Central Exclusive Higgs Production: Theory

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Most recent predictions

Harland-Lang, Khoze, Ryskin & Stirling: 0.5 to 2 fb

arXiv:1301.2552

Depending on parton distribution functions. CTEQ6L gives upper value and provides best agreement with CDF di-photon data. $S^2 = 1\%$ and $|y| < 2.5$

Cudell, Dechambre, Hernández: 0.3 to 2 fb

arXiv:1011.3653

'Our predictions are significantly lower than those of KMR'. $S^2 = 5\%$ (?). Gluon constrained by CDF dijet data.

No Sudakov derivative

Ryutin: 0.55 fb

arXiv:1211.2105

$S^2 = 3\%$.

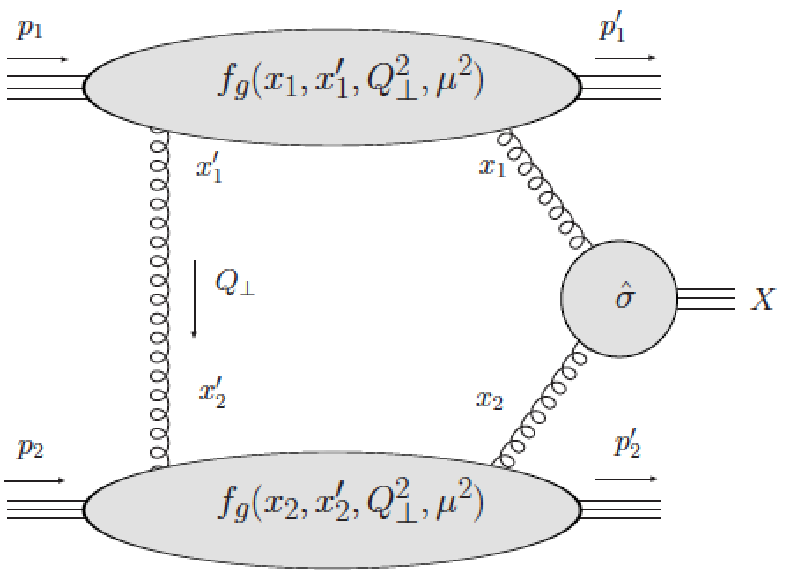
No Sudakov derivative

Maciula, Pasechnik & Szczurek: $0.2 \sim 0.4$ fb

$S^2 = 3\%$.

Higher scale in Sudakov

arXiv:1011.5842



Agreed uncertainty of a factor 3

How things changed since my 2005 HERA/LHC review (2 fb):

Coughlin & JRF
arXiv:0912.3280

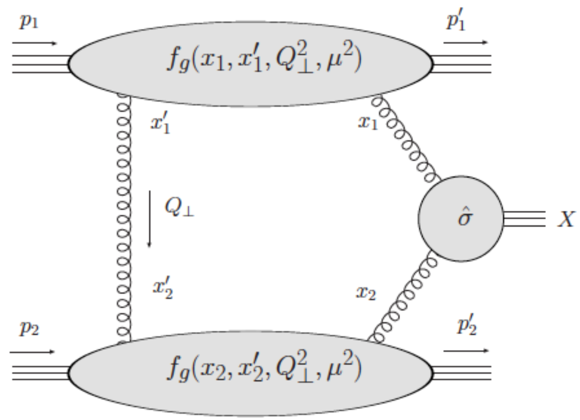
1. Correction to the Sudakov factor

2. New data & suggestion of a lower gap survival

3. New parton distributions

4. Higgs discovery

Key elements in the calculation



$$\mathcal{A}_{\rm CEP} \approx \int \frac{{\rm d}Q_\perp^2}{Q_\perp^4} \frac{\partial}{\partial \ln(Q_\perp^2)} \left[H_g\left(\frac{x_1}{2}, \frac{x_1}{2}; Q_\perp^2\right) \sqrt{T(Q_\perp, m_H)} \right]$$
$$\times \frac{\partial}{\partial \ln(Q_\perp^2)} \left[H_g\left(\frac{x_2}{2}, \frac{x_2}{2}; Q_\perp^2\right) \sqrt{T(Q_\perp, m_H)} \right]$$
$$\times \frac{\pi^3 2^4 (-i)}{x_1 x_2 (N^2-1)} \overline{\mathcal{M}}(gg \to H) \, .$$

