Nov 13 2020

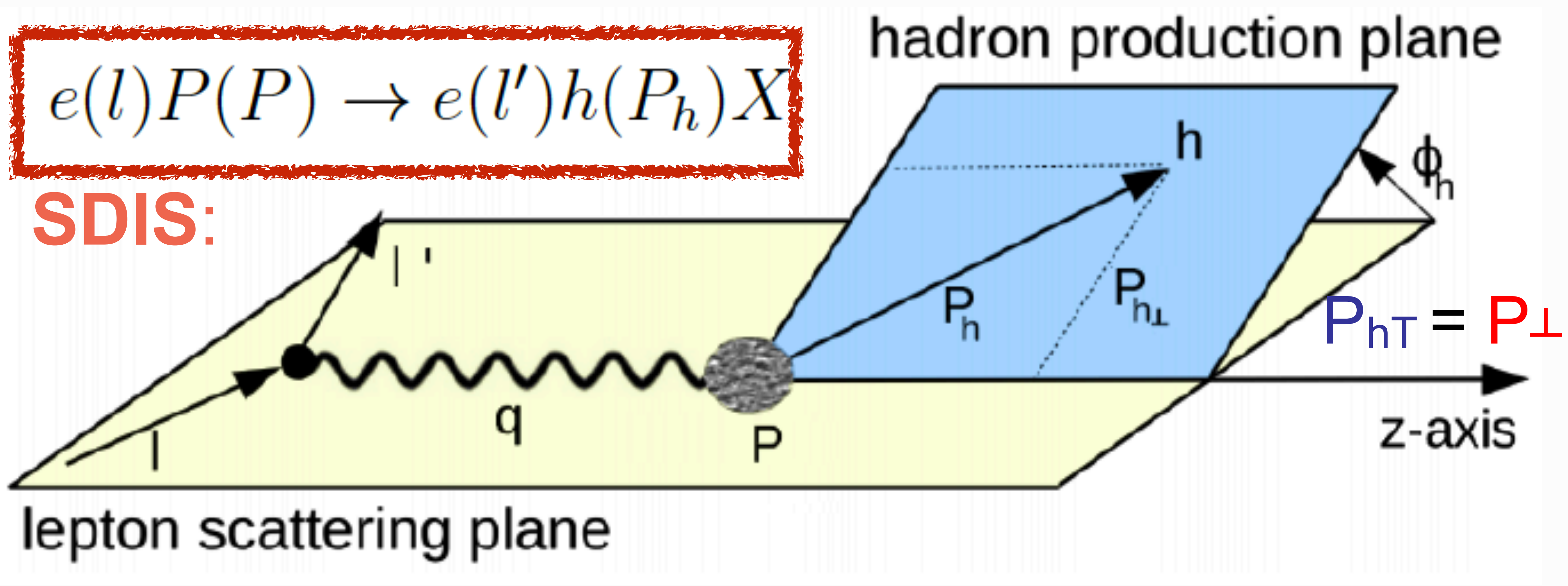
SIDIS Single Pion Multiplicity with CLAS12

Giovanni Angelini (GWU)

CLAS COLLABORATION MEETING

Jefferson Lab
Exploring the Nature of Matter

Introduction



$$e(l)P(P) \rightarrow e(l')h(P_h)X$$

SDIS:

$P_{hT} = P_{\perp} + z\, k_{\perp}$

$Q^2 = -(l-l')^2$	Transfer momentum
$W^2 = (P+q)^2$	Squared Invariant mass of the final state
$x = \frac{Q^2}{2P\cdot q}$	Quark longitudinal momentum fraction
$y = \frac{P\cdot q}{P\cdot l}$	Fractional energy of the virtual photon
$z = \frac{P\cdot P_h}{P\cdot q}$	Final state hadron momentum fraction
P_{hT}	Transverse Momentum of the hadron

Multplicity definition:

$$\frac{d^2M^h(x,Q^2,z,P_{hT}^2)}{dz dP_{hT}^2} = \left(\frac{d^4\sigma^h}{dx dQ^2 dz dP_{hT}^2}\right) \Big/ \left(\frac{d^2\sigma^{DIS}}{dx dQ^2}\right).$$

Rewriting the cross sections in terms of structure functions:

$$m_N^h(x,z,P_{hT}^2,Q^2) = \frac{\pi F_{UU,T}(x,z,P_{hT}^2,Q^2) + \pi\,\varepsilon F_{UU,L}(x,z,P_{hT}^2,Q^2)}{F_T(x,Q^2) + \varepsilon F_L(x,Q^2)}$$

- Accessing partonic transverse momentum

- Accessing fragmentation function

Structure Function: $F \propto DF \otimes FF$

Partonic Distribution Function. **Fragmentation Function**

Fragmentation Function

$$D_i^H(z) \approx \int dx^- e^{-iP_H^+ x^-/z}\, \mathrm{Tr}\left[\gamma^+ \underbrace{\langle 0|\Psi(0)\mathcal{P}|H(P_H^+)X\rangle\langle H(P_H^+)X|\mathcal{P}'\bar{\Psi}(x)|0\rangle}_{\text{Bi-Local Operator}}\right],$$

Non perturbative. Needs to be extracted from data.

CLAS12 Overview

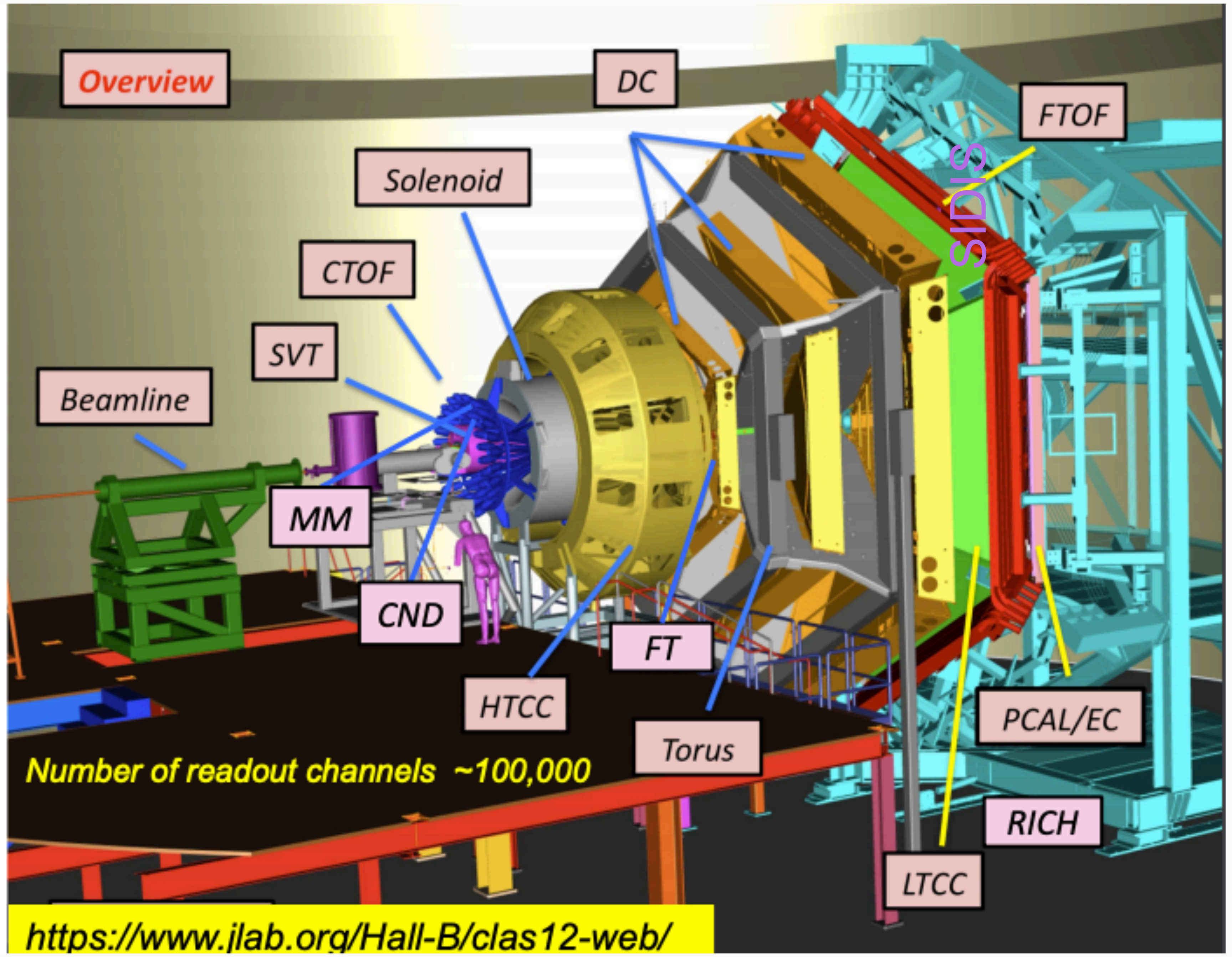
- $L = 10^{35}\ cm^{-2}\, s^{-1}$
- Polarized electron beam (85%)

Overview article

The CLAS12 Spectrometer at Jefferson Laboratory
Nucl. Instrum. Meth. A, Volume 959, 2020

Forward Detector:
- *TORUS magnet*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *RICH detector*
- *Forward ToF System*
- *Pre-shower calorimeter*
- *E.M. calorimeter (EC)*
- *Forward Tagger*

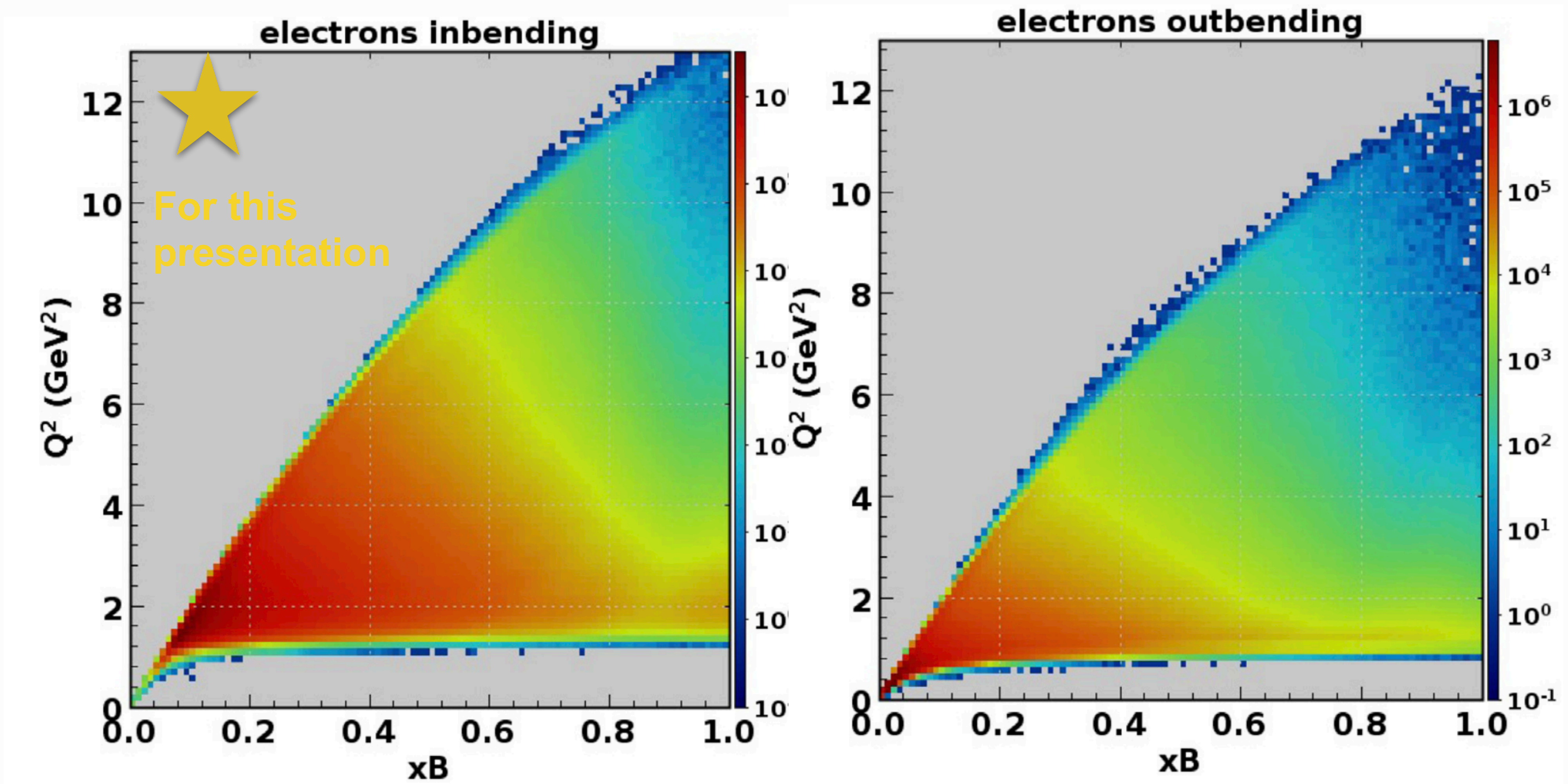
Central Detector:
- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Micromegas*
- *Central ToF system*
- *Neutron detector*
- *Backward Angle Neutron detector*



Charged PID

Track
FTOF
Cherenkovs
Calorimeter

The analysis will use the RG-A fall 2018 data . The processed data correspond to 99mC , about 1/6 of RG-A approved statistics and 1/3 of the RG-A collected statistics.



Analysis info and result preservation

The analysis is being performed using the JNP package realized by the Collaboration.

With the idea in mind of preservation of analysis and software: I have developed generic tools:

- Particle has been extended into a ParticleREC class containing all the information from useful detector used for the PID. The class returns sector for each detector, momenta, z, PT, rapidity, etc..

- Fiducial class interface that for each ParticleREC load standardized cuts (RG-A common analysis note) or allows the user to implement polygonal cuts on the x-y-z positions , or x-y-z / θ-φ functional cuts. For the sampling fraction one can use standard cuts or load its own form

```
FiducialCuts SIDIS_Cuts = new FiducialCuts();
```

→ It contains a map of PID and associated names of routines. User can simply redefine it .

PID: → **Detector Cut 1** → Standard or user defined
Detector Cut 2
Detector Cut 3 ..

```
if(SIDIS_Cuts.Status(electronRec)==true ) {
```

→ It returns the status of the fiducial cuts applied to that ParticleREC

My goal is to collaborate with other analyzer (example Andrey Kim) to improve the framework and submit to the Software group so to have a uniform Java analysis package with documentation to be validate and shared in collaboration.

Analysis info and result preservation

From SKIM 4, the code applies fiducial cuts and PID CUTS to produce a new “Final Hipo file”

I use schemaBuilder from JNP

```
SchemaBuilder schemaBuilder = new SchemaBuilder("SIDIS::ePiX",120,1);
 schemaBuilder.addEntry("event", "I", "event  id");
 schemaBuilder.addEntry("helicity", "B", "event helicity");
 schemaBuilder.addEntry("pid", "I", "Pion id");
 schemaBuilder.addEntry("e_p", "F", "Trigger electron momentum");
 schemaBuilder.addEntry("e_theta", "F", "Trigger electron theta");
 schemaBuilder.addEntry("e_phi", "F", "Trigger electron phi ");
 schemaBuilder.addEntry("Q2", "F", "Q2 of the event");
 schemaBuilder.addEntry("W", "F", "W of the event");
 schemaBuilder.addEntry("x", "F", "x of the event");
 schemaBuilder.addEntry("y", "F", "y of the event");
 schemaBuilder.addEntry("epsilon", "F", "epsilon of the event");
 schemaBuilder.addEntry("pi_p", "F", "Pion momentum");
 schemaBuilder.addEntry("pi_theta", "F", "Pion theta");
 schemaBuilder.addEntry("pi_phi", "F", "Pion phi");
 schemaBuilder.addEntry("z", "F", "x z of the pion");
 schemaBuilder.addEntry("pt", "F", " PT  of the pion (with respect virtual photon)");
 schemaBuilder.addEntry("phi", "F", "Phi (trento) of the pion");
 schemaBuilder.addEntry("xf", "F", "x Feynman of the pion");
 schemaBuilder.addEntry("mX", "F", " Missing mass ehX");
 schemaBuilder.addEntry("eta", "F", "Rapidity in Breit frame");
 schemaBuilder.addEntry("status", "I", "Status of the cuts");
```

Status is given as the sum of detectors cuts:

Loose(1) - Medium(2) - Tight(3)

212322

El Vertex: Lose
el SF : Lose
el CAL FC: Medium
el DC FC: Tight
Pion vertex: Medium
Pion Chi2PiD: Medium

```
Bank tuple = new Bank(schemaW,1);
tuple.putInt("event", 0, (int) evento);
tuple.putByte("helicity", 0, (byte) helicity);
tuple.putInt("pid", 0, 211);
tuple.putFloat("e_p", 0, (float) electronRec.p());
tuple.putFloat("e_theta", 0, (float) electronRec.theta());
tuple.putFloat("e_phi", 0, (float) electronRec.phi());
tuple.putFloat("Q2", 0, (float) Q2);
tuple.putFloat("W", 0, (float) vecW2.mass());
tuple.putFloat("x", 0, (float) xB);
tuple.putFloat("y", 0, (float) y_var);
tuple.putFloat("epsilon", 0, (float) epsilon);
tuple.putFloat("pi_p", 0, (float) New_Pi.getMomentum());
tuple.putFloat("pi_theta", 0, (float) New_Pi.getTheta());
tuple.putFloat("pi_phi", 0, (float) New_Pi.getPhiClas12());
tuple.putFloat("pt", 0, (float) New_Pi.getPt());
tuple.putFloat("phi", 0, (float) New_Pi.getPhi());
tuple.putFloat("xf", 0, (float) New_Pi.getXF());
tuple.putFloat("mX", 0, (float) New_Pi.getMissMass());
tuple.putFloat("eta", 0, (float) New_Pi.getEtaBar());
tuple.putInt("status", 0, 100);
```

