Cross-section for top quark production at LHC
an update

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in collaboration with **P. Uwer**

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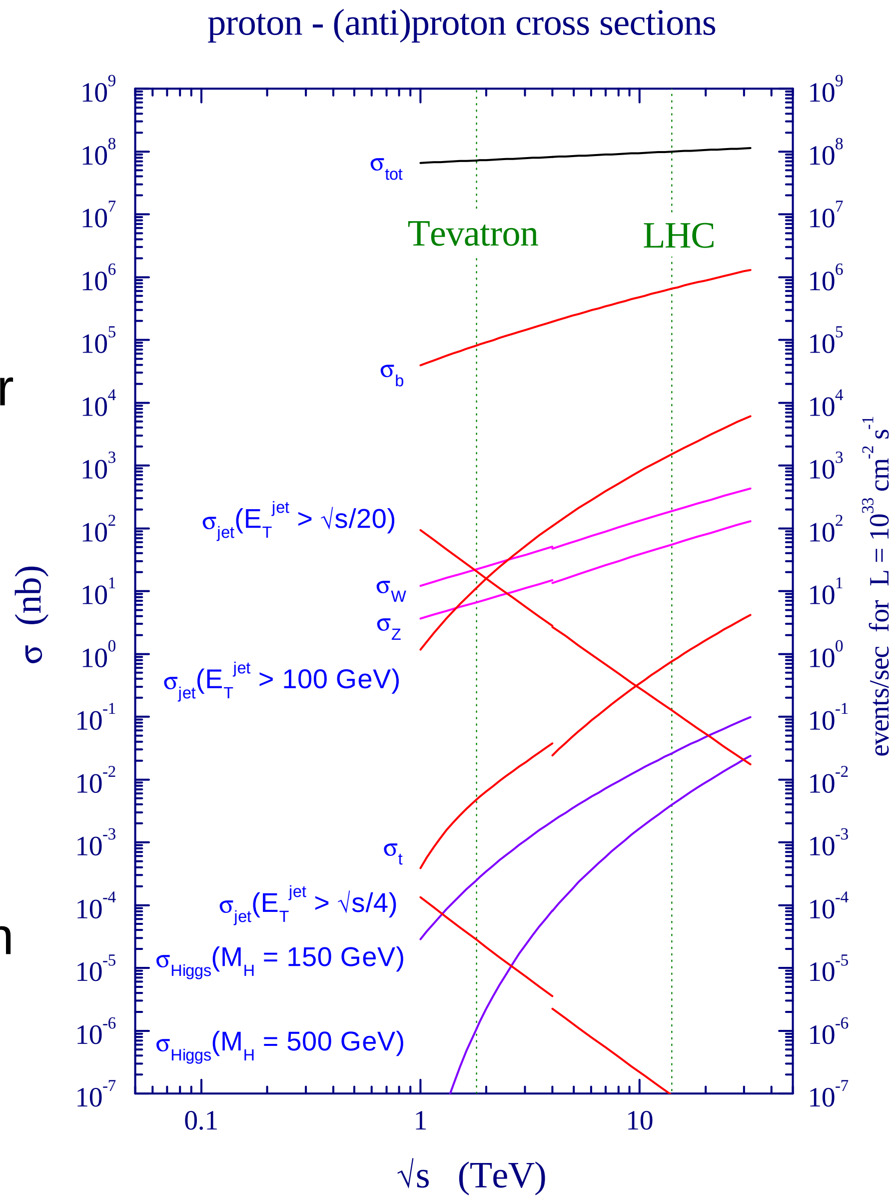
Top-production at the LHC

- LHC will accumulate very high statistics for $t\bar{t}$-pairs
  - low luminosity run: $8 \cdot 10^6$ events/year (high luminosity run: 10 times more)
  - mass measurement $\Delta m_t = \mathcal{O}(1)$GeV (constraints on Standard Model Higgs mass m_h)
  - top-spin correlations
  - search for anomalous couplings
- Tops make up large part of background in Higgs or new physics searches