Sums all leading and next-to-leading logarithms, i.e. $\alpha_s^n L^{2n-1}$ in cross-section.

Ignores Coulomb/Glauber exchanges that break factorization (‘gap survival’).

$$\frac{\partial\sigma}{\partial\hat{s}\partial y\partial \boldsymbol{p}_{1\perp}'^2\partial \boldsymbol{p}_{2\perp}'^2} = S^2 e^{-b(\boldsymbol{p}_{1\perp}'^2+\boldsymbol{p}_{2\perp}'^2)}\frac{\partial\mathcal{L}}{\partial\hat{s}\partial y}d\hat{\sigma}(gg\to X)$$

$$\frac{\partial\mathcal{L}}{\partial\hat{s}\partial y} = \frac{1}{\hat{s}}\left(\frac{\pi}{N^2-1}\int\frac{d\boldsymbol{Q}_\perp^2}{\boldsymbol{Q}_\perp^4}f_g(x_1,x_1',\boldsymbol{Q}_\perp^2,\mu^2)f_g(x_2,x_2',\boldsymbol{Q}_\perp^2,\mu^2)\right)^2$$

$$f_g(x,x',\boldsymbol{Q}_\perp^2,\mu^2)\approx R_g\frac{\partial}{\partial\ln\boldsymbol{Q}_\perp^2}\left(\sqrt{T(\boldsymbol{Q}_\perp,\mu)}\,xg(x,\boldsymbol{Q}_\perp^2)\right)$$

$$R_g\approx\frac{2^{2\lambda+3}}{\sqrt{\pi}}\frac{\Gamma(\lambda+5/2)}{\Gamma(\lambda+4)} \qquad xg(x,Q^2)\sim x^{-\lambda}$$

Shuvaev et al, hep-ph/9902410

$$T(\boldsymbol{Q}_\perp, m_H) = \exp\left(-\int_{Q_\perp^2}^{m_H^2} \frac{\mathrm{d}\boldsymbol{q}_\perp^2}{\boldsymbol{q}_\perp^2} \frac{\alpha_s(\boldsymbol{q}_\perp^2)}{2\pi} \int_0^{1-|q_\perp|/m_H} \mathrm{d}z \left[z P_{gg}(z) + n_f P_{qg}(z)\right]\right)$$

Only the UV cutoff on the $q_\perp$ integral is not fixed to single logarithmic accuracy.

