Hadron production by equal-velocity quark combination mechanism in high energy collisions

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Refs:

- arxiv:2008.03017v2, arxiv:2007.14588v1,
- Phys.RevC.102.014911(2020), Chin.Phys. C44, 014101(2020),
- Eur.Phys.J. C78, 344 (2018), Phys.Rev. C97, 064915 (2018),
- Phys. Lett. B774, 516(2017), Phys. Rev. D96,094010(2017), Phys. Rev. C95, 064911(2017).

outline

1. Quark (re-)combination/coalescence mechanism
2. Quark Number Scaling (QNS) property in p_T spectra of hadrons in pp and p-Pb collisions at LHC
3. Equal-Velocity Combination (EVC) of quarks and antiquarks at hadronization
4. EVC of light-flavor quarks
5. EVC of light-flavor quarks and charm quarks
6. Apply EVC to hadronic elliptic flow v_2 in heavy-ion collisions
7. Energy-scan study for hadronic p_T spectra in Au+Au collisions at $\sqrt{s_{NN}}$ =7.7−200 GeV
8. Summary and outlook

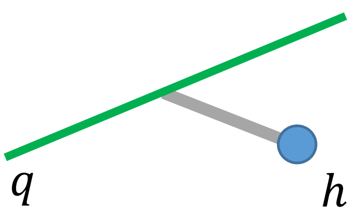
1. Hadronization

- **the process of the formation of hadrons out of final-state quarks and/or gluons produced in high energy reactions**
- **Non-perturbative QCD process**
- **Currently modeled and/or parameterized in phenomenological methods.**

Two pictures:

Fragmentation

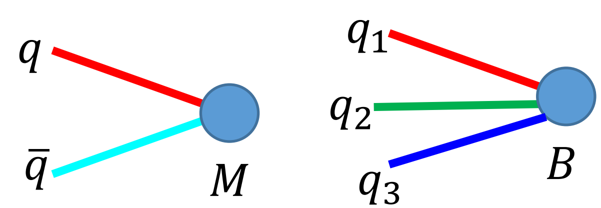
String fragmentation,
cluster fragmentation,
etc.



Probability $D_{q\to h}(z)$

Combination

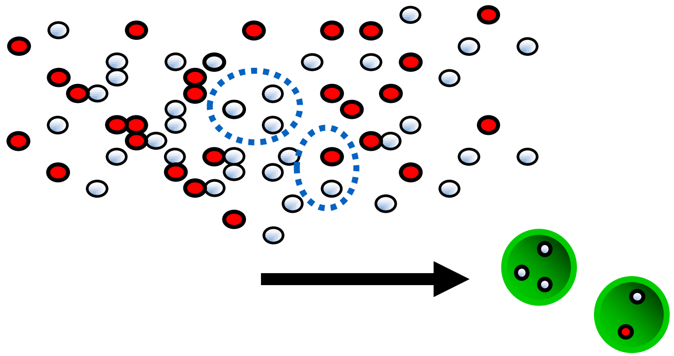
quark (re-)combination,
parton coalescence,
etc.



Combination models on market

- **quark recombination model**
  R. J. Fries, B. Muller, C. Nonaka, S. A. Bass,
  e.g., Phys. Rev. C **68**, 044902 (2003)
- **parton coalescence model**
  V. Greco, C. M. Ko, P. Lévai, L.W. Chen, et al.
  e.g., Phys. Rev. C **68**, 034904 (2003)
- **quark recombination model**
  R. C. Hwa and C. B. Yang, e.g, Phys. Rev. C **70**, 024904 (2004)
- **resonance recombination model**
  L. Ravagli, R. Rapp, e.g., Phys.Lett. B 655,126 (2007)
  M. He, R.J. Fries, R. Rapp, e.g., Phys.Rev.C 82, 034907 (2010)
- **quark combination model (Shandong Group)**
  Q.B.Xie, F.L.Shao, et al., e.g., Phys. Rev. C71,044903 (2005)
  phenomenological combine rule
- **transport model**
  P.F.Zhuang, et al, e.g., Phys. Rev. C76, 014907(2009)
- **quark molecular dynamics model**
  M. Hofmann et al, e.g., Nucl. Phys. B 478,161(2000)
- **variational model**
  A.Alala, etal, e.g., Phys. Rev. C77,044901(2009)

….



what kind of quarks?

how to combine?

how to test in experiments?

2.

Quark Number Scaling (QNS) property in p_T spectra of hadrons in pp and p-Pb collisions at LHC

Refs:

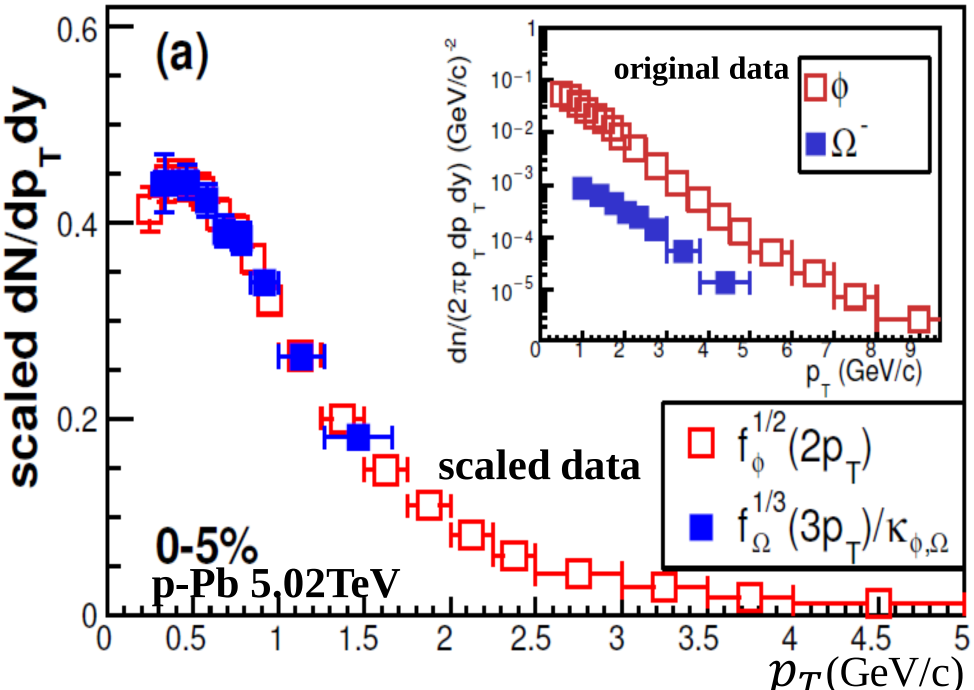
- Jian-wei Zhang, Hai-hong Li, Feng-lan Shao, and Jun Song, Chin.Phys. C44, 014101(2020).
- Jun Song, Xing-rui Gou, Feng-lan Shao, Zuo-tang Liang, Phys. Lett. B774, 516(2017).
- Xing-rui Gou, Feng-lan Shao, Rui-qin Wang, Hai-hong Li, Jun Song, Phys. Rev. D96,094010(2017).

Manipulate exp data of p_T spectra for $\Omega(sss)$ and $\phi(s\bar{s})$ in p-Pb collisions at 5.02 TeV

(1) divide p_T bin by quark number, $p_{T_\Omega}/3$, $p_{T_\phi}/2$,

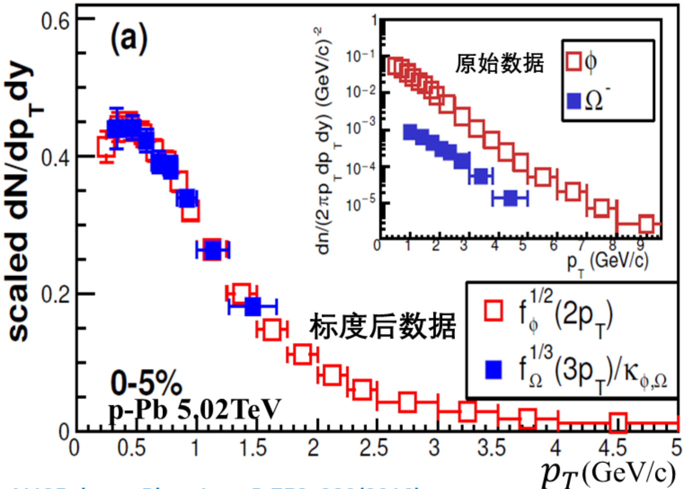
(2) take the inverse quark number power of density dN_h/dp_Tdy, i.e. $dN_\Omega^{1/3}/dp_Tdy$ and $dN_\phi^{1/2}/dp_Tdy$

(3) Divide the scaled Ω data by a constant κ to keep the same magnitude with that of ϕ



ALICE data： Phys. Lett. B 758, 389(2016).
Eur. Phys. J. C76, 245 (2016)

$$f(p_T) \equiv dN_h/dp_T dy$$



ALICE data： Phys. Lett. B 758, 389(2016).
Eur. Phys. J. C76, 245 (2016)

mathematic relationship

$$f_\Omega^{1/3}(3p_T) = \kappa_{\phi,\Omega} f_\phi^{1/2}(2p_T)$$

in another form

$$f_\Omega(3p_T) = \kappa_\Omega f_s^3(p_T)$$

$$f_\phi(2p_T) = \kappa_\phi f_s^2(p_T)$$

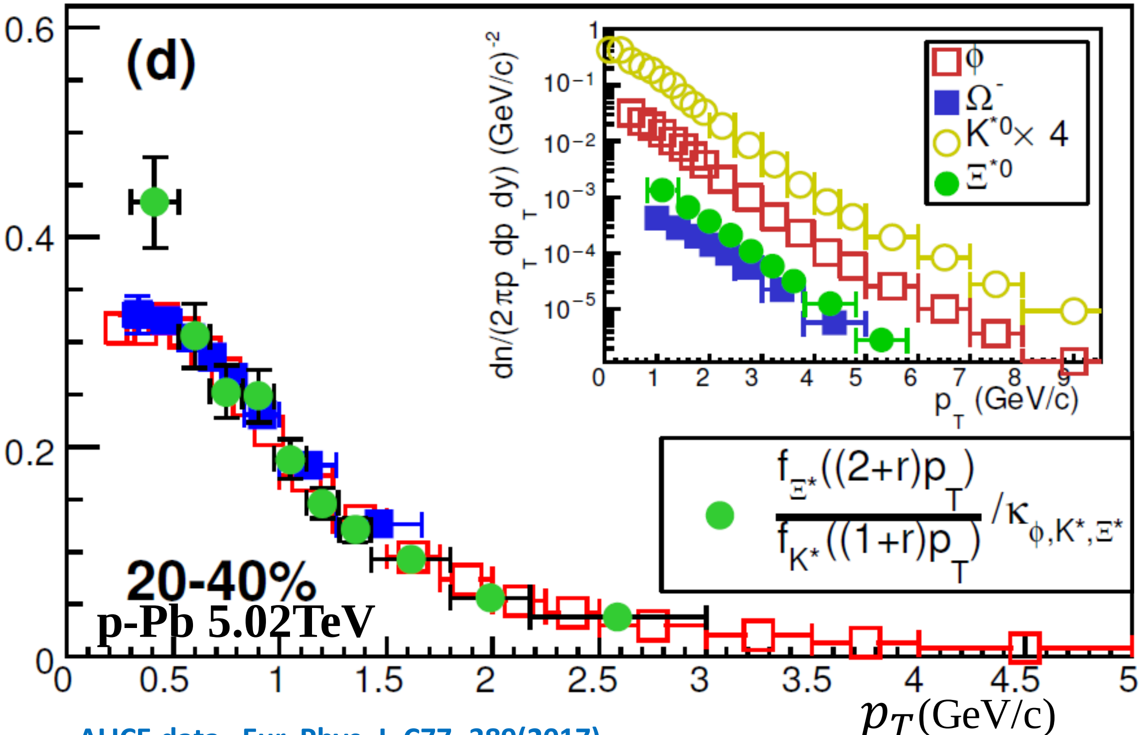
Coefficients κ_ϕ, κ_Ω, $\kappa_{\phi,\Omega}$ are independent of p_T

A clear signal of quark combination at hadronization!

For $\Xi^{*0}(uss)$ and $K^{*0}(d\bar{s})$, we also find

$$\frac{f_{\Xi^{*0}}((2+r)p_T)}{f_{K^{*0}}((1+r)p_T)} = \kappa_{K^*,\Xi^*} f_s(p_T)$$

where $r \approx 0.67$



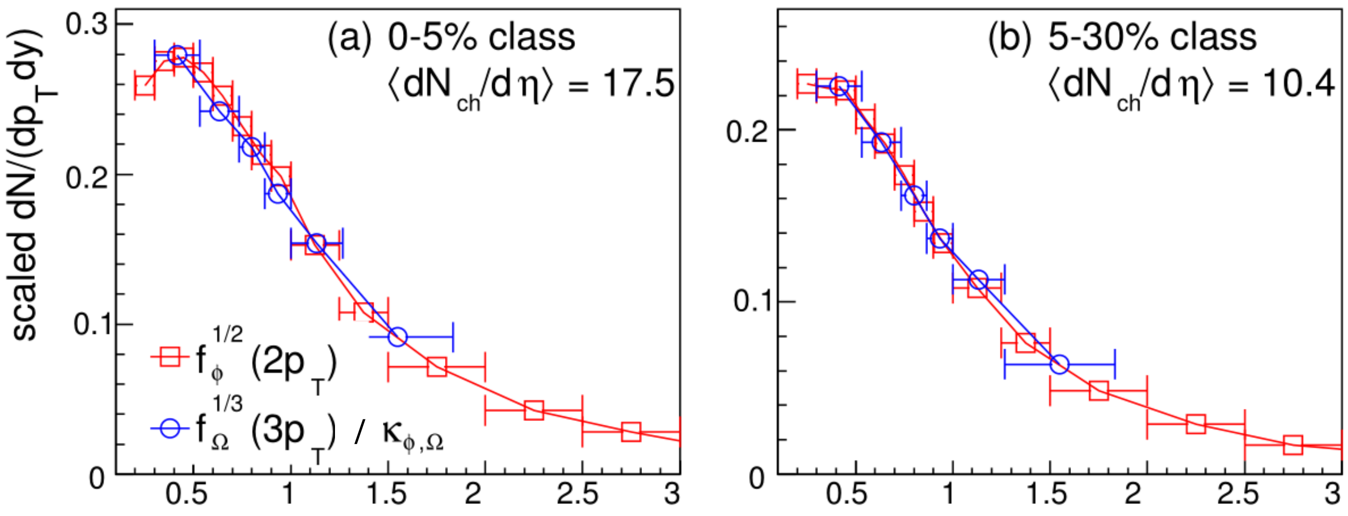
ALICE data, Eur. Phys. J. C77, 389(2017)

