Soft gluon resummation for Slepton pair-production

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in collaboration with

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Outline

- Introduction
- Kinematics and factorization at threshold
- K factor, Invariant mass distribution, Total cross section
- Conclusions

Introduction

Drell-Yan

- important role in the description of **hard interactions in QCD** [Altarelli, Ellis, Martinelli 79']
- serves as **prototype** for other (Drell-Yan like) collider processes (production of new particles)

slepton pair production in the context of a **Supersymmetric** extension of SM

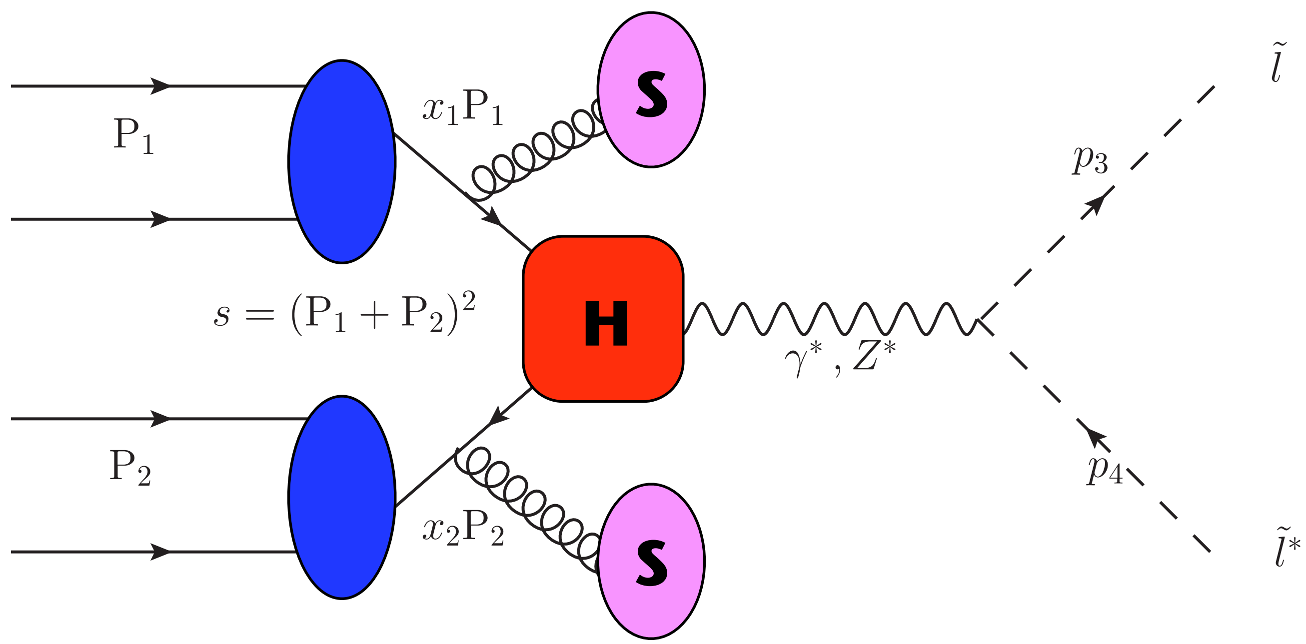
[Baer, Harris, Reno 97'; Beenakker, Klasen, Krämer, Plehn, Spira, Zerwas 99']

- sleptons expected to be among the lightest supersymmetric particles
- signal: energetic lepton pair + missing energy
- for a precise prediction, big threshold logarithms need to be resummed [Bozzi, Fuks, Klasen 07']. We perform resummation in the context of **effective field theory** [Becher, Neubert, Xu 07']

Kinematics at Threshold

Differential cross section as a function of:

$$\left\{ \quad z = \frac{M^2}{\hat{s}} \qquad \tau = \frac{M^2}{s} \qquad \beta_{\tilde{l}} = \sqrt{1 - \frac{4m_{\tilde{l}}^2}{M^2}} \qquad M^2 = (p3+p4)^2 \right.$$



In the Threshold Limit

$$z \longrightarrow 1$$

emitted gluons in the final state are **SOFT**

parton luminosity function

$$\frac{d\sigma^{\text{thresh}}}{dM^2} = \frac{\pi\alpha_{\text{em}}\beta_{\tilde{l}}^3}{9M^2 s}\sum_q\left[e_q^2 - \frac{e_q(g_L^q+g_R^q)(g_L^{\tilde{l}}+g_R^{\tilde{l}})}{1-m_Z^2/M^2} + \frac{(g_L^{q\,2}+g_R^{q\,2})(g_L^{\tilde{l}\,2}+g_R^{\tilde{l}\,2})}{2(1-m_Z^2/M^2)^2}\right]\int_\tau^1 \frac{dz}{z}\, C(z,M,m_{\tilde{g}},m_{\tilde{q}},\mu_f)\,\mathcal{L}(\tau/z,\mu_f)$$

hard - scattering kernel

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

$$C(z,M,m_{\tilde{g}},m_{\tilde{q}},\mu_f) = H(M,m_{\tilde{g}},m_{\tilde{q}},\mu_f)\,S(\sqrt{\hat{s}}(1-z),\mu_f) + \mathcal{O}(1-z)$$

Factorizes!

hard function: virtual corrections

soft function: real emission of soft gluons

Resummation in SCET

soft function contains plus distributions of the form

$$\alpha_s^n \left[\frac{\ln^m(1-z)}{1-z}\right]_+ \qquad m = 0, \ldots, 2n-1 \qquad \ln^m(1-z) \sim \ln^m\left(\frac{\mu_s}{\mu_h}\right)$$

Large Logs: need to be resummed

- Within effective field theory the hard and the soft function are calculated as matching coefficients of operators defined in SCET (Becher, Neubert, Xu, 07')

- The resummation of threshold logarithms arising in the z→1 region can be accomplished by **solving RG equations** for the hard and soft function

