Transverse momentum resummation in $b\bar{b} \to H$

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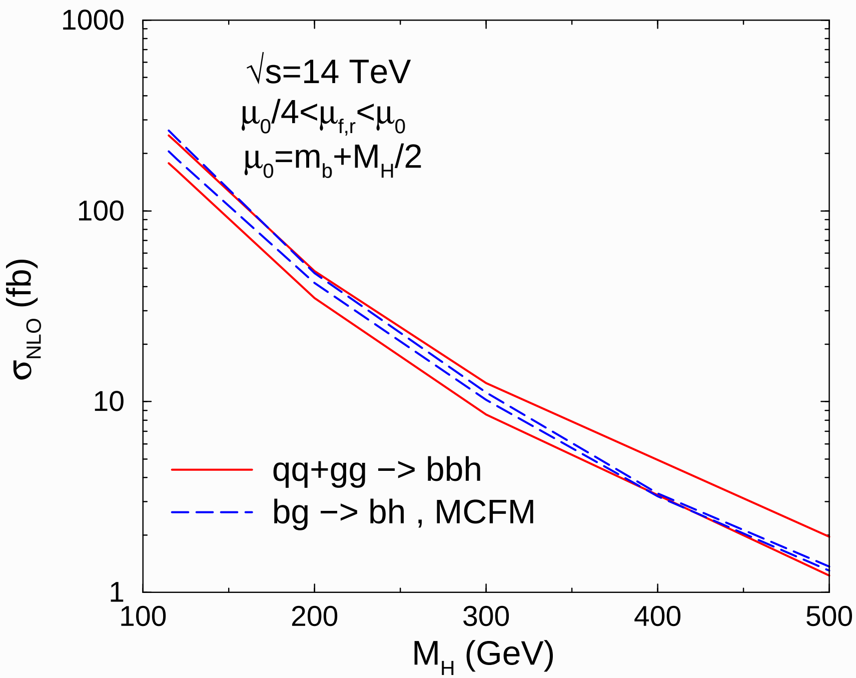
- q_T resummation in a massive variable flavor number (S-ACOT) scheme
  - *P. N., N. Kidonakis, F. Olness, C.-P. Yuan, Phys. Rev. D67, 074015 (2003)*
- Tevatron and LHC phenomenology
  - Overview of the method + W, Z, and (some) Higgs production
    - *S. Berge, P. N., F. Olness, hep-ph/0509023*
    - *early results shown at LoopFest 3, April 2004*
  - inclusive $b\bar{b} \to H$ in SM and MSSM
    - *A. Belyaev, P. N., C.-P. Yuan, hep-ph/0509100*
  - NLL resummation for $b\bar{b} \to Hb$ *(B. Field's talk)*

Massive 4-flavor and massless 5-flavor schemes in $b + \bar{b} \rightarrow H + N\, b$ ($N = 0, 1,$or 2): which scheme is correct?

Sometimes both

(e.g. σ_{tot} for $M_H \ll 1$ TeV)



