Summary of EIC Yellow Report Inclusive Group Studies

https://arxiv.org/abs/2103.05419

Barak Schmookler

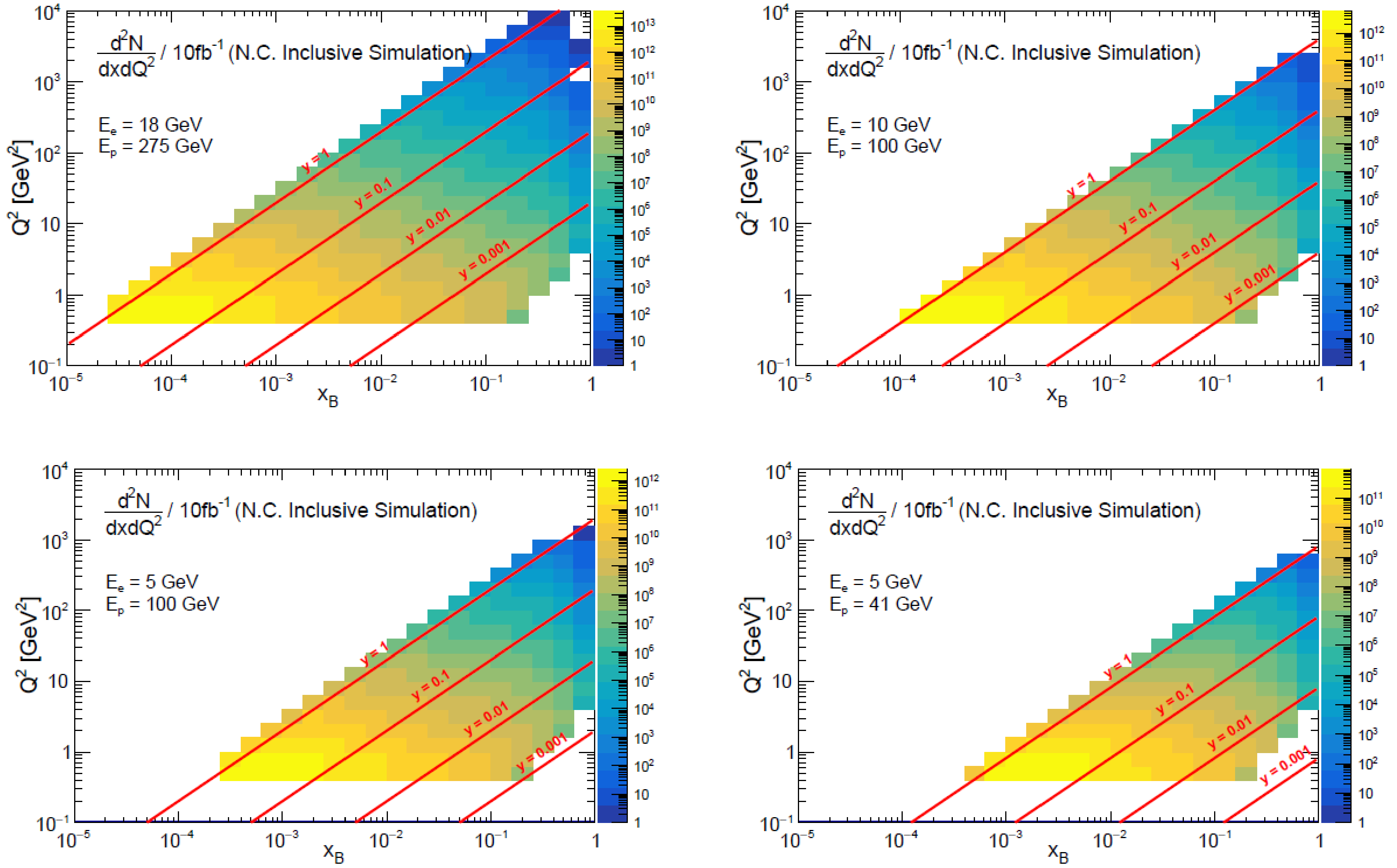
Contributions from the Inclusive Group

Inclusive Physics of Interest

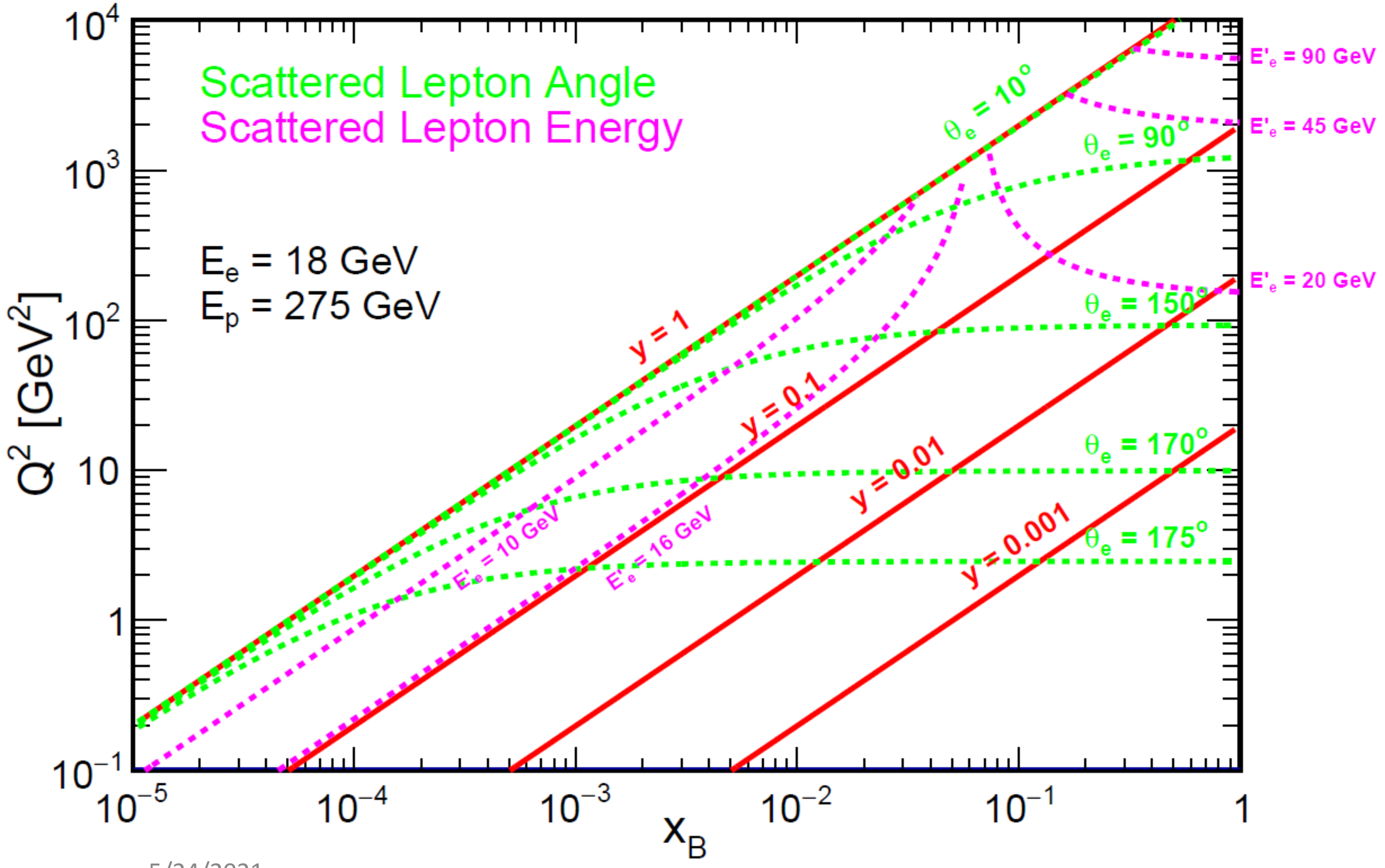
Measurement	Main Detector Requirements	Anticipated Plot	Physics Topic/goal	Responsible persons
inclusive $A_{\|\|}$ / $A_{\perp}$ for proton, deuterium, ^3He	Standard inclusive	$A_{\|\|}(x,y,Q^2), A_{\perp}$ $g_1(x)$, $g_{2/T}(x)$ vs Q^2 $\Delta g(Q^2)$ vs x	Gluon & Quark Helicity $\Delta g(x,Q^2)$, Δu^+, Δd^+	
inclusive A_{PV}	Standard inclusive	A_{PV} vs x for $W^{+/-}$ $g^W{}_5(x)$ vs Q^2 $\Delta s^+(Q^2)$, $s^+(Q^2)$ vs x	Strange Pol and Unpolarized $\Delta s^+(x,Q^2)$, $s^+(x,Q^2)$	
$\boldsymbol{\sigma}_{red}(x,Q^2)$, $\boldsymbol{\sigma}^{c/b}{}_{red}(x,Q^2) \rightarrow F_2, F_L, F_2{}^{c/b}$	Standard inclusive + heavy quark tag	$\boldsymbol{\sigma}_{red}(x,y)$ vs Q^2 $\boldsymbol{\sigma}^{c/b}{}_{red}(x,y)$ vs Q^2 $g(Q^2)$ vs x	Proton PDFs $q(x,Q^2)$, $g(x, Q^2)$	
$\boldsymbol{\sigma}_{red}(x,Q^2)$, $\boldsymbol{\sigma}^{c/b}{}_{red}(x,Q^2) \rightarrow F_2, F_L, F_2{}^{c/b}$	Standard inclusive + heavy quark tag	$\boldsymbol{\sigma}_{red}(x,y)$ vs Q^2 $\boldsymbol{\sigma}^{c/b}{}_{red}(x,y)$ vs Q^2 $F_L(Q^2)$ vs x $F^{c/b}{}_L(Q^2)$ vs x	Nuclear PDFs $q(x,Q^2)$, $g(x, Q^2)$	
$\boldsymbol{\sigma}_{red}(x,Q^2)$, $\boldsymbol{\sigma}^{c/b}{}_{red}(x,Q^2) \rightarrow F_2, F_L, F_2{}^{c/b}$	Standard inclusive + heavy quark tag	$\boldsymbol{\sigma}_{red}(x)$ vs Q^2 $\boldsymbol{\sigma}^{c/b}{}_{red}(x)$ vs Q^2 $\Delta F_L/F_L$ vs x, Q^2	Non-linear QCD dynamics	
EW inclusive A_{PV}	Standard inclusive	$A_{PV}(y)$ vs Q^2 $\sin^2\boldsymbol{\theta}_w$ vs Q^2	BSM & Precision EW ($\sin^2\boldsymbol{\theta}_w$)	
$\frac{d\sigma^{NC}}{dxdyd\phi}$ Triply differential NC X-sec	Standard inclusive	Updated Fig.6 in ***PhysRevD.98.115018*** for CM energies smearing.	Lorentz and CPT Violating Effects	

