Fifth International Conference on
PERSPECTIVES IN HADRONIC PHYSICS
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

22 - 26 May 2006

Searching for Strange Quark Matter with the
CMS/CASTOR Detector at the LHC

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These are preliminary lecture notes, intended only for distribution to participants
Searching for Strange Quark Matter with the CMS/CASTOR Detector at the LHC

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http://cmsdoc.cern.ch/castor/

V International Conference on PERSPECTIVES IN HADRONIC PHYSICS Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

ICTP 22-26 May, 2006
CASTOR Calorimeter at CMS
Exotic Events in Cosmic Rays
Phenomenological Models & MC Simulations
“Strangelet” Identification Analysis
CASTOR Prototypes - Beam test Results
Summary
CASTOR Calorimeter at CMS
CMS Forward Detectors

CASTOR
5.2 < η < 6.6

TOTEM T2

HF

TOTEM T1

IP
CASTOR Calorimeter

Segmentation: 16(azimuth) x 14( in depth) = 224 channels
CASTOR Calorimeter

Stage I
16x10 = 160 Channels

Stage II
16x4 = 64 Channels

PMT

Air-core Light Guide subtending 5 W/Q plates

W/Q plates

EM section 20 X₀

H section 10.3  λ₁
Exotic Events in Cosmic Rays
Typical Emulsion / Lead Chambers
Exotic Cosmic Ray Events

CENTAURO SPECIES

Abnormal hadron dominance (in N and E), high $p_T$, low multiplicity

- CENTAURO of original type (5 “classical” Chacaltaya + over a dozen others)
  $N_h \sim 100$, $p_T \sim 1.75$ GeV/c

- MINI-CENTAUROS
- CHIRONs

STRONGLY PENETRATING COMPONENT

cascades, clusters, halos,
frequently accompanying CR hadron-rich events.

Figure 2.5: Diagram of the number of hadrons and hadronic energy fraction: Chacaltaya events with the total visible energy greater than 100 TeV [38]: (o) Centauro, (x) Mini-Centauro, (●) others; (⋆) C-K [36].
Long Flying Component
(Strangelet ?)

Measurement settings:
100 µm shower core diameter → threshold ~ 3 TeV

1.5 $\lambda_I$ Hadron limit
3.6 $\lambda_I$

3.6 $\lambda_I$
3.2 $\lambda_I$
Phenomenological Models
MC Simulations
Estimates for Centauro at LHC

- **Energy density**
  \[ \varepsilon \sim 3 - 25 \text{ GeV/fm}^3, \]

- **Temperature**
  \[ T \sim 130 - 300 \text{ MeV} \]

- **Baryo-chemical potential**
  \[ \mu_b \sim 0.9 - 1.8 \text{ GeV/fm}^3 \]

**CNGEN**

Centauro & Strangelet Generator

- Central collision at the top of the atmosphere
  \[ E_p \sim 1740 \text{ TeV} \]

- QUARK MATTER FIREBALL in the baryon-rich fragmentation region
  - High \( \mu_q \) suppresses production of \((u \bar{u}), (d \bar{d})\), favoring \( g \rightarrow s \bar{s} \)

- **SQM FIREBALL**
  - Stabilizing effects of \( s \) quarks \( \rightarrow \) long lived state

- **EXPLOSION**
  - \( \sim 75 \) non strange baryons + strangelet \((A \sim 10 - 15)\)

- Strangelessness distillation mechanism

C. Greiner et al.,

Astroparticle Phys. 2(1994)167
Pressure of (u,d) quark-gluon plasma

Minimization of Bag energy \((dE/dR = 0)\) in spherical DQM distribution with radius \(R\) and \(N_q\) massless quarks.

\[
P_{qg} = \frac{8}{45}\pi^2 T^4 + \mu_q^2 T^2 + \frac{\mu_q^4}{2\pi^2} = (2.034N_q/4\pi)(1/R^4) = B
\]

For CR Centauro \((\mu_q \sim 600 \text{ MeV}, T \sim 130 \text{ MeV}, N_q \sim 225)\)

\[R = r_o N_b^{1/3} \sim 1.43 \text{ fm} \quad \Rightarrow \quad r_o = 0.34 \text{ fm} \quad (\sim r_o \text{ ‘collapsed’ nucleus})\]

Ground state of hadronic matter

QCD true Ground State

SQM: “Strangelet” Neutron Star
Stable Strangelet interaction in CASTOR MC-algorithm

Strangelet is considered with radius:  \( R = r_0 A^{1/3} = \left[ \frac{3\pi \cdot A_{\text{str}}}{2 \left( 1 - \frac{2a_s}{\pi} \right) \left( \mu_s^3 + \left( \mu_s^2 - n_s^2 \right)^{3/2} \right)} \right]^{1/3} \)

The rescaled \( r_0 \) is determined by the number density of the strange matter: \( n = A/V = (1/3)(n_u+n_d+n_s) \)

where \( n_i = \partial \Omega_i/\partial \mu_i; \Omega(m_i,\mu_i,a_s) \), taking into account the QCD \( O(a_s) \) corrections to the properties of SQM.

