Recoil free jet observables at sPHENIX

Yang-Ting Chien

Predictions for sPHENIX, BNL
July 21st, 2022

Phys. Lett. B 815 (2021) 136124 (2005.12279), 2205.05104 ; Phys. Rev. D 105 (2022) 5, L051502

In collaboration with Rudi Rahn, Solange Schrijnder van Velzen, Ding Yu Shao, Wouter J. Waalewijn, Bin Wu,
And also Abhay Deshpande, Mriganka Mouli Mondal, George Sterman, Weibin Zhang

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Disclaimer:
Can only mostly talk about extrapolation from LHC pp with very preliminary simulation studies, and ideas.

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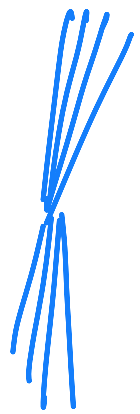
Outline

- How can we do precision hard probes (or jet physics) at sPHENIX?
    - Meaning: precise measurement and sensitivity to distinct phase spaces
- Underlying events “recoil” jet observables significantly
- Recoil-free jet observables to precisely benchmark medium modifications
    - Recoil-free photon-jet or dijet angular decorrelation
        - Polarized proton beams
    - Leading and next-to-leading hadron charge correlation

Challenges from correlated underlying events

Jets in pp



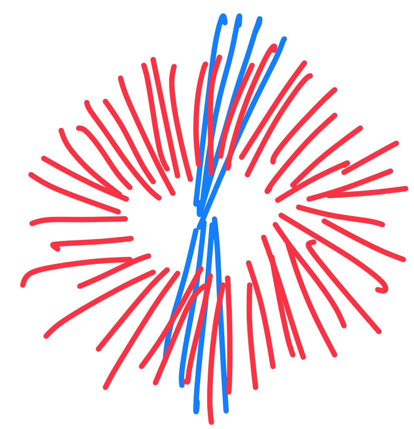
+

minimum bias in AA

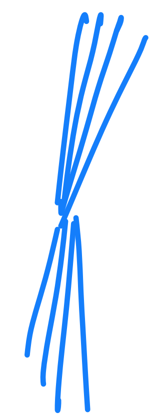
≠

AA with jets

It is <u>NOT</u> clear whether the mapping (i.e. subtraction)



Machine Learning →



applies to real AA events

counter example: what if one jet is severely quenched? what will the subtraction do to that region?

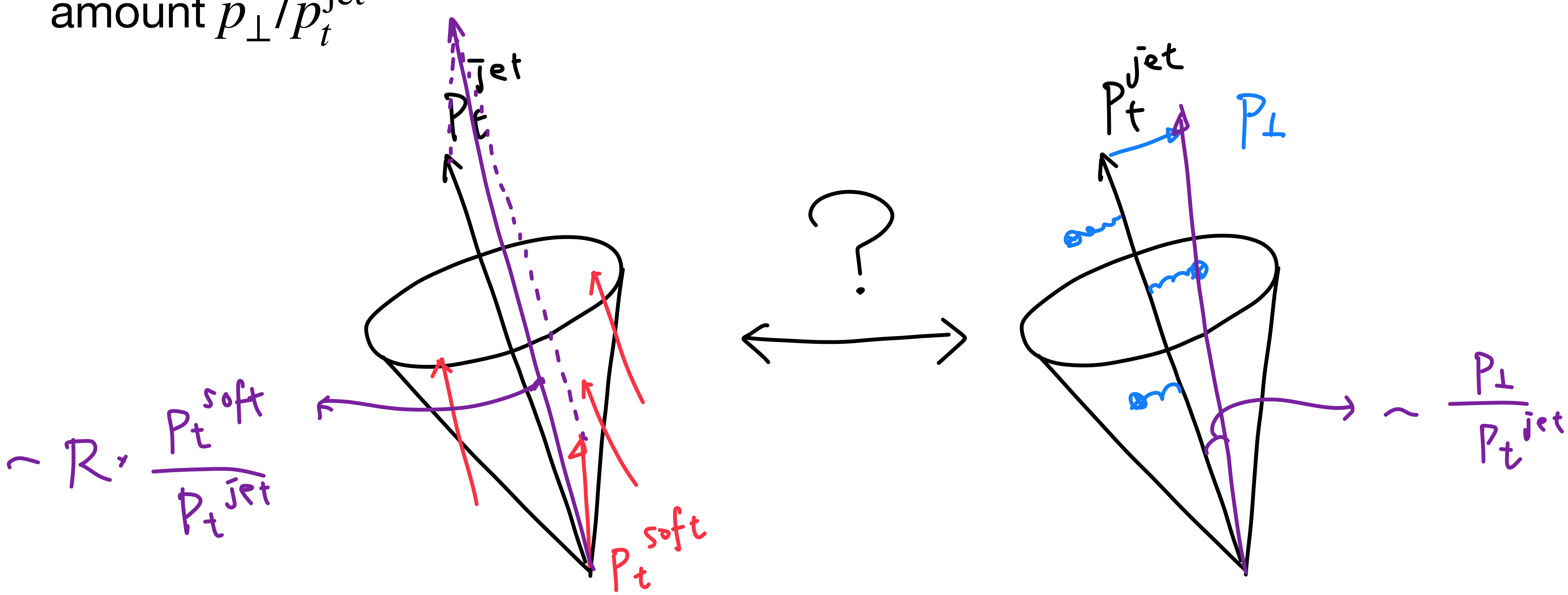
This is different from pileup mitigation

From a different angle:

- Are there observables which are not affected by such subtractions? Or, equivalently, don't require subtractions?

