Slepton pair production at hadron colliders

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Abstract. In R-parity conserving supersymmetric (SUSY) models, sleptons are produced in pairs at hadron colliders. We show that measurements of the longitudinal single-spin asymmetry at possible polarization upgrades of existing colliders allow for a direct extraction of the slepton mixing angle. A calculation of the transverse-momentum ($q_T$) spectrum shows the importance of resummed contributions at next-to-leading logarithmic (NLL) accuracy in the small and intermediate $q_T$-regions and little dependence on unphysical scales and non-perturbative (NP) contributions.

INTRODUCTION

The Minimal Supersymmetric Standard Model [1, 2], one of the most promising extensions of the Standard Model (SM), postulates a symmetry between fermionic and bosonic degrees of freedom in nature, predicting thus the existence of a fermionic (bosonic) SUSY partner for each bosonic (fermionic) SM particle. Its main advantages are the stabilization of the gap between the Planck and the electroweak scale [3], gauge coupling unification at high energy scales [4], and a stable lightest supersymmetric particle as a dark matter candidate [5]. Spin partners of the SM particles have not yet been observed and in order to remain a viable solution to the hierarchy problem, SUSY must be broken at low energy via soft mass terms in the Lagrangian. As a consequence, the SUSY particles must be massive in comparison to their SM counterparts, and the Tevatron and the LHC will perform a conclusive search covering a wide range of masses up to the TeV scale.

We focus on slepton pair (slepton-sneutrino associated) production at hadron colliders through Drell-Yan type processes $q\bar{q} \rightarrow \gamma, Z^0 \rightarrow \tilde{\ell} \tilde{\ell}^*$, and $q\bar{q}' \rightarrow W^+ \rightarrow \tilde{\ell} \tilde{\nu}^*, \tilde{\nu}^* \tilde{\ell}$. Due to their purely electroweak couplings, sleptons are among the lightest SUSY particles in many SUSY breaking scenarios and often decay directly into the stable lightest SUSY particle plus the corresponding SM partner. A slepton-pair signal at hadron colliders will therefore consist in a highly energetic lepton pair, which will be easily detectable, and associated missing energy.

FIXED ORDER CALCULATIONS

The neutral current cross section for the production of non-mixing slepton pairs in collisions of quarks with definite helicities has been calculated in [6], and an extension including the mixing of the left- and right-handed interaction eigenstates has been performed in [7]. Experimentally, proton beams are much more easily polarized than
antiproton beams, and it may be easy to implement the polarization of the proton beam for a possible upgrade of the Tevatron [8].

In Fig. 1, we show the longitudinal single-spin asymmetry $A_L$ as a function of the cosine of the stau mixing angle, for a typical mSUGRA scenario based on the SPS 1a' model [9] where the trilinear coupling $A_0$ varies. The predictions are very sizeable in the entire viable $A_0$ range and depend strongly on the stau mixing angle. Unfortunately, the parton density uncertainty is still large, but it should be reduced considerably in the future through more precise measurements. Furthermore, the SM background can be distinguished from the SUSY signal through its asymmetry with opposite sign.

The QCD corrections to the total slepton-pair hadroproduction cross section have been calculated in [10], and a complete analysis including the SUSY-QCD corrections has been performed in [11]. Since massive squarks and gluinos are involved in the loops, the genuine SUSY corrections are expected to be considerably smaller than the standard QCD ones, as it is presented in Fig. 2. The SUSY-QCD $K$-factors are approached in the asymptotic limit of large $\tilde{q}$/$\tilde{g}$ masses by the QCD $K$-factors.

**TRANSVERSE-MOMENTUM SPECTRUM AT NLL**

A precise knowledge of the $q_T$-balance is of vital importance for the discovery of SUSY particles. The Cambridge (s)transverse mass proves to be particularly useful for the determination of slepton masses [12] and spin [13], the two key features distinguishing them from SM leptons [14, 15]. Furthermore, both detector kinematical acceptance and efficiency depend on $q_T$.

When studying the $q_T$-distribution of a slepton pair produced with invariant mass $M$ in a hadronic collision, it is appropriate to separate the large- and small-$q_T$ regions. At large $q_T$, the use of fixed-order perturbation theory is fully justified, since the perturbative series is controlled by a small expansion parameter, $\alpha_s(M^2)$. However, at small $q_T$, the coefficients of the perturbative expansion are enhanced by powers of large logarithmic
terms, $\ln(M^2/q^2_T)$, and fixed-order calculations diverge as $q_T \to 0$. These logarithms are due to multiple soft-gluon emission from the initial state and have to be resummed to all orders in $\alpha_s$ in order to obtain reliable predictions. At intermediate $q_T$, the resummed result has to be consistently matched with fixed-order perturbation theory in order to obtain predictions with uniform theoretical accuracy over the entire $q_T$-range.

We have recently implemented the formalism proposed in [16] and computed the $q_T$-spectrum of a slepton pair produced at the LHC by combining NLL resummation and $\mathcal{O}(\alpha_s)$ perturbation theory in [17]. In Fig. 3, we choose the SPS7 mSUGRA benchmark point [18], which gives a light $\tilde{t}_1$ of 114 GeV, and we show the $q_T$-distribution for $\tilde{t}_1$ pair production. We can see that the LO result (dashed line) diverges as $q_T \to 0$, and the asymptotic expansion of the resummation formula at $\mathcal{O}(\alpha_s)$ (dotted line) is in very good agreement with LO at small and intermediate $q_T$. In the small and intermediate $q_T$-regions, the effect of resummation (solid line) is clearly visible.

The quantity $\Delta$ gives an estimate of the contributions from different NP parameterizations (LY-G [19], BLNY [20], KN [21]), which are under good control since their effect is always less than 5% for $q_T > 5$ GeV. The perturbative uncertainty, estimated by allowing $\mu_F = \mu_R$ to vary between $M/2$ and $2M$, is clearly improved with respect to the pure fixed-order calculations, reducing the scale dependence from 10% to 5% for $q_T$ values up to 100 GeV. Moreover, when integrated over $q_T$, the NLL+LO curve leads to a total cross section in good agreement with the total cross section at $\mathcal{O}(\alpha_s)$ [11].

## CONCLUSIONS

The recent luminosity upgrade of the Tevatron and the imminent start-up of the LHC put the discovery of SUSY particles with masses up to the TeV-scale within reach. Since this discovery depends critically on the missing transverse-energy signal, a precise knowledge not only of the total cross section, but also of the $q_T$-spectrum is mandatory. We have performed a first step in this direction by resumming multiple soft-gluon emission for slepton-pair production at NLL level and matching it to the fixed-order
FIGURE 3. Differential cross section for the process \( pp \rightarrow \tilde{\tau}_1 \tilde{\tau}_1^* \) at the LHC. NLL+LO matched result, LO result, asymptotic expansion of the resummation formula and \( \Delta \)-parameter are shown.

calculation. (S)transverse mass measurements will then lead to precise slepton mass and spin determinations, while polarization of the initial hadron beams may allow for an extraction of the slepton mixing angle and the underlying SUSY-breaking parameters.

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