Detector requirements from the Inclusive Group

N.C. Kinematic Phase Space and Yields



Scattered Electron Kinematics

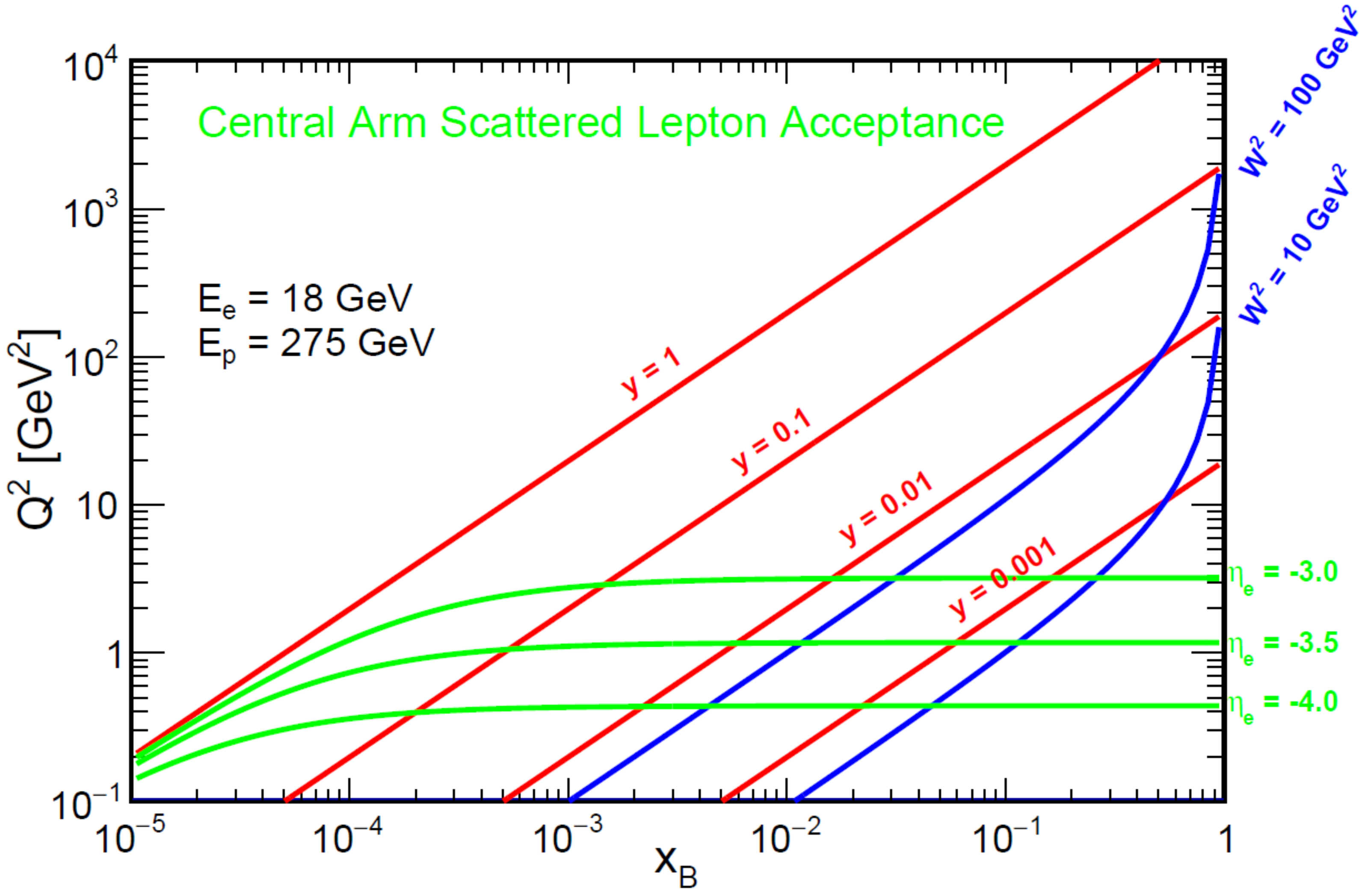


$$Q^2 = 4EE' \cos^2\left(\theta_p^{e'}/2\right)$$

$$y = 1 - \frac{E'\left(1 - \cos\theta_p^{e'}\right)}{2E}$$

$$x = \frac{Q^2}{sy}$$

Scattered Electron Kinematics



$$Q^2 = 4EE' \cos^2\left(\theta_p^{e'}/2\right)$$

$$y = 1 - \frac{E'(1 - \cos\theta_p^{e'})}{2E}$$

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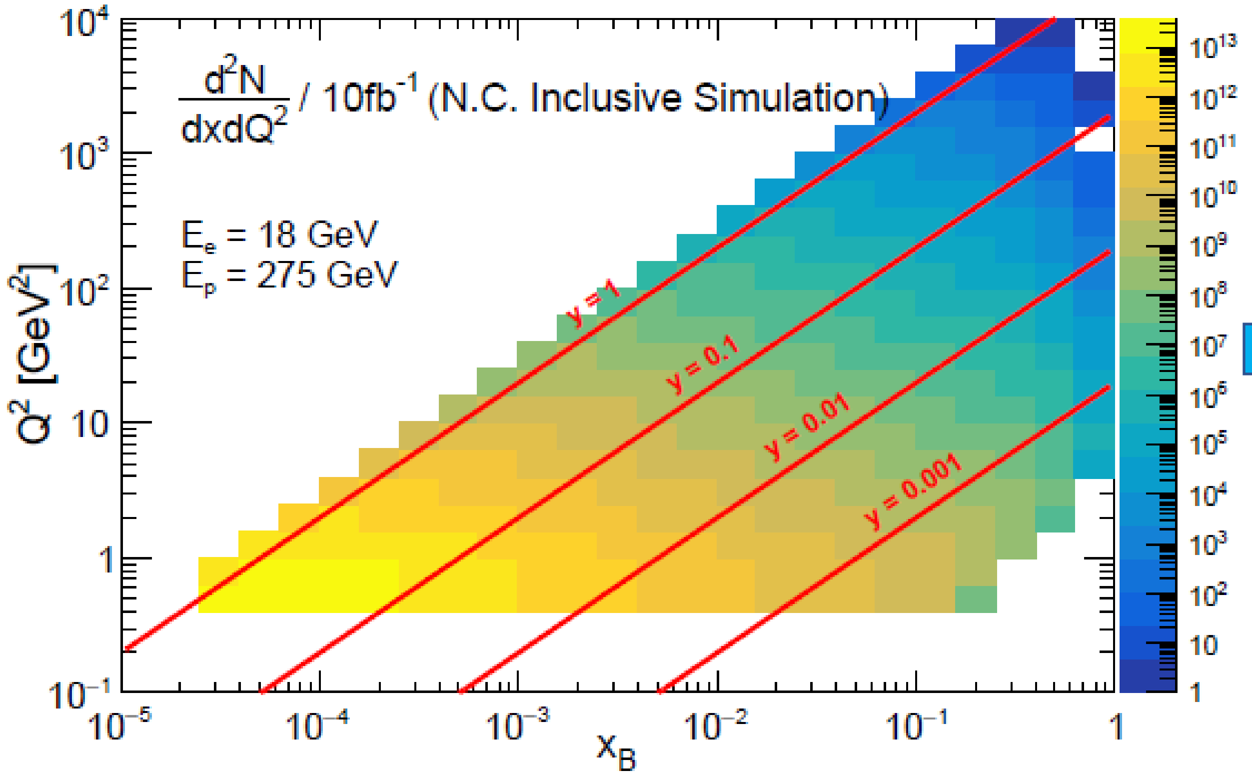
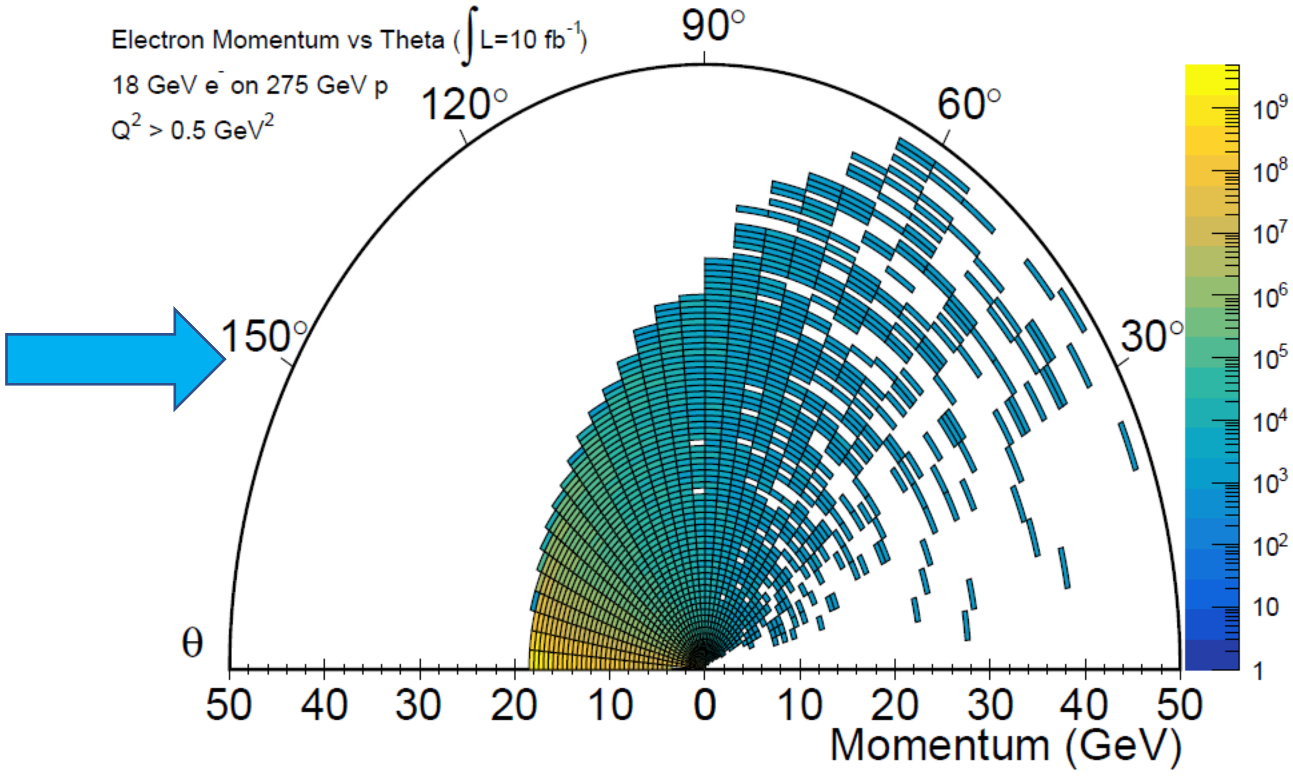
Scattered Electron Kinematics and Yields





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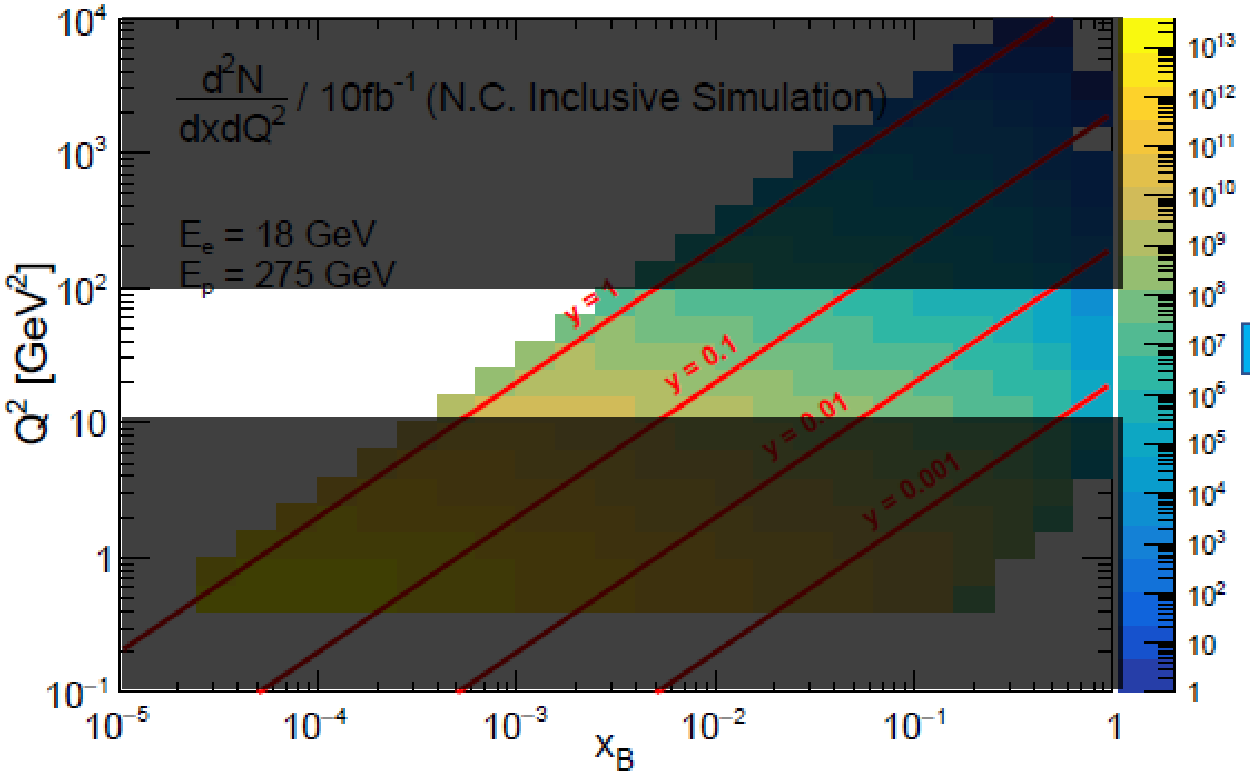
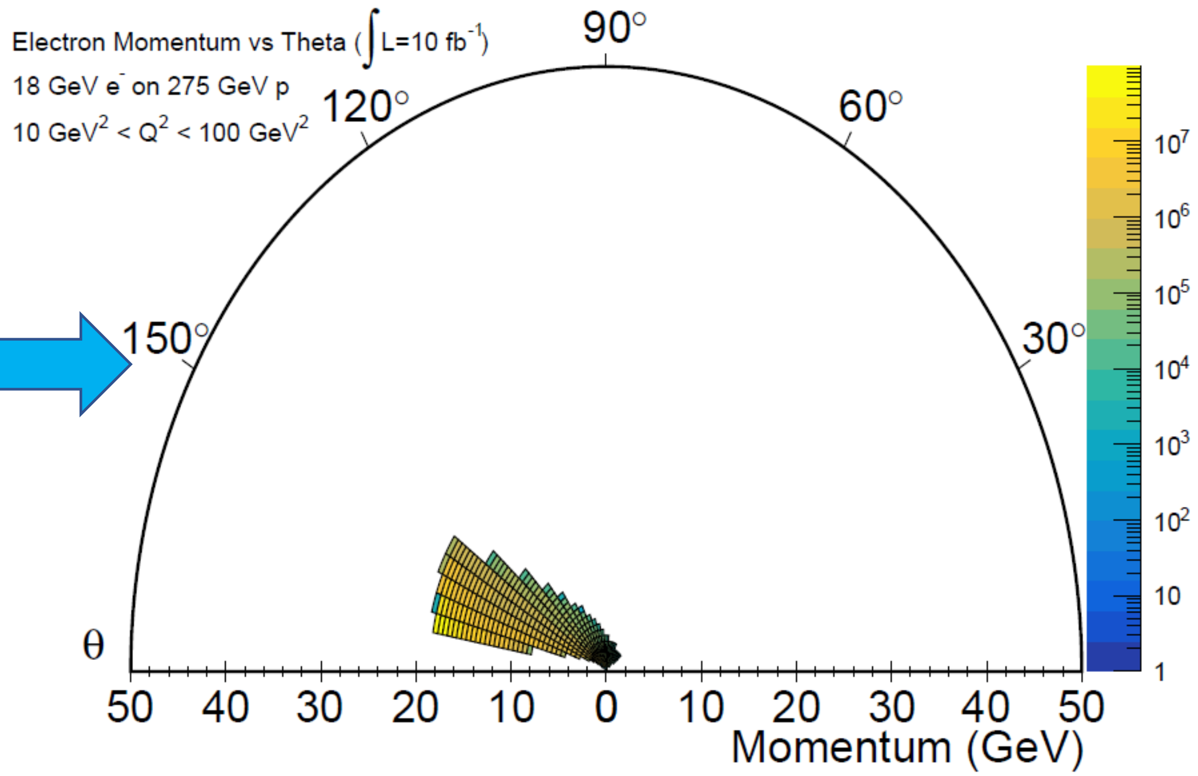
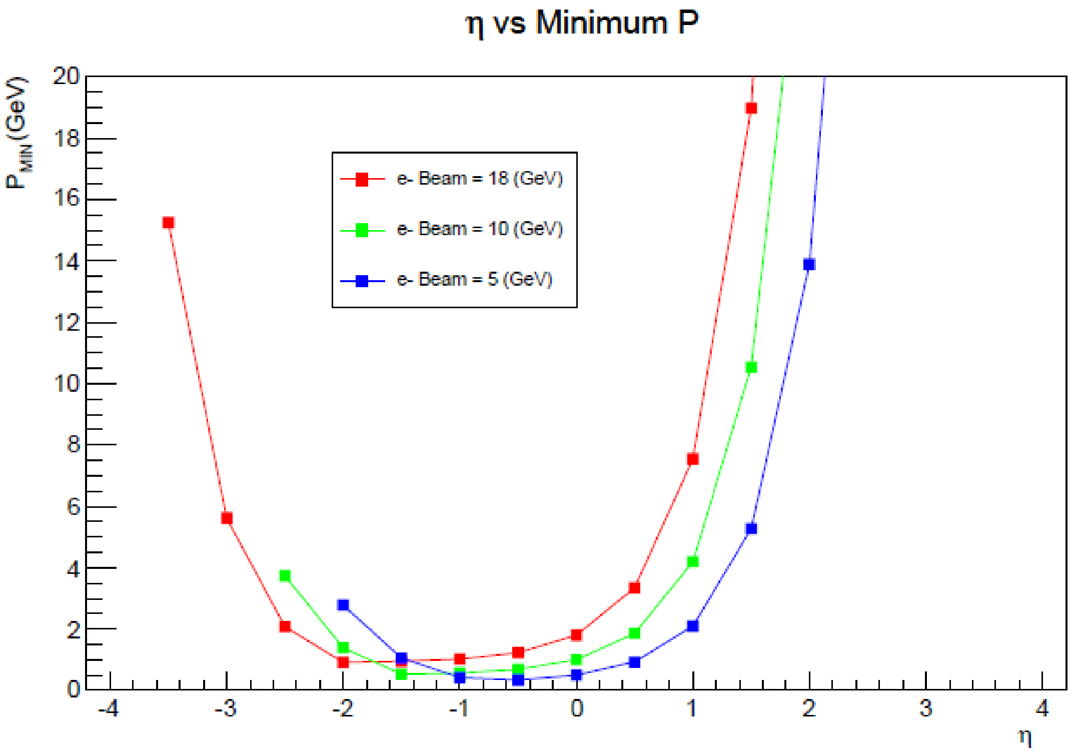




