Correlations with fluctuating strings

Wojciech Broniowski

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research with **Piotr Bożek and Martin Rohrmoser**

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Outline

Motivation: understand the nature of initial-stage fluctuations with strings

- Strings/flux tubes
- Wounded quarks
- Simple model with fluctuating string end-points
- Forward-backward multiplicity correlations

Strings

String models '70

Dual Parton Model (Capella et al.)

Dual parton model 229

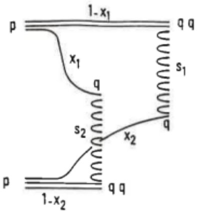
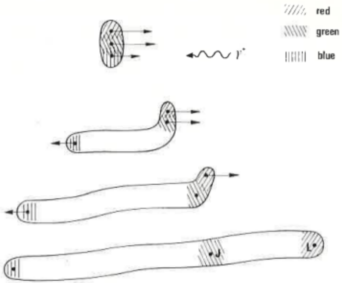


Fig. 1.2. Dominant two-chain diagram describing multiparticle production in high energy proton–proton collisions. The two quark–diquark chain structure results from an s-

Lund model (Anderson et al.)

B. Andersson et al., Parton fragmentation and string dynamics

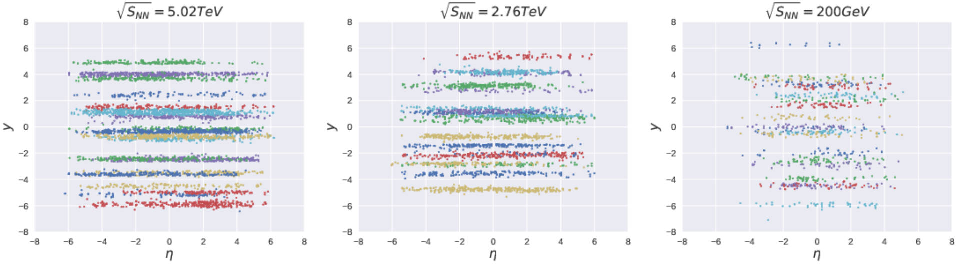


One quark in a proton is hit by a virtual photon (or a W or another hadron), and a colour flux tube is stretched

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

Strings are spatial objects

AMPT [Wu et al. 2018]



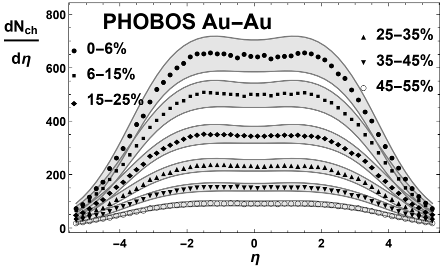
String end-points fluctuate in (here: space-time rapidity) η, uniform production of particles along the string (same thickness)

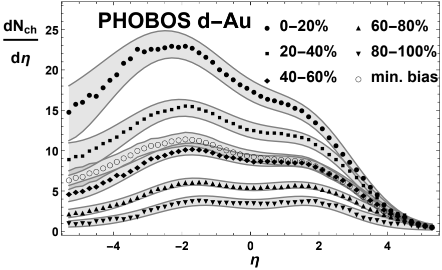
Wounded quarks

[Białas, Czyż, Furmański, Fiałkowski, Słomiński, Zieliński, 1977]

Rapidity spectra for RHIC@200GeV

Original idea with wounded nucleons by [Białas, Czyż, 2004], redone with quarks by [Barej, Bzdak, Gutowski, 2018]





$$\frac{dN_{\rm ch}}{d\eta} = \langle N_A \rangle f(\eta) + \langle N_B \rangle f(-\eta)$$

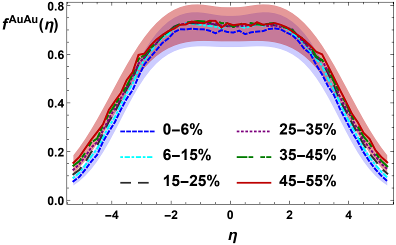
$f(\eta)$ - average universal emission profile from a string associated to a given quark
The symmetric and antisymmetric parts can be obtained from the data:

$$f_s(\eta) = \frac{dN/d\eta(\eta) + dN/d\eta(-\eta)}{\langle N_+ \rangle}, \quad f_a(\eta) = \frac{dN/d\eta(\eta) - dN/d\eta(-\eta)}{\langle N_- \rangle}$$

