The Abdus Salam
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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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for the CMS/CASTOR Group

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

V International Conference on
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at Relativistic Energies

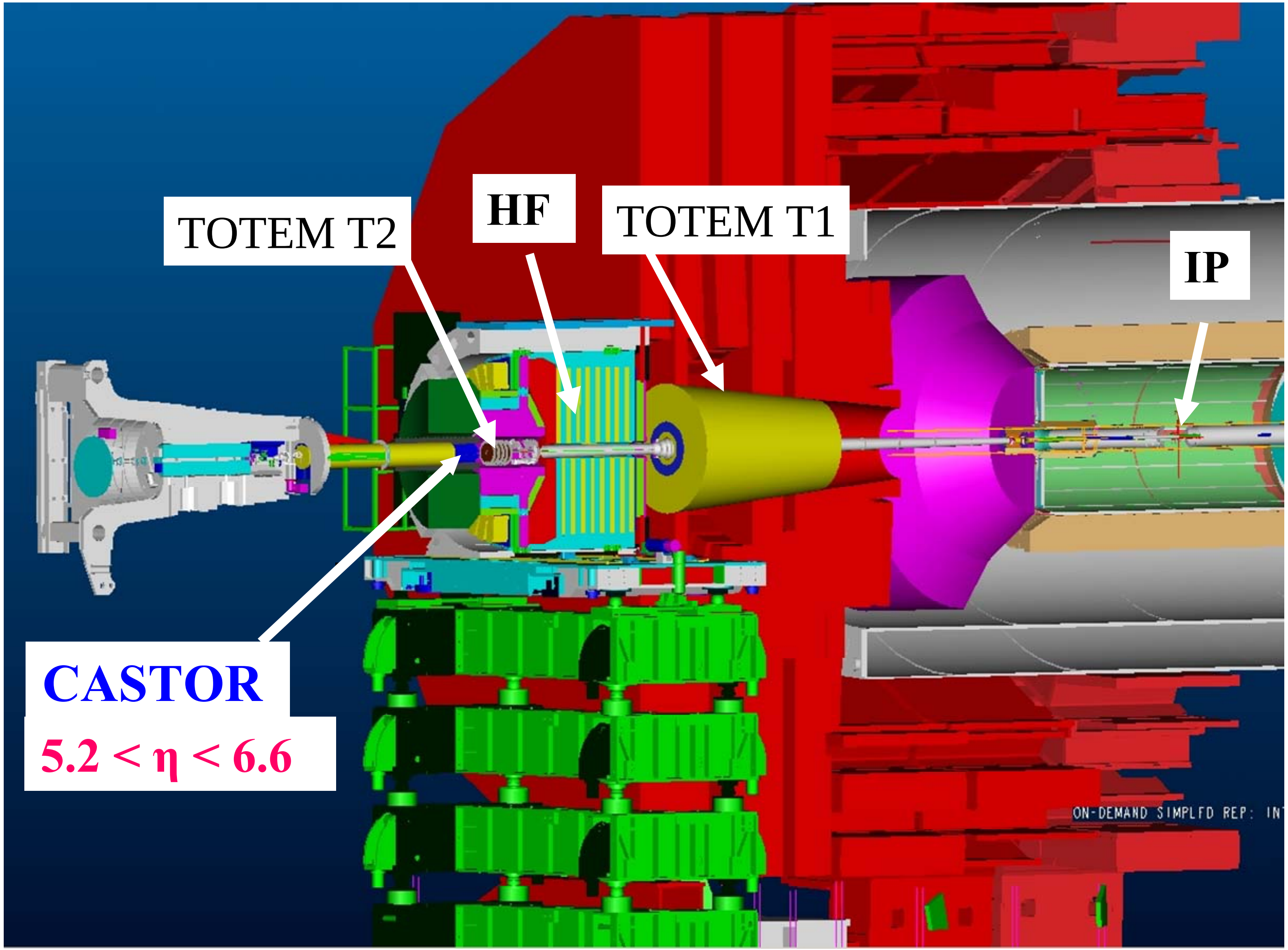
ICTP 22-26 May, 2006

Outline

- CASTOR Calorimeter at CMS
- Exotic Events in Cosmic Rays
- Phenomenological Models & MC Simulations
- "Strangelet" Identification Analysis
- CASTOR Prototypes - Beam test Results
- Summary

