Requirements on the scattered electron at the EIC

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(for the Inclusive conveners)

Introduction

- The inclusive physics group produced a short report (which can be found here) focusing on the question of detector requirements for the scattered electron. While this report focused on the negative endcap requirements for inclusive physics at the EIC, given the universal importance of accurately identifying and reconstructing the scattered electron, many of the conclusions should of course be generally applicable to other physics processes.
- These requirements are divided into three categories: angular and momentum acceptance; momentum (energy) resolution; and electron purity.

Acceptance

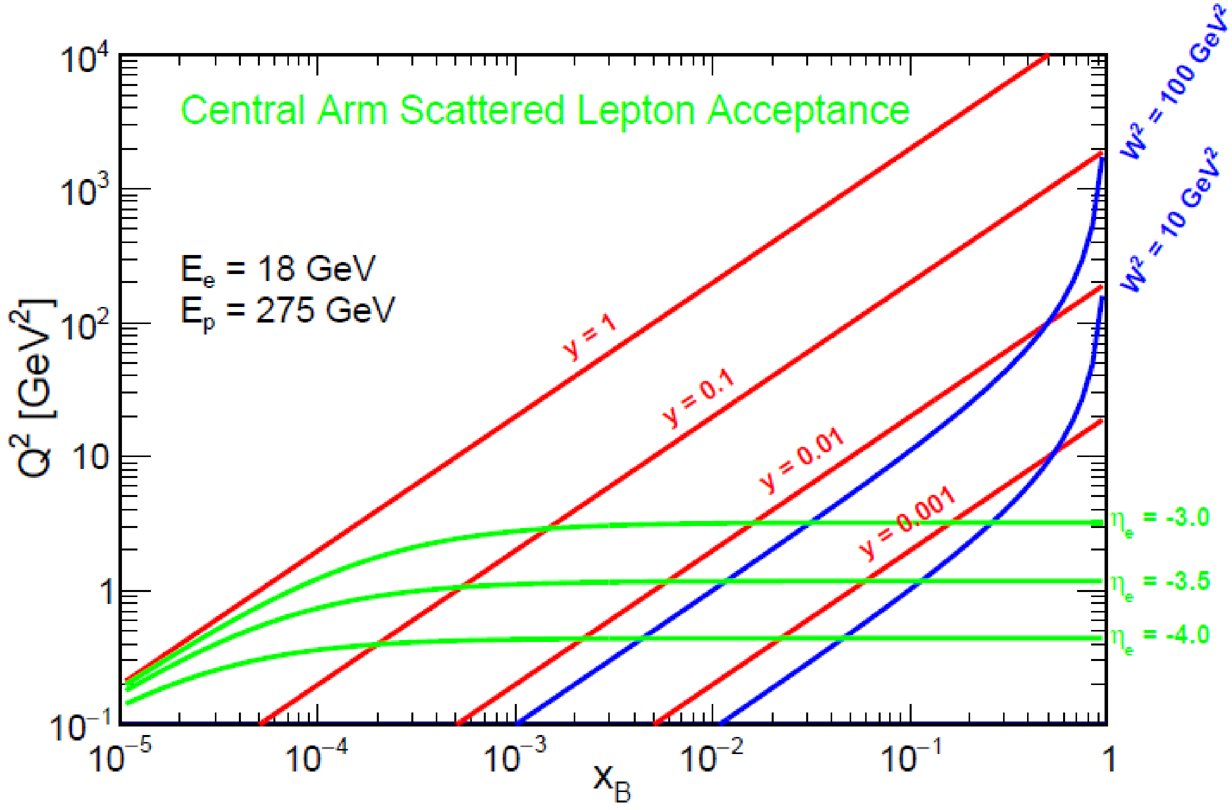
- For the beam energies that will be used at the EIC and considering scattered electrons in the pseudo-rapidity range of $-4 < \eta < 4$ (where $Q^2 \gg m_e^2$), we can relate the inclusive kinematic variables to the scattered electron angles and energies as

$$y_e = 1 - \frac{E'_e}{2E_e}(1 - \cos\theta_e) \ ,$$
$$Q_e^2 = 4E_e E'_e \cos^2(\theta_e/2) \ ,$$
$$x_e = \frac{Q_e^2}{s y_e} \ .$$

