Heavy Flavours in ALPGEN

Mauro Moretti

Dept. of Phys. and INFN Ferrara

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Outline

- ALPGEN packages with heavy flavours.
- Matching with final state heavy flavours.
- Comparison of HERWIG and PITHYA gluon splitting into $b\bar{b}$ ($t\bar{t}b\bar{b}$ process).
- Merging ME and PS with "soft" $b\bar{b}$ pairs produced by PS
- Merging ME and PS with $b\bar{b}$ ME over all phase space
- Summary

Motivations

skipping why we are interested into associate production of heavy flaovurs pairs and Weak bosons or $t\bar{t}$ pair

- The goal is to merge ME and PS description of processes with a (at least a) heavy flavour (c, b) pair often in association with weak bosons or top pairs.
- Gluon splitting into $q\bar{q}$ pair is better described by ME for "large" invariant mass of the pair whereas PS performs better in the low invariant mass regime.
- Both m_c and m_b are above the typical IR cut-off of PS and it is sensible to investigate how well the pair production is modelled and in what cynematical regime.
- The rate for associate production of Z, W and $b\bar{b}$ pair (although with a large systematic error) seems to be above both matched LO prediction and NLO prediction.
- Studies of the dedicated packages in `ALPGEN` have raised some issues about the possibility of a smooth ME PS interplay.

Heavy flavours in ALPGEN

- Avaliable processes: $W, Z, H\bar{Q}Q + jets$, $W, Z\gamma\bar{Q}Q + jets$, $\bar{Q}Q + jets$ and $\bar{Q}Q\bar{Q}Q + jets$ where $Q = c, b, t$ and $jets$ stand for gluons or light quarks
- Top quark is decayed in the narrow width approximation and (within the same approximation) spin correlation among top decay products is fully retained.
- Up to eight (to be increased in the next release) final state partons in the ME.
- ME is interfaced with PS and MLM matching is used to consistenlty sum up samples of different multiplicities avoiding double counting.

Matching ME and PS

A brief resume of MLM matching

- Goal: merge PS and ME description avoiding double counting and retaining the complementary good features of both approaches.
- ME events are generated with a set of *generation cuts* to avoid IR / Collinear singularity (and to enrich the event samples in the interesting regions)
- Events are showered and a veto procedure is applyed:
  1. using a jet algorithm final state jets are reconstructed
  2. if the number of jets is different from the number of ME final state coloured parton the event is rejected (described by a sample with a different jet multiplicity)
  3. a coloured parton “matches” a jet if its direction is “close” to the jet direction. If at least one parton doesn’t match a jet the event is rejected (the parton don’t originate a jet which is instead due to hard PS emission)
  4. the procedure needs to be modified for the highest ME parton multiplicity to allow the PS to emit additional jets.

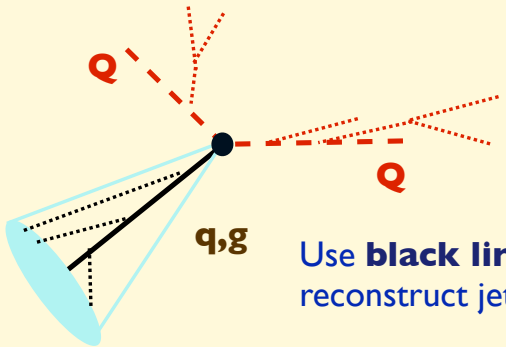
Matching ME and PS for heavy quarks

- Heavy quarks are massive in the ME description and *are allowed to cover any region in phase space* no cut is required in principle.
- the MLM matching proceed as follows:
  1. the heavy quark and the radiation from the heavy quark is "removed" from the event
  2. the MLM algorithm is applied to the leftover radiation
  3. using only the heavy quark and its emitted radiation jets are reconstruced: if more than one jet or a jet well separated from the heay quark appear the event is rejected
  4. again a slight variant needs to be used for the highest jet multiplicity: in this case extra jets are allowed, *provided their* E_T *is lower than matched jets one*

Matching ME and PS for heavy quarks II

Treatment of heavy quarks: final states

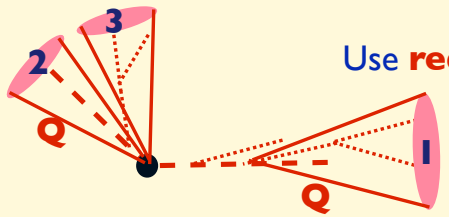
1st pass of merging prescription does not require matching of heavy quarks:



Leave **red lines** (hvq shower daughters) out of jet reconstruction

Use **black lines** (ISR+light-parton FSR) to reconstruct jets for matching

2nd pass of merging clusters the heavy quark shower daughters:



Use **red lines** only to reconstruct jets

* If jet contains the heavy quark itself (e.g. **1** and **2**), keep event
* If jet does not contain the heavy quark itself (e.g. **3**), treat it as extra jet:
  - reject event if exclusive sample
  - keep if E_T smaller than all matched jets

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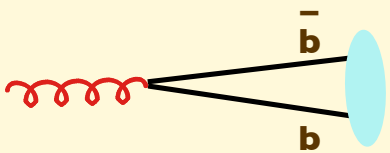
Matching ME and PS for heavy quarks III

Comments

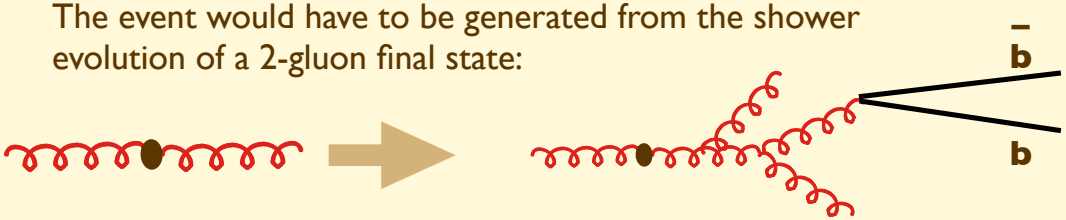
This prescription is used since HVQs can be generated in ALPGEN without cuts in p_T and in ΔR_{QQ}.

If we were to apply a matching cut on HVQs, we would e.g. reject an event with a final state like this:



since both b and bbar match the same jet

The event would have to be generated from the shower evolution of a 2-gluon final state:



=> great loss of efficiency, need to mix samples from different processes, ...

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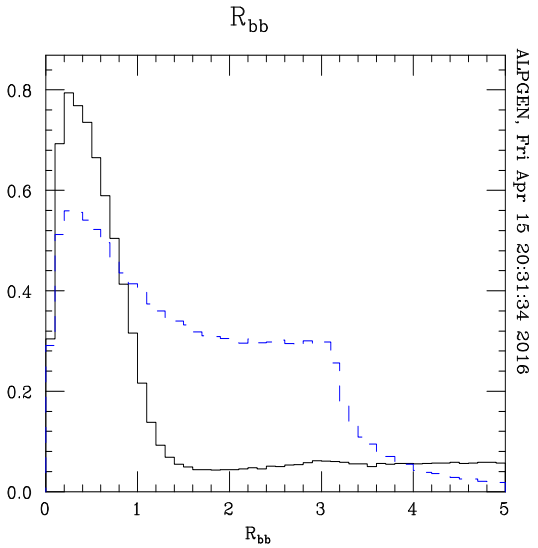
$t\bar{t}b\bar{b}$ event samples and definition of "observables"

- S_j sample is constructed with *exclusive samples* with $0, 1, \ldots .., j-1$. and the *inclusive sample* with at least j jets.
- the analysis is performed at the parton level, before hadronization
- most of the distributions refers to b parton (quarks). b quarks from top decay are non included into the analysis.
- *jets* are reconstructed with Page's getjet.f routines. A "b-jet" is a reconstructed jet which contains at least a b quark, indipendent of its energy and it is labeled J_b in the following
- Alpgen samples are generated with generation level cuts $p_{Tj} > 20GeV$, $R_{jj} > 0.7$, $|\eta_j| < 5$ and matching parameters $p_{Tj} > 25GeV$, $R_{jj} > 0.7$, $|\eta_j| < 5$
- we shall concentrate on the distributions which exhibit the most relevant issues: the invariant $b\bar{b}$ mass m_{bb} and b separation R_{bb}

$t\bar{t}b\bar{b}$ event samples and definition of "observables" II

- 4f scheme used, difference with 5f negligible for this channel (at least for the studied obeservables . . .)
- PYTHIA 6.3, Herwig 6.510
- work in progress and most plots are preliminary

