Pseudoscalar Higgs Resummation

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Outline

- Current Higgs limits
- Pseudoscalar Higgs (Full and HQET)
- What is (total and differential) resummation?
- Resumming gg and $b\bar{b}$ initial states
- Resummation coefficients for gg and $b\bar{b}$ initial state pseudoscalar production (new)
- Scalar and pseudoscalar p_t spectra (new)
- Conclusions

Limits

- New combined DØ/CDF top quark mass (hep-ex/0404010)
- New bounds on the SM Higgs mass

$$m_{\text{top}} = 178.0 \pm 4.3 \text{ GeV} \rightarrow m_H = 117^{+67}_{-45} \text{ GeV}$$

Pseudoscalar has slightly different exclusion limits in MSSM. With large $\tan\beta$ and lower mass $\rightarrow$ discovery possibility

$$m_{A^0} > 90.4 \text{ GeV}, \ \text{CL} = 95\%$$

$$\tan\beta > 1$$

Pseudoscalar Higgs

- MSSM pseudoscalar Higgs couples to quarks

$$-ig_{A^0}A^0\bar{\psi}_i\gamma_5\psi_i\frac{m_i}{v}$$

- g_{A^0} different for up- and down-type quarks

$$\mathrm{down}\,\mathrm{g}_{\mathrm{A}^0}=\tan\beta \quad \mathrm{up}\,\mathrm{g}_{\mathrm{A}^0}=\frac{1}{\tan\beta}$$

- The importance of the bottom quark in the resummation formalism requires calculations in the full theory. gg initial state with only top quark can use HQET

HQET Effective Lagrangian

Calculate an effective Lagrangian with $M_t \to \infty$

$$\mathcal{L}_{A^0 gg} = -g_{A^0} \frac{A^0}{v} \left[C_1^0 \mathcal{O}_1^0 + C_2^0 \mathcal{O}_2^0 \right]$$

$$\mathcal{O}_1^0 = G^a_{\mu\nu} \tilde{G}^{a,\mu\nu} \quad \mathcal{O}_2^0 = \partial_\mu \left(\sum_q \bar{q} \gamma^\mu \gamma_5 q \right)$$

$$C_1 = -\frac{\alpha_\mathrm{s}}{\pi} + \mathcal{O}(\alpha_\mathrm{s}^4) \quad C_2 = \left(\frac{\alpha_\mathrm{s}}{\pi} \right)^2 \left(\frac{1}{8} - \frac{1}{4} \ln \frac{\mu^2}{M_t^2} \right) + \mathcal{O}(\alpha_\mathrm{s}^3)$$

In HQET pseudoscalar cross-section is bigger by $9/4$

$g_{A^0} = \alpha_\mathrm{s}/2\pi > \alpha_\mathrm{s}/3\pi = g_H$

Resummation Formalism

Consider Higgs (Φ) threshold production at LO

$$z = \frac{M_\Phi^2}{\hat{s}} \to 1$$

Large logarithms appear in the cross-sections

$$\mathrm{threshold} \sim \alpha_s^n \frac{\ln^{2n-1}(1-z)}{(1-z)_+} \quad z \to 1$$

$$\mathrm{recoil} \sim \frac{\alpha_s^n}{p_t^2} \ln^{2n-1} \frac{M_\Phi^2}{p_t^2} \quad p_t \to 0$$

Formalism "Resums" Logs

Formally takes into account soft gluons to all orders to correct the small p_t behavior of the cross-sections.

- Impact parameter b
- b is Fourier conjugate to p_t
- Inverse Fourier (Bessel) transform back to p_t
- Behavior is encoded into the resummation coefficients
- A, B, C coefficients are the important results

Allows one to construct finite differential (and total) cross-sections over the entire p_t range when combined with pQCD calculations.

Formalism

$$\frac{d\sigma^{\rm resum}}{dp_t^2\, dQ^2\, d\phi} = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2 \int_0^\infty db\, \frac{b}{2} J_0(bp_t)\, f_{a/h_1}(x_1, b_0/b)\, f_{b/h_2}(x_2, b_0/b)$$

$$\times \frac{s}{Q^2} W_{ab}(x_1 x_2 s; Q, b, \phi),$$

$$W_{ab}(s; Q, b, \phi) = \sum_c \int_0^1 dz_1 \int_0^1 dz_2\, C_{ca}(\alpha_{\rm s}(b_0/b), z_1)\, C_{\bar{c}b}(\alpha_{\rm s}(b_0/b), z_2)$$

