Soft gluon resummation in SCET at hadron colliders

Leonardo Vernazza

Institute for Physics, Johannes Gutenberg University, Mainz

Based on :

A. Broggio, M. Neubert, LV, 1111.0864, 1111.6624
A. Broggio, A. Ferroglia M. Neubert, LV, L.-L.Yang, in progress

Southern Methodist University, Dallas, 02/13/2012

Outline

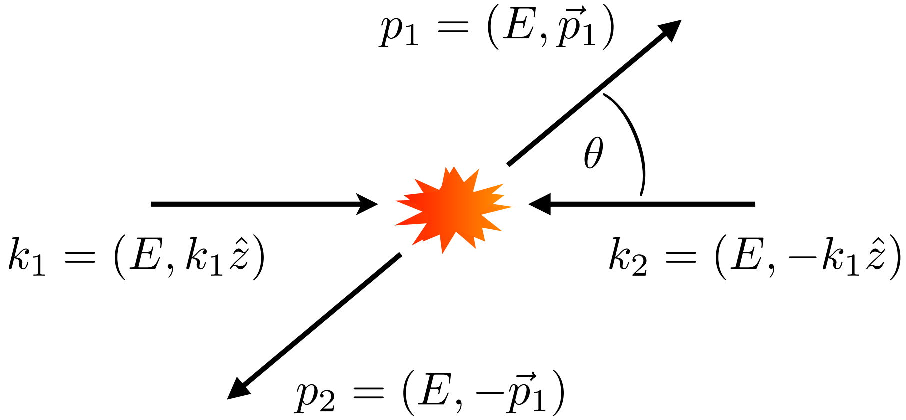
- Introduction: Collider processes, factorization and resummation in SCET
- Slepton pair production: invariant mass and total cross section
- Squark (stop) pair production: outline in SCET
- Conclusion

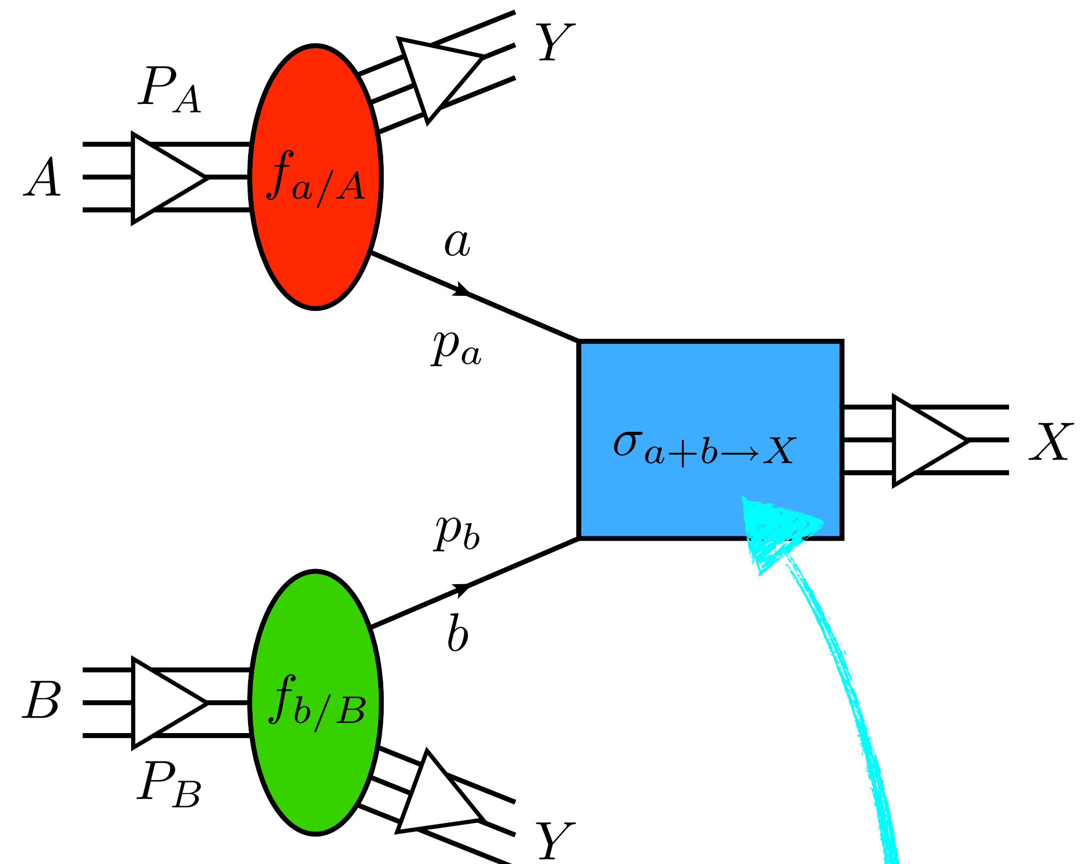
Basics of resummation in SCET

Processes at hadron colliders

- Collider processes characterized by many scales: $s,\ s_{ij},\ p_i^2,\ \Lambda_{\rm QCD},\ \dots$
- As a consequence, large Sudakov logarithms arise, which need to be resummed.
- Effective field theories provide a modern approach based on scale separation (factorization theorems) and RG evolution (resummation).

Processes at hadron colliders





where $p_1 = x_1 P_1$ $\quad p_2 = x_2 P_2$ $\quad \hat{s} = x_1 x_2 s$

$$d\sigma(P_1, P_2) = \sum_{i,j} \int dx_1 dx_2 \, f_i(x_1, \mu) \, f_j(x_2, \mu) \, d\hat{\sigma}(p_1, p_2, \alpha_s(\mu), Q)$$

(Courtesy of A. Broggio)

Basics of resummation

- $d\sigma$ has large double logs from real emission in the soft limit $\lambda \to 0$
- Defining $L \equiv \log\lambda \sim 1/\alpha_s$, $d\sigma$ has perturbative expansion

$$d\sigma \sim \overbrace{\underbrace{1+\alpha_s(L^2+L+1+O(\lambda))}_{\text{NLO}}+\alpha_s^2(L^4+L^3+L^2+L+1+O(\lambda))}^{\text{approx. NNLO}}+O(\alpha_s^3)$$

$$\sim \exp(\underbrace{\underbrace{L^2\alpha_s+L\alpha_s}_{\text{NLL}}+L\alpha_s^2}_{\text{NNLL}}+\ldots)+O(\lambda)$$

- Resummation exponentiates large logs
- One can consider different soft limits:

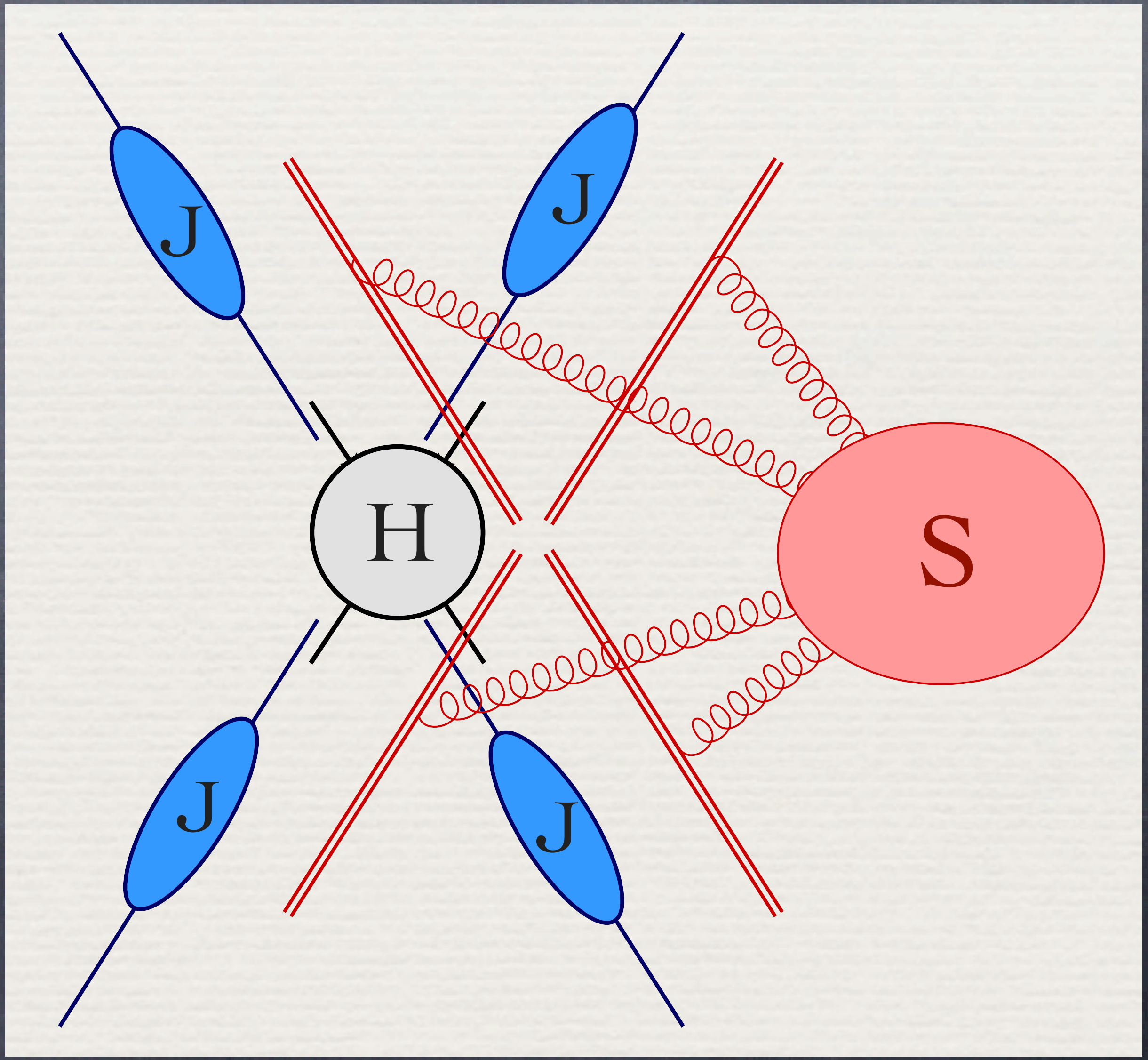
	Observable	Soft limit
Production Threshold	σ	$\beta=\sqrt{1-4m^2/\hat{s}}\to 0$
Single-particle-inclusive	$d\sigma/dp_{\mathrm{T}}$	$s_4=(p_4+k)^2-m^2\to 0$
Pair-invariant-mass	$d\sigma/dM$	$(1-z)=1-M^2/\hat{s}\to 0$

Soft-collinear factorization

Sen 1983; Kidonakis, Oderda, Sterman 1998

- Physics occurring at different scales factorizes into different objects:

$$d\sigma \sim H(\{s_{ij},\mu\})\prod_i J_i(p_i^2,\mu)\otimes S(\{\Lambda_{ij}^2,\mu\})$$



- Define components in term of field theory objects in SCET
- Resum large logs in momentum space using RG equations

Soft-collinear effective field theory (SCET)

- Two step matching procedure:
  - Integrate out hard modes, describe collinear and soft modes by fields in SCET;
  - Integrate out collinear modes and match into a theory of Wilson lines.
- The anomalous dimension for the hard function is known:

$$
\begin{aligned}
\Gamma(\{p\},\{p\},\mu) = {} & \sum_{(i,j)} \frac{\mathbf{T}_i \cdot \mathbf{T}_j}{2} \gamma_{\text{cusp}}(\alpha_s) \ln \frac{\mu^2}{-s_{ij}} + \sum_i \gamma^i(\alpha_s) \\
& - \sum_{(I,J)} \frac{\mathbf{T}_I \cdot \mathbf{T}_J}{2} \gamma_{\text{cusp}}(\beta_{IJ}, \alpha_s) + \sum_I \gamma^I(\alpha_s) \sum_{(I,j)} \frac{\mathbf{T}_I \cdot \mathbf{T}_j}{2} \gamma_{\text{cusp}}(\alpha_s) \ln \frac{m_I \mu}{-s_{Ij}} \\
& + \sum_{(I,J,K)} i f^{abc} \mathbf{T}_I^a \mathbf{T}_I^b \mathbf{T}_I^c \, F_1(\beta_{IJ}, \beta_{JK}, \beta_{KI}) \\
& + \sum_{(I,J,K)} i f^{abc} \mathbf{T}_I^a \mathbf{T}_I^b \mathbf{T}_I^c \, f_2\!\left(\beta_{IJ}, \ln \frac{-\sigma_{Jk} v_J \cdot p_k}{-\sigma_{Ik} v_I \cdot p_k}\right) + O(\alpha_s^3).
\end{aligned}
$$

