Jet Substructure at EIC

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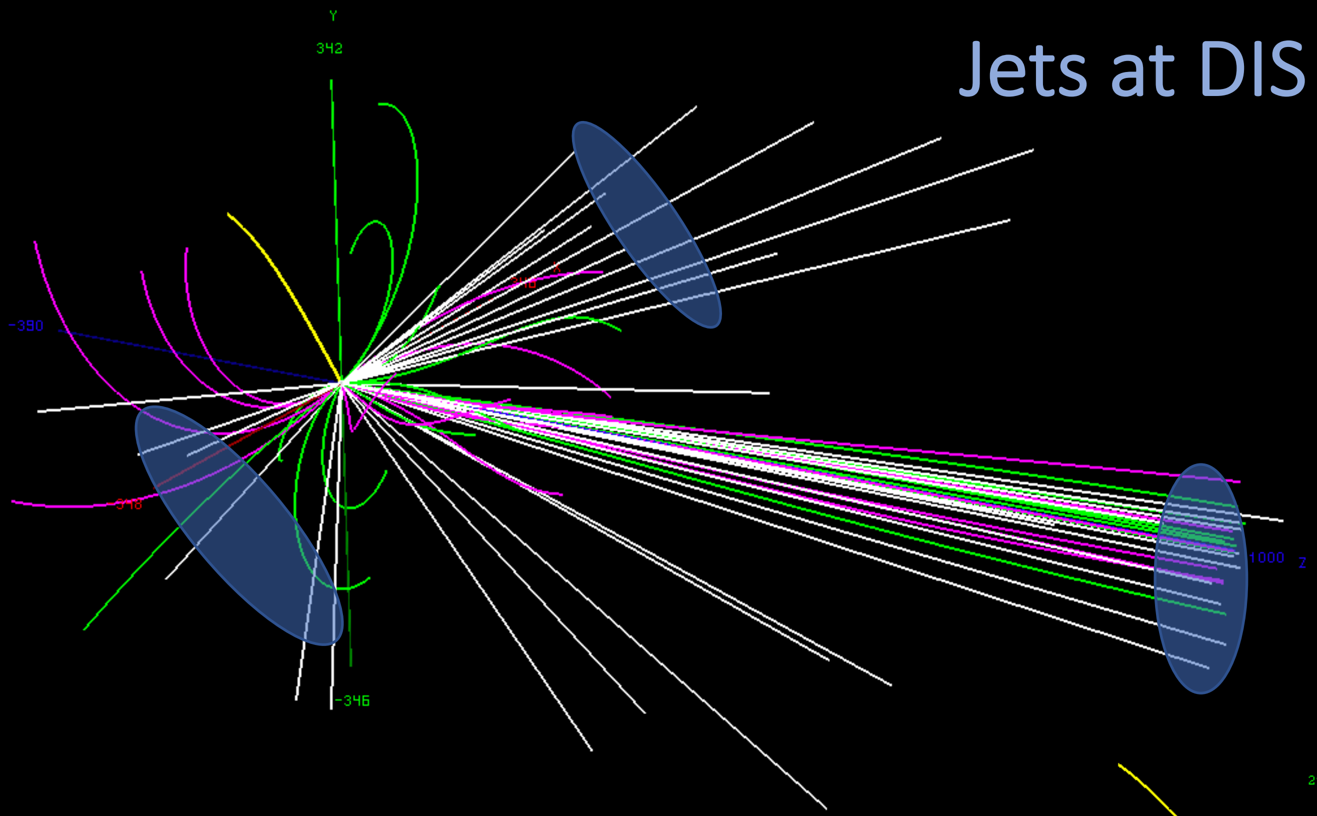
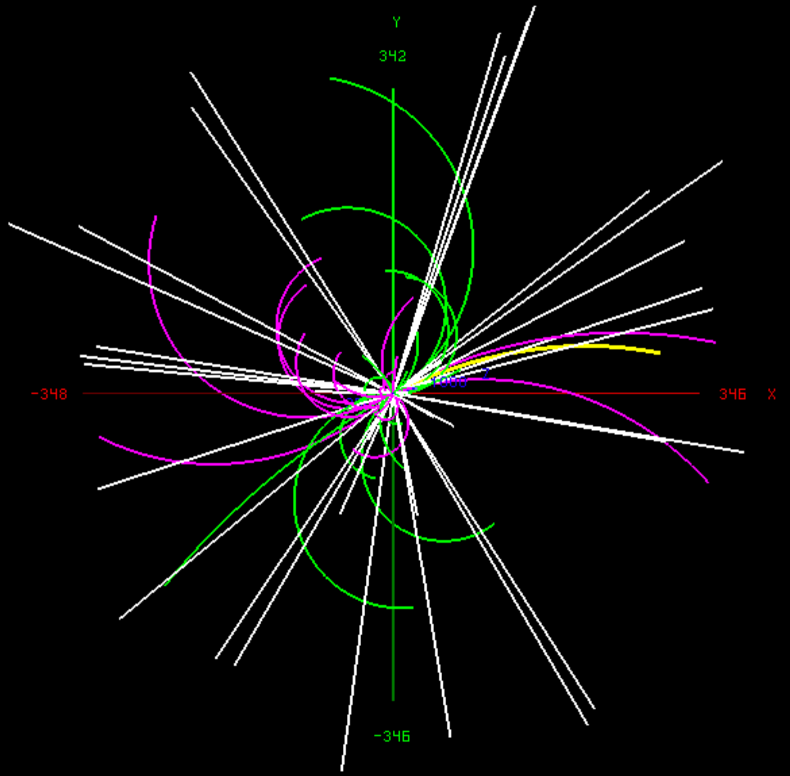
Introduction

- Jets and their structure
  - Correlations in momentum, charge and flavor : leading and next to leading particles in a jet
  - access to the dynamics of fragmentation and color entanglement in QCD
- Observable
  - Charge asymmetry
  - Connection to dihedron fragmentation function
- Pythia event studies
  - Acceptance of Jet and constituent particles
  - Charge asymmetry and in combination of various particle species
  - At various center of mass energies at EIC
- Summary and Outlook

Jets at DIS

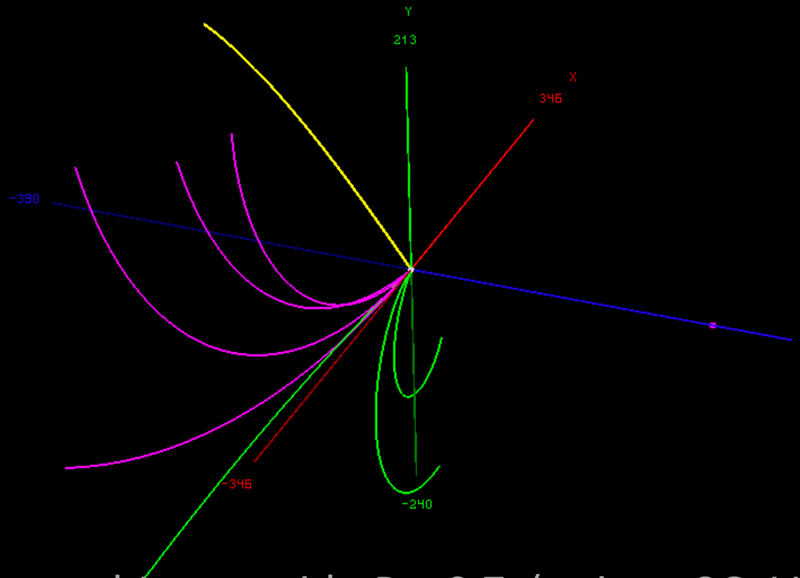




Leading momentum particles in the jet – $K, \bar{p}$

Particles in Jet :

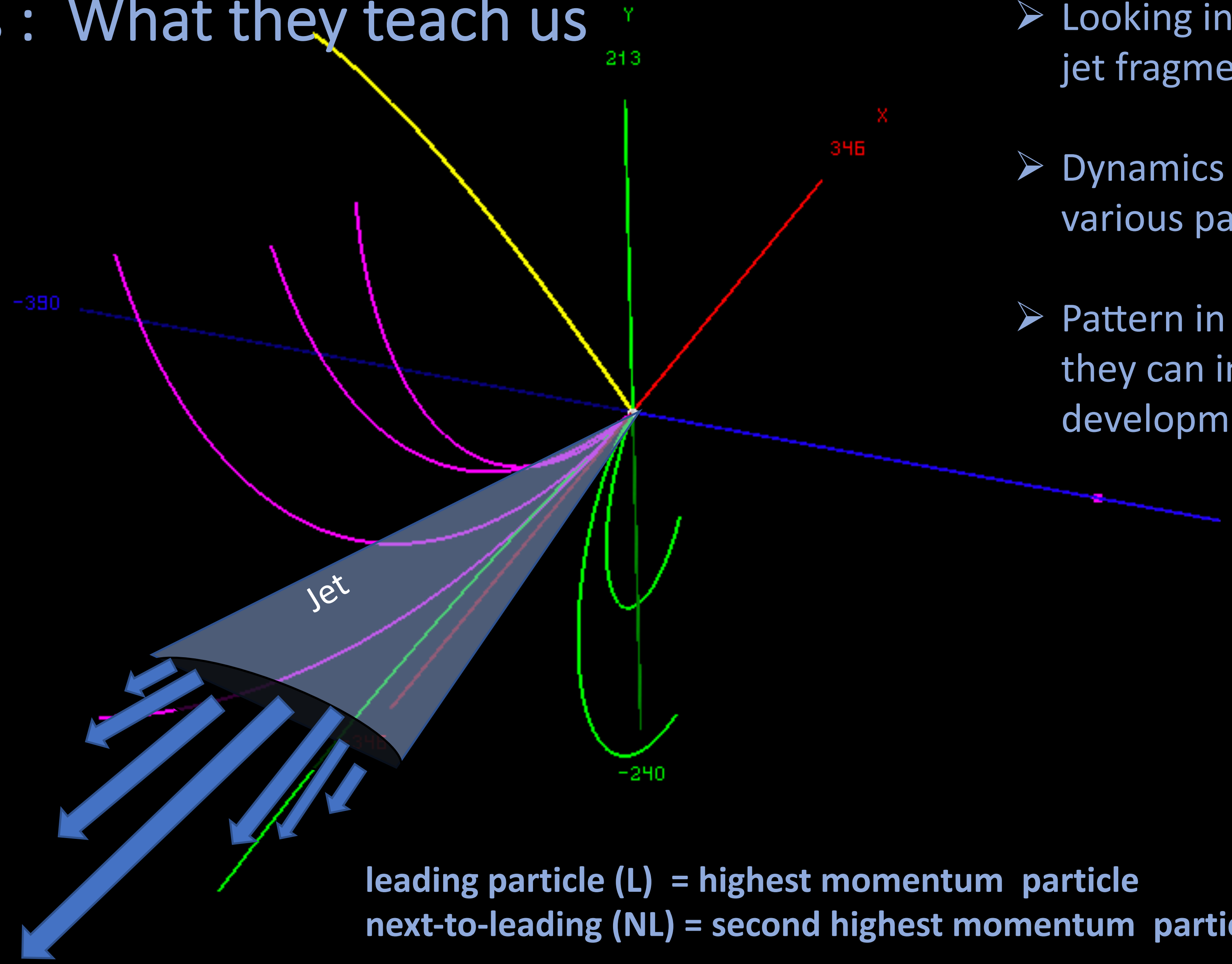
Px	Py	Pz	PID
-7.64	-4.41	-4.21	321
-2.06	-1.89	-1.40	-2212
-1.44	-0.87	-0.69	-211
-1.07	-0.08	0.04	2212
-0.58	-0.45	-0.53	-211
-0.70	-0.39	- 0.39	-211
-0.65	-0.52	-0.04	211



Scattered-electron
+ve particles
-ve particles
Neutral particles

Charged Jet – anti-kt R = 0.7 (p_T-jet > 8GeV)

Jets : What they teach us



- Looking in the nonperturbative aspect of jet fragmentation
- Dynamics that led to fragmentation of various particle species in certain ways
- Pattern in charge and flavor separation : they can inform in future theoretical development

leading particle (L) = highest momentum particle
next-to-leading (NL) = second highest momentum particle

Momentum-charge correlations

- Leading particle (L) and next-to-leading (NL) are **both pions generated in two pictures**

i) "**random**" picture : L is fixed and NL is random and both L and NL pions are charged

$$N_{C\bar{C}}^{\text{random}} = N_{CC}^{\text{random}} = \frac{N^{\text{random}}}{2}$$

$C\bar{C}$ indicates opposite charges
CC same charge

Ii) "**alternating**" picture : perturbative shower gives q_L followed by $\bar{q}'_{NL}$, which form pions by sharing a soft pair:

$$q_L + \bar{q}_{NL} \rightarrow q_L + (\bar{q}_s + q_s) + \bar{q}'_{NL} \rightarrow \pi(q_L, \bar{q}_s) + \pi(q_s, \bar{q}'_{NL})$$