HERWIG vs PITHYA PS



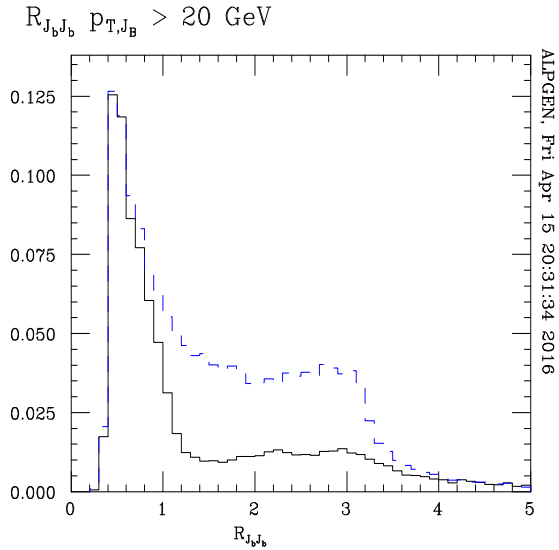
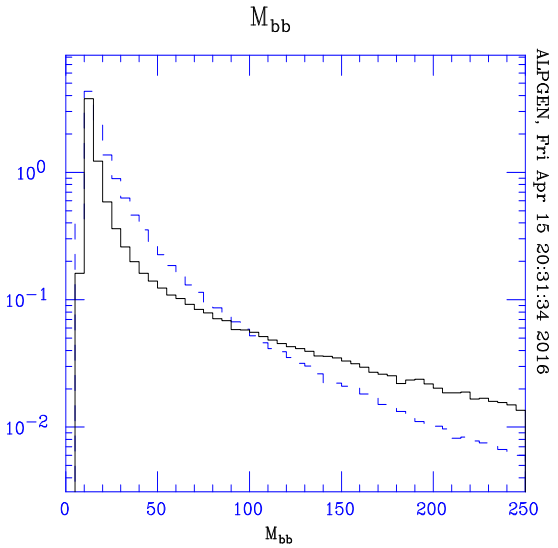


Figure: R_{bb} left panel, and $R_{J_b J_b}$ right panel. $P_{T J_b} > 25 GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos Herwig, dashed PYTHYA.

HERWIG vs PITHYA PS II



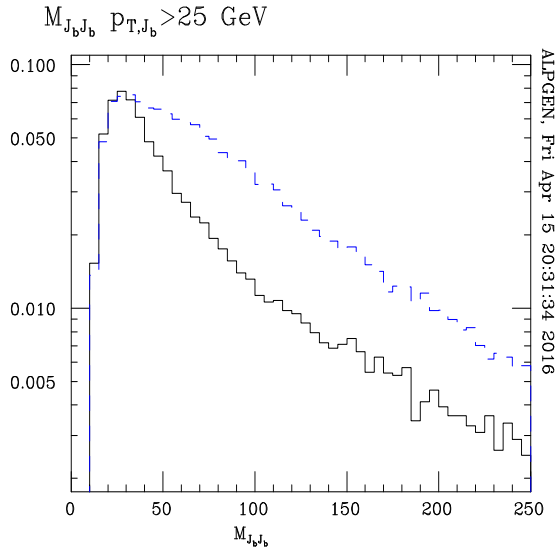


Figure: m_{bb} left panel, $m_{J_b J_b}$ right panel. $P_{T J_b} > 25 GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos Herwig, dashed PYTHYA.

