Jet Substructure at EIC

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Introduction

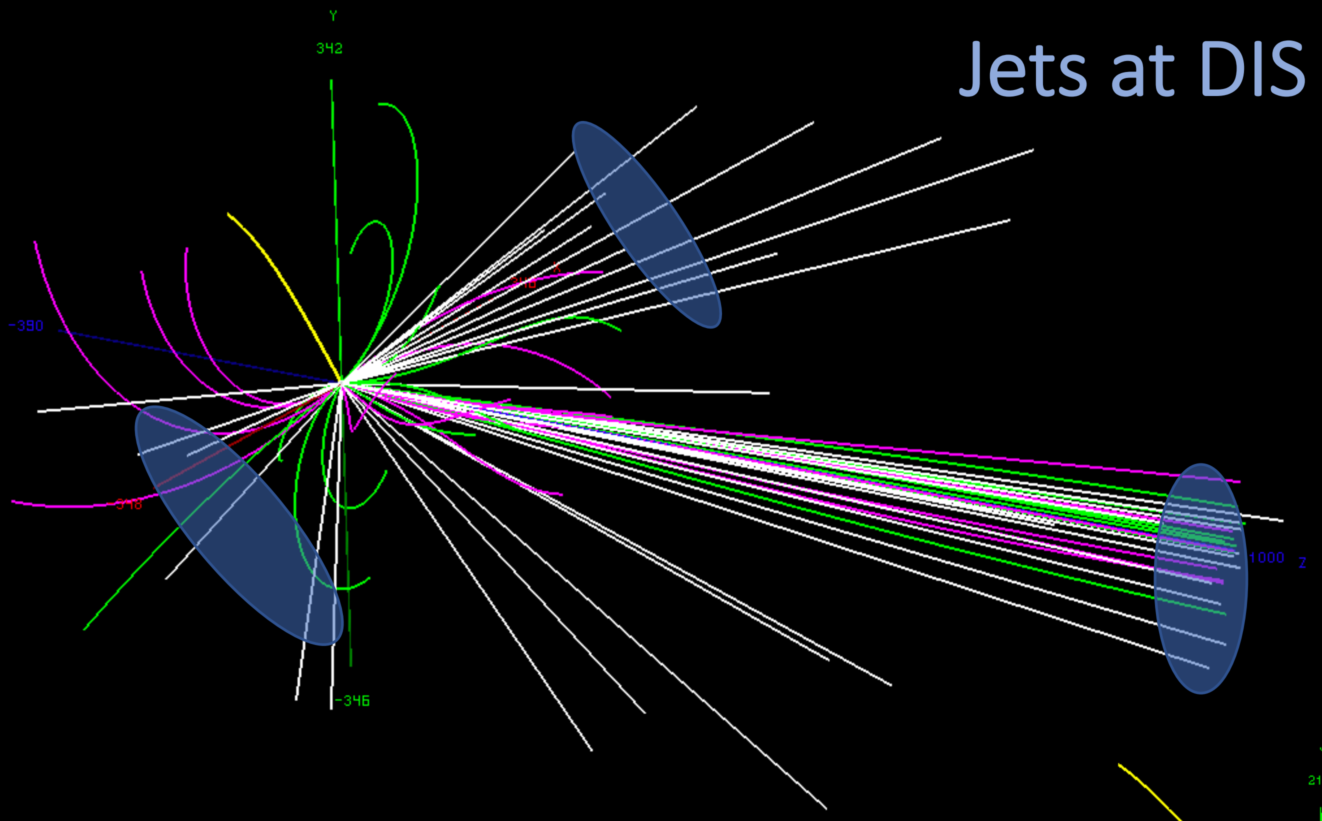
- Jets and their structure
  - Correlations in momentum, charge and flavor : leading and next to leading particles in a jet
  - access to the dynamics of fragmentation and color entanglement in QCD

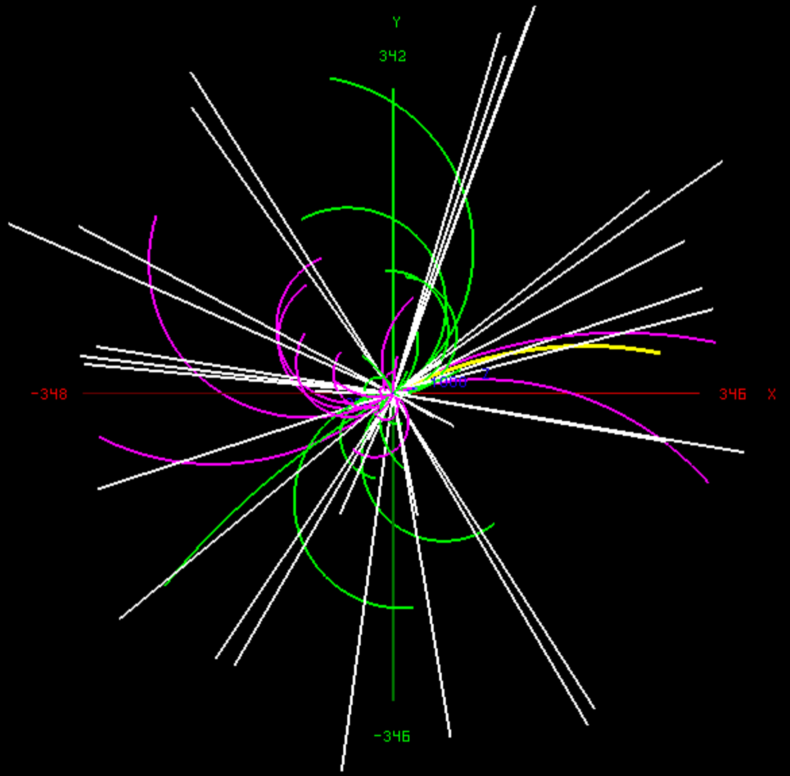
- Observable
  - Charge asymmetry and connection to dihedron fragmentation function

- Pythia event studies on the observable and PID limits
  - Acceptance of Jets with with limits in PID
  - Charge asymmetries for two different PID limits in central region

- Summary

Jets at DIS

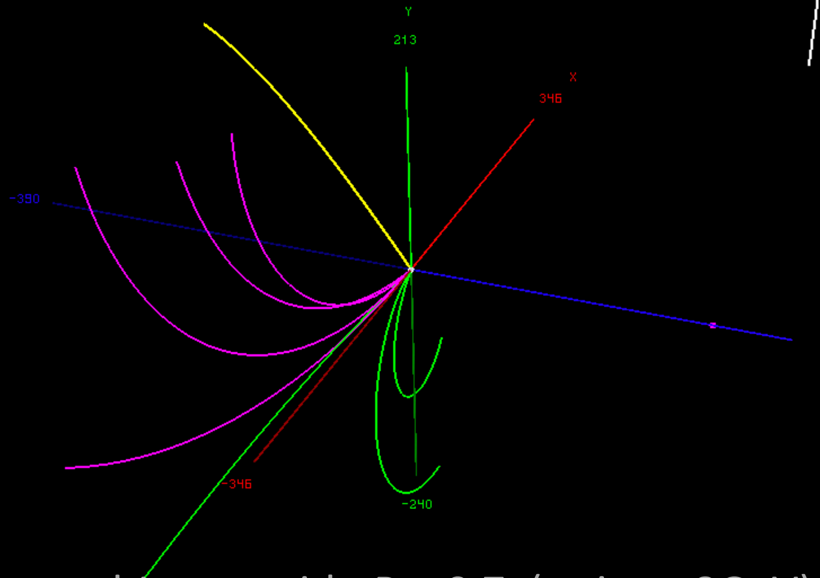




Leading momentum particles in the jet – $K, \bar{p}$

Particles in Jet :