$N_{C\bar{C}}^{\text{alternating}} = N^{\text{alternating}}$ and $N_{CC}^{\text{alternating}} = 0$

- **The observable :**

$$r_{\text{asy}} \equiv \frac{N_{CC} - N_{C\bar{C}}}{N_{CC} + N_{C\bar{C}}} = \frac{1-a}{2} - \left(\frac{1-a}{2} + a\right) = -a$$

- ✓ provided every event results from one of these two processes, with no interference
- ✓ percentage of "alternating" = a; and percentage of random events = 1-a

➢ ***r_{asy}*** is a measurement of the fraction of hadronizations that are "string-like", alternating between quark and antiquark (classical picture)

Measurements of r_{asy} and expressing in terms of di-hadron fragmentation functions

- **Measurements of r_{asy} :**
  - differentially in fractions z_L and z_{NL} in a jet,
  - "transverse" kinematic variables:
    - ✓ relative transverse momentum
    - ✓ pair invariant mass
    - ✓ pair formation time
    - ✓ including polarization where applicable

- **r_{asy} and its connection with generalized di-hadron fragmentation functions**

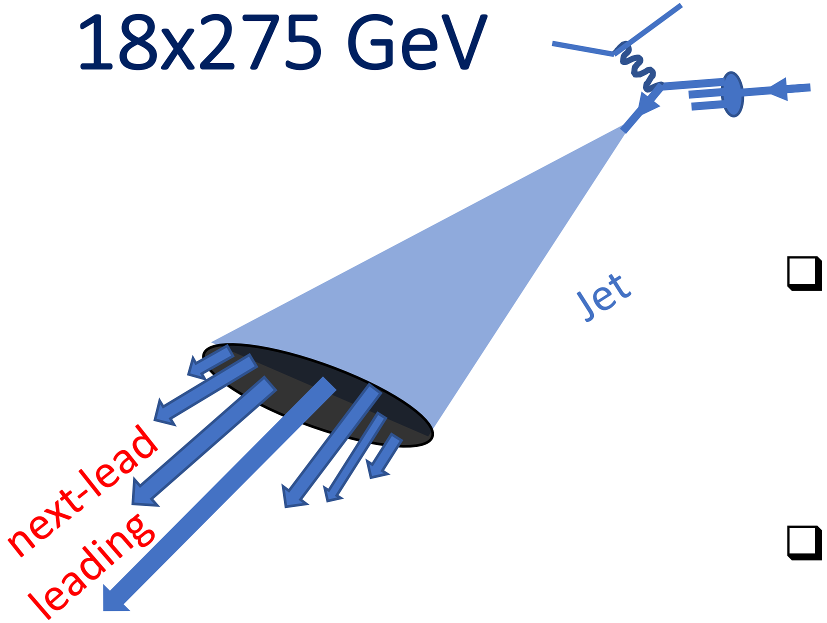
generalized di-hadron fragmentation functions for any hadrons h_1, h_2 : $D^{>}_{h_L,h_{NL}}(z_L z_{NL})$

$$N^{>}_{h_L,h_{NL}} = \int_0^1 dz_L \int^{\min(z_L,1-z_L)} dz_{NL} D^{>}_{h_1,h_2}(z_L, z_{NL}, Q)$$

When z_L and z_{NL} are large enough, this is the usual di-hadron distribution $D^{>}(x_1, x_2, Q) = D(x_1, x_2, Q)$ when $x_2 > 1 - x_1 - x_2$

$$r_S = \frac{\sum_{h_1,h_2 \in S} Q_{h_1} Q_{h_2} N^{>}_{h_1,h_2}}{\sum_{h_1,h_2 \in S} |Q_{h_1} Q_{h_2}| N^{>}_{h_1,h_2}}$$

18x275 GeV



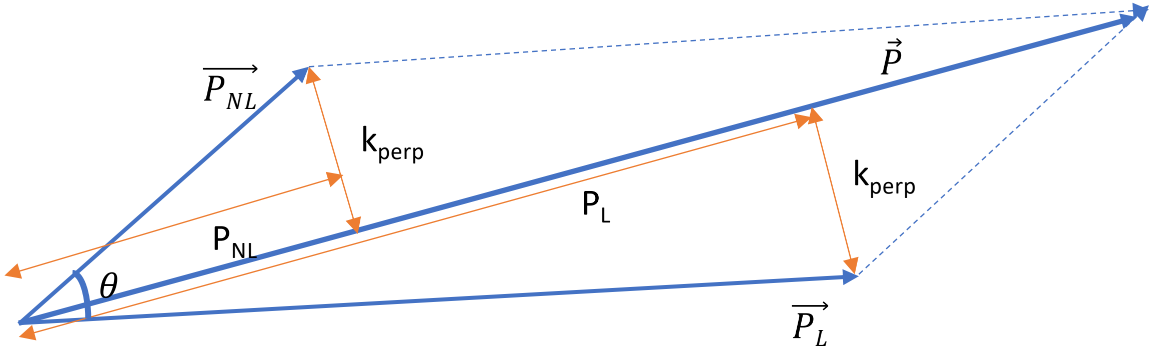
$$r_{\text{asy}} \equiv \frac{N_{CC} - N_{C\overline{C}}}{N_{CC} + N_{C\overline{C}}}$$

- Construct r_{asy} with particle compositions with various parameters
  - ✓ Leading particle (**π**) and next leading particles (**π/K/p**)
  - ✓ Leading particle (**K**) and next leading particles (**K/ π /p**)
  - ✓ Leading particle (**p**) and next leading particles (**p/π/K**)

- Looking via
  - ✓ Momentum-next lead particle/momentum of leading particle
  - ✓ Faction of jet momentum carried by leading particle
  - ✓ Angle between the leading and next to leading particles ($\Delta\theta$)
  - ✓ relative transverse momentum (k_{perp})
  - ✓ pair invariant mass
  - ✓ Formation time : $[2z(1-z)\ P] / k_{perp}^2$

PYTHIA-6 : 1M events :
Q2 > 65 GeV

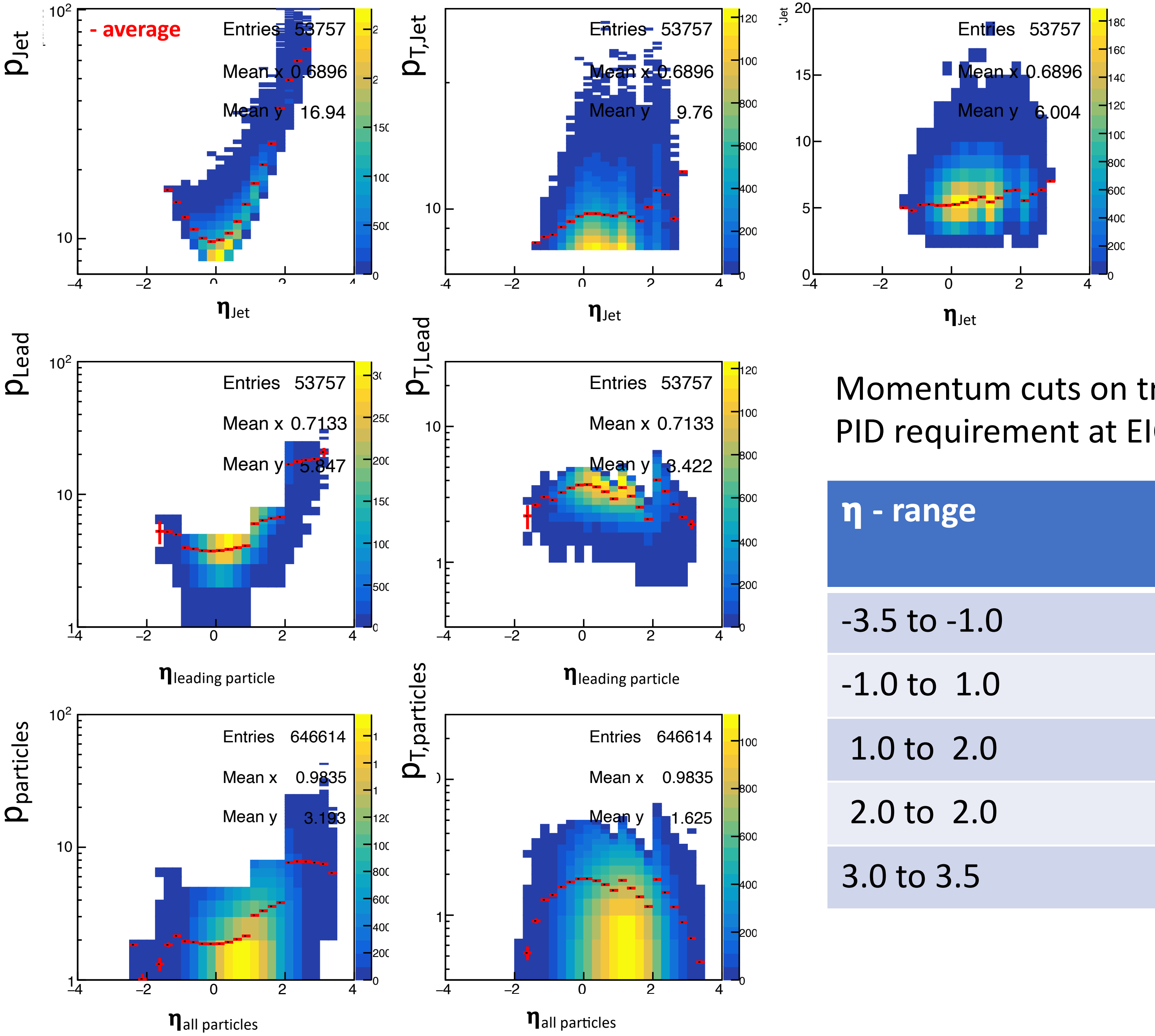
Jet Reconstruction :
anti-kt R = 0.7
Jet pt > 8GeV
pt-tracks > 0.2GeV
track |eta| < 3.5
Jet |eta| < 2.8



$z = P_{NL}/(P_{NL}+P_L)$
$P_L = (1-z)P$
$P_{NL} = zP$

Acceptance

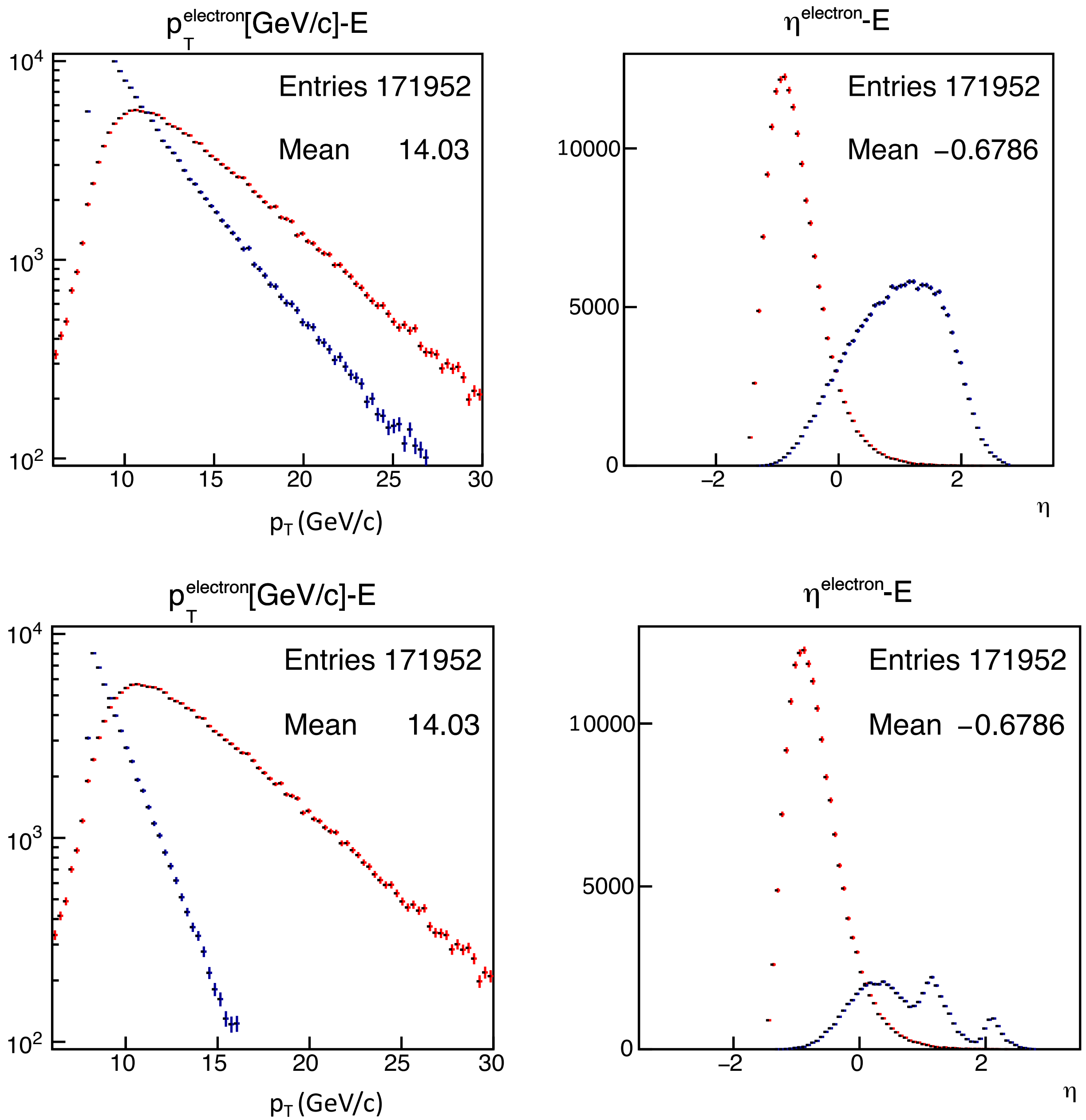
18x275 GeV



Momentum cuts on tracks for approximate PID requirement at EIC at different **η** regions

