NACP-02 perturbation correction factors for the NPL primary standard of absorbed dose to water in high energy electron beams

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Outline

1. Calibration procedure at NPL
2. Model of ion chamber for MC simulations
3. Validation of MC model with backscatter simulations and measurements
4. Perturbation correction factors in water
5. Perturbation correction factors in graphite
6. Implications for the NPL electron beam calibration

NPL Calibration Procedure: high energy electrons

(1) Define reference depth in water

$$d_w = 0.6R_{50,w} - 0.1cm$$

(2) Use range scaling to get depth in graphite

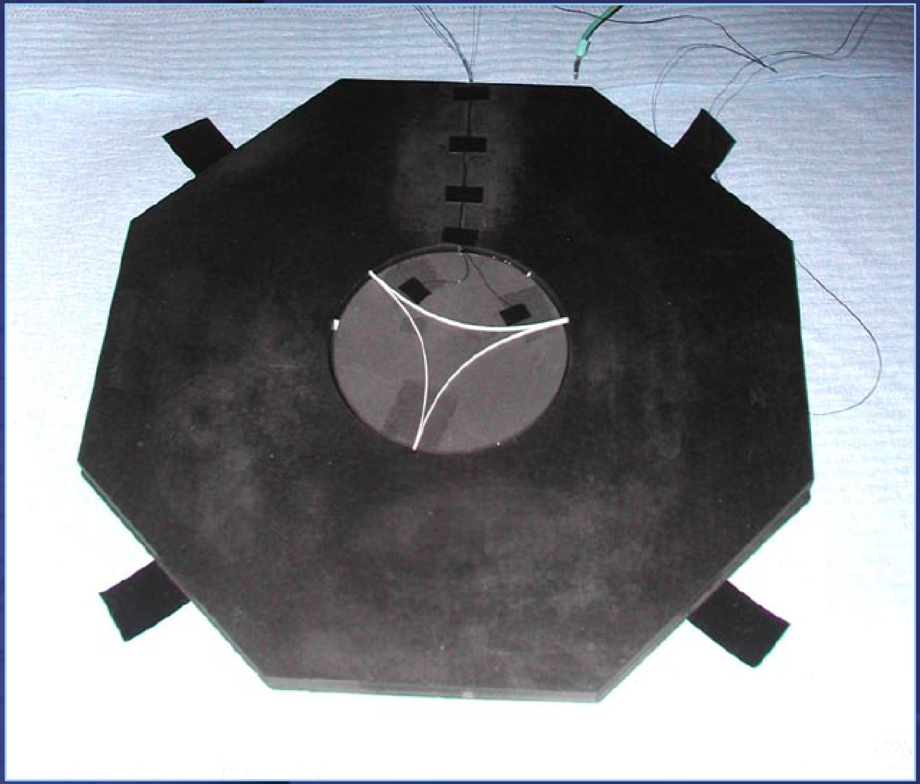
$$d_g = d_w R_{50,g} / R_{50,w}$$

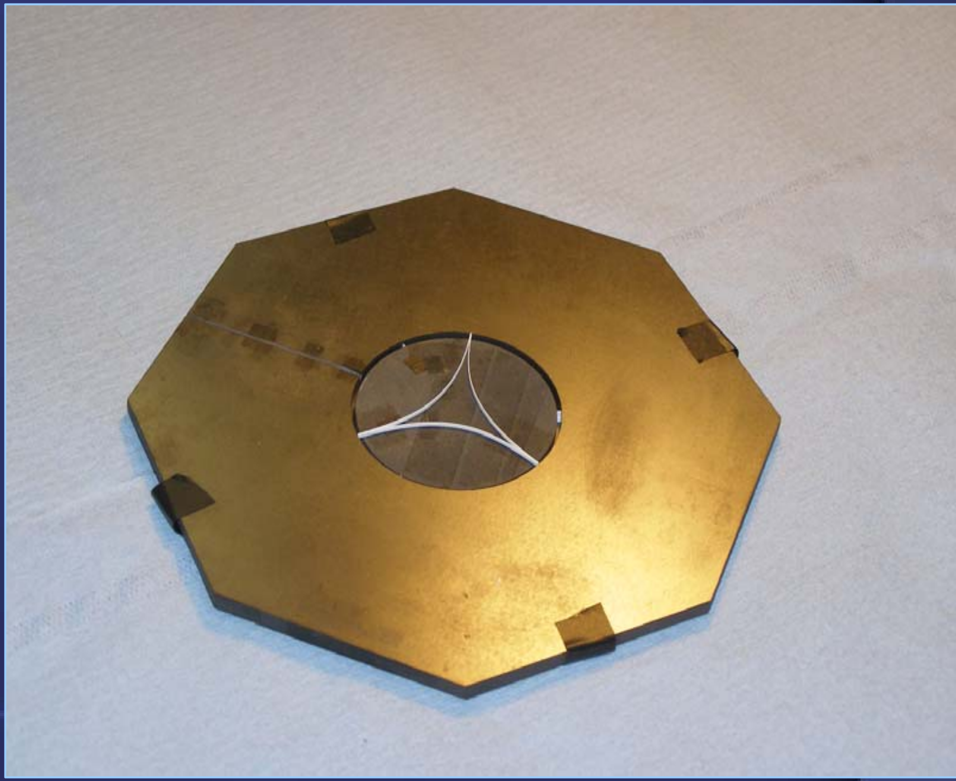
(3) Calibrate chamber against the calorimeter, in graphite, at the NPL

$$N_{D,ref,g} = \frac{D_g}{M_{ref,g}}$$

(McEwen *et al* 1998)

NPL Calibration Procedure: high energy electrons





Calorimeter for high energy electrons

NPL Calibration Procedure: high energy electrons

(4) Theoretical conversion of graphite to water

$$N_{D,ref,w} = N_{D,ref,g} \frac{p_{ref,w}}{p_{ref,g}} \frac{s_{w,air}}{s_{g,air}}$$

(5) Compare user and reference chambers at d_w in water, at NPL

$$N_{D,user,w} = N_{D,ref,w} \frac{M_{ref,w}}{M_{user,w}}$$

(McEwen *et al* 1998)

Current Protocols: electron perturbation correction factors

For well guarded plane parallel plate ion chambers

$$p_Q = p_{cav} p_{wall}$$

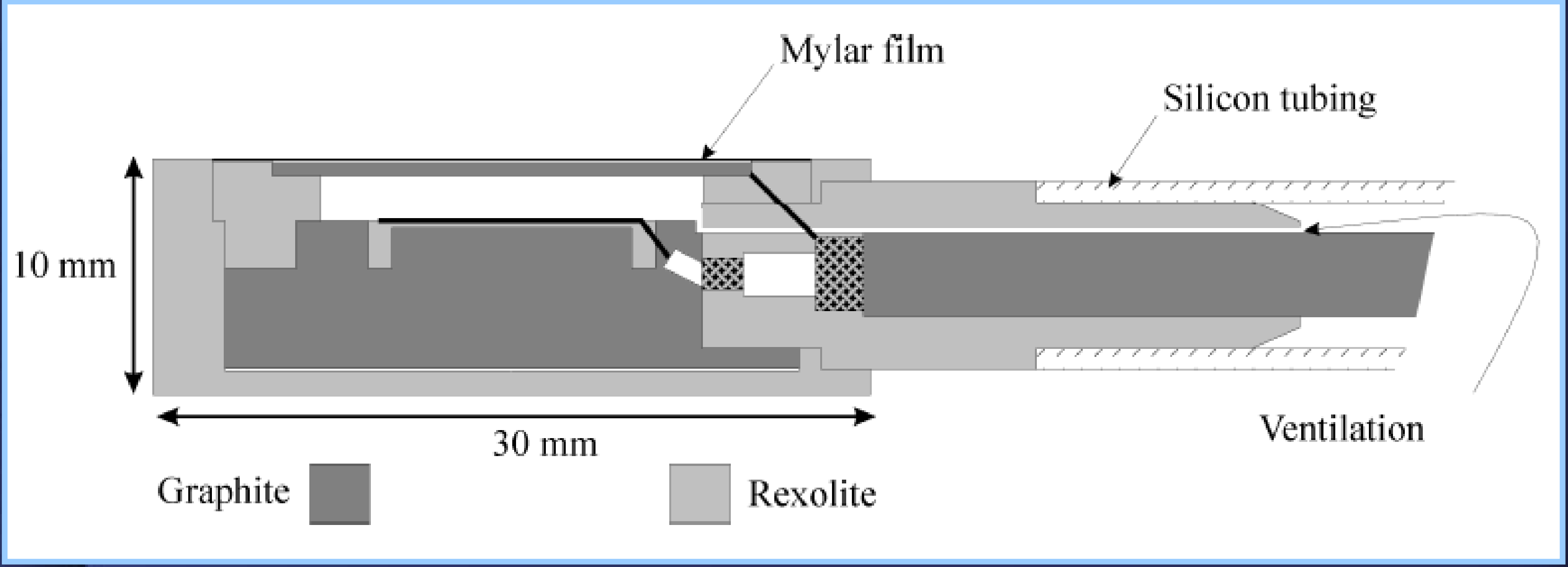
$$p_{cav} = 1$$

A plane parallel chamber with adequately large guard ring can eliminate the in-scattering effects

$$p_{wall} = 1$$

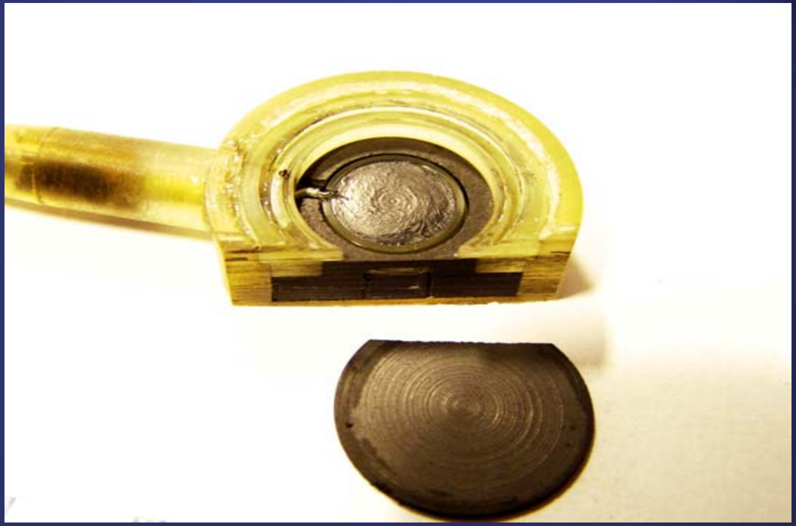
Scarce amount of data available at the time and large uncertainties