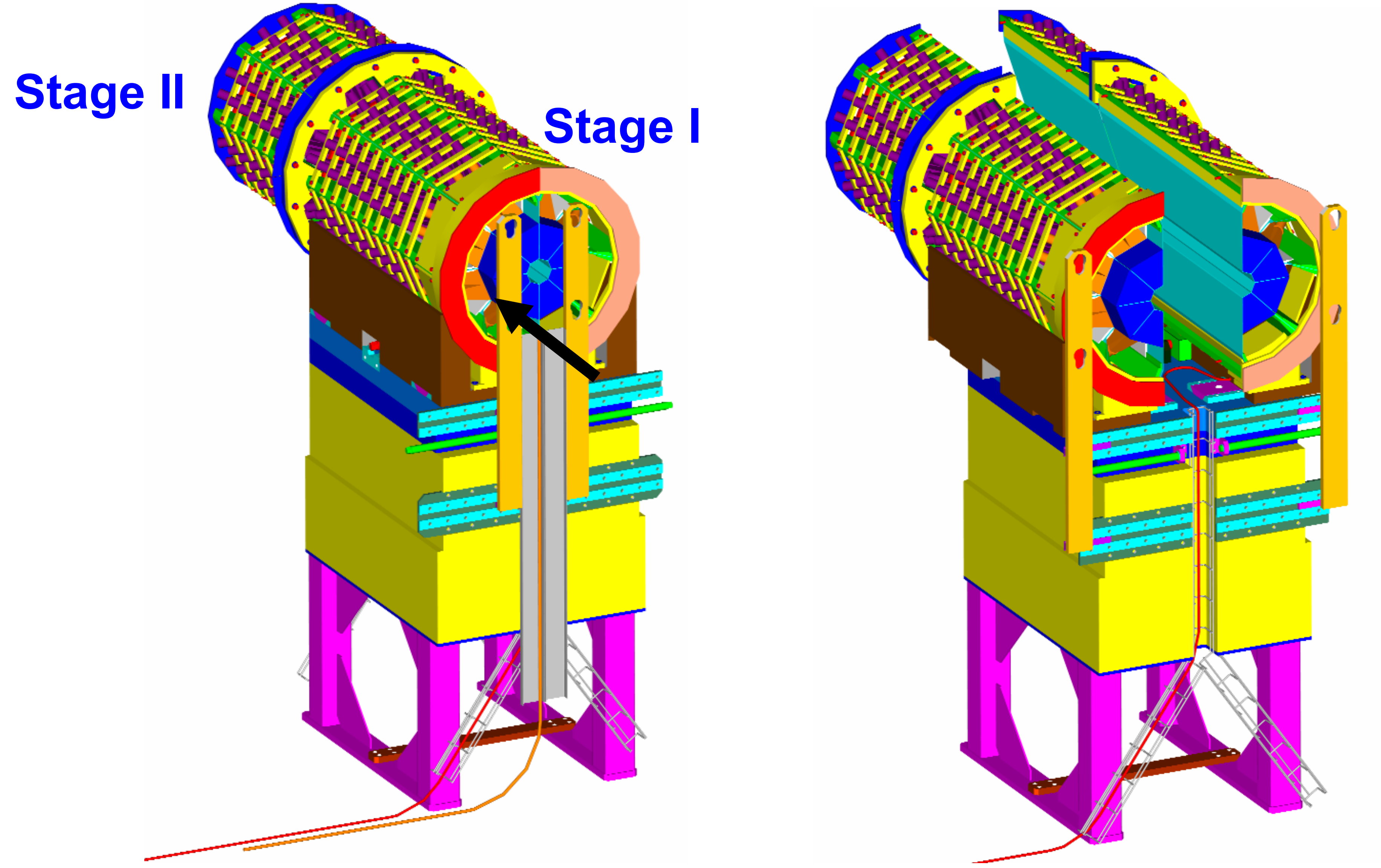
CASTOR Calorimeter at CMS

CMS Forward Detectors

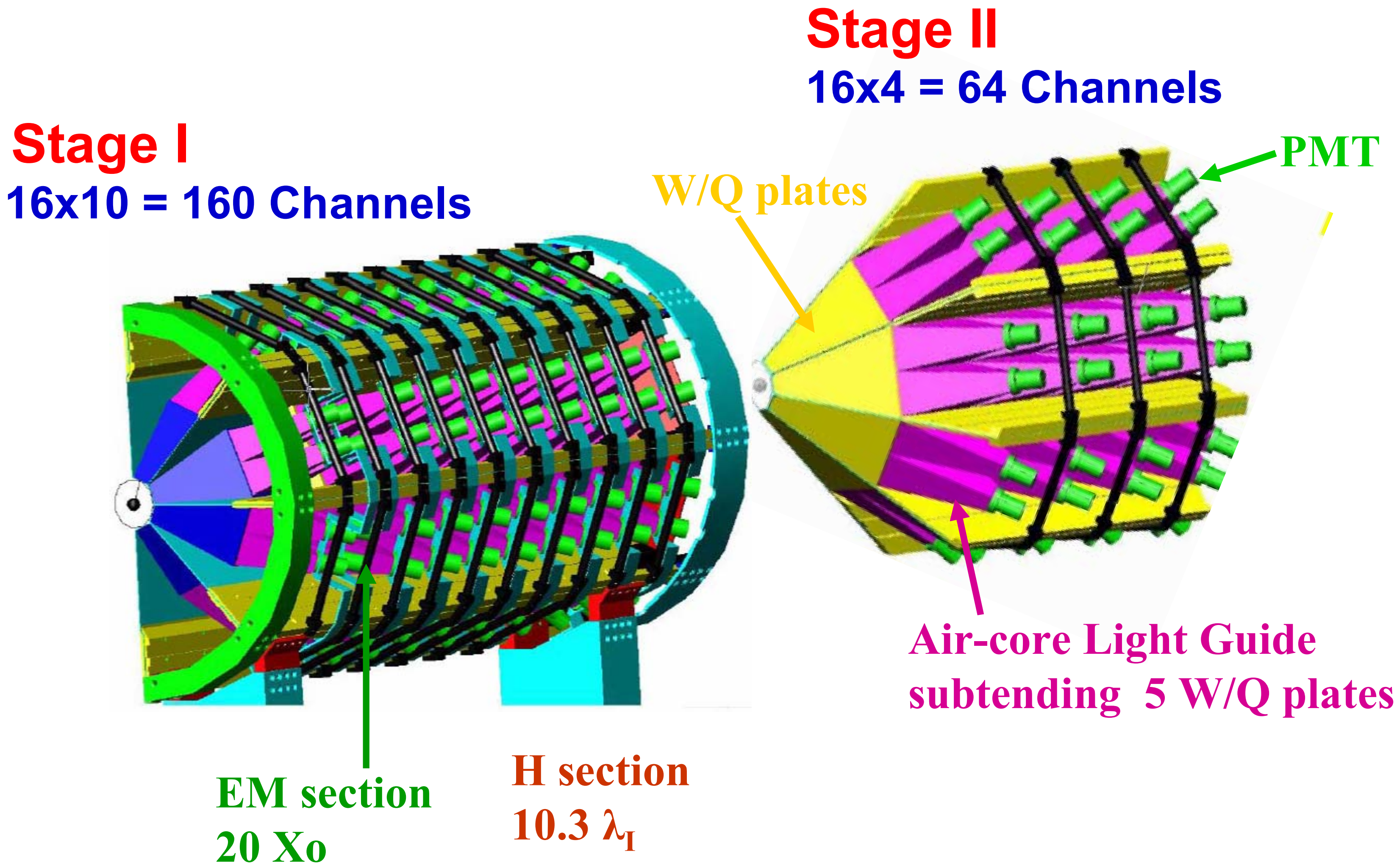


CASTOR Calorimeter

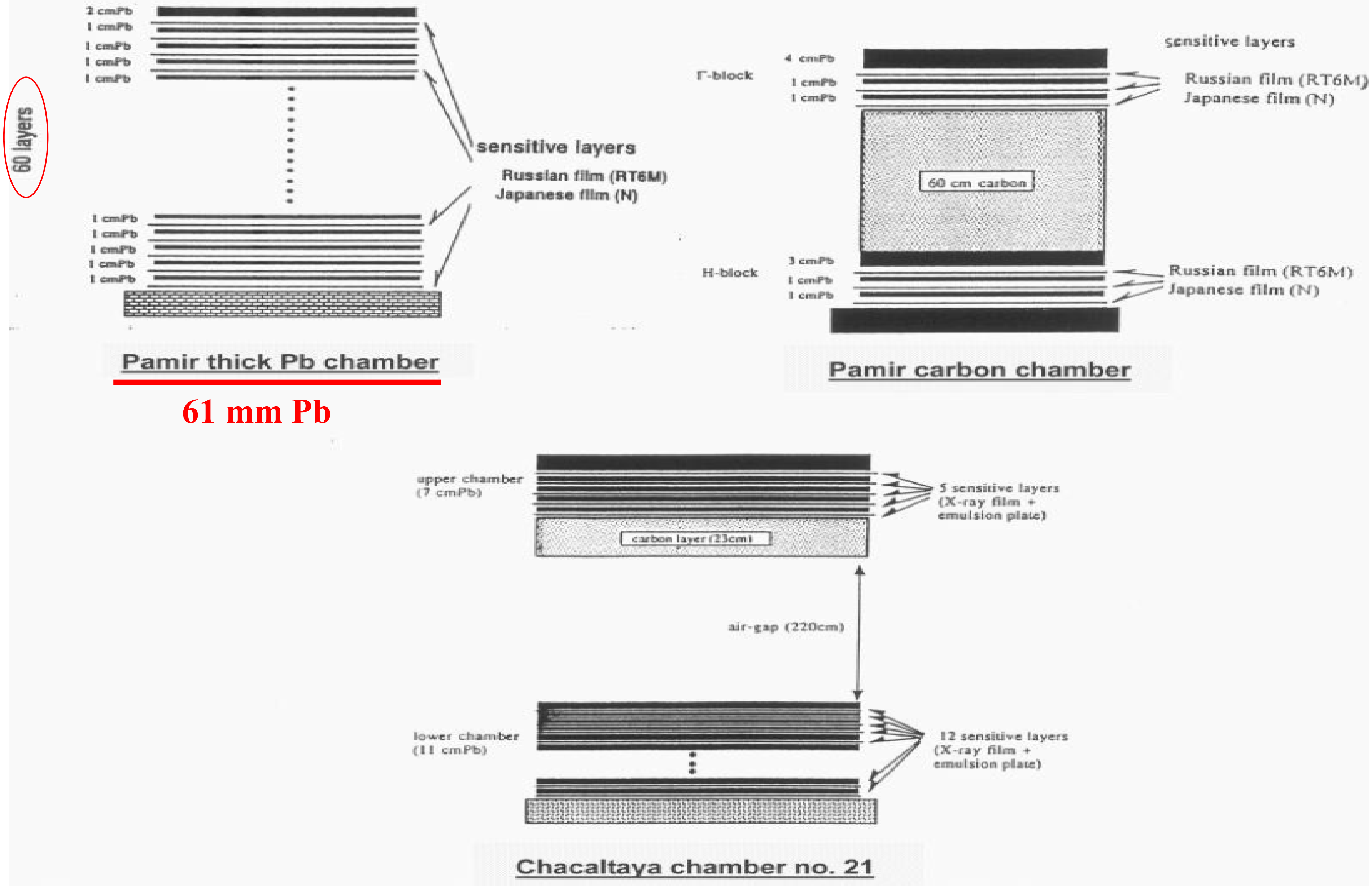
Segmentation: 16(azimuth) x 14(in depth) = 224 channels



CASTOR Calorimeter



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.

ADP, Zeits. Phys. A- Atomic Nuclei 333(1989)355

E.G.-D. Phys. Part. Nucl34(2003)285

Hadron – Rich CR Events

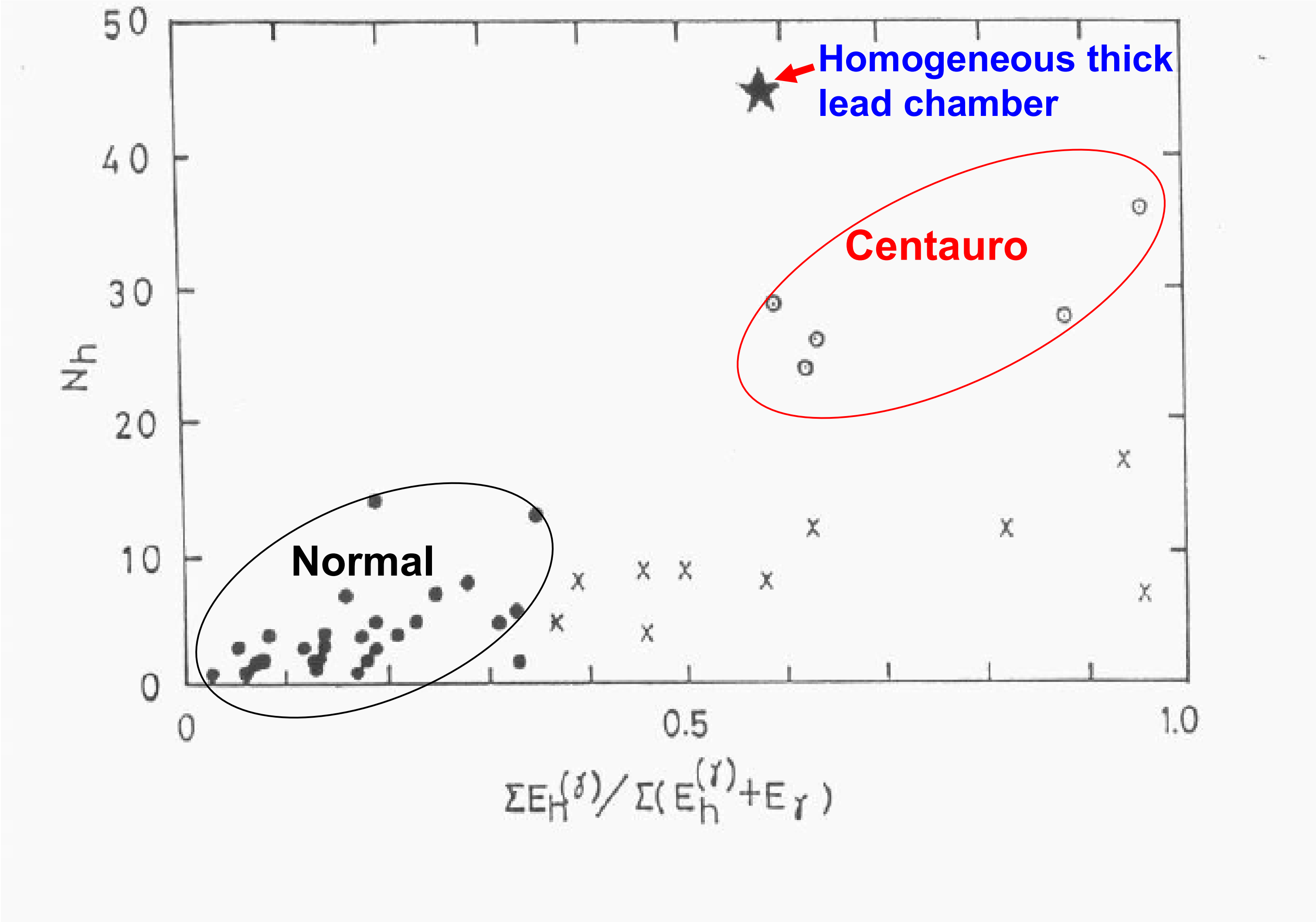
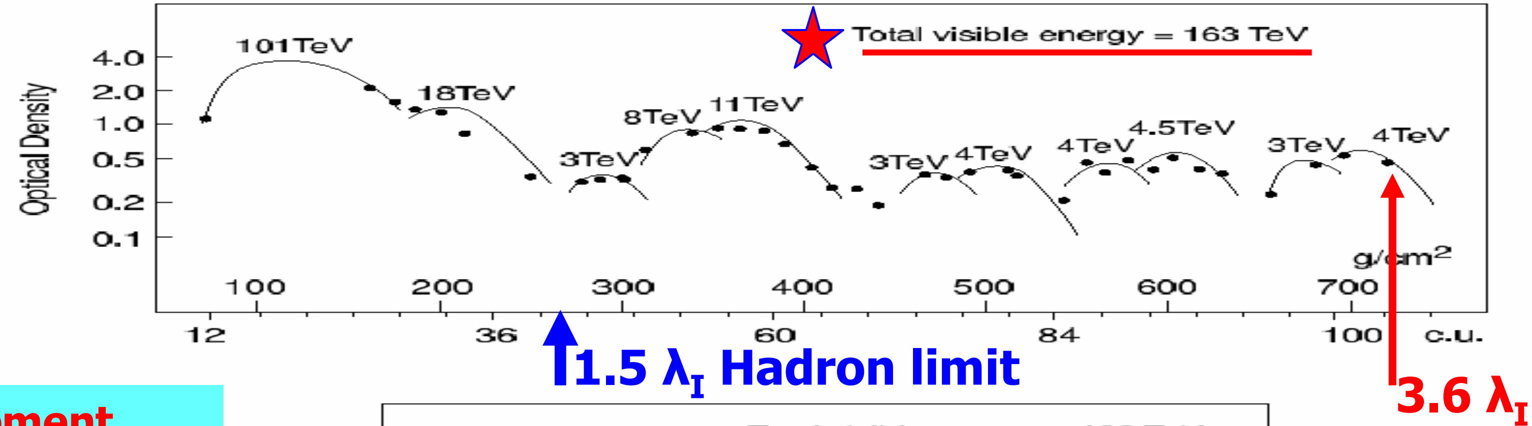


Figure 2.5: Diagram of the number of hadrons and hadronic energy fraction: Chacaltaya events with the total visible energy greater than 100 TeV [38]: (∘) Centauro, (×) Mini-Centauro, (•) others; (⋆) C-K [36].

