QCD resummation for SUSY production

Irene Niessen
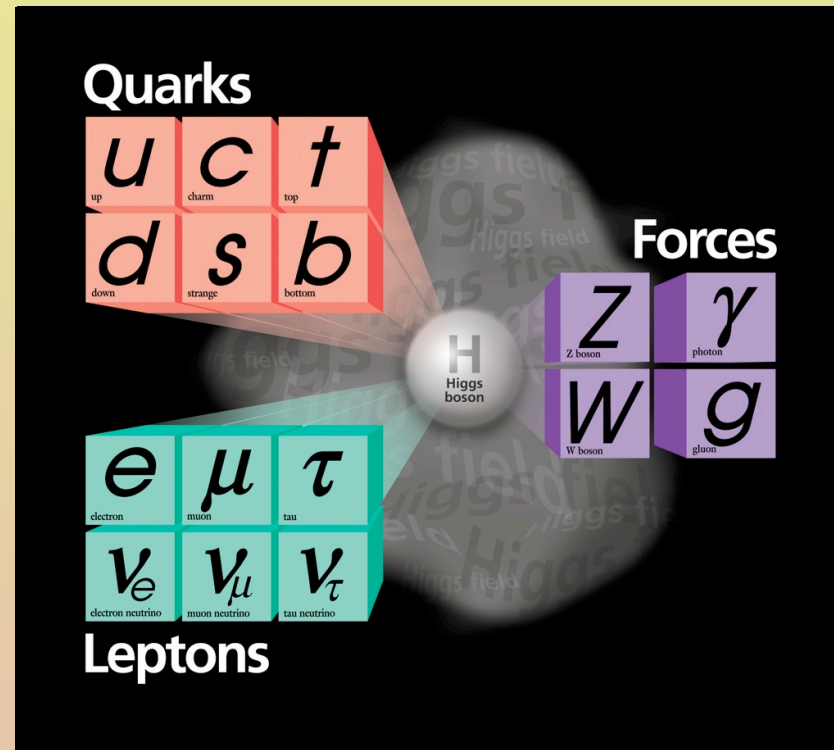
Radboud University Nijmegen

In collaboration with Wim Beenakker, Silja Brensing, Michael Krämer, Anna Kulesza and Eric Laenen
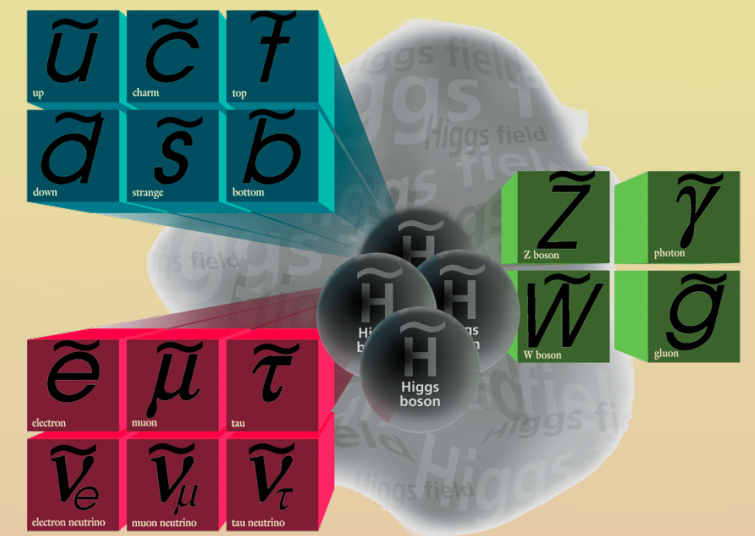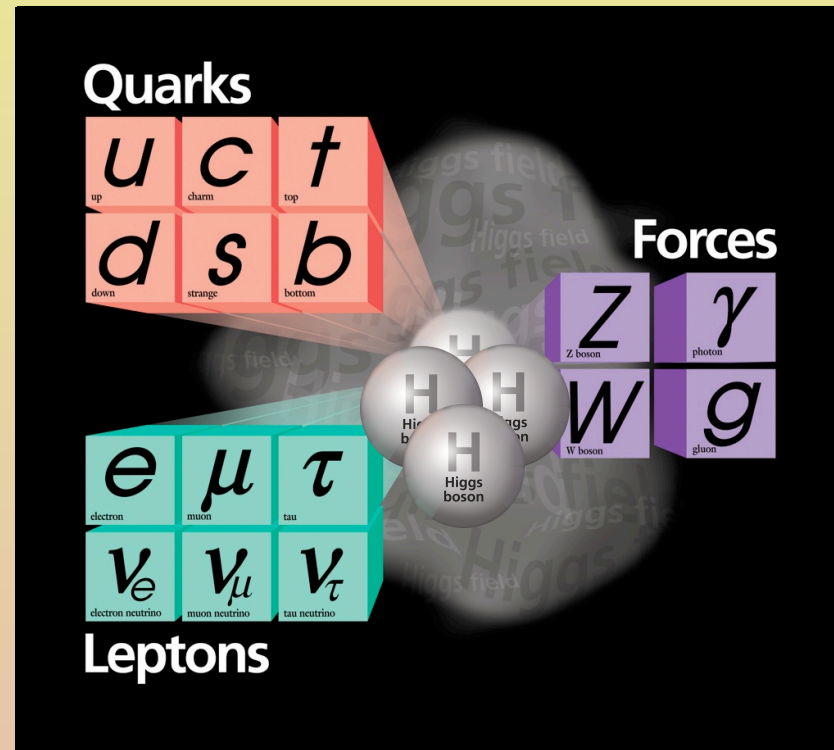
APPS, 30 November 2011, Amsterdam

Supersymmetry

- Hierarchy problem
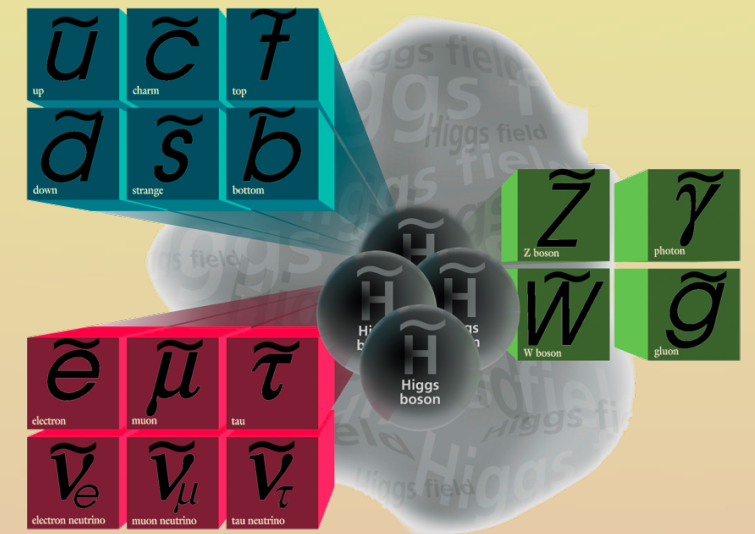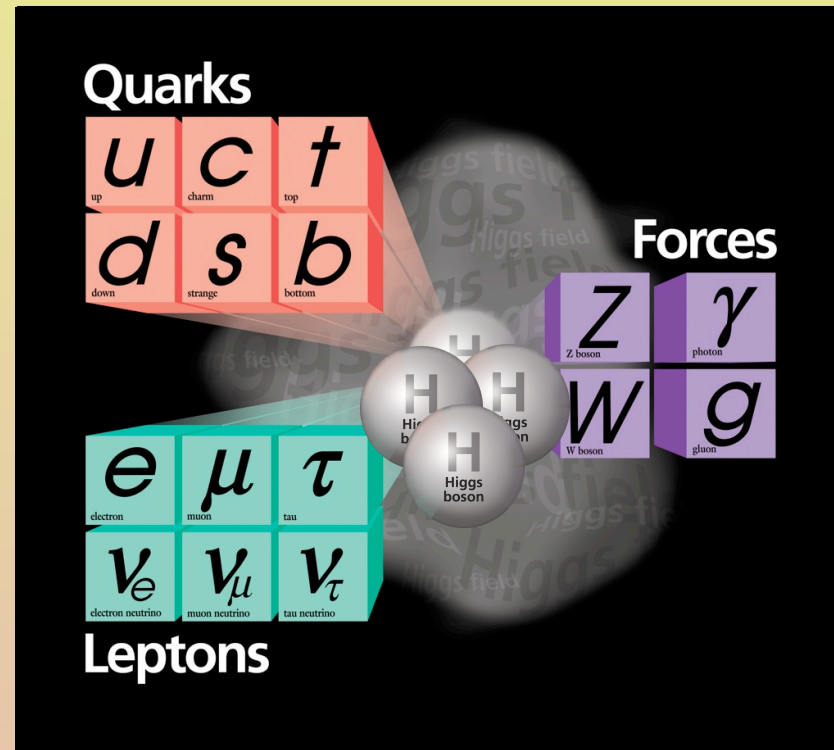- Gauge coupling unification
- Dark matter

