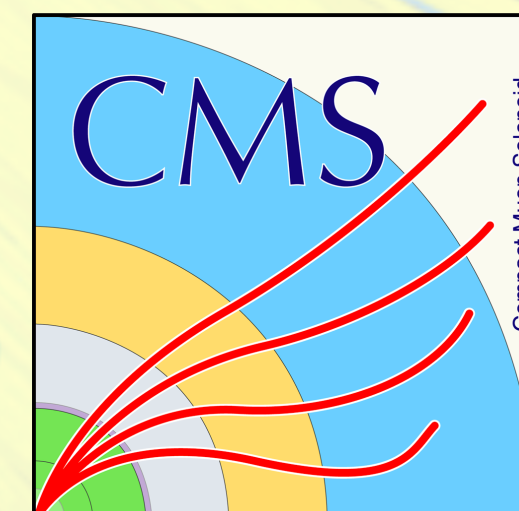


# Collectivity of Heavy Flavor Hadrons in pp and pPb Collisions with the CMS Detector

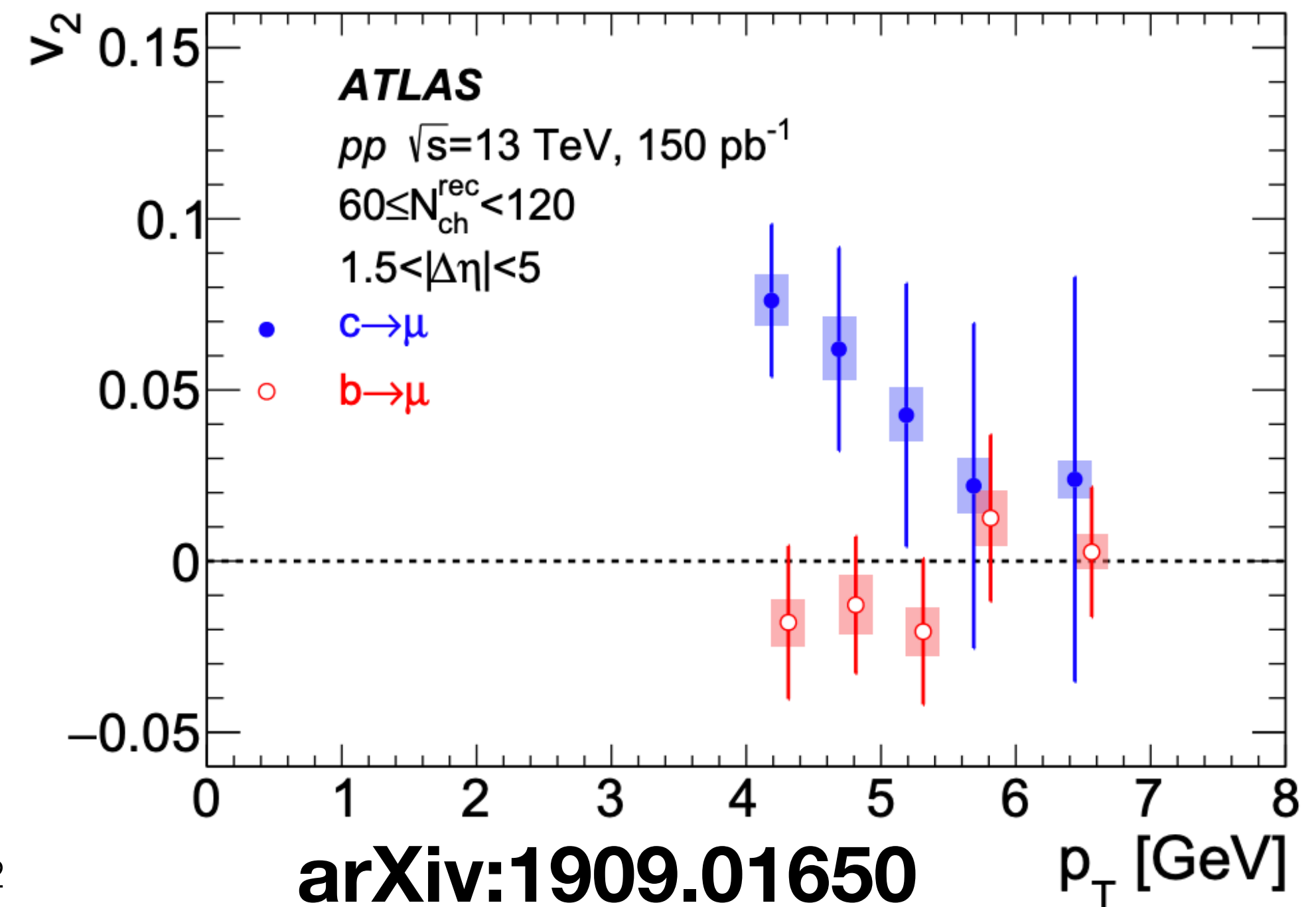
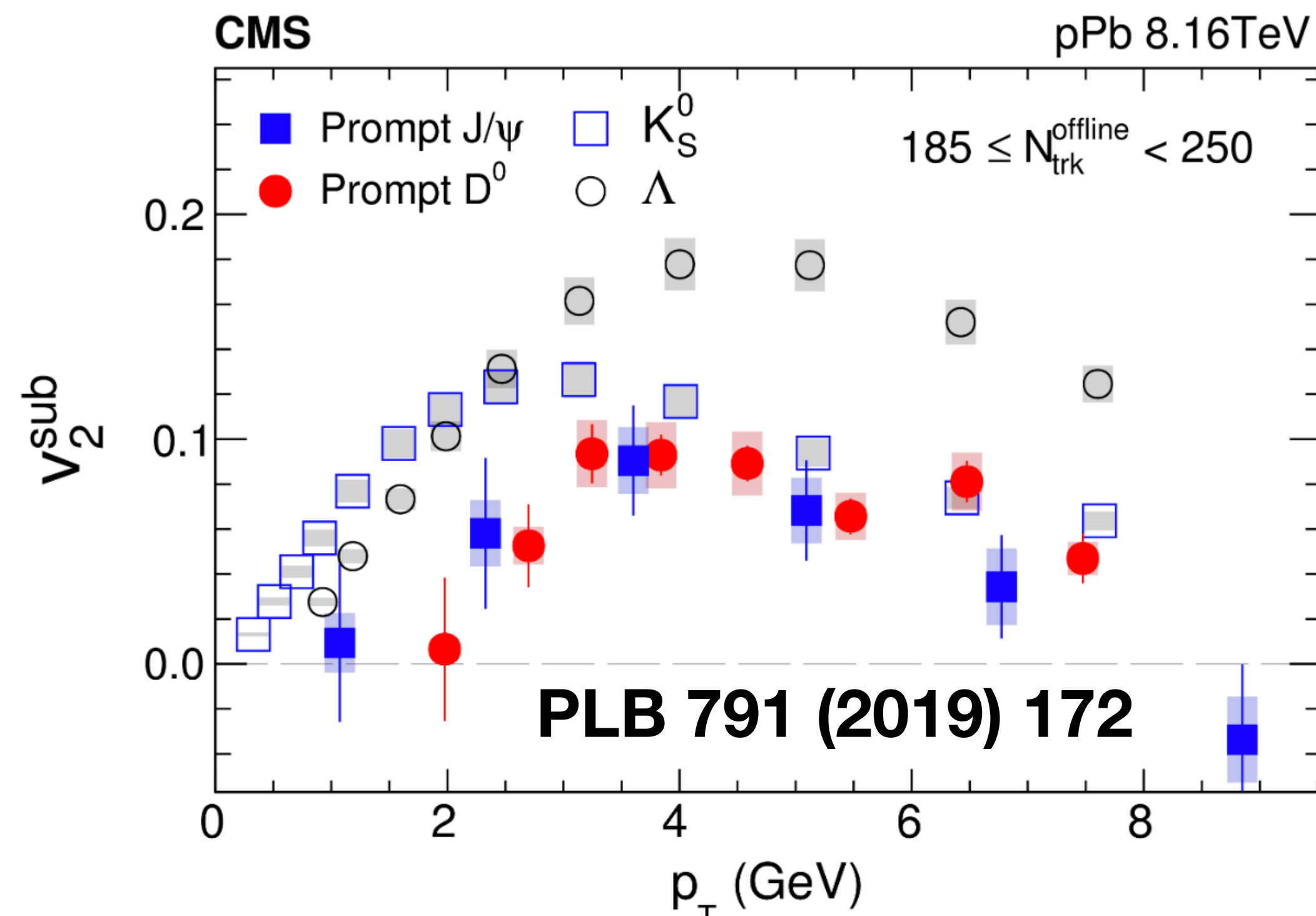
Austin Baty for the CMS Collaboration  
Rice University

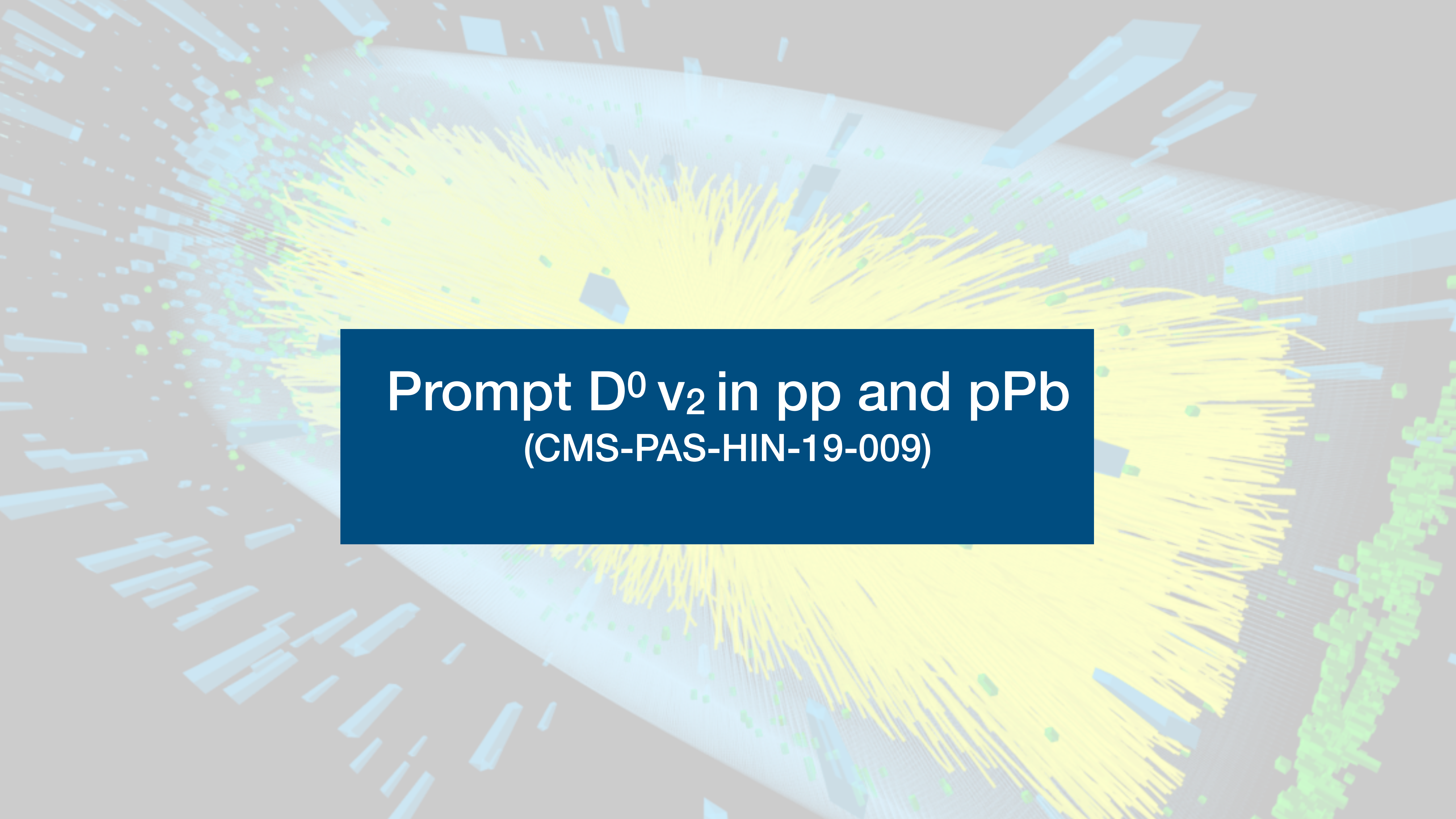
November 5th  
Quark Matter 2019  
Wuhan, China



# Introduction

- Heavy quarks are produced in the initial stages of a collision
  - Experience the full evolution of any medium
  - Indicator of initial state correlations (CGC)
- Charm  $v_2$  observed in pPb collisions via prompt  $D^0$  and  $J/\psi$
- Heavy-flavor  $\mu$  indicate charm  $v_2 >$  bottom  $v_2$  in pp
  - Full reconstruction of prompt (non-prompt)  $D^0$  lets us probe lower  $p_T$  behavior of c (b) quark

