Quantized fragmentation of three-dimensional QCD string

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Abstract

Recent developments of the model of quantized helical QCD string are presented, notably the baryon production. An overview of the experimental evidence is discussed as well as possible applications.

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1 Introduction

The work presented here is the latest development on a subject presented regularly in this conference. The very first time we heard of helical QCD string, the conferences venue was the ancient site of Delphi, Greece [1], and Alessandro De Angelis was presenting DELPHI results [2] disproving the idea by measuring the observable suggested by authors of [3], which was freshly out of print at that time. I remember vividly Prof. Bo Andersson from Lund, present in the audience, complaining about the right of a theorist to enjoy at least a half an hour of glory before being disproved. The untimely death of Prof. Andersson in 2002 and the gap between LEP and LHC datataking delayed further work but by 2012, we had the experimental confirmation of azimuthal ordering of hadrons which could be attributed to underlying helical field [4], using slightly modified observables and minimun bias data from LHC. The model got a significant boost after it was noticed that three-dimensional string allows to explore causal connections between string break-up vertices, opening a wide range of model building opportunities [5].

2 Induced gluon splitting

Let's consider a case of a massless quark - or antiquark - pulled by the string tension tangential to the (helical) string in close analogy with standard (one-dimensional) Lund string [6]. As the quark propagates along the string with the speed of light, it acquires a longitudinal and transverse momentum component, and the curvature of the helical string translates part of the accumulated transverse energy into (dynamic) quark mass. In this case, there is just one possible scenario for causally connected string vertices, and that's the one in which the quark triggers a split of gluon ($g \rightarrow q\bar{q}$). This "light-front" string fragmentation has another interesting property and that is the decoupling of the transverse and longitudinal momenta components, where the mass and the intrinsic transverse momentum of the resulting hadron is entirely driven by the transverse shape of the string (a constant string tension κ=1GeV/fm is used in the model, as in the standard Lund fragmentation). Such a hadron production scenario is suitable for creation of hadrons with limited internal degrees of freedom (lightest hadrons). The lightest hadrons decaying into (1,3,5) pions are pseudoscalar mesons (π, η, η') and comparison of their mass spectra with the fragmentation of helical string reveals a quantized fragmentation pattern where string splits in phase intervals $\Delta\Phi$ ~2.8 rad, with κR ~0.07GeV, R standing for the radius of helix (Fig.1). The scheme also fits formation of ω meson, a vector meson which takes 4 quanta of helical string and decays into n<4 pions (3,preferably).

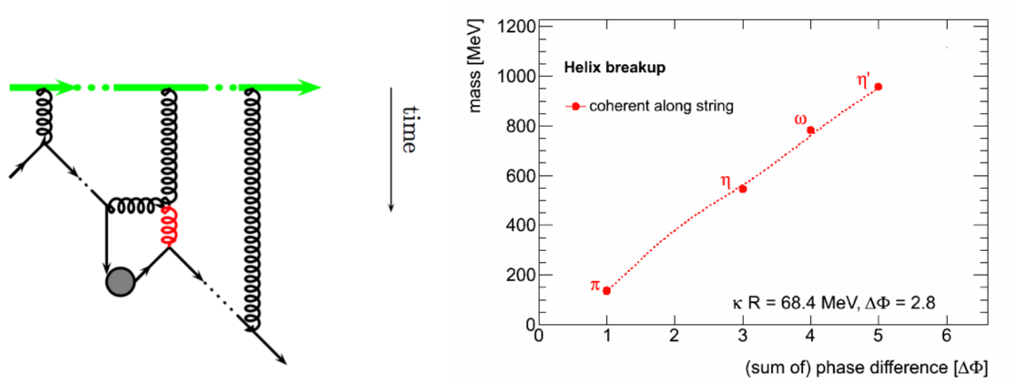

Figure 1: Left: Scheme of causal (induced) gluon splitting - the excited gluon marked in red decays promptly into a $Q\bar{Q}$ pair. Right: Causal approach to string breaking reveals the quantized nature of the process. Plots taken from [7].