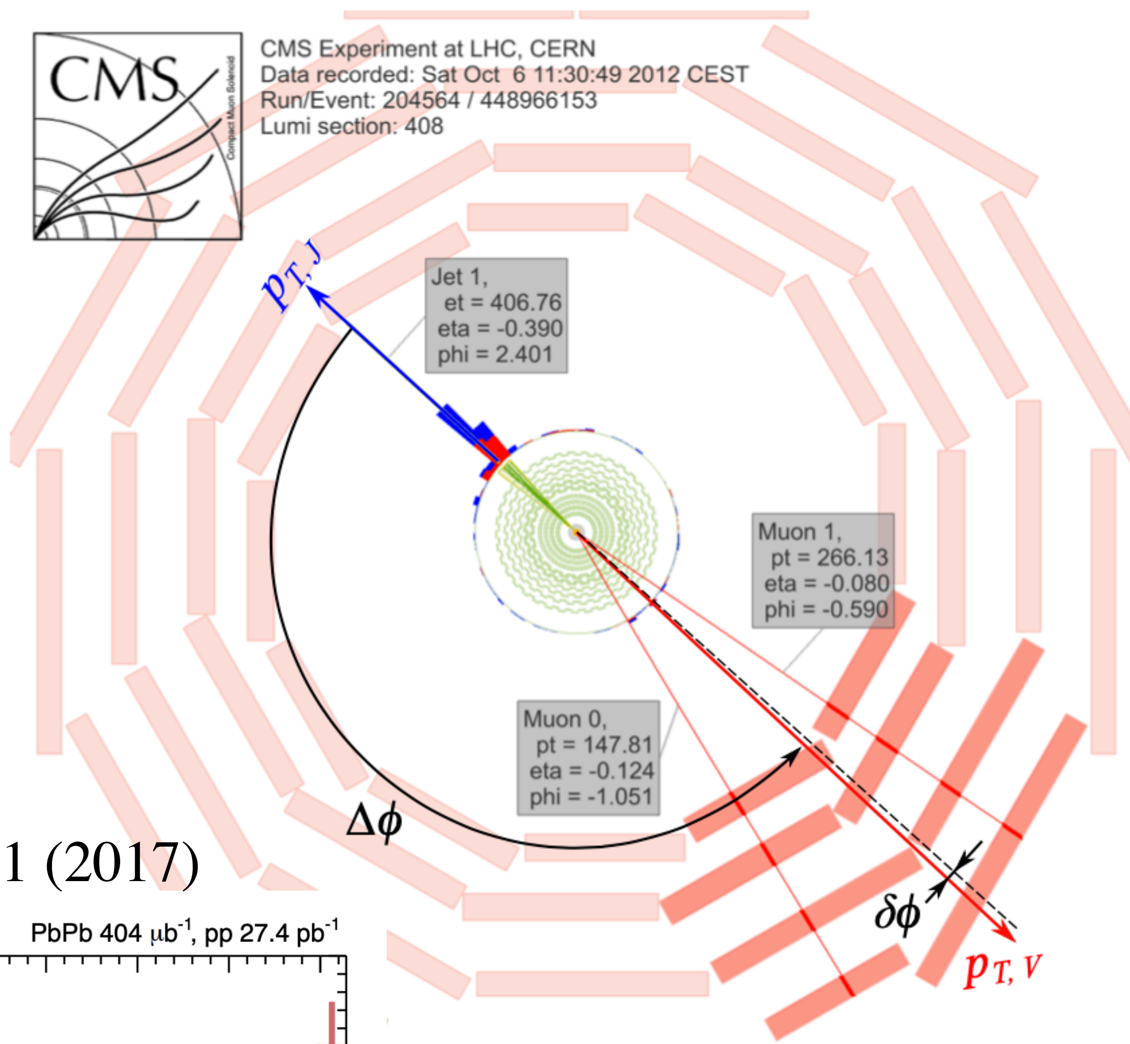
Recoil sensitive observable

- If an observable depends on soft-radiation, it is recoil-sensitive.
  - Standard jet reconstruction is recoil-sensitive
  - Inclusion of some soft radiation p_t^{soft} (due to UE fluctuations) at a typical angular scale $\mathcal{O}(R)$ will change the jet direction by an amount $R \times p_t^{\text{soft}}/p_t^{\text{jet}}$
  - Medium transverse momentum transfer $p_\perp$ will deflect the jet direction by an amount $p_\perp/p_t^{\text{jet}}$

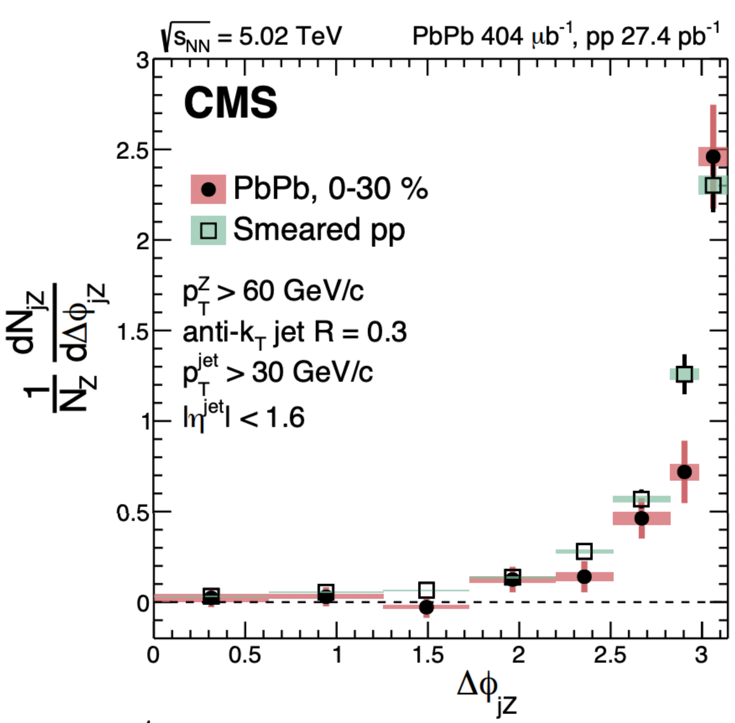


Boson-jet azimuthal decorrelation

Definition: $\Delta\phi \equiv |\phi_V - \phi_J|$ ($\delta\phi \equiv \pi - \Delta\phi$): a stringent test of QCD in pp



PRL 119, 082301 (2017)



Precise predictions rely on

1. Fixed-order calculations

   NLO, NNLO,$\cdots$

2. Resummation of $\ln\delta\phi$
   - Parton branching method
   - Pythia, Herwig,$\cdots$
   - TMD factorization
   - SCET

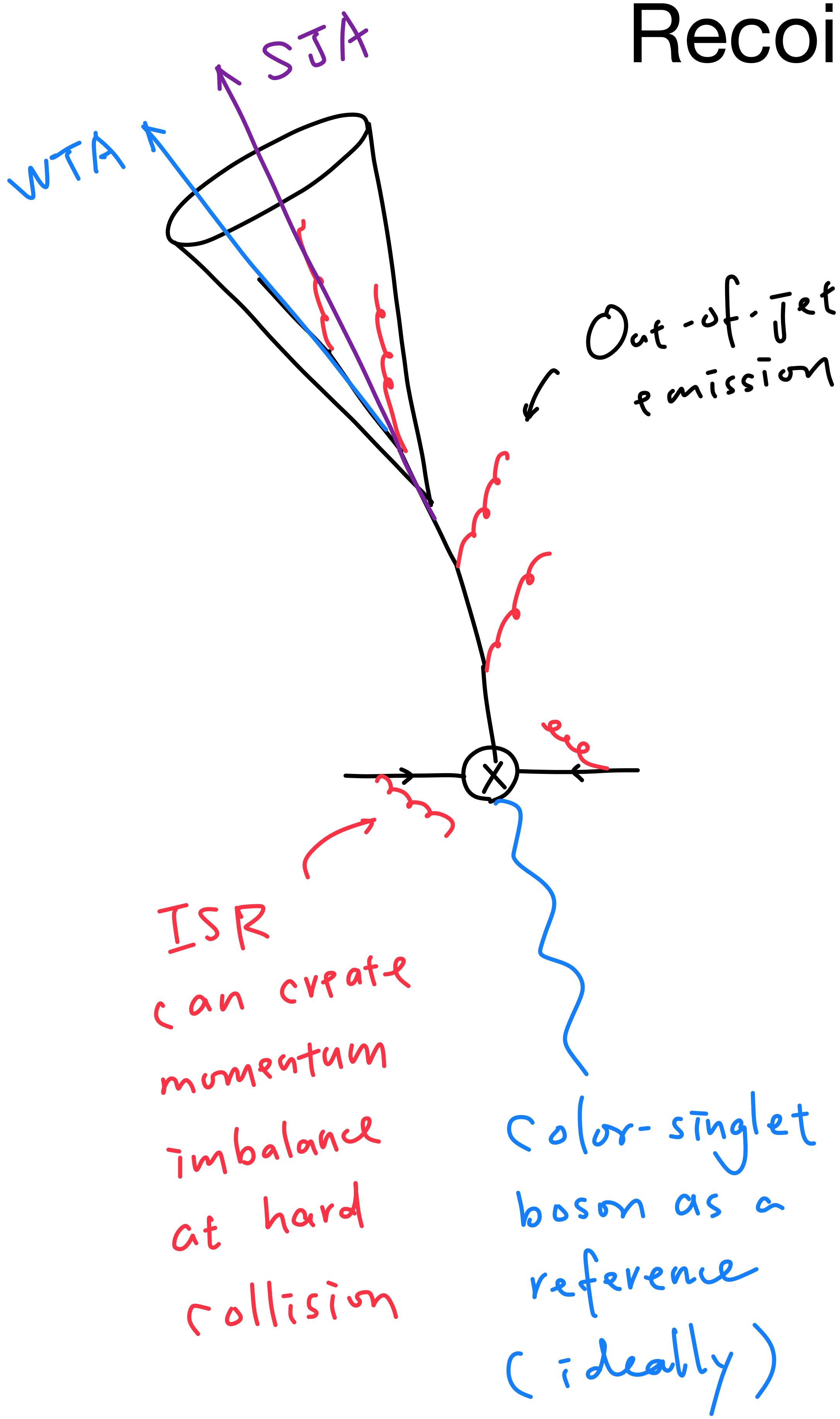
3. Validity of factorziation

   Is it broken by Glauber modes?

Today I will not discuss much the theory calculation.

