Low-x Jets and Hadronic Calorimetry

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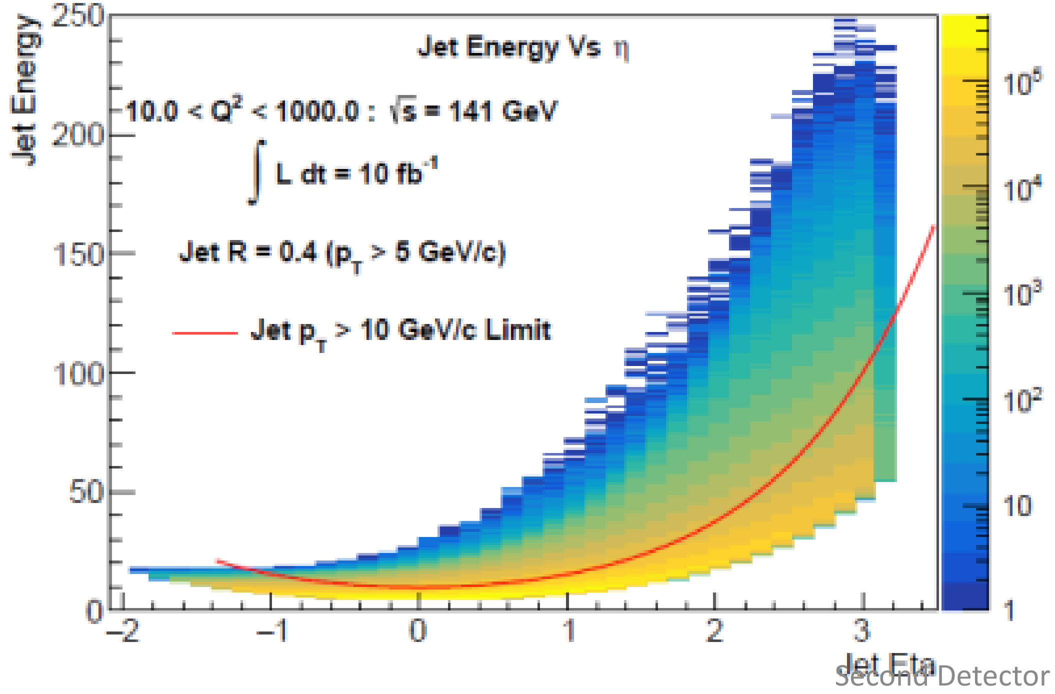
Second Detector Workshop - Warsaw

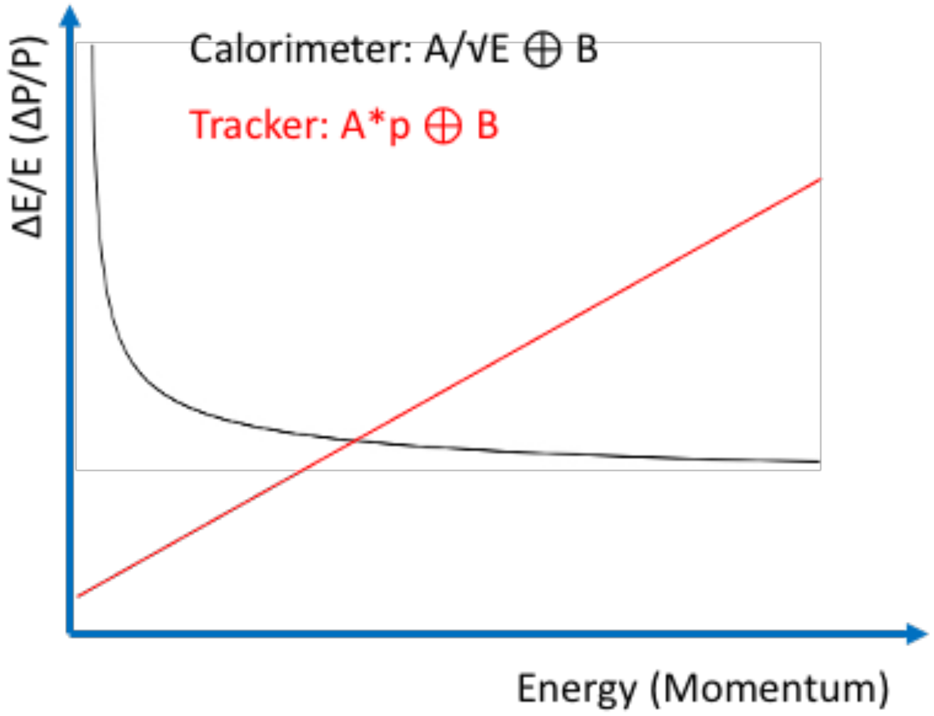
Outline

- ❑Kinematics Overview and Jet Reconstruction
- ❑ePIC Backward HCal
- ❑Performance Considerations

HCal Function at the EIC

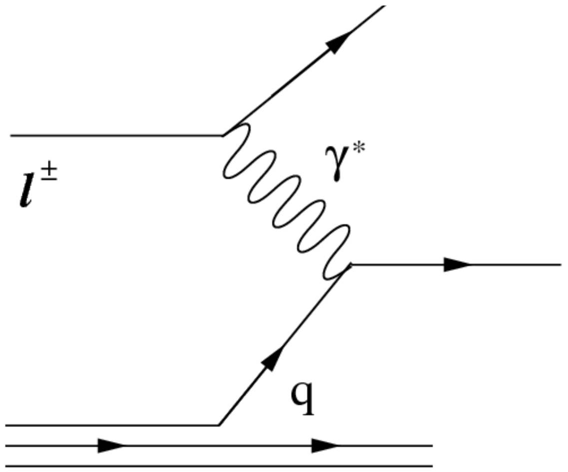
- Particles and jets will have relatively low momenta except in the forward region – track momentum resolution superior to calorimeter resolution for much of the phase space
- Track momentum + PID = Energy determination
- Hadron calorimeters needed for measurements of neutral hadrons (neutrons and K_L)
- Possible muon ID? KLM?

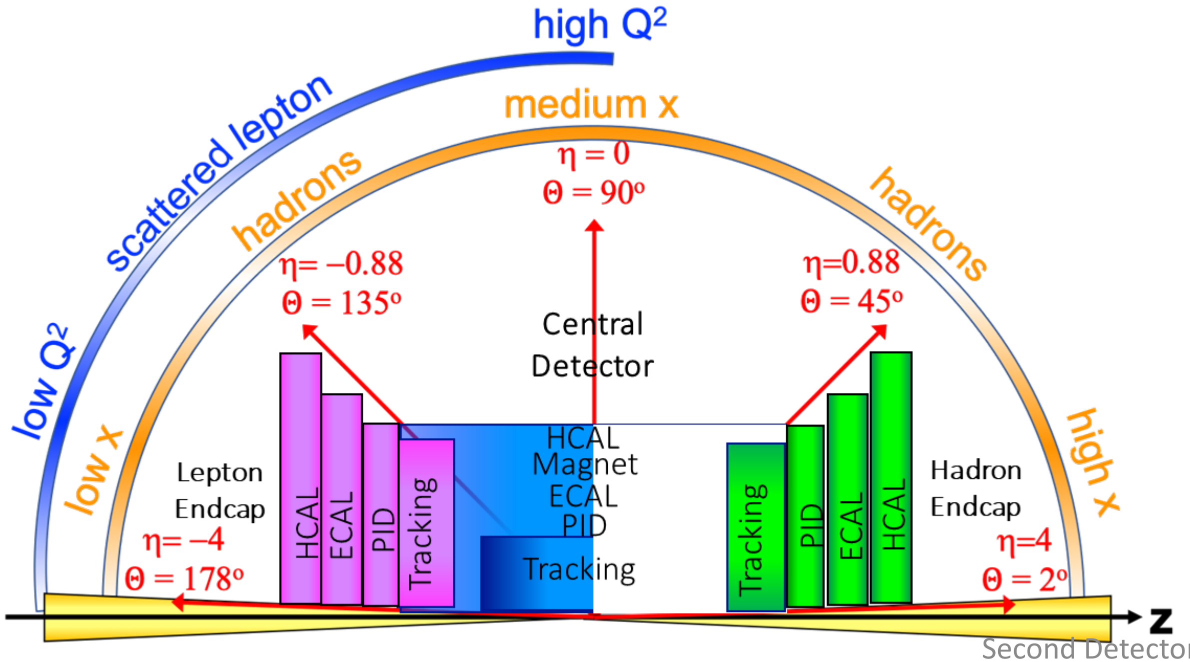


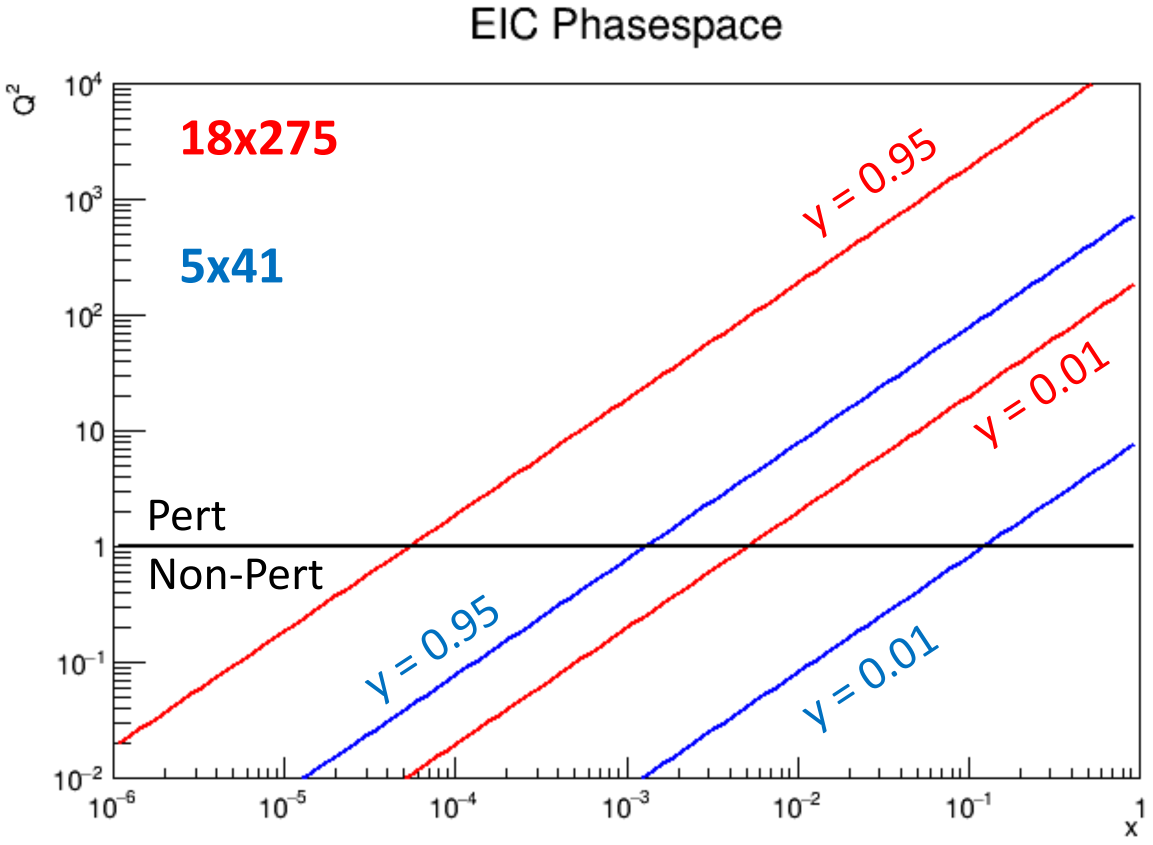


- As particle energy increases, calorimeter resolution improves while tracker resolution degrades
- Tracker resolution and acceptance degrades at forward rapidity/backward
- Smaller particle momentum in backward regions – calorimeter as a neutral veto