Supersymmetry

- ✓ Hierarchy problem
- ✓ Gauge coupling unification
- ✓ Dark matter

Supersymmetry
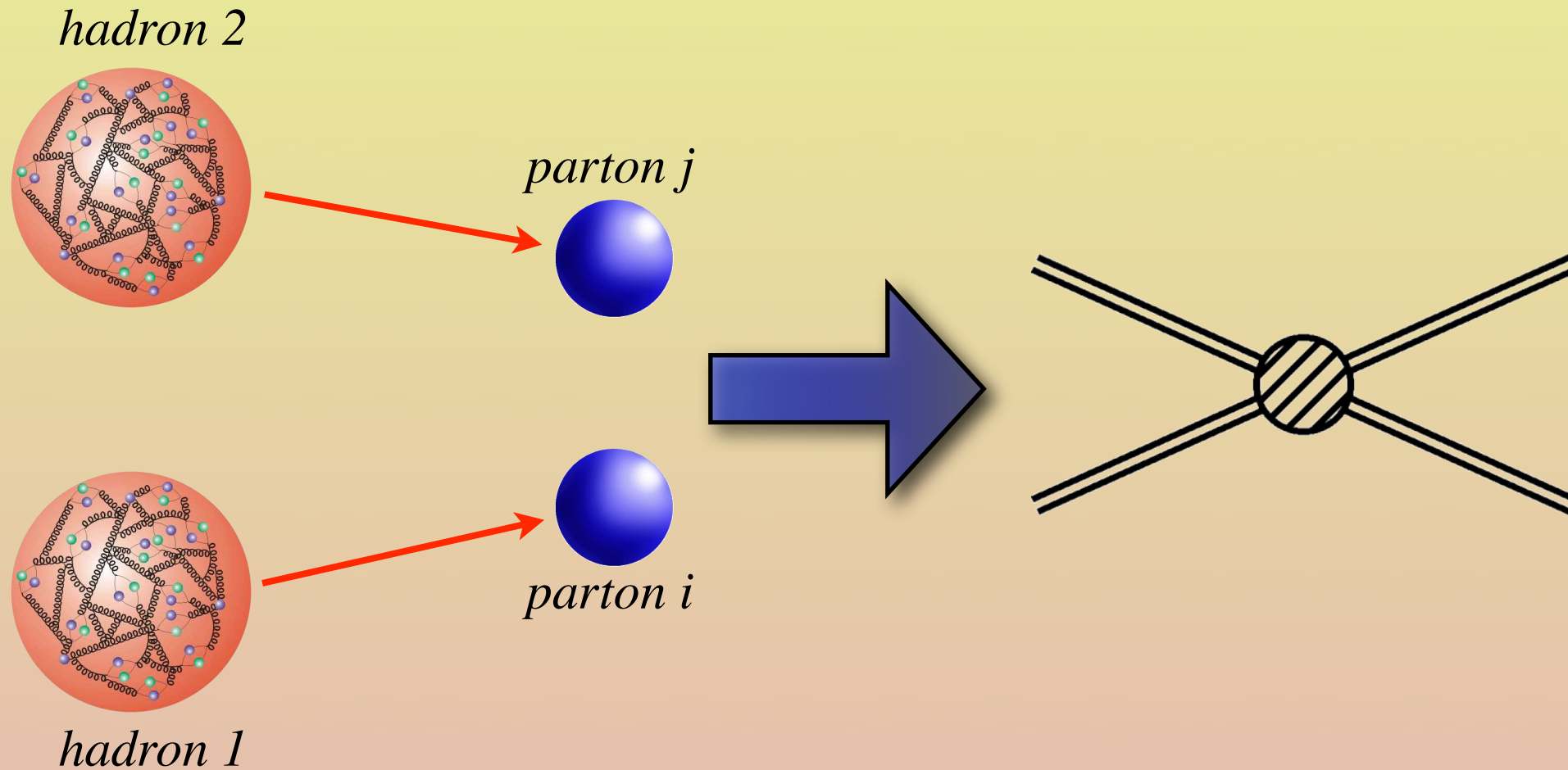

- ✓ Hierarchy problem
- ✓ Gauge coupling unification
- ✓ Dark matter

- SUSY particles are heavy

Colliding Protons

hadron 2

parton j

parton i

hadron 1

Colliding Protons

hadron 2

parton j

parton i

hadron 1

$$\sigma_{h_1 h_2 \to kl}(\{m^2\}) = \iint \sum_{i,j} f_{i/h_1}(x_1, \mu) f_{j/h_2}(x_2, \mu) \sigma_{ij \to kl}(\{m^2\}, \mu^2) dx_1 dx_2$$

Colliding Protons

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Colliding Protons

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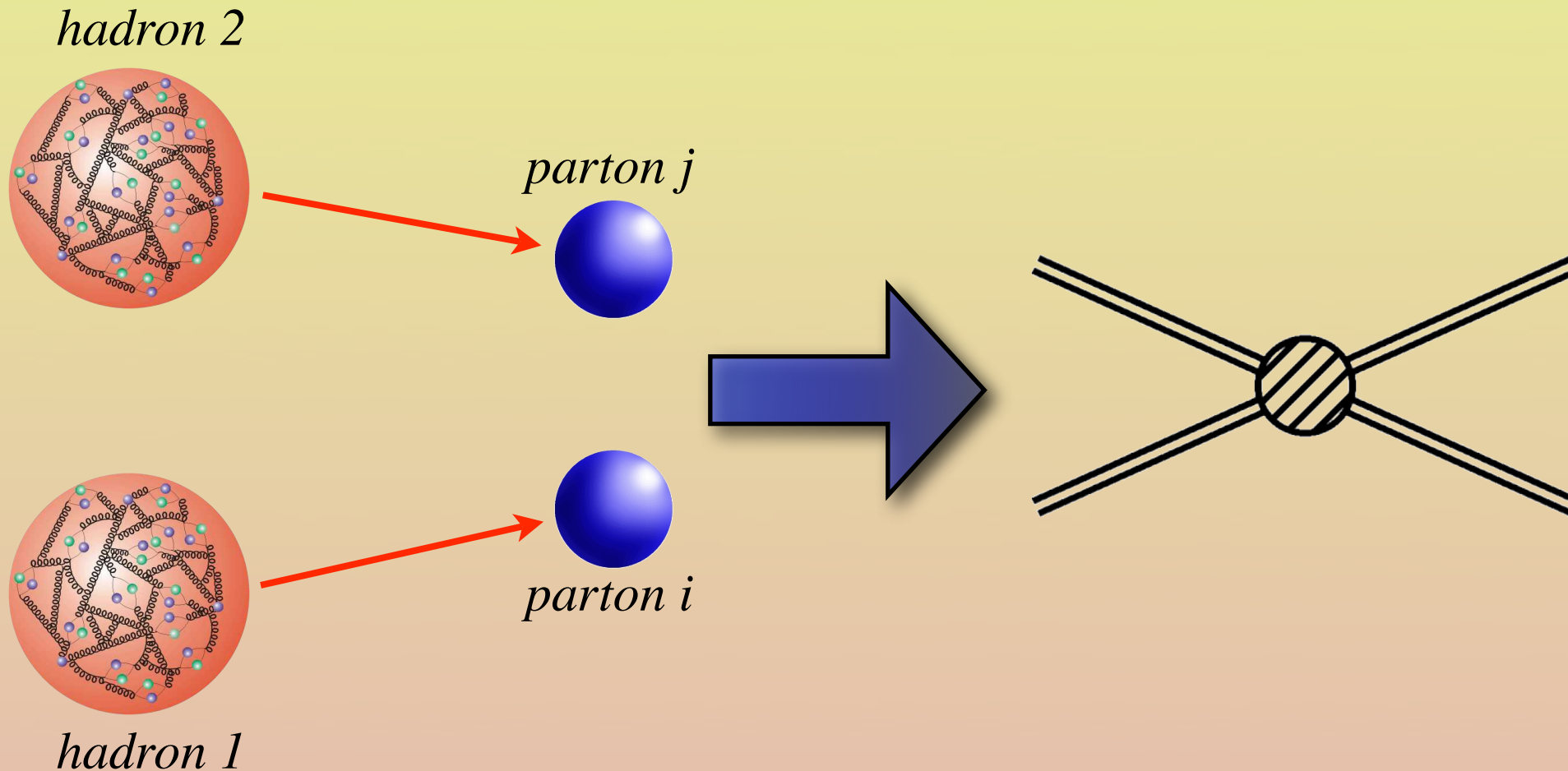*parton i*

