Partonic Effects on the charm azimuthal correlations in relativistic $p+p$ collisions

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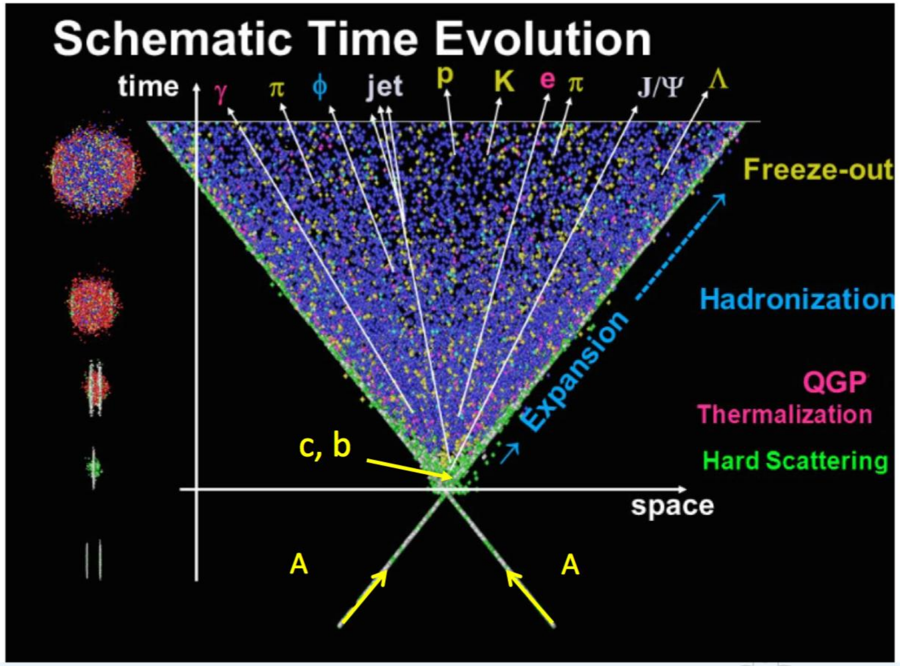
HP2026 Satellite Workshop on Jets and Heavy Flavor Physics

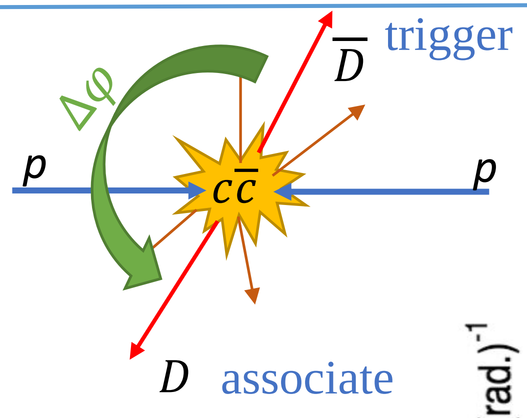
Heavy Flavor Quarks

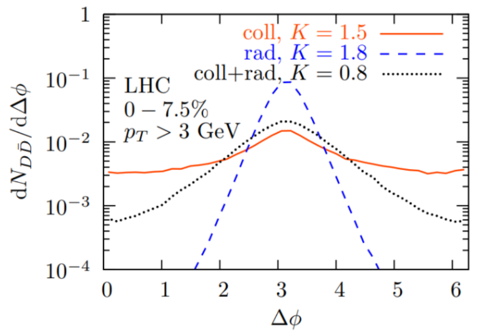
- 1. $m_Q \gg \Lambda_{\mathrm{QCD}}$
- Can use pQCD to estimate cross section
- 2. $m_Q \gg T_{\mathrm{QGP}}$
- Production mainly restricted to initial hard scattering
- Thermalization time ~ fire ball lifetime



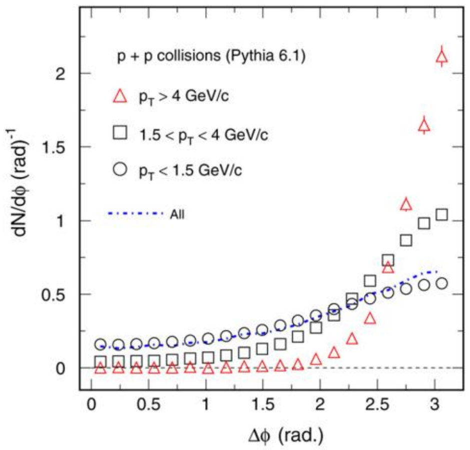
Azimuthal Correlation for HF (Partonic Wind?)

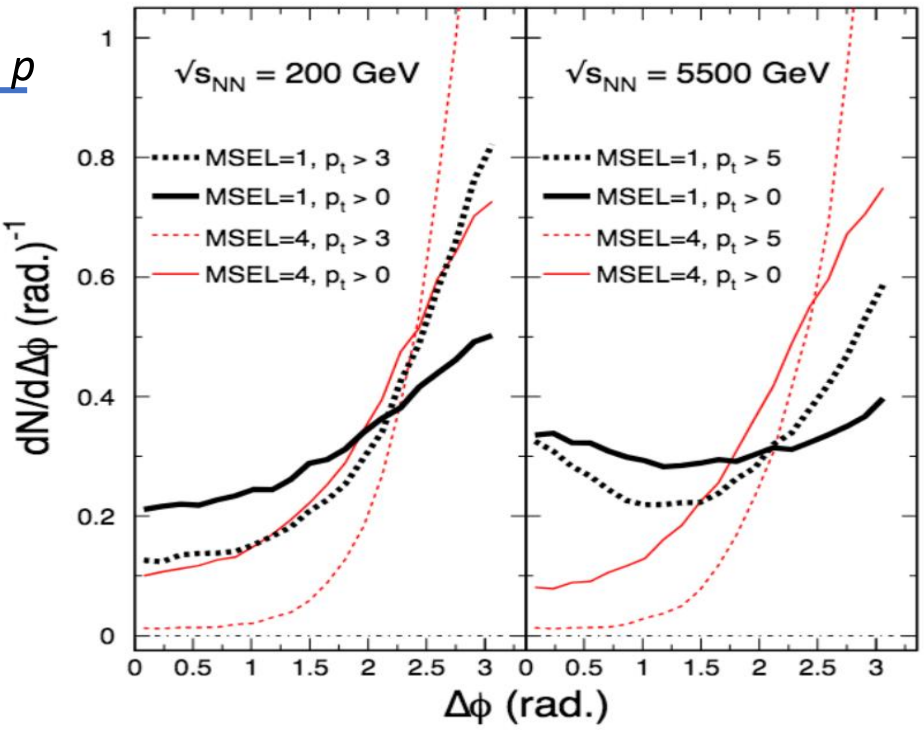
- D meson($c\bar{u}/\bar{c}u$)
  - → Inherit initial Charm
  - → Collisional Energy Loss
- Azimuth Correlation
  - → Broadened by High-Order pQCD effect
  - → Sensitive to Partonic effect





Marlene Nahrgang *et al*
J. Phys.: Conf. Ser.(2014) **509** 012047

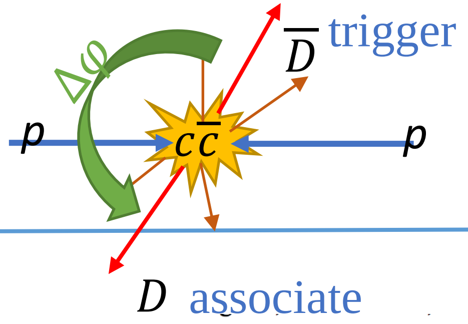




4: LO (pair production) , 1: NLO (E-loss, FE,GS)

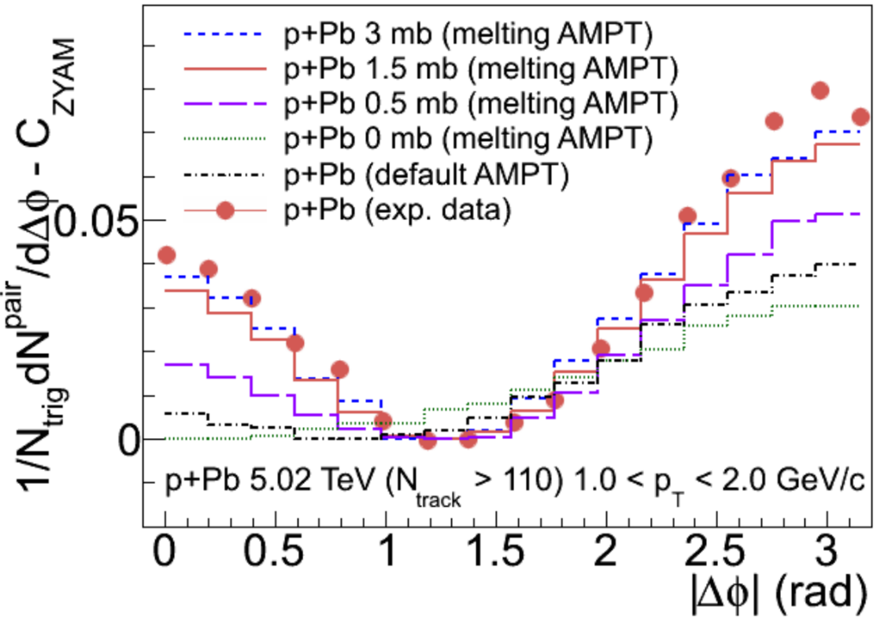
XL Zhu, N. Xu, PF Zhuang,
Phys. Rev. Lett 100.152301

Partonic Interactions

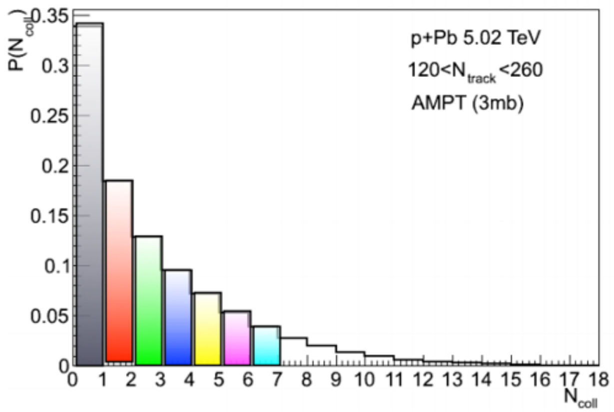


G.-L. Ma and A. Bzdak, Phys.Lett. B 739 (2014) 209.