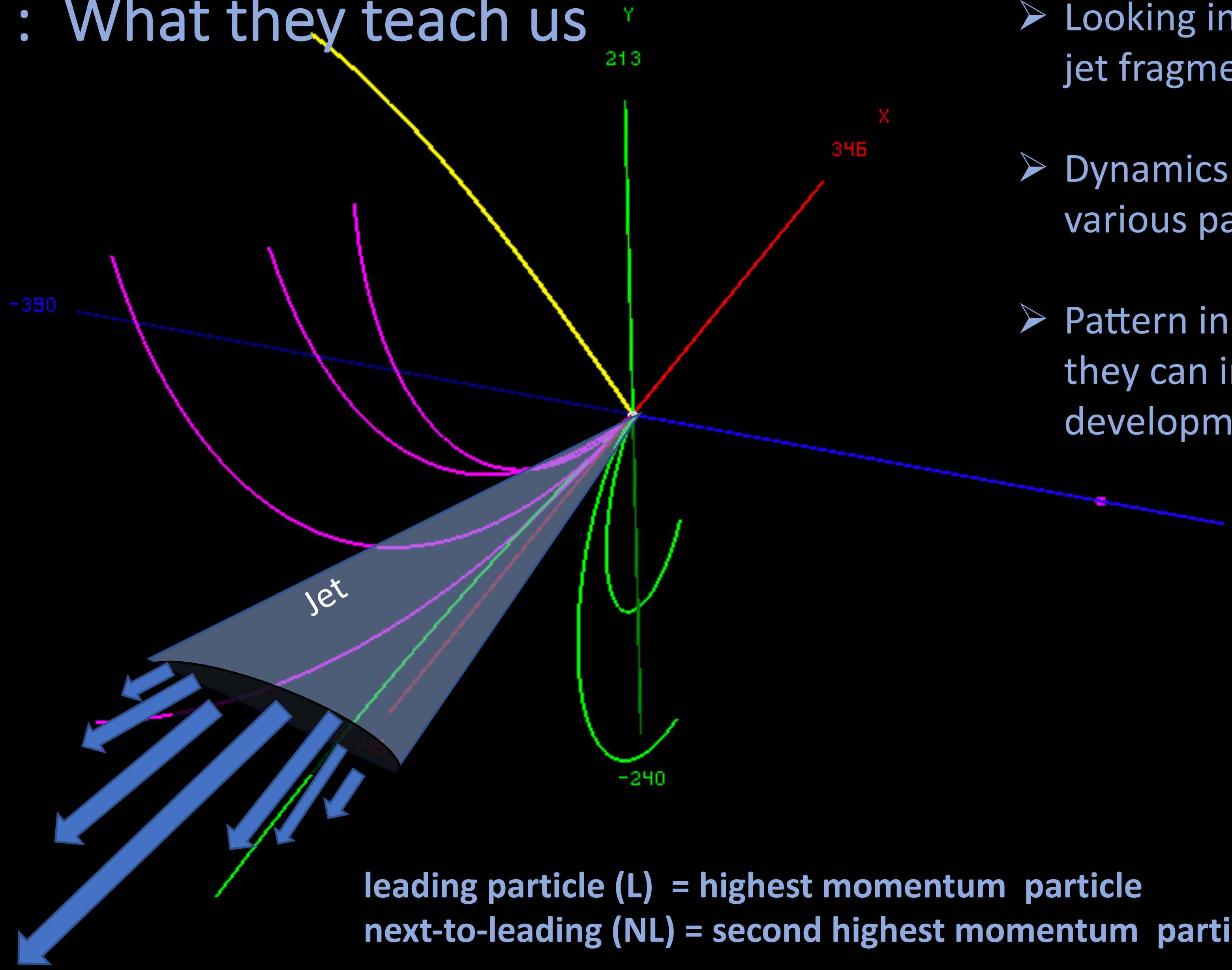
Px	Py	Pz	PID
-7.64	-4.41	-4.21	321
-2.06	-1.89	-1.40	-2212
-1.44	-0.87	-0.69	-211
-1.07	-0.08	0.04	2212
-0.58	-0.45	-0.53	-211
-0.70	-0.39	- 0.39	-211
-0.65	-0.52	-0.04	211



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

Scattered-electron
+ve particles
-ve particles
Neutral particles

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

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

$C\overline{C}$ 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:

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

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

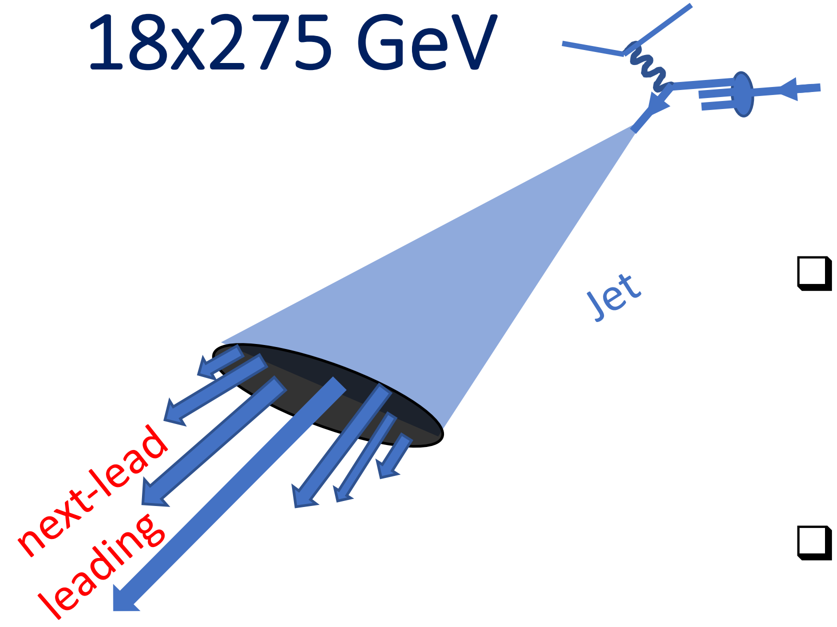
- **The observable :**

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

  - ✓ 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)

18x275 GeV



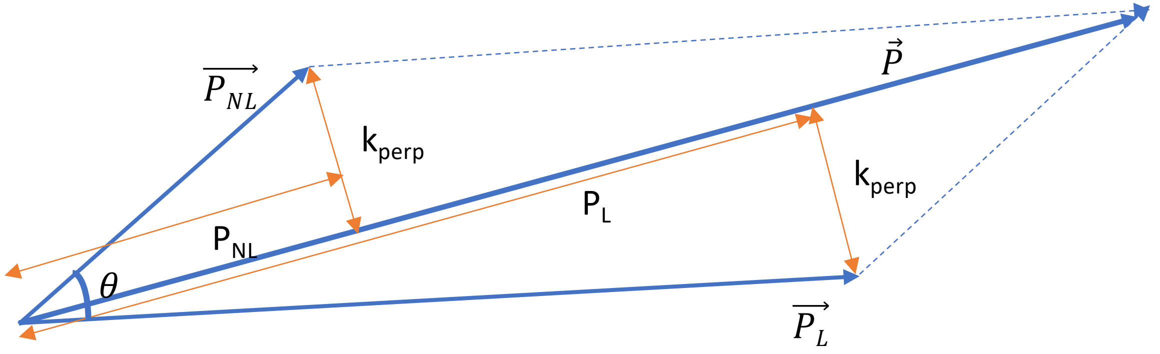
$$r_{\rm asy} \equiv \frac{N_{CC} - N_{C\overline{C}}}{N_{CC} + N_{C\overline{C}}}$$

- ❑ 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 :
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

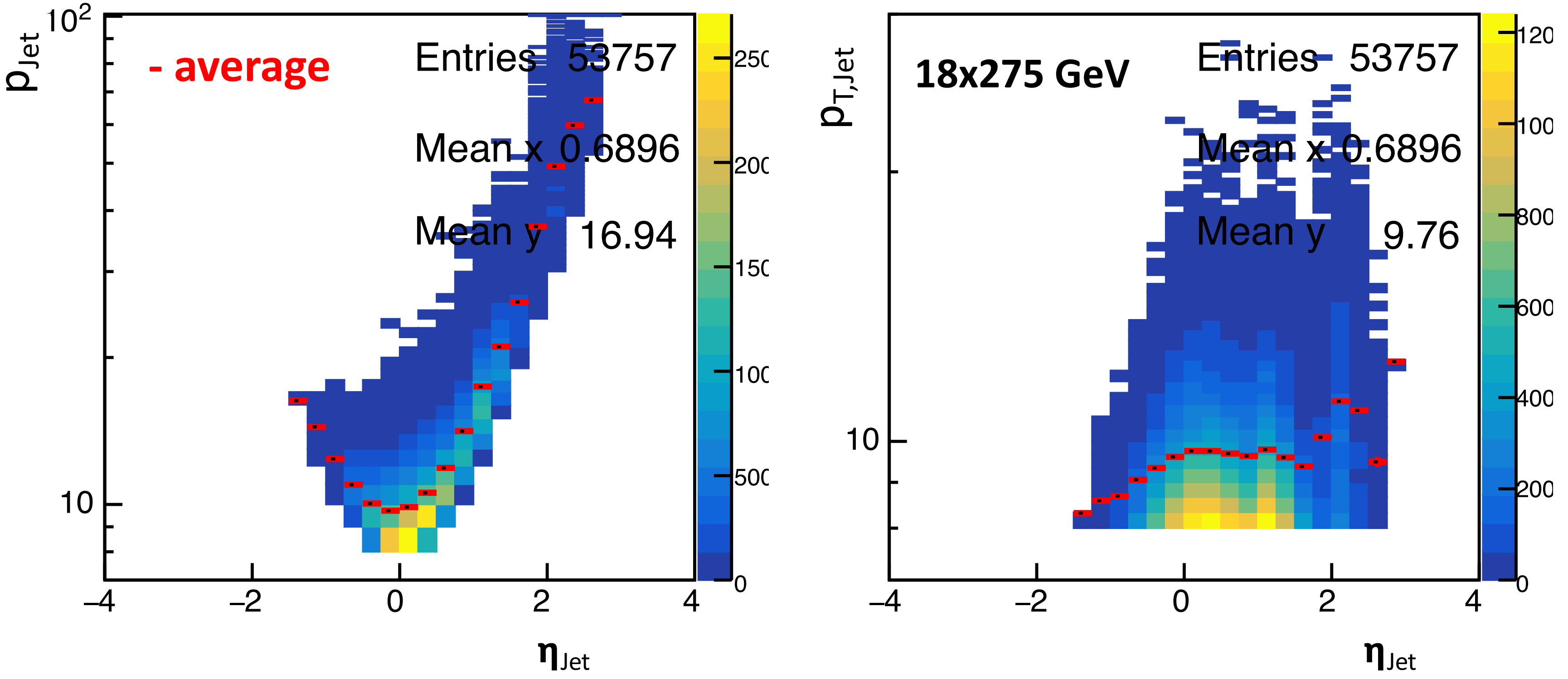


$z = P_{NL}/(P_{NL}+P_L)$
$P_L = (1-z)P$
$P_{NL} = zP$

Acceptance

Momentum cuts on tracks for approximate PID requirement at EIC at different **η** regions (currently we made one hard limit at certain momentum)