Mean interaction path:  \( \lambda_{\text{str-W}} = \frac{A_w \cdot m_N}{\pi \left( 1.12 \cdot A_w^{1/3} + r_0 A_{\text{str}}^{1/3} \right)^2} \)

Strangelets passing through the detector collide with W nuclei:

*Spectator part* is continuing its passage.

*Wounded part* produces particles in a standard way.

\[ \Rightarrow A'_{\text{str}} = A_{\text{str}} - N_n \]

Particles produced in successive interactions initiate electromagnetic-nuclear cascades.

Process ends when strangelet is destroyed.

MC - Stable Strangelet in CASTOR

Stable Strangelets: $E = 5-7.5$ TeV; $E = 12-16$ TeV

CASTOR Geometry configuration

1 layer: 5mm W+2mm quartz plate $\sim 2.37 X_0$
1 RU = 7 layers per readout unit
16 (in $\phi$) x 18 (in z) readout channels
Total depth: $\sim 300 X_0$, 10.5 $\Lambda_{int}$

LOW ENERGY STRANGELETS ($\sim 5$ TeV)
MAY BE SEEN ABOVE BACKGROUND

P. Katsas
Strangelet Identification Analysis

P. Katsas
CASTOR Calorimeter

Segmentation

14 Sections/Sector (longitudinal)

16 Sectors (azimuthal)

Figure 1: CASTOR front view.
HIJING Pb+Pb Event at $\sqrt{s} = 5.5$ TeV

$E_{\text{tot}} \sim 130$ TeV
$\sim 8$ TeV/sector

$N < 100/$sector

Figure 3: Pseudorapidity and energy distribution of the produced particles for a central HIJING event.
Total Energy Distribution in Sectors - HIJING

Calorimeter Depth (RUs)

Energy
Energy distributions in CASTOR

**HIJING**

Total Energy in Sector  |  Energy in RU

**Strangelet in one sector**

Total Energy in Sector  |  Energy in RU

Average of 16 Sectors

A = 15  
E = 7.5 TeV

Sector  |  (Depth)  |  RU
Strangelet identification & Analysis

- Event-by-event analysis
- Analysis procedure in 2 steps:

\[ \sigma_E = \frac{E_i - \langle E \rangle}{\sigma_{sd}} \]

\[ \sigma_{\text{fluctuations}} = \frac{\text{energy distribution per RU}}{\text{average distribution}} \]

\[ \langle E \rangle = \text{mean energy in sectors} \]

(i = 1 – 16 sectors)

Large magnitude of energy fluctuations in RUs manifest abnormal transition curves
Analysis Results w/t background

$E_{\text{str}} = 7.5 \text{ TeV}$

$E_{\text{str}} = 10 \text{ TeV}$

$\sigma_{\text{fluctuations}}$

sector containing Strangelet + HIJING

sectors containing HIJING Pb+Pb

EM+H section

EM-cut only H-section
Prototypes - Beam test Results

L. Gouskos

CMS Reports
NIM publications
CASTOR Proto I Beam Test
Energy Resolution - Electrons

Resolution of CASTOR Proto II: 4 APD's

- $\chi^2 / \text{ndf} = 0.2937 / 3$
- $p0 = 0.001154 \pm 0.2115$
- $p1 = 0.4767 \pm 0.09652$
- $p2 = 1.967 \pm 0.7082$

Resolution of CASTOR Proto II: 6 APD's

- $\chi^2 / \text{ndf} = 0.1439 / 3$
- $p0 = 0.03247 \pm 0.007557$
- $p1 = 0.3586 \pm 0.1063$
- $p2 = 1.743 \pm 0.6166$

Resolution of CASTOR Proto II, PMT's

- $\chi^2 / \text{ndf} = 2.816 / 2$
- $p0 = 3.485e-10 \pm 0.01674$
- $p1 = 0.5085 \pm 0.0287$
- $p2 = 1.34 \pm 0.5643$
Energy Resolution - Hadrons

Resolution of Castor Proto II: Pions with 4 APD's

Resolution of Castor Proto II: Pions with 6 APD's
$E_e = 200 \text{ GeV}$
Spatial X-scan – Electrons
Width of Shower

$\sigma_{EM} = 1.9 \text{ mm}$
Spatial X-scan – Pions
Width of Shower

\[ \sigma_H = 5.3 \text{ mm} \]
CASTOR is the experimental tool for ‘Centauro’ and ‘Strangelet’ search in the forward rapidity at CMS.

Identification through measurements of:

- Extreme imbalance between hadronic and electromagnetic energy.
- Non-uniform azimuthal energy deposition.
- Penetrating objects beyond the range of normal hadrons → abnormal longitudinal energy deposition pattern.

Observation of Centauro and (meta) stable SQM will have significant implications for QM-Physics and Astrophysics.