$m_s \approx 500MeV$

$m_u \approx 330MeV$

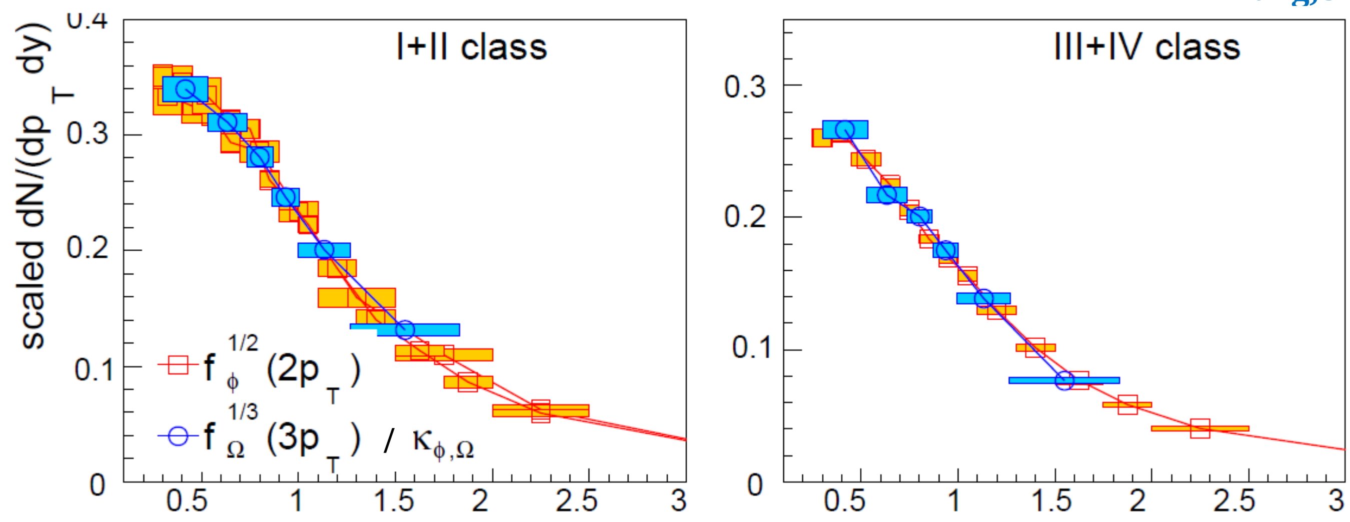
$$\frac{m_u}{m_s} \approx r$$

Gou,Shao,Song…,PRD96(2017), 094010



pp at $\sqrt{s}$ =7TeV

Zhang,Shao,Song,CPC(2020)



pp at $\sqrt{s}$ =13TeV

3.

Equal-Velocity Combination (EVC) of quarks and antiquarks at hadronization

Start from general formula in momentum space

$$f_{B_j}(p_B) = \int dp_1 dp_2 dp_3 \;\; R_{B_j}(p_1, p_2, p_3; p_B) \;\; f_{q_1 q_2 q_3}(p_1, p_2, p_3)$$
$$f_{M_j}(p_M) = \int dp_1 dp_2 \;\; R_{M_j}(p_1, p_2; p_M) \;\; f_{q_1 \bar{q}_2}(p_1, p_2)$$

Assume independent distribution of (anti-)quarks

$$f_{q_1 q_2 q_3}(p_1, p_2, p_3) = f_{q_1}(p_1) f_{q_2}(p_2) f_{q_3}(p_3)$$
$$f_{q_1 \bar{q}_2}(p_1, p_2) = f_{q_1}(p_1) f_{\bar{q}_2}(p_2)$$

equal velocity combination (EVC) approximation

$$R_{B_j}(p_1,p_2,p_3;p_B)=\kappa_{B_j}\prod_{i=1}^{3}\delta(p_i-x_i p_B)$$

$$R_{M_j}(p_1,p_2;p_M)=\kappa_{M_j}\prod_{i=1}^{2}\delta(p_i-x_i p_M)$$

momentum fraction

for meson $\boldsymbol{x_{1,2}=\frac{m_{1,2}}{m_1+m_2}}$, for baryon $\boldsymbol{x_{1,2,3}=\frac{m_{1,2,3}}{m_1+m_2+m_3}}$,

$m_s=500$ MeV, $m_u=m_d=330$ MeV.

We obtain

$$f_{B_j}(p_B)=\kappa_{B_j}f_{q_1}(x_1p_B)f_{q_2}(x_2p_B)f_{q_3}(x_3p_B)$$

$$f_{M_j}(p_M)=\kappa_{M_j}f_{q_1}(x_1p_M)f_{\bar{q}_2}(x_2p_M)$$

For combination of s and $\bar{s}$

$$f_\Omega(3p_T) = \kappa_\Omega f_s^3(p_T)$$
$$f_\phi(2p_T) = \kappa_\phi f_s^2(p_T)$$

$$f_\Omega^{\frac{1}{3}}(3p_T) = \kappa_{\phi,\Omega} f_\phi^{\frac{1}{2}}(2p_T)$$

$f_s(p_T) = f_{\bar{s}}(p_T)$ is taken at LHC

For combination of $u(d)$ and s, denote $\frac{x_u}{x_s} = \frac{m_u}{m_s} = r$

$$f_{\Xi^{*0}}\big((2+r)p_T\big) = \kappa_{\Xi^{*0}}\, f_s^2(p_T) f_u(r\, p_T)$$
$$f_{K^{*0}}\big((1+r)p_T\big) = \kappa_{K^{*0}}\, f_s(p_T) f_{\bar{d}}\,(r\, p_T)$$

$$\frac{f_{\Xi^{*0}}\big((2+r)p_T\big)}{f_{K^{*0}}\big((1+r)p_T\big)} = \kappa_{\phi,K^*,\Xi^*} f_\phi^{\frac{1}{2}}(2p_T)$$

Consider stochastic combination and flavor-blind of strong interaction

$$\frac{\kappa_{M_j}}{A_{M_j}} = C_{M_j} P_{q\bar{q}\to M}$$
$$\frac{\kappa_{B_j}}{A_{B_j}} = C_{B_j} N_{iter} P_{qqq\to B}$$

$A_{B_j} = 1/\int dp_T \prod_{i=1}^{3} f_{q_i}^{(n)}(x_i p_T)$, $A_{M_j} = 1/\int dp_T f_{q_1}^{(n)}(x_1 p_T) f_{\bar{q}_2}^{(n)}(x_2 p_T)$ are normalization coefficients of jointed quark distributions.

$P_{q\bar{q}\to M} \approx \frac{2}{x(1-z^2)}\left[1 - z\frac{(1+z)^a+(1+z)^a}{(1+z)^a-(1+z)^a}\right]$, averaged probability of $q\bar{q} \to M$

$P_{qqq\to B} \approx \frac{8}{3x^2(1+z)^3}\frac{(1+z)^a}{(1+z)^a-(1+z)^a}$, averaged probability of $qqq \to B$

Song,Shao, PRC 88, 027901(2013)

N_{iter}=1,3,6 for three identical, two identical and three different flavors

$x = N_q + N_{\bar{q}}$, $z = (N_q - N_{\bar{q}})/x$, $a = 1 + \frac{1}{3}\left(\overline{N}_M/\overline{N}_B\right)_{z=0} \approx 4.86 \pm 0.1$ light-flavor sector

N_q number of all quarks; $N_{\bar{q}}$ that of all antiquarks

C_{M_j} and C_{B_j} are fine-tune parameters

$$C_{M_j} = \begin{cases} \frac{1}{1+R_{V/P}} & for\ J^P = 0^- \ mesons \\ \frac{R_{V/P}}{1+R_{V/P}} & for\ J^P = 1^- \ mesons \end{cases} \qquad C_{B_j} = \begin{cases} \frac{R_{O/D}}{1+R_{O/D}} & for\ J^P = (1/2)^+ baryons \\ \frac{1}{1+R_{O/D}} & for\ J^P = (3/2)^+ baryons \end{cases}$$

$R_{V/P} \approx 0.5$
$R_{O/D} \approx 2.0$

Include decay contributions

$$f_{h_j}^{(final)}(p) = f_{h_j}(p) + \sum_{i \neq j} \int dp' f_{h_i}(p') D_{ij}(p', p)$$

decay function $D_{ij}(p', p)$ is determined by the decay kinematics and decay branch ratios in PDG

Model inputs: $\boldsymbol{f_{q_i}(p)}$ **fixed by experimental data**

4.

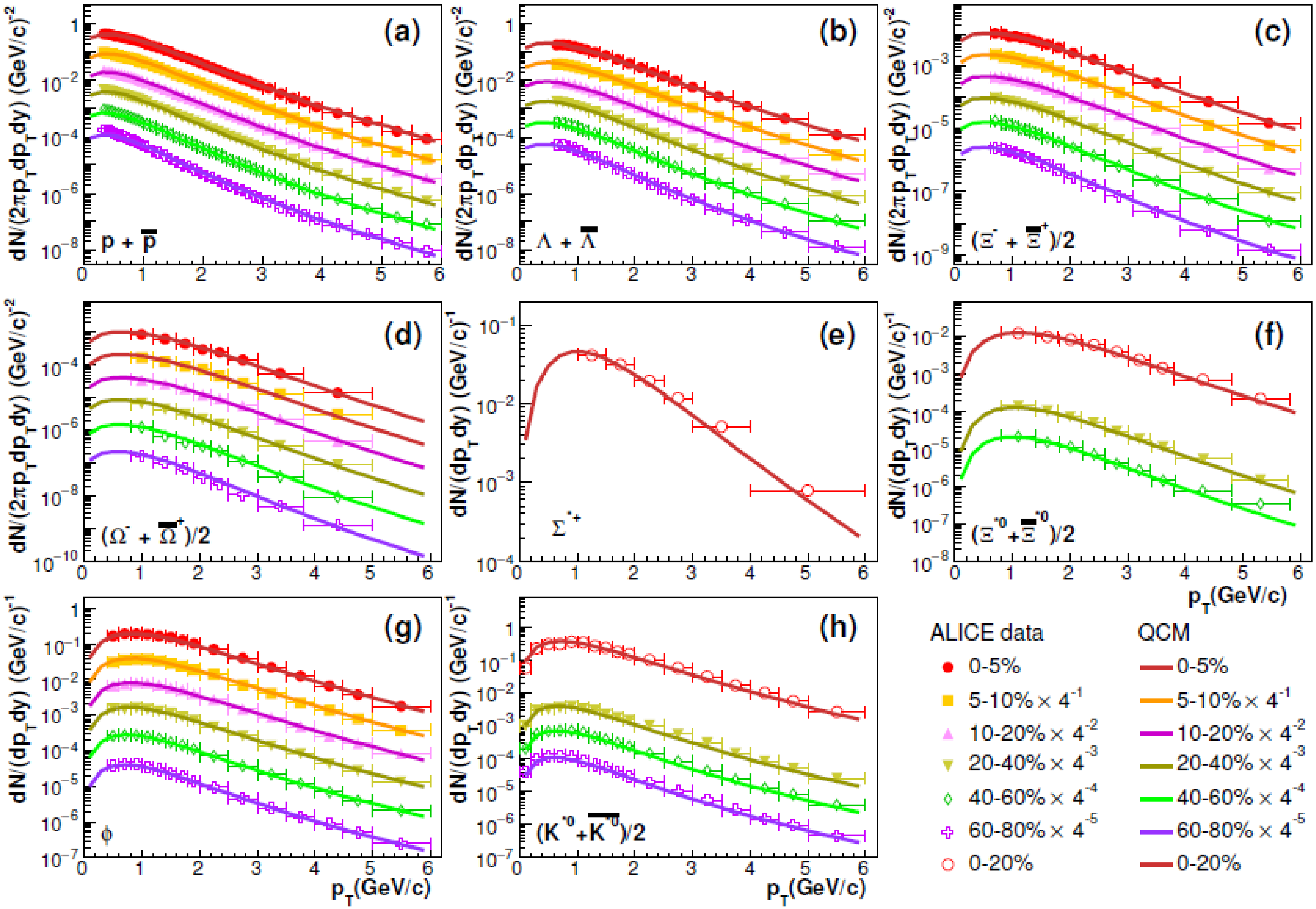
EVC of light-flavor quarks

Refs:

- Jian-wei Zhang, Hai-hong Li, Feng-lan Shao, and Jun Song, Chin.Phys. C44, 014101(2020).
- Jun Song, Xing-rui Gou, Feng-lan Shao, Zuo-tang Liang, Phys. Lett. B774, 516(2017).
- Xing-rui Gou, Feng-lan Shao, Rui-qin Wang, Hai-hong Li, Jun Song, Phys. Rev. D96,094010(2017).
- Feng-lan Shao, Guo-jing Wang, Rui-qin Wang, Hai-hong Li, Jun Song, Phys. Rev. C95, 064911(2017).

