Forward-backward correlations and decorrelations

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Collectivity and correlations in high-energy hadron and nuclear collisions, **Benasque**, 5-18 August 2018

research with **Piotr Bożek**

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NATIONAL SCIENCE CENTRE
POLAND

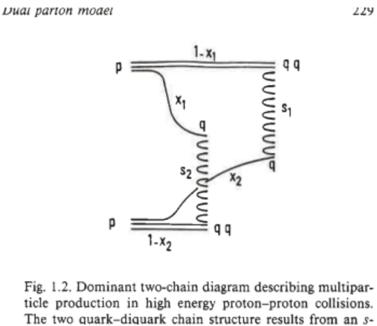
Outline

- Strings/flux tubes: phenomenological FB picture
- Collectivity: shape-flow transmutation
- FB flow decorrelation (torque effect)
- FB multiplicity correlations

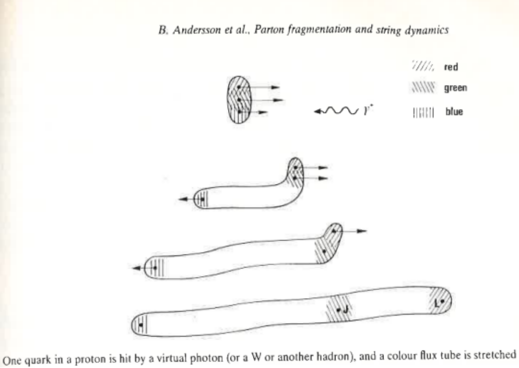
String

String models '70

Dual Parton Model (Capella et al.)



Lund model (Anderson et al.)

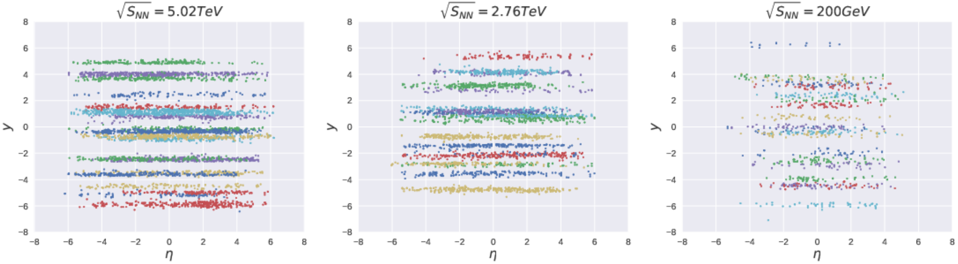


Basis of many successful codes (Pythia, HIJING, AMPT, EPOS, ...)

[CGC+Pythia, Schenke, Schlichting, Tribedy, Venugopalan 2016]

Strings are spatial objects

AMPT [Wu et al. 2018]

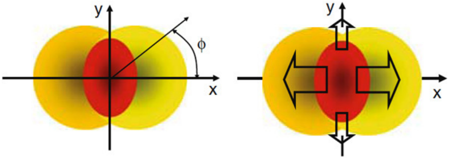


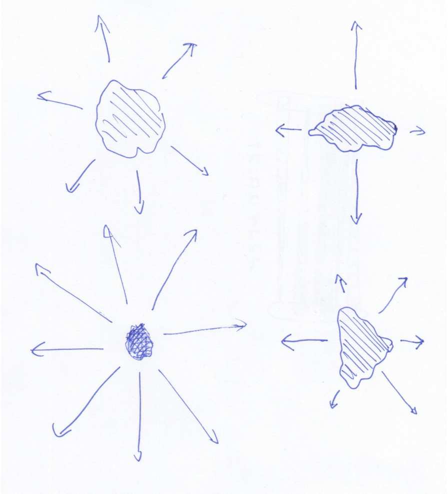
String end-points fluctuate in η, uniform production of particles from the string, rescattering (!)

