Higher-order corrections to top-antitop pair and single top quark production

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- **QCD corrections and threshold resummation**
- **Two-loop soft anomalous dimensions**
- **Top pair production at Tevatron and LHC**
- **Single top production at Tevatron and LHC**

QCD corrections and resummation

QCD corrections significant for top quark production

NLO corrections fully known **Progress in NNLO corrections**

Incomplete cancellations of infrared divergences between virtual diagrams and real diagrams with soft (low-energy) gluons

Soft corrections $\left[\frac{\ln^k(s_4/m^2)}{s_4}\right]_+$ **with** $k \leq 2n-1$ **and** s_4 **distance from threshold**

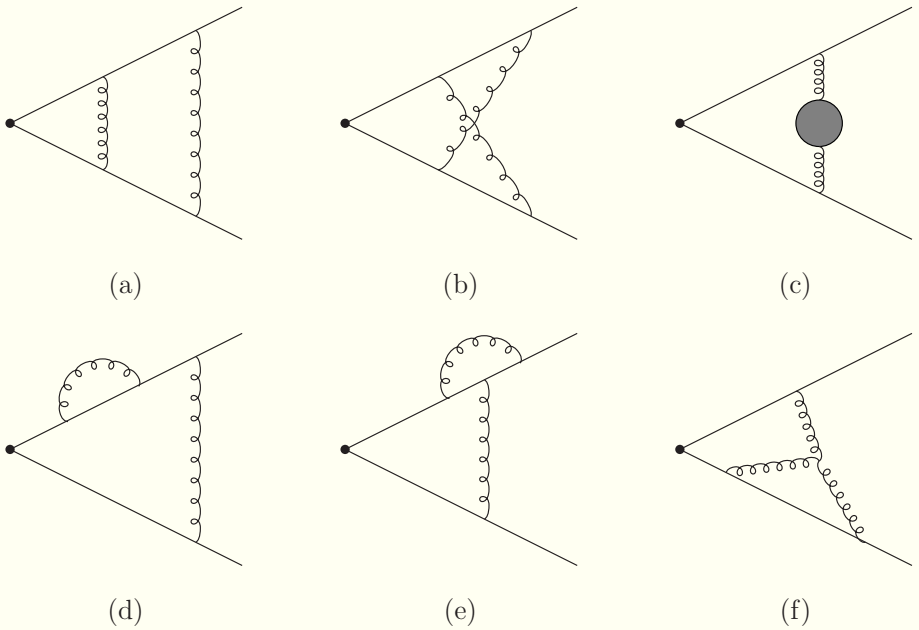
Soft-gluon corrections are dominant near threshold

Resum (exponentiate) these soft corrections

At NLL (NNLL) accuracy requires one-loop (two-loop) calculations in the eikonal approximation

Approximate NNLO cross section from expansion of resummed cross section

Two-loop soft-gluon resummation for top quarks



Calculation of two-loop soft anomalous dimension N.K., Phys. Rev. Lett. 102, 232003 (2009)

Eikonal approximation – Isolate UV poles in dimensional regularization

This allows NNLL resummation

Other recent progress Sterman et al; Becher&Neubert; Beneke et al

Theoretical formalisms and applications

NLL (and beyond) resummation at differential level (NK,Sterman)

-Full dependence on kinematics

Inclusive calculations (approximation- not exact kinematics dependence):

Cacciari et al - NLL

Moch& Uwer - claim NNLL, but missing terms; expanded to NNLO

Fully differential calculations (NK, R. Vogt; based on NK, Sterman formalism):

NNLO expansion with soft terms, including most NNLL

-sensitivity to exact kinematics

-total cross section and p_T distributions

Top quark hadroproduction

Dominant process is pair production $q\bar{q} \rightarrow t\bar{t}$ and $gg \rightarrow t\bar{t}$

