Probing the partonic degree of freedom in small systems

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(for Yuanyuan Wang)

Peking University

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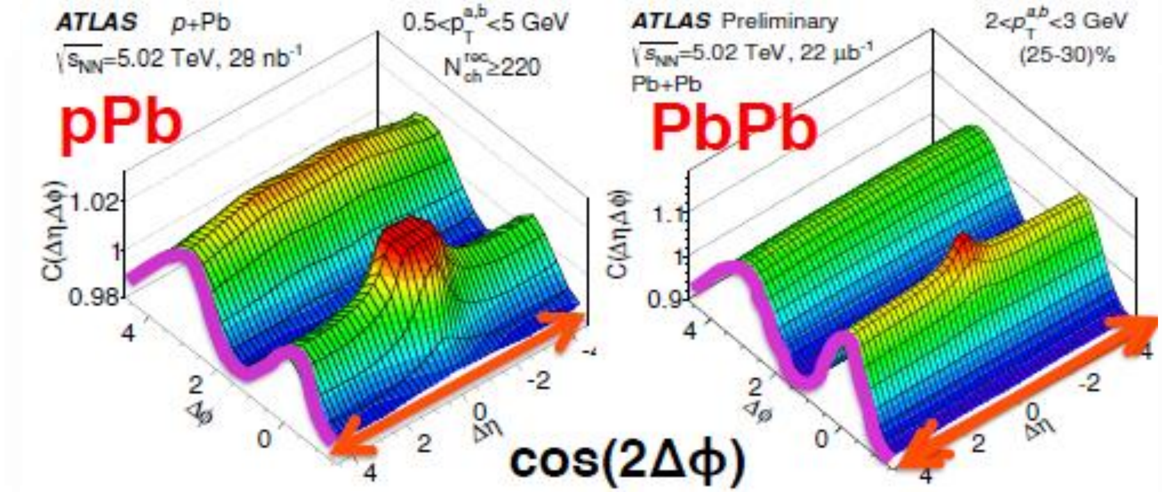
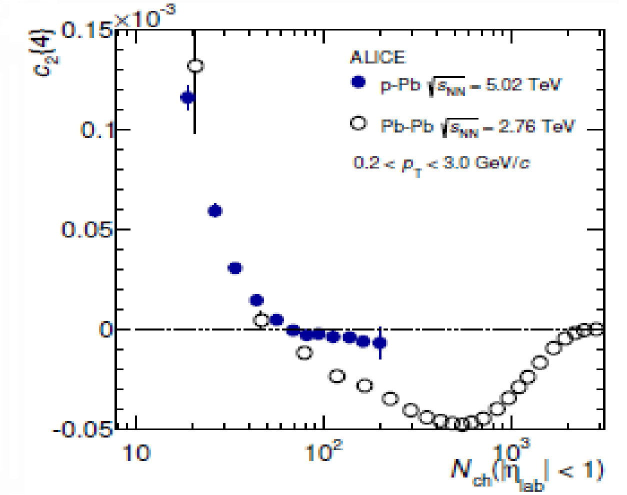
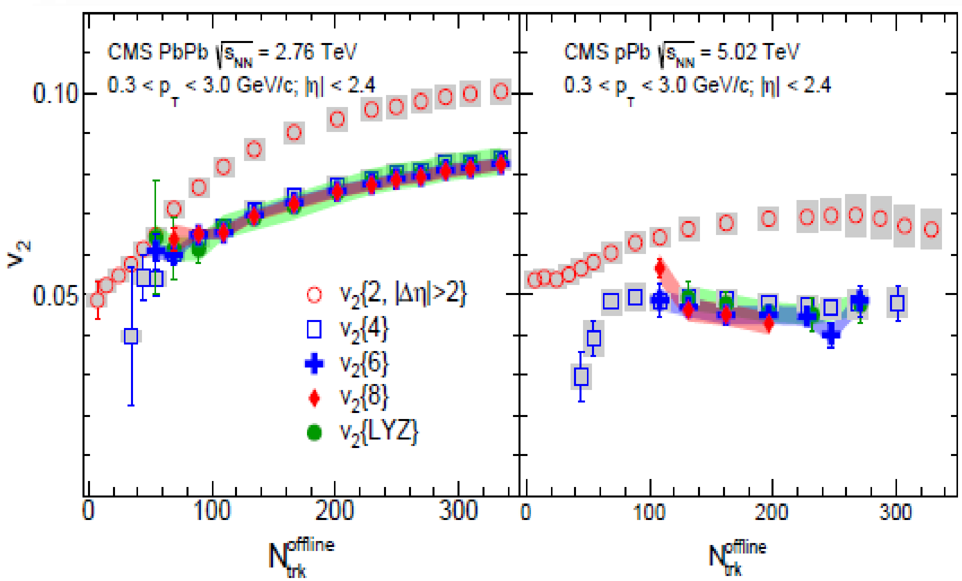
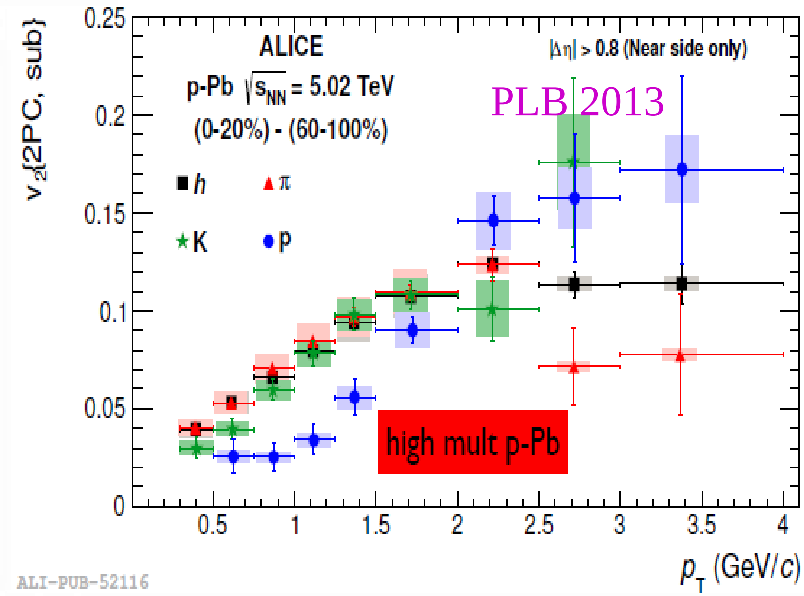
Jun 21, 2023

