Production of digluon and quark-antiquark dijets in central exclusive processes

Antoni Szczurek

Institute of Nuclear Physics (PAN), Kraków, Poland and
Rzeszów University, Rzeszów, Poland

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Frontiers of QCD: From puzzles to discoveries,
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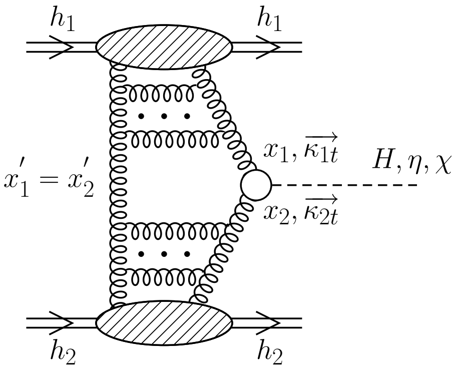
Introduction

Exclusive reaction: $pp \to pXp$
($X = H, Z, \eta', \eta_c, \eta_b, \chi_c, \chi_b$, jj, $c\bar{c}$, $b\bar{b}$. W^+W^-).

At high energy - one of many open channels (!)
$\Rightarrow$ rapidity gaps.

- Search for Higgs primary task for LHC.
  Do we see already the signal? (Tuesday CERN presentations)
- Diffractive production of the Higgs boson an alternative to inclusive production.
  Could give information on the Spin of the object
  proposed by Brodsky, Schäfer-Nachtmann-Schopf and Białas-Landshoff (simplified QCD approach)
  A new QCD look with UGDFs (Khoze-Martin-Ryskin).
- $H \to b\bar{b}$ versus $b\bar{b}$ continuum
- exclusive diffractive production of $Q\bar{Q}$ interesting by itself

The QCD mechanism for exclusive Higgs production



3-body process

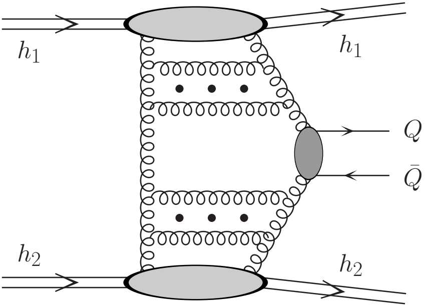
KMR: on-shell matrix element

Pasechnik-Szczurek-Teryaev: off-shell matrix element

Standard Model Higgs, literature

- V.A. Khoze, A.D. Martin, M.G. Ryskin,
  Phys. Lett. **401** (1997) 330.
- V.A. Khoze, A.D. Martin, M.G. Ryskin,
  Eur. Phys. J. **C14** (2000) 525.
- A.B. Kaidalov, V.A. Khoze, A.D. Martin, M.G. Ryskin,
  Eur. Phys. J. **C33** (2004) 261.
- J. R. Forshaw,
  arXiv:hep-ph/0508274;
- J. R. Forshaw,
  Nucl. Phys. Proc. Suppl. **191**, 247-256 (2009).
  [arXiv:0901.3040 [hep-ph]].
- T. D. Coughlin and J. R. Forshaw,
  JHEP **1001**, 121 (2010)

The QCD mechanism for exclusive $q\bar{q}$



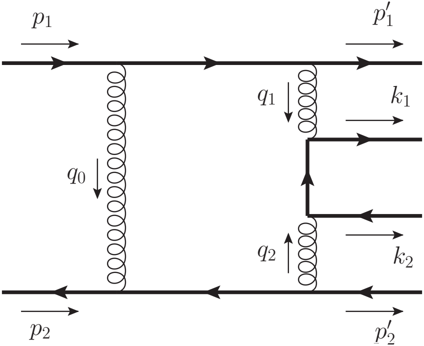
$q\bar{q} = b\bar{b}$: background to exclusive Higgs production

4-body process

with exact matrix element (without $J_z = 0$ selection rule)

with exact kinematics in the full phase space

Kinematics



Kinematics, continued

Decomposition of gluon momenta into longitudinal and transverse parts in the high-energy limit is

$$q_1 = x_1 p_1 + q_{1,t}, \qquad q_2 = x_2 p_2 + q_{2,t}, \qquad 0 < x_{1,2} < 1,$$
$$q_0 = x_1' p_1 + x_2' p_2 + q_{0,t}, \quad x_1' \sim x_2' \ll x_{1,2}, \quad q_{0,1,2}^2 \simeq q_{0/1/2,t}^2.$$

Making use of energy-momentum conservation laws

$$q_1 = p_1 - p_1' - q_0, \qquad q_2 = p_2 - p_2' + q_0, \qquad q_1 + q_2 = k_1 + k_2$$

we write

$$s\, x_1 x_2 = M_{q\bar{q}}^2 + |\mathbf{P}_t|^2 \equiv M_{q\bar{q},\perp}^2, \qquad M_{q\bar{q}}^2 = (k_1 + k_2)^2 \ ,$$

$M_{q\bar{q}}$ – invariant mass of the $q\bar{q}$ pair, and $\mathbf{P}_t$ its transverse 3-momentum.

The amplitude for $pp \to pp Q\bar{Q}$

$$\mathcal{M}^{pp\to ppq\bar{q}}_{\lambda_q\lambda_{\bar{q}}}(p_1', p_2', k_1, k_2) = s\,\frac{\pi^2}{2}\,\frac{\delta_{c_1 c_2}}{N_c^2-1}\,\Im\int d^2 q_{0,t}\; V^{c_1 c_2}_{\lambda_q\lambda_{\bar{q}}}(q_1, q_2, k_1, k_2)$$
$$\frac{f^{\rm off}_{g,1}(x_1, x_1', q_{0,t}^2, q_{1,t}^2, t_1)\, f^{\rm off}_{g,2}(x_2, x_2', q_{0,t}^2, q_{2,t}^2, t_2)}{q_{0,t}^2\; q_{1,t}^2\; q_{2,t}^2}\,,$$

where λ_q, $\lambda_{\bar{q}}$ are helicities of heavy q and $\bar{q}$.
$f^{off}_{g,1}(......)$ and $f^{off}_{g,2}(......)$ - off-diagonal unintegrated gluon distributions

$$x_1 = \frac{m_{3,t}}{\sqrt{s}}\exp(+y_3) + \frac{m_{4,t}}{\sqrt{s}}\exp(+y_4)\,,$$
$$x_2 = \frac{m_{3,t}}{\sqrt{s}}\exp(-y_3) + \frac{m_{4,t}}{\sqrt{s}}\exp(-y_4)\,.$$

$gg \longrightarrow Q\bar{Q}$ vertex

$$V^{c_1 c_2}_{\lambda_q \lambda_{\bar{q}}}(q_1, q_2, k_1, k_2) \equiv n^+_\mu n^-_\nu V^{c_1 c_2, \mu\nu}_{\lambda_q \lambda_{\bar{q}}}(q_1, q_2, k_1, k_2),$$

$$V^{c_1 c_2, \mu\nu}_{\lambda_q \lambda_{\bar{q}}}(q_1, q_2, k_1, k_2) = -g^2 \sum_{i,k} \left\langle 3i, \bar{3}k | 1 \right\rangle \times$$

$$\bar{u}_{\lambda_q}(k_1)(t^{c_1}_{ij} t^{c_2}_{jk} b^{\mu\nu}(q_1, q_2, k_1, k_2) - t^{c_2}_{kj} t^{c_1}_{ji} \bar{b}^{\mu\nu}(q_1, q_2, k_1, k_2)) v_{\lambda_{\bar{q}}}(k_2),$$

$$b^{\mu\nu}(q_1, q_2, k_1, k_2) = \gamma^\nu \frac{\hat{q}_1 - \hat{k}_1 - m}{(q_1 - k_1)^2 - m^2} \gamma^\mu ,$$

$$\bar{b}^{\mu\nu}(q_1, q_2, k_1, k_2) = \gamma^\mu \frac{\hat{q}_1 - \hat{k}_2 + m}{(q_1 - k_2)^2 - m^2} \gamma^\nu .$$

$gg \longrightarrow Q\bar{Q}$ vertex

The tensorial part:

$$V^{\mu\nu}_{\lambda_q\lambda_{\bar{q}}}(q_1, q_2, k_1, k_2) = g_s^2(\mu_R^2)\, \bar{u}_{\lambda_q}(k_1)\left(\gamma^\nu \frac{\hat{q}_1 - \hat{k}_1 - m}{(q_1 - k_1)^2 - m^2}\gamma^\mu - \gamma^\mu \frac{\hat{q}_1 - \hat{k}_2 + m}{(q_1 - k_2)^2 - m^2}\gamma^\nu\right) v_{\lambda_{\bar{q}}}(k_2).$$

Matrix element calculated numerically for different spin polarizations of Q and $\bar{Q}$

$gg \longrightarrow Q\bar{Q}$ vertex

The exact form of the vertex depends on the frame of reference (proton-proton c.m.s., $Q\bar{Q}$ c.m.s.).