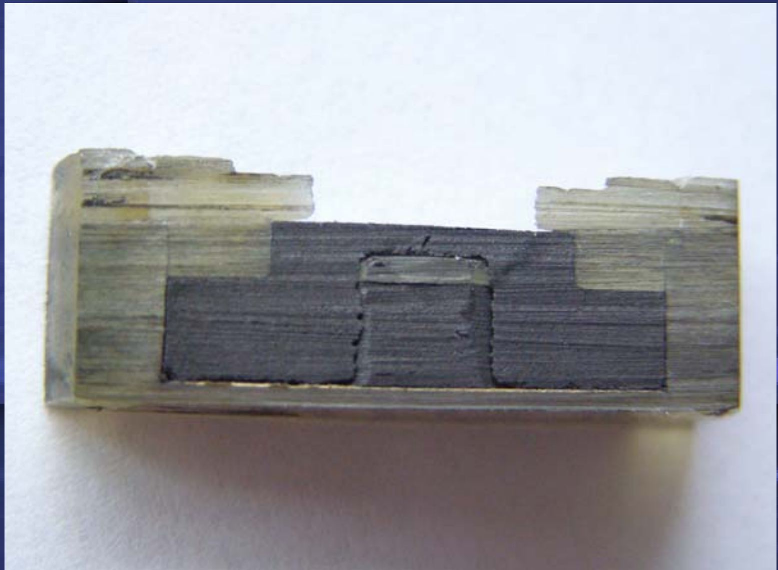
Monte Carlo model of NACP ion chamber

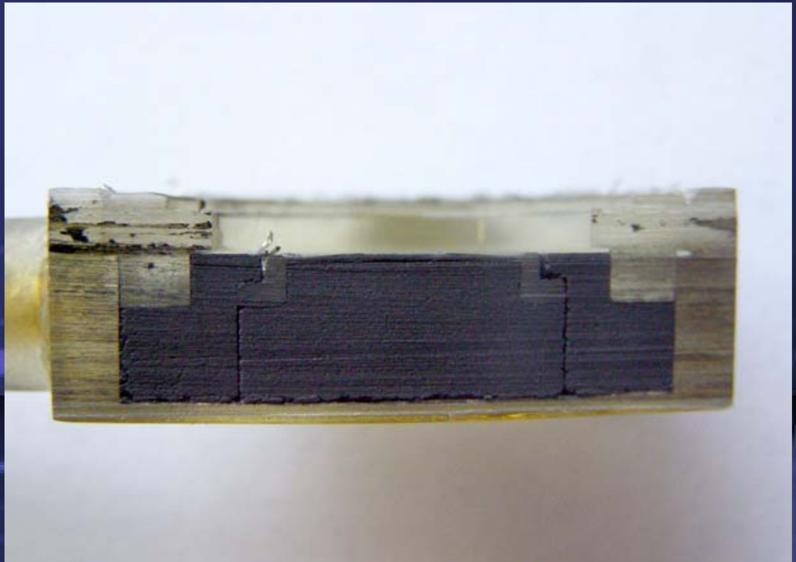


NACP-02 plane parallel ion chamber (NPL report CIRM13)

Monte Carlo model of NACP ion chamber



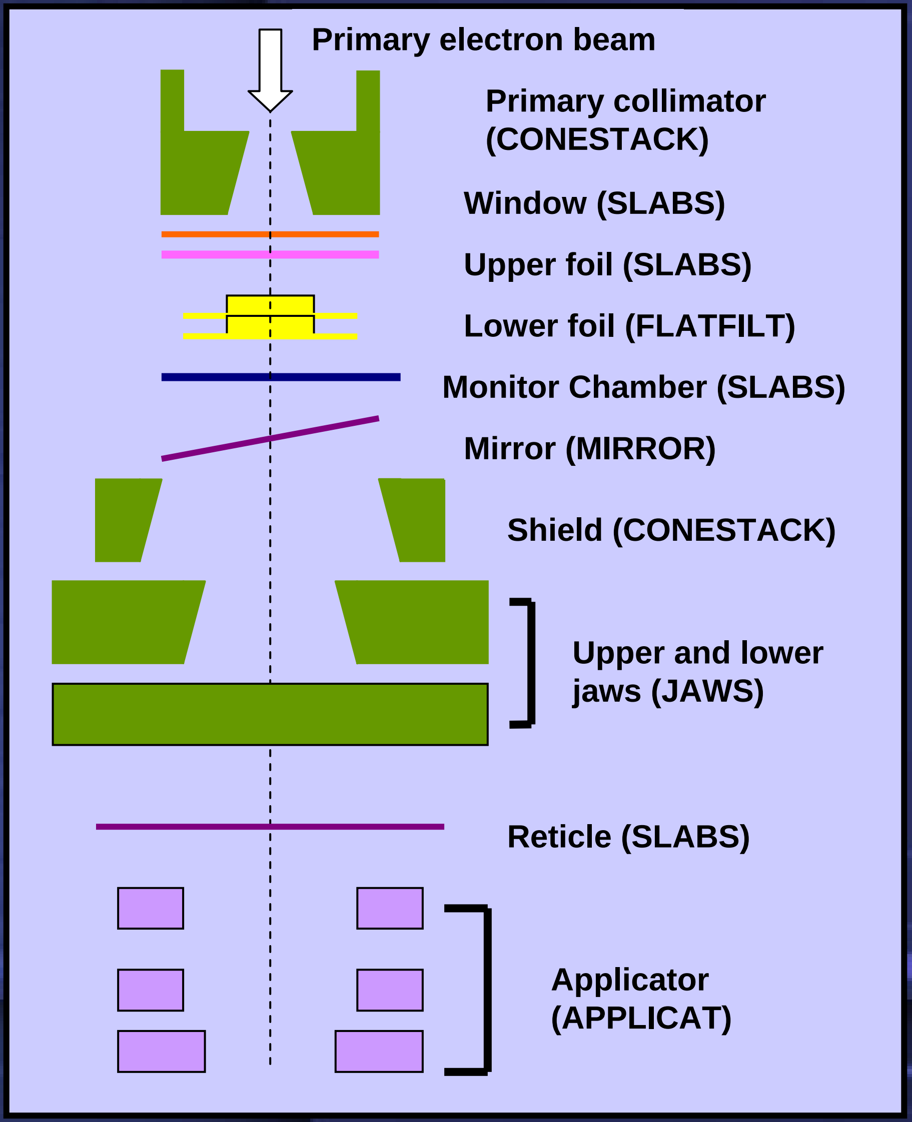


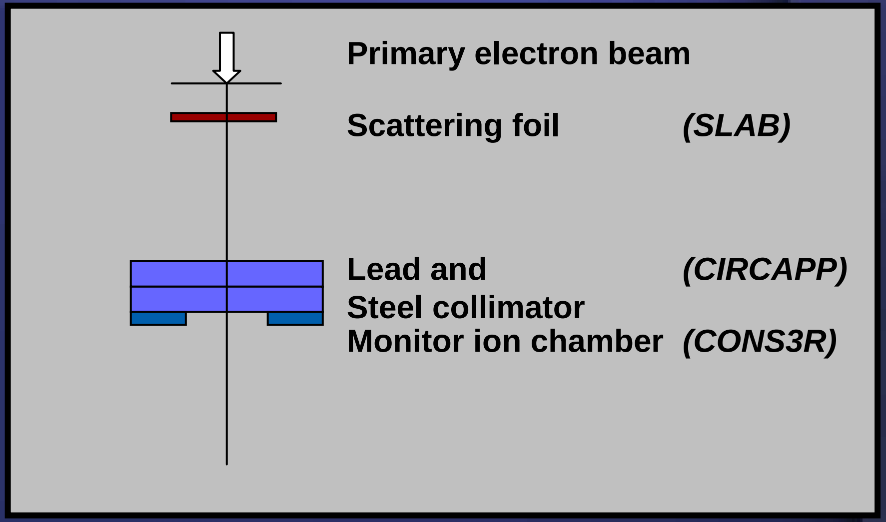


Monte Carlo model of NACP ion chamber

MC NACP model for DOSRZnrc and CAVRZnrc (not to scale)

Monte Carlo model of linacs





NPL Linac (SSD 2m)

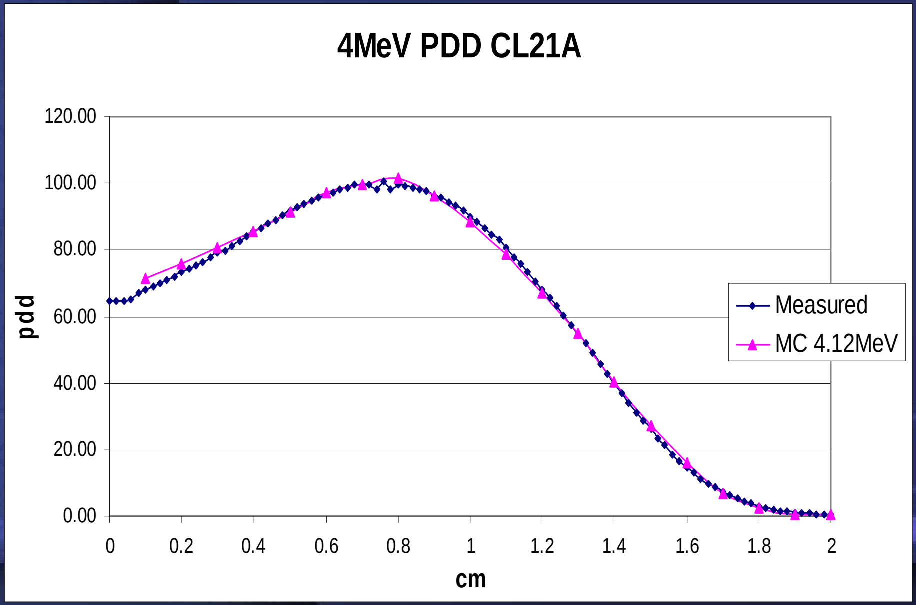
Varian Linac (SSD 1m)

