Study of the fragmentation process of a transversely polarized quark

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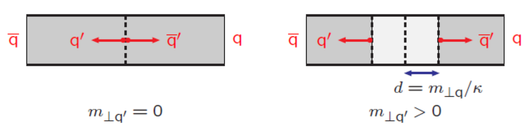
I. Introduction

Many fundamental scattering processes like e+e-, pp, lepton-p share a basic subprocess: the fragmentation of a color singlet system (i.e quark-antiquark) into hadrons: q + antiq —> h1+h2+...hn
It describes how quarks and antiquarks are confined toghether in bound states: resonances and stable hadrons.
Confinement is a peculiar property of the current theory of strong interactions, the ***Quanum Chromodynamics*** (QCD) and it's existence resides in the non abelian nature of the theory. It is believed to arise throught the creation of a stringlike flux tube by the chromoelectric field.
Phenomenologicaly the fragentation process is analyzed throught the ***"fragmentation functions"*** (FF) which can be extracted from the measured cross sections in the different processes mentioned above.

Space story of the string in color representation.

Spacetime story of the string.

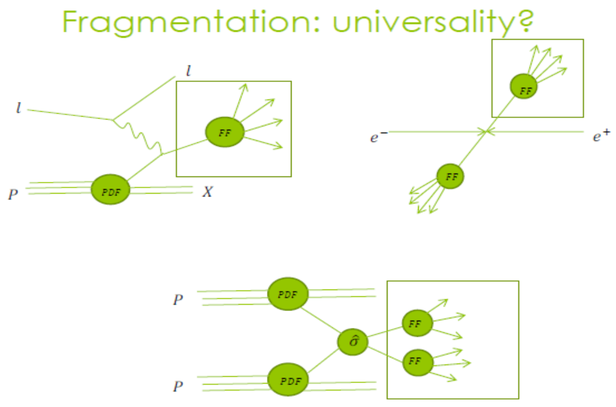
How does the string break?



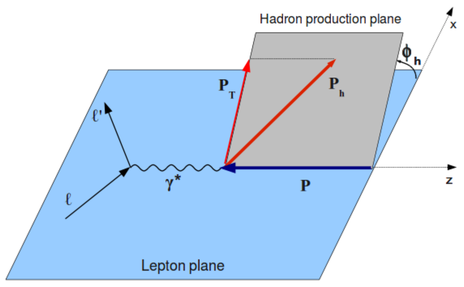
String breaking modelled by tunneling:

$$\mathcal{P} \propto \exp\left(-\frac{\pi m_{\perp q}^2}{\kappa}\right) = \exp\left(-\frac{\pi p_{\perp q}^2}{\kappa}\right) \exp\left(-\frac{\pi m_q^2}{\kappa}\right)$$

Schwingher mechanism for pair production in strong field.



Left: different scattering processes where the fragmentation functions can be measured.
Right: SIDIS process.



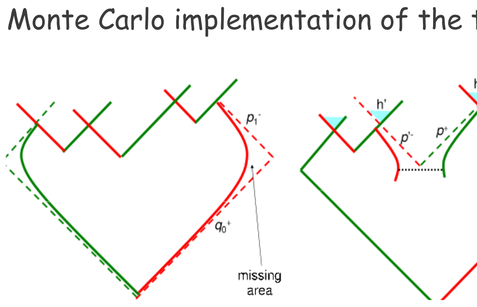
II. Unpolarized fragmentation

Using the classical string theory supplemented with a stochastical decay process, many effective models, such as the ***symmetric Lund model*** and the ***Artru-Menessier-Bowler model*** (AMB), succeed in the description of the unpolarized (all spin effects are neglected) fragmentation of a color singlet system. In such theories the chromoelectric flux tube is treated as a massive relativistic string which can decay into hadrons (fragmentation). The decay can be thought as a radioactive decay: there is a constant probability per unit space and time during the spacetime history of the string for the decay to happen via local quark-anqtiquark pair production.
The local massive pair creation is a quantum mechanical effect, explained through ***Schwinger mechanism***.
Although these theories reproduce many phenomenological observarions, they fail in the description of observed spin effects.

