Detector Characteristics: Fluence Perturbation Effects and Volume Averaging

Yunuen Cervantes Espinosa, PhD
Postdoctoral fellow
Université Laval, Quebec, Canada

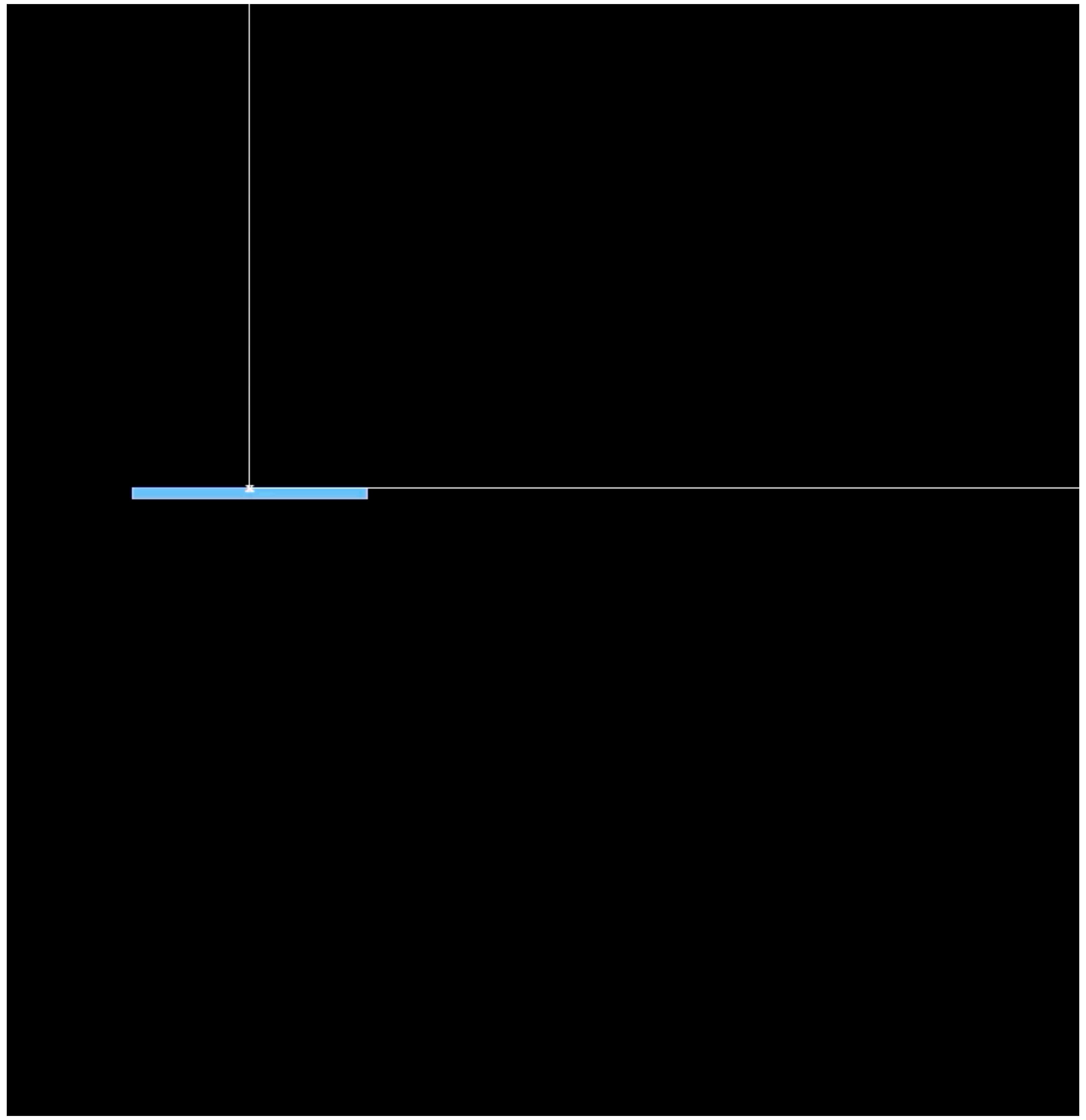
Effect of the magnetic field

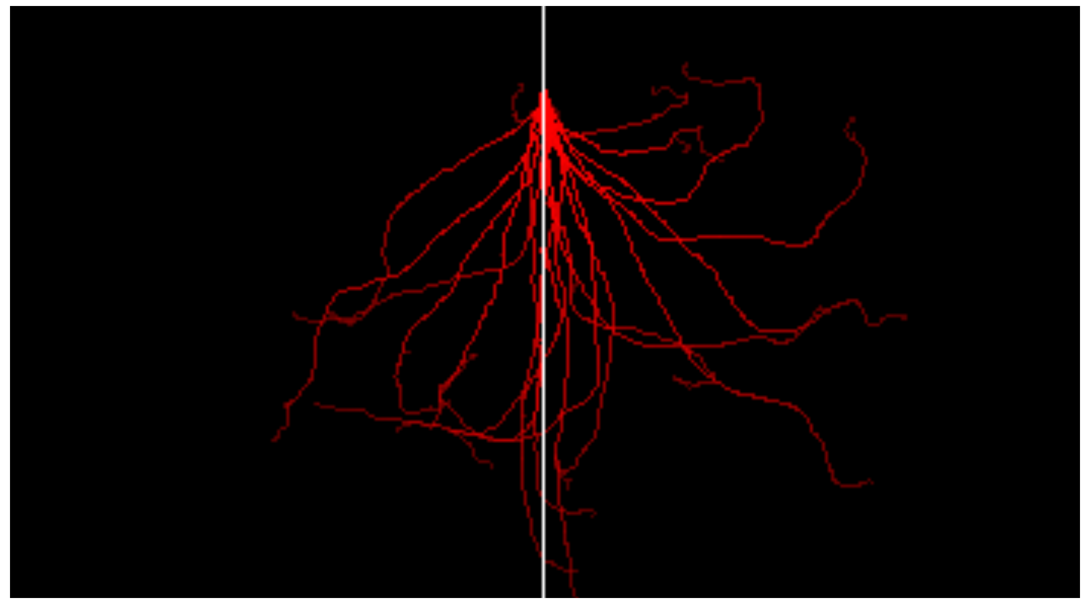
- The B-field influences the electron motion via the Lorentz force:

$$\overrightarrow{F_L} = -e \cdot \vec{v} \times \overrightarrow{B}$$

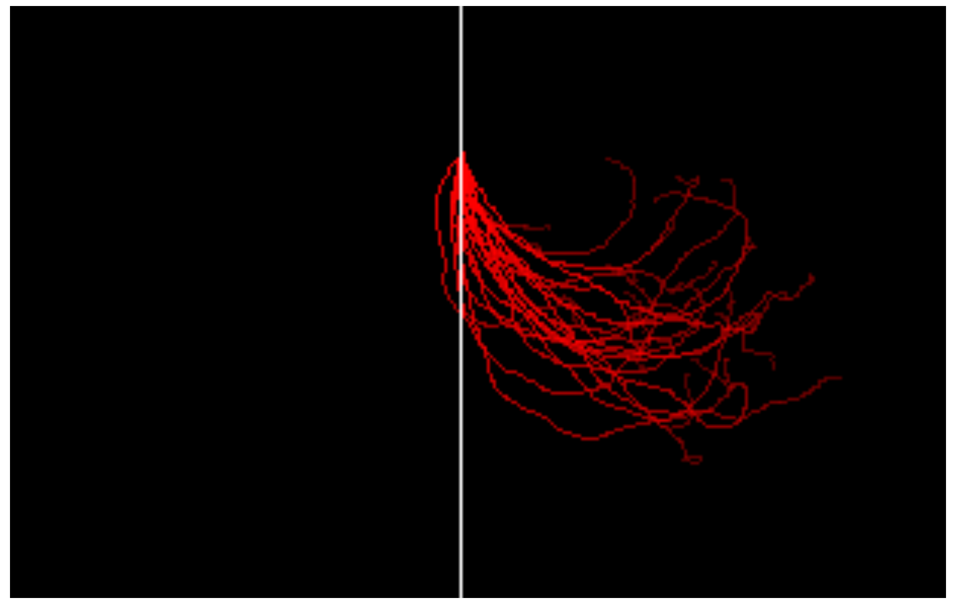
- The electron trajectory depends on:
  - Medium properties.
  - Strength and direction of the B-field.

- Modification of radiation field.
- Modification of detector signal.

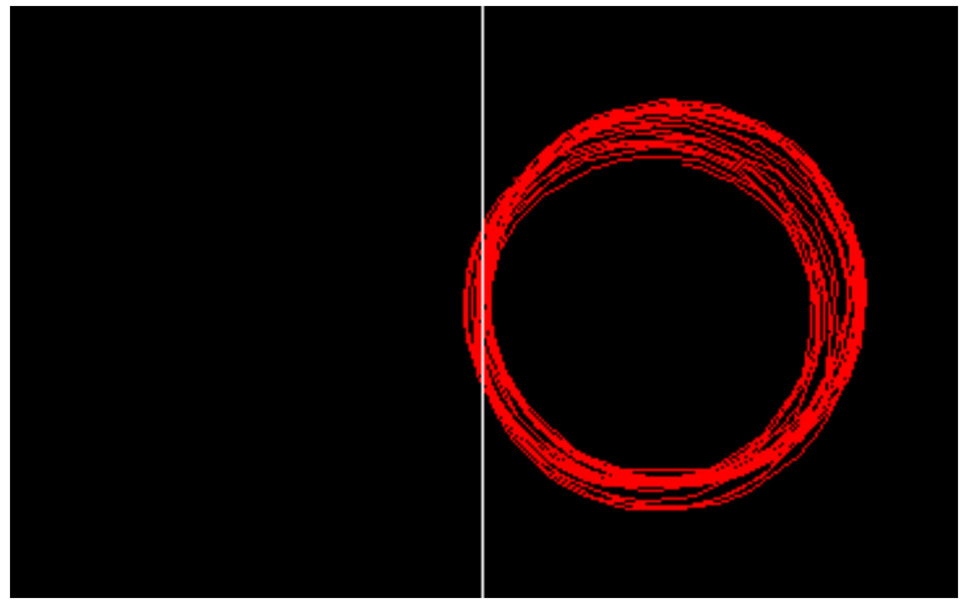




Water, 0 T



Water, 1.5 T

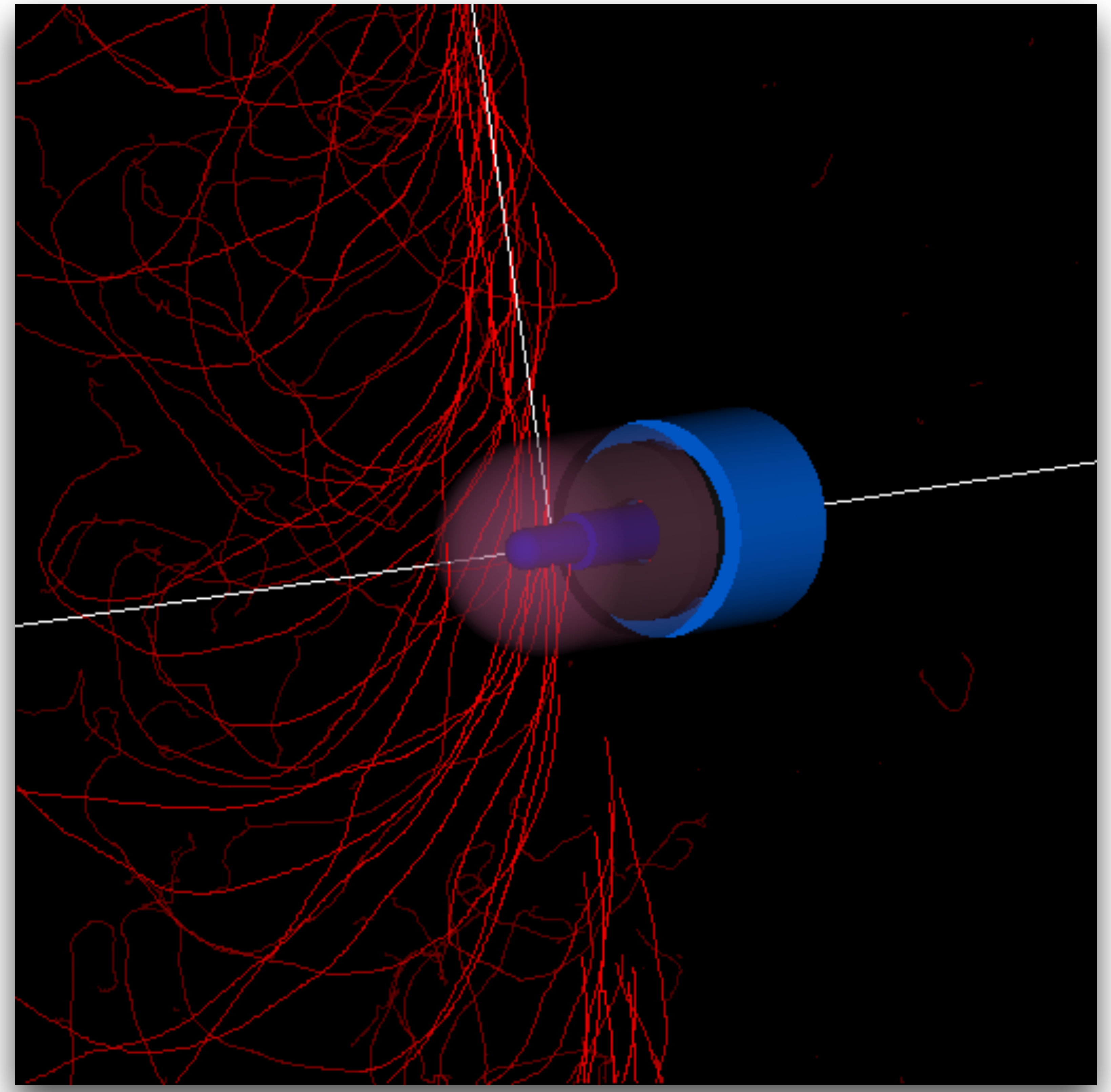


Air, 1.5 T

Electron fluence perturbation in MRgRT beams

The presence of any radiation detector perturbs the particle fluence at the point of measurement. Depending on:

- Detector geometry and composition.
- Irradiation conditions such as beam energy, field size and magnetic field.