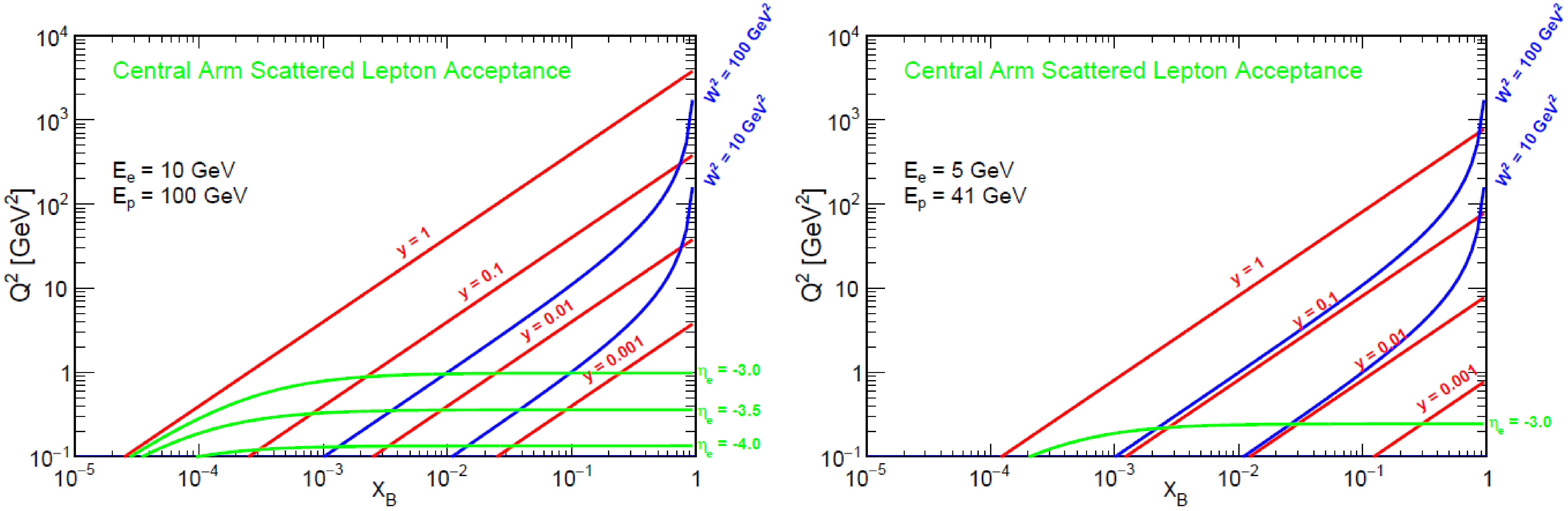
- Note how neither Q^2 nor y depend explicitly on the proton beam energy.

Angular Acceptance

- For many EIC physics processes which have a requirement that $Q^2 > 1$ GeV^2, an angular acceptance of $\eta \gtrapprox -3.6$ will allow full coverage at the highest EIC beam energy setting. At lower energies, this same acceptance coverage would allow access to lower values of Q^2 (see next slide).
- Any processes which require $Q^2 < 1$ GeV^2 at the highest energy setting will need an extended acceptance below $\eta \approx -3.6$.
- For inclusive physics, coverage below $Q^2 = 1$ GeV^2 has strong motivations: to study the perturbative to non-perturbative transition; to give access to lowest possible x, which is well-aligned with the central EIC physics aims to study mass generation and dense systems of gluons; and to minimize the 'gap' in Q^2 coverage between the central detector and the far-backwards low-Q^2 tagger.



Angular Acceptance

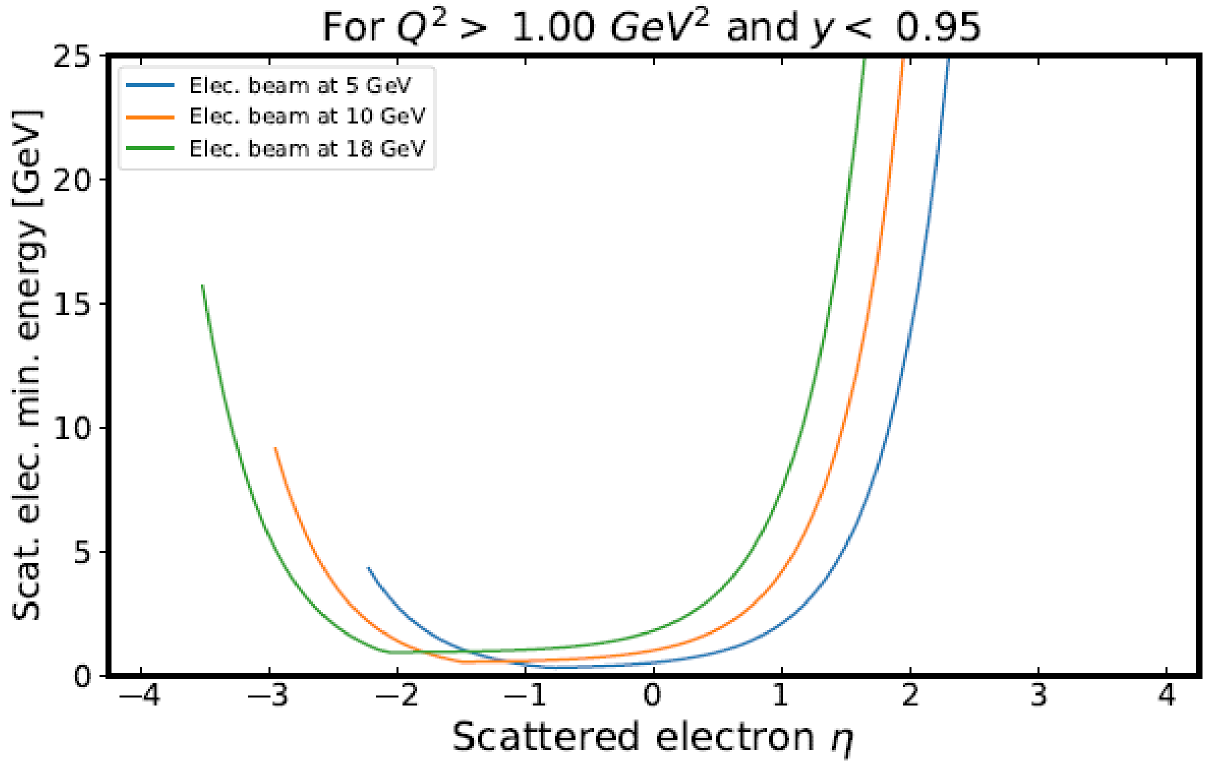


Minimum momentum (energy)