η - range	Momentum cut (GeV/c^2)
-3.5 to -1.0	7
-1.0 to 1.0	5
1.0 to 2.0	8
2.0 to 2.0	25
3.0 to 3.5	45

The effect of momentum cuts in traverse momentum and acceptance of jets

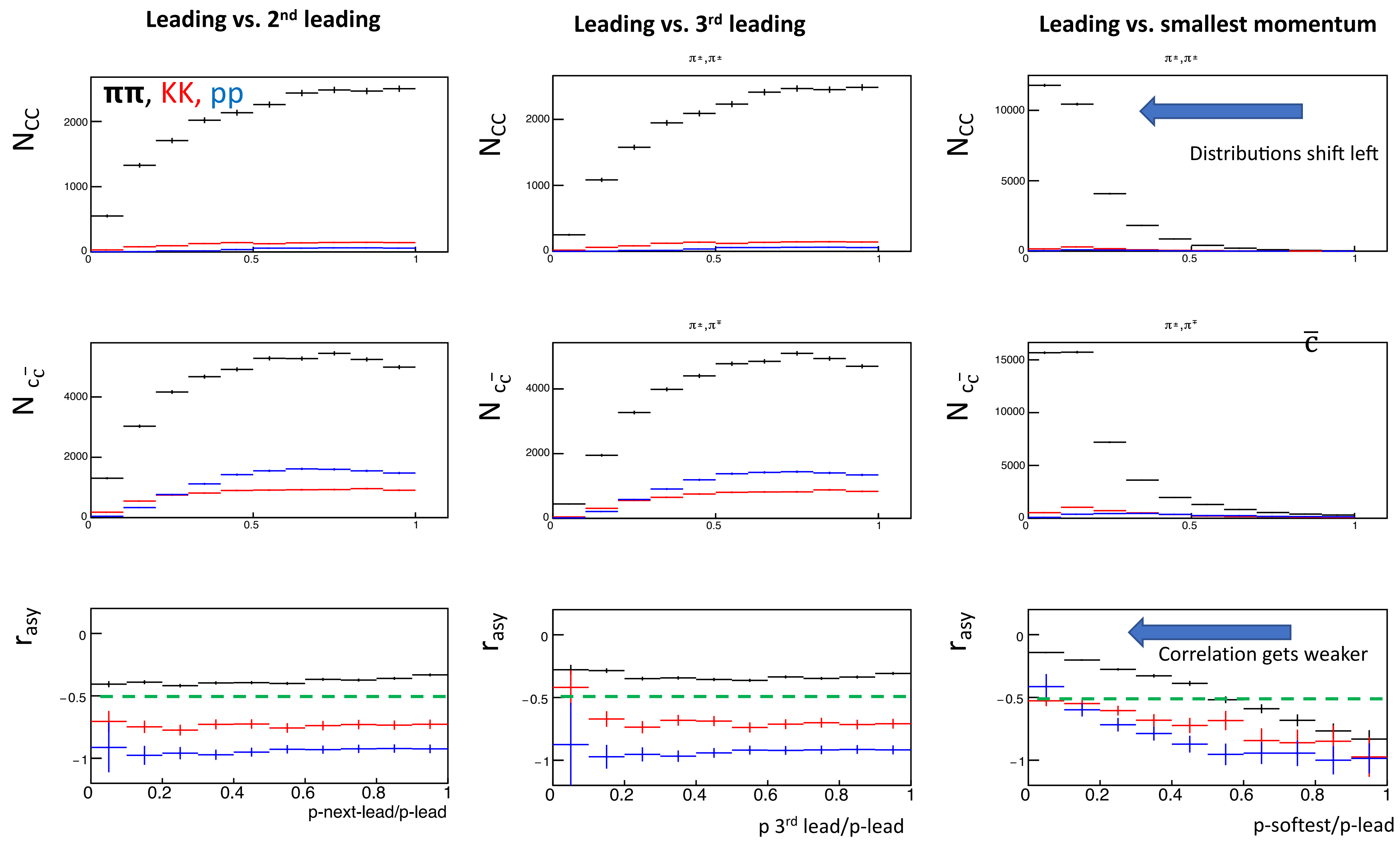


RED-electron
BLUE-JET

NO momentum cuts

After momentum cuts

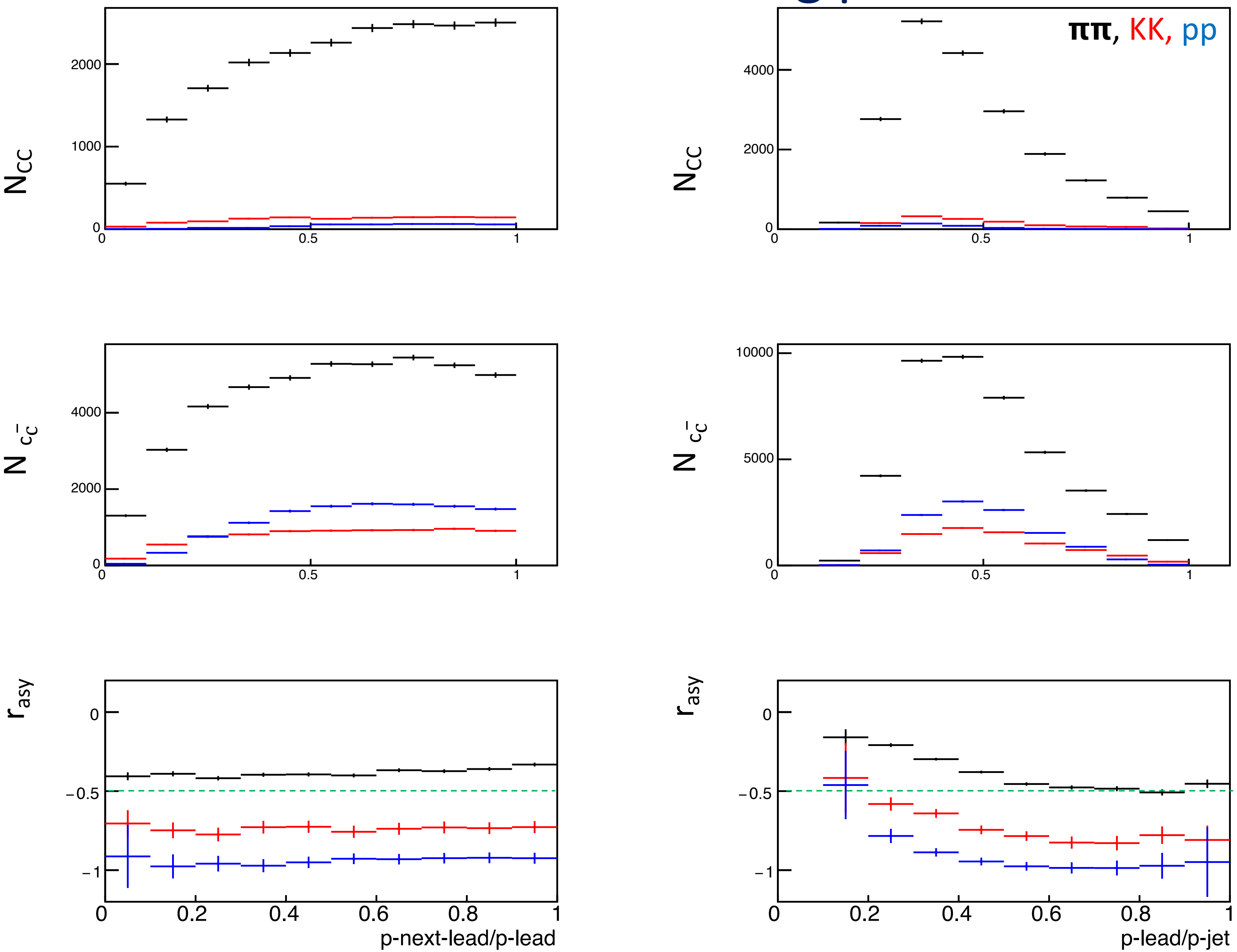
Correlation with different particles



Correlations retain with other leading order particles

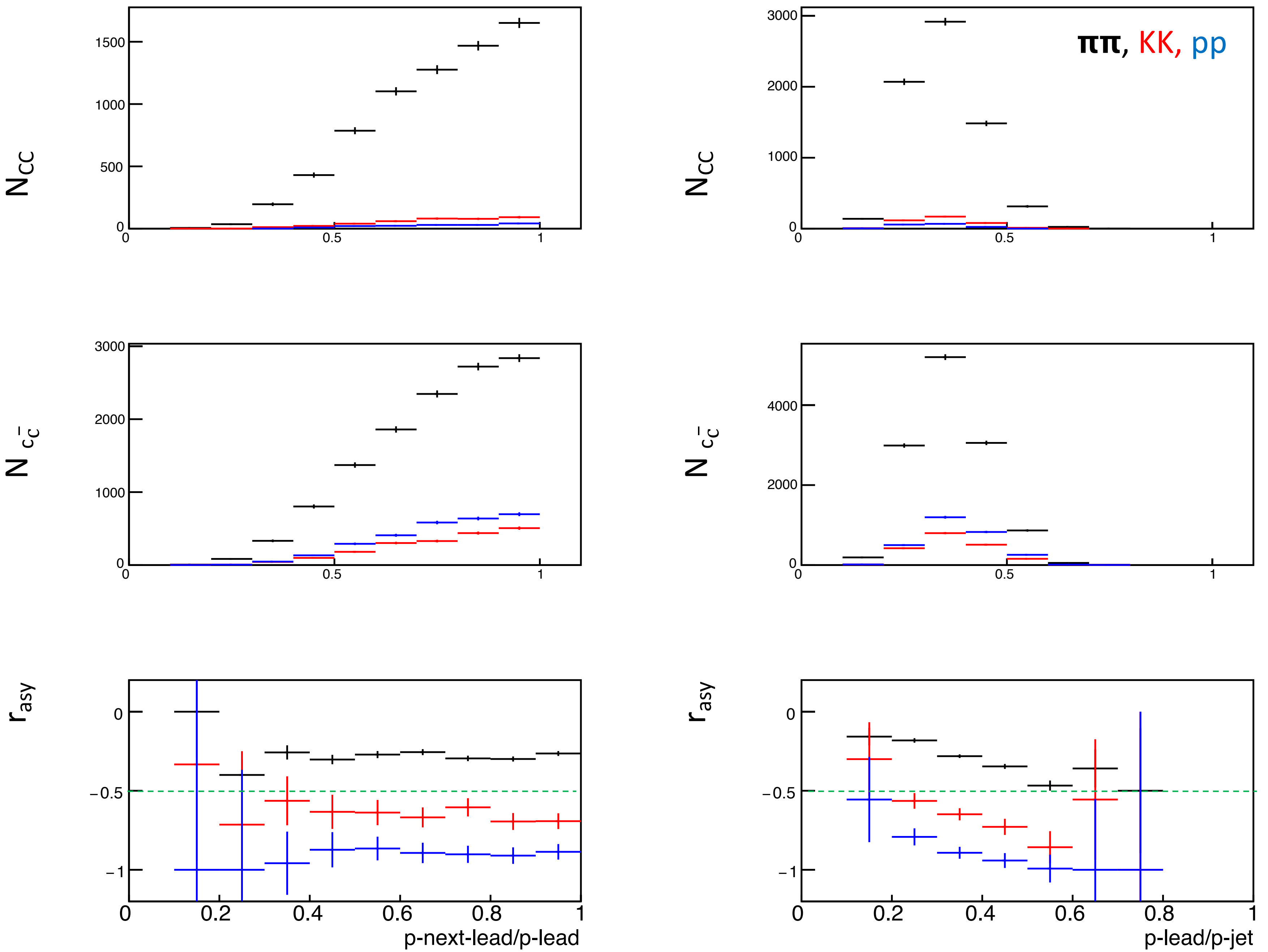
Correlation with two leading particles

NO momentum cuts



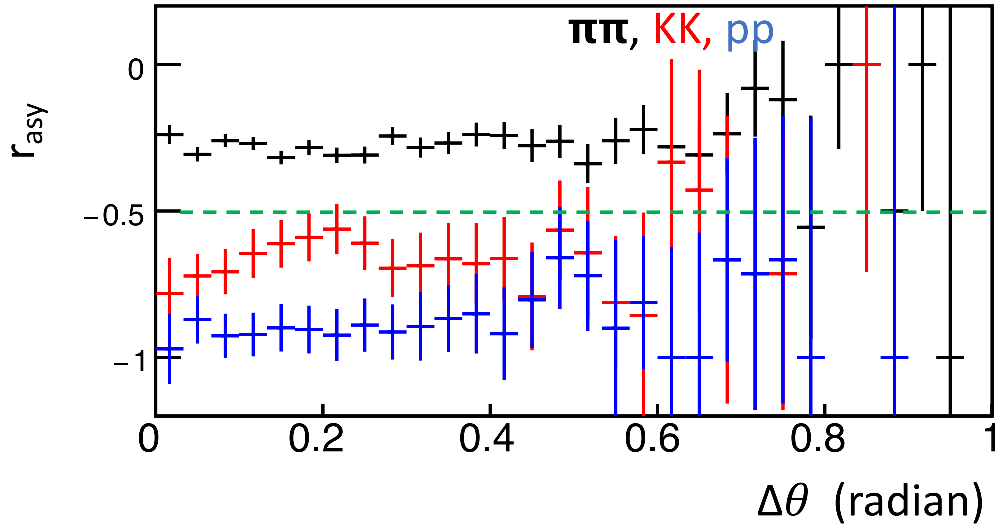
- The strength of correlations are different for pions, kaons and proton

