# CORE and Physics Beyond the Standard Model

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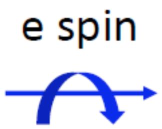
# Outline

- ➢Inclusive electron parity-violating asymmetry ($A_{pv}$) and pion suppression requirements
- ➢Simulating negative pion background to scattered electron
- ➢CORE pion suppression capabilities -- parameterization and *Fun4All* simulation

# Parity-violating asymmetry at the EIC



$$A_{\mathrm{PV}}^{\mathrm{electron}} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\left[g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V^e \frac{Y_-}{2Y_+}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}\right]$$

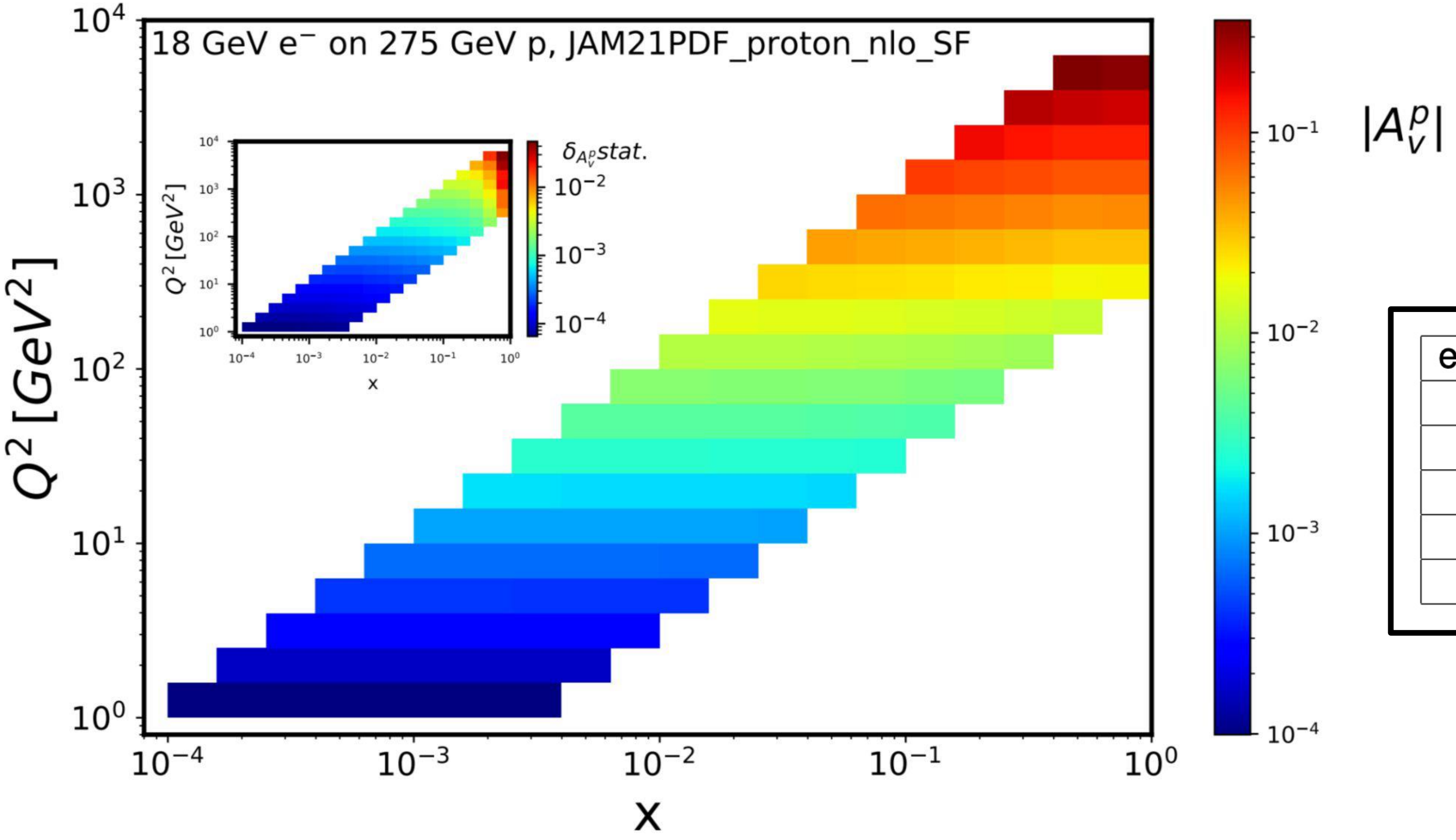
Callan-Gross relation used

**Statistical uncertainty on asymmetry measurement:**

$$\sigma_{A_{pv}} = \frac{\sqrt{1 - A_{pv,meas}^2}}{P_e\sqrt{N}} \approx \frac{1}{P_e\sqrt{N}}$$

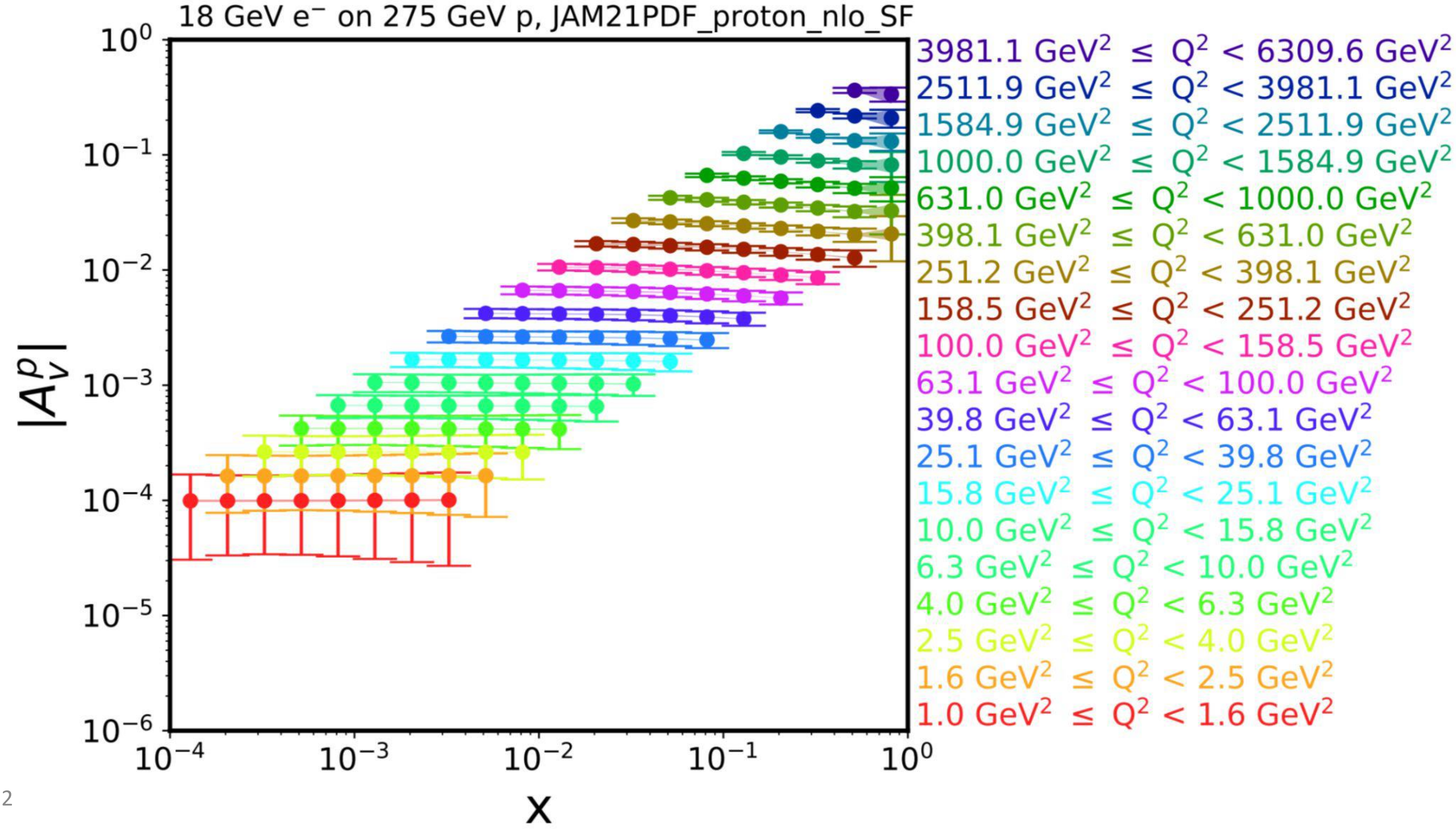
- **Inclusive parity-violating asymmetry measurements can be used to constrain PDFs**
- **Using eD data, extraction of weak mixing angle is possible**
- **See recent CFNS workshop for details.**

# Expected asymmetries and statistical uncertainties at the EIC

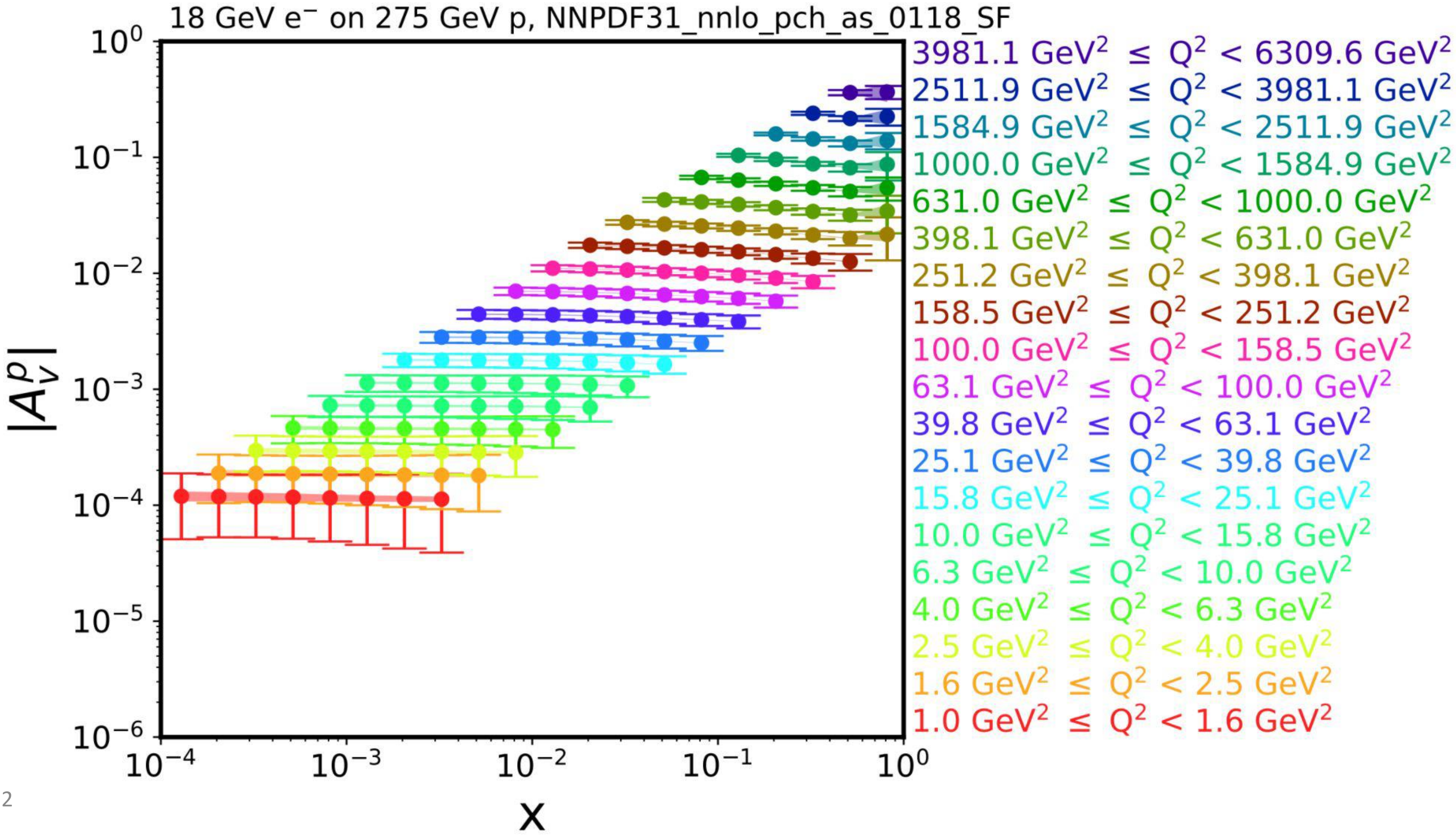


| e-beam E | p-beam E | $\sqrt{s}$ (GeV) | inte. Lumi. ($fb^{-1}$) |
|---|---|---|---|
| 18 | 275 | 140 | 15.4 |
| 10 | 275 | 105 | 100.0 |
| 10 | 100 | 63 | 79.0 |
| 5 | 100 | 45 | 61.0 |
| 5 | 41 | 29 | 4.4 |