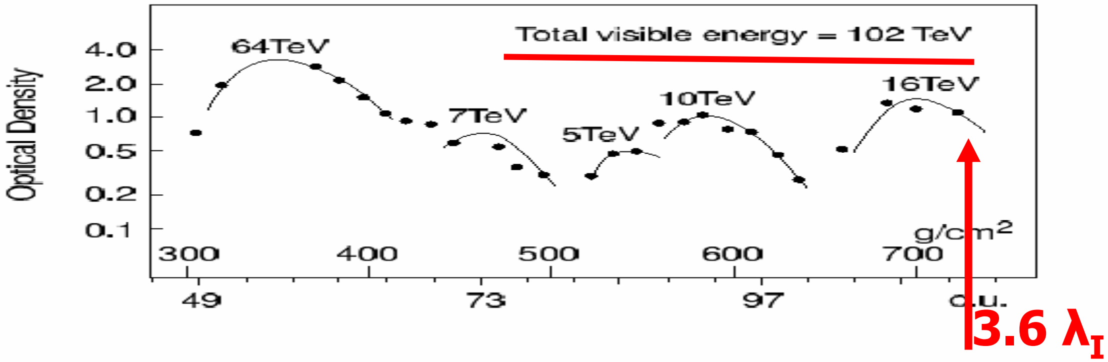
Long Flying Component

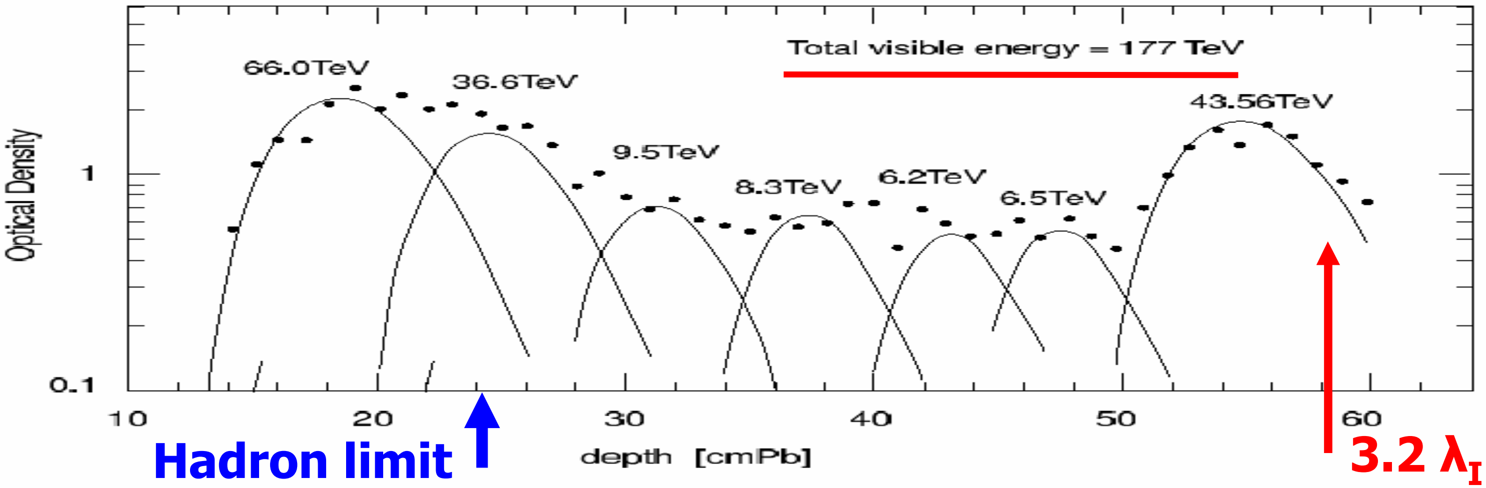
(Strangelet ?)



Measurement settings:

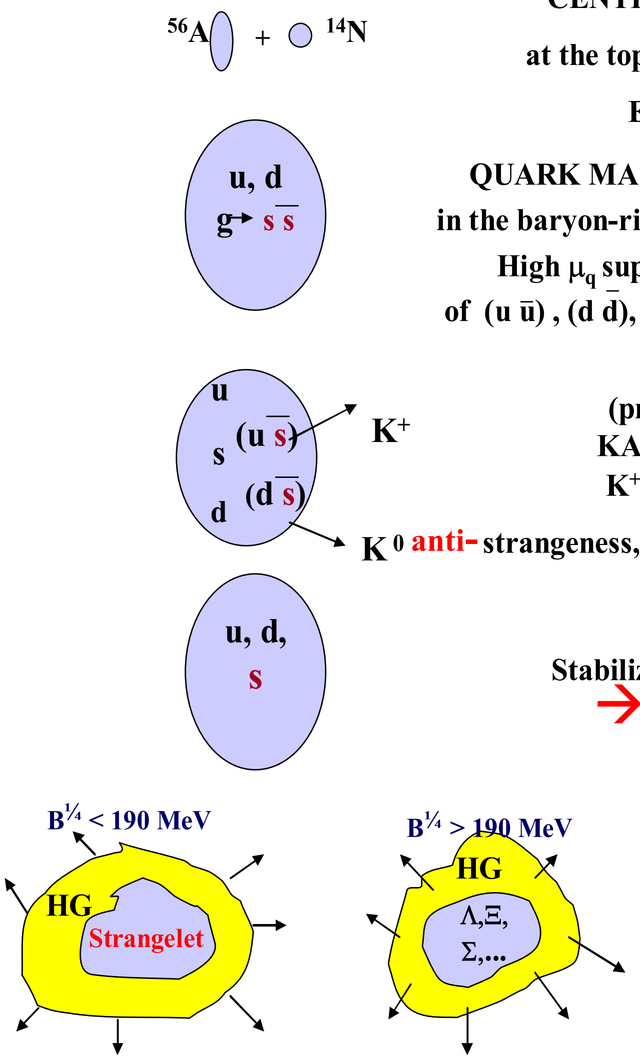
100 μm shower core diameter → threshold ~ 3 TeV





Phenomenological Models
MC Simulations

CENTAURO FIREBALL EVOLUTION



CENTRAL COLLISION

at the top of the atmosphere

$E_p \sim 1740$ TeV

QUARK MATTER FIREBALL

in the baryon-rich fragmentation region

High μ_q suppresses production

of $(u\bar{u})$, $(d\bar{d})$, favoring $g \to s\bar{s}$

(pre-equilibrium)

KAON EMISSION

K^+, K^0 carry out:

anti-strangeness, positive charge, entropy

SQM FIREBALL

Stabilizing effects of s quarks

→ long lived state

EXPLOSION

~75 non strange baryons + strangelet ($A \sim 10$ -15)

Strangeness distillation mechanism.

C. Greiner et al., Phys. Rev. D38 (1988)2797

Estimates for Centauro at LHC

- Energy density
  $\varepsilon \sim 3$ - 25 GeV/fm^3,
- Temperature
  $T \sim 130$ - 300 MeV
- Baryo-chemical potential
  $\mu_b \sim 0.9$ - 1.8 GeV/fm^3

CNGEN

Centauro & Strangelet Generator

Phys. Rev. D45(1992)3134
Astroparticle Phys. 2(1994)167
Astroparticle Phys. 13(2000)173
Phys. Atom. Nucl. 67(2004)396

Conditions for DQM-bag Stability
$P_{qg} = B$

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.

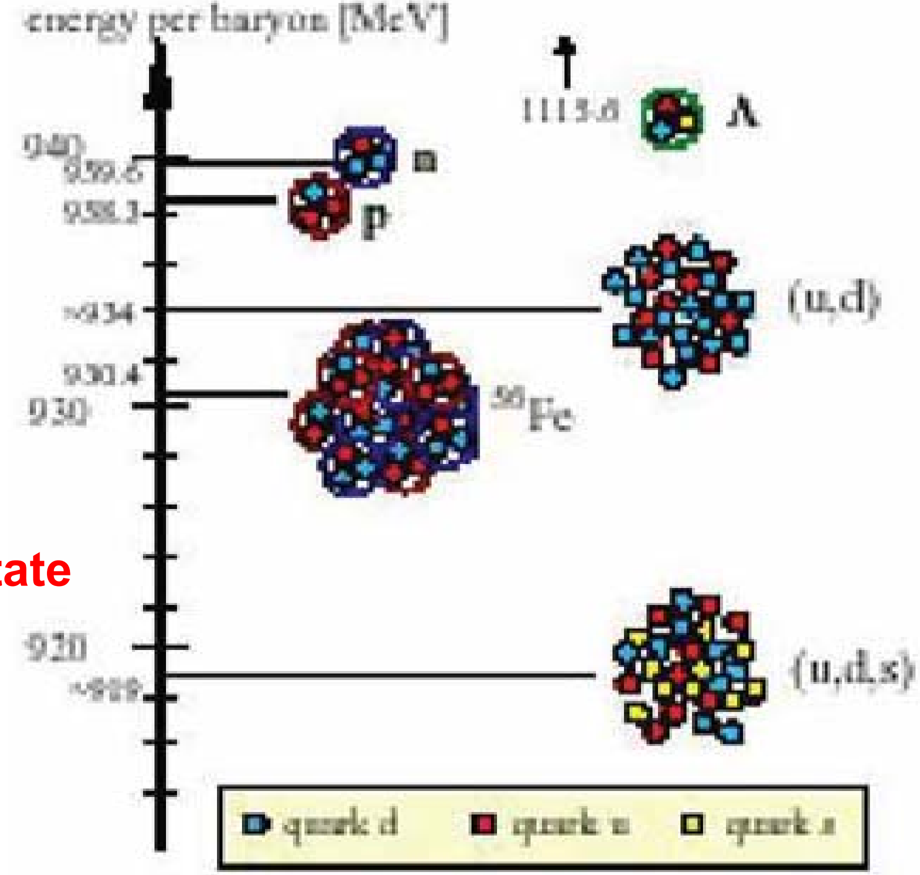
$$P_{qg} = (8/45)\pi^2 T^4 + \mu_q^2 T^2 + \mu_q^4/2\pi^2 = (2.034N_q/4\pi)(1/R^4) = B$$

For CR Centauro ($\mu_q \sim 600$ MeV, $T \sim 130$ MeV, $N_q \sim 225$)

$R = r_o N_b^{1/3} \sim$ 1.43 fm → $r_o = 0.34$ fm (~ r_o 'collapsed' nucleus)

Astroparticle Phys.13(2000)173

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: $R = r_0 A^{1/3} = \left[\dfrac{3\pi \cdot A_{str}}{2\left(1-\dfrac{2a_s}{\pi}\right)\left[\mu_s^3 + \left(\mu_s^2 - m_s^2\right)^{3/2}\right]}\right]^{1/3}$

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

Mean interaction path:

$$\lambda_{str-W} = \frac{A_W \cdot m_N}{\pi\left(1.12 \cdot A_W^{1/3} + r_0 A_{str}^{1/3}\right)^2}$$

Strangelets passing through the detector collide with W nuclei:

***Spectator* part is continuing its passage.**

***Wounded* part produces particles in a standard way.**

$$\Rightarrow A'_{str} = A_{str} - N_n$$

Particles produced in successive interactions initiate electromagnetic-nuclear cascades.