Bin Wu, presented at DESY

Recoil free observable



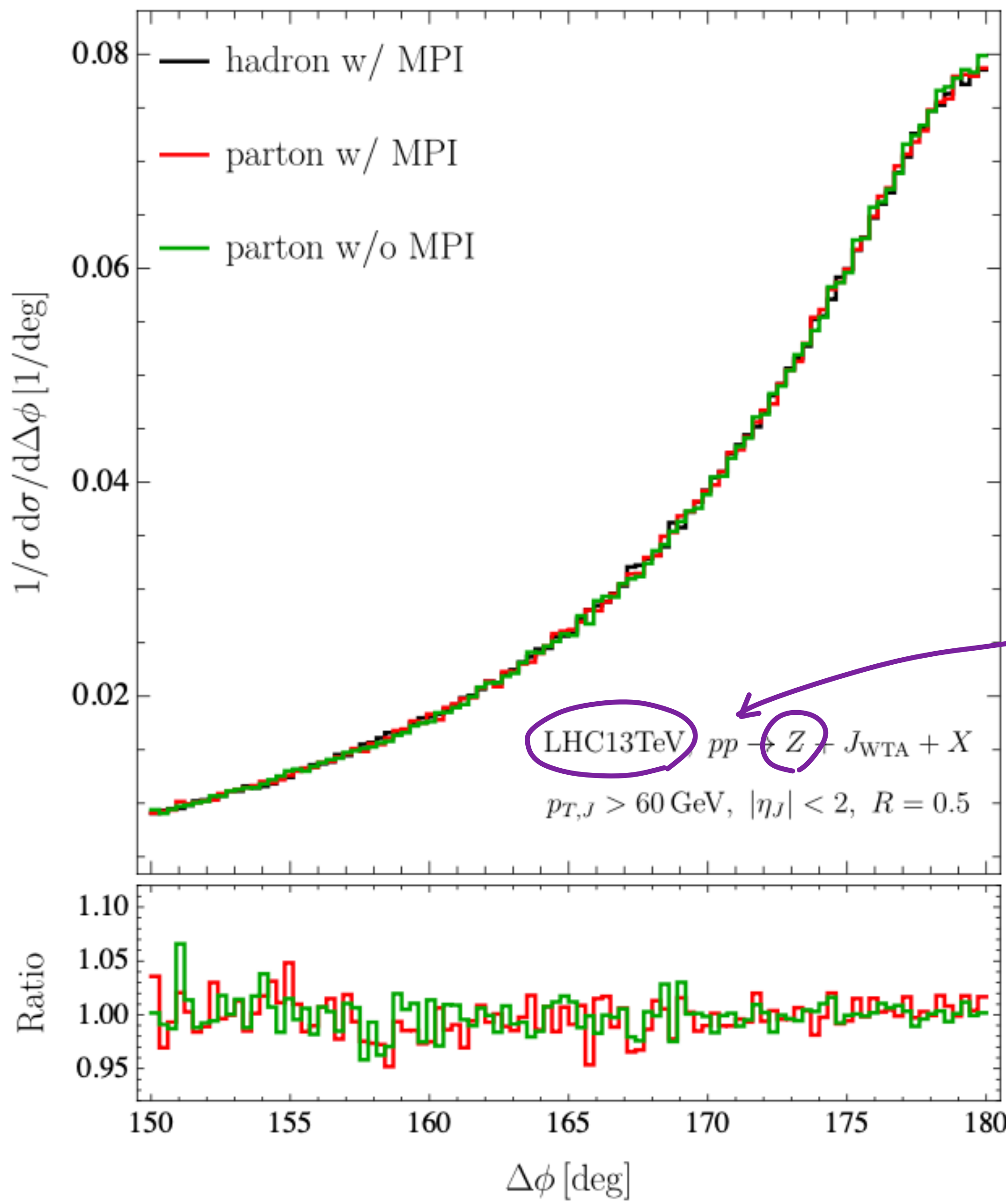
SJA: standard jet axis

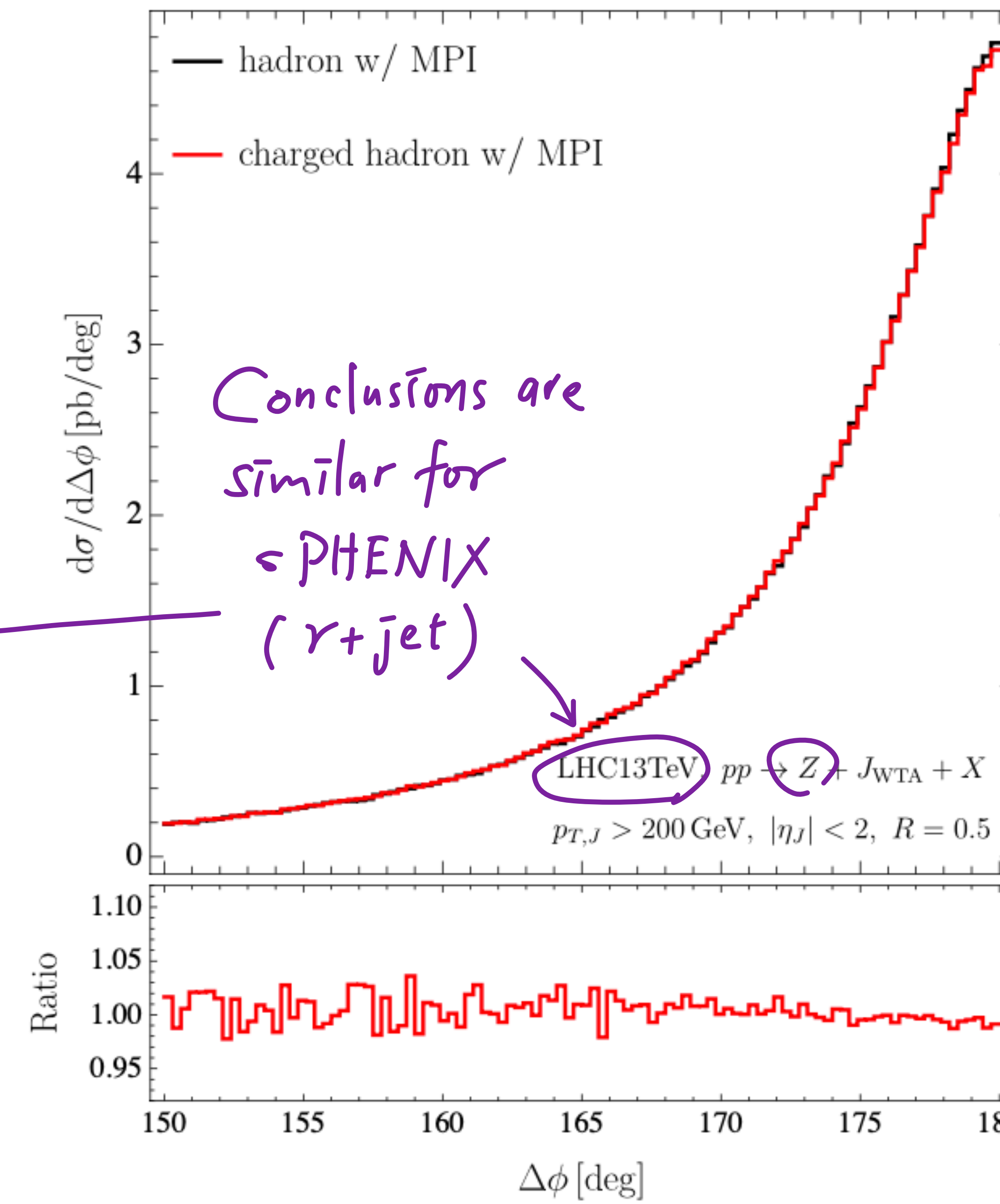
Sensitive to in-jet & out-of-jet radiation distinction

WTA: winner-take-all axis or in general recoil free axis

* Trace the most dominant (winner) energy flow
* WTA axis is actually sensitive to all soft emissions and collinear splittings

Hadronization, multi-parton interaction and charge tracks





WTA axis insensitive to hadronization & multi-parton interaction (MPI)