SM, s_{ij}, hard

$\downarrow$

SCET, p_i^2, collinear

$\downarrow$

Wilson lines, Λ_{ij}^2, soft

Literature

- Soft gluon resummation has been applied to various processes in the Standard model:

- Drell-Yan and deep inelastic scattering,

  Becher, Neubert, Pecjak, 2007
  and Becher, Neubert, Xu, 2007

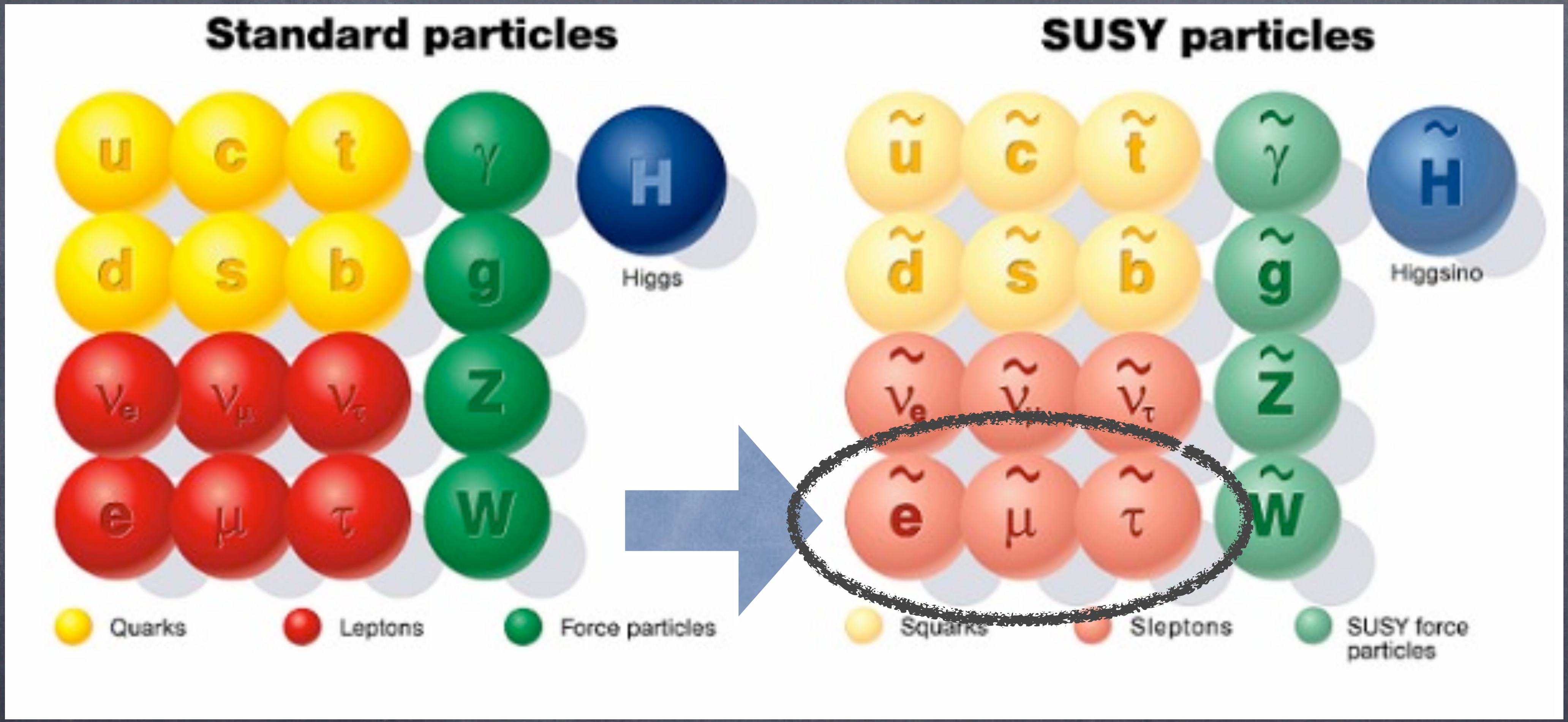
- Higgs production, Ahrens, Becher, Neubert, Yang, 2008

- Top pair production

  Ahrens, Ferroglia, Neubert, Pecjak, Yang, 2009,2010,2011
  Beneke, Falgari, Klein, Schwinn, 2010, 2011

- We are interested to apply it to the production of supersymmetric particles.

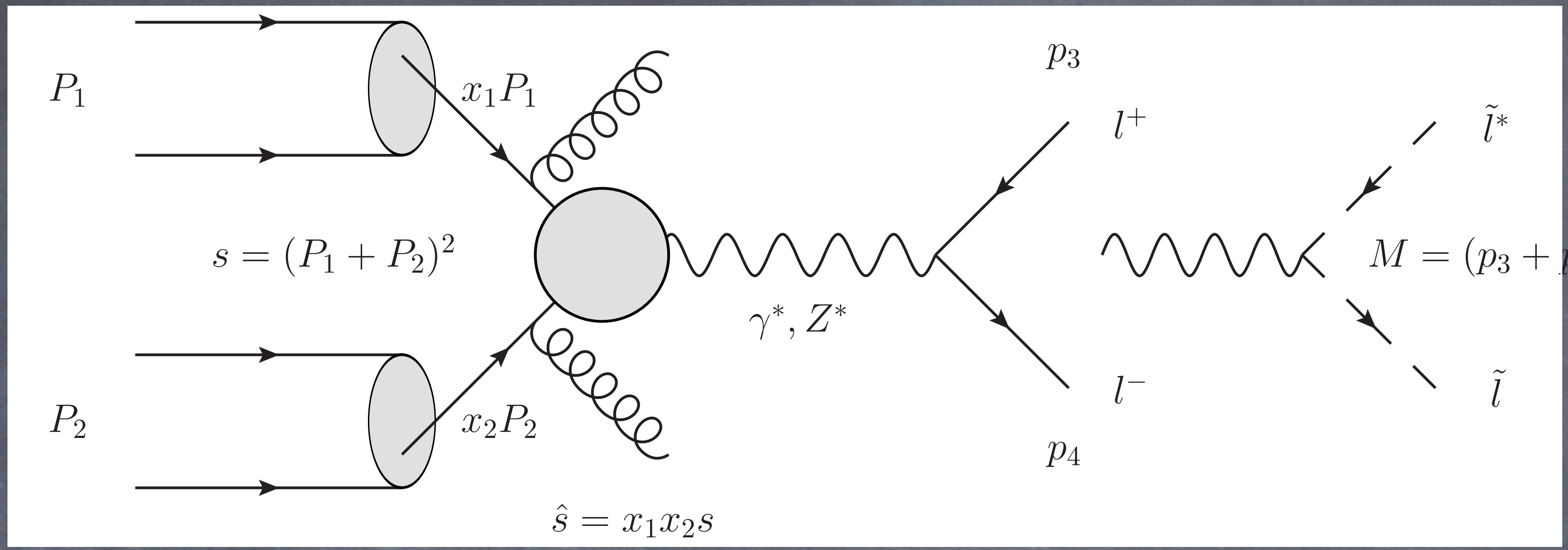
Drell-Yan type processes in supersymmetry: slepton pair production



Slepton pair production

- Drell-Yan type processes are the simplest example where to apply resummation: only two partons are involved.
- Slepton pair production has a small cross section, but a simple signature: a couple of energetic leptons plus missing energy.
- Slepton are expected to be among the ligthest supersimmetric particles.
- Threshold soft gluon resummation has been performed at NLO+NLL. (Bozzi, Fuks, Klasen 2007). We improve it in SCET obtaining the invariant mass spectrum at NLO +NNNLL.

Kinematics and factorization at threshold



- In the limit $M^2 / \hat{s} \equiv z \to 1$ the invariant mass spectrum reads (Becher, Neubert, Xu 2007) $(\tau = M^2 / s)$

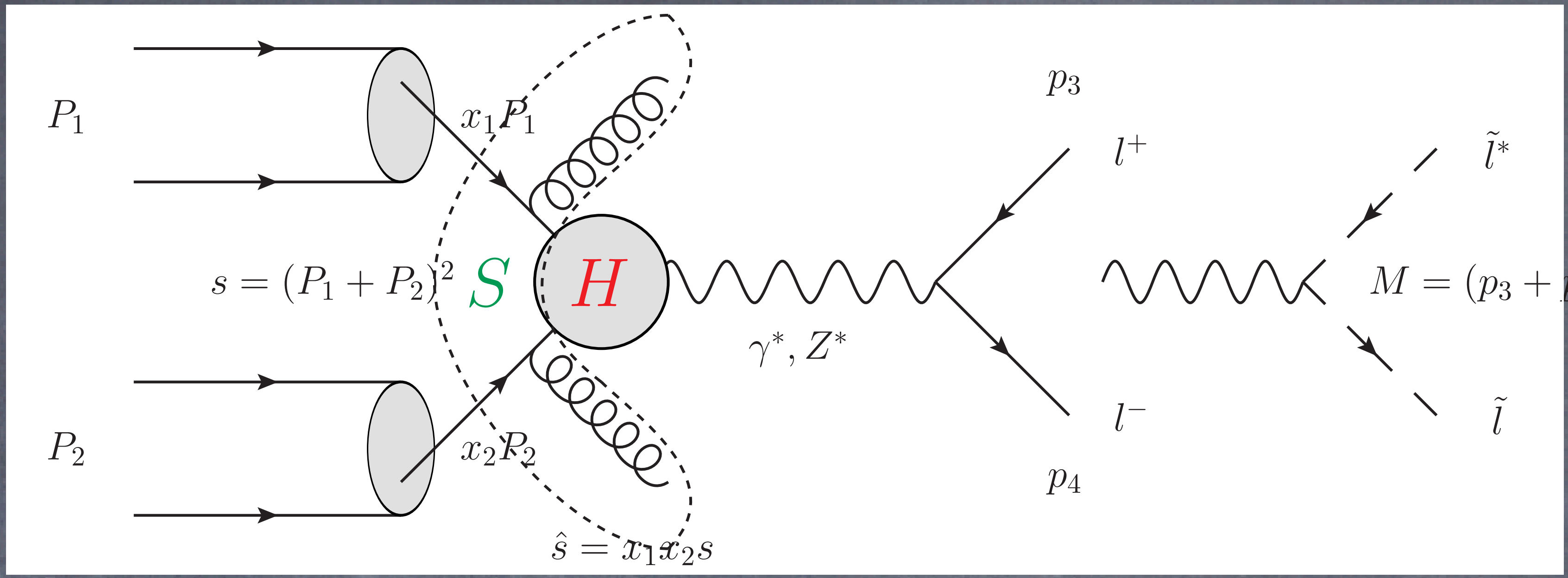
$$\frac{d\sigma^{\text{thresh}}}{dM^2} = \frac{\pi\alpha^2 \beta_{\tilde{l}}^3}{3N_c M^2 s} \sum_q \left[e_q^2 - \frac{e_q (g_L^q + g_R^q) g^{\tilde{l},Z}}{1 - m_Z^2 / M^2} + \frac{1}{2} \frac{((g_L^q)^2 + (g_R^q)^2)(g^{\tilde{l},Z})^2}{\left(1 - m_Z^2 / M^2\right)^2} \right]$$

$$\times \int_\tau^1 \frac{dz}{z} C(z, M, m_{\tilde{q}}, m_{\tilde{g}}, \mu_f) ff(\tau / z, \mu_f),$$

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

  defines the parton luminosity function

Kinematics and factorization at threshold



- $C(z,M,m_{\tilde{q}},m_{\tilde{g}},\mu_f)$ contains large Sudakov logs due to real emission, in the limit in which it becomes soft, $M^2/\hat{s} \equiv z \to 1$

