

$D^0 \rightarrow D_s^+$ Elliptic-Flow Splitting under Event-Shape Engineering

A differential probe of sequential charm hadronization

Yu-Jie Huang

Collaborators: Wei Dai, Jiaying Zhao, Tan Luo, Ben-Wei Zhang, Enke Wang

China University of Geosciences (Wuhan)

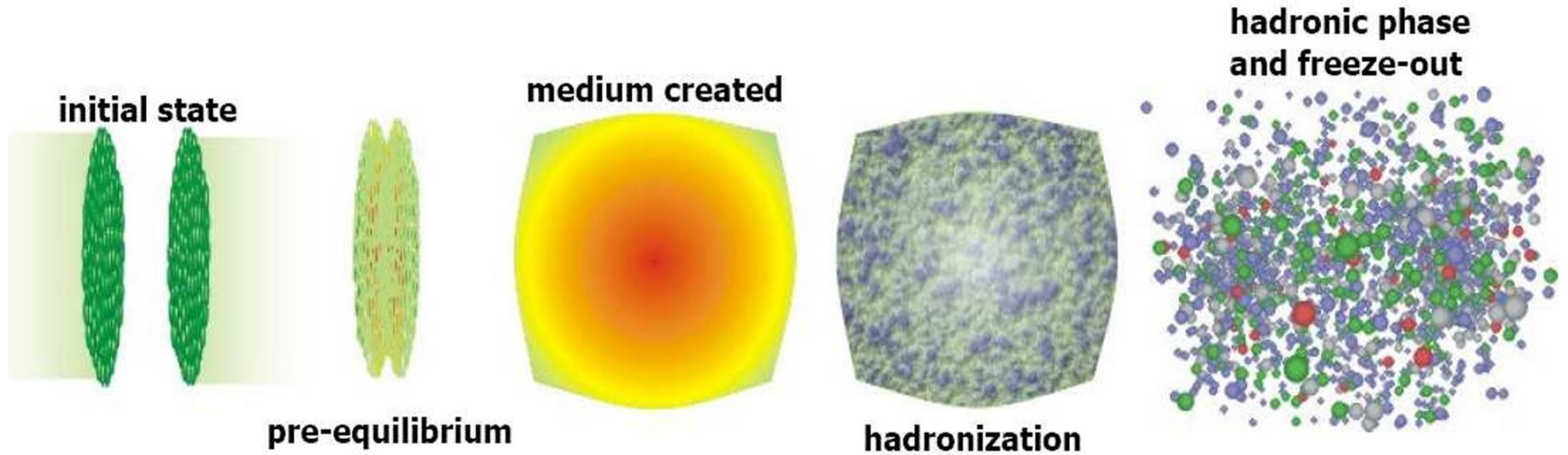
October 2026



Outline

1. **Physics question:** why can $\nu_2(D^0) > \nu_2(D_S^+)$?
2. **Method:** Event-Shape Engineering and SHELL
3. **Results:** Flow Splitting and Species-Dependent ESE Response
4. **Control tests and conclusions**

Heavy Flavor Across the Collision Evolution



Early production

Charm quarks originate from hard scatterings before the QGP forms.

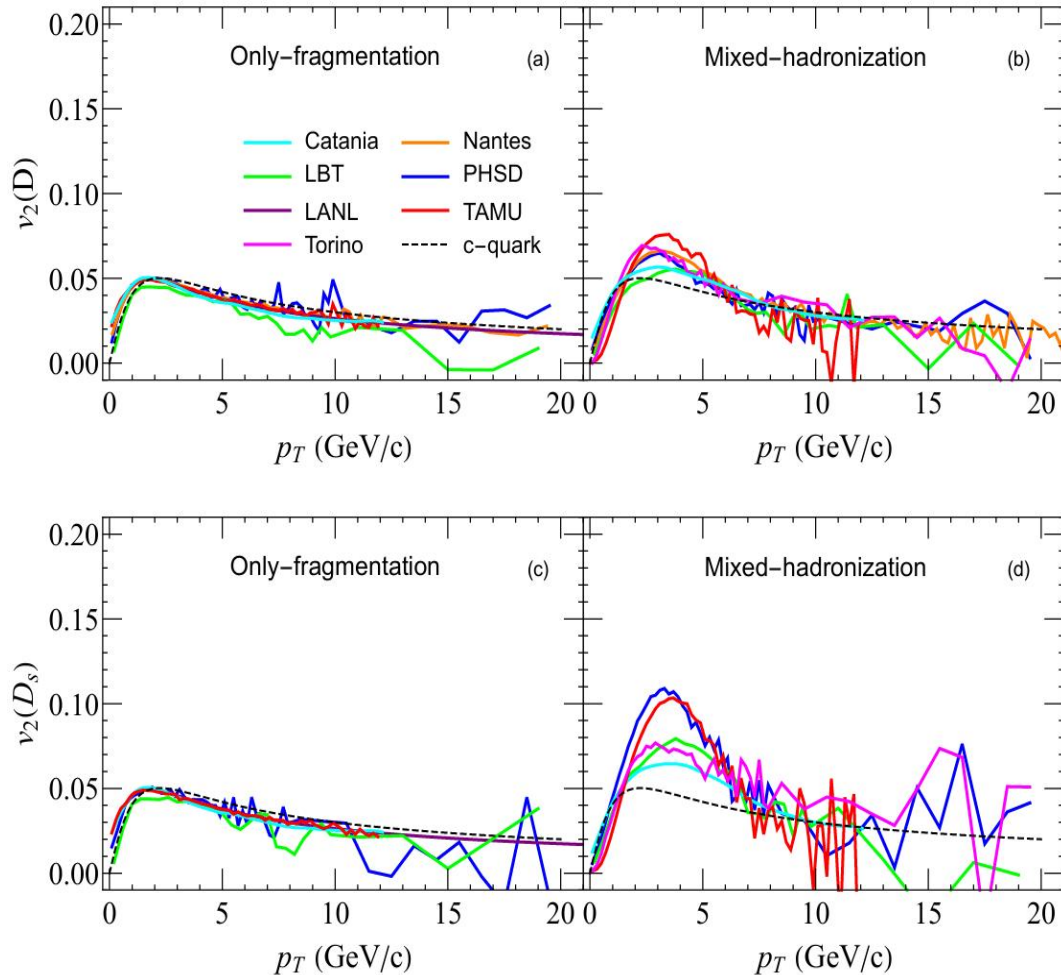
QGP transport

They exchange energy and momentum with thermal partons and inherit the collective flow.

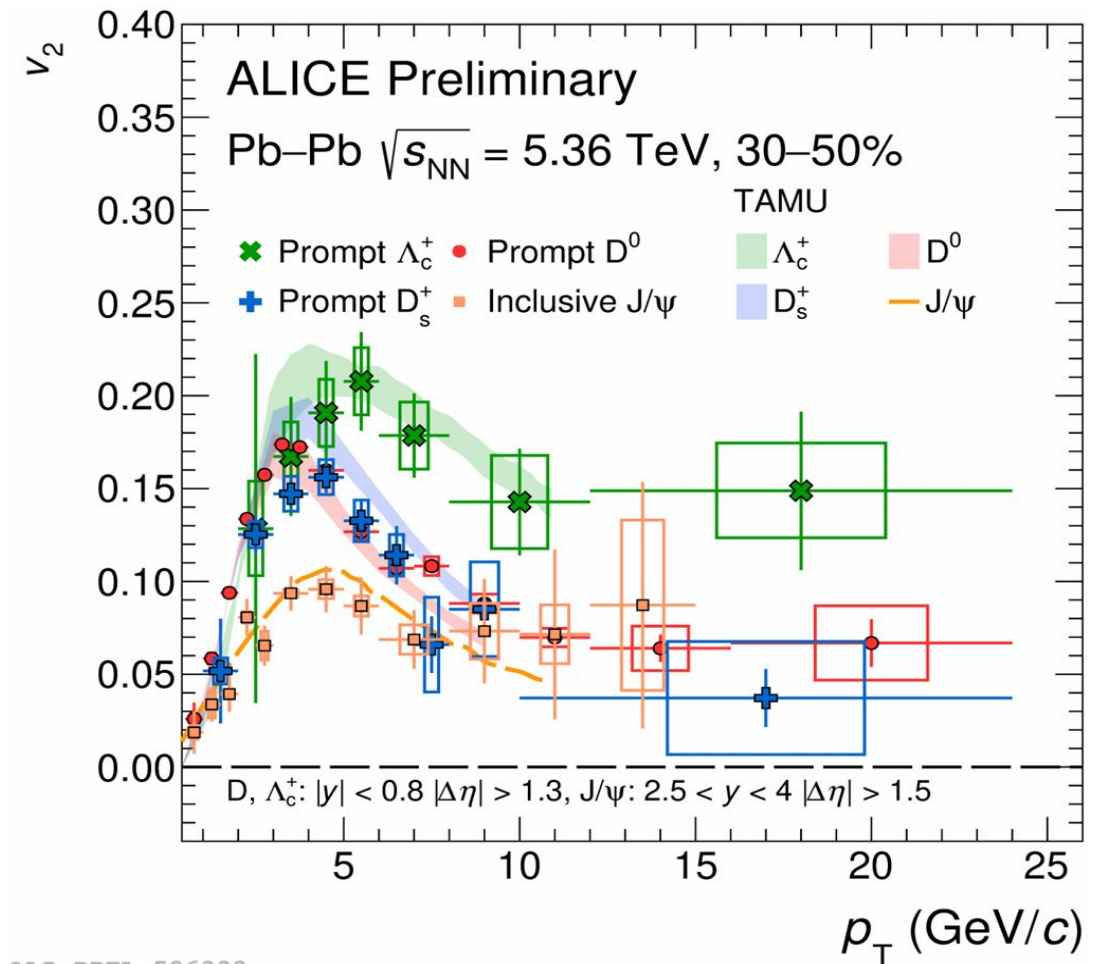
Hadronization

The final D mesons capture both charm flow and the hadronization mechanism.

