# QED Corrections to Top Pair Production at the LHC

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# Outline

- motivation & present status
- QED corrections
- hadronic cross section
- numerical results
- conclusions and outlook

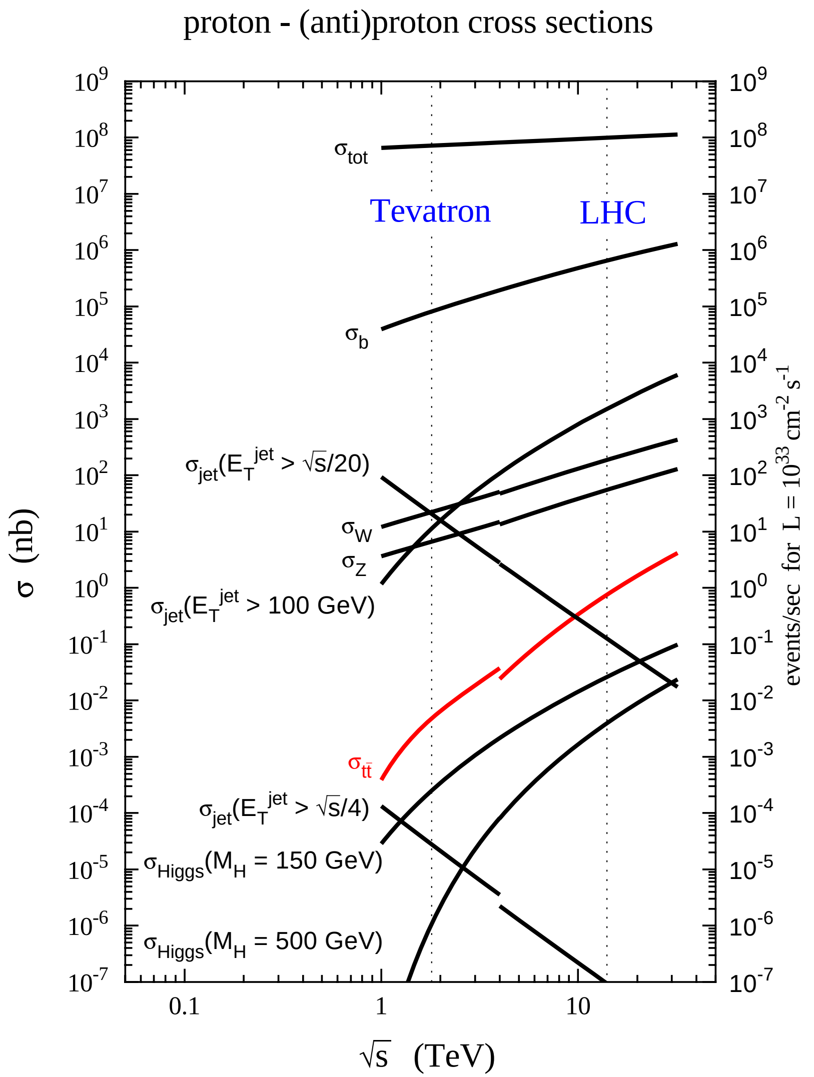
# Motivation

LHC :

- pp collisions at $\sqrt{S} = 14$ TeV
- $\sigma_{t\bar{t}}$ ~ 800 pb
- about 8 million $t\bar{t}$ pairs/year
- top factory

Tevatron :