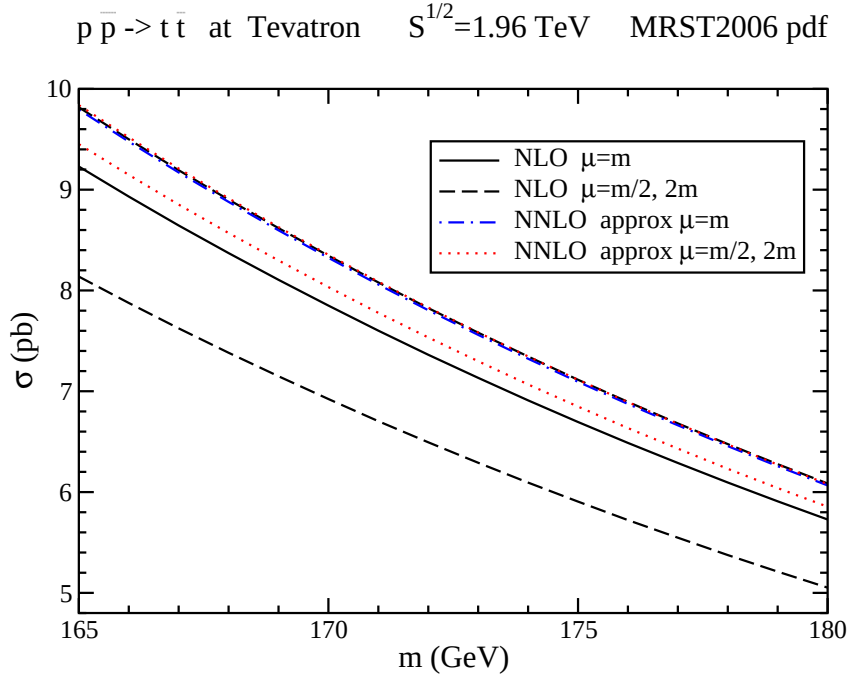
Very good agreement of theory (with soft-gluon corrections) with Tevatron data

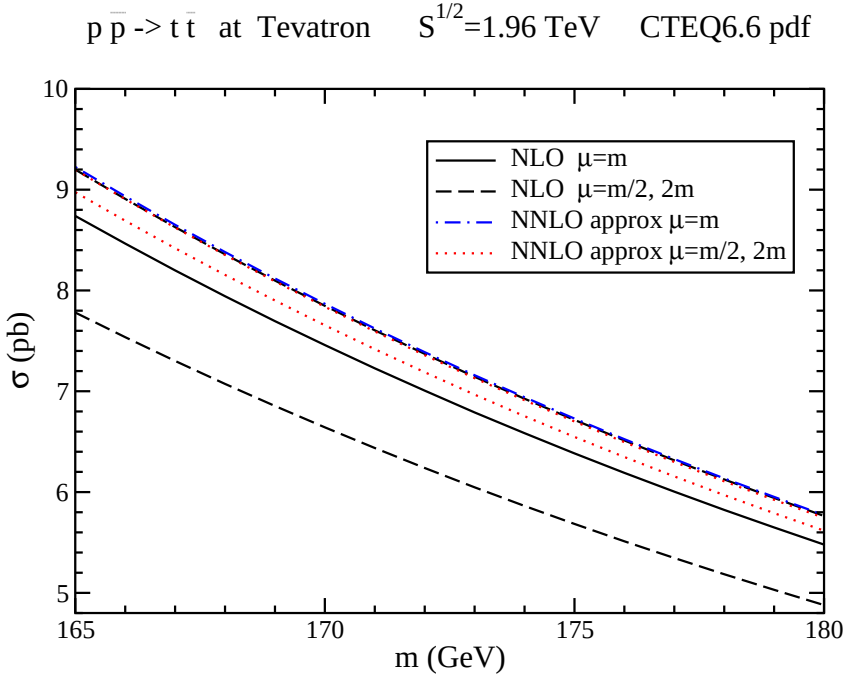
Theory and experiment have reduced uncertainties

Recent observation of single top production
- cross section consistent with theory

