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# MULTI COLOUR X-GAMMA RAY INVERSE COMPTON BACK-SCATTERING SOURCE

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*Abstract*

We present a simple and new scheme for producing multi colour Thomson/Compton radiation with the possibility of controlling separately their polarization, based on the interaction of one single electron beam with two and more laser pulses that can come from the same laser setup or from two different lasers system and that collide with the electrons at different angle inside one optical cavity. One of the most interesting cases for medical applications is to provide two X-ray pulses across the iodine K-edge at 33.2 $\sim keV$. The iodine is used as contrast medium in various imaging techniques and the availability of two spectral lines accross the K-edge allows one to produce subtraction images with a great increase in accuracy.

## INTRODUCTION

Colour x-ray imaging will provide significant development to screening or diagnostic radiography, because the colour components contain extra information and allow to discriminate the chemical composition of the absorbing tissues [1]. Experiments on dual colour have been recently carried on with free-electron lasers (FELs) as radiation sources [2] and promising proposals aimed to generate two-colour X-ray emission in Compton sources [3–5] have been investigated. Thomson and Compton sources, even though less brilliant than FELs, produce radiation with short wavelength, high power, ultrashort time duration, large transverse coherence and tunability, full polarization control, ensuring limited costs of construction and maintenance and dimensions compatible with the space that can be allocated in hospitals and medical centres. Existing and constructed Thomson sources are important tools for generating tunable quasimonochromatic x/gamma rays suitable for different applications. In this paper we present a simple and new scheme for producing two colour Thomson/Compton radiation with the possibility of controlling independently the polarization of the two beamlets. It is based on the interaction of one single electron beam with two light pulses that can come from the same laser setup or from two different lasers colliding with the electrons at different angle. One of the most interesting cases for medical applications is to provide two X-ray pulses across the iodine K-edge at 33.2 keV. The iodine is used as contrast medium in various imaging techniques and the availability of two spectral lines below and beyond the K-edge allows to produce subtraction images with a great increase in accuracy. The application to this range of X-rays is presented and discussed.

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## SCHEME OF THE SOURCE AND BASIC EQUATIONS

The Thomson/Inverse Compton scattering is the process occurring when an electron belonging to a high-brightness electron beam collides with the photons of a laser pulse, generating X or gamma radiation. The geometry of the scattering is represented in Fig. 1, where $\alpha_0$ is the interaction angle of the scattering.

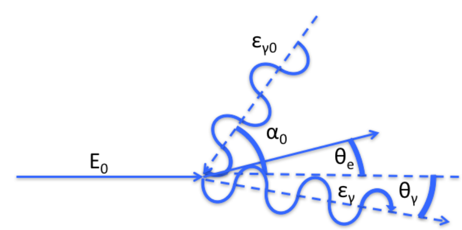


Figure 1: Kinematic of the Compton back scattering.

The radiation energy is upshifted with respect to the lasers's by the relation:

$$\varepsilon_{\gamma m} = \frac{4\gamma^2 \varepsilon_L \cos^2 \frac{\alpha_0}{2}}{4\gamma \frac{\varepsilon_L}{mc^2} \cos^2 \frac{\alpha_0}{2} + 1} \approx 4\gamma^2 \varepsilon_L cos^2 \frac{\alpha_0}{2} \tag{1}$$

where $\varepsilon_L$ is the laser photon energy, $\gamma$ the electron Lorentz factor and $\varepsilon_\gamma$ the emitted photon energy and the electron recoil term can be disregarded. The scheme we are proposing for producing two colour radiation is based on the interaction of the electron beam with two light pulses that can come from the same laser setup or from two different lasers and that collide with the electrons at different angle, as shown in Fig. 2. If one the first scattering is head-on, the angle of the second one is chosen in order to fix the relative separation between the two radiation pulses $\Delta\varepsilon/\varepsilon = sin^2(\alpha_0/2)$ . Figure 3 shows the dependence of the scattered photon energy on the angle, for typical values of a Thomson source (see Table 1) as the STAR Project [6].

Fig. 4 presents evaluation of the spectrum of the scattered photons for different values of the angle of the second laser $\alpha_{02}$ collimated into the fixed acceptance angle performed with the Monte-Carlo code CAIN [7].

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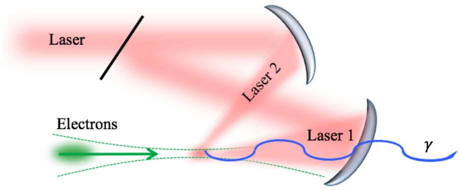


Figure 2: Scheme of the use of a split laser sent to the interaction point at two different interaction angle.

