Probe the partonic degree of freedom in high multiplicity p+Pb collisions

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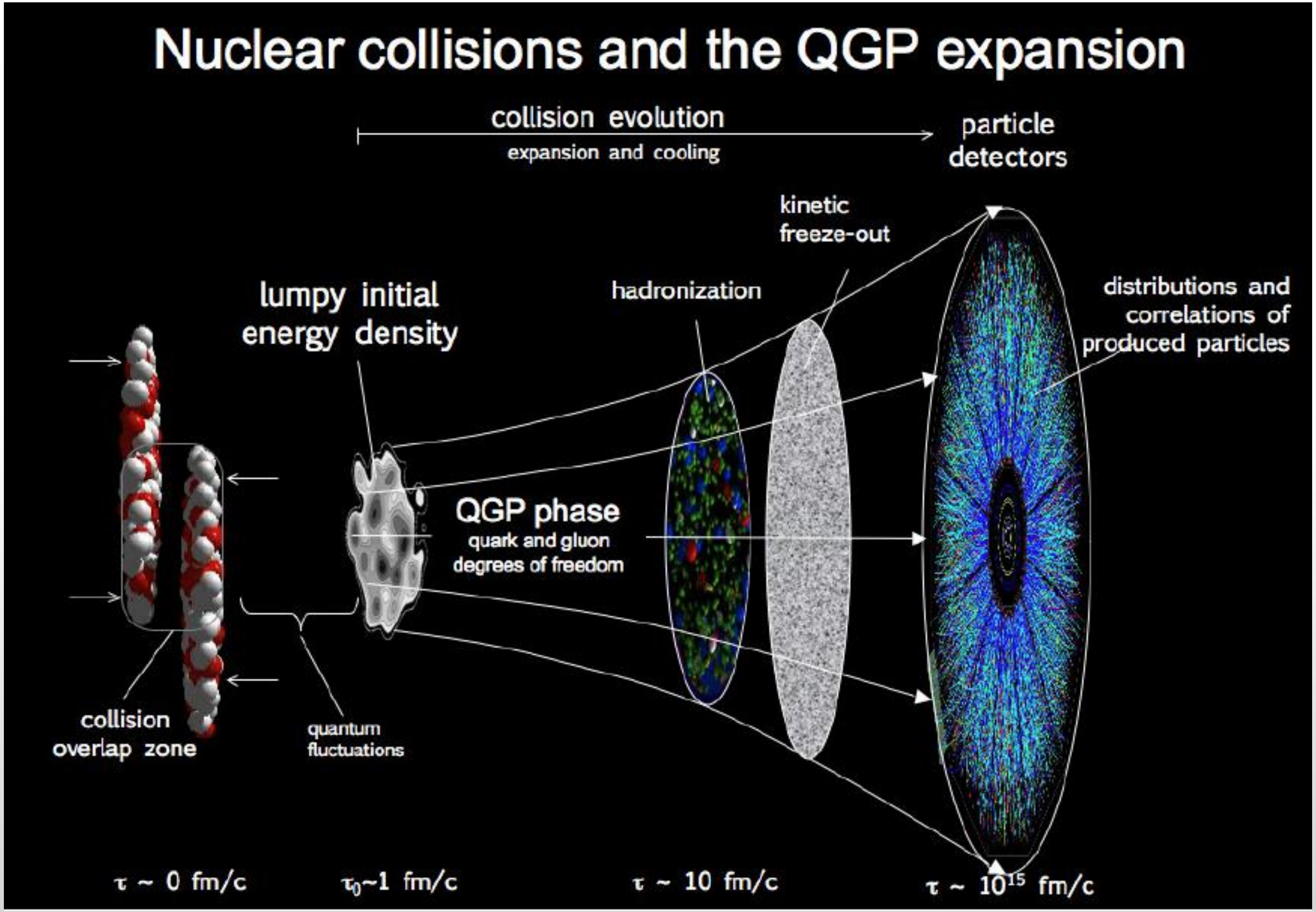
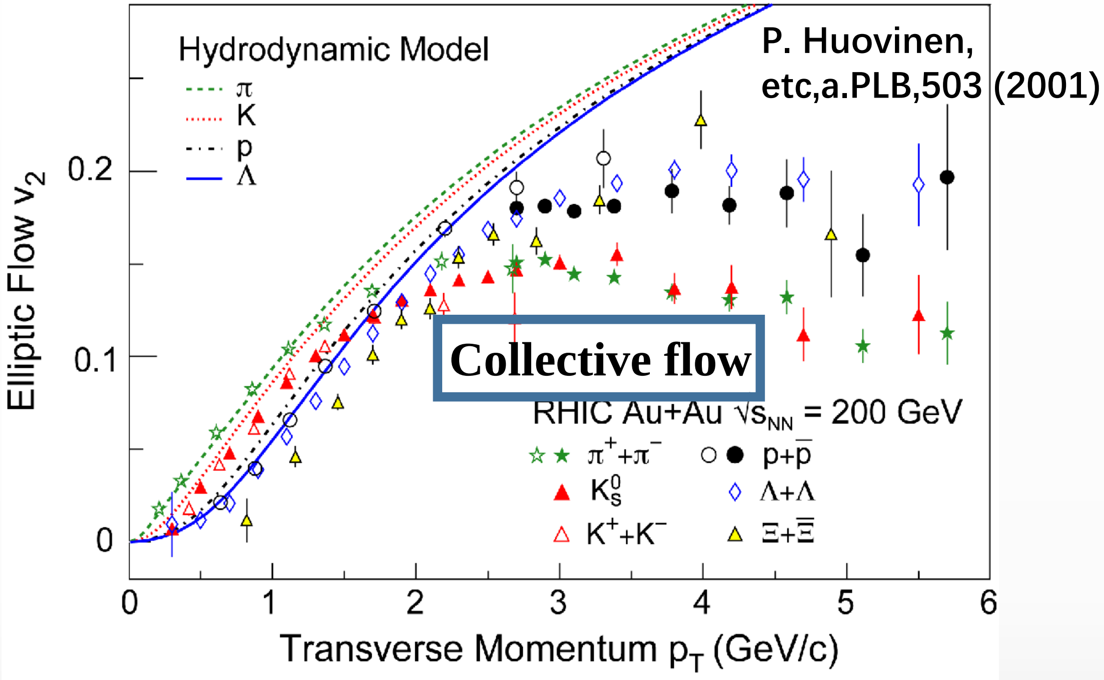
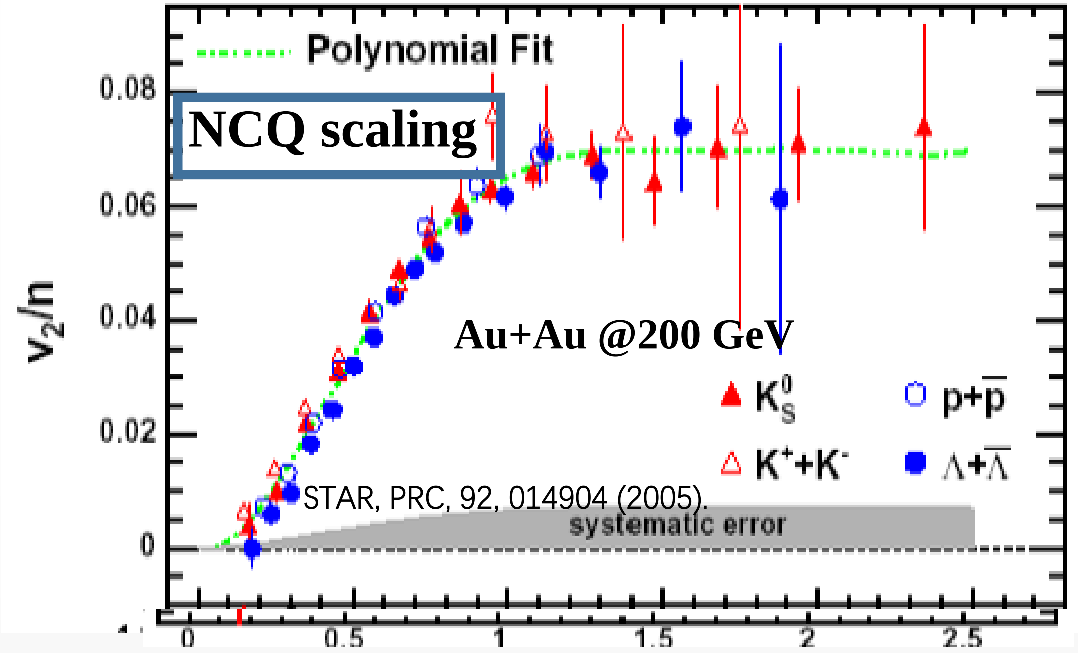
Stage of heavy-ion collisions