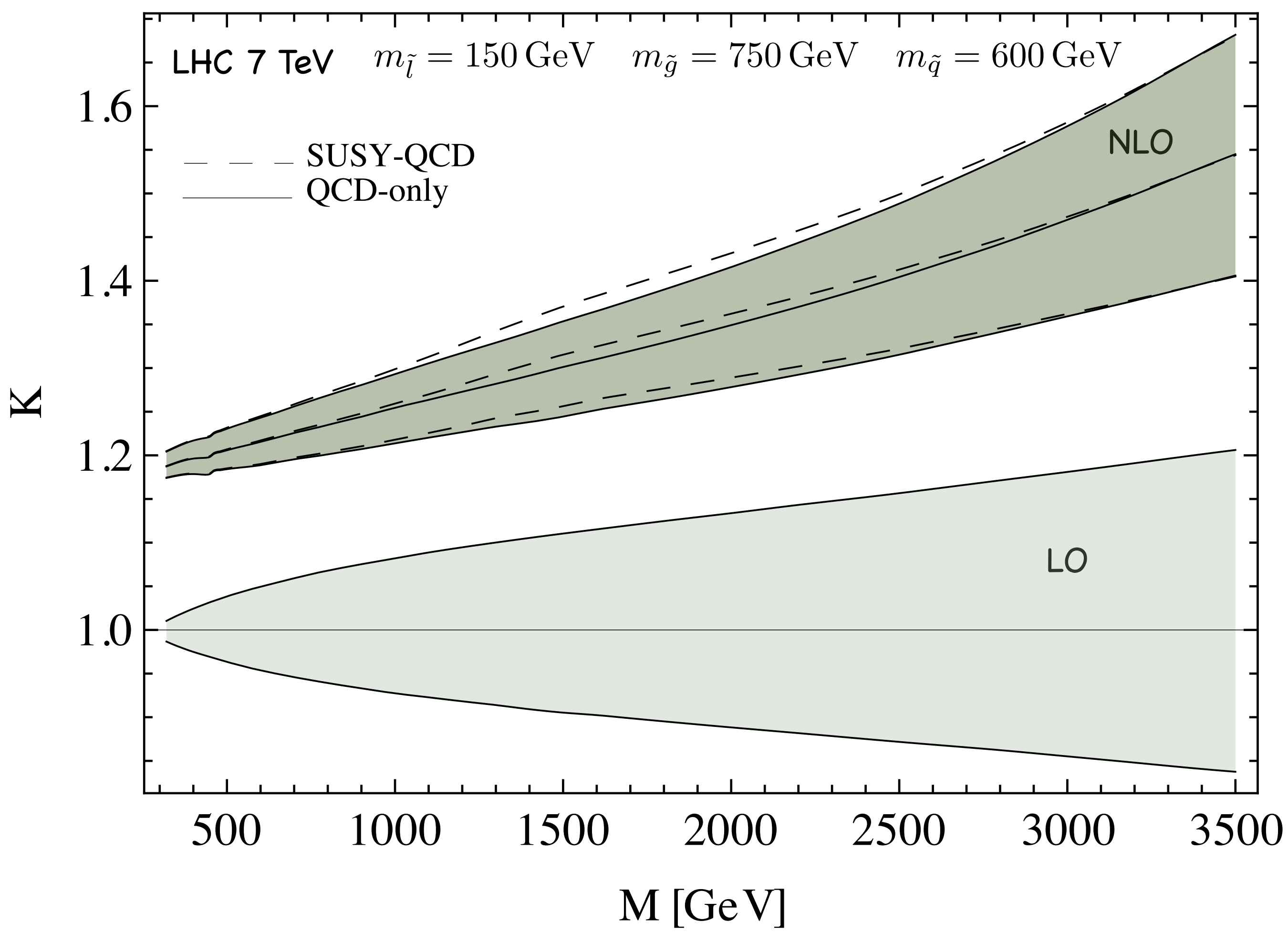
$$C(z, M, m_{\tilde{g}}, m_{\tilde{q}}, \mu_f) = |C_V(M^2, m_{\tilde{g}}, m_{\tilde{q}}, \mu_h)|^2 U(M, \mu_h, \mu_s, \mu_f) \frac{z^{-\eta}}{(1-z)^{1-2\eta}} \tilde{s}\left(\ln\frac{M^2(1-z)^2}{\mu_s^2 z} + \partial_\eta, \mu_s\right) \frac{e^{-2\gamma_E \eta}}{\Gamma(2\eta)}$$

Evolution function which evolves the soft μ_s and the hard μ_h scale to a common factorization scale μ_f

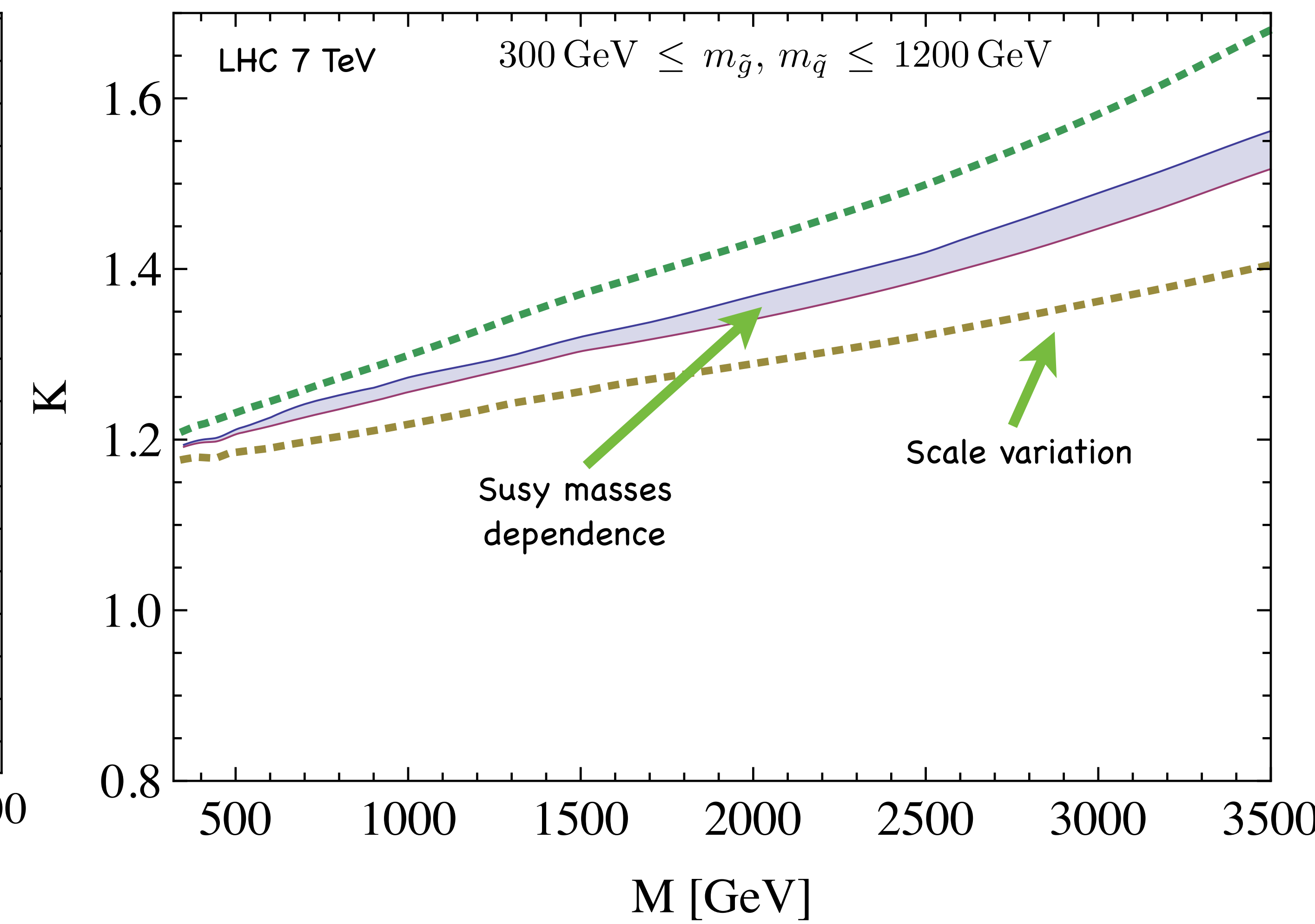
- The hard and the soft function in the resummed expression should be evaluated at their own characteristic scale

