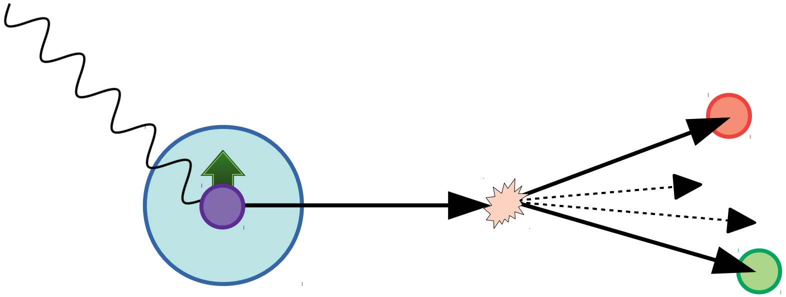
Dihadrons at the EIC



Christopher Dilks

4 May 2020

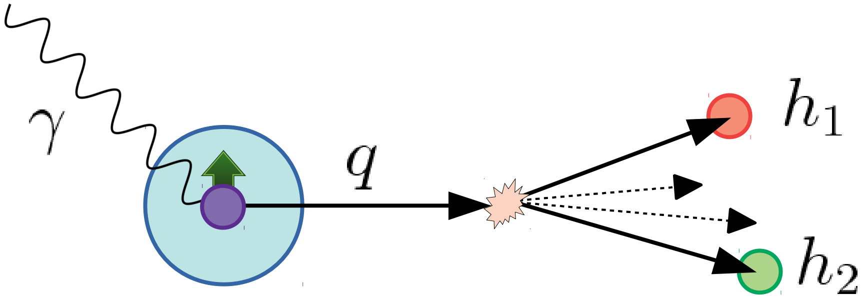
YR-SIDIS Meeting

Duke UNIVERSITY

Dihadrons: Probing Spin-Orbit Correlations in Hadronization

Unpolarized SIDIS:

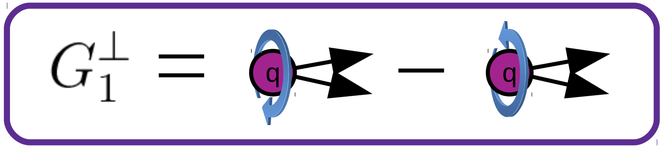
- **Cahn Effect**: quark transverse momentum leads to azimuthal modulations of SIDIS cross section
- **Boer-Mulders Effect:** Non-collinear quarks in an unpolarized proton can have transverse polarization, also contributing azimuthal modulations

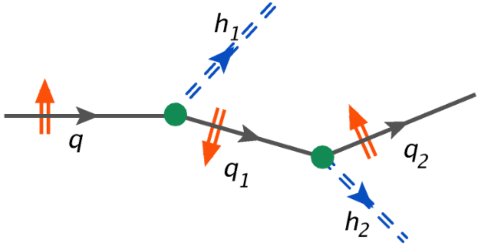


- **Boer-Mulders and Cahn effects are comparable in single hadron production**
  - HERMES and COMPASS data, e.g. Phys.Rev.D 81 (2010) 114026
- **Dihadrons can help decouple BM from Cahn**
  - Extra degree of freedom in dihadrons
    - Cahn effect impacts dihadron total momentum direction P_h
    - Utilize azimuthal angle about P_h, in addition to the azimuth about the virtual photon
- **Advantages from a broader and higher Q^2 range at an EIC**
  - Broader Q^2 range probes evolution effects
  - Higher Q^2 suppresses Cahn effect in single-hadron asymmetries (Cahn is twist-4)
  - Lower Q^2 for overlap with other SIDIS experiments

Dihadrons: Probing Spin-Orbit Correlations in Hadronization

Longitudinally polarized SIDIS:



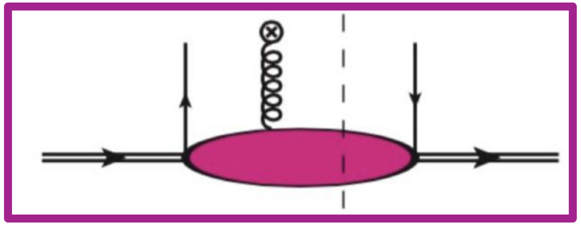


Helicity DiFF $G_1^{\perp}$:

- **Not yet constrained by data!**
- **Spin-orbit correlations** in hadronization
- Fragmenting quark acquires transverse polarization via ‘wormgear’ splitting in the quark-jet hadronization model
- Preliminary CLAS12 data indicate **significant effect**, dependent on invariant mass

Collinear Twist-3 PDFs e(x) and $h_L(x)$:

- **CLAS6 data provided the first e(x) extraction, consistent with models; CLAS12 data are in agreement**
- Physical Interpretation via moments of e(x):
  - **Transverse color-force** on a transversely polarized struck-quark, in an unpolarized proton
  - **πN sigma terms:**
    - Quark mass contribution to proton mass
    - Quark chromomagnetic dipole moment → CP-odd π-N coupling
- **No experimental constraints yet for $h_L(x)$**



Transversely polarized SIDIS: **Access several additional TMDs**

Transverse Momentum Dependent Distributions and Fragmentation Functions

Twist-2 TMDs

QUARKS	*unpolarized*	*chiral*	*transverse*
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_{1T}, $h_{1T}^\perp$

Twist-3 TMDs

N/q	U	L	T
U	$f^\perp$	$g^\perp$	h , e
L	$f_L^\perp$	$g_L^\perp$	h_L , e_L
T	f_T , $f_T^\perp$	g_T , $g_T^\perp$	h_T , e_T , $h_T^\perp$, $e_T^\perp$

e, h_L, and g_T are collinear

Dihadron Fragmentation Functions (DiFFs)

$h_1 h_2/q$	U	L	T
UU	$D_{1,OO}$		$H_{1,OO}^\perp$
LU	$D_{1,OL}$		$H_{1,OL}^\perp$
LL	$D_{1,LL}$		$H_{1,LL}^\perp$
TU	$D_{1,OT}$	$G_{1,OT}^\perp$	$\begin{cases} H_{1,OT}^\perp & \text{if } m<0 \\ H_{1,OT}^\sphericalangle & \text{if } m>0 \end{cases}$
TL	$D_{1,LT}$	$G_{1,LT}^\perp$	$\begin{cases} H_{1,LT}^\perp & \text{if } m<0 \\ H_{1,LT}^\sphericalangle & \text{if } m>0 \end{cases}$
TT	$D_{1,TT}$	$G_{1,TT}^\perp$	$\begin{cases} H_{1,TT}^\perp & \text{if } m<0 \\ H_{1,TT}^\sphericalangle & \text{if } m>0 \end{cases}$

Dihadron Structure Functions → PDF convolved with DiFF

F_{UU}: $f_1 \otimes D_1$, $h_1^{\perp} \otimes H_1$, $h \otimes H_1$

F_{LU}: $f_1 \otimes G_1$, $e \otimes H_1$

F_{UL}: $g_{1L} \otimes G_1$, $h_{1L}^{\perp} \otimes H_1$, $h_L \otimes H_1$

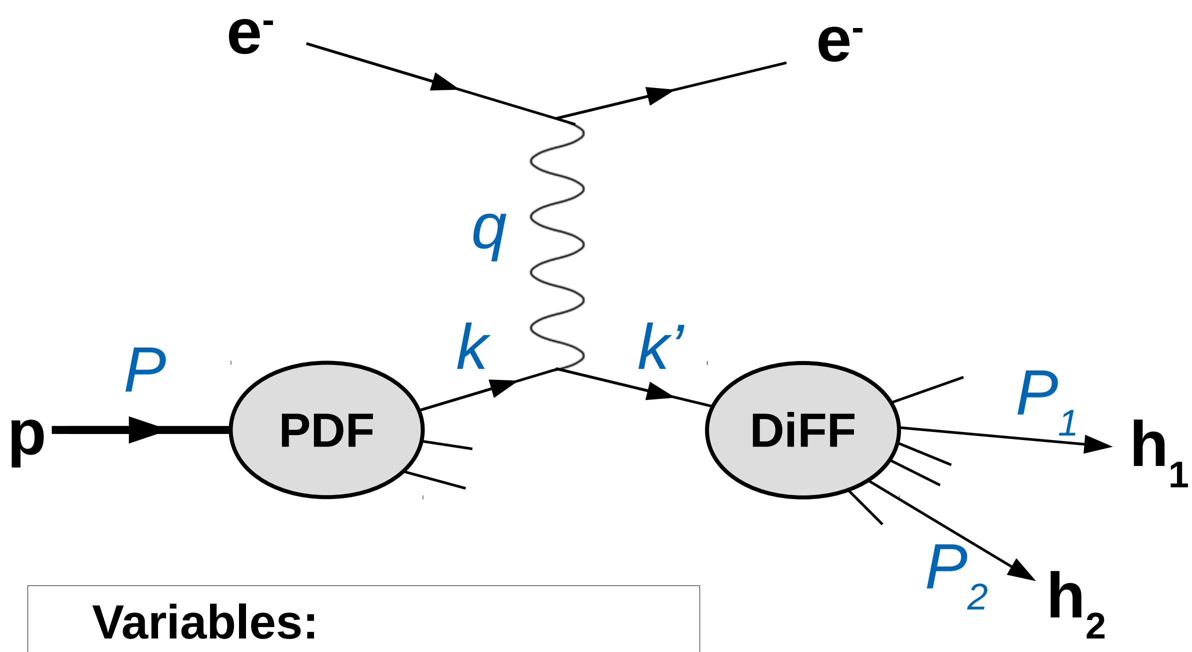
F_{LL}: $g_{1L} \otimes D_1$, $e_L \otimes H_1$

F_{UT}: $f_{1T}^{\perp} \otimes D_1 + g_{1T} \otimes G_1$, $h_1 \otimes H_1$, $h_{1T}^{\perp} \otimes H_1$, $f_T \otimes D_1$, $f_T^{\perp} \otimes D_1$, $h_T \otimes H_1$, $h_T^{\perp} \otimes H_1$

F_{LT}: $g_{1T} \otimes D_1 + f_{1T}^{\perp} \otimes G_1$, $g_T \otimes D_1$, $g_T^{\perp} \otimes D_1$, $e_T \otimes H_1$, $e_T^{\perp} \otimes H_1$

- Dihadrons are sensitive to a *zoo* of PDFs and DiFFs
- Cross section modulations
  - Boer-Mulders Function
- Longitudinal spin asymmetries
  - Helicity DiFF $G_1^{\perp}$
  - Collinear Twist-3 PDFs
- Transverse Spin Asymmetries
  - Sivers, Wormgear, Transversity, Pretzelocity
  - Twist-3 TMDs
- θ-dependence → DiFF partial waves

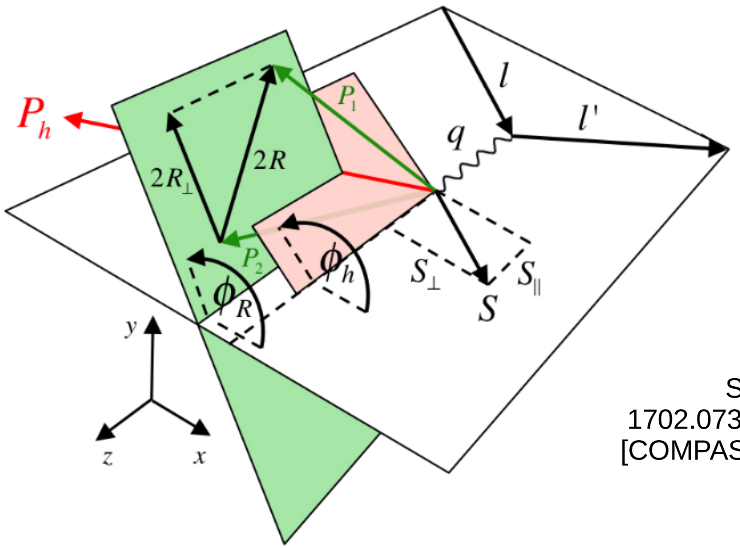
Dihadron Kinematics



Momenta and Angles

$$P_h = P_1 + P_2 \rightarrow \phi_h$$

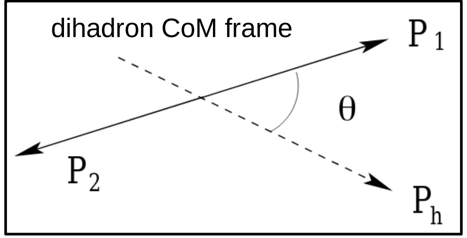
$$R = \frac{1}{2}(P_1 - P_2) \rightarrow \phi_R$$



Sirtl
1702.07317
[COMPASS]

Variables:
- Scale: Q^2
- Bjorken-x: x
- Feynman-x: x_F
- Invariant Mass: M_h
- Fragmentation fraction: z
- Missing Mass: M_X

Dihadron CoM production angle:



Event Selection

$Q^2 > 1\ \text{GeV}^2$ cut for event generator

$E'_e < E_e$ scattered electron has less energy than incident electron

$W > 3\ \text{GeV}$ exclude elastic / resonance region

$0.01 < y < 0.95$ lower bound is to avoid region in which calculating x, Q2, etc. via the e' momentum may differ from that from JB method

$x_{F_h} > 0$ ensures hadrons are produced in the current fragmentation region

$z_h > 0.01$ cuts out long M_h tail at z~0 peak (need to think about...)

$z_{h_1 h_2} < 0.95$ helps avoid exclusive region

For Kinematic Maps, focus on $\pi^+\pi^-$

Dataset

Energies:
- 5x41 $\sqrt{s}$ = 28.7 GeV
- 5x100 $\sqrt{s}$ = 44.7 GeV
- 10x100 $\sqrt{s}$ = 63.3 GeV
- 18x275 $\sqrt{s}$ = 140.7 GeV

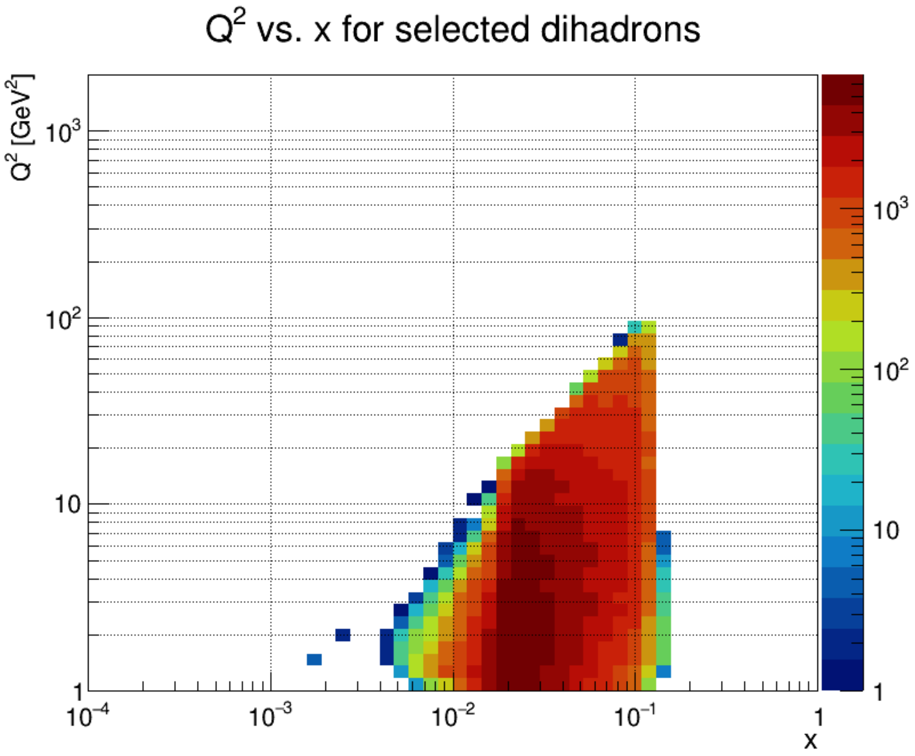
Event Generation
- Pythia8 + DiRE (plan to switch to Pythia6+RADGEN soon)
  - 1M events
  - Radiative corrections (including QED) enabled via `PDF:lepton=on`
  - All other parameters follow `dis_example.cmnd` in the escalate tutorial notebook
- Kinematic maps below focus on 10x100 and 18x275

Fast Simulation
- `eic_smear` with the `handbook` detector setting
- uses custom standalone eJANA plugin for production of dihadron trees

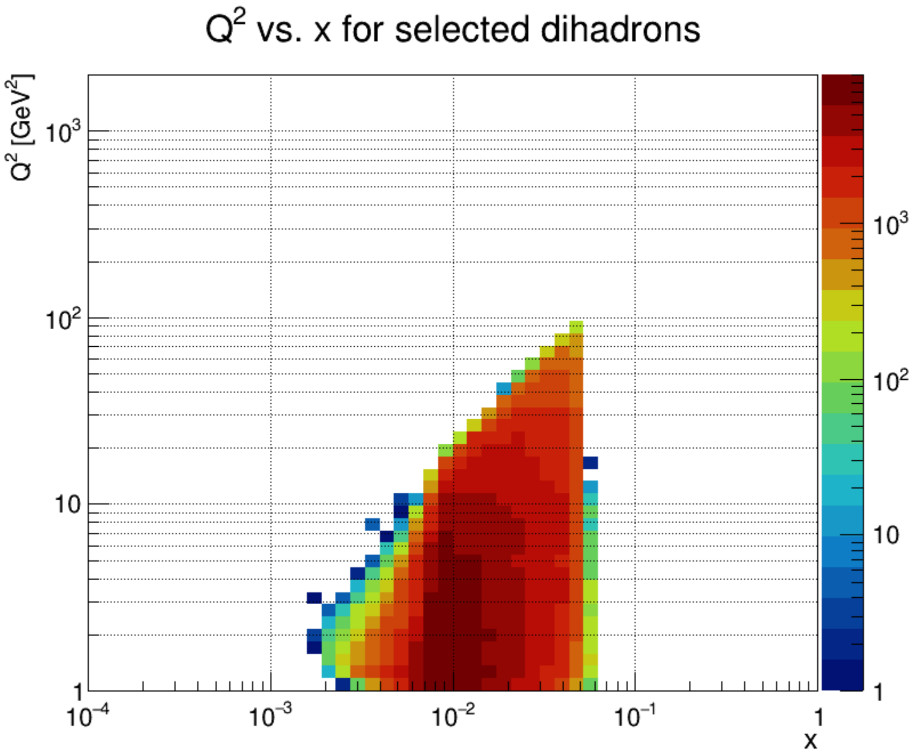
Analysis
- Dihadron trees compatible with CLAS analysis code, generalized for EIC
  - Architecture for asymmetry fits / projections is ready
  - Projections for partial wave amplitudes is also possible
- Kinematic Studies
- PID studies

