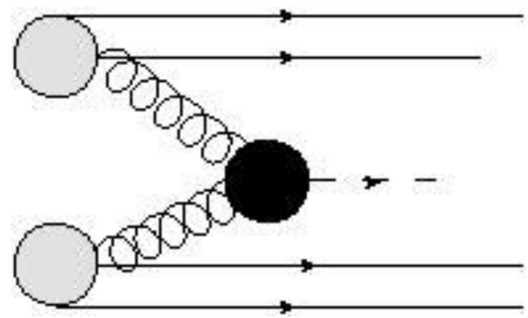
Theoretical uncertainties in Higgs cross-section at low tranverse momentum

Varun Vaidya
Dept of Physics ,
CMU

SCET 2015

Based on the work with Duff Neill (MIT) and Ira Rothstein (CMU)
(arXiv : 1503.00005)

P + P → H + X



- Higgs transverse momentum Pt <Mh

- Motivation : Precision calculation of Higgs cross section at low transverse momentum using EFT -> smoking gun for new on shell physics
  [Arnesen , Rothstein , Zupan :Phys. Rev. Lett. 103, 151801]

- EFT for higgs production via gluon fusion

$$O = C_t Tr[G^{\mu\nu} G_{\mu\nu}] h$$

$$R_T \equiv \frac{\sigma(H : p_T^H > p_T^{\min})}{\sigma(H)}$$

- Reduced perturbative uncertainty

- Insensitive to heavy new physics

- A sufficiently light particle will show up as a deviation from SM contributions

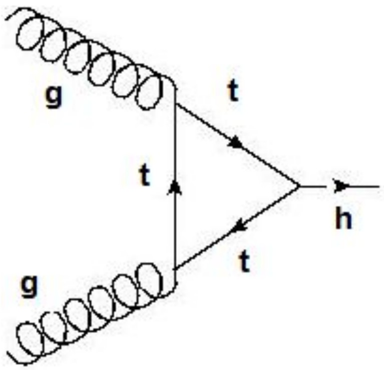
$$m^2 \sim m_H^2 + p_T^2$$

- A possible channel to search for MSSM
  (Spira et. al. : JHEP 0606 (2006) 035

- Probing the top -higgs Yukawa coupling, composite higgs models and natural supersymmetry via a boosted Higgs + Jet
  Grojean .et al. JHEP 1405, 022 (2014),
  Schlaffer et. al. Eur. Phys. J. C 74, 3120 (2014)

- Dominant partonic contribution is by the process of gluon fusion

$g+g \rightarrow H+X$ which proceeds via the quark loop



- Top quark has the largest effect

- A hierarchy of 4 relevant scales : Λ_{QCD} << Pt << Mh << Mt

- We need to factorize the physics at different scales to resum large logs and separate non-perturbative physics.

Factorization

1. Integrating out the top quark field, operator at leading order in λ=Mh/Mt

$$O = C_t Tr[G^{\mu\nu} G_{\mu\nu}] h$$

2. Matching onto SCET II with λ = Pt/Mh

$$\mathrm{Tr}[G^{\mu\nu}(x) G_{\mu\nu}(x)] \; = H(m_h) \left(\mathcal{B}^{a\mu}_{n\perp}(x) \mathcal{B}^{a}_{\bar{n}\perp\mu}(x) \right)$$

$$\mathcal{B}^{a\mu}_{n\perp}(x) = S^{aa'}_n(x) B^{a'\mu}_{n\perp}(x)$$

$$B^{a\mu}_{n\perp}(x) = \frac{2}{g} \mathrm{Tr}\left[T^a \left[W^\dagger_n(x) i D^\mu_{n\perp} W_n(x) \right] \right]$$

Cross Section:

$$\frac{d^2\sigma}{dP_t^2 dy} \sim H(M_h) C_t^2 \int dbb J_0(bP_t)\Big[f_n^{\mu\nu}(b, z_1) f_{\mu\nu,\bar{n}}\,(b, z_2) S(b)\Big]$$

TMDPDF

$$f^{\mu\nu}_{\perp\, g/P}(z, \vec{p}_\perp) = (\bar{n}\cdot p_n)\langle p_n|[B^{A\mu}_{n\perp}(0)\delta(p_n z - \overline{\mathcal{P}}_n)\delta^{(2)}(\vec{p}_\perp - \vec{\mathcal{P}}_\perp)B^{A\nu}_{n\perp}(0)]|p_n\rangle$$