Shape-flow transmutation

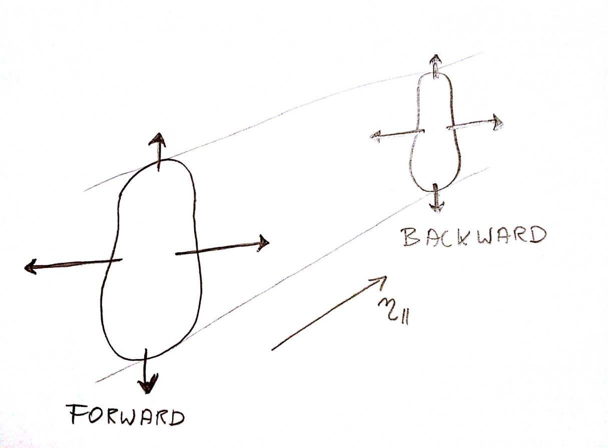
Shape-flow transmutation

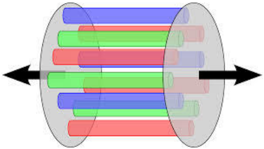
many particles, final/intermediate-state interactions, generation of flow





FB shape similarity → flow similarity → ridges





The FB similarity is a result of early dynamics and is not obtained from hydro or transport; these use it to generate the ridge correlations via the shape-flow transmutation

Surfers

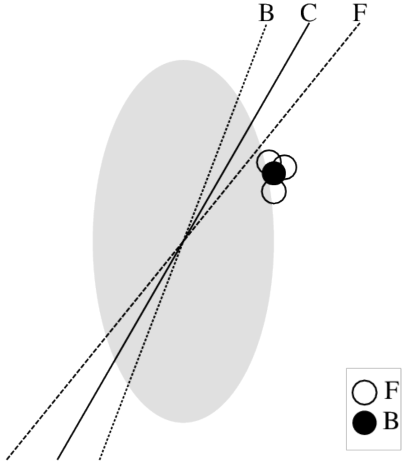
FB correlations

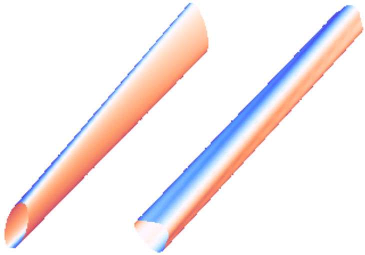
- One expects strong FB correlations, e.g., for FB event plane angles (direction of flow), harmonic flow magnitude, or $\langle p_T \rangle$ [Piotr Bożek's talk last week]
- Focus on departures from perfect correlations
- Need to use measures that cancel trivial decorrelations, e.g. from statistical hadronization (standard)

Torque

The torque effect

Twisted event-plane angles [Bożek, WB, Moreira 2010]

