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

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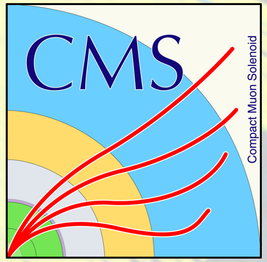
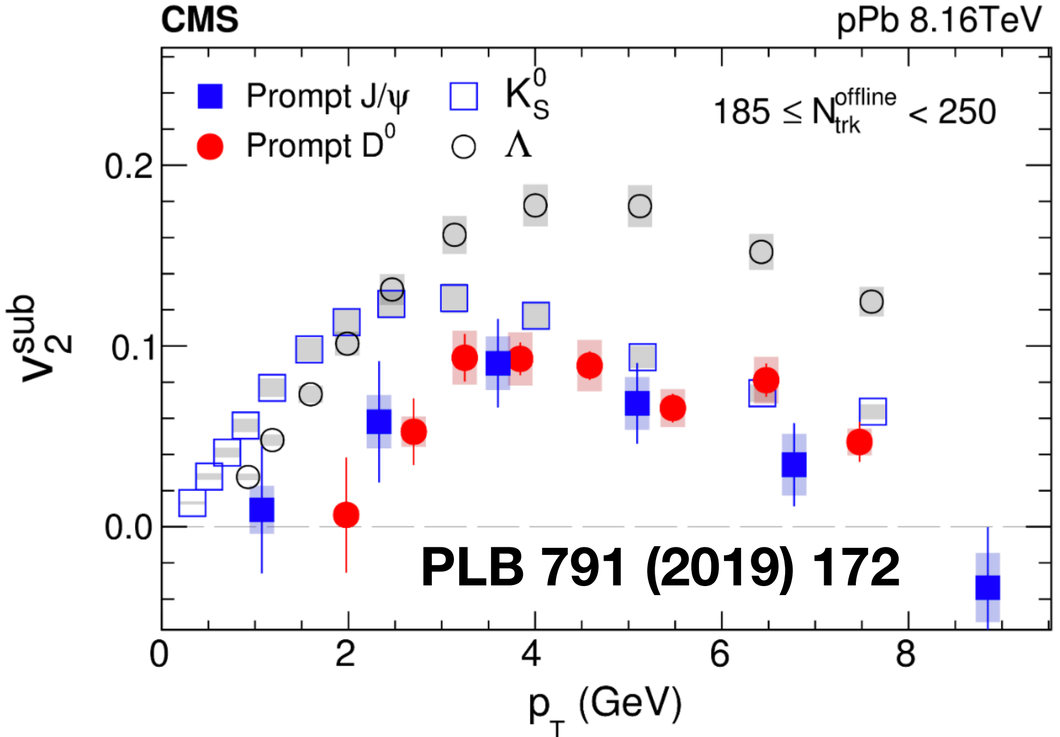


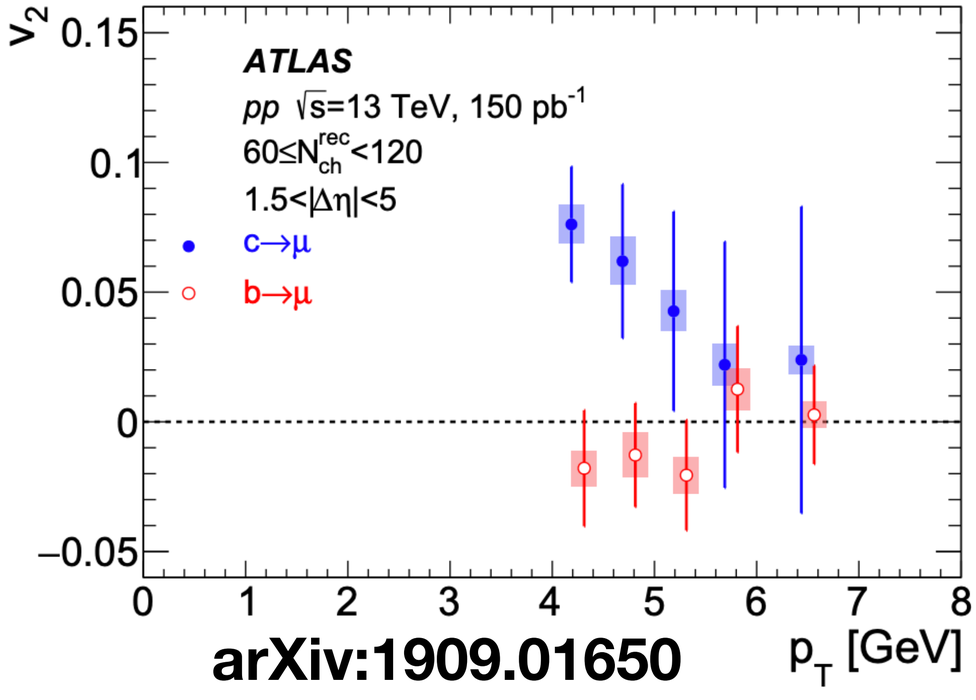
Introduction

- **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/ψ**

- **Heavy-flavor μ 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**



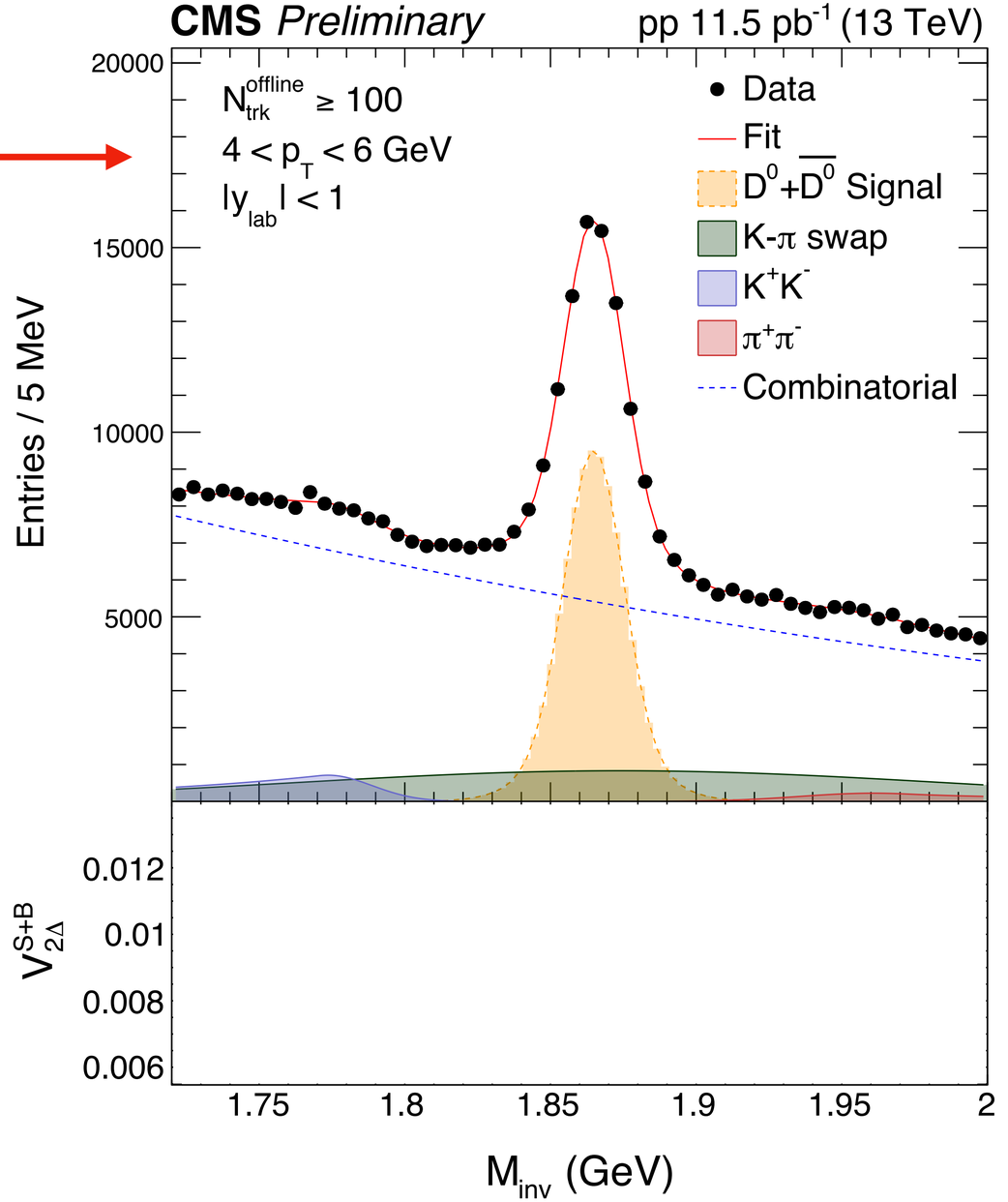


Prompt D^0 v_2 in pp and pPb

(CMS-PAS-HIN-19-009)