Correlations & Flow in small systems



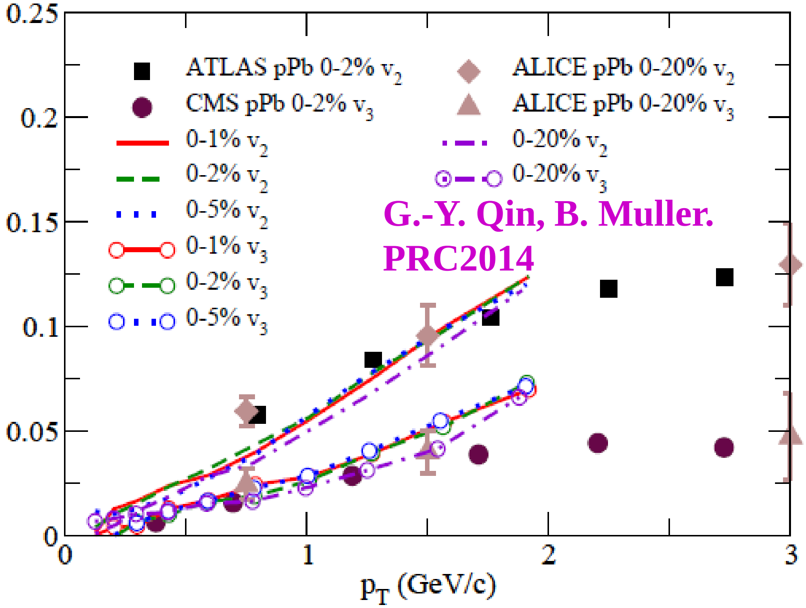


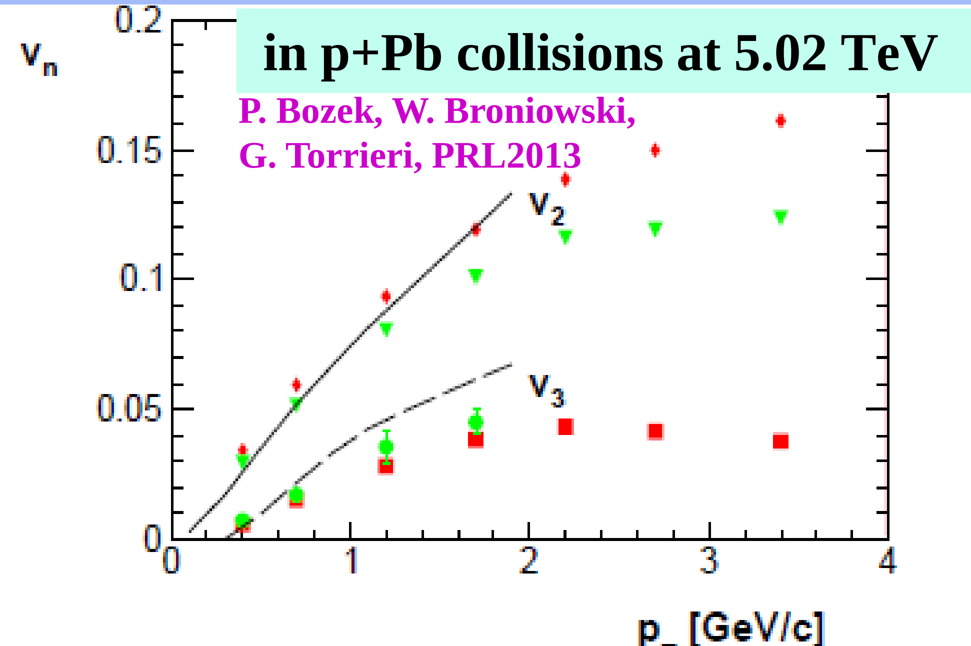


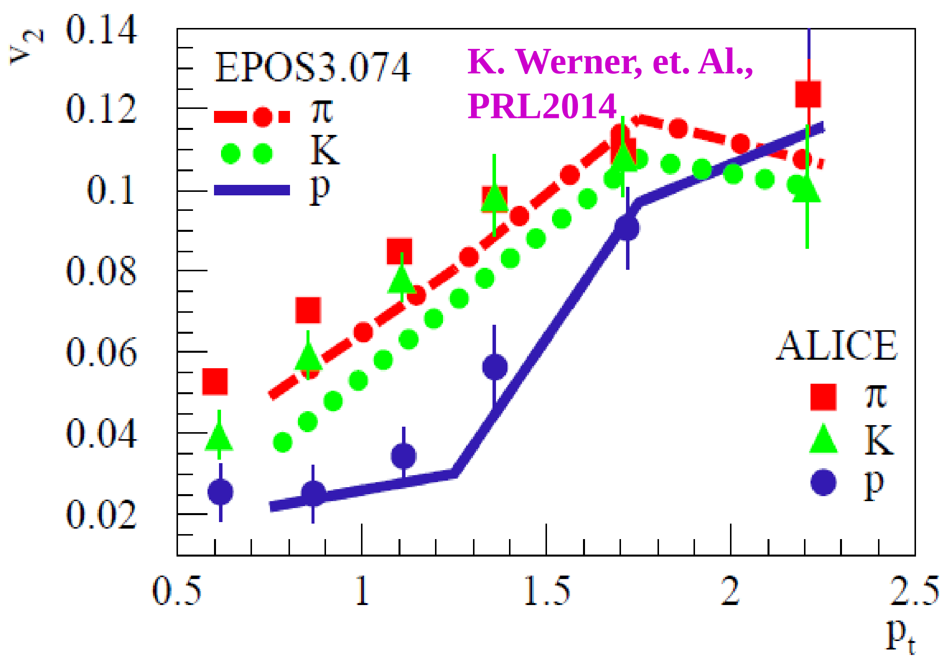


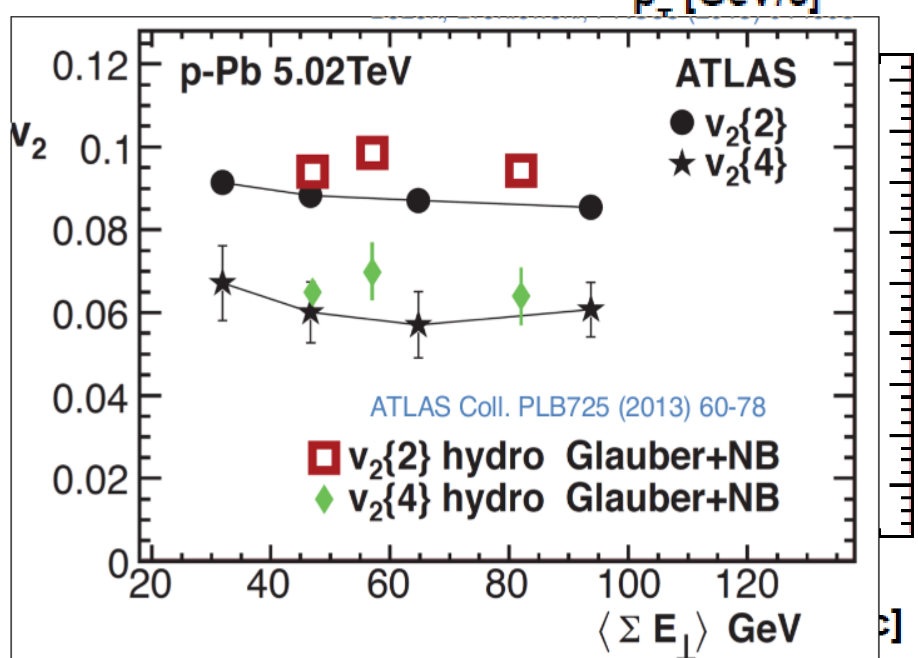
-Many flow-like signals have been observed in high multiplicity events

Flow in small systems-- Hydro Simulations









Initial state or Final state effects?

Initial state effects: – Various Models interpolations

-K. Dusling and R. Venugopalan, PRL 2012, PRD2013, NPA 2014

-A. Dumitru and A. V. Giannini, NPA 2015, A. Dumitru and V. Skokov PRD2015

-B. Schenke, S. Schlichting, P. Tribedy, and R. Venugopalan, PRL2016

-K. Dusling et al, Phys. Rev. Lett 120 042002 (2018)

-C. Zhang, et al Phys. Rev. Lett. 122, no. 17, 172302 (2019).

… … … …

Final state interactions:

-P. Bozek, W. Broniowski, G. Torrieri, PRL2013

-K. Werner, et. Al., PRL2014

-G.-Y. Qin, B. Muller. PRC2014

-Y. Zhou, X. Zhu, P. Li, and H. Song, PRC2015

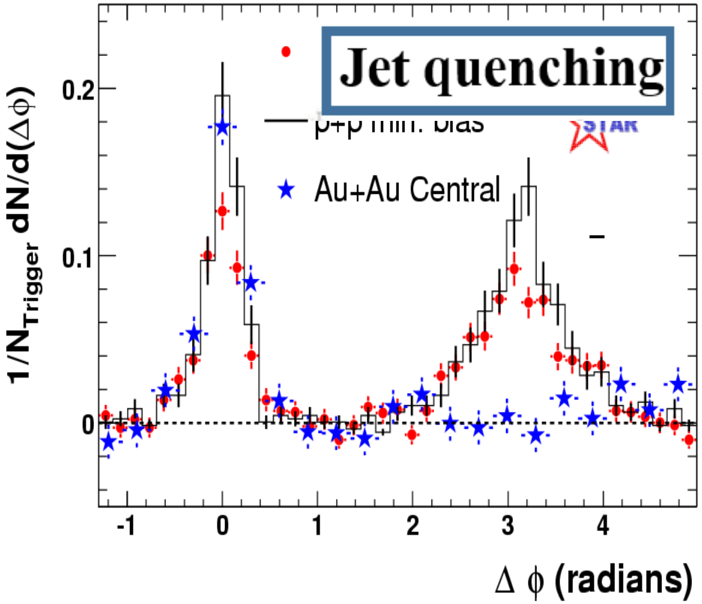
- P. Bozek, A. Bzdak, and G.-L. Ma, PLB2015

- P. Romatschke, Eur.Phys.J. C77 21(2017)

-W. Zhao, Y. Zhou, H. Xu, W. Deng and H. Son
Phys. Lett. B 780, 495 (2018)

