Probing the partonic degree of freedom in high multiplicity p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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based on: **W. Zhao**, W. Zhao, C. M. Ko, Y. X. Liu, G. Y. Qin and H. Song, Phys. Rev. Lett. **125**, no. 7, 072301 (2020).

Sophisticated Coalescence model

Mesons and baryons' momentum distributions by recombining of quarks:

$$\frac{dN_M}{d^3\mathbf{P}_M} = g_M \int d^3\mathbf{x}_1 d^3\mathbf{p}_1 d^3\mathbf{x}_2 d^3\mathbf{p}_2 f_q(\mathbf{x}_1,\mathbf{p}_1) f_{\bar{q}}(\mathbf{x}_2,\mathbf{p}_2) \times W_M(\mathbf{y},\mathbf{k}) \delta^{(3)}(\mathbf{P}_M - \mathbf{p}_1 - \mathbf{p}_2)\,, \quad (1)$$

and

$$\frac{dN_B}{d^3\mathbf{P}_B} = g_B \int d^3\mathbf{x}_1 d^3\mathbf{p}_1 d^3\mathbf{x}_2 d^3\mathbf{p}_2 d^3\mathbf{x}_3 d^3\mathbf{p}_3 f_{q_1}(\mathbf{x}_1,\mathbf{p}_1) \times f_{q_2}(\mathbf{x}_2,\mathbf{p}_2) f_{q_3}(\mathbf{x}_3,\mathbf{p}_3) W_B(\mathbf{y}_1,\mathbf{k}_1;\mathbf{y}_2,\mathbf{k}_2) \times \delta^{(3)}(\mathbf{P}_B - \mathbf{p}_1 - \mathbf{p}_2 - \mathbf{p}_3)\,, \quad (2)$$

$g_{B(M)}$ is the statistic factor, $f_{q,\bar{q}}(\mathbf{x}_1,\mathbf{p}_1)$ is the phase-space distribution of (anti)quarks, normalized as $\int d^3\mathbf{x} d^3\mathbf{p} f_{q,\bar{q}}(\mathbf{x},\mathbf{p}) = N_{q,\bar{q}}$, $W_{M(B)}$ is the winger function of meson(baryon).

V. Greco, C. M. Ko and P. Levai, Phys. Rev. Lett. **90**, 202302 (2003).

Framework of Hydro-Coal-Frag

-- **Thermal hadrons**: generated by hydro. with Cooper-Frye.

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

-- **Coalescence hadrons**: generated by quark coalescences, including thermal-thermal, thermal-hard and hard-hard coalescence, with the corresponding ground and excited states.

a. ***Thermal partons*** generated by hydro with $P_T > P_1$.