It can be shown:
$q_1^{\nu} V_{\lambda_q \lambda_{\bar{q}}, \mu\nu} = 0$ for each λ_q, $\lambda_{\bar{q}}$
$q_2^{\mu} V_{\lambda_q \lambda_{\bar{q}}, \mu\nu} = 0$ for each λ_q, $\lambda_{\bar{q}}$
gauge invariance

Define:
$V_{\lambda_q \lambda_{\bar{q}}} = n_{\mu}^{+} n_{\nu}^{-} V_{\lambda_q \lambda_{\bar{q}}, \mu\nu}$
Then:
$V_{\lambda_q \lambda_{\bar{q}}} \rightarrow 0$ when $q_{1t} \rightarrow 0$ or $q_{2t} \rightarrow 0$

$gg \to Q\bar{Q}$ vertex

Let us take $Q\bar{Q}$ c.m.s. frame
In general the vertex is a function of many variables:
$V^{c_1 c_2}_{\lambda_q \lambda_{\bar{q}}}(q_1, q_2, k_1, k_2; m_Q)$

Two matrix elements are independent: $V_{+-}(...)$ and $V_{++}(...)$
formulas are shown explicitly in our paper

Let us go to massless quarks:
$V_{++} \to 0$ when $m_q \to 0$ ($J_z = 0$ only)
$\frac{|V_{++}|}{|V_{+-}|} \ll 1$ for large $M_{q\bar{q}}$

Off-diagonal unintegrated gluon distributions

KMR method ($x_1' \ll x_1$ and $x_2' \ll x_2$)

$$
\begin{aligned}
f_1^{\mathrm{KMR}}(x_1, Q_{1,t}^2, \mu^2, t_1) &= R_g \frac{d[g(x_1, k_t^2) S_{1/2}(k_t^2, \mu^2)]}{d \log k_t^2}\Big|_{k_t^2 = Q_{1t}^2} F(t_1) \\
&\approx R_g \frac{d g(x_1, k_t^2)}{d \log k_t^2}\Big|_{k_t^2 = Q_{1,t}^2} S_{1/2}(Q_{1,t}^2, \mu^2) \; F(t_1) \, ,
\end{aligned}
$$

$$
\begin{aligned}
f_2^{\mathrm{KMR}}(x_2, Q_{2,t}^2, \mu^2, t_2) &= R_g \frac{d[g(x_2, k_t^2) S_{1/2}(k_t^2, \mu^2)]}{d \log k_t^2}\Big|_{k_t^2 = Q_{2t}^2} F(t_2) \\
&\approx R_g \frac{d g(x_2, k_t^2)}{d \log k_t^2}\Big|_{k_t^2 = Q_{2,t}^2} S_{1/2}(Q_{2,t}^2, \mu^2) \; F(t_2) \, ,
\end{aligned}
$$

based on the Shuvaev method for collinear off-diagonal PDFs.

Sudakov-like form factor

It was proposed (Martin-Ryskin:)

$$S_{1/2}(q_t^2, \mu^2) = \sqrt{T_g(q_t^2, \mu^2)}\ .$$

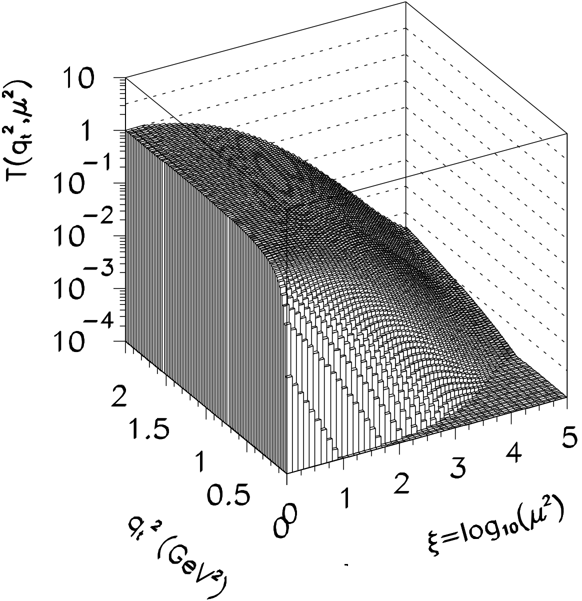
$$T_g(q_\perp^2, \mu^2) = \exp\left(-\int_{q_\perp^2}^{\mu^2} \frac{d\mathbf{k}_\perp^2}{\mathbf{k}_\perp^2} \frac{\alpha_s(k_\perp^2)}{2\pi} \int_0^{1-\Delta} \left[zP_{gg}(z) + \sum_q P_{qg}(z) \right] dz \right), \tag{1}$$

where the upper limit is taken to be

$$\Delta = \frac{k_\perp}{k_\perp + aM_{q\bar{q}}}\ . \tag{2}$$

KMR: a = 0.62, Coughlin-Forshaw: a=1

Sudakov form factor



The $pp \longrightarrow ppQ\bar{Q}$ cross section

Exact four-body kinematics

$$d\sigma = \frac{1}{2s}|\mathcal{M}_{2\to4}|^2(2\pi)^4\delta^4(p_a + p_b - p_1 - p_2 - p_3 - p_4)$$
$$\times \frac{d^3p_1}{(2\pi)^3 2E_1}\frac{d^3p_2}{(2\pi)^3 2E_2}\frac{d^3p_3}{(2\pi)^3 2E_3}\frac{d^3p_4}{(2\pi)^3 2E_4}$$

with exact (including quark mass) $2 \longrightarrow 4$ amplitude.

Exclusive Higgs production

R. Maciuła, R. Pasechnik and A. Szczurek,
Phys. Rev. **D82** (2010) 114011, Phys. Rev. **D83** (2011) 114034.
R. Pasechnik, O. Terryaev and A.S.,
Eur. Phys. J. **C47** (2006) 429.

Subprocess amplitude for $g^*g^* \to H$

$$T^{ab}_{\mu\nu}(q_1,q_2) = i\delta^{ab}\frac{\alpha_s}{2\pi}\frac{1}{v}\Bigg([(q_1q_2)g_{\mu\nu} - q_{1,\nu}q_{2,\mu}]G_1 +$$

$$+ \quad \left[q_{1,\mu}q_{2,\nu} - \frac{q_1^2}{(q_1q_2)}q_{2,\mu}q_{2,\nu} - \frac{q_2^2}{(q_1q_2)}q_{1,\mu}q_{1,\nu} + \frac{q_1^2q_2^2}{(q_1q_2)^2}q_{1,\nu}q_{2,\mu}\right] G_2\Bigg),$$

$v = (G_F\sqrt{2})^{-1/2}$ is the electroweak parameter. Let us introduce:

$$\chi = \frac{M_H^2}{4m_f^2} > 0, \qquad \chi_1 = \frac{q_1^2}{4m_f^2} < 0, \qquad \chi_2 = \frac{q_2^2}{4m_f^2} < 0,$$

Since $m_H^2 \gg |q_1^2|, |q_2^2|$

$$G_1(\chi,\chi_1,\chi_2) = \frac{2}{3}\left[1 + \frac{7}{30}\chi + \frac{2}{21}\chi^2 + \frac{11}{30}(\chi_1+\chi_2) + ...\right],$$

$$G_2(\chi,\chi_1,\chi_2) = -\frac{1}{45}(\chi - \chi_1 - \chi_2) - \frac{4}{315}\chi^2 + \dots .$$

