Probe initial stages and final state interactions with heavy flavor spectra and DD̄ correlations in PbPb

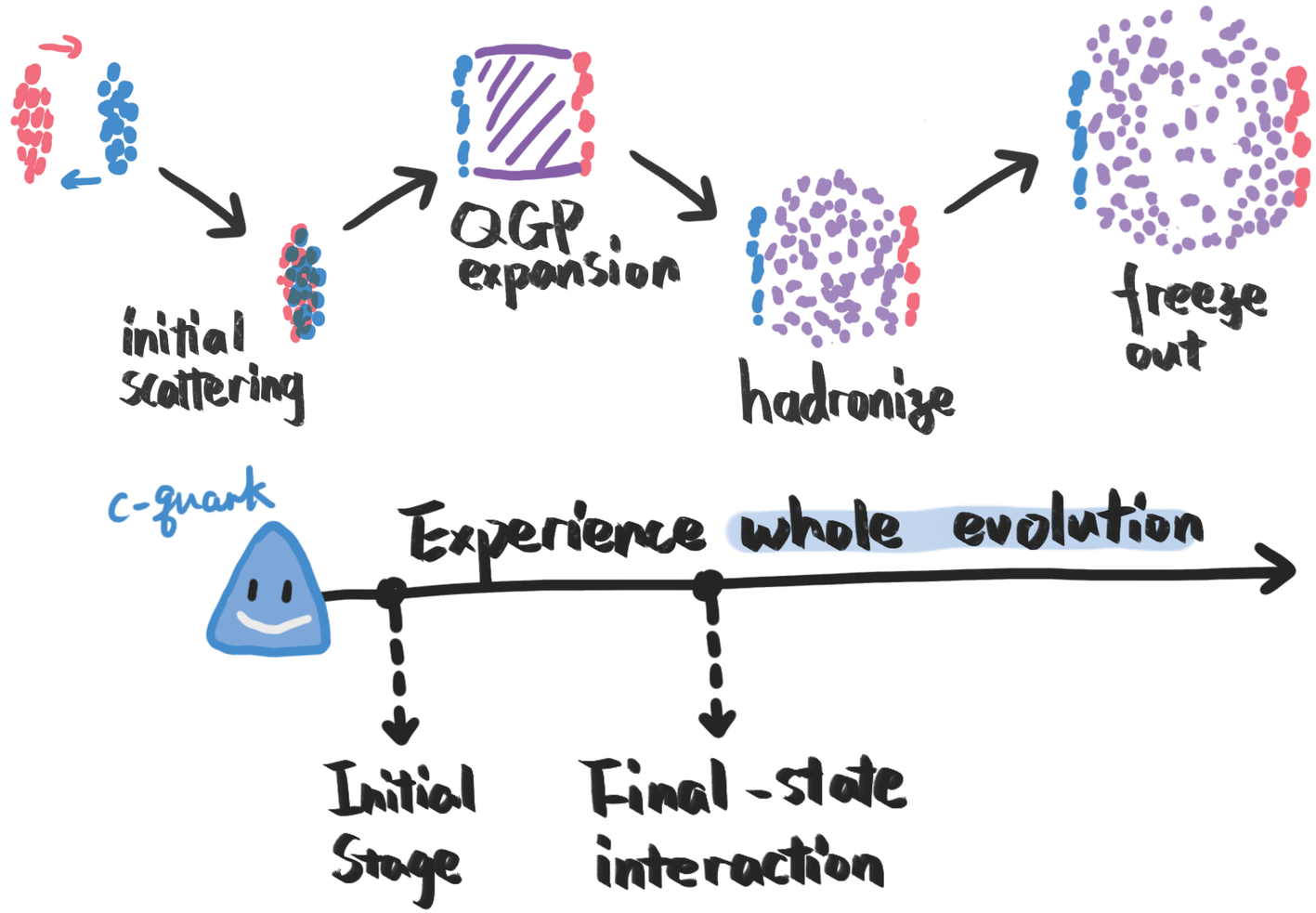
Jing Wang
for the CMS Collaboration

The 6th International Conference on the Initial Stages
of High-Energy Nuclear Collisions
2021.1.11

The MIT HIG's work is supported by US DOE-NP

Probe IS + FS interactions: why HF? (1/4)

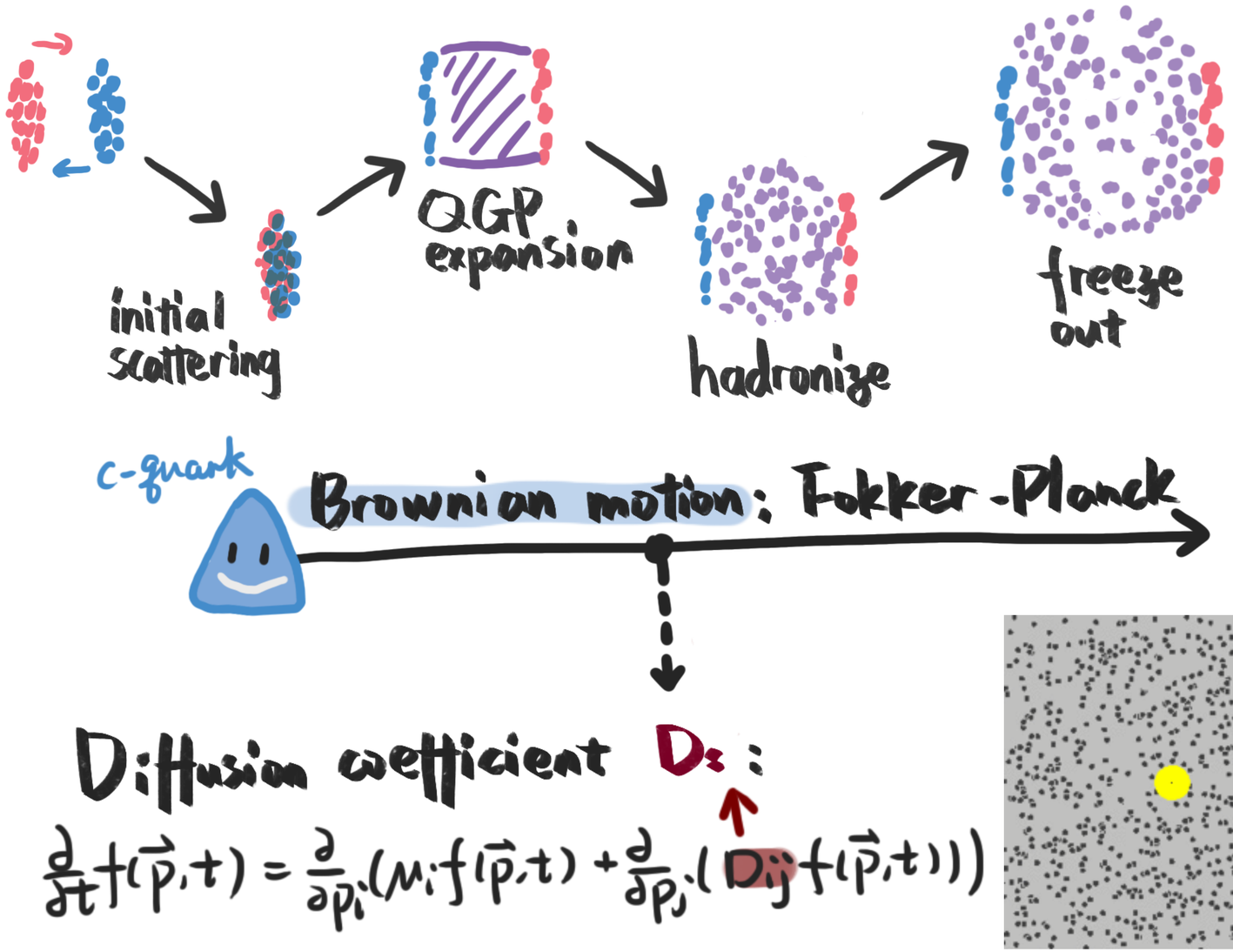
- **Slow but hard:** produced in early hard process even at low p_T ($Q \sim m_c, m_b$, $\tau \sim 1/Q$)



Probe IS + FS interactions: why HF? (2/4)

- **Slow but hard:** produced in early hard process even at low p_T ($Q \sim m_c, m_b$, $\tau \sim 1/Q$)

- **"Simple":** Brownian motion diffusion, diffusion coefficient D_s ($m_c, m_b \gg T_{QGP}$)

