Diffractive exclusive production of heavy quark pairs at high energy proton-proton collisions

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Introduction

Exclusive reaction: $pp \to pXp$
($X = H, Z, \eta', \eta_c, \eta_b, \chi_c, \chi_b$, jj, $J/\Psi, \Upsilon$, ...).

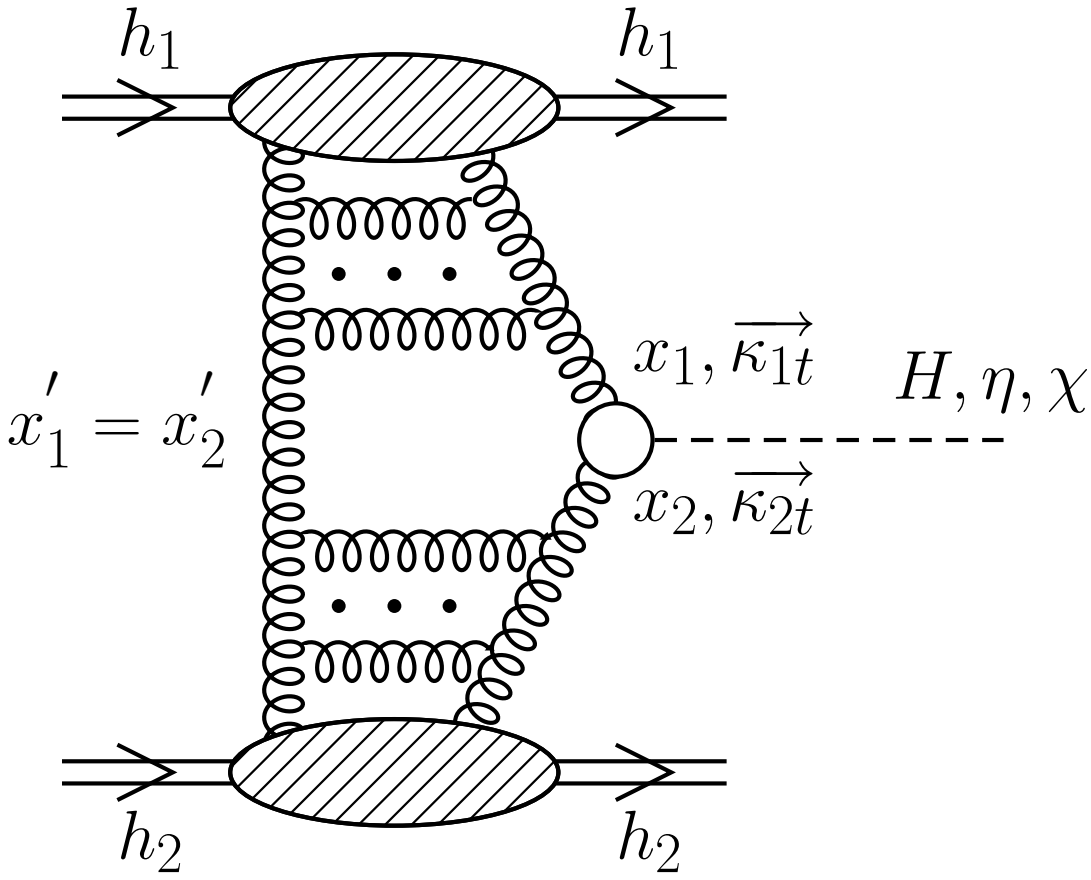
At high energy - one of many open channels (!)
$\Rightarrow$ rapidity gaps.

- Search for Higgs primary task for LHC.
  Diffractive production of the Higgs an alternative to inclusive production.
  A new QCD mechanism (Khoze-Martin-Ryskin).
- $H \to b\bar{b}$ versus $b\bar{b}$ continuum
- exclusive diffractive production of $Q\bar{Q}$ interesting by itself

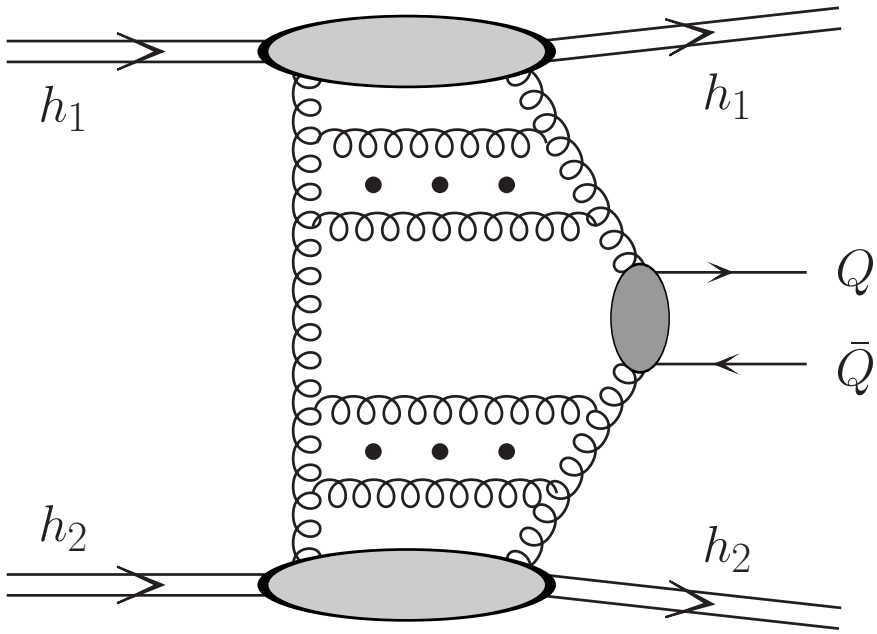
Collaboration

in collaboration with:
Rafal Maciuła and Roman Pasechnik
1) "Exclusive double-diffractive production of open charm in proton-proton and proton-antiproton collisions",
Phys. Lett. **B685** (2010) 165.
2) a paper in preparation

The QCD mechanism for exclusive Higgs production



The QCD mechanism for exclusive $Q\bar{Q}$ production



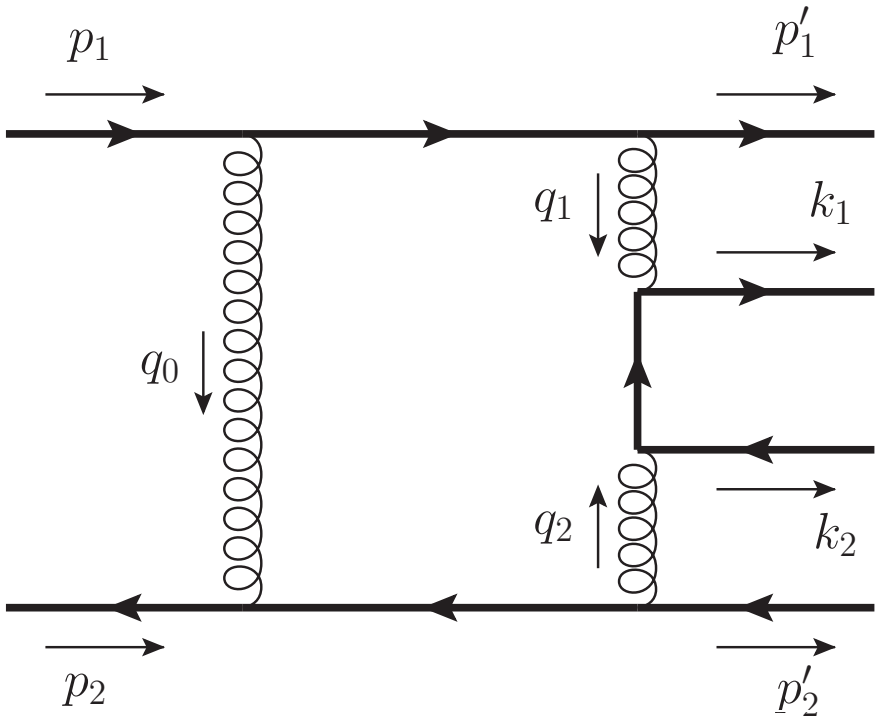
$c\bar{c} \to b\bar{b}$: background to exclusive Higgs production

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:

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

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 $pp \to ppQ\bar{Q}$

$$\mathcal{M}^{pp\to ppq\bar{q}}_{\lambda_q\lambda_{\bar{q}}}(p_1', p_2', k_1, k_2) = s\,\frac{\pi^2}{2}\,\frac{\delta_{c_1c_2}}{N_c^2-1}\,\Im\int d^2q_{0,t}\; V^{c_1c_2}_{\lambda_q\lambda_{\bar{q}}}(q_1, q_2, k_1, k_2)$$
$$\frac{f^{\rm off}_{g,1}(x_1, x_1', q^2_{0,t}, q^2_{1,t}, t_1) f^{\rm off}_{g,2}(x_2, x_2', q^2_{0,t}, q^2_{2,t}, t_2)}{q^2_{0,t}\, q^2_{1,t}\, q^2_{2,t}}\,,$$

where λ_q, $\lambda_{\bar{q}}$ are helicities of heavy q and $\bar{q}$.

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

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

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

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

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

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

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

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

The tensorial part:

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

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

Off-diagonal unintegrated gluon distributions

KMR method

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

$$\approx R_g \frac{d g(x_1, k_t^2)}{d \log k_t^2}\Big|_{k_t^2 = Q_{1,t}^2} S_{1/2}(Q_{1,t}^2, \mu^2)\, F(t_1)\,,$$

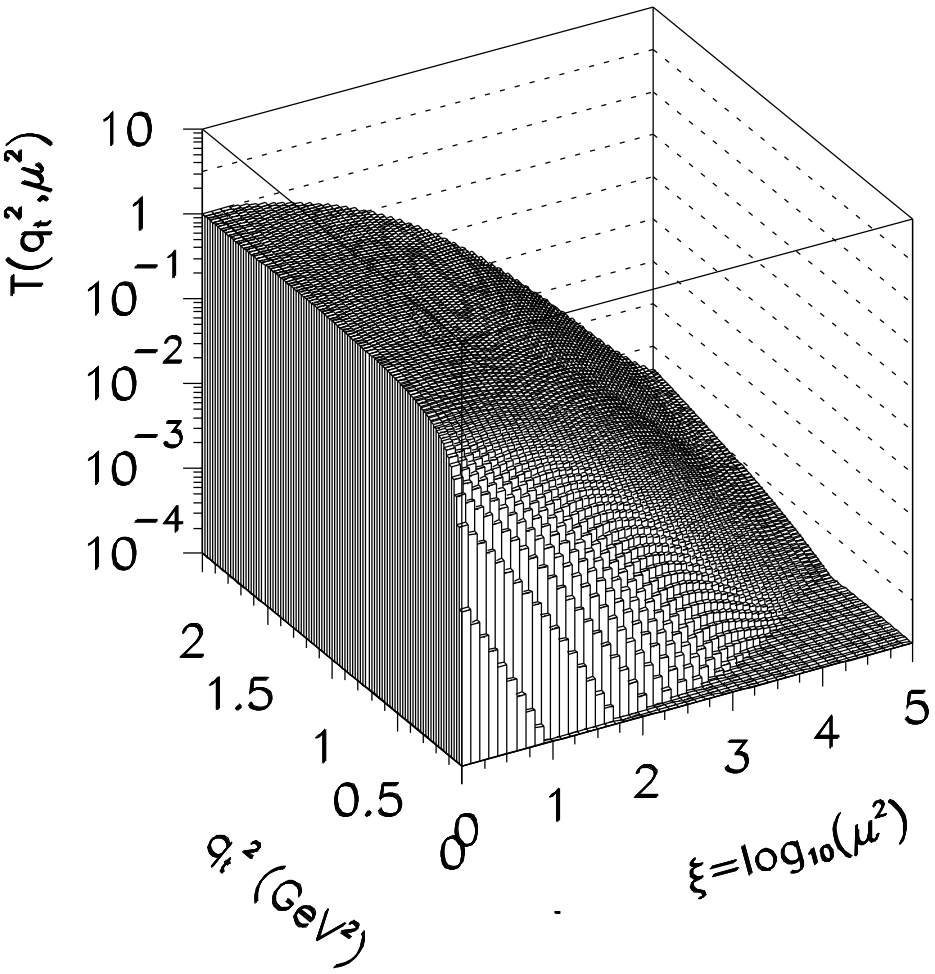
$$f_2^{\mathrm{KMR}}(x_2, Q_{2,t}^2, \mu^2, t_2) = R_g \frac{d[g(x_2, k_t^2) S_{1/2}(k_t^2, \mu^2)]}{d \log k_t^2}\Big|_{k_t^2 = Q_{2t}^2} F(t_2)$$

$$\approx R_g \frac{d g(x_2, k_t^2)}{d \log k_t^2}\Big|_{k_t^2 = Q_{2,t}^2} S_{1/2}(Q_{2,t}^2, \mu^2)\, F(t_2)\,,$$

