

Probing collectivity in small systems using heavy quarks with CMS

Zhenyu Chen
Rice University

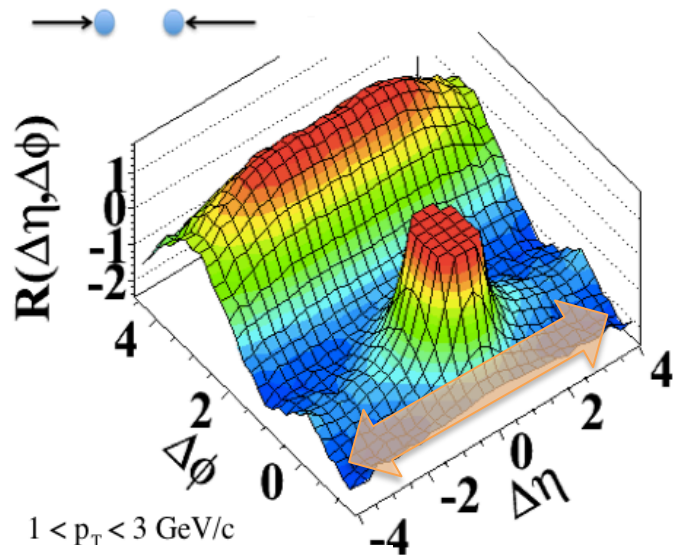


CIPANP 2018, Palm Springs



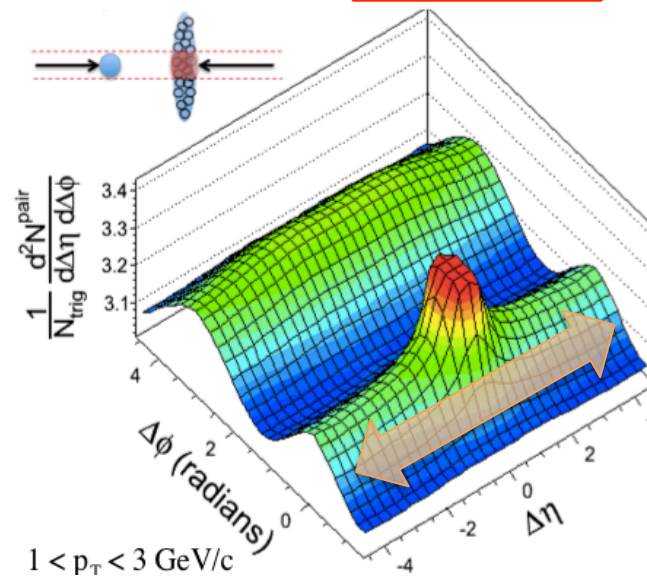
Omnipresent “Ridge”

(a) pp $\sqrt{s} = 7$ TeV, $N_{\text{trk}}^{\text{offline}} \geq 110$



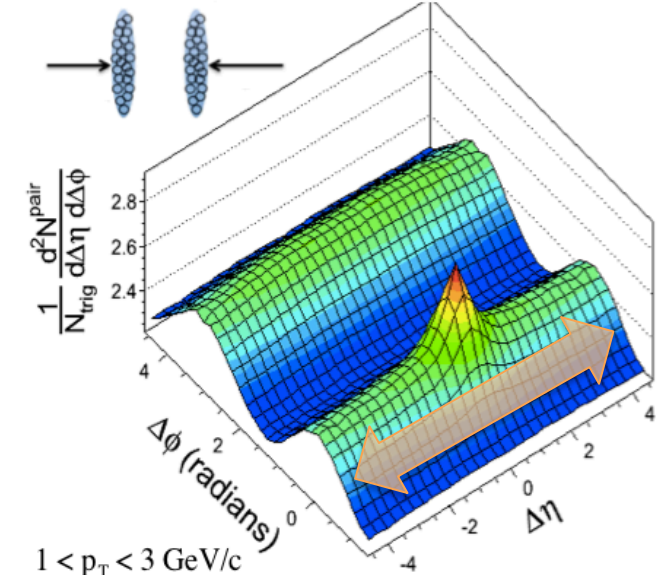
$1 < p_{\text{T}} < 3$ GeV/c
JHEP 09 (2010) 091

(b) pPb $\sqrt{s_{\text{NN}}} = 5.02$ TeV, $220 < N_{\text{trk}}^{\text{offline}} \leq 260$



$1 < p_{\text{T}} < 3$ GeV/c
PLB 724 (2013) 213

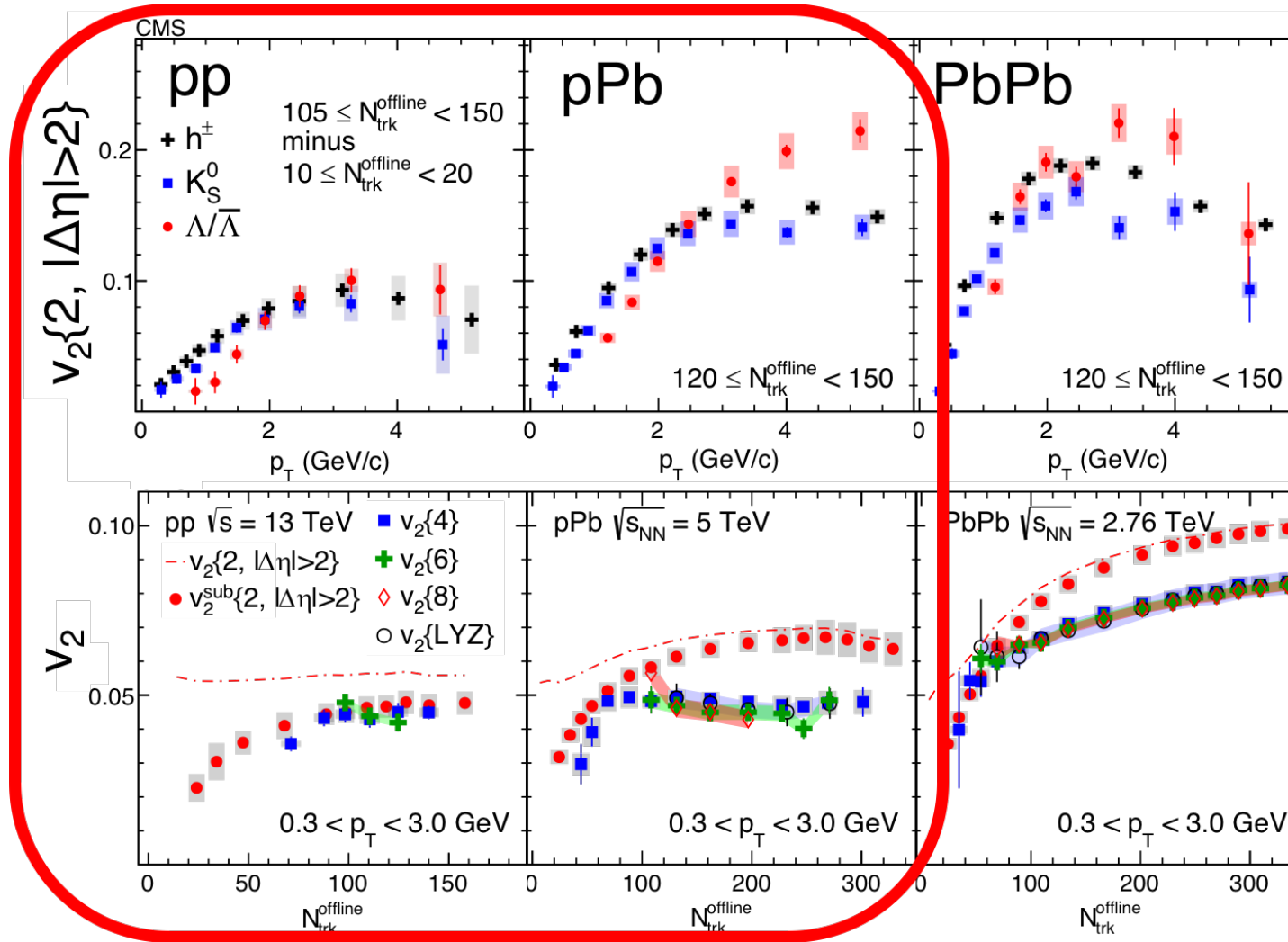
(c) PbPb $\sqrt{s_{\text{NN}}} = 2.76$ TeV, $220 < N_{\text{trk}}^{\text{offline}} \leq 260$



$1 < p_{\text{T}} < 3$ GeV/c
PLB 724 (2013) 213

What is the origin of the “Ridge” in small system?
A small droplet of QGP? Other QCD effect (CGC)?

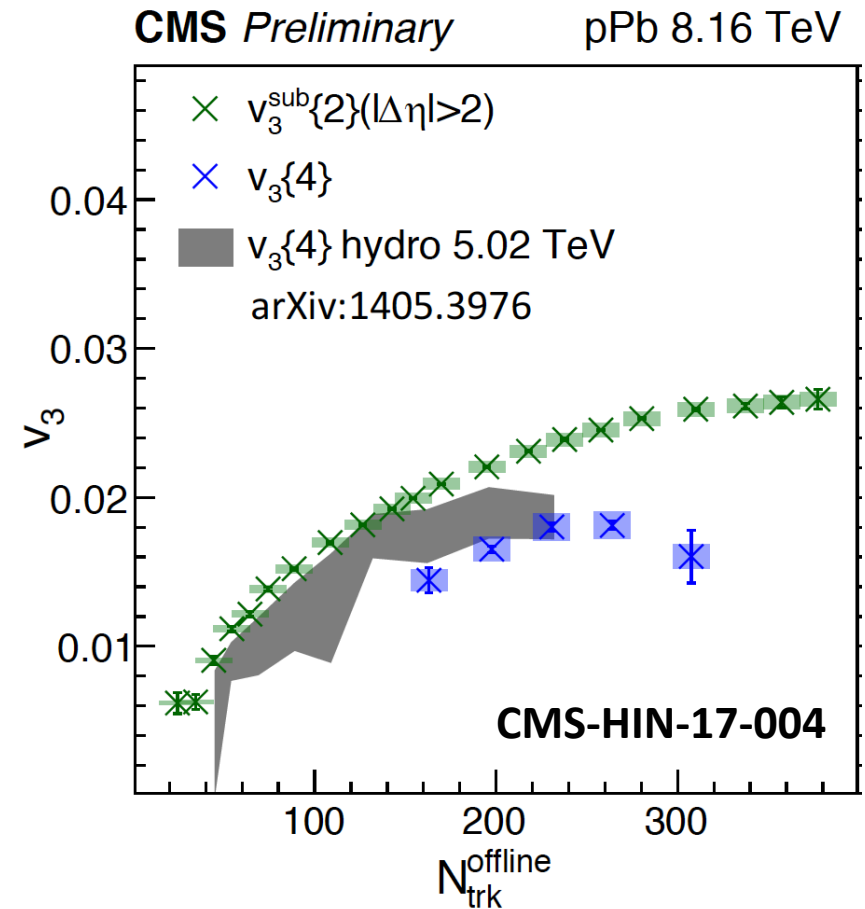
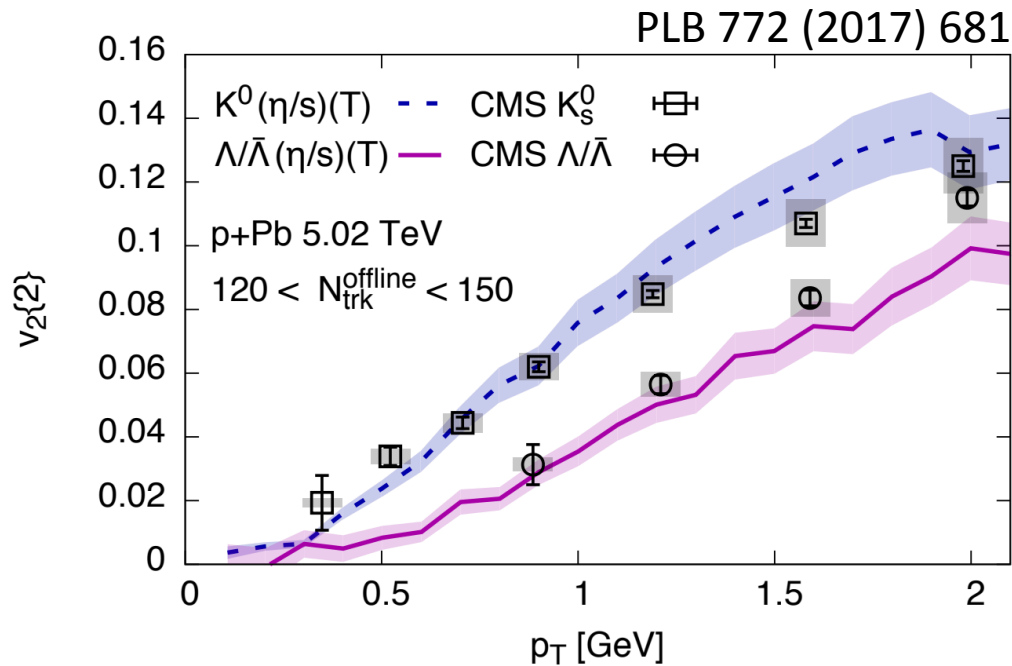
Collectivity in small systems



Collectivity of bulk particle production in small systems

Collectivity in small systems

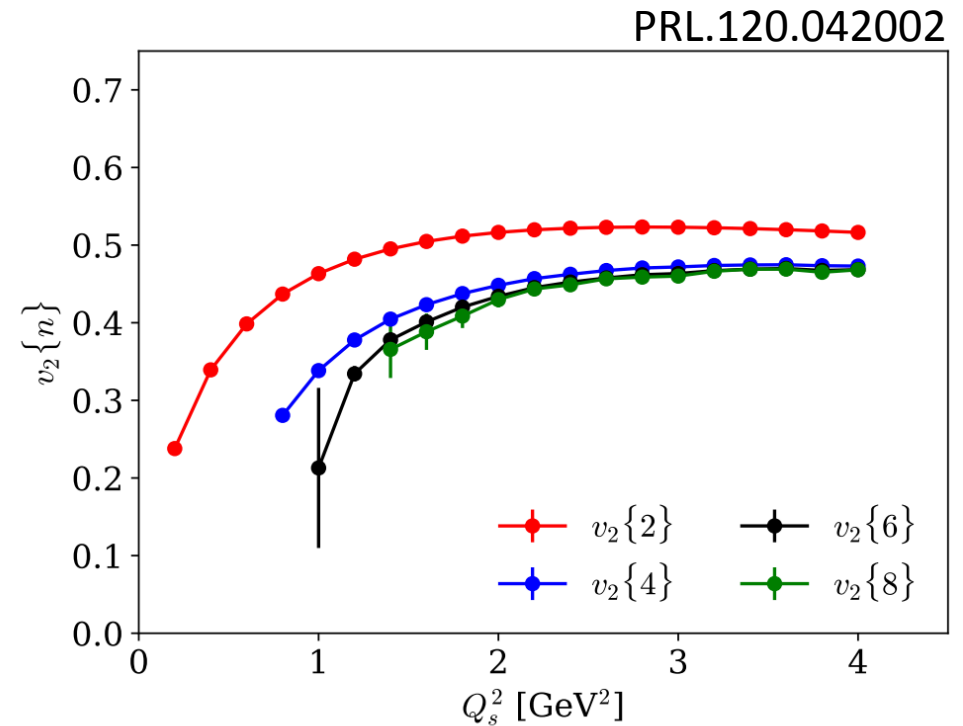
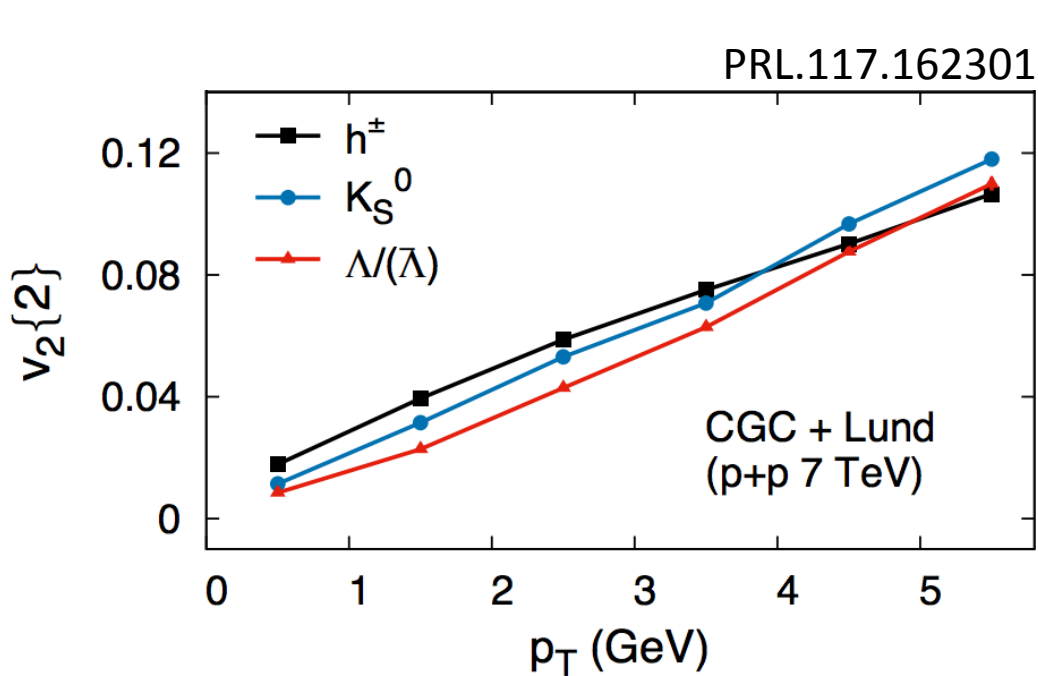
Hydrodynamic models