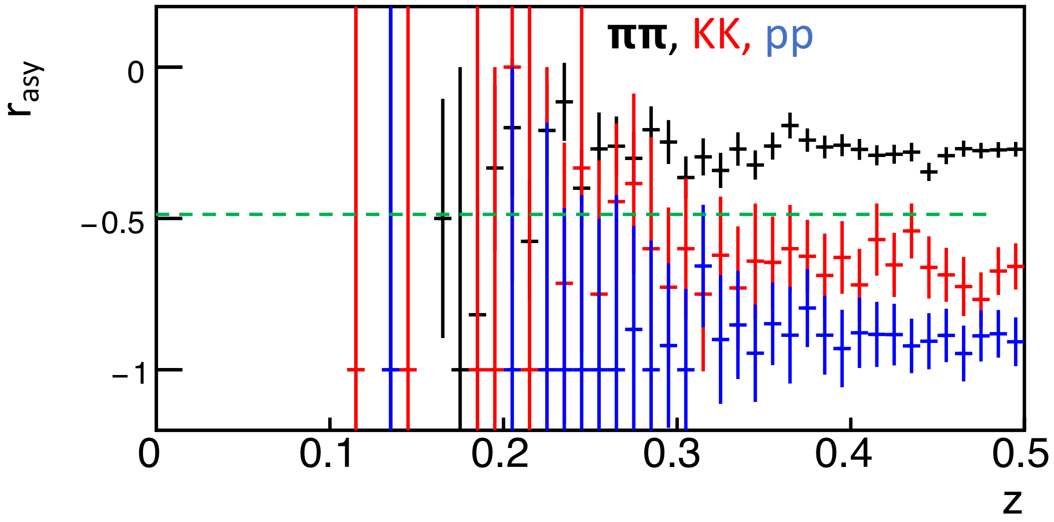
After momentum cuts



- The strength of correlations are different decrease as an acceptance effect
- Acceptance changes in certain regions due to momentum cuts

Dependence on $\Delta\theta$ and z

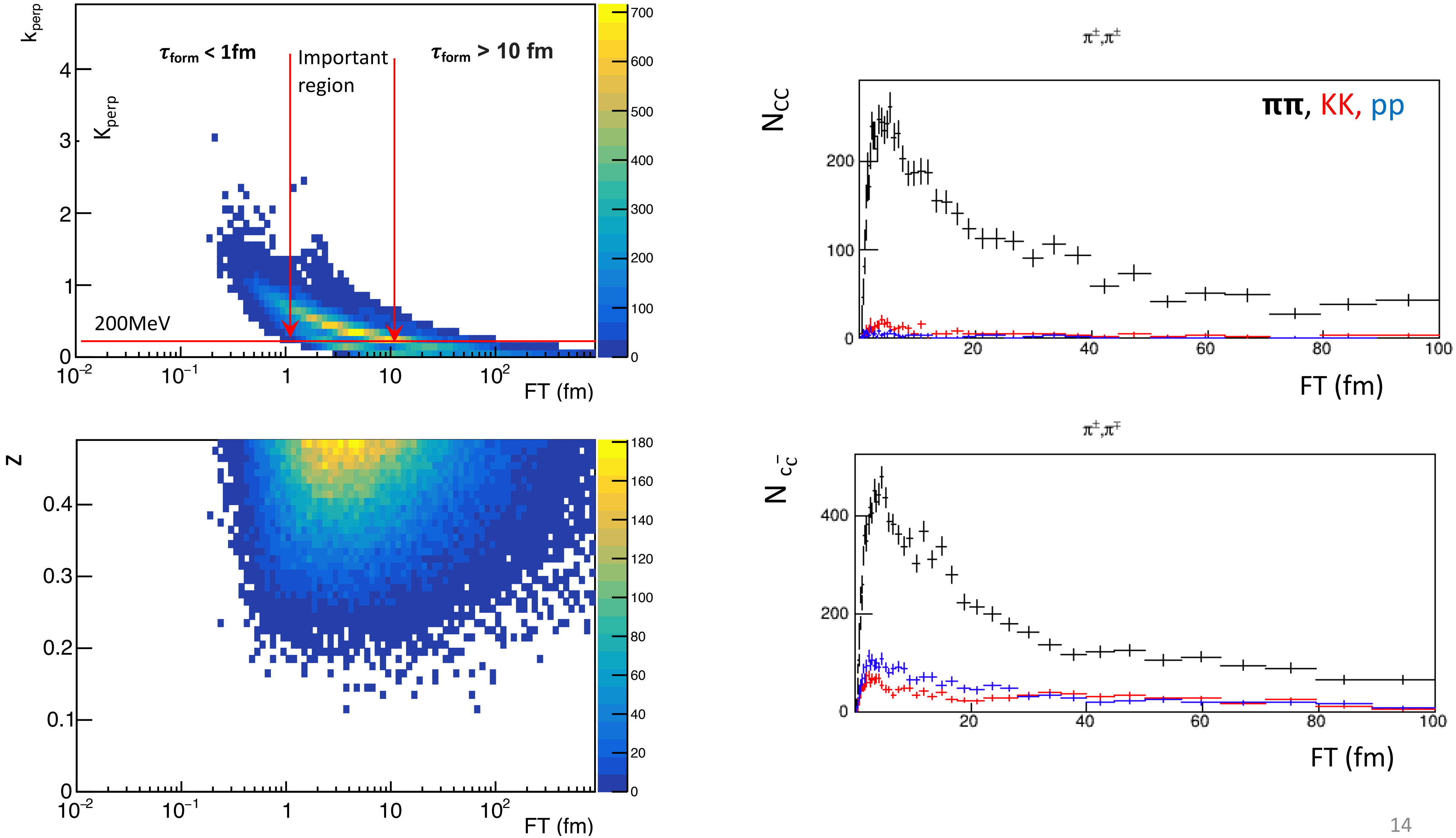




- r_{asy} values remain almost flat opening angle and z with some little variations

Formation time

Formation time, $\tau_{form} = [2z(1-z)\ P] / k_{perp}^2$



Formation time

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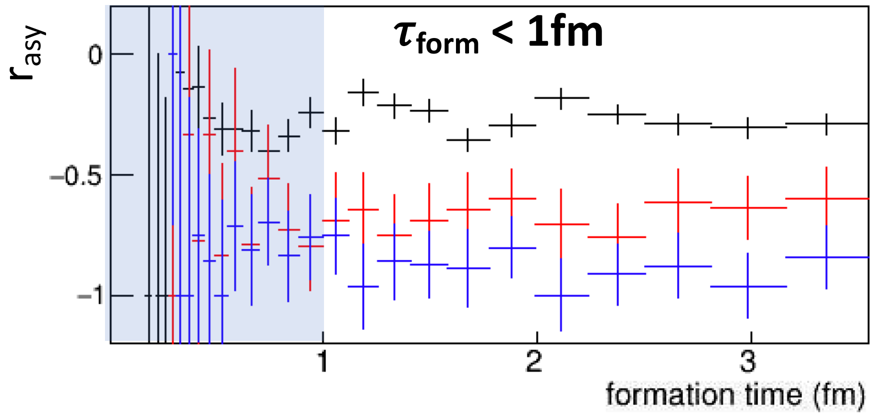
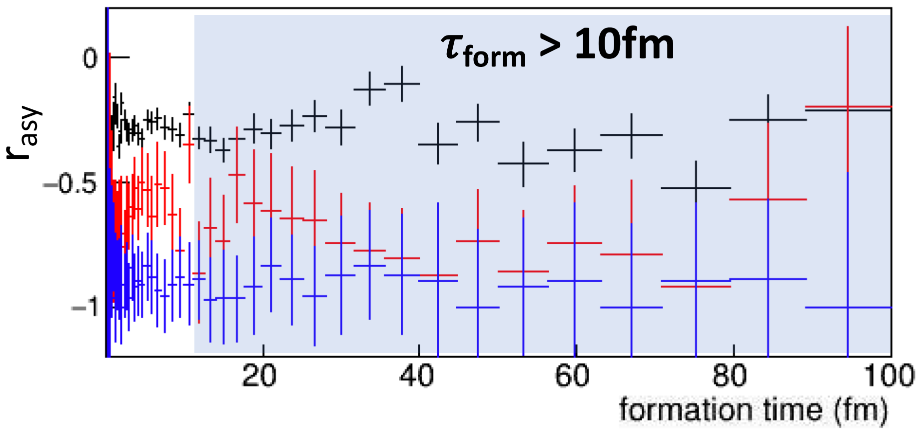
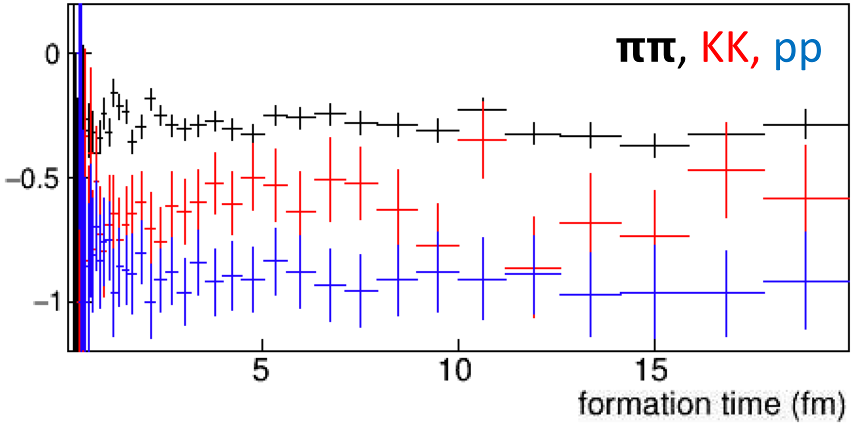