Sudakov-like form factor

It was proposed Martin-Ryskin:

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



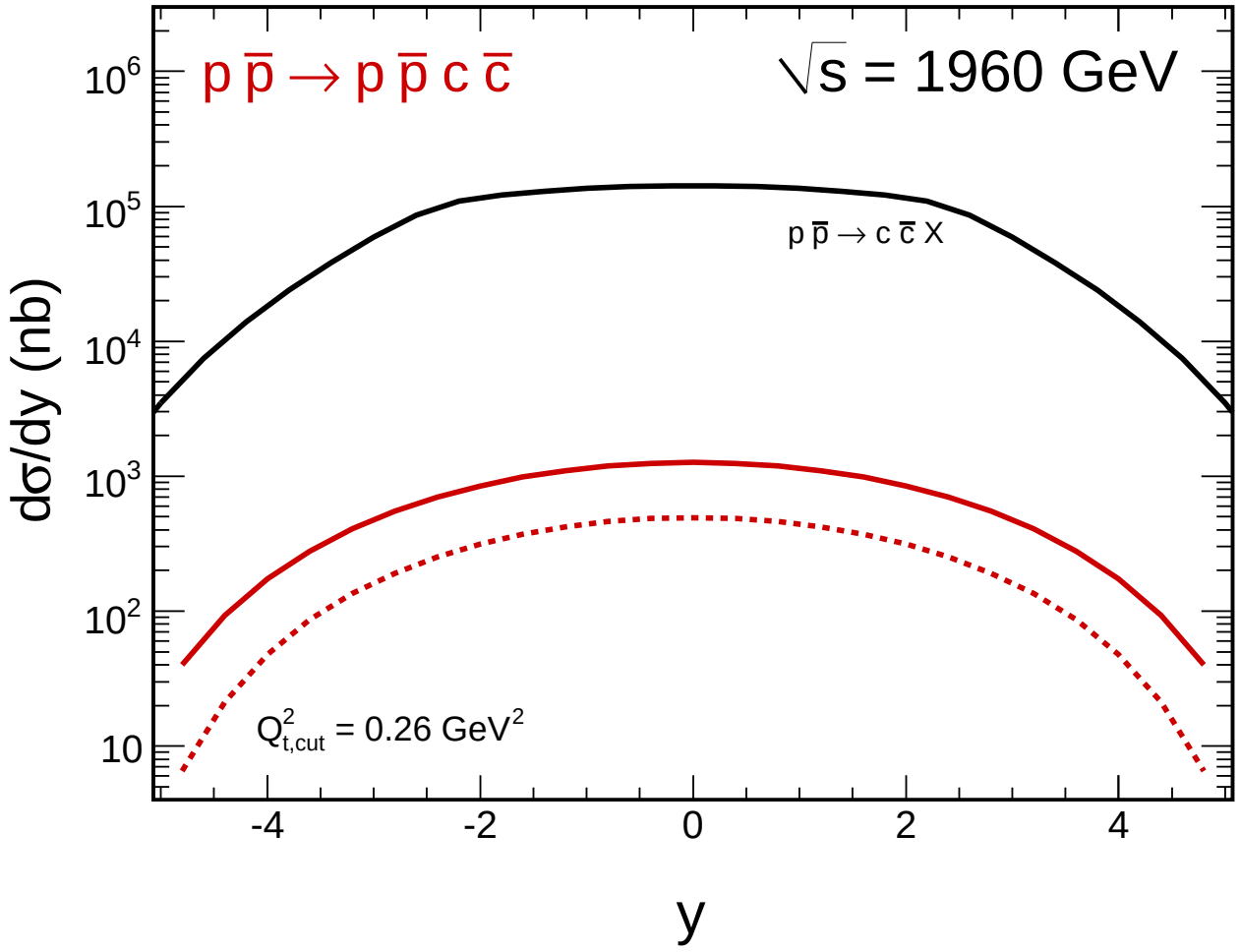
The $pp \longrightarrow ppQ\bar{Q}$ cross section

Exact four-body kinematics

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

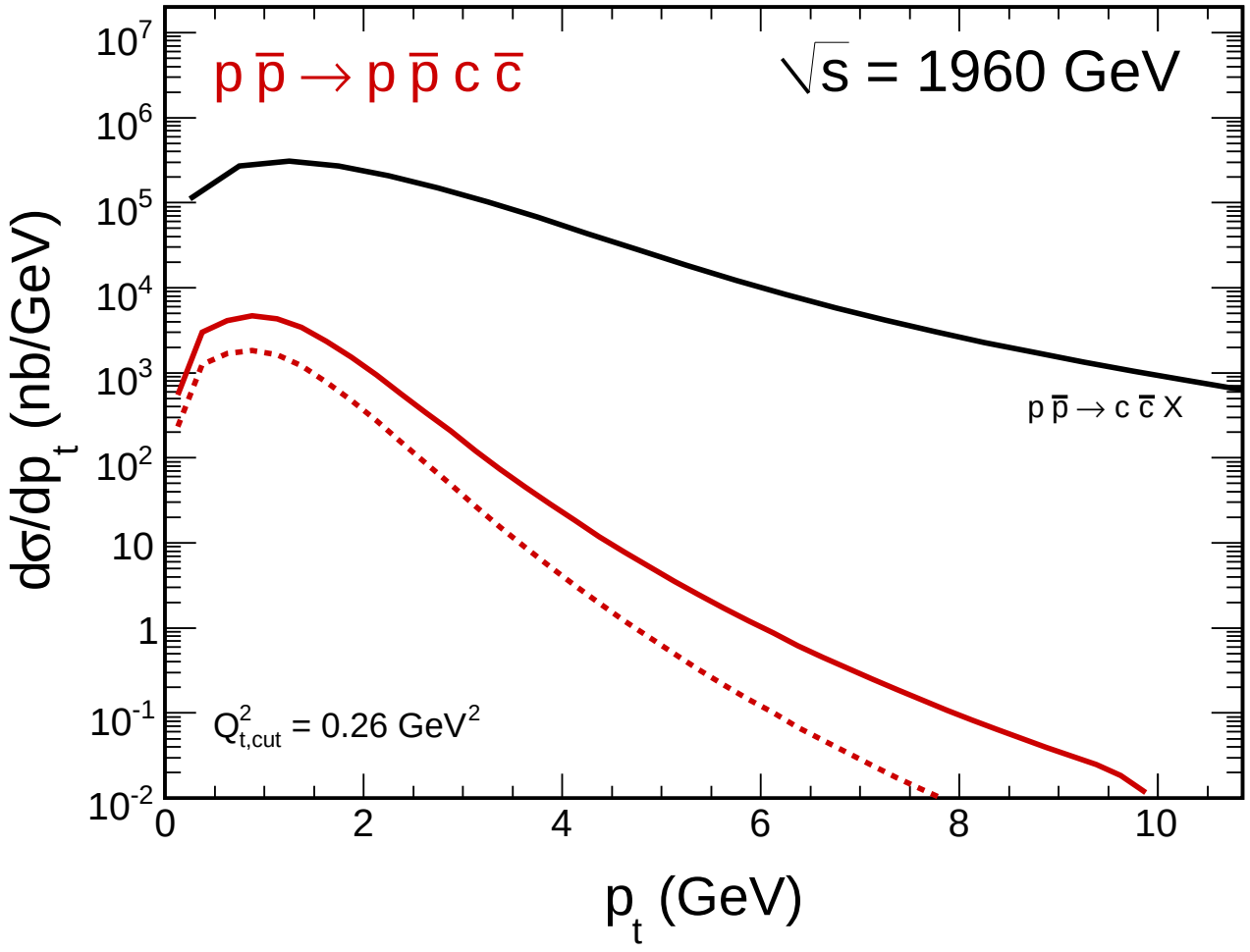
with exact (including quark mass) $2 \longrightarrow 4$ amplitude.

The $pp \to ppc\bar{c}$ cross sections



inclusive ($gg \to c\bar{c}$ only) within k_t-factorization with Kwieciński UGDF

The $pp \longrightarrow ppc\bar{c}$ cross sections



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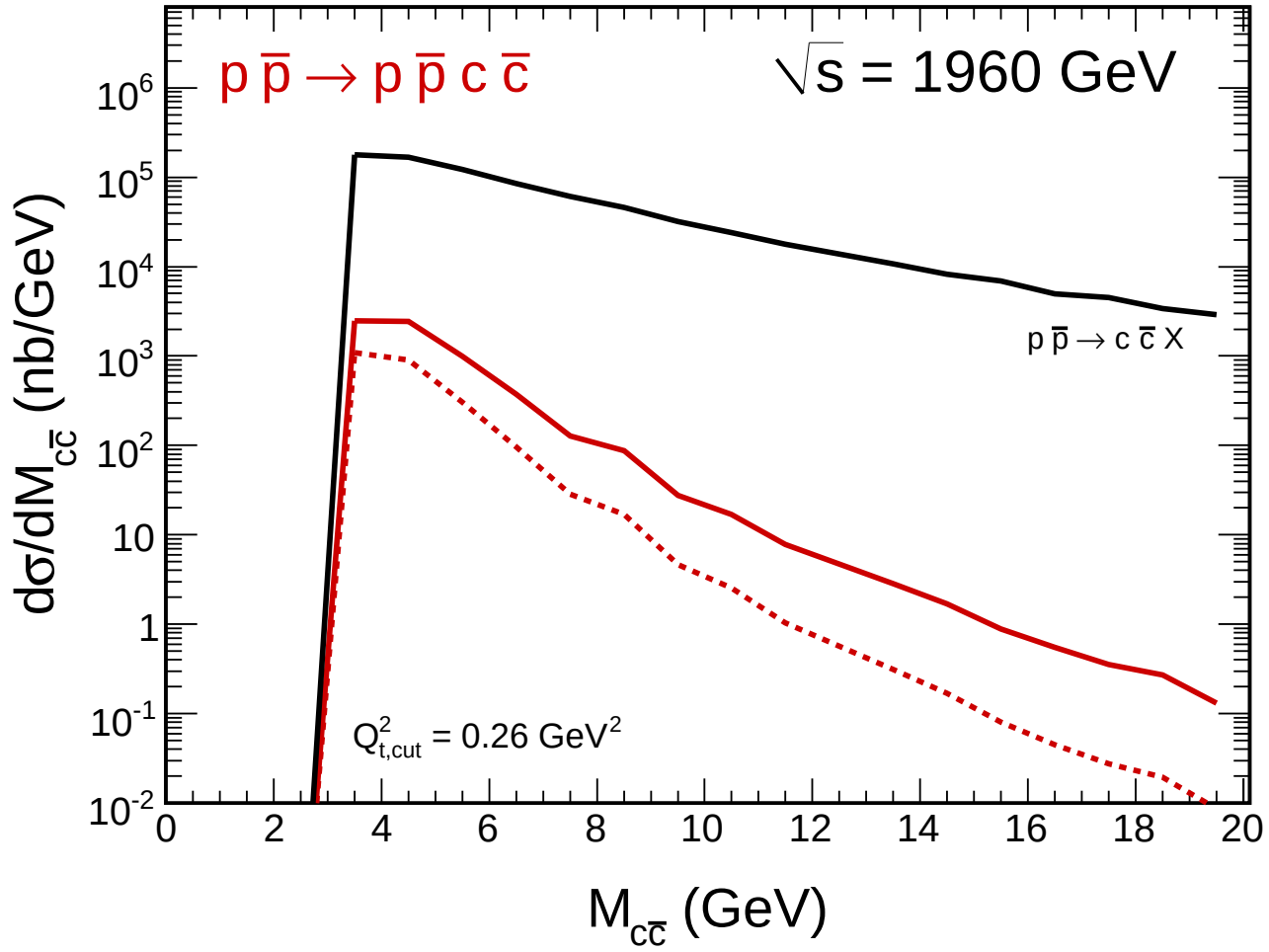