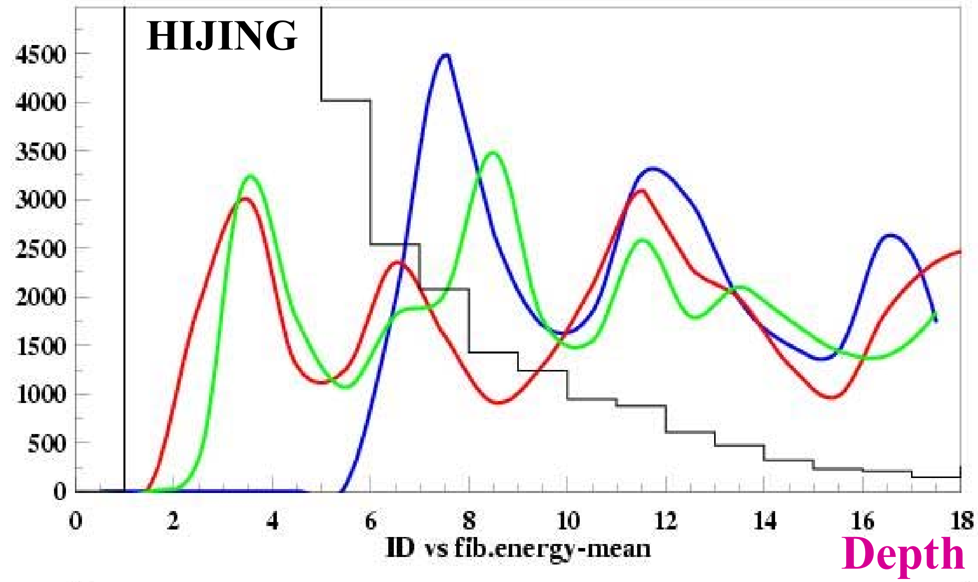
Process ends when strangelet is destroyed.

E. Farhi, R. Jaffe, *Phys.Rev.*D30(1984)2379; M. Berger, R. Jaffe, *Phys.Rev.*C 35(1987)213, G.Wilky, Z.Wlodarczyk, J.Phys.G22(1996)L105; E. Gładysz, Z. Włodarczyk, J.Phys.G23(1997)2057

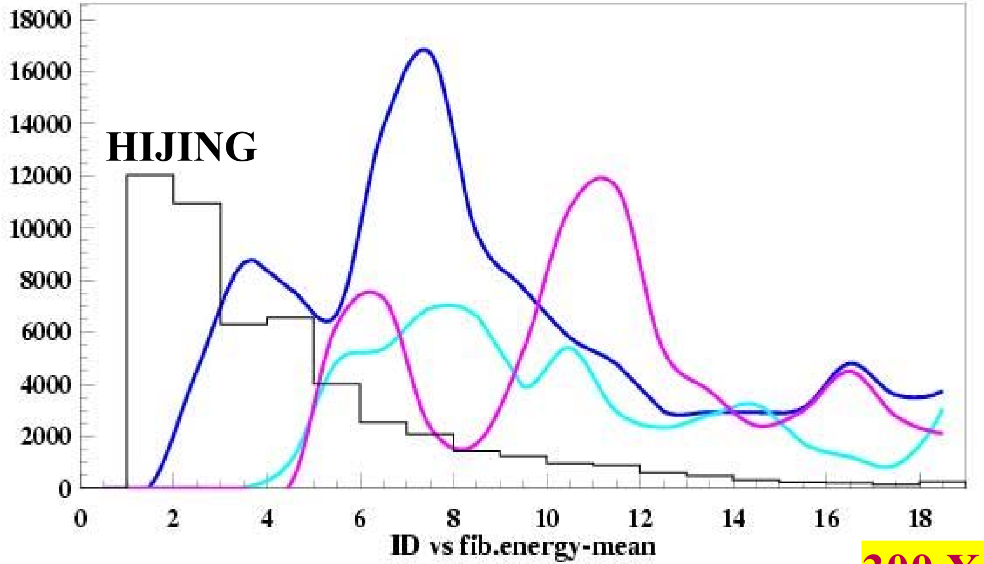
MC - Stable Strangelet in CASTOR

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

P. Katsas



Depth



$300\ X_0$

CASTOR Geometry configuration

1 layer: 5mm W+2mm quartz plate ~2.37 X_0

1 RU = 7 layers per readout unit

16 (in ϕ) x 18 (in z) readout channels

Total depth: ~300 X_0, 10.5 Λ_{int}

LOW ENERGY STRANGELETS (~5 TeV)

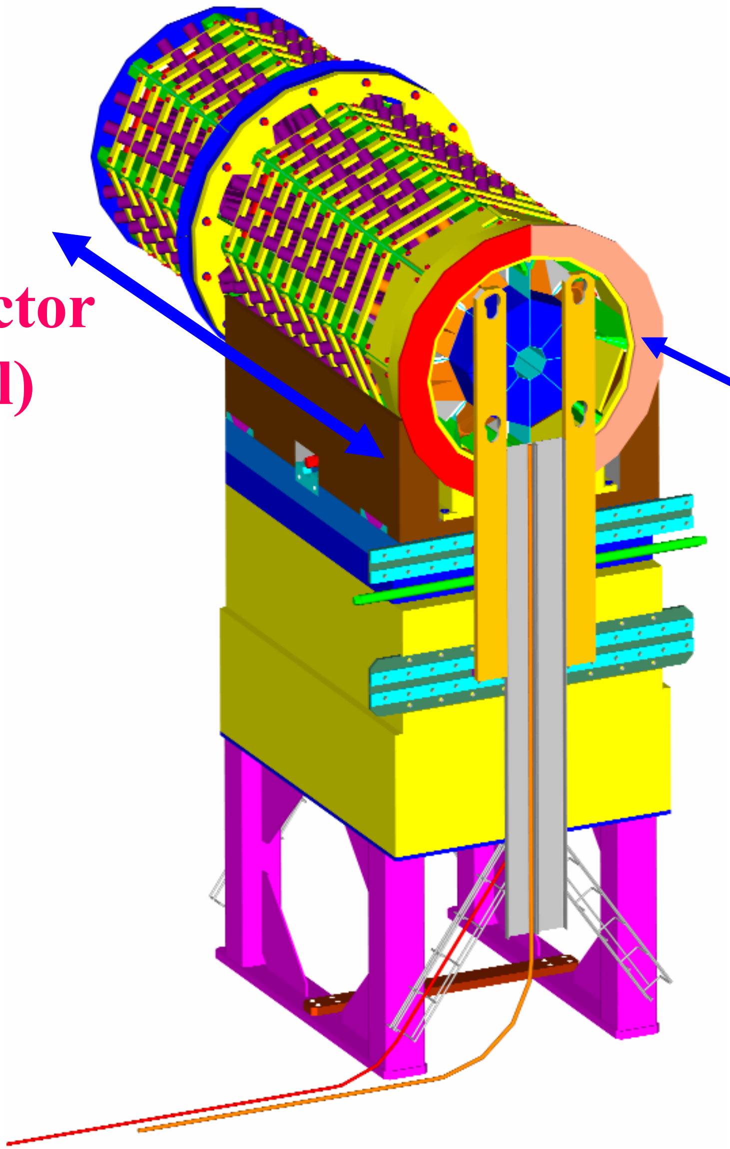
MAY BE SEEN ABOVE BACKGROUND

Strangelet Identification Analysis

P. Katsas

CASTOR Calorimeter

Segmentation



14 Sections/Sector (longitudinal)

16 Sectors (azimuthal)

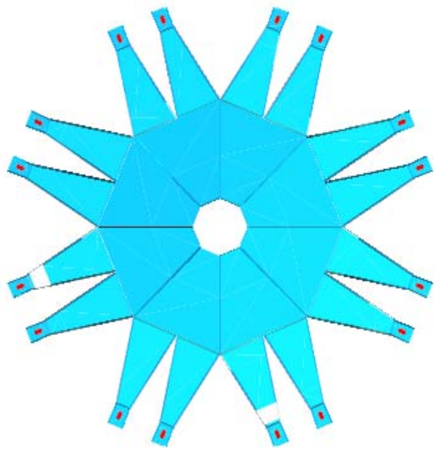


Figure 1: CASTOR front view.