The D^0 -- D_s^+ Flow-Ordering Puzzle



Simultaneous calculations give $v_2(D_s^+) > v_2(D^0)$.

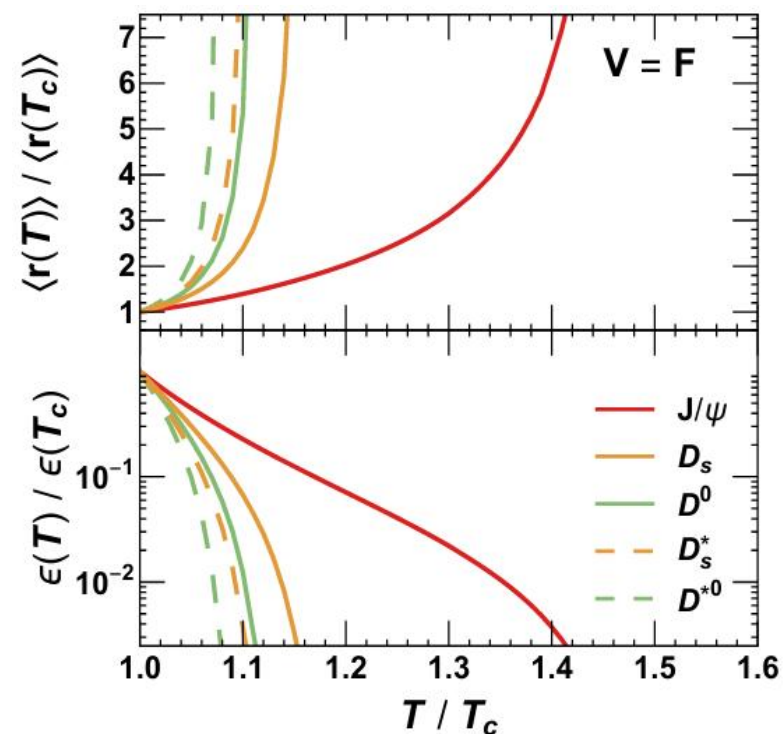


ALI-PREL-596333

ALICE data favor $v_2(D^0) > v_2(D_s^+)$ at intermediate p_T .

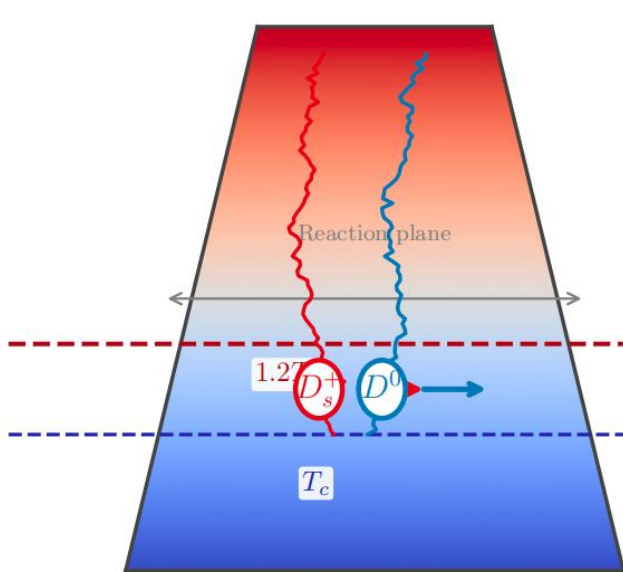
Do charm hadrons with different binding energies really form at the same T_c ?

Binding Hierarchy Motivates Sequential Hadronization

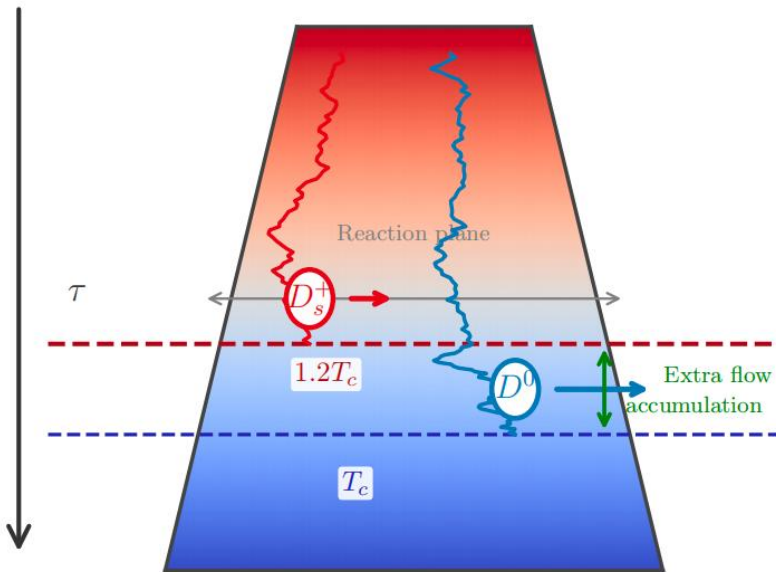


The D_s^+ meson exhibits greater thermal stability than the D^0 meson.

Simultaneous Hadronization (Baseline)



Sequential Hadronization



Simultaneous: Both D_s^+ and D^0 form at T_c .

Sequential: D_s^+ forms earlier at $1.2T_c$, and D^0 forms later at T_c .

$$D_s^+ @ 1.2T_c \implies D^0 @ T_c \implies v_2^C(T_c) > v_2^C(1.2T_c)$$

The later D^0 mesons inherit additional charm-quark elliptic flow accumulated between $1.2T_c$ and T_c .

From Flow Accumulation to Geometry Control

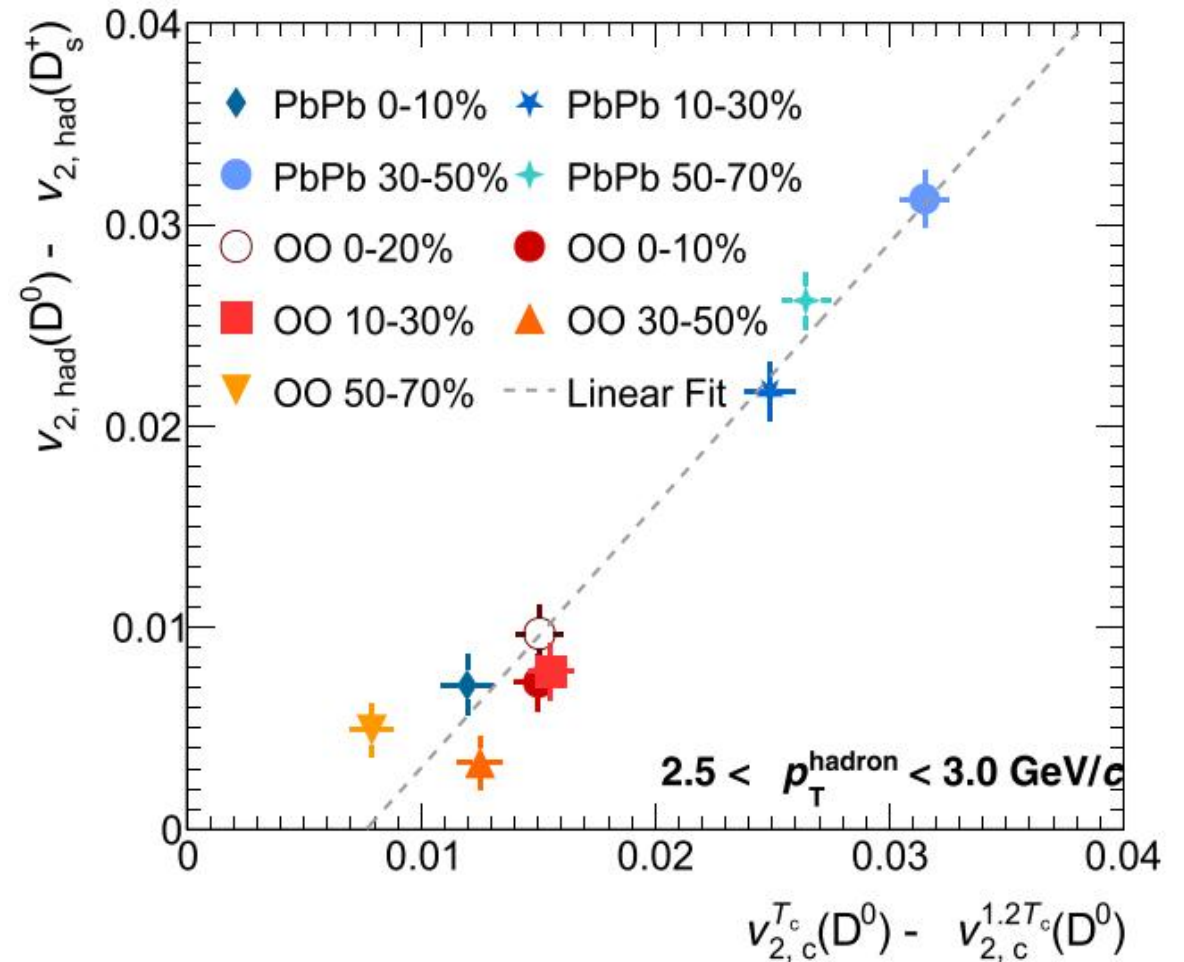
The final (D^0 - D_s^+) flow splitting strongly correlates with the additional charm-quark elliptic flow accumulated between $1.2T_c$ and T_c .