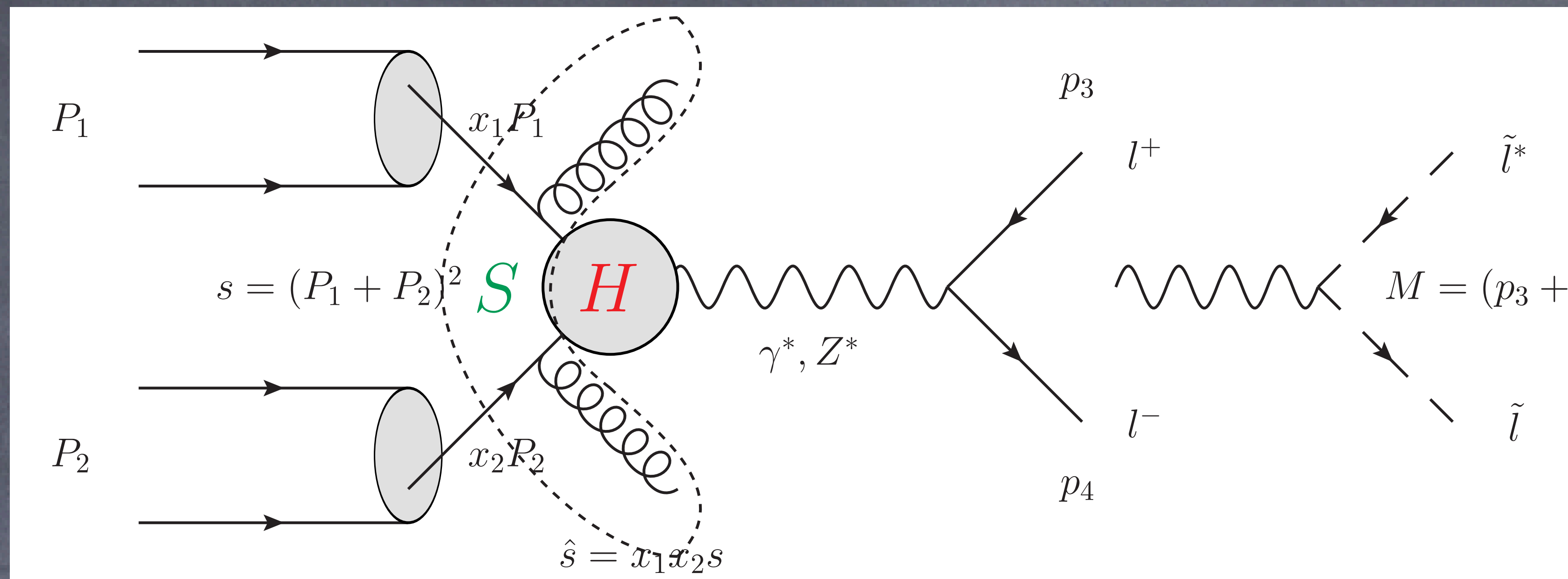
$$C(z,M,m_{\tilde{q}},m_{\tilde{g}},\mu_f)|_{\mathrm{SM}} = \delta(1-z)$$

$$+\frac{C_F\alpha_s}{\pi}\left\{\delta(1-z)\left(\frac{3}{2}\ln\frac{M^2}{\mu_f^2}+\frac{2\pi^2}{3}-4\right)+2\left[\frac{1}{1-z}\ln\frac{M^2(1-z)^2}{\mu_f^2 z}\right]_+\right\}+O(\alpha_s^2)$$

"hard scale" $M \sim \mu_h$ $\qquad$ $M(1-z) \sim \mu_s$ "soft scale"

- In the soft limit, the contribution propotional to 1/(1-z) gives the dominant contribution to the cross section ("leading singular terms")

Kinematics and factorization at threshold



- $C(z, M, m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)$ factorizes into two terms, which can be computed by means of soft collinear effective field theory:

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

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

hard function

RG evolution

soft function

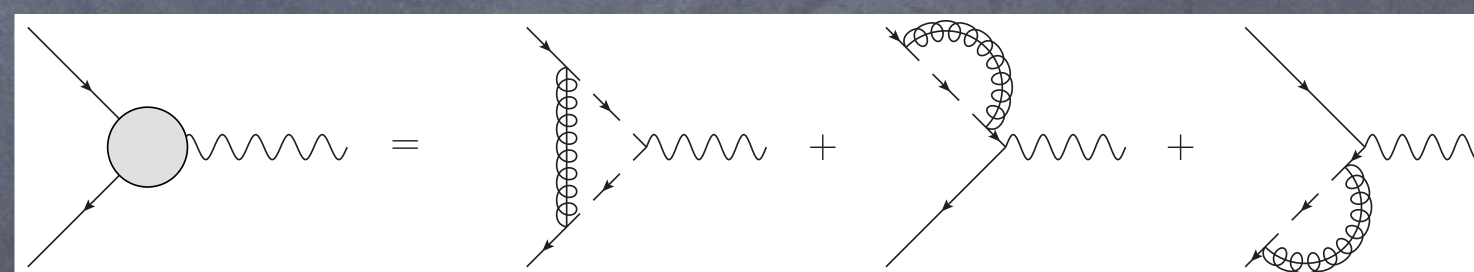
- The soft scale arise dinamically upon integration over z, when $z \to 1$

Hard function

- $C_V(-M^2, m_{\tilde q}, m_{\tilde g}, \mu_h)$ is calculated in perturbation theory, it reads

$$C_V(-M^2, m_{\tilde q}, m_{\tilde g}, \mu_h) = 1 + \frac{\alpha_s}{4\pi}\left[c_V^{(1)}(-M^2,\mu_h) + c_{V,\mathrm{SUSY}}^{(1)}(-M^2, m_{\tilde q}^2, m_{\tilde g}^2)\right]$$
$$+\left(\frac{\alpha_s}{4\pi}\right)^2\left[c_V^{(2)}(-M^2,\mu_h) + c_{V,\mathrm{SUSY}}^{(2)}(-M^2, m_{\tilde q}^2, m_{\tilde g}^2, \mu_h)\right]$$

- The supersimmetric part follows from calculating



- and reads

$$c_{V,\mathrm{SUSY}}^{(1)} = C_F\left\{\frac{5}{2} - \frac{m_{\tilde g}^2}{m_{\tilde g}^2 - m_{\tilde q}^2} + \frac{2(m_{\tilde g}^2 - m_{\tilde q}^2)}{M^2} + \left[\frac{m_{\tilde g}^4}{\left(m_{\tilde g}^2 - m_{\tilde q}^2\right)^2} + \frac{2m_{\tilde g}^2}{M^2}\right]\ln\frac{m_{\tilde g}^2}{m_{\tilde q}^2}\right.$$
$$\left. - \left[1 + \frac{2(m_{\tilde g}^2 - m_{\tilde q}^2)}{M^2}\right] f_B(M^2, m_{\tilde q}^2) + 2\left[\frac{m_{\tilde g}^2}{M^2} + \frac{\left(m_{\tilde g}^2 - m_{\tilde q}^2\right)^2}{M^4}\right] f_C(M^2, m_{\tilde q}^2, m_{\tilde g}^2)\right\}.$$

- The RG evolution of $C_V(-M^2, m_{\tilde q}, m_{\tilde g}, \mu_h)$ is known:

$$\frac{d}{d\ln\mu} C_V(-M^2, m_{\tilde q}, m_{\tilde g}, \mu_h) = \left[\Gamma_{\mathrm{cusp}}(\alpha_s)\left(\frac{M^2}{\mu^2} - i\pi\right) + \gamma^V(\alpha_s)\right] C_V(-M^2, m_{\tilde q}, m_{\tilde g}, \mu_h)$$

Soft function

- After integrating out the hard modes, the theory is described by collinear and soft field in SCET.

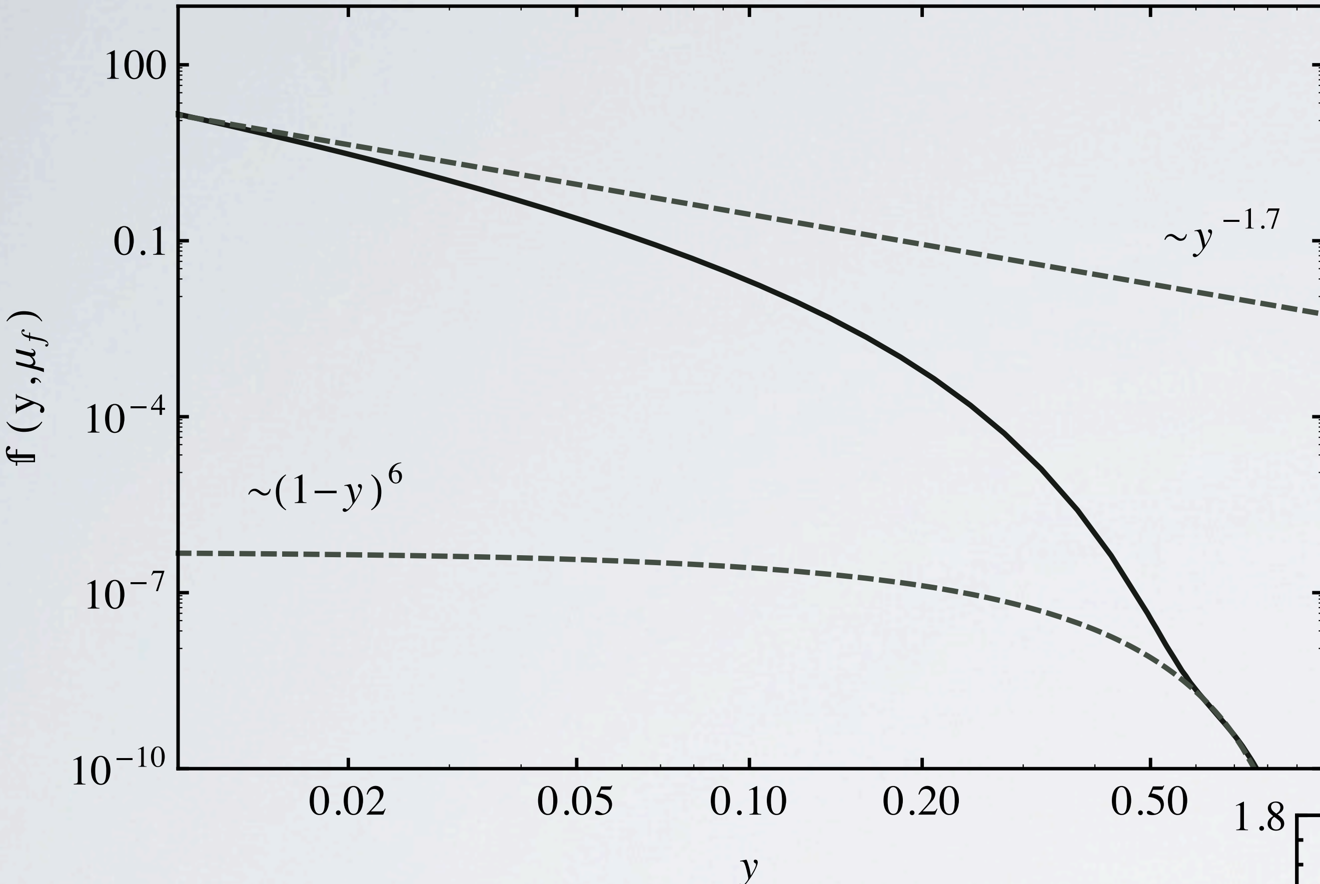
- At leading power, only the $n_i \cdot A_s$ component of the soft-gluon field interacts with the collinear fields. These "iconal" interactions can be described by means of Wilson lines, along the light-cone directions n_i :

$$S_n(x) = \mathbf{P}\exp\left(ig\int_{-\infty}^{0} ds\, n \cdot A_s(x+sn)\right)$$

