

# String fragmentation and diquark breaking in coplanar emission

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**Abstract.** A Monte carlo generator for coplanar emission is elaborated on the basis of partonic models and Schwinger mechanism for particle production. The very strong string tension of the valence diquark is taken as the source of very large  $p_t$ 's necessary to produce the alignments of secondaries. The preliminary coplanar generation is considered here in the case of small diffractive masses in the forward direction.

**Keywords:** coplanar emission, diquark breaking

## I. INTRODUCTION

The coplanar emission appearing around  $10^{16}$  eV in X-ray emulsion chambers experiments merits a special attention. Our simulations have demonstrated that such phenomena can be explained by fluctuations with standard physics [1]. However, in the case of two events observed in the stratosphere, several features contradict such explanation [2]. For a better understanding of the properties of those events with a minimal cascading, we are developing a specific Monte Carlo generator. The violent rupture of the string under very high tension between the partners of the valence diquark is considered as the source of the large  $p_t$ 's needed for the alignments.

## II. PARTONIC MODELS AND COPLANAR EMISSION

Observing that a major part of the visible energy in the coplanar events is contained in the clusters of daughter particles involved in the alignment, we start by the circumstance of small diffractive masses. The classical 2-string component of the Dual Parton Model [3] is shown in Fig. 1a. One synopsis with valence diquark breaking is shown in Fig. 1b. The 3 valence quark are recombined here picking an antiquark from the sea pairs of  $q-\bar{q}$  to emerge as mesons. The diffractive mass is generated as indicated in [4] in order to follow the  $1/M^2$  distribution. A similar situation is considered for the diquark breaking occurring in double diffraction dissociation. The wavy line on the graph corresponds to a single pomeron consisting of gluons and sea quarks.

We have developed a very fast Monte Carlo generation procedure based on the inverse integral method (with a dedicated numerical algorithm) to produce the respective momenta of valence quarks and sea quarks as well as for gluons. The generation for valence quarks up and gluons is presented for example in Fig. 2a and 2b, corresponding to the structure functions [5]:

$$xu_v(x) = 1.8x^{0.5}(1-x)^3 \quad (1)$$

for the valence quark up (1) and (2) for the gluons

$$xg(x) = 3.5(1-x)^6 \quad (2)$$

Those simple forms have just been taken for example, but our generator can be tuned easily to more sophisticated types of structure functions.

## III. STRING TENSION IN COPLANAR EVENTS

According to the simplified presentation of Wong [6], one pair  $q-\bar{q}$  is created when the distance  $L$  separating both valence quarks exceeds a threshold value (Fig. 3a). The string fragmentation corresponds to a tension  $\kappa = 1/2\pi\alpha'$  of about 1 GeV/fm,  $\alpha'$  being the Regge slope. The transverse momentum of the quarks emitted is related to the tension by the relation (3)

$$\sqrt{\langle p_t \rangle^2} = \sqrt{\frac{\kappa}{\pi}} \quad (3)$$

Such relation provides the classical values of  $\langle p_t \rangle = 0.25$  GeV/c for quarks and 0.35 GeV/c for the pions where the pairs  $q-\bar{q}$  are recombined. Above an energy threshold of about 200 GeV (in CMS) per valence quarks (corresponding to a proton projectile of 10 PeV in the Laboratory system, a new string appears between the partners of the valence diquark (Fig. 3b).

The tension increases with the distance and the breakdown happens as soon as the minimal energy of excitation required is available; the maximal distance between the valence quarks associated to this minimal energy is obtained when the 3 quarks are aligned. Such circumstance excludes the classic recombination of the leading cluster (one valence diquark with one quark of the sea giving a pilot proton, a neutron or a  $\Delta$  resonance); this could explain why the penetrating power of the cosmic air showers appears to level off in the "knee" energy range. At energies more close to the LHC, the fragmentation of 3 separated valence quarks will still be observed, but the alignment will be smeared out. The most simple recombination for the 3 valence quarks of the projectile will happen with antiquarks of the sea giving the emission of 3 energetic hadrons for instance as a collimated trident of 3 charged pions (or charged pions and  $K_0$ ) in Fig. 4.

