SPC REPORT ON LSAG DOCUMENTS

The CERN Scientific Policy Committee (SPC) was asked by the President of the CERN Council to examine the documents produced by the LHC Safety Assessment Group (LSAG) and to provide Council with an independent opinion on the conclusions stated in those documents. A dedicated SPC panel was set up, composed of Peter Braun-Munzinger, Matteo Cavalli-Sforza, Gerard 't Hooft, Bryan Webber and Fabio Zwirner. The documents made available to the panel were: "Review of the Safety of LHC Collisions", by the LHC Safety Assessment Group (LSAG report); "Astronomical Implications of Hypothetical Stable TeV-Scale Black Holes", by S.B.Giddings and M.L.Mangano (GM paper). After thorough review, discussion and ensuing endorsement by the full SPC, the requested opinion is summarized in the present document.

Introduction

When new accelerators such as the LHC are built, exploring higher energies than their predecessors, it is legitimate to ask whether there is any danger related to the production of new particles or states of matter not previously created artificially. Such a question was already addressed in the past: by an ad hoc Committee for the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory (RHIC) in 1999, and by the LHC Safety Study Group at CERN (LSSG) in 2003. Both reports concluded that there was no danger. The following objects of concern were considered, with emphasis on the last two, discussed in both reports: magnetic monopoles, vacuum bubbles, strangelets, black holes.

Concerns have recently been expressed on the possibility that microscopic, stable, neutral black holes may be produced at the LHC and then accrete matter sufficiently fast to pose a risk to Earth. This highly hypothetical possibility had already been excluded on the basis of very strong arguments, and most experts of the field consider this scenario as impossible. However, the LSAG report now provides, on the basis of the GM paper, a much stronger safety proof, relying only on solid experimental facts and firmly established theory, which should remove any residual concern. More generally, the LSAG report reviews the previous safety studies in the light of additional experimental results and theoretical understanding, and is able to confirm, update and extend the LSSG conclusions as described below.

No other exotic particles whose existence has been discussed in the scientific literature would pose any potential danger at the LHC. The methodology used by LSAG would be applicable to the evaluation of possible risks associated with other exotic particles or new states of matter that might be suggested in the future.

The LHC compared with cosmic-ray collisions

Section 2 of the LSAG report shows quantitatively that collisions of cosmic rays of the highest energies with the Earth, the Sun and other astronomical bodies occur naturally at energies equivalent to or larger than those of LHC collisions, and in numbers that exceed them by extremely large factors. The results and the considerations given in this section are the basis for the safety proofs given later in the paper.

The starting point of the proof is the observed and well-known flux (per square cm per second) of cosmic rays at center-of-mass energies that exceed those at the LHC by one to a few factors of 10. Considering the surfaces of the target planets and stars and their observed age, it is easily shown that such energetic LHC-like cosmic rays have already hit the Earth (or the Sun) in numbers equivalent to one hundred thousand (or one billion) times the total number of collisions expected over the duration of LHC experiments. Analogously, in the whole Universe, the equivalent of $3 \cdot 10^{13}$ complete LHC experiments are performed every second. As shown in the LSAG report, and reviewed below, the hypothesis that the LHC operation would threaten the existence of the Earth is irreconcilable with the fact that the Earth, the Sun and other objects in the Cosmos have persisted for billions of years in spite of their continuous exposure to energetic cosmic rays.

The comparison between cosmic ray collisions with target planets or stars and LHC collisions makes use of special relativity. Special relativity has been tested accurately in the laboratory for particles with velocities similar to and higher than the relative velocity of the two relevant reference frames; moreover, the experimental data on cosmic rays at energies up to more than an order of magnitude above the equivalent LHC energy are in agreement with special relativity.

Vacuum bubbles and magnetic monopoles

We fully endorse the conclusions of the LSAG report concerning the possible production of bubbles of new vacuum or magnetic monopoles, discussed in Section 3. The continuous bombardment of the Earth and other astronomical bodies by cosmic rays at centre-of-mass energies at and above that of the LHC means that such processes, if they exist, have occurred and are still occurring at a high rate throughout the Universe.

In the case of vacuum bubbles, the velocity of the object, once formed, is not relevant as it would have expanded and caused visible large-scale effects, whatever its state of motion and wherever it appeared, even in distant galaxies. Therefore no such objects are ever created within the energy range of cosmic ray collisions.

It is worth remarking in this context that head-on collisions between cosmic rays, at centre-of-mass energies enormously greater than those that will ever be accessible in Earth-based experiments, occur sufficiently frequently on cosmic scales that we can be completely confident that catastrophic disruption of the vacuum will never be a possibility at the LHC or any future accelerator.