DIS Event Kinematics





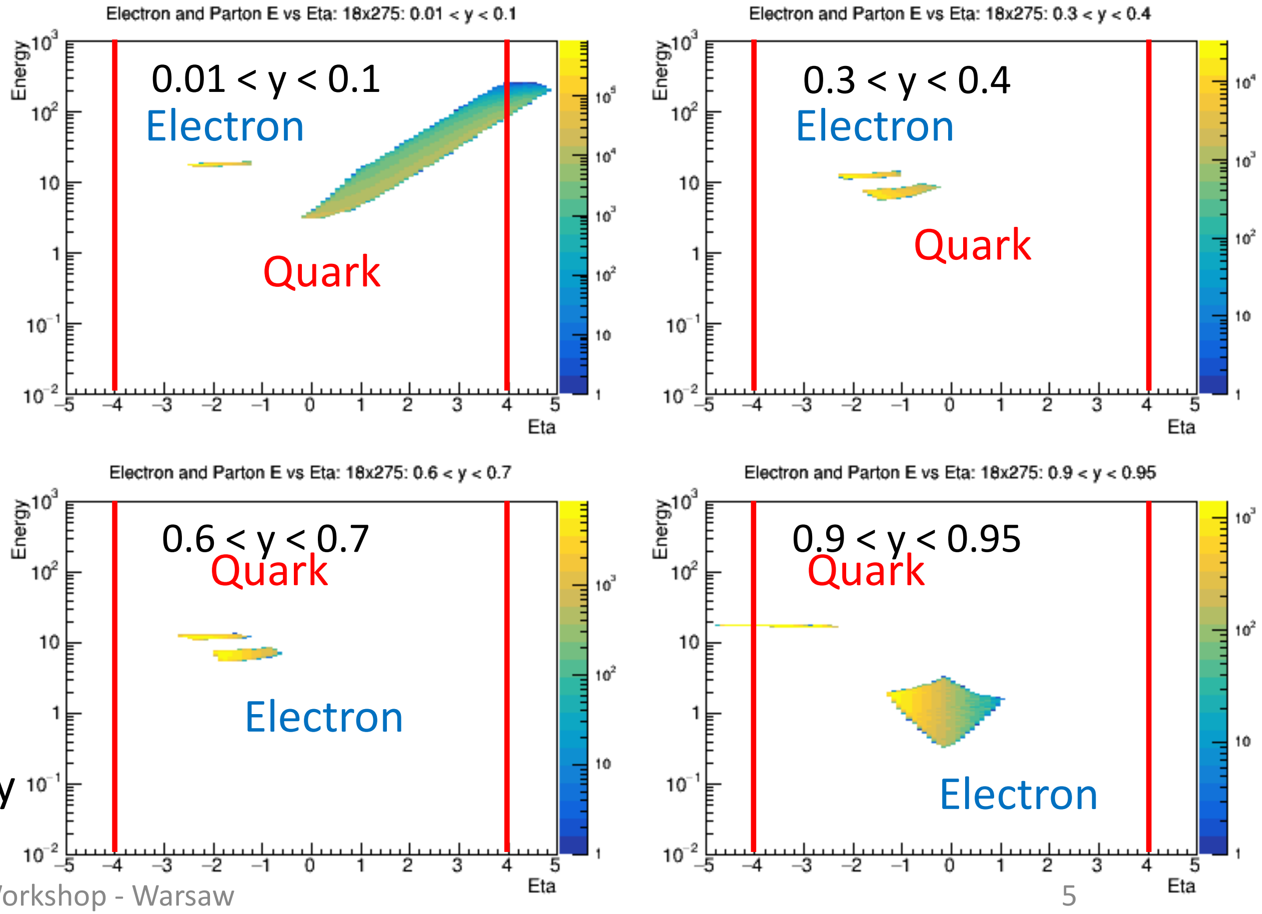


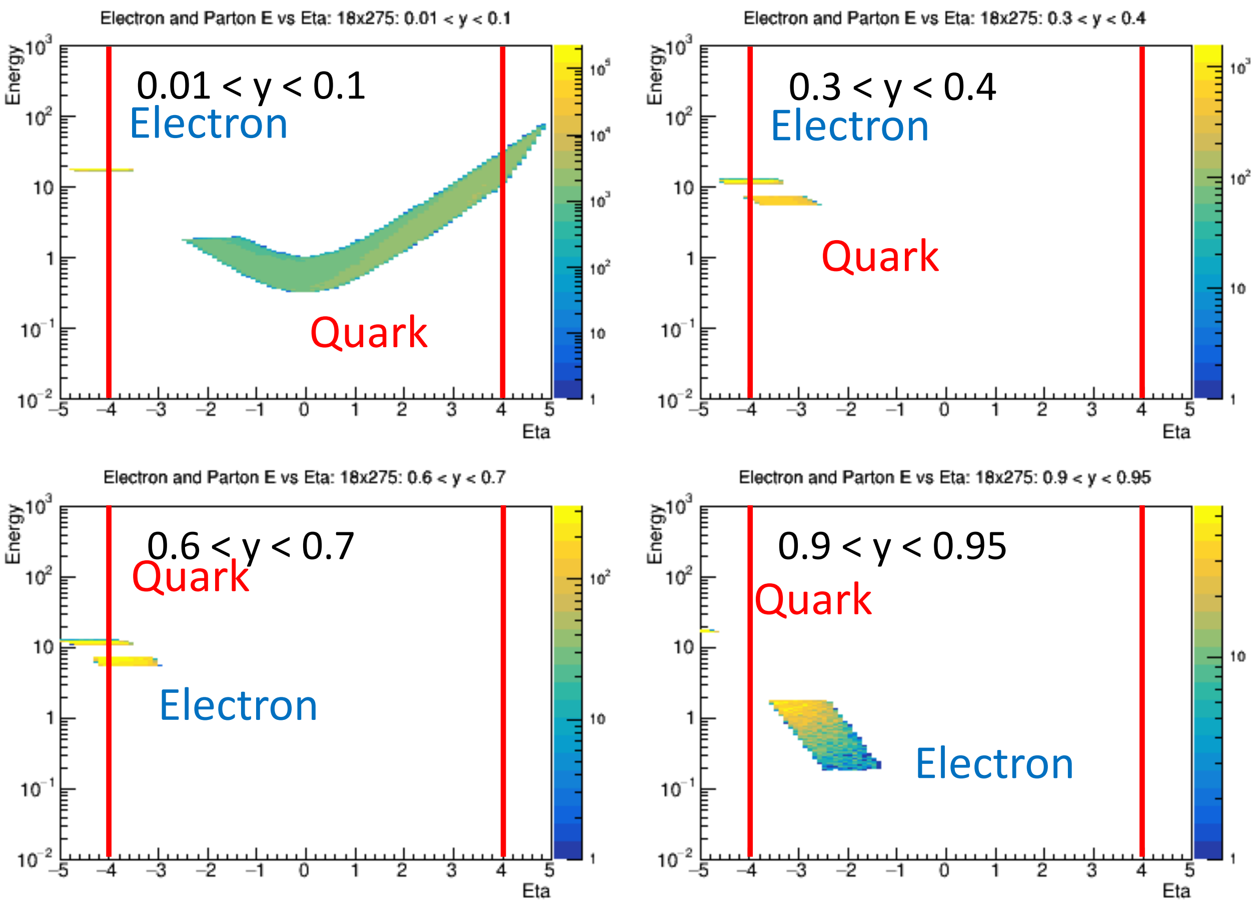
- ❑ For the leading order process, jet location and energy are dictated by the event kinematics (x, Q^2, y)
- ❑ For a given Q^2, inelasticity determines x value probed and pseudorapidity of the jet
  - ➢ Low y -> high x, jet at positive pseudorapidity
  - ➢ High y -> low x, jet at negative pseudorapidity

Electron and Struck Quark (18x275)

- ❑ Look at energy vs pseudorapidity of the scattered electron and struck quark as a function of y and Q^2
- ❑ For fixed Q^2, as y increases, electron eta increases while parton eta decreases

$10 < Q^2 < 100$



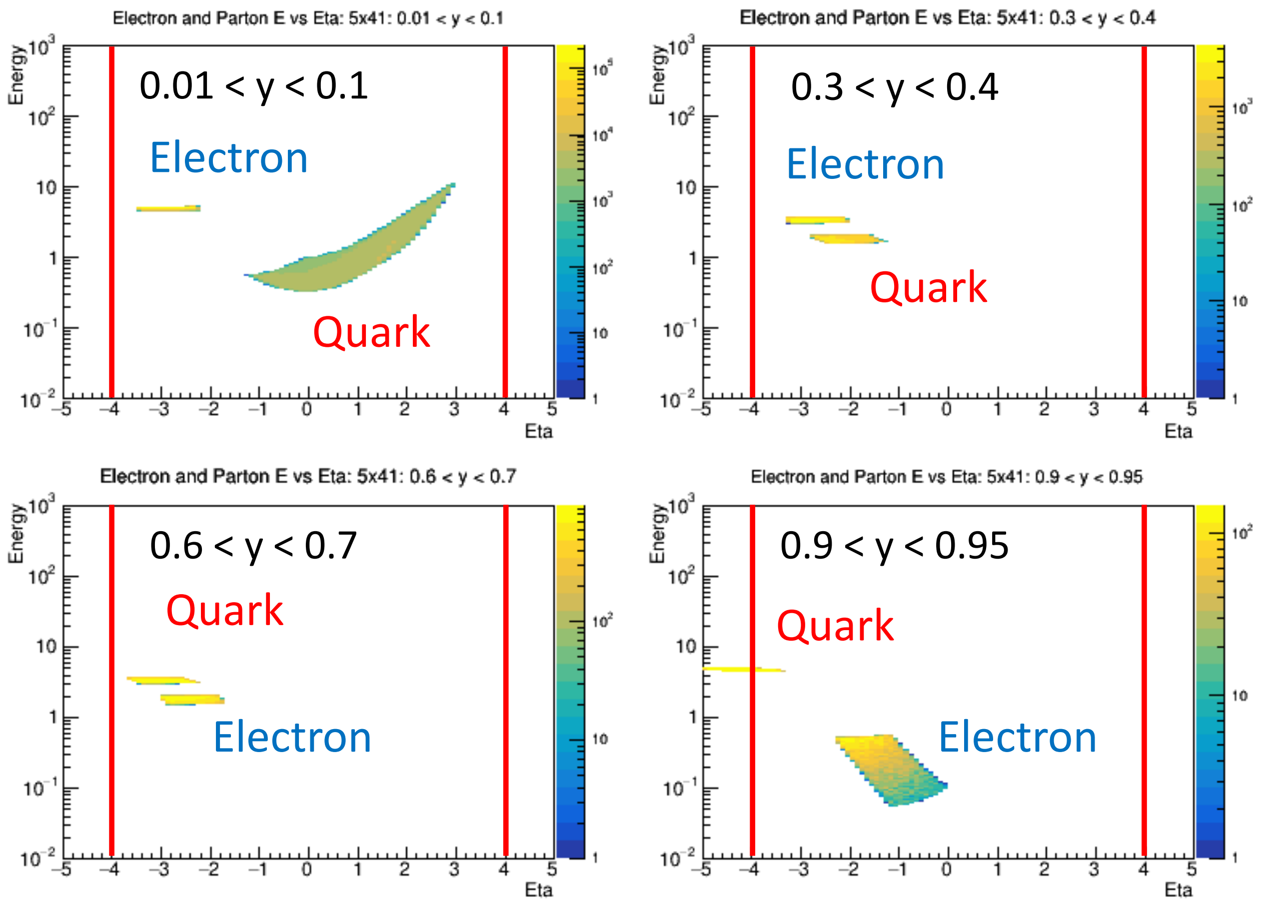


$0.1 < Q^2 < 1.0$

- ❑ As y -> 0, the struck quark can take the full ion beam energy
- ❑ As y -> 1, the struck quark takes the full electron beam energy
- ❑ Different detector considerations in forward and backward regions

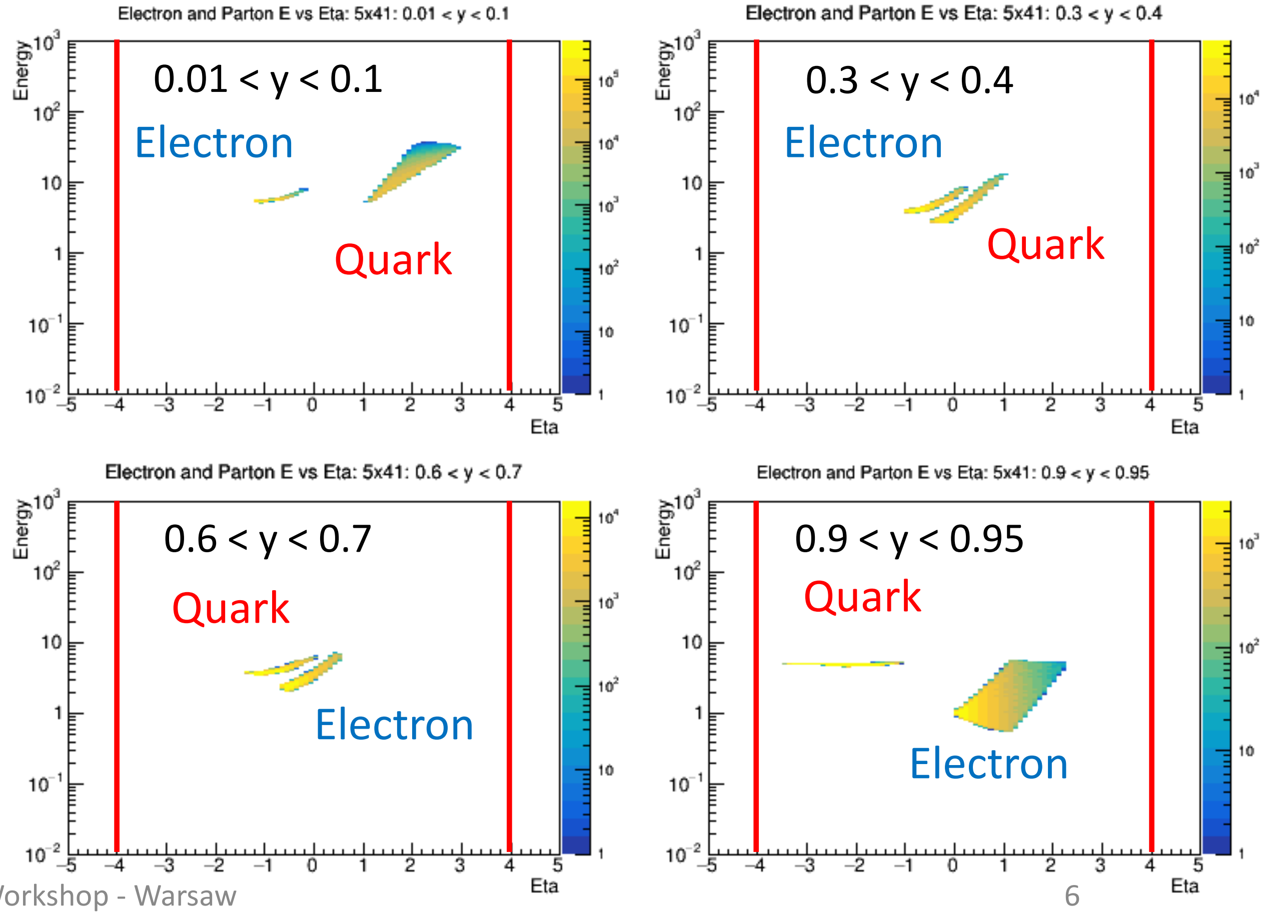
Electron and Struck Quark (5x41)

- ❑ Maximum parton / jet energy in. the backward region will be determined by the electron beam energy



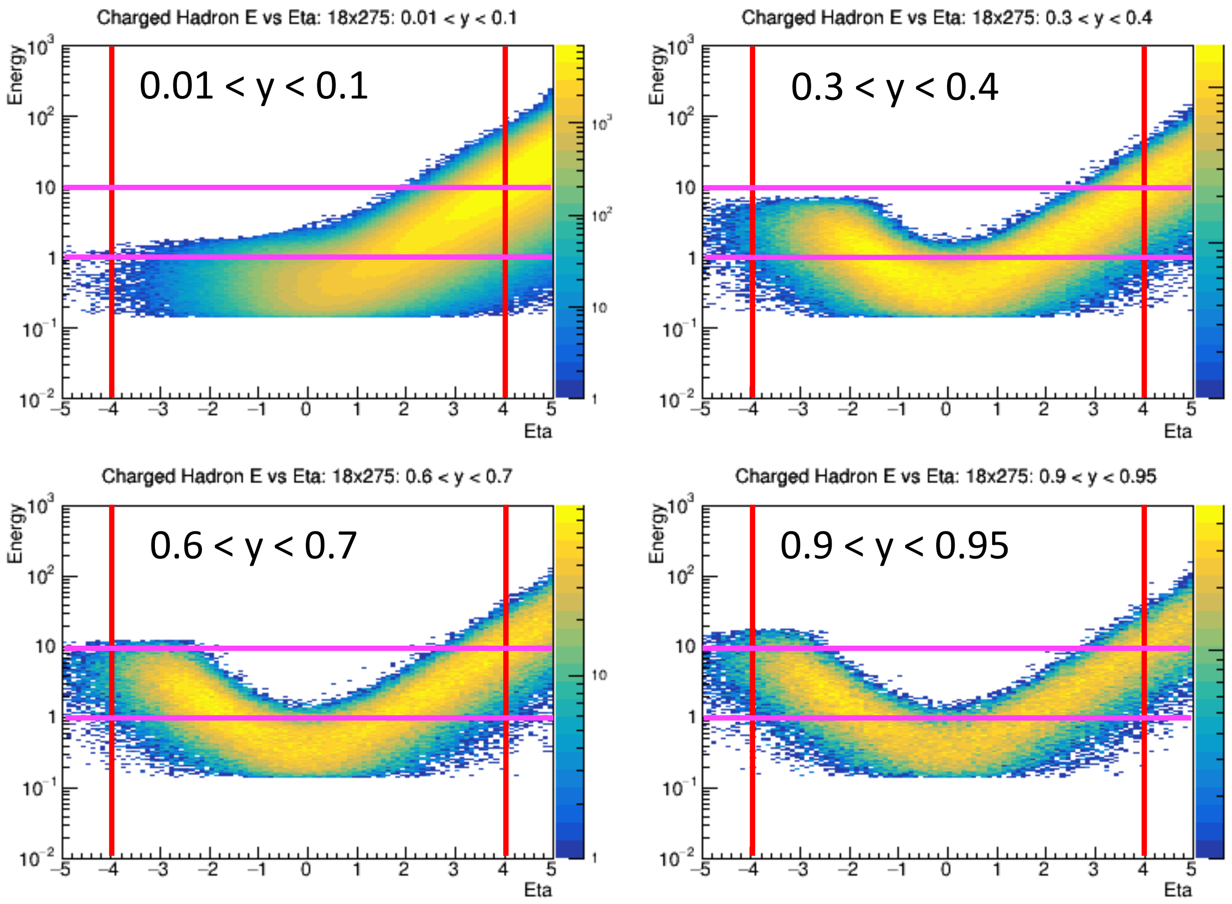
$0.1 < Q^2 < 1.0$

$10 < Q^2 < 100$



- ❑ As Q^2 increases, both the scattered electron and struck quark move to larger eta for all values of y

