HE.6.2.02

Formation of Centauro and Strangelets in Nucleus–Nucleus Collisions at the LHC and their Identification by the ALICE Experiment [1]

A.L.S. Angelis[1], J. Bartke[2], M.Yu. Bogolyubsky[3], S.N. Filippov[4], E. Gładysz-Dziaduś[2], Yu.V. Kharlov[3], A.B. Kurepin[4], A.I. Maevskaya[4], G. Mavromanolakis[1], A.D. Panagiotou[1], S.A. Sadovsky[3], P. Stefanski[2] and Z. Włodarczyk[5]

[1]*Division of Nuclear and Particle Physics, University of Athens,Greece.*

[2]*Institute of Nuclear Physics, Cracow, Poland.*

[3]*Institute for High Energy Physics, Protvino, Russia.*

[4]*Institute for Nuclear Research, Moscow,Russia.*

[5]*Institute of Physics, Pedagogical University, Kielce, Poland.*

Abstract

We present a phenomenological model which describes the formation of a Centauro fireball in nucleus-nucleus interactions in the upper atmosphere and at the LHC, and its decay to non-strange baryons and Strangelets. We describe the CASTOR detector for the ALICE experiment at the LHC. CASTOR will probe, in an event-by-event mode, the very forward, baryon-rich phase space 5.6 $\leq \eta \leq$ 7.2 in 5.5×A TeV central $Pb + Pb$ collisions. We present results of simulations for the response of the CASTOR calorimeter, and in particular to the traversal of Strangelets.

1 Introduction:

The physics motivation to study the very forward phase space in nucleus–nucleus collisions stems from the potentially very rich field of new phenomena, to be produced in and by an environment with very high baryochemical potential. The study of this baryon-dense region, much denser than the highest baryon density attained at the AGS or SPS, will provide important information for the understanding of a Deconfined Quark Matter (DQM) state at relatively low temperatures, with different properties from those expected in the higher temperature baryon-free region around mid-rapidity, thought to exist in the core of neutron stars.

The LHC with an energy equivalent to 10^{17} eV for a moving proton impinging on one at rest, will be the first accelerator to effectively probe the highest energy cosmic ray domain. Cosmic ray experiments have detected numerous most unusual events which have still not been understood. These events, observed in the projectile fragmentation rapidity region, may be produced and studied at the LHC in controlled conditions. Here we mention the "Centauro" events and the "long-flying component". Centauros (Lates, Fugimito & Hasegawa 1980) exhibit relatively small multiplicity, complete absence (or strong suppression) of the electromagnetic component and very high $\langle p_{\mathrm{T}} \rangle$. In addition, some hadron-rich events are accompanied by a strongly penetrating component observed in the form of halo, strongly penetrating clusters (Hasegawa & Tamada 1996, Baradzei et al. 1992) or long-living cascades, whose transition curves exhibit a characteristic form with many maxima (Arisawa et al. 1994, Buja et al. 1982).

2 A model for the formation of Centauro and Strangelets

A model has been developed in which Centauros are considered to originate from the hadronization of a DQM fireball of very high baryon density ($\rho_{\mathrm{b}} \gtrsim 2\ \mathrm{fm}^{-3}$) and baryochemical potential ($\mu_{\mathrm{b}} >> \mathrm{m_n}$), produced in ultrarelativistic nucleus–nucleus collisions in the upper atmosphere (Asprouli, Panagiotou & Gładysz-Dziaduś 1994, Panagiotou et al. 1992, Panagiotou et al. 1989). In this model the DQM fireball initially consists of u, d quarks and gluons. The very high baryochemical potential prohibits the creation of $\mathrm{u\bar{u}}$ and $\mathrm{d\bar{d}}$ quark pairs because of Pauli blocking of u and d quarks and the factor exp $(-\mu_{\mathrm{q}}/\mathrm{T})$ for $\bar{\mathrm{u}}$ and $\bar{\mathrm{d}}$ antiquarks, resulting in