Exclusive Higgs production

$$\mathcal{M}^{off-shell}_{pp\to ppH} = s\pi^2 \frac{1}{2} i \frac{\delta_{ab}}{N_c^2 - 1} \int d^2 q_{0,t} V^{ab}_{g^* g^* \to H}(q^2_{1\perp}, q^2_{2\perp}, P^2_{\perp}) \frac{f^{\rm off}_{g,1}(x_1, x', q^2_{0\perp}, q^2_{1\perp}, t_1) f^{\rm off}_{g,2}(x_2, x', q^2_{0\perp}, q^2_{2\perp}, t_2)}{q^2_{0,t} q^2_{1,t} q^2_{2,t}},$$

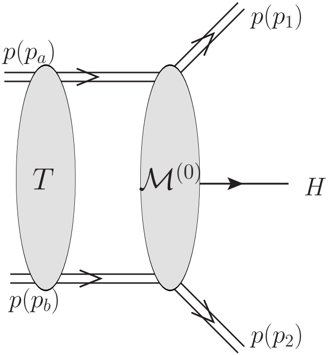
$$V^{ab}_{g^* g^* \to H}(q^2_{1\perp}\, q^2_{2\perp}, P^2_{\perp}) = n^+_\mu n^-_\nu \, T^{ab}_{\mu\nu}(q_1, q_2) = \frac{4}{s} \frac{q^\mu_{1\perp}}{x_1} \frac{q^\nu_{2\perp}}{x_2} T^{ab}_{\mu\nu}(q_1, q_2),$$

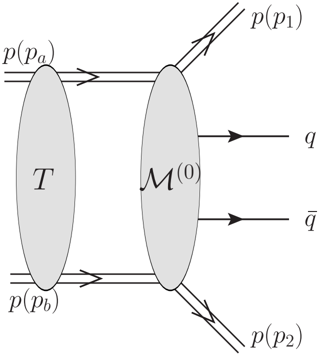
$$q_1^\mu T^{ab}_{\mu\nu} = q_2^\nu T^{ab}_{\mu\nu} = 0,$$

The cross section

$$d\sigma_{pp\to pHp} = \frac{1}{2s} |\mathcal{M}|^2 \cdot d^3 PS, \quad d^3 PS = \frac{1}{2^8 \pi^4 s} dt_1 dt_2 dy_H d\Phi \,.$$

Absorption effects





Absorption effects, continued

$$S^2_{\rm eik}(\mathbf{p}_{1,t},\mathbf{p}_{2,t}) = \frac{|\mathcal{M}^{bare}(\mathbf{p}_{1,t},\mathbf{p}_{2,t}) + \mathcal{M}^{res}(\mathbf{p}_{1,t},\mathbf{p}_{2,t})|^2}{|\mathcal{M}^{bare}(\mathbf{p}_{1,t},\mathbf{p}_{2,t})|^2} \qquad (3)$$

where $\mathbf{p}_{1/2,t}$ are the transverse momenta of the final protons
The elastic rescattering amplitude at high energy:

$$\mathcal{M}_{res} = i\int \frac{d^2k_t}{8\pi^2}\frac{1}{s}\beta(t_1)\beta(t_2)\mathcal{M}_{bare}M_0 e^{B(s)k_t^2/2}\ , \qquad (4)$$

where $t_1 \approx -(\vec{k}_t - \vec{p}_{1t})^2$ and $t_2 \approx -(\vec{k}_t - \vec{p}_{2t})^2$
If $\beta(t) = e^{bt/2}$ the amplitude can be written as:

$$\mathcal{M}^{res}(\mathbf{p}_{1,t},\mathbf{p}_{2,t}) \simeq \frac{iM_0(s)}{4\pi s(B+2b)}\exp\left(\frac{b^2|\mathbf{p}_{1,t}-\mathbf{p}_{2,t}|^2}{2(B+2b)}\right)\cdot\mathcal{M}^{bare}(\mathbf{p}_{1,t},\mathbf{p}_{2,t})$$

where $\mathrm{Im}M_0(s) = s\sigma^{\rm tot}_{pp}(s)$
(the real part is small at high energies)
B is the t-slope of the elastic pp differential cross section,
$b \simeq 4\ GeV^{-2}$ is the t-slope of the proton form factor.

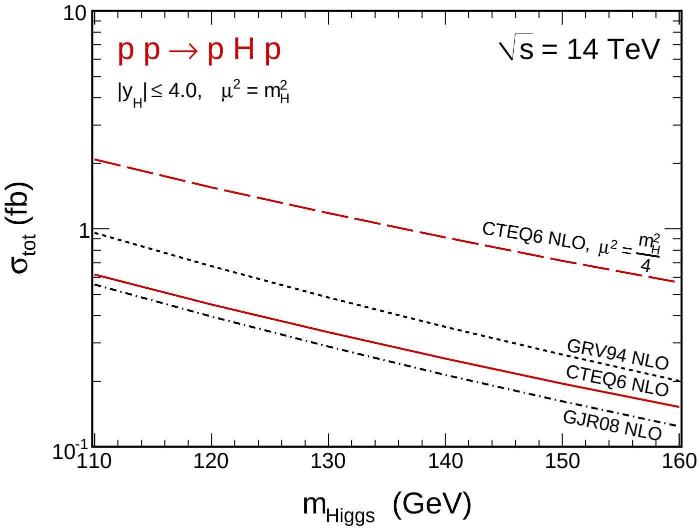
Absorption effects, continued

Absorption effects:

- Elastic rescattering (single channel)
- Inelastic rescattering (multi channel in general)
  In practice two-channel approaches.
- Enhanced diagram corrections (Khoze-Martin-Ryskin)

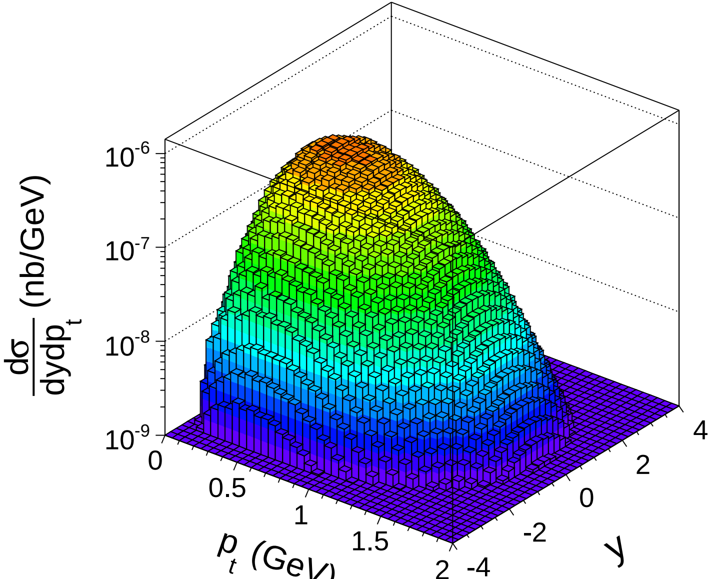
Very often the cross sections and even distributions are multiplied by a soft gap survival probability
Here we follow this approach ($S_g = S_g(s)$)
This is not yet consistent!

Exclusive Higgs production

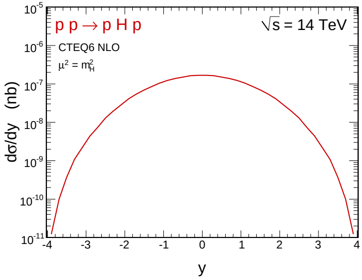


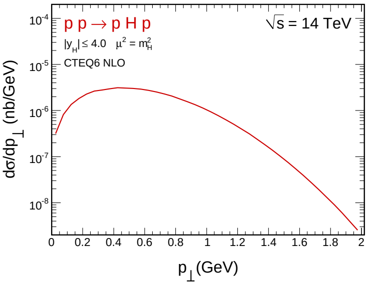
very small cross sections !