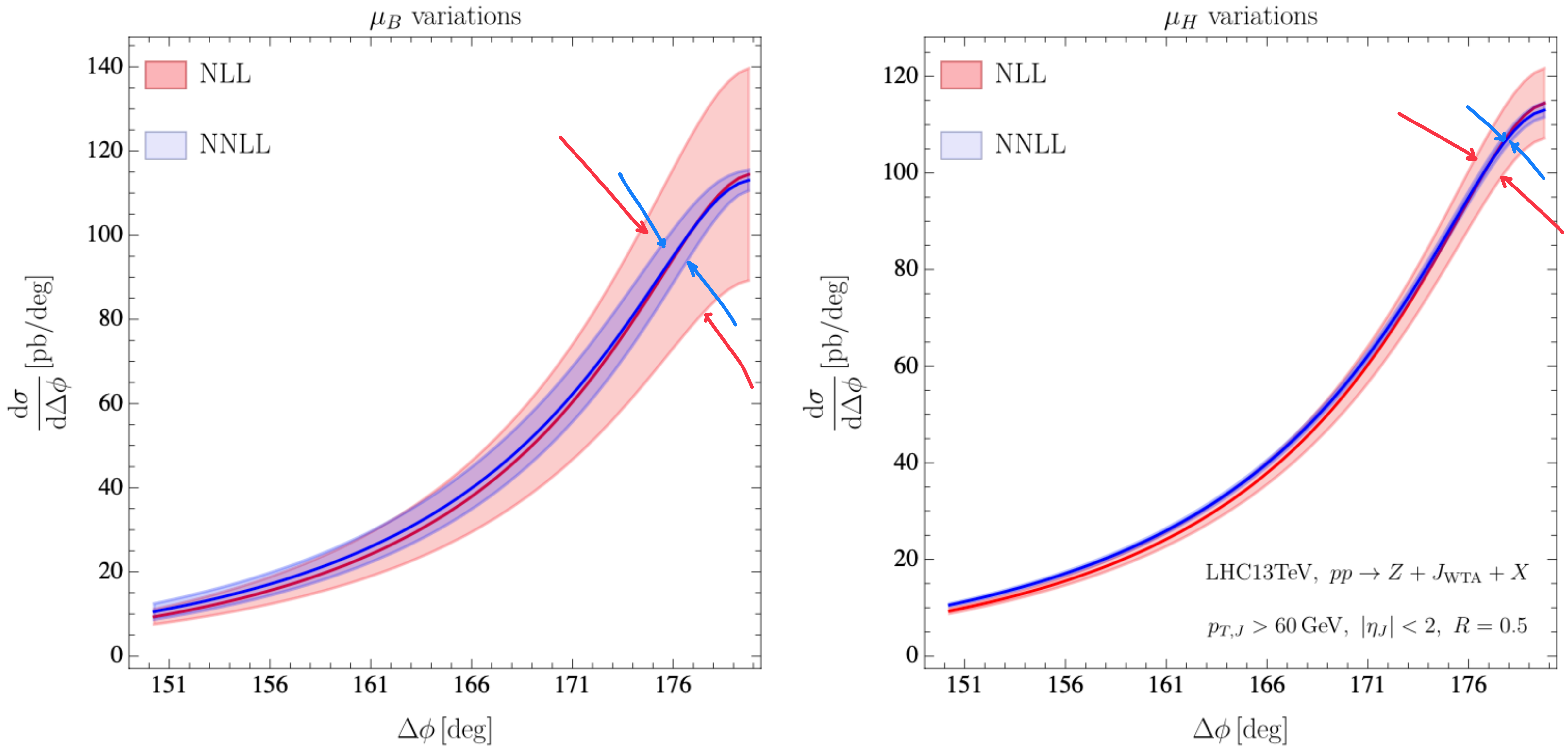
Insensitive to pileup & heavy ion UE

Can exploit high angular resolution of charge tracks.

From NLL to NNLL

Theory calculation ongoing with DY Shao, W Waalewijn, R Rahn & B. Wu

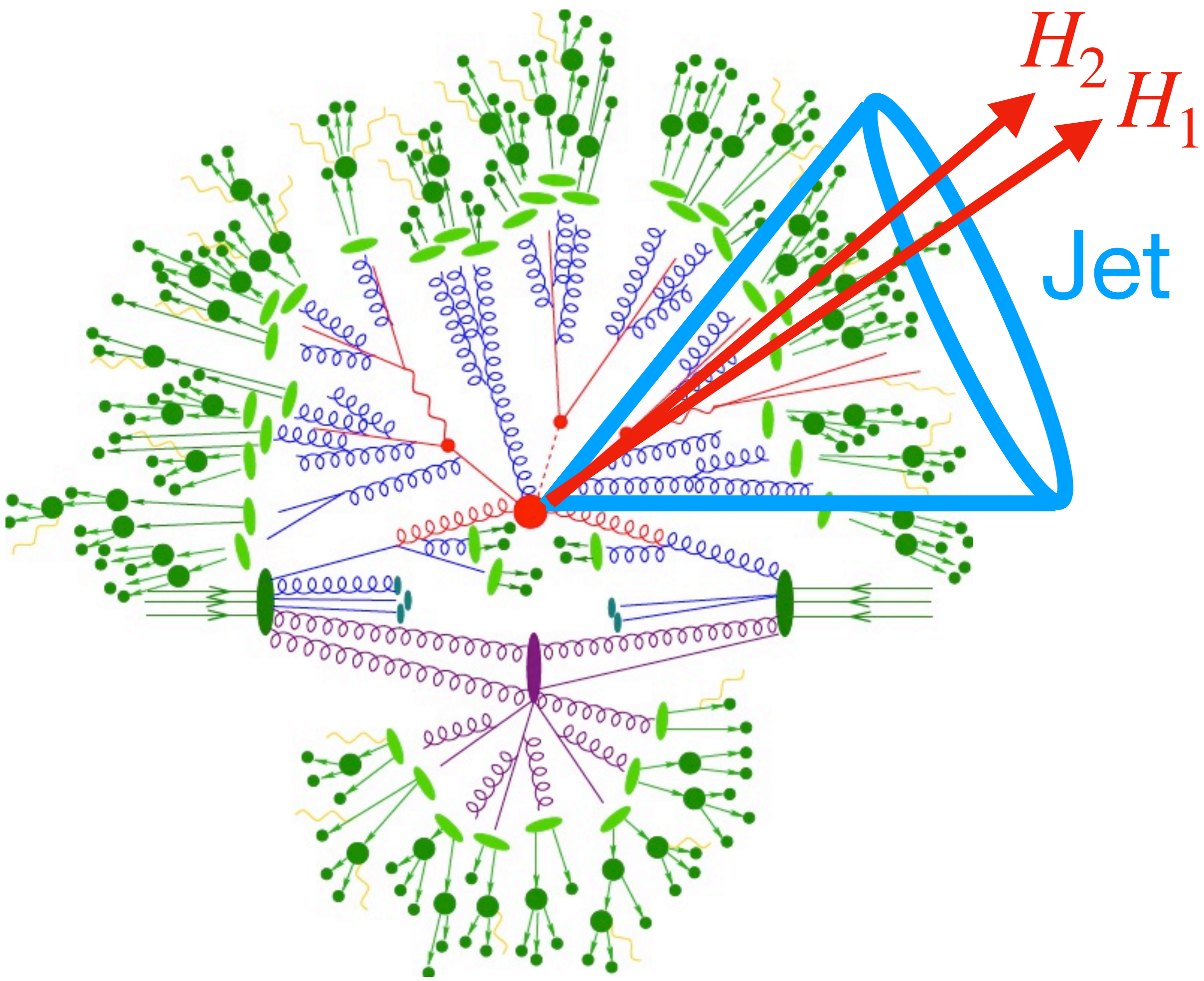
PP & AA



One important advantage of using recoil-free axis is that, it allows us to increase theory precision to NNLL, so that we can extract medium modification