η - range	Momentum cut (GeV/c²)
-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



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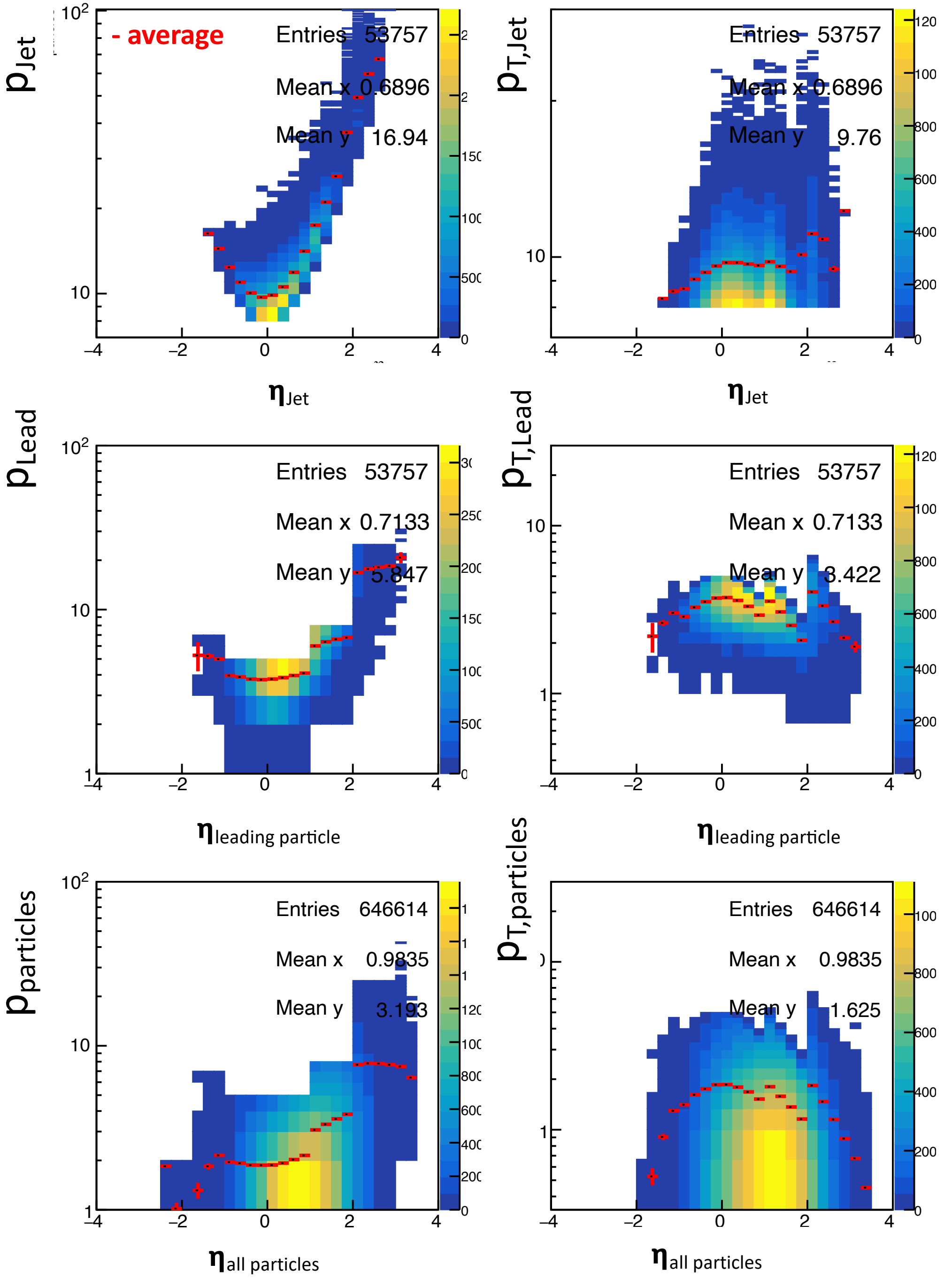
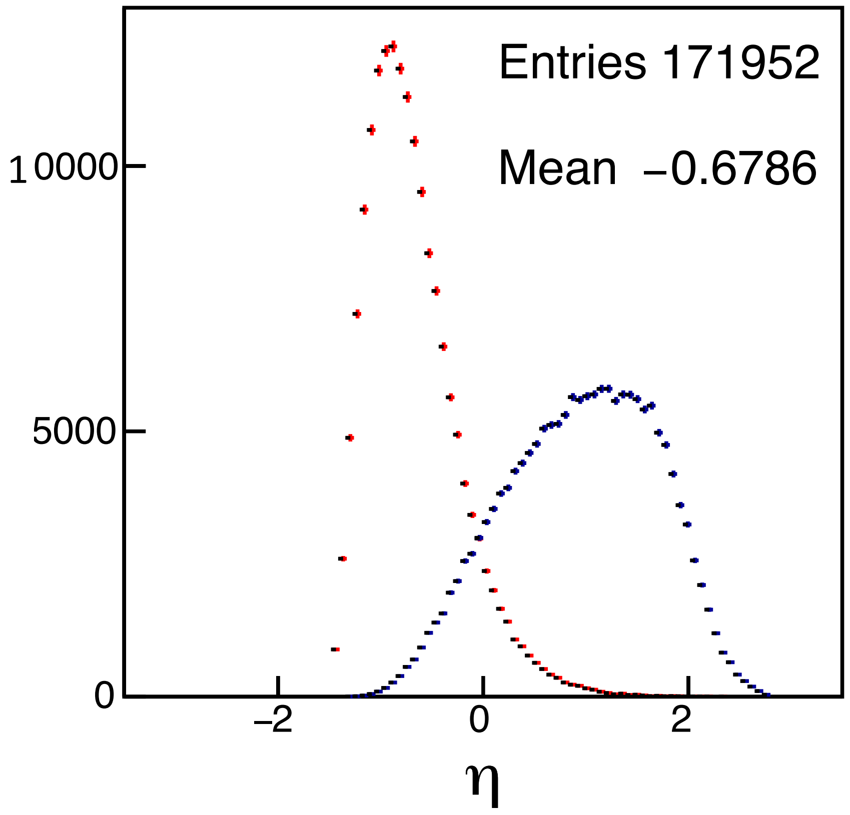
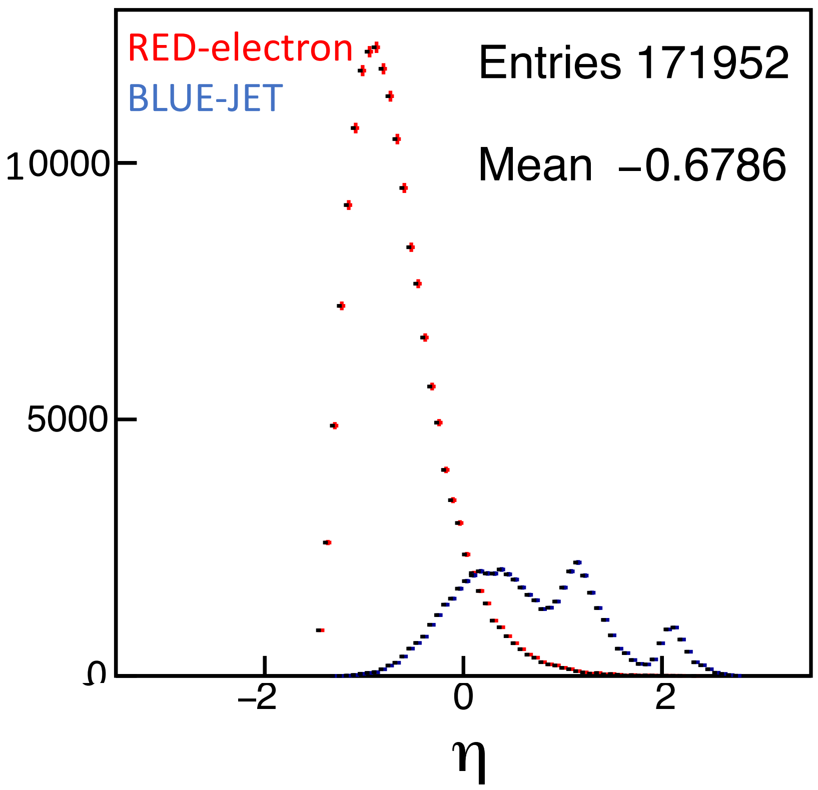