p-Pb collisions at 5.02 TeV

Song,Gou,Shao,Liang, Phys.Lett. B774 (2017), 516

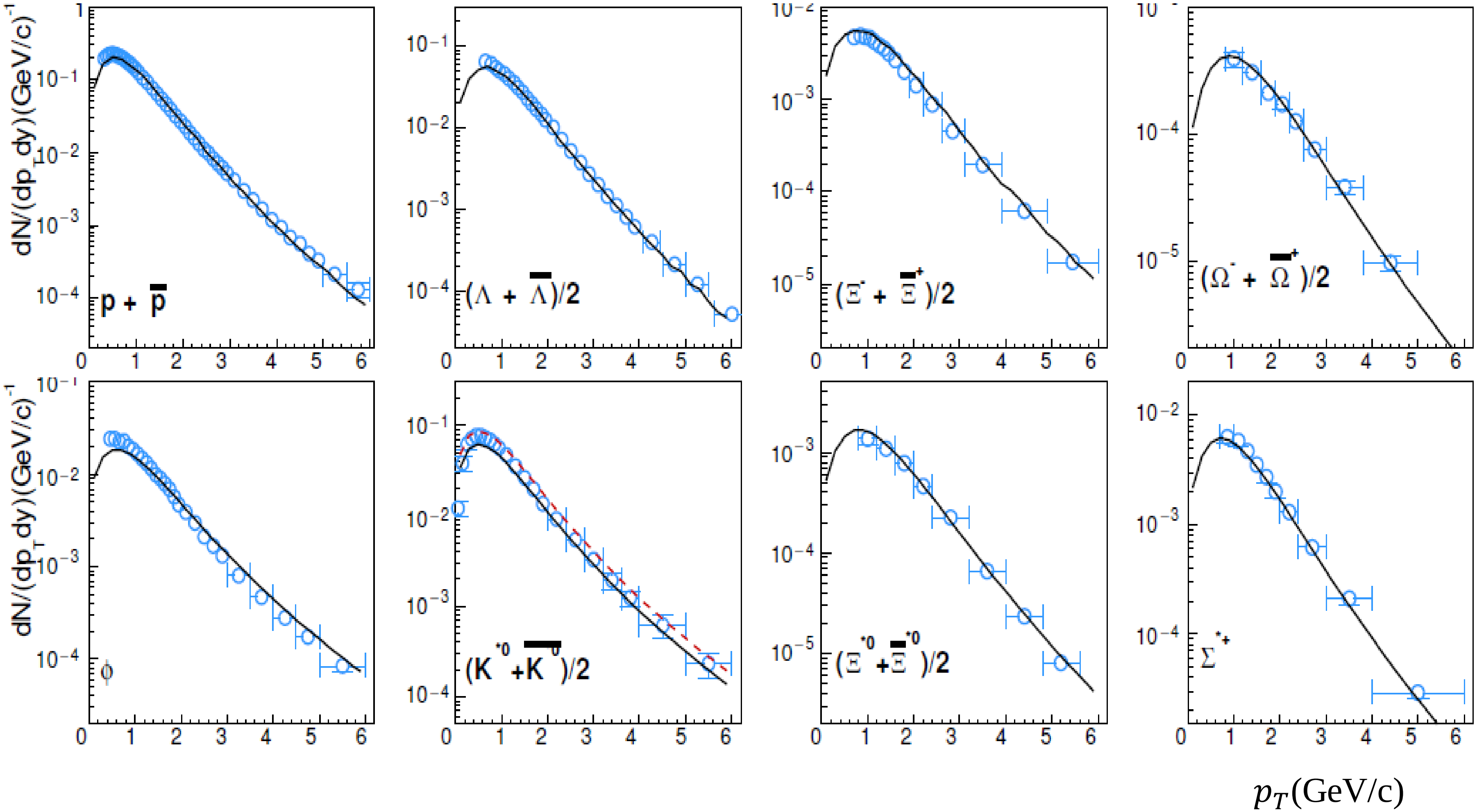


Two inputs:

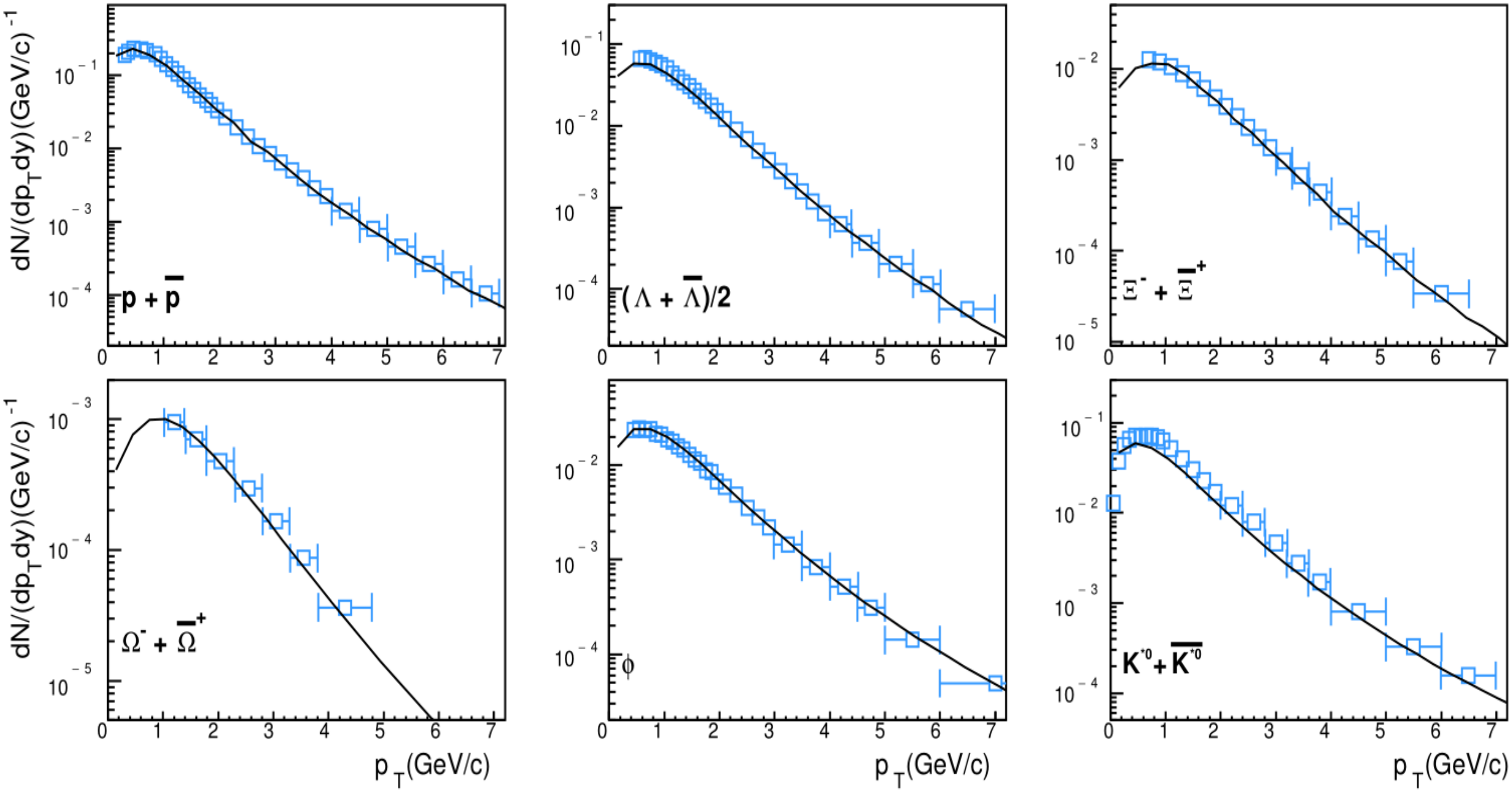
$$f_u(p_T) = f_d(p_T) = f_{\bar{u}}(p_T) = f_{\bar{d}}(p_T)$$
$$f_s(p_T) = f_{\bar{s}}(p_T)$$

pp collisions at 7 TeV

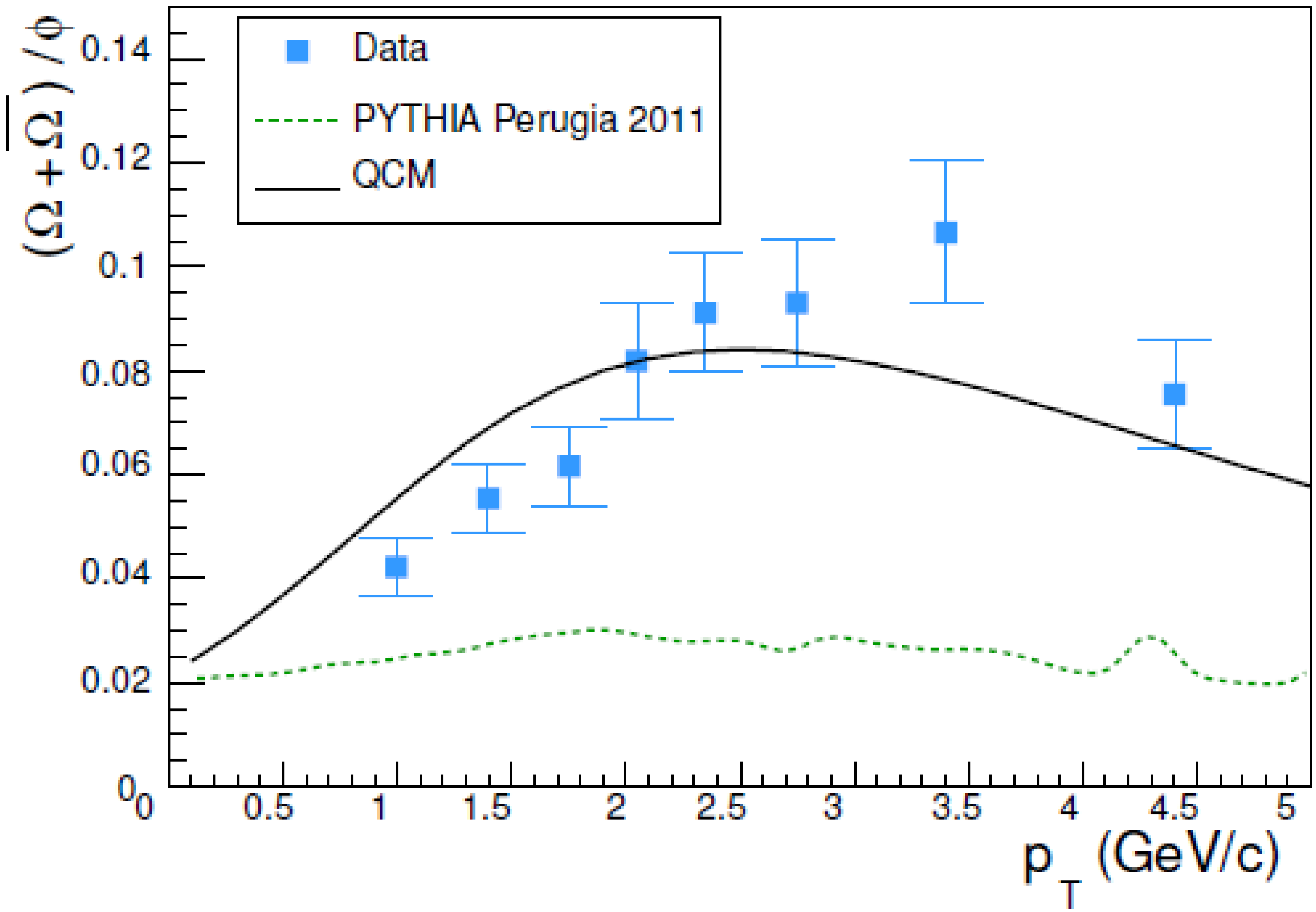
Minimum bias events



pp collisions at 13 TeV



Baryon/Meson ratio



Minimum bias events in pp collisions at 7 TeV

Kaon and pion production in EVC

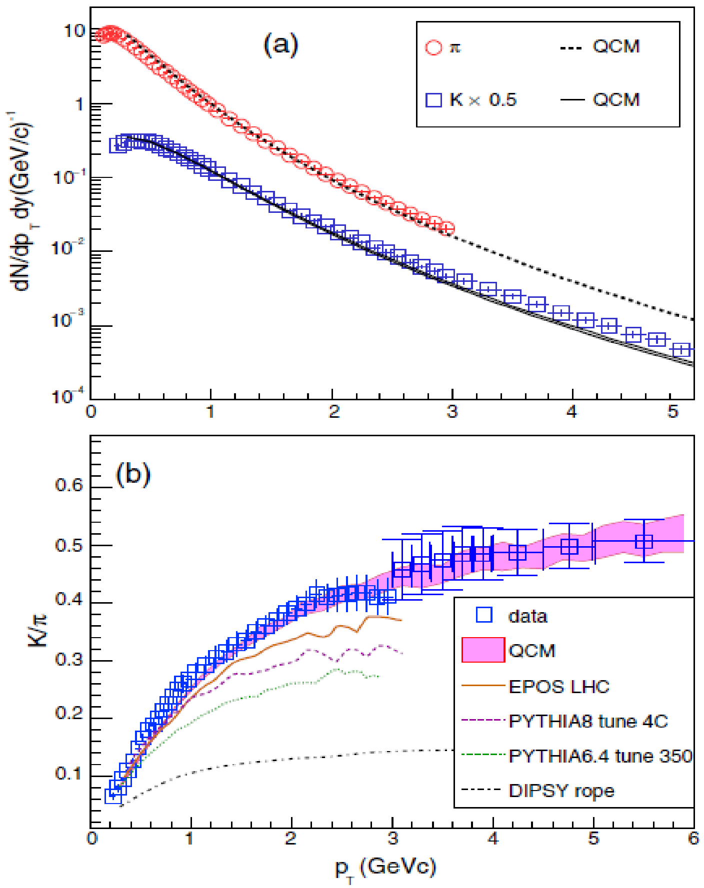


FIG. 10. Midrapidity p_T spectra of kaon and pion in minimum-bias pp collisions at $\sqrt{s} = 7$ TeV and the ratio between them. Symbols are experimental data [22,58] and results of other models and/or event generators are taken from [22,51].

reconcile off-shell issue

$$u + \bar{d} \rightarrow \pi^+ + X$$

$$u + \bar{s} \rightarrow K^+ + X$$

***X* is identified as pions.**

5.