(x,Q^2) Plane for 5x41 and 5x100

5x41 GeV

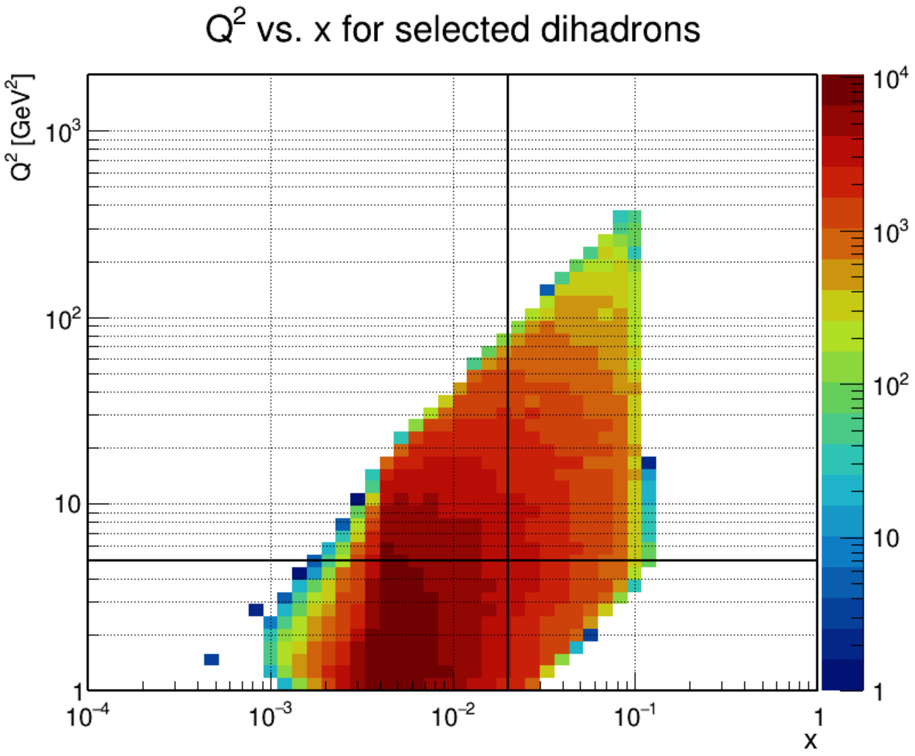


5x100 GeV

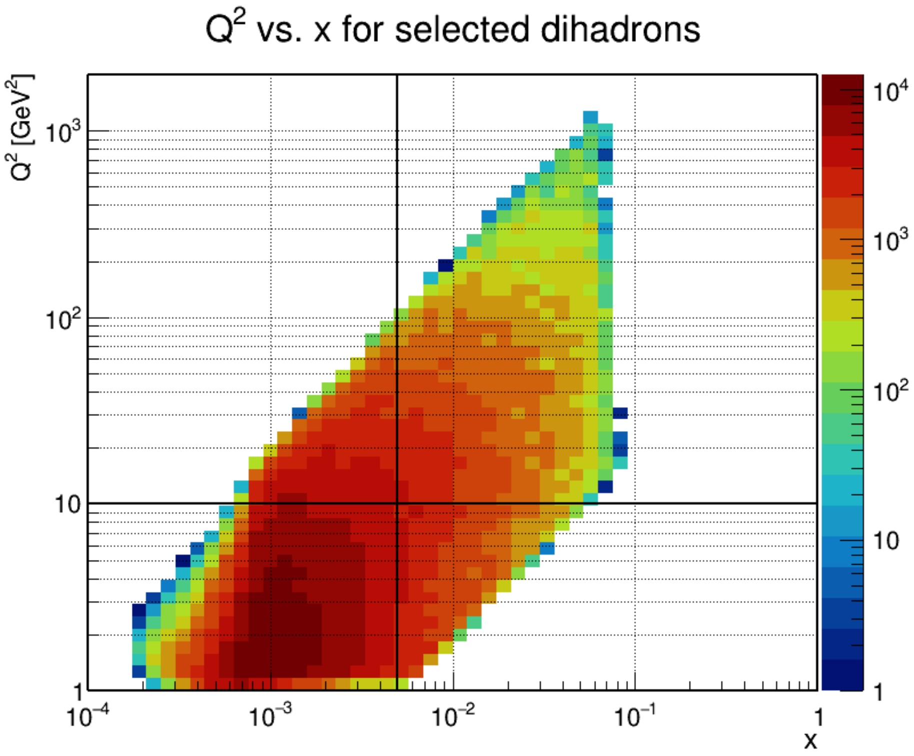


(x,Q^2) Plane for 10x100 and 18x275, and Binning for Kinematic Maps

10x100 GeV



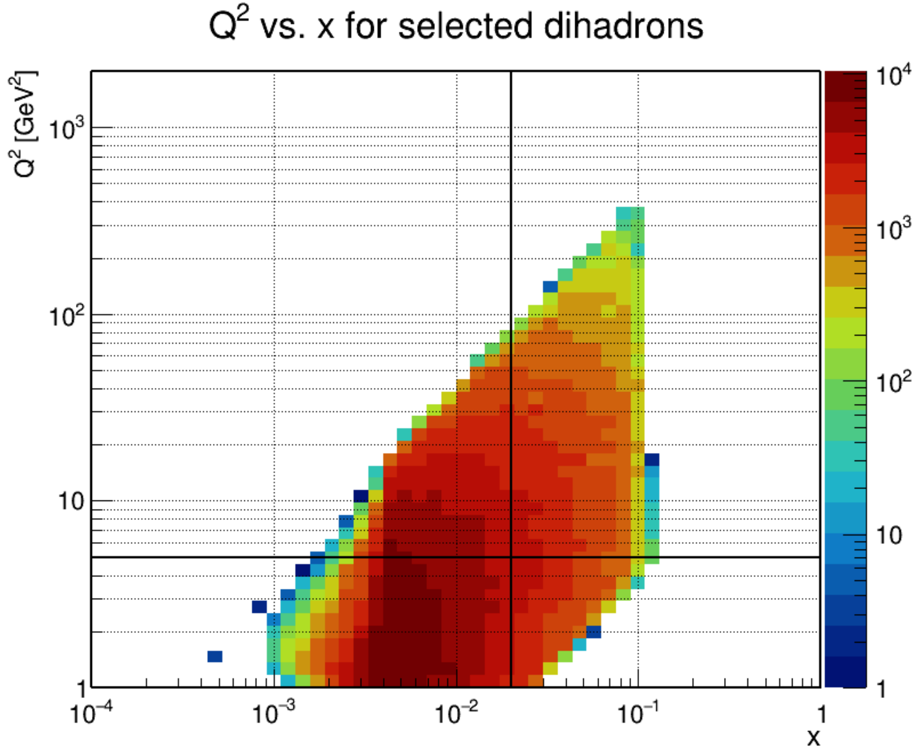
18x275 GeV

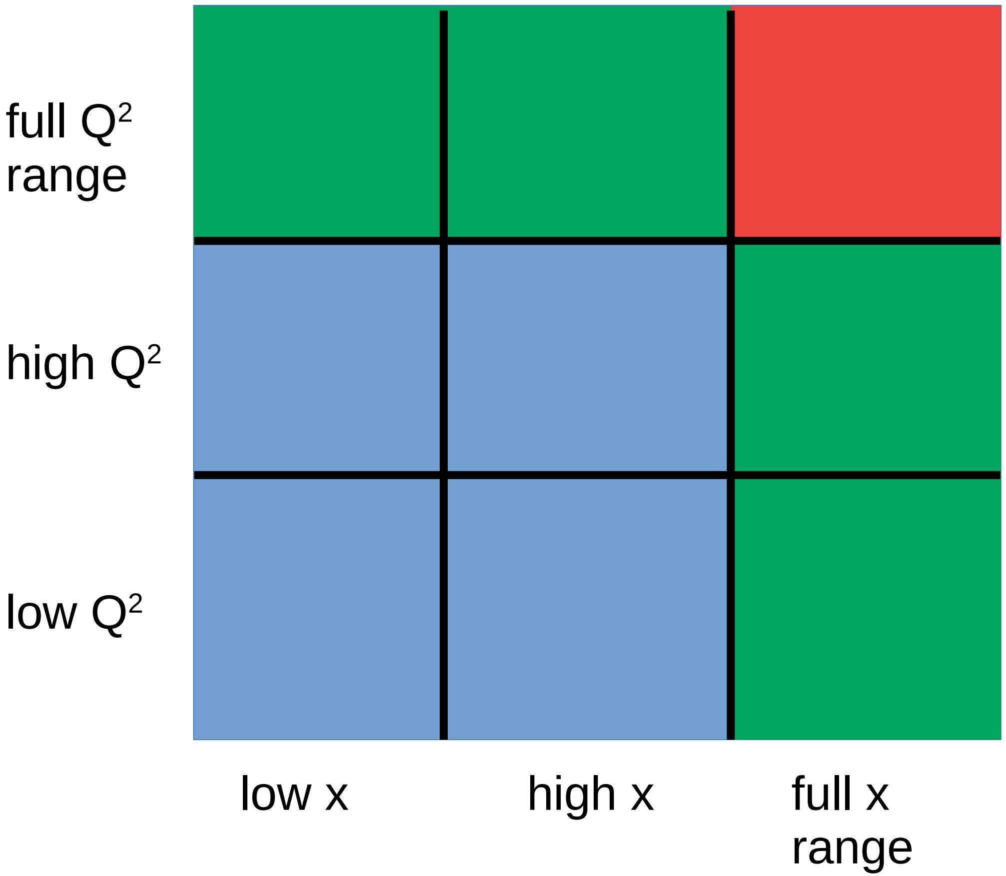


The next slides will focus on these two beam energy settings

Solid black lines demarcate (x,Q^2) bin boundaries, used in the following slides

(x,Q^2) Binning → Matrix of Plots



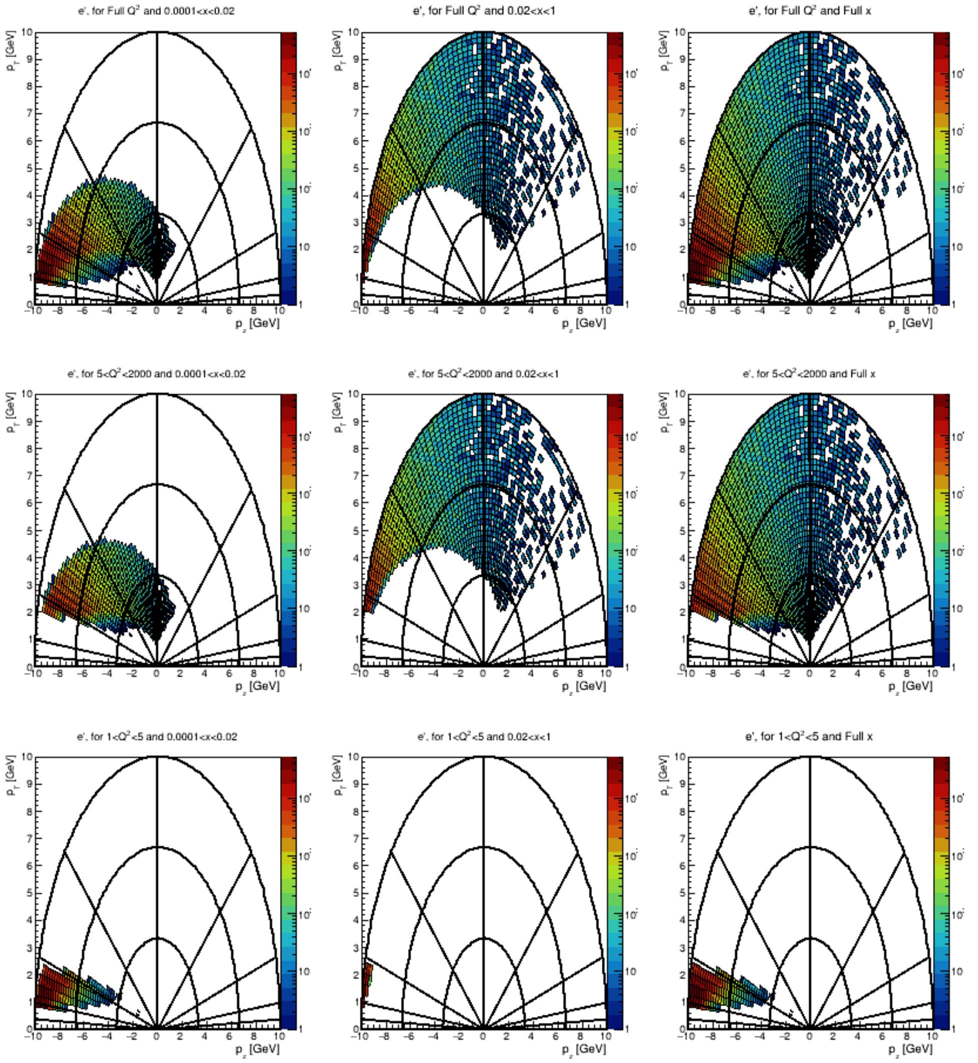


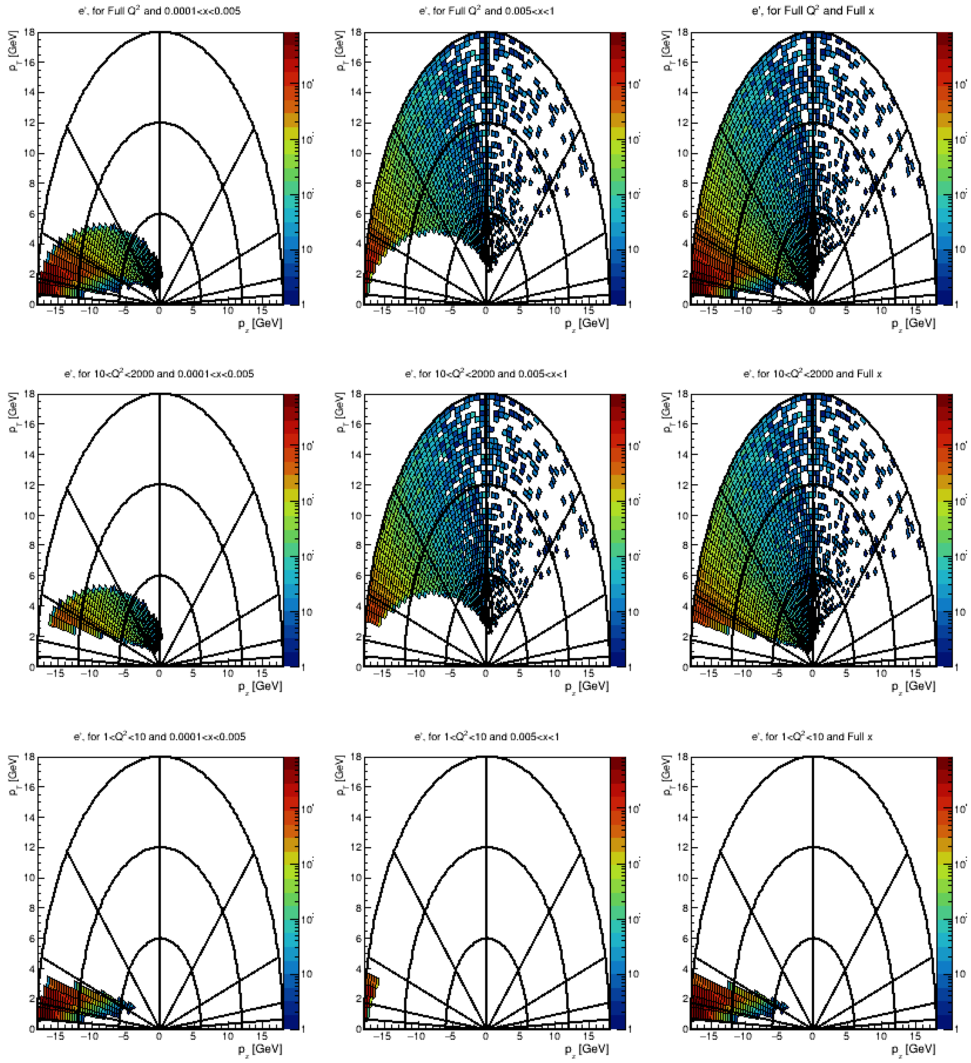
- Bottom-left four entries are the 4 bins shown in the (x,Q^2) plane
- Top row and right row respectively integrate over Q^2 and x
- Top-right entry is for the full x and Q^2 ranges

