Performance studies of the final prototype for the CASTOR forward calorimeter at the CMS experiment

S. Başeğmez (Çukurova University), D. d' Enterria (CERN), L. Gouskos (University of Athens), I. Katkov (DESY & Moscow State University), **P. Katsas** (University of Athens), L. Khein (DESY & Moscow State University)

*on behalf of the CMS Collaboration

CASTOR
Centauro And Strange Object Research

Abstract

We present results of the performance of the final prototype of the CASTOR quartz-tungsten sampling calorimeter, to be installed in the very forward region of the CMS experiment at the LHC. The energy linearity and resolution, as well as the spatial resolution of the prototype to electromagnetic and hadronic showers are studied with E= 10-200 GeV electrons, E= 20-350 GeV pions, and E= 50, 150 GeV muons in beam tests carried out at CERN/SPS in 2007.

Introduction

The CASTOR (Centauro And Strange Object Research) detector is a quartz-tungsten sampling calorimeter, which will be installed in the CMS experiment at 14.38 m from the interaction point, covering the pseudorapidity range 5.1 < n < 6.6. The detector will contribute mainly to forward QCD studies (diffractive, low-x) and cosmic-rays-related physics in both proton-proton [1] and heavy-ion [2] collisions at LHC energies.

The results of the beam test and simulation studies with CASTOR prototype I [3] and prototype II [4] allowed us to define a third prototype. The beam tests were carried out in the H2 line at CERN *Super Proton Synchrotron* (SPS) during two weeks in Aug-Sept 2007.

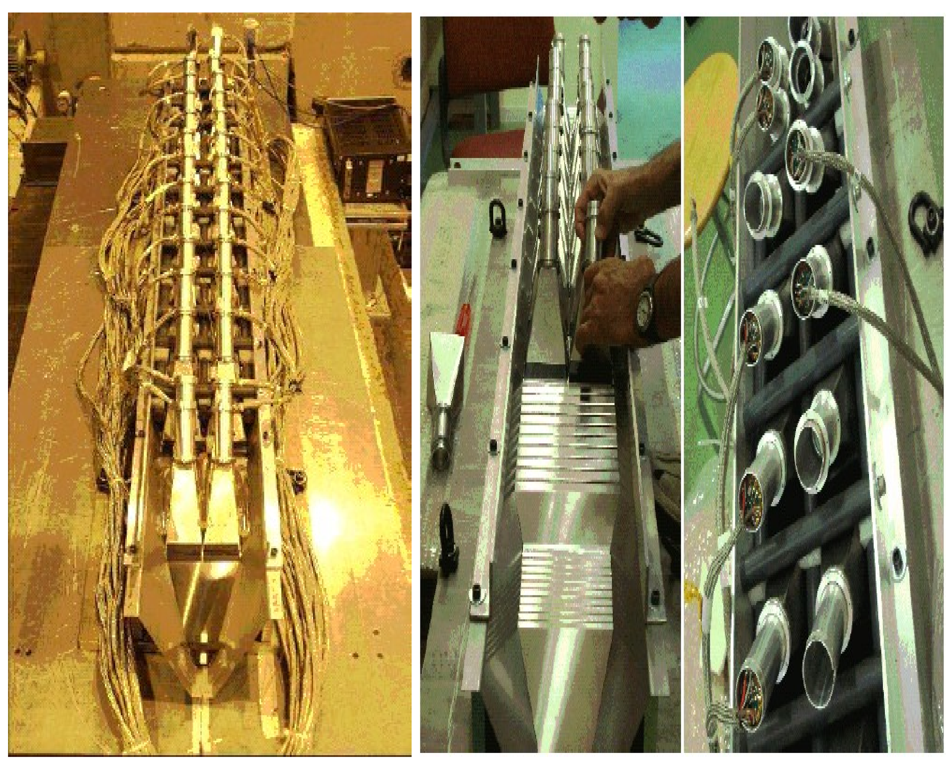

***Figure 1**. Photograph of the fully instrumented octant prototype at the beam test (left) and successive stages of the octant calorimeter assembly with W/Q-plates, air-core light guides and PMTs (left & right)*

Technical description

The prototype was one full-length octant, consisting of the electromagnetic (EM) and hadronic (HAD) sections, with a total of 28 readout-units (RUs) constructed with successive layers of tungsten (W) plates as absorber and fused silica quartz (Q) plates as active medium (see Fig. 1). The Cherenkov, light produced by the passage of relativistic particles through the quartz medium, is collected in sections of 5 W/Q layers (sampling units) along the length of the calorimeter and focused by air-core light guides onto the PMTs.

