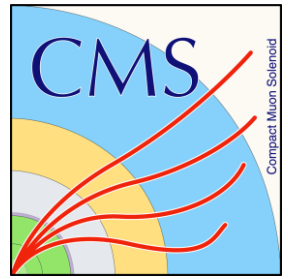
Probing QCD medium effects in pPb collisions via heavy flavor productions and correlations with the CMS experiment

Yousen Zhang

for the CMS experiment

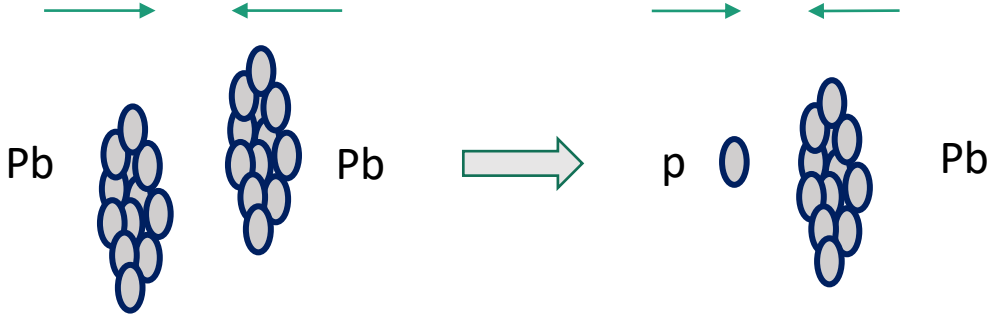
Rice University



Hard Probes 2020

June 1, 2020

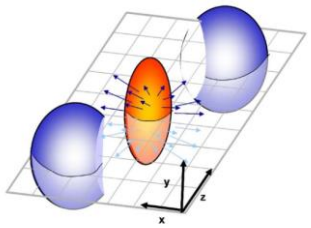
Collectivity in small systems

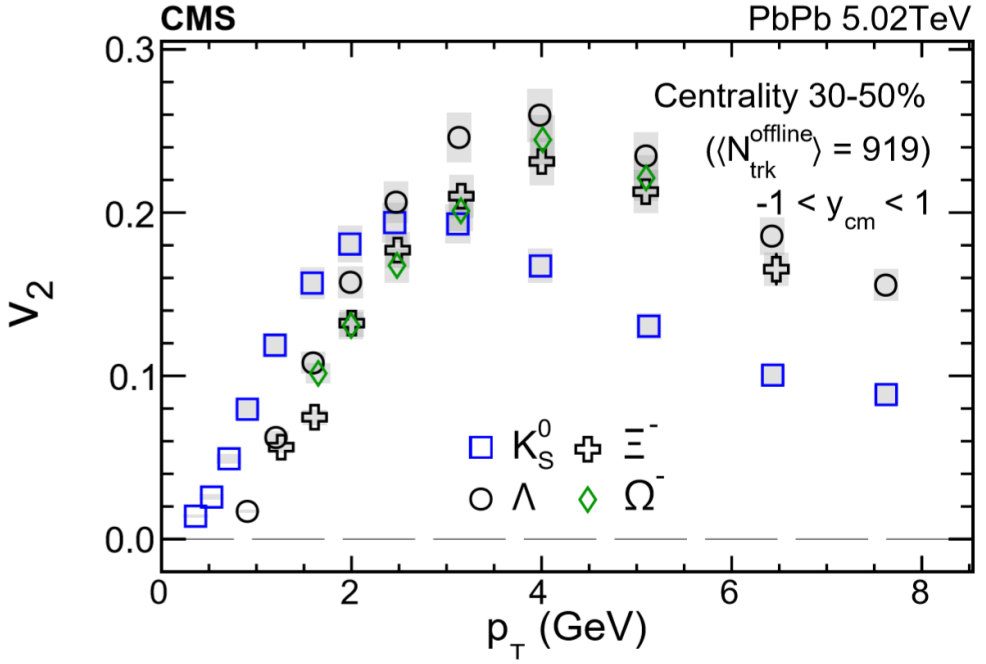


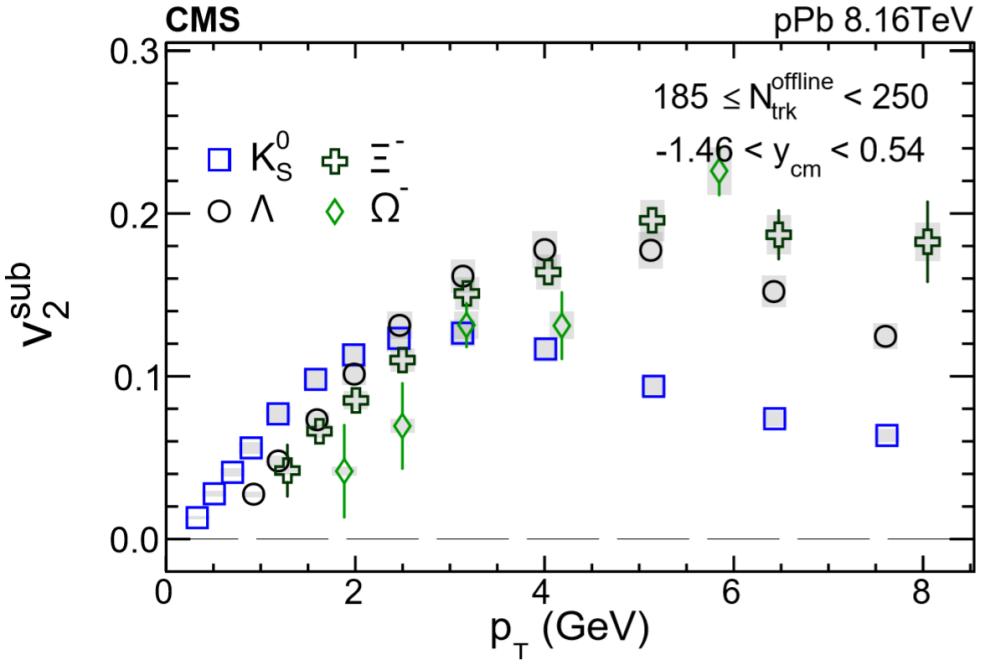
A smaller system

- Positive v_2 of light flavor hadrons
- Mass order shows common velocity
- Similar observations to large systems

Is the origin of collectivity in pPb collisions the same as that in PbPb? – from the hot medium effects?





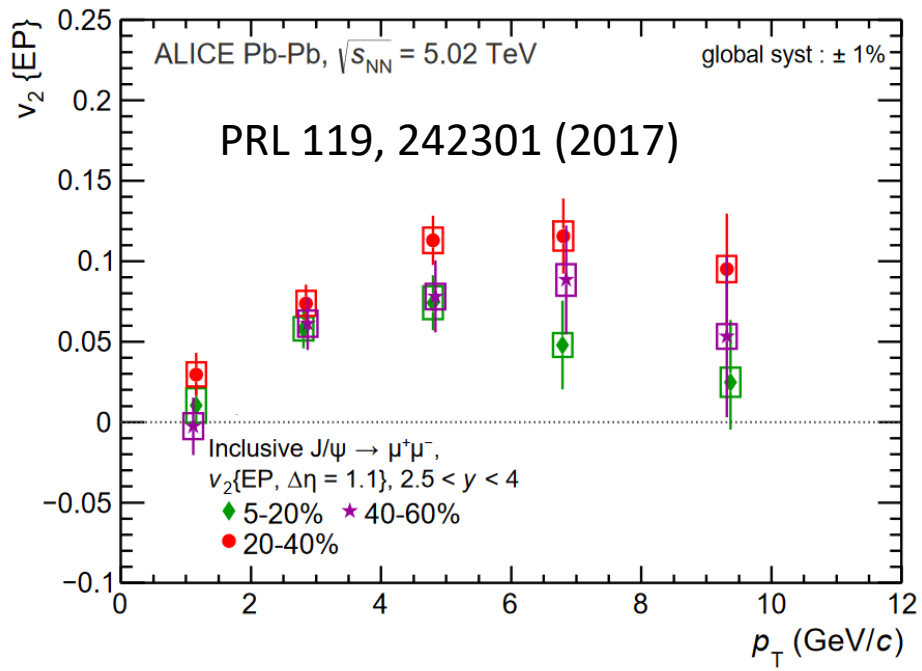


PRL 121, 082301 (2018)

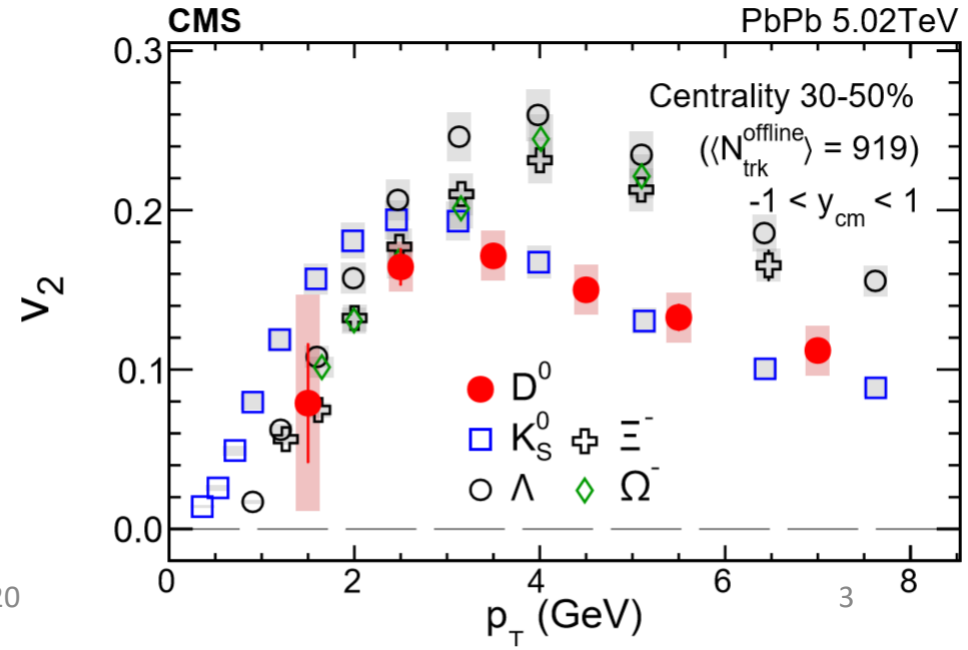
Heavy flavor in large systems

- QGP droplet in heavy ion collisions
  - Hot dense medium, partons interacts strongly
  - Perfect fluid, Initial geometric eccentricity hydrodynamically propagate to final states
- Heavy flavor quarks – good probes to initial condition
  - can only be created at initial stage
  - Experience the entire evolution
  - Large v_2 for open charm mesons and charmonia

$$E\frac{\mathrm{d}^3N}{\mathrm{d}^3\mathbf{p}} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_\mathrm{t}\mathrm{d}p_\mathrm{t}\mathrm{d}y}\left(1+2\sum_{n=1}^{\infty}v_n\cos[n(\varphi-\Psi_\mathrm{RP})]\right)$$

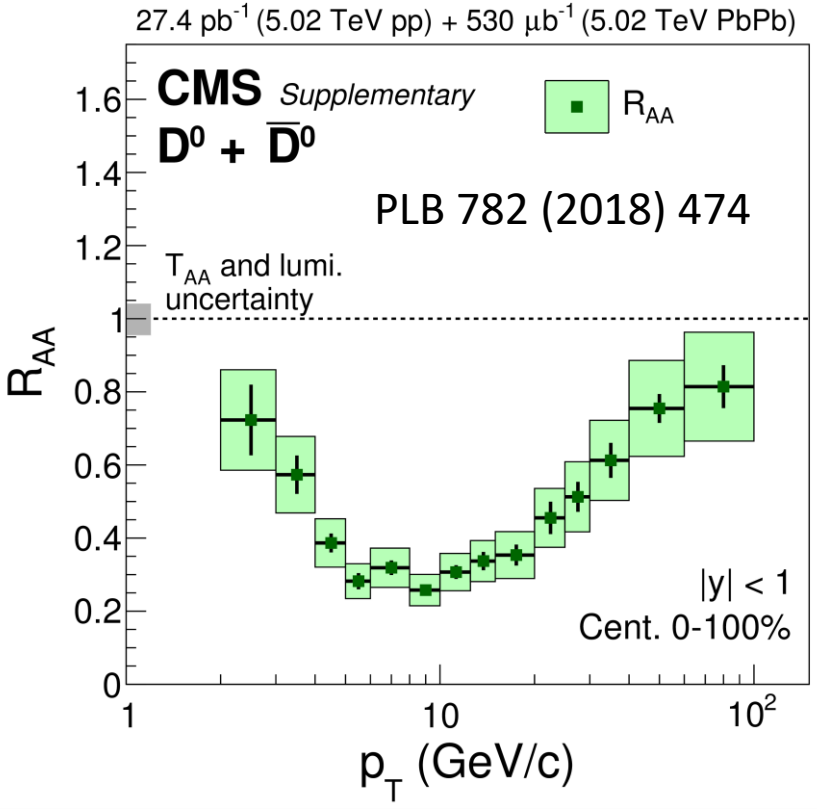


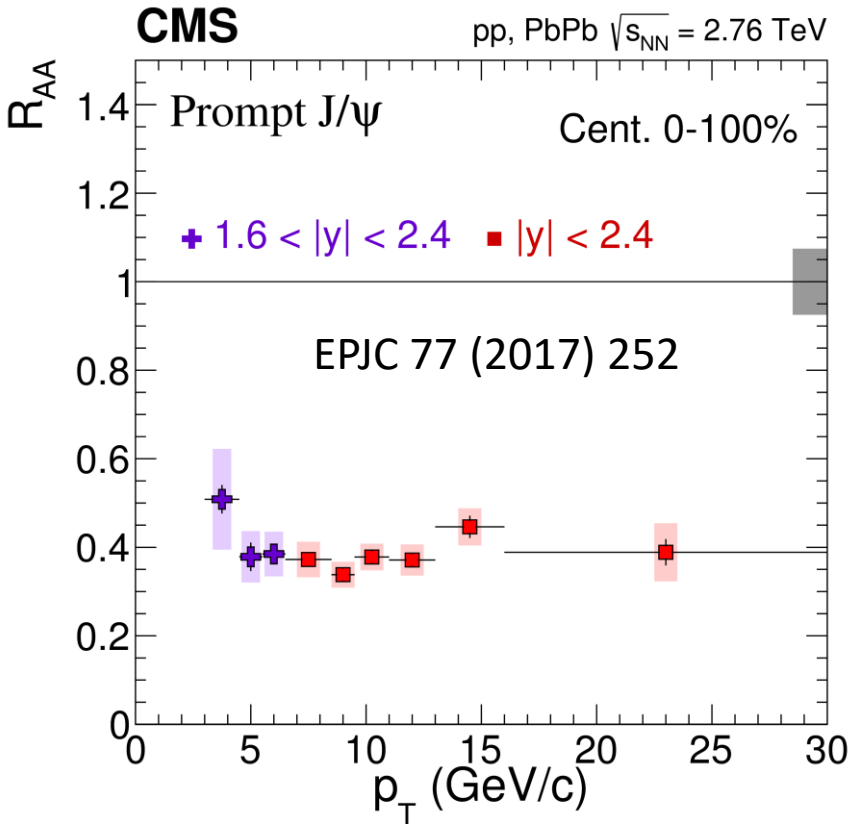
PRL 120, 202301 (2018), PRL 121, 082301 (2018)