Although the model is very simple and does not take into account mass of quarks, it nevertheless describes the mass spectrum with the precision of up to 3%, and inversely, the mass spectrum constraints the string parameters $\Delta\Phi, \kappa R$ with similar precision.

3 Baryon production

For a closely packed helix string winding (small pitch), one can imagine the induced gluon splitting can take place across string loops as shown in Fig. 2. A sequence of two induced breakups of this type produces coherent systems of 3 quark and 3 antiquarks which may emerge as baryonic states. It turns out the lightest baryons (nucleons) fit within the scheme of quantized helical string fragmentation quite naturally, as n=5 states. There is no need to introduce new parameters in the model, nor adjust the string parameters, and nucleon mass is reproduced with 1% precision [7].

It is interesting to note [7] that not only Λ baryon mass is obtained from n=6 state modelling without further adjustements, but also as an unbound p+π state ends up with mass equivalent to Λ^0 resonance in the quantized fragmentation of helical string with parameters constrained by mass of pseudoscalar mesons. This raises a possibility that part of Λ baryon production does not follow the established quark model description and may not imply a strange quark creation.

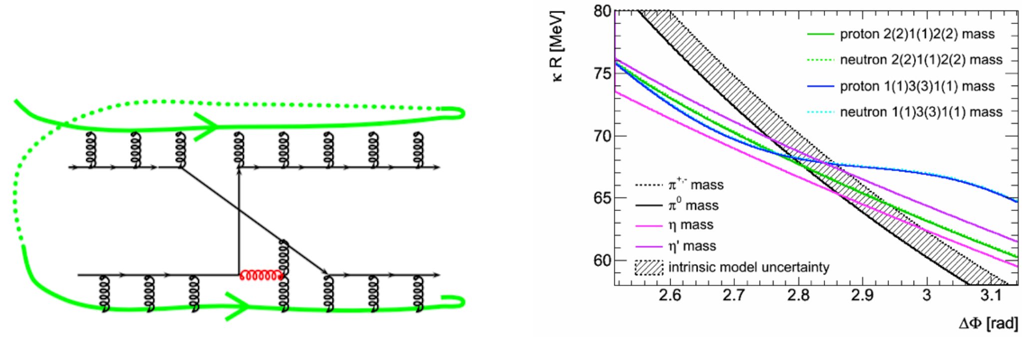

Figure 2: Left: Scheme of causal (induced) gluon splitting across string loop - the excited gluon marked in red decays promptly into a $Q\bar{Q}$ pair. Right: Relation between string parameters and hadron mass. Nucleon mass corresponds to expectation of the quantized fragmentation scheme, within model uncertainties. Plots taken from [7].

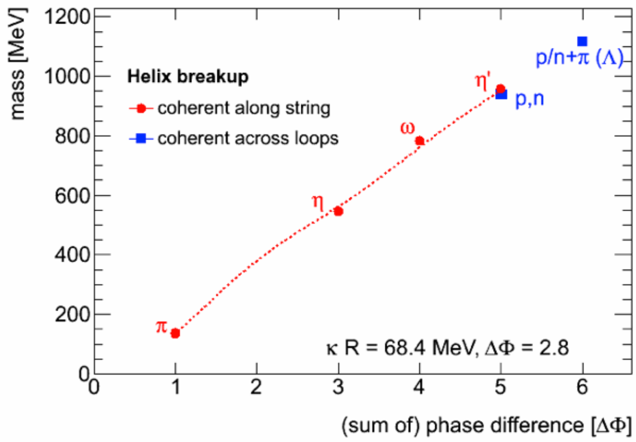

Figure 3: Spectrum of light mesons and baryons matching the scheme of quantized string fragmentation via induced (causal) string breakup. Plot taken from [7].