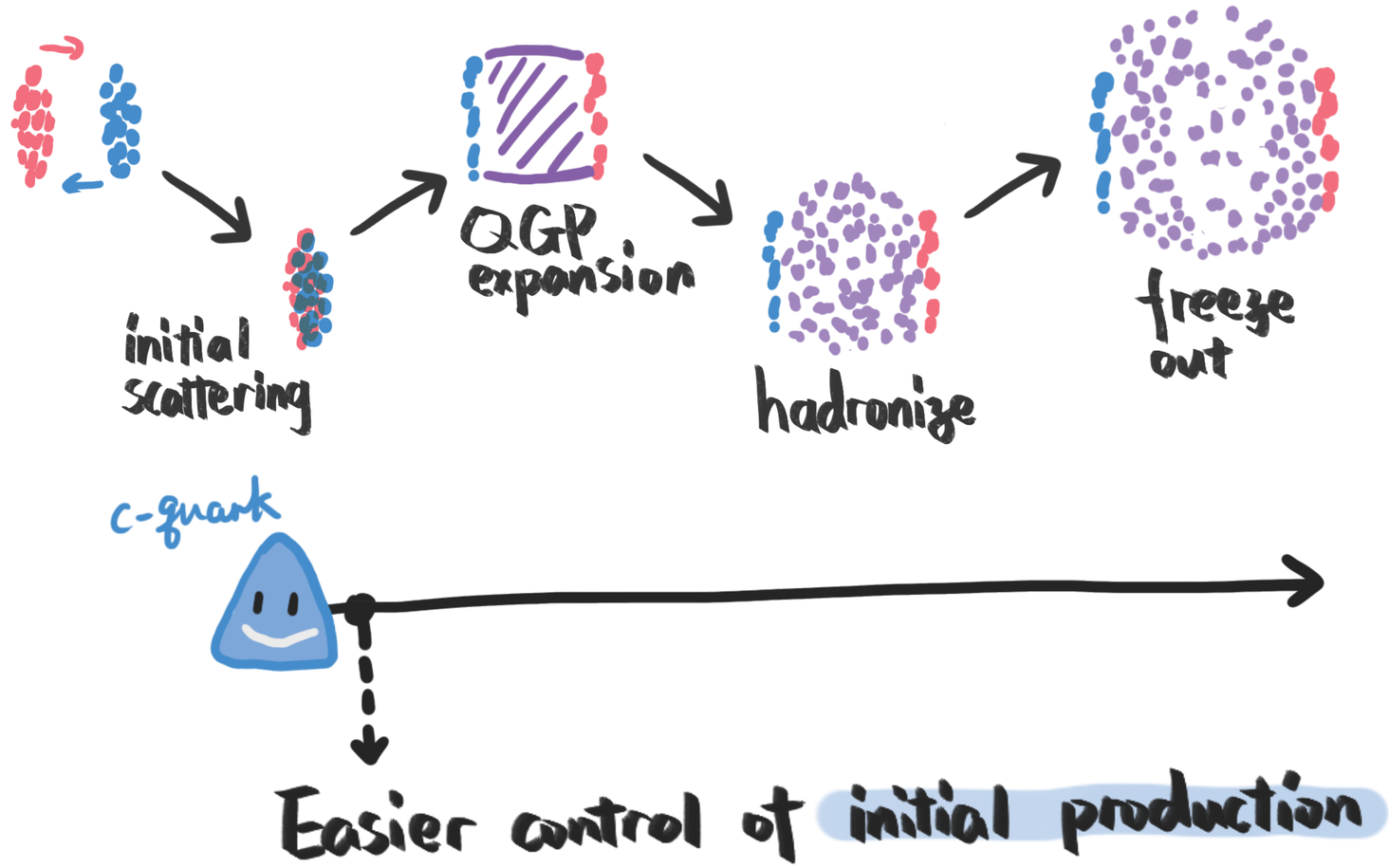


Probe IS + FS interactions: why HF? (3/4)

- **Slow but hard:** produced in early hard process even at low p_T ($Q \sim m_c, m_b, \tau \sim 1/Q$)

- **"Simple":** Brownian motion diffusion, diffusion coefficient D_s ($m_c, m_b \gg T_{QGP}$)

- **"Feasible":** production calculable with pQCD at low p_T ($m_c, m_b \gg \Lambda_{QCD}$)



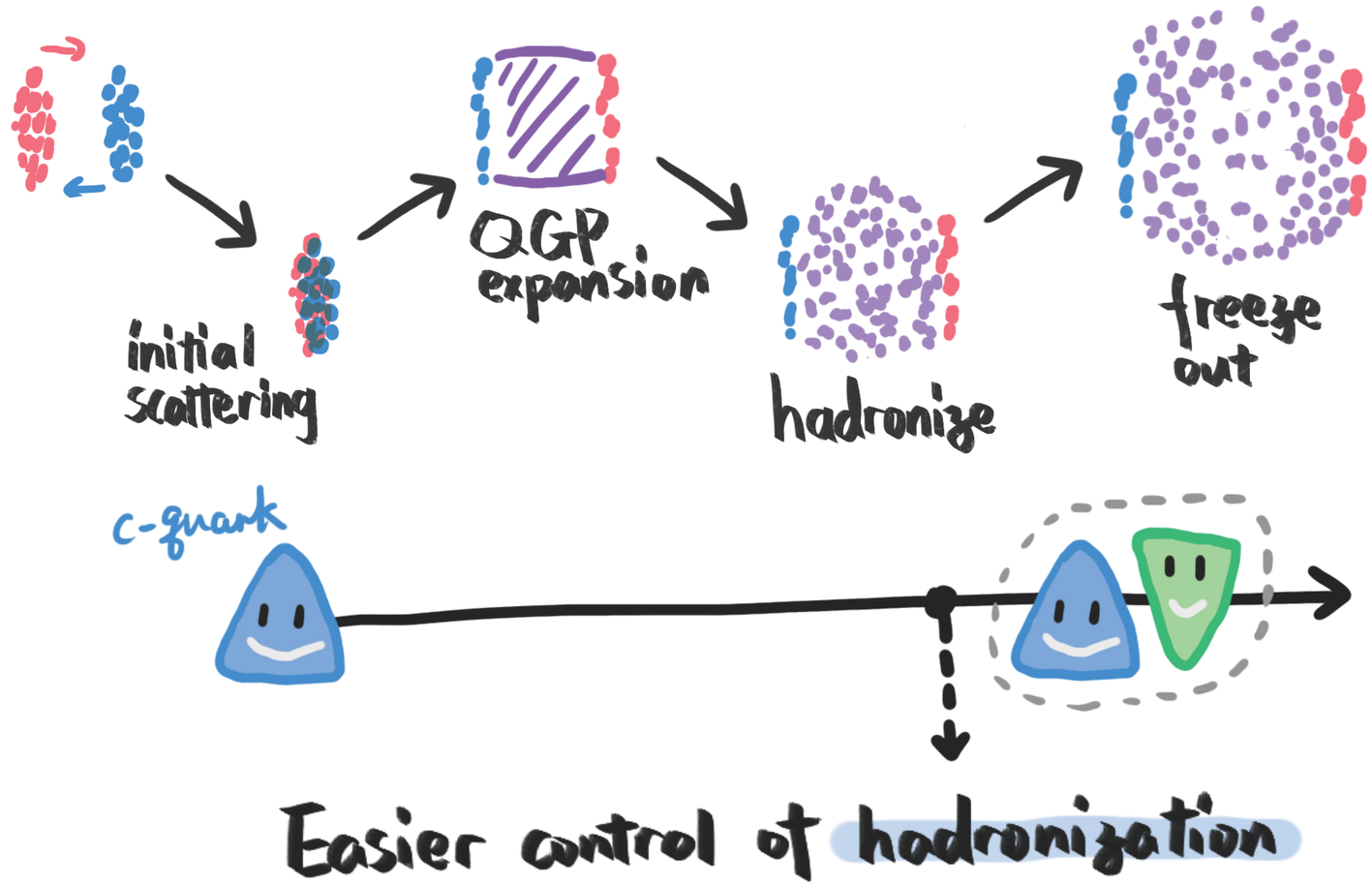
Probe IS + FS interactions: why HF? (4/4)

- **Slow but hard:** produced in early hard process even at low p_T ($Q \sim m_c, m_b, \tau \sim 1/Q$)

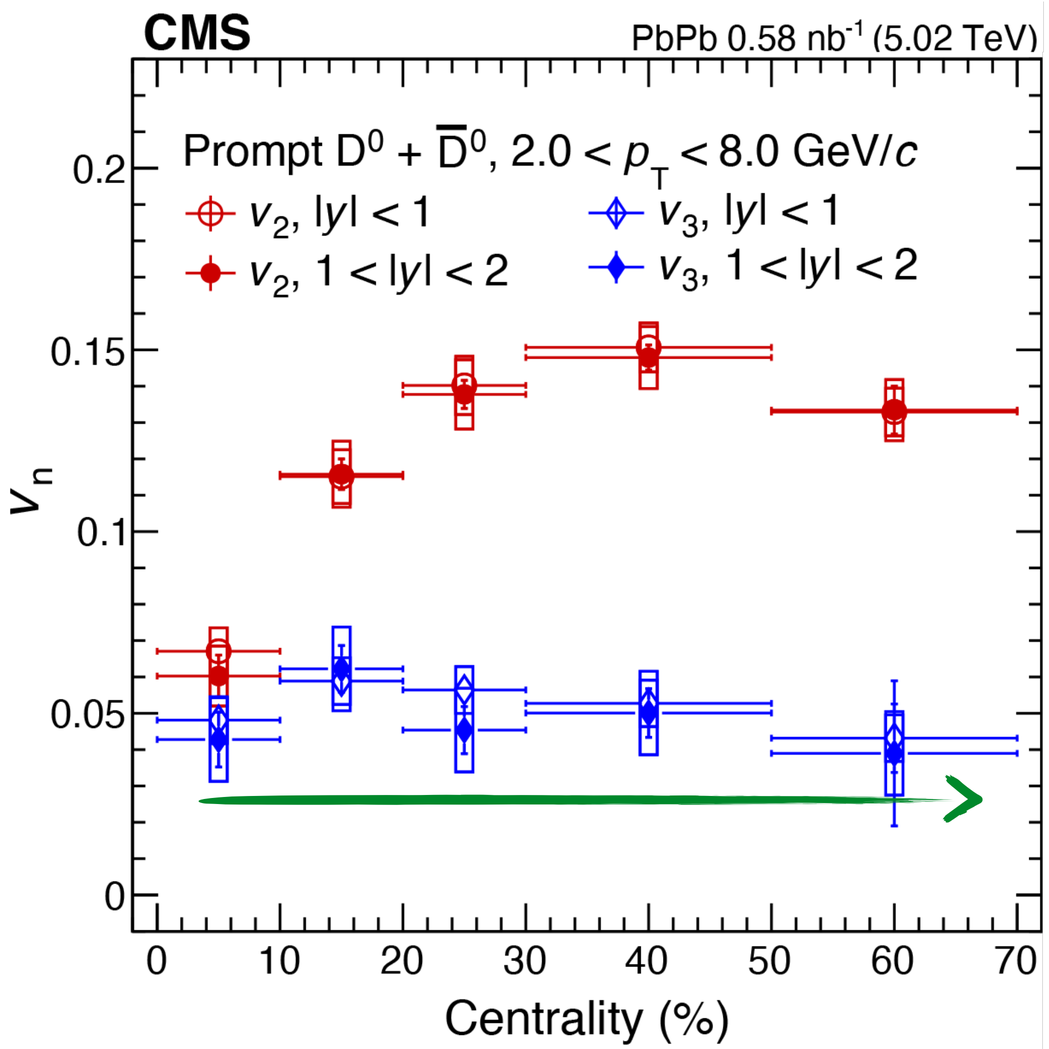
- **"Simple":** Brownian motion diffusion, diffusion coefficient D_s ($m_c, m_b \gg T_{QGP}$)