Dawson, Jackson, Reina, Wackeroth, hep-ph/0408077

M_H , Q, and q_T are Higgs mass, virtuality, and transverse momentum

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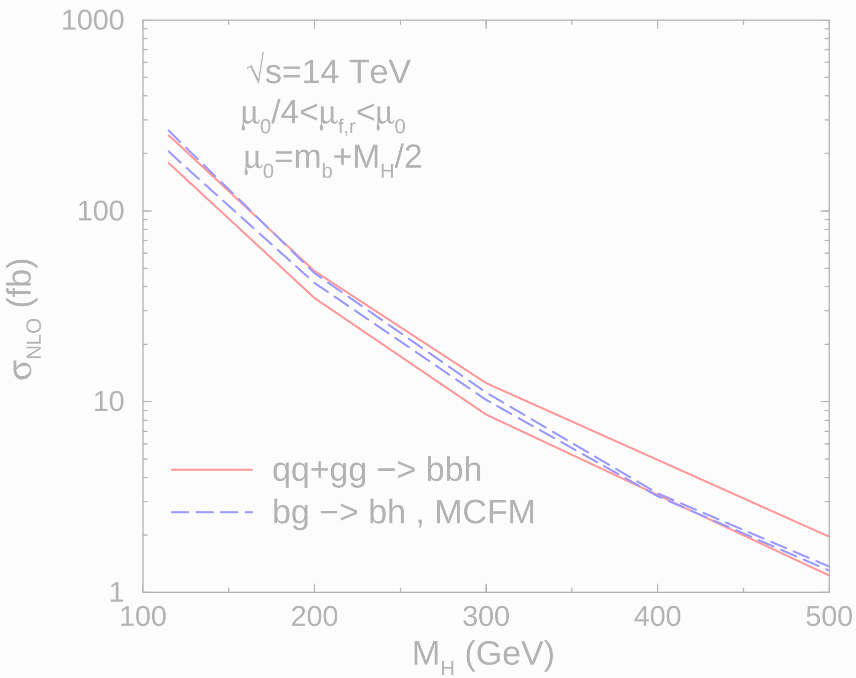

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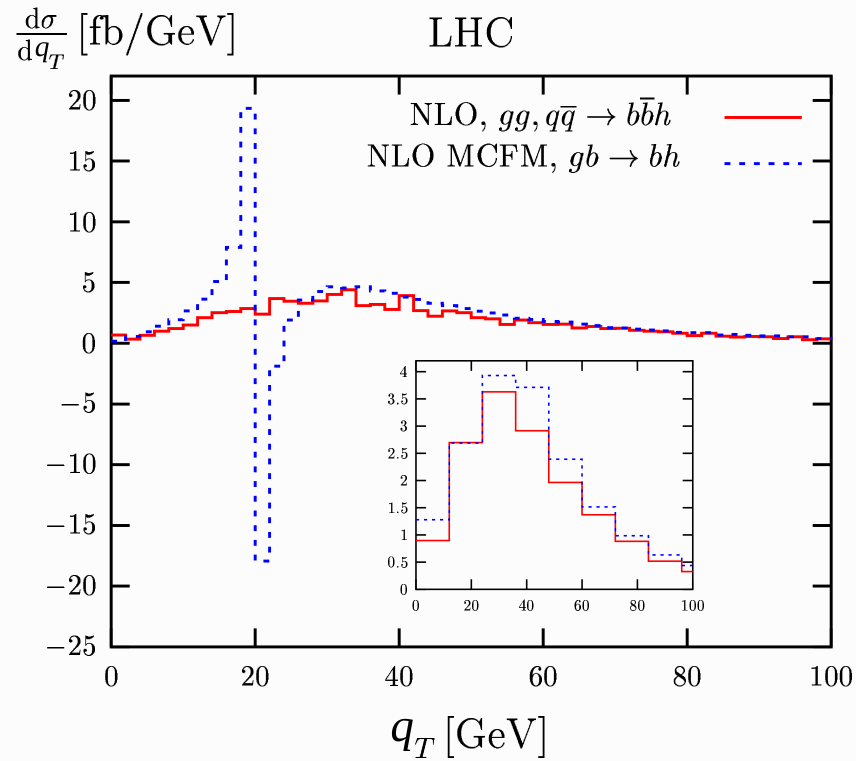
Sometimes none

(e.g. $d\sigma/dq_T$ at $q_T \ll M_H$)