For the generation of the respective transverse momenta of the quarks, we follow again the consequences of Schwinger theory to establish a gaussian transverse momentum distribution. The tunnelling process taking the opportunity to a quark to emerge from the negative energy sea region as a quark in the positive energy

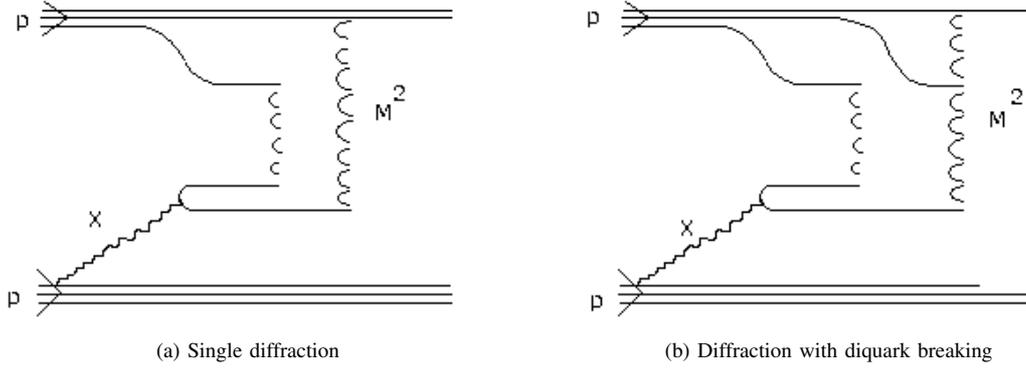


Fig. 1: Two component diagram for the single diffraction (a). Single diffraction and valence diquark breaking (b).

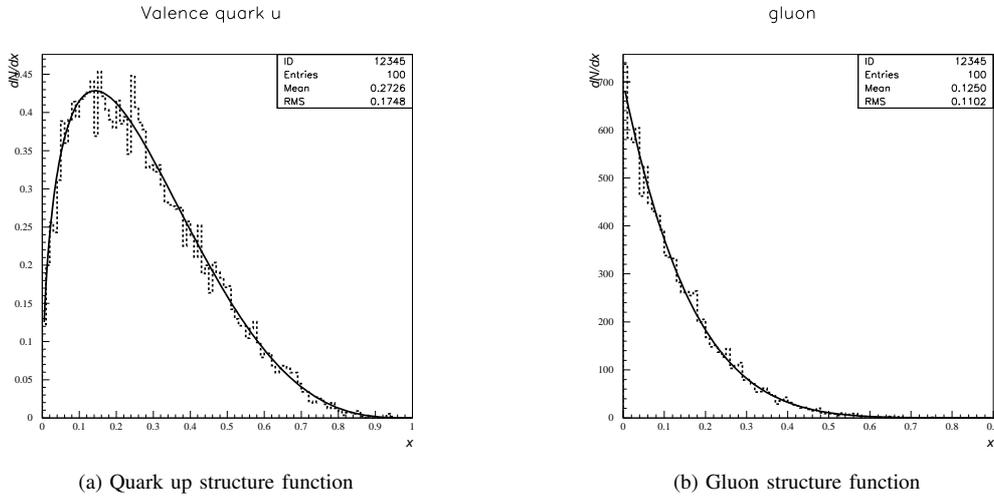


Fig. 2: Momentum generation for quark up (a) and gluons (b).

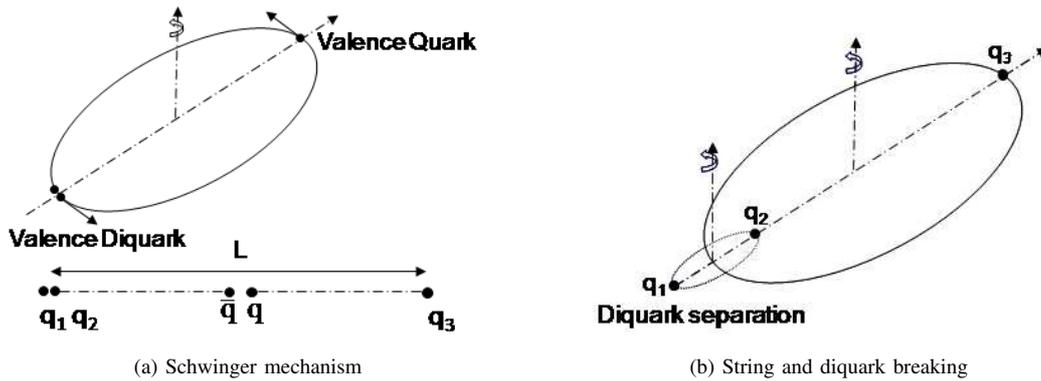


Fig. 3: (a) String tension between valence quark and valence diquark of a proton projectile; (b) for additive string with intense tension between both partners of the valence diquark

continuum has been developed thanks to the additive mass generated by the quark  $p_t$ .

Taking into account the vector potential, the Klein Gordon equation and finally the Schrödinger equation [6], the following relations have been derived. First, the minimum separation threshold to produce a  $q\bar{q}$  is

expressed as  $L_{\min} = \frac{2m_t}{\kappa}$ ,  $m_t$  being the transverse mass of the quark.  $L_{\min}$  is about 1 fm for a quark mass of 0.325 MeV (quark masses here are understood as in potential models and differs from the estimation of current quark masses).