- The soft function in case of Drell-Yan-type processes reads

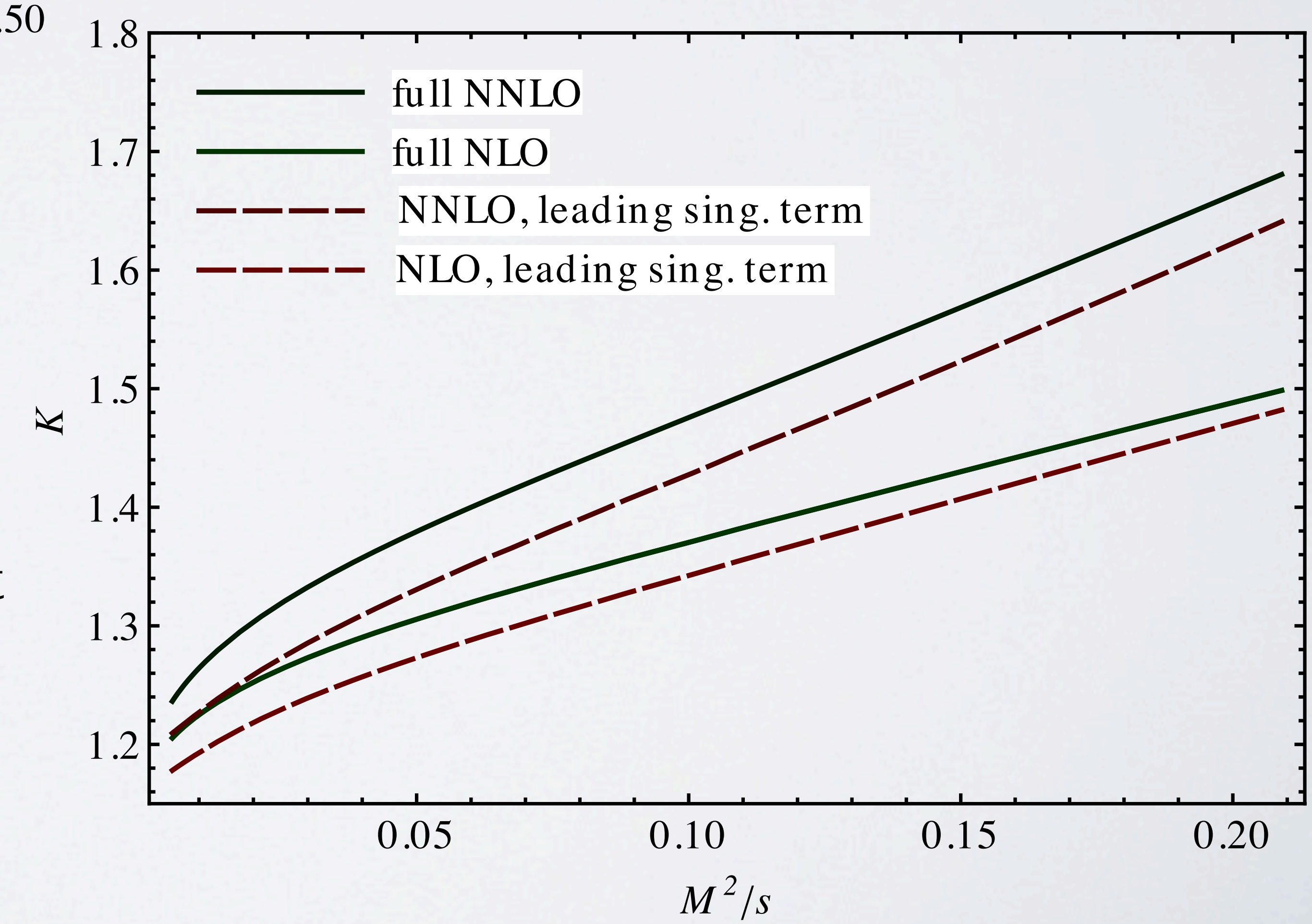
$$S(\sqrt{\hat{s}}(1-z),\mu_f) = \sqrt{\hat{s}}\int \frac{dx^0}{2\pi} e^{i\sqrt{\hat{s}}(1-z)x^0/2} \frac{1}{N_c}$$
$$\times \langle 0|\,\mathrm{Tr}\,\overline{\mathbf{T}}\left[S_n^\dagger(x^0,\vec{x}=0)S_{\bar{n}}(x^0,\vec{x}=0)\right]\mathbf{T}\left[S_{\bar{n}}^\dagger(0)S_n(0)\right]|0\rangle$$

SYSTEMATIC STUDIES: LEADING SINGULAR TERMS AND PARTON LUMINOSITY FALL-OFF



- How is the partonic threshold region parametrically enhanced?
- When the invariant mass of the slepton pair reach the hadronic center of mass region,

$$z \geq M^2 / s \equiv \tau \to 1,$$

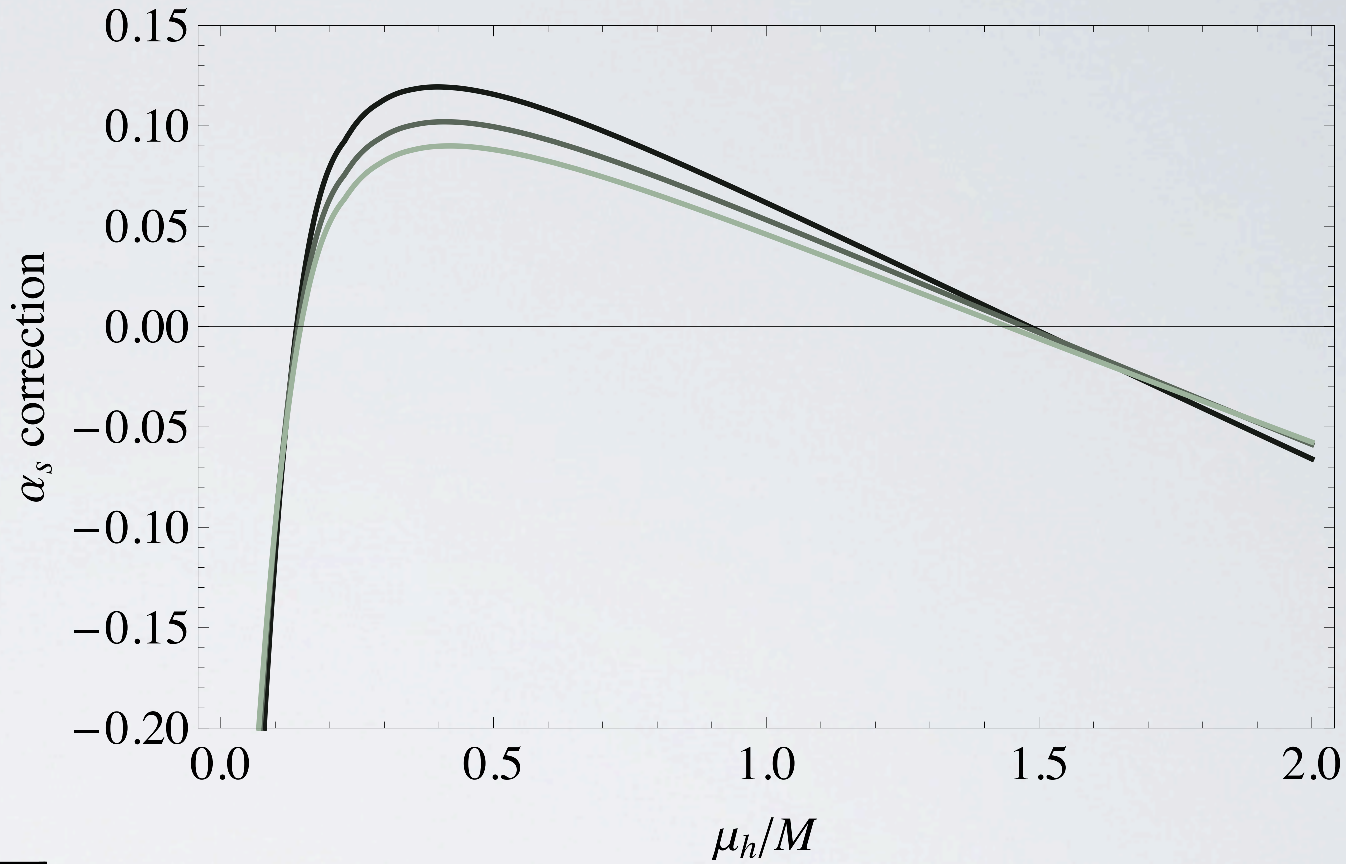


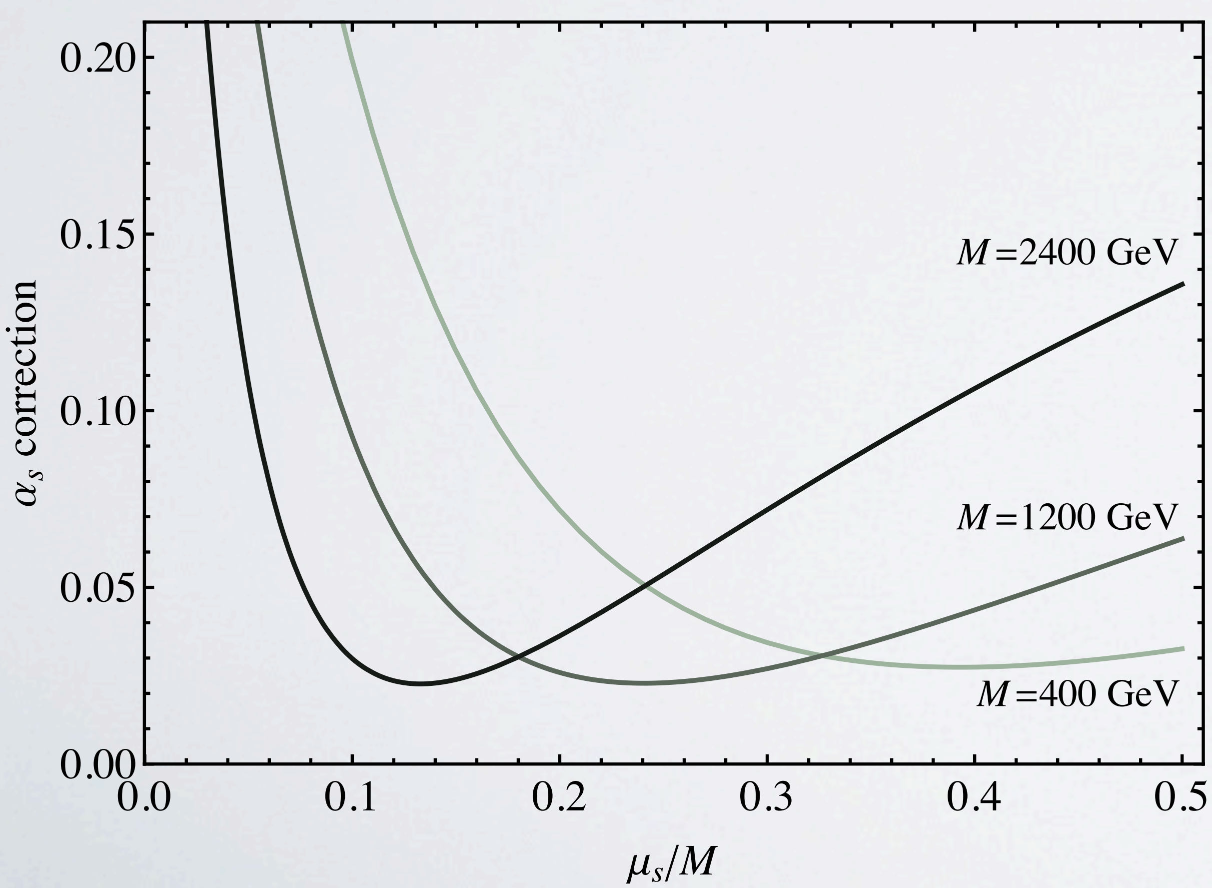
- Dynamically, if the parton luminosity function multiplying the hard scattering kernes is steeply falling with $1-z$.
- One find that this is indeed the case, and the leading singular terms indeed account for around 95% of the total invariant mass.

