Impact of the true sensitive volume on ion chamber response in magnetic fields

Victor N. Malkov, David W. O. Rogers

Carleton Laboratory for Radiation Physics, Carleton University

MCMA 2017

Ottawa Medical Physics Institute

CLRP

Carleton UNIVERSITY

Introduction

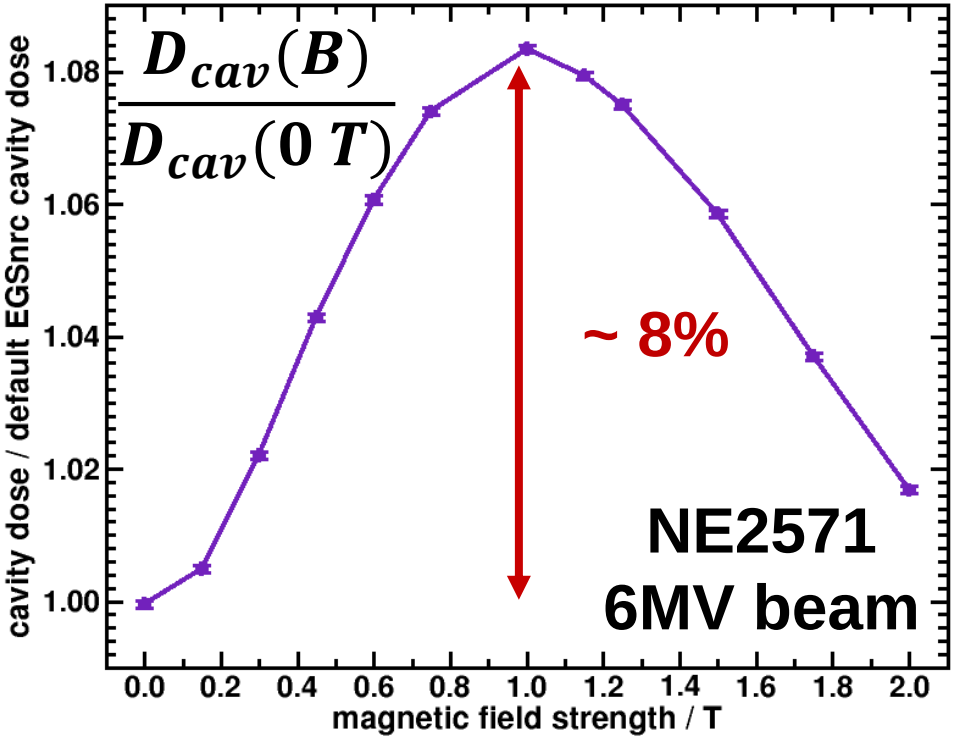
- **Combining MRI + Radiation Therapy**
  - **Magnetic resonance guided radiation therapy (MRgRT)**
  - **Sources: Co-60, linacs (6 MV, 7 MV)**
  - **Magnetic fields strengths: 0.35 – 1.5 T**

Introduction

- Combining MRI + Radiation Therapy
  - Magnetic resonance guided radiation therapy (MRgRT)
  - Sources: Co-60, linacs (6 MV, 7 MV)
  - Magnetic fields strengths: 0.35 – 1.5 T
- **The B-field distorts electron trajectories**
  - **Local hot/cold spots in the dose distribution**

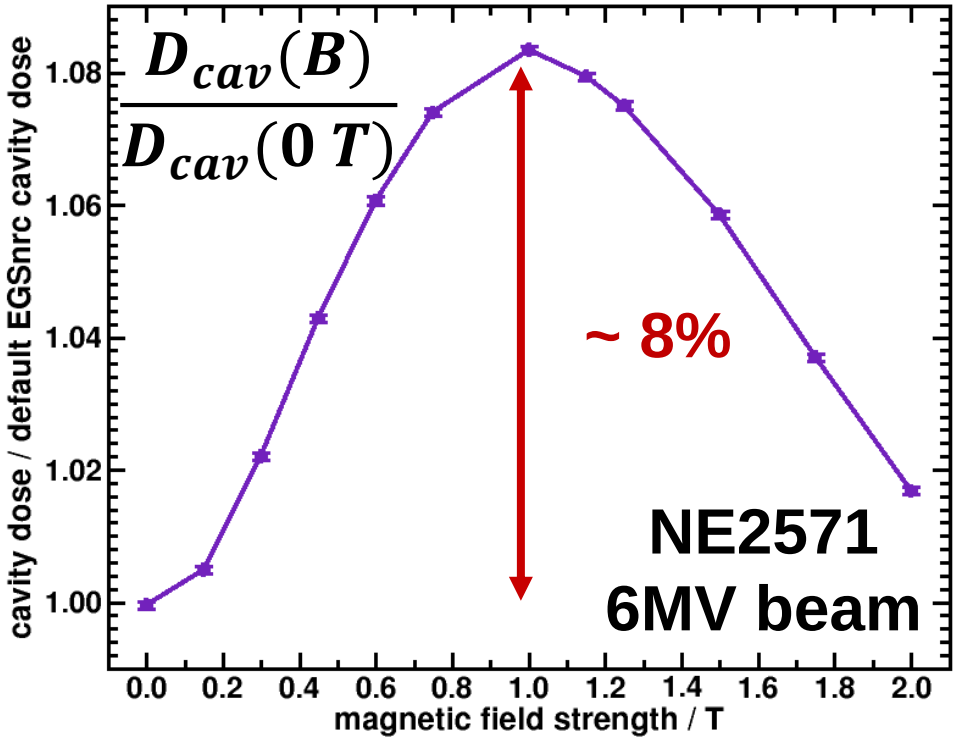
Introduction

- Combining MRI + Radiation Therapy
  - Magnetic resonance guided radiation therapy (MRgRT)
  - Sources: Co-60, linacs (6 MV, 7 MV)
  - Magnetic fields strengths: 0.35 – 1.5 T
- The B-field distorts electron trajectories
  - Local hot/cold spots in the dose distribution
  - **Changes in ion chamber dose**



Introduction

- Combining MRI + Radiation Therapy
  - Magnetic resonance guided radiation therapy (MRgRT)
  - Sources: Co-60, linacs (6 MV, 7 MV)
  - Magnetic fields strengths: 0.35 – 1.5 T
- The B-field distorts electron trajectories
  - Local hot/cold spots in the dose distribution
  - **Changes in ion chamber dose**



Need correction factors!

Magnetic fields in EGSnrc

- **All simulations are performed using egs_chamber**

Magnetic fields in EGSnrc

- All simulations are performed using egs_chamber
- **Magnetic field effects are accounted for using a recently implemented and validated set of macros.**

Magnetic fields in EGSnrc

- All simulations are performed using egs_chamber
- **Magnetic field effects are accounted for using a recently implemented and validated set of macros.**

Charged particle transport in magnetic fields in EGSnrc

V. N. Malkov[a)] and D. W. O. Rogers[a)]
Carleton Laboratory for Radiotherapy Physics, Physics Department, Carleton University, Ottawa, Ontario K1S 5B6, Canada

(Received 7 January 2016; revised 30 May 2016; accepted for publication 8 June 2016; published 29 June 2016)

Magnetic fields in EGSnrc

- All simulations are performed using egs_chamber
- Magnetic field effects are accounted for using a recently implemented and validated set of macros.

Charged particle transport in magnetic fields in EGSnrc

V. N. Malkov[a)] and D. W. O. Rogers[a)]
Carleton Laboratory for Radiotherapy Physics, Physics Department, Carleton University, Ottawa, Ontario K1S 5B6, Canada

(Received 7 January 2016; revised 30 May 2016; accepted for publication 8 June 2016; published 29 June 2016)

- **Passes the Fano test at the 0.1% level**

Magnetic fields in EGSnrc

- All simulations are performed using egs_chamber
- Magnetic field effects are accounted for using a recently implemented and validated set of macros.

Charged particle transport in magnetic fields in EGSnrc

V. N. Malkov[a] and D. W. O. Rogers[a]
Carleton Laboratory for Radiotherapy Physics, Physics Department, Carleton University, Ottawa, Ontario K1S 5B6, Canada

(Received 7 January 2016; revised 30 May 2016; accepted for publication 8 June 2016; published 29 June 2016)

- Passes the Fano test at the 0.1% level
- **Agreement with experiment excellent to about 1T**
  - **Air gaps around the chamber**
  - **Direction of the incoming beam**

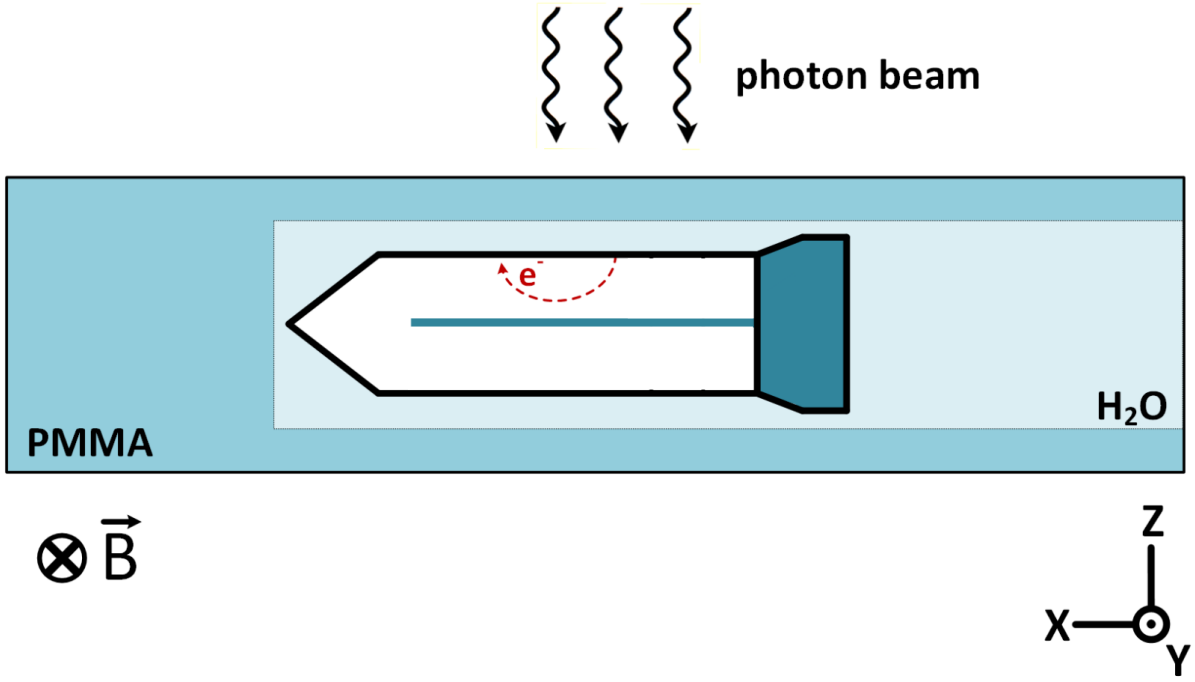
Sensitive volume – the problem!

- **Compare to recent experiments by Agnew et al. [1]**

[1] Agnew, J et al. PMB *62*(5), 1731 (2017)

Sensitive volume – the problem!