hadron 1

$$\sigma_{h_1 h_2 \rightarrow kl}(\{m^2\}) = \iint \sum_{i,j} f_{i/h_1}(x_1,\mu) f_{j/h_2}(x_2,\mu) \sigma_{ij \rightarrow kl}(\{m^2\},\mu^2) dx_1 dx_2$$

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Colliding Protons

hadron 2

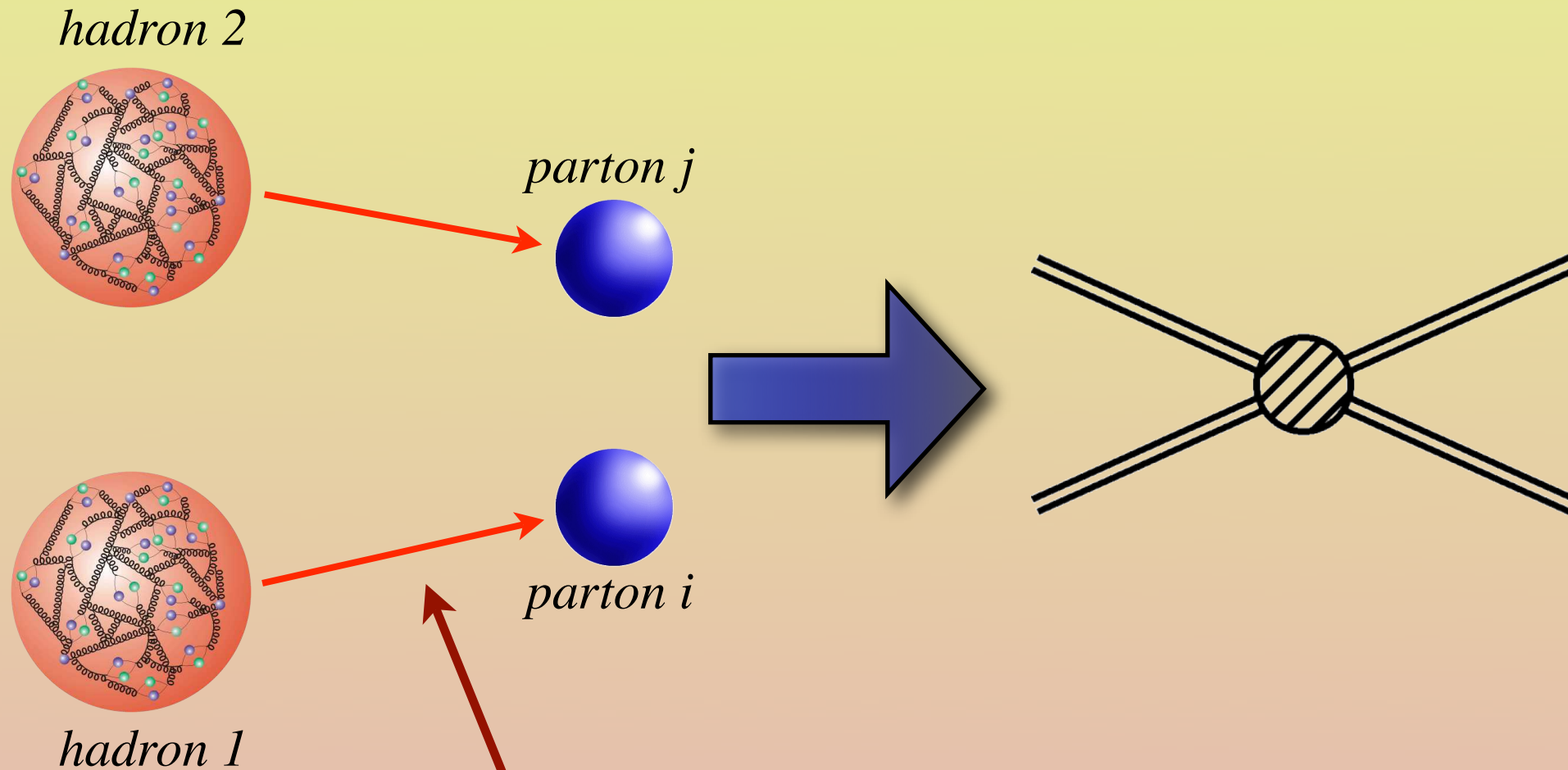"LOW ENERGY"

parton j

hadron 1

parton i

μ

"HIGH ENERGY"

$$\sigma_{h_1 h_2 \rightarrow kl}(\{m^2\}) = \iint \sum_{i,j} f_{i/h_1}(x_1,\mu) f_{j/h_2}(x_2,\mu) \sigma_{ij \rightarrow kl}(\{m^2\},\mu^2) dx_1 dx_2$$