Electron Momentum Acceptance



$Q^2 > 1\ GeV^2$ and $y < 0.95$ constraints applied

$E^{e^-}_{beam}$ (GeV)	η bin	$p^{e^-}_{min}$ (GeV)
18	(-3.5,-2)	0.9
18	(-2,-1)	0.9
18	(-1, 0)	1.0
18	(0, 1)	1.8
10	(-3.5,-2)	1.4
10	(-2,-1)	0.5
10	(-1, 0)	0.6
10	(0, 1)	1.0
5	(-3.5,-2)	2.8
5	(-2,-1)	0.4
5	(-1, 0)	0.3
5	(0, 1)	0.5

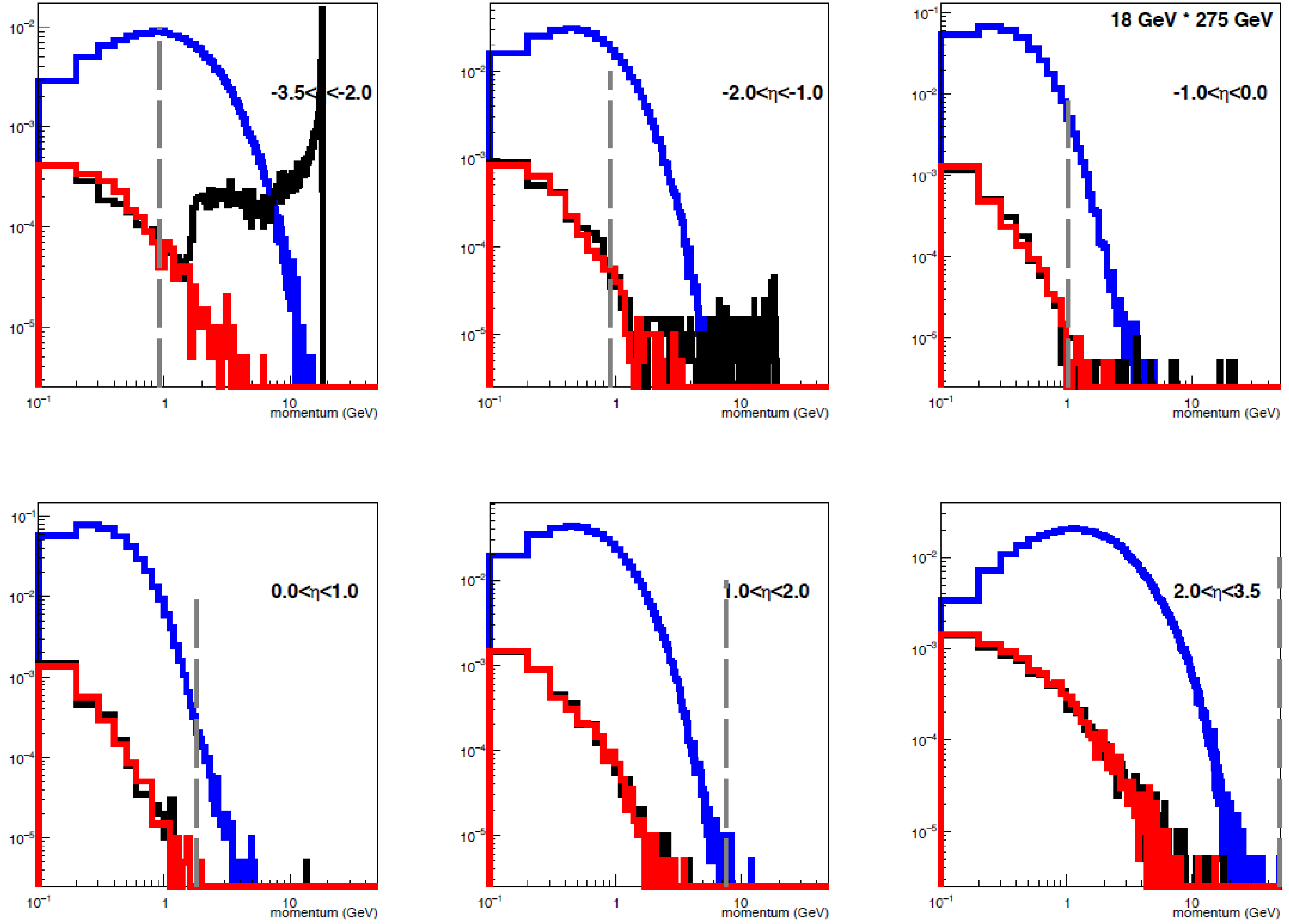
Scattered Electron Background

18x275 GeV

Electrons

Pions

Positrons



Estimated π/e Ratios

$E_{beam}^{e^-}$ (GeV)	η bin	$p_{min}^{e^-}$ (GeV)	Max π^-/e^-	final π^-/e^- ratio
18	(-3.5,-2)	0.9	200	0.02
18	(-2,-1)	0.9	800	0.08
18	(-1, 0)	1.0	1000	0.1
18	(0, 1)	1.8	100	0.01
10	(-3.5,-2)	1.4	10	0.001
10	(-2,-1)	0.5	400	0.04
10	(-1, 0)	0.6	800	0.08
10	(0, 1)	1.0	1000	0.1
5	(-3.5,-2)	2.8	0.1	0.00001
5	(-2,-1)	0.4	100	0.01
5	(-1, 0)	0.3	500	0.05
5	(0, 1)	0.5	1000	0.1

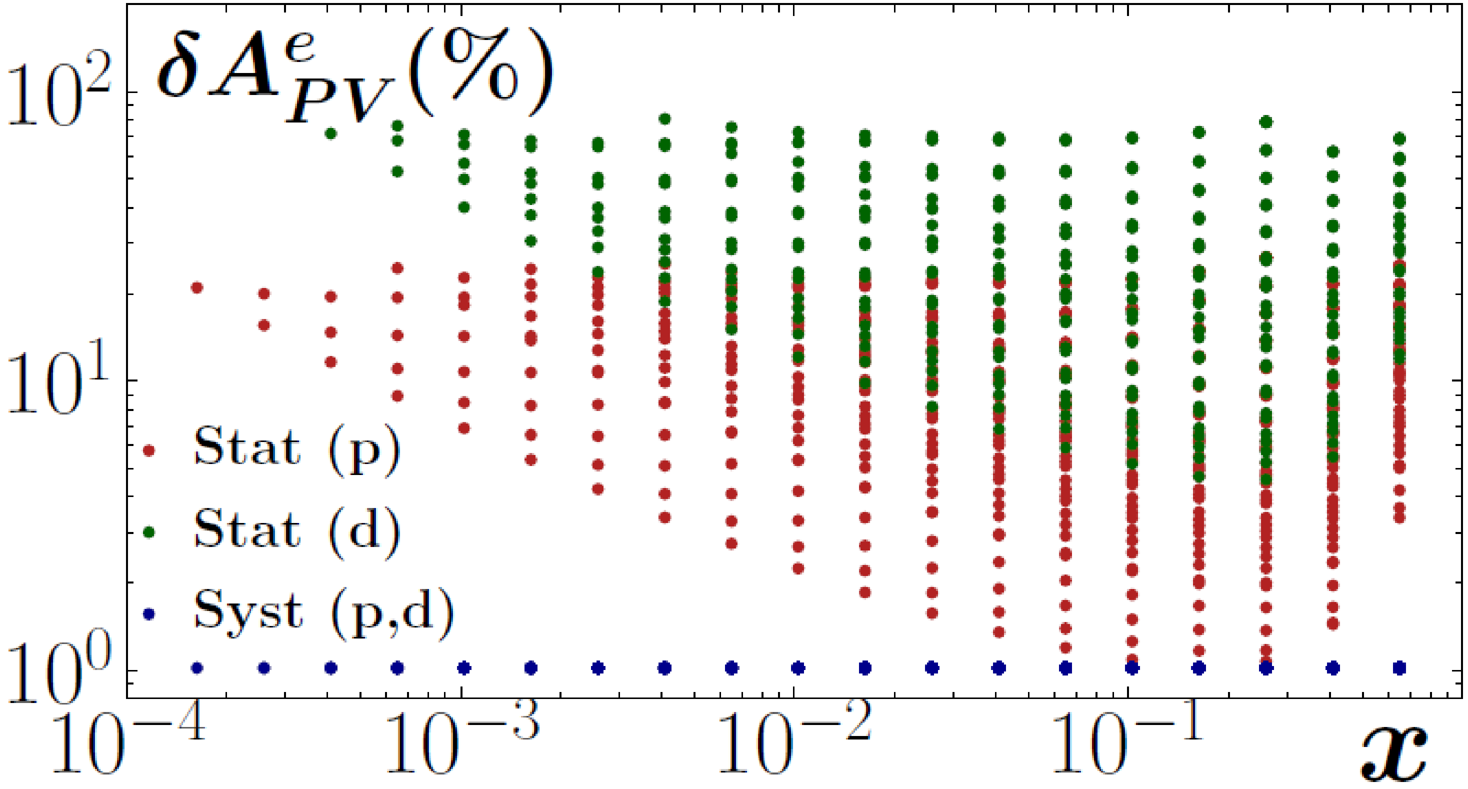
Pion contamination

1) Inflates statistical errors because it is typically treated as a dilution

2) Incurs ~1% systematic error

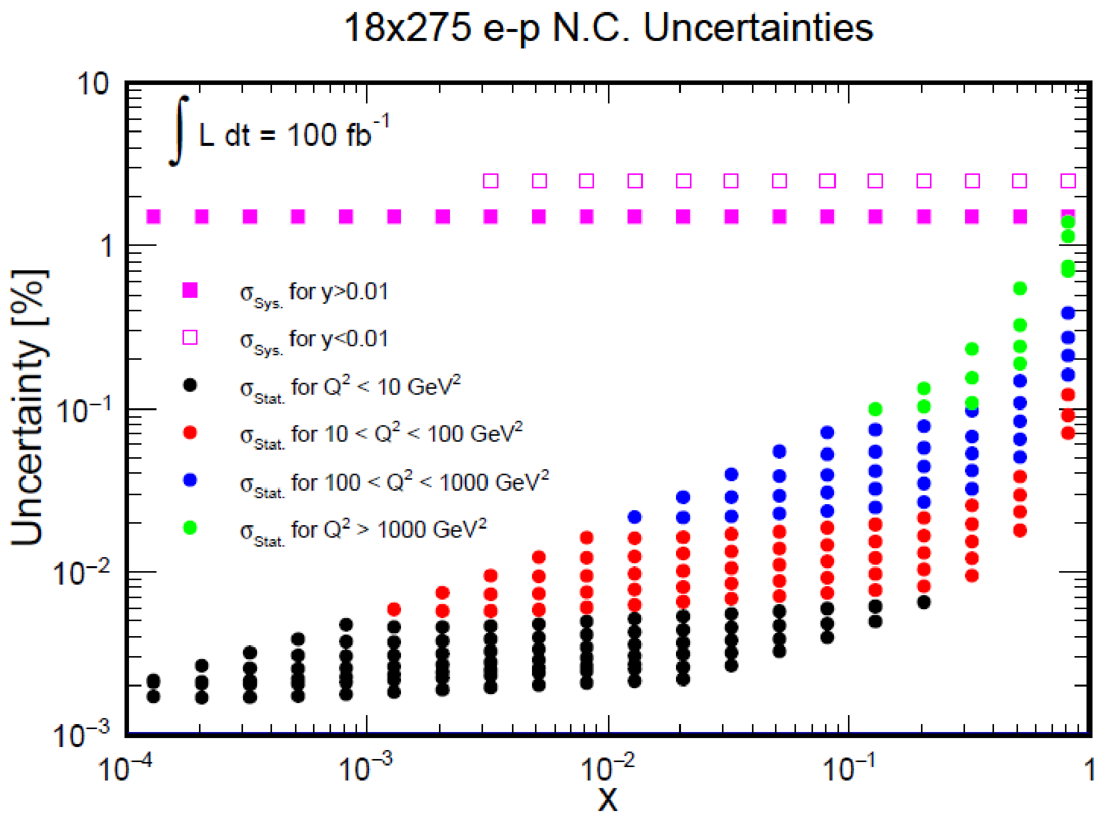
Tightest constraints come from electron parity violating asymmetries A_{PV}^{e-}