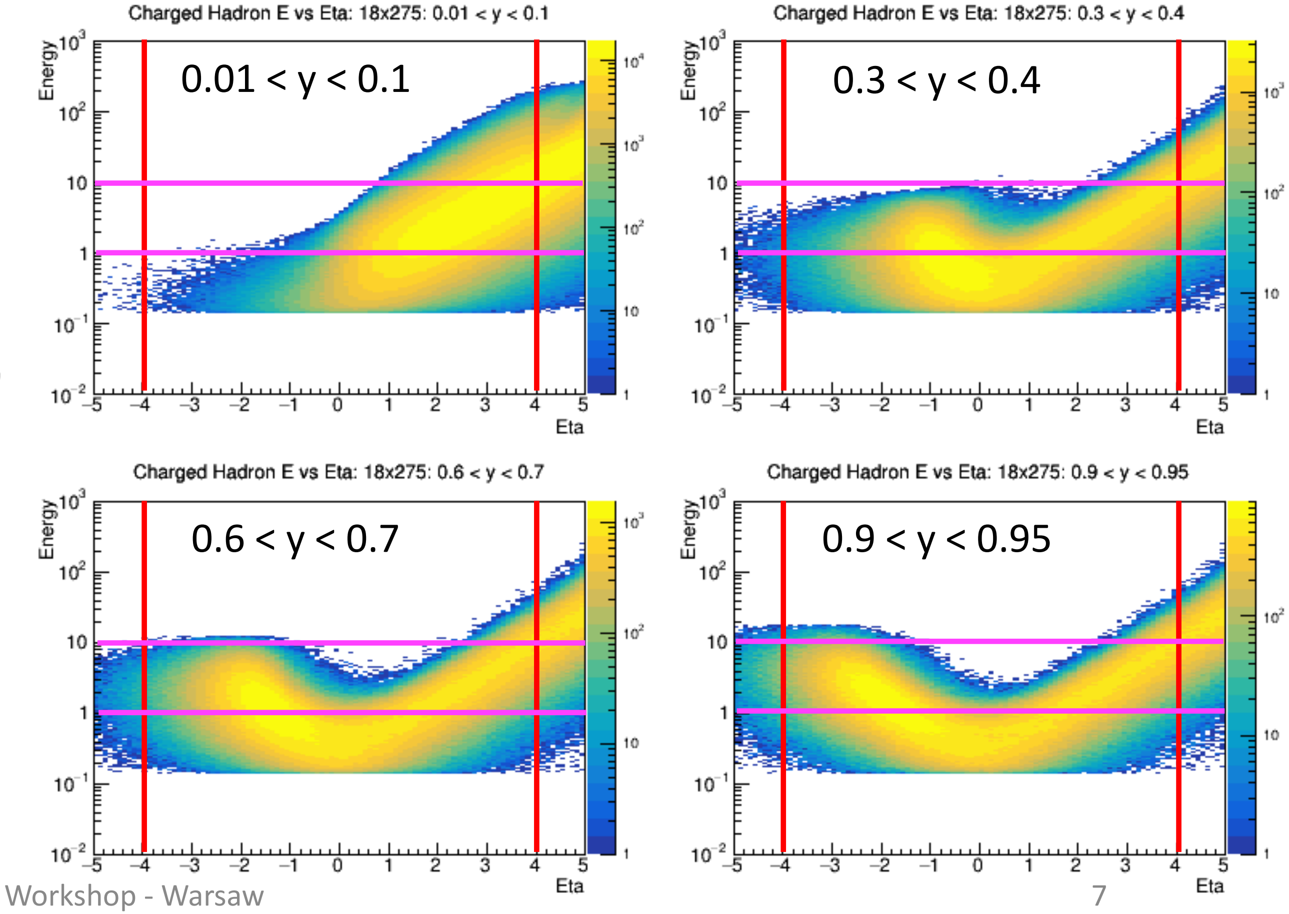
(Charged) Particle Distributions (18x275)



0.1 < Q^2 < 1.0

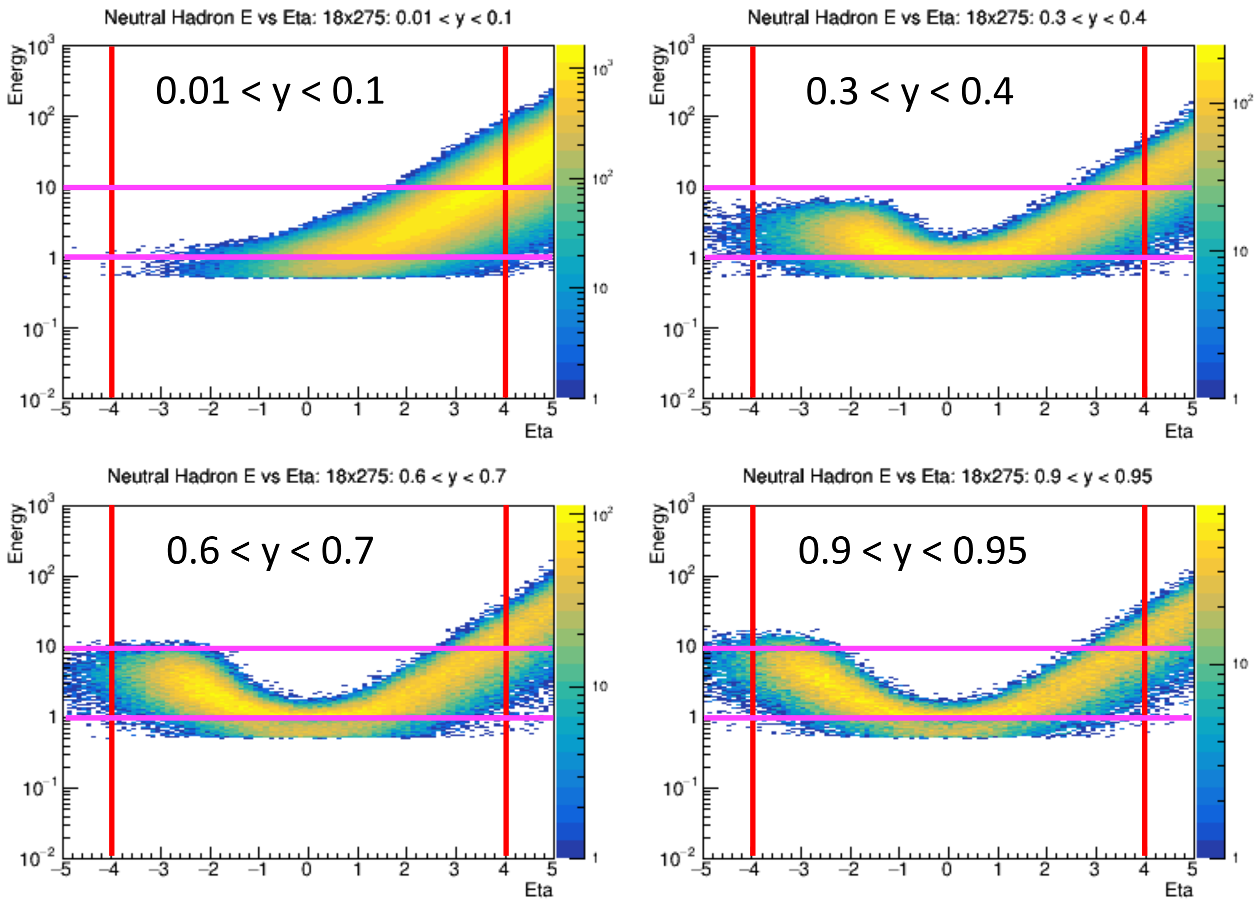
- Charged hadron energy vs eta distributions all show roughly similar features – high energy forward, low at mid-rapidity, and a slight rise in the backward region

10 < Q^2 < 100



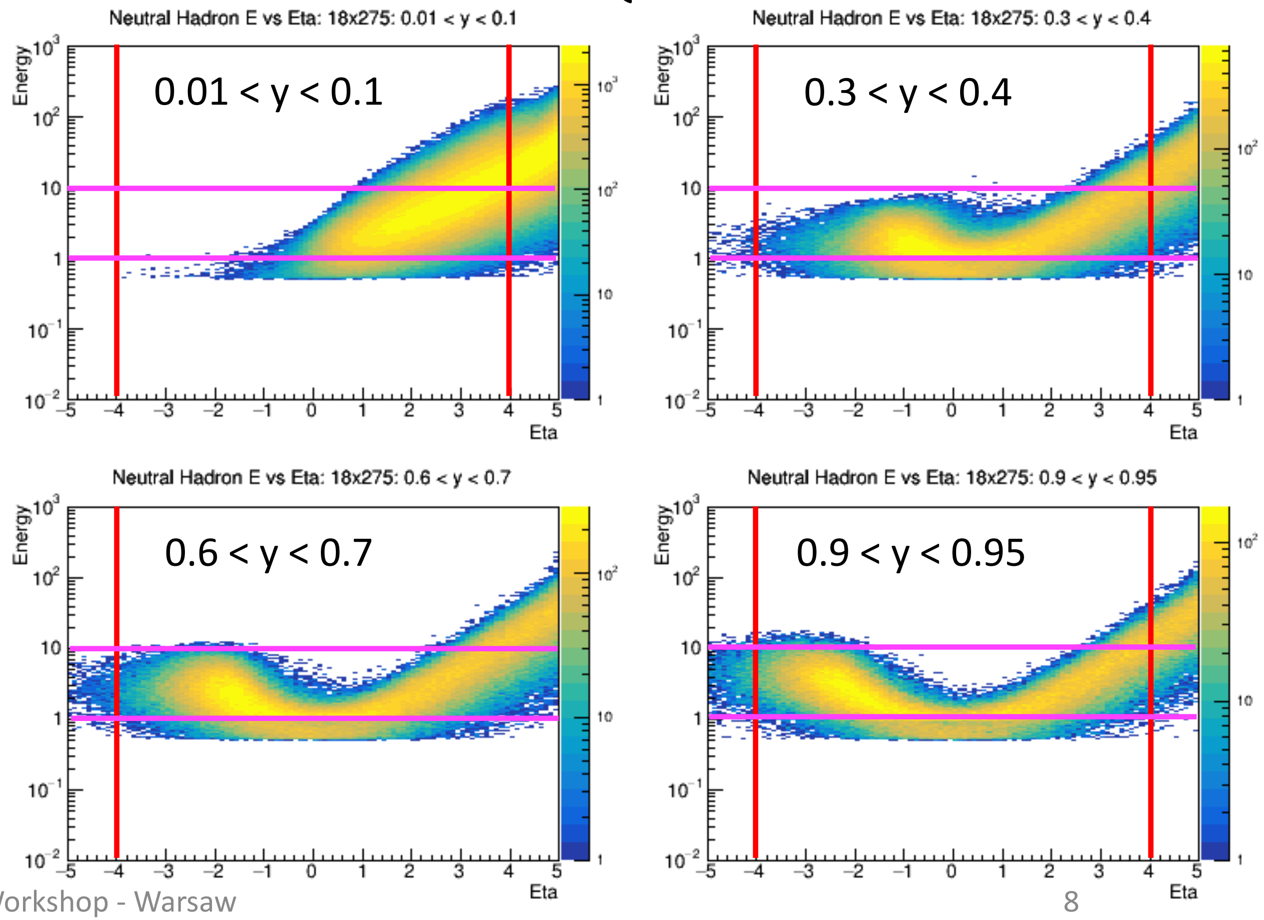
Neutral Hadrons (18x275)

- Neutral hadron energy vs eta distributions very similar to charged particles
- Minimum energy is larger due to rest mass of the K_L



$1 < Q^2 < 10$

$10 < Q^2 < 100$



- How well can we reconstruct the parton kinematics from these particles?
- Can we form jets away from the struck parton?

Jet Algorithms

Anti_k_T

$$d_{ij} = \min[p_{ti}^{-2}, p_{tj}^{-2}]\Delta R_{ij}/R$$

EE_kT (Spherically Invariant)

$$d_{ij} = 2 * \min[E_i^2, E_j^2](1 - \cos \Delta_{ij})$$

Centauro

$$d_{ij} = \left[(\Delta f_{ij})^2 + 2 f_i f_j (1 - \cos \Delta\phi_{ij})\right] / R^2$$

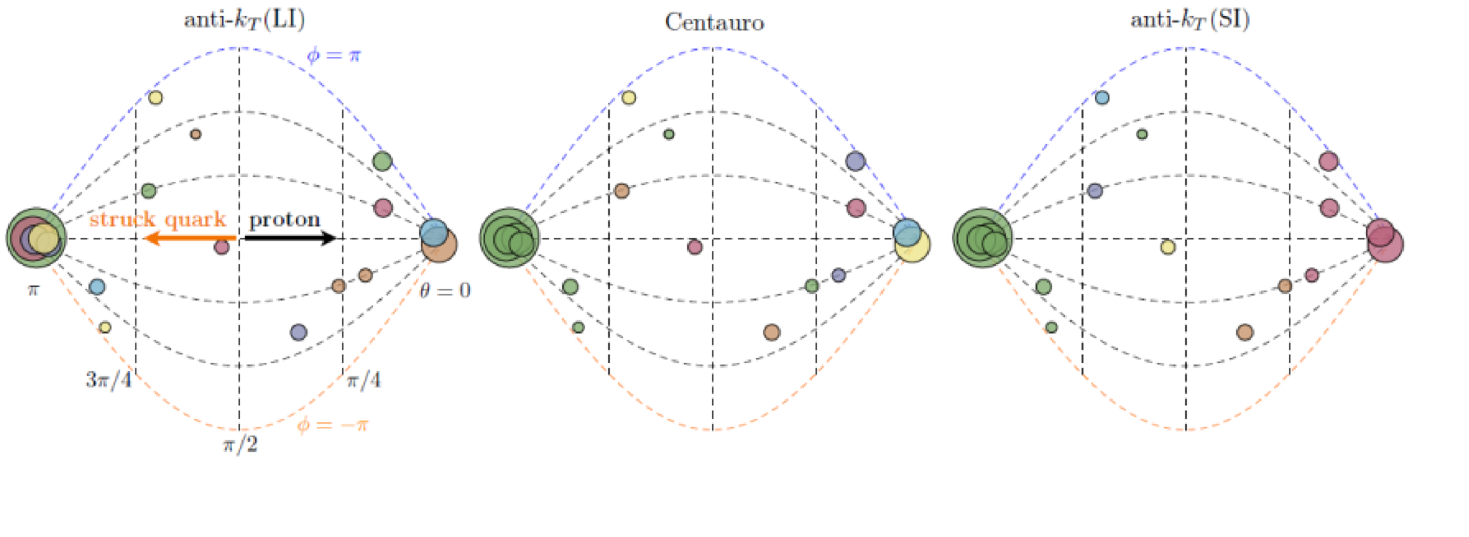
Asymmetric measure is necessary

$$f(x) = x + \mathcal{O}(x^2)$$

$$\bar{\eta}_i = -\frac{2Q}{\bar{n} \cdot q} \frac{p_i^{\perp}}{n \cdot p_i}$$

$$\bar{\eta}_i(\mathrm{BF}) = 2p_i^{\perp}/p_i^{+}$$

- Sequential recombination algorithms, especially Anti_k_T, have been the "industry standard" at hadron colliders for a number of years
- Is this appropriate for very forward jets or Born-level jets in the Breit frame where transverse momenta are by definition small?
- Look at alternative distance measures such as spherically invariant and symmetric EE_k_T or longitudinally invariant and anti-symmetric centauro algorithms