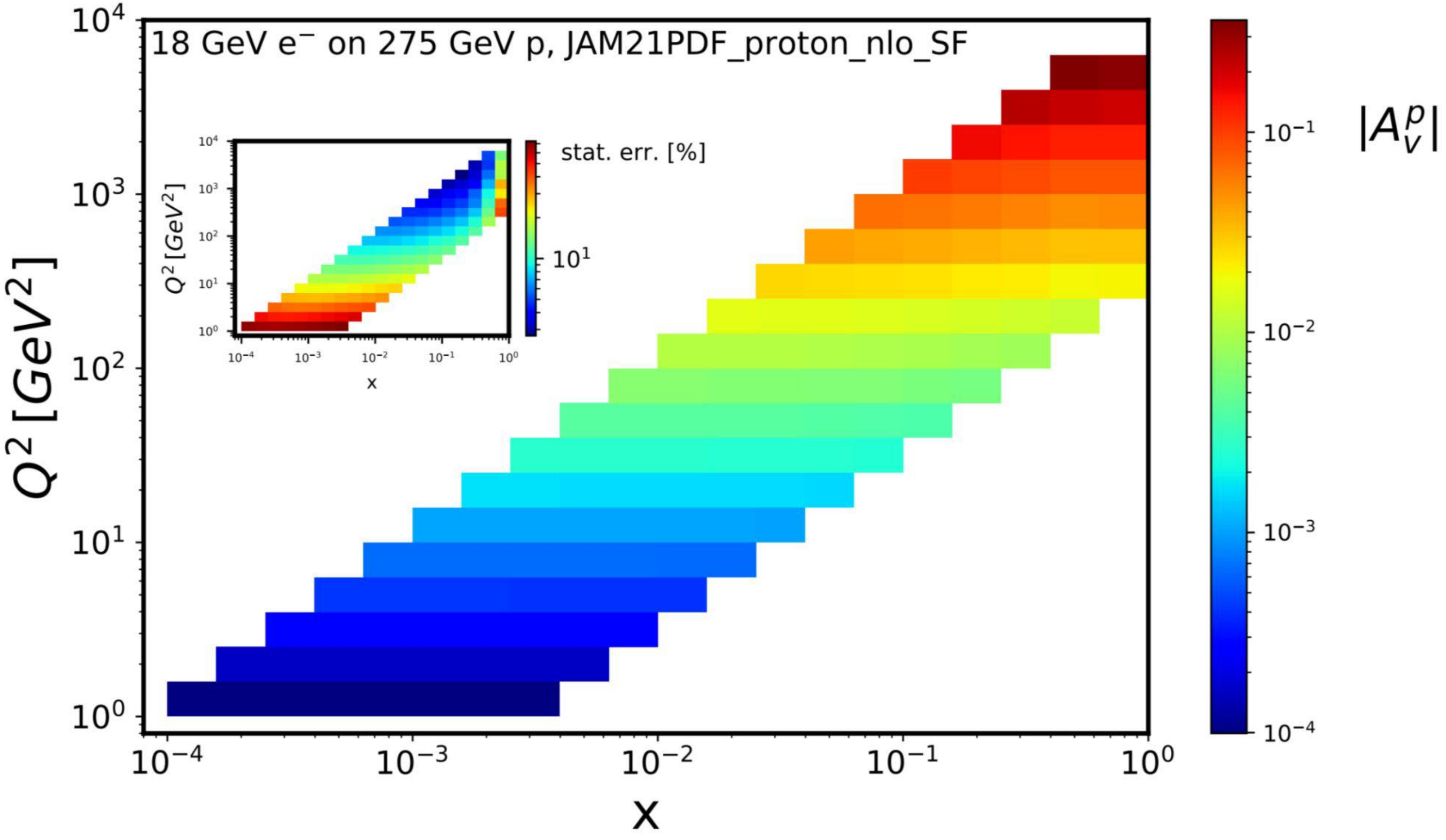
# Expected asymmetries and statistical uncertainties at the EIC



# Results are similar between PDF sets



# Strictest requirement on electron purity



**The statistical error can go down to ~1%. And a (very) strict requirement on the uncorrelated systematic error would be that it is always less than 1%.**

# Strictest requirement on electron purity

$A_{PV}^{e^-} \Rightarrow$ $A_{PV}^{e^-}$ is tiny

$A_{PV}^{\pi^-} \sim 0$

$\textcircled{II} \gg \textcircled{I}$

$$\left(\frac{\Delta A_{PV}^{e^-}}{A_{PV}^{e^-}}\right)^{\pi^-}_{sys} = \sqrt{\underbrace{\Delta f_{\pi^-}^{2}}_{\textcircled{I}} + \underbrace{\frac{f_{\pi^-}^{2}}{A_{PV}^{e^-\,2}}\left(A_{PV}^{\pi^-}+\Delta A_{PV}^{\pi^-}\right)}_{\textcircled{II}}}$$

$\downarrow$ systematic error due to $\pi^-$ contamination

$\downarrow$ $\textcircled{I}$ error on $\pi^-$ contamination in $e^-$ sample

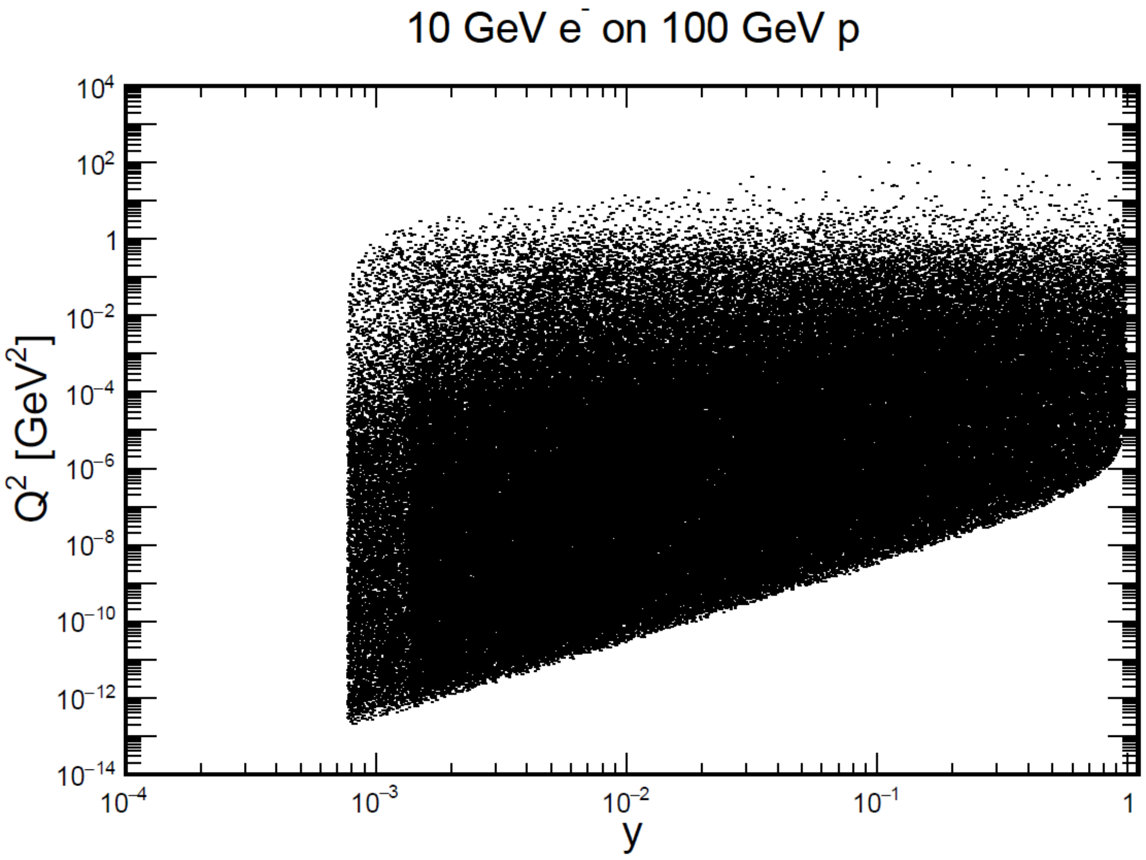
$\downarrow$ $\textcircled{II}$ uncertainty on $A_{PV}^{\pi^-}$

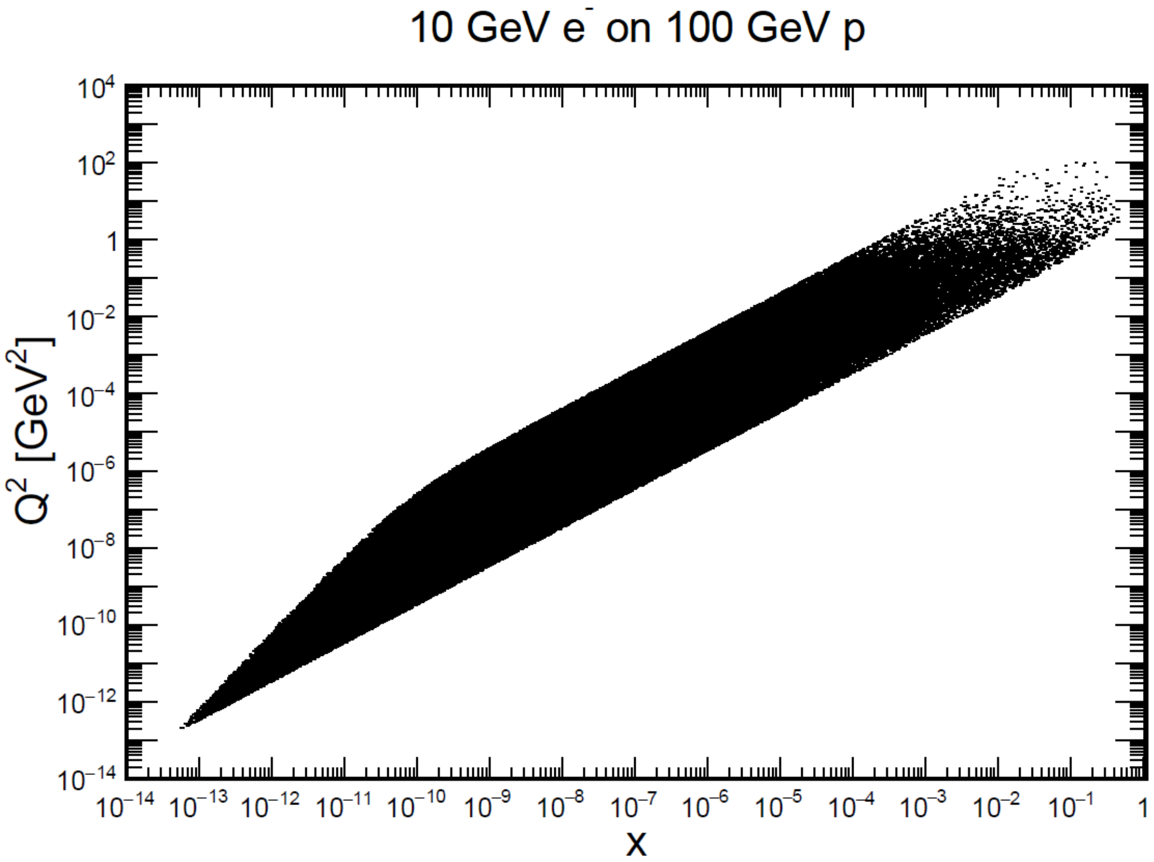
$$\left(\frac{\Delta A_{PV}^{e^-}}{A_{PV}^{e^-}}\right)_{\pi^- sys} \simeq f_{\pi^-}\left(\frac{A_{PV}^{\pi^-}+\Delta A_{PV}^{\pi^-}}{A_{PV}^{e^-}}\right)$$

$$\simeq f_{\pi^-}$$

**In order to limit the (uncorrelated) systematic uncertainty to 1%, we need a final pi-/e- ratio of better than $10^{-2}$**