Heavy flavor in large systems

- Nuclear modification
  - Open charm suppression, suffer energy loss
  - Charmonium suppression, Debye screening radius < binding radius





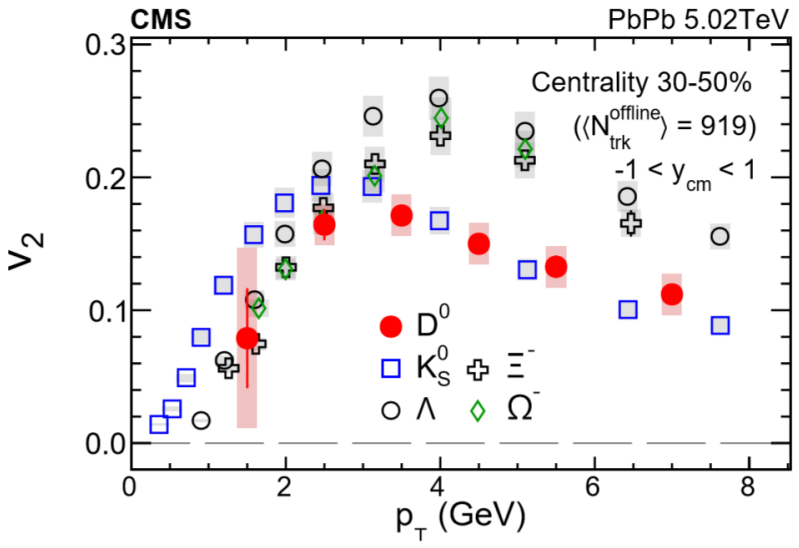
Hot medium effects in small systems?

- Possibly find similar observations in small systems if there is any hot medium effect
  - Collectivity,
    - v_2 for prompt D^0 mesons, prompt J/ψ mesons, beauty quarks …
  - Nuclear modifications
    - R_{pPb} for prompt D^0 mesons, prompt J/ψ mesons …
  - ……

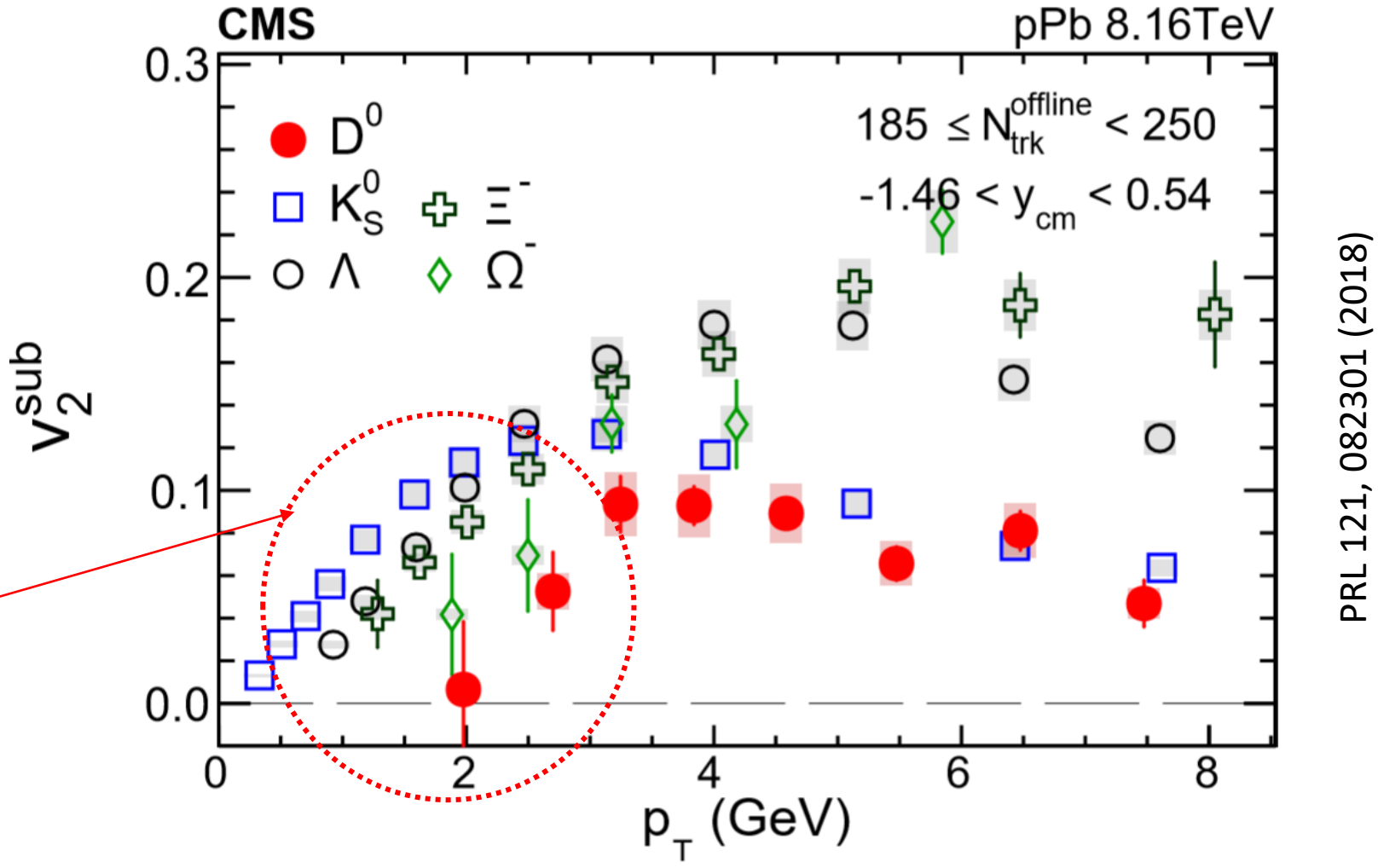
Observable	Large system	Small system
v_2 for light flavor	✓	✓
v_2 for open charm/ charmonia	✓/ ✓	✓/✓
v_2 for open bottom/ bottomonia	✓/ ✓	✓
Modifications for light flavor	✓	✓
Modifications for open charm/ charmonia	✓/ ✓	✓/✓
Modifications for open bottom/ bottomonia	✓/ ✓	✗/✓

Prompt D^0 ($c\bar{u}$) in pPb Collisions

PRL 120, 202301 (2018)



- Mass order at low p_T -- common flow velocity
- Similar to PbPb

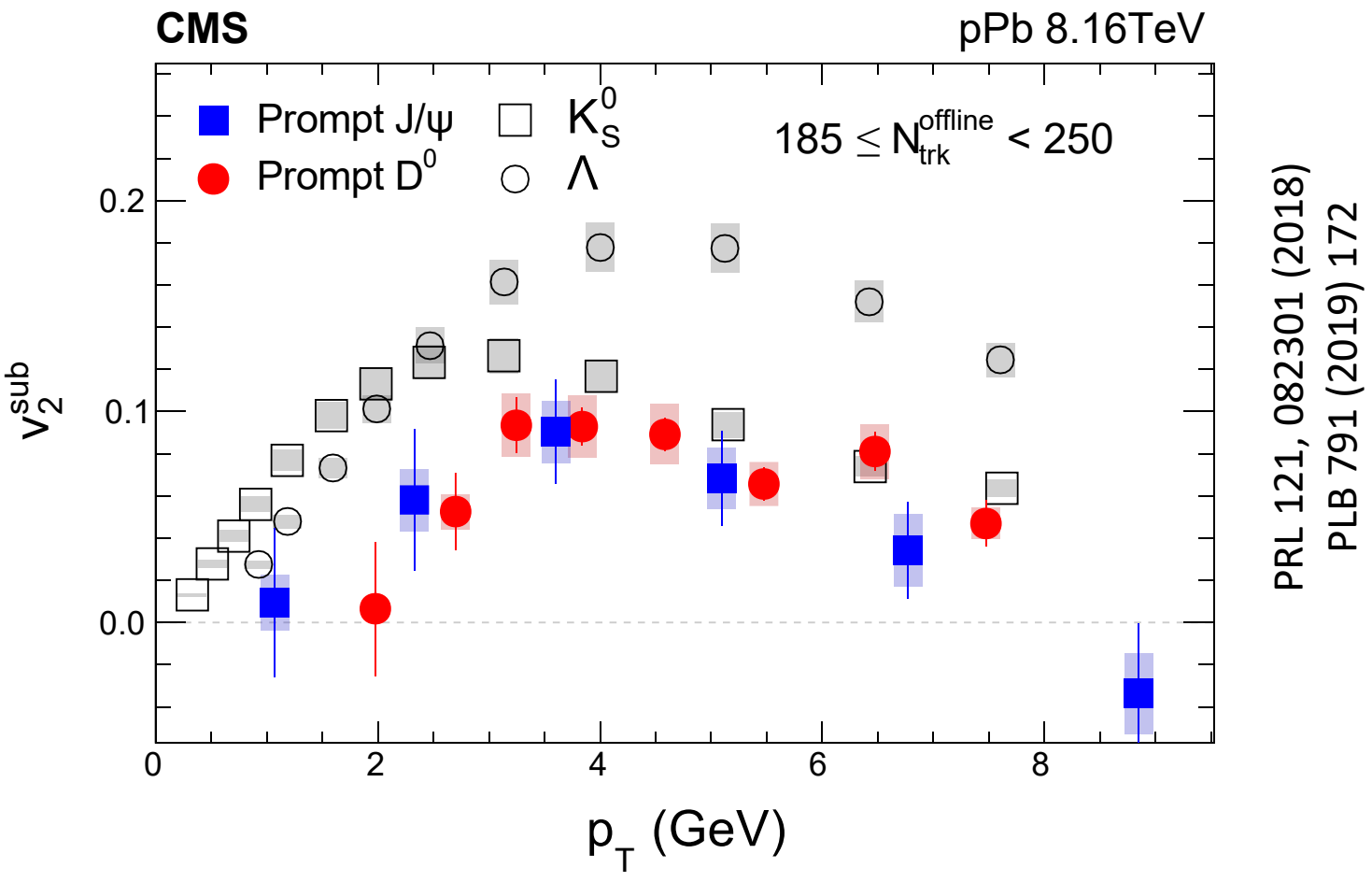


PRL 121, 082301 (2018)

Prompt J/ψ($c\bar{c}$) in pPb Collisions

- Can also observe positive v_2 signal for **prompt J/ψ**
- Calculations based on medium effects inconsistent with data
- Caveat: medium effects may not strong enough in MB samples