EVC of charm and light-flavor quarks

Refs:

- Jun Song, Hai-hong Li, Feng-lan Shao, Eur.Phys.J. C78, 344 (2018).
- Hai-hong Li, Feng-lan Shao, Jun Song, Rui-qin Wang, Phys.Rev. C97, 064915 (2018).

single-charmed hadrons in EVC

$$f_D(p_T) = \kappa_D f_c\left(\frac{r_{cu}}{1+r_{cu}}p_T\right) f_{\bar{u}}\left(\frac{1}{1+r_{cu}}p_T\right)$$

$$f_{D_s}(p_T) = \kappa_{D_s} f_c\left(\frac{r_{cs}}{1+r_{cs}}p_T\right) f_{\bar{s}}\left(\frac{1}{1+r_{cs}}p_T\right)$$

$$f_{\Lambda_c}(p_T) = \kappa_{\Lambda_c} f_c\left(\frac{r_{cu}}{2+r_{cu}}p_T\right) f_u^2\left(\frac{1}{1+r_{cu}}p_T\right)$$

0.75-0.85 0.15-0.25

$$r_{cu} = \frac{m_c}{m_u}$$

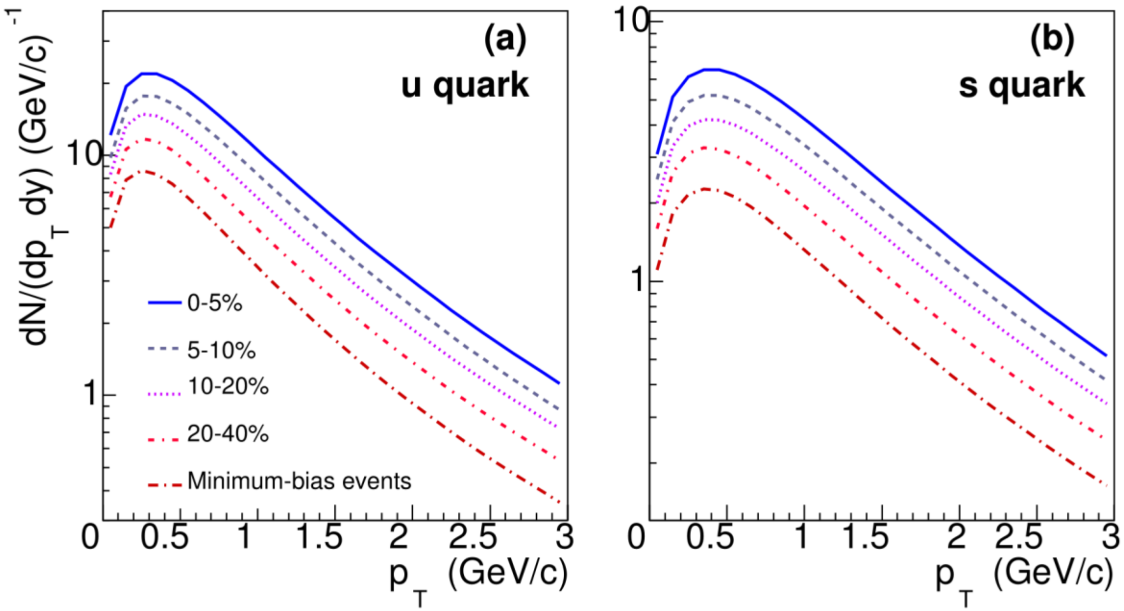
$$r_{cs} = \frac{m_c}{m_s}$$

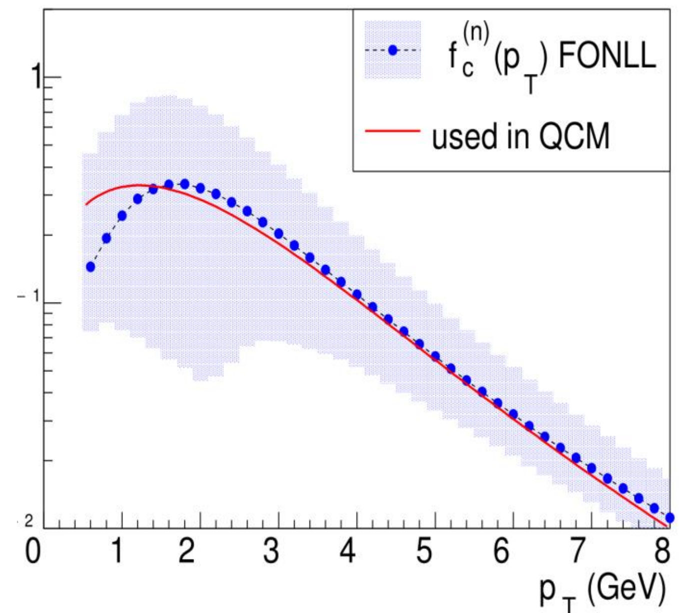
$$m_c = 1.5\ \text{GeV}$$

Song, Li, Shao, Eur.Phys.J. C (2018)
Li, Shao,Song, PRC(2018)

Quark spectra at hadronization are known.

e.g., in p-Pb collisions at 5.02 TeV

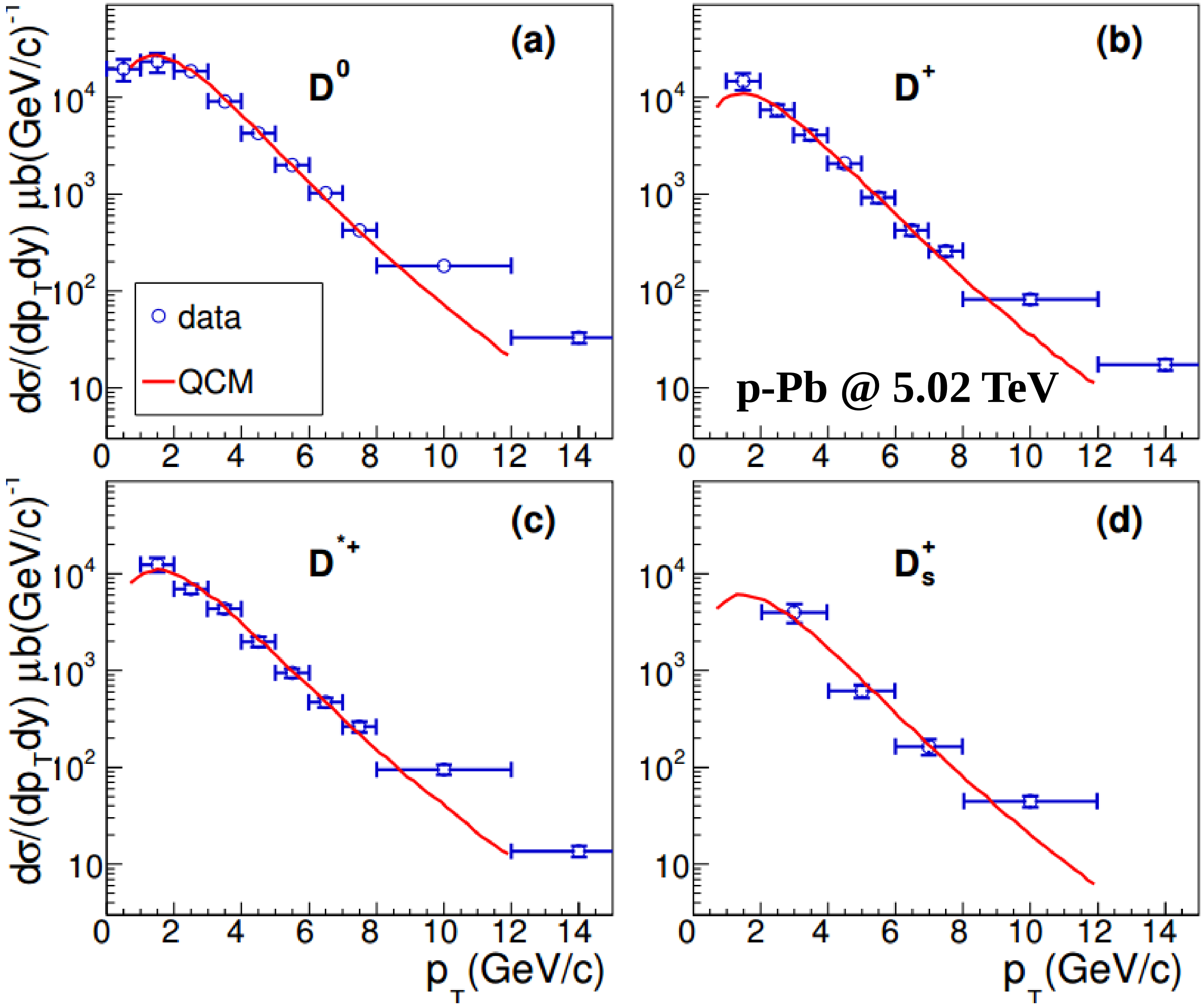




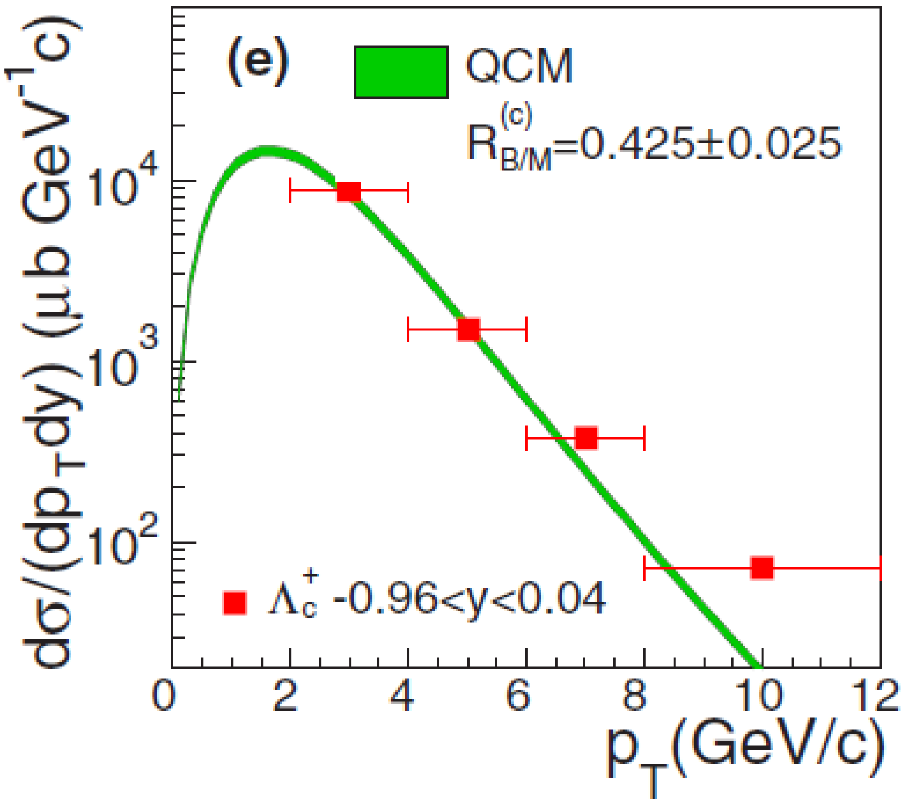
obtained from light-flavor hadrons

consistent with pQCD calculations

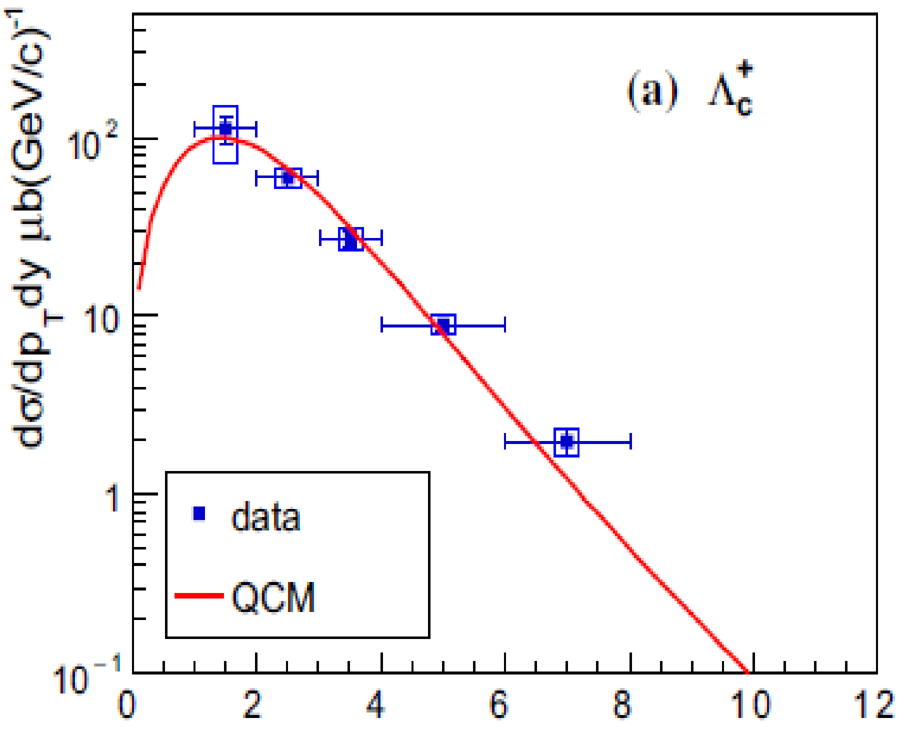
c quark of $p_{T,c} \lesssim 6$ + l quark of $p_{T,l} \lesssim 2$ GeV/c



