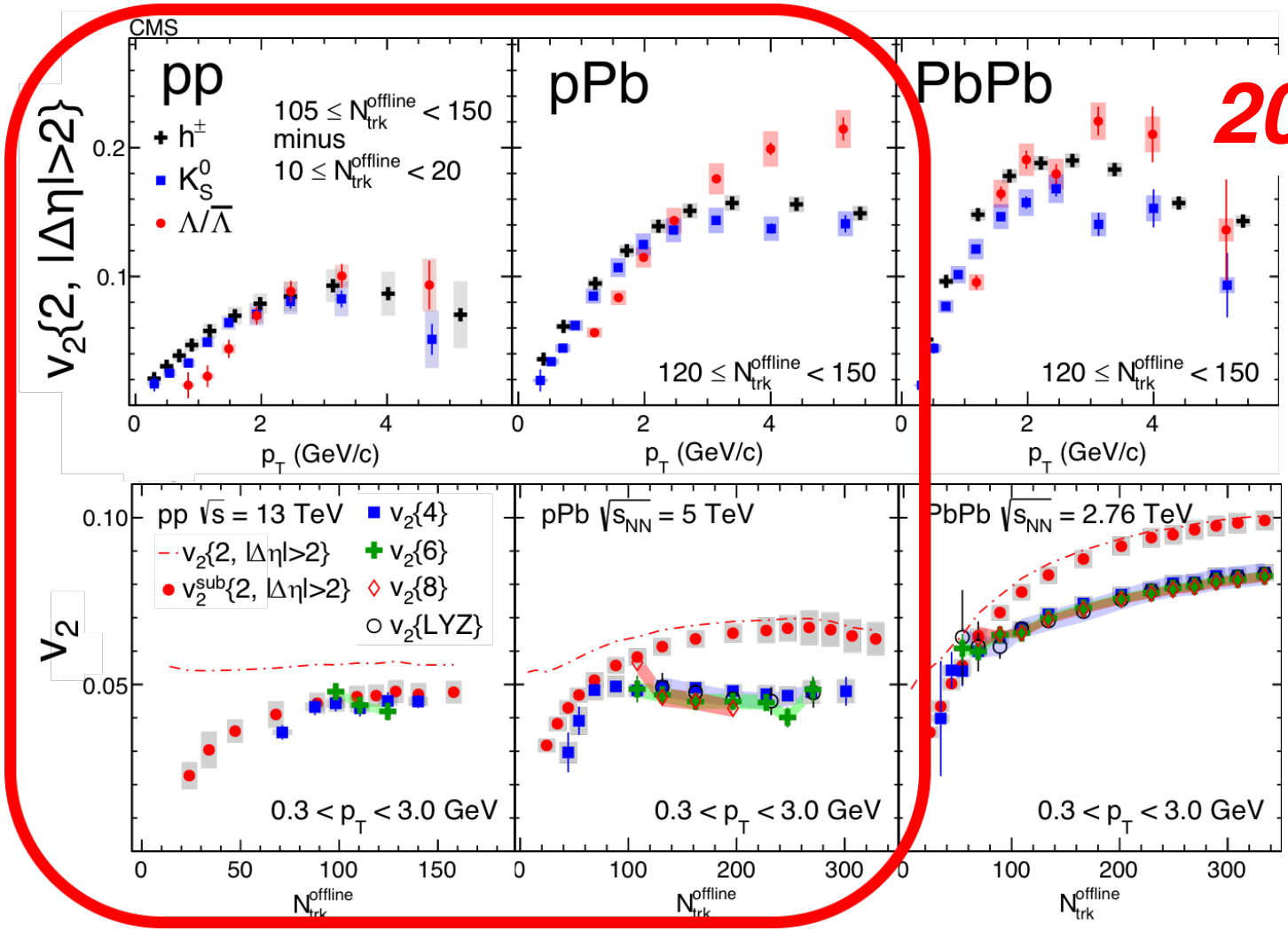
Long-range collectivity of charm and strange hadrons in pPb with CMS

Zhenyu Chen, Wei Li
(Rice University)
for the CMS collaboration

Quark Matter 2018, Venice, Italy

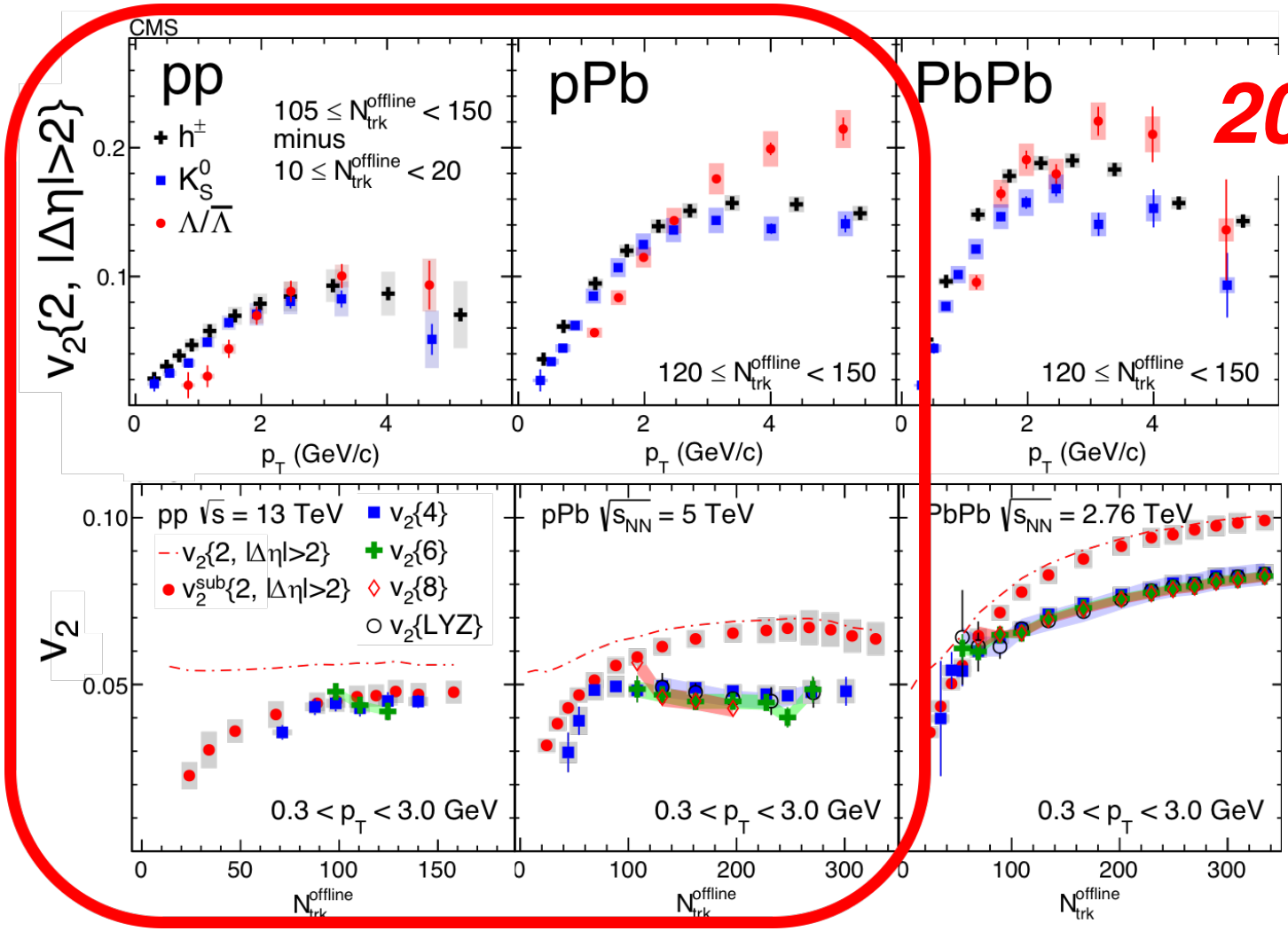
Collectivity in small systems



2010-2017

Collectivity of bulk particle production in small systems

Collectivity in small systems



2010-2017

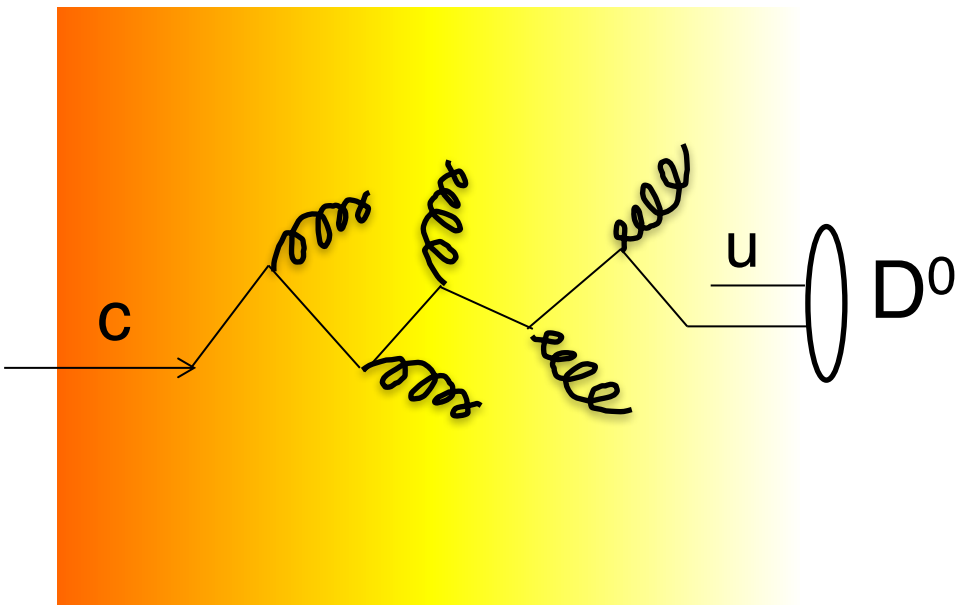
Collectivity of bulk particle production in small systems

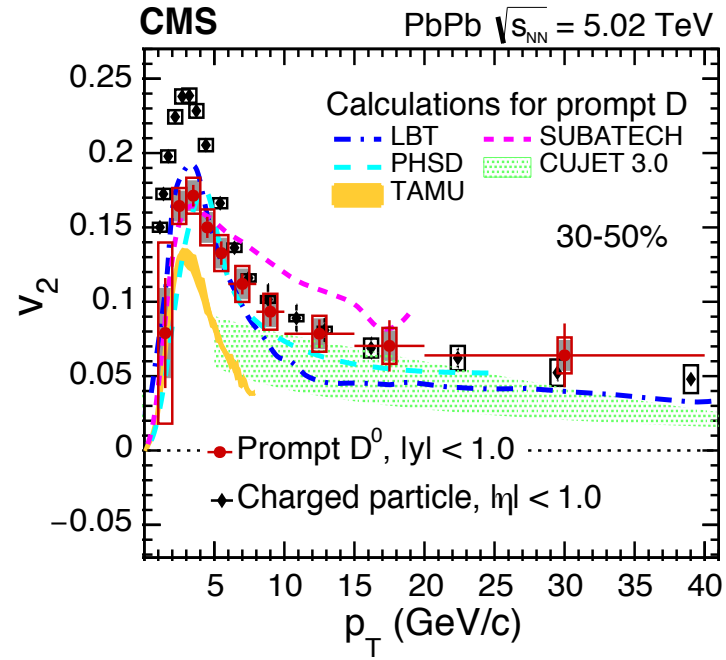
QM2018: what about heavier quarks (i.e., *c,b*)?

Heavy quarks in QGP

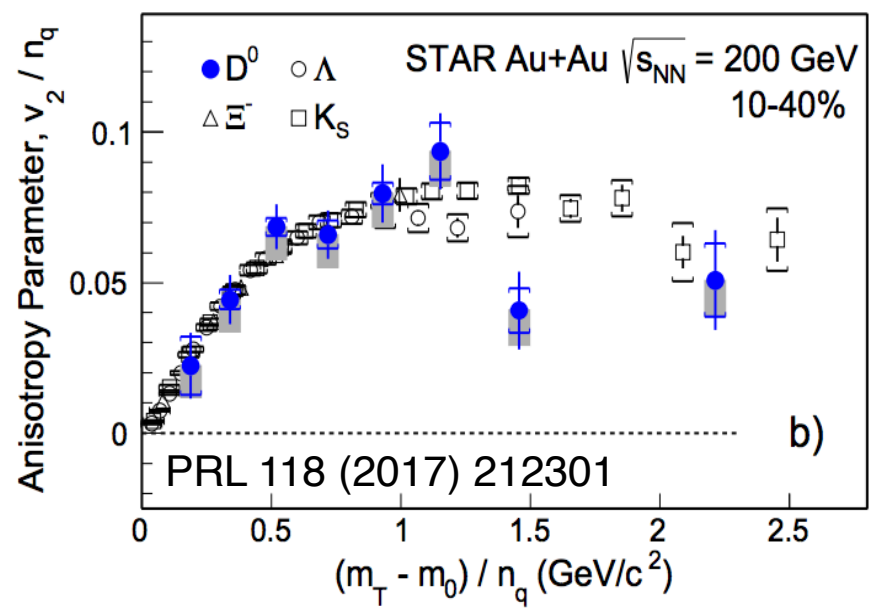
arXiv:1708.03497

Large AA systems





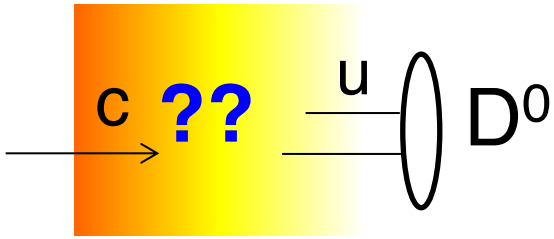
Charms expected to flow!!



Charms thermalized in AA!?

Heavy quarks in small systems

Collectivity (v_2) 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

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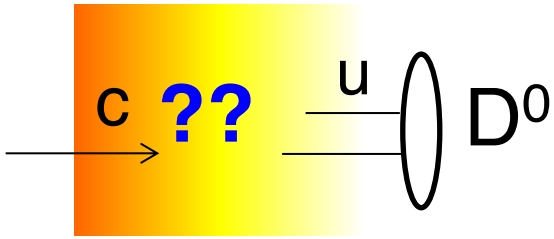

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Interaction with a (tiny) QGP?

Thermalization for a small size?

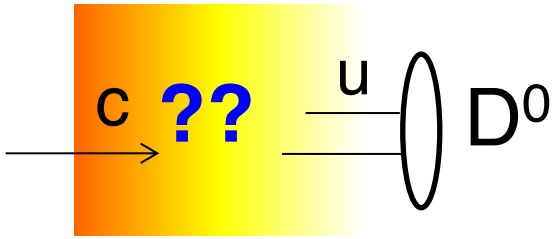
OR

A new window for initial correlations?

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

Heavy quarks in small systems

Collectivity (v_2) for heavy quarks in small system?



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Comparing to *bulk system* (light quarks/gluons)

$\mathbf{K^0_s, \Lambda, \Xi^-, \Omega^-}$

Heavy quarks in small systems

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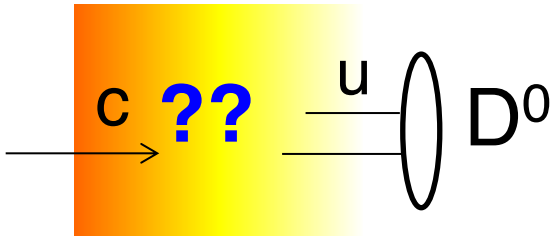

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A new window for initial correlations?