- **"Feasible":** production calculable with pQCD at low p_T ($m_c, m_b \gg \Lambda_{QCD}$)

- **Clean:** hardly produced in medium ($m_c, m_b \gg T_{QGP}$)



Probe Initial Stage: Prompt D^0 v_3

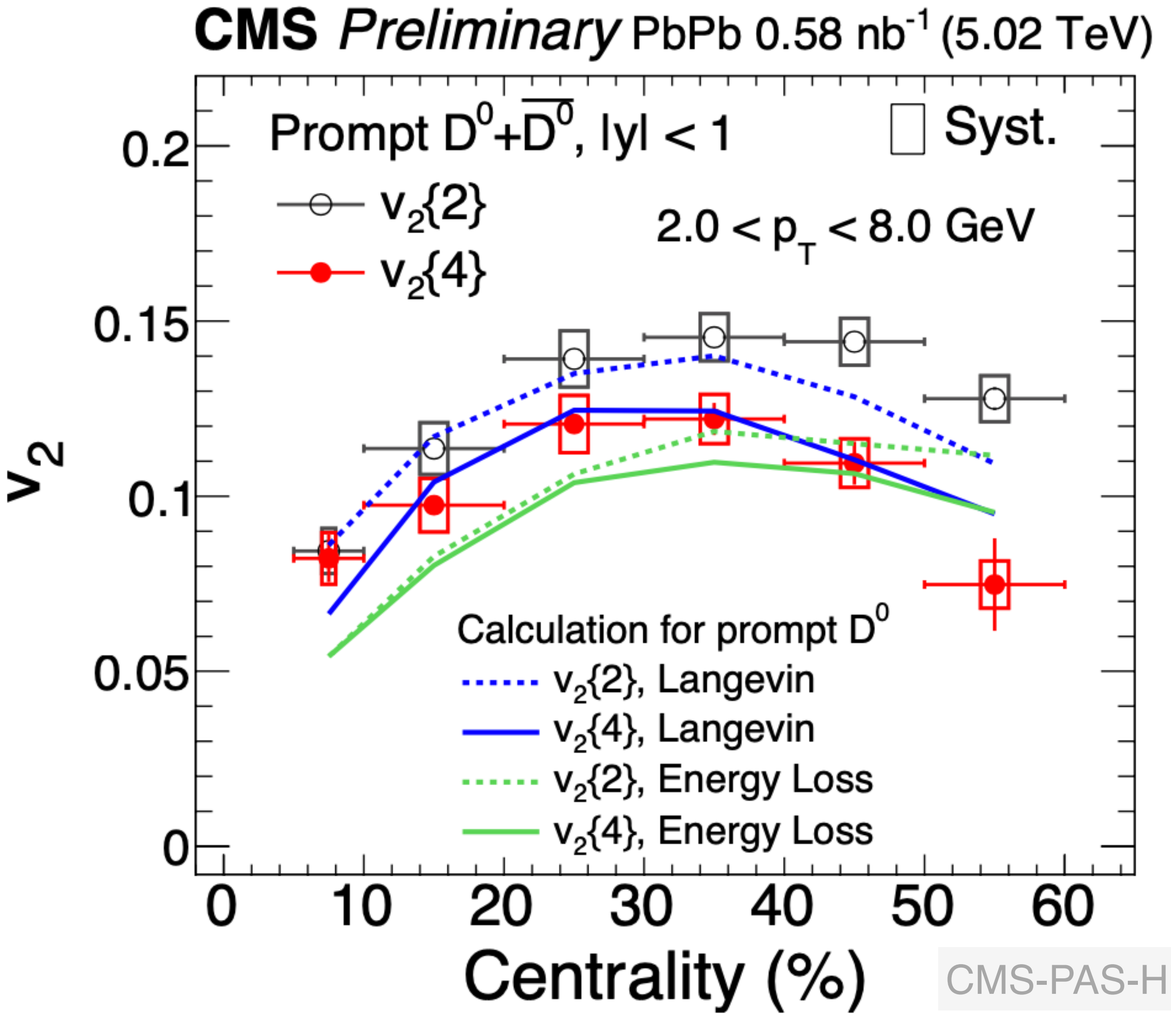


Prompt D^0 v_3 coefficients

- Non-zero v_3
  ➡ Heavy quarks can also probe initial geometry
- No obvious centrality dependence as expected
  ➡ Opposite to v_2
- No rapidity dependence

arXiv:2009.12628
Submitted to PLB

Probe Initial Stage: Prompt D^0 $v_2\{4\}$



D^0 + 3 charged particles D^0 + 1 charged particle

Prompt D^0 $v_2\{4\}$ compared to $v_2\{2\}$

- Probe event-by-event fluctuations

flow fluctuation

➡ $v_n\{2\}^2 \approx \langle v \rangle^2 + \delta + \sigma^2$, $v_n\{4\}^2 \approx \langle v \rangle^2 - \sigma^2$,

non-flow : negligible

- Fluctuations include initial geometry (low-p_T) and energy loss (high-p_T) fluctuation
- D^0 $v_2\{4\}$ < $v_2\{2\}$: charm quark can probe the E-by-E fluctuation by multi-particle correlation