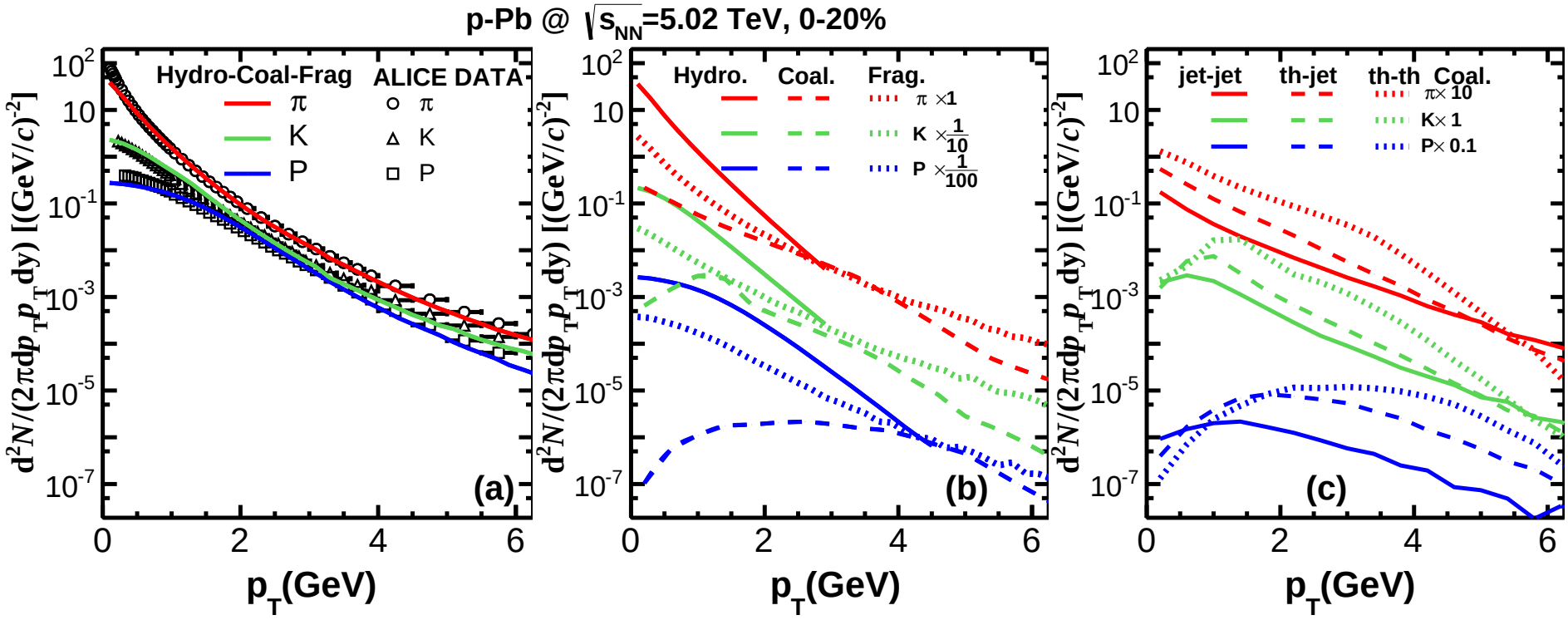
b. ***Hard partons*** generated by PYTHIA8, then suffered with energy loss by LBT with α=0.15. Get the hard parton with $P_T > P_2$.

-- **Fragmentation process**: the remnant hard quarks feed to fragmentation .

-- All hadrons feed to the UrQMD model.

NOTE: the main two parameters, $p_{T1} = 1.6GeV$ and $p_{T2} = 2.6GeV$ are fixed by spectra of pions, kaons and protons at intermediate p_T. The parameters of hydro and LBT are fixed by other places already.