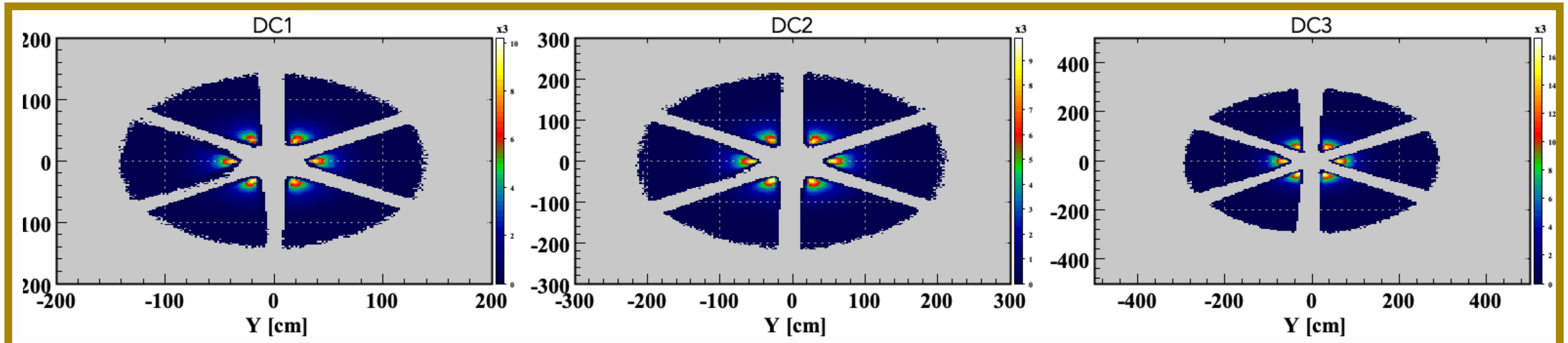
The final Hipo file is 10^-3 smaller than SKIM4

If Fiducial cuts and PID cuts will be part of a cross-checked code analysis cross-checks will become very simply for future talks/presentations

Event Selection

$Q^2 > 1\ GeV^2$ | $W > 2GeV$ | $y < 0.75$

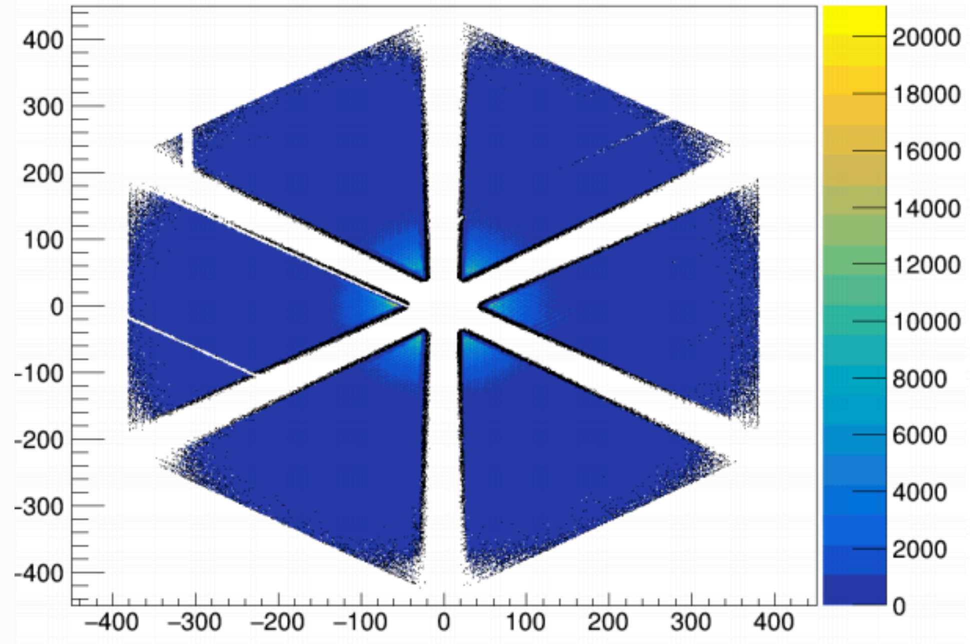
Pion momenta between 1.25 GeV/c - 5 GeV/c



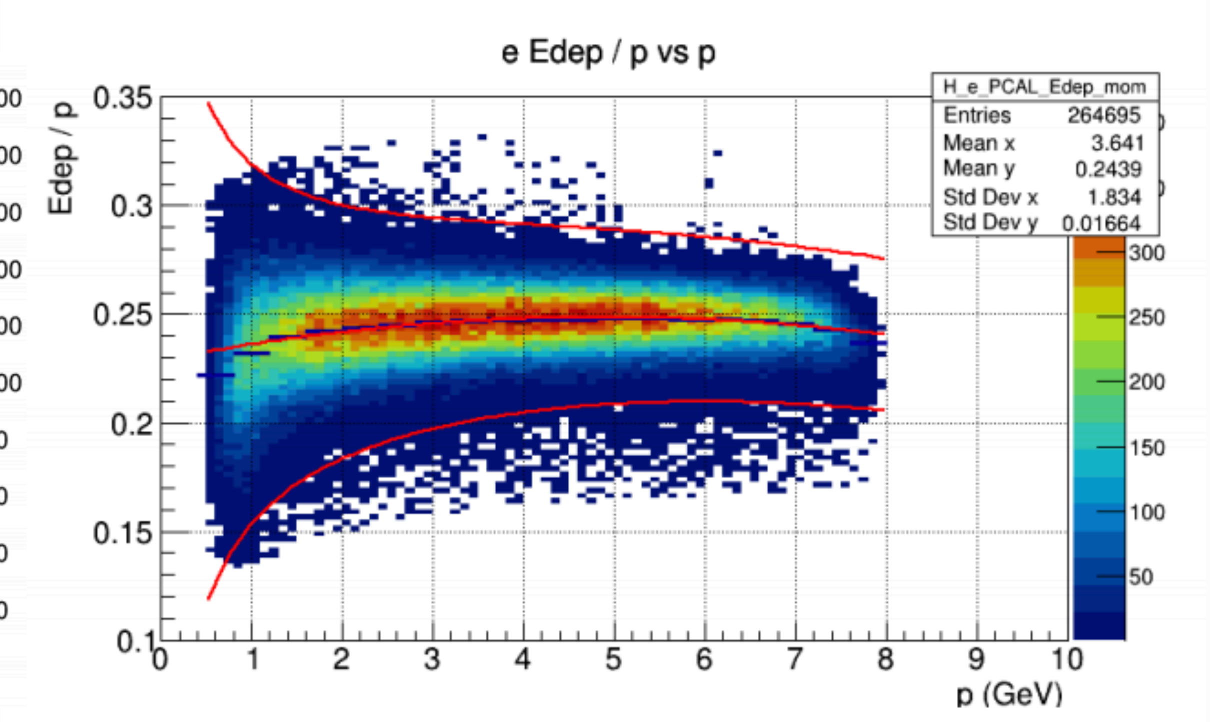
Electrons Hits on the 3 DC regions, after fiducial cuts

- **Minimum energy cut PCAL**
- **Electron Vertex -12 cm to 13 cm**
- **Pion Vertex Cut:**
  |El Vertex - Pion Vertex | <20 cm
- **Chi2PID: following the momentum parametrization of RG-A Common Analysis**
- Missing Mass> 1.5 GeV/c

PCAL:



Sampling Fraction: 3.5 sigmas



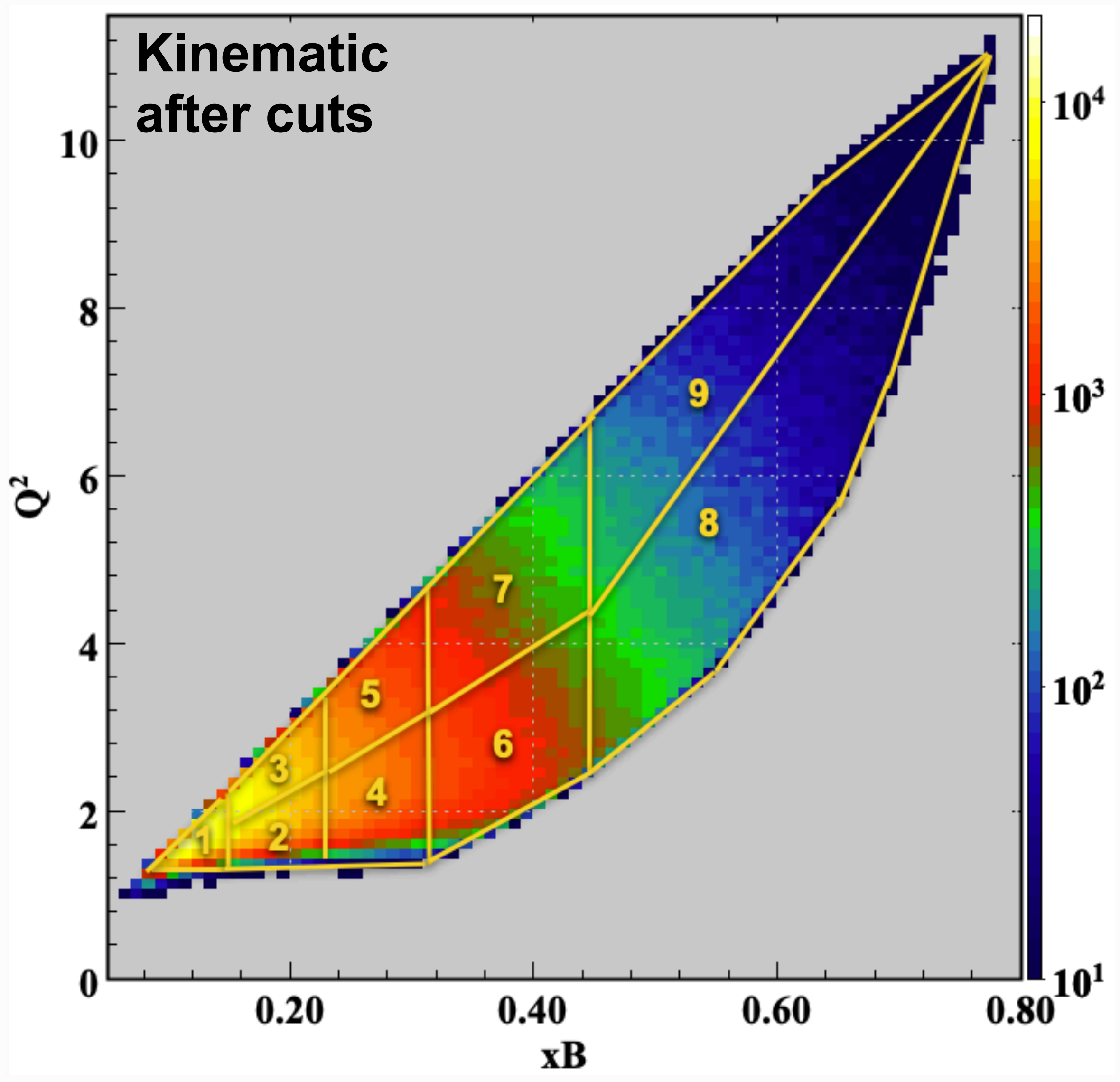
Projection of the final multiplicity analysis

