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Orthogonal Collision of Particles Produces New Physical State

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Abstract

Collider is a machine or device that usually causes two beams of high-speed particles moving to collide in a straight line. The fundamental purpose of a collision is to obtain an abnormal mass-energy density and attempt to discover new physics and new substances namely new physical states. However, linear collisions are not easy to achieve the above purpose. Through the comparable experiment of rear-end collision, head-on collision and orthogonal collision of two low-velocity particles, this paper theoretically proposes a new idea that the orthogonal collision between two-beam high-velocity particles can really produce an abnormal mass-energy density. This machine based on the new idea of orthogonal collision can not only greatly reduce the construction cost of colliders, but also is the most effective way to achieve the purpose of collision.

Keywords

Collider, Orthogonal Collision, Mass-Energy Density, New Physical State

1. Introduction

Exploring mysteries of the universe and finding new matter are the basic goal of physical research. The equipment for such an exploration is a collider. Usually, a linear collider is a constructed device in which two-type or one-type particles with high speeds collide each other in a straight line to form a concentrated energy or a new physical state, such as the appearance of Higgs particles [1] [2] [3]. The conventional linear collider is constructed in a way that it first uses several accelerators to gradually accelerate the two streams of particles that are injected, and then a head-on collision happens when they reach a certain beam strength and energy [4] [5]. It means that accelerator and collider are actually one system. In the storm of particle collisions, only a few particles collide. People are going to measure the signs of particle collisions from electric light and flint. The collider is an instrument for measuring experiments with high-energy particles and discovering "new states" or "new matter". Therefore, colliders have a wide range of applications in high-energy particle physics, condensed matter physics, plasma physics and astrophysics [6] [7] [8] [9].

In order to get the energy of a linear collider, it is first necessary to produce high-energy (or high-speed) particles. The acquisition of high-energy particles requires a variety of particle accelerators. Since the 1960s, many types of accelerators or colliders have emerged [10] [11] [12]. For example, according to the type of accelerated particles, they can be divided into positron-electron collider, electron-proton collider, electron-ion collider, heavy ion collider, and other particle colliders [13] [14] [15]. According to the accelerated particle energy, they can be divided into low-energy, medium-energy and high-energy accelerators, even ultrahigh energy accelerators [16] [17] [18].

Centroid or center-of-mass dynamics of particles is complex in all linear colliders [19] [20] [21] [22]. The effectiveness of a collider can be simply compared with a moving-static collision and a moving-moving collision. When high-energy particles bombard a stationary target in a collider, only the center-of-mass energy (CME) is effective during particle collision, which accounts for only a part of total energy. However, if two beams of high-energy particles moved head-on with high energies $E_{1,2}$ collide, the combined centroid system has the beam energies about $2E$ [22]. Their total energy from moving-static collision and moving-moving collision can be simply calculated by using an addition.

There are two famous colliders in the world [23]. One is the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory in Long Island, USA, which was the only heavy ion collider in the world from 1984 when it was proposed to build the plan until it was put into operation in 2000 [24] [25]. The other is the Large Hadron Collider, located near Geneva, across the border between Switzerland and France, which officially opened on September 10, 2008, becoming the world's largest particle accelerator facility [26] [27]. The cost is in the billions of Euros [28] [29]. The existence of the Higgs boson was confirmed in 2012 [2] [30]. Recently, new exotic particle structures, including exotic four-quark particles, have been observed at the Large Hadron Collider [5]. The discovery of new particles has led to the desire to build larger ring colliders [3] [31] [32]. Of course, such collider would cost tens of billions of Euros.

Physicists are going to keep accelerating elementary particles and then having them collide head-on, for taking apart elementary particles that are smaller than atoms to get smaller particles. In order to create new tiny elementary particles, one must concentrate a large amount of energy into a very small volume, which is to obtain a higher energy density. The Relativistic Heavy Ion Collider is a device that connects particles at all levels of acceleration one after another. Heavy ions start from the series of electrostatic accelerators, pass particles through a transmission line to a linear accelerator and inject them into an intensifier, then send them to alternating gradient synchrotrons to accelerate, and finally inject them to a relativistic heavy ion collider through a beam transmission line. In the relativistic heavy ion collider, the same heavy ions collide with each other, accumulating and storing in two independent superconducting storage rings. Finally, two beams of heavy ion collide to obtain a higher energy density and look for a state of matter called quark-gluon plasma.