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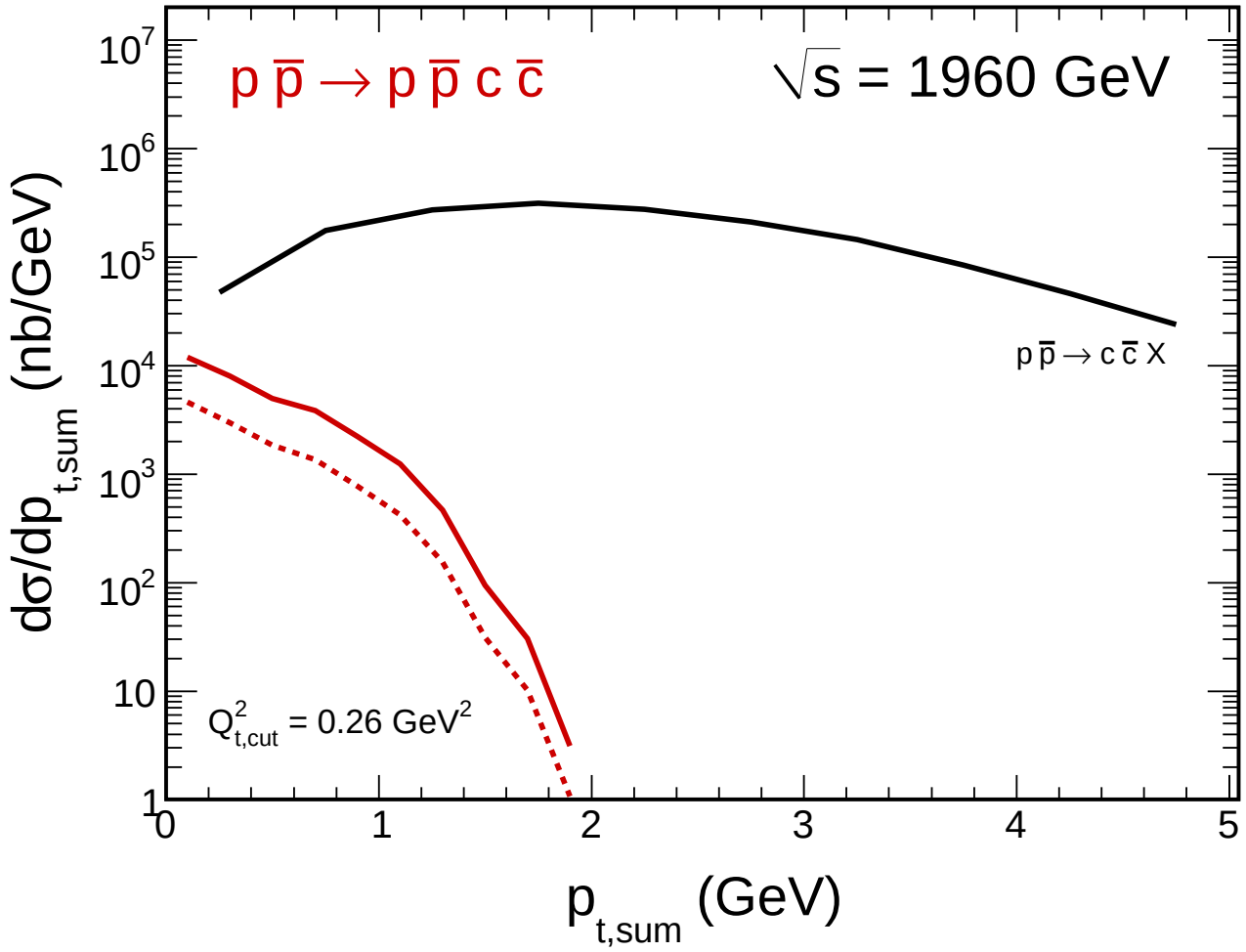
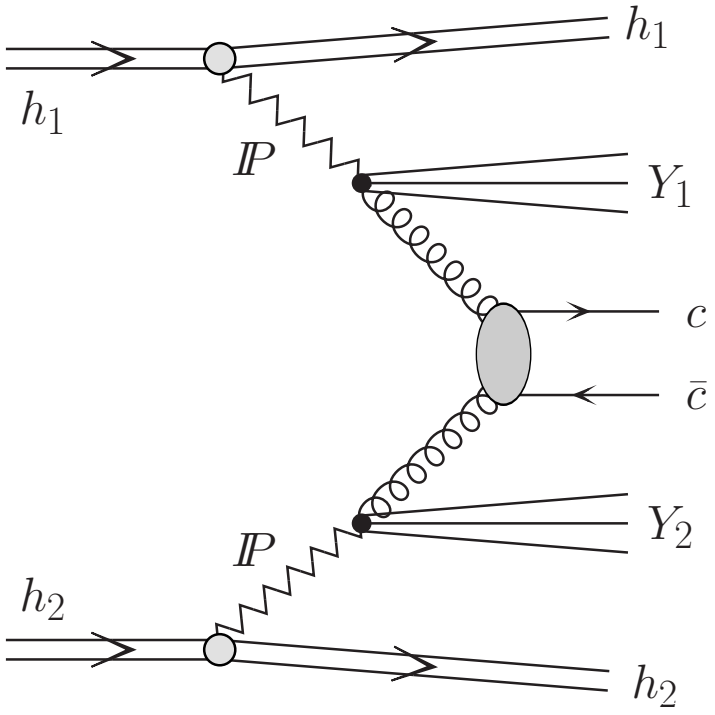


$\vec{p}_{t,sum} = \vec{p}_{3,t} + \vec{p}_{4,t}$

Other similar processes



was calculated by M. Machado: 0.1% of inclusive,
10 times less

Summary of the EDD $c\bar{c}$ production

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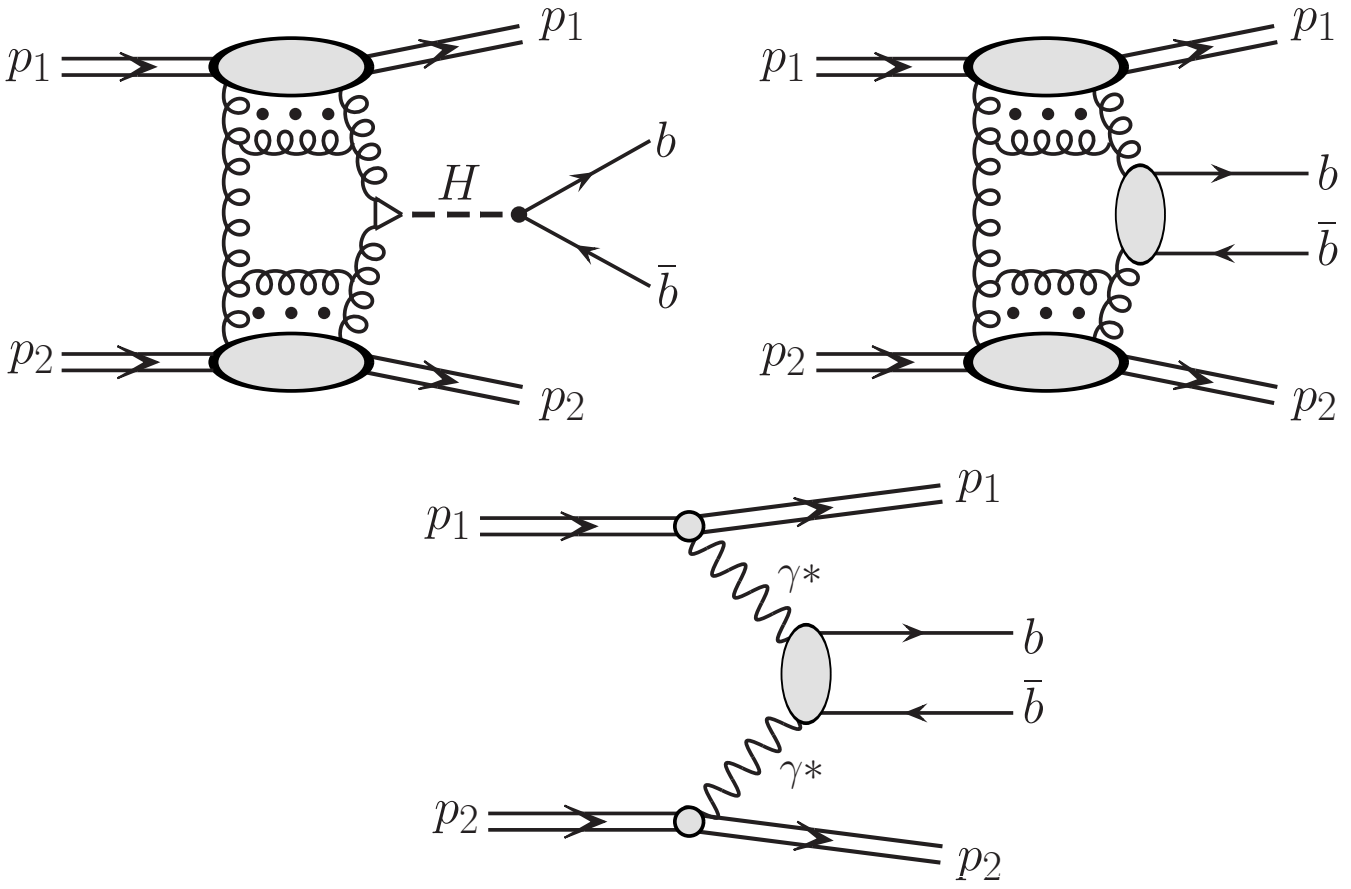
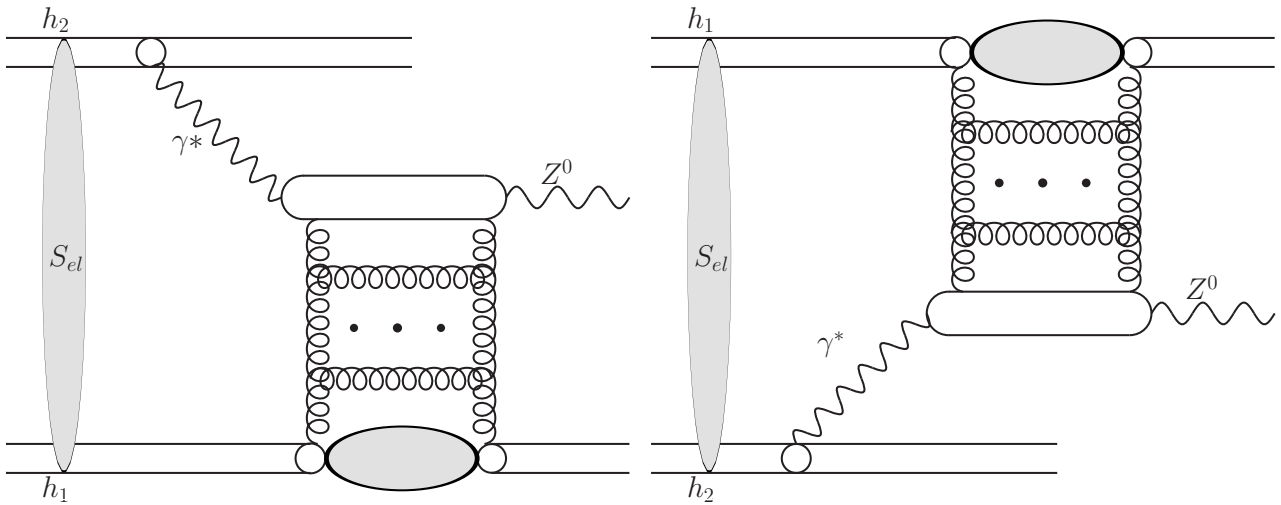
- How to measure the process?
- Repeat for EDD $b\bar{b}$ production (background for EDD Higgs).

