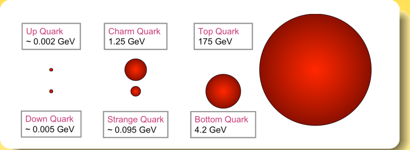
b-mass effects in $b\bar{b} \to h$

21/12/15, Milan Meeting, Davide Napoletano

Outline

Introduction



$\Lambda_{QCD} \sim 250$ MeV,
A quark Q is **heavy** $\Leftrightarrow m_Q \gg \Lambda_{QCD}$.

$m_u, m_d, m_s \ll \Lambda_{QCD} \Rightarrow$ light quarks

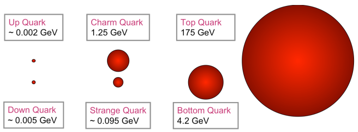
$m_c > \Lambda_{QCD}$ but not by much!

- b quark only quark such that

$$\Lambda_{QCD} \ll m \ll M(m_W, m_Z, m_H, m_t)$$

- b phenomenology crucially important at the LCH, from flavour physics, to Higgs characterisation and measurements and as window to New Physics.
- From a theoretical viewpoint we need better control on this kind of processes which appear as both BSM signals and SM irreducible backgrounds.
- Important examples: H and Z associated production.
- Historically two approaches:

Introduction



$\Lambda_{QCD} \sim 250$ MeV,
A quark Q is **heavy** $\Leftrightarrow m_Q \gg \Lambda_{QCD}$.

$m_u, m_d, m_s \ll \Lambda_{QCD} \Rightarrow$ light quarks

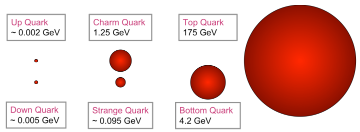
$m_c > \Lambda_{QCD}$ but not by much!

- b quark only quark such that

$$\Lambda_{QCD} \ll m \ll M(m_W, m_Z, m_H, m_t)$$

- b phenomenology crucially important at the LCH, from flavour physics, to Higgs characterisation and measurements and as window to New Physics.
- From a theoretical viewpoint we need better control on this kind of processes which appear as both BSM signals and SM irreducible backgrounds.
- Important examples: H and Z associated production.
- Historically two approaches:

Introduction



$\Lambda_{QCD} \sim 250$ MeV,
A quark Q is **heavy** $\Leftrightarrow m_Q \gg \Lambda_{QCD}$.

$m_u, m_d, m_s \ll \Lambda_{QCD} \Rightarrow$ light quarks

$m_c > \Lambda_{QCD}$ but not by much!

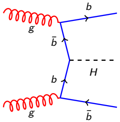
- b quark only quark such that

$$\Lambda_{QCD} \ll m \ll M(m_W, m_Z, m_H, m_t)$$

- b phenomenology crucially important at the LCH, from flavour physics, to Higgs characterisation and measurements and as window to New Physics.
- From a theoretical viewpoint we need better control on this kind of processes which appear as both BSM signals and SM irreducible backgrounds.
- Important examples: H and Z associated production.
- Historically two approaches:

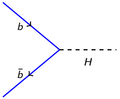
4F versus 5F scheme

4F scheme



- × Doesn't re-sum possibly large logs, but it does have them explicitly
- × Higher orders are computationally more difficult
- ✓ Mass effects present at any order
- ✓ MC@NLO no problem

5F scheme



- ✓ Stabler predictions, re-summation of IS large logs into b-PDF
- ✓ Higher order easily accessible
- × Differential features effects are pushed to higher orders
- × Implementation in MC depends on the $g \to b\bar{b}$ splitting implemented

Improved theoretical predictions

Directions

- Matching the two schemes, **FONLL, SCET, etc...**
- Somehow difficult to extend to differential distributions

- Design of a 5F-improved scheme to include mass effects
- In principle easy to do, but full of subtleties (**Factorisation, Parton-Shower...**)

Improved theoretical predictions

Directions

- Matching the two schemes, **FONLL, SCET, etc...**
- Somehow difficult to extend to differential distributions

- Design of a 5F-improved scheme to include mass effects
- In principle easy to do, but full of subtleties (**Factorisation, Parton-Shower...**)

Improved theoretical predictions

Directions

- Matching the two schemes, **FONLL, SCET, etc...** **TOTAL RATES**
- Somehow difficult to extend to differential distributions

- Design of a 5F-improved scheme to include mass effects **SHAPES**
- In principle easy to do, but full of subtleties (**Factorisation, Parton-Shower...**)

I've been working on both approaches.
The former being essentially a concluded work.