… … … …

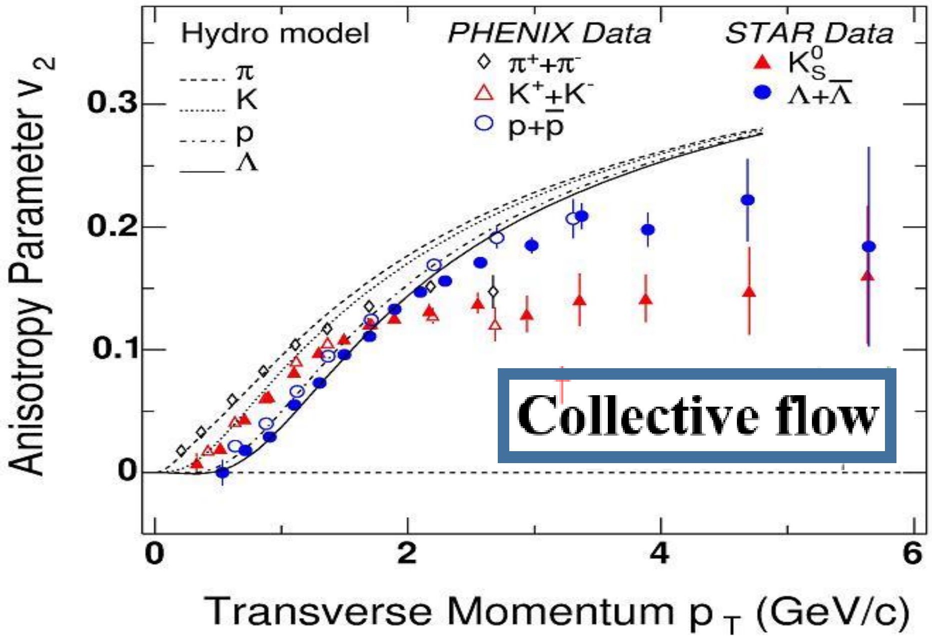
Reminder: QGP signals in large systems

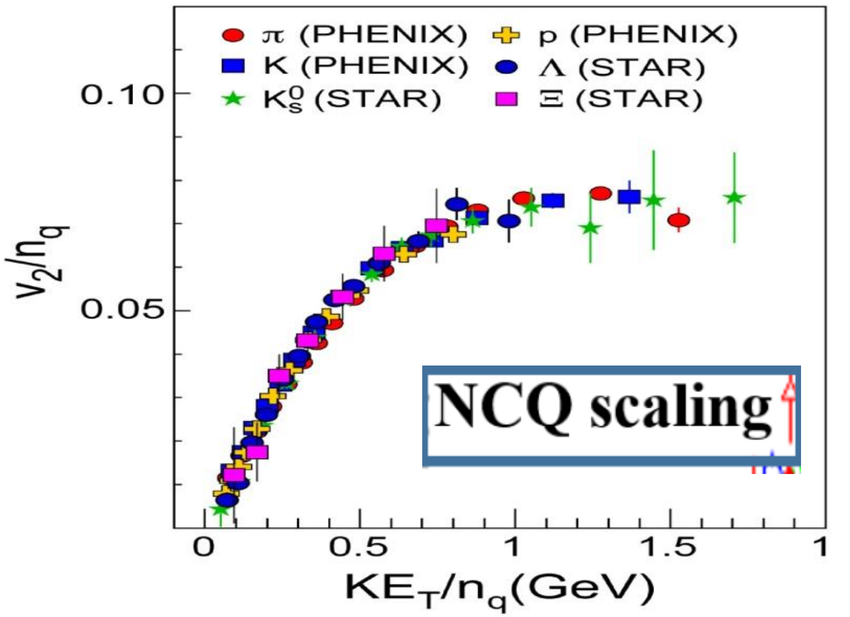


Au+Au

QGP was discovered @RHIC

- **-strong elliptic flow**
- **-jet quenching**
- **-NCQ scaling of elliptic flow**





Probing the partonic degree of freedon

in p-Pb collisions

QGP signals in p-Pb collisions?

Low P_T | **Intermediate P_T** | **High P_T**

0 — **2 GeV** — **6 GeV** — **P_T**

<u>Collective Flow:</u>

Hydrodynamics

final states interaction

Initial state effects ?

<u>Hard Probes:</u>

no longer leave obvious hints due to the limited size.

NCQ scaling of v_2 in p-Pb collisions

Low P_T | **Intermediate P_T** | **High P_T**

0 — 2 GeV — 6 GeV — P_T

Collective Flow:

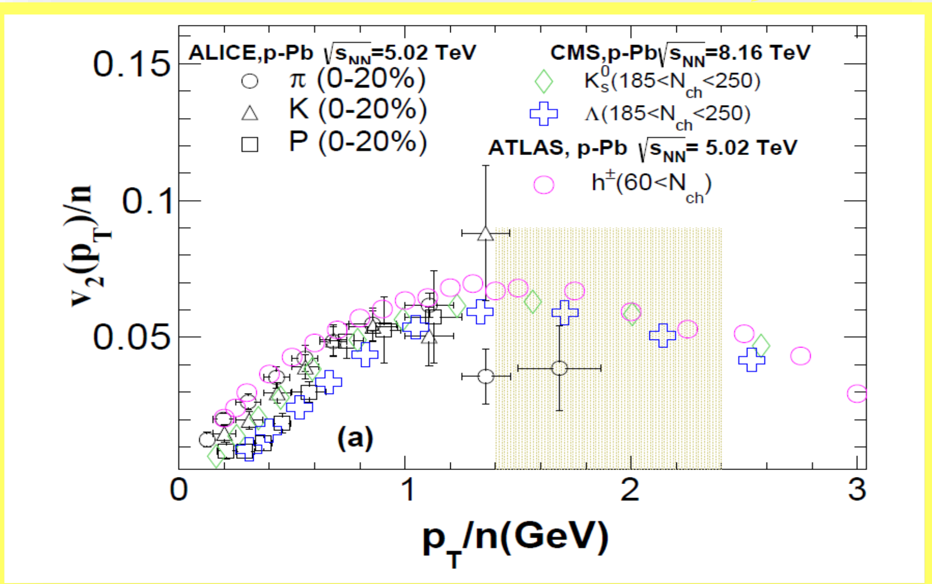
Hydrodynamics
final states interaction
Initial state effects ?

NCQ Scaling of V2:

-Recent Exp measurements-
-need systematic theoretical investigation

Hard Probes:

no longer leave obvious hints due to the limited size.



ALICE data: PLB,726, 164 (2013).
CMS data: PRL, 121, 082301 (2018).
ATLAS data: PRC, 96, 024908 (2017).

-Where does such approximate NCQ scaling of v_2 come from?

-Is it an indication of partonic degree of freedom?

coalescence model & NCQ scaling of v_2

Coalescence model for large systems (Au+Au)

$$\frac{dN_M}{d^3\mathbf{P}_M} = g_M \int d^3\mathbf{x}_1 d^3\mathbf{p}_1 d^3\mathbf{x}_2 d^3\mathbf{p}_2 f_q(\mathbf{x}_1,\mathbf{p}_1) f_{\bar{q}}(\mathbf{x}_2,\mathbf{p}_2) \times W_M(\mathbf{y},\mathbf{k}) \delta^{(3)}(\mathbf{P}_M - \mathbf{p}_1 - \mathbf{p}_2)$$

$$\frac{dN_B}{d^3\mathbf{P}_B} = g_B \int d^3\mathbf{x}_1 d^3\mathbf{p}_1 d^3\mathbf{x}_2 d^3\mathbf{p}_2 d^3\mathbf{x}_3 d^3\mathbf{p}_3 f_{q_1}(\mathbf{x}_1,\mathbf{p}_1) \times f_{q_2}(\mathbf{x}_2,\mathbf{p}_2) f_{q_3}(\mathbf{x}_3,\mathbf{p}_3) W_B(\mathbf{y}_1,\mathbf{k}_1;\mathbf{y}_2,\mathbf{k}_2) \times \delta^{(3)}(\mathbf{P}_B - \mathbf{p}_1 - \mathbf{p}_2 - \mathbf{p}_3)$$