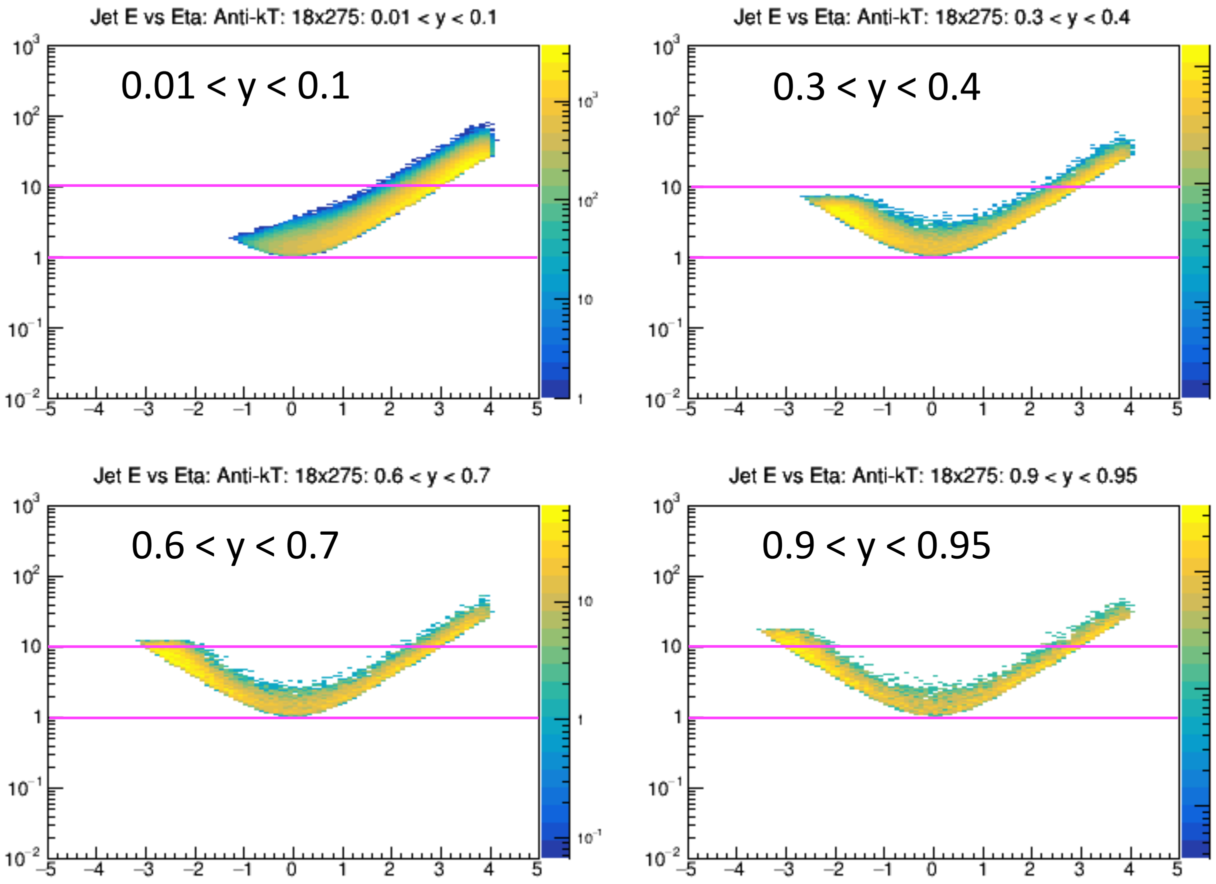


Longitudinally invariant Symmetric

Longitudinally invariant Asymmetric

Spherically invariant Symmetric

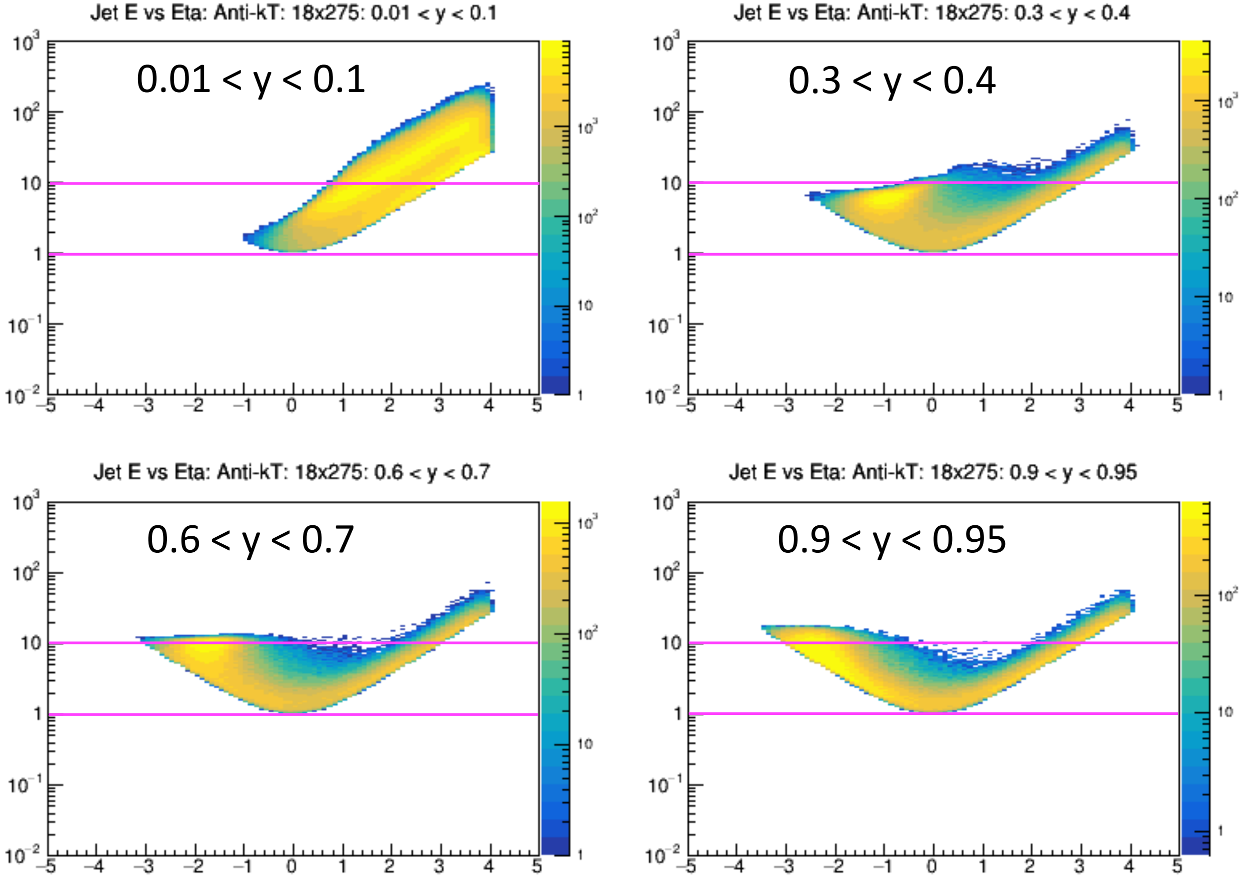
Jet Distributions: Anti_k_T (18x275)



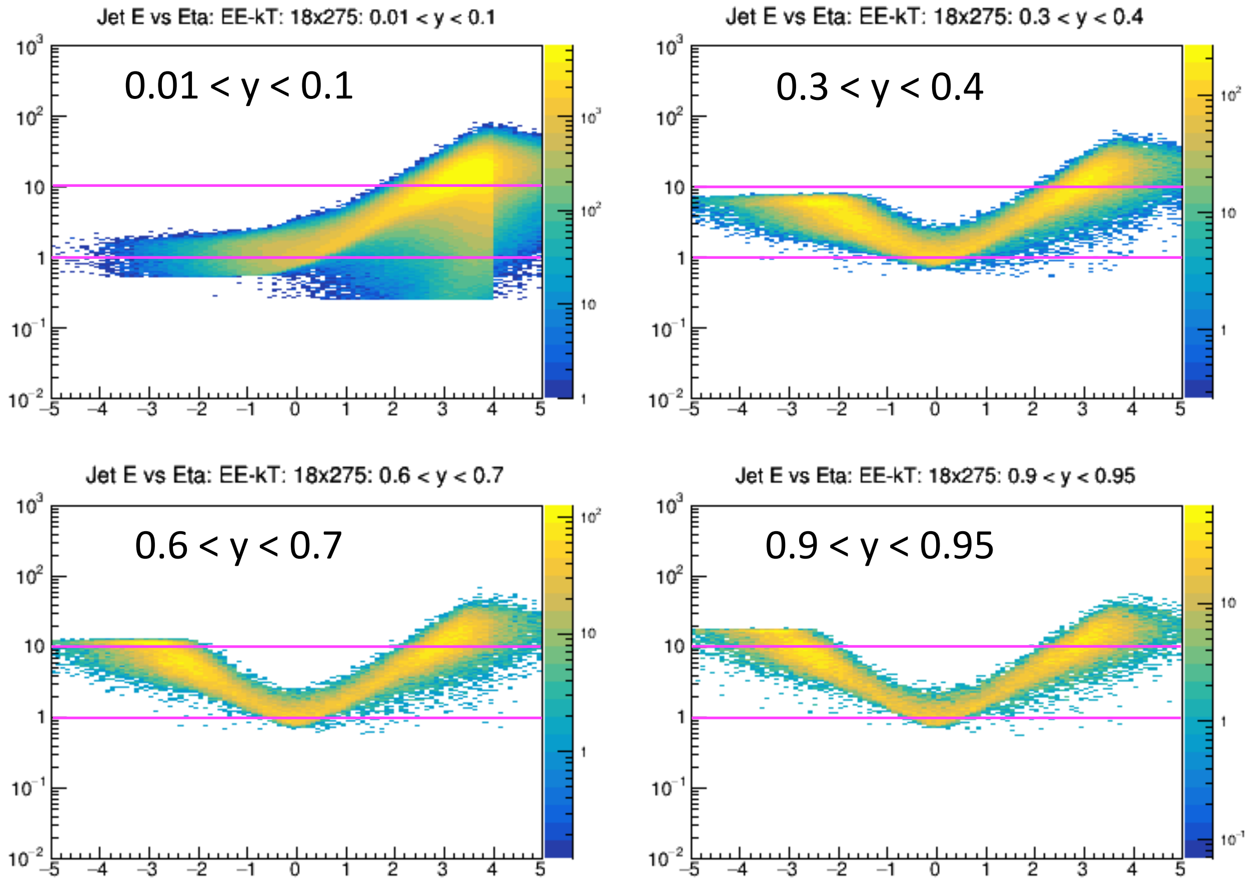
$0.1 < Q^2 < 1.0$

- ❑ Run inclusive Anti_k_T on all stable particles (|eta| < 4) with 1 GeV minimum p_T cut
- ❑ Jets roughly follow particle distributions

$10 < Q^2 < 100$



Jet Distributions: EE_k_T (18x275)

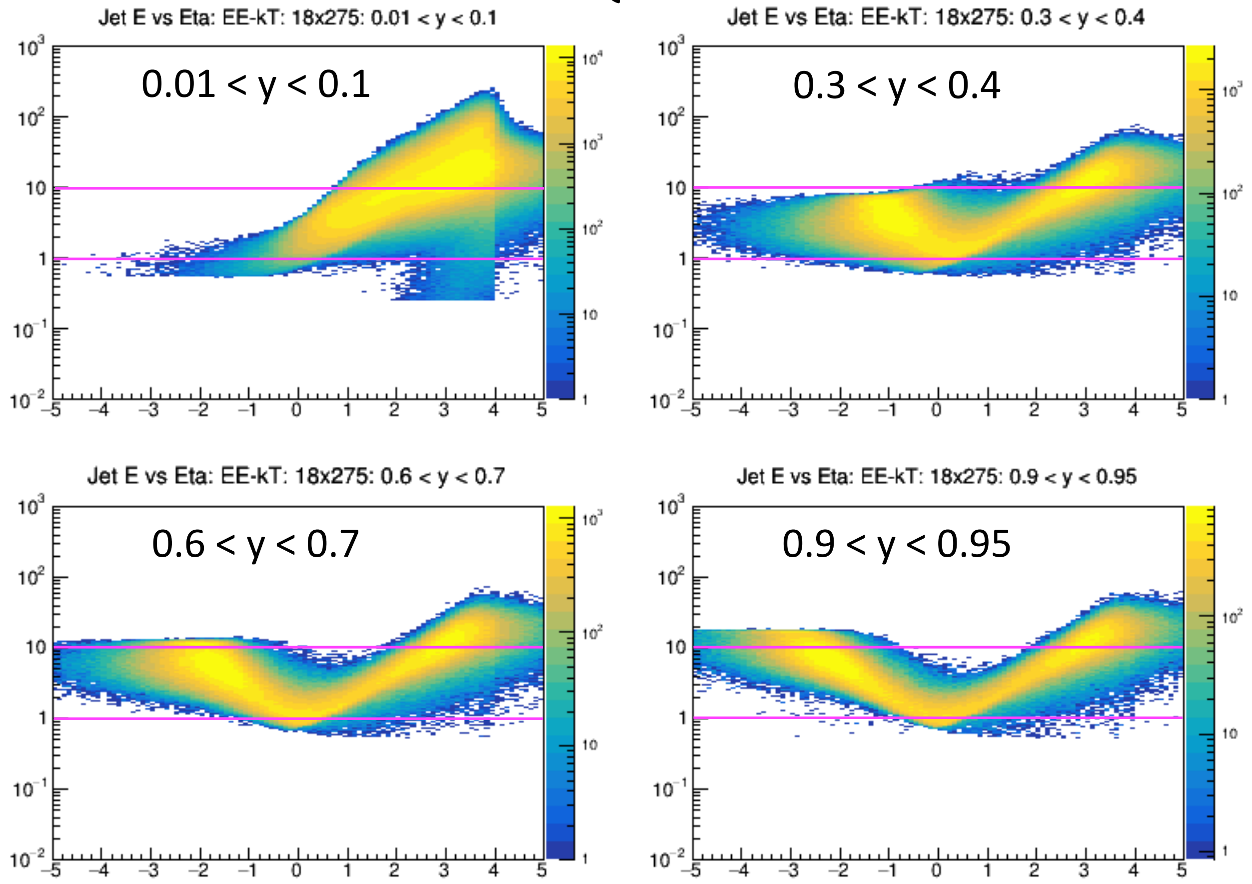


$0.1 < Q^2 < 1.0$

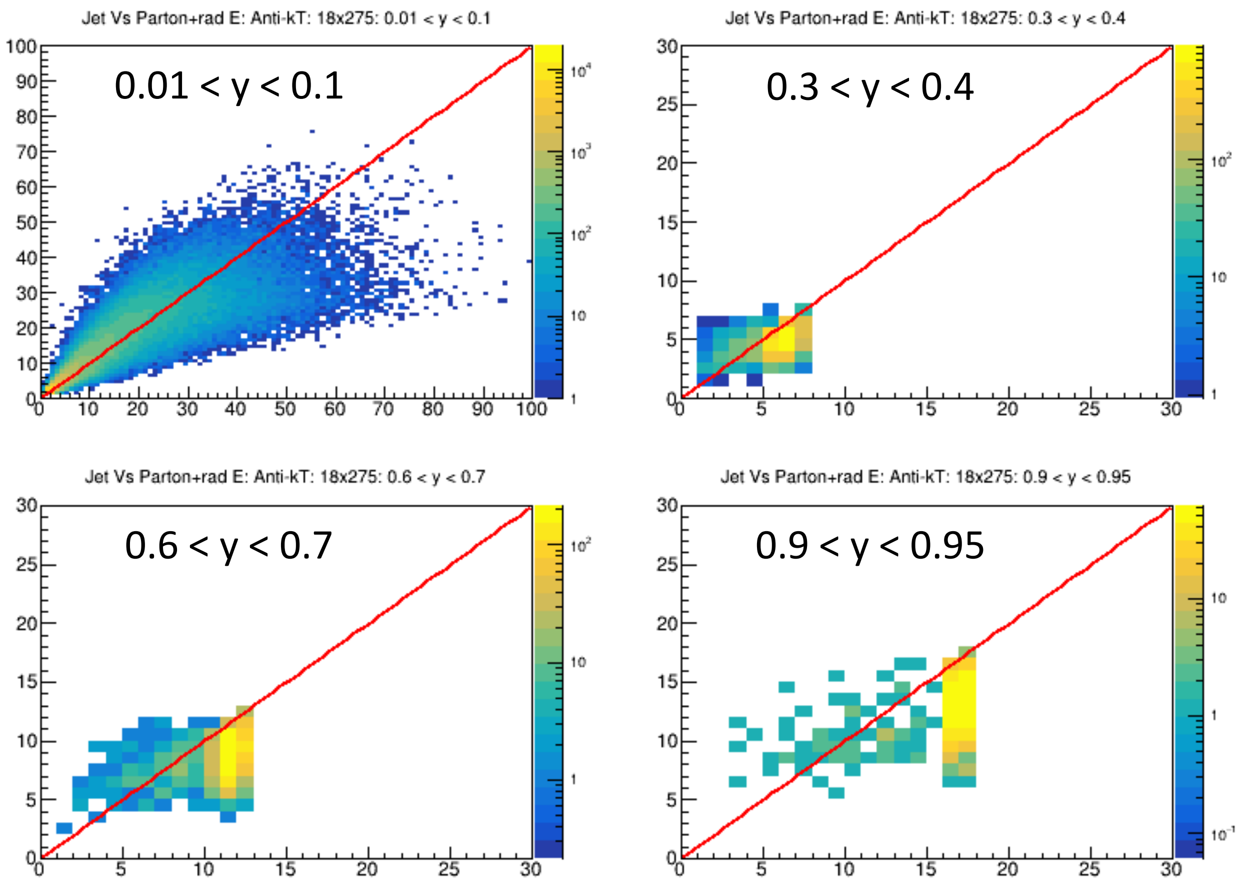
- ❑ Need to understand the artifact around eta = 4, must be related to particle eta cut

- ❑ Overall distributions are similar for EE_k_T algorithm
- ❑ In general, see larger number of jets, more jets at higher eta, and more jets away from struck quark