[1]Further information at: http://home.cern.ch/∼angelis/castor/Welcome.html

the fragmentation of gluons into s$\bar{s}$ pairs predominantly. In the hadronization which follows this leads to the strong suppression of pions and hence of photons, but allows kaons to be emitted, carrying away strange antiquarks, positive charge, entropy and temperature. This process of strangeness distillation transforms the initial quark matter fireball into a slightly strange quark matter state. The finite excess of s quarks and their stabilizing effects, in addition to the large baryon density and binding energy and the very small volume, may prolong the lifetime of the Centauro fireball, enabling it to reach mountain-top altitudes (Theodoratou & Panagiotou 1999). In the subsequent decay and hadronization of this state non-strange baryons and strangelets will be formed. Simulations show that strangelets could be identified as the strongly penetrating particles frequently seen accompanying hadron-rich cosmic ray events (Gładysz-Dziaduś & Włodarczyk 1997, Gładysz-Dziaduś & Panagiotou 1995)

In this manner, both the basic characteristics of the Centauro events (small multiplicities and extreme imbalance of hadronic to photonic content) and the strongly penetrating component are naturally explained. In table 1 we compare characteristics of Centauro and strongly penetrating components (Strangelets), either experimentally observed or calculated within the context of the above model, for cosmic ray interactions and for nucleus–nucleus interactions at the LHC.

Table 1. Average characteristic quantities of Centauro events and Strangelets produced in Cosmic Rays and expected at the LHC.

Centauro	Cosmic Rays	LHC
Interaction	"$Fe + N$"	$Pb + Pb$
$\sqrt{s}$	$\gtrsim$ 6.76 TeV	5.5 TeV
Fireball mass	$\gtrsim$ 180 GeV	$\sim$ 500 GeV
y_{proj}	≥ 11	8.67
γ	$\geq 10^4$	$\simeq 300$
η_{cent}	9.9	$\simeq 5.6$
$\Delta\eta_{cent}$	1	$\simeq 0.8$
$< p_T >$	1.75 GeV	1.75 GeV (*)
Life-time	10^{-9} s	10^{-9} s (*)
Decay prob.	10 % (x $\geq$ 10 km)	1 % (x $\leq$ 1 m)
Strangeness	14	60 - 80
f_s (S/A)	$\simeq 0.2$	0.30 - 0.45
Z/A	$\simeq 0.4$	$\simeq 0.3$
Event rate	$\gtrsim$ 1 %	$\simeq$ 1000/ALICE-year
"Strangelet"	Cosmic Rays	LHC
Mass	$\simeq$ 7 - 15 GeV	10 - 80 GeV
Z	$\lesssim 0$	$\lesssim 0$
f_s	$\simeq 1$	$\simeq 1$

(*) assumed

3 Design of the CASTOR detector

With the above considerations in mind we have designed the CASTOR (Centauro And STrange Object Research) detector (Angelis et al. 1997) for the ALICE heavy ion experiment at the LHC, in order to study the very forward, baryon-dense phase space region. CASTOR will cover the pseudorapidity interval $5.6 \leq \eta \leq 7.2$ and will probe the maximum of the baryon number density and energy flow. It will identify any effects connected with these conditions and will complement the physics program pursued by the rest of the ALICE experiment in the baryon-free mid-rapidity region. Figure 1 depicts the net baryon number pseudorapidity distribution as predicted by the HIJING Monte-Carlo generator for an average central $Pb + Pb$ collision at the LHC, with the acceptance of CASTOR superimposed on the plot.

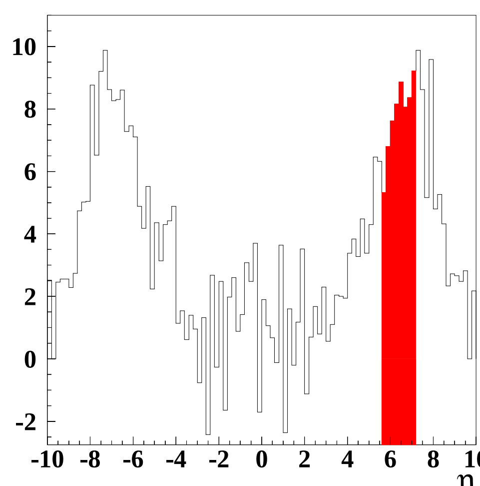

Figure 1: Average net baryon number pseudorapidity distribution obtained from 50 central $Pb + Pb$ HIJING events.

