Analytic resummation for Higgs p_T in $gg \to H$: Choosing the resummation scale for the bottom

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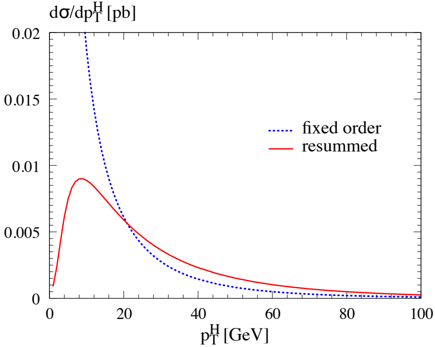
p_T resummation

- production of colorless particle (mass M)
- problem: p_T distribution diverges at $p_T \to 0$
- reason: large logs $\ln p_T^2/M^2$ for $p_T \ll M$

$$\begin{aligned} \alpha_s : \quad & \ln(p_T^2/M^2),\ \ln^2(p_T^2/M^2) \\ \alpha_s^2 : \quad & \ln(p_T^2/M^2),\ \ln^2(p_T^2/M^2),\ \ln^3(p_T^2/M^2),\ \ln^4(p_T^2/M^2) \\ \ldots \end{aligned}$$

- solution: all order resummation



Transverse momentum resummation

- developed already 30 years ago

  [Parisi, Petronzio '79], [Dokshitzer, Diakonov, Troian '80], [Curci, Greco, Srivastava '79], [Bassetto, Ciafaloni, Marchesini '80], [Kodaira, Trentadue '82], [Collins, Soper, Sterman '85]

$$\frac{d\sigma_N^{(\mathrm{res})}}{dp_T^2} \sim \int dy \int db \, \frac{b}{2} \, J_0(b\, p_T)\, S(b, A, B)\, \mathcal{H}_N \, f_N \, f_N$$

- we use newer formulation including various improvements:

  [Catani, de Florian, Grazzini '01], [Bozzi, Catani, de Florian, Grazzini '06]

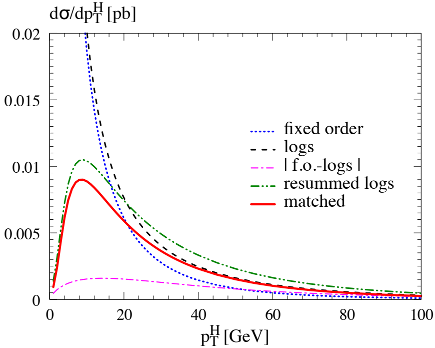
  - H embodies whole process dependence
  - $L = \ln(Q^2\, b^2 / b_0^2) \rightarrow L' = \ln(Q^2\, b^2 / b_0^2 + 1)$

    $\rightarrow$ reduction of impact at high p_T (low b)
    $\rightarrow$ unitarity constraint

Matching

- matched (resummed) cross section:

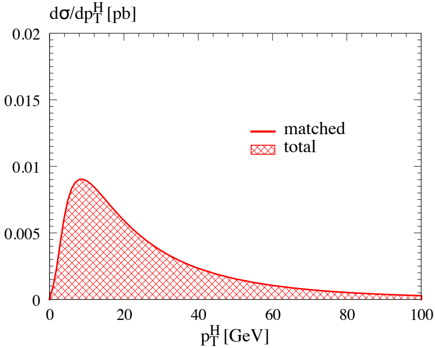
$$\left[\frac{\mathrm{d}\sigma}{\mathrm{d}p_T^2}\right]_{\text{f.o.+l.a.}} = \left[\frac{\mathrm{d}\sigma}{\mathrm{d}p_T^2}\right]_{\text{f.o.}} - \left[\frac{\mathrm{d}\sigma^{(\text{res})}}{\mathrm{d}p_T^2}\right]_{\text{f.o.}} + \left[\frac{\mathrm{d}\sigma^{(\text{res})}}{\mathrm{d}p_T^2}\right]_{\text{l.a.}}$$



Matching

- unitarity (due to $L \to L'$):

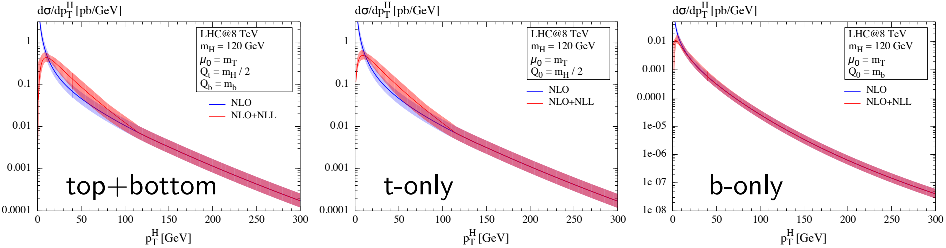
$$\int \mathrm{d}p_T^2 \left[\frac{\mathrm{d}\sigma}{\mathrm{d}p_T^2}\right]_{\text{f.o.+l.a.}} \equiv \left[\sigma^{(\text{tot})}\right]_{\text{f.o.}} .$$



Resummed Higgs p_T distribution in SM

Current recommendation (for SM):

- $Q_t = m_H/2 \quad (m_H/4 < Q_t < m_H)$
- $Q_b = m_b \quad (m_b/3 < Q_b < 3\, m_b)$
- $\mu_\mathrm{R} = \mu_\mathrm{F} = m_T = \sqrt{m_H^2 + p_T^2} \quad (m_T/2 < \mu_{\mathrm{R/F}} < 2\, m_T)$



t-only: bad matching at high p_T $\rightarrow$ cured by NNLO+NNLL (EFT)
$\rightarrow$ improved by smaller Q_t ($\sim m_H/2.5$)

b-only: resummation switched off $p_T \gtrsim 7\,\mathrm{GeV}$, reason: $Q_b = m_b$

