

# Heavy flavour (production) at the LHC in Run 2

An experimental perspective

**Andy Buckley**

University of Glasgow

HF@LHC, Durham, 20 April 2016

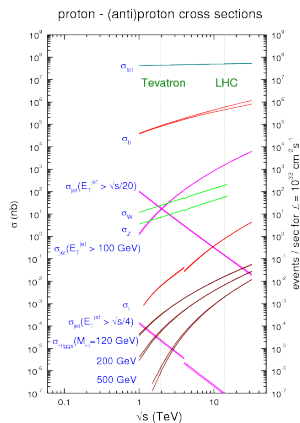


University  
of Glasgow



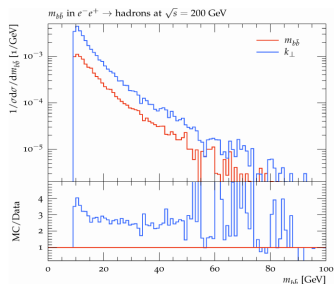
# Heavy flavour in Run 2

- ▶ 8 TeV  $\rightarrow$  13 TeV: more energy = more  $\sigma_{bb}$ ... but not really key, many other things grow at least as fast
- ▶ But increased emphasis on precision and rare processes, esp. Higgs  $\rightarrow$   $bb$  channels ( $ttH$  and  $VH$ )
- ▶ Also much-enhanced cross-sections in boosted phase-space: cool, but means signal and  $g \rightarrow bb$  overlap
- ▶ **How well can we understand the background QCD  $b$  production (and decay  $\Rightarrow$  tagging/reco performance)?**
- ▶ And can being smart about SM physics complement “data mining” experimental techniques?



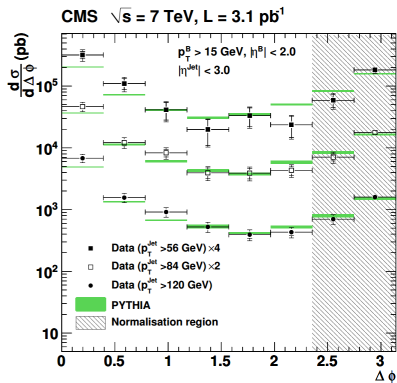
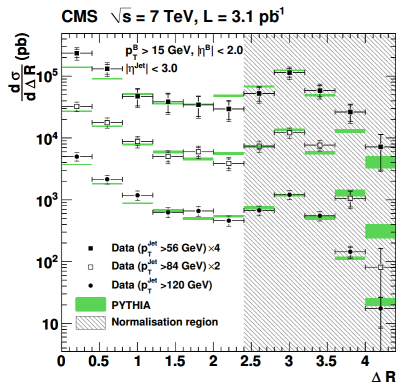
# $bb$ modelling in MC

- ▶  $g \rightarrow bb$  gluon splitting to HF not necessarily well modelled by parton shower: no divergence in splitting function, so is collinear expansion good?
- ▶ How about...
  - HF production in PDF evolution, and their interfacing to MEs and showers?
  - Flavour-number schemes? Is there a globally optimal scheme? Are there obviously *locally* optimal schemes?
  - Mass schemes? Scale choices? Matching details?
  - How to *realistically* minimise these theory uncertainties?
- ▶ *So many issues/channels/observables, so little (my) certainty!*



Gluon splitting scale-dependence,  
FK 2013?

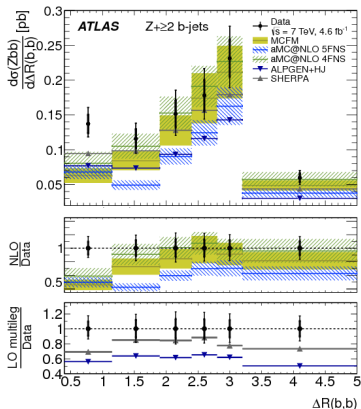
# MC vs. data



CMS inclusive  $bb$  from secondary vertices [[arXiv:1102.3194](https://arxiv.org/abs/1102.3194)]

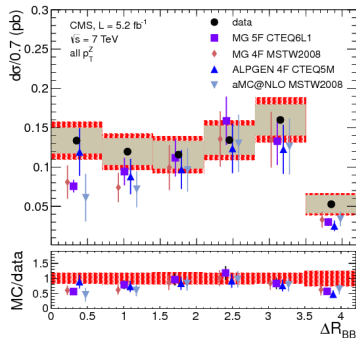
Rivet: CMS\_2011\_S8973270

# MC vs. data



ATLAS  $Z + bb$  [arXiv:1407.3643]

Rivet: ATLAS\_2014\_I1306294



CMS  $Z + bb$  [arXiv:1310.1349]

Rivet: CMS\_2013\_I1256943

# Questions for theorists

More questions from expt to theory than *vice versa*... so far



“If you like eating sausages...”