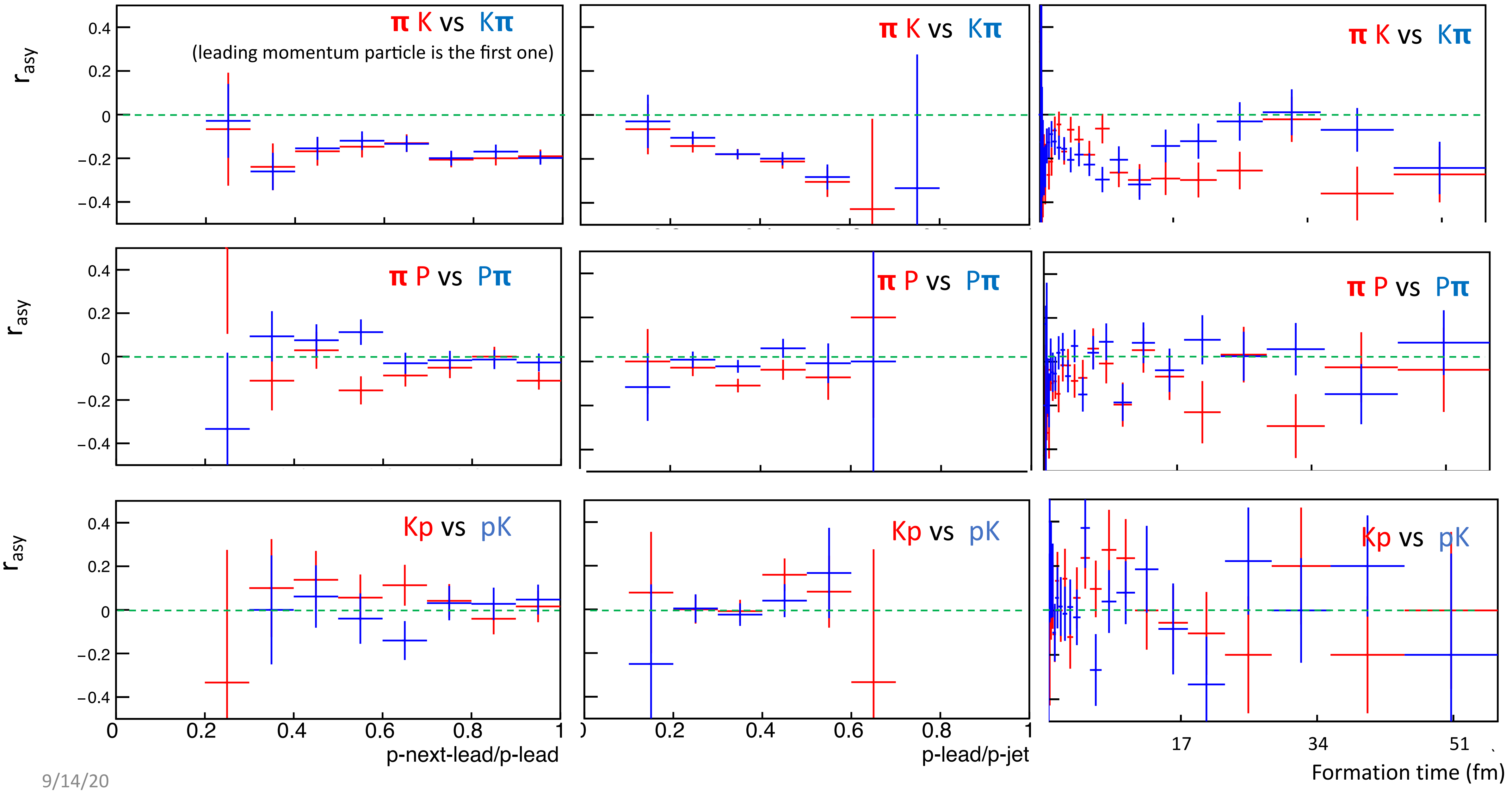


τ_{form} < 1fm : L and NL particles seem to separate after a very short time, which might decorrelate their hadronization.

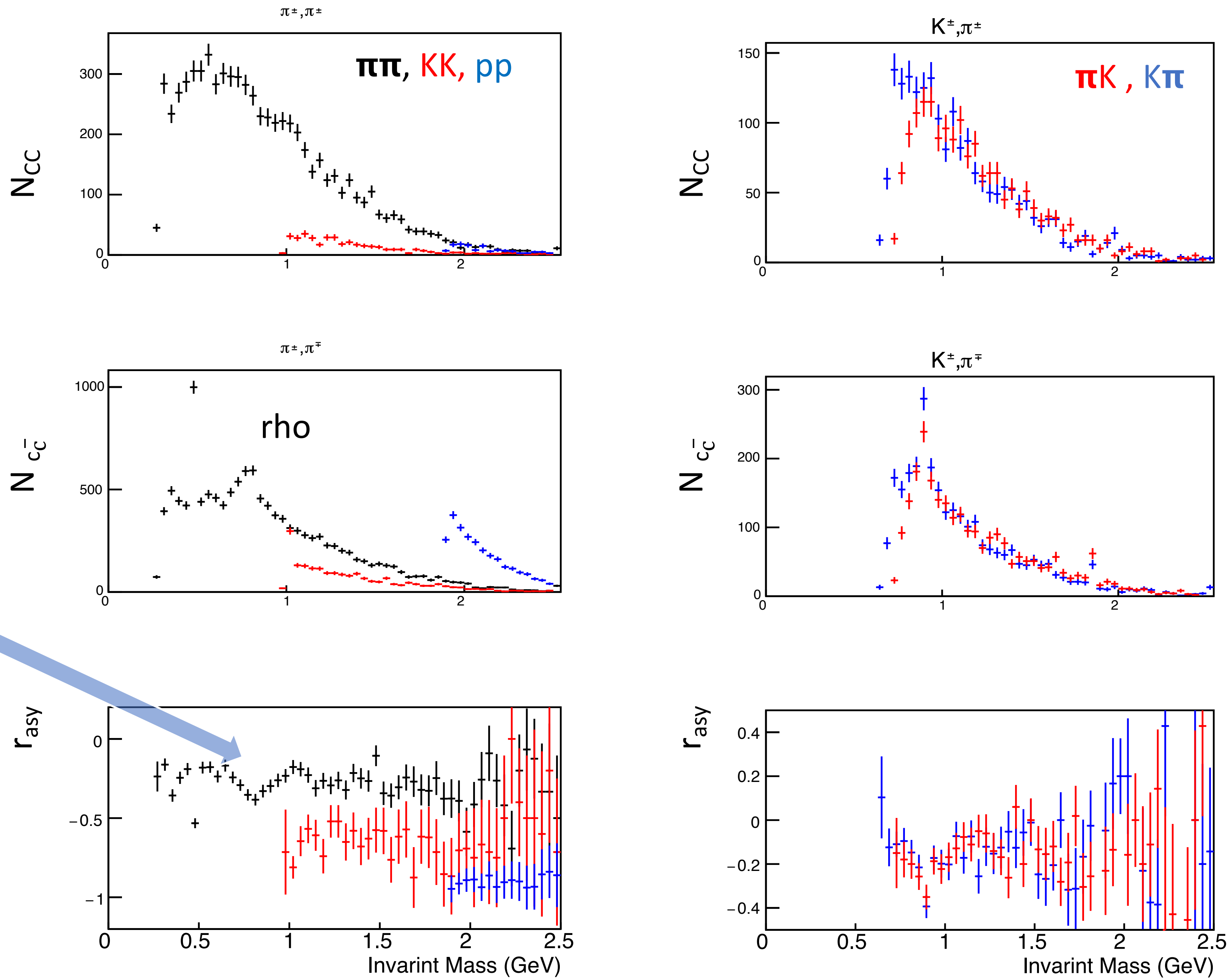
τ_{form} > 10 fm (K_{perp}< 200 MeV) **:** nonperturbative transverse momenta in the jet, and we don't think that going to longer τ_{form} or smaller k_{perp} leads to new dynamics

Important region to study in data τ_{form} = "a few fermi" and "a few dozen fermi", k_{perp} = "a few GeV" to "several hundred MeV"

Combination of different leading particles



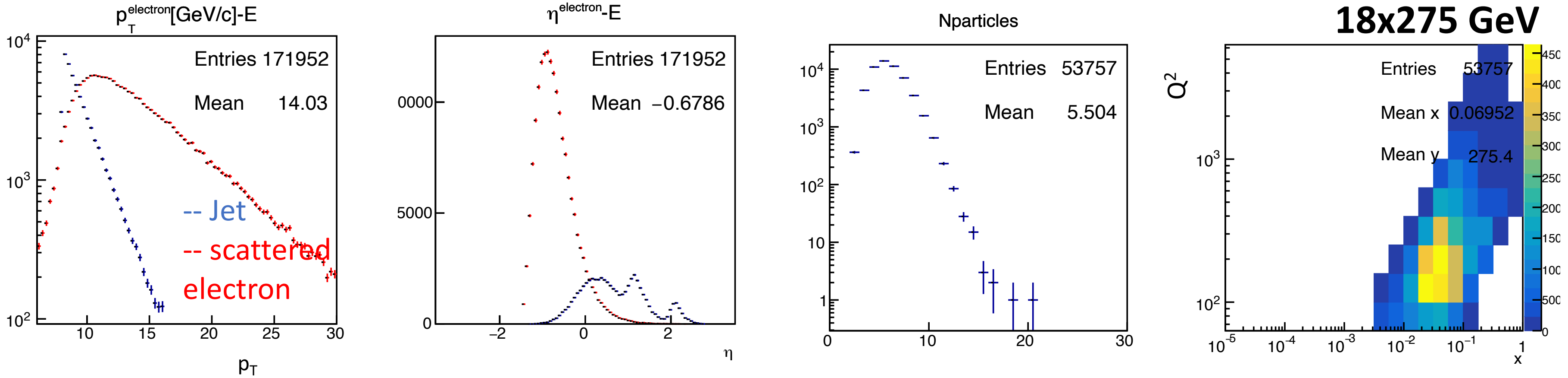
Invariant mass



Resonance decorrelate the asymmetry

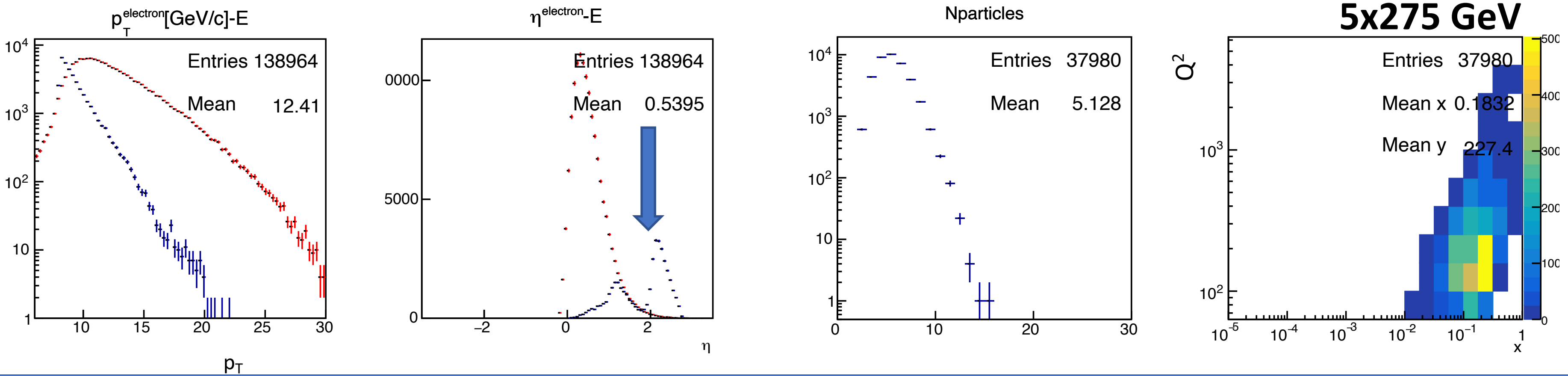
Acceptance at various collision energies