In the universe, matter and particles have three basic properties: mass, charge (electric charge and color charge), and spin (momentum). Among them, spin is the basic form of motion of matter (particles) in the universe. For the motion of stars in the Milky Way, it has both the tangential velocity around the center and the radial velocity towards the center. When two stars (particles) reach to each other, they may not move in a straight line, but in different directions, and will rotate with each other and even merge or collide in the end.

If two stars of equal mass and velocity collide head-on in a straight line, the energy of their collision is the sum of their respective energies which can be expected. New energy (or extra energy or abnormal energy) produced by a linear collision is not expected. How can a collider produce new unpredictable energies and new unpredictable matter (particles)? This paper first examines the form of linear collision with a rear-end collision and a head-on collision respectively. Then, an orthogonal collision is described and compared with the linear collision. However, in order to physically describe the performance of the three forms of collisions, we will focus on describing the interaction of the two low-velocity particles. It can be easily to generalize the collision performance of two particles to the interaction of two beams of high-velocity particles. At the end of the paper, conclusions and discussion are given. The study could answer a part of questions proposed by particle physicists who are fretting that they do not know what their next collider will be [33].

2. Linear Collision Form

In the real world, common collision events occur between vehicles or ships or airplanes with their relative moving speeds. Two cars can have a rear-end collision or a head-on collision in a straight-line road. Right angle collisions and other collisions at different angles can also occur between them on a crossing road point. Among them, the most definitive events can be mathematically described by three special angles of a 0-degree rear-end collision, a 180-degree head-on collision and a 90-degree right-angle collision. We focus on studying the energy formed by the collision of these three different angles.

We here design a test structure shown in **Figure 1** that compares a positron-electron collision in different forms. First, on the left-hand side of **Figure 1**, positrons and electrons are accelerated in a linear accelerator. They then separate and enter into a circular cavity on the right-hand side. The circular radius of the annular cavity is r.

In general, two beams of high-energy particles are widely used in the theoretical description of accelerator-colliders. The goal of accelerators is trying to

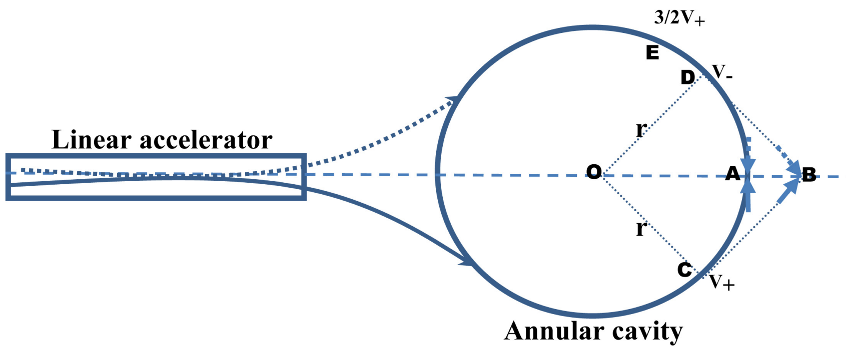

Figure 1. Three ways for negative-positive particles collided in a collider. Letter A denotes the linear collision point and letter B is at the orthogonal collision point. Point O indicates the center of an annular cavity with a radius of r, v_+ is the velocity of a positive particle at the tangent point C, v_- is the velocity of a negative particle at the tangent point D, and $3/2v_+$ is the velocity of a positive particle at the point E. Four points of the square are at O, C, B, D. The rectangular box is a linear accelerator. Solid arrows indicate the moving of positive particles and dashed arrows indicate the moving of negative particles.