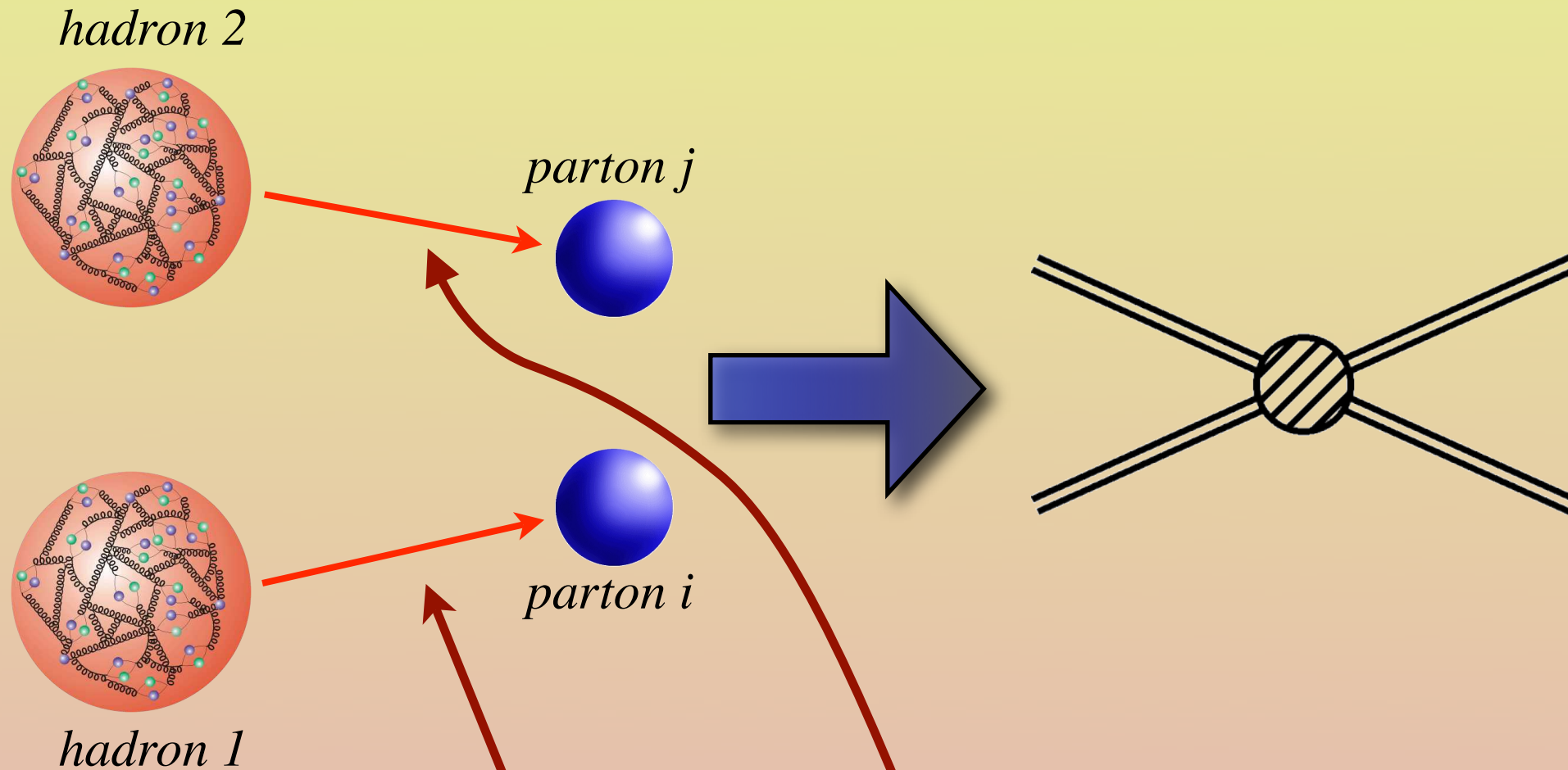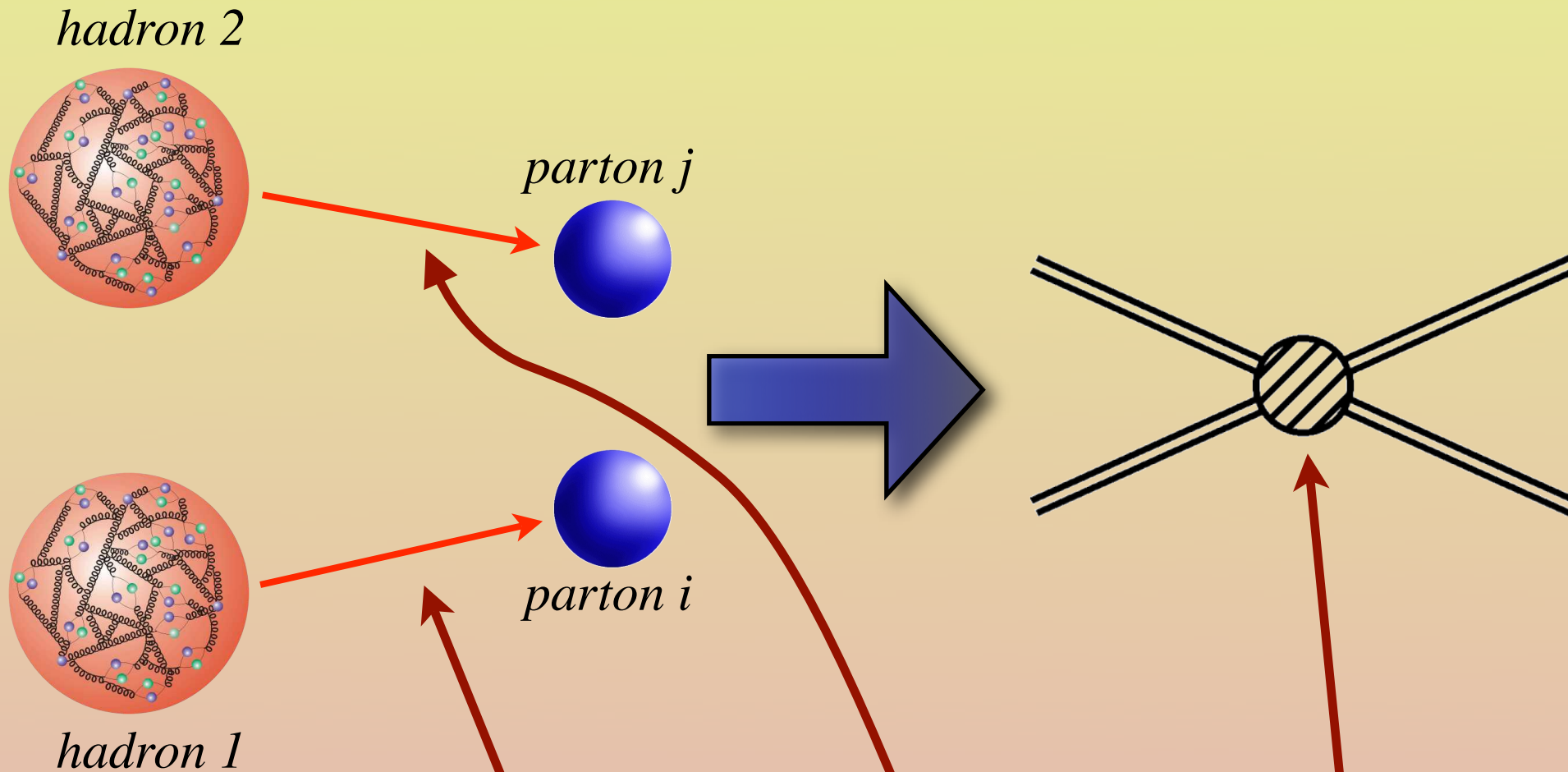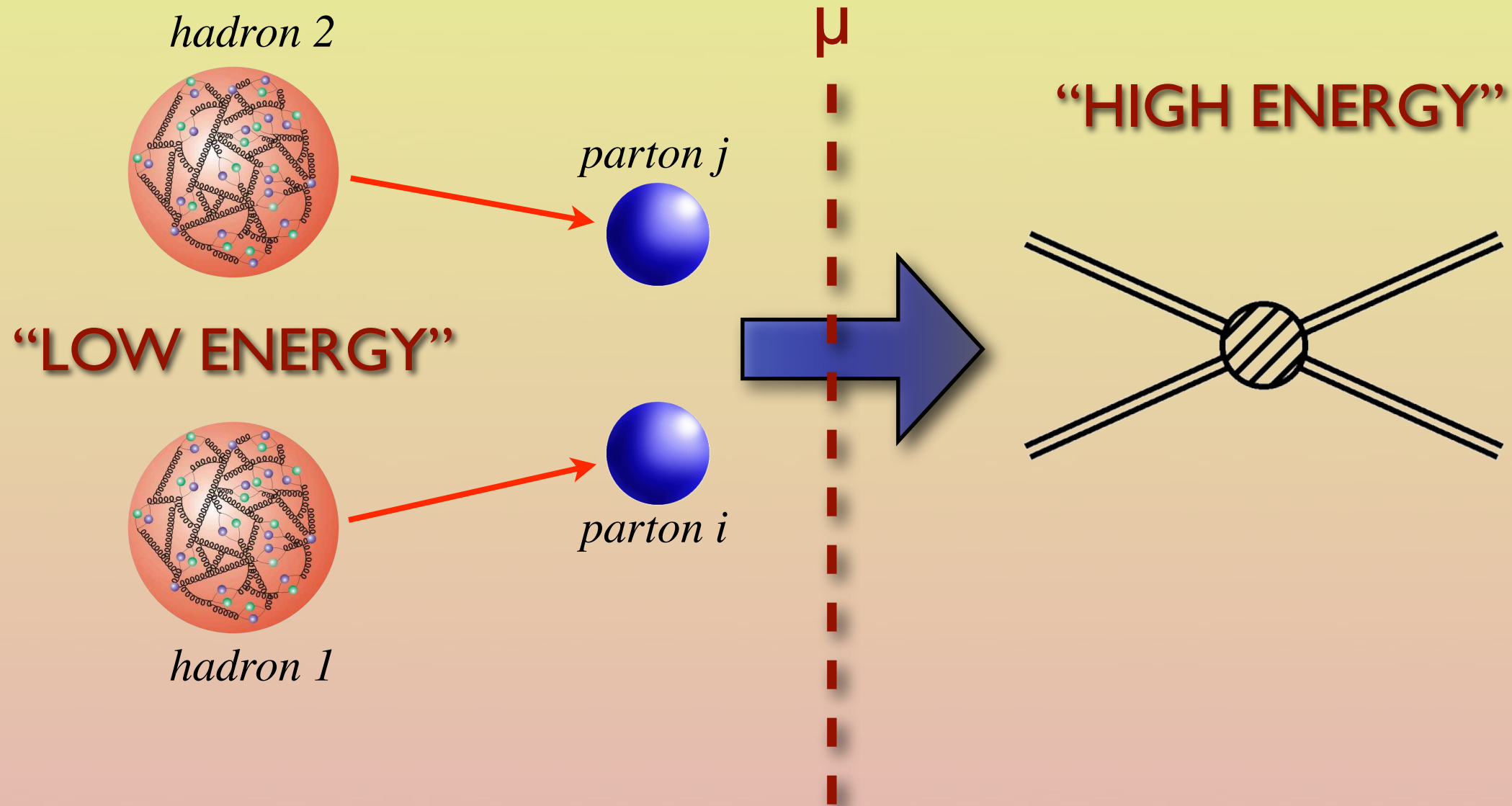# Scale dependence