Changing collision systems simultaneously modifies:

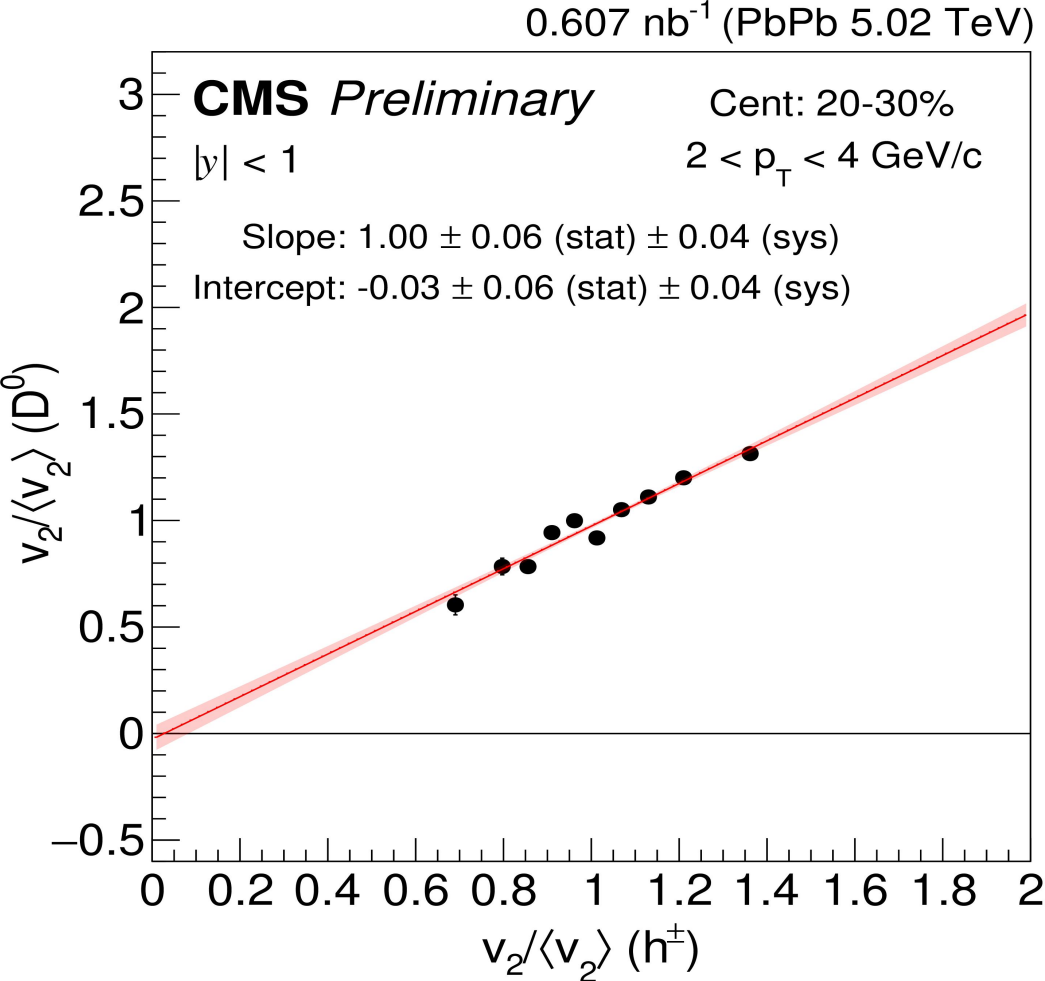
- system size and fireball lifetime
- the $1.2T_c \rightarrow T_c$ evolution time gap
- initial geometry and its fluctuations

The question we ask next

Can we isolate the geometry dependence of the flow splitting at fixed centrality?



Event-Shape Engineering Probes Geometry at Fixed Centrality



Definition of q_2

$$Q_2 = \sum_{j=1}^M e^{2i\phi_j}$$

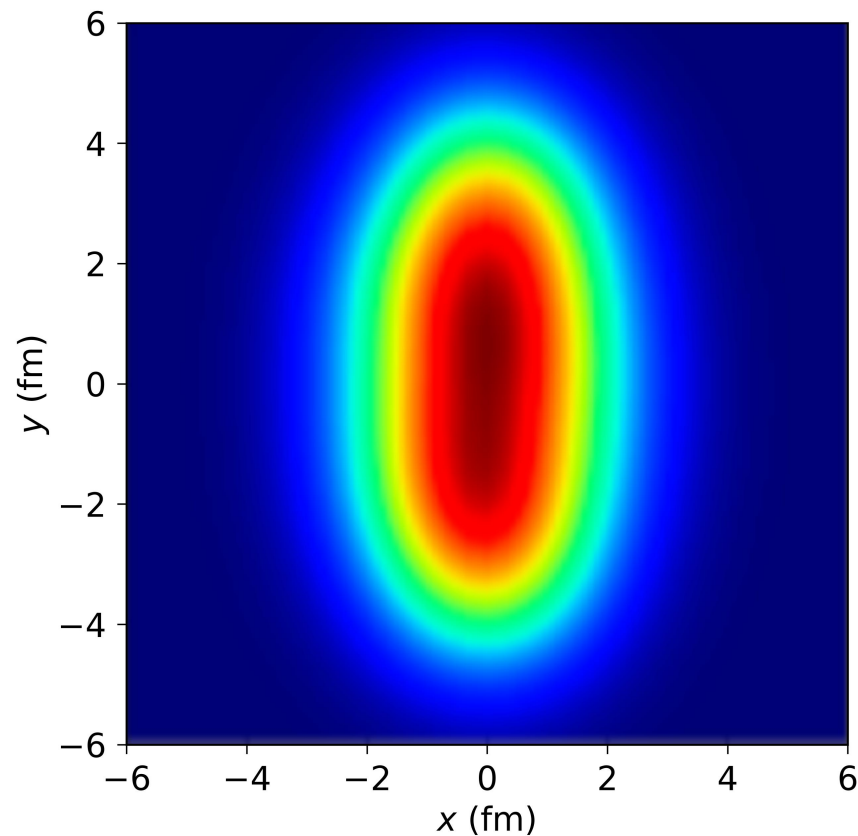
Second-order flow vector constructed
from charged particles,

$$q_2 = \frac{|Q_2|}{\sqrt{M}}$$

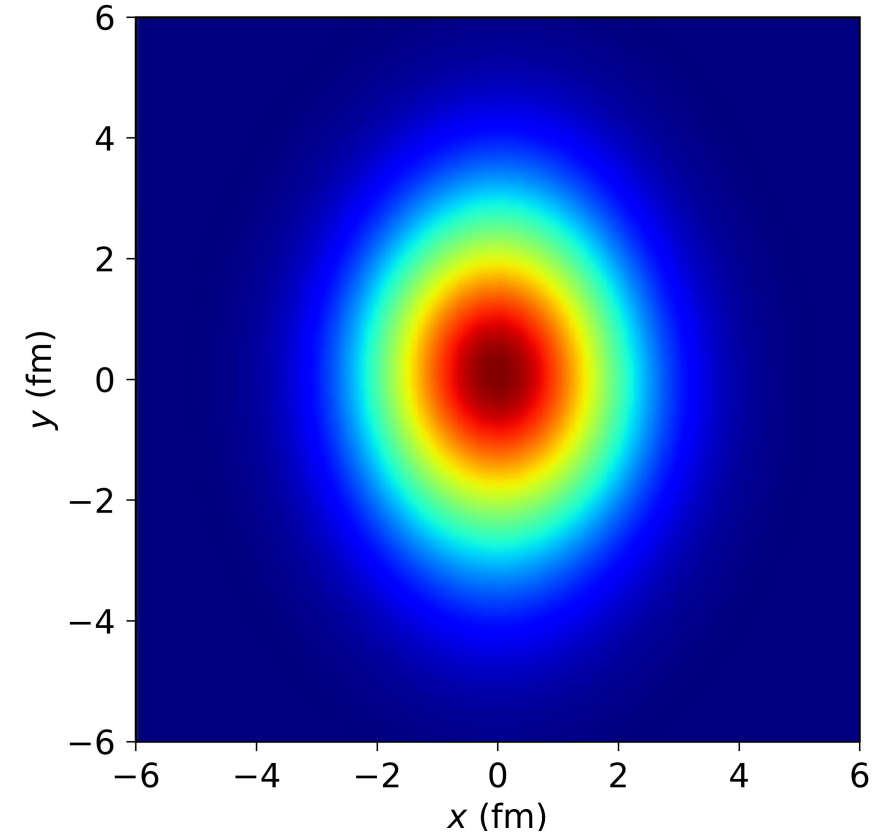
Why ESE

CMS result shows that the normalized elliptic flow of D^0 mesons closely follows that of charged particles, supporting the use of bulk particles for event-shape selection.