Opportunities for study of electroweak properties of the top

Top quark pair cross section at the Tevatron





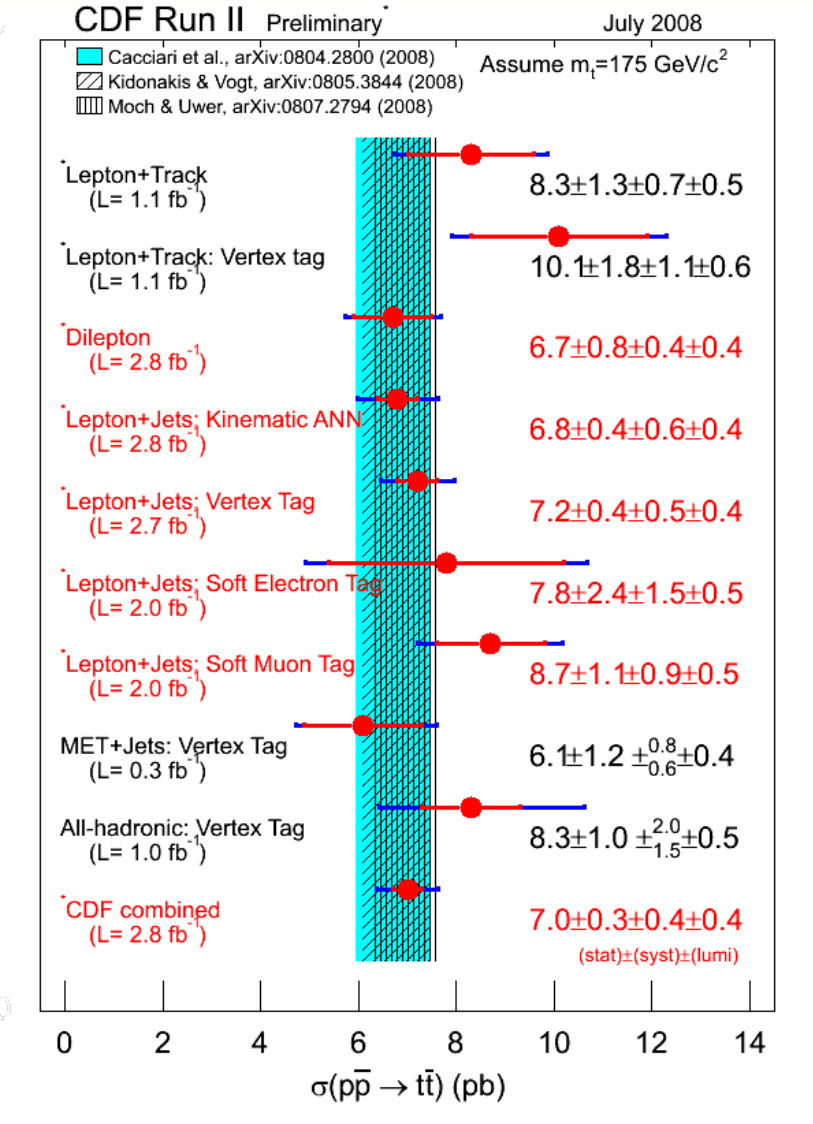
(NK, R. Vogt)

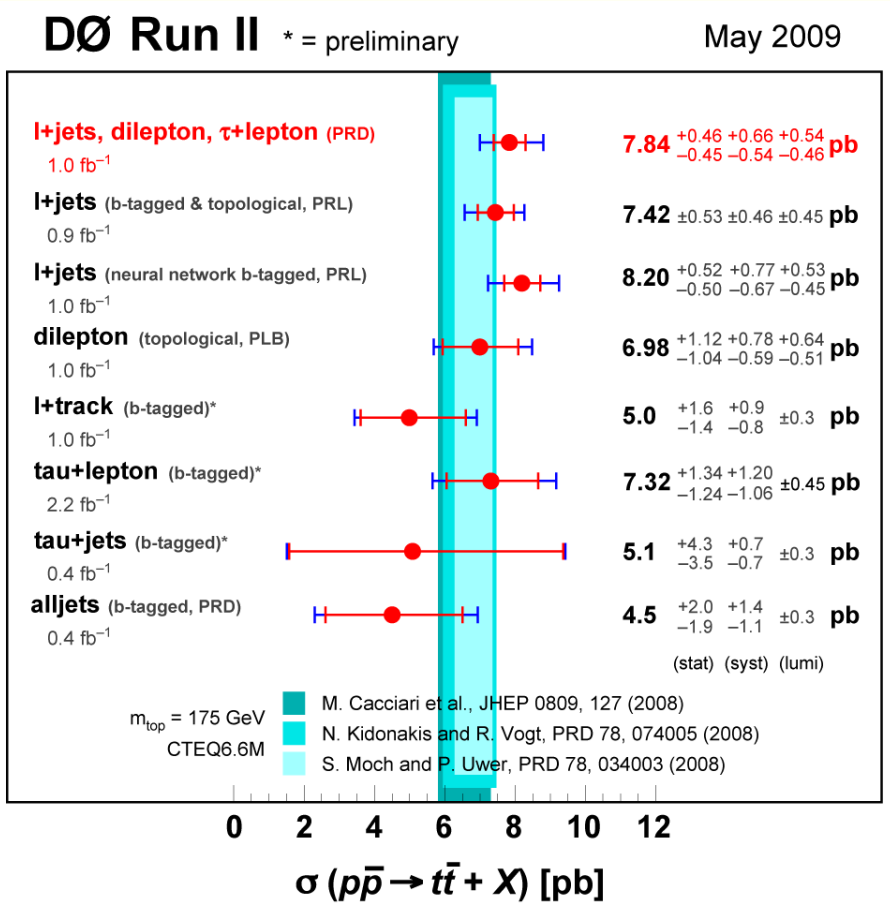
$$\sigma^{\rm NNLOapprox}_{p\bar{p}\to t\bar{t}}(1.96\,{\rm TeV}, m=172\,{\rm GeV}, {\rm MRST}) = 7.80 \pm 0.31\,^{+0.03}_{-0.27}\,^{+0.23}_{-0.19}\,{\rm pb} = 7.80\,^{+0.39}_{-0.45}\,{\rm pb}$$