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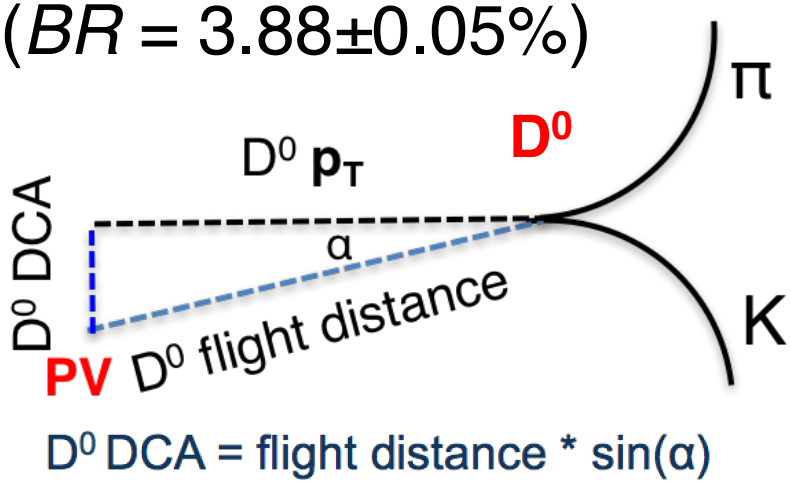
Comparing to *bulk system* (light quarks/gluons)

K^0_s, Λ, Ξ^-, Ω^- (also 1st time in small systems)

CMS, arXiv:1804.09767, submitted to PRL

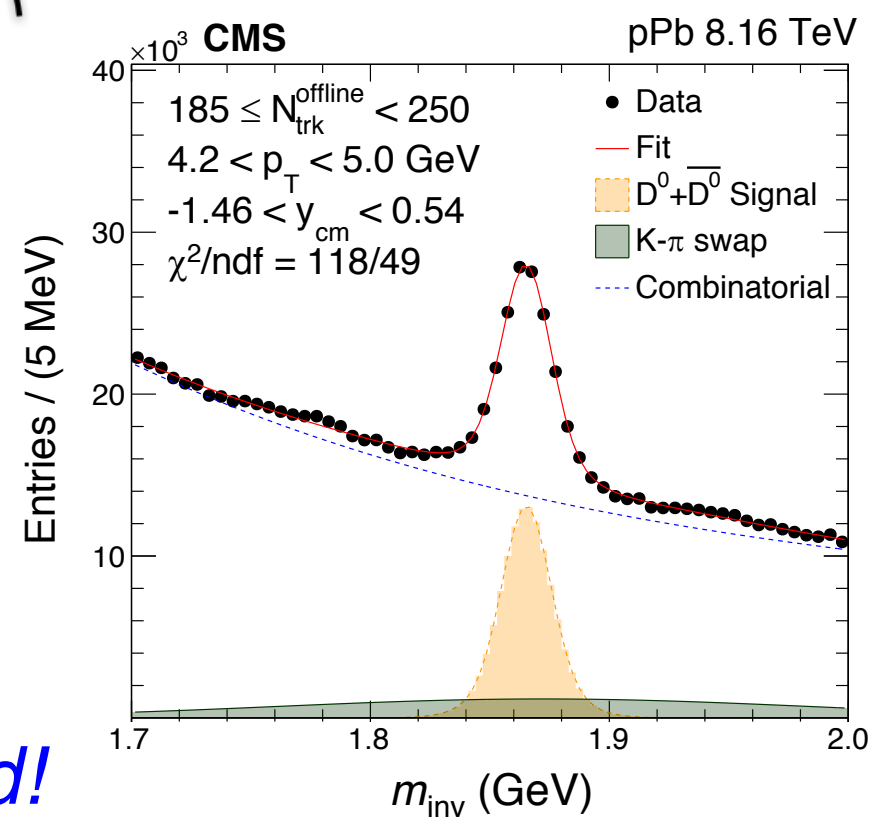
D^0 meson in pPb at CMS

$D^0 \rightarrow K{+}\pi\,(BR = 3.88{\pm}0.05\%)$



(No PID for π/K)

arXiv:1804.09767



2016 pPb @ 8.16 TeV:

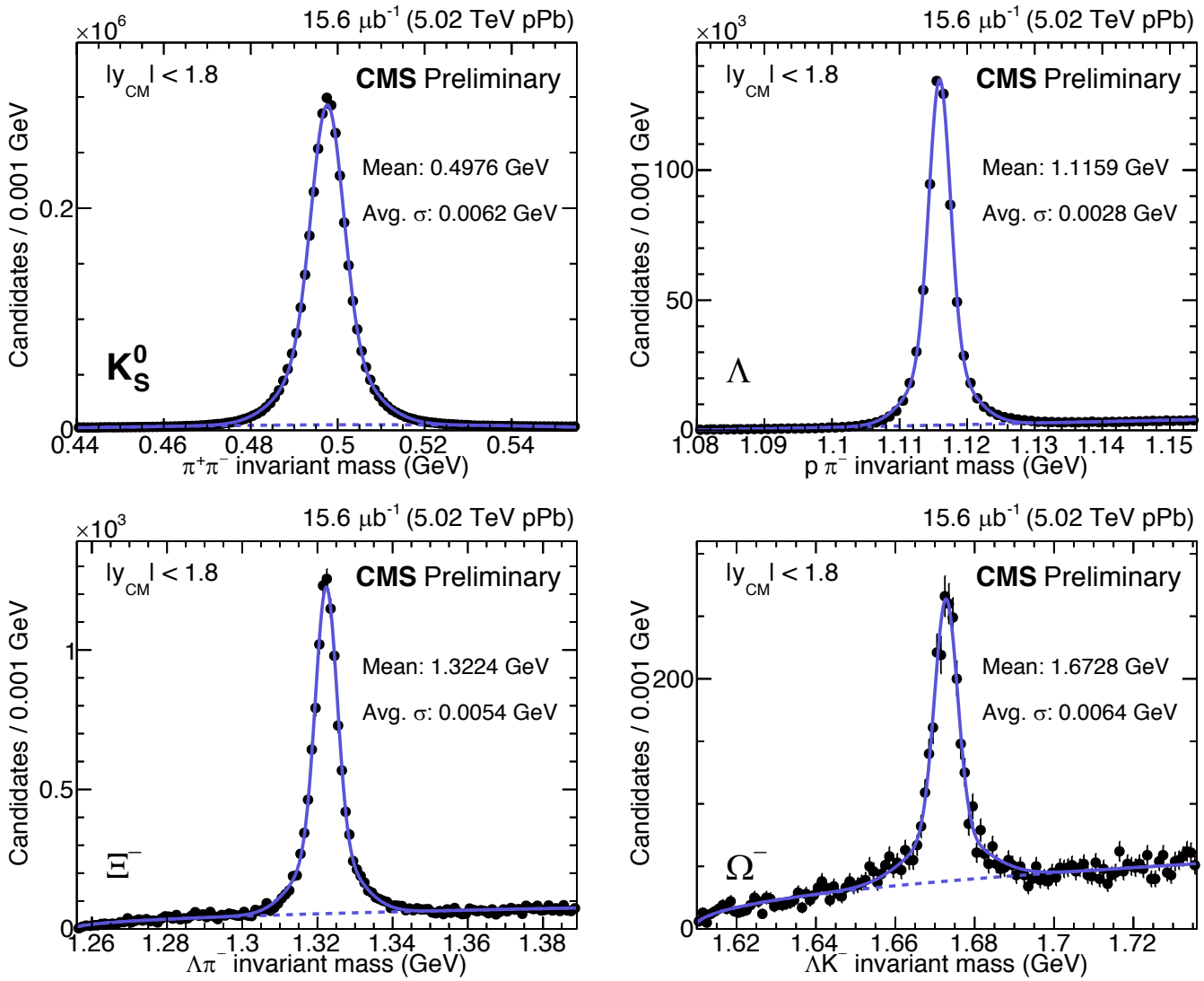
- High Multiplicity ($N_{trk} \geq 185$, top 0.33%): **550 million**
- Minimum Bias: **7 billion**

Large number of events needed!

D^0 from B decay: ~ 1-7%

Strange hadron reconstruction

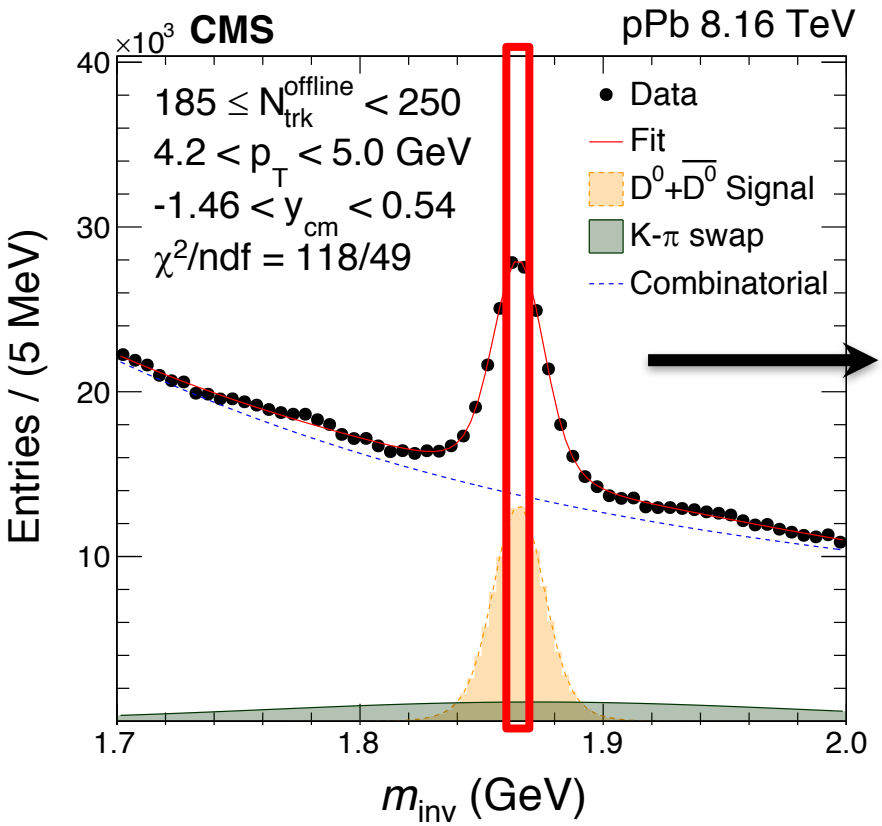
CMS-PAS-HIN-16-013



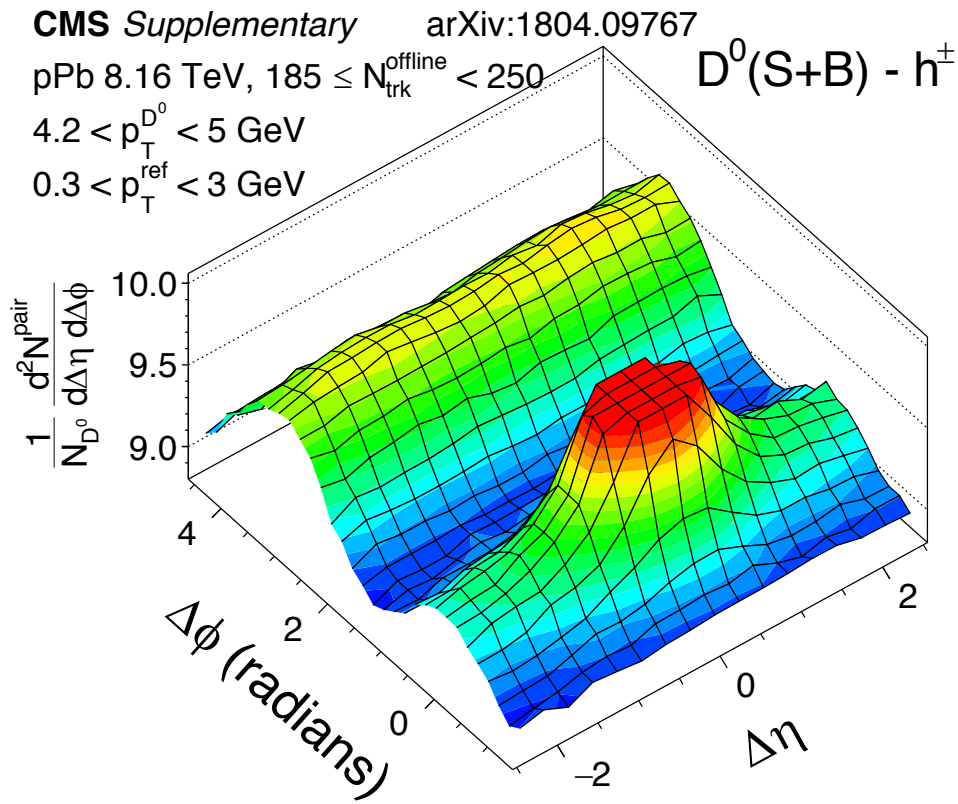
Well established in many earlier measurements