<u>10x100 GeV</u>

e’ p_T vs. p_z Polar Plots

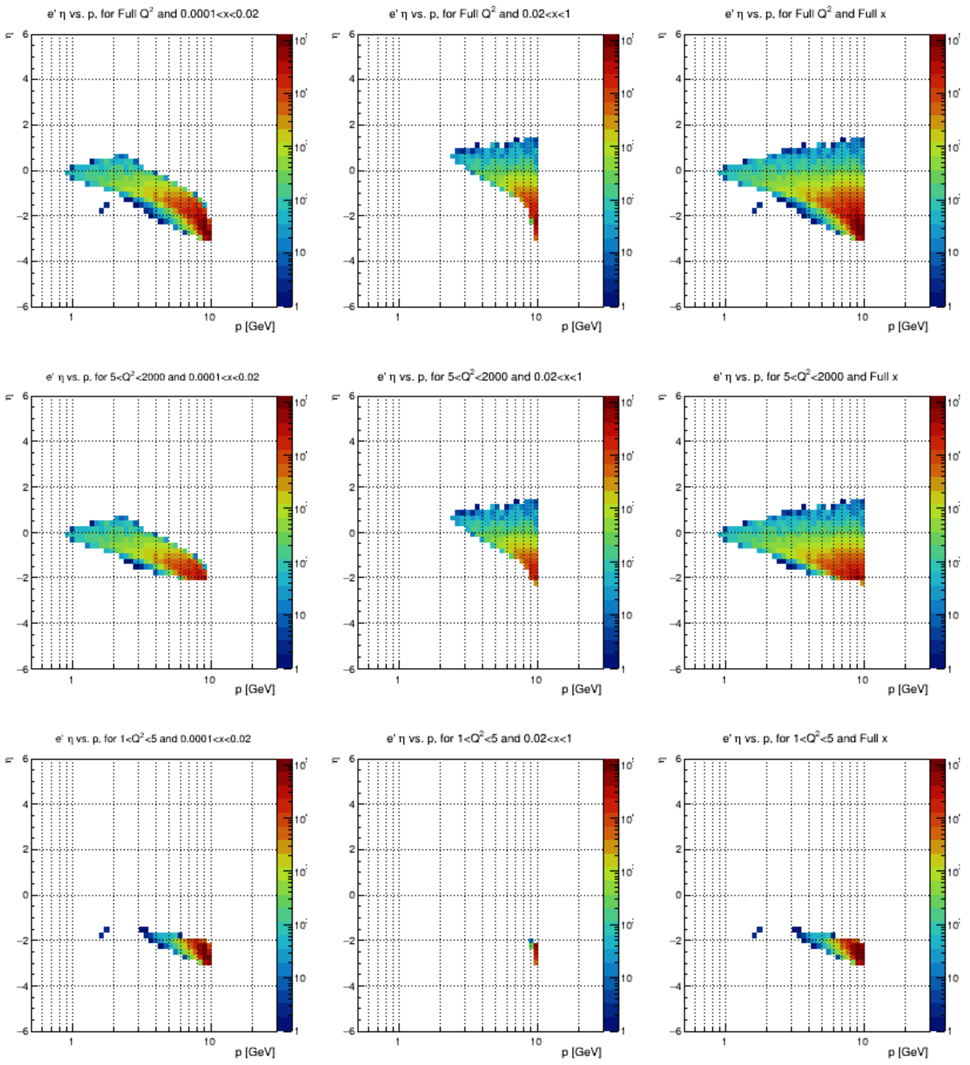
<u>18x275 GeV</u>



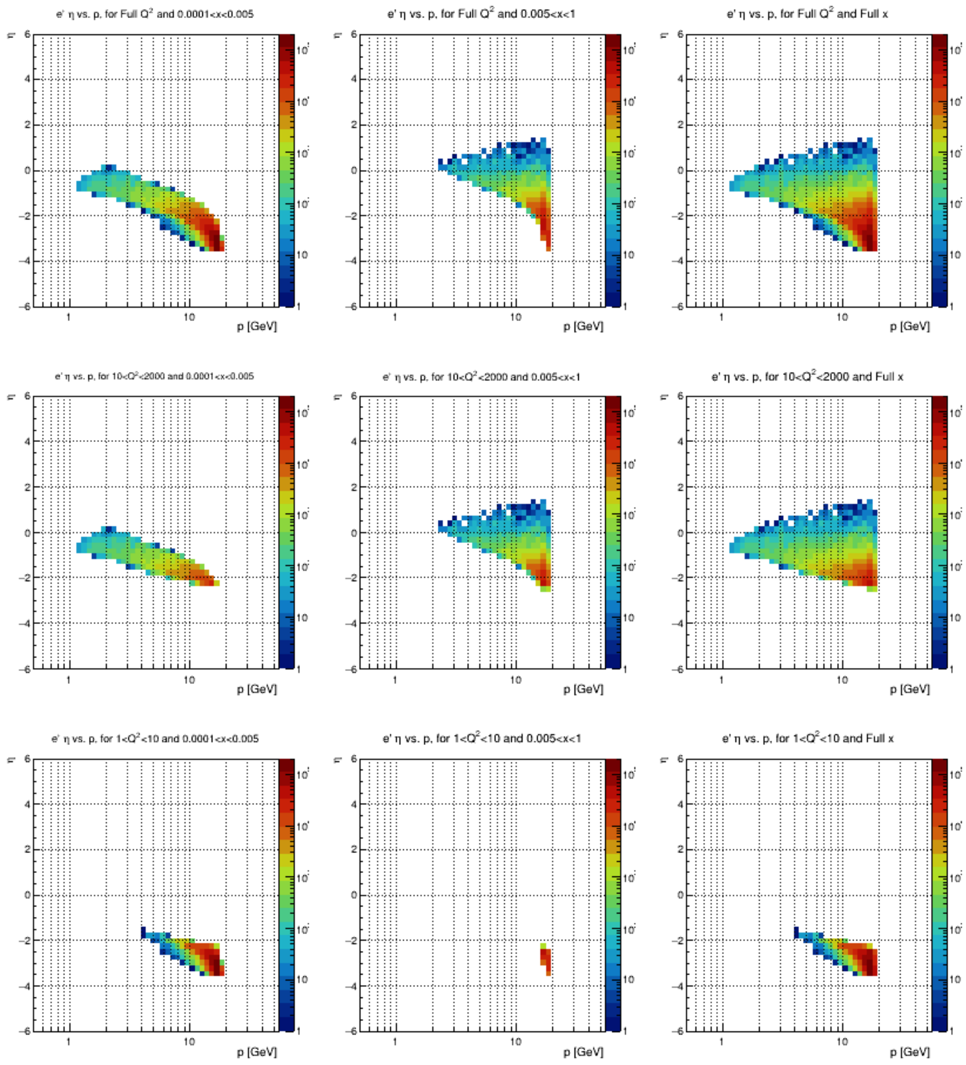


e’ η vs. p

10x100 GeV

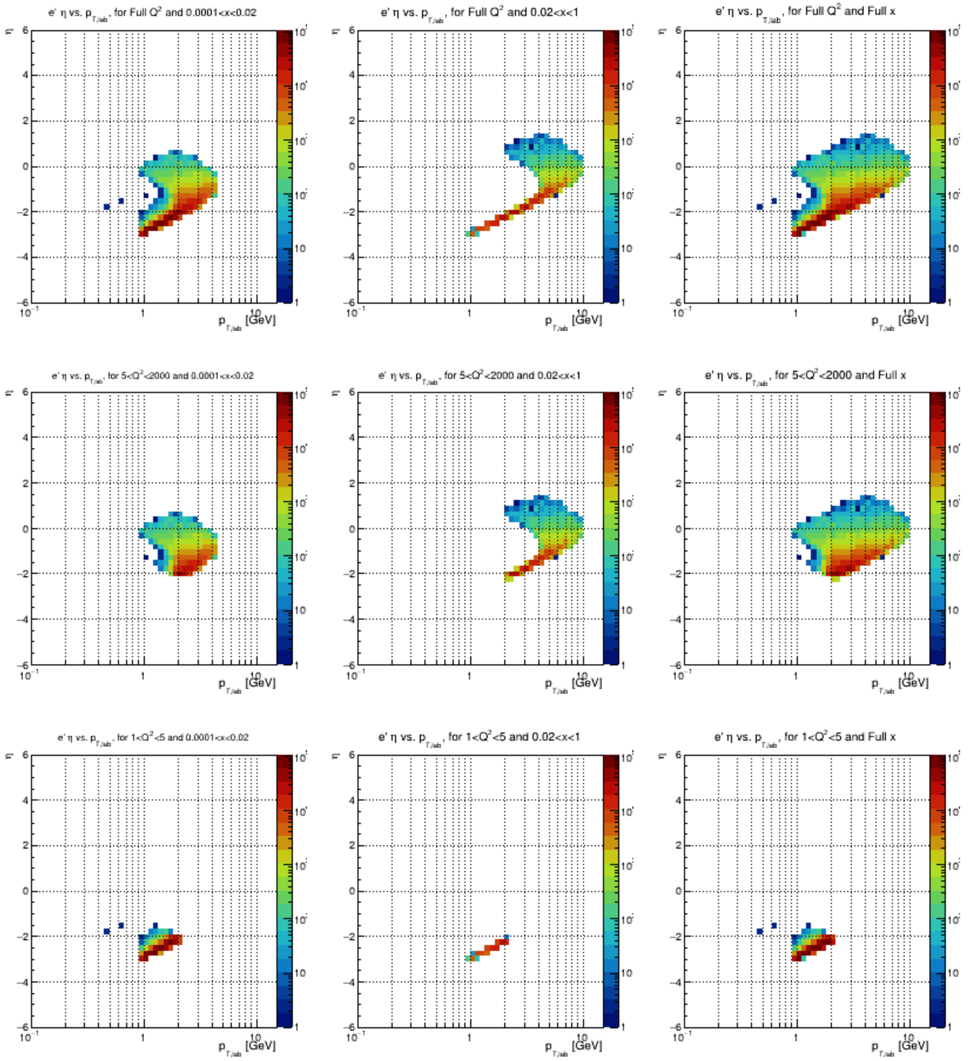


18x275 GeV

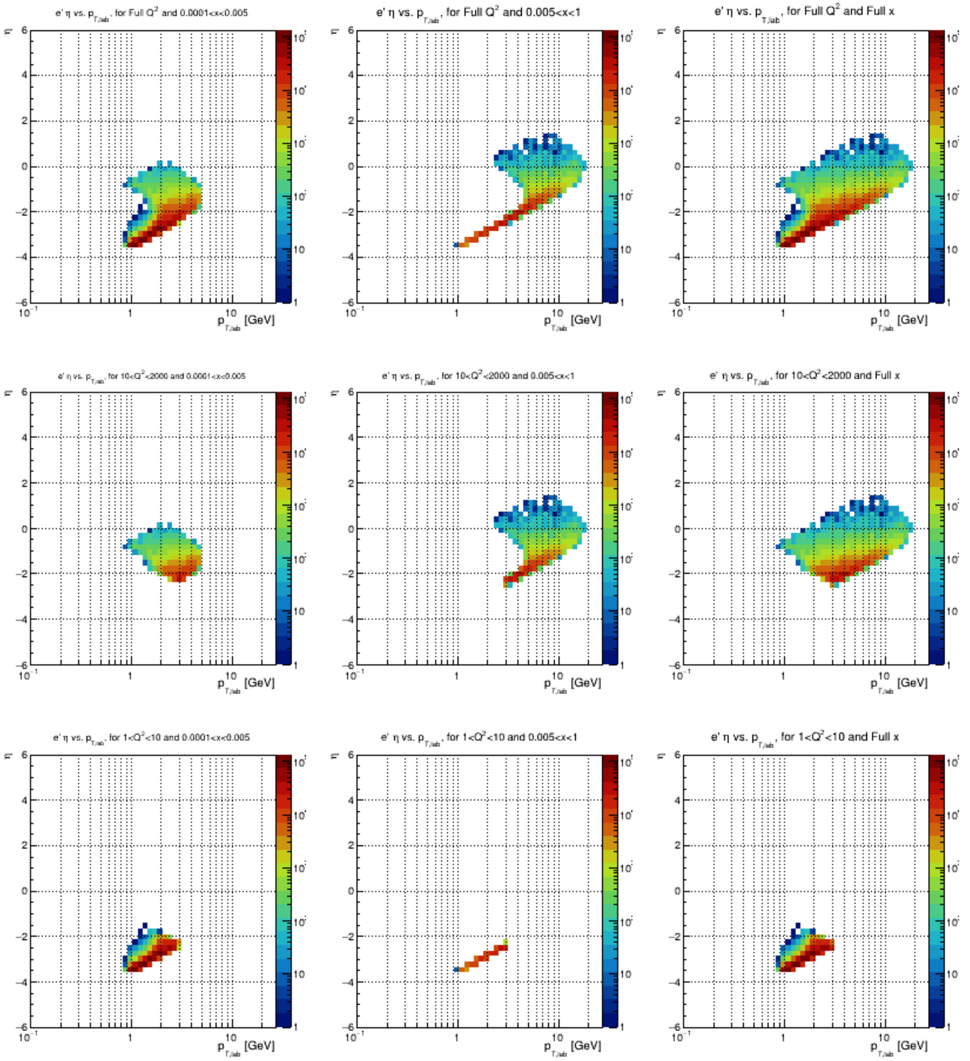


e’ η vs. p_T

10x100 GeV



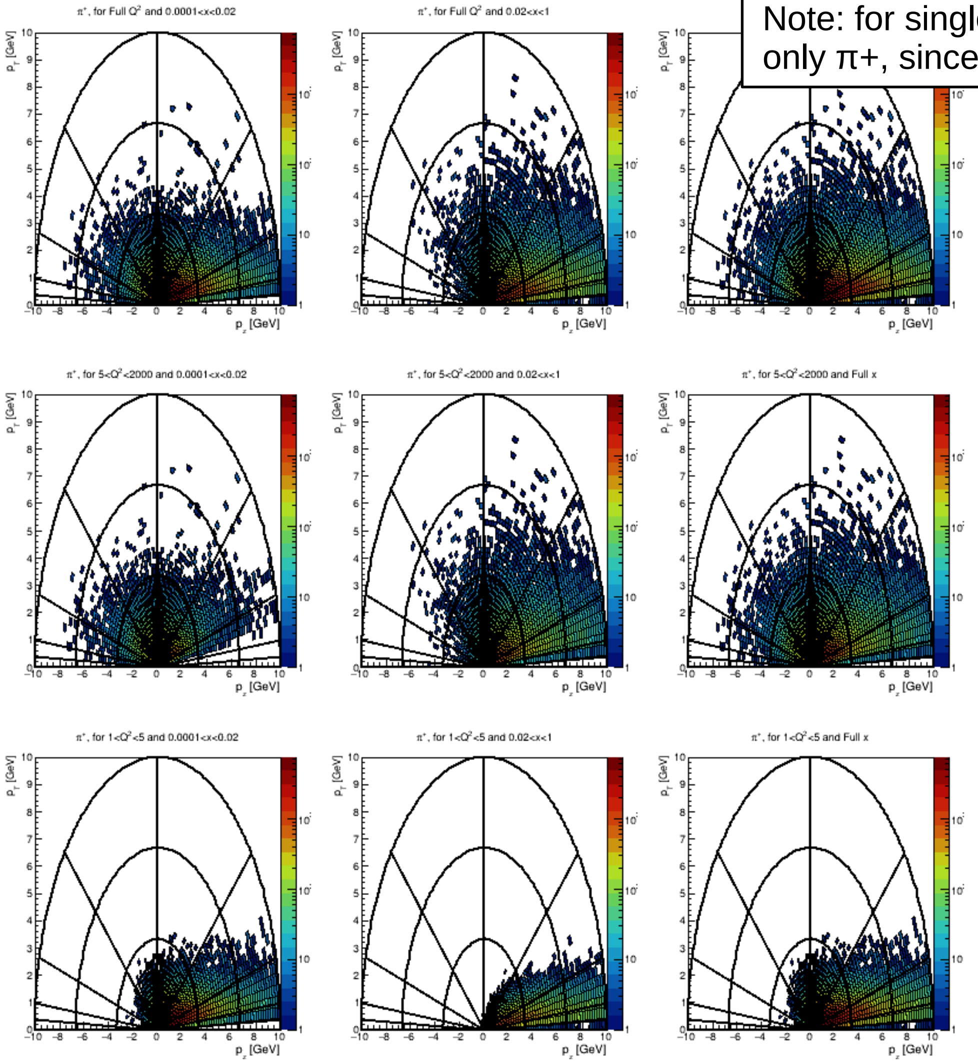
18x275 GeV



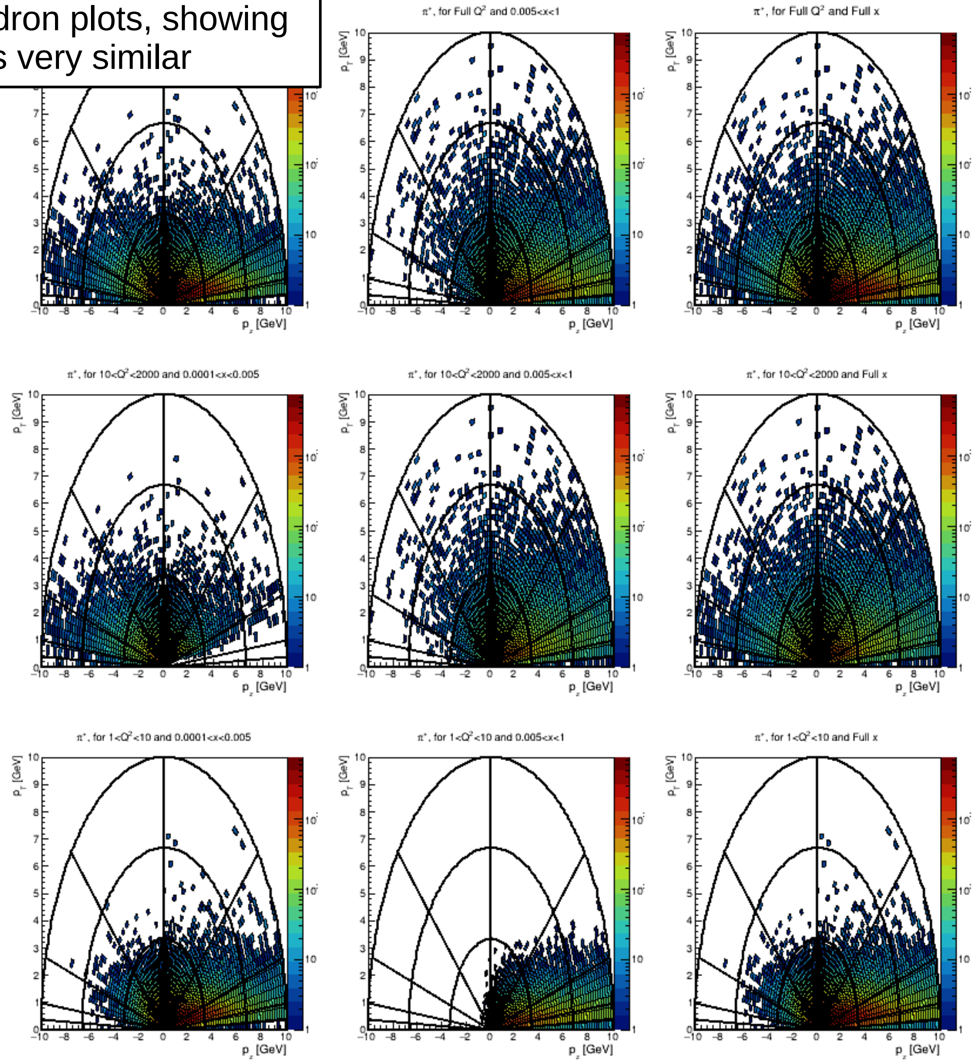
π^+ p_T vs. p_z Polar Plots

