Calculation of beam quality correction factors for particle beams using Gate/Geant4

Guillaume Houyoux
Radiophysics and MRI physics laboratory
Université Libre de Bruxelles - Institut Jules Bordet

H.U.B
HÔPITAL UNIVERSITAIRE DE BRUXELLES
ACADEMISCH ZIEKENHUIS BRUSSEL

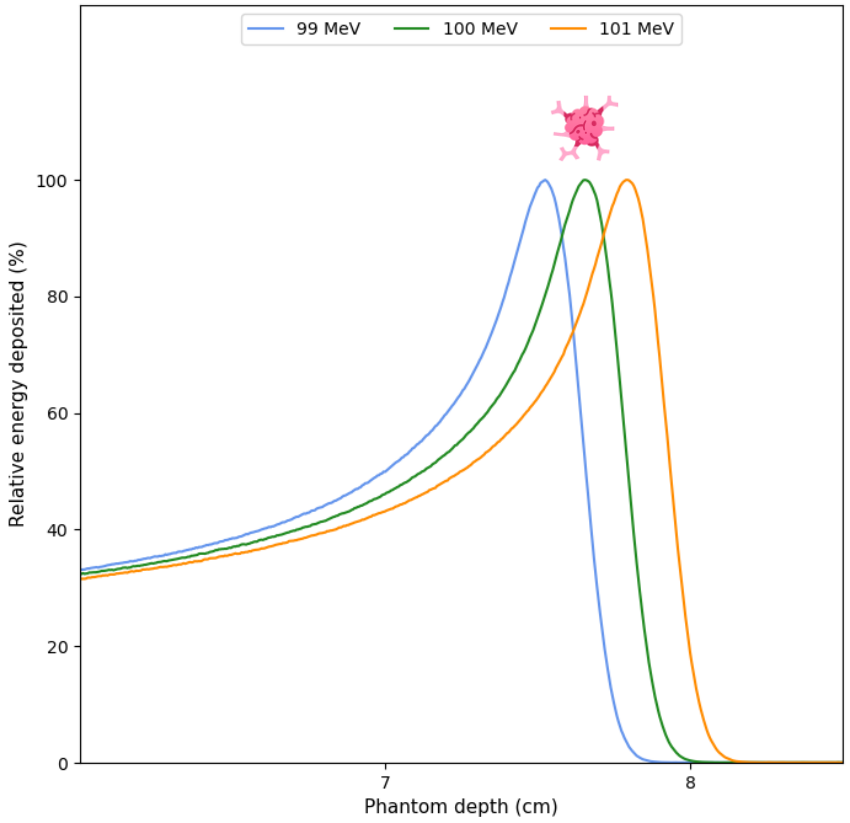
INSTITUT JULES BORDET INSTITUUT
Hôpital Erasme | ULB
Hôpital Universitaire des Enfants Reine Fabiola
Universitair Kinderziekenhuis Koningin Fabiola