Leading and next-to-leading hadrons

Therefore also recoil-free

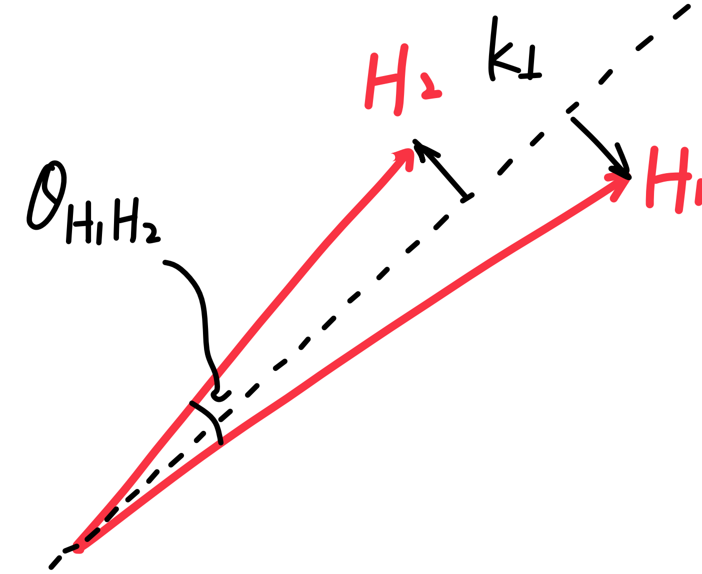


H_1 : leading hadron

H_2 : next-to-leading hadron

$p = p^{H_1} + p^{H_2}$

$z = p^{H_2}/p$



Two-particle correlation

- Focus exclusively on
  - collinear regions around dominant energy flows: jets
  - energetic hadrons since soft hadrons are abundant and hard to disentangle their origins

Hadronization of most energetic partons

Charge correlation

convention: $h_1 h_2$ same sign

$$r_c(X) = \frac{\mathrm{d}\sigma_{h_1h_2}/\mathrm{d}X - \mathrm{d}\sigma_{h_1\overline{h_2}}/\mathrm{d}X}{\mathrm{d}\sigma_{h_1h_2}/\mathrm{d}X + \mathrm{d}\sigma_{h_1\overline{h_2}}/\mathrm{d}X}$$

TASSO (1985), CERN ISR (1979), LEP (1984), NA22 (1989), Bass, Danielewicz and Pratt (2000)

↑ "Balance function" as a function of rapidity, inclusive

$-1 \leq r_c \leq 1$

$r_c \to -1$ when $d\sigma_{h_1\overline{h_2}} \gg d\sigma_{h_1h_2}$

$r_c \to 0$ when H_2 not correlated with H_1

- Leading dihadron correlation: conditional probability of observing H_2 in the presence of H_1
- Comparing the cross sections of h_1h_2 and $h_1\overline{h_2}$ to quantify the flavor constraints
- Evolution of r_c w.r.t. kinematic phase space X

We focus on two novelties:

① Leading dihadrons exclusively

② Dependence on X: z, $k_\perp$, τ_{form}, ...