The effect of momentum cuts in pseudorapidity acceptance of jets

NO momentum cuts



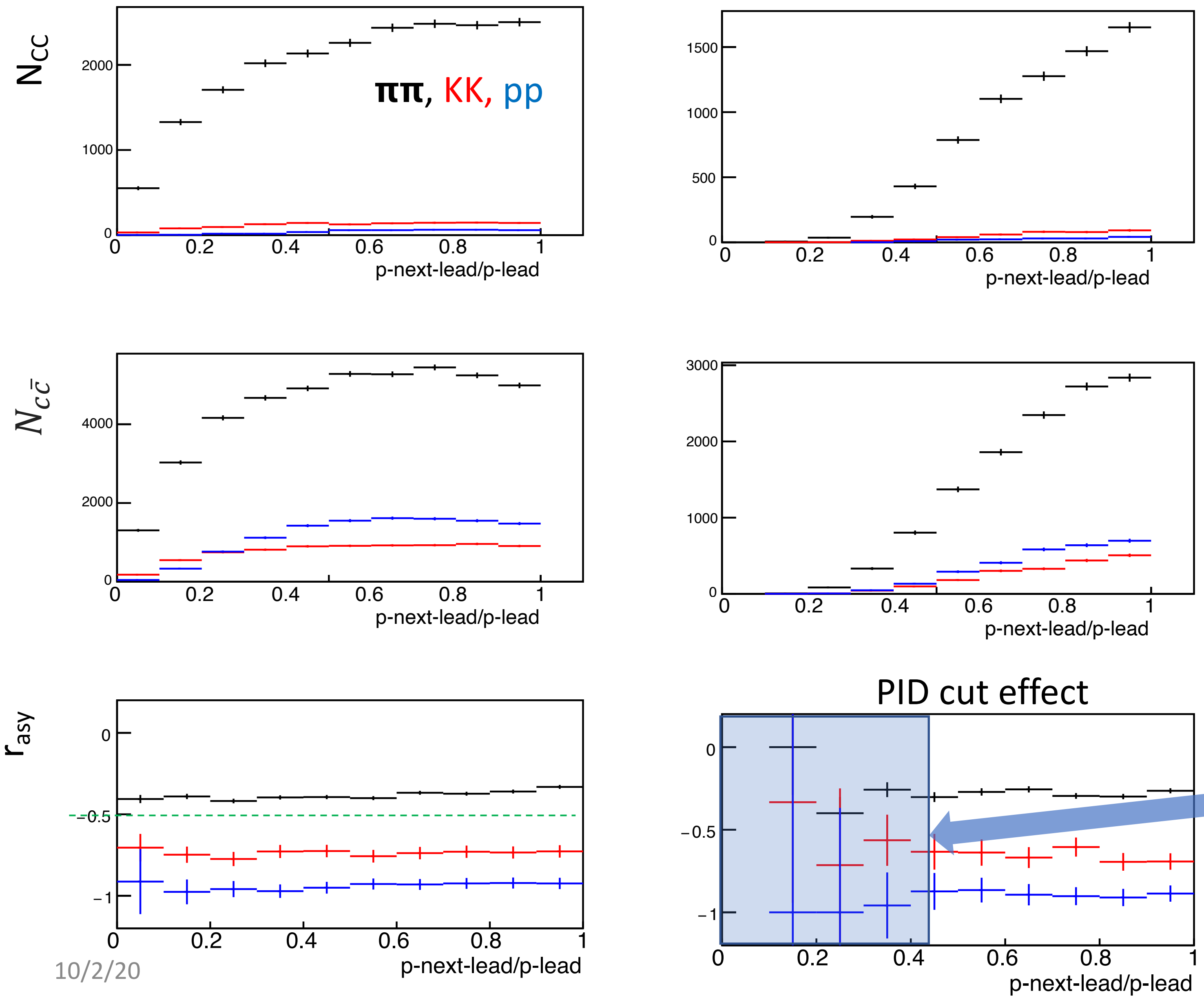
After momentum cuts



PID limit has huge impact on jet acceptance when leading particle's PID is performed

Correlation with two leading particles

NO momentum cuts | **After momentum cuts**



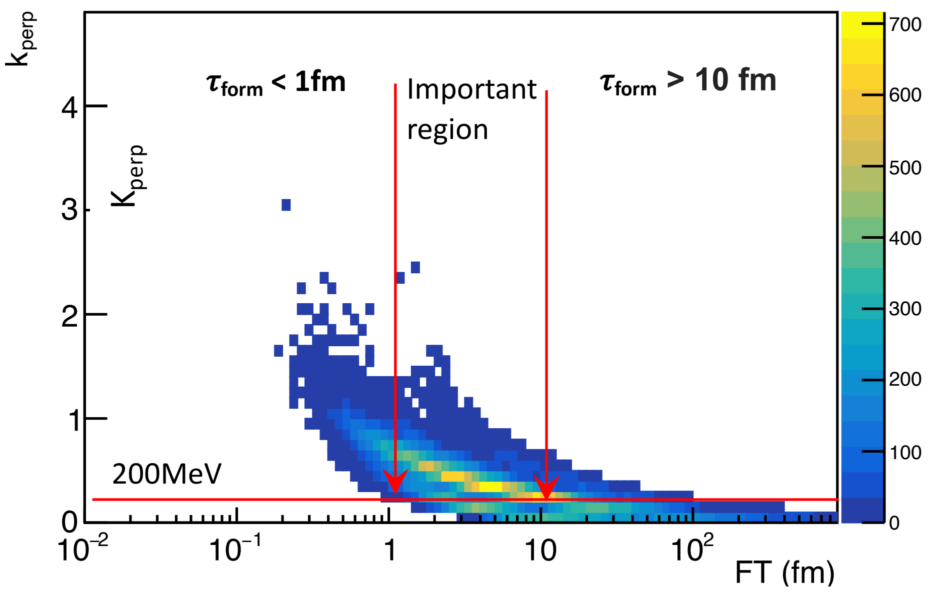
$$r_{\mathrm{asy}} \equiv \frac{N_{CC} - N_{C\overline{C}}}{N_{CC} + N_{C\overline{C}}}$$

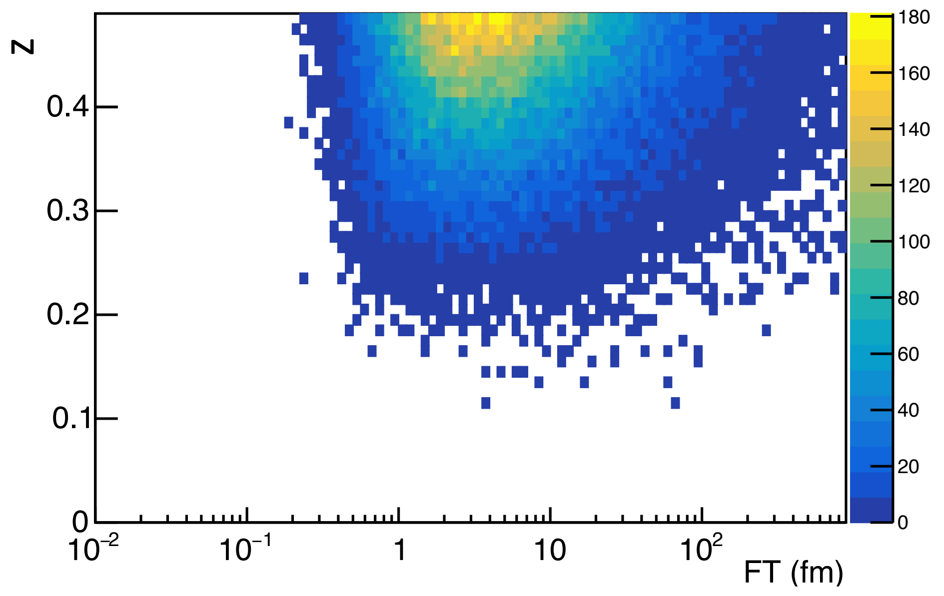
- The strength of correlations are different for pions, kaons and proton

