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Early spin determination at the LHC?

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ABSTRACT

If signals of new physics are discovered at the LHC it will be crucial to determine the spin structure of the new model. We discuss a method that can help to address this question with a low integrated luminosity, $\mathcal{L} = 1\ \text{fb}^{-1}$, at $\sqrt{s} = 14$ TeV. Based on the differences in angular distributions of primarily produced particles we show that a significant difference can be observed in the final state jet-pairs rapidity distance. An additional advantage of the method is that it does not rely on any particular structure of the couplings in the decay chain. We simulate samples for models with supersymmetric and UED-like spin structure and show that a distinction can be made early on.

1. Motivation

The Large Hadron Collider (LHC) has started operating and will soon probe physics at the TeV scale, perhaps revealing the origins and mechanism of the electroweak symmetry breaking. One of the most promising candidates for explaining this phenomenon is supersymmetry (SUSY) [1,2]. In supersymmetric theories each Standard Model (SM) particle is paired with a superpartner of spin different by 1/2. In particular, spin-1/2 quarks will be accompanied by spin-0 squarks, and spin-1 gluons by spin-1/2 gluinos. Another possibility is provided by models with universal extra dimensions (UED) [3]. In such models each SM particle will have a tower of different mass Kaluza–Klein (KK) partners of the same spin.

Since different models of new physics predict different spins for the newly discovered states, the determination of spins will be of extreme importance for establishing the new theory. Generically, SUSY and UED also have a different mass structure, but model-independent measurements of both masses and spins will be required in order to get handle on the underlying model. In this Letter we consider the possibility of distinguishing models with the same mass structure but the spin structure of either SUSY or UED. We will not refer here to any particular UED model, assuming only that it inherits all the properties (masses and couplings) of the analyzed SUSY scenario apart from the spin. Whilst we are only interested in the generic spin structure, we will refer to the same-spin partners as KK-particles for ease of notation. As a benchmark we choose two mSUGRA derived scenarios.

So far there have been a number of features suggested that would hint at the particular spin structure at the LHC (see also [4]):

- The total cross section [5].
- Observation of higher KK modes [6].
- Kinematic distributions of quarks from quark partners decays [7,8].
- Particle production in vector boson fusion [9].
- Invariant masses of lepton–jet [10–14] and lepton–photon [15] pairs in squark/KK-quark and gluino/KK-gluon [16] decay chains.
- Kinematic reconstruction of missing momentum [17,18].
- Angular distributions of leptons from sleptons [19–21] or s-channel resonances decays [22], and b-jets from bottom squarks decays [23].

Most of these methods require significant statistics and consequently a high luminosity (typically $\mathcal{L} \sim \mathcal{O}(100)\ \text{fb}^{-1}$) or a very specific decay chain. Here, we propose an extension of the method originally proposed in [19] for sleptons, to the first and second generation squarks/KK-quarks. In a large class of models, strongly-

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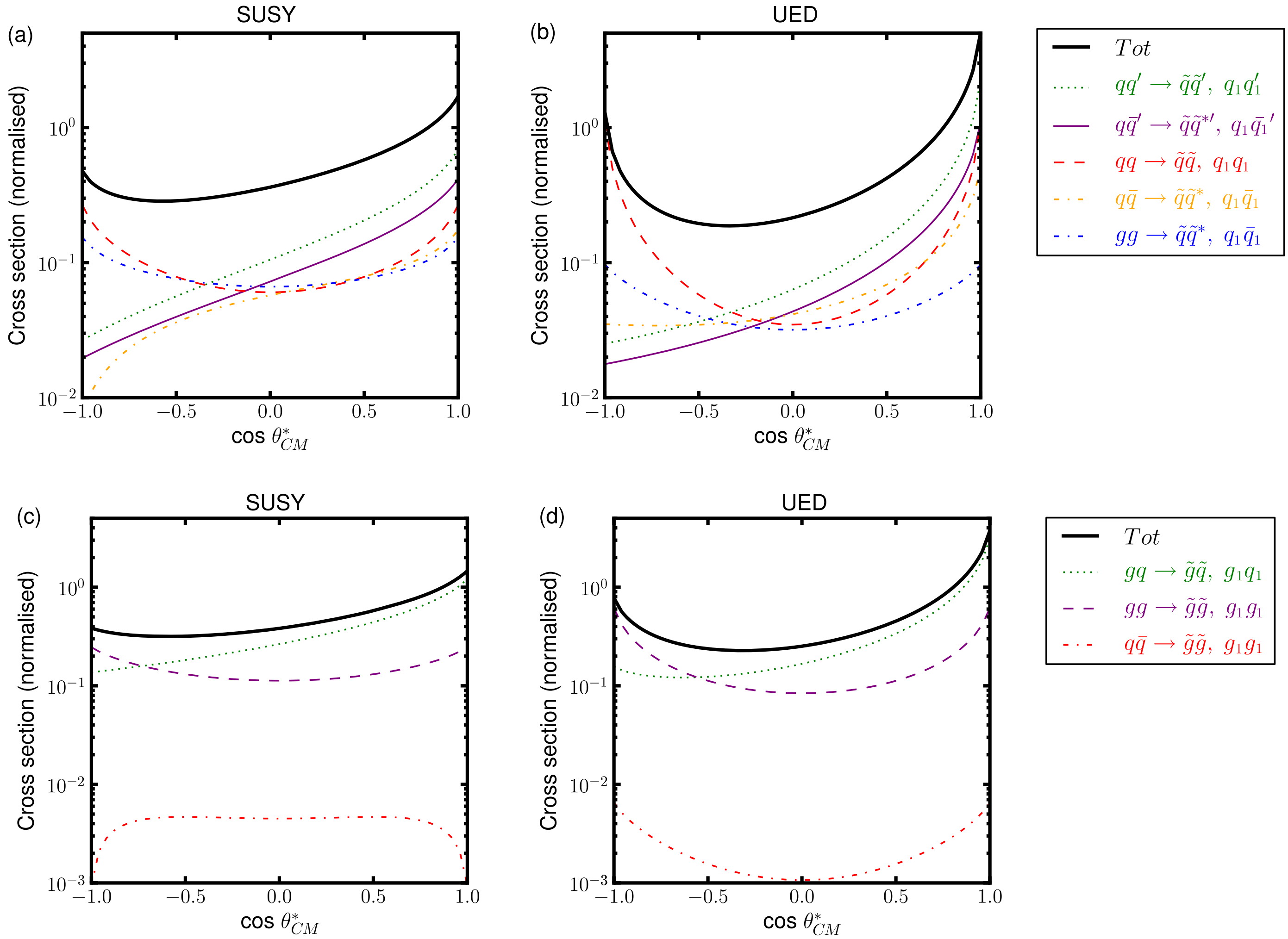

