Matter-antimatter asymmetry may interfere with the detection of neutrinos

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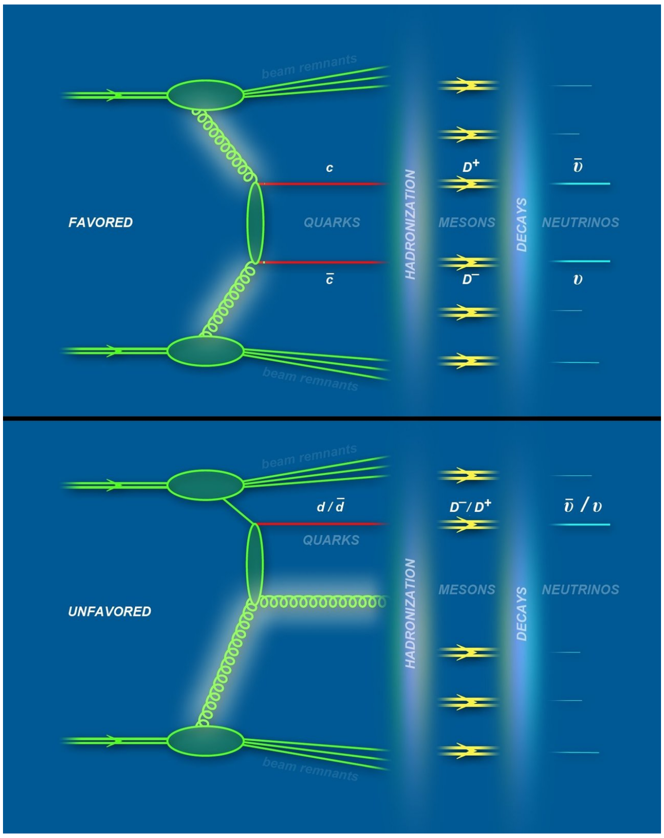

Comparison of mechanisms of favored and unfavored fragmentation of quarks. (Source: IFJ PAN). Credit: IFJ PAN

From the data collected by the LHCb detector at the Large Hadron Collider, it appears that the particles known as charm mesons and their antimatter counterparts are not produced in perfectly equal proportions. Physicists from Cracow have proposed their own explanation of this phenomenon and presented related predictions about consequences that are particularly interesting for high-energy neutrino astronomy.

In the first moments after the Big Bang, the universe was filled with equal amounts of particles and antiparticles. While it was cooling down, matter and antimatter began to merge and annihilate, becoming radiation. The matter that survived annihilation now comprises the universe, but this imbalance is poorly understood. In order to decipher this great mystery of modern science, physicists are trying to better understand all the mechanisms responsible for even the smallest disproportions in the production of particles and antiparticles. A group of scientists from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow, associated with the LHCb experiment at the Large Hadron Collider in Geneva, recently looked into one of these processes: the asymmetry appearing at the birth of charm mesons and antimesons. The conclusions from the analysis could be of very tangible practical significance.

According to modern physics, quarks are the most important indivisible building blocks that make up matter. We know of six flavours of quarks: up (u), down (d), strange (s), charm (c), bottom (b) and top (t); each flavour also has its own antimatter counterpart (often marked with a dash above the letter, read as "bar"). Quarks are generally formed in quark-antiquark pairs. They are extremely sociable particles: almost immediately after coming into being, they bind into hadrons, or groups of two, three, and sometimes more quarks or antiquarks, bonded with gluons (i.e. particles transferring strong nuclear interactions). The process of combining quarks/antiquarks into complexes is called hadronization.

Unstable hadrons built from quark-antiquark pairs are called mesons. If one of the quarks in a meson is a charm quark, the particle is called a charm meson and is denoted by the letter D (or for the charm antiquark: D with a bar above it). A pair built of a charm quark and a down antiquark is a D+ meson, and one consisting of a charm antiquark and down quark is a D- meson.