D^0 mass peak

- **8.16 TeV pPb and 2017/18 13 TeV low-pileup pp data**
- **Fit $D^0 \to K\pi$ mass peak**
  - **Selections optimized with a BDT**



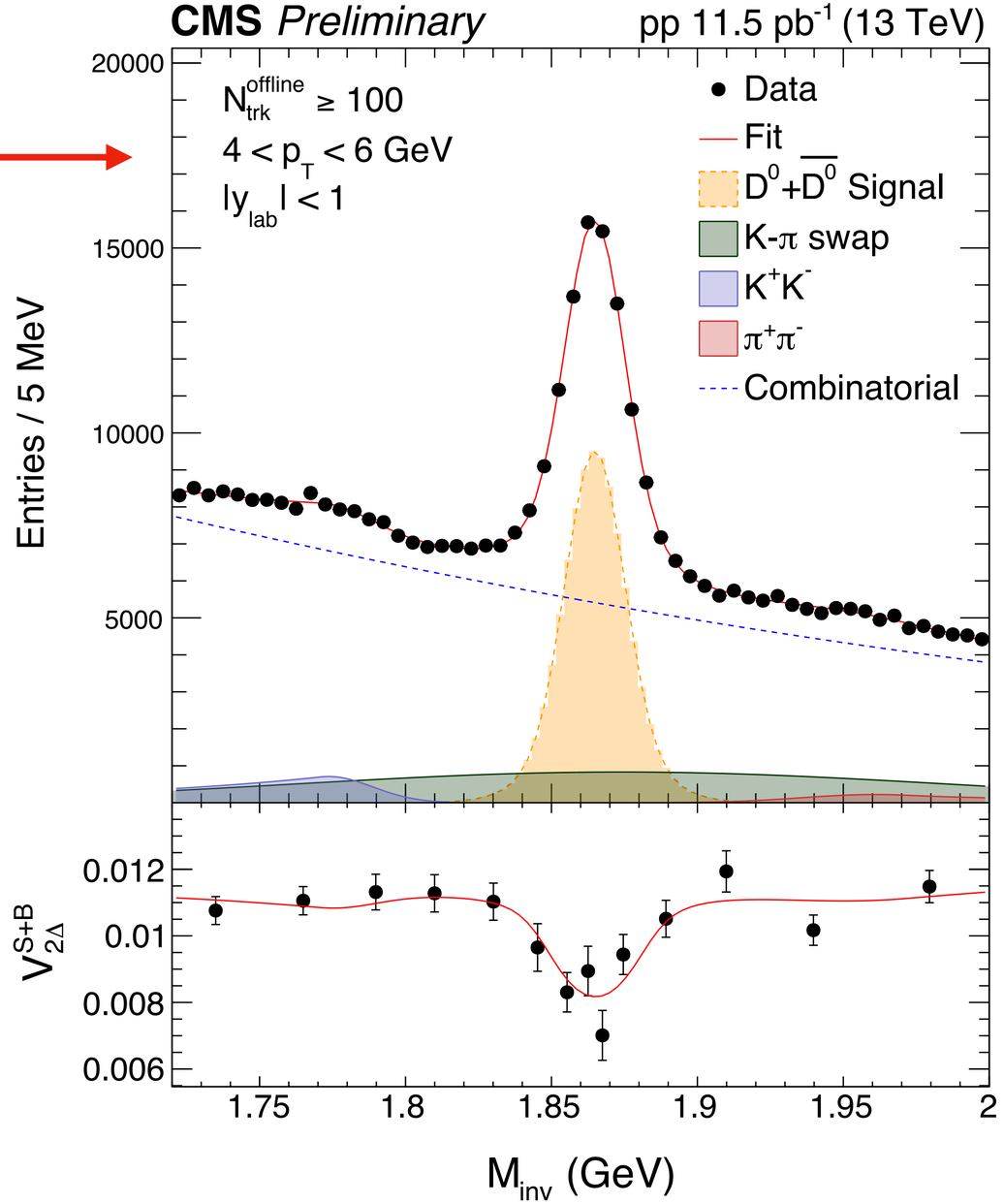
V_2^{signal} extraction Procedure

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

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

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

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

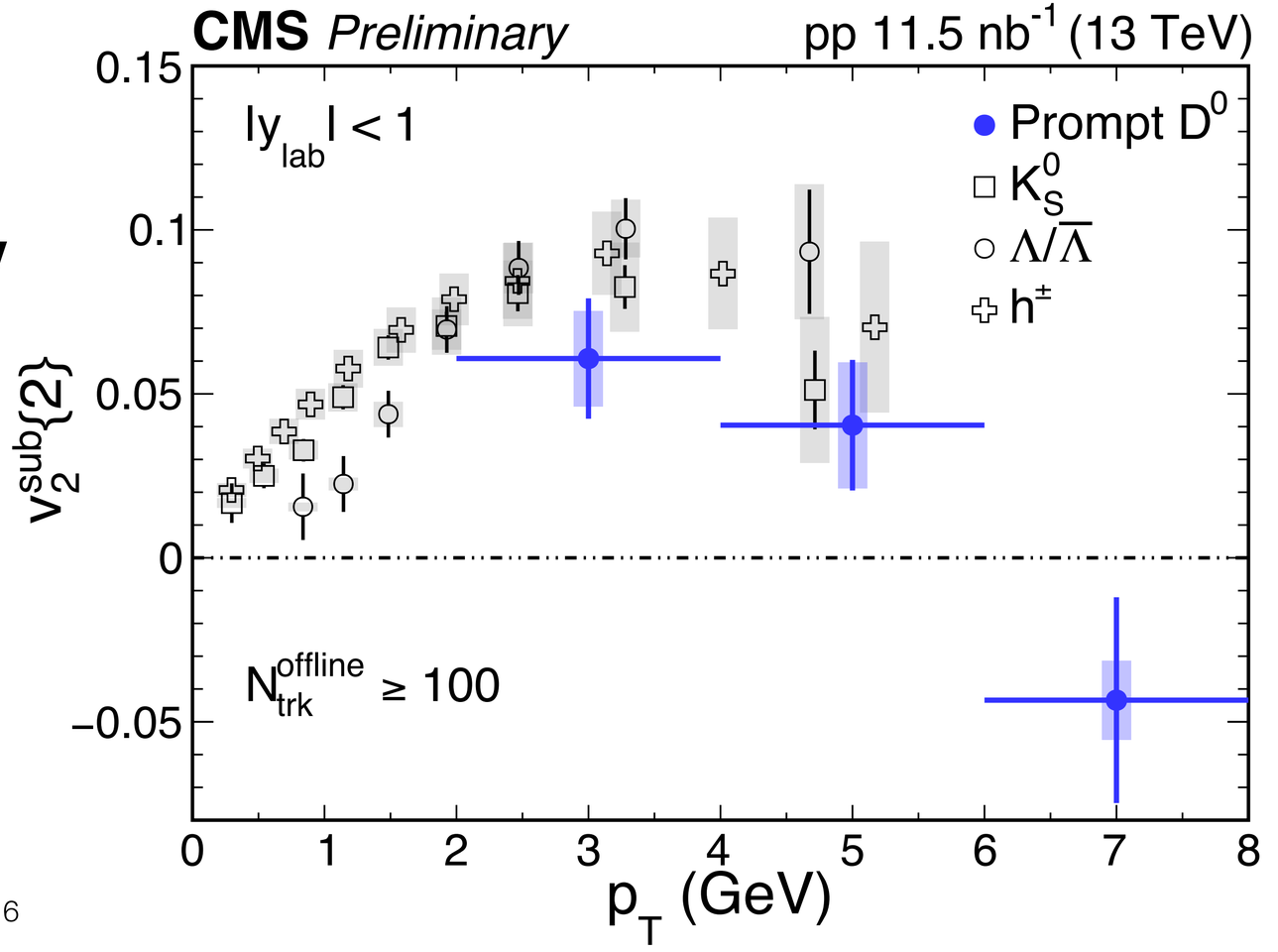


13 TeV pp Prompt D^0 v_2

- **Apply non-flow subtraction**
- **v_2 extracted from $V_{2\Delta}^{signal}$ using charged reference particles (0.3 < p_T < 3 GeV)**