Fig. 1. Polar distributions of (a) squarks, (b) KK-quarks, Eq. (1); (c) gluinos, (d) KK-gluons, Eq. (2), in the hard process CM frame normalized to the respective total cross sections at $\sqrt{s} = 14$ TeV. Contributions from left and right states have been summed over. For simplicity we take $m_{\tilde{q}} = m_{\tilde{g}} = 500$ GeV, however, a departure from this assumption does not change the qualitative behaviour of the cross sections. Note that, as dictated by the hard process matrix element, the curves with distinguishable particles in the initial and final state are not symmetric with respect to the incoming parton but will be symmetric with respect to the proton beam.

interacting states will provide the first observation of any new physics. Therefore, they offer the opportunity to get hints of the spin structure with early data. Here, we consider an integrated luminosity of $\mathcal{L} = 1$ fb^{-1} at 14 TeV center-of-mass energy (cms), however, the method is also applicable at lower center-of-mass energies.

The Letter is organized as follows. In the next section we define our observable and present a proof of concept that it might be useful in studying spin structure of the underlying model. In Section 3 we discuss our benchmark scenario and details of the event simulation. Section 4 contains the results of the simulations and discussion. Finally, we conclude in Section 5.

2. Spin-sensitive observable

The production of gluinos and squarks of the 1st and 2nd generation is in many scenarios a dominant source of supersymmetric particles. It is, therefore, one of the most promising channels for SUSY searches at the LHC [24]. We will show in this Letter that with early data (1 fb^{-1}) we can already deduce important hints about the spin of the produced particles. We focus here on the di-jet channel (i.e. at least two hard jets, see Section 4 for details) for which the sample sources at the parton level are

$$pp \to \tilde{q}_i\tilde{q}_j^{(\prime)}, \qquad pp \to \tilde{q}_i\tilde{q}_j^{*(\prime)}, \tag{1}$$

$$pp \to \tilde{g}\tilde{g}, \qquad pp \to \tilde{g}\tilde{q}_i, \tag{2}$$

as well as the charge conjugated processes (for squarks), followed by the decays e.g.

$$\tilde{q}_i \to q\tilde{\chi}^0_n, \qquad \tilde{q}_i \to q'\tilde{\chi}^\pm_k, \qquad \tilde{g} \to q\tilde{q}_i, \quad \text{etc.}, \tag{3}$$

where $i, j = L, R$, $n = 1, \ldots, 4$, $k = 1, 2$ and q' denotes a quark of different flavour. Of course, the decay chains will very much depend on the details of the spectrum of the model. One particular example leading to a di-jet signal common in mSUGRA scenarios is

$$pp \to \tilde{q}_R\tilde{q}_R \to qq\tilde{\chi}^0_1\tilde{\chi}^0_1, \tag{4}$$

whereas in UED the respective process is

$$pp \to q_{R1}q_{R1} \to qq\gamma_1\gamma_1, \tag{5}$$

where q_{R1} and γ_1 are the KK-partners of the right-handed quark and the photon, respectively. However, many different processes from Eqs. (1) + (3) and (2) + (3) can contribute to the di-jet final state and therefore, we consider a fully inclusive signal. In addition, at a hadron collider, extra QCD jets will appear when we include initial state radiation (ISR) and final state radiation (FSR).