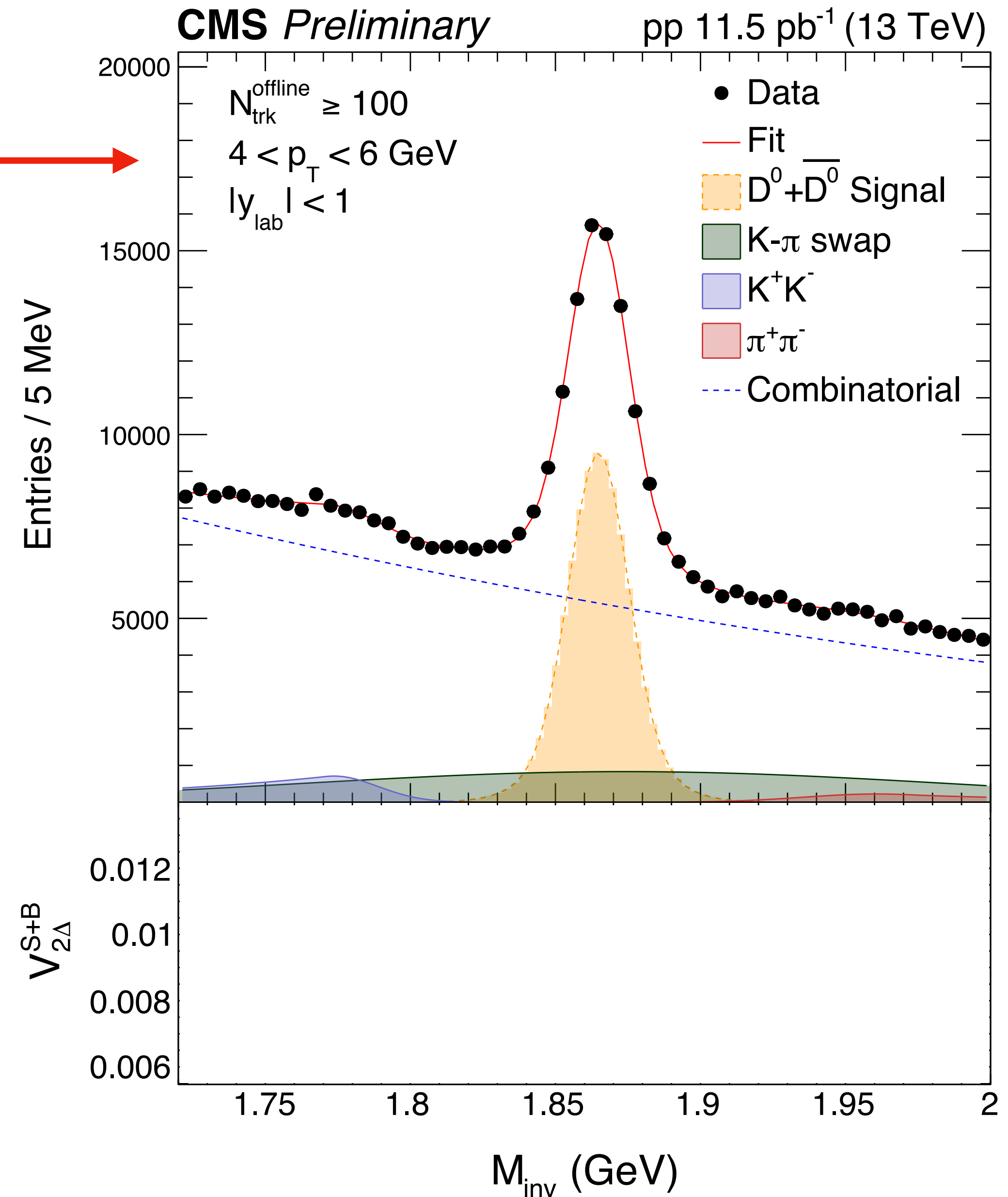




Prompt  $D^0$   $v_2$  in pp and pPb  
(CMS-PAS-HIN-19-009)

# D<sup>0</sup> mass peak

- 8.16 TeV pPb and 2017/18 13 TeV low-pileup pp data
- Fit D<sup>0</sup>→Kπ mass peak
- Selections optimized with a BDT



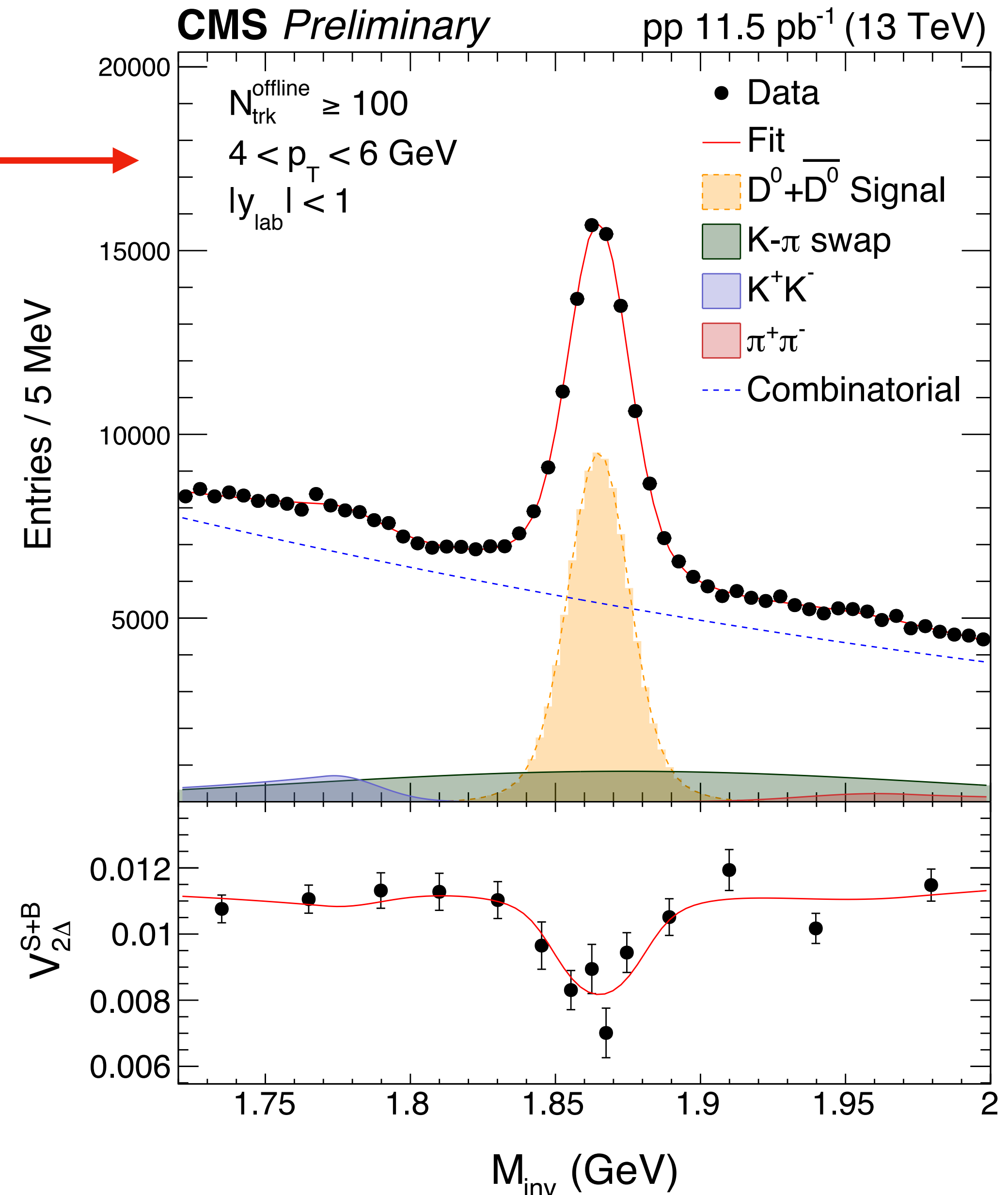
# $V_2$ signal extraction Procedure

- 8.16 TeV pPb and 2017/18 13 TeV low-pileup pp data
- Fit  $D^0 \rightarrow K\pi$  mass peak
- Selections optimized with a BDT
- Get candidate  $V_2$  Fourier component vs. mass
- Two-particle correlation technique

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

- Fit  $V_{2\Delta}^{\text{Signal+Bkg}}$  vs. mass to extract  $V_{2\Delta}^{\text{signal}}$
- Signal fraction  $\alpha$  taken from mass fit results

$$V_{2\Delta}^{\text{S+B}}(m_{\text{inv}}) = \alpha(m_{\text{inv}}) V_{2\Delta}^{\text{signal}} + [1 - \alpha(m_{\text{inv}})] V_{2\Delta}^{\text{Bkg}}(m_{\text{inv}})$$



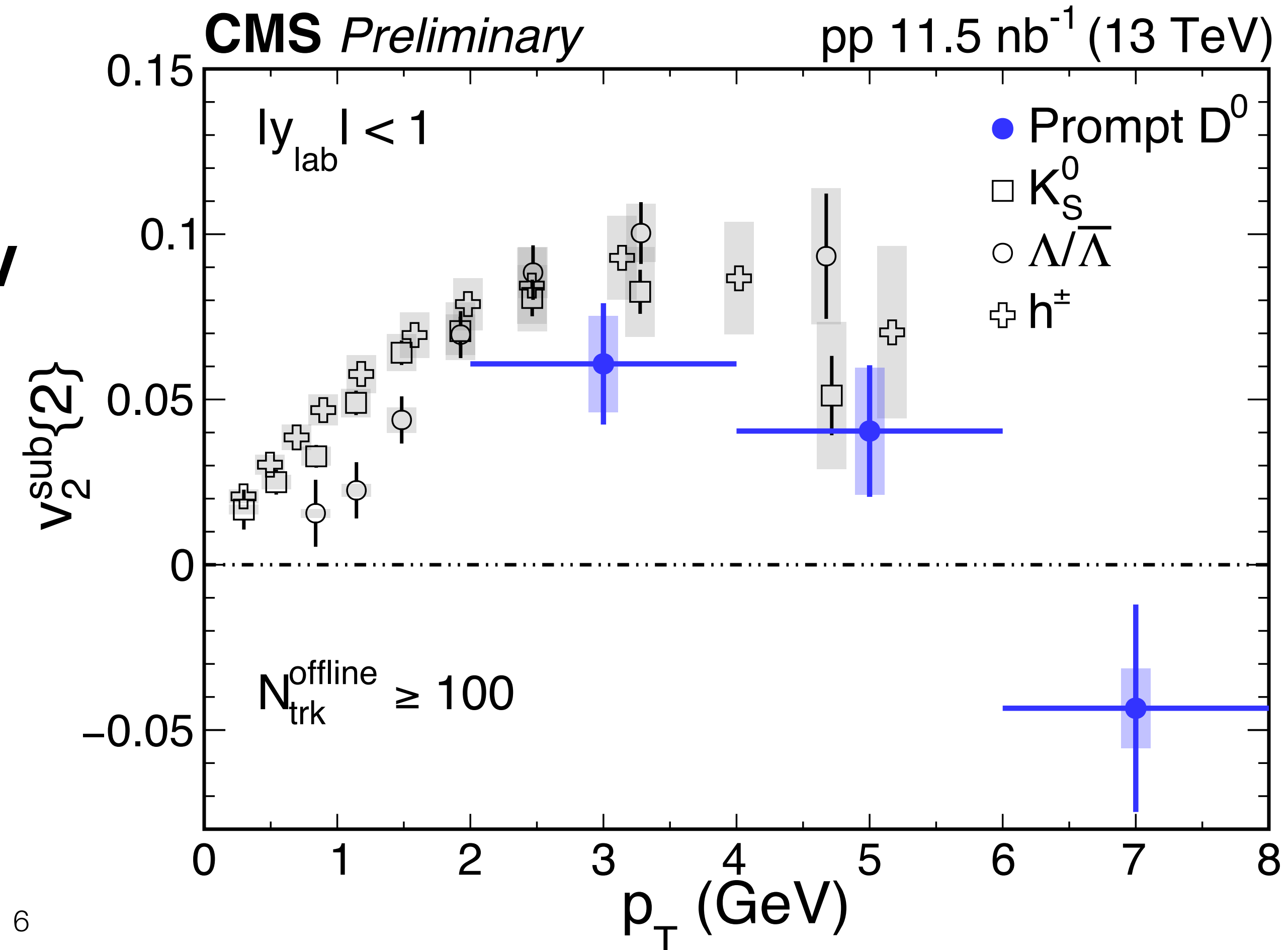
# 13 TeV pp Prompt D<sup>0</sup> v<sub>2</sub>