Soft Function

$$\mathcal{S}(0,0,\vec{p}_\perp) = \frac{1}{(N_c^2-1)}\langle 0|S_n^{ac}(0)S_{\bar{n}}^{ad}(0)\delta^2(p_\perp - \mathcal{P}_\perp)S_n^{bc}(0)S_{\bar{n}}^{bd}(0)|0\rangle$$

Separating out the non-perturbative physics : $\lambda = \Lambda_{QCD}/Pt$

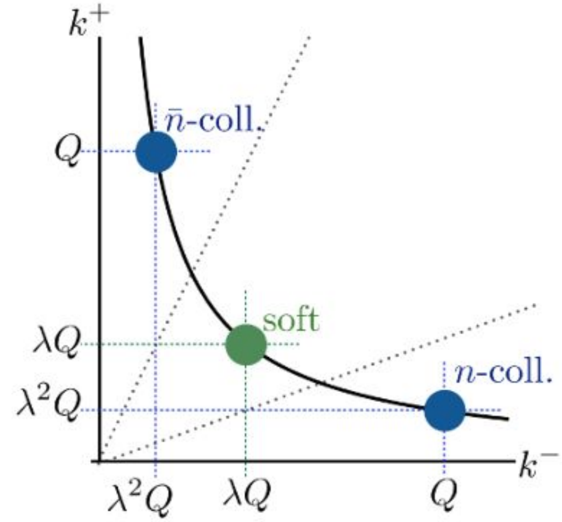
Match the TMDPDF onto the PDF

$$f_{\perp g/P}^{R\,\mu\nu}(z,\vec{p}_\perp) = \sum_k \frac{1}{z}\int_z^1 \frac{dz'}{z'}\Big\{\frac{g_\perp^{\mu\nu}}{2} I_{\perp 1\,g/k}(z/z',\vec{p}_\perp^{\,2}) + \Big(\frac{\vec{p}_\perp^{\,\mu}\vec{p}_\perp^{\,\nu}}{\vec{p}_\perp^{\,2}} + \frac{g_\perp^{\mu\nu}}{2}\Big) I_{\perp 2\,g/k}(z/z',\vec{p}_\perp^{\,2})\Big\} f_{k/P}^{R}(z')$$

Match the Soft function onto the Identity operator

- New divergences due to Factorization: usually regulated by dim. reg.

- Rapidity divergences due to separation of the soft and collinear regions: a new regulator is needed that breaks residual boost invariance