v_2 for
Prompt J/ψ
Prompt D^0



PRL 121, 082301 (2018)
PLB 791 (2019) 172

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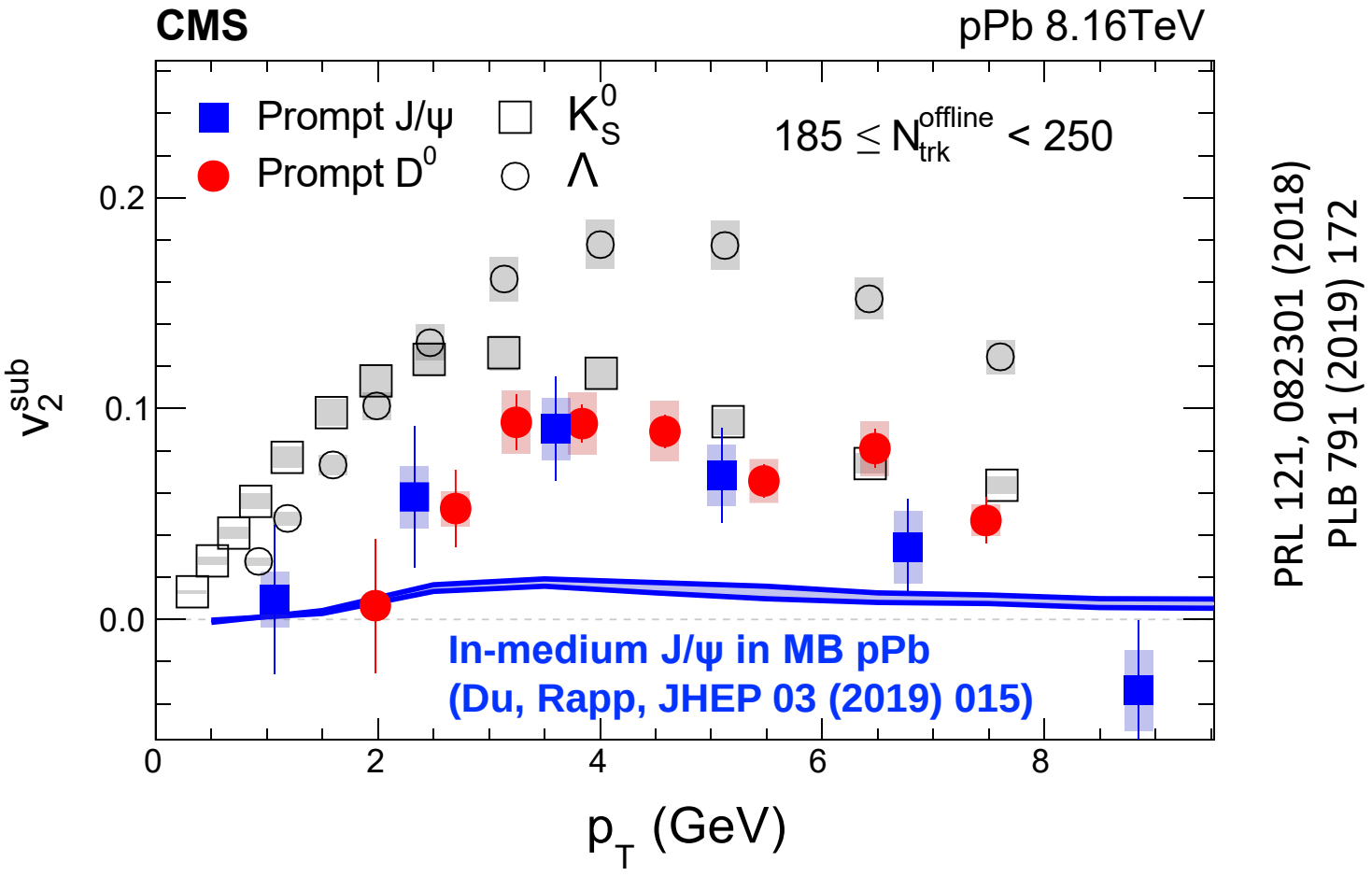
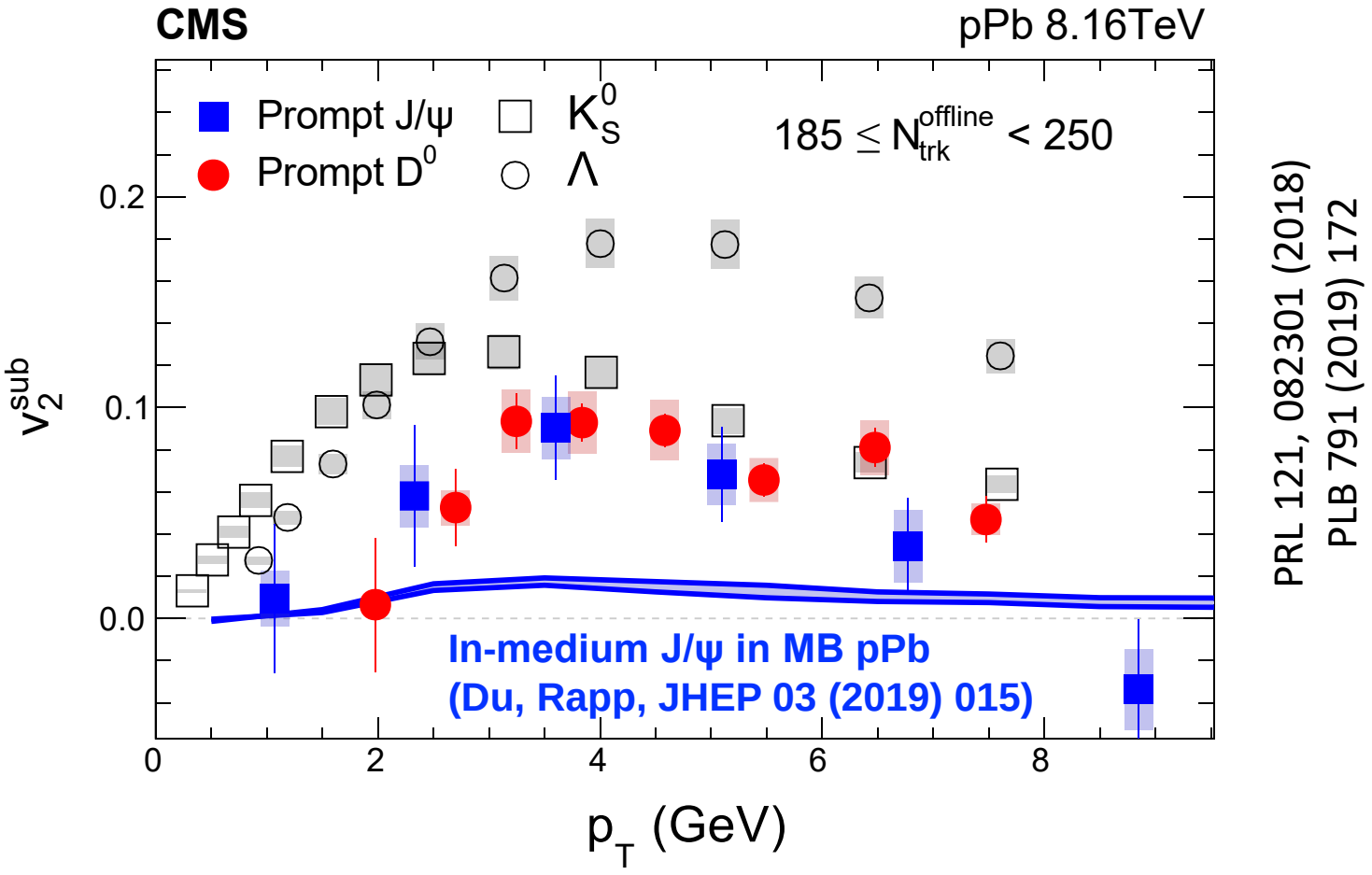


Prompt J/ψ($c\bar{c}$) in pPb Collisions

- Can also observe positive v_2 signal for prompt J/ψ
- Calculations based on medium effects inconsistent with data
- Caveat: medium effects may not strong enough in MB samples

low temperature (energy density), weak hot medium effect

high temperature, strong hot medium effects



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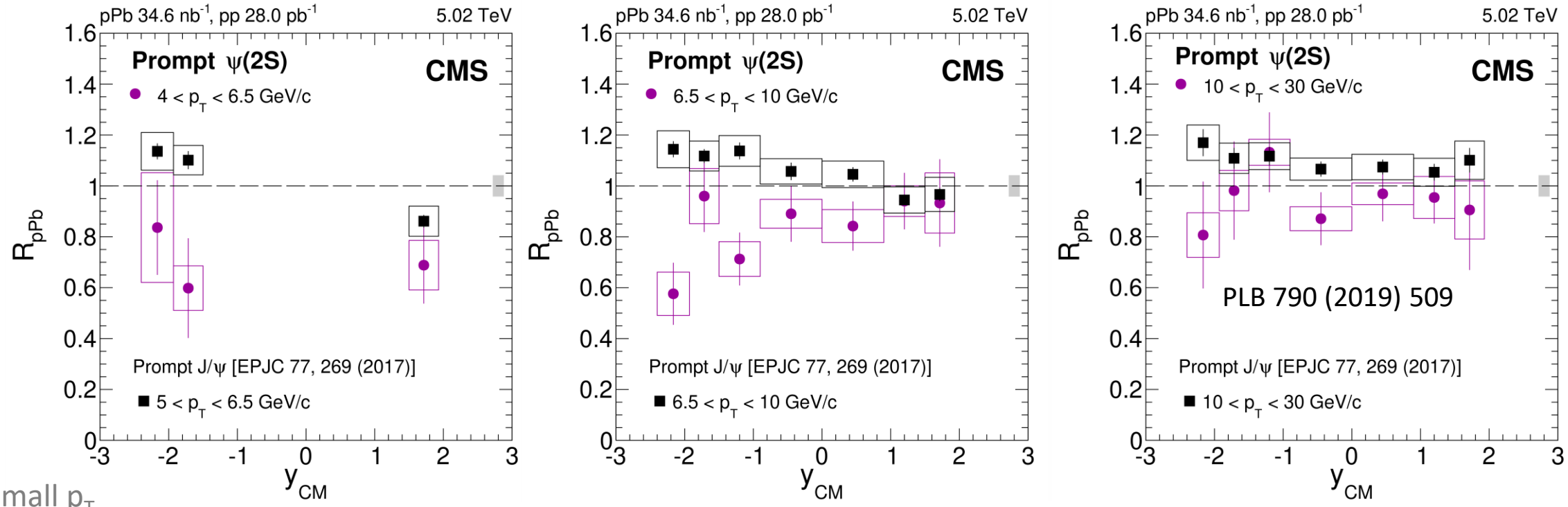
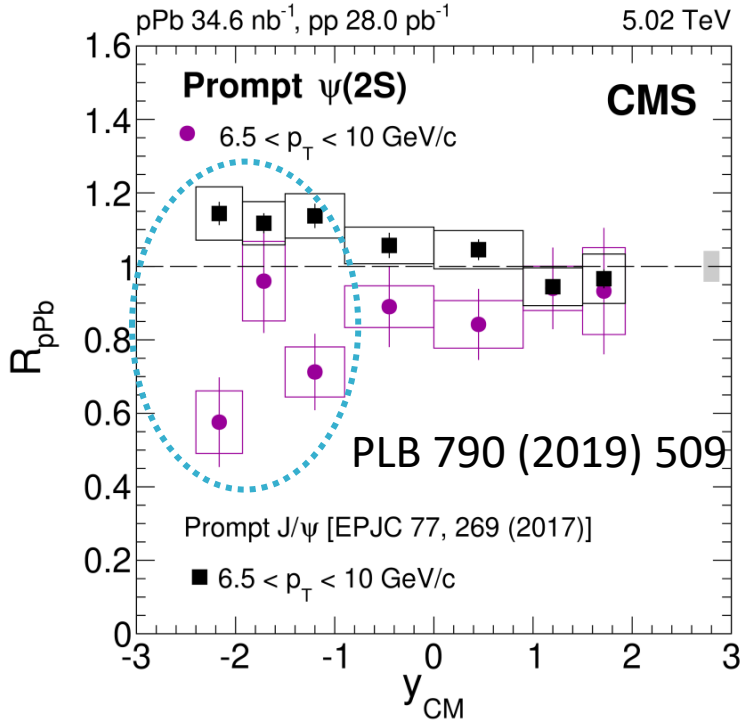
Modifications for charmonia in pPb collisions



Small p_T → Large p_T

- Modifications for **prompt J/ψ** and **prompt ψ(2S)** consistent with unity
- ψ(2S) slightly suppressed in backward (Pb-going) compared to J/ψ
- A hint for final state effects

Modifications for charmonia in pPb collisions

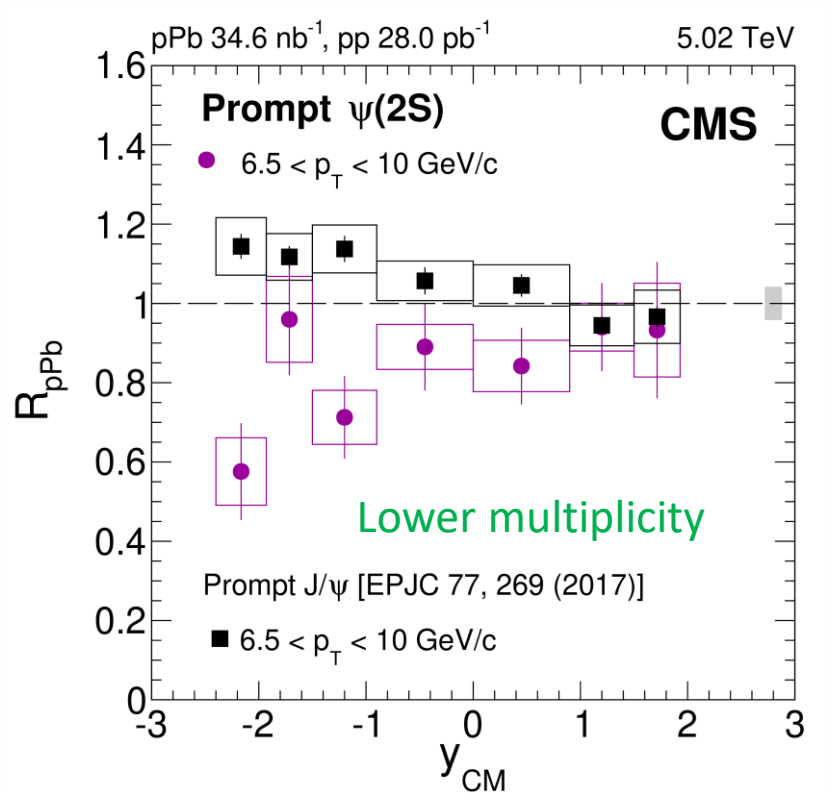


Pb-going ← → p-going

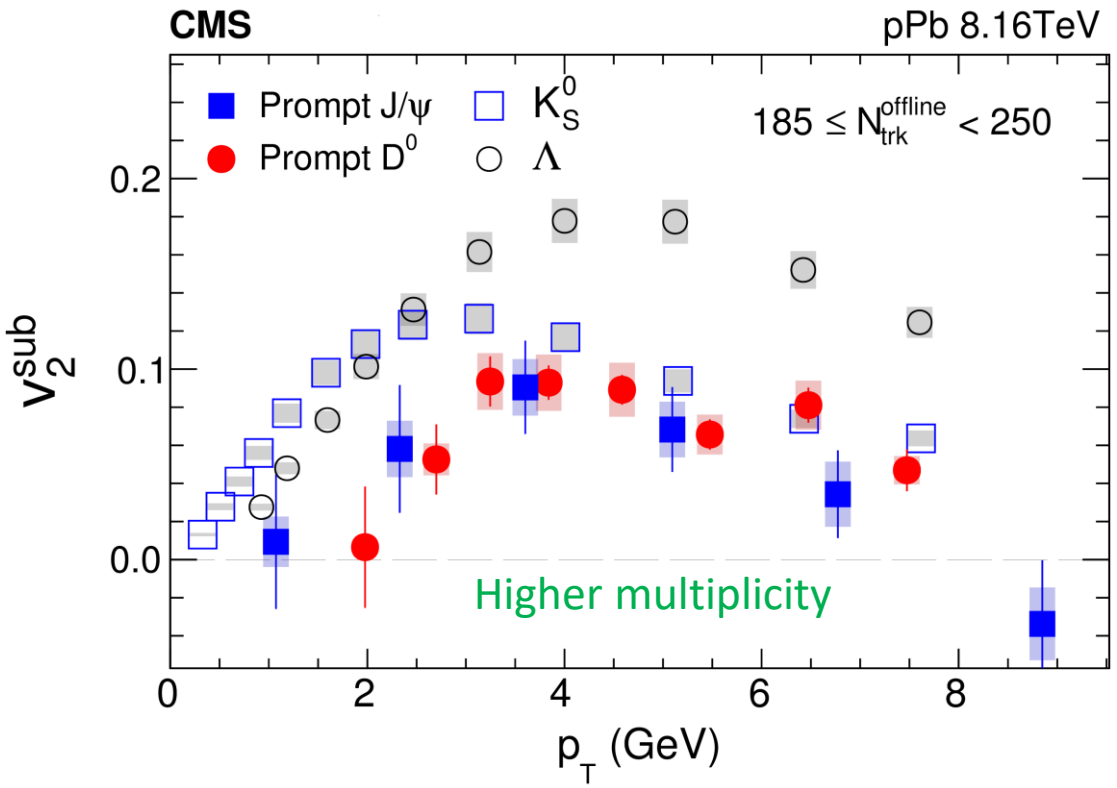
- Modifications for J/ψ and ψ(2S) consistent with unity
- **Prompt ψ(2S)** slightly suppressed in **backward (Pb-going)** compared to prompt J/ψ
- A hint for final-state effects?