- Compare to recent experiments by Agnew et al. [1]

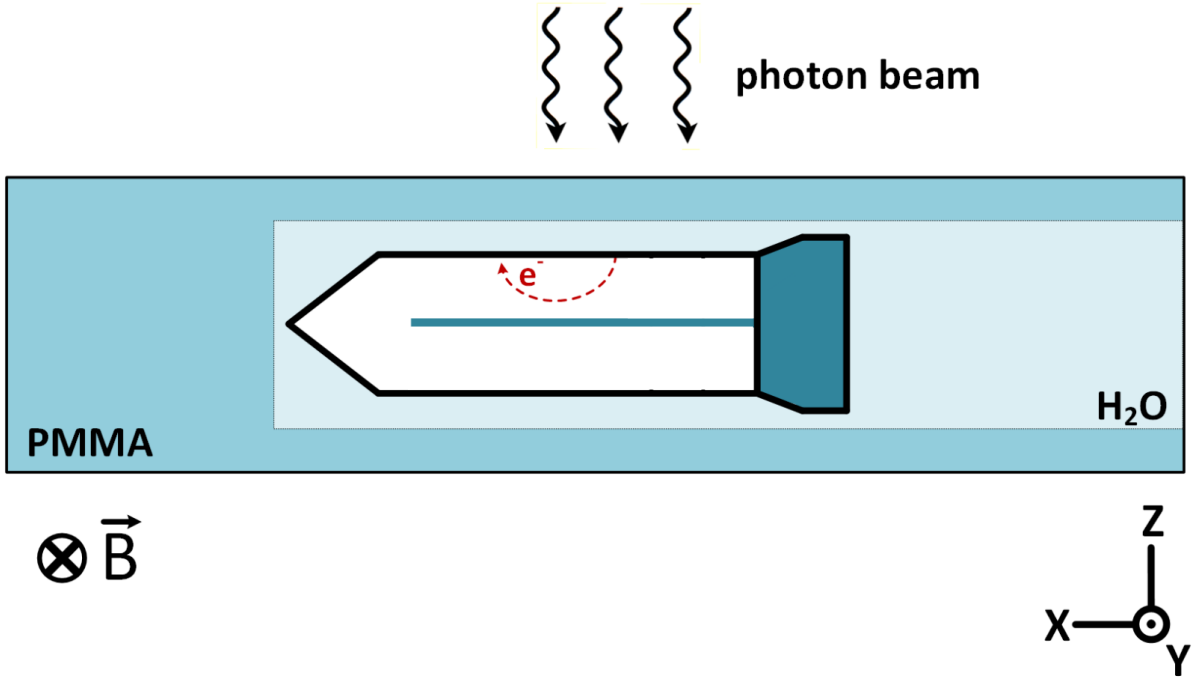


$$\frac{M(B)}{M(0\,T)}$$

[1] Agnew, J et al. PMB *62*(5), 1731 (2017)

Sensitive volume – the problem!

- Compare to recent experiments by Agnew et al. [1]



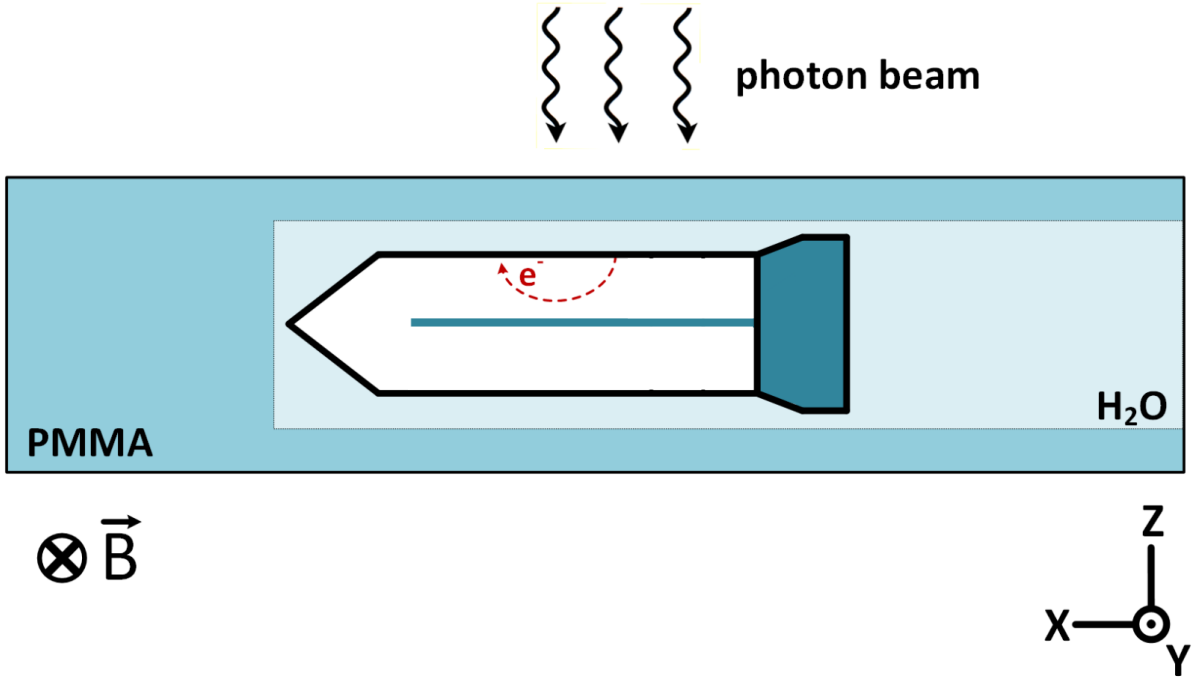
$$\frac{M(B)}{M(0\,T)}$$

$$\frac{D_{cav}(B)}{D_{cav}(0\,T)}$$

[1] Agnew, J et al. PMB *62*(5), 1731 (2017)

Sensitive volume – the problem!

- Compare to recent experiments by Agnew et al. [1]



$$\frac{M(B)}{M(0\,T)}$$

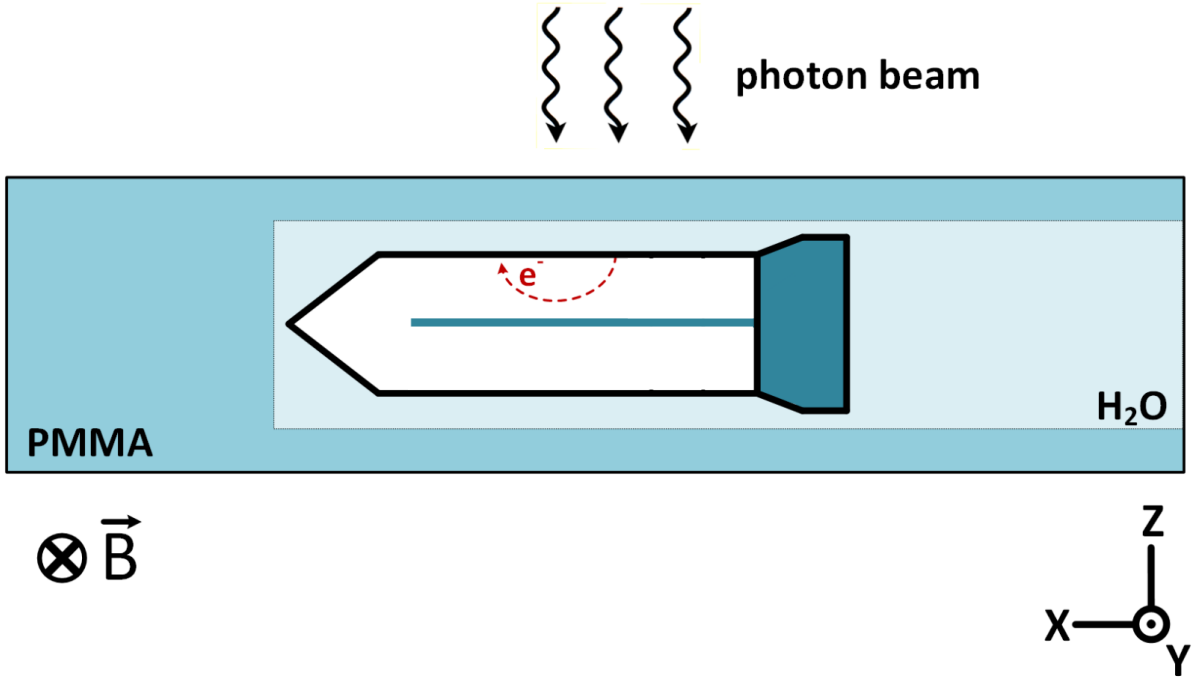
$$\frac{D_{cav}(B)}{D_{cav}(0\,T)}$$

- **Orientation is used in all published experiments**

[1] Agnew, J et al. PMB *62*(5), 1731 (2017)

Sensitive volume – the problem!

- Compare to recent experiments by Agnew et al. [1]



$$\frac{M(B)}{M(0\,T)}$$

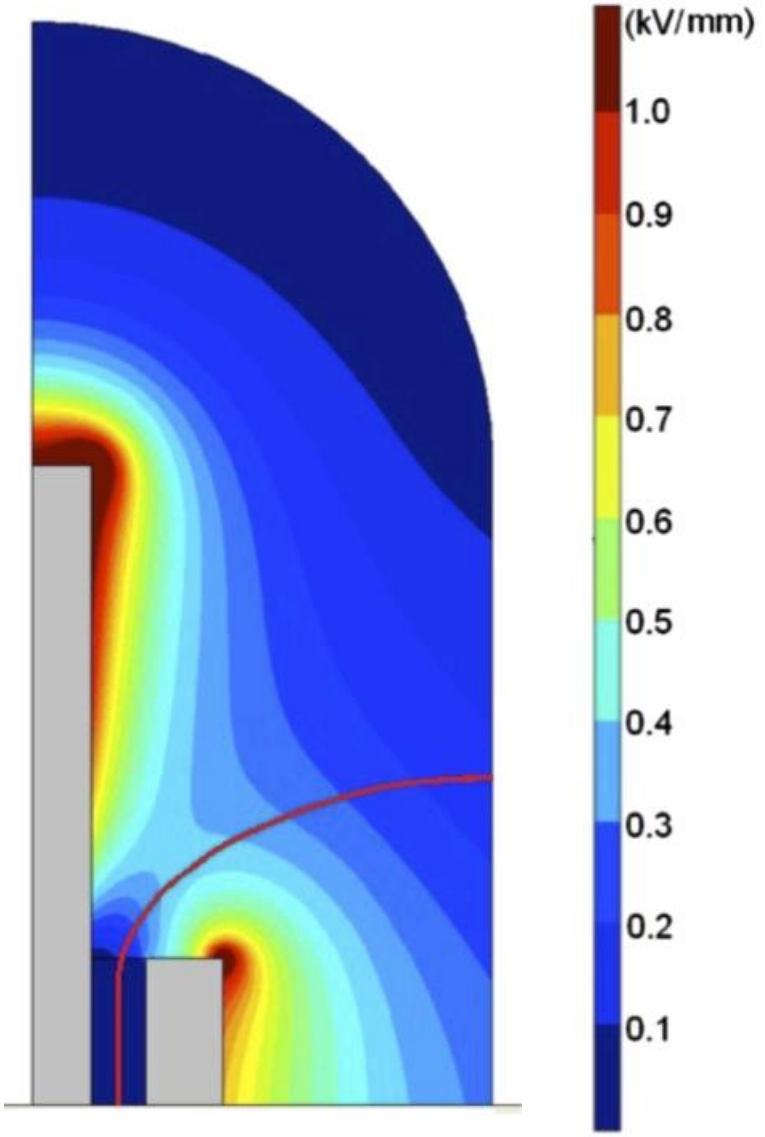
$$\frac{D_{cav}(B)}{D_{cav}(0\,T)}$$

- Orientation is used in all published experiments
- **Noted several percent discrepancies**

[1] Agnew, J et al. PMB *62*(5), 1731 (2017)

Sensitive volume – the problem!