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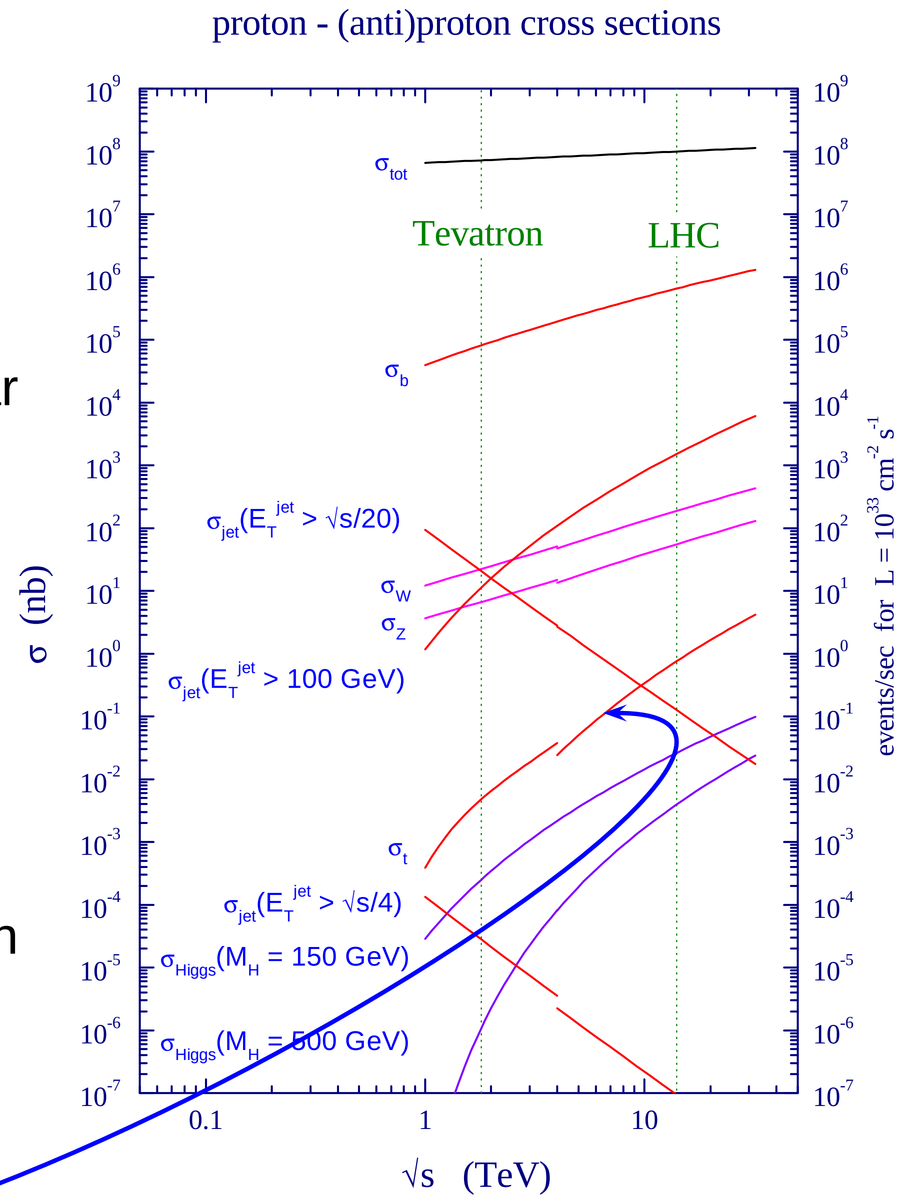

We are here !

Hard scattering at colliders

- QCD theory $\longrightarrow$ **factorization** of cross section
  - separate sensitivity to dynamics form different scales
  - center-of-mass energy S, factorization scale μ

$$\sigma_{\rm pp}\left(S,m^2\right)=\sum_{\rm ij} L_{\rm ij}\left(\mu^2\right)\otimes\hat{\sigma}_{\rm ij}\left(S,m^2,\mu^2,\alpha_s(\mu)\right)$$