$\sigma\,(\,pp \to \tilde{q}\bar{\tilde{q}} + X\,)\,[pb]$

$\sqrt{S} = 7\,\text{TeV}$

$\mu_0 = m_{\tilde{q}} = m_{\tilde{g}} = 1200\,\text{GeV}$

LO
NLO

μ/μ_0

Resummation

$$LO \quad 1$$

$$NLO \quad \alpha_s L^2 \quad \alpha_s L \quad \alpha_s$$

$$NNLO \quad \alpha_s^2 L^4 \quad \alpha_s^2 L^3 \quad \alpha_s^2 L^2 \quad \alpha_s^2 L \quad \alpha_s^2$$

$$N^3 LO \quad \alpha_s^3 L^6 \quad \alpha_s^3 L^5 \quad \alpha_s^3 L^4 \quad \alpha_s^3 L^3 \quad \alpha_s^3 L^2 \quad \alpha_s^3 L \quad \alpha_s^3$$

$$N^4 LO \quad \cdots$$

$$L = \log(8\beta^2) \qquad \beta = \sqrt{1 - \rho} \qquad \rho = \frac{4m^2}{s}$$

Resummation

$$
\begin{array}{llllllll}
LO & 1 \\
NLO & \alpha_s L^2 & \alpha_s L & \alpha_s \\
NNLO & \alpha_s^2 L^4 & \alpha_s^2 L^3 & \alpha_s^2 L^2 & \alpha_s^2 L & \alpha_s^2 \\
N^3LO & \alpha_s^3 L^6 & \alpha_s^3 L^5 & \alpha_s^3 L^4 & \alpha_s^3 L^3 & \alpha_s^3 L^2 & \alpha_s^3 L & \alpha_s^3 \\
N^4LO & \cdots
\end{array}
$$

$$
\tilde{f}(N) = \int_0^1 d\rho\, \rho^{N-1} f(\rho)
$$

$$
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$$

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$$\tilde{f}(N) = \int_0^1 d\rho \rho^{N-1} f(\rho) \qquad L \to \log(N)$$

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$$\tilde{\sigma}^{\text{resum}} = \tilde{\sigma}^{\text{thr}} e^{L P_1(\alpha_s L)} e^{P_2(\alpha_s L)} e^{\alpha_s P_3(\alpha_s L)}$$

Resummation

$$LO \quad \colorbox{yellow}{1}$$

$$NLO \quad \colorbox{yellow}{$\alpha_s L^2$} \quad \alpha_s L \quad \alpha_s$$

$$NNLO \quad \colorbox{yellow}{$\alpha_s^2 L^4 \quad \alpha_s^2 L^3 \quad \alpha_s^2 L^2$} \quad \alpha_s^2 L \quad \alpha_s^2$$

$$N^3LO \quad \colorbox{yellow}{$\alpha_s^3 L^6 \quad \alpha_s^3 L^5 \quad \alpha_s^3 L^4$} \quad \alpha_s^3 L^3 \quad \alpha_s^3 L^2 \quad \alpha_s^3 L \quad \alpha_s^3$$

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LO

Resummation

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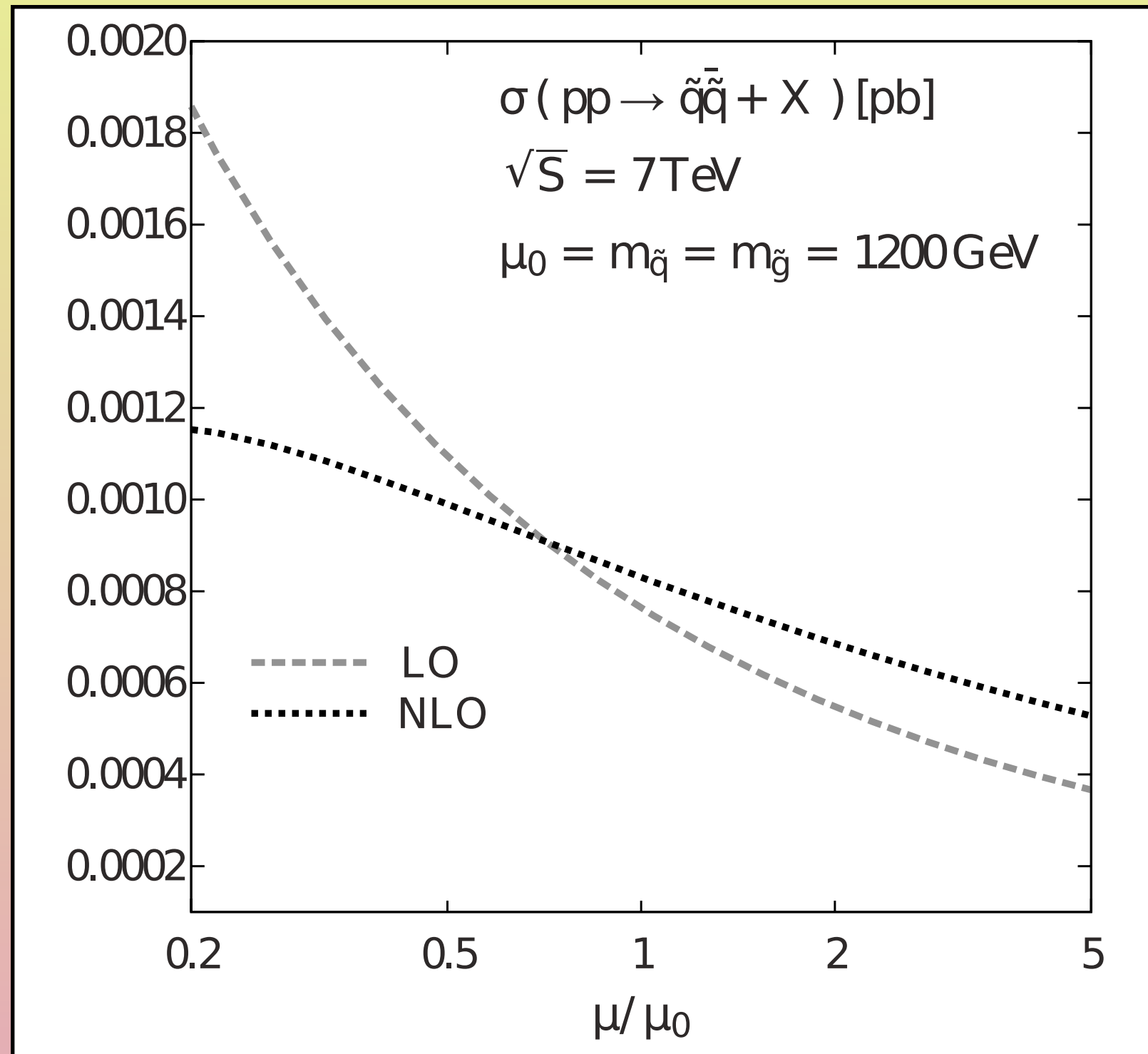$$N^4LO \qquad \ldots$$