Exclusive Higgs production

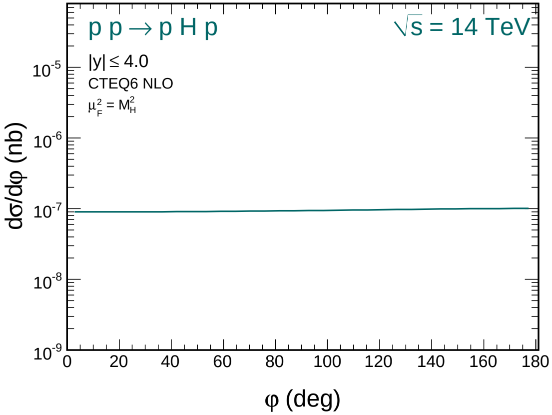


Exclusive Higgs production



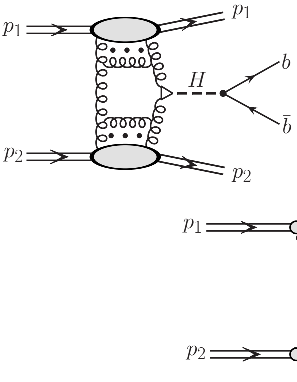


Exclusive Higgs production



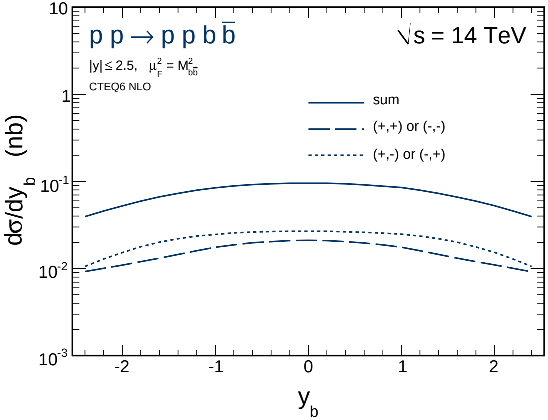
naively: scalar $\cos^2\phi$, pseudoscalar $\sin^2\phi$

Exclusive $b\bar{b}$ production



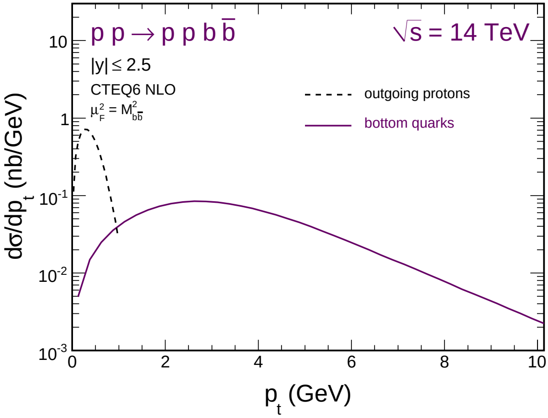
Maciula, Pasechnik, Szczurek,
arXiv:1011.5842, Phys. Rev. **D83** (2011) 114034.

Exclusive diffractive $b\bar{b}$ production



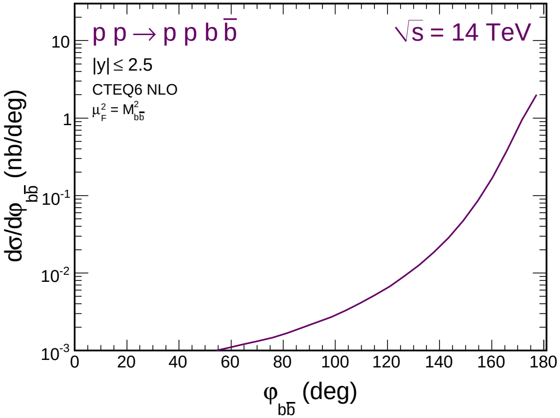
CTEQ6

Exclusive diffractive $b\bar{b}$ production



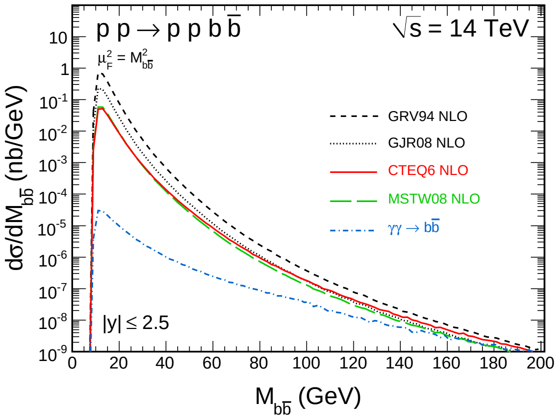
CTEQ6

Exclusice diffractive $b\bar{b}$ production



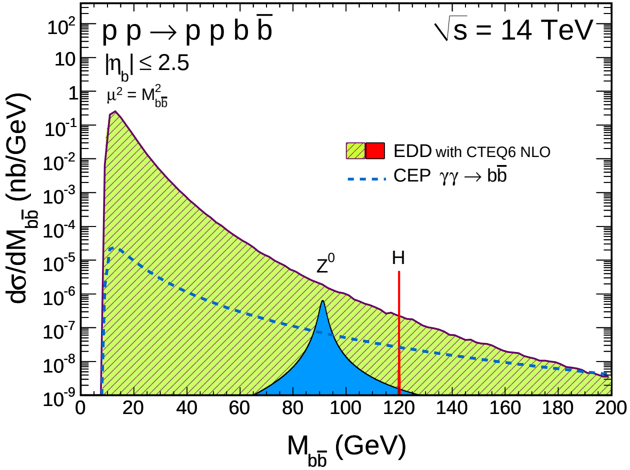
CTEQ6

Exclusive diffractive $b\bar{b}$ production

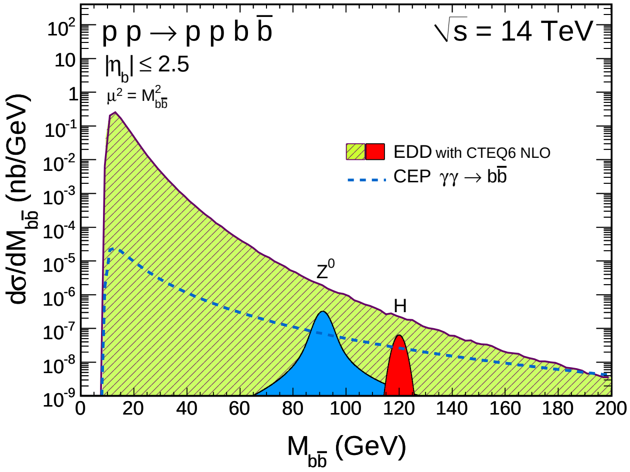


different UPDFs

M_{bb} spectrum, theory

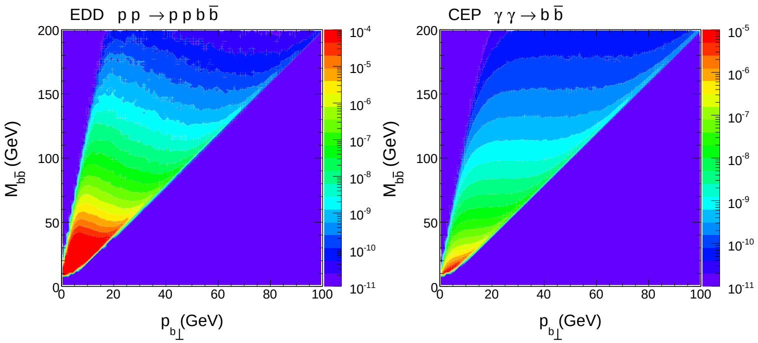


M_{bb} spectrum, experiment



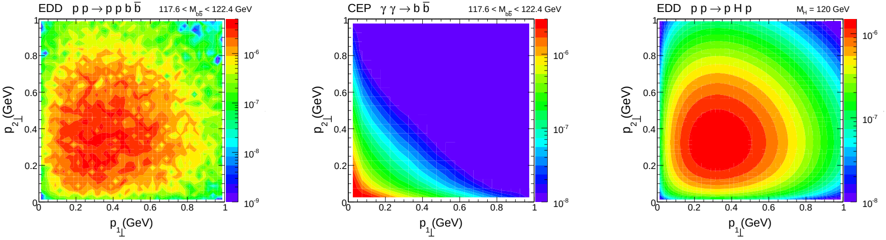
- Looks rather difficult
- How to improve the signal-to-background ratio ?

How to get $M_{b\bar{b}} = M_H$?