HERWIG + ME ($t\bar{t} + jets$) vs PITHYA+ ME, V214

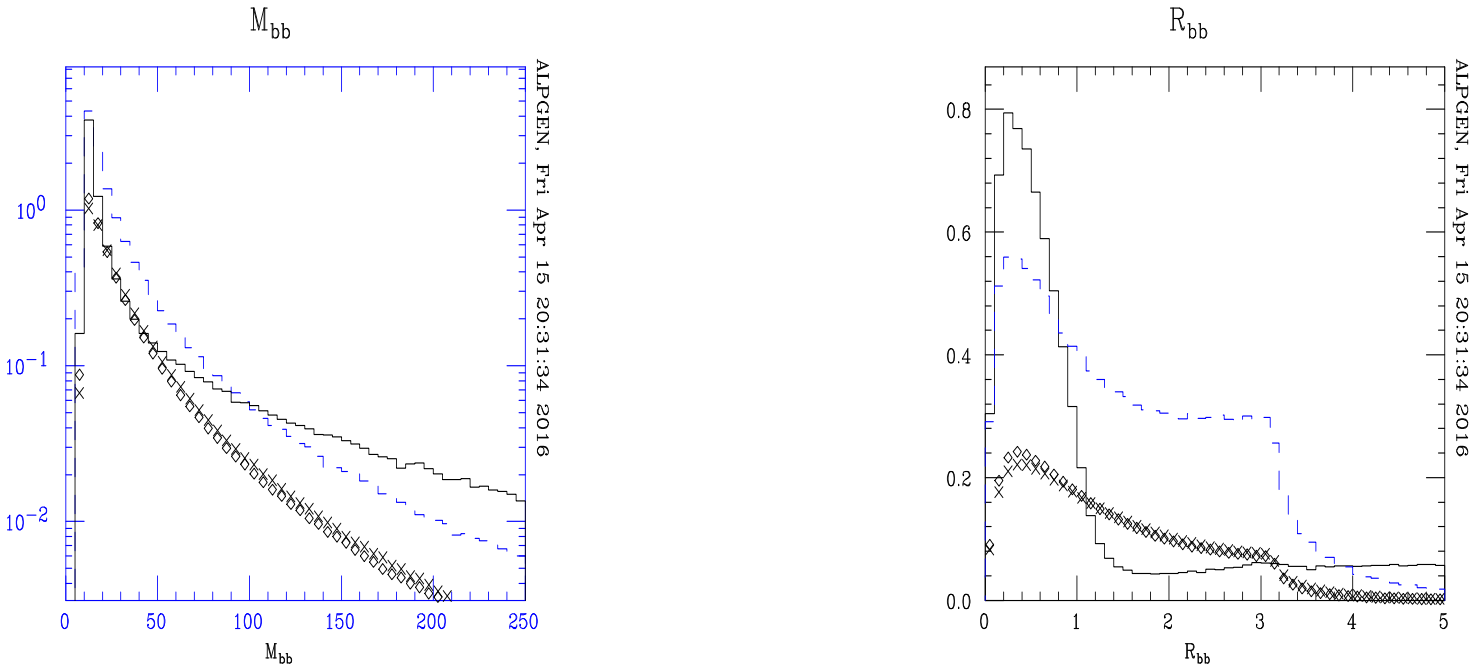
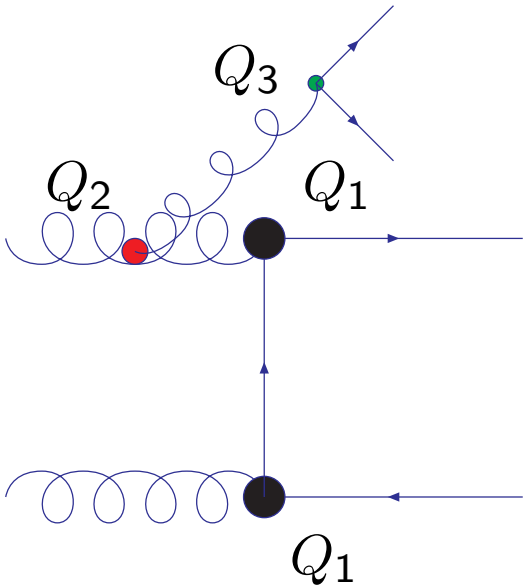


Figure: m_{bb} left, R_{bb} right Continuos Herwig, dashed PYTHIA, crosses ALPGEN 4Q + HERWIG, diamonds ALPGEN 4Q + PYTHIA. ALPGEN 4Q no cut on b

CKKW like reweighting of the ME

- PS largerly overshoots ME, a smooth interplay impossible.
- among the PS / ME differences the only one capable to explain the large difference is the Q^2 dependence of α_S: whereas the $t\bar{t}b\bar{b}$ ME is computed with a common α_S the gluon emission and subsequent splitting in the PS will happen (mostly) at lower scale ($\Rightarrow$ larger α_S).
- to better mimic PS beahviour CKWW like reweighting of the ME is applied in the following

CKKW reweighting of ME



ME computed with $\alpha_s(Q_1)$ then reweighted by
$\alpha_s(Q_1)\alpha_S(Q_2)\alpha_S(Q_3)/\alpha_S^3(Q_1)$

HERWIG + ME ($t\bar{t} + jets$)