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LO

LL   NLL

NLL: scale dependence

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- - - LO
······ NLO
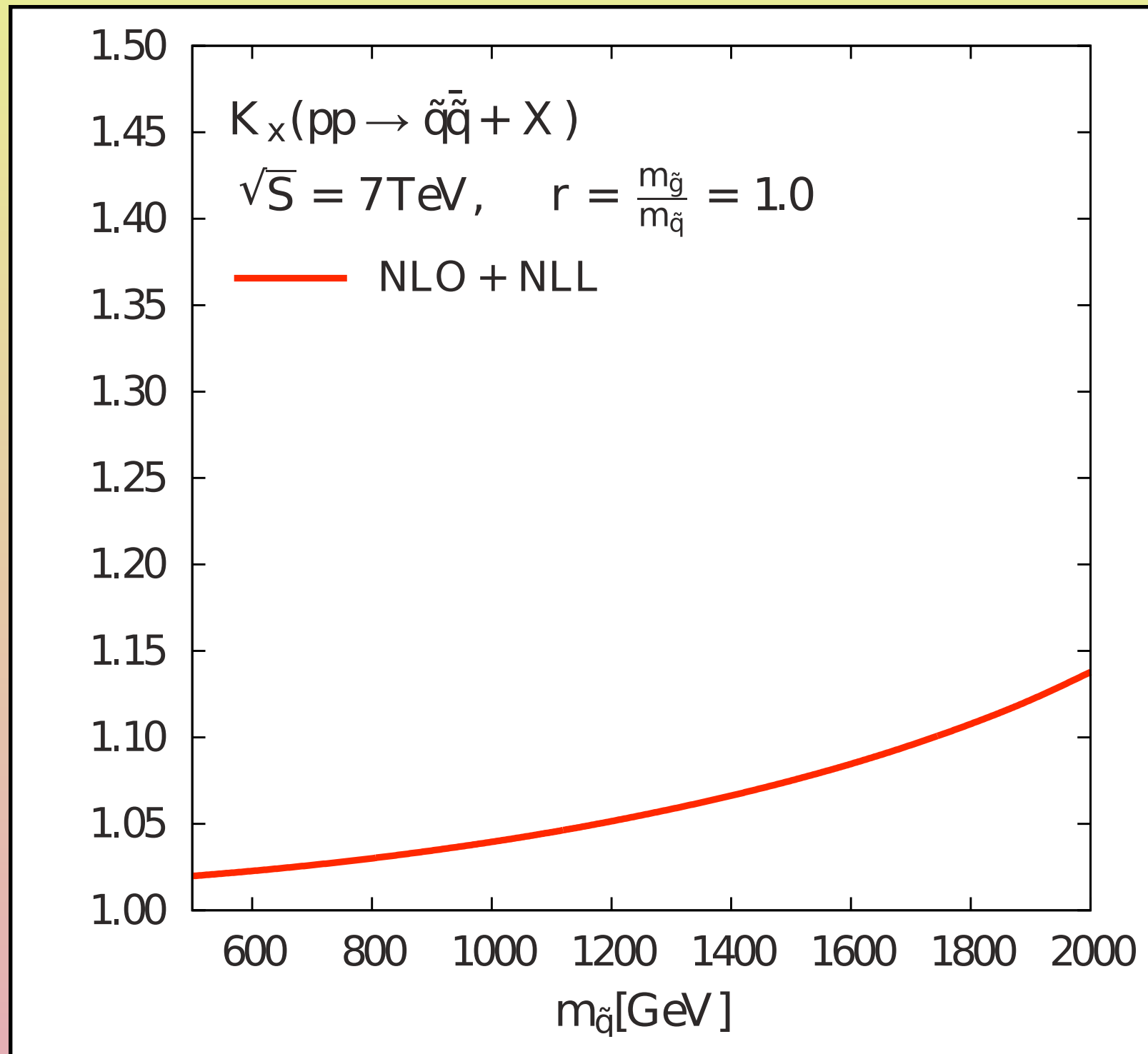——— NLO + NLL

NLL: K-factor

NLLfast

- Grid and fast interpolation code for NLL resummation in SUSY-QCD

  - MSTW 2008 NLO PDFs

  - Masses from 500 GeV to 2000 GeV

  - LO, NLO (PROSPINO) and NLL cross sections

  - Uncertainty from scale, PDF and $\alpha_{\rm s}$

- http://web.physik.rwth-aachen.de/service/wiki/bin/view/Main/SquarksandGluinos

Going beyond

$$L = \log(N)$$

LO 1

NLO $\alpha_s L^2$ $\alpha_s L$ α_s

$NNLO$ $\alpha_s^2 L^4$ $\alpha_s^2 L^3$ $\alpha_s^2 L^2$ $\alpha_s^2 L$ α_s^2

$N^3 LO$ $\alpha_s^3 L^6$ $\alpha_s^3 L^5$ $\alpha_s^3 L^4$ $\alpha_s^3 L^3$ $\alpha_s^3 L^2$ $\alpha_s^3 L$ α_s^3

$N^4 LO$ $\ldots$

$$\tilde{\sigma}^{\mathrm{resum}} = \tilde{\sigma}^{\mathrm{thr}} e^{L P_1(\alpha_s L)} e^{P_2(\alpha_s L)} e^{\alpha_s P_3(\alpha_s L)}$$

LO

LL

NLL

Going beyond

$$L = \log(N)$$

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$NNLO$	$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	α_s^2	
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$N^4 LO$	$\ldots$					

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NLO

LL   NLL   NNLL

NNLL resummation

$$\sigma^{\mathrm{NLO,thr}} = C^{NNLL}\sigma^{\mathrm{LO,thr}}$$

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$$C^{\mathrm{NNLL}} = \left(1 + \frac{\alpha_{\mathrm{s}}}{\pi}\,\mathcal{C}^{\mathrm{Coul},(1)}(N,\{m^2\},\mu^2)\right)\left(1 + \frac{\alpha_{\mathrm{s}}}{\pi}\,\mathcal{C}^{(1)}(\{m^2\},\mu^2)\right)$$

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$$\propto \frac{1}{\beta}f(\beta)$$
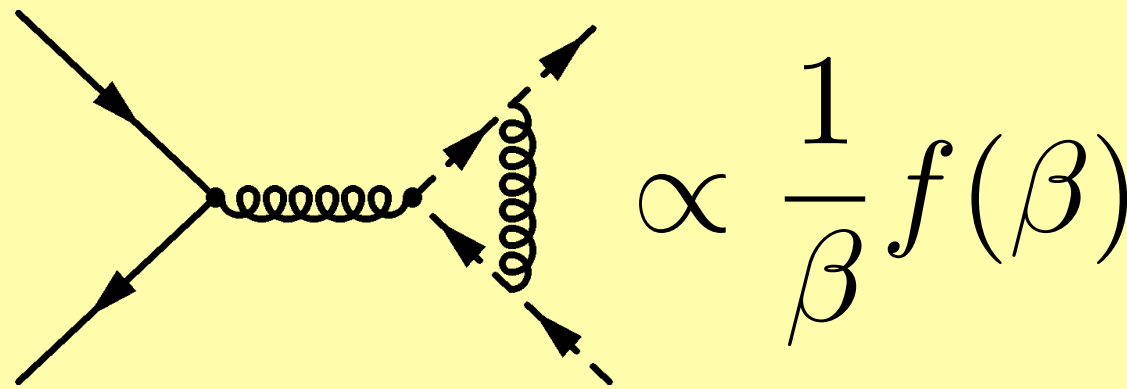
Leading Coulomb
corrections
(bound state effects)

