A NEW DETECTOR AT ERHIC STUDYING THE TRANSITION REGION

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A new detector is proposed for the future eRHIC accelerator in order to measure proton structure functions F_2 and F_L in the transition region, namely, at $Q^2 \approx 1$ GeV^2, and at small and large x. It is composed of a dipole magnet centered on the IP and silicon trackers along the beam line, so as to measure precisely electrons and hadrons with small scattering angles.

1 Introduction

One of the important discoveries at HERA is the rapid increase of the proton structure function F_2 as Bjorken-x decreases, as indicated by the parameter λ, defined as

$$\lambda = -\partial \ln F_2 / \partial \ln x \, .$$

The λ values as measured at ZEUS are shown in Figure 1 (left) for different Q^2. The H1 collaboration has similar results [1]. While at large Q^2, λ increases as Q^2

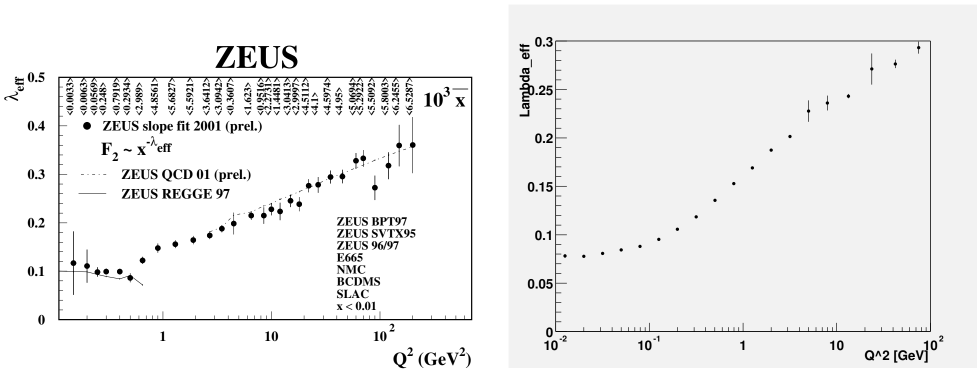


Figure 1. λ as measured at ZEUS (left) and with the proposed detector (right).

increases, at $Q^2 \approx 1$ GeV^2 and below, λ reaches the value of ≈ 0.08 [2], which is an observed feature in hadron-hadron interaction. A precise measurement of F_2 at this transition region would play an important role in testing perturbative

QCD (pQCD) and studying the long range interaction. However, both ZEUS and H1 detectors have limited acceptance for electrons with small scattering angle, resulting in relatively large errors on F_2 and λ.

The longitudinal structure function F_L is proportional to the gluon density and serves as another important test for pQCD. At Q^2=2 to 5 GeV^2, the next leading order (NLO) and NNLO calculations show large variations on gluon density and F_L [3]. Current measurements of F_L at HERA [4] are not precise enough to distinguish different models yet [5]. Much more precise measurements are needed.

It is also very interesting to measure F_2 at $x > 0.5$ in the medium Q^2 region. The measurements can be performed with a dedicated detector as discussed in detail in the following chapters.

2 Detector design and performance

A new eRHIC collider is proposed at BNL with 10 GeV electrons (positrons) on 200 GeV protons. A detector is designed dedicated to the measurement of F_2 and F_L with Q^2 in the range 0.1 to 100 GeV^2. The goal is to measure the momenta of electrons with small scattering angles (η up to -5) with a resolution up to a few percent. Thus the proposed detector has the following features.

First, a 7m long dipole magnet is positioned around the IP with a 0.3T field perpendicular to the beam. The dipole bends electrons with small angles out of the beampipe. It also bends out 0-degree electrons with small enough energy, enabling us to cover a large W region and measure luminosity within the same detector.