Collectivity of bulk particle production in small systems

Collectivity in small systems

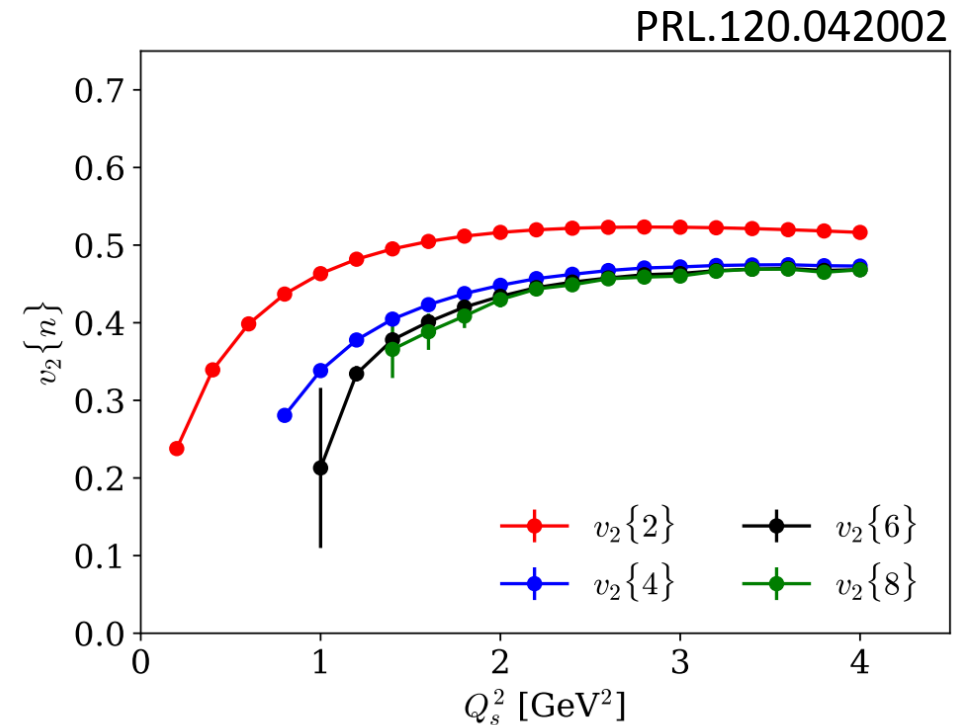
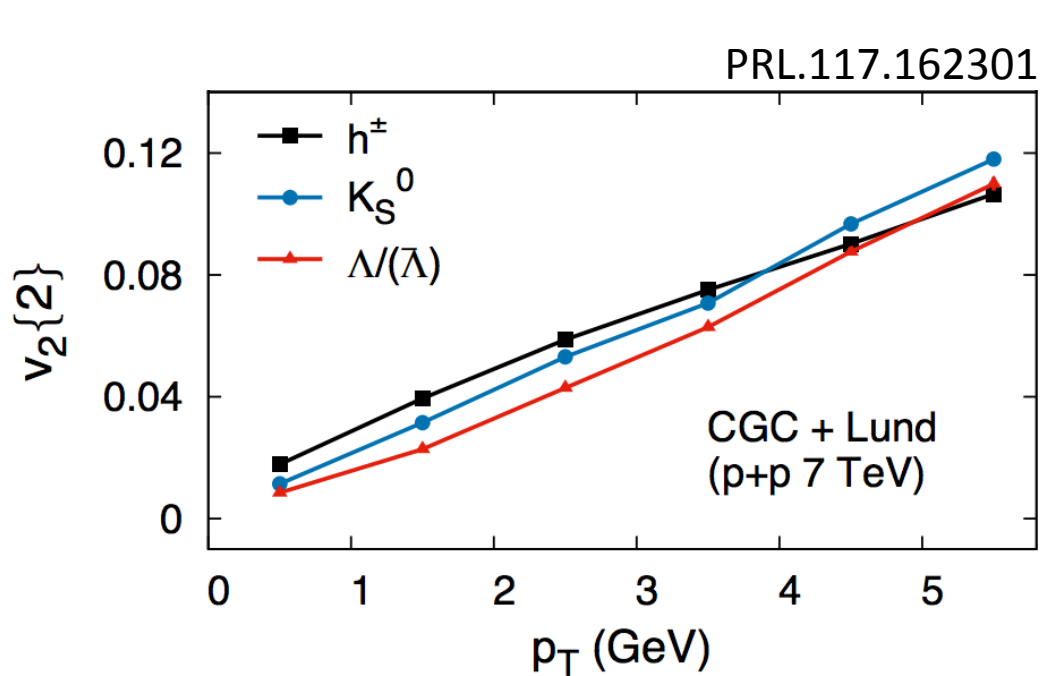
Color Glass Condensate models



Collectivity of bulk particle production in small systems

Collectivity in small systems

Color Glass Condensate models

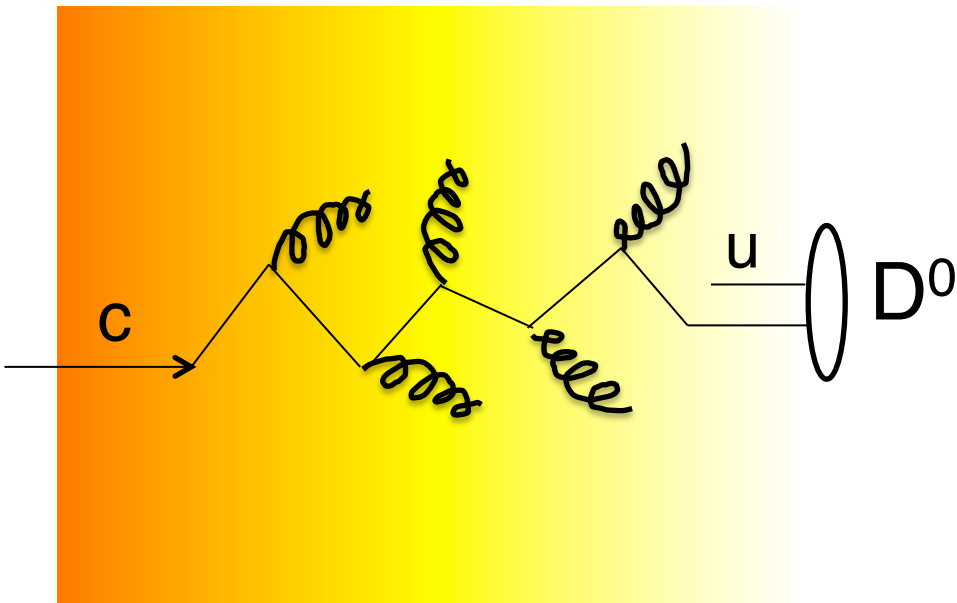


Collectivity of bulk particle production in small systems

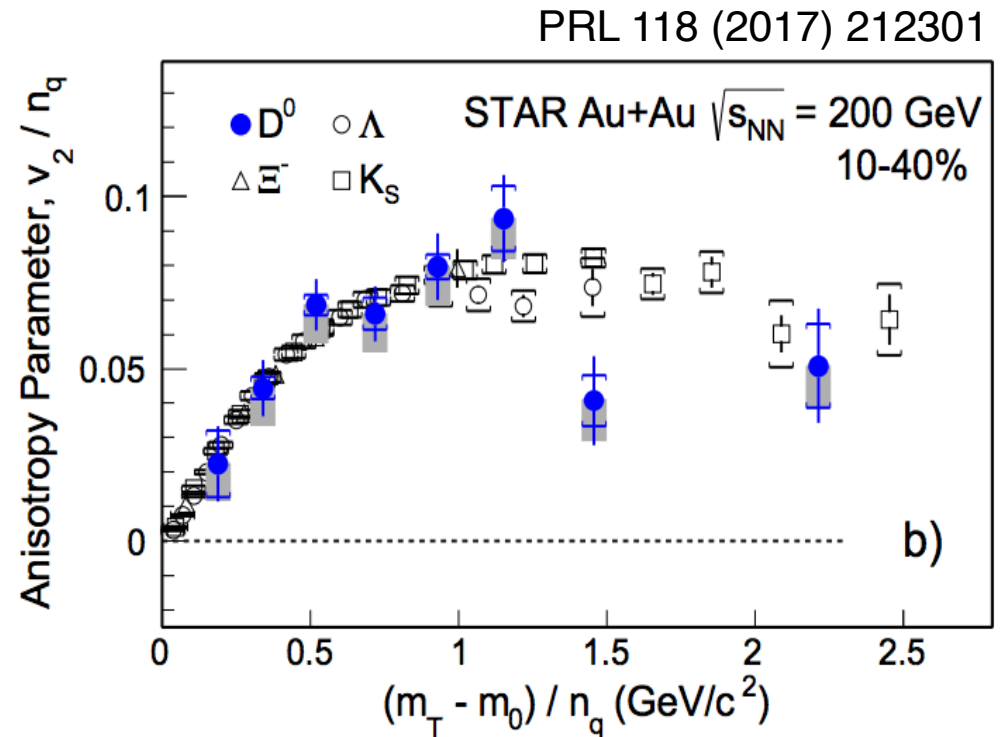
What about heavier quarks (i.e., c, b)?

Heavy quarks in QGP

Large AA systems



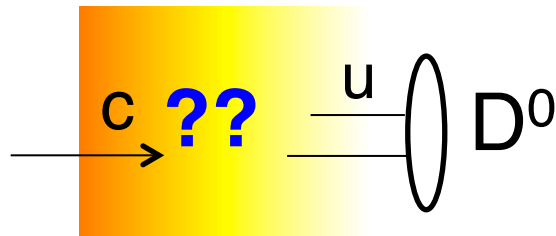
Charms expected to flow!!



Charms thermalized in AA!?

Heavy quarks in small systems

Collectivity for heavy quarks in small system?

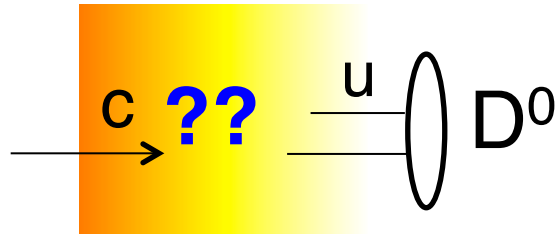


Interaction with a (tiny) QGP?
Thermalization for a small size?

e.g., in pA/pp

Heavy quarks in small systems

Collectivity for heavy quarks in small system?



e.g., in pA/pp

Interaction with a (tiny) QGP?
Thermalization for a small size?

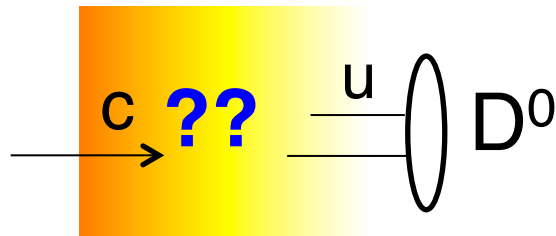
OR

A new window for initial correlations?

(Y. Ma et. al., arXiv:1803.11093)

Heavy quarks in small systems

Collectivity for heavy quarks in small system?



Interaction with a (tiny) QGP?
Thermalization for a small size?

e.g., in pA/pp

OR

A new window for initial correlations?

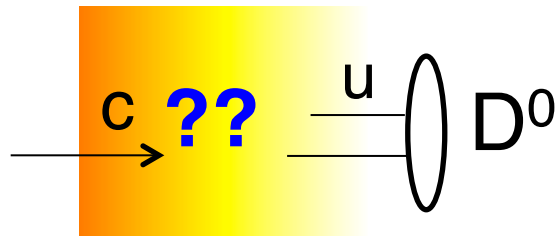
(Y. Ma et. al., arXiv:1803.11093)

Comparing to bulk system (light quarks/gluons)

K_s^0 , Λ , Ξ^- , Ω^-

Heavy quarks in small systems

Collectivity for heavy quarks in small system?



Interaction with a (tiny) QGP?
Thermalization for a small size?

e.g., in pA/pp

OR

A new window for initial correlations?

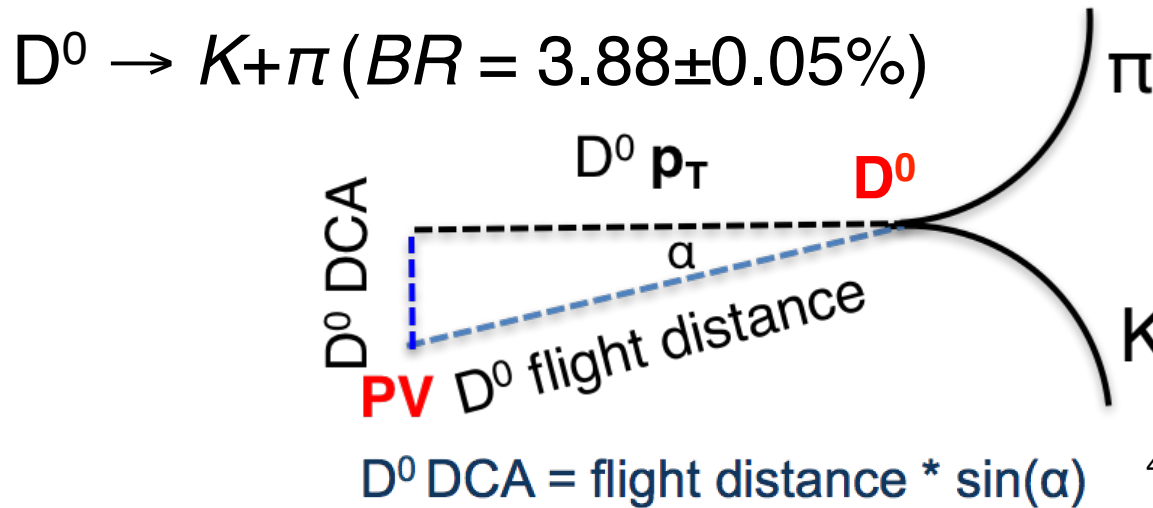
(Y. Ma et. al., arXiv:1803.11093)

Comparing to bulk system (light quarks/gluons)

K_s^0 , Λ , Ξ^- , Ω^-

(also first time in small systems)