For the electromagnetic section, the W-plates have a thickness of 5 mm and the Q-plates 2 mm. For the hadronic section, the W- and Q-plates have a larger thicknesses of 10 mm and 4 mm, respectively. The W/Q-plates are inclined 45° with respect to the direction of the impinging particles, in order to maximize the Cherenkov light output in the quartz. The EM section is divided in two successive RUs and has a total of 20.12 Xo or 0.77 λι lengths. The HAD section has 12 RUs, corresponding to 9.24 λι. In total, the CASTOR prototype has ~10λι.

Muon beam

Muon energy spectra at 50 and 150 GeV were measured in the EM and HAD sections. Figure 2 shows the muon peaks measured for the 150 GeV beam. The good pedestal-MIP separation allowed us to use the muon signal for the intercalibration of different channels of the CASTOR prototype.

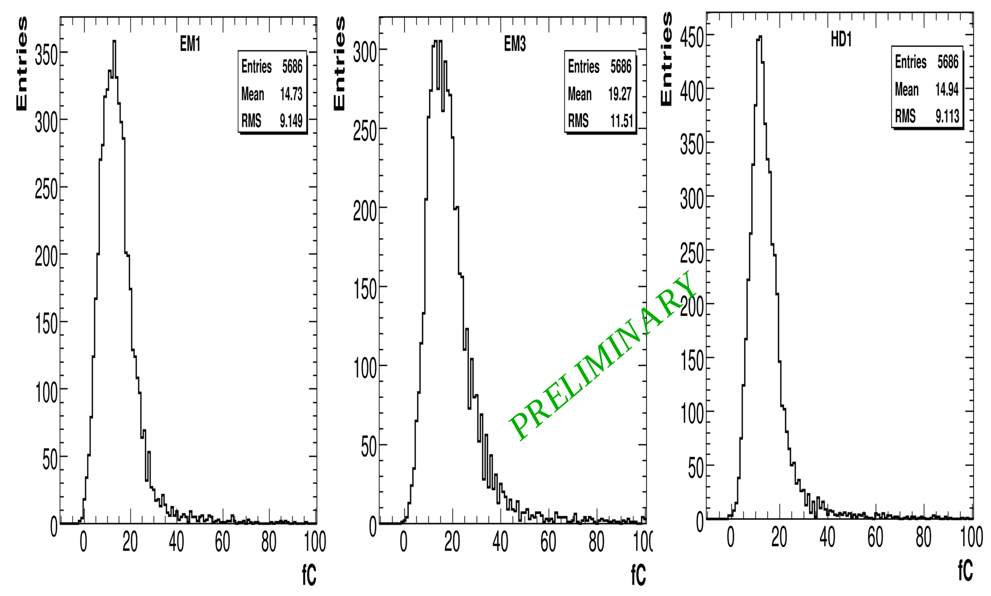

***Figure 2**. Energy spectra, pedestal subtracted, measured in the two EM and first HAD sections of the final CASTOR prototype with a muon beam of 150 GeV energy.*

Electron Beam

For all studies, a central point in the calorimeter was selected. The energy resolution and linearity was studied with electron beams of energy 10-200 GeV. Examples of electron signal peaks, fitted by Gaussian distributions, are shown in Figure 3 for beams of various energies.

