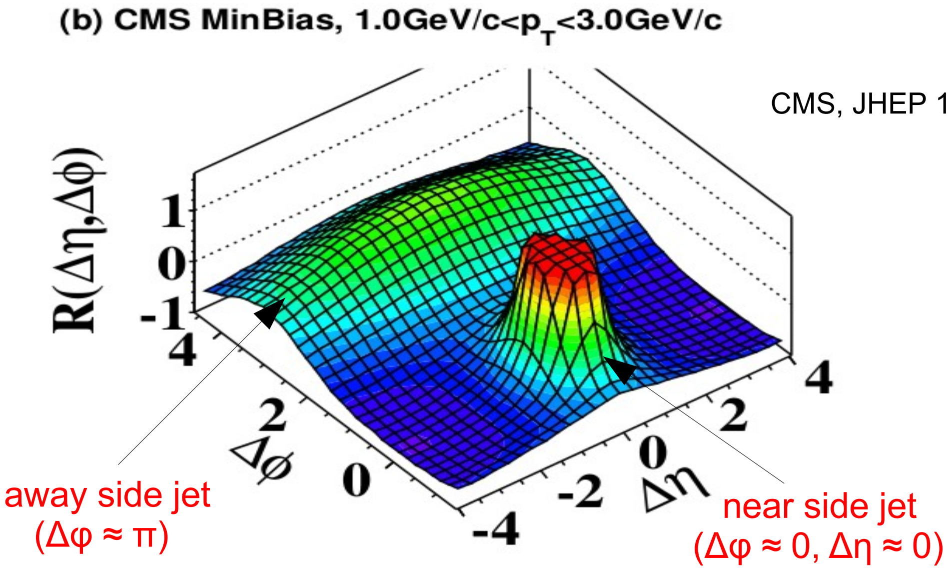
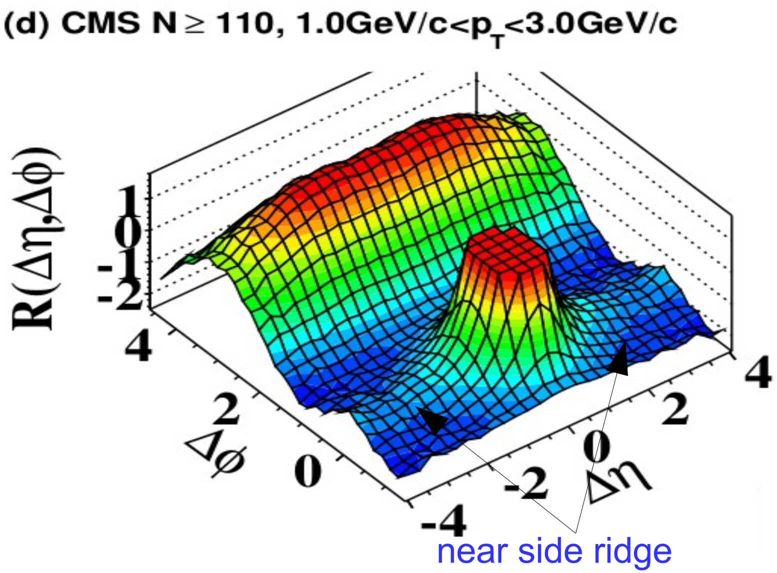
Flow in small collision systems

A. Dobrin
(Institute of Space Science)

Ridge in pp: first observation



CMS, JHEP 1009 (2010) 091

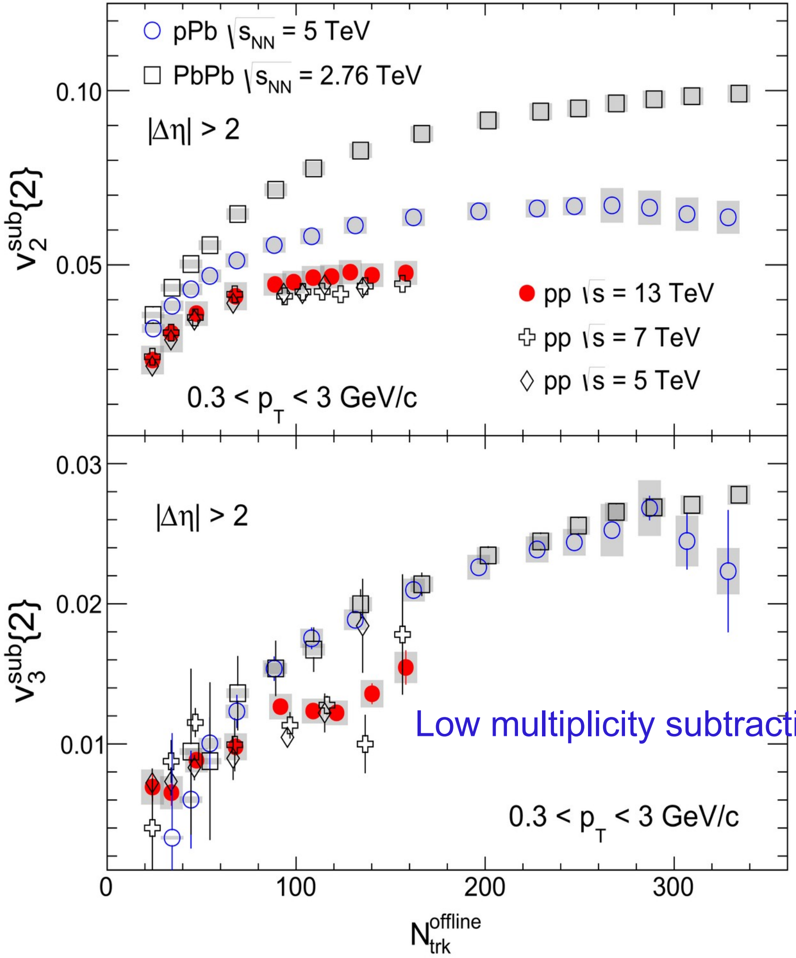


- Minimum bias pp
  - Jet peak on the near side (+ resonances)
  - Recoil jet on the away side
- High multiplicity pp
  - Near side ridge, typical of collective systems
    - Decomposed into Fourier harmonics v_n