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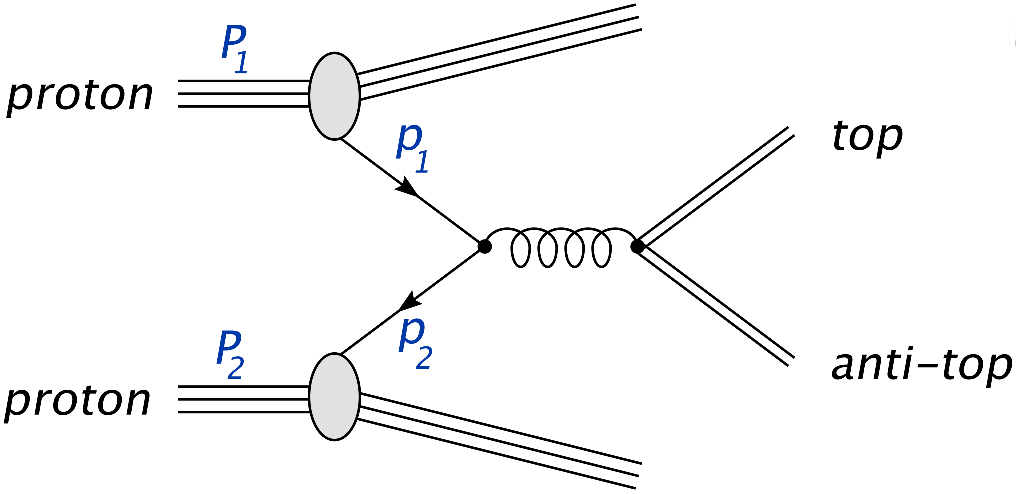
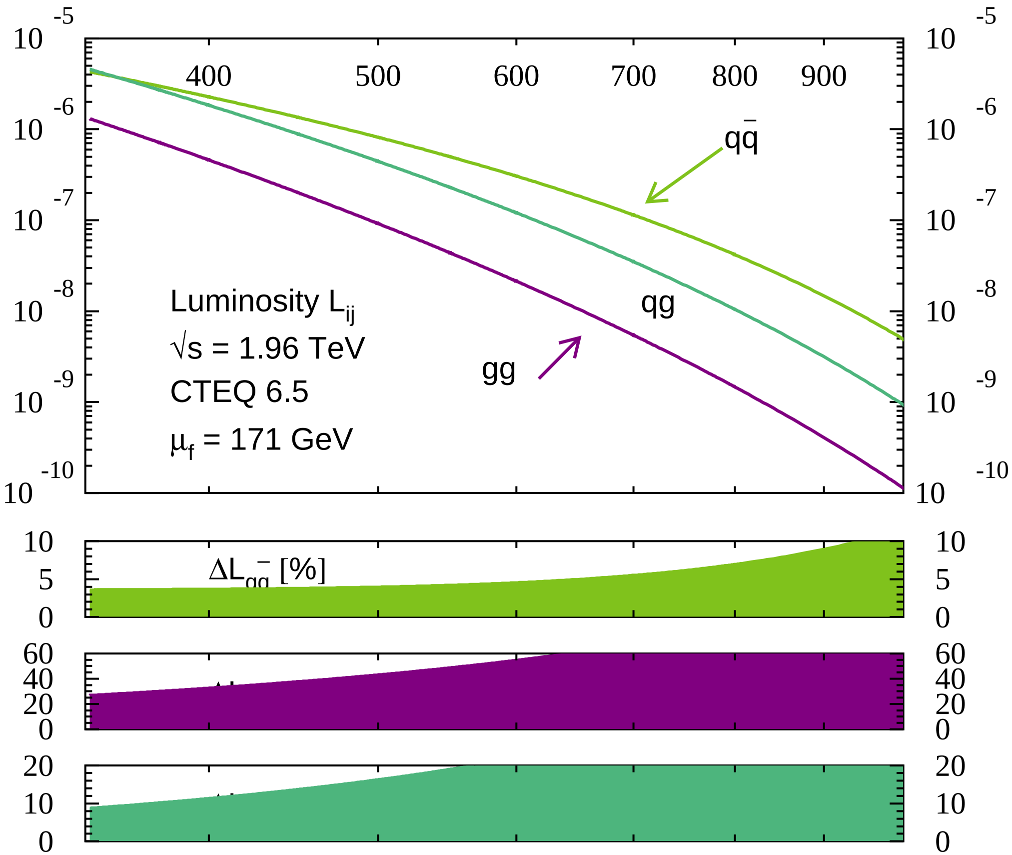