EDD $b\bar{b}$ production



Exclusive Z^0 production



Cisek, Schäfer, Szczurek,
Phys. Rev. **D80** (2009) 074013.

Exclusive Higgs production

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

$$T^{ab}_{\mu\nu}(q_1,q_2) = i\delta^{ab}\frac{\alpha_s}{2\pi}\frac{1}{v}\Big\{[(q_1q_2)g_{\mu\nu} - q_{1\mu}q_{2\nu}]G_1(q_1,q_2) + \left[q_{1\mu}q_{2\nu} - \frac{q_1^2}{(q_1q_2)}q_{1\mu}q_{1\nu} - \frac{q_2^2}{(q_1q_2)}q_{2\mu}q_{2\nu}\right]G_2(q_1,q_2)\Big\}$$

$v = (G_F\sqrt{2})^{-1/2}$ (Pasechnik-Teryaev-Szczurek)
Eur. Phys. J. **C47** (2006) 429.
Let us introduce:

$$\chi = \frac{m_H^2}{4m_f^2} > 0, \quad \chi_1 = \frac{q_1^2}{4m_f^2} < 0, \quad \chi_2 = \frac{q_2^2}{4m_f^2} < 0.$$

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

$$\mathcal{M}_{pp\to ppH} = s\pi^2 \frac{1}{2}\frac{\delta_{ab}}{N_c^2-1} \Im \int d^2 q_{0,t}\; V^{ab}_{g^*g^*\to H}(q_1,q_2,k)$$

$$\frac{f^{\rm off}_{g,1}(x_1,x_1',q_{0,t}^2,q_{1,t}^2,t_1) f^{\rm off}_{g,2}(x_2,x_2',q_{0,t}^2,q_{2,t}^2,t_2)}{q_{0,t}^2\, q_{1,t}^2\, q_{2,t}^2} \,,$$

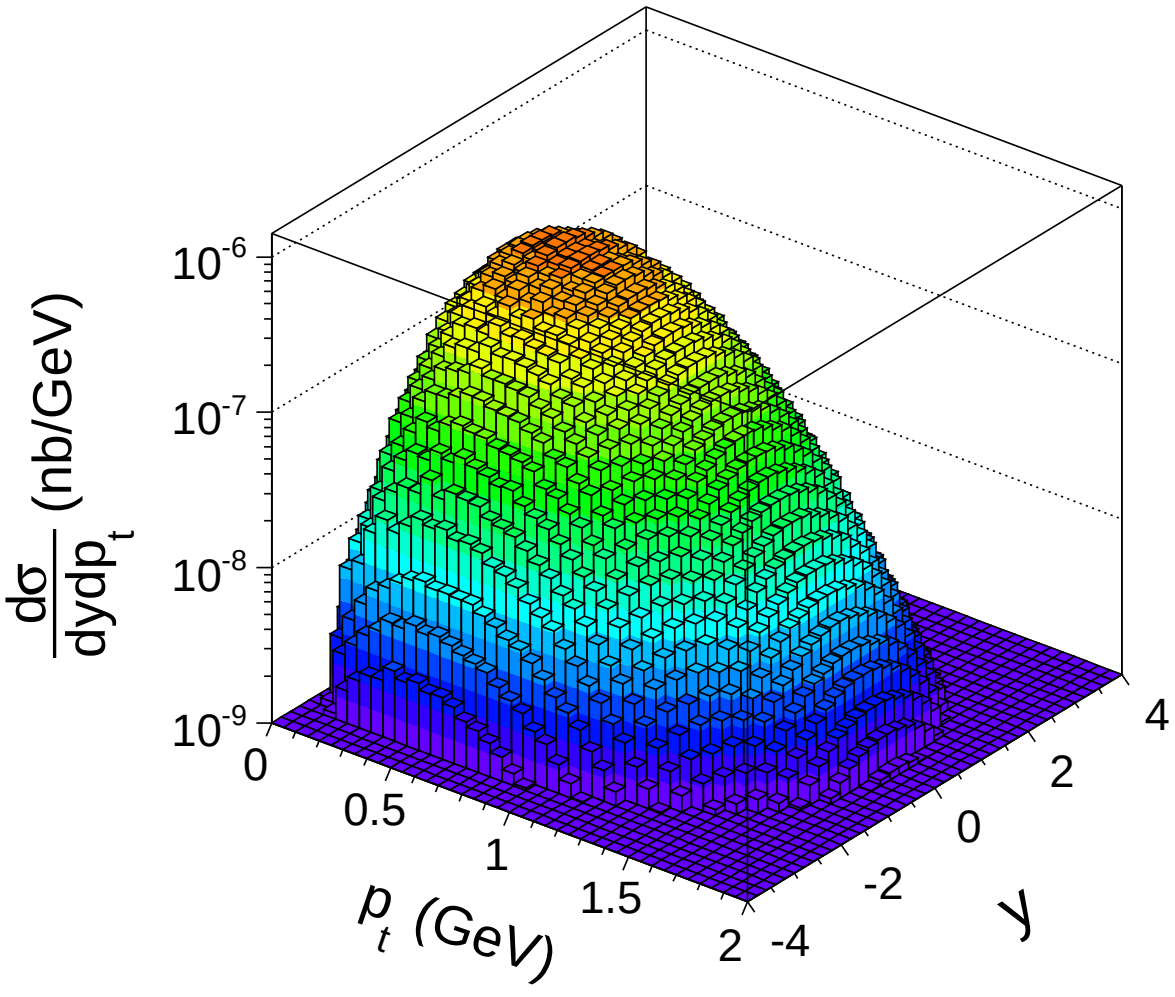
$$V^{ab}_{g^*g^*\to H}(q_1,q_2,k) = n_\mu^+ n_\nu^- T^{ab}_{\mu\nu}(q_1,q_2) = \frac{4}{s}\frac{q_{1t}^\mu}{x_1}\frac{q_{2t}^\nu}{x_2} T^{ab}_{\mu\nu}(q_1,q_2)\,.$$

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

The cross section

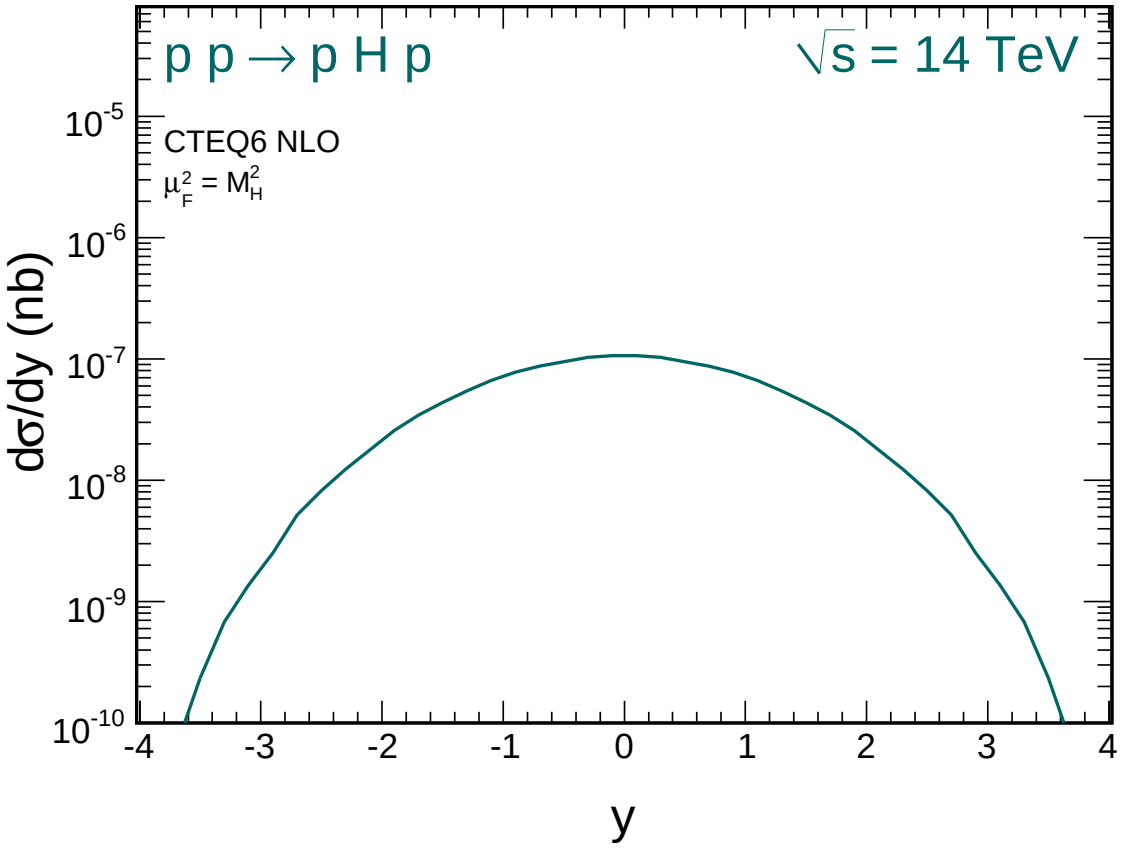
$$d\sigma_{pp\to pHp} = \frac{1}{2s}|\mathcal{M}|^2 \cdot d^3PS \quad , \quad d^3PS = \frac{1}{2^8\pi^4 s} dt_1 dt_2 dy_H d\phi\,.$$