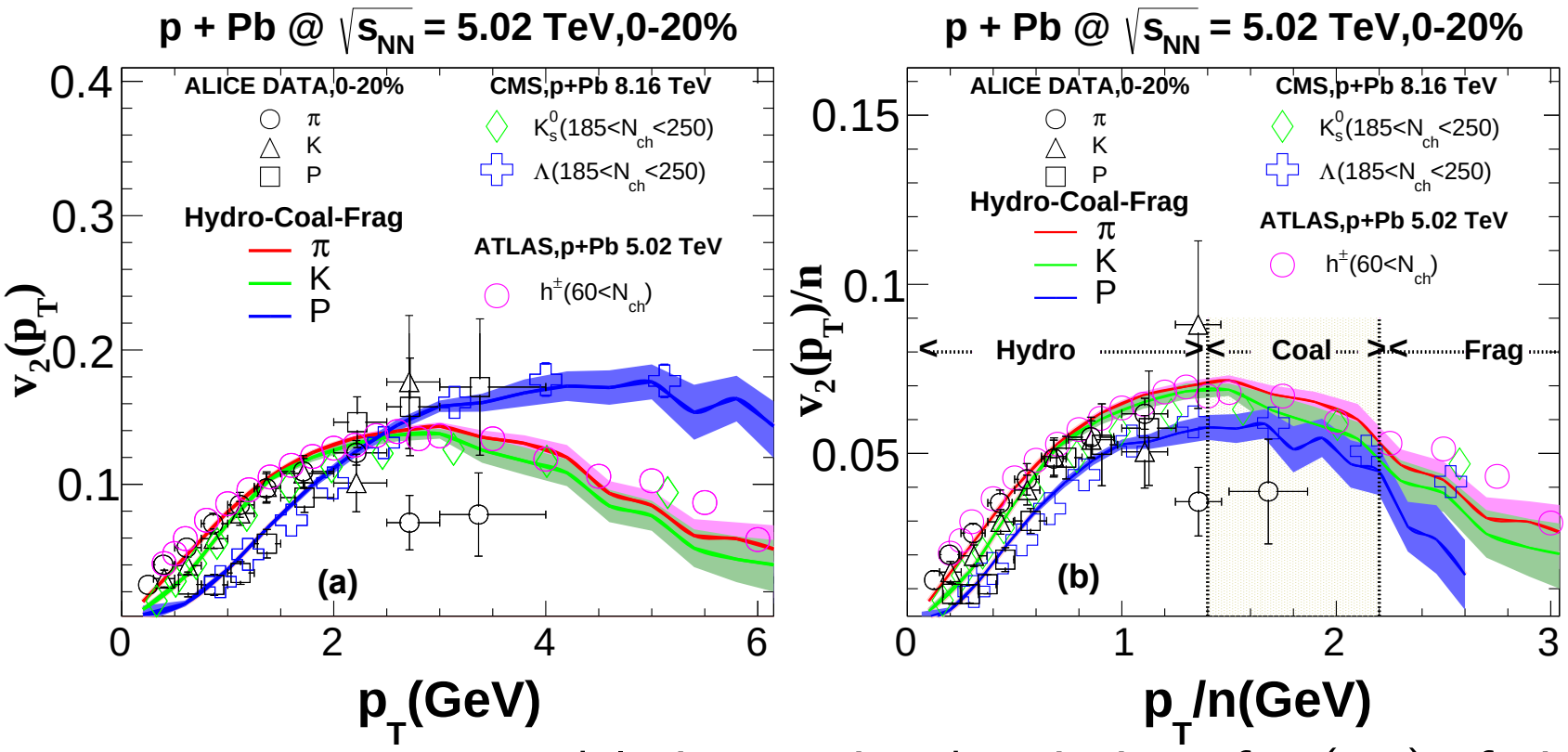
Spectra of π, K, P and P/π



- Low p_T: hydrodynamics dominates.
- Intermediate p_T: coalescence and fragmentation.
- High p_T : Fragmentation dominates.
- Coalescence hadrons: Thermal-thermal coalescence dominates.