Fixed order result

- The "pure" virtual QCD and the "pure" SUSY-QCD contributions can be distinguished at one loop
- The **supersymmetric** contribution is **small** compared to QCD
- Susy virtual effects would never be appreciable in the lepton invariant mass distribution of the usual Drell-Yan

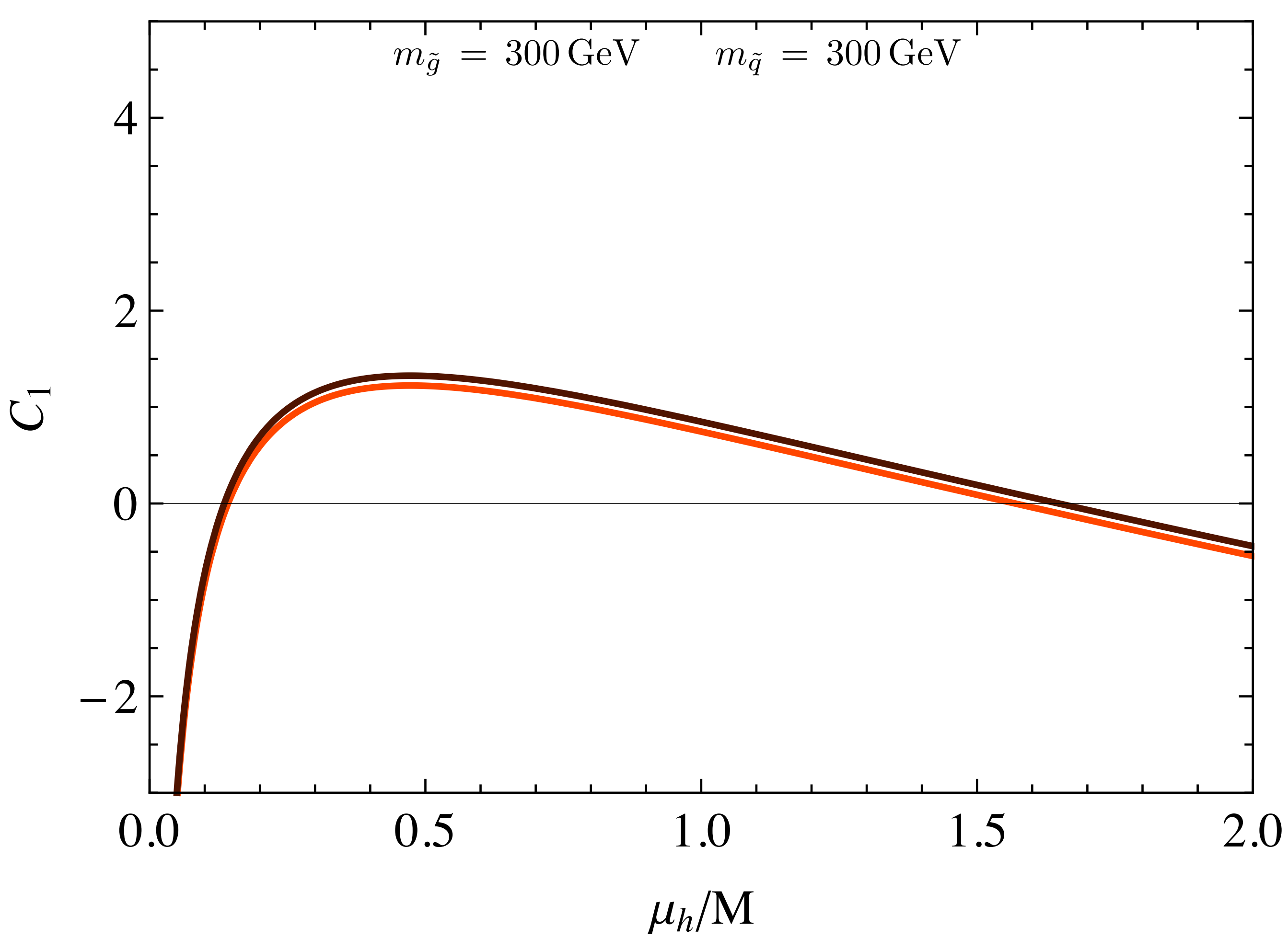


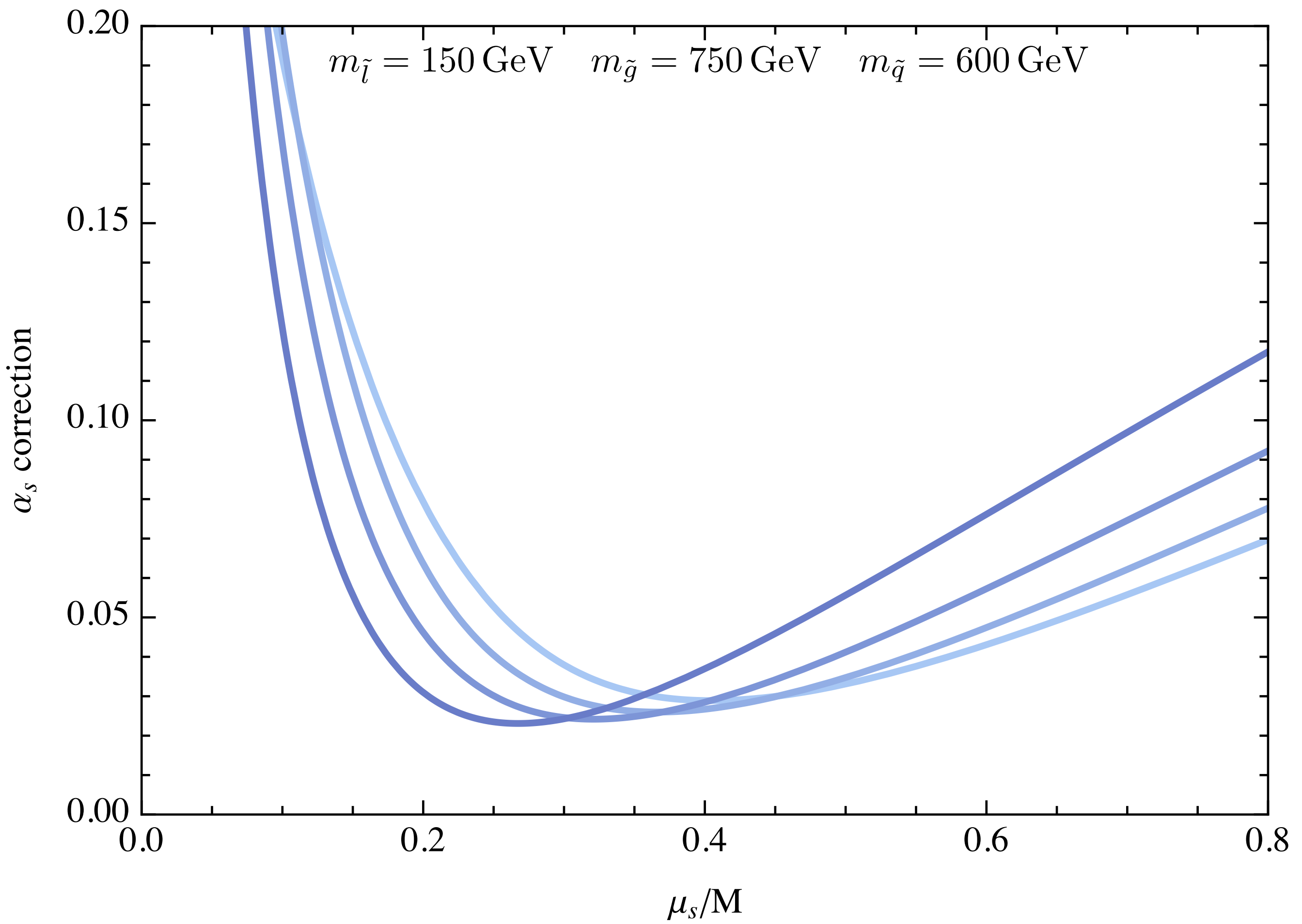
Total variation from susy virtual effects



