Suppression of Parametric Down Conversion

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Introduction

Parametric down conversion is the effect of a spontaneous decay of photons (commonly called "pump") into pairs of highly correlated photons, commonly called "signal" and "idler." The effect is well known in the near-visible-light regime and has been demonstrated for x-rays in 1971 [1] and later [2, 3, 4]. A nonlinear optical medium is required, which can also support matching of the pump, signal and idler wave vectors. In the case of x-rays, one can make use of the nonlinearity of quasifree electrons whose binding energy is much less than the x-ray photon energy. This nonlinearity can be understood by iterating the Lorentz equation, where the first iteration gives Thomson scattering and nonlinear optical effects appear in higher iterations due to the Lorentz force. It is so small that, for example, harmonic generation with x-rays seems to be out of the question at 3rd-generation synchrotron radiation sources. In the case of parametric down conversion, however, the high virtual power density of vacuum fluctuations at x-ray energies compensates for the small nonlinearity. Thus, down converison is a very weak but observable effect with a cross section of the order of 10^{-9} of that for Thomson scattering at x-ray energies of the order of 10 keV. Wave vector matching is done by detuning slightly from a crystal reflection in either Bragg or Laue geometry (see any of [1, 2, 3, 4] for details).

Recent experiments [5] suggest that there is a suppression of the effect for a geometry where the angle between signal and idler wave vectors is very small (mrad). In order to test for that suppression, we did the experiment described in this report.

Methods and Materials

As in all our previous experiments [3, 4, 5], the sample of choice was a diamond, crystallinity being reqired for wave vector matching and carbon having a low absorption cross section for the converted photons. For the detection of down conversion events, silicon drift-chamber detectors were used, and energy-resolved time-correlation spectra were taken. Because the objective of the beam time was to compare the event rates at larger (several degrees) and smaller (few mrad) angular separations between the detectors, the setup had to permit placement of the detectors both close to (i.e., 2 m) and far from (i.e., 25 m) the sample. To meet these requirements, the sample was placed in the B hutch of 1-ID and a diamond (111) reflection sent the 25 keV x-ray beam upward to the sample diamond where the (111) reflection brought the beam back into the horizontal direction. Because the down-converted photons exit the sample at opposite angles relative to the reflected beam, it was then possible to detect them at larger angular separation in the B hutch, or at small angular separation 25 m downstream in the C hutch (see Fig. 1). Because of the low conversion cross section - the highest event rate (to our knowledge) ever observed in down conversion of x-rays is a bit less than 0.1/s, see [4] - background suppression is critical. This background is mostly due to fortuitous coincidences of diffusely scattered x-rays, falsely recognized as having the energy of the down-converted photons due to the spread of the energy resolution characteristic of the detectors. In order to reduce the contribution to the background due to elastic scattering of the pump beam in air, the beam path was evacuated from a point about 2 cm after the sample to just before the detectors.

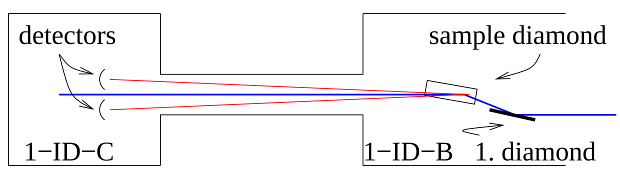

Figure 1: *A schematic of the setup with x-ray monochromator, first diamond reflecting up, sample diamond reflecting into the horizontal direction, and down converted photons at a small angular separation in the C-hutch.*

Conversion events were detected by a combination of coincidence and energy analysis of events in the two detectors. This was done by use of a multichannel, energy- and time-resolving event logger, designed by one of us (B.W.A.). The raw data can be sorted for correlations in time and photon energy, with zero time delay at the energies of signal and idler indicating down conversion events and everything else (i.e., wrong photon energies and non-zero time differences) giving a measure of the background.

Results

Figures 2 and 3 show time correlation spectra of energy-selected events in the two detectors for a large and small angular separation between the detectors, both at the respective detuning from the (111) reflection to satisfy the wave vector matching condition.

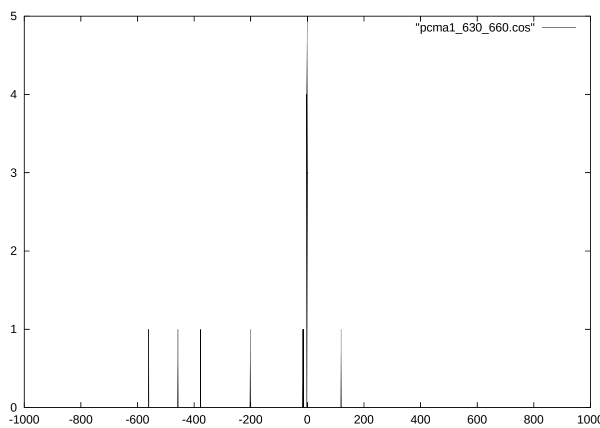

Figure 2: *Time correlation of energy-selected events for a large ($\pm 1^{\circ}$) angular separation between the detectors. The peak indicates coincidence over background.*

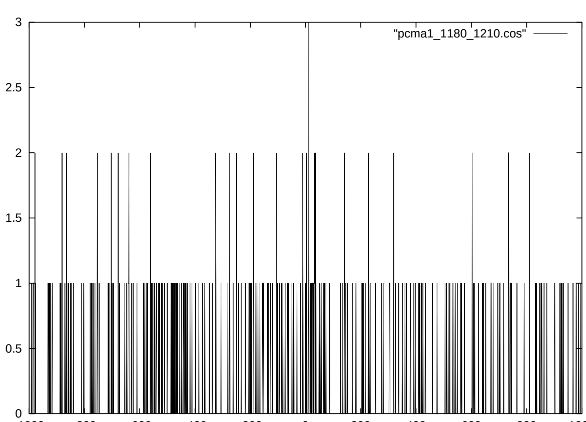

Figure 3: *Time correlation of energy-selected events for a small (± 1 mrad) angular separation between the detectors. The coincidence peak is much less distinct than for larger angular separation (Fig. 2).*

Discussion

Although the data do indicate a reduced event rate at small angular separation between signal and idler photons, further work is required to really settle this issue. One possibility to reduce the large background in the small-angle data would be to cool the sample to liquid nitrogen temperature and thus reduce the thermal diffuse scattering. One could also try to use a mirror, set at an angle to suppress the pump photons, but to reflect at the signal and idler energies. This has been tried once at the ESRF with some success [5]. On the theoretical side, work is in progress to explain the suppression in terms of a destructive two-photon interference process.

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[5] B. Adams, unpublished (2001).