In the case of magnetic monopoles, such objects could have been produced in cosmic ray collisions, but they are by definition highly ionizing and would therefore have been stopped inside the Earth or any other target body. The continuing existence of astronomical bodies shows that, if produced, magnetic monopoles must be harmless.

Microscopic black holes

Section 4 of the LSAG report addresses potential dangers associated with the production of microscopic black holes at the LHC. For the cases that were already considered in previous reports, it confirms their conclusions that there is absolutely no danger. In addition, Section 4 reviews the highly hypothetical production of neutral stable black holes, and the possibility that these black holes could be trapped inside the Earth. While such a possibility is dismissed by most of the experts, it is conceivable, and it could have potentially dangerous consequences if these highly hypothetical, neutral, stable microscopic black holes could accrete matter on Earth on time scales shorter than the natural lifetime of the solar system. For this to occur, a number of increasingly unlikely conditions should be satisfied: 1) the fundamental scale of gravity should be within the LHC energy range, possible only if extra spatial dimensions with very peculiar properties do exist; 2) Hawking radiation, and more general arguments for the decay of any black holes produced at the LHC, should fail; 3) the Schwinger mechanism, by which a charged black hole becomes electrically neutral via particle-antiparticle creation near the horizon, should still work, even though it is based on physical principles very close to those underlying Hawking radiation.

Going beyond the RHIC and LSSG reports, the above-mentioned possibility is now directly addressed by the LSAG report, on the basis of the GM paper, which is the most detailed and specialized presentation of all the scientific evidence we have on this issue. The GM paper admits from the start the possibility that compelling but not experimentally tested mechanisms, such as Hawking radiation, could be suppressed or absent. It chooses instead a conservative or "worst-case" scenario at every instance where an experimental or theoretical uncertainty is encountered. It then uses observational data on cosmic rays and on astronomical objects such as the Sun or compact stars to exclude any danger at the LHC.

In particular, at the LHC energy, any danger for the Earth on time scales lower than or comparable to the natural lifetime of the solar system can be ruled out on the basis of its contradiction with the observation of white dwarf stars of known mass, age and other properties. This conclusion, while entirely valid for the LHC, would need further work to be extended to conceivable future colliders of much higher energies. A powerful argument applicable also to higher energies is formulated making reference to observed neutron stars, but this argument relies on properties of cosmic rays and neutrinos that, while highly plausible, do require confirmation, as can be expected in the coming years.

On the basis of all these findings, we can conclude that there is no danger of whatever kind from the hypothetical production of black holes at the LHC.

Strangelets

Section 5 of the LSAG report deals with the possibility that particles containing strange quark matter, so-called 'strangelets', could be created in Pb-Pb collisions at the LHC and,

if stable and negatively charged, could coalesce with normal matter to possibly catalyze conversion of the world into strange matter. This case was already discussed in detail in the RHIC and LSSG reports. There it was argued, as recalled in the LSAG report, that: a) strangelet production at RHIC energies would be less likely than strangelet production in nucleus-nucleus collisions at lower energies such as at the Brookhaven AGS and CERN SPS accelerators; indeed, no trace of strangelet production was found in nearly a decade of Pb-Pb or Au-Au collision experiments performed at high luminosity; b) high energy cosmic rays bombarding the Moon for billions of years have yielded no evidence for events connected with strangelet production.

The results from seven years of running the RHIC program have in fact provided evidence that strangelet production is even less likely at the higher energy of the LHC. They have yielded strong experimental support for the hypothesis that particles are produced from a heat bath at a limiting temperature. The LSAG report shows that, on that basis, strangelet production at the LHC energy, since it involves particles with baryon number, will be less likely than at the lower RHIC energy. Hence, the data from the RHIC program strongly reinforce the arguments collected at the start of the RHIC program: there is no conceivable danger from strangelet production at LHC energy.

Conclusions

The LSAG report considered four specific objects of concern: magnetic monopoles, vacuum bubbles, strangelets, black holes. For vacuum instability and magnetic monopoles, the conclusions of previous reports are confirmed and, in the latter case, reinforced. For strangelets, the conclusions of previous reports are confirmed and reinforced by the analysis of RHIC data. For black holes, the LSAG report goes much beyond previous reports, on the basis of the GM paper. Replacing some highly plausible theoretical concepts of the previous reports with irrefutable observational data on cosmic rays and on astronomical bodies such as the Sun or compact stars, interpreted using firmly established theory, further layers of safety are added to the previously existing ones, excluding any possibility that the highly hypothetical production of black holes at the LHC could create a danger of whatever kind.

To summarize, we fully endorse the conclusions of the LSAG report: there is no basis for any concerns about the consequences of new particles or forms of matter that could possibly be produced at the LHC.