A Monte Carlo Study of the Electron Clouds Produced by Polarized X-Rays in Xenon

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Abstract – **Information about the polarization of x-ray photons can be determined by probing the direction of emission of photoelectrons and the profile of the electron cloud produced in the detecting medium. In this work we present Monte Carlo results for the electron clouds produced in xenon by the absorption of x-rays, considering a simple non-relativistic dipole approach to the angular differential photoionization cross-sections.**

I. INTRODUCTION

The development of polarization sensitive x-ray detectors has been a subject of growing interest due to their importance in research fields such as x-ray astronomy and astrophysics [1], [2].

A possibility of measuring the x-ray photon polarization arises from the fact that the photoelectrons are emitted with anisotropic angular distributions which, in addition to a dependence on photon energy and photoionized atomic shell, will have a memory of the polarization direction [3], [4]. The profile of the electron cloud produced by the photoionization events can be traced with pixellated gas detectors for x-rays [5]-[7].

For the absorption of electron beams, we have investigated earlier the profile of the electron cloud produced in Xe gas, using a detailed Monte Carlo simulation which follows the electrons individually along their successive free paths and elastic and inelastic collisions with the gas atoms until all electrons reach down to sub-ionization energies [8], [9], taking into account the variation of electron energy along the free paths and the anisotropy of the scattering.

For the absorption of unpolarized x-rays, we have used Monte Carlo simulation to investigate a variety of topics relevant for noble gas x-ray detectors [10]-[12]. The calculations reproduce in detail the x-ray photoionization events and the cascade decay of the residual atomic ions, involving the emission of photoelectrons, Auger electrons and fluorescence x-rays, and, as described above, the calculations follow the slow-down process of all electrons in the gas.

Starting from these detailed Monte Carlo codes, we now include the absorption of polarized x-rays. In the present work, the simulation will register the growth and drift of the electron cloud produced in Xe by the absorption of polarized and unpolarized x-ray photons.

II. RESULTS

Photoelectrons resulting from the interaction with x-ray photons are preferentially emitted at 90 degrees to the x-ray propagation direction. In addition, photoelectric effect is very sensitive to polarization: when x-rays are linearly polarized, the angular distribution becomes preferentially aligned with the polarization vector, so that detection of the photoelectrons and profile characteristics of the secondary electron cloud produced in the medium can be used to probe the polarization of the absorbed x-rays. In a simple non-relativistic dipole approximation, the photoelectron emission follows the angular differential photoionization cross-sections described in eq. 1 and eq. 2 [3],[4] for un-polarized and linearly polarized photons respectively,

$$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 - \frac{1}{2}\beta\, P_2\left(\cos\underline{\theta}\right)\right] \qquad (1)$$

$$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 + \beta\, P_2\left(\cos\theta\right)\right] \qquad (2)$$

where $\underline{\theta}$ and θ are the polar angles relative to the x-ray propagation and polarization directions, P_2 is the second order Legendre polynomial and β is the dipole parameter.

In Fig. 1 we show the electron cloud produced in xenon at 10 atmospheres by a beam of 50 keV electrons [8], obtained with a previous Monte Carlo code prepared for the direct absorbtion of high energy electrons in the gas.

The present code is prepared to deal with the absorption of un-polarized and linearly polarized x-rays, within the simplified approximations represented by eq. 1 and eq. 2.

In Fig. 2 and Fig. 3 we show some representative results, describing the clouds obtained when linearly polarized 25 keV and 50 keV photons are absorbed in xenon at 1 atmosphere. The alignment of the clouds profiles with the polarization direction is clear in both cases. We observe that the cloud is larger for 25 keV than it is for 50 keV photons, because for 25 keV most photoelectrons are emitted from the L-shell (binding energy $E_{L1} = 5.4$ keV, ~21 keV photoelectrons), while in the case of 50 keV photons the K-shell becomes accessible to photoionization and most photoelectrons are then ejected from the K-shell ($E_K = 34.6$ keV, ~15 keV photoelectrons).

In the near future, the Monte Carlo code for the absorption of polarized x-rays will model relativistic effects and include first-order non-dipole corrections to the electric-dipole approximation, whose importance, even in the soft x-ray range, has been well established by recent theoretical and experimental studies [13], [14].