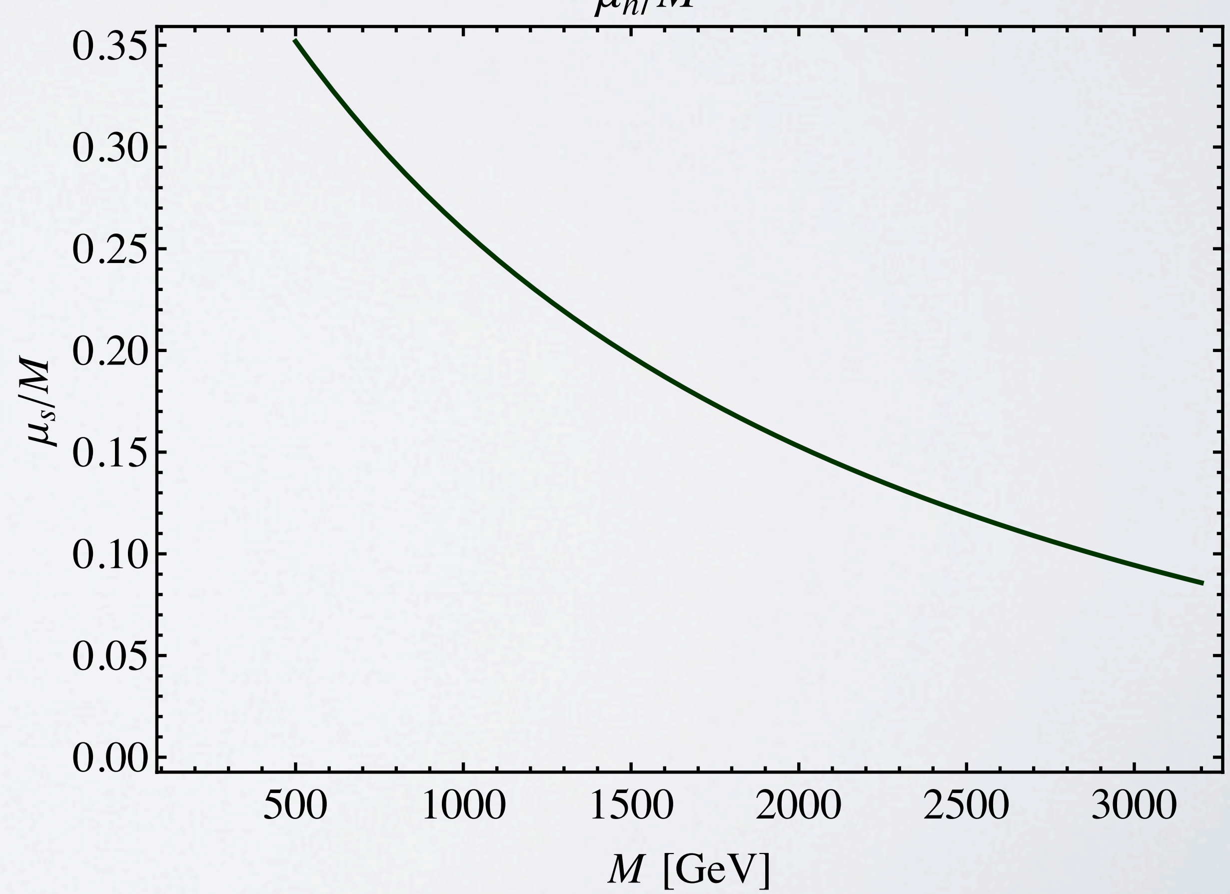
SISTEMATIC STUDIES: SCALE DEPENDENCE

- Natural criterion: choose matching scales such that the Wilson coefficients (hard and soft function) can be calculated in fixed-order perturbation theory.

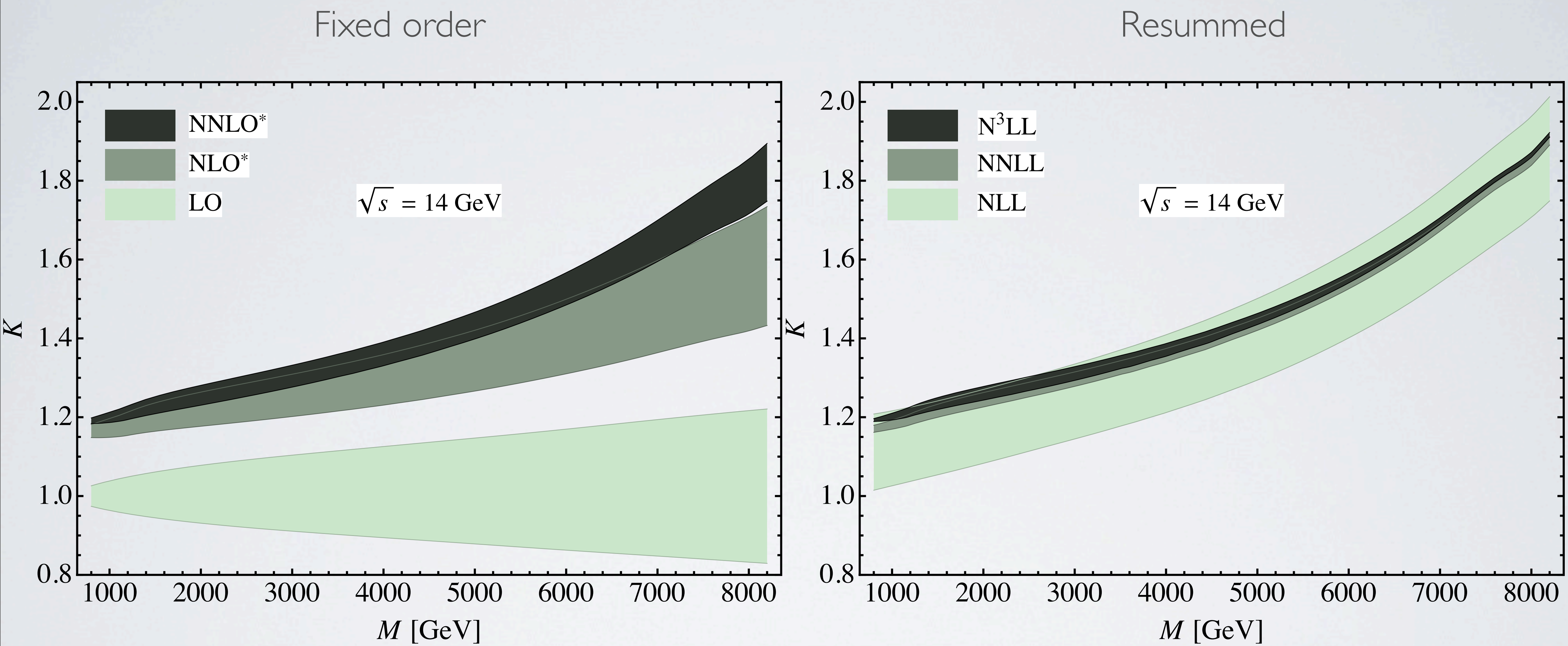
- The supersymmetric contribution has no influence on the choice of the matching scales.





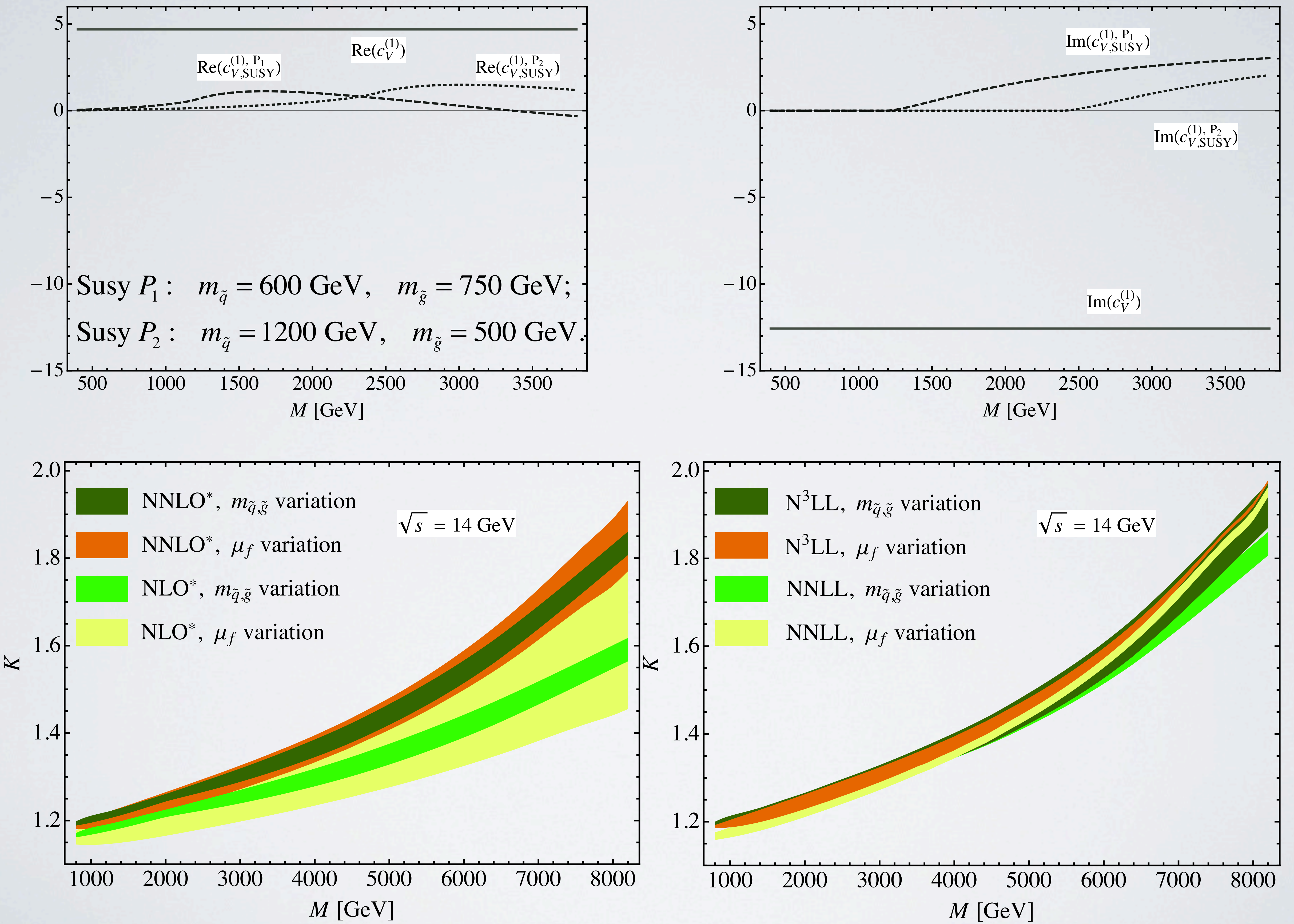


SISTEMATIC STUDIES: FIXED ORDER VS RESUMMED K FACTOR

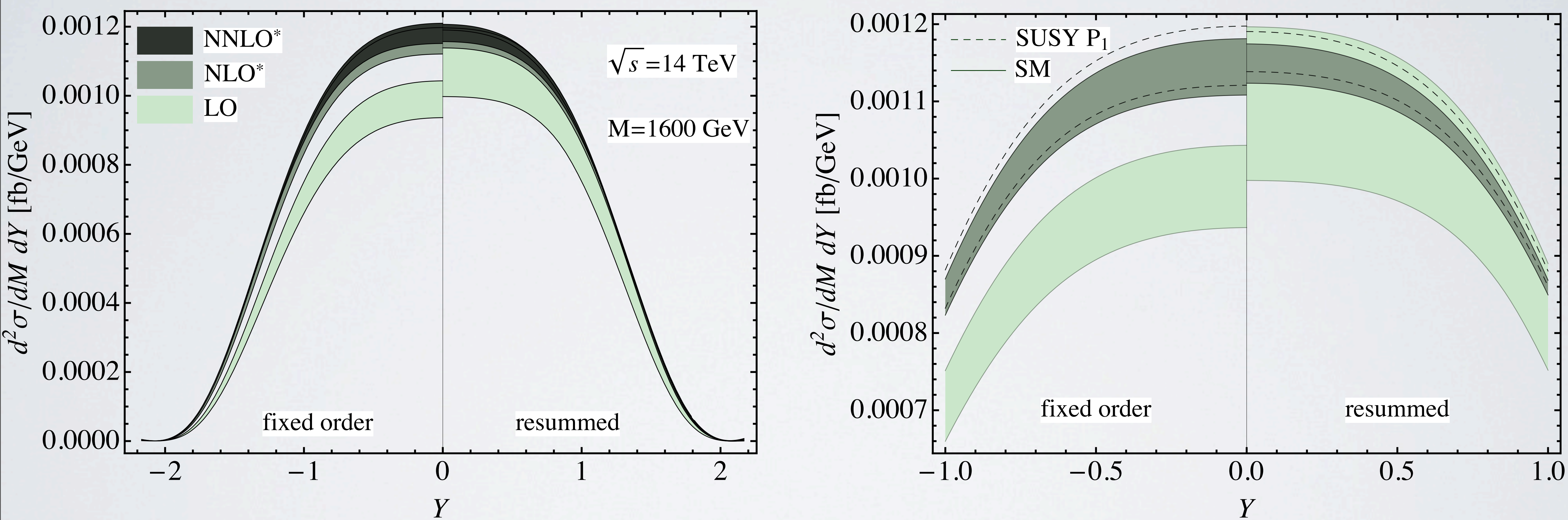


$$\frac{d\sigma}{dM} = K(M^2, m_{\tilde{q}}^2, m_{\tilde{g}}^2, \tau)\frac{d\sigma}{dM}|_{LO},$$