Monte Carlo samples

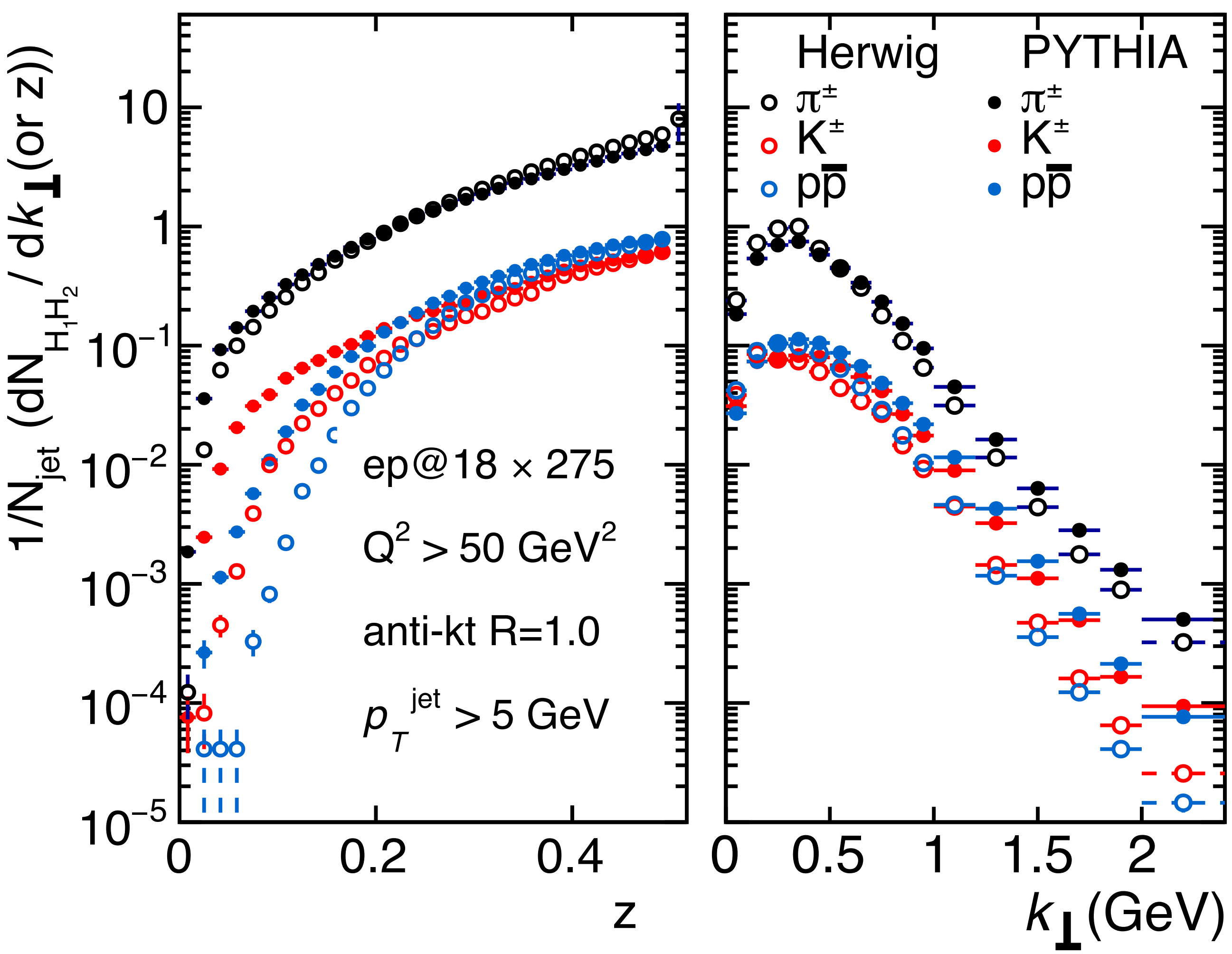
highest design energy

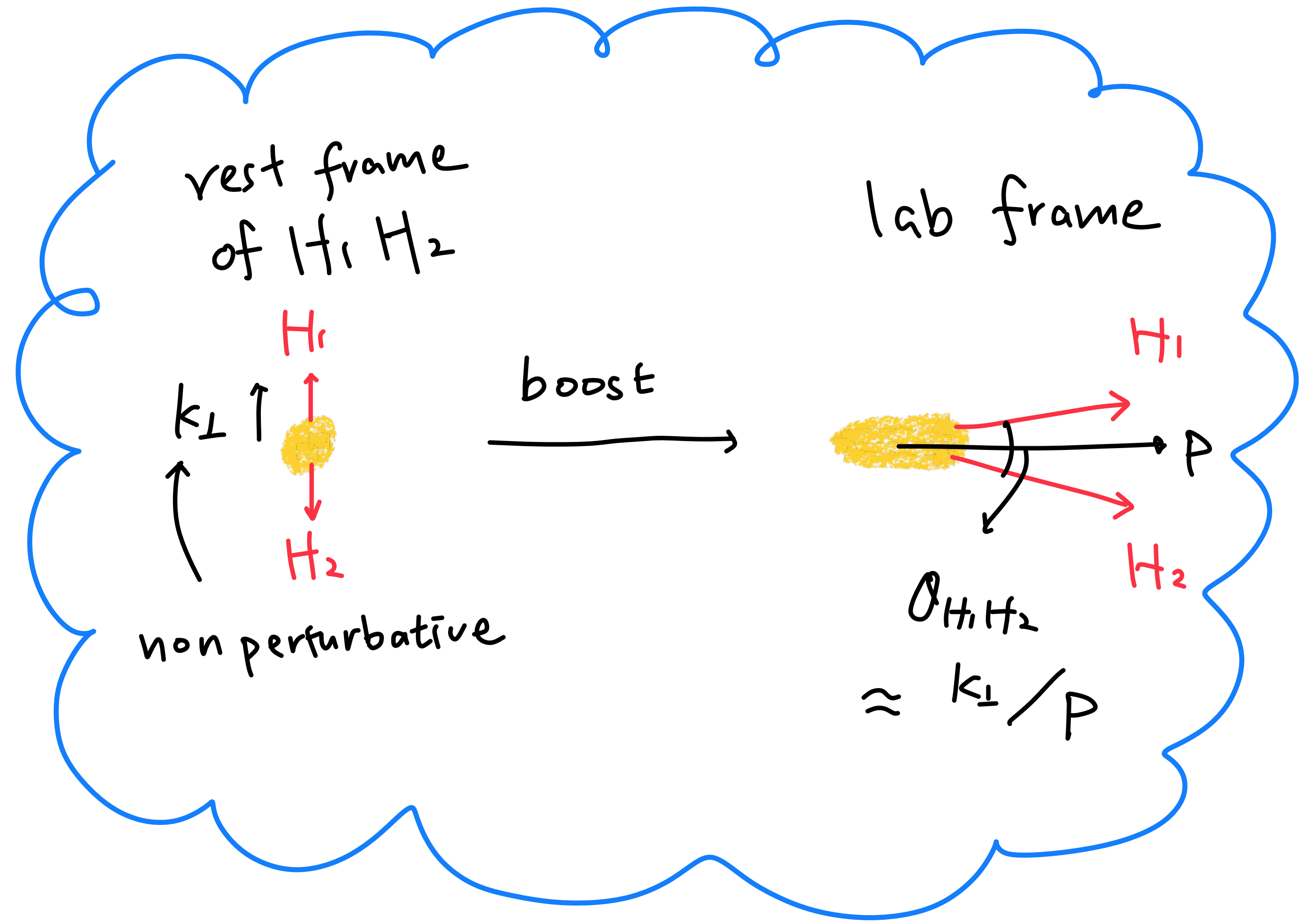
- 18 GeV electron beam + 275 GeV proton beam
- PYTHIA 6.428 and Herwig 7.1.5
- Impose $Q^2 > 50\ \mathrm{GeV}^2$ so that we have higher p_T jets
- 10 million events
- Jets: $p_T^{\mathrm{particle}} > 0.2\ \mathrm{GeV}$, $-1.5 < \eta < 3.5$, anti-k_t $R = 1.0$, $p_T^{\mathrm{jet}} > 5\ \mathrm{GeV}$

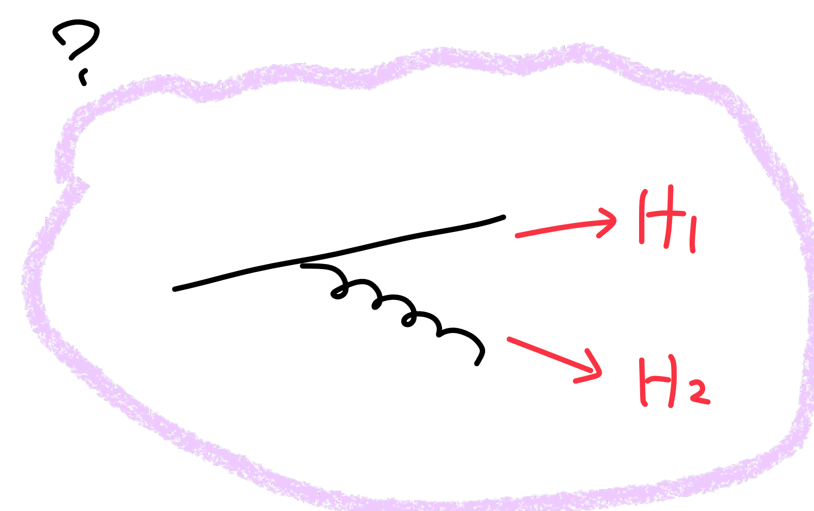
relatively high p_T at EIC energy

Mostly these jets are from struck quarks dominated by valence u and d quarks

Leading dihadron kinematics





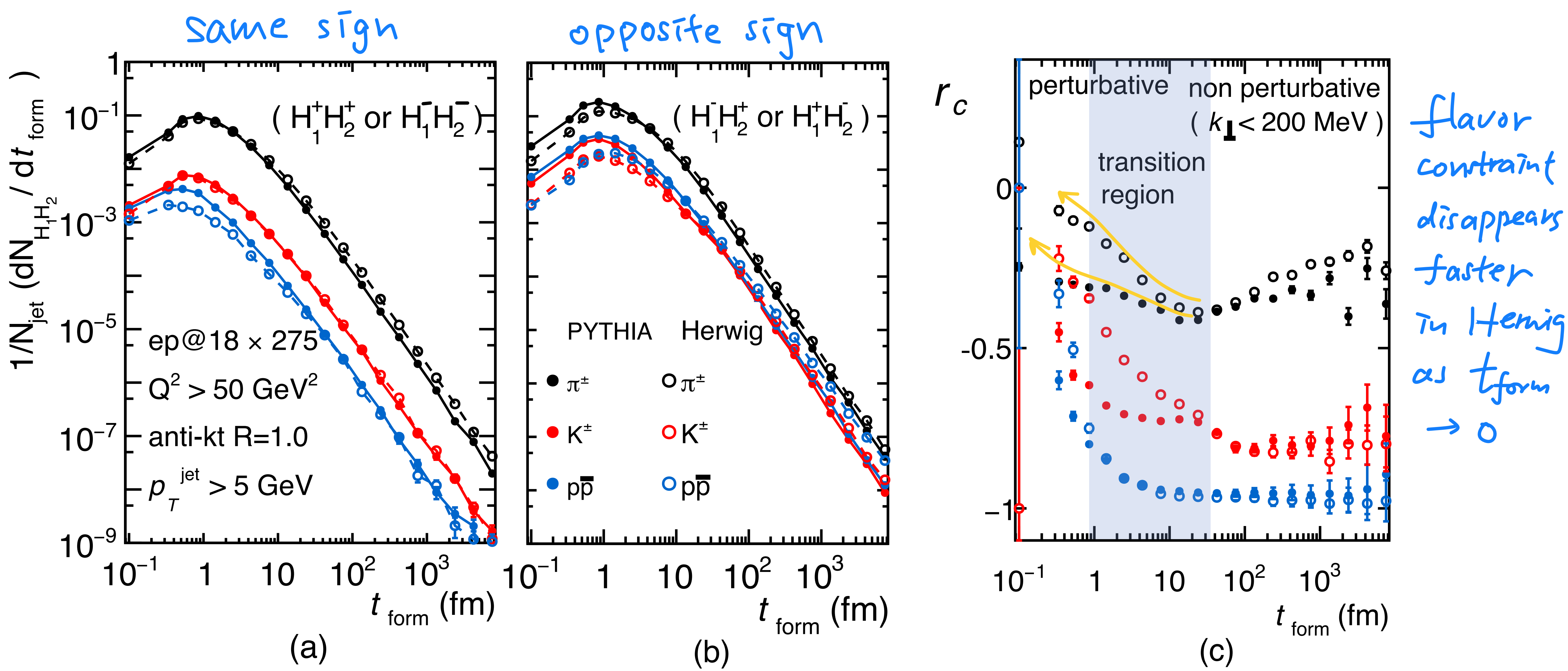


- z maximizes at $z = 0.5$, not from perturbative splitting
- Characteristic low $k_\perp$ and cross section falling exponentially