W. Zhao, C.M.Ko, Y.X.Liu, G,Y.Qin and H. Song, Phys. Rev. Lett. **125**, no. 7, 072301 (2020).

$v_2(p_T)$ and NCQ scaling

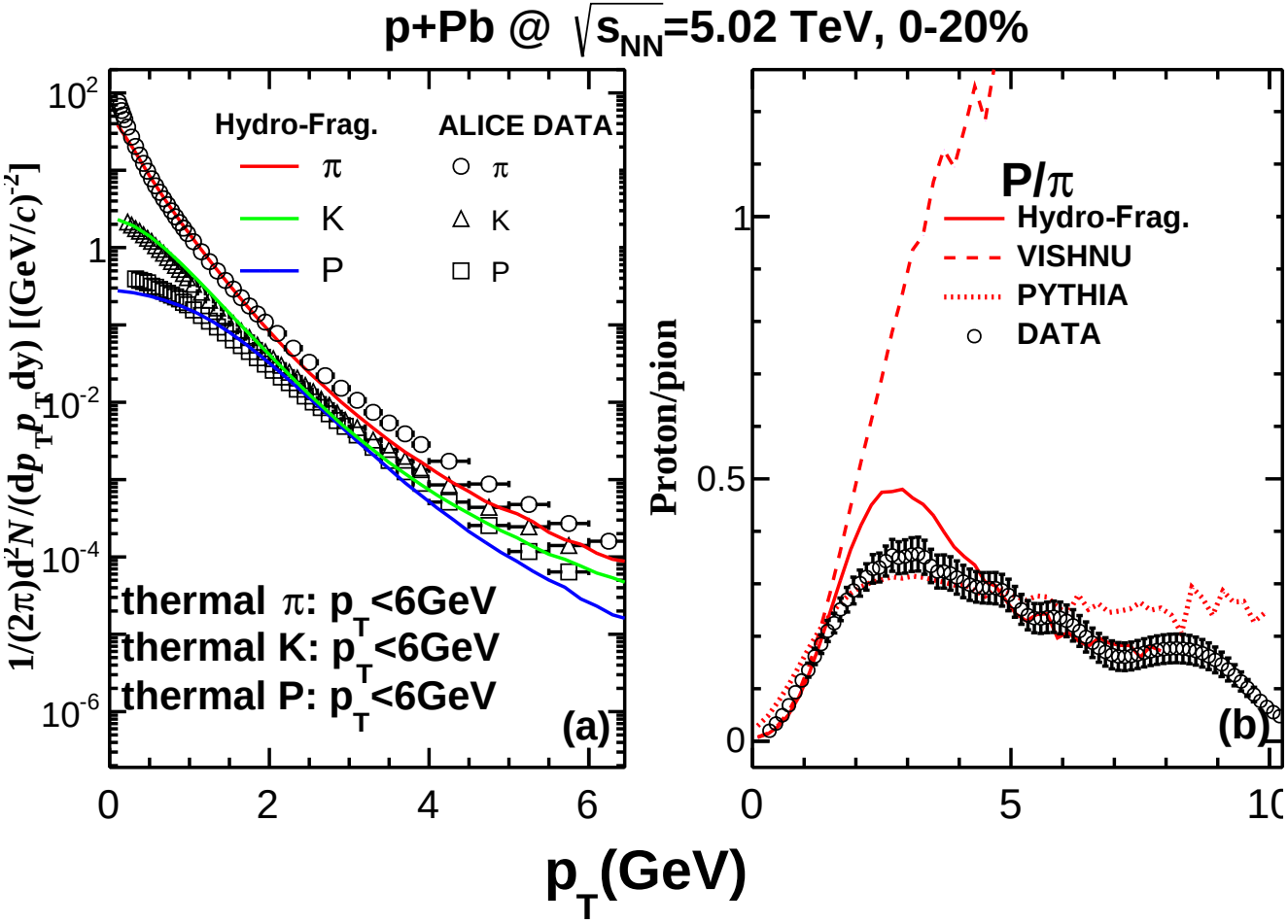


- Hydro-Coal-Frag model gives a nice description of $v_2(p_T)$ of pion, kaon and proton over p_T from 0 to 6 GeV.
- At intermediate p_T, Hydro-Coal-Frag model can get the approximately NCQ scaling at data shown.