Exclusive Higgs production



This distribution is used to produce distributions of b and $\bar{b}$

Exclusive Higgs production



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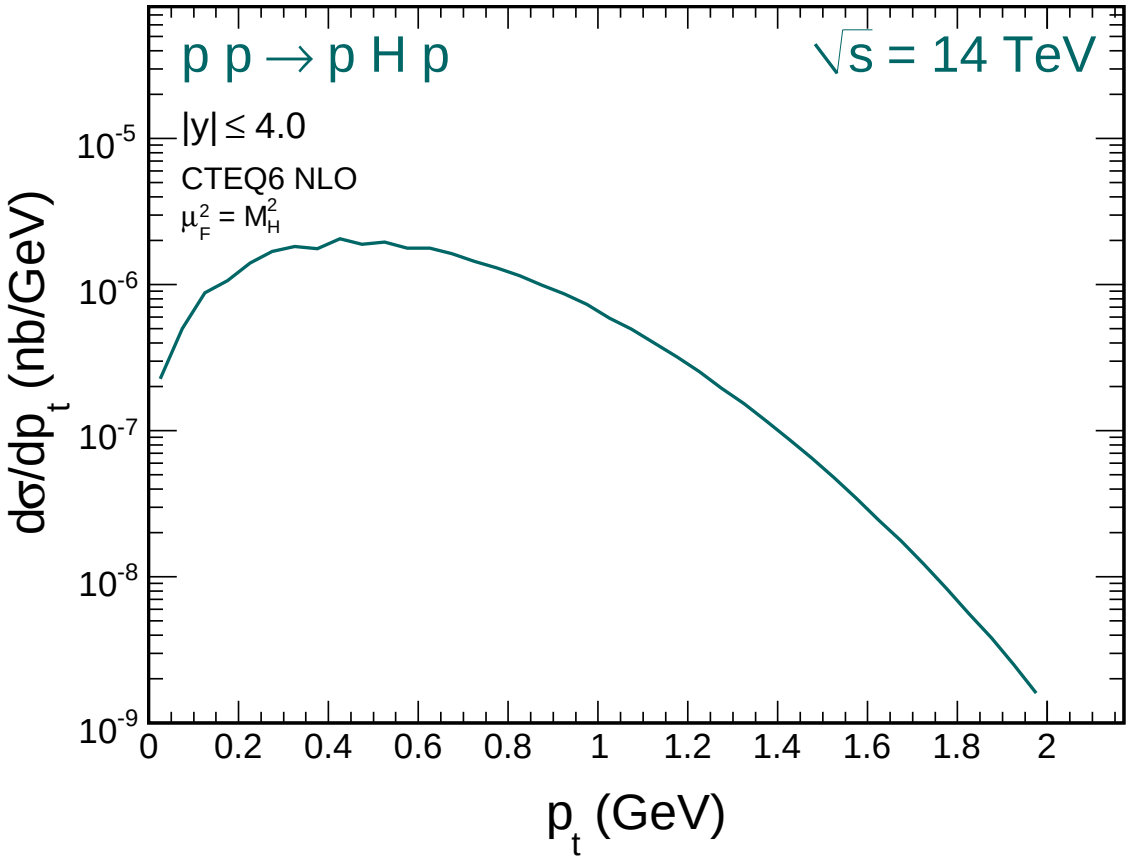
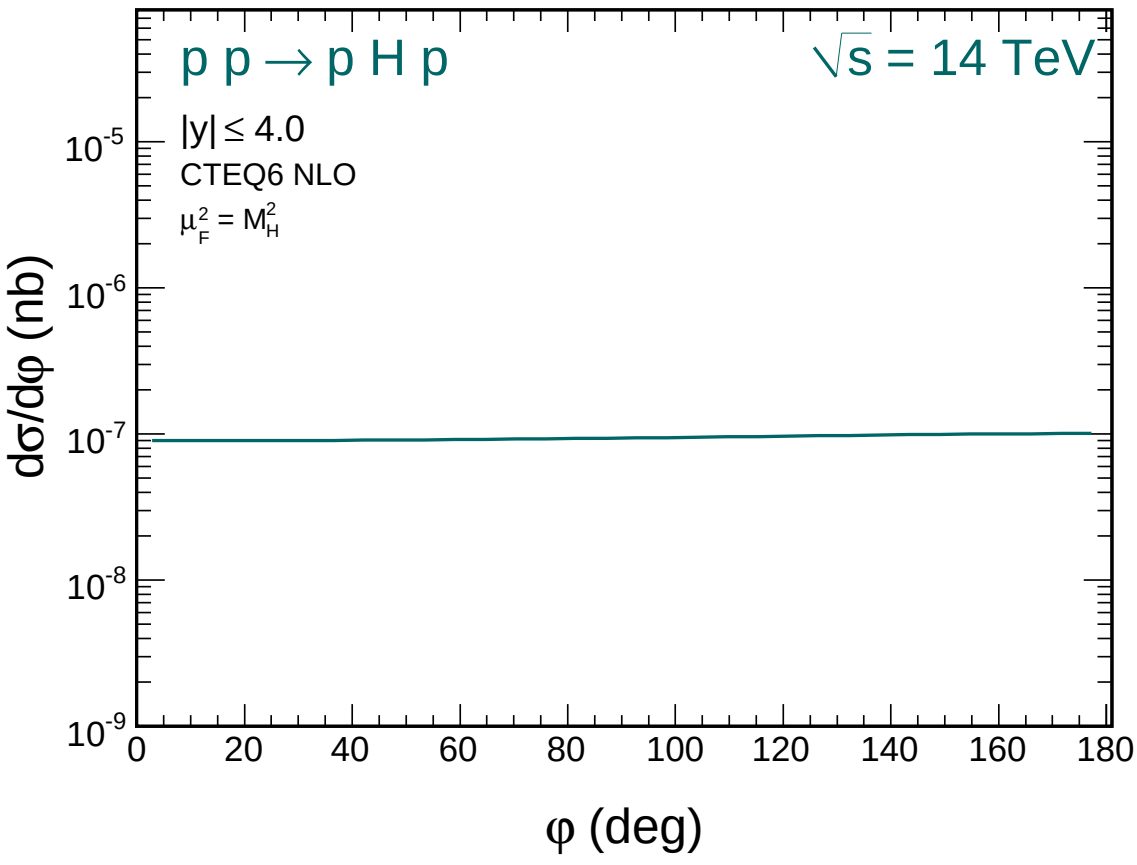
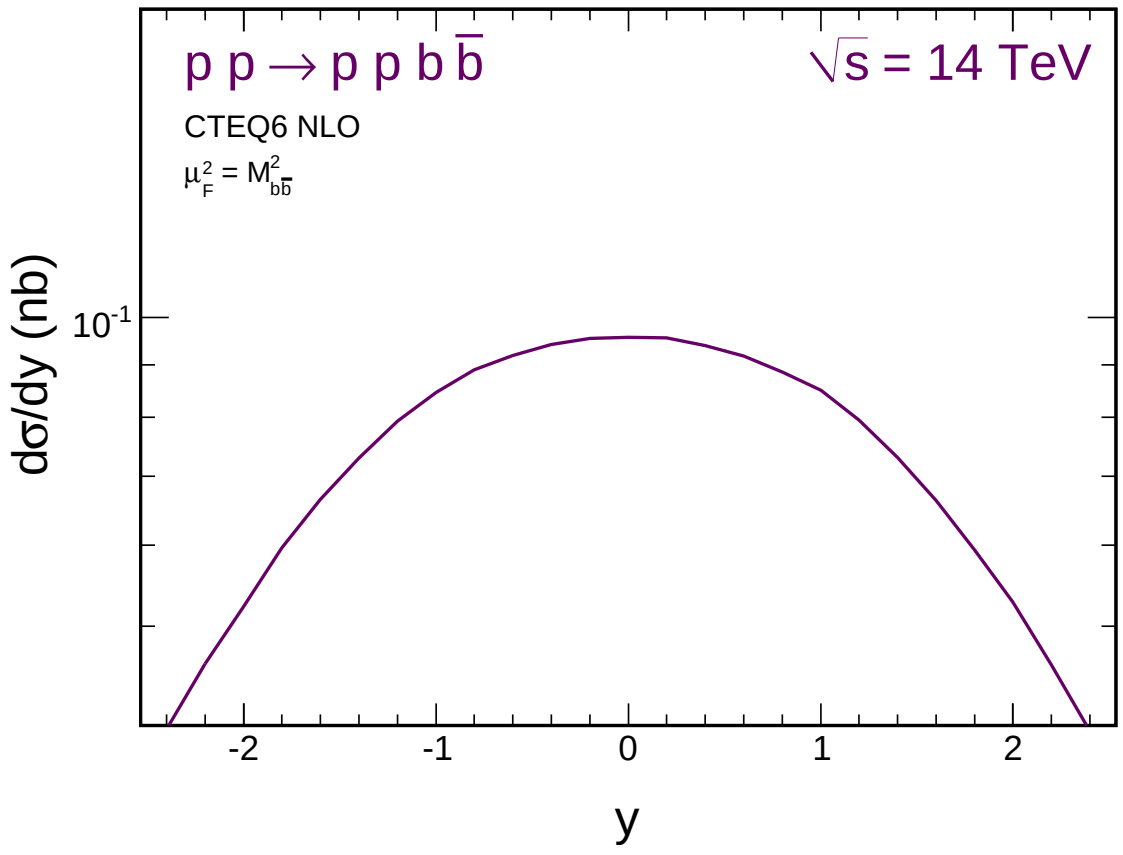


Exclusive Higgs production



CTEQ6

EDD $b\bar{b}$ production



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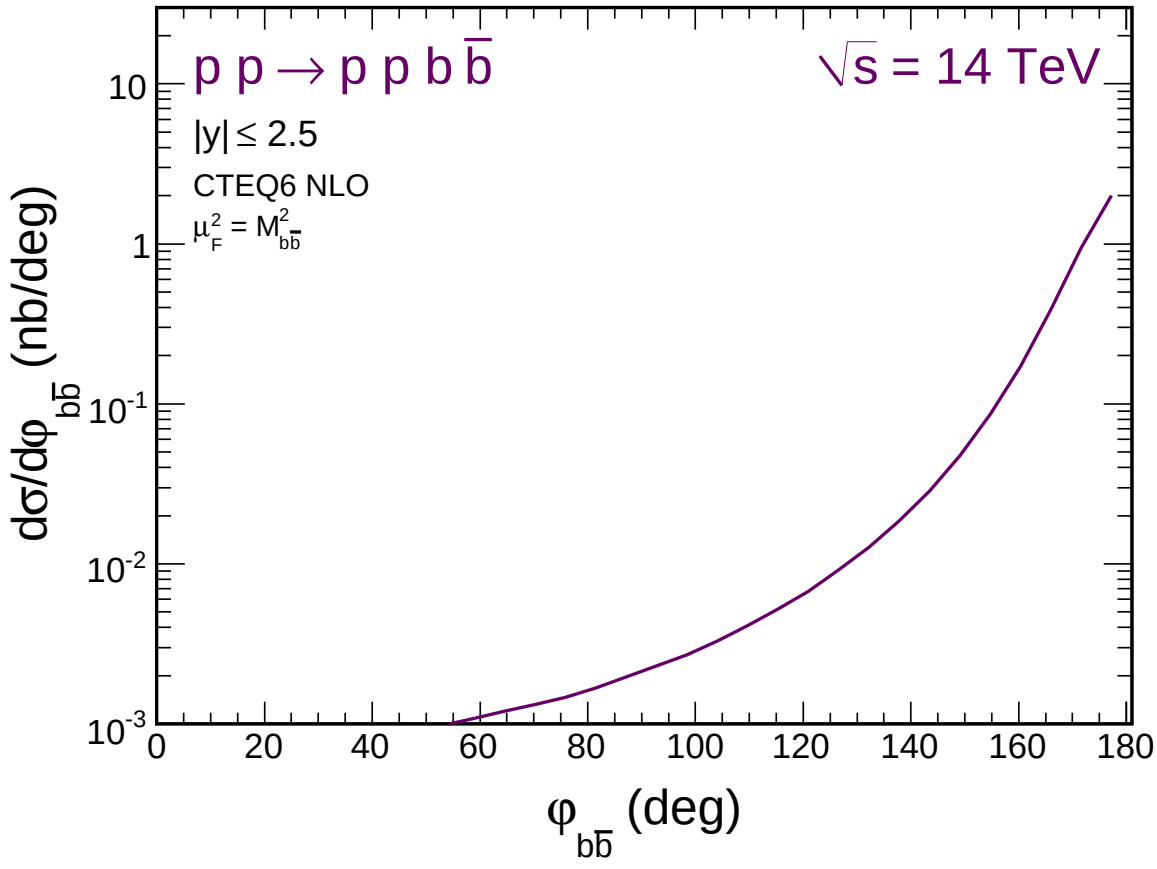