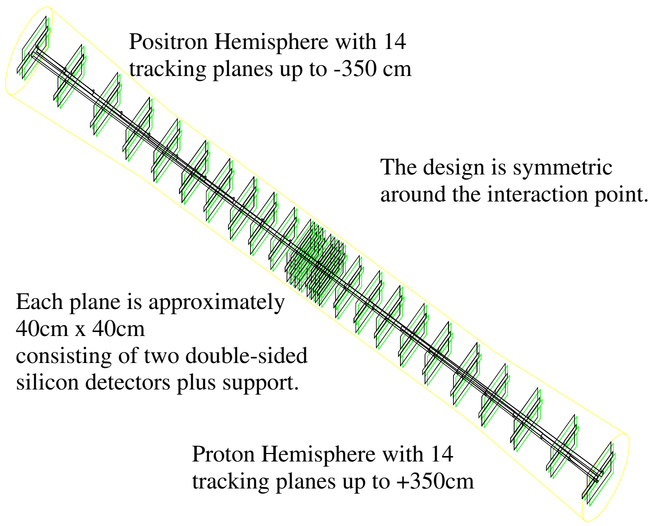
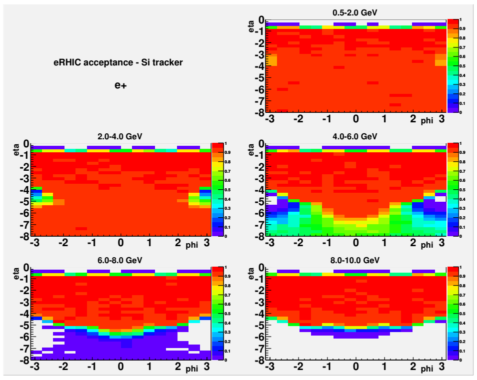


Figure 2. Overview over the silicon tracker. In the central region the system is confined to cylinder with a radius of 30 cm in order to leave space for the calorimetry inside the magnet.



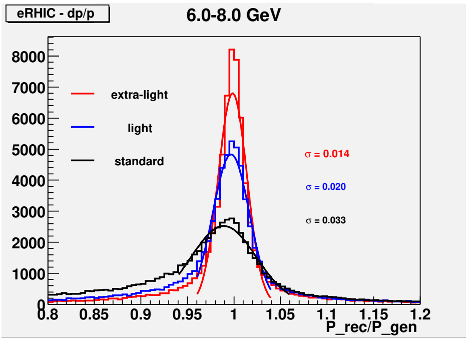


Figure 3. The left plot shows the electron acceptance as a function of η and ϕ for different energy bins. The right plot shows the momentum resolution for electrons between 6 and 8 GeV with three different material budgets.

Inside the dipole 28 double-sided silicon planes are placed perpendicular to the beam as shown in Figure 2. They are used to measure the momentum of the scattered electron. The positions of the Si planes are optimized for maximum acceptance, at least three hits per track, and momentum resolution. The Si planes themselves have to be constructed with minimal material in order to reduce multiple scattering. They are placed symmetrically around IP, so that the momentum of forward particles in the proton direction can be measured with the same precision.

The acceptance of the Si tracker is shown on the left side of Figure 3. For 10 GeV electrons, the acceptance is above 90% up to η of -5, while at ZEUS and H1 the acceptance ends at $|\eta|<2$ for central tracking detectors and $|\eta|<3$ for calorimeters. The effect of material on the momentum resolution is studied with three different material budgets. The "standard" detector has a 0.5mm thick Al beampipe and a 1.2mm carbon fiber support for the Si planes. The "light" one has only the carbon support and the "extra-light" has neither. The resolutions achieved for electrons between 6 and 8 GeV with the three different scenarios are shown on the right side in Figure 3. They range from 1.4 to 3.3%. It is obvious that the material budget is of upmost importance.

Figure 4 shows the EM barrel, catcher and endwall calorimeters as well as the forward hadronic calorimeter. All EM calorimeters are Si-W sandwich calorimeters with a depth of 25 X_0. The Si and W plate thicknesses are adjusted such that the energy resolution is $\approx 15\%/\sqrt{E}$ everywhere. The read-out is longitudinally grouped into 3 sections, thus enhancing the e/π separation. After cutting on E/P with E the energy as measured in the calorimeter and P the momentum as measured by the Si tracker, and comparing the energy deposits in the three calorimeter sections, a pion rejection power of 15 can be reached down to energy 1 GeV while keeping electron efficiency above 85%. This satisfies our requirement for background rejection. The barrel calorimeter also measures 90 degree electrons, where Si tracker has no acceptance. The forward hadronic calorimeter is a copy of the ZEUS for-

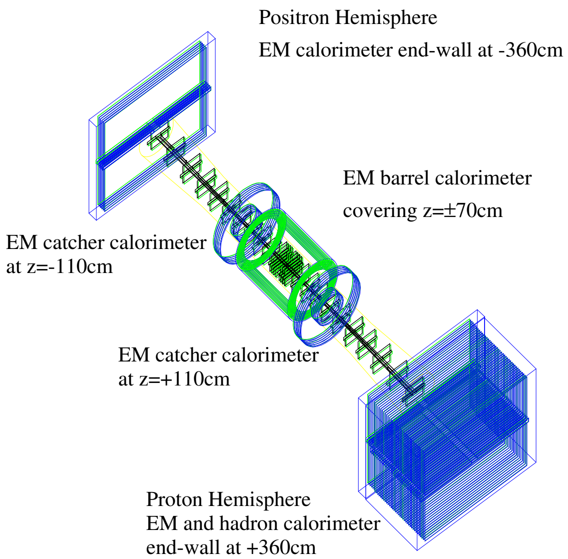


Figure 4. Schematic overview over the detector components within $\approx \pm 5$ m of the interaction point. The silicon planes as shown in Figure 2 are visible. The calorimeter system consists of a central barrel, a catcher ring on each side, the end-walls and the forward hadronic calorimeter in the proton beam direction.

ward uranium-scintillator sandwich calorimeter. It has ≈6 interaction lengths with a resolution of $35\%/\sqrt{E}$ and is used to measure F_2 at $x > 0.5$.