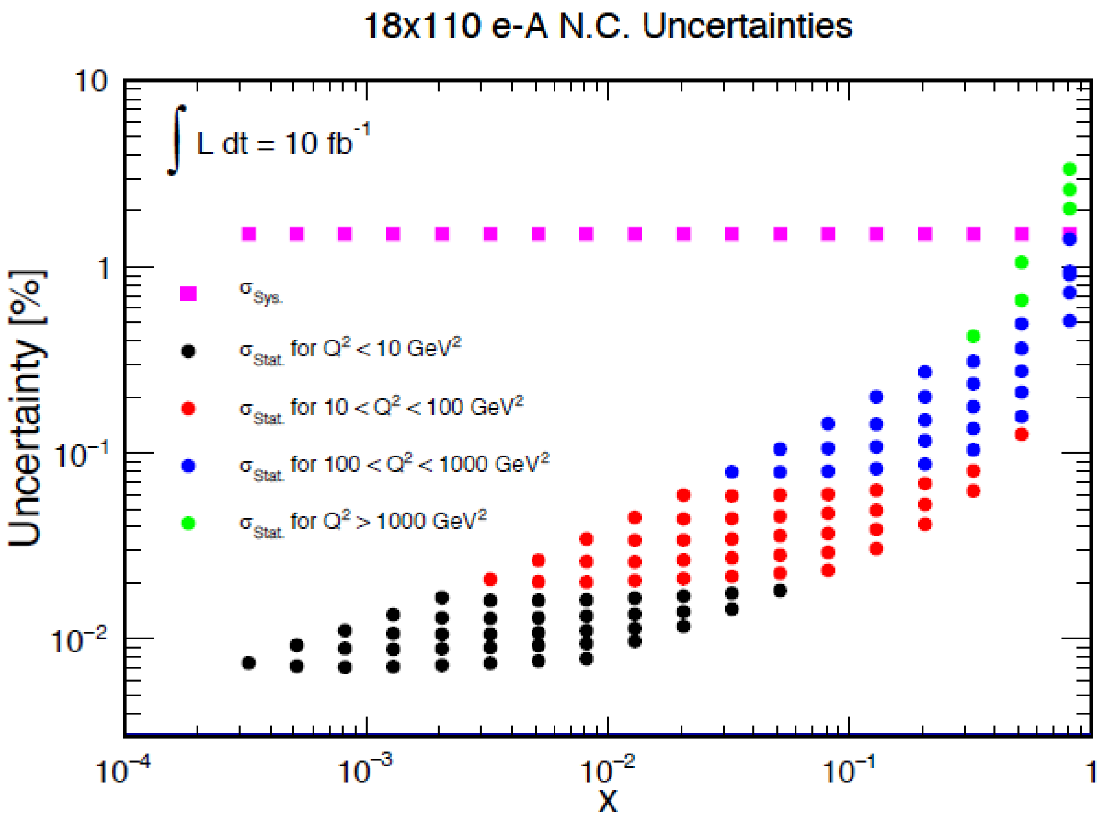
Requirement on final π/e Contamination



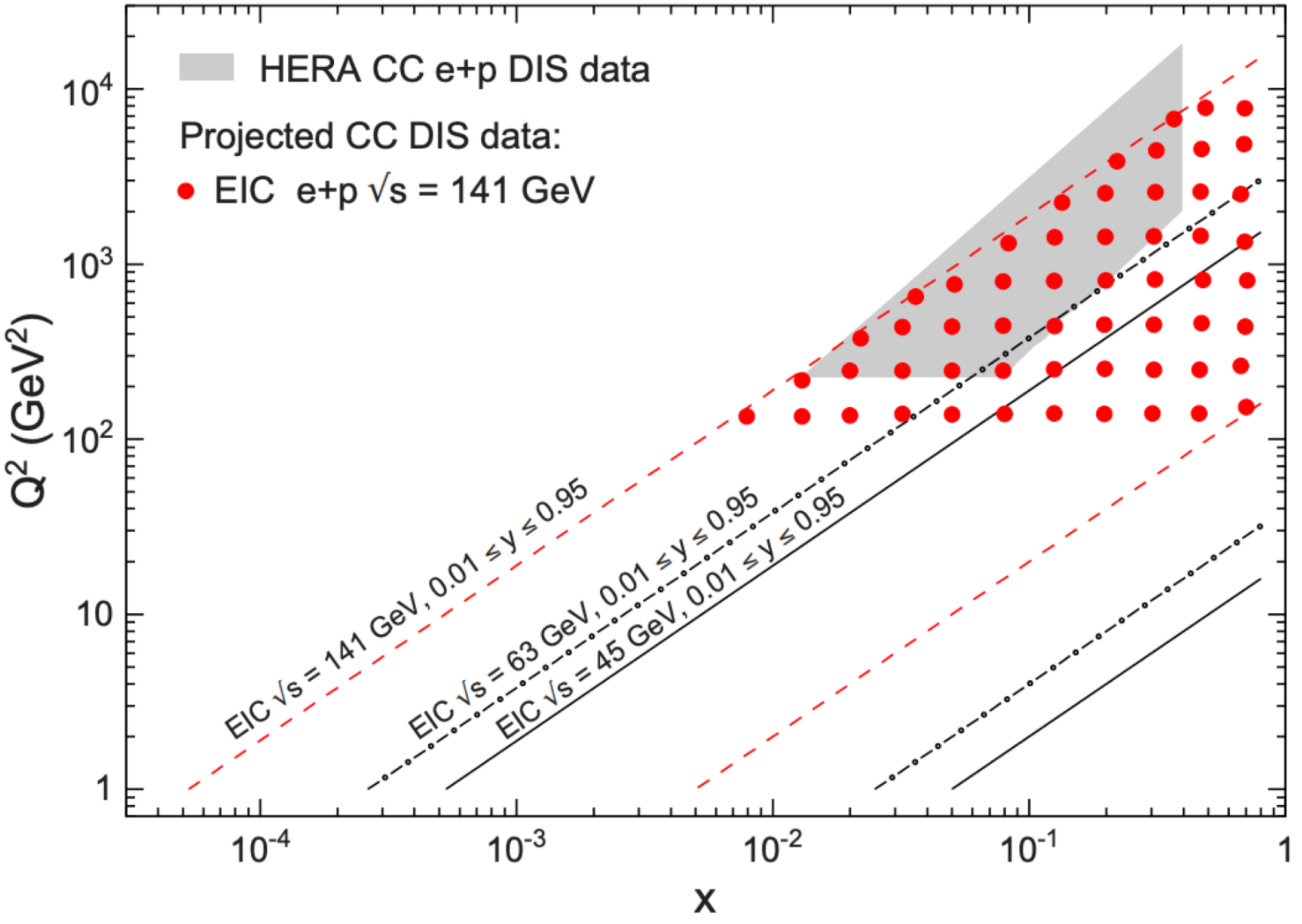
1) Limit pion contamination systematic error to be ~10% of statistical error.
2) Translates into a requirement of pi/e = $1\text{x}10^{-3}$
3) This requirement is never met in the central region (-2 < η < 1)
4) Room for improvement with implementation of PID algorithms.

Estimated uncertainties for N.C. Cross sections





C.C. Phase Space and Reconstruction

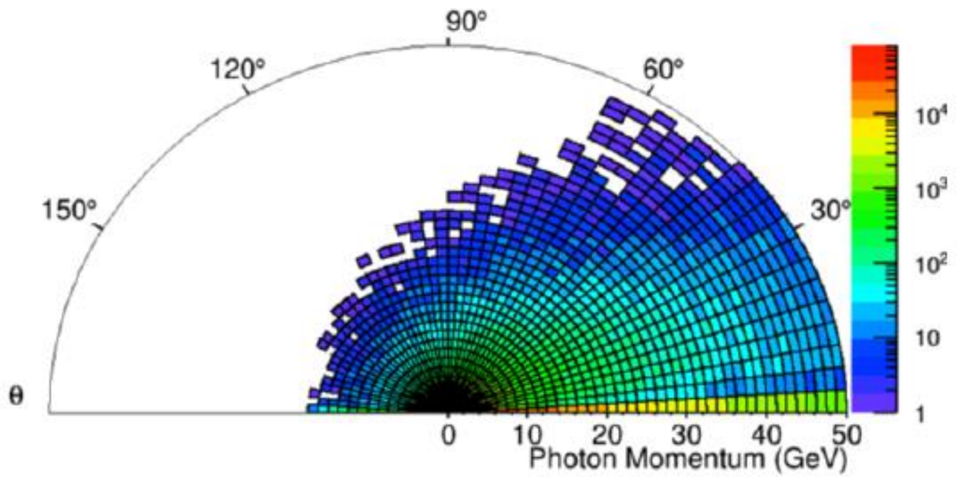


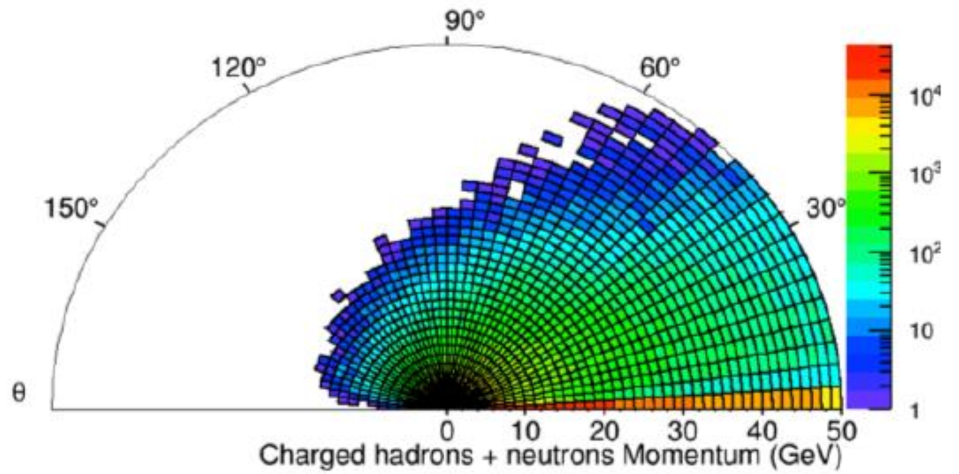
$$Q^2_{JB} = \frac{p_T^2}{1 - y_{JB}}$$

$$y_{JB} = \frac{(E - p^z)}{2E}$$

$$x_{JB} = \frac{Q^2_{JB}}{s y_{JB}}$$

Hadronic Reconstruction





$$Q^2_{JB} = \frac{p_T^2}{1 - y_{JB}}$$

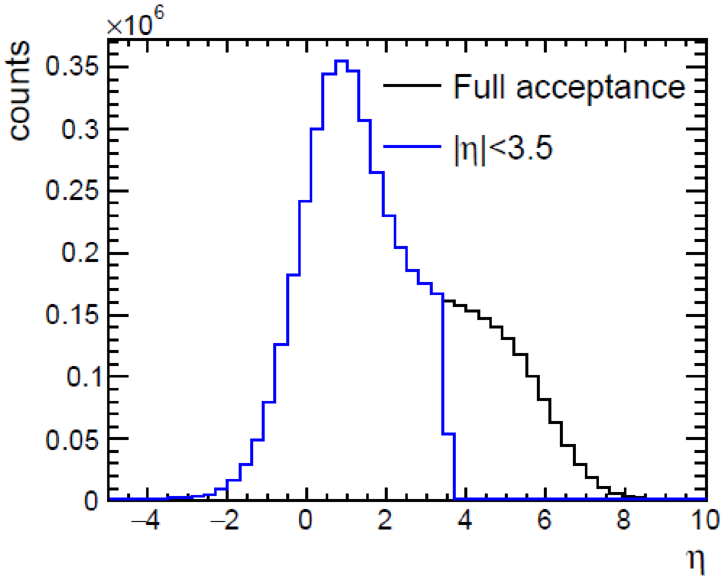
$$p_T^2 = (\sum_h P_h^x)^2 + (\sum_h P_h^y)^2$$

$$y_{JB} = \frac{(E - p^z)}{2E}$$

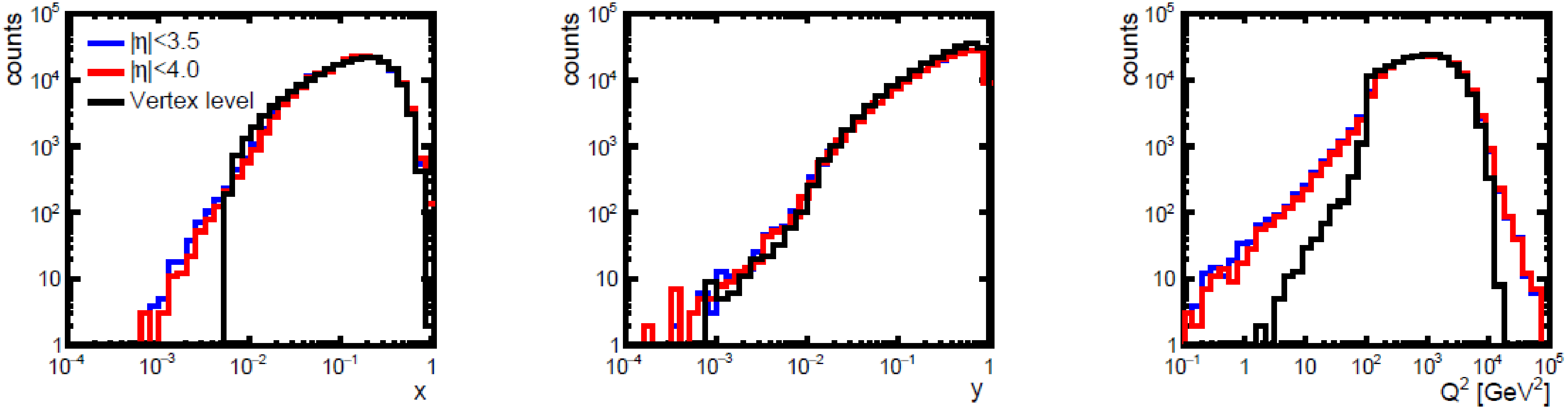
$$(E - p^z) = \sum_h (E_h - p_h^z)$$

$$x_{JB} = \frac{Q^2_{JB}}{s y_{JB}}$$

Hadronic Reconstruction



Angular distribution of hadrons and photons show that J.B. reconstruction is affected by central detector forward acceptance.