How Event-Shape Selection Is Performed



large- q_2 events: more elliptic profile

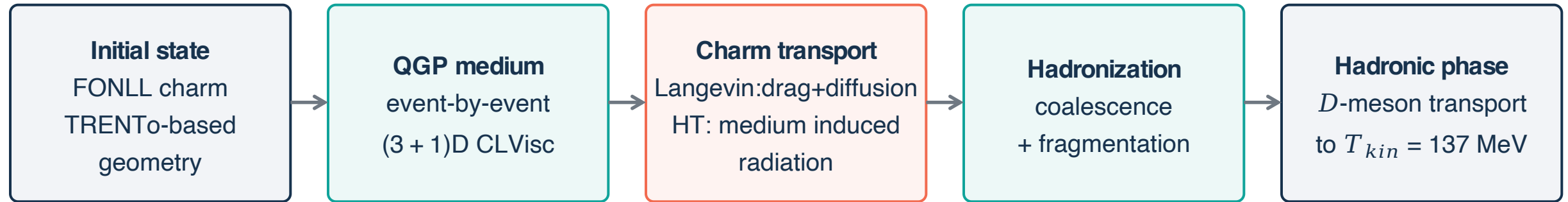


small- q_2 events: more circular profile

Event selection: Top/bottom 20% of bulk q_2 at fixed centrality.

ESE probes whether D^0 and D_s^+ elliptic flow respond differently to event geometry at fixed centrality.

Testing Hadronization Scenarios with SHELL



Simultaneous

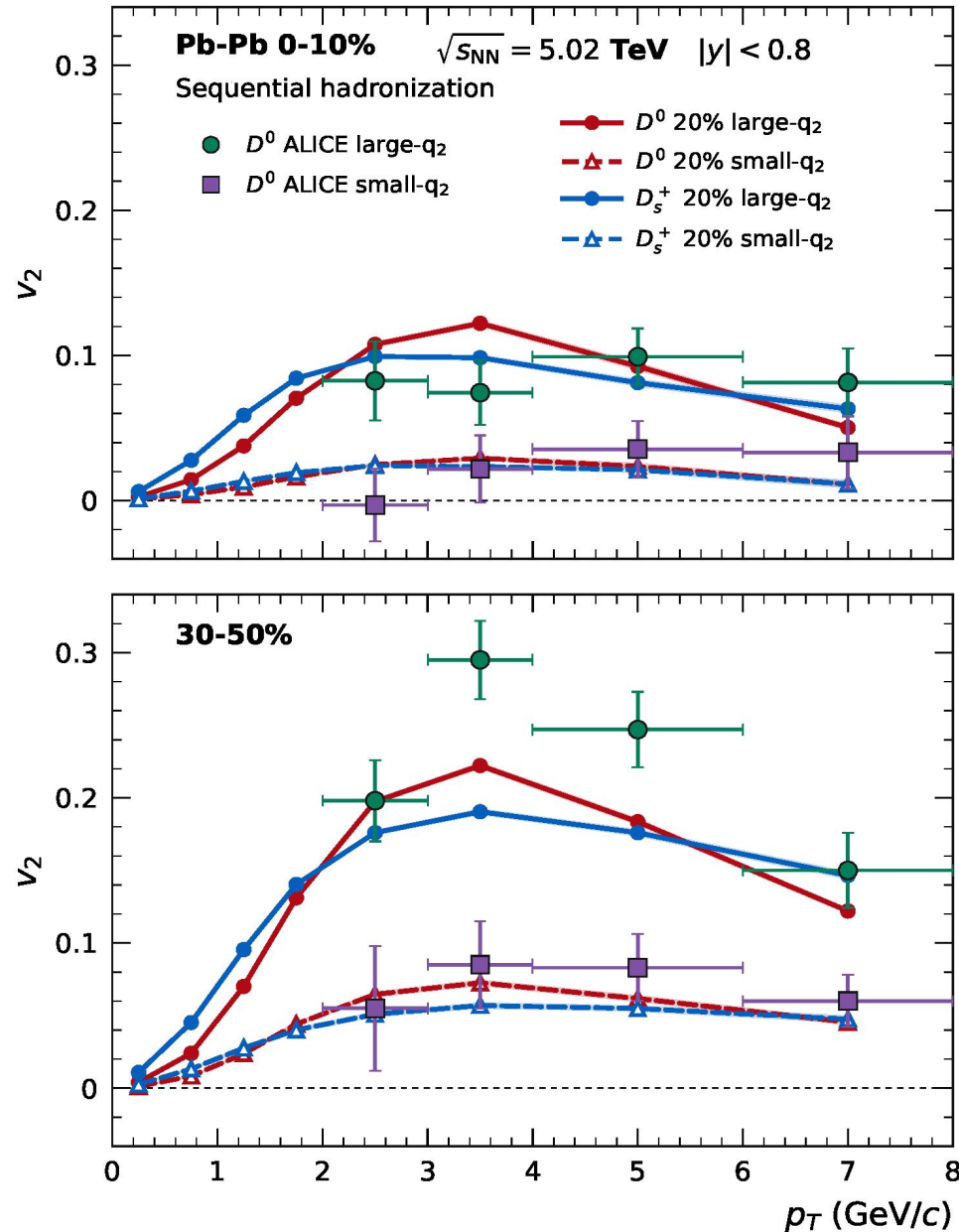
$$D_S^+, D^0 @ T_c$$

Sequential

D_S^+ coalescence @ $1.2 T_c$,
Remaining charm quarks @ T_c

Within the same transport framework, we implement both hadronization scenarios and compare their responses to event-shape selection.

Species-Dependent Elliptic Flow under ESE

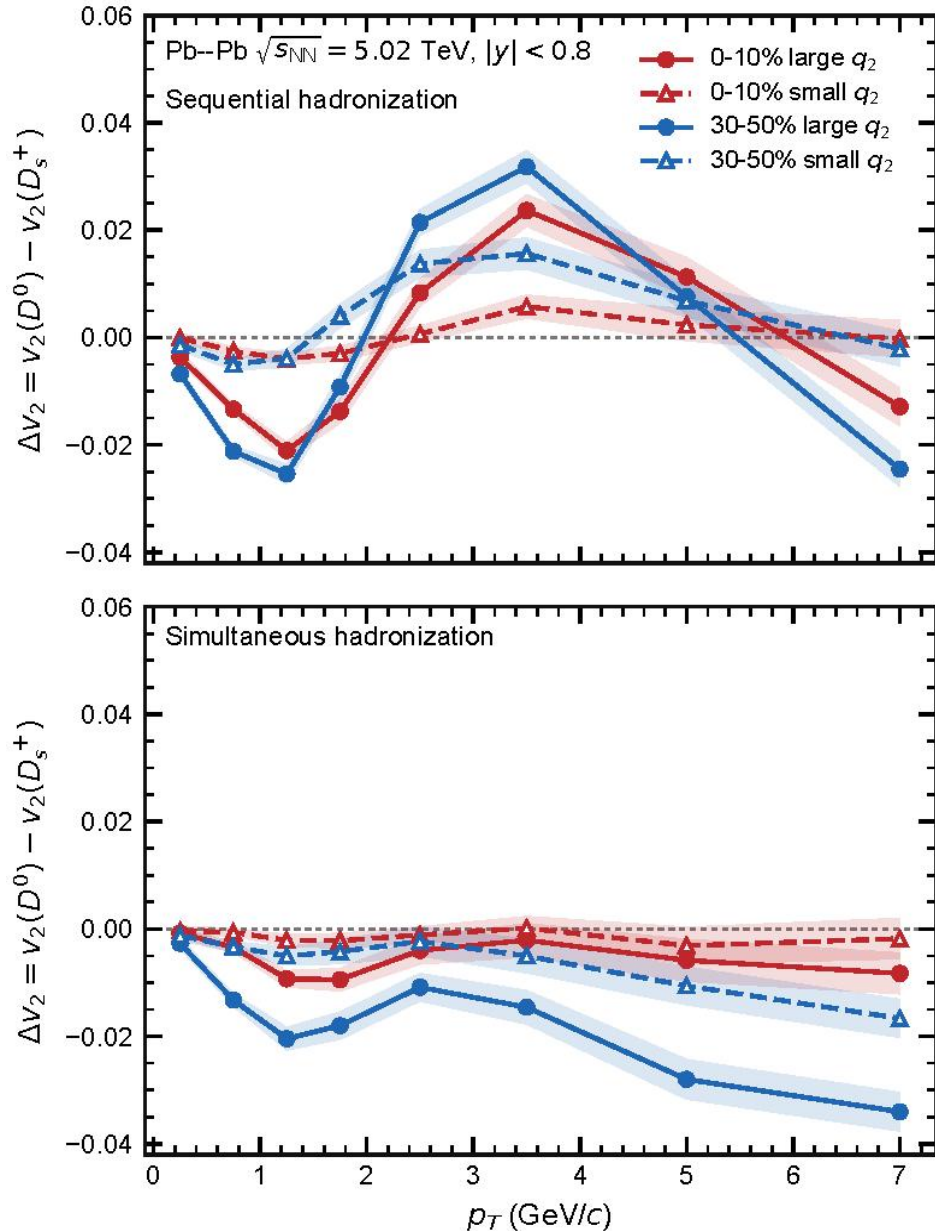


- The D^0 results agree with ALICE data within uncertainties, while the D_s^+ results are predictions.
- In the sequential scenario, $v_2(D^0) > v_2(D_s^+)$ emerges at intermediate p_T .