- thermal - thermal parton coalescence

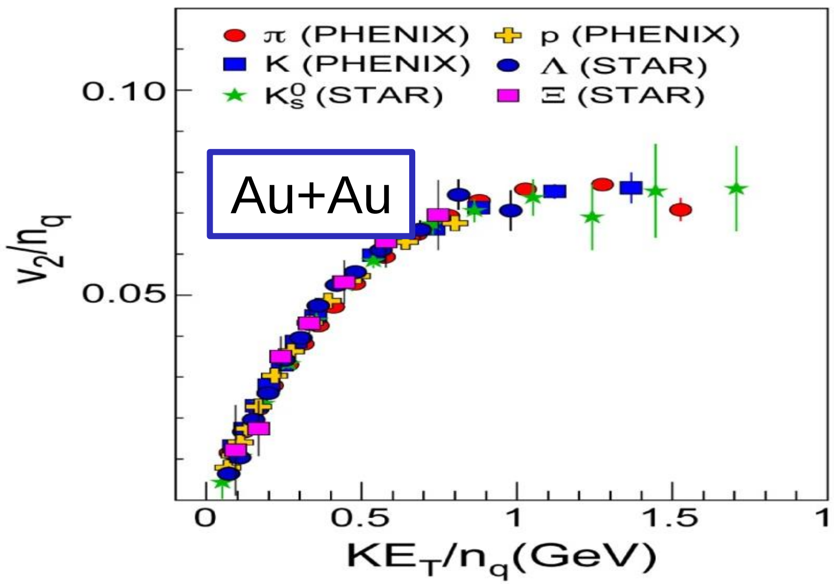
Au+Au collisions

QGP was discovered @RHIC

-strong elliptic flow

-jet quenching

-NCQ scaling of elliptic flow



coalescence model & NCQ scaling of v_2

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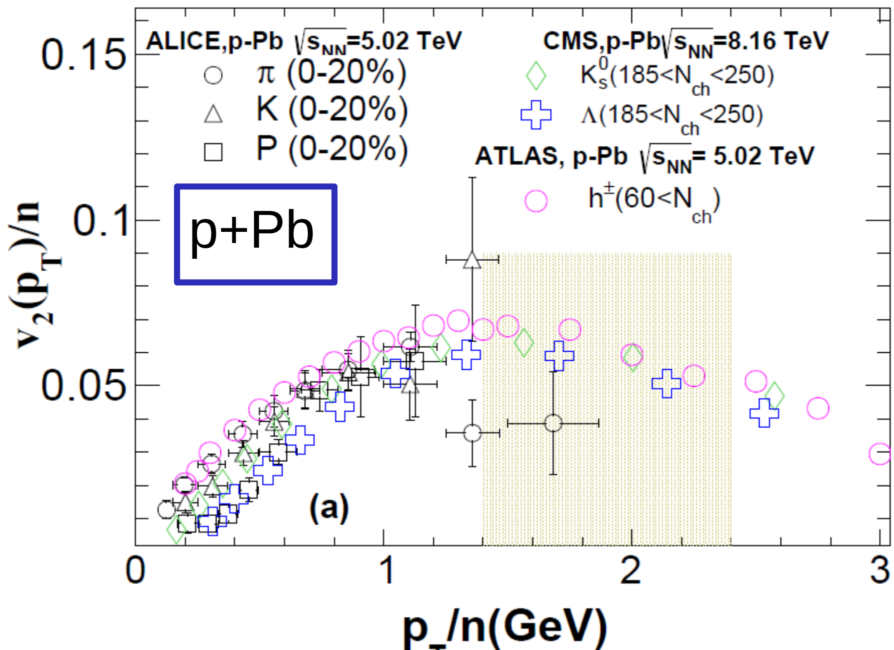
- thermal - thermal parton coalescence

Small collision systems (p-Pb):

-the effects from mini-jets/ fragmentations from high p_T becomes important

Coalescence processes:

- **thermal - thermal parton coalescence**
- **thermal - hard parton coalescence**
- **hard - hard parton coalescence**



Hydro-Coal-Frag Hybrid Model

Zhao, Ko, Liu, Qin & Song.
Phys. Rev. Lett. 125 7 072301(2020)

Thermal hadrons (VISH2+1):

-generated by hydro. with Cooper-Frye.

-Meson: $P_T < 2P_1$; baryon: $P_T < 3P_1$.

Coalescence hadrons (Coal Model):

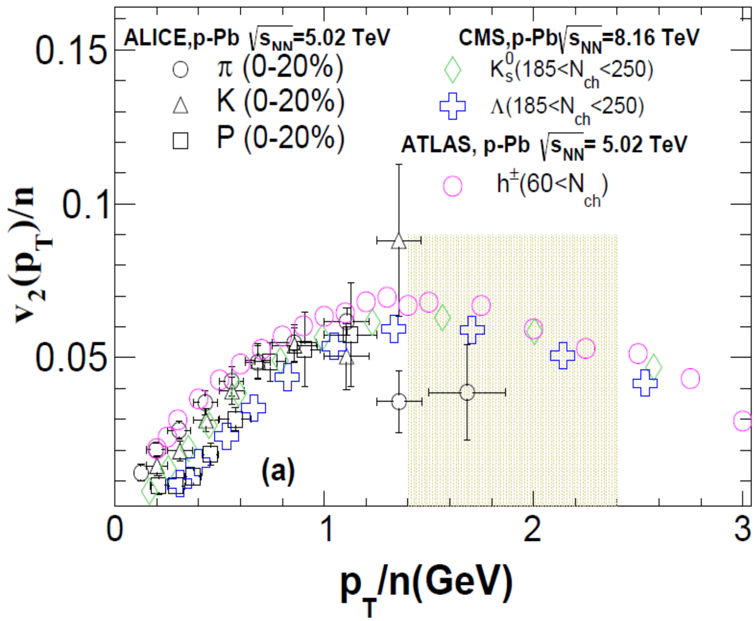
-generated by coalescences model including thermal-thermal, thermal-hard & hard-hard parton coalescence.

Fragmentation hadrons (LBT):

-*Hard partons* generated by PYTHIA8, then suffered energy loss by LBT

UrQMD afterburner:

-All hadrons are feed into UrQMD for hadronic evolution, scatterings and decays.



Main Parameters:

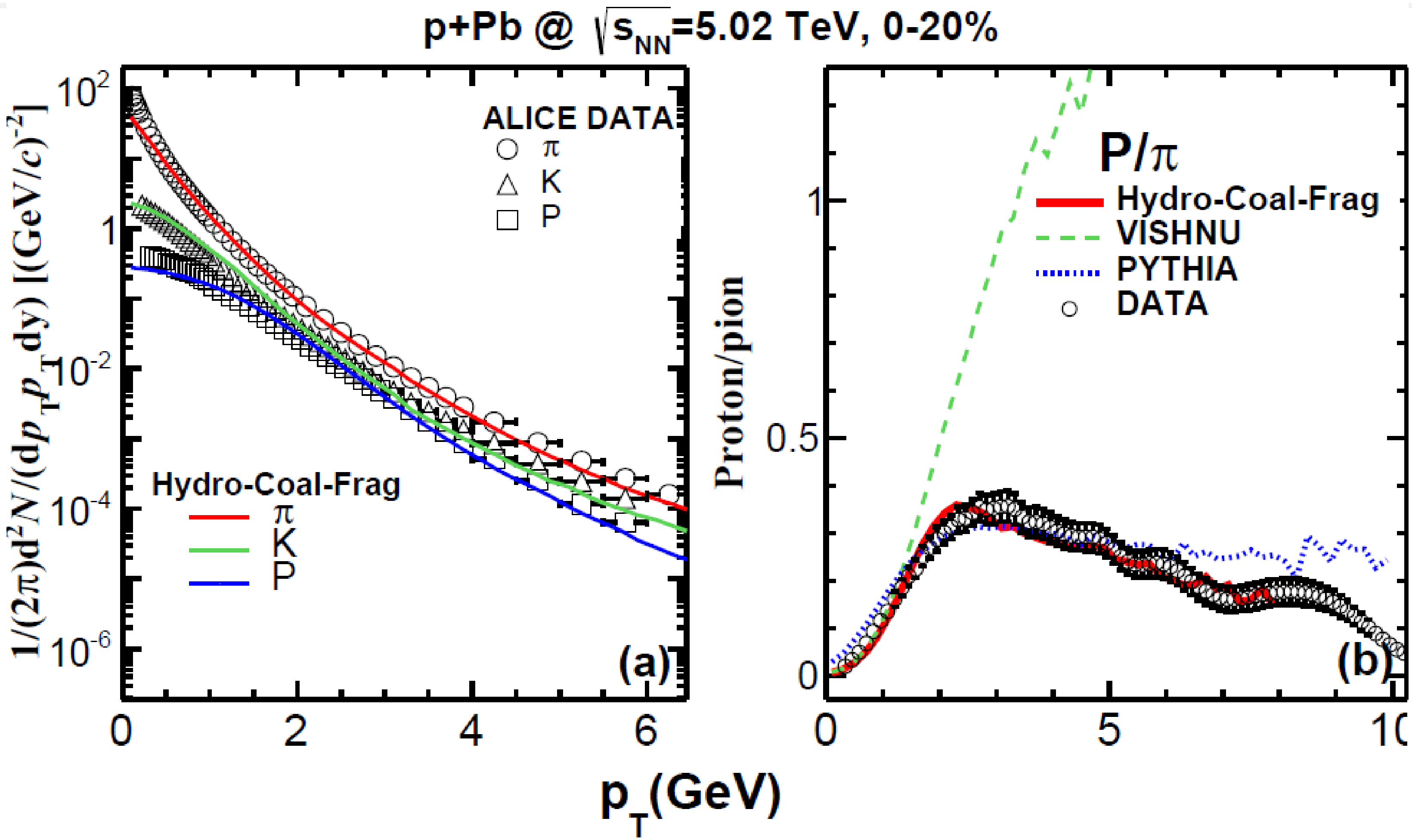
-***Thermal partons*** **from hydro with** $P_T > P_1$.