The transition region from soft patron emission to hard is very important

Formation time

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





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

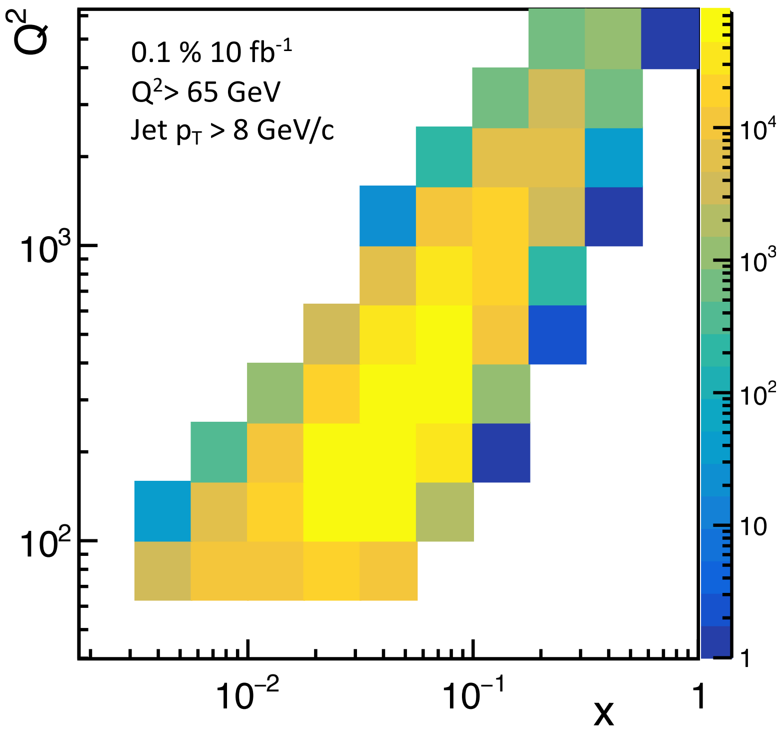
Important region to study in data τ_{form} = "a few fermi" and "a few dozen fermi", k_{perp} = “a few GeV” to “several hundred MeV”

Different PID limits at Barrel region : a comparative study

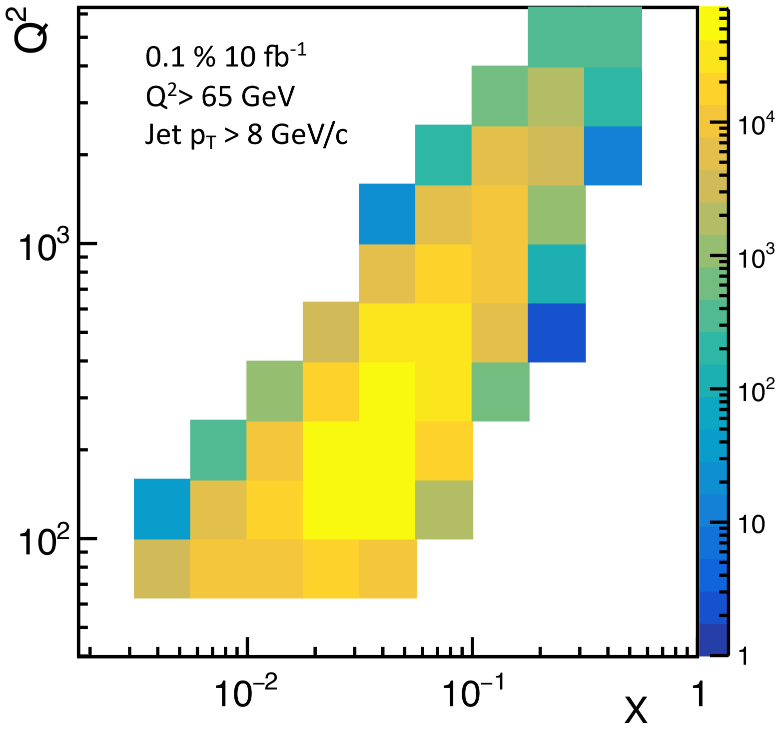
η - range	Momentum cut (GeV/c^2)
-1.0 to 1.0	No limit
-1.0 to 1.0	10
-1.0 to 1.0	5

Acceptance in x-Q^2

η - range	Momentum cut (GeV/c^2)
-1.0 to 1.0	No limit



η - range	Momentum cut (GeV/c^2)
-1.0 to 1.0	10



η - range	Momentum cut (GeV/c^2)
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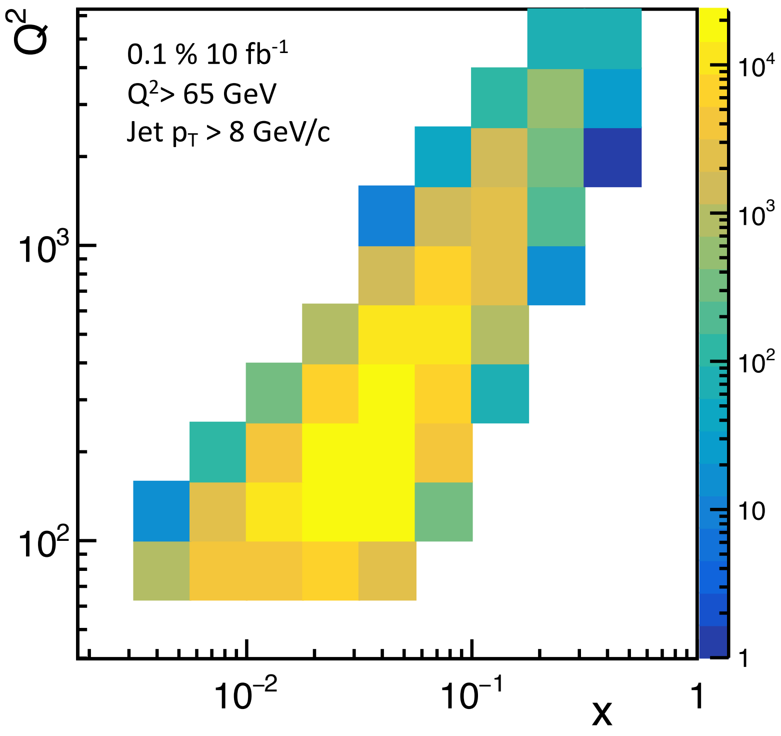
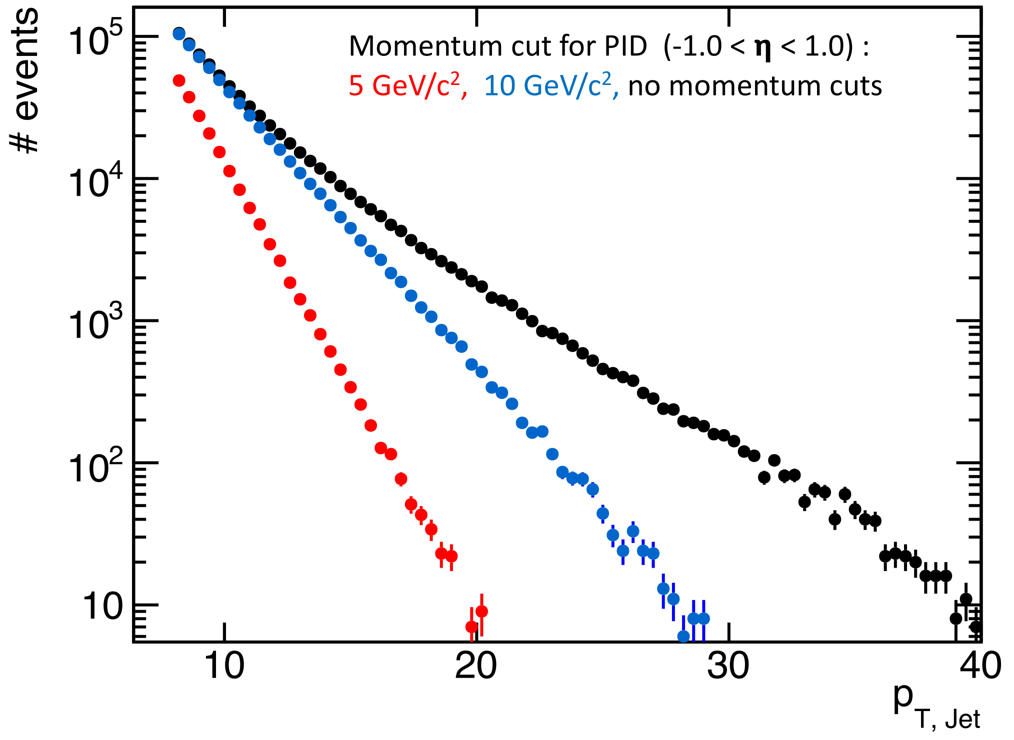
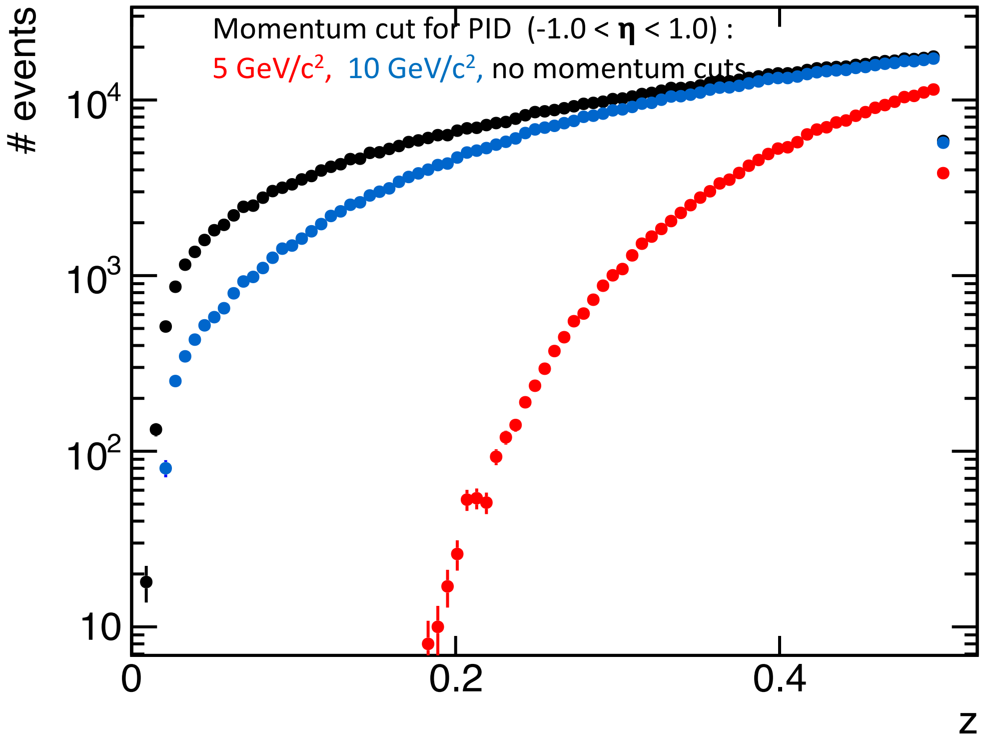