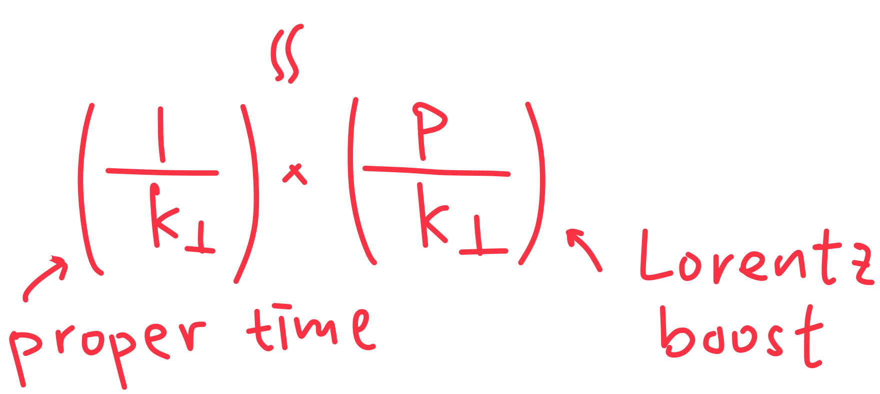
Altarelli-Parisi $\propto 1/z$

$\propto 1/k_\perp$

Leading dihadron formation time



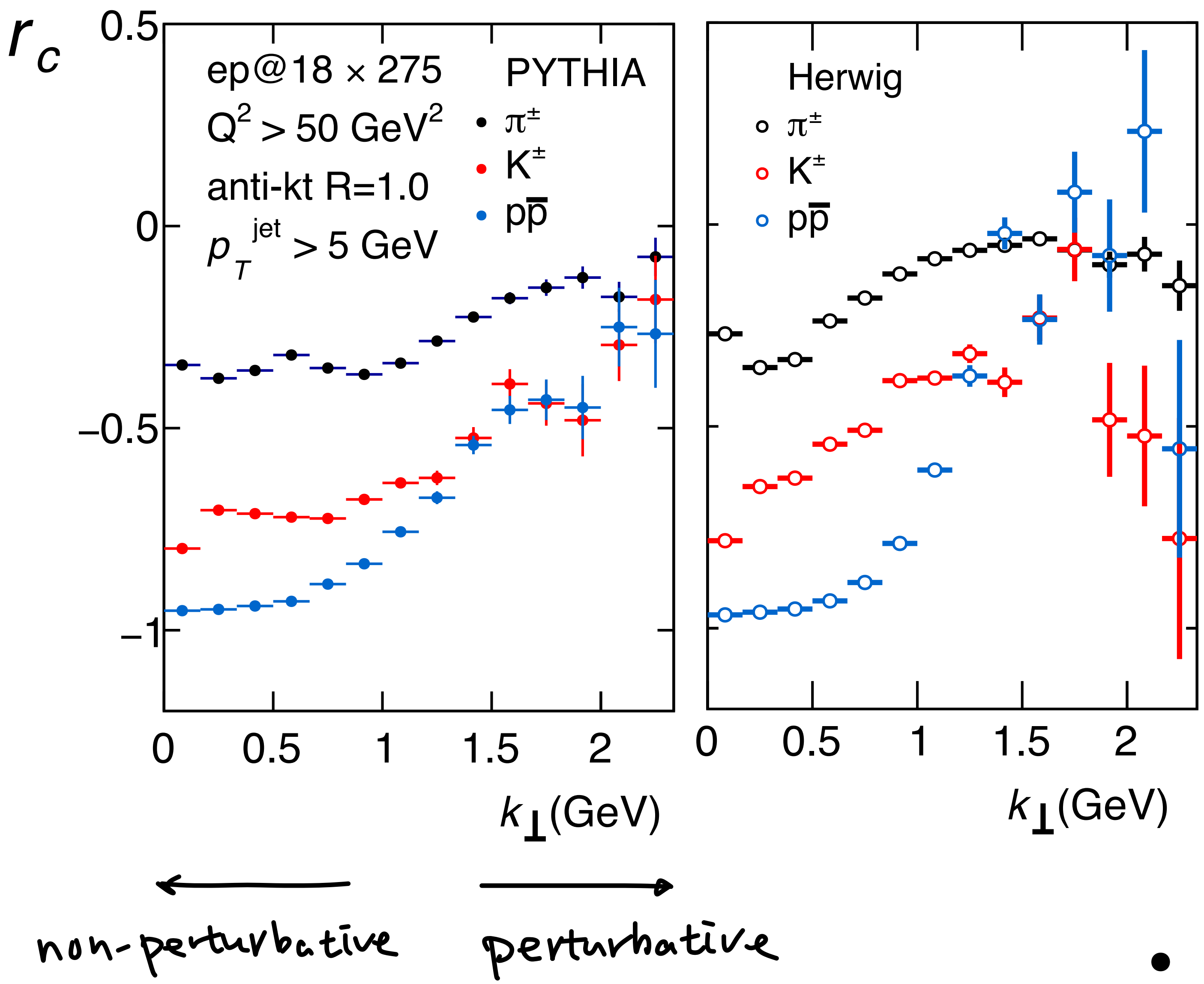
$$t_{\text{form}} = z(1-z)p/k_\perp^2$$



- Formation time peaks around 1 to 10 fm
- $|r_c|$ maximizes at large formation time
- Significant difference between PYTHIA and Herwig

more "local"

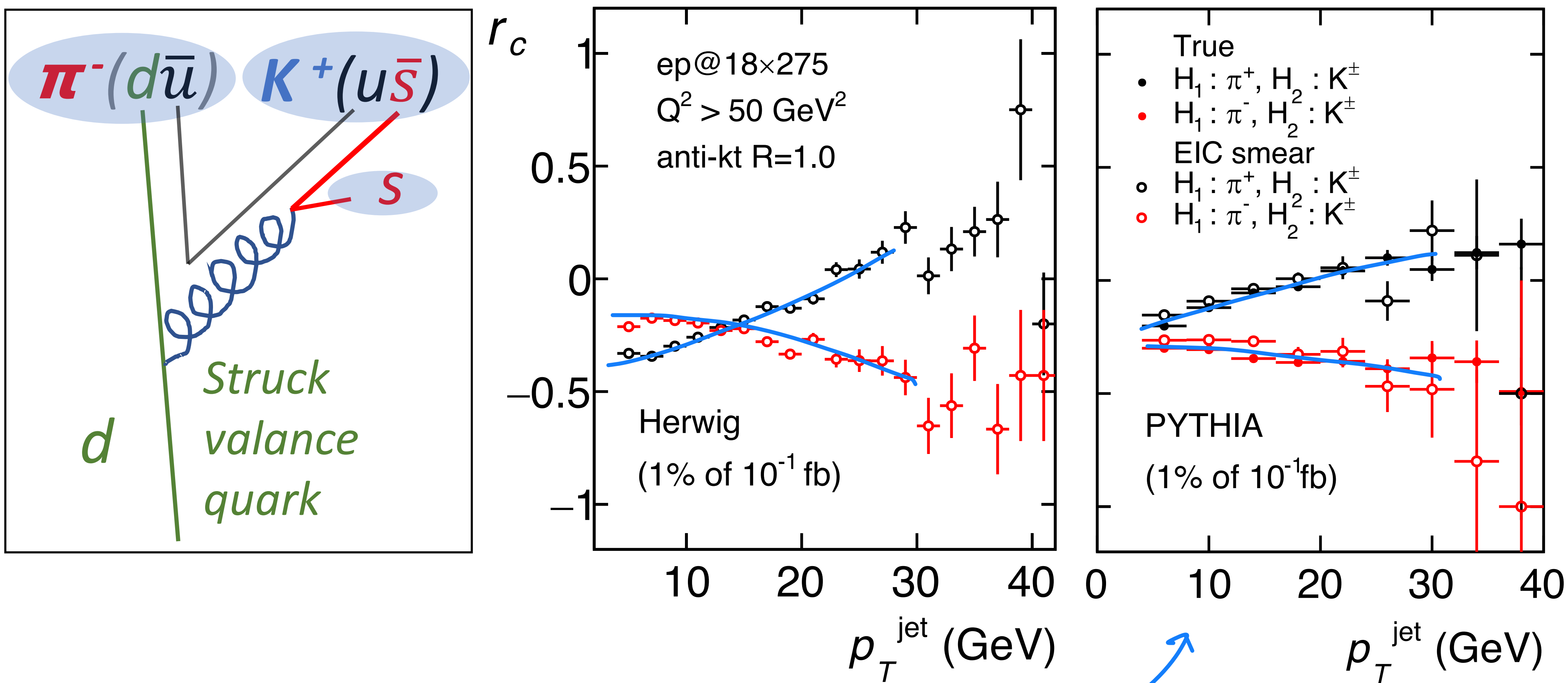
Leading dihadron relative $k_\perp$



- $|r_c|$ maximizes at small $k_\perp$ and decreases as $k_\perp$ increases on the scale of 1-2 GeV
- Suggesting strong nonperturbative correlation at play

Flavor tagging and πK correlation

* πK separation required.