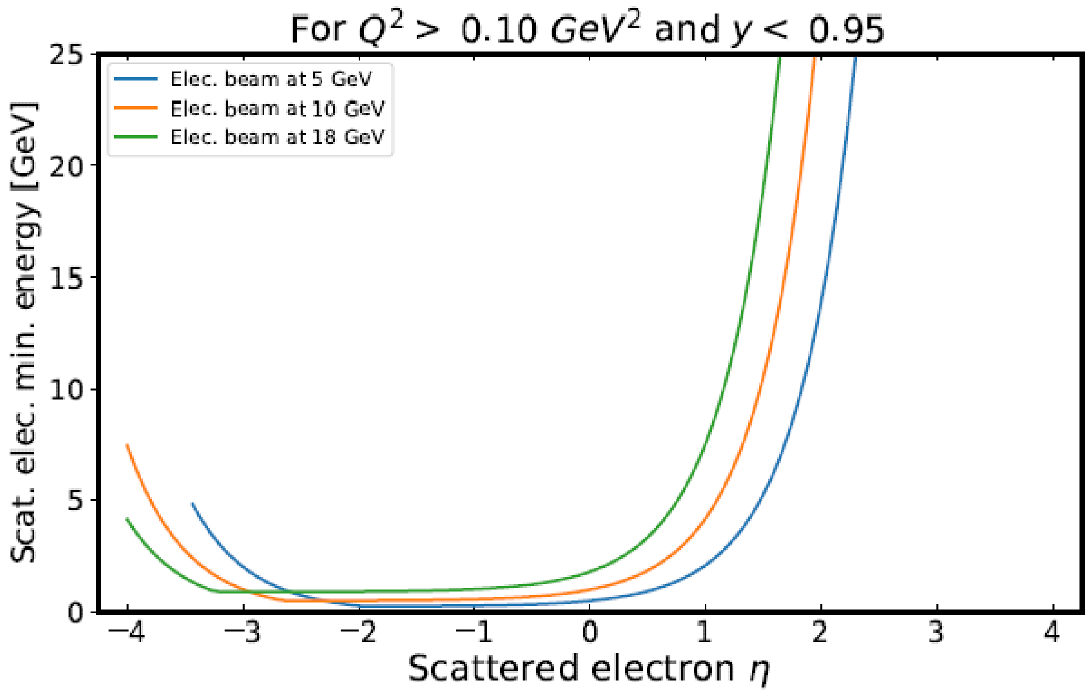
- For a fixed electron beam energy and scattered electron angle, Q^2 increases as the energy of the scattered electron increases, while y decreases.
- For all physics analyses, a cut of $y < 0.95$ will be applied. The minimum energy is also affected by the minimum Q^2 which needs to be measured. These two requirements place a minimum-energy threshold on the scattered electron energy, above which full acceptance is needed.

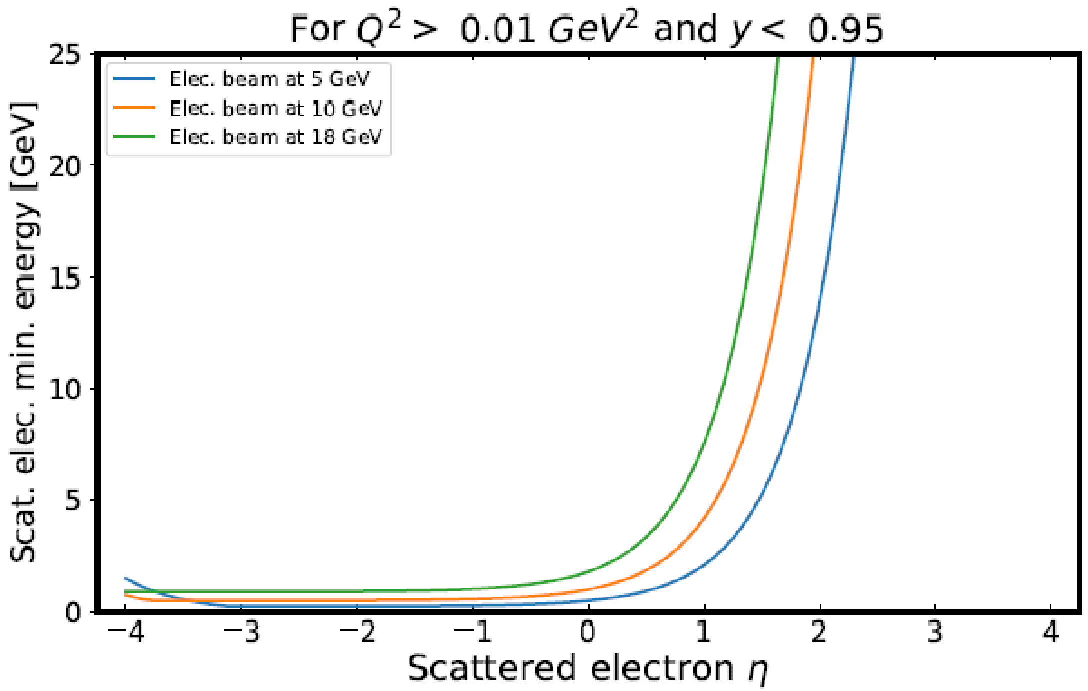
Minimum momentum (energy)