Covers wider x-Q^2 phase with high momentum PID

$p_{T,Jet}$ and z reach for different PID limits at Barrel region

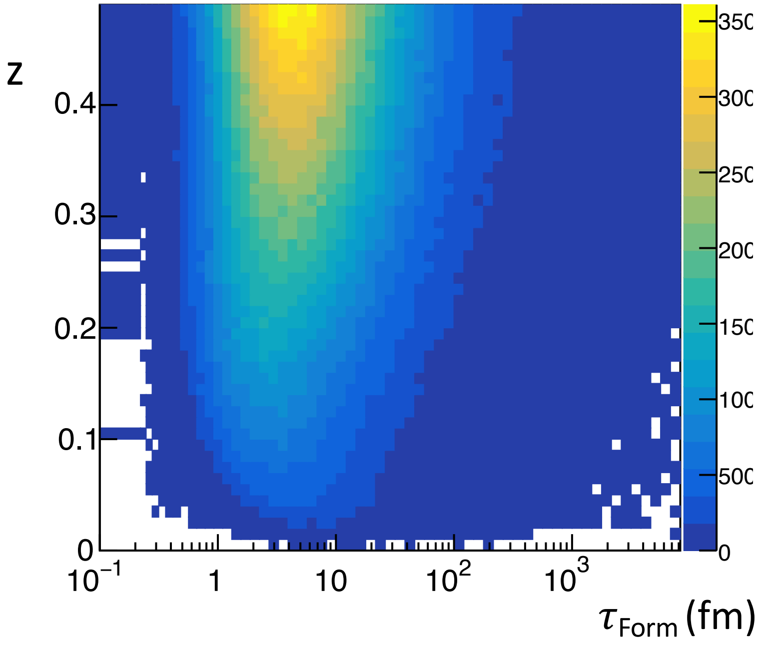
$z = P_{NL}/(P_{NL}+P_L)$

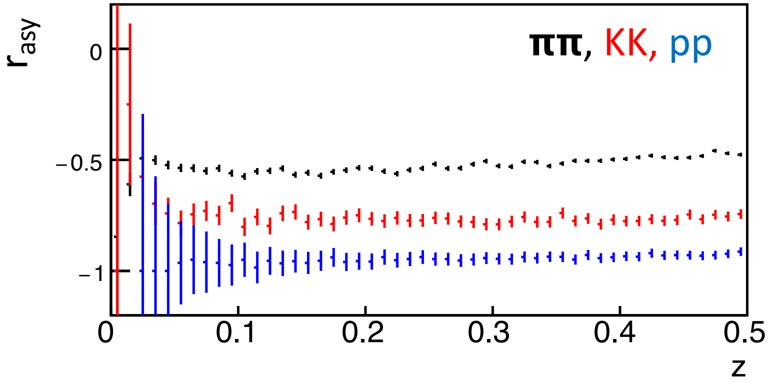




- PID up to 10 GeV/c^2 impose significant limitation in small z and high $\mathbf{p_{T,Jet}}$ reach
- However, increasing PID performance up to 10 GeV/c^2 would :
  - ✓ significantly cover small z
  - ✓ enhance $\mathbf{p_{T,Jet}}$ limit od measurement

η - range	Momentum cut (GeV/c^2)
-1.0 to 1.0	No limit





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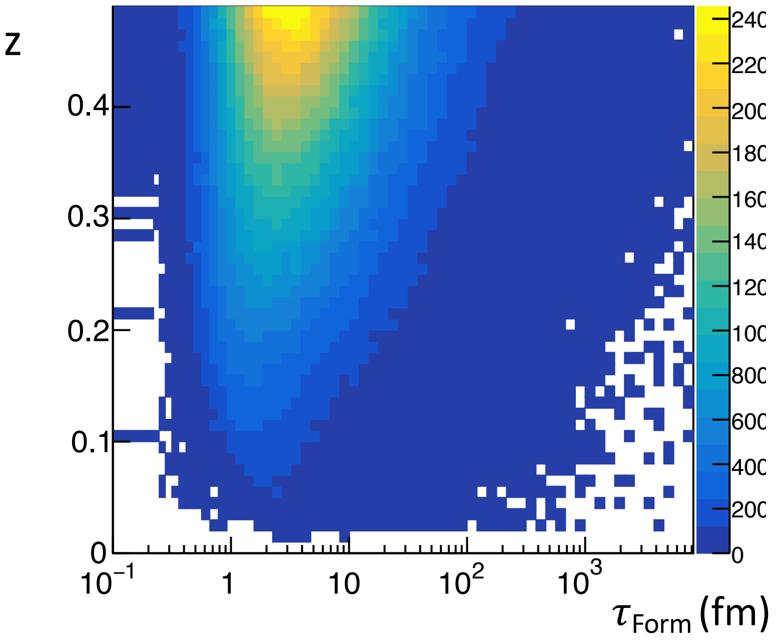

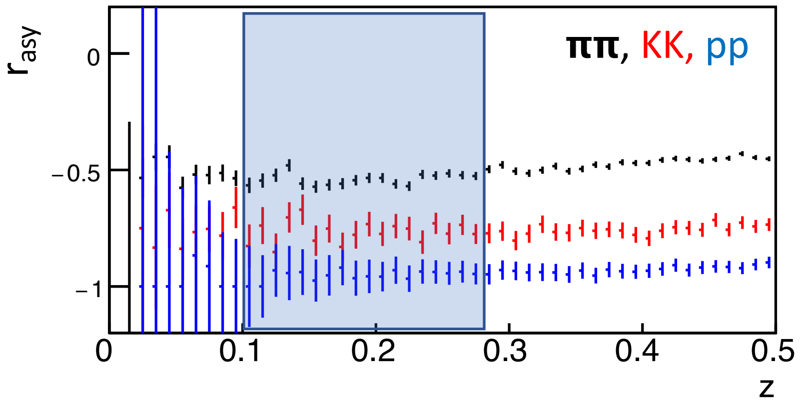

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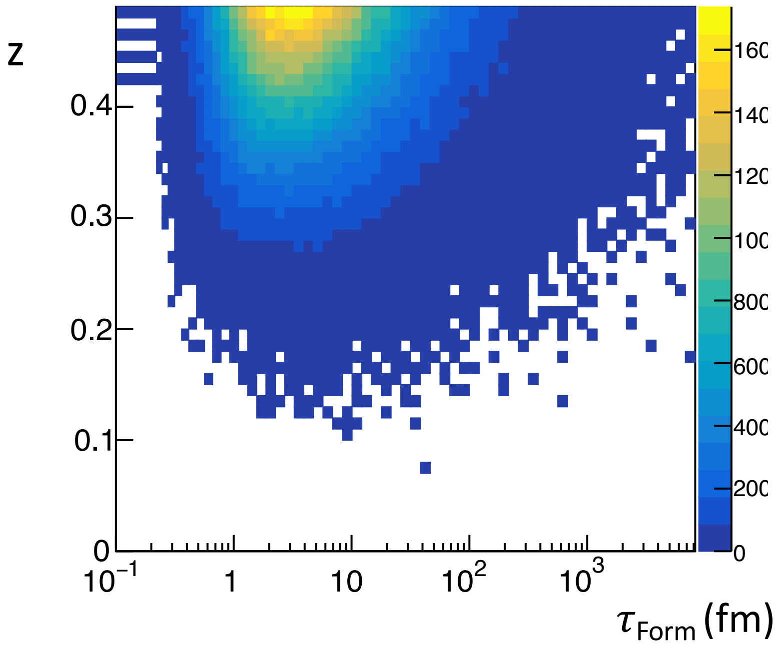

