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Longitudinal correlation in heavy-ion collisions

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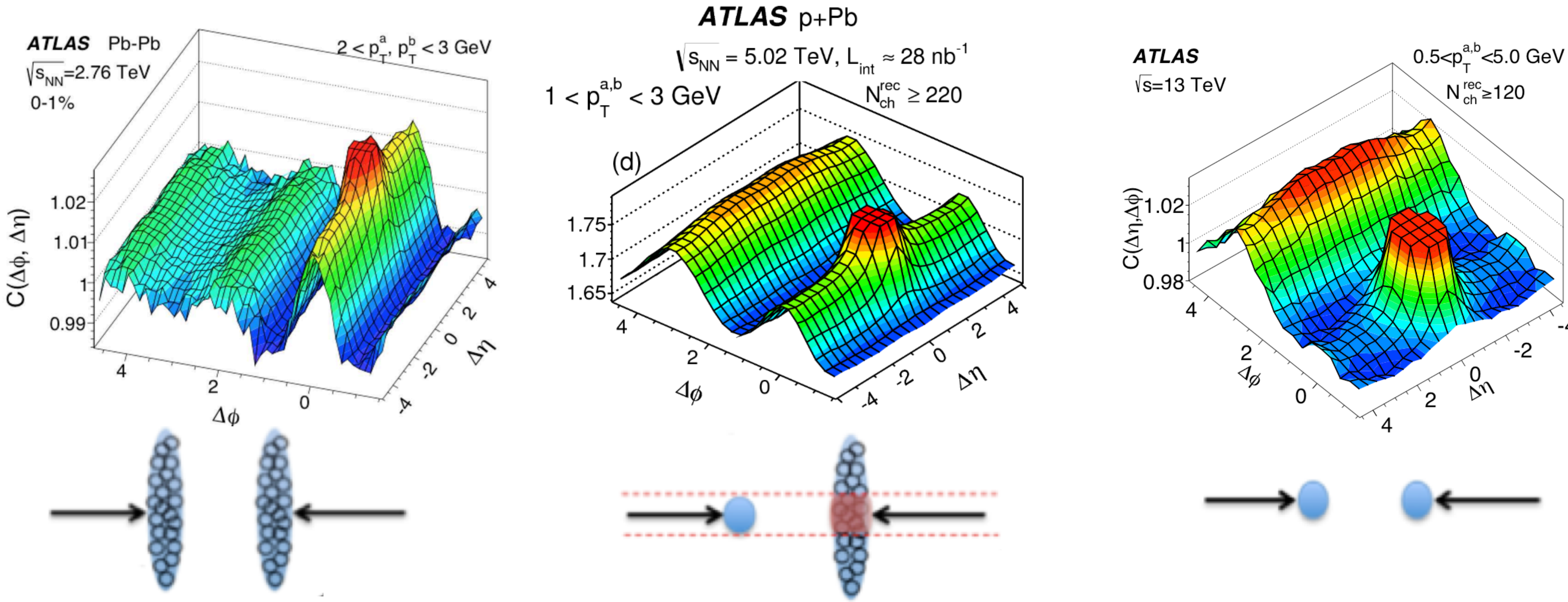
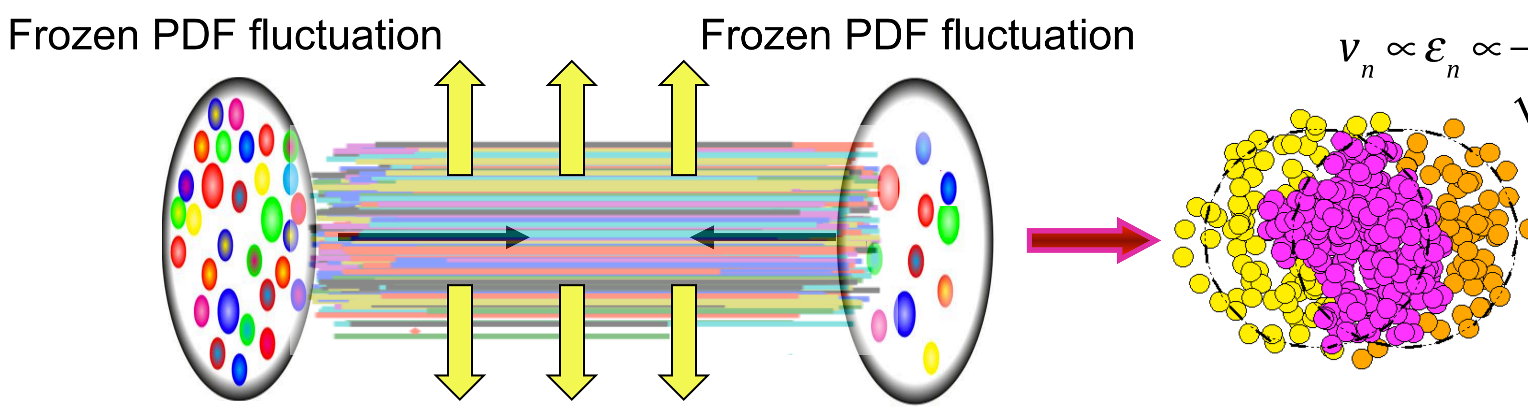
QCD Chirality Workshop 2016

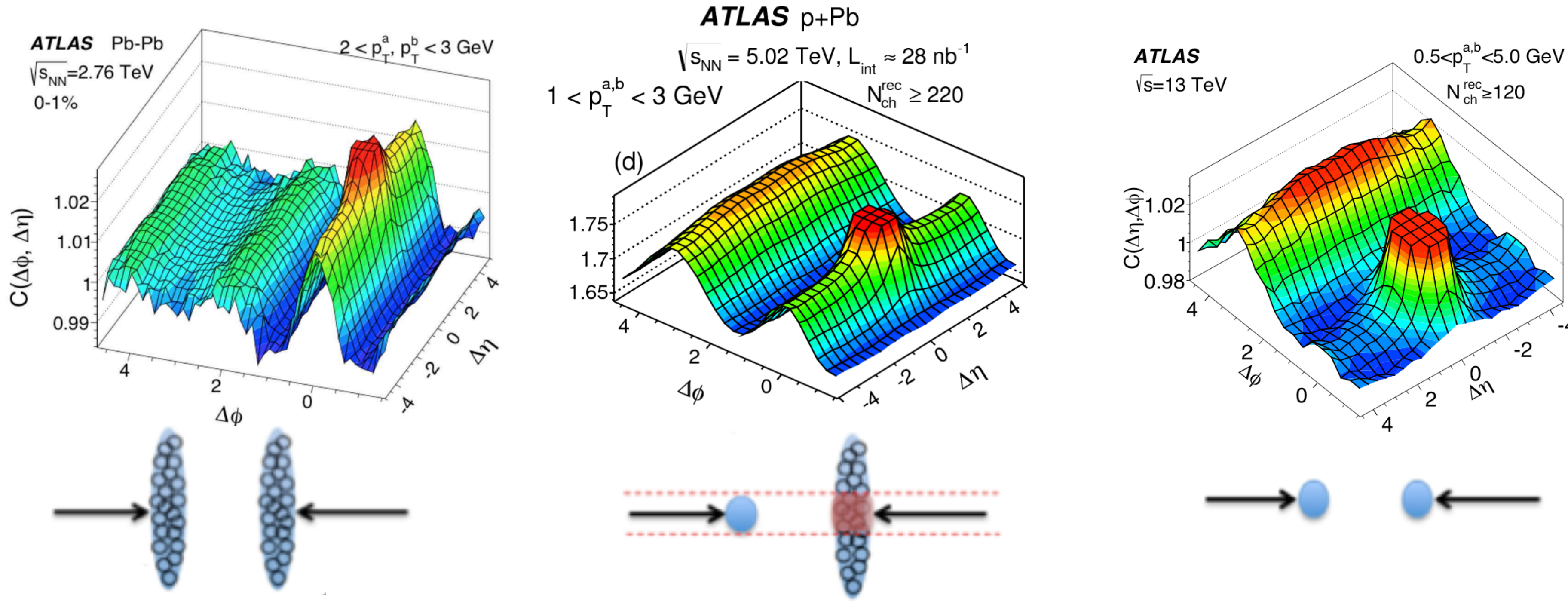


Nature of sources seeding these long-range collective ridges?



$$v_n \propto \varepsilon_n \propto \frac{1}{\sqrt{n_{sources}}}$$

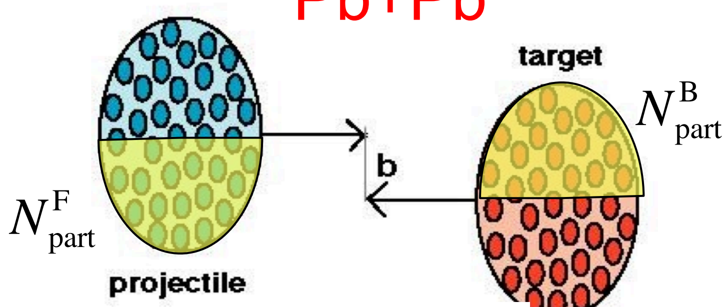
How many such sources, their sizes & transverse distribution?



Nature of sources seeding these long-range collective ridges?

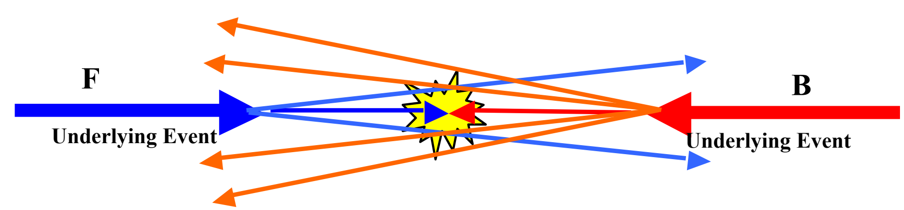
Particles (entropy) are produced early in collision

