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Support for massless particles in Chaos Many-Body Engine simulations of nuclear collisions at relativistic energies

I.V. Grossu [a,*], C. Besliu [a], Al. Jipa [a], D. Felea [b], E. Stan [b], T. Esanu [a,c]

[a] University of Bucharest, Faculty of Physics, Bucharest-Magurele, P.O. Box MG 11, 077125, Romania

[b] Institute of Space Science, Laboratory of High Energy, Astrophysics and Advanced Technologies, Bucharest-Magurele, P.O. Box MG 23, 077125, Romania

[c] "Horia Hulubei" National Institute for R&D in Physics and Nuclear Engineering, IFIN-HH, Bucharest, Magurele, Romania

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ABSTRACT

Following the goal of improving the relativistic nuclear collisions toy-model proposed in Grossu et al. (2014), we added support for massless particles in all "Many-Body", "High Precision", and "Reactions" modules of the Chaos Many-Body Engine application. In this context, we discuss a first CMBE–HIJING comparative study on nuclear collisions at the maximum BNL energy. As a new high precision example of use, we implemented a 50 decimals precision simulation of a bound system composed by two massless particles with gravitational potential.

New version program summary

Program title: Chaos Many-Body Engine v06

Catalogue identifier: AEGH_v6_0

Program summary URL: http://cpc.cs.qub.ac.uk/summaries/AEGH_v6_0.html

Program obtainable from: CPC Program Library, Queen's University, Belfast, N. Ireland

Licensing provisions: Microsoft Public License (Ms-PL)

No. of lines in distributed program, including test data, etc.: 1087674

No. of bytes in distributed program, including test data, etc.: 46861801

Distribution format: tar.gz

Programming language: C# 4.0

Computer: PC

Operating system: Net Framework 4.0 running on MS Windows

RAM: 128 MB

Classification: 24.60.Lz, 05.45.a

Catalogue identifier of previous version: AEGH_v5_0

Journal reference of previous version: Computer Physics Communications 185 (2014) 3059

Does the new version supersede the previous version?: Yes

Nature of problem: Treatment of massless particles in simulations of relativistic many-body systems.

Solution method: Relativistic many-body OOP engine, including a reactions module.

Reasons for new version:

1. *Adding support for massless particles in CMBE simulations of relativistic many-body systems with reactions.*

Summary of revisions:

1. *Treatment of massless particles in all CMBE modules: Many-Body Engine, High Precision Framework, and Reactions Engine.*

* Corresponding author.
E-mail address: ioan.grossu@brahms.fizica.unibuc.ro (I.V. Grossu).

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2. *Simulations\Collider*: *Addition of some reactions with photons to the existing toy-model for chaos analysis of relativistic nuclear collisions at present BNL energies.*
3. *HighPrecision\Massless Particles: Implementation of a new high precision example of use (a bound system composed by 2-massless particles with gravitational potential).*
4. *Help\Options*: *CMBE options (e.g. the high precision maximum number of decimals).*
5. *GUI improvements (e.g. implementation of a new user control for high precision numbers I/O).*

Additional comments:

The Many-Body Engine Module. For regular particles, CMBE provides a calculated property (*Particle.RelativisticMass*) for obtaining the relativistic mass as a function of velocity. As this approach cannot be used for massless particles, the dependency on momentum ($m = p/c$) was considered instead. The main impact of this change is related to the implementation of the second Newton's law. Thus, the *Next* methods, of both *Nbody* and *BigNBody* classes, were modified accordingly.

The Reactions Engine Module. The previous mentioned relation between momentum and relativistic mass was also used for the massless particles involved in both bi-particle reactions and decays (the *ReactionEngine.GetreactionOutput* and *ReactionEngine.GetDecayOutput* methods). For the particular case when the decay massless products are emitted along the movement direction we applied the Doppler shift equation [2]:

$$\upsilon_o = \upsilon_e \frac{1 \pm \beta}{\sqrt{1 - \beta^2}} \tag{1}$$

where υ_o is the observed frequency, and υ_e the emitted frequency.

The Toy-Model for Relativistic Nuclear Collision at present BNL energies. Following the goal of improving the relativistic nuclear collisions toy-model proposed in [1], we added the following reactions with photons (see the *ColliderReactions.xml* configuration file):

$$\begin{aligned}
\pi^0 &\rightarrow \gamma + \gamma \\
\gamma + p &\rightarrow \tilde{p} + p + p \\
\gamma + \tilde{p} &\rightarrow \tilde{p} + p + \tilde{p} \\
p + \tilde{p} &\rightarrow \gamma + \gamma \\
\gamma + n &\rightarrow \tilde{n} + n + n \\
\gamma + \tilde{n} &\rightarrow \tilde{n} + n + \tilde{n} \\
n + \tilde{n} &\rightarrow \gamma + \gamma .
\end{aligned}$$

HIJING [3,4] is a Monte Carlo program based on QCD models for multiple jets production. In Fig. 1 we present, for exemplification, a CMBE–HIJING comparative analysis for 100 Cu + Cu ultracentral collisions at 200 A GeV/c, the maximum BNL energy [5].

