EIC Detector Studies *

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1st March 2002

Abstract

The Yale ’2000 Workshop detector model is presented. A short summary of the Interaction Region Group of the EIC Accelerator Workshop is given.

The Yale ’2000 and present workshops extensively reviewed the physics programme for the Electron – Ion Collider (EIC). Also at Yale and during the EIC Accelerator Workshop (EICAW) possible options for the machine and the Interaction Region (IR) were discussed.

At Yale a model of a generic detector and the IR layout were proposed and discussed [1, 2]. The design criteria were:

• common detector for ep, eA, pp and pA collisions,
• reconstruction of “whole” ep and eA event,
• precise luminosity monitoring and control of radiative corrections,
• good detector quality in the fragmentation regions,
• minimal interference with the existing IR optics,
• use of the existing RHIC lattice in the spectrometer design,
• possibility of a polarized electron beam.

*Presented at EIC Workshop, 28 February – 2 March, 2002, BNL
These requirements are based on the H1 and ZEUS experiences and on the possible range of the machine parameters [3]. The electron–nucleus interaction leads to the production of jets, de-excitation gammas, “wounded” (struck by a probe) nucleons, re-scattered nucleons or heavier fragments. Figure 1 shows the pseudorapidity ($\eta$) spectrum of the final state particles for $e(10 \text{ GeV}) – Au(100 \text{ GeV/A})$ collisions. The ZEUS and H1 detectors at HERA prior to the machine and the detectors upgrade covered roughly the range of (-5;5). Forward detectors like the Roman Pots system or the forward neutron counter were able to cover some part of the
spectrum. However, their acceptance was limited. In the electron (current) direction, the bremsstrahlung and initial state QED radiation were measured in the photon counter. The leptons scattered at small angles were detected in the electron taggers. It is obvious from Fig. 1 that to achieve a “complete” event measurement an extended “nucleus/hadron spectrometer” is necessary. The optimal choice of the nuclei species would cover uniformly the range of

\[ R \approx A^{1/3} \]

Figure 2 shows the wounded nucleon average multiplicity as a function of \( A \) and compares the wounded nucleon multiplicity distributions in case of \( eCa \) and \( eAu \) interactions. The average multiplicity is approximately proportional to \( A^{1/3} \). Comparison of the distributions for calcium
and gold shows that the large multiplicity tail in eCa collisions can simulate gold-like conditions.

![Figure 3](image)

In Fig. 3 the cumulative multiplicity of neutrons as a function of the distance from the beam direction is shown. The multiplicity saturates at the distance of about 15 – 20 cm. This shows that the enlarged Zero Degree Calorimeter will play an important role in the inelastic event tagging. The proposed model detector (reviewed in EICAW by E. Barrelet, Figs. 4–6) was divided into three parts further subdivided into the detector components:

- hadron side:
Figure 4: Yale '2000 detector and IR model. Electron side layout.

- Roman pots: diffractive scattering on beam,
- high rigidity spectrometer: EM calorimeter for nuclear $\gamma(\pi^0)$; hadron calorimeter for measuring evaporation neutrons and for p and heavier fragments identification; tracking for measuring evaporation protons and heavier fragments,
- medium rigidity spectrometer: EM calorimeter for $\gamma(\pi^0)$; hadron calorimeter to measure wounded neutrons, protons and for identification of heavier fragments; tracking system to measure $\pi^\pm$, protons and fragments;
- rapidity gap tagger: to close the acceptance for charged particles and to tag diffractive events;

- parton side is a compact central detector:
  - the tracking chamber and the EM calorimeter inside a magnet – $N/8$,
  - the Spacal (H1) type end-caps,
- instrumented iron,
- $\mu$-vertex providing small angle tracking.

- lepton side:
  - instrumented beam pipe for electron tagging
  - photon counter for the luminosity and radiative correction control, electron beam diagnostics and monitoring.

Figure 5: Yale '2000 detector and IR model. Central detector layout.