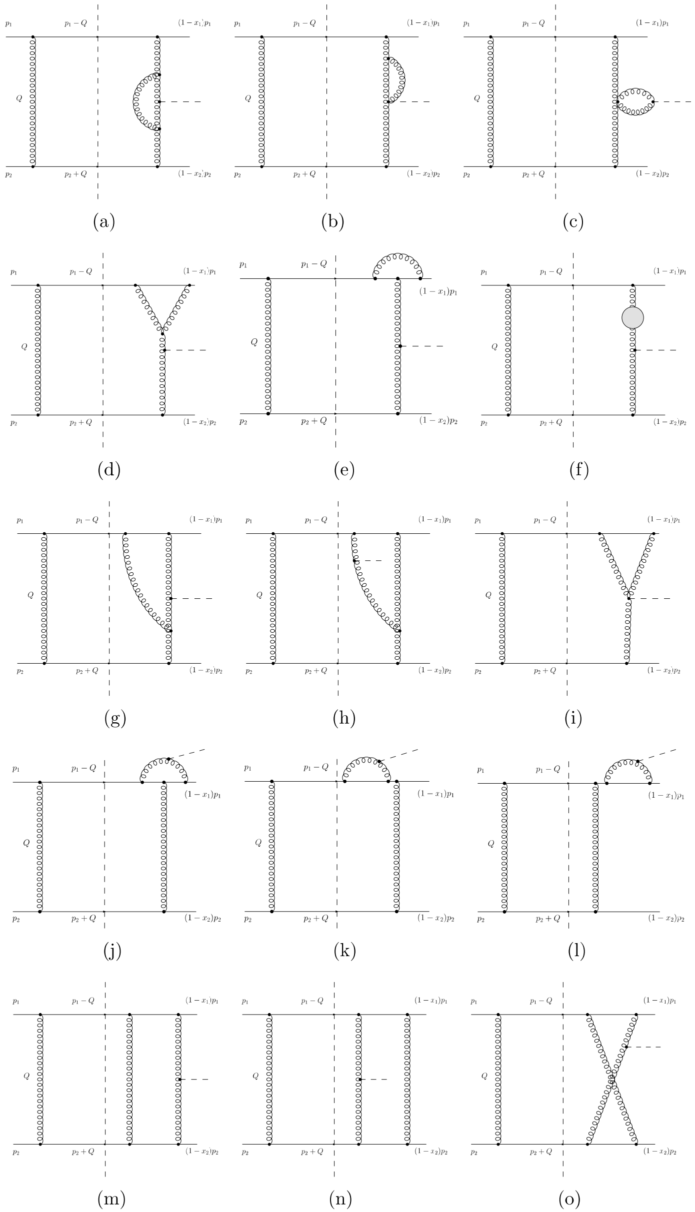
Limits require careful treatment of the soft gluon region.

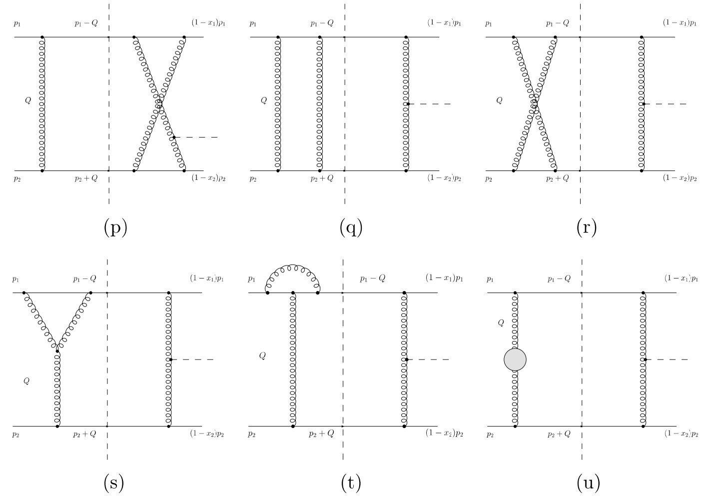
[Tim Coughlin PhD thesis]

Verified by fixed order calculation.

$$K \approx 1 + \frac{\alpha_S(M_H^2)}{\pi}\left[\pi^2 + \frac{11}{2}\right] \approx 1.5$$

Inclusive Higgs K-factor





$$
\begin{aligned}
A_{\rm NLO} = A_0(\mu) \int \frac{d\boldsymbol{Q}_\perp^2}{\boldsymbol{Q}_\perp^4} \Bigg(& -2C_F \frac{\alpha_s}{\pi} \frac{\mathcal{N}}{\epsilon^2} \left(\frac{\mu^2}{\boldsymbol{Q}_\perp^2}\right)^\epsilon - 3C_F \frac{\alpha_s}{\pi} \frac{\mathcal{N}}{\epsilon} \left(\frac{\mu^2}{\boldsymbol{Q}_\perp^2}\right)^\epsilon \\
& - C_A \frac{\alpha_s}{4\pi} \ln^2 \left(\frac{m_H^2}{\boldsymbol{Q}_\perp^2}\right) + 3\beta_0 \frac{\alpha_s}{\pi} \ln \left(\frac{\mu^2}{\boldsymbol{Q}_\perp^2}\right) \\
& + 2\epsilon_G(Q^2) \ln \left(\frac{s}{\boldsymbol{Q}_\perp^2}\right) \Bigg) \ .
\end{aligned}
$$