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





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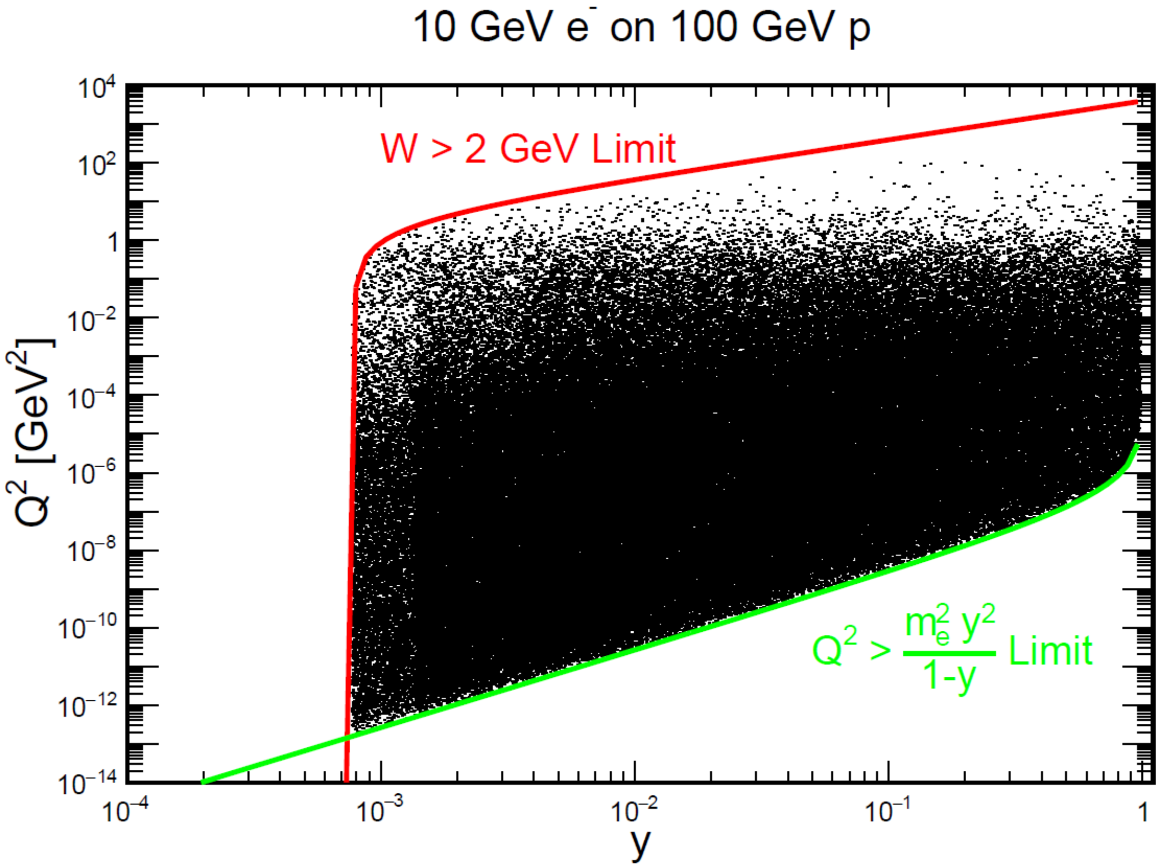