Note: for single hadron plots, showing only π+, since π- is very similar

10x100 GeV



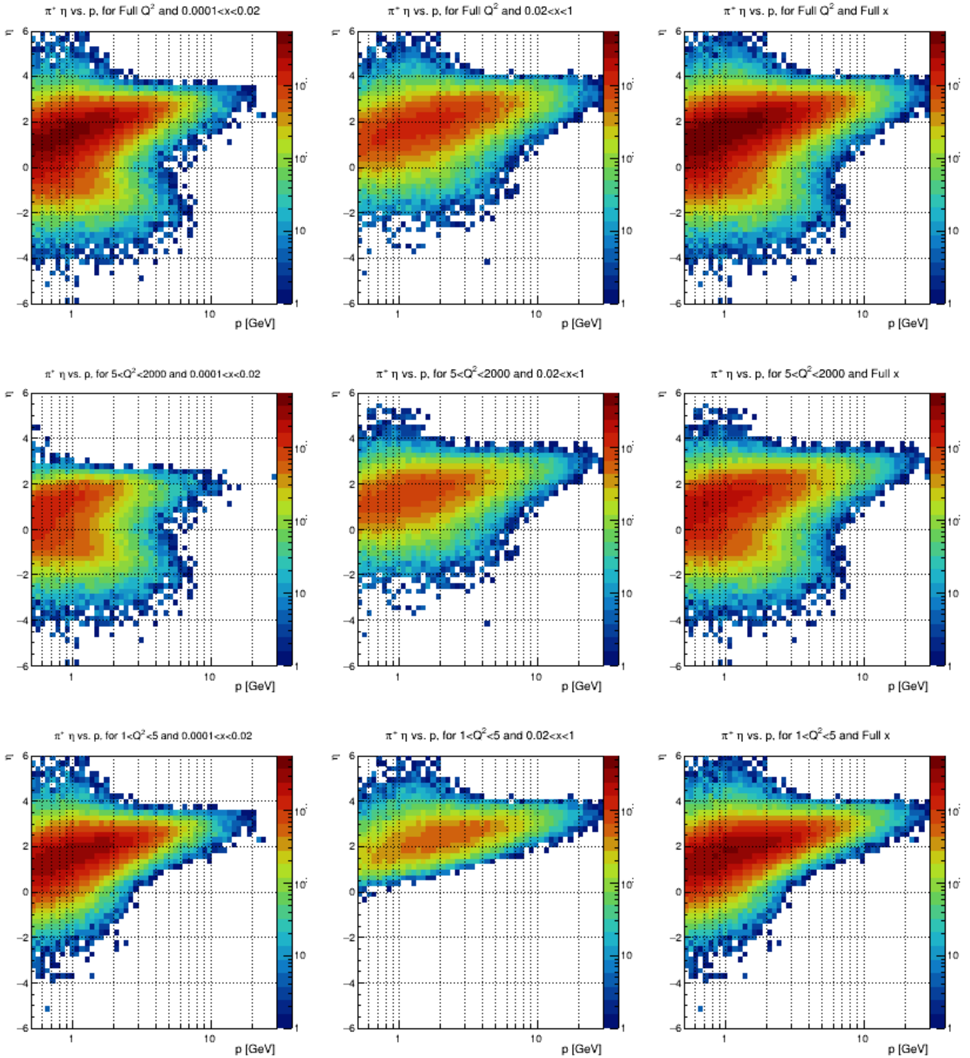
18x275 GeV

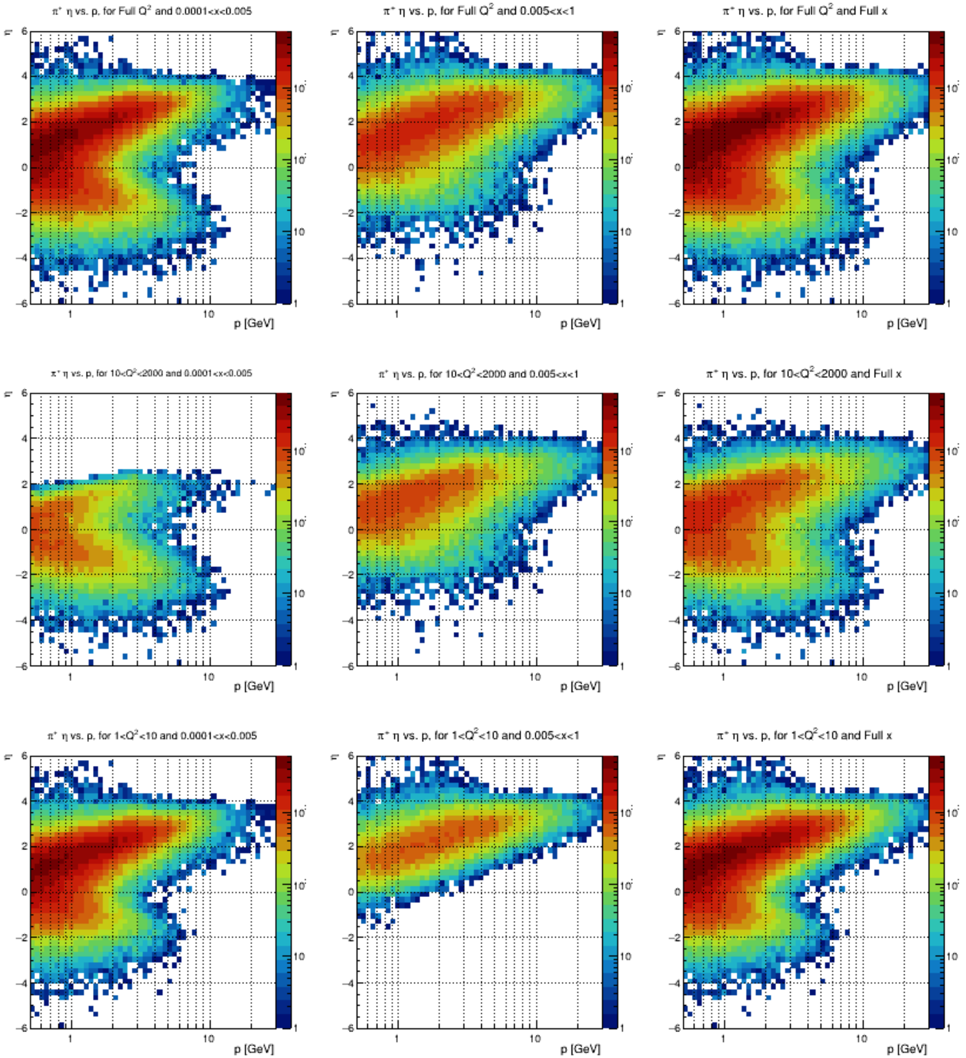


10x100 GeV

π^+ η vs. p

18x275 GeV

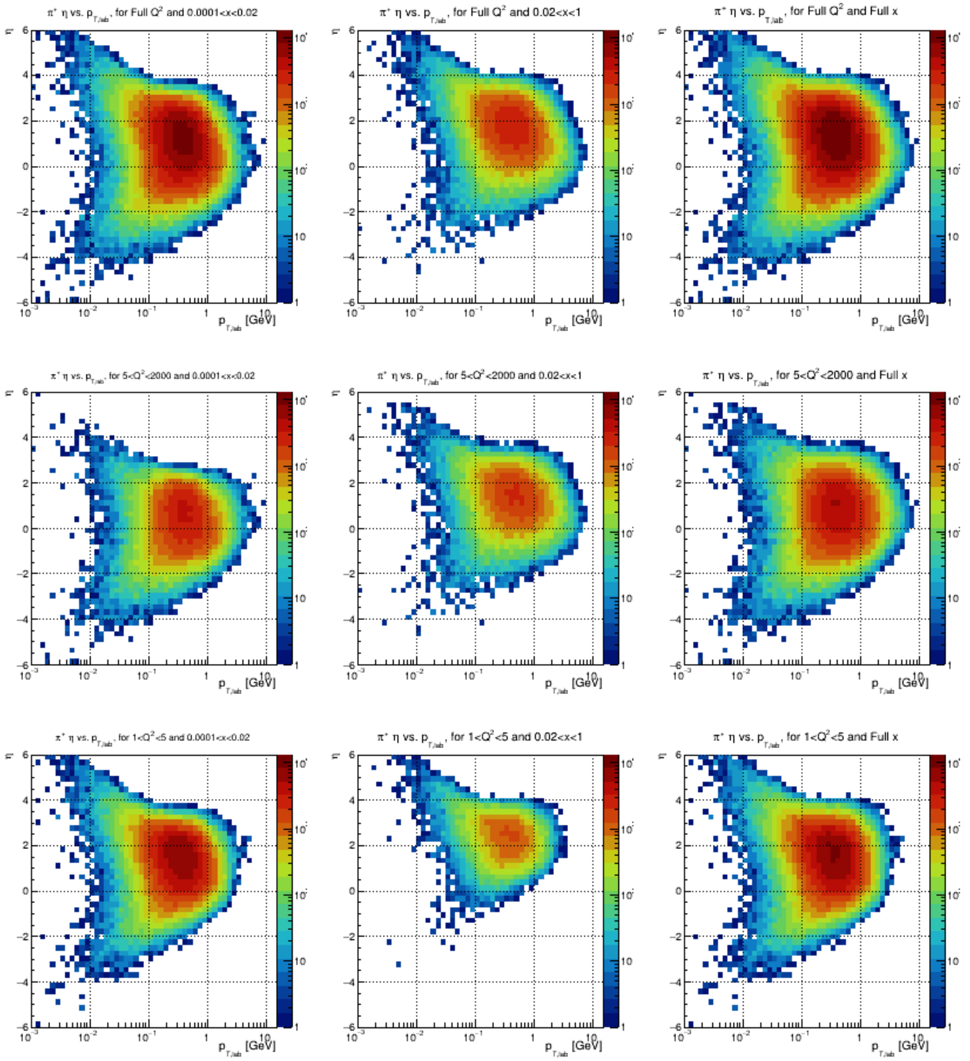


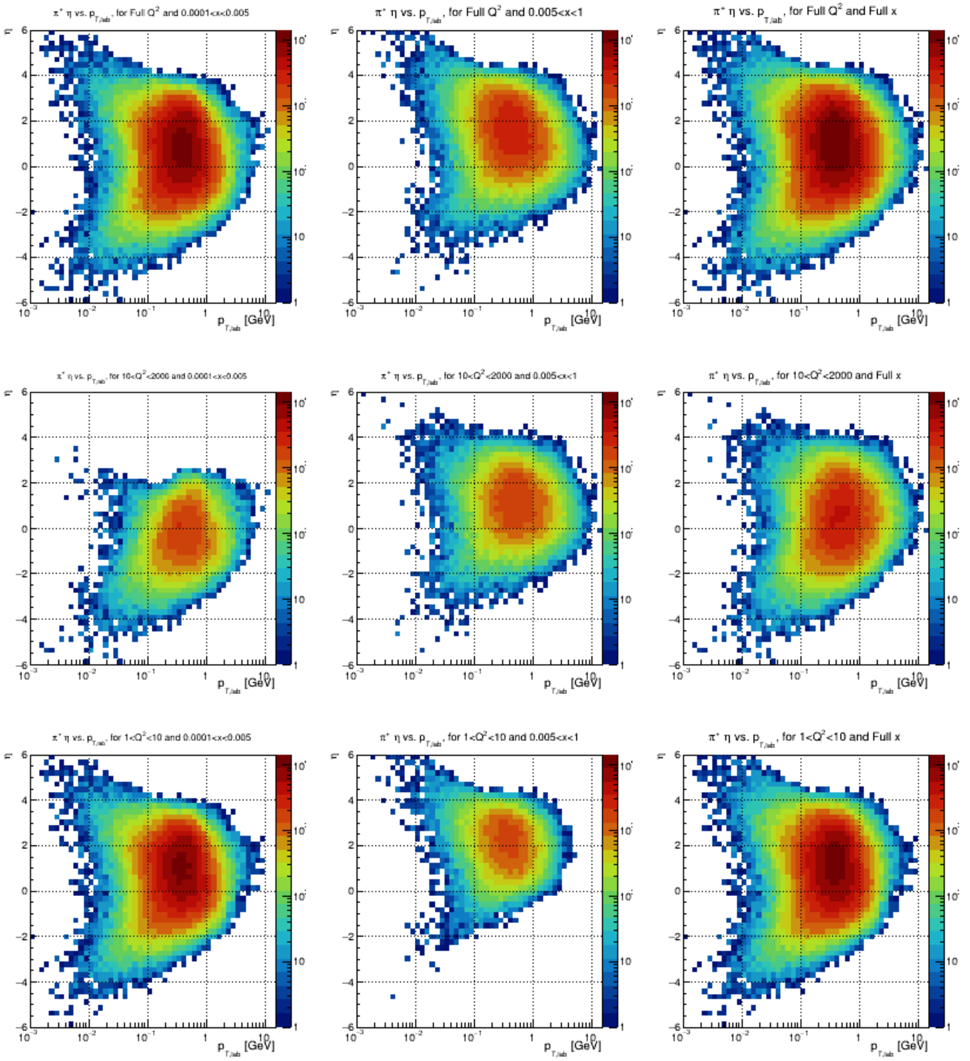


10x100 GeV

π^+ η vs. p_T

18x275 GeV

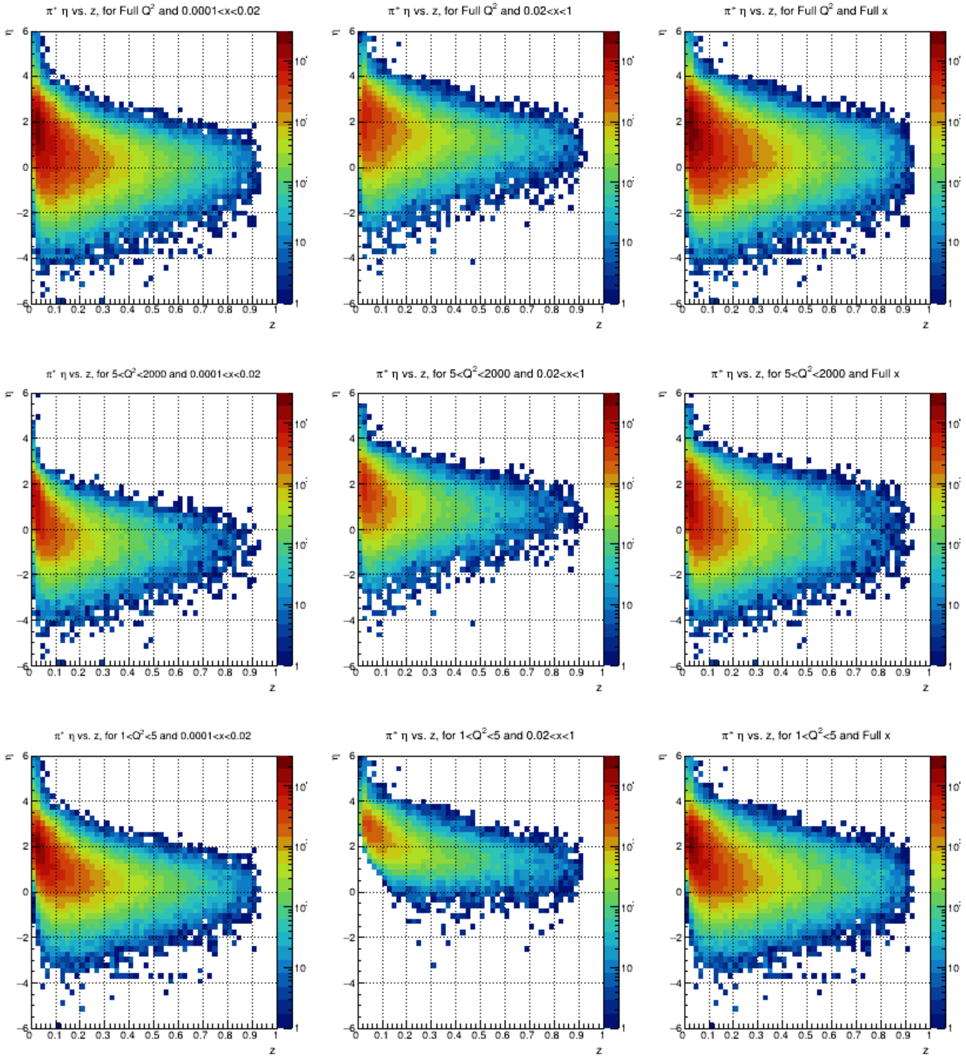


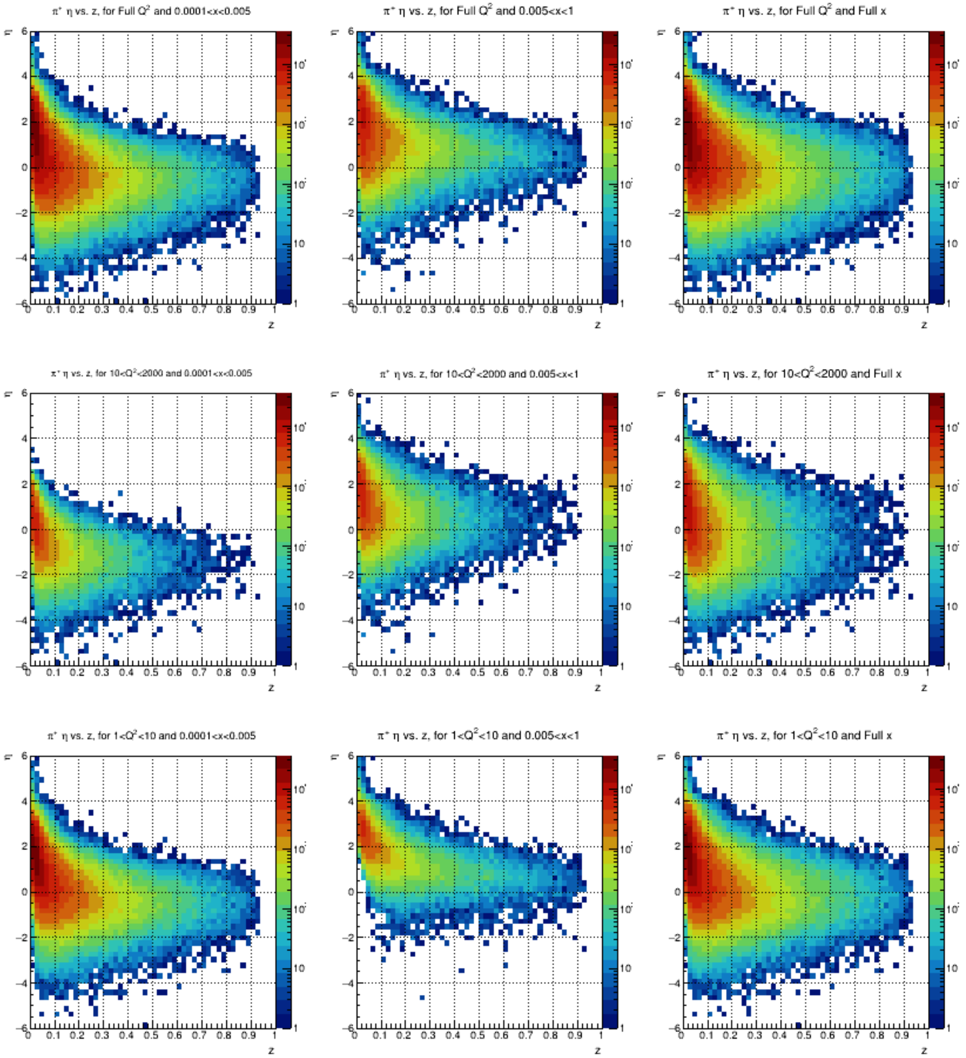


