

PHENIX Zero Degree Calorimeter (ZDC) and Shower Maximum Detector (SMD) Detector Basics

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Purpose, technology, dimensions

The Zero Degree Calorimeter (ZDC) is the only detector, that was built and installed in all four RHIC experiments in an identical form [1]. They were intended to serve as a *trigger*, *luminosity monitor* [2] and *event characterization* [3] detector. They are hadronic calorimeters, designed to measure evaporation neutrons emitted in a very narrow cone in the direction of the beams (whence “zero degree”) in high energy collisions of nuclei. In order to capture them, the North and South ZDCs (ZDCN, ZDCS) are placed about 18 m from the collision point, after the DX magnet that separates the two beams and steers them into their respective pipes (see Fig. 1). Evaporation neutrons have virtually zero p_T (modulo their intrinsic Fermi-momentum in the nucleus), specifically, at 100 GeV/nucleon beam energy they are expected to stay within a 2 mrad cone (± 3.6 cm) [1]). Thanks to this, a compact, just 10 cm wide ZDC could be built that fits between the beampipes. Note, that at lower beam energies the size of the cone increases (p_z decreases, while the transverse Fermi-momentum is unchanged), so the ZDC becomes less and less useful.

The ZDC consists of three identical modules, placed behind each other, read out separately (one PMT per module). It is a longitudinally segmented hadronic sampling calorimeter, with tungsten alloy absorbing plates interleaved with layers of PMMA based optical fiber (see Fig. 2 left) which are the active area. Charged secondaries from the hadronic shower generate Cherenkov-light in the fibers, which at the same time guide the light to the external photomultipliers. Since the Cherenkov-angle is about 45° , the tungsten plates and the fiber layers are all tilted, giving a wedge-shape to the modules (see Fig. 2 middle and right). At

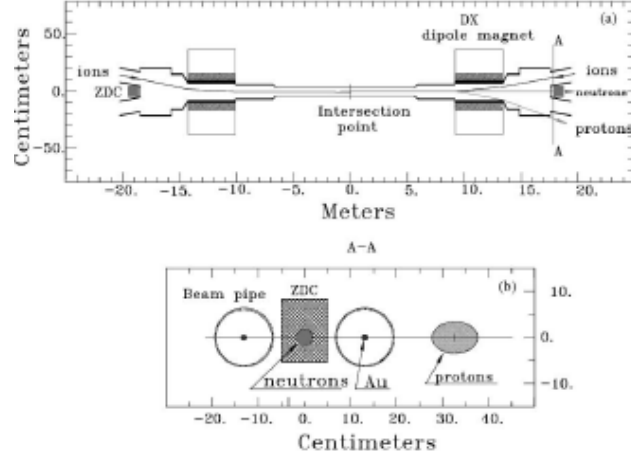


FIG. 1. ZDC location between the beampipes, downstream after the DX magnet ± 18 m from the collision point. (Figure taken from [1].)

both sides (N and S) four signals come out of the ZDC: the three individual PMTs and an analog sum for trigger purposes. The photomultipliers are 12-stage Hamamatsu R329-2 tubes.