$$1+\sum_{n=1}^{\infty} 2 v_n \cos\left(n\left(\varphi-\Psi_n\right)\right)$$

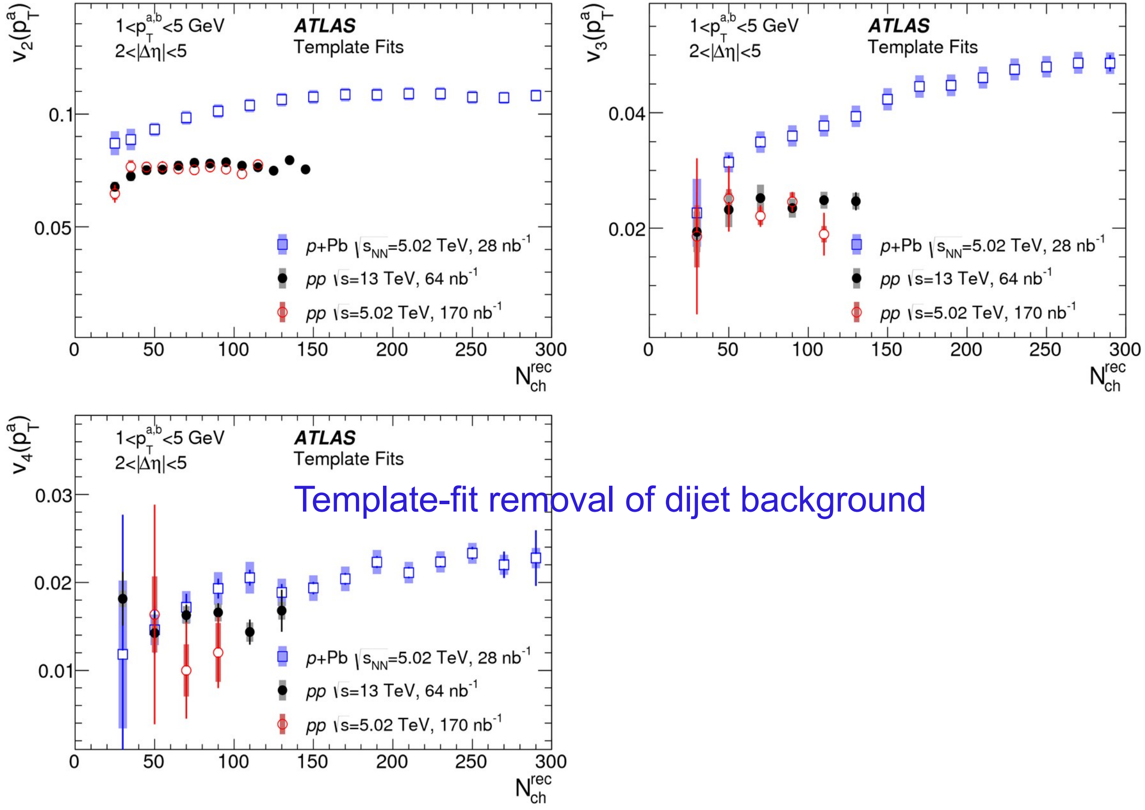
Two-particle correlations

CMS, PLB 765 (2017) 193



Low multiplicity subtraction

ATLAS, PRC 96 (2017) 024908



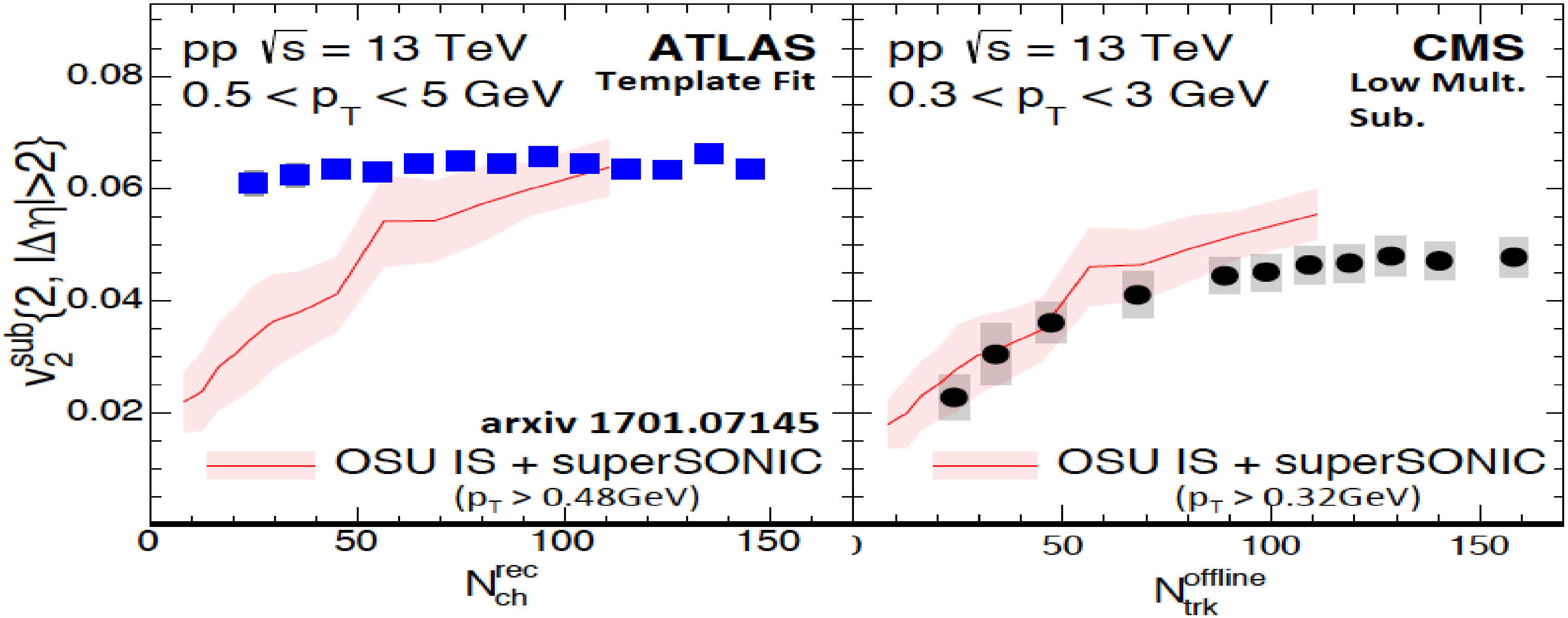
Template-fit removal of dijet background

v_n dependence on collision system but not on energy

Two-particle correlations: non-flow removal?