-***Hard partons*** **from LBT with** $P_T > P_2$.

Fixed by the p_T spectra

$P_{T1} = 1.6\text{GeV}$ and $P_{T2} = 2.6\text{GeV}$

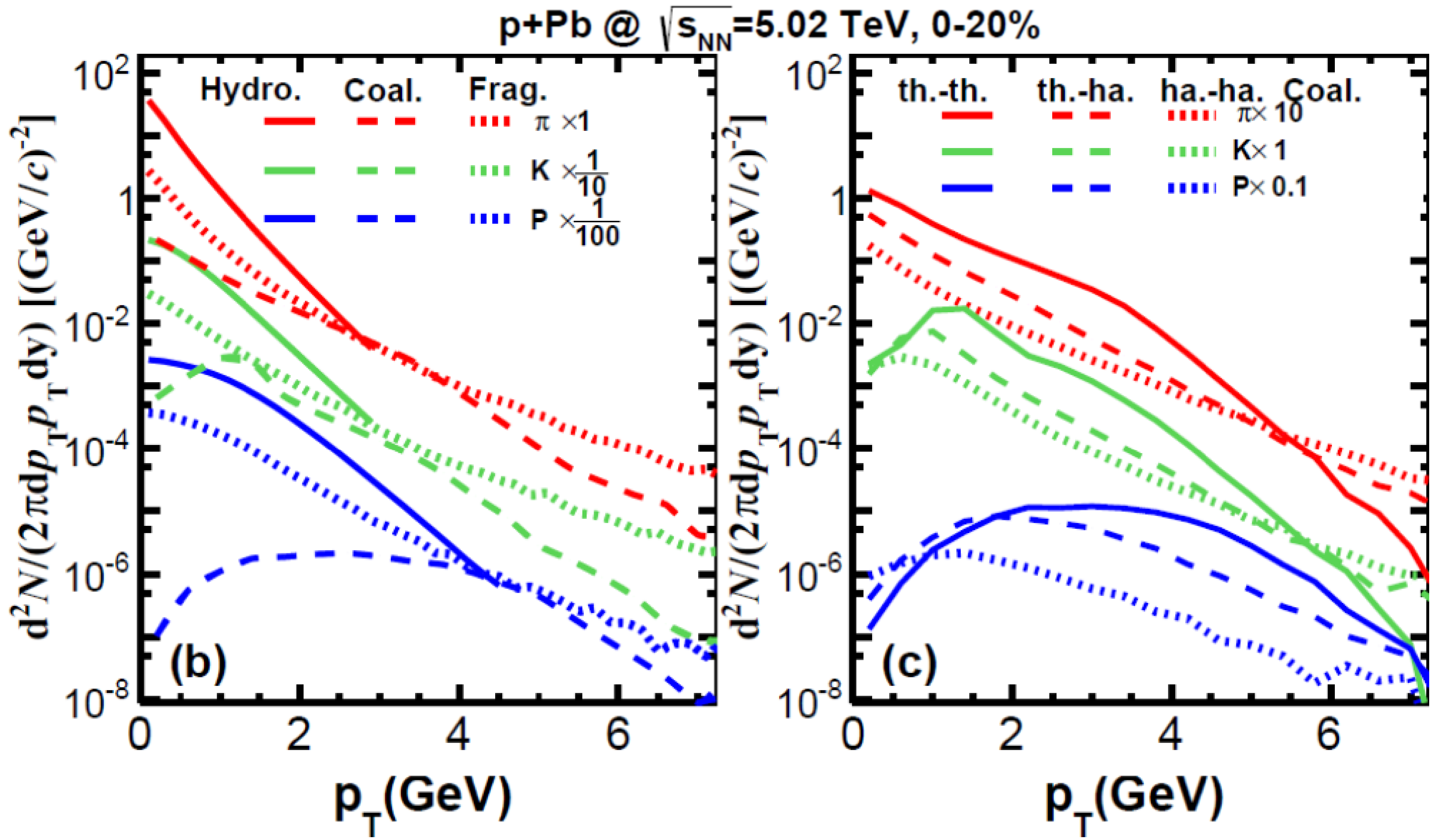
Spectra of pions, kaons and protons



-Hydro-Coal-Frag, gives a nice description of spectra of pion, kaon and proton as well as the P/π over p_T from 0 to 6 GeV.

Zhao, Ko, Liu, Qin & Song. Phys. Rev. Lett. 125 7 072301(2020)

Spectra of pions, kaons and protons

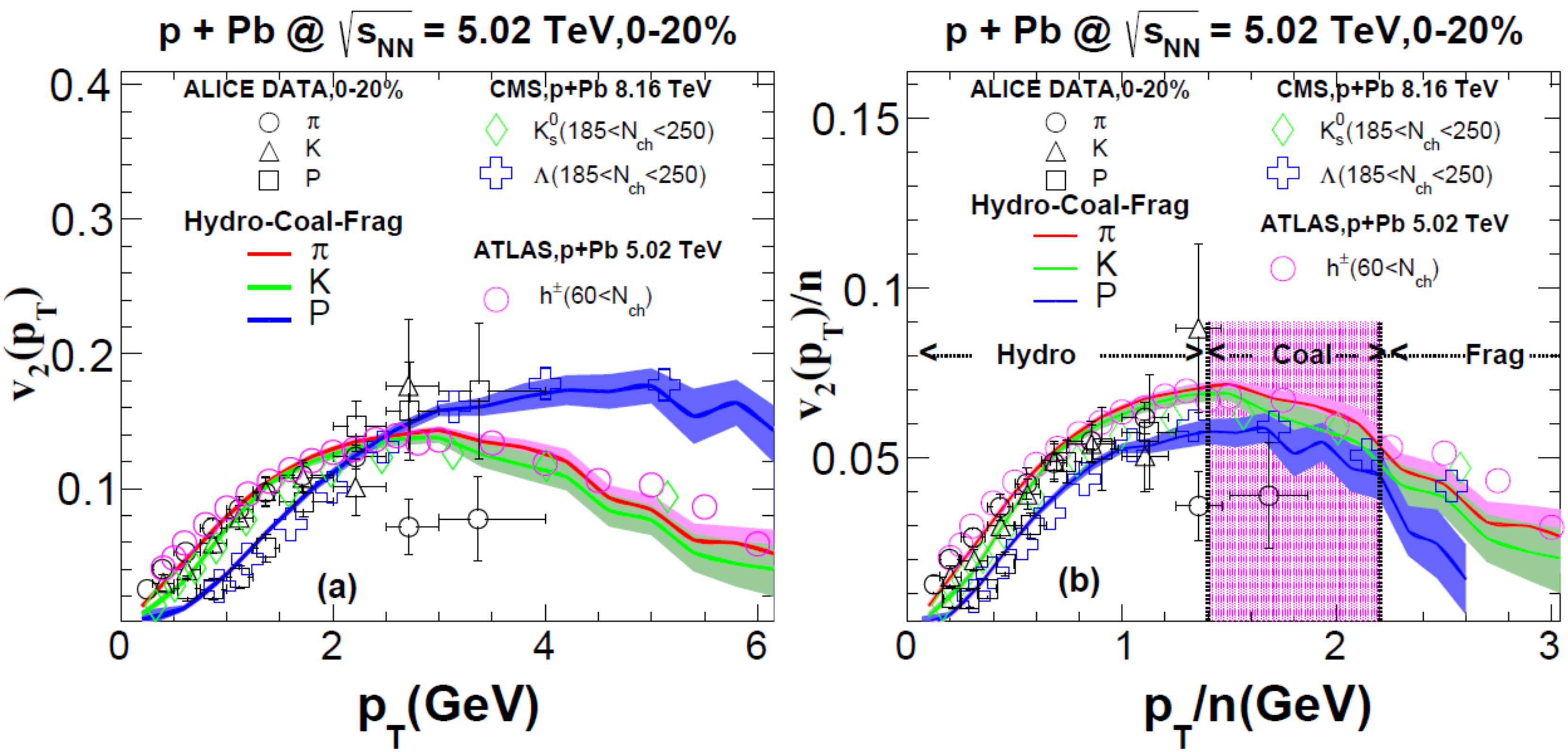


-Low p_T hadrons mainly come from hydro, Intermediate p_T hadrons mainly come from Coal. & Frag. High p_T hadrons come from Frag.

-Coalescence hadrons: Thermal-thermal coalescence contribute most at intermediate p_T.