09/11/2023

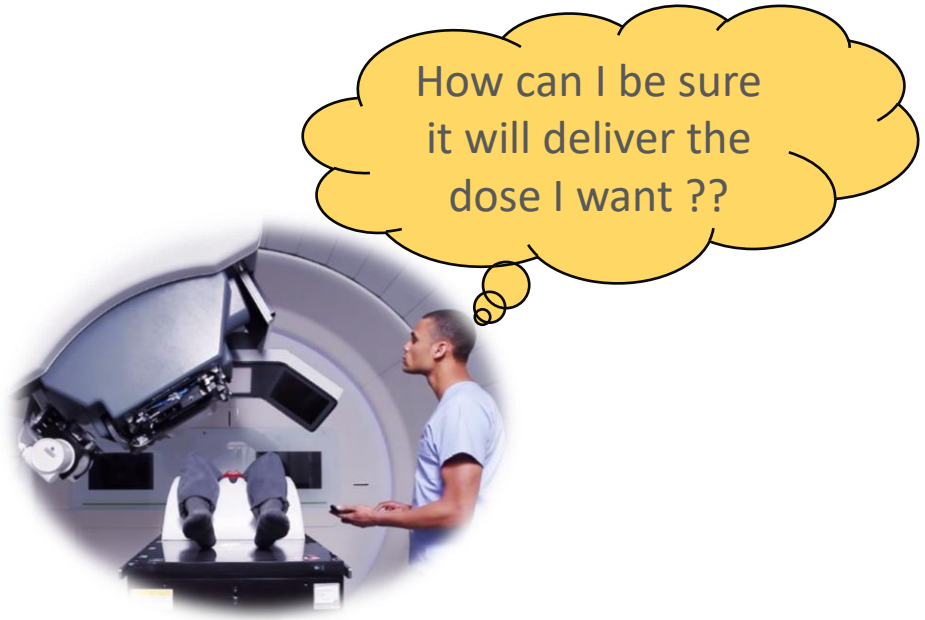
Disclosure

1) This project is in collaboration with *IBA Dosimetry*

Proton beam calibration



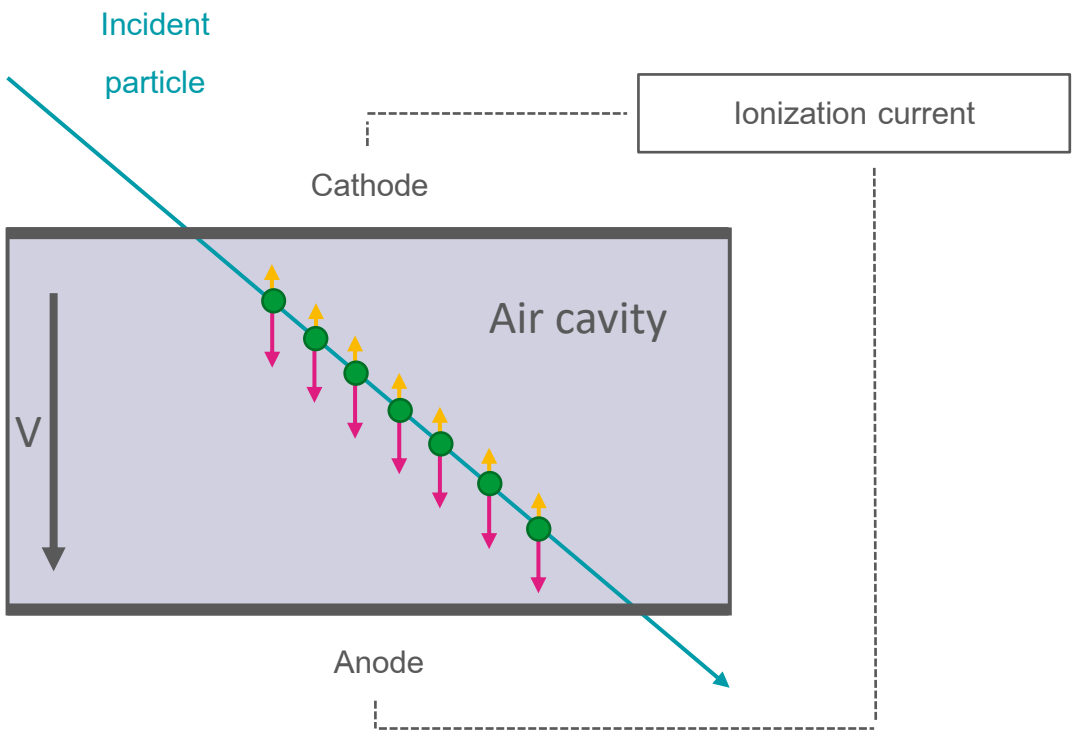
Energy	99 MeV	100 MeV	101 MeV
Range	7.60 cm	7.74 cm	7.88 cm



Proteus One (IBA)

It becomes therefore fundamental to use a calibrated proton beam to guarantee an optimal therapy treatment

Ionization chamber



The ionization current is directly related to the dose deposited inside the air cavity

Beam quality correction factor

Response of the ionization chamber

Correction for temperature, pressure, ion recombination and polarity

$$D_{w,Q} = M_Q \times N_{D,w,Q_0} \times \left(\prod_i k_i\right) \times k_{Q,Q_0}$$