ATLAS, PRC 96 (2017) 024908

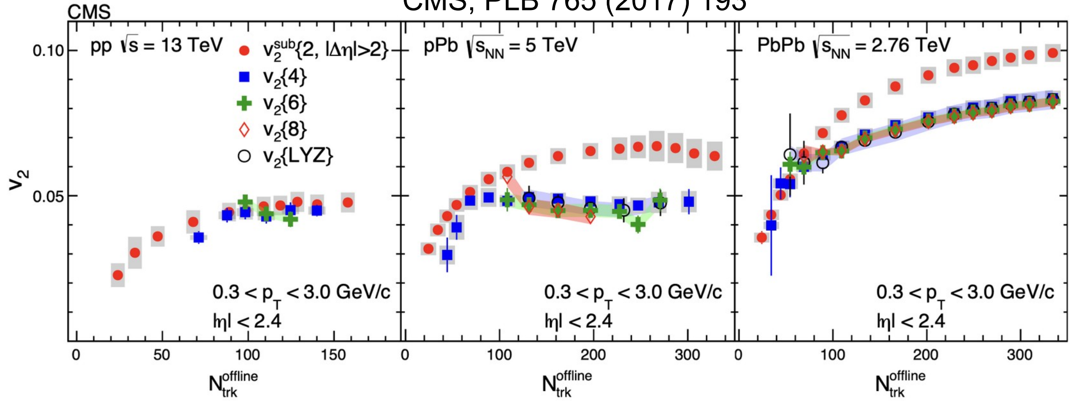
CMS, PLB 765 (2017) 193



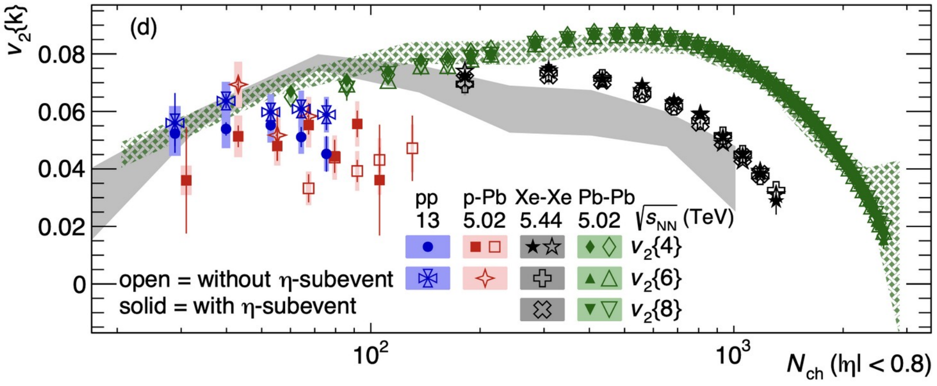
- Differences between ATLAS and CMS v_2 due to subtraction technique
  - Small difference even between ATLAS v_2 subtracted and CMS v_2 un-subtracted
- Comparison with theoretical calculations?

Multi-particle cumulants

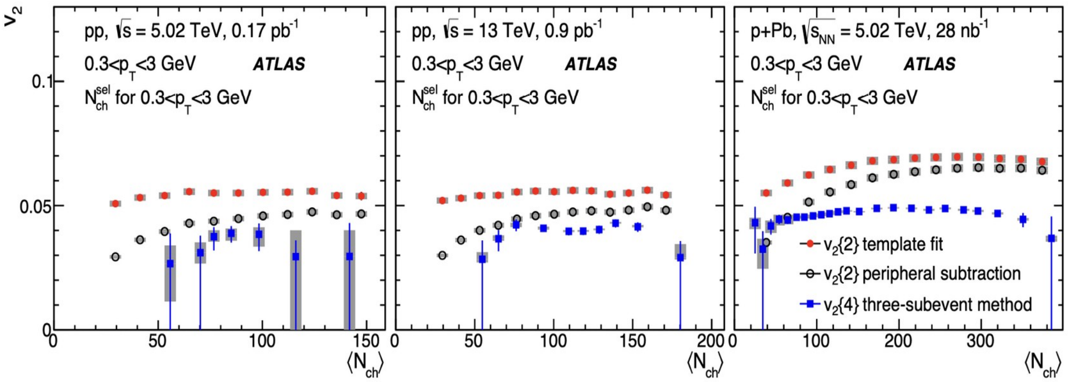
CMS, PLB 765 (2017) 193



ALICE, PRL 123 (2019) 142301



ATLAS, PRC 97 (2018) 024904



$$c_n\{2\}=\langle\langle 2\rangle\rangle=\langle\langle\cos(n(\varphi_1-\varphi_2))\rangle\rangle \qquad v_n\{2\}=\sqrt{c_n\{2\}}$$

