Femtoscopy for the NAPLIFE nano-fusion project

L.P. Csernai[1,2,3,4], T. Csörgő[1], I. Papp[1,5], M. Csete[1,6], A. Szenes[1,6], D. Vass[1,6], T.S. Biró[1], and N. Kroó[1] (part of NAPLIFE Collaboration)

[1]HUN-REN Wigner Research Centre for Physics, Budapest, Hungary
[2]Department of Physics and Technology, University of Bergen, Norway
[3]Frankfurt Institute for Advanced Studies, Frankfurt/Main, Germany
[4]Csernai Consult Bergen, Bergen, Norway
[5]HUN-REN Centre for Energy Research, Budapest, Hungary
[6]Department of Optics and Quantum Electronics, Uni. of Szeged, Hungary

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Abstract

The Hanbury-Brown and Twiss analysis is used to determine the size and timespan of emitted particles. Here we propose to adopt this method for laser induced nanoplasmonic inertial confinement fusion, to determine the parameters of emitted Deuterium and Helium^4 nuclei.

1 Introduction

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Two particle correlations are used to analyze the size, timespan, of hadronization in relativistic heavy ion collisions [1], including collective flow parameters [2, 3], based on the emitted Boson's wave function.

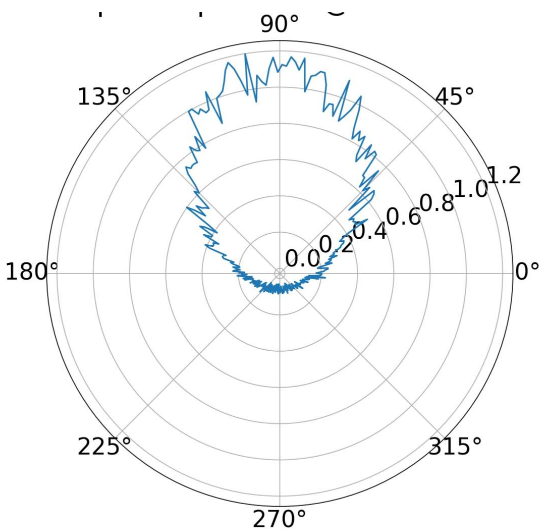

Figure 1: The angular distribution, of emitted protons along a nanorod antenna irradiated from **two** sides in the LWFC configuration, in the front/back directions, with a 30mJ constant intensity laser pulse with $I = 4 \cdot 10^{17}$ W/cm^2, with a step function profile in the rest frame of the antenna. The distribution is shown one period T_P after the initial transients, t_o, i.e. at $t_o + T_P = 11.94$ fs after the start of the irradiation. The antenna and the $\vec{E}$ field of the laser beam point int the 90^o direction. The outermost contour (1.0 MeV/c) belongs to the momentum of all protons emitted into a solid angle domain of $4\pi/300$. The momentum of the most energetic protons is 13 keV/c. The number of proton marker particles in the EPOCH generated sample is 337058.

Initial experimental verification measurements observed nuclear reactions, the formation of deuterium, due to energetic laser irradiation [4, 5, 6, 7]. This is attributed to proton acceleration, achieving neutron transmutation from target nuclei [8]. We proposed two-sided laser irradiation in one linear geometry to achieve energetic and stable ignition [9]. This configuration exploits the Laser Wake Field Acceleration (LWFA) mechanism to form a Laser Wake Field Collider (LWFC) [10]. Thus, the emitted protons and then the formed deuterium nuclei are accelerated primarily in the direction of the electric field (**E**) of the irradiation laser beam. As the laser beam is transversely polarized the particle emission is orthogonal to the direction of laser irradiation in the colliding beam configuration.

In the NAPLIFE project gold nanorod antennas are embedded in a polymer target. These are of resonant wavelength, consequently these serve as dipole accelerators of the neighboring protons and other charged particles. These nanoantennas are orthogonal to the direction of laser irradiation and parallel to the **E**-field of the laser beam. The direction of acceleration is the same, fluctuating following the direction of **E**. According our numerical simulations the direction of the accelerated protons is sharply centered around the direction of the **E**-field. The orientation is becoming angularly more peaked as the irradiation time is increasing. The number of accelerated and emitted protons (and ions) are also increasing with irradiation time.

Furthermore, the protons may reach multi-MeV energies, which are sufficient for nuclear reactions, particularly for transmutation reactions.