Physics in Medicine & Biology

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PAPER

Monte Carlo calculation of detector perturbation and quality correction factors in a 1.5 T magnetic resonance guided radiation therapy small photon beams

Yunuen Cervantes[1,2,*], Jasmine Duchaine[1,2], Ilias Billas[3,4], Simon Duane[3] and Hugo Bouchard[1,2,5]

- To provide physical insights on the effects of magnetic fields on detector response.
- To calculate detector perturbation factors in MRgRT beams of multiple field sizes.

Physics in Medicine & Biology

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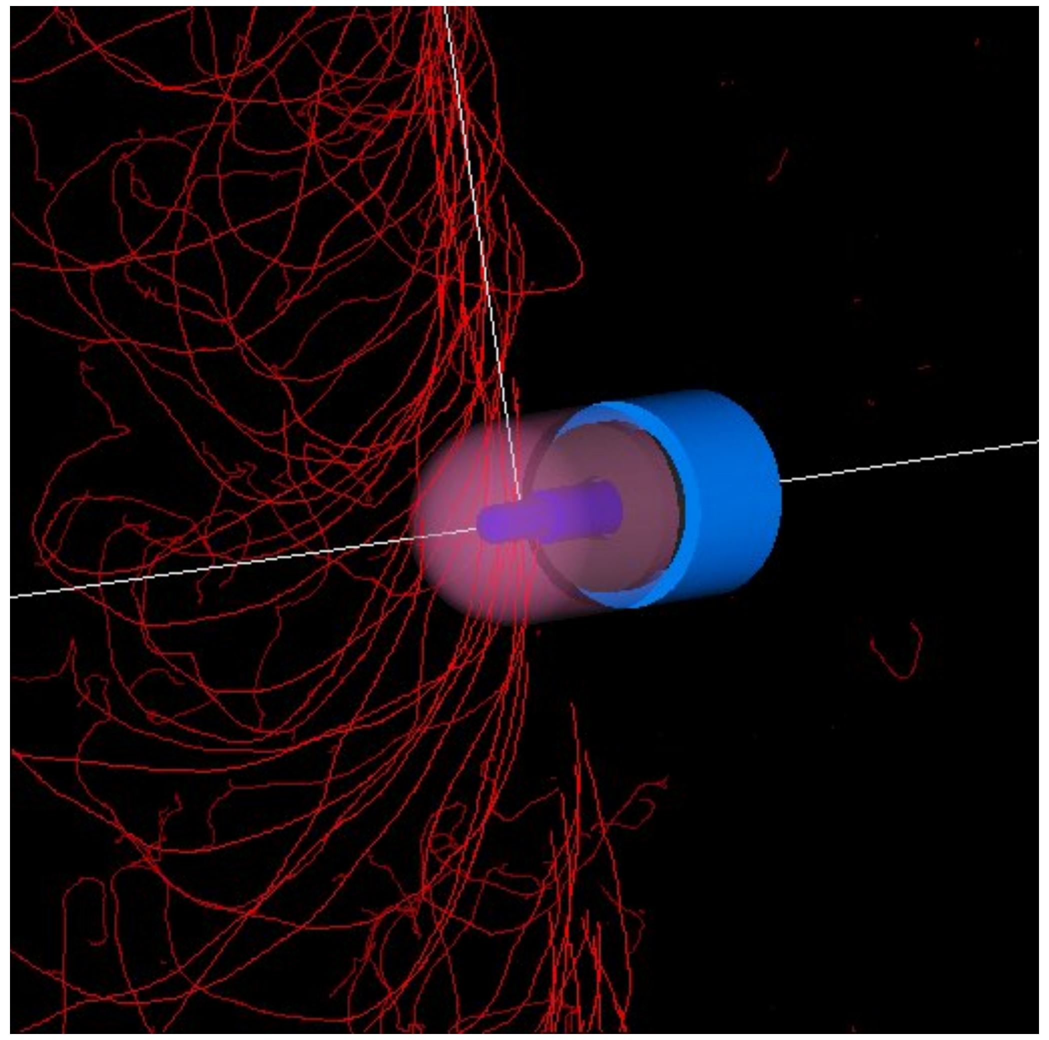
PAPER

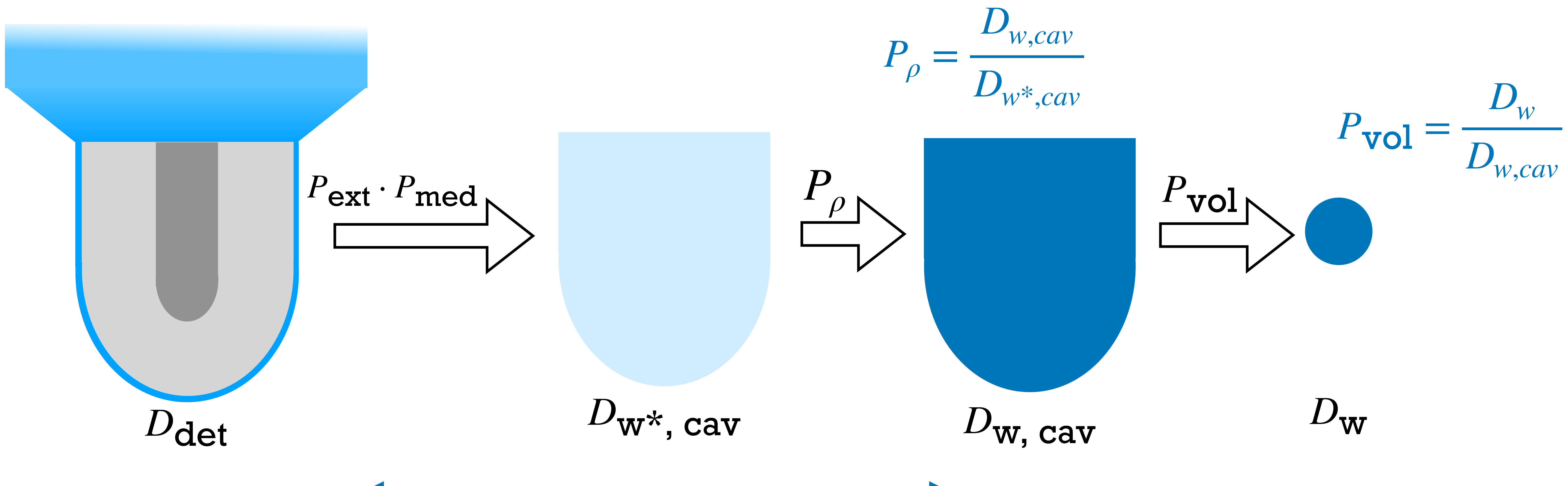
Monte Carlo investigation of electron fluence perturbation in MRI-guided radiotherapy beams using six commercial radiation detectors

Yunuen Cervantes[1,2,*], Simon Duane[3] and Hugo Bouchard[1,2,4]

- To evaluate the magnetic field effect on the electron fluence spectra in several types of detectors.