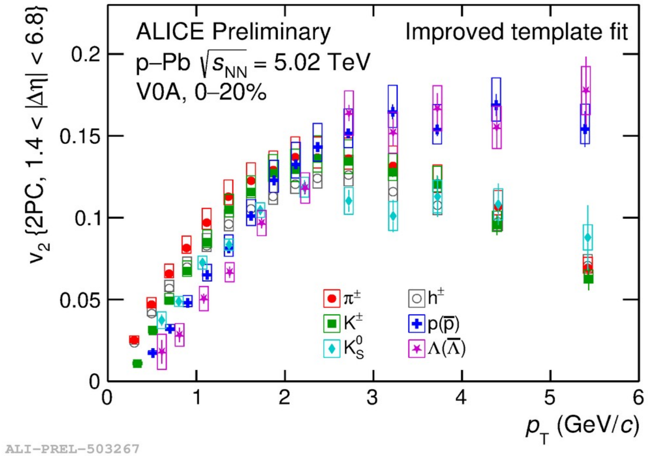
$$c_n\{4\}=\langle\langle 4\rangle\rangle-2\langle\langle 2\rangle\rangle^2 \qquad v_n\{4\}=\sqrt[4]{-c_n\{4\}}$$

$$c_n\{6\}=\langle\langle 6\rangle\rangle-9\langle\langle 4\rangle\rangle\langle\langle 2\rangle\rangle+12\langle\langle 2\rangle\rangle^3 \qquad v_n\{6\}=\sqrt[6]{c_n\{6\}/4}$$

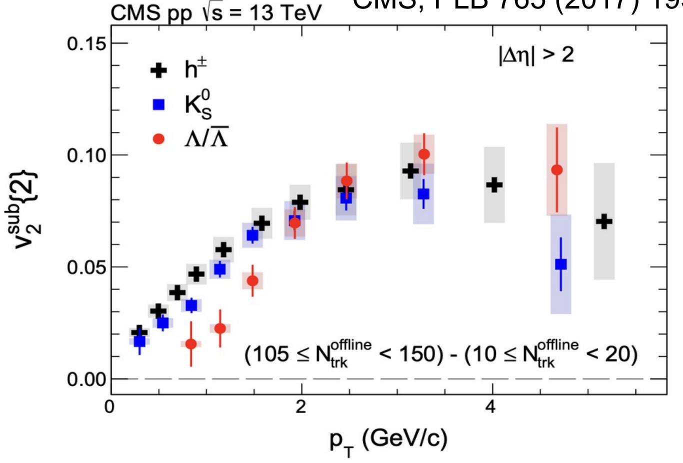
- CMS / ALICE: $v_2\{2\}\approx v_2\{4\}\approx v_2\{6\}$ → no fluctuations in pp?
- ATLAS: $v_2\{2\} > v_2\{4\}$
  - Weak energy dependence
  - Different methods to suppress non-flow

J. Jia et al., PRC 96 (2017) 034906

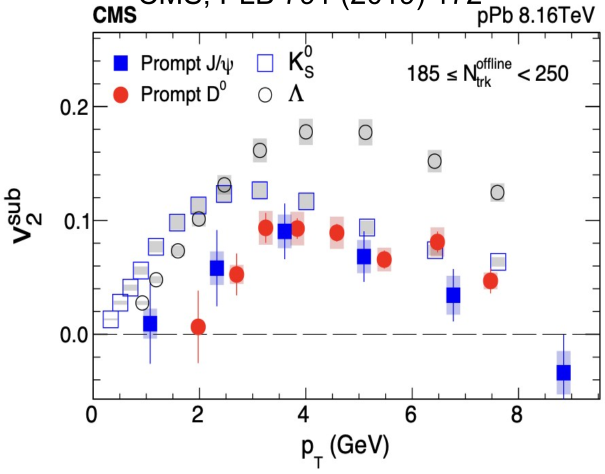
PID v_2: high multiplicity

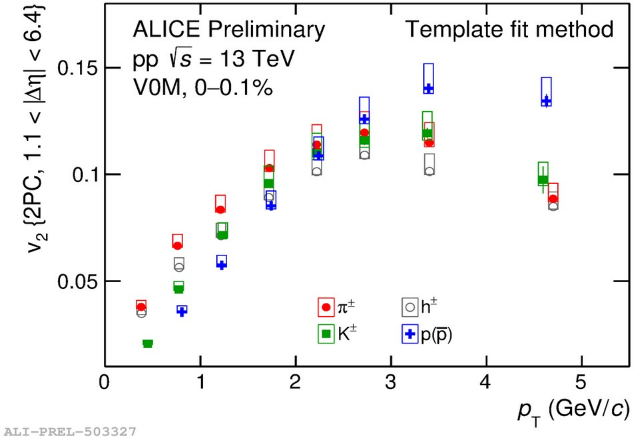


CMS, PLB 765 (2017) 193



CMS, PLB 791 (2019) 172

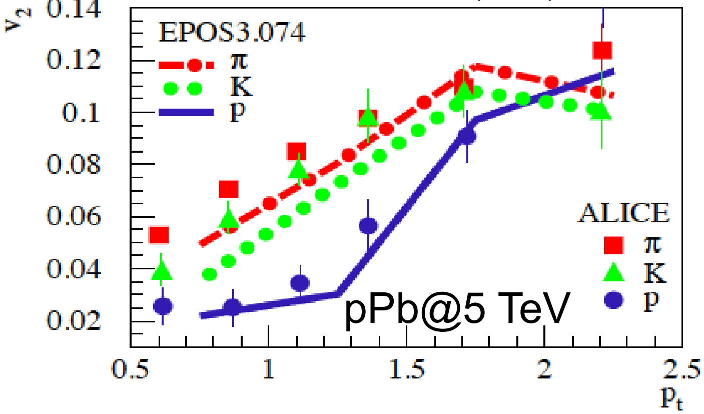




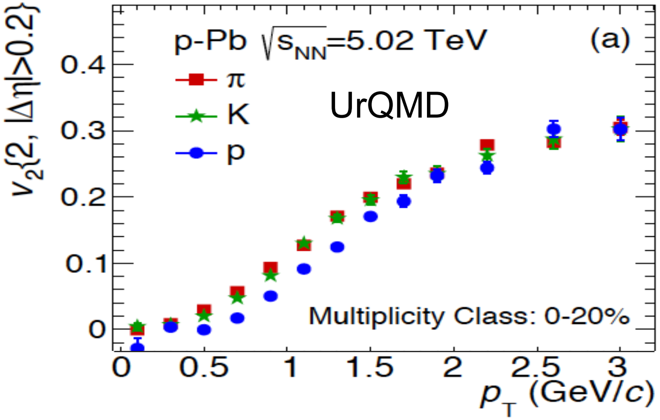
- Mass ordering observed in high multiplicity p-Pb and pp collisions
  - Test particle type dependence at high p_T
- Extend the measurements to multi-particle cumulants