$$\times \delta(Q^2 - z_1 z_2 s)\, \frac{d\sigma^{LO}_{\bar{c}c}}{d\phi}\, S_c(Q, b),$$

$$S_c(Q, b) = \exp\left\{ - \int_{b_0^2/b^2}^{Q^2} \frac{dq^2}{q^2} \left[A_c(\alpha_{\rm s}(q)) \ln \frac{Q^2}{q^2} + B_c(\alpha_{\rm s}(q)) \right] \right\}$$

$$A/B_c(\alpha_{\rm s}) = \sum_{n=1}^\infty \left(\frac{\alpha_{\rm s}}{\pi} \right)^n A/B_c^{(n)}, \quad C_{ab}(\alpha_{\rm s}, z) = \delta_{ab}\delta(1-z) + \sum_{n=1}^\infty \left(\frac{\alpha_{\rm s}}{\pi} \right)^n C_{ab}^{(n)}(z)$$

LO channel(s) are important

In HQET, there is only a gg initial state

- Gluon density is dominant for small x at Higgs mass scales
- The $\delta(1-z)$ in the gg channel makes the PDF convolution trivial, allowing one to work in z-space (also true for $b\bar{b}$ fusion)
- The $q\bar{q}$ and qg channels need full theory
- At LHC, the other channels contribute up to 40% of the cross-section
- Give different contributions at different p_t scales

Process Dependent Coefficients

It has been shown that the $A^{(1)}$, $A^{(2)}$, and $B^{(1)}$ coefficient functions are universal (same for DIS and Higgs with different Casimir factors)

$$\hat{\sigma}(ab \to \Phi + X) = \hat{\sigma}_0^{\Phi}\left(\delta_{ag}\delta_{bg}\delta(1-z) + \frac{\alpha_{\rm s}}{\pi}\Delta^{(1)}_{ab\to\Phi}(z) + \left(\frac{\alpha_{\rm s}}{\pi}\right)^2\Delta^{(2)}_{ab\to\Phi}(z) + \cdots\right)$$

The $A^{(n)}$ and $B^{(n)}$ coefficients are determined from exponentiating the cross-section. The barred variables are for the differential cross-sections.

$$\Delta\hat{\sigma}_{c\bar{c}} = \int_0^{q_t^2} dp_t^2 \frac{d\hat{\sigma}_{c\bar{c}}}{dp_t^2} + \hat{\sigma}_{c\bar{c}}^{\rm virt}$$
$$= 1 + \frac{\alpha_{\rm s}}{\pi}\left[-\frac{\bar{A}_c^{(1)}}{2}\ln^2\left(\frac{M_\Phi^2}{q_t^2}\right) - \bar{B}_c^{(1)}\ln\left(\frac{M_\Phi^2}{q_t^2}\right) + 2\bar{C}_{c\bar{c}}^{(1)}\right].$$

$C^{(n)}$ coefficients are determined from the Mellin moments of the correction factors $\Delta^{(n)}_{ab\to\Phi}$.

Differential Coefficients (new)

HQET gg initial state

$$\bar{A}_g^{(1),H} = C_A, \quad \bar{B}_g^{(1),H} = -\beta_0 = -\left(\frac{11}{6}C_A - \frac{2}{3}n_f T_R\right),$$

$$\bar{C}_{gg}^{(1),H} = \frac{11}{12}C_A + \frac{3}{2}C_A\zeta_2, \quad \bar{C}_{gg}^{(1),A^0} = C_A + \frac{3}{2}C_A\zeta_2$$

$b\bar{b}$ intial state

$$\bar{A}_b^{(1)} = C_F, \quad \bar{B}_b^{(1)} = -\frac{3}{2}C_F, \quad \bar{C}_{b\bar{b}}^{(1)} = \frac{1}{2}C_F\zeta_2.$$

Scalar and pseudoscalar $b\bar{b}$ coefficients are identical if massless quark propagators are used

Scalar/Pseudoscalar $B_g^{(2)}$ (new)

$$B_g^{(2),H} = C_A^2\left(\frac{23}{24} + \frac{11}{3}\zeta_2 - \frac{3}{2}\zeta_3\right) + n_f C_F T_R - n_f C_A T_R\left(\frac{1}{6} + \frac{4}{3}\zeta_2\right) - \frac{11}{18}C_F C_A$$

$$B_g^{(2),A^0} = C_A^2\left(\frac{1}{2} + \frac{11}{3}\zeta_2 - \frac{3}{2}\zeta_3\right) + \frac{1}{2}n_f C_F T_R - n_f C_A T_R \frac{4}{3}\zeta_2$$

Pseudoscalar is slightly bigger $27.772 > 26.814$. The same is true for the $C_{gg}^{(2)}$. See reference due to expression length.