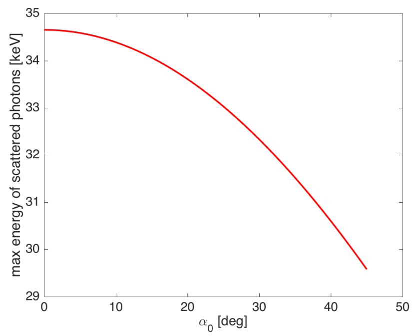


Figure 3: Dependence of the maximal energy of the scattered photons from the initial scattering angle $\alpha_0$ for the $\gamma = 84$, $\varepsilon_{\gamma 0} = 1.2$ eV.

Table 1: Parameters of Electron Beam and Laser System

| Electron beam Parameters | |
|---|---|
| Electrons mean energy [MeV] | 43.2 |
| Bunch charge [nC] | 1 |
| Bunch length rms [μm] | $10^3$ |
| Nominal normalized $\epsilon_{nx}$, $\epsilon_{ny}$ [mm.mrad] | 0.99, 0.98 |
| Nominal relative energy spread $\sigma_e$ % | 0.5 |
| Focal spot size $\sigma_x$, $\sigma_y$ [μm] | 15, 15 |
| Laser Parameters 1 | |
| Laser pulse energy (J) | 0.15 |
| Laser pulse length [psec] | 1 |
| Laser focal spot size w0 RMS [μm] | 60 |
| Collision angle [deg] | 0 |
| STOKES parameters | (0,0,-1) |
| Laser Parameters 2 | |
| Laser pulse energy (J) | 0.15 |
| Laser pulse length [psec] | 1 |
| Laser focal spot size w0 RMS [μm] | 24 |
| Collision angle [deg] | 30 |
| STOKES parameters | (0,0,+1) |

As can be seen, the radiation energy for $\alpha_0 = 0$ is about $E_1 = 34$ keV, above the iodine K-edge. A separation $\Delta\varepsilon/\varepsilon \approx 6.5\%$ between the energies of the two pulses means, for instance, to operate with one head-on collision and the other one at about 30°. In this case, the second line will be at $E_2 = 32$ keV. Furthermore, the number of scattered photons $N$ in a Thomson/Compton scattering at a generic angle $\alpha_0$ collimated in an acceptance angle $\Psi = \gamma\theta_{max}$, can be obtained on the basis of the luminosity as:

$$N^{\Psi} = \frac{f N_e N_L \int^{\Psi} d\Psi' \frac{d\sigma}{d\Psi'}}{2\pi\sqrt{\sigma_{y,e}^2+\sigma_{y,L}^2}\sqrt{\sigma_{x,e}^2+\sigma_{x,L}^2+(\sigma_{z,e}^2+\sigma_{z,L}^2)\tan^2(\frac{\alpha_0}{2})}}, \qquad (2)$$

where $\int^{\Psi} d\Psi' \frac{d\sigma}{d\Psi'}$ is the Compton cross section as a function of the acceptance angle $\Psi$ [8], $N_e$, $N_L$ are the number of interacting electrons and laser photons, $\sigma_x$ ($\sigma_{x,L}$) and $\sigma_y$ ($\sigma_{y,L}$) are the rms electron (laser) transverse dimensions at waist, $\sigma_z(\sigma_{z,L})$ is the electron (laser) beam length and $\theta_{max}$ being the maximum acceptance angle. If the two radiation pulses are required comparable photon numbers, the lengths $\sigma_z(\sigma_{z,L})$ should be as short as possible and the two laser pulses should be focused in a different way, in particular the first laser beam was focus at $w0_{L1} = 60$ μm and the other one at $w0_{L2} = 24$ μm as shown in Table 1. In Fig. 5 the total photon phase space is reported, for $\alpha_1 = 0$ and $a_2 = 30°$. Figure 6 presents the spectrum of the radiation collimated within an acceptance angle $\theta = 1$ mrad, with a good balance between the two spectral peaks. Another quantity that has to be controlled for separating the two spectral lines is the acceptance angle. Figure 7 presents the spectrum as function $\theta$ and shows that only for acceptance angles lower than $(E_2 - E_1)/E$ the two spectral lines present a reasonable separation.

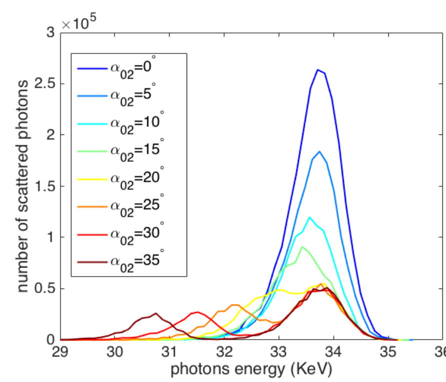


Figure 4: Spectra of the scattered radiations for the different initial angle for the second laser $\alpha_{02}$.