PID v_2: model calculations

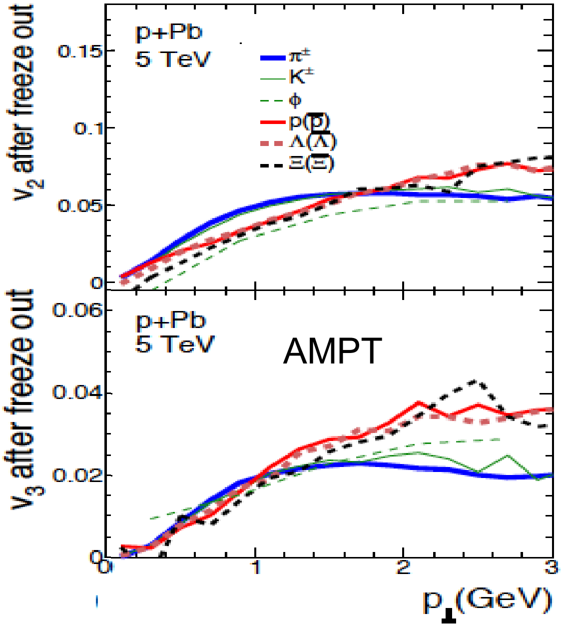
K. Werner et al, PRL 112 (2014) 232301



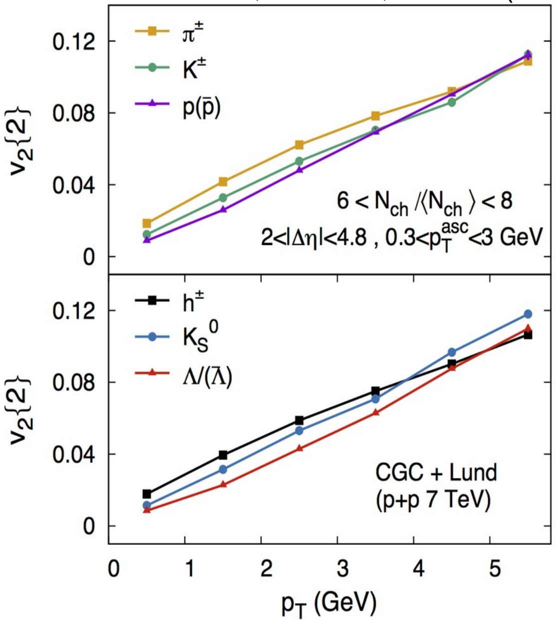
Y. Zhou et al, PRC 91 (2015) 064908



H. Li et al, arxiv: 1604.07387



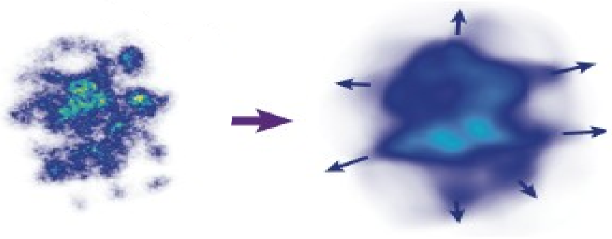
B. Schenke et al, PRL 117, 162301 (2016)



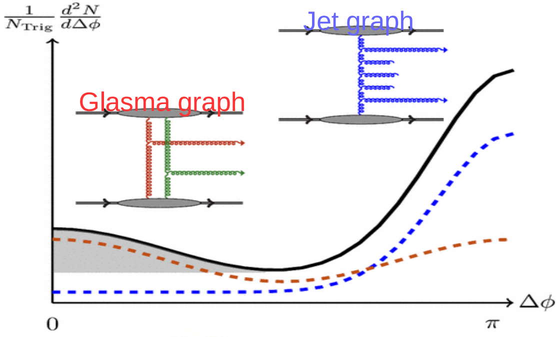
- Mass ordering qualitatively reproduced by
  - Hydrodynamic
  - AMPT (parton escape mechanism)
  - UrQMD (hadronic interactions)
  - CGC + Lund fragmentation (emission from common boosted source)