18x275 GeV

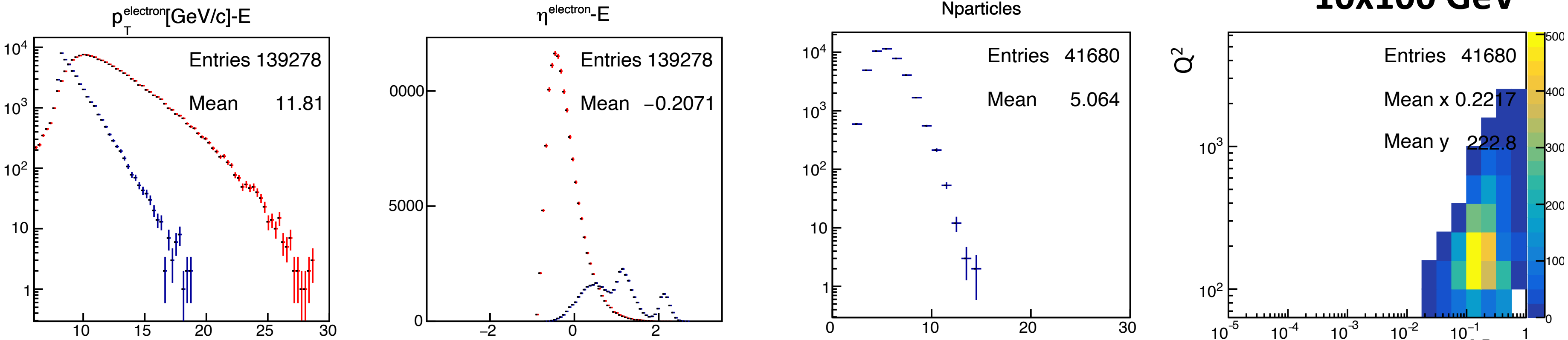


Most asymmetric – acceptance shift to Forward rapidity : 5x275 GeV

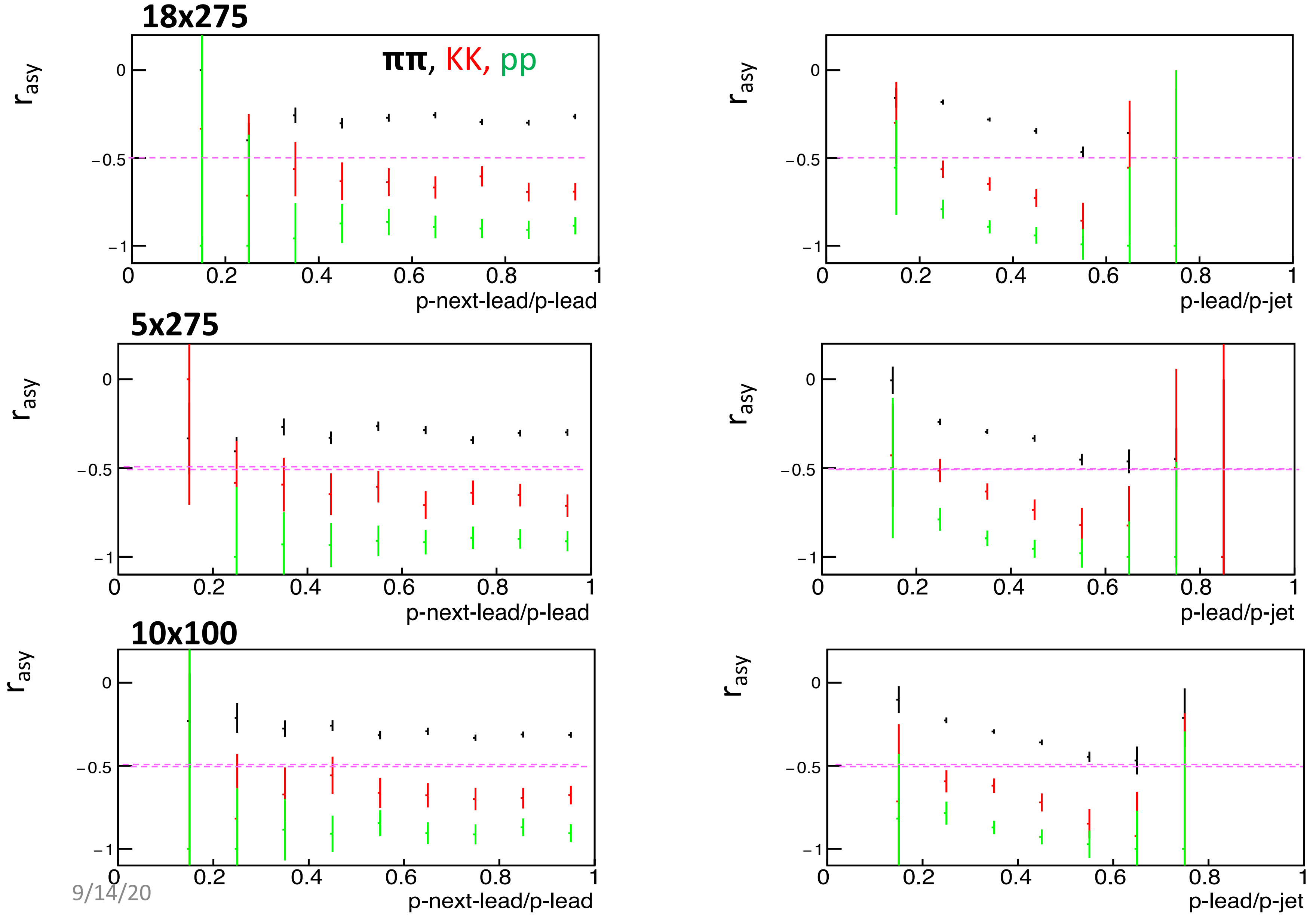
5x275 GeV



10x100 GeV



At different collision energies



- At various center of mass energies r_{asy} looks similar

Summary

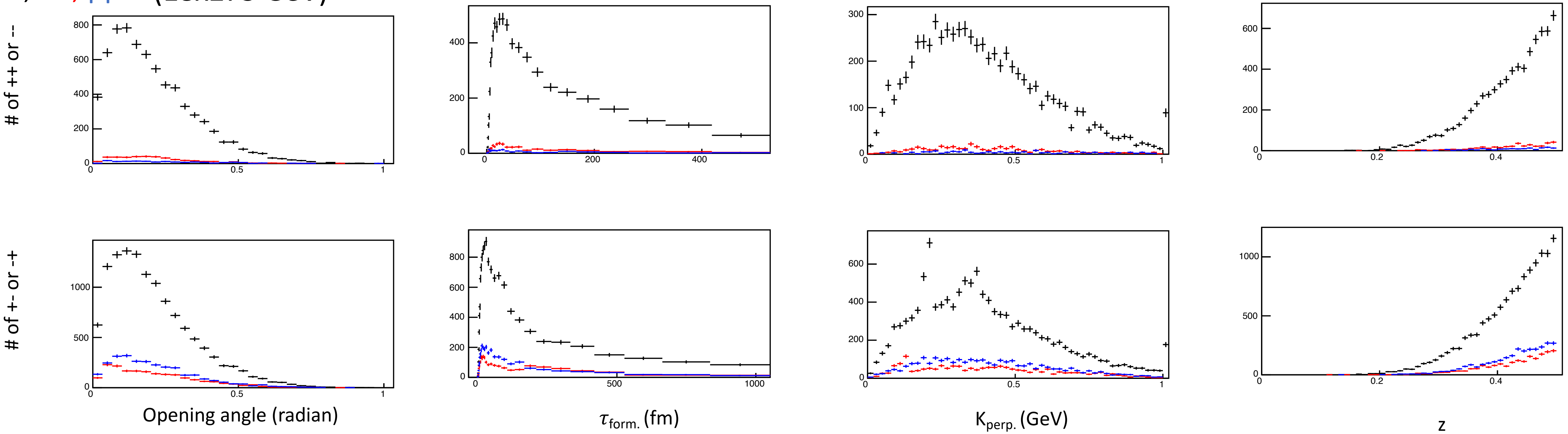
- Correlations in momentum, charge and flavor of leading particles in jet carry information of non perturbative aspect of jet fragmentation
- At EIC this can be measured with high momentum PID capabilities

- The embedded correlations in PYTHIA is studied at different set of collision energies for pions, kaons and protons

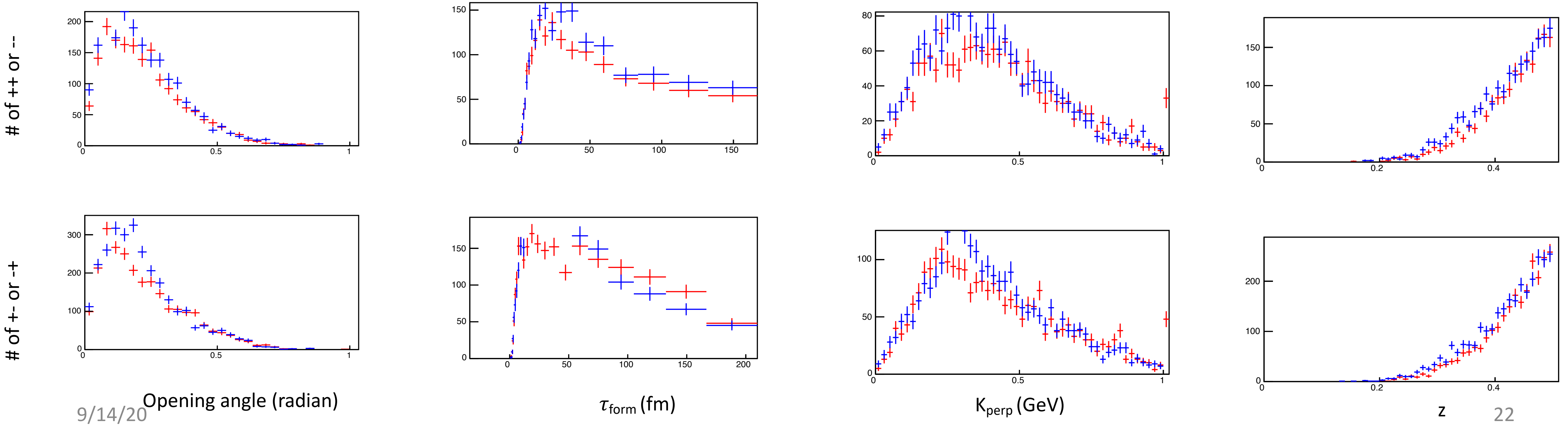
- We plan to study :
  - ✓ Bringing neutral particle in the correlations
  - ✓ other fragmentation models using HERWIG
  - ✓ Inclusion of jet charge in our study

- We would like to include the studies in Yellow Report activities backup

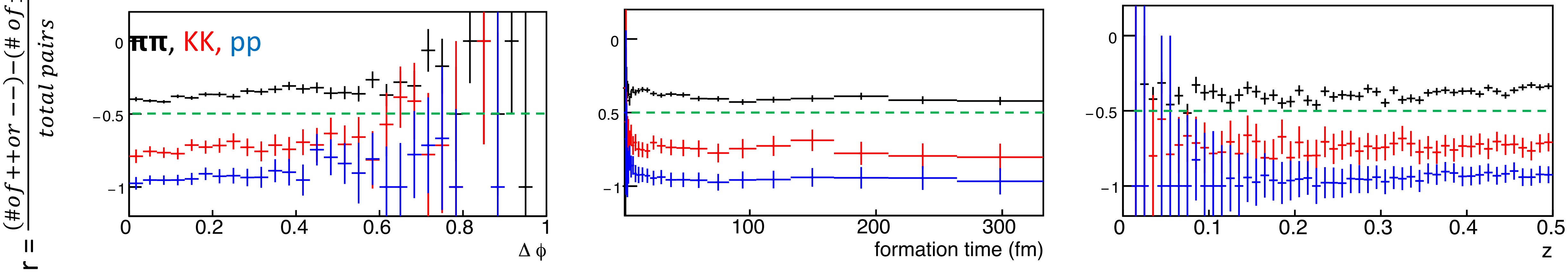
ππ, KK, pp (18x275 GeV)



