Soft gluon resummation for Drell-Yan and slepton-pair production at (N)NNLL in supersymmetry

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in collaboration with

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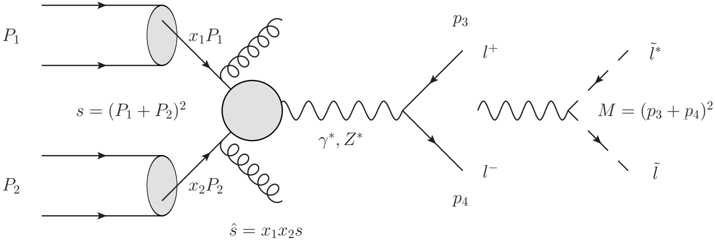
PLANCK 2011 **Lisbon, June 1, 2011**

Outline

Motivations

- The Drell-Yan lepton pair production is a very interesting process, (Altarelli, Ellis, Martinelli, 1979) which serve as a prototype for other collider processes, as well as a for number of relevant measurements. A precise prediction is welcome.
- Supersymmetry is one of the most well-motivated extension of the Standard Model. In this context, slepton pair production is an interesting process as well (Beenakker, Klasen, Krämer, Plehn, Spira, Zerwas, 1999), since sleptons are expected to be among the lightest supersymmetric particles.
- A possible signals would be a couple of highly energetic leptons plus missing energy.
- The calculation of the transverse-momentum spectrum can be used to determine the slepton masses.
- A precise calculation of the invariant mass require the resummation of threshold logs, (Bozzi, Fuks, Klasen, 2007) which we perform here in the context of effective field theory (Becher, Neubert, Xu, 2007) at (N)NNLL.

Kinematics and factorization at threshold



- In the limit $M^2/\hat{s} \equiv z \to 1$ one finds (Becher, Neubert, Xu, 2007)

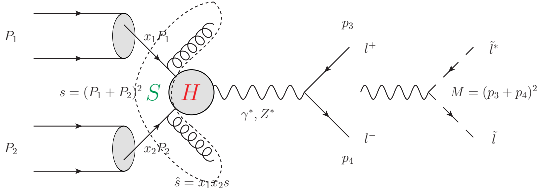
$$\frac{d\sigma^{\text{thresh}}}{dM^2} = \sigma_0 \sum_q \left[e_q^2 - \frac{1}{2} \frac{e_q (g_L^q + g_R^q)(g_L^l + g_R^l)}{1 - m_Z^2/M^2} + \frac{1}{4} \frac{({g_L^q}^2 + {g_R^q}^2)({g_L^l}^2 + {g_R^l}^2)}{(1 - m_Z^2/M^2)^2} \right] \int_\tau^1 \frac{dz}{z} C(z, M, \mu_f) \, ff(\tau/z, \mu_f),$$

where $\sigma_0 = \frac{4\pi\alpha_{EM}^2}{3N_c M^2 s}$ for leptons, $\sigma_0 = \frac{\pi\alpha_{EM}^2 \beta_{\tilde{l}}^3}{3N_c M^2 s}$ for sleptons, and

$$ff(y, \mu_f) = \int_y^1 \frac{dx}{x} \left[f_{q/N_1}(x, \mu_f) \, f_{\bar{q}/N_2}(y/x, \mu_f) + (q \leftrightarrow \bar{q}) \right]$$

defines the parton luminosity function.

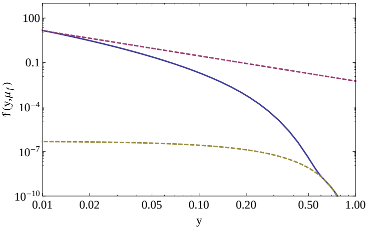
Kinematics and factorization at threshold

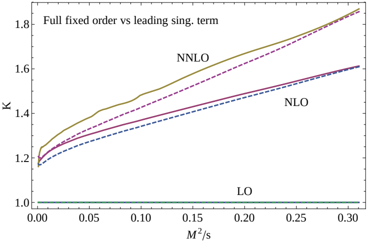


- Factorization theorem:

$$C(z,M,\mu_f) = H(M,\mu_f)\, S(\sqrt{\hat{s}}(1-z),\mu_f).$$

- In the limit $z\to 1$ a "dynamical" soft scale $\sqrt{\hat{s}}(1-z) \ll M$ arises, which give rise to large logs.
- Formally, this effect would be important only in the "true" threshold region $\tau = M^2/s \to 1 \le z$.
- The relevance of the threshold region $z\to 1$ is due to the steeply falling behavior of the parton luminosity function.