Determination of perturbation factors



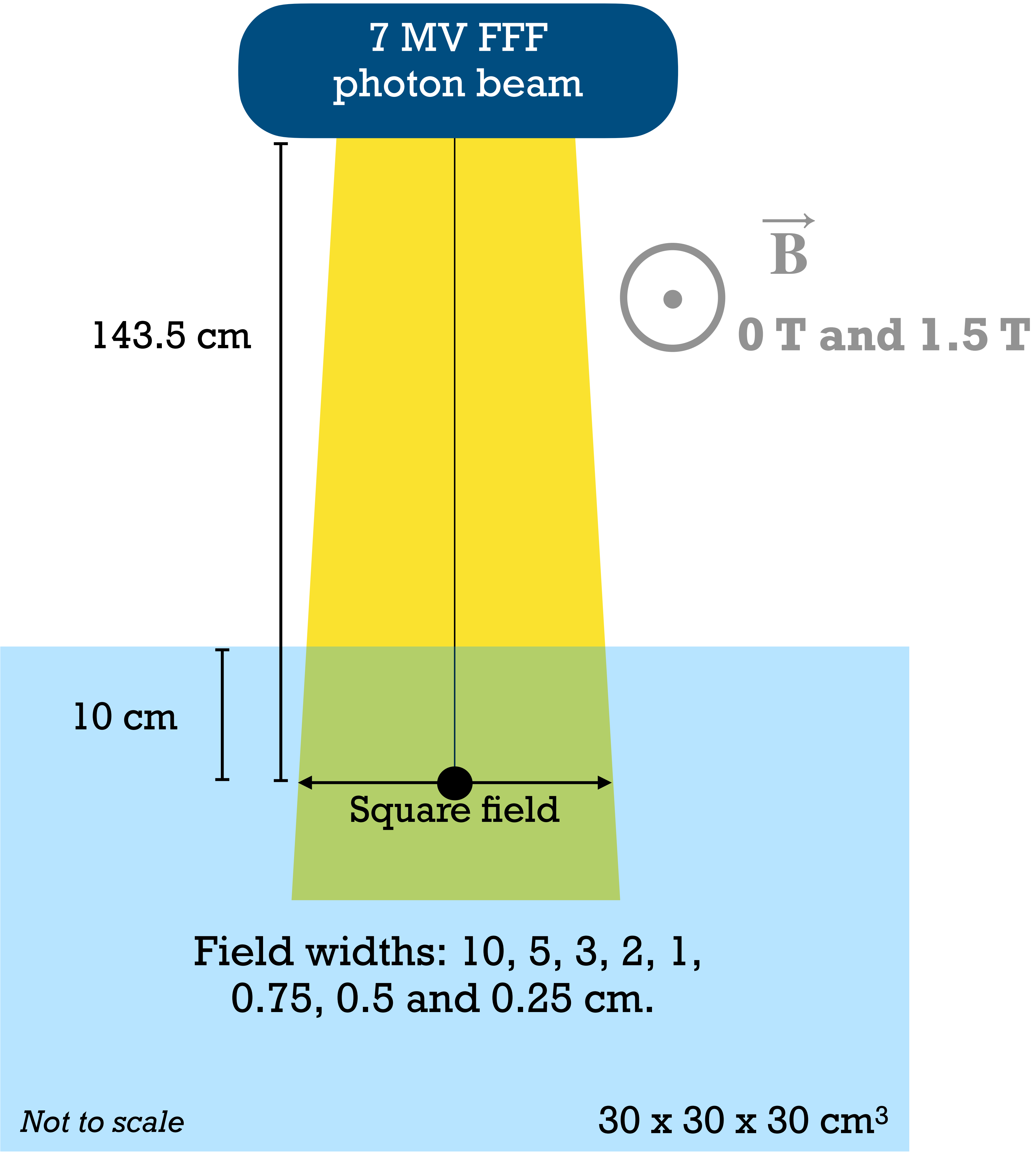


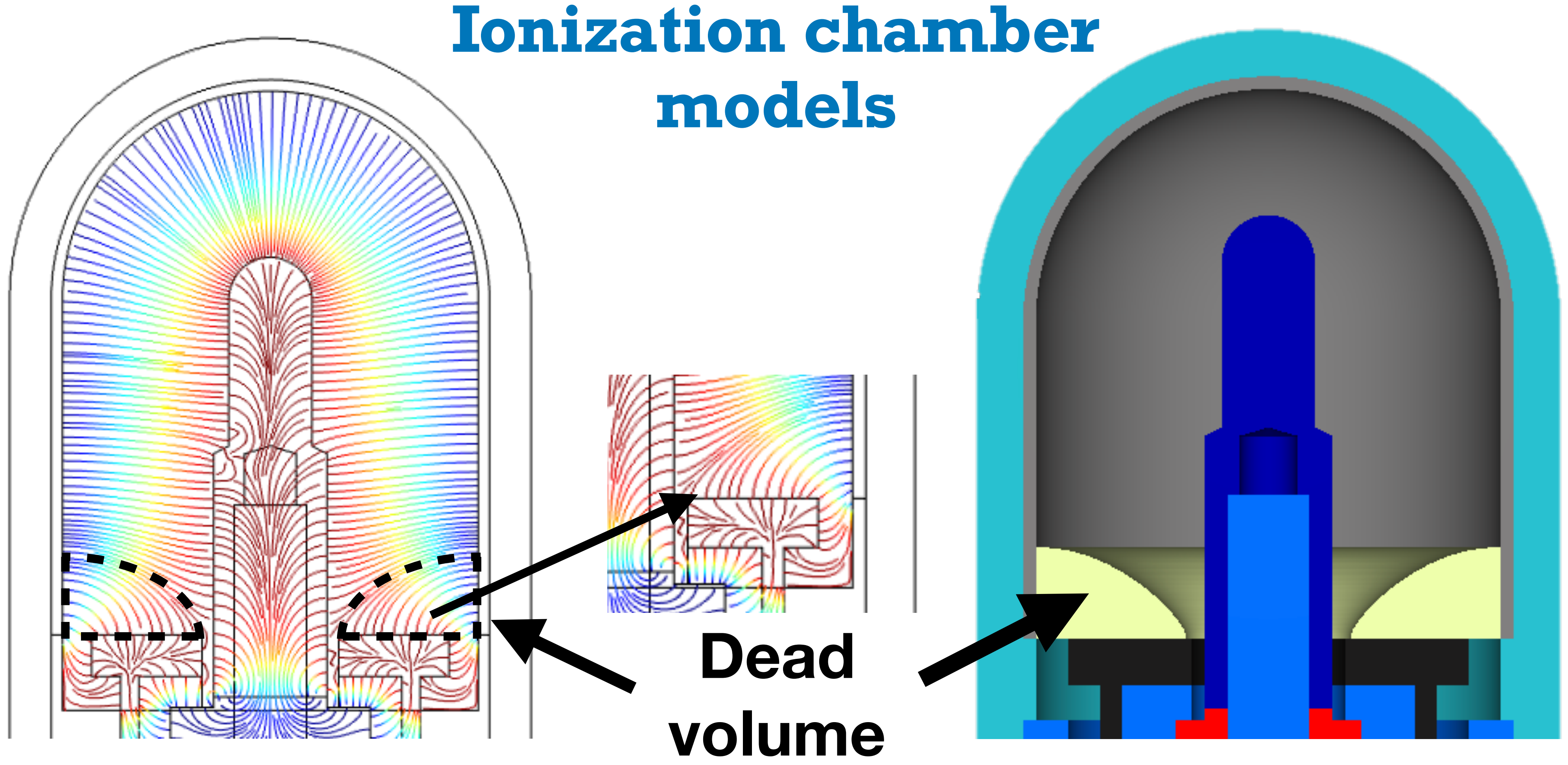
$$P_{\text{MC}} = P_{\text{ext}} P_{\text{med}} P_{\rho} = \frac{D_{\text{w,cav}}}{D_{\text{det}}}$$