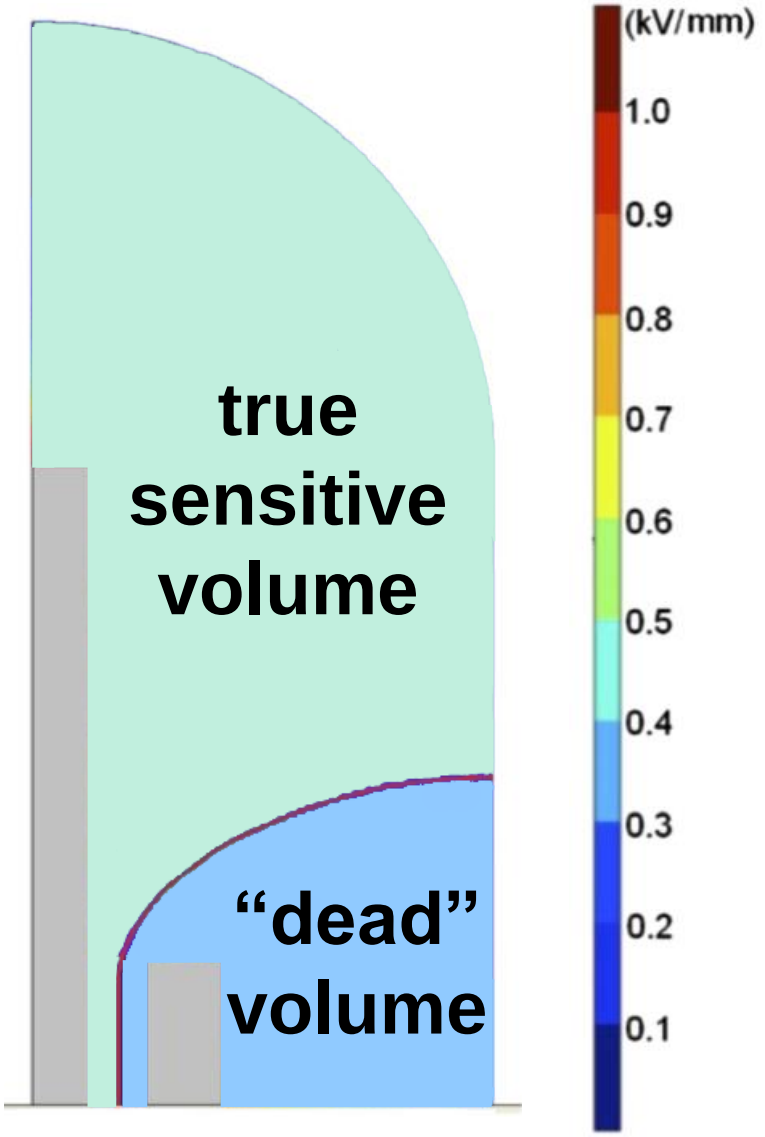
- **Fringing of the charge collecting electric field inside the ion chamber. [2]**



[2] Miller, J. R et al. Med. Phys. 43(5), 2141-2152 (2016)

Sensitive volume – the problem!

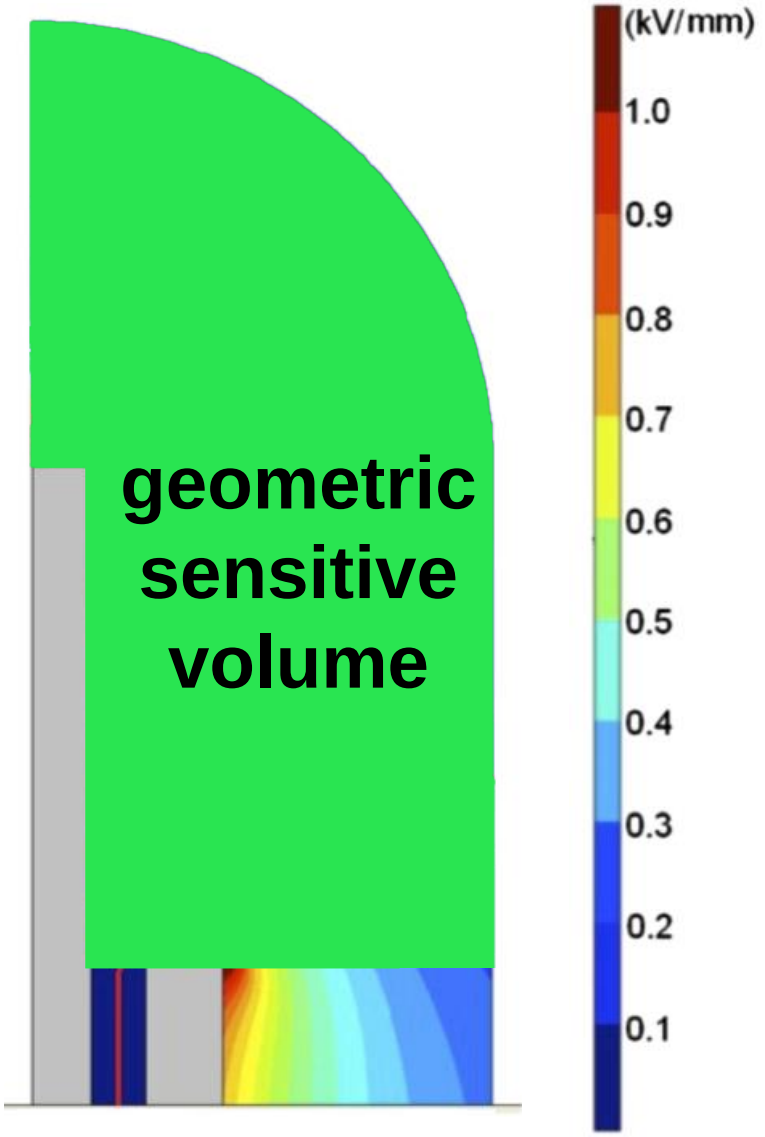
- **Fringing of the charge collecting electric field inside the ion chamber. [2]**



[2] Miller, J. R et al. Med. Phys. 43(5), 2141-2152 (2016)

Sensitive volume – the problem!

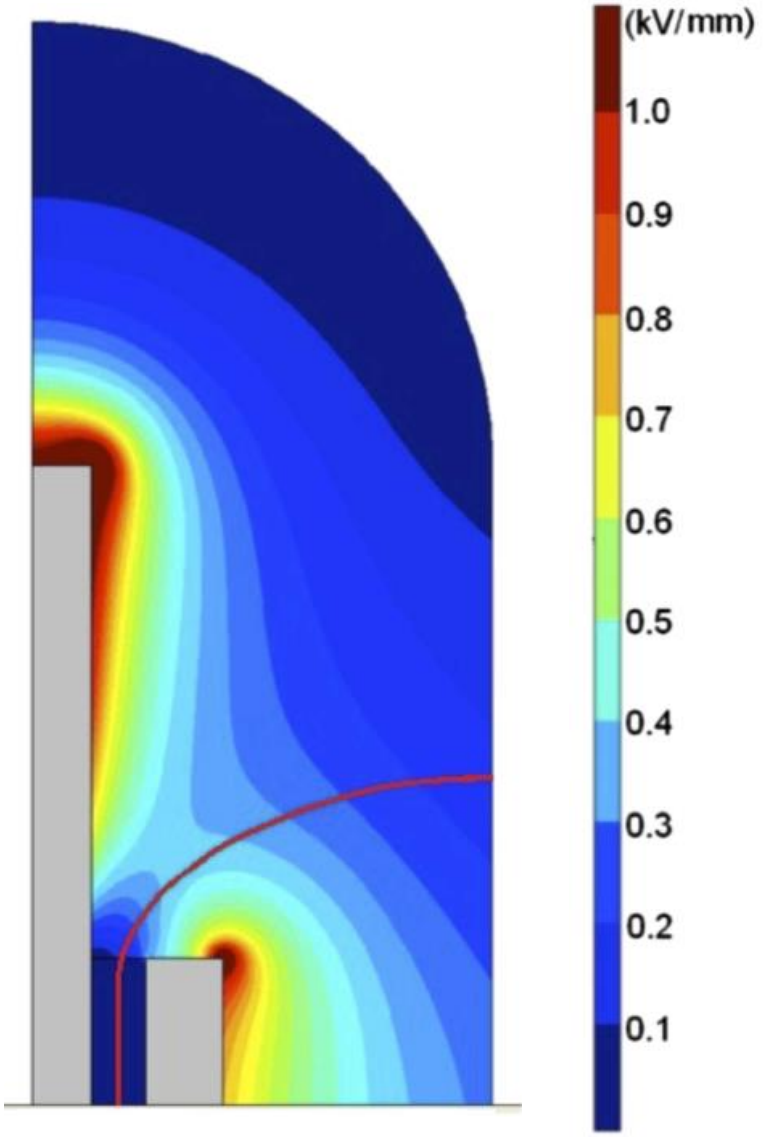
- Fringing of the charge collecting electric field inside the ion chamber. [2]
- **Monte Carlo usually uses the *geometric sensitive volume* instead of the potentially unknown *true sensitive volume*.**



[2] Miller, J. R et al. Med. Phys. 43(5), 2141-2152 (2016)

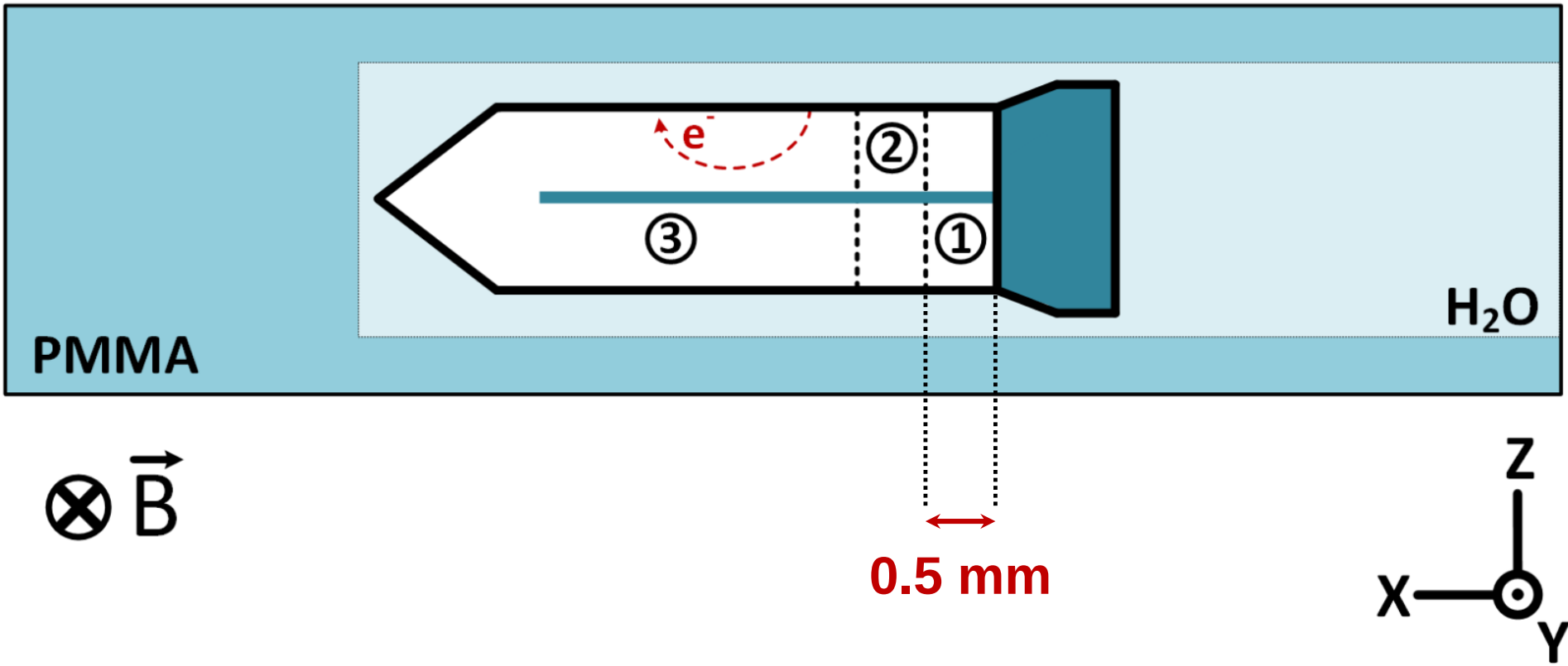
Sensitive volume – the problem!