$$\sigma^{\rm NNLOapprox}_{p\bar{p}\to t\bar{t}}(1.96\,{\rm TeV}, m=172\,{\rm GeV}, {\rm CTEQ}) = 7.39 \pm 0.30\,^{-0.03}_{-0.20}\,^{+0.48}_{-0.37}\,{\rm pb} = 7.39\,^{+0.57}_{-0.52}\,{\rm pb}$$

$$\sigma^{\rm NNLOapprox}_{p\bar{p}\to t\bar{t}}(1.96\,{\rm TeV}, m=172\,{\rm GeV}, {\rm MSTW}) = 7.24 \pm 0.24\,^{+0.03}_{-0.20}\,^{+0.18}_{-0.13}\,{\rm pb} = 7.24\,^{+0.30}_{-0.34}\,{\rm pb}$$

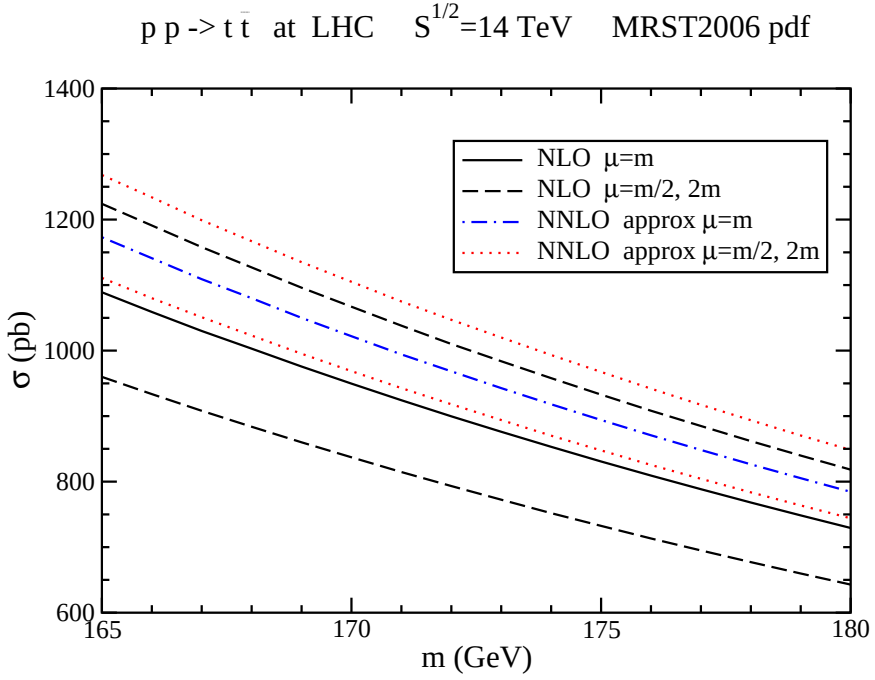
Kinematics uncertainty, scale variation, pdf errors

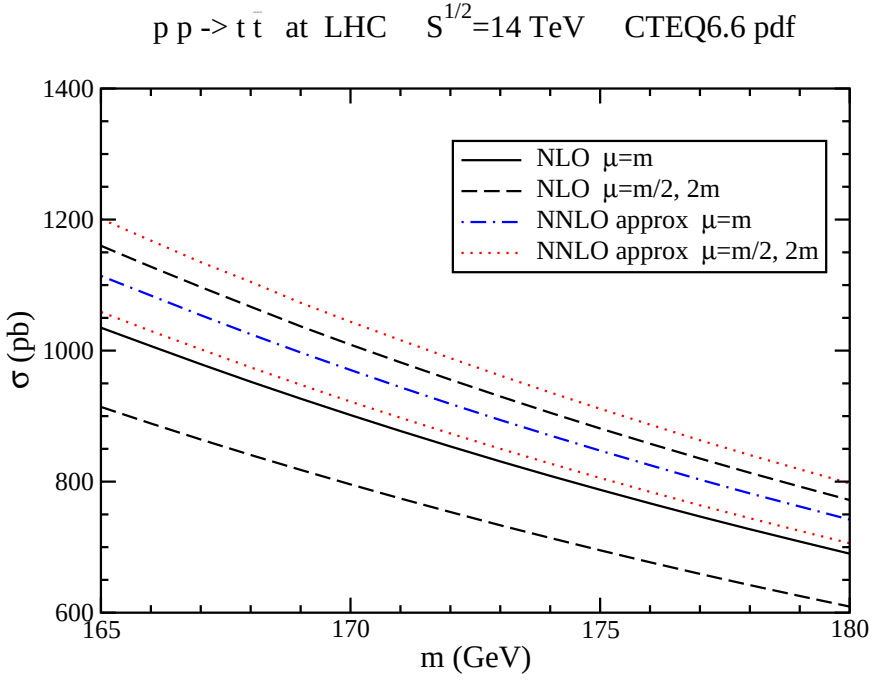




Experimental and theoretical uncertainties are of similar size

Top quark pair cross section at the LHC





(NK, R. Vogt)