NNLL resummation

$$\sigma^{\mathrm{NLO,thr}} = C^{NNLL}\sigma^{\mathrm{LO,thr}}$$

$$C^{\mathrm{NNLL}} = \left(1+\frac{\alpha_{\mathrm{s}}}{\pi}\mathcal{C}^{\mathrm{Coul},(1)}(N,\{m^2\},\mu^2)\right)\left(1+\frac{\alpha_{\mathrm{s}}}{\pi}\mathcal{C}^{(1)}(\{m^2\},\mu^2)\right)$$
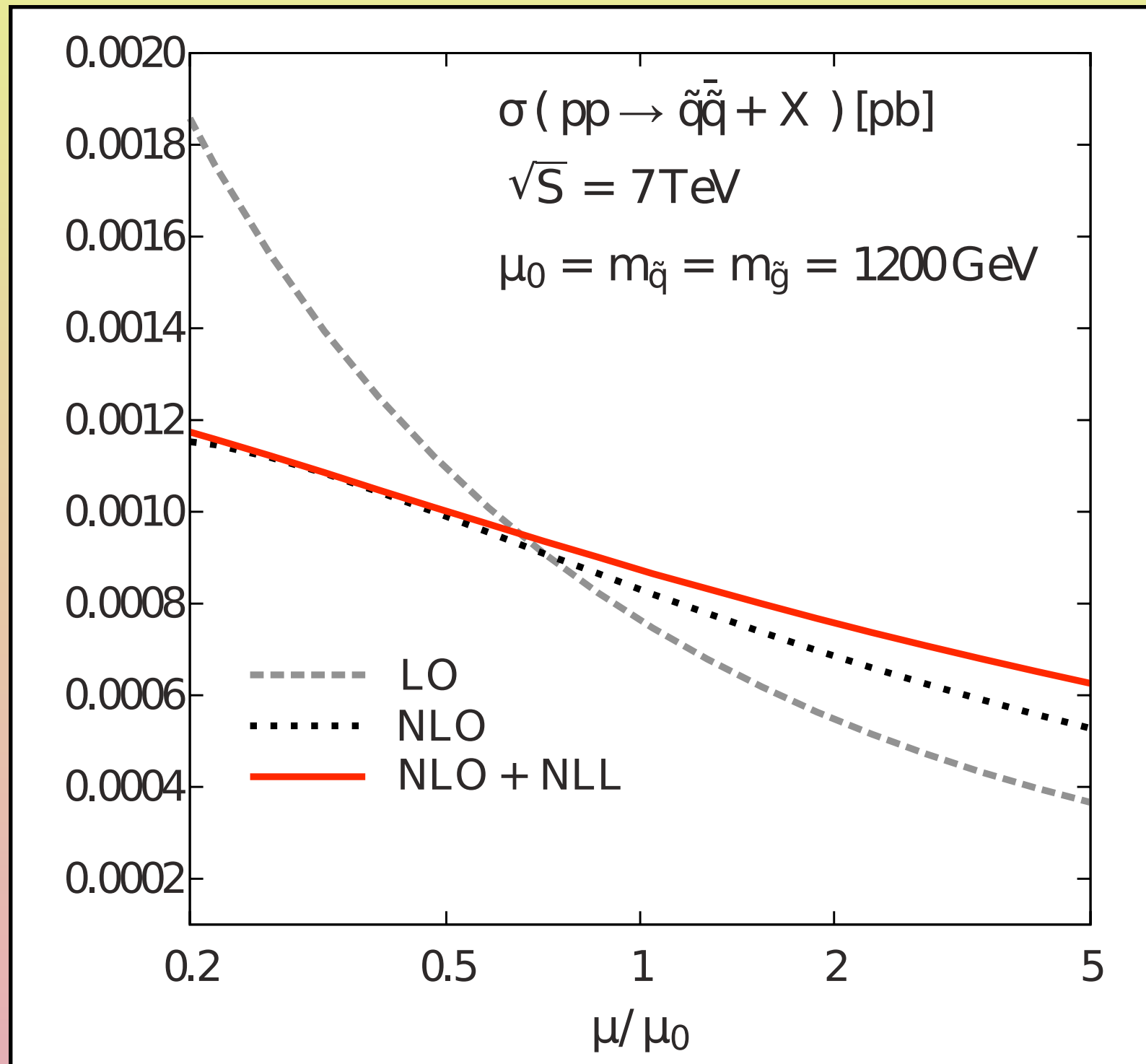

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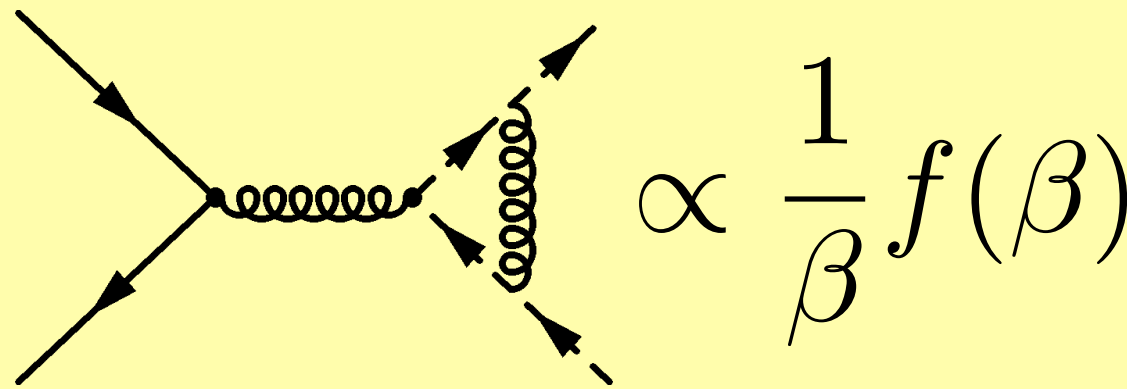
Leading Coulomb corrections
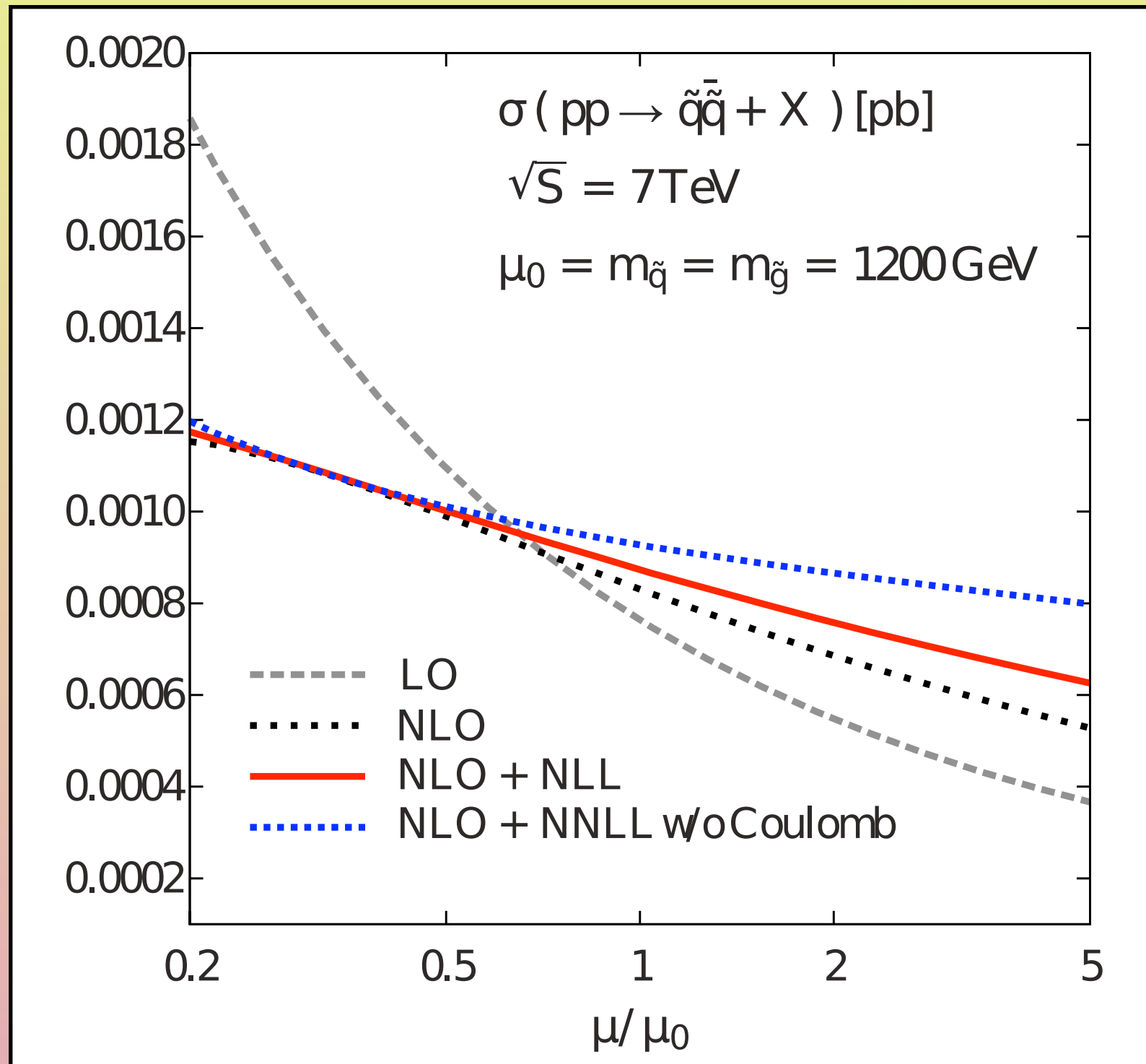(bound state effects)