# Questions for theorists

## Experimental measurement strategy

- ▶ Which are the most important analysis observables to tie down HF, particularly in  $V + b(b)$ ? What precision is needed to be useful?
- ▶ Are particular kinematic regimes expected *a priori* to be either very sensitive or very insensitive to the HF schemes in MC generators?
- ▶ Both theory and experiment uncertainties reduce in ratio observables. Are the theory reductions “accidental”, e.g. how independent are light and HF scale choices? Do more precise measurements via ratios just correspond to insensitive theory regions?

# Questions for theorists

## PDFs and matrix elements

- ▶ All HF flavour measurements for hadron colliders are in pole mass scheme. Is this the best scheme for LHC, cf. use of  $\overline{MS}$  at LEP and renormalons in relating the two?
- ▶ How hard is it to generate asymmetric PDFs for charm (and strange)?
- ▶ How far can we trust scale variations to estimate uncertainties on processes that don't appear at leading order in 4-flavour schemes?
- ▶ How low in  $p_T$  should we trust pQCD predictions of HF jets? Can measurements at low- $p_T$  constrain higher- $p_T$  behaviour?



# Questions for theorists

## Flavour number schemes

- ▶ Should we be using 4- or 5-flavour scheme?! 4f significantly underestimates  $Z + 1b$ : is this fixable, or should we only use 4f for  $2b$  final states?
- ▶ If we use 4f, what is the best way to do heavy flavour overlap removal (HFOR)? If we use 5f, what are we losing, and why?
- ▶ We are often told that for consistency with the PDF we should use a massless  $b$  in the ME for 5f calculations. Why does the  $b$ -mass have to be zero in the PDF? How significant would the mismatch effects be? How can it be best made consistent with massive  $bs$  further “downstream”?
- ▶ How do PDF and ME  $n_f$  interplay? We have Alpgen  $V + \text{jets}$  samples using a 4f ME and a 5f PDF and they look fine!
- ▶ Why is the parton shower ISR evolution not good at producing the spectator  $b$ -quark kinematics in 5f, i.e. not a good approximation to 4f ME? Aren't these diagrams also contained in 5f?
- ▶ Should 4f vs. 5f always be used as (part of) HF theory systematics?

# Questions for theorists

## Shower HF production & decays

- ▶ What is the status of  $g \rightarrow QQ$  in the shower MCs? Can we consistently get full/optimal coverage of model systematics?
- ▶ How well can low- $p_T$  measurements of HF production kinematics (due to stats) constrain high- $p_T$  behaviour?
- ▶ How does  $b$ -hadron decay mismodeling feed into tagging performance and the connected uncertainties? How best to address differences between generators? Would homogeneous use of EvtGen underestimate decay modelling systematics, and is there a lightweight way to perform variations?
- ▶ Could/would all MC generators standardise on a single decay table, collectively maintained?

## And so we begin...

- ▶ Every workshop says that it's more about discussion than "push" presentations
- ▶ I hope it's actually true for this one!
- ▶ Please have fun, discuss lots, hopefully start off something productive...



# Discussion points

- ▶ **Fragmentation functions:** non-portable from LEP? Route to an LHC measurement... of what?
- ▶  $g \rightarrow bb$ : Fabio question re. tagging  $\Rightarrow$  event samples for testing?
- ▶ **Role of 4-flavour:**
  - Is there *really* a “good for norm” / “good for shape” dichotomy?
  - Just using 4F in specific regions to validate easier-to-use 5F?
  - If 4F is needed to realistically cover systematics, how to HFOR? Just force light showering?
- ▶ Low- $p_T$ / forward heavy flavour: follow-up workshops
- ▶ EvtGen / MC decay table harmonisation / systematics coverage for sensitive uses
- ▶ Renormalisation schemes for HF masses: debate rolls on...