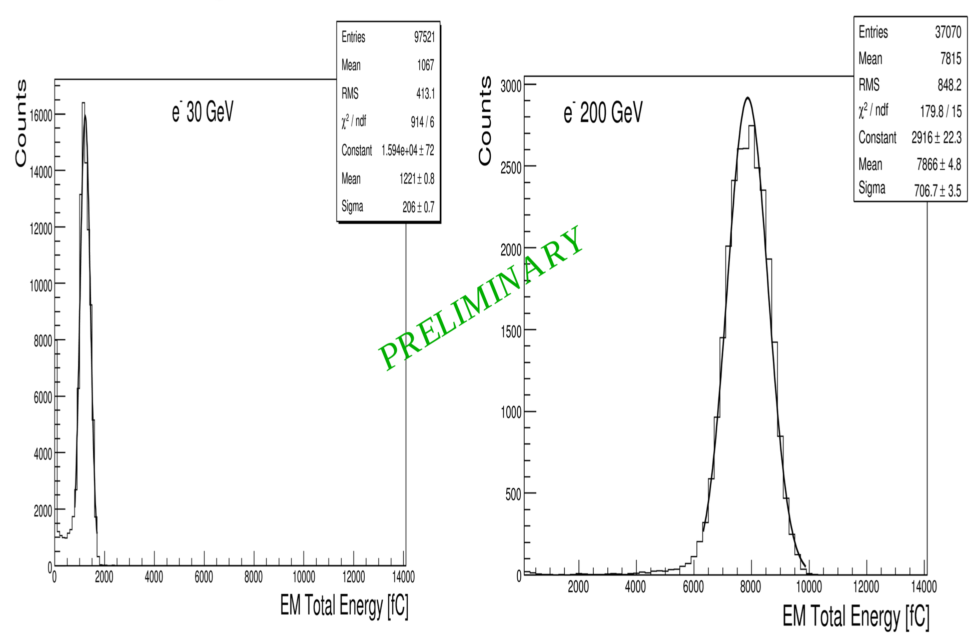

***Figure 3**. Energy response of the EM calorimeter to 30 and 200 GeV electrons respectively.*

The peak signal position is plotted as a function of the beam energy in Figure 4. The calorimeter response is found to be linear in the energy range explored. The relative energy resolution of the calorimeter was also studied by plotting the normalized width of the Gaussian signal amplitudes with respect to the incident beam electron energy and fitting with the functional form $\sigma/E = p_0 + p_1/E$ (Fig. 5).

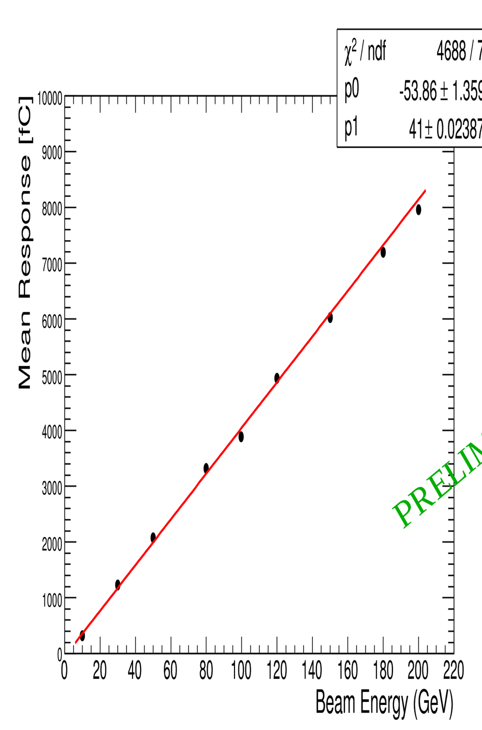

***Figure 4**. Energy response linearity of the EM sections.*

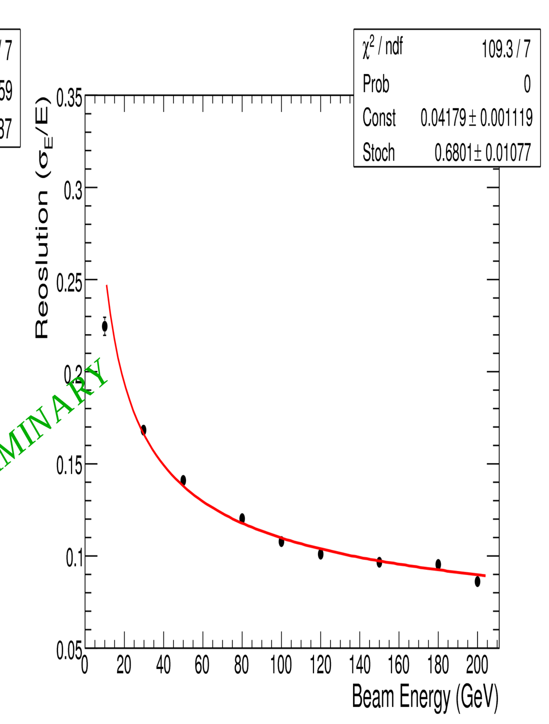

***Figure 5**. Energy resolution of the EM sections.*

An area scanning of the calorimeter was also performed in order to estimate the width of the EM shower profile (Figure 7). The x-derivative of the response was calculated, giving the width of the electromagnetic shower of sigma = 1.15 mm.