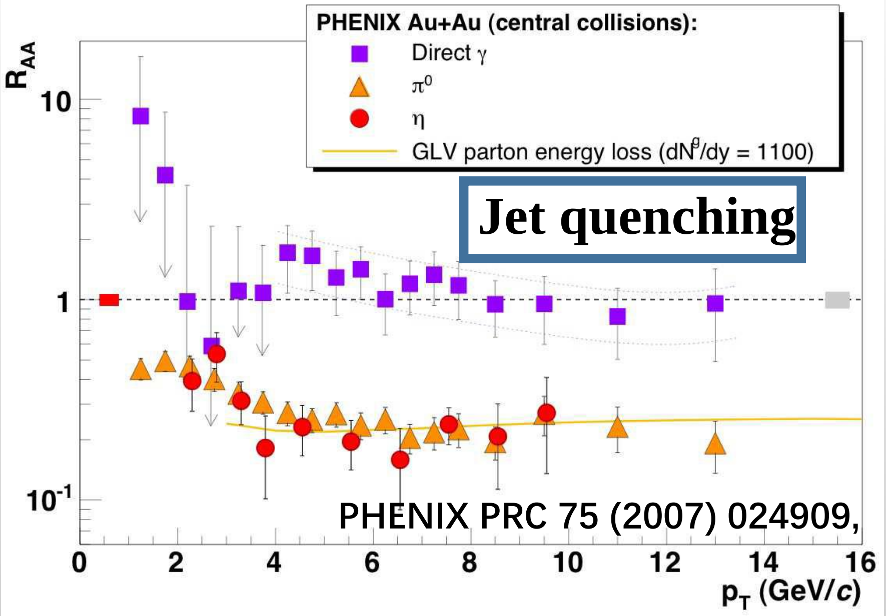


QGP signatures in heavy-ion collisions





p_T/n

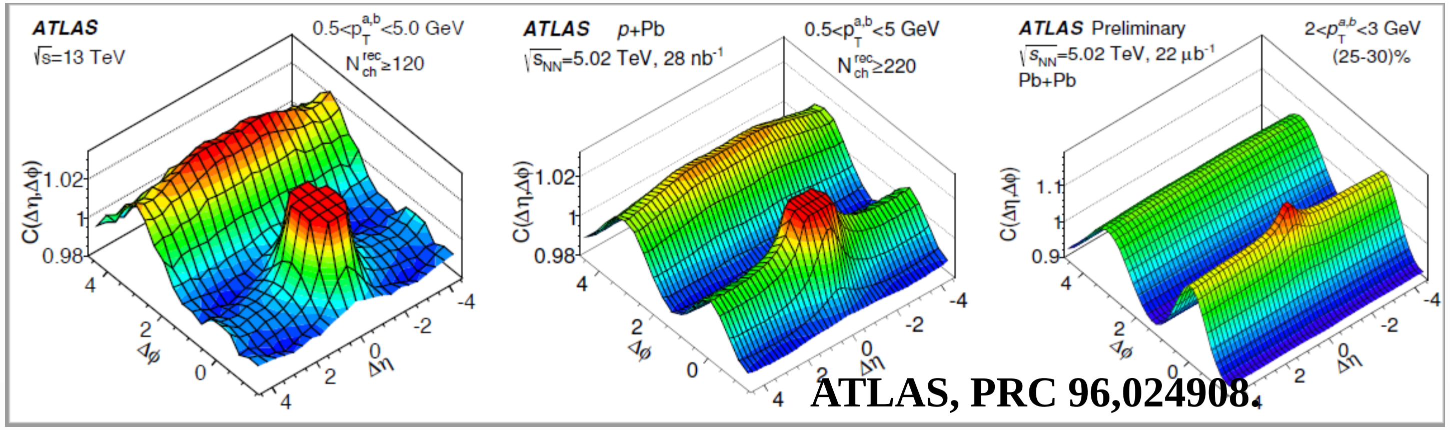


- **It has been announced that QGP has been found at RHIC in heavy-ion collisions.**

QGP in small system?

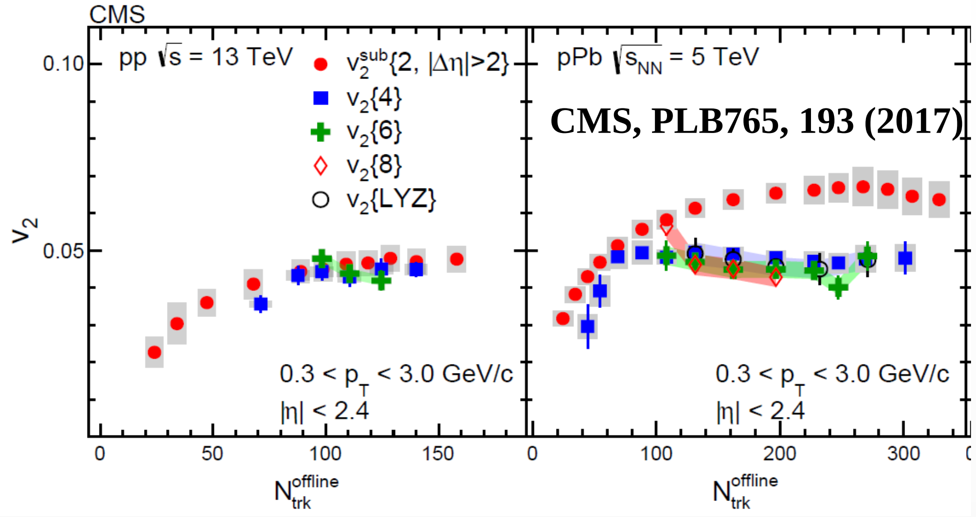
Collective flow? experimental observables in small system

- “ridge" structure in p+p, p+Pb and Pb + Pb system



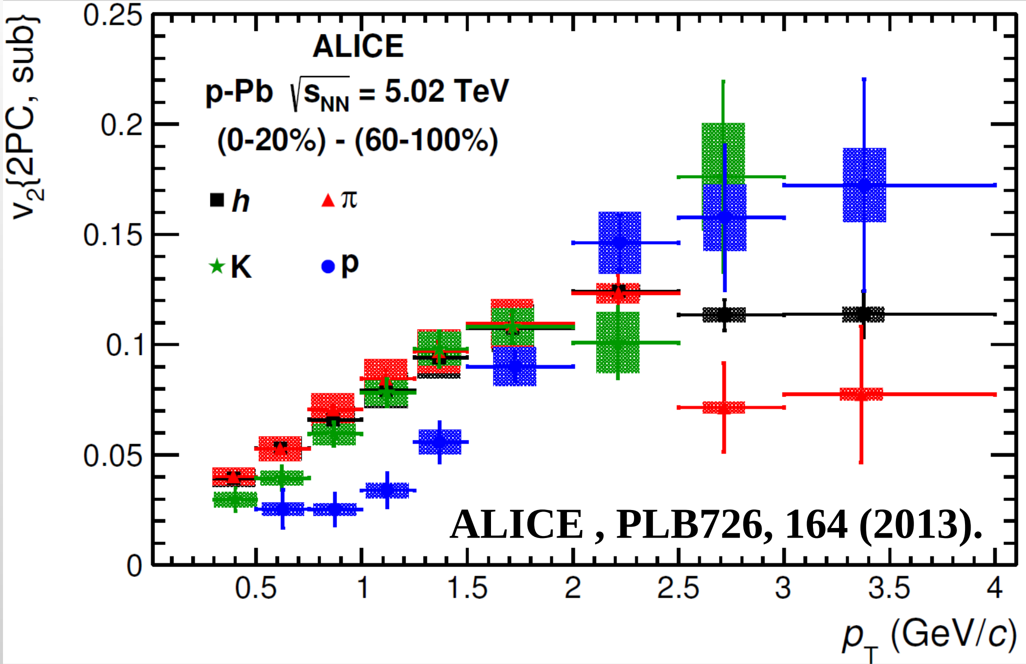
ATLAS, PRC 96,024908.

- Multi-particle correlation



CMS, PLB765, 193 (2017)

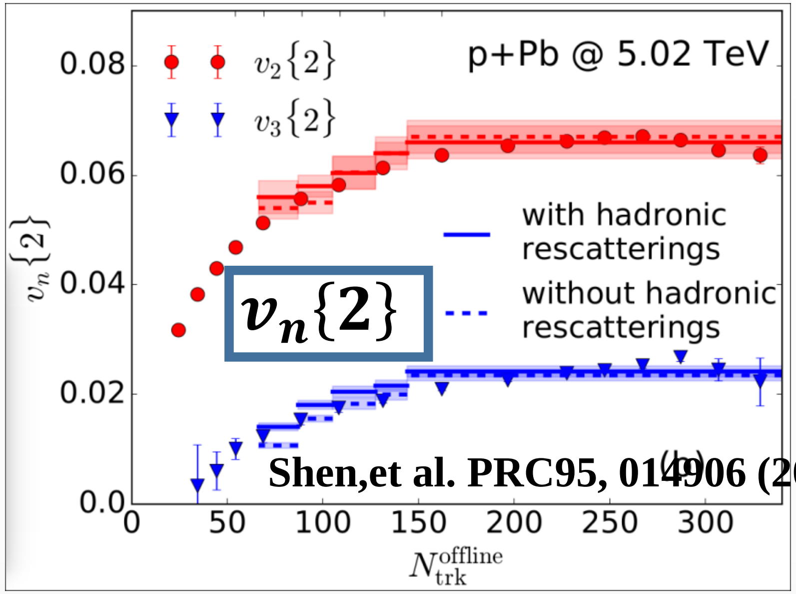
- Mass ordering of $v_2(\mathbf{p_T})$



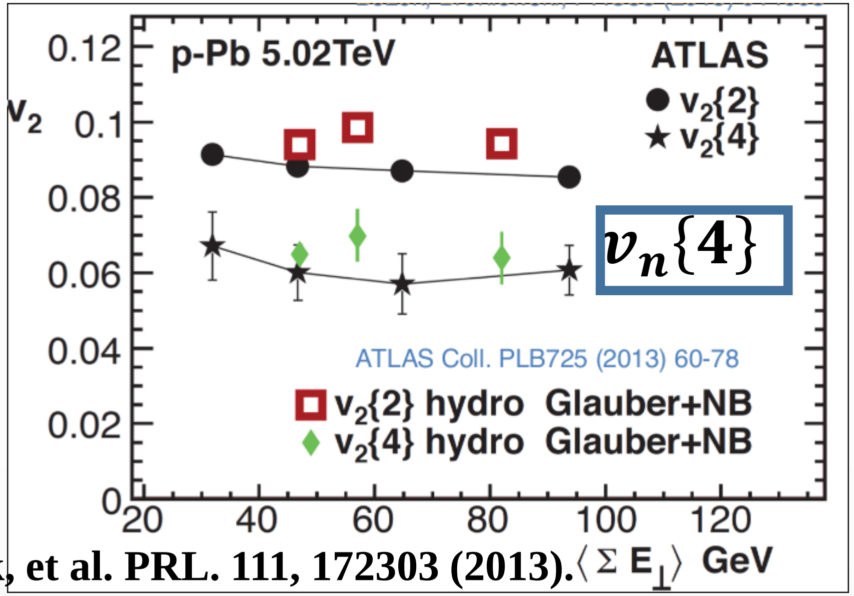
ALICE , PLB726, 164 (2013).

- **The indication of collectivity in high-mulitiplicty small system.**

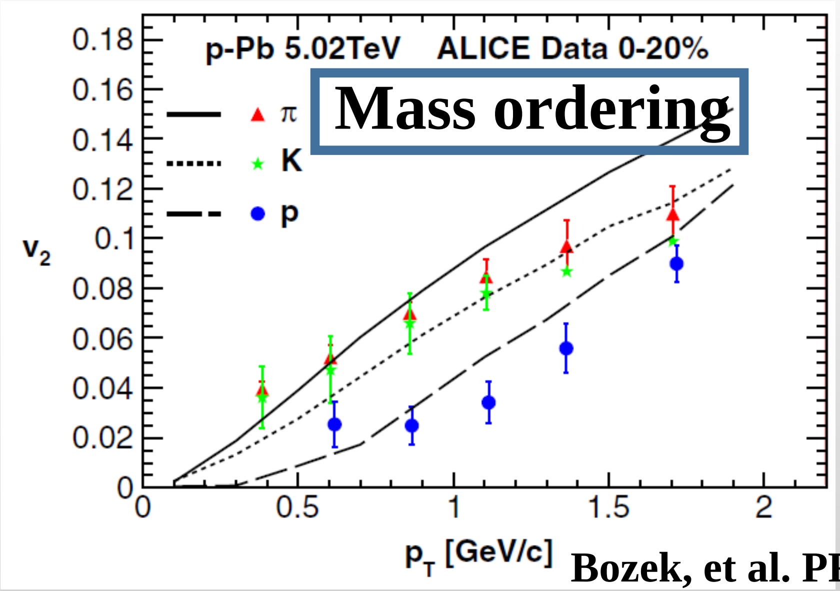
Hydrodynamics simulations in p-Pb



Shen,et al. PRC95, 014906 (2017).