accelerate particles and form a state of high speed, close to the speed of light c, so the interaction of particles in a collider needs to be expressed in relativistic terms, and one of the important factors is the Lorentz factor

$$\gamma_i = \frac{1}{\sqrt{1 - v_i^2 / c^2}}. \tag{1}$$

It is a parameter (an elastic ruler) varied from the velocity v_i of an object (or particle) relative to the speed of light c. Einstein introduced it into the relativistic momentum $p_i = \gamma_i m_i v_i$ and energy $E_i = \gamma_i(m_i c^2)$. The description of the center-of-mass energy and momentum and the interaction of two particles or two beams of particles must be carried out within the frame of this factor [22]. The usual collider uses a head-on collision of two beams of high-speed particles. Within a collider, there are different influence relationships and different collision opportunities between charged particles, so that there will be different collisions and moving angles among particles. Describing the complex interaction of these particles requires the use of wave dynamics, dynamical systems, instability analysis, external controlling fields, fluid modeling, nonlinear mathematics, and statistics [9] [34] [35] [36] [37] [38]. Colliders usually employ bunched beans of particles with approximately Gaussian distributions, where two bunch particles collided head-on with a frequency distribution can be expressed as the luminosity [22]. The development and application of these methods should be a broad field of particle physics.

Regardless of the particle number and speed of the two beams used by modern colliders, the purpose of colliders is to achieve how many pairs of particles exactly collide head-on per unit time. Only pairs of head-on collisions can achieve maximum energy density. Therefore, we focus on one of the pairs of oncoming particles to see how they interact. There are three special and valid cases of collision of two particles: head-on collision, rear-end collision, and orthogonal collision. Orthogonal collisions produce the most severe extreme events, indicating that the collisions produce the greatest energy density. In the development and design of colliders, this idea of orthogonal collision needs to be considered. Although the two beams of particles used in the future orthogonal colliders are also composed of a large number of particles, only the interaction of two particles is analyzed in this study in order to clearly describe the energy difference between orthogonal collisions and head-on collisions. Understanding the orthogonal collision of two low-velocity particles is the basis for further studying the orthogonal interaction of a large number of high-velocity particles.

A central part of this paper is an attempt to introduce the idea of orthogonal particle collisions for building future colliders. Therefore, it is not necessary to directly use the particle velocities obtained by high-speed and ultra-high-speed accelerators. Instead, we mainly compare the effects of the three-type collisions with low-velocity particles on various energies in this study.

According to the two low-velocity particles in the non-relativistic limit *i.e.*, when the velocities $v_{1,2} \ll c$ where c is the speed of light, we first examine a rear-end collision. The velocity at which an electron with mass m reaches the point D of the annular cavity is v_-. Also, we suppose that the velocity of a positron with its mass m reaching the point E is $3/2\,v_+$. Thereafter, we use a positive particle indicating a positron and a negative particle indicating an electron. Finally, the positive particle marked by + and the negative particle marked by – with their velocities collide each other at the point A and form new energy

$$m\left[3/2\,v_+\right]^2/2 - mv_-^2/2 = 5/8\,mv^2 . \tag{2}$$

The relative difference in the velocity between two particles is only $1/2\,v$, but the collision energy between them is $5/8\,mv^2$ (or $0.625mv^2$) as indicated in Equation (2), which is slightly larger than a particle energy $1/2\,mv^2$ (or $0.5mv^2$).

If the velocity of a positive particle is $2\,v_+$, its velocity is faster than that of negative one about a relative difference $1\,v$. In this case, the collision energy of a rear-end collision is $3/2\,mv^2$ (or $1.5mv^2$) showing in Equation (3).

$$m\left[4/2\,v_+\right]^2/2 - mv_-^2/2 = 3/2\,mv^2 . \tag{3}$$

We now look at the situation where two particles collide head-on each other. In **Figure 1**, a positive particle and a negative particle leave the linear accelerator and enter the annular cavity. They continue to travel in the annular cavity at the same velocity, but in different directions. When they reach the point A, a head-on collision event occurs. Before the point A, they are moving along a circular curve. But when they reach the limit of point A, the angle between two particles in the direction of motion is 180 degrees. The energy of this head-on collision is

$$mv_+^2/2 + mv_-^2/2 = mv^2 . \tag{4}$$

The energy at the time and at the point A for the head-on collision is the sum of two particle energies as indicated in Equation (4). Curiously, when the relative velocity difference of a rear-end collision is $1\,v$ while the relative velocity difference of a head-on collision is as large as $2v$, the energy of the rear-end collision is 1.5 times as large as the energy of the head-on collision. Actually, the velocity of a positive particle is $2v$ in the rear-end collision, which means that the positive particle must additionally increase a part of velocity v or a part of energy $0.5mv^2$.