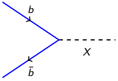
Outline

Computing NLO observable

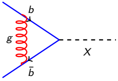
First problem ...

To compute a NLO observable we need:

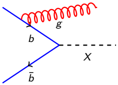
$$d\sigma = d\Phi_{\mathcal{B}} \left[\mathcal{B}(\Phi_{\mathcal{B}}) + \mathcal{V}(\Phi_{\mathcal{B}}) \right] + d\Phi_{\mathcal{B}+1} \mathcal{R}(\Phi_{\mathcal{B}+1})$$



$+$



$+$



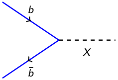
- $\mathcal{V}(\Phi_{\mathcal{B}})$ and $\int d\Phi_{\mathcal{B}+1}\, \mathcal{R}(\Phi_{\mathcal{B}+1})$ are separately soft (and collinear) divergent in $4d$
- $\int d\Phi_{\mathcal{B}}\, \mathcal{V}(\Phi_{\mathcal{B}}) + \int d\Phi_{\mathcal{B}+1}\, \mathcal{R}(\Phi_{\mathcal{B}+1})$ is finite!
- Need method to render the integrand finite for MC integration!
  $\Longrightarrow$ **Catani-Seymour Dipole formalism**.

Computing NLO observable

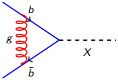
First problem ...

To compute a NLO observable we need:

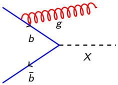
$$d\sigma = d\Phi_{\mathcal{B}} \left[\mathcal{B}(\Phi_{\mathcal{B}}) + \mathcal{V}(\Phi_{\mathcal{B}}) \right] + d\Phi_{\mathcal{B}+1} \mathcal{R}(\Phi_{\mathcal{B}+1})$$



$+$



$+$



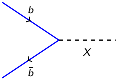
- $\mathcal{V}(\Phi_{\mathcal{B}})$ and $\int d\Phi_{\mathcal{B}+1} \mathcal{R}(\Phi_{\mathcal{B}+1})$ are separately soft (and collinear) divergent in 4*d*
- $\int d\Phi_{\mathcal{B}} \mathcal{V}(\Phi_{\mathcal{B}}) + \int d\Phi_{\mathcal{B}+1} \mathcal{R}(\Phi_{\mathcal{B}+1})$ is finite!
- Need method to render the integrand finite for MC integration!
  $\Longrightarrow$ **Catani-Seymour Dipole formalism**.

Computing NLO observable

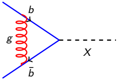
First problem ...

To compute a NLO observable we need:

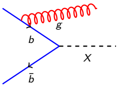
$$\mathrm{d}\sigma = \mathrm{d}\Phi_{\mathcal{B}}\left[\mathcal{B}(\Phi_{\mathcal{B}}) + \mathcal{V}(\Phi_{\mathcal{B}})\right] + \mathrm{d}\Phi_{\mathcal{B}+1}\mathcal{R}(\Phi_{\mathcal{B}+1})$$



$+$



$+$



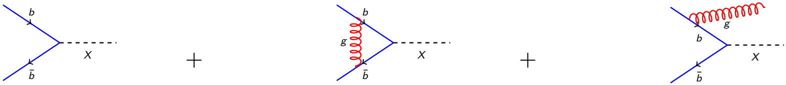
- $\mathcal{V}(\Phi_{\mathcal{B}})$ and $\int \mathrm{d}\Phi_{\mathcal{B}+1}\,\mathcal{R}(\Phi_{\mathcal{B}+1})$ are separately soft (and collinear) divergent in $4d$
- $\int \mathrm{d}\Phi_{\mathcal{B}}\,\mathcal{V}(\Phi_{\mathcal{B}}) + \int \mathrm{d}\Phi_{\mathcal{B}+1}\,\mathcal{R}(\Phi_{\mathcal{B}+1})$ is finite!
- Need method to render the integrand finite for MC integration!
  $\Longrightarrow$ **Catani-Seymour Dipole formalism**.