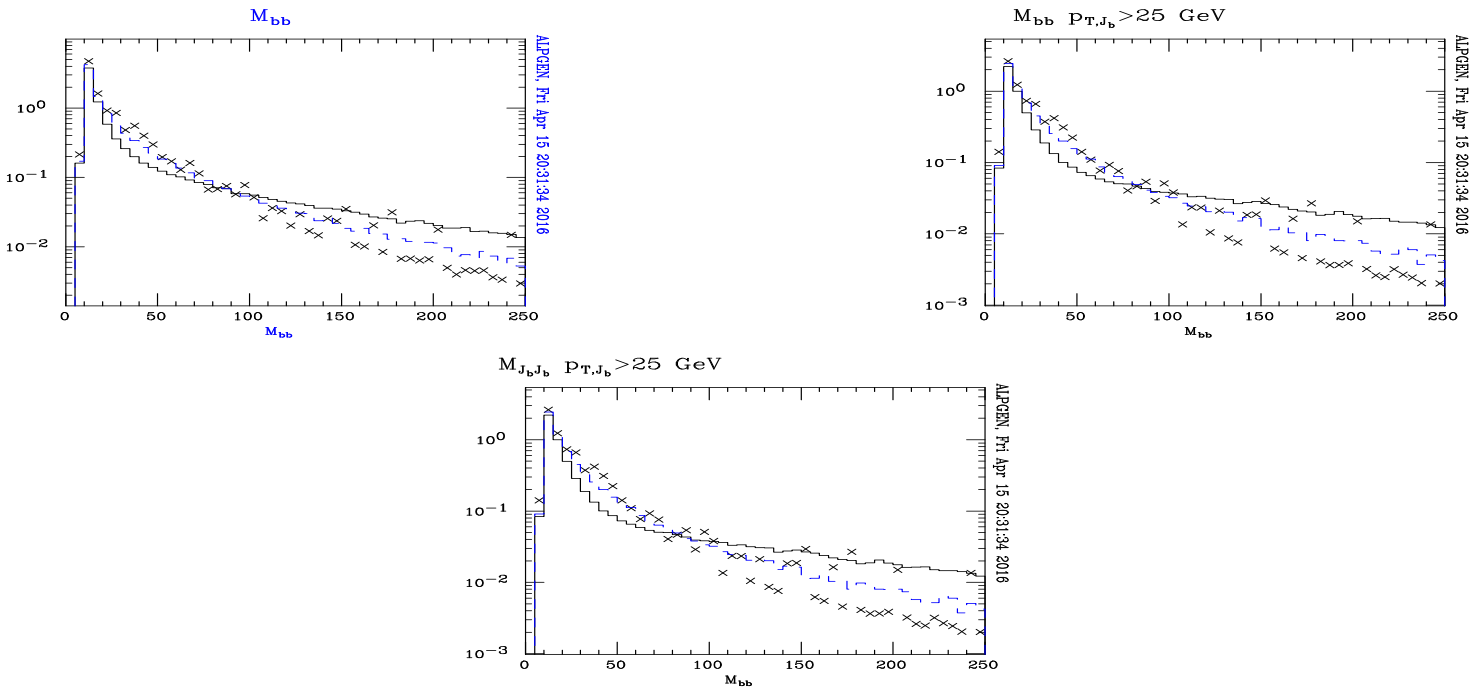


Figure: m_{bb} distribution: inclusive (left-upper panel), with at least one b-tagged jet (upper-right panel), $m_{J_B J_B}$ (lower panel). $P_{T J_b} > 25 GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos S_0, dahsed S_1, crosses S_2. Herwig.

HERWIG + ME ($t\bar{t} + jets$)