Pb+Pb



$$A_{\rm part} = \frac{N_{\rm part}^{\rm F} - N_{\rm part}^{\rm B}}{N_{\rm part}^{\rm F} + N_{\rm part}^{\rm B}}$$

p+p



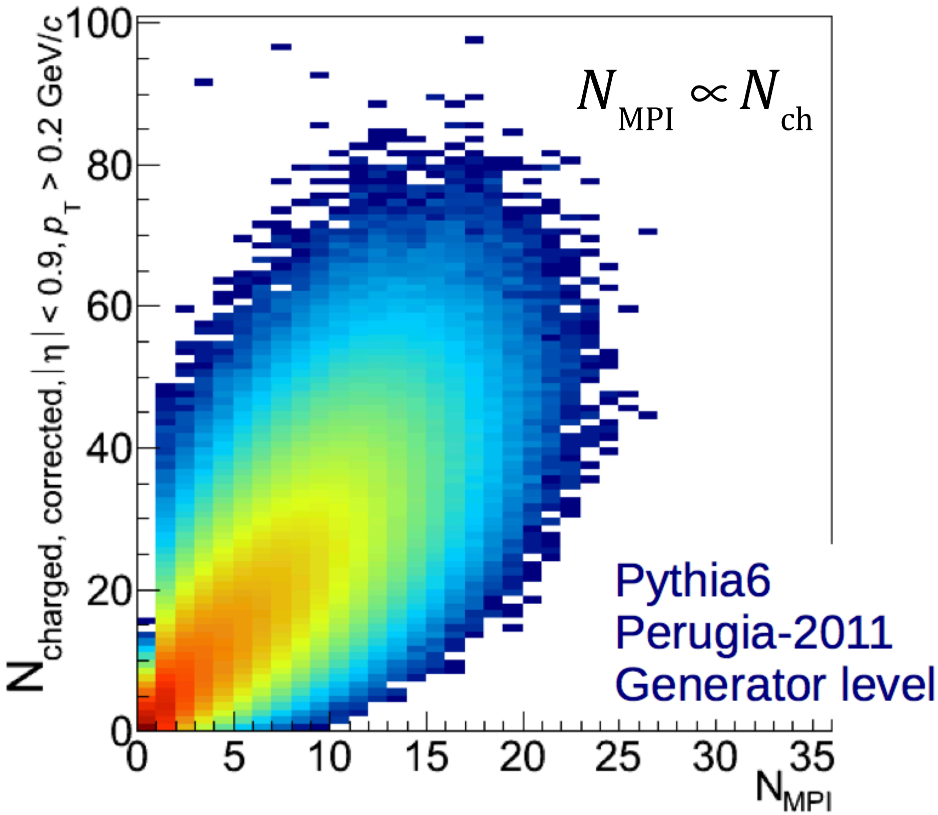
MPI: $n_f \neq n_b$ $\quad A_n = \frac{n_f - n_b}{n_f + n_b}$

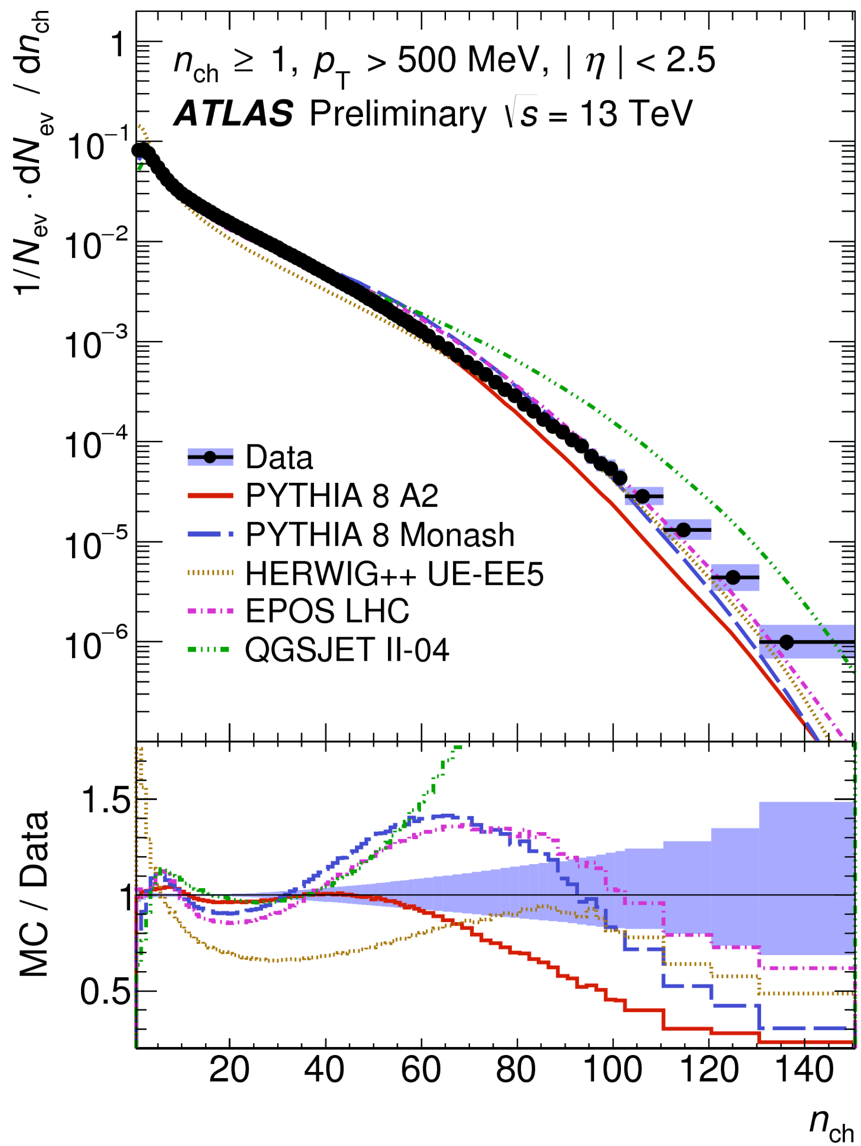
Forward/backward multiplicity/flow correlations provide a handle

Importance of sub-nucleonic sources

- Multi-parton interactions (MPI) required to described N_{ch} distribution

$$\langle N_{\mathrm{MPI}}(p_{\mathrm{T,\,min}})\rangle = \frac{\sigma_{\mathrm{interaction}}(p_{\mathrm{T,\,min}})}{\sigma_{\mathrm{non\text{-}diffractive}}}$$

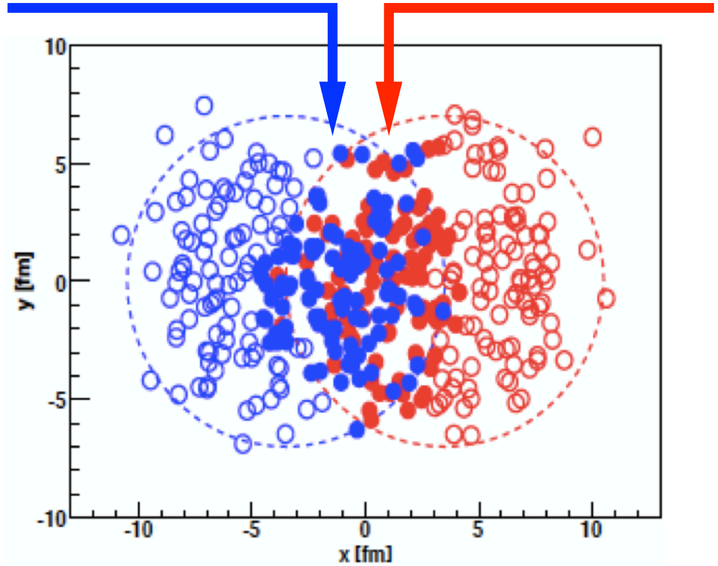




Three types of longitudinal correlations

Fluctuation of participants in two nuclei → size and transverse-shape different

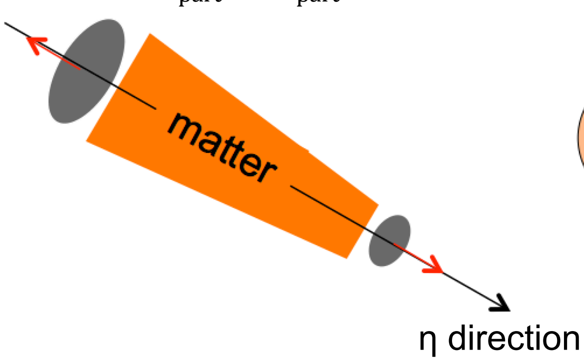
$N_{\mathrm{part}}^{\mathrm{F}}$ $\varepsilon_n^{\mathrm{F}} e^{in\Psi_n^F}$



$N_{\mathrm{part}}^{\mathrm{B}}$ $\varepsilon_n^{\mathrm{B}} e^{in\Psi_n^B}$

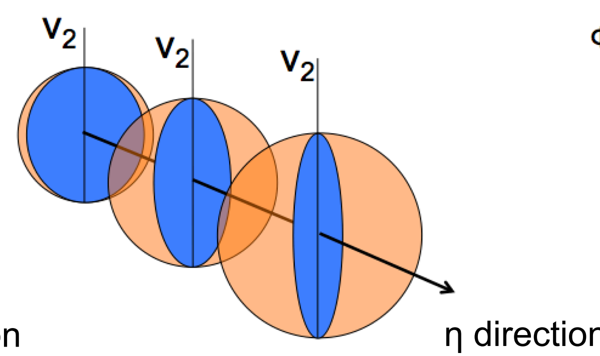
Consequences:

(a) $N_{\mathrm{part}}^{\mathrm{F}} \neq N_{\mathrm{part}}^{\mathrm{B}}$



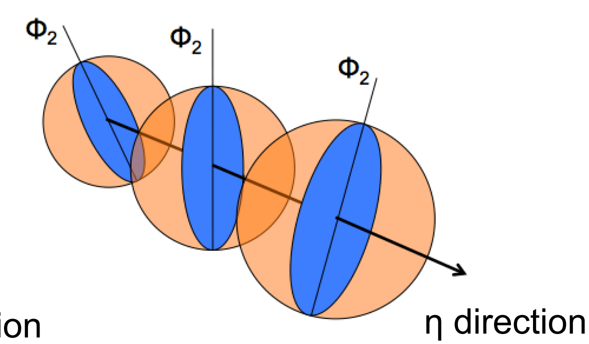
Asymmetry in multiplicity

(b) $\varepsilon_2^{\mathrm{F}} \neq \varepsilon_2^{\mathrm{B}}$



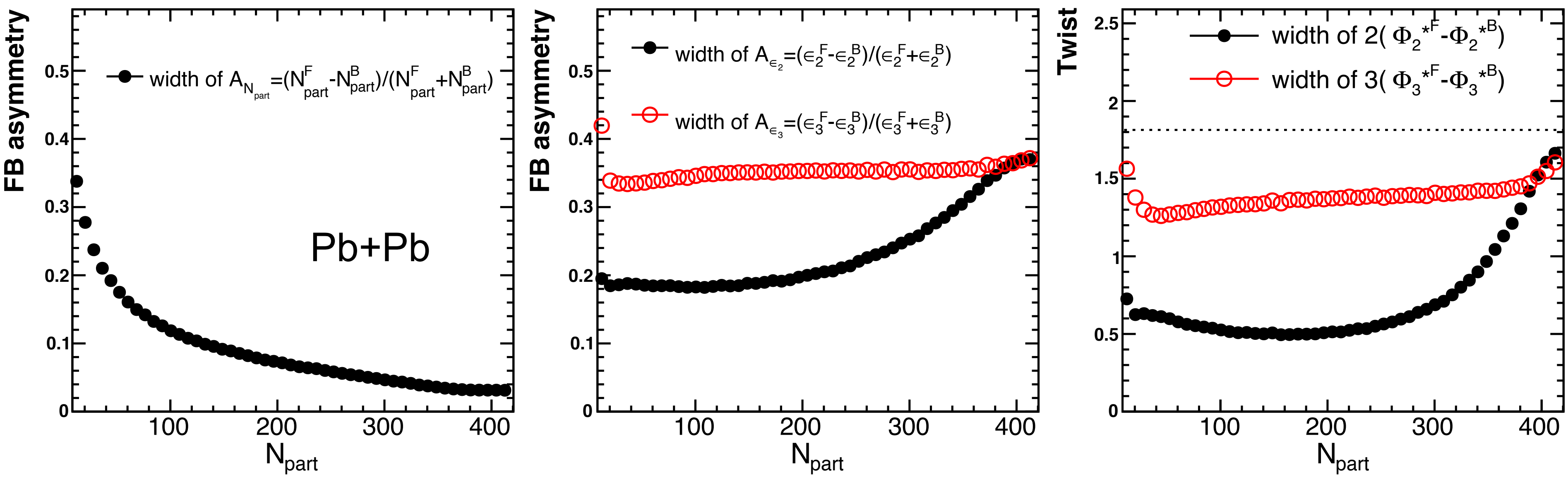
Asymmetry in flow magnitude

(c) $\Psi_2^{\mathrm{F}} \neq \Psi_2^{\mathrm{B}}$



Torque/twist of flow plane

Glauber model estimation



- N_{part}-asymmetry large in peripheral.
- 2^{nd} order: ε-asymmetry and twist largest in central
- 3^{rd} order: ε-asymmetry and twist ~ independent of centrality