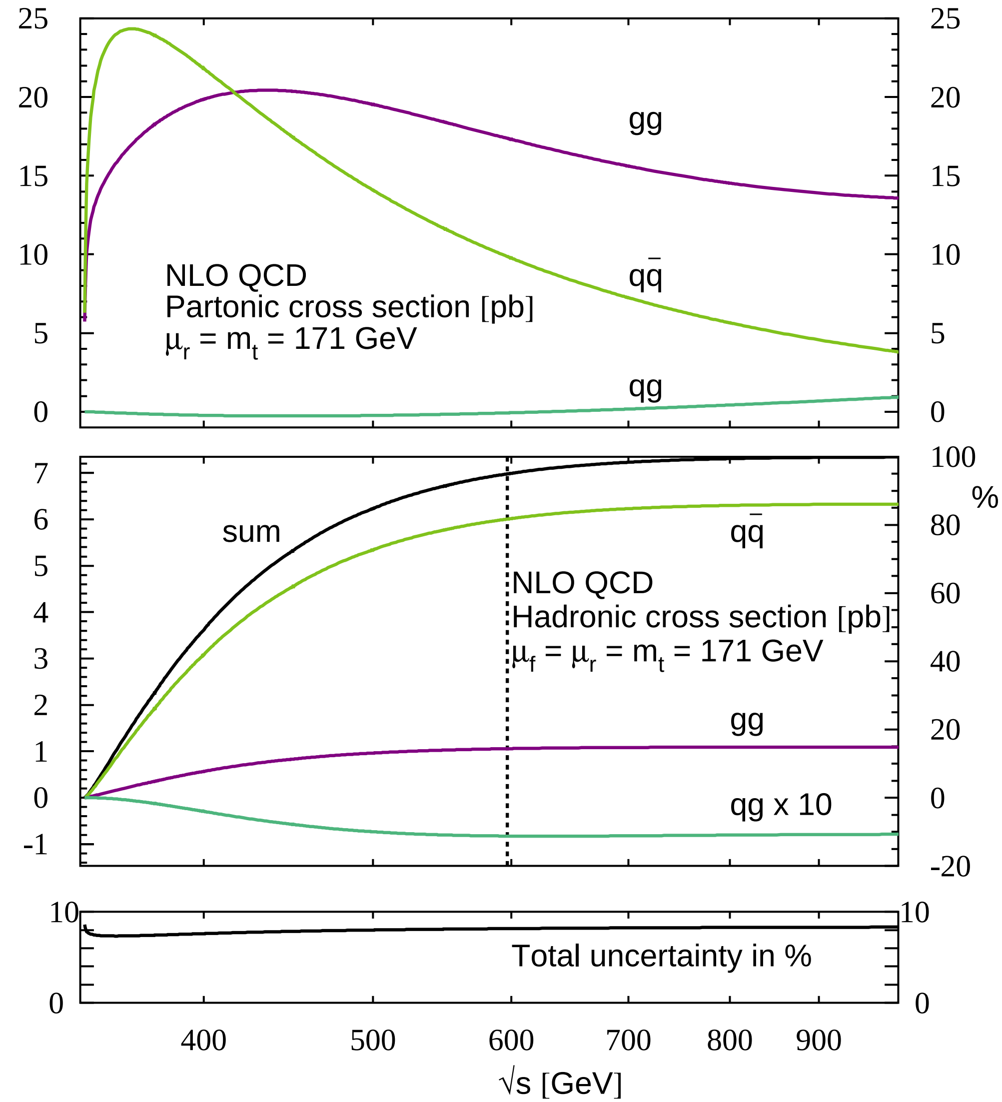
- Parton luminosity
  $L_{\rm ij} = PDF_{\rm i} \otimes PDF_{\rm j}$
- Theory predictions for $\hat{\sigma}_{\rm ij}$ in QCD with partonic channels
  - LO:
    $\rm q + \bar{q} \to Q + \bar{Q}$
    $\rm g + g \to Q + \bar{Q}$
  - NLO:
    $\rm q + g \to Q + \bar{Q} + \mathit{X}(q)$
  - NNLO:
    $\rm q + q \to Q + \bar{Q} + \mathit{X}(qq)$
    $\rm \bar{q} + \bar{q} \to Q + \bar{Q} + \mathit{X}(\bar{q}\bar{q})$