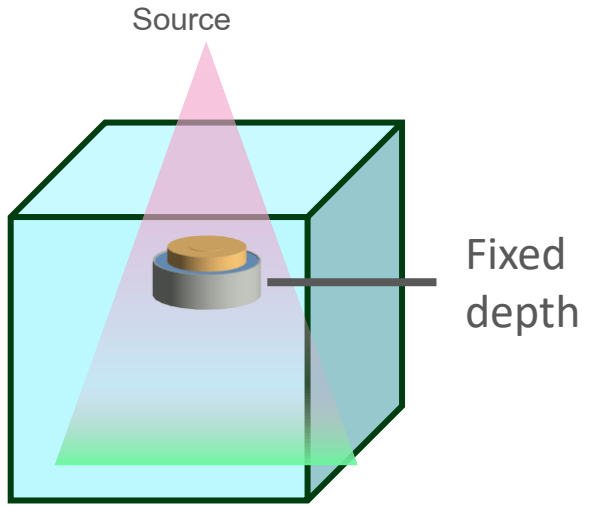
Calibration factor

Beam quality correction factor

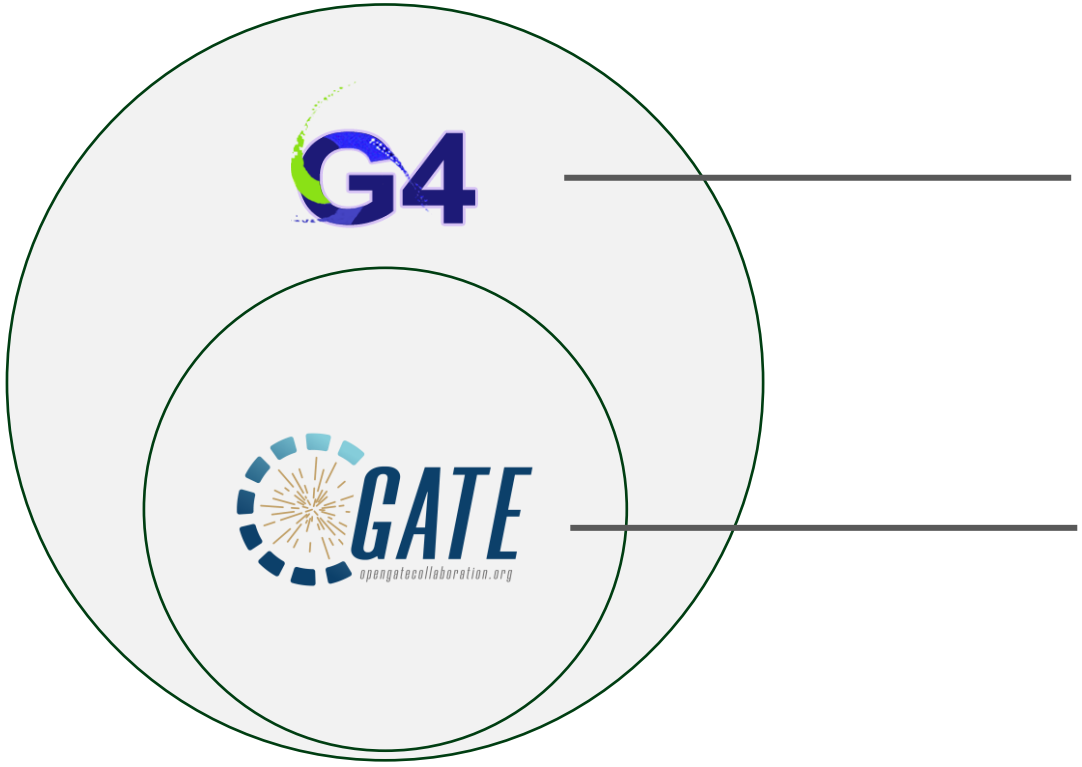
Q = proton
Q_0 = γ from Co 60
w = water

$$k_{Q,Q_0} = \frac{\left(D_{water} \Big/ \overline{D}_{chamber}\right)_Q}{\left(D_{water} \Big/ \overline{D}_{chamber}\right)_{Q_0}} \times \frac{W_{air,Q}}{W_{air,Q_0}}$$

Mean energies required to create an ion pair in air



The Monte Carlo code : Gate



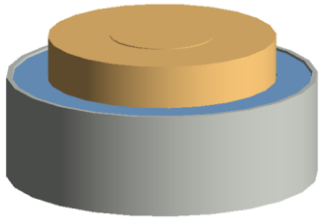
Applications : Simulates the passage of radiation through matter

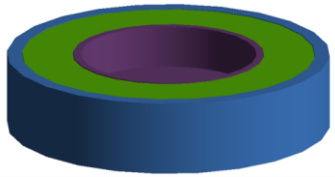
- High Energy Physics (LHC)
- Space and Radiation Science
- **Medical Physics**

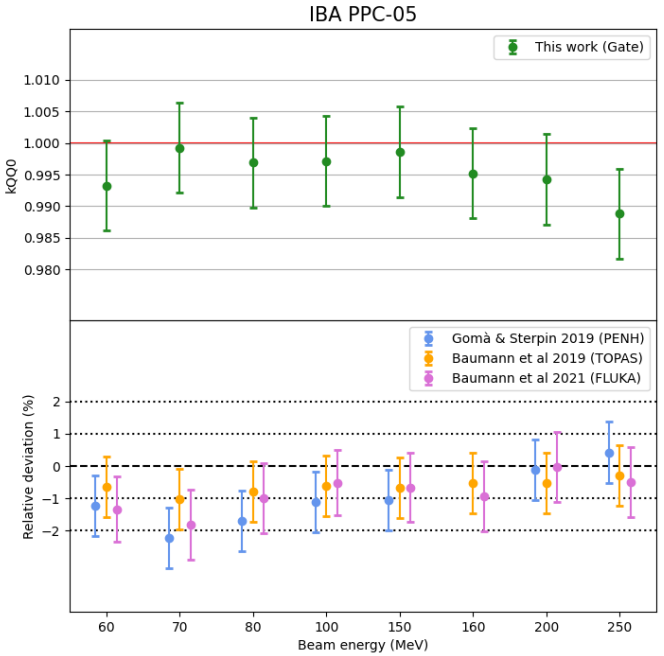
- Medical imaging devices
- Imaging reconstruction algorithms
- Dose calculation in radiation therapy