$10 < Q^2 < 100$



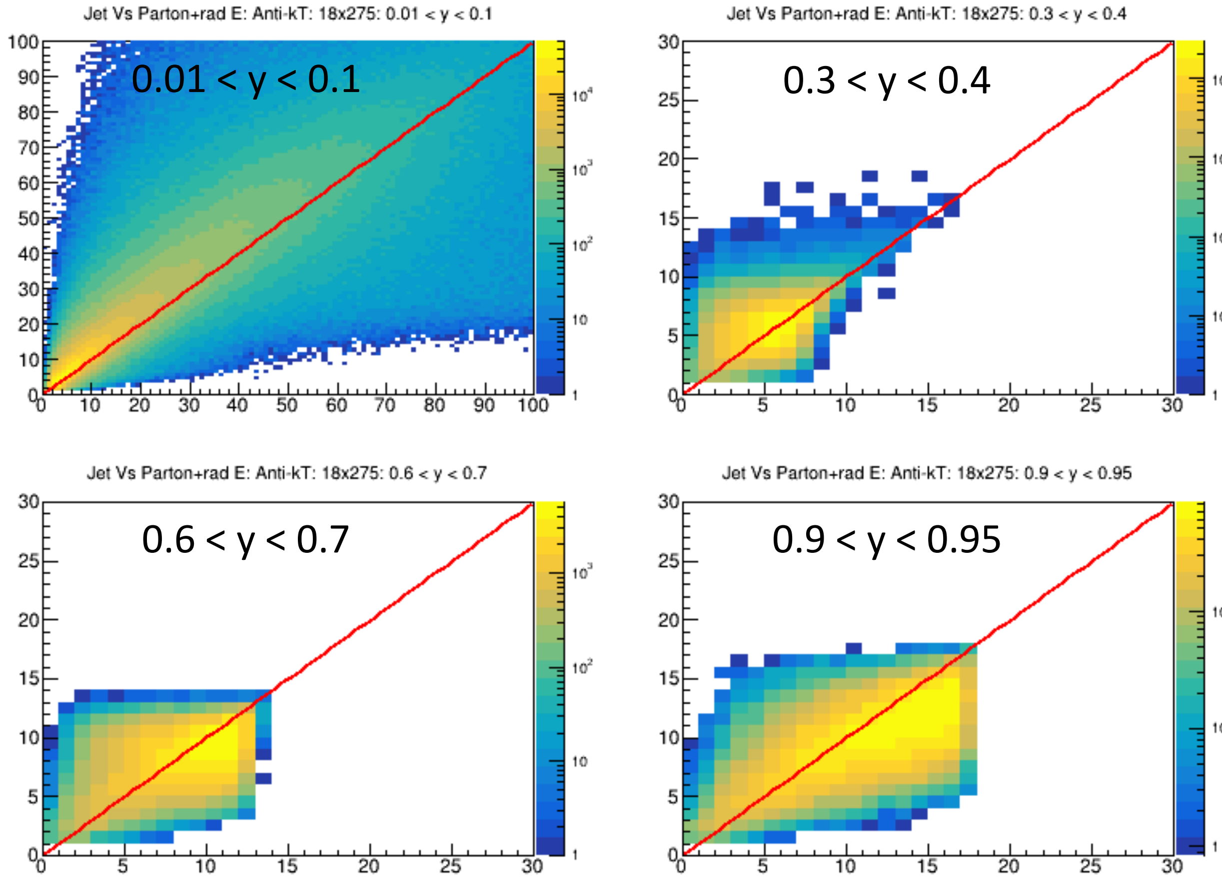
Jet – Parton Energy Comparison: Anti_k$_T$ (18x275)



$0.1 < Q^2 < 1.0$

- ❑ How well do jets represent the parton?
- ❑ Plot jet energy vs parton+FSR energy for different Q^2 and inelasticity

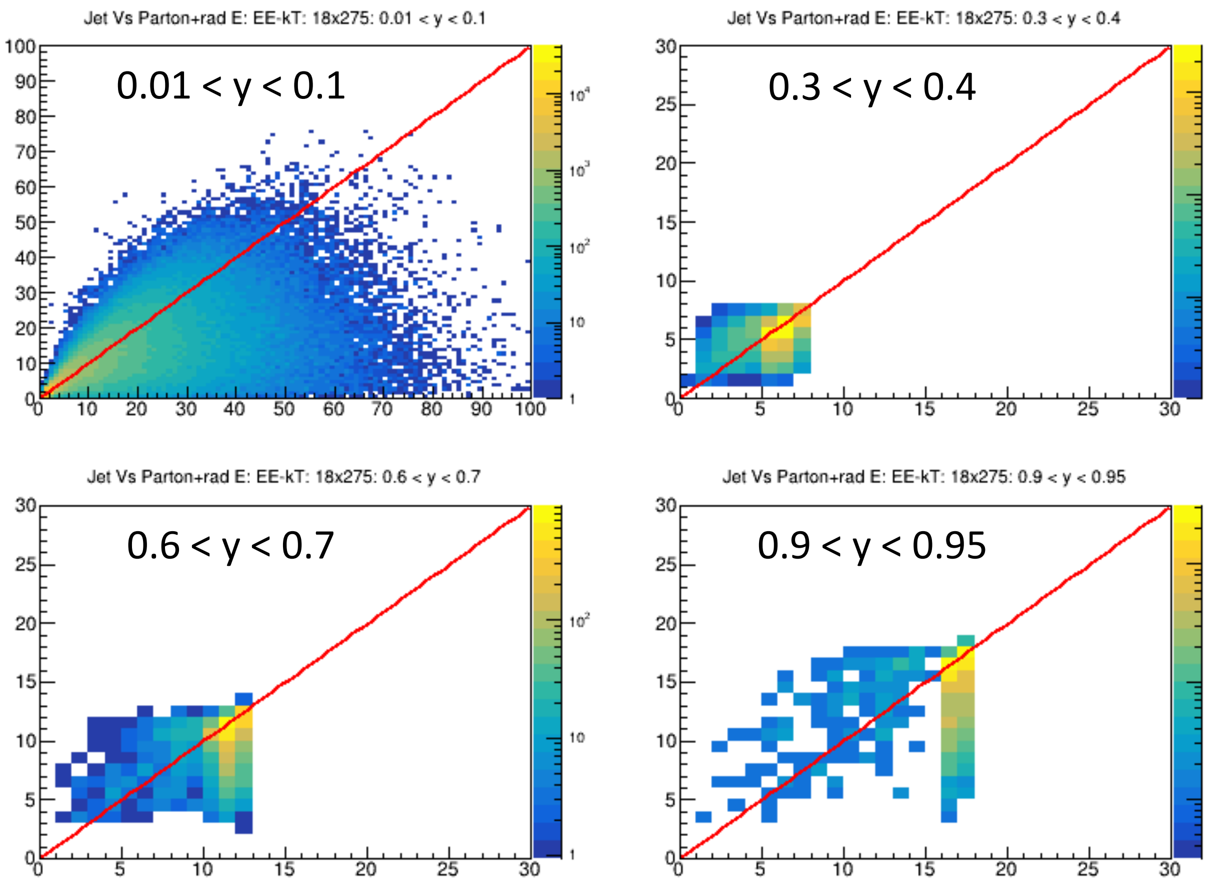
$10 < Q^2 < 100$



- ❑ Performance degrades somewhat at larger y (backward jets)

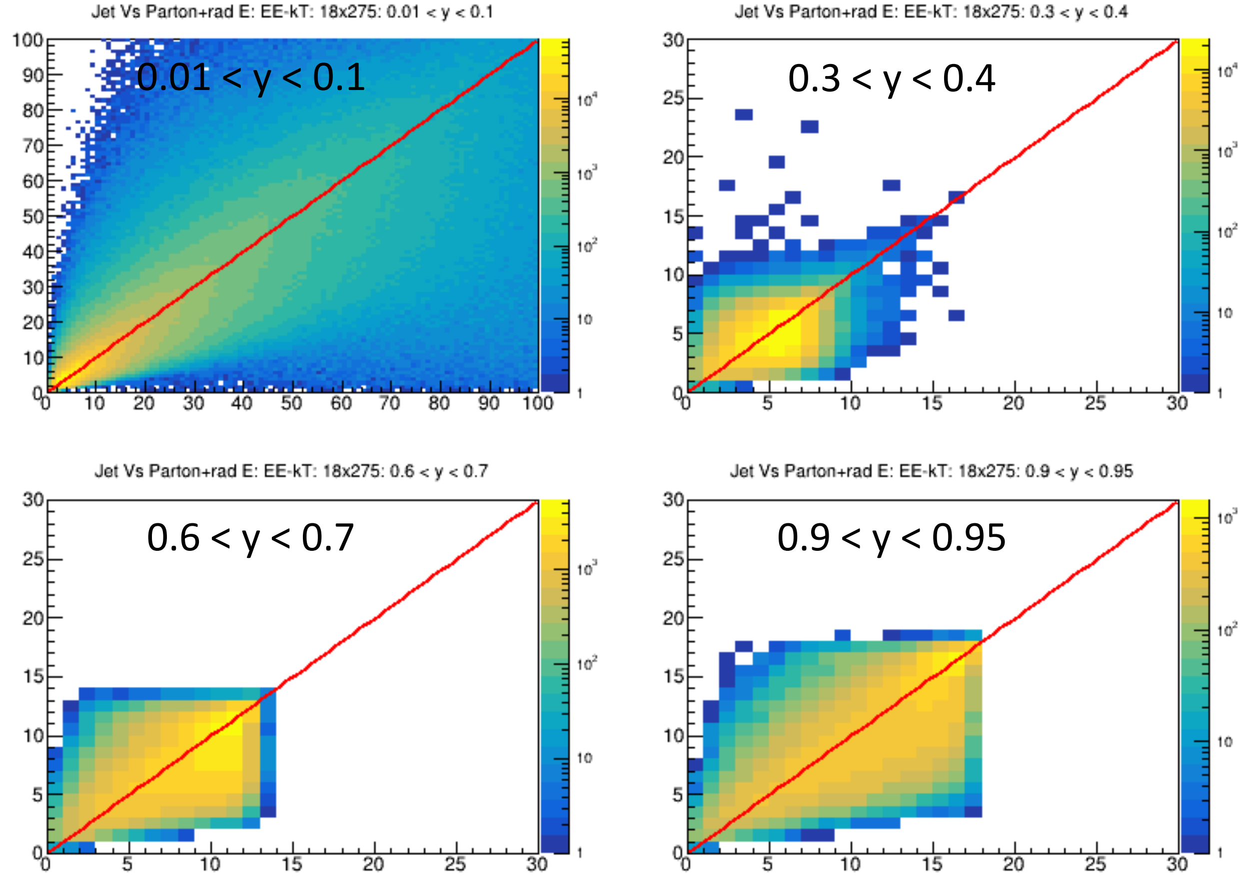
Jet – Parton Energy Comparison: EE_k_T (18x275)

- Better agreement between parton and jet seen with EE_kT algorithm, especially at high y



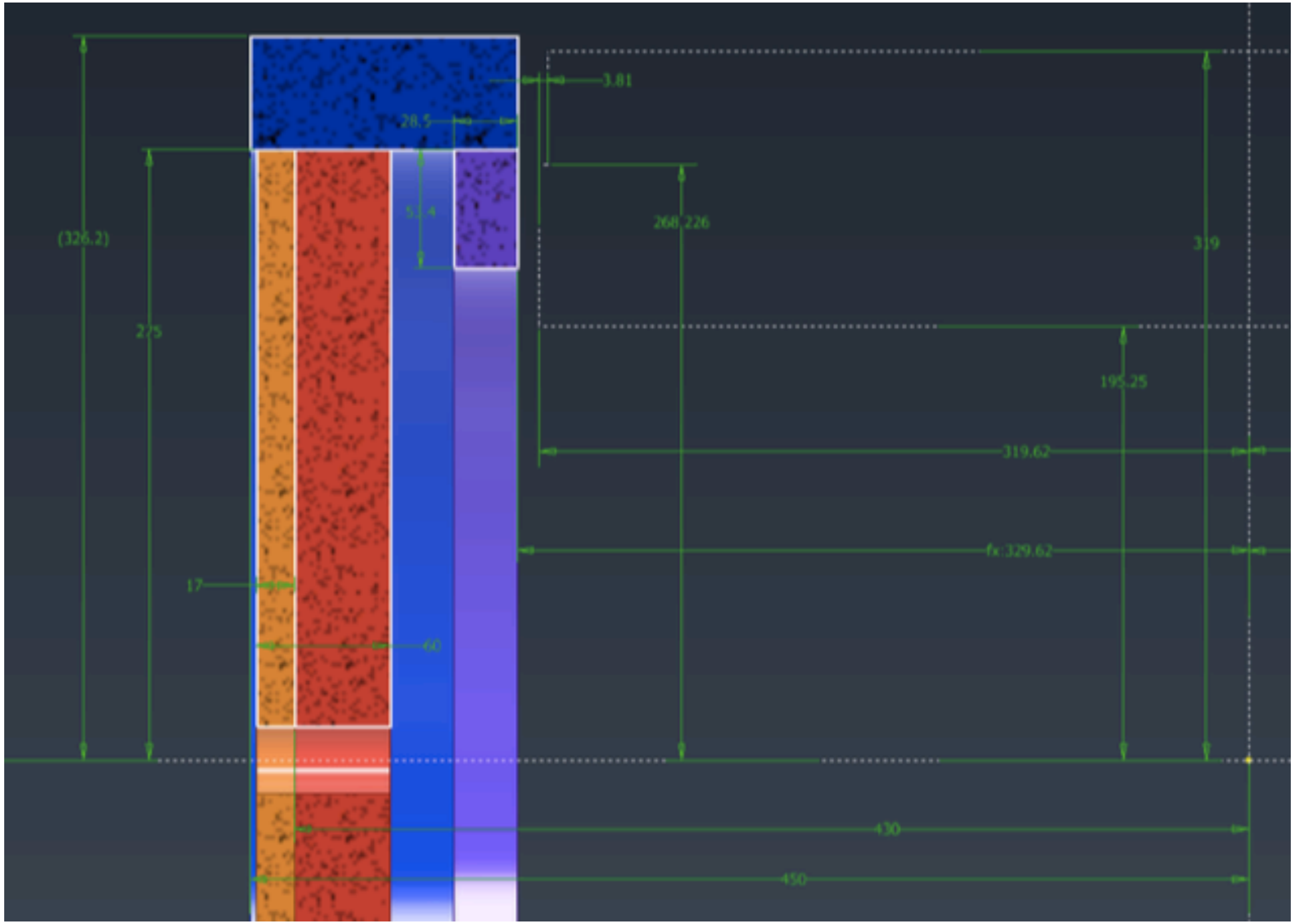
$0.1 < Q^2 < 1.0$

$10 < Q^2 < 100$



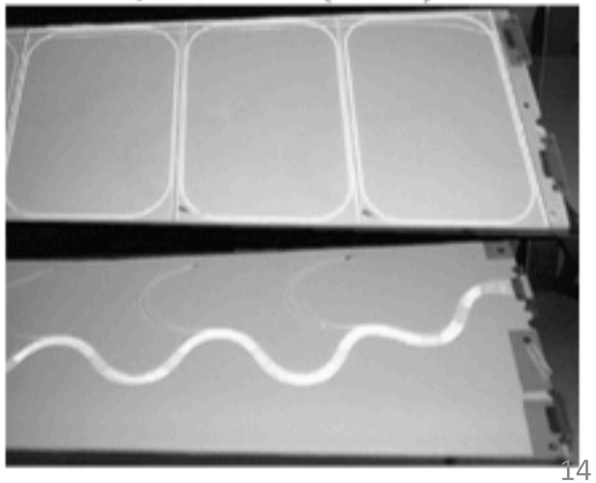
ePIC Backward HCal Design

Work done by Leszech – see talk in ePIC meeting



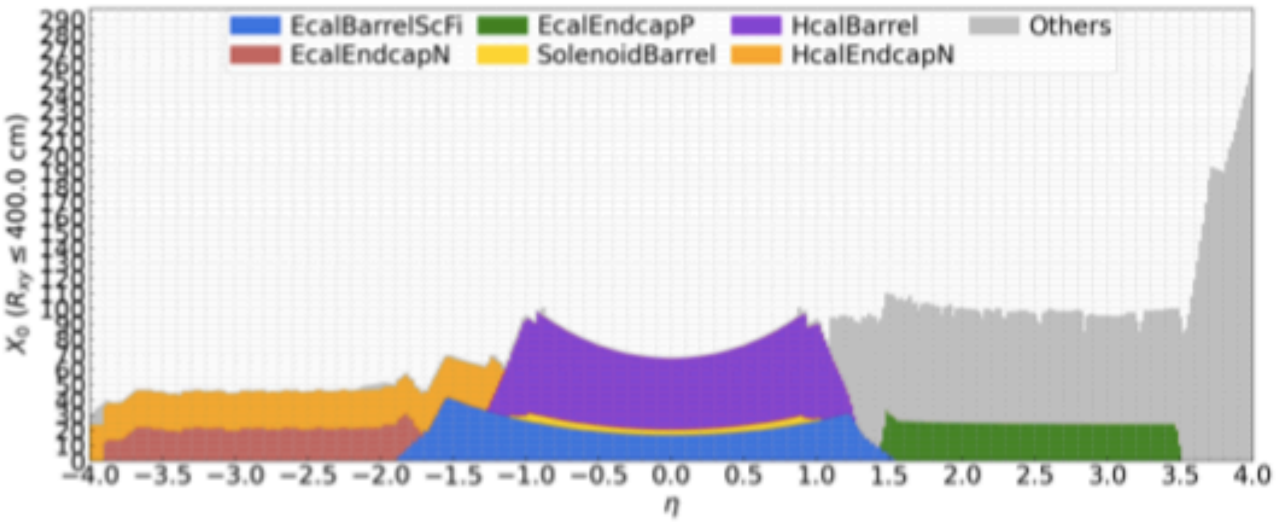
- Current design consists of 10 layers stainless steel (40 mm) and plastic scintillator (4 mm)
- Plan to reuse existing scintillating megatiles from current STAR EEMC
- Current design decouples flux return steel and HCal for more flexibility