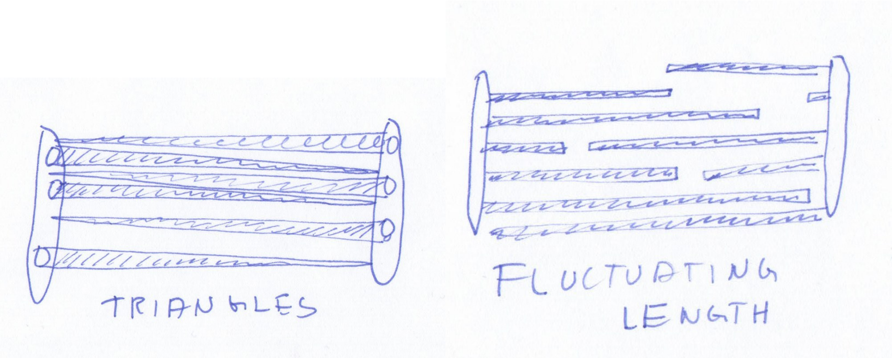




F and B initial transverse distributions are not exactly the same

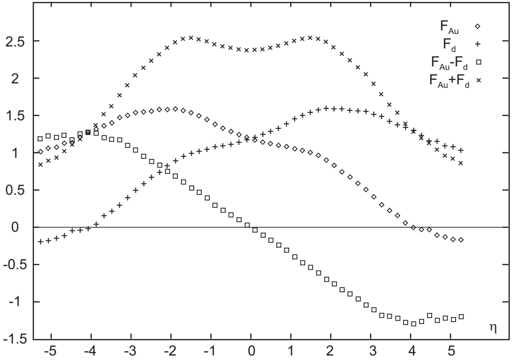
Average emission profiles

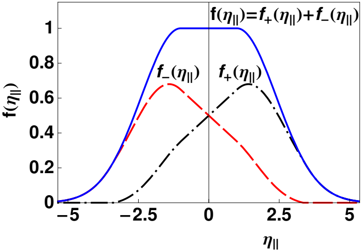
Simpler than fluctuating strings (only in the few following slides)



Phenomenological average emission profiles

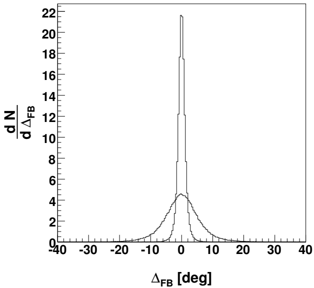
[Białas, Czyż, Acta Phys. Polon. B36, 905 (2005)]





Torque angle distribution from Glauber

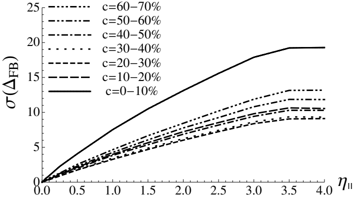
$$\Delta_{FB} = \Psi_2(\eta) - \Psi_2(-\eta)$$

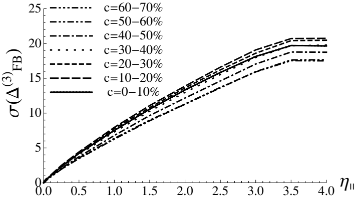


$\Delta\eta = 1$ (narrow) and 5 (wide)

decorrelation increases with $\Delta\eta$

width of the torque angle distribution





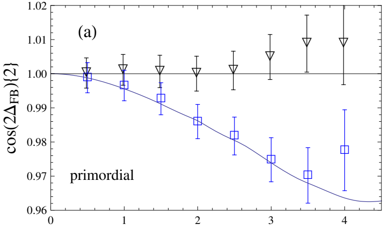
$n = 2$: largest decorrelation for central collisions

$n = 3$: similar decorrelation for all centralities

2-bin measure

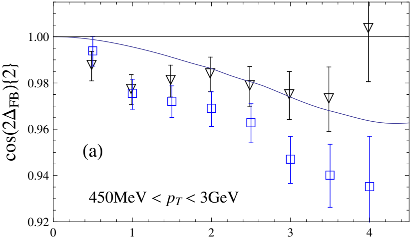
$$\cos(2\Delta_{FB})\{2\} = \frac{\langle\langle \cos[2(\phi_i(F) - \phi_j(B))]\rangle\rangle}{\sqrt{\langle v_2^2(F)\rangle}\sqrt{\langle v_2^2(B)\rangle}}$$

primordial particles, torque vs no torque



η

charged particles, torque vs no torque



η

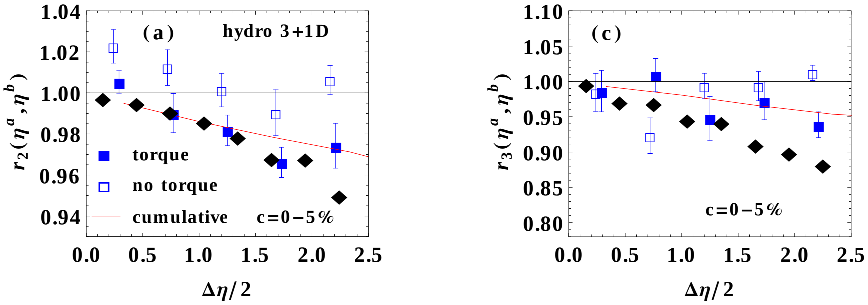
Substantial nonflow (resonance decays) contribution