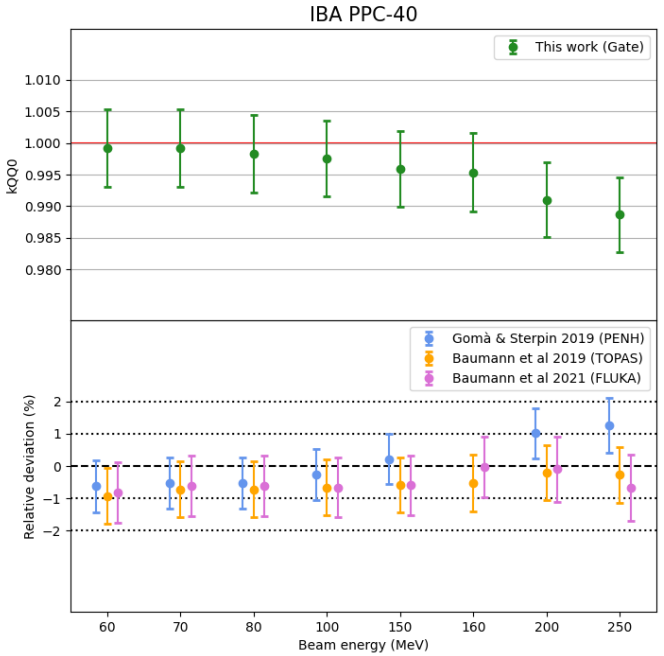
Determination of kQ factors for known ionization chambers

kQ factor for PPC-05 and PPC-40



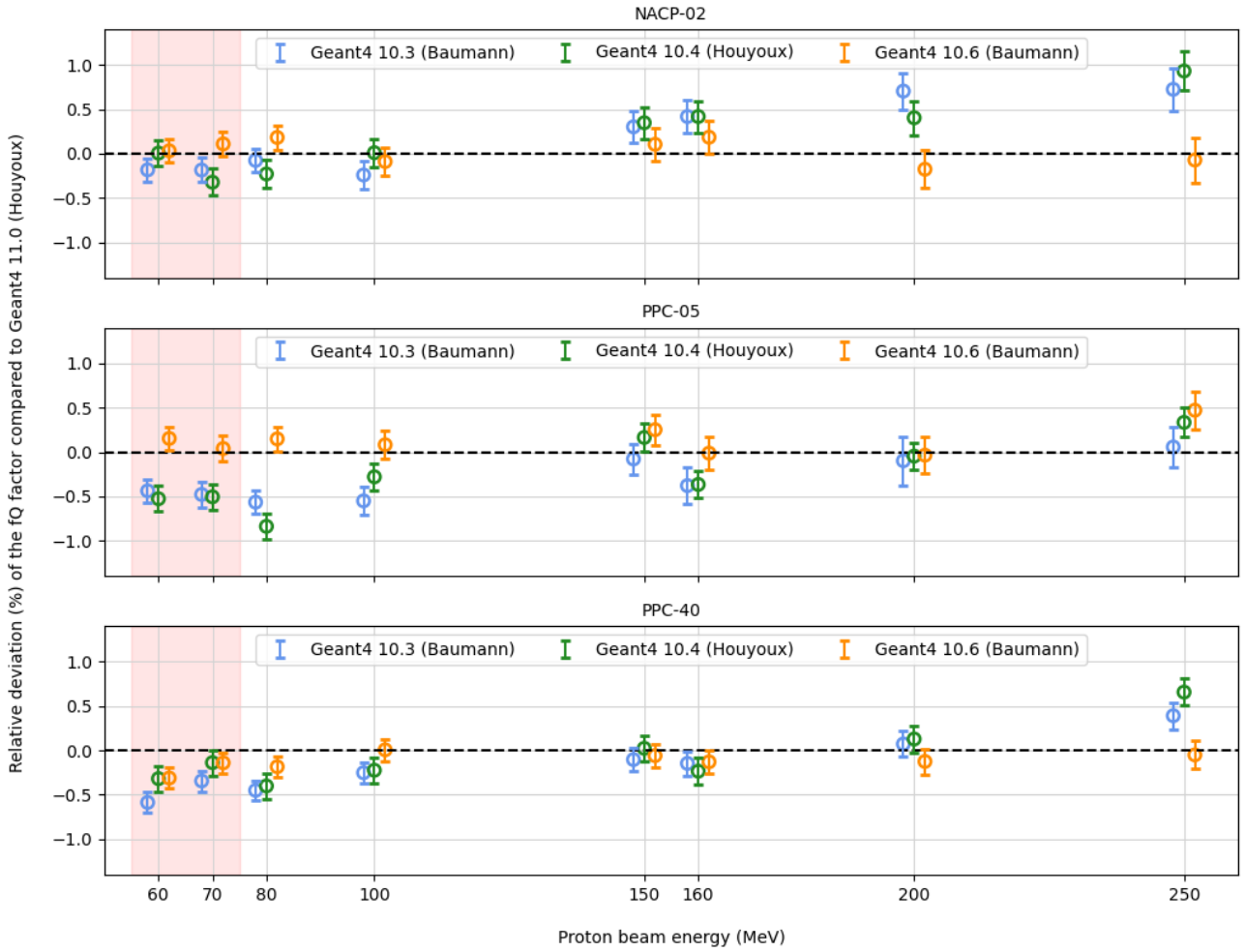






- Within error bars, the kQ factor has a value around 1
- Nuclear reactions lead to a decrease of the kQ at high proton beam energies
- General agreement of the results within 0.6 %
- Larger deviations at low energies for the PPC-05

Caution to take with Geant4



$$k_{Q,Q_0} \propto {f_Q}/{f_{Q_0}} \text{ where } f_Q = {D_w}/{D_c}$$

1) The value of the f_Q factor can be sensitive to the version of Geant4.