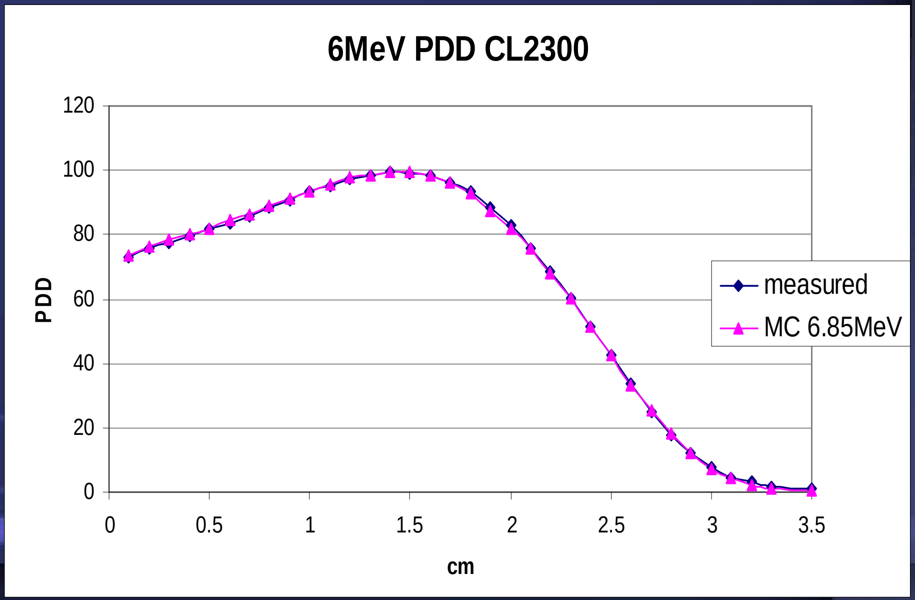
Linac electron energies

a) CL2300 energies 6, 9, 12, 15, 18 MeV (tuned within 1.5%)

b) CL21A energy 4MeV (buildup tuned within 3%, tail within 2%)

c) NPL linac energies 4, 6, 8, 10, 12, 16, 19MeV (R. Zakikhani)





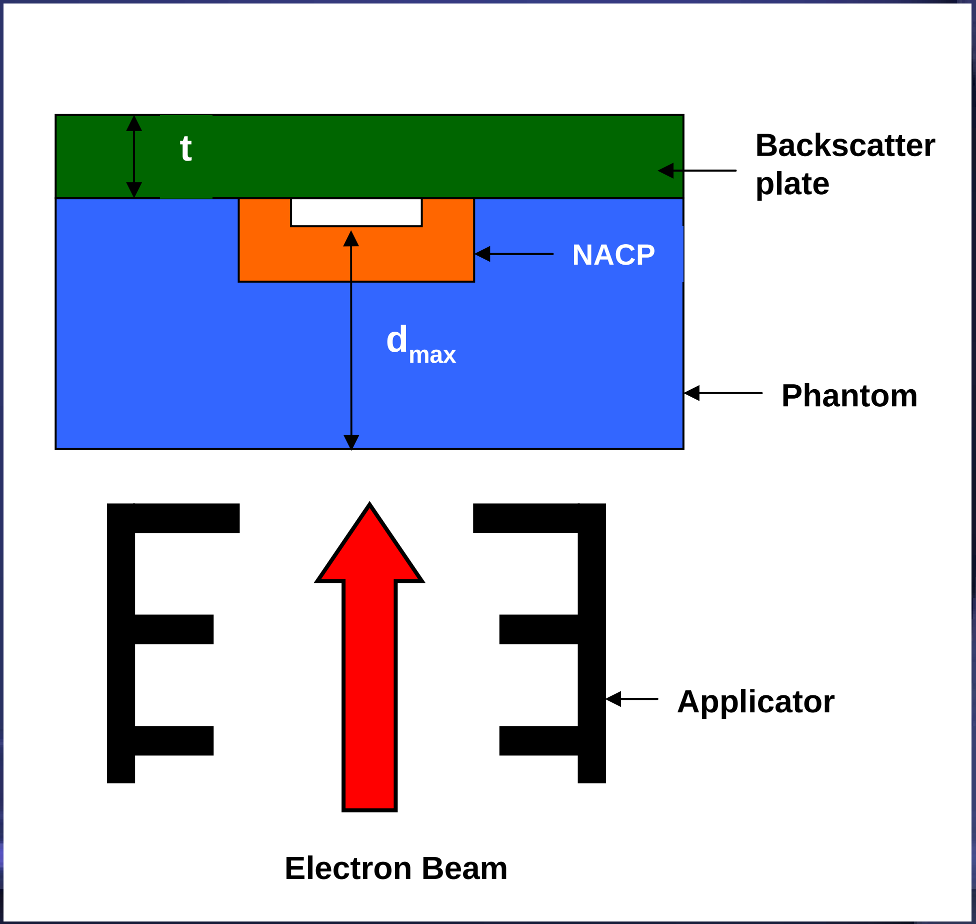
Validation of MC: Backscatter experiments and simulations

Backscatter factors wrt air for NACP-02:

- Water
- Graphite
- Aluminum
- Copper

Phantom material:

- PMMA (4-12 MeV)
- Solid water (15 & 18MeV)