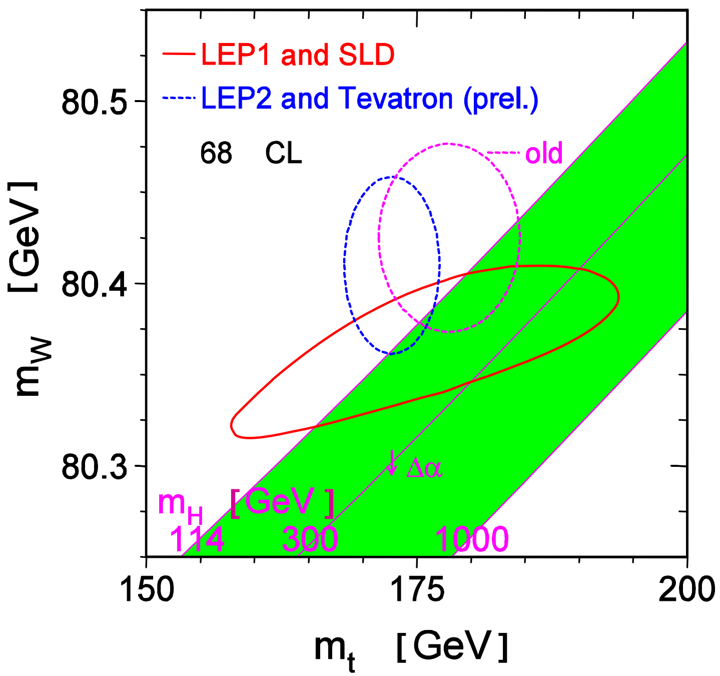
- $p\bar{p}$ collisions
- Run II at $\sqrt{S} = 1.96$ TeV
- $\sigma_{t\bar{t}}$ ~ 7 pb



# Motivation

top pair cross section :

- precise determination of the top mass
  - constraint on the Higgs mass
  - input parameter to SM extensions
- consistency checks of the SM
- search for new physics in the $t\bar{t}$ invariant mass spectrum




observed deviation → signal for new physics

**precise predictions are important**

# Motivation - Status

present status of higher order calculations :

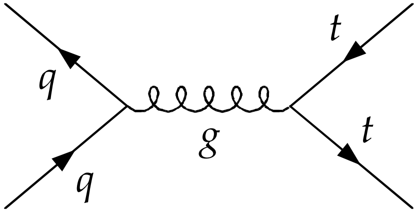
- QCD NLO corrections [Dawson, Ellis, Nason ’88]
- EW NLO corrections [Beenakker et al ’93]
- NLO+NLL resummation [Bonciani, Catani, Mangano, Nason ’98]

however, QED corrections are missing

- gauge invariant subclass of full EW corrections
- needed to complete the SM 1-loop picture
- zero mass of the photon leads to IR singularities which have to be compensated

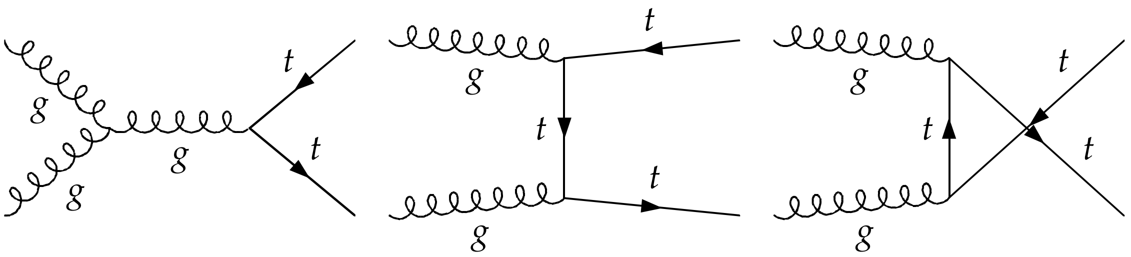
# Partonic Process – Born level

## quark – antiquark annihilation




~ 90% at the Tevatron

## gluon fusion




~ 90% at the LHC

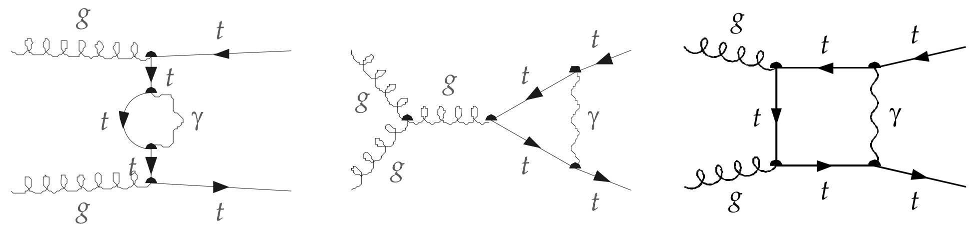
QED NLO contributions: $\mathbf{O(\alpha\alpha_s^2)}$