HIJING Pb+Pb Event at √s = 5.5 TeV

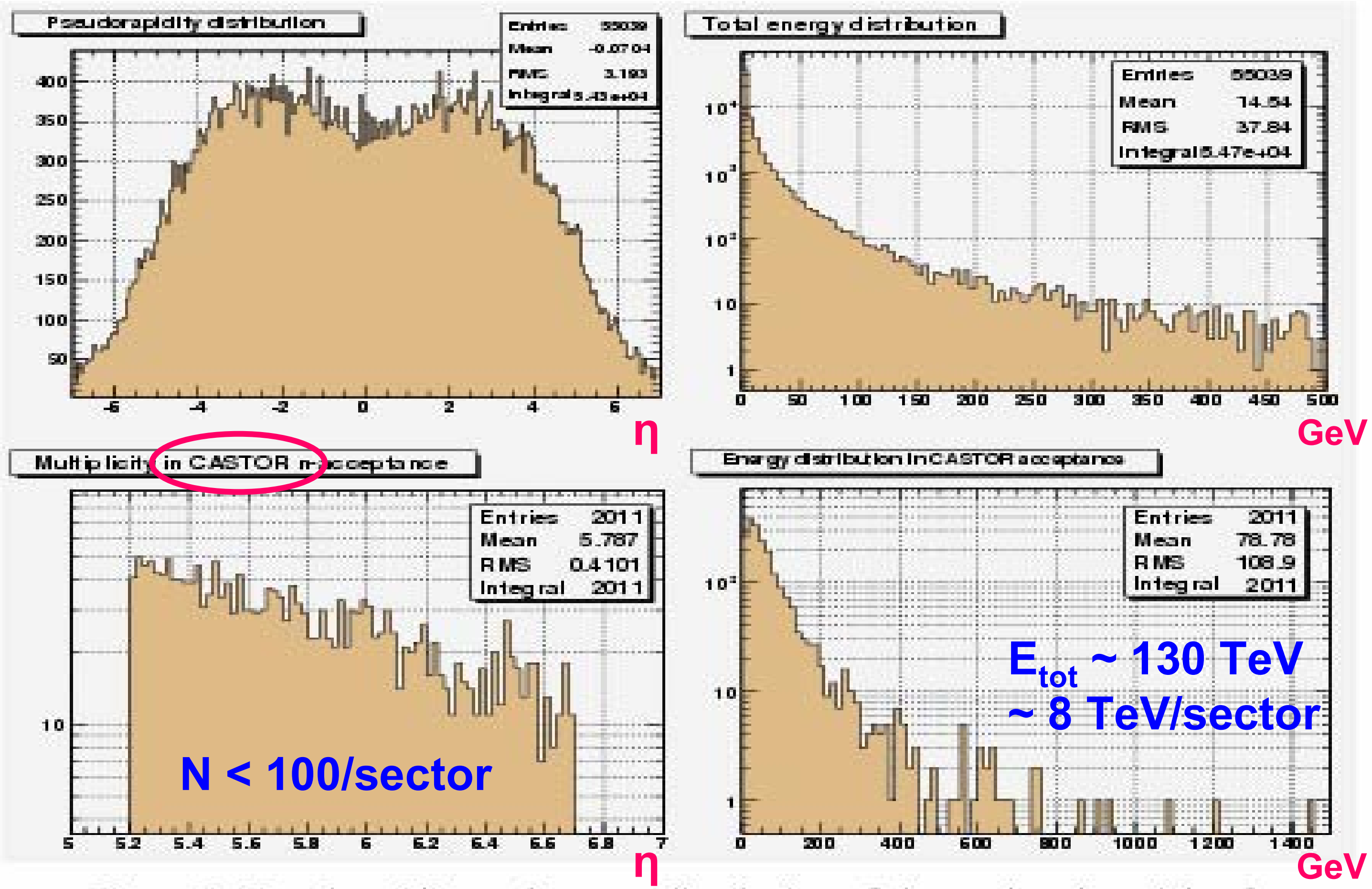
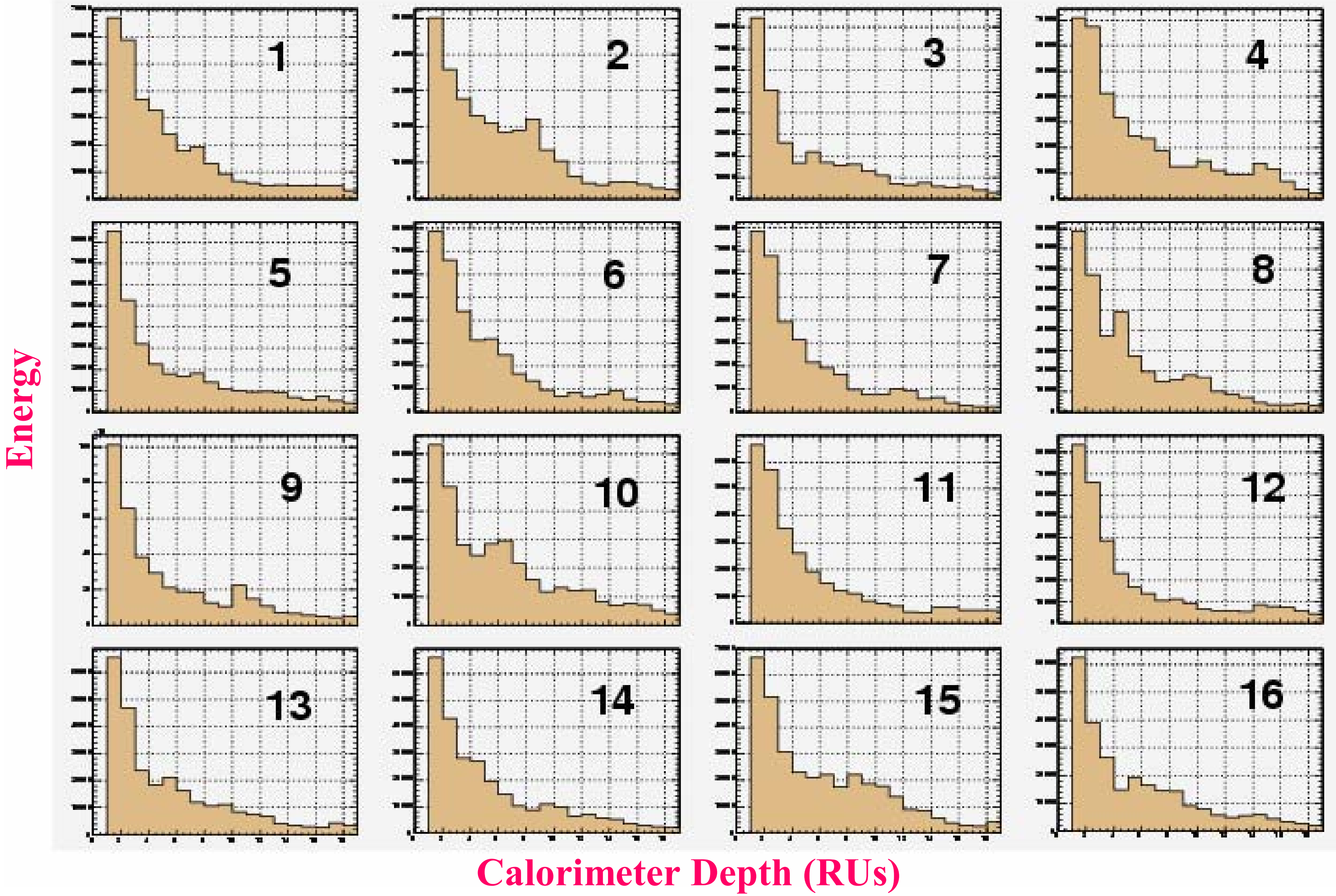


Figure 3: Pseudorapidity and energy distribution of the produced particles for a central HIJING event.