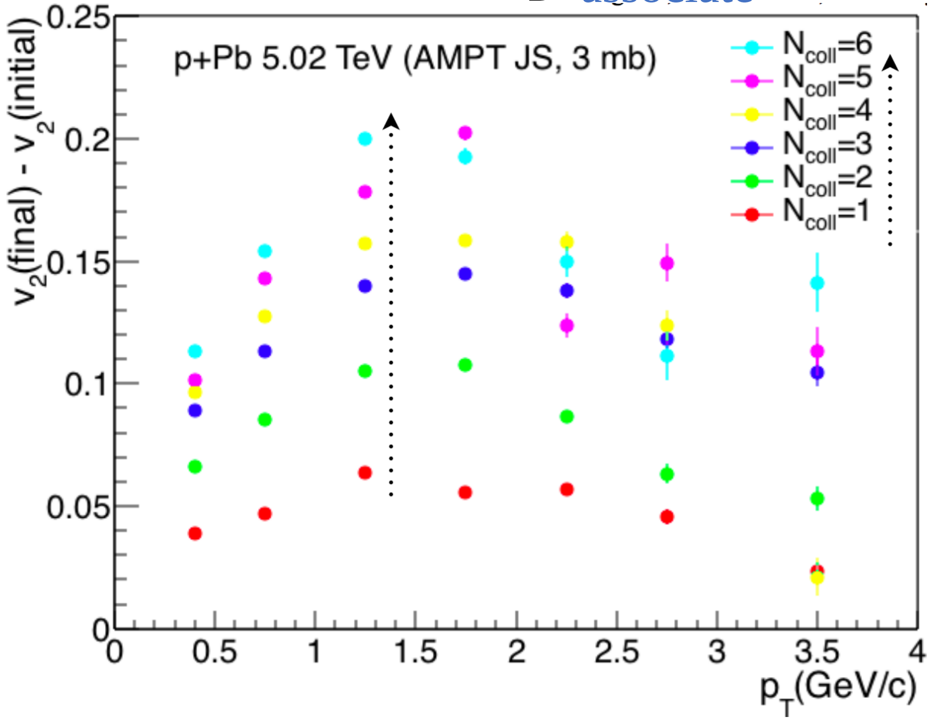
G.-L. Ma, A. Bzdak, Nucl. Phys. A 956, (2016) 745



Near Side, NS← →Far Side, FS



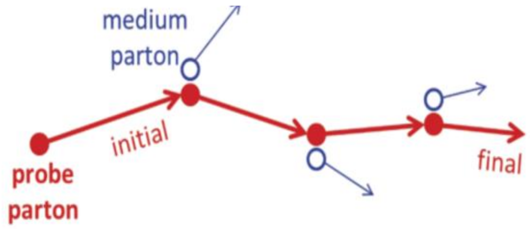
$$\boxed{\text{partons}} = \boxed{\text{Ncoll=0}} + \boxed{\text{Ncoll=1}} + \boxed{\text{Ncoll=2}} + \boxed{\text{Ncoll=3}} + \boxed{\text{Ncoll=4}} + \boxed{\text{Ncoll=5}} + \boxed{\text{Ncoll=6}} + \ldots$$



→ As the cross section of partonic interaction grows,
Signal strengthens at both sides

$$v_n = \langle \cos [n(\phi - \Phi_{rp})] \rangle$$

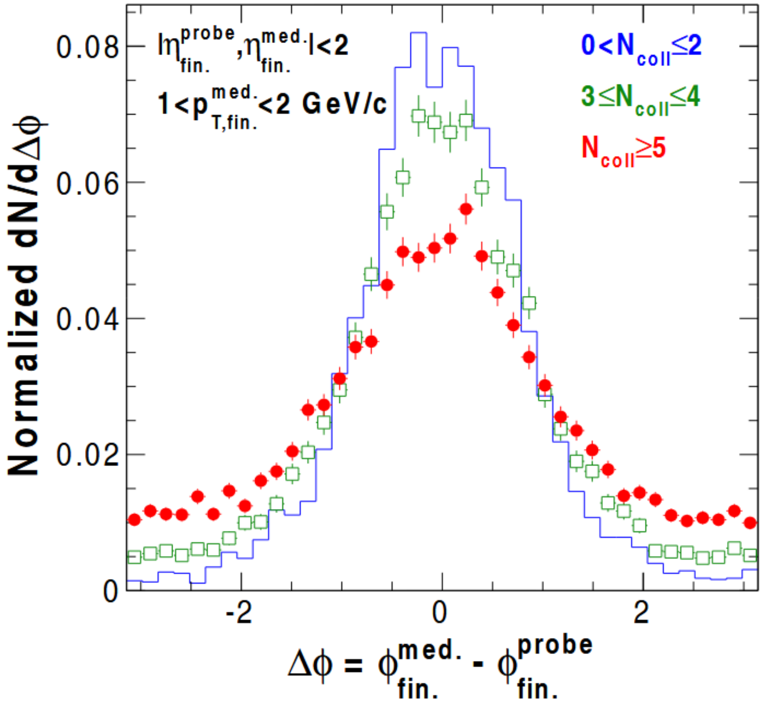
→ For transport models,
Partonic effect could contribute to flow formation

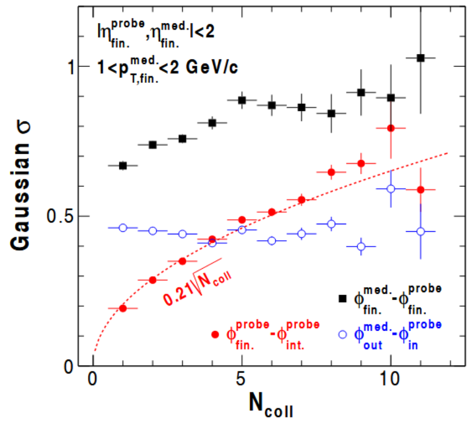


Partonic Interactions（Au+Au）

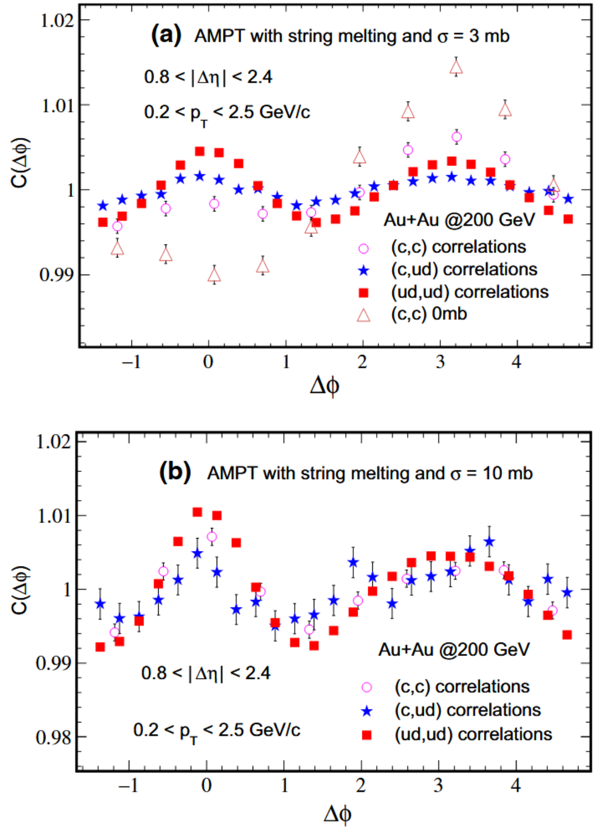
T. Edmonds, Nucl.Phys.A 966 (2017), 124-134

H. Wang, Nucl.Sci.Tech. 30 (2019) 12, 185





$$\frac{dN}{d\Delta\phi} = A\exp\left(-\frac{(\Delta\phi-\alpha)^2}{2\sigma^2}\right) + C$$



- L: Partonic Collision Times → Broadening Effect
- R: Changing Cross section → Affect Interactions
- Q: Could we apply a better Charm Production? Will there be more “detailed” effects?