10x100 GeV

π⁺ η vs. z

18x275 GeV

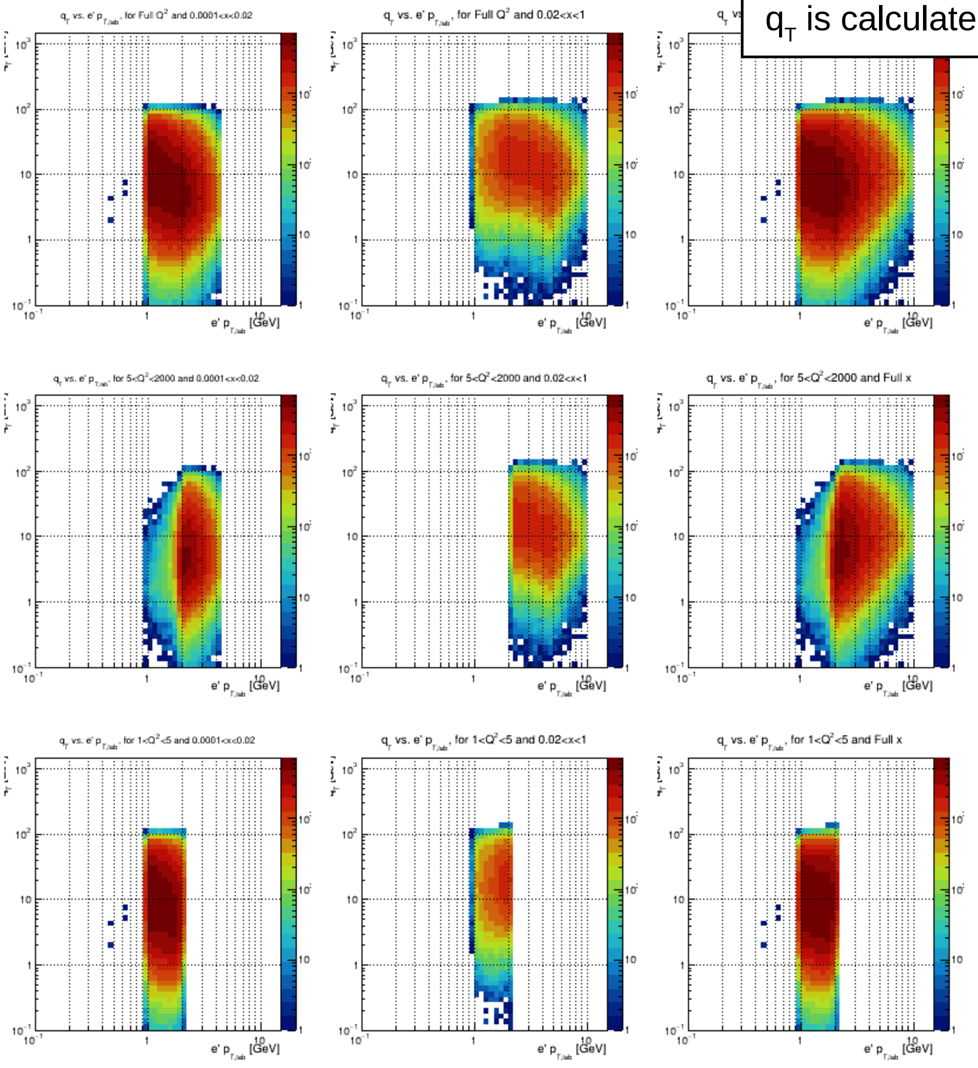




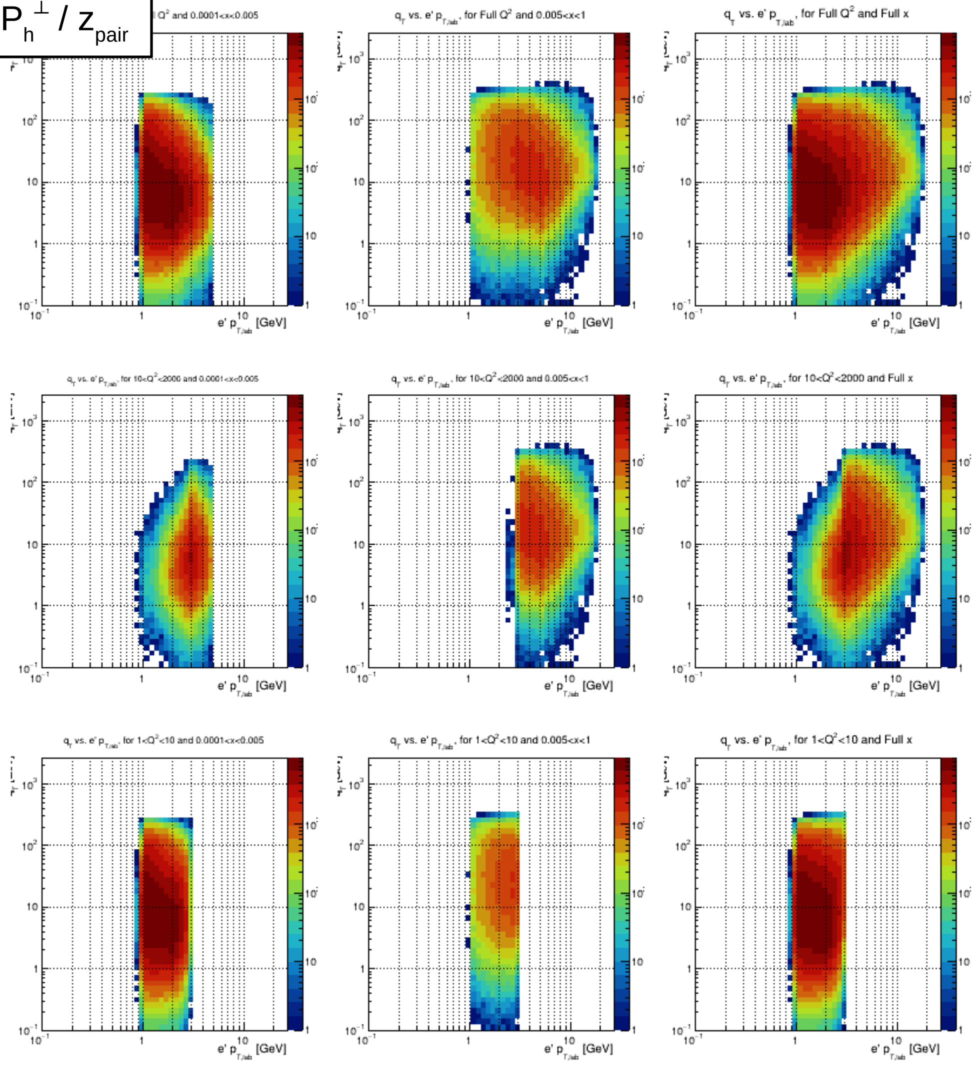
q_T vs. e' p_T

q_T is calculated as $P_h^{\perp} / z_{pair}$

10x100 GeV



18x275 GeV

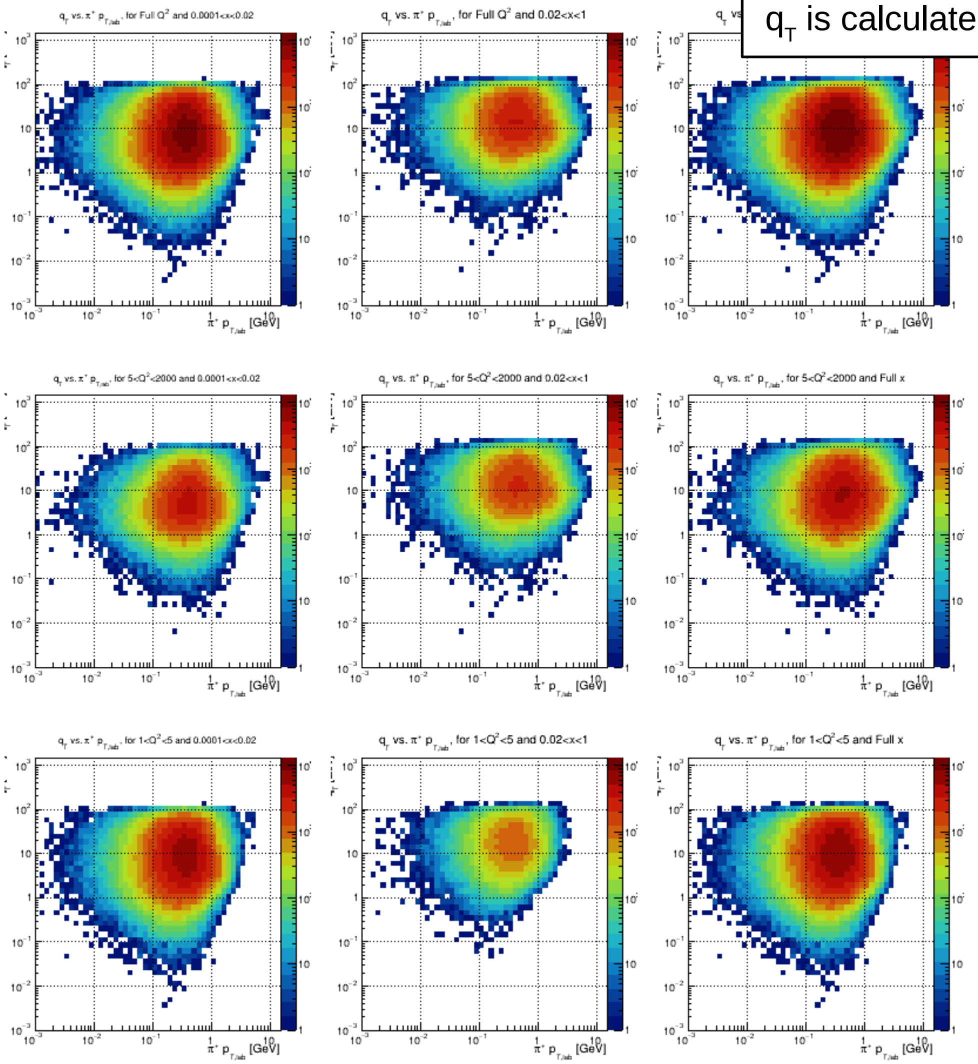


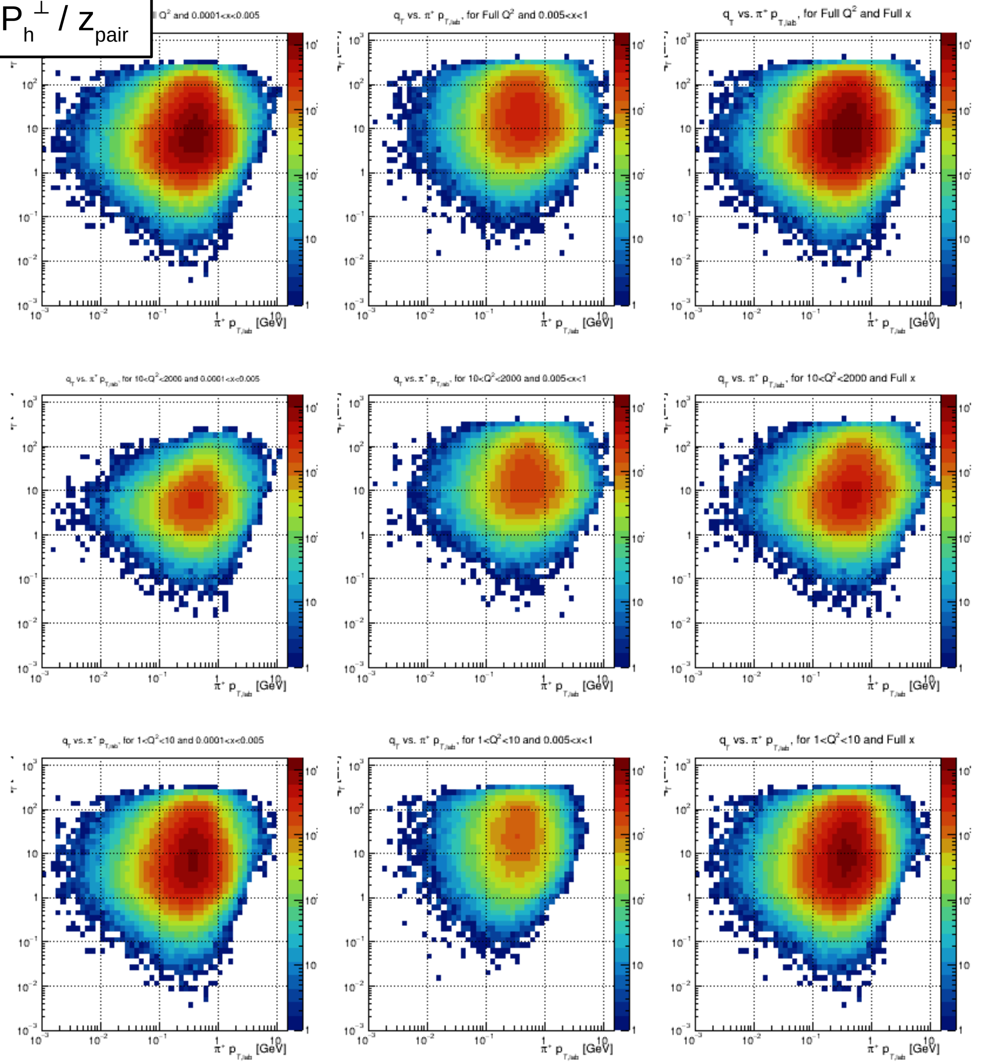
10x100 GeV

q_T vs. π^+ p_T

18x275 GeV

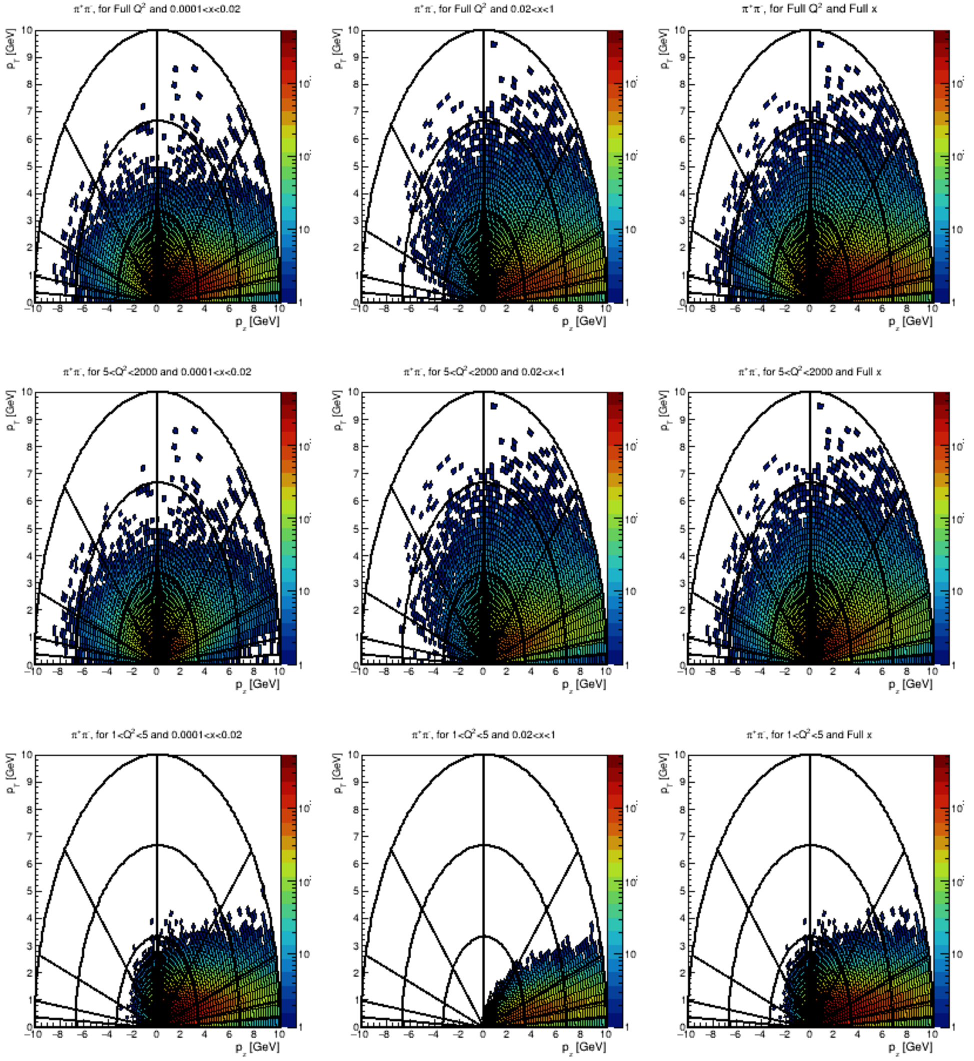
q_T is calculated as $P_h^{\perp} / z_{pair}$