Medium effects in pPb Collisions

- Multiplicity (system size) has an impact?



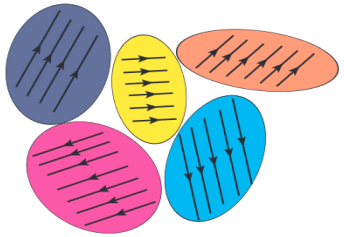
PLB 790 (2019) 509



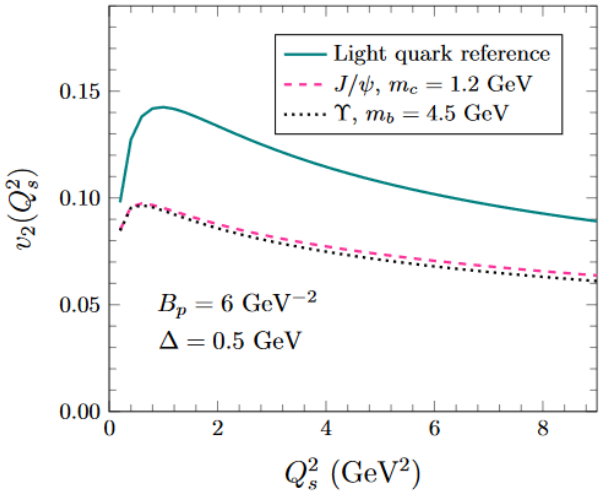
PRL 121, 082301 (2018)
PLB 791 (2019) 172

An alternative scenario

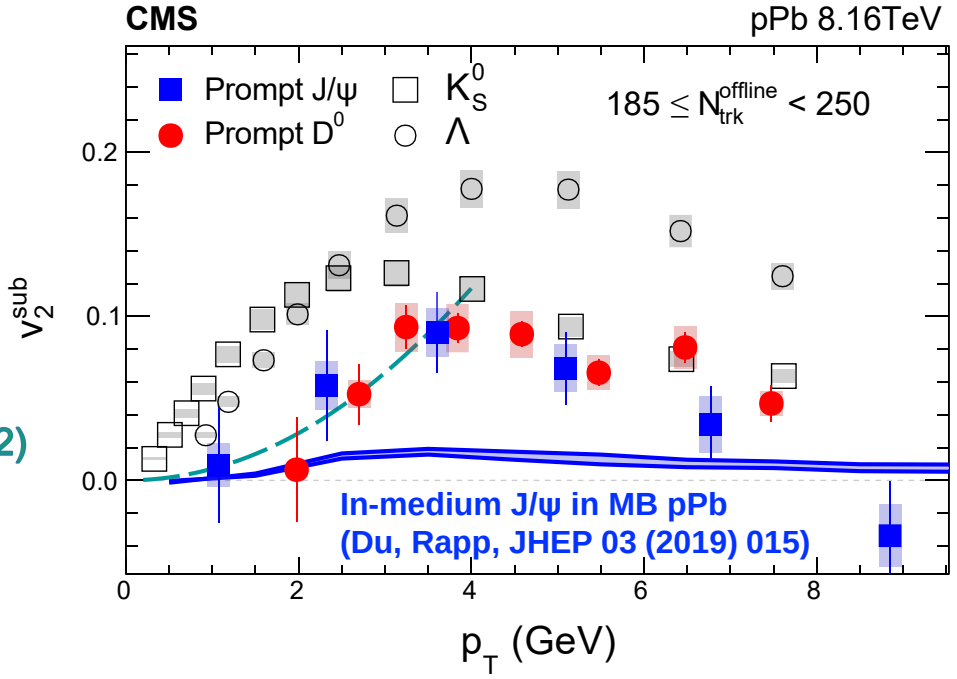
- An alternative scenario based on initial state interactions – Color Glass Condensate
  - Before collisions, non-zero color electric fields exist
  - Non-geometry-related and non-hydrodynamical evolution
  - Predict large v_2 for Υ and prompt J/ψ



Lappi, Schenke, Schlichting, Venugopalan
JHEP 01 (2016) 061



CGC (Zhang et. al.
PRL 122 (2019), 172302)



PRL 121, 082301 (2018)
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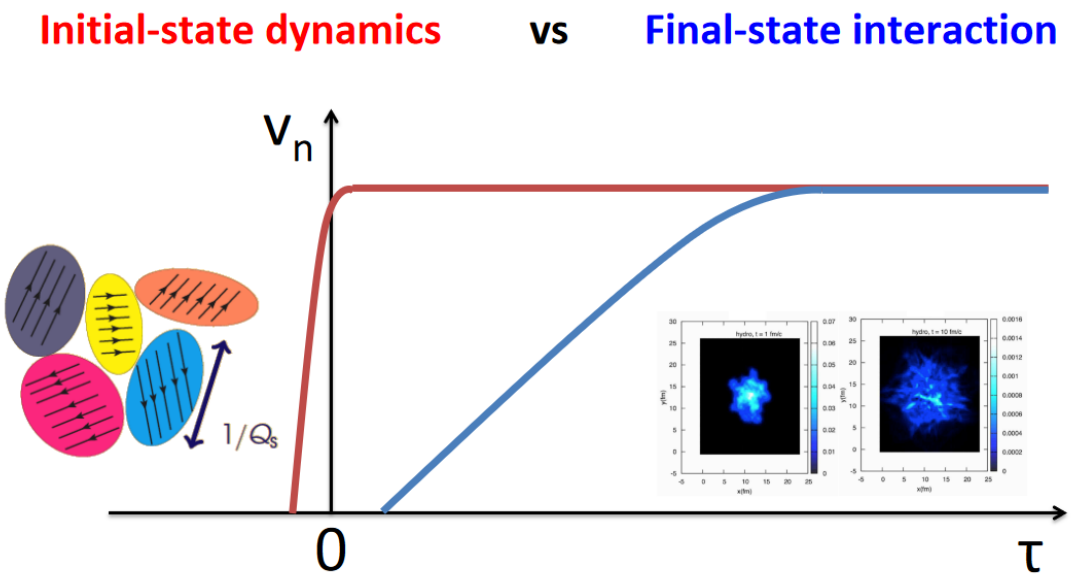
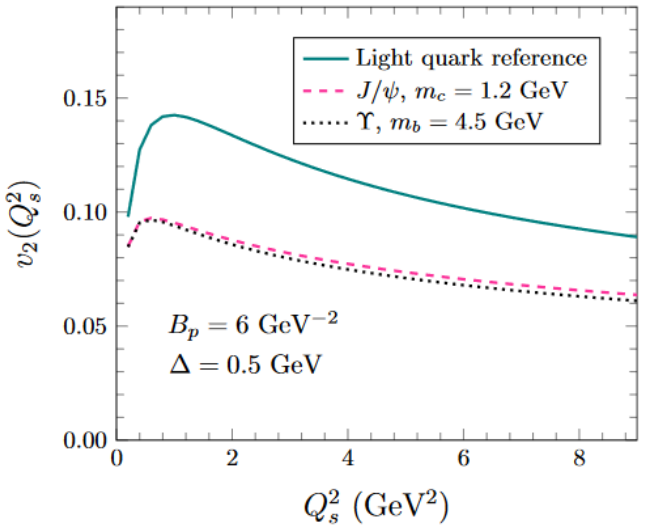
Beauty quarks in pPb Collisions

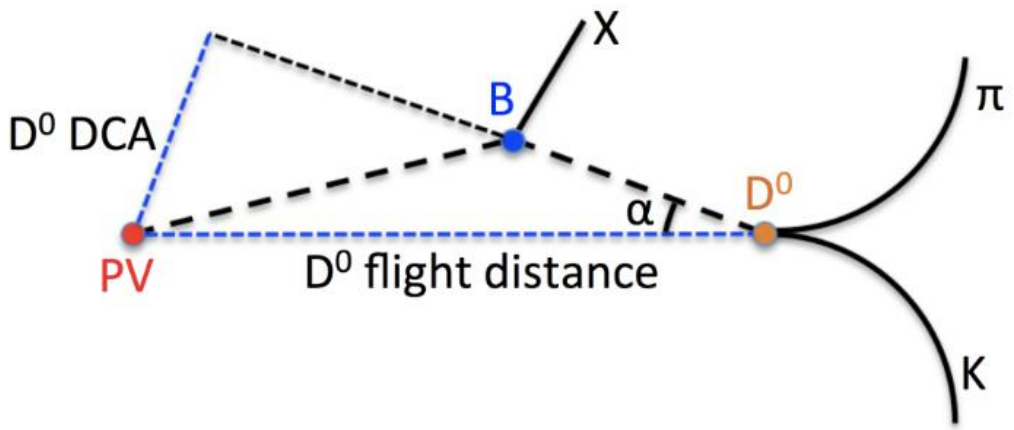
- Can we observe collectivity of even heavier quarks?
  - b quarks are very heavy and hard to thermalize
  - CGC calculations predict large v_2 for Υ comparable to prompt J/ψ (PRL 122 (2019), 172302)
  - b quarks provide new opportunities to study the medium effects and CGC