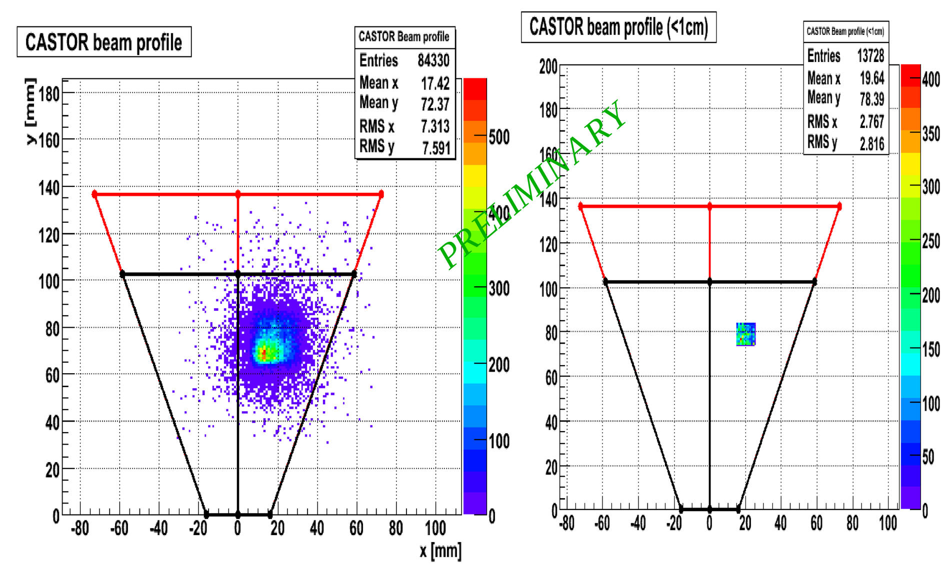

***Figure 6**. Profile of 200 GeV electron beam impinging on the right semi-octant of CASTOR, as measured by the scintillator-wire-chamber telescope. Right: Beam profile after imposing a cut and selecting hits within 1 cm in x and y directions.*

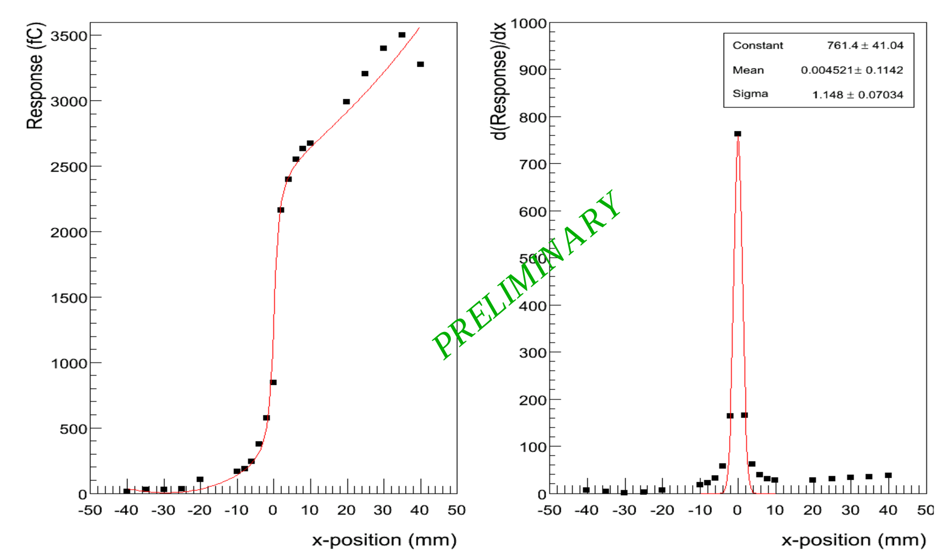

***Figure 7**. Response of the right semi-octant of the EM section as the beam scans the front face of the calorimeter. The derivative of the response with respect to x, indicates the width of the EM shower.*

Pion Beam

Pions of energy 20-350 GeV were used for the study of the hadronic energy and position responses of the final CASTOR prototype. The total CASTOR depth is 10 λι. Typical spectra, obtained with 80 and 180 GeV pions incident on the prototype, are shown in Figure 8, where the distribution of the total energy of the calorimeter is plotted. The peak of the total pion energy measured by the prototype was found to be well fitted with a convoluted Gaussian and Landau curve.