Total cross section

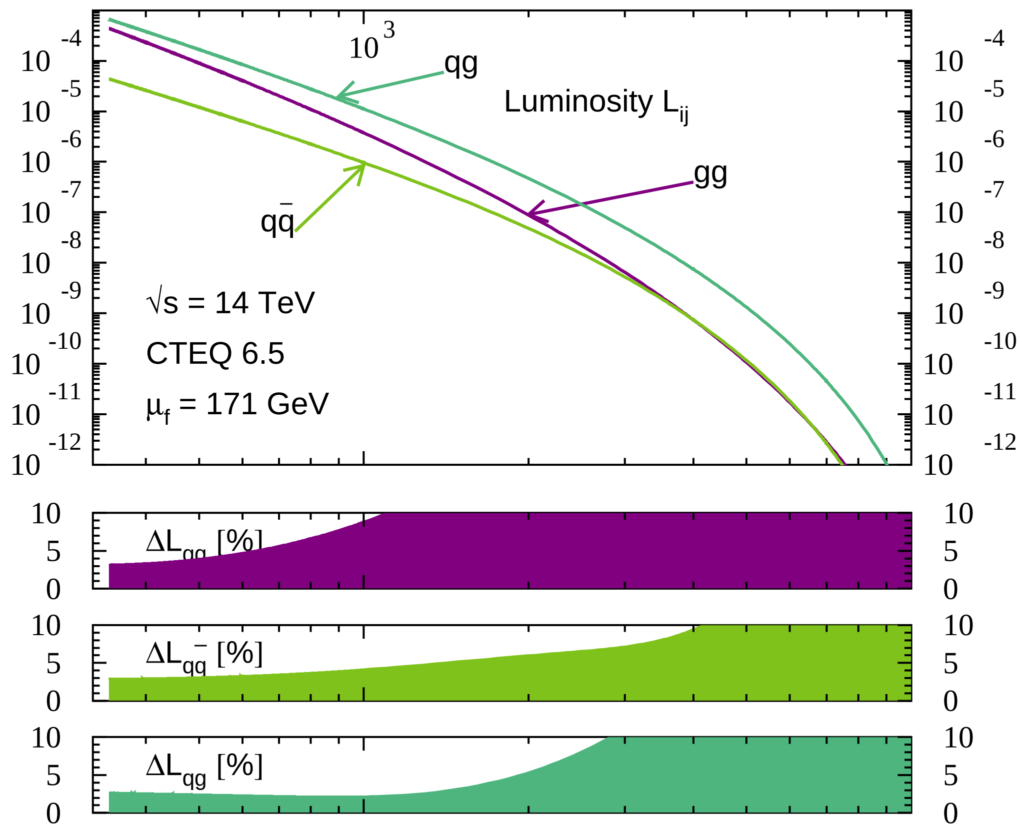
- Theory predictions for total cross section
  - NLO QCD Nason, Dawson, Ellis '88; Beenakker, Smith, van Neerven '89; Mangano, Nason, Ridolfi '92; Bernreuther, Brandenburg, Si, Uwer '04; ...
- Parton channels $\mathrm{q\bar{q}}$ and gg dominant
  - large parton luminosities $L_{\mathrm{q\bar{q}}}$ (Tevatron) and L_{gg} (LHC)
  - small qg $\longrightarrow$ at NLO (only $\mathcal{O}(1\%)$)
- Partonic threshold $s \simeq 4m^2$
  - Sudakov-type logarithms $\log(\beta)$ with velocity of heavy quark $\beta = \sqrt{1 - 4m^2/s}$
  - resummation important Kidonakis, Sterman '97; Bonciani, Catani, Mangano, Nason '98; Kidonakis, Laenen, S.M., Vogt '01; ...
    (however, at LHC much less than at Tevatron)
- High energy limit $s \gg m^2$
  - BFKL approach under active study Catani, Ciafaloni, Hautmann '91; ...; Ball '07