Diagrams (a) plus (g), (h), (m) – (p) generate the Sudakov double logarithm (Feynman gauge).

The latter ensure lower cut-off on $q_\perp$ integral is correct. They are also the diagrams that reggeize the gluon.

Collinear emissions: Beware the last rung

$$\mathcal{A}_{\rm CEP} \approx \int \frac{\mathrm{d}Q_\perp^2}{Q_\perp^4} \sum_{a,\bar{a}} \int \mathrm{d}\xi \int \mathrm{d}\bar{\xi}\, H_a(\xi,\eta;Q_\perp^2) H_{\bar{a}}(\bar{\xi},\bar{\eta};Q_\perp^2)$$
$$\times \left(-\frac{1}{2}\tilde{K}^{ga}\left(0,\frac{x_1}{2}\middle|y_1,y_2\right) - \frac{1}{2}\tilde{K}^{ga}\left(\frac{x_1}{2},0\middle|y_1,y_2\right)\right)$$
$$\times \left(-\frac{1}{2}\tilde{K}^{g\bar{a}}\left(0,\frac{x_2}{2}\middle|\bar{y}_1,\bar{y}_2\right) - \frac{1}{2}\tilde{K}^{g\bar{a}}\left(\frac{x_2}{2},0\middle|\bar{y}_1,\bar{y}_2\right)\right)$$
$$\times \frac{\pi^3 2^2(-i)}{x_1 x_2 (N^2-1)} \bar{V}_H \,.$$

$$\frac{\partial}{\partial \ln \mu_F} \boldsymbol{H}(\xi,\eta;\mu_F^2) = -\frac{\alpha_s}{2\pi}\int_{-1}^{1} \mathrm{d}\xi'\, \boldsymbol{K}_{(0)}\left(\frac{\eta+\xi}{2},\frac{\eta-\xi}{2}\middle|\frac{\eta+\xi'}{2},\frac{\eta-\xi'}{2}\right)\boldsymbol{H}(\xi',\eta;\mu_F^2)$$

If we ignore tilde over splitting kernel, K:

$$\mathcal{A}_{\rm CEP} \approx \int \frac{\mathrm{d}Q_\perp^2}{Q_\perp^4} \frac{\partial}{\partial \ln(Q_\perp^2)}\left[H_g\left(\frac{x_1}{2},\frac{x_1}{2};Q_\perp^2\right)\right] \frac{\partial}{\partial \ln(Q_\perp^2)}\left[H_g\left(\frac{x_2}{2},\frac{x_2}{2};Q_\perp^2\right)\right]$$
$$\times \frac{\pi^3 2^4(-i)}{x_1 x_2 (N^2-1)} \bar{V}_H \,.$$