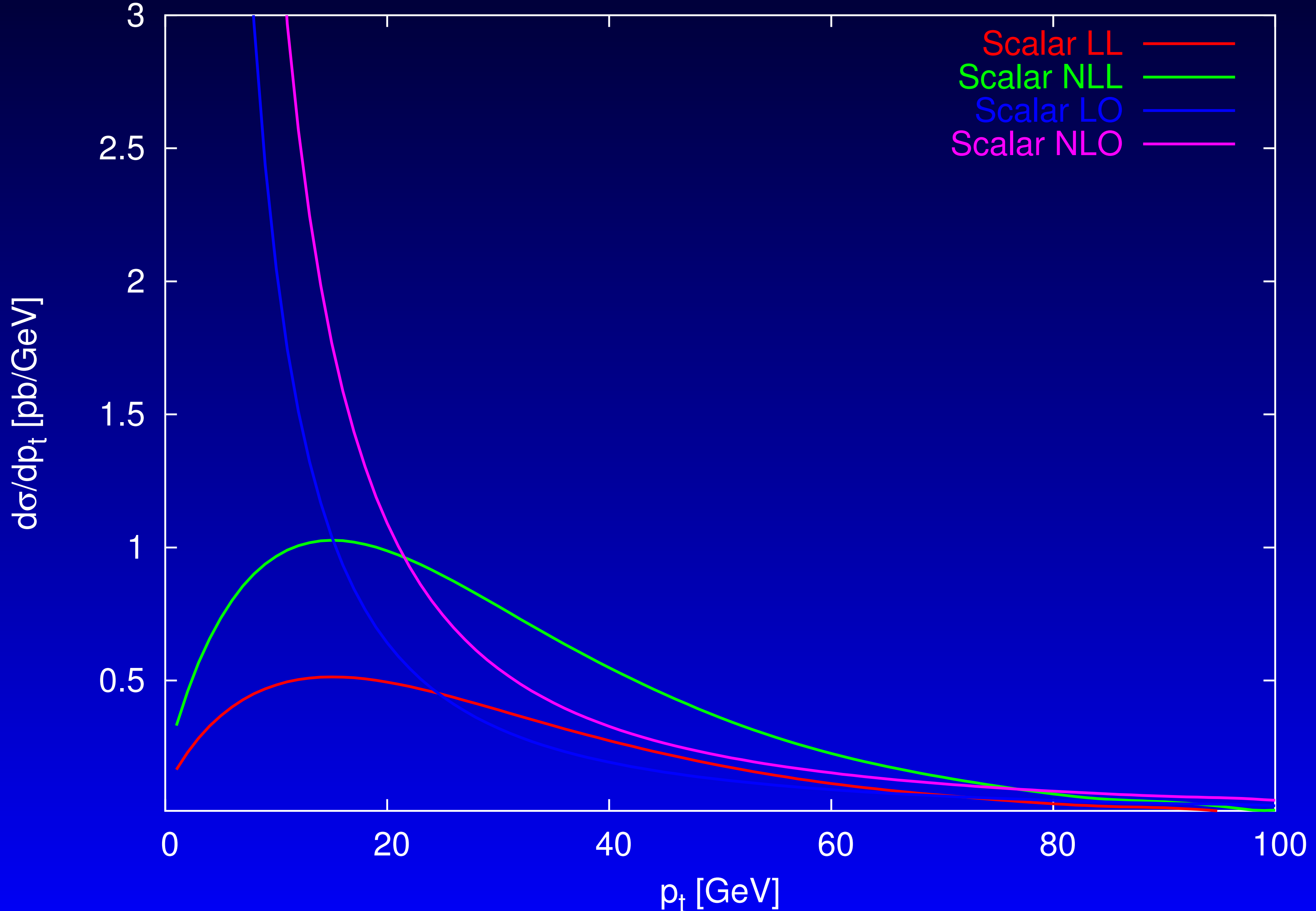
Bottom Quark Fusion (new)

$$A_b^{(2)} = \frac{1}{2} C_F \left(C_A \left(\frac{67}{18} - \zeta_2 \right) - \frac{10}{9} n_f T_R \right)$$