- P_{MC}: Overall perturbation factor
- P_{ρ}: Density perturbation factor
- P_{vol}: Volume averagingfactor

Bouchard et al (2015) formalism to determine the perturbation factors: $P_i = \frac{D_{i+1}}{D_i} \frac{\left(\frac{\overline{Z}}{A}\right)_i}{\left(\frac{\overline{Z}}{A}\right)_{i+1}}$

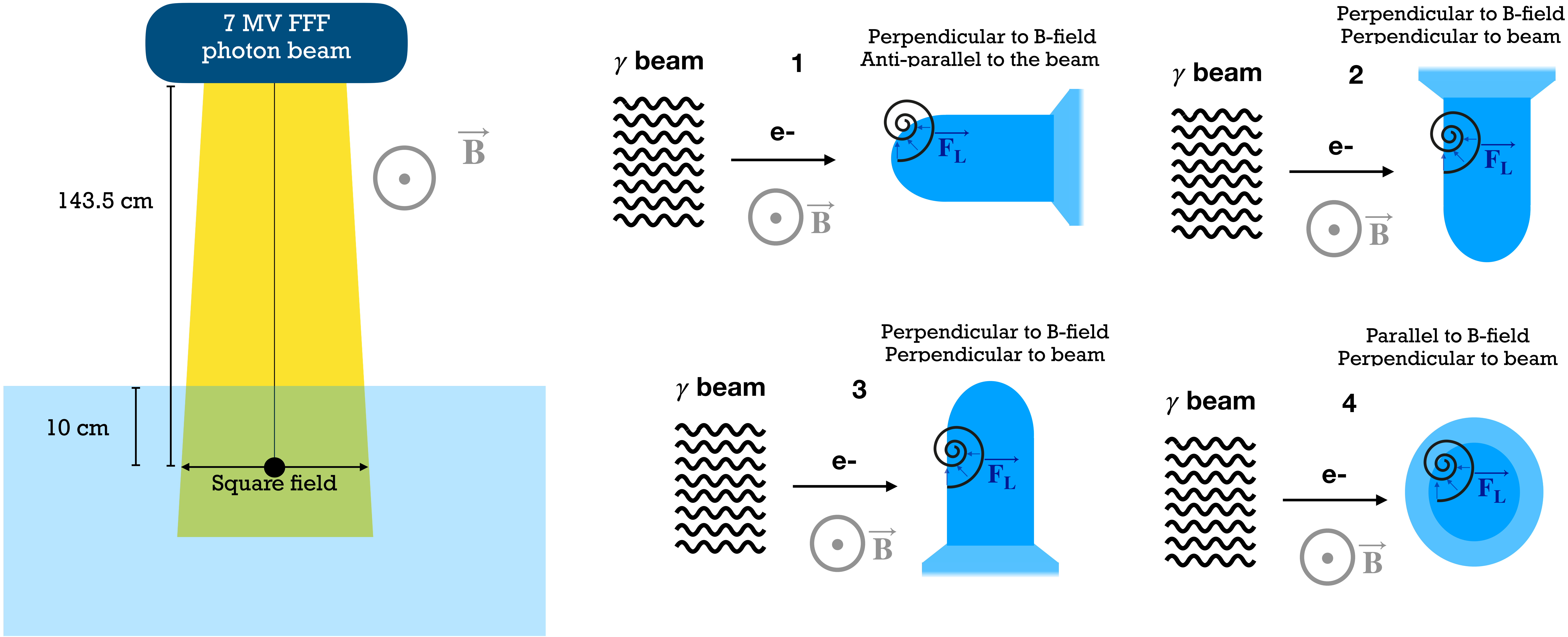
Monte Carlo simulations





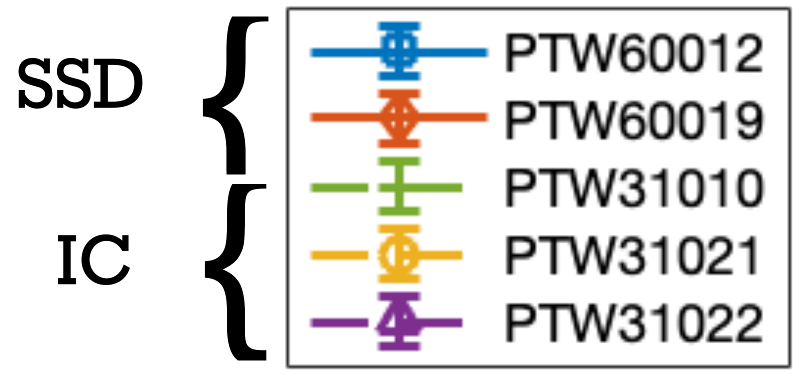
Detector	Solid State Detectors (SSD)		Ionization Chambers (IC)		
	PTW60012	PTW60019	PTW31022	PTW31021	PTW31010
Density [g cm^{-3}]	2.33	3.53	1.205 x 10^{-3}	1.205E^{-3}	1.205E^{-3}
Sen. vol. diameter [mm]	1	2.2	2.9	4.8	5.5
Sen. vol. length [mm]	0.030	0.001	2.9	4.8	6.5