[Glauber w/binary + 3D viscous hydro + THERMINATOR]

3-bin measure (CMS)

$$r_2(\eta_a,\eta_b) = \frac{\langle\langle \cos[n(\phi_i(-\eta_a) - \phi_j(\eta_b))]\rangle\rangle}{\langle\langle \cos[n(\phi_i(\eta_a) - \phi_j(\eta_b))]\rangle\rangle} \simeq \frac{\cos[n(\Psi(-\eta_a) - \Psi(\eta_b)]}{\cos[n(\Psi(\eta_a) - \Psi(\eta_b)]}$$

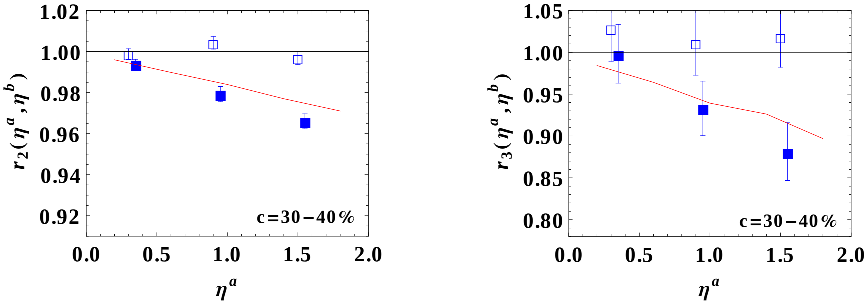
only pairs with large rapidity gap $\eta_a - \eta_b \rightarrow$ nonflow under control



- effect seen in the CMS data!
- semiquantitative agreement, need for more fluctuations
- other calculation (AMPT) also reproduce the data

$r_n(\eta_a, \eta_b)$ for Au-Au@200GeV

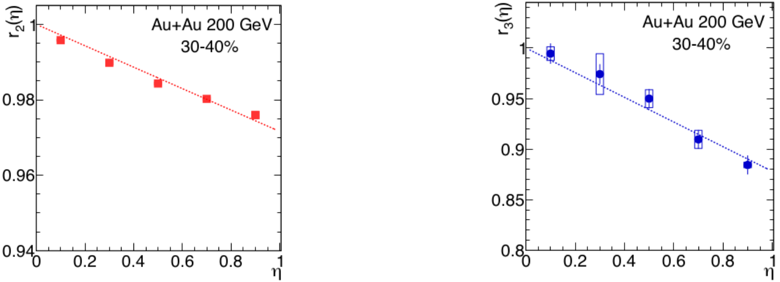
predictions [PB, WB, Olszewski 2015]



larger torque at RHIC than at the LHC energies

$r_n(\eta_a, \eta_b)$ for Au-Au@200GeV

Moawu for STAR@QM18

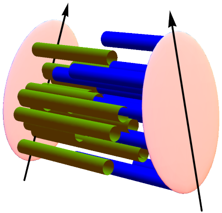


larger torque at RHIC than at the LHC energies

Fluctuations in energy deposition from each string

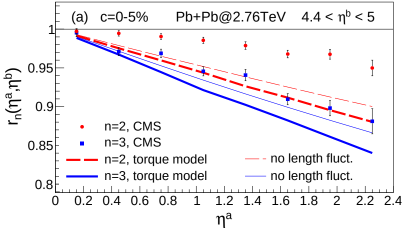
[PB, WB 2015, 2017]