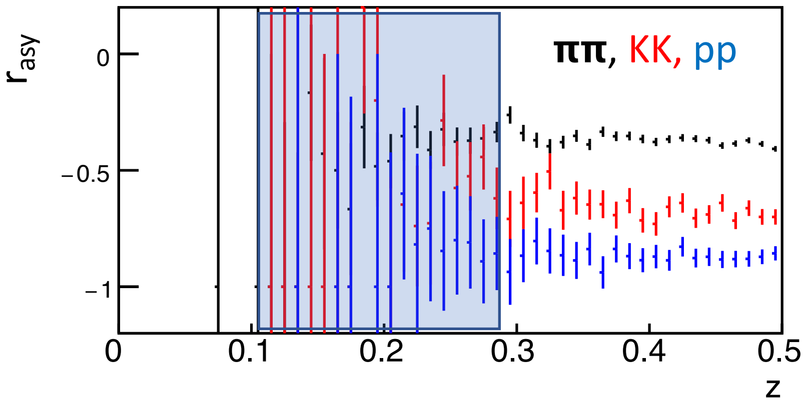

Better measurements at small z region with high momentum PID

η - range	Momentum cut (GeV/c^2)
-1.0 to 1.0	No limit

η - range	Momentum cut (GeV/c^2)
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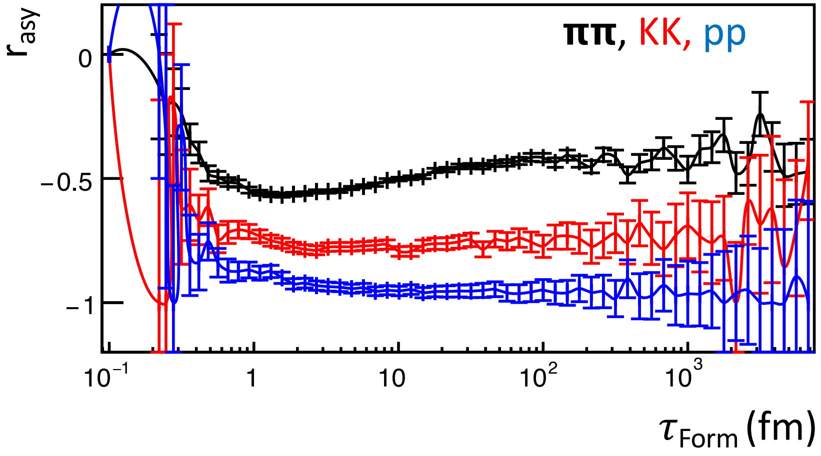
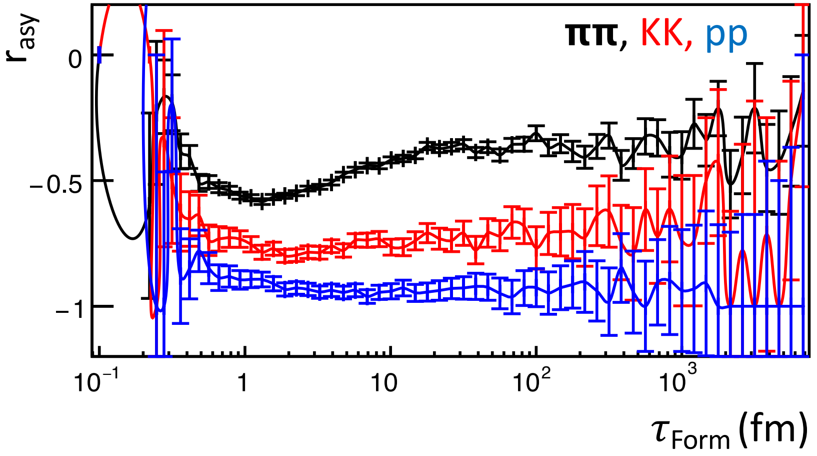
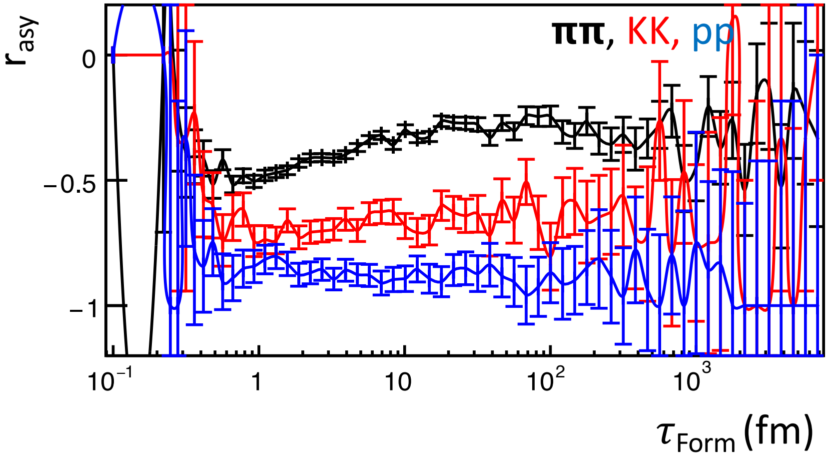
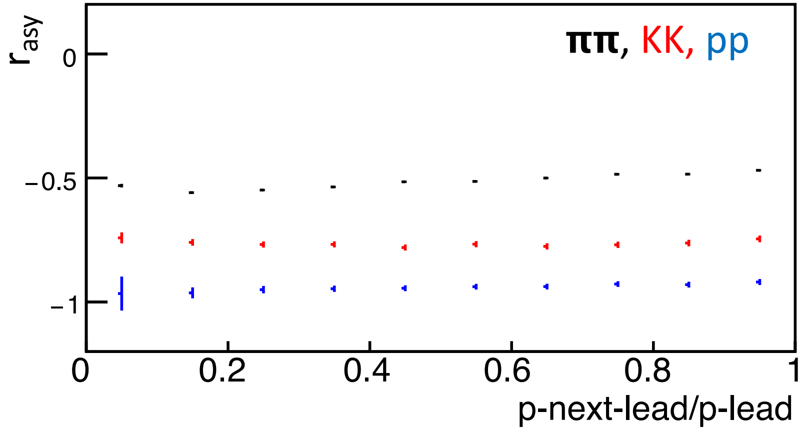
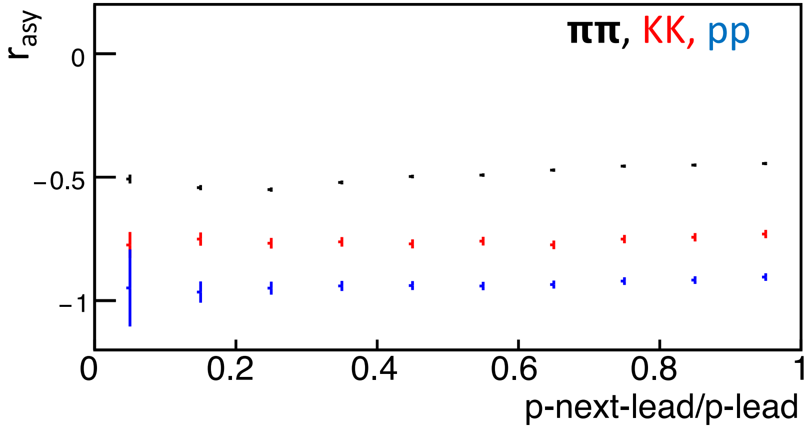
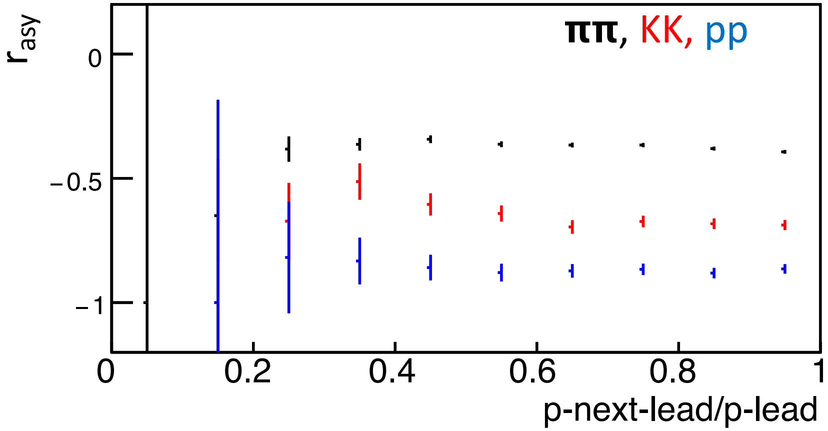












