Forward Physics Capabilities of CMS with the CASTOR and ZDC detectors

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The two calorimeters CASTOR and ZDCs enhance the hermeticity of the CMS detector at the LHC by extending the rapidity coverage in the forward region. After having described these detectors, their forward physics capabilities are presented. These latters include the study of parton shower, multiple parton interactions, diffraction and ultra high energy cosmic rays models. The processes to be measured to constrain these topics are multi-jet events with a forward jet, central-forward activity correlation, rapidity gaps and forward neutron production.

1 The forward calorimeters CASTOR and ZDCs

The CASTOR [1] calorimeter, illustrated on Figure 1, is located 14.37 m from the CMS interaction point and extends the forward rapidity coverage to the region $-6.6 < \eta < -5.2$. CASTOR presents a sandwich structure of tungsten (W) absorber plates and quartz plates as active material. It has an octagonal cylinder shape with an inner radius of 3.7 cm, an outer radius of 14 cm and a total depth of 10.3 λ_I. The collection of the signal is based on the production of Čerenkov photons which are transmitted to photomultiplier tubes through aircore lightguides, the W and quartz plates being inclined by 45 ° w.r.t. the beam axis to optimize the photon yield. The CASTOR calorimeter is divided in an electromagnetic section of 20.12 X_0 and an hadronic section of 9.5 λ_I. It has a 16-fold azimuthal segmentation in towers and a 14-fold longitudinal segmentation in sections, from which the 2 first are electromagnetic and the 12 remaining hadronic. It has no segmentation in η and consists therefore in a total of 224 channels. Castor has just been submitted to final tests in beam and installed inside of the CMS cavern at respectively the beginning and the end of this month of June 2009.

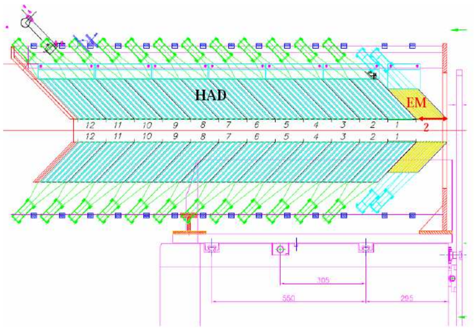

Figure 1: The CASTOR calorimeter.

The Zero Degree Calorimeters [2] (ZDCs), illustrated on Figure 2, are located 140 m from the interaction point in both the forward and backward directions. They enable to measure neutral particles produced at $|\eta| > 8.1$ and possess a full acceptance to measure neutral energy flow in the region $|\eta| > 8.3$. The ZDCs are also based on the production and detection of Čerenkov photons to build the calorimeter signal and present as CASTOR a sandwich structure of W plates as absorber and quartz fibers as active material.

Each of the ZDC calorimeters is divided in an electromagnetic section of 19 X_0 and an hadronic section of 5.6 λ_I. The electromagnetic section has a 5-fold horizontal segmentation to measure the pseudorapidity of the forward energy deposits, while the hadronic section has a 4-fold longitudinal segmentation. The ZDCs were already integrated into CMS for the 2008 first LHC run.

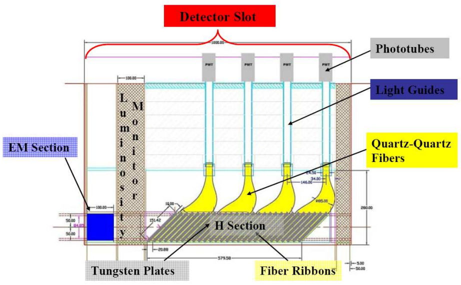

Figure 2: The ZDC calorimeter.

2 The CASTOR and ZDCs forward physics capabilities

The theoretical description of pp collisions at high energies involves the use of Matrix Elements (ME) associated to the hard scattering and Parton Showers (PS) linking the scattered partons with the final-state hadrons. The ME can be computed exactly at a given fixed order of the perturbative QCD expansion and for given values of the hard scale Q^2 and Björken variable x, while the PS takes into account higher order contributions by resuming a subset of leading diagrams at each order. The subset of leading diagrams considered depends on the values of x and Q^2 and various models exist to describe the PS evolution in the different phase-space regions.