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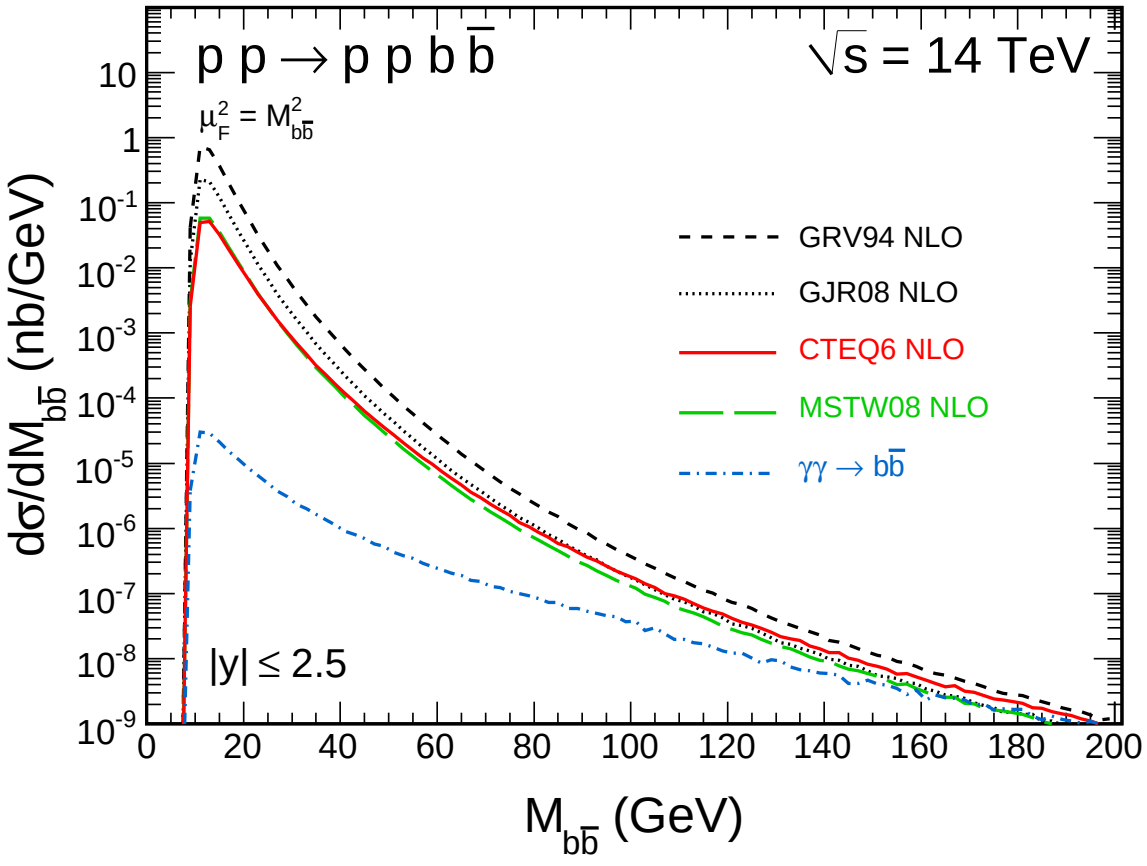
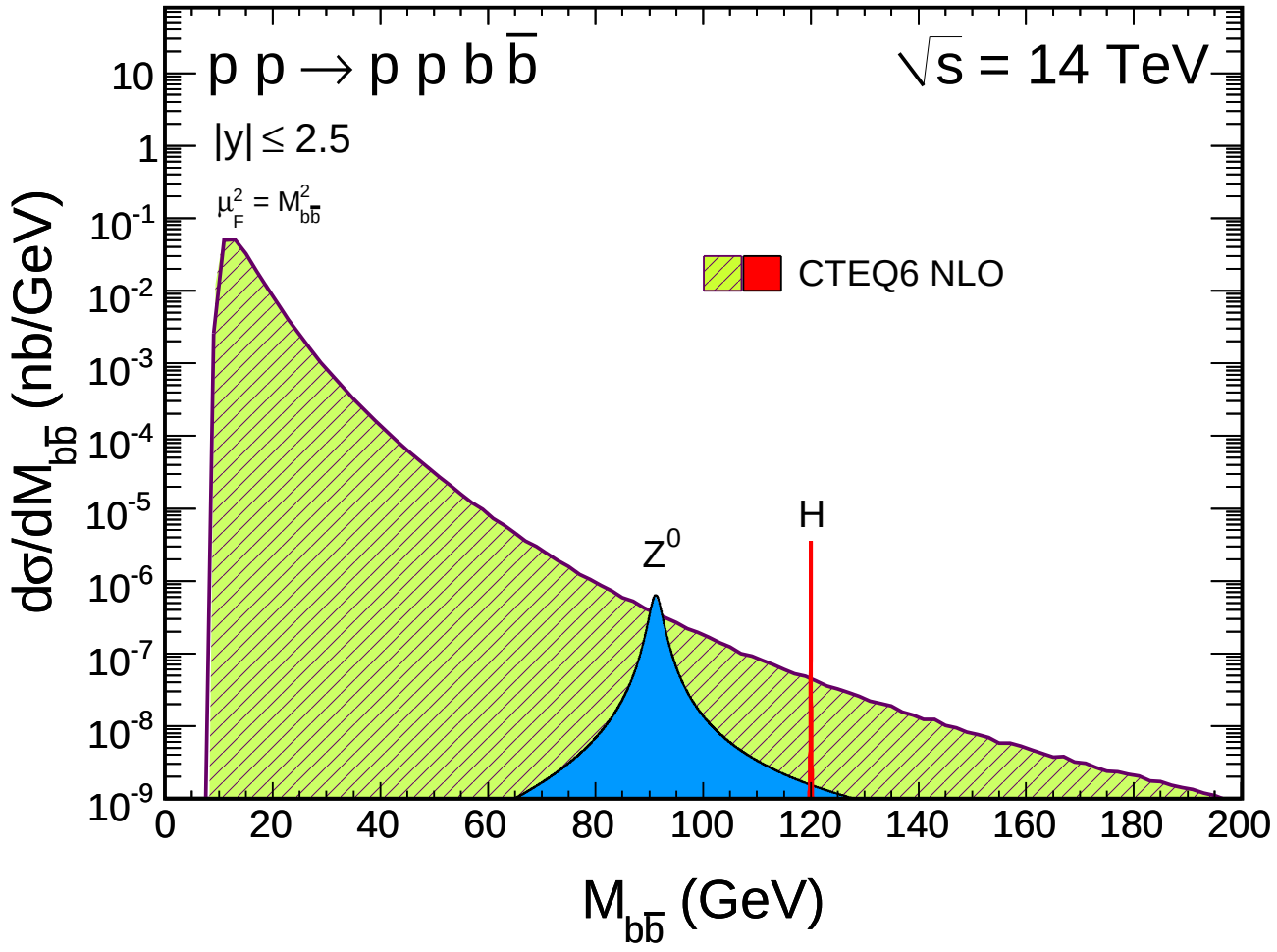


