Search for dark matter at high-power laser facilities : flawed luminosity calculations in QPS – Quasi parallel scattering.

Denis Bernard

Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS/IN2P3 91128 Palaiseau, France

Thanks to the tremendous progress made by high-efficiency high-repetition-rate highpower short-pulse lasers [1] and anticipating the availability of facilities such as ELI [2], a series of works have been published recently that propose to use lasers to search for new physics effects such as a dark matter scalar field S, in the stimulated collision of laser pulses [3, 4, 5, 6]. The proposed scheme is based on two principles;

- The stimulation of a γγ → S → γγ elastic scattering reaction by the presence in the initial state of a pulse of photons that are identical, in the Heisenberg sense, to one of the photon expected to be produced in the final state, as was proposed in Refs. [7] and [9, 10] and tested experimentally in Ref. [8];
- 2. The angular configuration proposed [3, 4, 5], named "Quasi parallel scattering" (QPS), is the collision of two copropagating lasers. The natural angular divergence of the laser provides a range of possible small angles θ for the collision of two particular photons and therefore a range of possible center-of-mass system energies for that collision, the range overlapping, hopefully, the narrow line resonance of the interaction through a scalar S having a given mass [3].

The availability of very small angles in this QPS configuration enables the search for objects with a very small mass $(m \ll 1 \text{ eV}/c^2)$ despite the high photon energy $(E \approx 1 \text{ eV})$ of the laser.

Alas, the expression of the luminosity used, eq. (5.1) of Ref. [3], eq. (34) of Ref. [4], eq. (32) of Ref. [5], is the expression for the collision of head-on beams, a configuration which is far from being the configuration used here. The luminosity for the head-on collision of two bunches is :

$$\mathcal{L}_0 = \frac{CN_1N_2}{A},\tag{1}$$

where N_1 and N_2 are the number of particles in beam 1 and 2, A is the transverse geometrical area over which the crossing takes place, and C is a numerical factor of order unity, that depends of the details of the transverse shapes of the beams. This expression is often also used for "small angle crossing", which in the context of accelerator physics means an almost head-on collision.

But here, where the two beams are co-propagating, the full expression [11] must be used,

$$\mathcal{L} = \frac{K}{2}\mathcal{L}_0 = \frac{K}{2}\frac{CN_1N_2}{A},\tag{2}$$

where K is a "Kinematic factor" :

$$K = \sqrt{(\vec{v}_1 - \vec{v}_2)^2 - (\vec{v}_1 \times \vec{v}_2)^2/c^2}.$$
(3)

Modern discussions of Møller's opus [11] can be found in Refs. [12, 13, 14]. Using the QPS θ angle definition, we get :

$$K = \sqrt{(2\sin\theta)^2 - (\sin 2\theta)^2},\tag{4}$$

that is $K/2 = \sin^2 \theta$.

- For head on collisions, $\theta = \pi/2$ and K/2 = 1, as was expected;
- For $\theta \approx 0$, as is the case here, $K/2 = [m/(2E)]^2$.

The missing factor, K/2, is extremely small for the resonance masses of interest ($m \ll 1 \text{ eV}/c^2$, see Fig.4 of Ref. [5]). The potential of high fluence lasers for exploring weakly interacting "vacuum fields" such as Dark Matter fields [15] may have been grossly over-estimated.

References

- G. Mourou, "High power Lasers new developments", in "High-Power Laser Workshop", SLAC October 1-2, 2013.
- [2] The Extreme Light Infrastructure (ELI) http://www.extreme-light-infrastructure.eu/
- [3] Y. Fujii and K. Homma, "An approach toward the laboratory search for the scalar field as a candidate of Dark Energy," Prog. Theor. Phys. **126**, 531 (2011) [arXiv:1006.1762 [gr-qc]].
- [4] K. Homma, D. Habs and T. Tajima, "Probing the semi-macroscopic vacuum by higherharmonic generation under focused intense laser fields," Appl. Phys. B 106:229-240 (2012), arXiv:1103.1748 [hep-ph].
- [5] K. Homma, "Sensitivity to Dark Energy candidates by searching for four-wave mixing of high-intensity lasers in the vacuum," Prog. Theor. Exp. Phys. 04D004 (2012), [arXiv:1211.2027 [hep-ph]].

- [6] K. Homma, D. Habs, G. Mourou, H. Ruhl and T. Tajima, "Opportunities of fundamental physics with high-intensity laser fields," Prog. Theor. Phys. Suppl. **193**, 224 (2012).
- [7] F. Moulin and D. Bernard, "Four-wave interaction in gas and vacuum. Definition of a third order nonlinear effective susceptibility in vacuum: $\chi^{(3)}_{vacuum}$," Opt. Commun. 164, 137 (1999) [physics/0203069 [physics.optics]].
- [8] D. Bernard *et al.*, "Search for Stimulated Photon-Photon Scattering in Vacuum," Eur. Phys. J. D **10**, 141 (2000) [arXiv:1007.0104 [physics.optics]].
- [9] E. Lundstrom *et al.*, "Using high-power lasers for detection of elastic photon-photon scattering," Phys. Rev. Lett. 96, 083602 (2006) [hep-ph/0510076].
- [10] J. Lundin et al., "Detection of elastic photon-photon scattering through four-wave mixing using high power lasers," Phys. Rev. A 74, 043821 (2006) [hep-ph/0606136].
- [11] C. Møller, "General Properties of the Characteristic Matrix in the Theory of Elementary Particles I", Danish Academy of Sciences, Matematisk-Fysiske Meddelelser, Vol. 23, No. 1 (1945)
- [12] W. Herr and B. Muratori, "Concept of luminosity," in "Intermediate accelerator physics. Proceedings, CERN Accelerator School, Zeuthen, Germany, September 15-26, 2003,"
- [13] M. A. Furman, "The Møller Luminosity Factor", LBNL-53553, CBP Note-543 (2003).
- [14] "The Luminosity for beam distributions with error and wake field effects in linear colliders," O. Napoly, Part. Accel. 40, 181 (1993).
- [15] T. Tajima, "Overview of High Field Science", in "High-Power Laser Workshop", SLAC October 1-2, 2013.