Zhao, Ko, Liu, Qin & Song. Phys. Rev. Lett. 125 7 072301(2020)

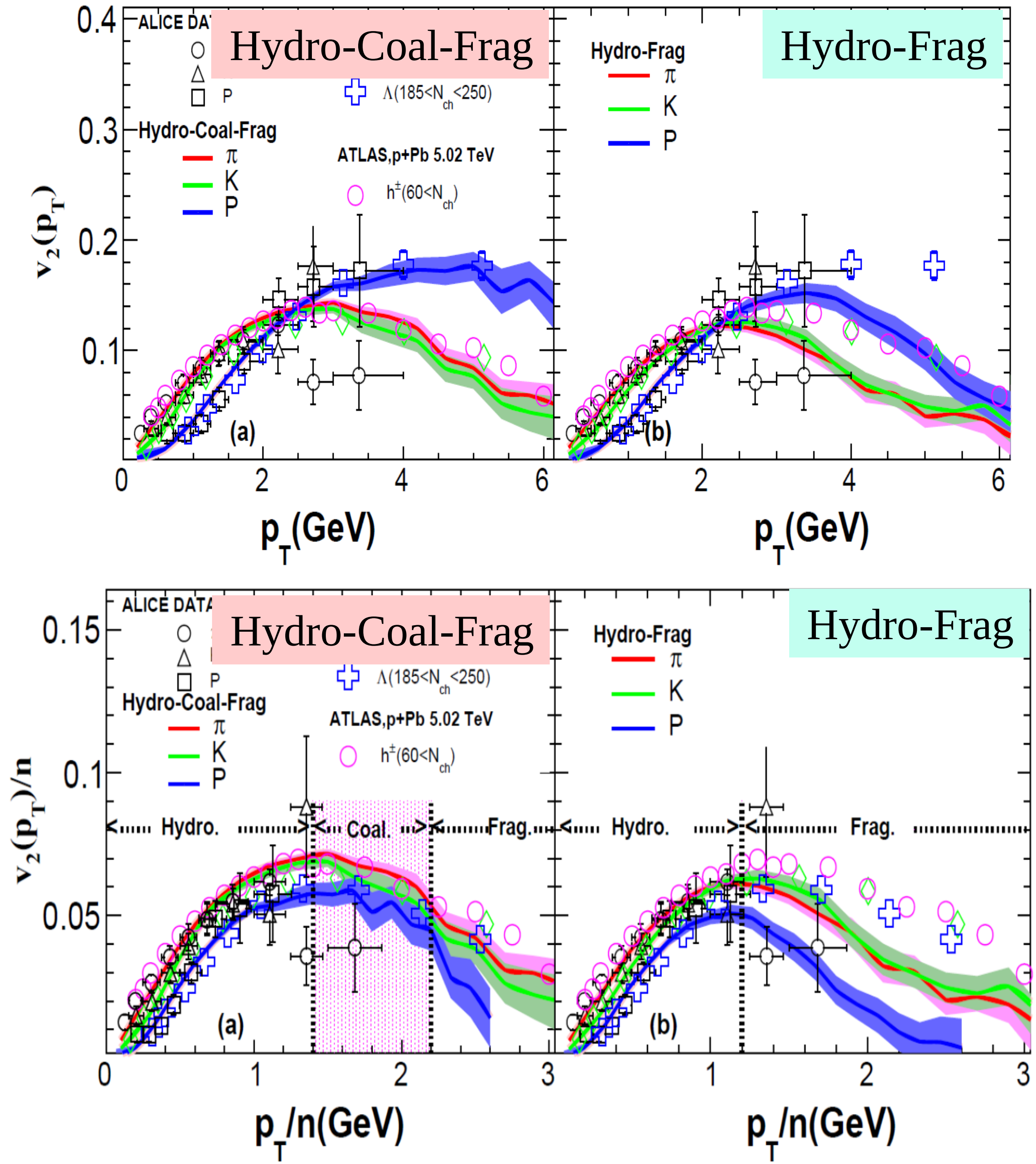
NCQ scaling of v_2 & hint partonic degree of freedom



-Hydro-Coal-Frag model gives a nice description of $v_2(p_T)$ of pion, kaon and proton from 0 to 6 GeV.

-At intermediate p_T, Hydro-Coal-Frag model obtains an approximate NCQ scaling as shown by the data.

Zhao, Ko, Liu, Qin & Song. Phys. Rev. Lett. 125 7 072301(2020)



The importance of quark coalescence in p-Pb collisions

Without coalescence, Hydro-Frag largely underestimates the $v_2(p_T)$ at intermediate p_T, violating the NCQ Scaling of v_2.

Strongly indication of partonic degree of freedom in small system !

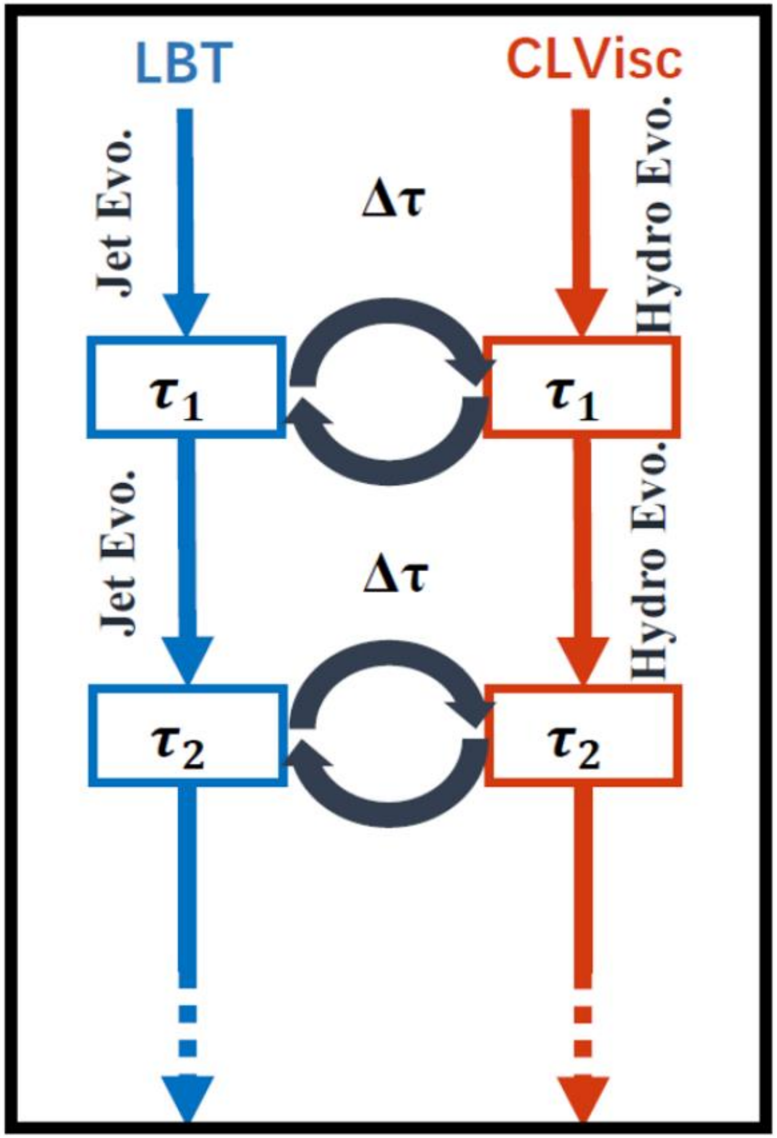
Zhao, Ko, Liu, Qin & Song, Phys. Rev. Lett. 125 7 072301(2020)

Probing the partonic degree of freedon in Pb-Pb collisions

Zhao, Chen, Luo, Ke & Wang.
Phys. Rev. Lett. 128 2 022302(2022).

CoLBT-Hydro Model + Hydro-Coal-Frag Model

CoLBT-Hydro Model



Chen, Cao, Luo, Pang & Wang.
Phys. Lett. B 810, 135783 (2020).