Two-particle correlation observables

- Most general 2PC: $C(\eta_1, \eta_2, \Delta\phi)$

$$C(\eta_1,\eta_2,\Delta\phi)=C_N(\eta_1,\eta_2)\left[1+2\sum_n V_{n\Delta}(\eta_1,\eta_2)\cos n\Delta\phi\right]$$

FB Multiplicity fluc.

$$C_N(\eta_1,\eta_2)=\frac{\langle N(\eta_1)N(\eta_2)\rangle}{\langle N(\eta_1)\rangle\langle N(\eta_2)\rangle}$$

Driven by N_{part} asymmetry

$$C_N \sim \langle (1+a_1\eta_1)(1+a_1\eta_2)\rangle$$

$$=1+\langle a_1^2\rangle \eta_1\eta_2$$

$$a_1 \propto \frac{N_{part}^F - N_{part}^B}{N_{part}^F + N_{part}^B}$$

FB flow fluc.

$$V_{n\Delta}(\eta_1,\eta_2)=\langle \mathrm{v}_n(\eta_1)\mathrm{v}_n(\eta_2)\cos n[\Phi_n(\eta_1)-\Phi_n(\eta_2)]\rangle$$

Driven by ε_n twist & asymmetry

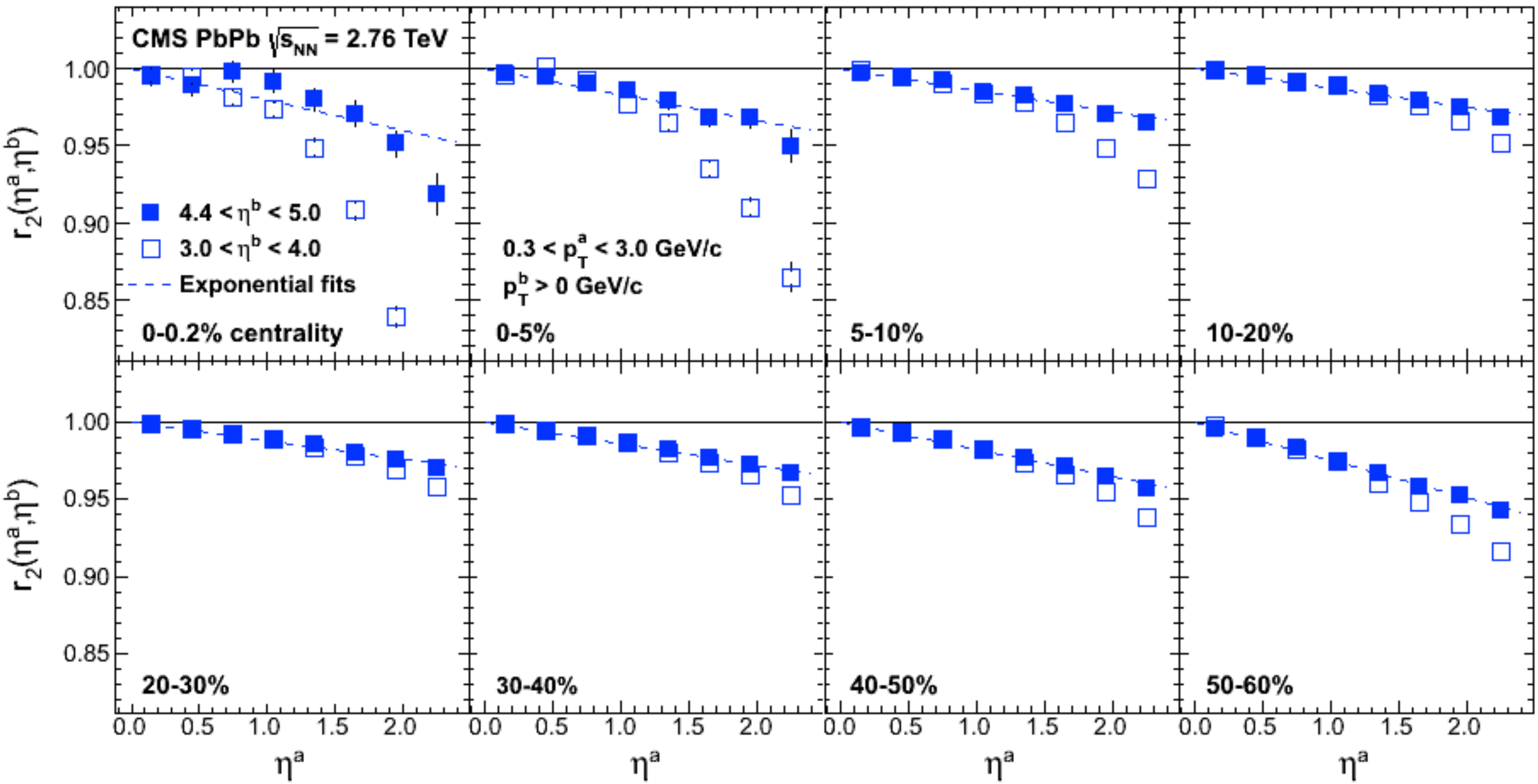
CMS observables

$$r(\eta,\eta_{ref})=\frac{V_{n\Delta}(-\eta,\eta_{ref})}{V_{n\Delta}(\eta,\eta_{ref})}$$

Large gap between η_{ref} and η,$-\eta$

2^{nd}-order flow

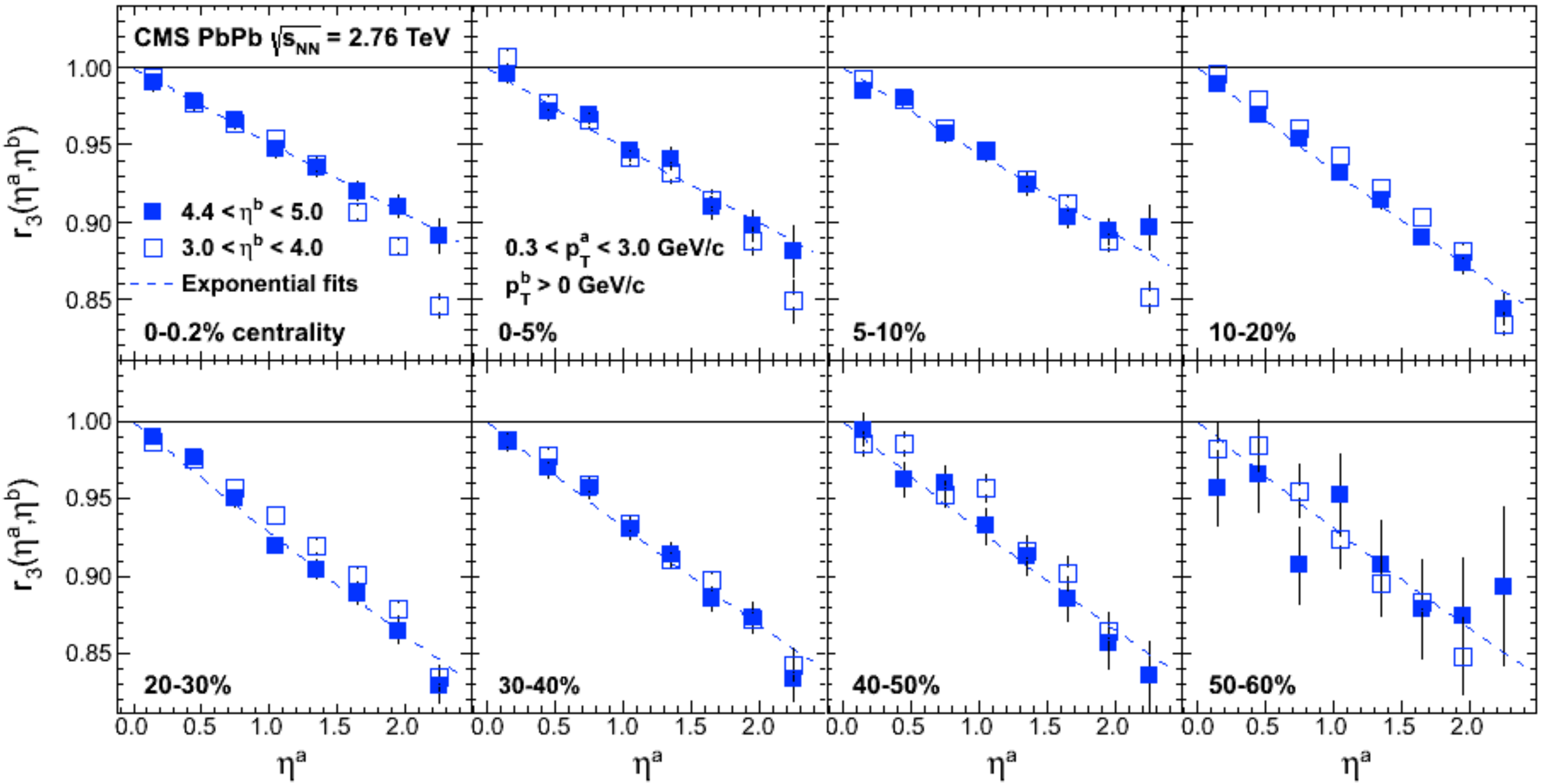
$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$



- Decrease toward mid-central collisions, then increase toward peripheral collisions