But, correct expression is

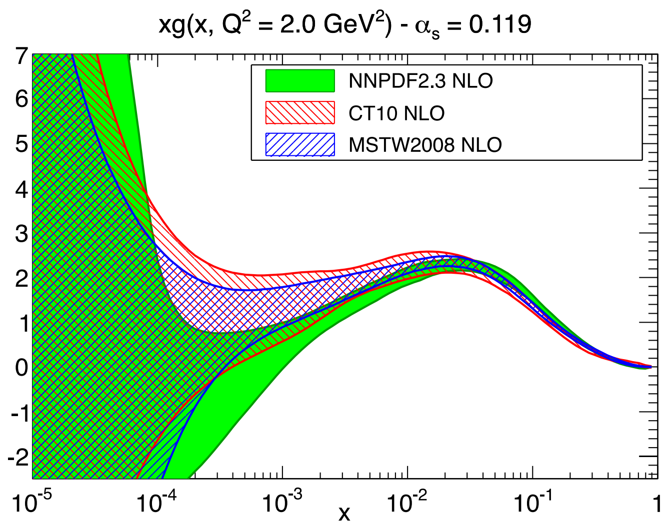
$$\tilde{K}^{ga}\left(\frac{x_1}{2},0\middle|y_1,y_2\right) = K^{ga}\left(\frac{x_1}{2},0\middle|y_1,y_2\right) - \delta^{ga}\delta\left(\xi-\frac{x_1}{2}\right)\frac{2}{\sqrt{T(Q_\perp,m_H)}}\frac{\partial\sqrt{T(Q_\perp,m_H)}}{\partial\ln(Q_\perp^2)}$$

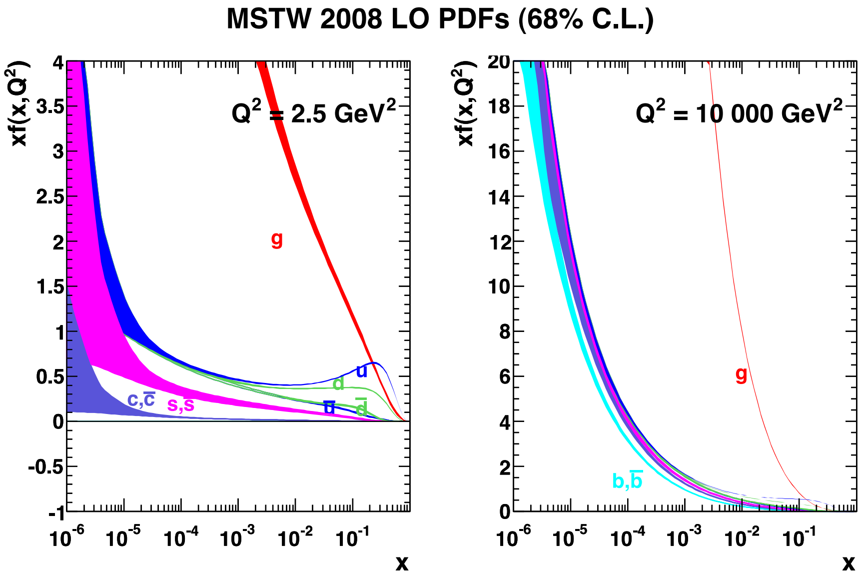
This is just Dokshitzer, Diakanov & Troyan (Physics Reports 58, 269 (1980))

Off-diagonal parton densities

Some uncertainty from off-diagonality: not well quantified.

Also uncertainty inherent in gluon pdf, e.g.





$$x \sim m_H/\sqrt{s} \sim 0.01$$

Scale and PDF dependence of the cross section (fb)

		Sudakov UV		QCD coupling	
	default	m_H	$m_H/4$	2Q	Q/2
CTEQ6L	0.9	0.8	1.3	1.5	0.5
CT10	0.3	0.3	0.4	0.4	0.2
MSTW2008LO	0.4	0.4	0.6	0.6	0.3
MSTW2008NLO	0.3	0.3	0.4	0.4	0.2
NNPDF21LO (0.13)	0.4	0.4	0.6	0.6	0.3
NNPDF23NLO	0.3	0.2	0.4	0.4	0.2
GJR08LO	1.0	0.9	1.3	1.4	0.6

1% gap survival

Preliminary

CDF di-photon data favour a large cross section:

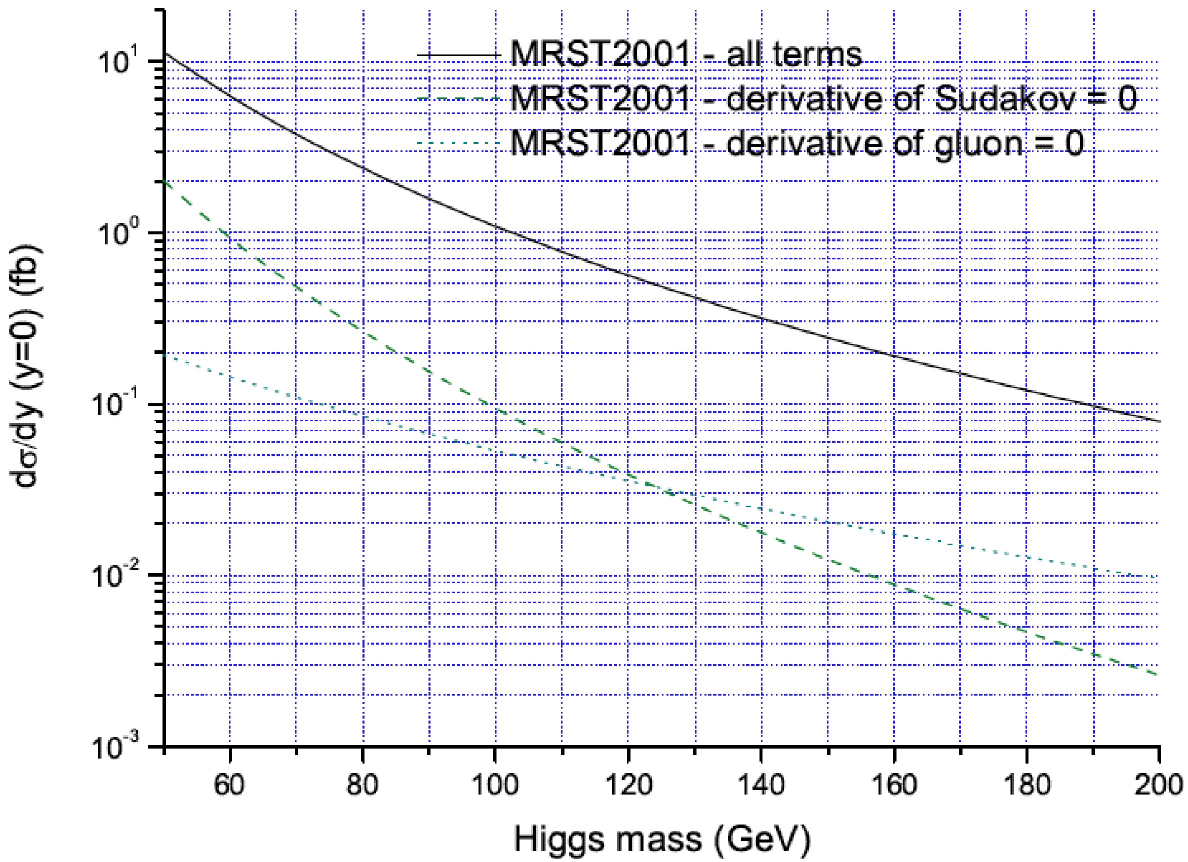
$$2.5 \pm 0.4 \pm 0.4 \text{ pb}$$

	MSTW08LO	CTEQ6L	GJR08LO	MRST99	CT10	NNPDF2.1
$\sqrt{s} = 1.96$ TeV ($\lvert\eta\rvert < 1$)	1.4	2.2	3.6	0.35	0.47	0.29
$\sqrt{s} = 7$ TeV ($\lvert\eta\rvert < 1$)	0.061	0.069	0.16	0.013	0.0094	0.0057
$\sqrt{s} = 7$ TeV ($\lvert\eta\rvert < 2.5$)	0.18	0.20	0.45	0.039	0.027	0.017

Table 5: $\gamma\gamma$ CEP cross sections (in pb) for different choices of gluon PDF, at $\sqrt{s} = 1.96$ and 7 TeV, and for different cuts on the photon pseudorapidity, η. The photons are restricted to have transverse energy $E_\perp > 2.5$ GeV at $\sqrt{s} = 1.96$ TeV and $E_\perp > 5.5$ GeV at $\sqrt{s} = 7$ TeV.