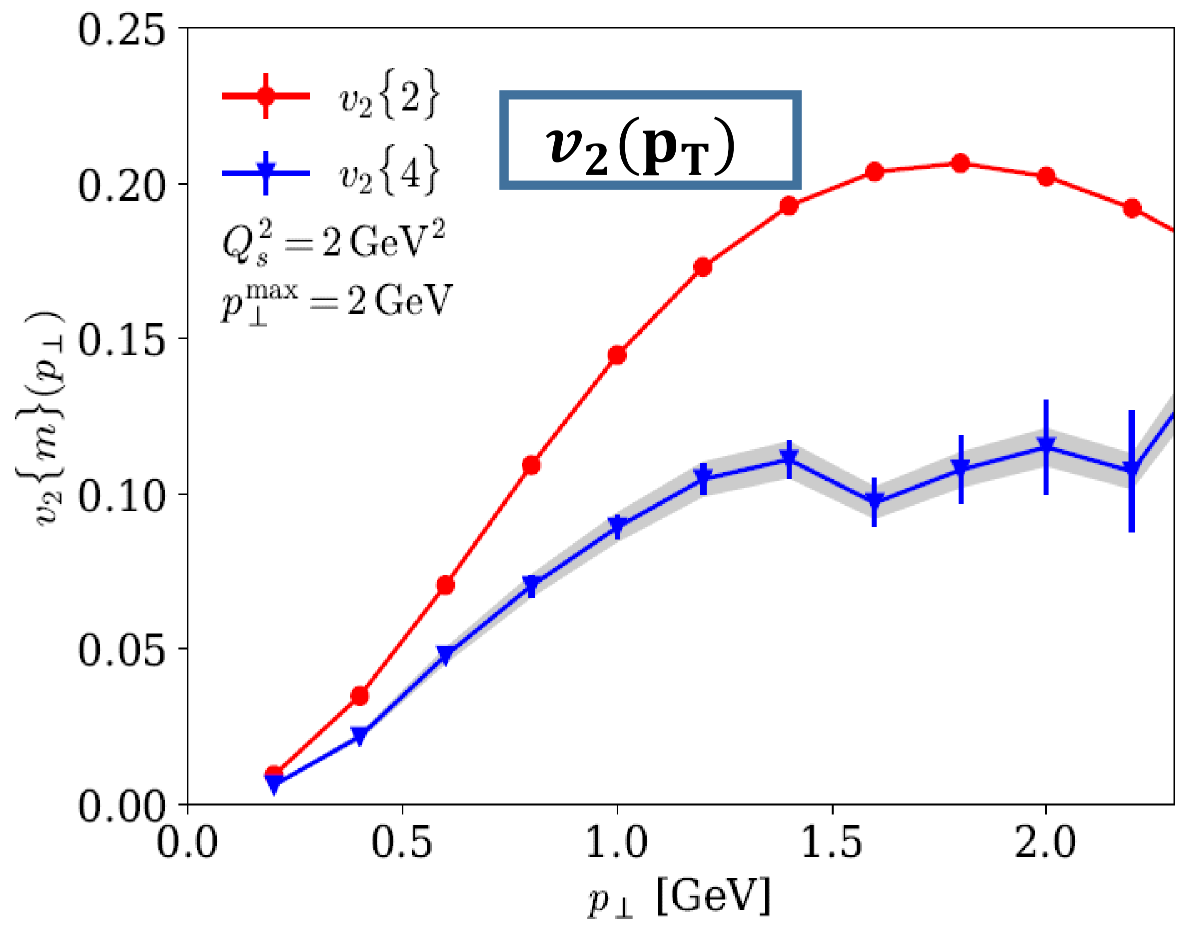
Bozek, et al. PRL. 111, 172303 (2013).



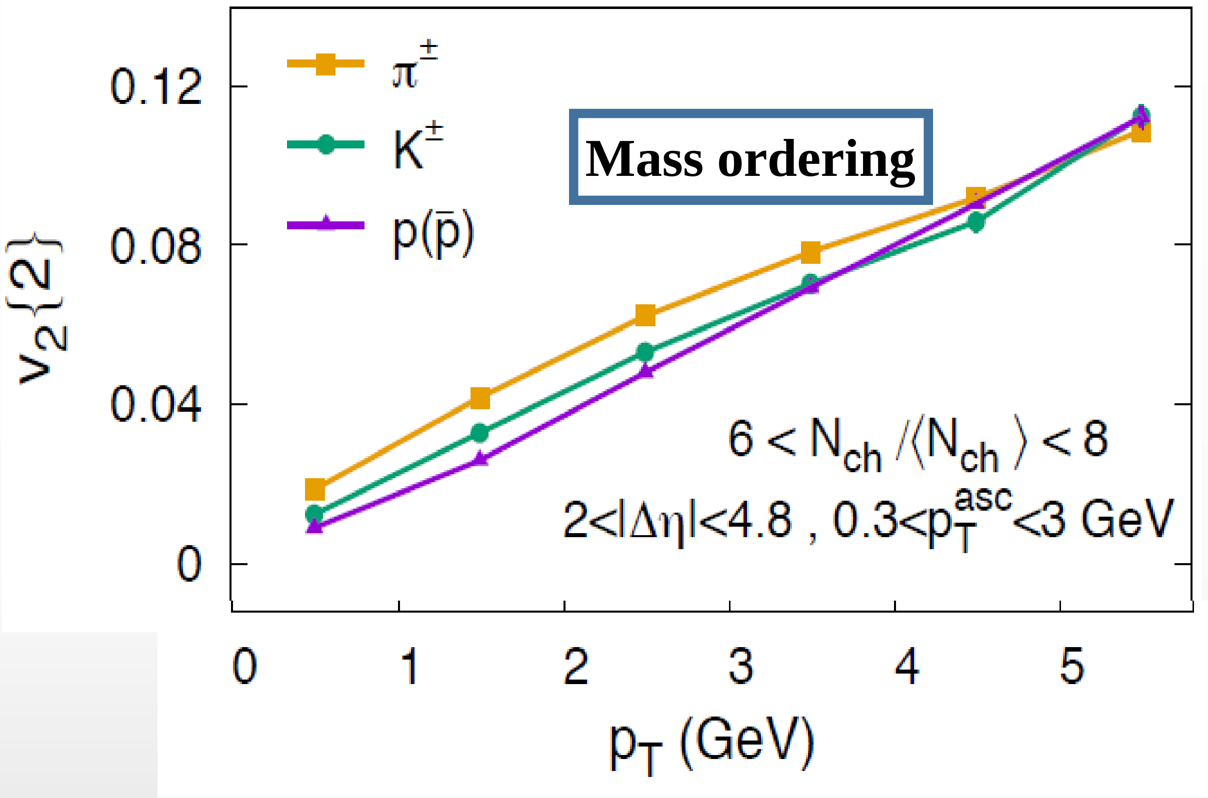
Bozek, et al. PRL. 111, 172303 (2013).

- Hydrodynamics can well reproduce "collectivity" features in p-Pb system.

"Collectivity" from initial state correlations in small system



K. Dusling, etc,al. PRL.120, 042002 (2018).



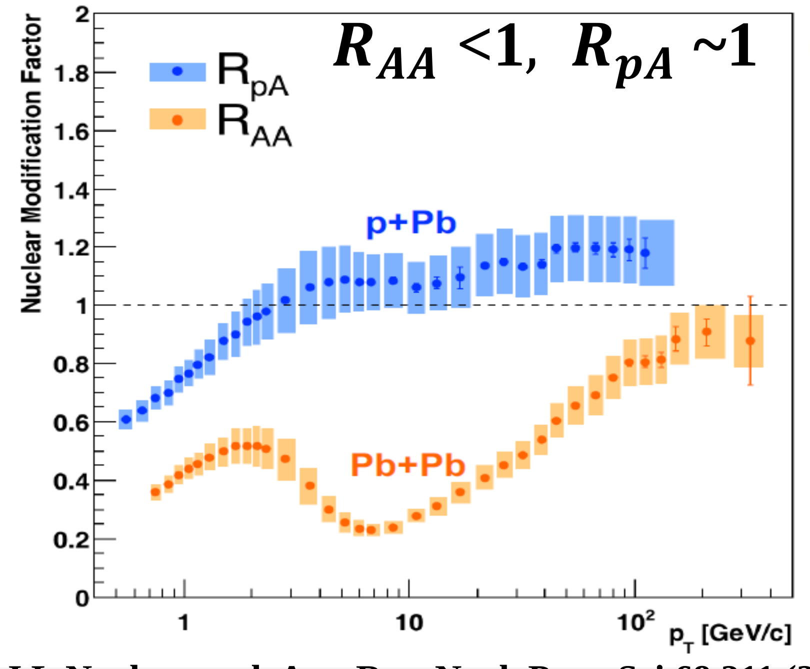
B.Schenke etc,al., PRL,117,162301(2016)

- **Initial state correlation also generate collectivity,multiparticle correlations and mass ordering in small system .**