Simulation Setup: PYTHIA+AMPT

- Partonic Production
- PYTHIA v8.1
- pQCD based on Monte Carlo
- Produce Hadron for AMPT

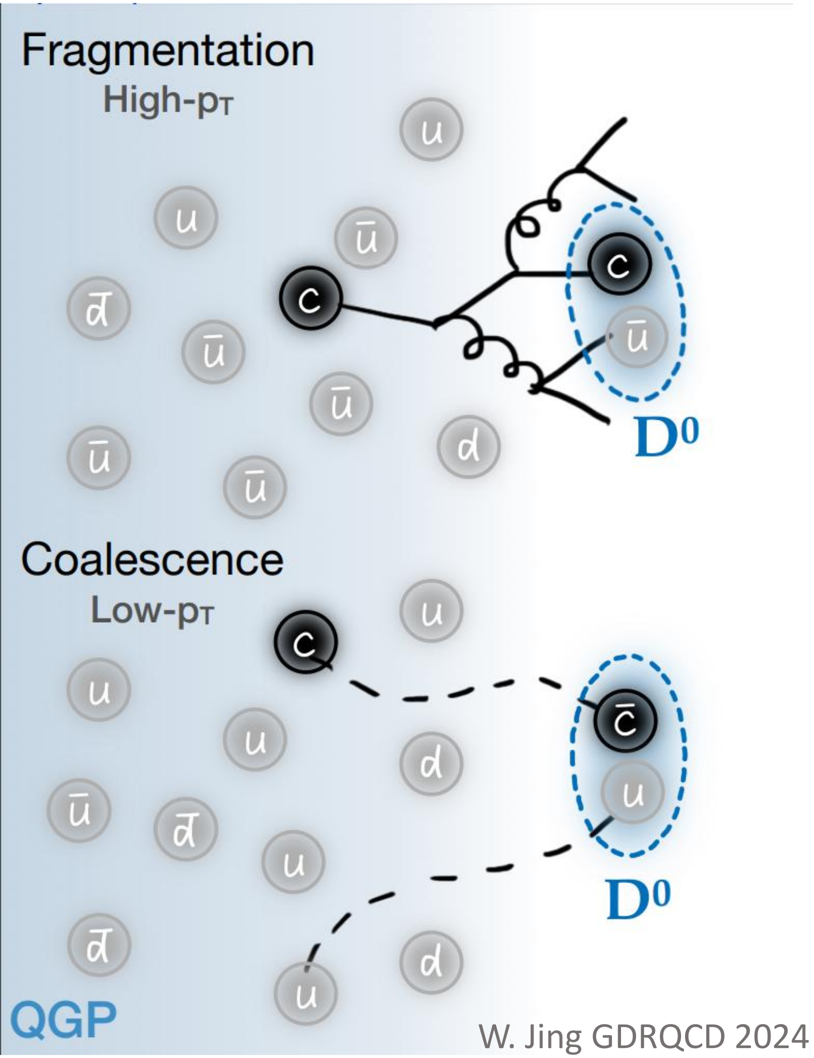
Hadron

- Partonic Evolution
- AMPT v2.26
- Using String-Melting to reconvert Hadrons back to Partons
- Evolve in AMPT

Outstanding
Heavy Quark Production

Comprehensive
Partonic Evolution Mechanism

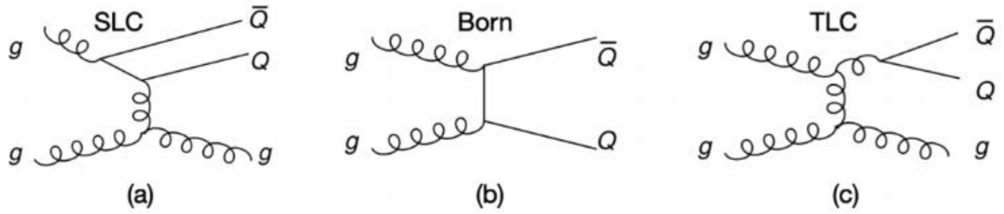
Heavy Flavor Production： PYTHIA



W. Jing GDRQCD 2024

- HF production from PYTHIA:

$$\frac{d\sigma^{Q\bar{Q}}}{dp_{\mathrm{T}}^2 dy_1 dy_2} = K \sum_{a,b} x_1 f_a(x_1,\mu_F^2) x_2 f_b(x_2,\mu_F^2) \frac{d\sigma^{ab\to Q\bar{Q}}}{d\hat{t}}$$

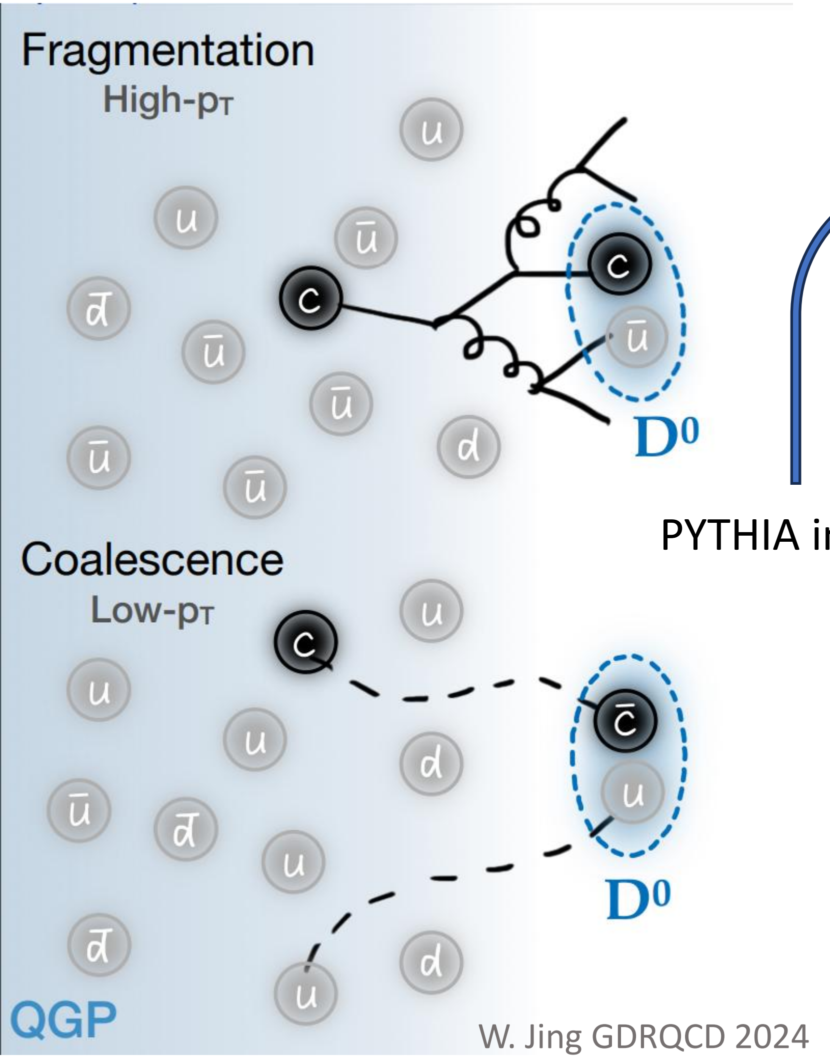


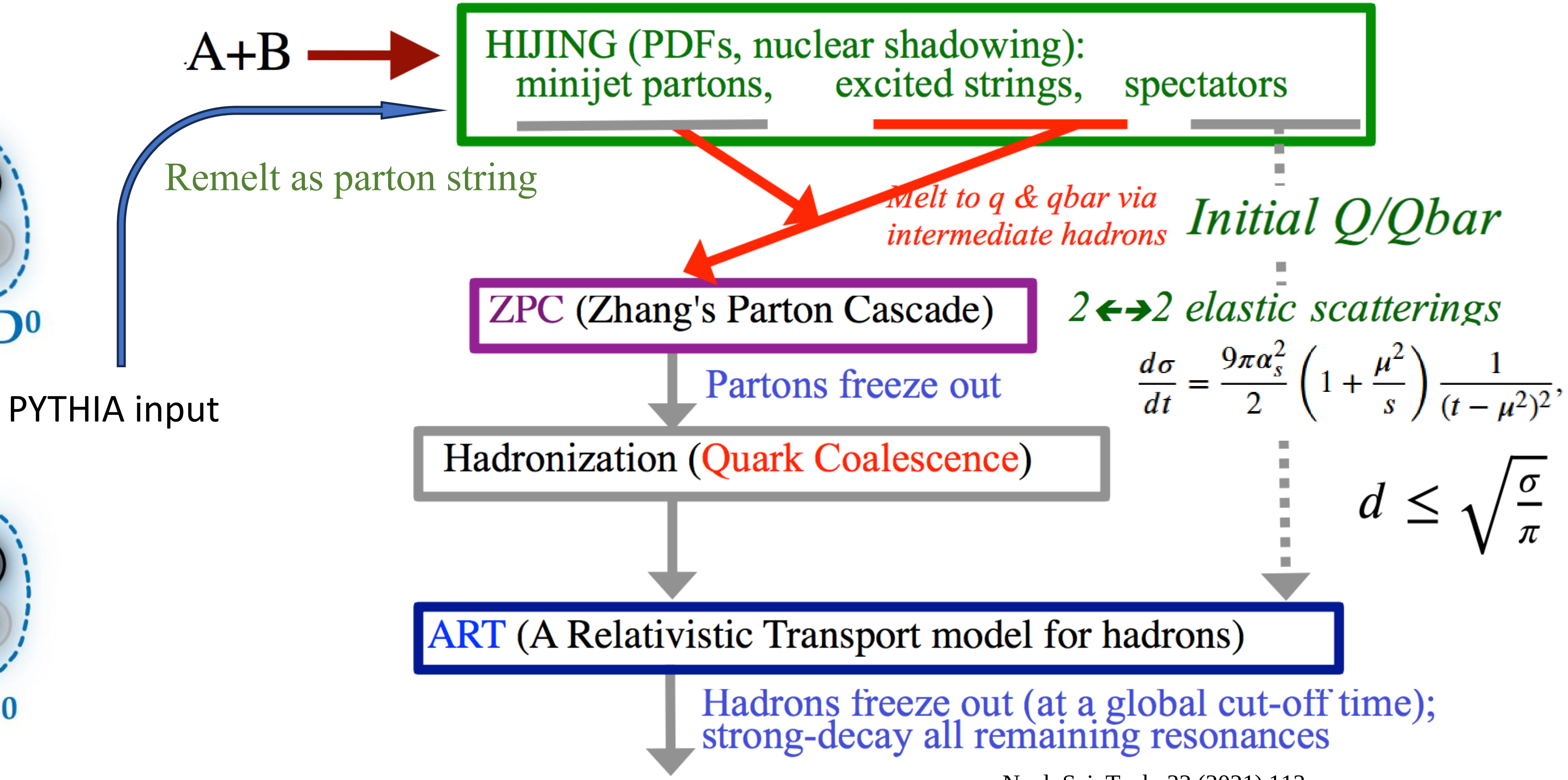
a) Flavor excitation (NLO process)
b) Flavor creation (Hard Process)
c) Gluon splitting (LO process)

$$g + g \to Q + \bar{Q}$$
$$q + \bar{q} \to Q + \bar{Q}$$
$$g \to Q + \bar{Q}$$
$$g + Q \to g + Q$$