2.1 Multi-jet events with a forward jet

The interest of forward physics to study the PS evolution comes from the fact that the differences between the predictions of the various models are more prominent in the forward region. The DGLAP [3] evolution equations as implemented in PYTHIA [4] and for which the gluon ladder is ordered in k_t predict PS in which the softest emissions are the ones closest to the proton remnant direction, while the BFKL [5] evolution equations for which the gluon ladder is ordered in x without any k_t ordering or the Color Dipole Model (CDM) as implemented in Ariadne [6] and in which the emissions are generated by color dipoles radiating independently predict arbitrarily large forward emissions as long as allowed by the kinematics. The measurement of multi-jet events with a forward jet in CASTOR is therefore an important tool to distinguish between the various models and to study the PS dy-

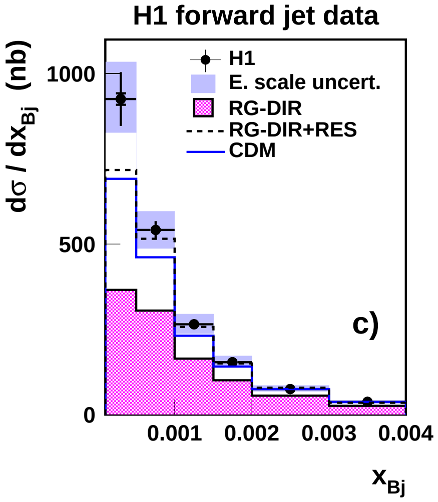

Figure 3: The hadron level cross section for forward jet production as a function of x_{bj} compared to the QCD Monte Carlo models RAPGAP [8] and Ariadne [6].

namics beyond the standard direct DGLAP approximation. This is illustrated on Figure 3 by the H1 results relative to the study of forward jet production in Deep Inelastic Scattering at HERA [7]. The data are compared to the QCD Monte Carlo models RAPGAP [8] and Ariadne [6], which respectively uses the DGLAP evolution equations and the Color Dipole Model to describe the Parton Shower.

The study of the distribution of the pseudorapidity separation between jets, $\Delta\eta$, in multi-jet events with a forward jet in CASTOR, would also enable to distinguish between the various PS models. By selecting events with different $\Delta\eta$ topologies, one can indeed look at the breaking of the k_t ordering at different places along the gluon ladder. One can for example enhance the available phase-space in x for BFKL-type radiations by looking to events with a forward jet in CASTOR and a central dijet system [7].

The CASTOR calorimeter can also be used to measure Mueller-Navelet dijet events [9] in which a jet is detected in each of the forward directions. This process is characterized by the presence of two hard scales - the transverse momentum of the two jets - which leads to a suppression of the emissions ordered in k_t as described by the DGLAP equation. It is also characterized by a large rapidity interval between the two jets of the dijet system, which leads to an enhancement of the BFKL-type radiations. The measurement of Mueller-Navelet dijet events is therefore well suited to access the dynamics beyond DGLAP, particularly through the study of the azimuthal decorrelation $\Delta\phi$ between the two jets of the system [10].

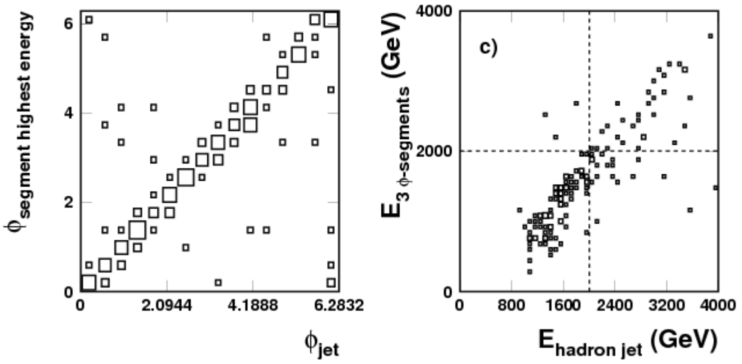

Figure 4: Azimuthal angle and energy of the jet at generated level and CASTOR level.