Hard probes in small system

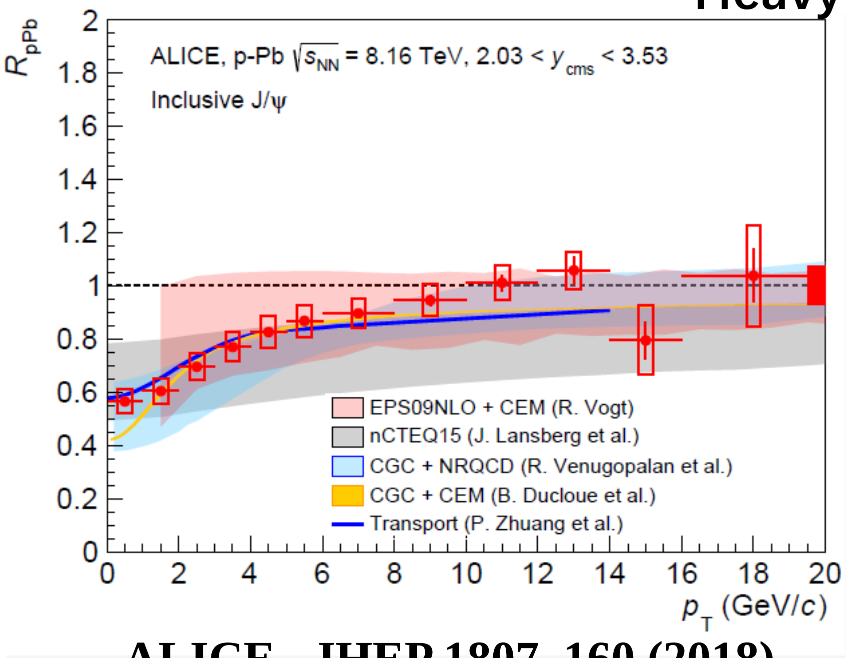
Light flavour

R_{AA} <1, R_{pA} ~1

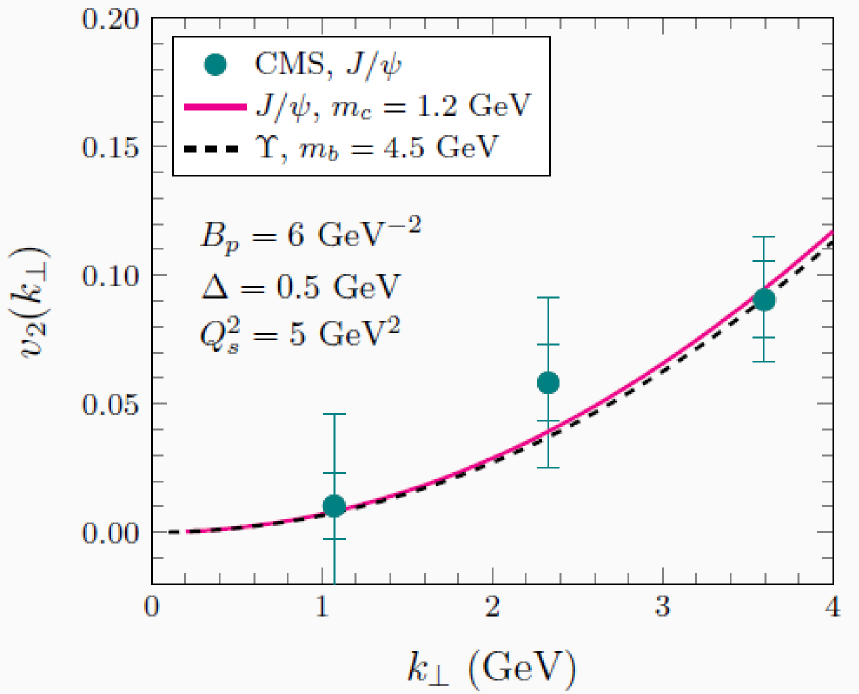


J.L.Nagle, eta,al. Ann.Rev. Nucl. Part. Sci 68,211 (2018)

Heavy flavour



ALICE, JHEP 1807, 160 (2018)

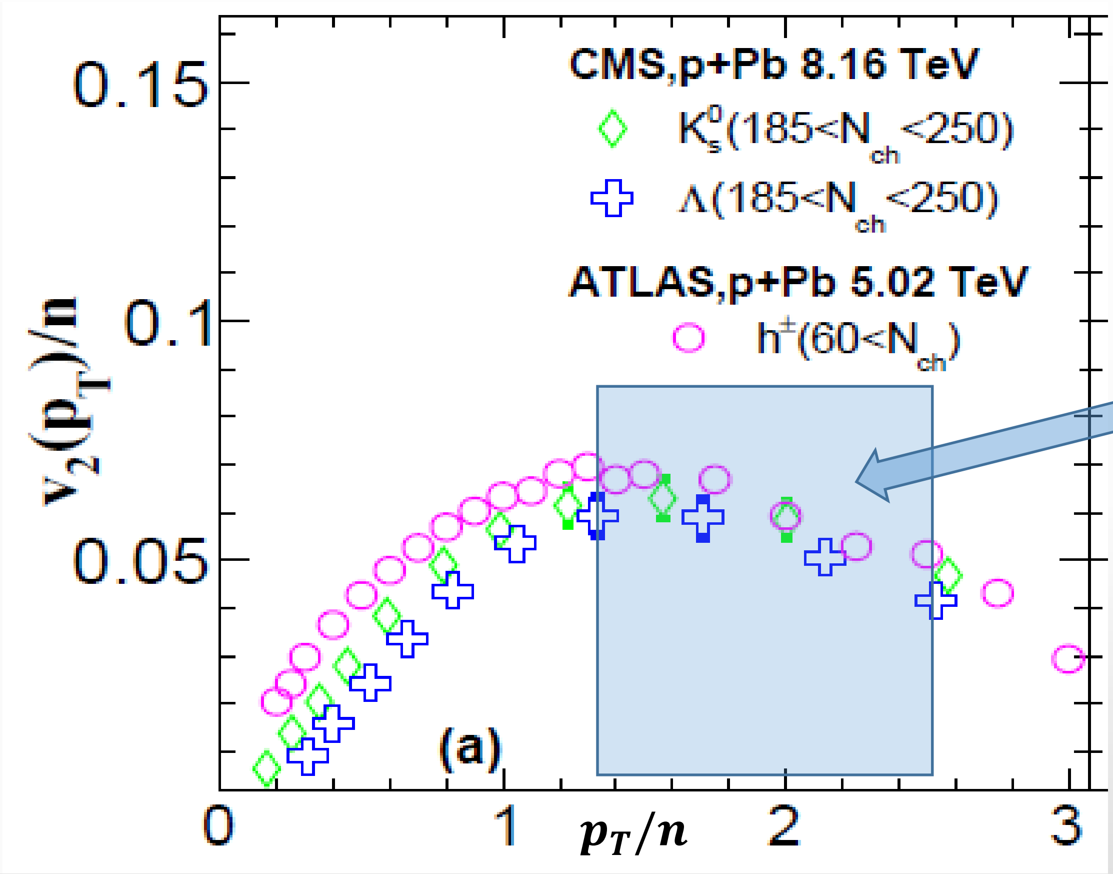


C. Zhang,eta,al. PRL. 122,172302 (2019).

- R_{pA} of light hadrons is consistent with one.
- R_{pA} of heavy flavour is comparable with cold nuclear effect and CGC.
- $v_2(\mathrm{p_T})$ of heavy flavour can be described by CGC model.

NCQ scaling in small system

- A "clean" signal is required to disentangle the origin of the collectivity and probe the partonic degree of freedom in small system.



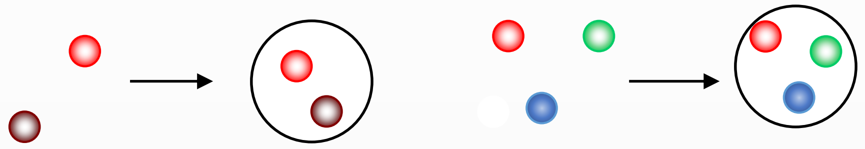
- Approximately NCQ scaling at intermedium p_T of high mulitilicity p-Pb collision.

Coalescence model and NCQ scaling

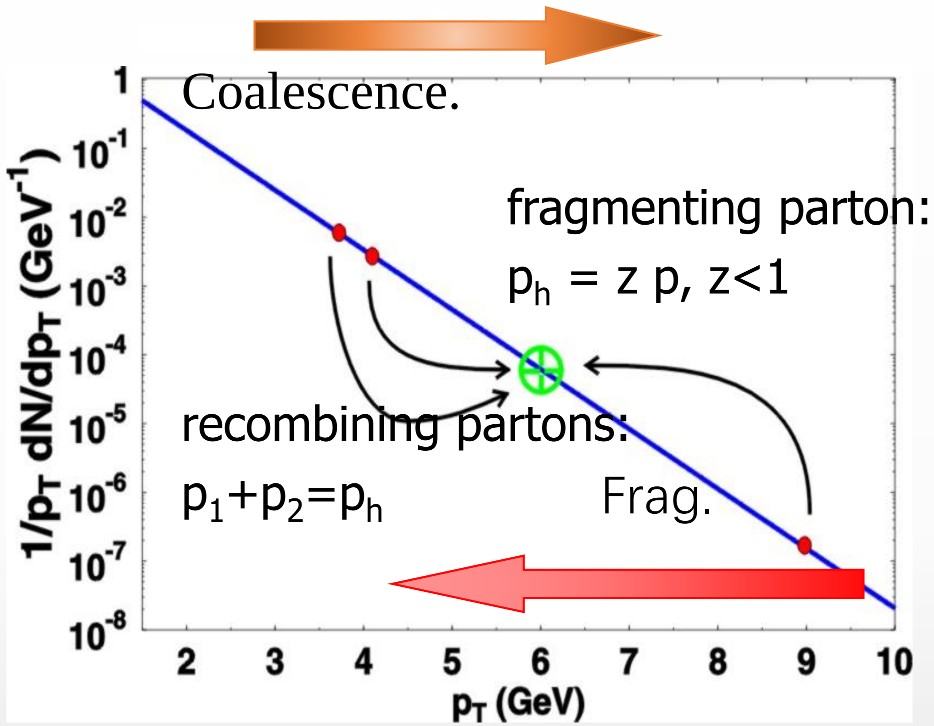
fragmentation and calescence model

- **Fragmentation: Leading parton with p_T leads to hadrons of $p_h = zp_T$ with z < 1.**

- **Coalescence: occurs in an instant.**



- **Quark are already there, and close in phase space.**
- **The parton spectrum is shifted to higher p_T in the hadron spectrum., $p_h = np_T$, n=2,3.**
- **Partonic hydro behavior shifted to higher p_T in hadrons.**