experimental setup

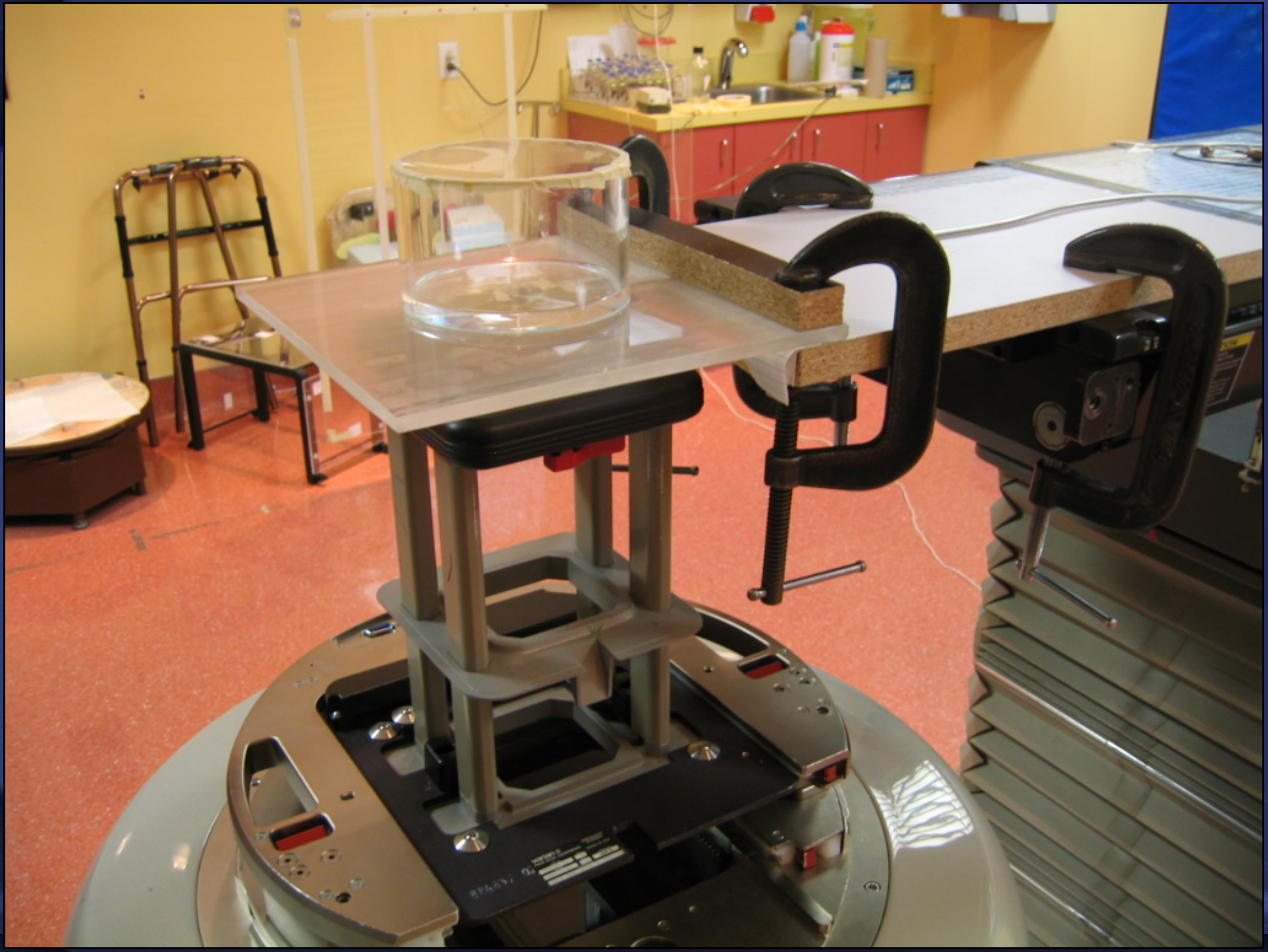
Backscatter Experimental Setup

NACP-02 chamber is flush with phantom surface

Backscatter Experimental Setup

Backscatter setup with aluminum plate covering NACP-02

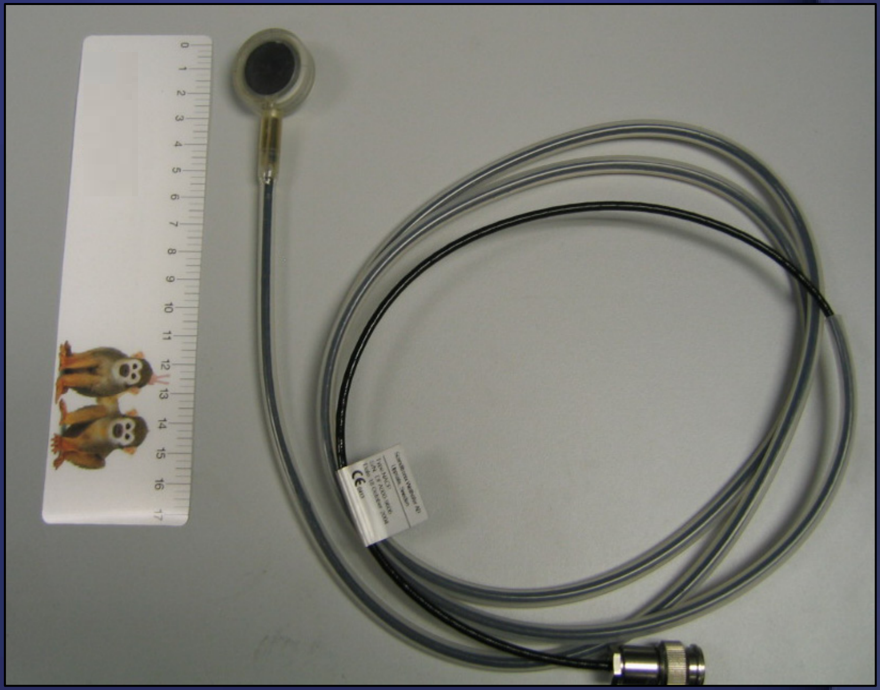
Backscatter Experimental Setup



Backscatter setup with water phantom on top of NACP-02

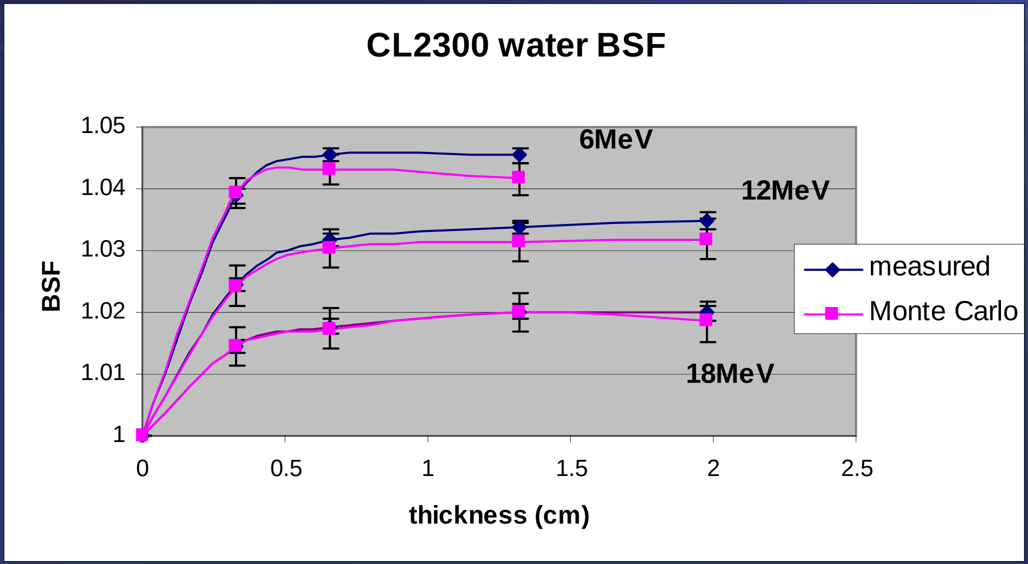
Tuning NACP-02 parameters

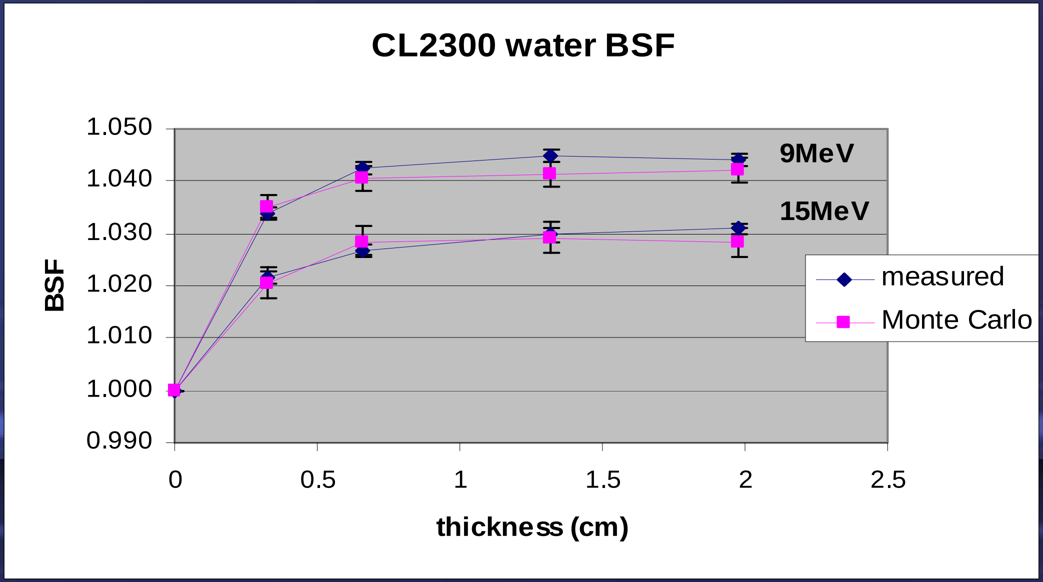
1. Varied graphite density (1.7 – 1.8 g/cm^3)
2. All options turned on (bound compton scattering, PE angular sampling, Rayleigh scattering, atomic relaxation)
3. Different beam sources (pt src vs. parallel src)
4. Varied window thickness