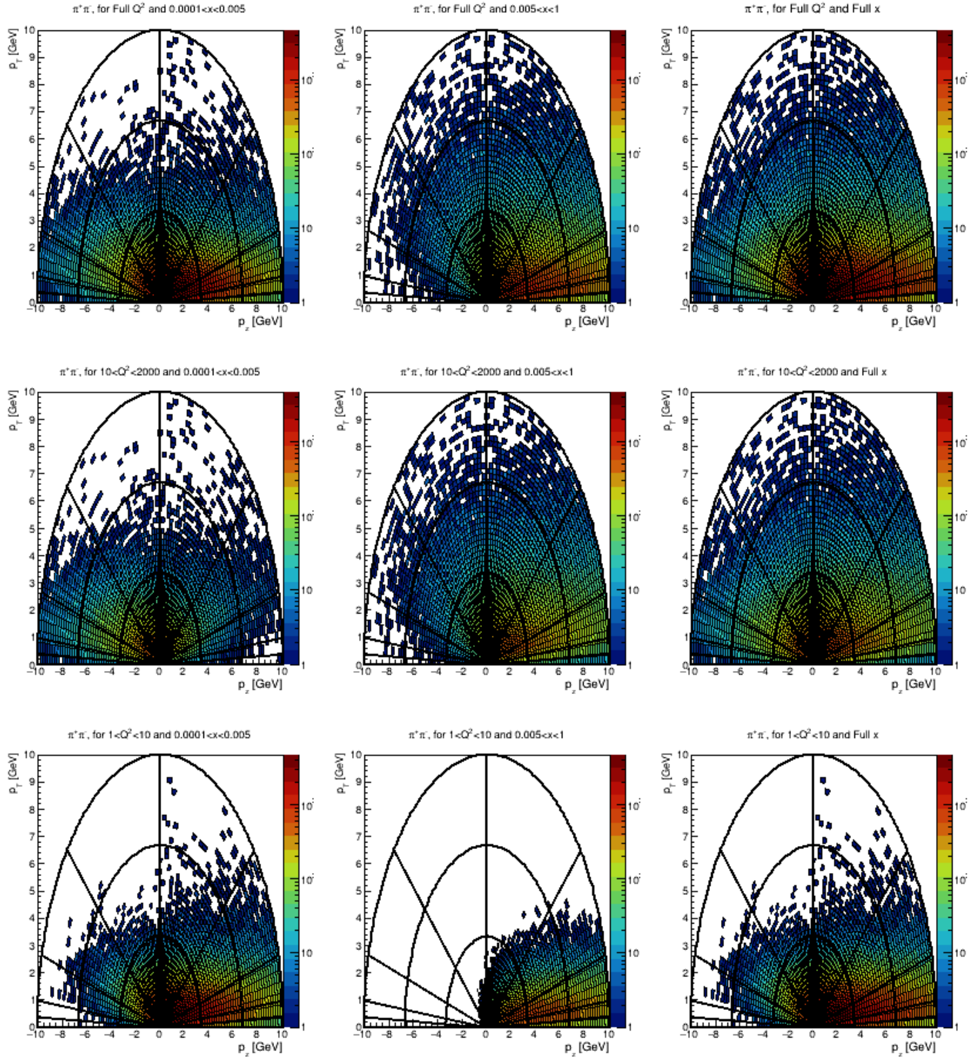


$\pi^+\pi^-$ p_T vs. p_z Polar Plots

10x100 GeV

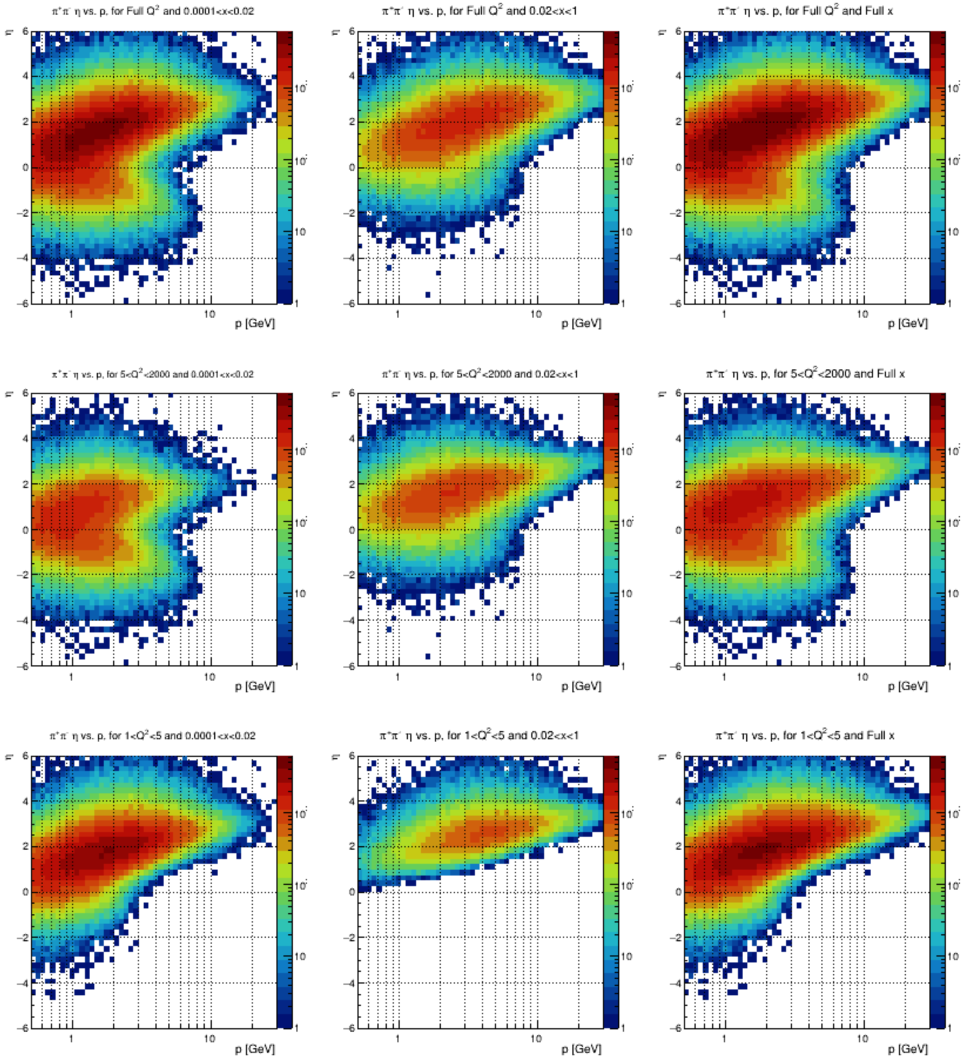


18x275 GeV

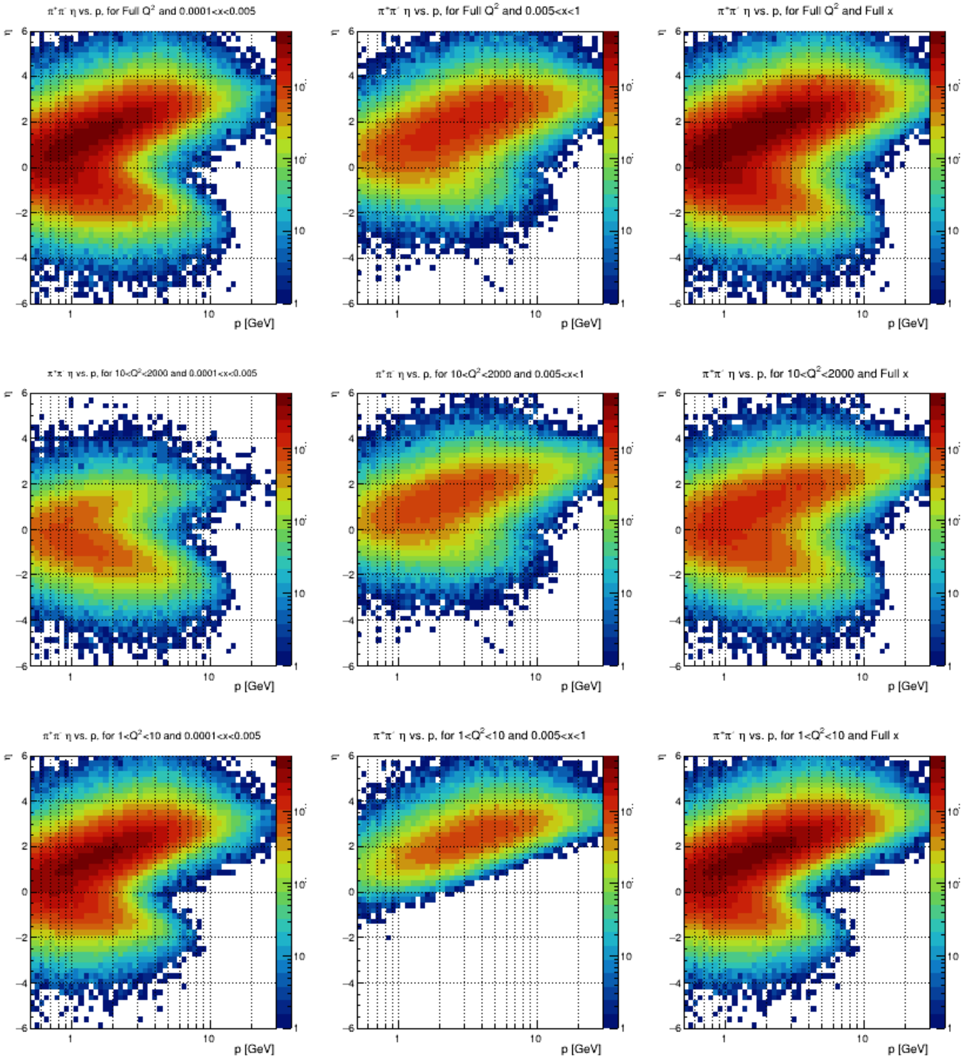


$\pi^+\pi^-$ η vs. p

10x100 GeV

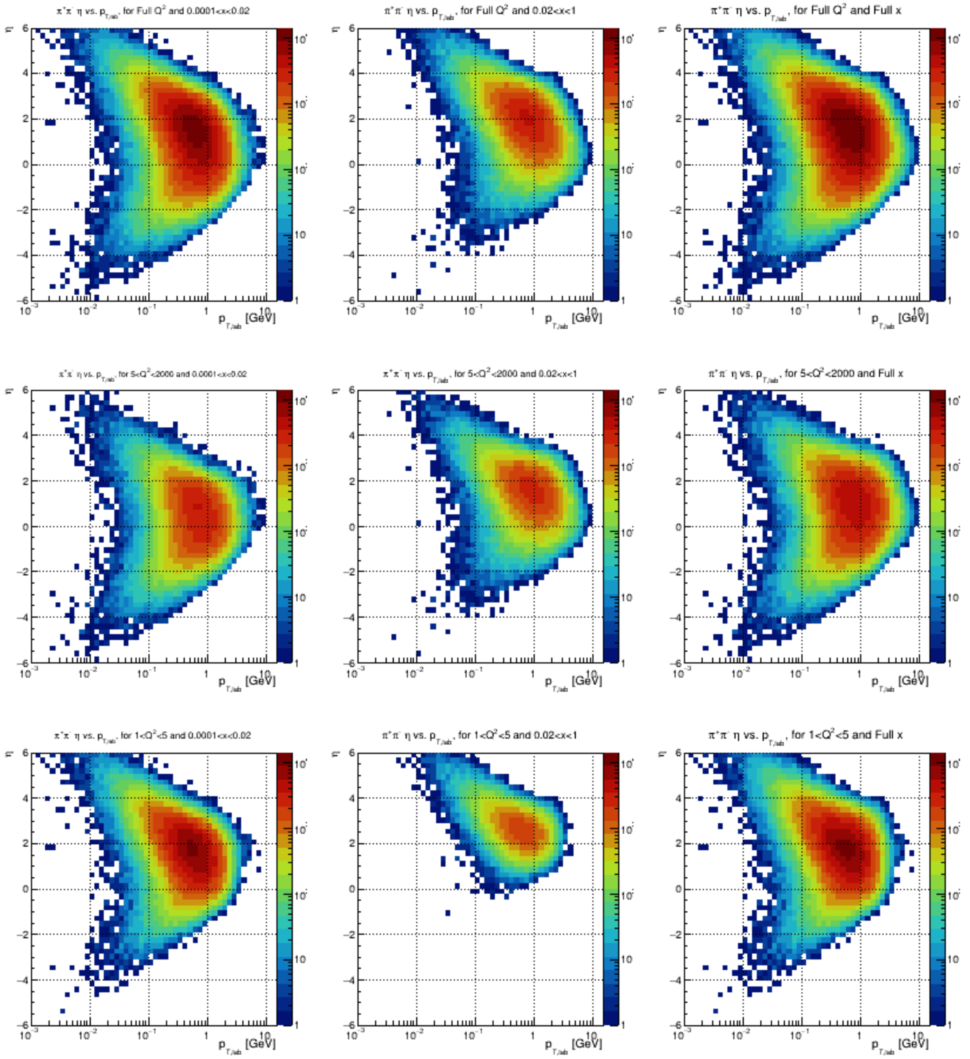


18x275 GeV

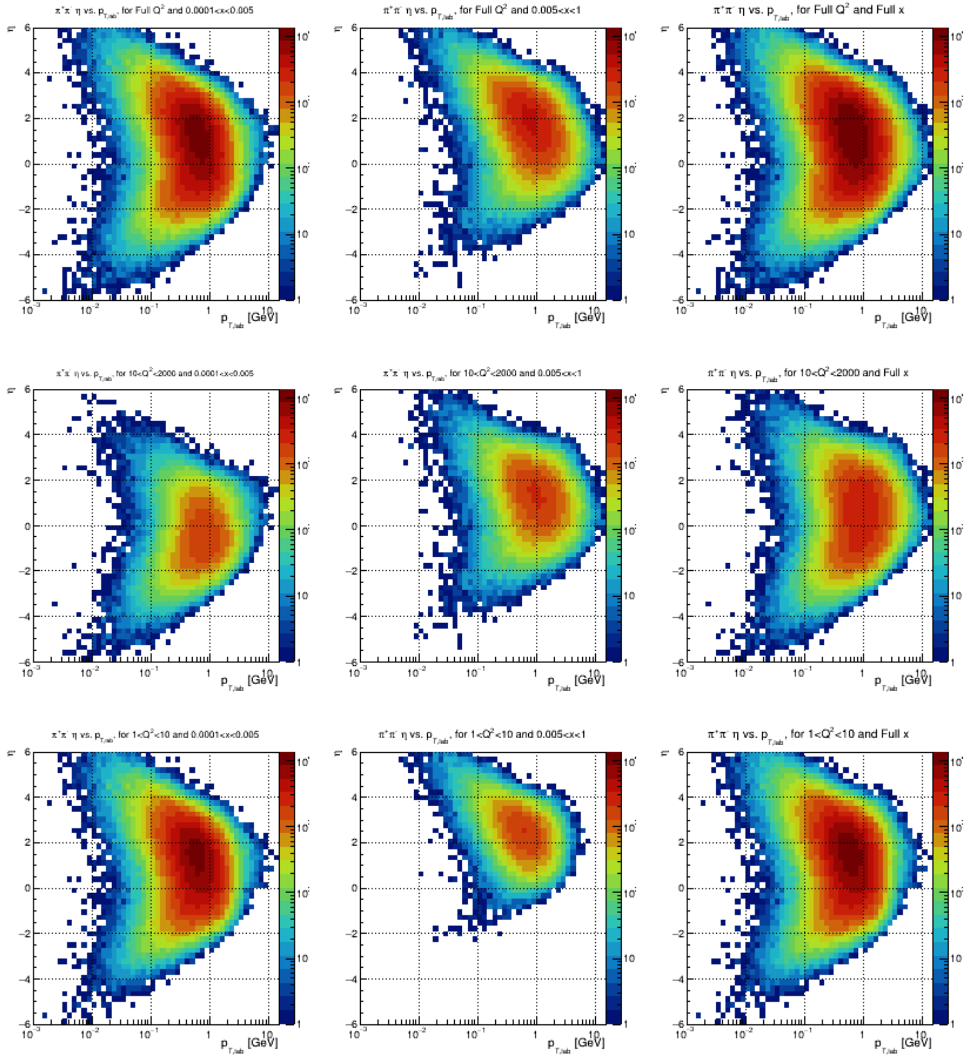


$\pi^+\pi^-$ η vs. p_T

10x100 GeV

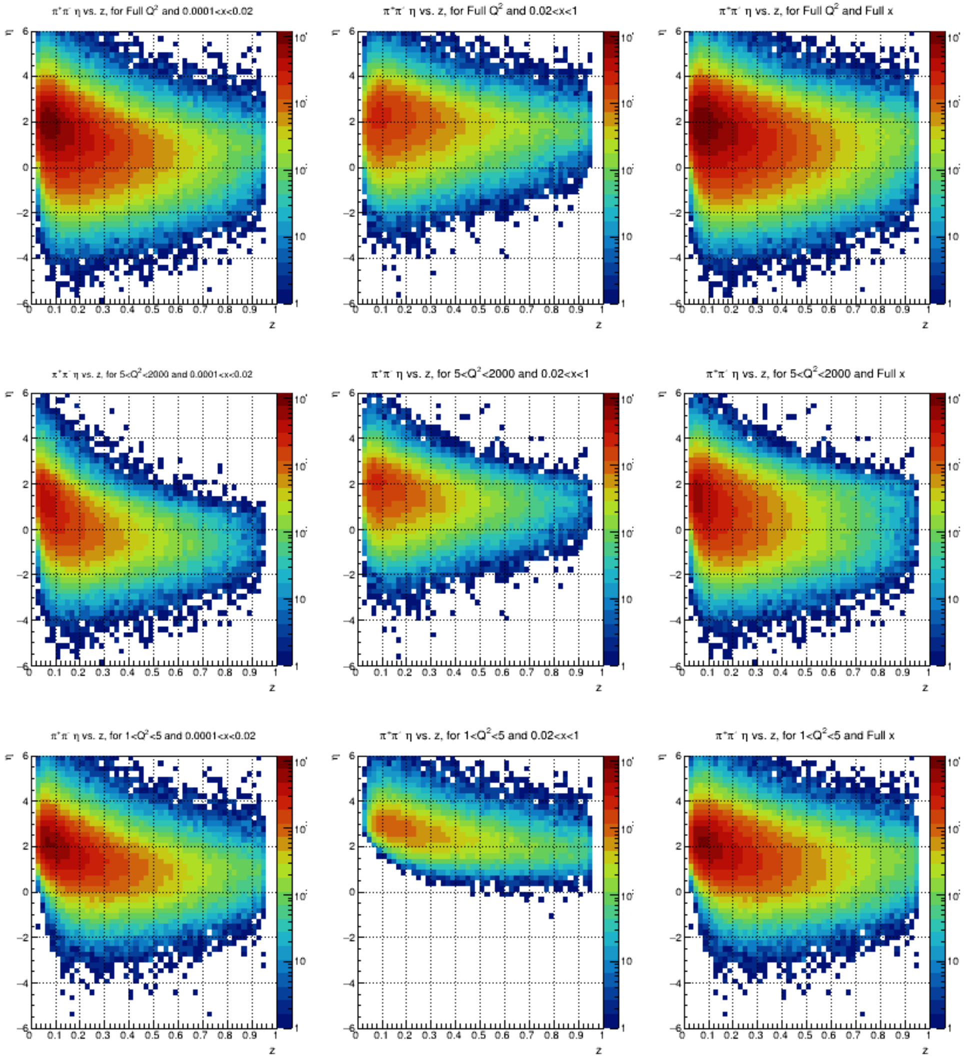


18x275 GeV

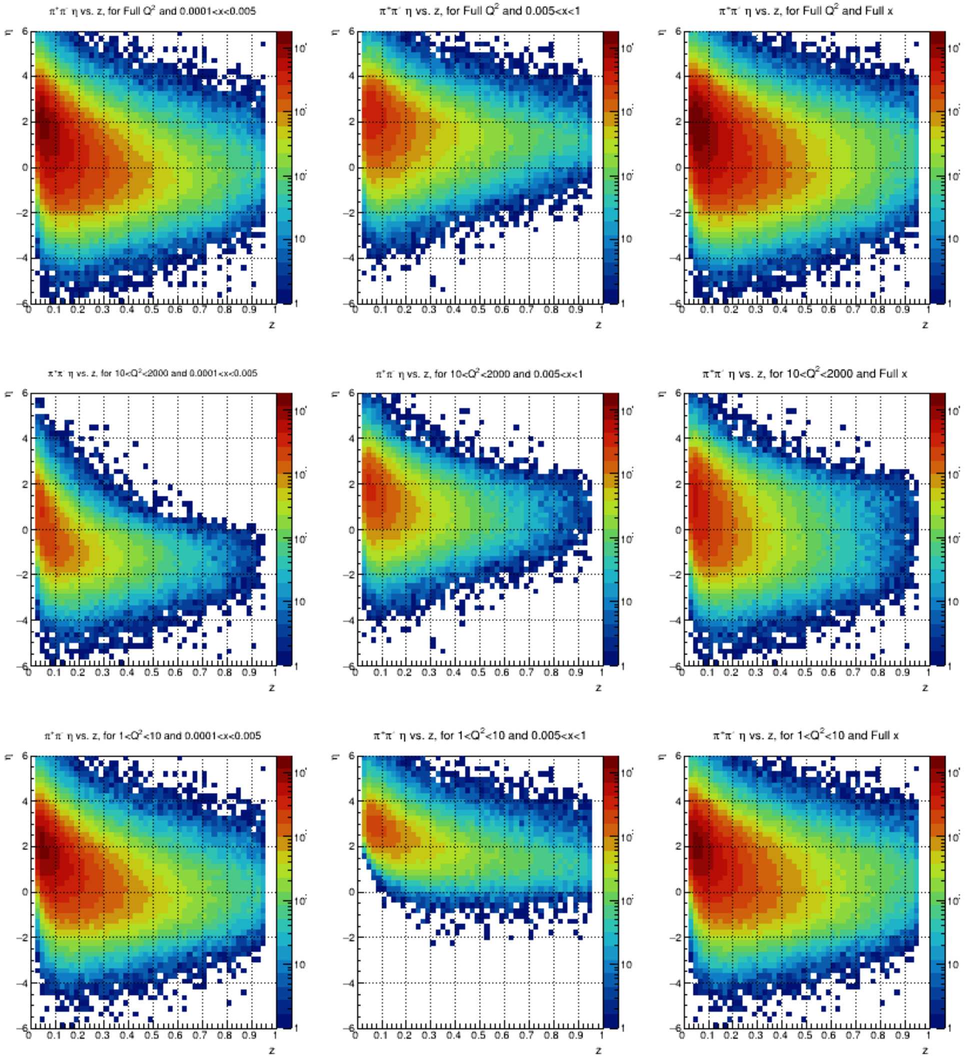


$\pi^+\pi^-$ η vs. z

10x100 GeV

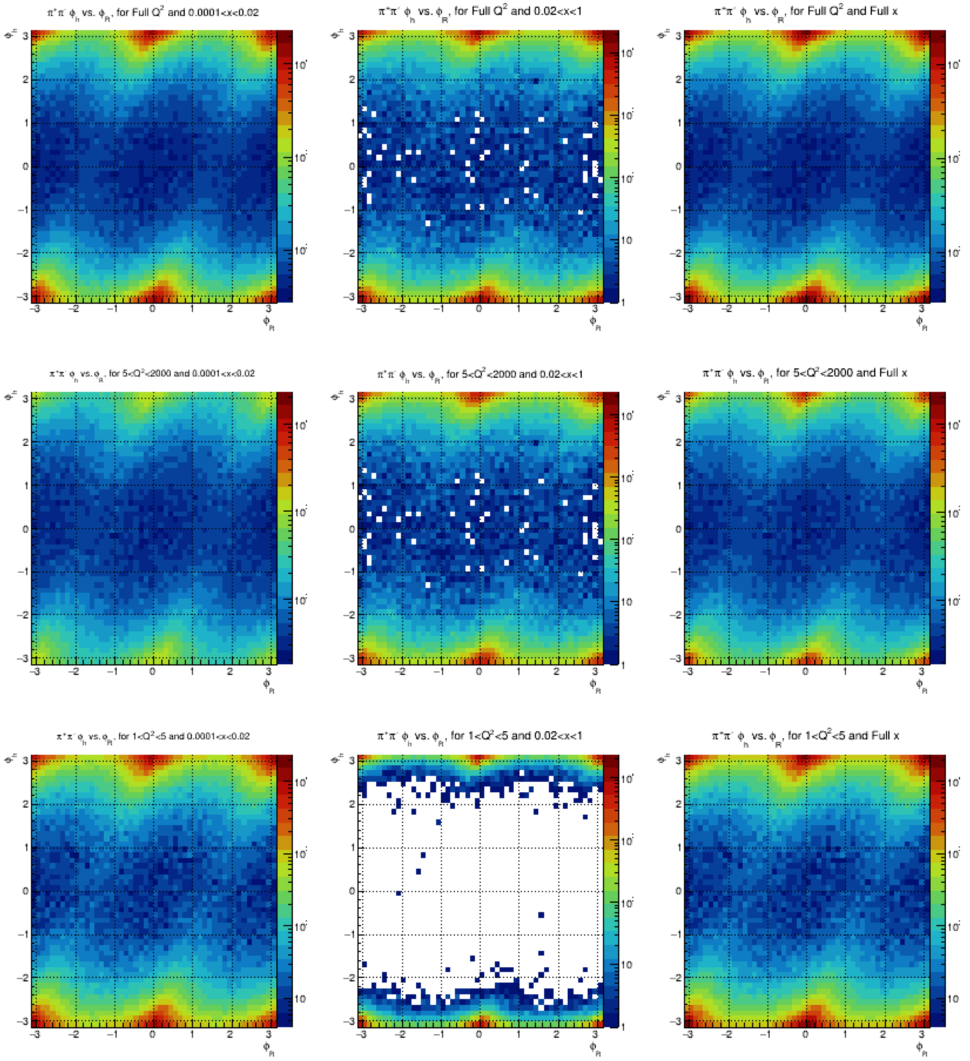


18x275 GeV

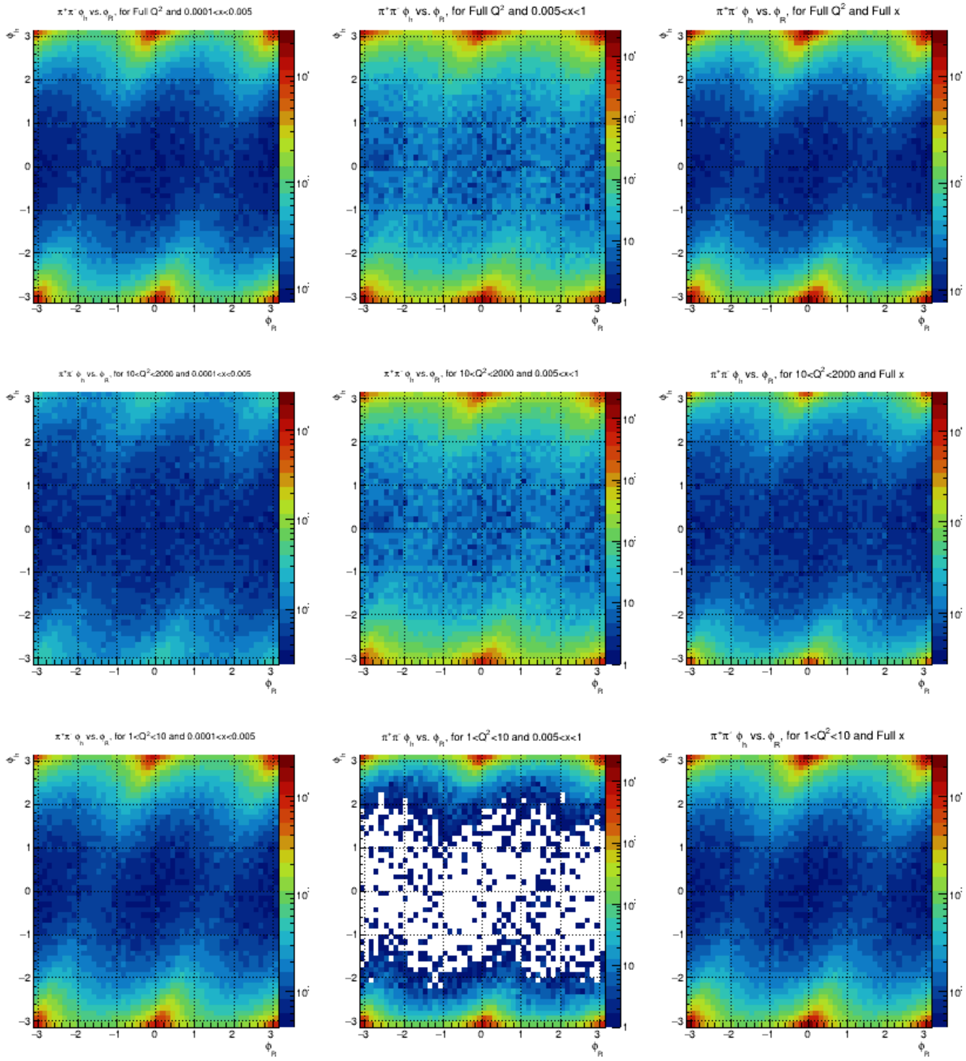


$\pi^+\pi^-$ ϕ_h vs. ϕ_R

10x100 GeV

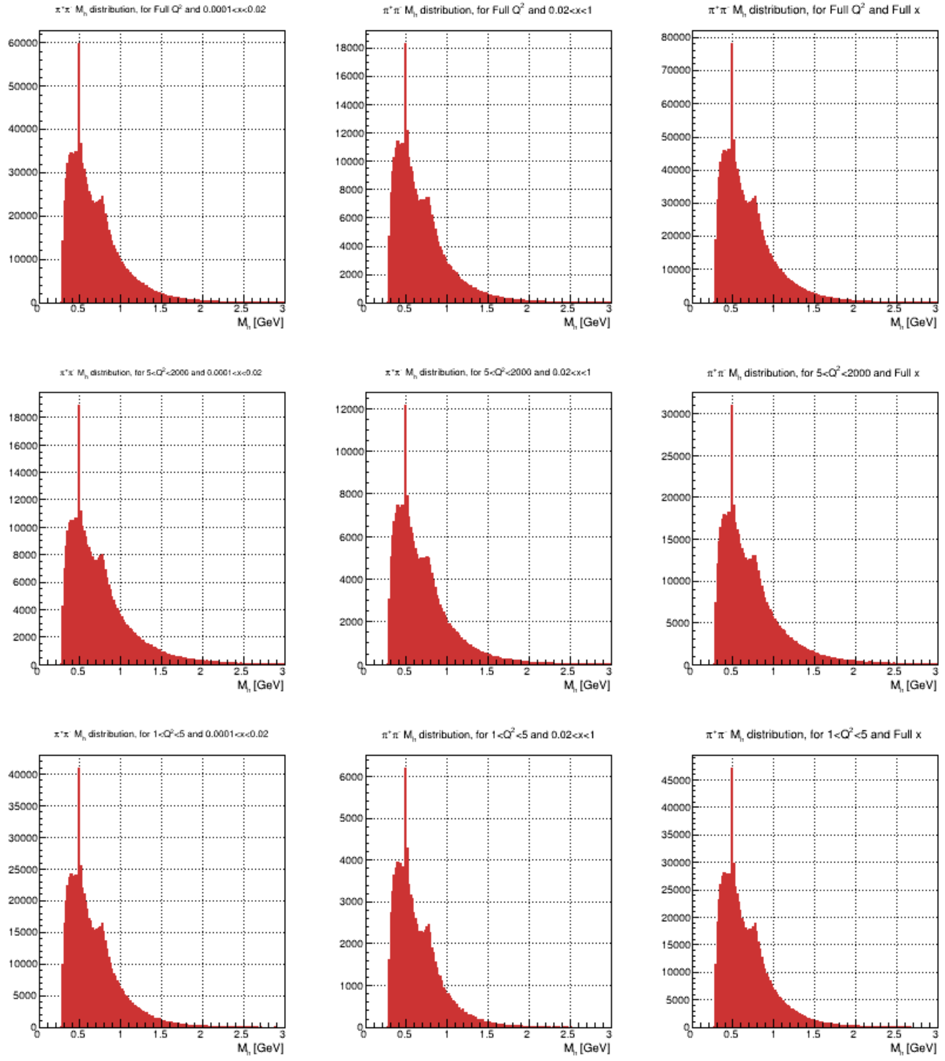


18x275 GeV

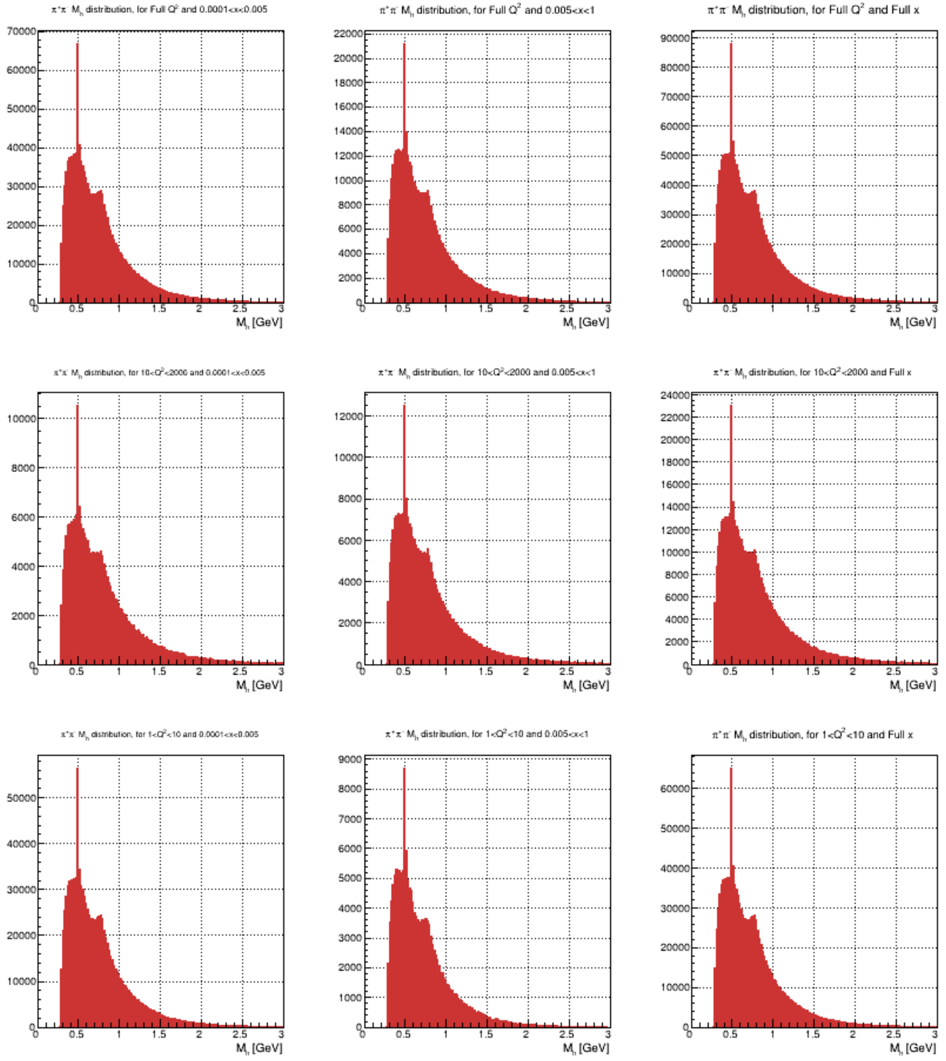


$\pi^+\pi^-$ M_h distribution

10x100 GeV