- Apply non-flow subtraction
- v<sub>2</sub> extracted from  $V_{2\Delta}^{signal}$  using charged reference particles ( $0.3 < p_T < 3 \text{ GeV}$ )

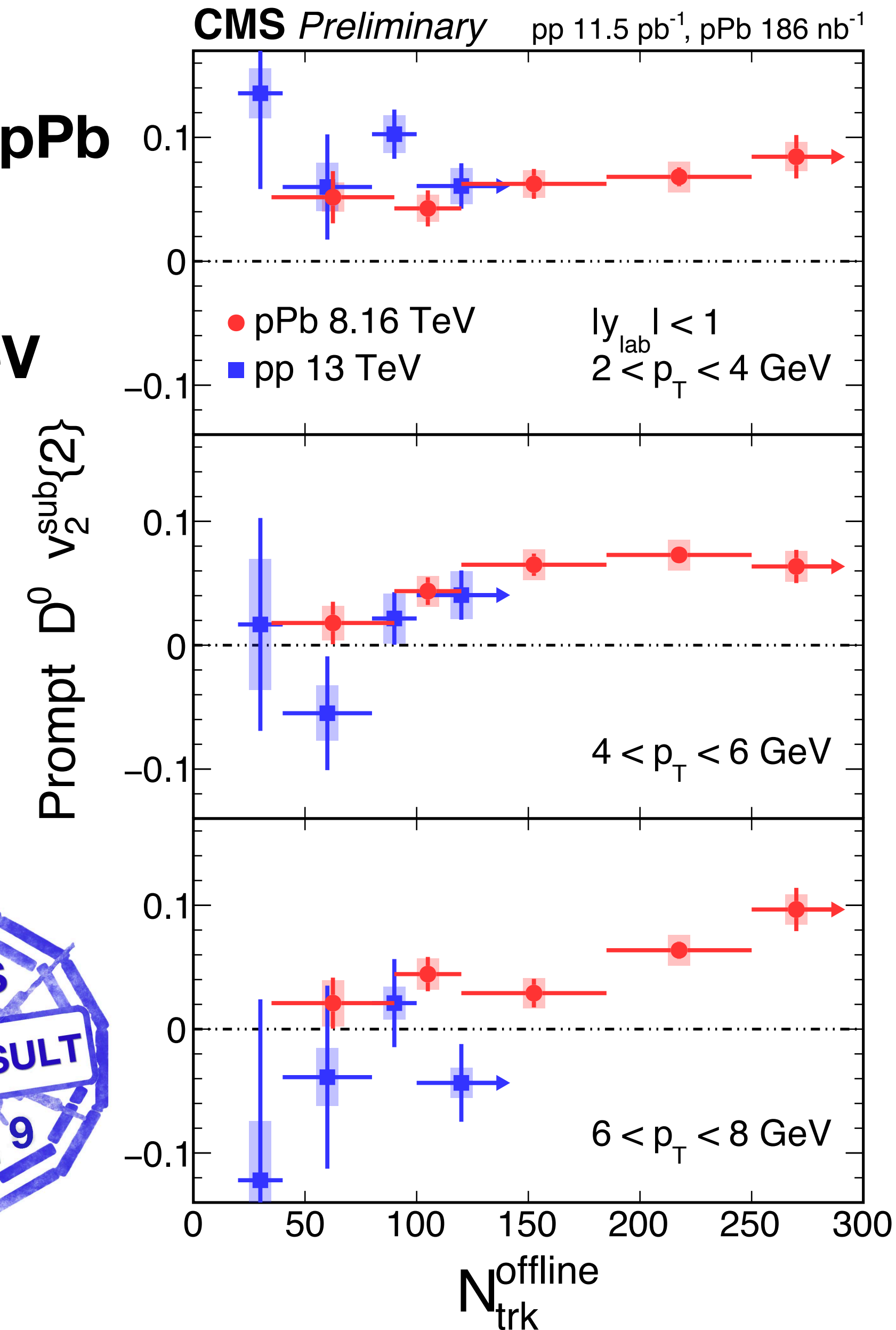
$$v_n(D^0) = V_{n\Delta}(D^0, \text{ref}) / \sqrt{V_{n\Delta}(\text{ref}, \text{ref})}$$

- v<sub>2</sub> slightly below strange hadrons at 2-4 GeV
  - Similar to trend in pPb collisions
- Consistent with zero at higher p<sub>T</sub>
- Limited by low-pileup pp luminosity
  - 11.5 pb<sup>-1</sup>



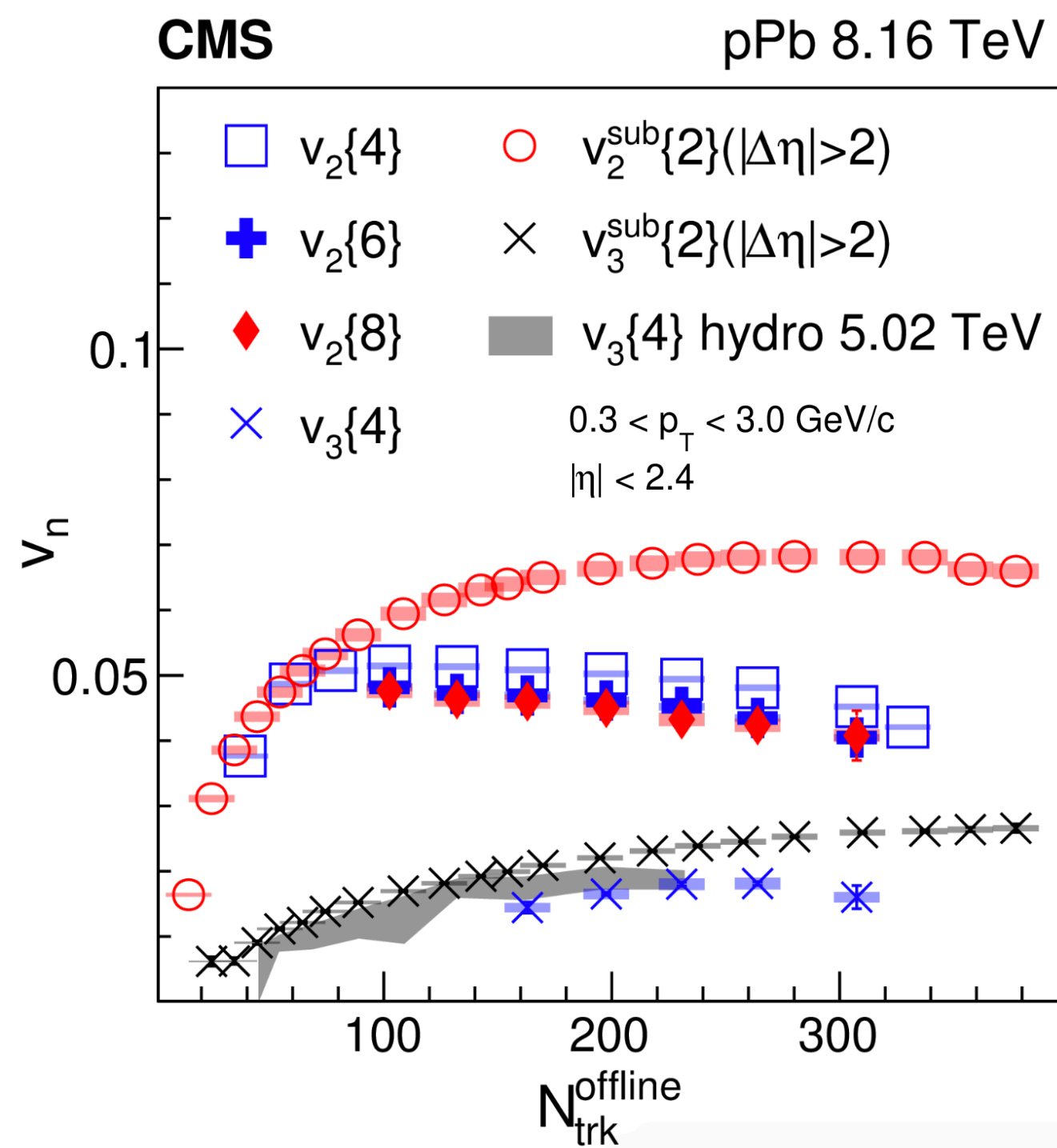
# Multiplicity Dependence

- First measurement of  $N_{\text{trk}}$  dependence of prompt  $D^0 v_2$  in pp & pPb
- No significant trend vs. multiplicity in pp
- Significant positive  $v_2$  in pPb down to  $N_{\text{trk}} = 50$  for  $2 < p_T < 6$  GeV
- Diminishing  $v_2$  in pPb as multiplicity decreases for  $p_T > 6$  GeV



# Multiplicity Dependence

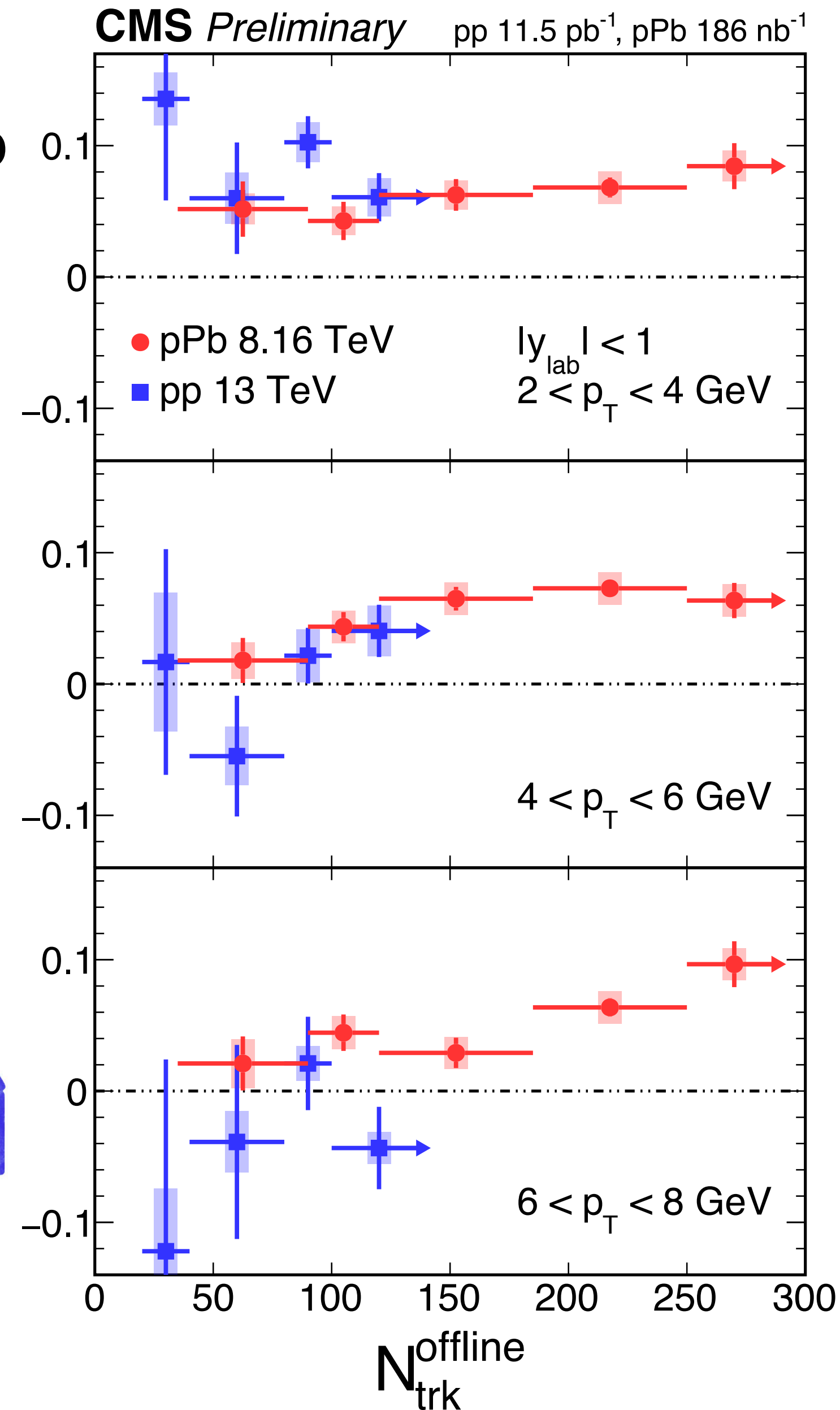
- First measurement of  $N_{\text{trk}}$  dependence of prompt  $D^0$   $v_2$  in pp & pPb
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pPb charged particle

$$v_2^{\text{sub}}\{2\}$$

[arXiv:1904.11519](https://arxiv.org/abs/1904.11519)