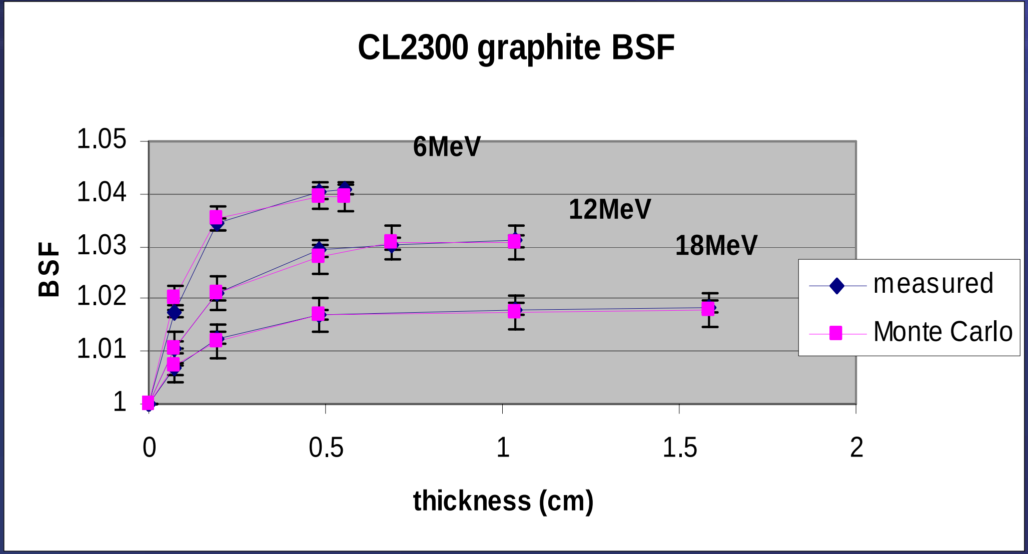
NACP-02 chamber

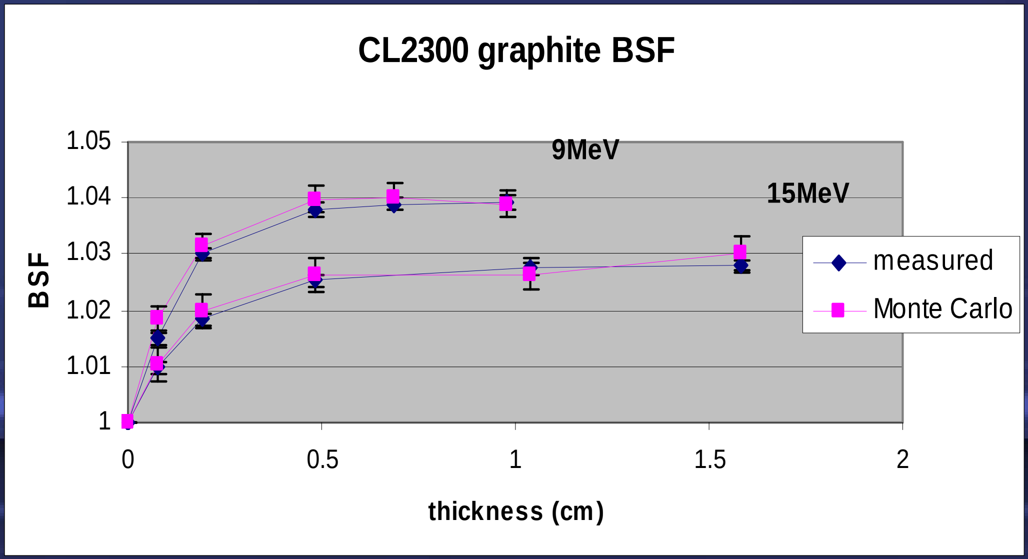
Backscatter Results: water



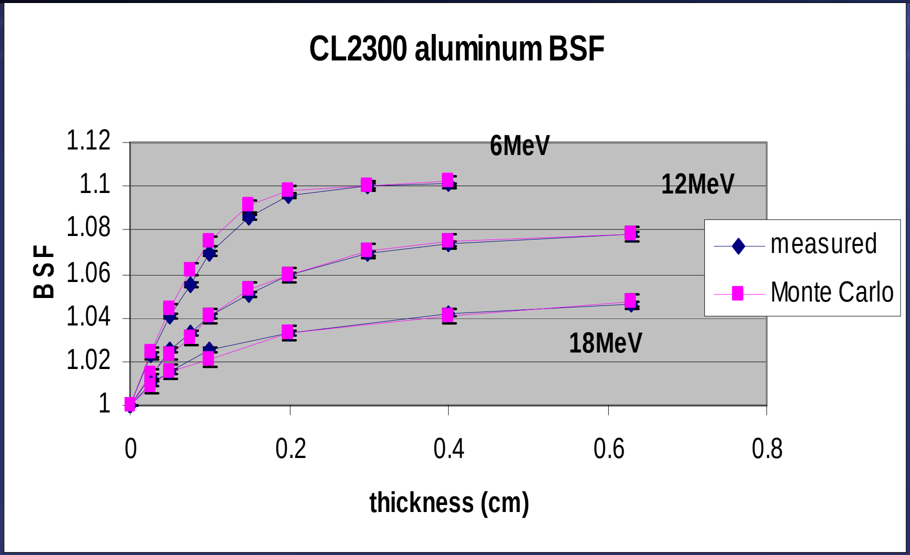


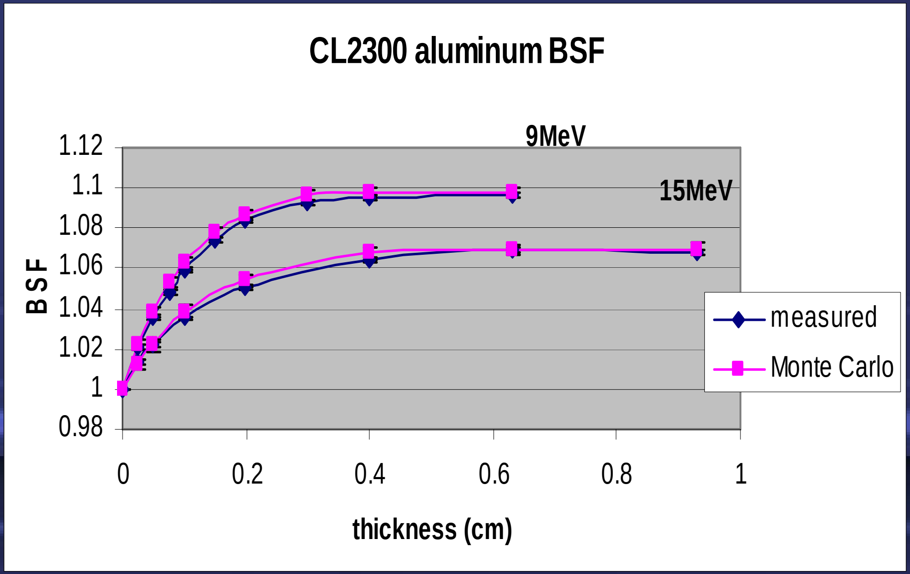
Backscatter Results: graphite



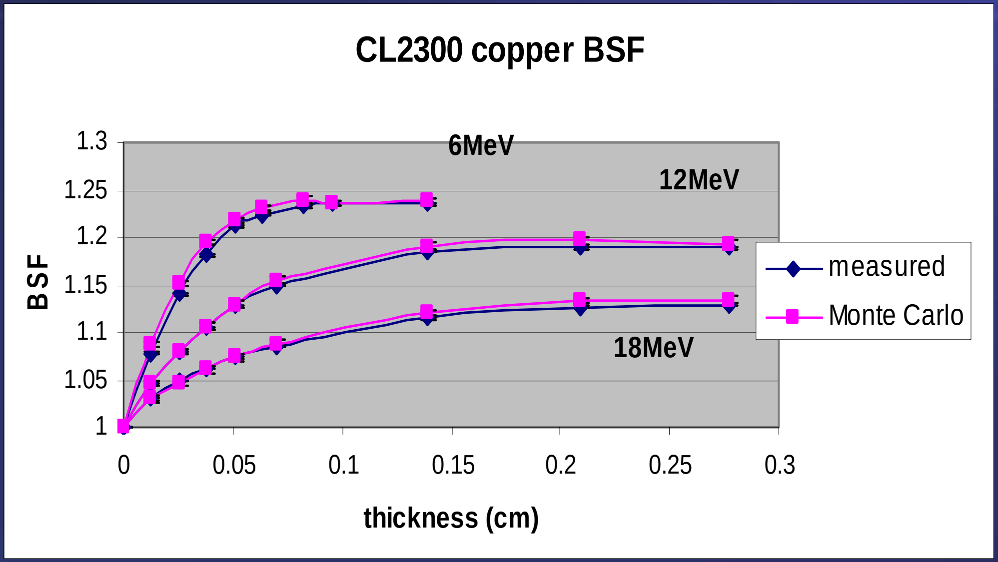


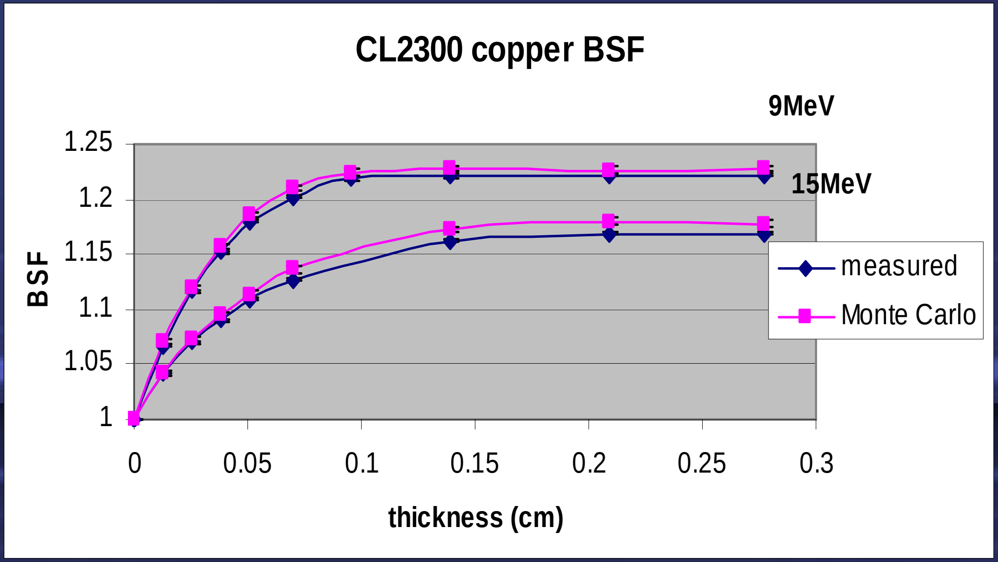
Backscatter Results: aluminum





Backscatter Results: copper





Backscatter Results

- Monte Carlo model based on manufacturer's specs resulted in BSF that were systematically 1-2% greater than measured

- Making the front window of the NACP chamber slightly thicker improved the match between measured and simulated BSF

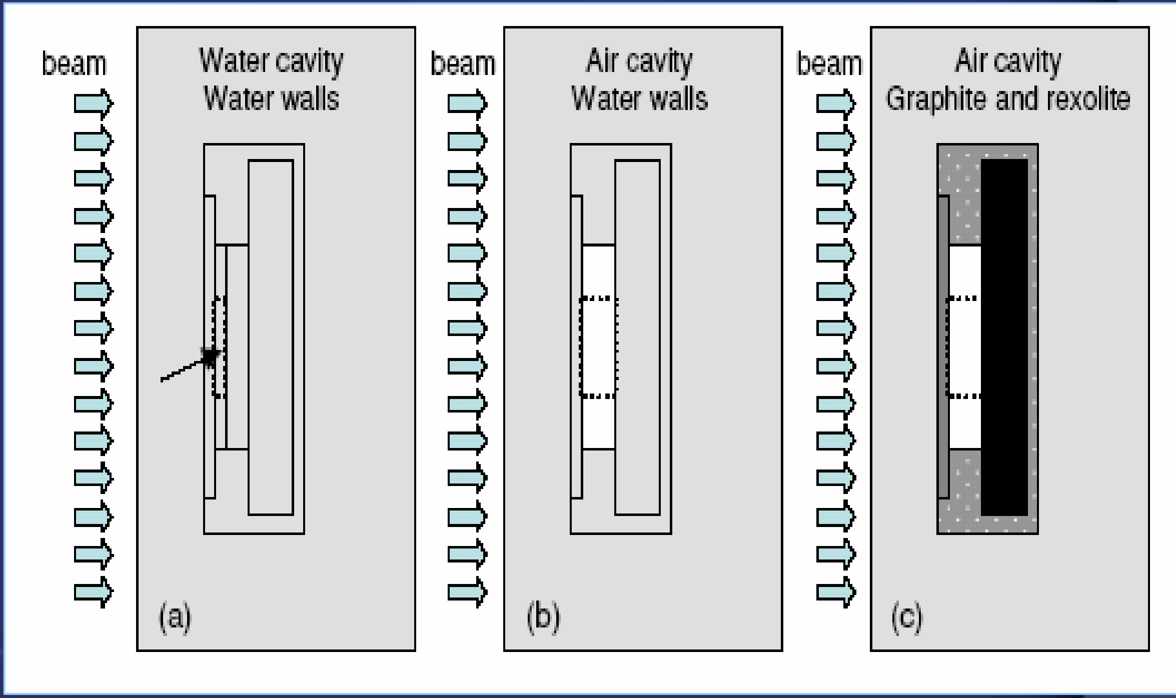
- Conclude that tuning the chamber model is an important step in the calculation of chamber perturbation correction factors.

