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Quasi-liquid crystals of electrons and positrons

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Summary. — A new statistical analysis of infrared synchrotron radiation (IR-SR) emitted by electrons and positrons at DAΦNE Φ-Factory (Frascati) and Bessy 2 (Berlin) reveals inner degrees of freedom within bunches of relativistic particles. We thus propose a new methodological approach towards a theory that describes the passage from a phase of maximum symmetry to a condensed phase having the qualities of a nematic mesophase of positrons and electrons.

1. – Materials and methods

Ultra fast uncooled photo-detector arrays based on HgCdTe (MCT) hetero-structures made by VIGO Systems S.A. [1] were used to perform real time bunch-by-bunch and turn-by-turn diagnostics at DAΦNE (Frascati) [2,3] and at Bessy 2, Helmholtz Zentrum, Berlin. The response of MCT photo-detectors in time (ns) was analyzed by a fine-grain unconventional category statistical calculus system developed and patented (2011) by the present author. Given the limited space requirements, we refer *amplius* to [4-6].

2. – Results

The result of the analysis is a "bilobed" IR-SR emission profile of each bunch, bearing the structure of a convolution of two peaks of which the second (hereinafter referred to as "delayed") of smaller amplitude and delayed by a few hundred ps compared to the first (hereinafter referred to as "main"), see fig. 1. We used to represent this bilobed profile as a finite sum of the *atomic representation* of a Banach algebra of *Gaussian humps*, a fascinating concept of Yves Meyer's theory of *ondelettes* (wavelets). So, as a tribute to Yves Meyer, we used to call the phenomenon herein described as the "*ondelette effect*" [7] . This choice expresses our methodological point of view and constraint, see [8]. Since the *ondelette* effect was also observed in Berlin and Hefei (People's Republic of China), we excluded that it was due to systematic errors (see also the analysis of time series, see [8]). Moreover, the velocity measurements at Frascati led to a small discrepancy in the value of the velocity of light, see [8].

3. – A nematic mesophase

The ondelette effect questions the validity of the "rigid bunch" hypothesis [9, 10]. Consider thus the distribution of N electrons in a circular machine where we have a

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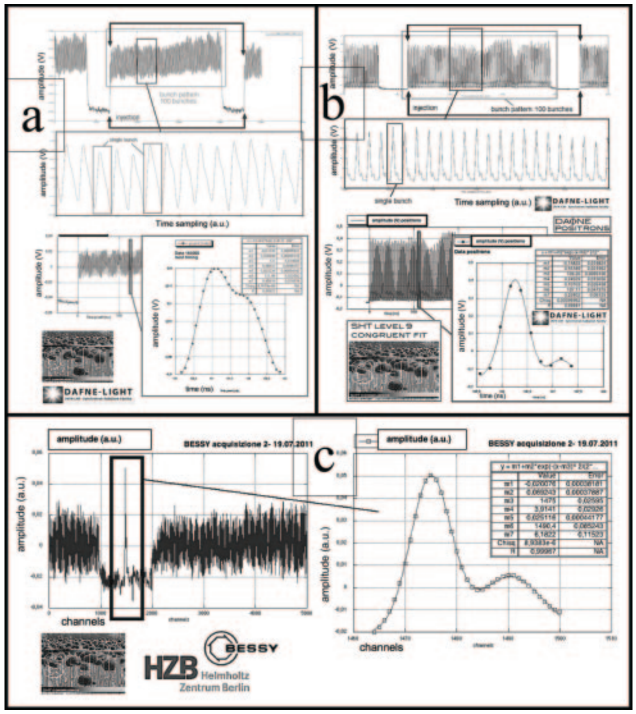

Fig. 1. – Ondelettes. (a) shows the plots of the amplitude (V) as a function of time (ns) of the IR-SR emission of a complete filling of 100 bunches of DAΦNE electrons (Frascati) with the detail of the bilobed SR-IR profile of each bunch and its atomic representation through a Banach algebra of Gaussian humps, a fascinating concept of Yves Meyer's theory of ondelettes or *wavelets*, hereinafter referred to simply for brevity as "*ondelettes*" [7]. (b) shows the plots of the amplitude (V) as a function of time (ns) of the IR-SR emission of a complete filling of 100 bunches of DAΦNE positrons (Frascati) with the detail of the bilobed SR-IR profile of each bunch and our *ondelettes*. (c) shows the plots of the amplitude (a.u.) as a function of time per channels (ns) of the IR-SR emission of a single bunch of BESSY2 electrons (Berlin) with the detail of the bilobed SR-IR profile of each bunch and our ondelettes. Data acquisition for DAΦNE electrons and DAΦNE positrons was carried out at SINDAB beam line by the group of Bocci *et al.*, see [2], while for BESSY2 electrons it was acquired directly by the present author at the IRIS beam line (HZ-Berlin), see [5]. All the graphs, diagrams, tables and analyses (statistics, linear and non-linear regressions (*ondelettes*), time series analysis, category analysis and so on), all the models, methods and theoretical hypotheses for both DAΦNE and BESSY2, were created and performed by the present author with an unconventional category fine grain statistical calculus and analysis, divided into 9 steps. We refer *amplius* to [4-6].

coherent radiation term (CSR) along with an incoherent radiation term (ISR) [11-13]. The spectrum of radiated power will be

$$\frac{\mathrm{d}P}{\mathrm{d}\lambda} = \frac{\mathrm{d}p}{\mathrm{d}\lambda}\left[N\left(1-g\left(\lambda\right)\right)+N^2 g\left(\lambda\right)\right], \tag{1}$$

where λ is the wavelength of the radiation, p the power emitted by a single particle, N is the number of particles per bunch and g the so-called "CSR form factor", given by the following equation: $g\left(\lambda\right) = \left|\int_{-\infty}^{+\infty} n\left(z\right) e^{2\pi \mathrm{i} \cos(\theta) z/\lambda} \mathrm{d}z\right|^2$, where $0 \leq g \leq 1$, $n(z)$ is the bunch normalized distribution and θ is the angle between the longitudinal direction