From Harland-Lang, Khoze, Ryskin & Stirling **arXiv:1204.4803**

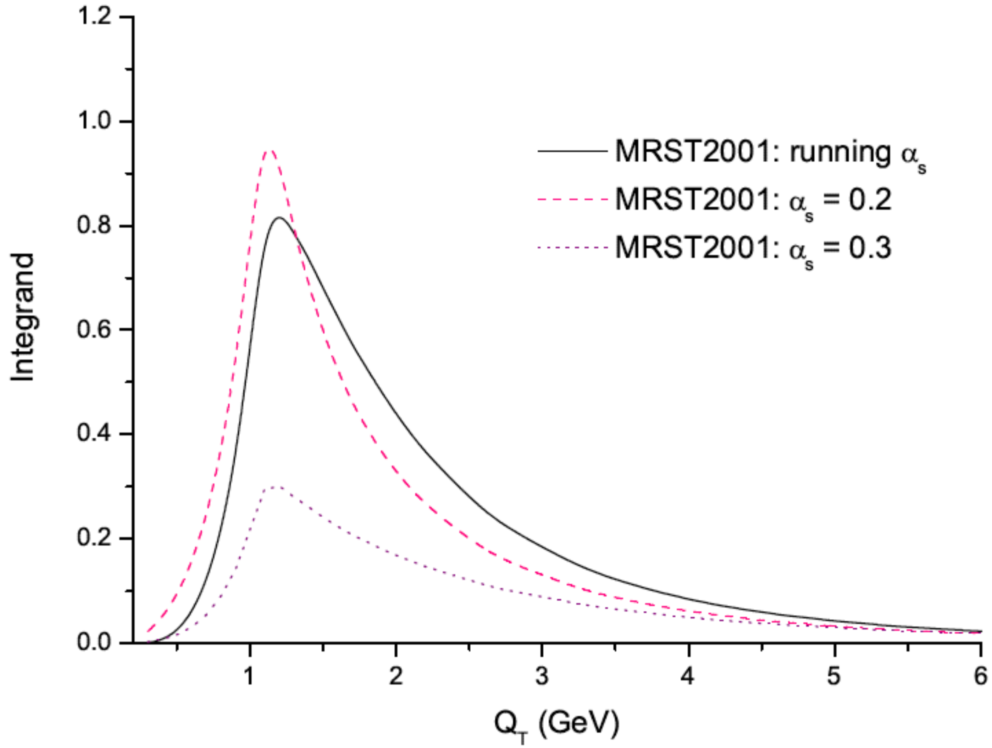
The derivative of the Sudakov matters



From **hep-ph/0508274**

Infra-red sensitivity

$$\exp(\langle \ln Q_T \rangle) \sim \frac{m_H}{2} \exp\left(-\frac{c}{\alpha_s}\right)$$



Cut-off the $Q_\perp$ integral at 0.4 GeV.

Continue gluon down to $Q^2 \to 0$.

The cross section is very insensitive to these details.

From hep-ph/0508274

1. The pQCD part of the calculation is under "reasonable" control (off-diagonal gluon uncertainty dominates).

2. Need a good model of factorization breaking exchanges (a.k.a. gap survival). Central production of other high-mass systems (di-photons & dijets) will really help us to understand it.

3. Correct treatment of Sudakov and TOTEM data pull cross section down.

4. Higher order corrections and CDF data push cross section up.

5. Nobody is claiming a cross section above 2 fb.