- Fringing of the charge collecting electric field inside the ion chamber. [2]
- Monte Carlo usually uses the *geometric sensitive volume* instead of the potentially unknown *true sensitive volume*.
- **Not an issue in the absence of a magnetic field**

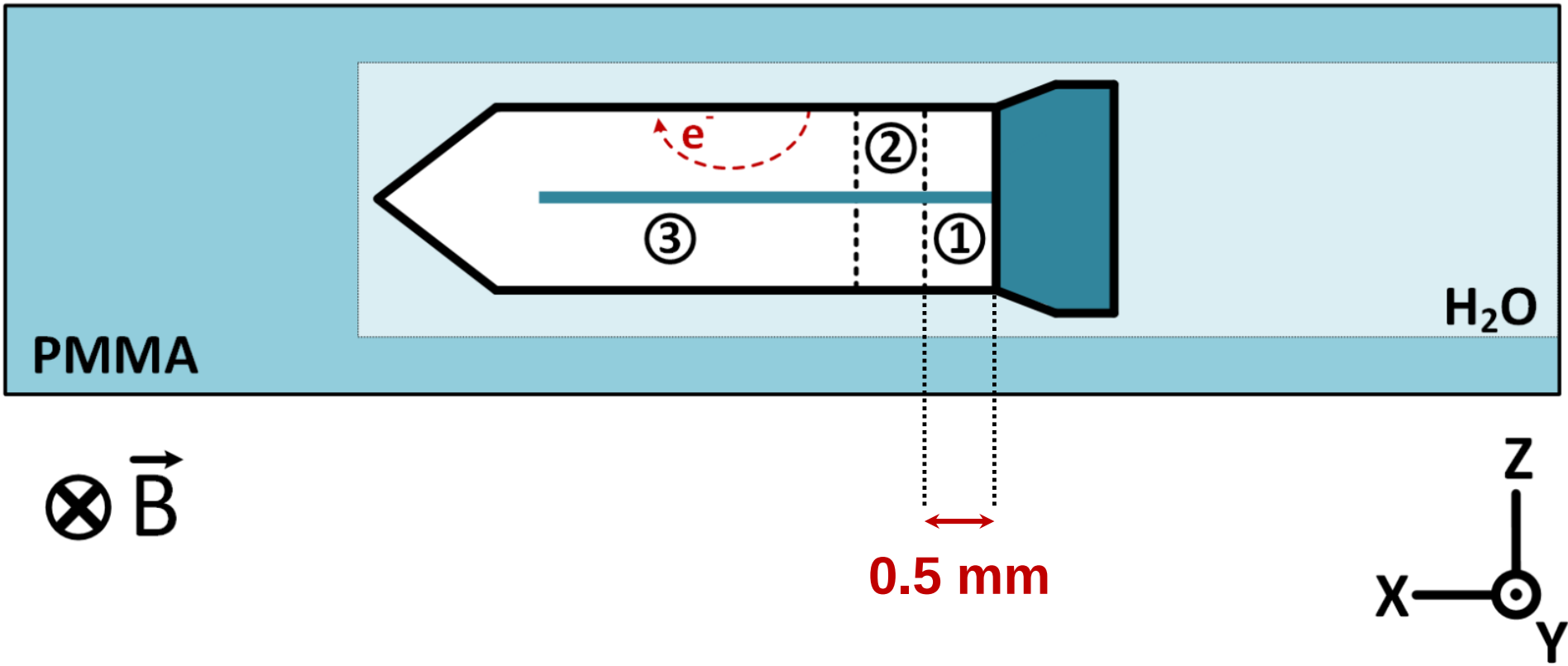


[2] Miller, J. R et al. Med. Phys. 43(5), 2141-2152 (2016)

Sensitive volume – the problem!

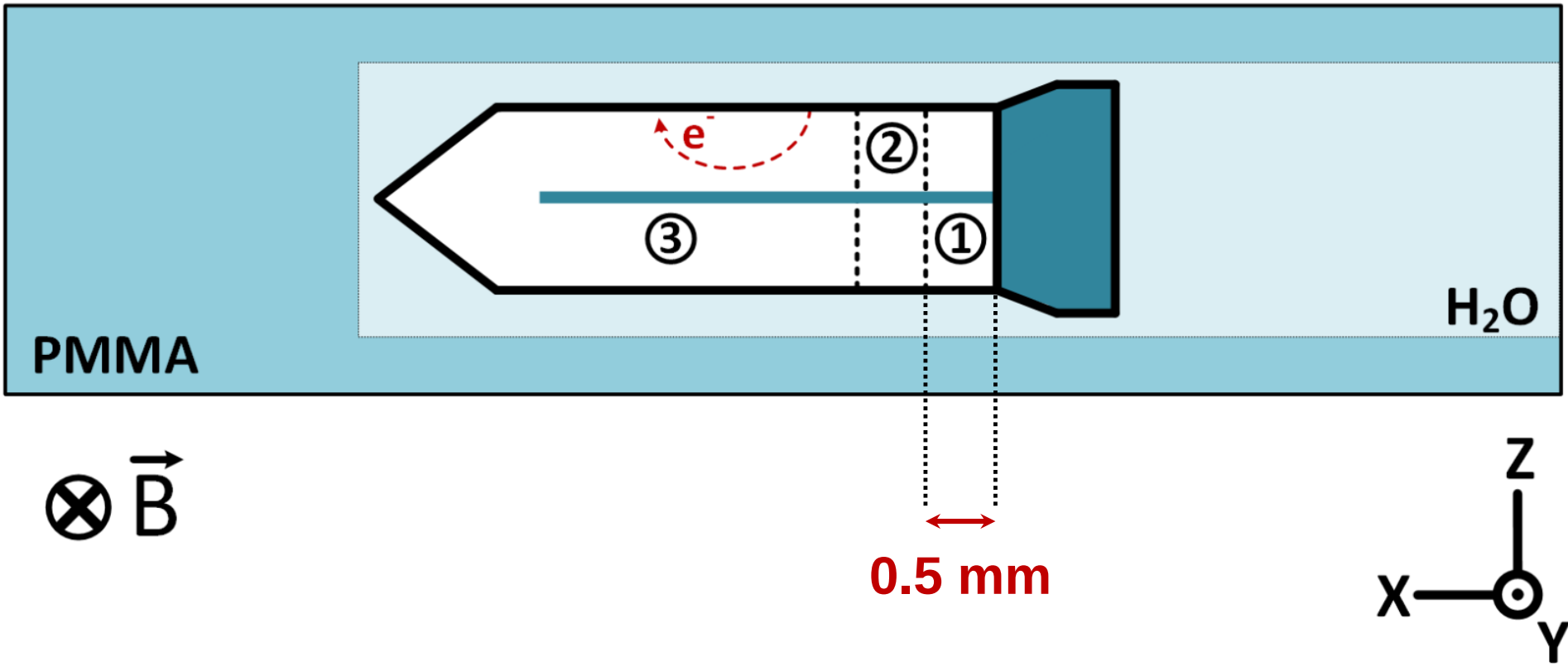


Sensitive volume – the problem!



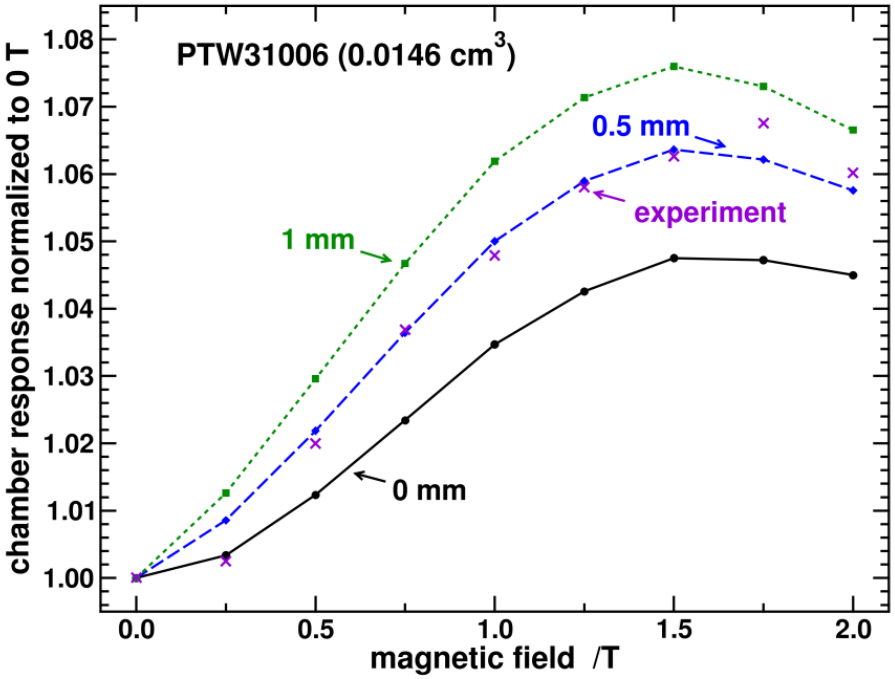
- **Simulate with 0 mm, 0.5 mm, or 1 mm of "dead" region excluded from the sensitive volume**

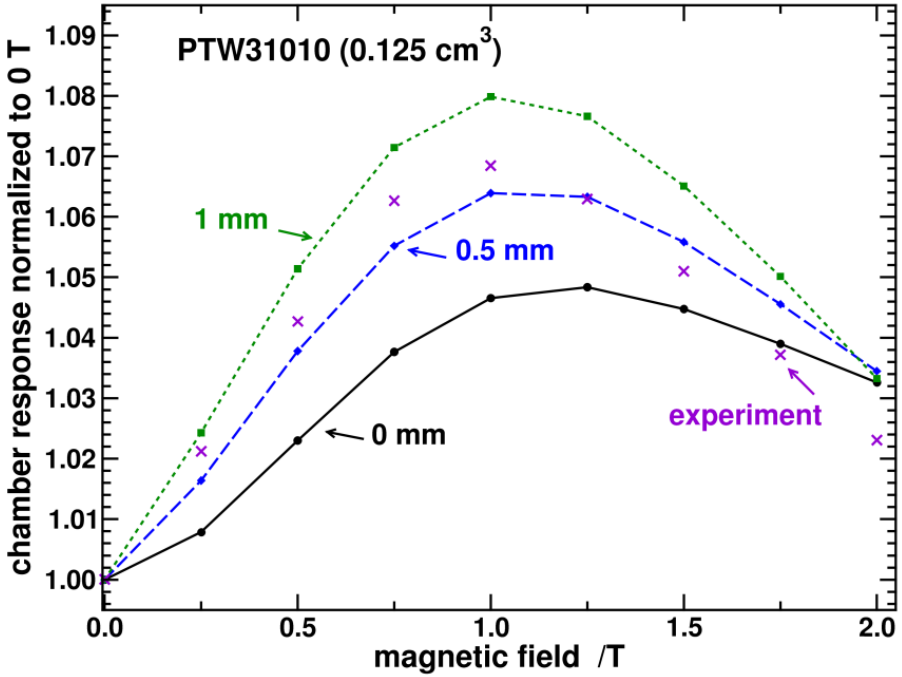
Sensitive volume – the problem!



