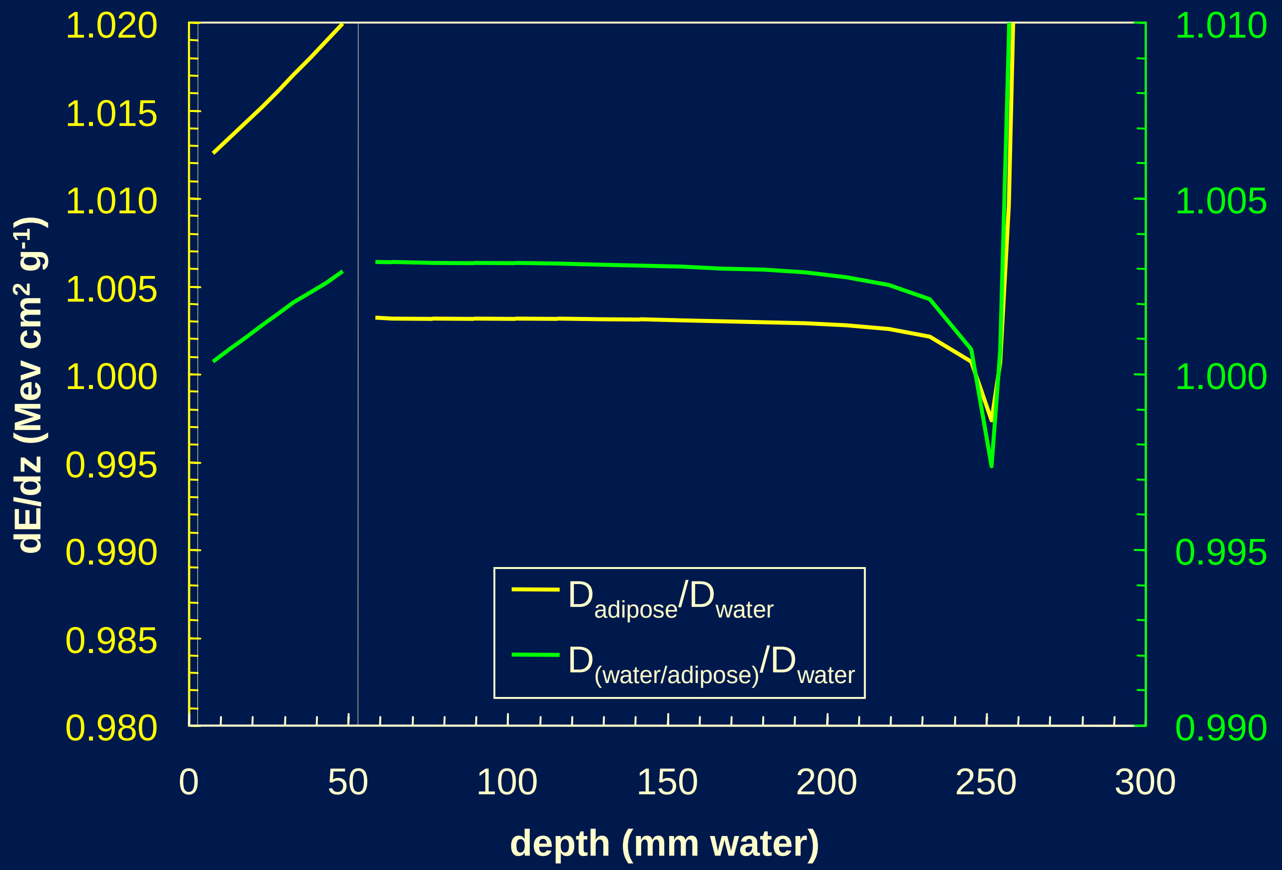
7. Clinical dose calculations



7. Clinical dose calculations



7. Clinical dose calculations



Conclusions

- Inelastic nuclear interactions:
  - Generally small effects
  - Small effects in ionisation chambers, but need further investigation
  - Fluence correction factors can be substantial
  - Effects in tissues can be substantial
  - Experimental evidence required