- Consider the case where the physics requires $Q^2 > 1$ GeV^2. The plot on the right shows as a function of η the minimum electron energy that satisfies both the $Q^2 > 1$ GeV^2 requirement and the $y < 0.95$ requirement.
- There are a few important features of this plot:
  1. The curves do not extend to the lowest possible values of pseudo-rapidities. This is because at the most negative values of η, the scattered electron can not be created at $Q^2 = 1$ GeV^2, only at lower values of Q^2.
  2. Starting at the most negative η value that is allowed, each minimum energy curve decreases towards more positive values of η. For this left part of the curve, the minimum energy is exactly at the $Q^2 = 1$ GeV^2 limit (while still satisfying the $y < 0.95$ requirement).
  3. Moving towards more positive values of η, each minimum energy curve reaches a global minimum value and then begins to grow. Once the curve begins to increase towards more positive values of η, the minimum energy of the scattered electron is at the $y = 0.95$ limit (while still satisfying the $Q^2 > 1$ GeV^2 requirement).

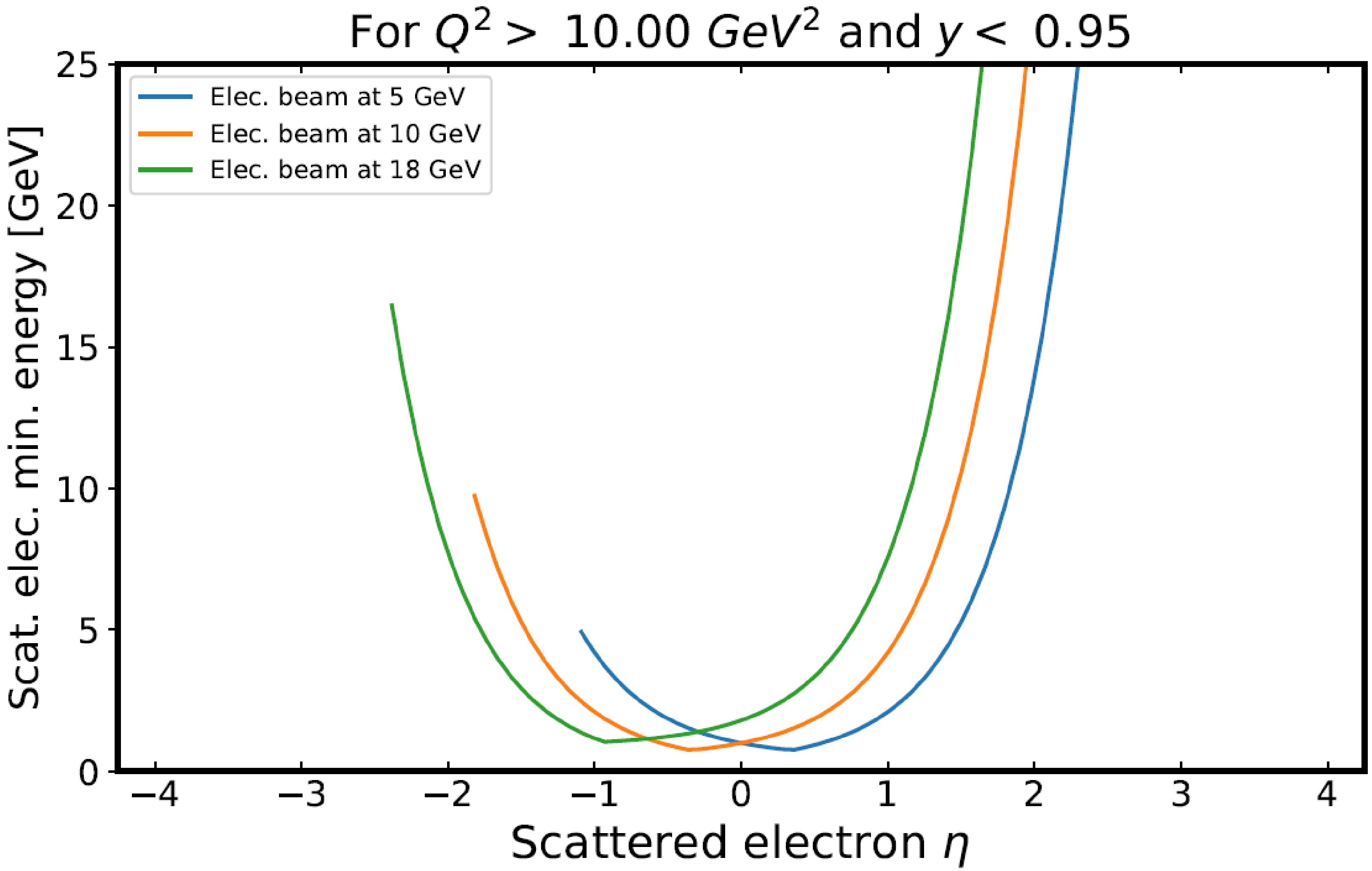


Minimum momentum (energy) – lower minimum Q^2



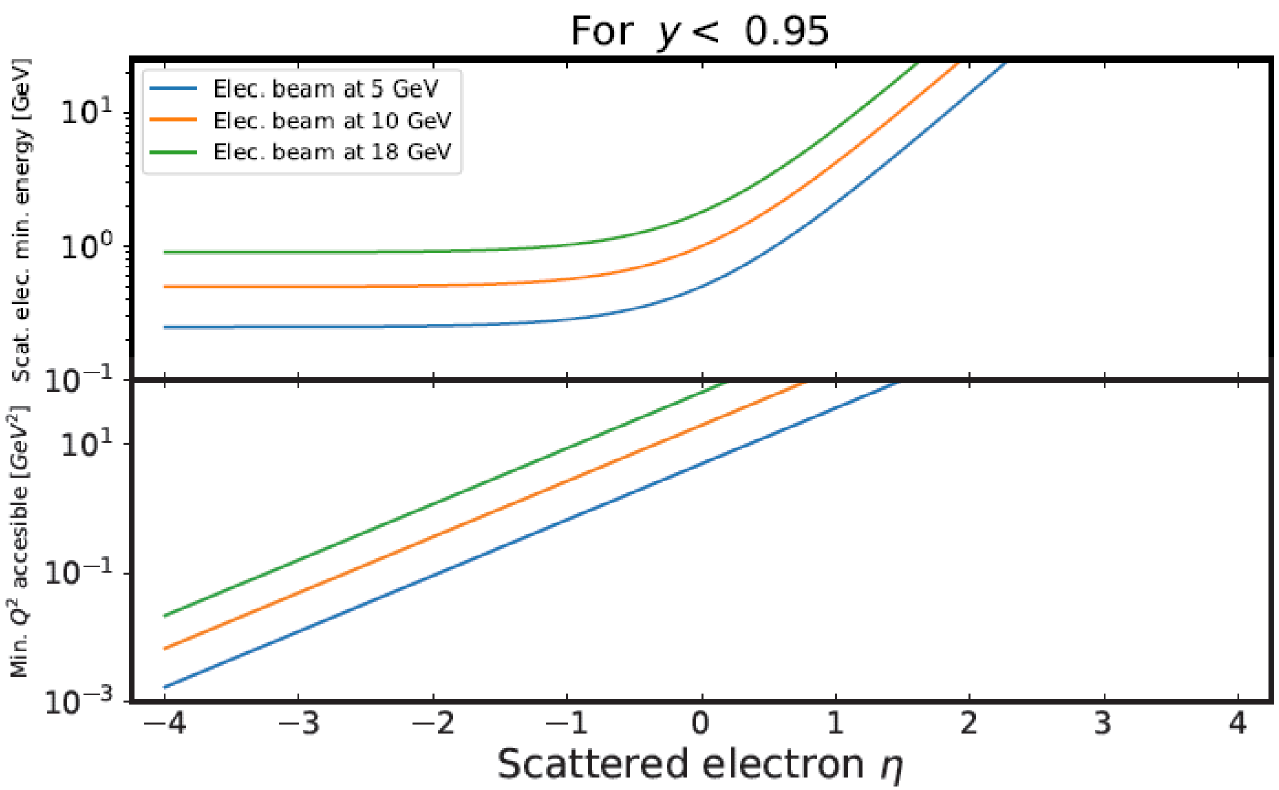


Minimum momentum (energy) – higher minimum Q^2



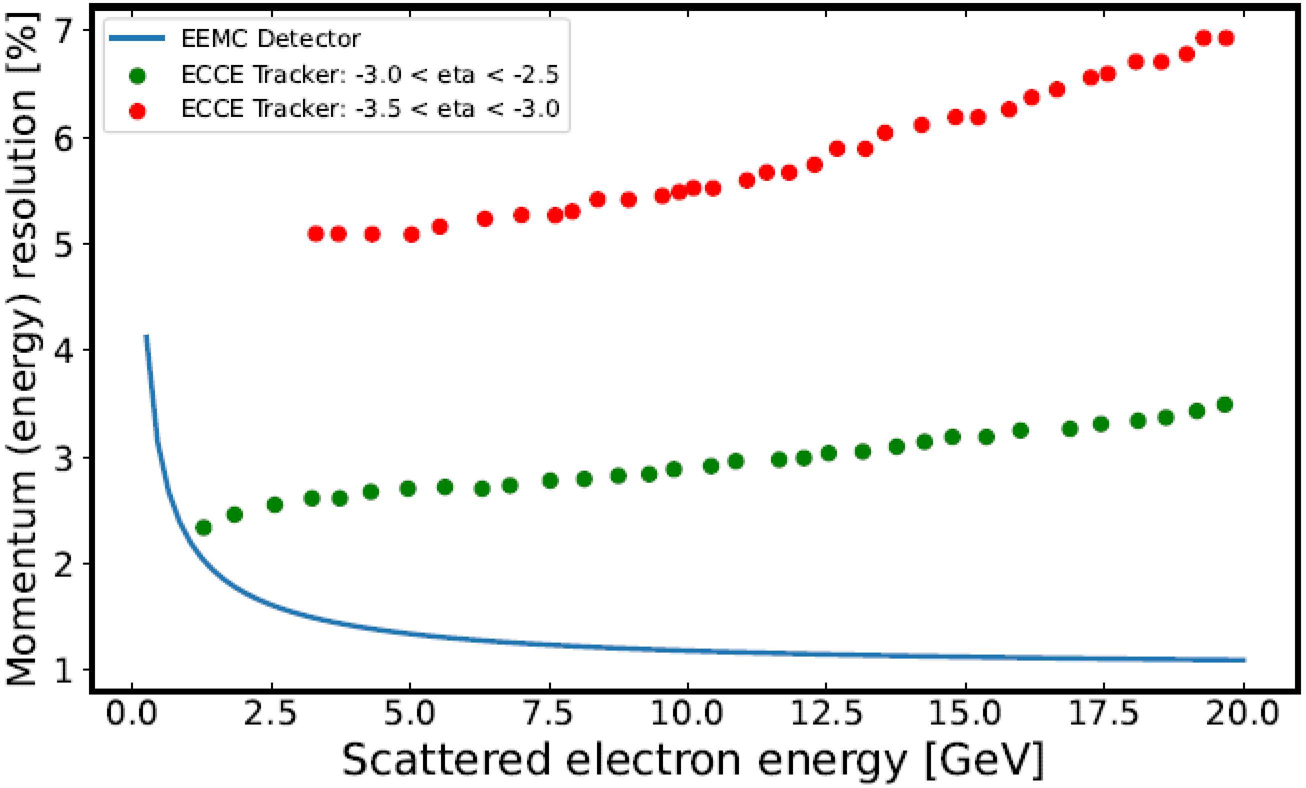
Minimum momentum (energy) – no minimum Q^2