Detector orientation

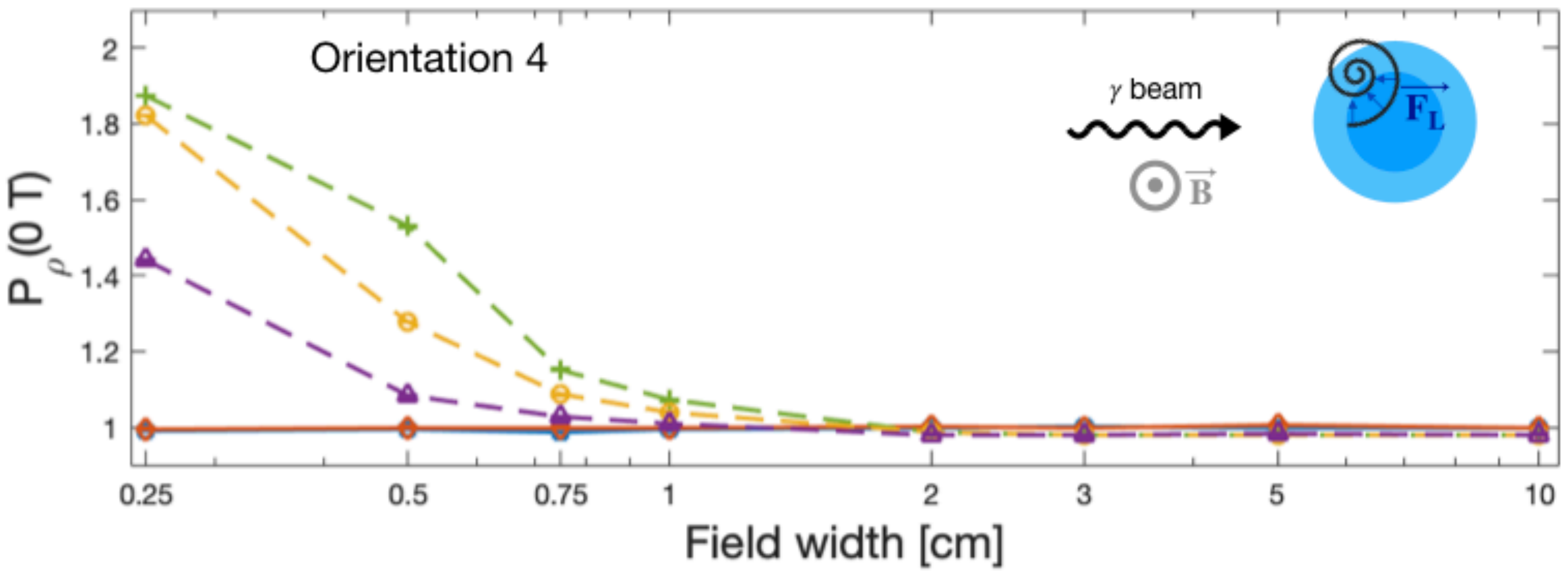


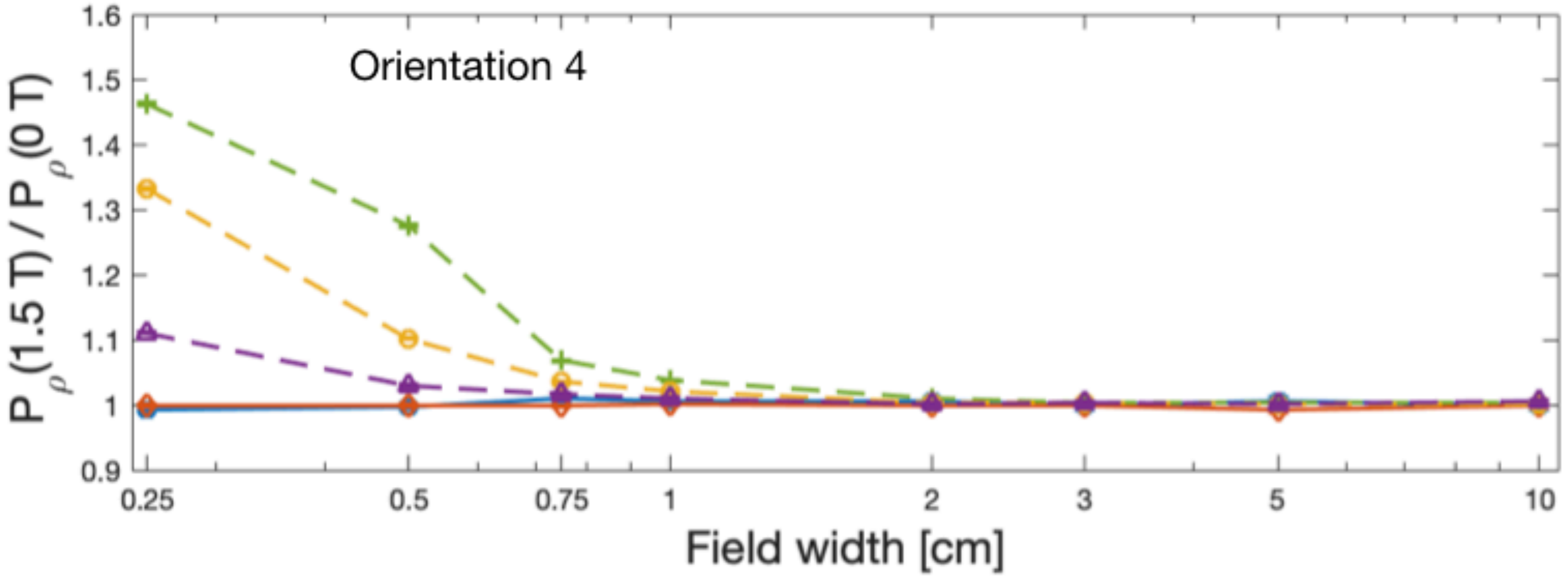
Results

Density perturbation factor: P_ρ



Effect of the magnetic field



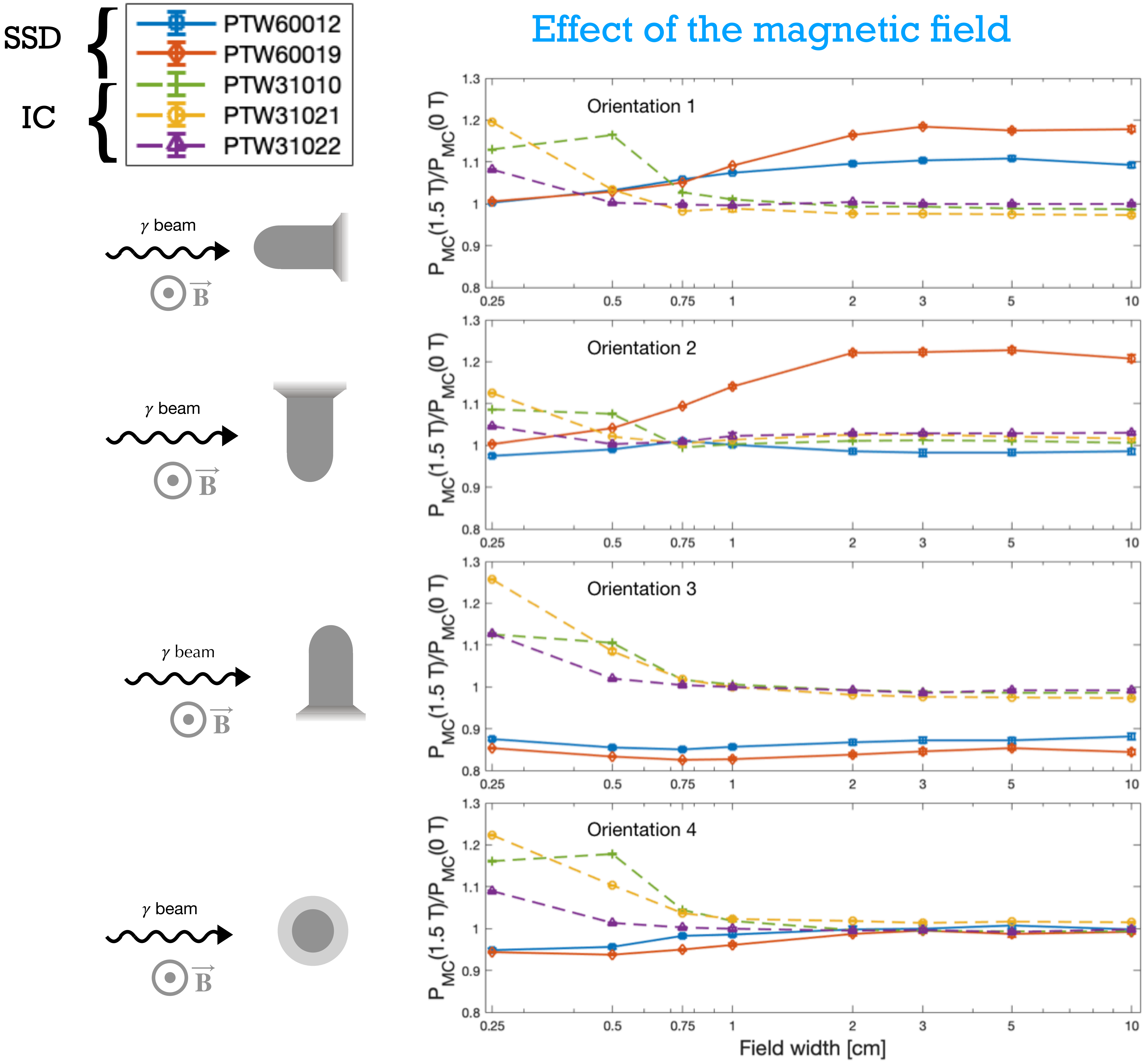


- For the chambers, P_ρ is one of the **dominating perturbation factors** in small fields with and without B-fields.