p_T spectrum of Λ_c^+

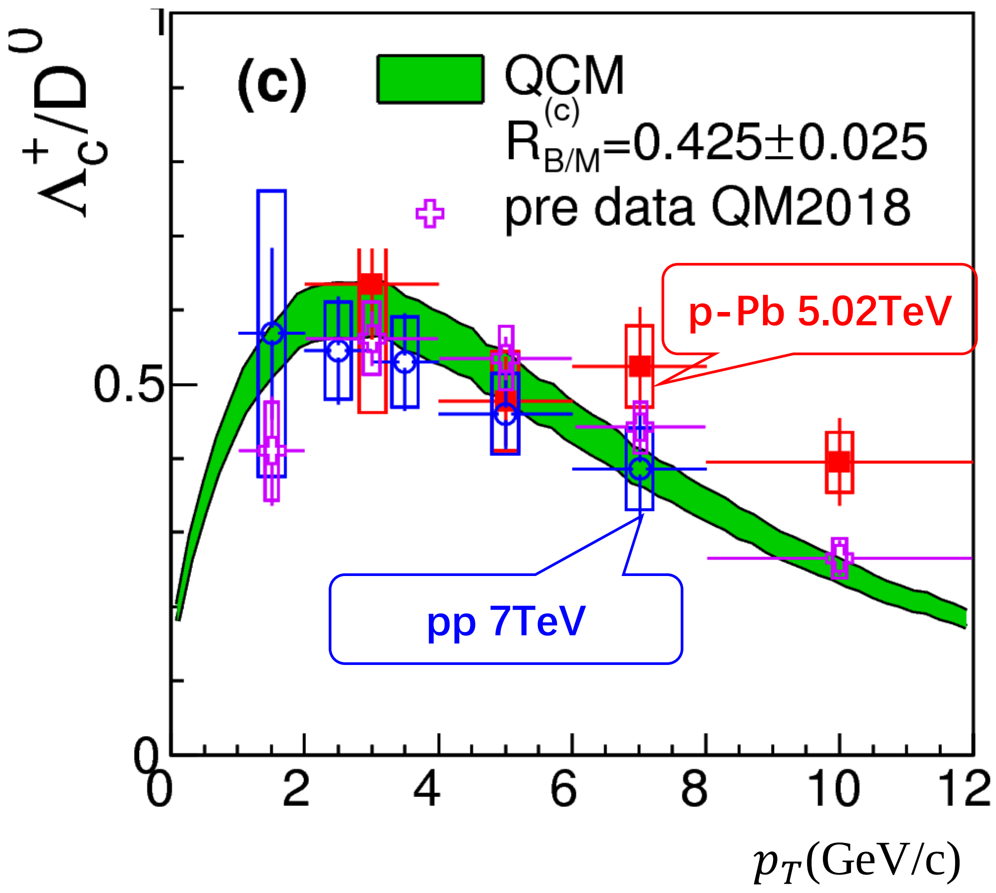


pPb @ 5.02 TeV

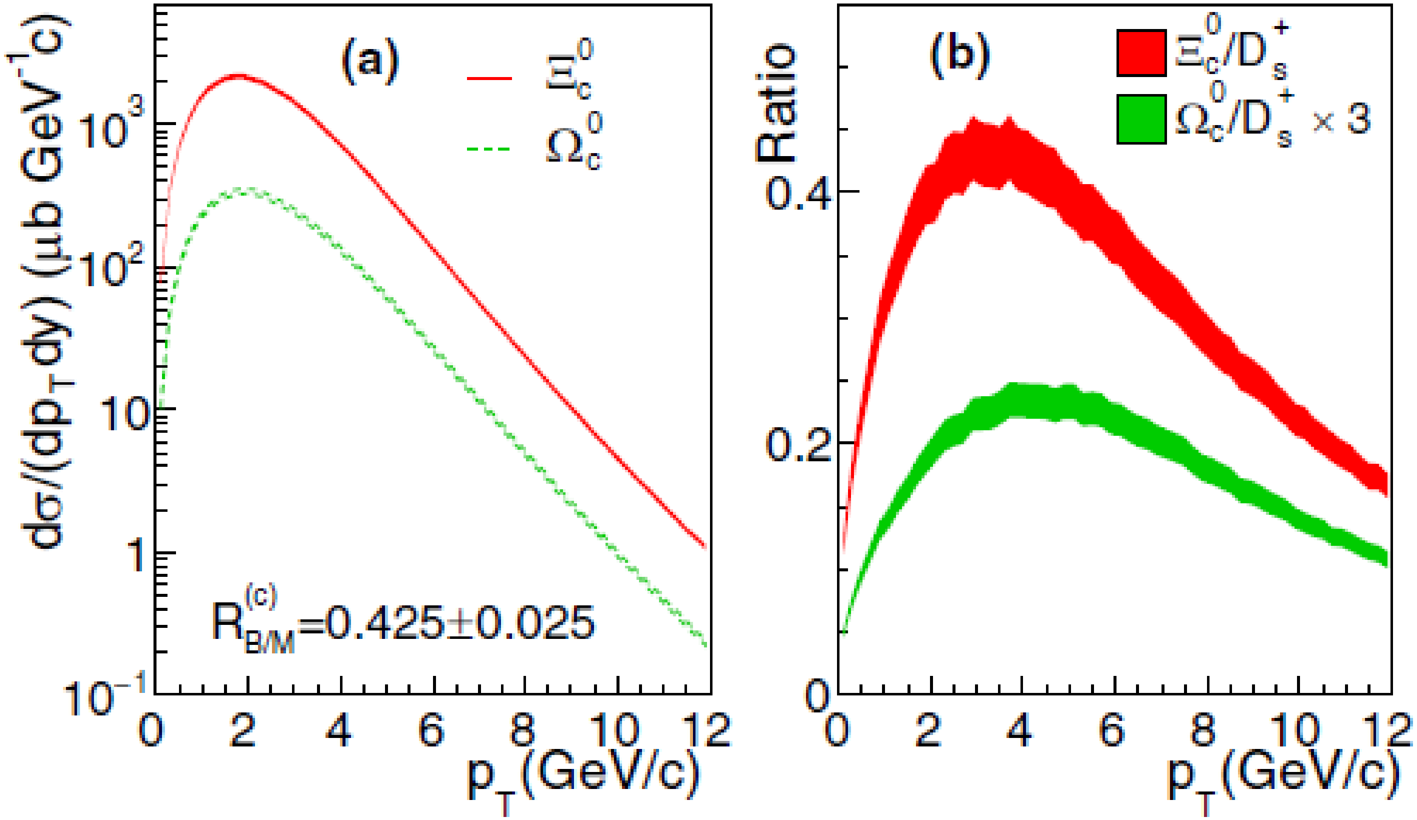


pp @ 7 TeV

p_T dependence of charmed Baryon/Meson ratio



Prediction of Ξ_c^0, Ω_c^0



pPb @ 5.02 TeV

6. Apply EVC to elliptic flow v_2 of hadrons

Refs:

- Jun Song, Hai-hong Li, and Feng-lan Shao, arxiv:2008.03017v2.

Applying EVC to $(\boldsymbol{p_T}, \boldsymbol{\varphi})$ plane

$$f_{M_i}(p_T,\varphi) = \kappa_{M_i}\, f_{q_1}(x_1 p_T,\varphi)\, f_{\bar{q}_2}(x_2 p_T,\varphi)$$
$$f_{B_i}(p_T,\varphi) = \kappa_{B_i}\, f_{q_1}(x_1 p_T,\varphi) f_{q_2}(x_2 p_T,\varphi) f_{q_3}(x_3 p_T,\varphi)$$

with quark distribution

$$f_q(p_T,\varphi) = f_q(p_T)\left[1 + 2\sum_{n=1}^{\infty} v_{n,q}(p_T)\cos(n\varphi)\right]$$

Hadron flow is

$$v_{n,h}(p_T) = \frac{\int f_h(p_T,\varphi)\cos(n\varphi)\, d\varphi}{\int f_h(p_T,\varphi) d\varphi}$$

We neglect $v_{1,q}$ ($\lesssim 10^{-3}$ at mid-rapidity in HIC) and $v_{n,q}^{3,4,..}$ and obtain

$$v_{2,M_i}(p_T)$$
$$= v_{2,q_1}(x_1 p_T)\left[1+\sum_{n=2}^{\infty}\frac{v_{n,q_1}(x_1 p_T)}{v_{2,q_1}(x_1 p_T)}v_{n+2,\bar{q}_2}(x_2 p_T)\right]$$
$$+ v_{2,\bar{q}_2}(x_2 p_T)\left[1+\sum_{n=2}^{\infty}\frac{v_{n,\bar{q}_2}(x_2 p_T)}{v_{2,\bar{q}_2}(x_2 p_T)}v_{n+2,q_1}(x_1 p_T)\right]$$

$$v_{2,B_i}(p_T)$$
$$= v_{2,q_1}(x_1 p_T)\left\{1+\sum_{n=2}^{\infty}\frac{v_{n,q_1}(x_1 p_T)}{v_{2,q_1}(x_1 p_T)}\left[v_{n+2,q_2}(x_2 p_T)+v_{n+2,q_3}(x_3 p_T)\right]\right\}$$
$$+ v_{2,q_2}(x_2 p_T)\left\{1+\sum_{n=2}^{\infty}\frac{v_{n,q_2}(x_2 p_T)}{v_{2,q_2}(x_2 p_T)}\left[v_{n+2,q_1}(x_1 p_T)+v_{n+2,q_3}(x_3 p_T)\right]\right\}$$
$$+ v_{2,q_3}(x_3 p_T)\left\{1+\sum_{n=2}^{\infty}\frac{v_{n,q_3}(x_3 p_T)}{v_{2,q_3}(x_3 p_T)}\left[v_{n+2,q_1}(x_1 p_T)+v_{n+2,q_2}(x_2 p_T)\right]\right\}$$

Finally, we obtain the simplest form

$$v_{2,M_i}\left(p_T\right) = v_{2,q_1}\left(x_1 p_T\right) + v_{2,\bar{q}_2}\left(x_2 p_T\right),$$

$$v_{2,B_i}\left(p_T\right) = v_{2,q_1}\left(x_1 p_T\right) + v_{2,q_2}\left(x_2 p_T\right) + v_{2,q_3}\left(x_3 p_T\right).$$

$$v_{2,p}\left(p_T\right) = 3 v_{2,u}\left(p_T/3\right), \tag{13}$$

$$v_{2,\Lambda}\left(p_T\right) = 2 v_{2,u}\left(\frac{1}{2+r} p_T\right) + v_{2,s}\left(\frac{r}{2+r} p_T\right), \tag{14}$$

$$v_{2,\Xi}\left(p_T\right) = v_{2,u}\left(\frac{1}{1+2r} p_T\right) + 2 v_{2,s}\left(\frac{r}{1+2r} p_T\right), \tag{15}$$

$$v_{2,\Omega}\left(p_T\right) = 3 v_{2,s}\left(p_T/3\right), \tag{16}$$

$$v_{2,\phi}\left(p_T\right) = 2 v_{2,s}\left(p_T/2\right) \tag{17}$$

$$r = \frac{x_s}{x_u} = \frac{m_s}{m_u}$$

Express quark v_2 via hadron's v_2

$$v_{2,u}\left(p_T\right) = \frac{1}{3} v_{2,p}\left(3p_T\right), \tag{18}$$

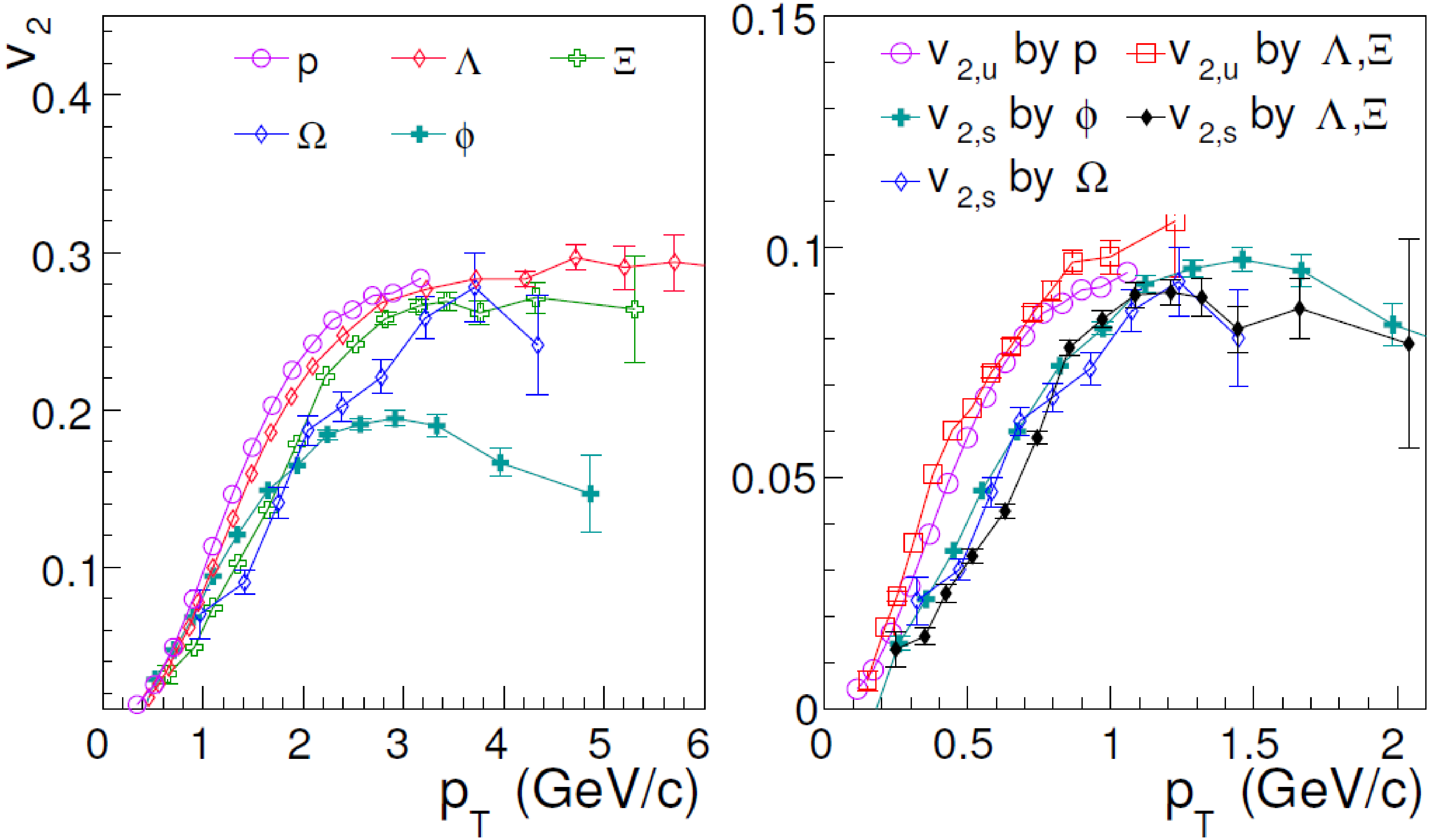
$$v_{2,u}\left(p_T\right) = \frac{1}{3}\left[2v_{2,\Lambda}\left((2+r)p_T\right) - v_{2,\Xi}\left((1+2r)p_T\right)\right], \tag{19}$$