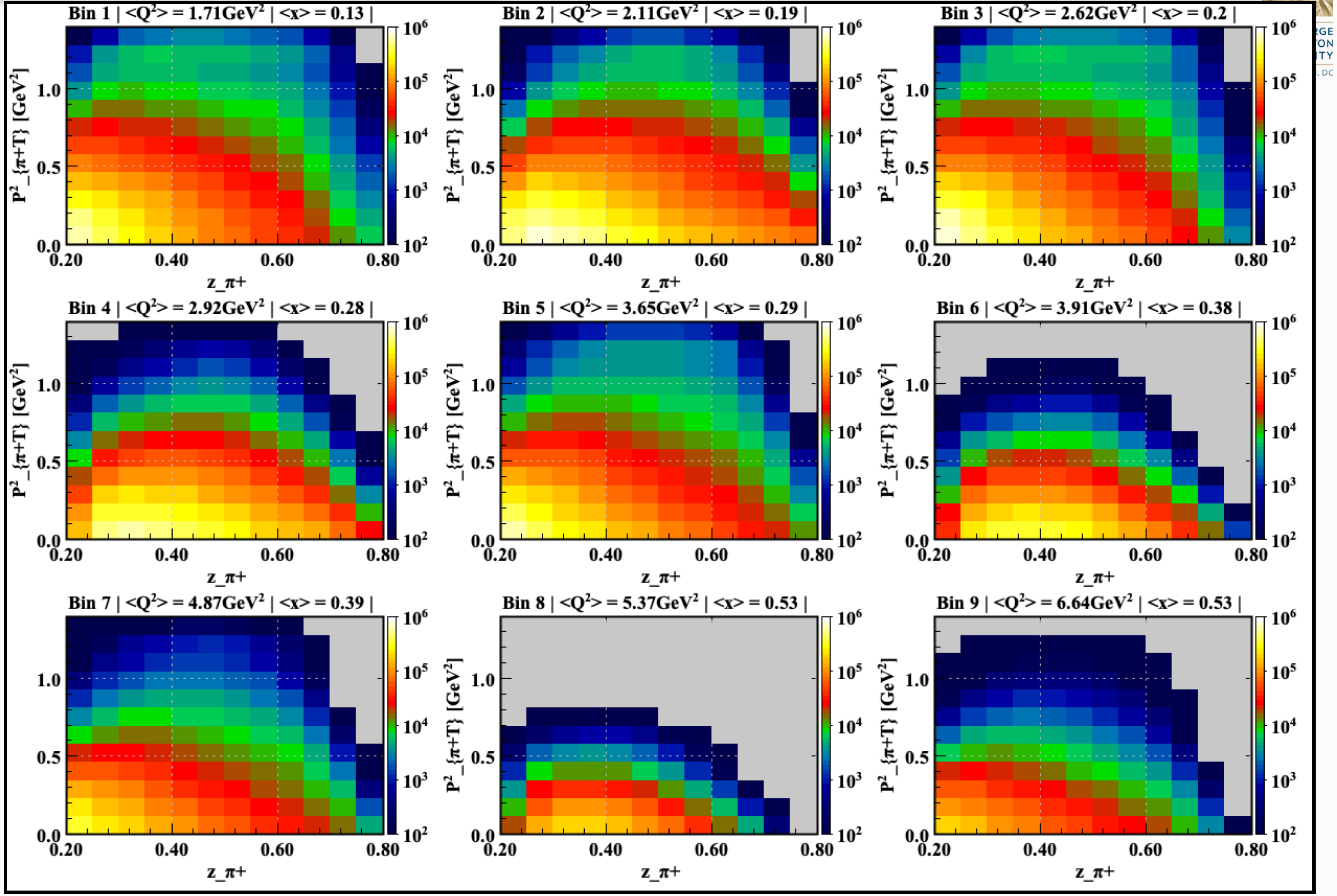
$Q^2 > 1\ GeV^2$ | W > 2GeV | y < 0.75

+PID Cuts
+ Missing Mass> 1.5 GeV/c
+ Fiducial cuts
+x_F >0

9 x 14 x 14 = 1764 bins

(Q^2, x) Z PT_2

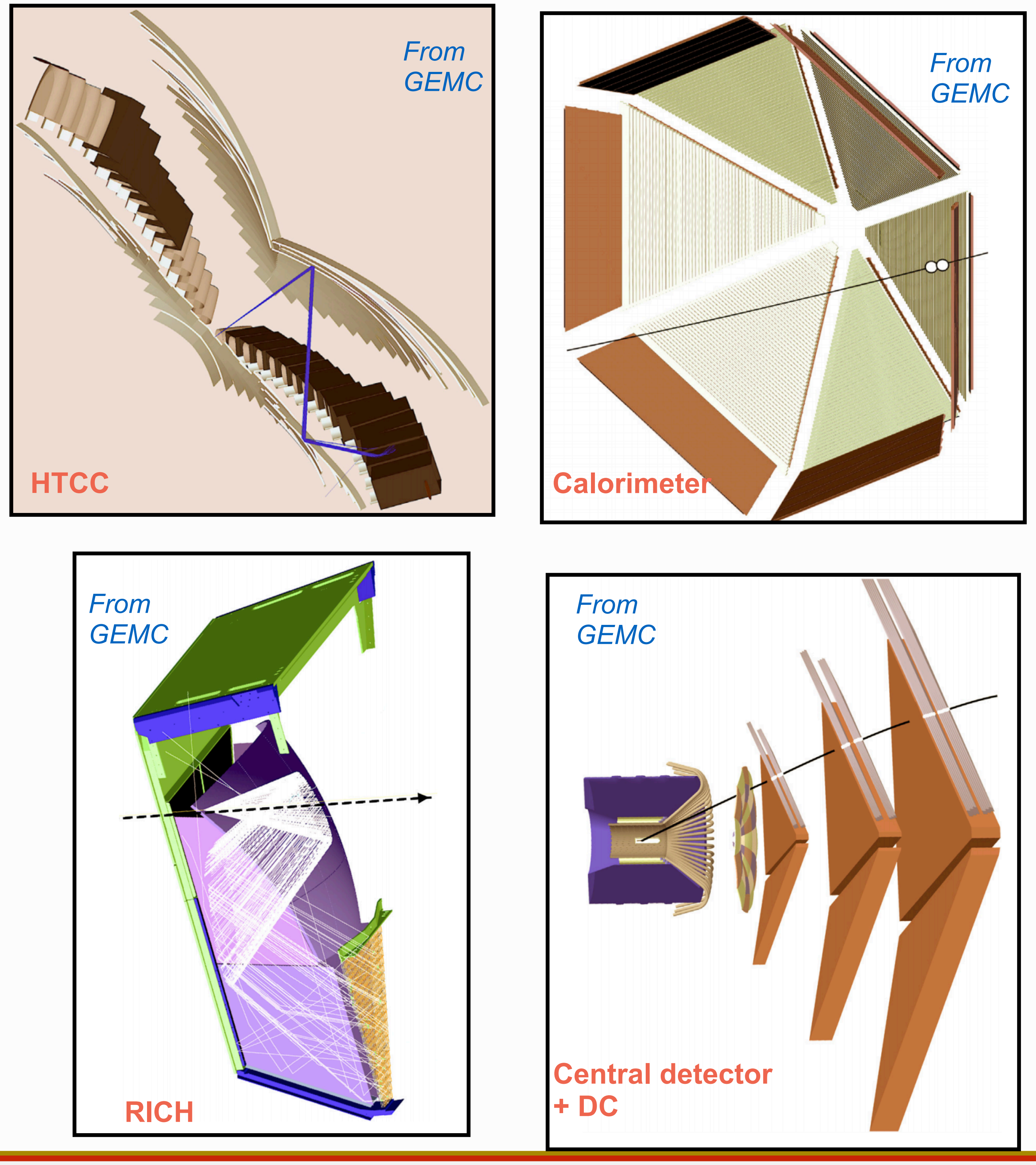




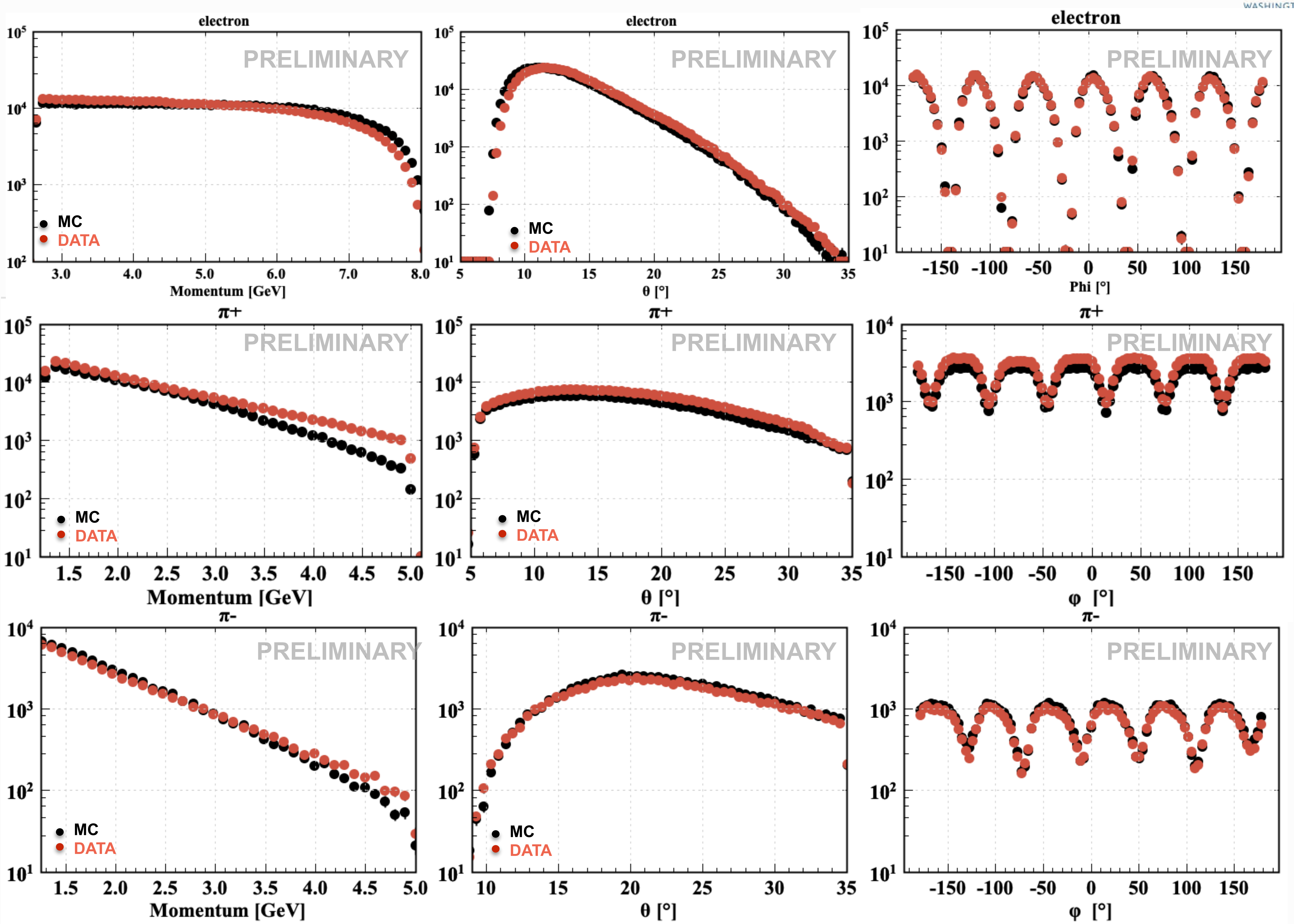
Monte Carlo simulations

Realistic Geant4 based detectors Simulations

The CLAS12 Geant4 simulation
Nucl. Instrum. Meth. A, Volume 959, 2020



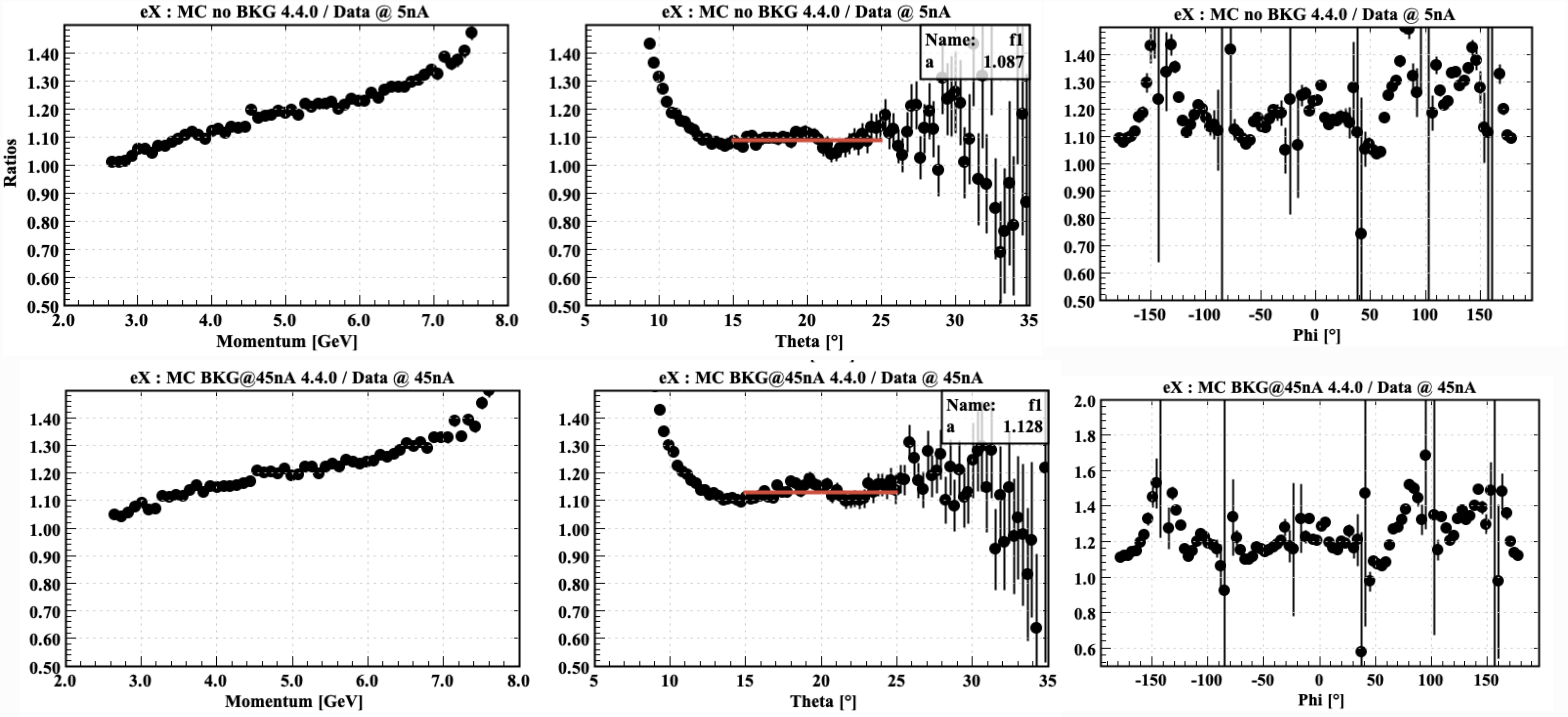
LEPTO based event generator



Production is undergoing: For this presentation we used 1/10th of the statistic on data because of the limited MC produced.

Monte Carlo simulations

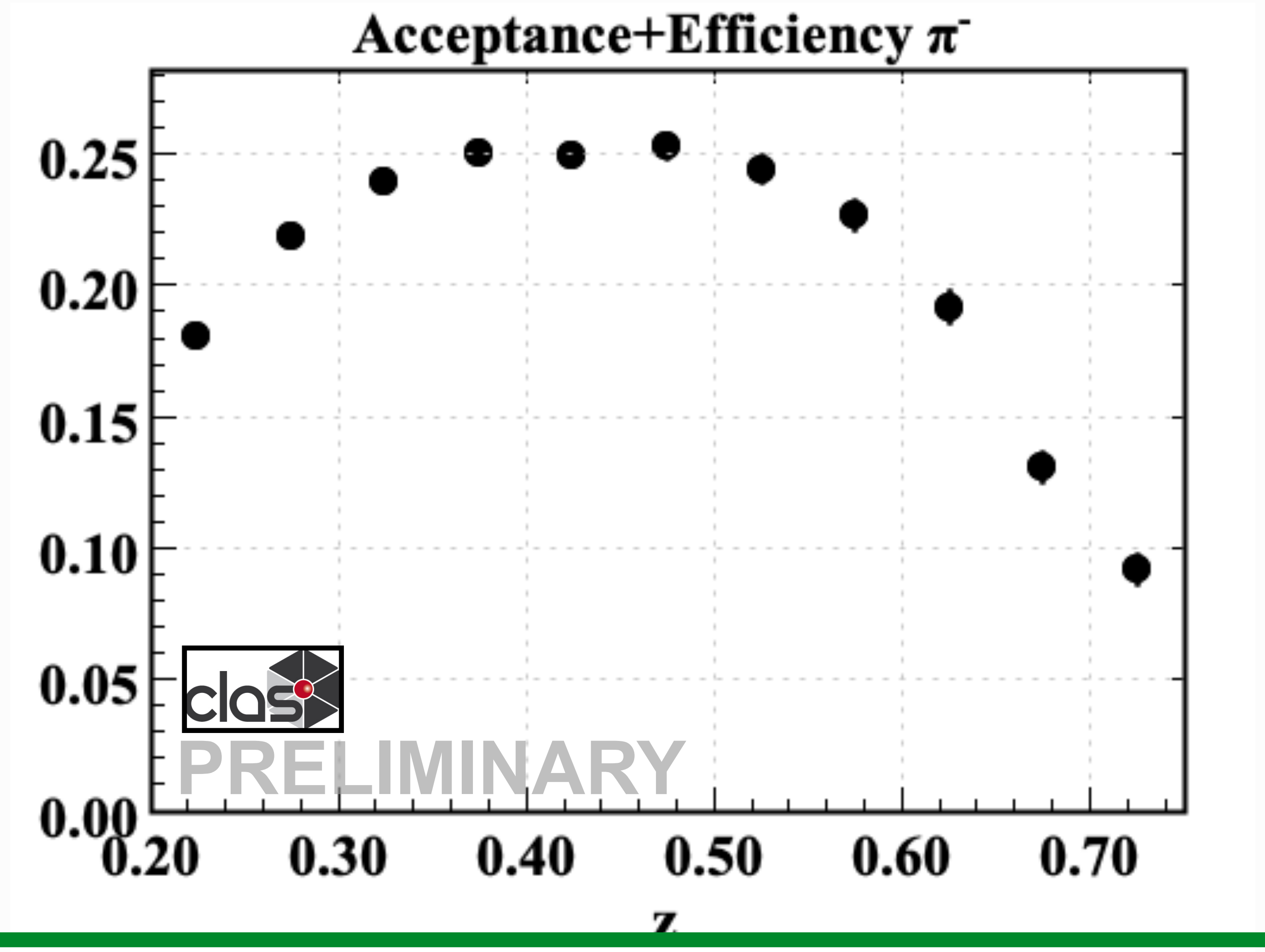
- The differences between MC and data suggest to implement tighter cuts that the one used for BSA.
- We are waiting for OSG release of 4.4.1 with calorimeter fixes

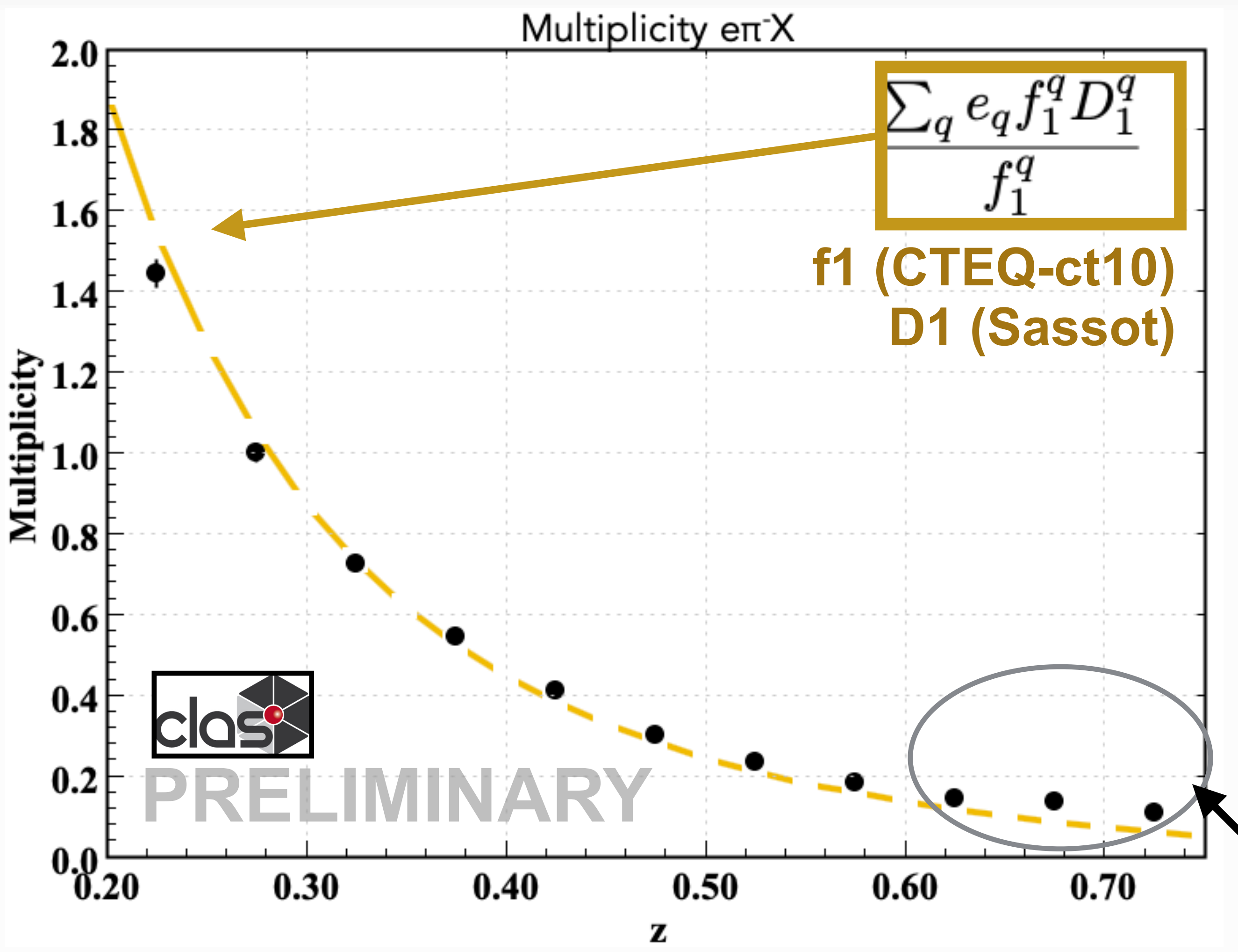


We are working on defining tighter cuts to avoid detector edges.