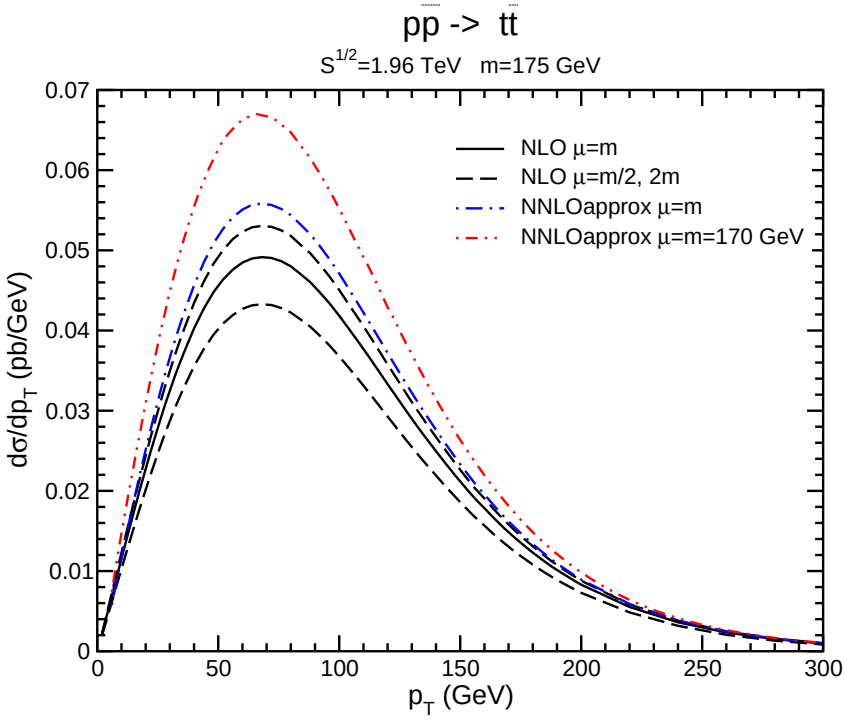
$$\sigma^{\mathrm{NNLOapprox}}_{pp\to t\bar{t}}(14\,\mathrm{TeV}, m = 172\,\mathrm{GeV}, \mathrm{MRST}) = 968 \pm 4\,^{+79}_{-50}\,^{+12}_{-13}\,\mathrm{pb} = 968\,^{+80}_{-52}\,\mathrm{pb}$$

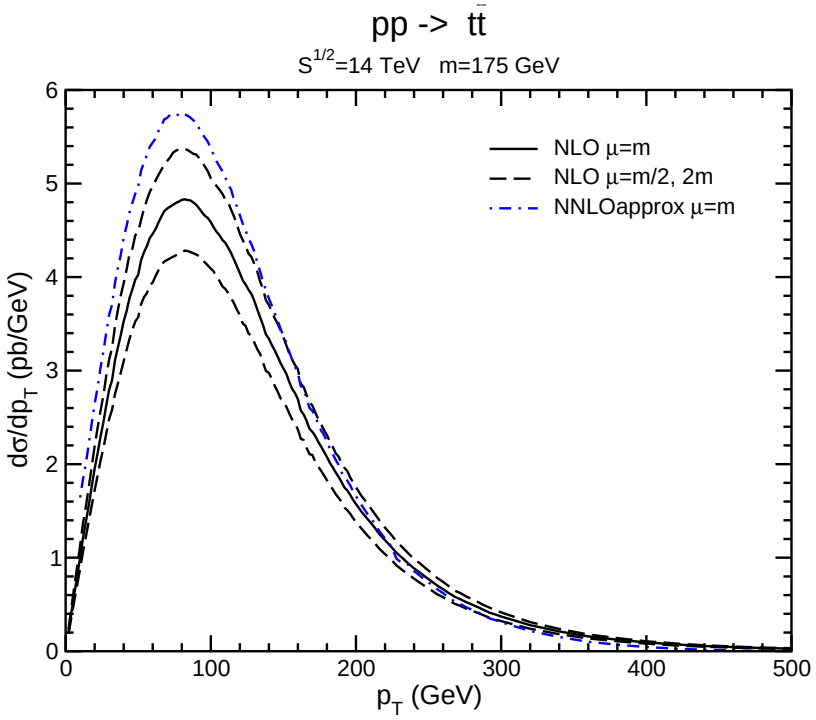
$$\sigma^{\mathrm{NNLOapprox}}_{pp\to t\bar{t}}(14\,\mathrm{TeV}, m = 172\,\mathrm{GeV}, \mathrm{CTEQ}) = 919 \pm 4\,^{+70}_{-45}\,^{+29}_{-31}\,\mathrm{pb} = 919\,^{+76}_{-55}\,\mathrm{pb}$$