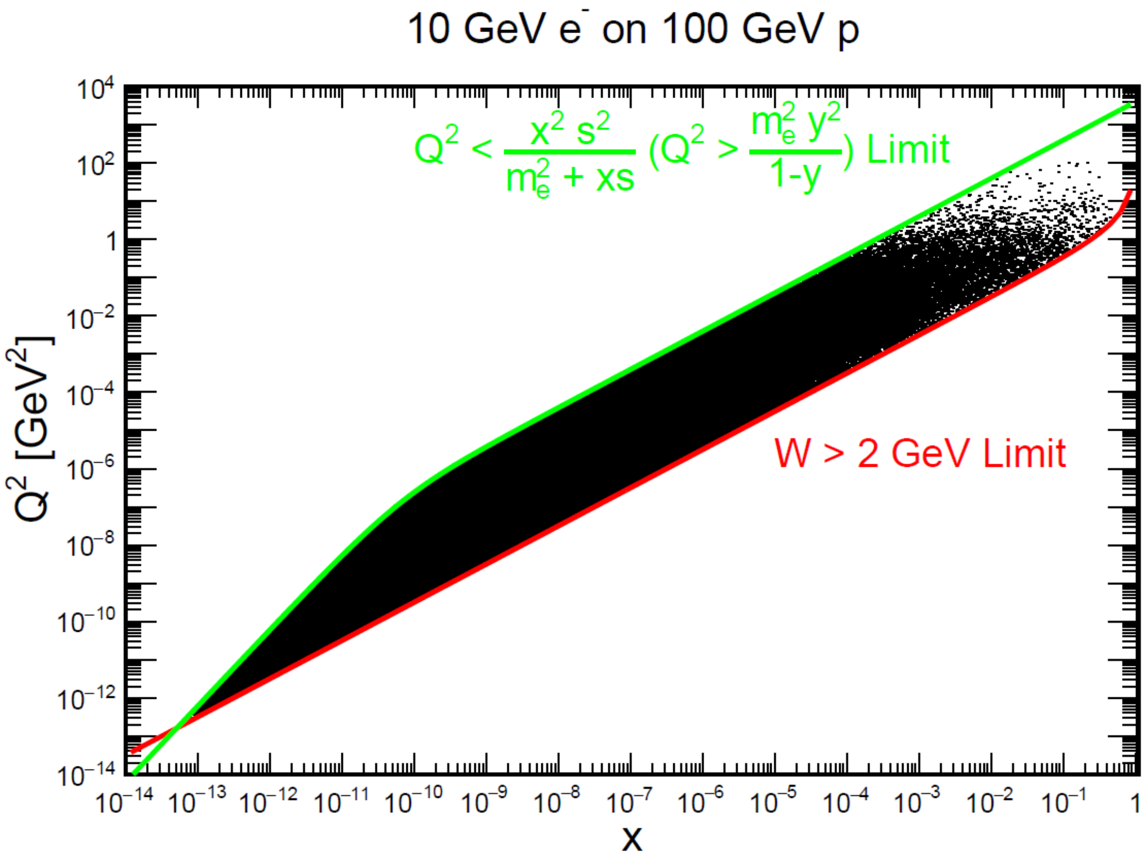

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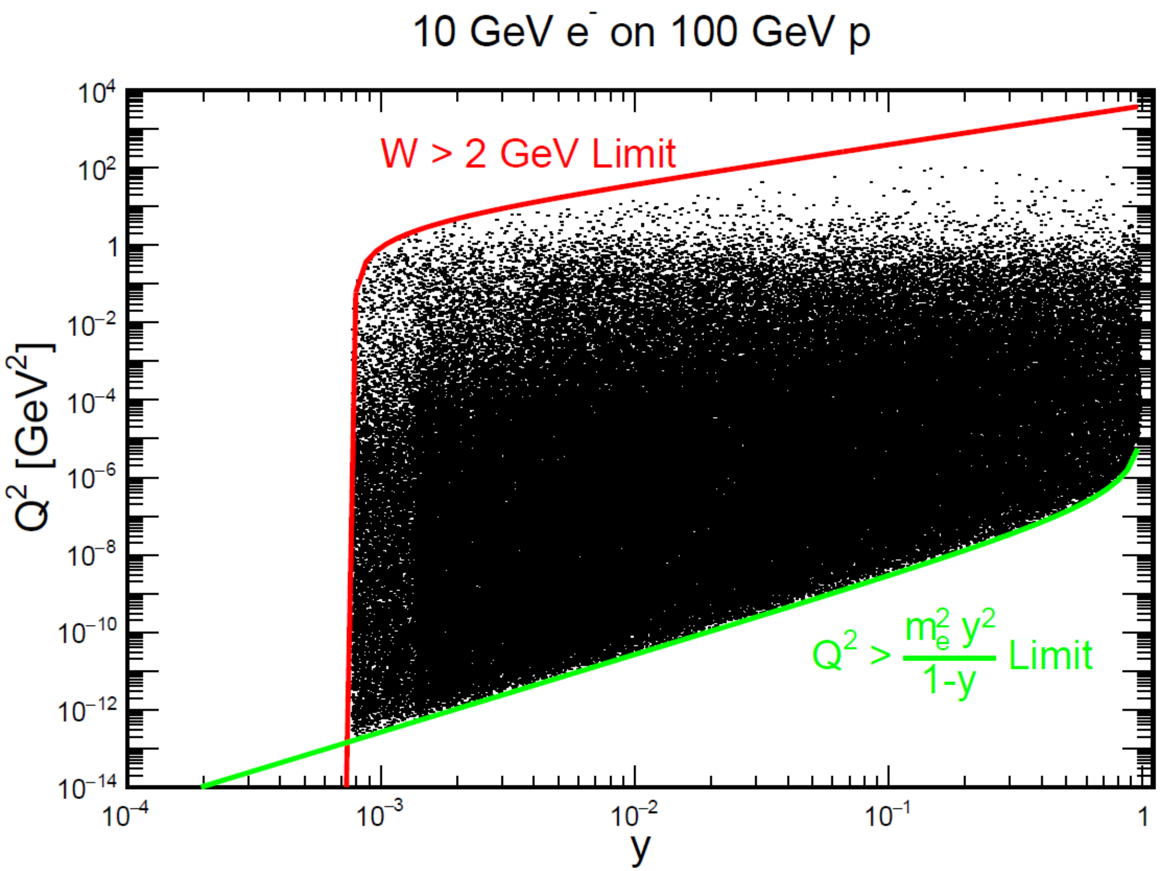
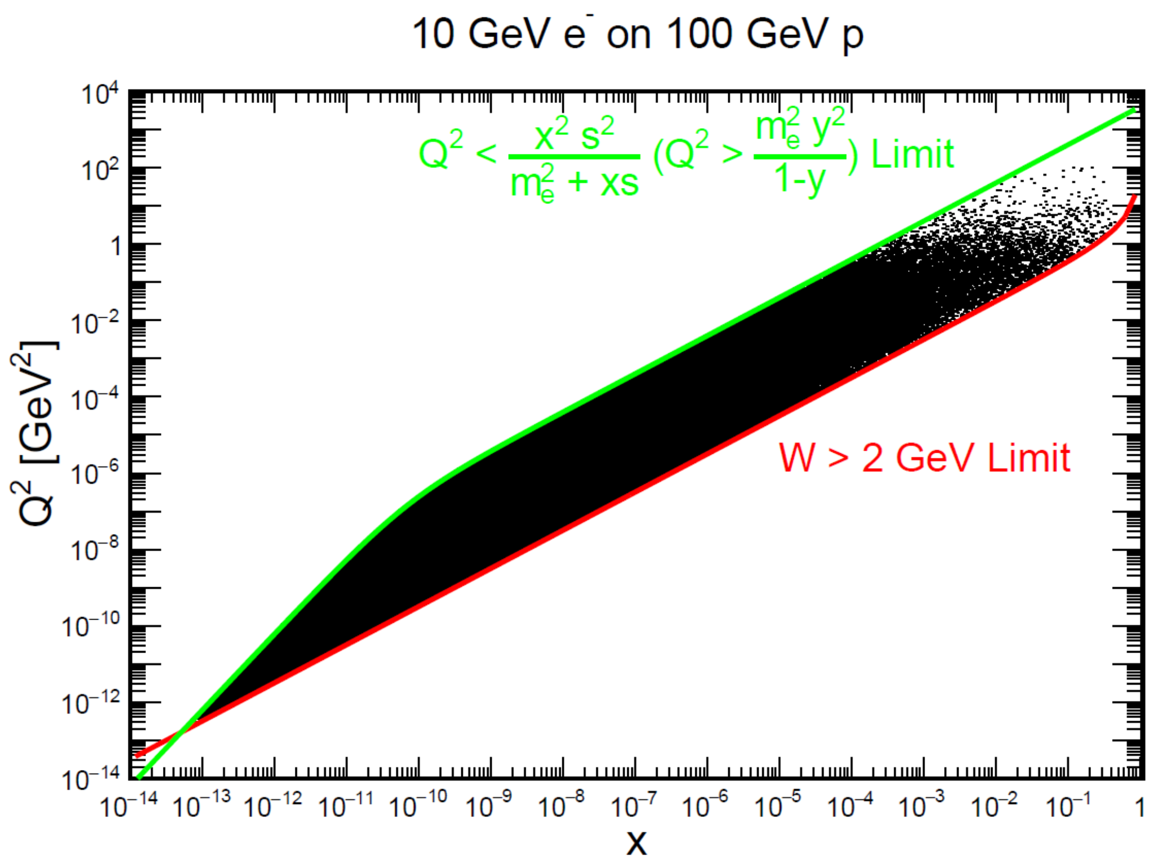
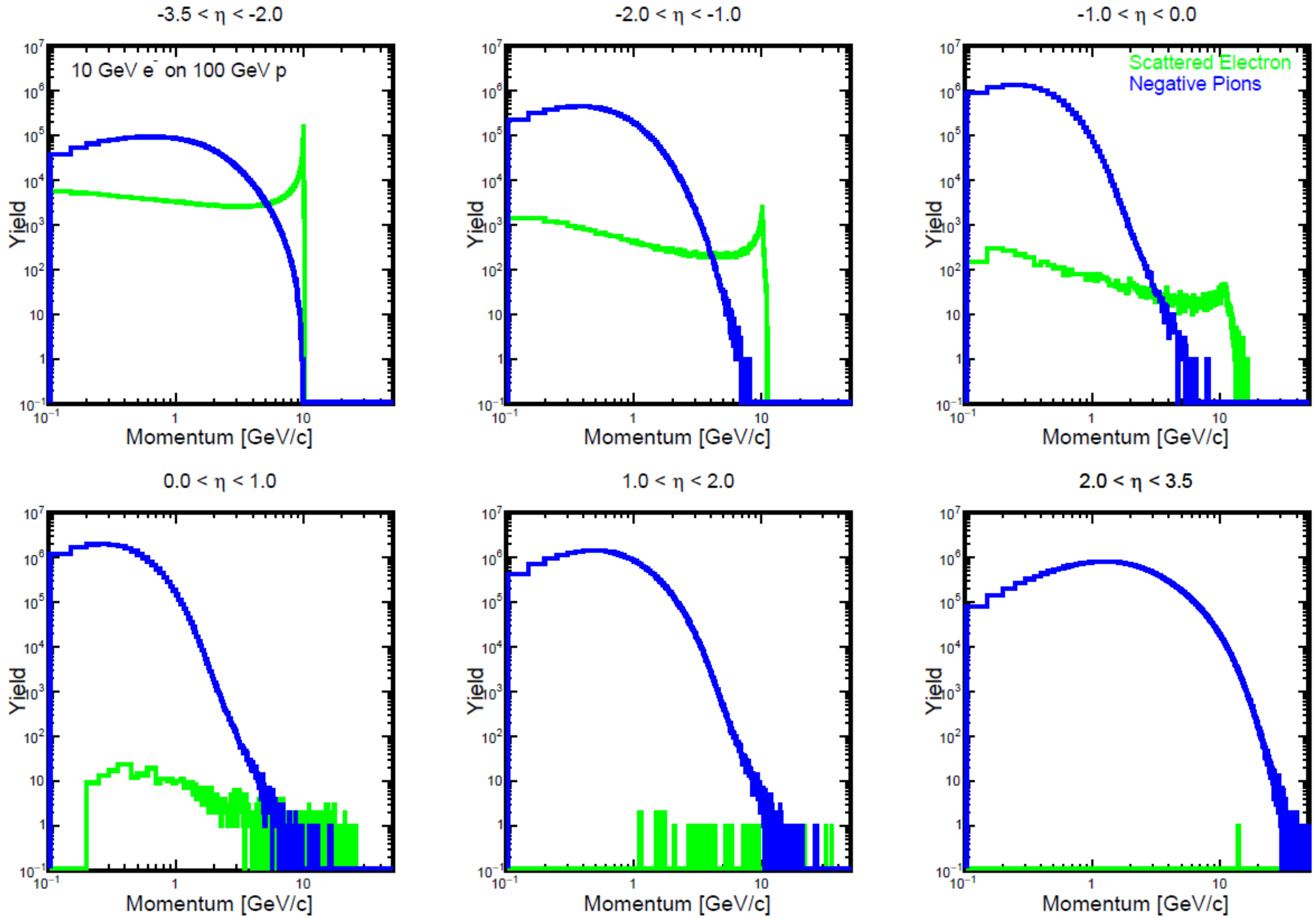


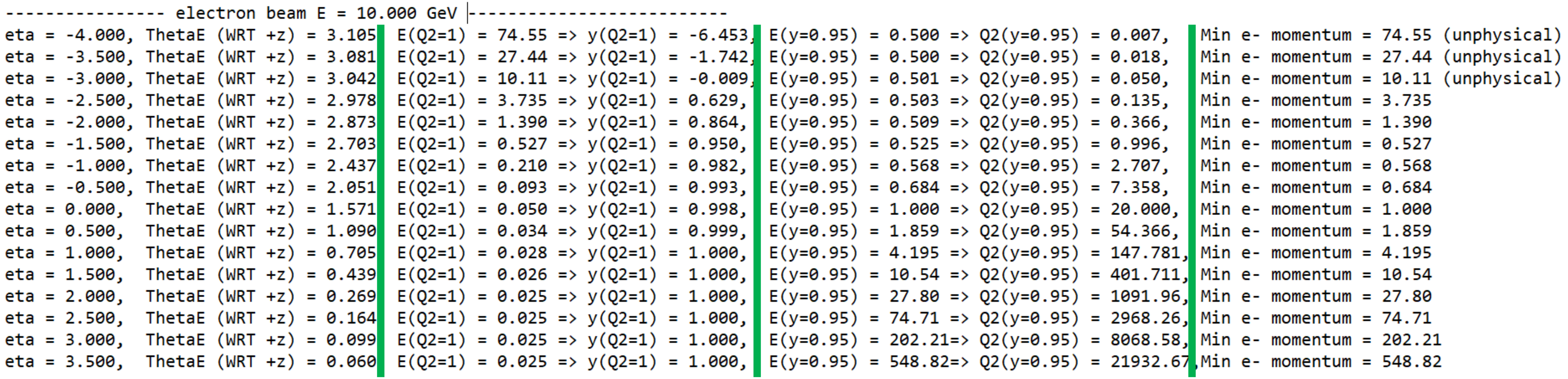


**I estimate that events with W< 2 GeV are ~5% of the total cross section. So, ignoring those events is a small effect.**

# Then look at the scattered electron (the signal) and negative pions (the background) momentum distributions in different angular bins in the central detector region



Also, at a given angle, we will only consider momentum values that satisfy both some minimum $Q^2$ requirement (>1 GeV$^2$) and maximum y requirement (< 0.95). This manifests in a minimum momentum value for each angular bin.



```
---------------- electron beam E = 10.000 GeV -------------------------
eta = -4.000, ThetaE (WRT +z) = 3.105  E(Q2=1) = 74.55 => y(Q2=1) = -6.453,  E(y=0.95) = 0.500 => Q2(y=0.95) = 0.007,    Min e- momentum = 74.55 (unphysical)
eta = -3.500, ThetaE (WRT +z) = 3.081  E(Q2=1) = 27.44 => y(Q2=1) = -1.742,  E(y=0.95) = 0.500 => Q2(y=0.95) = 0.018,    Min e- momentum = 27.44 (unphysical)
eta = -3.000, ThetaE (WRT +z) = 3.042  E(Q2=1) = 10.11 => y(Q2=1) = -0.009,  E(y=0.95) = 0.501 => Q2(y=0.95) = 0.050,    Min e- momentum = 10.11 (unphysical)
eta = -2.500, ThetaE (WRT +z) = 2.978  E(Q2=1) = 3.735 => y(Q2=1) = 0.629,   E(y=0.95) = 0.503 => Q2(y=0.95) = 0.135,    Min e- momentum = 3.735
eta = -2.000, ThetaE (WRT +z) = 2.873  E(Q2=1) = 1.390 => y(Q2=1) = 0.864,   E(y=0.95) = 0.509 => Q2(y=0.95) = 0.366,    Min e- momentum = 1.390