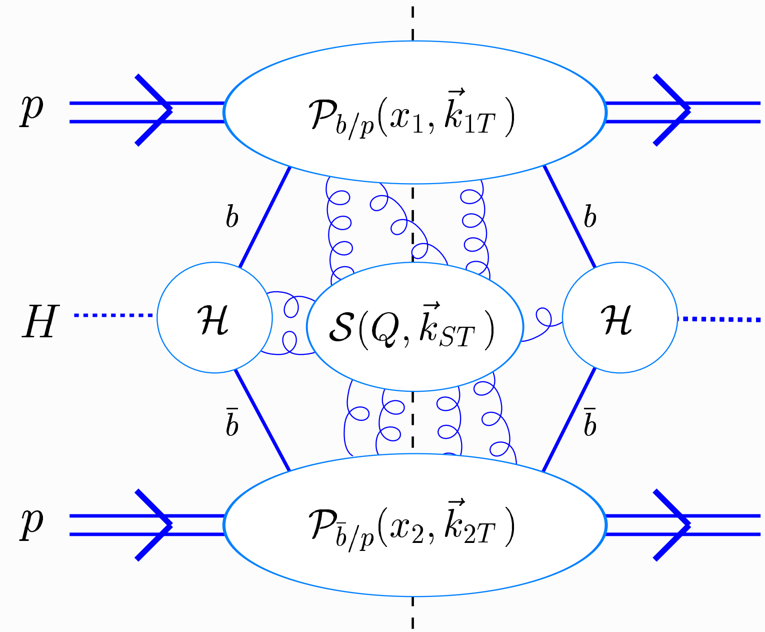


this talk

M_H , Q, and q_T are Higgs mass, virtuality, and transverse momentum

Perplexing collinear b-quarks: why both schemes fail at $q_T \to 0$

- Collinear b's are easily produced at $Q \sim M_H \gg m_b$
- Collinear logs $\ln^p(Q/m_b)$ must be resummed in the b-quark PDF's ~~(4-flavor scheme)~~
- Soft and collinear logs $\ln^{p'}(Q^2/q_T^2)$ must be resummed at $q_T \to 0$ using the Collins-Soper-Sterman (CSS) resummation



$$\left(\frac{d\sigma}{d\vec{q}_T}\right)_{q_T \to 0} \propto |\mathcal{H}(Q)|^2 \int d\vec{k}_{ST}\, d\vec{k}_{1T}\, d\vec{k}_{2T}\, \delta(\vec{k}_{ST} + \vec{k}_{1T} + \vec{k}_{2T} - \vec{q}_T) \times \mathcal{S}(Q, \vec{k}_{ST})\, \mathcal{P}_{b/p}(x_1, \vec{k}_{1T})\, \mathcal{P}_{\bar{b}/p}(x_2, \vec{k}_{2T})$$

The unintegrated bottom PDF's $\mathcal{P}_{b/p}(x, \vec{k}_T)$ depend on $k_T \in [0, \infty]$

Non-negligible dependence on m_b at $k_T \lesssim m_b$!

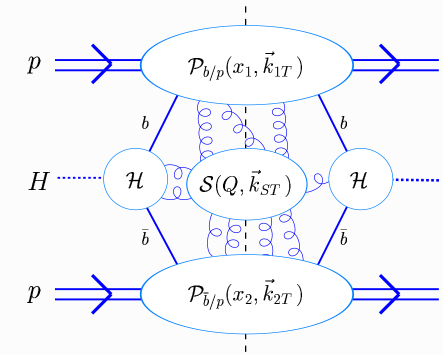
~~massless 5-flavor scheme~~

CSS resummation in a massive 5-flavor (S-ACOT) scheme

- resums all large logs $\ln(q_T^2/Q^2)$
- keeps the essential m_b dependence; drops the non-essential m_b dependence (simplifications!)
- realized at $\mathcal{O}(\alpha_s)$/NNLL accuracy
- is matched on the 5-flavor finite-order result at $q_T \sim Q$
- uses a new nonperturbative Sudakov function (KN'2005)
  - agreement with IR-renormalon estimates
  - reduced uncertainties and flavor dependence
- was studied for perturbative $b\bar{b}$ production, but can also include nonperturbative "intrinsic" b-quark contributions