The linear collision is the basic form of all modern colliders. In this way, all builders of colliders are working to increase the particle velocity expected before a collision. Therefore, the goal of a front-mounted multi-step acceleration device is to increase the velocity of particles for the final collision. In the case of the Relativistic Heavy Ion Collider, for example, particles which finally collide require the cumulative velocity accelerated during the pre-accelerators. First of all, a series of accelerators is to inject charged particles from the ground end of an accelerator into an acceleration tube, which is accelerated for the first time into a high-voltage electrode and changes the polarity of particle band through a charge conversion device. Then they enter the second acceleration tube to accelerate again, even for a third and fourth times, gradually increasing the velocity of particles. The final result is increasing the energy of heavy ions.

In order to gradually increase the velocity or energy of particles, the internal structure of a collider is complex and the length of a linear accelerator is also desirable to be long. In this way, the complexity of a constructed accelerator increases, and the spatial range also increases, which ultimately makes the cost of a collider greatly increased. This costs not only money, but also costs valuable resources and negatively impacts on the earth's environment.

3. Right-Angle Collision Form

We now switch another way to orthogonally collide a negative particle with a positive particle. In **Figure 1**, two low-velocity particles leave the linear accelerator to enter the annular cavity. They have velocities v_+ and v_- when they reach the point C and the point D, respectively. Then, instead of following the circular path to the point A, they start from the point C and the point D, and move at the same velocity along their tangent direction. They collide at the point B. At this time, the angle of collision between the negative particle and the positive particle is 90 degrees. It is a right-angle collision. Obviously, on the circumference of the annular cavity, the determination of point C and point D is unique. On the annular cavity, four points O, C, B, and D form a square while three points O, A, and B are in a straight line.

In the following, we look at their energies at the point B when they collide. Before point C and point D, two particles are moving along a circular track. They have centripetal forces with their unit vectors $\boldsymbol{n}_C$ and $\boldsymbol{n}_D$.

$$\boldsymbol{F}_C = \frac{m_+}{r} v_+^2 \boldsymbol{n}_C , \tag{5}$$

$$\boldsymbol{F}_D = \frac{m_-}{r} v_-^2 \boldsymbol{n}_D . \tag{6}$$

Two forces act at the point B, forming an event of collision which is named as a shear stress. Its expression is the vector product of two forces, *i.e.*,

$$\boldsymbol{\tau}_B = \left(\frac{m_+}{r} v_+^2\right) \cdot \left(\frac{m_-}{r} v_-^2\right) \cdot \left(\boldsymbol{n}_C \times \boldsymbol{n}_D\right). \tag{7}$$

The process of interaction is to bring the mass and energy of two particles from points C and D to collide at the point B. At the point B, the collision of particles is the formation of new physics, new energy, and new matter. New physics can be expressed in a new mathematical form. The formation of new energy is like a nuclear explosion while its extreme energy density is difficult to predict. New matter is the appearance of smaller particles that people have not yet discovered. Finding the newest and the smallest particles from colliders are a dream of physical scientists [30] [39].

When points C and D approach the point A, the collision of two particles is on a straight line. At this point, the angle at which two oncoming particles collide is $\alpha = 180$ degrees, i.e. $\boldsymbol{n}_C \times \boldsymbol{n}_D = \sin\alpha = 0$. Their shear stress is

$$\boldsymbol{\tau}_A = \left(\frac{m_+}{r} v_+^2\right) \cdot \left(\frac{m_-}{r} v_-^2\right) \cdot \left(\boldsymbol{n}_A \times \boldsymbol{n}_A\right) = 0. \tag{8}$$

Differing from at the point A, their angle between two particles is $\alpha = 90$ degrees at the point B, so the vector product equals to 1, namely $\boldsymbol{n}_C \times \boldsymbol{n}_D = \sin\alpha = 1$. The shear stress is

$$\tau_B = \left(\frac{m_+}{r} v_+^2\right) \cdot \left(\frac{m_-}{r} v_-^2\right) = \left(m_+ v_+^2\right)\left(m_- v_-^2\right) / r^2. \tag{9}$$

In the right-hand side of Equation (9), it expresses the mass-energy density per unit area. Equation (7) and Equation (9) show that the result of the collision between two forces is no longer a force, but a mass-energy density.