- By applying the $y < 0.95$ requirement only, we can consider the minimum possible scattered electron energy that would need to be measured. This is shown in the top panel of the right plot.
- The bottom panel then shows the Q^2 that is measured at that scattered electron energy. Note that since this minimum Q^2 is at the $y = 0.95$ limit, the measurement will be also be at the lowest x accessible.
- For example, in the case of a 5 GeV electron beam, being able to identify and reconstruct 250 MeV electrons at $\eta = -4$ would allow measurements down to $Q^2 \approx 10^{-3}$.



Momentum (energy) resolution

- The momentum (energy) resolution requirements for the scattered electron given in the yellow report are sufficient for all inclusive measurements.
- One important consideration is how best to perform the momentum (energy) reconstruction for the scattered electron in the electron endcap.
- If we consider again the case where we are interested in physics processes with $Q^2 > 1$ GeV^2, we see from the plot above that we only need to measure scattered electrons with energy greater than 5 GeV for $\eta < -3.0$.
- The higher Q^2 electron momentum reconstruction at these backwards angles will therefore rely on the EEMC detector, as can be seen in the right plot.



The tracking resolution curves shown above come from figure 2.7 in the ECCE proposal. The EEMC resolution is drawn assuming a 2% stochastic term and a 1% constant term.

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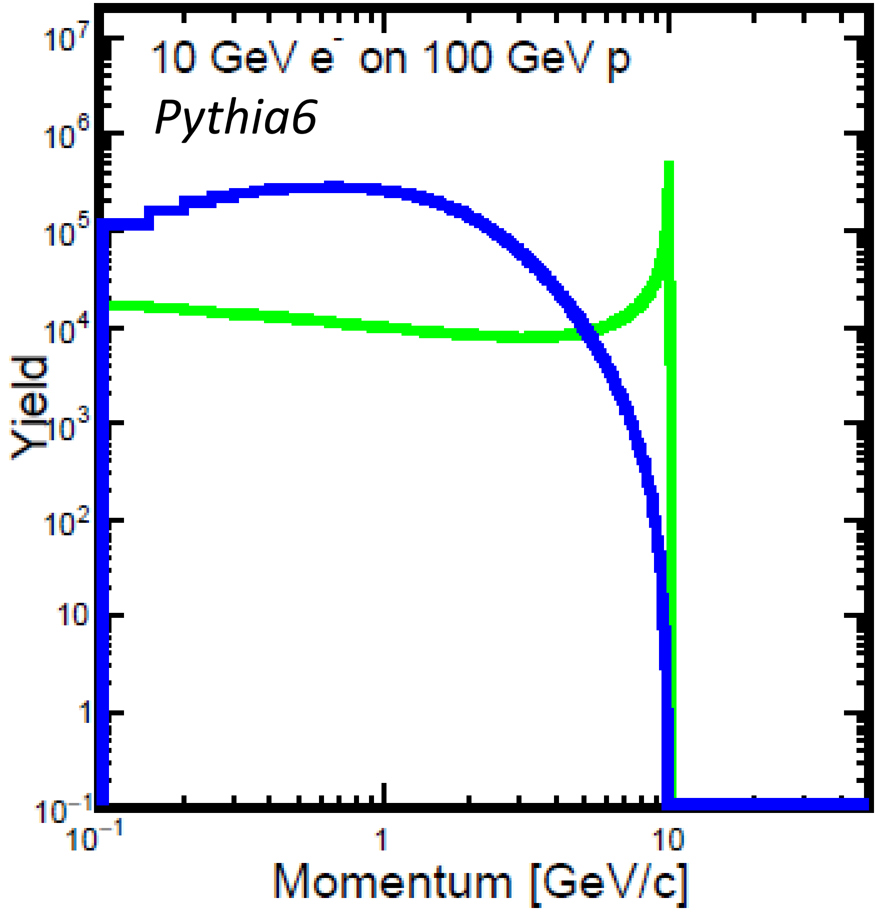
- If the lower-energy scattered electrons mentioned above can be measured, their reconstruction would of course use the tracker. The measurement of the scattered electron polar and azimuthal angles will also probably rely on the tracking detector for all scattered electron energies.
- Even when the electron momentum reconstruction is done primarily using the EEMC, it is important to maintain a reasonable tracking resolution for electron identification cuts (i.e. E-over-p cuts). However, it is difficult to quantify the tracker momentum resolution requirement in this case since the electron efficiency and purity are functions of the integrated detector response.