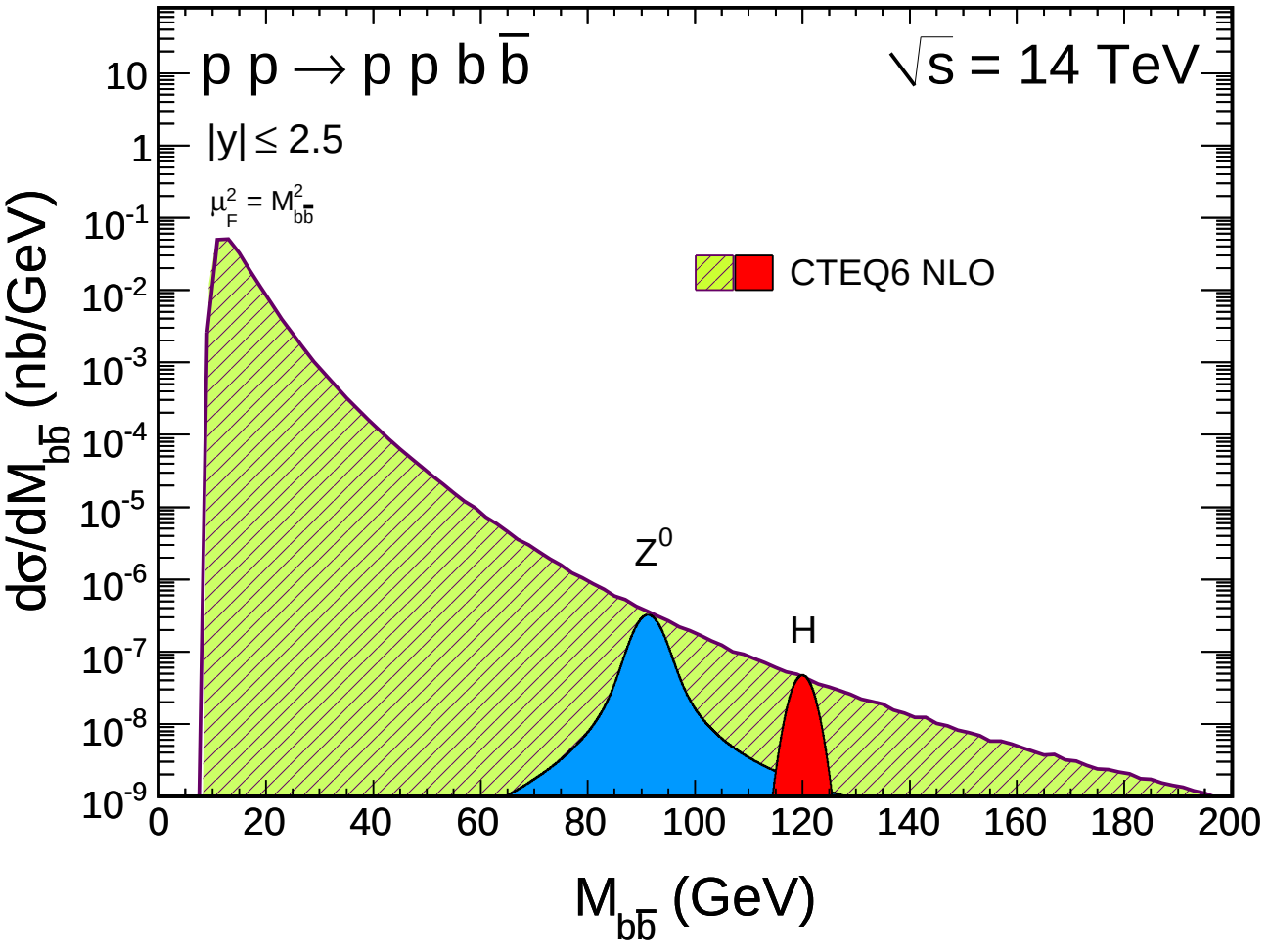
different UPDFs

M_{bb} spectrum, theory



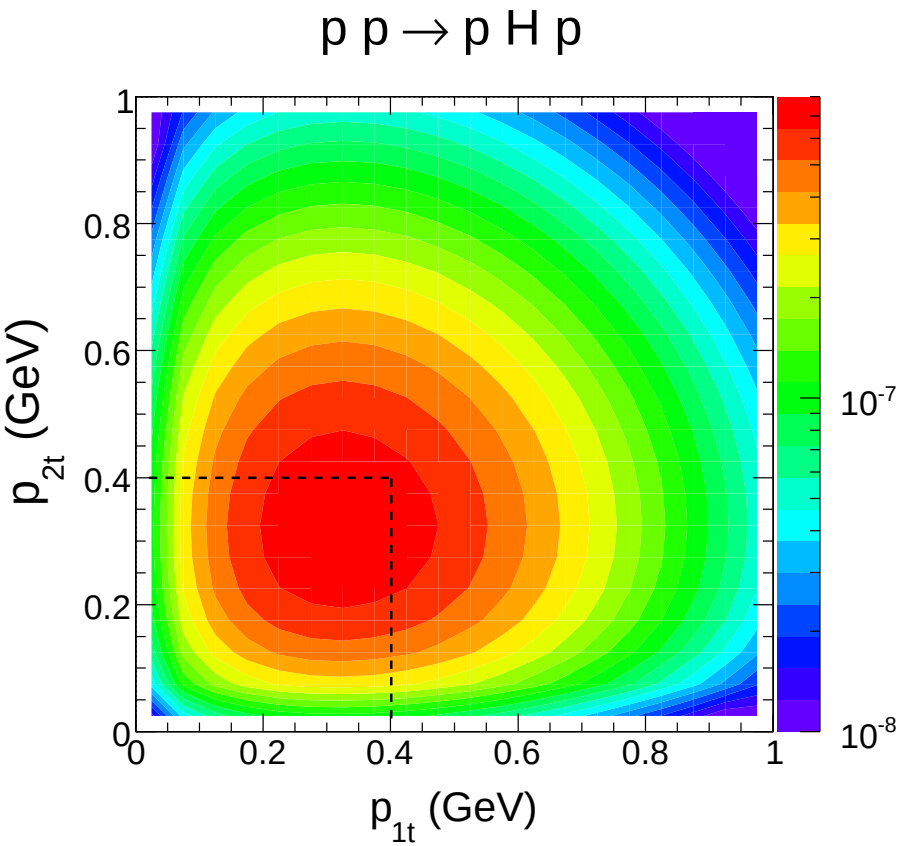
$$\rho(\mu) = \frac{1}{\pi} \frac{\mu \Gamma_H^{b\bar{b}}(\mu)}{[\mu^2 - M_H^2]^2 + [\mu \Gamma_H^{tot}(\mu)]^2}$$

M_{bb} spectrum, theory



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

Proton transverse momenta, Higgs case



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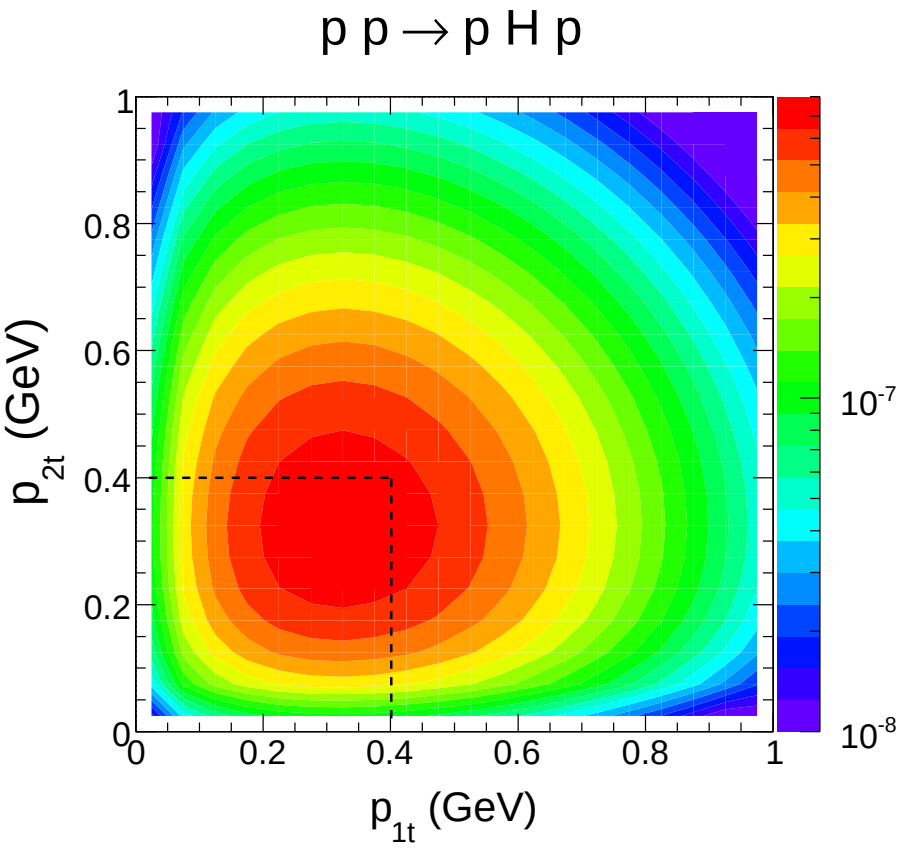
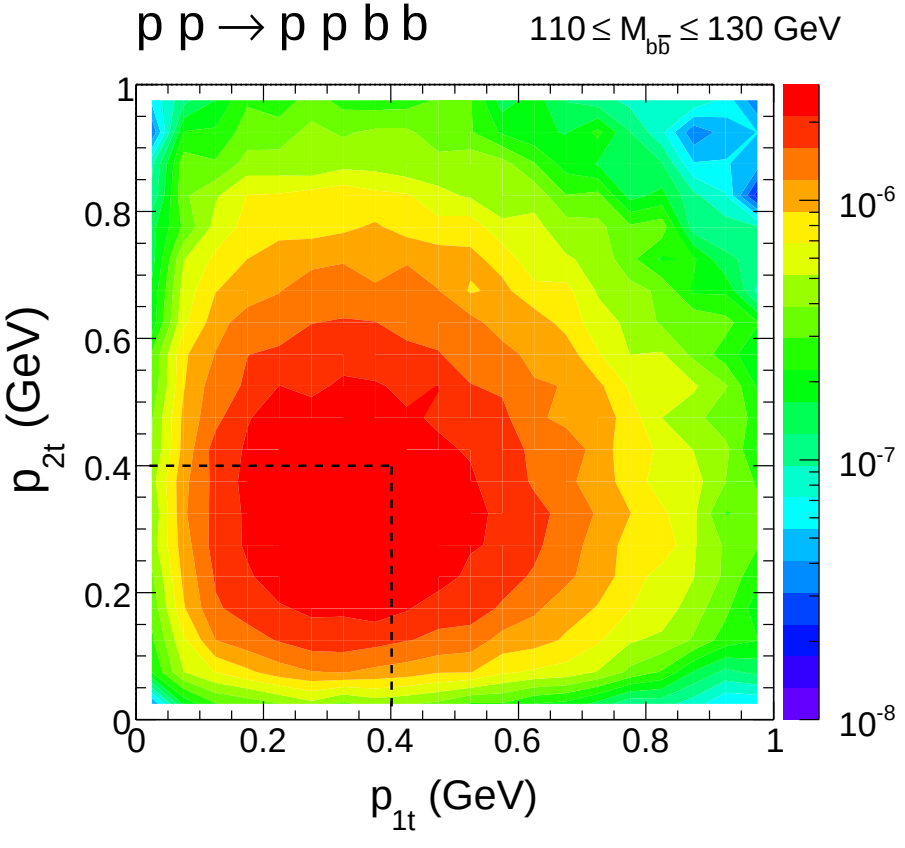
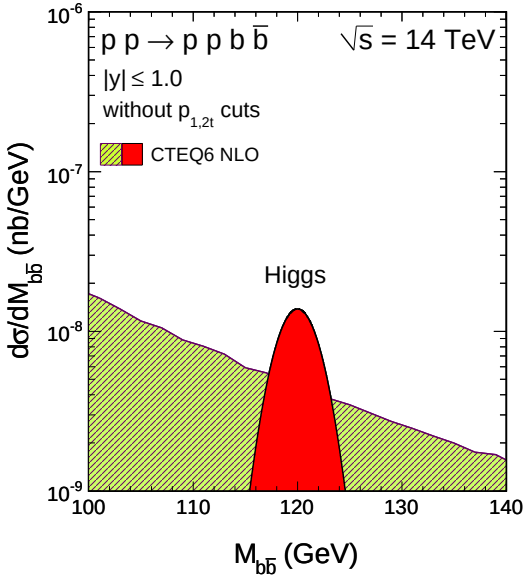
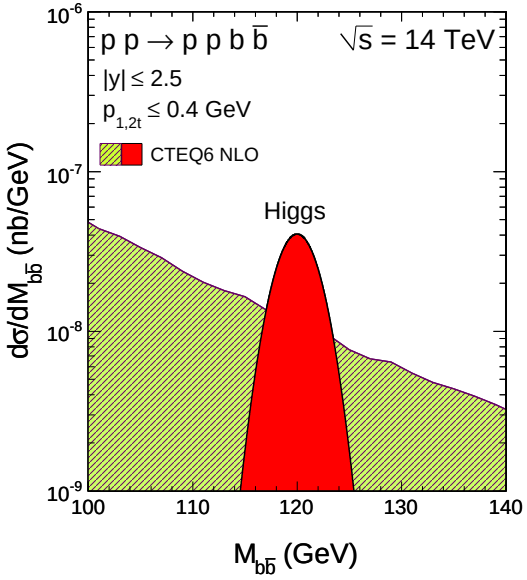
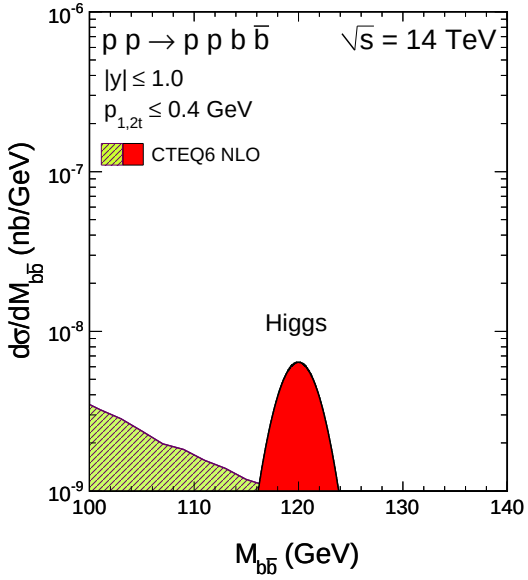