4 Correlations

The fact that quantization proceeds in transverse energy $E_T = \sqrt{m^2 + p_T^2}$ (with respect to string axis), rather than mass itself, implies that on top of hadron masses, also the intrinsic transverse momenta of hadrons are quantized, and correlations between adjacent hadrons predicted, at least for the case of helical string with constant pitch. For a chain of direct pions, the model predicts higher momentum difference for a pair of pions with rank difference 1 (adjacent) than for a pair with rank difference 2 (rank describes ordering of hadrons according to colour flow). In combination with the local charge conservation which forbids a creation of like-sign adjacent pions, the model predicts charge-asymmetry in rank=1,2 production, a threshold-like momentum difference for adjacent (unlike-sign) pion pairs (Q∼0.26 GeV) and an excess of like-sign pairs at low Q∼0.09 GeV). The measurement has been performed by ATLAS [8]. The signature of ordered hadron chains with predicted properties was found and it was established that the measured chains carry the entire like-sign pair enhancement traditionally attributed to Bose-Einstein interference. The measurement of the shape of correlations within ordered chains provides an independent evaluation of string parameters [7], and a good agreement is observed between results derived from study of hadron spectra and from correlations (Fig. 4).

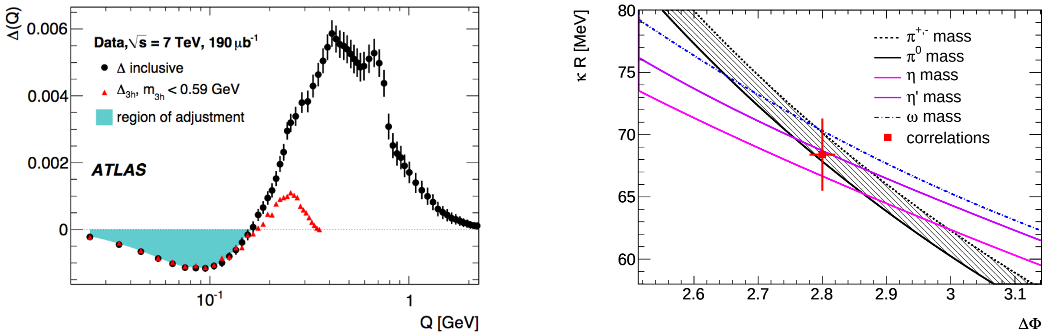

Figure 4: Left: ATLAS measurement of ordered hadron chains. The turquoise region marks the excess of like-sign pairs traditionally attributed to Bose-Einstein interference [8]. Right: Measurement of correlations provides an independent cross-check of string parameters, in good agreement with values obtained from study of hadron mass spectra [7].

5 Conclusion

The most natural explanation for the quantization of QCD field is that there is a limited number of gluons in the field, perhaps as few as two gluons per $\Delta\Phi$. This would mean the quantization, on which we may have quite a good experimental handle, wipes away the sea of non-perturbative gluons. Instead, we have a well ordered, sparsely populated QCD vacuum, which brings us back to the subject of the original "screwiness" paper [3].

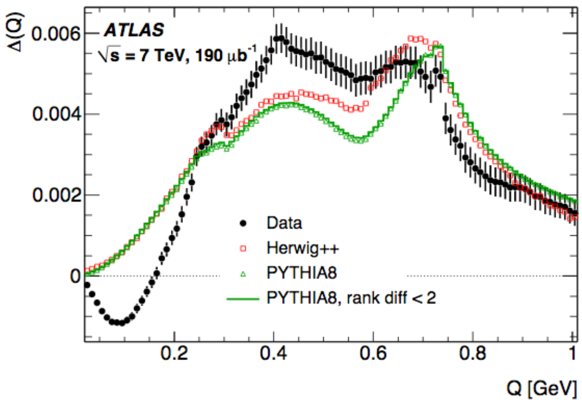

Figure 5: Conventional hadronization models fail to describe data, and the lack of quantum effects seems to be the primary source of discrepancies. Plot taken from [8].

Currently, the particle physics community does not have a reliable tool for the study of hadronization systematics, and the lack of quantum effects may well be the main source of discrepancies. Fig. 5 illustrates the situation with the ATLAS measurement of the difference between inclusive distribution of unlike-sign and like-sign hadron pairs (normalized to the number of charged particles in the sample), which reflects the resonance decay and correlations between adjacent hadrons [8]. Both conventional Lund fragmentation and the clusterization fail to describe the data in a similar way, because none of them takes into account natural quantum thresholds and other quantum effects.

Acknowledgements

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