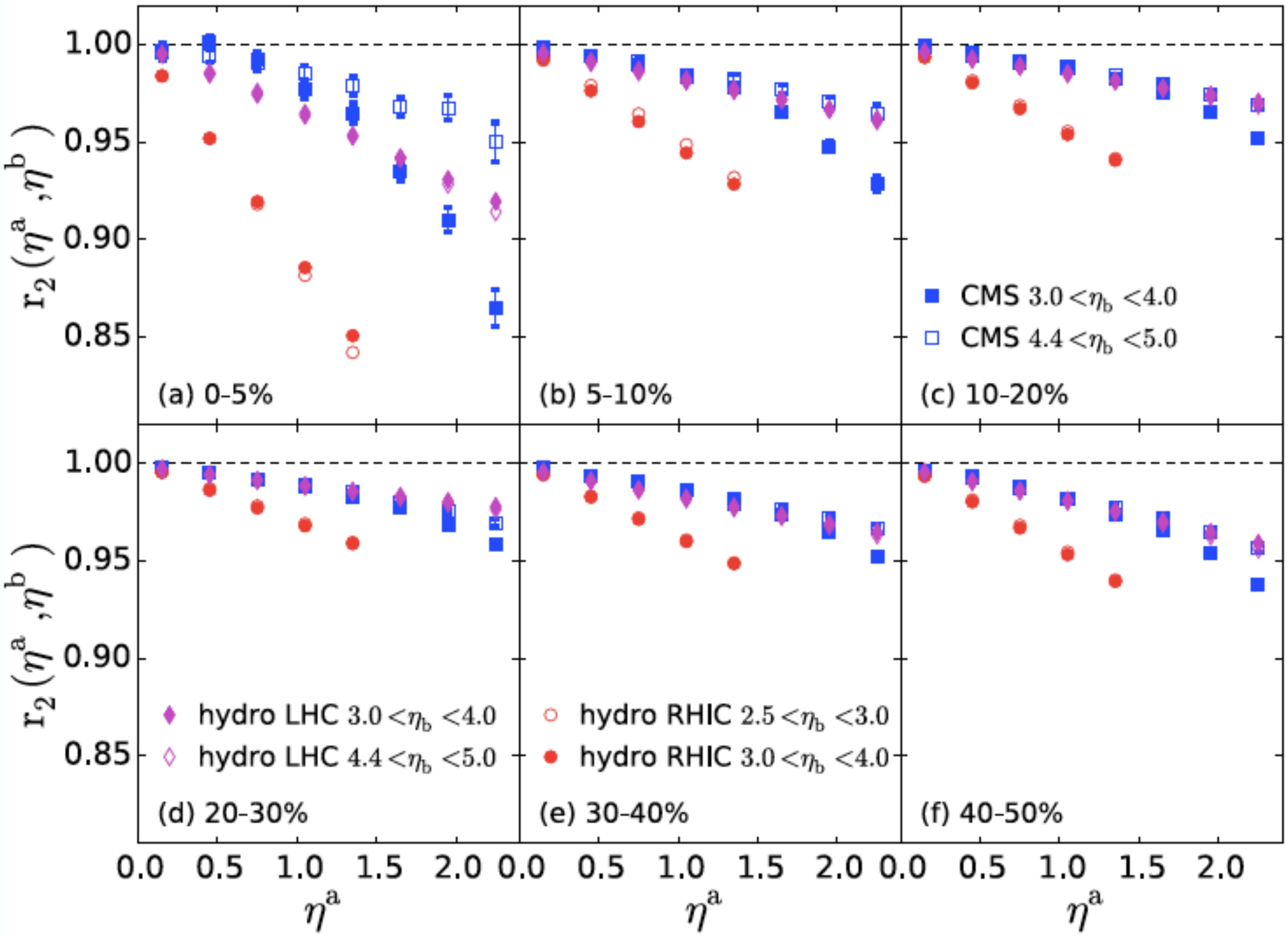
3rd-order flow

$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$



- Slight increase toward peripheral collisions
  - → Importance of e.g. subleading flow, subnucleon dof?

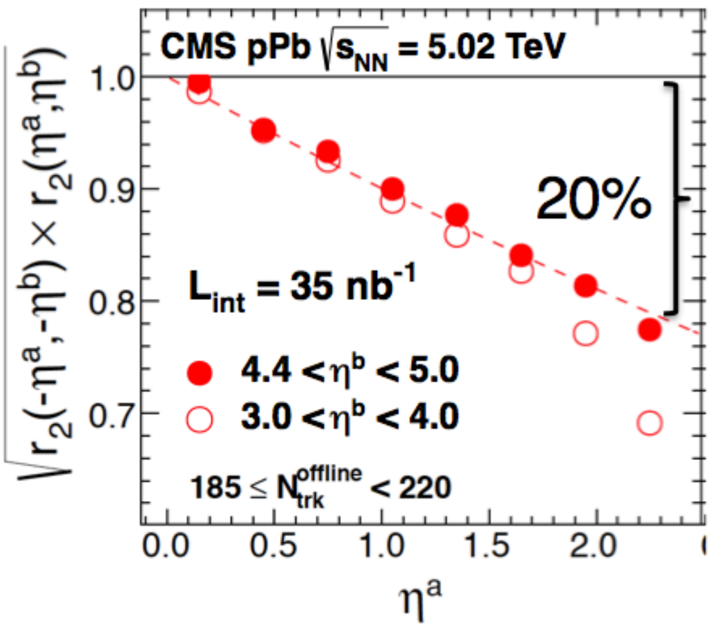
Compare to 3+1D hydrodynamics



Pang, arXiv:1511.04131!

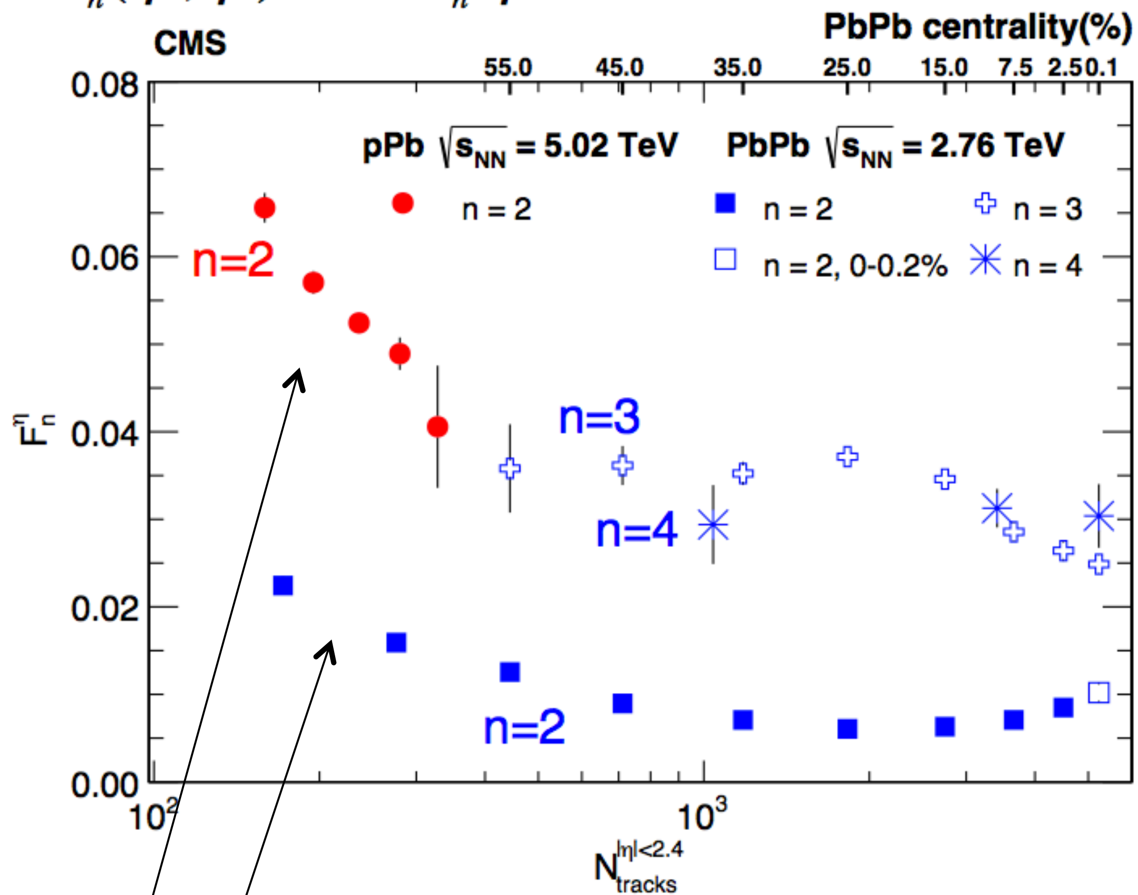
- Good agreement except for 0-5% !
- Much stronger effect at RHIC energy (investigate in BES)!

$r_2(\eta^a,\eta^b)$ in high-multiplicity pPb



Stronger effect in pPb!

$$r_n(\eta^a,\eta^b) = 1 - 2F_n^\eta \eta^a$$



The rise toward smaller system consistent with importance of subnucleonic dof.

0^{th}-order: FB multiplicity asymmetry

Observable

- 2-D pseudorapidity correlation function

$$C = \frac{\langle N(\eta_1) N(\eta_2) \rangle}{\langle N(\eta_1) \rangle \langle N(\eta_2) \rangle} = \langle R_S(\eta_1) R_S(\eta_2) \rangle_{events}$$

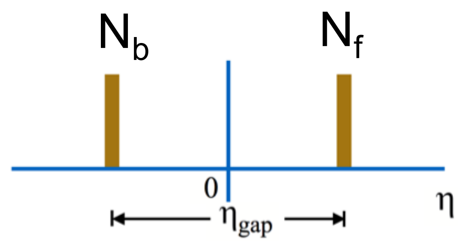
|η|<Y=2.4

Mixed events

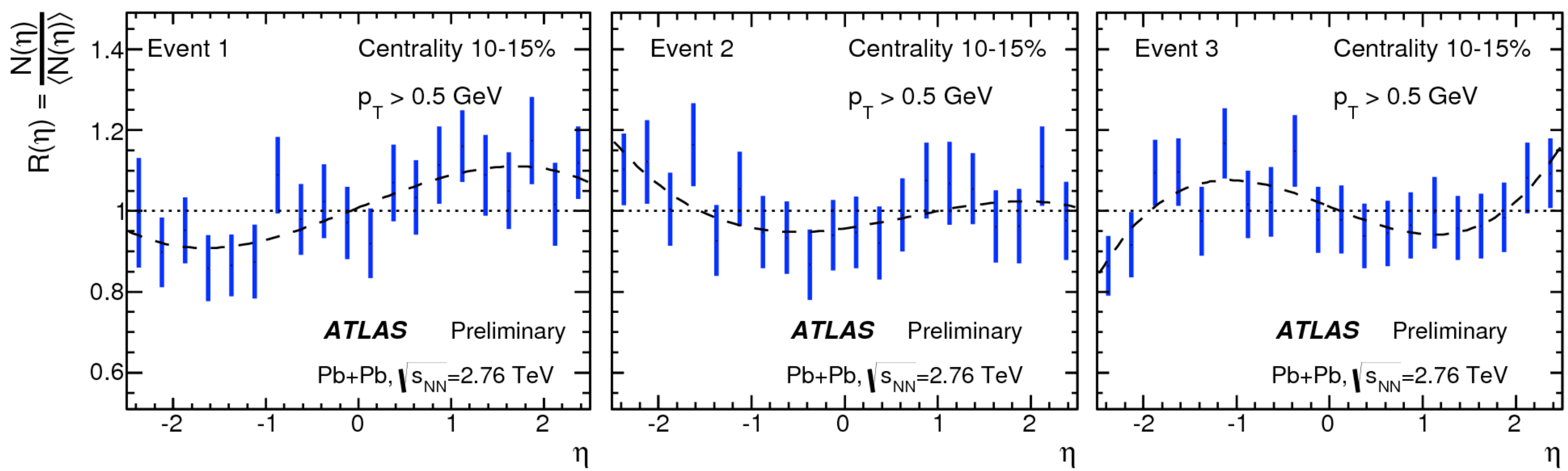
$$\boxed{R_S(\eta)} \equiv \frac{N(\eta)}{\langle N(\eta) \rangle}$$