Would be different for RHIC or LHC energies

String Melting+ AMPT： Partonic evolution



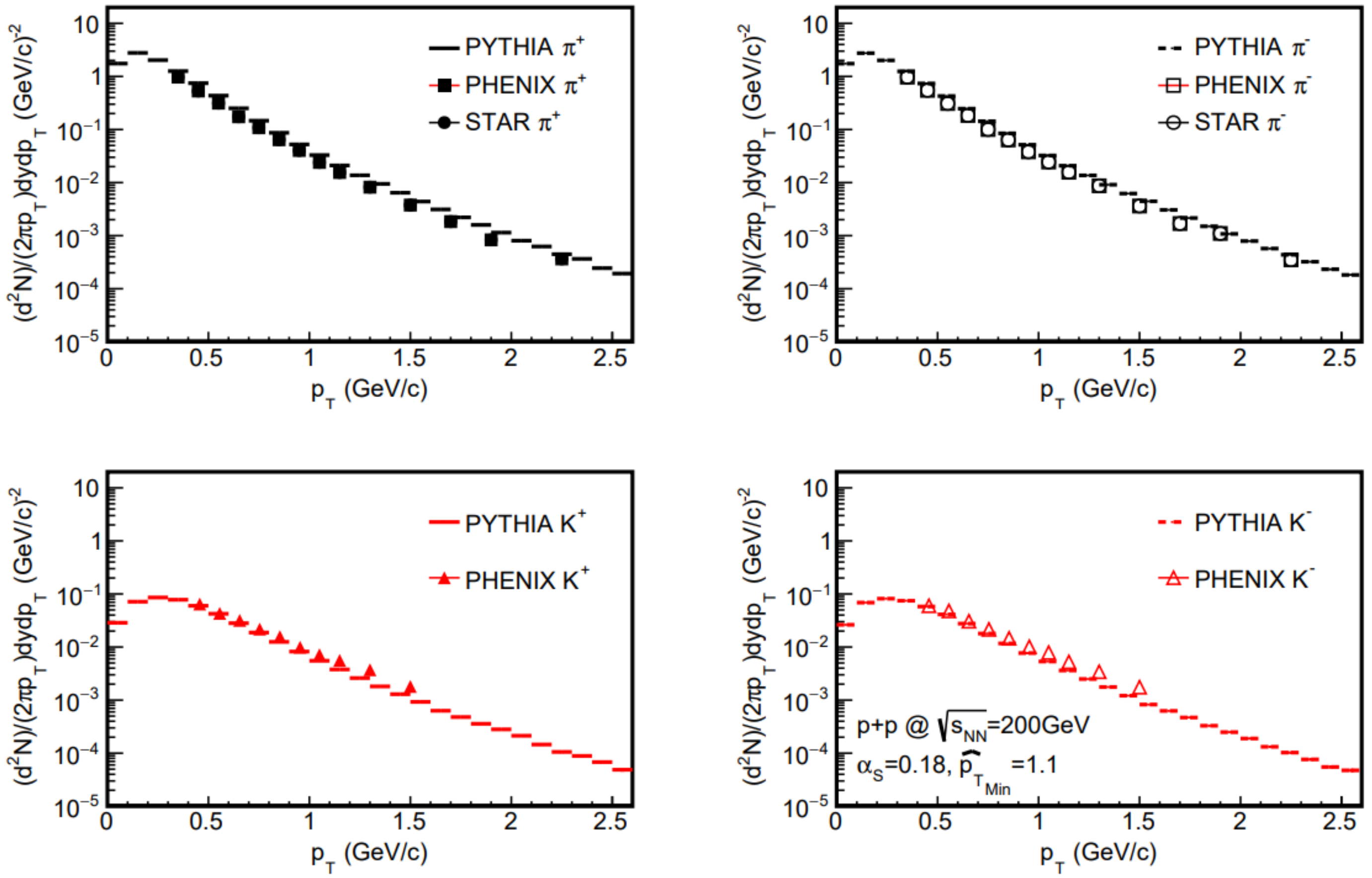


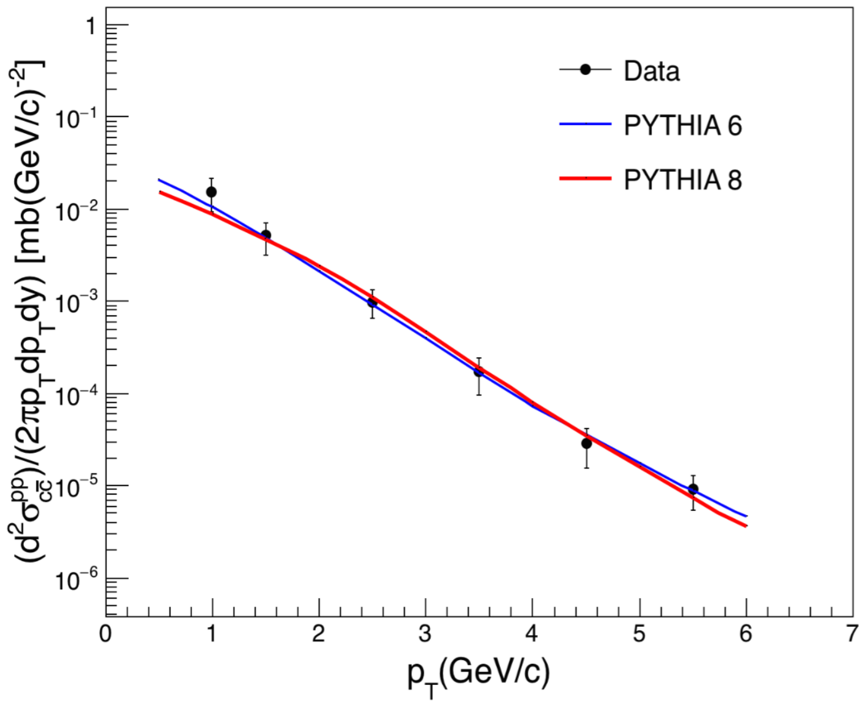
Final particle spectra

Nucl. Sci. Tech. 32 (2021) 113
Z.-W.Lin et al., Phys. Rev C 72, 064901 (2005)

PYTHIA parameters

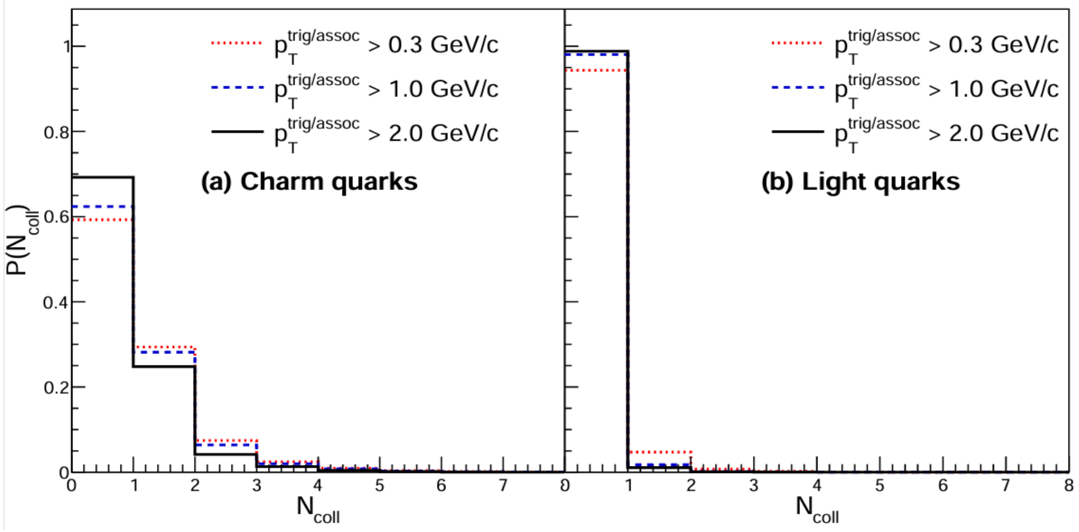
pp@200 GeV

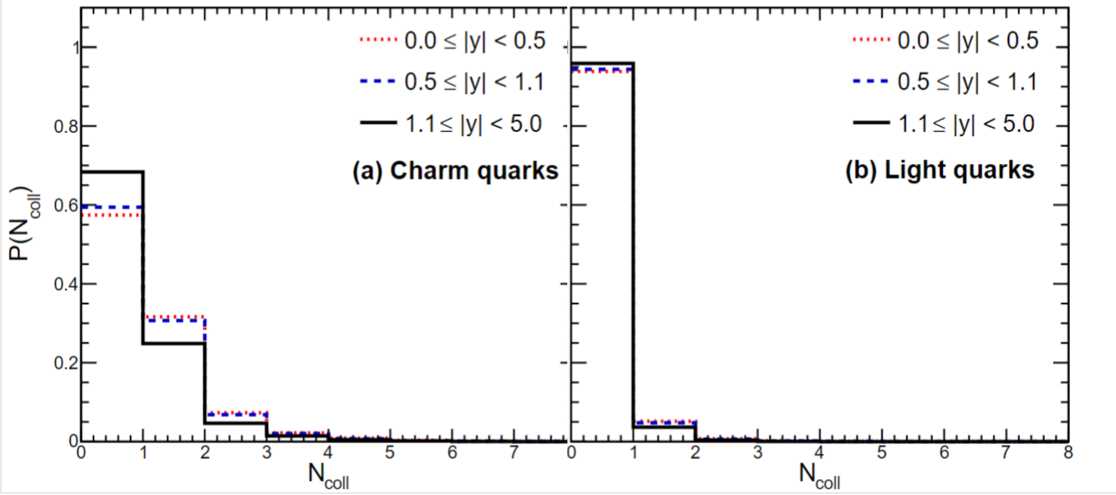




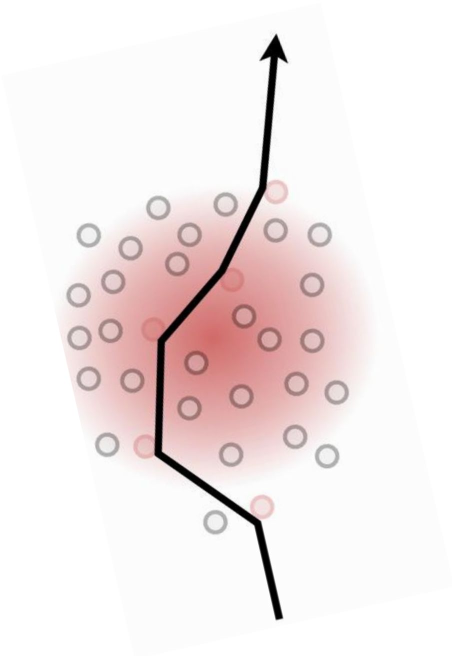
T. Sjöstrand and M. van Zijl, Phys. Rev. D 36, 2019
STAR Collaboration, Nucl.Phys.A 757 (2005), 102-183
PHENIX Collaboration, Nucl.Phys.A 757 (2005) 184-283