$$\sigma^{\mathrm{NNLOapprox}}_{pp\to t\bar{t}}(14\,\mathrm{TeV}, m = 172\,\mathrm{GeV}, \mathrm{MSTW}) = 949 \pm 3\,^{+64}_{-33}\,^{+16}_{-18}\,\mathrm{pb} = 949\,^{+66}_{-38}\,\mathrm{pb}$$

Kinematics uncertainty, scale variation, pdf errors

Top quark p_T distribution at Tevatron and LHC

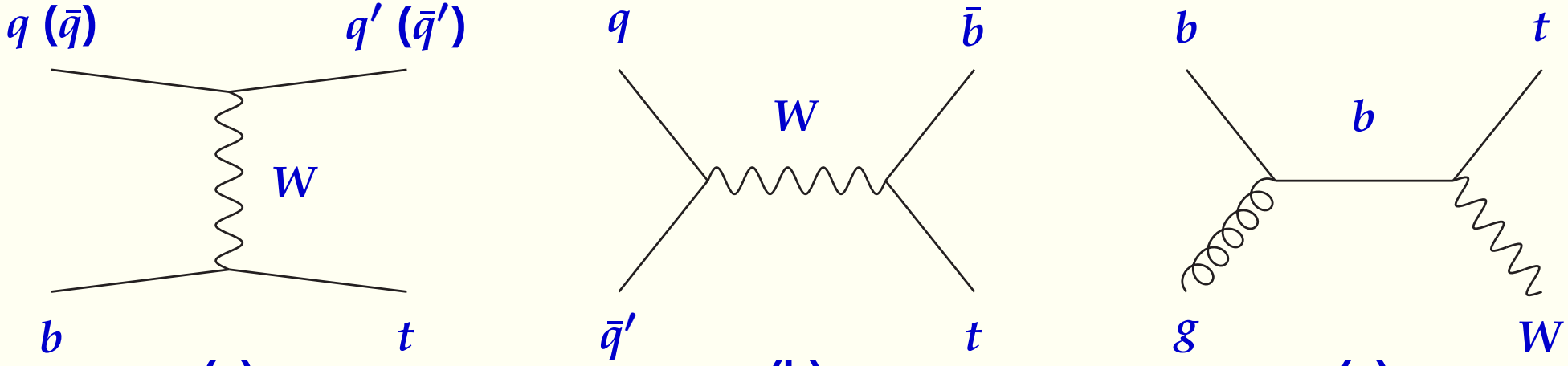




Enhancement at higher-order but similar shape

Single top quark production

Partonic processes at LO

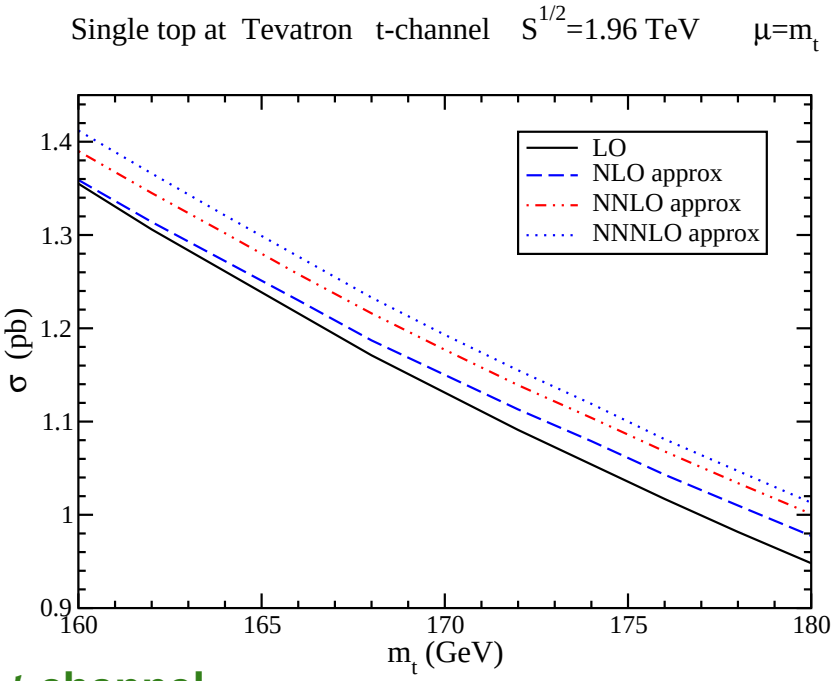


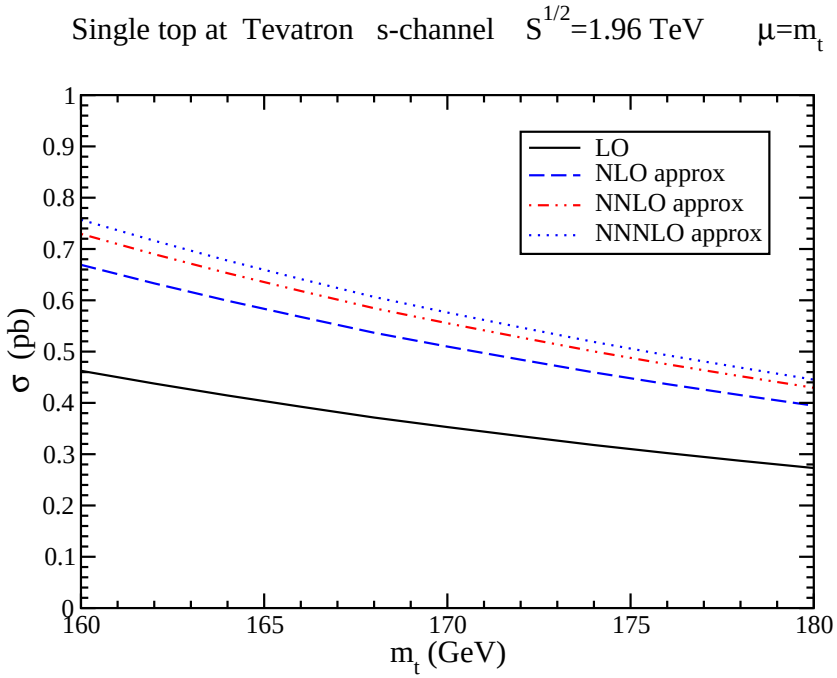