The CASTOR calorimeter is azimuthally symmetric around the beam pipe and is shown schematically in figure 2. It comprises electomagnetic and hadronic sections and is longitudinally segmented so as to measure the profile of the formation and propagation of cascades. The calorimeter is made of layers of active medium sandwiched between tungsten absorber plates. The active medium consists of planes of silica fibres and the signal is the Cherenkov light produced as they are traversed by the charged particles in the shower. The fibres are inclined at 45 degrees relative to the incoming particles in order to maximize the light output. The calorimeter is azimuthally divided into 8 self-supporting octants. In the current stage of the design each octant is longitudinally segmented into 80 layers, the first 8 ($\simeq$ 14.7 X_0) comprising the electromagnetic section and the remaining 72 ($\simeq$ 9.47 λ_I) the hadronic section. The calorimeter will be read out via air light guides made out of stiff plastic, internally painted with UV reflecting paint. The produced Cherenkov photons will propagate along the silica fibres to the lateral surfaces of the calorimeter where they will exit into the light guides. Inside the light guides they will be directed to PM tubes equipped with quartz photocathode entry windows to optimally match the wavelength of the Cherenkov light. It is envisaged to couple together the light output from groups of 4 consecutive active layers into the same light guide, giving a total of 20 readout channels along each octant.

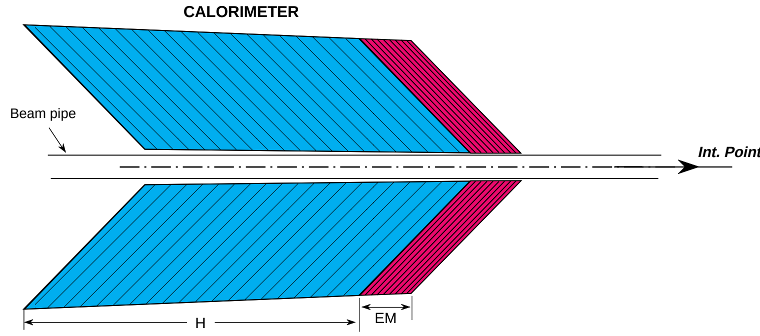

Figure 2: Schematic representation of the CASTOR calorimeter.

4 Simulation of the CASTOR calorimeter performance

We have made detailed GEANT simulations of the response of the CASTOR calorimeter. Figure 3 shows the total number of Cherenkov photons produced, retained and propagated inside the fibres, as a function of the incident particle energy for incident photons and hadrons from one central LHC $Pb + Pb$ HIJING event. About 210 Cherenkov photons per GeV are obtained for incident photons and 129 Cherenkov photons per GeV for incident hadrons. The accurate measurement of both the electromagnetic and hadronic energy components is a prerequisite for an effective Centauro search and the CASTOR calorimeter is optimized in that respect.

In addition we have simulated the interaction of a Strangelet with the calorimeter material, using the simplified picture described in (Angelis et al. 1998, Gładysz-Dziaduś & Włodarczyk 1997). As an example figure 4 shows the response of the calorimeter to one central LHC $Pb + Pb$ HIJING event, to which has been added a Strangelet of A_{str}=20, E_{str}=20 TeV and quark chemical potential μ_{str}=600 MeV (energy conservation has been taken into account). Figure 4a shows the energy deposition along the octant which contains the Strangelet, while figure 4b shows the average of the energy deposition along the remaining seven octants.

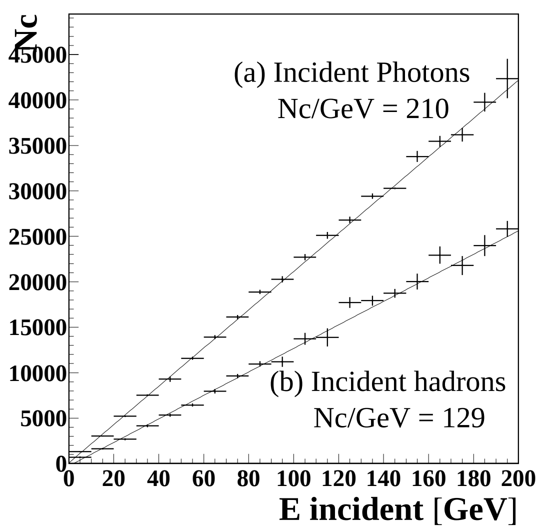

Figure 3: Simulation of the total number of Cherenkov photons produced, retained and propagated inside the fibres vs. incident particle energy: (a) For incident photons, (b) For incident hadrons.