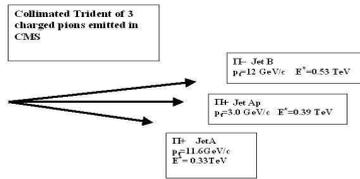


Fig. 4: Trident emission expected in colliders as suggested by emulsion chamber observations.

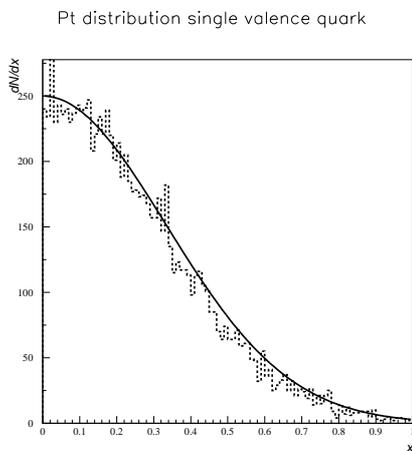


Fig. 5: Quark  $p_t$  generation following Schwinger mechanism

The gaussian distributions of the  $p_t$ 's are inferred as:

$$\frac{dN}{dp_t} = \exp\left(-\frac{\pi m_t^2}{\kappa}\right) \quad (4)$$

where  $m_t$  is the transverse mass of the parton of mass  $m$  with  $m_t^2 = m^2 + p_t^2$ . The generation of transverse momenta is shown in Fig. 5 giving for example an average quark transverse momentum  $\langle p_t \rangle = 0.26 \text{ GeV}/c$

Conversely to this situation following Fig. 3a, we can generate transverse momenta according to Fig. 3b concerning the partners of the valence diquark and the  $q\bar{q}$  pairs generated in the string of very high tension. The dependance for violent diquark breaking are presented in Fig. 6a and 6b for parton average  $\langle p_t \rangle = 8$  and  $11 \text{ GeV}/c$  respectively.

#### IV. SIMULATED AND OBSERVED COPLANAR EVENTS

The most energetic event JF2AF2 of Concorde data (1600 TeV deposited energy, suggesting a primary energy of 10 PeV [2]) exhibits the 4 most energetic  $\gamma$  rays (above 50 TeV) standing along a perfect straight line in a possible relation with the valence quarks of the projectile. Furthermore, 34  $\gamma$  rays aligned contain

808 TeV, i.e. 51% of all the visible energy. For the earliest Siberian balloon flight (SBF), the calorimeter was deep enough to collect the energy deposited also by the secondary hadrons with one energy threshold for  $\gamma$ 's and hadrons of 2 TeV. Taking into account the different energy thresholds of the XREC's used for both events, respectively 200 GeV for JF2af2 and 2 TeV for STRANA [7], we observe that the visible energy deposited in  $\gamma$  rays is very similar, as shown in table I.

TABLE I: Total energy deposited for JF2AF2 and STRANA (e.m. component).

	$\sum E_\gamma$	$N_\gamma$	$E_{th}$
JF2AF2	1586.	211	0.2
STRANA	1400.	76	2.

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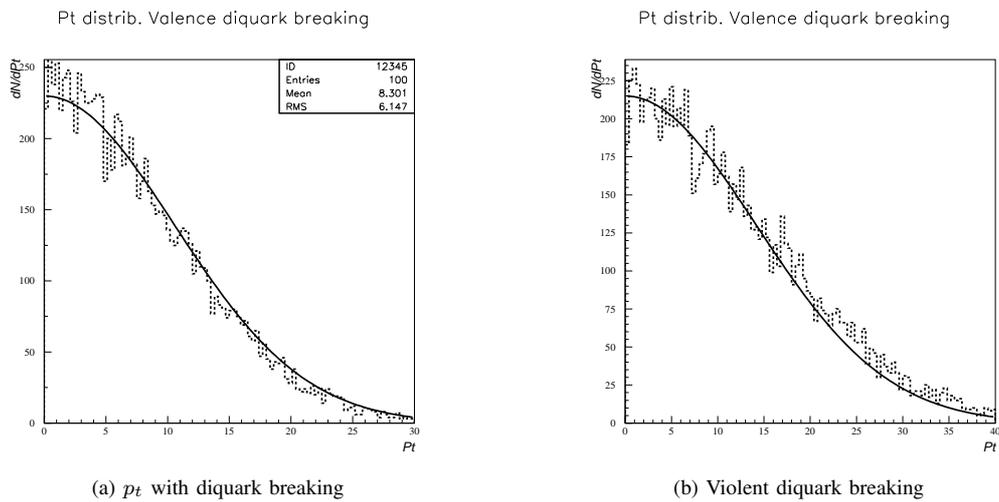


Fig. 6:  $p_t$  distributions of the partons concerned by the valence diquark breaking with  $\langle p_t \rangle = 8 \text{ GeV/c}$  (a) and  $\langle p_t \rangle = 11 \text{ GeV/c}$  (b)