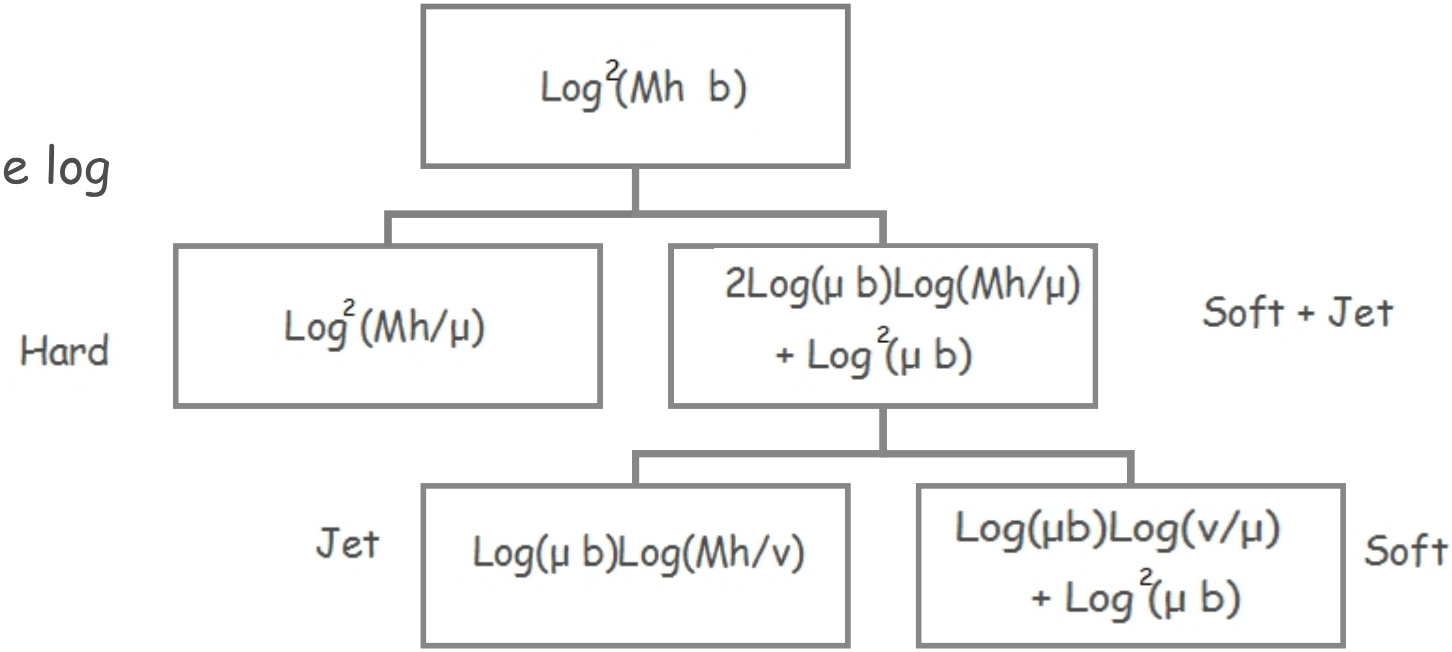
$$\mu\frac{d}{d\mu}S(b,\mu,\nu) = \gamma_\mu^S S(b,\mu,\nu)$$
$$\mu\frac{d}{d\mu}f^{\alpha\beta}(b,\mu,\nu) = \gamma_\mu^f f^{\alpha\beta}(b,\mu,\nu)$$
$$\mu\frac{d}{d\mu}H(M_h,\mu) = \gamma_\mu^H H(M_h,\mu)$$
$$\mu\frac{d}{d\mu}C_t(\mu) = \gamma_\mu^{C_t} C_t(\mu)$$

$$\nu\frac{d}{d\nu}S(b,\mu,\nu) = \gamma_\nu^S S(b,\mu,\nu)$$
$$\nu\frac{d}{d\nu}f^{\alpha\beta}(b,\mu,\nu) = \gamma_\nu^f f^{\alpha\beta}(b,\mu,\nu)$$

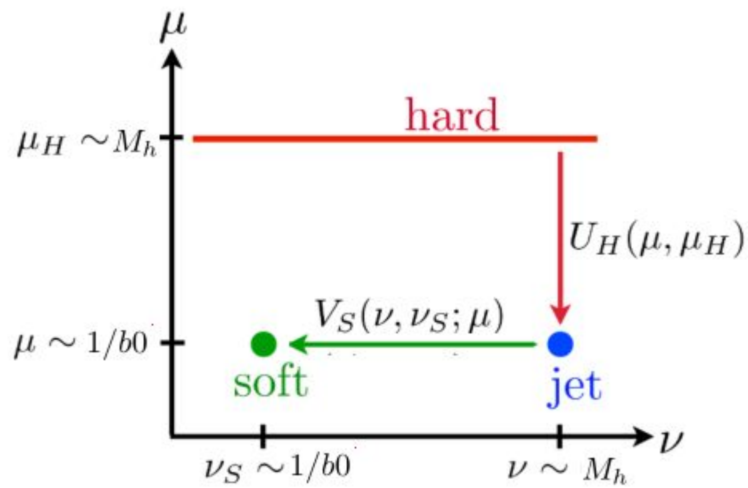
$$2\gamma_\nu^f + \gamma_\nu^S = 0.$$

$$2\gamma_\mu^{C_t} + \gamma_\mu^H + 2\gamma_\mu^f + \gamma_\mu^S = 0.$$

Splitting
the double log



Resummation in b space



- Running the hard to the IR in u.
- Running the Jet to the soft in v.