Single particle distribution

Traditional observables



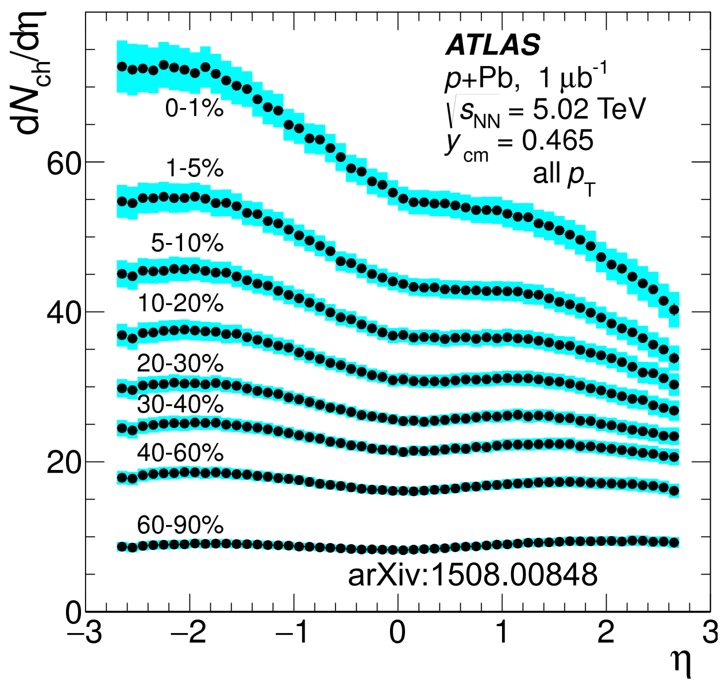
$$b = \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\sigma_{N_f} \sigma_{N_b}}$$

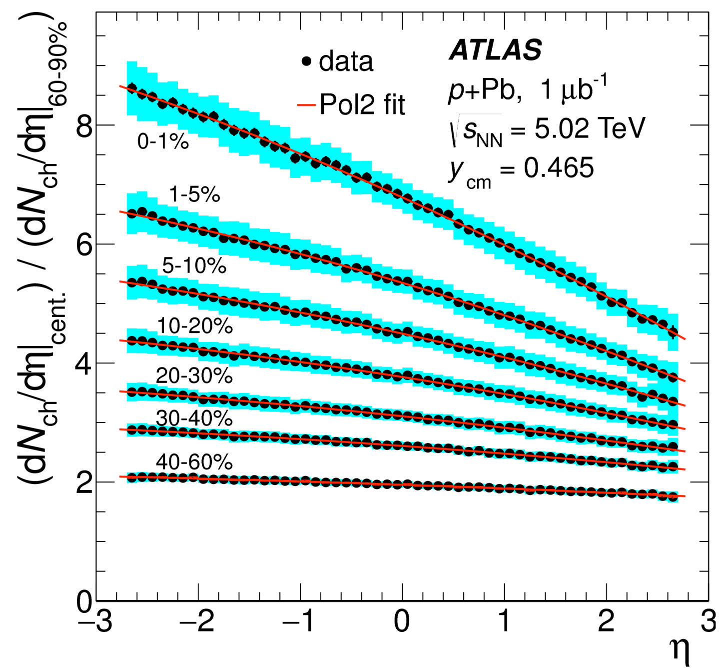


CF disentangles statistical fluctuation from dynamical fluctuation

Forward/backward multiplicity correlation

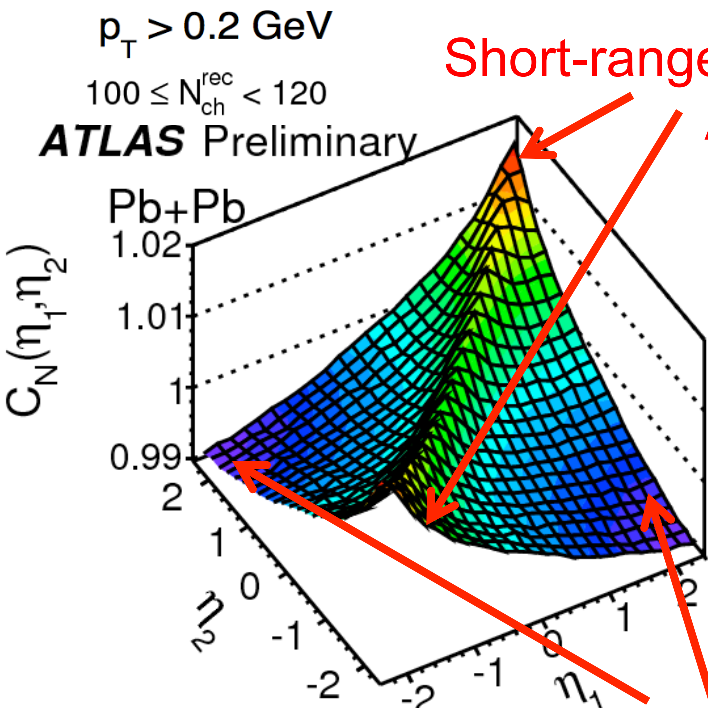
- dN/dη shape reflects asymmetry in num. of forward/backward sources
  - Seen directly in p+Pb collisions.





FB asymmetry is expected in Pb+Pb or pp collisions on event-by-event bases!

Property of the multiplicity correlation



Short-range correlation $\delta_{\mathrm{SRC}}(\eta_1, \eta_2)$

$\Delta\eta = \eta_1 - \eta_2 \sim 0$

Long range correlation $\mathrm{LRC}(\eta_1, \eta_2)$

large $|\Delta\eta|$

Data-driven method to separate SRC from LRC

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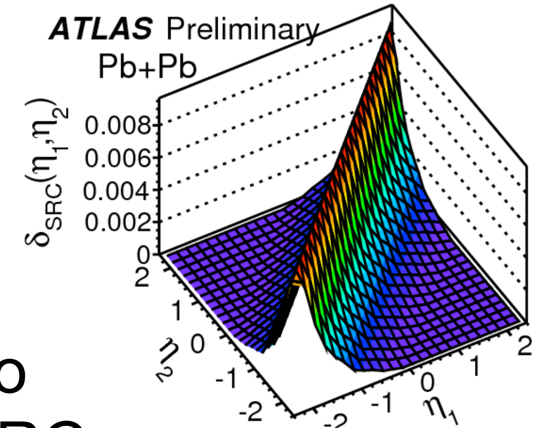

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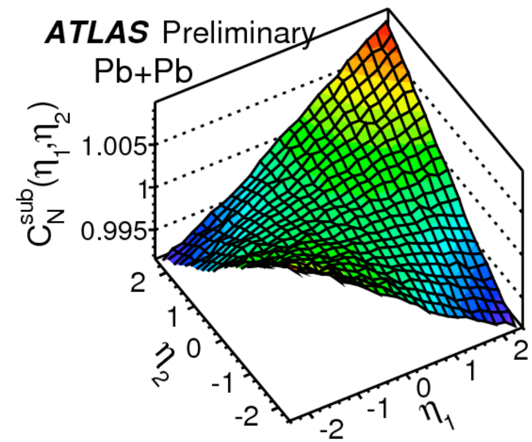
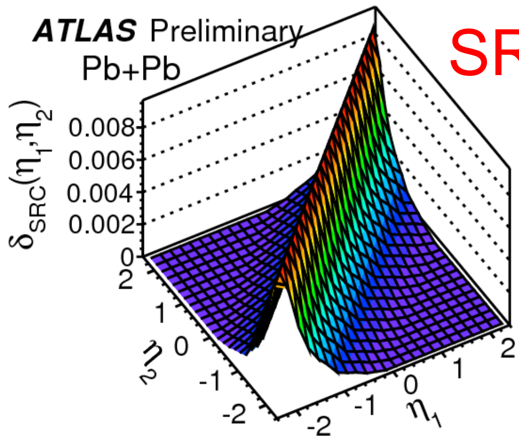


- SRC reflects correlations in the same source
- LRC reflects FB-asymmetry of number of sources, e.g. $A_{\mathrm{part}} = \frac{N_{\mathrm{part}}^{\mathrm{F}} - N_{\mathrm{part}}^{\mathrm{B}}}{N_{\mathrm{part}}^{\mathrm{F}} + N_{\mathrm{part}}^{\mathrm{B}}}$

Quantifying the SRC and LRC



SRC

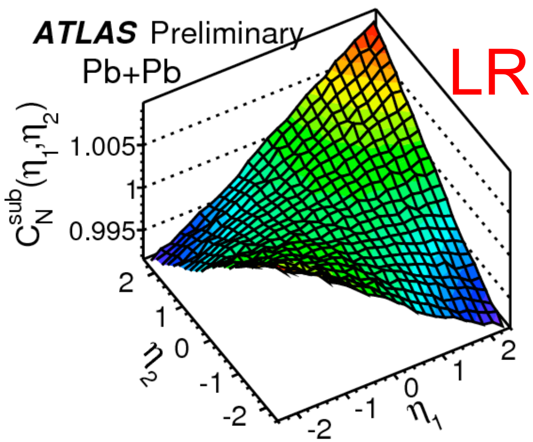
Quantify by average amplitude:

$$\Delta_{\mathrm{SRC}} = \frac{\int \delta_{\mathrm{SRC}}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2}$$

$|\eta|<Y=2.4$

$p_T > 0.2$ GeV

$100 \leq N_{ch}^{rec} < 120$



LRC

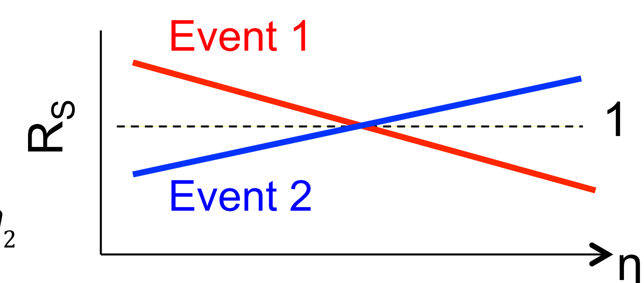
Shape approximate by:

$$C_N^{\mathrm{sub}}(\eta_1,\eta_2) \approx 1 + \langle a_1^2 \rangle \eta_1\eta_2$$

Implication: deviation from average is linear in η

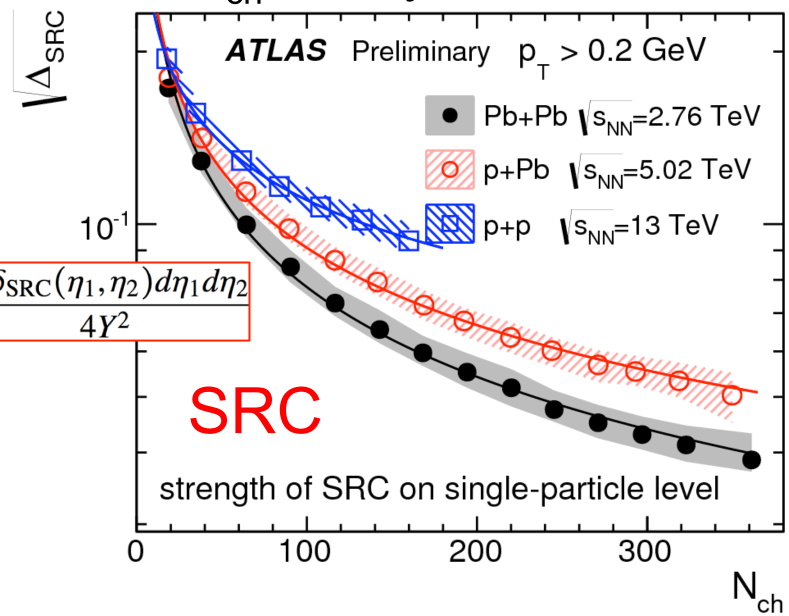
$$R_S(\eta) \equiv \frac{N(\eta)}{\langle N(\eta)\rangle_{evts}} \approx 1 + a_1\eta$$

$$C = \langle R_S(\eta_1) R_S(\eta_2) \rangle \approx 1 + \langle a_1^2 \rangle \eta_1\eta_2$$