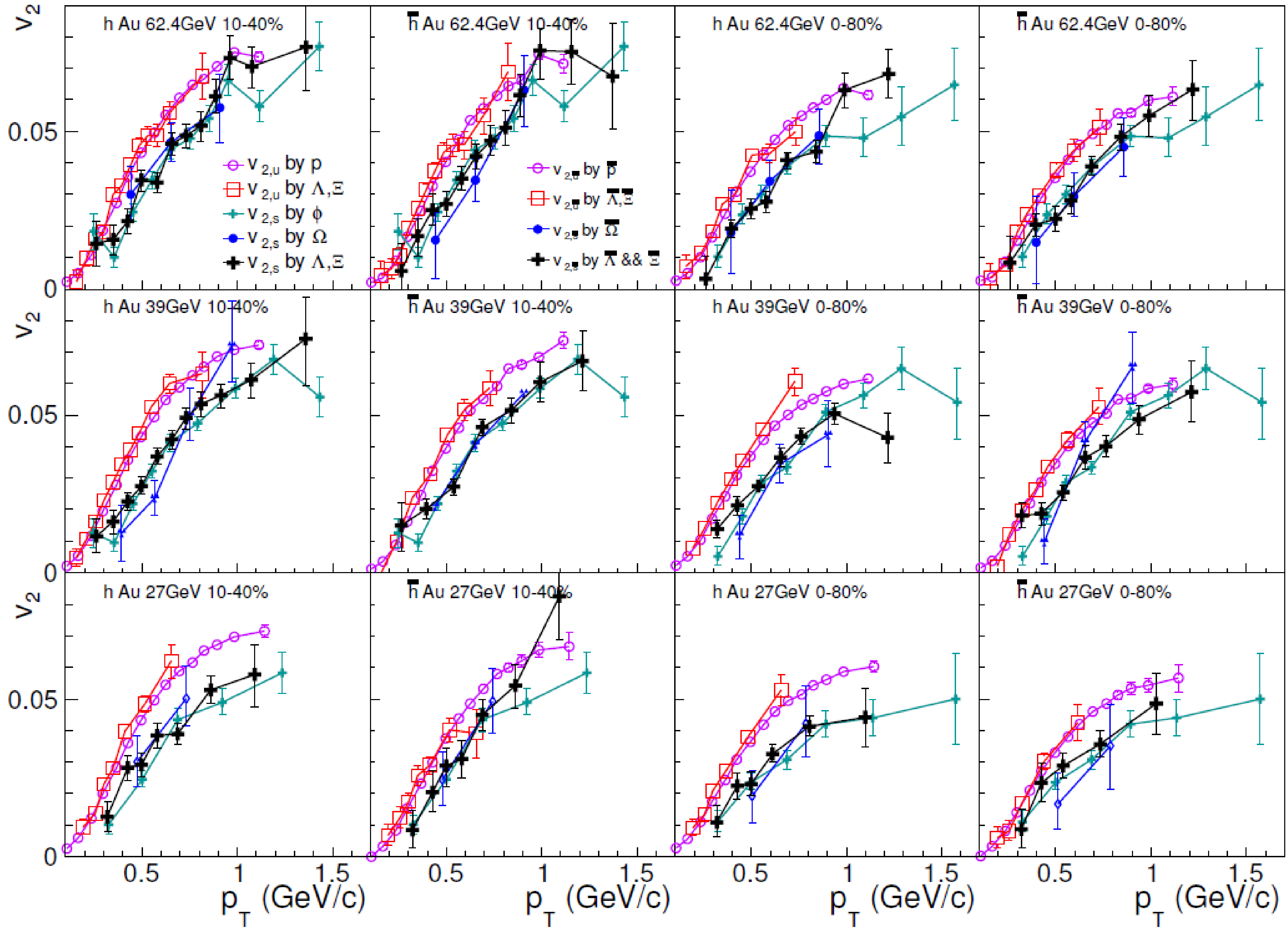
$$v_{2,s}\left(p_T\right) = \frac{1}{3} v_{2,\Omega}\left(3p_T\right), \tag{20}$$

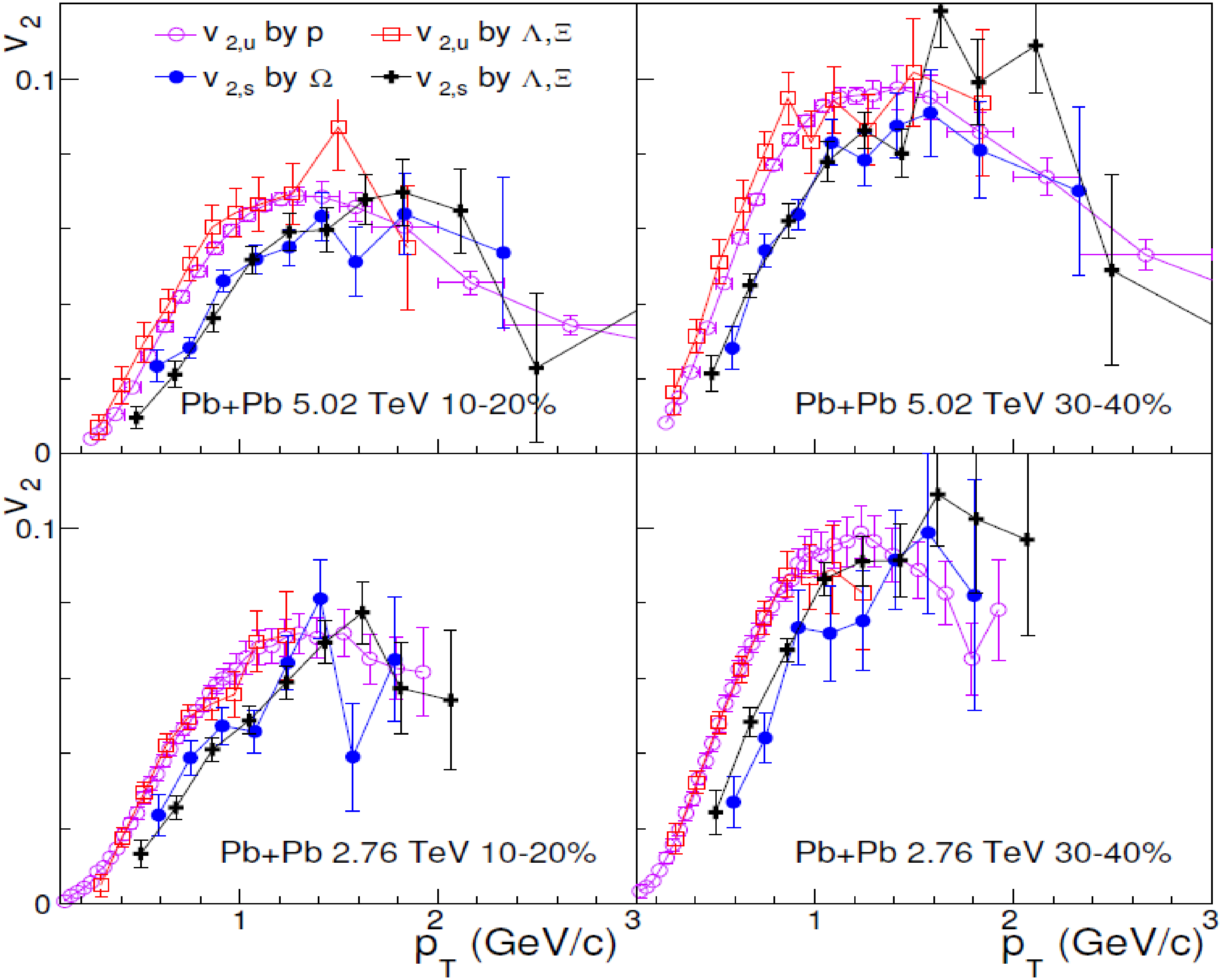
$$v_{2,s}\left(p_T\right) = \frac{1}{2} v_{2,\phi}\left(2p_T\right), \tag{21}$$

$$v_{2,s}\left(p_T\right) = \frac{1}{3}\left[2v_{2,\Xi}\left(\frac{1+2r}{r}p_T\right) - v_{2,\Lambda}\left(\frac{2+r}{r}p_T\right)\right]. \tag{22}$$

AuAu 200 GeV for 30-80% centrality

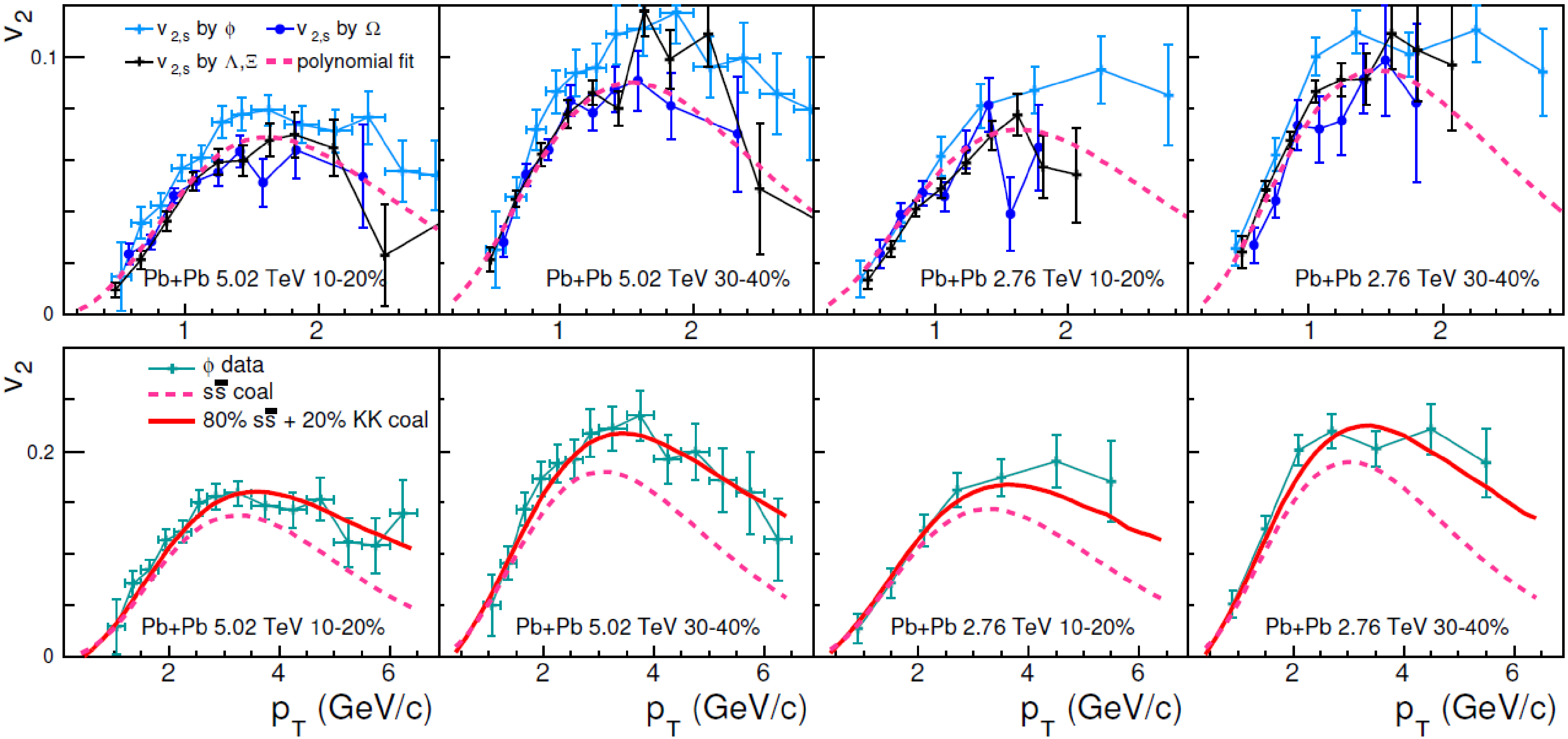



h Au 62.4GeV 10-40%
h̄ Au 62.4GeV 10-40%
h Au 62.4GeV 0-80%
h̄ Au 62.4GeV 0-80%
h Au 39GeV 10-40%
h̄ Au 39GeV 10-40%
h Au 39GeV 0-80%
h̄ Au 39GeV 0-80%
h Au 27GeV 10-40%
h̄ Au 27GeV 10-40%
h Au 27GeV 0-80%
h̄ Au 27GeV 0-80%
v 2,u by p
v 2,u by Λ,Ξ
v 2,s by ϕ
v 2,s by Ω
v 2,s by Λ,Ξ
v 2,ū by p̄
v 2,ū by Λ̄,Ξ̄
v 2,s̄ by Ω̄
v 2,s̄ by Λ̄ && Ξ̄
v2
0.05
0
0.5
1
1.5
pT (GeV/c)



$v_{2,u}$ by p
$v_{2,u}$ by Λ,Ξ
$v_{2,s}$ by Ω
$v_{2,s}$ by Λ,Ξ
v_2
0.1
0
Pb+Pb 5.02 TeV 10-20%
Pb+Pb 5.02 TeV 30-40%
Pb+Pb 2.76 TeV 10-20%
Pb+Pb 2.76 TeV 30-40%
1
2
3
p_T (GeV/c)

ϕ production at LHC



$$v_{2,\phi}^{(final)}(p_T) \approx 2\left[(1-z)\,v_{2,s}\left(\frac{p_T}{2}\right) + z\,v_{2,K}\left(\frac{p_T}{2}\right)\right]$$

$s\bar{s}$

KK coal

v_2 of charm quark

$D^0(c\overline{u})$ meson v_2 in EVC QCM

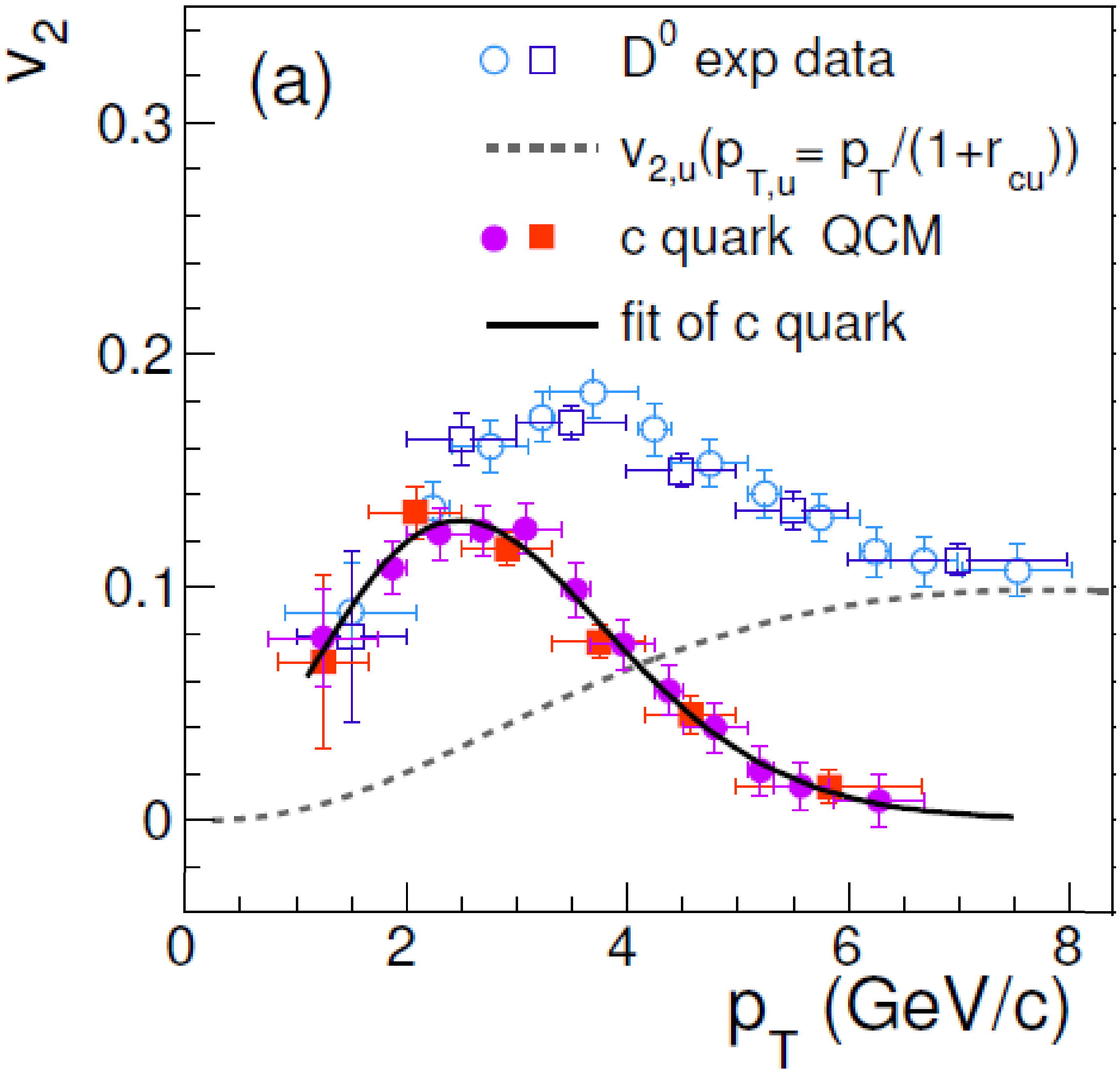
$$v_{2,D}\left(p_T\right) = v_{2,u}\left(\frac{1}{1+r_{cu}}p_T\right) + v_{2,c}\left(\frac{r_{cu}}{1+r_{cu}}p_T\right) \quad (27)$$