Calculating Electron Perturbations Correction Factors: in water

$$p_{cav} \times (s_{w,air}) = \frac{D_a}{D_b}$$

$$p_{wall} = \frac{D_b}{D_c}$$

$$p_Q \times (s_{w,air}) = \frac{D_a}{D_c}$$



(Verhaegen *et al* 2006)

Electron Perturbation Correction factors: water d_{ref} NPL

p_{wall} :

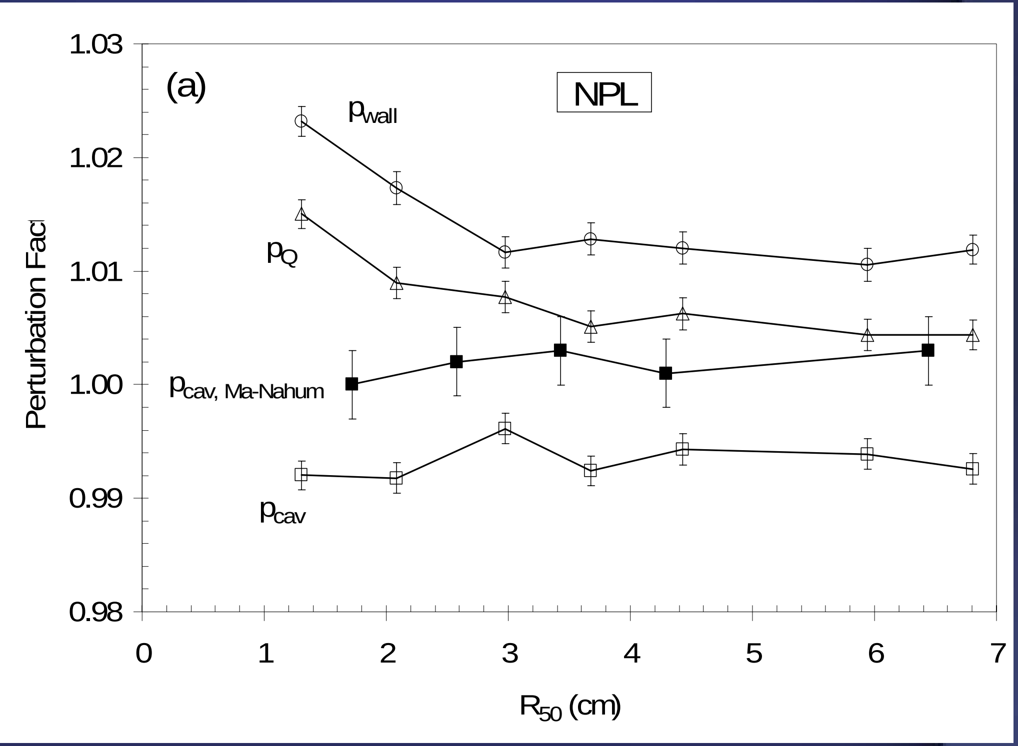
- > 1 by 2.3% for 4MeV
- > 1 by ~1% for other energies

p_{cav}:

- < 1 by ~1% for all energies

p_Q :

- > 1 by (1.5% for 4MeV, 0.4% for 19MeV)



NACP chamber (Verhaegen *et al* 2006)

Electron Perturbation Correction factors: water d_{ref} CL2300

p_{wall}:

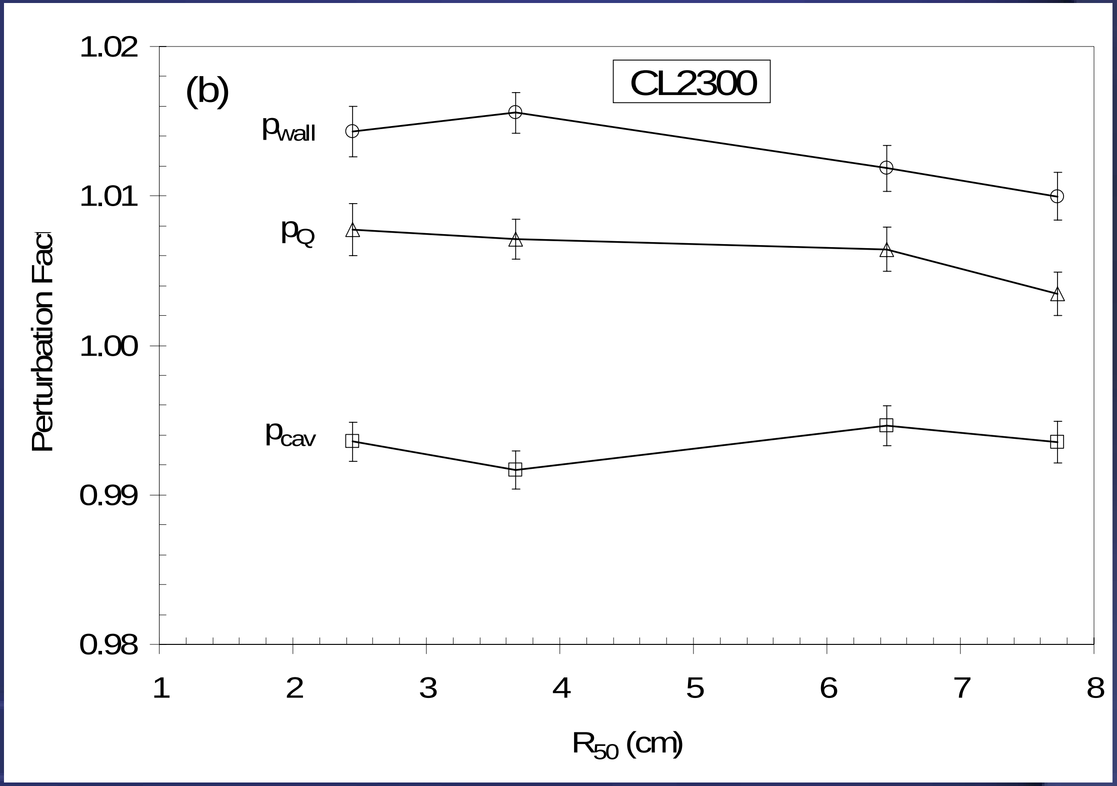
- > 1
- greatest for 6MeV (1.014)

p_{cav}:

- < 1 for all energies

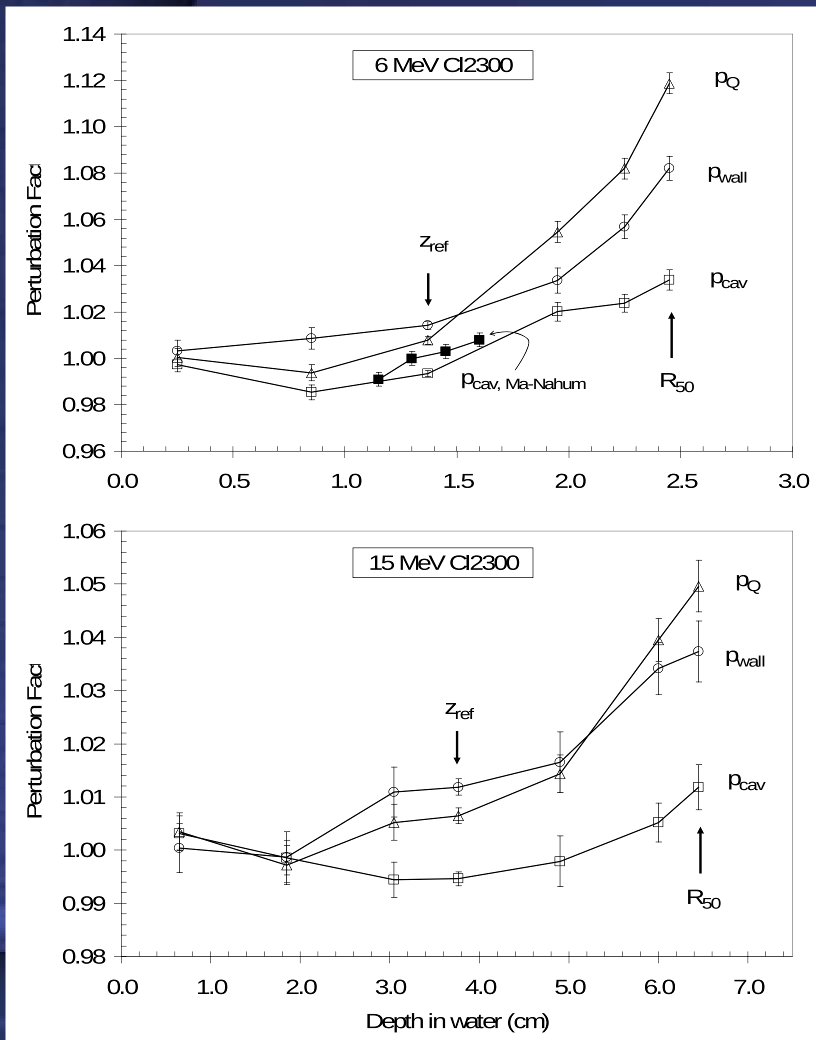
p_Q :

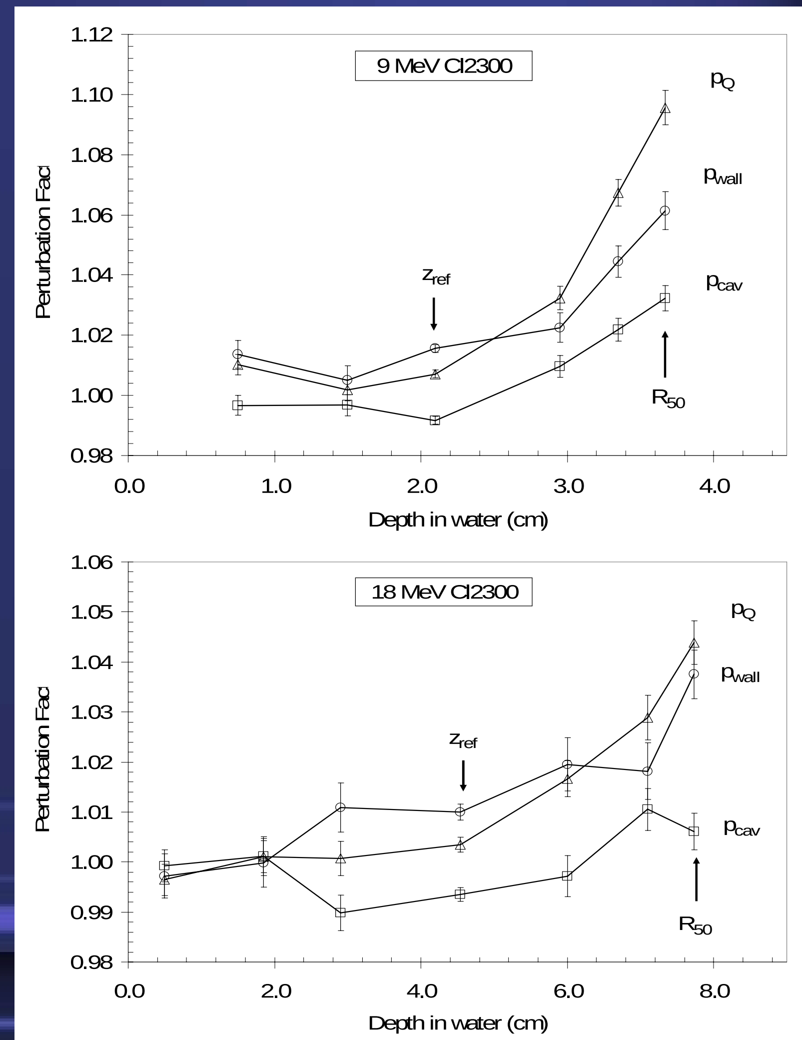
- > 1 for all energies



NACP chamber (Verhaegen *et al* 2006)

Electron Perturbation Correction factors: water CL2300





NACP chamber (Verhaegen *et al* 2006)

Electron Perturbation Correction factors: water

Including p_Q when converting PDI to PDD leads to a correction as large as 10% of local dose around R_{50} for 6MeV. However, the change in R_{50} is less than 1mm.