Collision Times Distribution





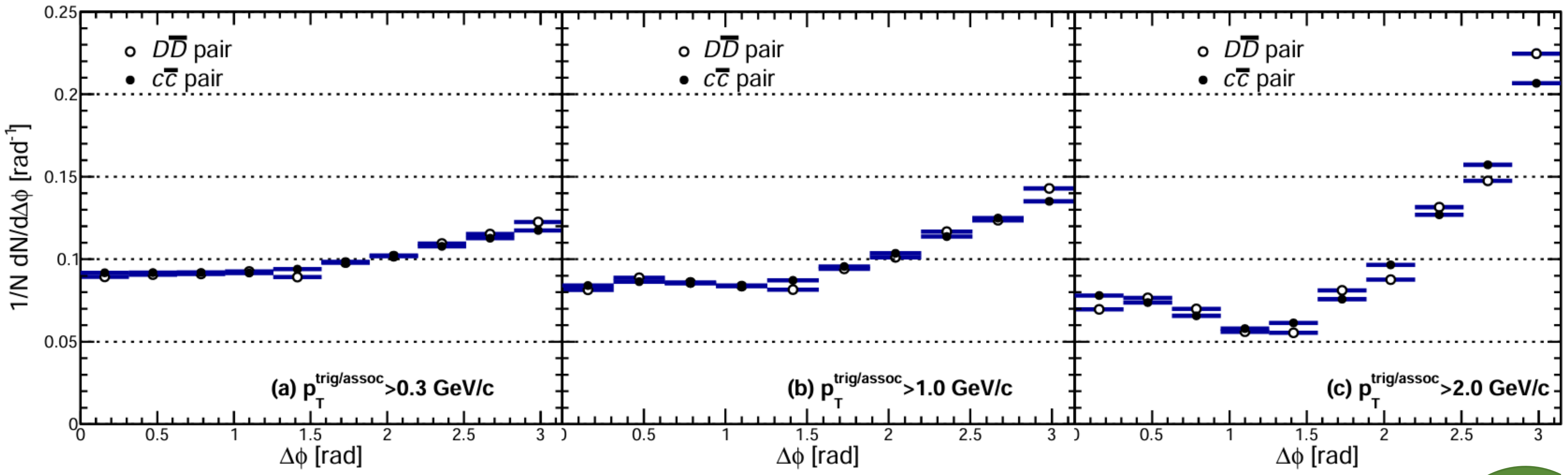
- Trigger by transverse momentum
  - → Higher pT, Less number of collisions
  - → Charm suffers more scatterings
  - Mass effect?

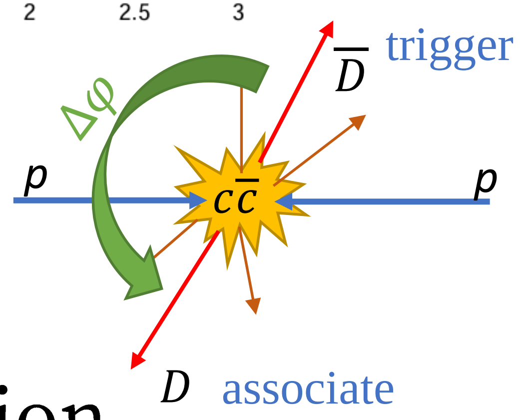


- Divide by rapidity
  - Charm Still collides more
  - Eg. Zero scatterings (black solid line)
    - → ~60% of charm quarks
    - → >90% of light quarks

Angular Correlation of HF

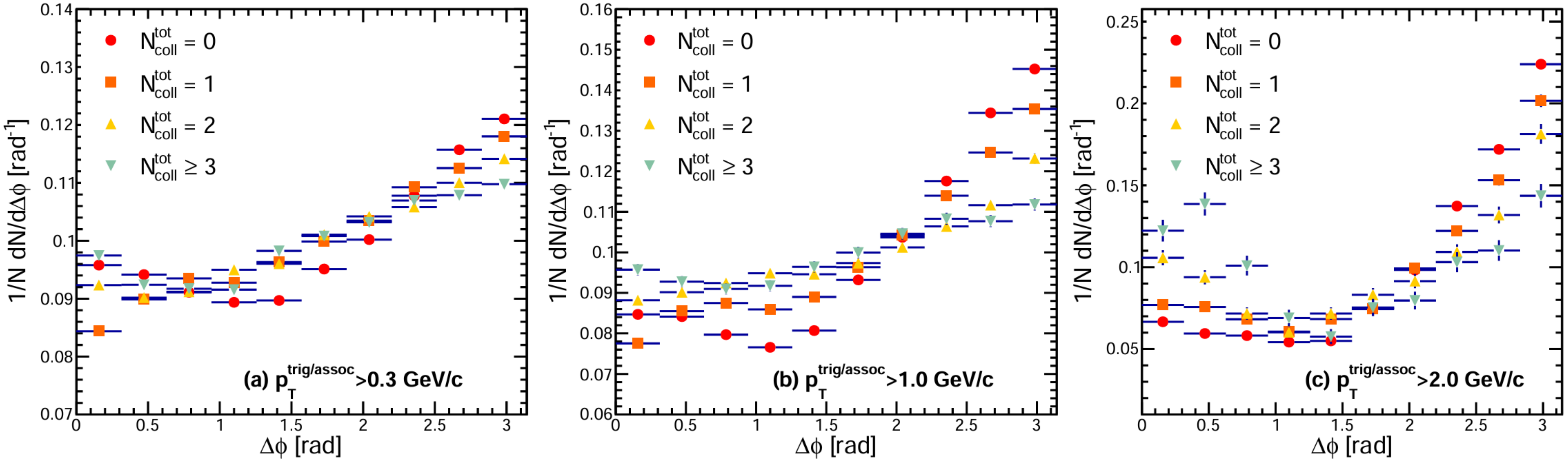
pp@200 GeV





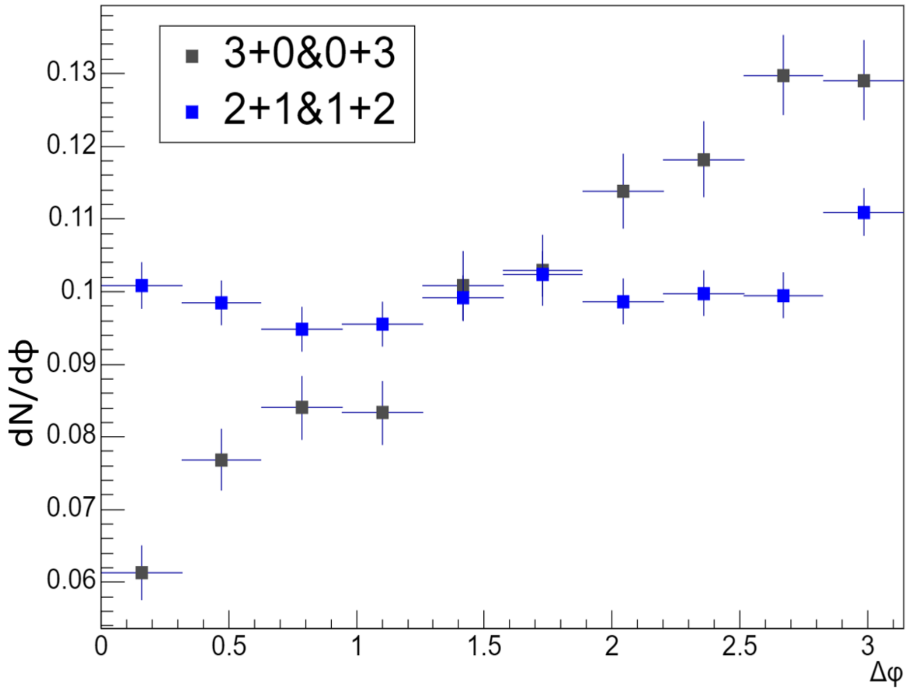
- Trigger dependence:
  - As pT trigger grows, NS lower and FS higher
  - A Near-Side peak appears at a high p_T trigger
- Hadronization → Limited Modifications on correlation