CSS cross sections in impact parameter (b) space

$$\left.\frac{d\sigma}{dQ^2 dy dq_T^2}\right|_{q_T^2 \ll Q^2} \propto |\mathcal{H}(Q)|^2 \int \frac{d^2b}{(2\pi)^2} e^{-i\vec{q}_T\cdot\vec{b}}$$
$$\times \quad e^{-S(b,Q)} \overline{\mathcal{P}}_{b/p}(x_1, b, m_b) \overline{\mathcal{P}}_{\bar{b}/p}(x_2, b, m_b)$$



where

$$\overline{\mathcal{P}}_{b/p}(x, b, m_b) \equiv \sum_{i=g,u,d\ldots} \left[\mathcal{C}_{b/i} \otimes f_{i/p}\right](x, b, m_b; \mu_F)$$

$f_{i/p}(x, \mu_F)$ (with $\mu_F = b_0/b \sim 1/b$) are the conventional PDF's

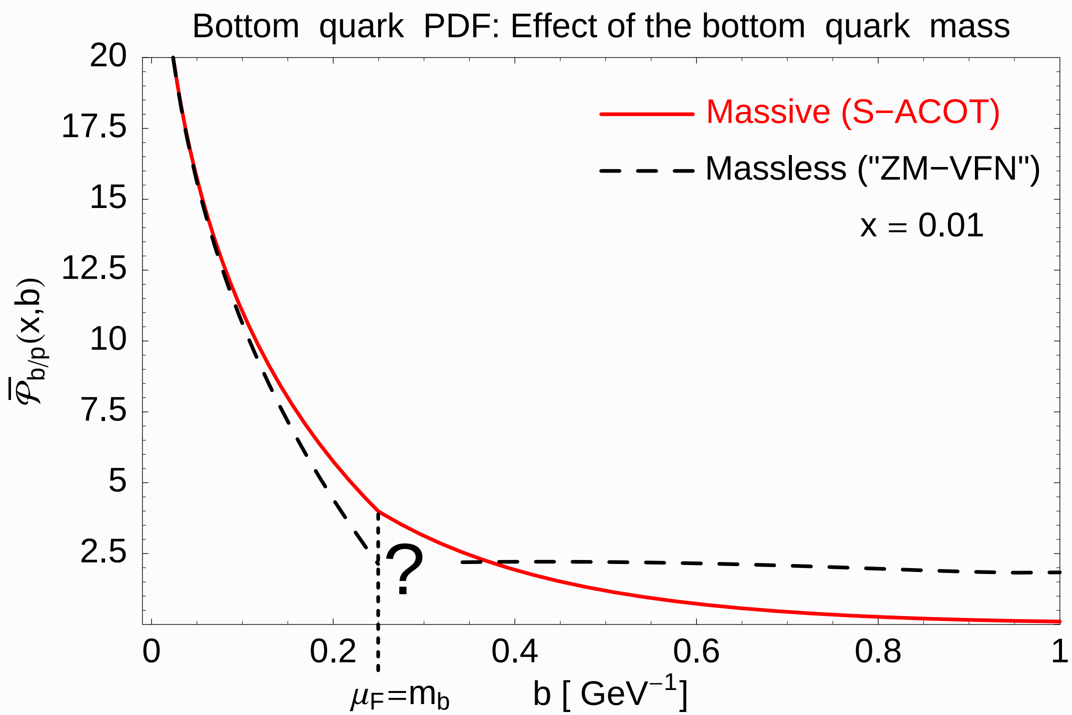
m_b dependence is

- kept in $\overline{\mathcal{P}}_{b/p}(x, b, m_b)$
- dropped in $S(b, Q)$ and other terms (rules of S-ACOT scheme)
- $S(b, Q)$ and $\mathcal{C}_{ai}(x_A, b, m_b; \mu_F)$ are approximated well in PQCD

$\overline{\mathcal{P}}_{b/p}(x, b, m_b)$: S-ACOT calculation vs. a naive massless calculation