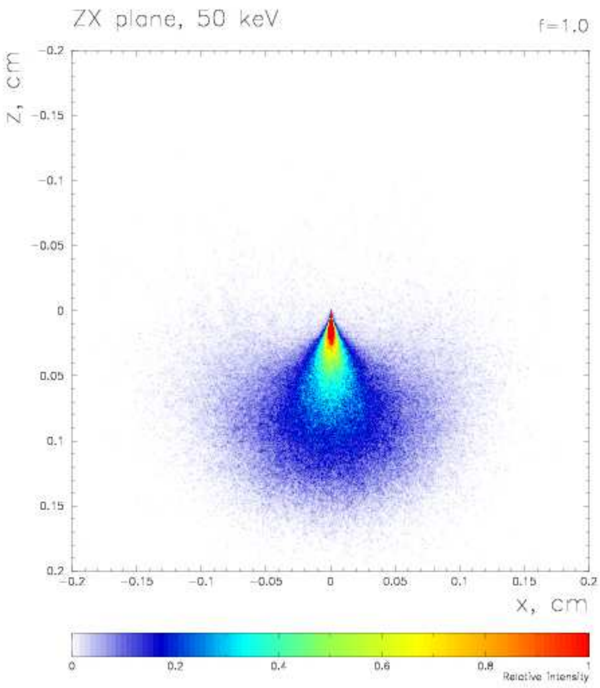

Fig. 1 - Electron cloud produced in xenon at 10 atmosphertes by a beam of 50 keV electrons.

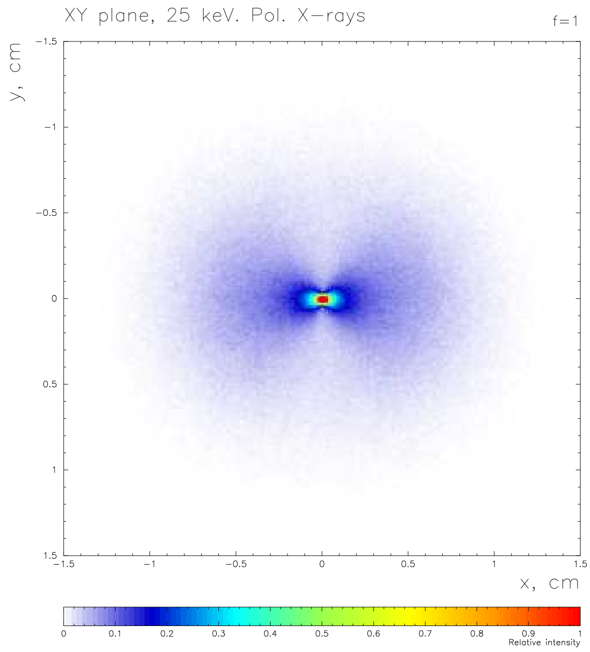

Fig. 2 - Electron cloud produced in xenon at 1 atmosphere by the absorption of 25 keV linearly polarized x-ray photons.

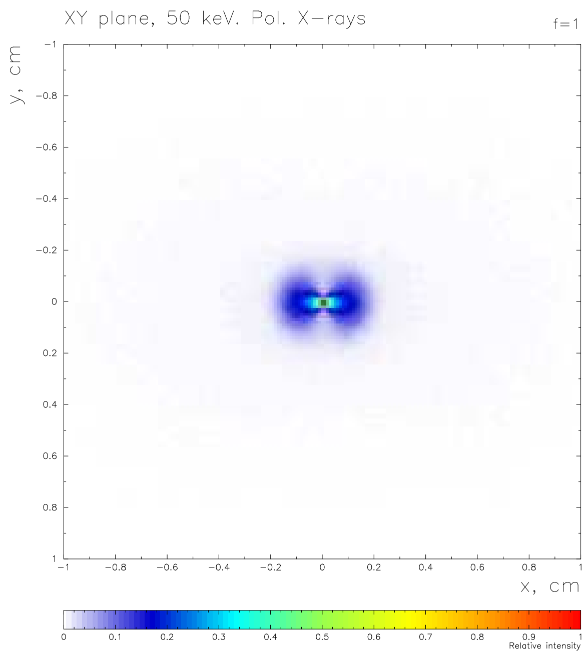

Fig. 3 - Electron cloud produced in xenon at 1 atmosphere by the absorption of 50 keV linearly polarized x-ray photons.