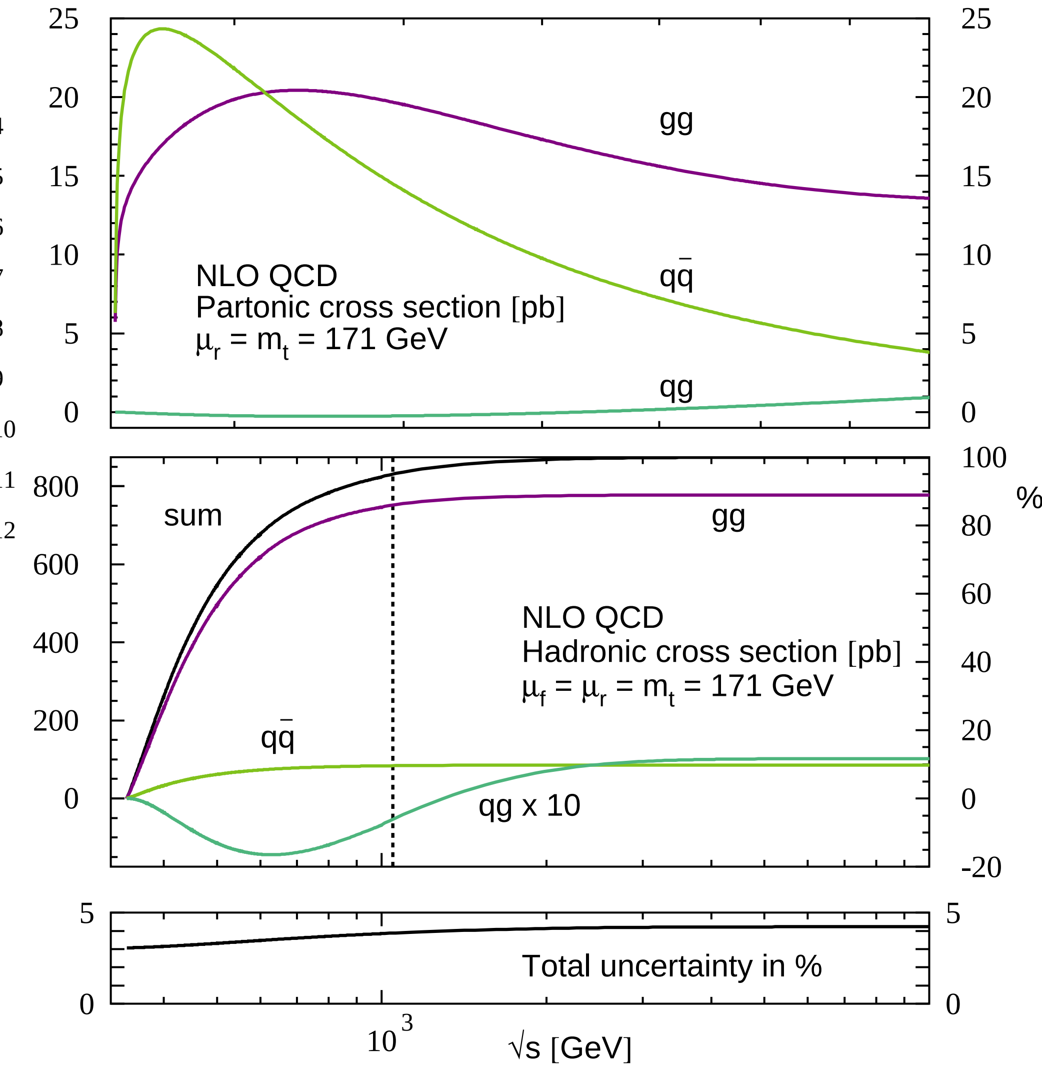
Total cross section at Tevatron





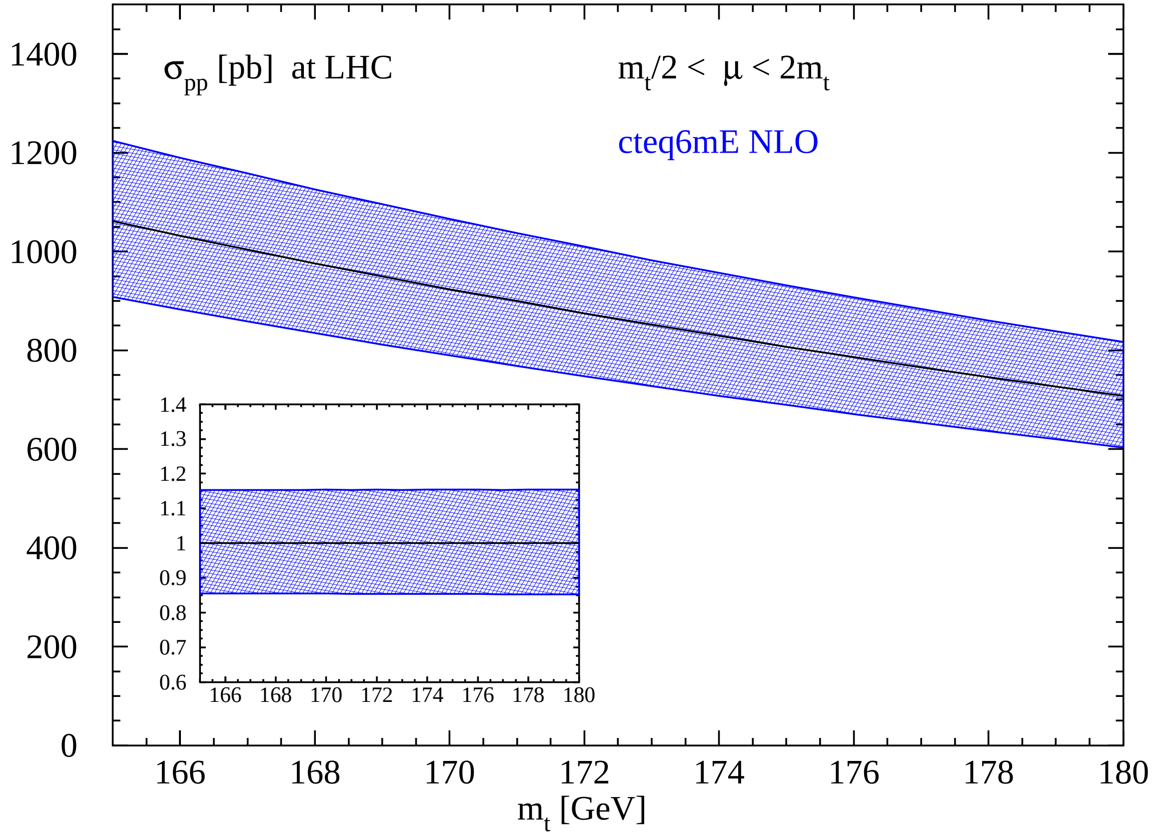
Total cross section at LHC





LHC total cross section

- Total theory uncertainty in QCD at NLO is of order $\mathcal{O}(15\%)$
  - scale uncertainty $\mathcal{O}(10\%)$
  - PDF uncertainty $\mathcal{O}(5\%)$ with additional dependence on PDF sets (e.g. $\mathcal{O}(3\%)$ shift in central value from CTEQ6mE to CTEQ6.5)



Heavy-quark hadro-production at two loops in QCD

- First steps beyond NLO: S.M., Mitov '06
  - look at soft and collinear limits of massive QCD amplitudes
  - relate massive to massless amplitudes in limit $m \to 0$
  - make folkore statement quantitative

$$\ln(m) \to \frac{1}{\epsilon} + \text{finite terms in } \epsilon$$

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- Amplitude for heavy-quark production in $q\bar{q}$-annihilation

$$|\mathcal{M}\rangle = 4\pi\alpha_s \left[|\mathcal{M}^{(0)}\rangle + \left(\frac{\alpha_s}{2\pi}\right) |\mathcal{M}^{(1)}\rangle + \left(\frac{\alpha_s}{2\pi}\right)^2 |\mathcal{M}^{(2)}\rangle + \mathcal{O}(\alpha_s^3) \right]$$