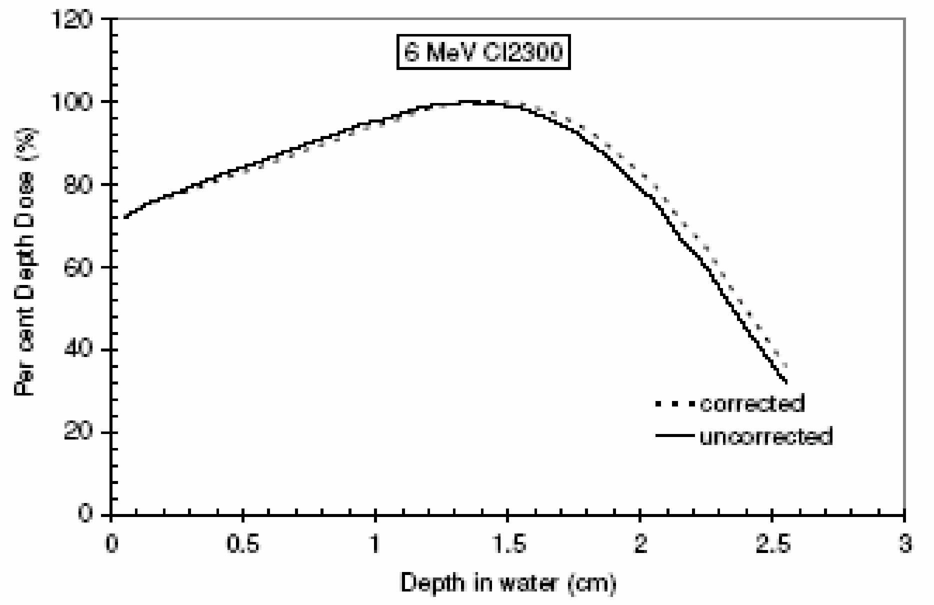


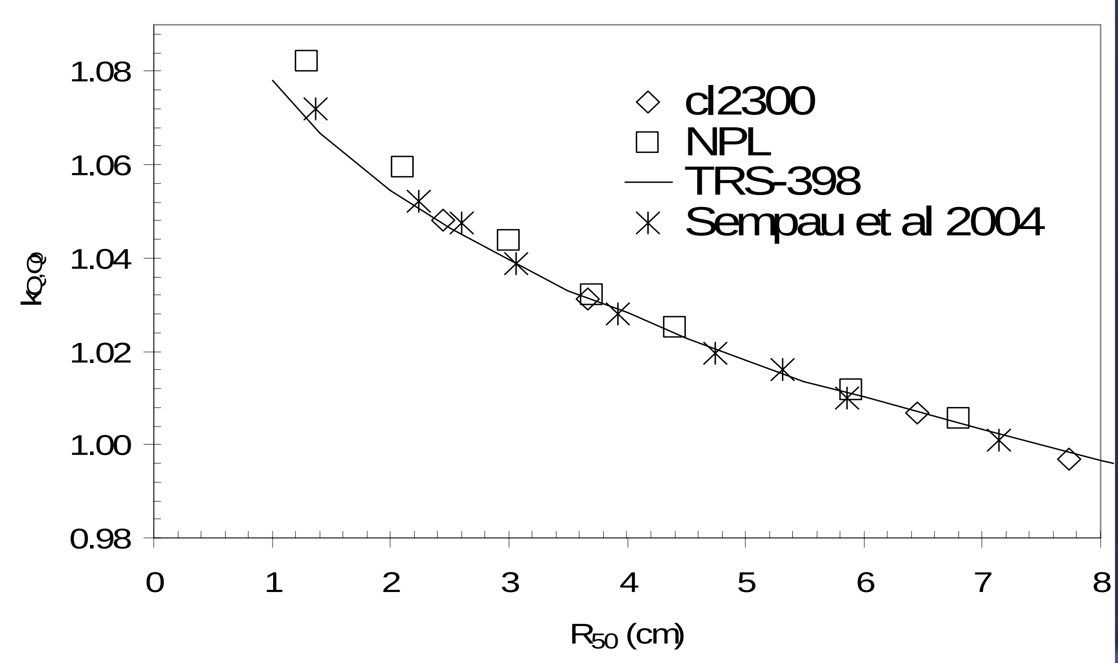
Figure 8. Measured 6 MeV per cent depth dose profile, uncorrected and corrected for p_Q perturbation factor.

(Verhaegen *et al* 2006)

Electron Perturbation Correction factors: water

$$k_{Q,Q_0} = \frac{(s_{w,air})_Q}{(s_{w,air})_{Q_0}} \times \frac{p_Q}{p_{Q_0}}$$

$$p_Q = p_{cav}\, p_{wall}$$



Comparison of calculated $k_{Q,Qo}$ values with Verhaegen *et al* (2006). TRS-398 (Andreo *et al* 2000) and Sempau *et al* (2004).

Electron Perturbation Correction factors: water

p_{wall}

Verhaegen *et al* 2006, Buckley *et al* 2006

•1.023 – 1.007 for the lowest to highest beam energies (4MeV NPL – 21MeV Siemens)

$p_{rearwall}$

For lowest to highest E:

•1.014 – 1.005 (McEwen *et al* 2006)

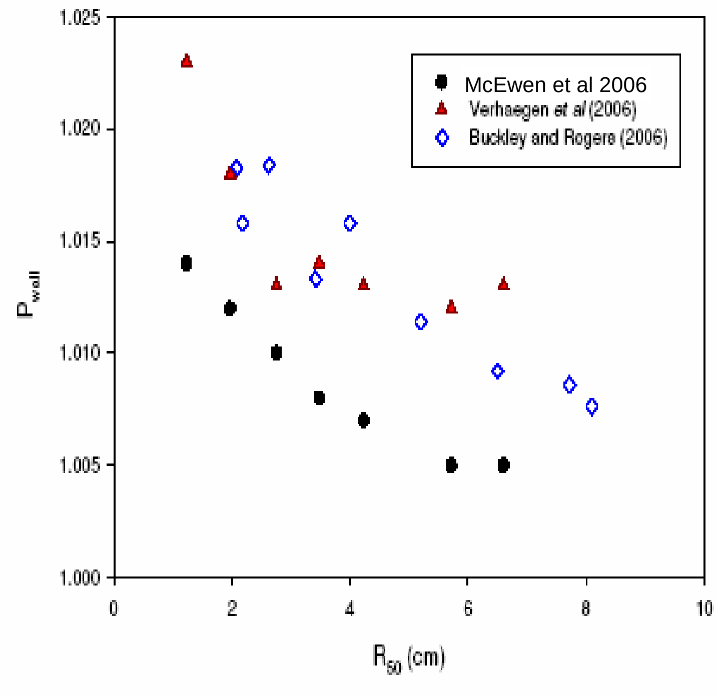
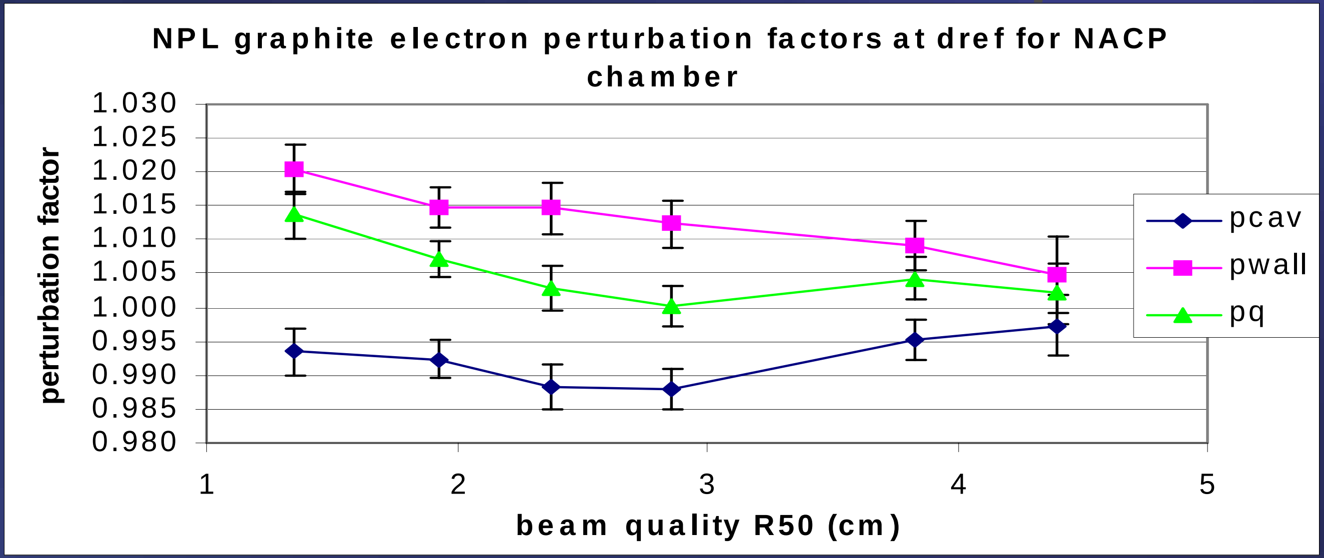


Figure 6. Comparison of recent p_{wall} determinations for the NACP chamber in a water phantom. Verhaegen *et al* and Buckley and Rogers both used the Monte Carlo system EGSnrc.