STAR EEMC 6° megatile - 12 tiles in η direction (radial) each



Calorimeter Material Scans

- HCal Radiation Length ~24 X0
- HCal Interaction Length ~2.4 0
- Currently the scintillator tiles do not cover the same volume as steel absorber



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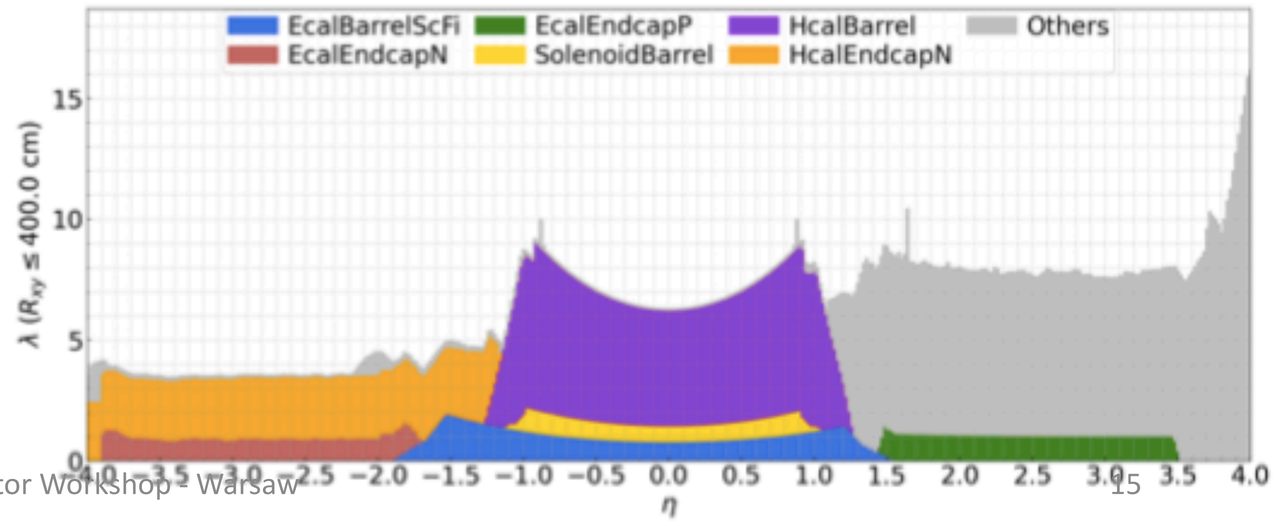


HCals in the Yellow Report: Neutral Veto

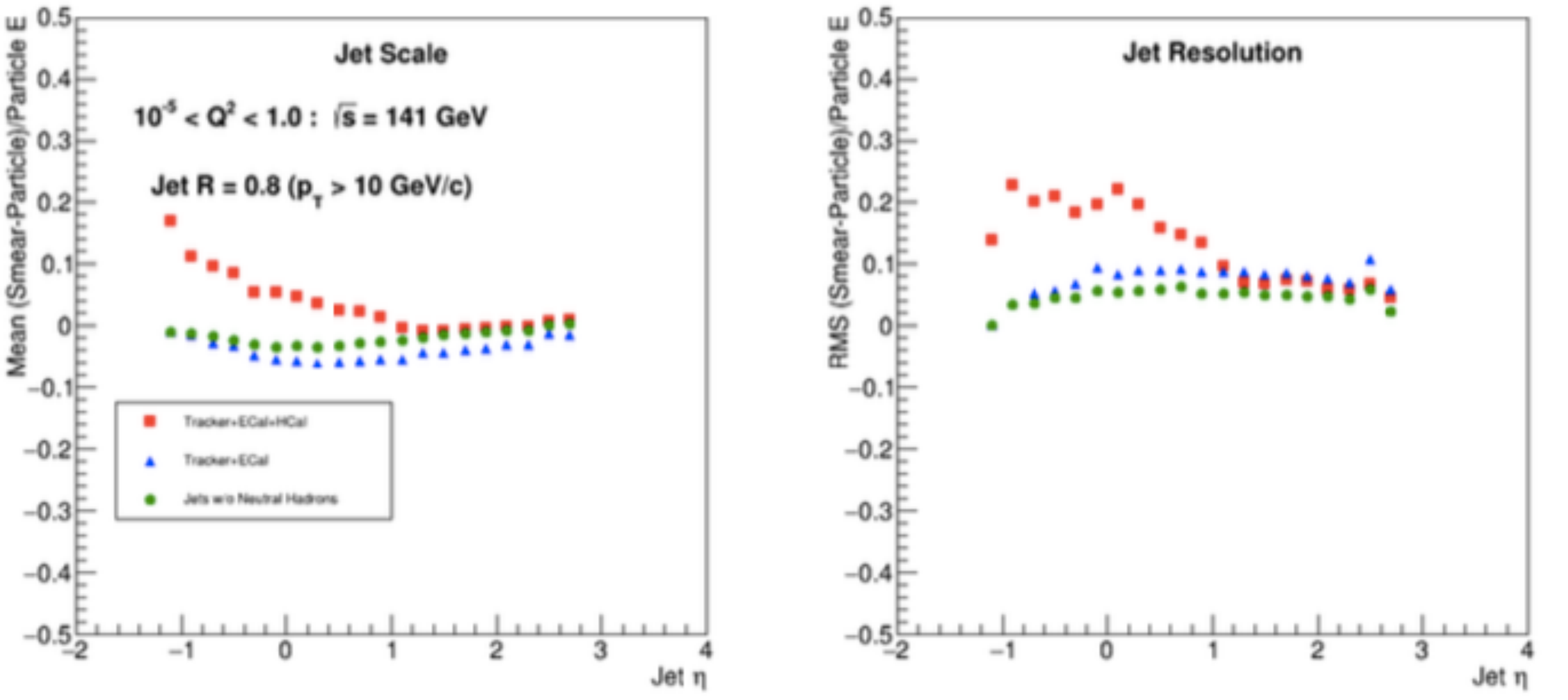


Figure 8.57: Demonstration of the effect of selecting only jets which do not contain a neutral hadron (green circles) on the jet energy scale (left) and resolution (right) as compared to the cases when all subsystems are used in jet finding (red squares) and when HCal information is excluded (blue triangles).

- Yellow report era studies saw that neutral hadrons can spoil JES and JER for low energy jets
- Vetoing jets with neutral hadrons using the HCal could substantially improve resolution
- This was very primitive detector effects modeling
- Need to confirm in modern full simulation

HCals in the Yellow Report: Resolution

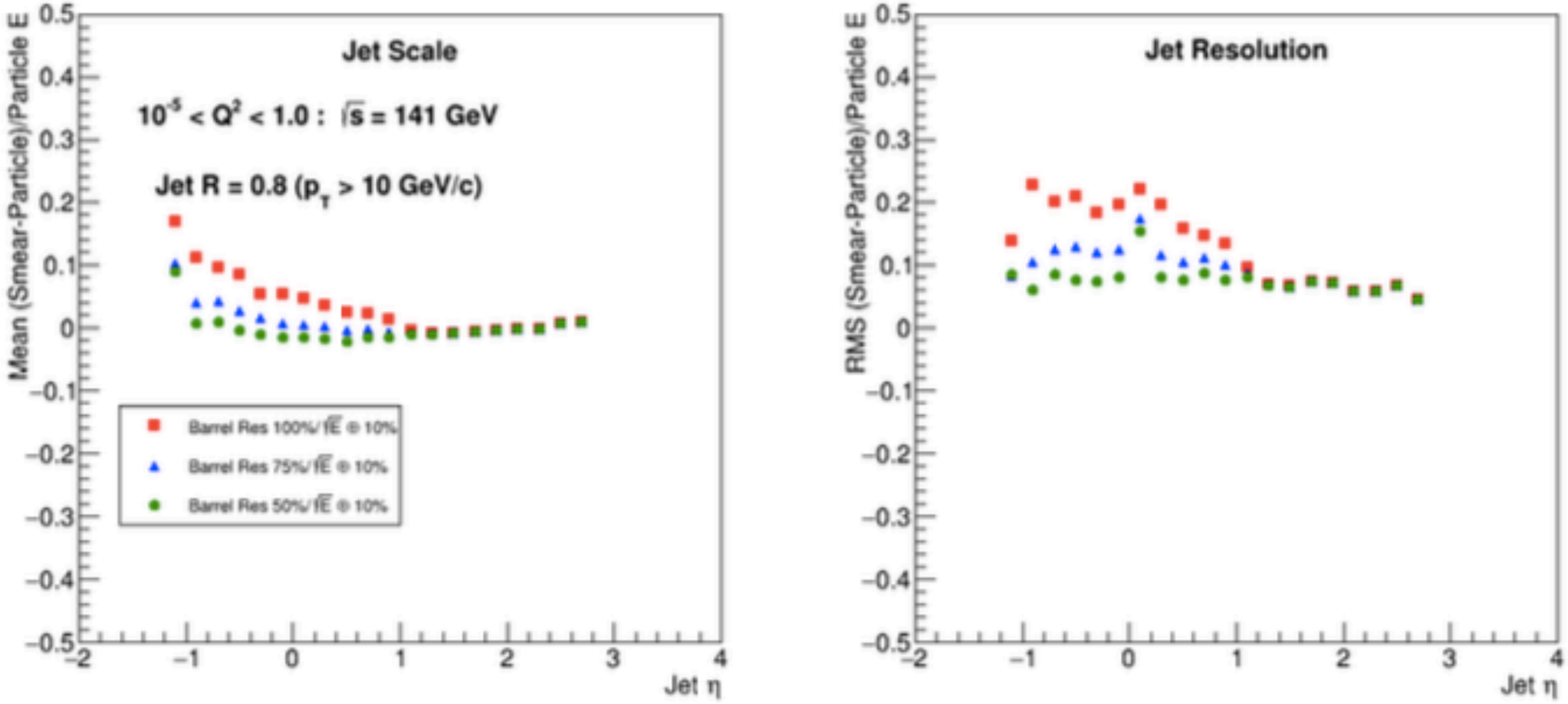


Figure 8.56: Jet energy scale (left) and resolution (right) as a function of jet pseudorapidity when selecting smeared jets with $p_T > 10$ GeV$/c$ for different values of HCal energy resolution: $100\%/\sqrt{E} \oplus 10\%$ (red squares), $75\%/\sqrt{E} \oplus 10\%$ (blue triangles), and $50\%/\sqrt{E} \oplus 10\%$ (green circles).

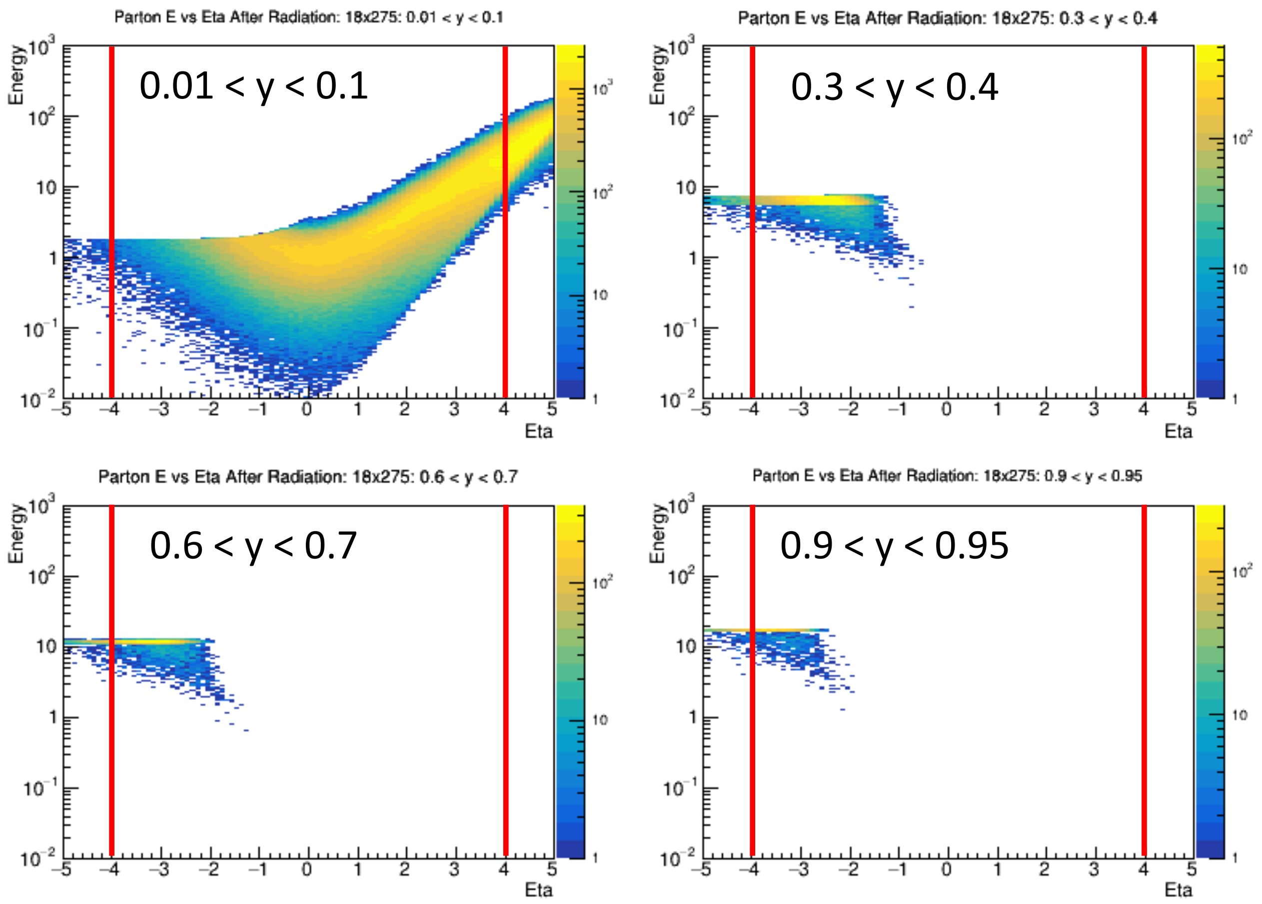
- ❑ Can HCal with better resolution help?
- ❑ Seems that resolution around 50% can compensate for neutral fluctuations
- ❑ Again, needs to be confirmed in modern simulation

Discussion

- What physics aspects do we want to highlight? -> input to design
  - Low-x and saturation
  - Target vs current fragmentation?
- What aspects of the HCal design can be complimentary to ePIC?
  - Depth
  - Segmentation
  - Resolution
- Complementarity is fine, but what specs do we need to design to?
  - What simulation studies do we need?