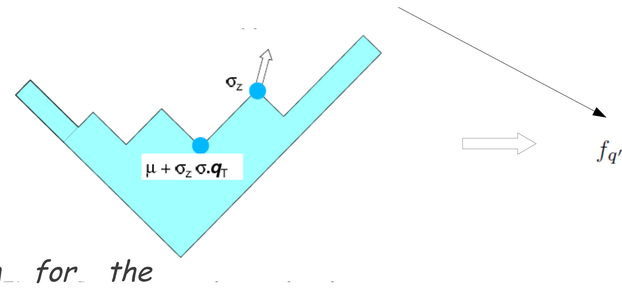
$$f_{q',h,q}(\zeta, \mathbf{q}_T', \mathbf{q}_T)$$
$$\propto Z^{a\{q\}}\ (1/Z-1)^{a\{q'\}}\ \exp\left(-b\,\frac{m_h^2+\mathbf{p}_T{}^2}{Z}\right).$$

III. Collins effect

Among the fragmentation functions, the ***Collins function*** which describes the fragmentation of a transversely polarized quark in an unpolarized hadron, is currently under active study. In the Semi-Inclusive Deep Inelastic process (SIDIS) it is convoluted with the ***"transversity"*** distribution h1 which encodes information regarding the structure of the hadron's ***"transverse spin"***, complementary to what we learn from the ***helicity*** distribution.
A model which includes the **spin** in the fragmentation process was proposed in 2009 by X. Artru and later on has been refined. It is a string fragmentation model supplemented with the ***$^3P_0$ mechanism*** where the quarks and antiquarks paris which break the string are created in wave functions with *L=1 , S=1, L+S=0* quantum numbers: such a mechanism can explain the Collins effect observed in real experiments.
Formally, the spin effects are taken into account through the $^3P_0$ mechanism in a path integral formulation of the massive relativistic string decay from where we can extract the ***polarized splitting function*** crucial for a Monte Carlo implementation of the theory.

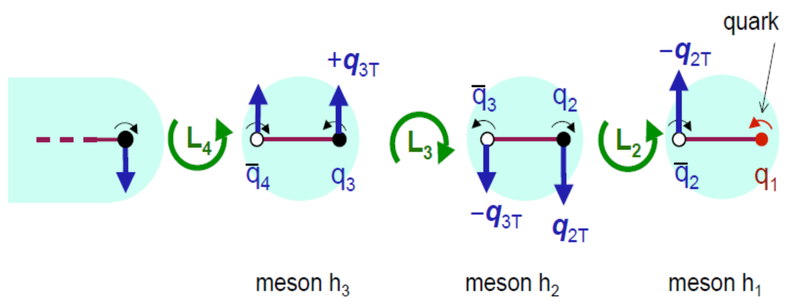


$$\mathcal{M}(q_A\bar{q}_B \to h_1 h_2 ... h_N) = \exp\left[(-i\kappa_C + 2i\kappa)\,\mathcal{A}\right]$$
$$\times (q_A^+ p_1^-)^{\alpha\{q_A\}} \times (-p_1^+ p_2^- - i0)^{\alpha\{q_1\}} \cdots \quad (14)$$
$$\cdots (-p_{N-1}^+ p_N^- - i0)^{\alpha\{q_{N-1}\}} \times (p_N^+ \bar{q}_B^-)^{\alpha\{q_B\}}$$
$$\times g\{q_B, h_N, q_{N-1}\} \cdots g\{q_2, h_2, q_1\}\, g\{q_1, h_1, q_0\}\,.$$



$$f_{q',h,q}(\zeta, \mathbf{q}_T', \mathbf{q}_T)$$

Feynman diagram for the massive string decay.