# QED 1-loop corrections

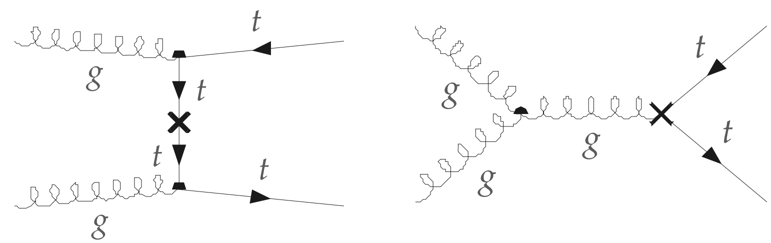
classification of virtual corrections:

- no gluon field and strong coupling renormalisation
- **IR divergences**

**cancel if add**

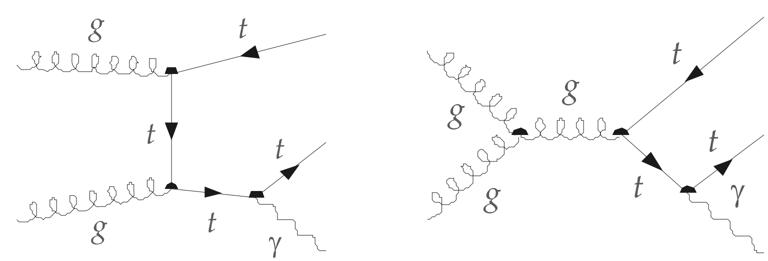



self vertex box




counter terms

real corrections – photon bremsstrahlung




bremsstrahlung

IR finite { virtual corrections / real corrections

# QED 1-loop corrections

## gluon fusion & quark-antiquark annihilation:

- IR singularities regularised by photon mass parameter $\lambda$
- soft singularities combined using phase space slicing (substraction method)
- phase space slicing:
- photon bremsstrahlung – soft part: $E_\gamma \leq \Delta E$ analytically, soft photon approximation
  – hard part: $E_\gamma > \Delta E$ numerically, Monte Carlo
- $\sigma_{1\text{-loop}} = \sigma_{Born}\,(1 + \delta_{virt} + \delta_{soft}) + \sigma_{hard}$ - independent of $\lambda$, $\Delta E$

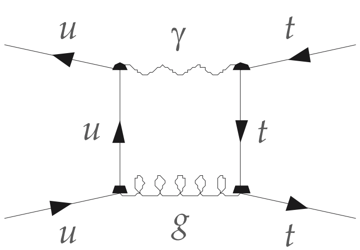
## quark-antiquark annihilation:

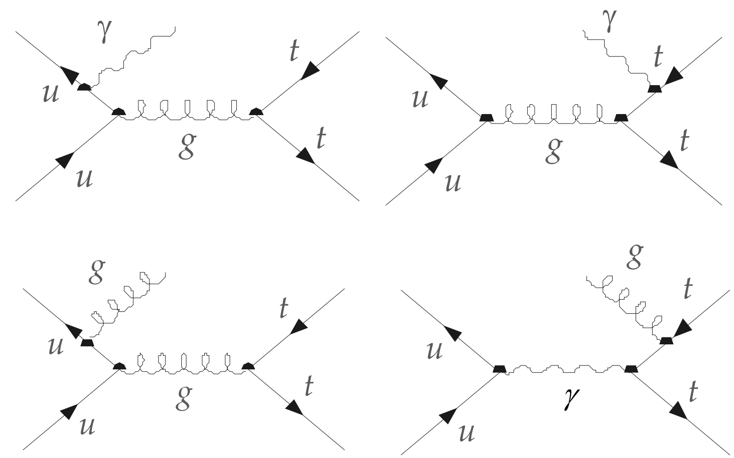
- quark masses neglected unless in loop integrals
- collinear singularities regularised by quark mass $m_q$ – large terms log $m_q$ – in the initial state only
- photon spectrum – collinear part: $\theta_{f\gamma} \leq \Delta\theta$ analytically
  – non-collinear part: $\theta_{f\gamma} > \Delta\theta$ numerically, Monte Carlo
- $\sigma_{1\text{-loop}} = \sigma_{Born}\,(1 + \delta_{virt} + \delta_{soft} + \delta_{coll}) + \sigma_{hard,non\text{-}coll}$ - independent of $\lambda$, $\Delta E$, $\Delta\theta$
- log $m_q$ still survive

