QCD RESUMMATION IN THE FRAMEWORK OF SUPERSYMMETRY

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Motivated by current searches for electroweak superpartners at the Large Hadron Collider, we present precision predictions for pair production of such particles in the framework of the Minimal Supersymmetric Standard Model. We make use of various QCD resummation formalisms and match the results to pure perturbative QCD computations. We study the impact of scale variations and compare our results to predictions obtained by means of traditionally used Monte Carlo event generators.

1 Introduction

After almost half a century of theoretical developments and experimental discoveries in high-energy physics, an extremely coherent picture arises as the so-called Standard Model of particle physics. Since this theory contains a fundamental scalar field, the stabilization of its mass with respect to radiative corrections is questionable. This has led to a plethora of new physics models among which weak-scale supersymmetry [1,2] (SUSY) is one of the most appealing option since it encompasses in addition, *e.g.*, gauge coupling unification and a candidate for dark matter.

The current non-observation of any hint for strong superpartners has shifted the experimental attention to the production of electroweak sleptons, neutralinos and charginos. Investigations at the Large Hadron Collider (LHC), at a center-of-mass energy of $\sqrt{S_h} = 7$ and 8 TeV, have already allowed to impose bounds of several hundreds of GeV on their masses [3,4]. These analyses however rely on leading order (LO) computations [5,6,7] supplemented by QCD next-to-leading order (NLO) corrections [8]. Since such predictions suffer from rather large theoretical uncertainties, soft-gluon resummation of the large logarithmic terms arising at small transverse momentum or close to the production threshold have to be accounted for and matched to fixed order [9,10,11,12,13,14,15].

We briefly review, in Section 2, three resummation formalisms that can be employed for such precision calculations and illustrate their main effects in Section 3 for gaugino pair production.

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In addition, we also confront the resummed predictions to results obtained using LO Monte Carlo event generators including multiparton matrix element merging after parton showering. We summarize our work in Section 4.

2 Soft gluon resummation: a brief insight

We focus on the hadroproduction of pairs of electroweak superpartners with an invariant mass M and a transverse momentum p_T. After a Mellin transform with respect to M^2/S_h, the differential cross section $\mathrm{d}^2\sigma/\mathrm{d}M^2\mathrm{d}p_T^2$ can be expressed, in conjugate N-space, as a product of the partonic cross section σ_{ab} with the densities $f_{a,b}$ of the partons a, b in the colliding hadrons,

$$M^2 \frac{\mathrm{d}^2\sigma}{\mathrm{d}M^2\mathrm{d}p_T^2}(N-1) = \sum_{ab} f_a(N,\mu_F^2) f_b(N,\mu_F^2) \sigma_{ab}(N, M^2, p_T^2, \mu_F^2, \mu_R^2) \ . \tag{1}$$

Under this form where factorization and renormalization scales μ_F and μ_R are explicitly indicated, we can resum to all orders in the strong coupling α_s the large logarithmic terms arising when p_T tends towards zero and/or close to the production threshold. In this case, the partonic cross section can be refactorized into a closed exponential form, respectively reading

$$\sigma_{ab}^{(\text{res.})}(N, M^2, \mu_F^2, \mu_R^2) = \mathcal{H}_{ab}(M^2, \mu_F^2, \mu_R^2) \exp\Big[\mathcal{G}_{ab}(N, M^2, \mu_F^2, \mu_R^2)\Big] \ , \tag{2}$$

$$\sigma_{ab}^{(\text{res.})}(N, M^2, p_T^2, \mu_F^2, \mu_R^2) = \int_0^\infty \mathrm{d}b \frac{b}{2}\ J_0(b p_T)\ \mathcal{H}_{ab}(M^2, \mu_F^2, \mu_R^2) \exp\Big[\mathcal{G}_{ab}(N, b, M^2, \mu_F^2, \mu_R^2)\Big] \ , \tag{3}$$

in the threshold (after integrating upon p_T) and small-p_T regime. The hard part of the cross section is described by the function $\mathcal{H}_{ab}$ whereas the Sudakov form factor $\mathcal{G}_{ab}$ embeds soft and collinear parton radiation and absorbs the large logarithms. Eq. (3) also contains an inverse Fourier transform, J_0 denoting the 0^{th}-order Bessel function, so that the singularities of the integrand have to be handled after deforming the integration contour into the complex plane [16].