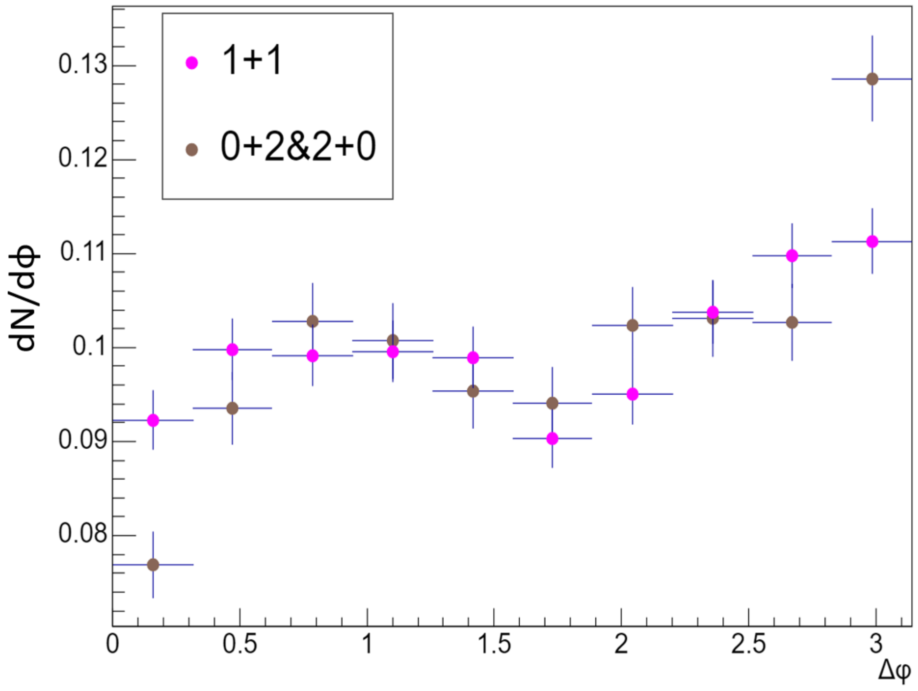
Angular Correlation: $N_{\mathrm{coll}}^{\mathrm{tot}}$ Collision Times

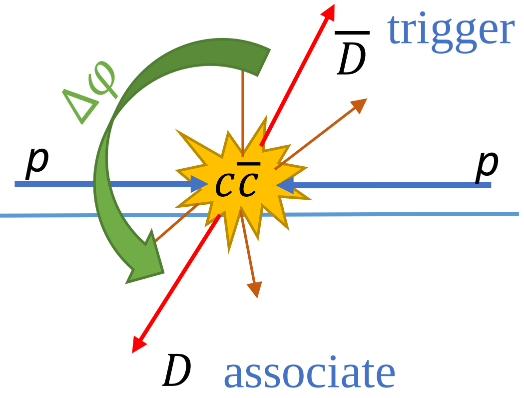


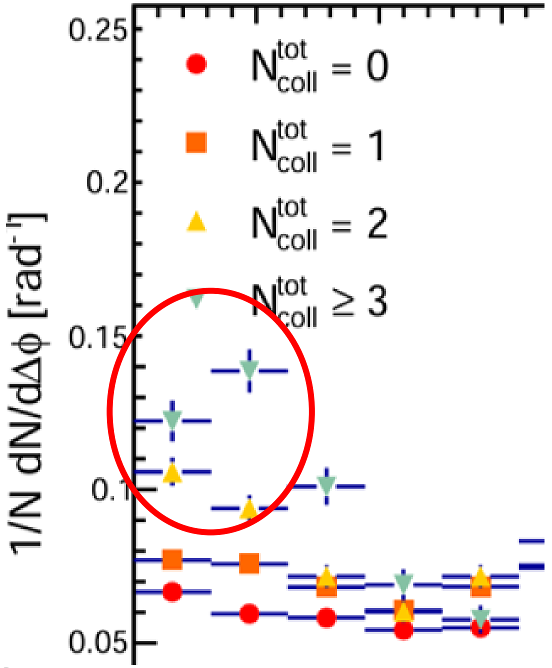
- Far Side (Right, $\Delta\phi\sim\pi$)
  - FS Drops as $N_{\mathrm{coll}}^{\mathrm{total}}$ grows
    - →broadening effect
  - Similar trend for different p_{T} range
- Near Side (Left, $\Delta\phi\sim 0$)
  - NS Grows as $N_{\mathrm{coll}}^{\mathrm{total}}$ grows
    - Prerequisite：Already Collides（≠0）
  - Non-Monotonic:
    - Without Scatterings → With Scatterings

Understanding $N_{\text{coll}}^{\text{tot}}$





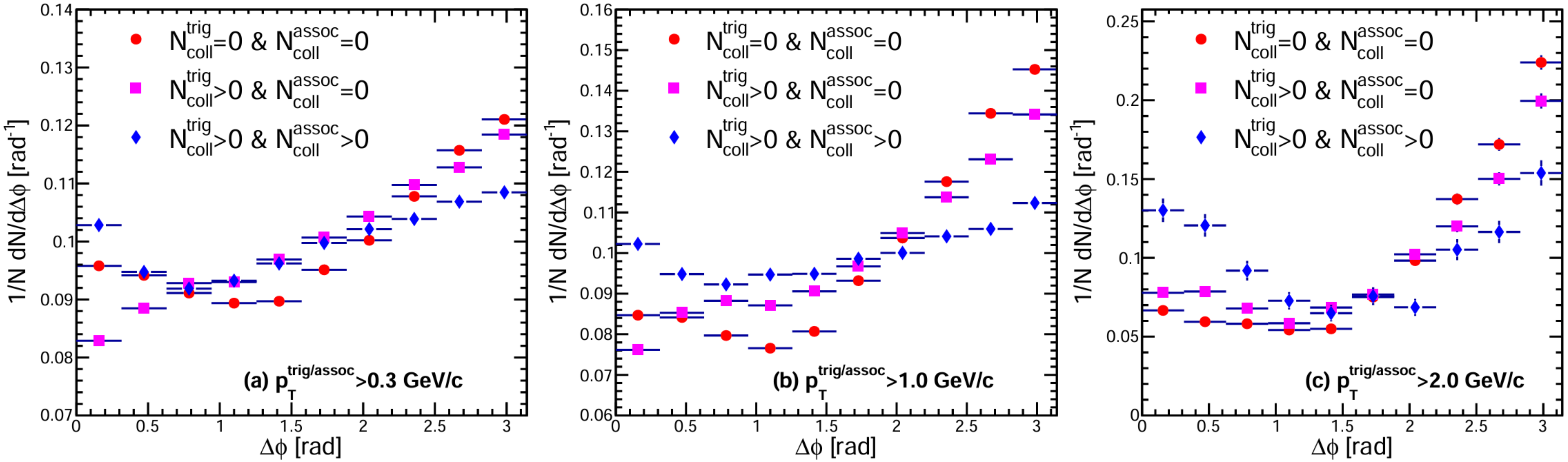




- $N_{\text{coll}}^{\text{total}} = N_{\text{coll}}^{\text{trig}} + N_{\text{coll}}^{\text{assoc}}$
- The shape is not only affected from total collision times alone
- But also whether it has collide, especially on Near-Side

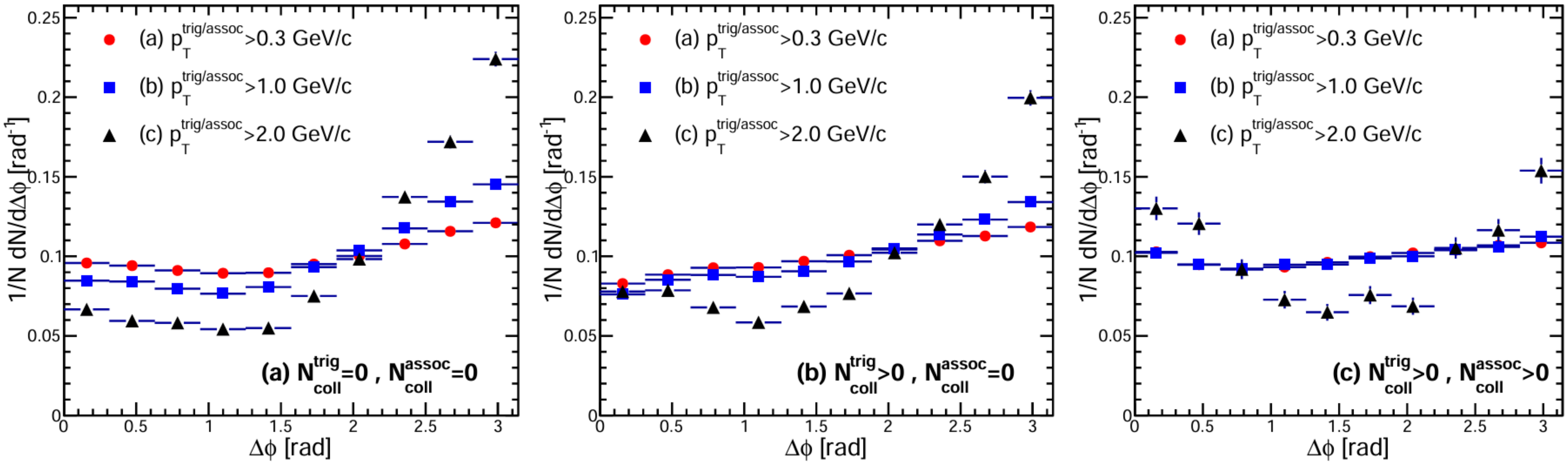
Competition under high collision times

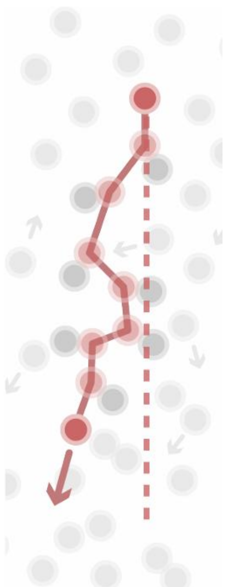
Angular Correlation: Collide-or-Not



- Present a clearer pattern
- Far side resembles $N_{\mathrm{coll}}^{\mathrm{total}}$ → Signal drops as N_{coll} grows → broadening
- Both Collides→ NS and FS are similar→Weak Initial Contribution