W. Zhao, C.M.Ko, Y.X.Liu, G,Y.Qin and H. Song, Phys. Rev. Lett. **125**, no. 7, 072301 (2020).

The importance of quark coalescence process in p-Pb system

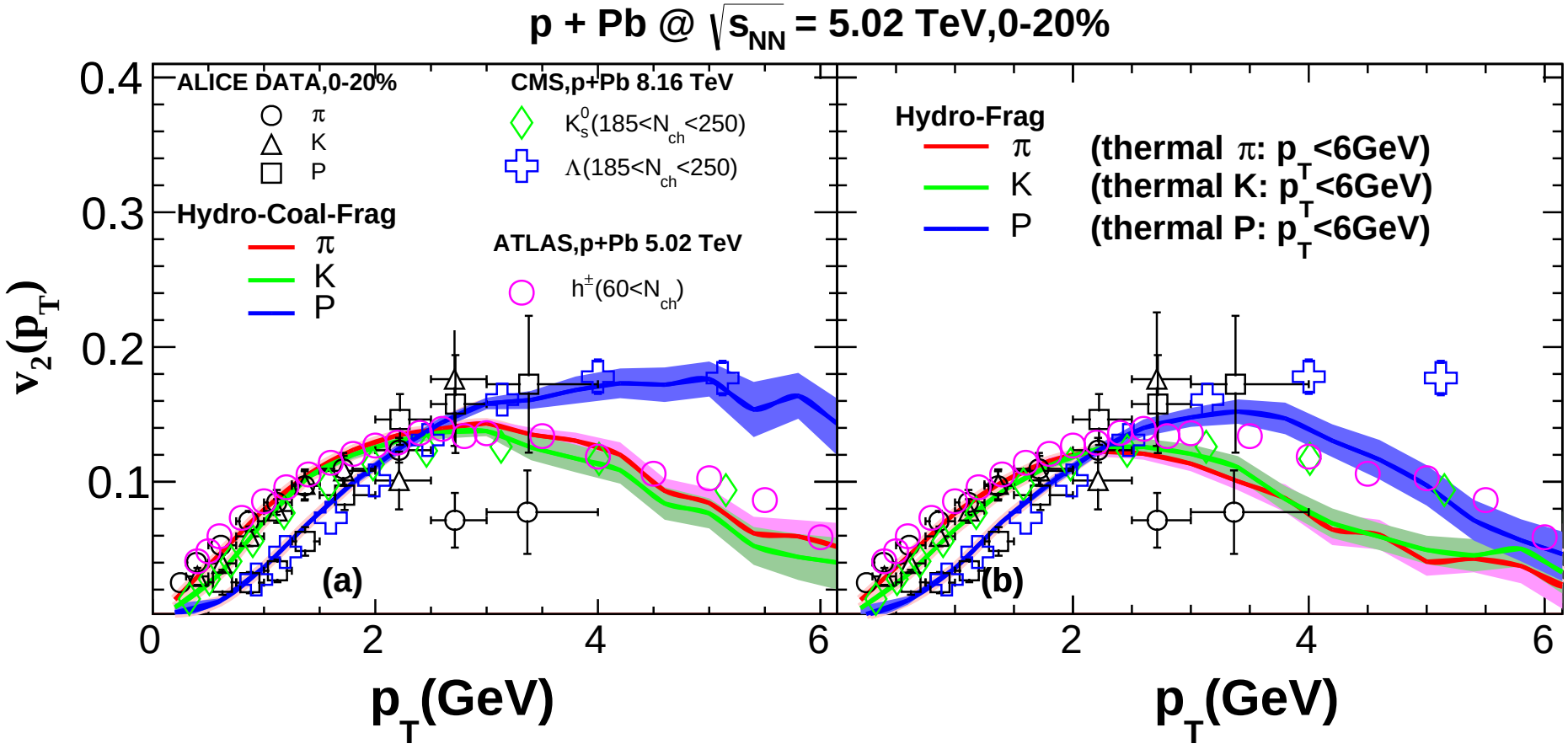
spectra of Hydro-Frag



- Hydro-Frag underestimates the spectra at intermediate p_T.
- Hydro-Frag also fail to reproduce the P/π.