Sources of collectivity

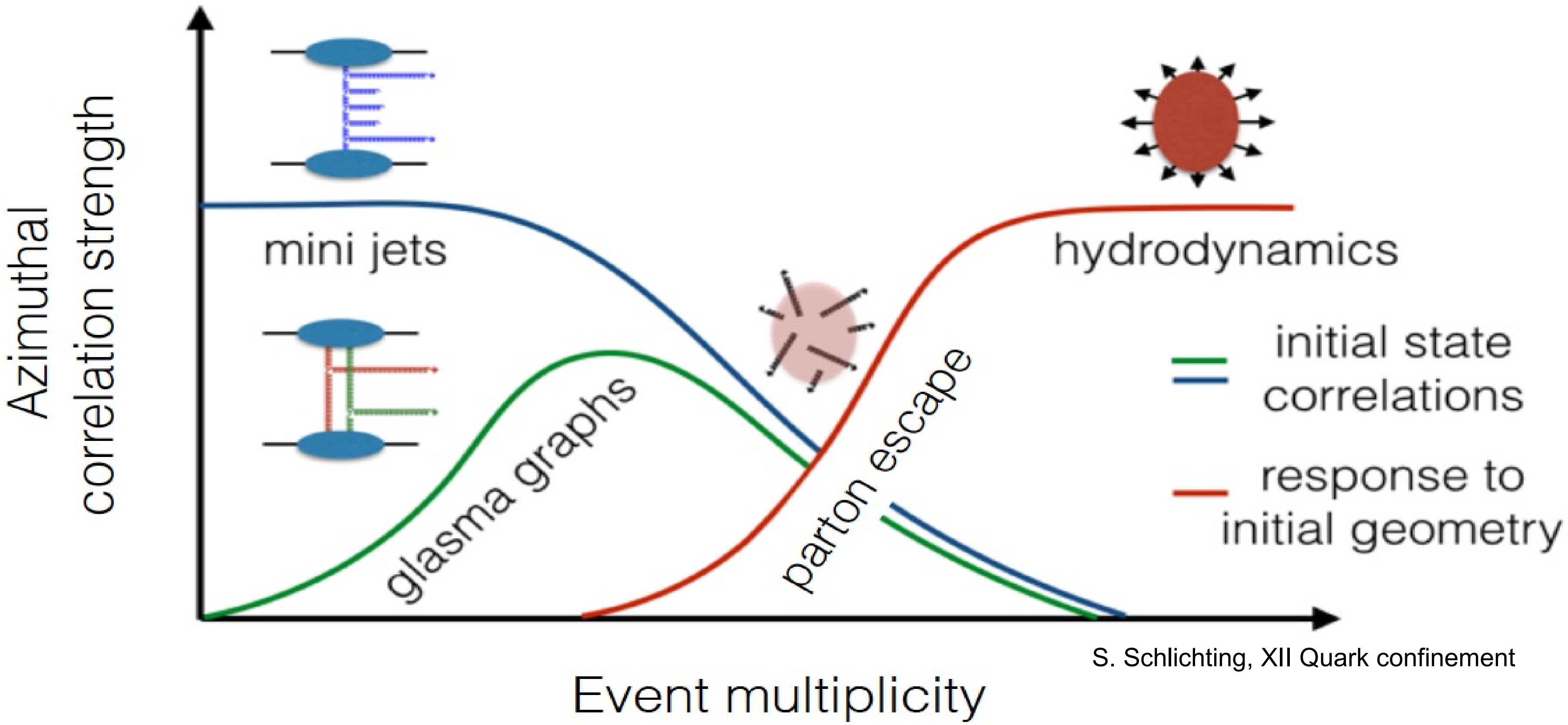
- Final state effects
  - Initial spatial eccentricities converted into momentum anisotropies via final state interactions
    - Hydrodynamics
    - Parton transport
    - Parton escape



- Initial state effects
  - Initial momentum anisotropies from initial interactions
    - Color Glass Condensate (CGC) Glasma
    - Color-field domains
    - Numerical solutions



Initial state vs final state effects

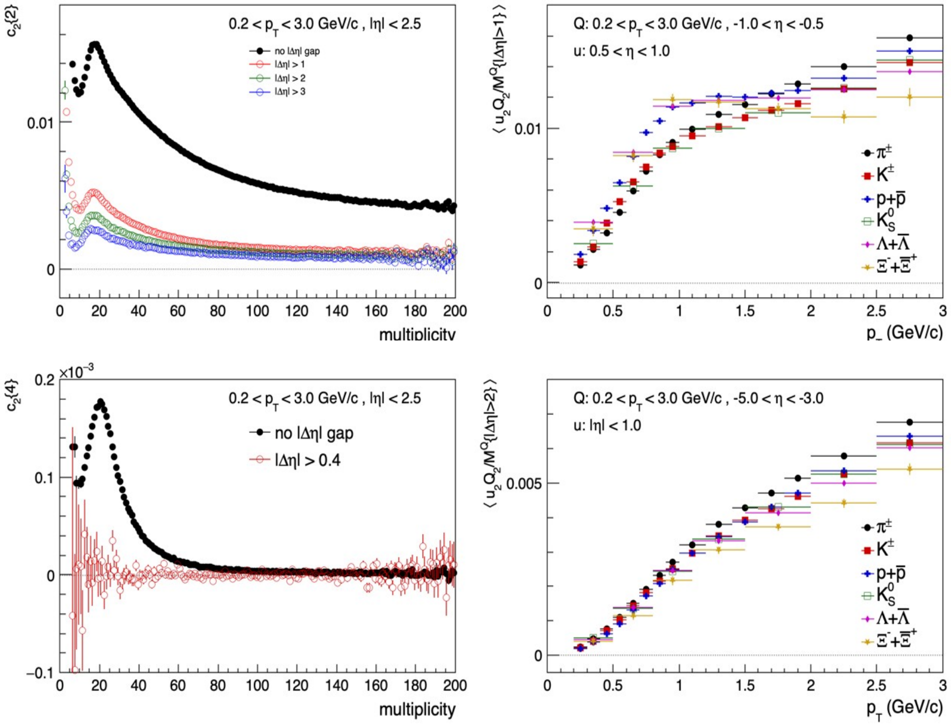


S. Schlichting, XII Quark confinement

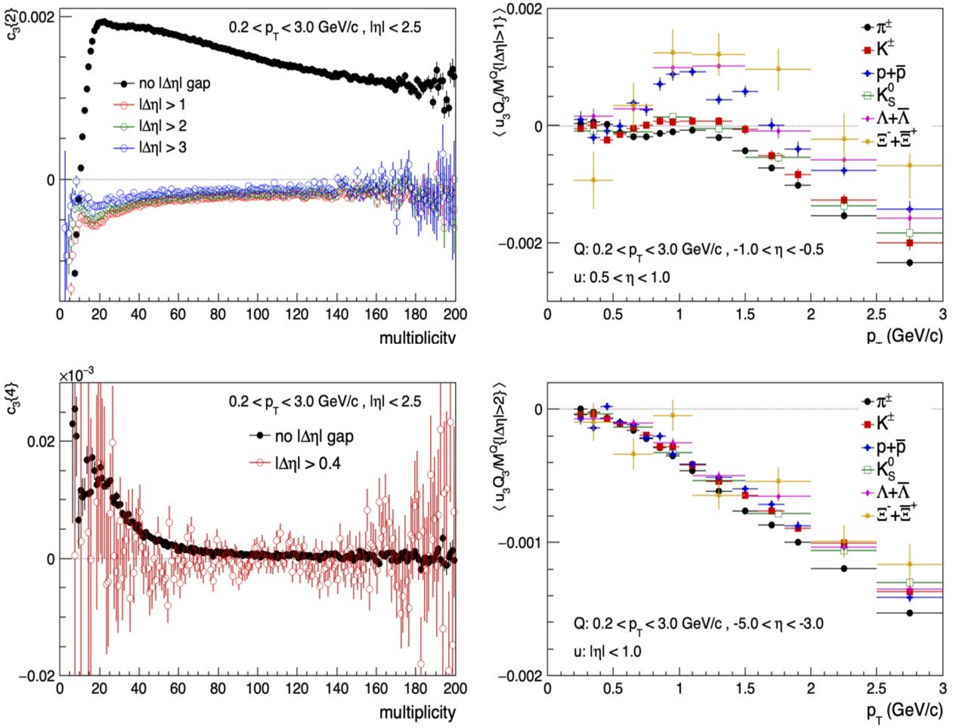
How to disentangle different regimes?