SISTEMATIC STUDIES: SUSY CONTRIBUTION

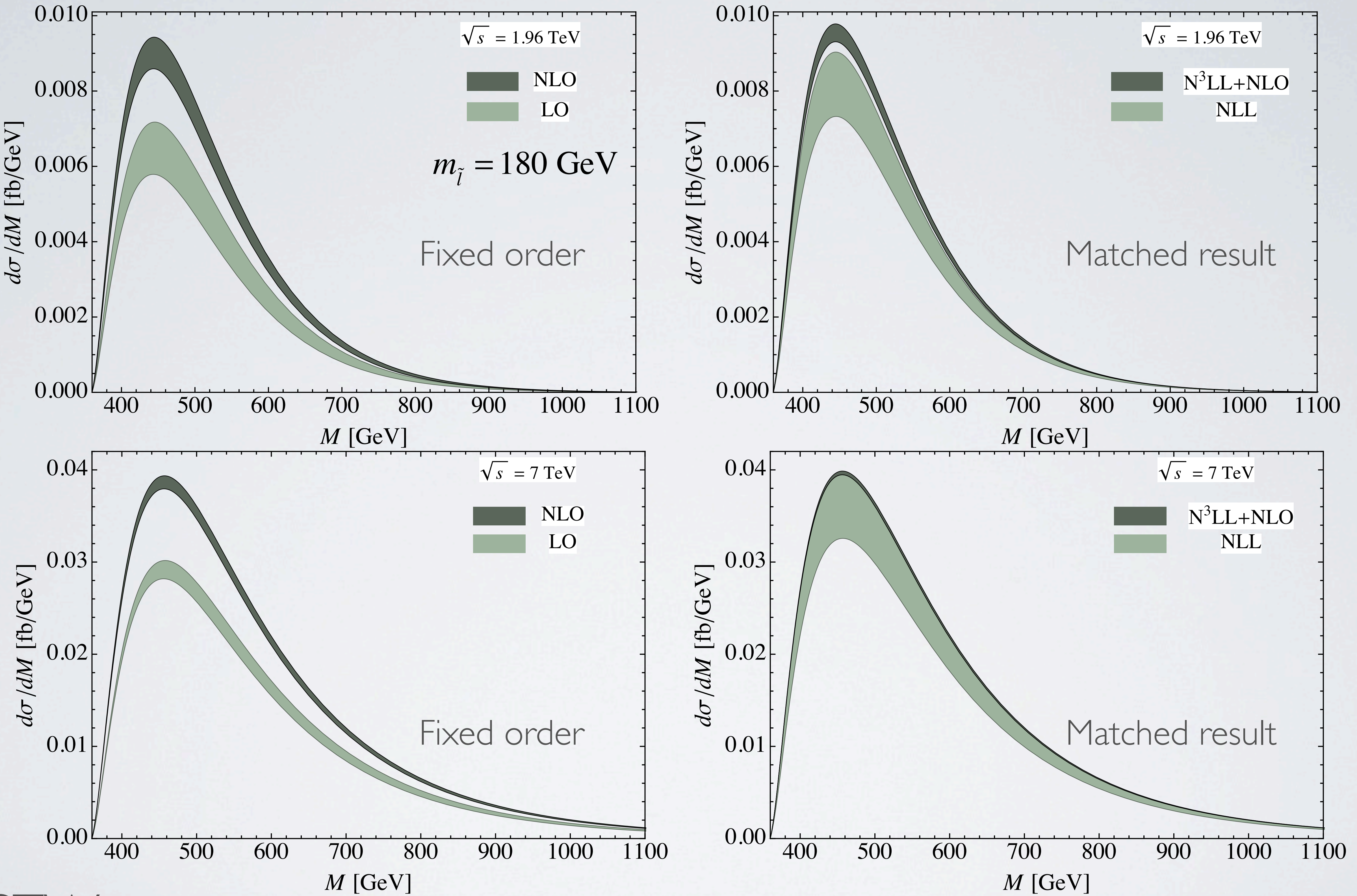


SUSY CONTRIBUTION: DRELL-YAN RAPIDITY DISTRIBUTION



"pure" NLO supersymmetric correction very small

SLEPTON PAIR PRODUCTION: INVARIANT MASS



MSTW 2008

$$d\sigma^{\mathrm{N^nLL+NLO}} = d\sigma^{\mathrm{N^nLL}}\,|_{\mu_h,\mu_s,\mu_f} + \left(d\sigma^{\mathrm{NLO}}\,|_{\mu_f} - d\sigma^{\mathrm{N^nLL}}\,|_{\mu_h=\mu_s=\mu_f}\right)\Big|_{O(\alpha_s)}\,.$$

MSTW 2008

SLEPTON PAIR PRODUCTION: TOTAL CROSS SECTION

Susy point P_1 : $m_{\tilde{l}} = 180$ GeV, $m_{\tilde{q}} = 600$ GeV, $m_{\tilde{g}} = 750$ GeV;

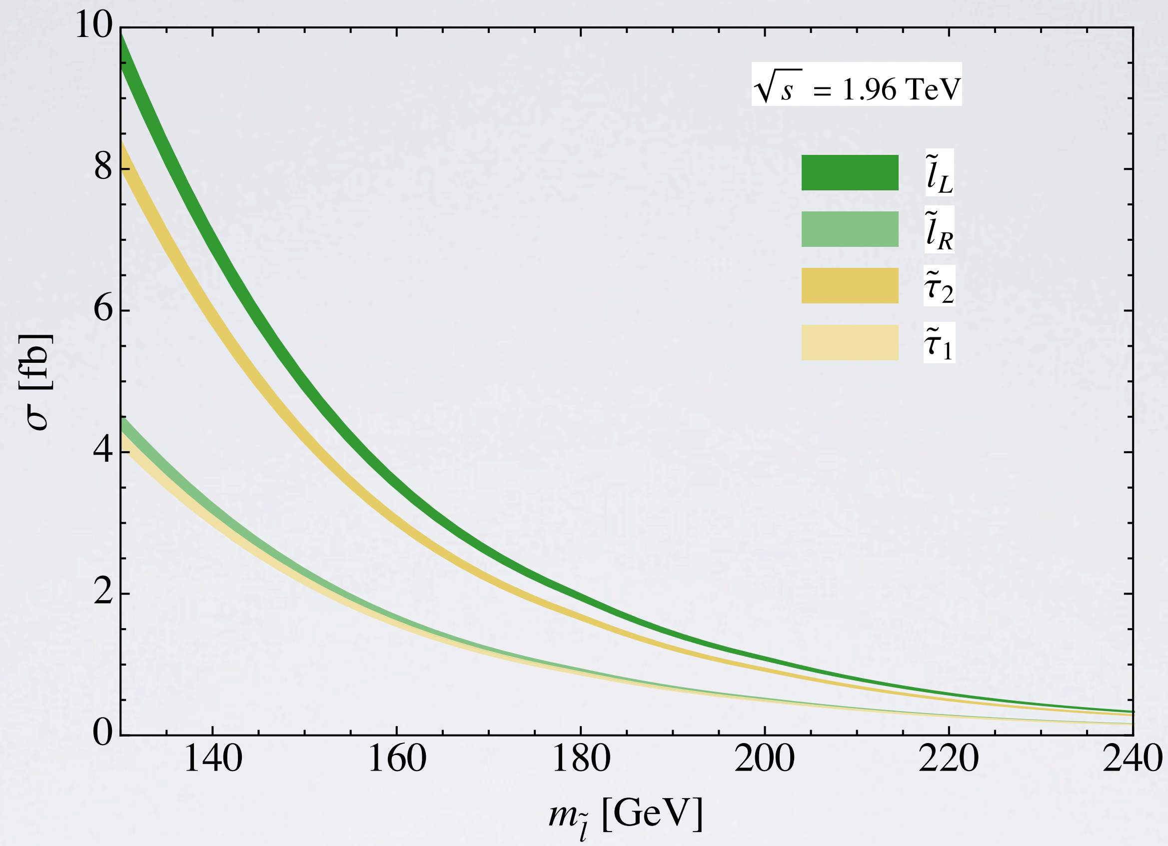
Susy point P_2 : $m_{\tilde{l}} = 360$ GeV, $m_{\tilde{q}} = 1200$ GeV, $m_{\tilde{g}} = 500$ GeV.

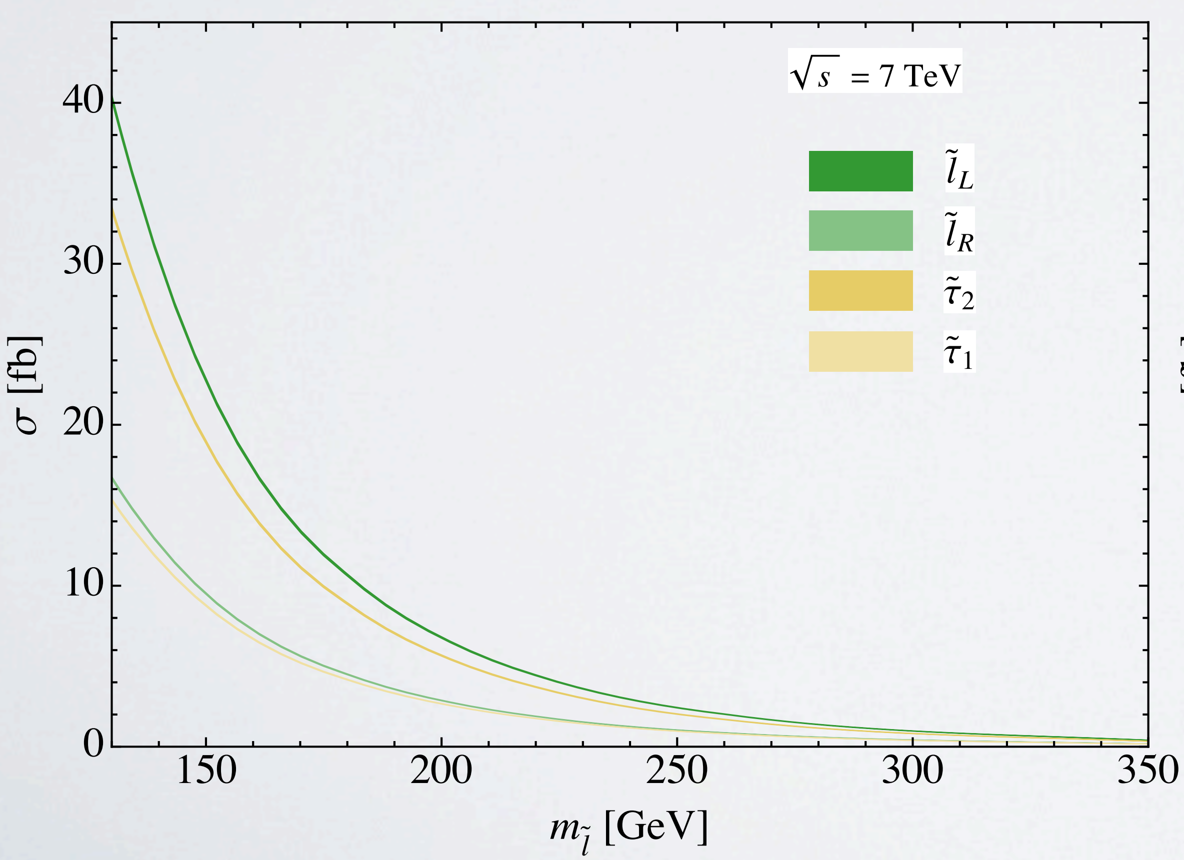
	Tevatron (SUSY point P_1)	LHC (7 TeV, SUSY point P_1)
σ_{LO}	$1.31^{+0.17\,+0.08}_{-0.14\,-0.06}$	$8.01^{+0.39\,+0.31}_{-0.36\,-0.34}$
σ_{NLL}	$1.65^{+0.22\,+0.12}_{-0.13\,-0.08}$	$9.59^{+1.20\,+0.41}_{-0.64\,-0.37}$
σ_{NLO}	$1.83^{+0.09\,+0.14}_{-0.10\,-0.10}$	$10.56^{+0.24\,+0.48}_{-0.22\,-0.43}$
$\sigma_{\mathrm{NNLL+NLO}}$	+7% $1.93^{+0.04\,+0.14}_{-0.05\,-0.10}$ -100%	$10.63^{+0.08\,+0.48}_{-0.13\,-0.37}$
$\sigma_{\mathrm{N^3LL+NLO}}$	$1.96^{+0.04\,+0.14}_{-0.05\,-0.11}$	$10.81^{+0.08\,+0.48}_{-0.06\,-0.37}$
	LHC (14 TeV, SUSY point P_1)	LHC (14 TeV, SUSY point P_2)
σ_{LO}	$28.14^{+0.25\,+0.70}_{-0.34\,-0.94}$	$1.88^{+0.09\,+0.07}_{-0.08\,-0.08}$
σ_{NLL}	$33.36^{+4.19\,+1.10}_{-2.27\,-1.01}$	$2.24^{+0.26\,+0.09}_{-0.14\,-0.08}$
σ_{NLO}	$36.65^{+0.45\,+1.28}_{-0.35\,-1.19}$	$2.45^{+0.05\,+0.11}_{-0.05\,-0.10}$
$\sigma_{\mathrm{NNLL+NLO}}$	$37.16^{+0.23\,+1.30}_{-0.42\,-1.03}$	$2.47^{+0.02\,+0.11}_{-0.03\,-0.08}$
$\sigma_{\mathrm{N^3LL+NLO}}$	$37.80^{+0.17\,+1.32}_{-0.10\,-1.05}$	$2.51^{+0.02\,+0.11}_{-0.01\,-0.08}$