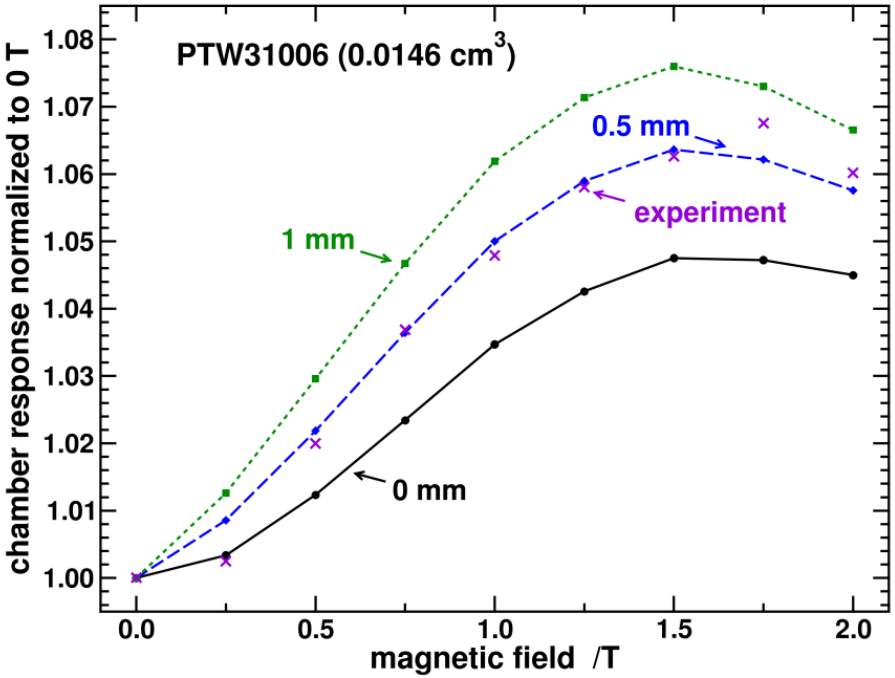
- Simulate with 0 mm, 0.5 mm, or 1 mm of “dead” region excluded from the sensitive volume
- **Results shown for PTW 31010 and 31006**

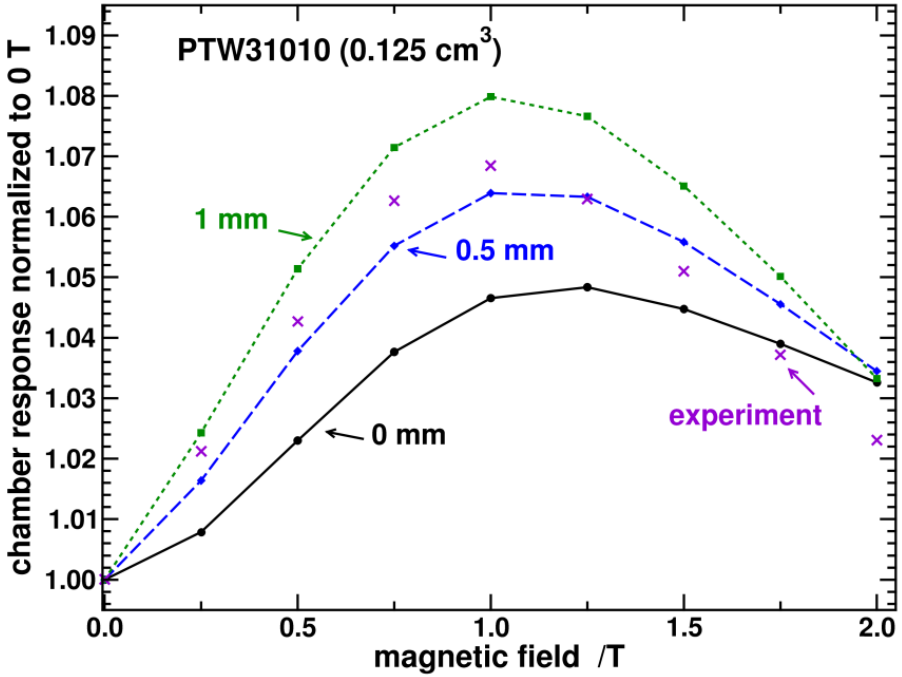
Sensitive volume – results





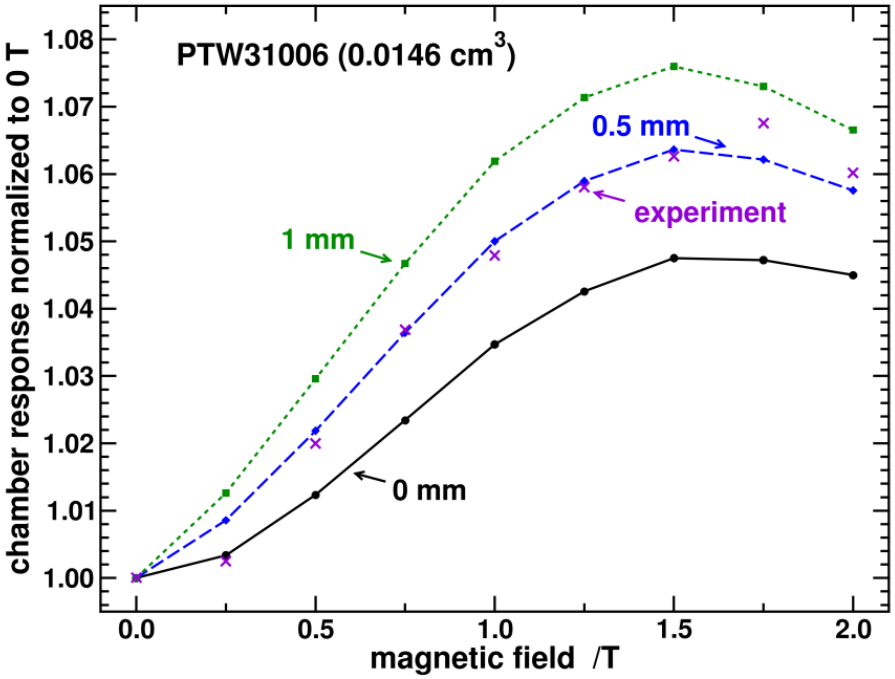
Sensitive volume – results

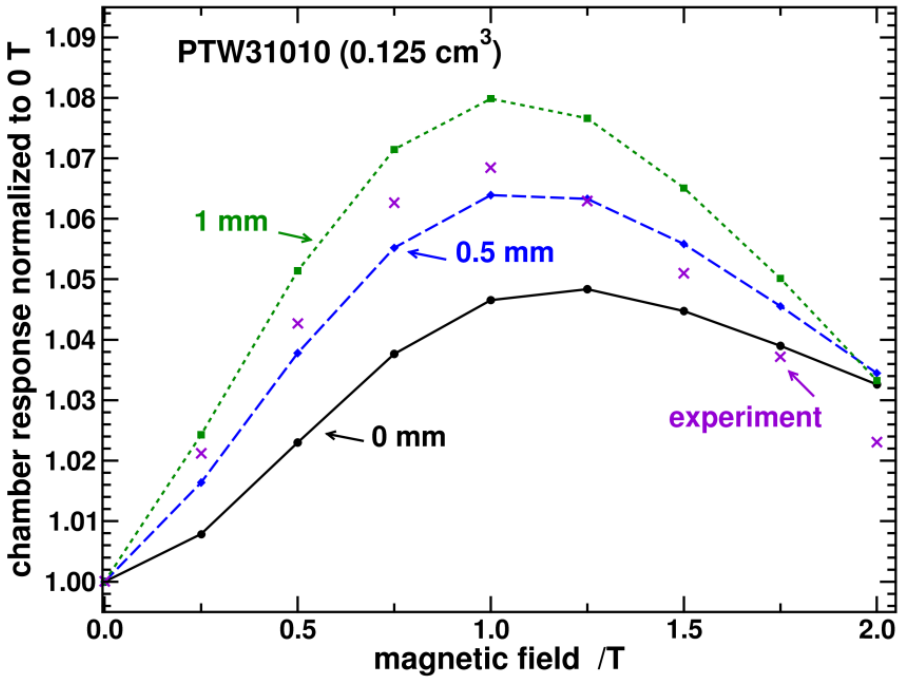




- **"Dead" region does not reflect the true sensitive volume exactly**

Sensitive volume – results





- "Dead" region does not reflect the true sensitive volume exactly
- **Simulate the E-field or find an optimal orientation**

TG-51 in magnetic fields

TG-51 in magnetic fields

$$D_w = MN_{D,w}^{Co60} k_Q$$

B = 0 T

TG-51 in magnetic fields

$$D_w = MN_{D,w}^{Co60} k_Q$$ **B = 0 T**

with magnetic field

$$\boldsymbol{D_w = MN_{D,w}^{Co60} k_Q^{mag}}$$ **B > 0 T**

TG-51 in magnetic fields

$$D_w = MN_{D,w}^{Co60} k_Q$$ **B = 0 T**

with magnetic field

$$\boldsymbol{D_w = MN_{D,w}^{Co60} k_Q^{mag}}$$ **B > 0 T**

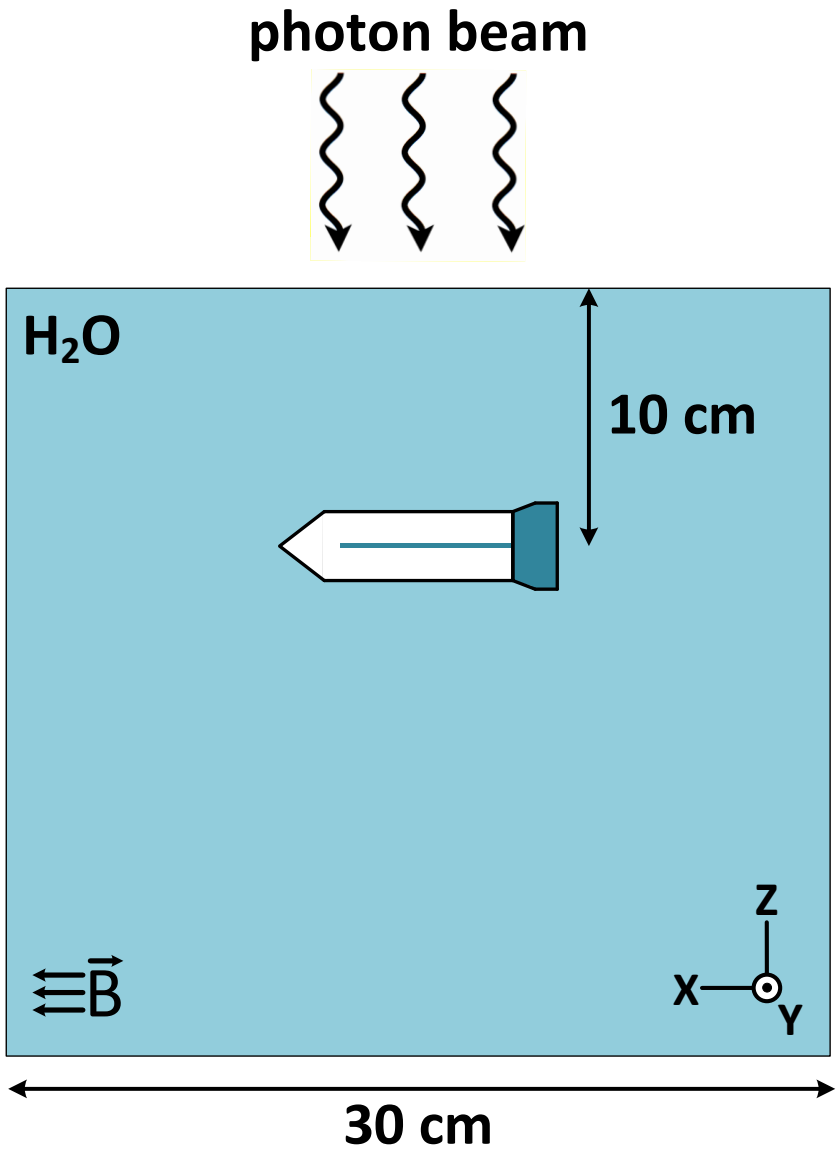
quality and B-field corr. factor

Calculating k_Q^{mag}

$$k_Q^{mag} = \frac{\left(\frac{D_w}{D_{cha}}\right)_Q^B}{\left(\frac{D_w}{D_{cha}}\right)_{^{60}Co}^{B=0T}}$$