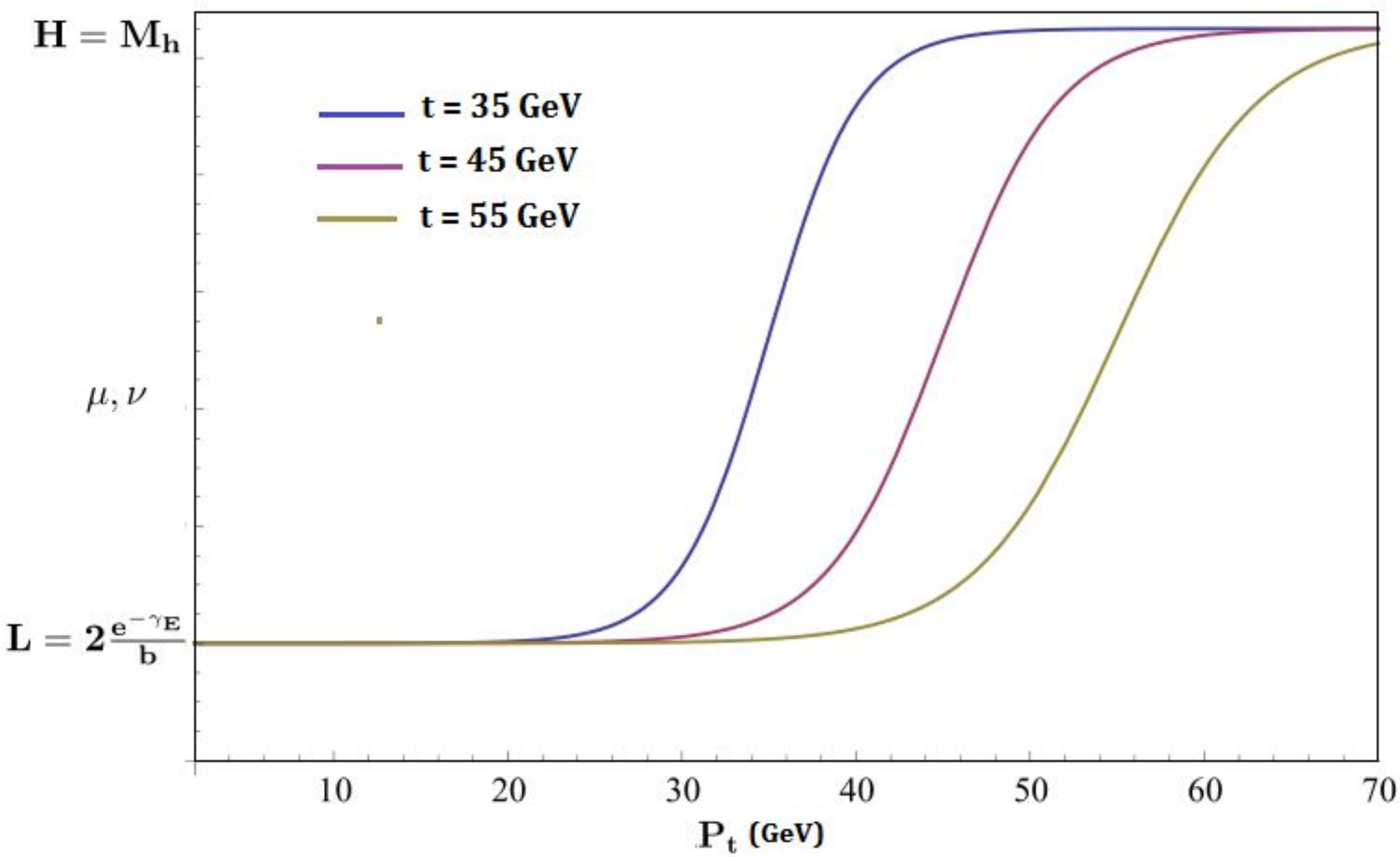
- Power Counting in the resummed exponent:
- Leading Log (LL) : $\sim Exp[\alpha^n Log^{n+1}(H/L)]$
- Next to Leading Log (NLL): $\sim Exp[\alpha^n Log^{n+1}(H/L) + \alpha^n Log^n(H/L)]$
- Next to Next to Leading Log (NNLL) :

$$\sim Exp[\alpha^n Log^{n+1}(H/L) + \alpha^n Log^n(H/L) + \alpha^n Log^{n-1}(H/L)]$$