D^0 – charged hadron correlations

$185 \leq N_{trk} < 250$



$|m_{inv} - m_{D0}| < 0.005$ GeV



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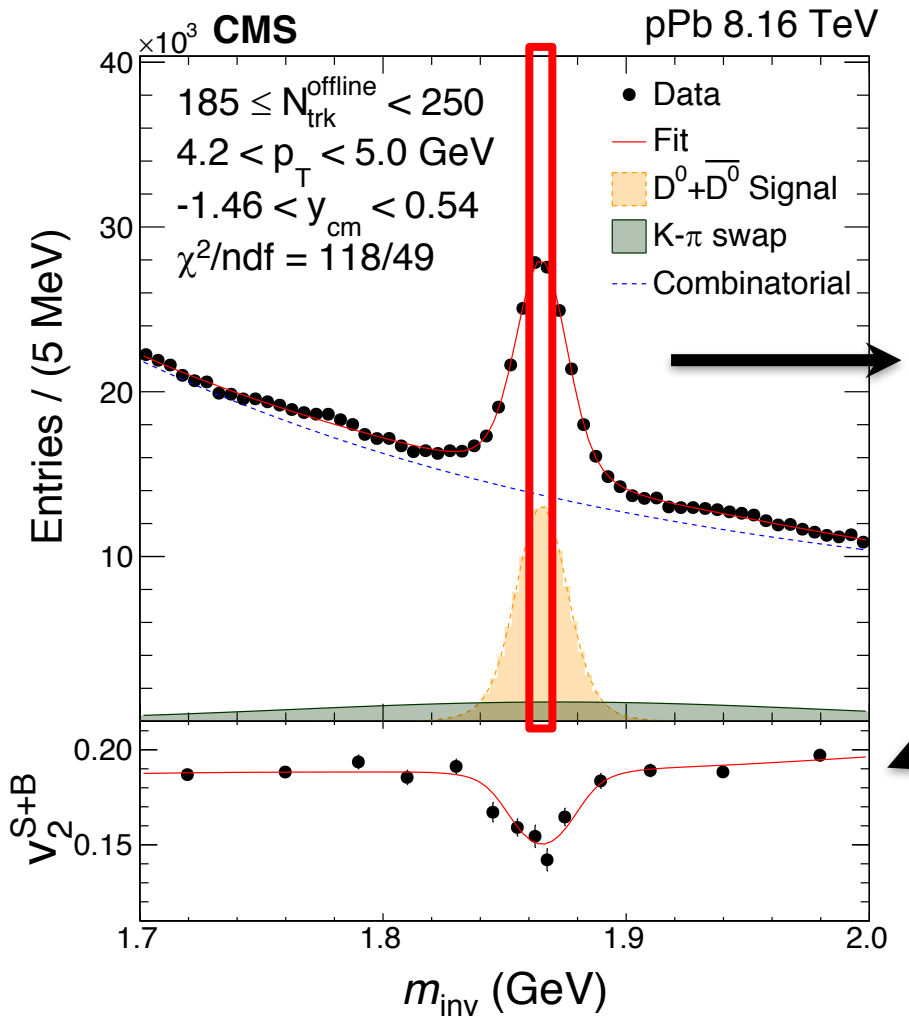
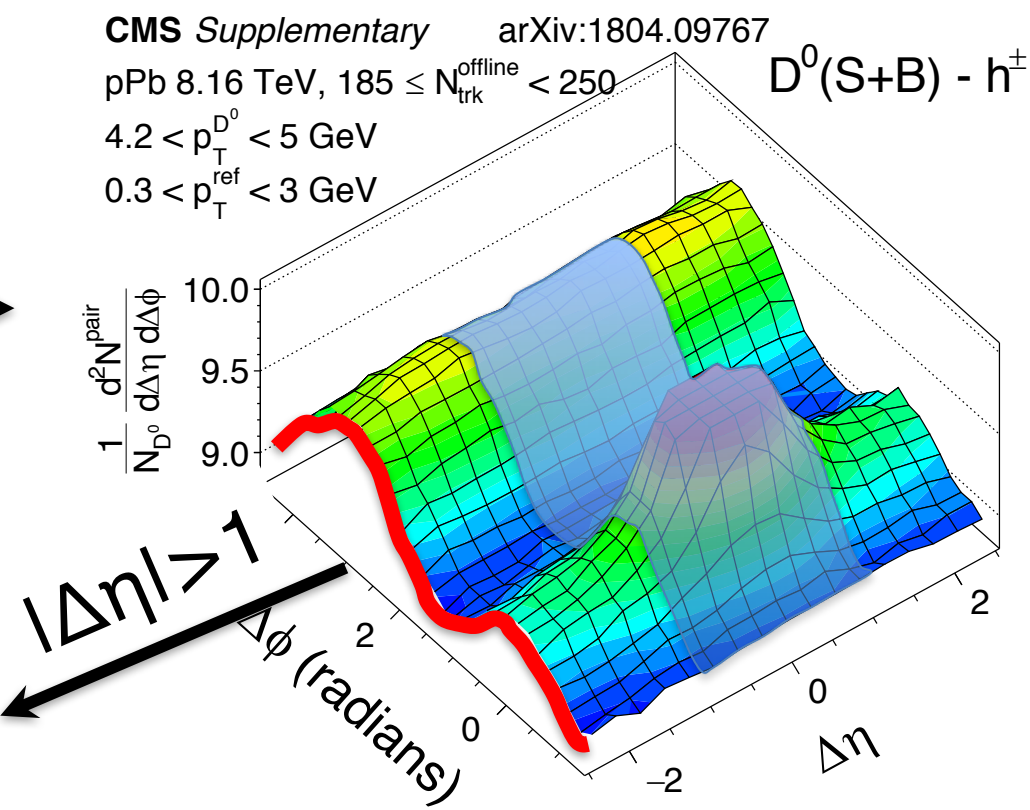
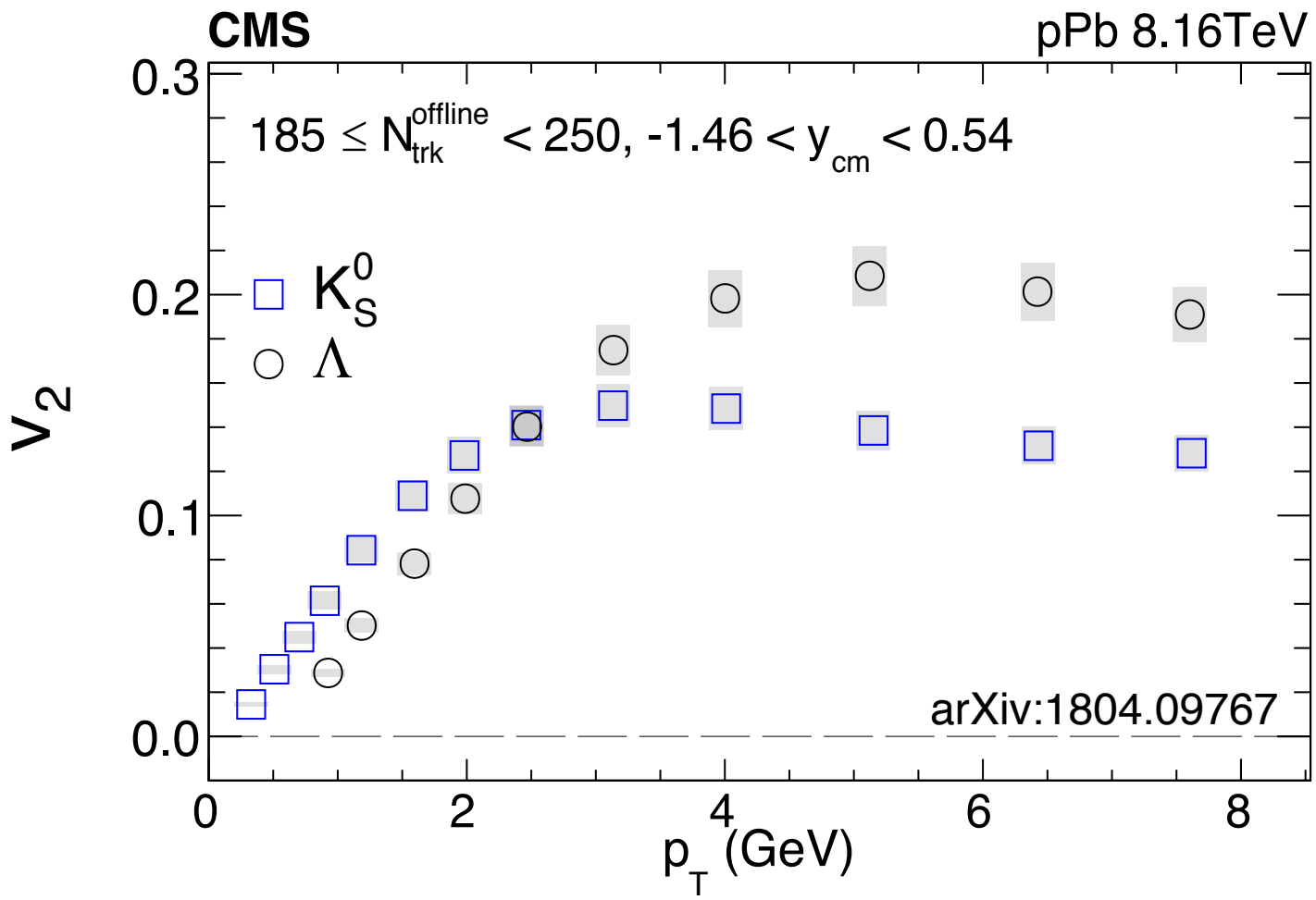




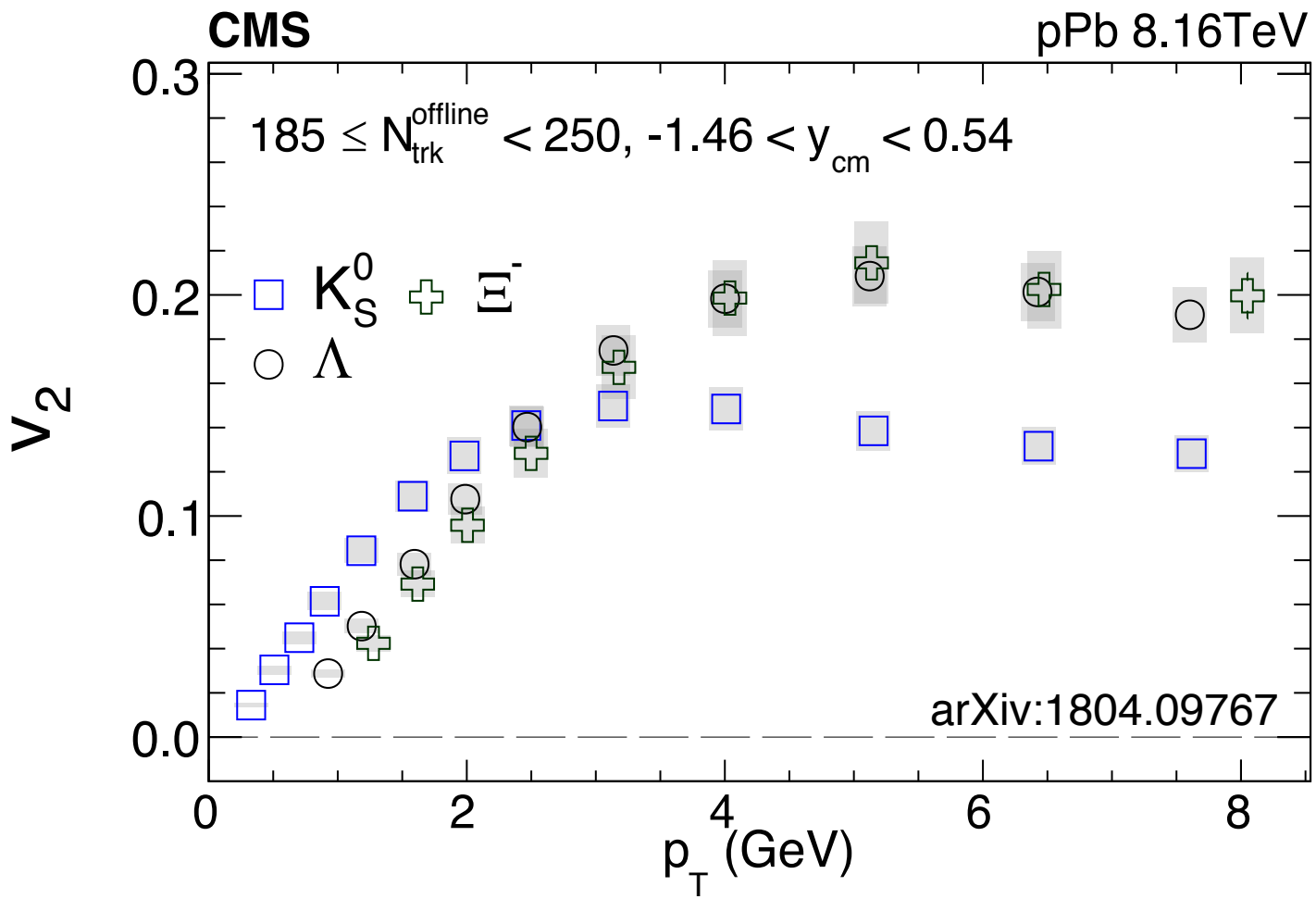
$$v_n^{Sig+Bkg}(m_{inv}) = \alpha(m_{inv})\boxed{v_n^{sig}} + (1-\alpha(m_{inv}))v_n^{Bkg}$$

Strange and charm hadron v_2 in pPb



Mass ordering for light, strange hadrons

Strange and charm hadron v_2 in pPb



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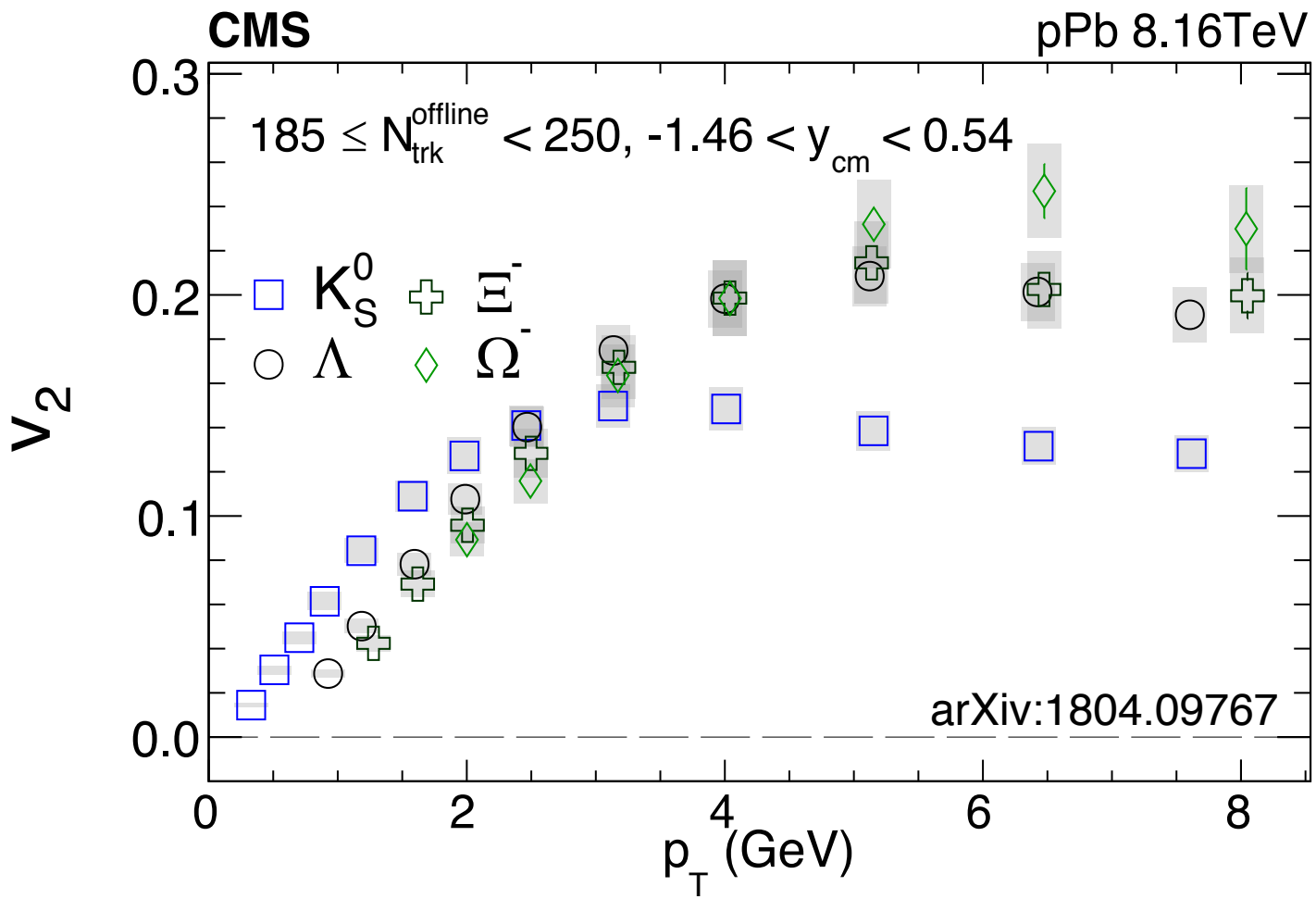