- There is no unique way to define $\overline{\mathcal{P}}_{b/p}(x, b, m_b)$ at $b \gtrsim 1/m_b$ in the massless 5-flavor scheme ($\mathcal{C}_{b/i}$ are not computable; $\Rightarrow$ arbitrary $d\sigma/dq_T$)
- Earlier studies *(e.g. Balazs, He, Yuan, 1998)* have used an effective massless approximation ("ZM-VFN")
- We would like to see how much the approximate "ZM-VFN" result deviates from the exact S-ACOT result

$\overline{\mathcal{P}}_{b/p}(x,b,m_b)$: S-ACOT vs. "ZM-VFN"



$\mu_F \sim 1/b$

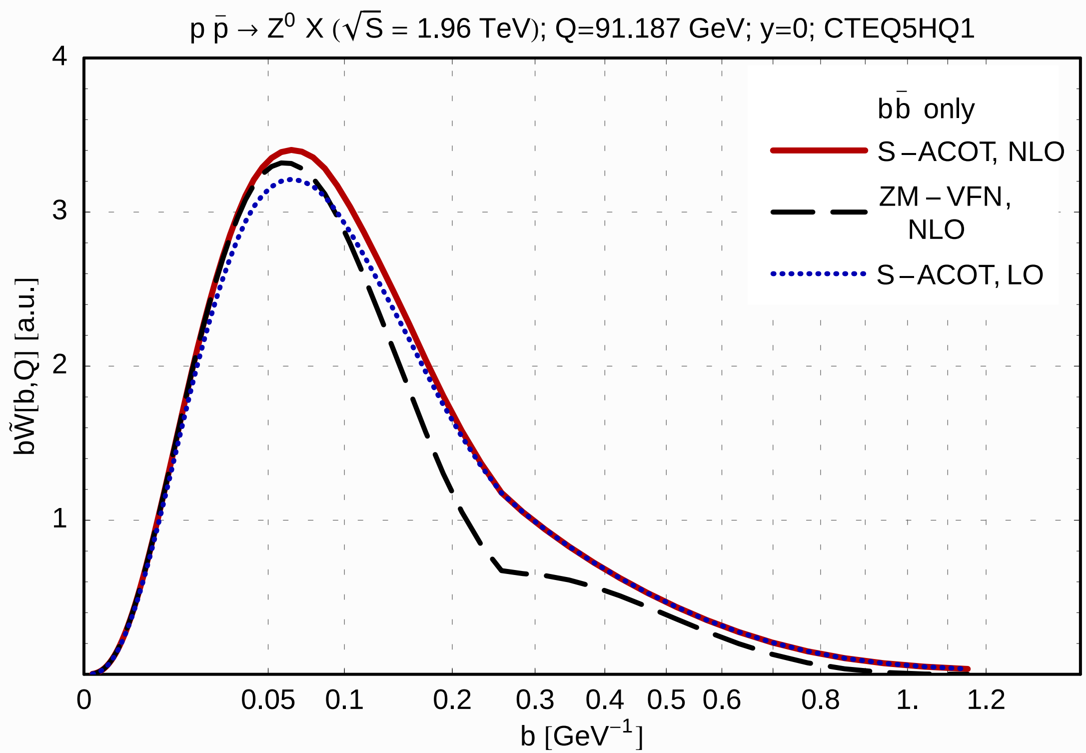
"ZM-VFN" $\overline{\mathcal{P}}_{b/p}(x,b)$

- underestimates the S-ACOT result at $b \lesssim 1/m_b$
- is ill-defined at $b \gtrsim 1/m_b$

Massive (S-ACOT) $\overline{\mathcal{P}}_{b/p}(x,b)$

- reduces to the massless result at $b^2 \ll 1/m_b^2$ ($\mu_F^2 \gg m_b^2$)
- vanishes at $b^2 \gg 1/m_b^2$ (decoupling of b-quarks)
- is automatically continuous at the switching point ($\mu_F = m_b$)

m_b dependence vs. the Sudakov suppression (on the example of $\widetilde{W}(b,Q)$ for $b\bar{b} \to Z^0$)