M_{bb} spectrum, cuts

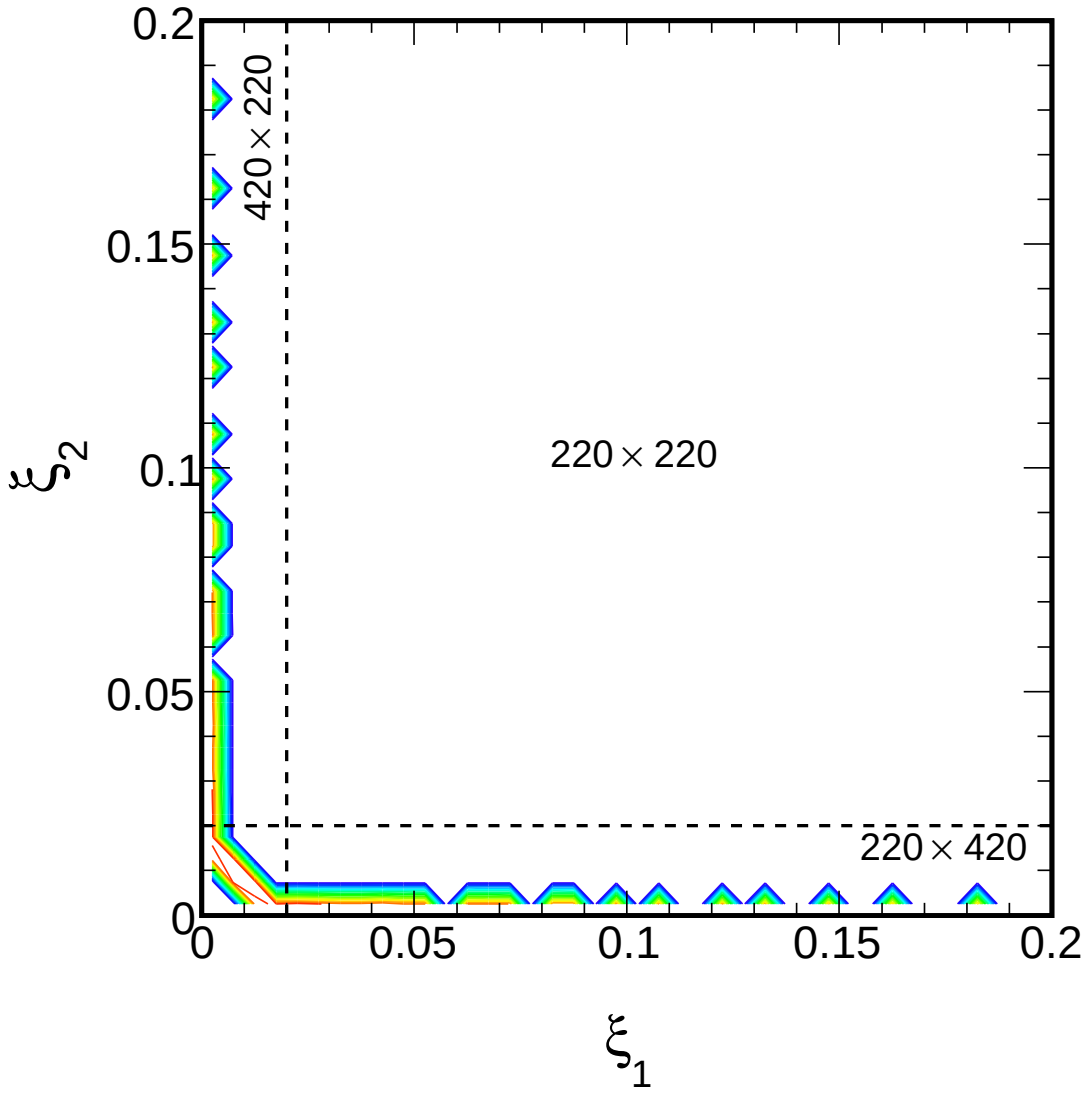






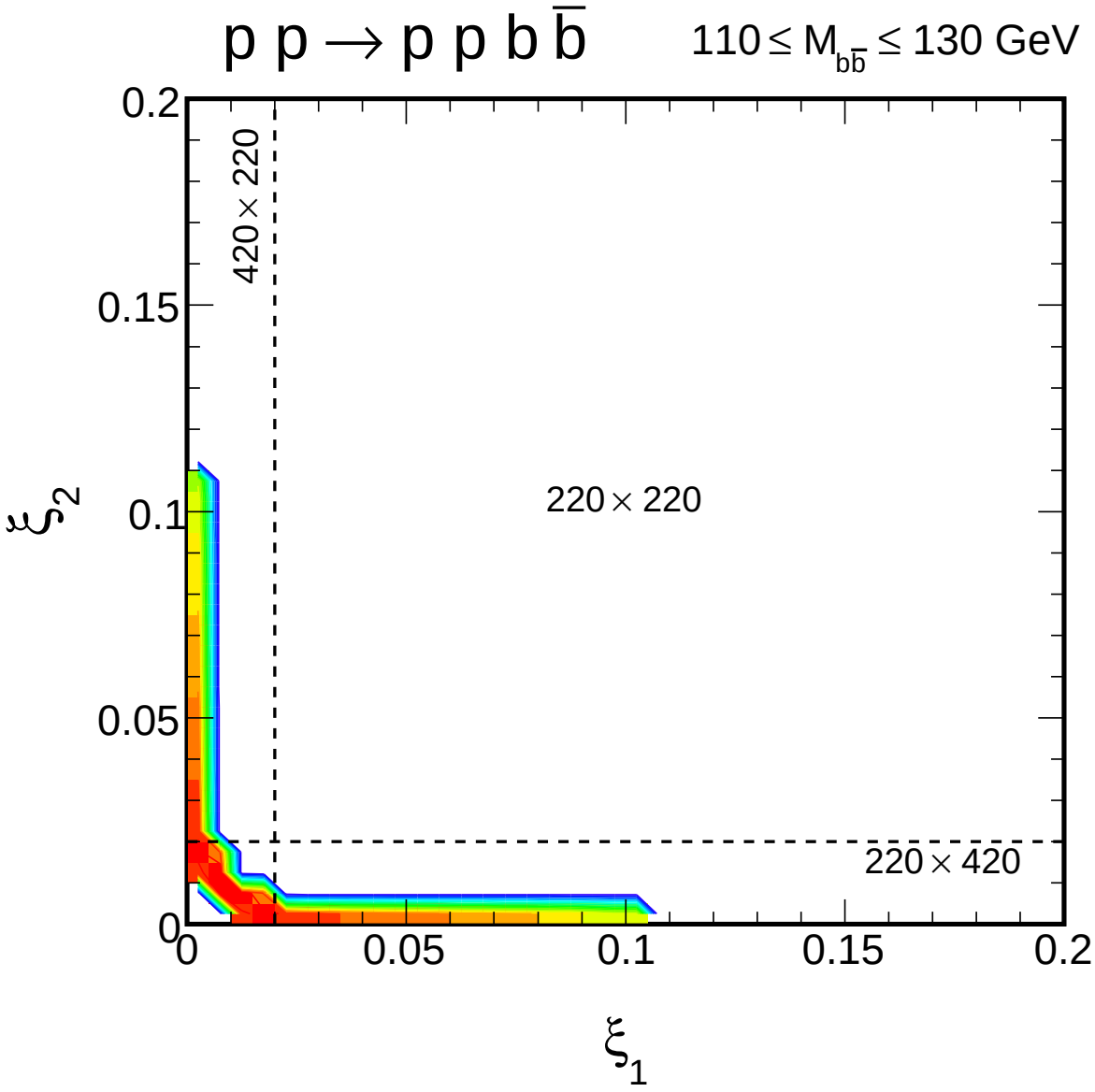
But very small cross sections

Long. momentum frac. distributions, Higgs case



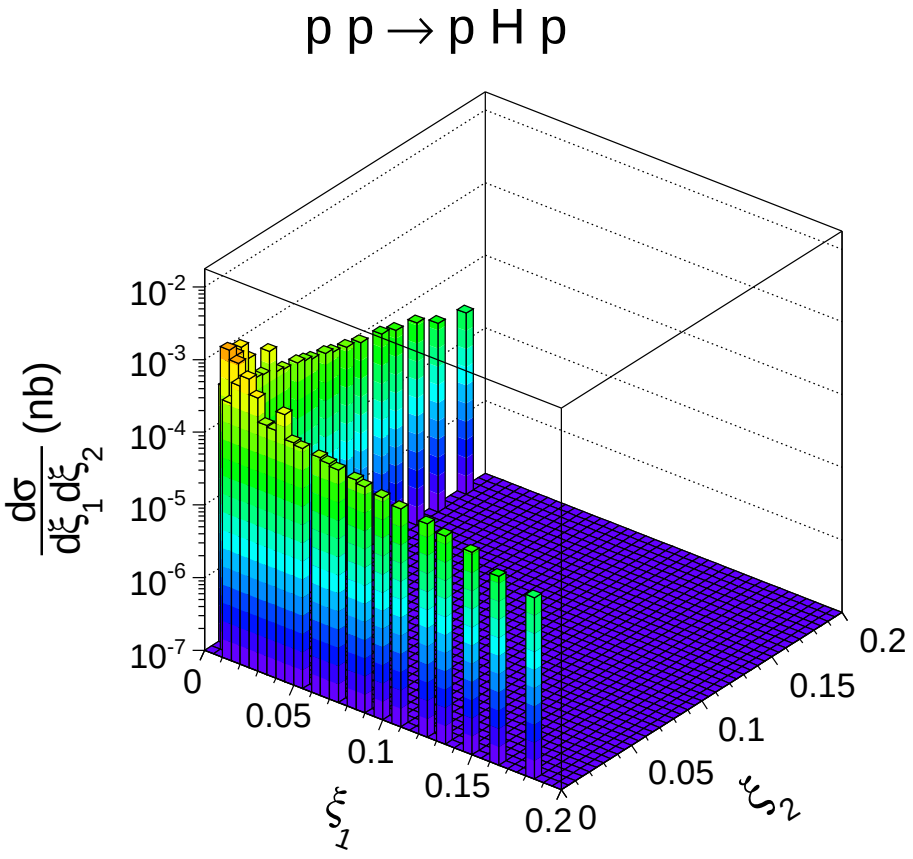
detector ranges marked by the dashed line

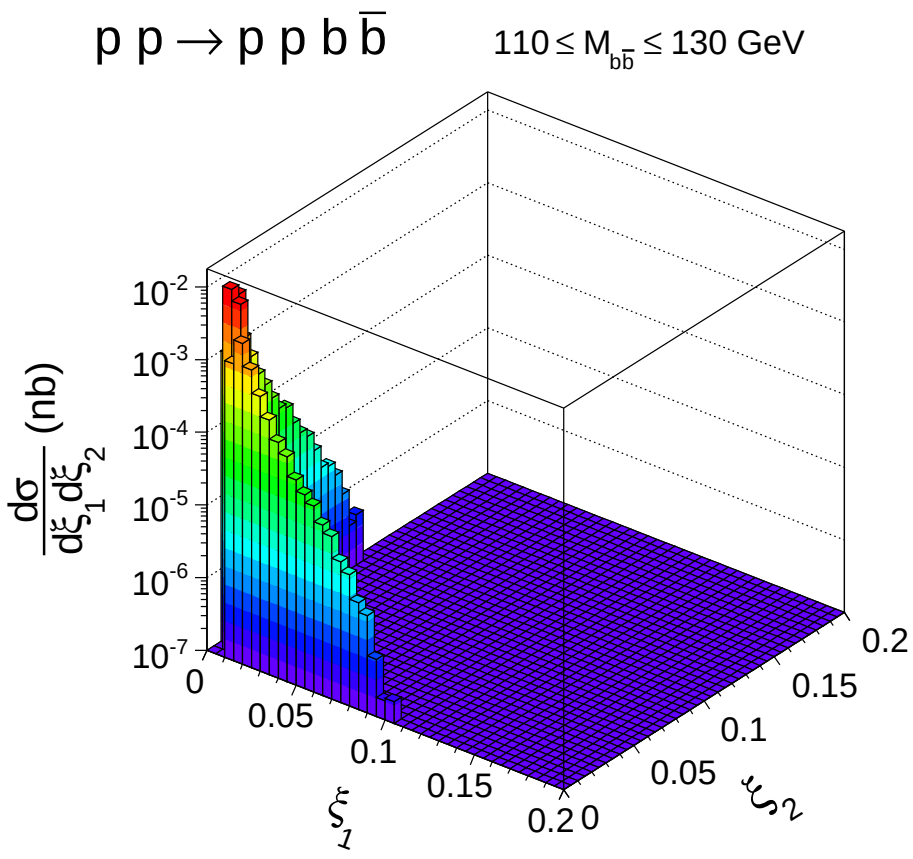
Long. mommentum frac. distributions, $b\bar{b}$ case



detector ranges marked by the dashed line

Longitudinal momentum fraction distributions





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

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- Further studies are necessary.