Coalescence and NCQ scaling

- **Meson's momentum distributions by recombining of quarks:**

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

- **Baryon's momentum distributions by recombining of quarks:**

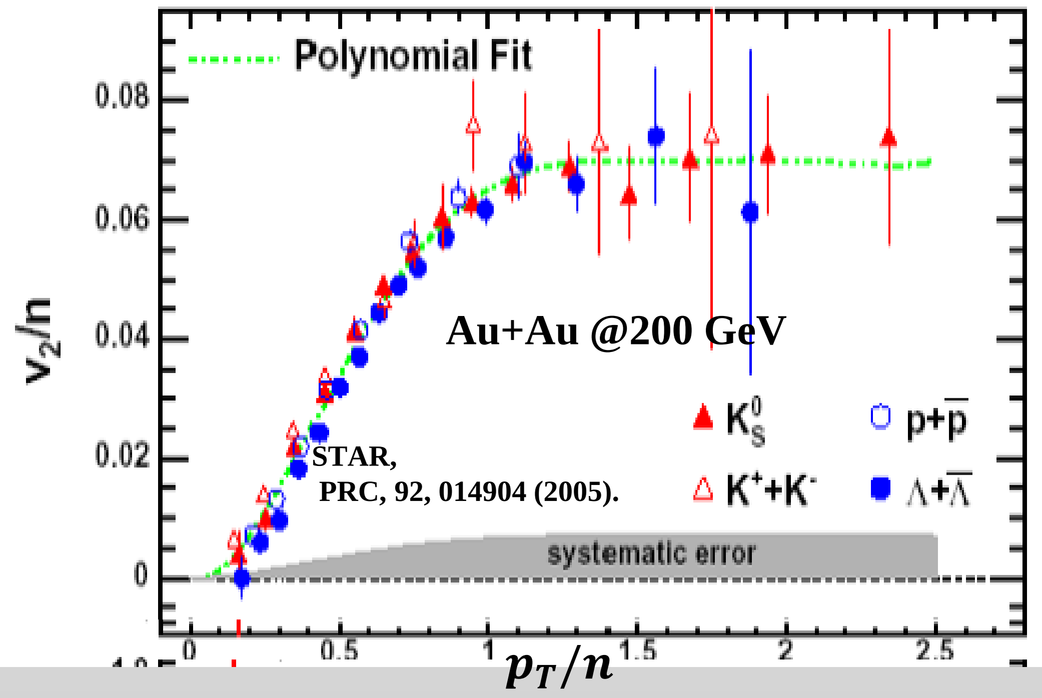
$$\frac{dN_B}{d^3\mathbf{P}_B} = g_B \int d^3\mathbf{x}_1 d^3\mathbf{p}_1 d^3\mathbf{x}_2 d^3\mathbf{p}_2 d^3\mathbf{x}_3 d^3\mathbf{p}_3 f_{q_1}(\mathbf{x}_1,\mathbf{p}_1) \times f_{q_2}(\mathbf{x}_2,\mathbf{p}_2) f_{q_3}(\mathbf{x}_3,\mathbf{p}_3) W_B(\mathbf{y}_1,\mathbf{k}_1;\mathbf{y}_2,\mathbf{k}_2)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

- **$f_{q,\bar{q}}(x,p)$ is the phase-space distribution of (anti)quarks, $W_{M/B}$ is the Winger function of meson (baryon), $g_{M/B}$ is the degeneracy of meson (baryon).**

R.J.Fries, V.Greco and P.Sorensen, Ann. Rev.Nucl.Part.Sci. 58, 177 (2008)

Naïve coalescence and NCQ scaling

- **If narrow wave function in momentum space:** $W_{M/B} \sim \delta(\mathbf{P} - \mathbf{p_1} - \mathbf{p_2})$ **and quark exhibits the same elliptic flow:**
- **quark's elliptic flow:** $f_a(\mathbf{p}_T) = \bar{f}_a(p_T)\,(1 + 2v_{2,q}(p_T)\cos 2\phi)$
- **the meson's elliptic flow:** $v_2^M(p_T) = \frac{2v_{2,q}(p_T/2)}{1+2v_{2,q}^2(p_T/2)} \sim 2v_{2,q}(p_T/2)$
- **the baryon elliptic flow:** $v_2^B(p_T) = \frac{3v_{2,q}(p_T/3)}{1+6v_{2,q}^2(p_T/3)} \sim 3v_{2,q}(p_T/3)$



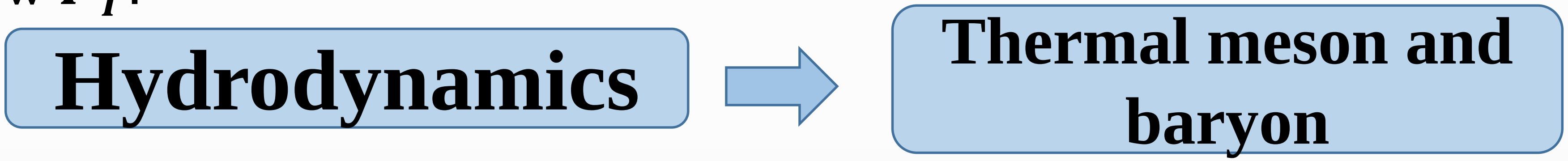
- **NCQ scaling is clean signal to probe partonic degree of freedom in heavy-ion collisions.**

R.J.Fries, V.Greco and P.Sorensen, Ann. Rev.Nucl.Part.Sci. 58, 177 (2008)

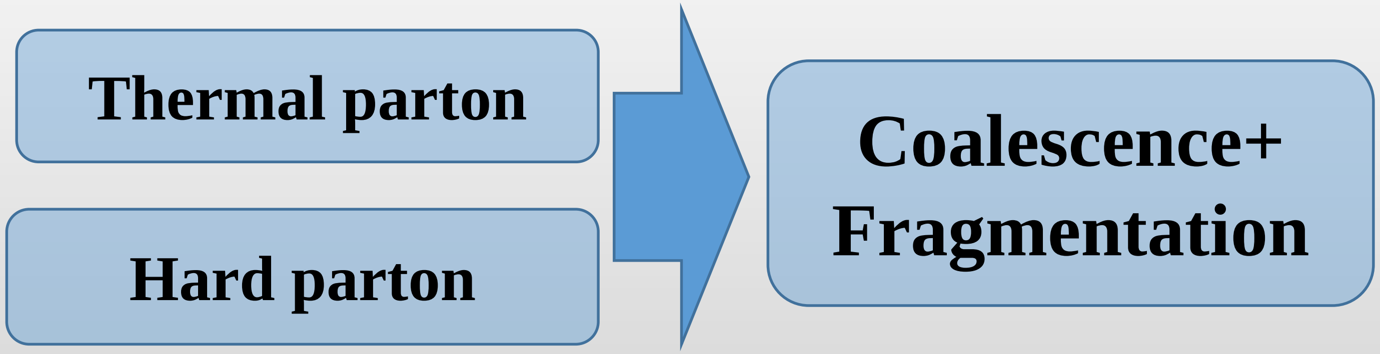
Probe the partonic degree of freedom in high multiplicity p+Pb collisions

Framework

1. Low P_T:

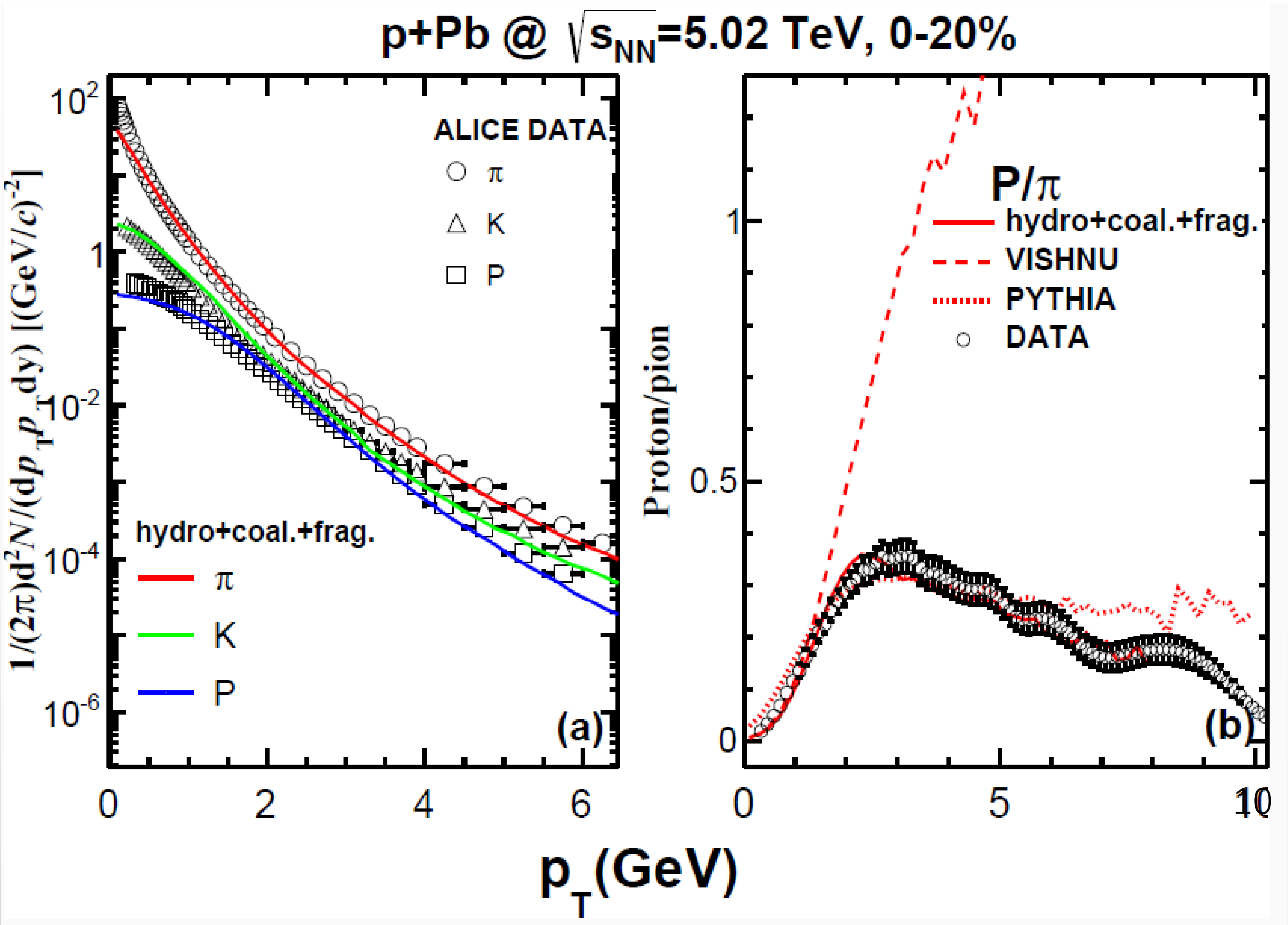


2. Get the thermal parton with from hydro and the hard parton from Pythia8, then suffered with energy loss by LBT. Coalescence the quarks, (thermal-thermal, thermal-jet, jet-jet coalescence) the remnant hard quarks subjected to fragmentation.