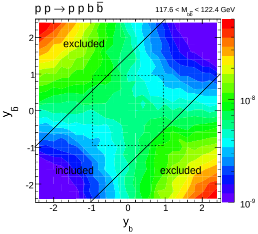
large transverse momenta or large rapidity difference

(p_{1t}, p_{2t}) distributions for different mechanisms

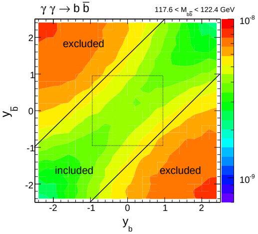


diffractive background QED background diffractive Higgs

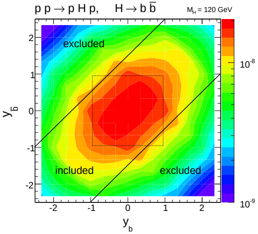
$(y_b, y_{\bar{b}})$ distributions for different mechanisms



diffractive background

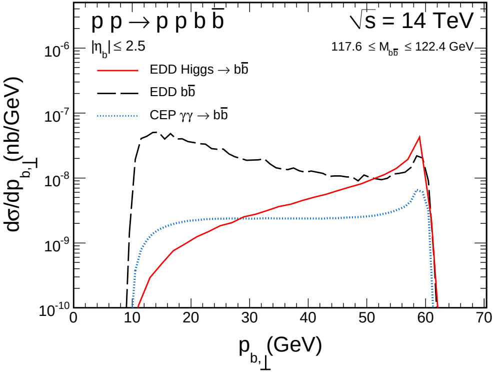


QED background

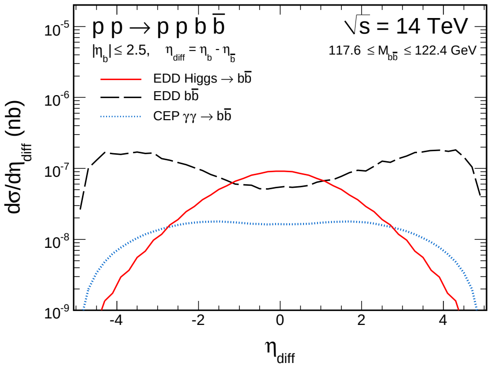


diffractive Higgs

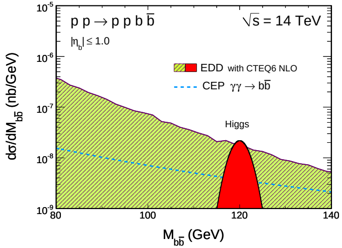
Jet transverse momenta

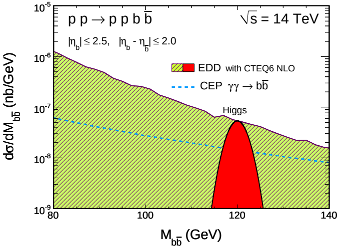


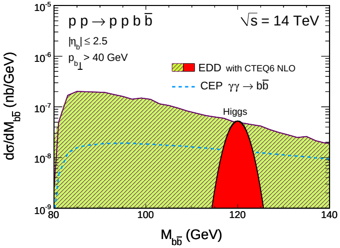
Rapidity difference

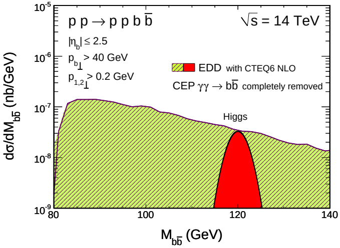


M_{bb} spectrum, cuts

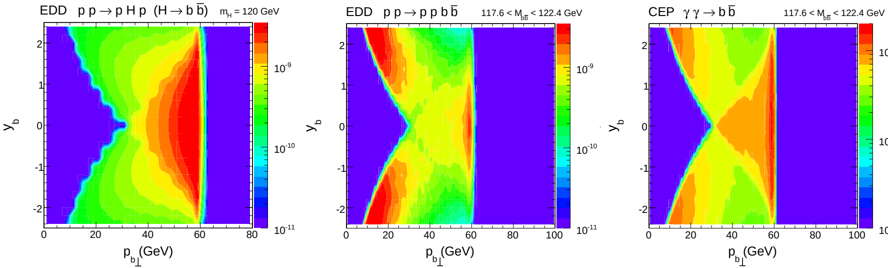






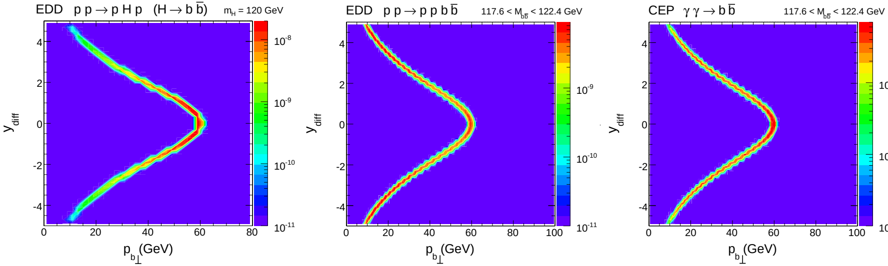


How to cut?



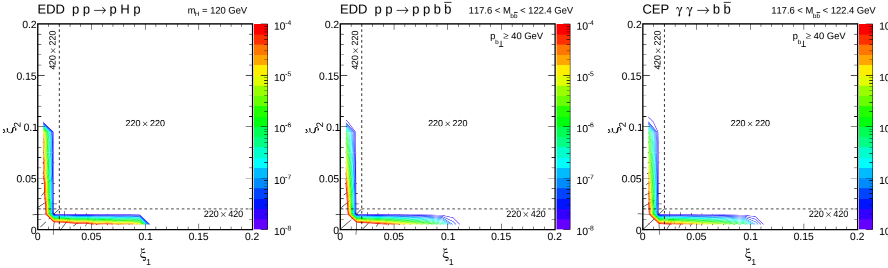
both cut in rapidity and transverse momentum is possible

Correlation of variables



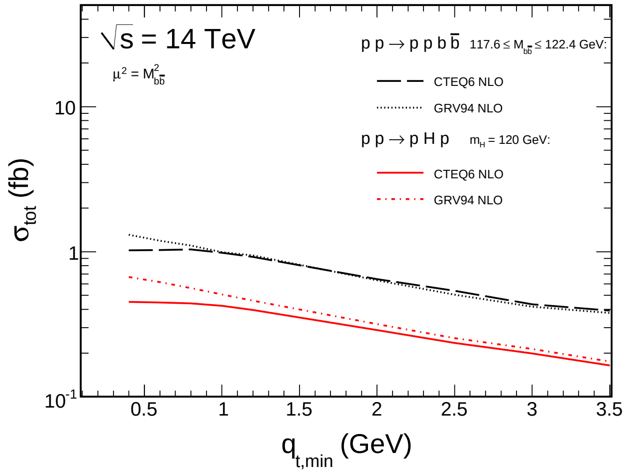
For narrow bin in $M_{b\bar{b}}$
$y_{diff} = y_b - y_{\bar{b}}$ and jet transverse momentum are strongly correlated.

Longitudinal momentum fraction loss



$\xi_1 = (p_{1f} - p_{1i})/p_{1i}$
$\xi_2 = (p_{2f} - p_{2i})/p_{2i}$
RP220, FP420 detectors were planned

Lower cut on gluon transverse momenta



Slow dependence on the cut

Beyond Standard Model

CP-conserving Minimal Supersymmetric Standard Model (MSSM)

- B.E. Cox, F.K. Loebinger, A. Pilkington, JHEP 0710 (2007) 090.
- S. Heinemeyer, V.A. Khoze, M.G. Ryskin, W.J. Stirling, M. Tasevsky, G. Weiglein, Eur. Phys. J. C53 (2008) 231.
- S. Heinemeyer, V.A. Khoze, M.G. Ryskin, W.J. Stirling, M. Tasevsky, G. Weiglein, arXiv:1012.5007 [hep-ph].