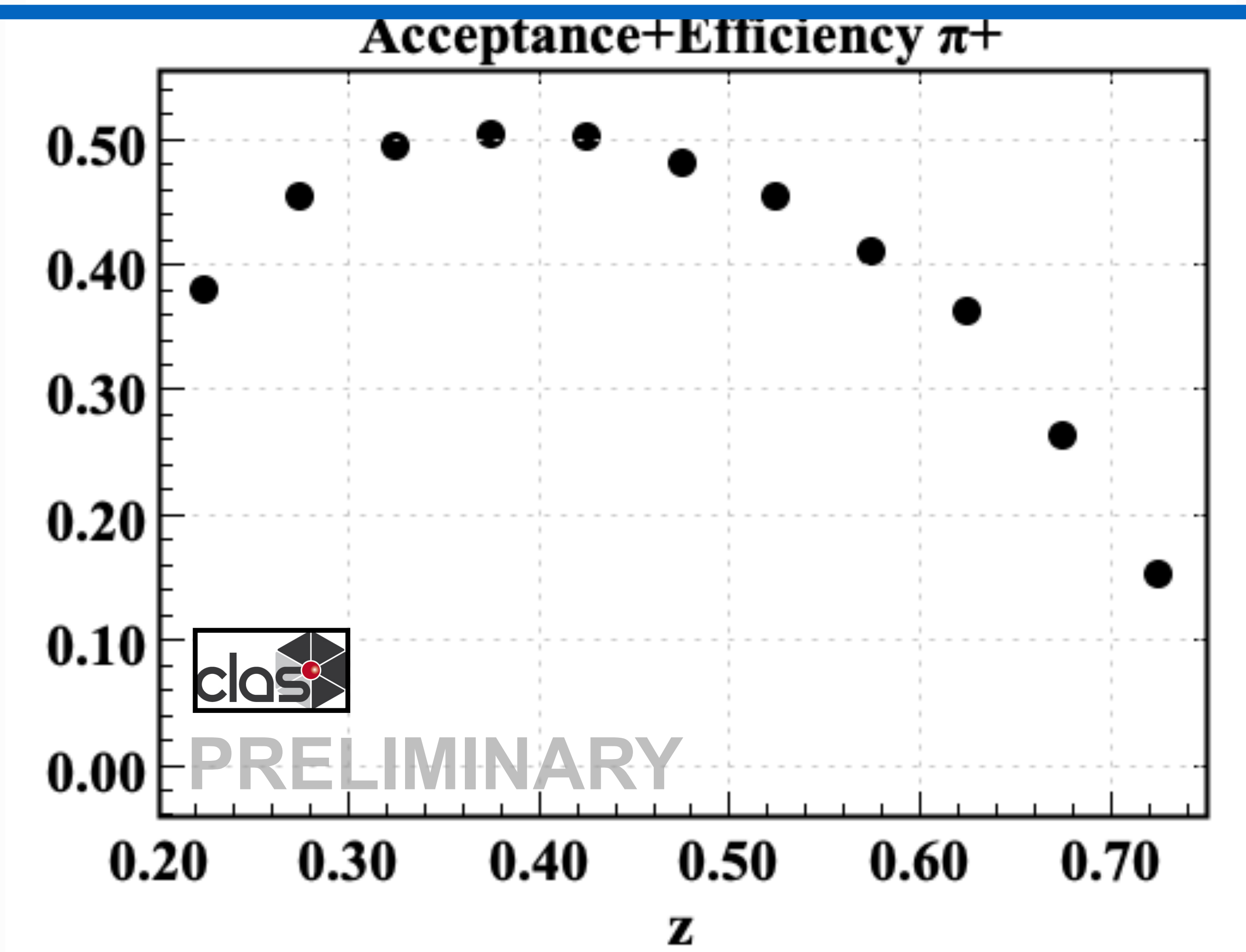
Multiplicity vs z

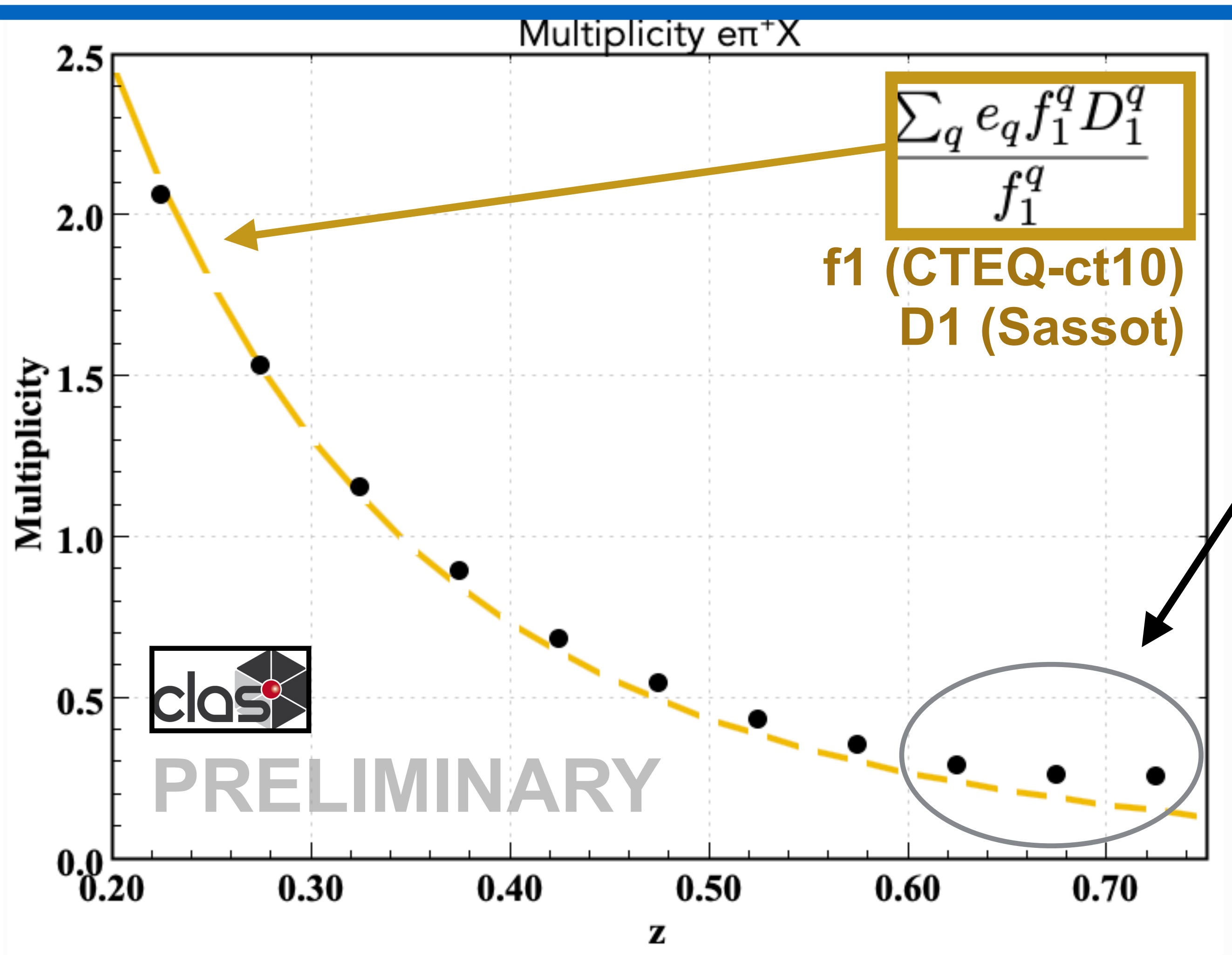
ep->eπ-X





ep->eπ+X





Under study,
Possible
higher twist effects

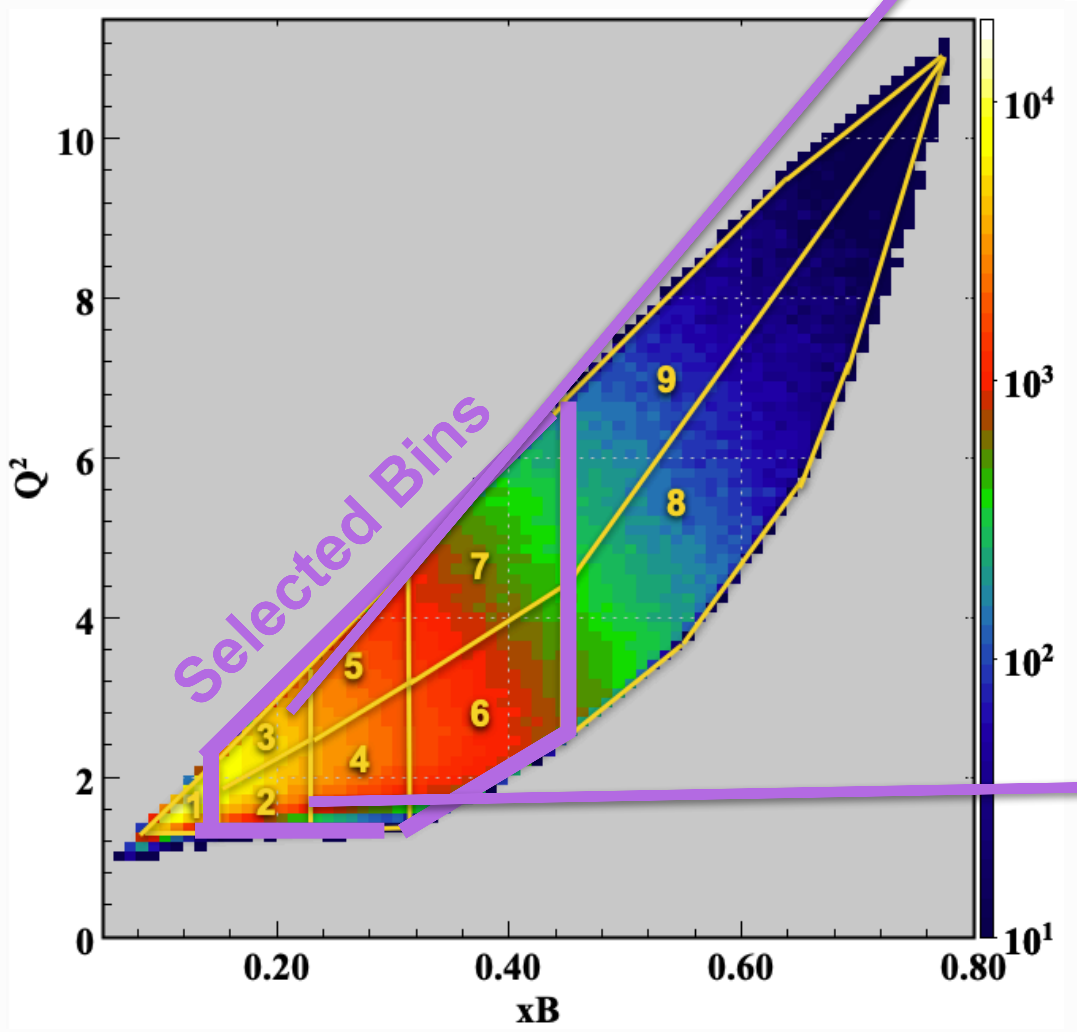
Multiplicity vs z and PT^2 : Acceptance π-

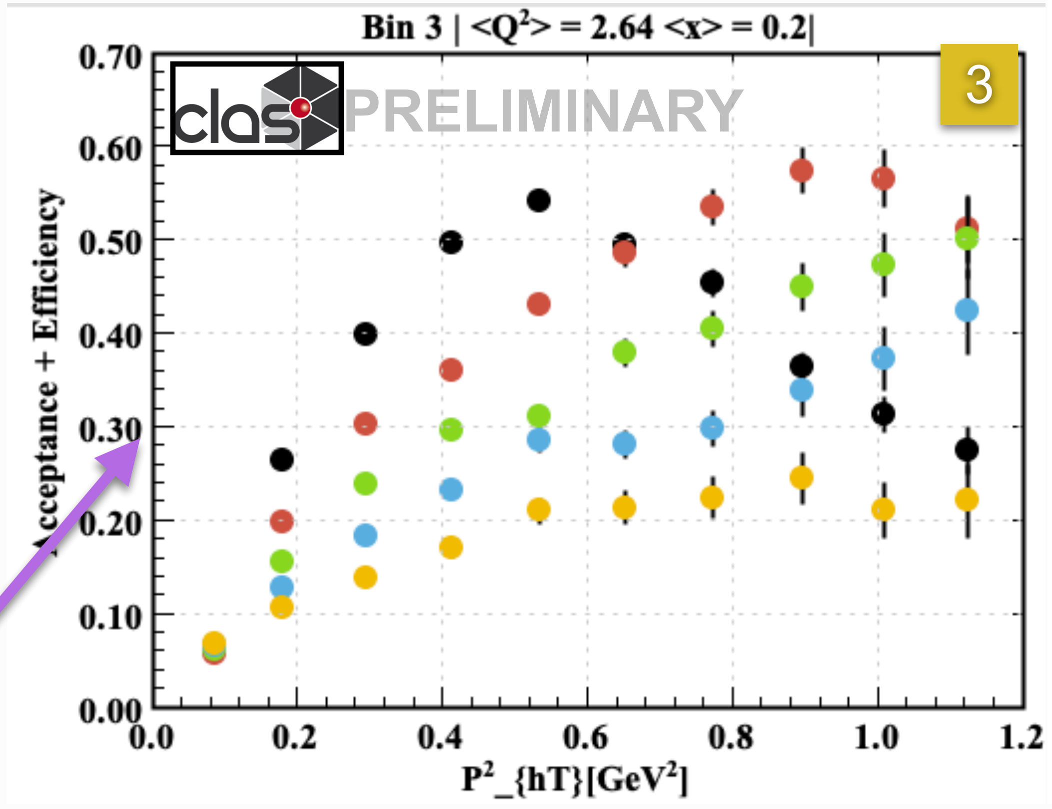
THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