Choice of the matching scales

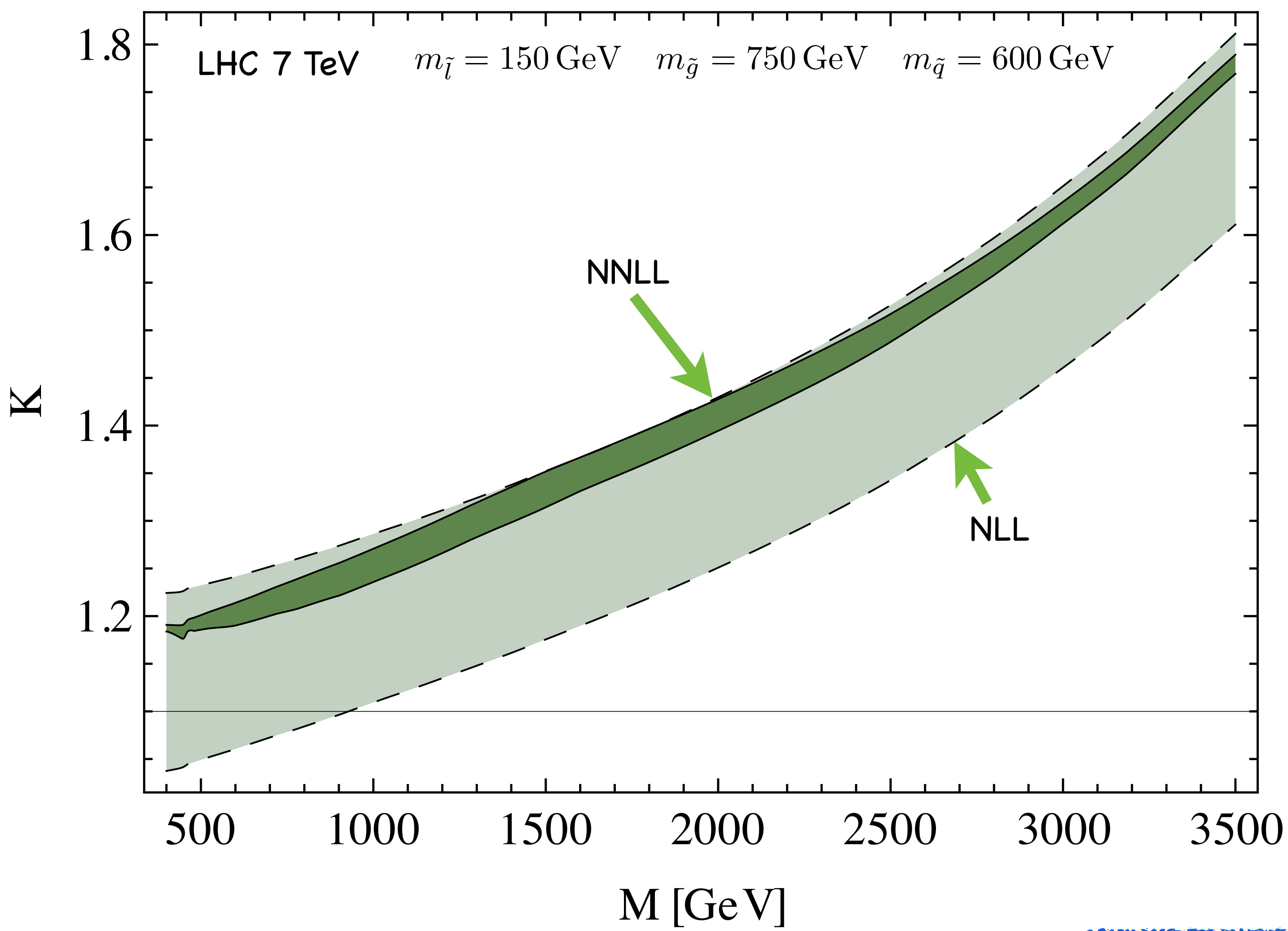
- The matching scales μ_h and μ_s should be chosen such that the the perturbative expansions of the Wilson coefficients are well behaved
- The hard matching scale should be chosen of order M
- The soft matching scale is a dynamic scale which depends on τ and M (it must be determined separately for each process)