- For the SSD, the B-field effect on P_ρ is 1% or less.

Overall perturbation factor: $P_{MC} = P_{ext}P_{med}P_{\rho}$

Effect of the magnetic field



SSD are affected by the B-field at large field sizes

IC are affected by the B-field at small field sizes

microDiamond is affected by the B-field at large field sizes

IC are affected by the B-field at small field sizes

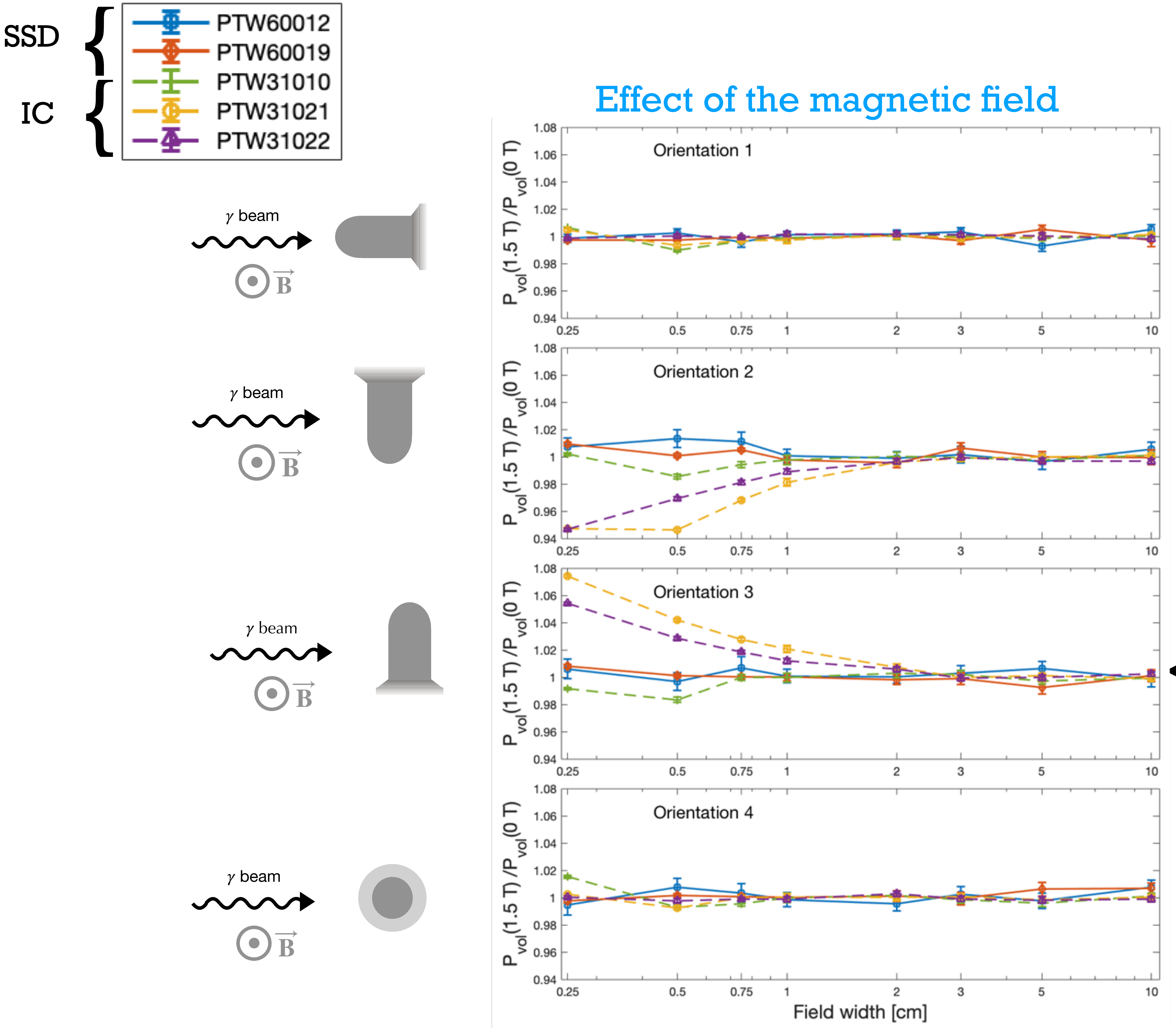
IC are affected by the B-field at small field sizes

SSD: Constant B-field effect over all field sizes

IC are affected by the B-field at small field sizes

B-field effect is mostly constant and slightly decreases for the smaller fields

Volume averaging factor: P_{vol}



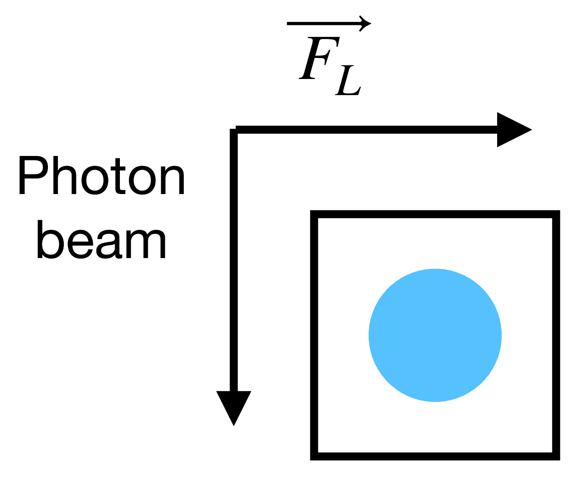
- For SSD and chamber (PTW31010), the B-field effect on P_{vol} is of 1% or less from unity in all orientations an independent of field size.

For spherical IC, the B-field effect decreases with decreasing field size.