At large values of Pt,

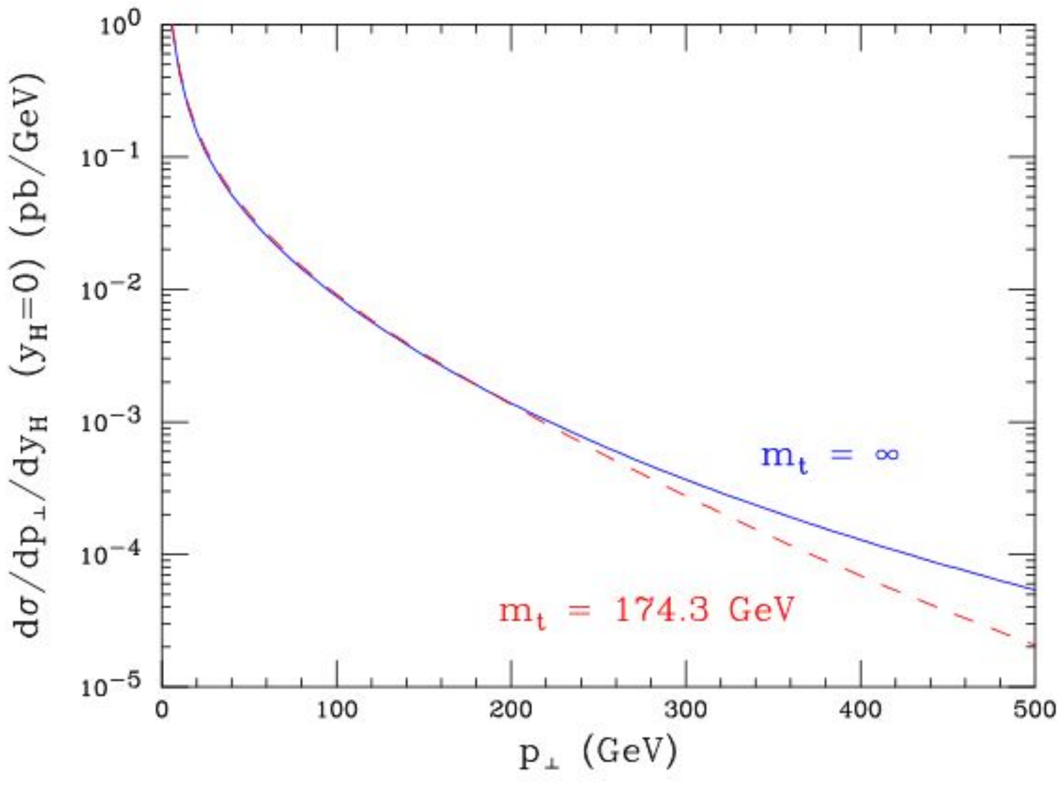
- logs are small → resummation no longer required
- Power corrections in Pt/Mh are important
- To maintain accuracy, matching onto the full theory NNLO cross-section is needed.
- Turning off resummation smoothly in u and v using profiles : Cancellation between singular and non-singular terms

Profiles to turn off resummation outside the region of validity of the EFT



Error analysis :

- Expansion in 4 parameters : Mh/Mt, Pt/Mh, Λ_{QCD}/Pt and α_s



- Mt $\longrightarrow \infty$ limit works extremely well for Pt < Mh

- Power corrections in Pt/Mh accounted for by matching onto full theory NNLO cross section

- Power corrections in Λ_{QCD} /Pt are important at very low values of Pt. Solution is to include higher dimensional operators in both the soft and colinear sectors.