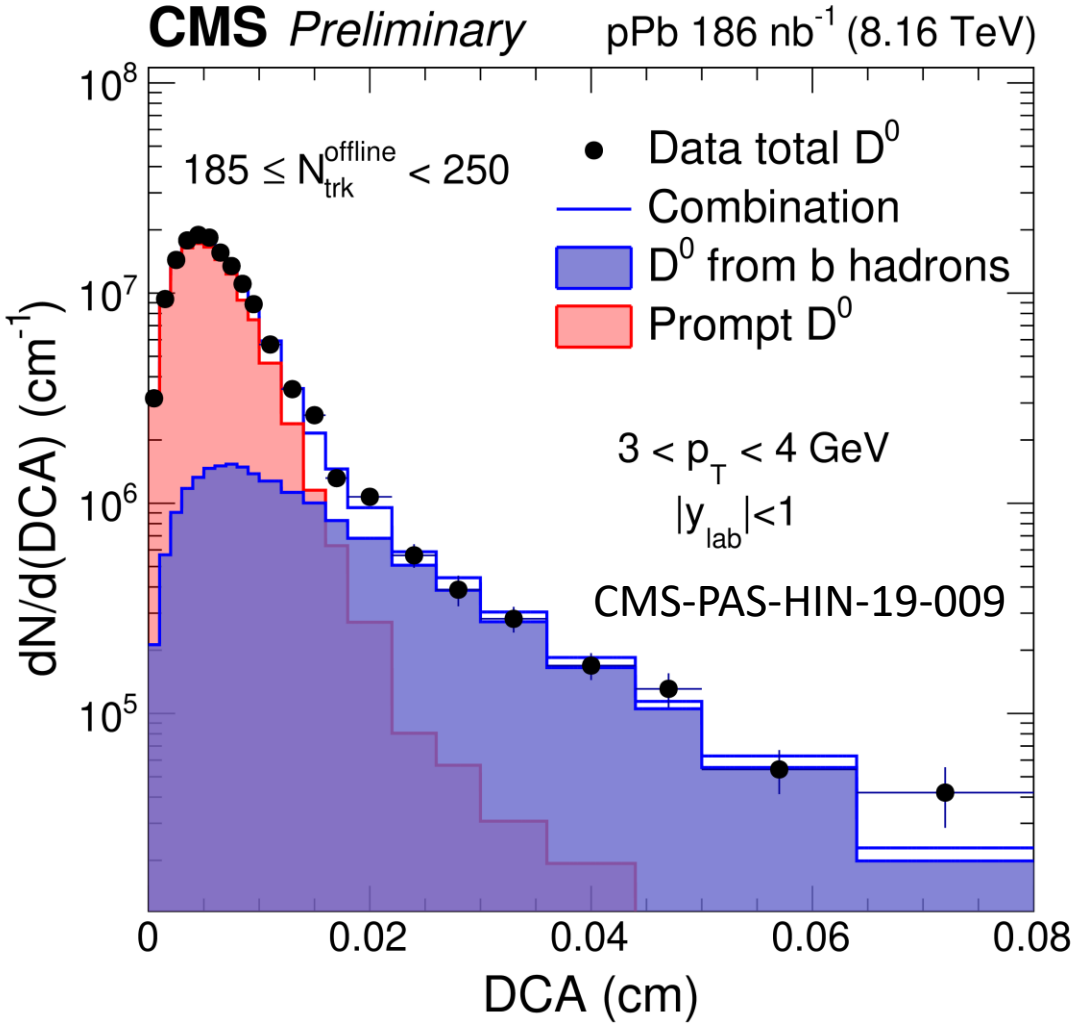




Nonprompt D^0 in pPb Collisions

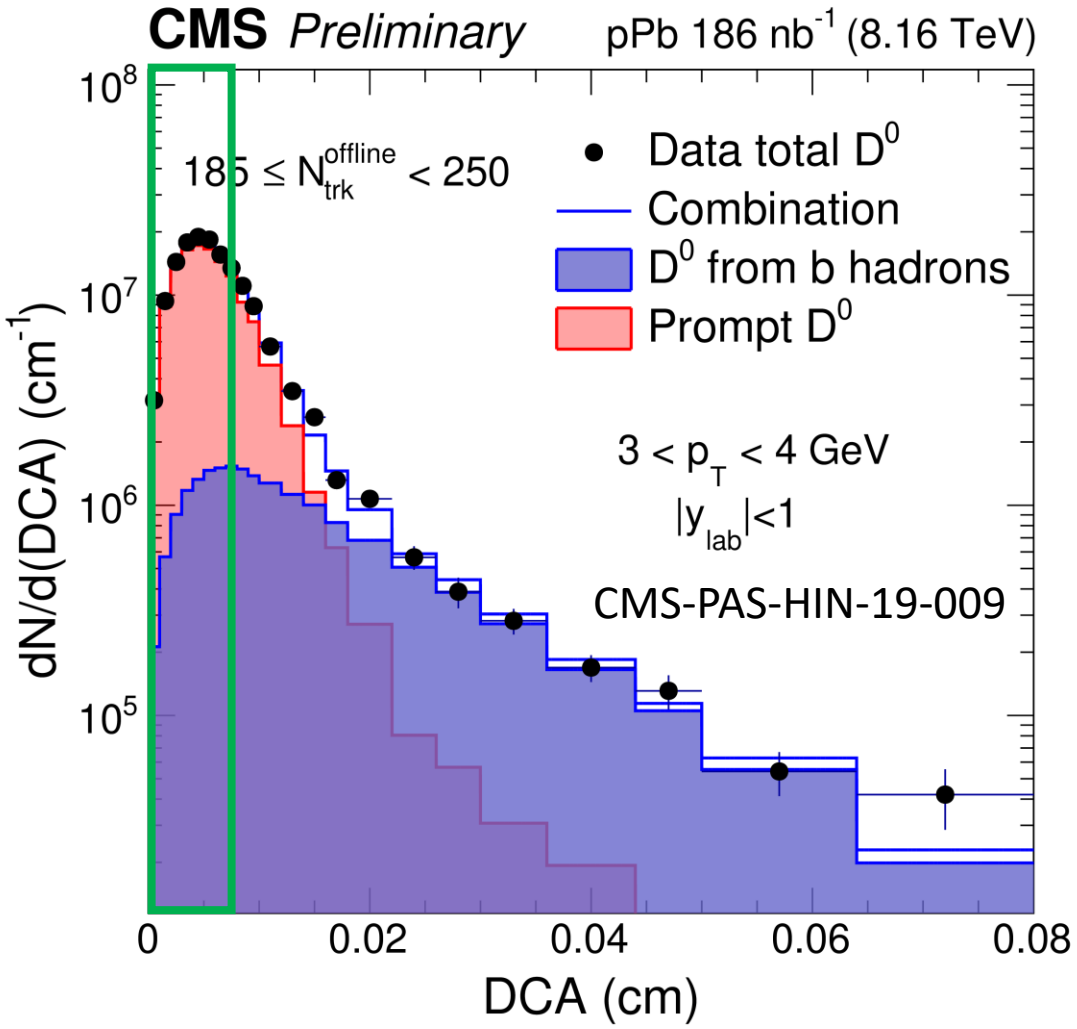
- Nonprompt D^0 originates form b hadron
- Distinguish prompt and nonprompt D^0 by DCA distribution





Nonprompt D^0 in pPb Collisions

- Evaluate $V_{2\Delta}^{signal}$ in each integrated DCA bin with two particle correlation function
- Extrapolate signal with linear fit
- v_2 obtained from using charged particles as reference



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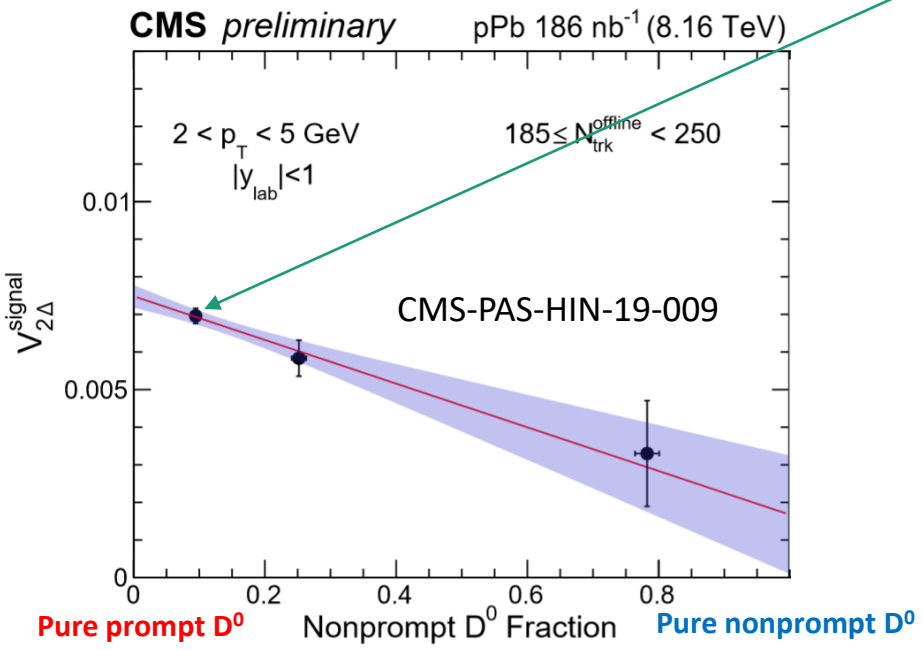