$^3P_0$ *mechanism.*

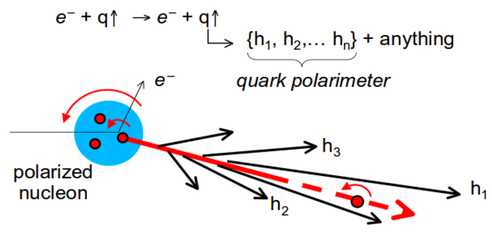
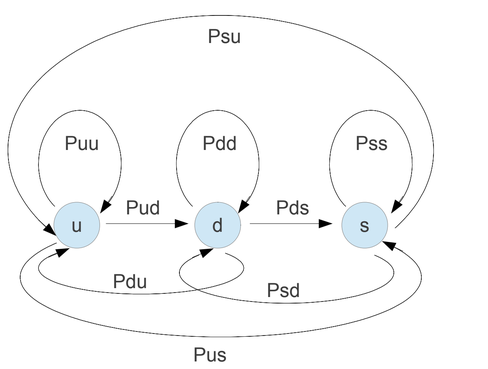


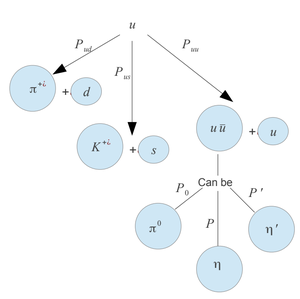
Illustration of the Collins effect.

IV. Our goal

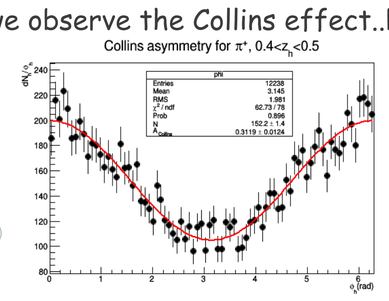
Our projects consists in the realization of a Monte Carlo simulation for the fragmentation of a polarized jet and the subsequent comparison with COMPASS data.
In the generation of the polarized hadronic jet we have to deal with the basic process q —> h + q': the distributions for the generation of the hadron's h four momentum is derived from theory, the flavour splitting probabilities from symmetries such as isospin and ***"quark chain reversal"..***
The tuning of the theory is done according to observable quantities measured in the COMPASS experiment: azimuthal distributions of final hadrons, azimuthal correlations between charged hadrons, multiplicities, transverse momentum, rapidity distributions..
In the preliminary code we observe the Collins effect..but further work is required for the simulation of the full SIDIS process.

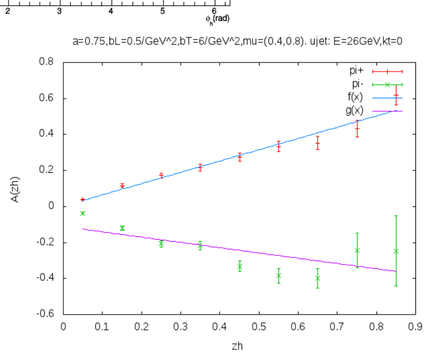


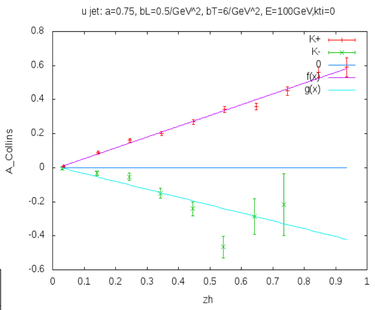
*Graph representation of the **transition probability kernel** for the flavour splittings.*

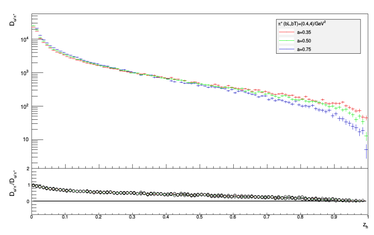


Flavour propagation in the branchings of a u quark which fragments producing peudoscalar mesons.









Premilinary plots of the Collins asymmetry and of the Collins function.