A review of Monte Carlo calculated f_Q factors for ionization chambers in clinical proton beams

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Dosimetry

- Clinical dosimetry typically based on the determination of absorbed dose-to-water
- Measurement conditions defined in dosimetry protocols or Codes of Practice
  AAPM TG-51, IAEA TRS-398, DIN 6800-2
- Commonly used detectors: air-filled ionization chambers

https://www.rpdinc.com/c/549-category/ptw-farmer-chamber.jpg

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Calibration factor (typically determined in ^{60}Co radiation)

Absorbed dose-to-water

Further correction factors (e.g. air pressure and temperature)

$$D_w = (M - M_0) \cdot N_{D_w,Q_0} \cdot k_{Q,Q_0} \cdot \prod_i k_i$$

Measured charge (corrected for background)

Beam quality correction factor

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- Beam quality correction factor $\boldsymbol{k_{Q,Q_0}}$
  - Corrects for the different response of the ionization chamber in different beam qualities
    - Q_o: calibration beam quality (e.g. ^{60}Co-radiation)
    - Q: user beam quality (in this work: protons)
  - Corrects chamber reading by a few percent
  - If Q_o is ^{60}Co-radiation: $\boldsymbol{k_Q}$ is used instead of $\boldsymbol{k_{Q,Q_0}}$

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- Determination of $\boldsymbol{k_Q}$ in IAEA TRS-398 Code of Practice (CoP)

$$k_{Q,Q_0} = \frac{\left(s_{\mathrm{w,air}}\right)_Q}{\left(s_{\mathrm{w,air}}\right)_{Q_0}} \cdot \frac{P_Q}{P_{Q_0}} \cdot \frac{(W_{\mathrm{air}})_Q}{(W_{\mathrm{air}})_{Q_0}}$$

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Stopping-power ratio water-to-air

Correction for fluence perturbations

Energy needed to create electron-ion pair

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Energy needed to create electron-ion pair

- Mixture of calculated, measured and Monte Carlo data
- Assumptions for protons: $\boldsymbol{P_Q = 1}$ due to missing data

Monte Carlo calculated f_Q and k_Q factors

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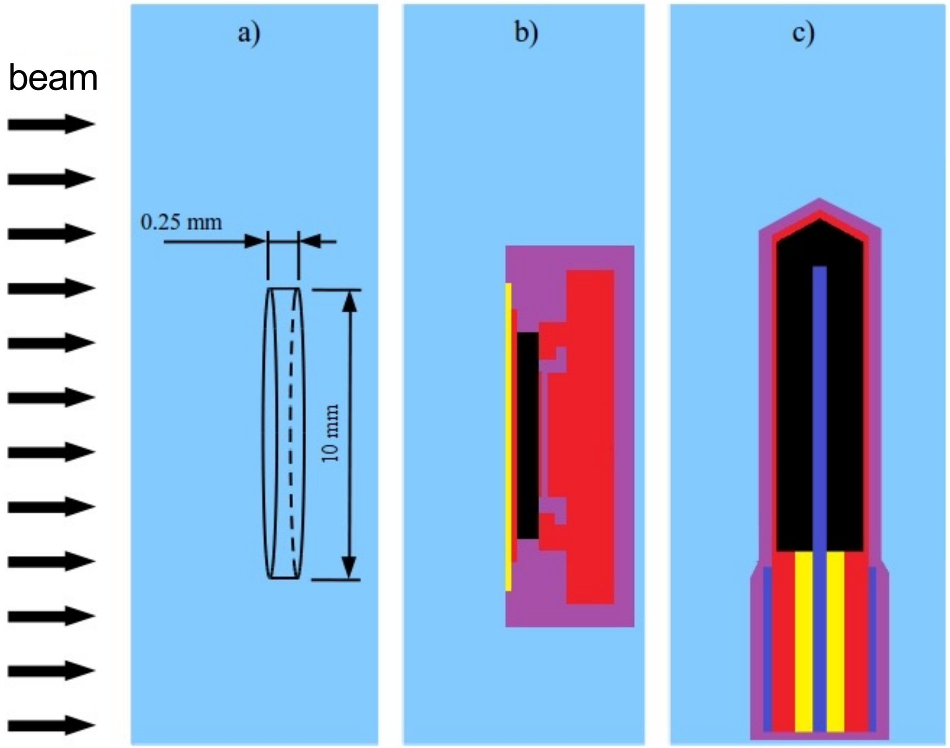
- Monte Carlo calculation:
  - Determination of absorbed dose-to-water D_w in water-filled reference volume
  - Determination of dose D_det absorbed in air-filled cavity of ionization chamber