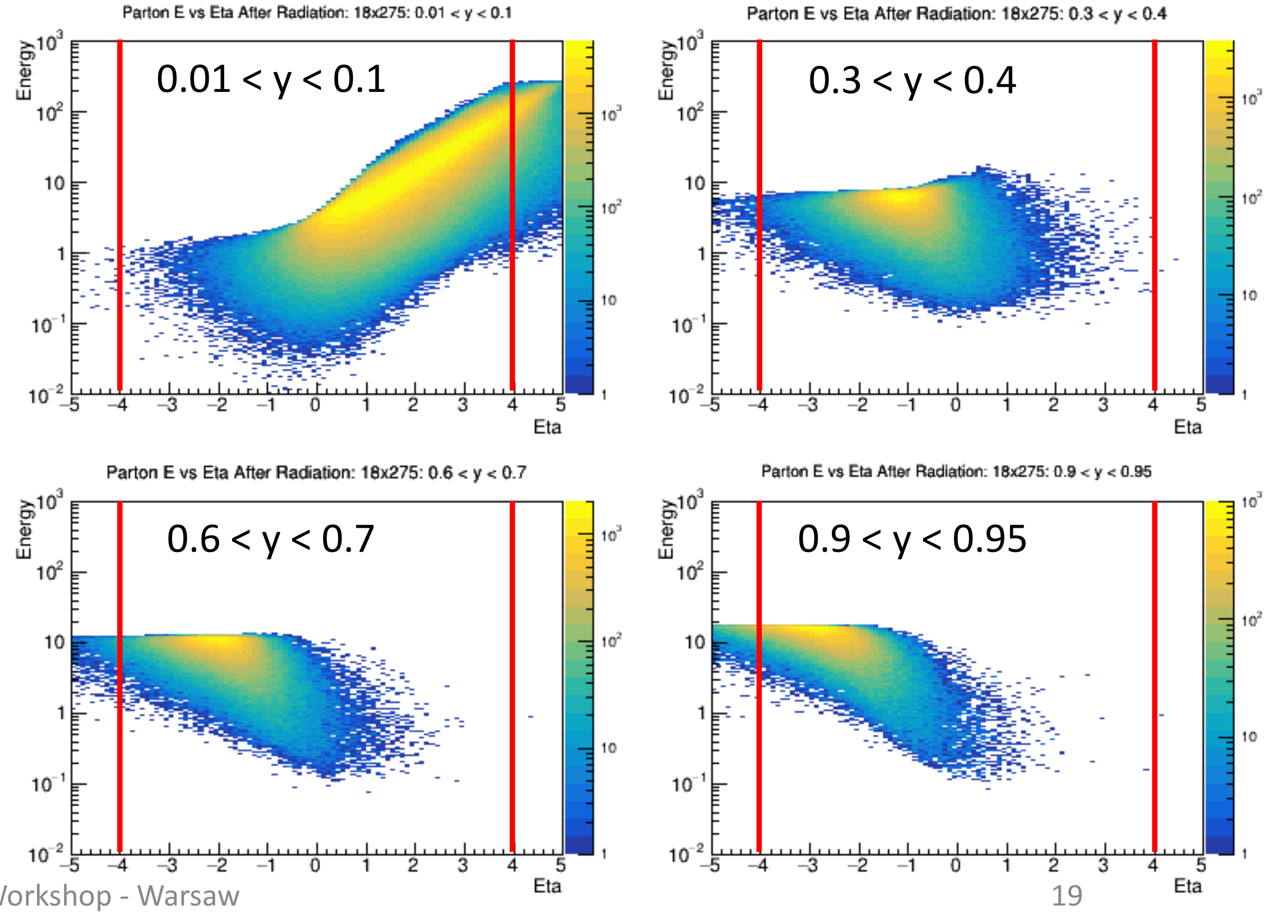
Struck Quark + FSR (18x275)

- For Born-level process, struck quark kinematics are correlated with event kinematics
- Final state radiation can alter quark kinematics significantly



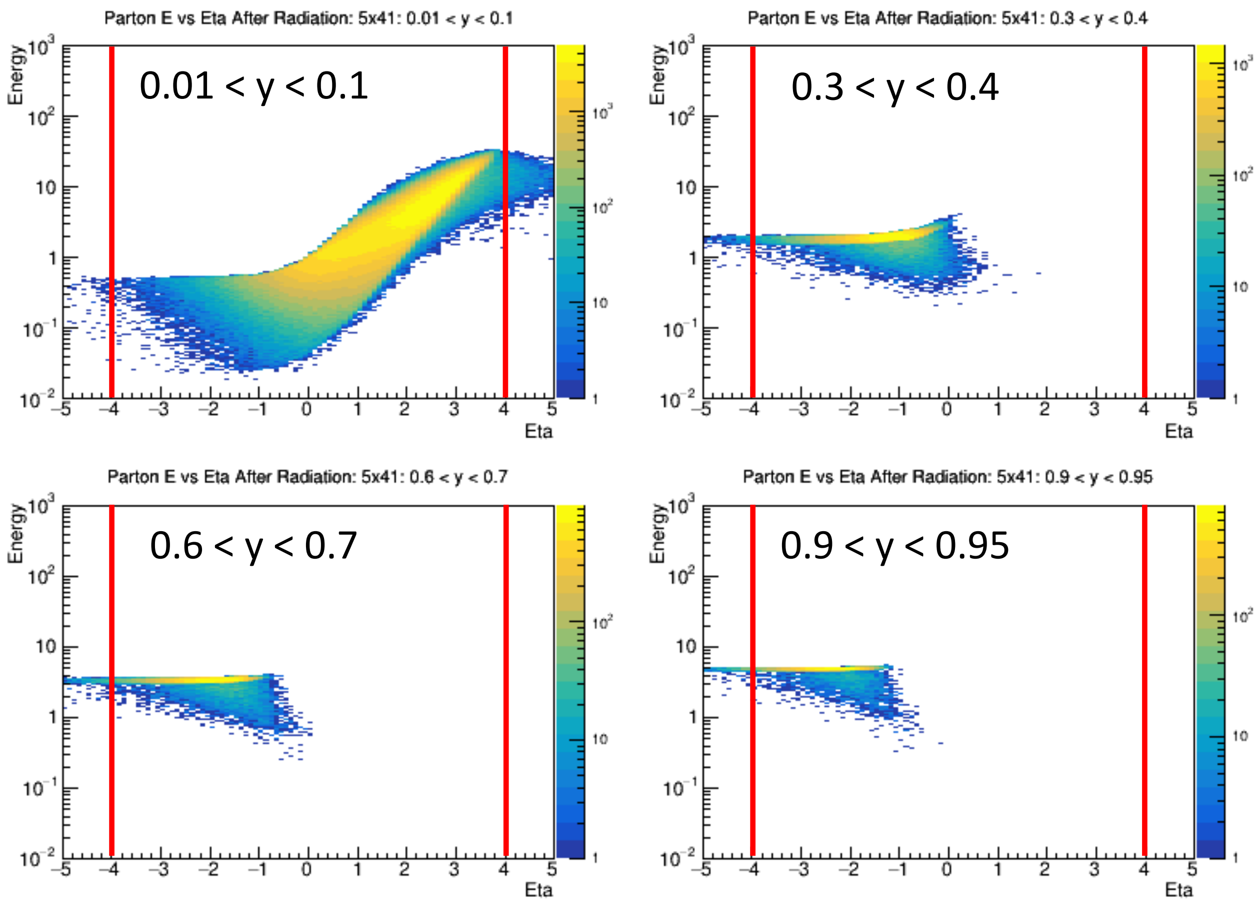
$0.1 < Q^2 < 1.0$

$10 < Q^2 < 100$



Struck Quark + FSR (5x41)

- Behavior as a function of Q^2, y, and beam energy is still seen



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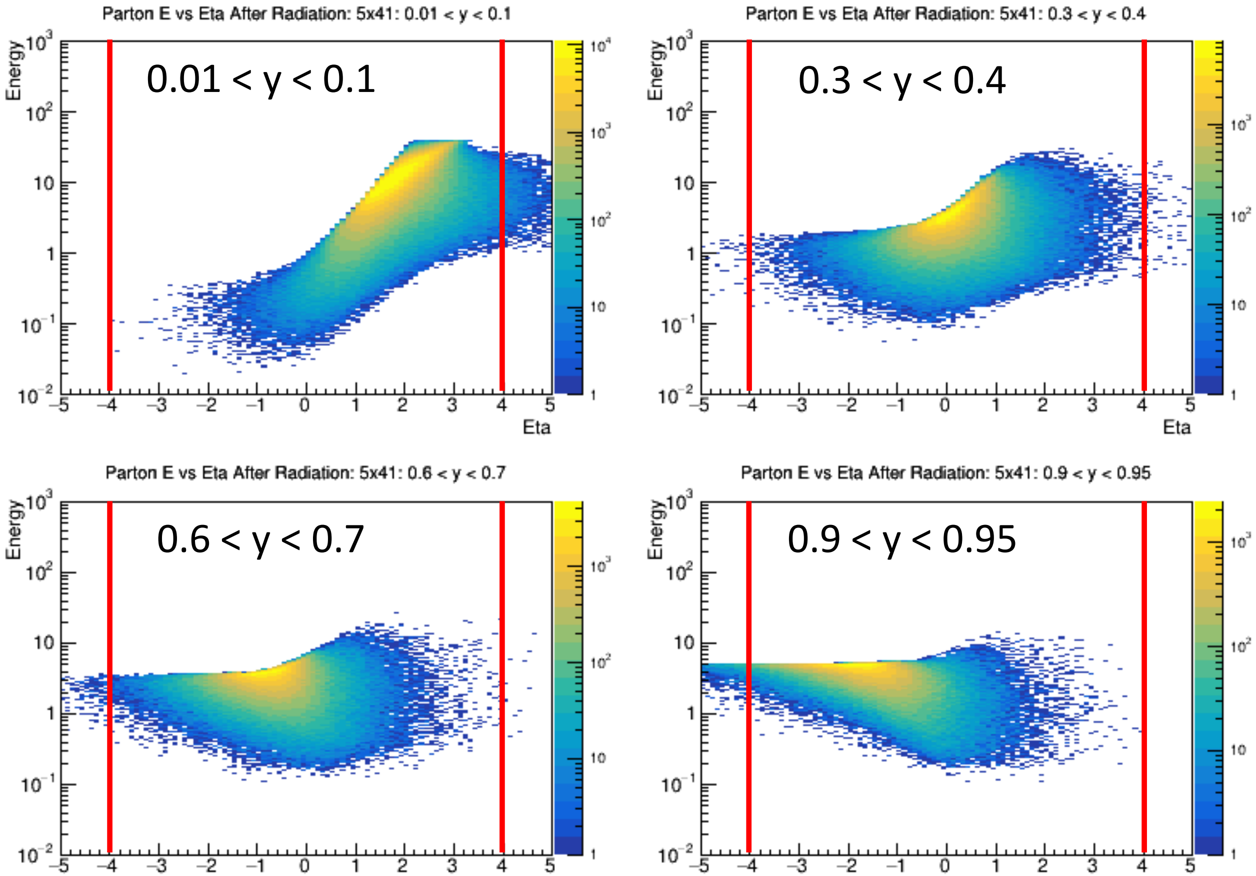
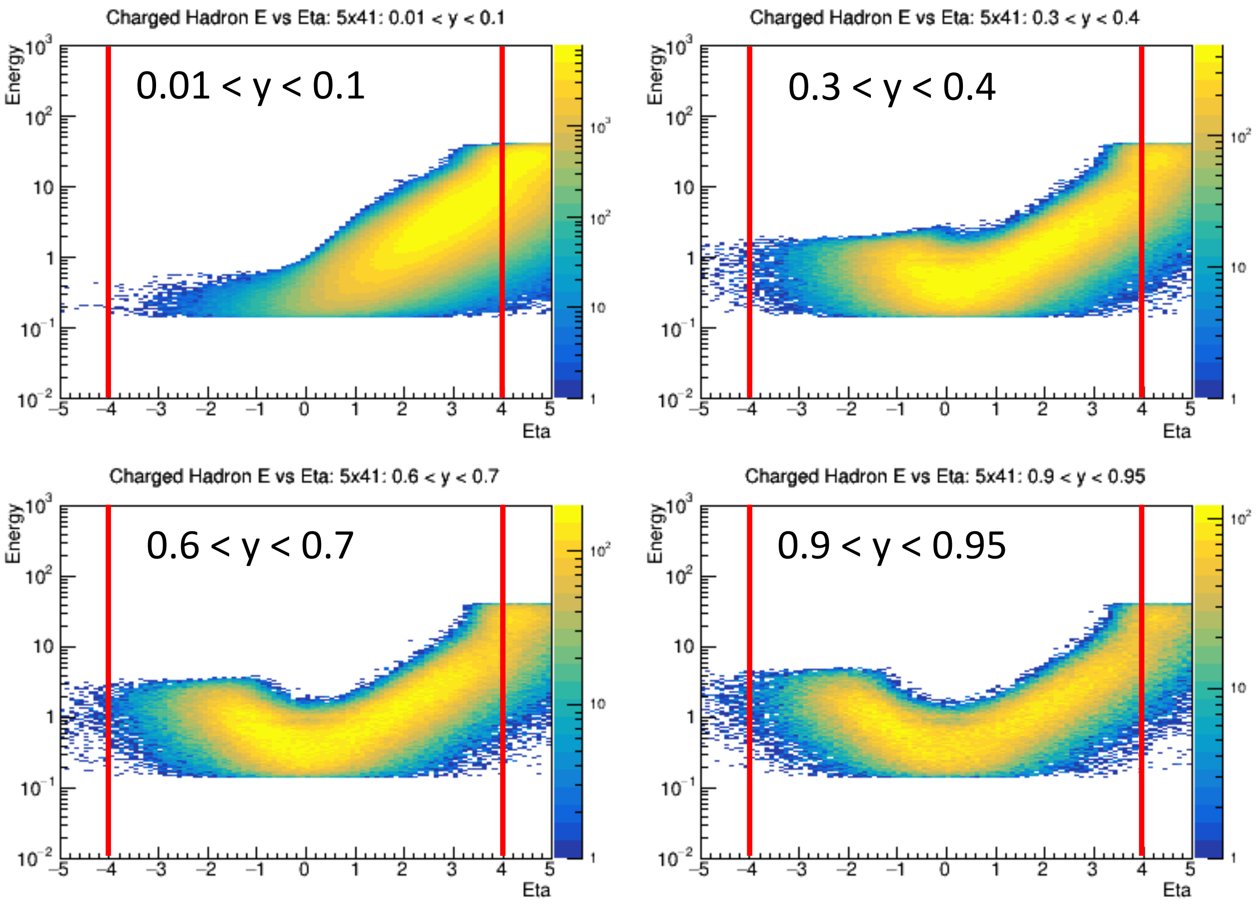


(Charged) Particle Distributions (5x41)