Total Energy Distribution in Sectors - HIJING

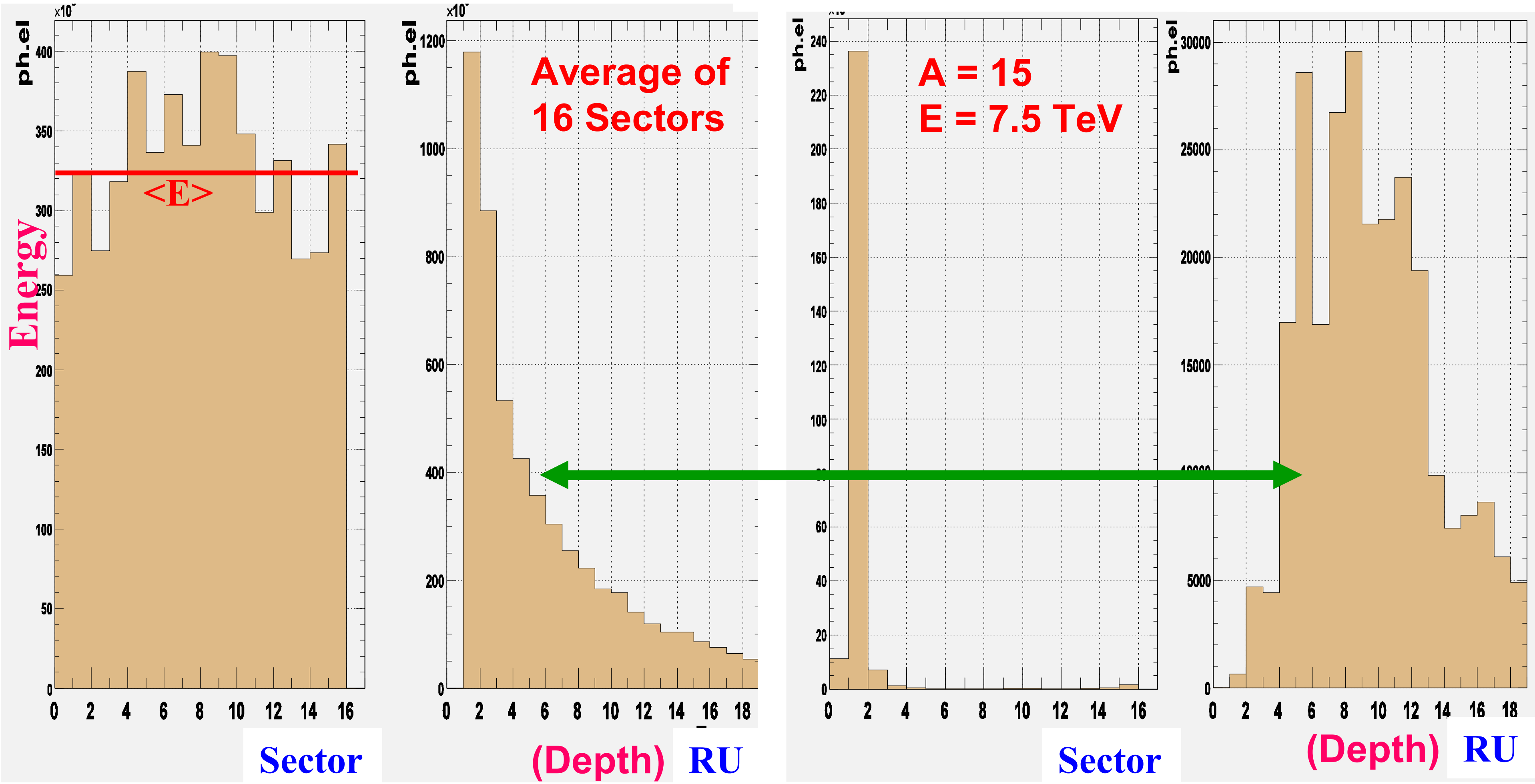


Energy distributions in CASTOR

HIJING

Strangelet in *one* sector

Total Energy in Sector Energy in RU Total Energy in Sector Energy in RU



Strangelet identification & Analysis

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

Strangelet signatures

Azimuthal asymmetry in energy deposition

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

<E> = mean energy in sectors

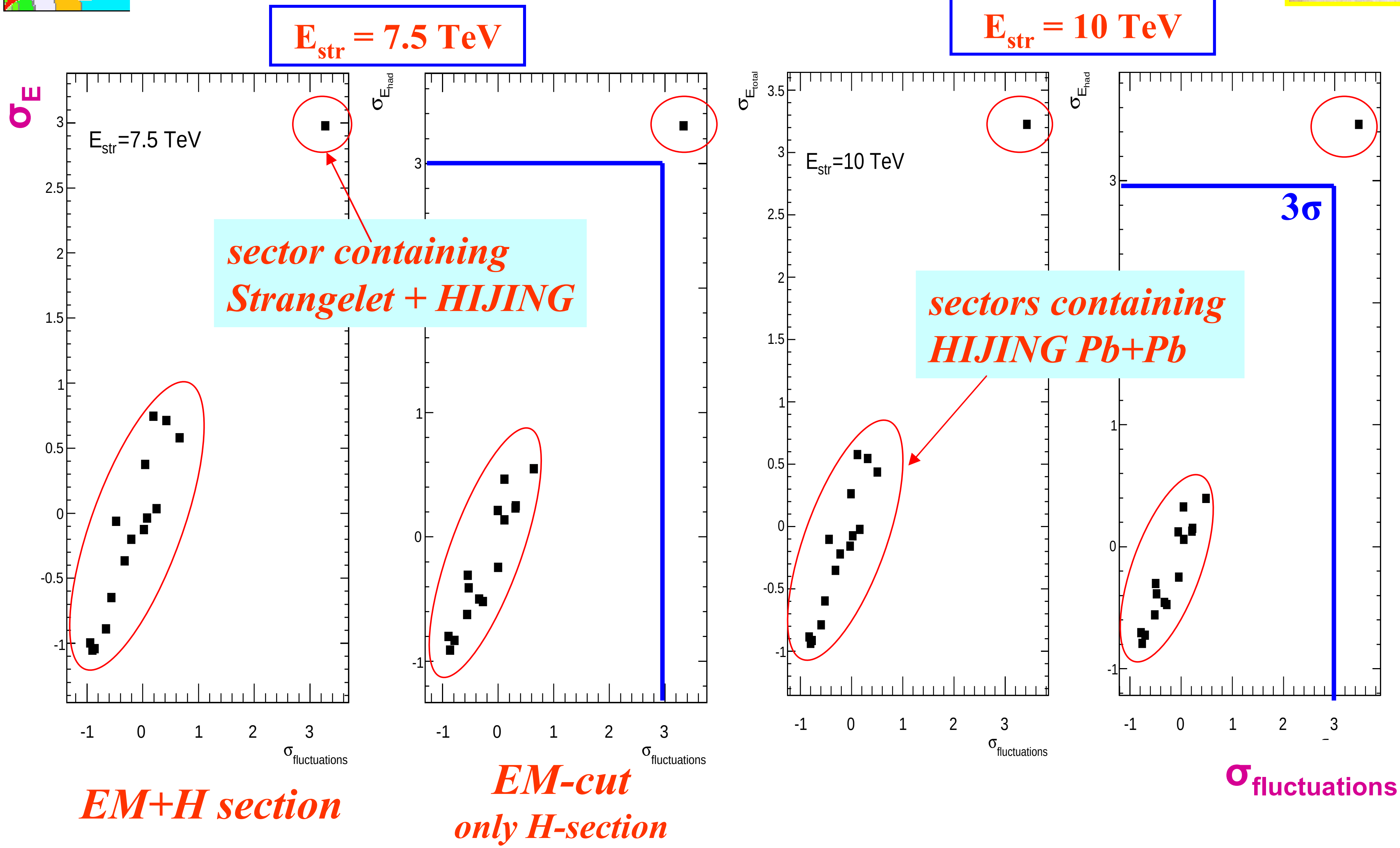
(i = 1 – 16 sectors)

Longitudinal transition curves

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

Large magnitude of energy fluctuations in RUs manifest abnormal transition curves