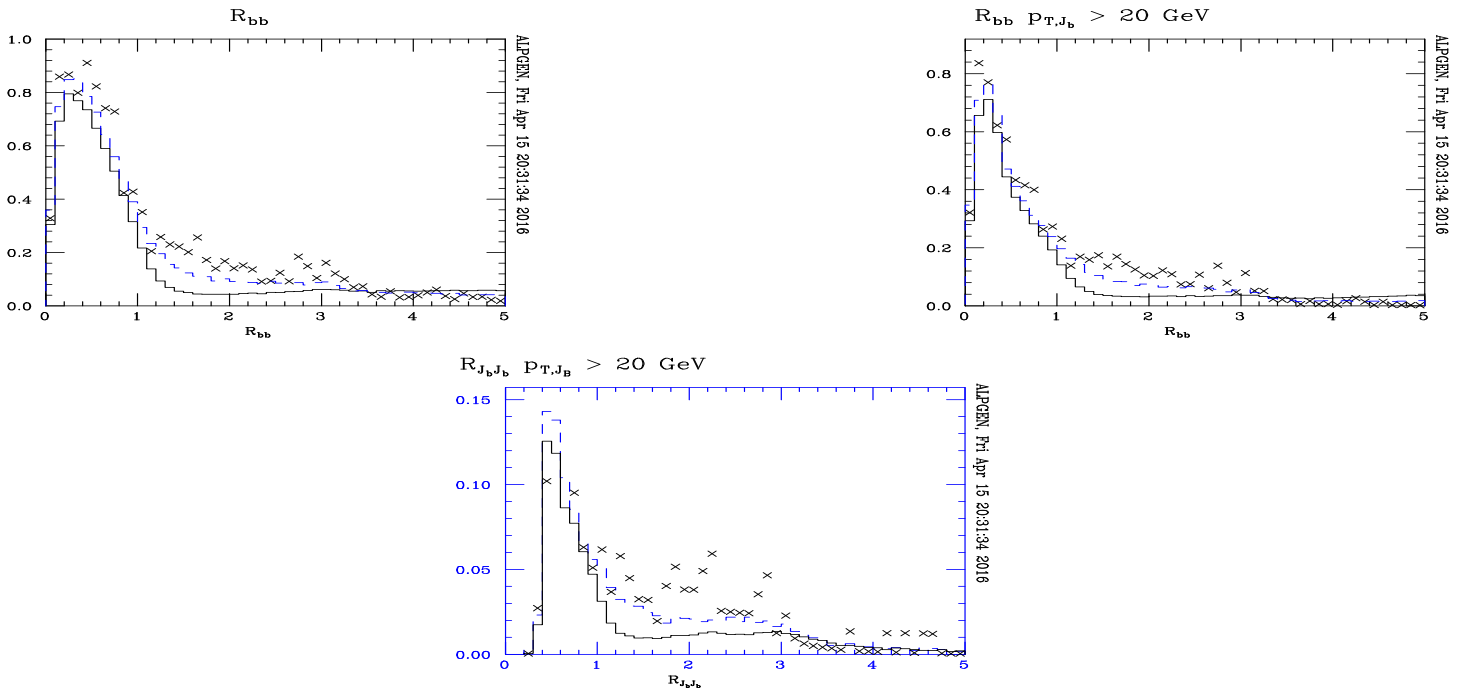


Figure: R_{bb} distribution: inclusive (left-upper panel), with at least one b-tagged jet (upper-right panel), $R_{J_B J_B}$ (lower panel). $P_{T J_b} > 25 GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos S_0, dahsed S_1, crosses S_2. Herwig.

PYTHIA + ME ($t\bar{t} + jets$)