Beyond Standard Model

In this model:
3 neutral h, H, A $(M_h < M_H)$,
2 charged H^+, H^-
A is CP-odd
In this model there are two-parameters: M_A and $\tan\beta$

$$M^2_{h,H} = \frac{1}{2}[M^2_A + M^2_Z \pm \sqrt{(M^2_A + M^2_Z)^2 - 4M^2_A M^2_Z cos^2 2\beta}]$$
$$M^2_{H^\pm} = M^2_A + M^2_W \qquad (6)$$

The situation much more complicated than in SM

- If $M_H \approx M_A > 2M_W$ then h has almost SM coupling
- Large enhancement in the region of relatively small M_A and large $\tan\beta$

Beyond Standard Model

Triplet Higgs model:

M. Chaichian, P. Hoyer, K. Huitu, V.A. Khoze, A.D. Pilkington, JHEP 0905 (2009) 011.

Presentation of results for different model parameters (c_H, doublet-triplet mixing).

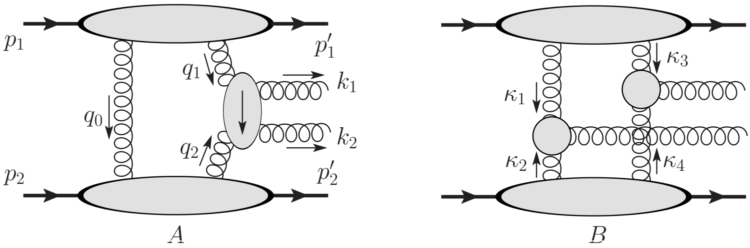
Model description can be found in:

E. Accomando et al. hep-ph/0608079 (a review), "CP studies and Non-Standard Higgs Physics".

Summary of the EDD Higgs and $b\bar{b}$ production

- Exclusive double diffractive $b\bar{b}$ was calculated using UGDFs obtained with different integrated gluon distributions.
- Exact matrix elements for the Higgs and continuum have been calculated (analytically and numerically), including explicit quark masses for $b\bar{b}$
- $\sigma < 1$ fb (Cudell-Dechambre-Hernandez)
- Sizeable cross sections for $c\bar{c}$ and $b\bar{b}$ have been obtained, i.e. the processes can be measured.
- The continuum constitutes irreducible background to exclusive Higgs production.
- If the experimental resolution is included the signal to background ratio is less than 1.
- This can be further improved if cuts on rapidities and transverse momenta of b quarks/antiquarks and/or on transverse momenta of protons are imposed.

Mechanism of gluonic dijet production



Maciula,Pasechnik,AS, arXiv:1109.5930, Phys. Rev. **D84** (2011) 114014.
Ivanov,Cudell

CDF experimental data

- T. Aaltonen *et al.* (CDF Collaboration),
  Phys. Rev. D **77**, 052004 (2008) [arXiv:0712.0604 [hep-ex]],
- A. A. Affolder *et al.* (CDF Collaboration),
  Phys. Rev. Lett. **88**, 151802 (2002) [arXiv:hep-ex/0109025],
- A. A. Affolder *et al.* (CDF Collaboration),
  Phys. Rev. Lett. **85**, 4215 (2000).

Not real measurement !!! Extracted by subtraction of inclusive diffractive contribution

Theoretical calculations

Quick summary:

- A.D. Martin, M.G. Ryskin, V.A. Khoze, Phys. Rev. **D56** (1997) 5867.
  (the main idea)
- B.E. Cox, A. Pilkington,
  Phys. Rev. D72 (2005) 094024.
  (first Monte Carlo similations (Exhume), no details)
- J.-R. Cudell, A. Dechambre, O. Hernandez, I.P. Ivanov,
  Eur. Phys. J. **C61** (2009) 369.
  (detailed calculations, discussion of uncertainties)
- A. Dechambre, O. Kepka, Ch. Royon, R. Staszewski,
  Phys. Rev. **D83** (2011) 054013.
  theoretical uncertainties with FPMC generator

Theoretical ingredients

We use standard light-cone decomposition:

$$q_1 = x_1 p_1 + q_{1\perp}, \quad q_2 = x_2 p_2 + q_{2\perp}, \quad q_0 = x_1' p_1 + x_2' p_2 + q_{0\perp} \simeq q_0$$

$$p_3 = \beta_1 p_1 + \alpha_1 p_2 + k_{1\perp}, \quad p_4 = \beta_2 p_1 + \alpha_2 p_2 + k_{2\perp}\,.$$

$$C_1^\mu(v_1, v_2) = p_1^\mu \left(\beta_1 - \frac{2\mathbf{v}_1^2}{s\alpha_1}\right) - p_2^\mu \left(\alpha_1 - \frac{2\mathbf{v}_2^2}{s\beta_1}\right) - (v_{1\perp} + v_{2\perp})^\mu,$$

$$C_2^\mu(v_1, v_2) = p_1^\mu \left(\beta_2 - \frac{2\mathbf{v}_1^2}{s\alpha_2}\right) - p_2^\mu \left(\alpha_2 - \frac{2\mathbf{v}_2^2}{s\beta_2}\right) - (v_{1\perp} + v_{2\perp})^\mu\,.$$

Amplitudes of $pp \to p(gg)p$

$$\mathcal{M}^{A}_{ab}(\lambda_1,\lambda_2) = is\,\mathcal{A}\,\frac{\delta_{ab}}{N_c^2-1}\int d^2\mathbf{q}_0\,\frac{f_g^{\rm off}(q_0,q_1)f_g^{\rm off}(q_0,q_2)\cdot\epsilon^*_\mu(\lambda_1)\epsilon^*_\nu(\lambda}{\mathbf{q}_0^2\mathbf{q}_1^2\mathbf{q}_2^2}$$
$$\left[\frac{C_1^\mu(q_1,r_1)C_2^\nu(r_1,-q_2)}{\mathbf{r}_1^2}+\frac{C_1^\mu(q_1,r_2)C_2^\nu(r_2,-q_2)}{\mathbf{r}_2^2}\right],$$
$$\mathcal{M}^{B}_{ab}(\lambda_1,\lambda_2) = -is\,\mathcal{A}\,\frac{\delta_{ab}}{N_c^2-1}\int d^2\boldsymbol{\kappa}_1\,\frac{f_g^{\rm off}(\kappa_1,\kappa_3)f_g^{\rm off}(\kappa_2,\kappa_4)\cdot\epsilon^*_\mu(\lambda_1)\epsilon^*_\nu}{\boldsymbol{\kappa}_1^2\boldsymbol{\kappa}_2^2\boldsymbol{\kappa}_3^2\boldsymbol{\kappa}_4^2}$$
$$C_1^\mu(\kappa_1,-\kappa_2)C_2^\nu(\kappa_3,-\kappa_4),$$

where $C^\mu(\kappa,\kappa')$ – Lipatov vertices.
V. S. Fadin and L. N. Lipatov,
Sov. J. Nucl. Phys. **50**, 712 (1989)
Yad. Fiz. **50**, 1141 (1989).

Diagram B

$$x_1 \simeq \frac{p_{3\perp}}{\sqrt{s}} \exp(+y_3)\,, \qquad x_2 \simeq \frac{p_{4\perp}}{\sqrt{s}} \exp(-y_3)\,,$$
$$x_3 \simeq \frac{p_{3\perp}}{\sqrt{s}} \exp(+y_4)\,, \qquad x_4 \simeq \frac{p_{4\perp}}{\sqrt{s}} \exp(-y_4)\,.$$

$$f_g^{\mathrm{off}}(x_1, x_3, \boldsymbol{\kappa}_1^2, \boldsymbol{\kappa}_3^2, \mu_1^2, \mu_2^2; t) = \sqrt{f_g(x_1, \boldsymbol{\kappa}_1^2, \mu_1^2) f_g(x_3, \boldsymbol{\kappa}_3^2, \mu_2^2)} \cdot F(t_1)\,,$$
$$f_g^{\mathrm{off}}(x_2, x_4, \boldsymbol{\kappa}_2^2, \boldsymbol{\kappa}_4^2, \mu_1^2, \mu_2^2; t) = \sqrt{f_g(x_2, \boldsymbol{\kappa}_2^2, \mu_1^2) f_g(x_4, \boldsymbol{\kappa}_4^2, \mu_2^2)} \cdot F(t_2)\,.$$

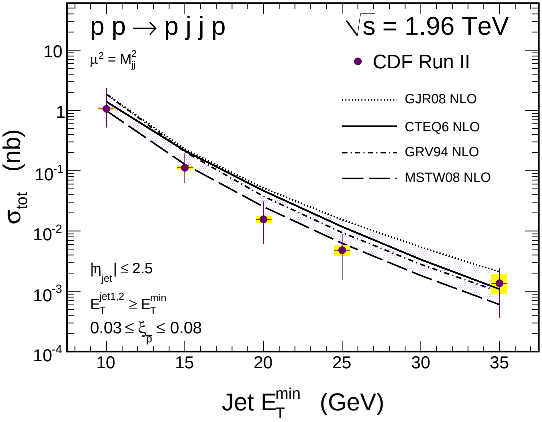
Smooth interpolation between on-diagonal UGDFs

Above on-diagonal UGDfs include Sudakov form factors in the same way as in the KMR UGDF

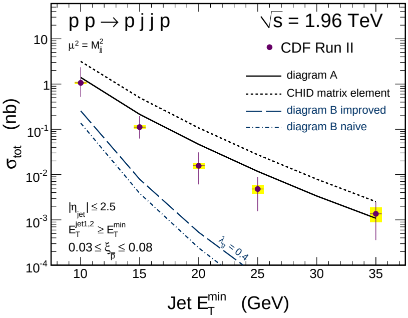
Very simplistic(!)