# QED 1-loop corrections

## quark-antiquark annihilation – more complications:

- IR divergences coming from the gluon
- photon bremsstrahlung cancels only the photonic IR singularities
- need gluon bremsstrahlung - look for appropriate contribution of $O(\alpha\alpha_S^2)$
  - QED Born leads to $O(\alpha^2\alpha_S)$
  - interference of QCD & QED – zero at the Born level
  - non-zero for gluon bremsstrahlung in the initial–final state interference
- interplay between QED & QCD interactions



# Hadronic Cross Section

$$\sigma(P_1,P_2)=\sum_{i,j}\int \mathrm{d}x_1\mathrm{d}x_2\,\underbrace{f_i(x_1,Q)f_j(x_2,Q)}_{\text{parton distribution functions}}\,\underbrace{\hat{\sigma}_{ij}(p_1,p_2,Q)}_{\text{partonic cross section}}$$

$p_{1,2}=x_{1,2}P_{1,2}$

parton distribution functions — partonic cross section

$$\frac{\mathrm{d}L_{ij}}{\mathrm{d}\tau}=\frac{1}{1+\delta_{ij}}\int_\tau^1\frac{\mathrm{d}x_1}{x_1}\left[f_i(x_1,\mu)f_j\left(\frac{\tau}{x_1},\mu\right)+(1\leftrightarrow 2)\right]$$

parton luminosity

$\tau=x_1x_2$

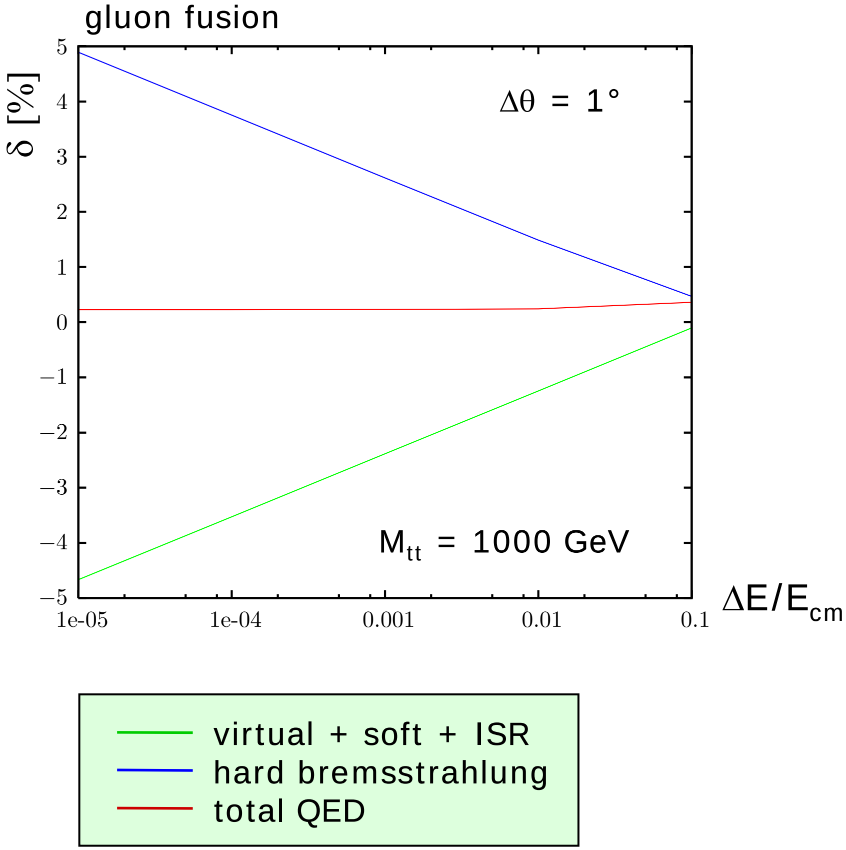
$$\sigma(S)=\sum\int_{\tau_0}^1\frac{\mathrm{d}\tau}{\tau}\left(\frac{1}{S}\frac{\mathrm{d}L_{q\bar{q}}}{\mathrm{d}\tau}\hat{s}\,\hat{\sigma}_{q\bar{q}}(\hat{s})+\frac{1}{S}\frac{\mathrm{d}L_{gg}}{\mathrm{d}\tau}\hat{s}\,\hat{\sigma}_{gg}(\hat{s})\right)$$