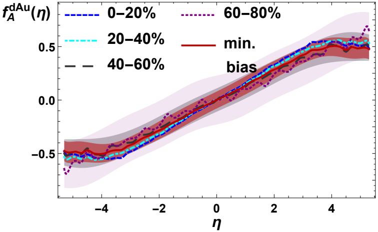
$N_\pm = N_A \pm N_B$

Universality of $f(\eta)$

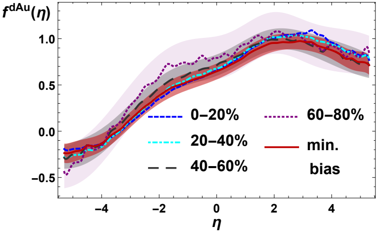
symmetric part:



antisymmetric part:



entire profile:



$\langle N_A \rangle$, $\langle N_B \rangle$... from GLISSANDO

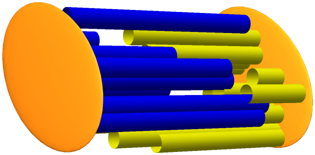
Forward peaked profile! $\rightarrow$

Fluctuating end-points

One-end fluctuations

end point 1: rapidity y_1 fluctuates; distribution $g(y_1)$

end point 2: rapidity fixed to $\sim$ beam rapidity y_b



String has a uniform radiation, with strength controlled by ω:

$s(\eta, y_1, y_b) = \omega\theta(y_1 < \eta < y_b)$

$$\begin{aligned} f(\eta) &= \omega \int_{-y_b}^{y_b} dy_1 g(y_1)\theta(y_1 < \eta < y_b) = \omega \int_{-y_b}^{\eta} g(y_1) dy_1 \\ &= \omega[G(\eta) - G(-y_b)] = \omega G(\eta) \end{aligned}$$

Or: $g(y_1) = \left.\frac{df(\eta)}{d\eta}\right|_{\eta=y_1}$ – uniquely determined

Two-end fluctuations

[Rohrmoser, WB, 2018]

With the radiation profile

$$s(\eta, y_1, y_2) = \omega \left[\theta(y_1 < \eta < y_2) + \theta(y_2 < \eta < y_1)\right]$$

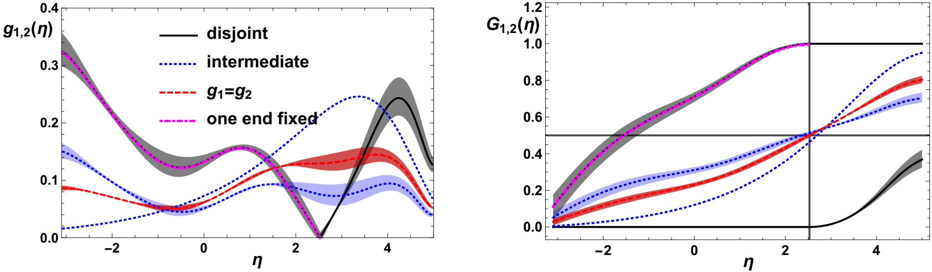
and end point distributions $g_1(y_1)$ and $g_2(y_2)$, we find

$$f(\eta) = \int_{-y_b}^{y_b} dy_1 \int_{-y_b}^{y_b} dy_2 g_1(y_1) s(\eta, y_1, y_2) g_2(y_2)$$

$\Rightarrow f(\eta) = \omega \left\{G_1(\eta)[1 - G_2(\eta)] + G_2(\eta)[1 - G_1(\eta)]\right\}$

No uniqueness, but one may provide bounds for G_1 and G_2!