3. All hadrons feed to the UrQMD model.

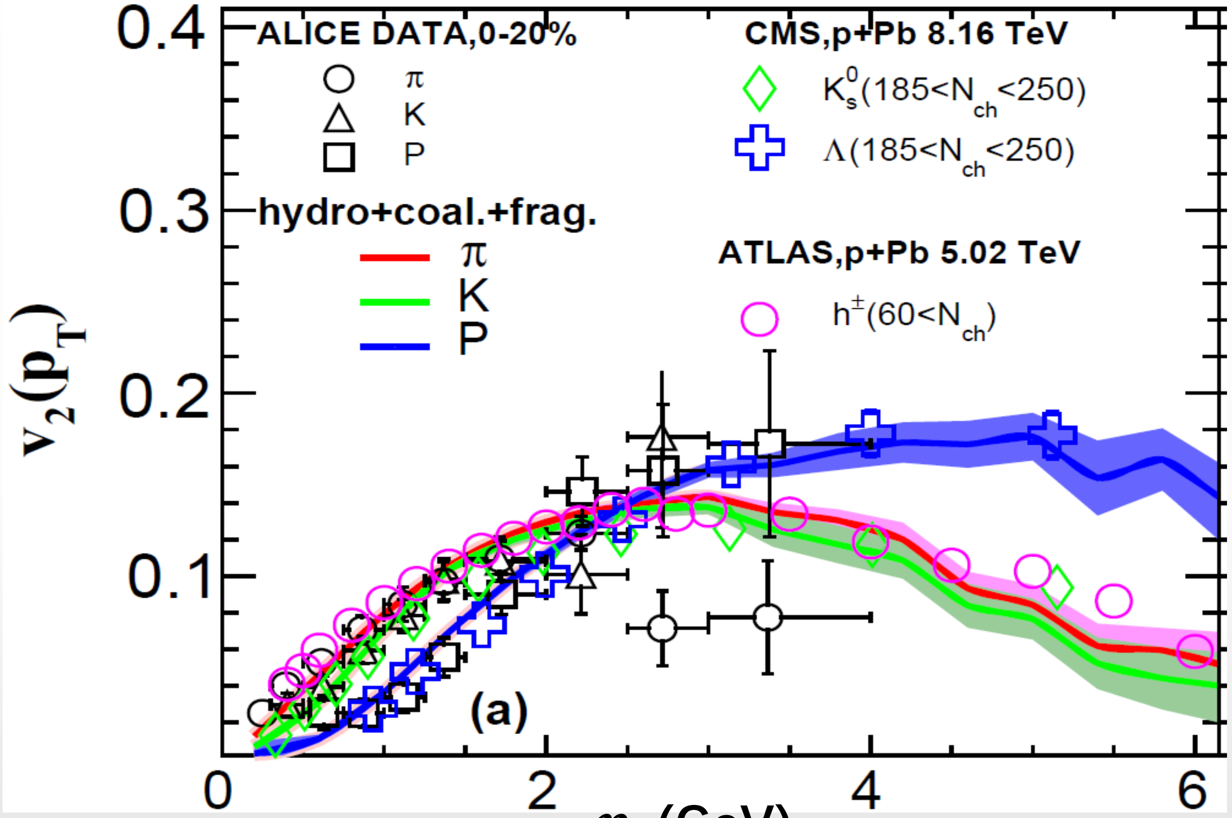
Spectra and P/π



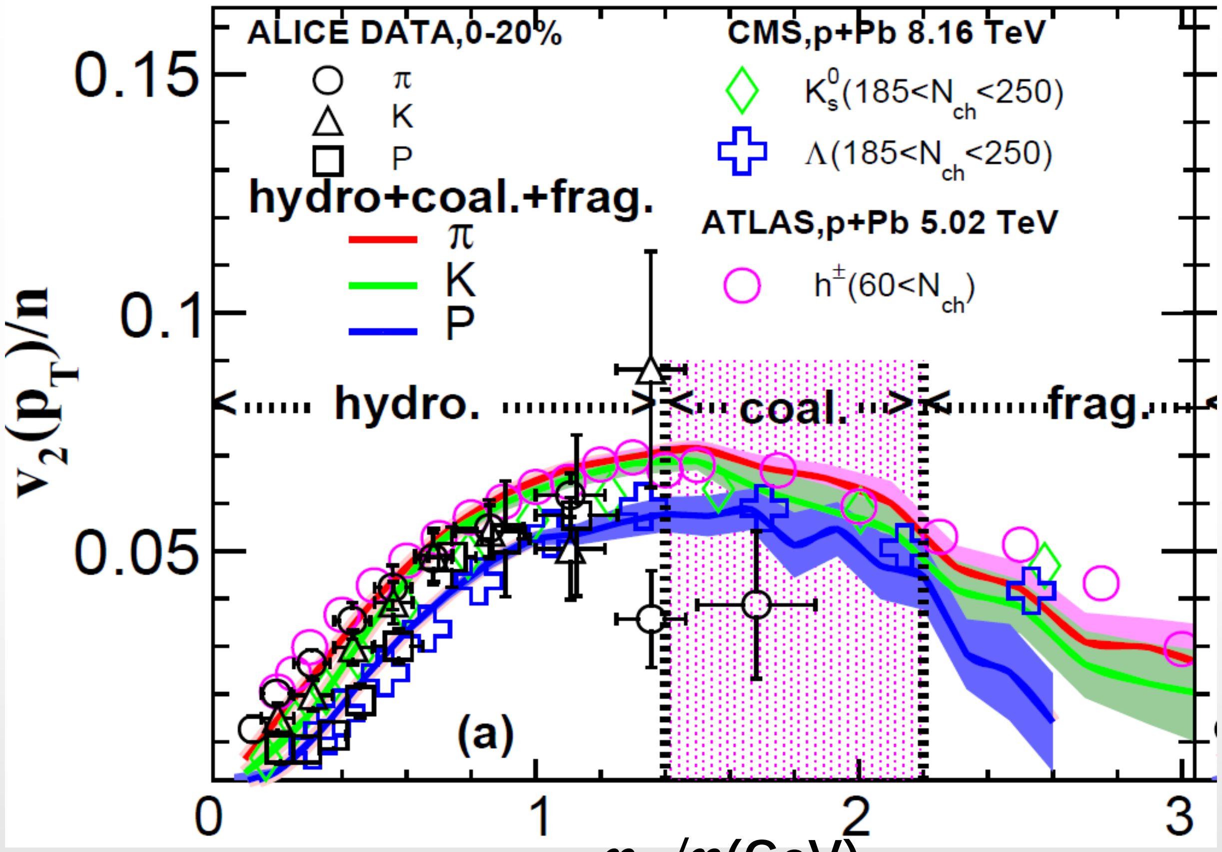
- **Our framework well describe the spectra and P/π at 0-6 GeV.**