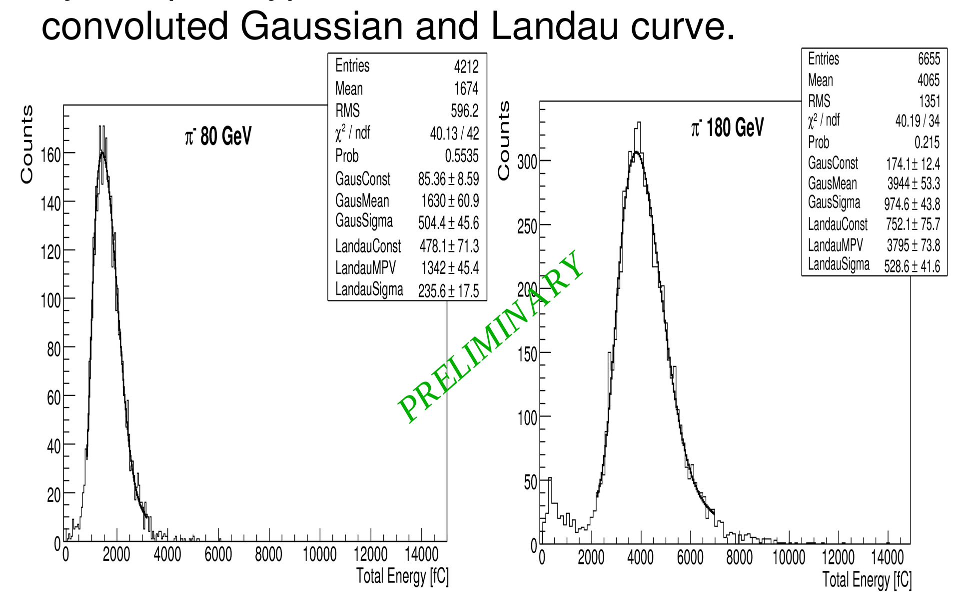

***Figure 8**. Total energy spectra measured in the CASTOR prototype, after pedestal subtraction, for an incoming pion beam of 80 and 180 GeV.*

The energy response (position and width of the pion peak) was obtained by fitting the spectrum measured for all beam energies. The corresponding hadronic energy linearity and resolution were thus obtained.

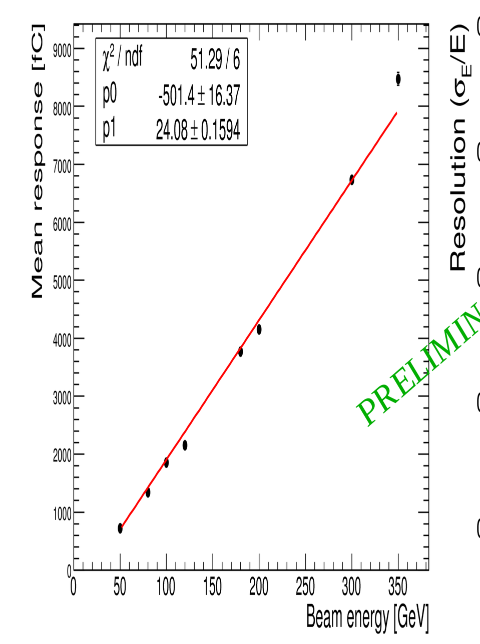

***Figure 9**. Energy response linearity of CASTOR prototype to pions.*

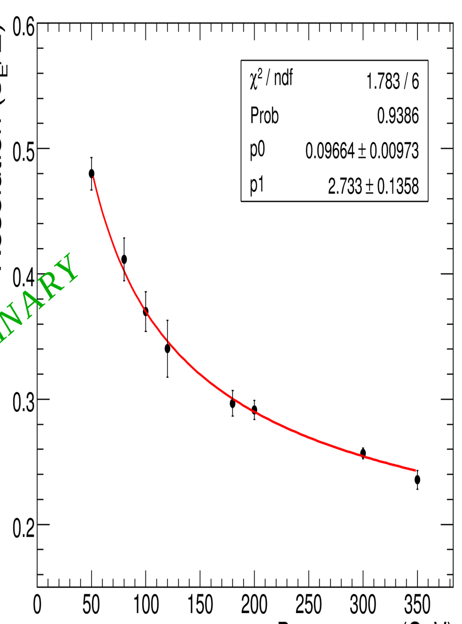

***Figure 10**. Energy resolution of CASTOR prototype to pions.*

The spatial response of the prototype calorimeter to pions was obtained from the (2) EM and (6) HAD RUs in the semi-octant sector, by moving the beam along the x-direction. Two runs with pion beams impinging on the center of each semi-octant were used to equalize the response of the corresponding left and right semi-octant sectors.