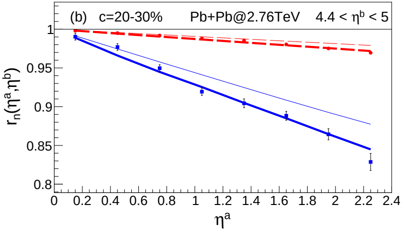
[Brodsky, Gunion, Kuhn, PRL 39 (1977) 1120]

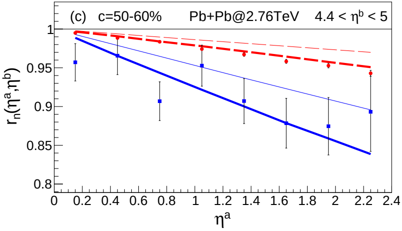


- the position (in rapidity) of string end-points is random
- long range fluctuations
- each string fluctuates differently ⟶ event-plane decorrelation in p-Pb
- average emission profile the same as in the previous model

$r_n(\eta_a, \eta_b)$ w/fluctuating strings (initial state only)

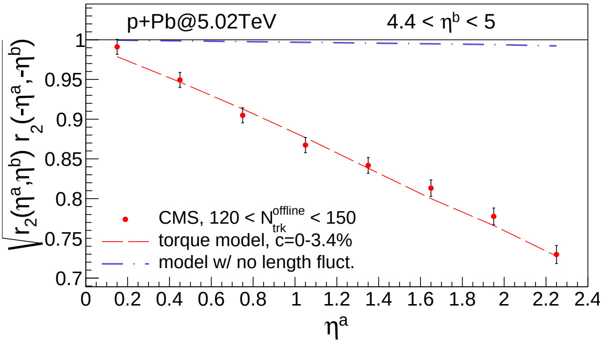






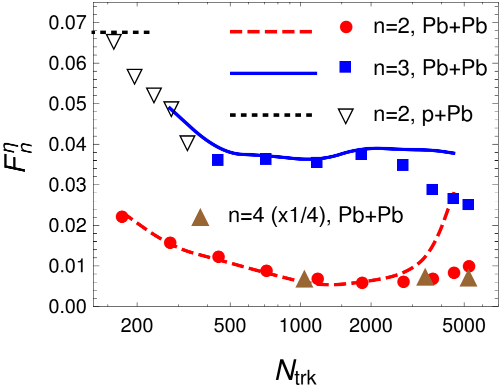
fluctuations improve description except for the most central collisions

Fluctuating strings in p-Pb



end-point fluctuations crucial to describe the event-plane decorrelation in p-Pb

The slope F_n^η



- fair description of mid-central collisions
- overestimates decorrelation for central collisions
- $F_4 \simeq 4F_2$

FB multiplicity fluctuations

Definitions

$$C(\eta_1,\eta_2)=\frac{\langle\rho(\eta_1,\eta_2)\rangle}{\langle\rho(\eta_1)\rangle\langle\rho(\eta_2)\rangle}$$

ATLAS:

$$C_N(\eta_1,\eta_2)=\frac{C(\eta_1,\eta_2)}{\int_{-Y}^{Y}d\eta_2\,C(\eta_1,\eta_2)\int_{-Y}^{Y}d\eta_1\,C(\eta_1,\eta_2)}$$

[Bzdak, Teaney 2013, Jia 2015]

$$a_{nm}=\int_{-Y}^{Y}\frac{d\eta_1}{Y}\int_{-Y}^{Y}\frac{d\eta_2}{Y}C(\eta_1,\eta_2)T_n\left(\frac{\eta_1}{Y}\right)T_m\left(\frac{\eta_1}{Y}\right)$$
$$T_n(x)=\sqrt{2+1/2}P_n(x)$$