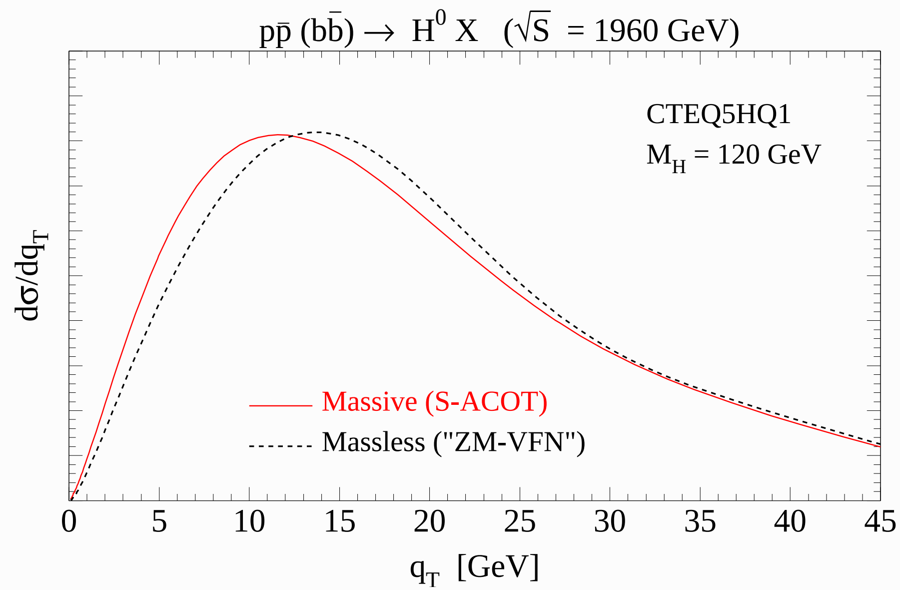


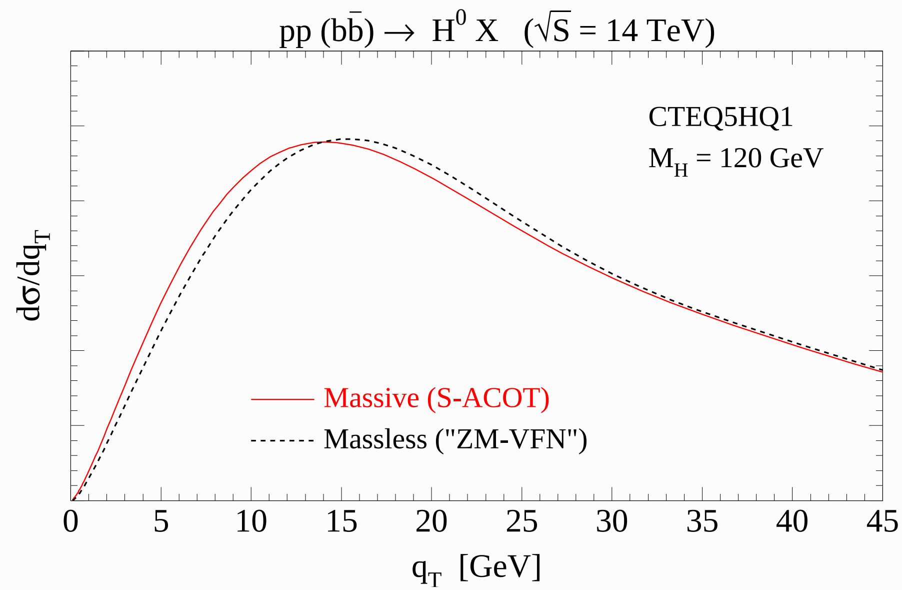
Impact parameters $b \gtrsim 1/m_b$ are suppressed by

- the Sudakov factor $e^{-S(b,Q)}$
- μ_F dependence of $f_{i/p}(x,\mu_F)$ at $x \ll 1$

- The most pronounced m_b dependence is seen at the Tevatron for $Q < 100 - 200$ GeV