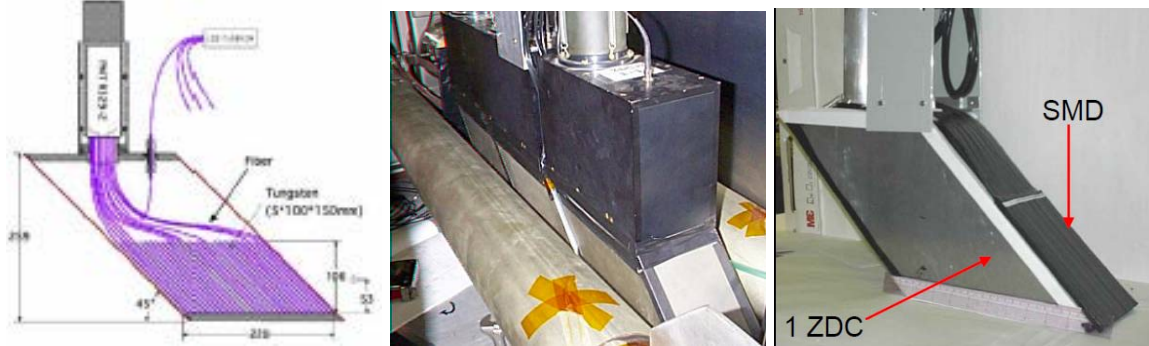


FIG. 2. (Left) Drawing of the fiber layer interspersed between W plates and the path to the readout PMT. (Middle) Picture of the three ZDC modules between the beam pipes. Note the tilted front and back face of the active section. (Right) The shower maximum detector in front of a ZDC module. During data taking it is located between the first and second ZDC module. (Figures taken from [4].)

Each ZDC module is $1.7\lambda_I$ (nuclear interaction length) and about $50X_0$ (radiation length). The longitudinal segmentation makes it possible to eliminate accidental high energy photons, since they will deposit all their energy in the first ZDC module, while full energy neutrons will

always have energy in the second and third modules as well. – While most charged particles will be swept out of the narrow ZDC acceptance, secondaries (e.g. from interactions with the beampipe) might end up there; these can be eliminated by the “forward scintillator” right in front of the ZDC [5].

The energy resolution in the three modules combined is 19% for 100 GeV protons, dominated by non-compensation ($e/h = 1.78$ [1]). In situ calibration can be done with single neutron hits. As seen in Fig. 3, the single neutron peak is well visible even in normal 200 GeV Au+Au collisions, but can be enhanced if one selects events where at least one of the BBCs didn’t fire (single diffraction events).

The timing resolution is about 120 ps for 100 GeV neutrons [5], which translates into an ~ 2.5 cm vertex position resolution in heavy ion collisions. The difference $(t_{ZDCN} - t_{ZDCS})/c$ gives the collision vertex, while $(t_{ZDCN} + t_{ZDCS})/2$ provides the time of the collision. Note that while these quantities are available, actual analyses usually use the vertex and collision time derived from the BBC.

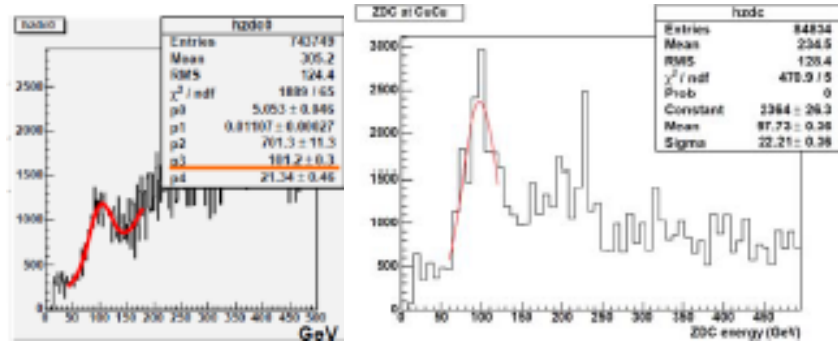


FIG. 3. ZDC calibration with single neutrons. (Left) Normal heavy ion collisions at 100 GeV/nucleon. (Right) Selecting “Coulomb” excitation events – no signal in BBC in at least one arm. (Figures taken from [5].)

Shower Maximum Detector (SMD)

The ZDC provides no information on *where* the neutron hit, although for some observables it is indispensable, like single transverse asymmetry A_N of forward neutron production in p+p collisions [4, 6] and p+A collisions [7]. In order to recover the impact point, a Shower Maximum Detector (SMD) has been installed between the first and second ZDC module. It

consists of two layers of plastic scintillator strips: the horizontal x coordinate is sampled by 7 strips, each 15 mm wide, the vertical y direction by 8 strips, each 20 mm wide, tilted by 45° . Each strip is read out separately. For all practical purposes charged secondaries from the hadronic shower at this point (1.7 interaction length deep) are minimum ionizing, therefore, the signal in each strip is proportional to the number of charged particles crossing. Weighting the strip positions with their charged multiplicity (total signal) allows to measure the center of gravity (x, y) of the shower. The resolution varies from 10 mm at low multiplicity to 3 mm at 100 or more charged secondaries [5]. An online monitoring plot for the ZDC/SMD detector in Au+Au collisions, including typical energy deposits, reconstructed vertex position, and SMD position measurements (essentially beam position) is shown in Fig. 4.