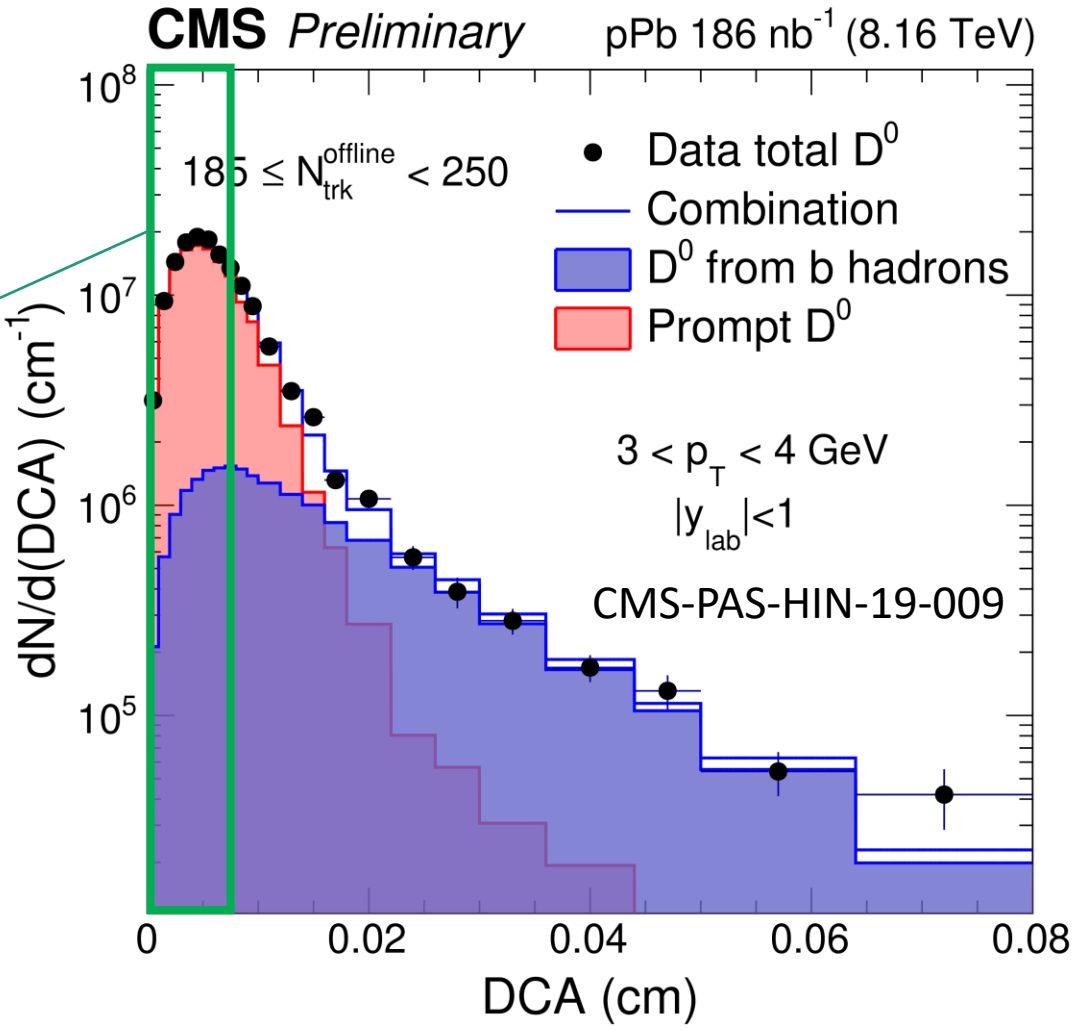

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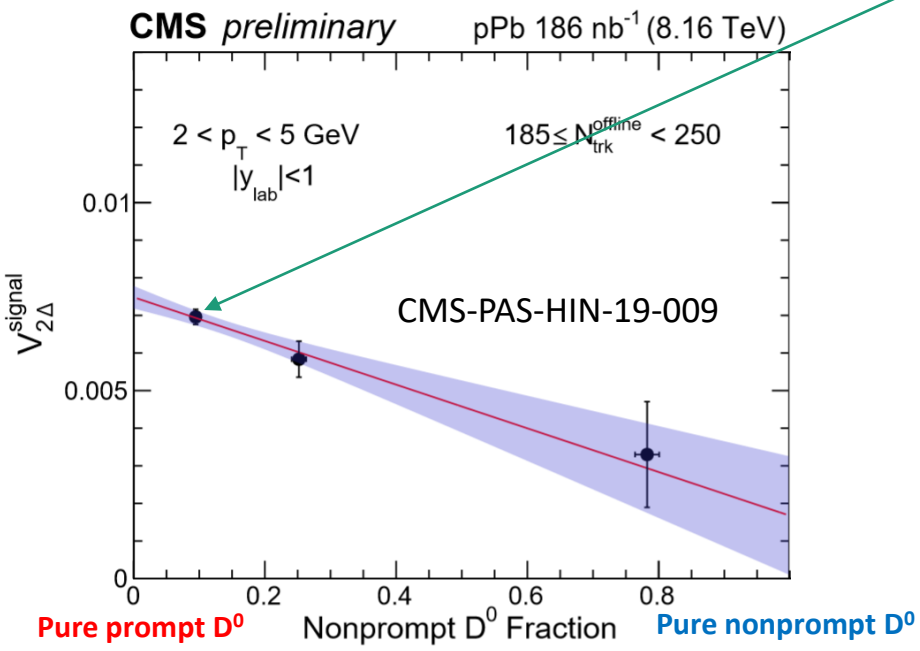
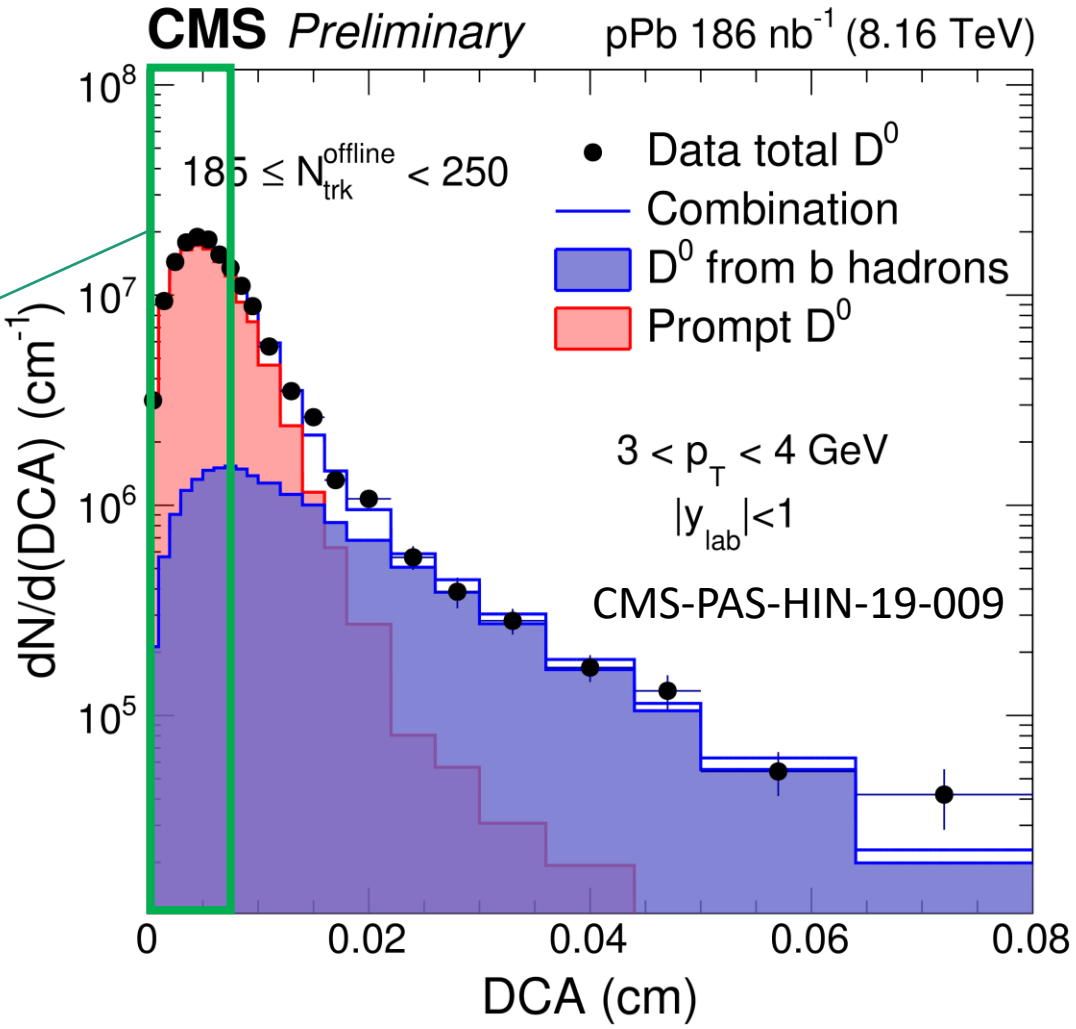
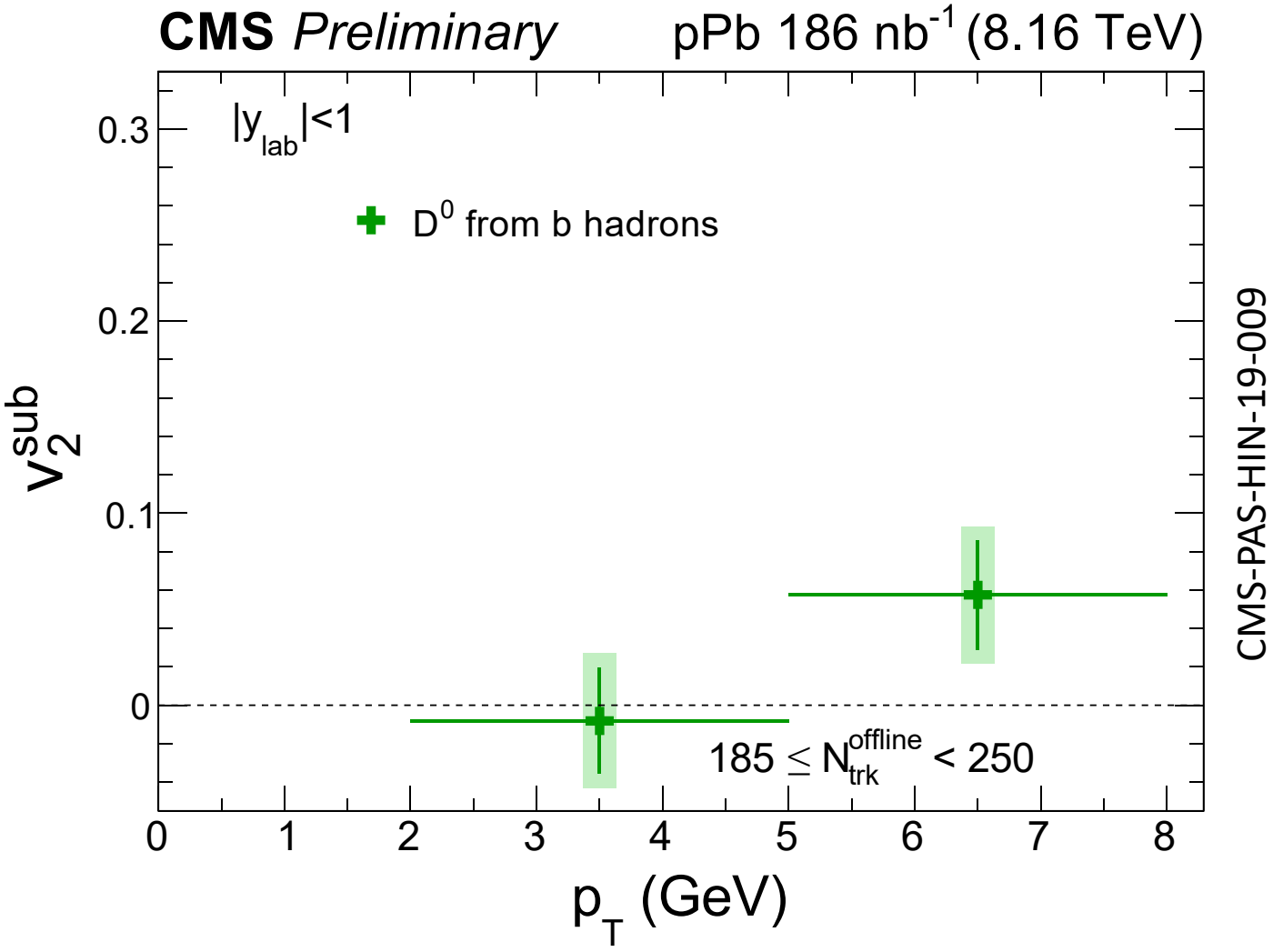




Nonprompt D^0 in pPb Collisions

- First measurement of **b flow** in pPb collisions
- Indication of flavor hierarchy between charm and beauty at low p_T
- Comparison between CGC calculations and data



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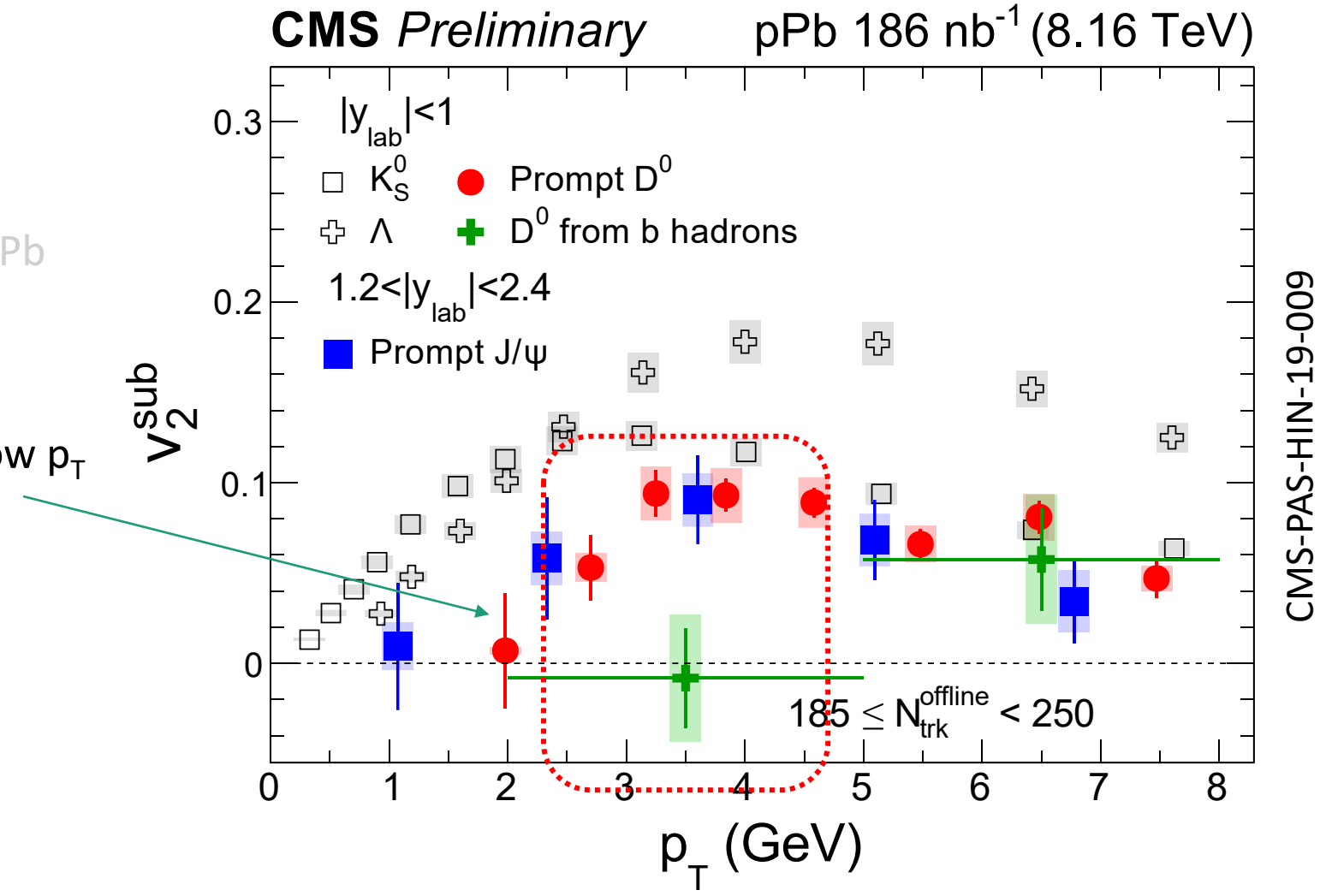

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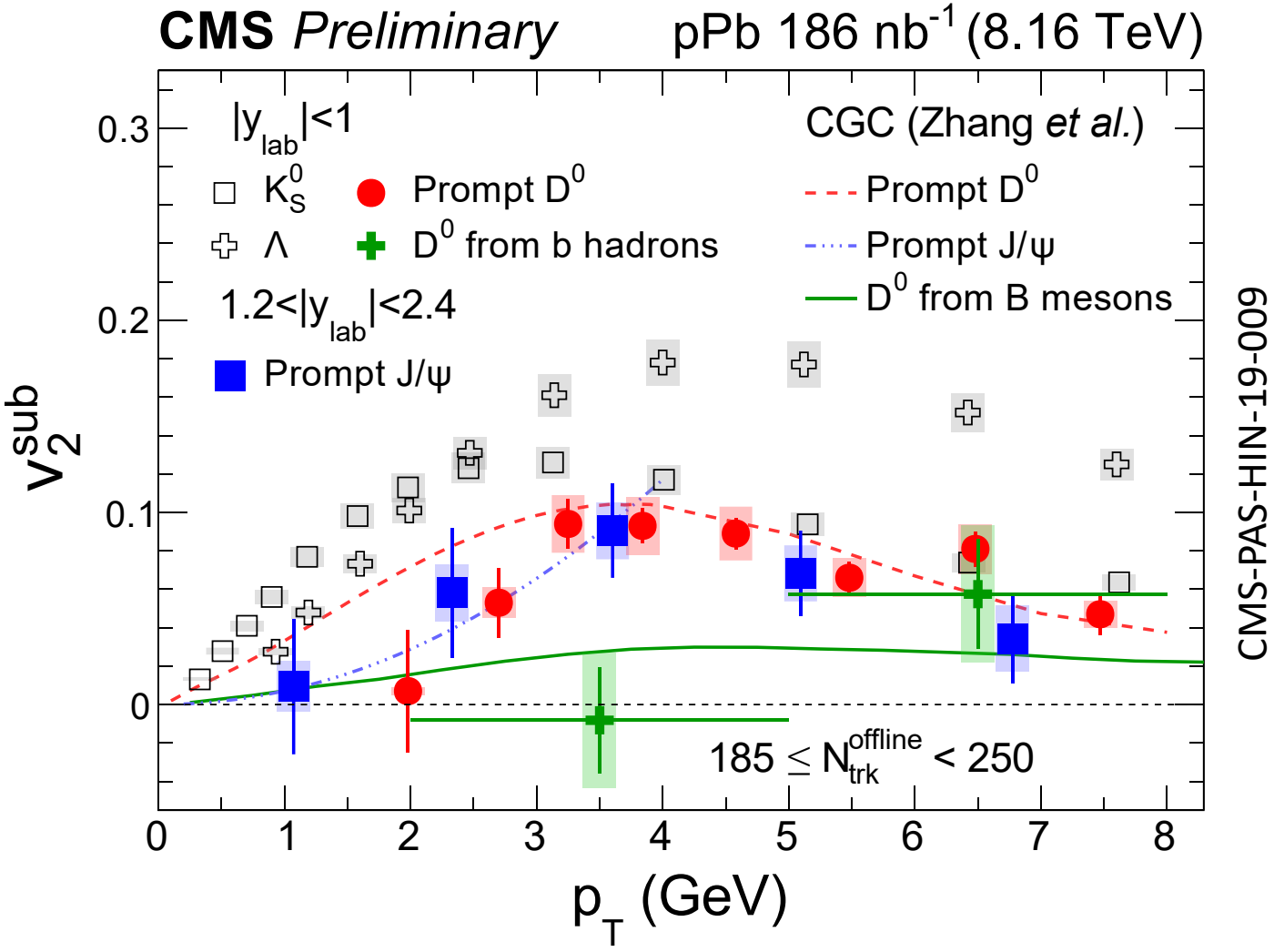
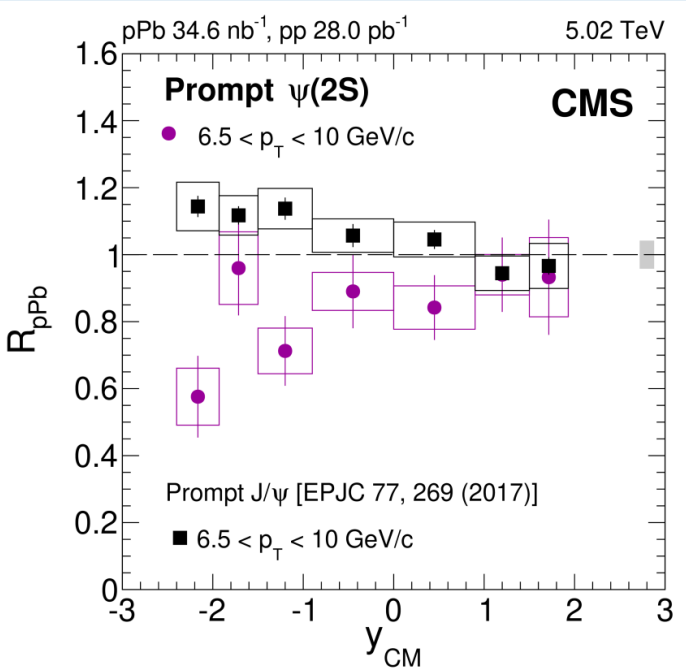
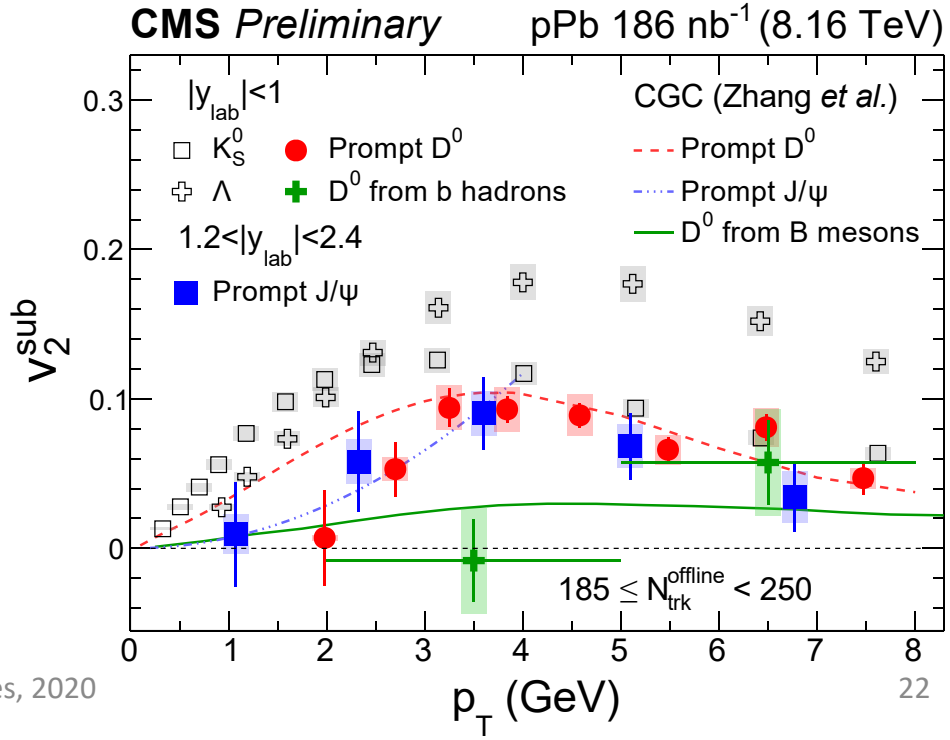