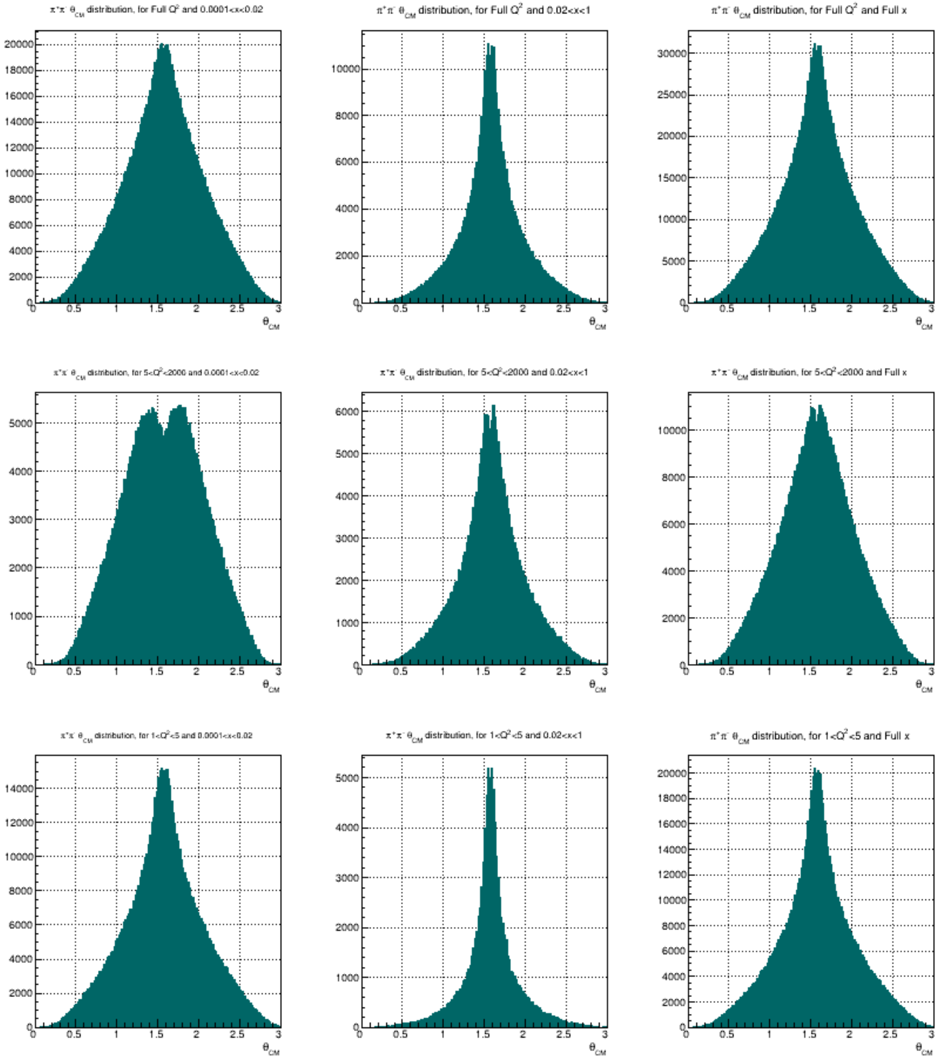


18x275 GeV

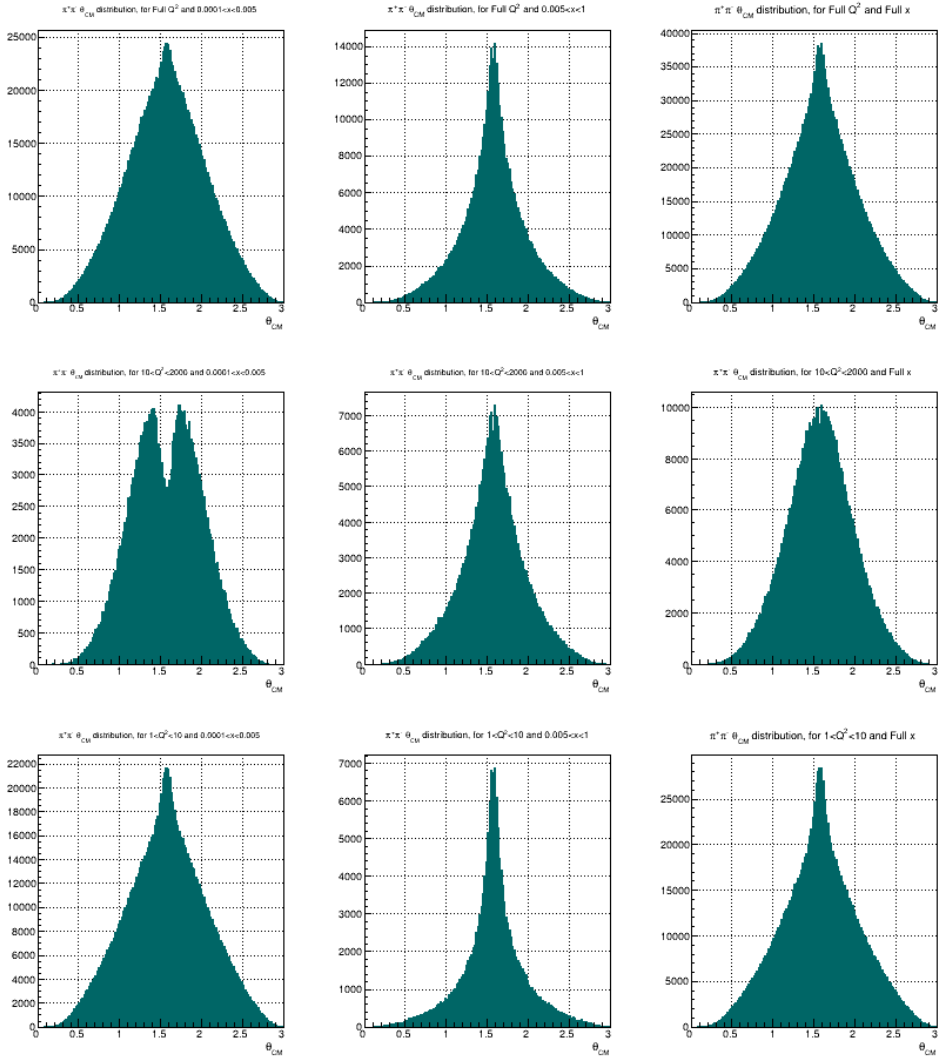


$\pi^+\pi^-$ θ_{CM} distribution

10x100 GeV



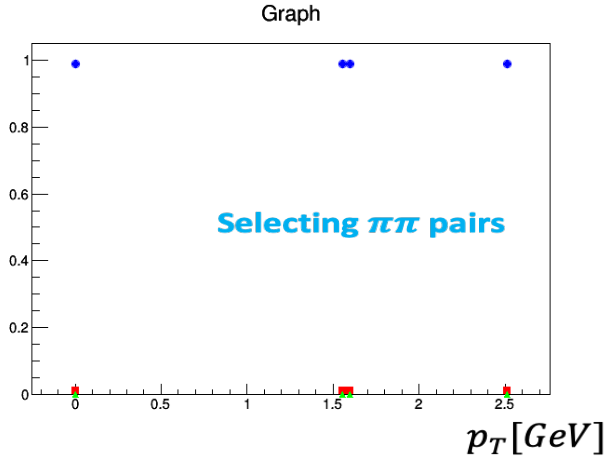
18x275 GeV

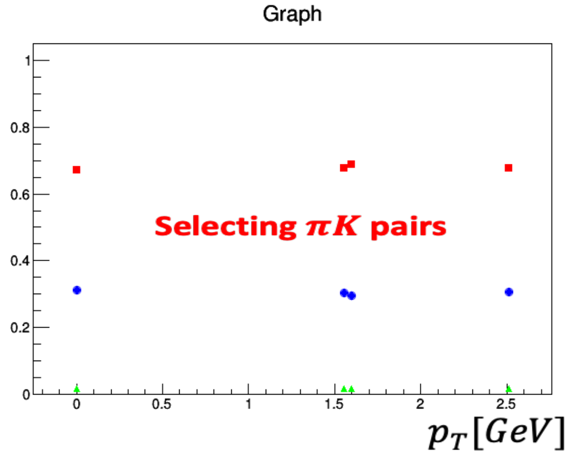


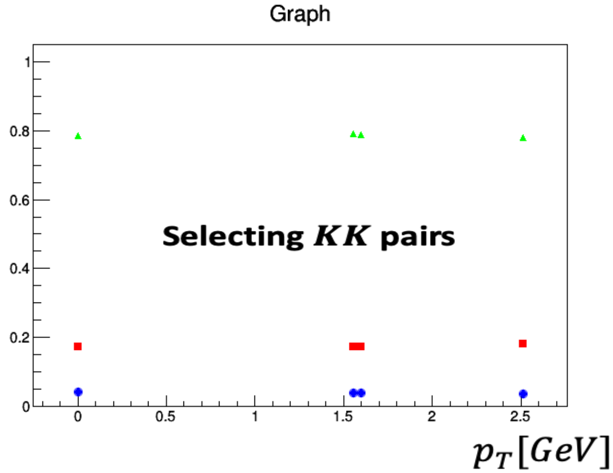
PID Performance

Anselm Vossen

Using 2 σ separation

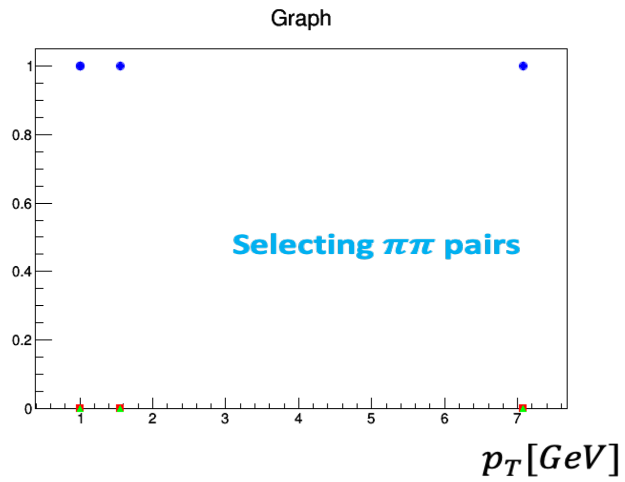


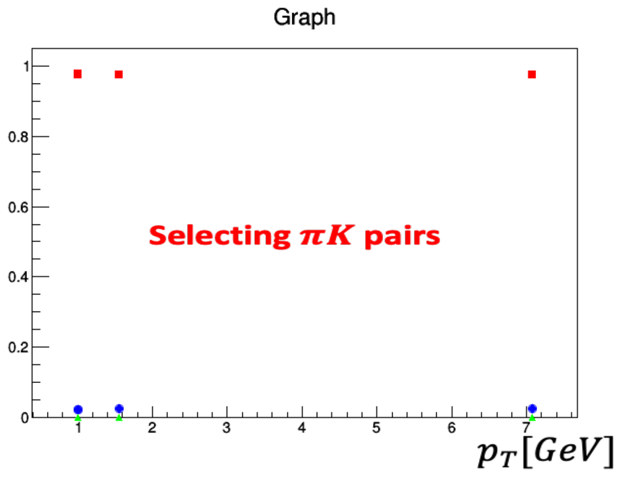


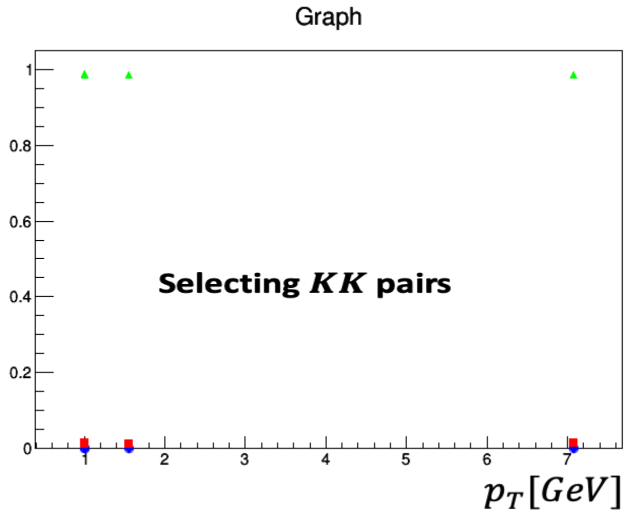


- **Fraction of reconstructed $\pi\pi$ pairs**
- **Fraction of reconstructed πK pairs**
- **Fraction of reconstructed KK pairs**

Using 3 σ separation

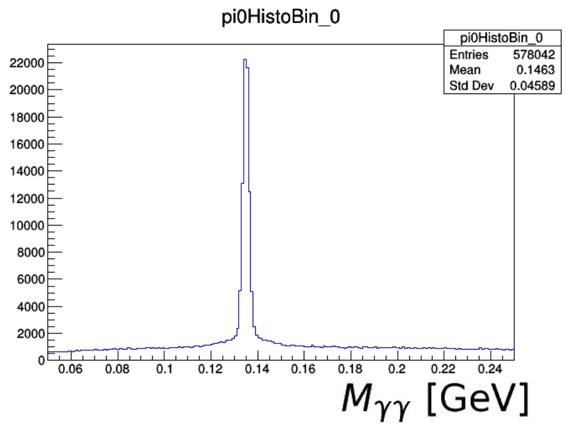




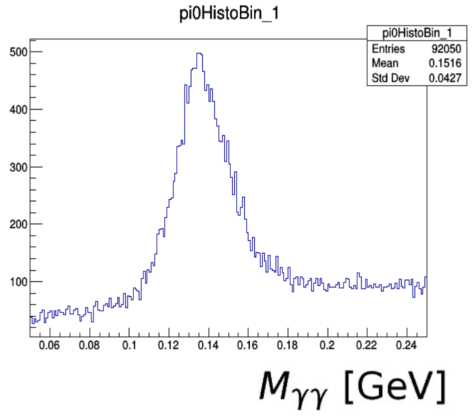


- **Fraction of reconstructed $\pi\pi$ pairs**
- **Fraction of reconstructed πK pairs**