- increasing PID performance up to 10 GeV/c^2 would significantly make better measurement in small z and small p-net-lead/p-lead region

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 compared to the experiments in HERA

- PID with 5 GeV/c momentum limit keeps much of the important region inaccessible

- Enhancing momentum reach 10 GeV/c is very useful in reaching the very important inaccessible region
  - ✓ Covers wider x-Q^2 phase space
  - ✓ Access smaller z region
  - ✓ enhance $\mathbf{p_{T,Jet}}$ limit of measurement

- Such studies going in very forward region

backup

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 : $D^{>}_{h_L,h_{NL}}(z_L z_{NL})$

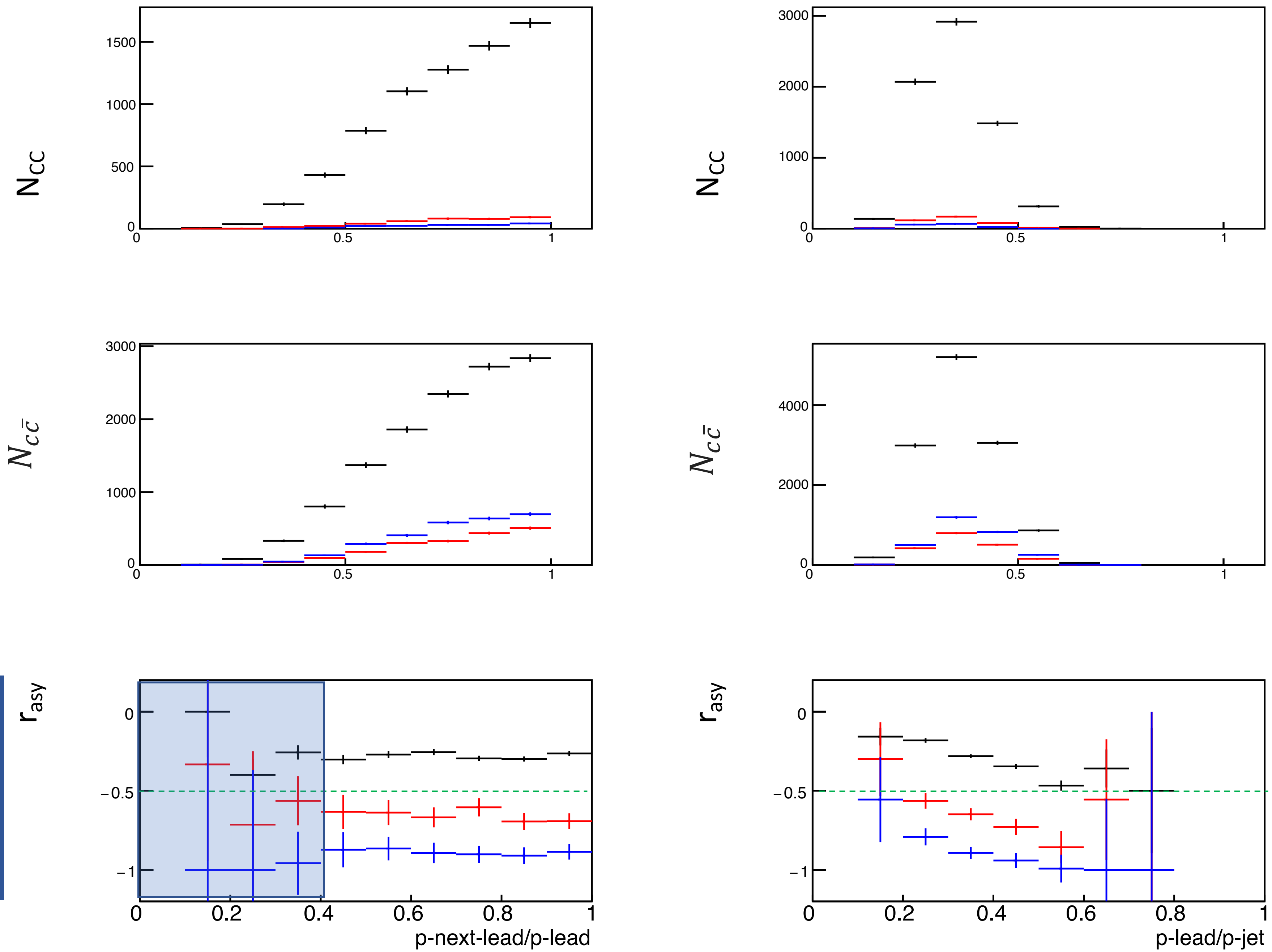
$$N^{>}_{h_L,h_{NL}} = \int_0^1 dz_L \int^{\min(z_L,1-z_L)} dz_{NL} D^{>}_{h_1,h_2}(z_L, z_{NL}, Q)$$

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

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

After momentum cuts

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



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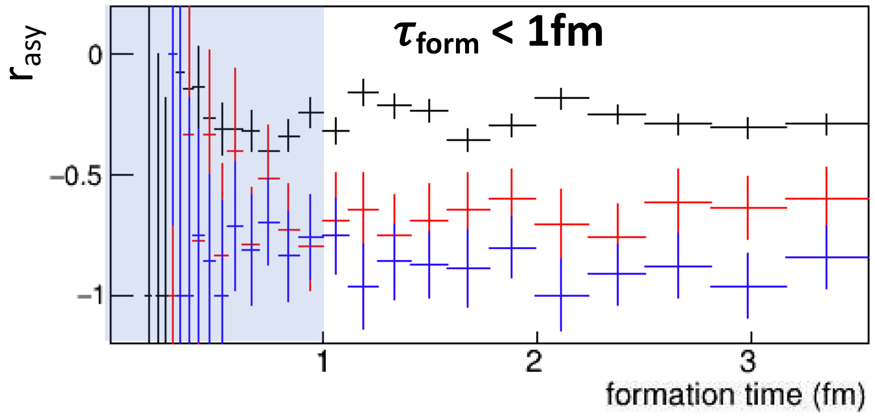

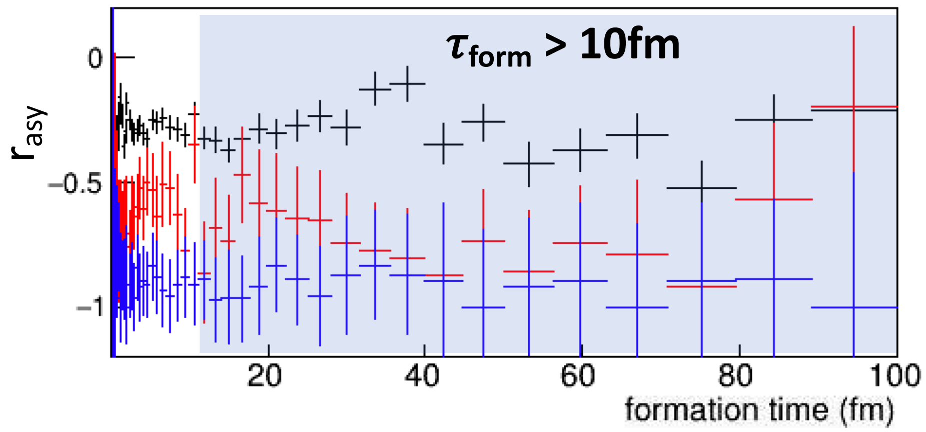

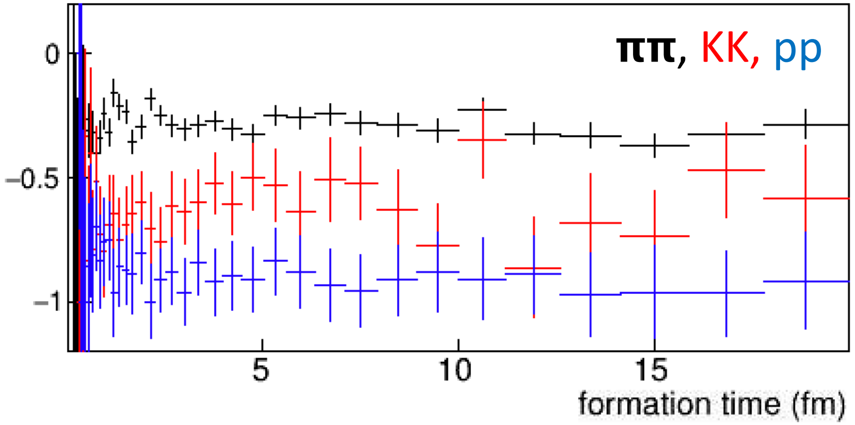

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