Variations in $d\sigma/dq_T$ due to mass effects



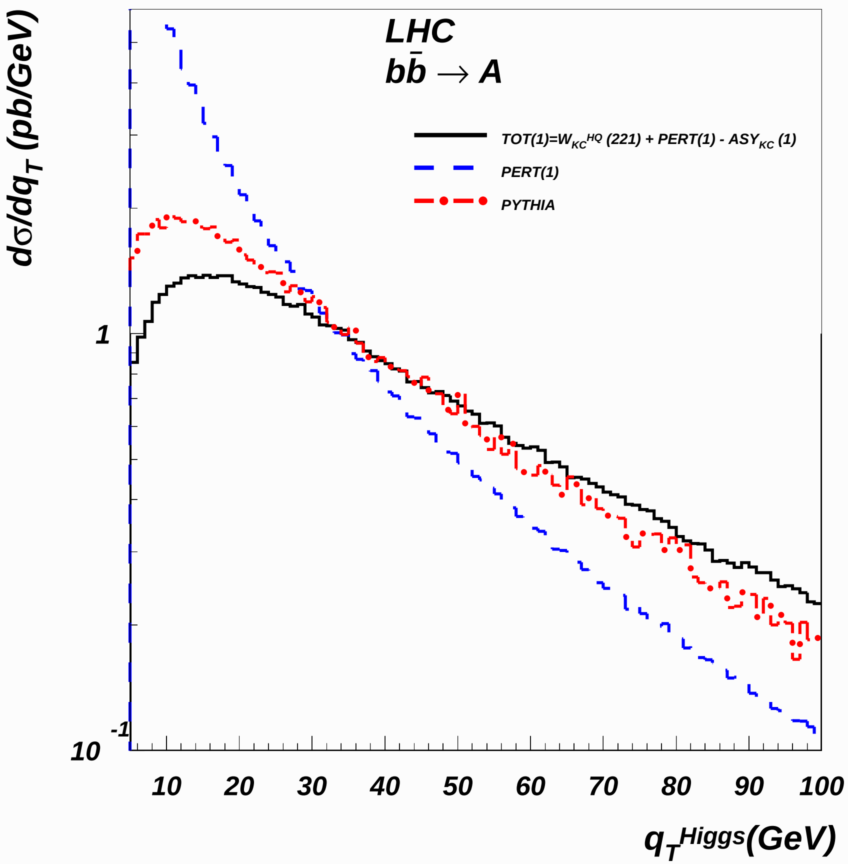


Tevatron, $M_H = 120$ GeV: the "ZM-VFN" peak is shifted by 2 GeV ($\approx$ 17%) w.r.t. to the S-ACOT peak

Peak shifts at the LHC

m_H (GeV)		120	250	600
Position of the maximum (GeV)	"ZM-VFN"	15.4	16.8	18.8
	S-ACOT	14.1	15.8	18.2
Difference in the positions (GeV)		1.3	1.0	0.6

Kinematical effects at $q_T \approx M_H$



$f_{b/p}(x, \mu_F)$ is a rapidly varying function of x and μ_F

$\Rightarrow$Approximate phase space in NNLL $\widetilde{W}(x_1, x_2, b, Q)$ must be chosen carefully to obtain trustworthy $d\sigma/dq_T$ at $q_T \approx Q$

We correct for the PS approximation by assuming

$$x_{1,2} \equiv \frac{\sqrt{Q^2+q_T^2}}{\sqrt{s}} e^{\pm y}$$

in $\widetilde{W}(x_1, x_2, b, Q)$

The effect of the kinematical correction is comparable to the effect of momentum conservation in parton showering (Pythia)

Conclusions

- Small-q_T resummation for c and b quarks must be realized in a massive VFN scheme in order to be theoretically consistent
- Dependence on $m_{c,b}$ leads to softer q_T distributions in $b\bar{b} \to H$ at the Tevatron and LHC
- Signatures of m_b dependence may be observed experimentally with high detector resolution (they are also important in M_W measurement)