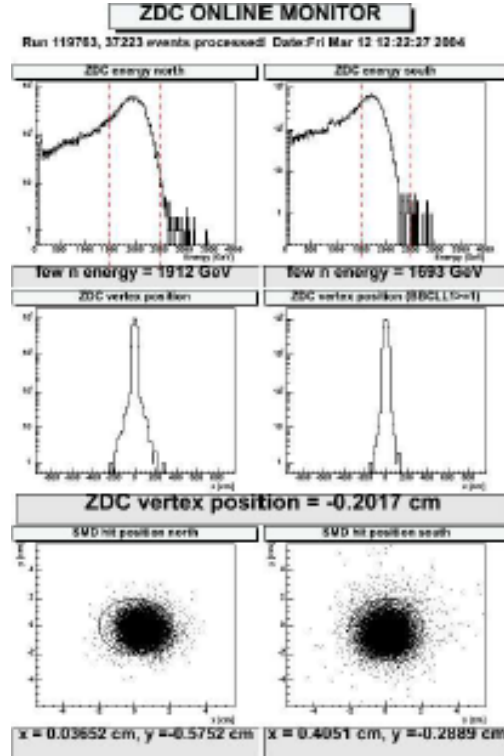


FIG. 4. Online monitoring plot for the ZDC and SMD detectors. (Figure taken from [5].)

ZDC trigger

The ZDC was usually included in the trigger mix. While most the time the BBC is used to trigger (inelastic) collisions and determine centrality, the ZDC trigger is indispensable for analyses of forward neutron asymmetry [7] and ultraperipheral collisions [8]. For more details see [9].

Centrality “clock” – ZDC vs BBC

In the early heavy ion runs collision centrality has been defined using a combination of the ZDC and BBC signals. In Fig. 5 the ZDC vs BBC analog signal is plotted, both normalized to their maximum value. In the most peripheral collisions there are barely any hits in the BBC, but the energy in ZDC changes rapidly with 1, 2, 3... spectator neutrons (amplified by the “neutron skin” of heavy ions). However, the ZDC quickly saturates, already around 70% peripheral collisions. While the overlap (participant) region is still quite small, the remaining (spectator) part is mostly breaking up into heavier fragments or many lighter nuclear fragments, rather than free protons and neutrons [10]. As one moves to smaller and smaller impact parameters (higher centrality), the BBC signal increases monotonically, while the ZDC decreases, since there are less and less neutrons in the spectator part, and even of those few most will be part of nuclear fragments. The ZDC, however, can be useful in categorizing very peripheral events (fast rising left band), where the BBC doesn’t have any sensitivity at all, so this “entrality clock” plot is worth keeping in mind.

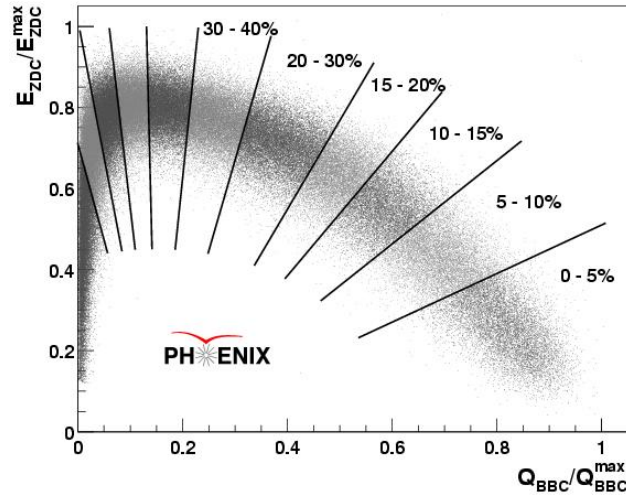


FIG. 5. Centrality clock: ZDC vs BBC analog signal, both normalized to their maximum value, and the corresponding centrality bins. (Figure taken from [11].)

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