Computing NLO observable

First problem ...

To compute a NLO observable we need:

$$d\sigma = d\Phi_{\mathcal{B}}\left[\mathcal{B}(\Phi_{\mathcal{B}}) + \mathcal{V}(\Phi_{\mathcal{B}})\right] + d\Phi_{\mathcal{B}+1}\mathcal{R}(\Phi_{\mathcal{B}+1})$$

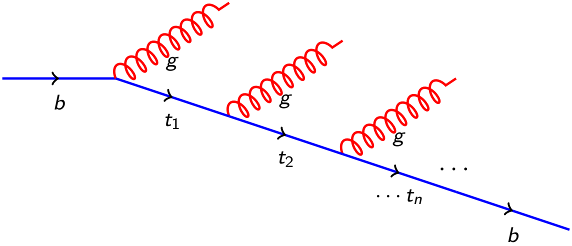


$$d\sigma = d\Phi_{\mathcal{B}}\left[\mathcal{B}(\Phi_{\mathcal{B}}) + \mathcal{V}(\Phi_{\mathcal{B}}) + \mathcal{I}(\Phi_{\mathcal{B}})\right] + d\Phi_{\mathcal{B}+1}\left[\mathcal{R}(\Phi_{\mathcal{B}+1}) - \mathcal{S}(\Phi_{\mathcal{B}} \otimes \Phi_1)\right]$$

- Massive and massless dipoles are not the same.

Parton Shower

Subsequent emission

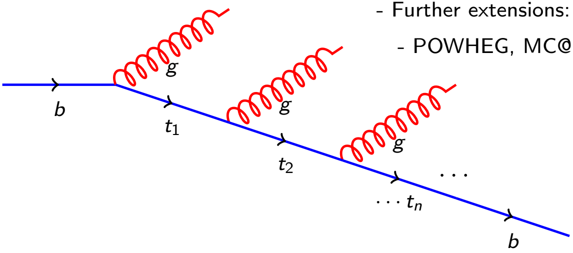


Parton Shower

Subsequent emission

Splitting probability: usually modelled by splitting functions

- Extension to Real **MEs**
- Further extensions: subtraction Kernels
- POWHEG, MC@NLO, SHERPA ...



Massive extensions so far only present for final state quark...

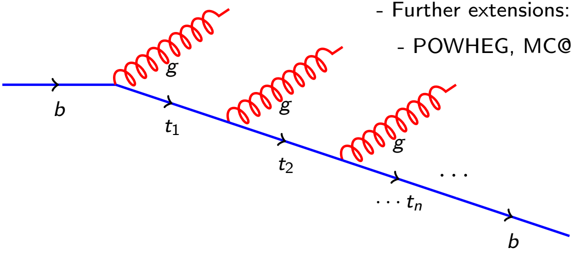
Subsequent emission

Splitting probability: usually modelled by splitting functions

- Extension to Real **MEs**

- Further extensions: subtraction Kernels

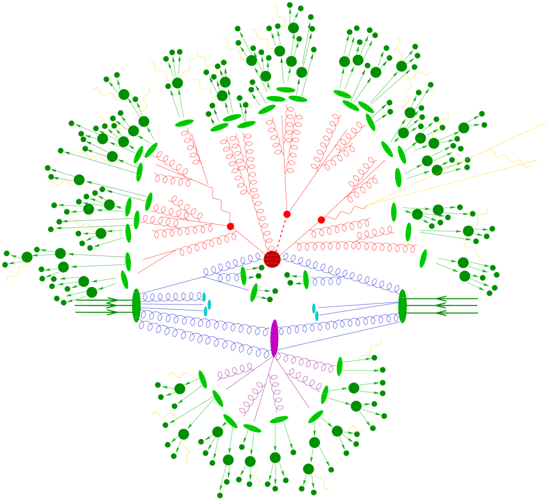
- POWHEG, MC@NLO, SHERPA ...