D⁰ meson in pPb at CMS

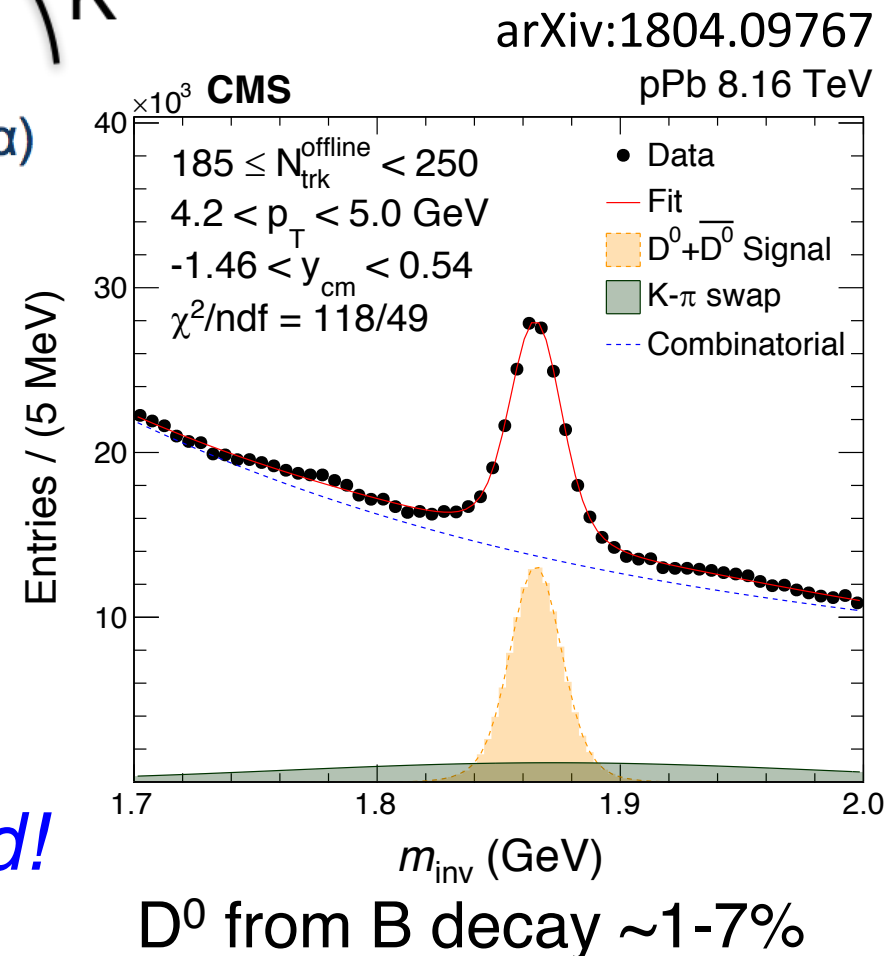


(No PID for π/K)

2016 pPb @ 8.16 TeV:

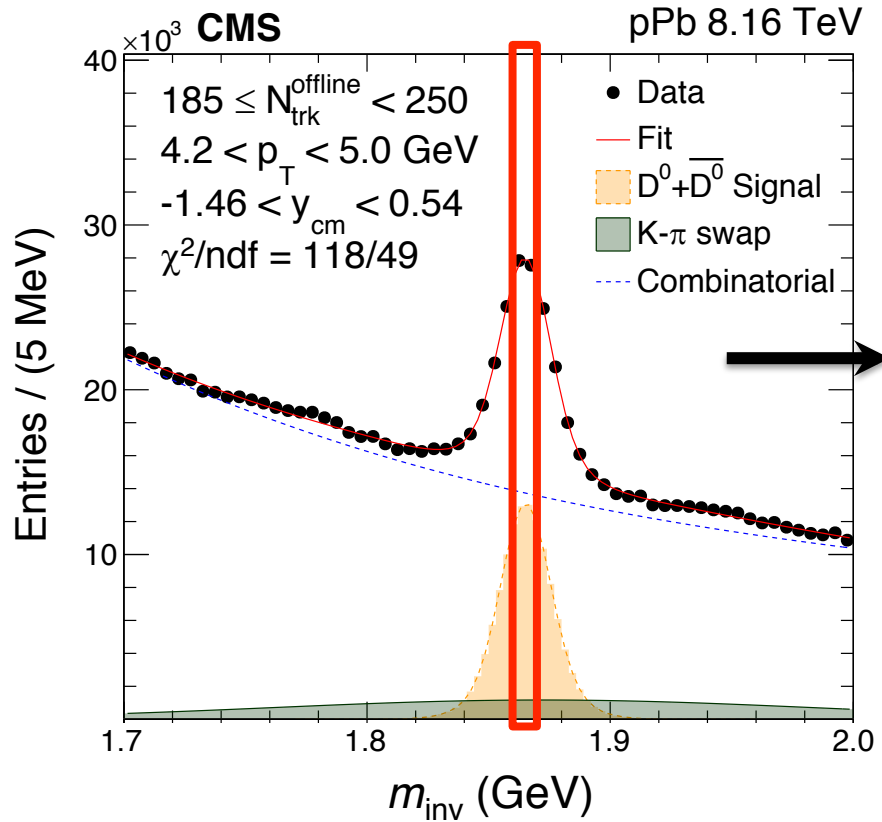
- High Multiplicity ($N_{\text{trk}} > 185$, top 0.33%): **550 million**
- Minimum Bias: **7 billion**

Large number of events needed!

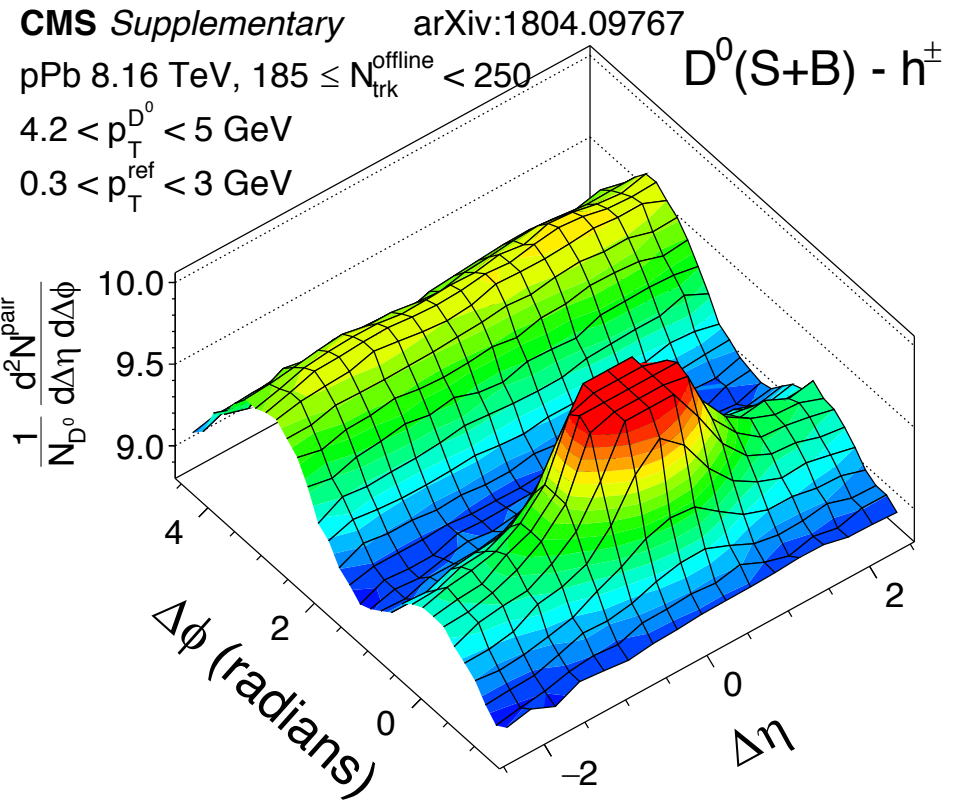


D⁰ – charged hadron correlations

$185 \leq N_{\text{trk}} < 250$

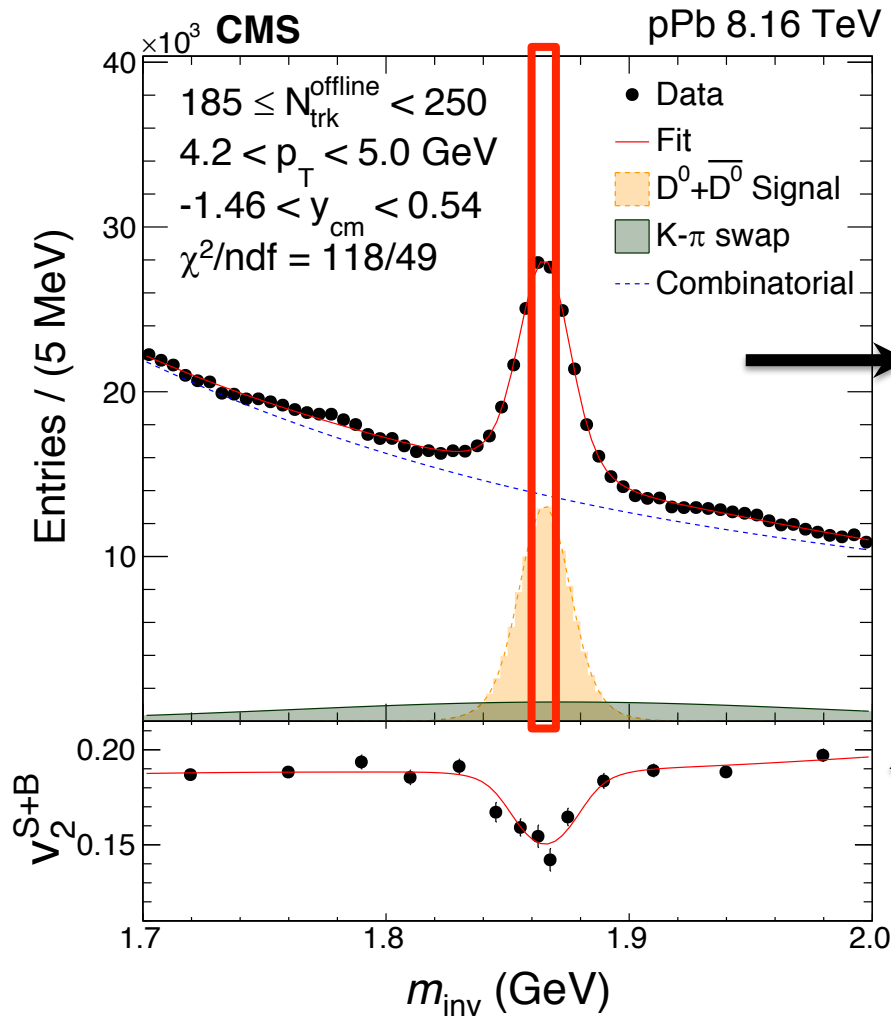


$|M_{\text{inv}} - M_{\text{D}^0}| < 0.005$ GeV



D⁰ – charged hadron correlations

$185 \leq N_{\text{trk}} < 250$



$|M_{\text{inv}} - M_{D^0}| < 0.005 \text{ GeV}$

CMS Supplementary

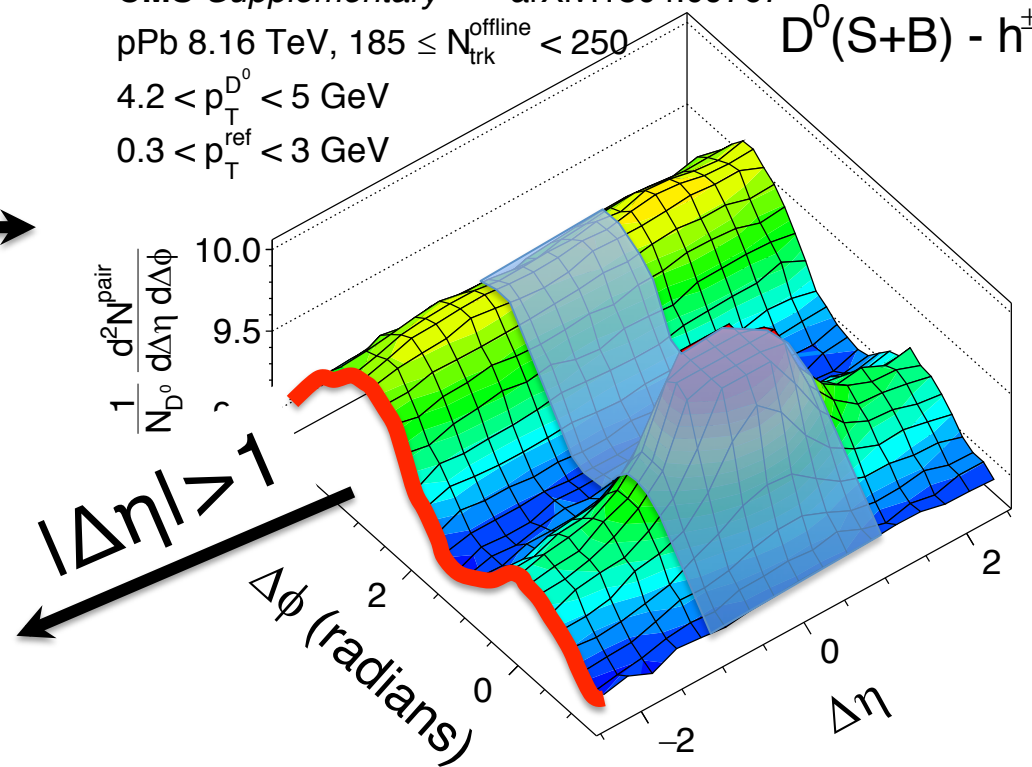
arXiv:1804.09767

pPb 8.16 TeV, $185 \leq N_{\text{trk}}^{\text{offline}} < 250$

$4.2 < p_T^{D^0} < 5 \text{ GeV}$

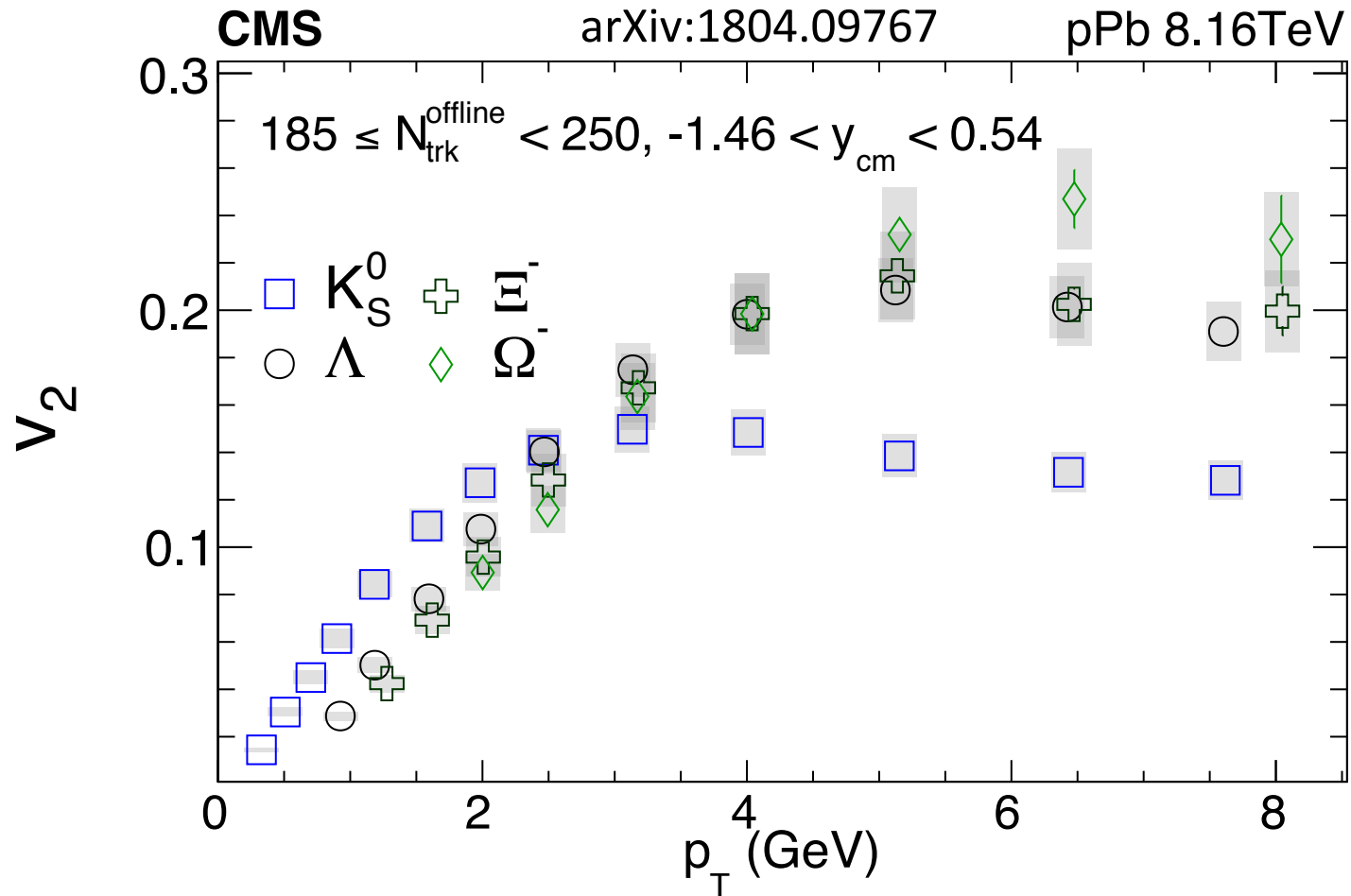
$0.3 < p_T^{\text{ref}} < 3 \text{ GeV}$