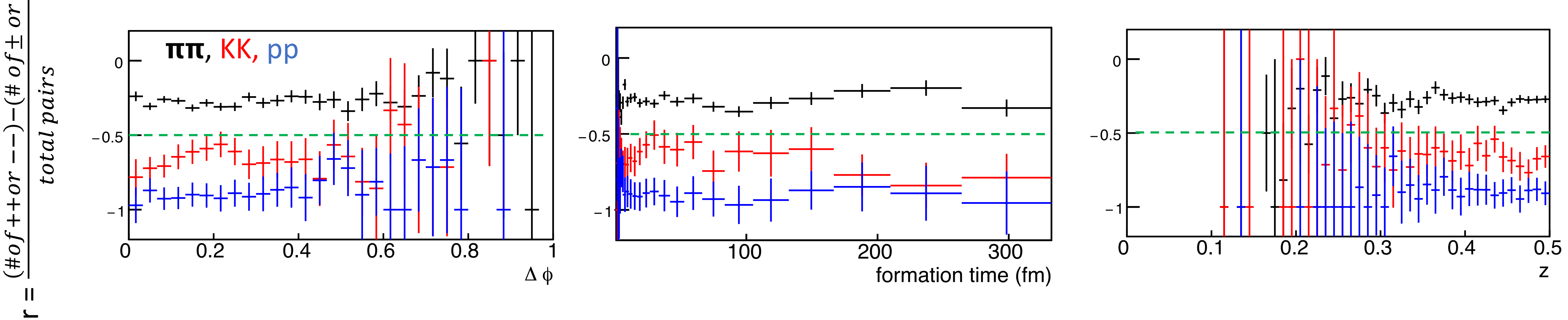
π K vs Kπ



NO momentum cuts



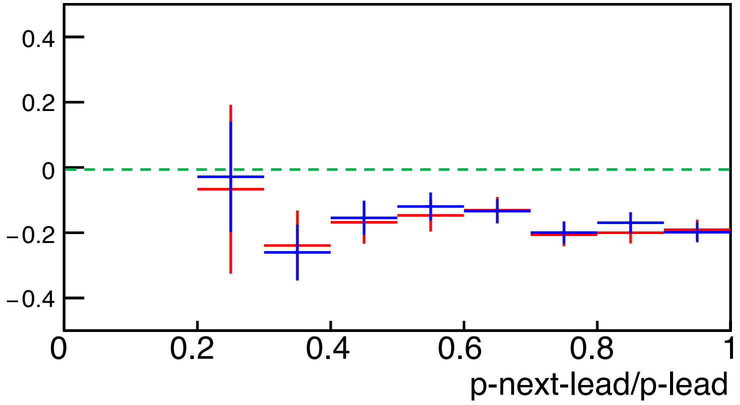
After momentum cuts

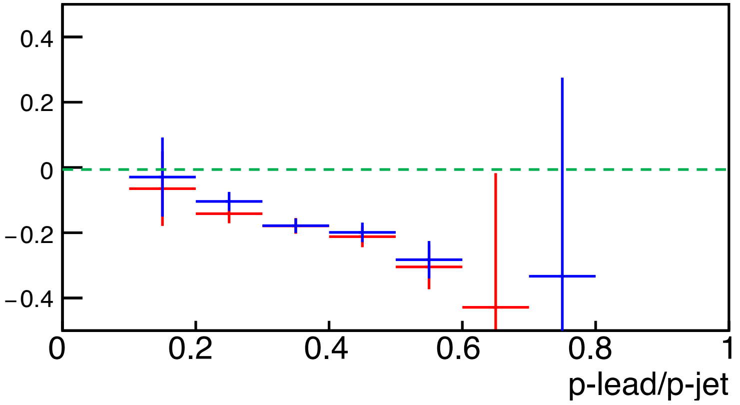


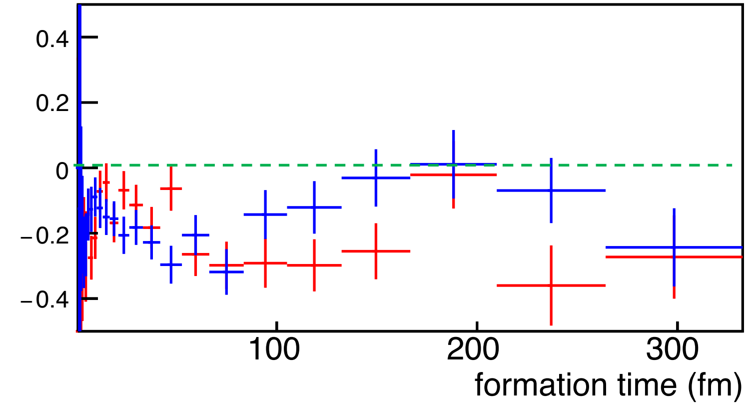
π K vs Kπ - with p cut

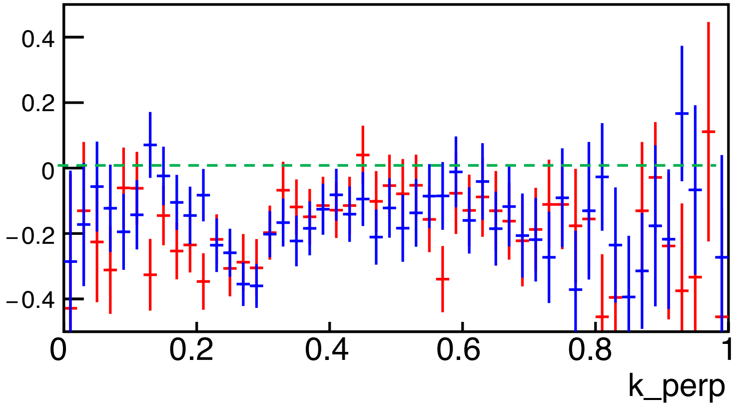
(leading momentum particle is the first one)

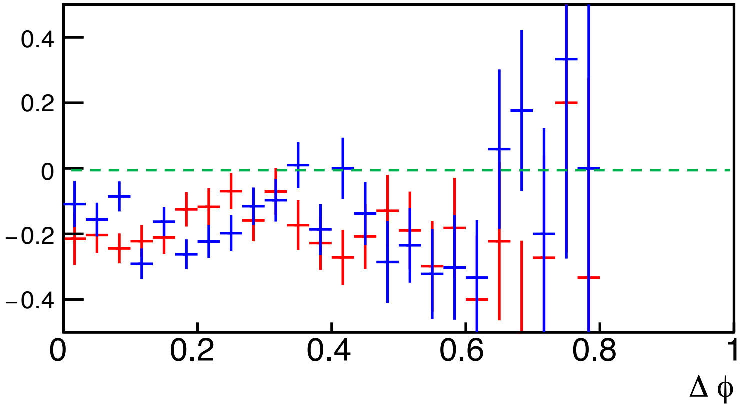
$r = \frac{(\# of ++ or --) - (\# of \pm or \mp)}{total\ pairs}$







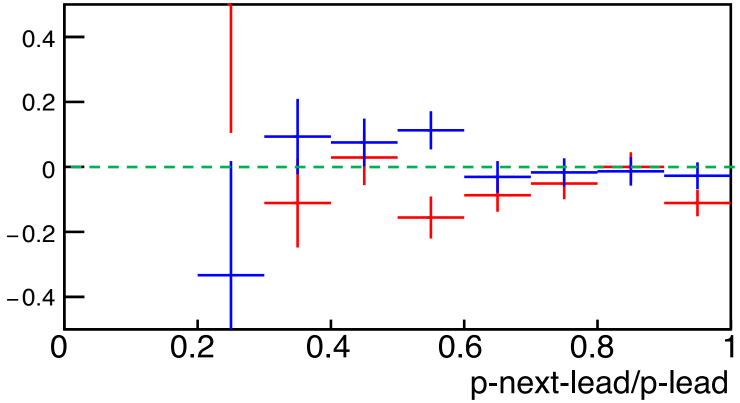


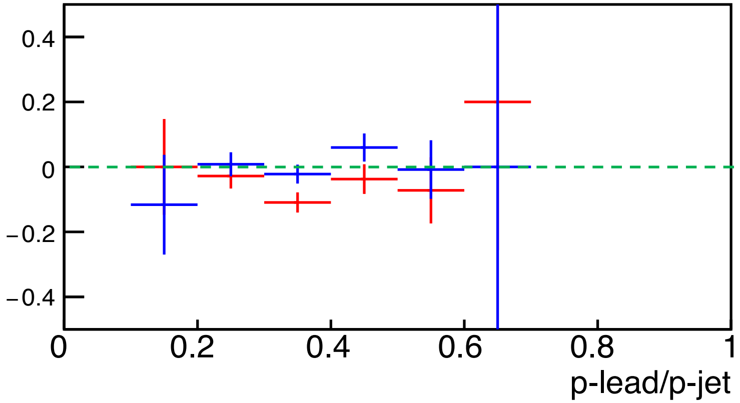


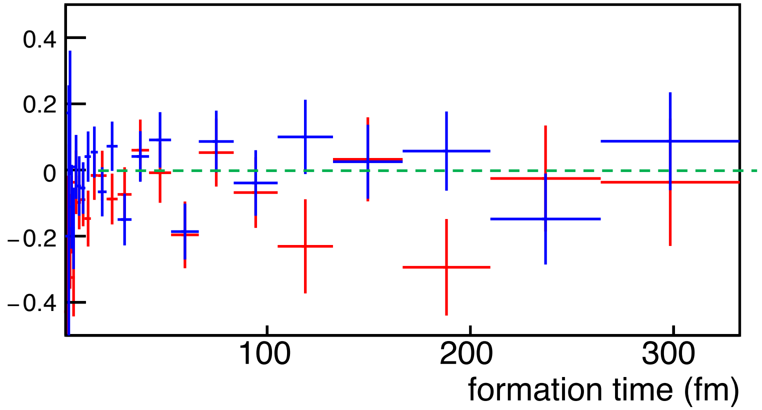
π P vs Pπ - with p cut

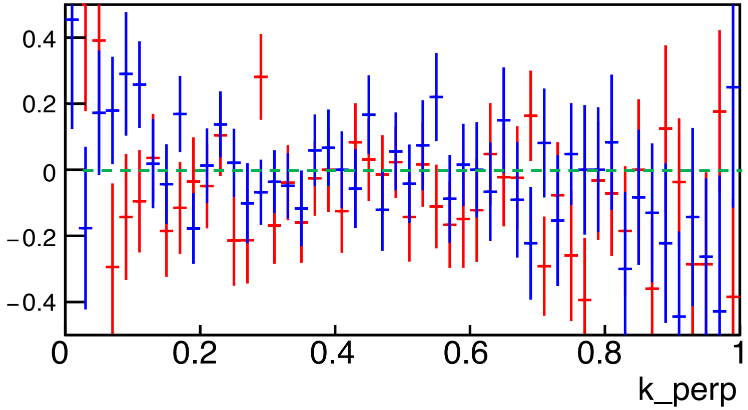
(leading momentum particle is the first one)

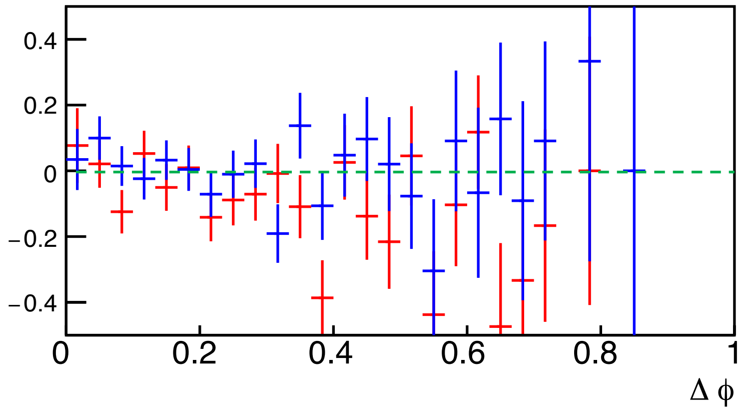
$$r = \frac{(\#of ++ or --) - (\#of \pm or \mp)}{total\ pairs}$$





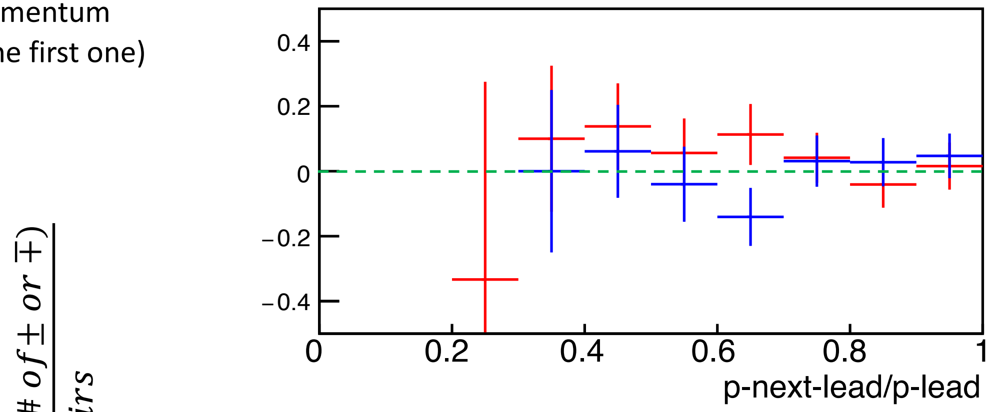


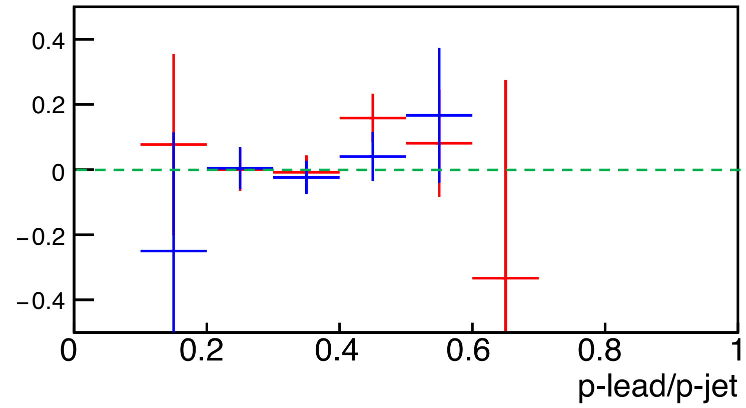


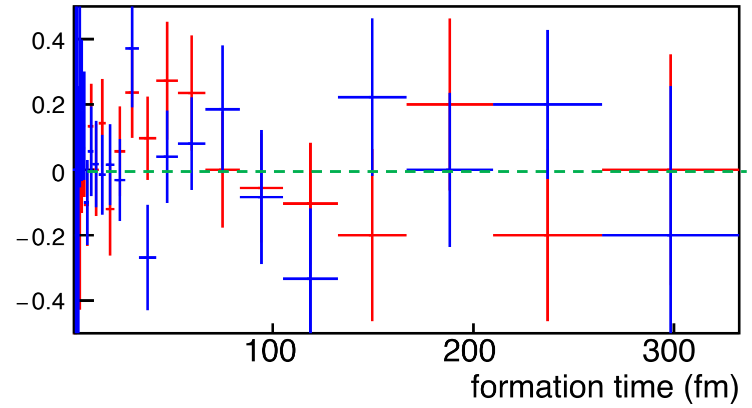


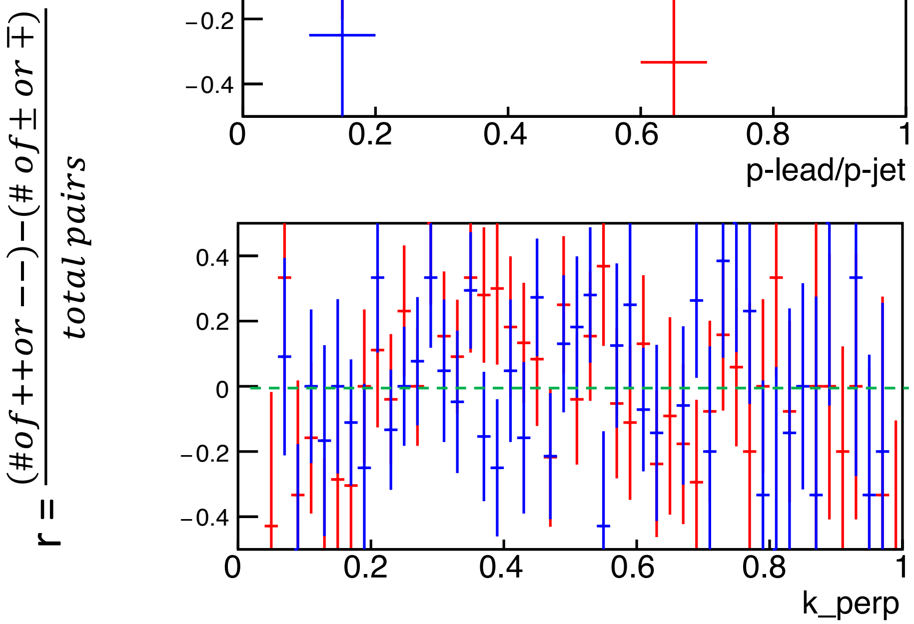
Kp vs pK - with p cut

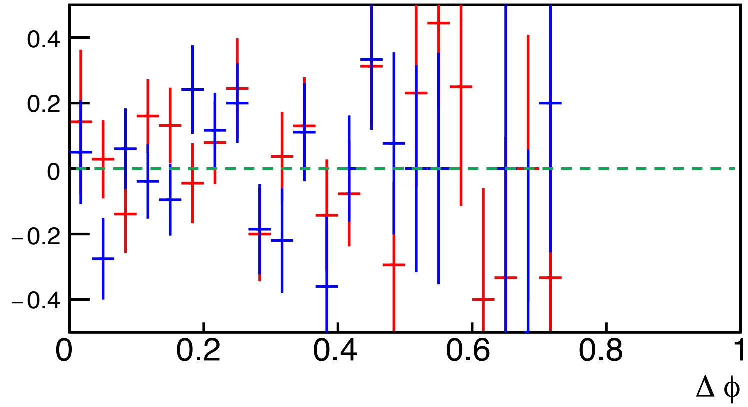
(leading momentum particle is the first one)