2) This sensitivity can depend on :
   - The ionization chamber
   - The energy regime considered

The origin of these deviations is currently studied.

How does the geometry of an IC impact the value of the k_Q ?

Chain production of an ionization chamber

In an engineering point of view, two ionization chambers of the same model cannot be identical

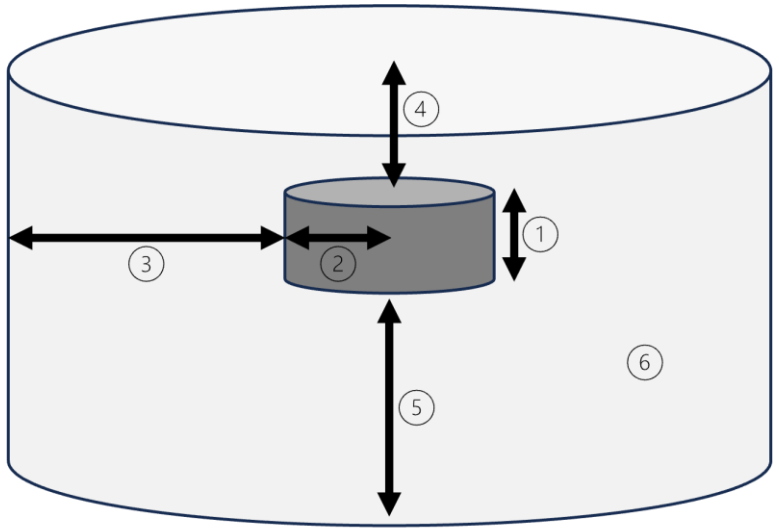
Dimension can vary up to ~ 10 %

Does it impact the value of the kQ factor ?