Questions

Why is the splitting stronger in semi-central collisions, even at small q_2 ?
 How does the earlier formation of D_s^+ affect its elliptic-flow response?

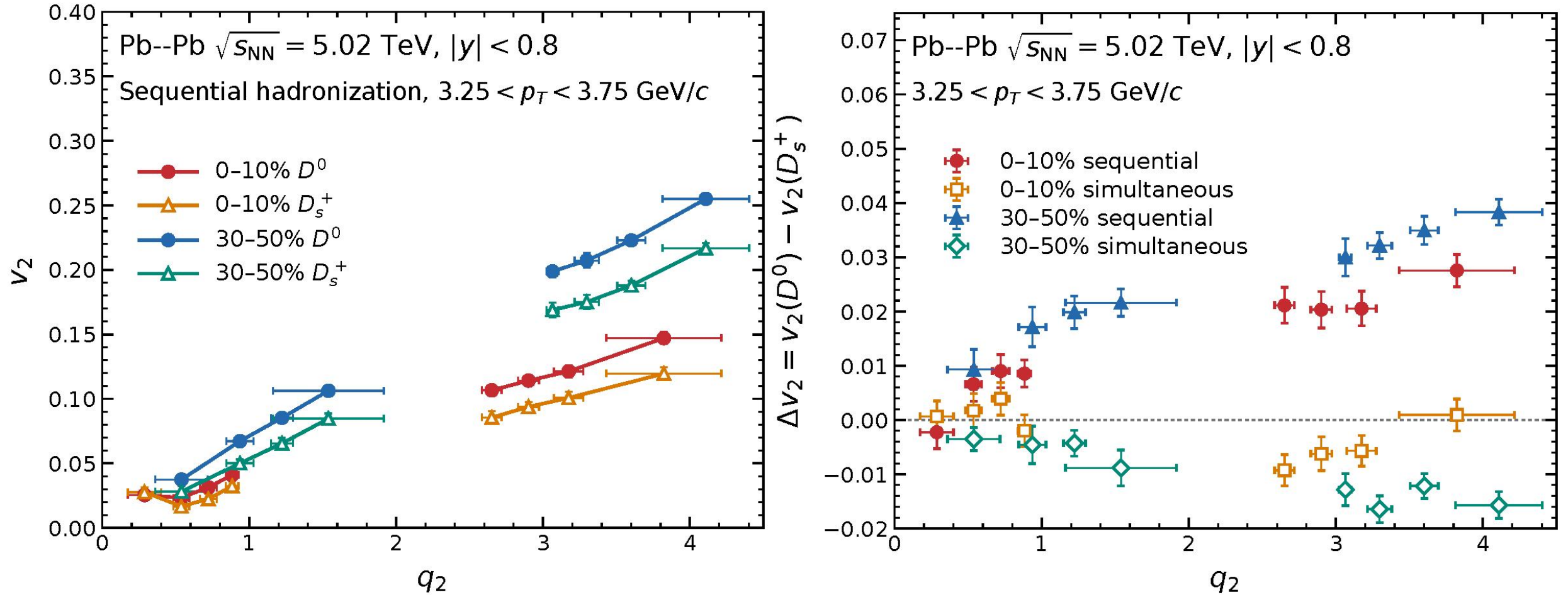
ESE Enhances the Positive $D^0 - D_s^+$ Flow Splitting



- Sequential hadronization: Positive $v_2(D^0) - v_2(D_s^+)$ emerges at intermediate pT.
- The positive flow splitting is stronger in large- q_2 events, especially at 30–50% centrality.
- Simultaneous baseline: No positive splitting appears under the same ESE selection.

The enhanced positive splitting in large- q_2 events motivates a closer look at its continuous q_2 dependence.

Continuous q_2 Reveals Species-Dependent Flow Responses

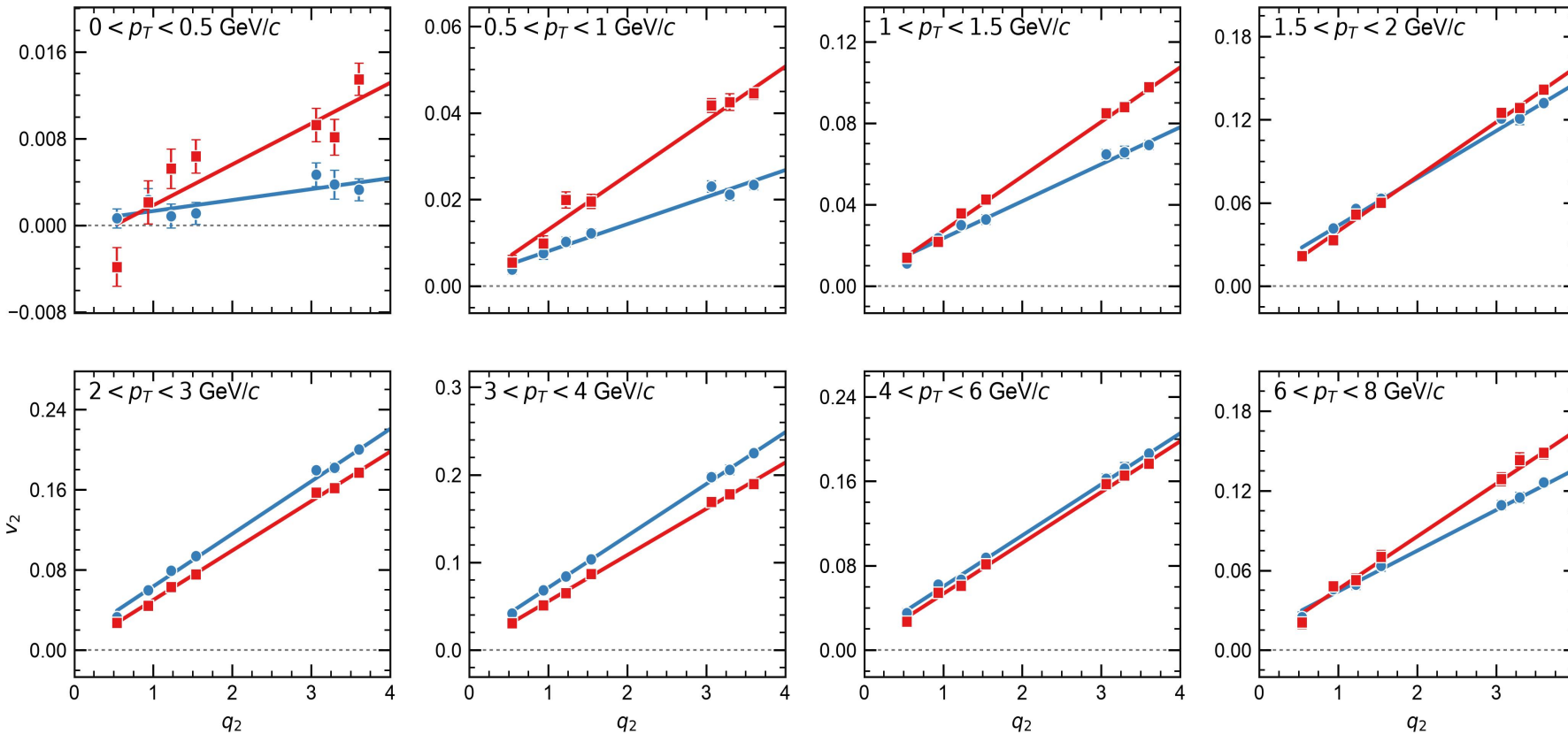


- D^0 exhibits a stronger v_2 response to q_2 than D_s^+ in sequential hadronization.
- Δv_2 increases with q_2 for sequential hadronization, while the simultaneous baseline remains near zero or negative.