3 Results on F_2 & F_L

Neutral current deep inelastic scattering (NC DIS) events are generated using Herwig with Q^2 of 0.01 to 100 GeV^2 and y of 0.001 to 1.0. The detector response is simulated with Geant3. A matching is done between the tracks fitted from the Si tracker hits and the energy clusters in the EM calorimeters that survive the e/π separation cuts. The matched track with the highest momentum is selected as the final-state electron. x and Q^2 are calculated using the electron 4-momenta. The resolutions on x and Q^2 are shown in Figure 5. Using the standard material budget, the resolution on Q^2 ranges from 5 to 10%, the resolution on x is $\approx$ 10% at large y, becoming worse as y decreases. The resolution is better for the extra-light detector.

The x-Q^2 bins are selected to have $\approx 2\sigma$ bin width. Only bins with both efficiency and purity above 20% are selected to measure F_2. Figure 6 shows the F_2 points measured with the standard detector assuming 100 pb^{-1} luminosity. Systematic uncertainties originating in the Si tracker momentum scale, CAL energy scale and hit finding efficiency are included. Each uncertainty is assumed to be 1% or less. F_2 can be measured to 2% down to Q^2 0.05GeV^2.

The measured F_2 points in fixed Q^2 bins are fitted as a function of x. The resulting λ values are shown in Figure 1 (right plot). More λ points are achieved

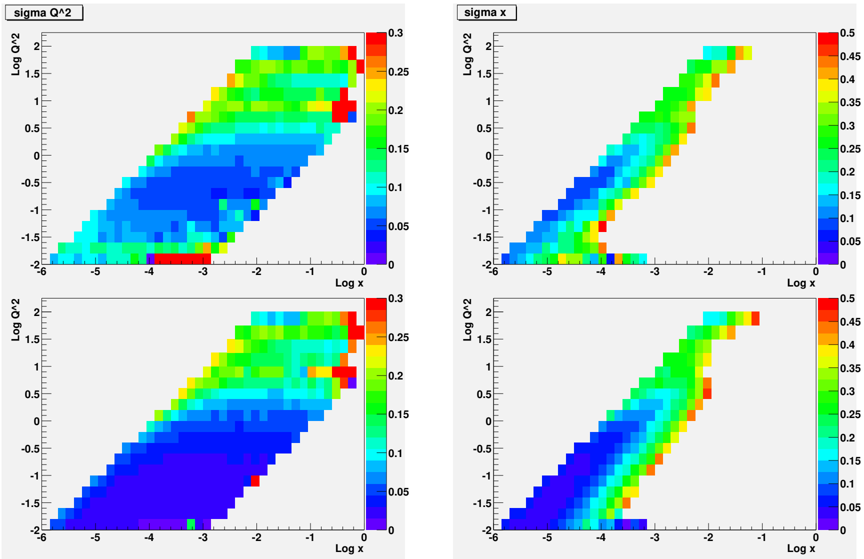


Figure 5. The relative resolutions in Q^2 and x are given for the standard [top] and extra-light [bottom] detectors as a function of Q^2 and x.

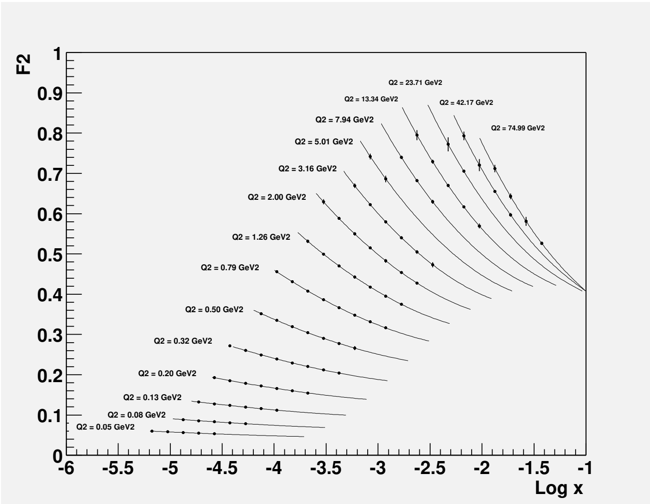


Figure 6. F_2 with standard material budget. Points are F_2 in x-Q^2 bins with efficiency and purity above 20%. Solid lines are ALLM [6] parametrization.