W. Zhao, C.M.Ko, Y.X.Liu, G,Y.Qin and H. Song, Phys. Rev. Lett. **125**, no. 7, 072301 (2020).

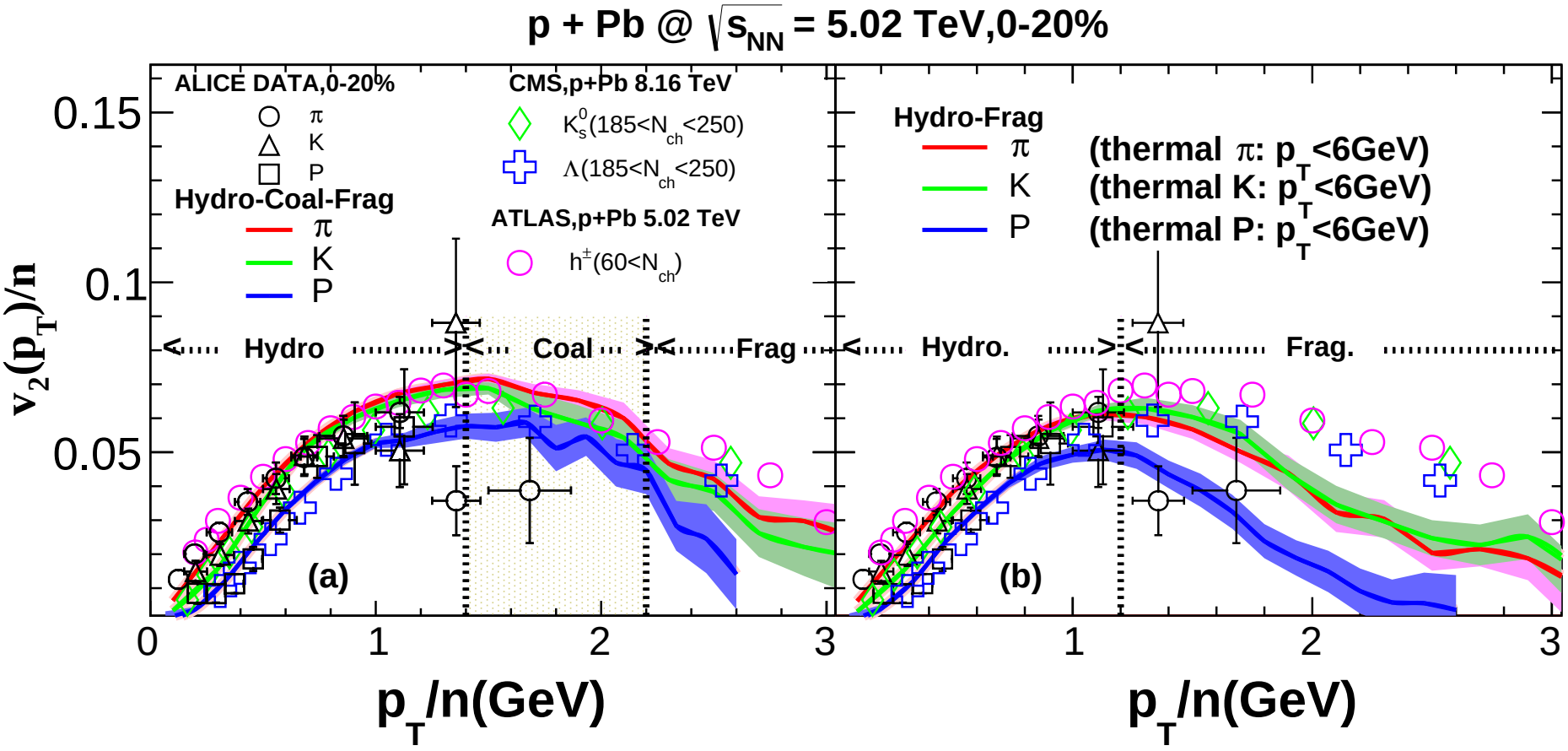
$v_2(p_T)$ of Hydro-Coal-Frag, and Hydro-Frag



- Without coalescence, Hydro-Frag greatly underestimates the $v_2(p_T)$ at intermediate p_T.

W. Zhao, C.M.Ko, Y.X.Liu, G,Y.Qin and H. Song, Phys. Rev. Lett. **125**, no. 7, 072301 (2020).

NCQ scaling of Hydro-Coal-Frag, and Hydro-Frag



- Without coalescence, Hydro-Frag will greatly violate the NCQ scaling at intermediate p_T, with the deviation of NCQ scaling at the level of $\pm 50\%$.