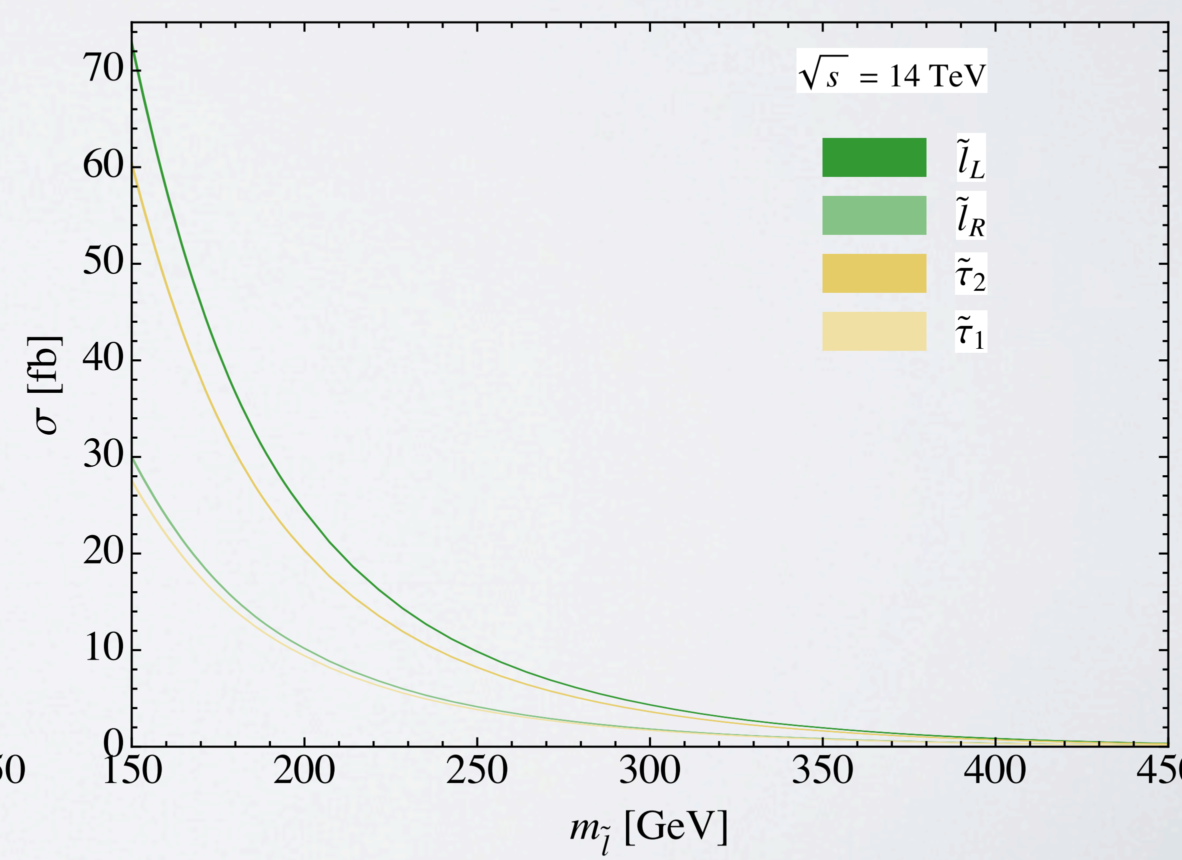
$$d\sigma^{\mathrm{N^nLL+NLO}} = d\sigma^{\mathrm{N^nLL}}\big|_{\mu_h,\mu_s,\mu_f} + \left(d\sigma^{\mathrm{NLO}}\big|_{\mu_f} - d\sigma^{\mathrm{N^nLL}}\big|_{\mu_h=\mu_s=\mu_f}\right)\Big|_{O(\alpha_s)} .$$

SLEPTON PAIR PRODUCTION: TOTAL CROSS SECTION

MSTW
2008



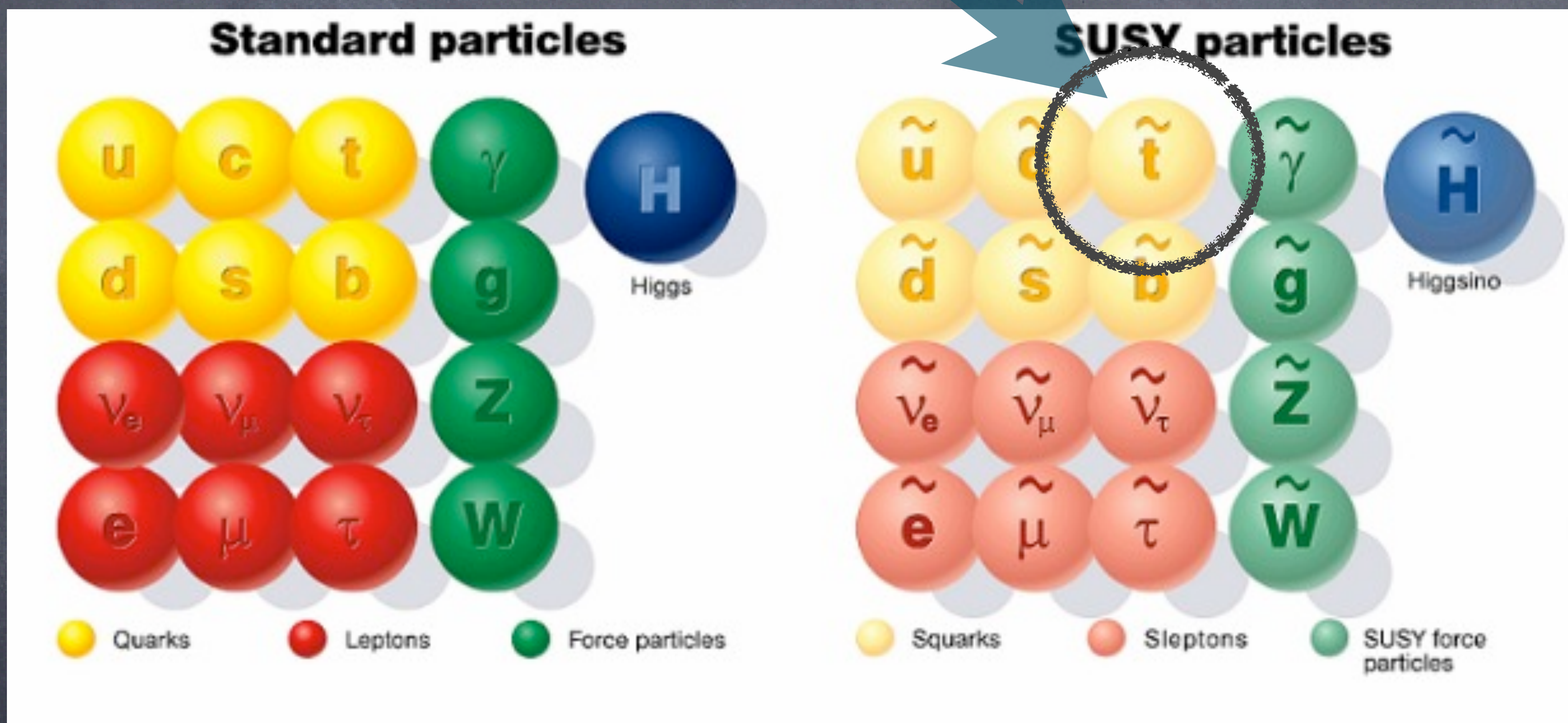




Soft gluon resummation for slepton pair production

- Using methods of soft-collinear effective field theory we achieve soft gluon resummation at the NNNLL.
- We obtain results for the invariant mass distribution and the total cross section at the NLO+NNNLL.
- "Pure" supersymmetric correction at NLO small.
- NNNLL resummation useful to reduce significantly the scale uncertainty by a factor 2 from the NLO to the NLO+NNNLL result.
- After resummation, the largest source of uncertainty comes from the PDF.
- The increase in the invariant mass distribution and total cross section is less significative, up to 7% at the Tevatron and up to 3% at the LHC