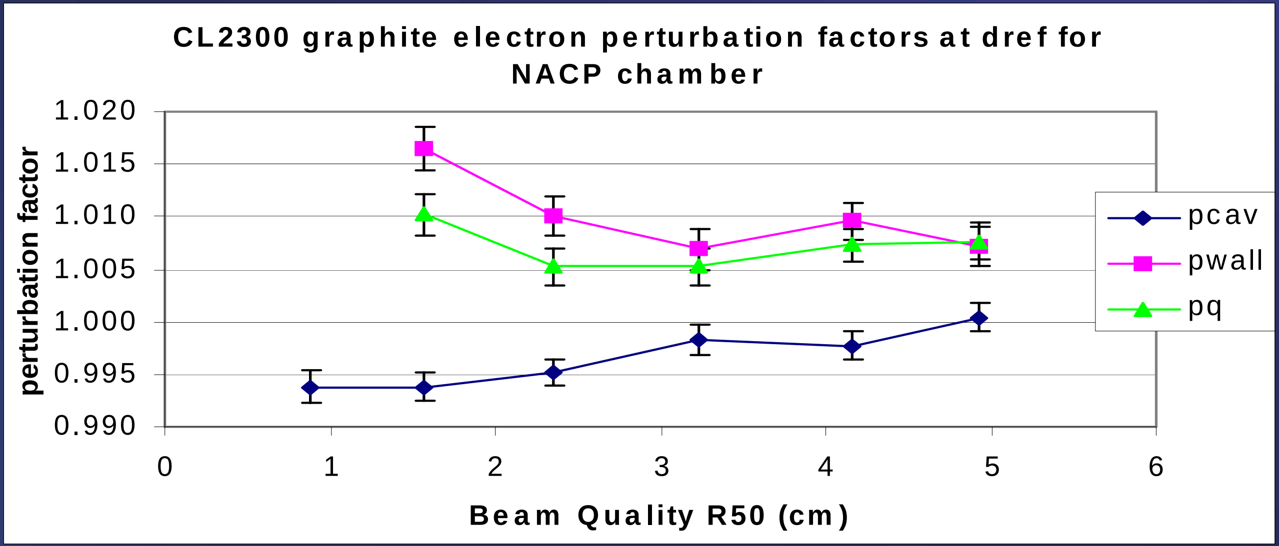
(McEwen *et al* 2006)

Electron Perturbation Correction factors: graphite d_{ref} NPL



Energy	R50 (cm)	pcav	SDOM (±%)	pwall	SDOM (±%)	pq	SDOM (±%)
6	1.348	0.9934	0.34%	1.0204	0.37%	1.0137	0.34%
8	1.927	0.9924	0.27%	1.0148	0.30%	1.0071	0.27%
10	2.374	0.9884	0.33%	1.0147	0.37%	1.0029	0.33%
12	2.858	0.9880	0.30%	1.0124	0.35%	1.0003	0.30%
16	3.826	0.9952	0.30%	1.0092	0.35%	1.0043	0.30%
19	4.394	0.9974	0.46%	1.0047	0.56%	1.0021	0.45%

Electron Perturbation Correction factors: graphite d_{ref} CL2300



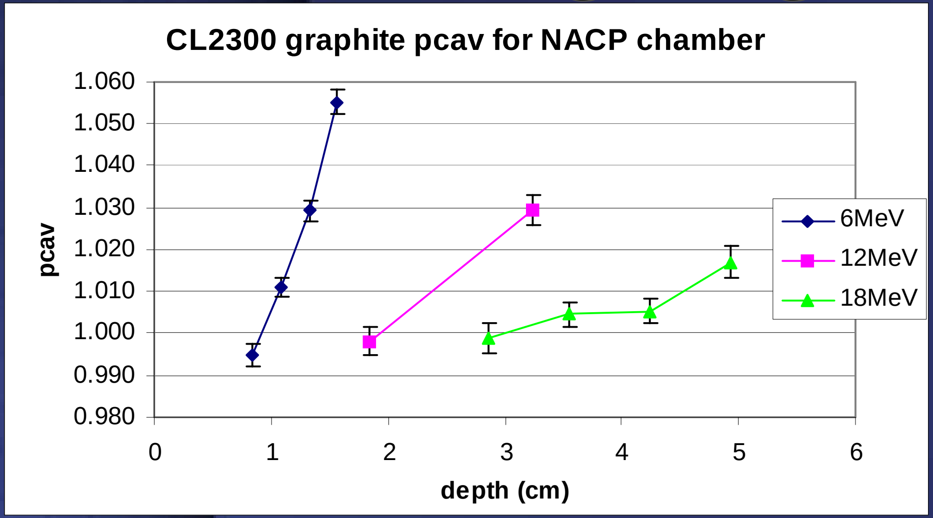
Energy	R50 (cm)	pcav	SDOM (±%)	pwall	SDOM (±%)	pq	SDOM (±%)
4	0.881	0.9938	0.16%	simulations in progress			
6	1.569	0.9938	0.14%	1.0165	0.20%	1.0102	0.19%
9	2.359	0.9953	0.12%	1.0100	0.18%	1.0052	0.17%
12	3.235	0.9983	0.14%	1.0069	0.19%	1.0052	0.18%
15	4.154	0.9978	0.14%	1.0096	0.18%	1.0073	0.16%
18	4.934	1.0004	0.14%	1.0072	0.18%	1.0076	0.17%

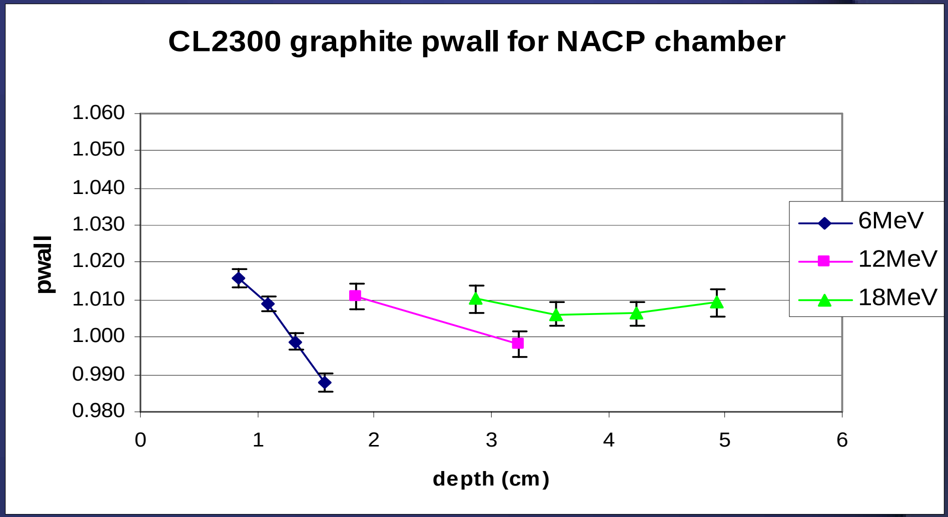
Implications for the NPL electron beam calibration

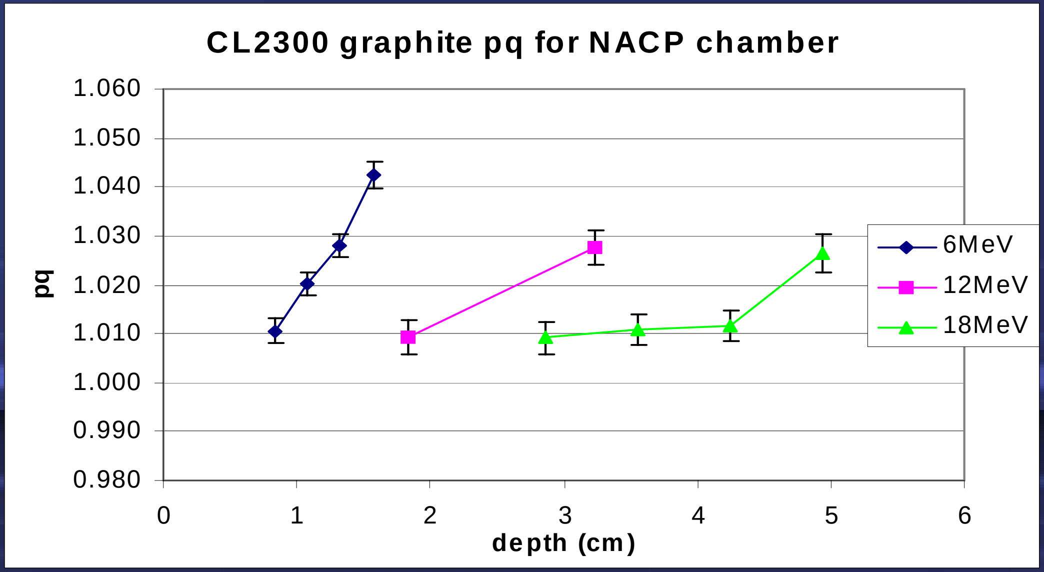
$$N_{D,ref,w} = N_{D,ref,g} \frac{p_{ref,w}}{p_{ref,g}} \frac{s_{w,air}}{s_{g,air}}$$

Energy	R50 (cm)	$p_{ref,w}/p_{ref,g}$	SDOM (±%)
6	1.348	0.9953	0.37%
8	1.927	1.0006	0.31%
10	2.374	1.0022	0.36%
12	2.858	1.0059	0.33%
16	3.826	1.0000	0.33%
19	4.394	1.0023	0.47%

Preliminary results from ongoing investigations







Conclusion

1. Validating Monte Carlo ion chamber model with measurements is important
2. Electron perturbation factors for plane-parallel ionization chambers are not equal to unity.
3. Perturbation factors are greatest for lowest energies.
4. Perturbation factors increase with depth and are very sensitive to chamber model at depths away from d_{ref}
5. NPL calibration procedure may need to be updated to include non-unity perturbation factors (simulations for better statistics in progress)