Extracting the ESE Response Coefficient χ

30–50%, sequential hadronization

—●— D^0 —■— D_s^+



- Linear response fit:

$$v_2\{SP\} = \chi q_2 + v_2^{(0)}.$$

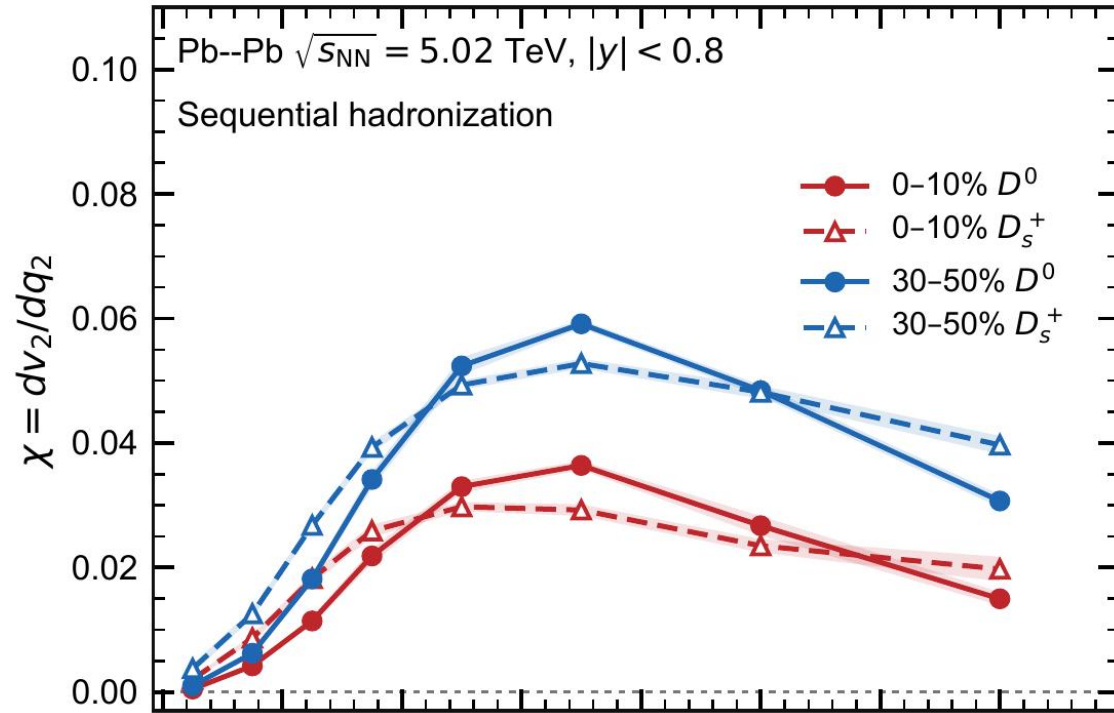
- Response coefficient:

$$\chi = \frac{dv_2}{dq_2}$$

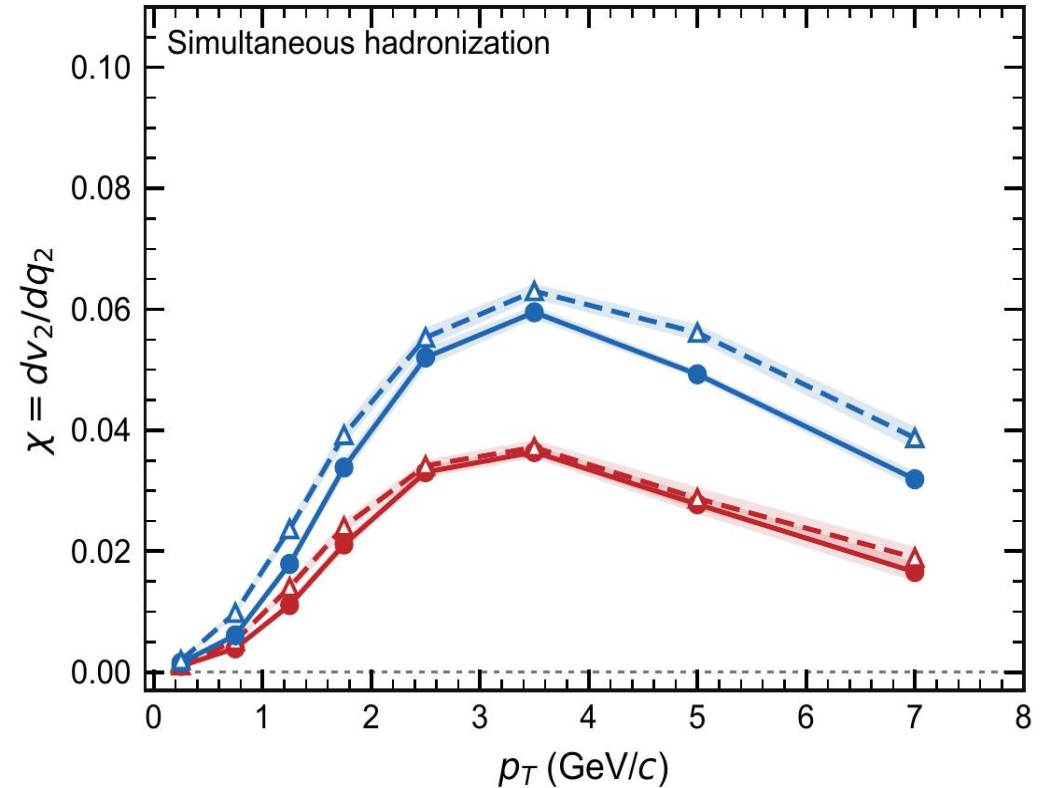
- Measures the elliptic-flow response to event shape.

The linear fit describes the intermediate- p_T response with $R^2 \gtrsim 0.98$.

Sequential Produces a Species-Dependent ESE Response



Sequential: D^0 responds more strongly to event shape than D_s^+ at intermediate p_T .

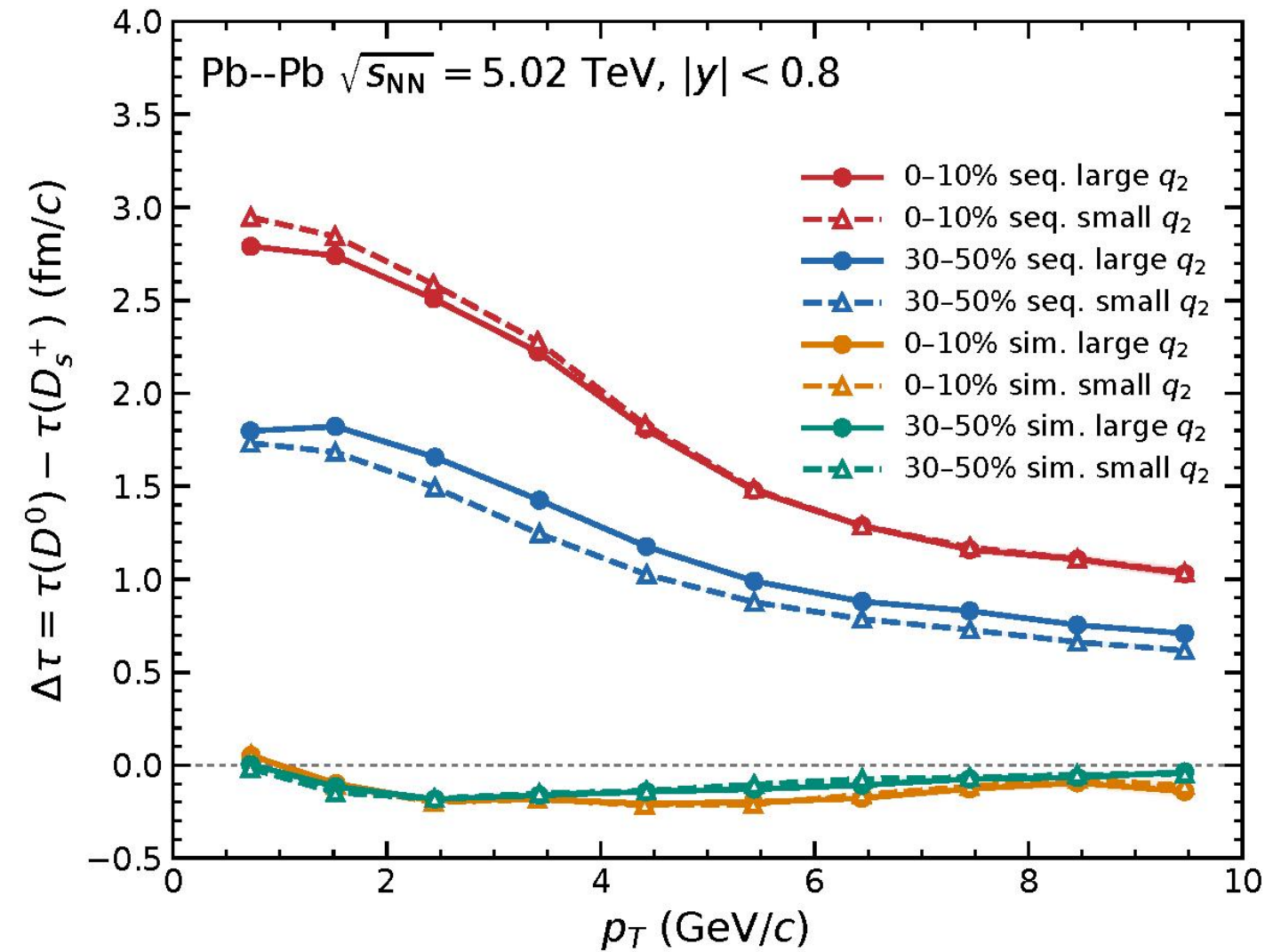


Simultaneous: the two species show nearly the same event-shape response.

Response-slope fingerprint

The species-dependent response slope, $\chi(D^0) > \chi(D_s^+)$, provides a differential signature of sequential hadronization.