eta = -1.500, ThetaE (WRT +z) = 2.703  E(Q2=1) = 0.527 => y(Q2=1) = 0.950,   E(y=0.95) = 0.525 => Q2(y=0.95) = 0.996,    Min e- momentum = 0.527
eta = -1.000, ThetaE (WRT +z) = 2.437  E(Q2=1) = 0.210 => y(Q2=1) = 0.982,   E(y=0.95) = 0.568 => Q2(y=0.95) = 2.707,    Min e- momentum = 0.568
eta = -0.500, ThetaE (WRT +z) = 2.051  E(Q2=1) = 0.093 => y(Q2=1) = 0.993,   E(y=0.95) = 0.684 => Q2(y=0.95) = 7.358,    Min e- momentum = 0.684
eta = 0.000,  ThetaE (WRT +z) = 1.571  E(Q2=1) = 0.050 => y(Q2=1) = 0.998,   E(y=0.95) = 1.000 => Q2(y=0.95) = 20.000,   Min e- momentum = 1.000
eta = 0.500,  ThetaE (WRT +z) = 1.090  E(Q2=1) = 0.034 => y(Q2=1) = 0.999,   E(y=0.95) = 1.859 => Q2(y=0.95) = 54.366,   Min e- momentum = 1.859
eta = 1.000,  ThetaE (WRT +z) = 0.705  E(Q2=1) = 0.028 => y(Q2=1) = 1.000,   E(y=0.95) = 4.195 => Q2(y=0.95) = 147.781,  Min e- momentum = 4.195
eta = 1.500,  ThetaE (WRT +z) = 0.439  E(Q2=1) = 0.026 => y(Q2=1) = 1.000,   E(y=0.95) = 10.54 => Q2(y=0.95) = 401.711,  Min e- momentum = 10.54
eta = 2.000,  ThetaE (WRT +z) = 0.269  E(Q2=1) = 0.025 => y(Q2=1) = 1.000,   E(y=0.95) = 27.80 => Q2(y=0.95) = 1091.96,  Min e- momentum = 27.80
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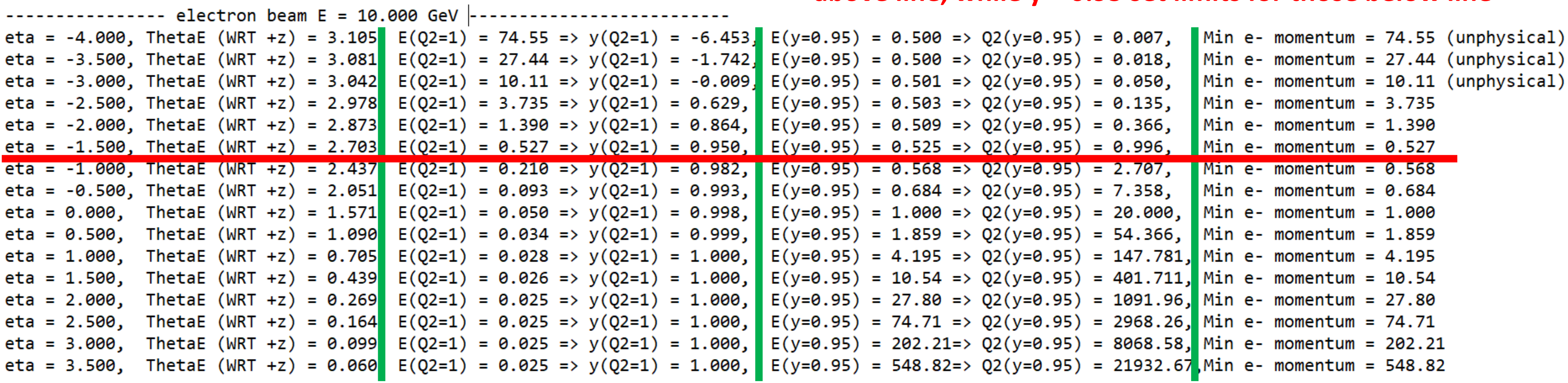
eta = 3.000,  ThetaE (WRT +z) = 0.099  E(Q2=1) = 0.025 => y(Q2=1) = 1.000,   E(y=0.95) = 202.21=> Q2(y=0.95) = 8068.58,  Min e- momentum = 202.21
eta = 3.500,  ThetaE (WRT +z) = 0.060  E(Q2=1) = 0.025 => y(Q2=1) = 1.000,   E(y=0.95) = 548.82=> Q2(y=0.95) = 21932.67,Min e- momentum = 548.82
```