We can also select a point at which two particles collide on the extension line outside point B. Then the angle between two moving vectors of particles is $\alpha < 90$ degrees, so that

$$\boldsymbol{n}_C \times \boldsymbol{n}_D = \sin\alpha < 1,\ 0^\circ < \alpha < 90^\circ. \tag{10}$$

If we choose a point at where two particles collide on the inside extension line between point A and point B. Then the angle between two moving vectors of particles is $180 > \alpha > 90$ degrees, thus

$$\boldsymbol{n}_C \times \boldsymbol{n}_D = \sin\alpha < 1,\ 90^\circ < \alpha < 180^\circ. \tag{11}$$

Therefore, the mass-energy (or energy) density of their collision is the greatest only when two particles orthogonally collide at the point B as indicated in Equation (9).

From **Figure 1** and Equation (9), the mass-energy density of two particles leaving the annular cavity is $\left(m_+ v_+^2\right)\left(m_- v_-^2\right) / r^2$. This mass-energy density can be quantitatively estimated. According to the conservation of mass and energy, when two particles orthogonally collide at the point B, the collision point is a very small three-dimensional space. Then, the mass-energy $\left(m_+ v_+^2\right)\left(m_- v_-^2\right)$ that was originally distributed over the large area r^2 should now be concentrated in a very small volume. It is interesting that the mass-energy density on the square area r^2 will be concentrated in a very small volume r_B^3 with $r_B \ll r$ through this process of orthogonal collision. Here, the mass-energy dimension of two particles before collision is per unit area (in fact, particles also have thickness), and then the dimension at the time of collision is per unit volume (the volume space has the particle scale). The three-dimensional mass-energy density after collision is huge and incalculable. This is the formation of new physics and new matter.

4. Comparison of Different Collision Energies

To facilitate a comparison of the ratio between energy magnitudes of three collision scenarios, we take each mass of negative and positive particles as *m*. According to Equations (2) and (3), the energy ratio of a head-on collision to a rear-end collision is

$$R_{h-r} = \frac{mv^2}{(5/8)mv^2} = 8/5. \tag{12}$$

The energy of a head-on collision is 1.6 times as large as the energy of a rear-end collision. Conversely, a rear-end collision energy is 0.6 times to that of a head-on collision. In reality, the damage caused by the collision of two cars in the rear-end collision is smaller than that caused by the head-on collision. This also shows that no one is trying to construct a machine of rear-end collision in physical field.

Here, a question is remained. What is the energy ratio of an orthogonal collision to a linear collision in this type of collider? We consider that the radius of an annular cavity is one unit length $r = 1$, then the mass-energy density on the unit area of the collision at the point B is

$$\tau_B = \left(mv_+^2\right)\left(mv_-^2\right) = \left(mv^2\right)mv^2. \tag{13}$$

When it compares to the case of a head-on collision, the energy ratio is

$$R_{o-h} = \left(mv^2\right)mv^2 \big/ mv^2 = mv^2. \tag{14}$$

It can be found that the energy ratio formed from an orthogonal collision to a head-on collision is not a definite value, but a multiple of the change in mass and velocity of a particle.

When comparing the two energies of orthogonal collision and rear-end collision, their energy ratio is

$$R_{o-r} = \left(mv^2\right)mv^2 \Bigg/ \left(\frac{5}{8}mv\right)^2 = \frac{8}{5}mv^2. \tag{15}$$

Interestingly, the difference between Equations (14) and (15) is only 1 and 8/5 (or 1.6). This comparison shows that the energy of a head-on collision is slightly larger than that of a rear-end collision.