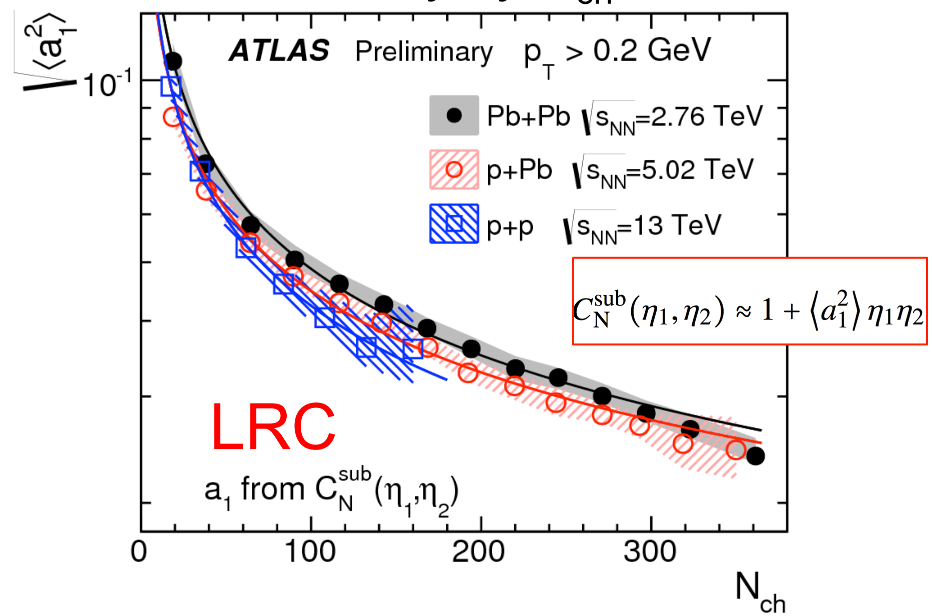
Dependence on N_{ch} and collision systems

both N_{ch} and system size



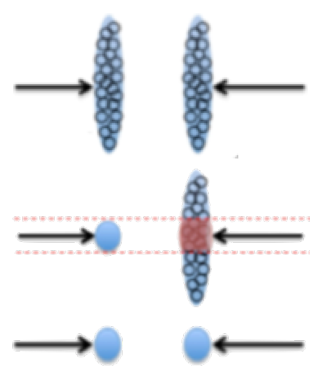
$$\Delta_{\rm SRC} = \frac{\int \delta_{\rm SRC}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2}$$

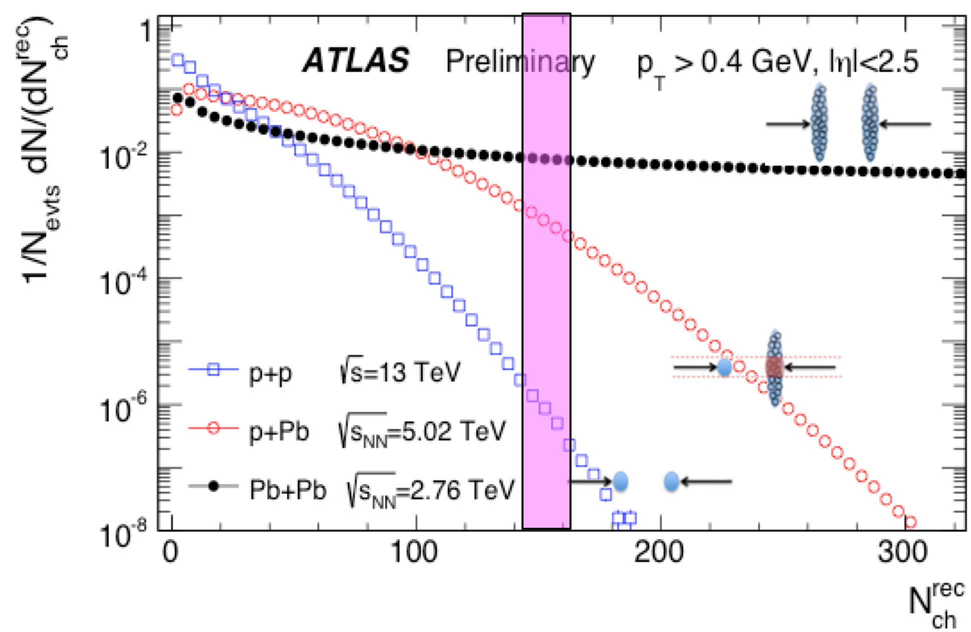
only by N_{ch}



$$C_N^{\rm sub}(\eta_1,\eta_2) \approx 1 + \langle a_1^2\rangle \eta_1\eta_2$$

Compare:



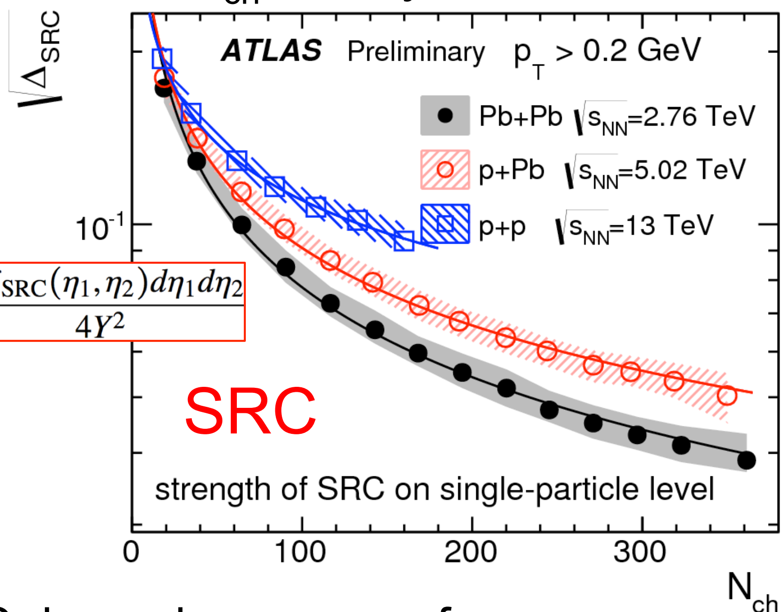


SRC/LRC control by

N_{ch} or transverse geom. size?

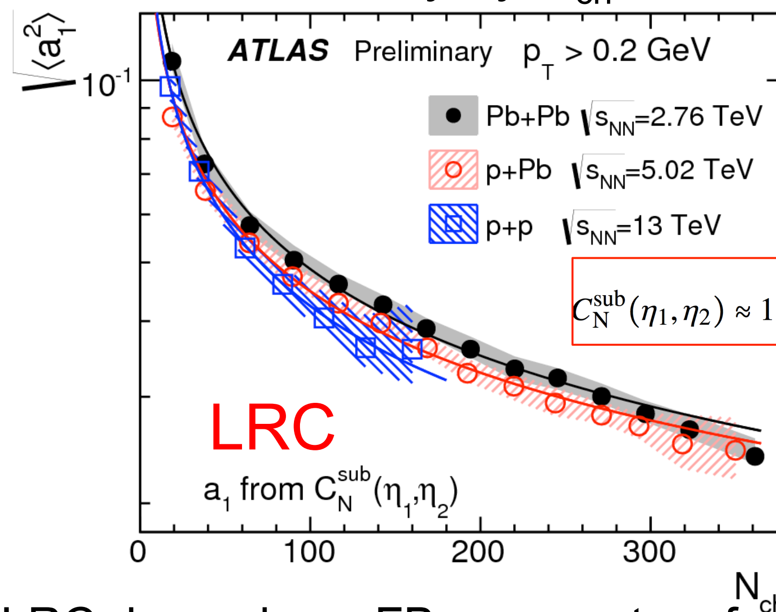
Dependence on N_{ch} and collision systems

both N_{ch} and system size



$$\Delta_{SRC} = \frac{\int \delta_{SRC}(\eta_1,\eta_2)d\eta_1 d\eta_2}{4Y^2}$$

only by N_{ch}



$$C_N^{sub}(\eta_1,\eta_2) \approx 1 + \langle a_1^2\rangle \eta_1\eta_2$$

SRC depends on num. of sources

LRC depends on FB asymmetry of sources

$$n = n_f + n_b \propto N_{ch}$$

$$A_n = \frac{n_f - n_b}{n_f + n_b}, \qquad \langle a_1^2\rangle \propto \langle A_n^2\rangle$$

"independent source picture": $\sqrt{\Delta_{SRC}} \sim \sqrt{\langle a_1^2\rangle} \sim \frac{1}{n^\alpha} \sim \frac{1}{N_{ch}^\alpha}, \alpha \sim 0.5$