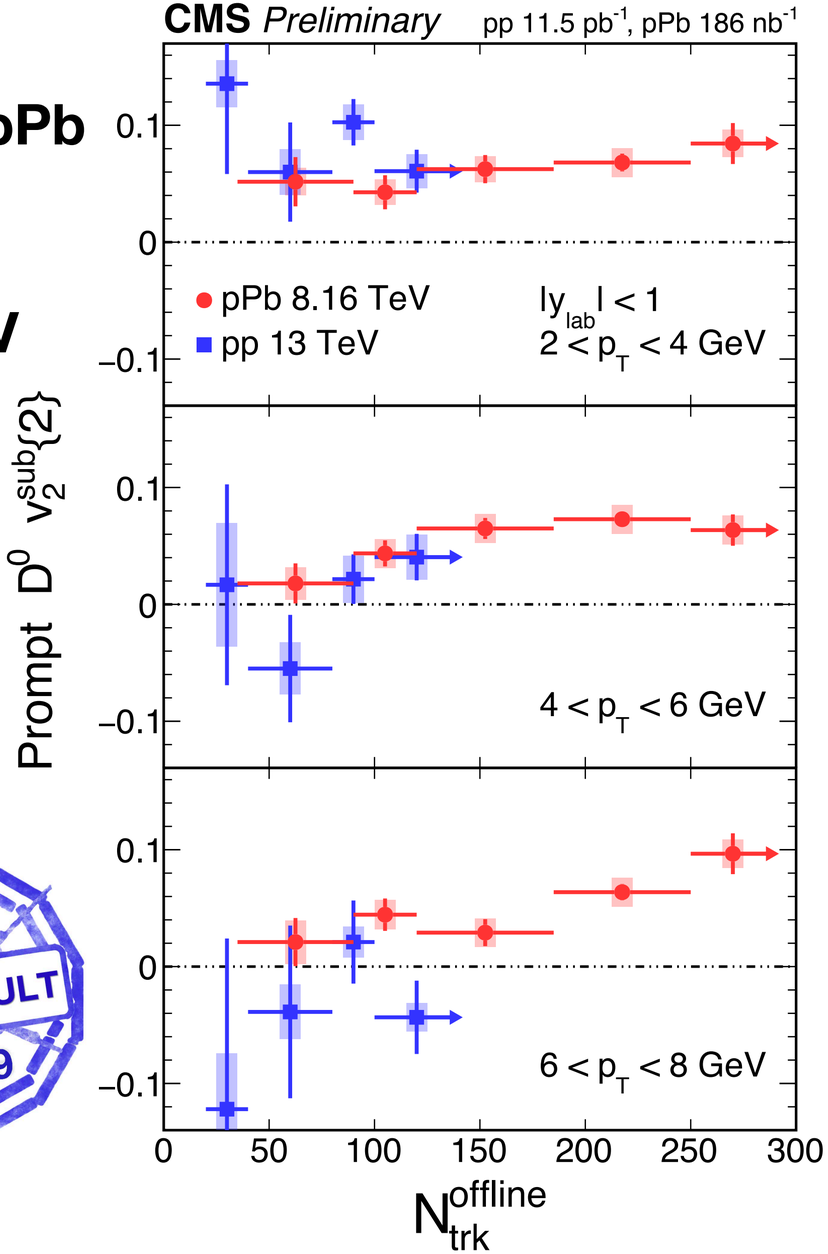
$$v_n(\mathrm{D}^0) = V_{n\Delta}(\mathrm{D}^0, \mathrm{ref}) / \sqrt{V_{n\Delta}(\mathrm{ref}, \mathrm{ref})}.$$

- **v_2 slightly below strange hadrons at 2-4 GeV**
  - **Similar to trend in pPb collisions**
- **Consistent with zero at higher p_T**
- **Limited by low-pileup pp luminosity**
  - **11.5 pb^{-1}**



Multiplicity Dependence

- First measurement of N_{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 $N_{trk} = 50$ for $2 < p_T < 6$ GeV
- Diminishing v_2 in pPb as multiplicity decreases for $p_T > 6$ GeV



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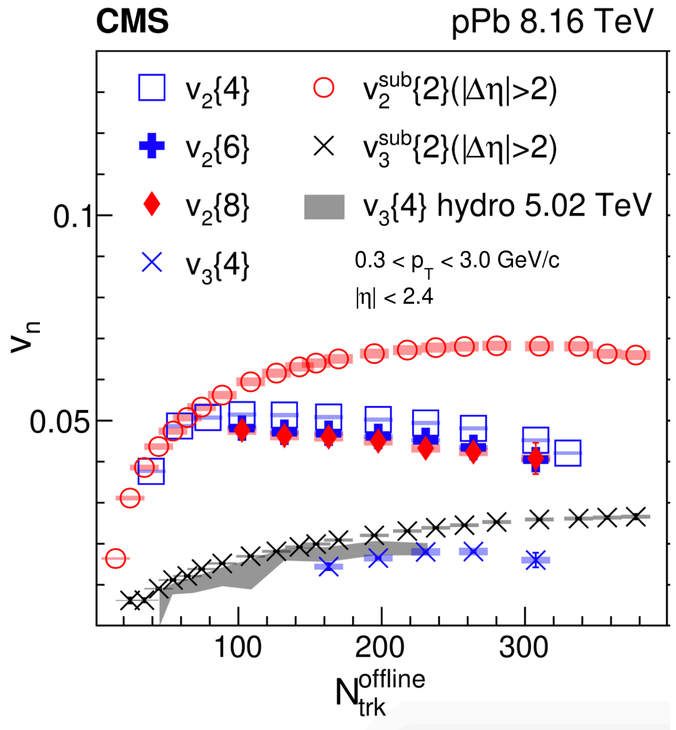
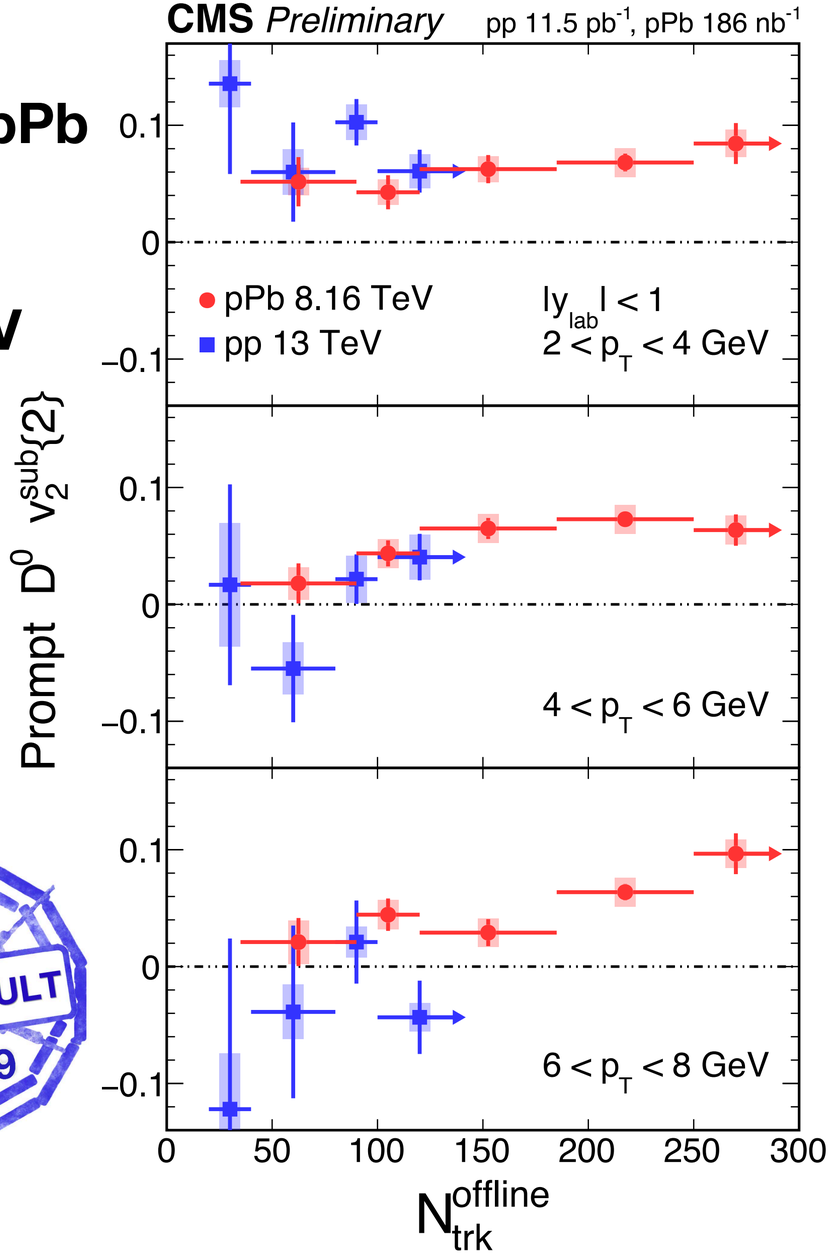