(a) (b) (c)

significant difference

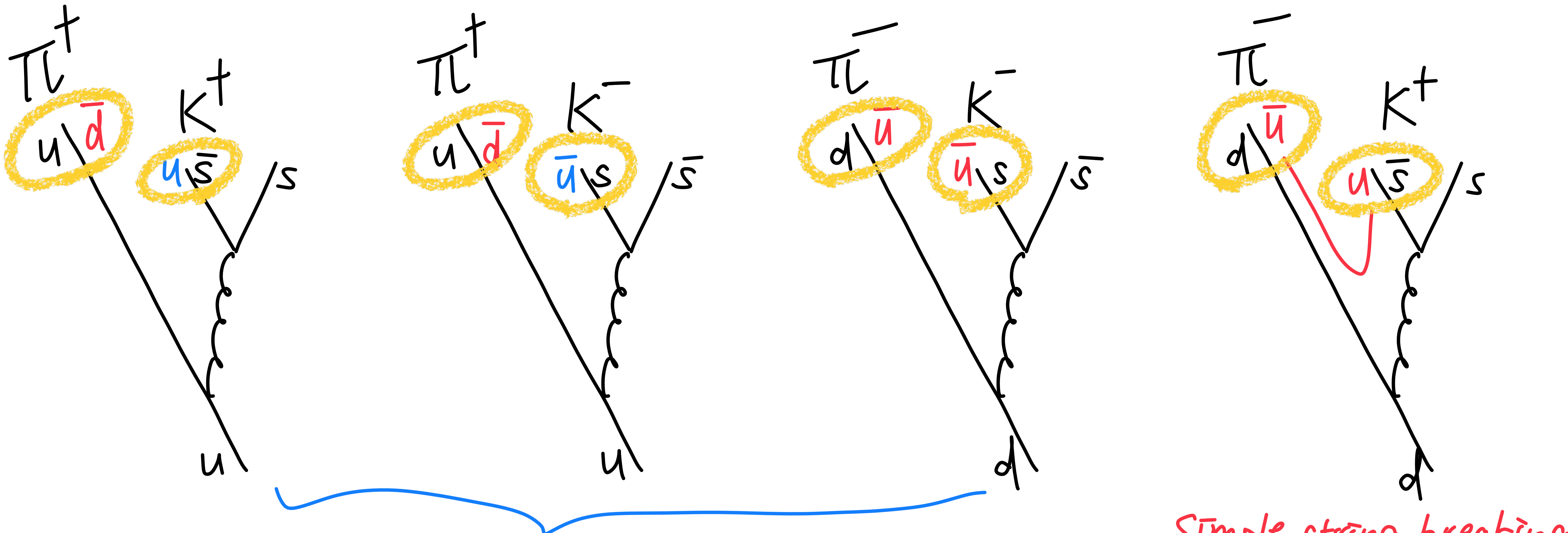
$H_1 = \pi^-$ Red: $r_c = \dfrac{\sigma_{\pi^-K^-} - \sigma_{\pi^-K^+}}{\sigma_{\pi^-K^-} + \sigma_{\pi^-K^+}}$

$H_1 = \pi^+$ Black: $r_c = \dfrac{\sigma_{\pi^+K^+} - \sigma_{\pi^+K^-}}{\sigma_{\pi^+K^+} + \sigma_{\pi^+K}}$

- Excellent agreement between EIC smear and true distributions

measurable at EIC

Flavor constraints



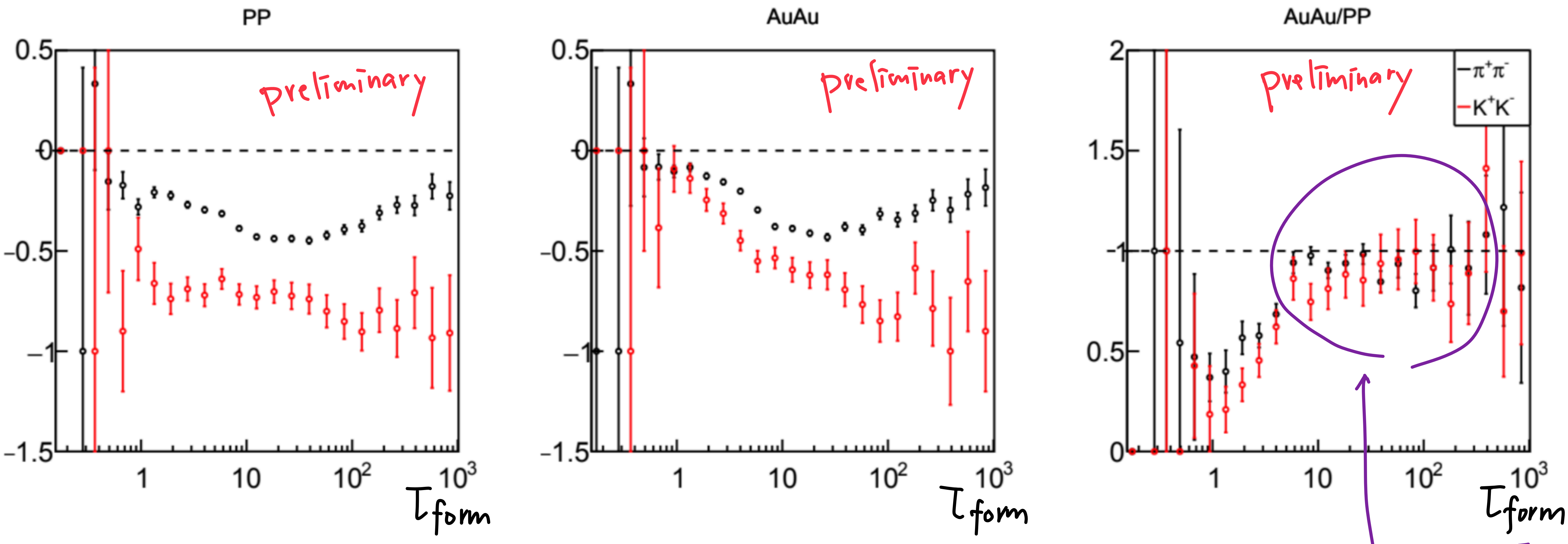
No simple string configuration

Simple string breaking allowed

Therefore $\pi^- K^+$ is preferred in string hadronization compared to $\pi^- K^+$, resulting in large $|r_c|$. Cluster hadronization shows different flavor constraints.

Credit : Weibin Zhang

Medium modification of charge correlation



Simulation studies using JEWEL 2.2.0 for $\sqrt{s} = 220$ GeV

* Di-jet (so with gluon jets)
* particle selection: $|\eta| < 3$, $P_t > 1.5$ GeV
* Anti-kt $R = 0.4$, $P_t^{jet} > 20$ GeV

Not surprising because JEWEL uses Pythia hadronization.

Summary

- Recoil free photon-jet and di-jet angular decorrelation might be useful to more quantitatively pin down the idea of jet broadening in heavy ion collision: yes, or no?
  - It scans through all the parton showers so might be maximally sensitive to medium effect
- Leading dihadron charge correlation, on the other hand, focus on hadronization, the latest stage of jet formation
  - Medium modification: yes, or no?

Recoil-free observables might be clean benchmarks of medium modifications.