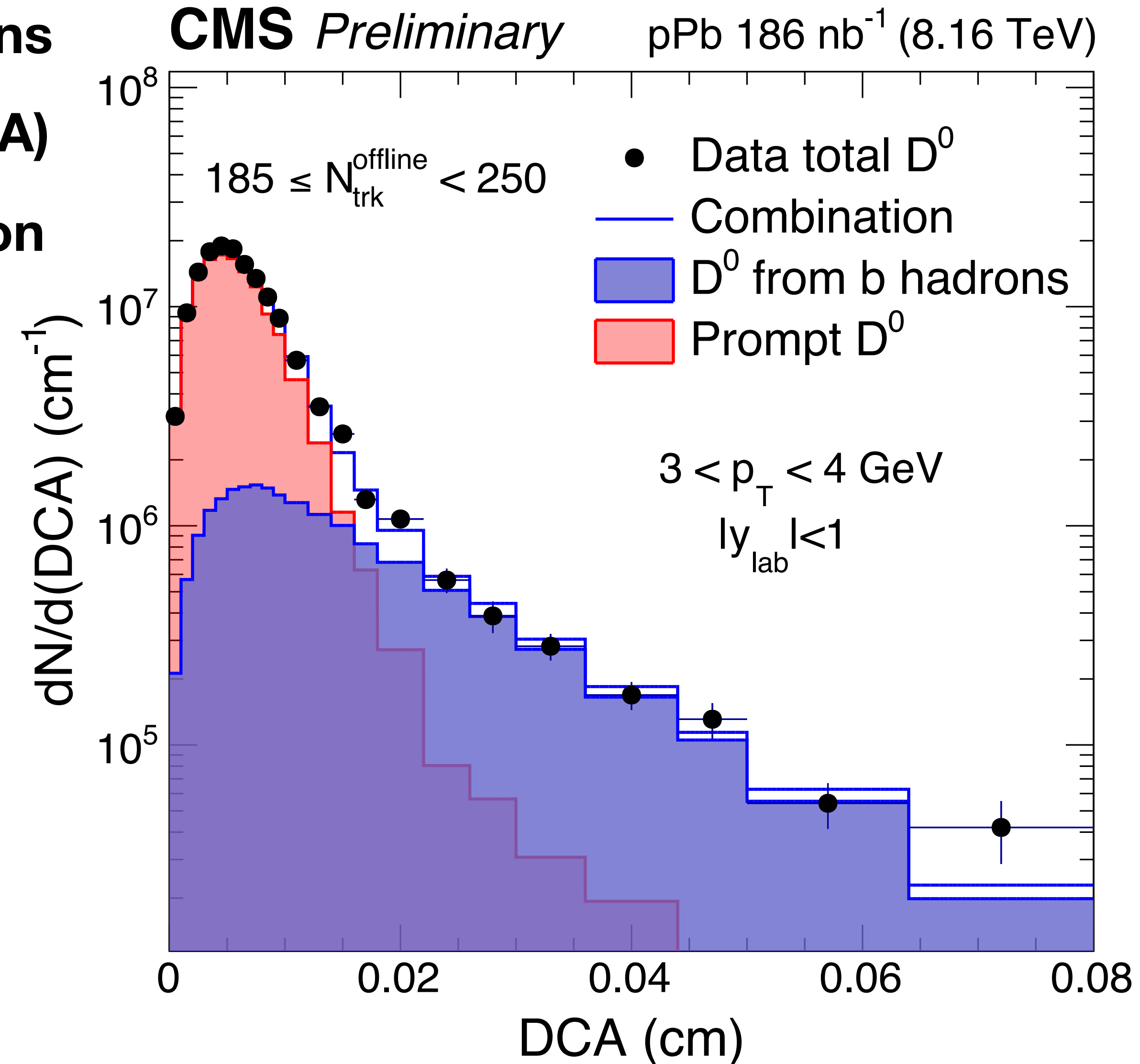
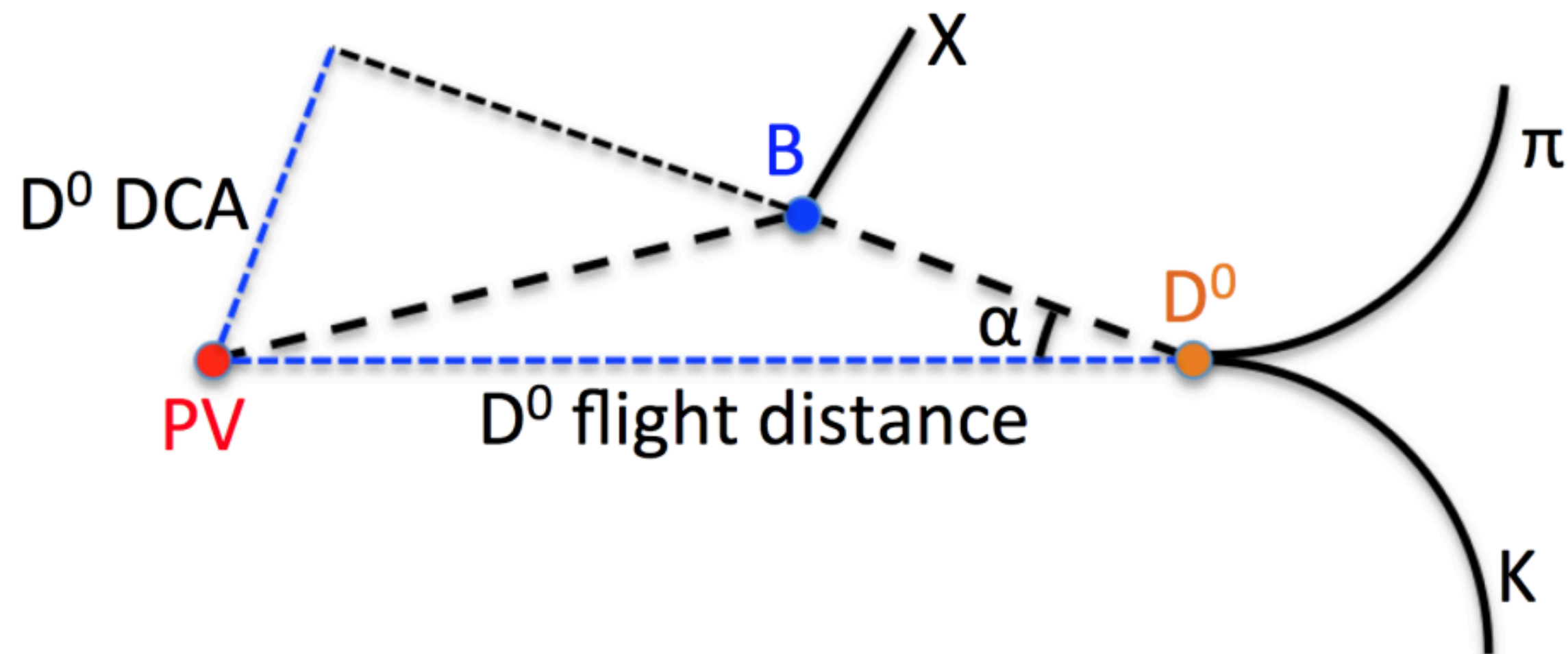


The background of the slide is a 3D visualization of a particle detector, likely the CMS detector. It shows a complex cylindrical structure with various components, including a central solenoid and an outer calorimeter. The visualization is rendered in shades of blue, yellow, and green, with a perspective view looking down the length of the detector. The central region is highlighted with a bright yellow glow, suggesting a particle interaction or decay process.