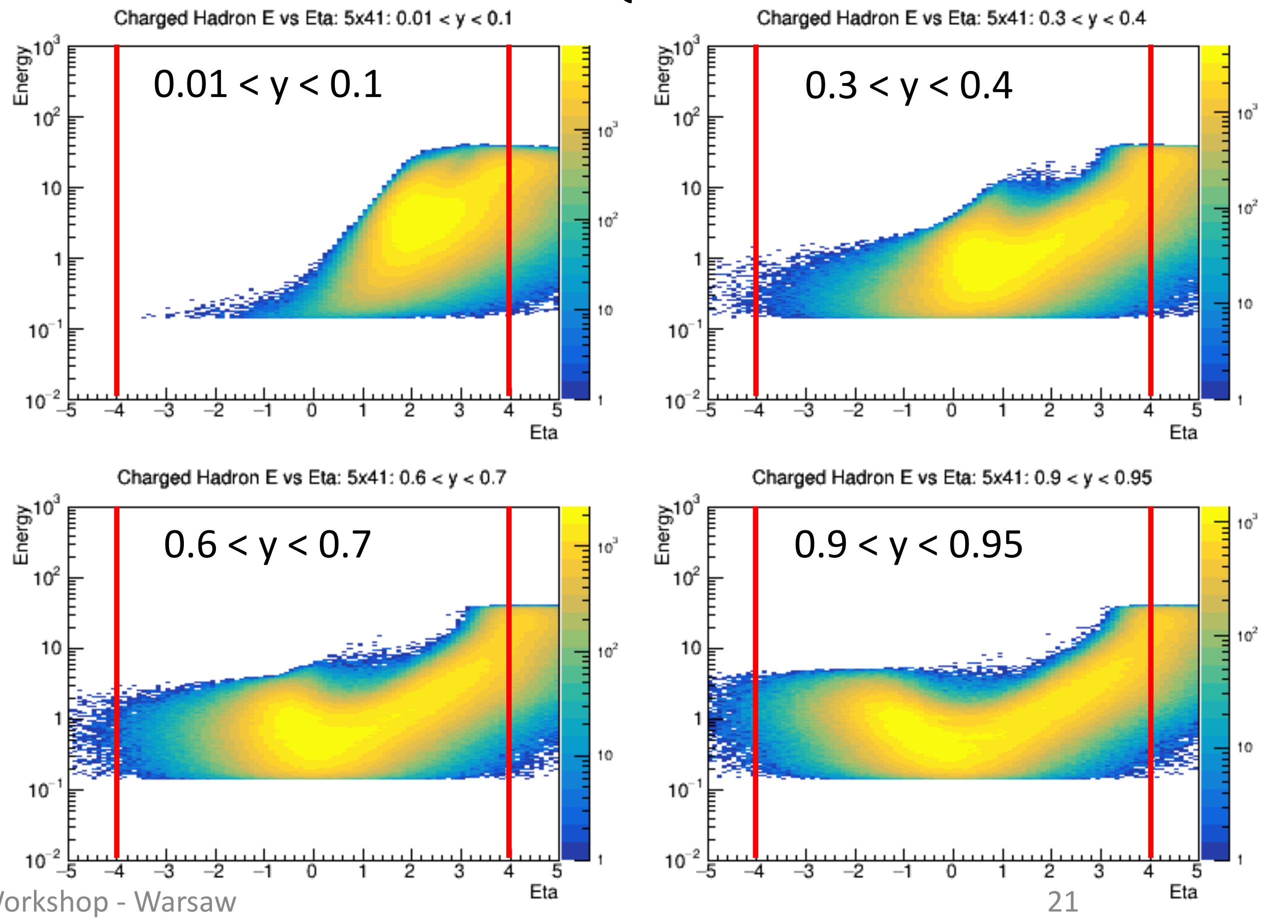


$0.1 < Q^2 < 1.0$

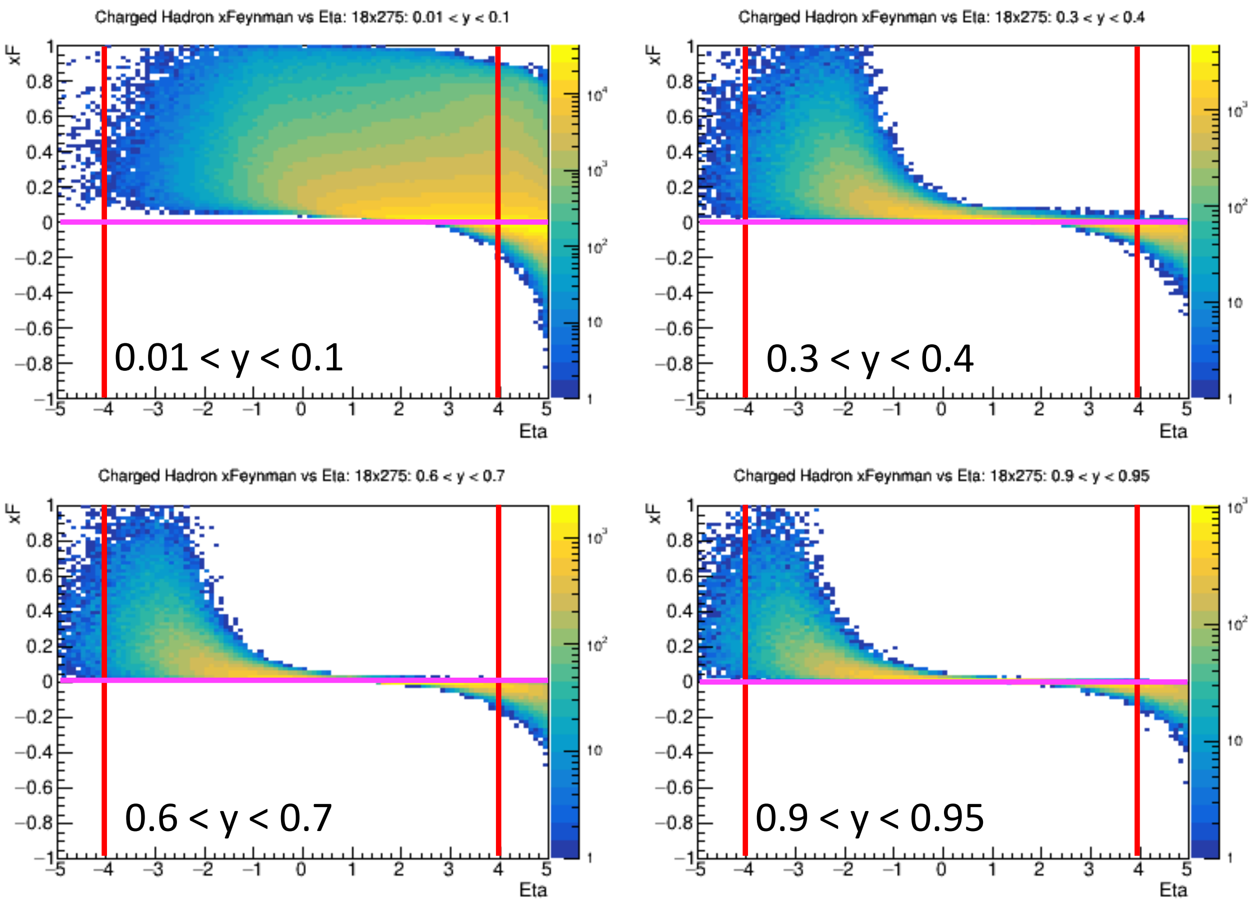
- ❑ Particle production not associated only with struck parton
- ❑ Gammas and neutrals follow same pattern

- ❑ Of course, it is final state hadrons which are measured
- ❑ Differences with y and Q2 are now somewhat less pronounced

$10 < Q^2 < 100$



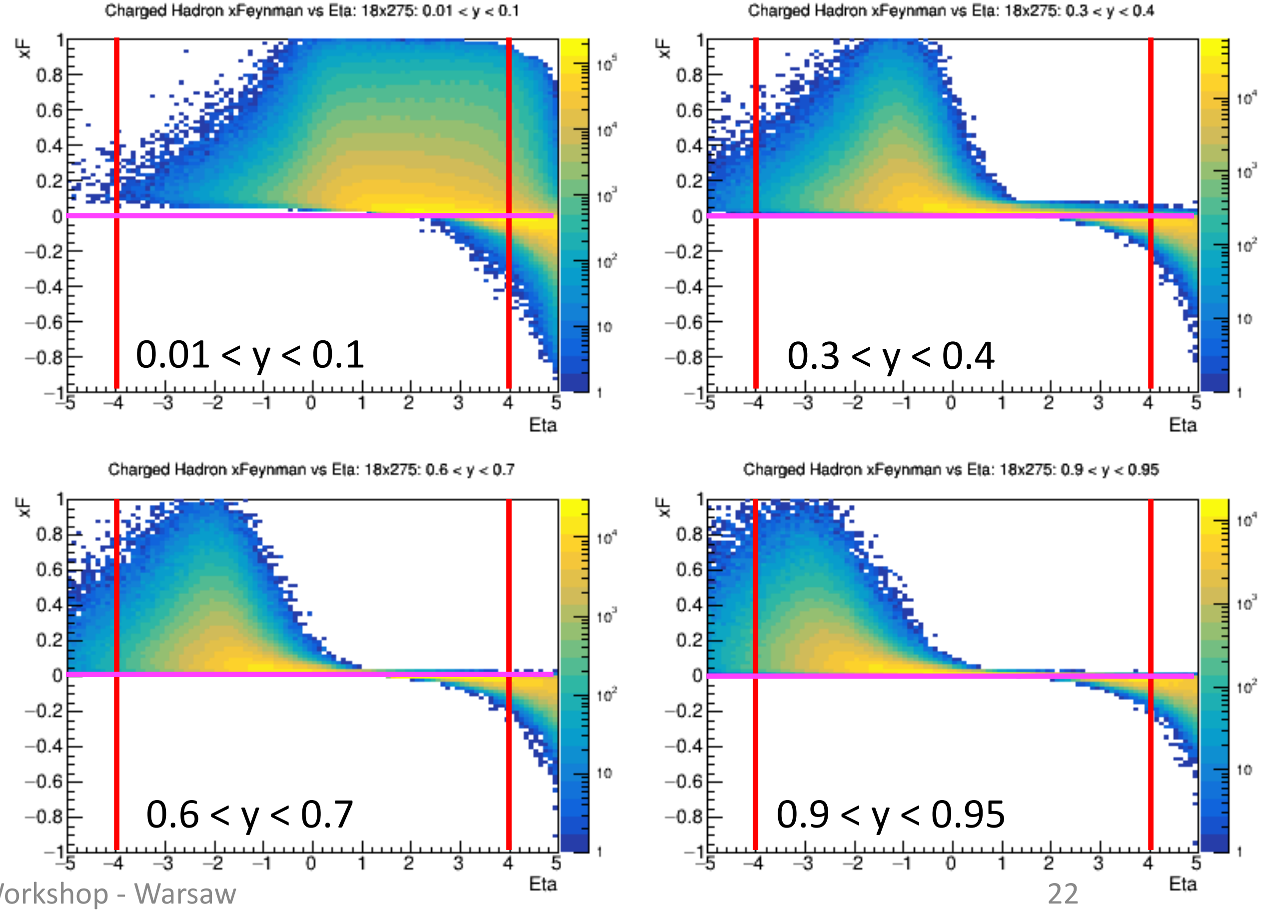
(Charged) Particle x-Feynman (18x275)



$0.1 < Q^2 < 1.0$

- ❑ Define xF as 2*particle_pZ/W in the hadron-boson center of mass frame
- ❑ Z-axis defined w.r.t. the virtual photon

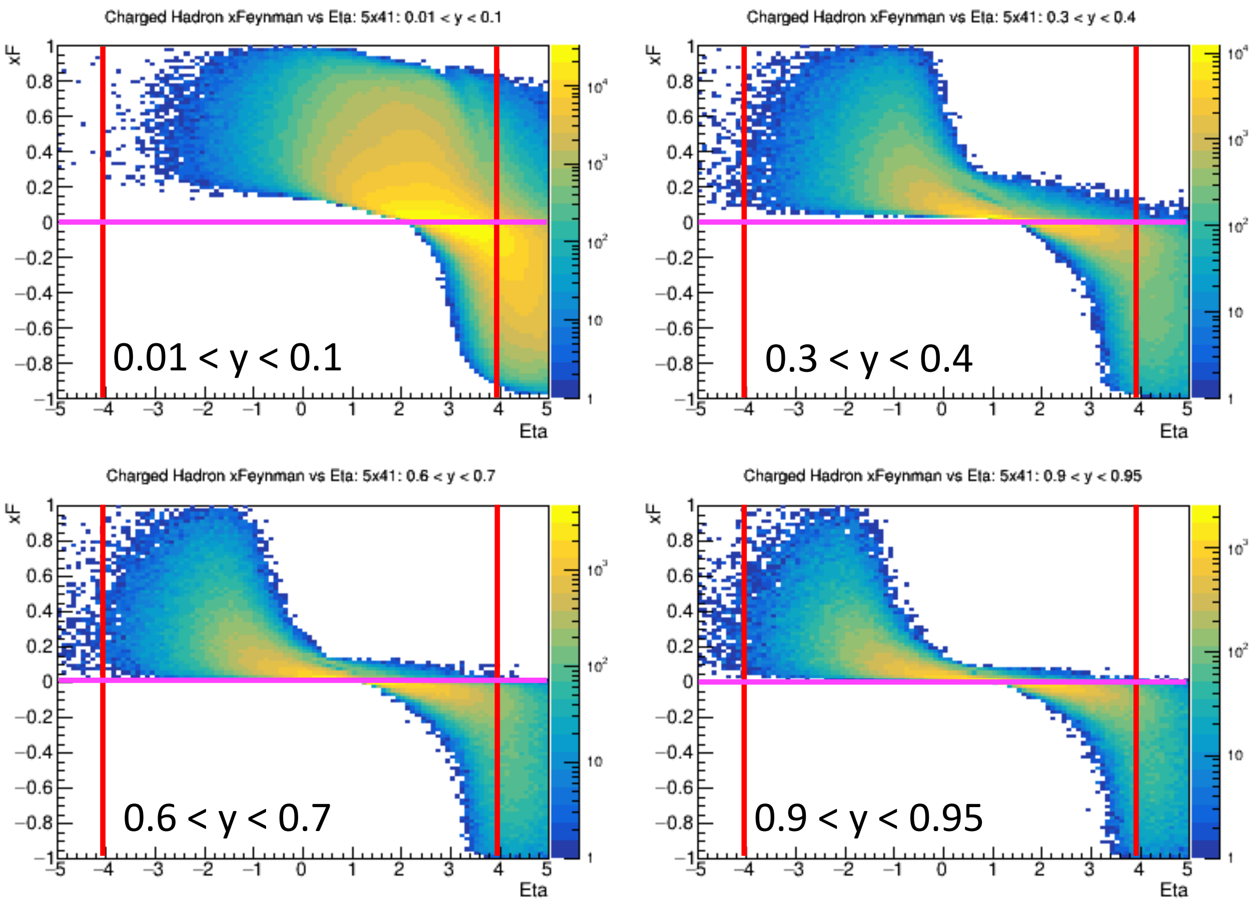
$10 < Q^2 < 100$



- ❑ Positive xF indicates particles more associated with the struck quark

(Charged) Particle x-Feynman (5x41)

- ❑ Larger negative xF particles come into the detector acceptance for lower beam energies



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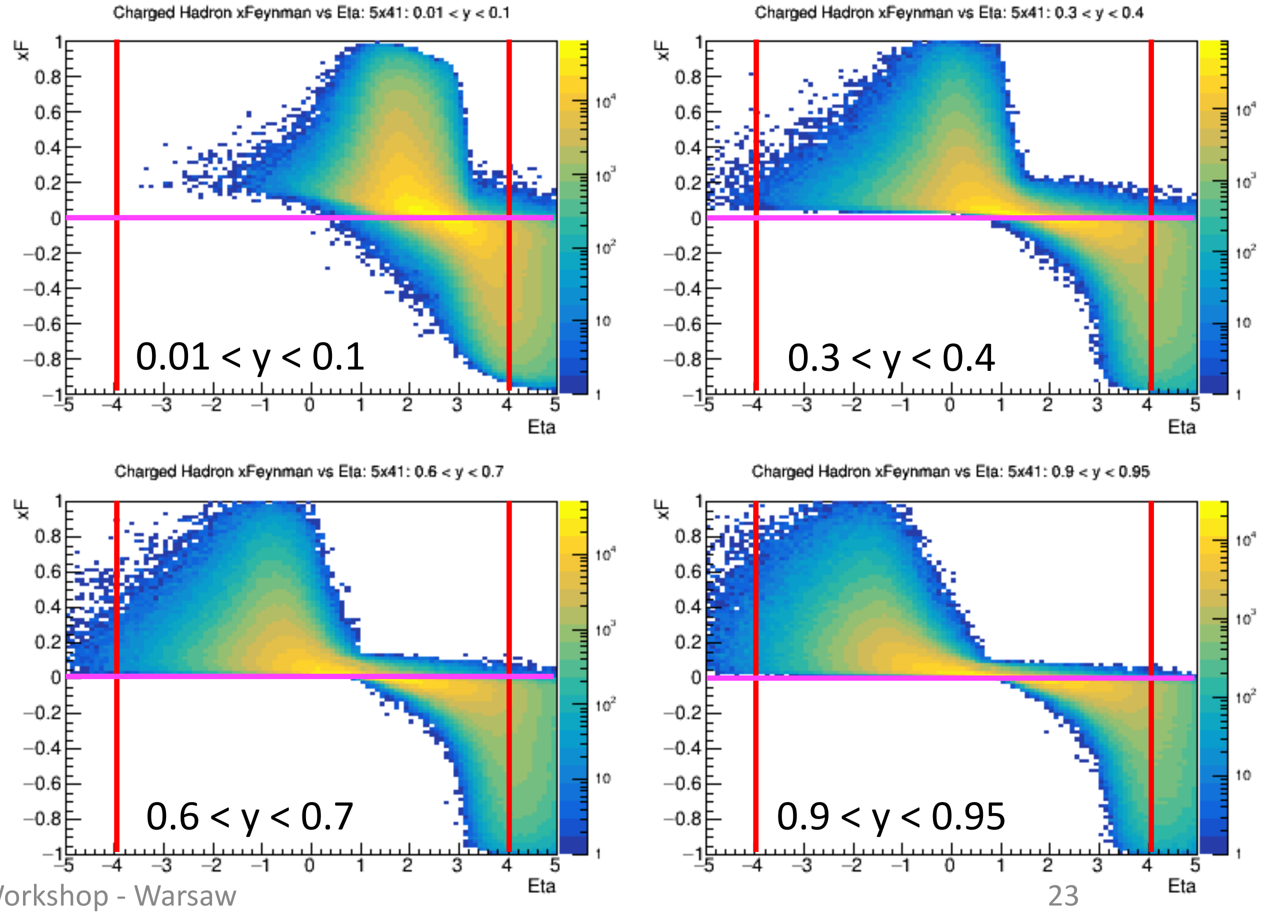

- ❑ Study differences in fragmentation in these regions
- ❑ Look at correlations between these regions