$D^0(\text{S+B}) - h^\pm$



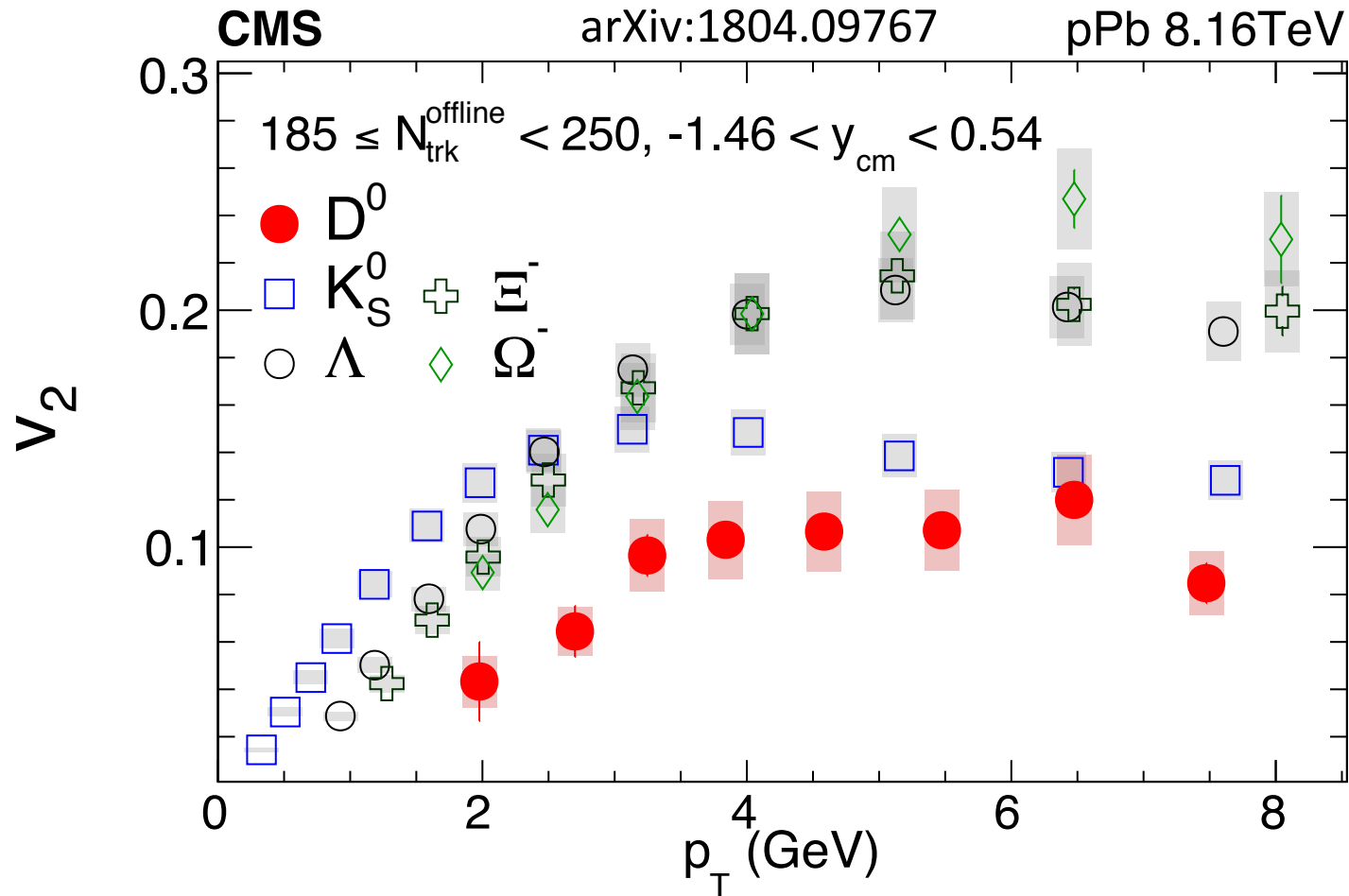
$$v_n^{\text{Sig+Bkg}}(m_{\text{inv}}) = \alpha(m_{\text{inv}}) v_n^{\text{sig}} + (1 - \alpha(m_{\text{inv}})) v_n^{\text{Bkg}}$$

Strange and charm hadron v_2 in pPb



Mass ordering for light, strange hadrons

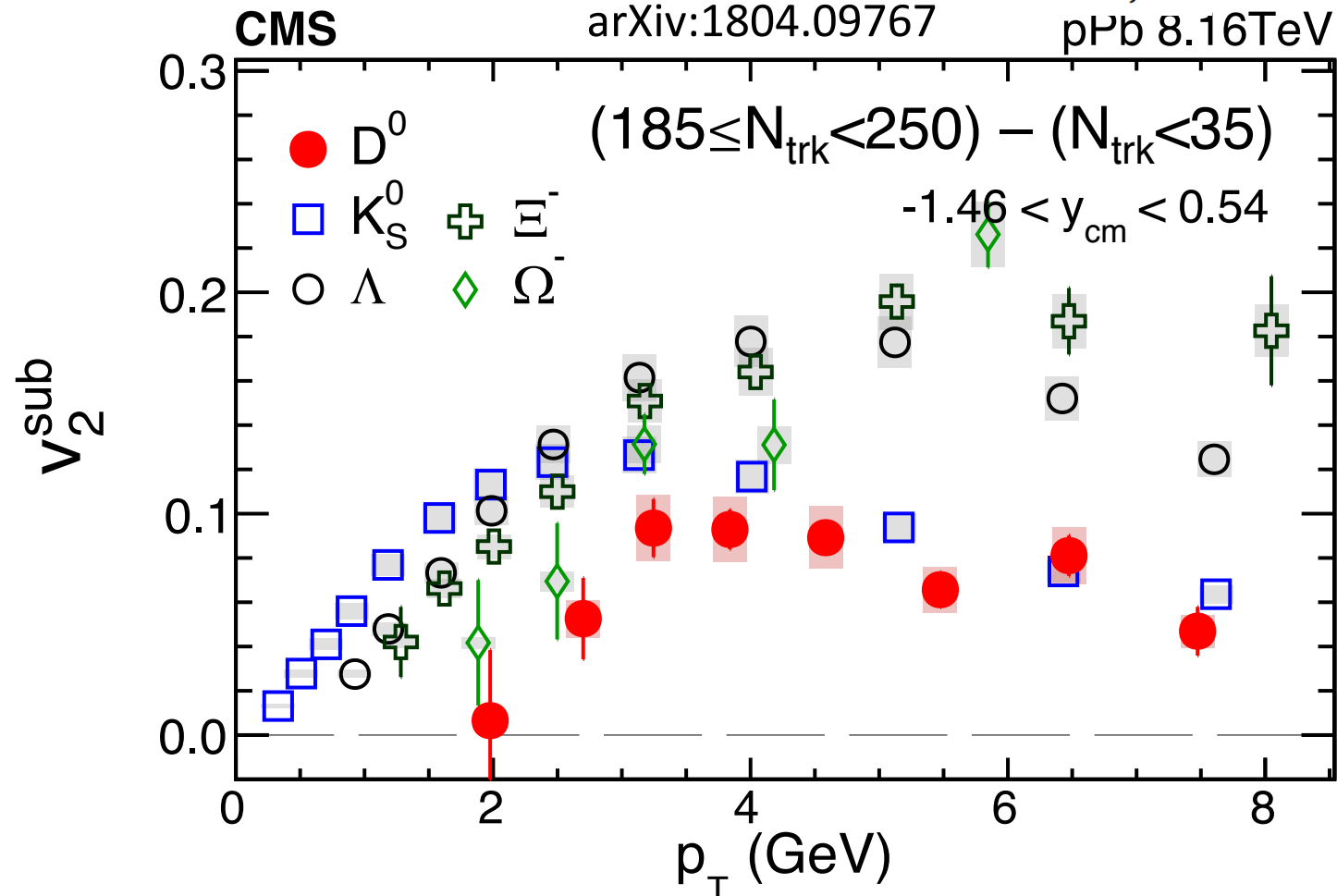
Strange and charm hadron v_2 in pPb



Significant $D^0 v_2$, follow mass ordering at low p_T
 D^0 similar to K_S^0 (both mesons) at higher p_T

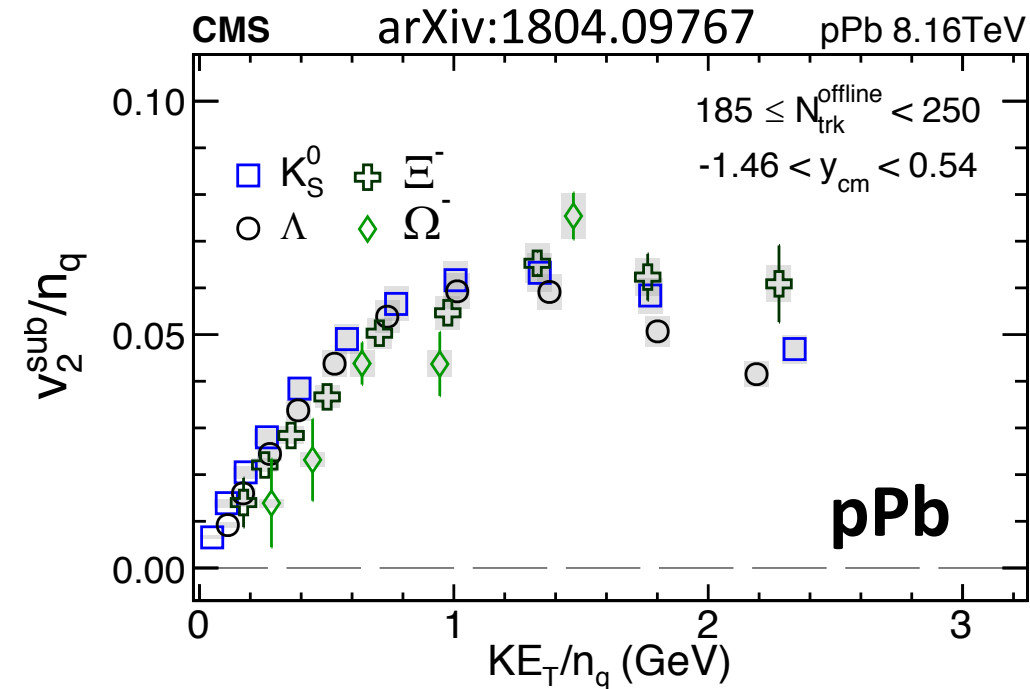
Strange and charm hadron v_2 in pPb

Removing “nonflow”: $V_2^{\text{sub}} = V_2^{\text{HM}} - V_2^{\text{LM}} \frac{N_{\text{assoc}}^{\text{LM}} y_{\text{jet}}^{\text{HM}}}{N_{\text{assoc}}^{\text{HM}} y_{\text{jet}}^{\text{LM}}}$



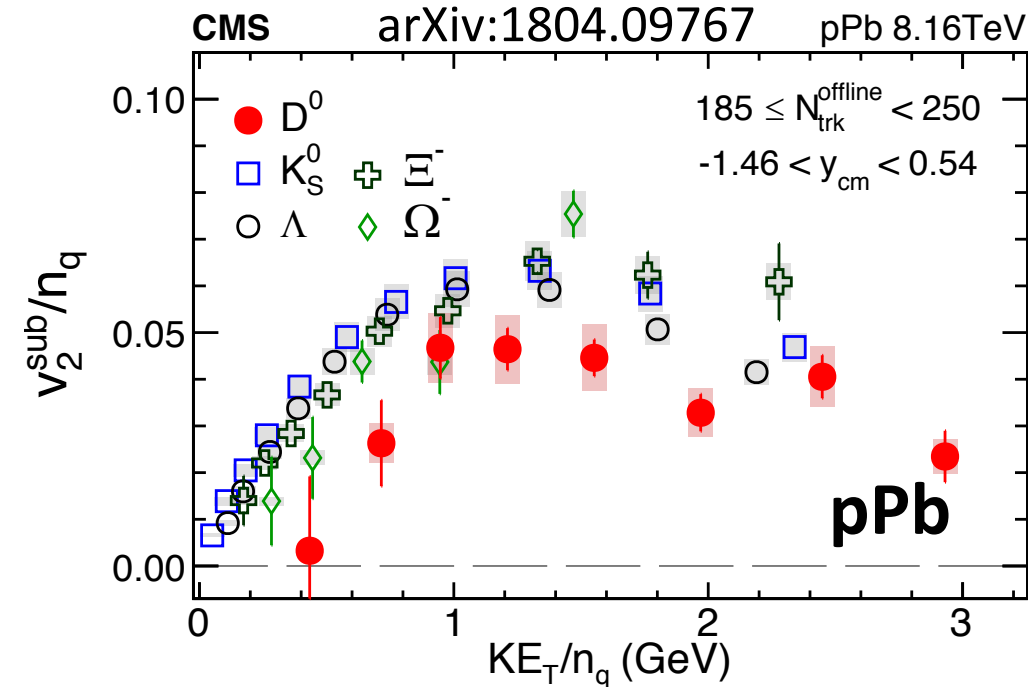
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Quark number scaling in pPb



Approx. scaling for strange hadrons

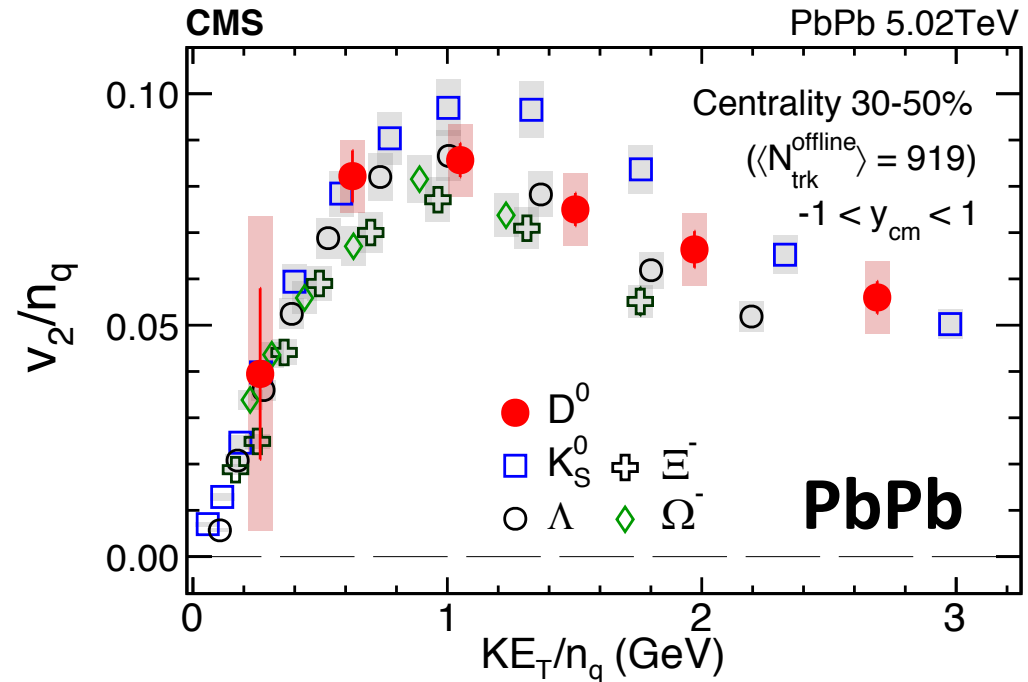
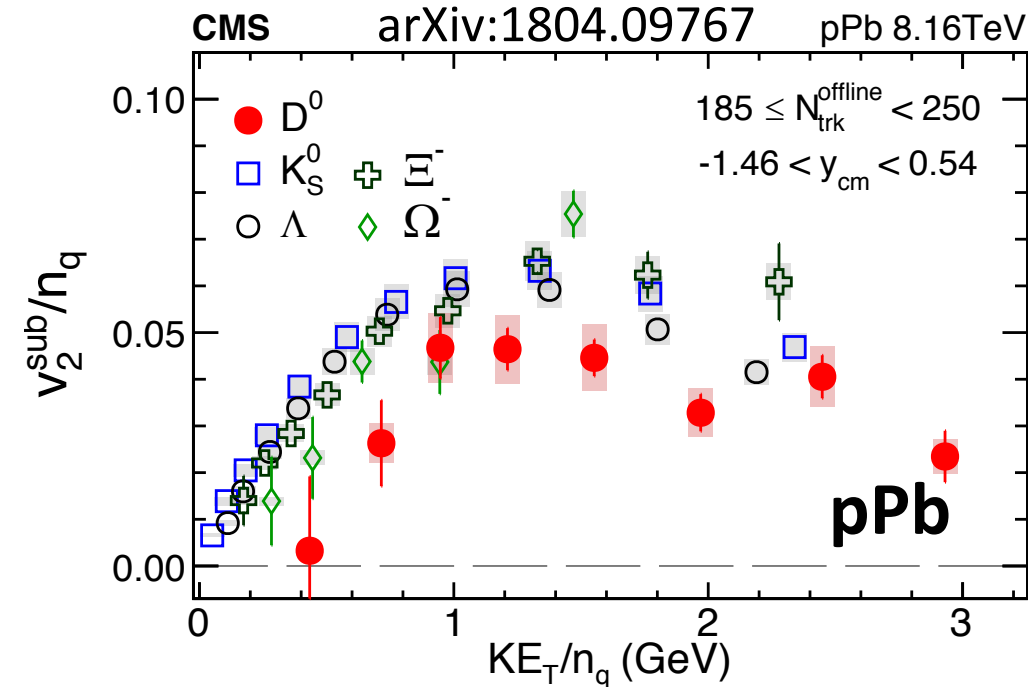
Quark number scaling in pPb