pPb charged particle

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

arXiv:1904.11519

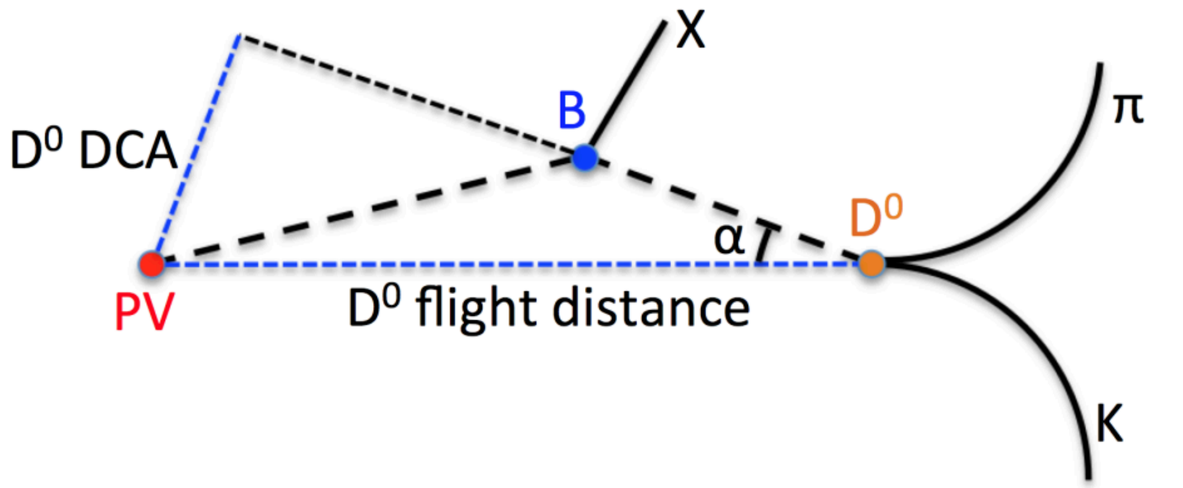


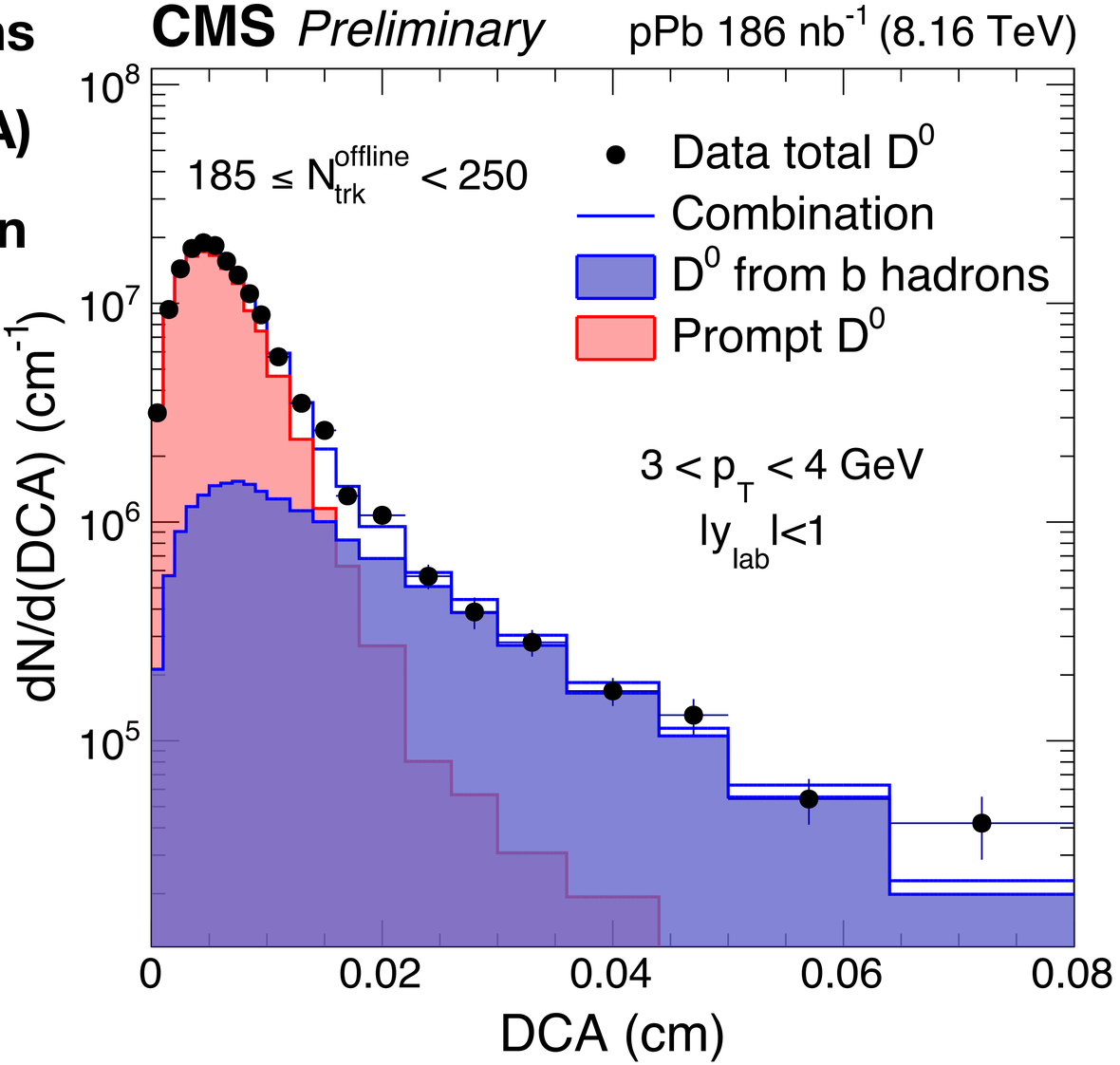
Non-prompt D^0 v_2 in pPb

(CMS-PAS-HIN-19-009)