Although the logarithmic contributions must be resummed when they are large, the full perturbative computation, only partially accounted for by resummation, is expected to be reliable otherwise. Therefore, the fixed order ($\sigma^{(\text{f.o.})}$) and resummed ($\sigma^{(\text{res.})}$) results have to be consistently combined by subtracting from their sum their overlap $\sigma^{(\text{exp.})}$,

$$\sigma_{ab} = \sigma_{ab}^{(\text{res.})} + \sigma_{ab}^{(\text{f.o.})} - \sigma_{ab}^{(\text{exp.})} \ . \tag{4}$$

Since both $\sigma^{(\text{res.})}$ and $\sigma^{(\text{exp.})}$ are computed in Mellin space, an inverse transform is in order. To handle the singularities arising at the level of the N-space cross section, the integration contour is distorted following the principal value procedure and minimal prescription [17,18].

The form of the quantities introduced above depends on the resummation regime. Transverse-momentum resummation deals with logarithms arising at small p_T, while threshold resummation takes care of those appearing close to the production threshold. Finally, joint resummation allows for resumming both types of logarithms simultaneously. We refer to the RESUMMINO manual and references therein for the relevant analytical expressions at the next-to-leading logarithmic (NLL) accuracy [19].

3 Gaugino pair production at the next-to-leading logarithmic accuracy

In Fig. 1, we address the production of an associated $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ pair at the LHC, for $\sqrt{S_h} = 14$ TeV. We adopt the LM9 benchmark scenario [20], where both gauginos have a mass of about 150 GeV whereas gluinos and squarks lie above 1 TeV, and employ the CTEQ6 parton densities [21]. On the left panel of the figure, we present spectra in the invariant mass of the gaugino pair. The LO results (dotted) are found to be considerably smaller than NLO predictions with or without

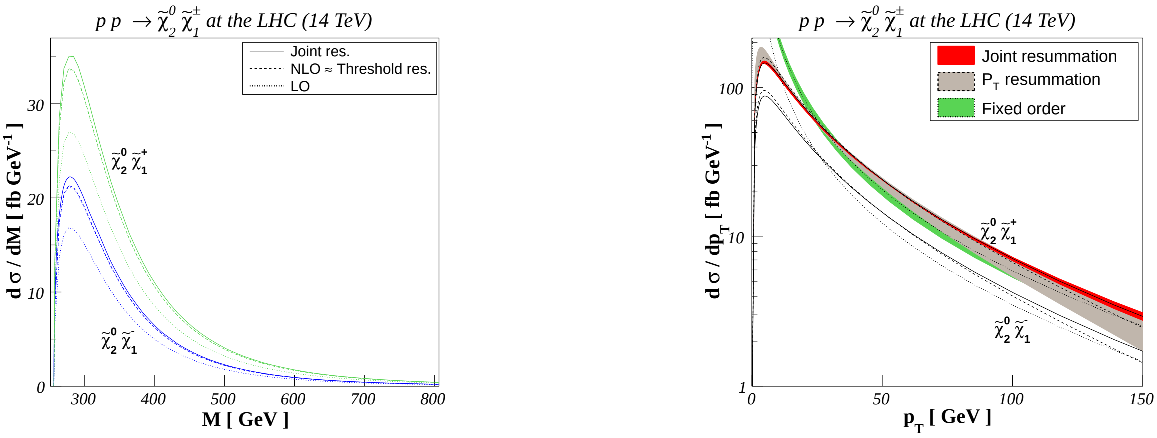

Figure 1: Invariant mass (left) and transverse-momentum (right) distributions of an associated $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ pair produced at the LHC, at fixed order and after matching to resummation. Scale uncertainties are indicated for the p_T spectra.