From D^0 data, we get charm quark v_2

$$v_{2,c}\left(p_T\right) = v_{2,D}\left(\frac{1+r_{cu}}{r_{cu}}p_T\right) - v_{2,u}\left(\frac{1}{r_{cu}}p_T\right). \quad (28)$$

where $r_{cu} = m_c/m_u$=5

In Pb+Pb collisions at 5.02 TeV for 30-50% centrality

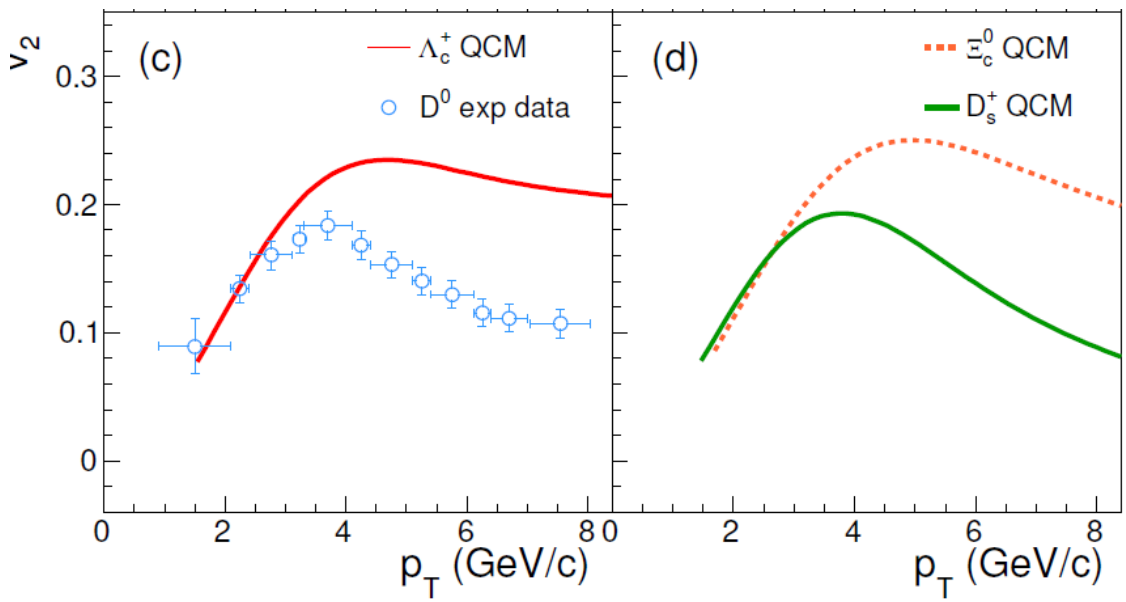


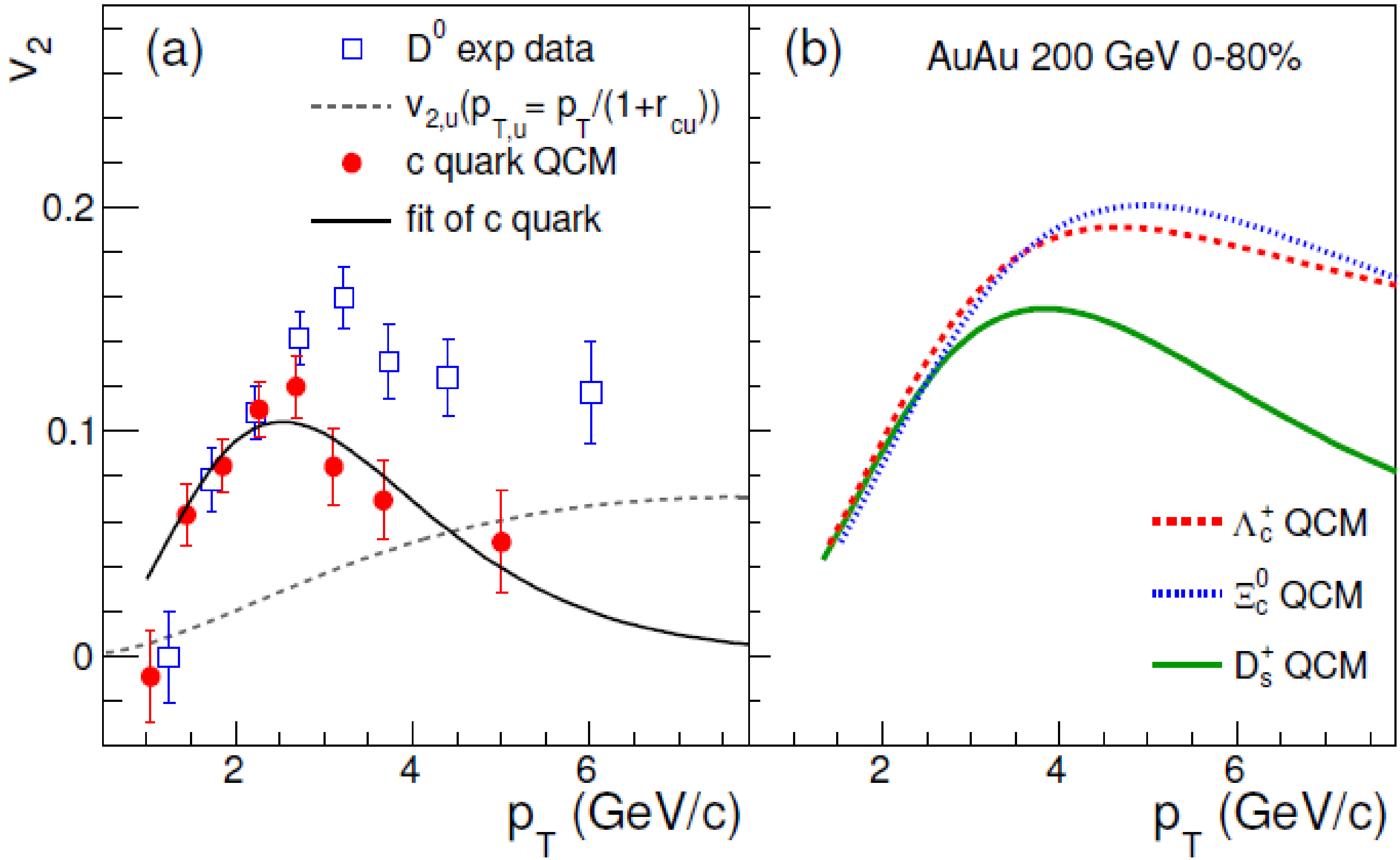
$$v_{2,D_s}(p_T) = v_{2,s}\left(\frac{1}{1+r_{cs}}p_T\right) + v_{2,c}\left(\frac{r_{cs}}{1+r_{cs}}p_T\right)$$

$$r_{cs} = m_c/m_s$$
$$r_{cu} = m_c/m_u$$

$$v_{2,\Lambda_c}(p_T) = 2v_{2,u}\left(\frac{1}{2+r_{cu}}p_T\right) + v_{2,c}\left(\frac{r_{cu}}{2+r_{cu}}p_T\right)$$

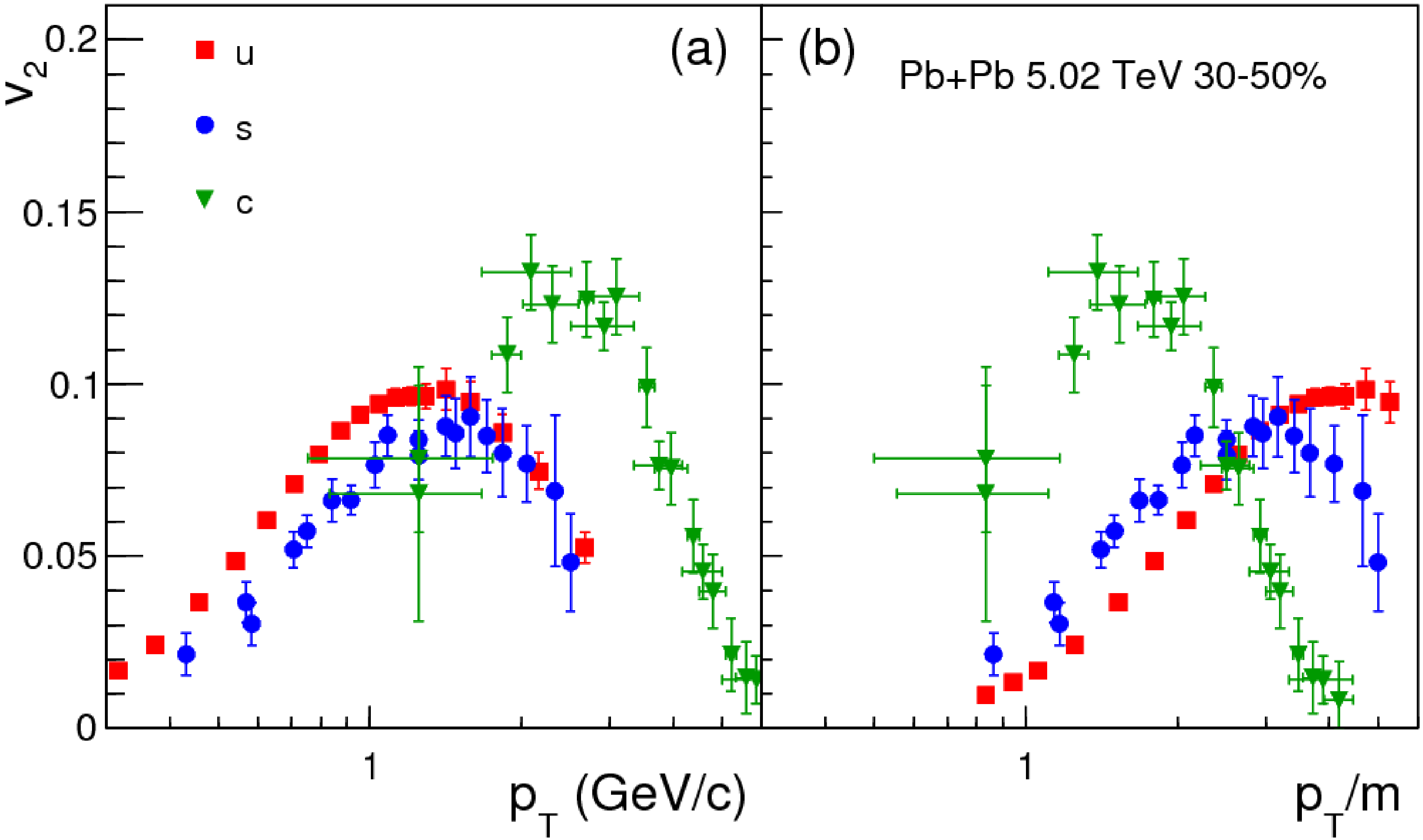
$$v_{2,\Xi_c}(p_T) = v_{2,u}\left(\frac{1}{1+r+r_{cu}}p_T\right) + v_{2,s}\left(\frac{r}{1+r+r_{cu}}p_T\right) + v_{2,c}\left(\frac{r_{cu}}{1+r+r_{cu}}p_T\right)$$





(a)
D^0 exp data
v_{2,u}(p_{T,u} = p_T/(1+r_{cu}))
c quark QCM
fit of c quark
v_2
0.2
0.1
0
2
4
6
p_T (GeV/c)
(b)
AuAu 200 GeV 0-80%
Λ_c^+ QCM
Ξ_c^0 QCM
D_s^+ QCM
2
4
6
p_T (GeV/c)

Compare v_2 of up, strange and charm quarks



7.