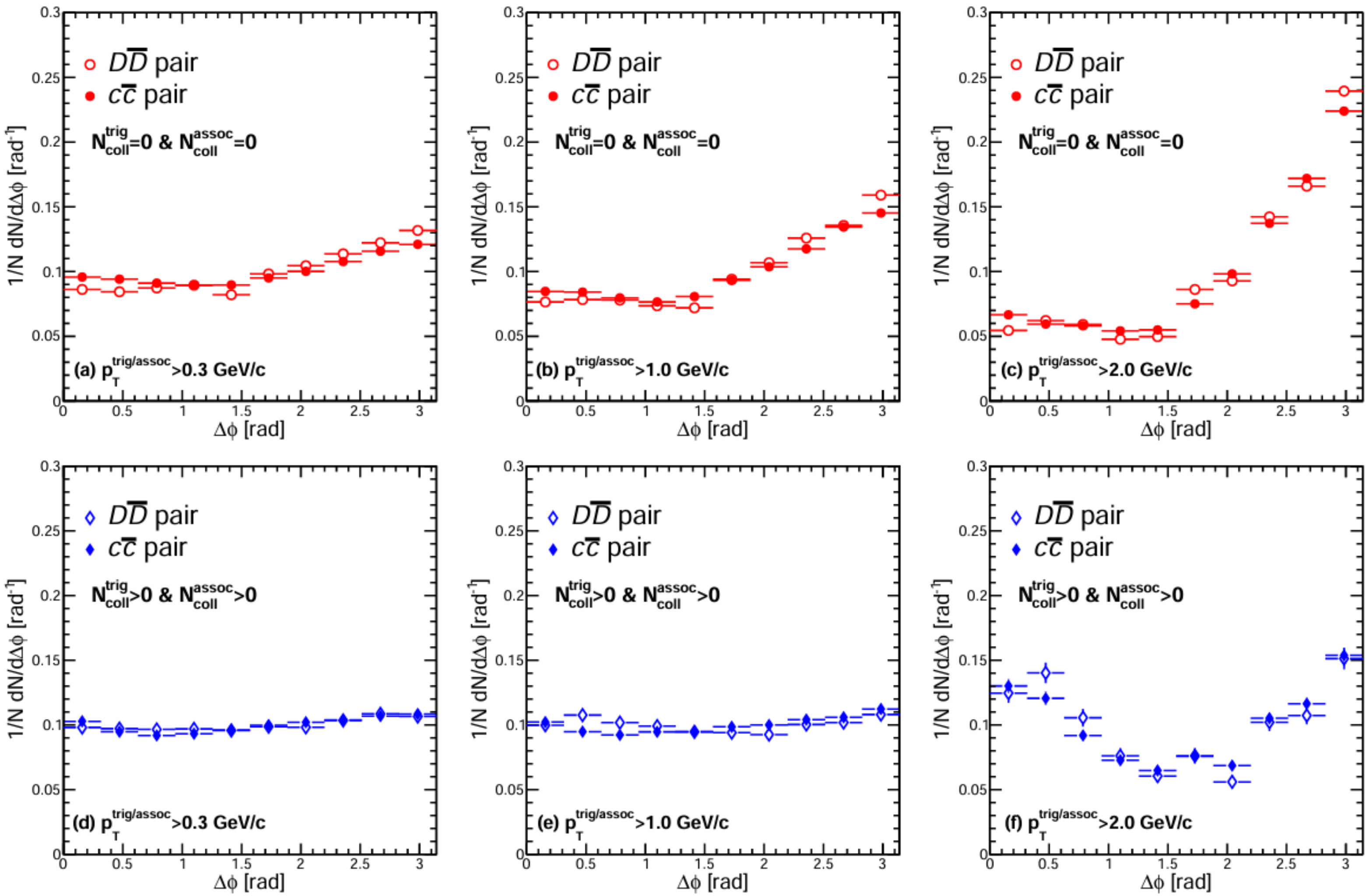
Angular Correlation from p_T dependence





- L: Zero Scattering, clear p_T separation
- M: Non-zero Scattering (one side), p_T separates weaker, prominent at FS
- R: Non-zero Scattering (both sides), > 0.3, 1 GeV/c identical, correlation is mainly contributed from > 2 GeV/c

Hadronization Effect ($c \to D$)



- Above: Zero Scatterings
- Max diff between *c* and *D* at Near Side
  - → Closer angle leads to coalescence J/ψ ?
  - → Need more model study

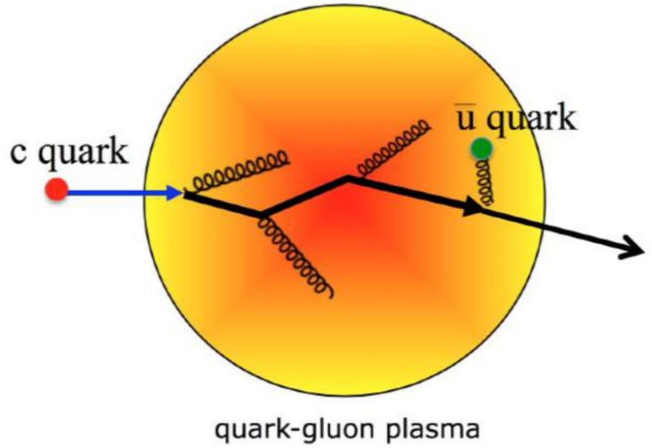
- Below: Both Scatterings
- The correlation of *c* and *D* become closer

- Experimentally,
- $D\overline{D}$ can be used to approximate $c\bar{c}$

Summary

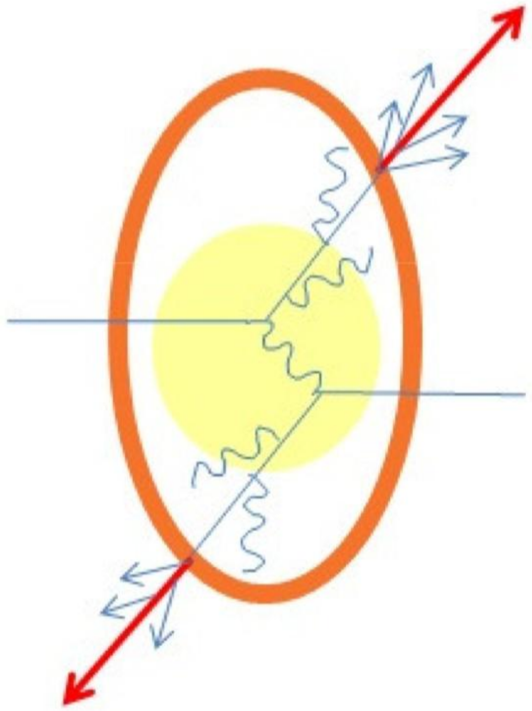
- An innovative framework combining AMPT with PYTHIA input
  - exploit the advantages of both in studying partonic evolution
- Categorized charm quark interactions from the perspective of elastic scattering
- Challenged the conventional assumption
  - that the correlation depends solely on the total number of collisions,
- But also *whether* a scattering occurred may be a more informative classification criterion

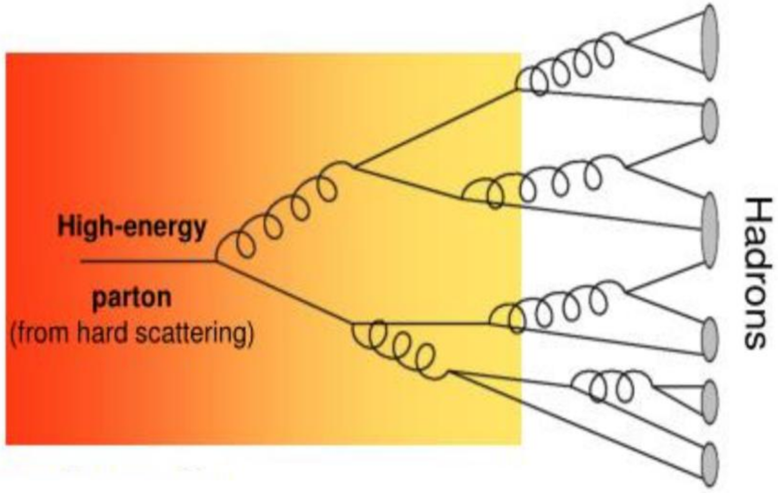
- Input from experiment (sPHENIX)
  - Semi-leptonic decay from $D \rightarrow e + \nu + X$ *to start with*
  - Using *D-e* correlations
- Different Energy/System → Flow effect?
  - pA: pQCD and fragmentation； AA: medium effect