$$y = 1 - \frac{E_{e'}\,(1-\cos\theta)}{2E_e}$$

$$Q^2 = 4E_e\,E_{e'}\,cos^2\frac{\theta}{2}$$

Also, at a given angle, we will only consider momentum values that satisfy both some minimum $Q^2$ requirement (>1 $\mathrm{GeV}^2$) and maximum y requirement (< 0.95). This manifests in a minimum momentum value for each angular bin.

**$Q^2 > 1\ \mathrm{GeV}^2$ cut sets minimum momentum for scattering angles above line, while $y < 0.95$ set limits for those below line**



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```

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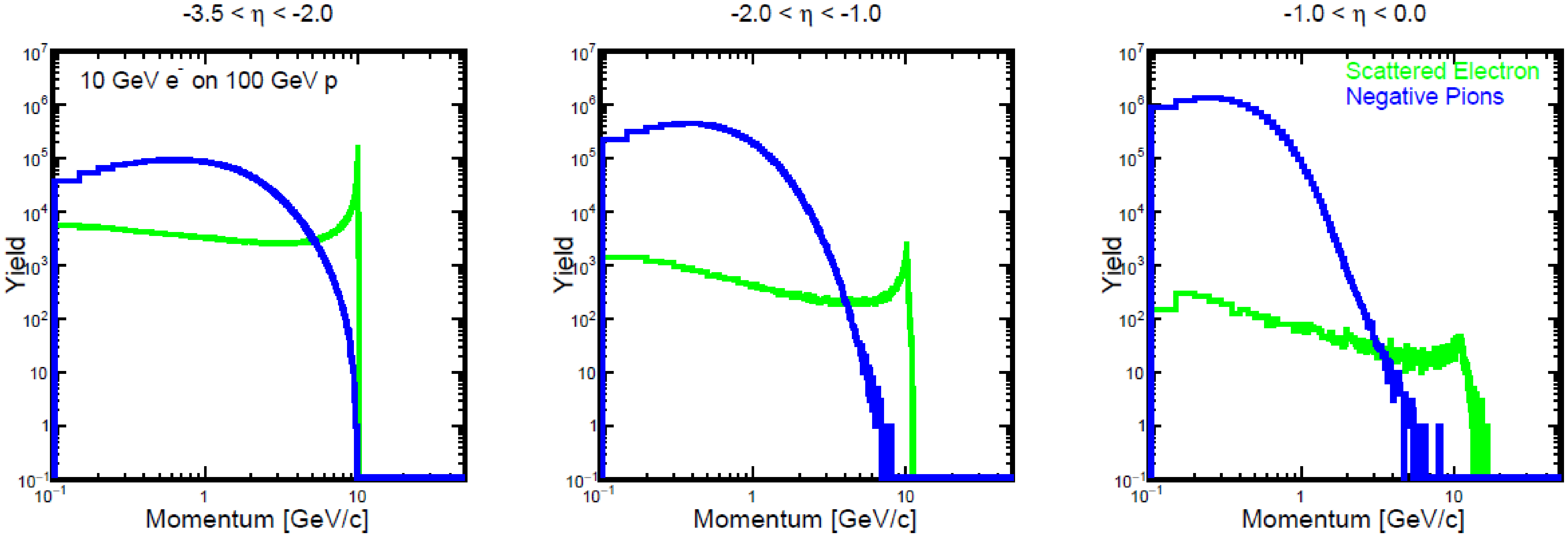
$$Q^2 = 4E_e\,E_{e'}\,cos^2\frac{\theta}{2}$$

# Focus on negative pseudo-rapidity region



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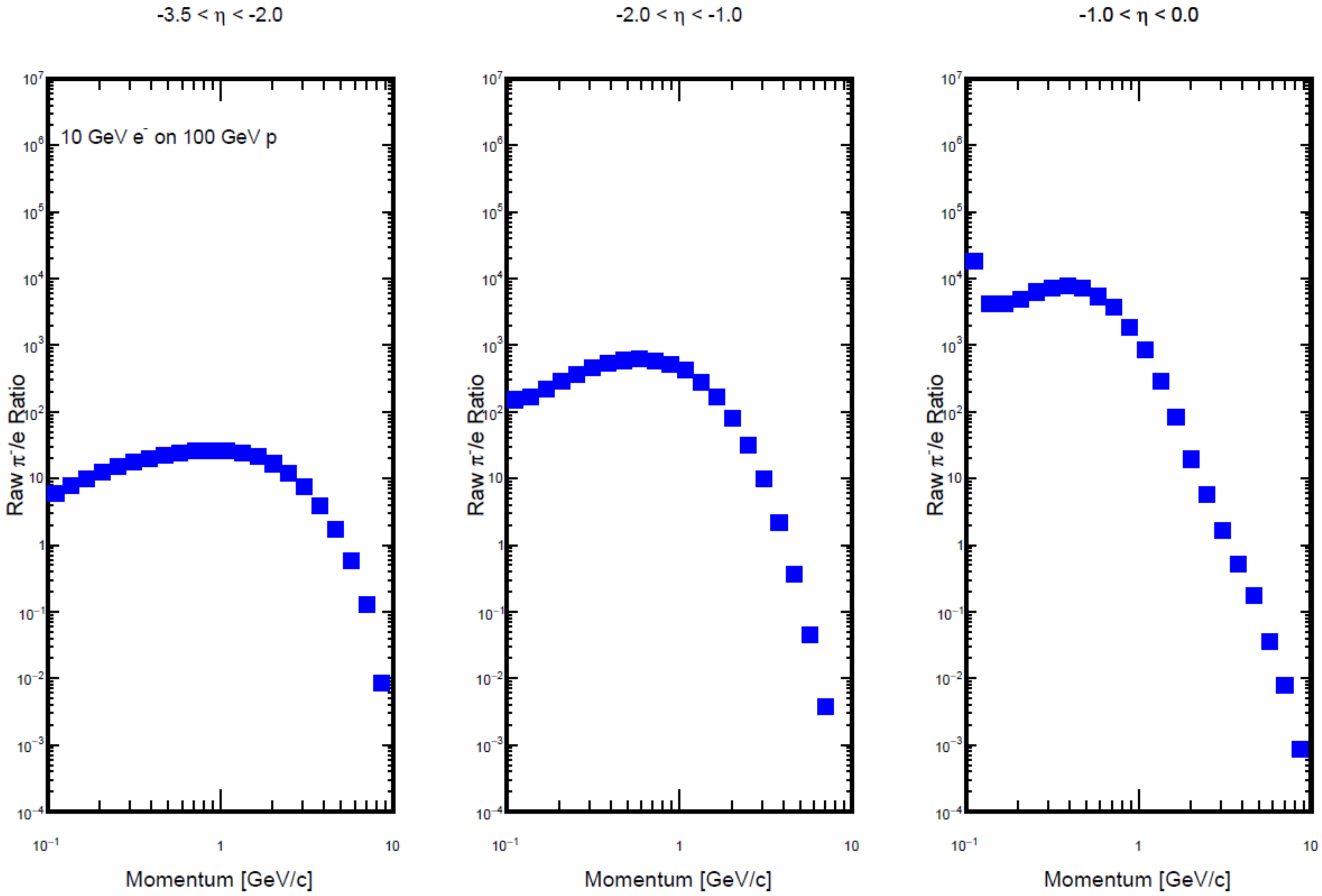
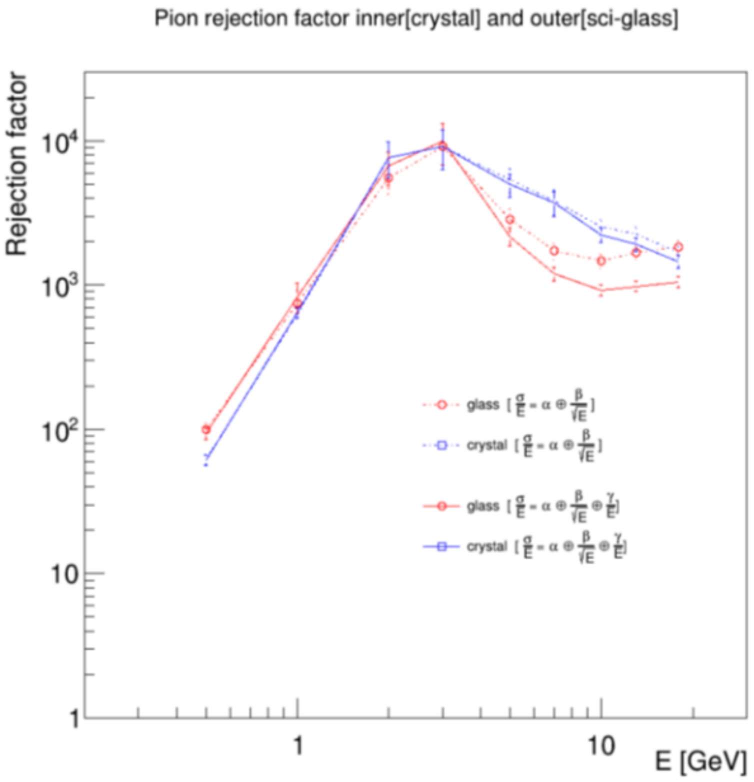
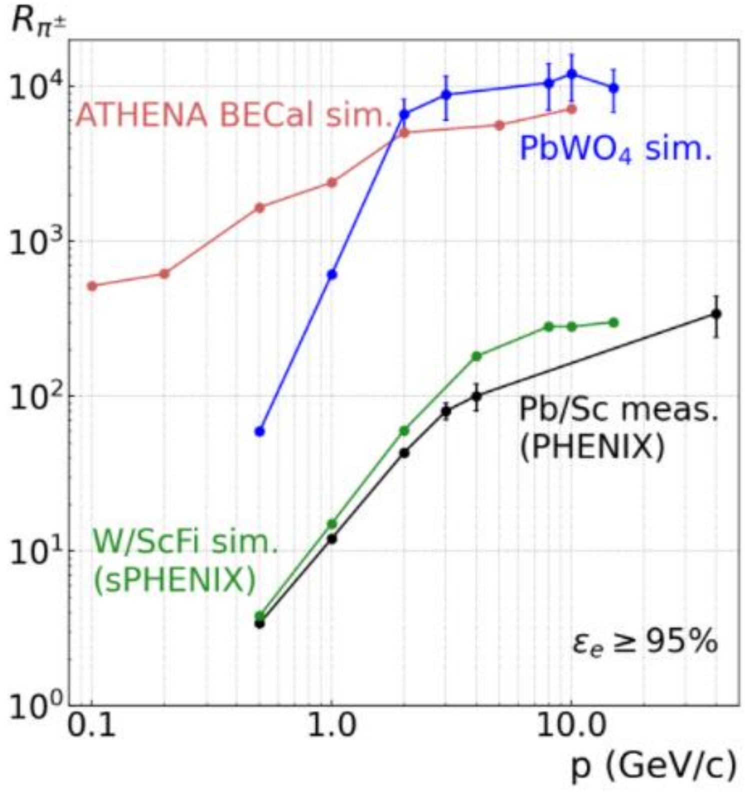
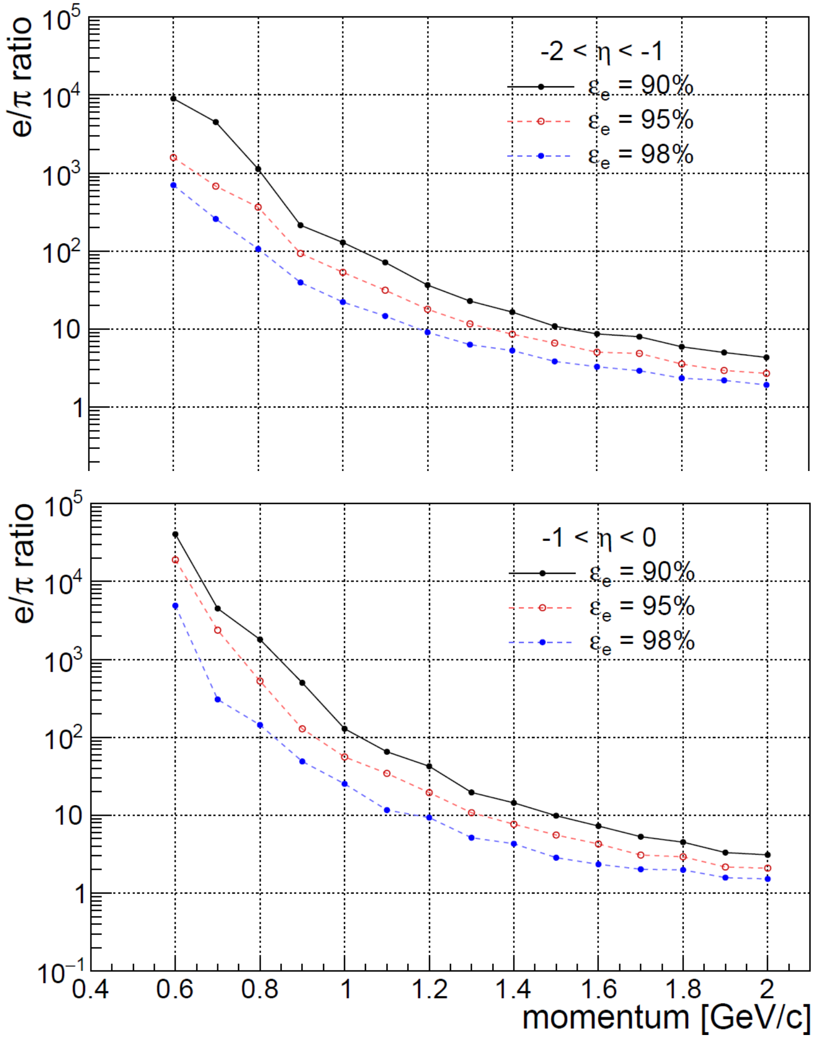