$$f_Q = \left(\frac{D_\mathrm{w}}{D_\mathrm{det}}\right)_Q = \left(s_\mathrm{w,air}\right)_Q \cdot P_Q$$



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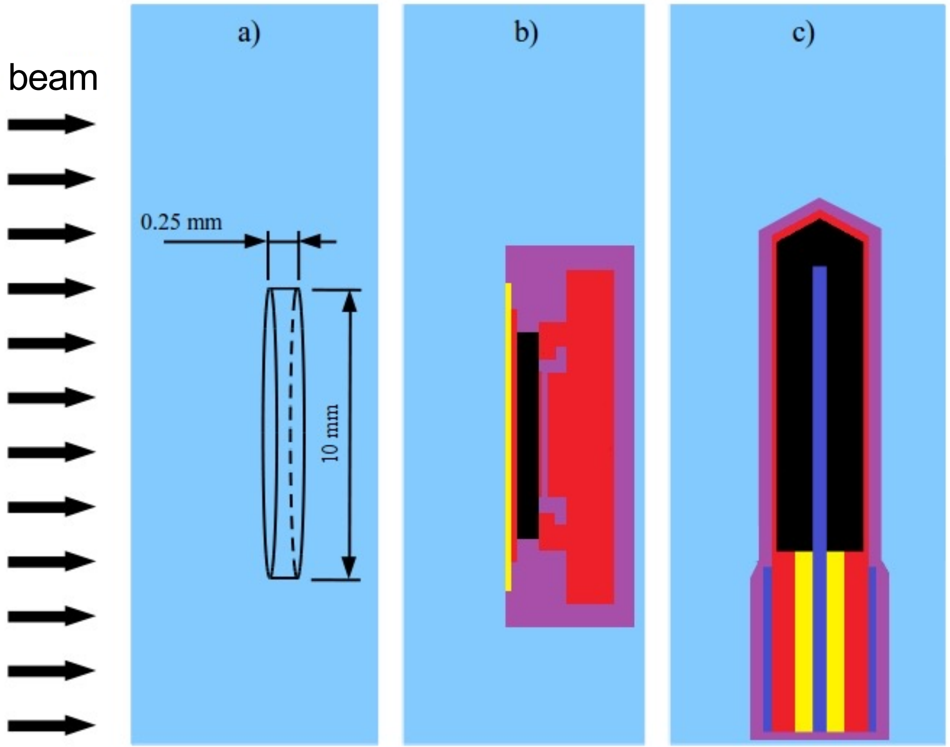
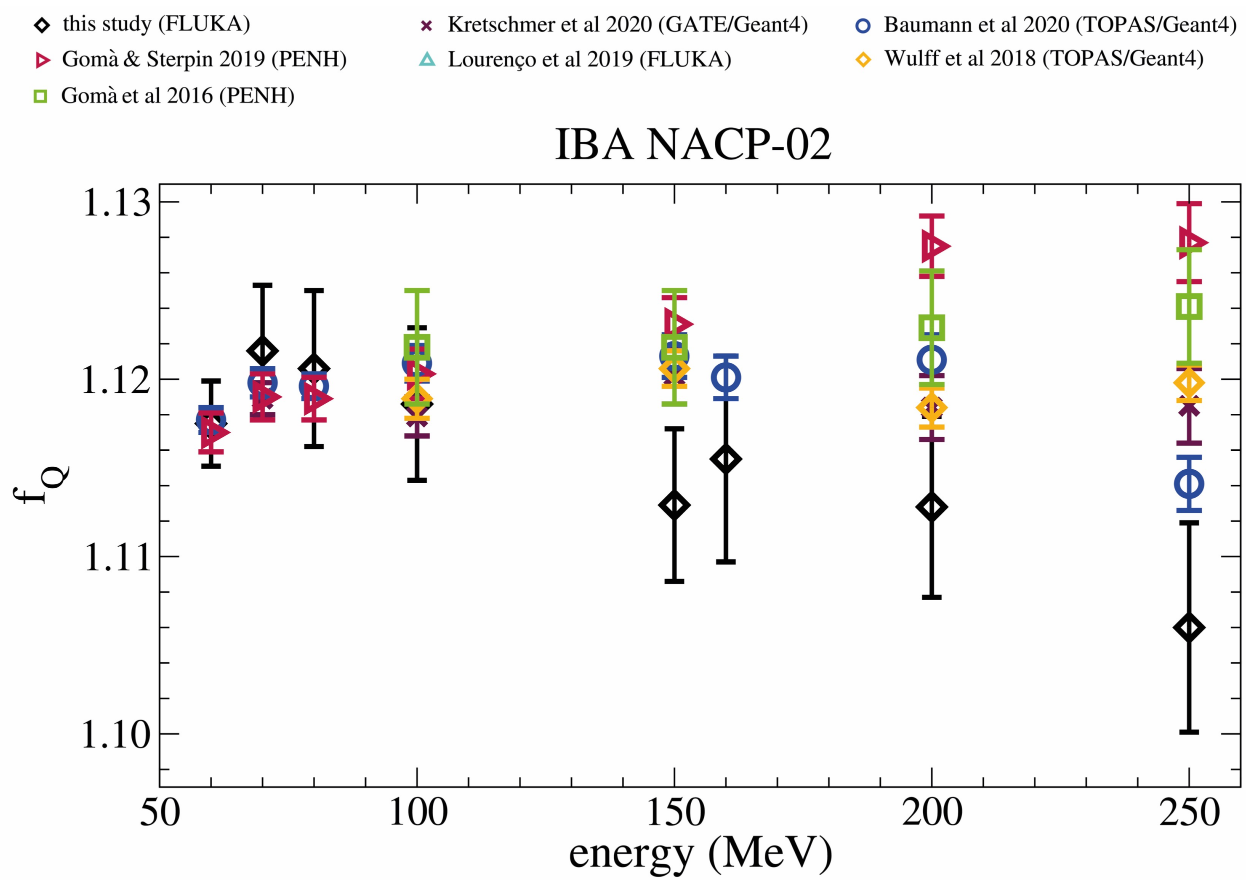
$$k_Q = \frac{f_Q}{f_{Q_0}} \cdot \frac{(W_{air})_Q}{(W_{air})_{Q_0}}$$