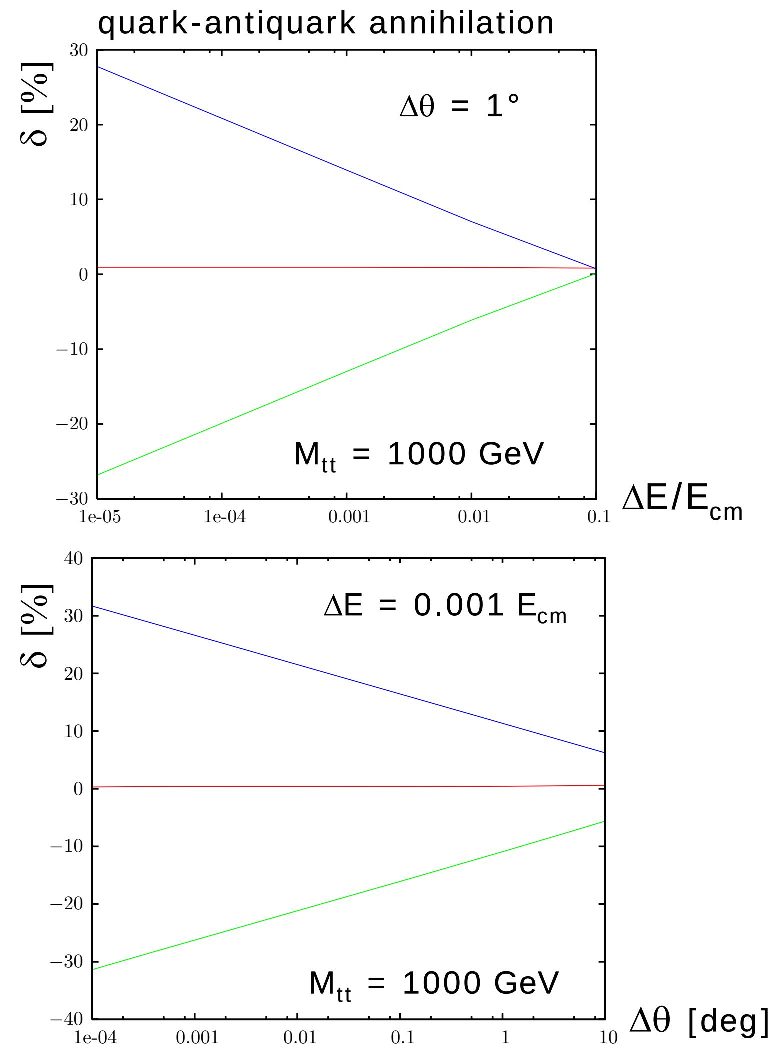
$\tau_0=4m_t^2/S$

- absorb initial state collinear singularities into PDF's using a factorisation scheme
- result independent of $m_q$ but dependent on factorisation scale Q
- need PDF at NLO QED
- finally available: MRST2004QED (QED NLO in DIS scheme) [Martin et al. 2004]
- comparison between PDF with and without QED NLO would become more plausible if QCD part also included