$v_2(p_T)$ and NCQ scaling

P+Pb@$\sqrt{s} = 5.02\ TeV$,0-20%

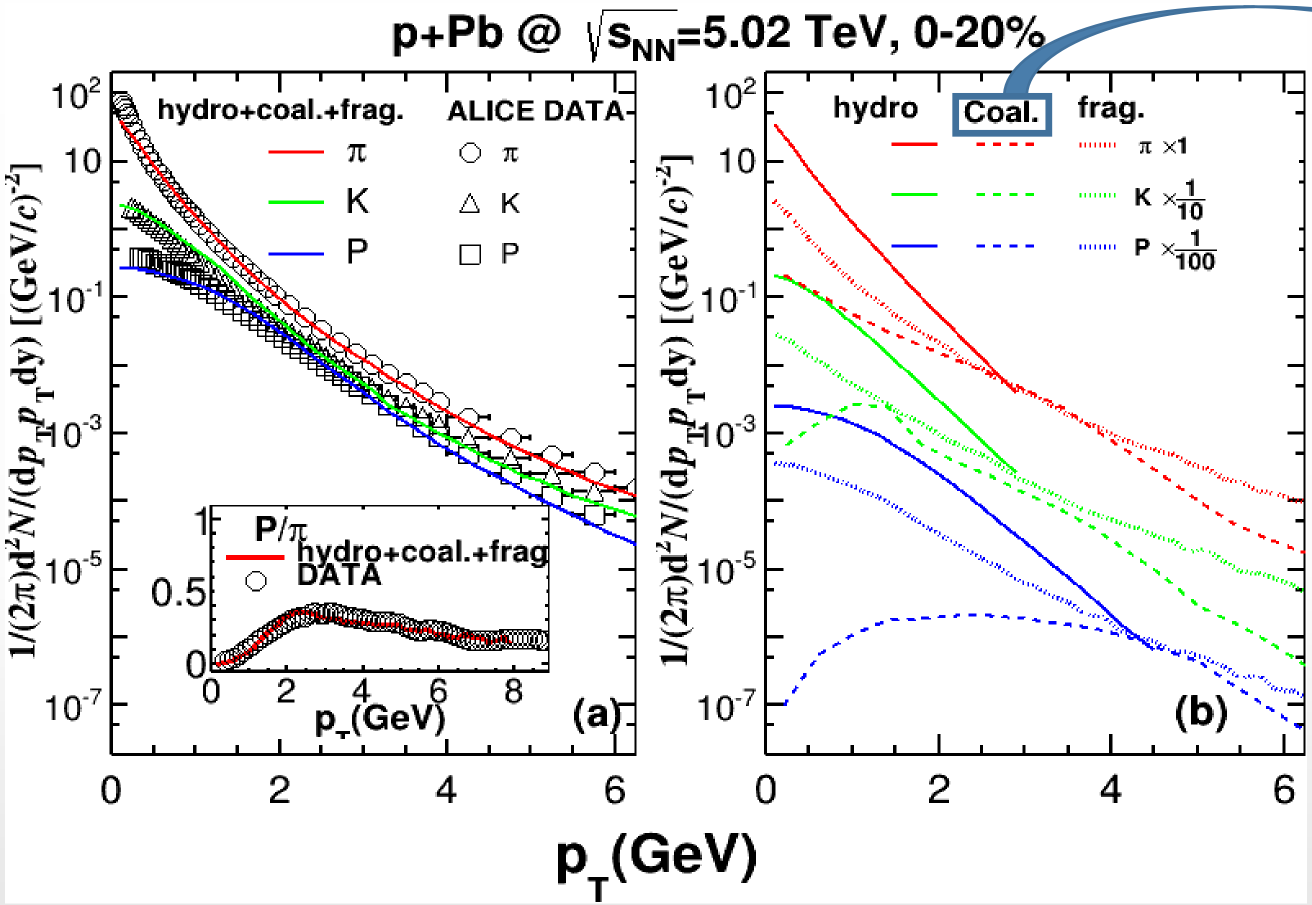


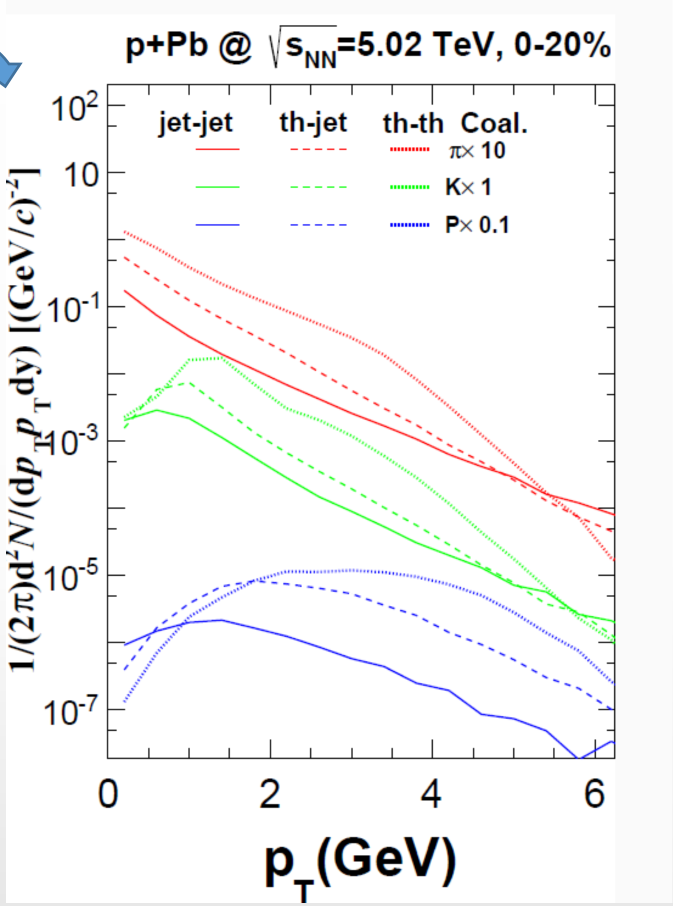
P+Pb@$\sqrt{s} = 5.02\ TeV$,0-20%



- Combine hydro and jet with coalescence and fragmentation, we can well describe the $v_2(p_T)$ from 0-6 GeV.
- At intermedium p_T, we can get the approximately NCQ scaling at data shown.

Hydro. Coalescence and fragmentation contributions



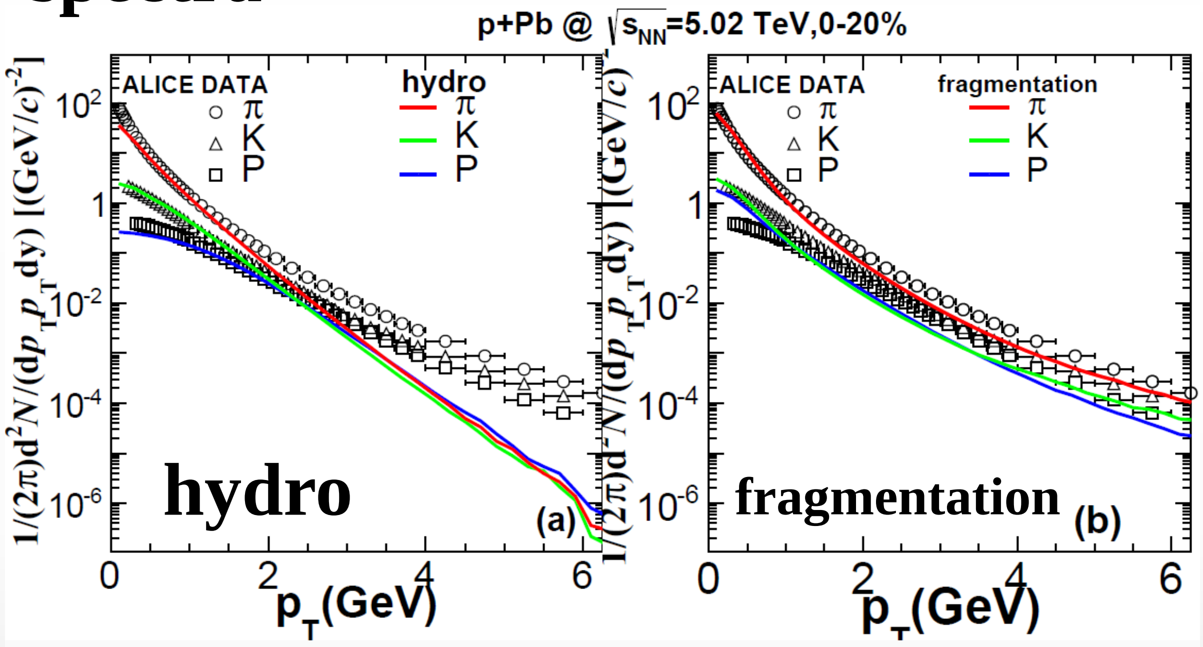


- Hydro dominates at low p_T, at inter-medium p_T, coal. and frag. both have contributions. Fragmentation dominates high p_T .
- Thermal-thermal coalescence dominates in the coalescence process.
- Thermal-jet coalescence will violate the NCQ scaling.

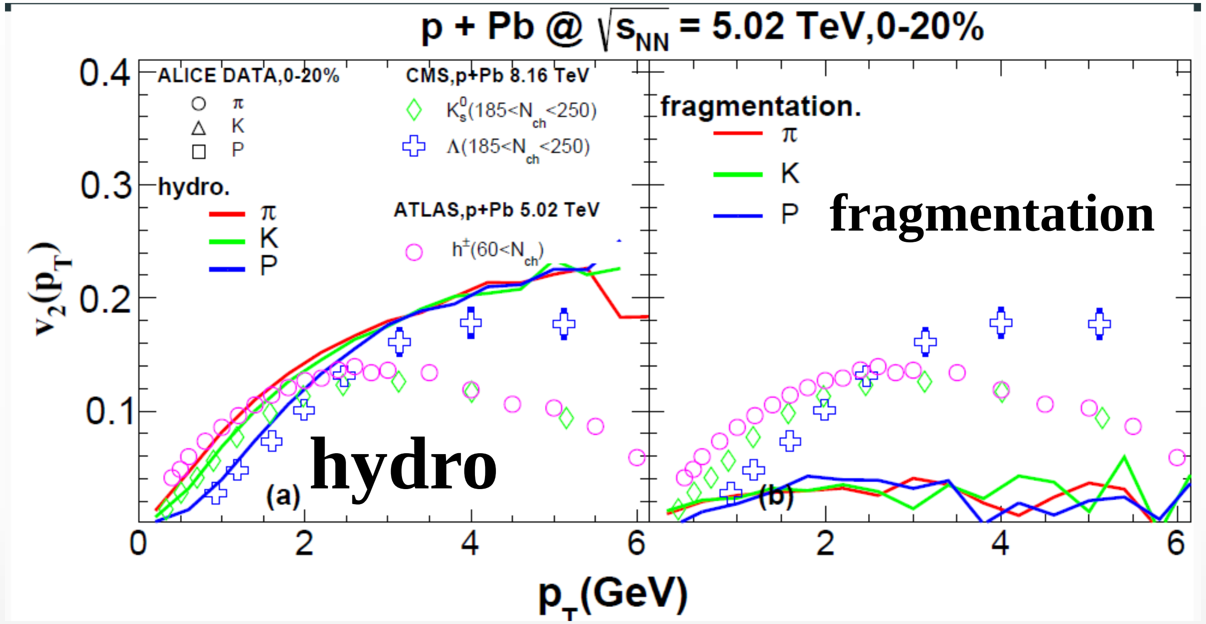
The importance of coalescence process in p-Pb system

Explore p-Pb system by hydro or min-jet.