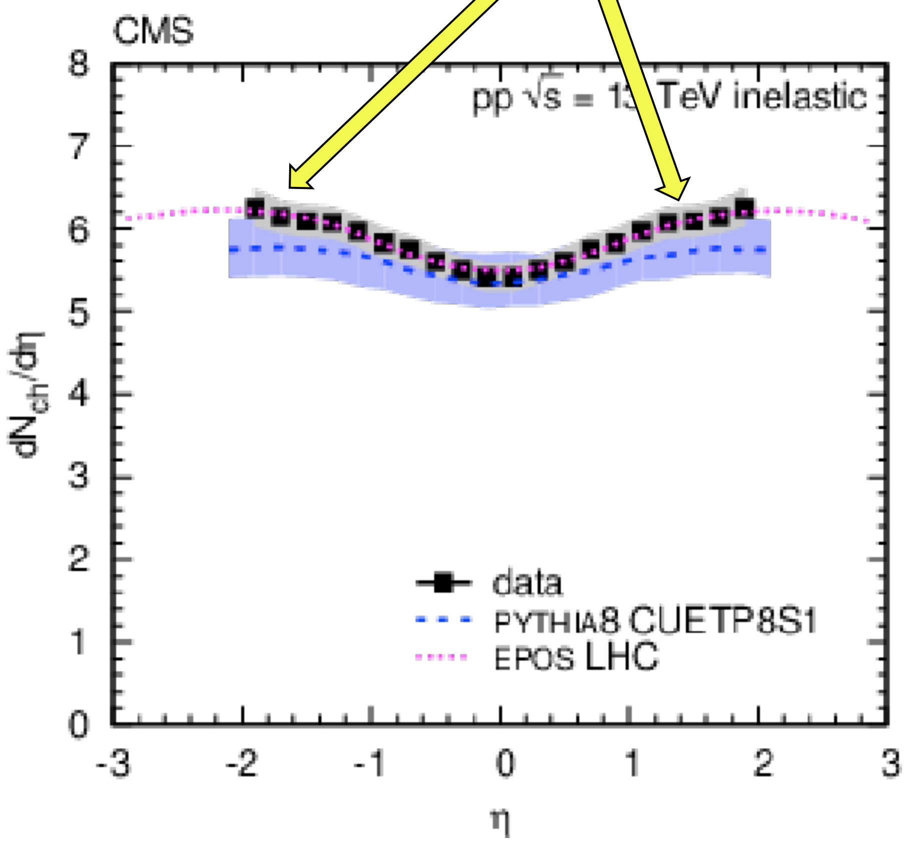
- Fit with c/N_{ch}^α

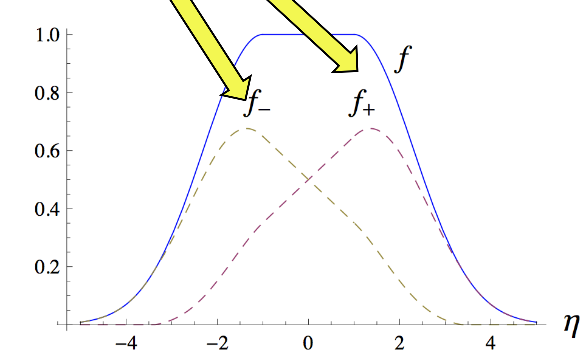
	Pb+Pb	p+Pb	pp
α for $\sqrt{\Delta_{SRC}}$	0.502 ± 0.022	0.451 ± 0.020	0.342 ± 0.030
α for $\sqrt{\langle a_1^2\rangle}$	0.467 ± 0.011	0.448 ± 0.019	0.489 ± 0.032

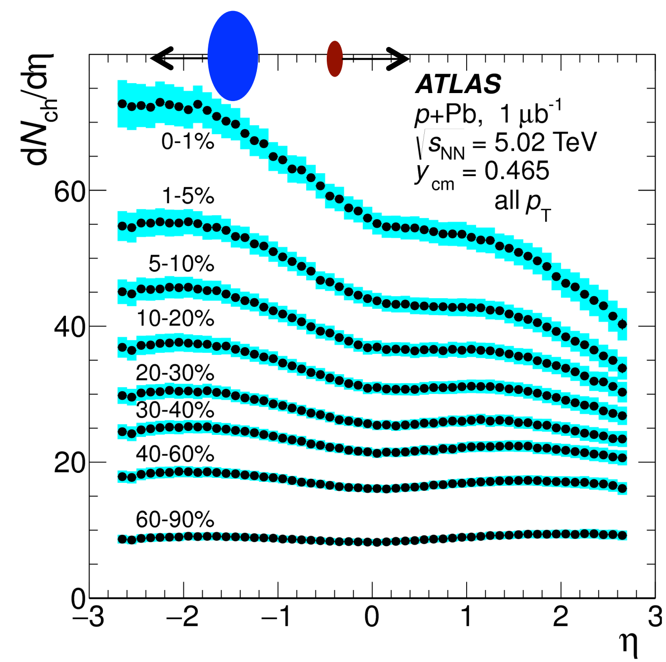
- ➢ LRC: num. of sources, n, controlled by N_{ch}, think in terms of partons !
- ➢ SRC: pp vs PbPb at same N_{ch} → n is similar but pairs/source is larger?

Features of dN/dη distribution

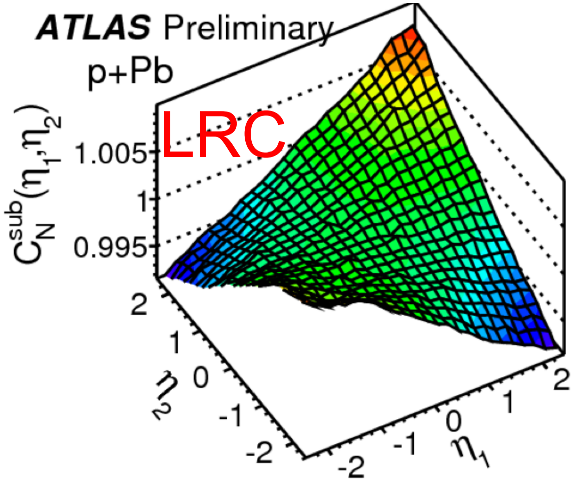
Double hump→ FB asymmetry?

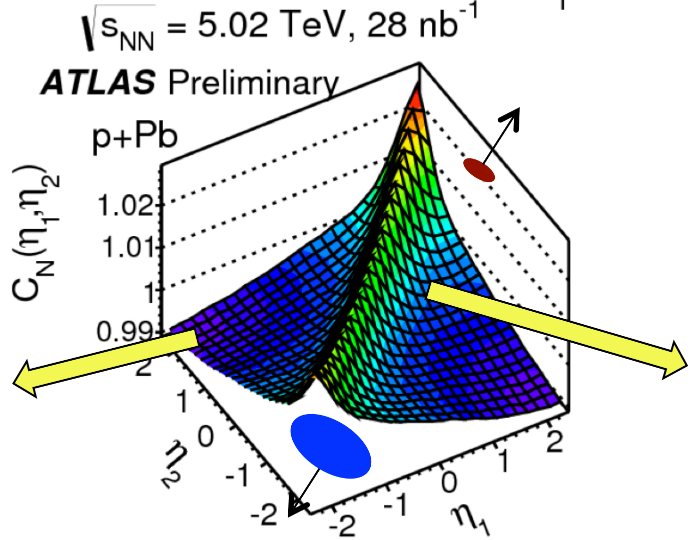


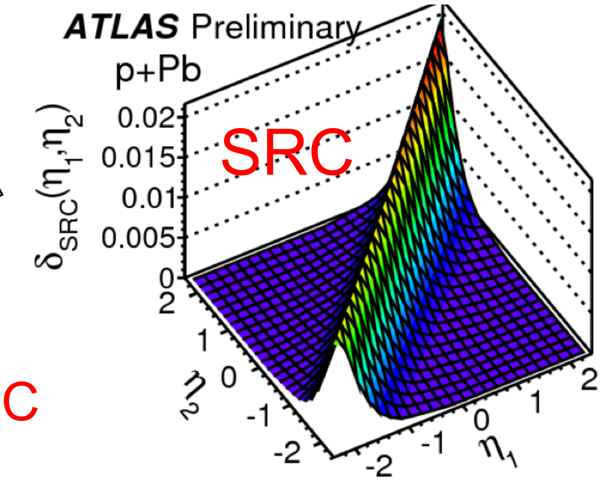




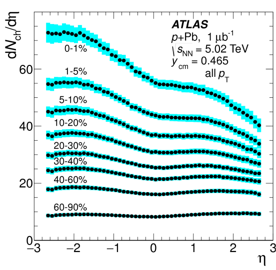
p+A collision suggest it is the latter
→p+p FB fluctuation is even larger!

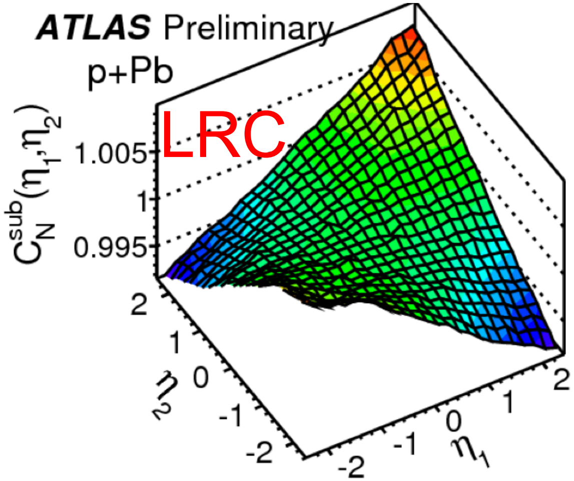


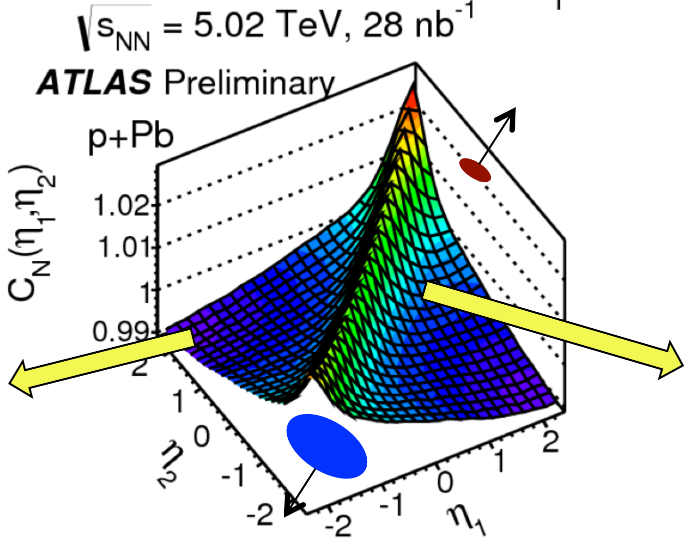


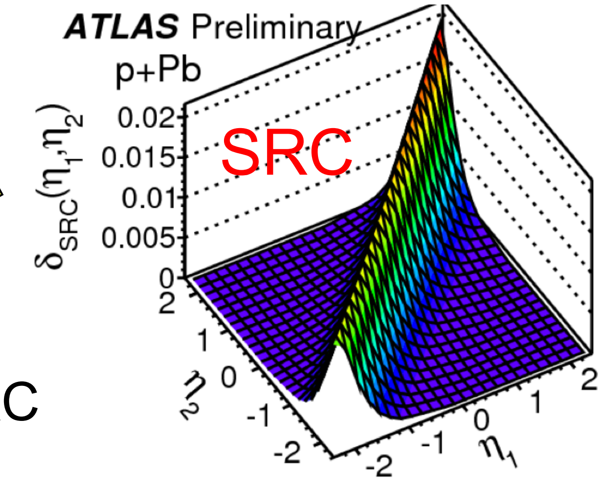


Asymmetry entirely due to SRC
→larger on proton side!



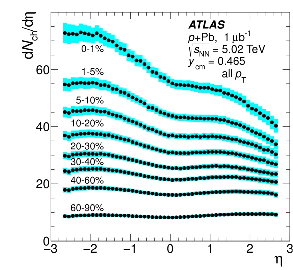






Asymmetry entirely due to SRC
→larger on proton side!

