Formation of Centauro in Pb + Pb Collisions at the LHC and their Identification in the ALICE Experiment

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.

E-mail: aris.angelis@cern,ch
Web: http://home.cern.ch/∼angelis/castor/Welcome.html

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 strangeness-rich objects. We describe the CASTOR calorimeter for the ALICE experiment at the LHC. CASTOR will probe 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 CASTOR to the passage of strangeness-rich objects.

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 an environment with very high baryochemical potential. The study of this baryon-dense region at the LHC is expected to provide important information for the understanding of a Deconfined Quark Matter (DQM) state at relatively low temperatures, which might exist in the core of neutron stars.

The LHC will be the first accelerator to effectively probe the highest energy cosmic ray domain. Cosmic ray experiments have detected numerous very unusual events which have still not been understood. These events, observed in the projectile fragmentation region, may be produced and studied at the LHC in controlled conditions. Here we mention the "Centauro" events and the "long-flying component". Centauros [1] 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 (SPC) observed in the form of halo, strongly penetrating clusters [2] or long-living cascades, whose transition curves exhibit a characteristic form with many maxima [3].

2. A model for Centauro formation

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 [4, 5, 6]. 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, resulting in the fragmentation of gluons predominantly into $\mathrm{s\bar{s}}$ pairs. In the hadronization which follows pions and hence photons are strongly suppressed. Kaons can however be emitted, cooling the system and carrying away strange

† Also at CERN.

antiquarks, positive charge and entropy. 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, along with 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 [7]. In the subsequent decay and hadronization of this state non-strange baryons but also strangeness-rich states will be formed. Simulations show that such states could be identified as the strongly penetrating particles frequently seen accompanying hadron-rich cosmic ray events [8, 9]

This way the basic characteristics of both the Centauro and the SPC are naturally explained. Table 1 compares characteristics of Centauro and SPCs, experimentally observed or calculated using the above model, for cosmic ray interactions and $Pb + Pb$ collisions at the LHC.

Table 1. Average characteristics of Centauro and Strange Objects formed in Cosmic Rays and expected at 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}	$\geq$ 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 %	$\simeq 10^3$/ALICE-year
Strange Object	**Cosmic Rays**	**LHC**
Mass	$\simeq$ 7 - 15 GeV	10 - 80 GeV
Z	$\lesssim$ 0	$\lesssim$ 0
f_s	$\simeq$ 1	$\simeq$ 1

(*) assumed

3. The CASTOR calorimeter

We have designed CASTOR (Centauro And STrange Object Research) [10] 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 $5.6 \leq \eta \leq 7.2$, where the maximum of the baryon number density is expected to lie. The CASTOR calorimeter is symmetric around the vacuum pipe and is divided into 8 azimuthal octants It is also segmented longitudinally so as to measure the profile of the formation and propagation of cascades and the electromagnetic and hadronic content of the incident energy. It is made of layers of active medium sandwiched between tungsten absorber plates. Silica fibres have been chosen as the active medium and the signal is the Cherenkov light produced as they are traversed by the charged particles in the cascades. The fibres are inclined at 45 degrees relative to the incoming particles in order to maximize the light output. The light from groups of consecutive active layers will be coupled into the same light guide, giving a total of 20 readout channels along each octant.

We have made detailed GEANT simulations of the CASTOR calorimeter response. In addition, we have simulated the interaction of a strangeness-rich object with the calorimeter using a simplified picture [8, 11]. As an example figure 1 shows the response of the calorimeter to one central LHC $Pb+Pb$ HIJING event, to which has been added a strange object of $\mathrm{A_{str}}$=20, $\mathrm{E_{str}}$=20 TeV and μ_{str}=600 MeV (energy conservation has been taken into account). The transition curves of this object show large energy deposition, long penetration and many-maxima structures similar to those observed in cosmic ray events.

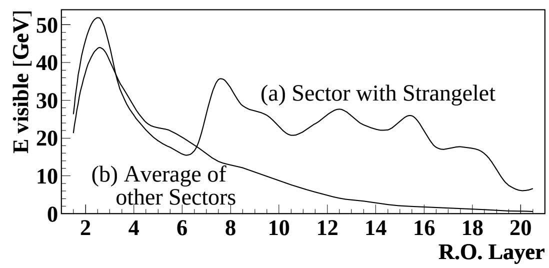

Figure 1. Simulation of the energy deposition in the CASTOR calorimeter: (a) Along the octant containing the strangeness-rich object, (b) Average of the other octants.

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

[1] Lates, C.M.G., Fugimito, Y. & Hasegawa, S. 1980 *Phys. Rep.* **65** 151.
[2] Hasegawa, S. & Tamada, M. 1996 *Nucl. Phys.* **B474** 225.
[3] Arisawa, T. et al. 1994 *Nucl. Phys.* **B424** 241.
[4] Asprouli, M.N., Panagiotou, A.D. & Gładysz-Dziaduś, E. 1994 *Astropart. Phys.* **2** 167.
[5] Panagiotou, A.D. et al. 1992 *Phys. Rev.* **D45** 3134.
[6] Panagiotou, A.D. et al. 1989 *Z. Phys.* **A333** 355.
[7] Theodoratou, O.P. & Panagiotou, A.D. 1999 26th ICRC.
[8] Gładysz-Dziaduś E. & Włodarczyk, Z. 1997 *J. Phys. G: Nucl. Part. Phys.* **23** 2057.
[9] Gładysz-Dziaduś E. & Panagiotou, A.D. 1995 Proc. Int. Symp. Strangeness & Quark Matter, eds. G. Vassiliadis et al., World Scientific, p.265.
[10] Angelis, A.L.S. et al. 1997 Note ALICE/CAS 97–07.
[11] Angelis, A.L.S. et al. 1998 INP 1800/PH, Kraków.