- spectra

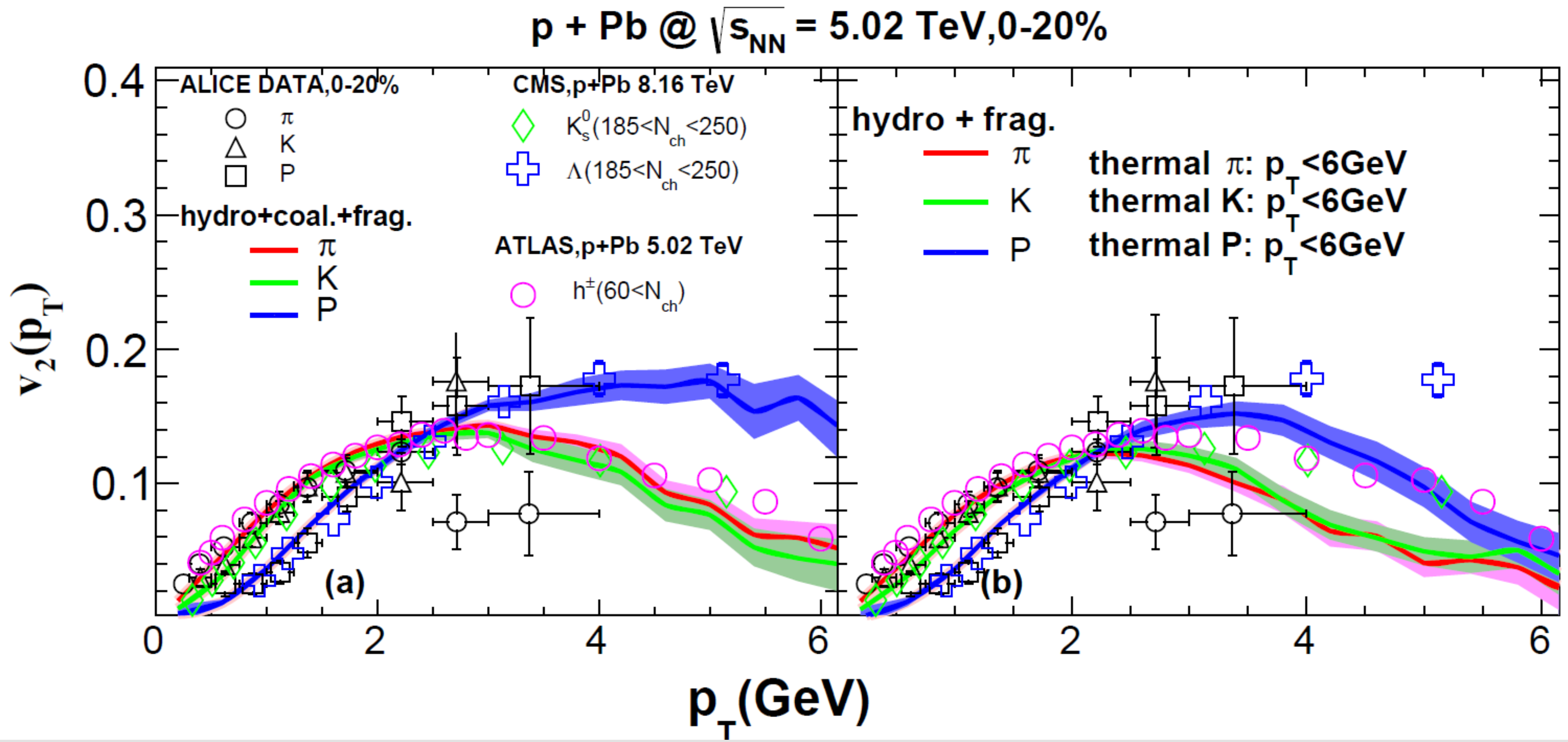


- $v_2(p_T)$



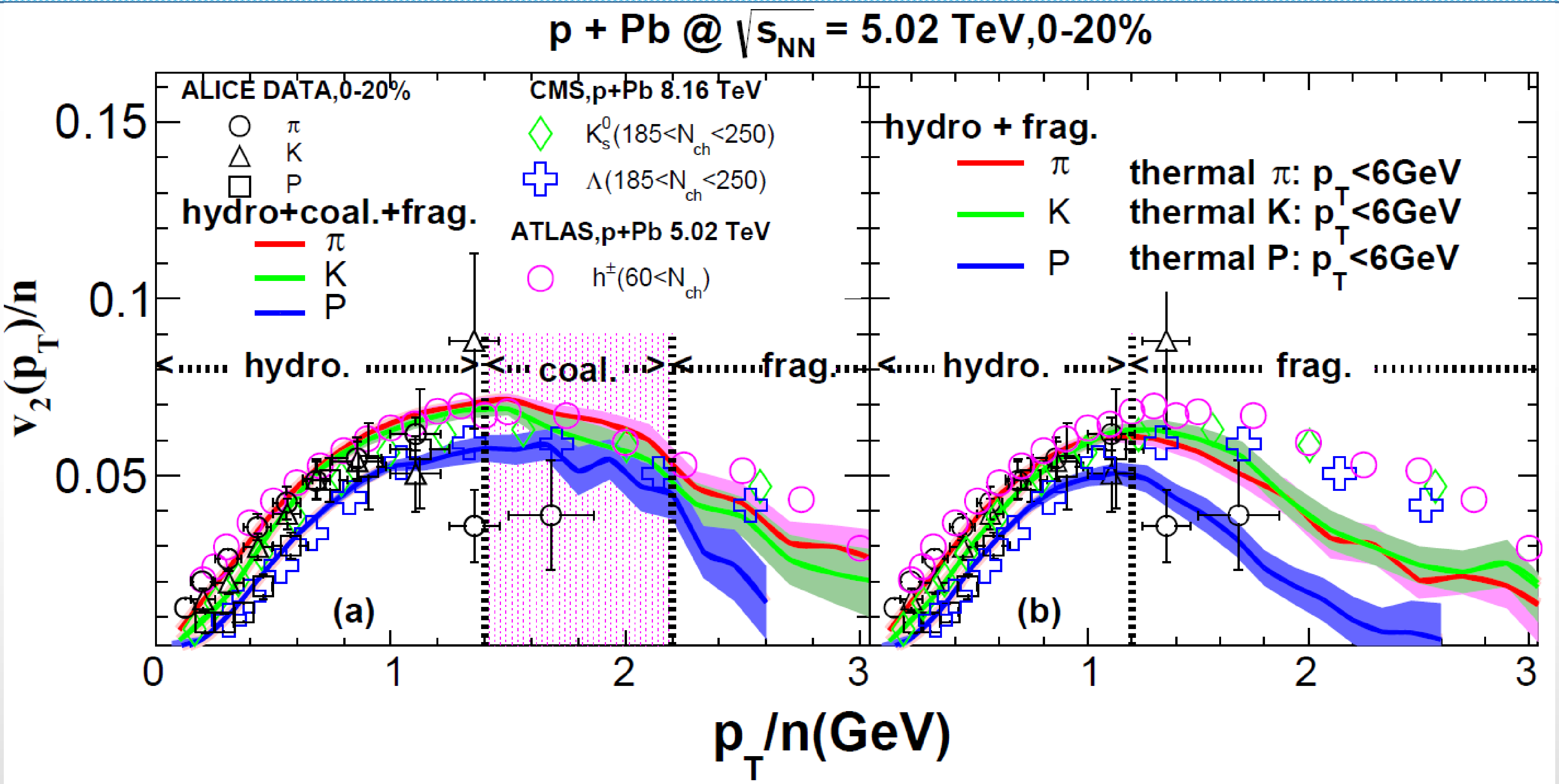
- Hydro works at low p_T , but fails at inter-medium p_T range.
- Fragmentation fails at low p_T range, and can't generate enough collective flow compared to measured data.

$v_2(p_T)$ of hydro+coal+frag and hydro+ frag.



- **Without coalescence, hydro+frag. significantly underestimates the $v_2(p_T)$ at inter-medium.**

NCQ scaling of hydro+coal+frag, and hydro+ frag.



- **Without coalescence, hydro+frag. will greatly violate the NCQ scaling at inter-medium p_T .**

Summary

- **NCQ scaling is a very clean to probe the partonic degree of freedom in small system.**
- **Coalescence is indispensable in high mulitiplicity p+Pb collisions. One needs combine hydro, coal. and frag. together to describe the spectra and $v_2(p_T)$ as well as the approximately NCQ scaling.**
- **Coalescnece implies the phase transition from partonic degree of freedom to hadronic degree of freedom during the evolution of p-Pb collisions.**
- **Fragmentation will violate the NCQ scaling at intermedium p_T in p+Pb system .**

Thanks

Back up

Framework of combine hydro and jet

Hydro. Coalescence,fragmentation fragmentation

0 P_T

1. Get the thermal hadrons from hydro by the Cooper-Frye.

Hydro + Cooper-Frye → meson(P_T< 3.2GeV)
baryon(P_T< 4.8GeV)

2. Get the thermal parton with $1.6 < P_T$ <4 GeV from hydro and the hard parton from Pythia8, then suffered with energy loss by LBT with α=0.15. Coalescence the quarks, the remnant hard quarks subjected to fragmentation in Pythia8.

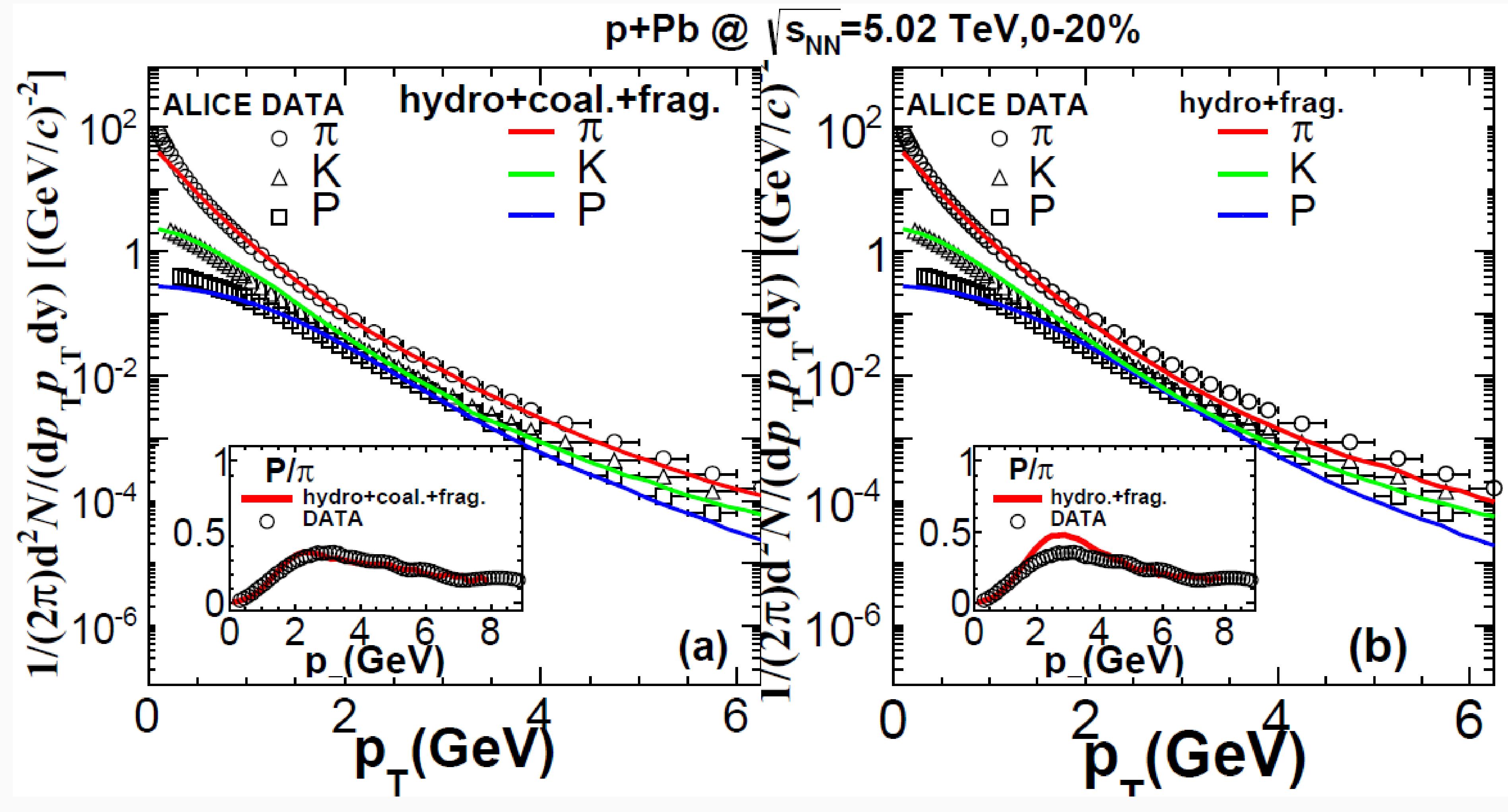
Thermal parton ($1.6 < P_T$< 6GeV)

Jet shower parton ($2.6GeV < P_T$)

→ Coalescence+ Fragmentation to hadron

3. All hadrons feed to the UrQMD model.

Spectra of hydro+coal+frag and hydro+ frag.



- **Without coalescence, hydro+frag. underestimate the spectra at inter-medium p_T and overeatimates the P/π ratio at the peak value.**