Summary and future

- A comprehensive study of heavy flavor collectivity in small systems
  - Observation of strong charm collectivity
  - First measurement of bottom collectivity in pPb collisions, which is much smaller
  - Hint of charmonia suppression for ψ(2S) via final-state effects
  - Medium effects or CGC still on debate
- Future
  - Modifications for heavy flavors
  - Correlations between heavy flavors
  - … …





Ackownledgement

U.S. DEPARTMENT OF ENERGY

Office of Science

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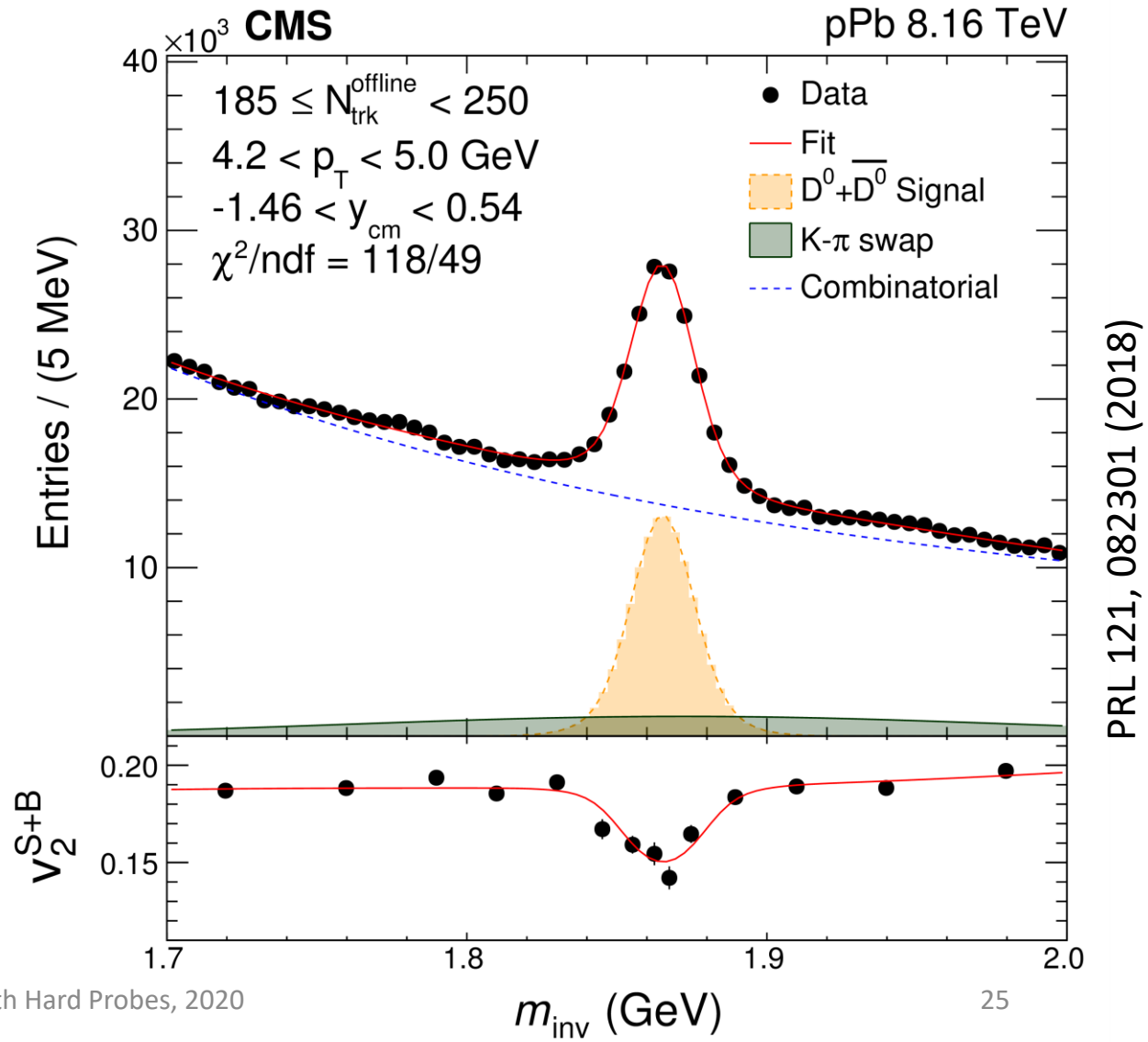
Backup

Prompt D^0 in pPb Collisions

- D^0 ($c\bar{u}$) reconstruction

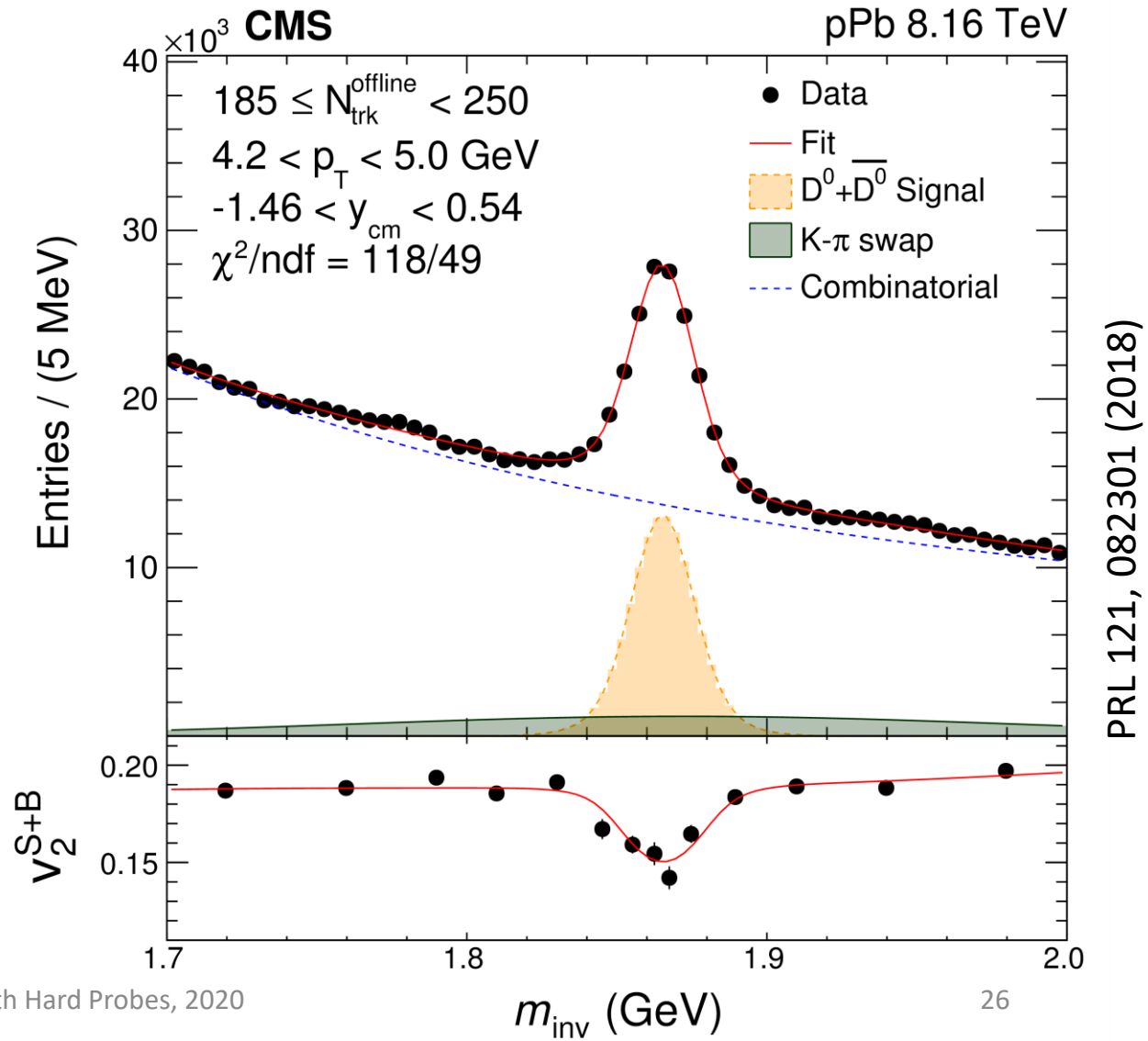


Prompt D^0 in pPb Collisions

- D^0 reconstruction
- Two particle correlation techniques

$$\frac{1}{N_{D^0}}\frac{dN^{pair}}{d\Delta\phi} = \frac{N_{assoc}}{2\pi}\left[1+\sum_{n=1}^{3}2V_{n\Delta}\cos(n\Delta\phi)\right]$$

