Zero Degree Calorimeters for Beam Optimization and Physics Measurement

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The Compact Muon Spectrometer (CMS) is a general - purpose detector for the study of proton - proton, proton - nucleus and nucleus - nucleus collisions at the LHC [1]. The two zero degree calorimeters (ZDCs) have been proposed to complement the existing detector in the very forward region (8.5 < η). The ZDCs are sampling calorimeters, the core of each structure consists of a tungsten plate/quartz fiber ribbon stack. The hadronic (HAD) has 24 layers of 15.5 mm thick tungsten plates and 24 layers of 0.7 mm diameter quartz fibers. The electromagnetic (EM) section is made of 33 layers of 2 mm thick tungsten plates and 33 layers of 0.7 mm diameter quartz fibers.

The HAD section is longitudinally segmented into 4 readout segments of ~1.4 nuclear interaction length each. The tungsten plates are tilted by 45°.The fibers are grouped together to form readout bundles. Four fiber bundles are coupled to four photomultiplier tubes with long air core light guides. The electromagnetic section segmented into 5 horizontal readout towers. The tungsten plates are oriented vertically.

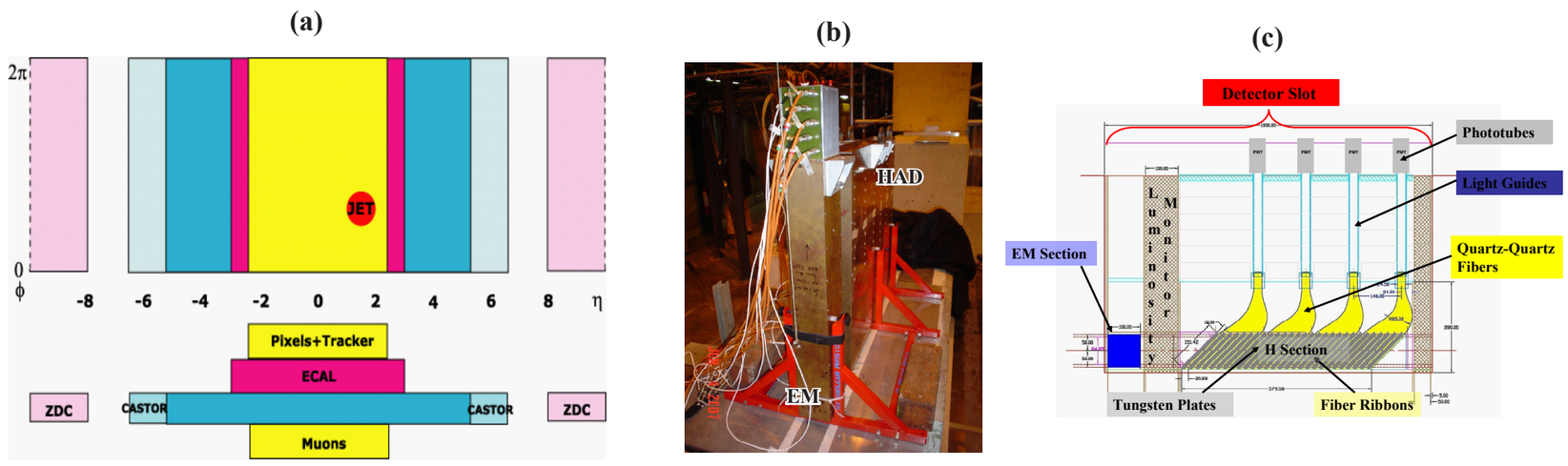

Figure 1. *(a) CMS acceptance of tracking, calorimetry and muon identification in pseudo-rapidity (η) and azimuth (φ). The size of a jet with cone radius R=0.5 is also depicted for illustration. (b) Picture of one of the ZDC detectors during the test beam run. (c) Schematic illustration of the TAN detector slot showing the location of the p - p luminosity monitor and the ZDC (EM section and HAD sections), the EM quartz-quartz fibers and PMTs not shown.*