Calculating k_Q^{mag}

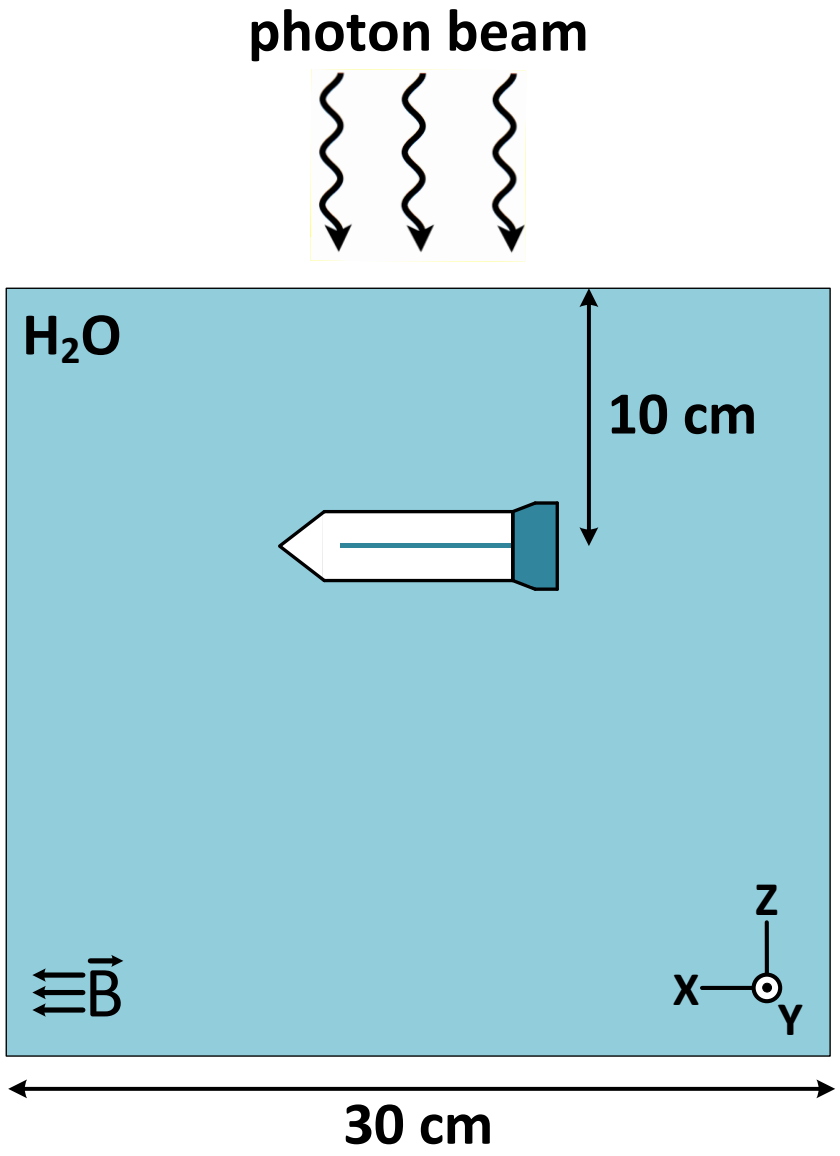
$$k_Q^{mag} = \frac{\left(\frac{D_w}{D_{cha}}\right)_Q^B}{\left(\frac{D_w}{D_{cha}}\right)_{^{60}Co}^{B=0T}}$$



Calculating k_Q^{mag}

$$k_Q^{mag} = \frac{\left(\frac{D_w}{D_{cha}}\right)_Q^B}{\left(\frac{D_w}{D_{cha}}\right)_{^{60}Co}^{B=0T}}$$

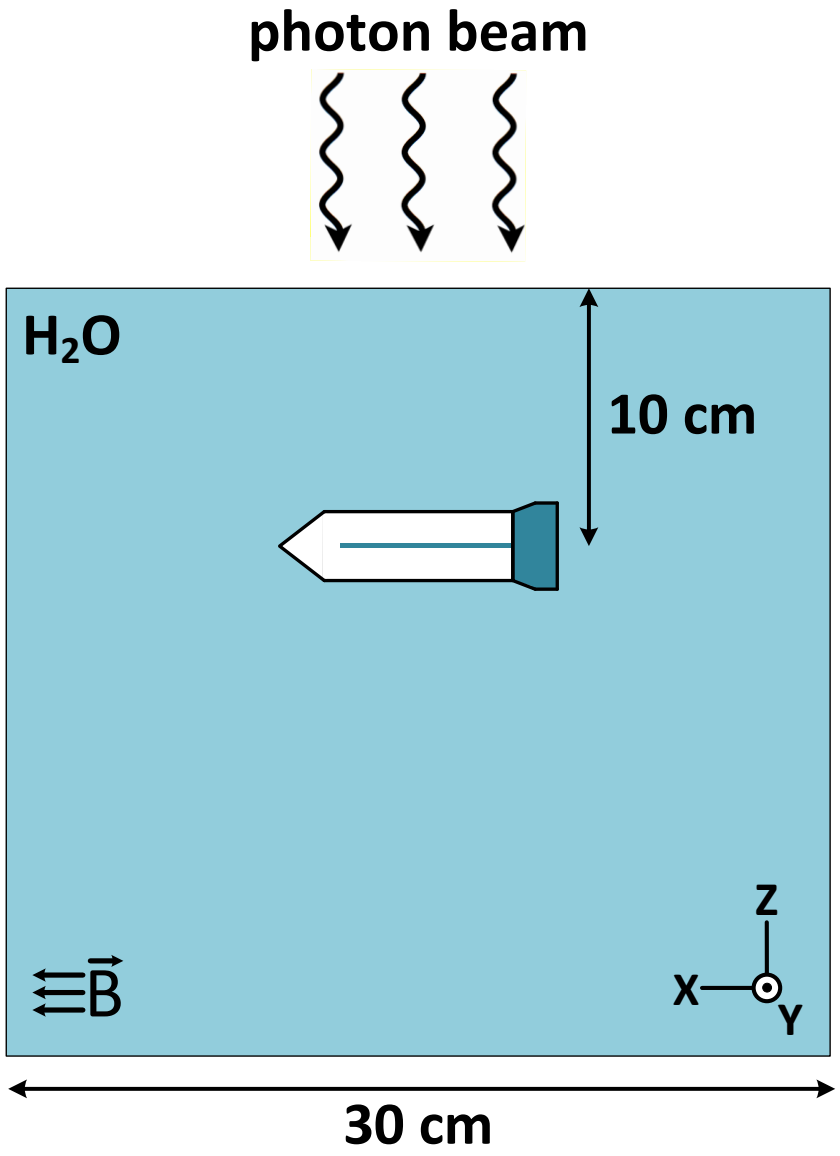
- **Water dose is scored in a water cylinder**



Calculating k_Q^{mag}

$$k_Q^{mag} = \frac{\left(\frac{D_w}{D_{cha}}\right)_Q^B}{\left(\frac{D_w}{D_{cha}}\right)_{^{60}Co}^{B=0T}}$$

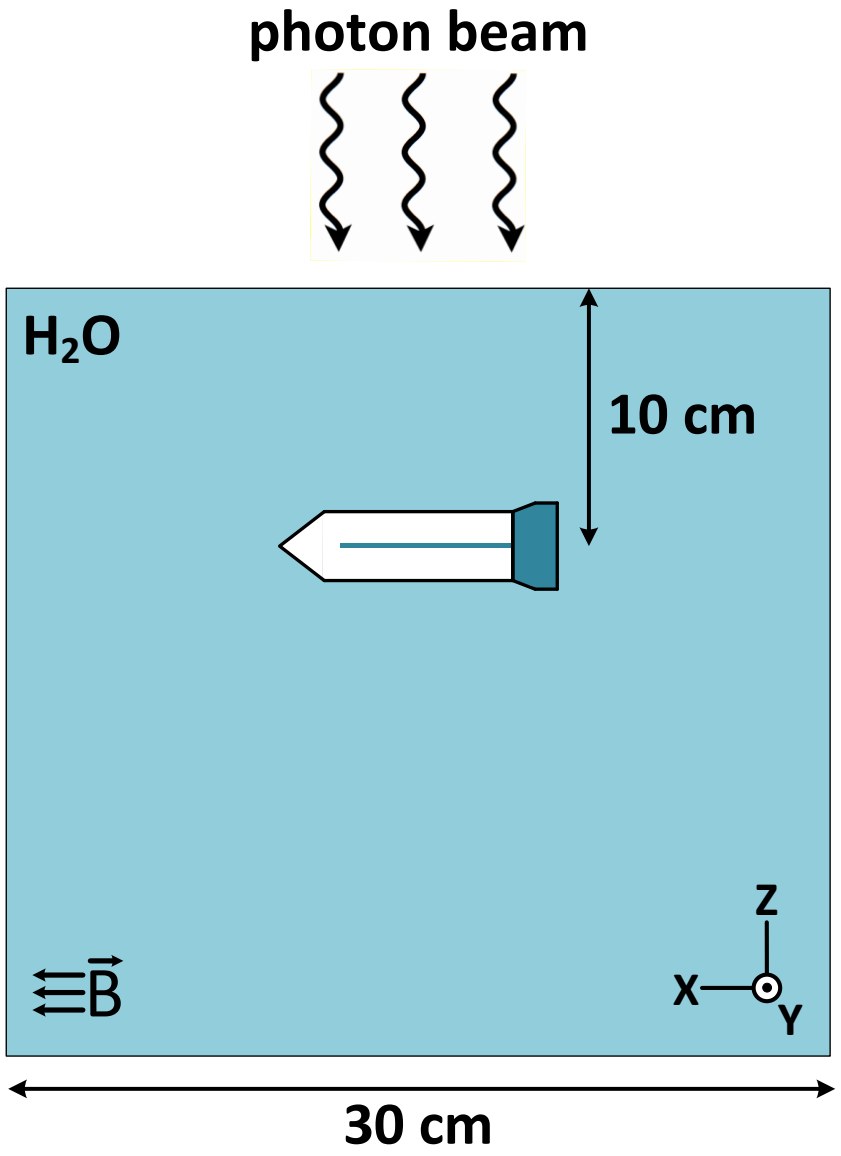
- Water dose is scored in a water cylinder
- **^{60}Co at 0.35 T**



Calculating k_Q^{mag}

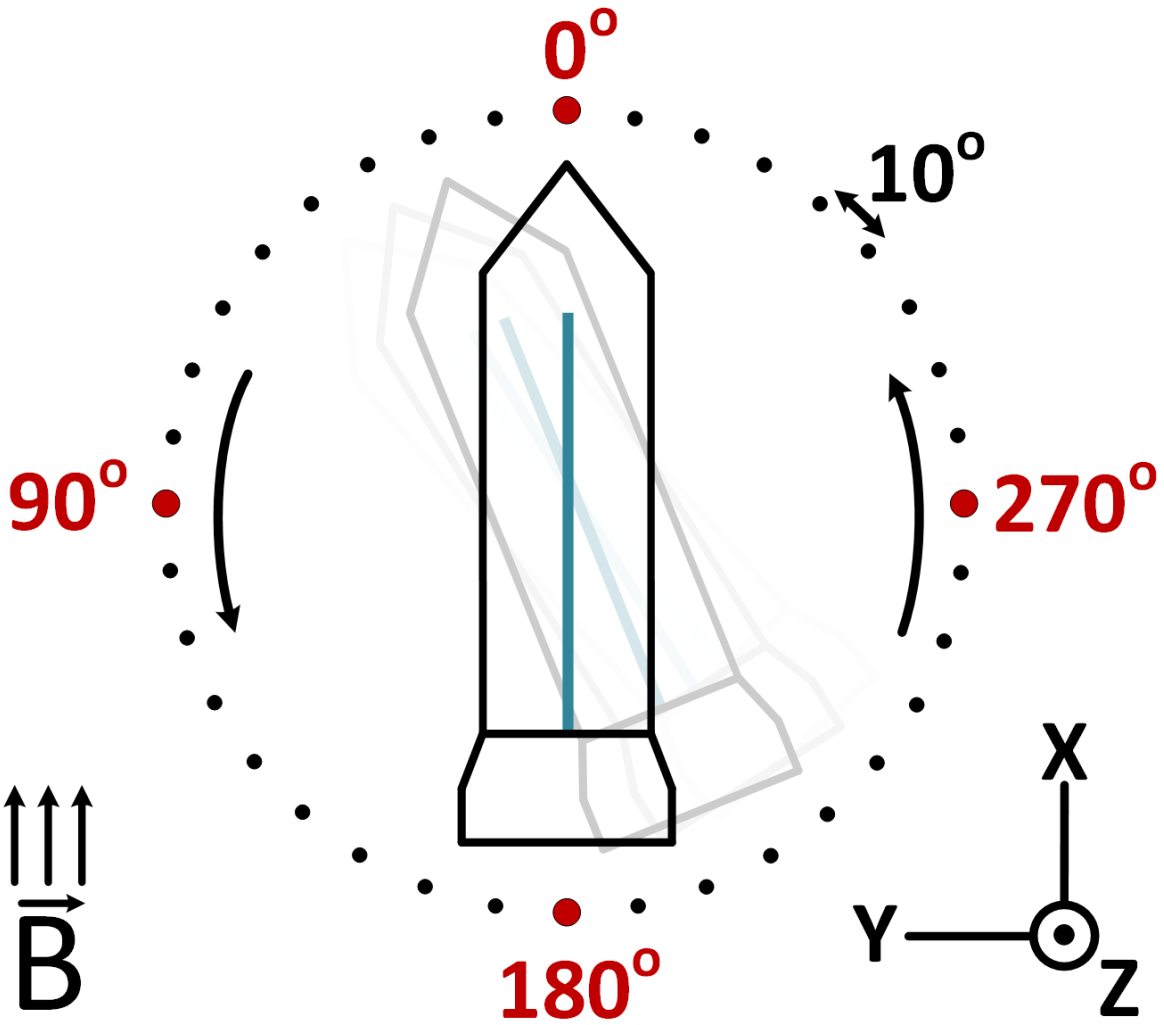
$$k_Q^{mag} = \frac{\left(\frac{D_w}{D_{cha}}\right)_Q^B}{\left(\frac{D_w}{D_{cha}}\right)_{^{60}Co}^{B=0T}}$$