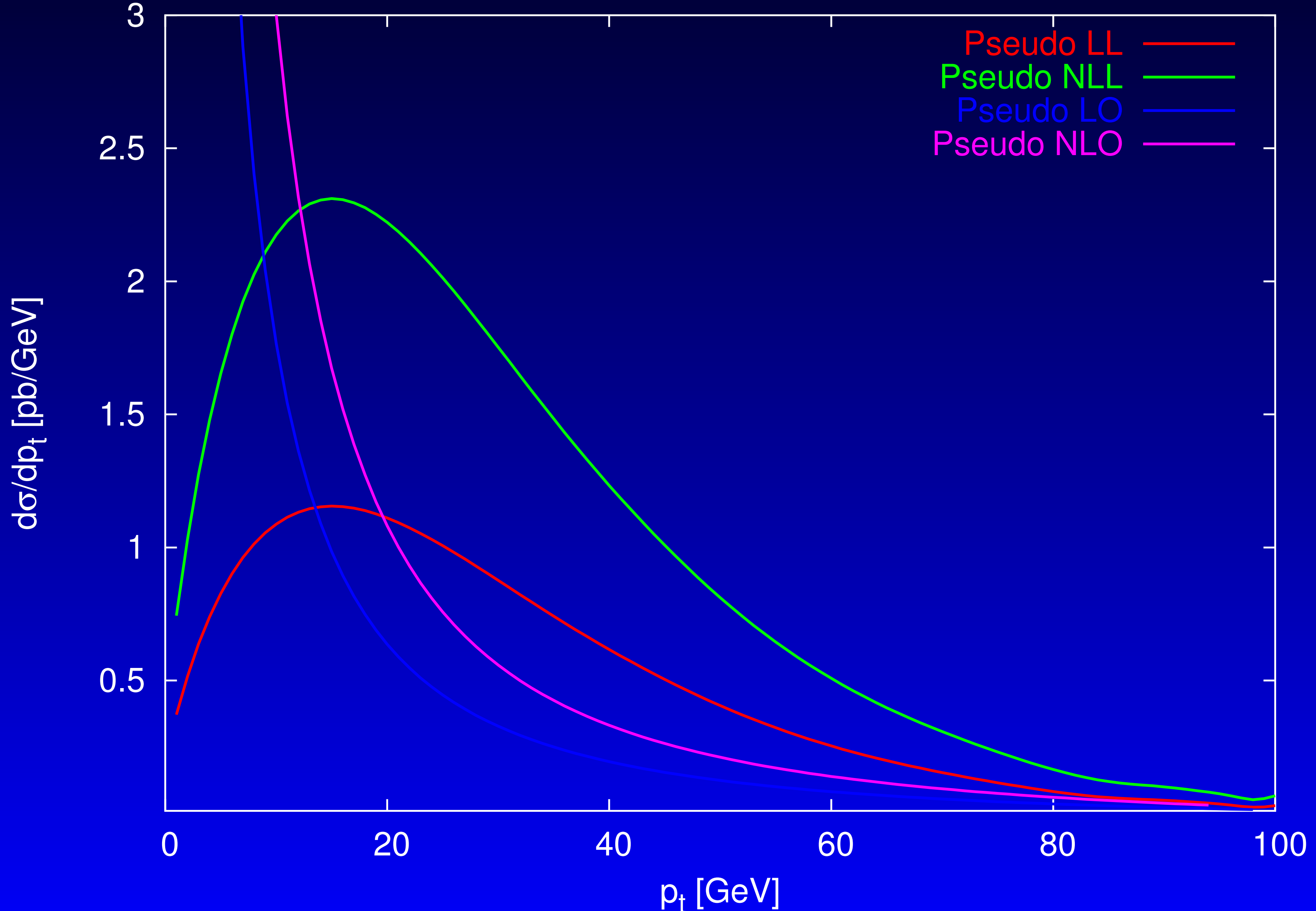
$$B_b^{(2)} = C_F^2 \left(\frac{3}{2}\zeta_2 - 3\zeta_3 - \frac{3}{16} \right)$$
$$- C_A C_F \left(\frac{11}{18}\zeta_2 - \frac{3}{2}\zeta_3 + \frac{13}{16} \right)$$
$$- n_f C_F T_R \left(\frac{1}{4} + \frac{2}{9}\zeta_2 \right)$$