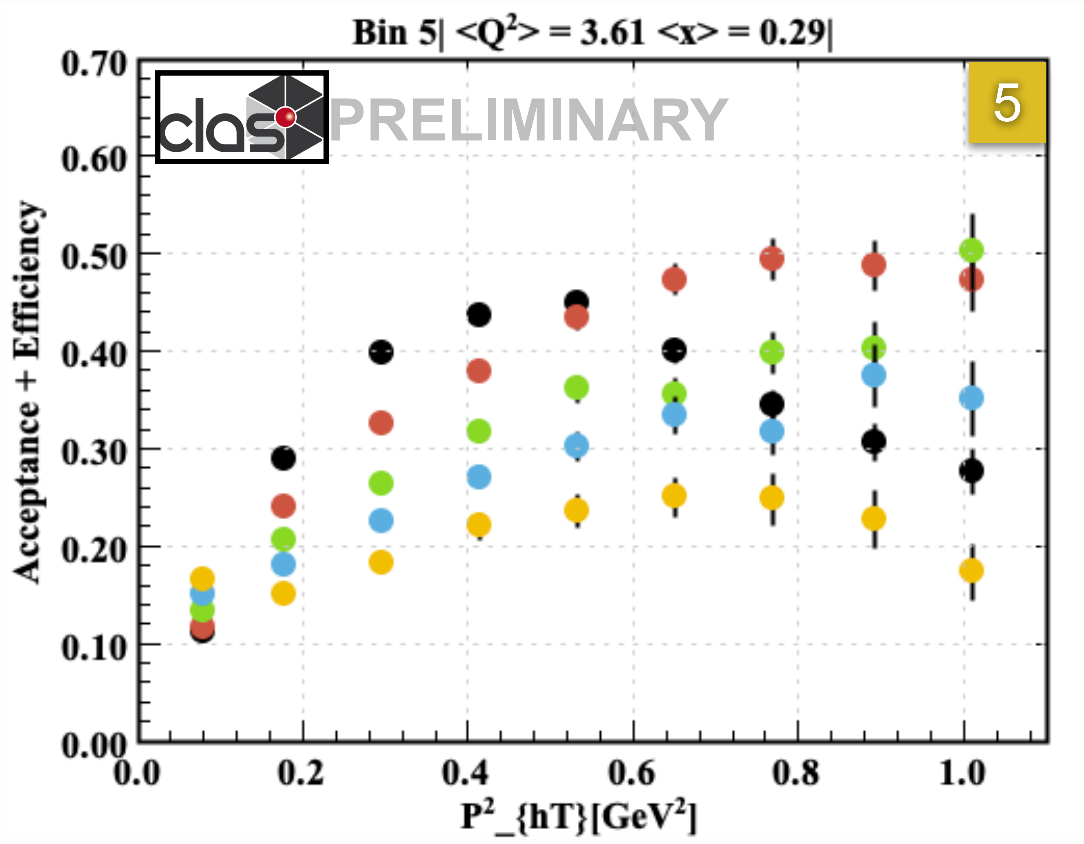
ep->eπ-X

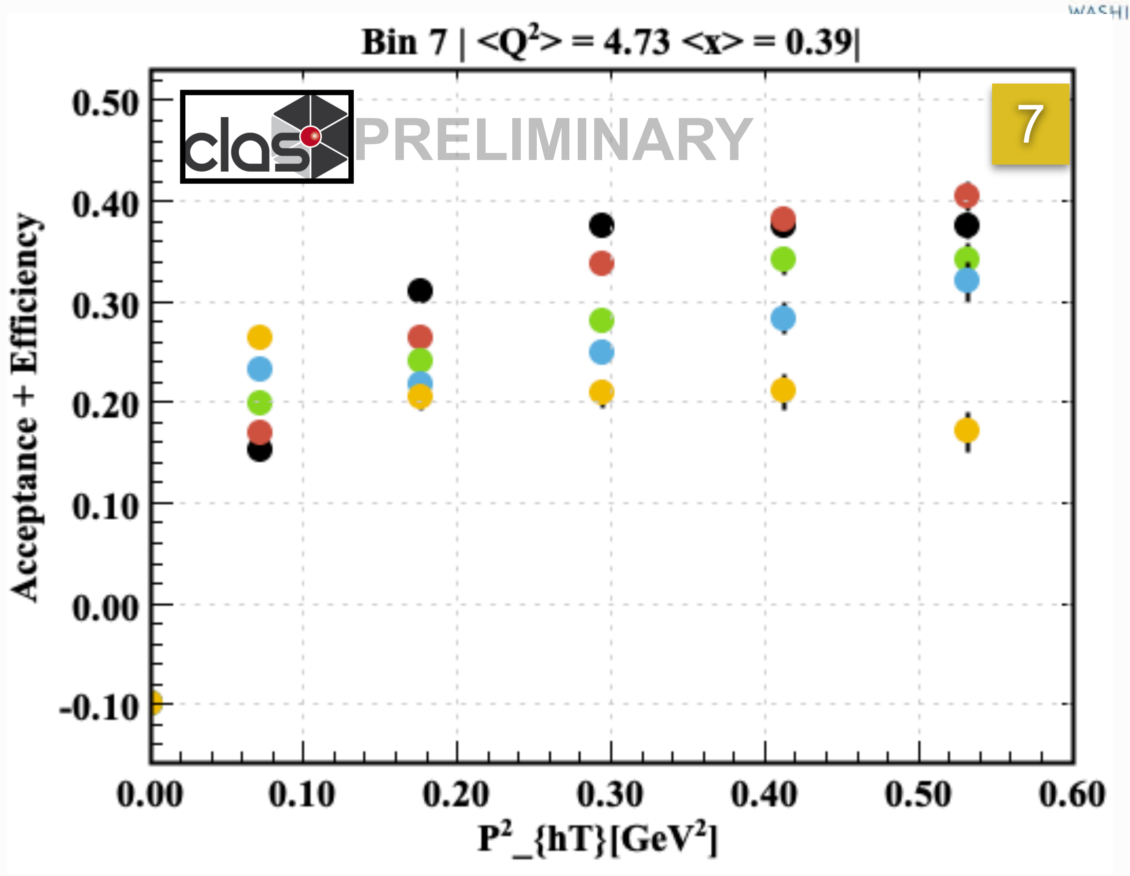
Color legend

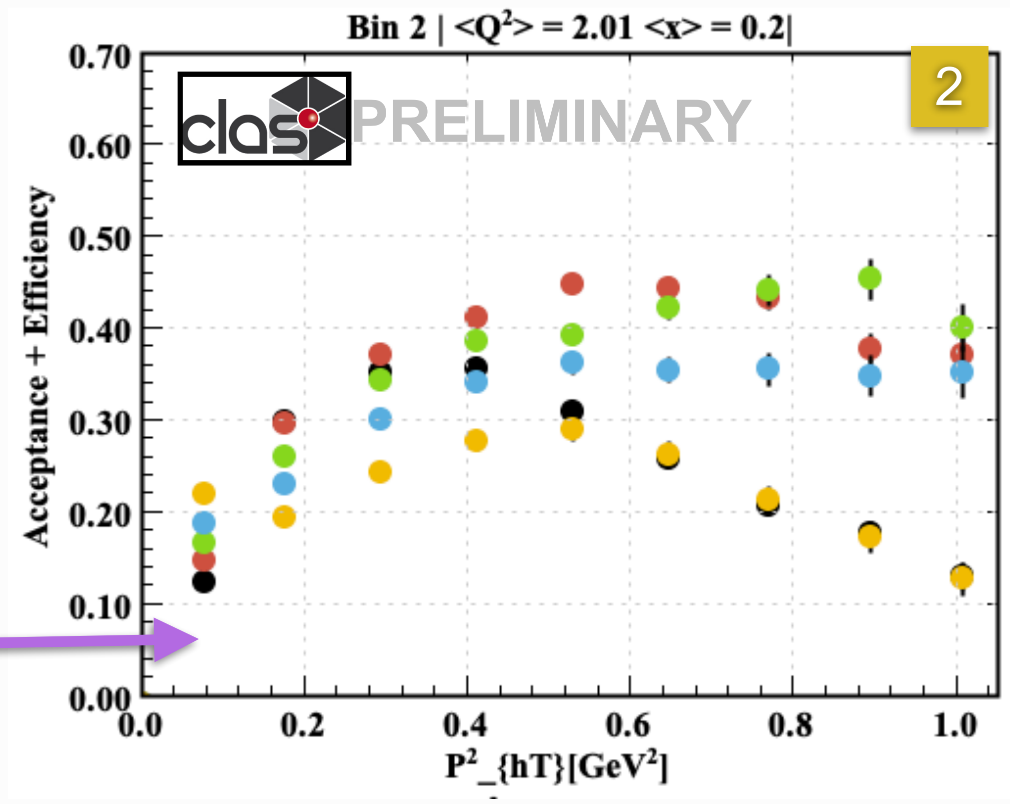
- 0.2<z<0.3
- 0.3<z<0.4
- 0.4<z<0.5
- 0.5<z<0.6
- 0.6<z<0.7

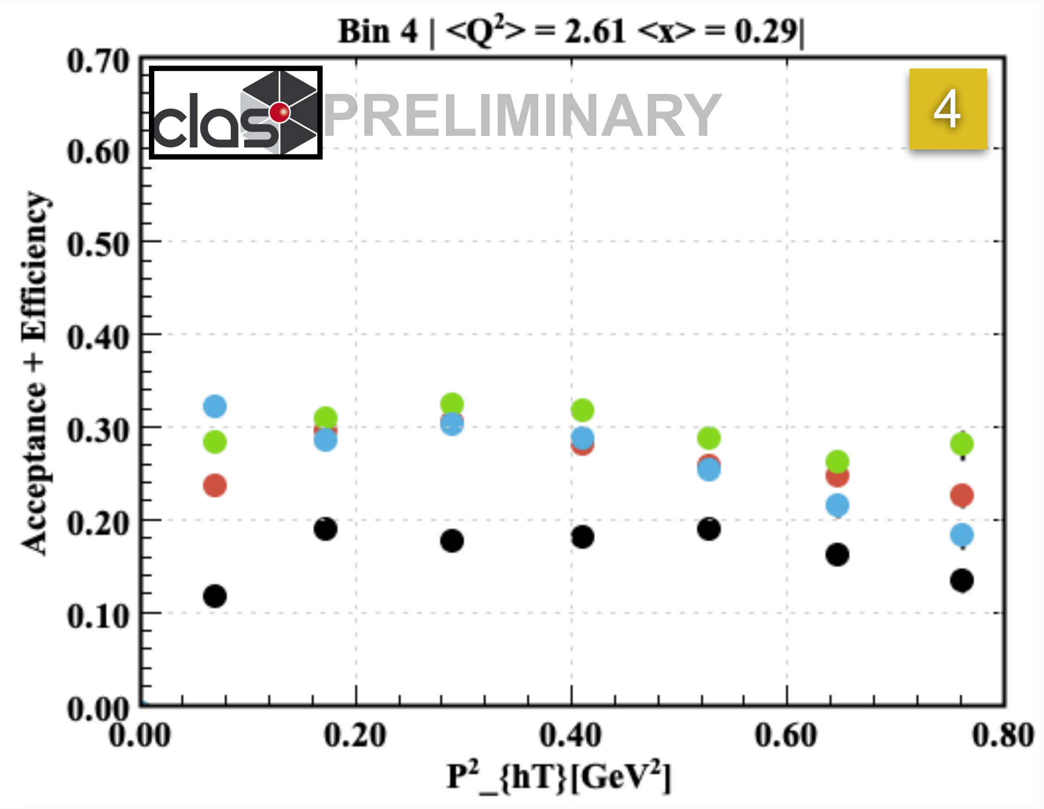


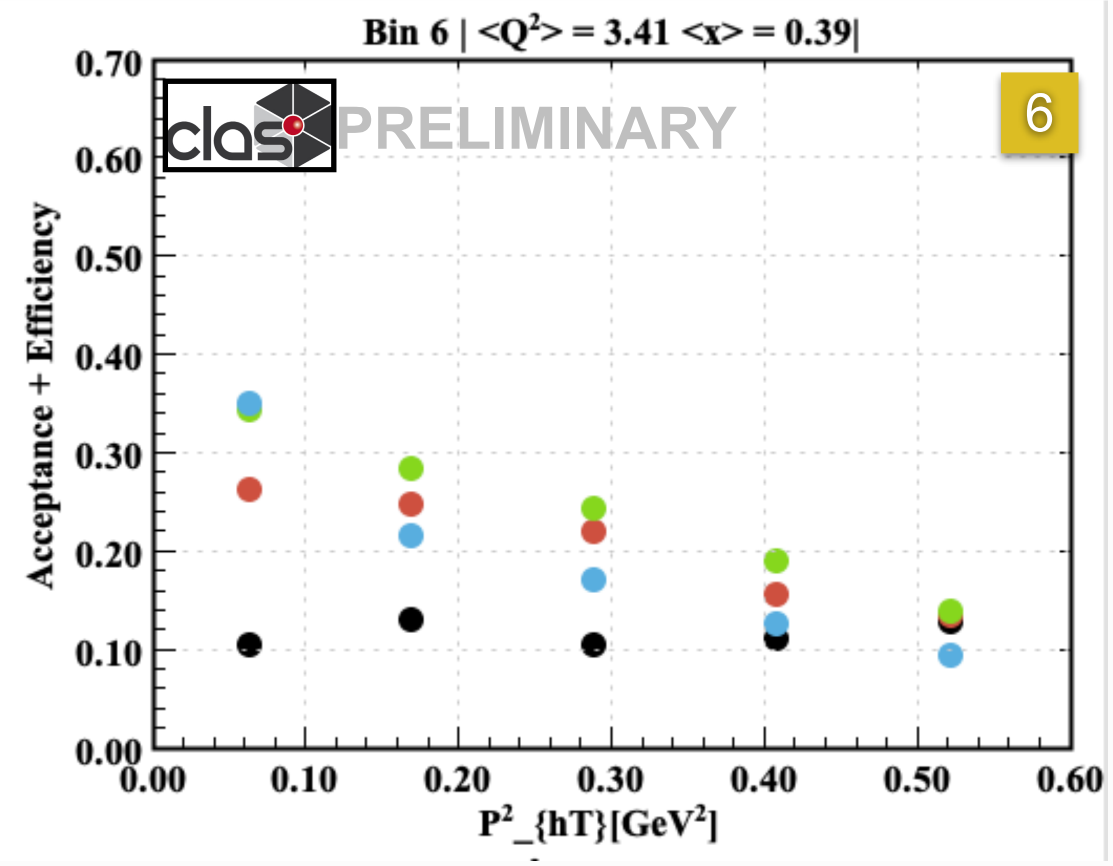












<x> =0.2 <x> =0.29 <x> =0.39

Multiplicity vs z and PT^2 : Multiplicity π-

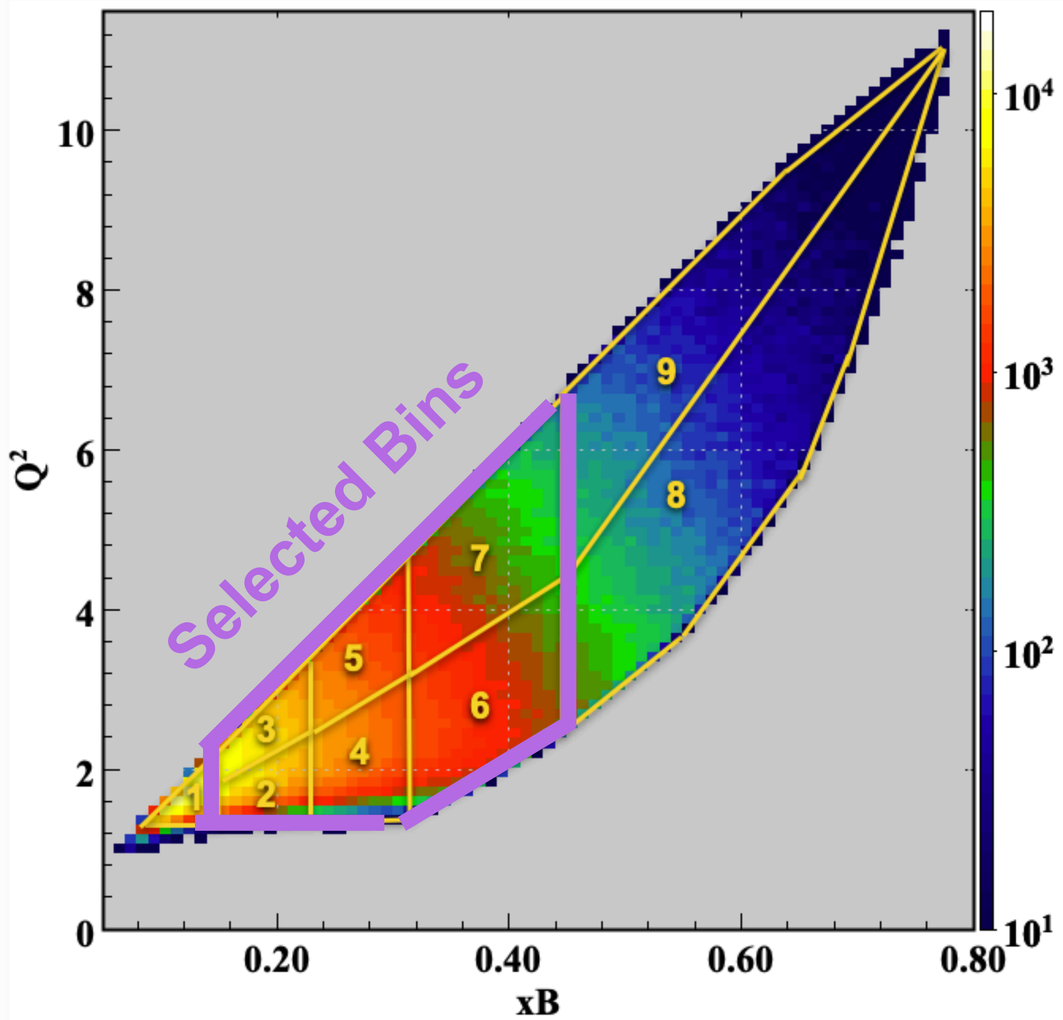
$$m_N^h(x,z,P_{hT}^2) = \frac{\pi}{\sum_a e_a^2\, f_1^a(x)} \times \sum_a e_a^2\, f_1^a(x)\, D_1^{a\to h}(z)\, \frac{e^{-P_{hT}^2/\left(z^2\langle k_{\perp,a}^2\rangle + \langle P_{\perp,a\to h}^2\rangle\right)}}{\pi\left(z^2\langle k_{\perp,a}^2\rangle + \langle P_{\perp,a\to h}^2\rangle\right)}$$