# ECal and DIRC expected performance





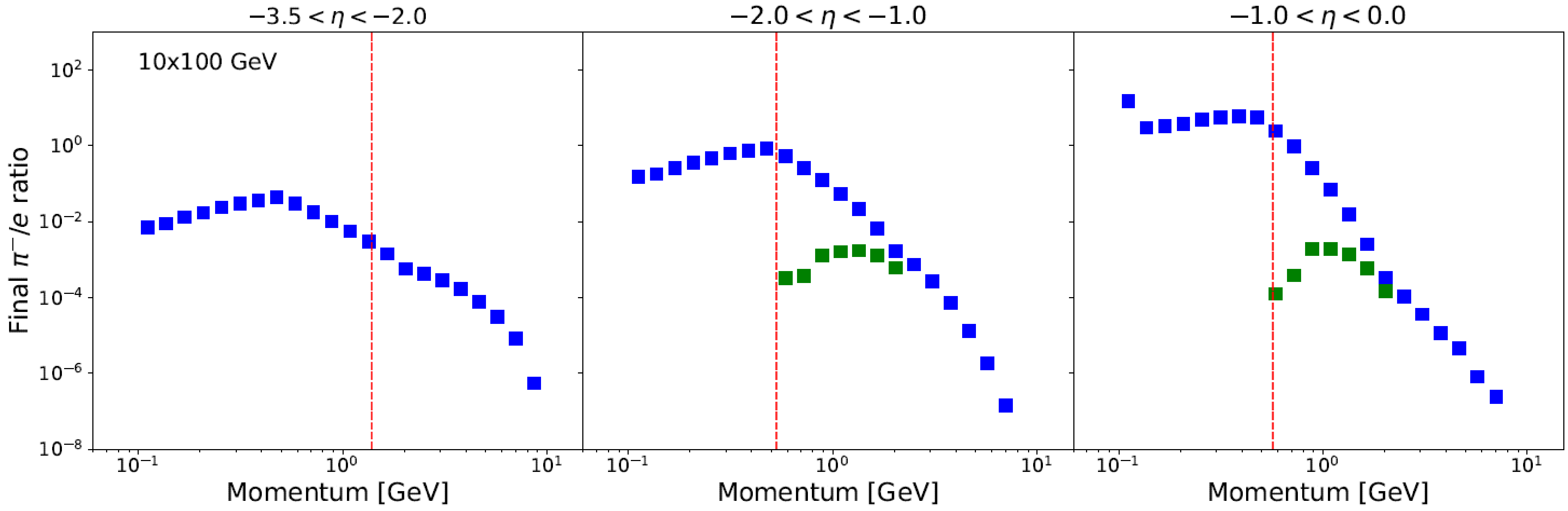


# Final pion-to-electron ratio with detector cuts

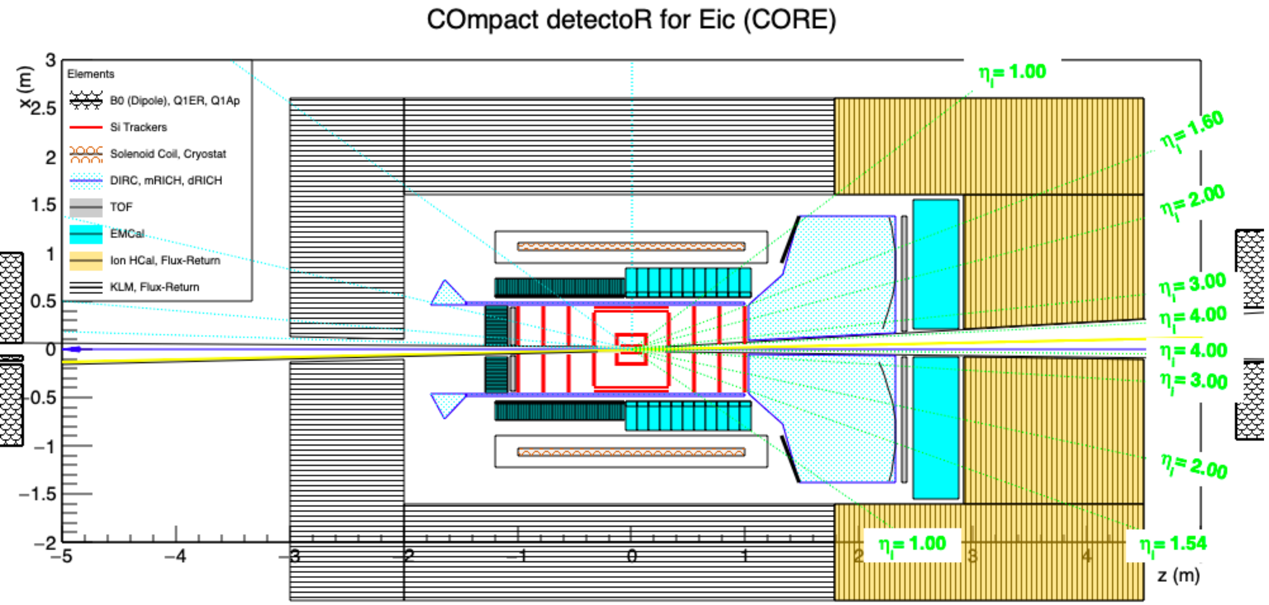
**ECal only**

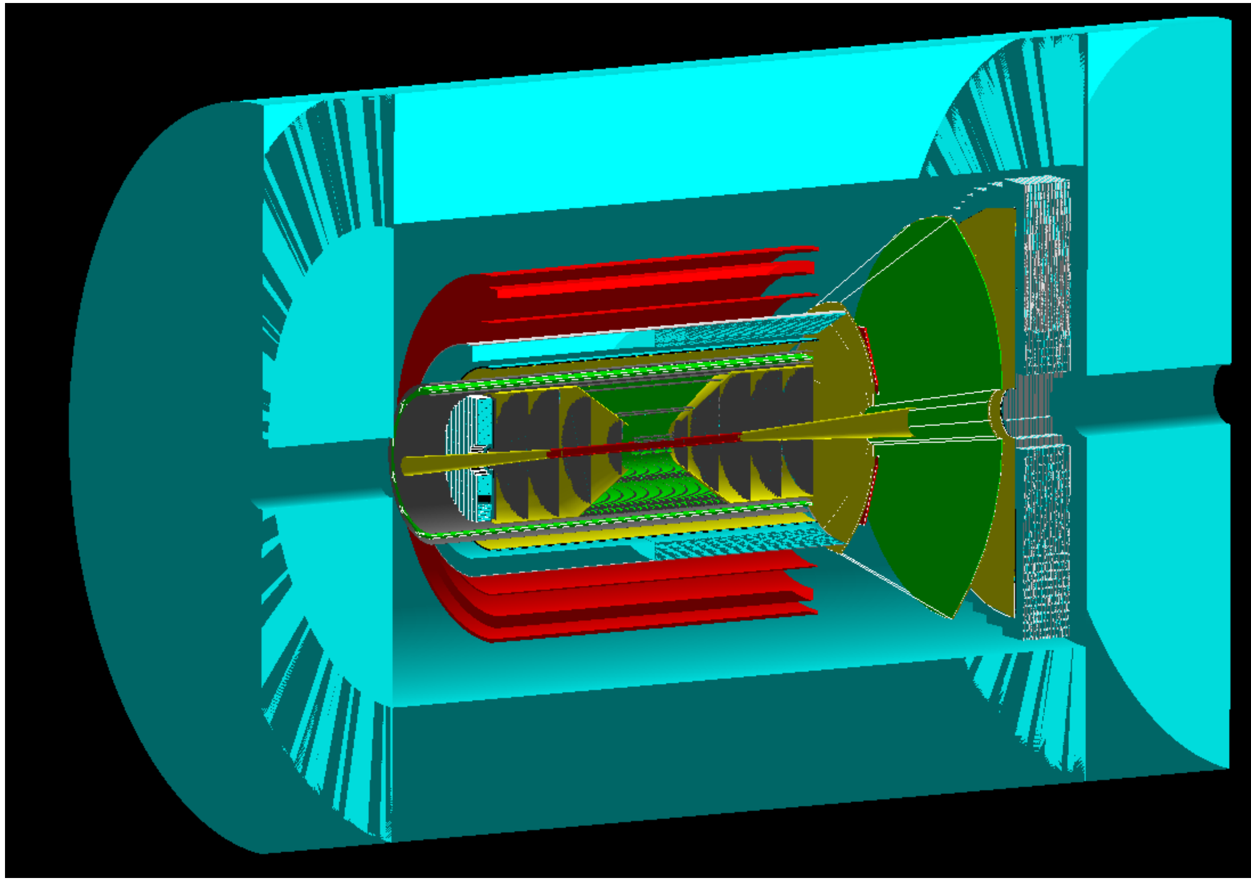
**ECal+DIRC**

**Additional cuts – such as on total E-$p_z$ – can be made to suppress photoproduction background.**



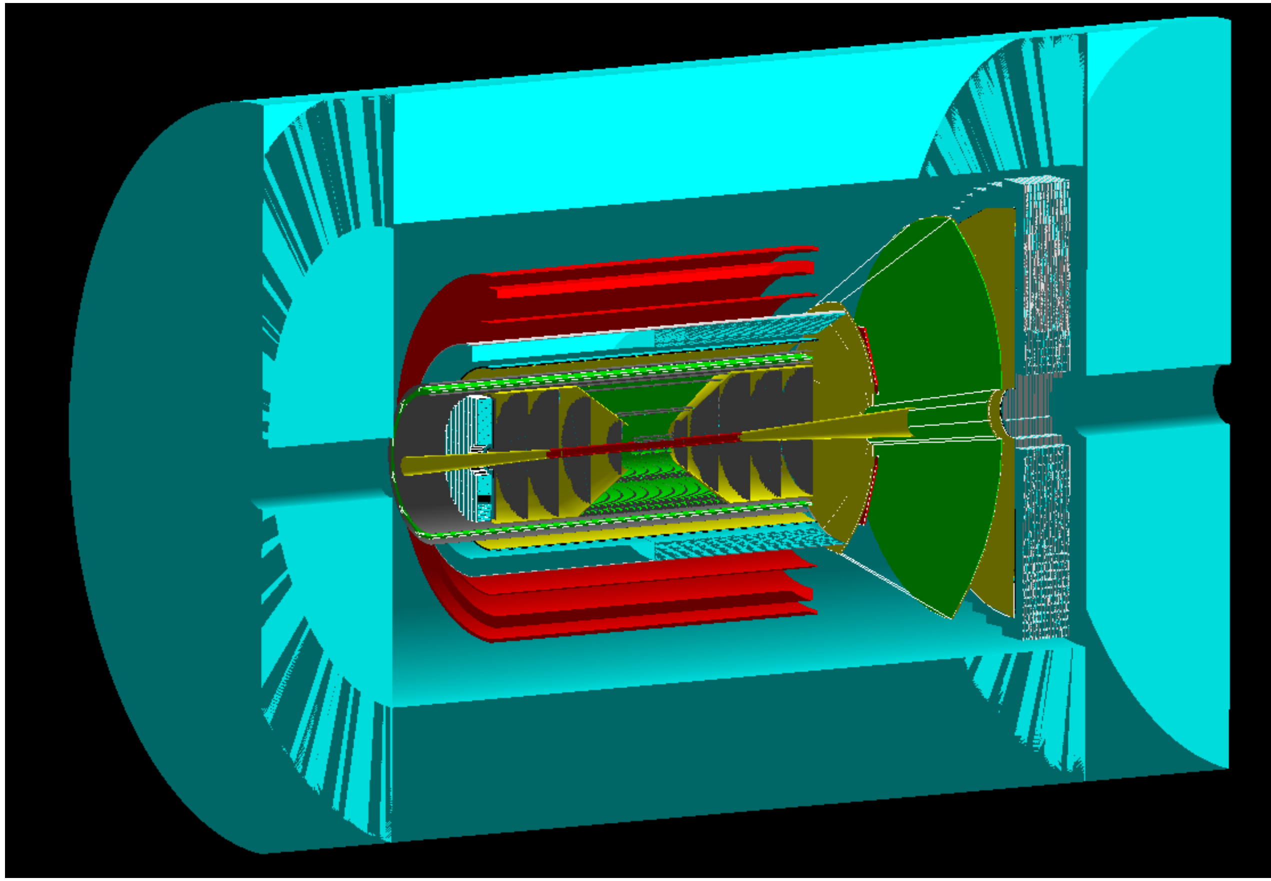
# Towards full detector simulation – CORE implementation in *Fun4All*



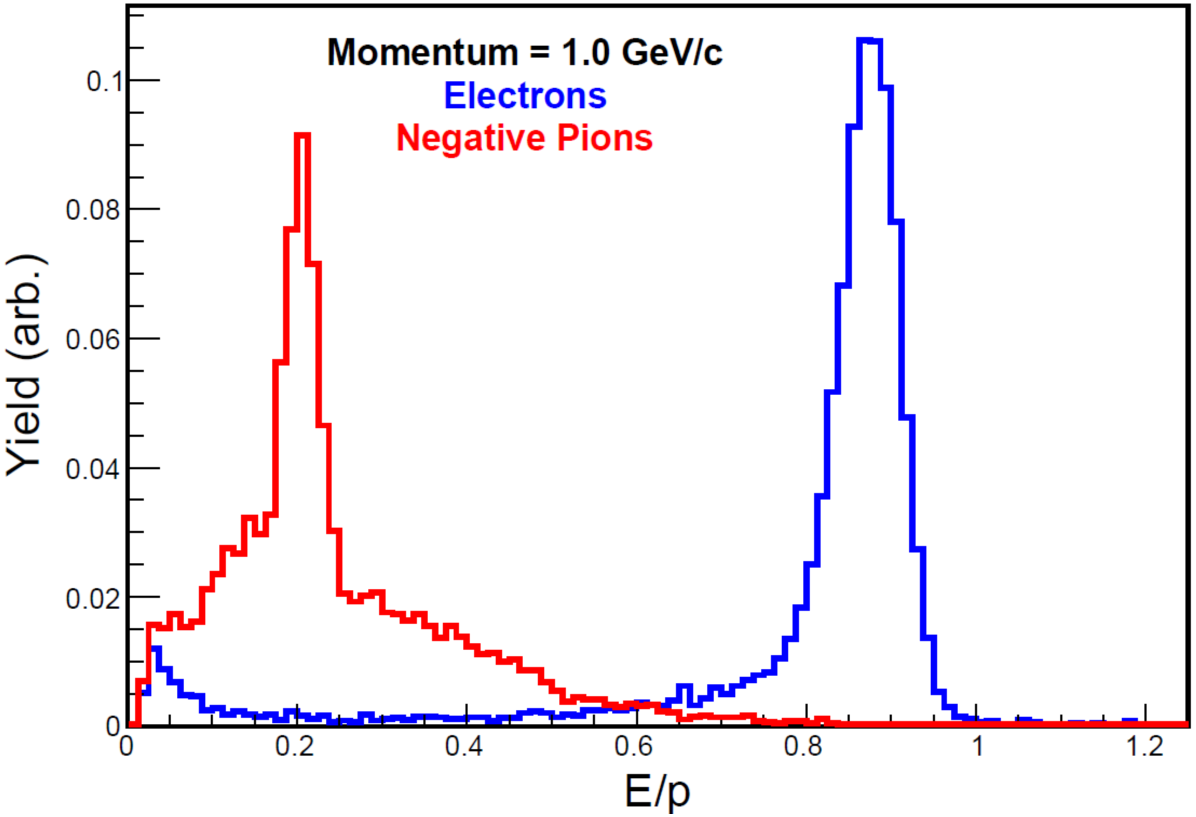


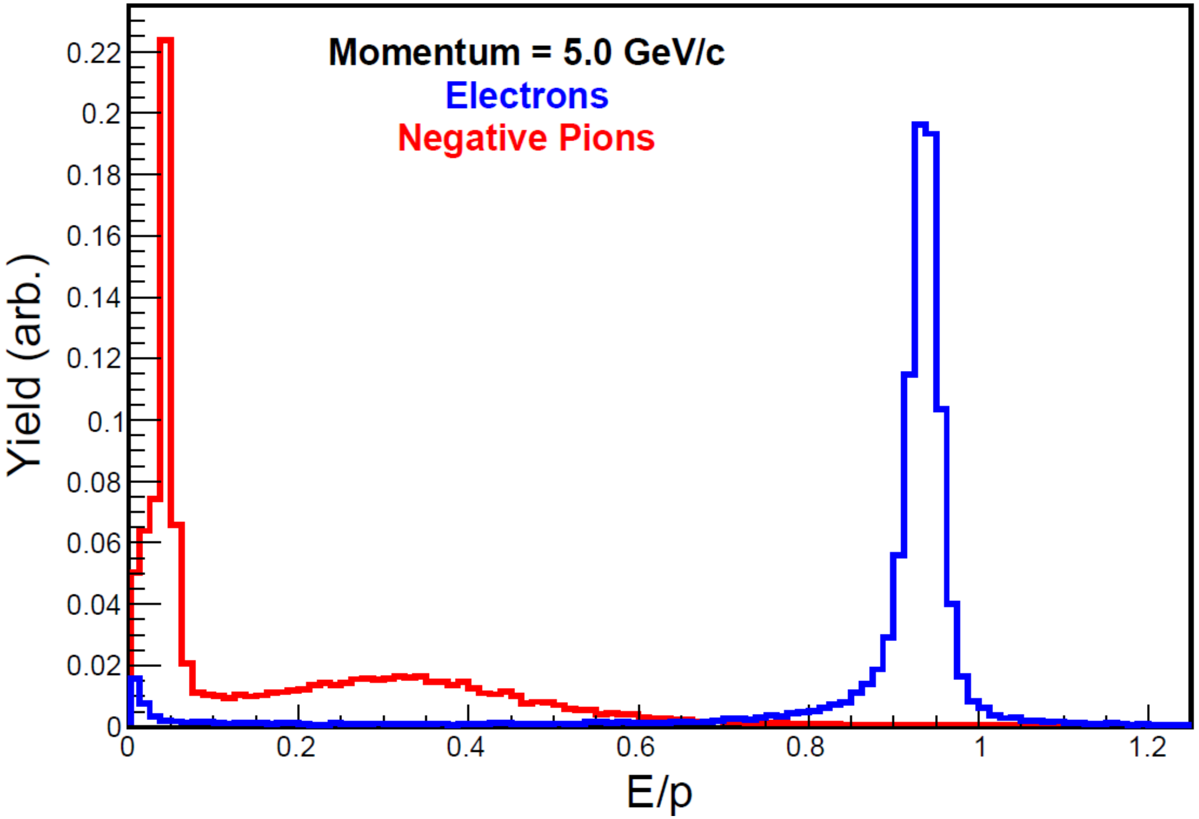
# Towards full detector simulation – CORE implementation in *Fun4All*

- Code is available on Github in this repository.
- The README explains how to download and run the simulation.
- Simulation and analysis examples for both tracking and electromagnetic calorimeter (including the results shown on the following slides) can be found in the same repository.