Massive extensions so far only present for final state quark...

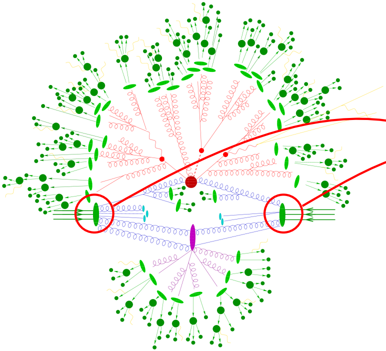
What else ... ?

MC event generation



What else ... ?

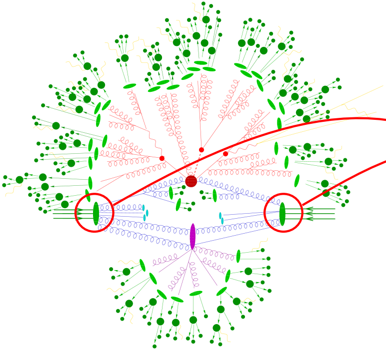
IS Factorisation



Standard factorisation with **Massless Partons**

What else ... ?

IS Factorisation

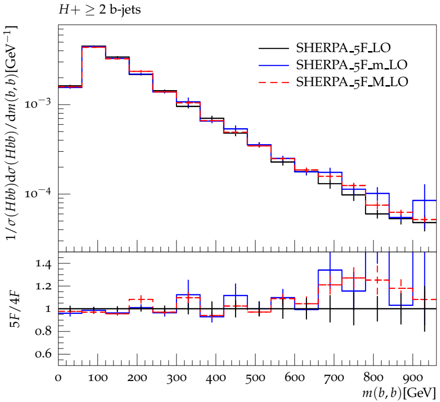


Standard factorisation with **Massless Partons**
Need to extend to **Massive quarks**
No yet fully done...