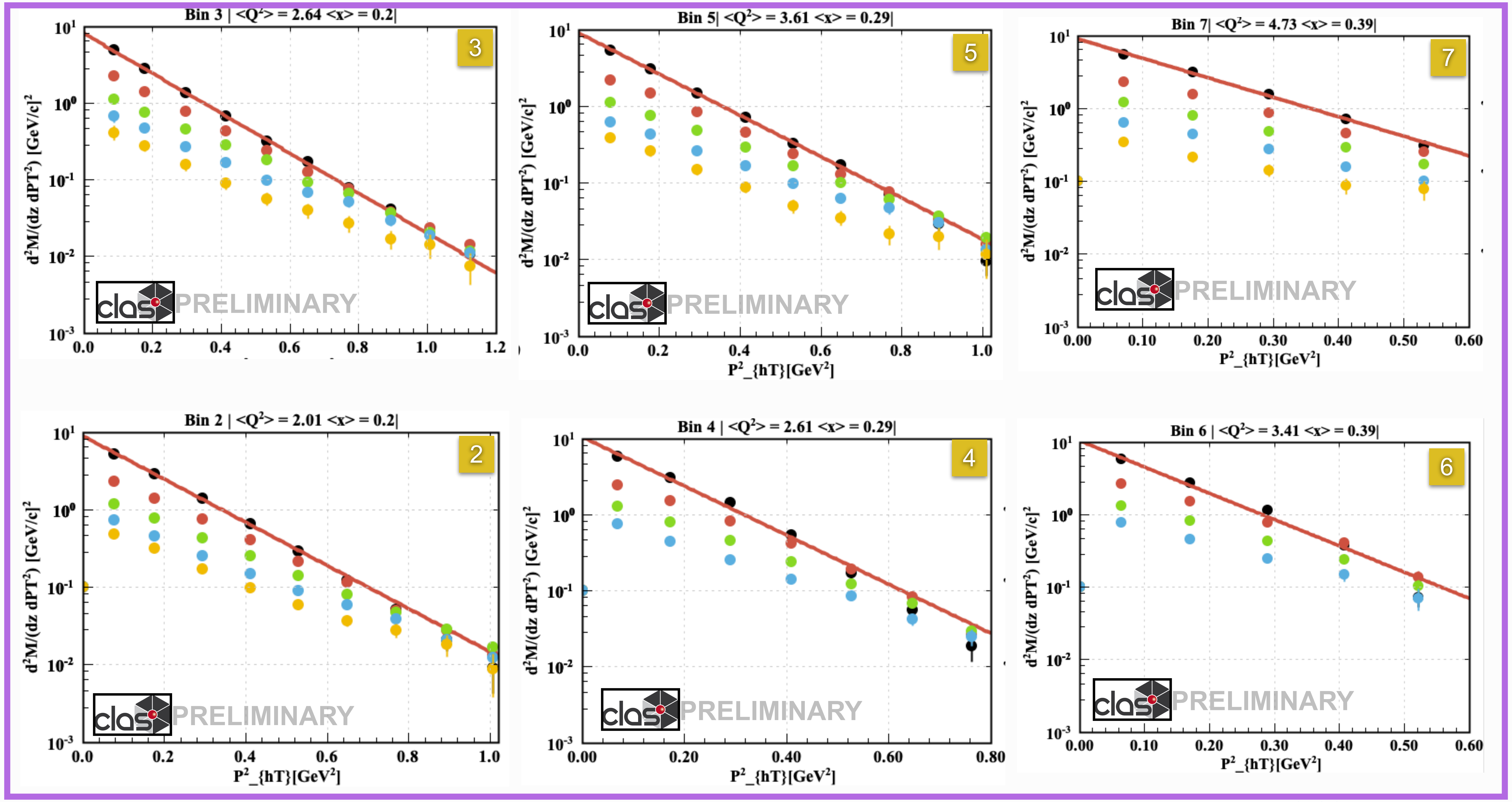
Fitted in the plots

ep->eπ-X

Color legend

- 0.2<z<0.3
- 0.3<z<0.4
- 0.4<z<0.5
- 0.5<z<0.6
- 0.6<z<0.7





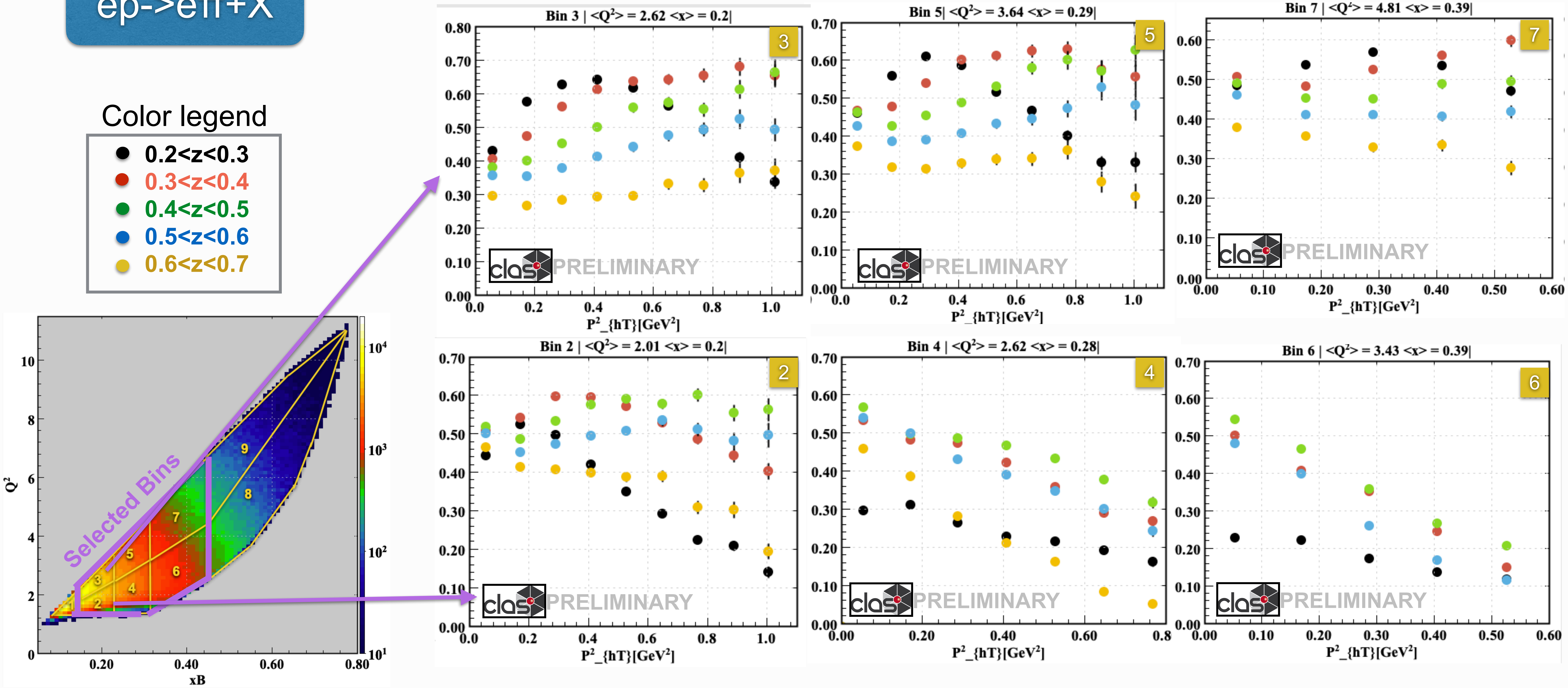
<x> =0.2 <x> =0.29 <x> =0.39

Multiplicity vs z and PT^2 :Acceptances π+

ep->eπ+X

Color legend

- 0.2<z<0.3
- 0.3<z<0.4
- 0.4<z<0.5
- 0.5<z<0.6
- 0.6<z<0.7



<x> =0.2

<x> =0.29

<x> =0.39

Multiplicity vs z and PT^2 : Multiplicity π+

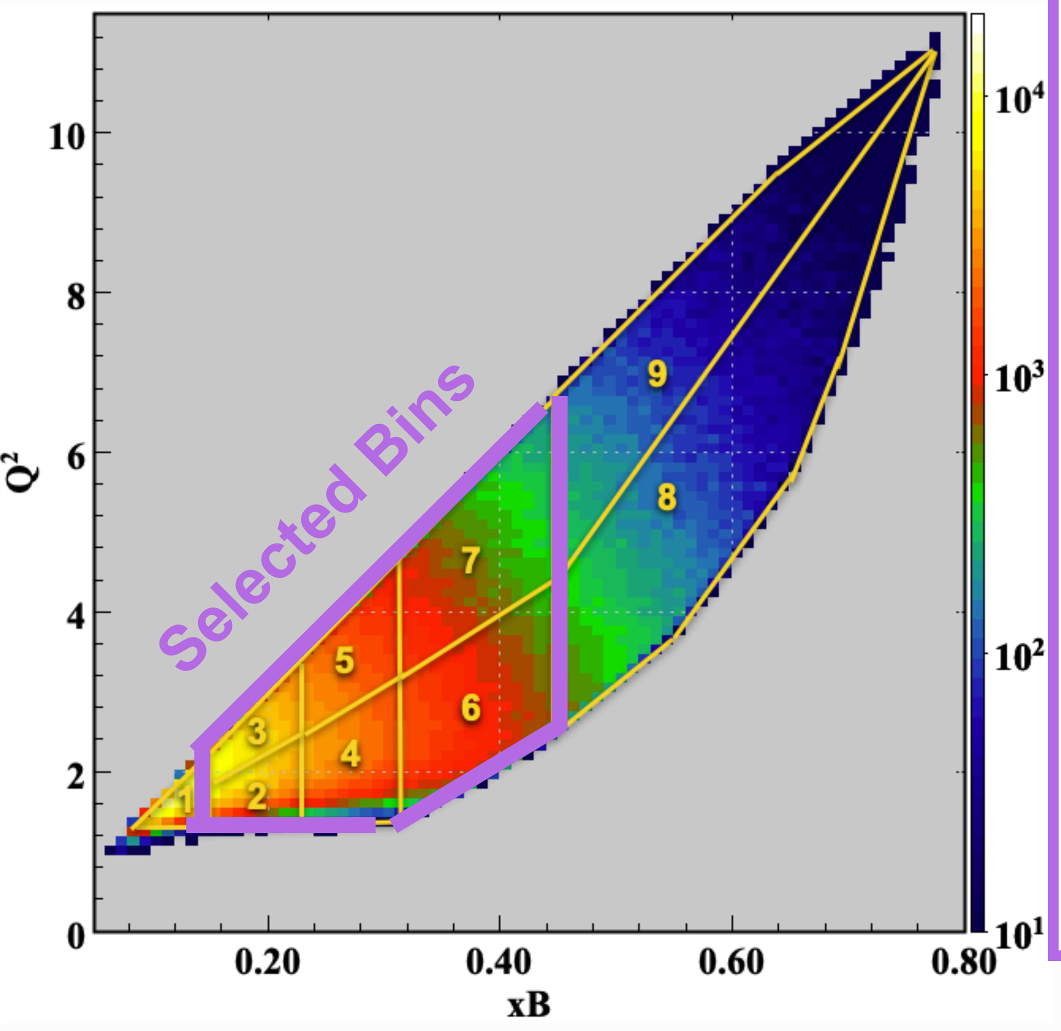
$$m_N^h(x,z,P_{hT}^2) = \frac{\pi}{\sum_a e_a^2 f_1^a(x)} \times \sum_a e_a^2 f_1^a(x) D_1^{a\to h}(z) \frac{e^{-P_{hT}^2/\left(z^2\langle k_{\perp,a}^2\rangle + \langle P_{\perp,a\to h}^2\rangle\right)}}{\pi\left(z^2\langle k_{\perp,a}^2\rangle + \langle P_{\perp,a\to h}^2\rangle\right)}$$

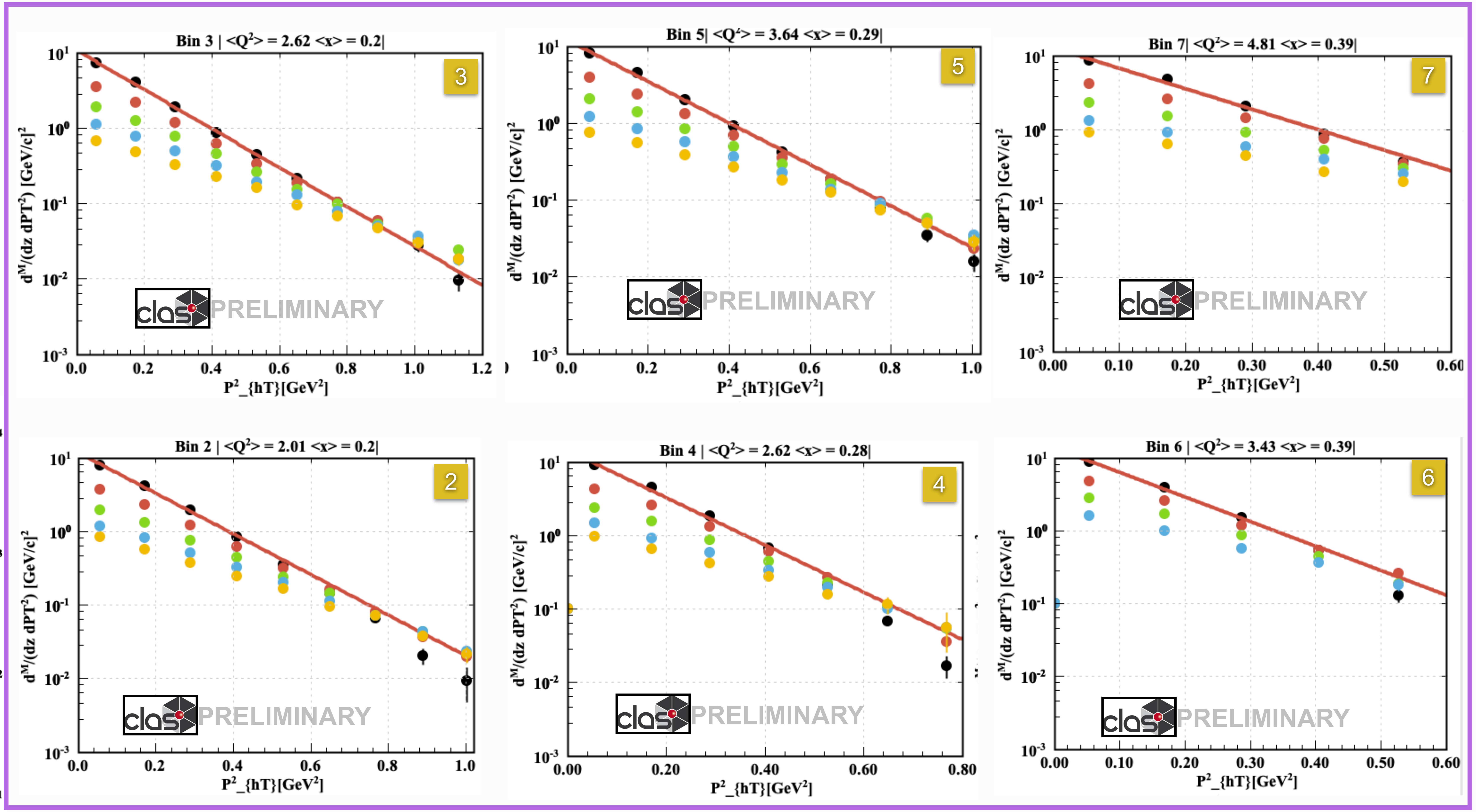
Fitted in the plots

ep->eπ+X

Color legend

- 0.2<z<0.3
- 0.3<z<0.4
- 0.4<z<0.5
- 0.5<z<0.6
- 0.6<z<0.7



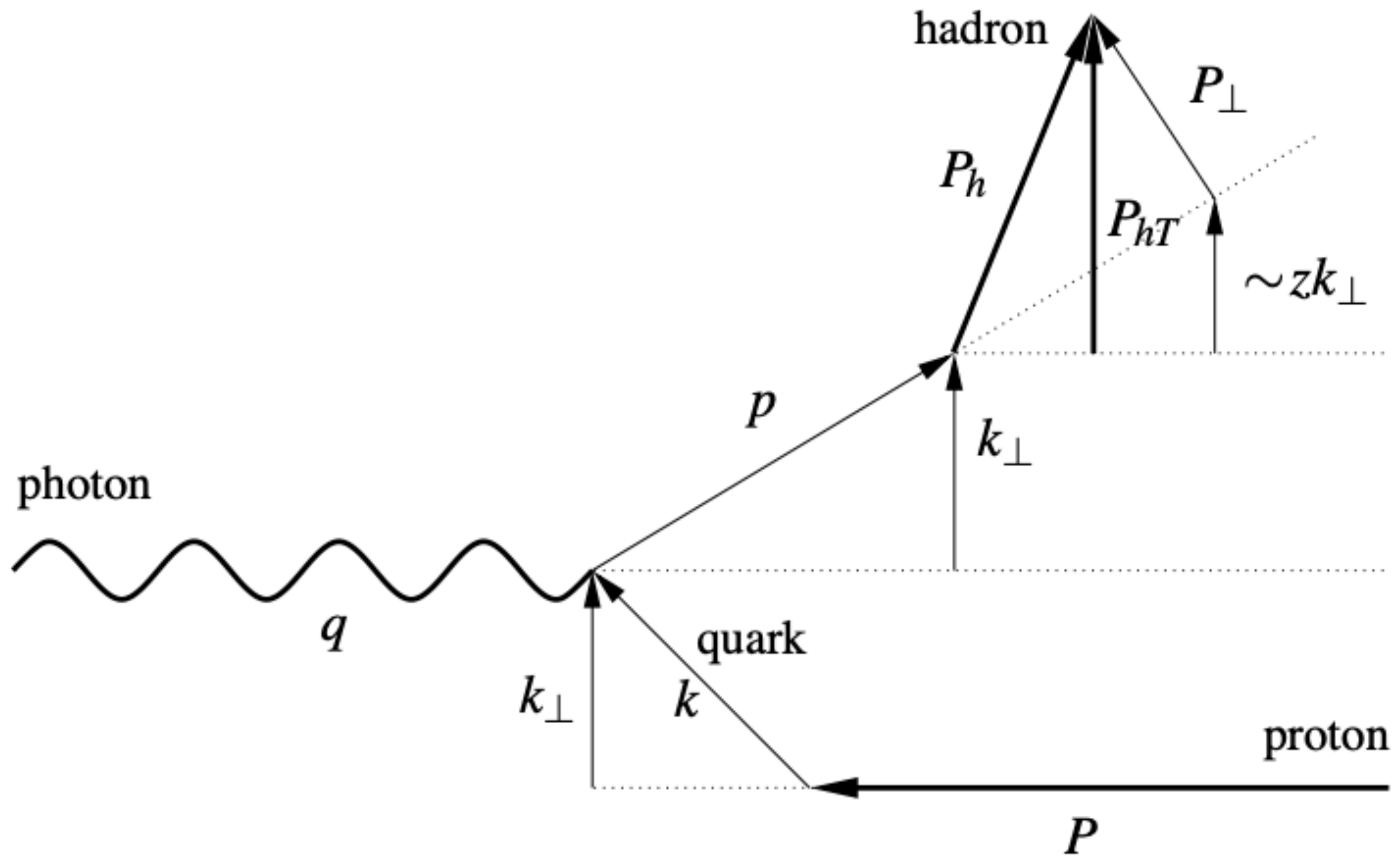


<x> =0.2 <x> =0.29 <x> =0.39

On the extraction on transverse momentum

We would like to extract average transverse momentum from our data

$$m_N^h(x,z,\boldsymbol{P}_{hT}^2) = \frac{\pi}{\sum_a e_a^2 f_1^a(x)} \times \sum_a e_a^2\, f_1^a(x)\, D_1^{a\to h}(z)\, \frac{e^{-\boldsymbol{P}_{hT}^2/\left(z^2\langle \boldsymbol{k}_{\perp,a}^2\rangle + \langle \boldsymbol{P}_{\perp,a\to h}^2\rangle\right)}}{\pi\left(z^2\langle \boldsymbol{k}_{\perp,a}^2\rangle + \langle \boldsymbol{P}_{\perp,a\to h}^2\rangle\right)}$$



$$\langle \boldsymbol{P}_{hT,a}^2\rangle = z^2\langle \boldsymbol{k}_{\perp,a}^2\rangle + \langle \boldsymbol{P}_{\perp,a\to h}^2\rangle\,.$$