Distributions fixed with $f(\eta)$



Possible cases:

- $g_1 = g_2$
- intermediate, here: g_1 from PDF parametrization; g_2 matched to $f(\eta)$!
- disjoint support of g_1 and g_2 = one-end fluctuating case

The disjoint case provides envelopes for $G_{1,2}$ for all possibilities

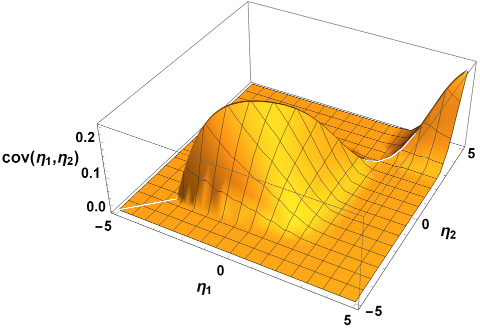
Correlations

Two-particle emission from a single string

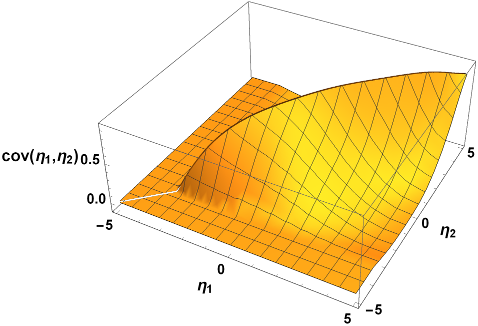
$$\begin{aligned} f_2(\eta_1,\eta_2) &= \omega^2\{G_1(\min(\eta_1,\eta_2))[1-G_2(\max(\eta_1,\eta_2))] \\ &+ G_2(\min(\eta_1,\eta_2))[1-G_1(\max(\eta_1,\eta_2))]\} \end{aligned}$$

$$\mathrm{cov}(\eta_1,\eta_2) = f_2(\eta_1,\eta_2) - f(\eta_1)f(\eta_2)$$

disjoint case



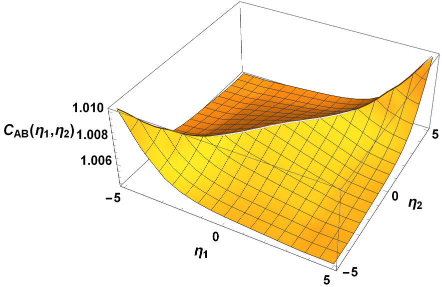
$g_1 = g_2$



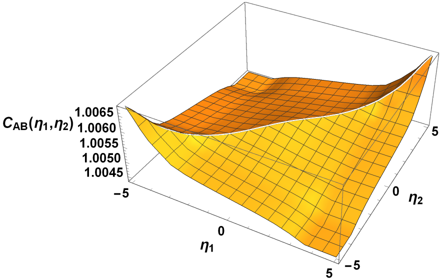
Correlations with multiple (independent) strings

$$C_{AB}(\eta_1, \eta_2) = 1 + \frac{\mathrm{cov}_{AB}(\eta_1,\eta_2)}{f_{AB}(\eta_1) f_{AB}(\eta_2)}$$

$g_1 = g_2$ (larger)



disjoint case (smaller)



with end-point fluctuations and number fluctuations [Bzdak, Teaney, 2012]

$$\mathrm{cov}_{\mathrm{AB}}(\eta_1, \eta_2) = \langle N_A \rangle \mathrm{cov}(\eta_1, \eta_2) + \langle N_B \rangle \mathrm{cov}(-\eta_1, -\eta_2) +$$
$$\mathrm{var}(N_A) f(\eta_1) f(\eta_2) + \mathrm{var}(N_B) f(-\eta_1) f(-\eta_2) + \mathrm{cov}(N_A, N_B) \left[f(\eta_1) f(-\eta_2) + f(-\eta_1) f(\eta_2) \right]$$

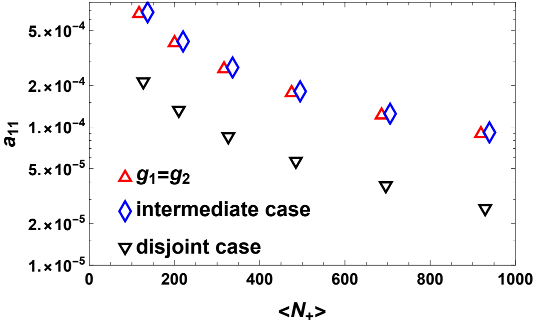
$$f_{\mathrm{AB}}(\eta) = \langle N_A \rangle f(\eta) + \langle N_B \rangle f(-\eta)$$