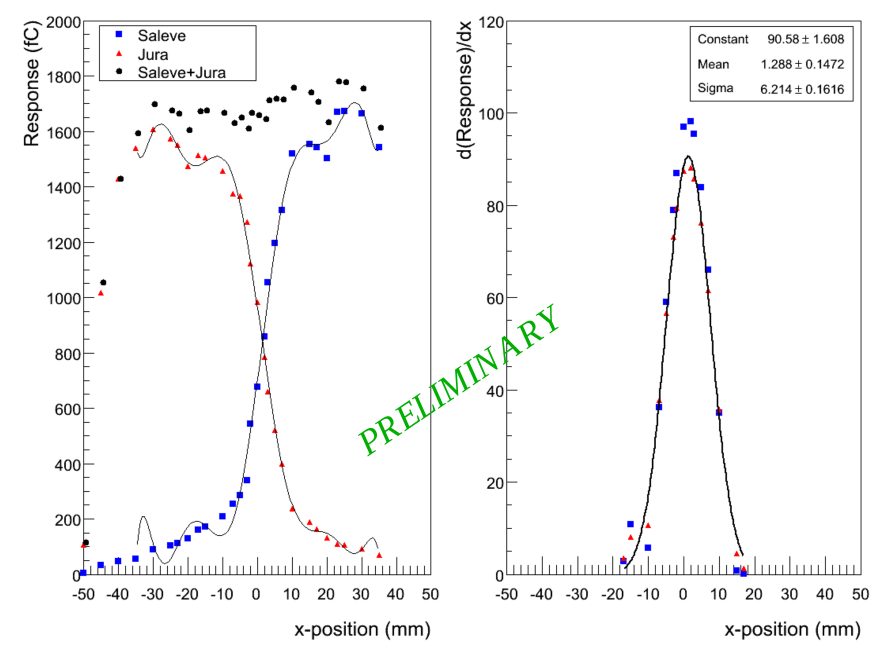

***Figure 11**. x-scan along the face of the prototype for 80 GeV pions. The derivative of the sigmoid curve, gives the width (sigma = 6.2 mm) of the hadronic shower distribution.*

Summary

We have presented a performance study of the energy and spatial responses of the final prototype of the CASTOR quartz-tungsten calorimeter of the CMS experiment. The main conclusions of this study can be summarized as follows:

- The PMTs feature a good pedestal-MIP separation. This allows one to use the muon signals to obtain the intercalibration coefficients of the different channels.
- The EM section of the calorimeter shows a good energy linearity. The resolution of the EM section is characterised by a stochastic term of ~68% and the constant term is around 4%.
- The spatial resolution of the EM section of the calorimeter is excellent. The width of a typical EM shower is ~1.15 mm.
- The full calorimeter (10 interaction lengths) shows a good energy linearity for hadronic (pion) showers. The measured stochastic (constant) term of the resolution is around 273% (10%). The spatial resolution of the calorimeter to hadrons is very good. The width of a typical pion shower is ~6.2 mm.

References

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[2] D. d' Enterria (ed.) [CMS Collab.], *CMS physics technical design report: Addendum on high density QCD with heavy ions*, J. Phys. G **34** (2007)

[3] X. Aslanoglou *et al.*, *First performance studies of a prototype for the CASTOR forward calorimeter at the CMS experiment*, CMS NOTE-2006/142, May 2006; arXiv:0706.2576 [physics.ins-det].

[4] X. Aslanoglou *et al.*, *Performance Studies of Prototype II for the CASTOR forward Calorimeter at the CMS Experiment*, CMS NOTE-2007/001, Eur. Phys. J. C **52** (2007) 495

[5] CASTOR web page: http://cmsdoc.cern.ch/castor/

Acknowledgements

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