“Flow” in PYTHIA 8.309 (default): minimum bias pp @ 13.6 TeV

“v_2”



“v_3”

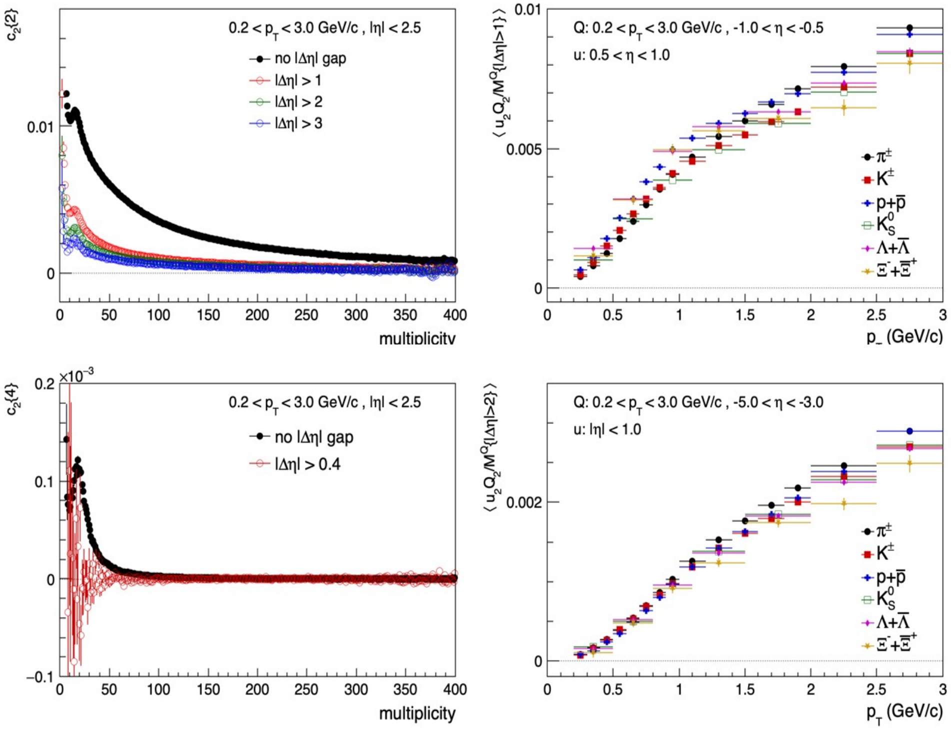


- Mass ordering when a large gap is used
- $c_2\{2\} > 0$ and $c_2\{4\} \sim 0$ at high multiplicities
  - Small dependence on $|\Delta\eta|$ gap for $c_2\{2\}$

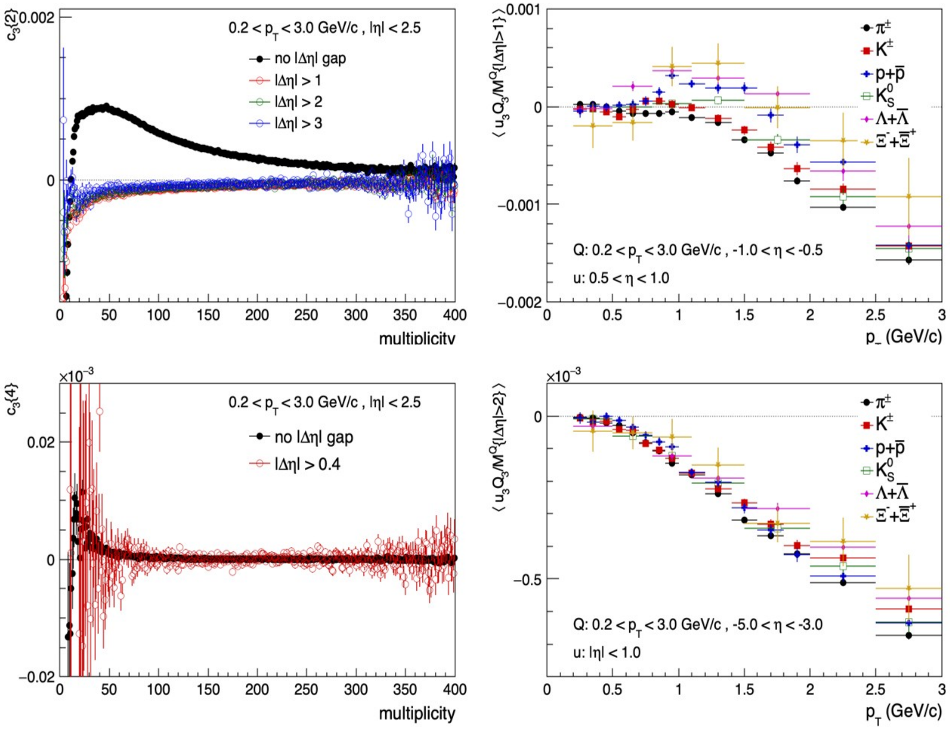
- No mass ordering
- $c_3\{2, |\Delta\eta|\} < 0$ and $c_3\{4\} \sim 0$ at high multiplicities
  - Small dependence on $|\Delta\eta|$ gap for $c_3\{2\}$