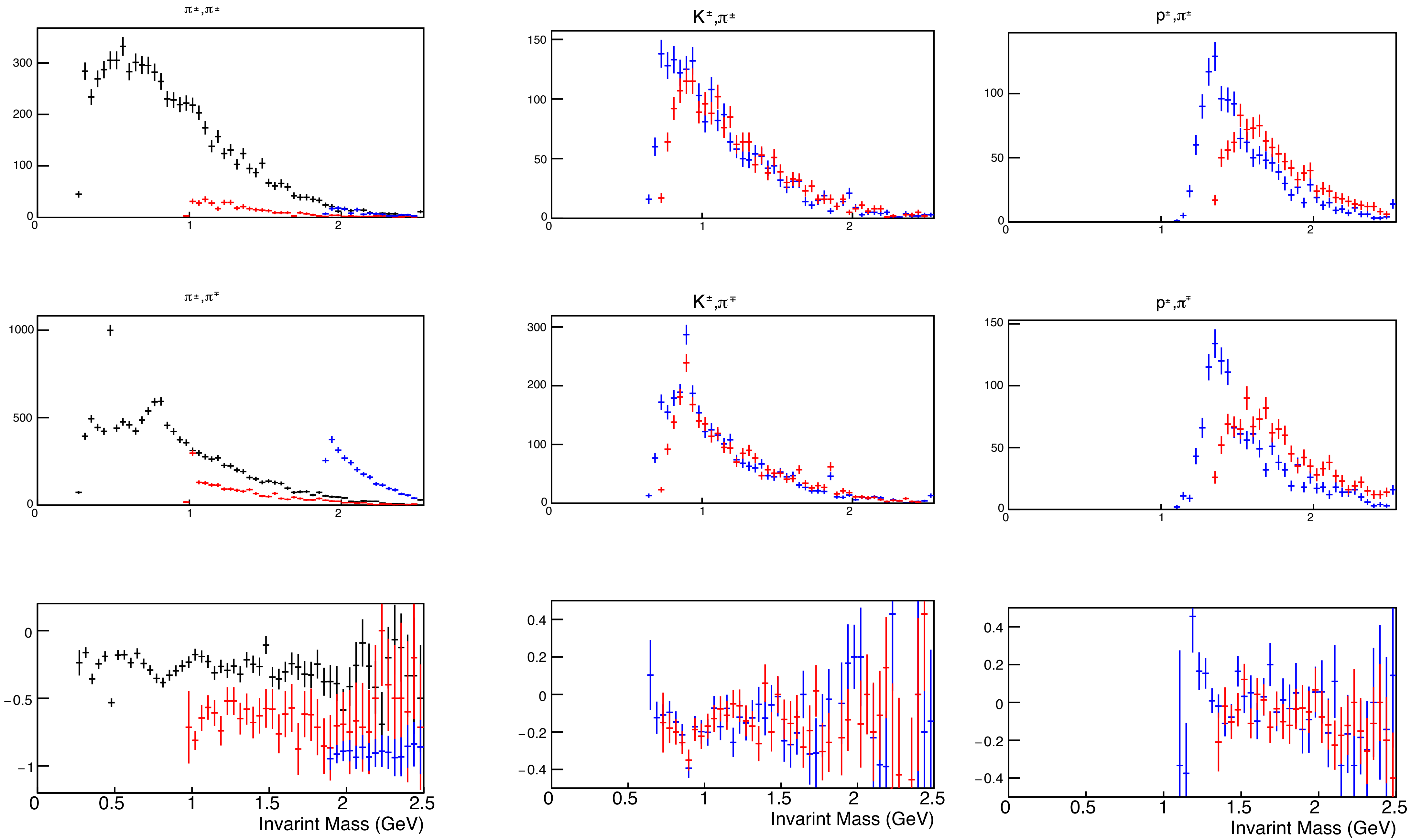








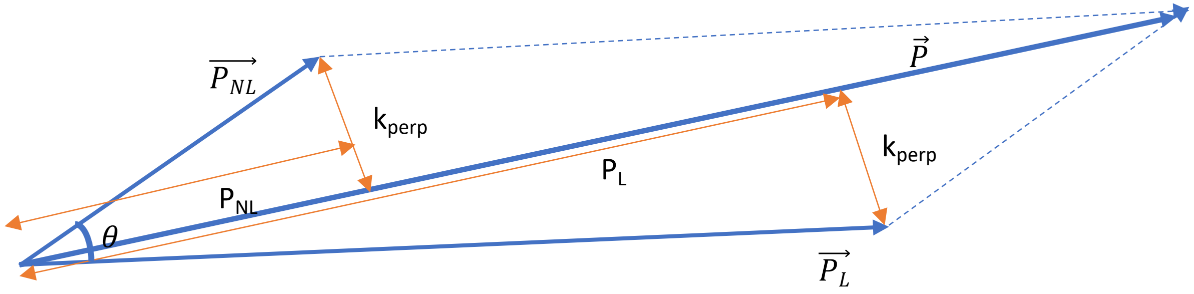



π±,π±
K±,π±
p±,π±
π±,π∓
K±,π∓
p±,π∓
Invarint Mass (GeV)
Invarint Mass (GeV)
Invarint Mass (GeV)

Q^2 = 65 GeV^2
Maximum Cross section = 2.2×10^4 mb

2.2×10^{-4} mb
2.2×10^8 fb
Integrated luminosity = 10 fb^{-1}
= 2.2×10^9 events
= 2200 M events

Formation time

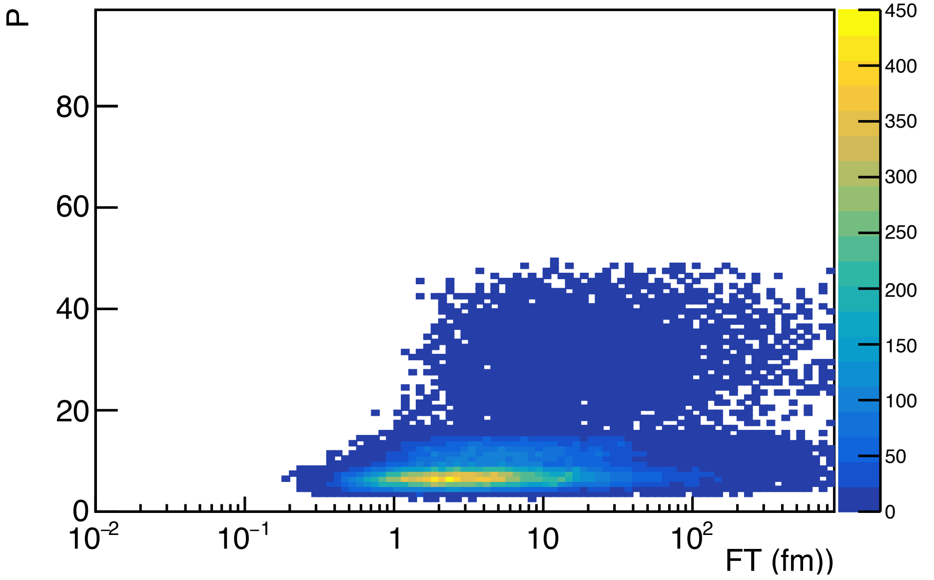


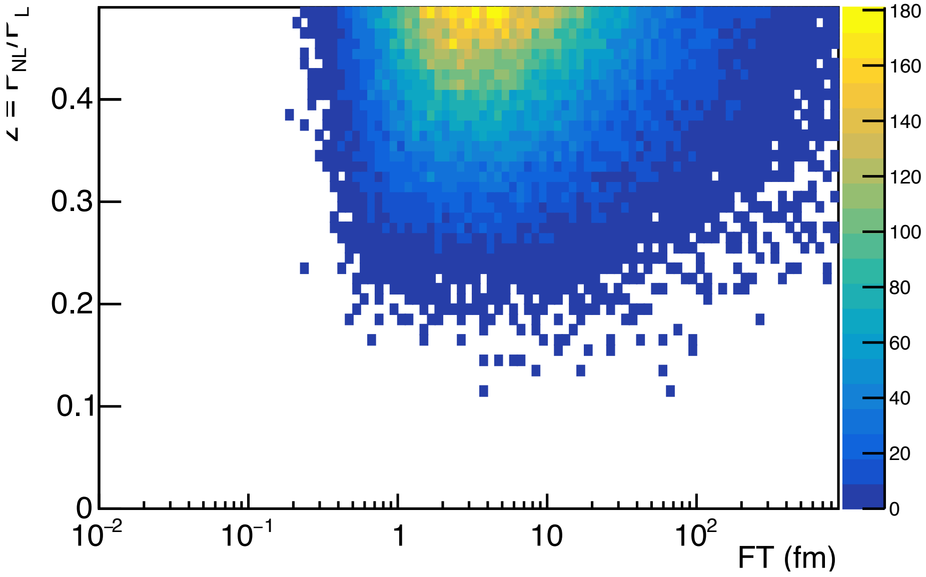
$z = P_{NL}/(P_{NL}+P_L)$
$P_L = (1-z)P$
$P_{NL} = zP$

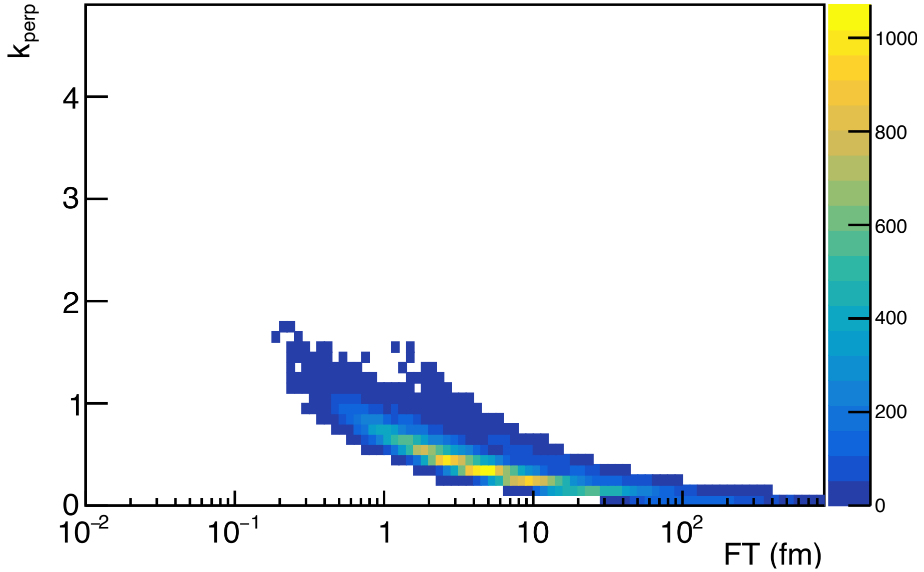
formation time = $[2z(1-z)\ P] / k_{perp}^2$

What is the interpretation of tau_form?
It's the inverse of the "energy deficit" in the lab frame if we imagine that two massless particles with 3-momenta $\overrightarrow{P_L}$ and $\overrightarrow{P_{NL}}$ emerged from the decay of an off-shell massless particle with total momentum $\vec{P}$.

Long formation times should correspond to particles that "stayed together" for a long time before separating.


P
FT (fm))


z = E_NL/E_L
FT (fm)


k_perp
FT (fm)