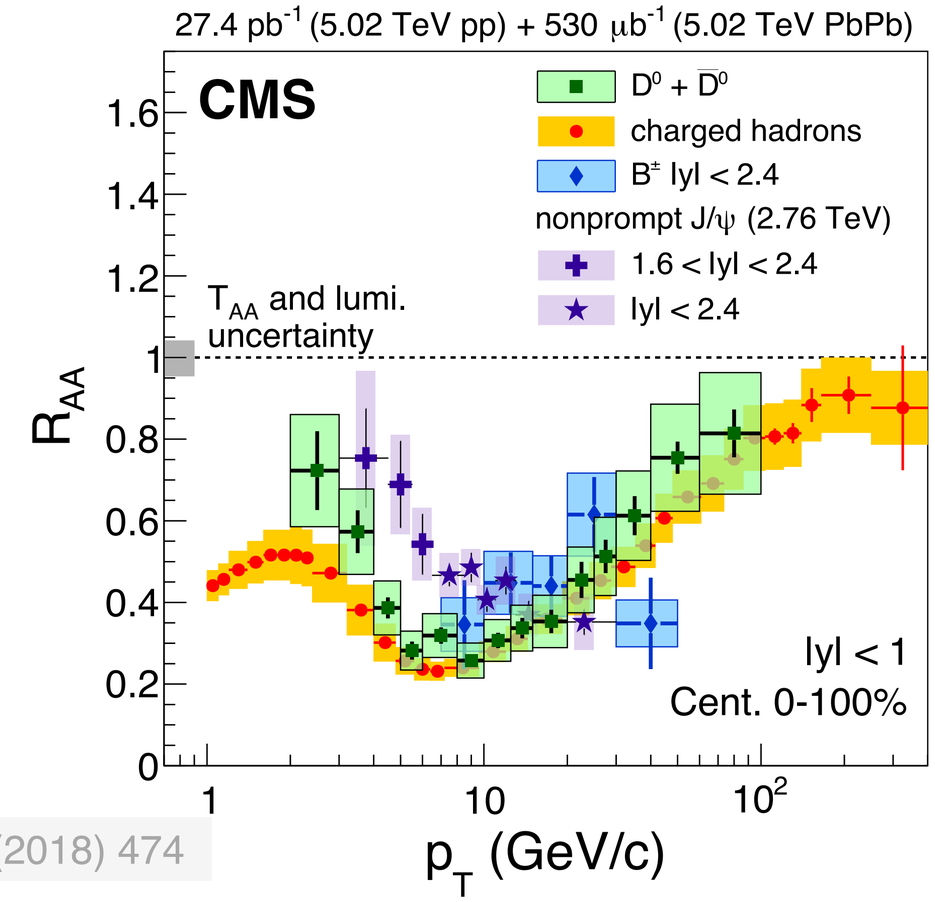
CMS-PAS-HIN-20-001

PRC 102 (2020) 024906

More details see Liuyao's talk

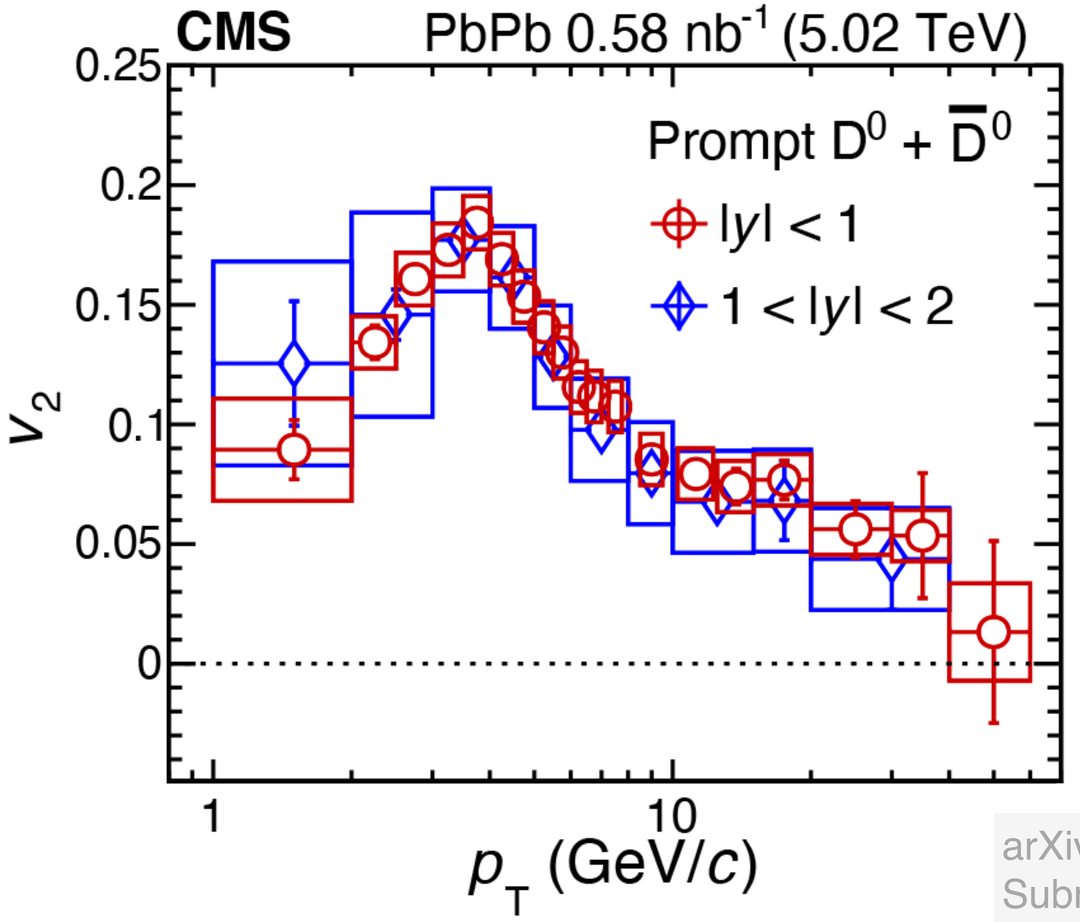
Probe Final-state Interaction: Spectra + Corr

R_{AA}



PLB 782 (2018) 474

v_2

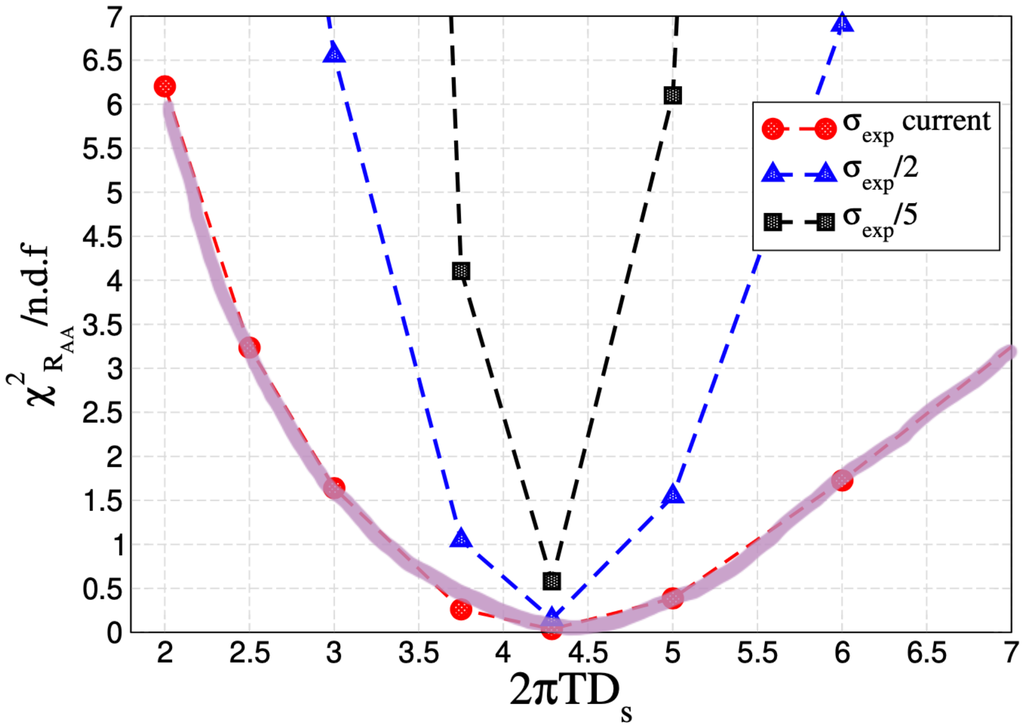


arXiv:2009.12628
Submitted to PLB

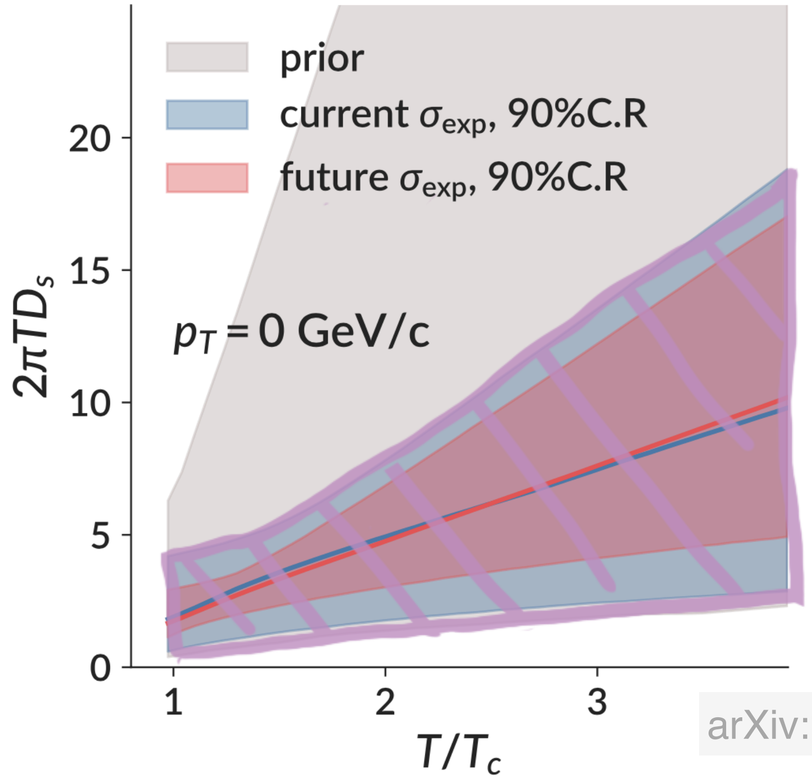
- Classic observables: R_{AA} and v_2 have been measured widely in heavy flavor regime

Extract Diffusion coefficient D_s

D_s extracted (Catania)



D_s extracted (LBT)

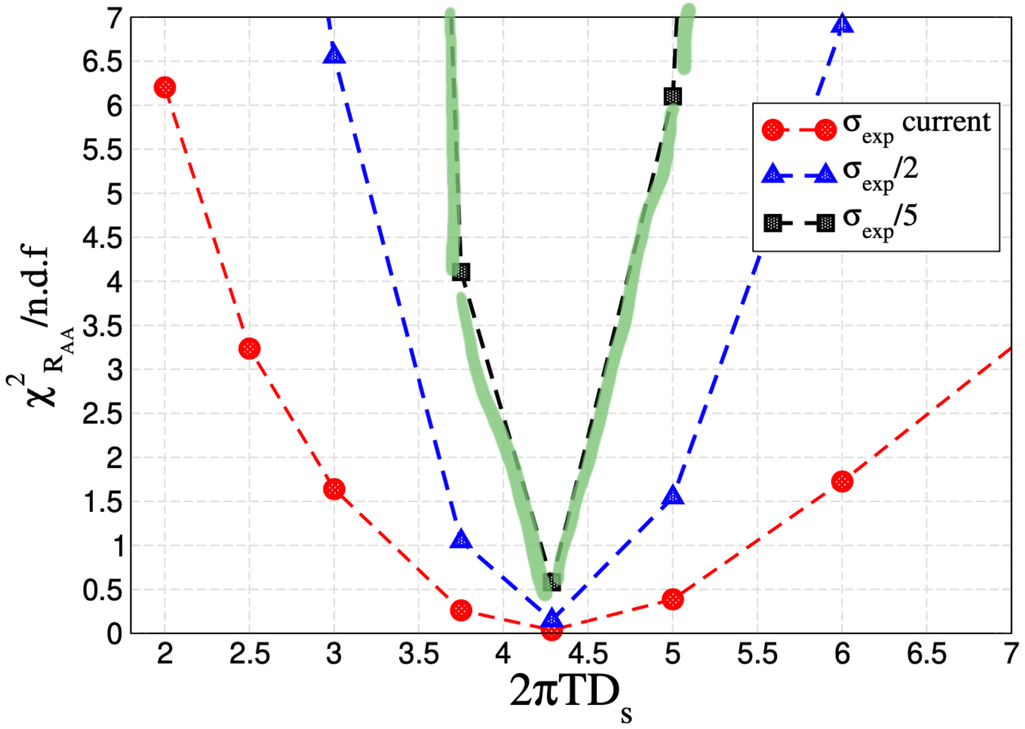


arXiv:1812.06772

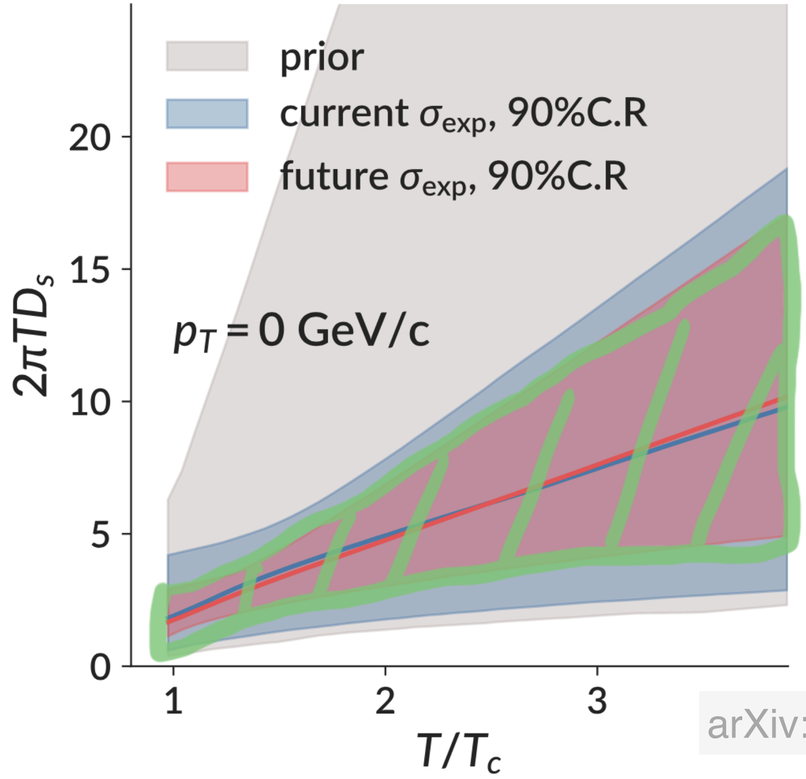
- D_s can be extracted by combining R_{AA} and v_2 measurements