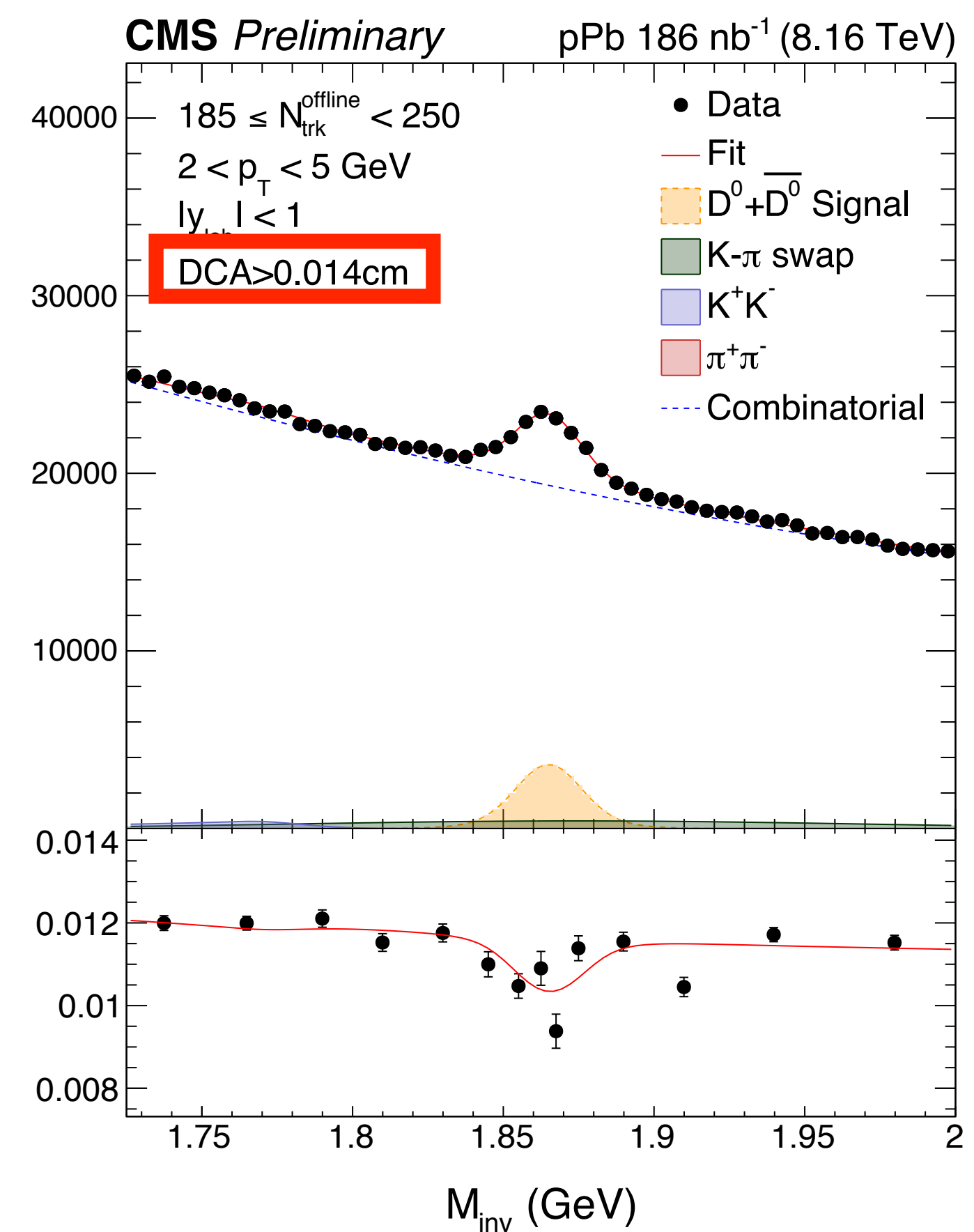
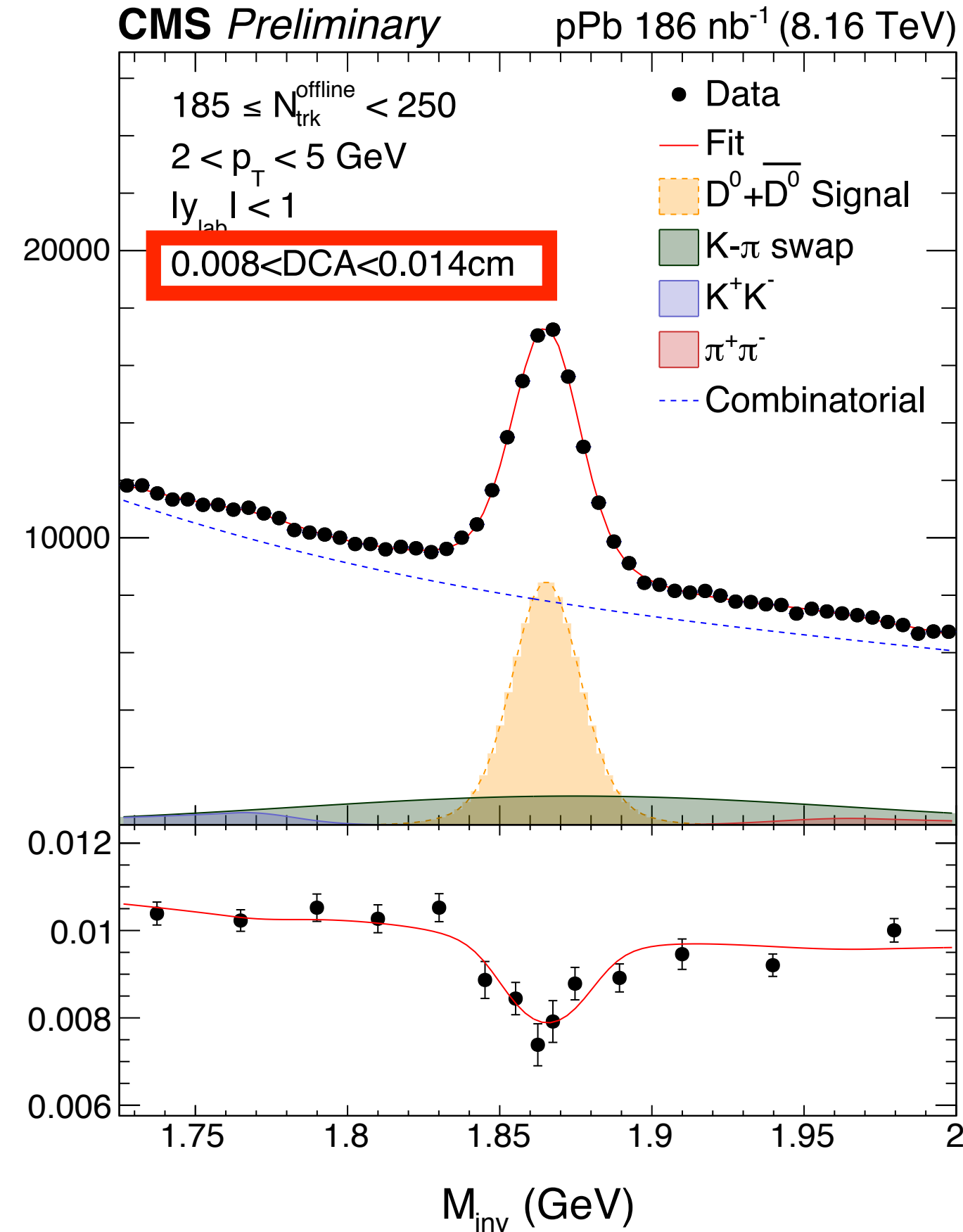
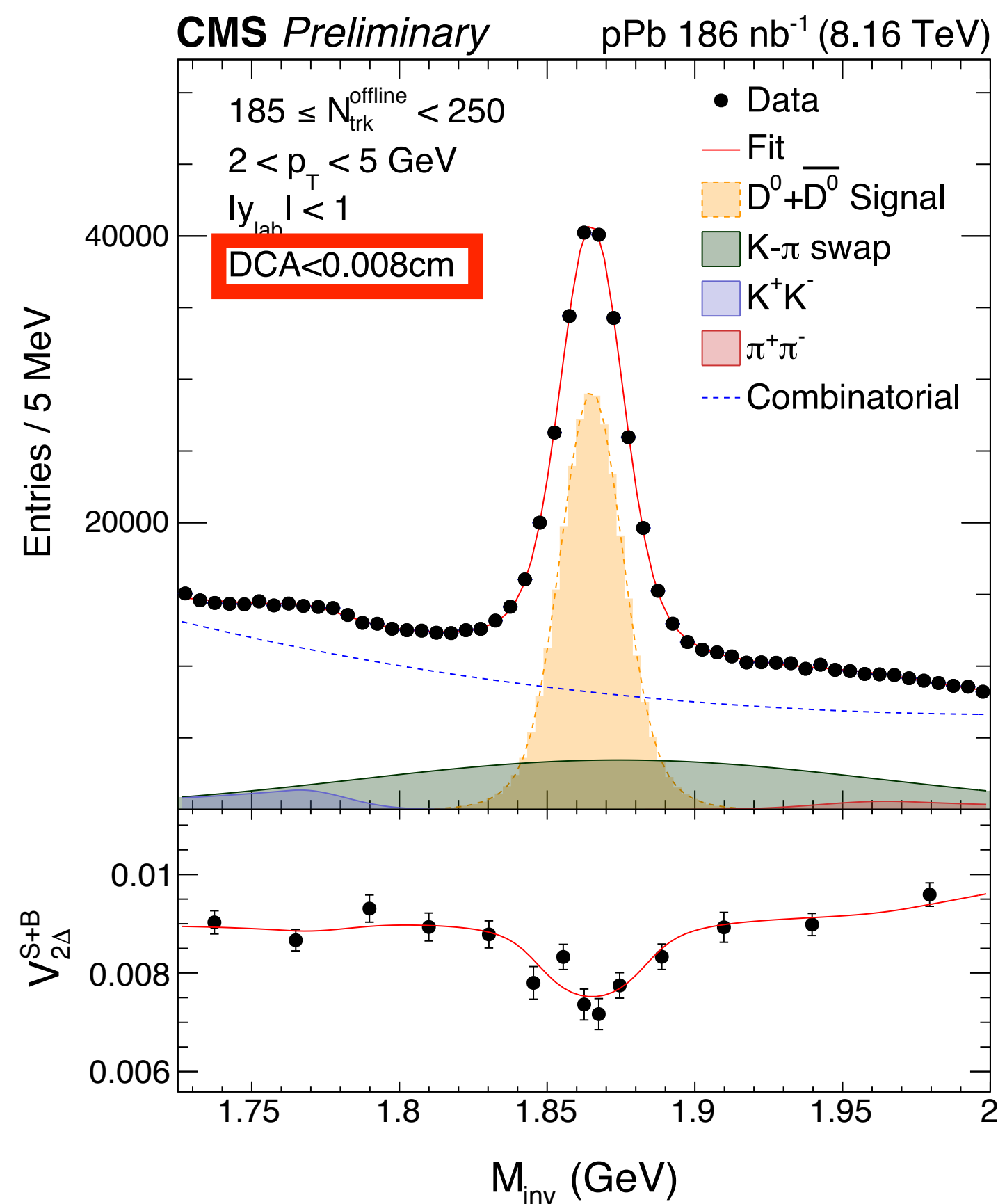
**Non-prompt  $D^0$   $v_2$  in pPb**  
(CMS-PAS-HIN-19-009)

# Non-prompt fraction

- Non-prompt  $D^0$  originate primarily from B hadrons
- Have a larger Distance of Closest approach (DCA)
- MC-based template fit to get non-prompt fraction

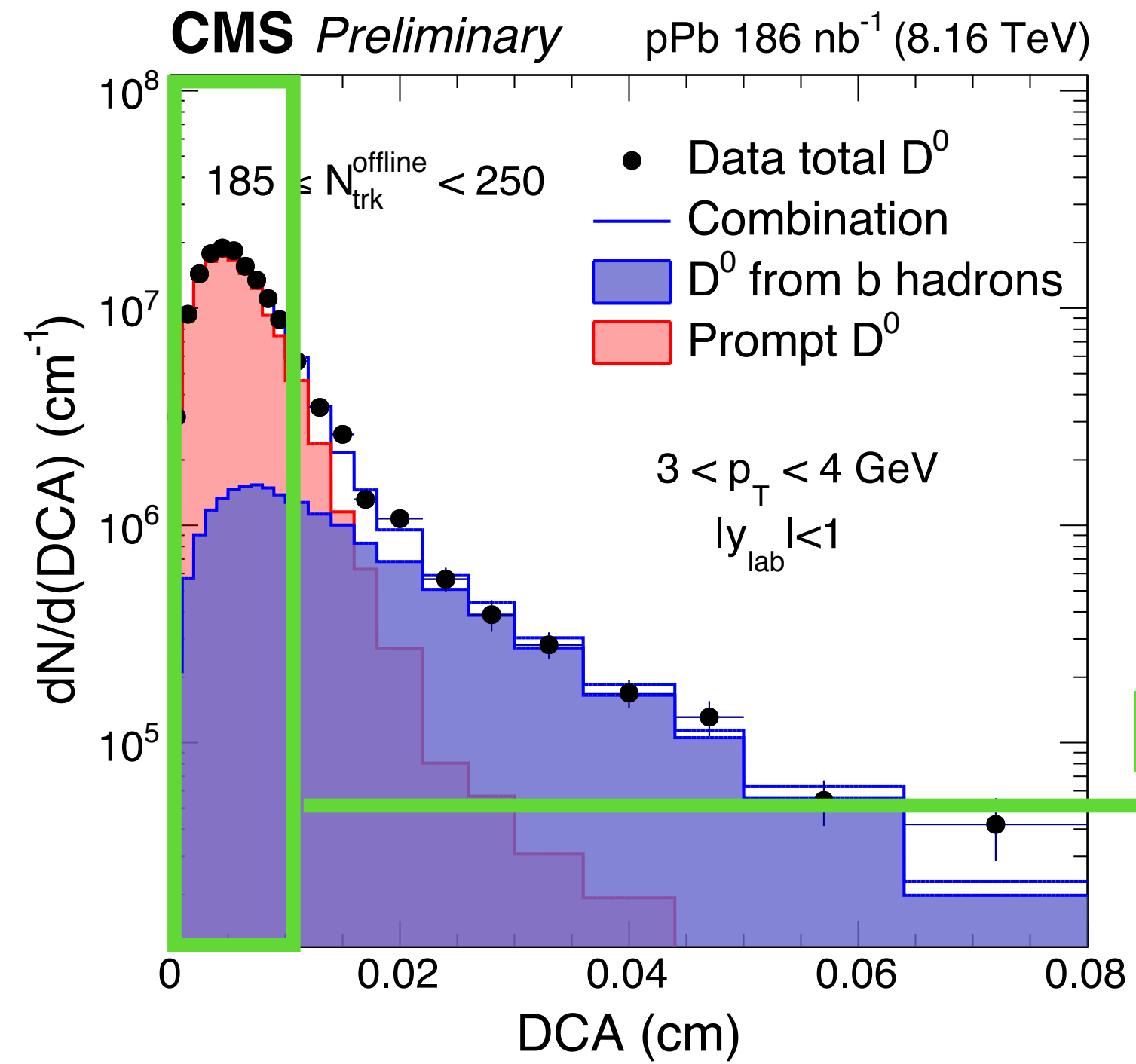
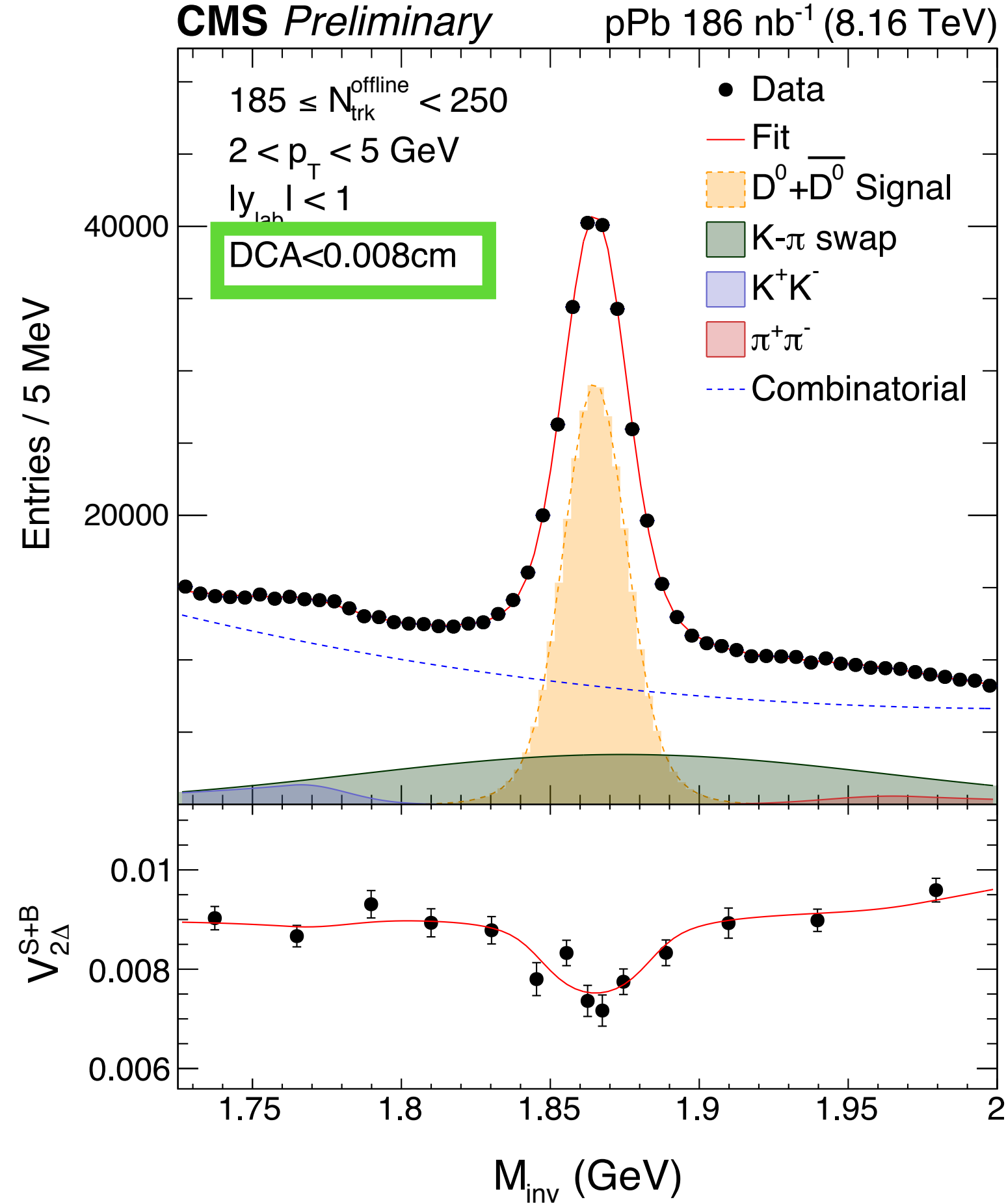