$\mu_1 = p_{3\perp}$ and $\mu_2 = p_{4\perp}$ or $\mu_1 = \mu_2 = M_{gg}$.

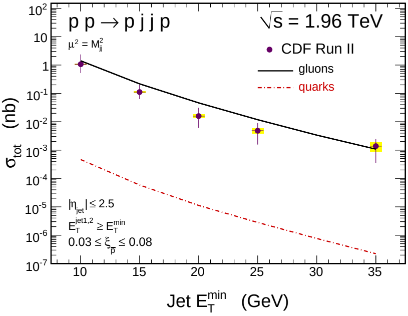
CDF data, PDFs



CDF data

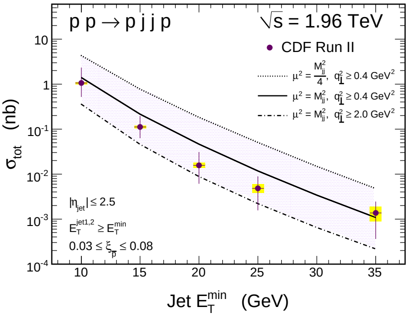


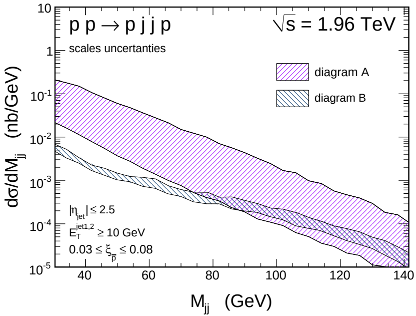
p p → p j j p
√s = 1.96 TeV
μ² = M²jj
CDF Run II
diagram A
CHID matrix element
diagram B improved
diagram B naive
λg = 0.4
|ηjet| ≤ 2.5
E_T^jet1,2 ≥ E_T^min
0.03 ≤ ξp̄ ≤ 0.08
σtot (nb)
Jet E_T^min (GeV)



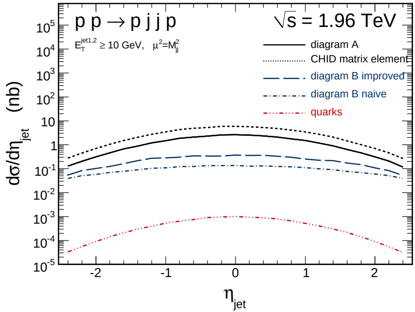
p p → p j j p
√s = 1.96 TeV
μ² = M²jj
CDF Run II
gluons
quarks
|ηjet| ≤ 2.5
E_T^jet1,2 ≥ E_T^min
0.03 ≤ ξp̄ ≤ 0.08
σtot (nb)
Jet E_T^min (GeV)

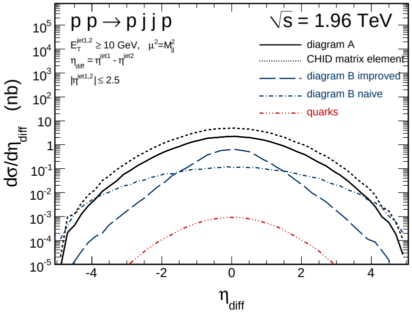
Theoretical uncertainties



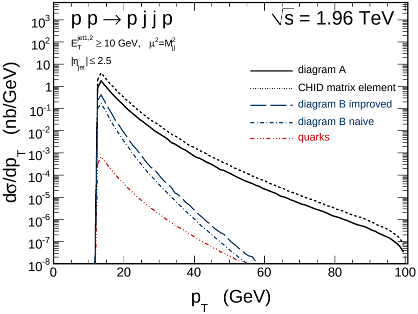


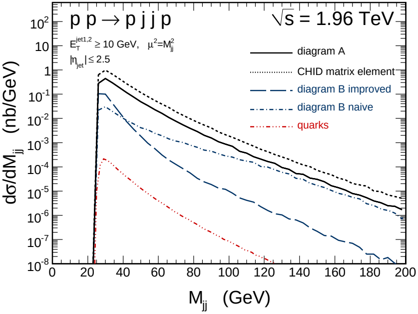
Rapidity distributions, Tevatron



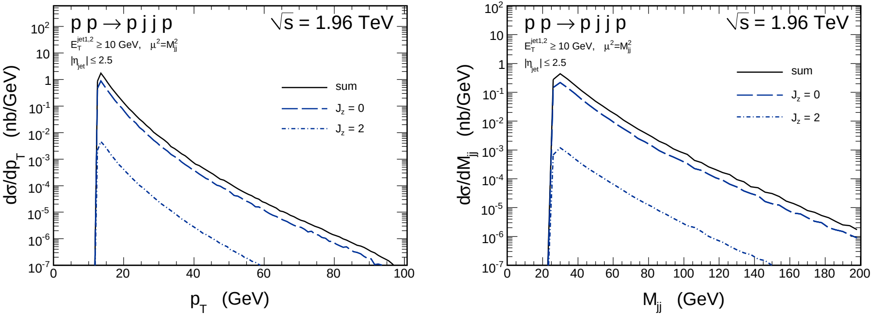


Other distributions, Tevatron

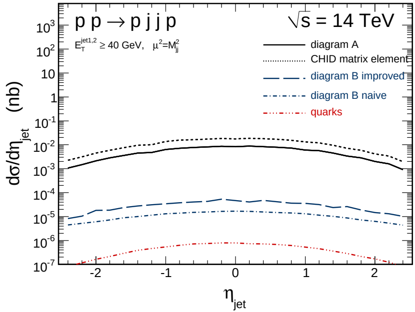


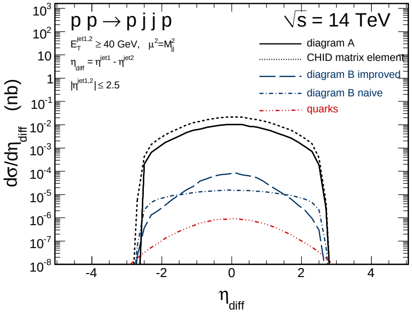


Helicity contributions

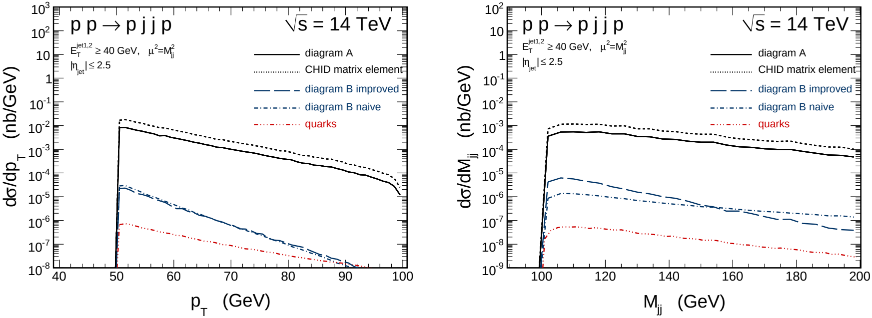


Rapidity distributions, LHC





Other distributions, LHC



Off-diagonal GPDs

Both gluons are outgoing (emitted).
In the collinear approach: ERBL kinematical region.