Diffusion coefficient D_s at statistics limit

D_s projection after Run 4 (Catania)



D_s projection after Run 4 (LBT)

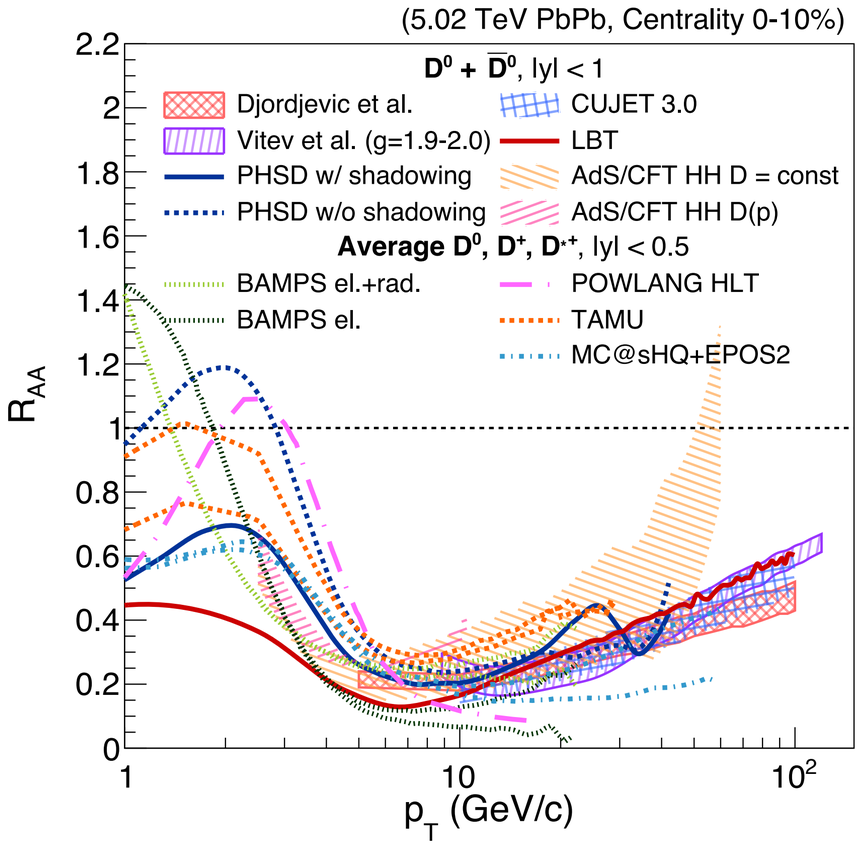


arXiv:1812.06772

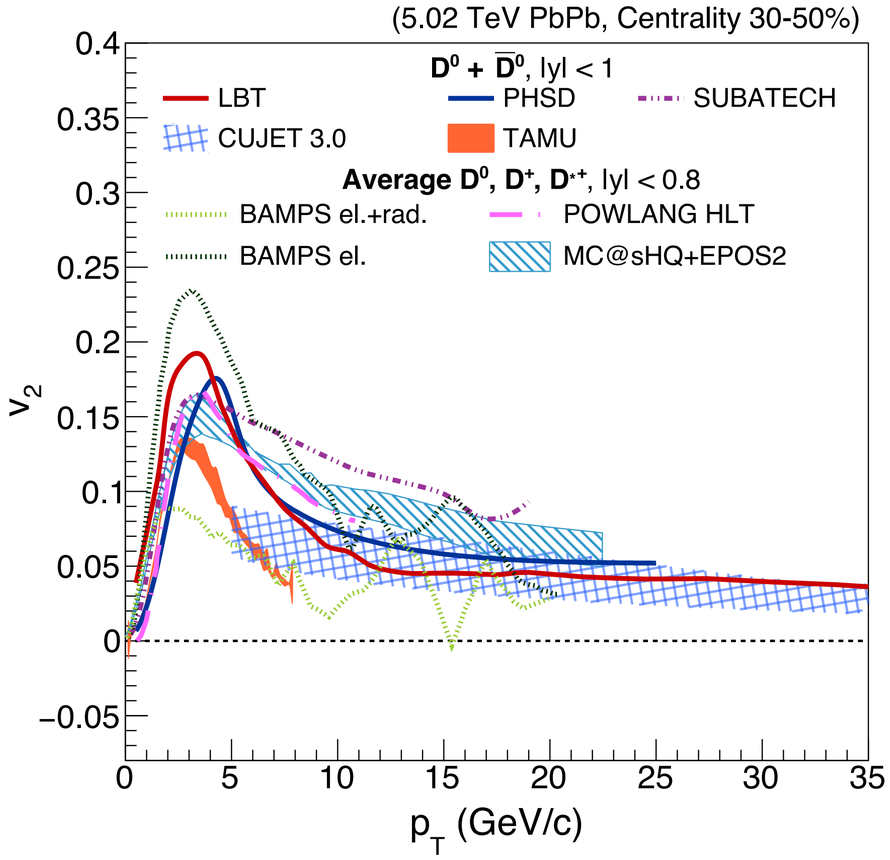
- D_s can be extracted by combining R_{AA} and v_2 measurements
- D_s still not ideally determined at statistics limit

Observables: R_{AA} and v_2

D R_{AA} models



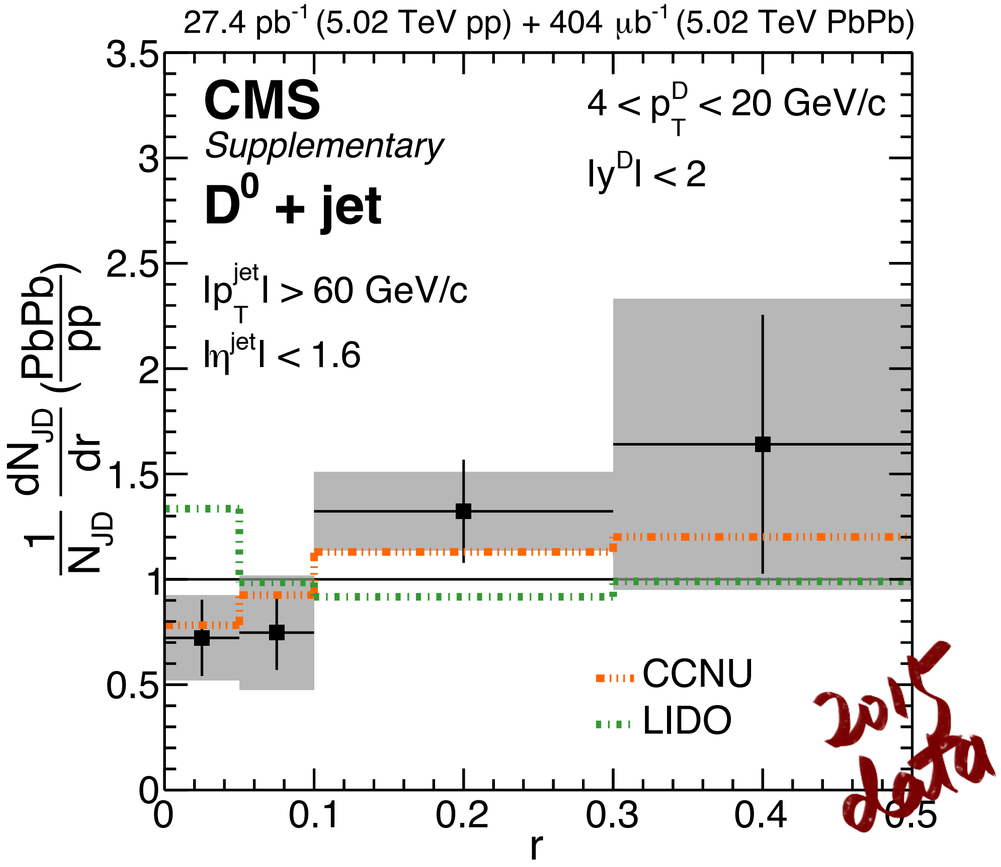
D v_2 models



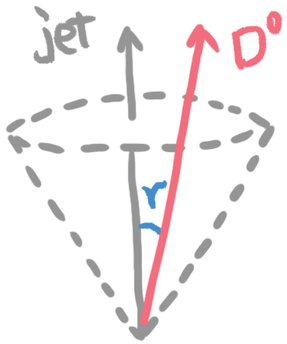
- R_{AA} and v_2 have weak discrimination power for energy loss mechanisms, diffusion coefficients and other model ingredients