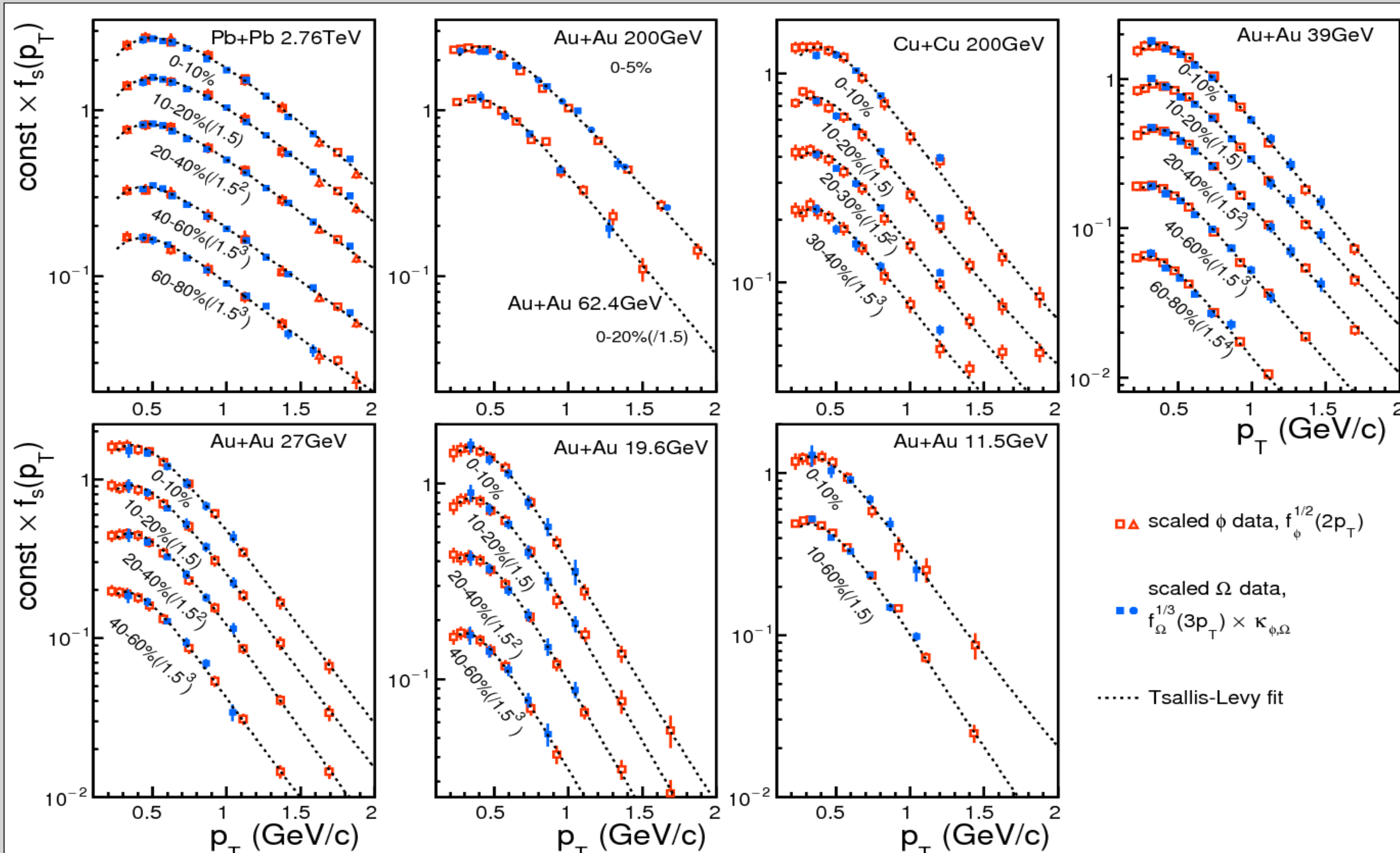
Energy-scan study for hadronic p_T spectra in Au+Au collisions at $\sqrt{s_{NN}} = 7.7 - 200$ GeV

Refs:

- Jun Song, xiao-feng Wang, Hai-hong Li, Rui-qin Wang, Feng-lan Shao, arxiv:2007.14588v1.
- Jun Song, Feng-lan Shao, and Zuo-tang Liang, Phys.RevC.102.014911(2020).

Song,Shao,Liang Phys.RevC.102.014911(2020)

QNS in heavy-ion collisions



Strangeness neutralization

Asymmetry factor : $z_S = \frac{N_{\bar{s}} - N_s}{N_{\bar{s}} + N_s}$

Table I. Strangeness asymmetry factor z_S calculated by yield data of strange hadrons and anti-hadrons in central Au+Au collisions [29, 41–45, 48].

$\sqrt{s_{NN}}$ (GeV)	$K^{+,-}$	Λ ($\bar{\Lambda}$)	Ξ^- ($\bar{\Xi}^+$)	Ω^- ($\bar{\Omega}^+$)	ϕ	z_S
200	48.9 ± 6.3 45.7 ± 5.2	16.7 ± 1.1 12.7 ± 0.9	2.17 ± 0.2 1.83 ± 0.2	0.53 ± 0.06	7.95 ± 0.11	-0.004 ± 0.06
62.4	37.6 ± 2.7 32.4 ± 2.3	15.7 ± 2.3 8.3 ± 1.1	1.63 ± 0.2 1.03 ± 0.11	0.212 ± 0.028 0.167 ± 0.027	3.52 ± 0.08	-0.019 ± 0.04
39	32.0 ± 2.9 25.0 ± 2.3	11.02 ± 0.03 3.82 ± 0.01	1.54 ± 0.01 0.78 ± 0.01	0.191 ± 0.006 0.139 ± 0.004	3.38 ± 0.03	-0.002 ± 0.05
27	31.1 ± 2.8 22.6 ± 2.0	11.67 ± 0.04 2.75 ± 0.01	1.57 ± 0.01 0.598 ± 0.006	0.154 ± 0.008 0.0972 ± 0.0049	3.01 ± 0.04	-0.006 ± 0.05
19.6	29.6 ± 2.9 18.8 ± 1.9	12.58 ± 0.04 1.858 ± 0.009	1.62 ± 0.02 0.421 ± 0.005	0.155 ± 0.01 0.0811 ± 0.0048	2.57 ± 0.04	-0.0002 ± 0.05
11.5	25.0 ± 2.5 12.3 ± 1.2	14.17 ± 0.08 0.659 ± 0.009	1.35 ± 0.02 0.169 ± 0.004	0.082 ± 0.012 0.0356 ± 0.0052	1.72 ± 0.04	-0.004 ± 0.05
7.7	20.8 ± 1.7 7.7 ± 0.6	15.3 ± 0.11 0.193 ± 0.006	1.19 ± 0.03 0.0667 ± 0.0044	0.0271 ± 0.0048 0.0075 ± 0.0013	1.21 ± 0.06	-0.021 ± 0.04

$$\frac{f_{\bar{s}}(p_T)}{f_s(p_T)} = \kappa_{\bar{\Omega},\Omega}\left[\frac{f_{\bar{\Omega}}(3p_T)}{f_{\Omega}(3p_T)}\right]^{1/3}$$

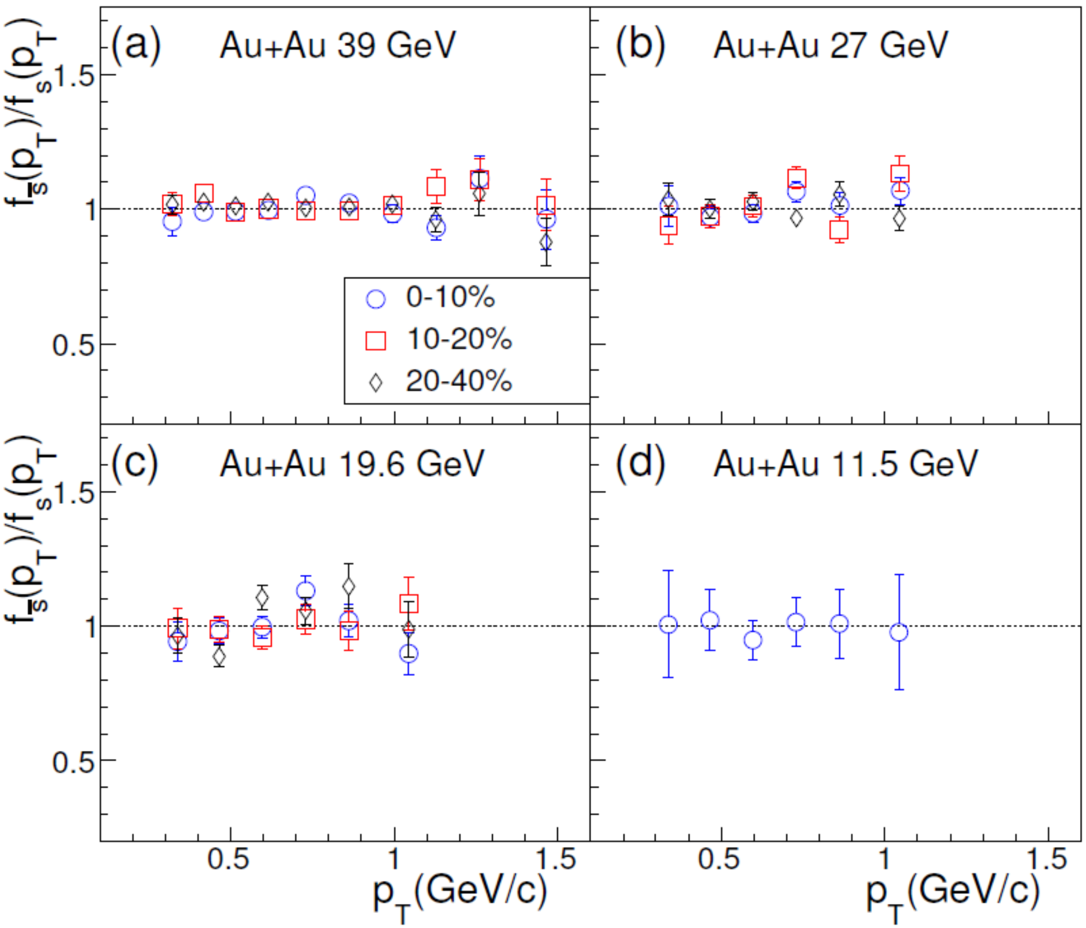


Figure 1. Ratio $f_{\bar{s}}(p_T)/f_s(p_T)$ in Au+Au collisions at different collision energies obtained from experimental data of Ω^- and $\bar{\Omega}^+$ in central and semi-central collisions [29, 48] by Eq.

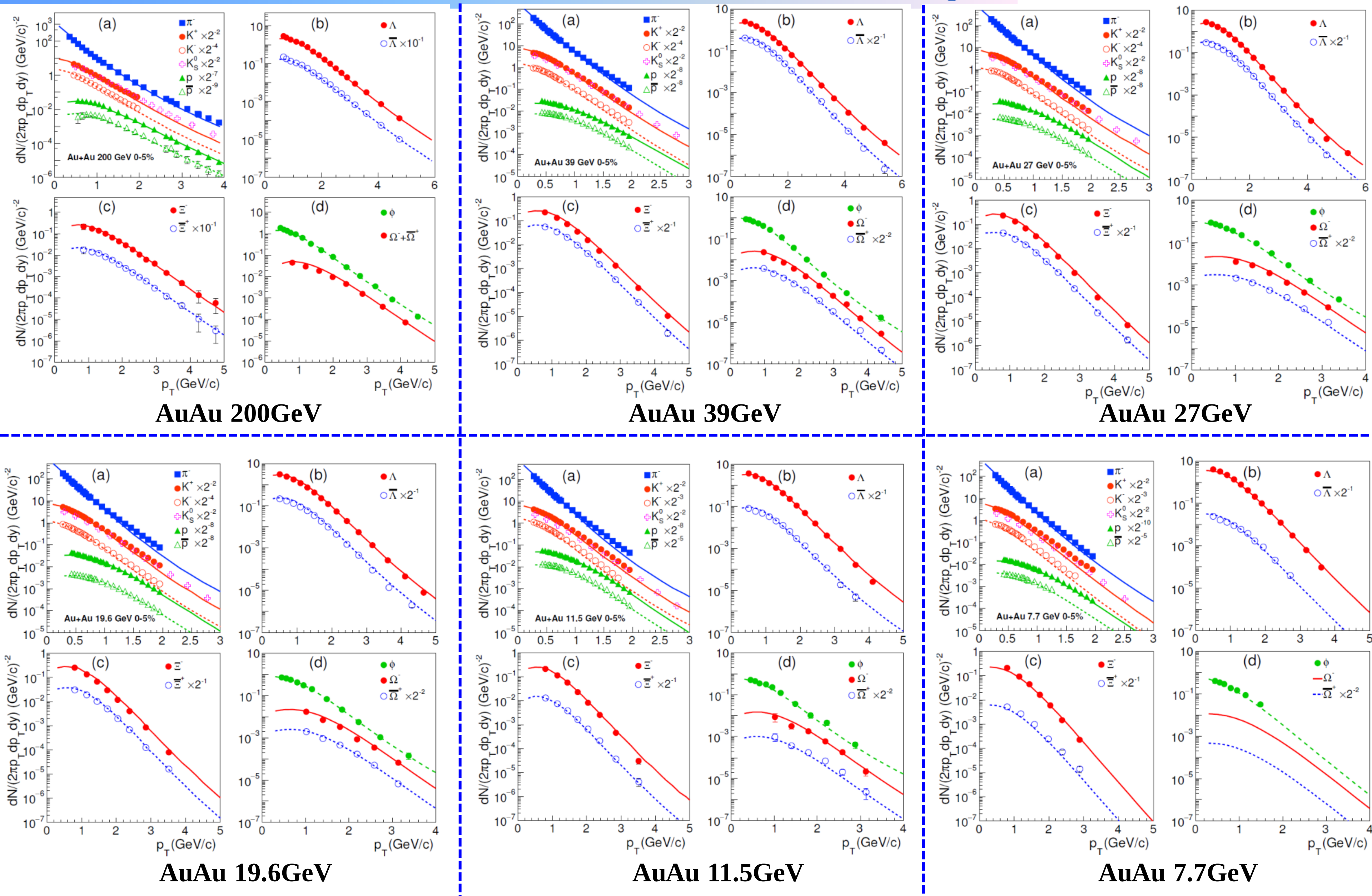
We have

$$f_s(p_T) \approx f_{\bar{s}}(p_T)$$

at midrapidity in HIC

p_T spectra at STAR BES energies

Song,Shao, et al., arxiv:2007.14588v1



Three inputs $f_u(p_T) \approx f_d(p_T)$, $f_{\bar{u}}(p_T) \approx f_{\bar{d}}(p_T)$, $f_s(p_T) \approx f_{\bar{s}}(p_T)$ at each energy.

Summary

EVC is an effective mechanism.

- ✓ **quark number scaling for hadronic p_T spectra.**
- ✓ **self-consistent description for p_T spectra of light-flavor hadrons as well as single-charmed hadrons in pp and pPb collisions at LHC energies.**
- ✓ **v_2 of hadrons in heavy-ion collisions.**
- ✓ **energy-scan test of hadronic p_T spectra in Au+Au collisions at $\sqrt{s_{NN}} = 7.7 - 200$ GeV.**

Outlook

- **Systematic analysis on the obtained quark distribution functions at hadronization.**
- **The underlying physics of EVC.**

Thanks !