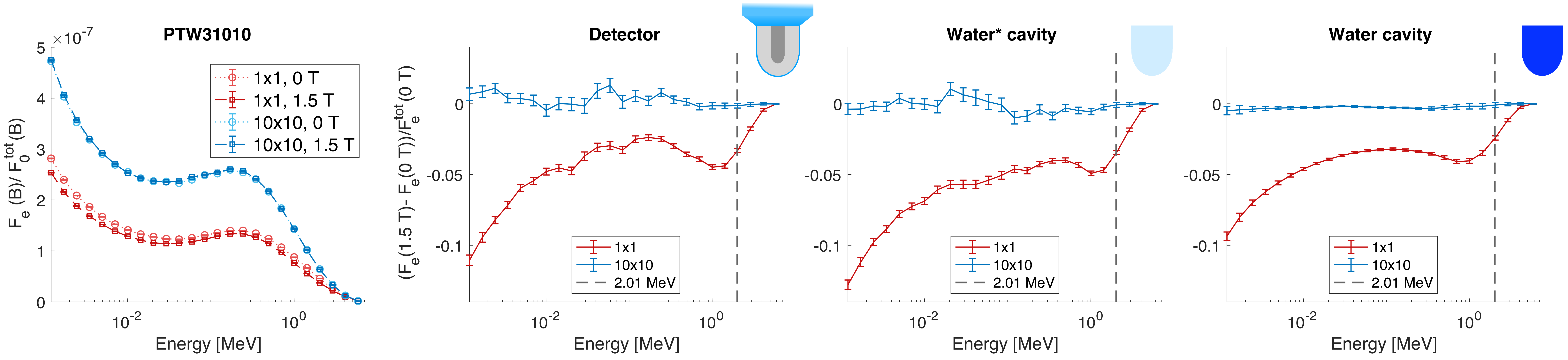
For spherical IC, the B-field effect increases with decreasing field size.

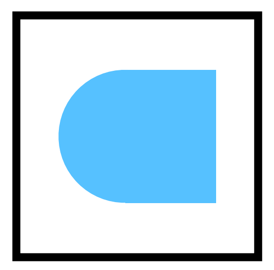
Electron fluence spectra in IC

Magnetic field effect : $\Delta_B = \dfrac{F_e(1.5\ T) - F_e(0\ T)}{F_e^{tot}(0\ T)}$



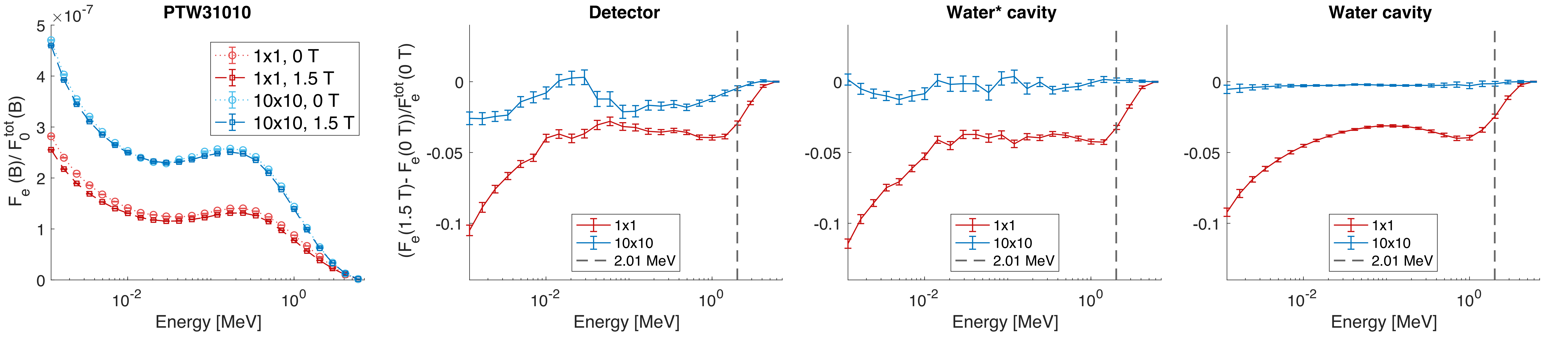
Parallel orientation





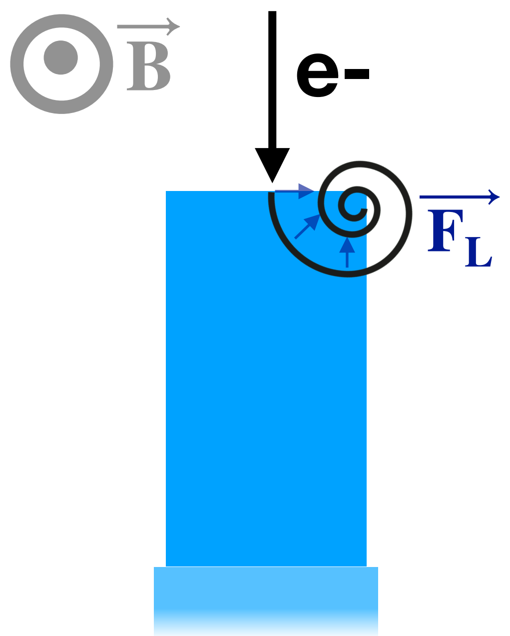
Perpendicular orientation

$\overrightarrow{F}_L$ towards stem

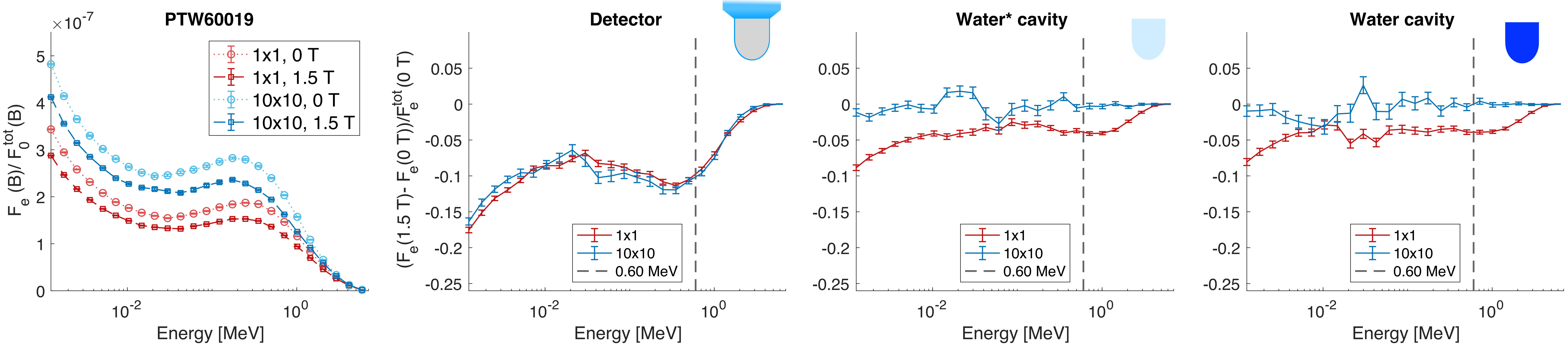


*Vertical line: energy at which the gyration radius equals the cavity diameter

Electron fluence spectra in SSD



Magnetic field effect : $\Delta_B = \dfrac{F_e(1.5\ T) - F_e(0\ T)}{F_e^{tot}(0\ T)}$



*Vertical line: energy at which the gyration radius equals the cavity diameter

Conclusions

- This study quantifies the B-field effect on detector dose response in small fields by isolating different perturbation factors.

- Solid-state detectors dose response is strongly affected by the magnetic field in all orientations, especially in orientation 1. The perturbation is mainly attributed to the **extracameral components**.

- For ionization chambers, the magnetic field predominantly affects the **density perturbation factor**.

- The B-field influence on Pvol is notable on spherical ionization chambers solely in orientations 2 and 3

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Corresponding email: yacee@ulaval.ca