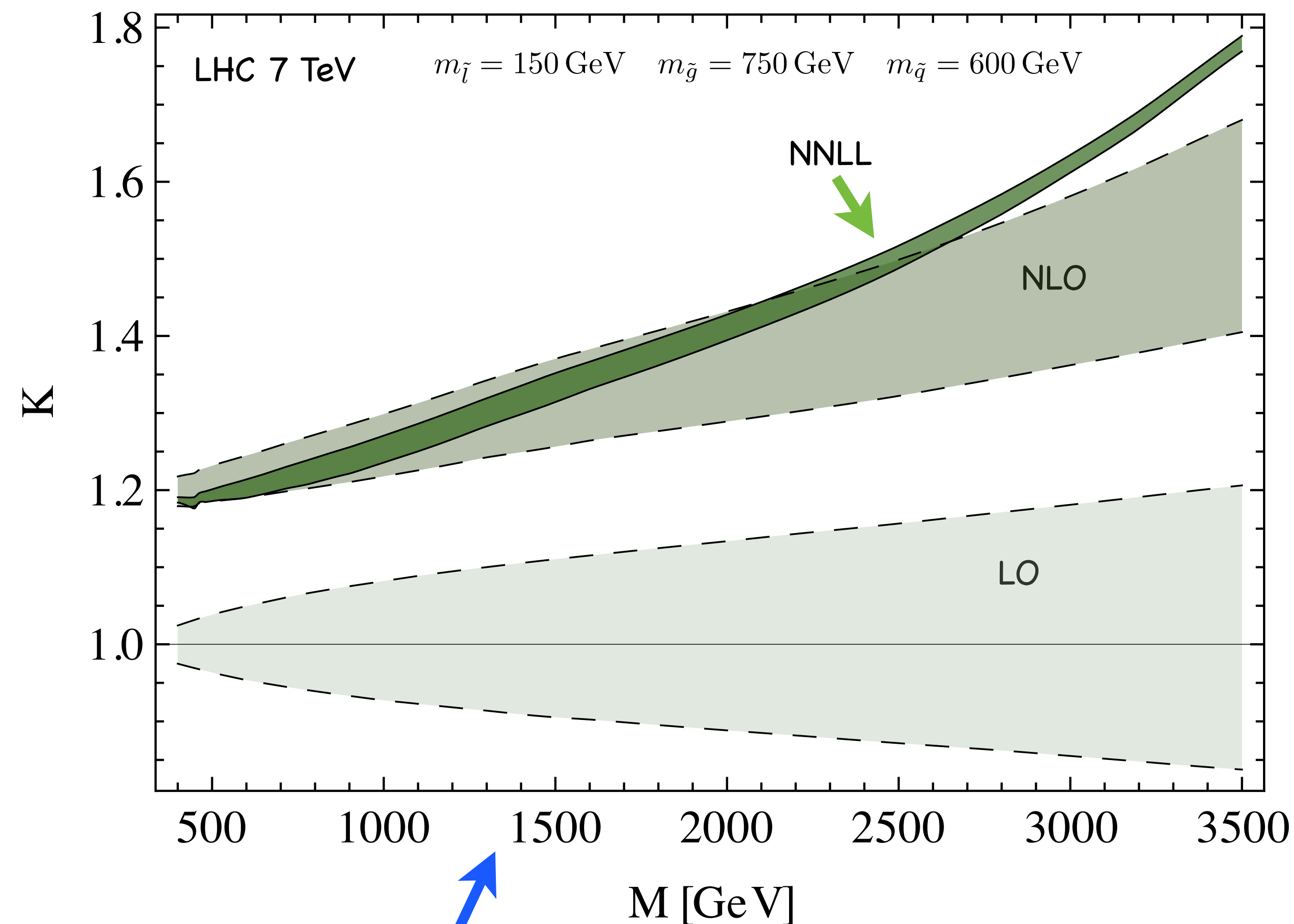




The supersymmetric contribution has no influence on the choice of the matching scales

K factor - NLO vs Resummed



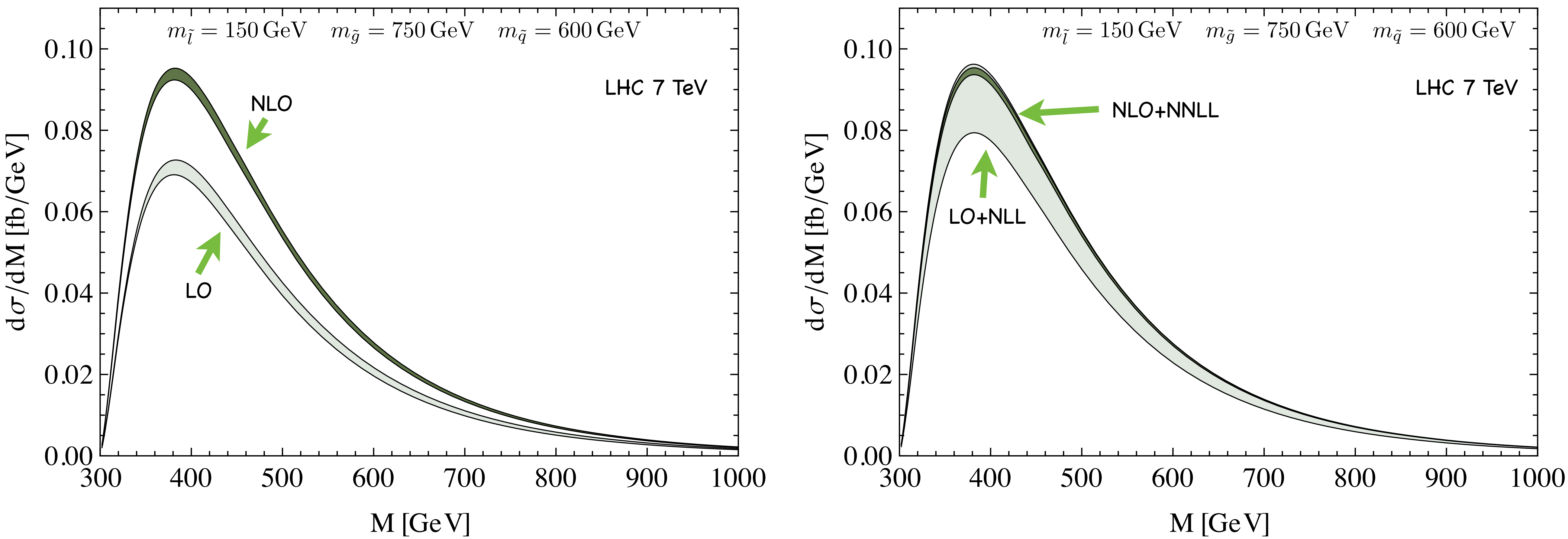


Reduced scale uncertainty!

Slepton pair invariant mass

$$d\sigma^{\rm NLO+NNLL} \equiv d\sigma^{\rm NNLL}\Big|_{\mu_h,\mu_s,\mu_f} + \left(d\sigma^{\rm NLO}\Big|_{\mu_f} - d\sigma^{\rm NNLL}\Big|_{\mu_h=\mu_s=\mu_f} \right)$$

Matching fixed order NLO and NNLL



Fixed Order

Matched

Total cross sections LHC 7 TeV

MSSM point: $m_{\tilde{l}} = 150\,\mathrm{GeV}$ $m_{\tilde{g}} = 750\,\mathrm{GeV}$ $m_{\tilde{q}} = 600\,\mathrm{GeV}$

Resummed and matched results with errors combined in quadrature

σ_{LO} [fb]	$16.90^{+0.63}_{-0.63}$
σ_{NLO} [fb]	$22.27^{+0.45}_{-0.38}$
σ_{NLL} [fb]	$20.18^{+2.61}_{-1.43}$
σ_{NNLL} [fb]	$22.00^{+0.18}_{-0.28}$
$\sigma_{\mathrm{NLO+NNLL}}$ [fb]	$\boxed{22.47^{+0.16}_{-0.26}}$

Preliminary!