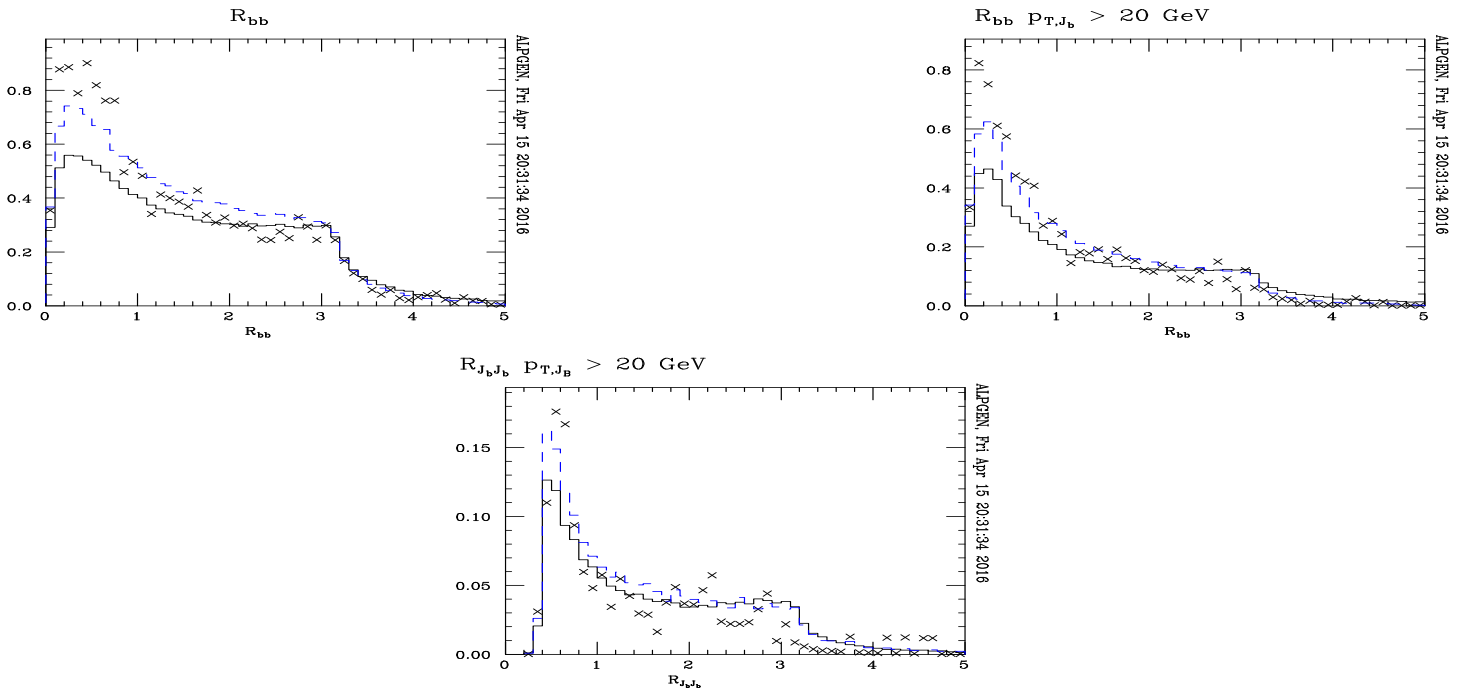


Figure: R_{bb} distribution: inclusive (left-upper panel), with at least one b-tagged jet (upper-right panel) $R_{J_B J_B}$ (lower panel). $P_{T J_b} > 25 GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos S_0, dahsed S_1, crosses S_2. Pythia.

PYTHIA + ME ($t\bar{t} + jets$) II

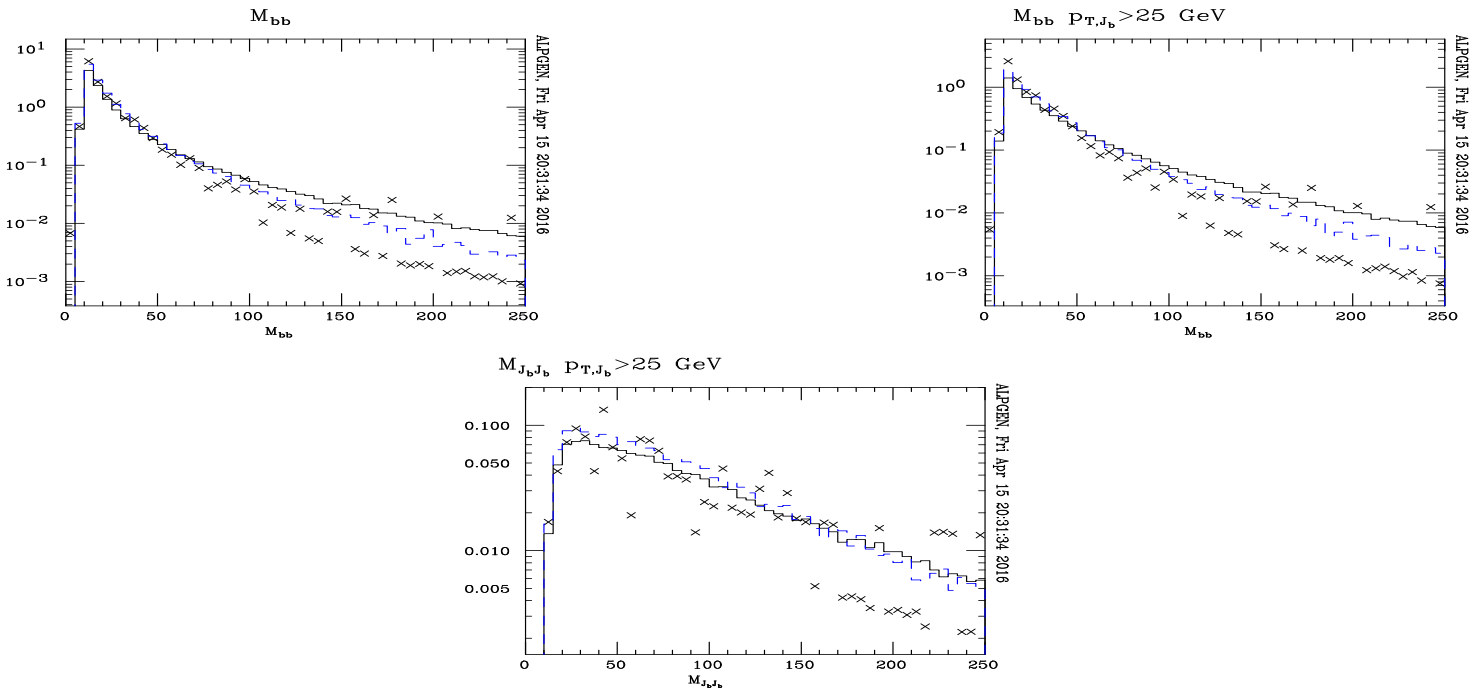


Figure: m_{bb} distribution: inclusive (left-upper panel), with at least one b-tagged jet (upper-right panel) $m_{J_B J_B}$ (lower panel). $P_{T J_b} > 25 GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos S_0, dahsed S_1, crosses S_2. Pythia.