The differences between CMBE and HIJING can be explained by both, dissimilarities in the reaction lists, and by the fact that HIJING takes into account the minijet production, with increasing weight for high-energy hadron and nuclear interactions. In relativistic heavy-ion collisions, minijets are responsible for the main transverse energy production in the central rapidity region. This generates, at least in part, the differences between HIJING and CMBE, mainly observed at mid-rapidity. Furthermore, HIJING also incorporates nuclear effects such as final state interactions and parton shadowing for heavy-ion interactions.

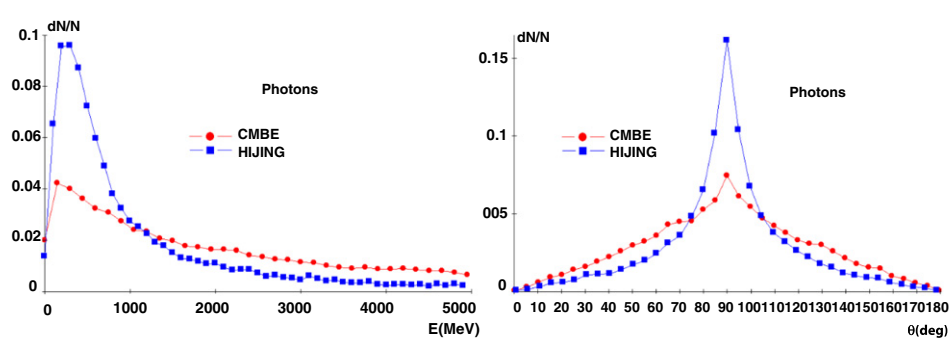

Fig. 1. CMBE–HIJING comparative study. Photon distributions for 100 Cu + Cu ultracentral collisions at 200 A GeV/c. Left: Energy distribution. Right: Angular distribution.

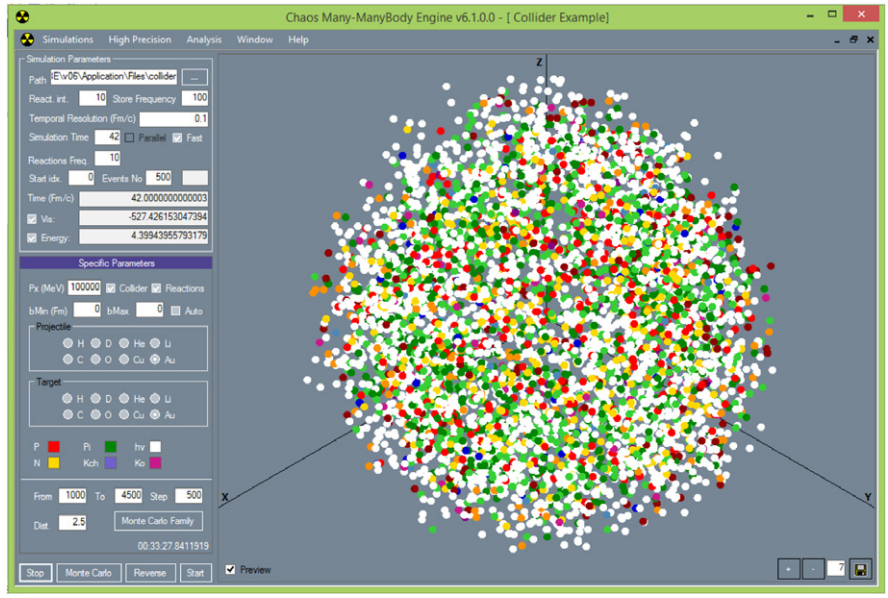

Fig. 2. Chaos Many-Body Engine v06.1. Au + Au collision at maximum BNL energy (preview).

High precision framework — new example of use. As an exemplification of CMBE high precision capabilities, we considered also a bound system composed of 2 identical massless particles with gravitational potential. By imposing also the stationary de Broglie wave condition, we obtained the following simple equations:

$$m = \sqrt{n} m_P \tag{2}$$

$$r = \sqrt{n} \frac{\hbar}{c m_P} \tag{3}$$

where m is the relativistic mass, r the system radius, n the principal quantum number, and m_P the Planck mass. Taking into account the magnitude order of quantities involved, we chose to work at 50 decimals precision (see the Help/Options, "Max. number of decimals" CMBE setting).

Acknowledgment

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