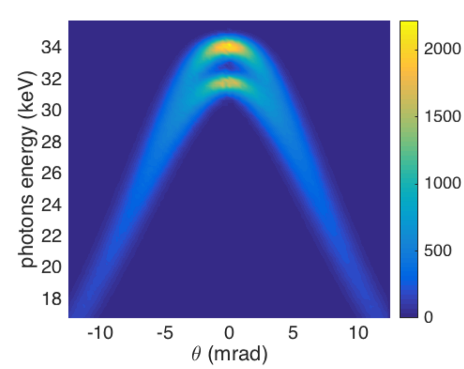


Figure 5: Energy angular distribution of the scattered radiation for the $\alpha_{02} = 30$ deg.

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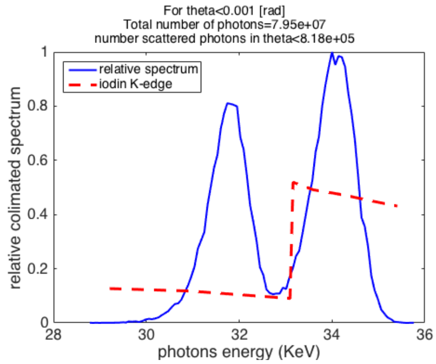


Figure 6: Relative spectrum of the scattered radiation for the $\alpha_{02}$ = 30 deg.

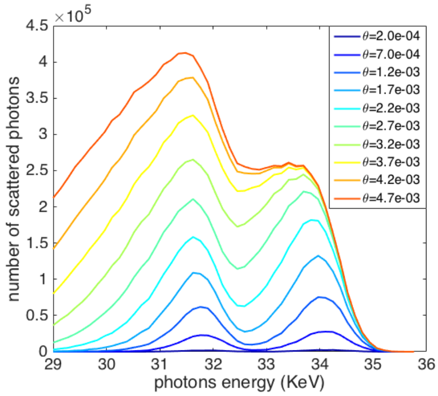


Figure 7: Spectra of the scattered radiations for the different collimation angles $\theta$.

## BRIXS TWO CAVITY SCHEME

Our proposal to use two colour scheme in the BriXS project [9, 10] consists in generating two X-rays colours at different times using two different degrees of freedom: the collision angle and the micropositioning of the optical table on which the optical cavities are aligned. Concerning the first point, we are talking about two optical cavities aligned at two different angles with respect to the electron beam (as shown in Fig. 8) so that the two focus points are at two slightly different heights (100 µm for example) Then, looking at the second point, changing the height of the optical table by means of micropositioners, we can change the point of collision and decide which of the two cavities contributes to the generation of the X-rays. As an alternative to this scheme we can also think of mounting the two cavities on two different optical tables in order to avoid the variation of the switch time between the two colour due to the variation of the distance between the two focus points for different alignment realization. It should be noted that the micropositioning of the optical table is a necessary request also in the case of the single cavity in order to obtain the collision between electrons and photons without touching neither the electron beam nor the optical cavity. Concerning the orders of magnitude, laser beam in the focal point is of the order of 50 µm and the repeatibility of the movements of the optical table is 1 µm or less, moreover, the velocity of the table is around 1 m/s, so it is possible to obtain switching time of the order of few hundreds of ms, and this is compatible with a medical application.

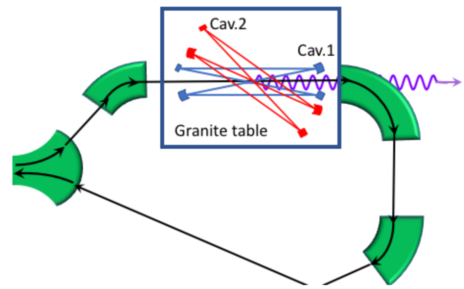


Figure 8: Scheme of installation of two cavity on jumping granite table.

## CONCLUSION

In this work we present a new scheme to produce two colour X-rays based on compact Compton sources. This scheme consists in the use of two laser pulses impinging on the same electron beam at two different angles, with frequencies given by formula 1. The potentialities of scattered radiations can be improved by using a different polarisation of the initial laser pulses. This scheme can be extended to the production of a sequence of two X-ray pulses with different colours separated also in time. This is of paramount importance for adjusting the time needed by the detectors to record and load the two images at two different colours, that is mandatory for digital subtraction.

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