# 8.16 TeV pPb Mass Peaks



- **Similar fit procedure as 13 TeV pp analysis**
- **Fit in 3 regions of candidate DCA**
- **Larger DCA implies larger non-prompt fraction**

# $V_2$ and non-prompt fraction



Integrate

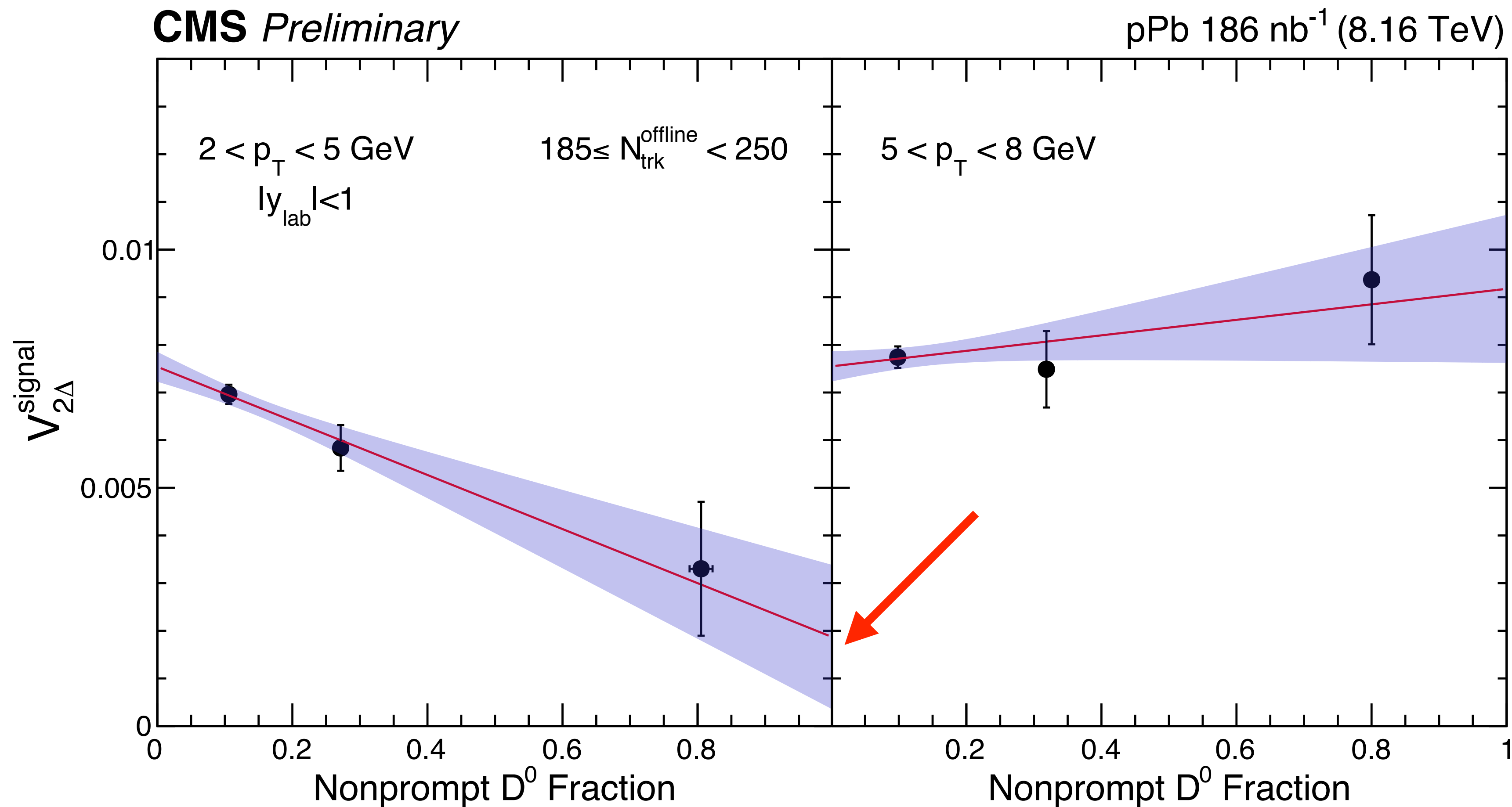
Non-prompt  
D<sup>0</sup> fraction

$V_{2\Delta}^{signal}$

$$V_{2\Delta}^{S+B}(m_{inv}) = \alpha(m_{inv}) V_{2\Delta}^{signal} + [1 - \alpha(m_{inv})] V_{2\Delta}^{Bkg}(m_{inv})$$

- Calculate  $V_{2\Delta}^{signal}$  and non-prompt fraction in each DCA selection
- Plot these two quantities against each other...

# Non-Prompt D<sup>0</sup> Extrapolation

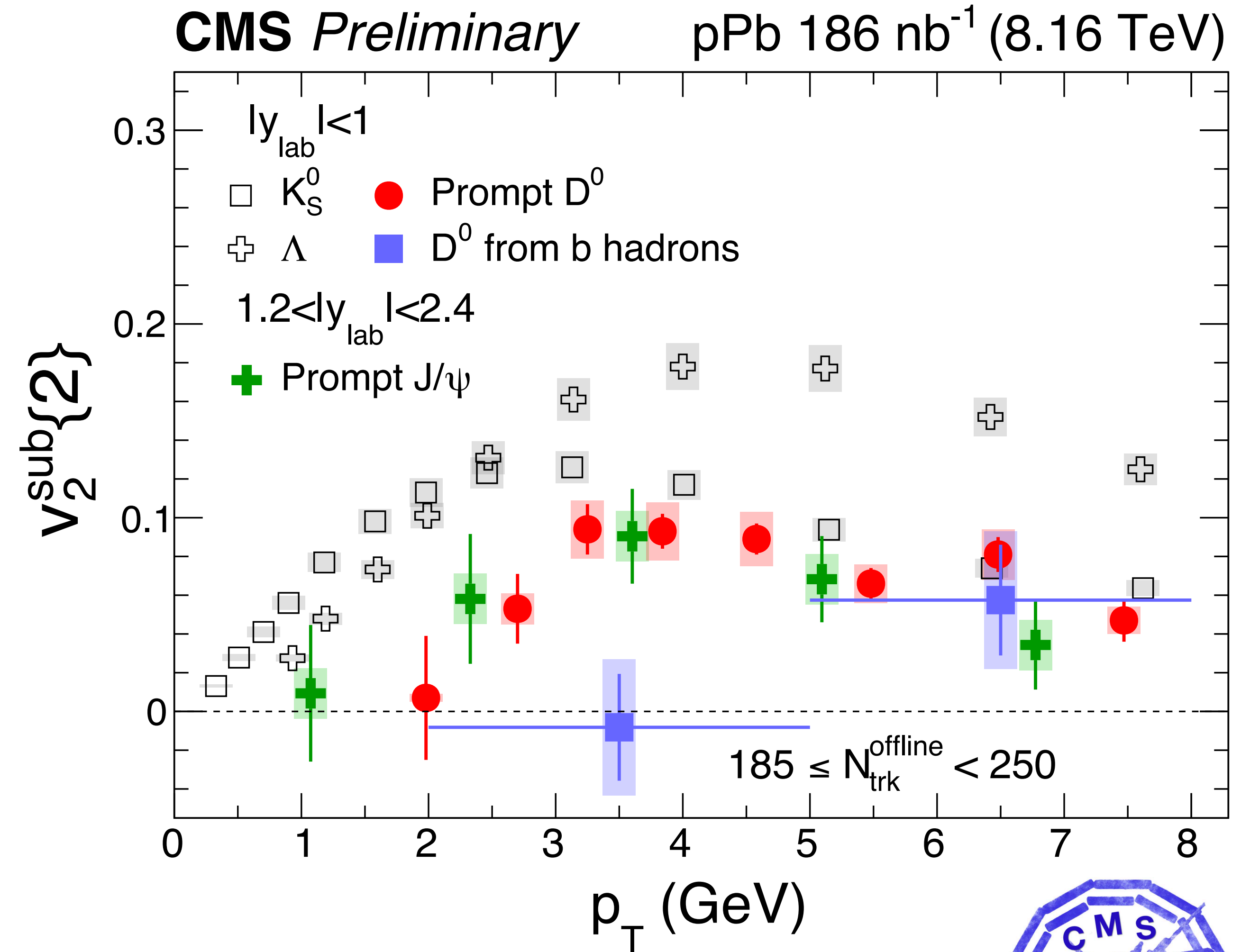


- **Extrapolate with linear fit**
- **Apply non-flow subtraction**

•  **$v_2$  extracted from  $V_{2\Delta}^{\text{signal}}$  using charged reference particles:**  $v_n(D^0) = V_{n\Delta}(D^0, \text{ref}) / \sqrt{V_{n\Delta}(\text{ref}, \text{ref})}$ .

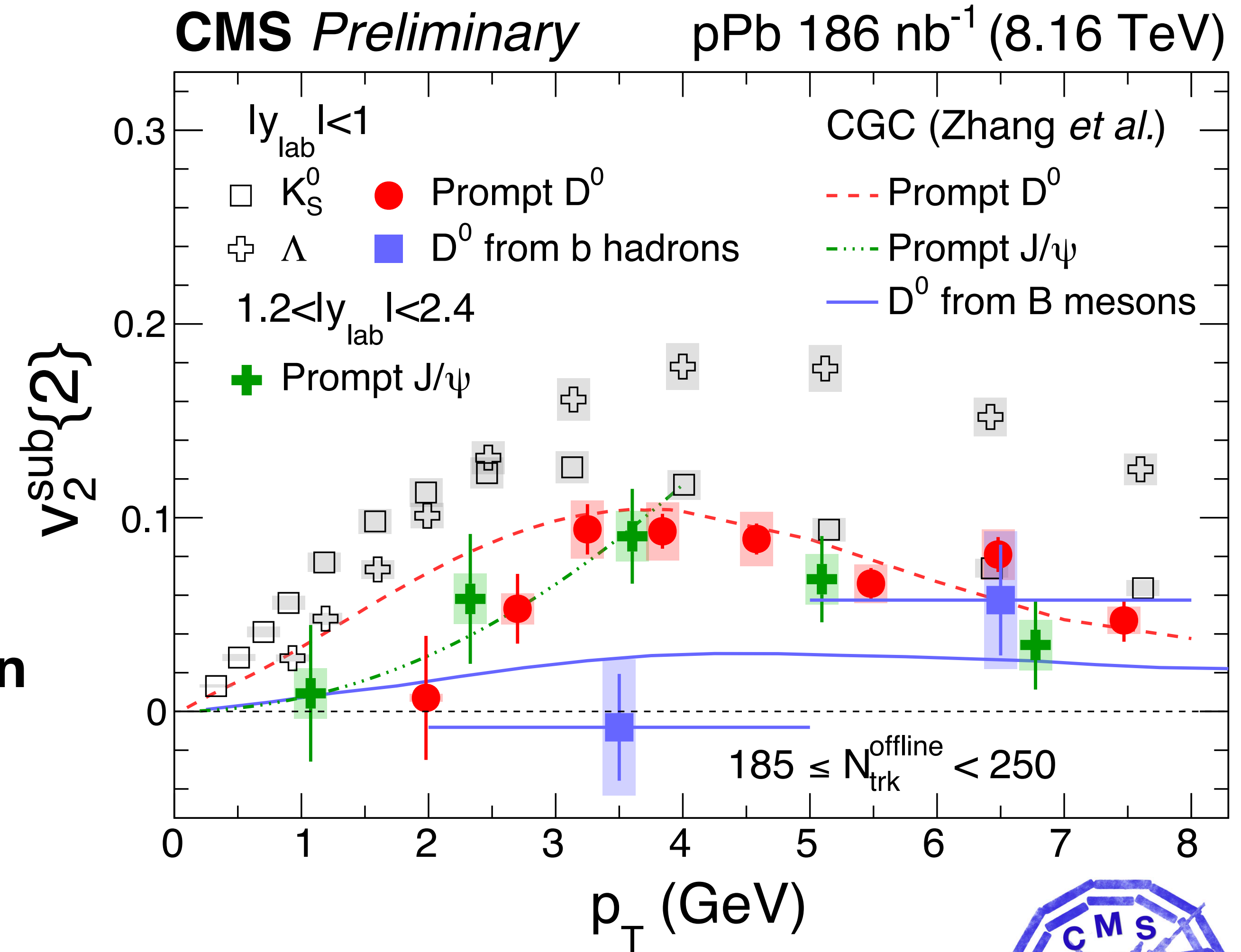
# Non-prompt $D^0$ $v_2$

- **Non-Prompt  $D^0$   $v_2$  consistent with zero**
- **Evidence for  $c > b$  quark ordering of  $v_2$** 
  - **Only in region from  $p_T = 2-5$  GeV**