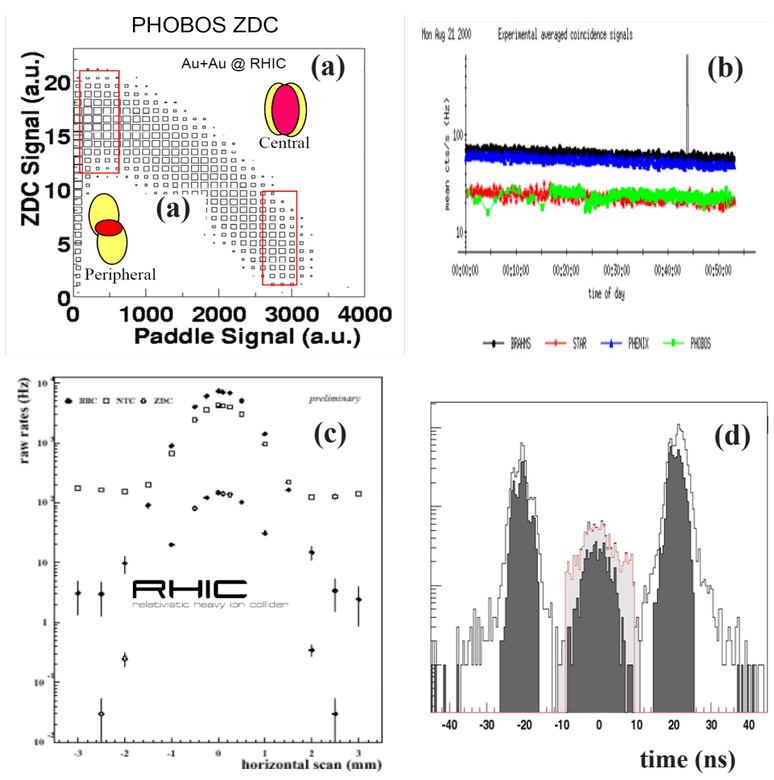

Figure 2. *(a) Correlation between ZDC signal and centrality (from beam-beam counters) [2]. (b) Coincidence rate from the ZDCs of RHIC experiments. (c) ZDC coincidence rate vs. beam displacement. (d) Time difference signal from PHOBOS' beam-beam counters, the light gray is the vertex cut generated with the ZDCs [2].*

Experience at RHIC has shown that the ZDC's provide a reliable measurements of real - time luminosity, beam tuning and accelerator monitoring during A + A, d + A and p + p running (Figure 2b, 2c). In addition, their "time" signals helped to discriminate effetively against beam gas backgrounds, complementing the methods for triggering (Figure 2c). Furthermore, since the ZDC are sensitive to the "spectator" nucleons (neutrons), they were used for the reliable measurement of the reaction centrality in A + A and d + A collisions at RHIC (Figure 3(a)). From RHIC's experience, it is expected that the ZDC will be very useful for luminosity monitoring, event selection and background cleanup in the level - 1 trigger at CMS. The ZDCs timing resolution (~90 ps) will allow vertex determination to a precision of few centimeters.

The design parameters that will allow the good performance of the ZDC s at the LHC were put to a test in beam test runs. Measurements were carried out in the SPS H2 beam at CERN in 2006 and 2007 [3]. The characteristics of the EM section were measured with 10, 30, 40, 50, 70, 100 and 150 GeV positrons, while pions with energies of 100, 150, 200, 300 and 350 GeV were used to measure the response of the EM + HAD combined system. The resolution (Figures 3a and 3b), the linearity (Figure 3c), and the response to the variation of the position of the beam along the transverse section of the calorimeters (Figure 3d), show that the ZDC's will measure successfully neutrons and very forward photons within the design parameters in heavy-ion and pp collisions at the LHC.

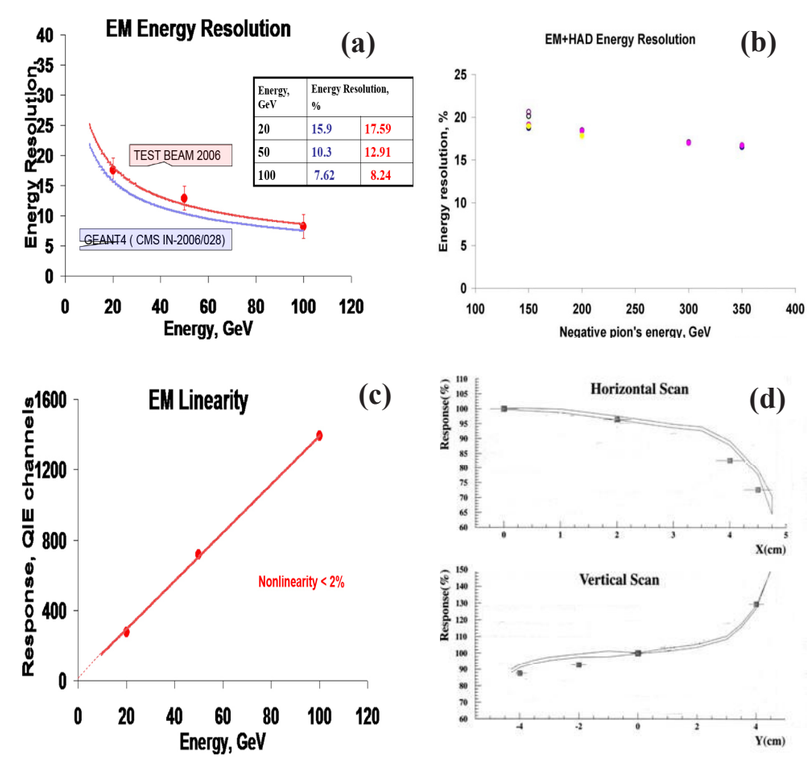

Figure 3. *(a) Resolution as function of energy for EM measured and simulated. (b) Resolution for EM+HAD section. (c) Linearity response for EM section. (d) Relative resolution (EM+HAD) as function of the transversal incident beam position, data from RHIC's ZDCs[4].*

There is a wide range of physics measurements that can be performed using the ZDC.