(a) t channel: $qb \longrightarrow q't$ and $\bar{q}b \longrightarrow \bar{q}'t$ ($ub \longrightarrow dt$ and $\bar{d}b \longrightarrow \bar{u}t$, etc.)

(b) s channel: $q\bar{q}' \longrightarrow \bar{b}t$ ($u\bar{d} \longrightarrow \bar{b}t$, etc)

(c) associated tW production: $bg \longrightarrow tW^-$

Single top production at the Tevatron - t and s channels





t channel

$$\sigma^{\mathrm{NNNLOapprox}}_{t-\mathrm{channel}}(m_t = 172\,\mathrm{GeV}, \mathrm{MRST}) = 1.14 \pm 0.06\ \mathrm{pb}$$

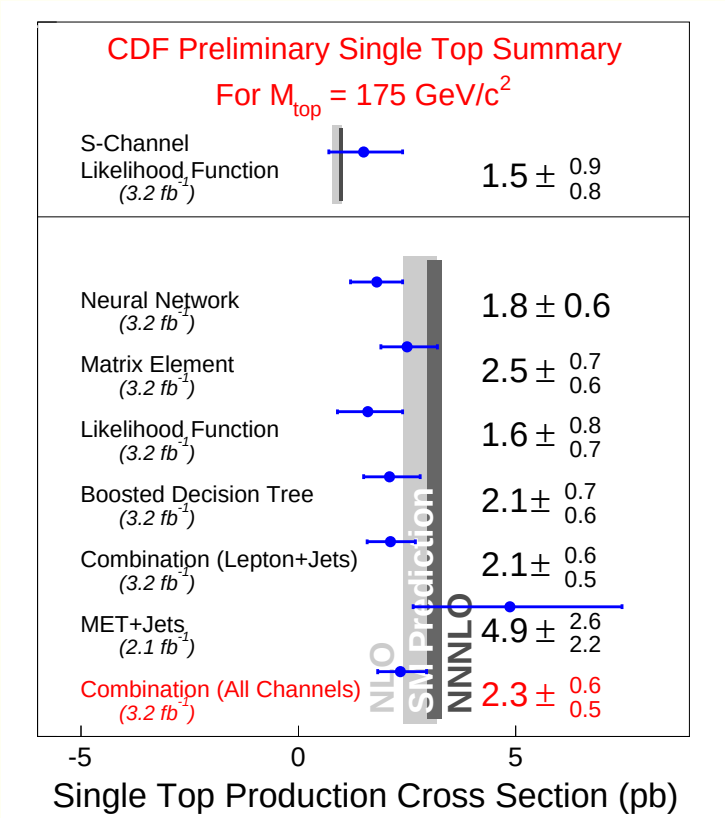
$$\sigma^{\mathrm{NNNLOapprox}}_{t-\mathrm{channel}}(m_t = 172\,\mathrm{GeV}, \mathrm{CTEQ}) = 1.07 \pm 0.11\ \mathrm{pb}$$