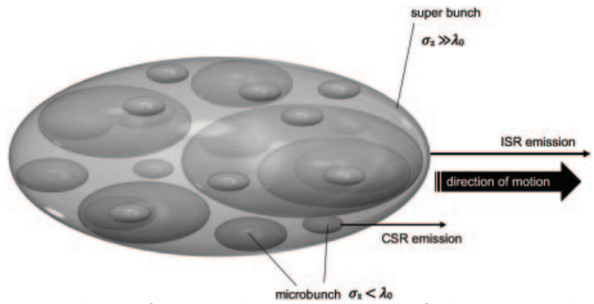

Fig. 2. – A nematic mesophase of "quasi-liquid crystals" of electrons and positrons.

z and the observation point. For $\theta = 0$ the form factor $g(\lambda)$ is precisely the square of the Fourier transform of the bunch distribution.

To define $\mathrm{d}p/\mathrm{d}\lambda$ I took into consideration the effect of the vacuum chamber screen. The cut-off wavelength is $\lambda_0 \approx 2h\sqrt{\frac{h}{\rho}}$, where h is the total height of the vacuum chamber and ρ the radius of curvature of the trajectory of the particle. Following our *ondelettes* (see fig. 2), we choose our form factor $g(\lambda)$ for Gaussian bunches. For $\theta = 0$ we will have $\frac{2\pi\sigma_z}{\sqrt{\ln(N)}} < \lambda < \lambda_0 = 2h\sqrt{\frac{h}{\rho}}$, where σ_z is the bunch length. Therefore, to have a CSR emission we will have "short" bunches with large cutting wavelengths. In the case of real machines, the CSR contribution can be observed in the frequency range of THz. The distribution made of "micro-bunches" of σ_z length will have a density given by $n\left(\sigma_z\right) = \sum_\alpha \delta\left(\sigma_z - \sigma_z^\alpha\right) \to \langle n\left(\sigma_z\right)\rangle$.

The range of scale variation for σ_z is given by $\Lambda < \sigma_z < R_s$, where Λ and R_s represent, respectively, the lower and upper cut-off scales, both depending on the cut-off wavelength λ_0 . That is, R_s is the maximum size of the distribution of micro-bunches. It is identified by the length of the whole cluster intended as "super-particle", as Hofmann's "rigid bunch" model. For scales such that $\Lambda < \sigma_z < R_s$ we have a distribution of micro-bunches that look like "spindles", all contained in a "super-particle" which emits synchrotron radiation along the direction of the motion. These micro-bunches are all ordered along a particular direction specified by a unit vector n_μ called "director", aligned with the direction of motion, while their centers of mass are distributed randomly (see fig. 2). We thus have a distribution of bunches of particles characterized by a break (only) in the rotational symmetry. This is a condensed state resulting from a spontaneous symmetry breaking from a maximum symmetry state (homogeneous and isotropic "fluid" phase) to a condensed phase where the rotational symmetry is broken. For *congruence* with our *ondelettes* (see fig. 1), the model that comes closest to this phenomenon is the nematic mesophase of a liquid crystal [14, 15]. Coherence is therefore the average density as a function of the bunch dimension σ_z in the scale range given by the above interval (Λ, Rs), as follows:

$$\lim_{\sigma_z \to \infty} \langle n\left(\sigma_z\right)\rangle \sim \lim_{\sigma_z \to R_s} \langle n\left(\sigma_z\right)\rangle \sim \sigma_z^{D_H}, \tag{2}$$

with $D_H \geq D_T$, where D_H is the *Hausdorff dimension* and D_T the topological dimension. Definitely, we have a nematic fractal mesophase of micro-spindles emitting IR-SR ondelettes along the common direction of motion (fig. 2). We used to call these structures "quasi-liquid crystals of electrons and positrons". Now we wonder the cause of the *ondelette* effect. Evidences tell us that when a high charge density or the number of electrons in a bunch exceeds a threshold value, microstructures spontaneously appear in the bunch, see [16, 17]. Ondelettes analysis is also a fast qualitative method *de visu* to detect inner bunch structures. From fig. 1 we have that the main Gaussian peak ("main") corresponds to the ISR emission of the whole bunch as a "super-particle" (super-spindle), while the small Gaussian peak ("delayed") corresponds to the coherent emission (CSR) of the inner micro-spindles (which represents the theory deviation from Hofmann's "rigid bunch model"). Considering therefore the interpolating Gaussian $\Psi(t; \mu, \sigma^2)$ in the ondelettes, where t represents the time abscissa (ns), we have that $\mu_{ISR} < \mu_{CSR}$ $\forall t$, $\forall$ bunch and $\Psi(\mu_{ISR}) > \Psi(\mu_{CSR})$, $\forall$ bunch. As μ_{CSR} is the average delay time (ns) of the internal micro-spindles, between the slowest and the fastest micro-spindle inside the super-spindle all aligned with the direction of motion (see fig. 2). Similarly, we note the difference $\Delta\Psi$in amplitude (V) between the two ondelettes taking into account that the ISR term in the power spectrum (eq. (1)) is proportional to N, while the CSR term is proportional to N^2. Recall that particle densities scale like fractals (eq. (2)). The density of the incoherent particles is therefore greater, as expected. Given the limited space, we reserve the right to continue in a future work.

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