- Related to accelerator physics at RHIC the absolute luminosity in AA collisions was measured via the electromagnetic dissociation channel.
- Together CMS's forward detectors, the ZDC will help to tag the rapidity gap in diffractive pp interactions.
- In pp and AA the ZDC will help to understand the particle multiplicity and energy flow the small Bjorken x region.
- In heavy ion collisions the ZDC will be capable of measuring the azimuthal distribution of neutral particles or flow.
- There are interesting channels of ultra-peripheral collisions (UPCs) where the RHIC ZDC were used for neutral particle tagging. The same measurements will become very important at the LHC.

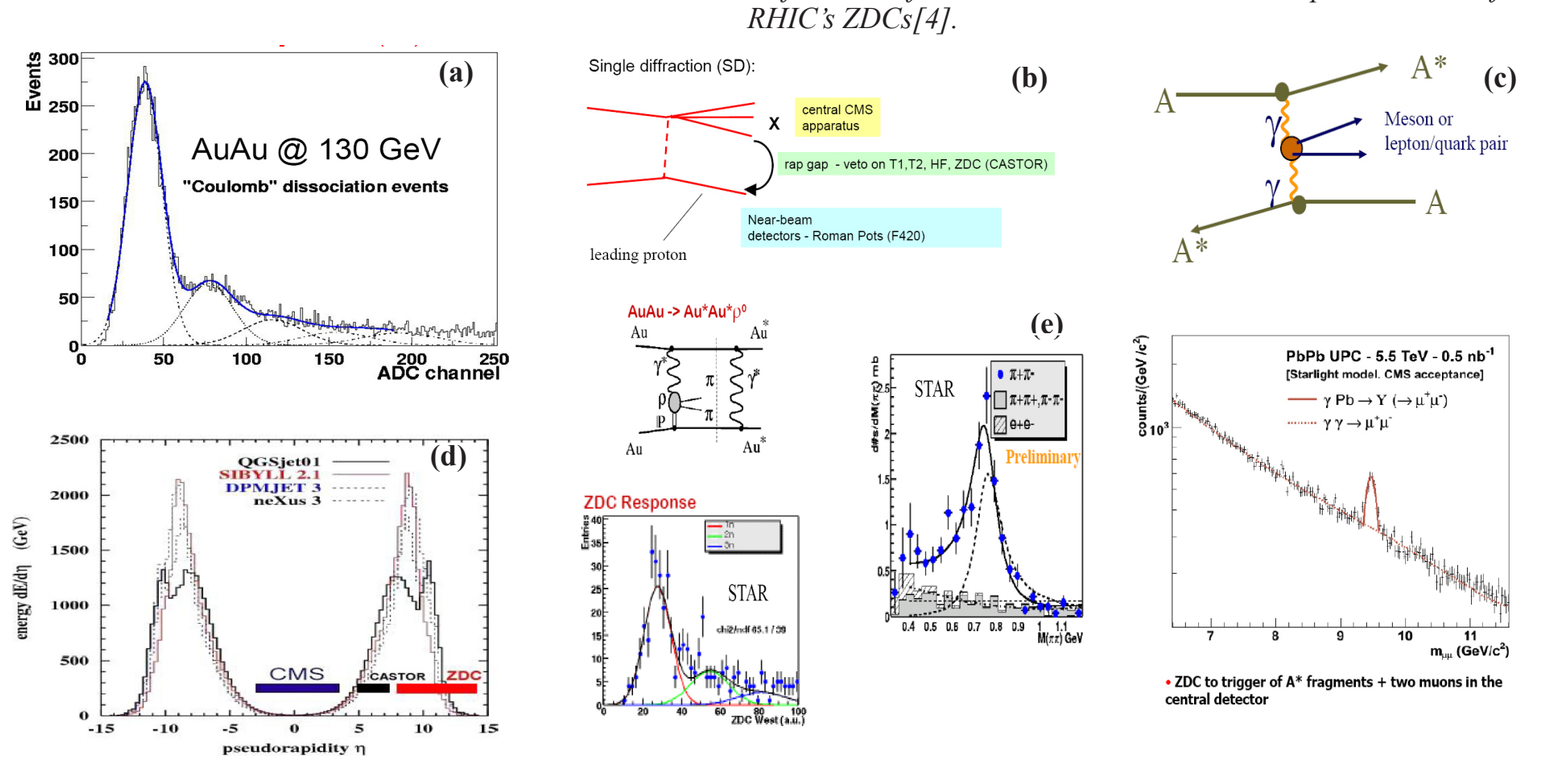

Figure 4. *(a) Neutron distribution measured at RHIC to calculate absolute luminosity [4]. (b) Scheme for SD event detection at CMS (c) Illustration for UPC γγ measurement of Y [5]. (d) Prediction of energy flow distribution for pp LHC collisons [6] (e) Measurement of light quarks in STAR using the ZDC [7].*

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