# Non-prompt $D^0$ $v_2$

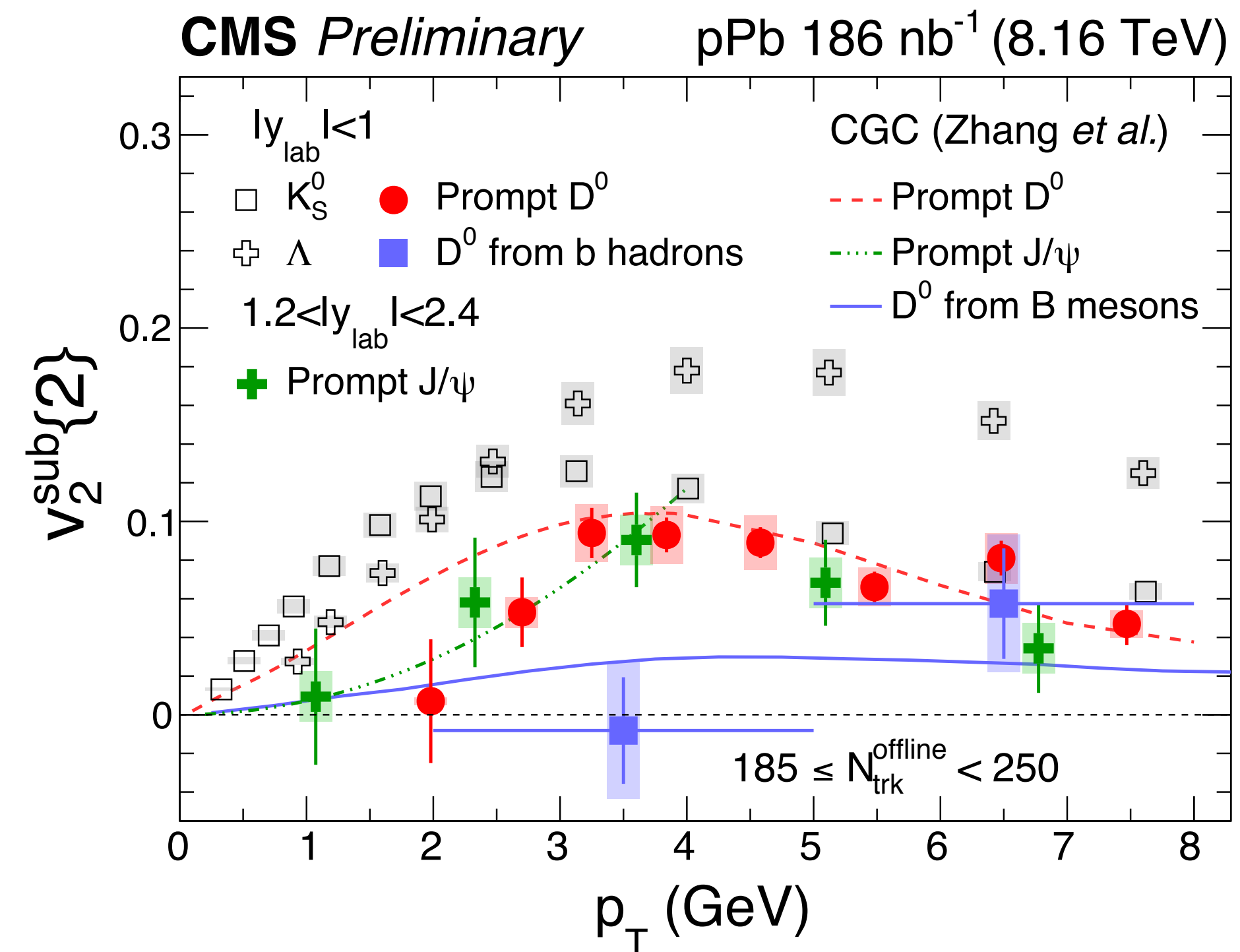
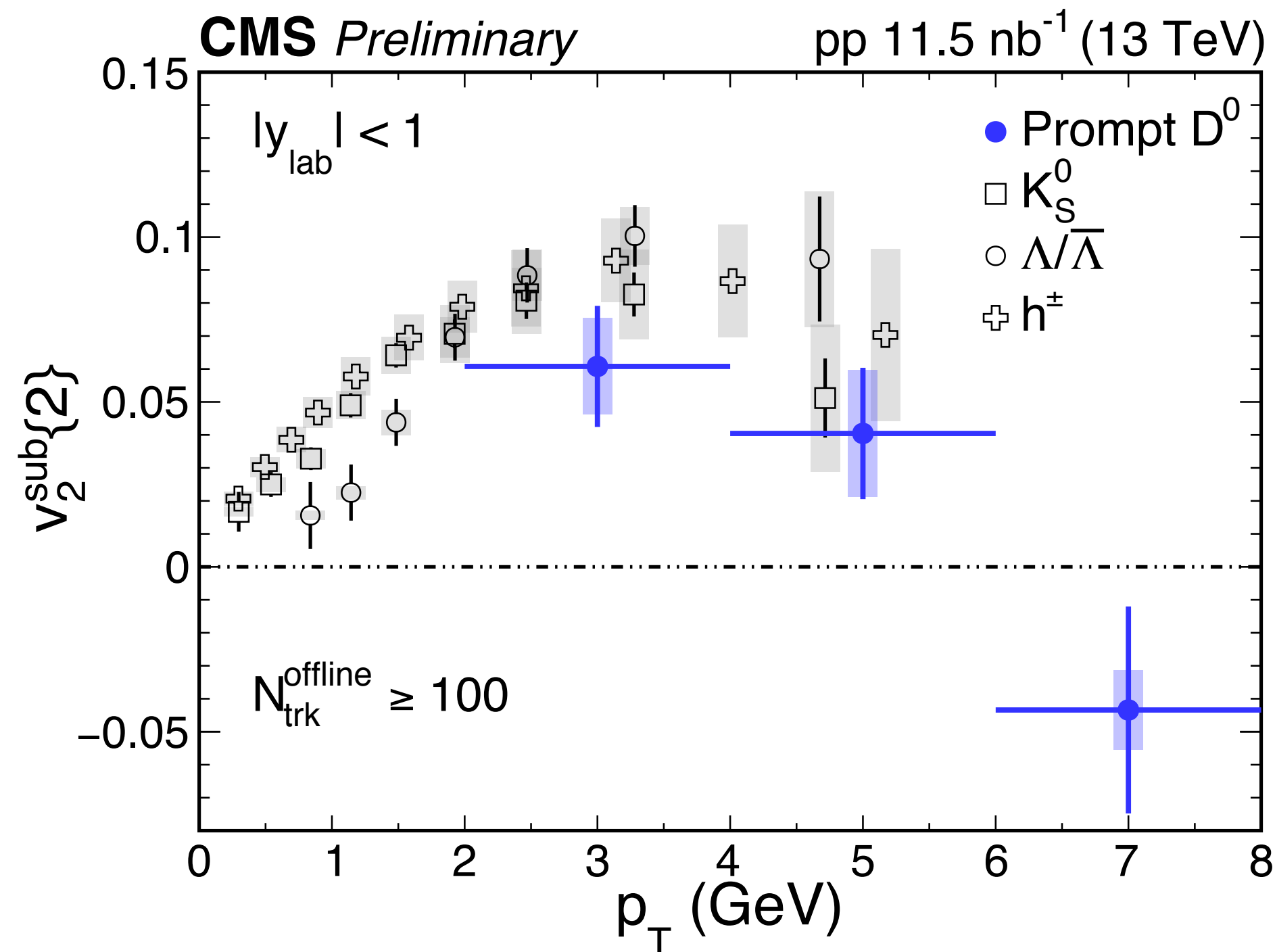
- **Non-Prompt  $D^0$   $v_2$  consistent with zero**
- **Evidence for  $c > b$  quark ordering of  $v_2$** 
  - **Only in region from  $p_T = 2-5$  GeV**
- **Prediction of  $b$   $v_2$  from CGC model**
  - **Feed-down & decay by PYTHIA 8**
- **Indicates  $b$  does not participate strongly in same collective phenomena**



# Summary

- Non-zero  $v_2$  seen for prompt  $D^0$  in 13 TeV pp collisions
- Multiplicity dependence measured for prompt  $D^0$  in pp and pPb
- Non-prompt  $D^0$   $v_2$  in pPb found to be compatible with zero
- Evidence of c and b flavor hierarchy of  $v_2$  in pPb
- Constrains models of the initial state of small systems

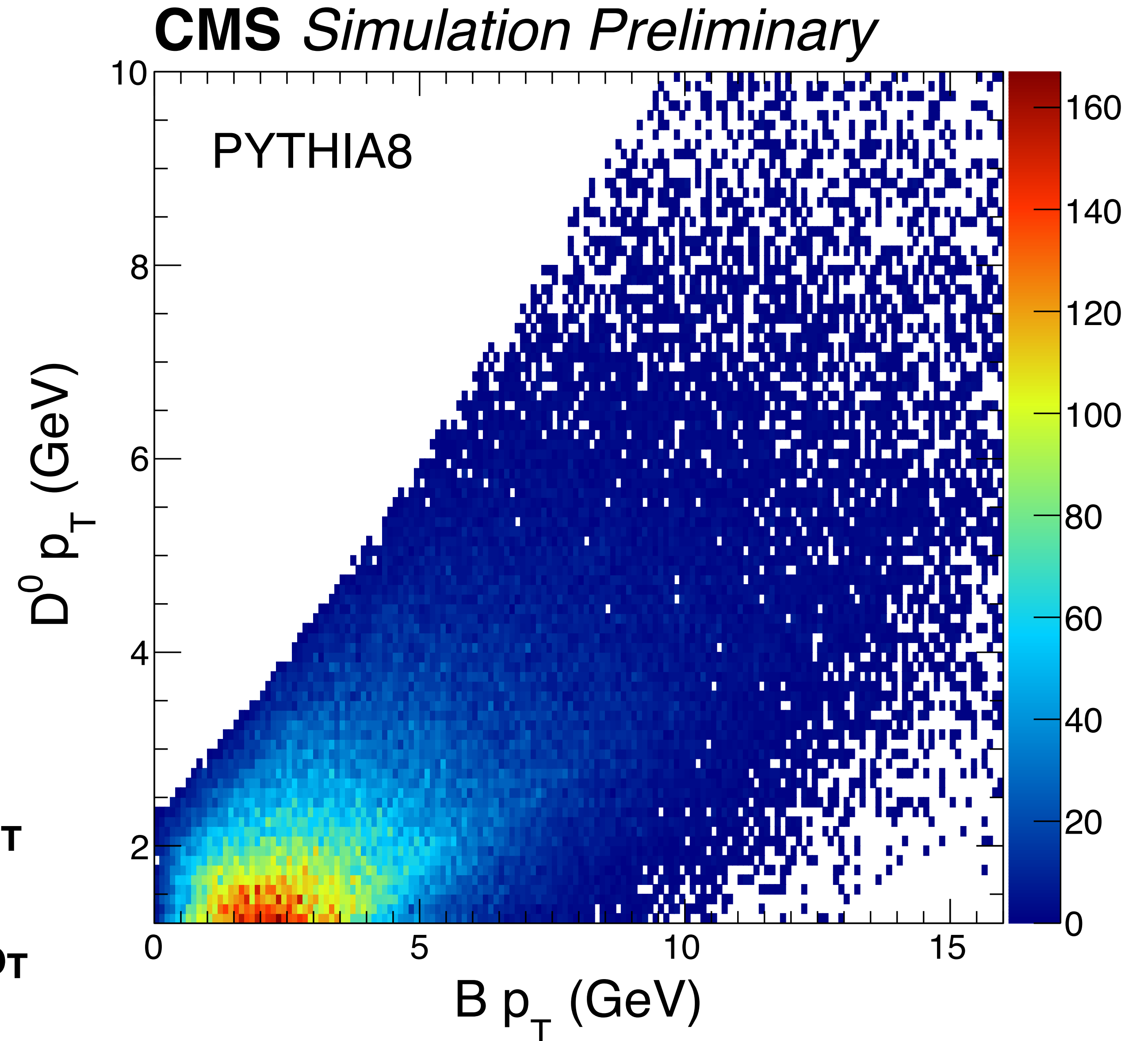
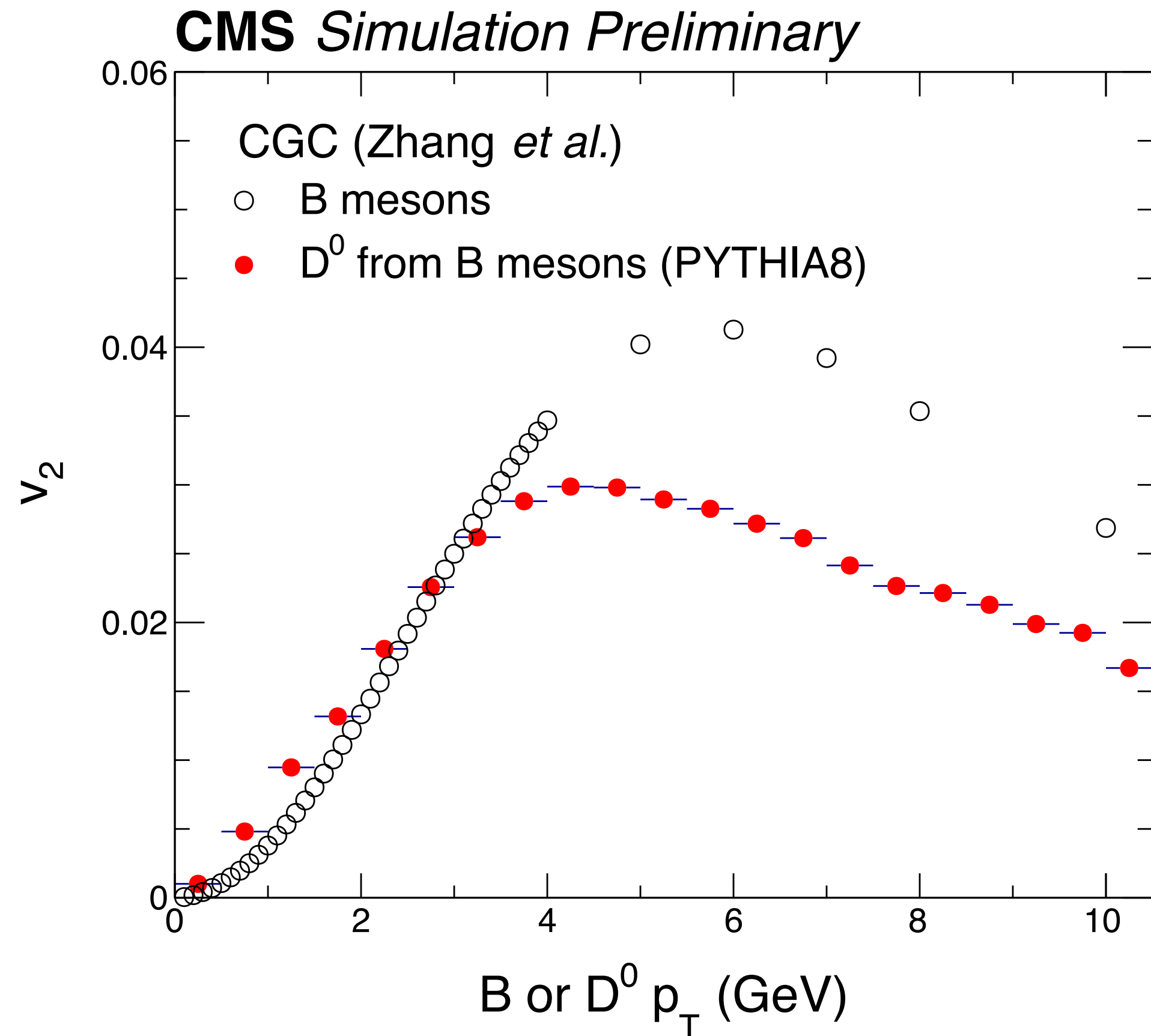
More information at  
**CMS-PAS-HIN-19-009**