Outline

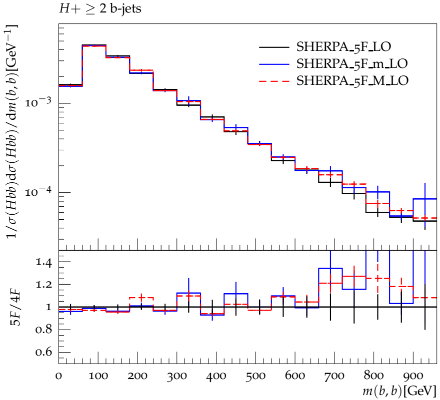
Mass effects @ LO

5F Massive vs 5F Massless



Mass effects @ LO

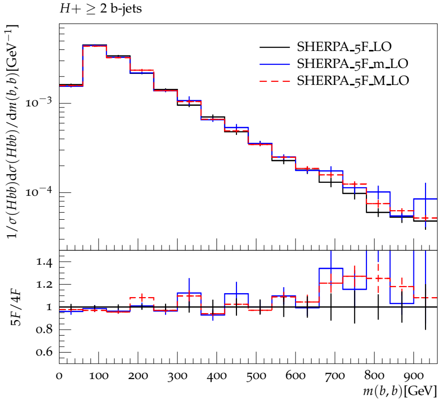
5F Massive vs 5F Massless



$\%_m$ = mass effects only in **MEs**
$\%_M$ = mass effects in **ME + PS**

Mass effects @ LO

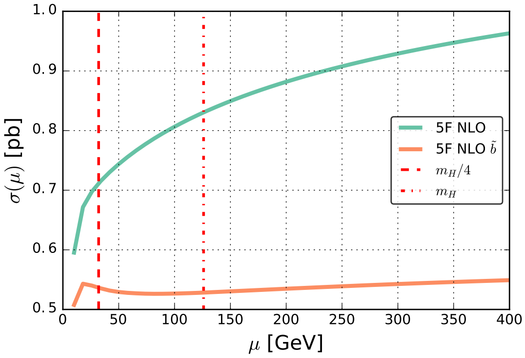
5F Massive vs 5F Massless



No significant effect it seems in terms of shapes

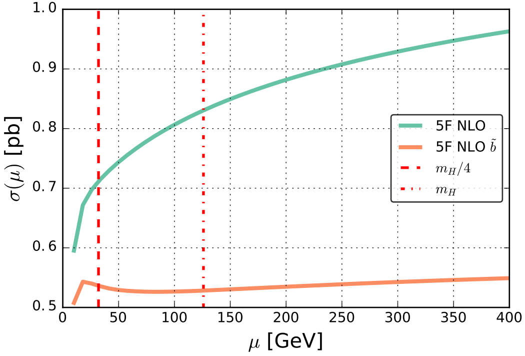
Resummation

Total rate, 5F scheme



Resummation

Total rate, 5F scheme

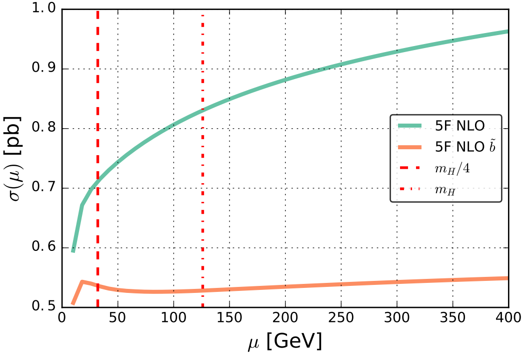


$\sigma_{b\bar{b}\to h}(\mu)$

Full 5F @ NLO vs 5F expanded b to $\mathcal{O}(\alpha_S^2)$

Resummation

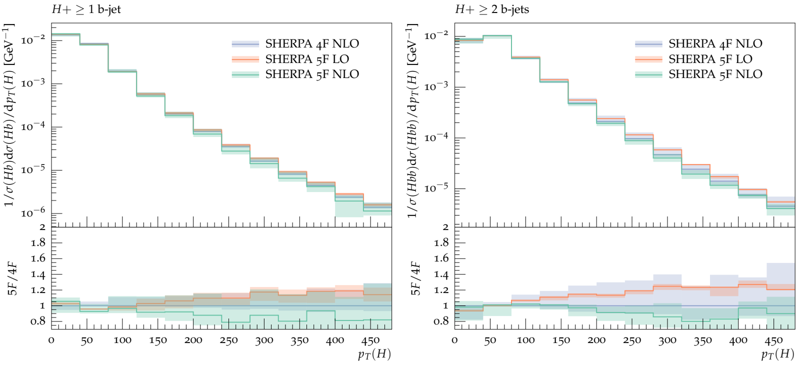
Total rate, 5F scheme



Resummation seems to have biggest impact.

Shape vs Rates

Not much difference shape-wise



Conclusions

Conclusions

- 4F, 5F, the old problem
- But it looks like differences are just in rates

- Difference mainly made up by resummation
- small, not negligible, mass effects

- 5F scheme is therefore slightly better
- Best option for MC is to include mass effects in the 5F
- By hopefully retaining the resummation!

Conclusions

Conclusions

- 4F, 5F, the old problem
- But it looks like differences are just in rates

- Difference mainly made up by resummation
- small, not negligible, mass effects

- 5F scheme is therefore slightly better
- Best option for MC is to include mass effects in the 5F
- By hopefully retaining the resummation!

Conclusions

Conclusions

- 4F, 5F, the old problem
- But it looks like differences are just in rates

- Difference mainly made up by resummation
- small, not negligible, mass effects

- 5F scheme is therefore slightly better
- Best option for MC is to include mass effects in the 5F
- By hopefully retaining the resummation!