- Relate massive amplitude (interference with Born) up to power corrections in the mass $\mathcal{O}(m)$
  - e.g. use massless result for $q\bar{q} \to q'\bar{q}'$-scattering
    Anastasiou, Glover, Oleari, Tejeda-Yeomans '00

$$\text{Re}\,\langle\mathcal{M}^{(0)}|\mathcal{M}^{(2)}\rangle^{(m)} =$$

$$\text{Re}\,\langle\mathcal{M}^{(0)}|\mathcal{M}^{(2)}\rangle^{(m=0)} + Z^{(1)}\text{Re}\,\langle\mathcal{M}^{(0)}|\mathcal{M}^{(1)}\rangle^{(m=0)} + Z^{(2)}\langle\mathcal{M}^{(0)}|\mathcal{M}^{(0)}\rangle^{(m=0)}$$

Results

- Full result for heavy-quark hadro-production at two loops in QCD in limit $m^2 \ll s, t, u$ S.M., Czakon, Mitov '07
  - number of colors N and light/heavy quarks n_l/n_h

$$2\mathrm{Re}\,\langle \mathcal{M}^{(0)} | \mathcal{M}^{(2)} \rangle = 2(N^2 - 1)\Bigg(N^2 A + B$$

$$+ \frac{1}{N^2} C + N n_l D_l + N n_h D_h + \frac{n_l}{N} E_l + \frac{n_h}{N} E_h + (n_l + n_h)^2 F \Bigg)$$

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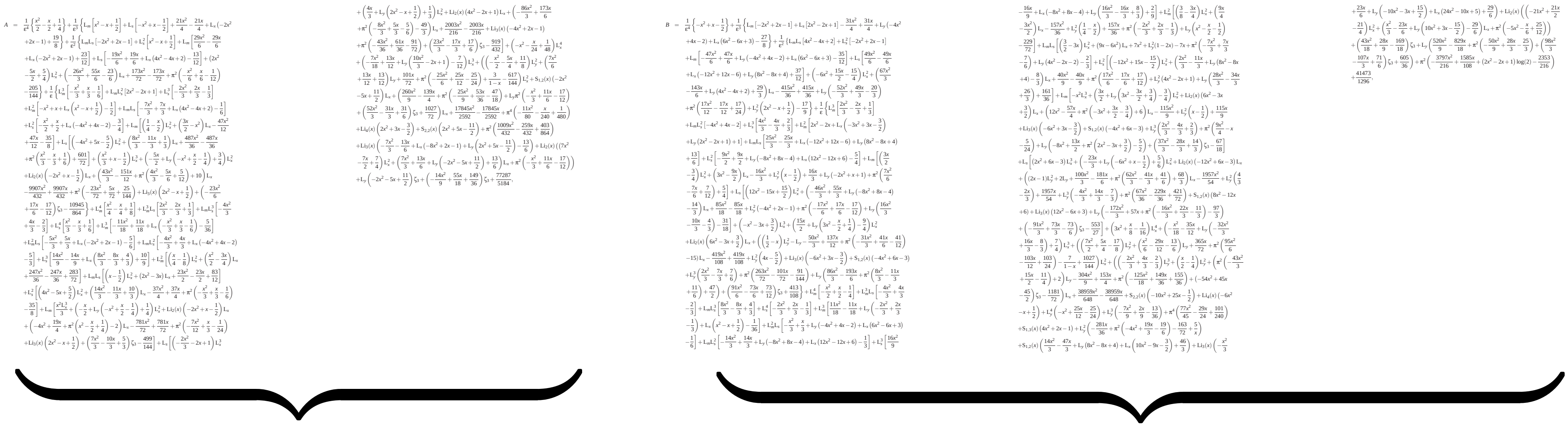

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Summary

Phenomenology

- Update on top-pair production at LHC
- Accuracy at NLO in QCD is of order $\mathcal{O}(15\%)$
  - scale uncertainty $\mathcal{O}(10\%)$ $\oplus$ PDF uncertainty $\mathcal{O}(5\%)$
  - additional dependence on PDF sets
- Numbers available soon . . .

Theory

- Factorization
  - relations between massless and massive amplitudes
  - amplitudes at NNLO in limit $m^2 \ll s, t, u$
- NNLO QCD corrections needed for accuracy better than $\mathcal{O}(10\%)$