- SRC at given η scale as $\approx \frac{n_{source} m^2}{(n_{source} m)^2} = \frac{1}{n_{source}} \propto 1 / dN/d\eta$

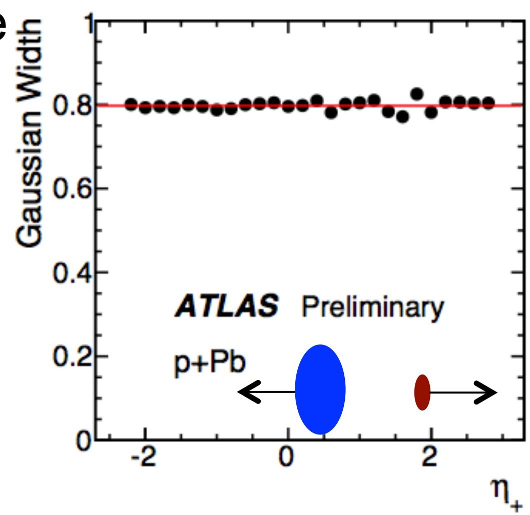


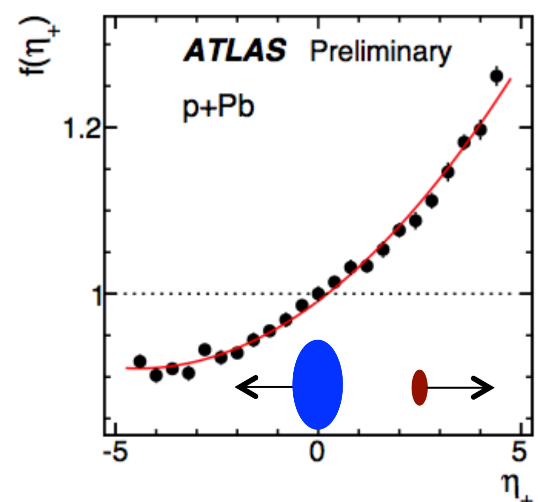
→ Strength of SRC vs η_+ reflects fluctuation of dN/dη shape

→ Amplitude increase on p-side

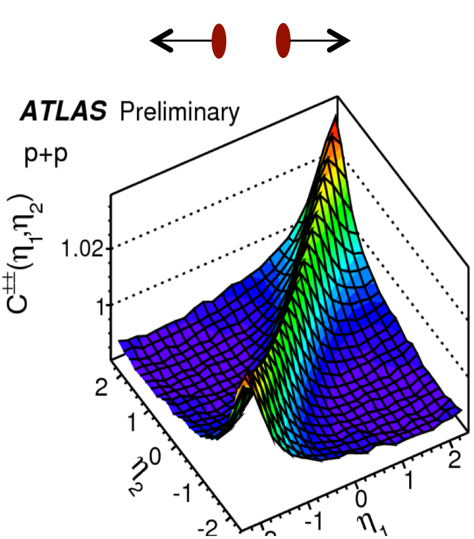
→ Width unchanged

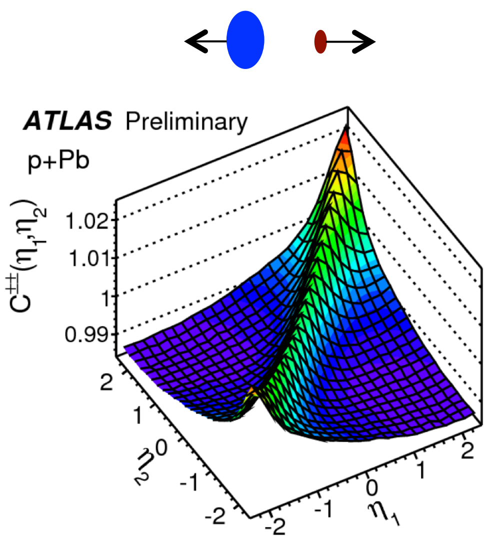
$$\eta_+ = \eta_1 + \eta_2$$
$$\eta_- = \eta_1 - \eta_2$$

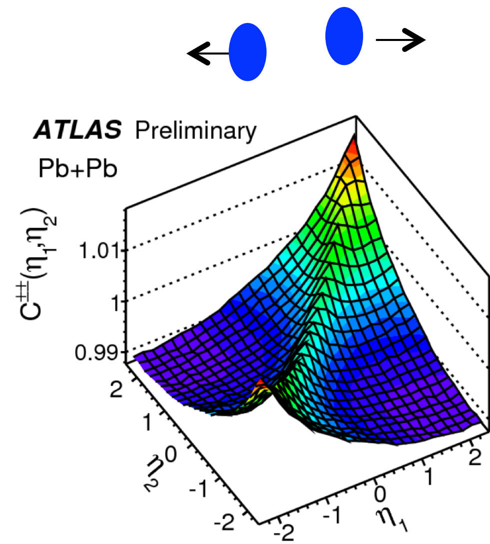




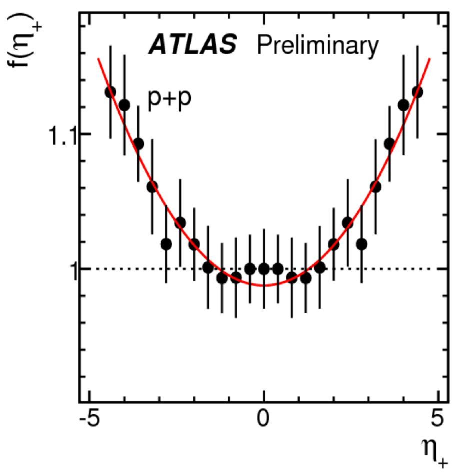
Compare pp to pPb, PbPb at same N_{ch}

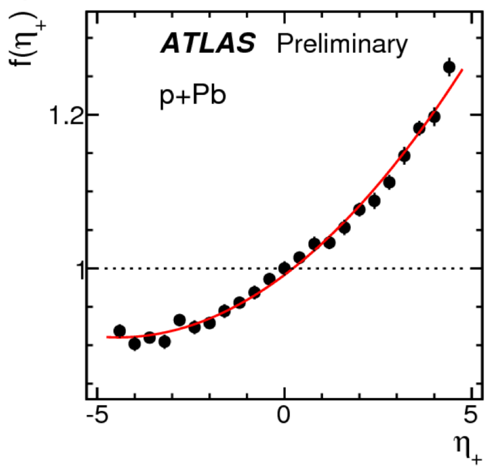


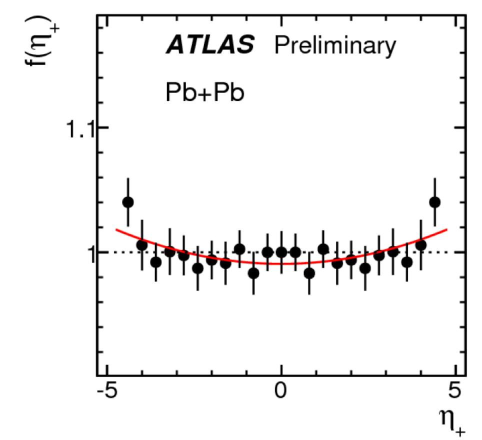




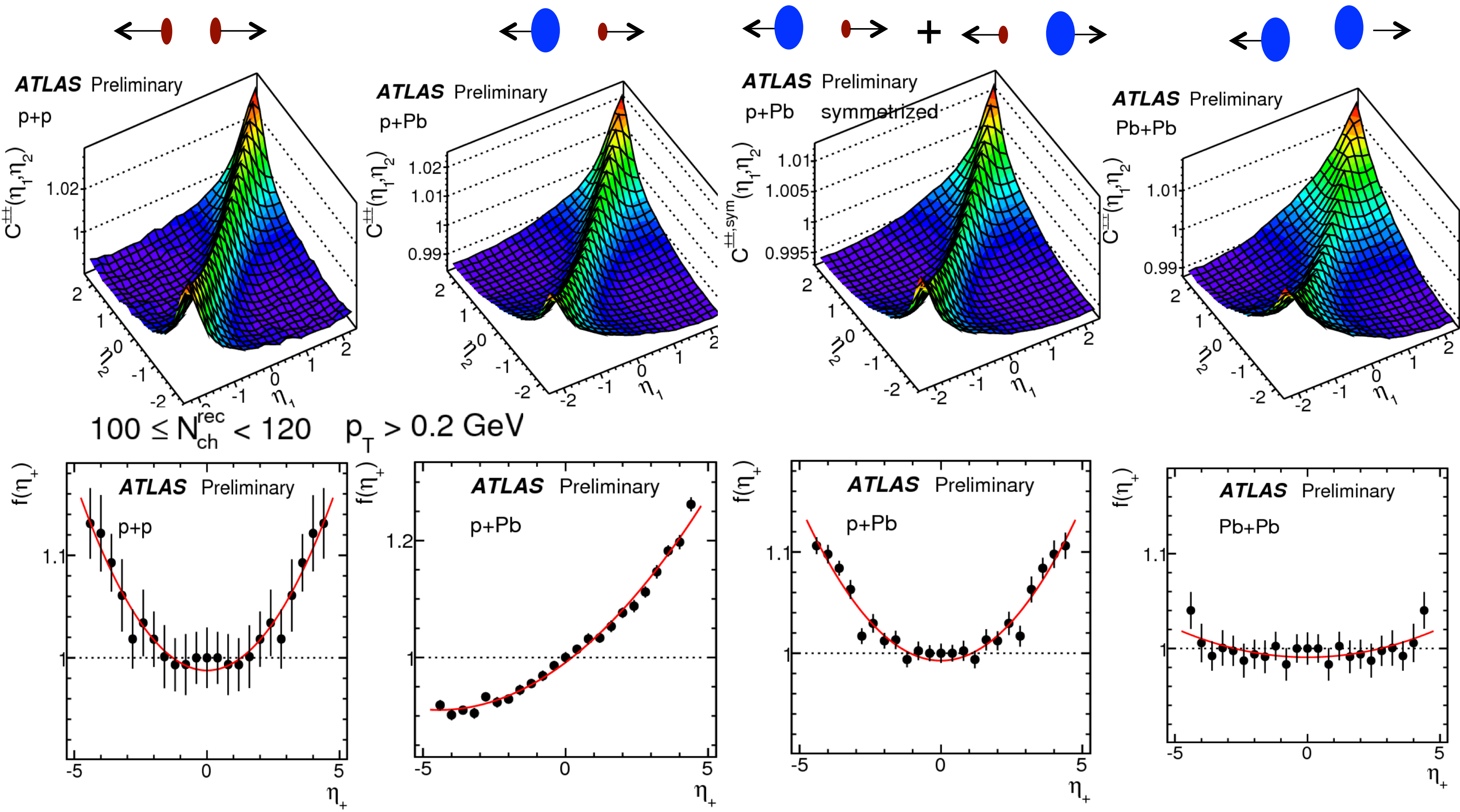
$100 \leq N_{ch}^{rec} < 120$ $p_T > 0.2$ GeV







Compare pp to pPb, PbPb at same N_{ch}



- High-multi. pp has same η correlation as symmetrized p+Pb given N_{ch}
  - → Ebye asym. of dN/dη in high-multi. pp is as large as that in pPb!!
  - → Pb+Pb collision more symmetric.

Summary

- Longitudinal correlation provide unique information on initial conditions in pp, pA and AA collisions

- Longitudinal flow correlations
  - consistent with rapidity dependent mixing of initial condition controlled by projectile and target participants

- Longitudinal multiplicity correlations
  - LRC depends only on total multiplicity of the event
  - SRC depends strongly on collision system and charge combination
  - Both follows power-law of N_{ch} with an index close to 0.5 $\rightarrow$ information on the number of sources for particle production?

  - FB asymmetry in pp is as strong as pPb in same multiplicity
    - High multiplicity pp collision is highly asymmetric system
    - Similar longitudinal initial condition in high multiplicity pPb and pp?