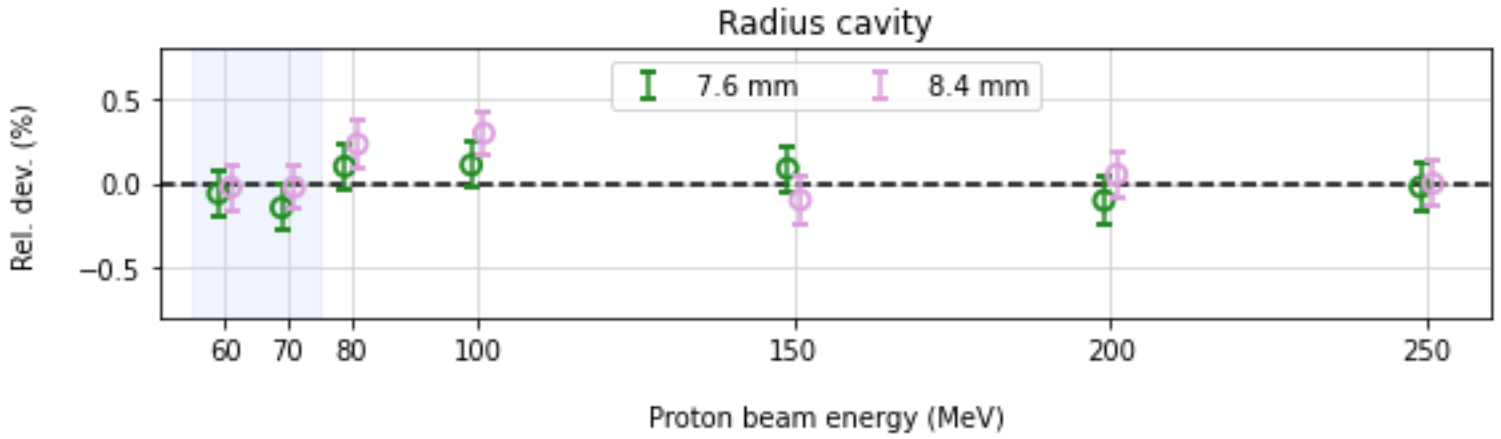
The simplest way of modelling an IC

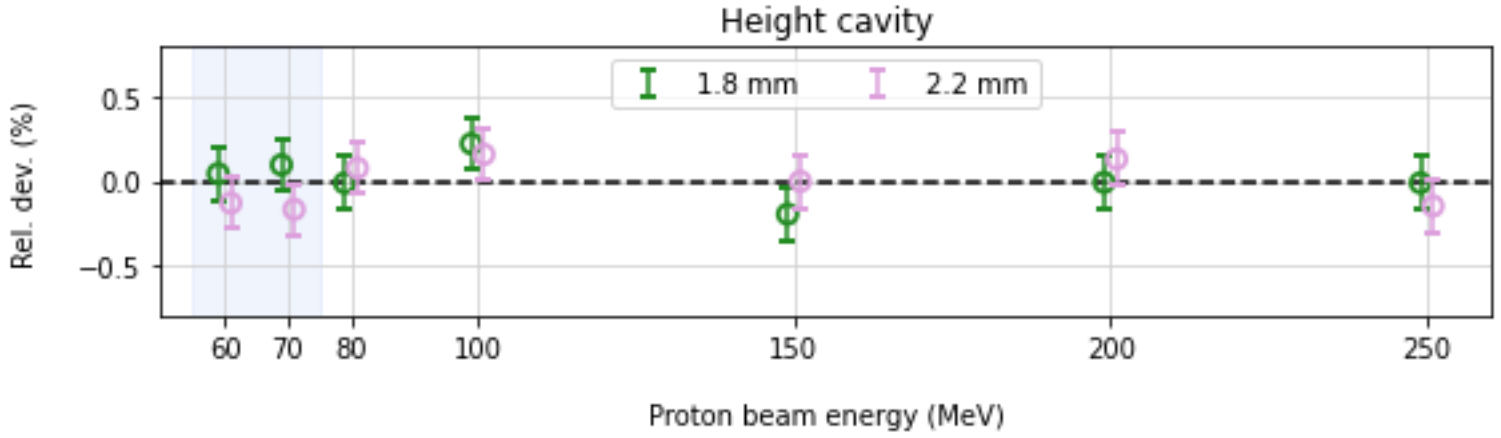
Assumption : "An ionization chamber is a cylindrical air cavity surrounded by as single layer of material called the body"

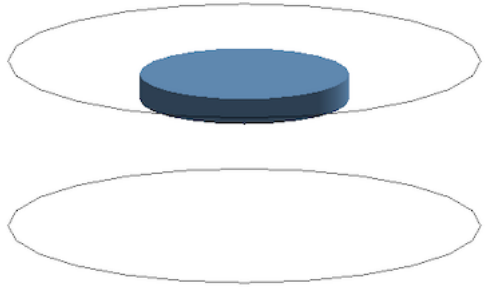
Parameter	Initial dimension
1) Height of the air cavity	2 mm
2) Radius of the air cavity	8 mm
3) Lateral thickness of the body	10 mm
4) Size of the entrance window	1 mm
5) Size of the exit window	10 mm
6) Composition of the body	PEEK