The feasibility to reconstruct forward jets in CASTOR has been studied by the Antwerpen and DESY groups. The results presented here have been obtained by Albert Knutsson and correspond to a generator level study based on Ariadne. The jets are defined at generator level according to the inclusive k_t algorithm and at CASTOR level according to a simplified approach by considering 16 sectors in ϕ and summing the energy longitudinally in each of these sectors. The azimuthal angle of the jet at CASTOR level is then given by the azimuthal angle of the highest energetic sector, while the energy of the jet is given by the energy of the highest energetic sector to which the energies of the two neighboring ones are added. One has to emphasize that no detector effects are taken into account. The correlation between the energy and the azimuthal angle of the jet at generated level and CASTOR level is shown on Figure 4 and found to be reasonably good.

2.2 Underlying Events and Multiple Parton Interactions

The Underlying Event (UE), defined as everything except the hard scattering component of a collision, is an unavoidable background which has direct implications on measurements at the LHC. It affects for example the jet reconstruction and the isolation cuts. The UE receives contributions from the Initial and Final State Radiation (gluon emissions), from the Beam Remnants (particles coming from the proton break-up) and from the Multiple Parton Interactions (MPI) which correspond to additional softer parton scatterings. If from an experimental point of view, it is impossible to separate the UE from the hard component, the topological structure of a pp collision however enables to define observables which are sensitive to the UE, like the average sum of charged particles transverse momentum in the transverse region w.r.t. the leading jet direction. The problem in the understanding of the UE at the LHC comes from the fact that different MPI models tuned to describe equally well Tevatron data for the above observable give very different predictions when extrapolated at the LHC energy [11]. The MPI occurring between the spectator partons, they strongly affect the forward energy flow and the measurement of energy deposit in CASTOR could therefore be sensitive to the various MPI models. The MPI induced correlation between the activities in the forward and central regions could furthermore be studied by looking at the charged particles multiplicities as a function of η for different energy deposits in CASTOR. Figure 5 illustrates such a study on the basis of a generator level analysis of inclusive QCD processes made with PYTHIA for several MPI tunes [12].

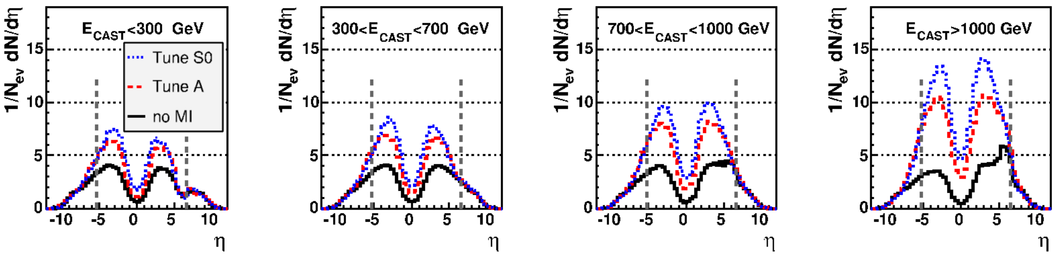

Figure 5: Charged particles multiplicities as a function of η for different CASTOR energy deposits. Shown is PYTHIA prediction for inclusive QCD processes and several MPI tunes.

2.3 Diffraction and rapidity gaps

Diffractive pp interactions, for which one or both protons stay intact, enable to study the perturbative QCD and the hadron structure through the measurement of the cross sections for diffractive jet, Z, W or heavy quark production. Diffraction also enables to study MPI and soft rescattering through the extraction of the rapidity gap survival probability. Diffractive processes will be selected at CMS by rejecting events with a forward activity in the Hadron Forward (HF) and CASTOR calorimeters. The use of CASTOR could yield in particular to an improved rejection of non-diffractive processes, while the ZDCs could be used to reduce the diffractive dissociation background [13].

2.4 ZDCs $p\,p$ forward physics program

The ZDCs being fast enough to give an answer at the level 1 trigger, they could be used online to select the diffractive events and to reject the diffractive dissociation background. The ZDCs also plan to measure the correlation between the neutral forward energy flow and the particle multiplicity in the central region. The measurement of the forward neutron production by the ZDCs could lead in particular to a better constraint on the low x part of the gluon pdf and the Ultra High Energy cosmic rays models [14]. The ZDCs could finally monitor the luminosity of the beam by looking at $p\,p$ bremsstrahlung events and forward neutron production.

3 Conclusion

The forward calorimeters CASTOR and ZDCs are planed to play an important role in the study of forward physics with the CMS detector at the LHC. Their program, extending from forward jet production to diffraction, could enable to measure a wide variety of observables.

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