Observables: Correlation

D-jet correlation vs. models



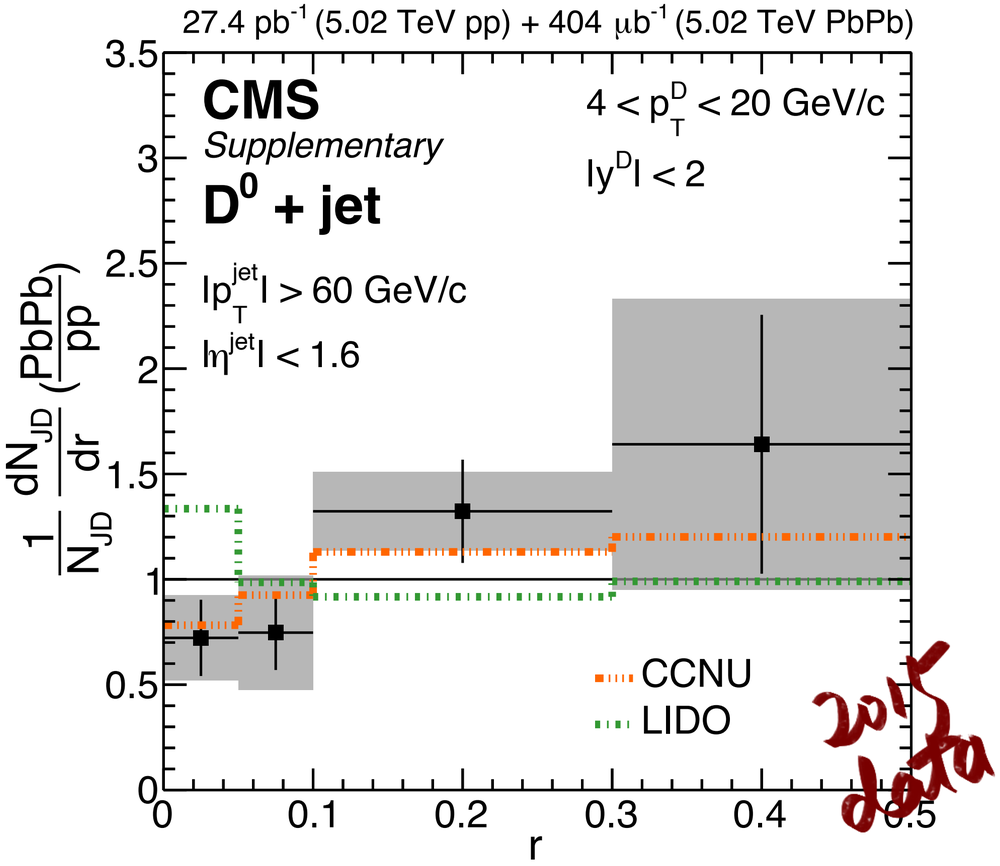
- Correlation is a more sensitive observable than inclusive R_{AA} and v_2
- D-jet correlation measured with 2015 data
  - ➡ first measurement of D^0 w.r.t. dominant energy flow axis
  - ➡ will update with 2018 data (higher statistics)



PRL 125 (2020) 102001

Observables: Correlation

D-jet correlation vs. models

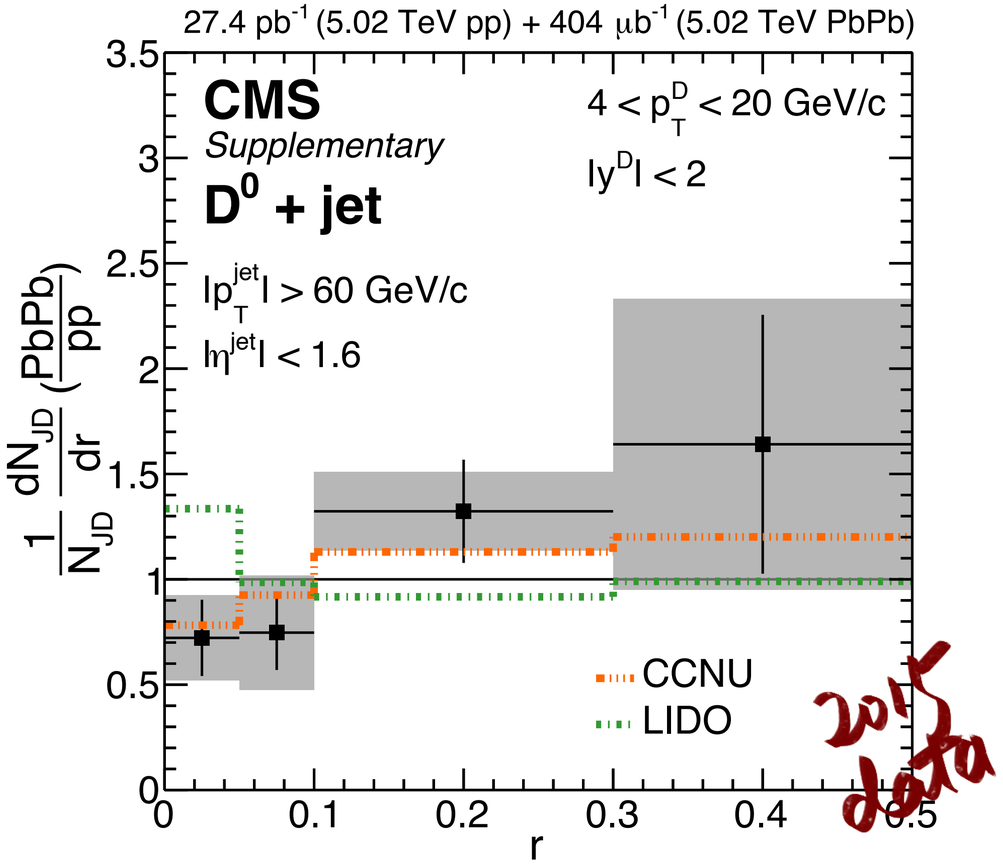


PRL 125 (2020) 102001

- Correlation is a more sensitive observable than inclusive R_{AA} and v_2
- D-jet correlation measured with 2015 data
  - ➡ first measurement of D^0 w.r.t. dominant energy flow axis
  - ➡ will update with 2018 data (higher statistics)
- However
  - ➡ Convoluted with complex jet shape modification and complication of jet calculation

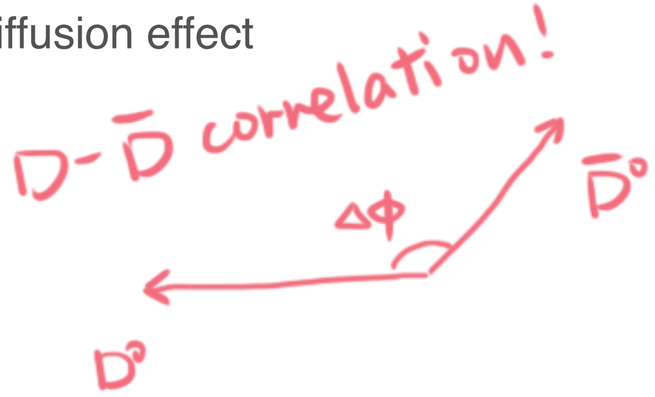
Observables: D-D̄ Correlation

D-jet correlation vs. models



PRL 125 (2020) 102001

- Correlation is a more sensitive observable than inclusive R_{AA} and v_2
- D-jet correlation measured with 2015 data
  - ➡ first measurement of D^0 w.r.t. dominant energy flow axis
  - ➡ will update with 2018 data (higher statistics)
- However
  - ➡ Convoluted with complex jet shape modification and complication of jet calculation
- D-D̄ correlation
  - ➡ Double the magnitude of diffusion effect
  - ➡ Low p_T accessible