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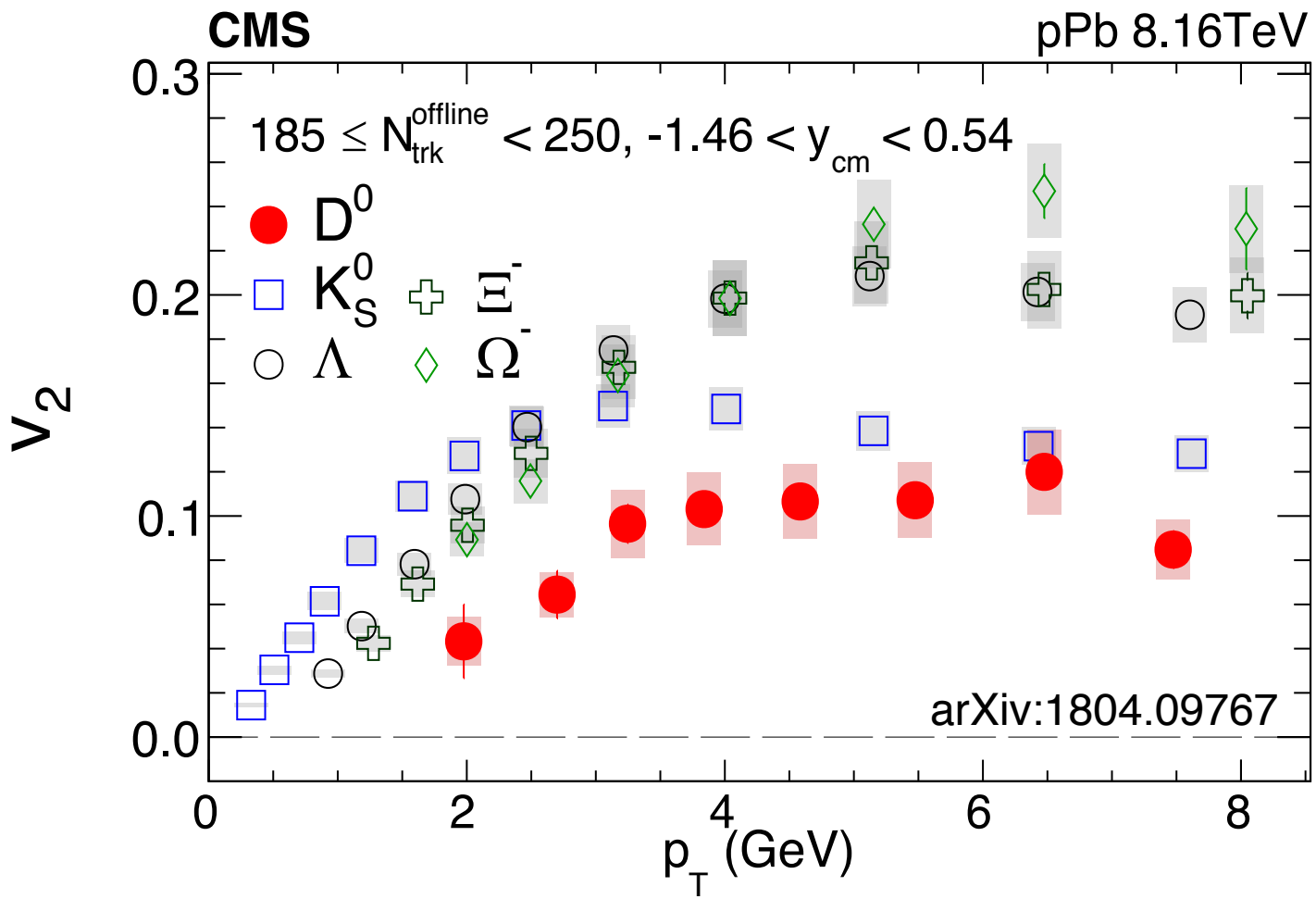
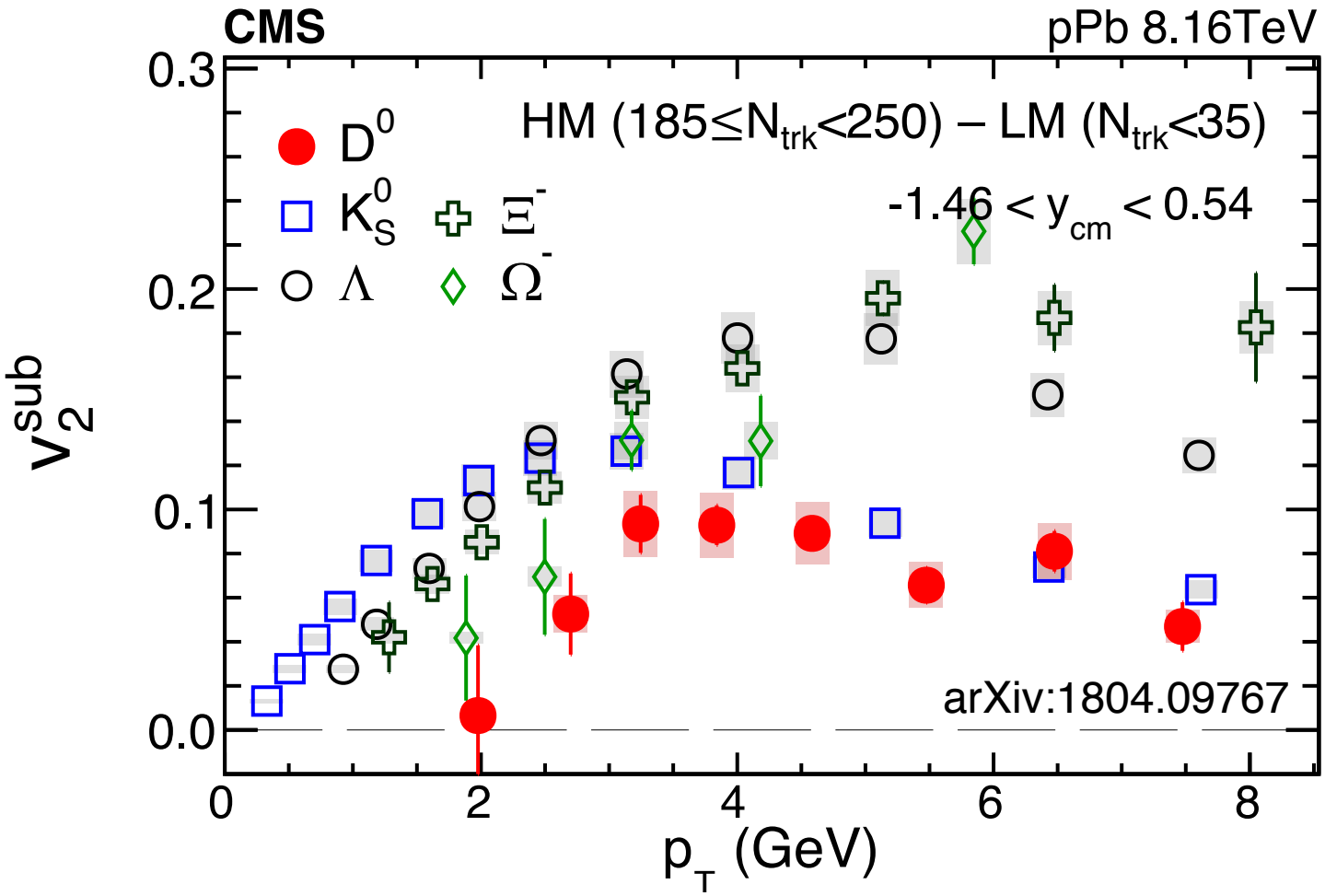


Significant D^0 v_2, follow mass ordering at low p_T

D^0 similar to K^0_s (both mesons) at higher p_T

Strange and charm hadron v_2 in pPb

Removing "nonflow": $V_2^{\mathrm{sub}} = V_2^{\mathrm{HM}} - V_2^{\mathrm{LM}} \frac{N_{\mathrm{assoc}}^{\mathrm{LM}}}{N_{\mathrm{assoc}}^{\mathrm{HM}}} \frac{Y_{\mathrm{jet}}^{\mathrm{HM}}}{Y_{\mathrm{jet}}^{\mathrm{LM}}}$



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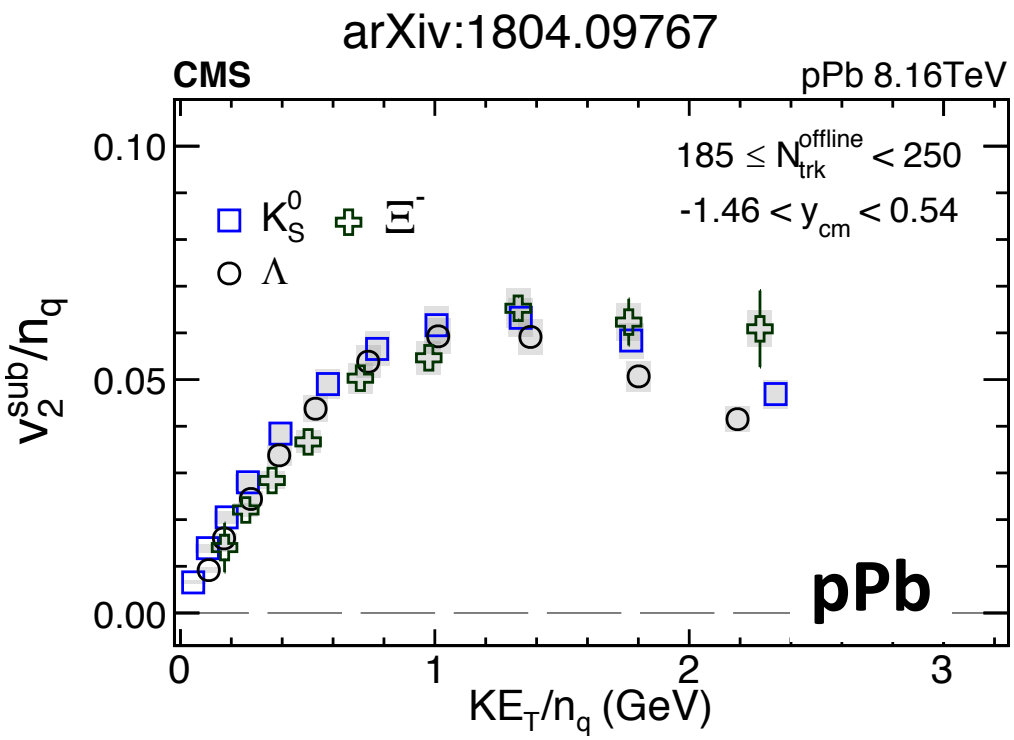
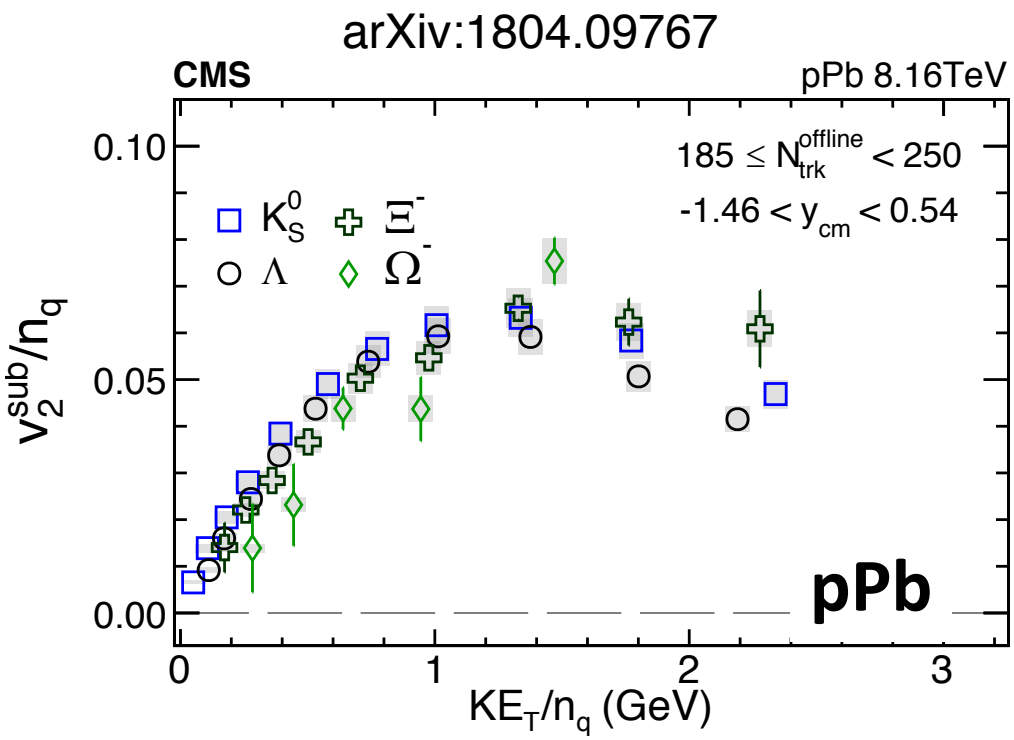
Quark number scaling in pPb



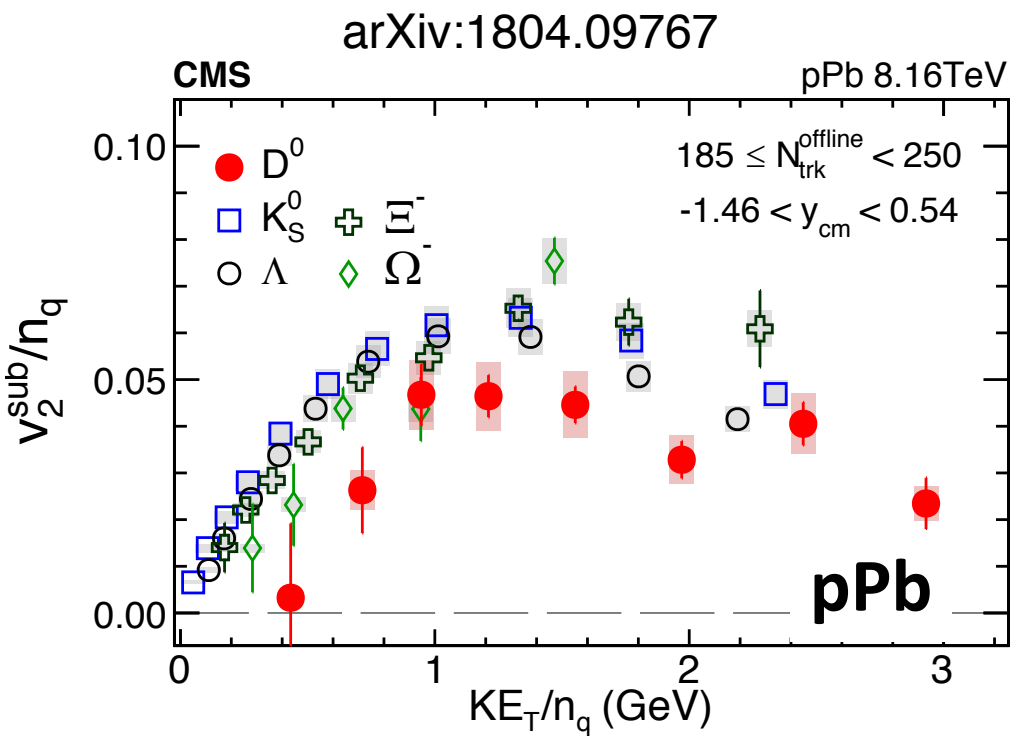
Approx. scaling for strange hadrons

Quark number scaling in pPb



Approx. scaling for strange hadrons except for Ω?

Quark number scaling in pPb

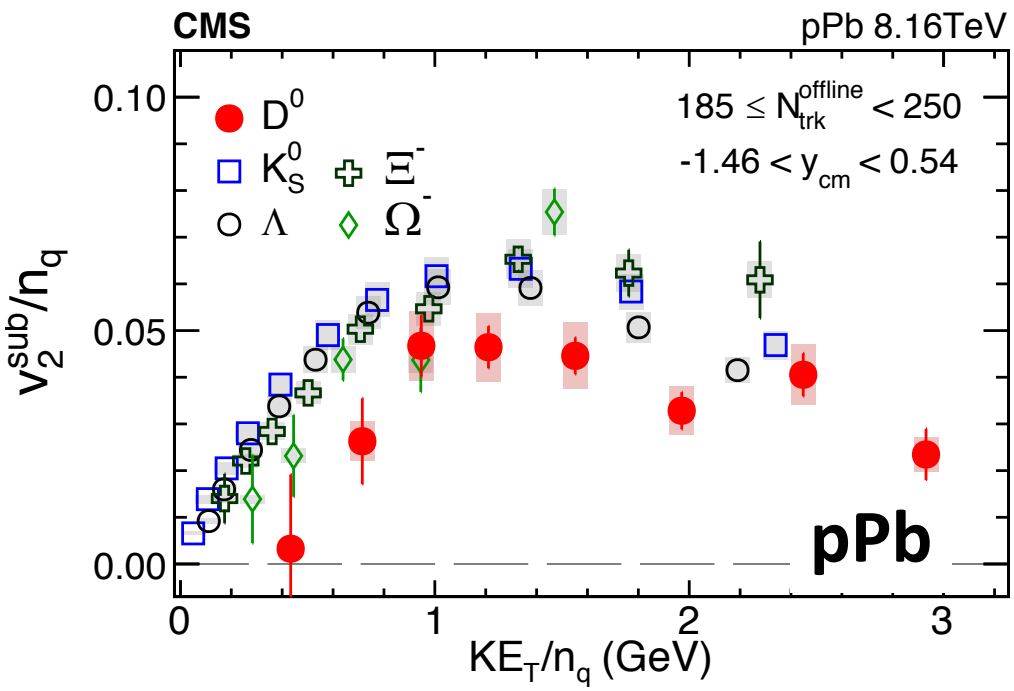


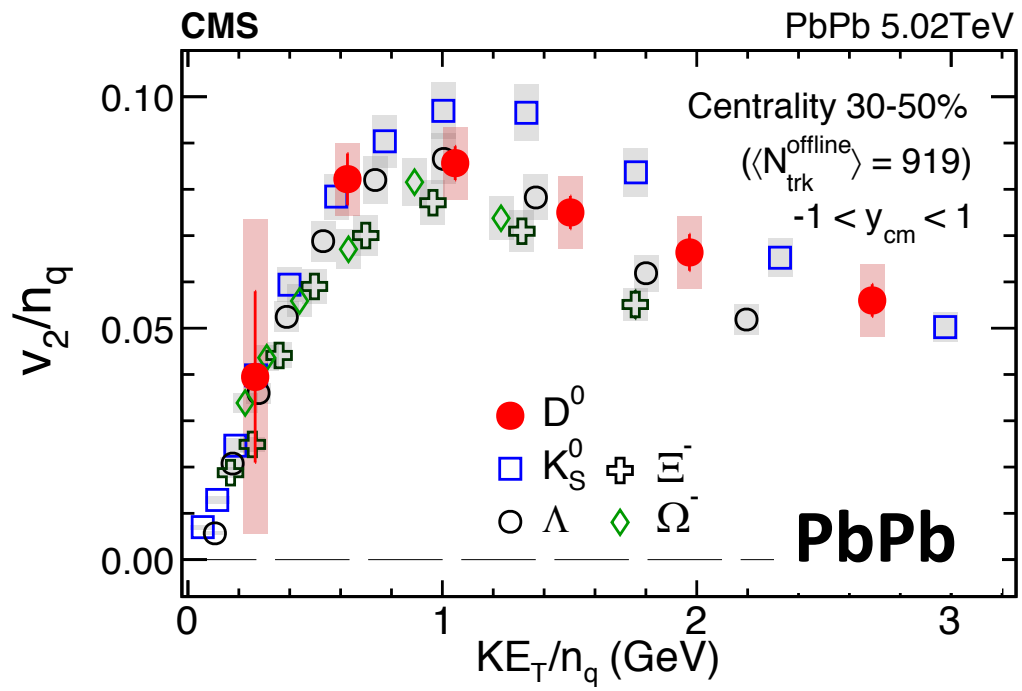
Approx. scaling for strange hadrons except for Ω?