"Flow" in PYTHIA 8.309 (Angantyr): minimum bias p-Pb @ 5.02 TeV

"v_2"



"v_3"

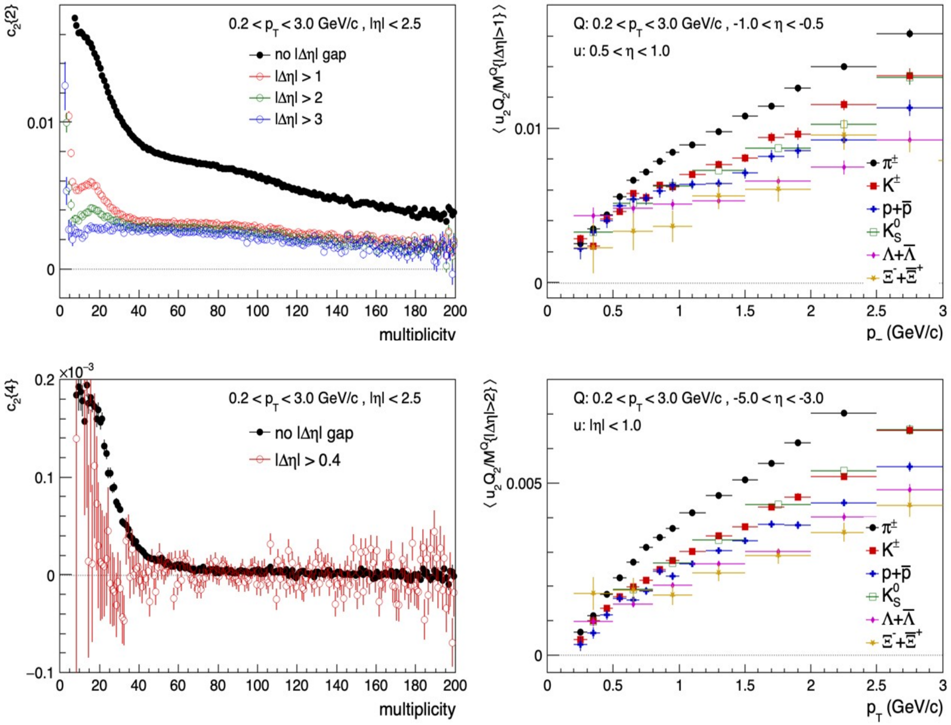


- Mass ordering when a large gap is used
- $c_2\{2\} \sim 0$ and $c_2\{4\} \sim 0$ at high multiplicities
  - Small dependence on $|\Delta\eta|$ gap for $c_2\{2\}$

- No mass ordering
- $c_3\{2, |\Delta\eta|\} \sim 0$ and $c_3\{4\} \sim 0$ at high multiplicities
  - Small dependence on $|\Delta\eta|$ gap for $c_3\{2\}$

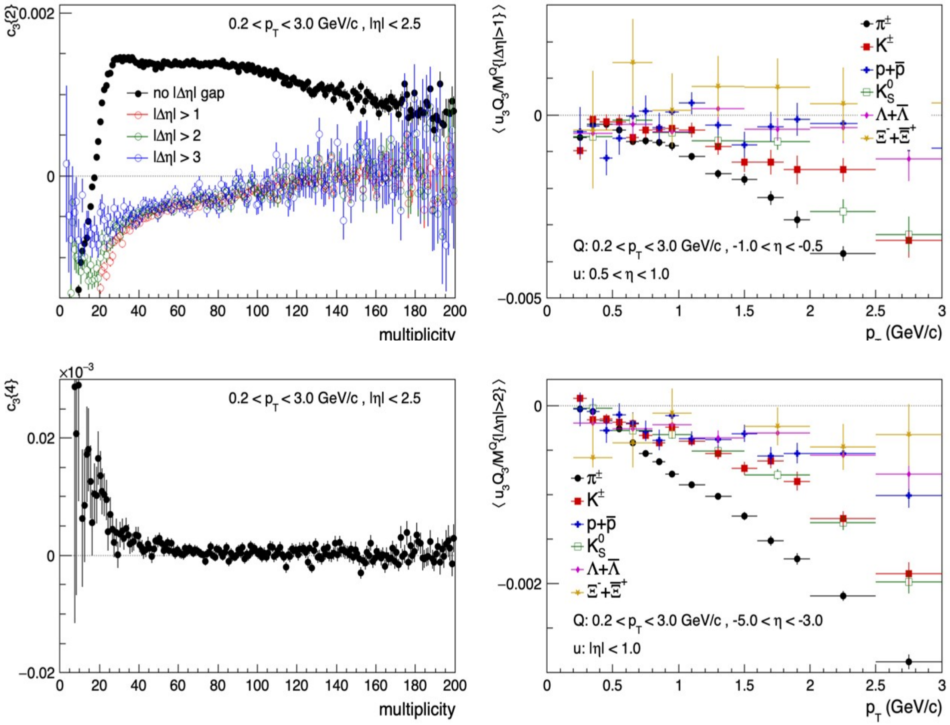
"Flow" in EPOS4 (hydro+rescattering): minimum bias pp @ 13.6 TeV

"v_2"



- Mass ordering more pronounced when a large gap is used
- $c_2\{2\} > 0$ and $c_2\{4\} \sim 0$ at high multiplicities
  - Small dependence on $|\Delta\eta|$ gap for $c_2\{2\}$

"v_3"



- A kind of mass ordering
- $c_3\{2, |\Delta\eta|\} \sim 0$ and $c_3\{4\} \sim 0$ at high multiplicities
  - Small dependence on $|\Delta\eta|$ gap for $c_3\{2\}$