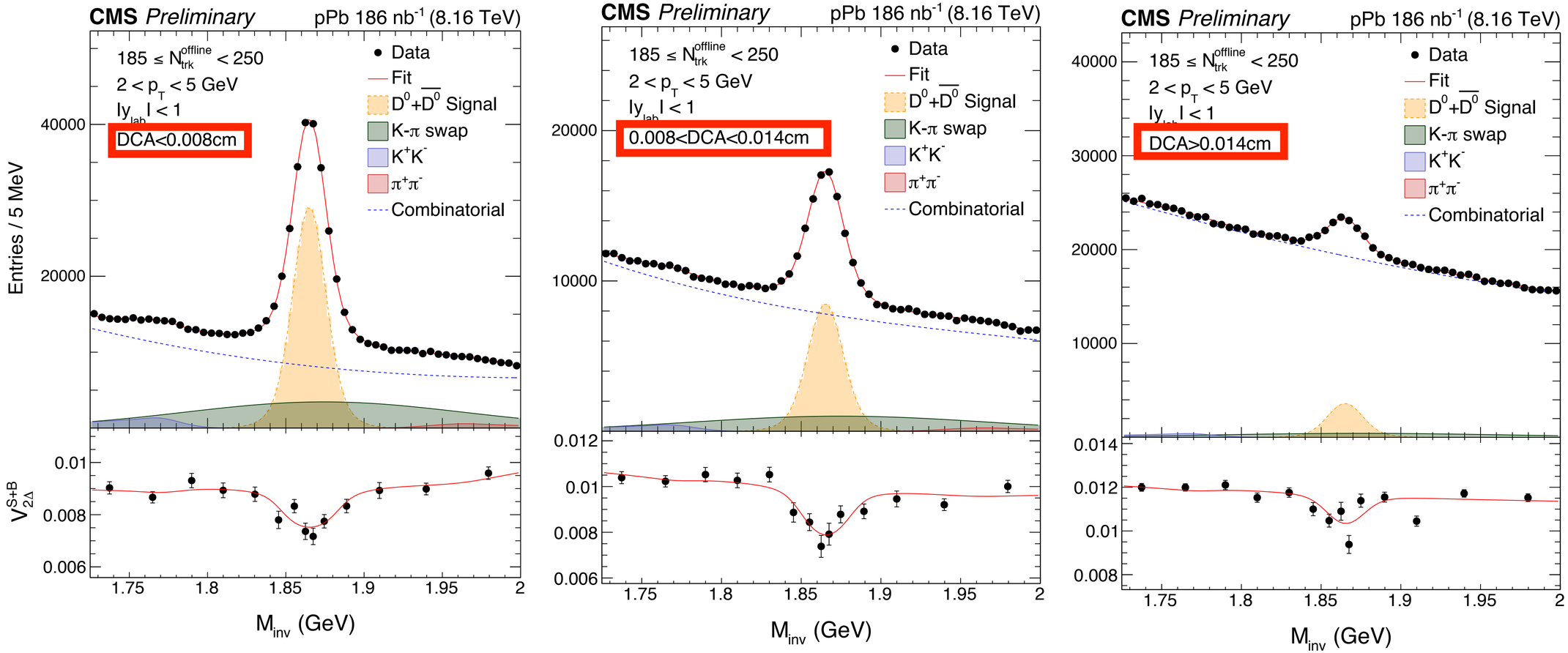
Non-prompt fraction

- **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**



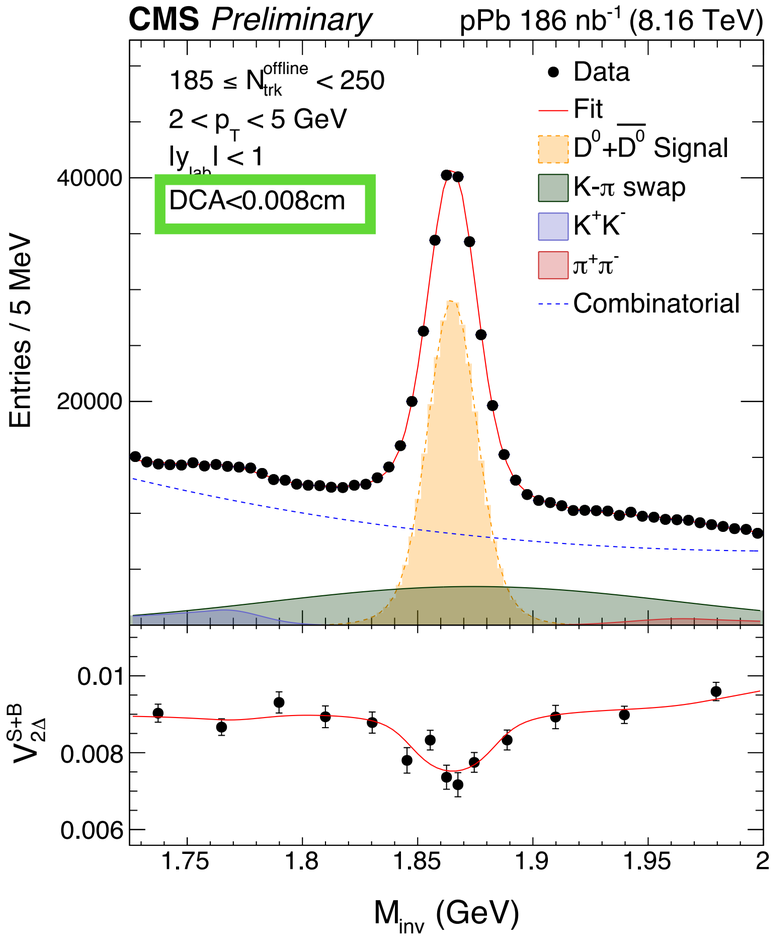


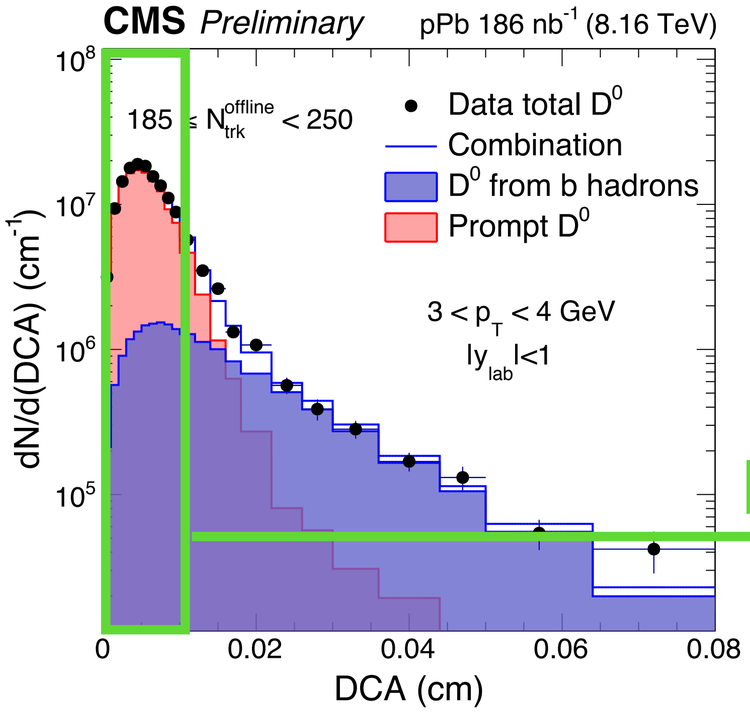
8.16 TeV pPb Mass Peaks



- **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





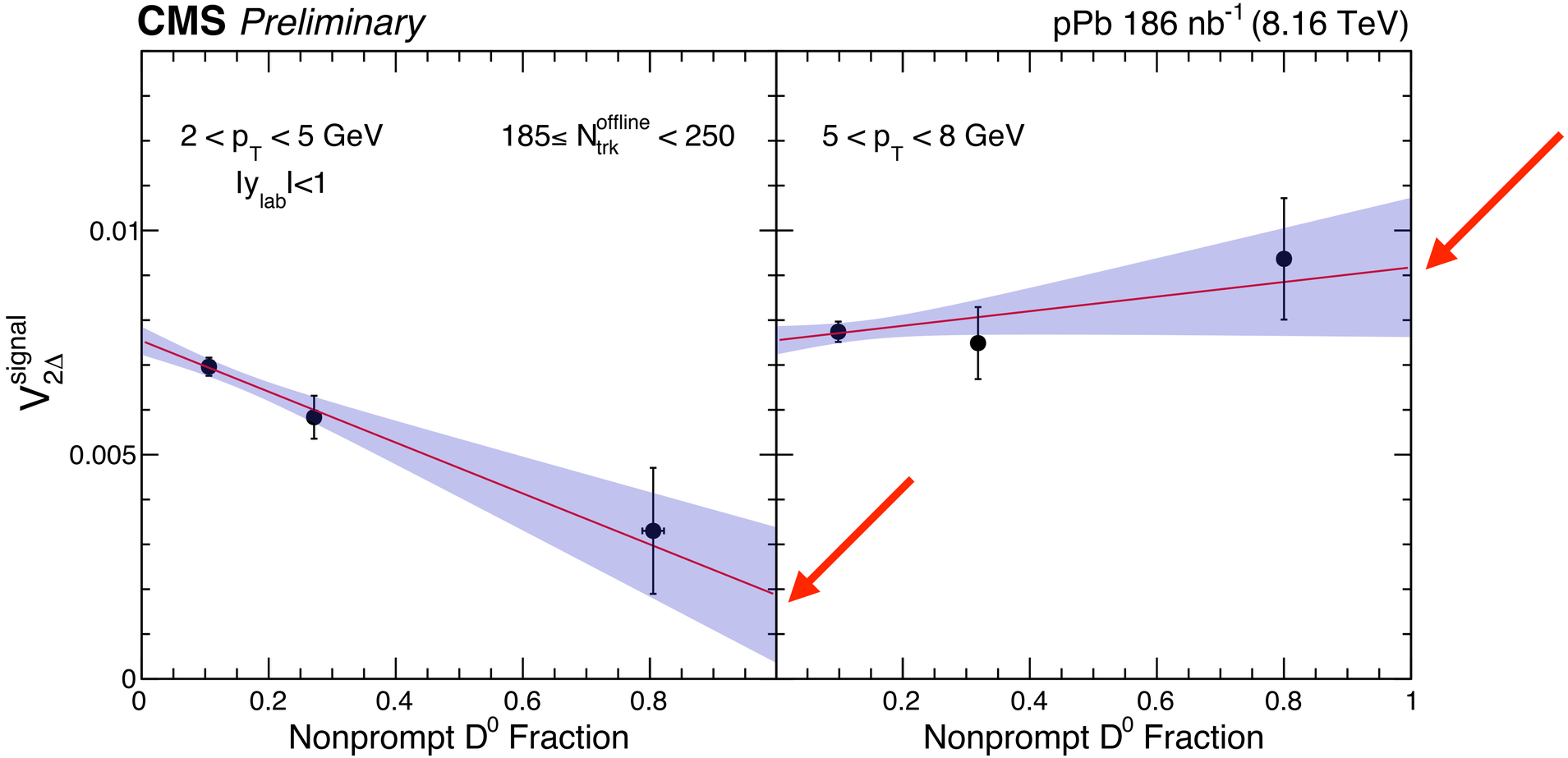
Integrate → **Non-prompt D^0 fraction**

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

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

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

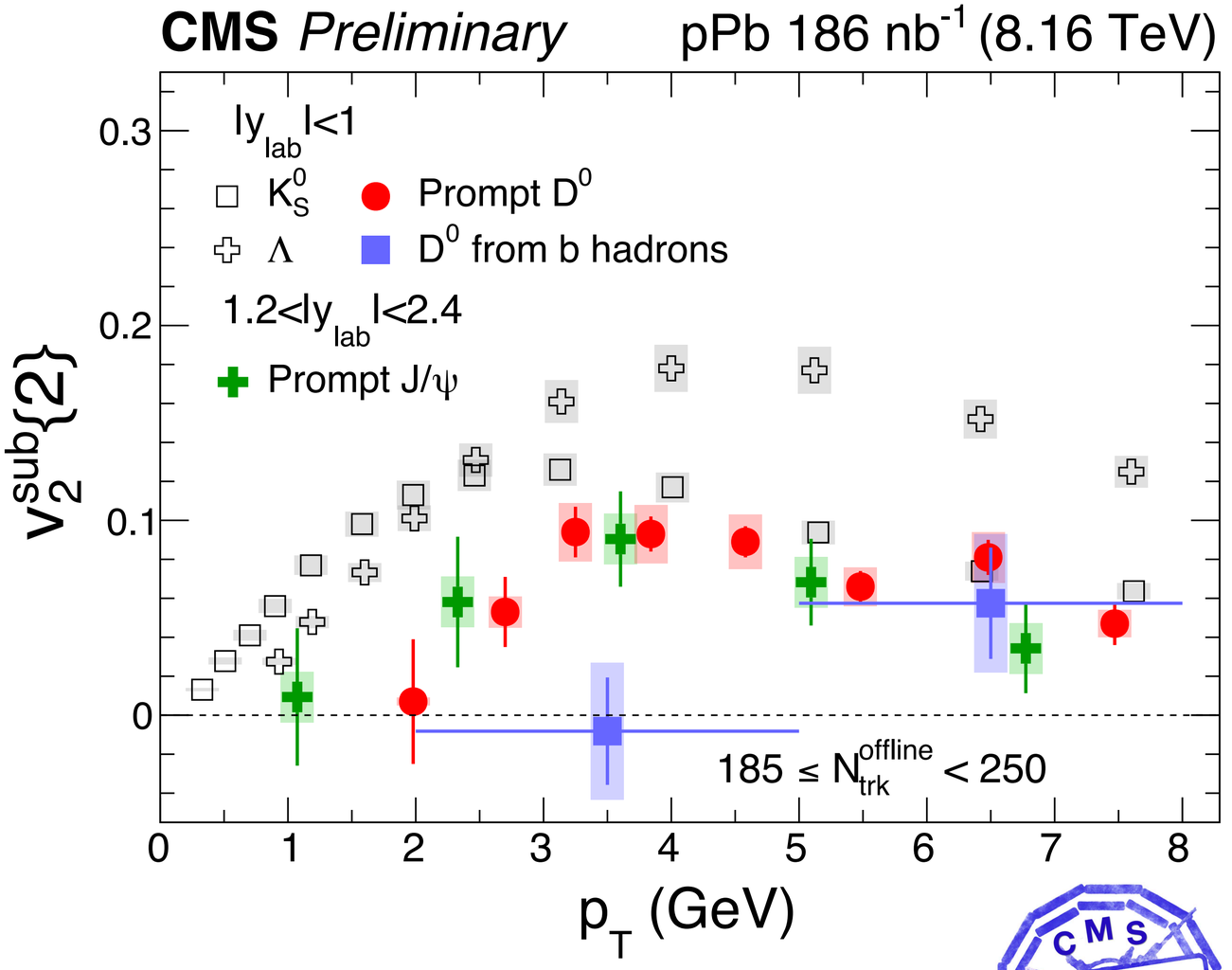
Non-Prompt D^0 Extrapolation



- **Extrapolate with linear fit**