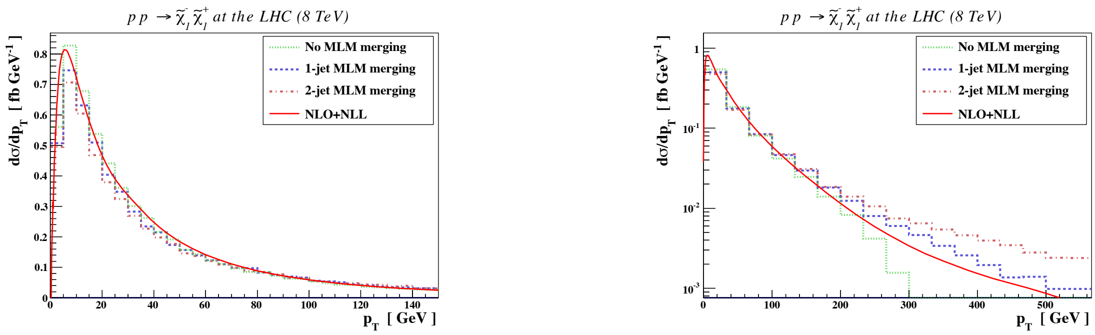

Figure 2: Distributions in the transverse momentum of a $\tilde{\chi}_1^+\tilde{\chi}_1^-$ pair produced at the LHC. We compare resummation results to several approaches by means of LO event generators including MLM merging techniques.

matching to NLL resummation. Since we restrict the distribution to the small invariant-mass region, far from the production threshold, threshold resummation does not lead to a significant effect with respect to NLO (dashed). In contrast, jointly resummed predictions (full) exceed the NLO ones due to the resummation of the large logarithms arising at small p_T.

On the right panel of Fig. 1, we show transverse-momentum spectra of the gaugino pair. While fixed-order predictions at $\mathcal{O}(\alpha_s)$ (dotted) diverge at small p_T due to uncanceled soft singularities from real gluon emission, resummed calculations exhibit a pronounced peak. For intermediate values of p_T, resummation effects are found to be still important with a K-factor greater than unity. We finally show that calculations using p_T (dashed) and joint (full) resummation agree with each other, although the scale uncertainty associated with the latter, estimated by varying both unphysical scales by a factor of two around the average mass of the two gauginos, is considerably smaller due to the resummation of threshold logarithms.

In Fig. 2, we focus on $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production at $\sqrt{S_h} = 8$ TeV and on the first SUSY scenario proposed by the LPCC [22]. It embeds sub-TeV squarks and gluinos and a lightest chargino of about 300 GeV. Using MadAnalysis 5 [23], we confront joint resummation (full) to predictions of the LO event generator MadGraph 5 [24], matched to Pythia 6 [25] for parton showering, the necessary UFO module [26] being exported from FeynRules [27,28,29,30,31]. We allow the generated events to contain zero (dotted), up to one (dashed) or up to two (dot-dashed) additional jets and merge them following the MLM merging scheme [32]. After normalizing the Monte Carlo results to the resummed prediction of 40.51 fb and employing the MSTW parton densities [33], we observe a very good agreement between all approaches in the small-p_T region. In contrast, in the large-p_T region, only Monte Carlo predictions including up to one extra parton agree with the resummed results, since both rely on the same matrix elements.

4 Summary

We have analyzed predictions for electroweak superpartner production at the LHC obtained by means of different resummation methods after a combination with NLO predictions. The results have been found to be more reliable and exhibit smaller uncertainties stemming from scale variation. A similar accuracy can be reached by means of LO Monte Carlo event generators after merging matrix elements possibly containing additional partons.

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