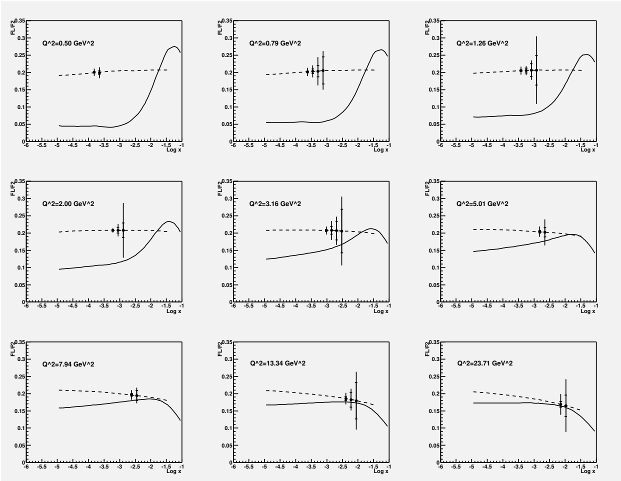


Figure 7. F_L/F_2 with extra-light material budget. Dashed line is the saturation model [7] and solid line MRST. The inner error bar for each point shows the statistical error and the outer bar the overall statistical and systematic error.

with smaller errors as compared to the ZEUS results (left plot).

In order to measure F_L another set of NC events with reduced proton beam energy of 100 GeV was generated assuming again 100 pb^{-1} luminosity. The same simulation and reconstruction procedure was applied to measure the cross section. F_L was then extracted. Figure 7 shows the ratio of F_L and F_2 as a function of x for different Q^2 bins. Also shown are the saturation model [7] predictions and the MRST parametrization. The results can distinguish between different models at low Q^2.

A different set of NC events was generated using DjangoH with Q^2 between 4 and 1000 GeV^2 and x between 0.1 and 1.0 to study F_2 measurement at high x. In addition to the reconstruction procedure described above to find the electron, the hadronic calorimeter is used to measure the leading jet energy. The electron 4-momenta is used to calculate Q^2, and the jet energy is used to calculate x. The relative x resolution is $\approx$10% at Q^2 above 30 GeV^2 and becomes 30-40% at lower Q^2 values. The x bin size is selected as $\approx 2\sigma$. The F_2 points in x bins with both efficiency and purity above 20% are shown in Figure 8. F_2 with x>0.5 can be measured as Q^2 down to $\approx$20 GeV^2. In order to reach x of 0.9 at Q^2 above 300 GeV^2, more than 20 fb^{-1} luminosity is needed.

4 Conclusion

A new detector for the planned eRHIC accelerator is proposed to study the transition region in *ep* scattering at $Q^2 \approx 1$ GeV^2. With this detector F_2 can be measured with less than 2% error at $Q^2 \approx 1$ GeV^2. F_2 can also be explored at x>0.5. In addition a determination of F_L is possible at low Q^2 and low x where predictions

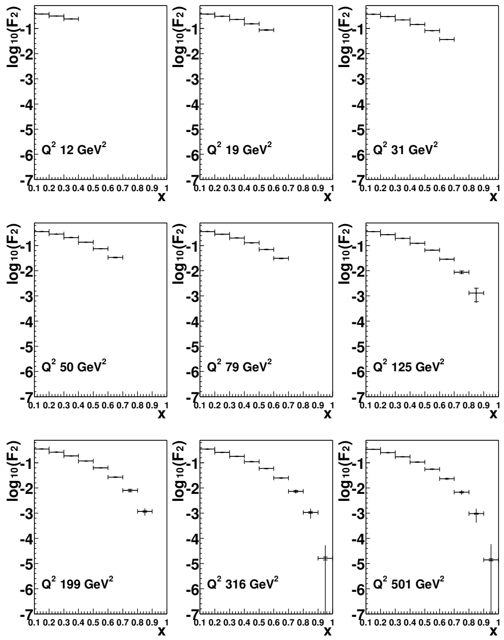


Figure 8. F_2 in x-Q^2 bins with both efficiency and purity above 20%. For this plot, the inner error bars are systematic only, the outer bars include statistical errors. These become dominant for the high Q^2 and high x regime.

vary the most. More details can be found in the white paper at [8].

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