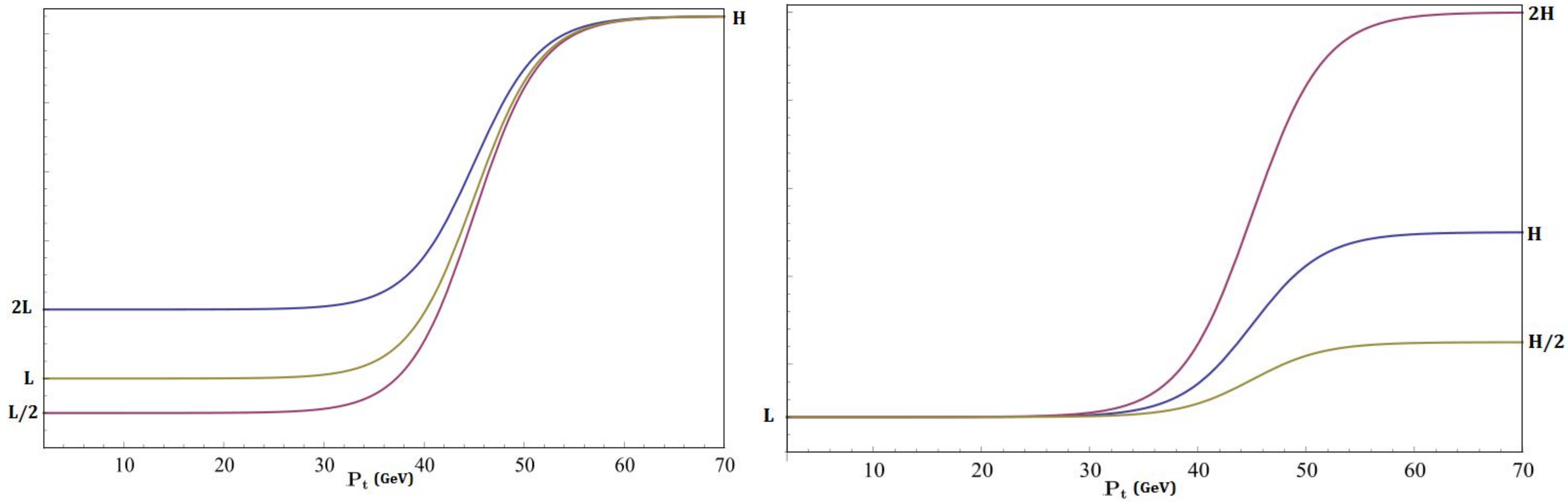
$$S_n^{ac}(0)S_{\bar{n}}^{ad}(0)\mathcal{P}_\perp^\alpha\mathcal{P}_\perp^\beta S_n^{bc}(0)S_{\bar{n}}^{bd}(0)$$

$$\left\{B_{n\perp}^{A\mu}(0)\delta(p_n z_1-\overline{\mathcal{P}}_n)\mathcal{P}_\perp^\sigma\mathcal{P}_\perp^\rho\left[B_{n\perp}^{A\nu}(0)\right]\right\}$$

A rough estimate of the errors in the absence of these operators is

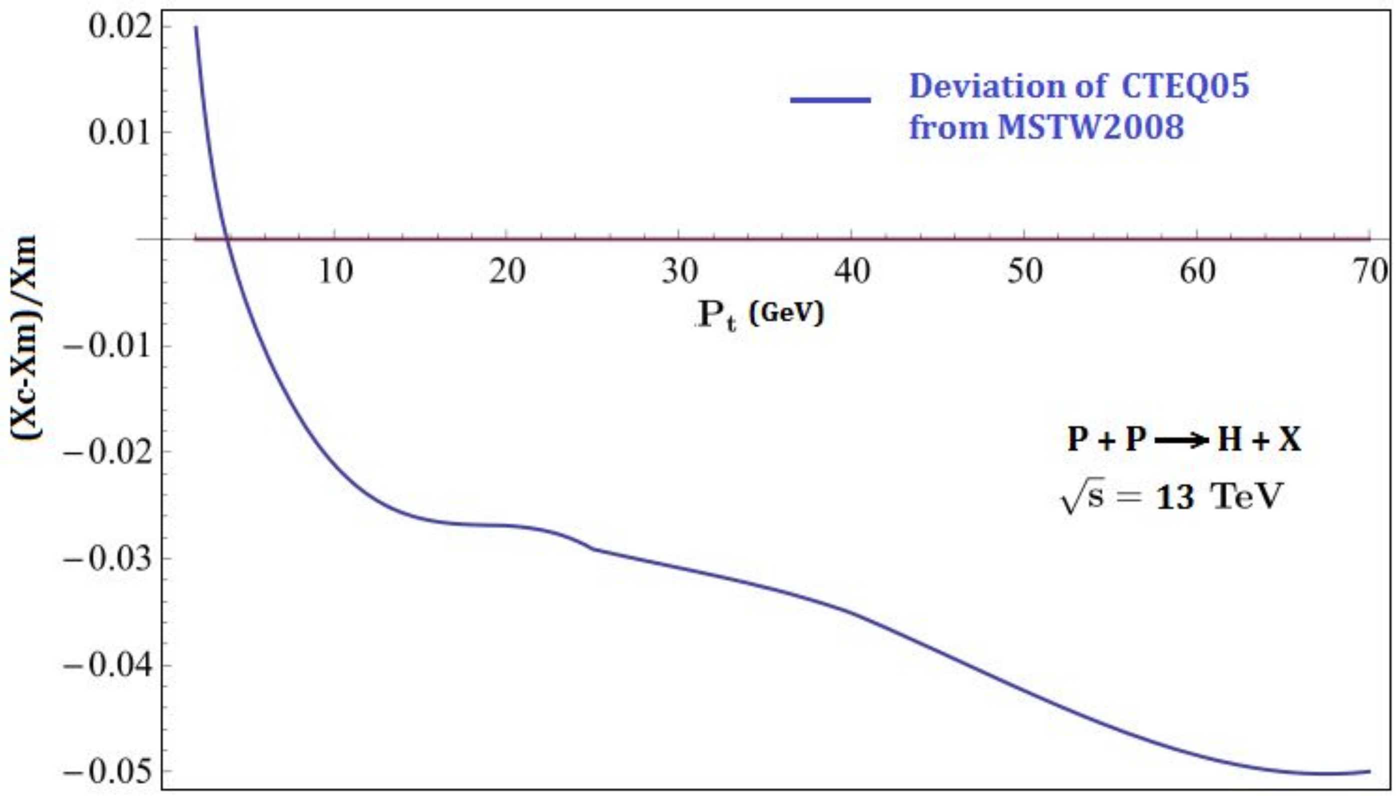
$$\frac{d\sigma}{dP_t}\left(1\pm\frac{\Lambda_{QCD}^2}{P_t^2}\right)$$