W. Zhao, C.M.Ko, Y.X.Liu, G,Y.Qin and H. Song, Phys. Rev. Lett. **125**, no. 7, 072301 (2020).

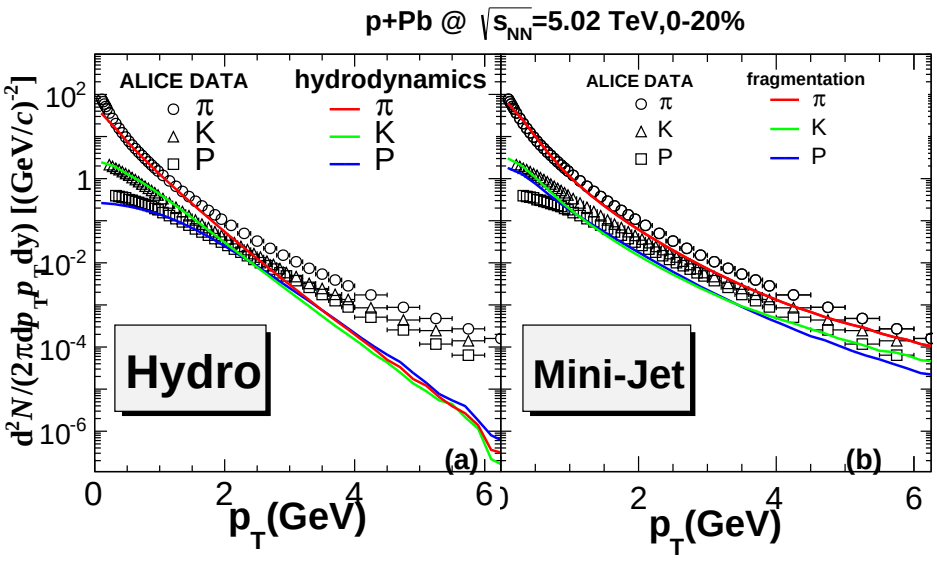
Summary

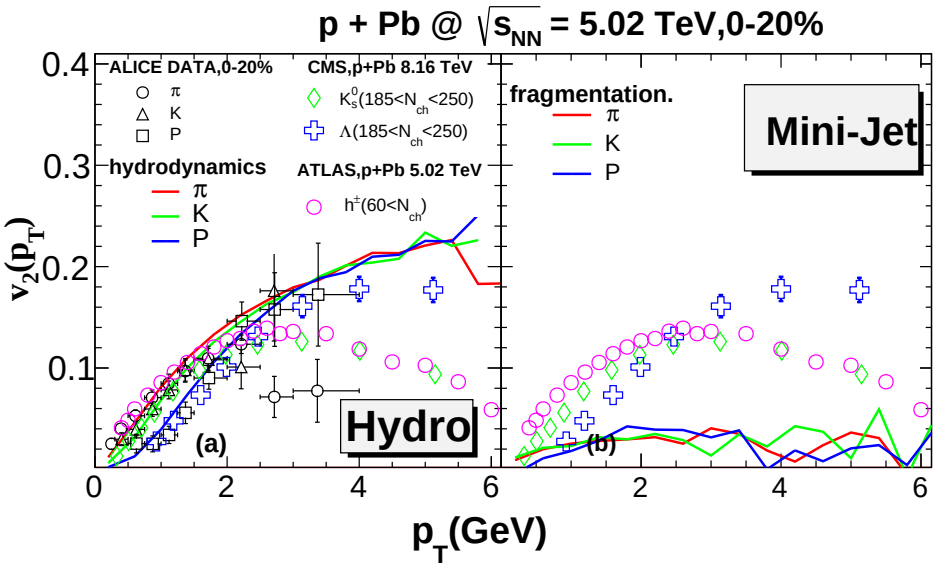
- NCQ scaling is a very important signal to probe the partonic degree of freedom in small system.
- Our model, `Hydro-Coal-Frag`, that combines `Hydro.`, `Coal.` and `Frag.` together can well describe the spectra, $v_2(p_T)$ and the approximately NCQ scaling at intermediate p_T.
- Quark coalescence is necessary in high multiplicity p+Pb collisions. Without quark coalescence, it would not only underestimate the magnitude of $v_2(p_T)/n$ but also greatly violate the NCQ scaling behavior at intermediate p_T, no matter how we tune the related parameters.
- This implies the possible formation of QGP in high multiplicity p-Pb collisions at LHC.

Thanks

Back up

Further explore p-Pb system by hydro or min-jet





- Hydrodynamics works at low p_T, but fails at intermediate and high p_T.
- Mini-jet can't generate enough flow at low and intermediate p_T.
- At intermediate p_T: one need to combine soft and hard parts.