D-D̄ Correlation Analysis

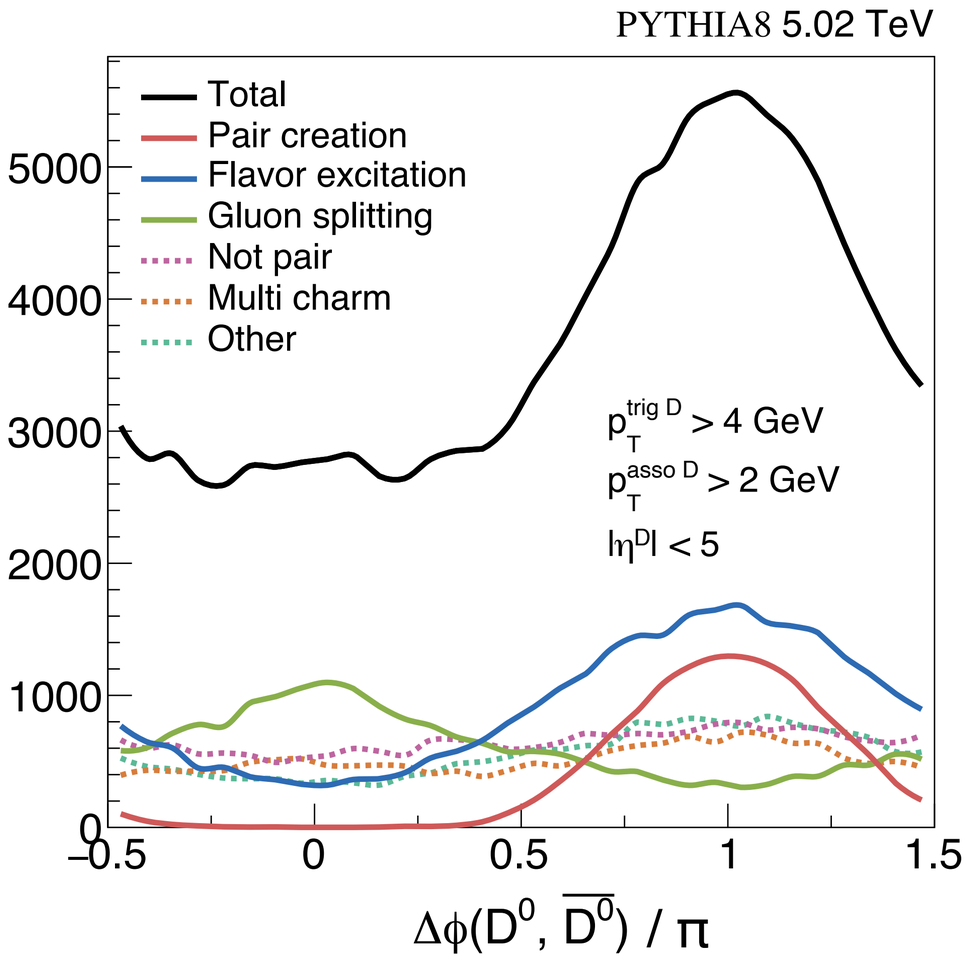
Analyzer

We are still working on it…
2018 data stats are feasible for this analysis

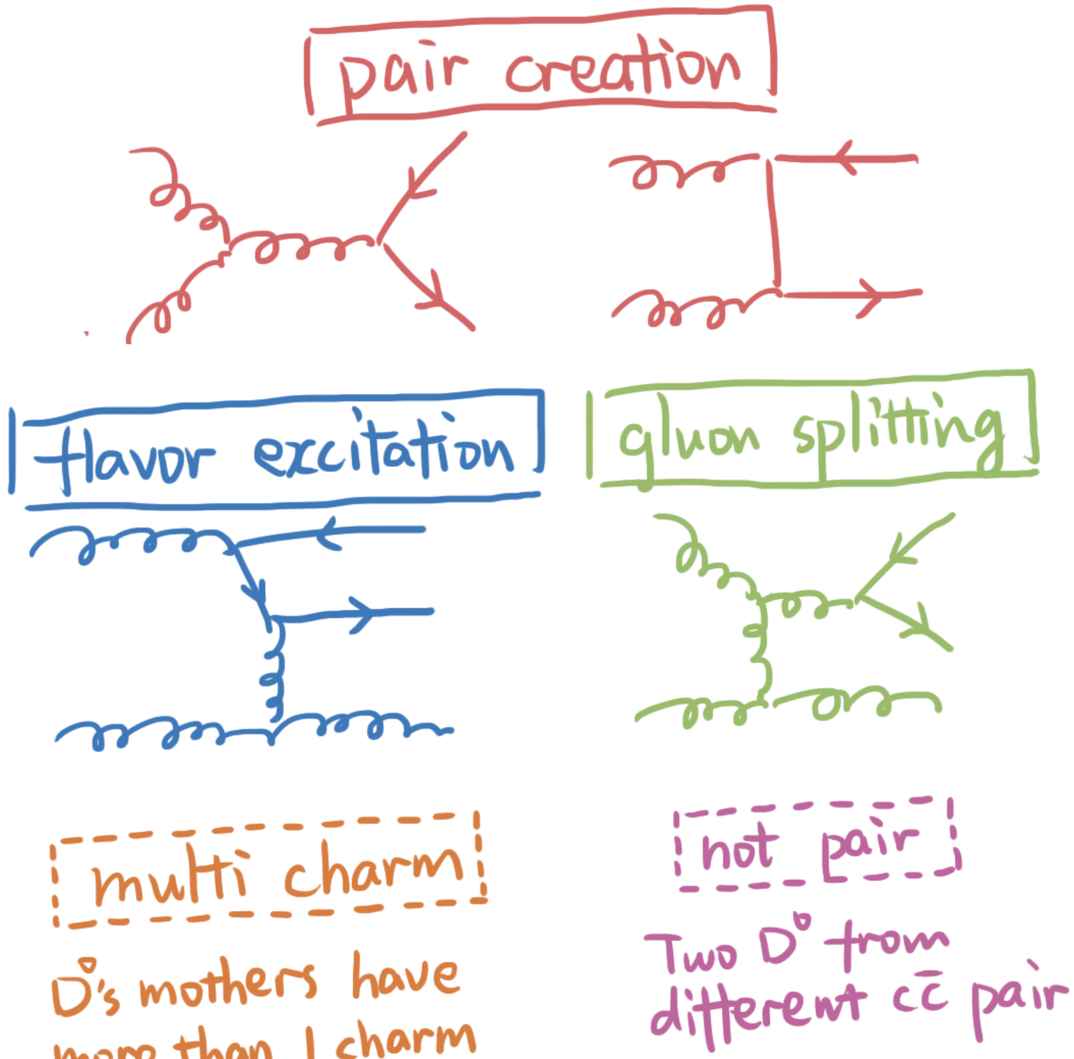
Analyzer

Looking forward to theoretical predictions!

D-D̄ Correlation in PYTHIA8

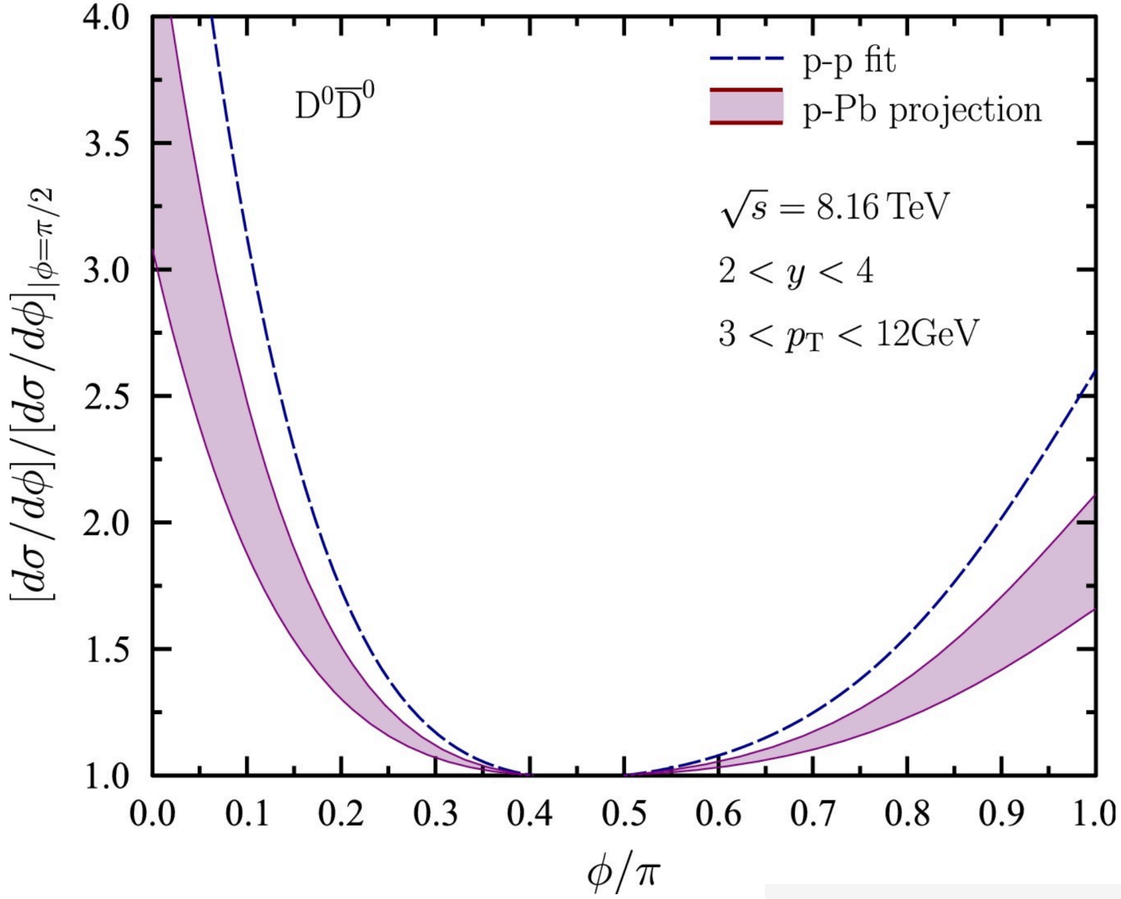


- Disclaimer: PYTHIA is LO generator
  ➡ NLO processes not accurate



D-D̄ Correlation in pPb

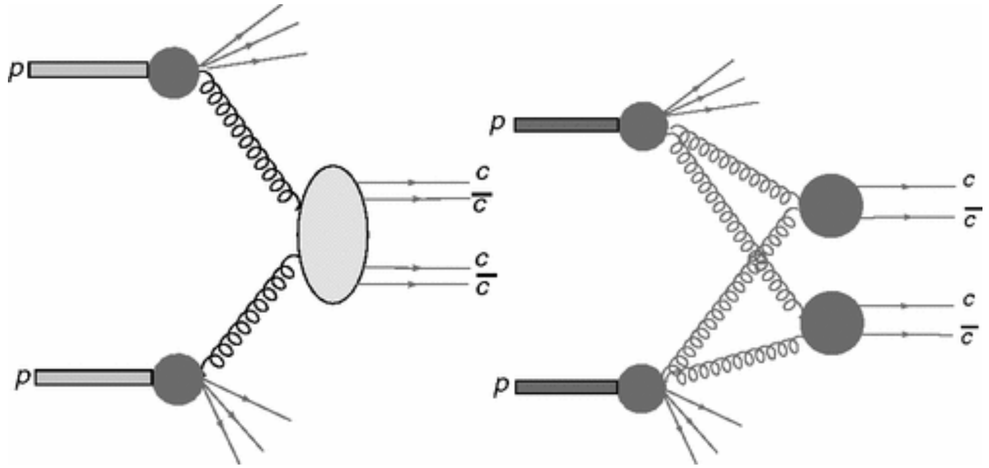
ΔΦ(DD̄) in pPb



- D-D̄ Correlation has been explored in pPb
  - ➡ to study SPS and DPS processes
  - ➡ theoretically [0] and experimentally [1]

Single parton scattering

Double parton scattering



[0] PLB 800 (2020) 135084
[1] PRL 125 (2020) 212001

PRD 85 (2012) 094034

More details see Hannu's talk

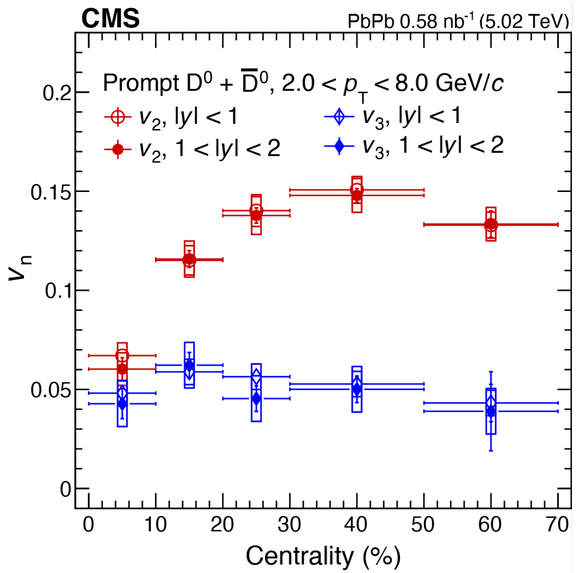
Summary

- Prompt D^0 v_3 and $v_2\{4\}$ have been measured to probe the initial stages of QGP