Approx. scaling for strange hadrons

D^0 v_2 consistently lower $\rightarrow v_2(c) < v_2(u,d,s)$

Quark number scaling in pPb

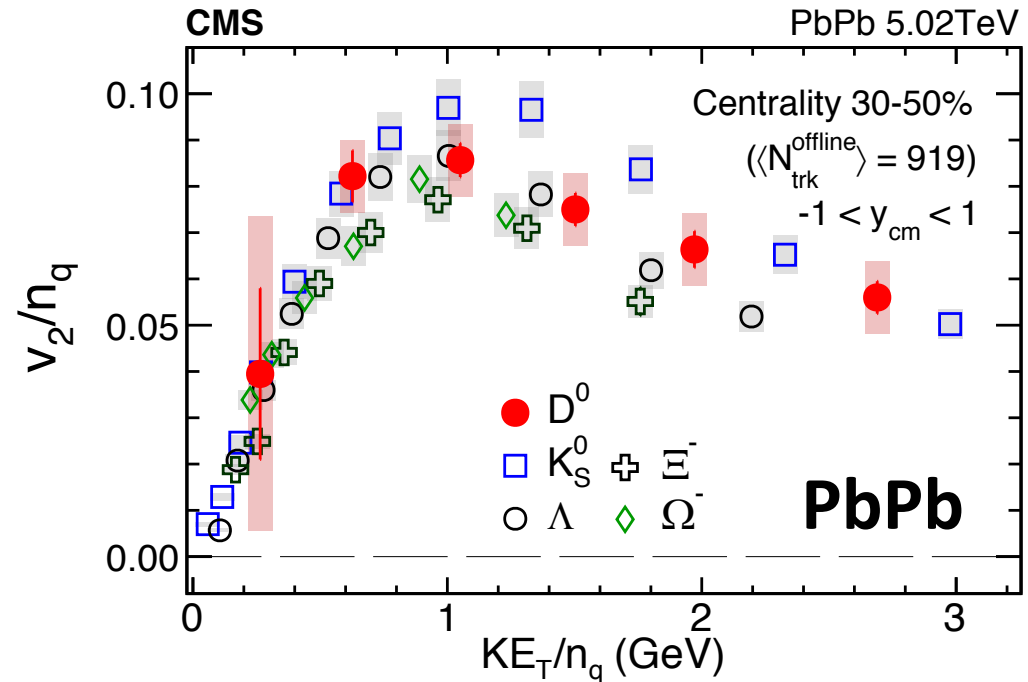
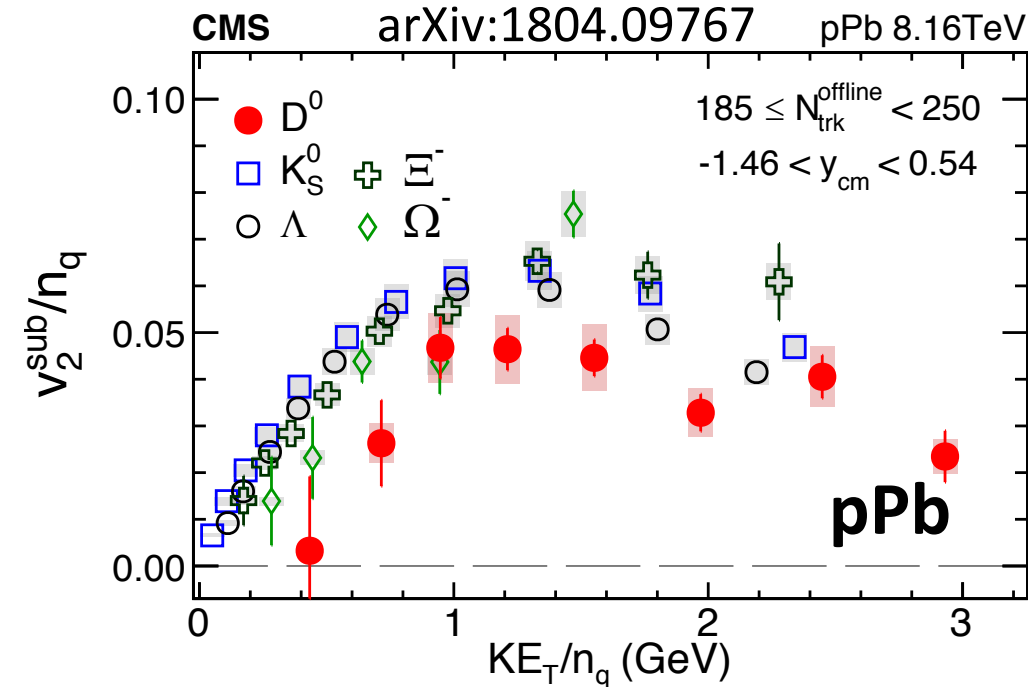


Approx. scaling for strange hadrons

D^0 v_2 consistently lower $\rightarrow v_2(\mathbf{c}) < v_2(\mathbf{u,d,s})$

Different behavior than observation in PbPb

Quark number scaling in pPb



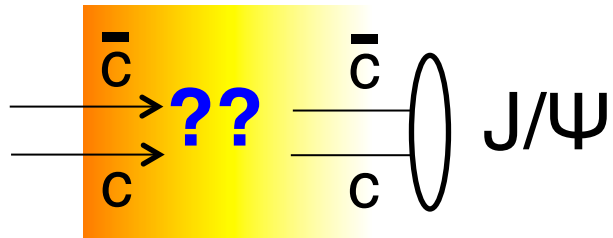
In hydro-QGP picture:

Less flow/thermalization for charm quarks in pPb due to a much reduced small system size?

Interpretations in CGC/glasma picture?

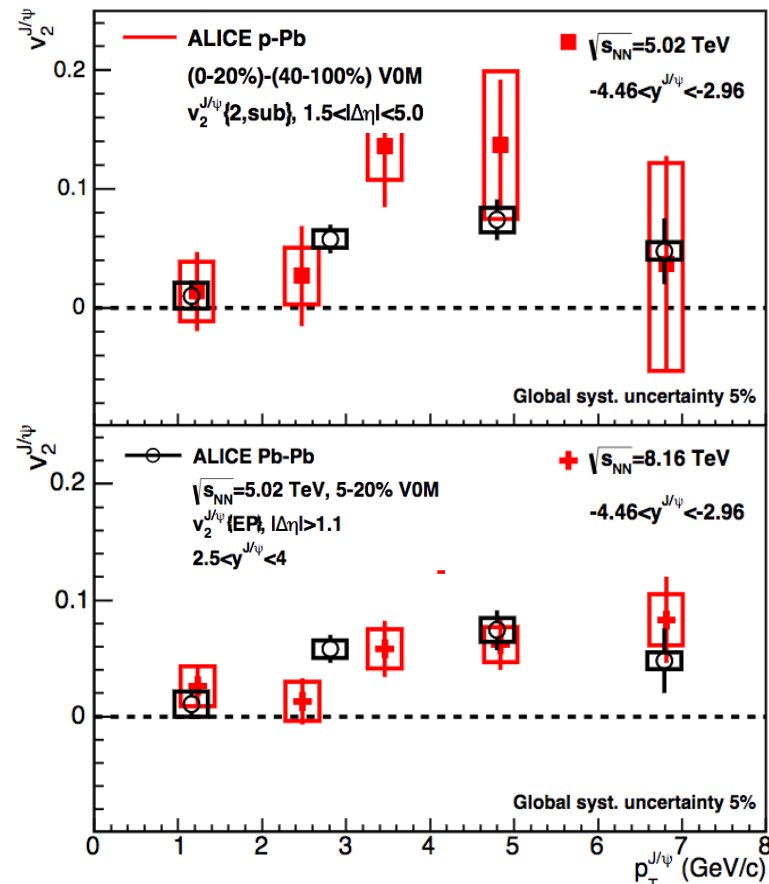
One more thing ...

Collectivity of *Charmonia* in small system?



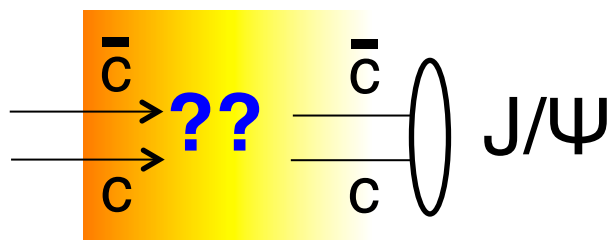
- Recombination of flowing $c\bar{c}$
- Initial correlations from Glamsa?

Inclusive J/ψ from ALICE



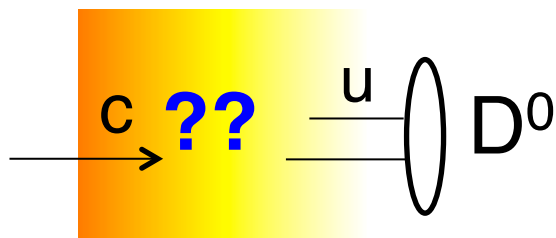
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Collectivity of *Charmonia* in small system?



- Recombination of flowing $c\bar{c}$
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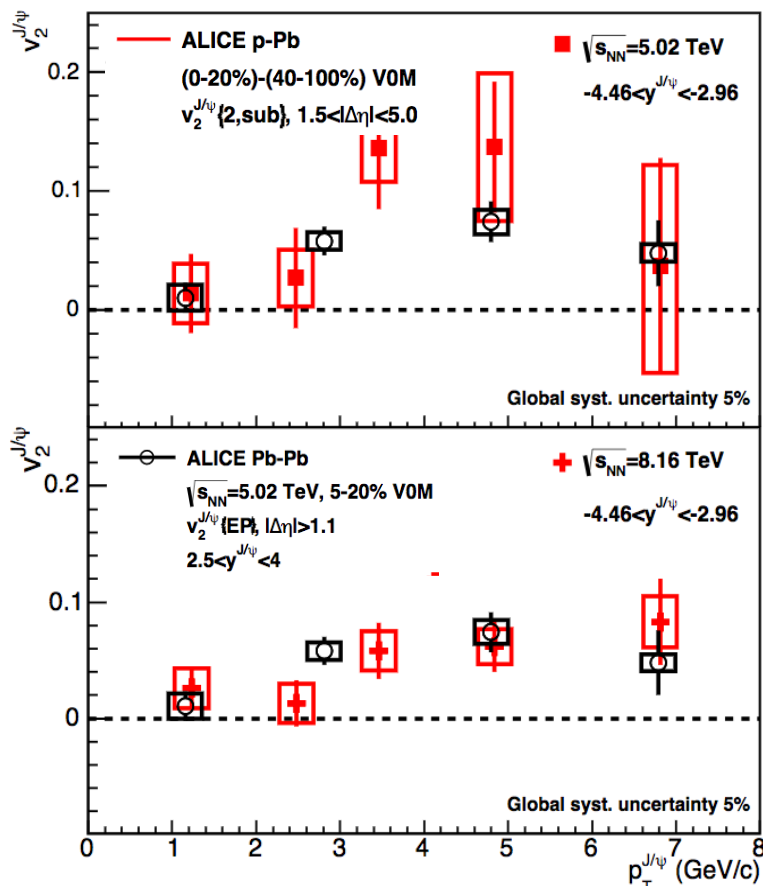
V.S.



$$v_2(c) < v_2(u,d,s)$$

$$\rightarrow v_2(J/\psi) < v_2(D^0)?$$

Inclusive J/ψ from ALICE



J/ψ(→μ⁺μ⁻) reconstruction in pPb

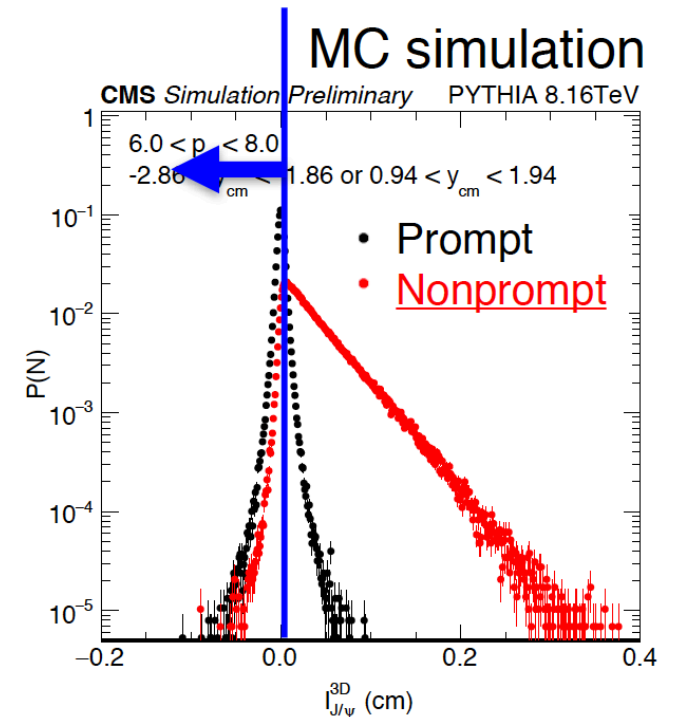
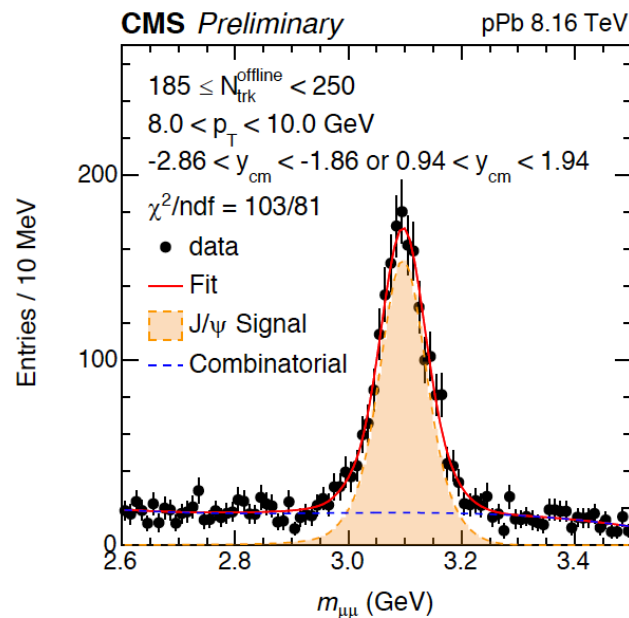
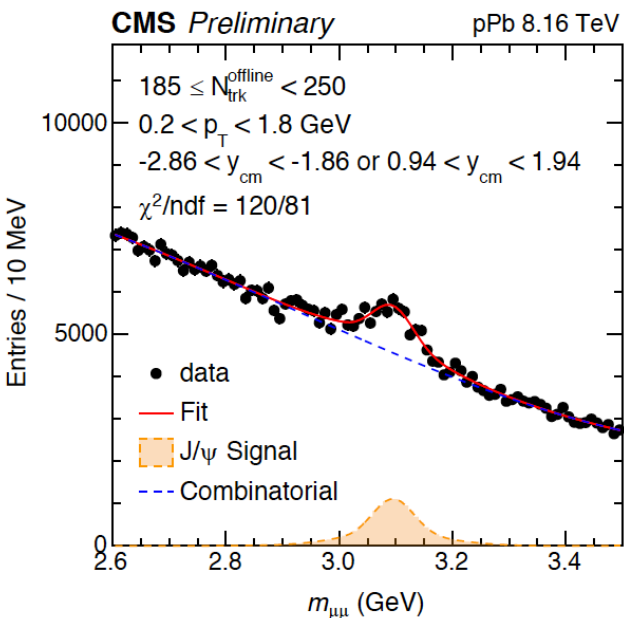
CMS-PAS-HIN-18-010