- **Apply non-flow subtraction**
- **v_2 extracted from $V_{2\Delta}^{signal}$ using charged reference particles:** $v_n(\mathrm{D}^0) = V_{n\Delta}(\mathrm{D}^0, \mathrm{ref}) / \sqrt{V_{n\Delta}(\mathrm{ref}, \mathrm{ref})}.$

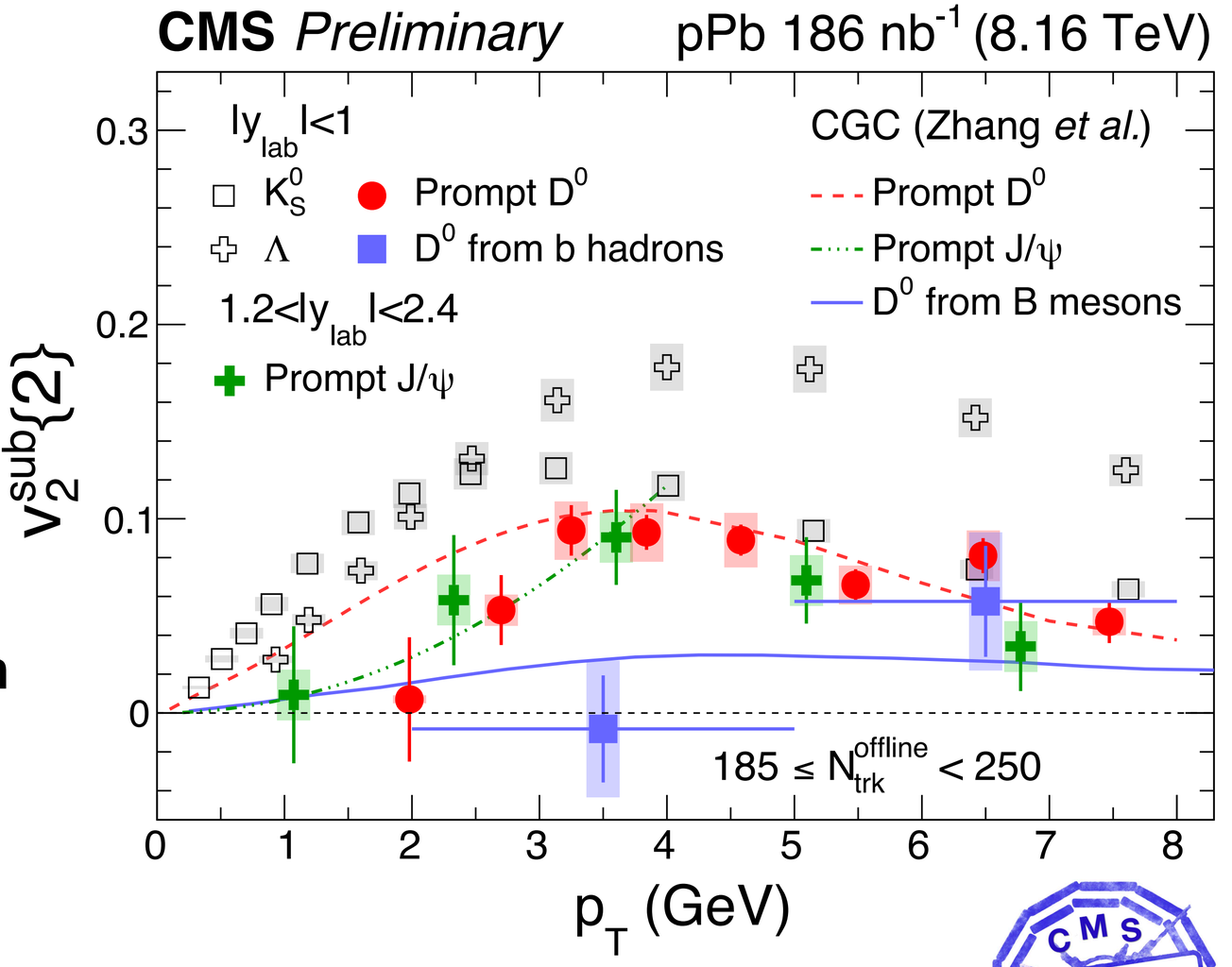
Non-prompt D^0 v_2

- **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

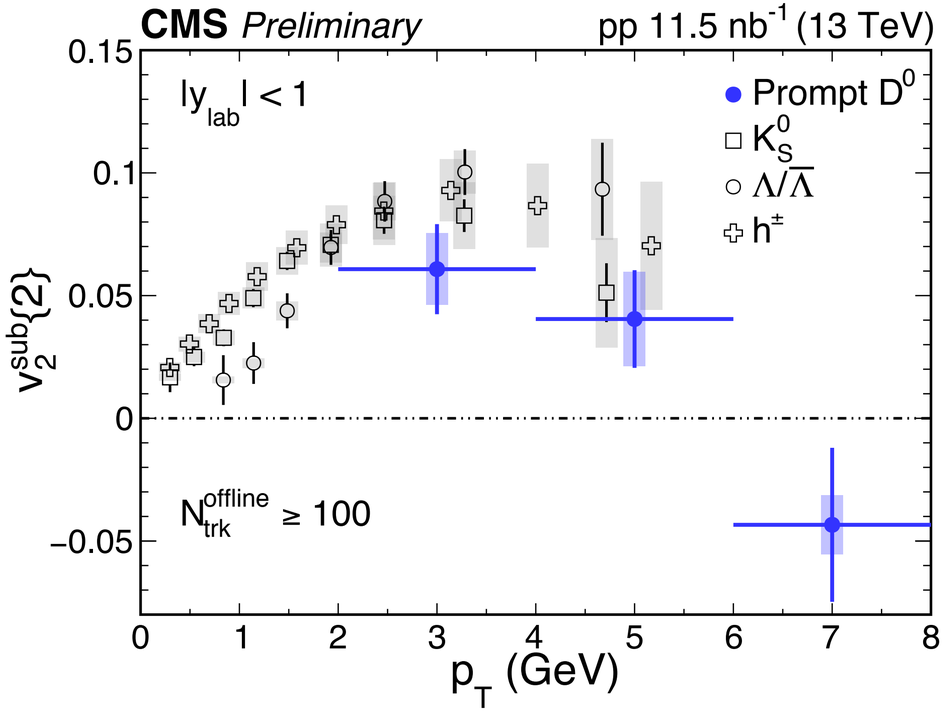
- **Non-Prompt D^0 v_2 consistent with zero**
- **Evidence for c > b quark ordering of v_2**
  - **Only in region from p_T = 2-5 GeV**
- **Prediction of b v_2 from CGC model**
  - **Feed-down & decay by PYTHIA 8**
- **Indicates b does not participate strongly in same collective phenomena**