Linear Boltzmann Transport Model
3+1D hydrodynamic model

LBT ⟷ CLVis

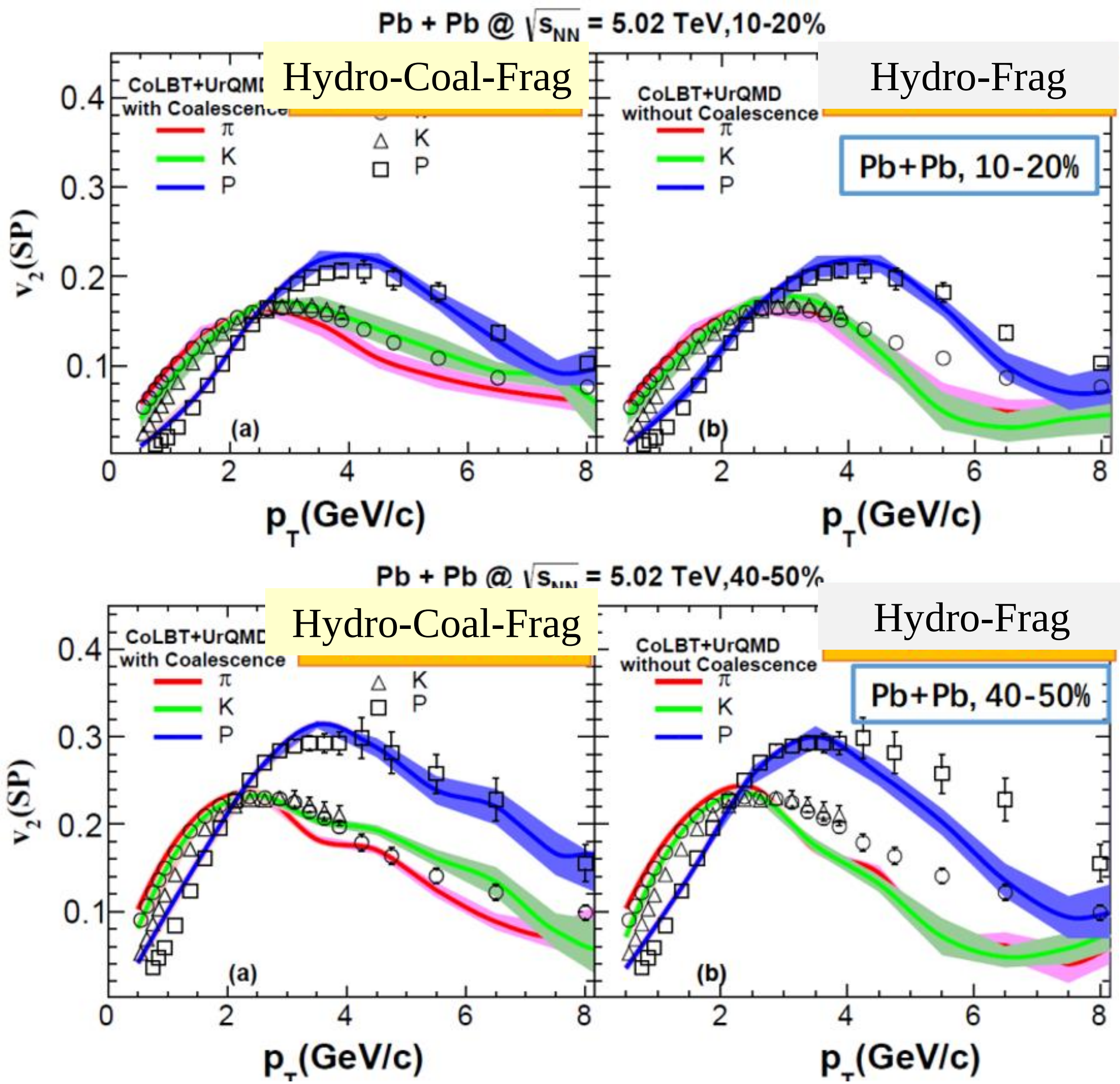
-Evolve the energetic partons and the bulk medium concurrently.

-Hadronization by Hydro-Coal-Frag followed by the UrQMD.

- **thermal - thermal parton coal**
- **thermal - hard parton coalescence**
- **hard - hard parton coalescence**

Zhao, Chen, Luo, Ke & Wang.
Phys. Rev. Lett. 128 2 022302(2022).

V_2 & the importance of quark coalescence



-CoLBT-hydro with coalescence works well for PID flow from 0 to 8 GeV.

-Quark coalescence is important for Pb+Pbcollisions at intermediate pr range.

thermal-hard parton Coalescence breaks up the NCQ scaling of v2

Zhao, Chen, Luo, Ke & Wang
Phys. Rev. Lett. 128 2 022302(2022).

Evaluating the partonic flow in p-Pb and p-p collisions

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Phys. Rev. Lett. 125 7 072301(2020)

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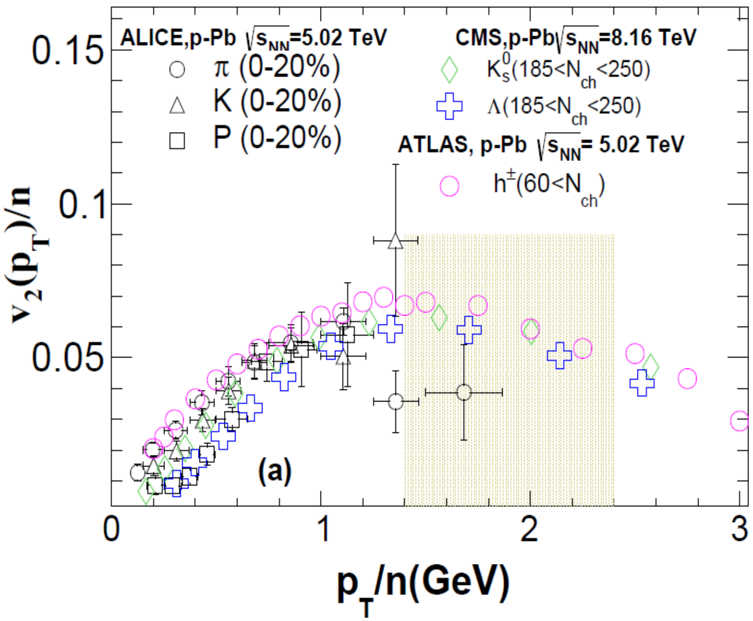