Monte Carlo calculated f_Q and k_Q factors

- In the recent years **PENH, FLUKA** and **GEANT4** (toolkits **GATE** and **TOPAS**)were used to calculate f_Q factors in clinical proton beams
- Good agreement (~1%) between different Monte Carlo codes for low energies
- Larger differences up to 2% for high energies
- Role of nuclear interactions:
  - Probable differences in complex modelling of nuclear interactions
  - Impact increases with energy
- In general, FLUKA leads to smallest values and PENH to largest



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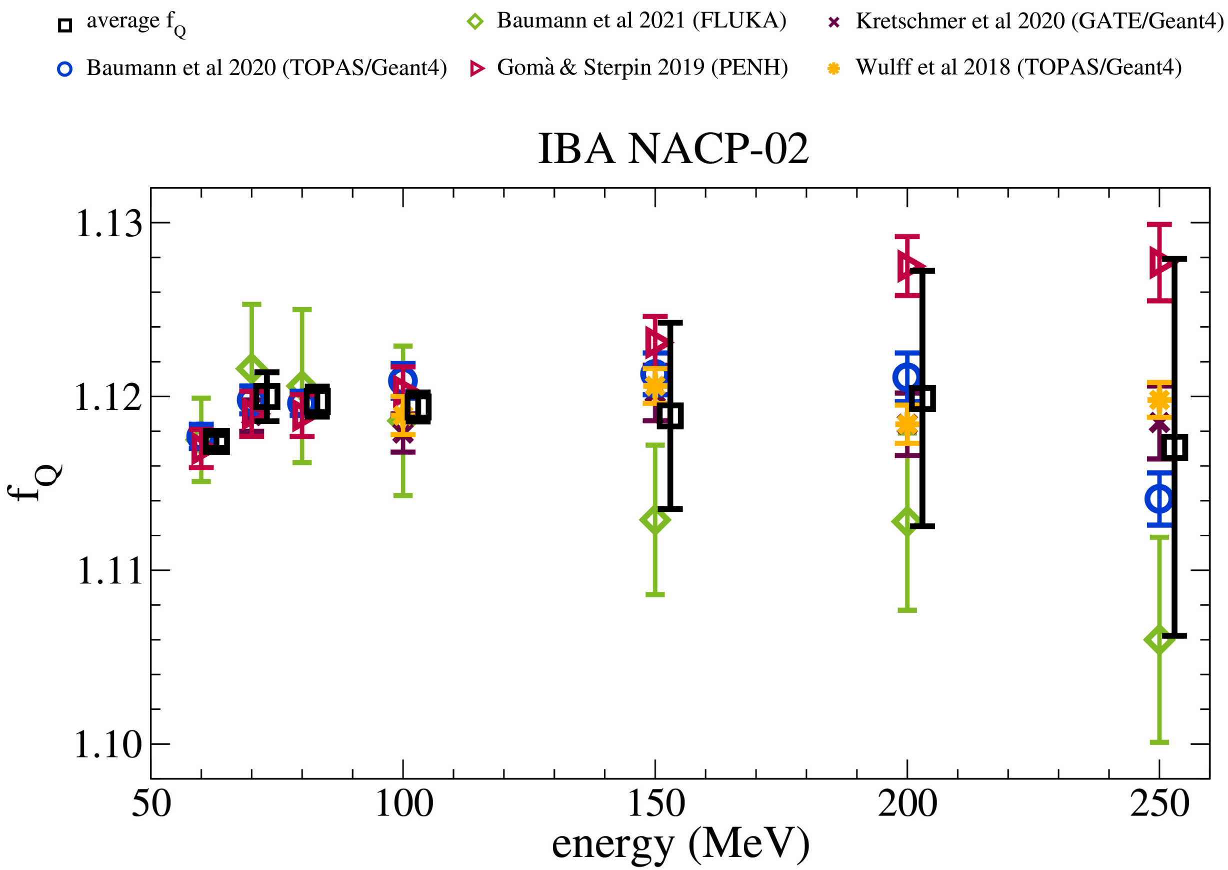
Monte Carlo calculated f_Q and k_Q factors

- Calculation of average Monte Carlo calculated f_Q factors:
- Average f_Q factors constant over energy within ~1%
- Overall uncertainty small (~0.3%) for low energies due to good agreement between different Monte Carlo codes
- Overall uncertainty increases with energy (~0.8%) for 250 MeV