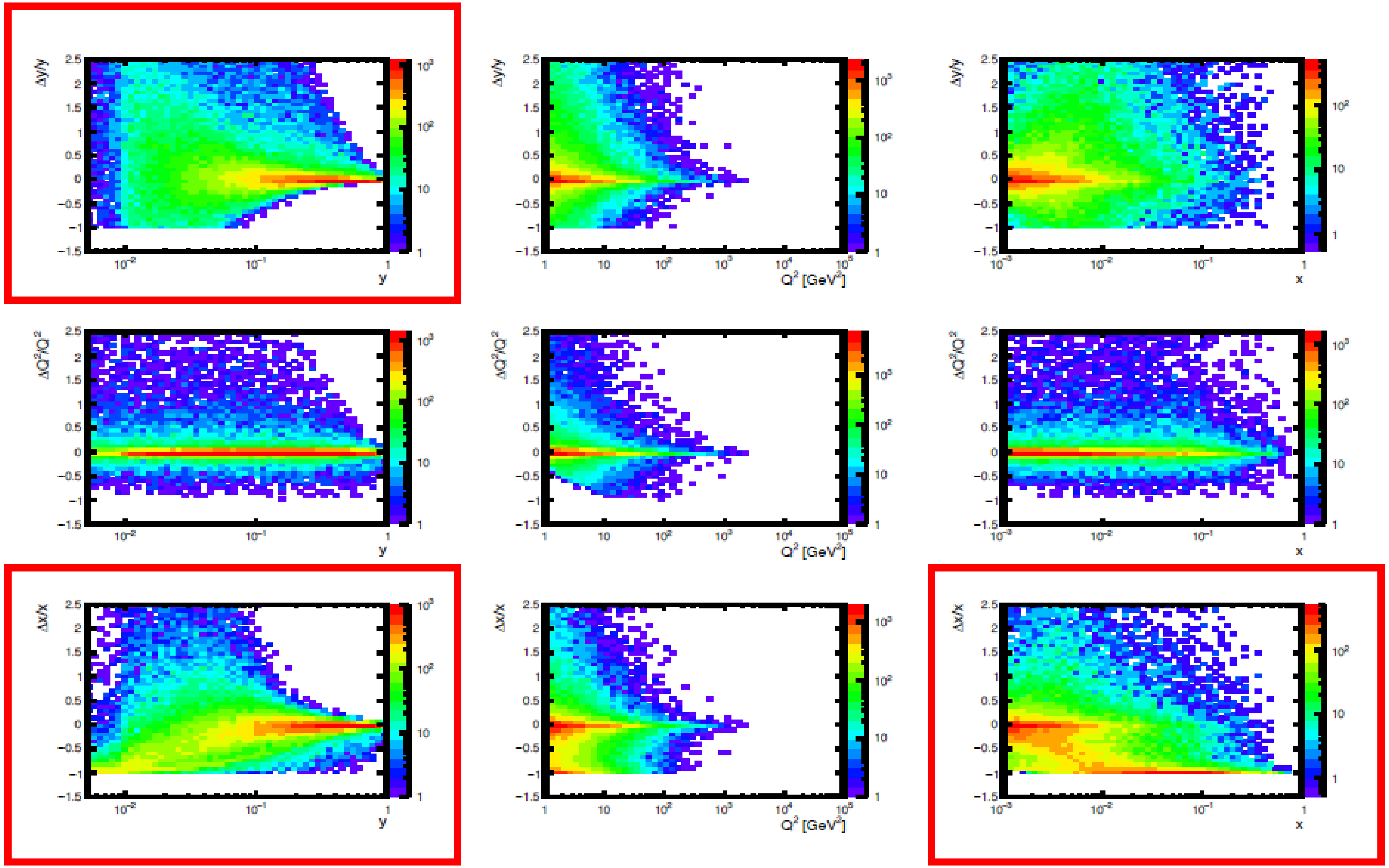
But increasing acceptance to η = +4 seems to have minimal impact on the kinematic reconstruction resolutions

J.B. reconstruction requires inelasticity > 0.01 cut

$\Delta x/x$ and $\Delta y/y$ diverge as $y \rightarrow 0$

$\Delta x/x$ develops systematic offset at $x \sim 10^{-2}$.

Caused by large positive fluctuations in y that then suppress x.



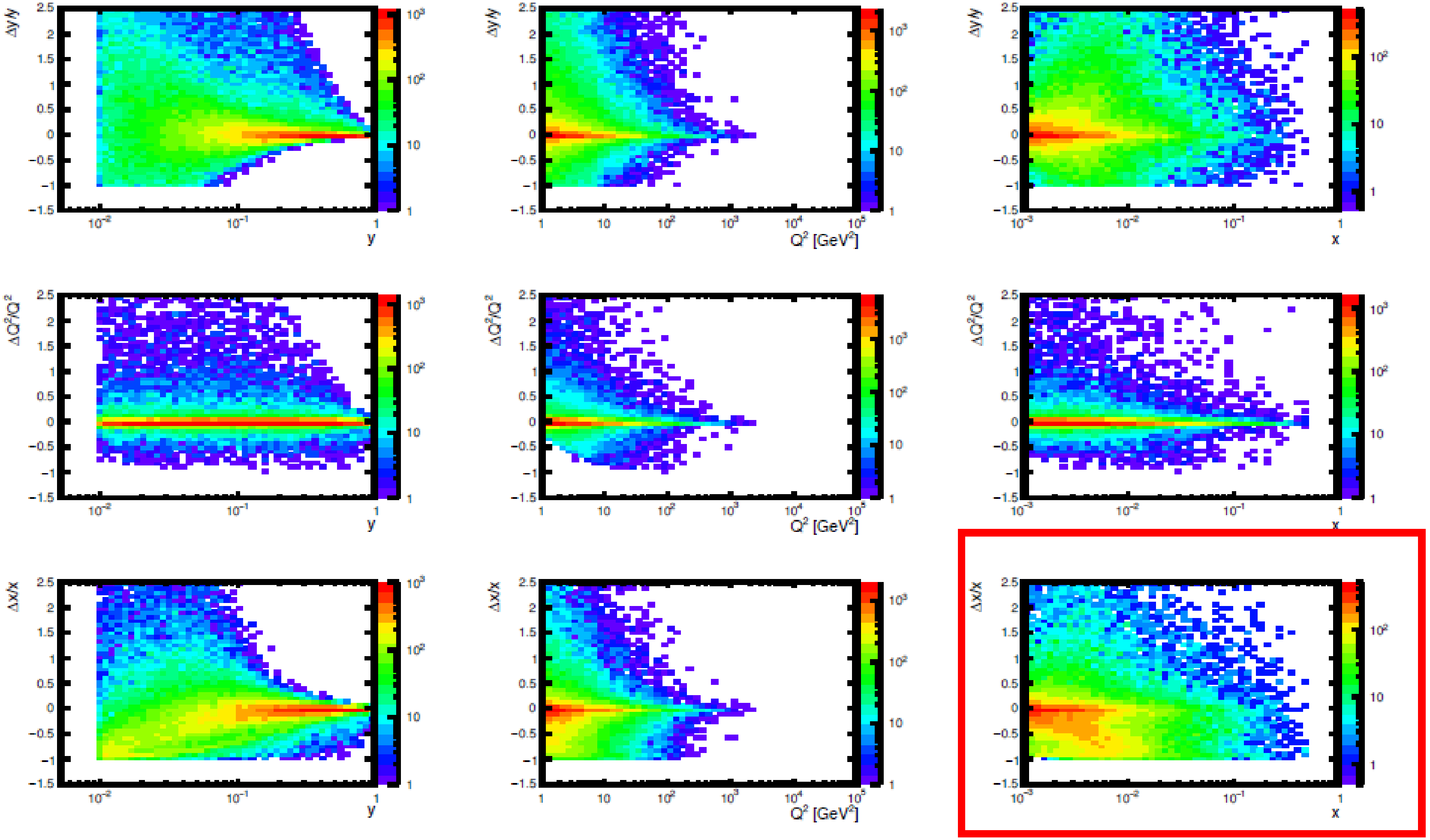
J.B. reconstruction requires inelasticity > 0.01 cut

$\Delta x/x$ and $\Delta y/y$ diverge as $y \to 0$

$\Delta x/x$ develops systematic offset at x ~10^{-2} .

Caused by large positive fluctuations in y that then suppress x.

Removed by y > 0.01 cut



Limitations in the Yellow Report – no ‘full’ analysis of physics observables was completed

- In the yellow report, the focus was on considering the event rates, acceptance and resolution, and raw backgrounds
- We did not complete a full analysis of the physics observables. This was because of several reasons:
  1. Since we were not working with a full detector simulation at the time, we did not have realistic particle ID cuts, efficiencies and background estimates
  2. We did not a detector material budget to accurately estimate external conversion backgrounds
  3. Realistic beam effects – such as crossing angle and divergence – had not been implemented
- In addition, our goal in the yellow report was to determine how accurately the inclusive measurements needed to be made. This meant studying the impact of different systematic uncertainty scenarios with the fitting groups. Much of this could be done by using the systematic uncertainties determined by previous experiments.

Limitations in the Yellow Report – raw backgrounds did not include realistic topological cuts