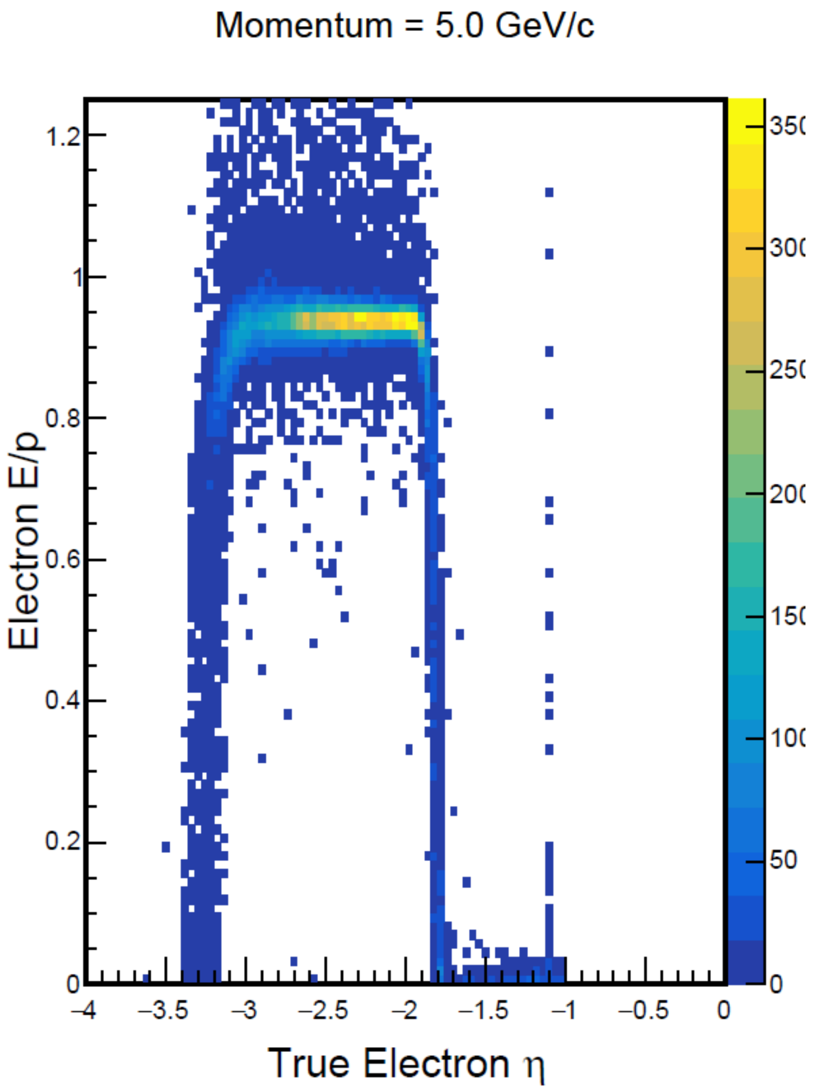


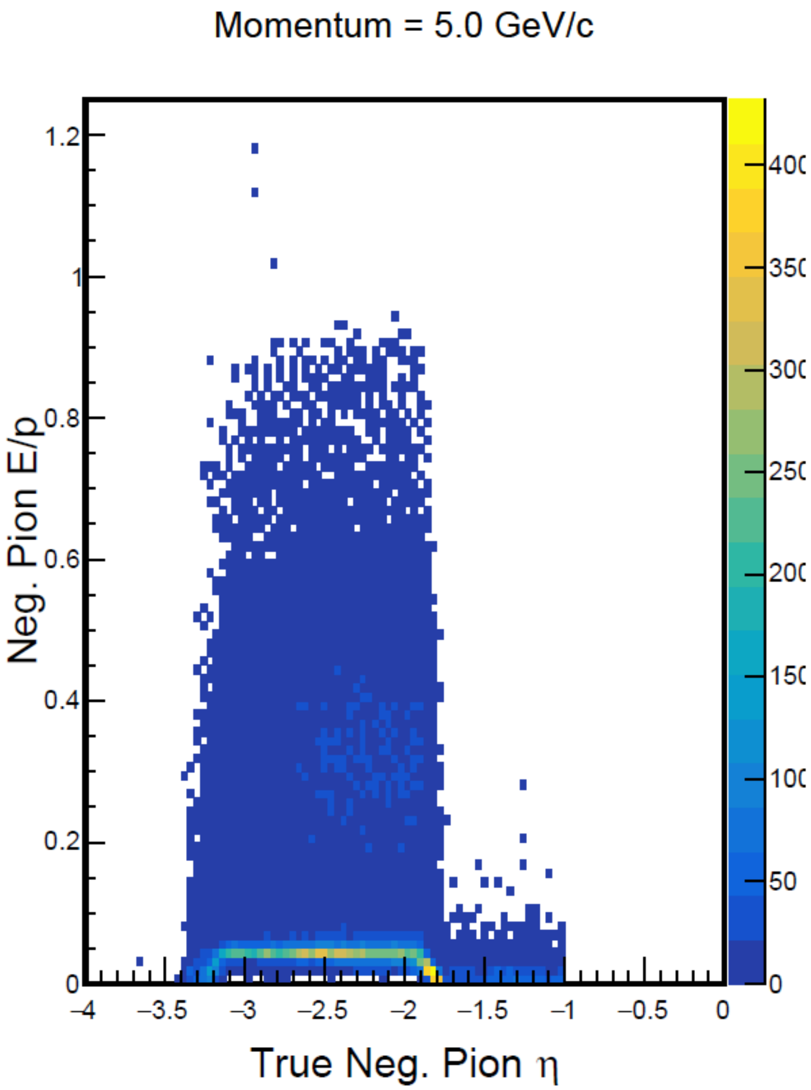
# Single particle simulation with backward ECal (EEMC)



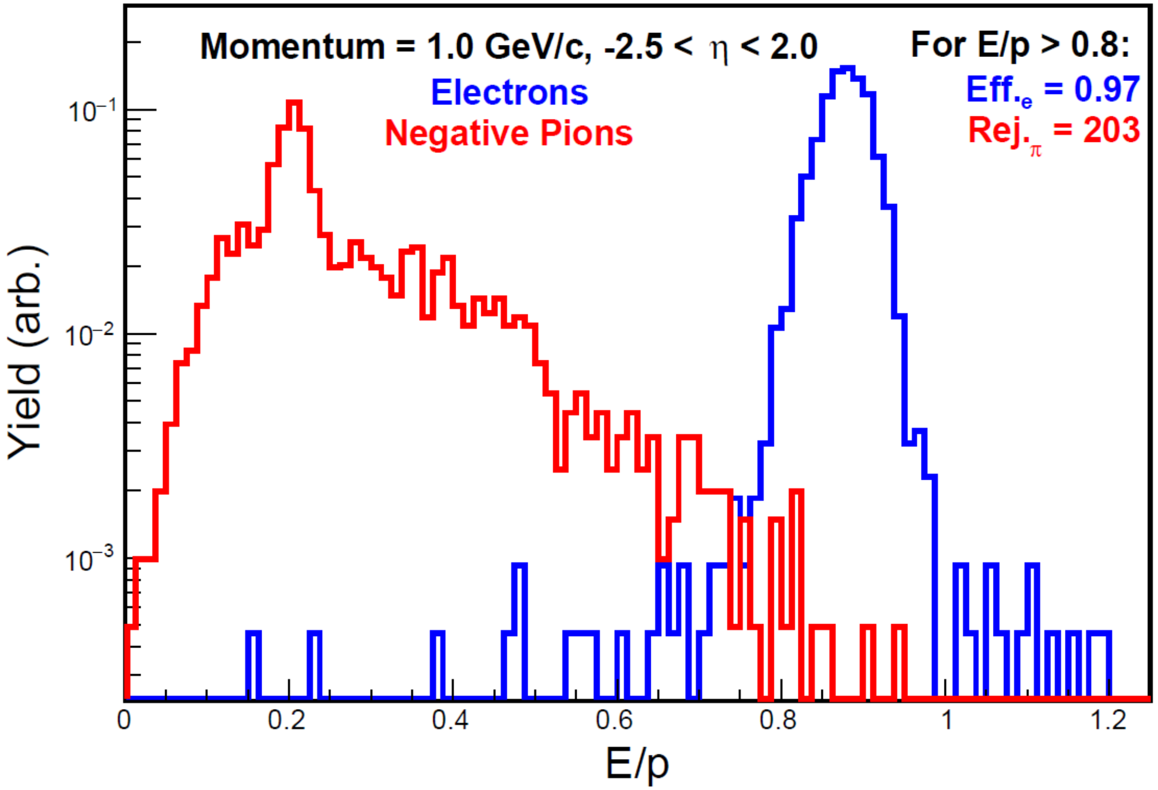


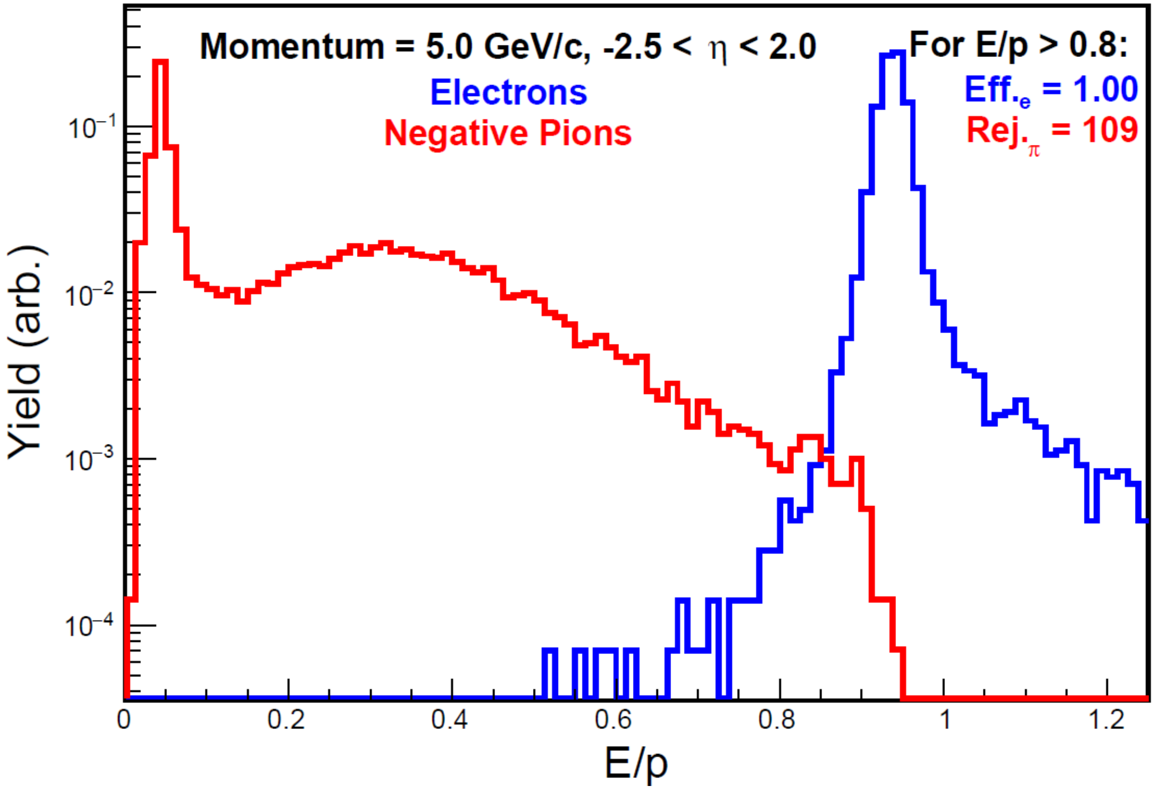
# Tails in electron distribution come from detector edges


Momentum = 5.0 GeV/c


Momentum = 5.0 GeV/c

# Calculate cut efficiency for stable region





# Conclusions

- ➢Parity-violating physics at the EIC require accurate measurements of small asymmetries. These measurements provide a stringent requirement on the scattered electron purity.
- ➢Parameterizations of the detector responses suggests CORE will be able to meet these requirements.
- ➢Full simulations are needed. A working version of the CORE detector has been implemented in the *Fun4All* framework. The implementation has working tracking, time-of-flight and calorimeter detectors. It currently only contains geometry descriptions for some other detector – such as the DIRC. In addition, no support structures have been included.