4 partons processes: squark (stop) pair production



Squark pair production

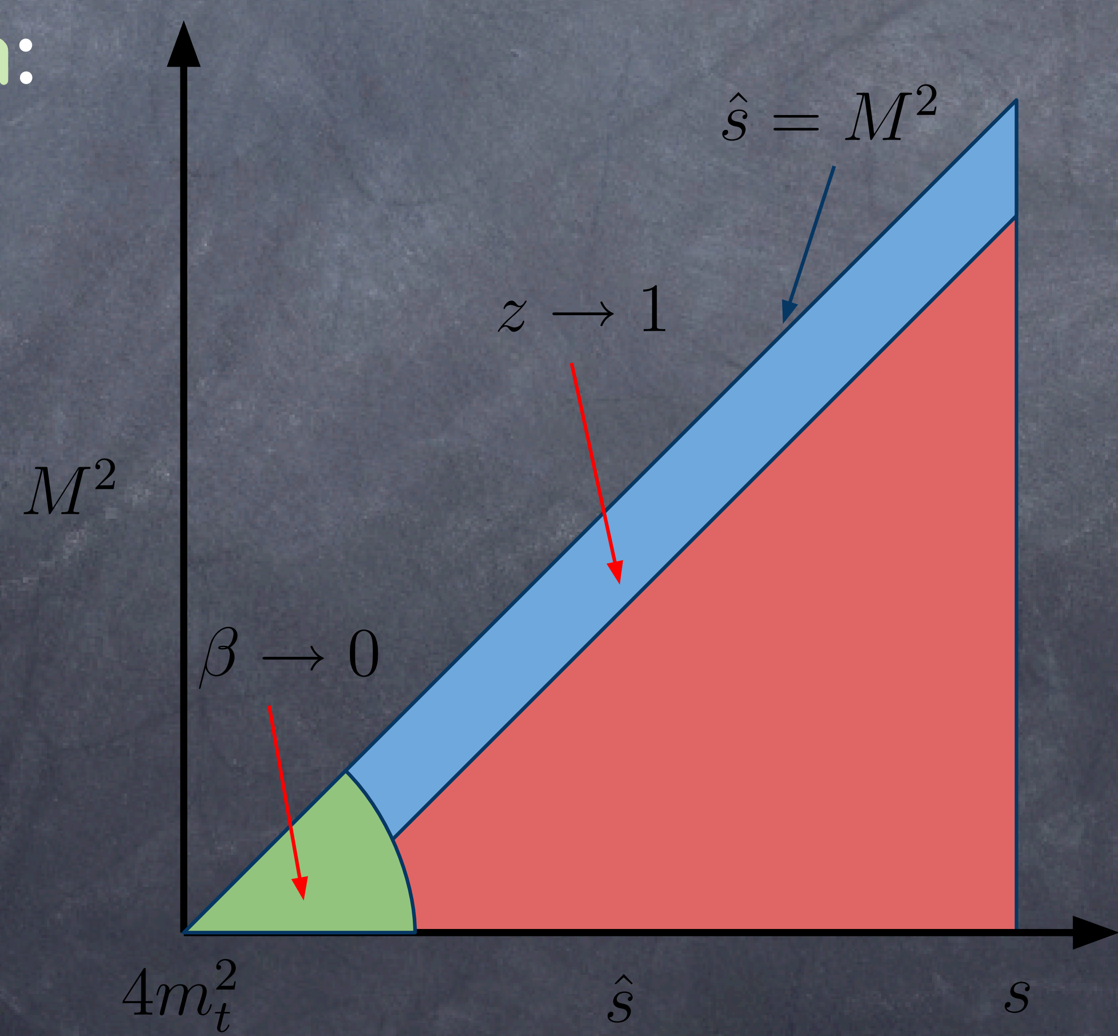
- If supersymmetry exsists, colored particles such as squark and gluinos are expected to be produced copiously in hadronic collision.
- They offer the highest sensitivity for supersymmetry searches at the Tevatron and LHC. (Experiments indicate already $m_{\tilde{q},\tilde{g}} \geq 1$ TeV)
- Accurate theoretical prediction are crucial to derive exclusion limits for squark and gluino masses.
- In case of discovery, they are useful for a precise determination of the sparticle masses and properties.
- Stop pair production is particularly interesting: one of the two mass eigenstates is expected to be the lightest squark.
- In case of a split scenario with heavy first two families, it could be the only squark in reach of LHC (with the gluino?)

Soft gluon resummation for squark/gluino production in the $\beta \to 0$ limit

- In Mellin space:
  - Kulesza, Motyka, 2009;
  - Beenakker, Brensing, Krämer, Kulesza, Laenen, Niessen, 2009, 2010, 2011;
  - Beenakker, Brensing, Krämer, Kulesza, Laenen, Motyka, Niessen, 2009, 2010, 2011;
  - Beenakker, Brensing, D'Onofrio, Krämer, Kulesza, Laenen, Martinez, Niessen, 2011
- In momentum space:
  - Beneke, Falgari, Schwinn, 2009, 2010;
  - Falgari, Schwinn, Wever, 2012;

Soft gluon resummation for squark/gluino production in the $\beta \to 0$ limit

- The $\beta \to 0$ limit resums a different type of soft contribution, around the "true" threshold region, while the $z-1 \to 0$ limit resums soft radiation for the whole invariant mass spectrum:



MSSM MASS SPECTRUM

Stop pair production

- The differential cross section in the threshold region reads

$$\frac{d^2\sigma^{\text{thresh}}}{dM\,d\cos\theta} = \sigma_0 \int_\tau^1 \frac{dz}{z} \Big[C_{gg}(z, M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)\, ff_{gg}(\tau/z, \mu_f)$$

$$+ C_{q\bar{q}}(z, M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)\, ff_{q\bar{q}}(\tau/z, \mu_f) + C_{\bar{q}q}(z, M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)\, ff_{\bar{q}q}(\tau/z, \mu_f) \Big]$$

- The hard scattering kernels $C_{ij}(z, M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)$ factorise into

$$C_{ij}(z, M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f) = \mathrm{Tr}\Big[\mathbf{H}_{ij}(M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)$$

$$\times \mathbf{S}_{ij}(\sqrt{\hat{s}}(1-z), \cos\theta, m_{\tilde{t}}, \mu_f) \Big] + O(1-z)$$

- Where now $\mathbf{H}_{ij}(M, \cos\theta, m_{\tilde{t}} m_{\tilde{q}}, m_{\tilde{g}}, \mu_f)$ and $\mathbf{S}_{ij}(\sqrt{\hat{s}}(1-z), \cos\theta, m_{\tilde{t}}, \mu_f)$ are matrices in color space.

- In this approach we resum logarithms of the form

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

Stop pair production: soft function

Ahrens, Ferroglia, Neubert, Pecjak, Yang, 2009, 2010, 2011

- The soft function and the anomalous dimension of the hard function are known, they are the same as for top pair production. The Laplace transform reads

$$\tilde{\mathbf{s}}(L,M,m_{\tilde{t}},\cos\theta,\mu)=\frac{1}{\sqrt{\hat{s}}}\int_0^\infty d\omega\exp\left(-\frac{\omega}{e^{\gamma_E}\mu e^{L/2}}\right)\mathbf{S}(\omega,M,m_{\tilde{t}},\cos\theta,\mu),$$

- and expanding in power of

$$\tilde{\mathbf{s}}=\tilde{\mathbf{s}}^{(0)}+\frac{\alpha_s}{4\pi}\tilde{\mathbf{s}}^{(1)}+\left(\frac{\alpha_s}{4\pi}\right)^2\tilde{\mathbf{s}}^{(2)}+\ldots$$

- one finds e.g. at leading order

$$\tilde{\mathbf{s}}_{q\bar{q}}^{(0)}=\begin{pmatrix} N & 0 \\ 0 & \frac{C_F}{2} \end{pmatrix},\qquad \tilde{\mathbf{s}}_{gg}^{(0)}=\begin{pmatrix} N & 0 & 0 \\ 0 & \frac{N}{2} & 0 \\ 0 & 0 & \frac{N^2-4}{2N} \end{pmatrix}.$$

Stop pair production: hard function

- The hard function has to be calculated from scratch. Defining

$$|\mathcal{M}_{\text{ren}}\rangle = 4\pi\alpha_s\left[|\mathcal{M}_{\text{ren}}^{(0)}\rangle + \frac{\alpha_s}{4\pi}|\mathcal{M}_{\text{ren}}^{(1)}\rangle + \ldots\right]$$

- and expanding as

$$\mathbf{H} = \alpha_s^2\frac{3}{8d_R}\left(\mathbf{H}^{(0)} + \frac{\alpha_s}{4\pi}\mathbf{H}^{(1)} + \ldots\right)$$

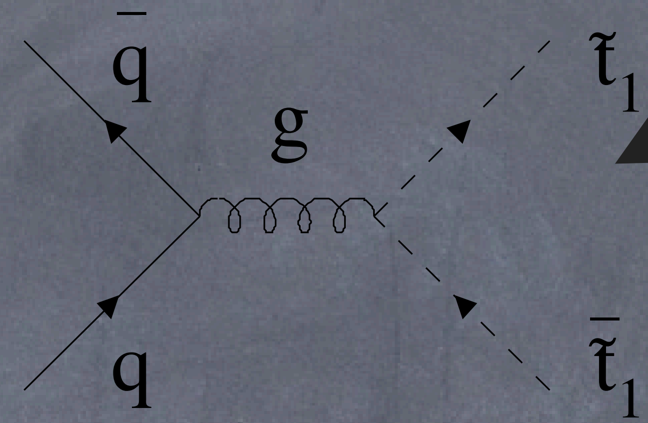
- one has

$$\mathbf{H}_{IJ}^{(0)} = \frac{1}{4}\frac{1}{\langle c_I|c_I\rangle\langle c_J|c_J\rangle}\langle c_I|\mathcal{M}_{\text{ren}}^{(0)}\rangle\langle\mathcal{M}_{\text{ren}}^{(0)}|c_J\rangle,$$

$$\mathbf{H}_{IJ}^{(1)} = \frac{1}{4}\frac{1}{\langle c_I|c_I\rangle\langle c_J|c_J\rangle}\left[\langle c_I|\mathcal{M}_{\text{ren}}^{(0)}\rangle\langle\mathcal{M}_{\text{ren}}^{(1)}|c_J\rangle + \langle c_I|\mathcal{M}_{\text{ren}}^{(1)}\rangle\langle\mathcal{M}_{\text{ren}}^{(0)}|c_J\rangle\right]$$

Stop pair production: hard function

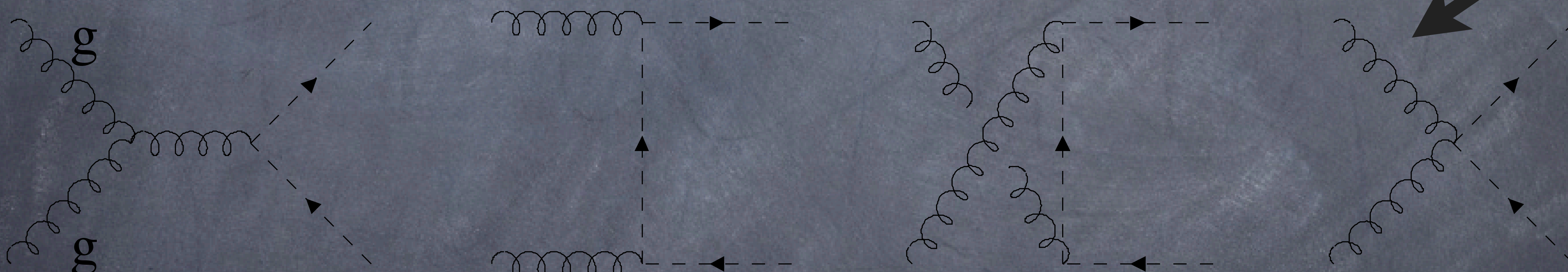
- At tree level one finds



Dominant at the Tevatron

$$\mathbf{H}^{(0)}_{q\bar{q}} = \begin{pmatrix} 0 & 0 \\ 0 & 2 \end{pmatrix} \frac{1}{t_1 + u_1} \left[\frac{t_1 u_1}{t_1 + u_1} + m_{\tilde{t}}^2 \right]$$

Dominant at the LHC



$$\mathbf{H}^{(0)}_{gg} = \begin{pmatrix} \frac{1}{N^2} & \frac{1}{N}\frac{t_1 - u_1}{M^2} & \frac{1}{N} \\ \frac{1}{N}\frac{t_1 - u_1}{M^2} & \frac{(t_1 - u_1)^2}{M^4} & \frac{t_1 - u_1}{M^2} \\ \frac{1}{N} & \frac{t_1 - u_1}{M^2} & N \end{pmatrix} \frac{m_{\tilde{t}}^4}{2 t_1 u_1} \left[-\frac{2M^2}{m_{\tilde{t}}^2} + \frac{t_1 u_1}{m_{\tilde{t}}^4} + 4 + 2\frac{t_1^2 + u_1^2}{t_1 u_1} \right]$$

Stop pair production

- $\mathbf{H}_{IJ}^{(0)}$ sufficient for a NLL resummation;
- Computation of $\mathbf{H}_{IJ}^{(1)}$ in progress; necessary for a resummation at the NNLL level.
- Aim: computation of the total cross section and the invariant mass distribution at the NLO+NNLL level.
- Beenakker, Brensing, Krämer, Kulesza, Laenen, Motyka, Niessen, 2009, 2010, 2011 obtain a sizeable increase in the total cross section (up to +20% from NLO to NLO+NLL), and a significative reduction of the scale uncertainty.
- Our calculation is useful to confirm this result, with a different resummation procedure, and to further increase the precision of the result.

Conclusion

- Methods of soft-collinear effective field theory allows to perform soft gluon resummation directly in momentum space.
- This has been applied successfully to Standard Model processes. We consider here production of supersymmetric particles.
- Resummation at the NLO+(N)NLL is required to reach a sufficient precision, in order to set lower limits on sparticle masses.
- We applied soft gluon resummation to slepton pair production. The error uncertainty is reduced by a factor 2 from the NLO to the NLO+NNNLL level. The total cross section increases by 7% at the Tevatron, and up to 3% at the LHC.
- Soft gluon resummation for stop pair production at the NNLL in progress.