# Numerical results

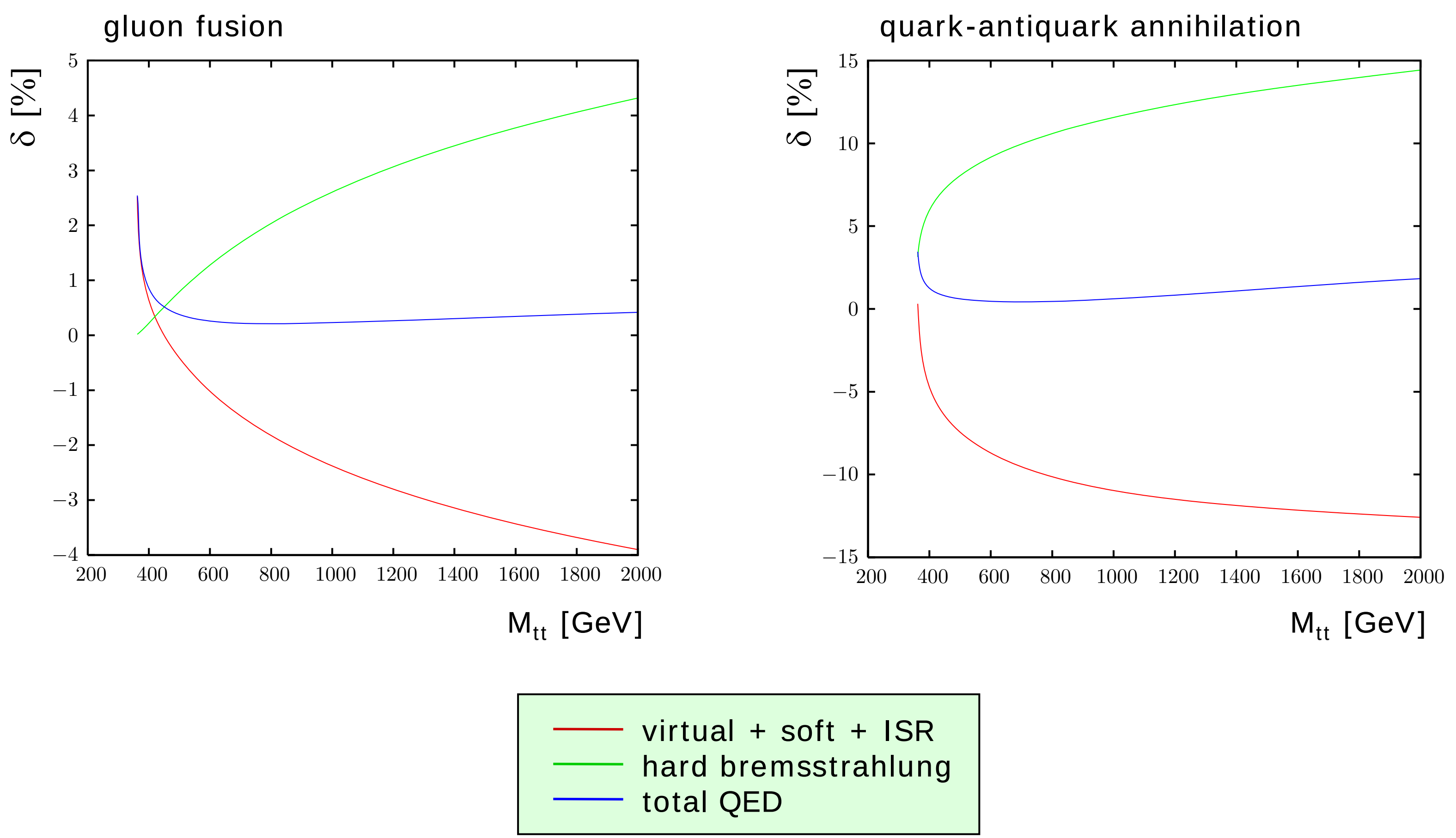
relative QED corrections
as a function of cutoff parameters:



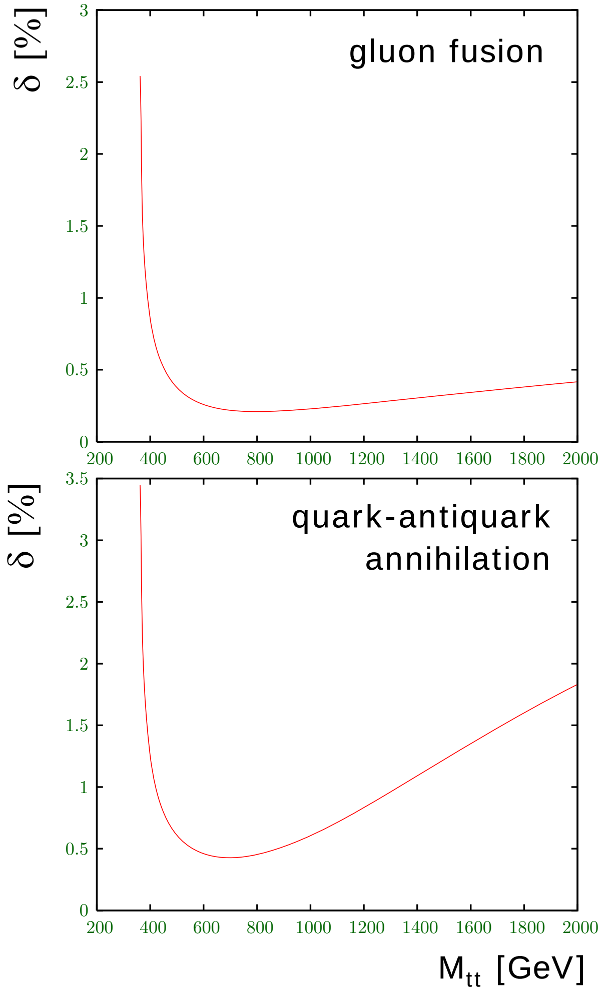
# Numerical results

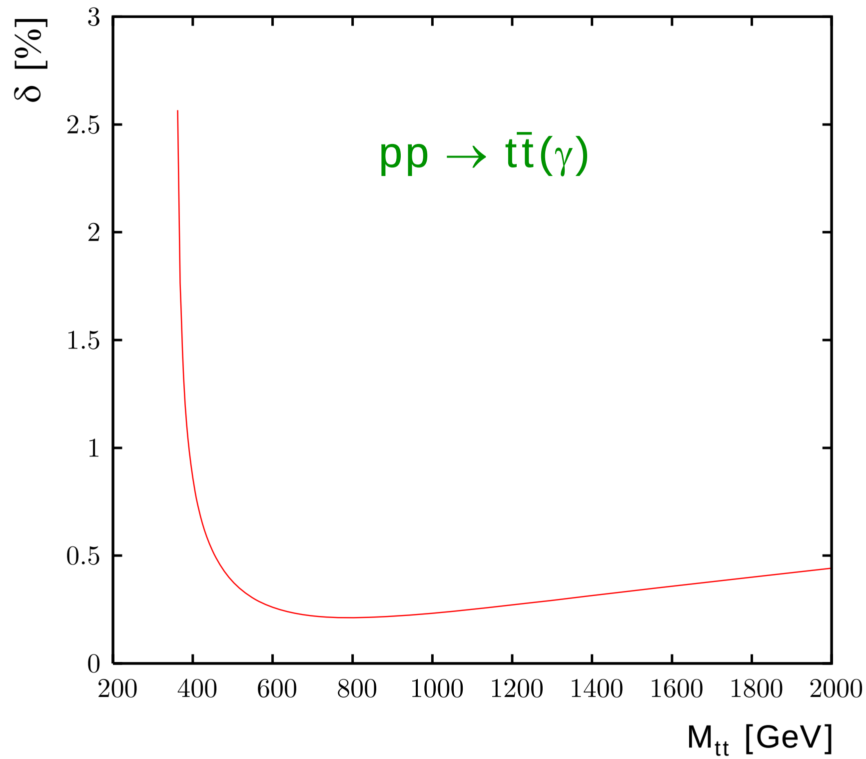
relative QED corrections - invariant mass distribution:



# Numerical results

relative total QED corrections - invariant mass distribution:




- PDF with QED NLO (MRST2004qed) vs. PDF without QED NLO $\rightarrow$ small difference
- QCD NLO leads to overestimation of scale dependence

# Conclusions & Outlook

– **SM 1-loop picture complete**

– QED corrections are larger in quark-antiquark annihilation
  $\Rightarrow$ more important for Tevatron

– need to include QCD corrections to obtain consistent picture and reduce scale dependence

– next step – combine QED and QCD