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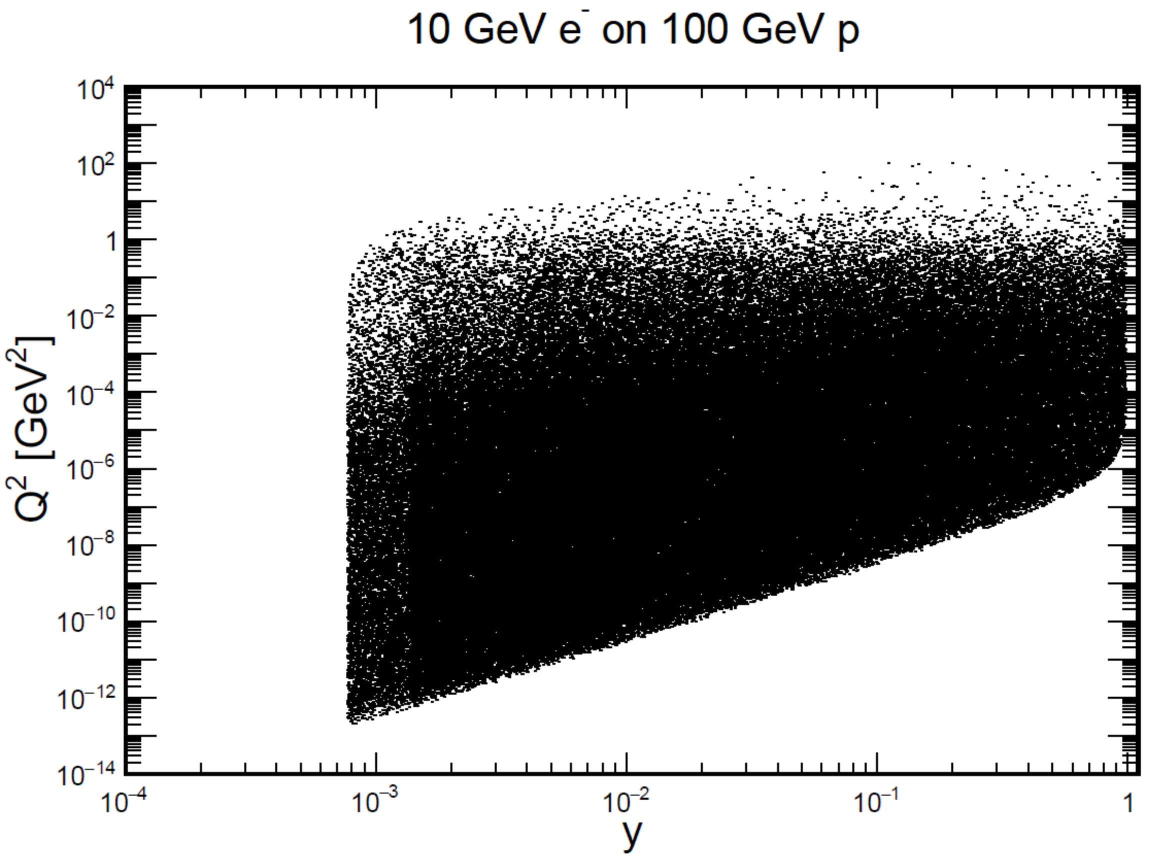
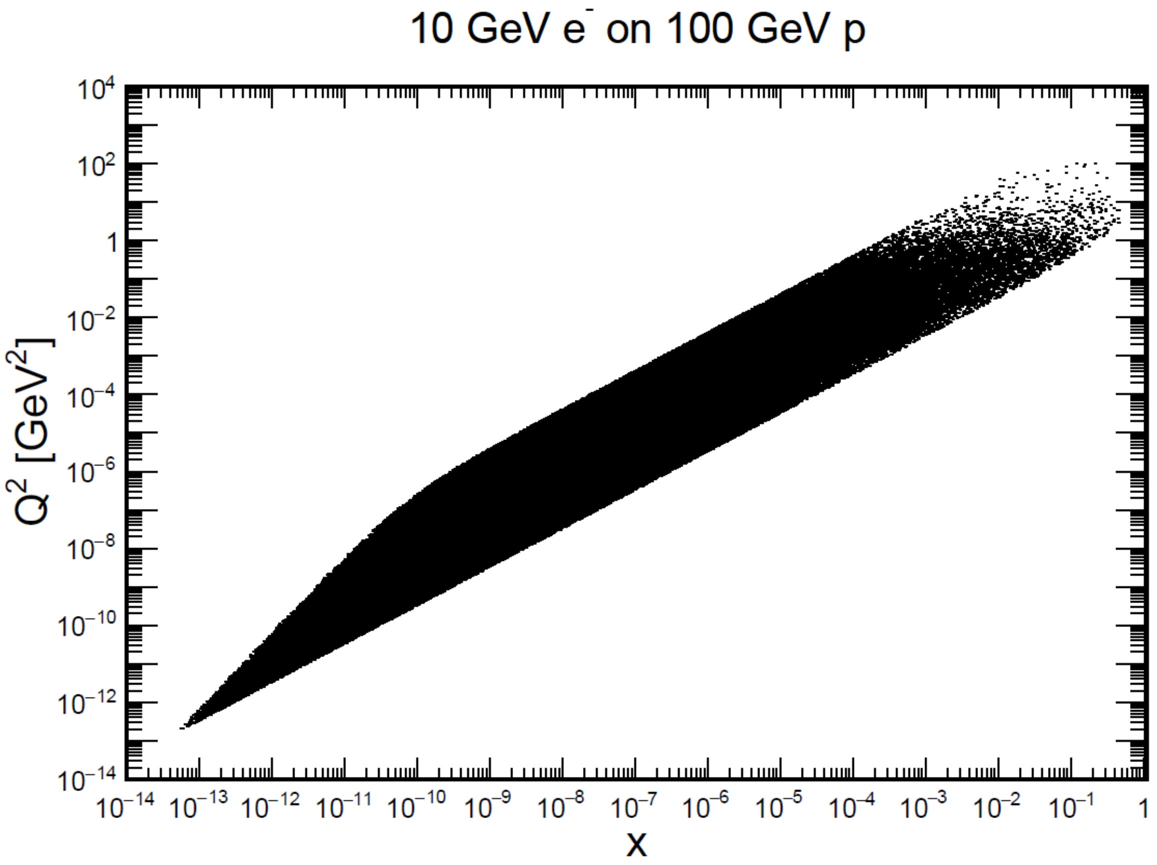
Start by using *Pythia6* to generate events all the way down to the minimum possible Q^2





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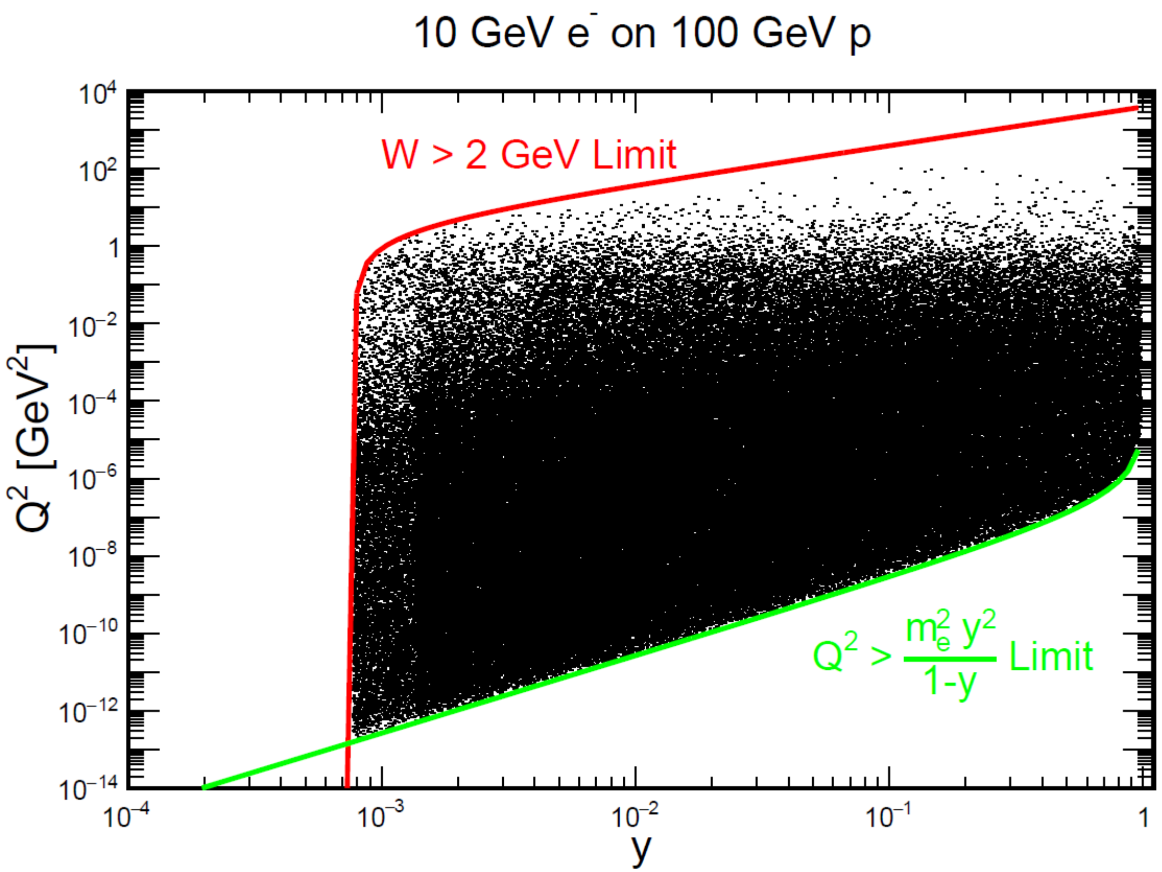