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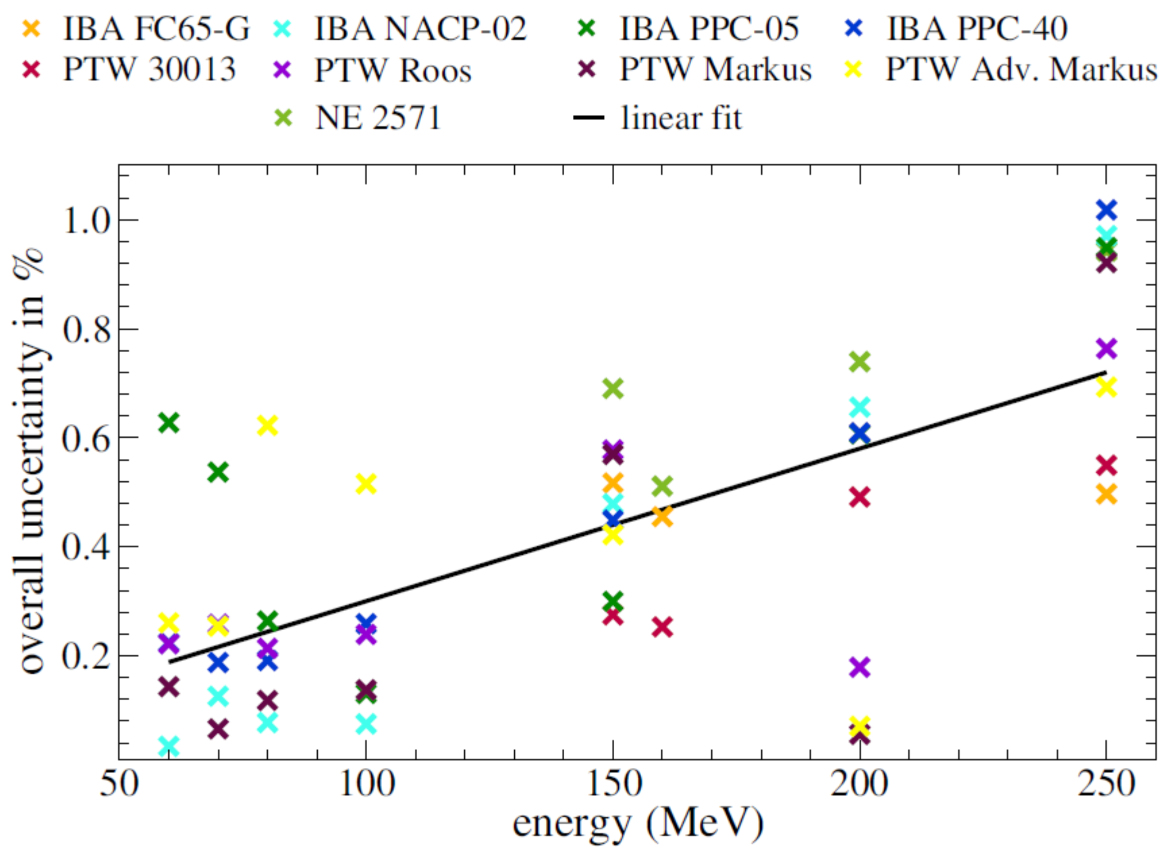
- Linear fit of uncertainties demonstrates dependence on energy