In our simulations the period of the irradiating laser beam is $T_P = 2.65$ fs, which corresponds to $\lambda = 800$ nm in vacuum. The total irradiation time for the beam to cross a target of 21 μm is about 106 fs. These correspond to our present experimental test parameters. We assume that the intensity of irradiation is constant in this time.

With increasing laser irradiation time, the energy of the Electro-Magnetic field is converted over to the energies of the accelerated and emitted ions and atoms. This leads to a decrease of the energy of the Electro-Magnetic field in the calculation box of the simulation [11].

2 Method of analysis

We use a high resolution, Particle In Cell EPOCH kinetic model, similarly as it is done for PICR fluid dynamics [2, 3]. The model was used to evaluate rotation in off-central high energy heavy ion reactions [12], to point out the possibility of Kelvin Helmholtz Instability (KHI) [13], the flow vorticity [14] and polarization/vorticity arising from local rotation [15]. The numerical viscosity and the resulting entropy production were also evaluated in this model [16].

In the field of ultra-relativistic heavy ion physics two particle correlation studies are used for a long time. These provide a high level of sophistication determining not only size and timespan of an emitting source, but also its shape, dynamics, expansion, and rotation. In the present, limited budget NAPLIFE laser fusion studies highly structured detector systems are not available, but one or two detectors are available. These enable us to draw some conclusions from two particle correlation studies

Smaller detector acceptances may also provide sufficient data for important and essential consequences [17, 18].

3 Correlation Function

The boson two-particle correlation function is defined as the inclusive distribution divided by the product of the inclusive one-particle distributions, such that [1]:

$$C(p_1, p_2) = \frac{P_2(p_1, p_2)}{P_1(p_1)P_1(p_2)}, \tag{1}$$

where p_1 and p_2 are the 4-momenta of particles.

Using the emission function $S(x, k)$, discussed in ref. [19], the correlation function from a fluid dynamical model result can be calculated [20, 21, 22, 23] with good precision. In this calculation one needs the flow velocity distribution and the local momentum distribution of the given type of particles at each location.

This is usually the Jüttner (CJ) distribution, assuming local thermal equilibrium as in fluid dynamics.

4 Non-thermal particle distribution

In case of the NAPLIFE project, we avoid the development of thermal equilibrium. The incoming laser beam is one dimensional, and the proton and ion distribution is also dominantly one dimensional in an orthogonal direction.

In such a situation the momentum distribution is also not isotropic, but typically distributed in one direction. For such out-of-equilibrium situations the so-called Cancelling Jüttner (CJ) distribution [24], is introduced in case of high energy particle momentum distribution as:

$$f_{CJ}(p^\mu) = \frac{\Theta(p^\mu d\sigma_\mu)\ n(x)}{C_\pi\ (2\pi\hbar)^3} \left(\exp\frac{-p^\mu u^R_\mu}{T} - \exp\frac{-p^\mu u^L_\mu}{T} \right), \tag{2}$$

where $d\sigma_\mu$ for a single nanorod is the unit normal vector pointing in the direction of the nanorod antenna, $n(x)$ is the local particle density.

The CJ distribution resembles strongly the distribution obtained in the EPOCH kinetic theory, The increasingly narrower distributions can be simulated with increasing velocity parameter, $\pm v$ in u^R_μ and u^L_μ.

In our case the particle emission is in the direction of the nanorod, which points into the direction of polarization of laser light. The deuterium and He^4 particles will have a main direction of emission in this direction. This will be the symmetry axis ($d\sigma^\mu$) of the distribution. The spread of the distribution around this direction can be fitted by the velocity, v and "temperature", T parameters of the CJ distribution.

The correlation function was evaluated in a simplified situation in ref. [26] demonstrating which kind of information can be gained by the two-particle correlation analysis.

In case of more involved time dependence of the source the correlation function becomes also more complex, which needs adequate analysis.

5 Outlook

At relatively small laser beam energy pulses as 30 mJ energy one can obtain nuclear reactions, deuterium production. This is due to the increased proton energy caused by the catalyzing effect of nanorod antennas. The volume and time extent of the "Irradiation Volume" was theoretically estimated [7]. Recent theoretical analyses indicate that nanorod antennas may catalyze proton acceleration [25], which enables nuclear transmutation and thus fusion reactions.

Two particle correlations with even one or two particle detectors only can provide experimental measure for the configuration of fusion ignition dynamically.

For targets with oriented nanorods the angular distribution of proton emission can be verified experimentally, which confirms the directed proton acceleration mechanism by the applied nanorod catalyzed fusion method [26].

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