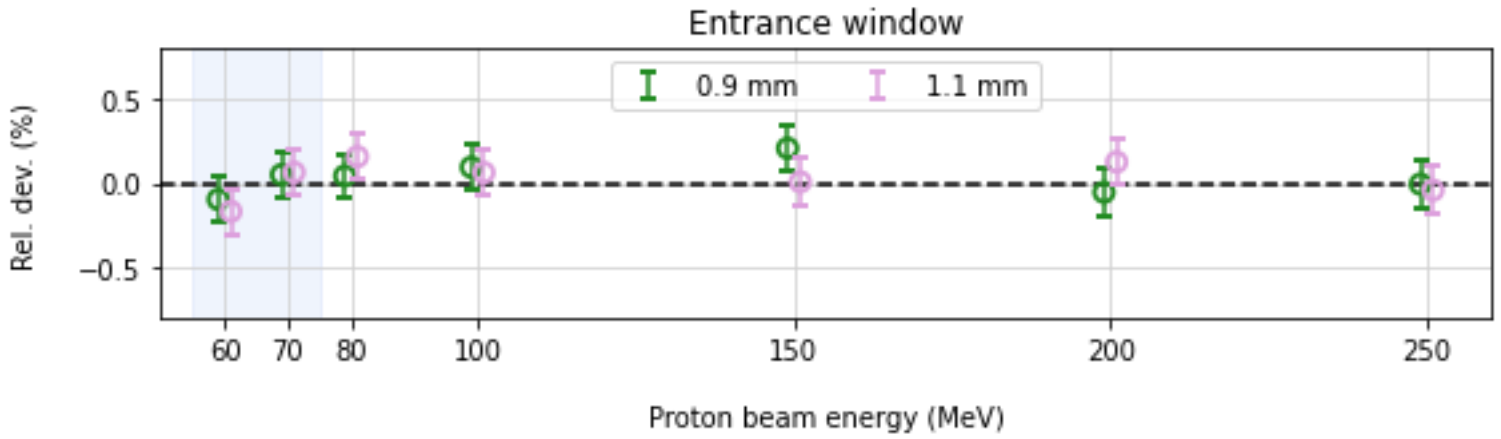
Influence of the cavity size on the fQ

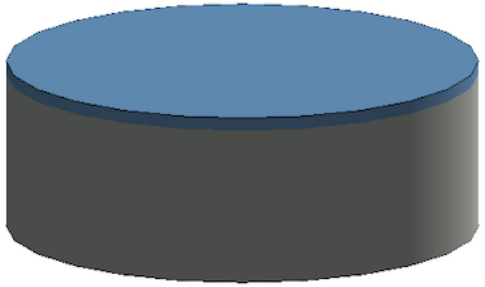


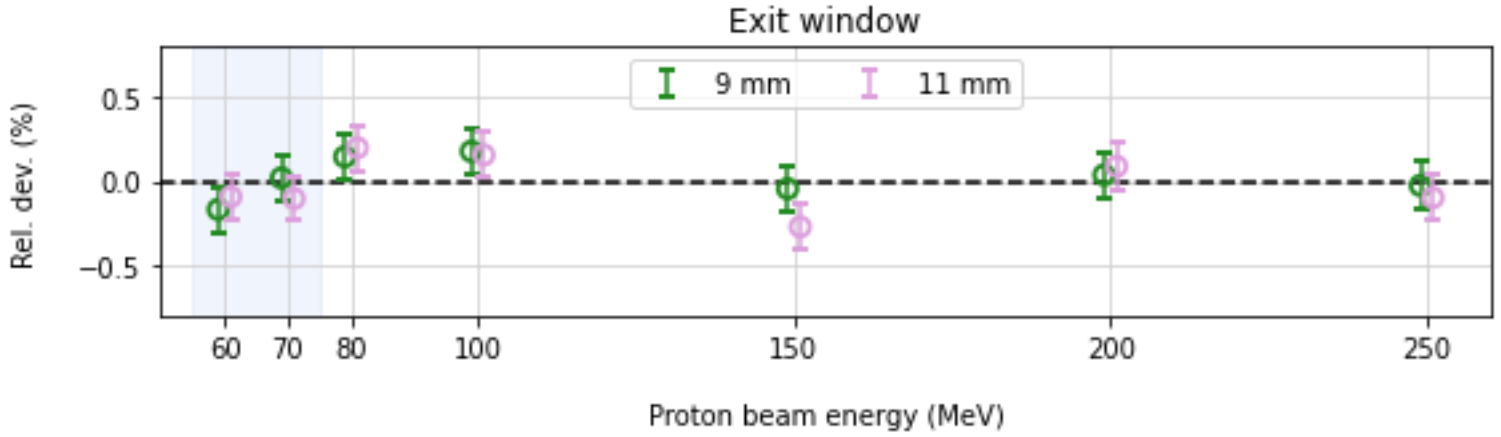


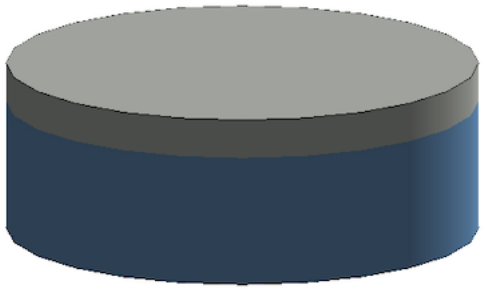


Influence of the geometrical windows on the fQ

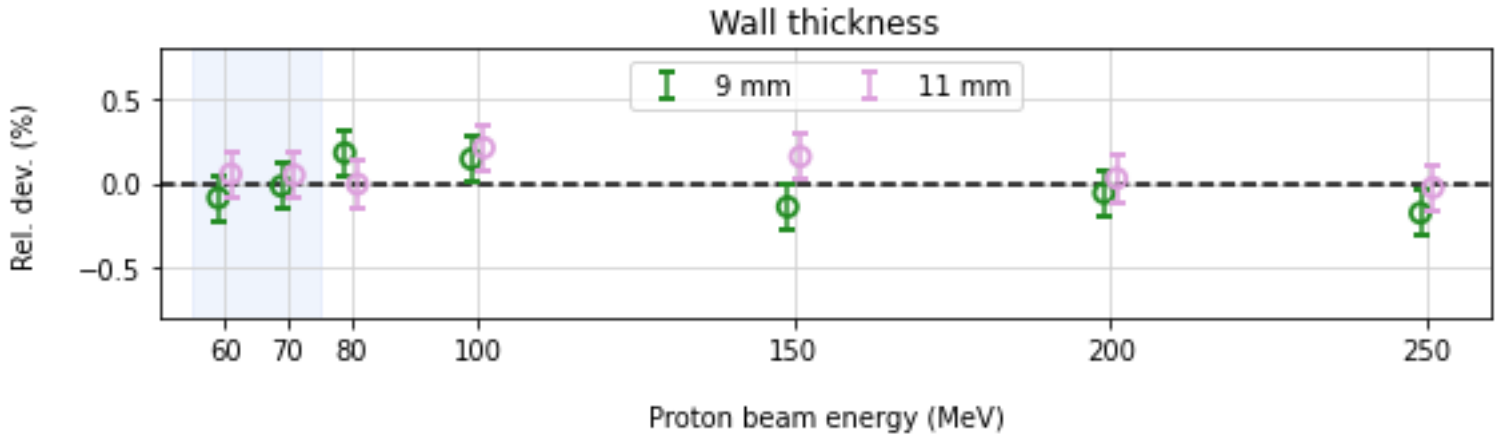


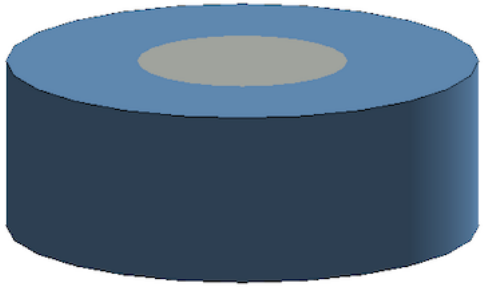


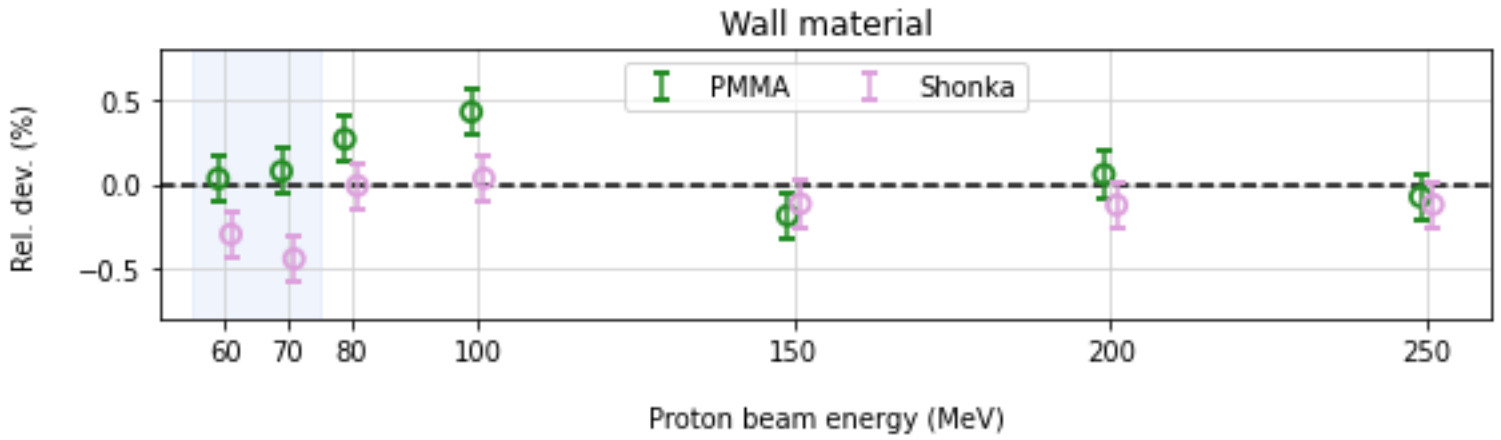


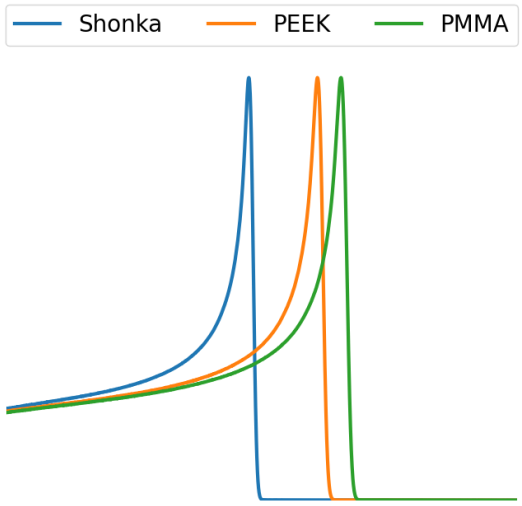


Influence of the wall on the fQ



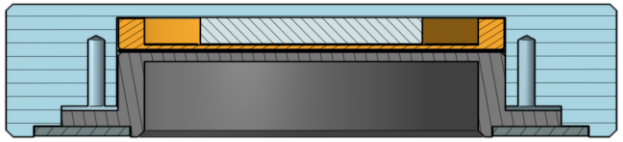






The limitations of the model

- We used a simplified geometry (only 2 pieces, no electrodes, ..)
- The parameters were modified 1 at the time.
- Only small variations (max. 10 %) were applied.
- Photon simulations ongoing to determine the full kQ factor.



Cross section PPC-40

Conclusion

1. We recovered k_{Q,Q_0} in protons for known ionization chambers using Gate as Monte Carlo simulation tool.
   - The k_{Q,Q_0} factor can be different than 1 at high proton energies