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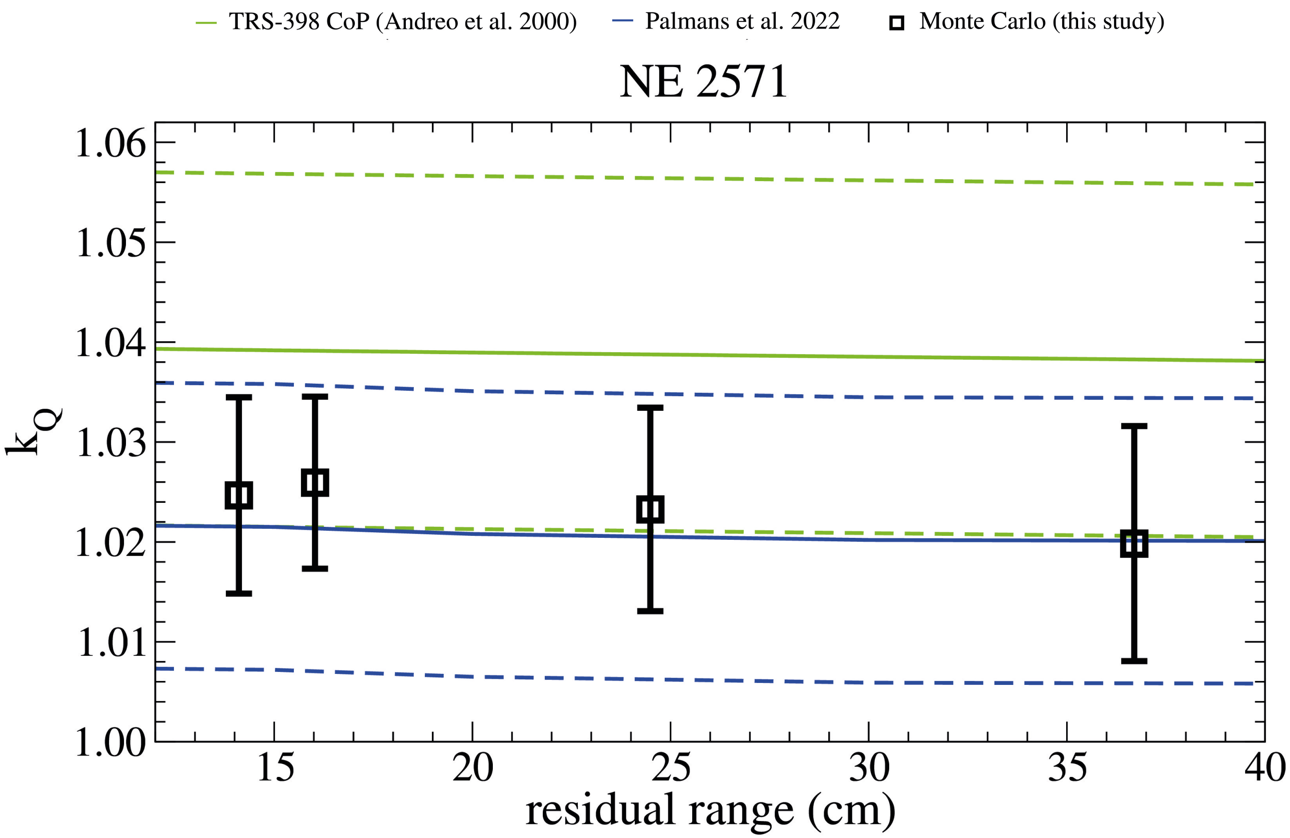
Monte Carlo calculated f_Q and k_Q factors