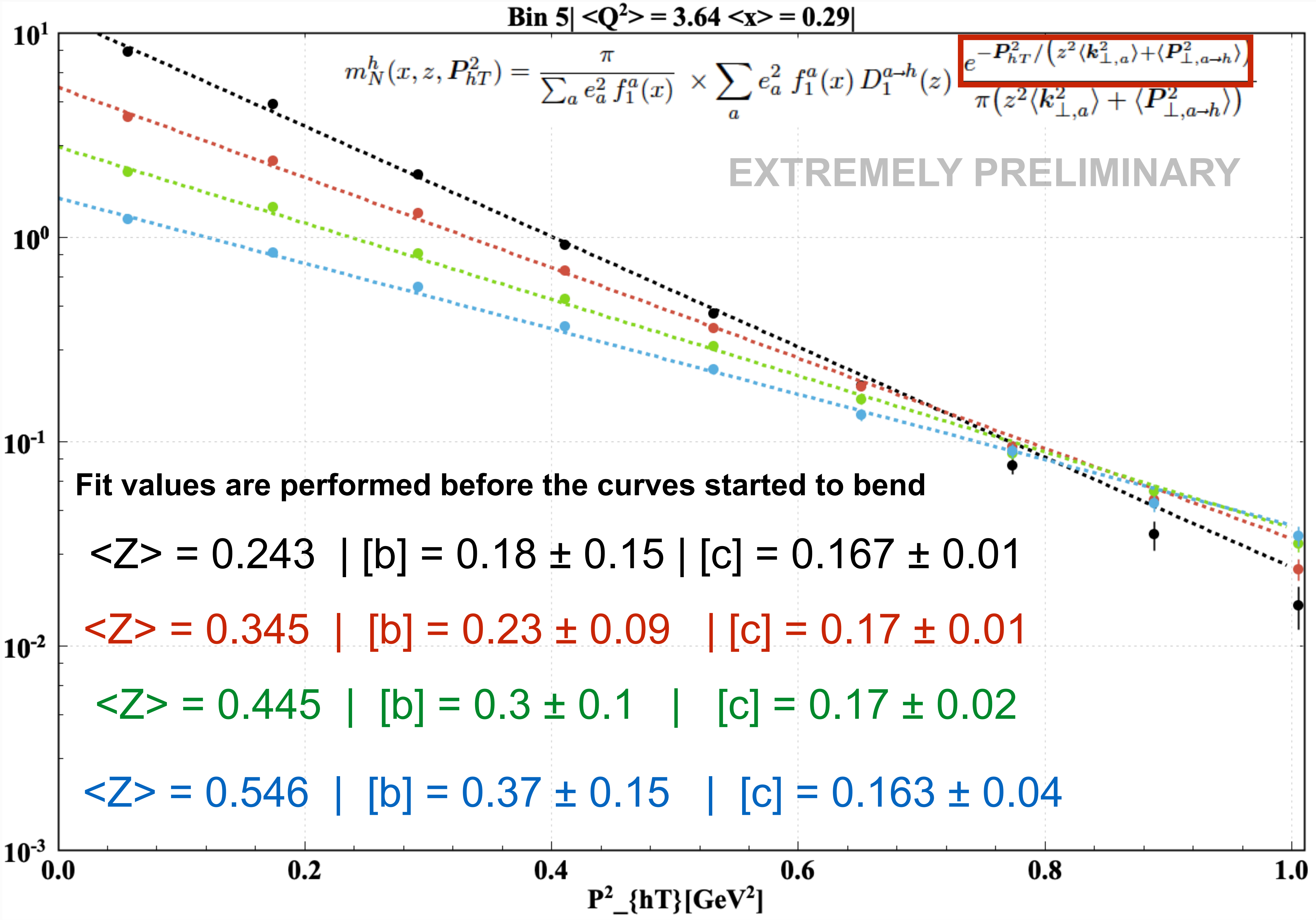
Momentum	Physical description
k	4-momentum of parton in distribution function
p	4-momentum of fragmenting parton
$\boldsymbol{k}_\perp$	light-cone transverse momentum of parton in distribution function
$\boldsymbol{P}_\perp$	light-cone transverse momentum of final hadron w.r.t. fragmenting parton
$\boldsymbol{P}_{hT}$	light-cone transverse momentum of final hadron w.r.t. virtual photon

From: Investigations into the flavor dependence of partonic transverse momentum

Signori et Al., https://arxiv.org/pdf/1309.3507.pdf

We need the full statistics for a trustable study. However here I am going to introduce you to the work in progress toward quark transverse momentum extraction.

On the extraction on transverse momentum



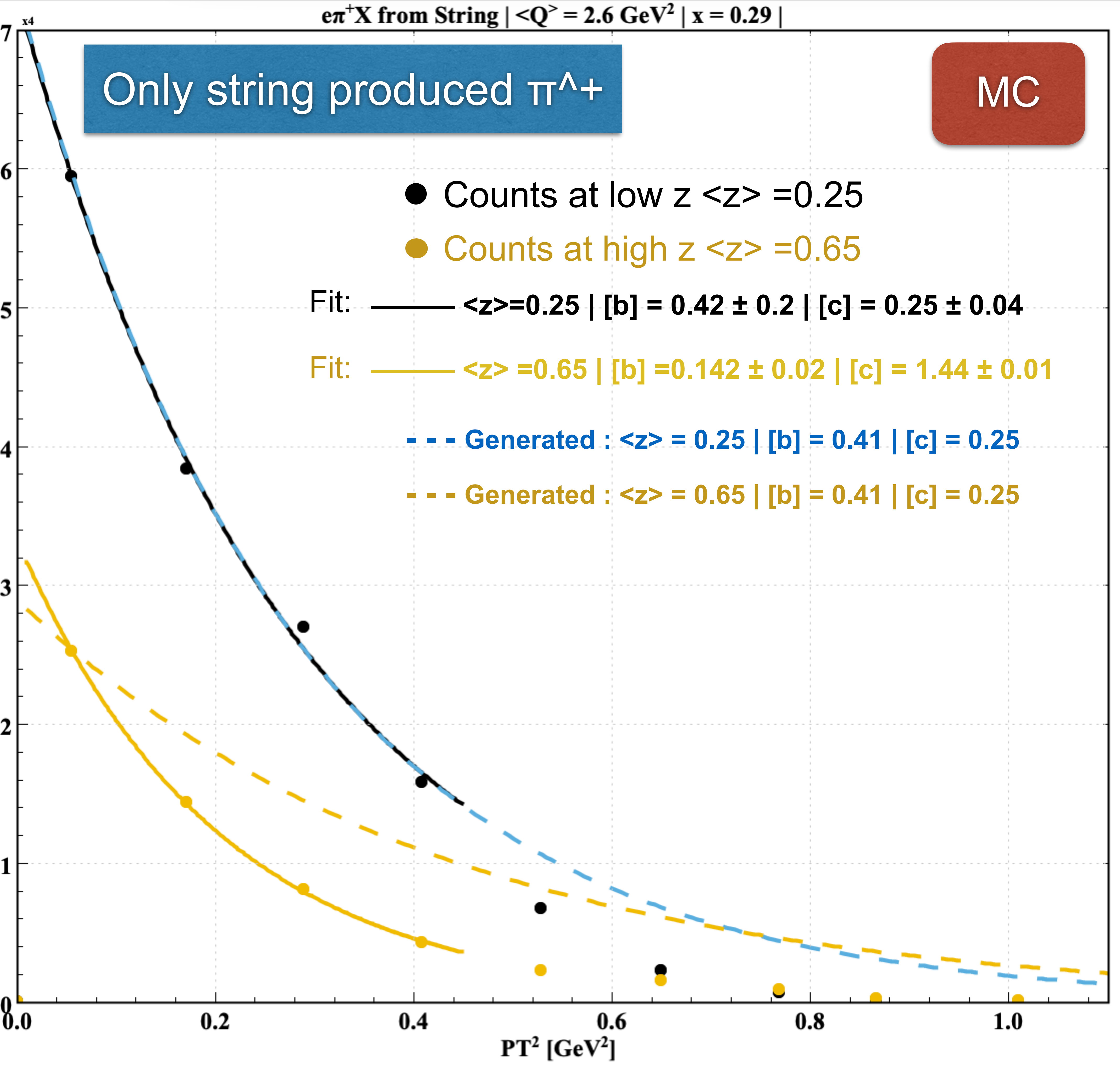
Fit : [a]*exp(-x/(<z>^{2} *[b]+[c]))

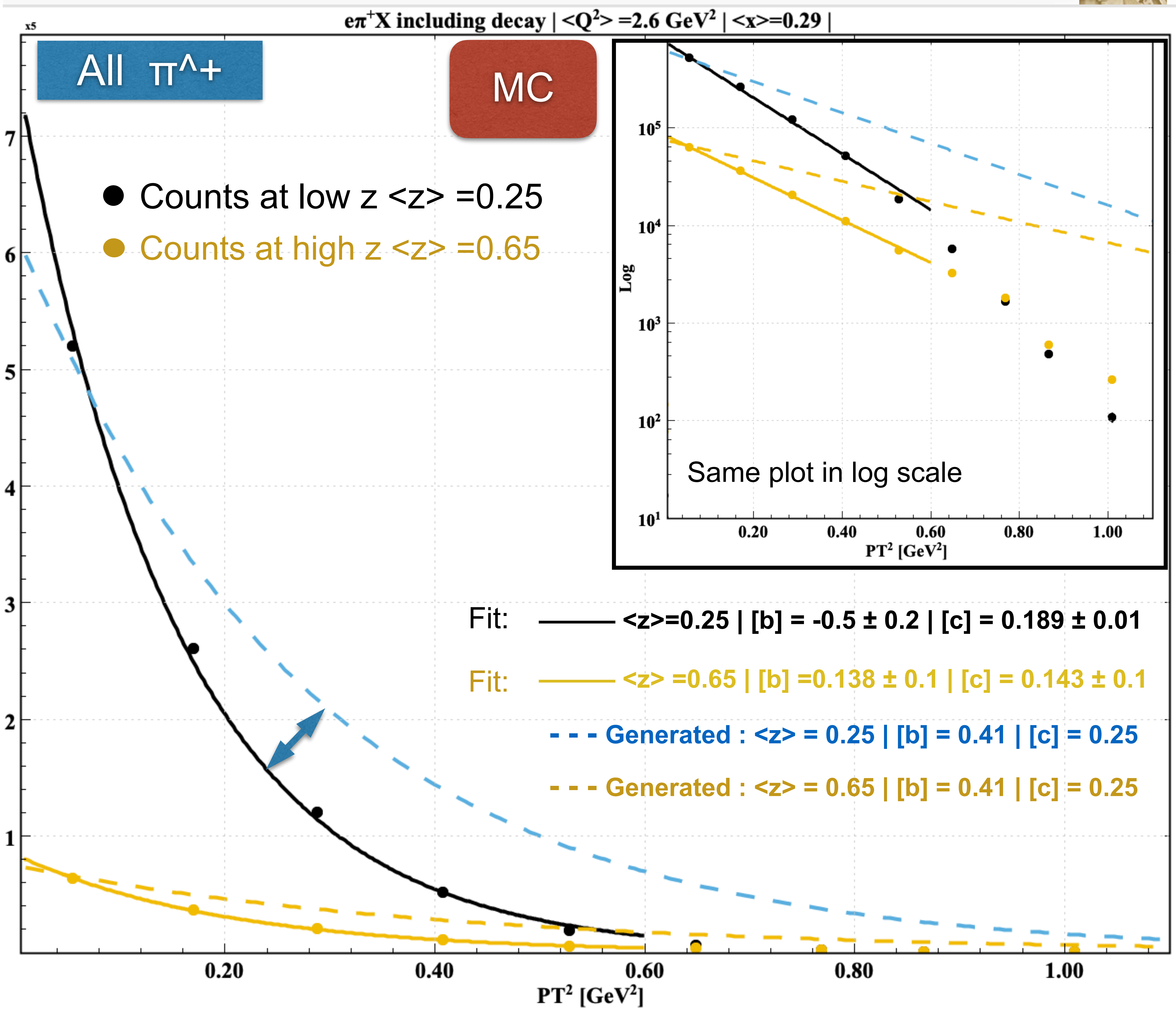
[b] ⟶ $\boldsymbol{k}_\perp$

[c] ⟶ $\boldsymbol{P}_\perp$

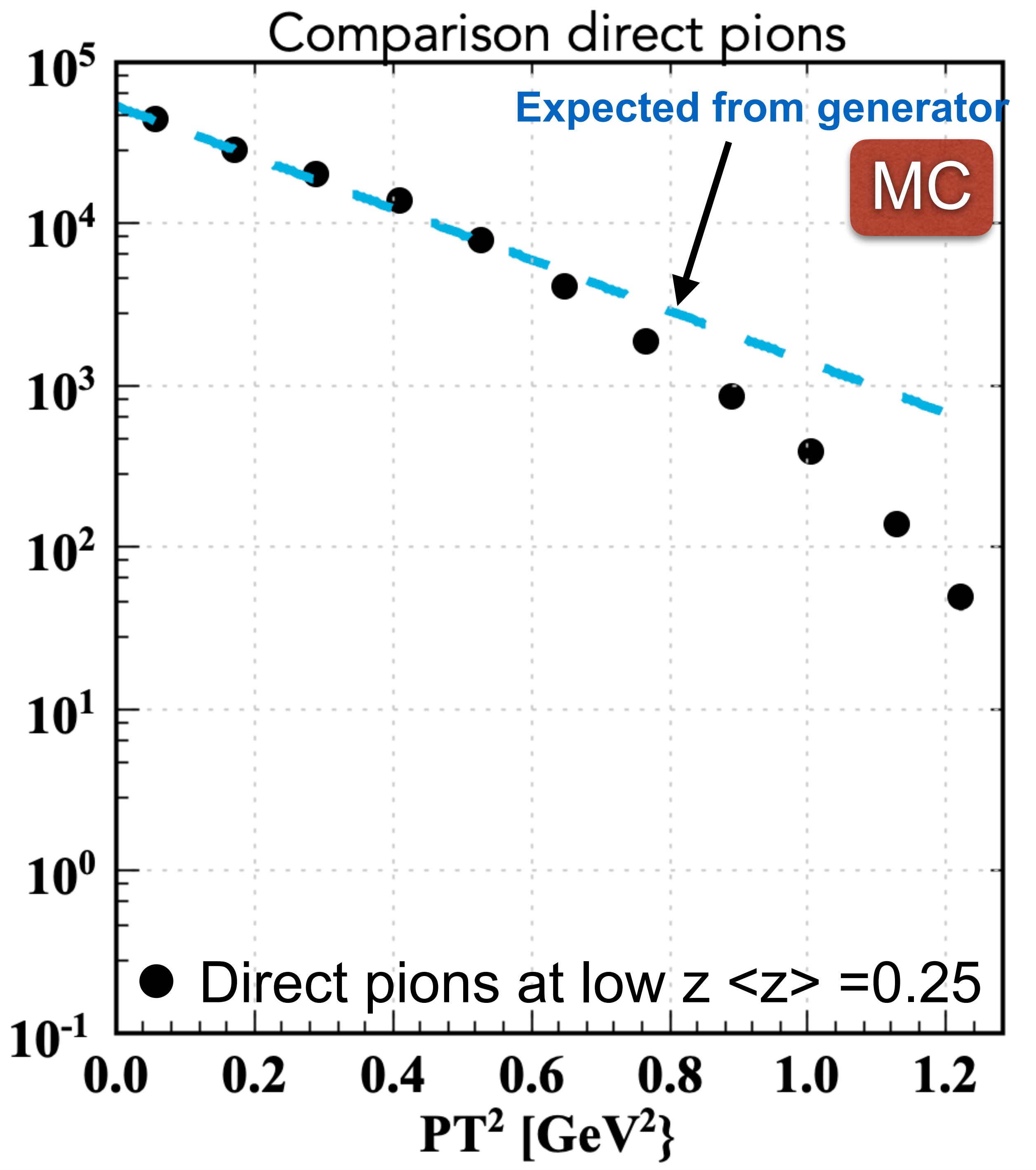
The increase of k perp as function of z has been observed by COMPASS.
We believe that this effect is due to electro produced vector mesons in current fragmentation region that decays into pions (+ phase space in CLAS kinematic)