In measurements conducted in the last quarter of a century, including recently as part of the LHCb experiment, an interesting asymmetry was noticed. It turned out that D+ and D- mesons are not always produced in exactly the same proportions. In the case of processes observed in LHCb, initiated in collisions of counter-current beams of high-energy protons, this asymmetry was small, less than one percent.

"Charm quarks are mainly formed during gluon collisions in so-called hard interactions, and after birth, they hadronise into D mesons. We investigated another meson formation mechanism, known as unfavoured quark fragmentation. Here, the charm meson is created as a result of hadronization of a light (up, down, or strange) quark or antiquark. By means of the nuances of this mechanism, the asymmetry between kaons and antikaons, i.e. K+ and K- mesons, was explained earlier. Until now, however, it has not been investigated whether a similar mechanism could explain the asymmetry between the relatively massive D+ and D- mesons," says Dr. Rafal Maciula (IFJ PAN), the first author of the publication in the journal *Physical Review D*.

The LHCb detector mainly measures particles diverging from the point of collision of protons at large angles to the original direction of movement of these protons. According to the Cracow-based physicists, the asymmetry in the production of D mesons should be much greater if particles produced in a forward direction are taken into account, that is, along the direction of the proton beams. This means that the currently observed disproportion may be just the tip of an iceberg. Calculations suggest that in the case of "forward" collisions, unfavoured fragmentation (d, u, s ' D) may be comparable to conventional fragmentation (c ' D). As a result, the asymmetry between D+ and D- mesons may reach a high percentage, even at lower collision energies than those currently occurring in the LHC.

The research of the physicists from the IFJ PAN may have far-reaching consequences for neutrino observatories such as the IceCube Observatory in Antarctica. This detector, in which 49 scientific institutions from 12 countries collaborate, monitors a cubic kilometre of ice, located almost a kilometre below the surface, using thousands of photomultipliers. Photomultipliers track subtle light flashes initiated by the interaction of ice-forming particles with neutrinos, elementary particles very weakly interacting with ordinary matter.

IceCube registers several hundred neutrinos a day. It is known that a large proportion of them are created in the Earth's atmosphere in processes initiated by cosmic rays and taking place with the participation of protons. Other neutrinos may come from the Earth's core or from the Sun. It is assumed, however, that neutrinos with significant energies have reached the detector directly from distant cosmic sources, including supernovae, merging black holes or neutron stars.

"When interpreting data from the IceCube detector, the production of neutrinos in the Earth's atmosphere caused by ordinary cosmic radiation, including collisions involving protons, is taken into account. The thing is that some of these processes, resulting in the formation of neutrinos with high energies, take place with the participation of D mesons. Meanwhile, we show that the mechanism of production of these mesons in the atmosphere can be much more efficient than previously thought. So, if our assumptions are confirmed, some of the highly energetic neutrinos registered, now considered to be of cosmic origin, have actually appeared just above our heads and are disturbing the real picture of events in the depths of space," explains Prof. Antoni Szczurek (IFJ PAN).

When just the tip of the iceberg can be seen, inferences about what the rest of it looks like is more than risky. The model proposed by the Cracow-based physicists has the status of a hypothesis today. Perhaps it does fully describe the mechanism that occurs in reality. But it may also be that other processes are responsible for the asymmetry in the production of D mesons, maybe partially or even in their entirety.

"Fortunately, no other competitive proposal predicts such a clear increase in asymmetry in the production of D mesons at lower collision energies. So to check our assumptions, it would suffice in the LHC accelerator to direct a single beam onto a stationary target, which would significantly reduce the collision energy. Our model therefore meets the criteria of very reliable science: it not only explains previous observations, but above all, it can be rapidly verified. In addition, this can be done very cheaply," says Prof. Szczurek.

More information: Rafa? Maciu?a et al, D meson production asymmetry, unfavored fragmentation, and consequences for prompt atmospheric neutrino production, *Physical Review D* (2018). DOI: 10.1103/PhysRevD.97.074001