   - The reading of the dose value on an ionization chamber must be corrected when using them for proton therapy

2. We studied how small geometrical variation could affect the k_{Q,Q_0} factor.
   - No significant deviations observed so far
   - A single k_{Q,Q_0} factor can be applied to every ionization chamber of the same type
   - The model should be complexified for accurate comparison
   - Photon calculations ongoing

Acknowledgments

- Nick Reynaert
- Sébastien Penninckx
- Dirk Van Gestel

- Kevin Souris
- Victor De Beco
- Gaëtan Duchene
- Alexandre Wattelar
- Séverine Rossomme
- Liu Hong

- Jean Bouchat
- David Remacle
- Yanis Chauvel
- Frédéric Péters

- Edmond Sterpin
- Marina Orts
- Sylvain Deffet
- Lies Verpoest

Calculation of beam quality correction factors for particle beams using Gate/Geant4

Guillaume.Houyoux@ulb.be

H.U.B
HÔPITAL UNIVERSITAIRE DE BRUXELLES
ACADEMISCH ZIEKENHUIS BRUSSEL

INSTITUT JULES BORDET INSTITUUT
Hôpital Erasme ULB
Hôpital Universitaire des Enfants Reine Fabiola
Universitair Kinderziekenhuis Koningin Fabiola

PPRIG

NPL

MaThRad