$$|x| < |\xi|, \qquad x = \frac{x_1 + x_2}{2}, \qquad \xi = \frac{x_1 - x_2}{2} .$$

In our case both x_1 and x_2 are small that is also x and ξ are small.
In this region the collinear off-diagonal distributions $H(x, \xi, \mu^2, t)$ can be estimated in a model independent way (Shuvaev et al.).
Assuming that at small x: $xg(x) = N_g x^{-\lambda_g}$ in the limit of small x and ξ one can write:

$$H_g(x, \xi, t) = N_g \frac{\Gamma(\lambda_g + 5/2)}{\Gamma(\lambda_g + 2)} \frac{2}{\sqrt{\pi}} \int_0^1 ds [x + \xi(1 - 2s)] \left(\frac{4s(1-s)}{x + \xi(1-2s)} \right)^{\lambda_g + 1} . \tag{11}$$

λ_g is a crucial parameter.
In the double logarithm approximation at small values of x:

$$\lambda_g = \sqrt{\frac{\alpha_s(\mu^2)}{\pi} \log\left(\frac{1}{x}\right) \log\left(\frac{\mu^2}{\mu_0^2}\right)} . \tag{12}$$

Off-diagonal GPDs

The distribution at $x < 10^{-4}$ and small factorization scales is poorly known.
Applicability of the double logarithmic formula is not well justified.
We assume a constant value of λ_g.
We define:

$$R_{coll}(x_1, x_2; \mu^2, t=0) = \frac{H_g(x, \xi; \mu^2, t=0)}{H_g(x, 0; \mu^2, t=0)} \; . \tag{13}$$

as a function of x_1, x_2. This is a measure of off-shell effects.
Therefore we propose:

$$f_g^{\rm off}(x, x', k_t^2, k'^2_t, \mu^2, t) = R_{coll}(x, x'; \mu^2, t=0) \cdot \sqrt{f_g(\bar{x}, k_t^2, \mu^2) f_g(\bar{x}, k'^2_t, \mu^2)} \cdot F(\tag{14}$$

where $\bar{x} = \frac{x+x'}{2}$, $\mu^2 = \mu_1^2 \simeq \mu_2^2$ and f_g are standard on-shell diagonal distribution.

$R(x_1, x_2, t = 0)$ for fixed λ_g

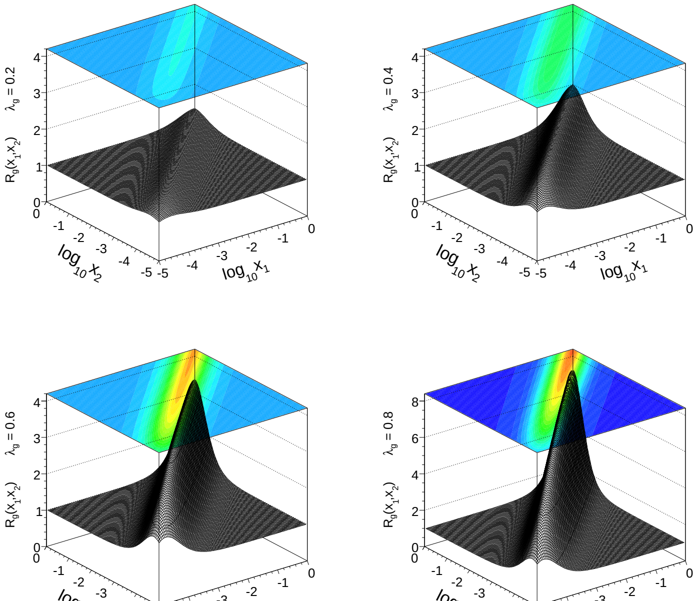
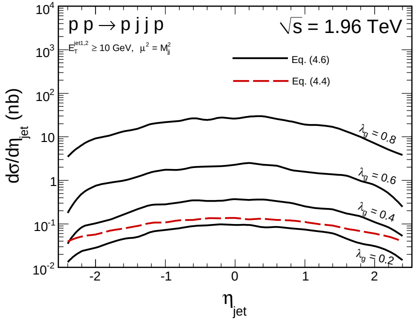
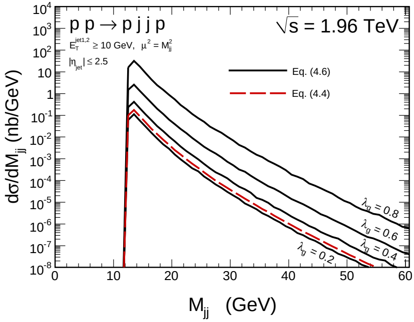


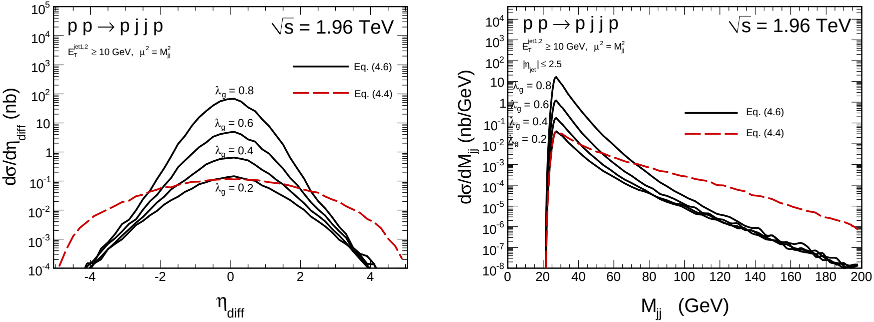
diagram B, new prescription





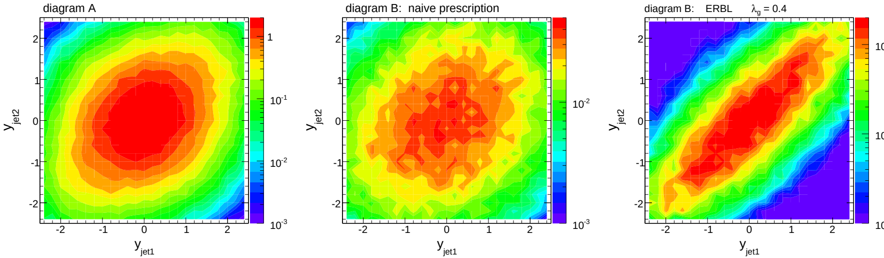
naive and improved results similar in shape

diagram B, new prescription



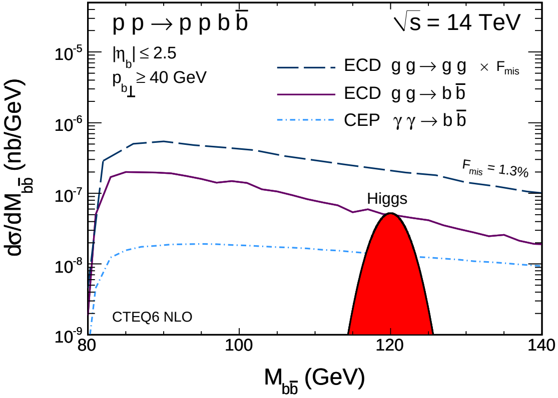
improved result very different than the naive one

$y_3 \times y_4$ correlations



naively jets from diagram B are not correlated
off-diagonal damping leads to the relatively strong correlations

Gluonic dijets as background to Higgs boson



gluon-gluon contribution comparable to the $b\bar{b}$ contribution

Summary of the EDD gluonic-dijet production

- Exclusive central diffractive *gg* was calculated using KMR UGDFs with exact kinematics including new diagram B.
- Matrix elements calculated using Lipatov vertices.
- Rough agreement with CDF data.
- Diagram B (typical ERBL region)
  naive estimate as for diagram A
  refined estimate
  Both predictions similar for some observables (η_1, η_2, p_t) and very different for other obsevables (η_{diff}, M_{jj})
- Quark-antiquark contribution negligible.
- Possible to separate or identify diagram-B contribution? It is probably small, Perhaps at very small transverse momenta.

Summary of the EDD gluonic-dijet production

- Exclusive dijets constitute very large (reducible) background for exclusive Higgs production when gluonic jets are misidentified as b-jets. Typically 1% misidentification probability i.e. 10^{-4} misidentification probability of digluons as $b\bar{b}$.