Choice of Q_b in 2HDM/MSSM

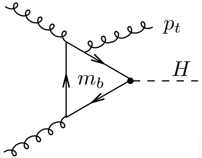
- NOT SOLVED:
  three scale problem (m_H, m_b and p_T)
  in MSSM: additional complication though squarks (moderate)
- FOR NOW: (workaround)
  introduce various resummation scales:
  Q_t (t-only), Q_b (b-only) and Q_{tb} (t-b-interference),

Choice of Q_b in 2HDM/MSSM

- $Q_b \equiv Q_{tb} = m_b$ in SM suggested due to appearance of terms

  [Grazzini, Sargsyan '13]

  $$\sim ln(m_b/p_T)$$

  - vanish as $p_T \to 0 \Rightarrow$ no factorization breaking, no Sudakov logs
  - directly related to $\ln(m_b/m_H)$ in total rate
  - HOWEVER: could spoil collinear/soft approximation
    $\Rightarrow$ Sudakov resummation would be unsufficient
  - BUT: if small, treated as all other finite terms (power corrections in p_T)
- choosing Q_b (and Q_{tb}) – 2 proposals:
  1. analyze size of finite terms

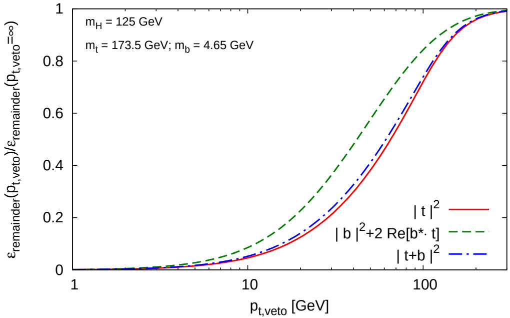
     [Banfi, Monni, Zanderighi '13]
  2. consider validity of collinear/soft approximation

     [Bagnaschi, Vicini]

1. size of finite terms

- considered for $p_{T,\text{veto}}^{\text{jet}}$ efficiencies

  [Banfi, Monni, Zanderighi '13]

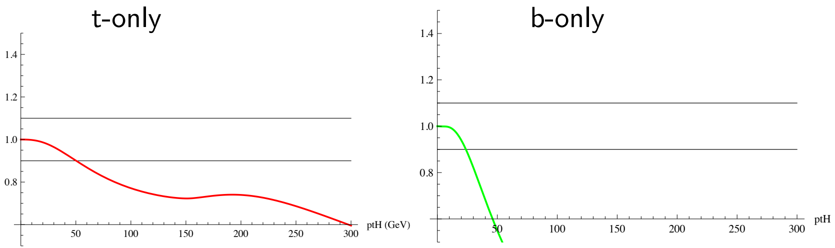


finite terms $\leq 50\% \;\to\; Q_t \sim 60\,\text{GeV},\; Q_b \equiv Q_{tb} \sim 35\,\text{GeV}$

2. validity of collinear approximation

- at matrixelement level for p_T Higgs $\rightarrow$ more in Alessandro's talk

  [Bagnaschi, Vicini]



max 10% deviation $\rightarrow$ $Q_t \sim 55\,\text{GeV}$, $Q_b \sim 25\,\text{GeV}$

"3." matching constrained in analytic resummation

- pragmatic way to determine Q for analytic resummation
- bad high p_T matching for large Q
- due to unitarity: cross section will even become negative
- prescription: require that cross section remains positive for $Q = 2\,Q_0$
- nearly perfect high p_T matching for obtained central scale Q_0
- physical connection:
  resummation where soft/collinear approximation unjustified
  $\rightarrow$ contribution from Sudakov too large
  $\rightarrow$ compensated by negative cross section to fullfill unitarity

high p_T matching $\rightarrow$ $Q_t \sim 50\,\text{GeV}$, $Q_b \sim 25\,\text{GeV}$, $Q_{tb} \sim 35\,\text{GeV}$

Importance of discussion

- in SM roughly 5-20% in t+b for small p_T
- BUT: $\sim$ 100% effect for b-only $\rightarrow$ huge effects in 2HDM/MSSM when b-loop dominant
- light Higgs SM-like, but heavy Higgs not
- HOWEVER: might be alleviated by $b\bar{b} \rightarrow H$ contribution NNLO+NNLL: [Harlander, Tripathi, MW '14]
- currently: inconsistent Q_b treatment between p_T Higgs and jet-veto

Conclusions

- correct treatment of 3-scale-problem desired
- until then: reasonable choice of Q_b crucial for bottom-loop
- resummation scales significantly larger than $Q_b = m_b$ favored by quantitative studies

1. finite terms $\leq 50\%$ $\rightarrow$ $Q_t \sim 60\,\text{GeV},\ Q_b \equiv Q_{tb} \sim 35\,\text{GeV}$
2. max 10% deviation $\rightarrow$ $Q_t \sim 55\,\text{GeV},\ Q_b \sim 25\,\text{GeV}$
3. high p_T matching $\rightarrow$ $Q_t \sim 50\,\text{GeV},\ Q_b \sim 25\,\text{GeV},\ Q_{tb} \sim 35\,\text{GeV}$

- b-only NLO p_T distribution might help (might take a while)
- resummation of $\ln(m_b/m_H)$ already important for total cross section; to be considered detached from Sudakov resummation
- choice of Q_b important for all approaches
  POWHEG – public [Bagnaschi, Degrassi, Slavich, Vicini]
  analytic resummation – beta version available [Mantler, MW]
  aMC@NLO – under validation [Mantler, MW]
- to be done: comparison!