The background is a complex, abstract digital composition. It features a dense field of thin, light blue lines radiating from a central point, creating a sense of depth and movement. Interspersed among these lines are various geometric shapes, including small squares and rectangles, some in shades of light blue and others in a vibrant yellow. The overall effect is that of a dynamic, data-driven environment, possibly representing a network or a complex system. The colors are primarily light blue and yellow, set against a very light, almost white background.

Backup

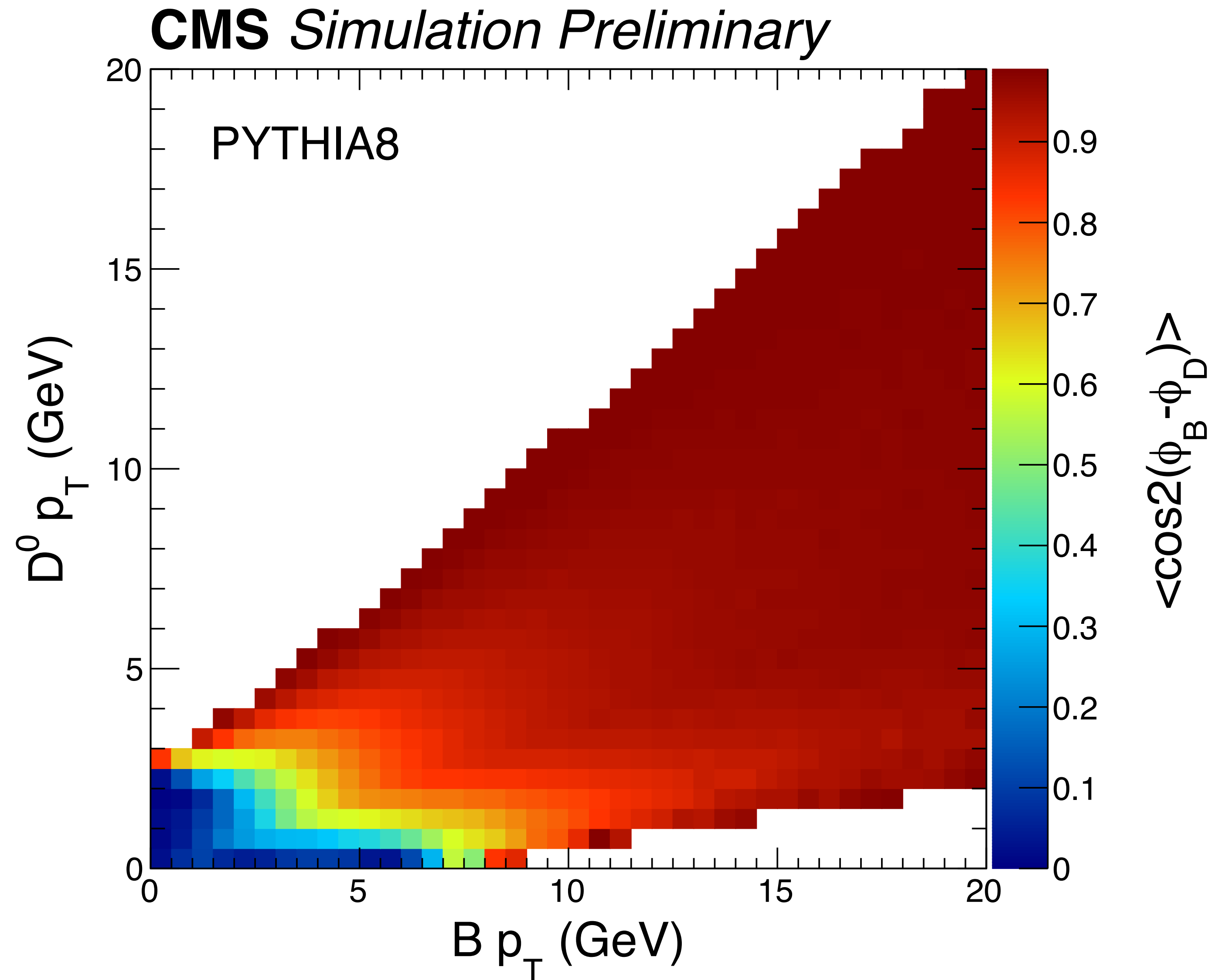
# B feed-down



- **Shifting between B and  $D^0$  depends on  $p_T$**
- **PYTHIA indicates  $D^0$  carries  $>50\%$  of B  $p_T$**

# Decay smearing effect on $v_2$

- **Some smearing of  $B v_2$  expected from decay kinematics**
- **Effect is fairly small in the  $p_T$  region studied here**



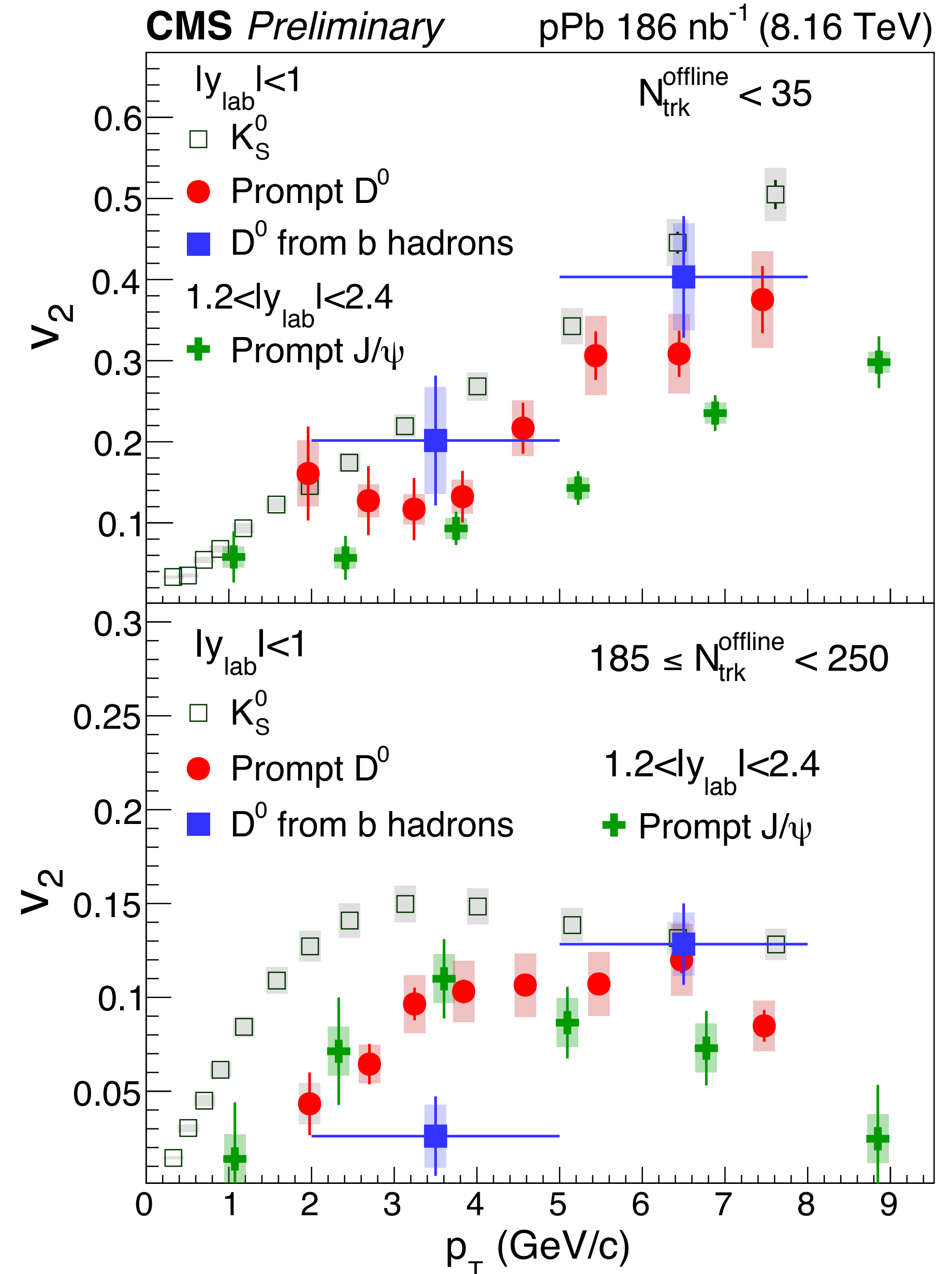
# Non-flow subtraction

- **Low-multiplicity used for non-flow subtraction**
- **Has a significant effect at high- $p_T$**

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

Scaling of the yield of jets with multiplicity

Scaling of the relative contribution of non-flow with multiplicity



# Signal fraction

$$\alpha(m_{\text{inv}}) = \frac{S(m_{\text{inv}}) + SW(m_{\text{inv}}) + S(m_{\text{K}^+\text{K}^-}) + S(m_{\pi^+\pi^-})}{S(m_{\text{inv}}) + SW(m_{\text{inv}}) + S(m_{\text{K}^+\text{K}^-}) + S(m_{\pi^+\pi^-}) + B(m_{\text{inv}})}$$

- Peak, swapped, KK, and  $\pi\pi$  candidates originate from legitimate  $D^0$  decays
- Expected to share similar  $v_2$