Electron purity

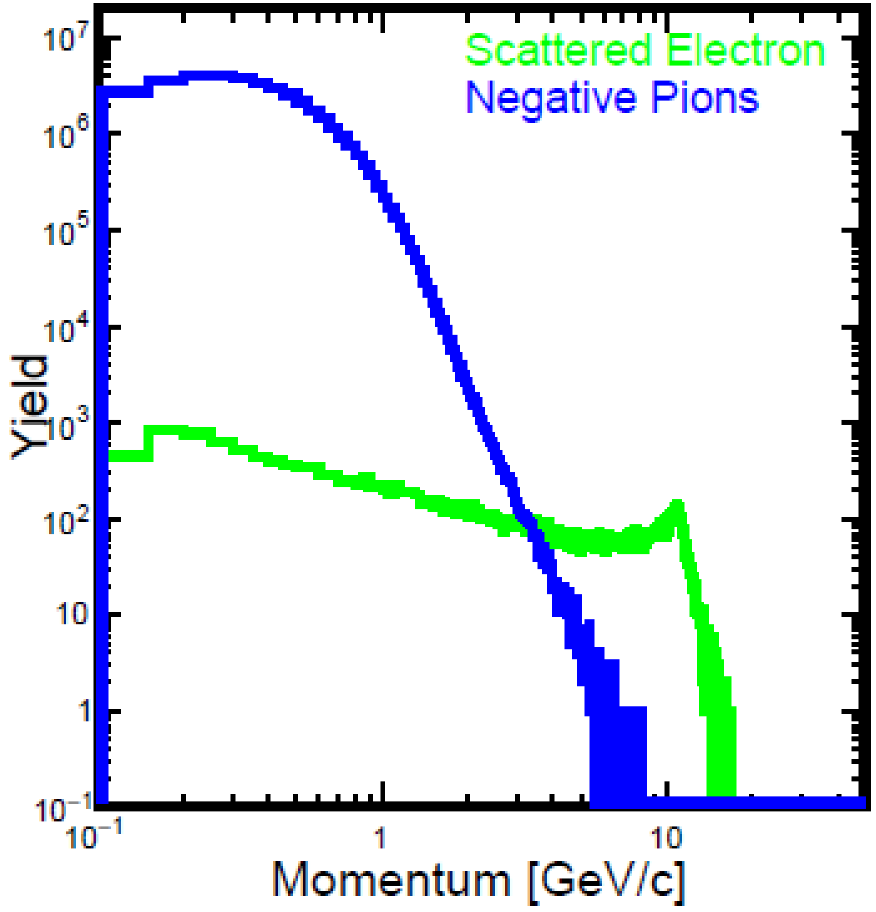
- Requirements on the scattered electron purity were determined by the inclusive working group during the yellow report. The requirement is given as 99% electron purity over the entire detector. This requirement is quite stringent and can be relaxed in certain regions of kinematic phase space, but there are a few good reasons to initially try to achieve this most stringent requirement:
    1. The most challenging place to meet the electron purity requirement is in the barrel region (see next slides). This has to do with the cross section dependence on Q^2, the momentum distribution of the negative pion background and the fact that, for $Q^2 > 1$ GeV^2 for example, lower momentum electrons only need to be reconstructed for more central pseudo-rapidities.
    2. As demonstrated in all the detector proposals − albeit using parameterized detector responses − the combination of tracking, EmCal, PID, and kinematic cuts can significantly remove the negative pion background. This suggests the more stringent requirement may be achievable. Once an adequate 'electron finder' algorithm is in place, electron purity will be a useful benchmark to compare detector configurations.
    3. During the yellow report, many of the physics studies done by groups other than the inclusive group assumed perfect electron purity and reconstruction efficiency. It is not obvious how sensitive these physics measurements are to the scattered electron identification, and so keeping a more stringent requirement would be wise for now.