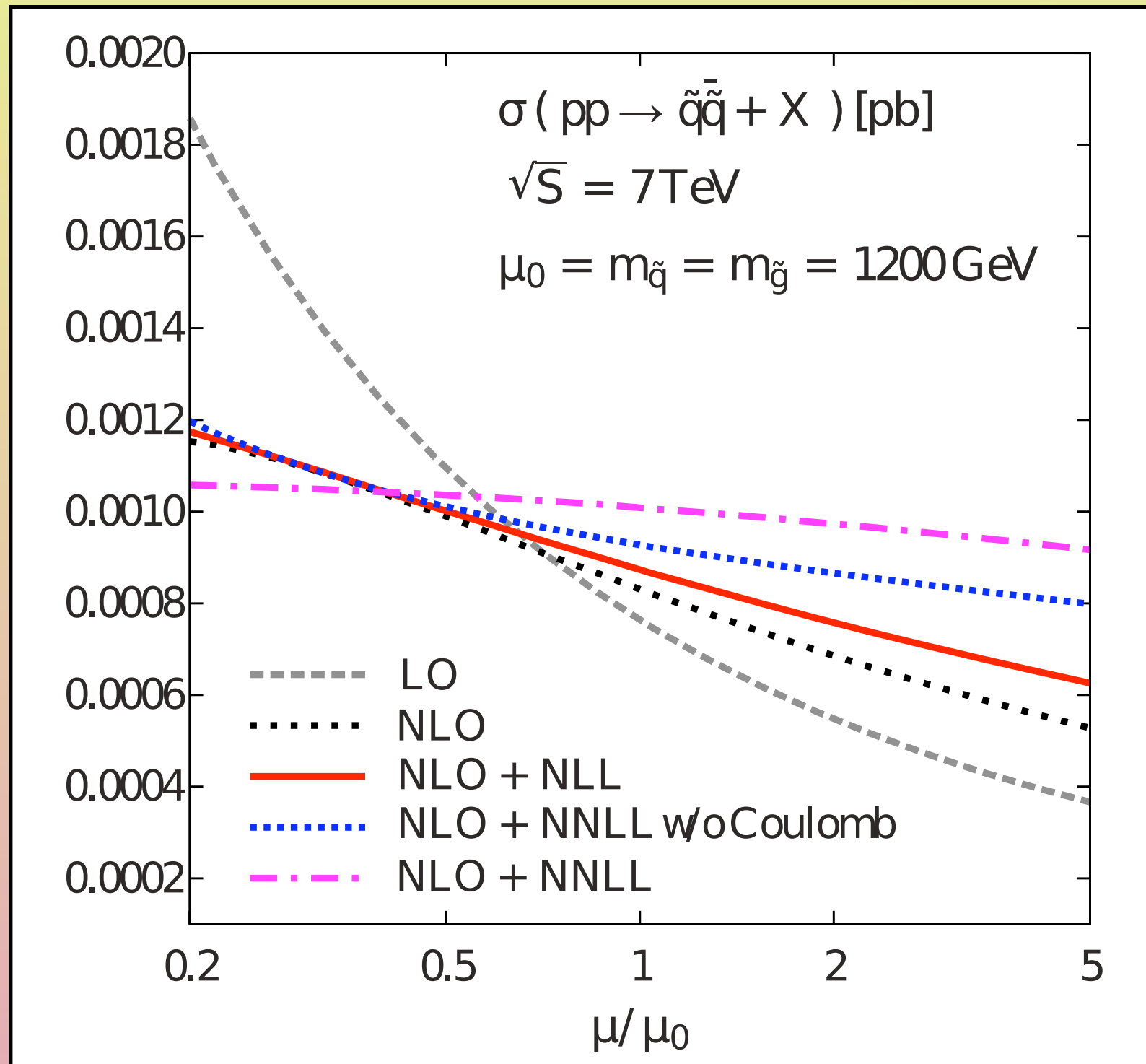Other NLO contributions

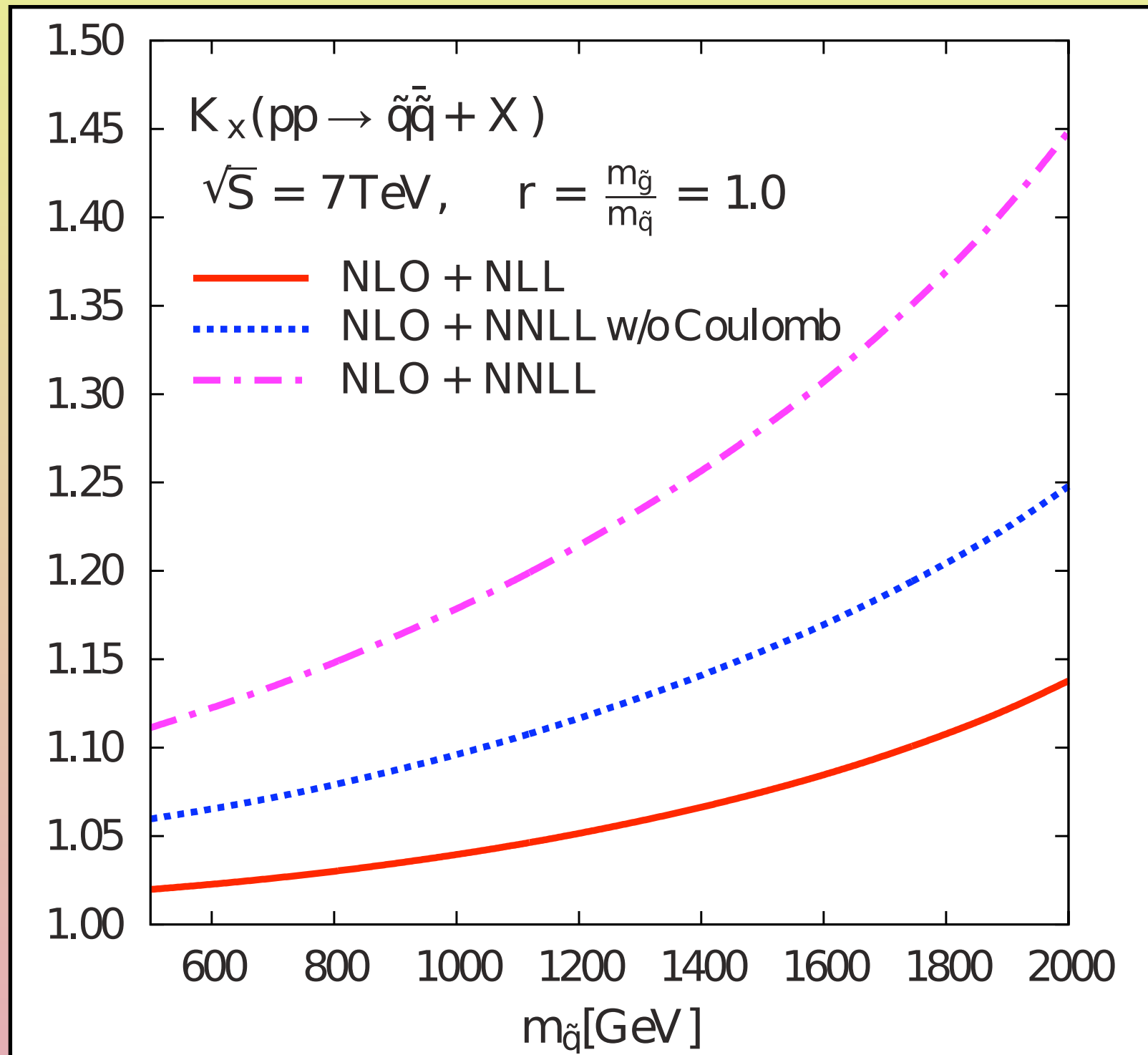# NNLL: scale dependence

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NNLL: K-factor

Conclusion

QCD resummation for SUSY:
- Reduces scale dependence
- Increases cross section at central scale
- NLLfast: code for NLL-resummed SUSY-QCD

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Still to do:

- Include anything experiments need in NLLfast
- Include other processes in NNLL calculation