See reference for $C_{b\bar{b}}^{(2)}$ coefficient

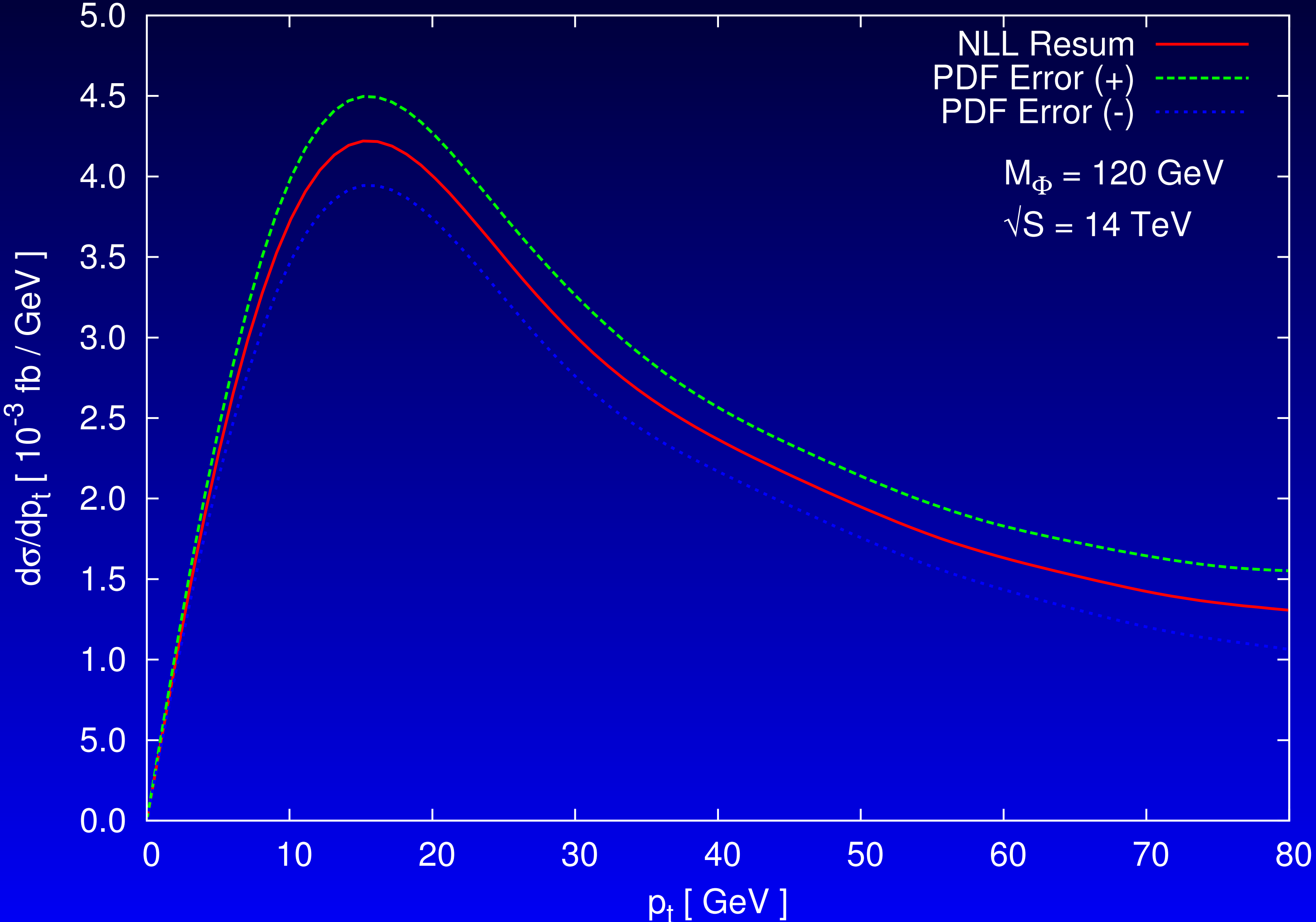
Scalar gg p_t spectrum (LHC, 120 GeV)



Pseudoscalar gg p_t spectrum (LHC, 120 GeV, $\tan\beta = 1$)



$b\bar{b}$ p_t Spectrum (SM couplings)



Conclusions

- gg resummed H/A^0 cross-sections differ by 9/4
- The absence of $q\bar{q}$ initial state in HQET causes problems $\longrightarrow b\bar{b}$ was calculated
- SM $b\bar{b}$ cross-section is small, but grows like $\tan^2\beta$ for the pseudoscalar
- Knowing the location of the p_t peak is important, especially if it is below the trigger p_t