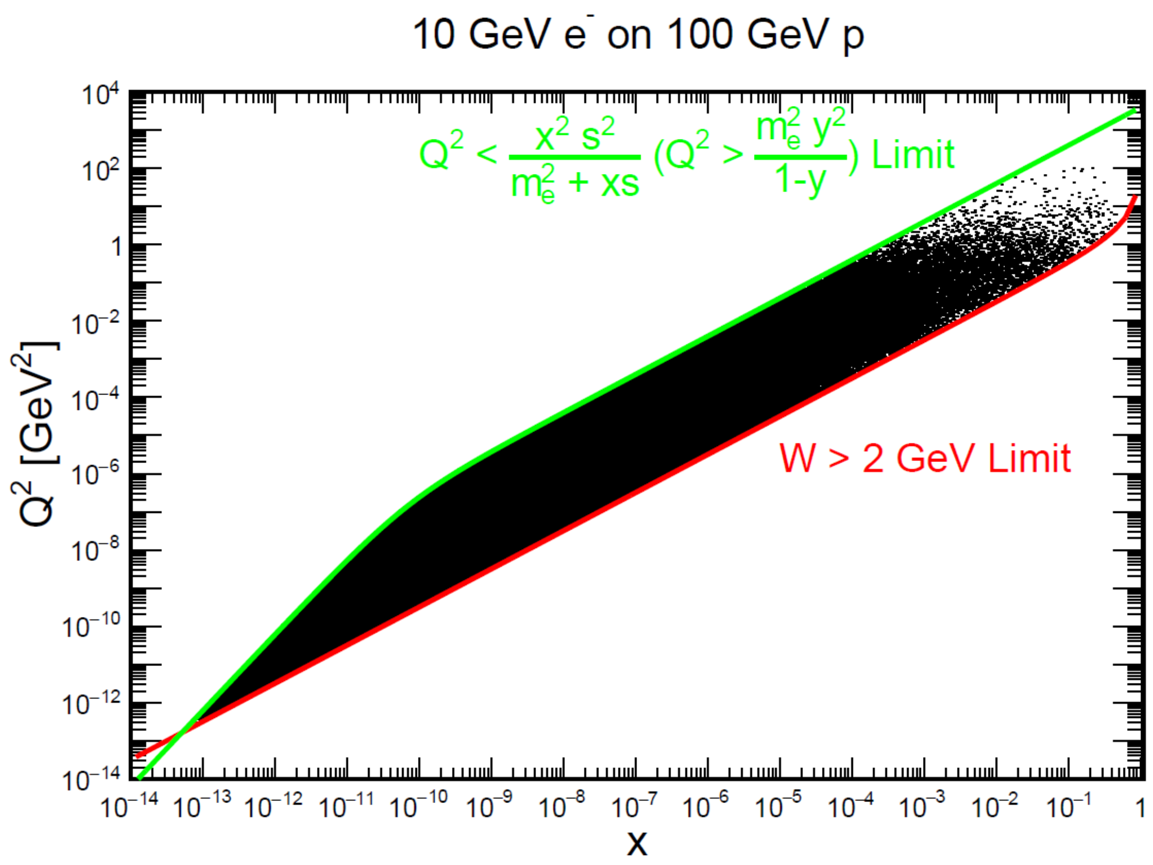

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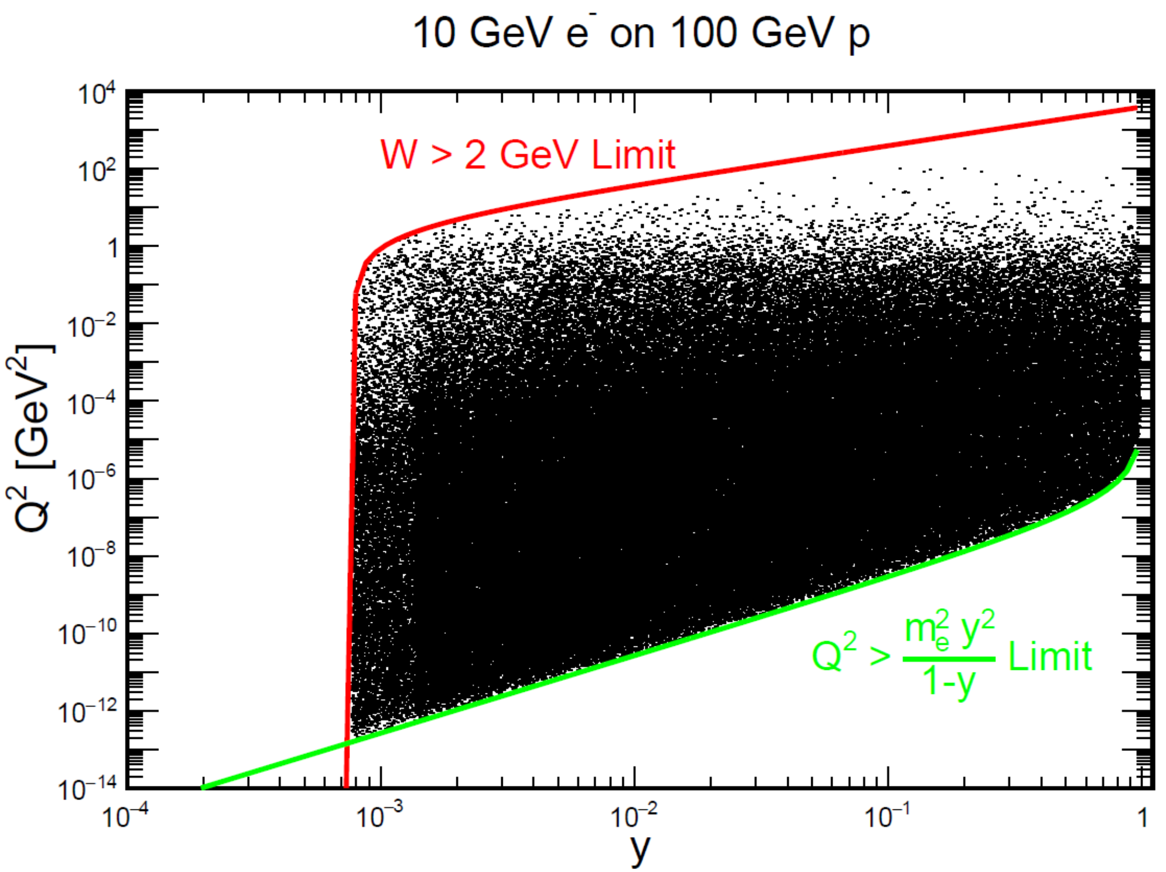
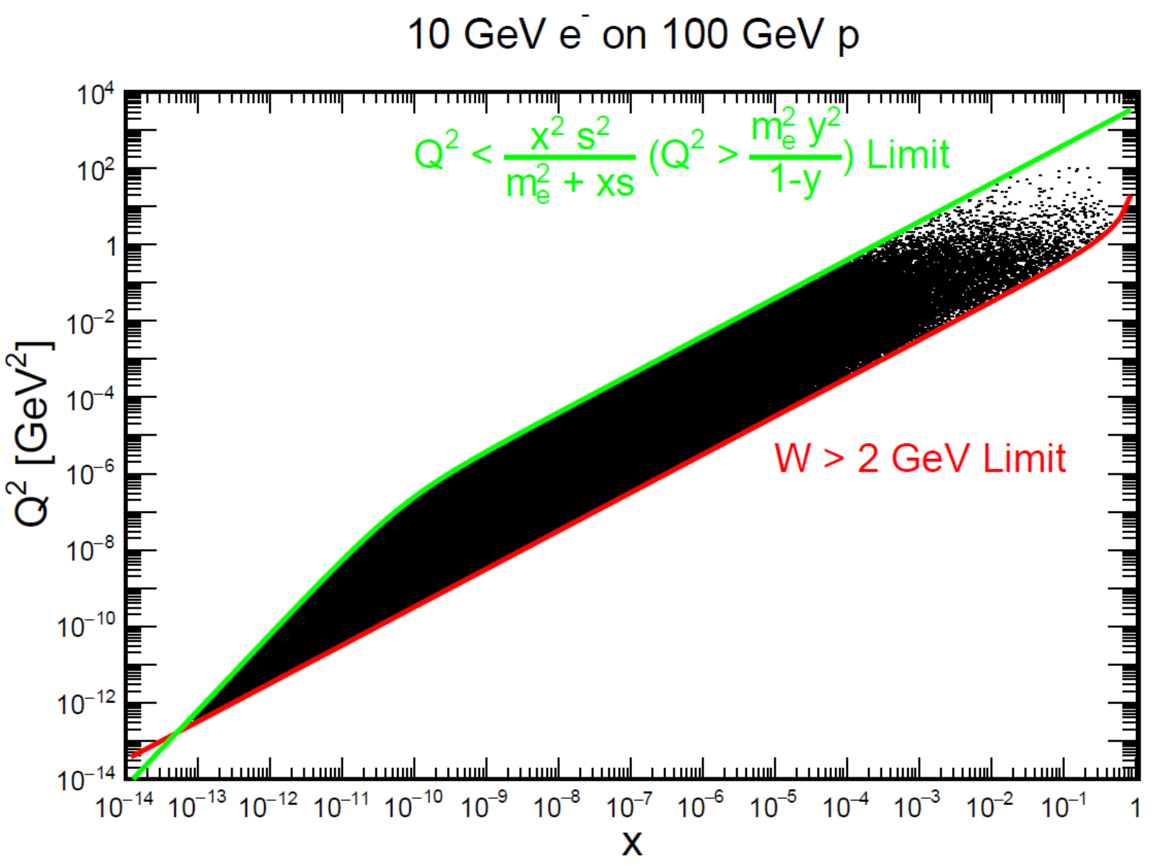
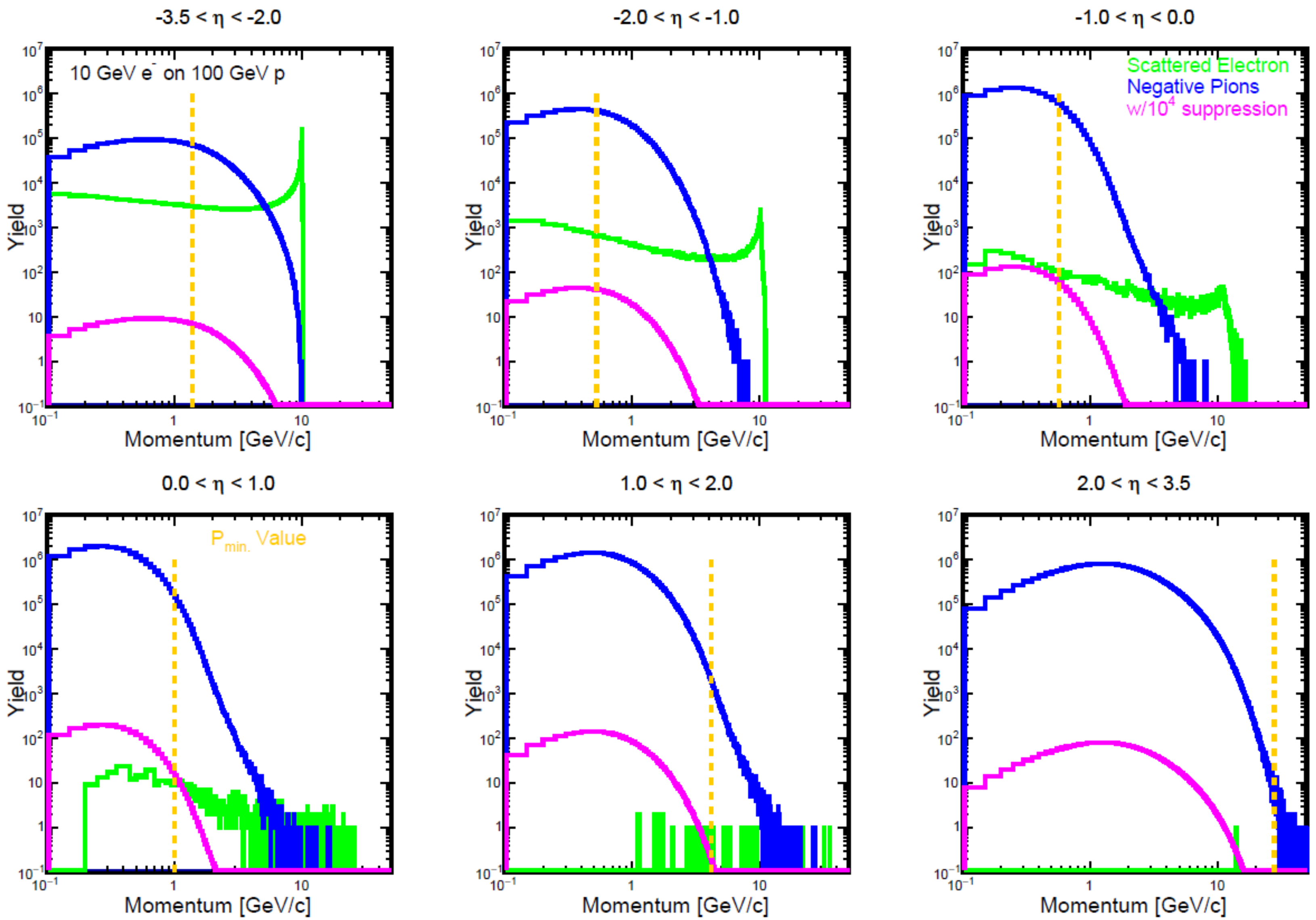


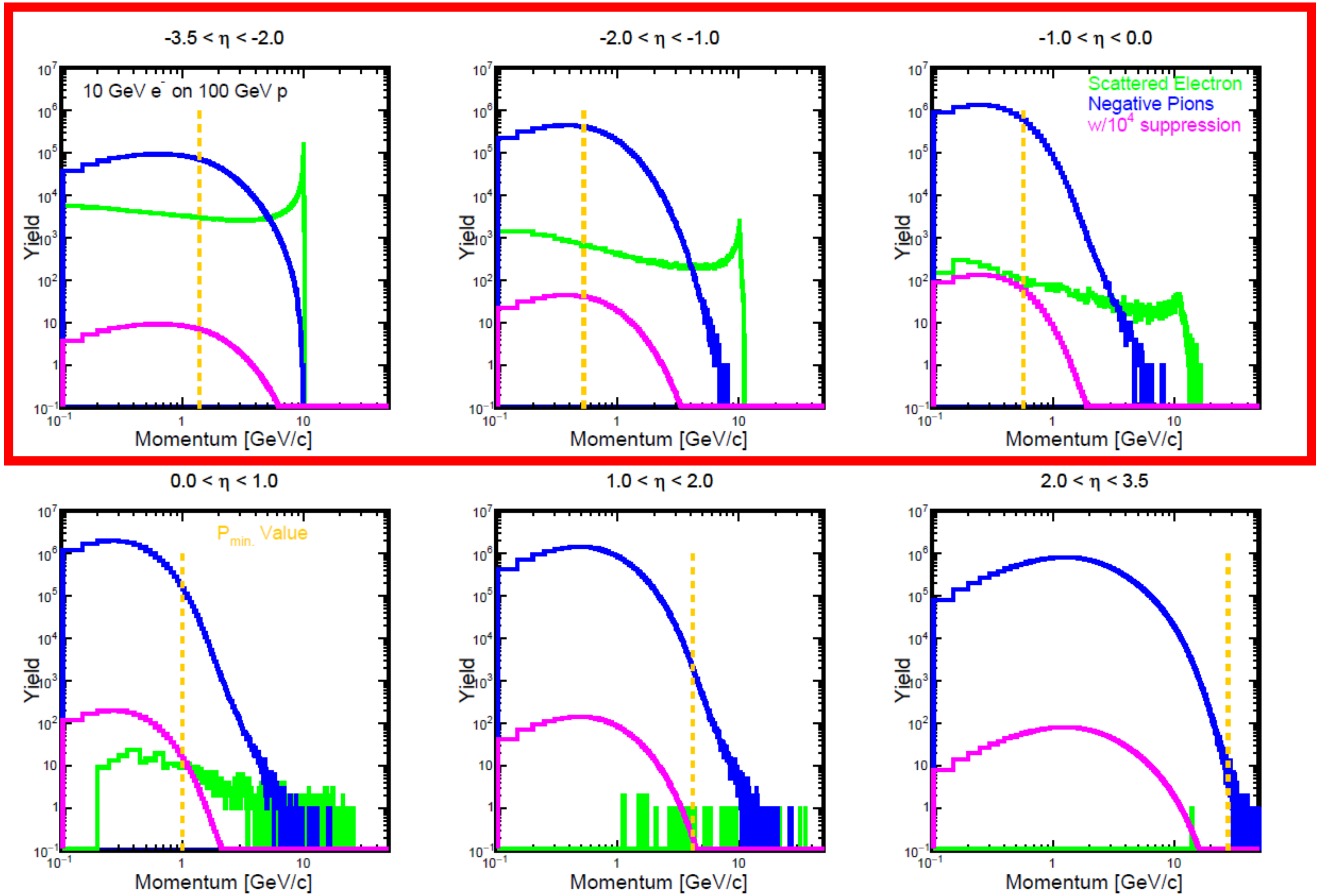


I estimate that events with W< 2 GeV are ~5% of the total cross section. So, ignoring those events is a small effect.

Also show (purple curve) how much pion contamination will be present if the EIC has 10^4 level suppression



Focus on the backward hemisphere with finer bins



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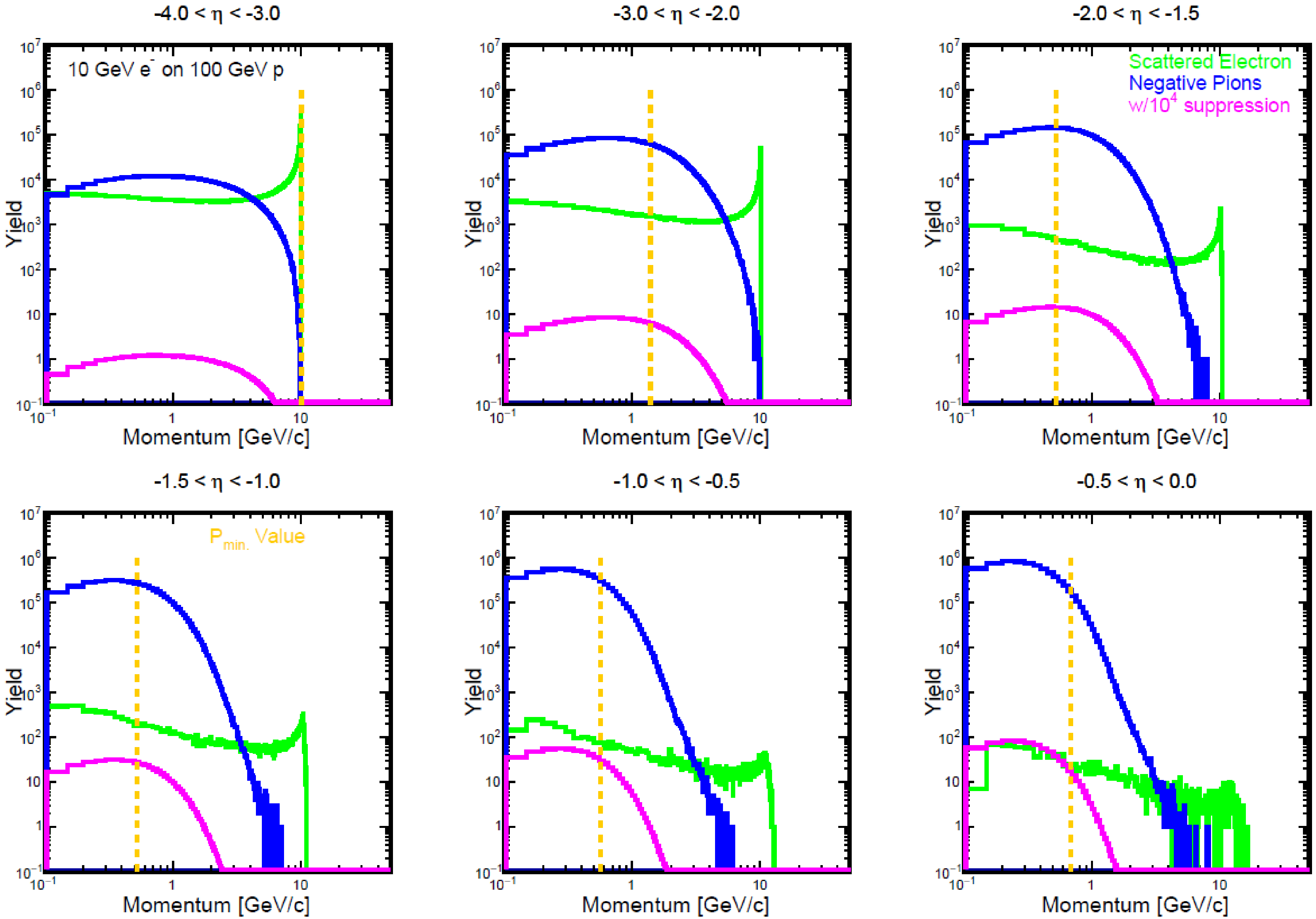


The strictest requirement comes from A_{pv}. Here, the fractional uncertainty on the asymmetry is equal to the final pion contamination. That is, in order to achieve a 1% uncertainty on the asymmetry, we would need a final pi/e ratio of better than 10^{-2}. As can be seen, for the more central rapidities, this requirement is not met with 10^4 level suppression.