The study of such simulated events shows that the signal from an octant containing a Strangelet is much larger than the average of the remainder, while its transition curve displays long penetration and many maxima structure such as observed in cosmic ray events.

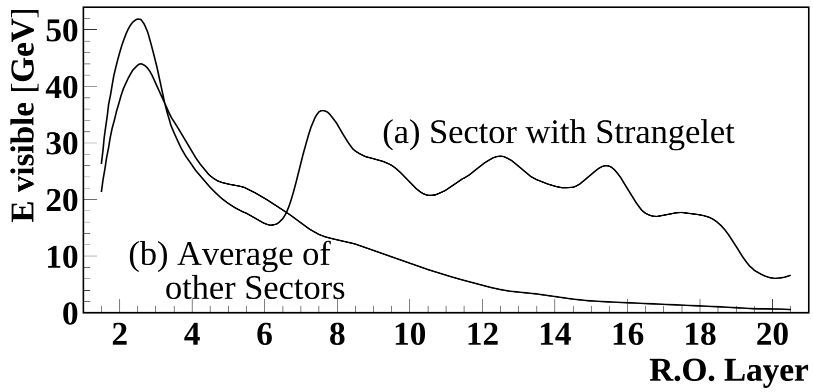

Figure 4: Simulation of the energy deposition in the readout layers (couplings of 4 consecutive sampling layers) of the CASTOR calorimeter: (a) In the octant containing the Strangelet, (b) Average of the other octants.

5 Conclusions

We have developed a model which explains Centauro production in cosmic rays and makes predictions for $Pb + Pb$ collisions at the LHC. Our model naturally incorporates the possibility of Strangelet formation and the "long-flying component" frequently seen accompanying hadron-rich cosmic ray events is assimilated to such Strangelets. We have designed a detector well suited to probe the very forward region in $Pb + Pb$ collisions at the LHC, where very large baryon number density and energy flow occur. CASTOR will identify any effects connected with these conditions, while it has been particularly optimized to search for signatures of Centauro and for long-penetrating objects. We have simulated the passage of Strangelets through the CASTOR calorimeter and we find large energy deposition, long penetration and many-maxima structures similar to those observed in cosmic ray events.

Acknowledgements

This work has been partly supported by the Hellenic General Secretariat for Research and Technology ΠΕΝΕΔ 1361.1674/31-1/95, the Polish State Committee for Scientific Research grants 2P03B 121 12 and SPUB P03/016/97, and the Russian Foundation for Fundamental Research grant 96-02-18306.

References

Angelis, A.L.S. et al. 1998, INP 1800/PH, Kraków 1998.

Angelis, A.L.S. et al. 1997, CASTOR draft proposal, Note ALICE/CAS 97–07.

Arisawa, T. et al. 1994, Nucl. Phys. B424, 241.

Asprouli, M.N., Panagiotou, A.D. & Gładysz-Dziaduś, E. 1994, Astropart. Phys. 2, 167.

Baradzei, L.T. et al. 1992, Nucl. Phys. B370, 365.

Buja, Z. et al. 1981, Proc. 17th ICRC, Paris Vol.11 p.104.

Gładysz-Dziaduś, E. & Włodarczyk, Z. 1997, J. Phys. G: Nucl. Part. Phys. 23, 2057.

Gładysz-Dziaduś, E. & Panagiotou, A.D. 1995, Proc. Int. Symp. on Strangeness & Quark Matter, eds. G. Vassiliadis et al., World Scientific, p.265.

Hasegawa, S. & Tamada, M. 1996, Nucl. Phys. B474, 225.

Lates, C.M.G., Fugimito, Y. & Hasegawa, S. 1980, Phys. Rep. 65, 151.

Panagiotou, A.D. et al. 1989, Z. Phys. A333, 355.

Panagiotou, A.D. et al. 1992, Phys. Rev. D45, 3134.

Theodoratou, O.P. & Panagiotou, A.D. 1999, $26^{\rm th}$ ICRC .