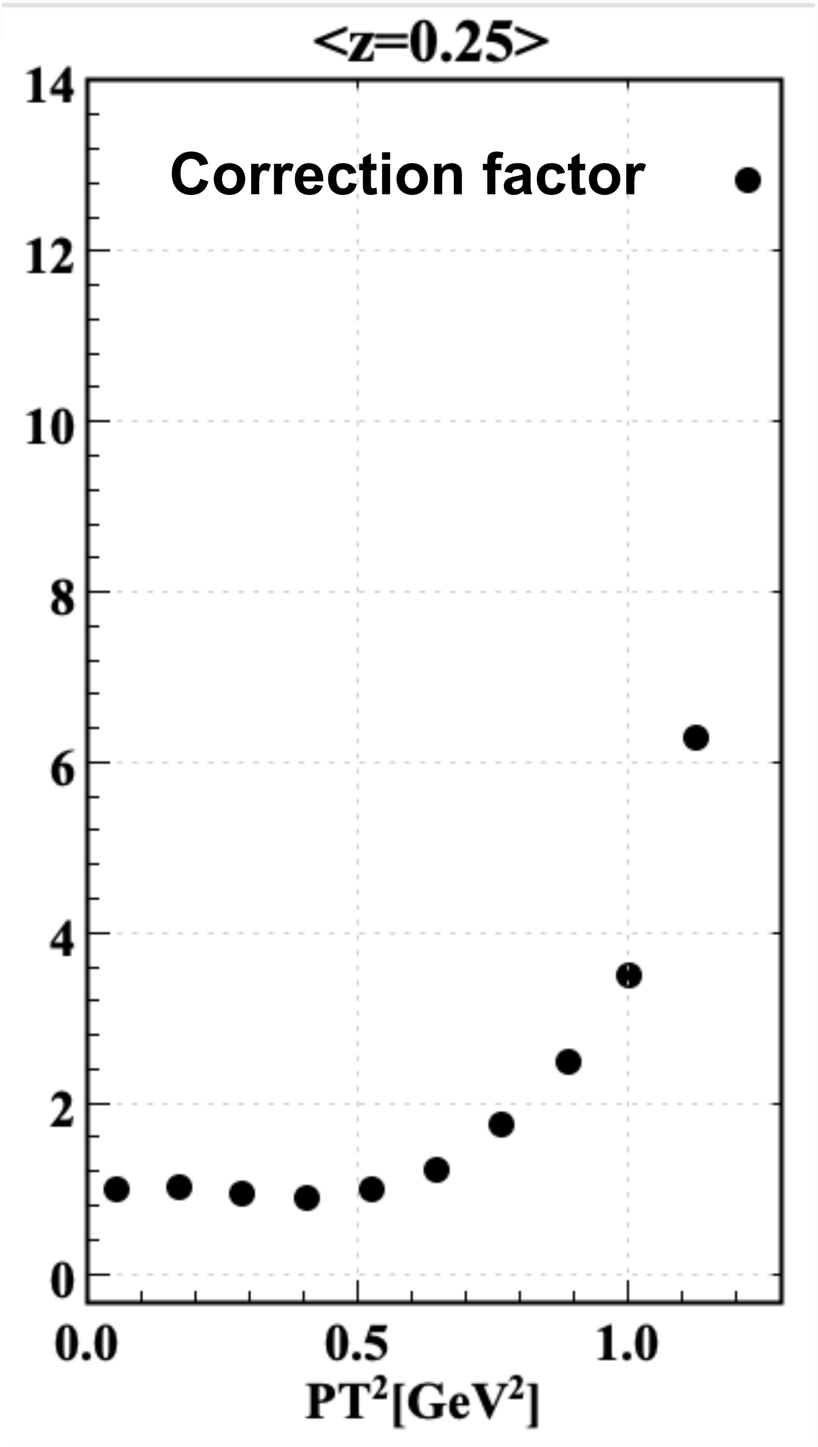
On the extraction on transverse momentum



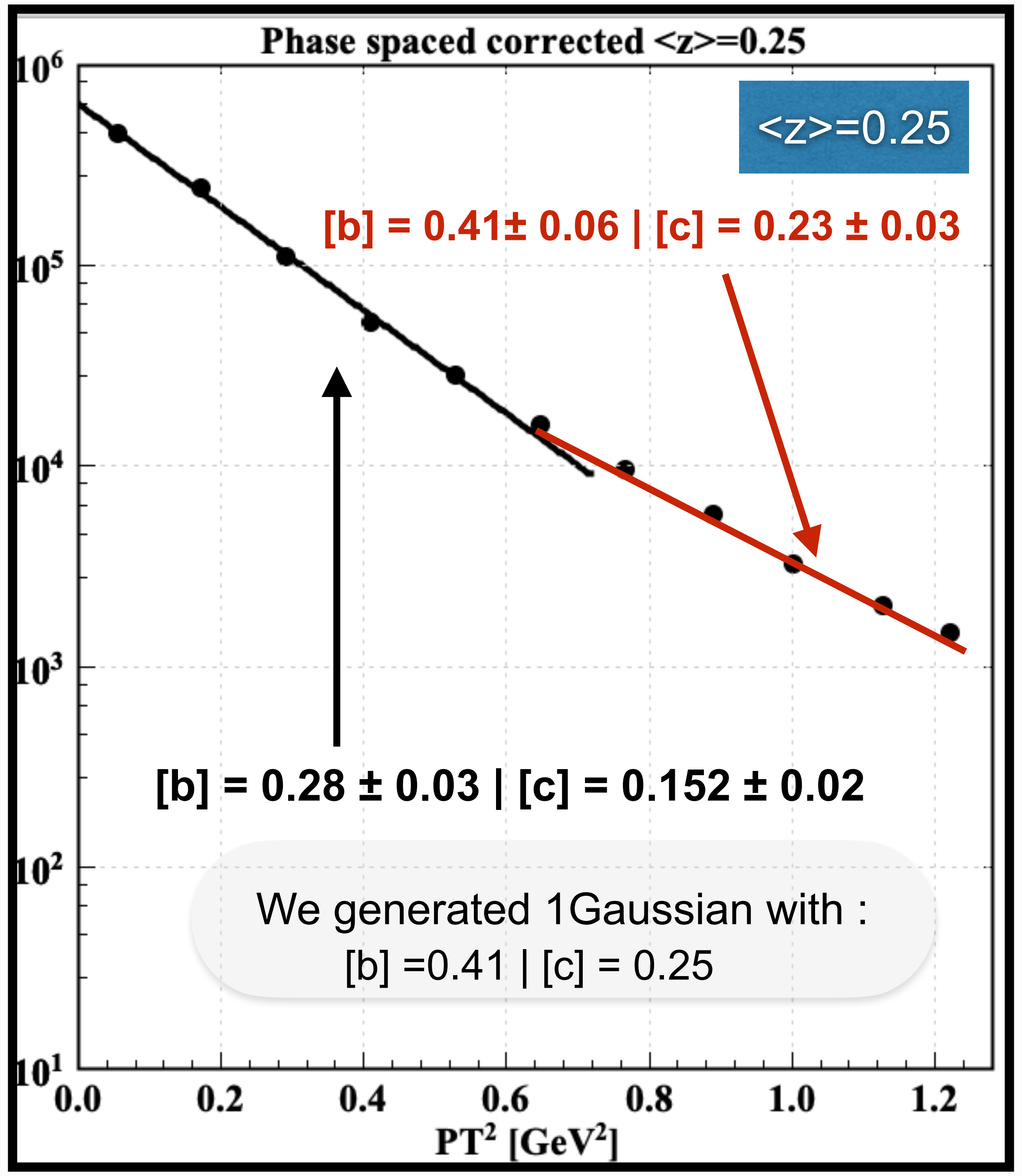


Phase space corrections



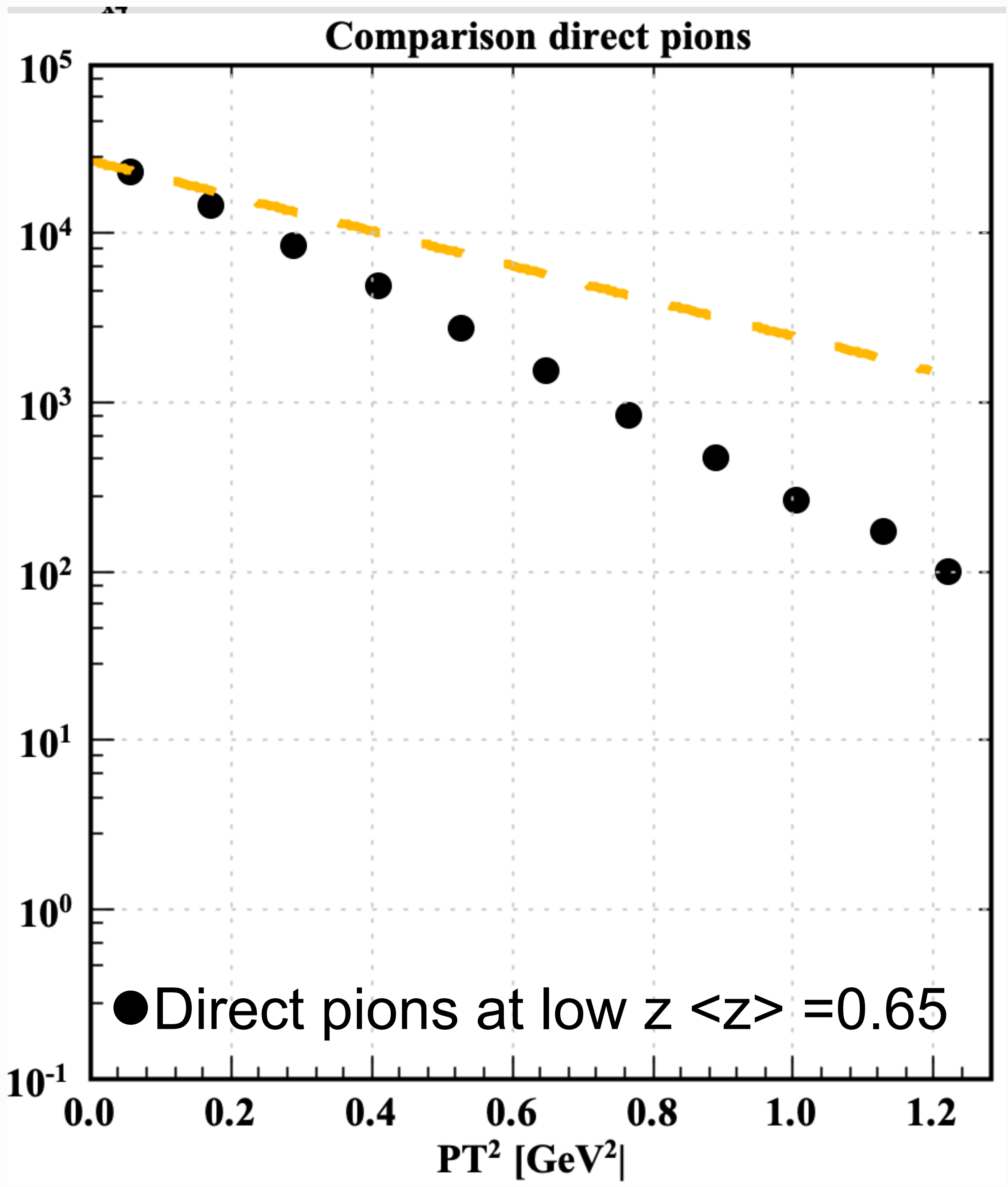


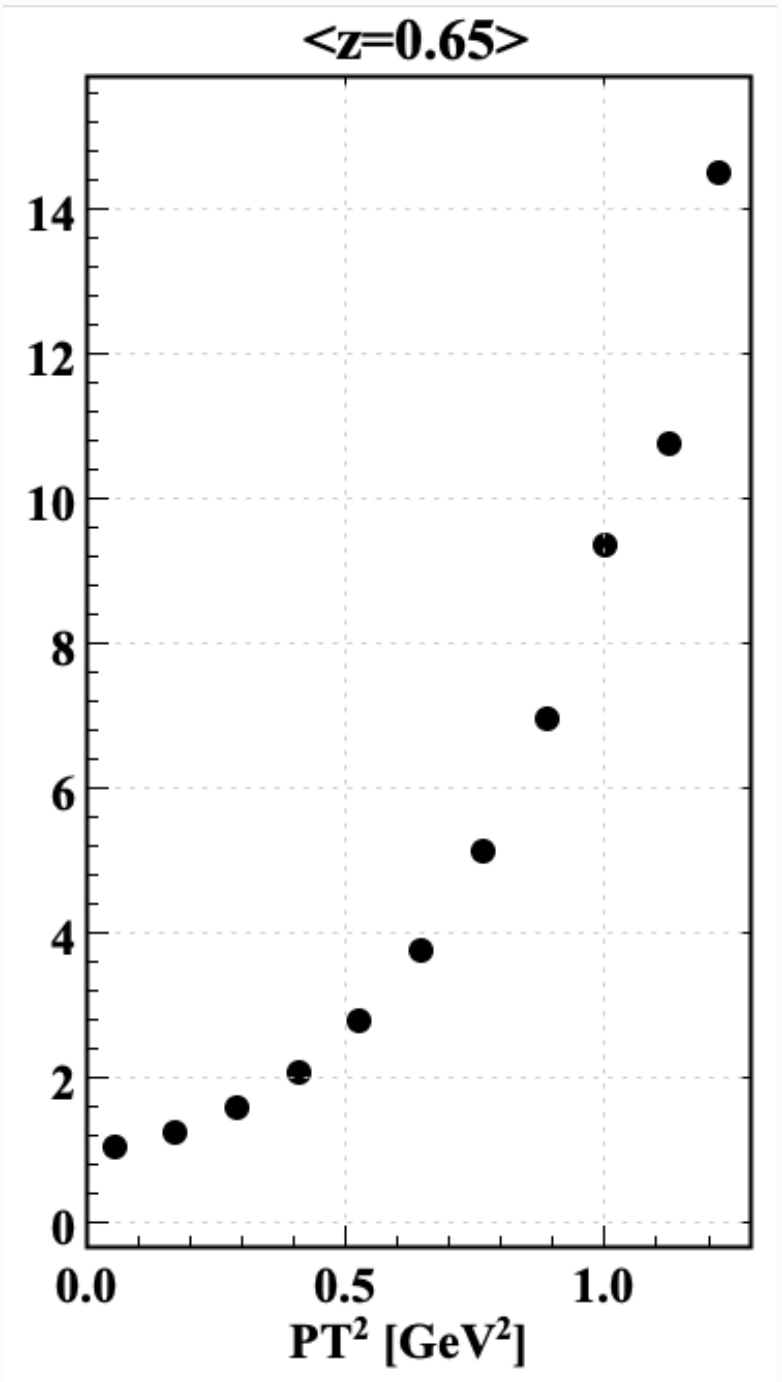
Applied to all pion sample



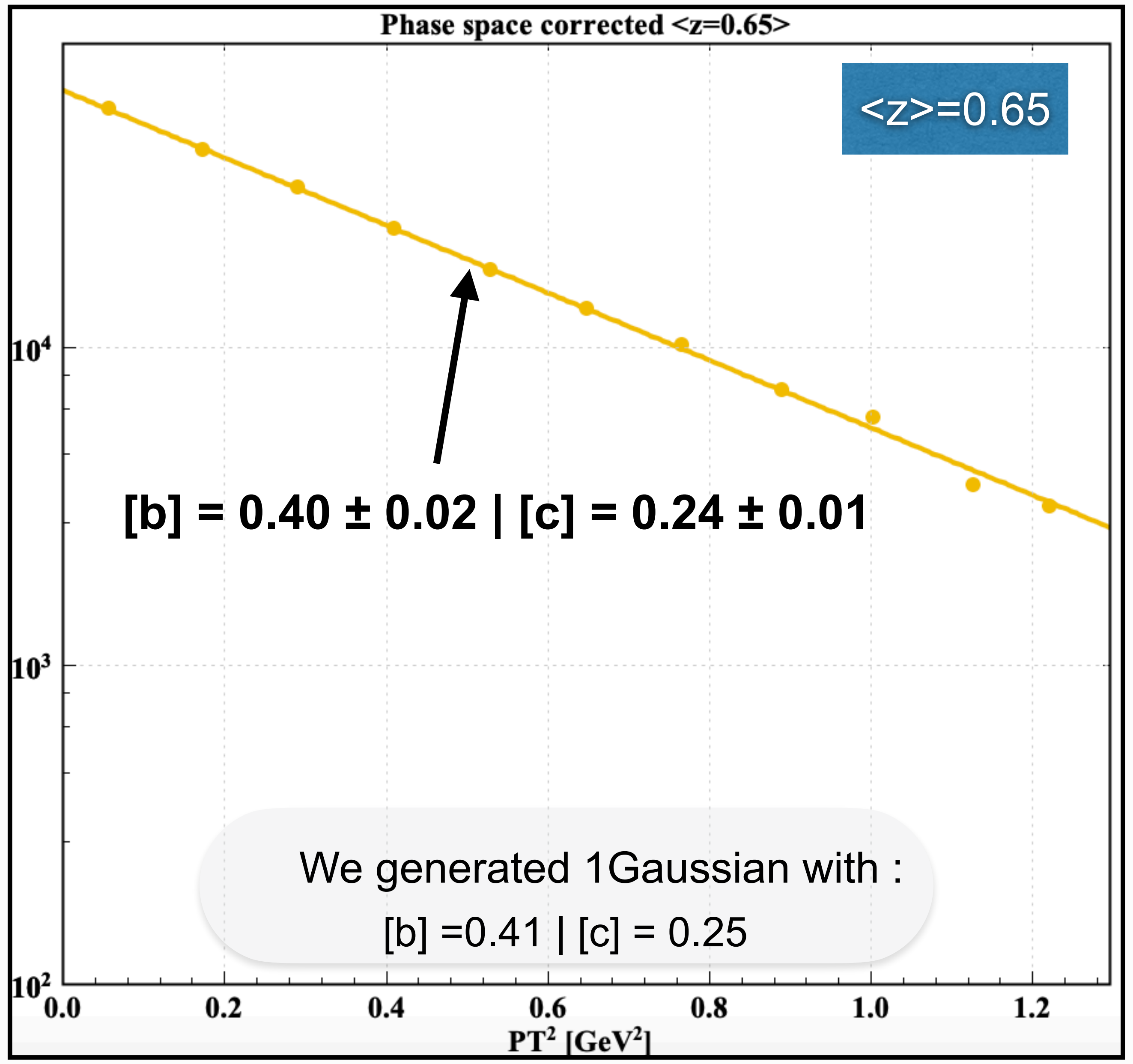
At low z, only the high PT shows the generated Gaussian transverse momentum distribution.

Phase space corrections





Applied to all pion sample



At High z the generated gaussian transverse momentum distributionls recovered over the whole PT range.

We are studying the Z dependance behavior

Summary + future plans

The measurement of charged pion multiplicity is being extracted using CLAS12.

We are working on increase our MC statistic and improve our fiducial cuts.

Effect of phase spaces and VM production under study.

Study on systematics and radiative effects will be performed.

We expect to complete this analysis by next year.

This work is supported by the DOE grant DE-SC0016583