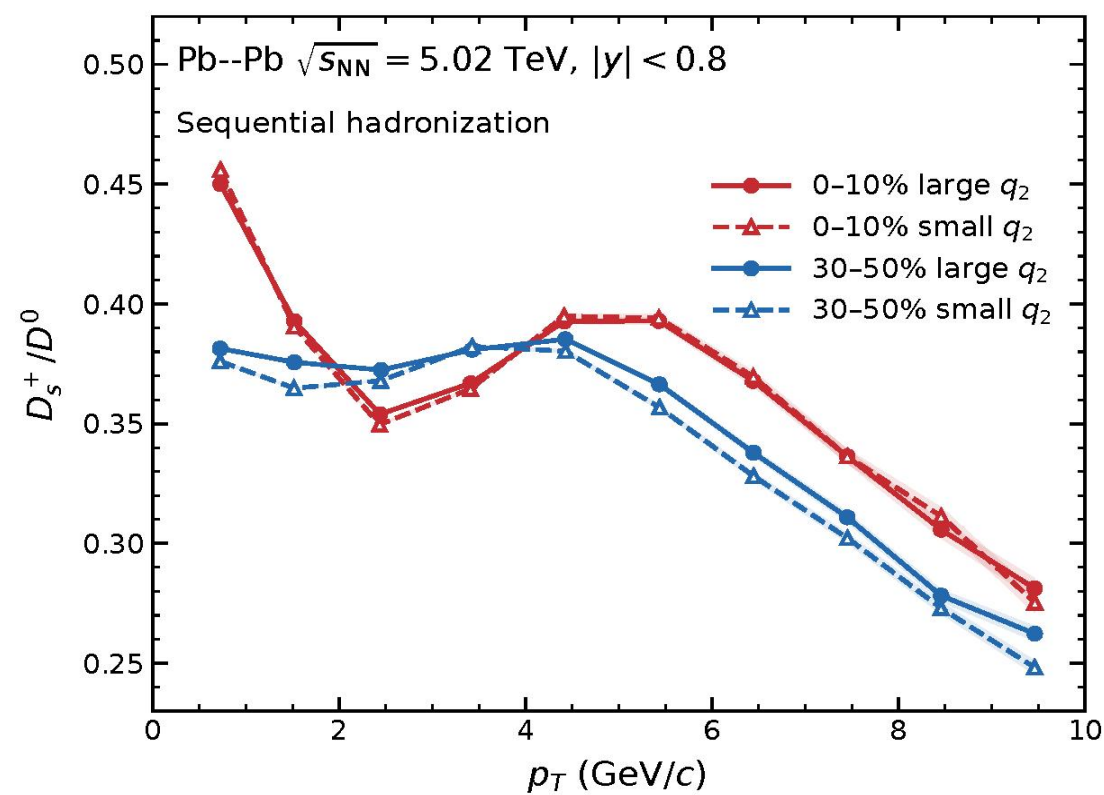
ESE Changes the Response, Not the Time Interval



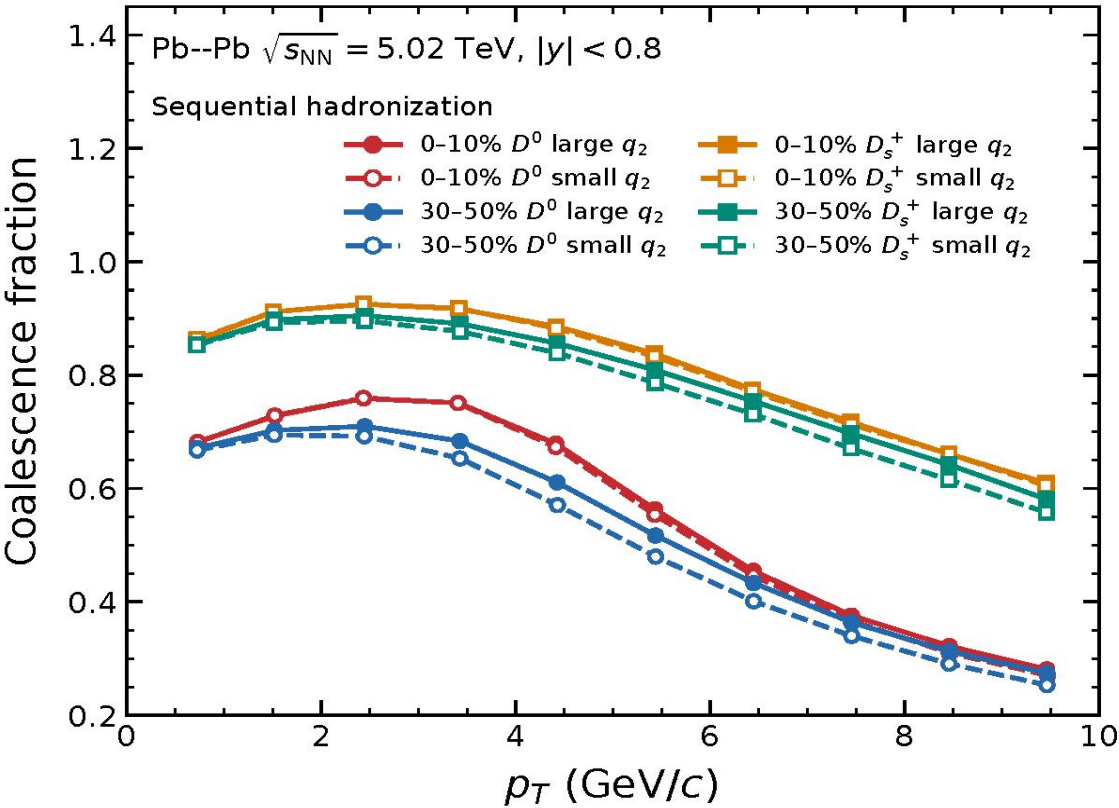
- Within a fixed centrality class, the large- q_2 and small- q_2 $\Delta\tau$ curves nearly overlap.
- In contrast, the corresponding Δv_2 shows a clear q_2 dependence.

ESE mainly probes the geometry-dependent charm-flow response, rather than a change in the hadronization-time interval.

ESE Flow Splitting Is Not Driven by Hadron Composition



Yield ratio: The D_s^+ / D^0 ratio is nearly unchanged between the large- q_2 and small- q_2 classes.



Coalescence fractions:
Weak dependence on q_2 for both D^0 and D_s^+

Control-test conclusion

The strong q_2 dependence of Δv_2 is therefore not driven by changes in relative yield or hadronization-channel composition.



Summary: ESE as a Differential Probe of Charm Hadronization

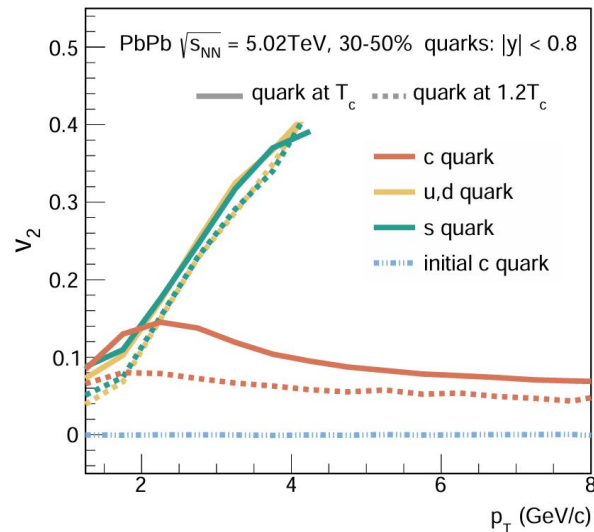
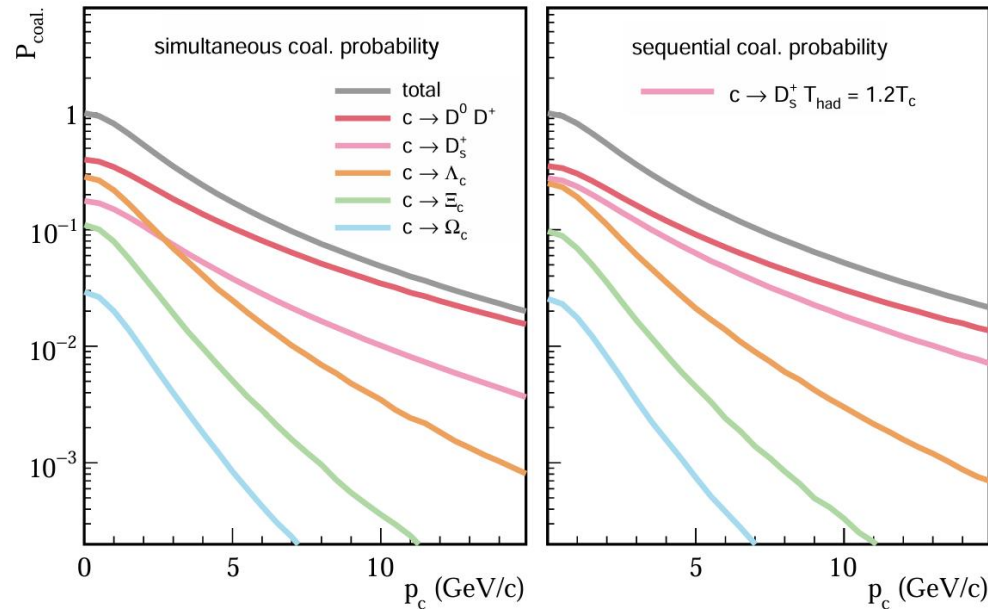
- Sequential hadronization generates a positive $D^0 - D_S^+$ flow splitting at intermediate p_T , while the simultaneous baseline does not.
- ESE amplifies this difference through a stronger q_2 response of D^0 than D_S^+ .
- Control tests show weak q_2 dependence of the formation-time interval, yield ratio, and coalescence fractions, supporting a dynamical-flow interpretation.

Thank you!