- From average Monte Carlo calculated f_Q factors k_Q factors were derived
- Comparison with IAEA TRS-398 CoP:
  - Differences up to 2.4%
  - Uncertainties for Monte Carlo calculated factors significantly smaller
- Comparison with previously published values from Palmans et al. 2022:
  - Derivation using experimentally determined and Monte Carlo calculated f_Q and k_Q factors
  - Description of fluence perturbations
  - Agreement on 1%-level, comparable uncertainties



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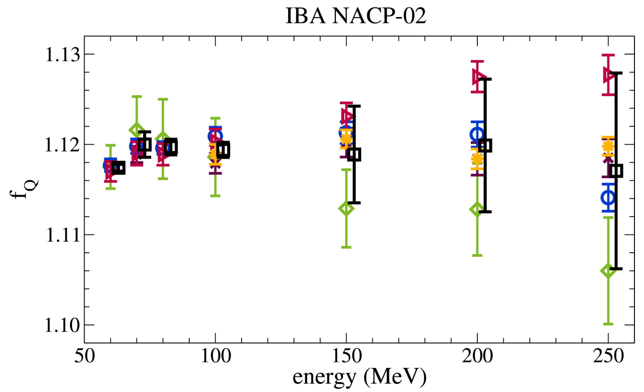
Conclusion

- Monte Carlo simulations are an efficient tool for the calculation of f_Q and k_Q factors in clinical proton beams

- General good agreement for low energies, larger differences for high energies
  - Probably due to different modelling of nuclear interactions



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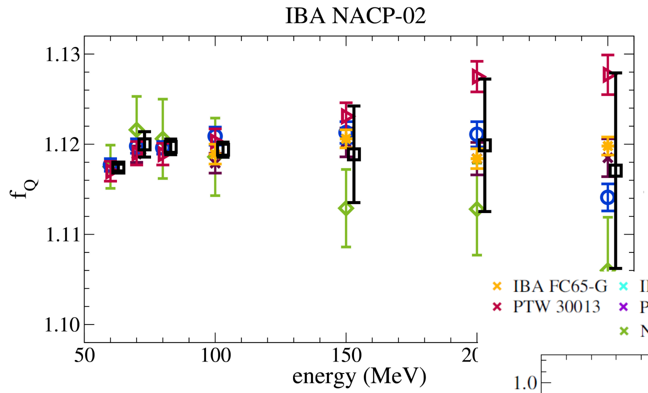