Analysis Results w/t background



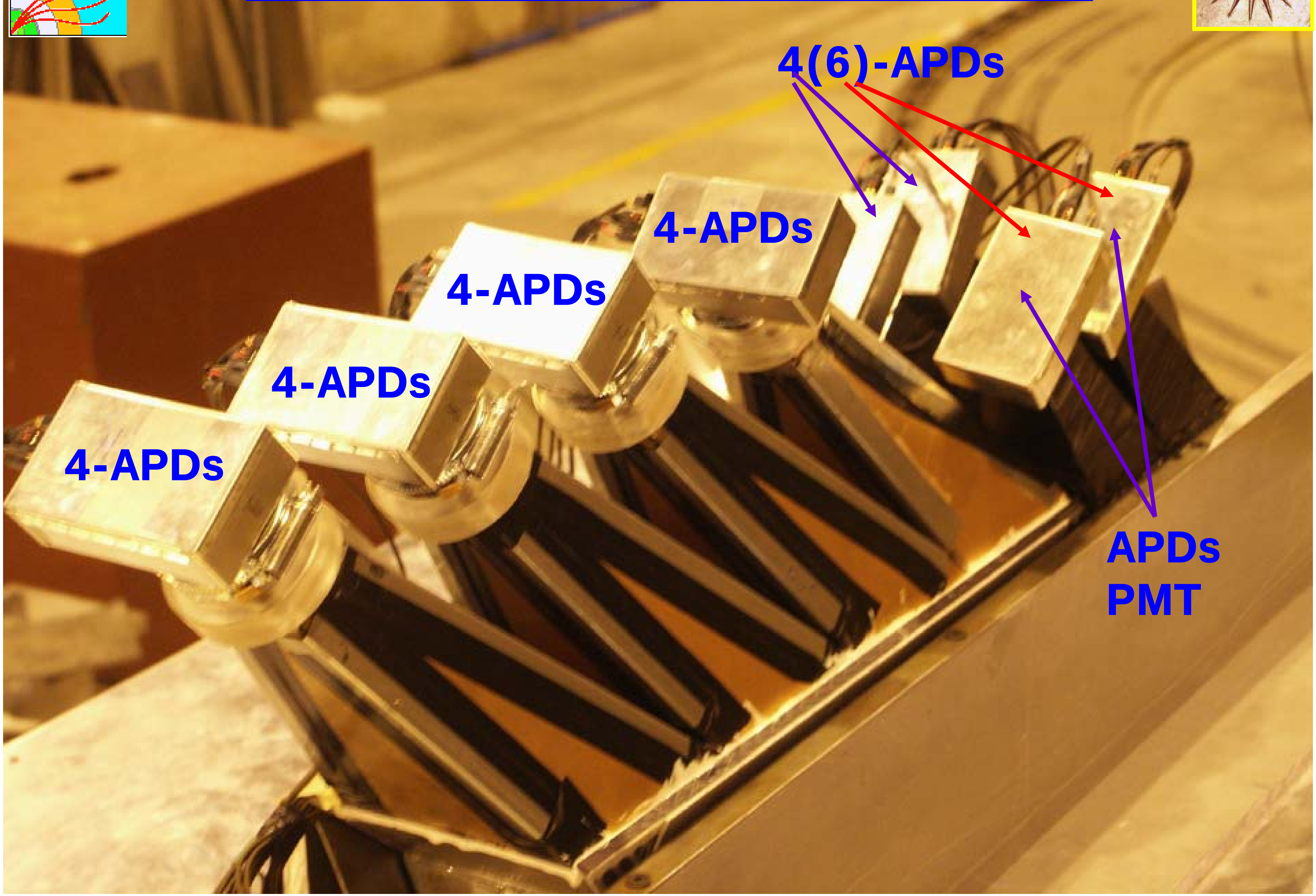
Prototypes - Beam test Results

L. Gouskos

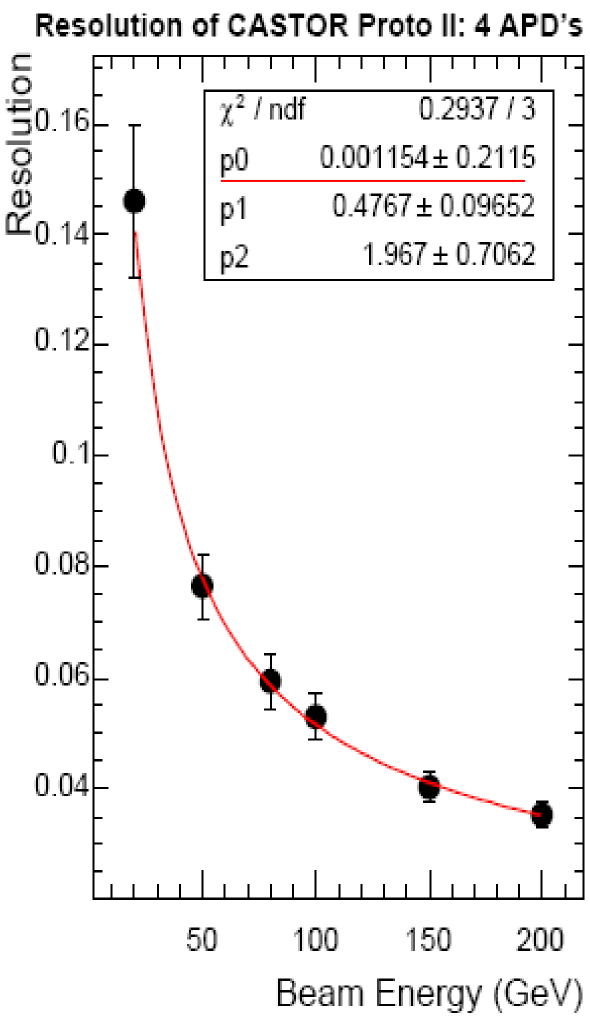
CMS Reports
NIM publications

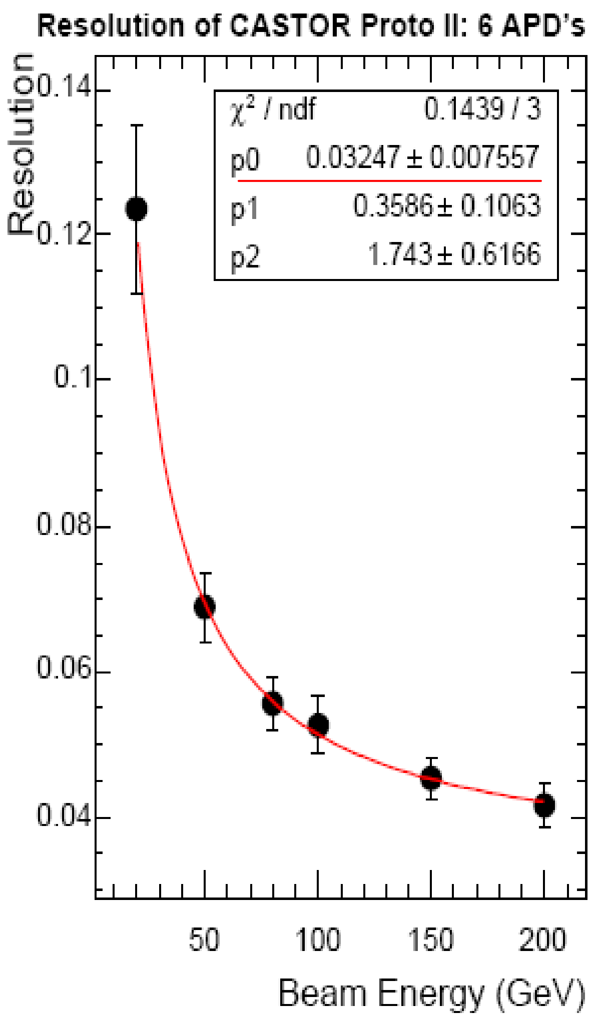
CASTOR Proto I Beam Test

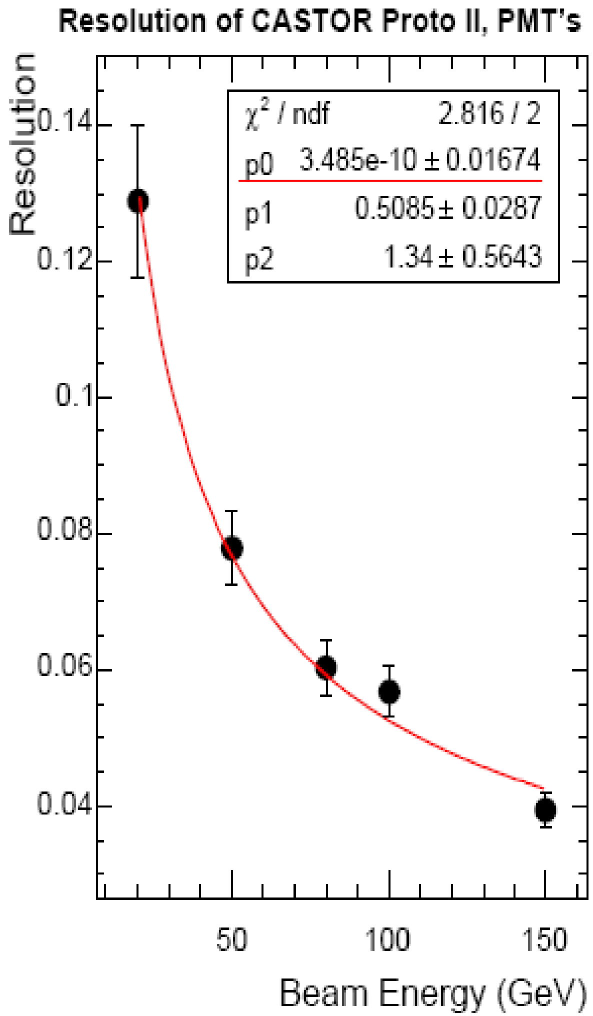
CASTOR Proto II Beam Test



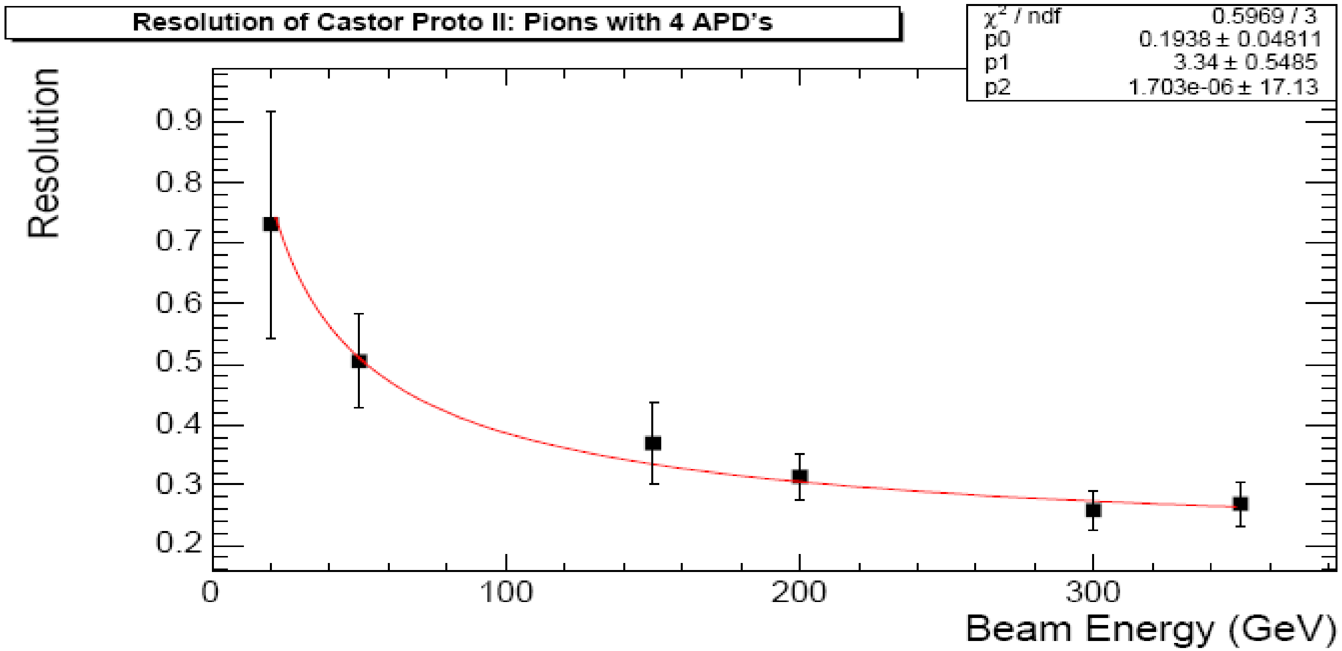
Energy Resolution - Electrons