Y - pseudorapidity acceptance

FB multiplicity correlations w/fluctuating strings

Average number of particles: $\langle N(\eta)\rangle = \langle N_A\rangle\langle f_A(\eta)\rangle + \langle N_B\rangle\langle f_B(\eta)\rangle$ with symmetric and antisymmetric parts $\langle f_{A,B}(\eta)\rangle = f_s(\eta) \pm f_a(\eta)$

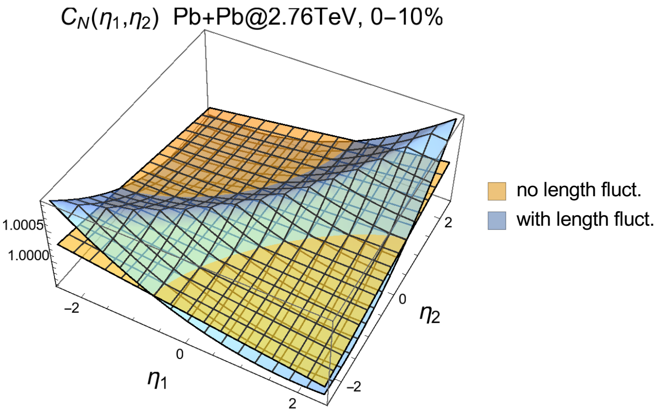
With $N_+ = N_A + N_B,\ \ N_- = N_A - N_B$, we have (for symmetric collisions)

$$\begin{aligned} C(\eta_1,\eta_2) &= 1 + \frac{1}{N_+^2}\Big\{\langle N_+\rangle \mathrm{cov}_{A,B}(\eta_1,\eta_2) \\ &+ \mathrm{var}(N_+) + \mathrm{var}(N_-)\frac{f_a(\eta_1)f_a(\eta_2)}{f_s(\eta_1)f_s(\eta_2)}\Big\} \sim \frac{1}{N_+} \end{aligned}$$

Correlations in elem. production + fluctuation of the number of sources [Bzdak & Teaney 2013]

$\mathrm{cov}_{A,B}(\eta_1,\eta_2) = \frac{y_b^2 - \eta_1\eta_2 - y_b|\eta_1-\eta_2|}{4y_b^2}$

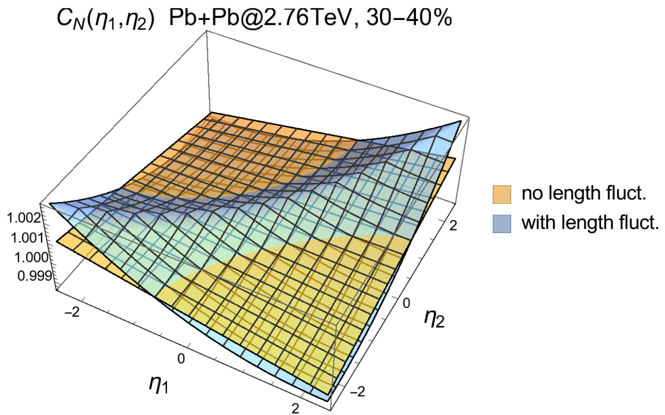
Results for C_N



Generation of the saddle in the ridge (seen in experiment)

Fluctuating string length yields a large contribution

Results for C_N



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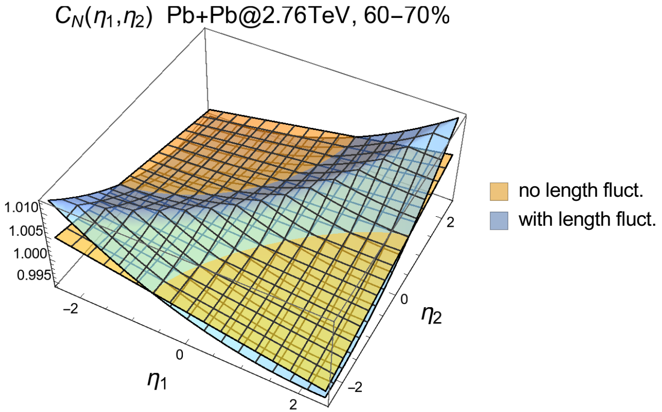