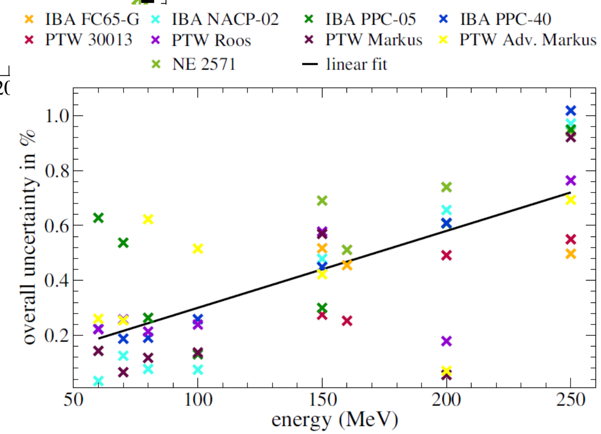

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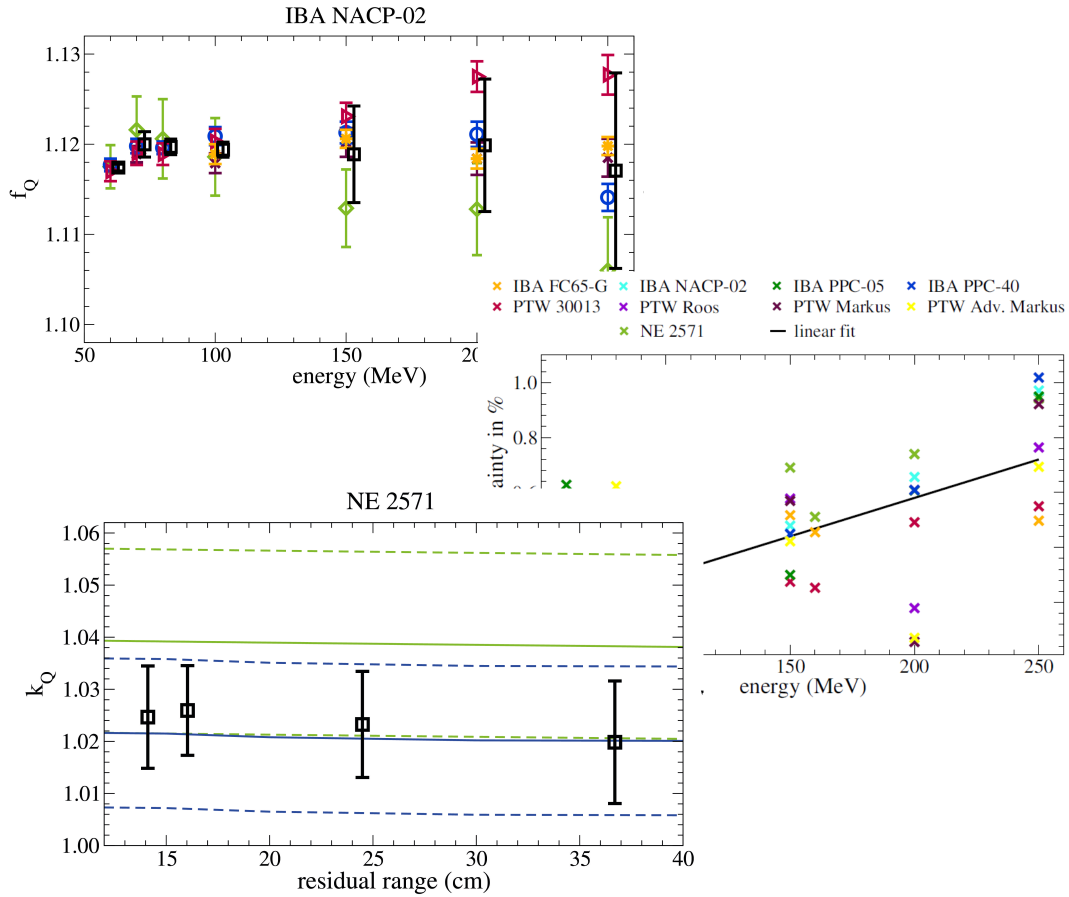
- General good agreement for low energies, larger differences for high energies
  - Probably due to different modelling of nuclear interactions
- Average Monte Carlo calculated f_Q factors are constant over energy; overall uncertainty increases with energy
- Monte Carlo calculated k_Q factors show differences up to 2.4% compared to IAEA TRS-398 CoP
- Better agreement (~1%) with values of upcoming version of IAEA TRS-398 CoP



Thank you very much for your attention!