As can be seen from Figs. 4–6 the electrons are early separated from the ions by the $DE$ magnet. Magnet’s parameters allow for the spin rotation and make it possible to bypass the $DX$ magnet with the electron beam pipe. The $DE$ magnet consists also a part of the spectrometer (medium rigidity) in the hadron direction. In the electron direction it is used to analyze the scattered electron energy. As an example a correlation between the $z$ coordinate of the electron exit point (from the beam pipe) and its energy is shown in Fig. 7. One can observe that the position determines the electron energy. The beam angular divergence will broaden the correlation curve. The exit
Figure 6: Yale '2000 detector and IR model. Hadron side layout.

position can be measured with help of the active beam pipe. For example with layers of the fibers. At the zero angle the gamma counter is placed. Its applications are mentioned above. In the central detector good energy measurement is achieved by the use of “good resolution” calorimeters combined with tracking. In addition, the $\mu$-vertex will help in the interaction vertex position determination and small angle tracking. The energy distribution of the final state particles emitted with $\eta < -6$ is shown in Fig. 8. A clear energy quantisation is seen for the nuclear fragments. The fragment energy determines its composition.

The level of the synchrotron radiation with critical energy about 60 keV is a drawback of the Yale model. On the entry into the detector (hadron side), it may deteriorate the active beam pipe and the central tracking performance. On the exit (electron side), it will influence the lepton measurements leading to increased pedestals’ widths. It also forces the use of the synchrotron radiation filters in front of the gamma counter.

The HERA IR region was discussed by U. Schneekloth. To achieve high luminosity the final focus magnets were introduced into the central detector. This, on one side, reduces the detector acceptance and on the other, leads to
high synchrotron radiation levels with about $10^{18}$ photons per second. The calculations shown by D. Pitzl show that a reduction factor of $10^{10}$ on the number of photons is needed. Partially, it was achieved with help of the synchrotron radiation collimators (Fig. 9).

An existing solution for the early separation of the beams was discussed by U. Wienands and is shown in Fig. [9]. The price paid for the very high luminosity in PEP are the magnets which are very close to the nominal vertex and the dead area up to 20° away from the beam direction. One should note that this limitation of the detector acceptance is of less importance in case of the $B$-factory. Such a solution may play a very important role in case of extreme luminosities as proposed in the Crab Crossing option (Fig. [11]) for the IR.

An improved solution for the IR was shown by B. Parker (Figs. [12]–[13]). He proposes to achieve an early separation of the beams by means of a small dipole component added to the solenoidal central field. This diminishes the synchrotron radiation influence (critical energy about 6 keV). Further, the septum magnet (in this case the Lambertson magnet, warm type) is introduced next to the central detector. The electron beam passes the field
free zone while ions traverse a 1 T dipole field. This option allows for the active beam pipe and provides the spectrometer functionality. One should also note that this option offers the head-on collisions and that all three beams are present in the interaction region.

Summarizing there is no doubt that a good design of the IR and that of the detector are very closely connected. It has to emerge from the co-operation of the machine and the experimental physicists. It has to be checked whether the current designs are optimal or they should be further improved or one has to look for anew, different designs. One should note that the ratio of the lepton to the ion energies has a large impact on the detector design. So has the lepton energy tunability and possible luminosity value. Obviously one should look for the hermetic option of the detector, with the machine lattice used for the spectrometric measurements. The “complete event” option is of great value and it makes the coverage a wide range of physics processes feasible. The bremsstrahlung is a good candidate for a precise luminosity measurement both on- and off-line, and for the fast on-line lepton beam diagnostics.

Figure 8: Energy distribution of different particle species for $-10 < \eta < -6$. 
Figure 9: Synchrotron radiation in the HERA IR.

Figure 10: PEP IR.
Figure 11: Crab Crossing in the IR.

Figure 12: Early separation of beams in Parker’s proposal.
References

[1] M. W. Krasny, Physics of eA Collisions at RHIC and HERA, *Proc. The 2nd eRHIC Workshop*, Yale, April 6 – 8, 2000.

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[4] Contributions to EICAW IR working group by: Etienne Barrelet, Slava Derbenev, Douglas Hasell, Jorg Kewisch, Brett Parker, Steve Peggs, Daniel Pitzl, Uwe Schneekloth, Uli Wienands.