Factorization in SCET

- Within effective field theory the hard and the soft function are calculated as matching coefficients of operators defined in SCET. (Becher, Neubert, Xu, 2007)
- The resummation of threshold logs is accomplished by solving RG equations for these quantities. (Becher, Neubert, 2006)

$$C(z, M, \mu_f) \;=\; H(M, \mu_f)\, S(\sqrt{\hat{s}}(1-z), \mu_f)$$

$$\swarrow \qquad\qquad\qquad \searrow$$

$$= |C_V(-M^2, \mu_h)|^2 U(M, \mu_h, \mu_s, \mu_f) \frac{z^{-\eta}}{(1-z)^{1-2\eta}}\, \tilde{s}_{\rm DY}\left(\ln\frac{M^2(1-z)^2}{\mu_s^2 z} + \partial_\eta, \mu_s\right) \frac{e^{-2\gamma_E \eta}}{\Gamma(2\eta)}.$$

- We consider the following perturbative expansion for $C_V(-M^2)$:

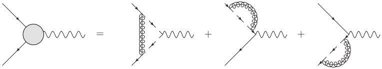
$$C_V(-M^2, \mu_h) = 1 + \frac{\alpha_s}{4\pi}\left(c^{(1)}_{V,\rm SM}(-M^2, \mu_h) + c^{(1)}_{V,\rm MSSM}(-M^2, m^2_{\tilde{q}}, m^2_{\tilde{g}})\right) + \left(\frac{\alpha_s}{4\pi}\right)^2 c^{(2)}_{V,\rm SM}(-M^2, \mu_h),$$

where

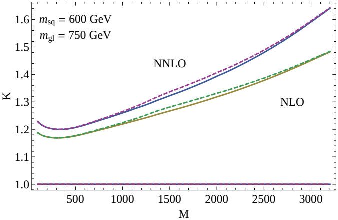
$$c^{(1)}_{V,\rm MSSM}(-M^2, m^2_{\tilde{q}}, m^2_{\tilde{g}}) = \frac{C_F}{M^2}\left[2(m^2_{\tilde{g}} - m^2_{\tilde{q}})\left(1 + B_0\left(M^2, m^2_{\tilde{q}}\right)\right) + 2m^2_{\tilde{g}} \ln\frac{m^2_{\tilde{g}}}{m^2_{\tilde{q}}} - 2C_0\left(M^2, m^2_{\tilde{q}}, m^2_{\tilde{g}}\right)\left(m^2_{\tilde{g}} - m^2_{\tilde{q}}\right)^2\right]$$

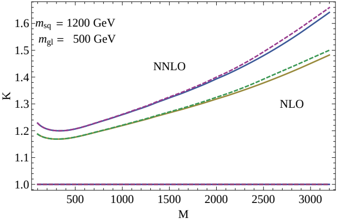
$$+ \quad C_F\left[\frac{5}{2} + \frac{m^2_{\tilde{g}}}{\left(m^2_{\tilde{q}} - m^2_{\tilde{g}}\right)} + \frac{m^4_{\tilde{g}}}{\left(m^2_{\tilde{q}} - m^2_{\tilde{g}}\right)^2} \ln\frac{m^2_{\tilde{g}}}{m^2_{\tilde{q}}} - 2m^2_{\tilde{g}} C_0\left(M^2, m^2_{\tilde{q}}, m^2_{\tilde{g}}\right) + B_0\left(M^2, m^2_{\tilde{q}}\right)\right].$$

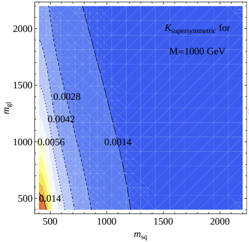
Fixed order result and supersymmetric contribution

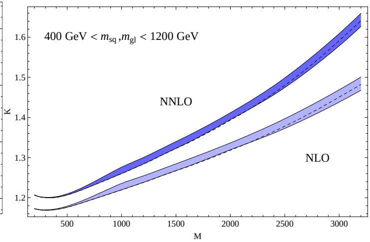


- The "pure" supersymmetric contribution to the Drell-Yan K factor is very small.



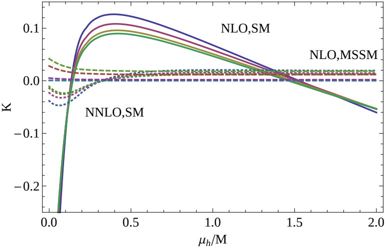


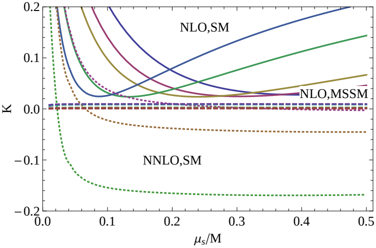


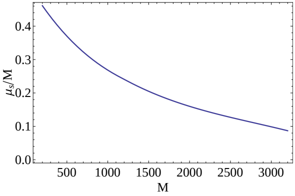


Choice of the matching scales

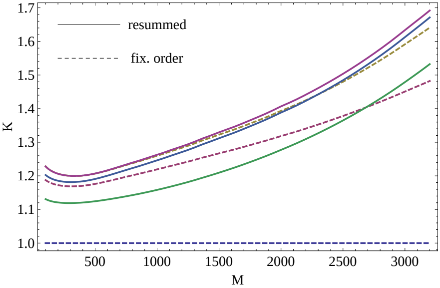
- Natural criterion: choose matching scales such that the Wilson coefficients (hard and soft function) can be calculated in fixed-order perturbation theory.
- The supersymmetric contribution has no influence on the choice of the matching scales.