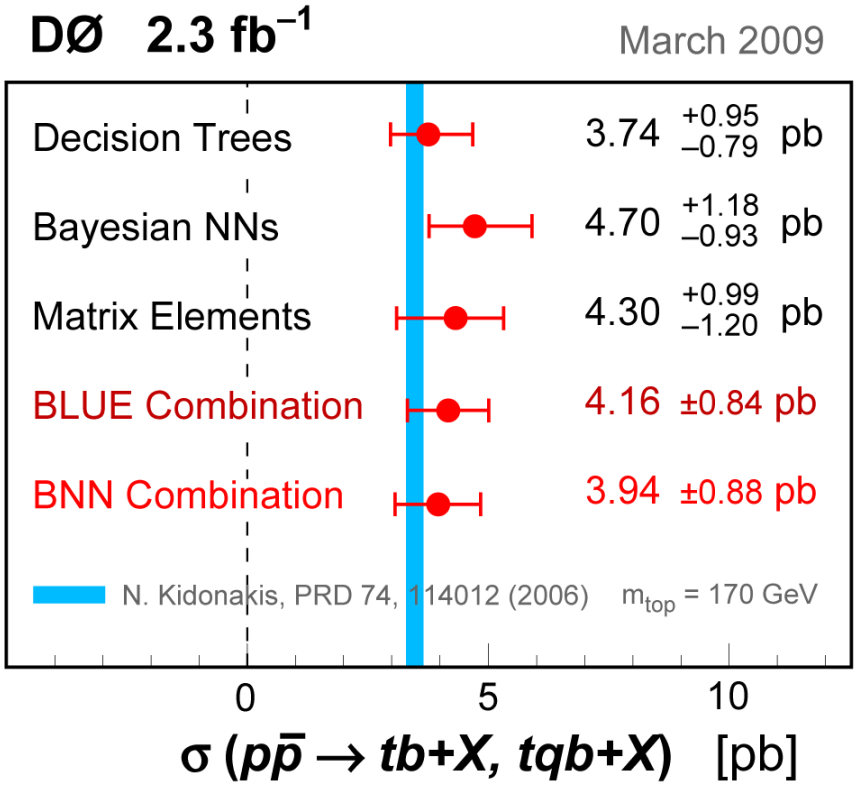
s channel

$$\sigma^{\mathrm{NNNLOapprox}}_{s-\mathrm{channel}}(m_t = 172\,\mathrm{GeV}, \mathrm{MRST}) = 0.53 \pm 0.02\ \mathrm{pb}$$

$$\sigma^{\mathrm{NNNLOapprox}}_{s-\mathrm{channel}}(m_t = 172\,\mathrm{GeV}, \mathrm{CTEQ}) = 0.54 \pm 0.03\ \mathrm{pb}$$

Cross section for anti-top production is identical





Experimental uncertainties are large

Single top production at the LHC

t channel

Threshold corrections not a good approximation of full QCD corrections

$$\sigma^{\text{NLO, top}}_{t-\text{channel}}(m_t = 172\,\text{GeV}, \text{MRST}) = 149 \pm 6\ \text{pb}$$

$$\sigma^{\text{NLO, antitop}}_{t-\text{channel}}(m_t = 172\,\text{GeV}, \text{MRST}) = 91 \pm 4\ \text{pb}$$

s channel

$$\sigma^{\text{NNNLOapprox, top}}_{s-\text{channel}}(m_t = 172\,\text{GeV}, \text{MRST}) = 7.7^{+0.6}_{-0.5}\ \text{pb}$$

$$\sigma^{\text{NNNLOapprox, antitop}}_{s-\text{channel}}(m_t = 172\,\text{GeV}, \text{MRST}) = 4.3 \pm 0.2\ \text{pb}$$

tW channel

$$\sigma^{\text{NNNLOapprox}}_{tW}(m_t = 172\,\text{GeV}, \text{MRST}) = 43 \pm 5\ \text{pb}$$

Cross section for $\bar{t}W$ production is identical

Summary and Outlook

- **Top pair and single top production at the Tevatron**
- **Data agrees with theory - uncertainties of similar size**
- **LHC - top quark factory**
- **Increased accuracy for top cross section**
- **Theoretical progress in higher-order QCD corrections**