High-multiplicity pPb ($185 \leq N_{\text{trk}} < 250$)

J/ψ from B reduced

$0.2 < p_T < 1.8$ GeV

$8 < p_T < 10$ GeV



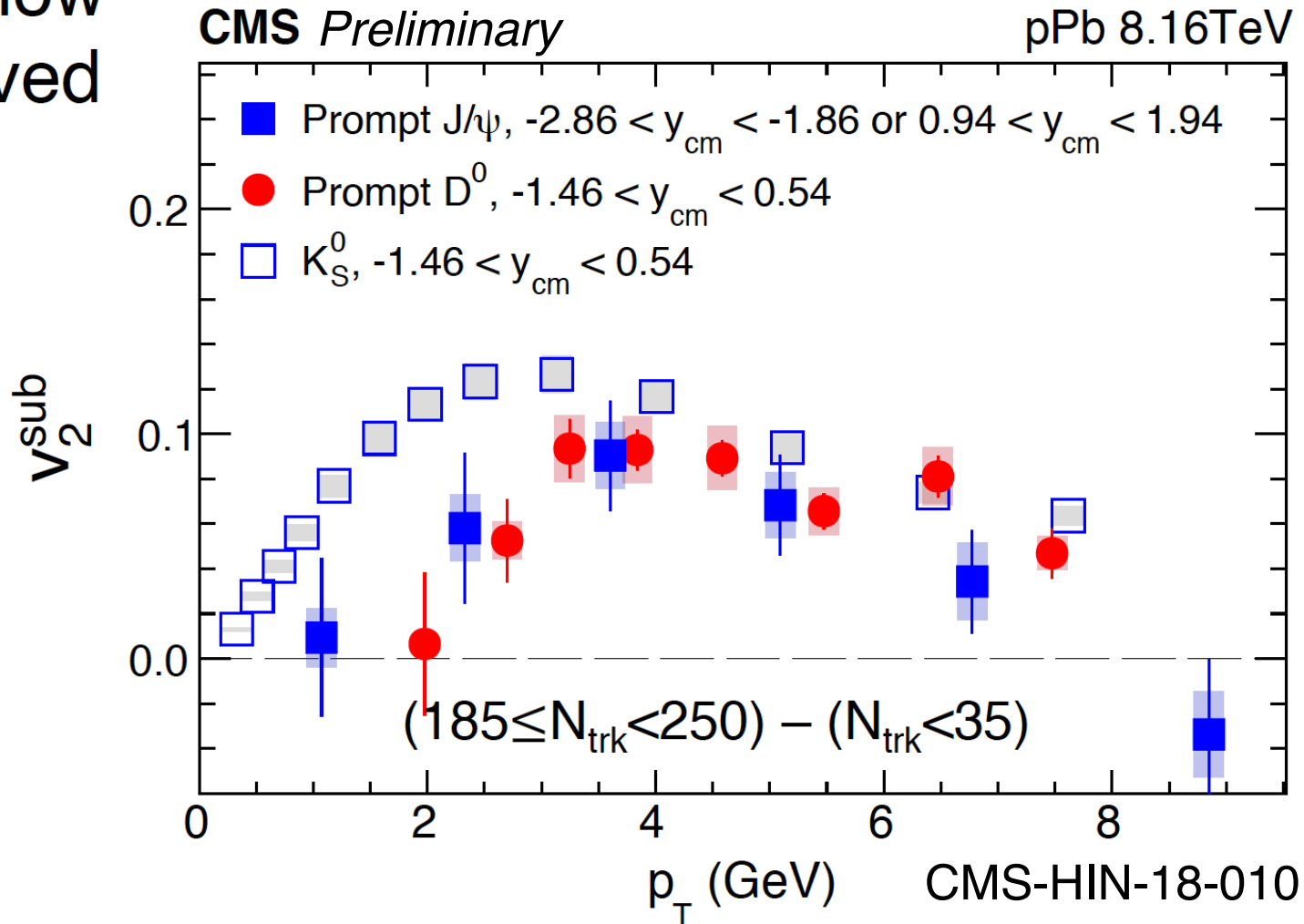
Good efficiency down to $p_T \sim 0$ GeV
at forward $1.4 < |y_{\text{lab}}| < 2.4$

$$l_{J/\psi}^{3D} = L_{xyz} m_{J/\psi} / |p_{\mu\mu}|$$

Residual: $\sim 5\%$
(systematics)

Prompt J/ψ meson v_2 in pPb

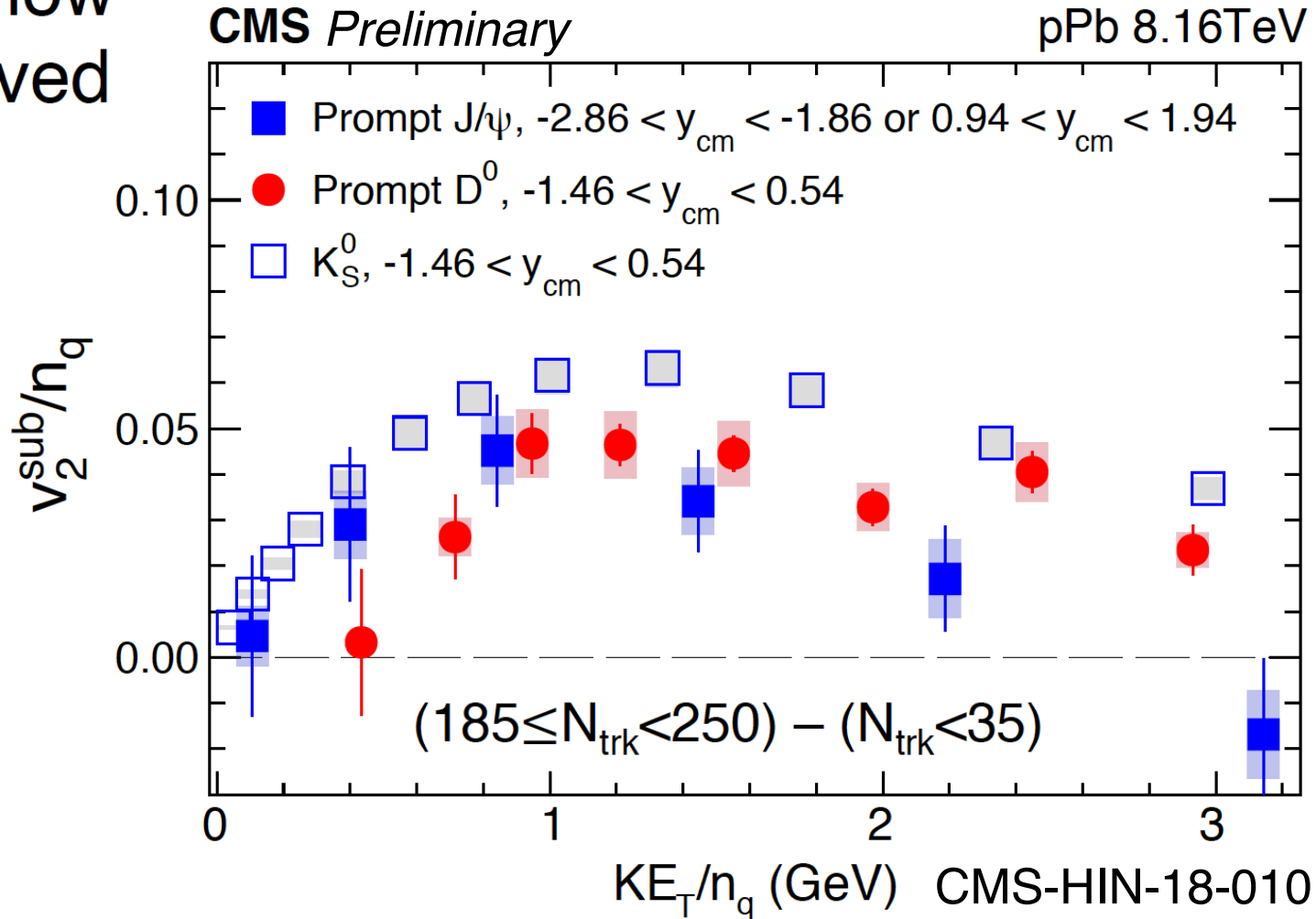
“Nonflow”
removed



Significant J/ψ v_2 \Rightarrow most direct evidence of charm v_2
J/ψ comparable to D^0 ? Both below light flavor K_S^0

Prompt J/ψ meson v_2 in pPb

“Nonflow”
removed

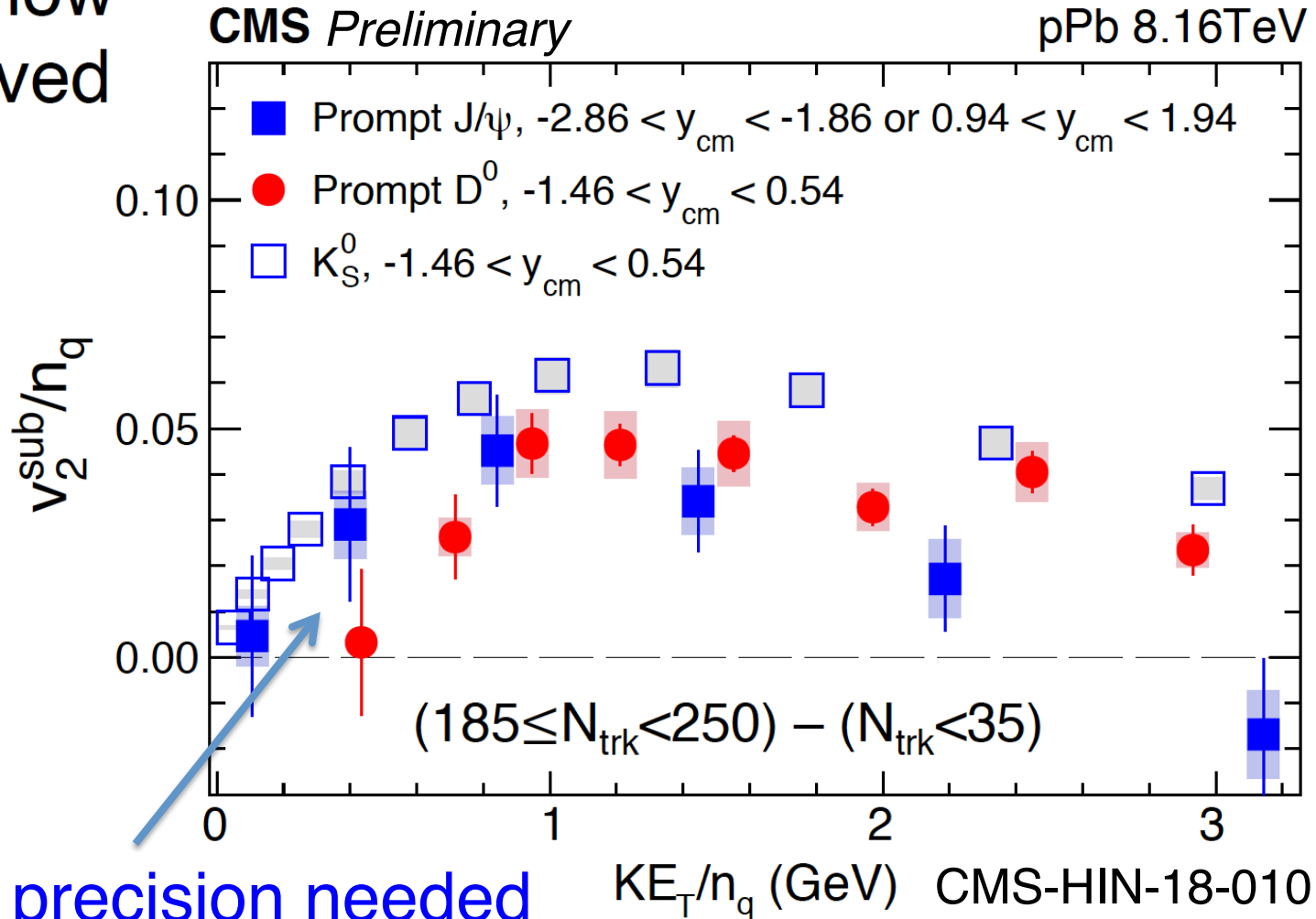


As a function of KE_T

$$v_2(D^0) \approx v_2(J/\psi) < v_2(K_S^0)?$$

Prompt J/ψ meson v_2 in pPb

“Nonflow”
removed



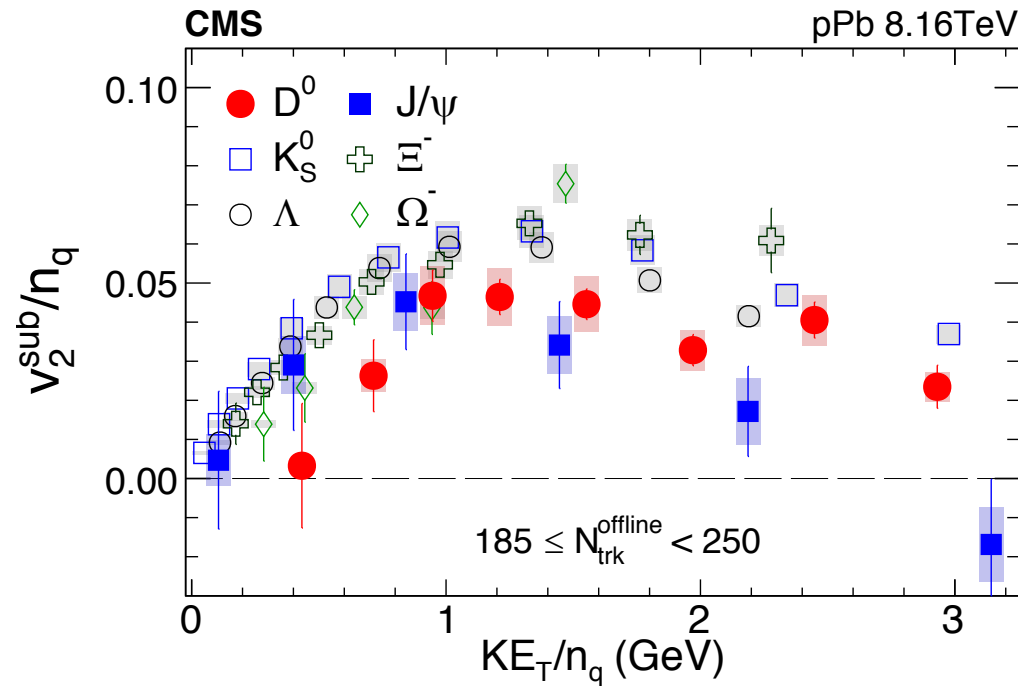
Better precision needed

As a function of KE_T

$$v_2(D^0) \approx v_2(J/\psi) < v_2(K_S^0)?$$

Summary

New results of charm (D^0 , J/ψ) and strange flow in pPb



Clear observation of v_2 signal for charm quarks

- Weaker collectivity than light quarks
- Different behavior from larger PbPb system

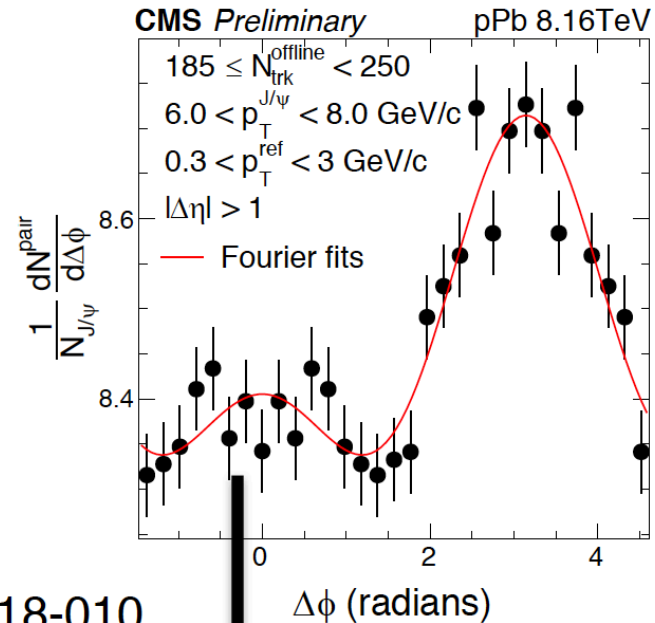
New insights to the origin of “Ridge” in small systems
(esp. with better precision, *bottom*; also in pp in the future)