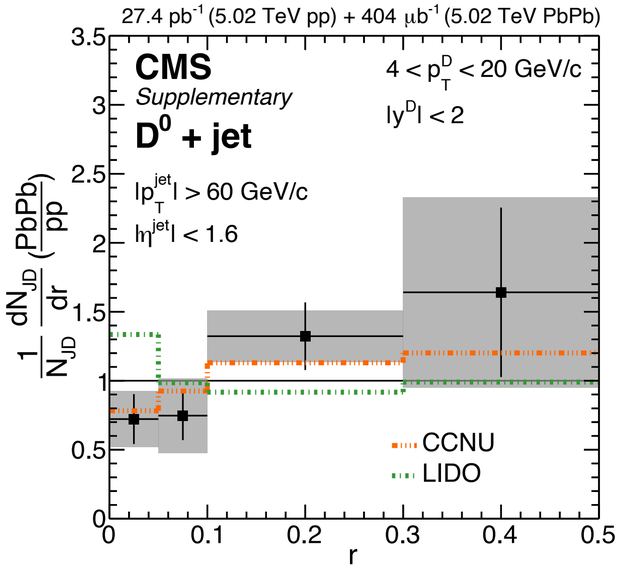
- Correlation between D^0 and jets have been measured
  ➡ more sensitive observable than R_{AA} and v_2

- D-$\bar{D}$ correlation measurement is under analyzing
  ➡ avoid complication in jet calculation
  ➡ lower p_T regime accessible

Thanks for your attention!



arXiv:2009.12628

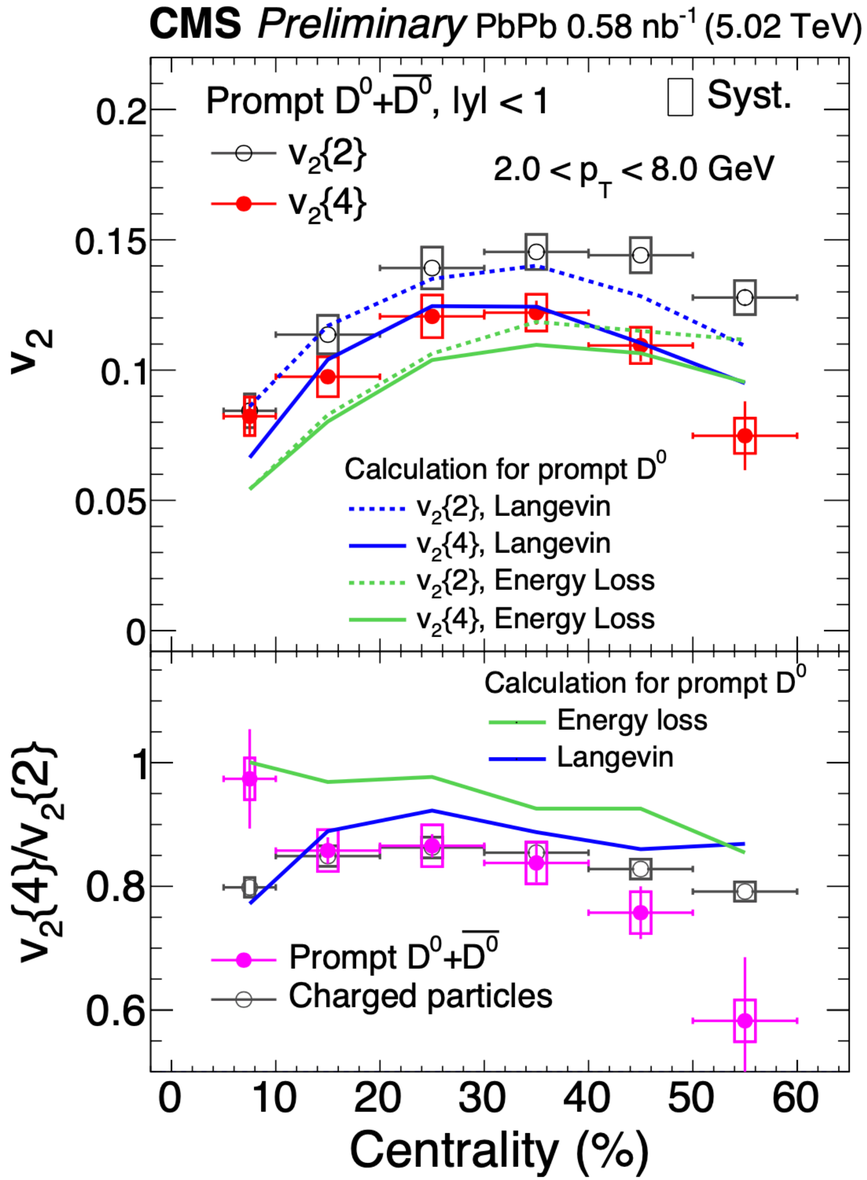


PRL 125 (2020) 102001

Back up

Thanks for your attention!

$v_2\{4\}$: D^0 vs. charged particles



CMS-PAS-HIN-20-001

- $v_2\{4\}/v_2\{2\}$ ratio
  - ➡ Charged particles: initial geometry (soft) fluctuation dominates
  - ➡ D^0 vs. charged particles: energy loss (hard) fluctuation

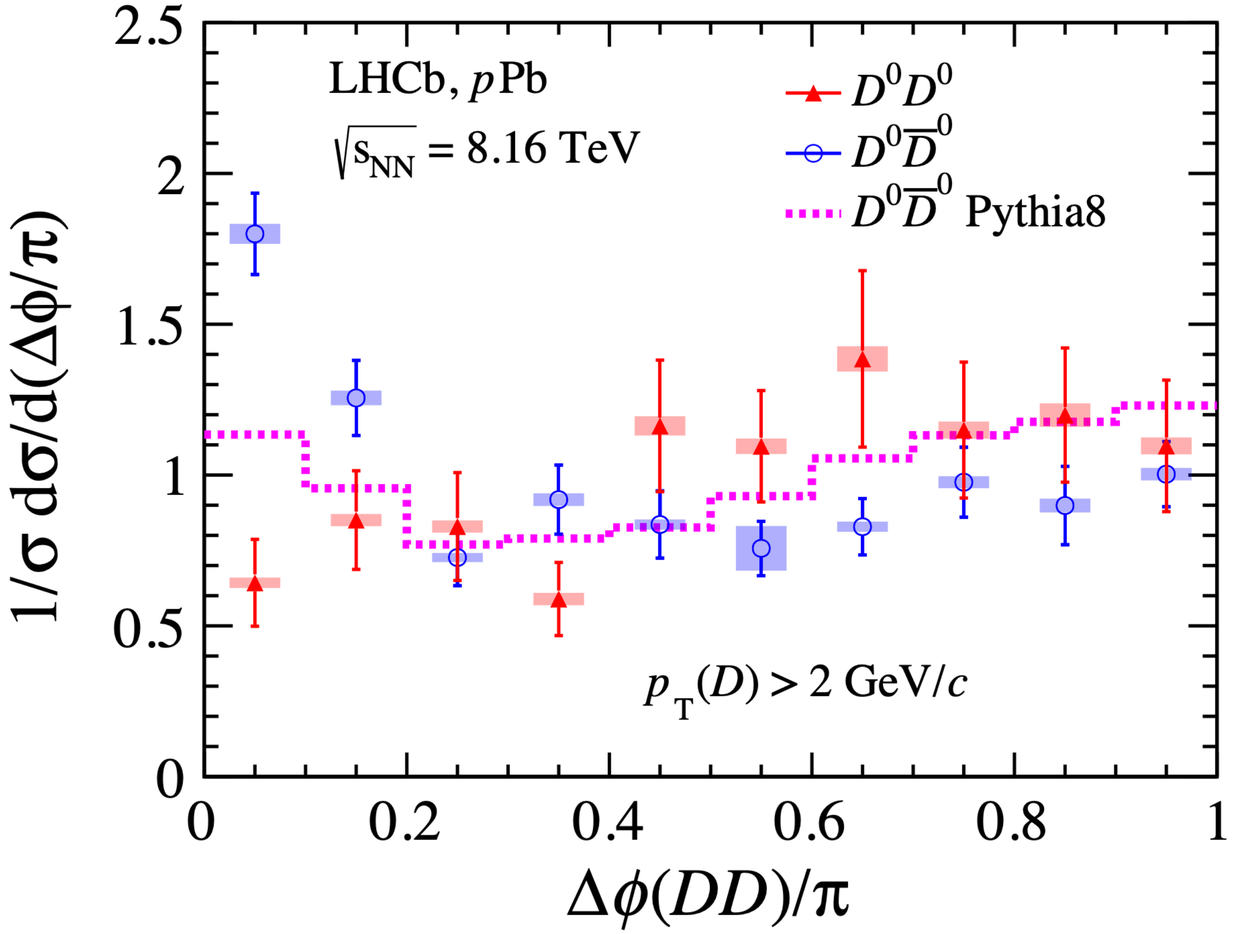
- Theory curves PRC 102 (2020) 024906
  - ➡ HQ interaction models (DAB-MOD)
    - ✓ Energy loss: parameterize dE/dx
    - ✓ Langevin: parameterize Ds
  - ➡ Initial conditions
    - ✓ MCKLN: a CGC k_T-factorization model
    - ✓ Trento: tuned to IP-Glasma

Charged particles

Prompt D^0

D-D̄ Correlation in pPb

PRL 125 (2020) 212001



PLB 800 (2020) 135084