D^0 v_2 consistently lower ➔ **$v_2(c) < v_2(u,d,s)$**

Quark number scaling in pPb

arXiv:1804.09767





Approx. scaling for strange hadrons except for Ω?

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Different trend in species dependence from PbPb

Quark number scaling in pPb

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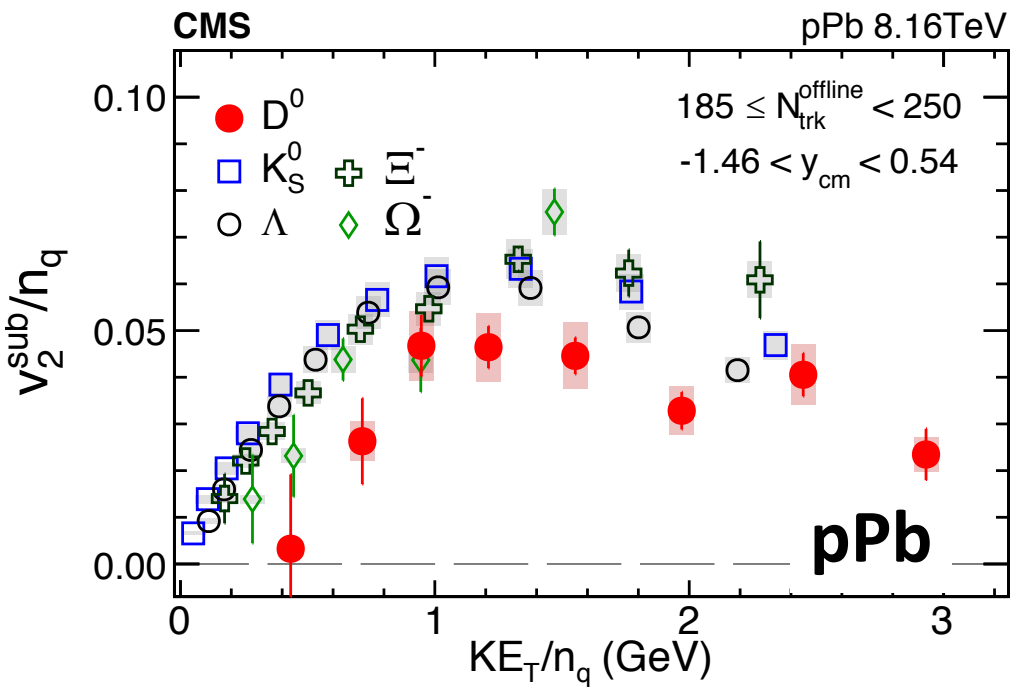
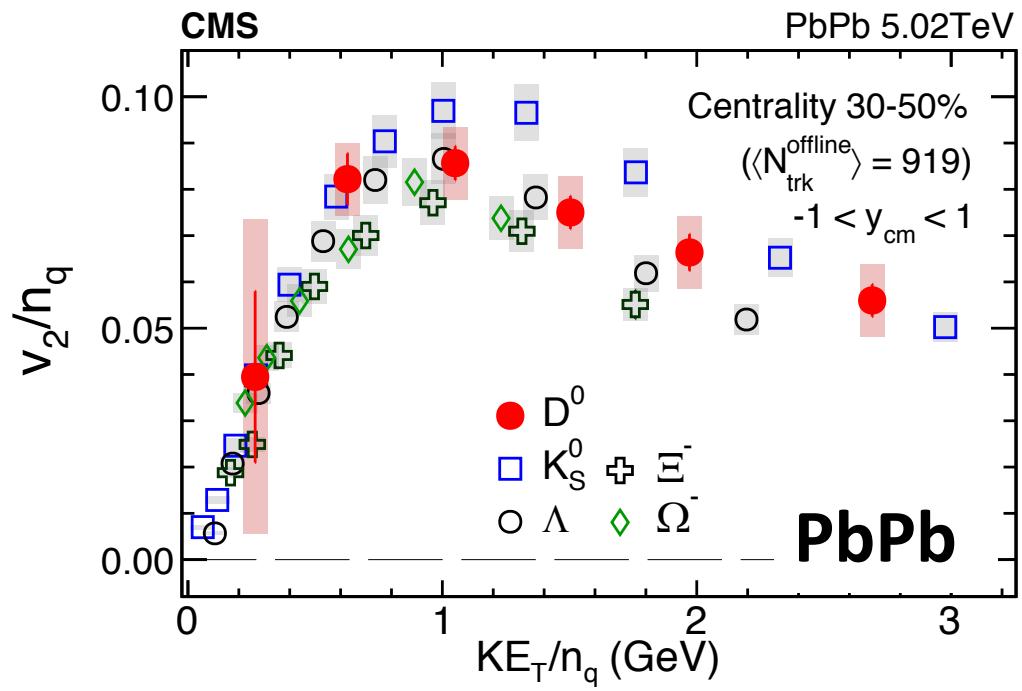




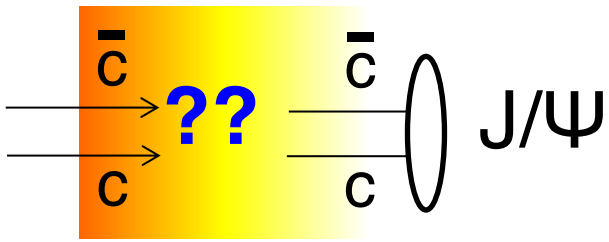
In hydro-QGP picture:

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

Interpretations in CGC/glasma picture?

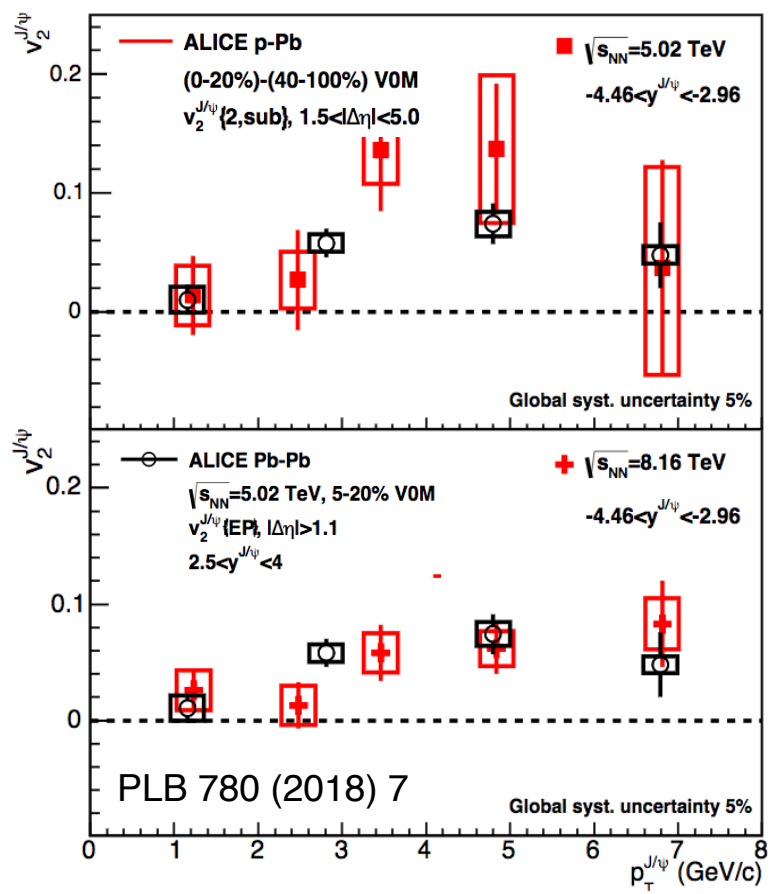
One more thing …

Collectivity of *Charmonia* in small system?



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

Inclusive J/Ψ from ALICE



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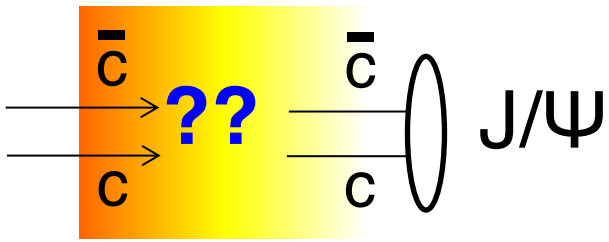

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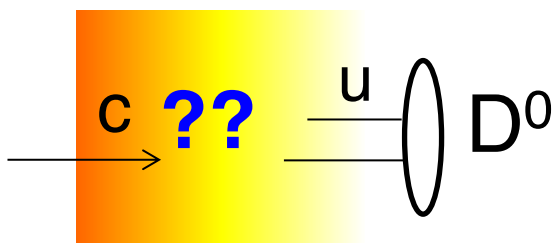
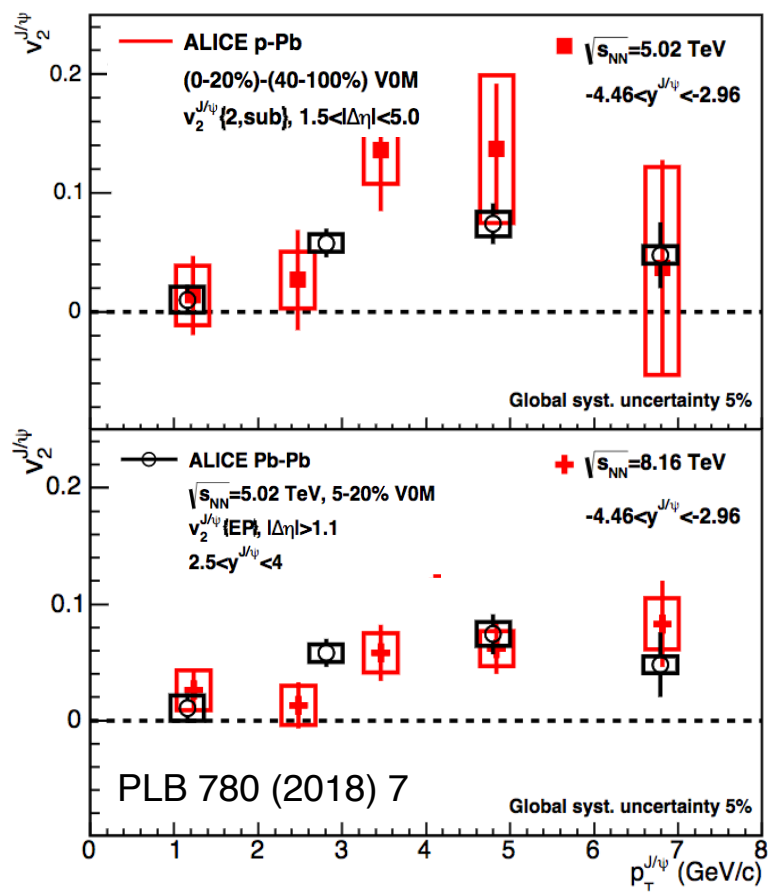
v.s.



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

➔ $v_2(J/\Psi) < v_2(D^0)$?

Inclusive J/Ψ from ALICE



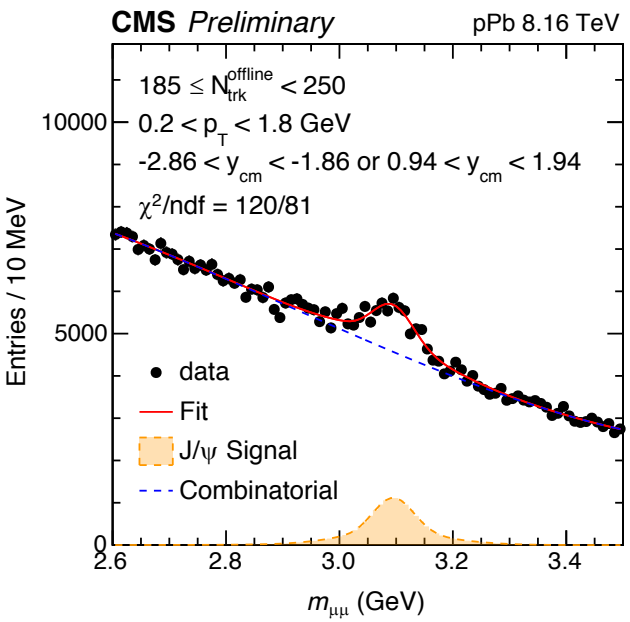
J/Ψ(→μ⁺μ⁻) reconstruction in pPb

CMS-PAS-HIN-18-010

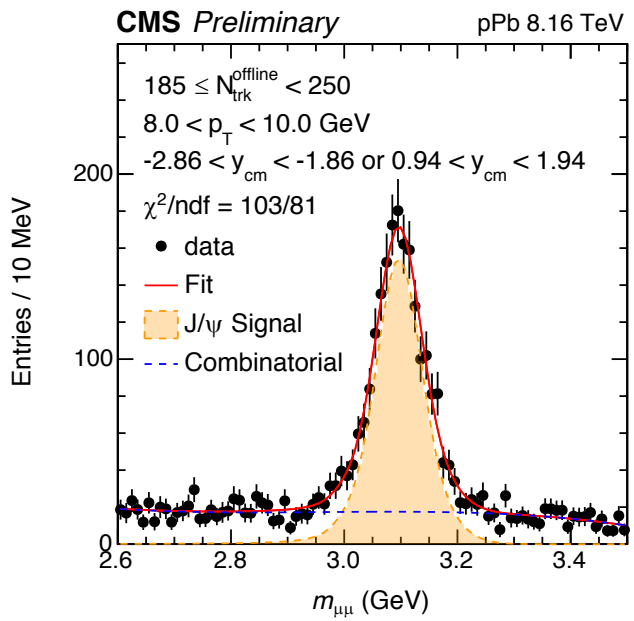
High-multiplicity pPb ($185 \leq N_{trk} < 250$)