$$v_n(D^0) = V_{n\Delta}(D^0, ref)/\sqrt{V_{n\Delta}(ref, ref)}$$

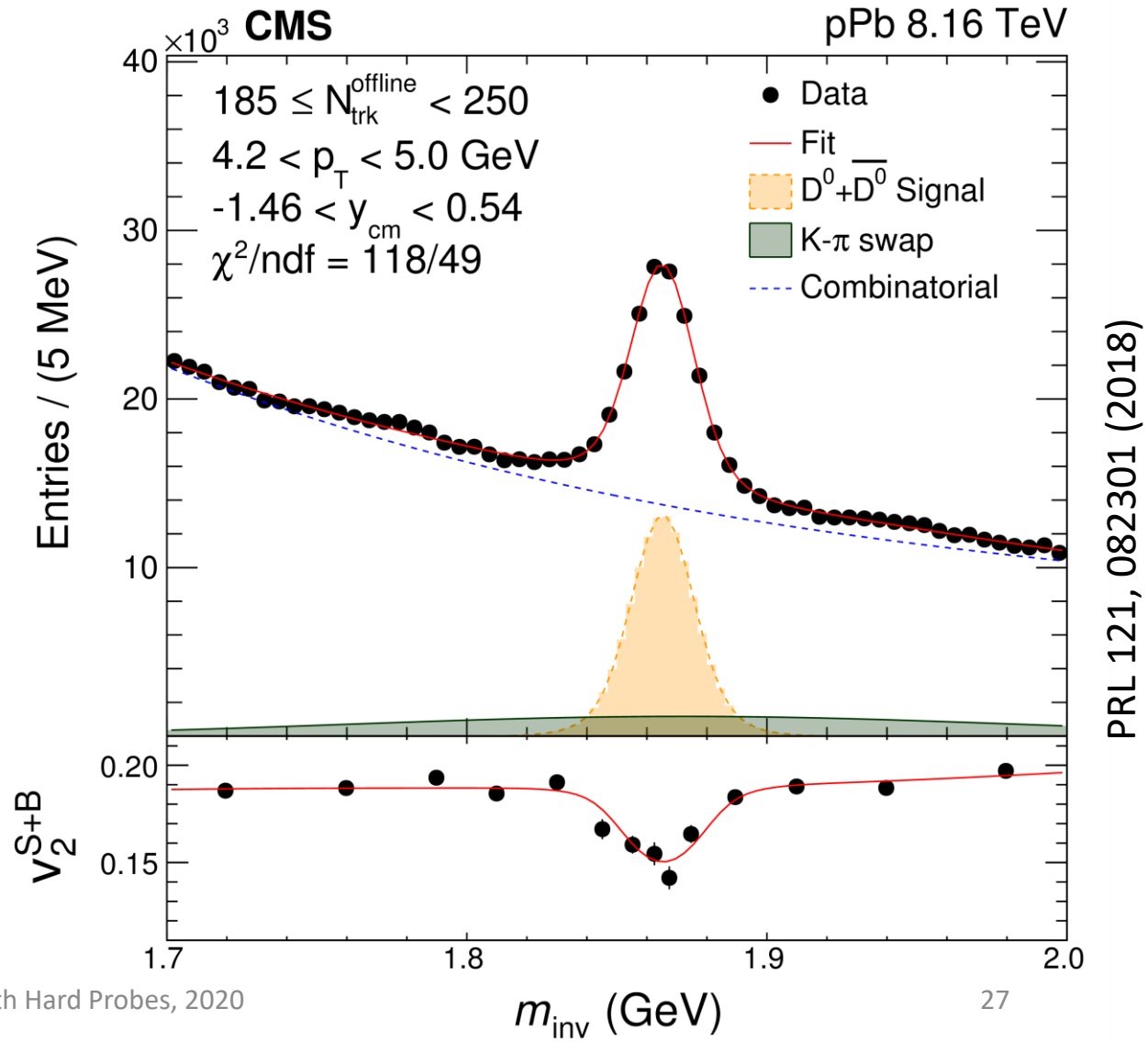


Prompt D^0 in pPb Collisions

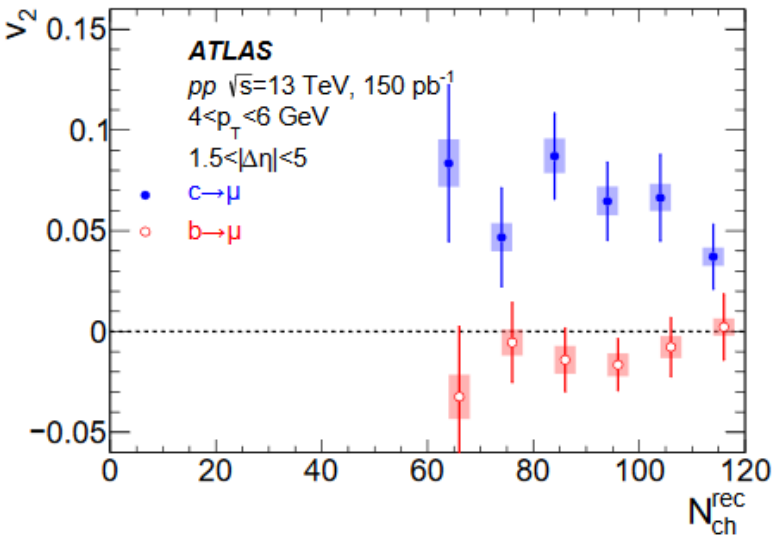
- D^0 reconstruction
- Two particle correlation techniques

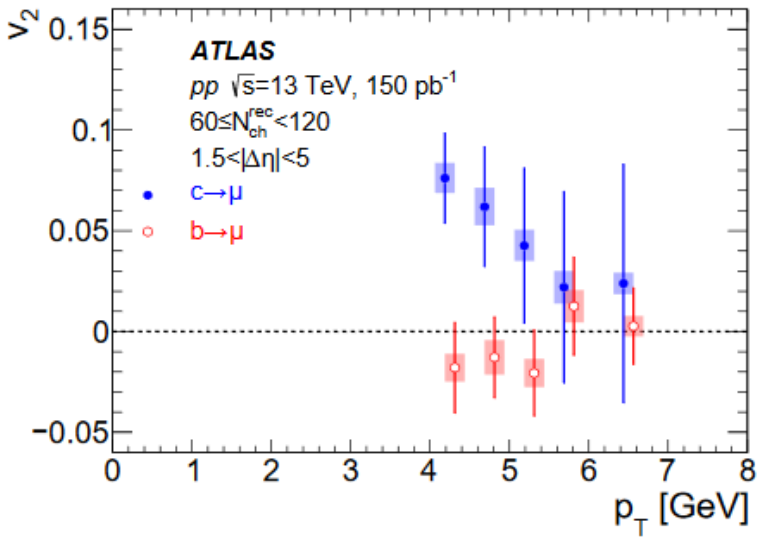
- Signal extraction

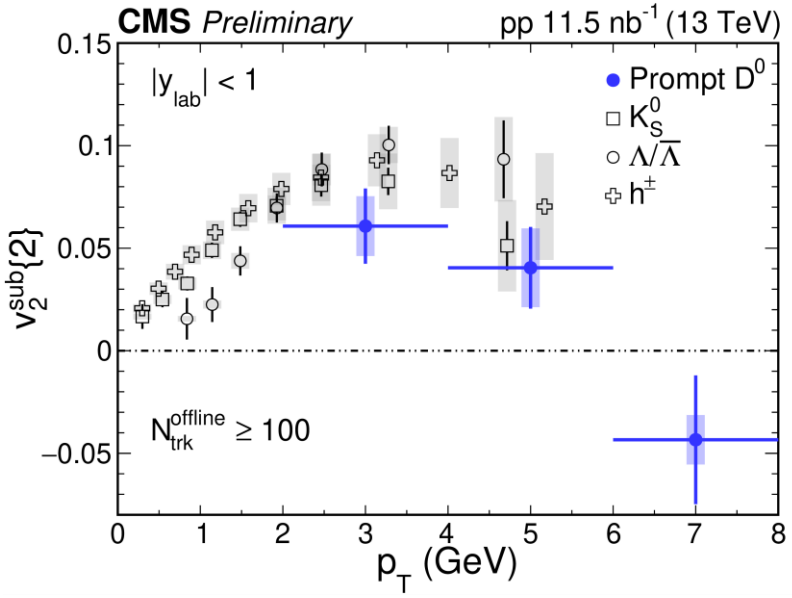
$$v_2^{S+B}(m_{\mathrm{inv}}) = \alpha(m_{\mathrm{inv}})v_2^S + [1-\alpha(m_{\mathrm{inv}})]v_2^B(m_{\mathrm{inv}})$$



Backup



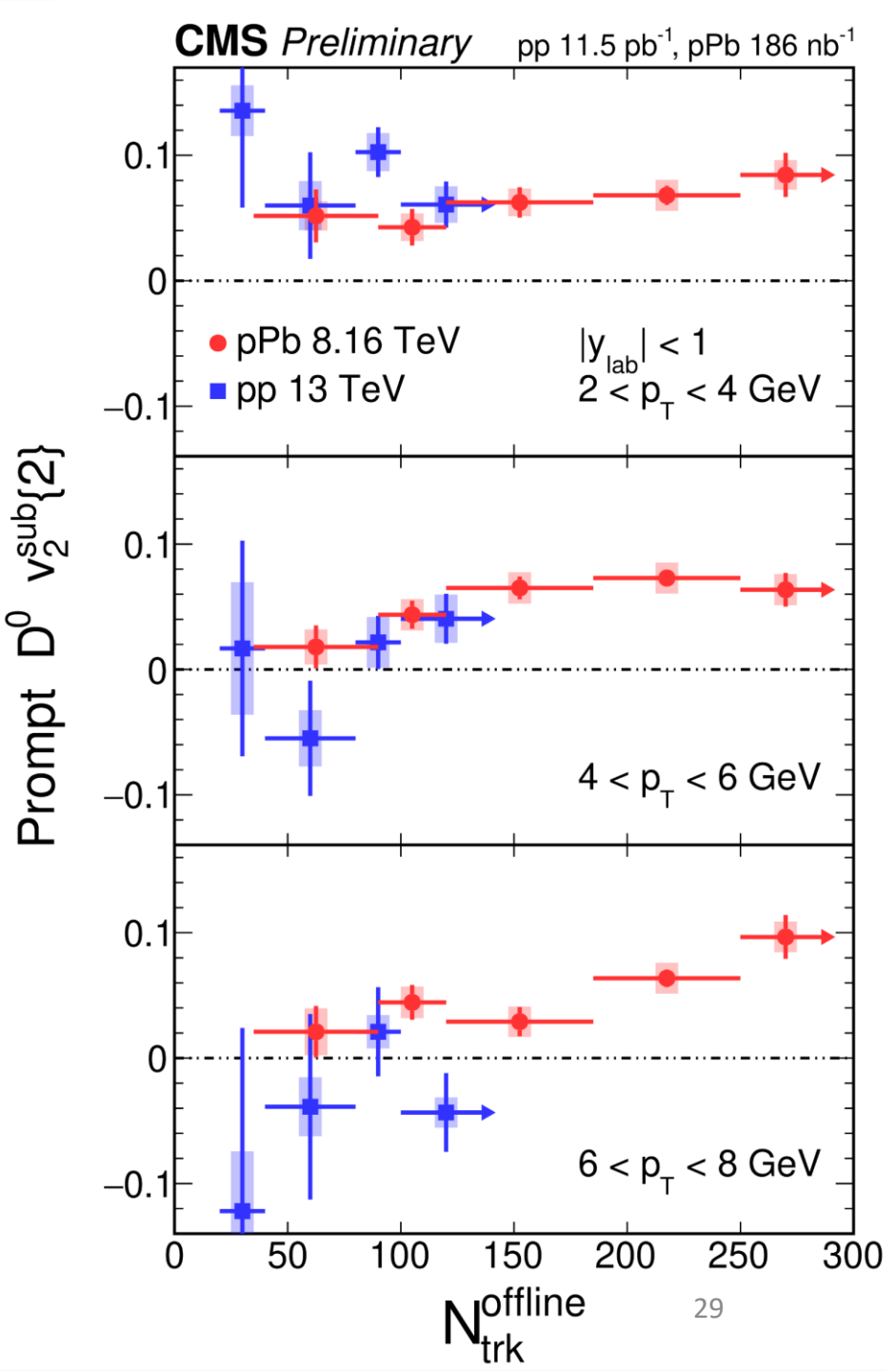




Phys. Rev. Lett. 124, 082301 (2020)

Backup System size and Collecitivity

- Positive v_2 is observed in high multiplicity events
- v_2 of prompt D^0 in pp collisions is comparable to that in pPb collisions with similar multiplicity under large uncertainty
- Non-zero v_2 of prompt D^0 mesons diminish towards low-multiplicity regimes

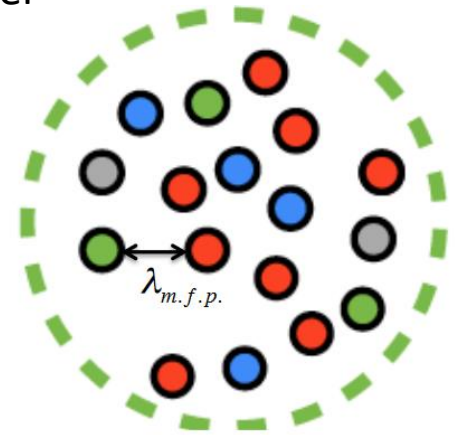


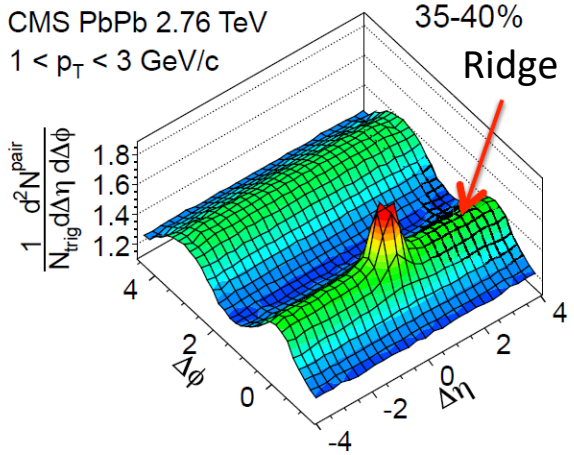
Backup nonflow

$$V_{n\Delta}^{\mathrm{sub}} = V_{n\Delta} - V_{n\Delta}(N_{\mathrm{trk}}^{\mathrm{offline}} < 35) \times \frac{N_{\mathrm{assoc}}(N_{\mathrm{trk}}^{\mathrm{offline}} < 35)}{N_{\mathrm{assoc}}} \times \frac{Y_{\mathrm{jet}}}{Y_{\mathrm{jet}}(N_{\mathrm{trk}}^{\mathrm{offline}} < 35)},$$

Backup

Large nuclei





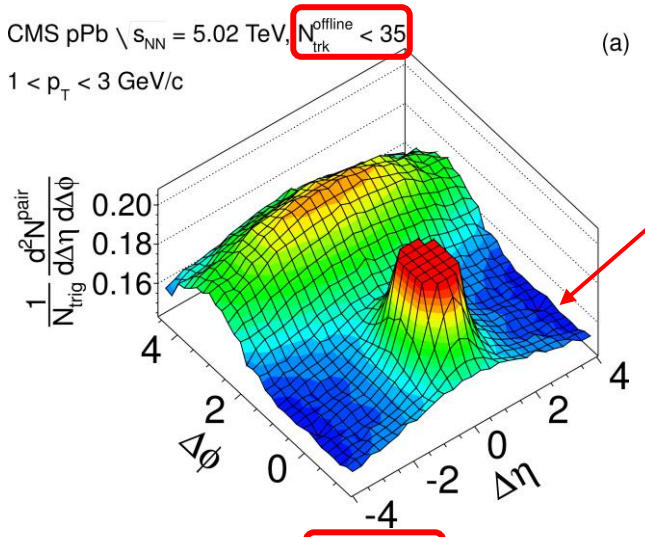
EPJC 72 (2012) 2012

Smaller system size

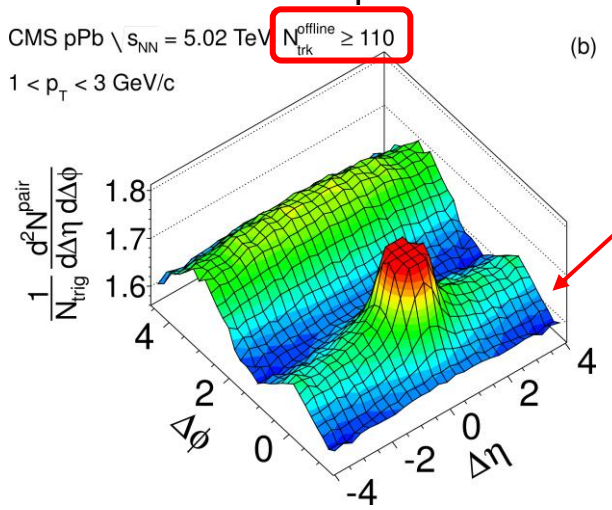
Small nucleon, low temperature (energy density)

Small nucleon, high T

PLB 718 (2013) 795



No ridge in low multiplicity events



Ridge in high multiplicity events