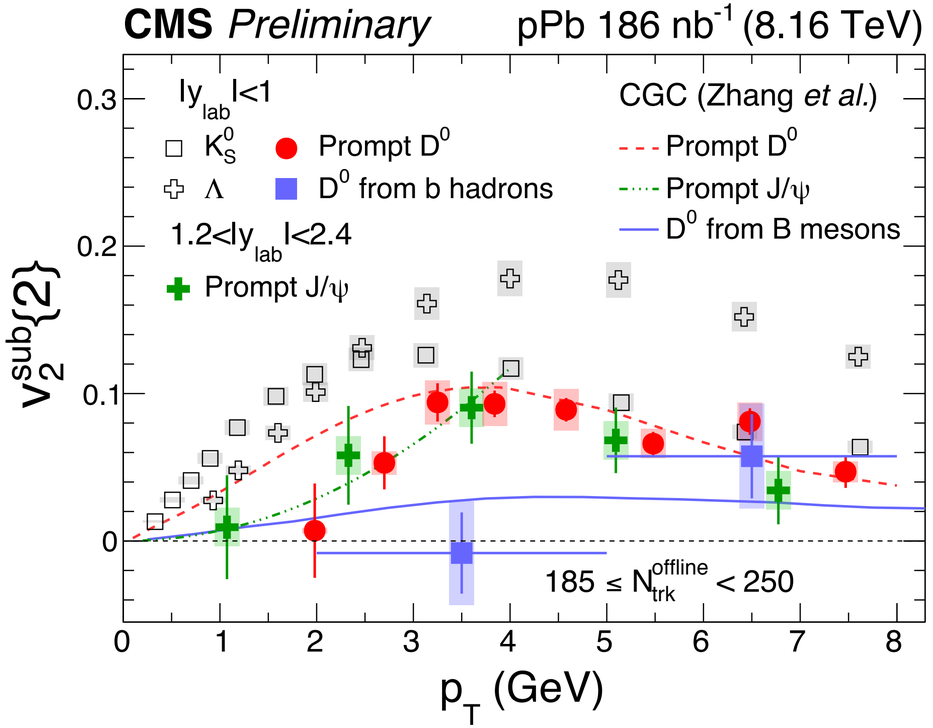


Summary

- **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**

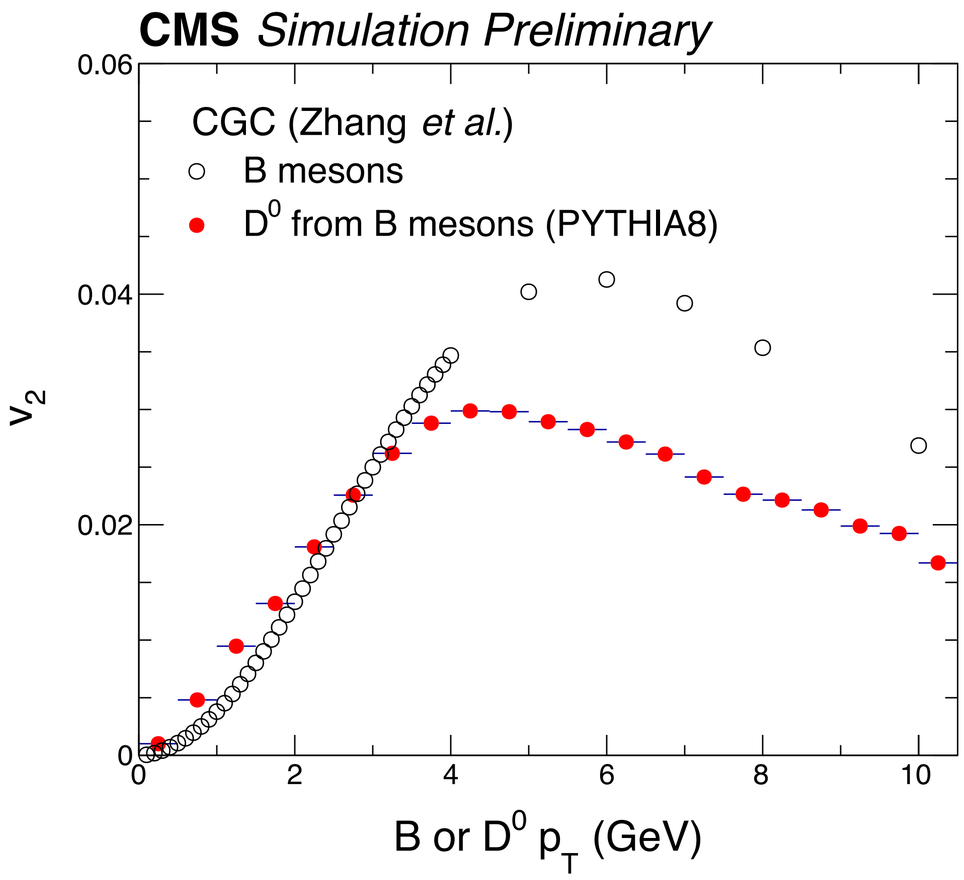
More information at CMS-PAS-HIN-19-009

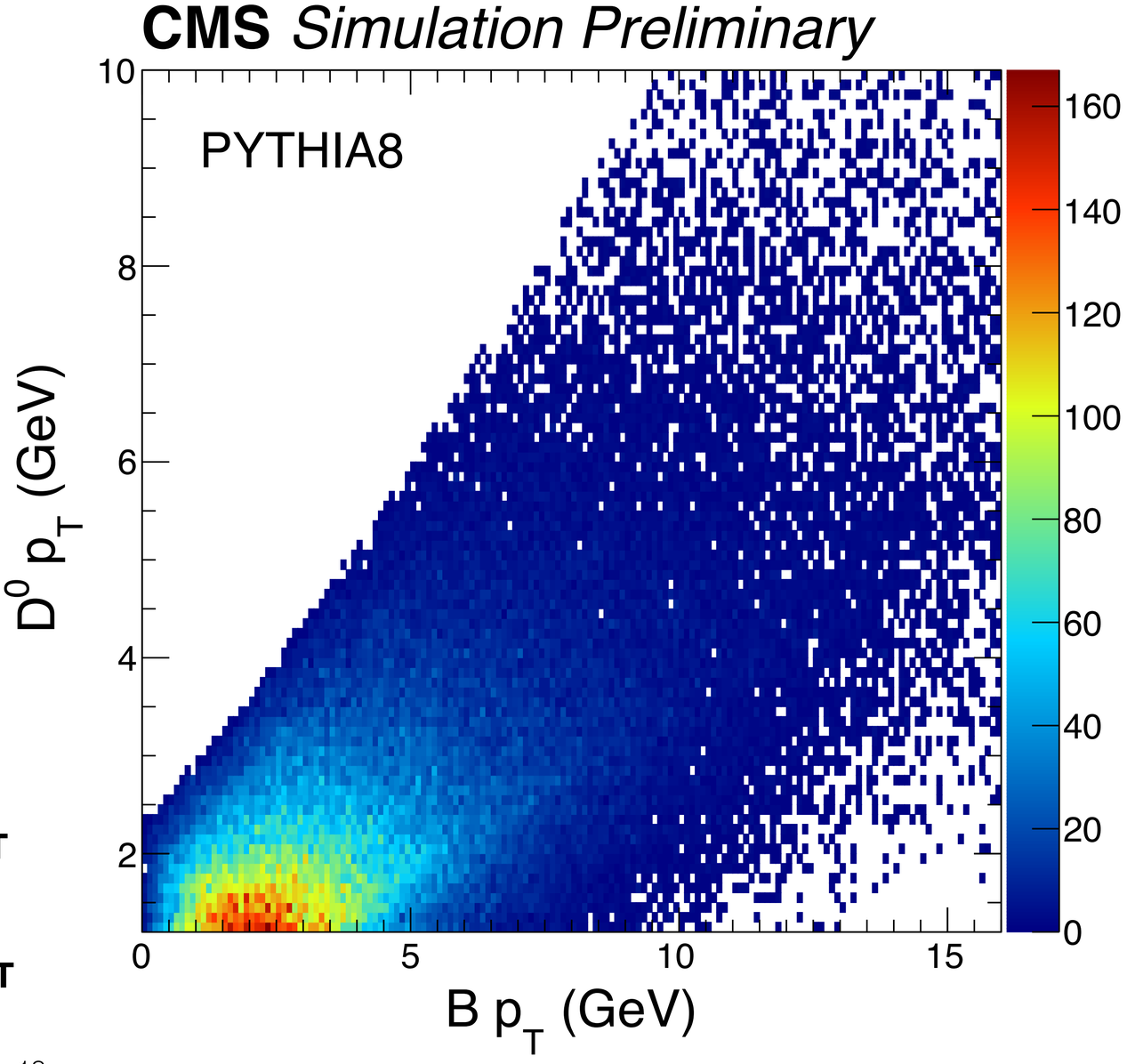




Backup

B feed-down

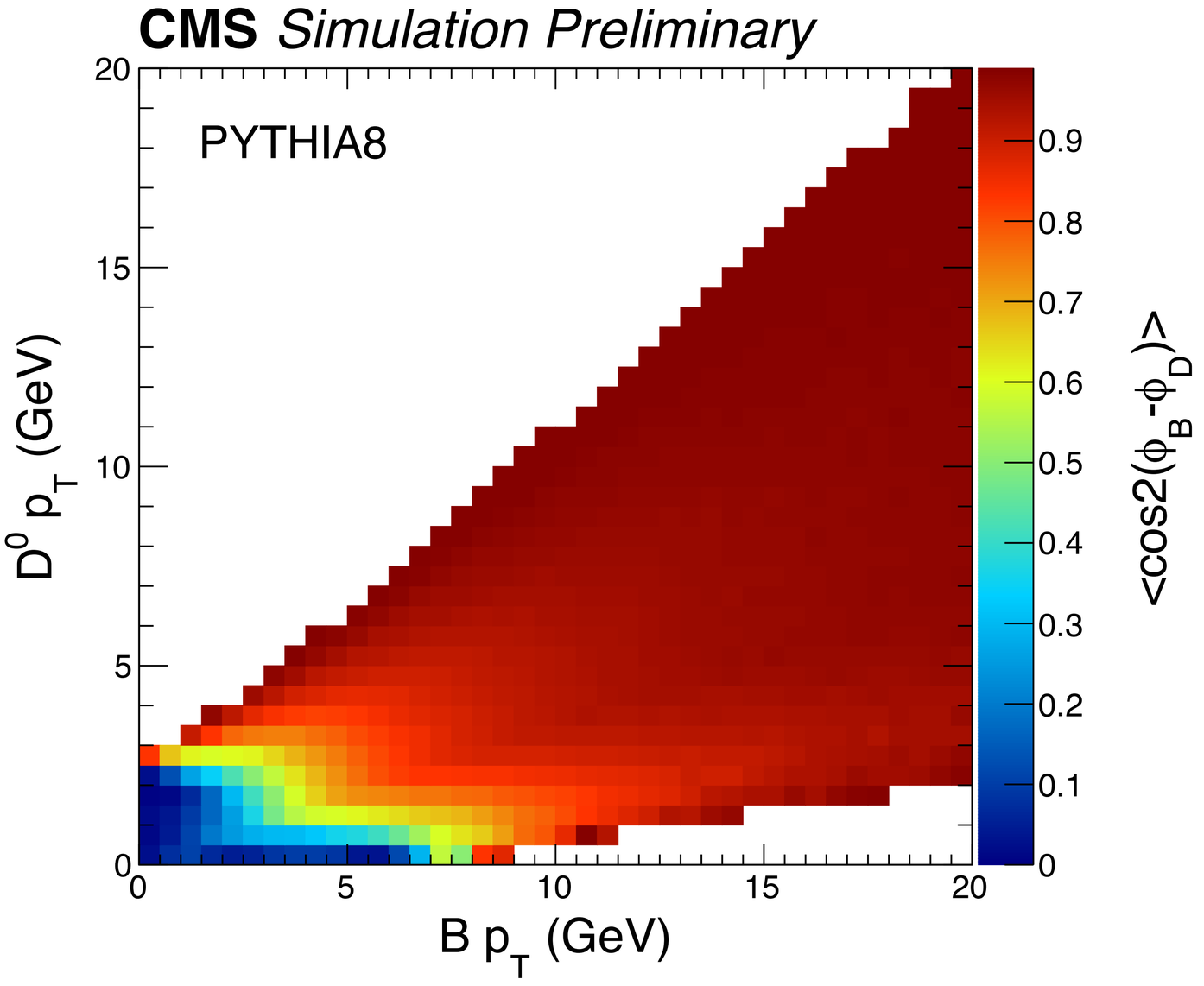




- **Shifting between B and D^0 depends on p_T**
- **PYTHIA indicates D^0 carries >50% of B p_T**

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**