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REFERENCES

[1] F. Lei, A.J. Dean and G.L. Hills, "Compton Polarimetry in Gamma-Ray Astronomy", Space Science Reviews, vol.82, p. 309-388, 1997.

[2] P. MésZáros, R. Novick, G. Chanan, M.C. Weisskopf and A. Szentgyörgyi, "Astrophysical Implications and Observational Prospects of X-Ray Polarimetry", Astrophys. J., vol. 324, p.1056-1067, 1988.

[3] D.J. Kennedy and S.T. Manson, "Photoionization of the Noble Gases: Cross Sections and Angular Distributions", Phys. Rev. A vol. 5. p. 227-247, 1972.

[4] B.H. Brandsen, C.J. Joachain, "Physics of Atoms & Molecules", Longman, New York, 2nd ed, 2003.

[5] E. Costa, P. Soffitta, R. Bellazinni, A. Brez, N. Lumb and G. Spandre, « An Efficient Photoelectric X-Ray Polarimeter for the Study of Black Holes and Neutron Stars", Nature vol. 411, p. 662-665, 2001.

[6] R. Bellazinni, F. Angelini, L. Baldini, A. Brez, E. Costa, G. di Persio, L. Latronico, M.M. Massai, N. Omodei, L. Pacciani, P. Soffitta and G. Spandre, "A Novel Gaseous X-Ray Polarimeter:Data Analysis and Simulation", Proc. SPIE vol. 4843, p.383-393, 2003.

[7] R. Bellazinni F. Angelini, L. Baldini, A.Brez, E. Costa, L. Latronico, N. Lumb, M.M. Massai, N. Omodei, P. Soffitta, G. Spandre, "X-ray Polarimetry with a Micro Pattern Gas Detector with Pixel Readout", IEEE Trans. Nucl. Sci. vol. 49, p. 1216-1220, 2002.

[8] P.J.B.M. Rachinhas, T.H.V.T. Dias, F.P. Santos, C.A.N. Conde and A.D. Stauffer, "A Monte Carlo Study of the Electron Cloud Produced in Xenon by Electrons with Energies up to 200 keV", presented at ICPEAC 99 - XXI International Conference on the Physics of Electronic and Atomic Collisions, 22-27 July 1999, Sendai, Japan.

[9] P.J.B.M. Rachinhas T.H.V.T. Dias, F.P. Santos, C.A.N. Conde, and A.D. Stauffer, "Absorption of Electrons in Xenon for Energies up to 200 keV: a Monte Carlo Simulation Study", IEEE Trans. Nucl. Sci. vol. 46, p. 1898-1900, 1999.

[10] T.H.V.T. Dias, F.P. Santos, A.D. Stauffer, and C.A.N. Conde, "Monte Carlo Simulation of X-Ray Absorption and Electron Drift in Gaseous Xenon", Phys. Rev. A vol. 48, p.2887-2902, 1993.

[11] T.H.V.T. Dias, J.M.F. dos Santos, P.J.B.M. Rachinhas, F.P. Santos, C.A.N. Conde and A.D. Stauffer, "Full-Energy Absorption of X-Ray Energies near the Xe L- and K-Photoionization Thresholds in Xenon Gas Detectors: Simulation and Experimental Results", J. Appl. Phys. vol. 82, p.2742-2753, 1997.

[12] F.P. Santos T.H.V.T. Dias, P.J.B.M. Rachinhas, C.A.N. Conde, and A.D. Stauffer, "Monte Carlo Simulation Study of the Fano Factor, W-value and Energy Resolution for the Absorption of Soft X-Rays in Xenon-Neon Gas Mixtures", J. Appl. Phys. vol. 89, p.8202-8213, 2001.

[13] A. Derevianko and W. R. Johnson, "Non-Dipole Effects in Photoelectron Angular Distributions for Rare Gas Atoms", At. Data Nucl. Data Tables vol. 73, p. 153-211, 1999.

[14] M. Trzhaskovskaya, V.K. Nikulin , V.I. Nefedov and V.G. Yarzhemsky, "Non-Dipole Second Order Parameters of the Photoelectron Angular Distribution for Elements Z = 1–100 in the Photoelectron Energy Range 1–10 keV", At. Data Nucl. Data Tables vol. 92, p. 245-305, 2006.