MSTW 2008 pdf used, LO, NLO, NNLO

Conclusions

- We calculated Slepton pair production considering the susy virtual effects and resumming threshold soft gluons to NNLL accuracy by means of effective field theory methods

- "Purely" supersymmetric corrections are small, therefore difficult to observe in the Drell-Yan invariant mass distribution

- We provided the results for the slepton pair invariant mass distribution and the total cross section at NLO + NNLL accuracy

- Resummation stabilize the result by reducing the scale dependence of the cross sections. It has a small impact (few percent) on the total cross section

Factorization at threshold

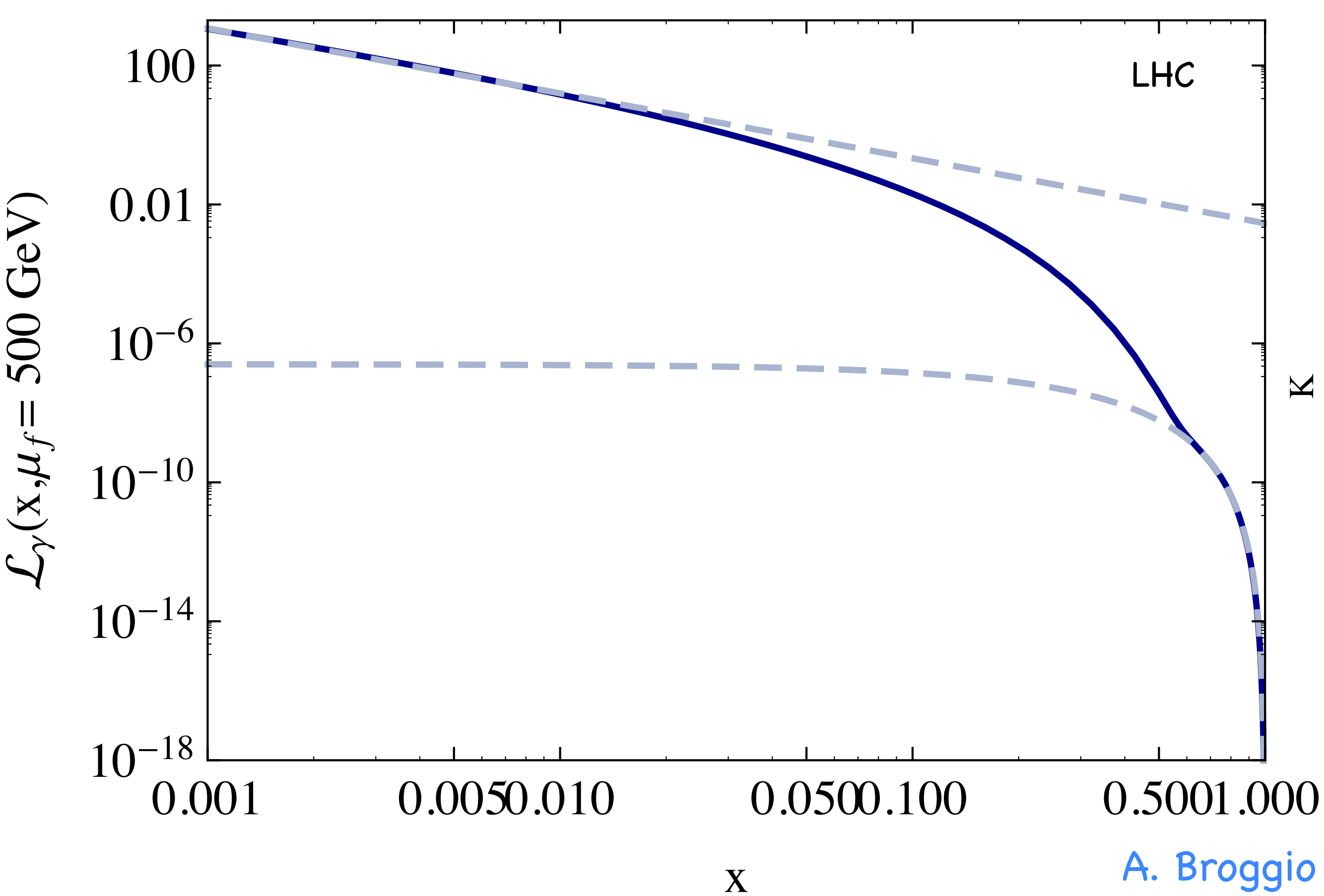
hard-scattering kernel factorizes:

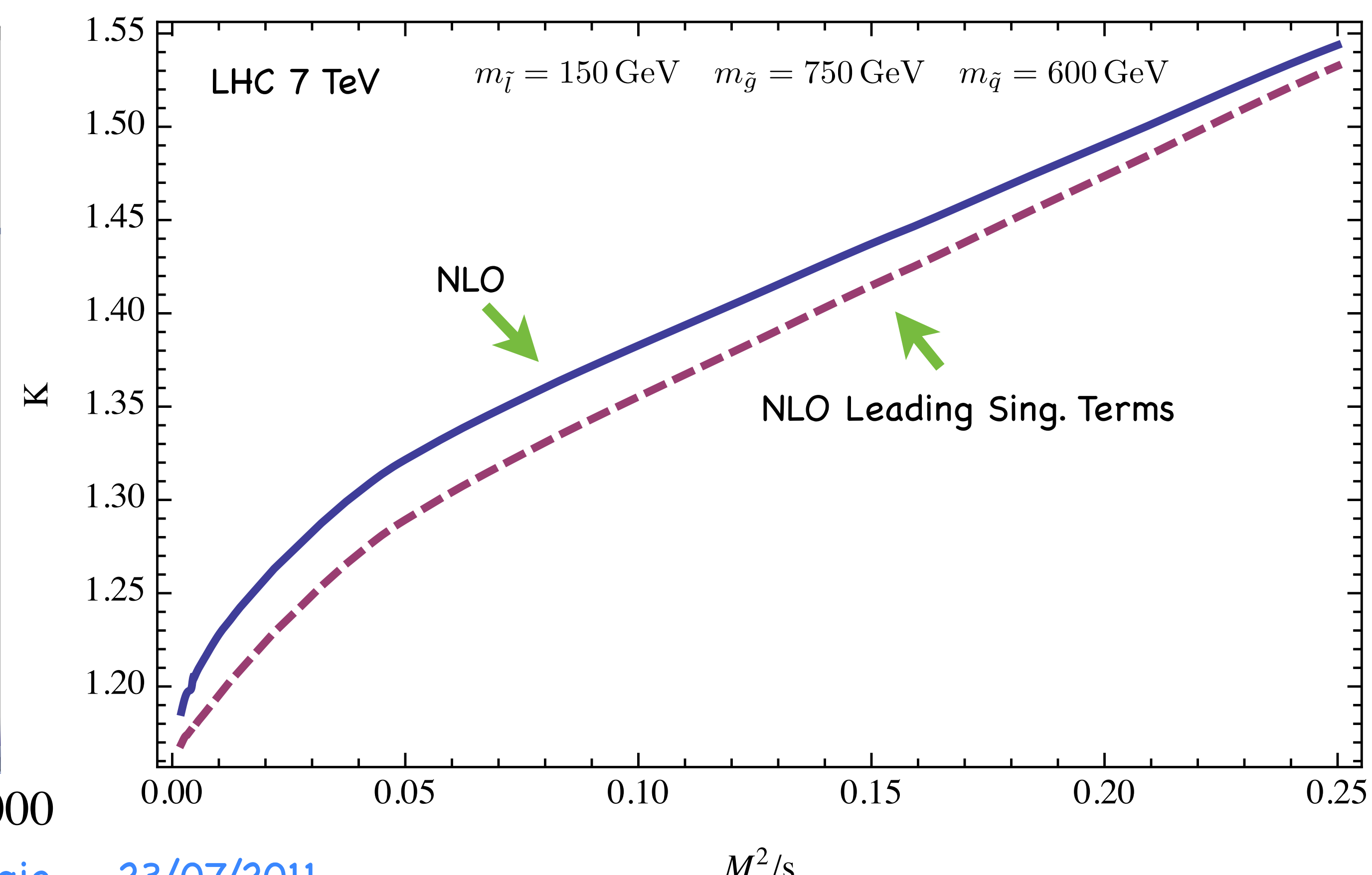
$$C(z, M, m_{\tilde{g}}, m_{\tilde{q}}, \mu_f) = H(M, m_{\tilde{g}}, m_{\tilde{q}}, \mu_f) S(\sqrt{\hat{s}}(1-z), \mu_f) + \mathcal{O}(1-z)$$

hard function: virtual corrections **soft function: real emission of soft gluons**