Questions & Discussion

Yu-Jie Huang | yujiehuang@cug.edu.cn

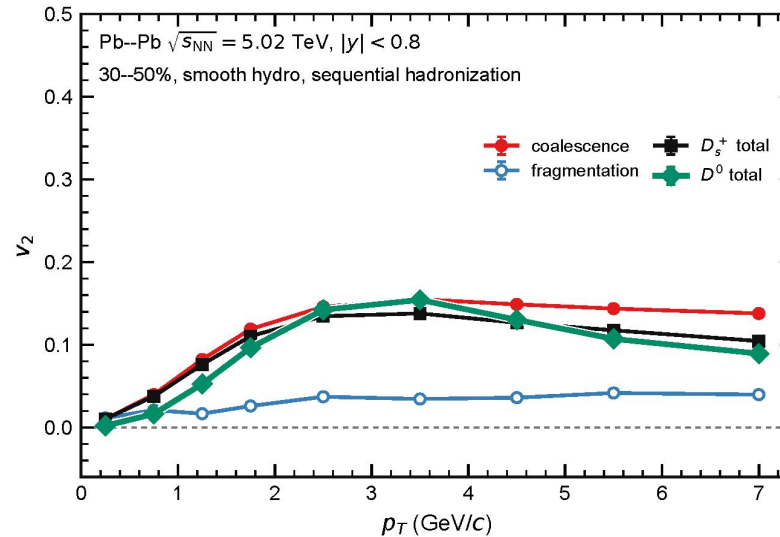
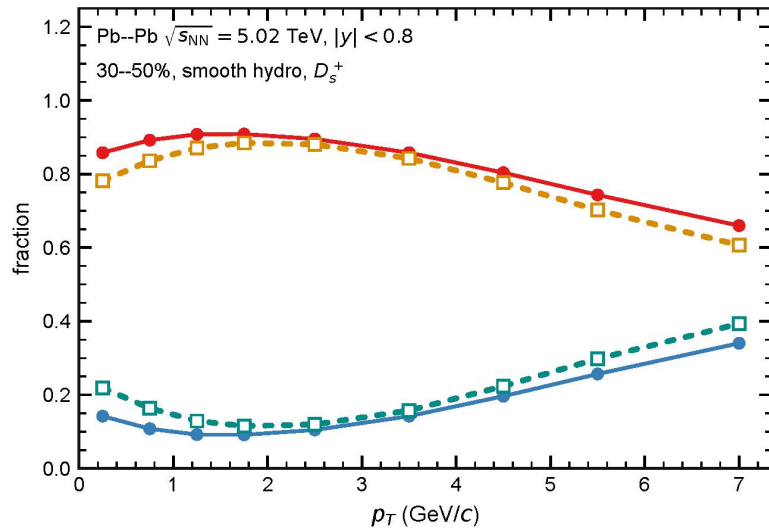
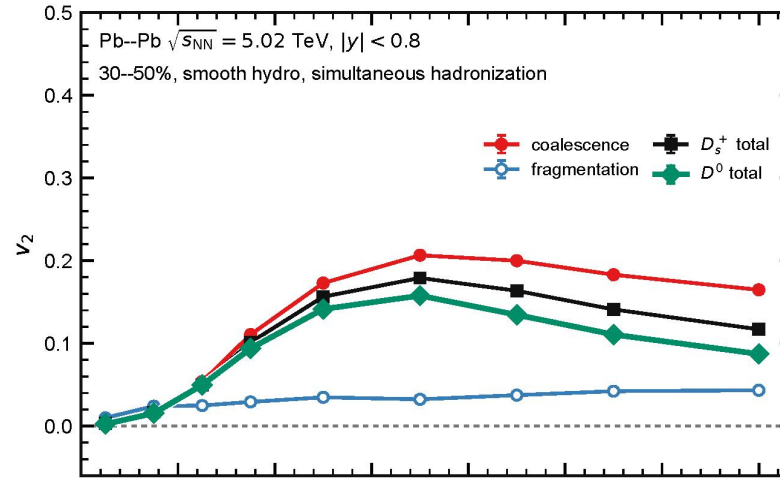
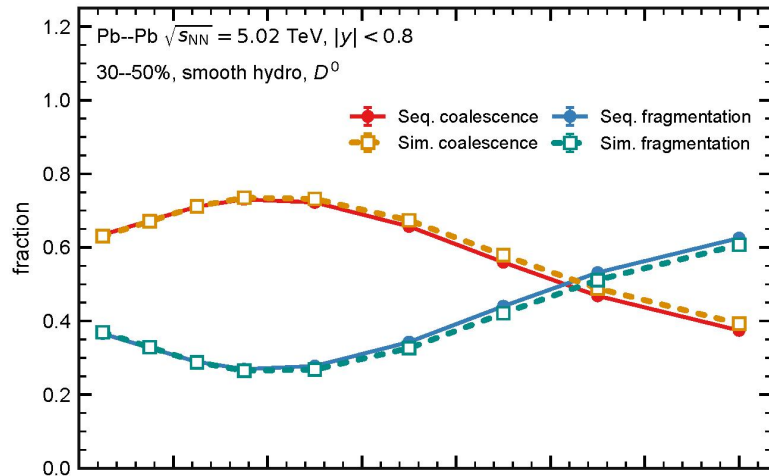
Sequential : Coalescence Sampling and Partonic Flow



- One extra sampling step at $1.2T_c$: try coalescing the charm quark into D_s^+ .
- Success: the D_s^+ is formed and the charm quark leaves the partonic phase.
- Failure: the charm quark keeps evolving to T_c , and hadronizes there.

Taking charm quarks out early changes the channel fractions; the ones that stay evolve longer and gain more flow.

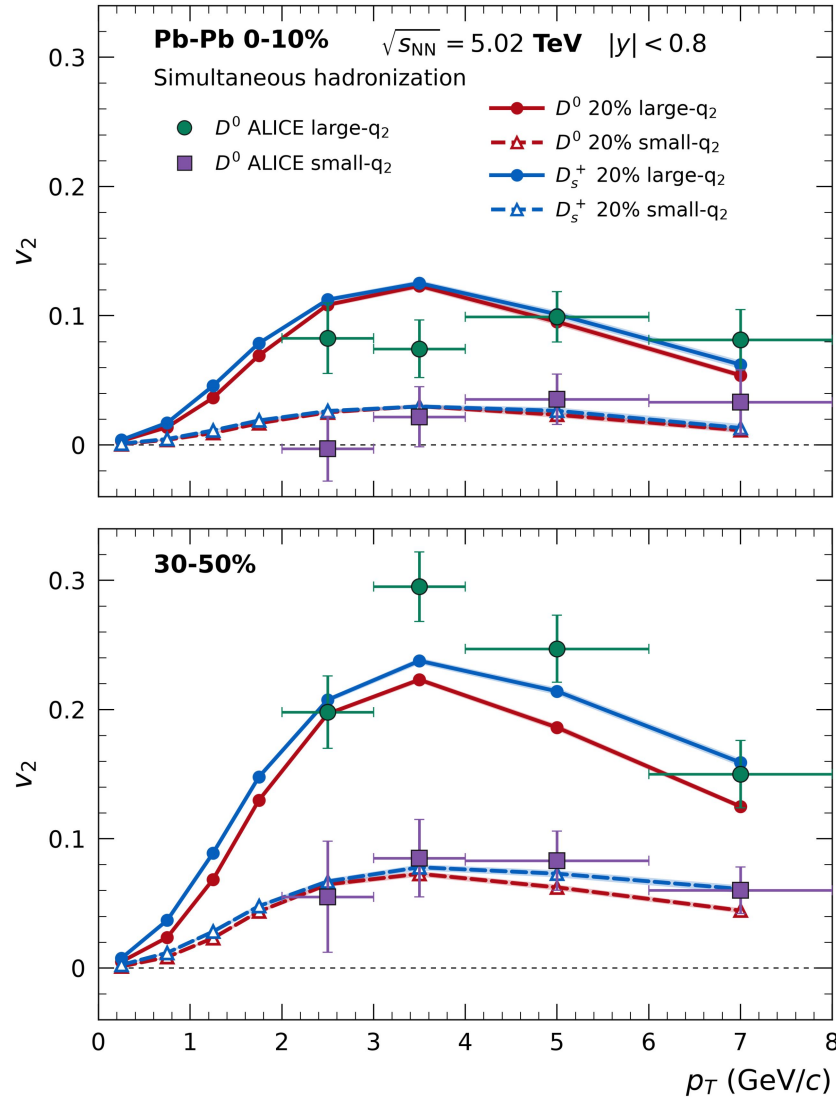
What Drives the Flow-Ordering Reversal?



- Sequential formation raises the D_s^+ coalescence fraction at $1.2T_c$; D^0 drops slightly. So the composition effect works against the data.
- Earlier D_s^+ formation reduces the partonic flow inherited by its coalescence component.

The reversal reduced partonic flow accumulation due to earlier hadronization, not from the composition change.

The Common- T_c Baseline Preserves the Ordering



- Large- q_2 events enhance the overall v_2 of both D^0 and D_s^+ .
- However, $v_2(D_s^+) > v_2(D^0)$ is preserved in both large- q_2 and small- q_2 classes.
- Thus, event-shape selection alone does not generate the hierarchy reversal.

The simultaneous baseline responds to ESE, but its species ordering remains unchanged.