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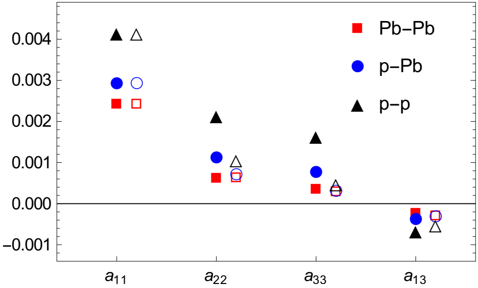
Fluctuating string length yields a large contribution

a_{nm} coefficients

Pb-Pb@2.76TeV, $c = 35 - 40\%$ ($N_{\rm ch} = 110$)

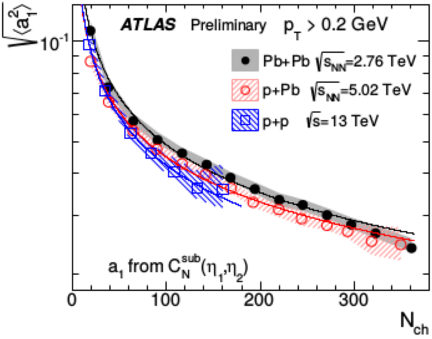


(filled – ATLAS, open – model)

ATLAS values of a_{11} were used to determine the proportionality coefficient between $N_{\rm ch}$ and the average number of sources for each reaction

Semiquantitative agreement also in [Monnai, Schenke 2015] and in AMPT

Scaling with the number of sources



$N_{\rm ch}/N_+$ fitted by adjusting $a_{11}^{\rm exp} = c^{\rm exp}/N_{\rm ch} = a_{11}^{\rm mod} = c^{\rm mod}/N_+$

Matching $\to N_{\rm ch} = 4.7 N_+$, acceptance $\Delta\eta = 4.8 \longrightarrow dN_{\rm ch}/d\eta \simeq 1 \times N_+$

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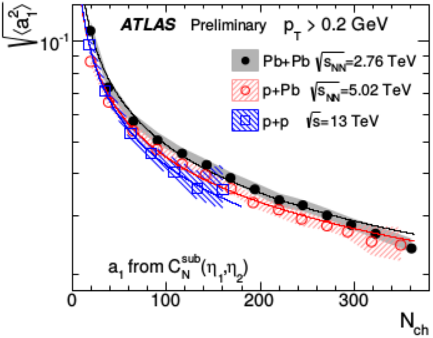

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From multiplicity data $dN_{\rm ch}/d\eta \simeq (3-4) \times N_W$ and $dN_{\rm ch}/d\eta \simeq 1.3 \times Q_W$

$\to$ wounded constituents)

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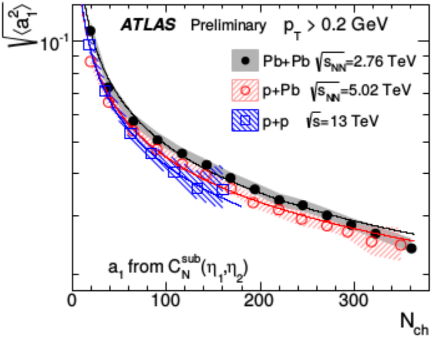

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$\to$ wounded constituents)

$N_{\rm ch} = 5.1 N_A$ for p-Pb@5.02TeV

$N_{\rm ch} = 8.1 N_+$ for p-p@13TeV – requires sources at partonic level

Conclusions

Conclusions

Uniform description of (very rich) data demanded:

1. spectra in p_T and y, v_n, HBT radii
2. $\langle p_T \rangle$ (de)correlation measures [PB's talk last week]
3. flow (de)correlation measures
4. a_{nm} coefficients
5. ...

Rapidity modeling of the initial state "external" to collectivity