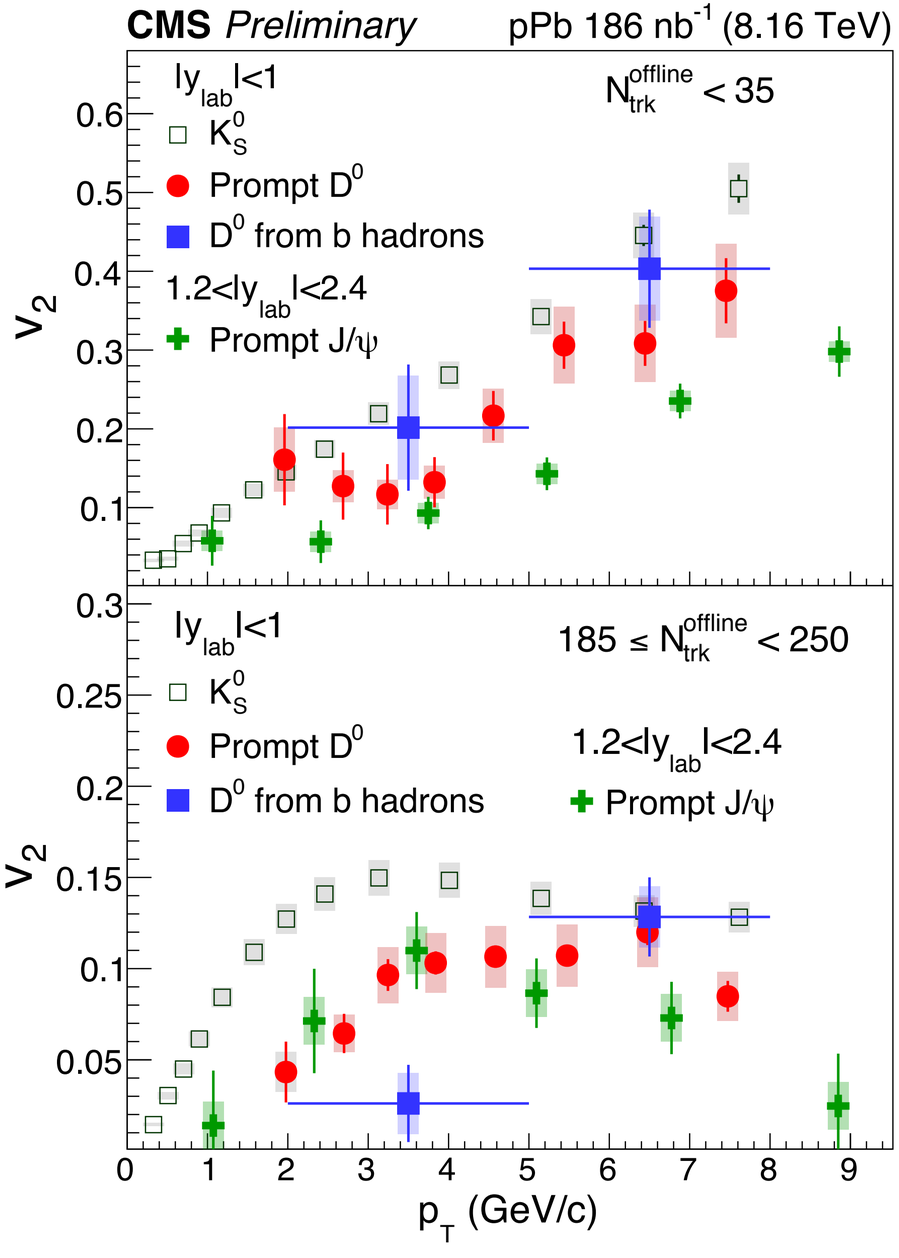
Non-flow subtraction

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

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

Scaling of the yield of jets with multiplicity

Scaling of the relative contribution of non-flow with multiplicity



Signal fraction

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

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