Error estimation due to higher order pertubative terms :
Variation in two independent scales u and v

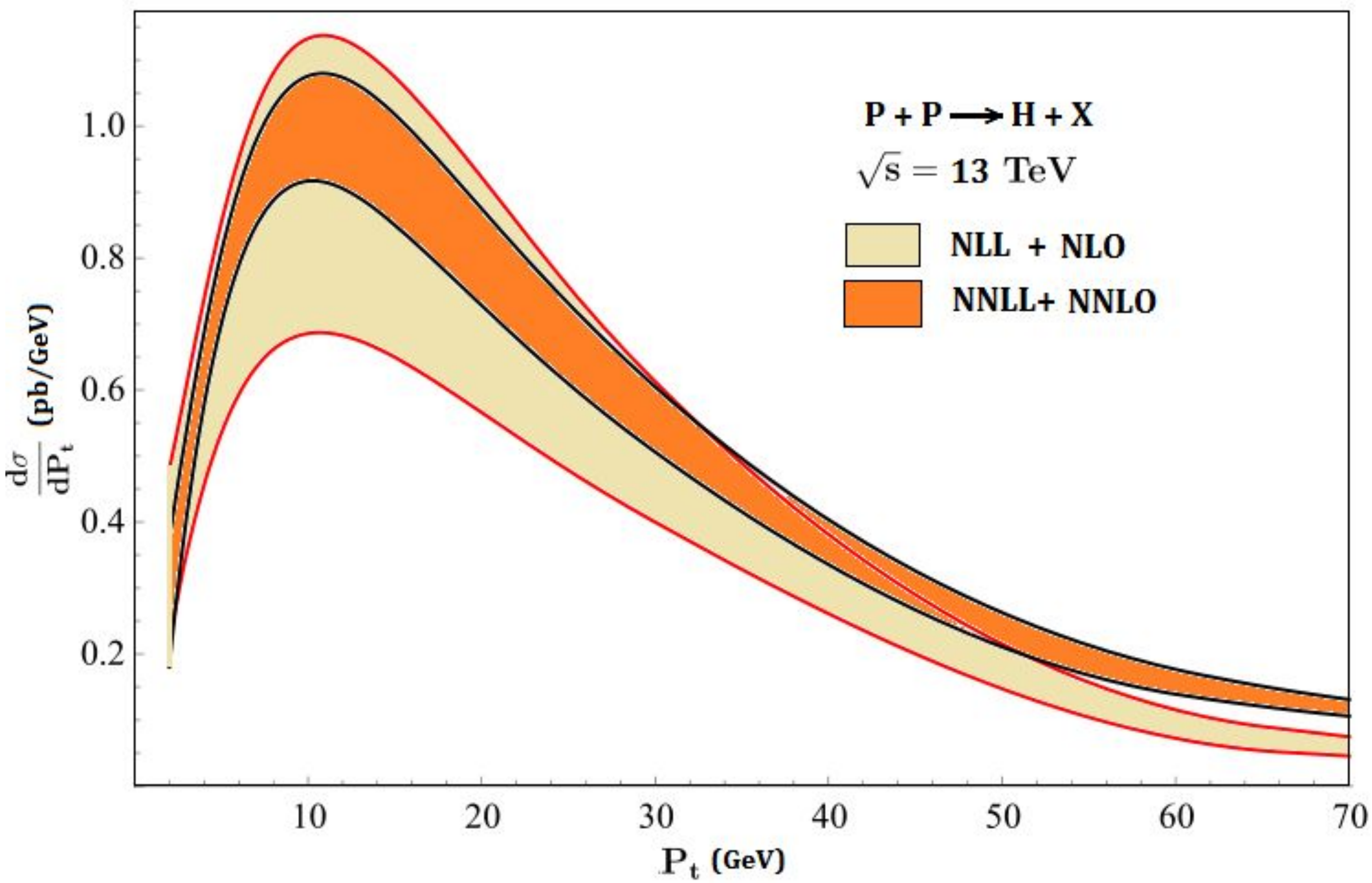


- Variation of scales at low Pt probes terms at N3LL
- Variation at high Pt estimates fixed order terms at O(α^3)

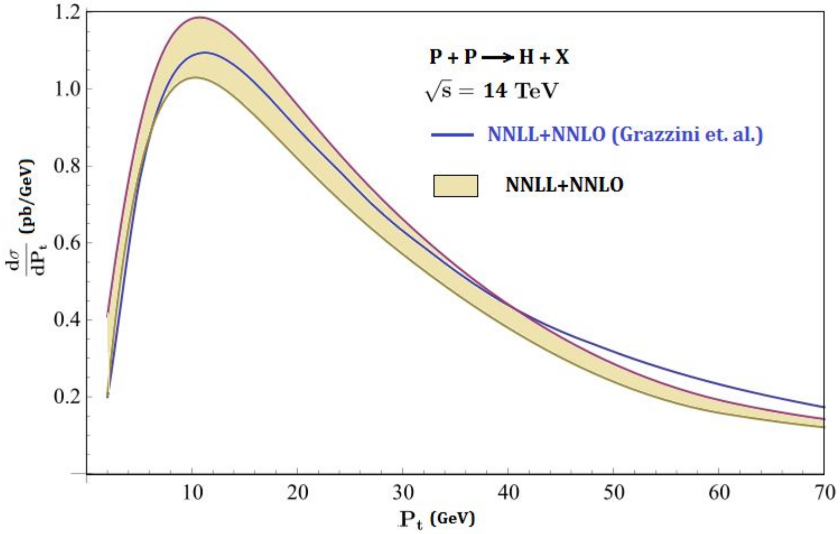
Variations due to different pdf sets

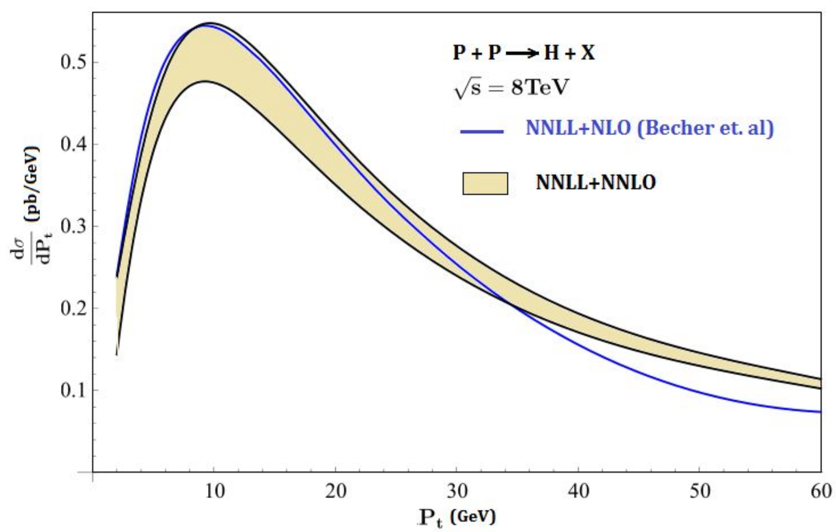


Combining all of these effects



Comparison with previous results





- Overshoot in the high Pt region

- Difference in the high Pt regime due to NLO vs NNLO matching

Summary

- A systematic way of resumming logs via the rapidity renormalization group
- A better control over error estimation via multiple scale variations
- Use of profiles to turn off resummation in the large Pt regime
- Matching onto full theory NNLO to maintain accuracy in the complete range of transverse momentum