Backups

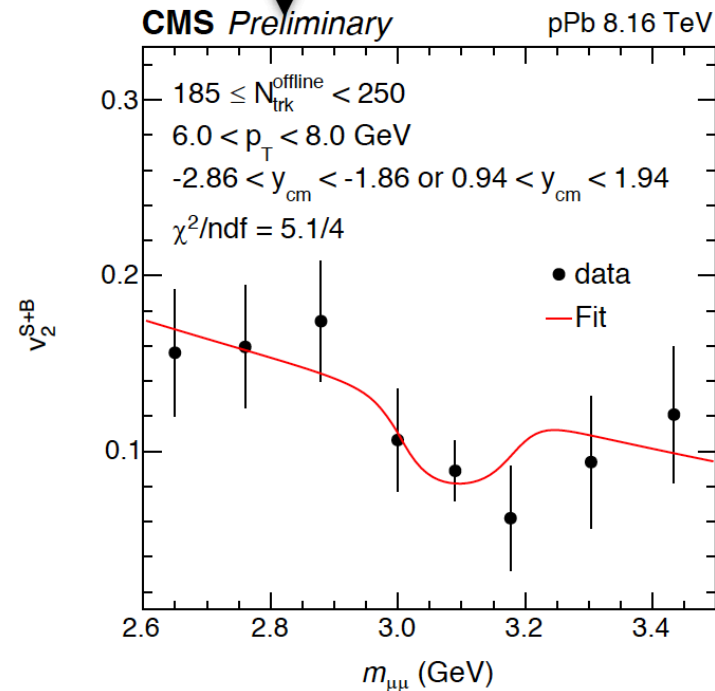
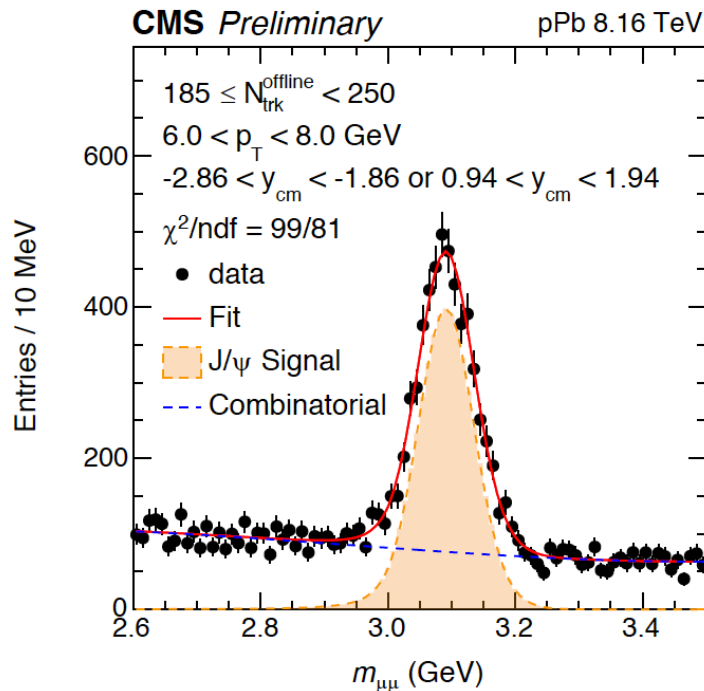
J/ψ – charged hadron correlation

Same technique as for D⁰ and strange hadrons

$|\Delta\eta| > 1$ projection

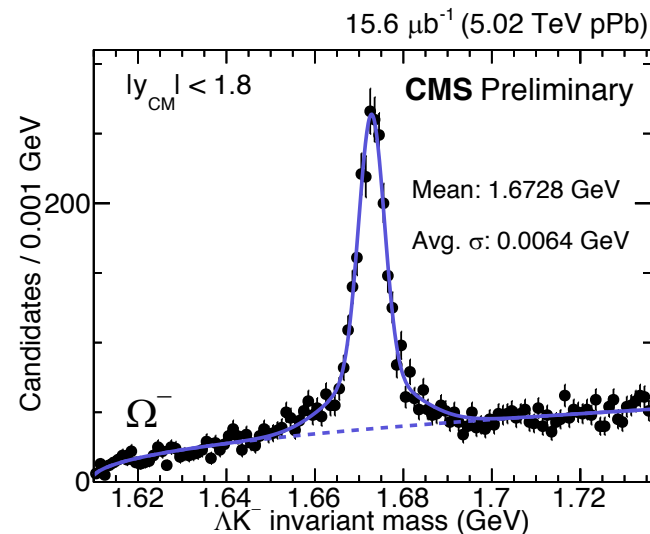
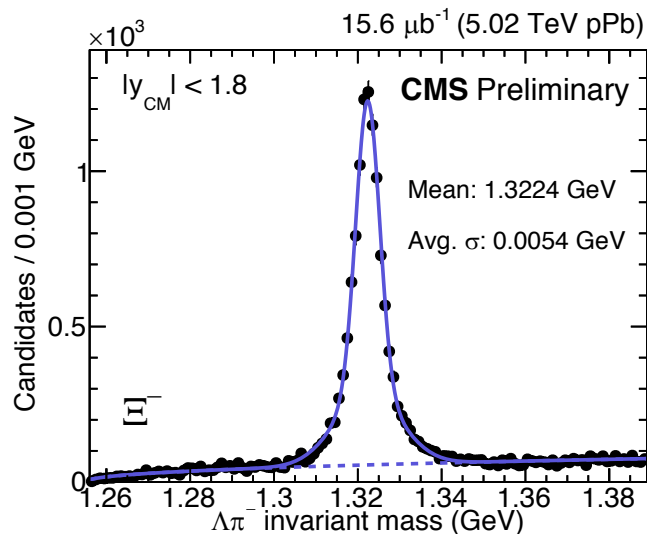
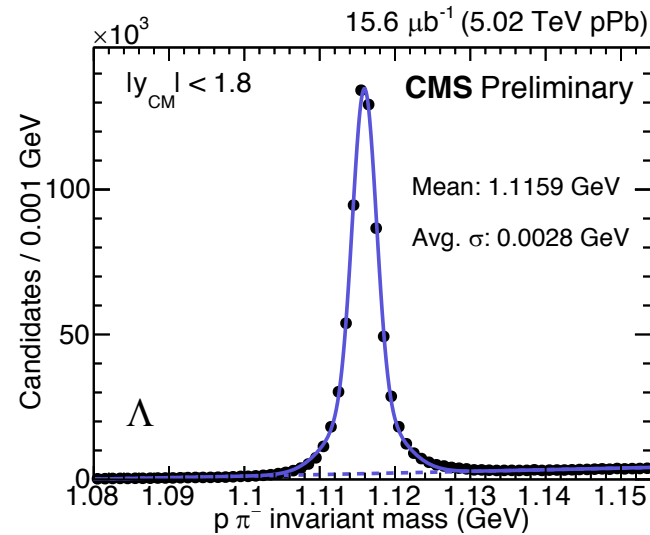
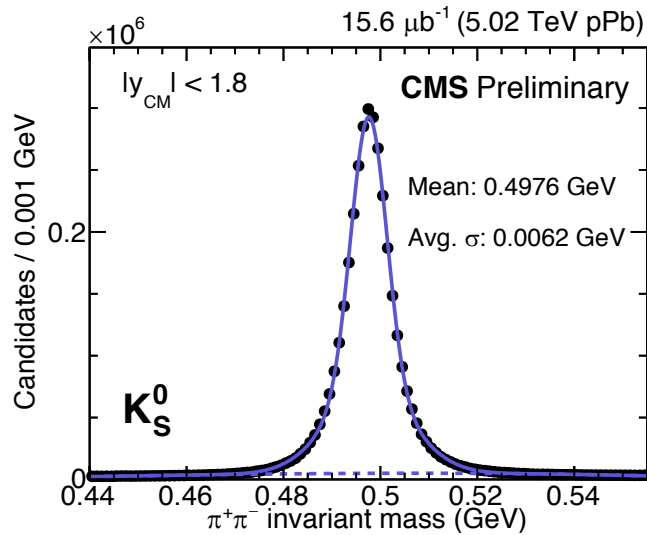


CMS-PAS-HIN-18-010



Strange hadron reconstruction

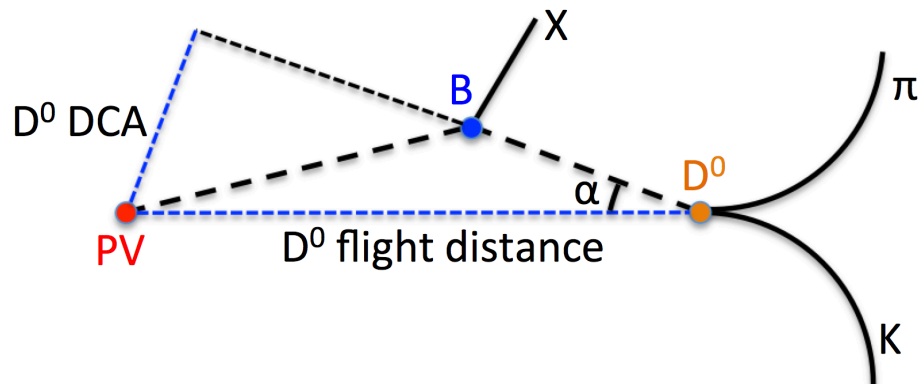
CMS-PAS-HIN-16-013



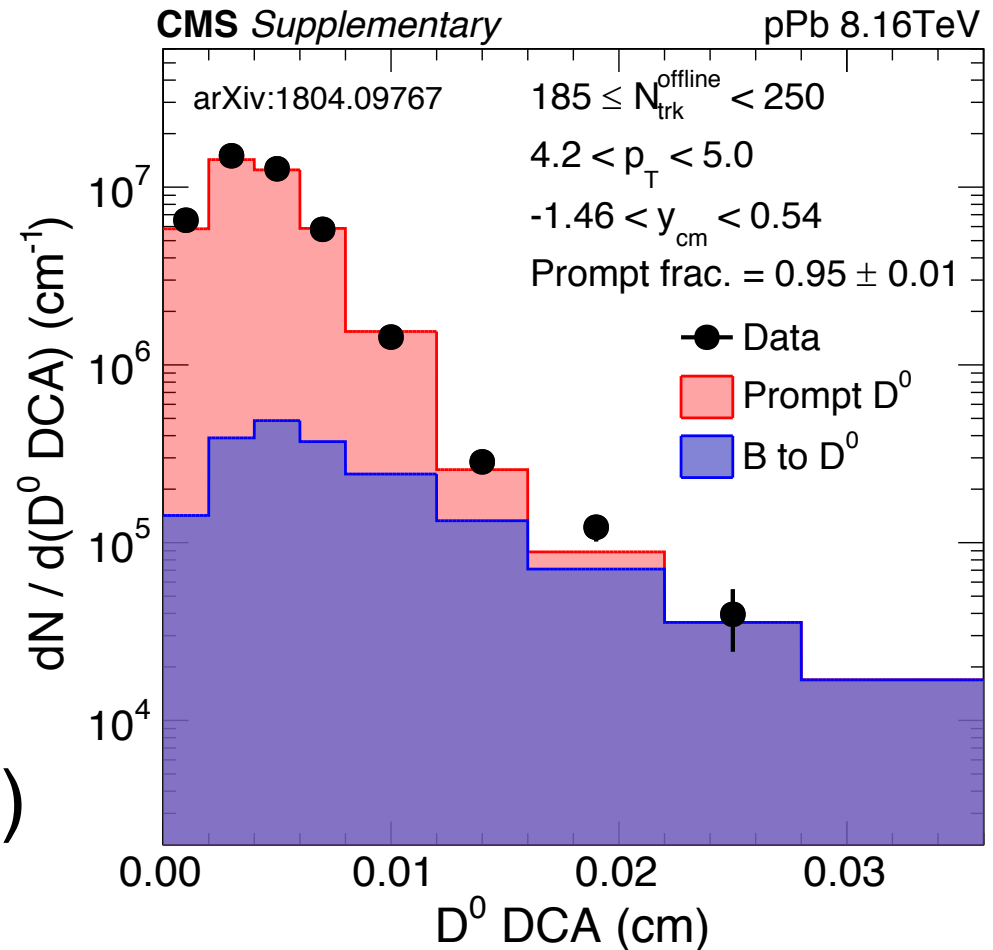
Well established in many earlier measurements

D⁰ meson in pPb at CMS

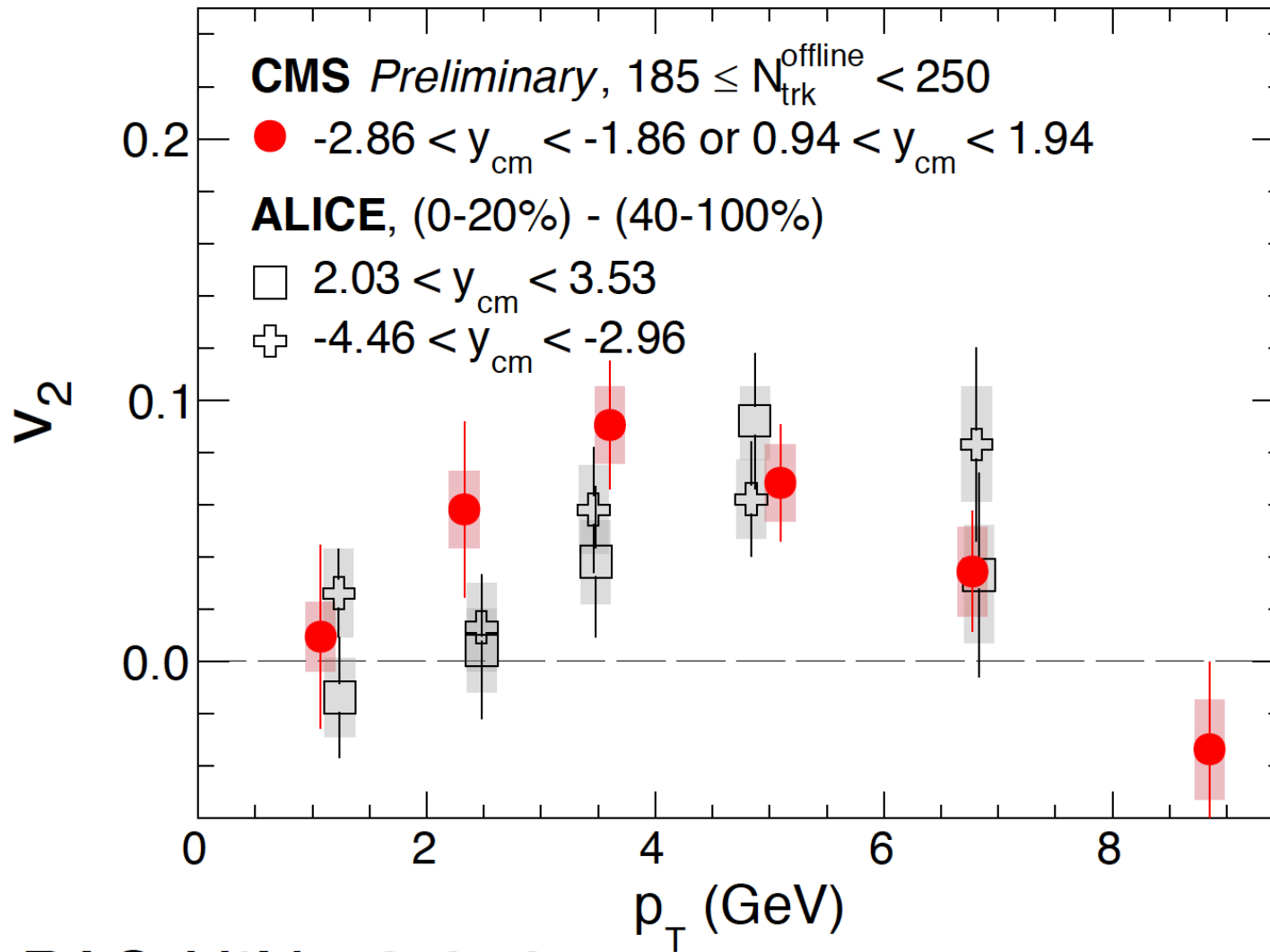
Suppress nonprompt D⁰ from B mesons



Residual NP D⁰: $\sim 1-7\%$
(considered as systematics)