- Water dose is scored in a water cylinder
- ^{60}Co at 0.35 T
- **Results for PTW 31010**



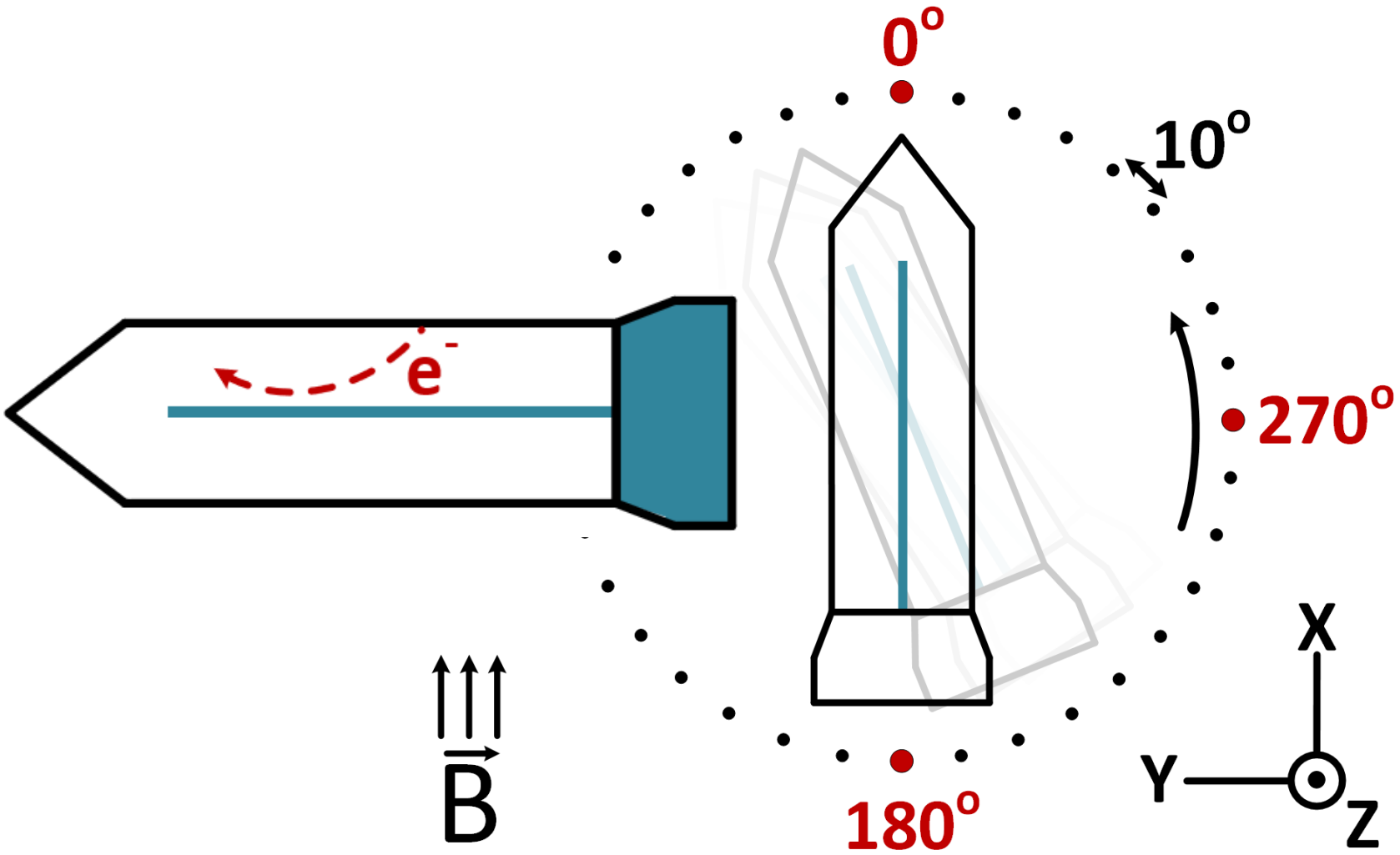
Rotating chamber

photon beam's eye view



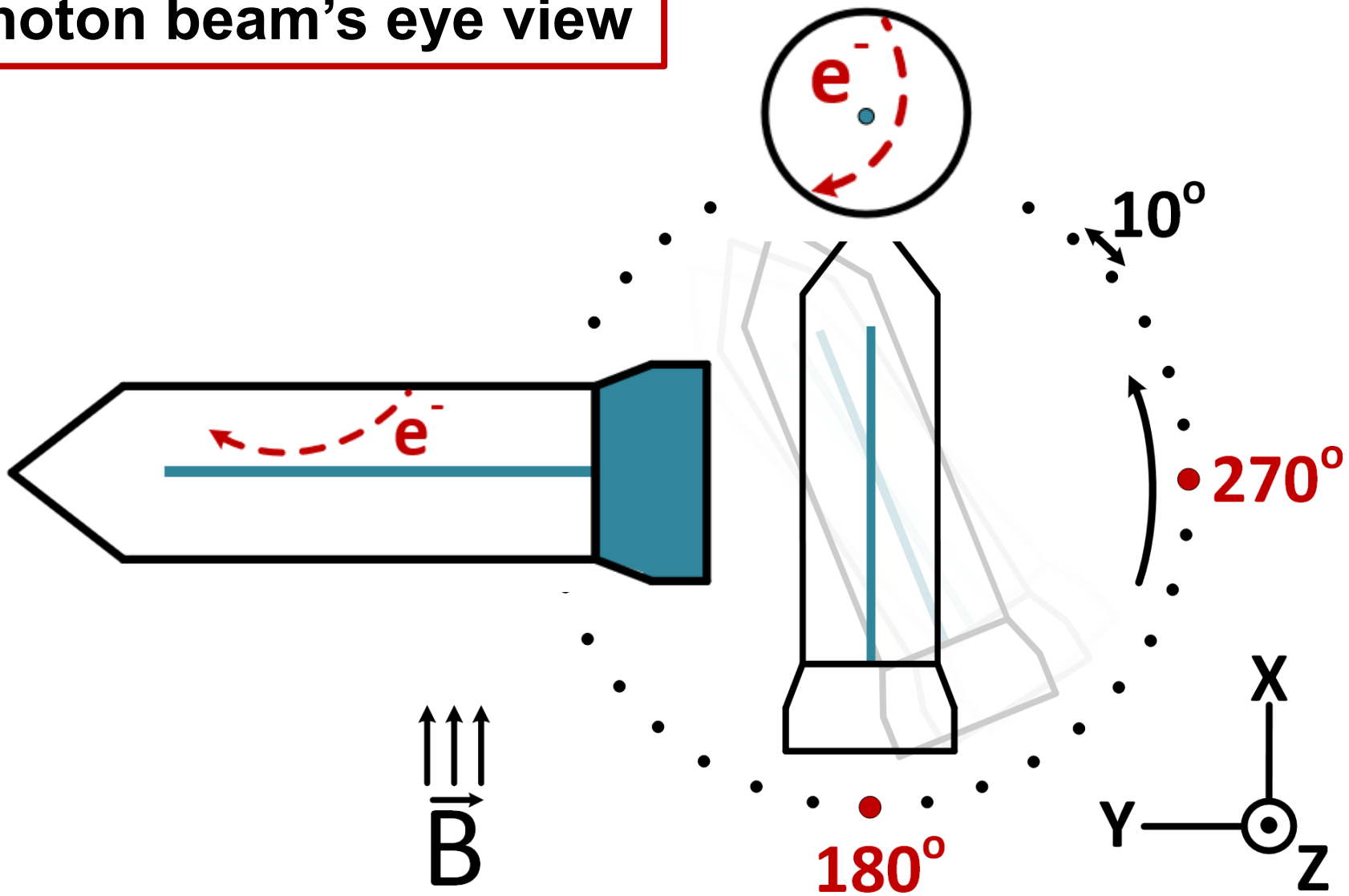
Rotating chamber

photon beam's eye view

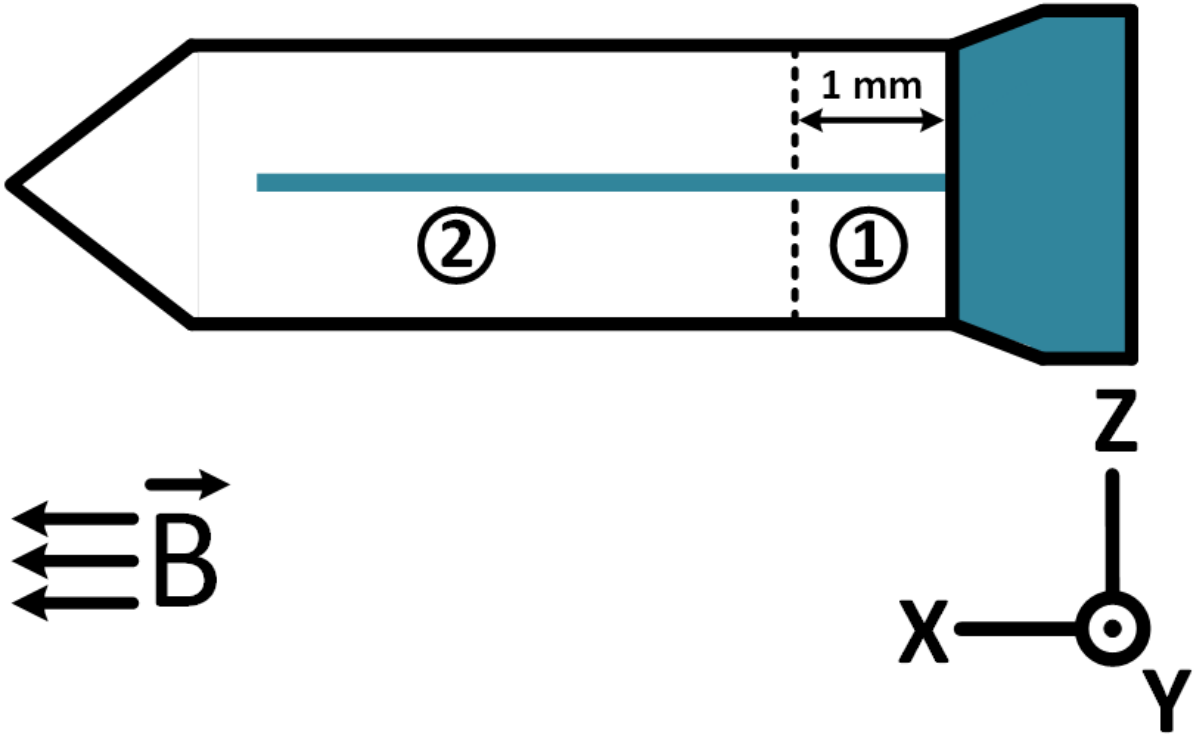


Rotating chamber

photon beam's eye view

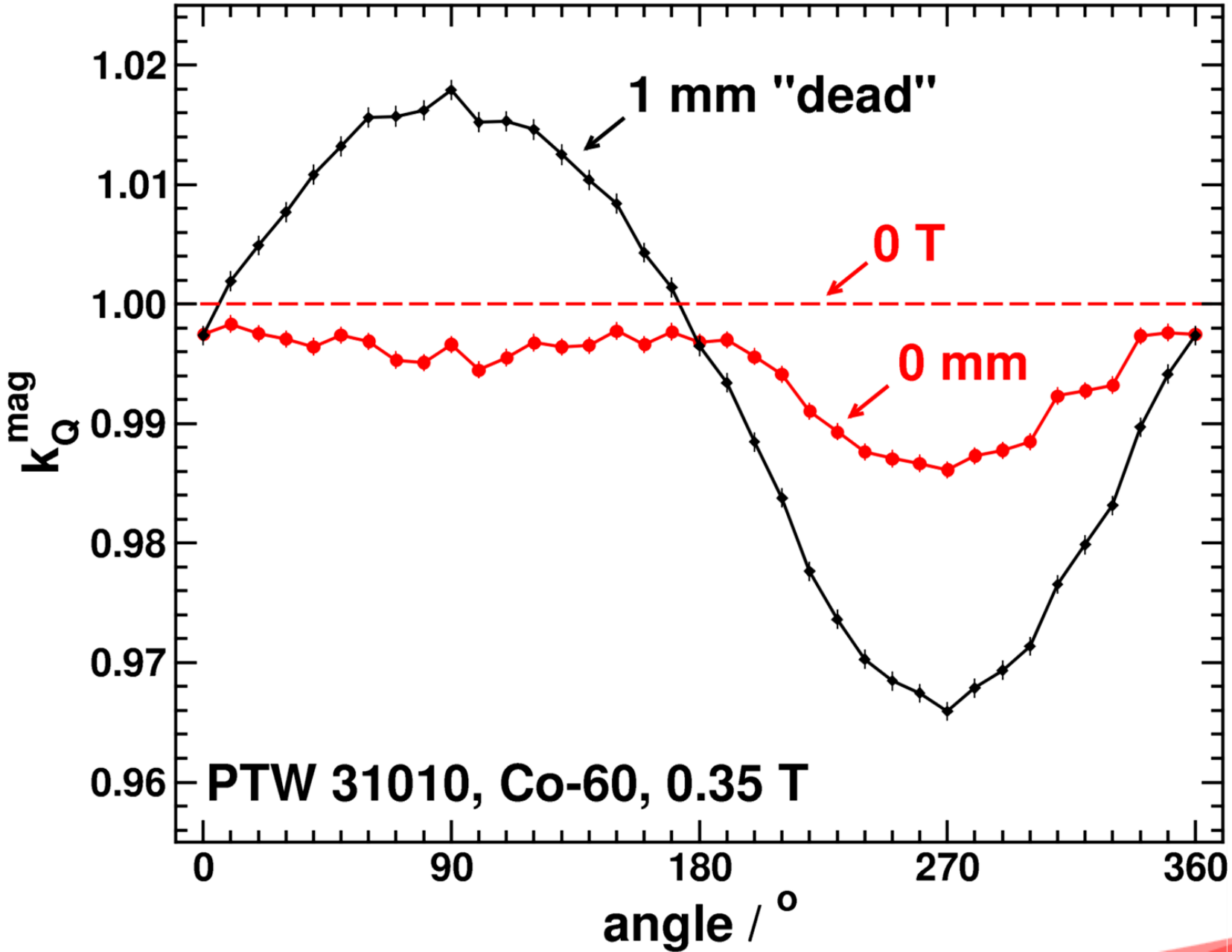


k_Q^{mag} - sensitive volume

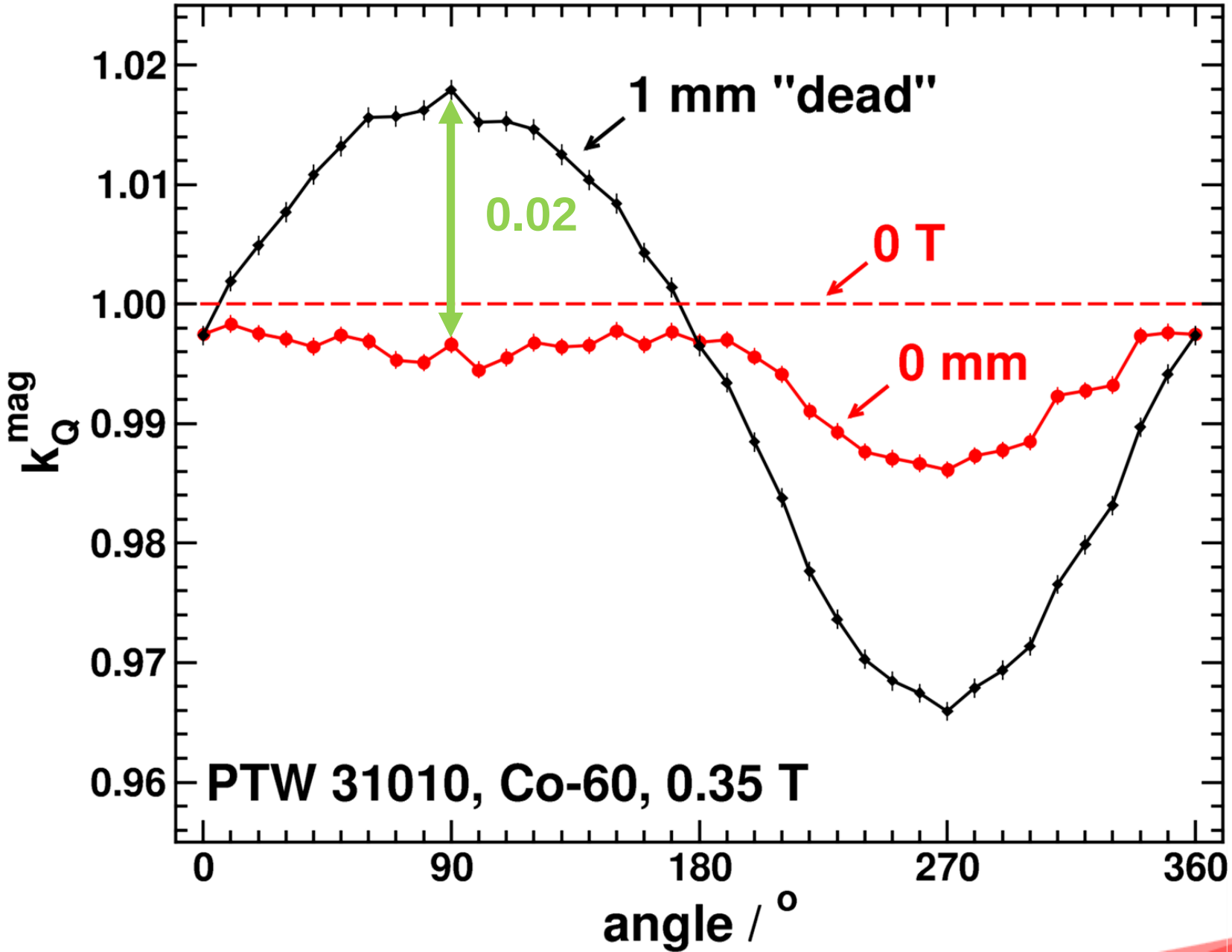


- **Calculate k_Q^{mag} as a function of angle with either 0 mm or 1 mm “dead” region**

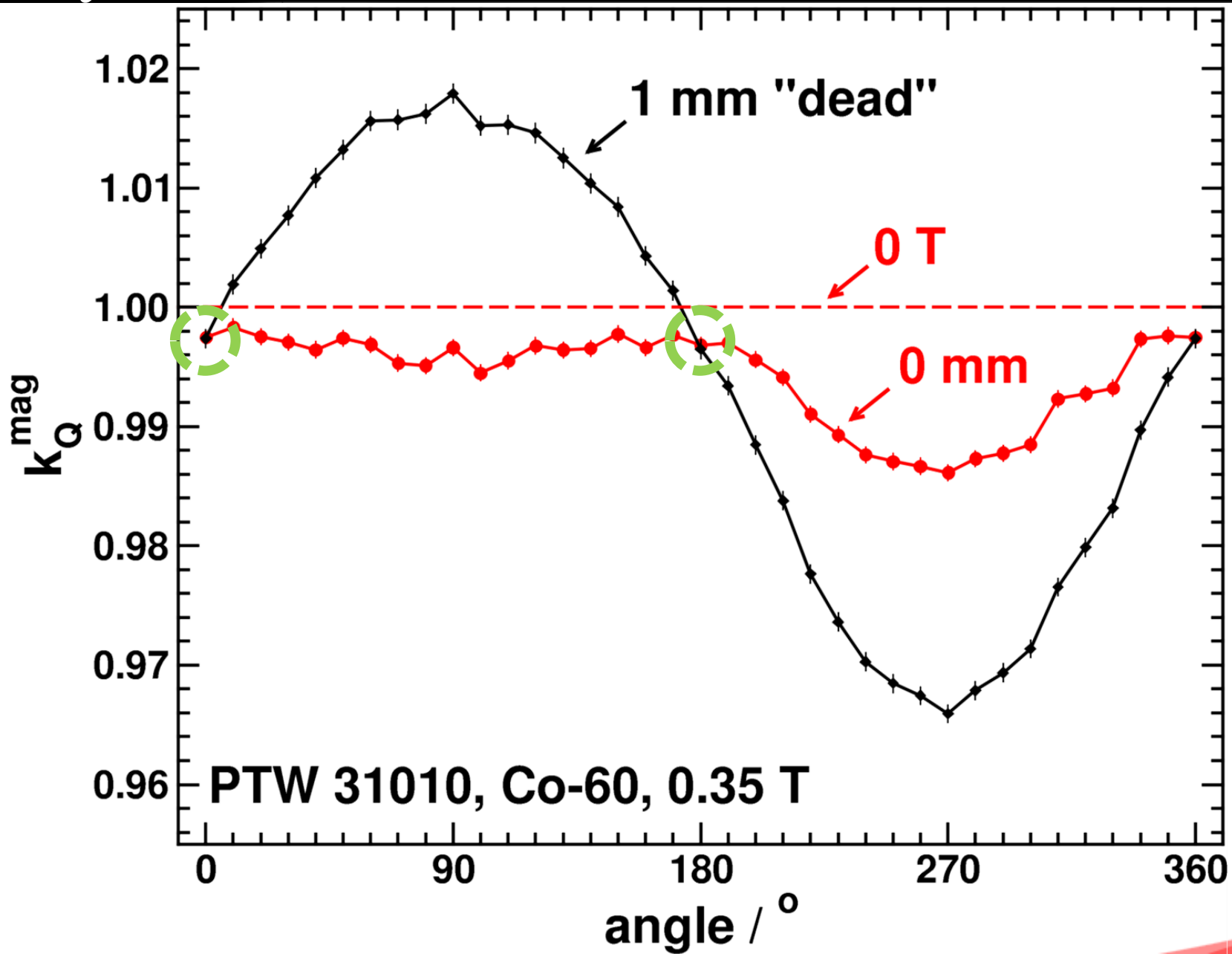
k_Q^{mag} - results



k_Q^{mag} - results



k_Q^{mag} - results



Conclusions

- **Sensitive volume important for magnetic fields**

Conclusions

- Sensitive volume important for magnetic fields
- **Optimal orientation (parallel to magnetic field):**
  - **Magnetic field effect is reduced**
  - **Sensitive volume not as important**

Conclusions

- Sensitive volume important for magnetic fields
- Optimal orientation (parallel to magnetic field):
  - Magnetic field effect is reduced
  - Sensitive volume not as important
- **Future work:**
  - **Comparison to other MC codes**
  - **Experimental results in the optimal orientation**

Conclusions

- Sensitive volume important for magnetic fields
- Optimal orientation (parallel to magnetic field):
  - Magnetic field effect is reduced
  - Sensitive volume not as important
- Future work:
  - Comparison to other MC codes
  - Experimental results in the optimal orientation
- **Code availability:**
  - **Available as a branch of the EGSnrc github code**
  - **At the CLRP website:**

    http://physics.carleton.ca/clrp/EMFmacros

Acknowledgements

- This work is supported by the Canada Research Chair program, Canada Foundation for Innovation, NSERC, OGS, and a Queen Elizabeth II GSST scholarship.

Thank you !

Ottawa Medical Physics Institute

Carleton UNIVERSITY