It can be noted that the addition of total energy is used in the collision of two particles along a straight line while the multiplication of total energy is used in the right-angle collision of two particles. The total energy of multiplication is larger than that of addition as long as the unit of each particle energy is larger than 2. It is true that we can get different mathematical values but used only multiplication and addition in a smaller number such as ($1 \times 1 = 1$) < ($1 + 1 = 2$), ($1 \times 2 = 2$) < ($1 + 2 = 3$), ($2 \times 2 = 4$) = ($2 + 2 = 4$), ($2 \times 3 = 6$) > ($2 + 3 = 5$), and ($3 \times 3 = 9$) > ($3 + 3 = 6$). These cases show that the value of one by any number is less than the sum between them while the value of two by two is equal to their sum.

The mass of a particle is very small, but the velocity when the particle is accelerated is very large. Of course, it is difficult to accelerate particles to the speed of light. For a particle with a mass unit of 1 gram, as long as the velocity of a negative particle or a positive particle reaches 1 m/s, the energy of an orthogonal collision is equivalent to the energy of two head-on collision particles. Actually, the velocity of a negative particle or a positive particle is rather large when they left accelerator to collide each other.

If we identify the head-on linear collision energy in Equation (3) and the orthogonal collision energy density in Equation (9), the energy ratio of the latter to the former increases with the square of particle velocity, as expressed in Equation (14). This analysis shows that the energy density of a collider in the form of orthogonal collision is rather large. This mechanism should be considered in the development of the next generation of colliders.

5. Conclusions and Discussion

Two particles or two beams of particles can collide at different angles. Specially, two particles can achieve a rear-end collision or a head-on collision along a straight line. In the rear-end collision, the particle in the back is 1.5 times faster than the particle in the front, but their energy of collision is only 0.6 times as large as that of a head-on collision. This shows that the energy of a head-on collision is larger than the energy of a rear-end collision. Whether two particles adopt linear acceleration or circular acceleration and if the final collision form of two particles is completed in a straight line, the collision energy is the sum of two-particle energies. The total energy of two beams of particles colliding head-on is roughly the sum of the energy that all pairs of particles can collide head-on. Therefore, the maximum energy produced by all current types of linear colliders can be expected. Of course, with the increase of an expected energy, the result of linear collision can also possibly form a fragmentation of original particles, but it is difficult to expect the formation of new physics, new energy and new matter or new particles. Thus, the linear collision is only a smashing machine.

In recent decades, the United States, Europe, Japan, China and other countries and agencies have built accelerators with different types, different energy levels and different motion tracks [3] [40] [41] [42]. The shape of particle motion orbit can be divided into a linear accelerator and a circular (ring) accelerator, but the final collision form of particles in a collider is the same, which is a head-on collision. To increase energy in the event of a head-on collision, one way is to increase expenses in constructing series of particle accelerators, such as the Large Hadron Collider, and other linear colliders in plans of Europe and China [3] [32] [43] [44]. This is called colliding dreams from physical scientists in Japan, China and Europe [33].

The study in this paper shows that orthogonal colliders can be currently manufactured by modifying the various annular head-on colliders that already exist around different places in the world. The basic principle of an orthogonal collider has been clearly expressed by the interaction of two low-velocity particles in this paper. This story described from two-particle orthogonal collision to two-beam-particle orthogonal collision can be well understood and generalized by public and scientific community under the non-relativistic limit. The orthogonal collision of two-beam high-velocity or high-energy particles can create more chances to form new matters in the relativistic frame. Therefore, various statistical and dynamic methods can also be applied to estimate the mass-energy density of orthogonal collisions.

The manufacture of orthogonal collider is relatively simple, just at the two determined points of a ring cavity with high-velocity or high-energy positrons and electrons moving along their tangent line and forming a crossing collision point outside the ring cavity. Another method is to construct a device that the particles emitted from two linear accelerators collide orthogonally. The ratio of the energy of an orthogonal collider to the energy of a linear collider is proportional to the square of their particle velocity. We believe that new physics and new matter can be produced by the orthogonal collision of two beam particles. Thus, the results in this paper could be useful for constructing a new generation of colliders and achieving the dream of physical scientists.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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