J/Ψ from B reduced

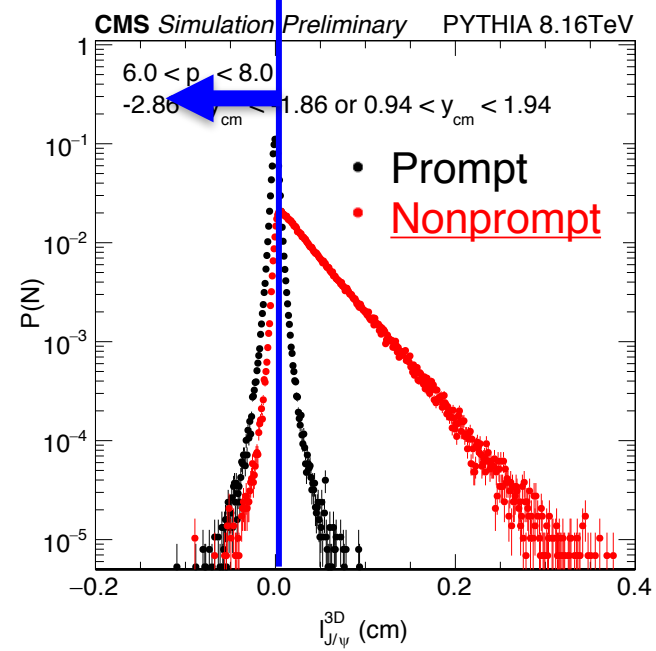
$0.2 < p_T < 1.8$ GeV



$8 < p_T < 10$ GeV



MC simulation



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

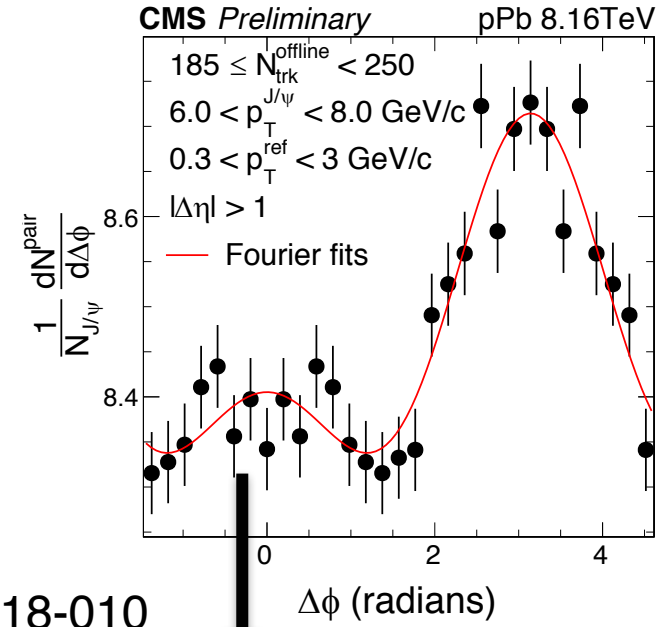
Good efficiency down to $p_T \sim 0$ GeV at forward $1.4 < |y_{lab}| < 2.4$

Residual: ~ 5% (systematics)

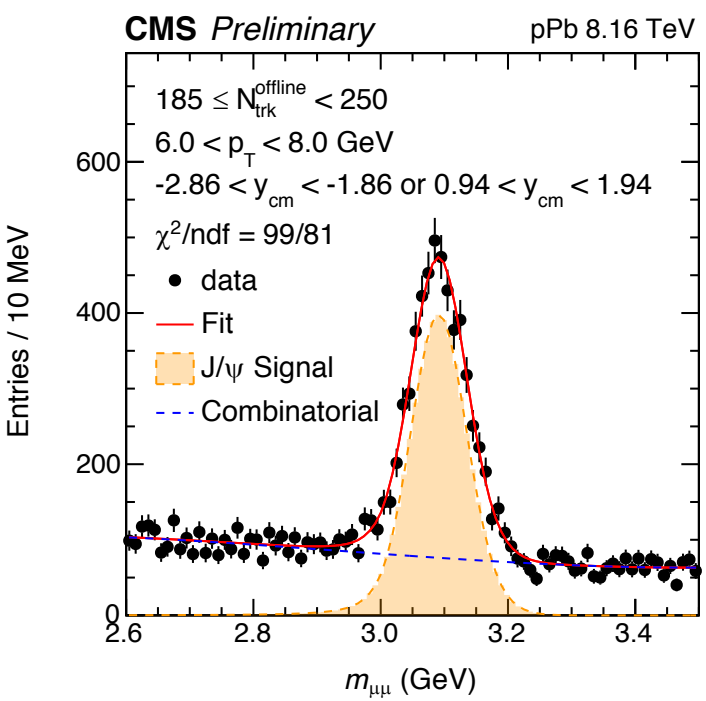
J/Ψ – charged hadron correlation

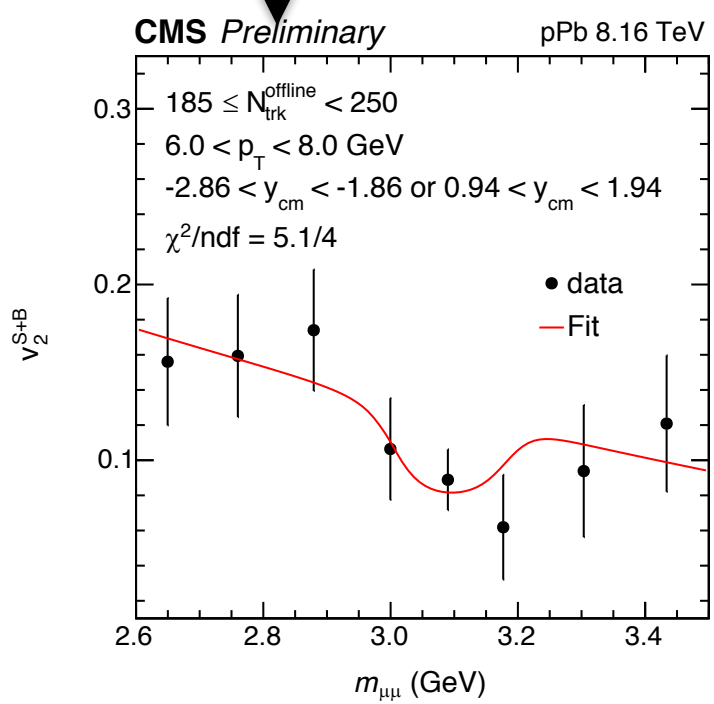
Same technique as for D^0 and strange hadrons