- **Fraction of reconstructed KK pairs**

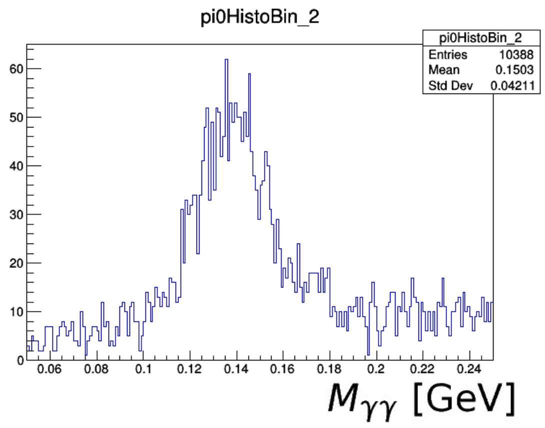
Reconstructing π^0 with $E_\gamma > 200\ MeV$



$-4.5 < \eta < -1.5$

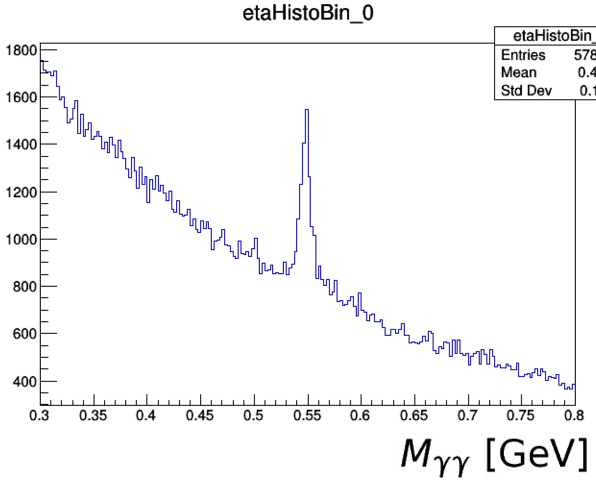


$-1.5 < \eta < 0.5$

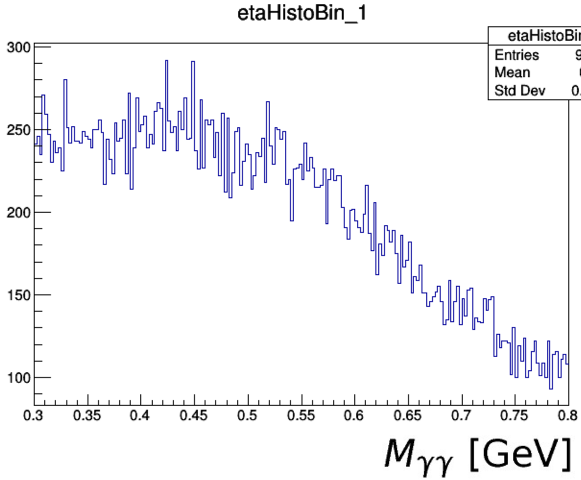


$0.5 < \eta < 4.5$

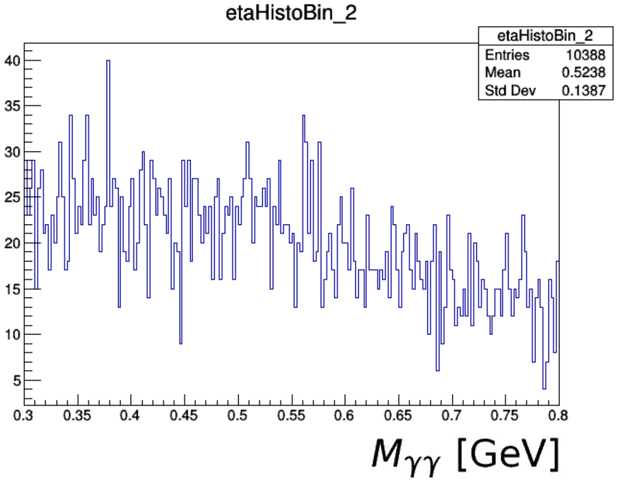
Reconstructing η with $E_\gamma > 200\ MeV$



-4.5 < η < −1.5



−1.5<η<0.5



0.5<η<4.5

Summary

- Dihadrons access spin-orbit correlations in hadronization and twist-3 (TMD)PDFs
- EIC simulation studies for SIDIS dihadrons are well underway
- Next Steps:
    - Asymmetry Projections
    - Partial Wave Projections
    - Impacts of p_T cuts
    - Additional dihadron channels, involving neutral pions and kaons
    - Fast simulation impact on dihadron kinematics