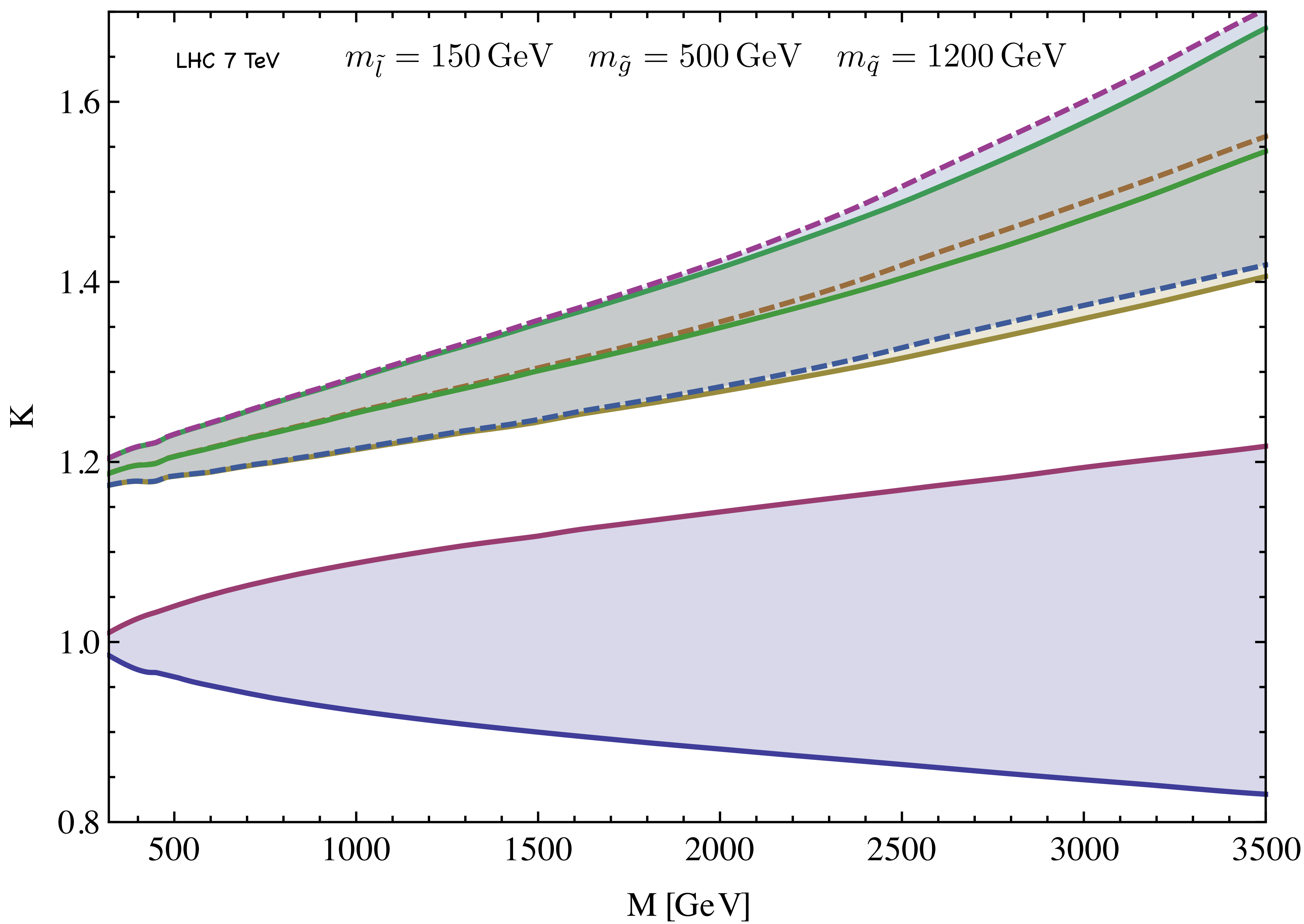
- **The threshold contributions are enhanced near the kinematic limit $\tau \sim 1$ and hence $z \geq \tau$ is near 1**

- **The relevance of the threshold region is due to the steeply falling behavior of the parton luminosity function**