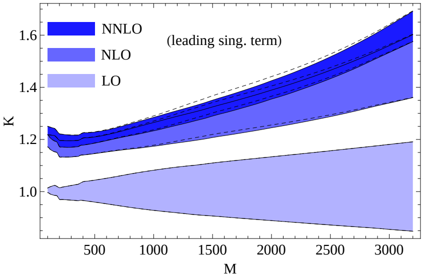


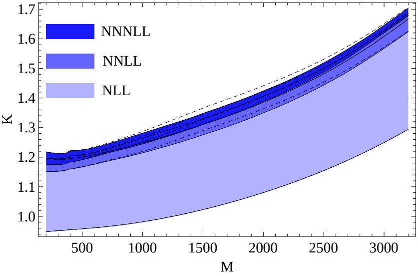




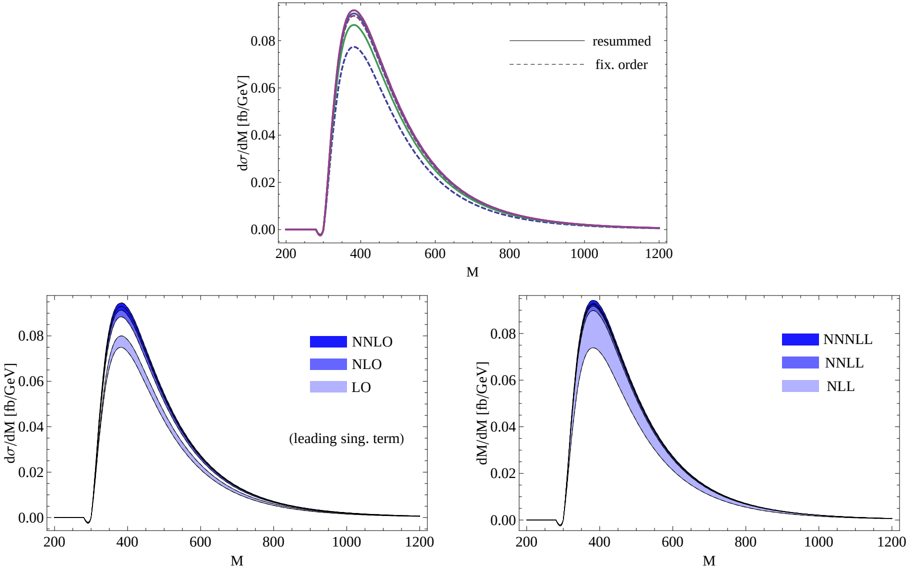
Fixed-order vs resummmed result: Drell-Yan K factor







Fixed-order vs resummmed result: slepton invariant mass



Total cross section for slepton pair production

RG-impr. PT	Log. approx	Γ_{cusp}	γ^V, γ^ϕ	C_V, $\tilde{s}_{\text{DY}}$
–	LL	1-loop	tree-level	tree-level
LO	NLL	2-loop	1-loop	tree-level
NLO	NNLL	3-loop	2-loop	1-loop
NNLO	NNNLL	4-loop	3-loop	2-loop

$$\sigma^{\text{matched}} = \sigma^{\text{thresh}}|_{\mu_h,\mu_s,\mu_f} + \left(\sigma^{\text{fixed order}}|_{\mu_f} - \sigma^{\text{thresh}}|_{\mu_h=\mu_s=\mu_f}\right).$$

MSSM point	σ_{LO}[fb]	$\sigma_{\text{NLO,fix}}$[fb]	$\sigma_{\text{NLO,match}}$[fb]
$m_{\tilde{q}}$=600 GeV, $m_{\tilde{g}}$=750 GeV, $m_{\tilde{l}}$=150 GeV	16.8	22.0	22.3
$m_{\tilde{q}}$=1200 GeV, $m_{\tilde{g}}$=500 GeV, $m_{\tilde{l}}$=150 GeV	16.8	22.0	22.3

Conclusion

- We calculated the Drell-Yan and slepton pair production in supersymmetry, resumming threshold soft gluons to (N)NNLL order in perturbation theory, by means of effective field theory methods.
- We have provided results for the (s)lepton pair invariant mass distribution and the total cross section.
- "Purely" supersymmetric corrections are very small, therefore difficult to observe in the Drell-Yan invariant mass distribution.
- The resummation improves the convergence of the perturbative expansion, while it has a small impact (few percent) on the slepton pair production total cross section.
- Resummation in the context of effective field theory allows to take easily into account higher order (logaritmic) effects and can be applied to more involved collider processes.