Electron purity

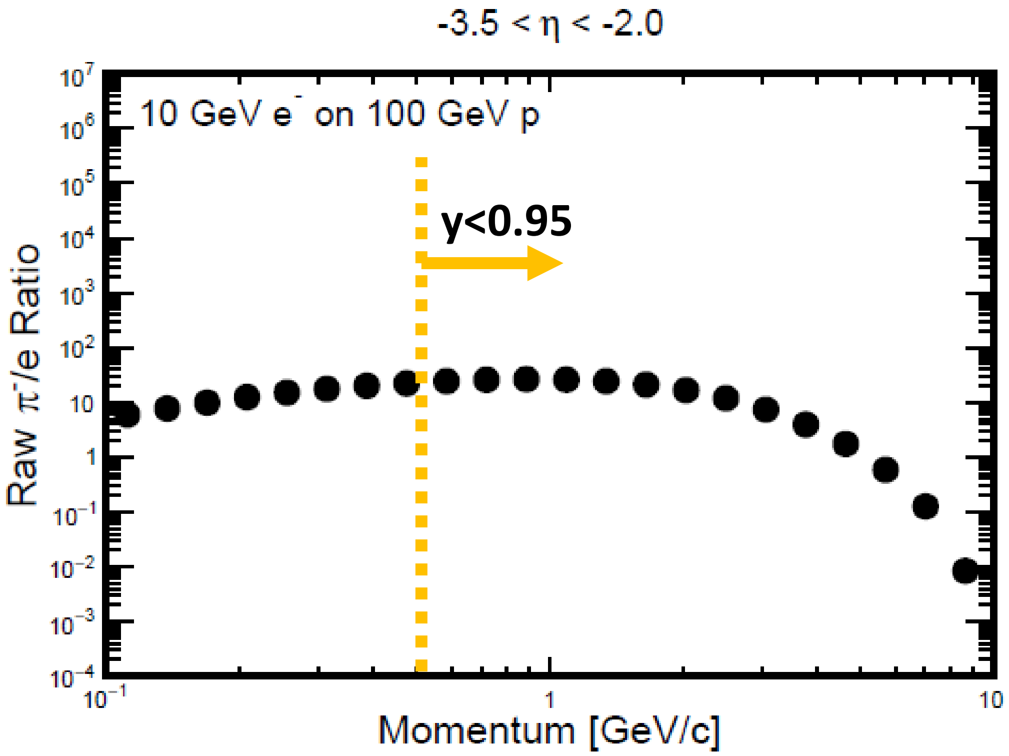
-3.5 < η < -2.0

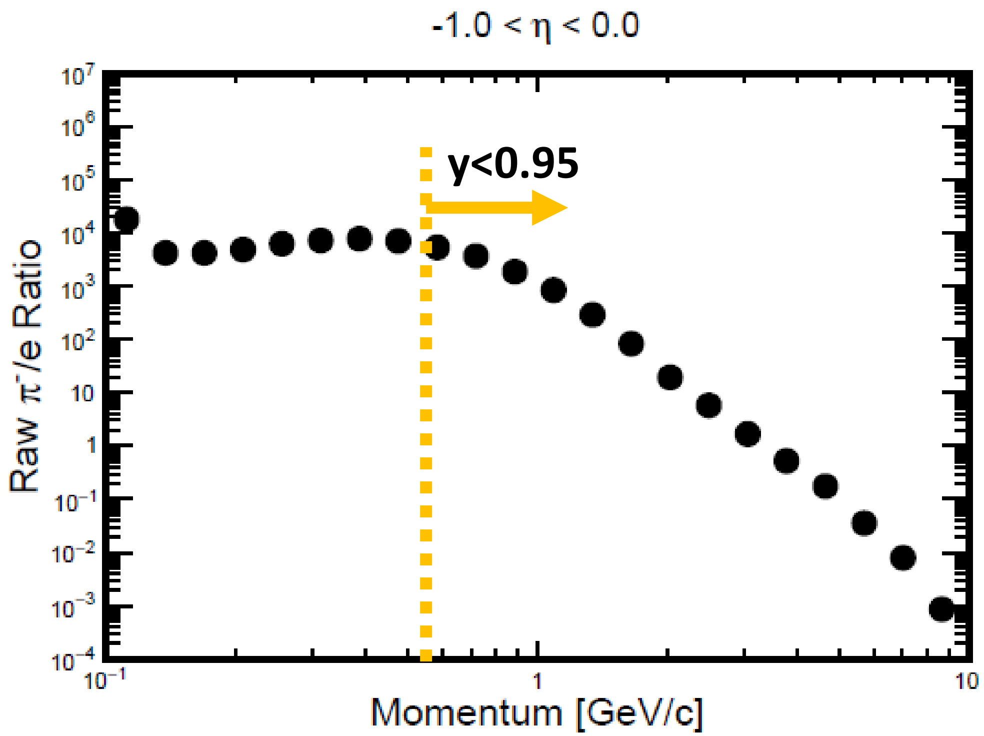


-1.0 < η < 0.0



Electron purity





Summary

- In order to cover the full $Q^2 > 1$ GeV^2 kinematic phase space for all beam energies, the scattered electron needs to be identified and reconstructed for $\eta > -3.6$. For these kinematics, the momentum (energy) reconstruction of the scattered electron in the negative endcap will rely on the EEMC detector.
- There are good physics motivations for extending the EIC measurements to lower Q^2 and x. This requires the scattered electron to be measured at lower energies and/or more negative pseudo-rapidities than in the $Q^2 > 1$ GeV^2 case. At the lowest electron beam energy, being able to measure the scattered electron down to 250 MeV at $\eta = -4$ would allow measurements down to $Q^2 \approx 10^{-3}$.
- We currently should aim for 99% scattered electron purity over the entire detector. This requirement can be adjusted for certain kinematic regions if it proves too difficult to achieve.