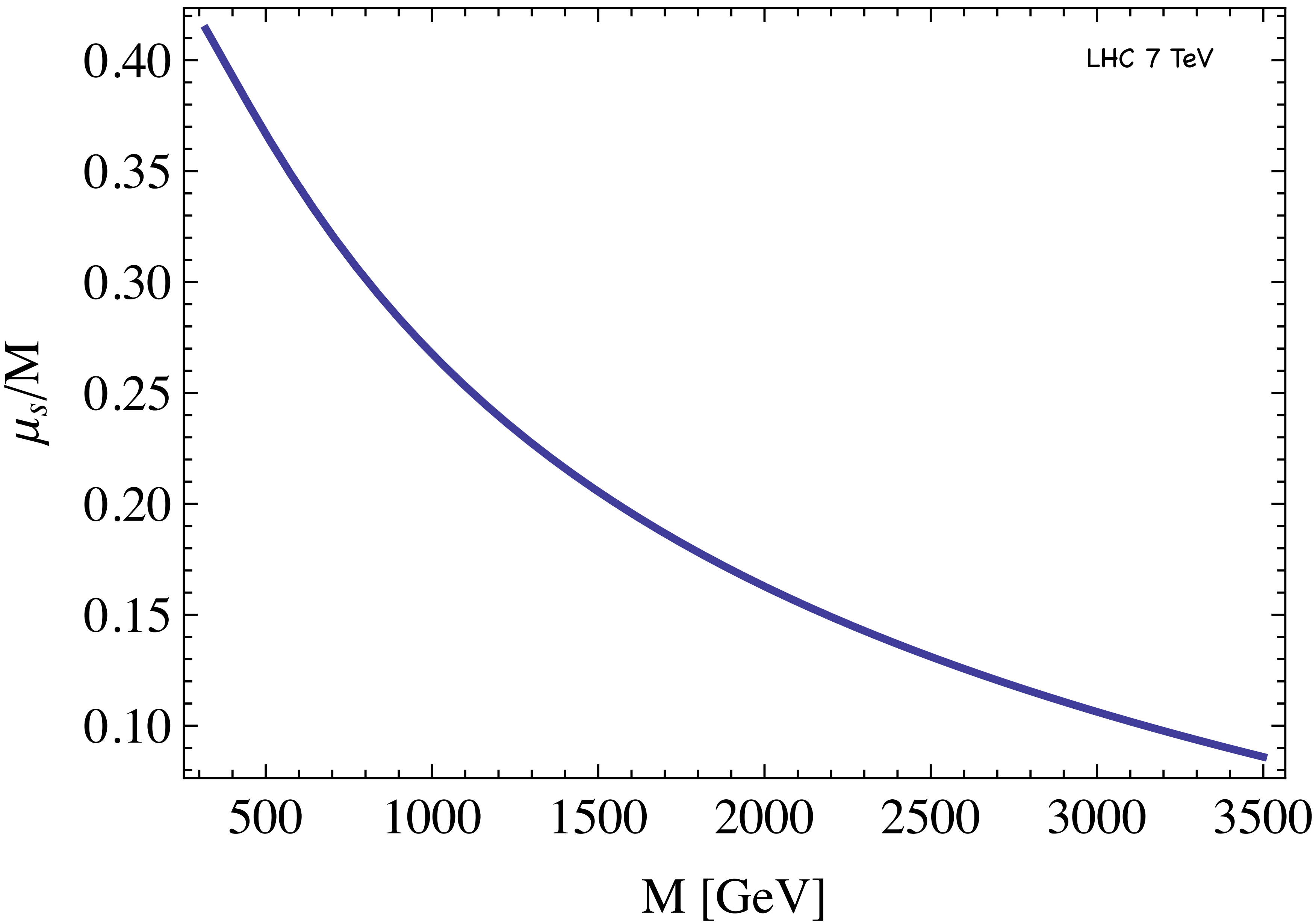




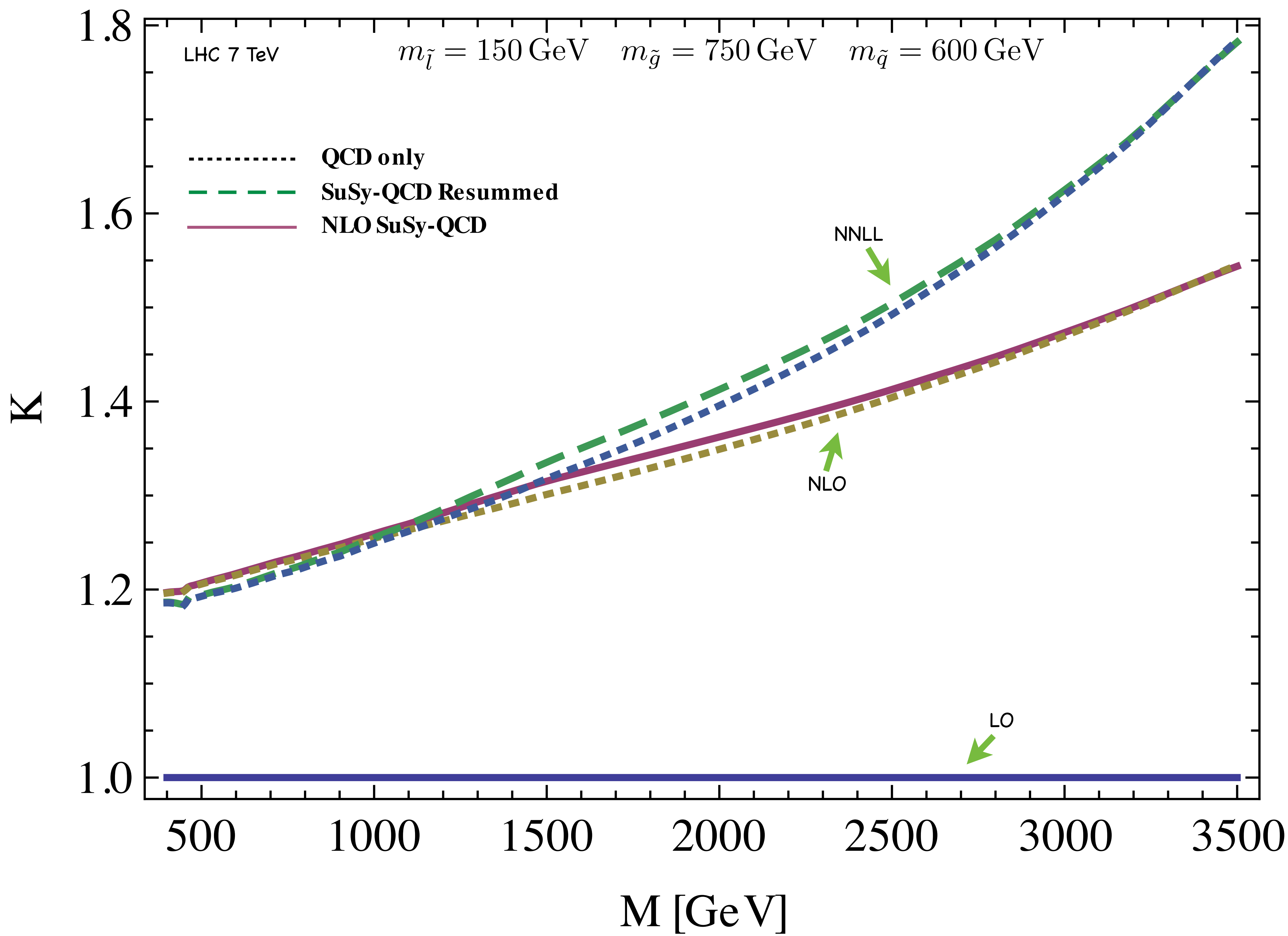
Different MSSM Benchmark Point



Soft scale


LHC 7 TeV
0.40
0.35
0.30
0.25
0.20
0.15
0.10
μ_s/M
500
1000
1500
2000
2500
3000
3500
M [GeV]

Resummation Effect



Log. accuracy table

(Becher, Neubert, Xu, 07')

RG-impr. PT	Log. approx.	Accuracy $\sim \alpha_s^n L^k$	Γ_{cusp}	γ^V, γ^ϕ	C_V, $\widetilde{s}_{\text{DY}}$
—	LL	$k = 2n$	1-loop	tree-level	tree-level
LO	NLL	$2n - 1 \le k \le 2n$	2-loop	1-loop	tree-level
NLO	NNLL	$2n - 3 \le k \le 2n$	3-loop	2-loop	1-loop
NNLO	NNNLL	$2n - 5 \le k \le 2n$	4-loop	3-loop	2-loop

for Sudakov problems the counting of logarithms is done in the exponent!

Logaritmic structure

(Chiu, Kelley, Manohar, 08')

$$
\mathsf{A} = \begin{pmatrix}
1 & & & & \\
\alpha \mathsf{L}^2 & \alpha \mathsf{L} & \alpha & & \\
\alpha^2 \mathsf{L}^4 & \alpha^2 \mathsf{L}^3 & \alpha^2 \mathsf{L}^2 & \alpha^2 \mathsf{L} & \alpha^2 \\
\alpha^3 \mathsf{L}^6 & & \ldots & & \\
\vdots & & & &
\end{pmatrix}
$$

Logaritmic structure of the scattering amplitude for Sudakov problems

Resummed Invariant Mass