|Δη|>1 projection



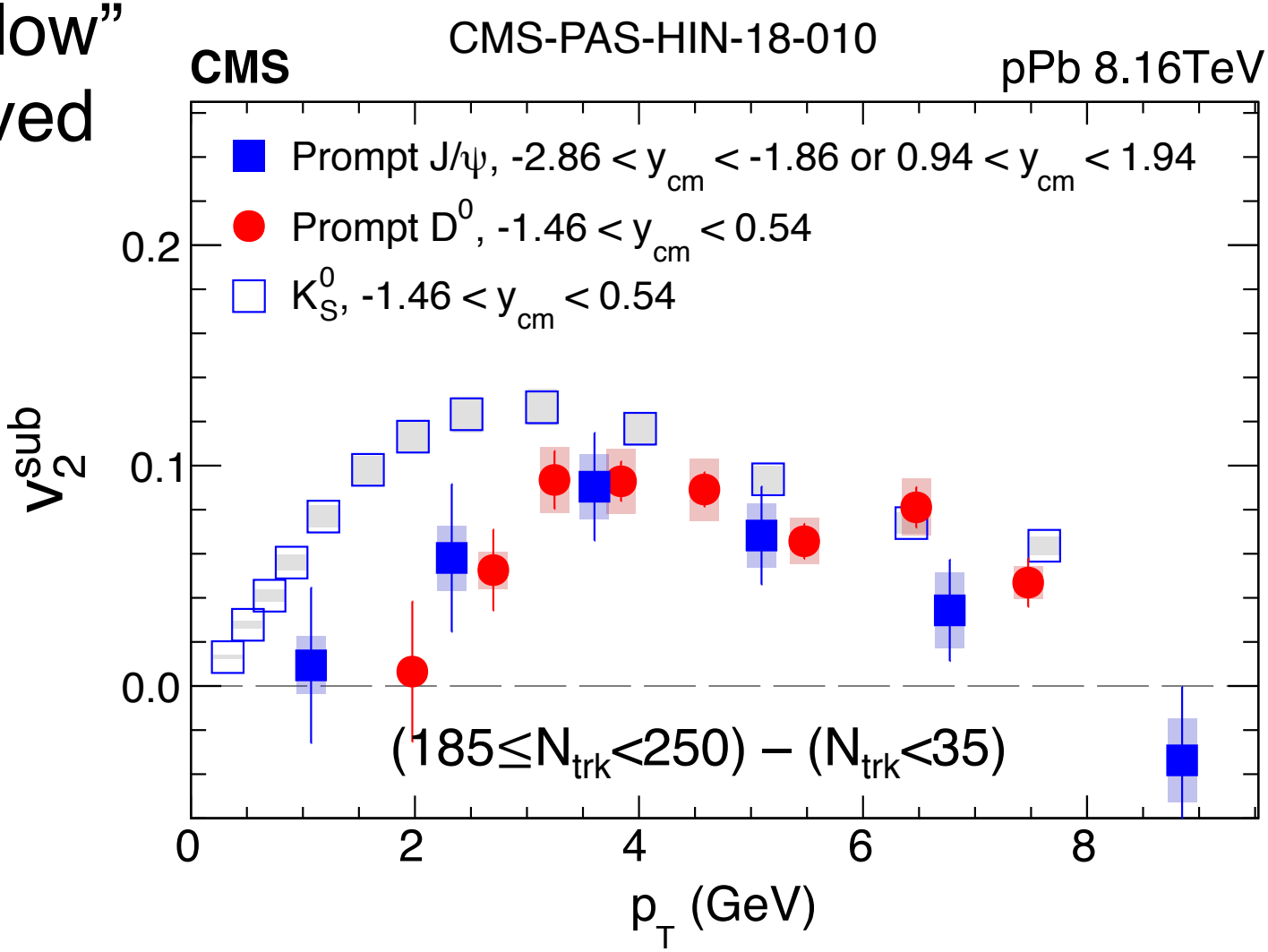
CMS-PAS-HIN-18-010





Prompt J/Ψ meson v_2 in pPb

"Nonflow" removed

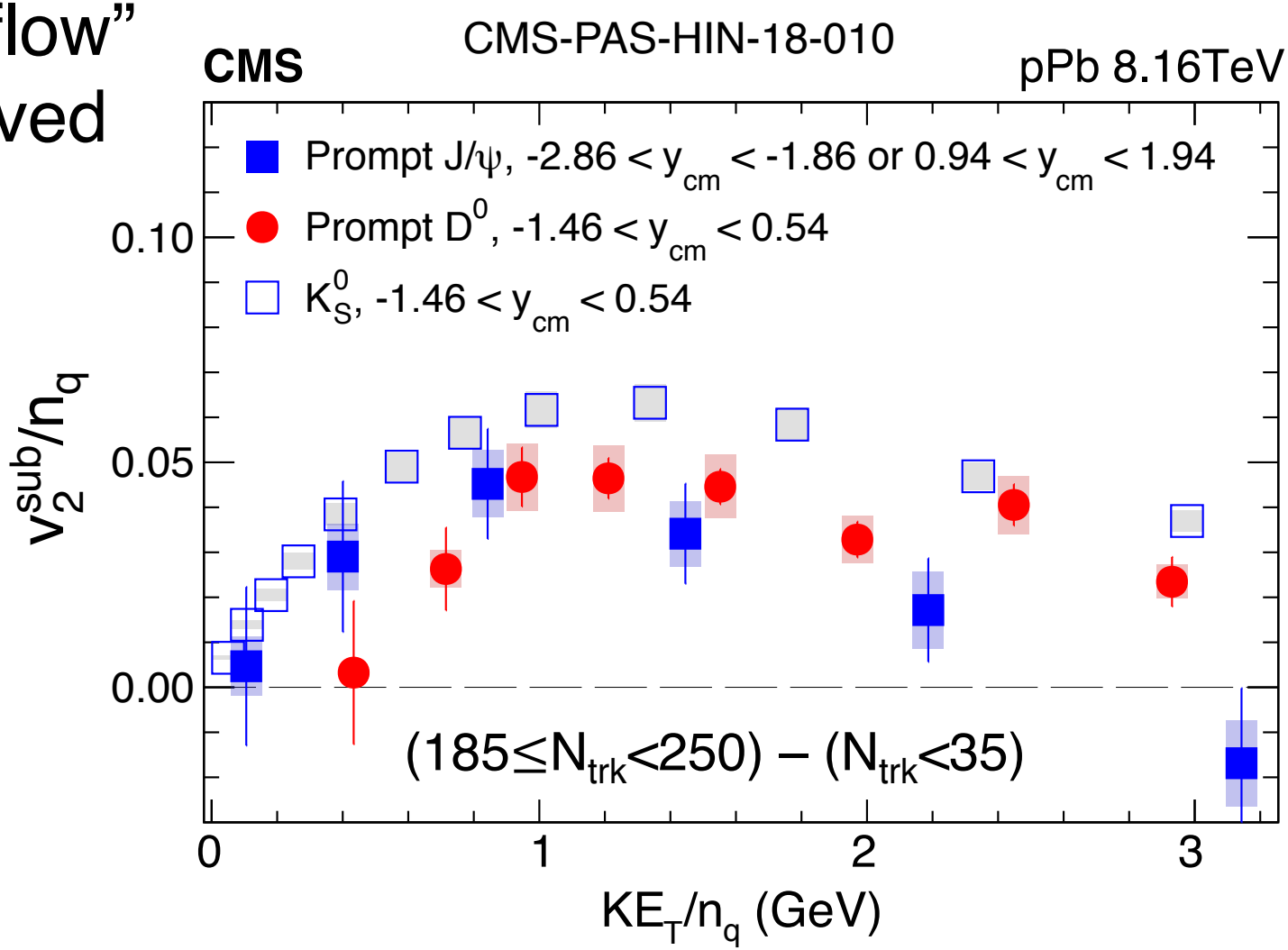


Significant J/Ψ v_2 ➡ most direct evidence of charm v_2

J/Ψ comparable to D^0? Both below light flavor K^0_s

Prompt J/Ψ meson v_2 in pPb

"Nonflow" removed

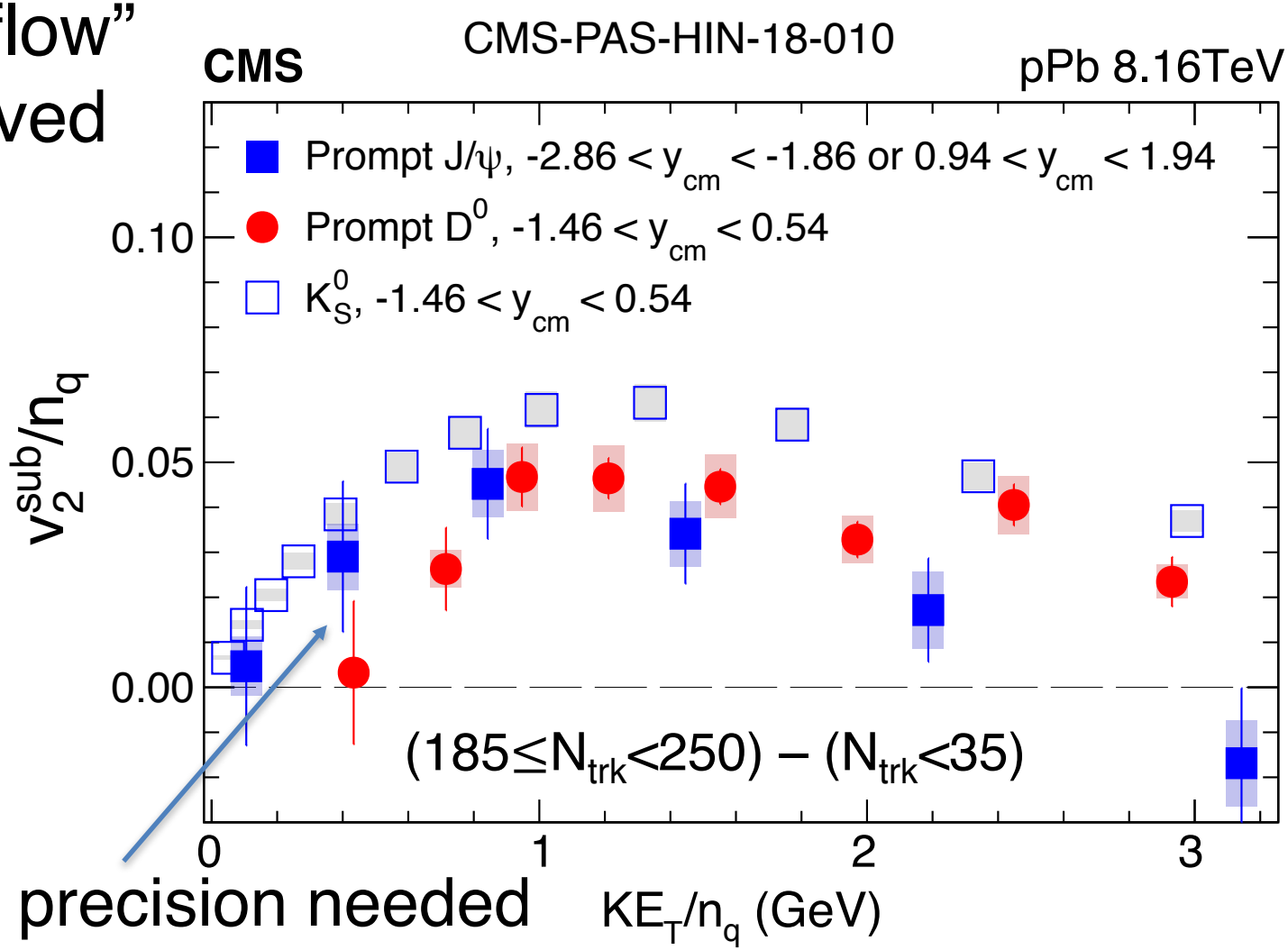


As a function of KE_T

$$v_2(D^0) \approx v_2(J/\Psi) < v_2(K^0_s)?$$

Prompt J/Ψ meson v_2 in pPb

"Nonflow" removed



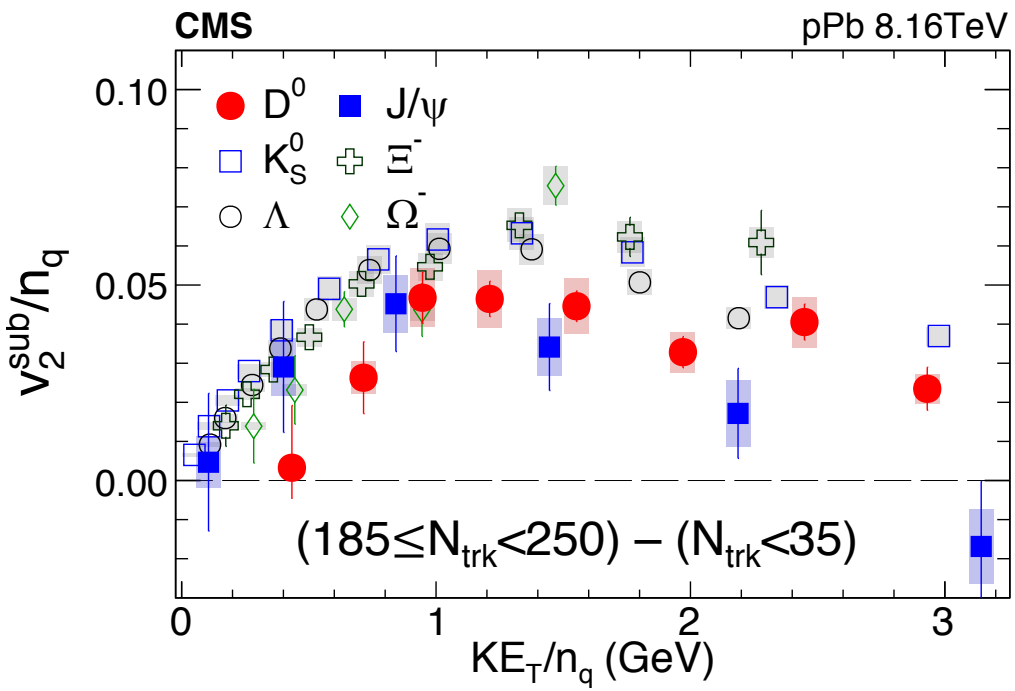
Better precision needed

As a function of KE_T

$$v_2(D^0) \approx v_2(J/\Psi) < v_2(K^0_s)?$$

Summary

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



Clear observation of v_2 signal for charm quarks

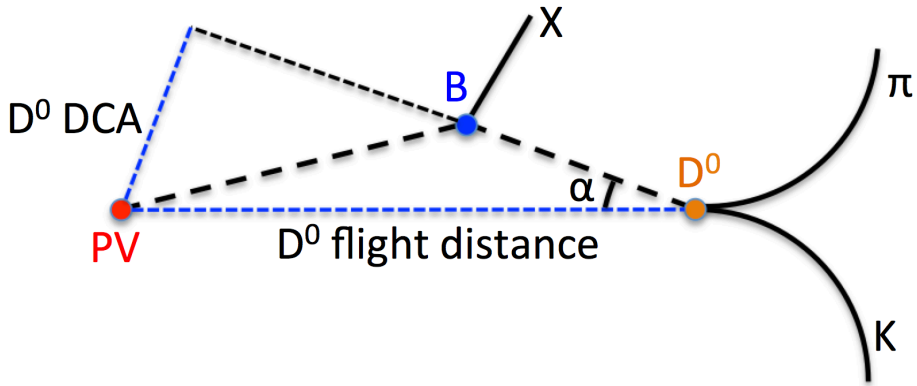
- Weaker collectivity than light quarks (?)
- Different trend in species dependence from PbPb

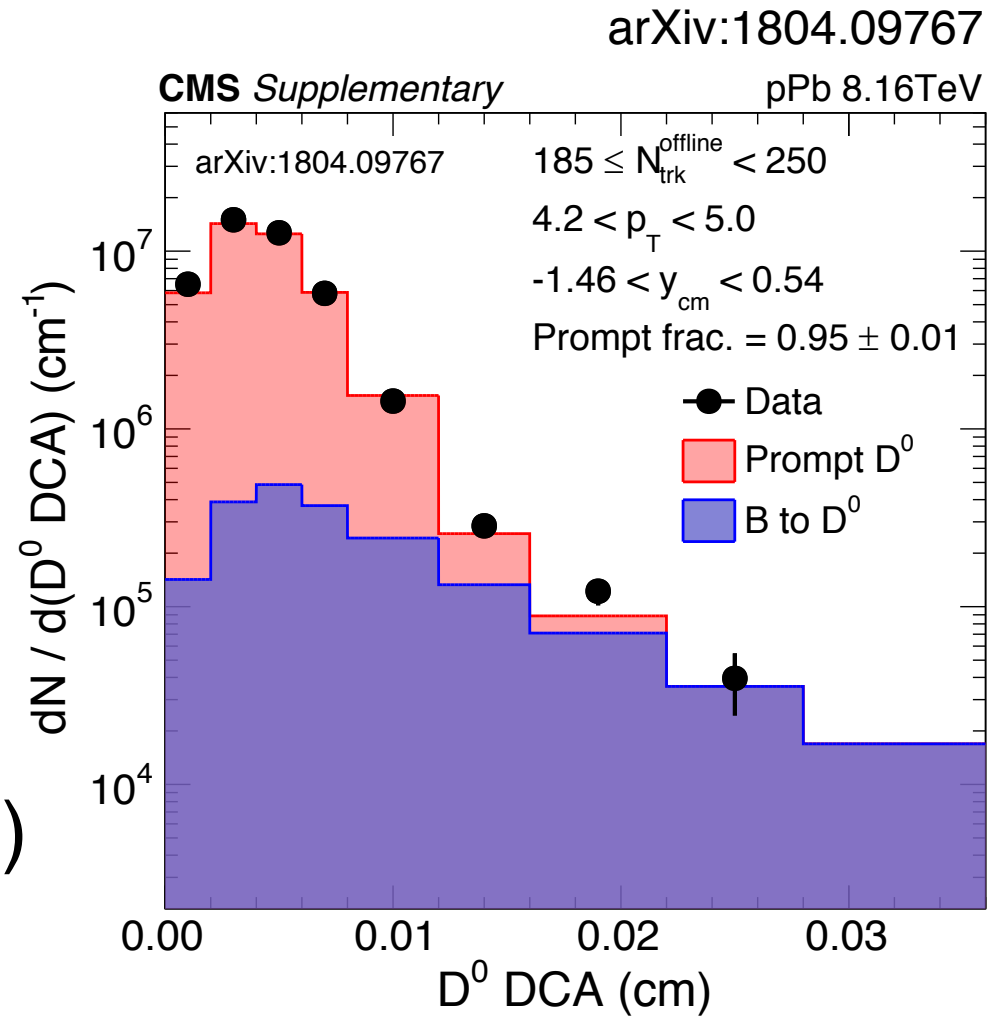
New insights to the origin of "Ridge" in small systems (eps. with better precision, *bottom*; also in pp in the future)