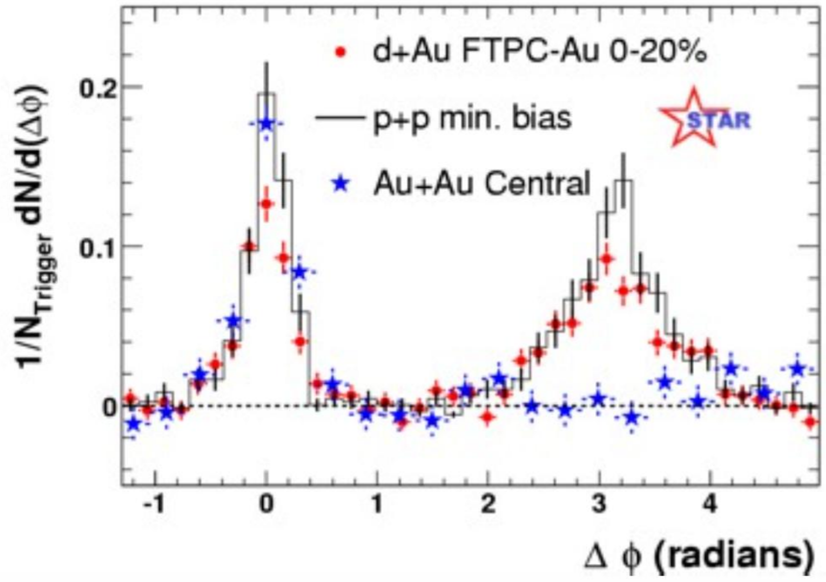


Backup Pages

Motivation: Partonic interaction

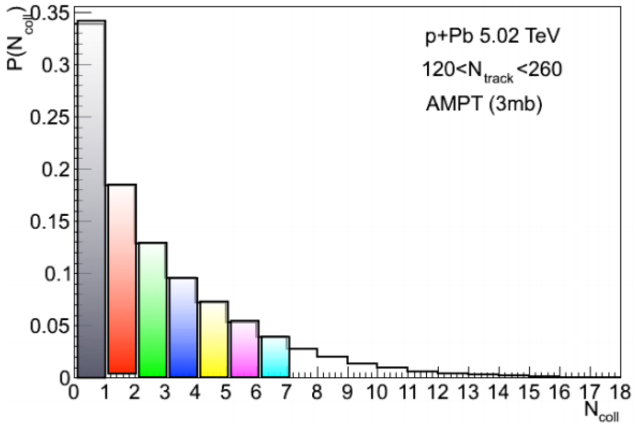




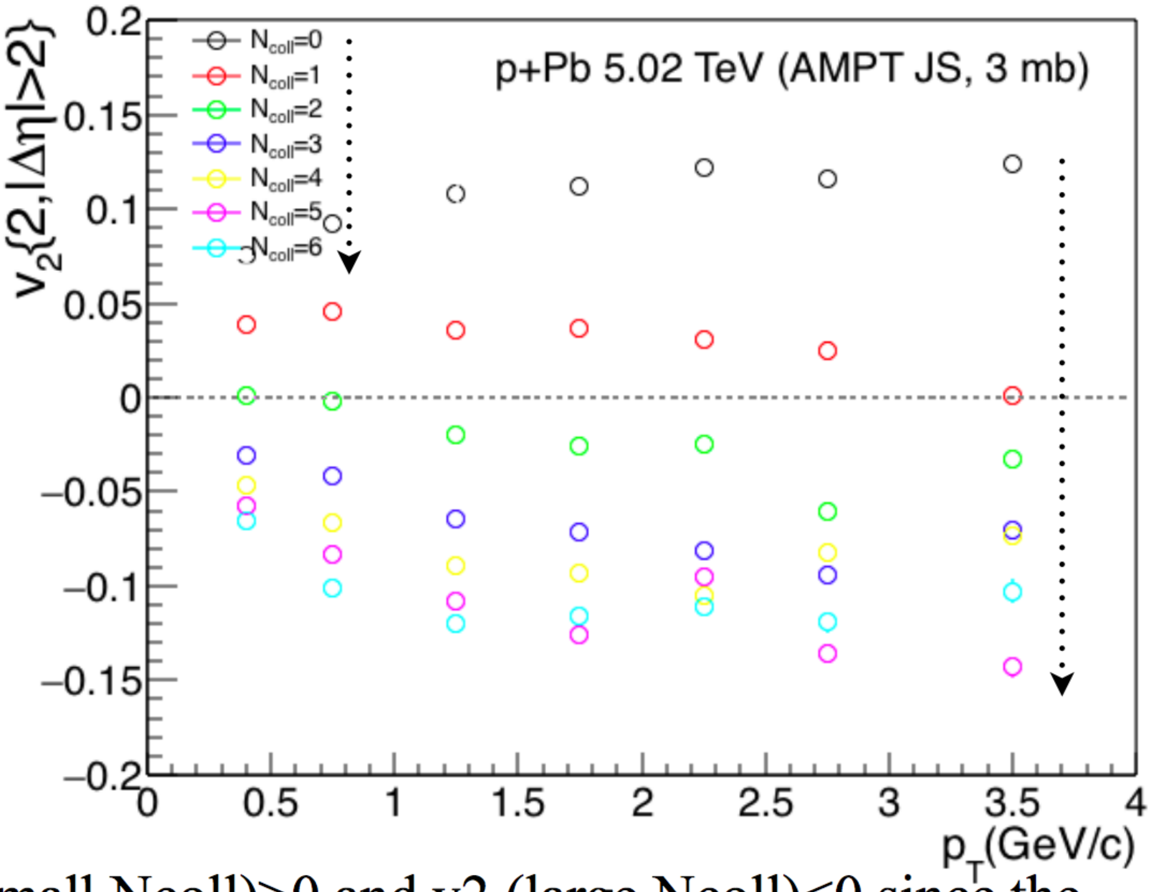


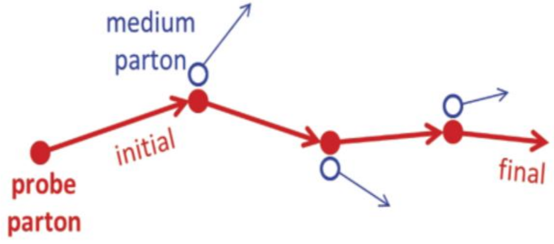
- Dihadron azimuthal correlation → probes medium effect
- Energy loss inside medium → partonic interaction

Motivation: Partonic interaction



partons = Ncoll=0 + Ncoll=1 + Ncoll=2 + Ncoll=3 + Ncoll=4 + Ncoll=5 + Ncoll=6 + ...

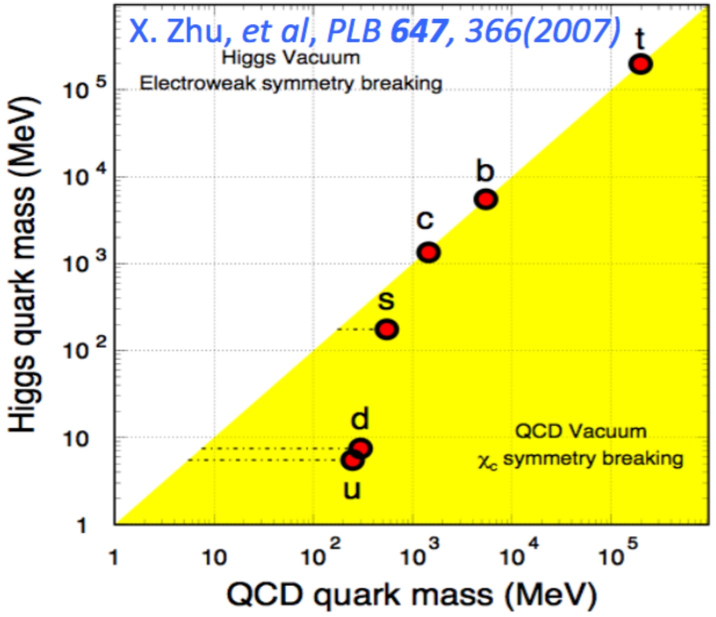


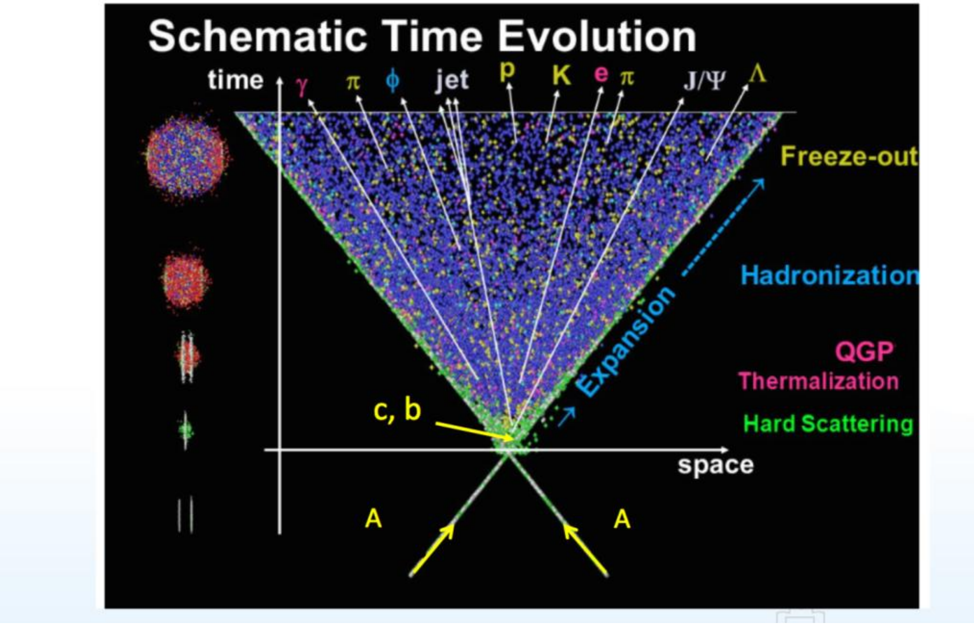


- In the initial state, v2 (small Ncoll)>0 and v2 (large Ncoll)<0 since the average v2 must be zero.

Guo-Liang Ma, Adam Bzdak, Nucl. Phys. A 956, 745–748

Motivation: Heavy flavor as a Probe

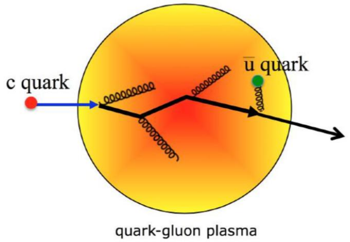




- Heavy quark produced in initial hard process => sensitive to the initial gluon density and distribution (pp/pA/AA)
- Couple differently with the medium than light quarks => reveal critical features of the medium (G. Greco, QM2017)

Summary

- Summary:
  - Combining pythia and AMPT offers an excellent way to probe partonic effects
  - Hadronization contributes considerably in charm correlation
  - Charm quark pairs can be categorized differently correspond to different physics



- Outlook:
  - Different energies with various system size(pp, pA, AA)
    - Testing pQCD and fragmentation
  - By comparing data with the model, we may able to quantify the initial partonic effect
  - sPHENIX experiment will explore the correalation further