Legendre a_{11} coefficient

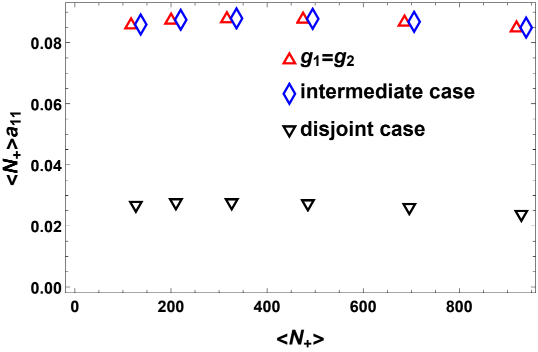
[Bzdak, Teaney, 2012, Jia, Radhakrishnan, Zhou, 2016]

$$a_{nm} = \int_{-Y}^{Y} \frac{d\eta_1}{Y} \int_{-Y}^{Y} \frac{d\eta_2}{Y} \frac{1}{\mathcal{N}_C} C(\eta_1, \eta_2) T_n\left(\frac{\eta_1}{Y}\right) T_m\left(\frac{\eta_2}{Y}\right)$$

with $\mathcal{N}_C = \int_{-Y}^{Y} \frac{d\eta_1}{Y} \int_{-Y}^{Y} \frac{d\eta_2}{Y} C(\eta_1, \eta_2)$, $Y = 1$ (RHIC)



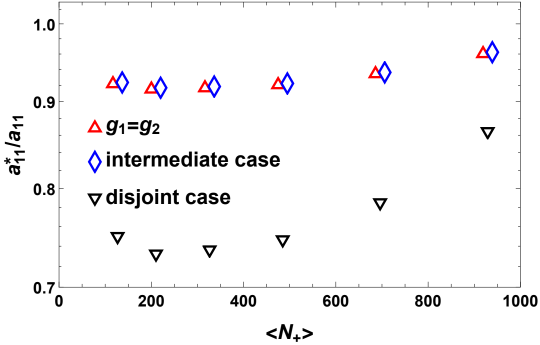
Scaling with $\langle N_+ \rangle$



The piece from string end-point fluctuations

$$C^*_{AB}(\eta_1,\eta_2) = \frac{\langle N_A\rangle \mathrm{cov}(\eta_1,\eta_2) + \langle N_B\rangle \mathrm{cov}(-\eta_1,-\eta_2)}{f_{AB}(\eta_1) f_{AB}(\eta_2)}$$

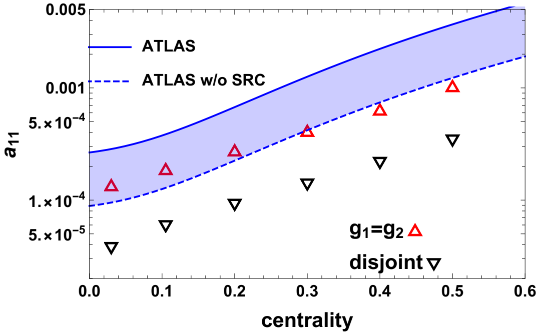
$$a^*_{nm} = \int_{-Y}^{Y} \frac{d\eta_1}{Y} \int_{-Y}^{Y} \frac{d\eta_2}{Y} \frac{1}{N_C} C^*(\eta_1,\eta_2) T_n\left(\frac{\eta_1}{Y}\right) T_m\left(\frac{\eta_2}{Y}\right)$$



End-point fluctuations dominate over the number fluctuations

Estimate for the LHC

[ATLAS 2015, Pb+Pb@2.76TeV]



Fluctuating both end-point helps!
(SRC=short-range component)

Conclusions

Conclusions

1. Fluctuation of both end-points yield much larger forward-backward correlations
2. Constraint from the one-body spectra used
3. Bounds follow for the string end-point distributions and a_{11}
4. The string end-point fluctuations dominate over fluctuations of the number of strings
5. For the LHC, agreement with the data for the case of both end-points fluctuating

More details: arXiv:1809.08666