Backups

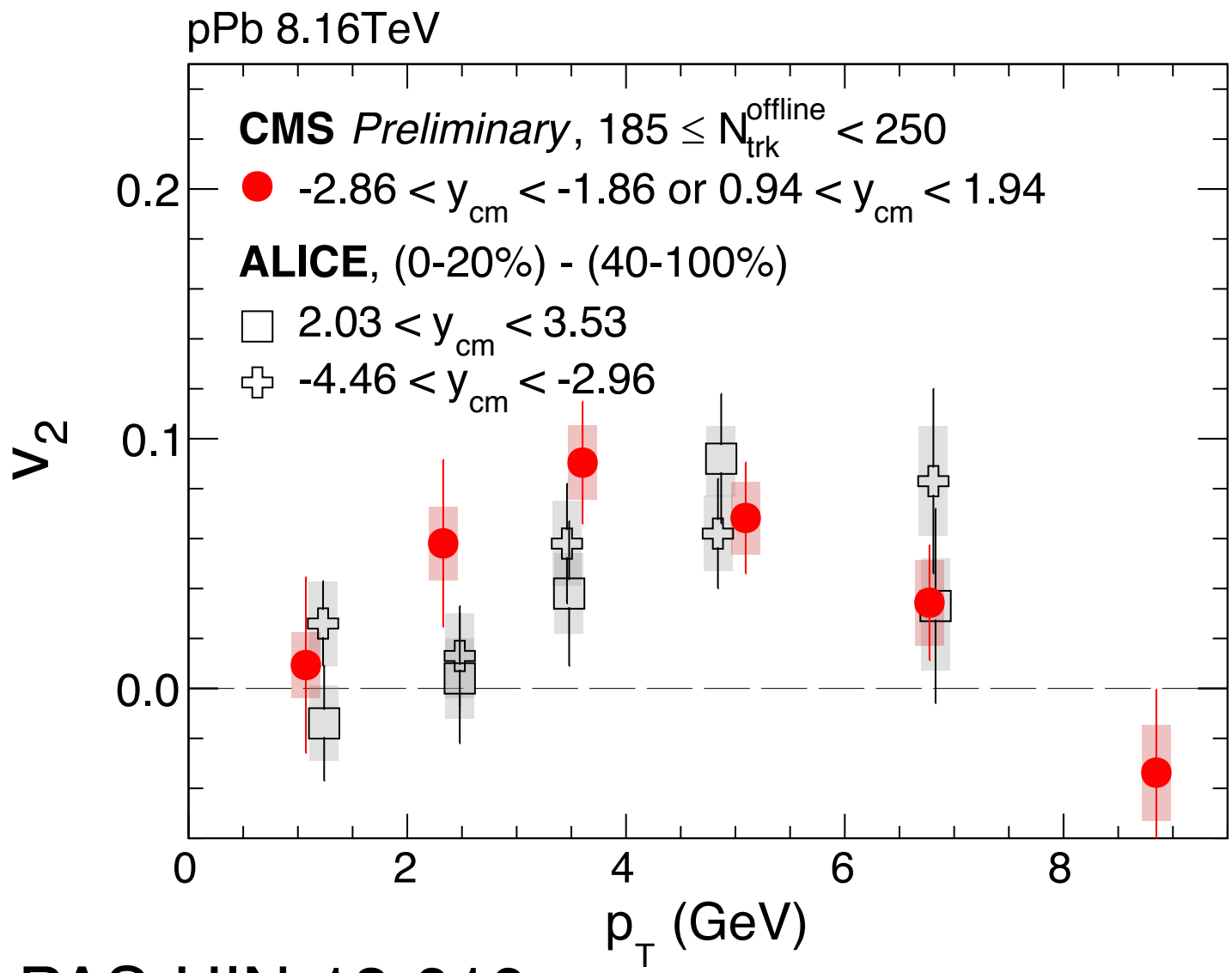
D^0 meson in pPb at CMS

Suppress nonprompt D^0 from B mesons

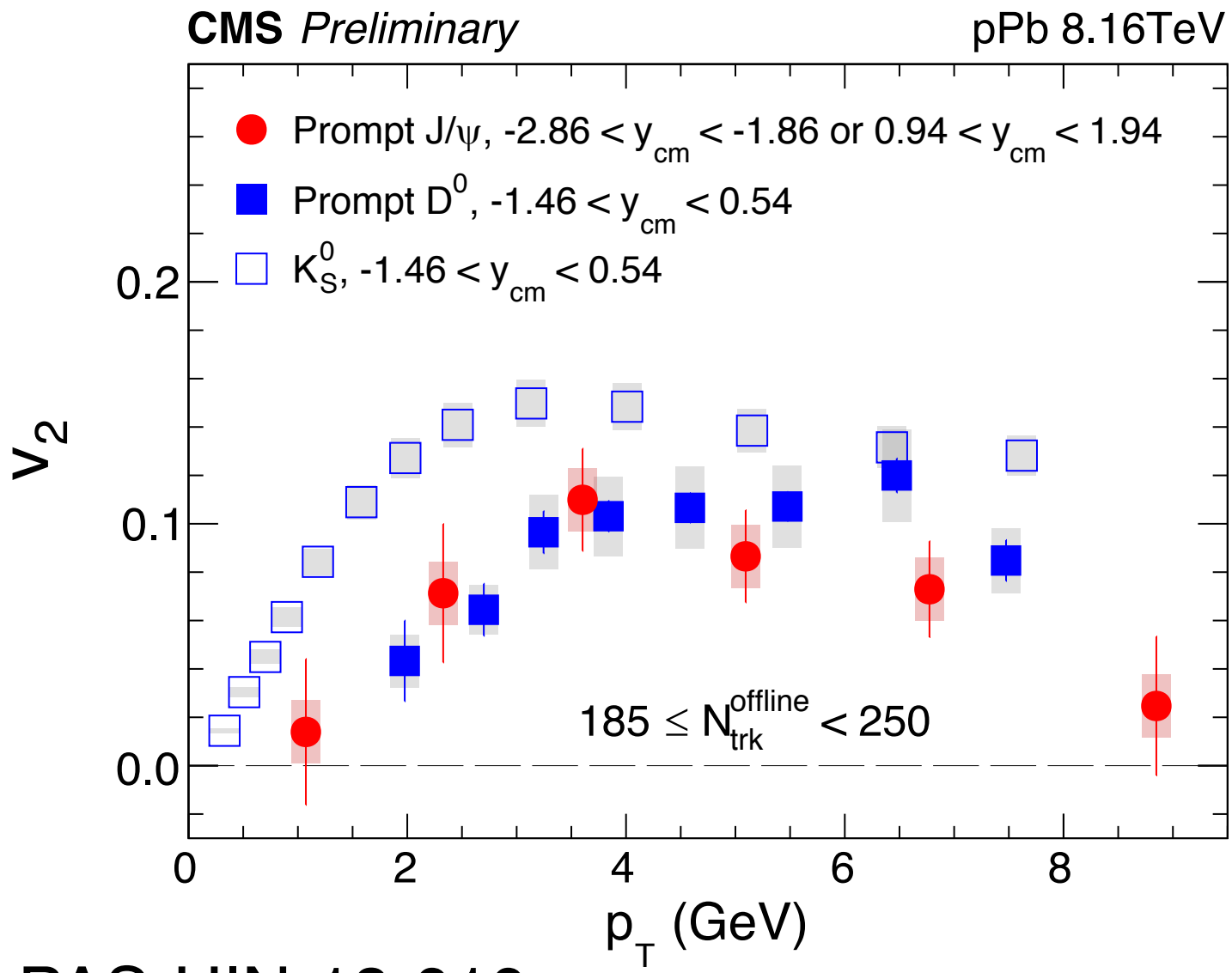




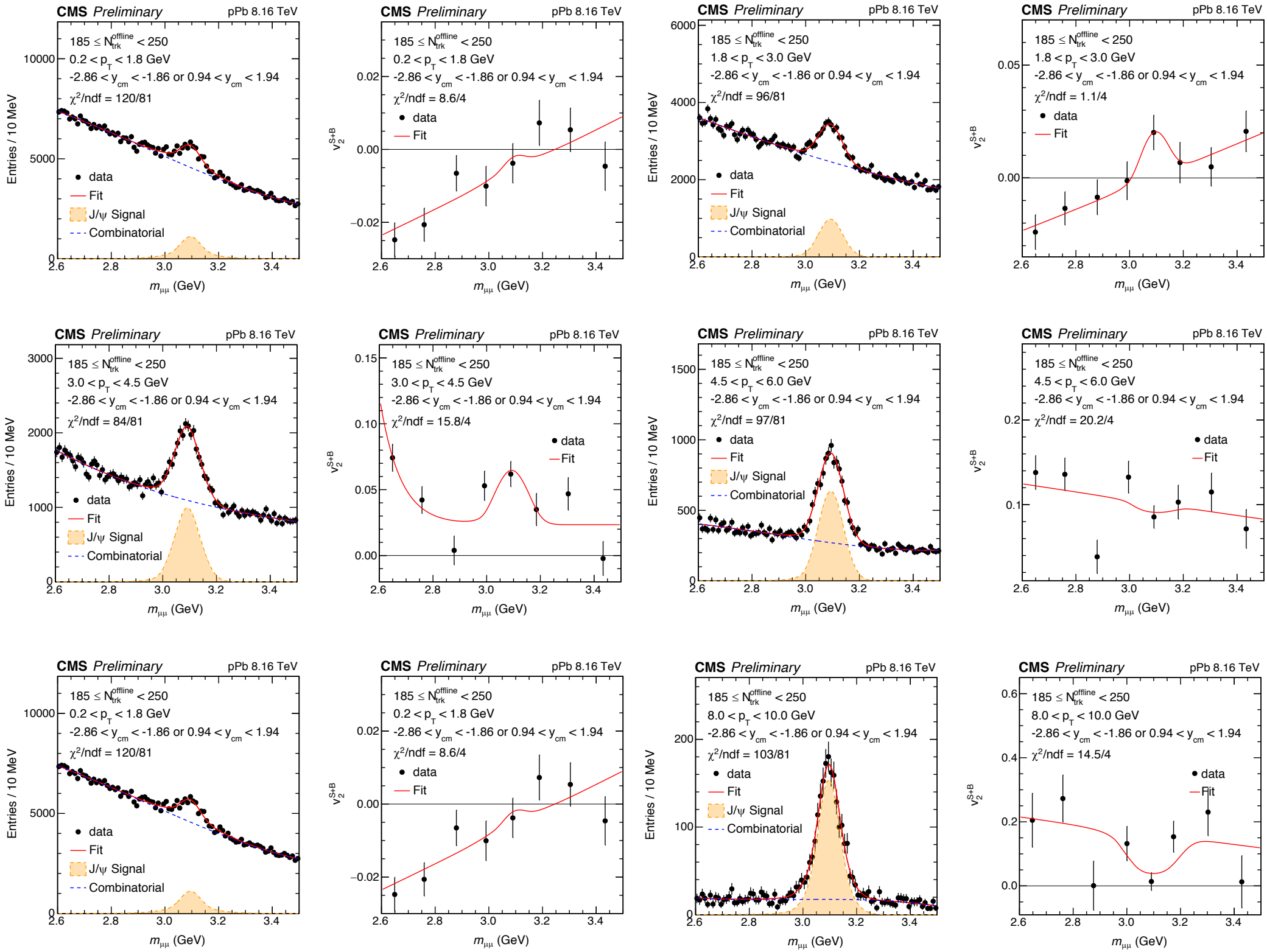
Residual NP D^0: ~ 1-7%
(considered as systematics)

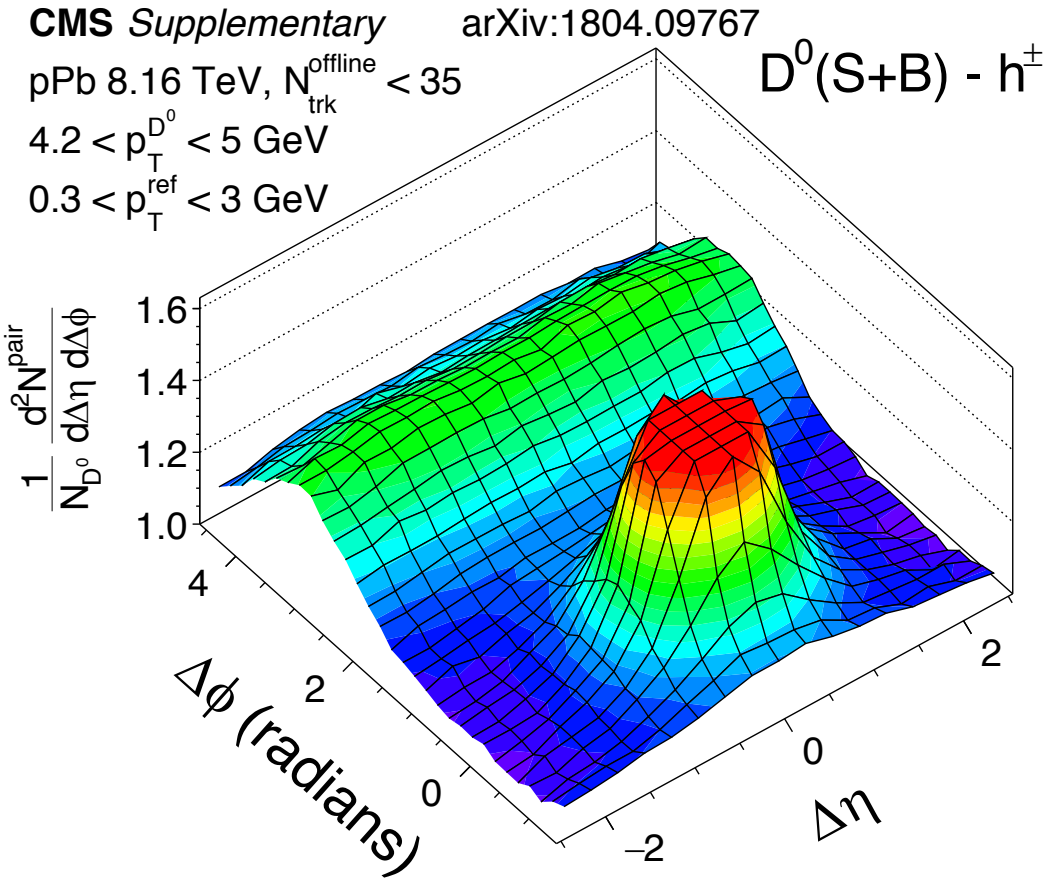


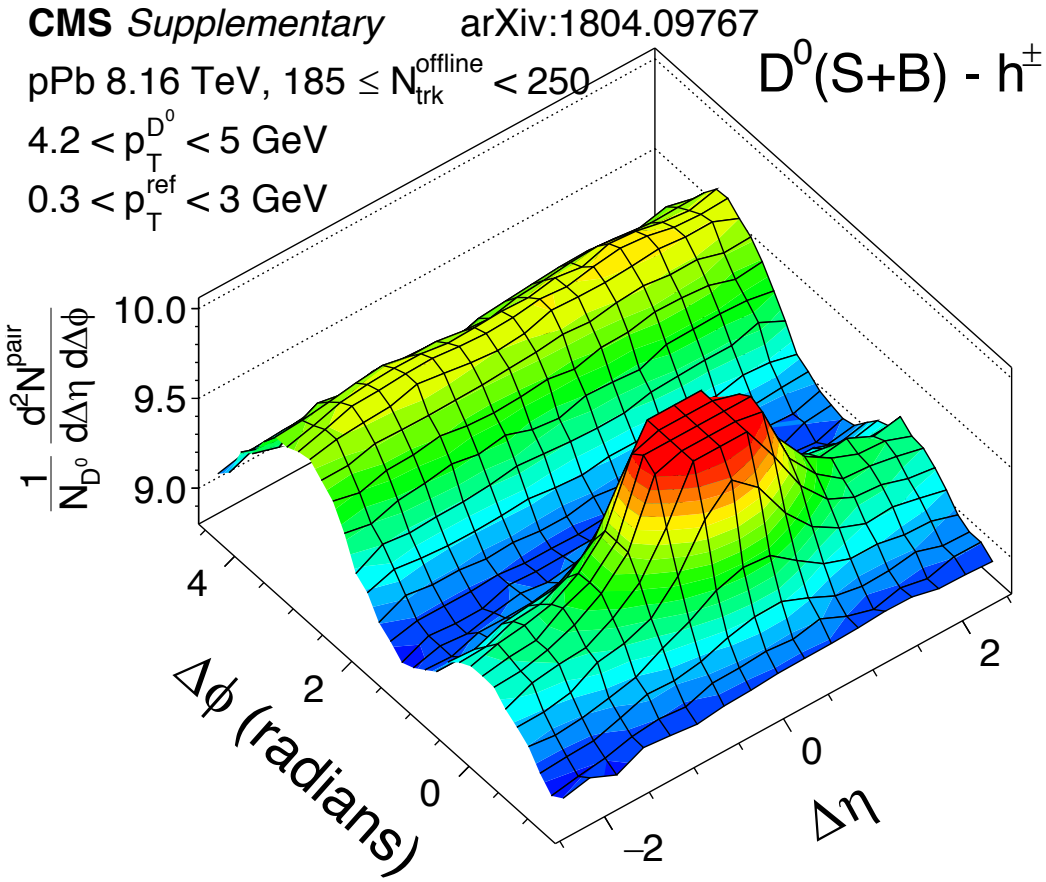
CMS-PAS-HIN-18-010

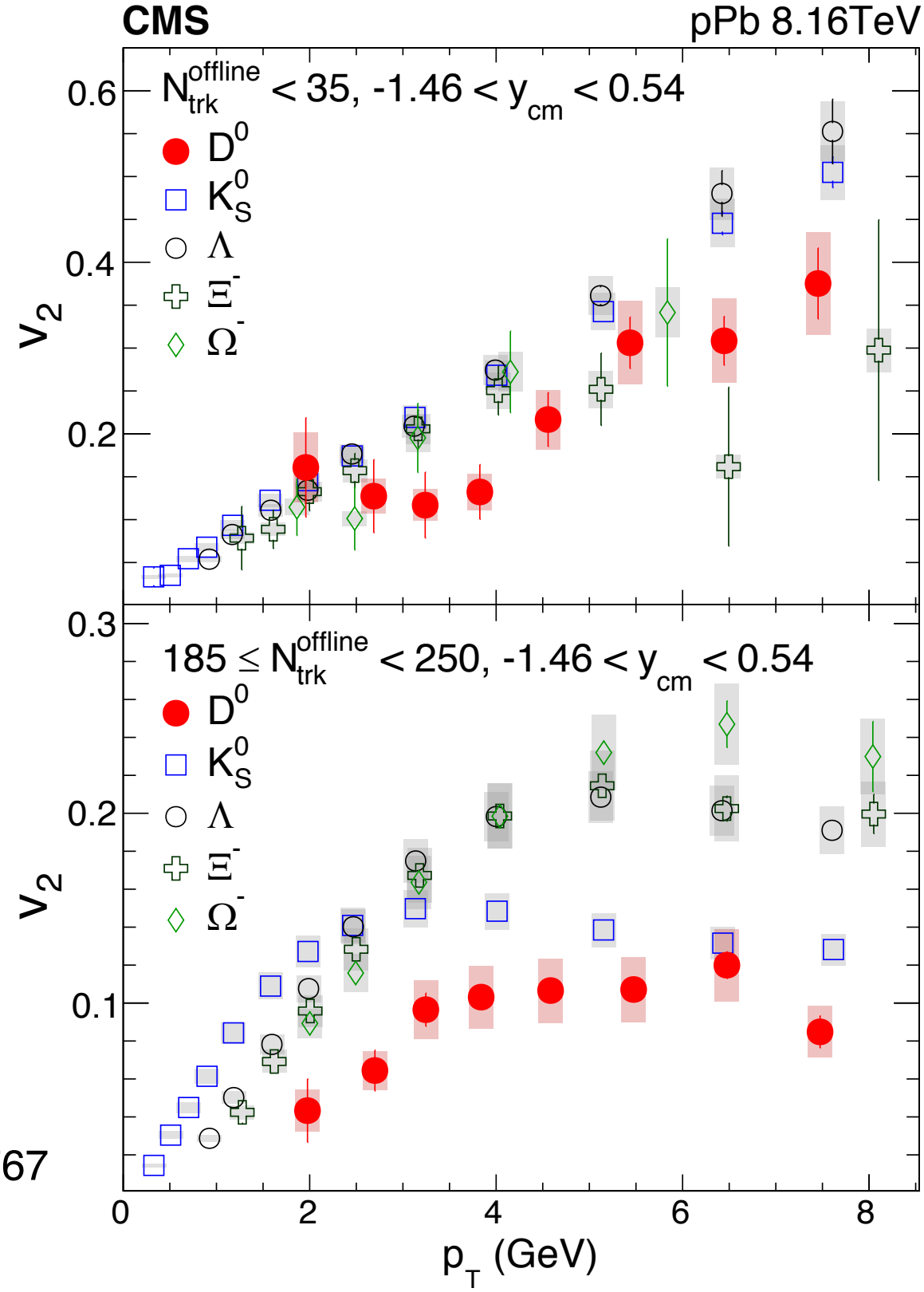


CMS-PAS-HIN-18-010


CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
0.2 < p_T < 1.8 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 120/81
data
Fit
J/ψ Signal
Combinatorial
Entries / 10 MeV
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
0.2 < p_T < 1.8 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 8.6/4
data
Fit
v_2^S+B
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
1.8 < p_T < 3.0 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 96/81
data
Fit
J/ψ Signal
Combinatorial
Entries / 10 MeV
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
1.8 < p_T < 3.0 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 1.1/4
data
Fit
v_2^S+B
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
3.0 < p_T < 4.5 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 84/81
data
Fit
J/ψ Signal
Combinatorial
Entries / 10 MeV
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
3.0 < p_T < 4.5 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 15.8/4
data
Fit
v_2^S+B
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
4.5 < p_T < 6.0 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 97/81
data
Fit
J/ψ Signal
Combinatorial
Entries / 10 MeV
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
4.5 < p_T < 6.0 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 20.2/4
data
Fit
v_2^S+B
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
0.2 < p_T < 1.8 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 120/81
data
Fit
J/ψ Signal
Combinatorial
Entries / 10 MeV
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
0.2 < p_T < 1.8 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 8.6/4
data
Fit
v_2^S+B
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
8.0 < p_T < 10.0 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 103/81
data
Fit
J/ψ Signal
Combinatorial
Entries / 10 MeV
m_μμ (GeV)
CMS Preliminary
pPb 8.16 TeV
185 ≤ N_trk^offline < 250
8.0 < p_T < 10.0 GeV
-2.86 < y_cm < -1.86 or 0.94 < y_cm < 1.94
χ²/ndf = 14.5/4
data
Fit
v_2^S+B
m_μμ (GeV)


CMS Supplementary
arXiv:1804.09767
pPb 8.16 TeV, $N_{trk}^{offline} < 35$
$4.2 < p_T^{D^0} < 5$ GeV
$0.3 < p_T^{ref} < 3$ GeV
$D^0(S+B) - h^{\pm}$
$\frac{1}{N_{D^0}} \frac{d^2N^{pair}}{d\Delta\eta\, d\Delta\phi}$
1.6
1.4
1.2
1.0
4
2
0
$\Delta\phi$ (radians)
−2
0
2
$\Delta\eta$


CMS Supplementary
arXiv:1804.09767
pPb 8.16 TeV, $185 \leq N_{trk}^{offline} < 250$
$4.2 < p_T^{D^0} < 5$ GeV
$0.3 < p_T^{ref} < 3$ GeV
$D^0(S+B) - h^{\pm}$
$\frac{1}{N_{D^0}} \frac{d^2N^{pair}}{d\Delta\eta\, d\Delta\phi}$
10.0
9.5
9.0
4
2
0
$\Delta\phi$ (radians)
−2
0
2
$\Delta\eta$



arXiv:1804.09767