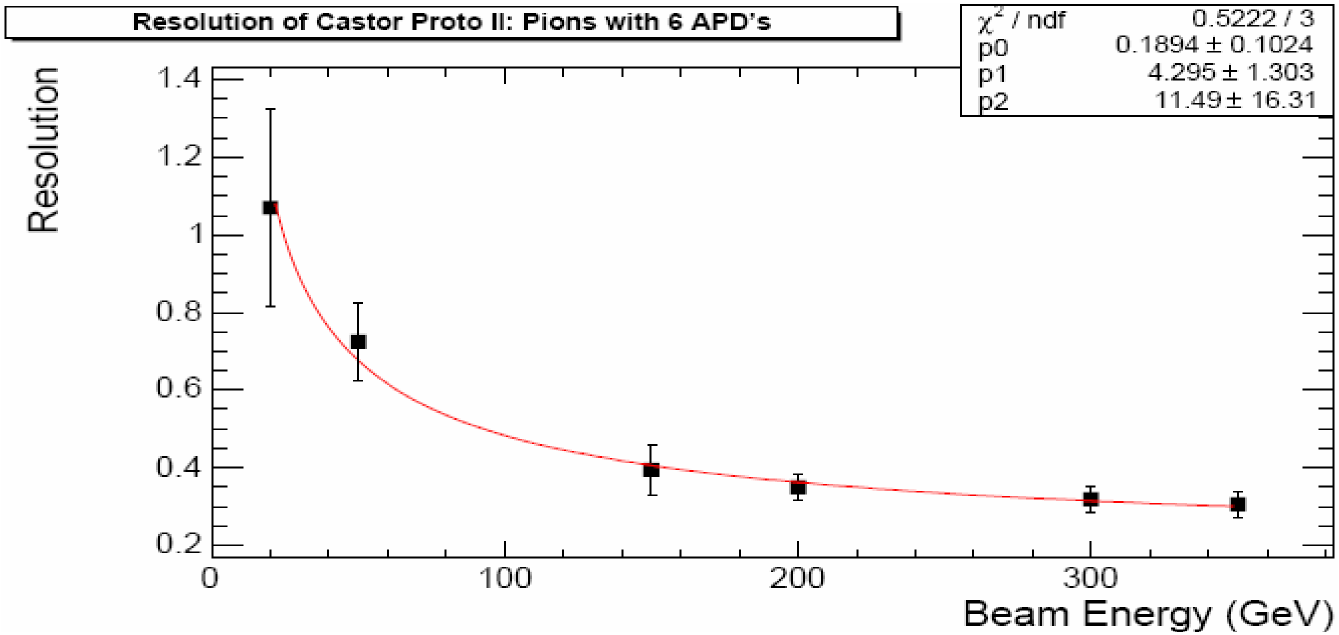




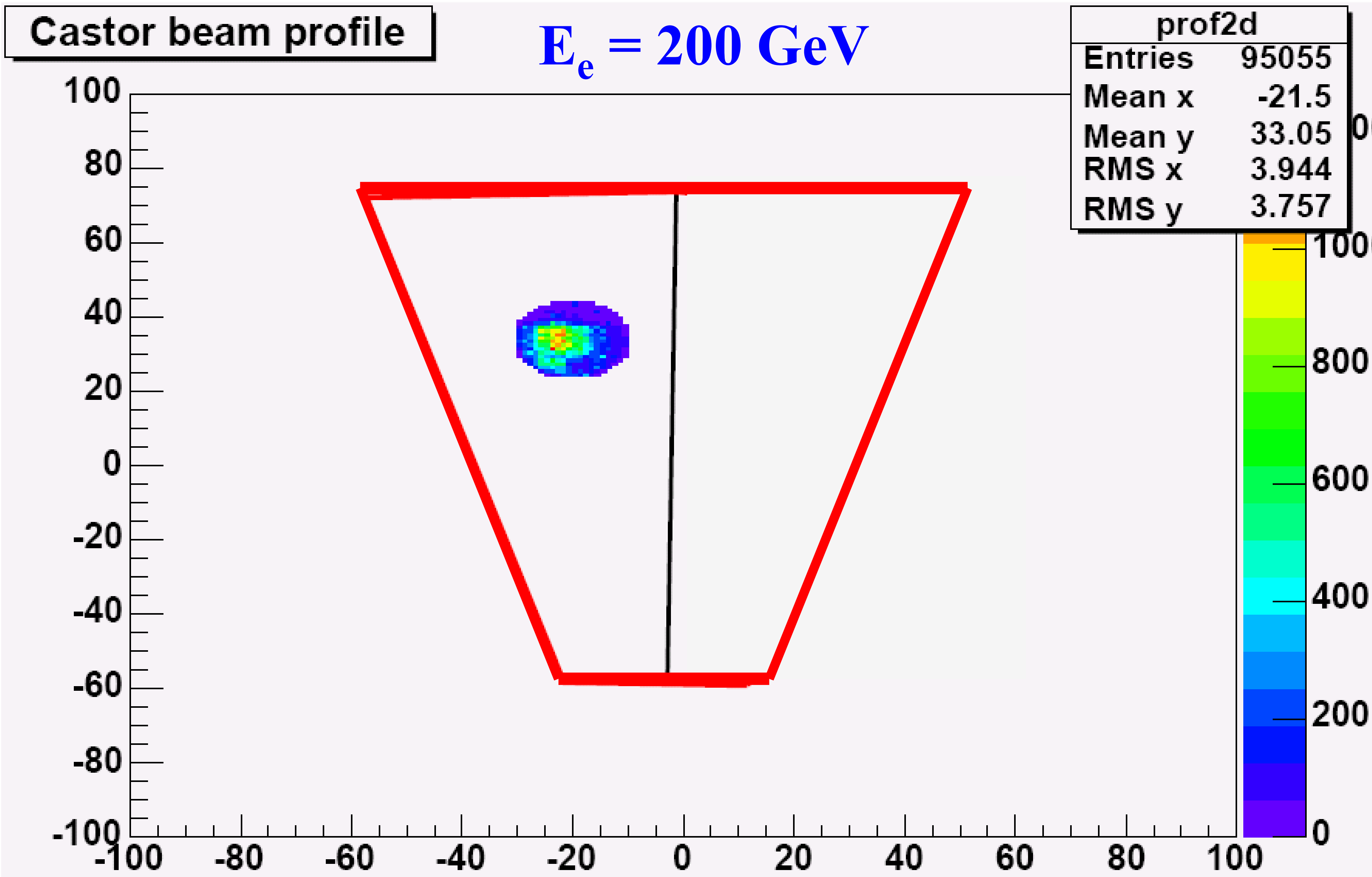


Energy Resolution - Hadrons

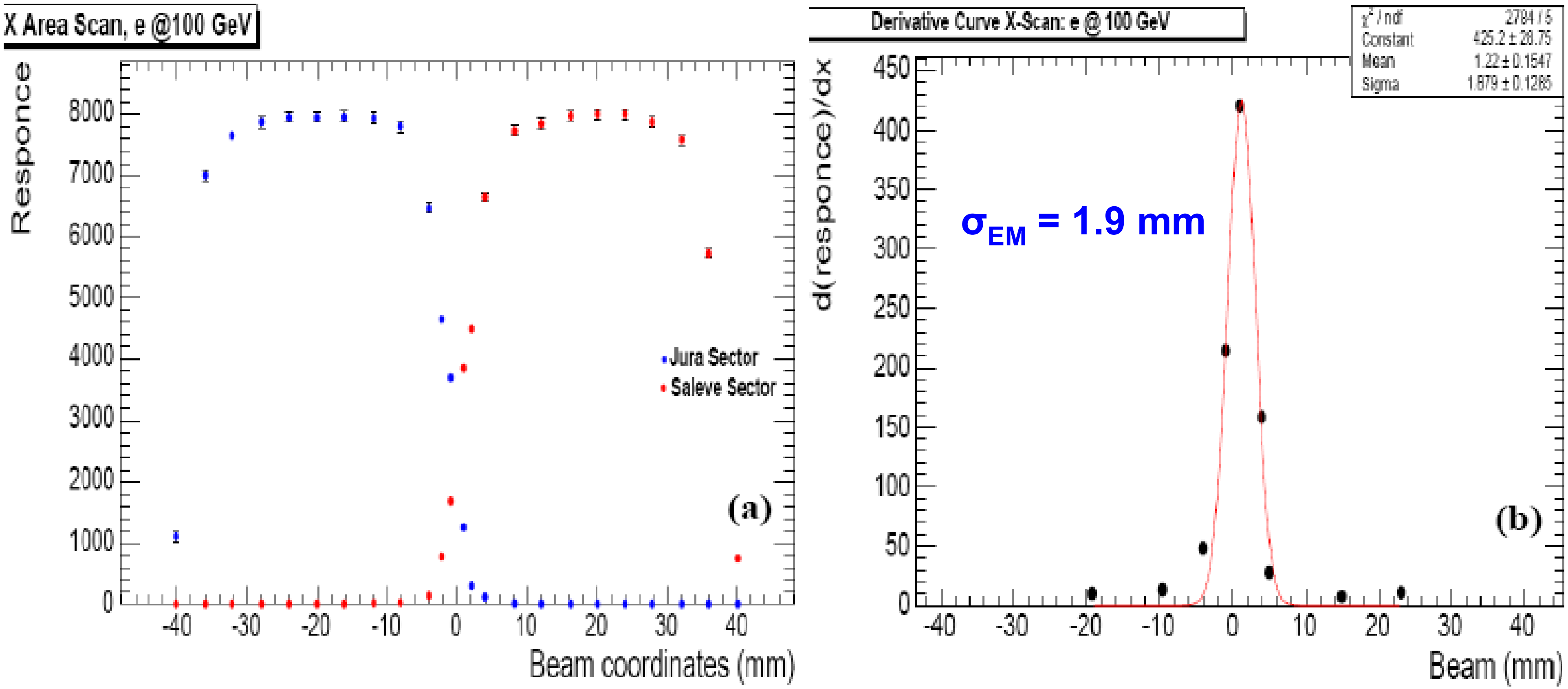




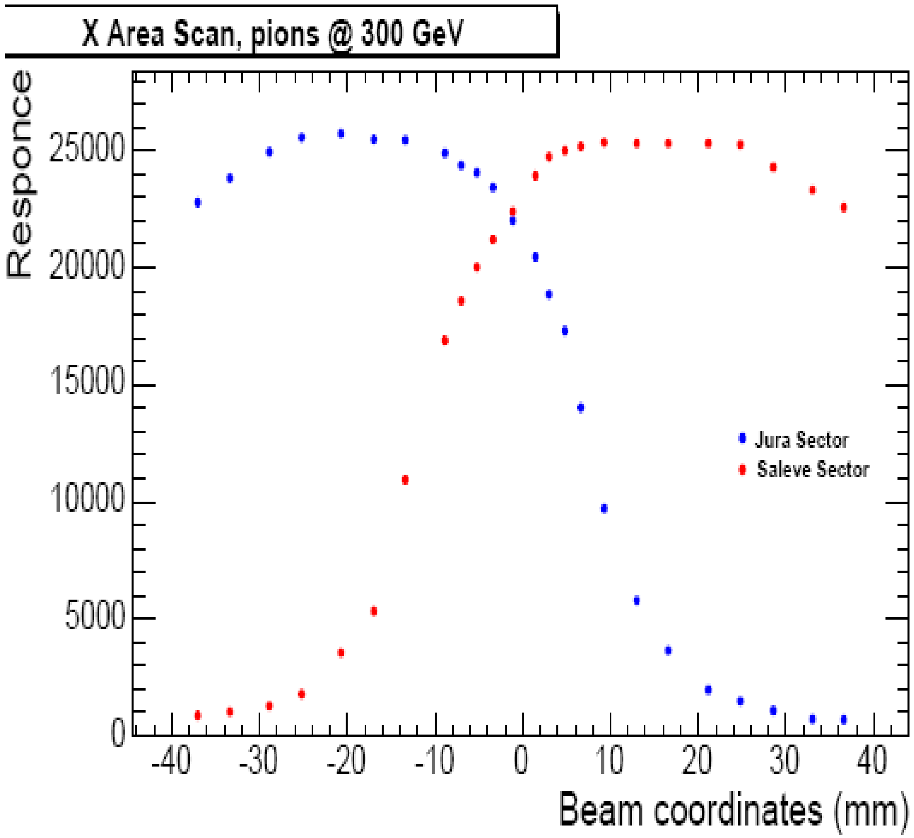
SEMI-OCTANT GEOMETRY PROJECTION

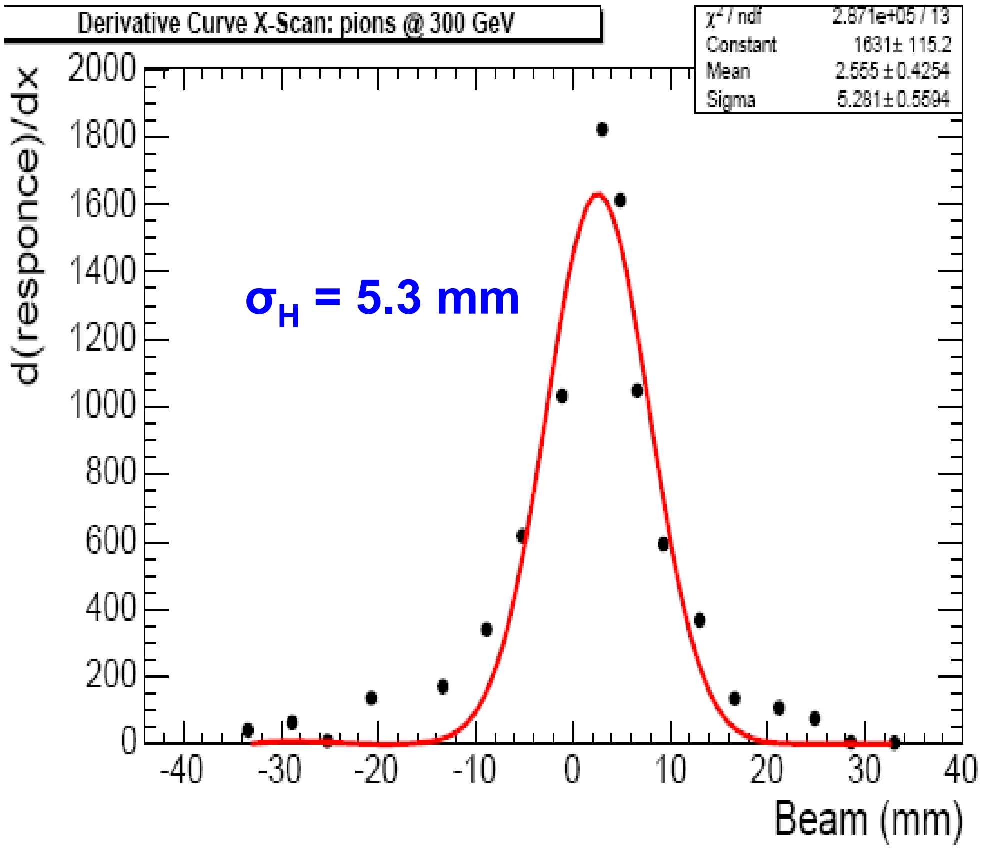


Spatial X-scan – Electrons
Width of Shower



Spatial X-scan – Pions
Width of Shower





Summary

- **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.