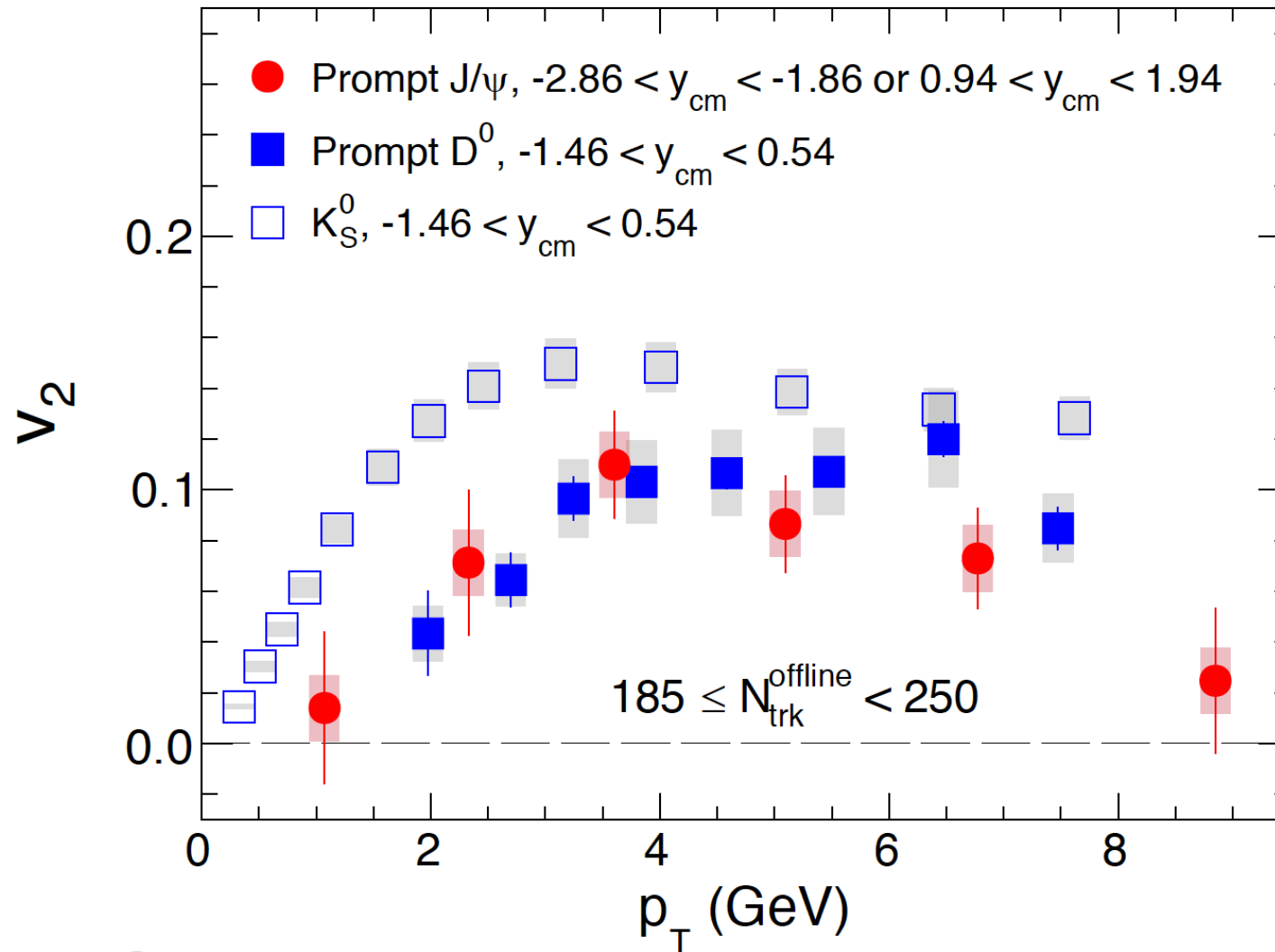
pPb 8.16TeV



CMS-PAS-HIN-18-010

CMS Preliminary

pPb 8.16TeV



CMS-PAS-HIN-18-010

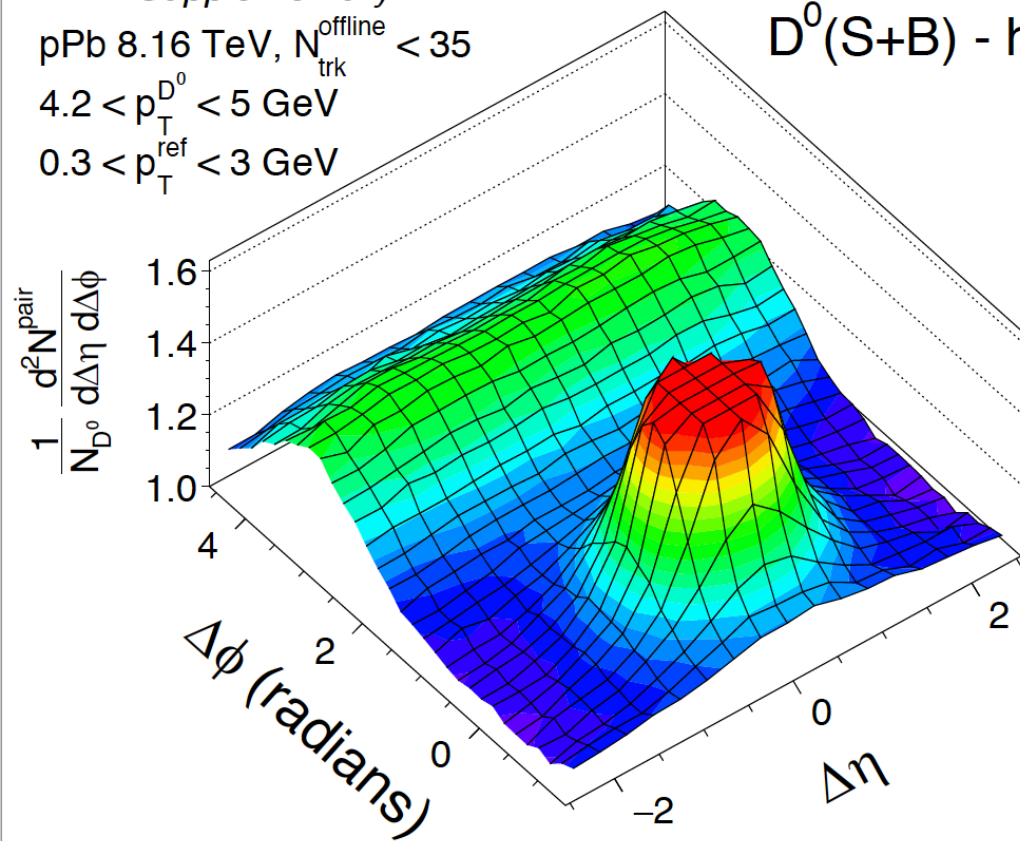
CMS Supplementary arXiv:1804.09767

pPb 8.16 TeV, $N_{\text{trk}}^{\text{offline}} < 35$

$4.2 < p_{\text{T}}^{\text{D}^0} < 5 \text{ GeV}$

$0.3 < p_{\text{T}}^{\text{ref}} < 3 \text{ GeV}$

$\text{D}^0(\text{S+B}) - \text{h}^{\pm}$



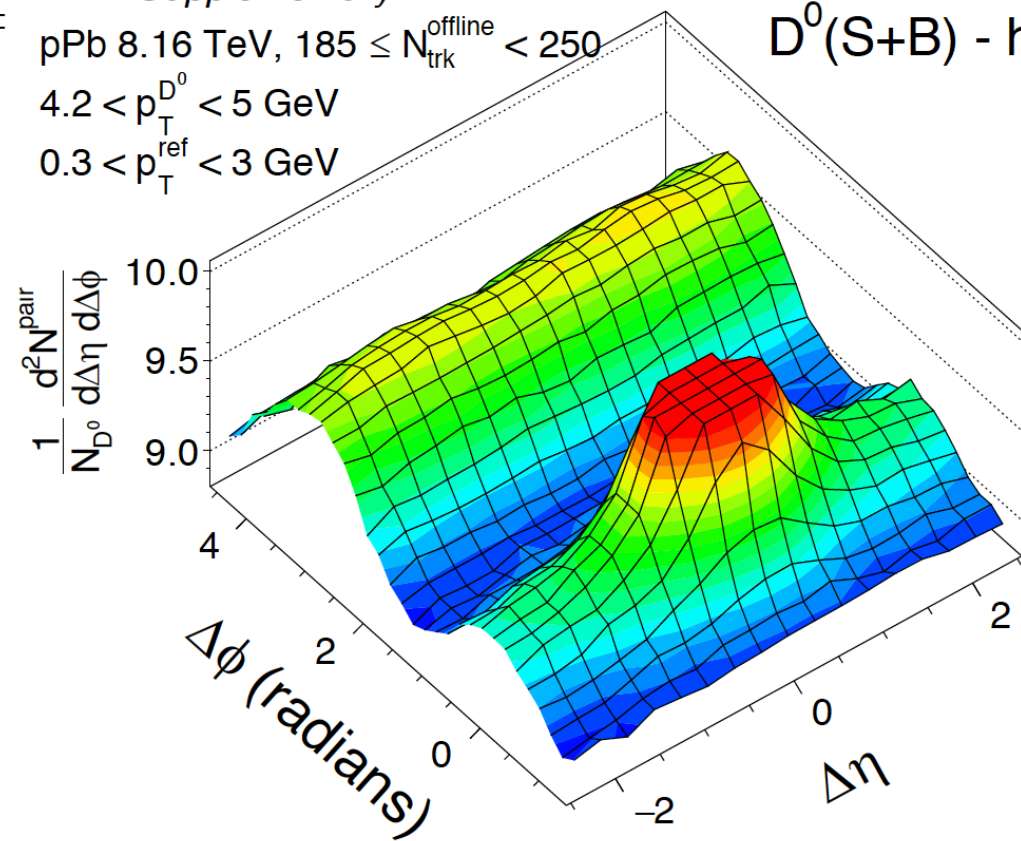
CMS Supplementary arXiv:1804.09767

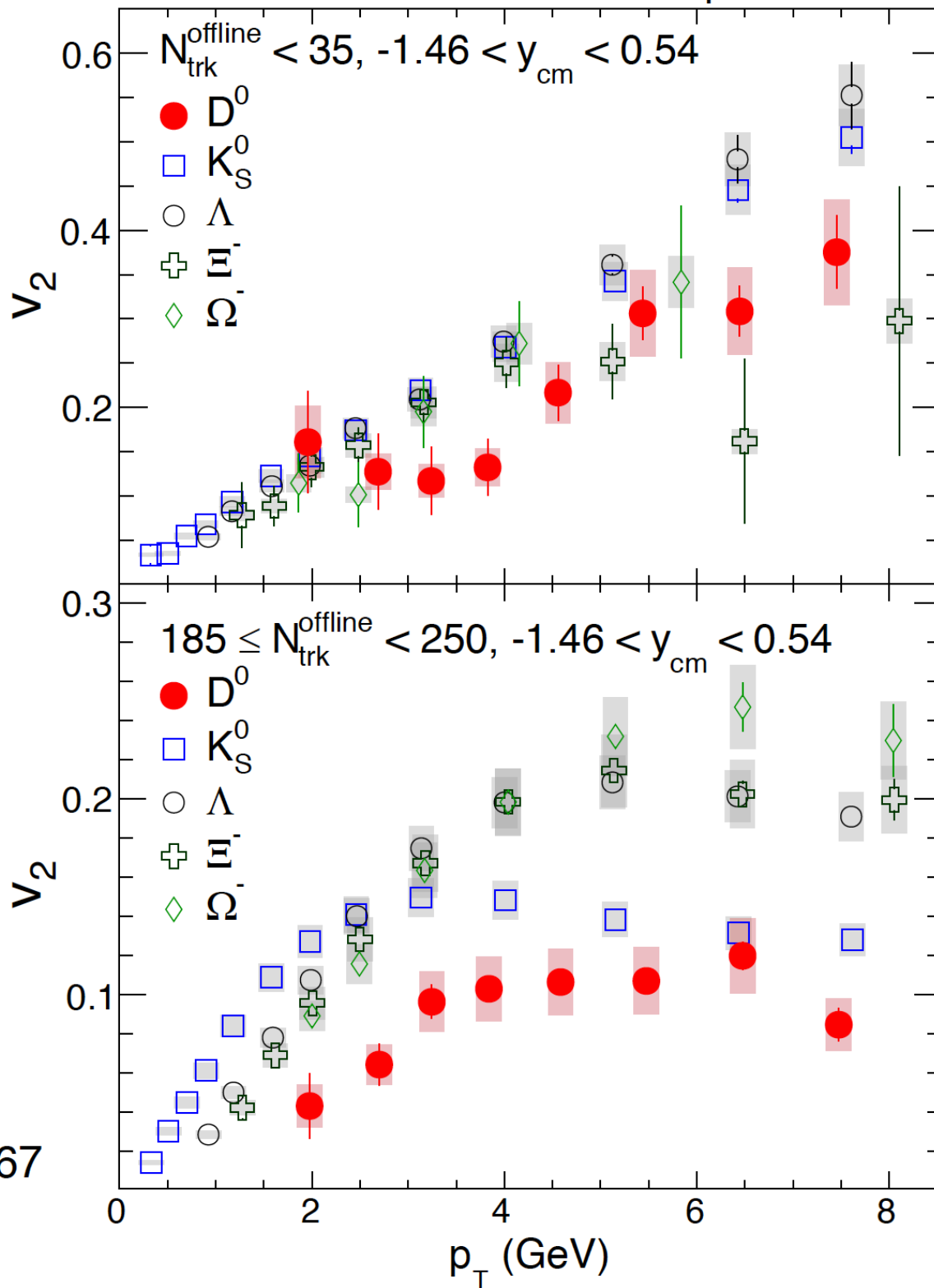
pPb 8.16 TeV, $185 \leq N_{\text{trk}}^{\text{offline}} < 250$

$4.2 < p_{\text{T}}^{\text{D}^0} < 5 \text{ GeV}$

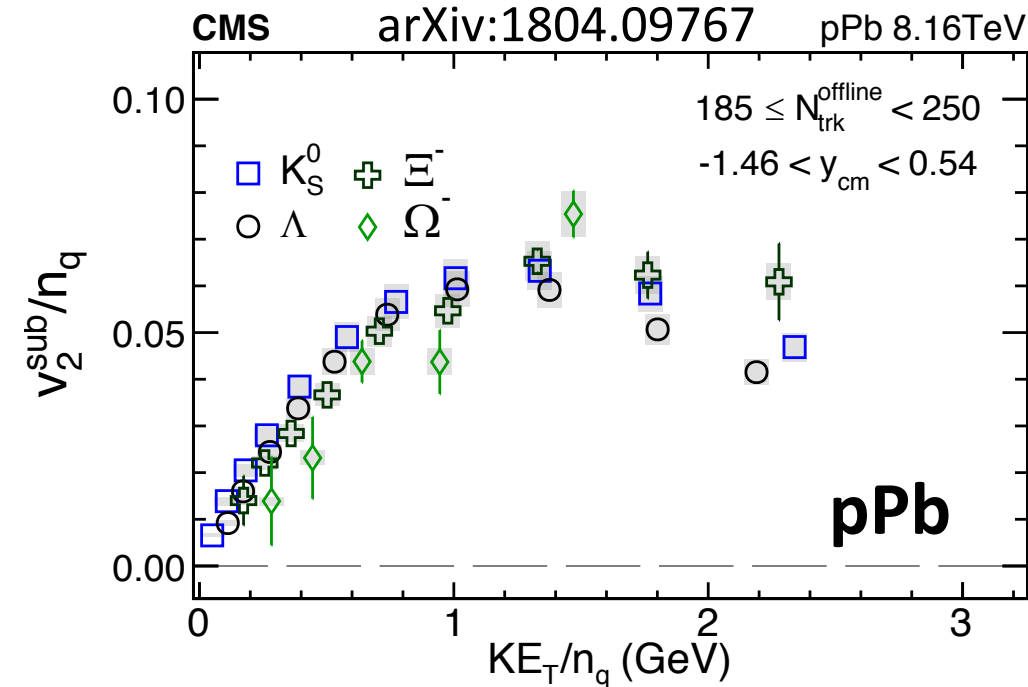
$0.3 < p_{\text{T}}^{\text{ref}} < 3 \text{ GeV}$

$\text{D}^0(\text{S+B}) - \text{h}^{\pm}$





Quark number scaling in pPb



Approx. scaling for strange hadrons except for Ω ? Or ϕ ?