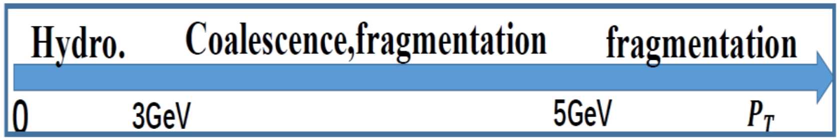

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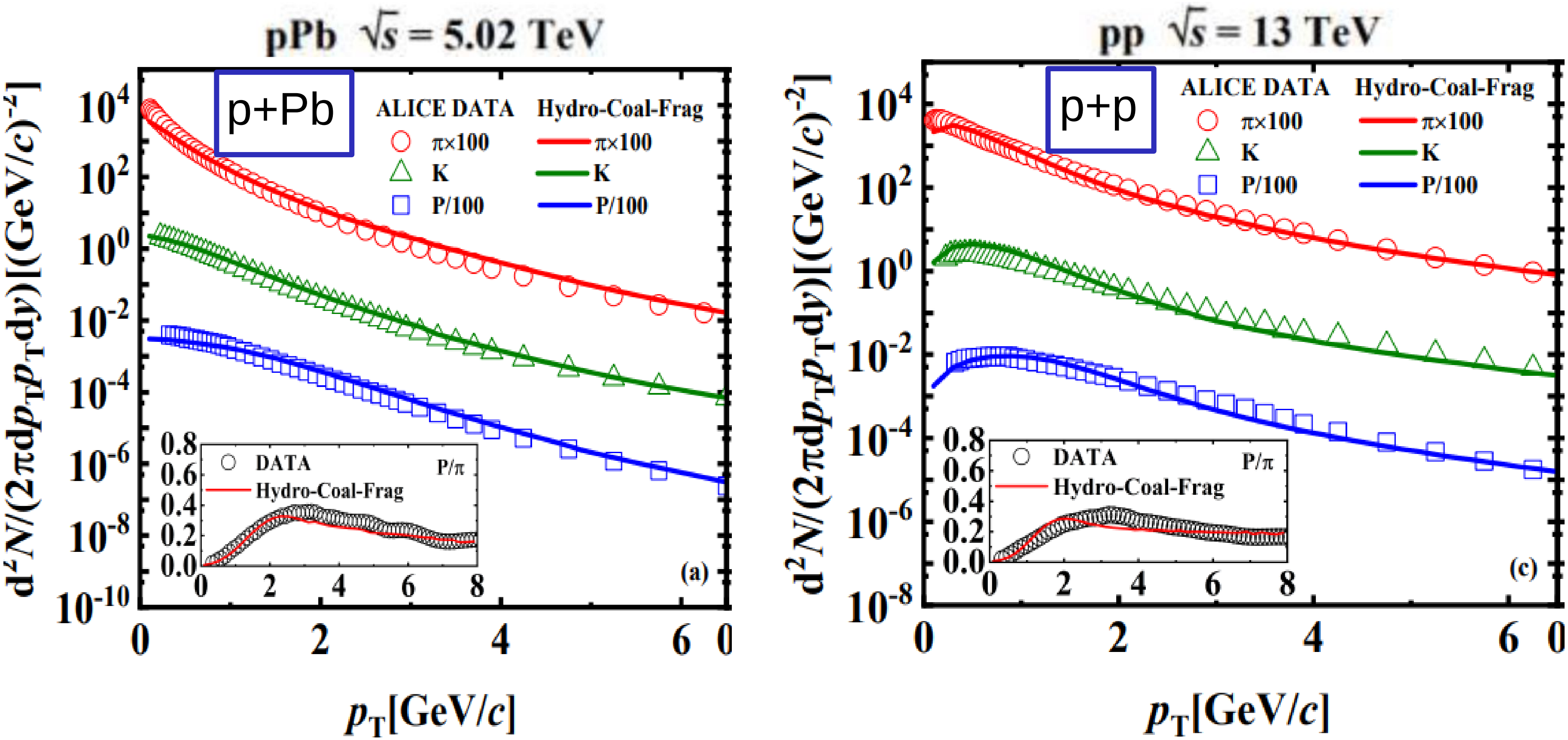
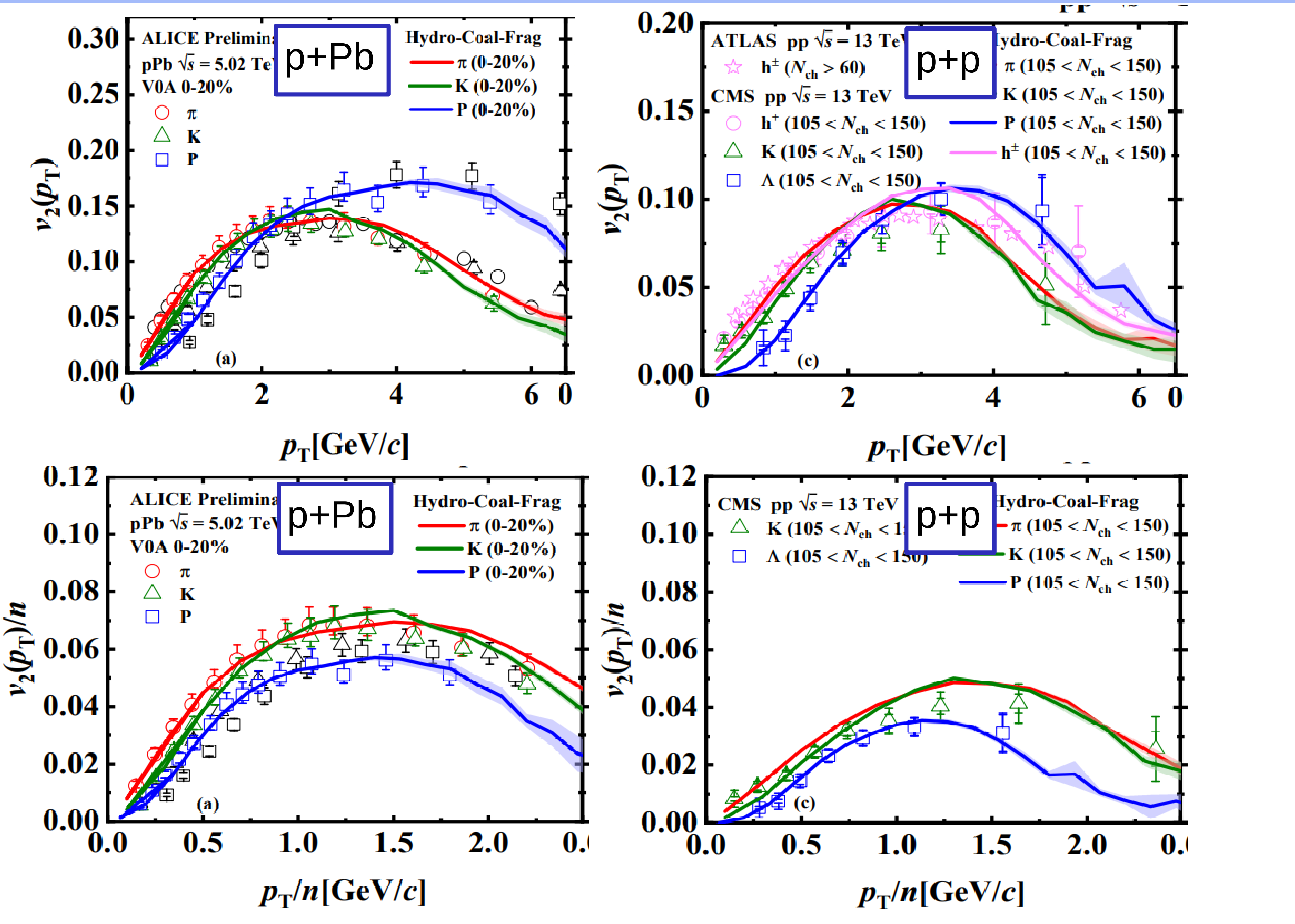
Spectra of pions, kaons and protons



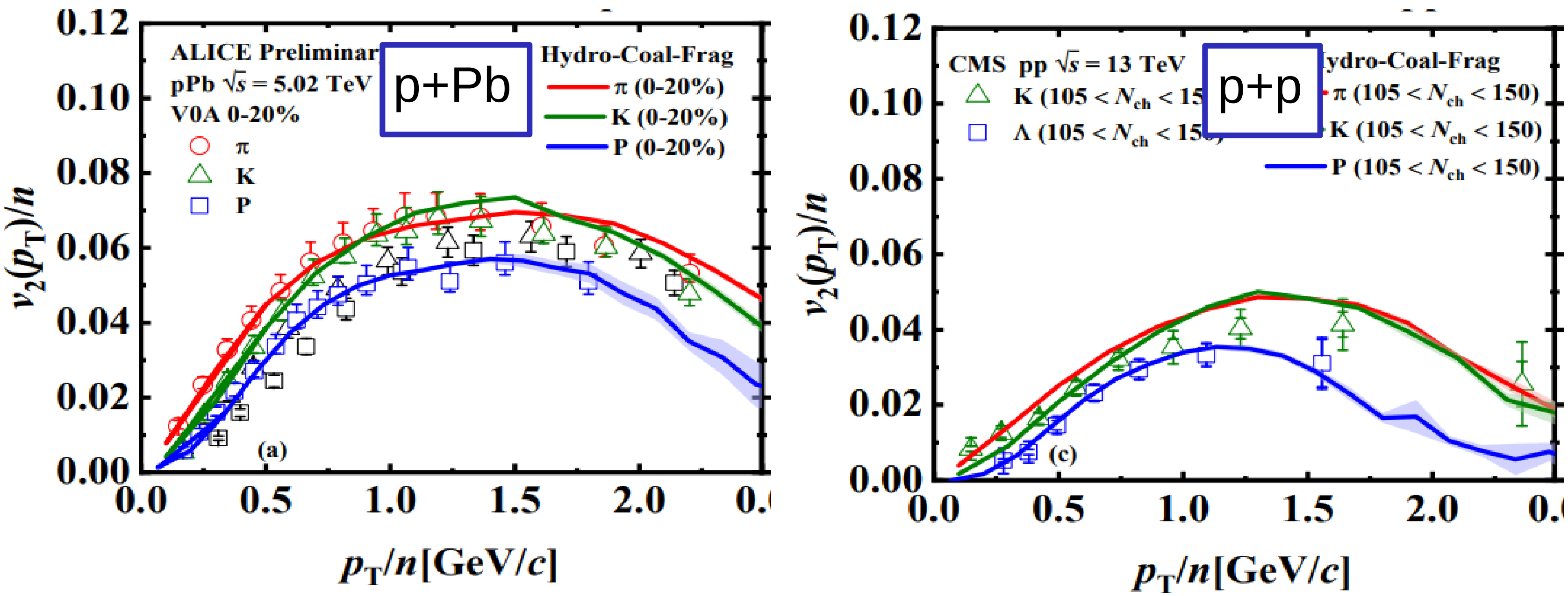
-Hydro-Coal-Frag model well describe the spectra of π, K and P and P/π at 0-6 GeV in both pp and p-Pb collisions.

Wang, Zhao & Song. Paper in preparation.

V_2 & the importance of quark coalescence



V_2 & the importance of quark coalescence



-Hydro-Coal-Frag model describes v2(P_T) & the approximately NCQ scaling at intermediate pT, for both pp and p-Pb collisions.

-The NCQ scaling become worse from p-Pb to p-p collisions

-Fragmentation tends to break-up the NCQ scaling at intermediate P_T

Wang, Zhao & Song. Paper in preparation.

SUMMARY

p-p and p-Pb collisions at LHC

-Hydro-Coal-Frag model well describe the spectra, $v_2(p_T)$ and NCQ scaling of π, K and P at 0-6GeV in both pp and p-Pb collisions.

-strongly indicates the partonic degrees of freedom in high multiplicity pp and p-Pb collisions.

-The NCQ scaling become worse for p-p collisions due to fragmentations

Pb-Pb collisions at LHCo

-CoLBT-Hydro with Hydro-Coal-Frag hadronization model well describe the spectra, $v_2(p_T)$ of π, K and P at 0-6GeV in Pb-Pb collisions.

-Coalescence is important for Pb-Pb collisions at intermediate PT.