Look at potential 'topological' variables to reduce pion contamination

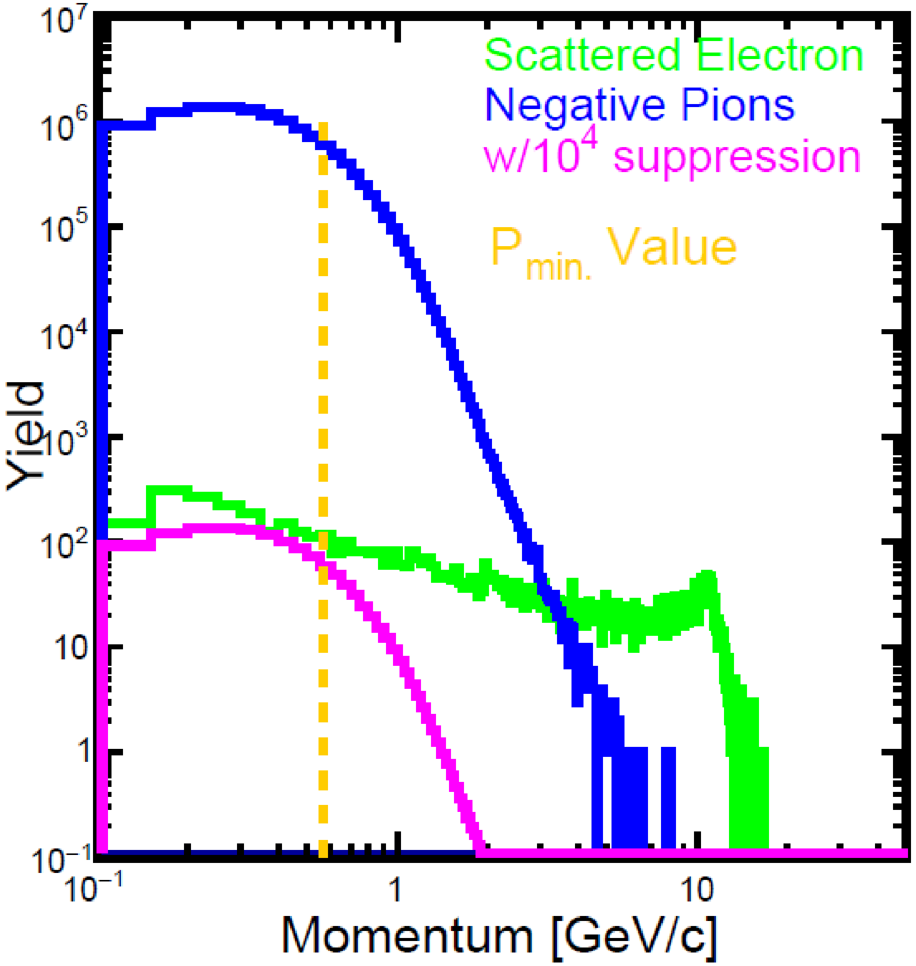
1. Sum the momenta vectors of all particles except the electron candidate with |η| < 3.5 . Compare the azimuthal angle of that sum to the azimuthal angle of the electron candidate (which is either a negative pion or the scattered electron). The idea is that for the reaction e + p -> e` + X, the X should be co-planar to the scattered electron, but not necessarily the pion.
2. Sum the total energy minus the z-component of the momentum for all particles with |η| < 3.5 . If all particles are detected

$$E_{Tot} - p_{z,Tot} = \left(E_e + E_p\right) - \left(-E_e + E_p\right) = 2E_e$$

For very low Q^2 events, the scattered electron will be lost down the beamline, and the above quantity will be smaller than $2E_e$. These events may contain a (or multiple) negative pion – which is a scattered electron candidate. We can possibly remove these events by a cut on the above variable.

The pion background is reduced by about a factor of 20 without reducing the scattered electron signal above the minimum momentum value

$-1.0 < \eta < 0.0$



Applying the two cuts

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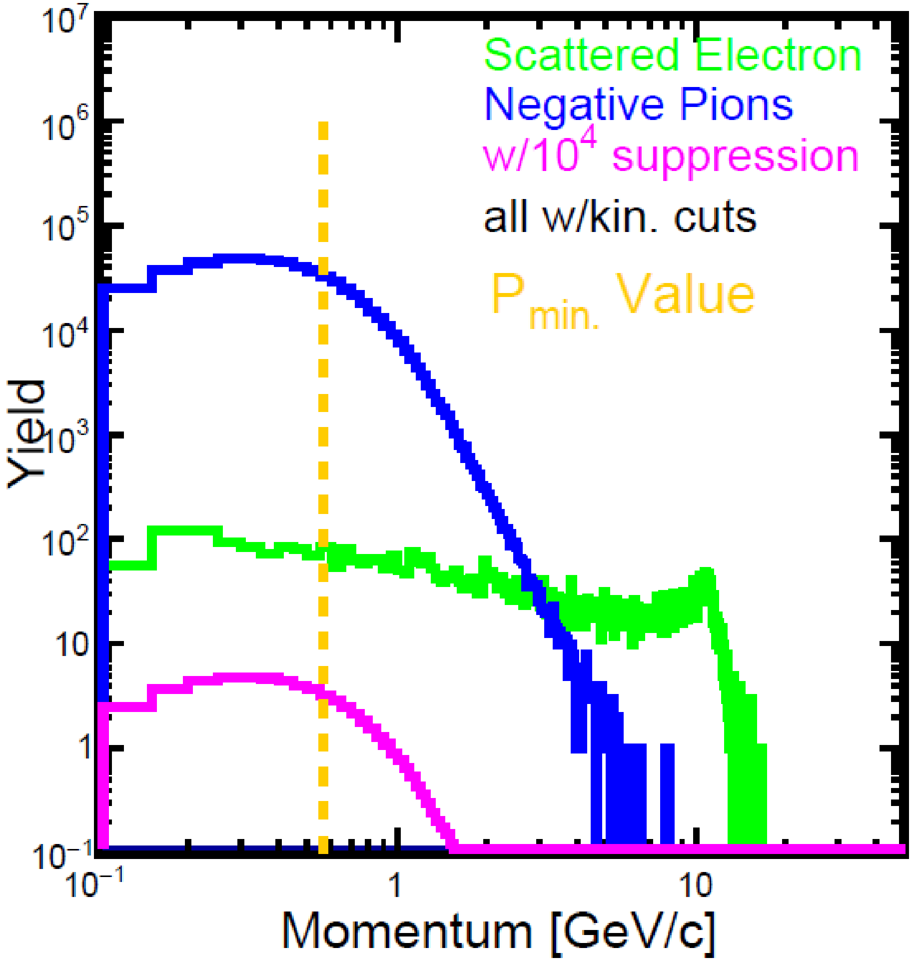

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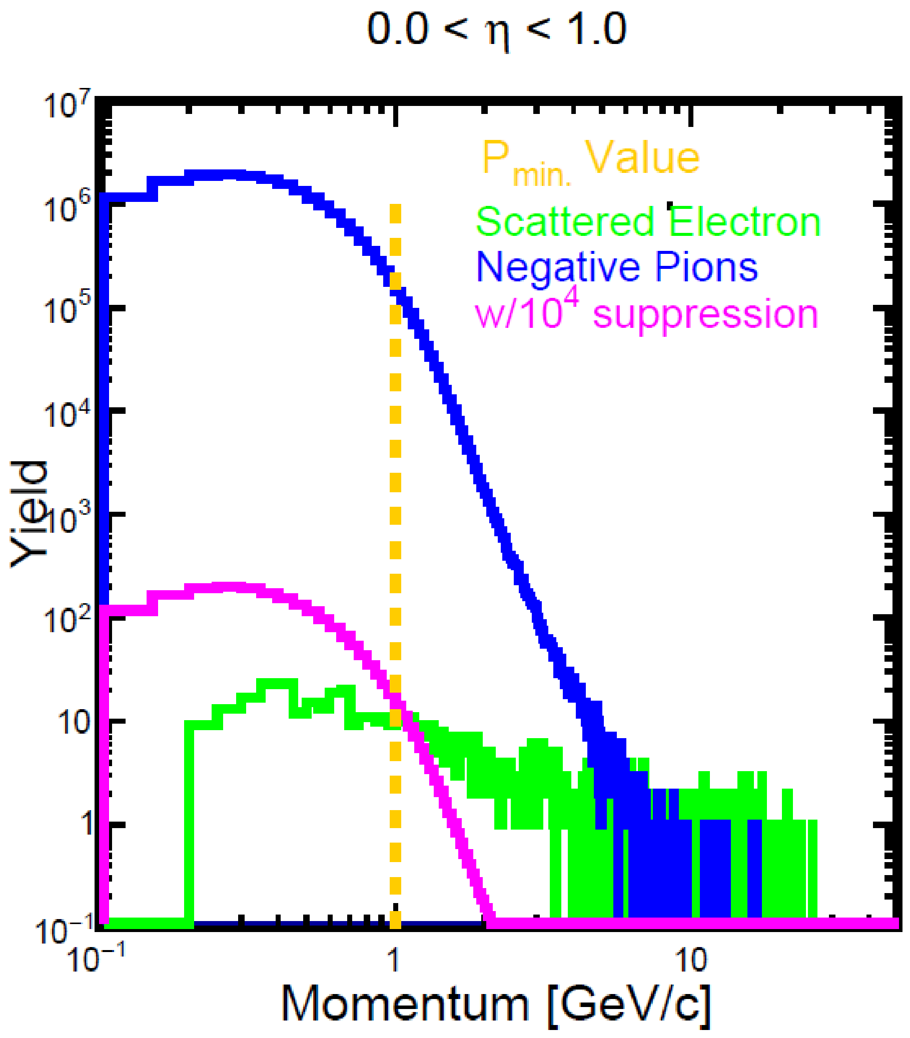

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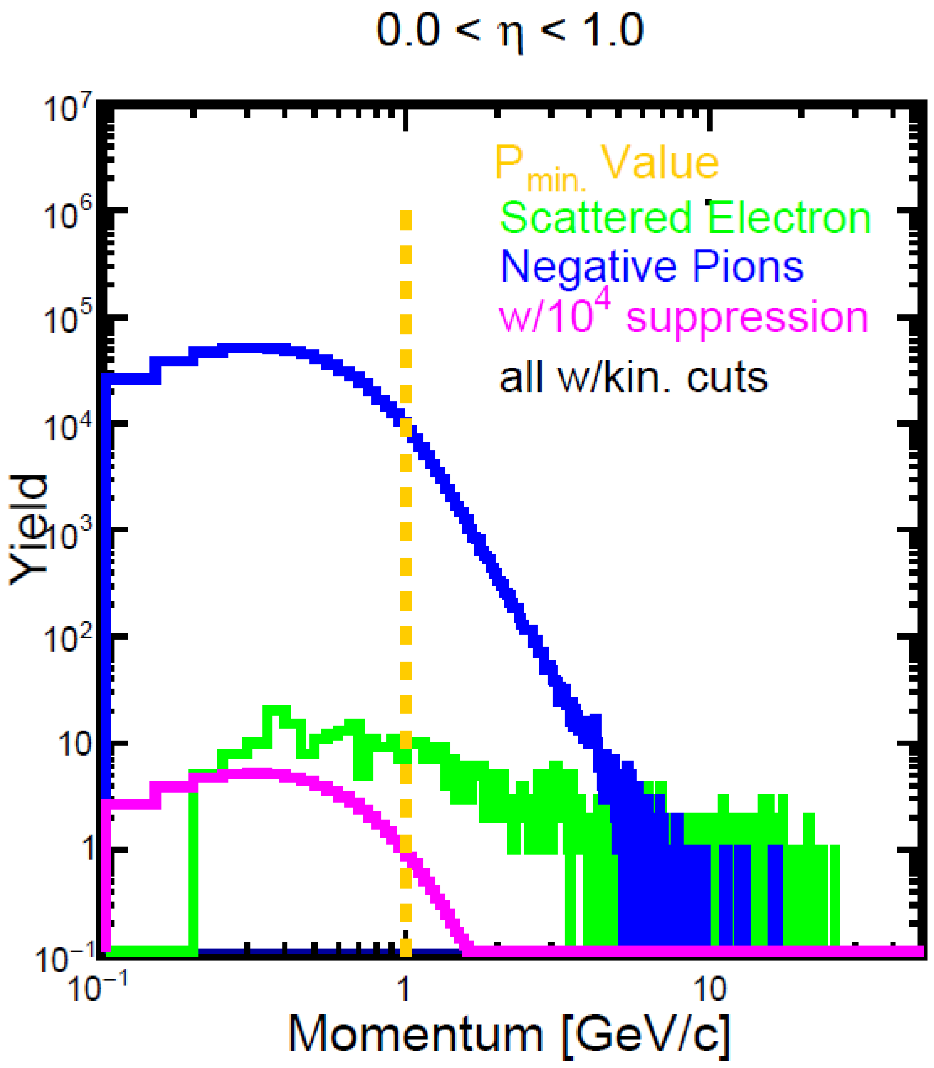

Summary

- I have provided a summary of the work done by the EIC yellow report inclusive reactions group. I have focused on chapter 8, which details the requirements.
- Chapter 7 focuses on the physics impacts for various systematic uncertainty scenarios.
- I also discussed some of limitations in the yellow report effort and the reasons for the approach taken, and some paths forward.