$t\bar{t}b\bar{b} + jets$ from ME

- Standard matching procedure doesn't seem to work... hard to achieve a smooth interplay
- with ALPGEN we have an additional possibility: describe $b\bar{b}$ pair over the all kinematically allowed phase space
- we study the process $t\bar{t}b\bar{b} + jets$ without imposing cuts on b quarks (ALPGEN 4Q package)
- Samples produced with $4Q$ package, $b\bar{b}$ from ME everywhere
- $t\bar{t}b\bar{b} + jets$ + PS, no cuts on $b \Rightarrow$ Herwig and Pythia pretty similar (expected $b\bar{b}$ completely ME driven)
- $t\bar{t}b\bar{b} + jets$ + PS below $t\bar{t}$ +PS *even in the Sudakov suppressed region*

PS+ ME ($t\bar{t}b\bar{b} + jets$)

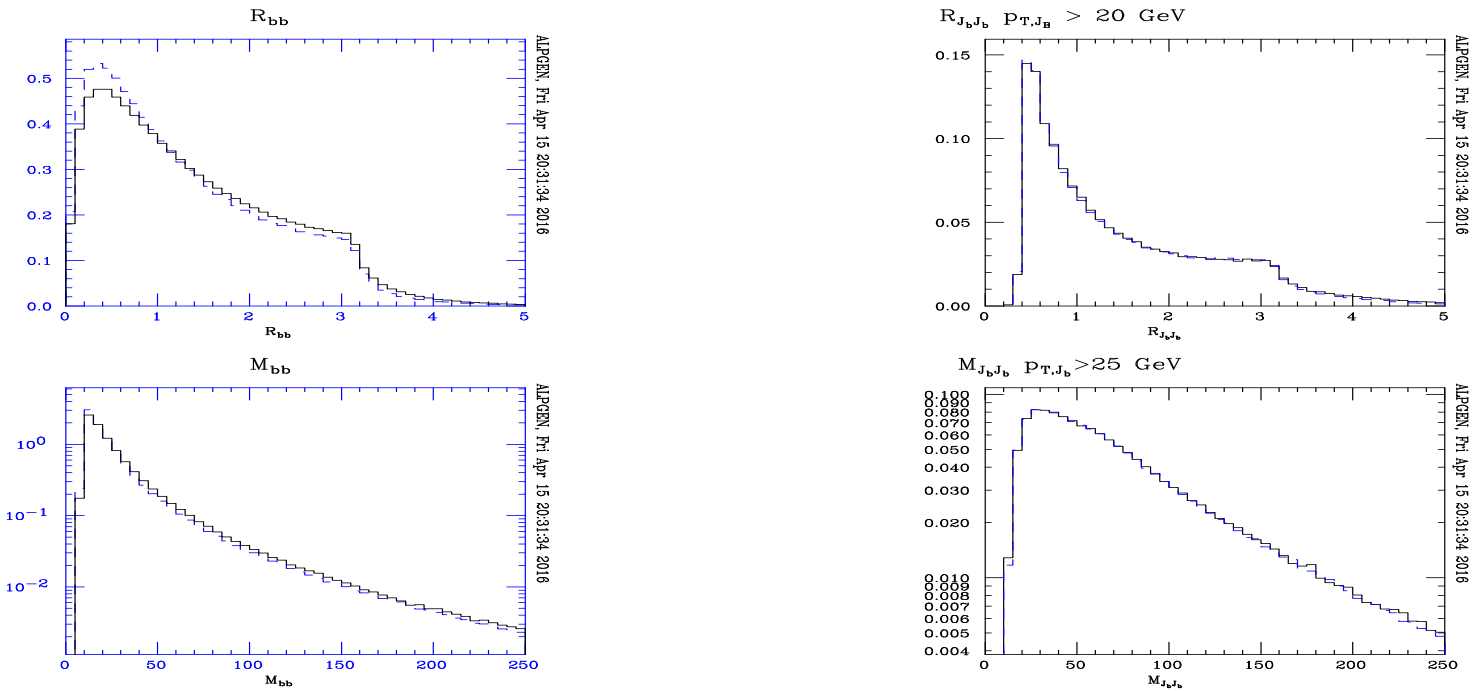


Figure: R_{bb} upper left, $R_{J_bJ_b}$ upper right, m_{bb} lower left and $m_{J_bJ_b}$ lower right. $P_{TJ_b} > 25GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos Herwig, dashed Pythia.

PS+ ME ($t\bar{t}b\bar{b} + jets$) vs PS $b\bar{b}$ pairs

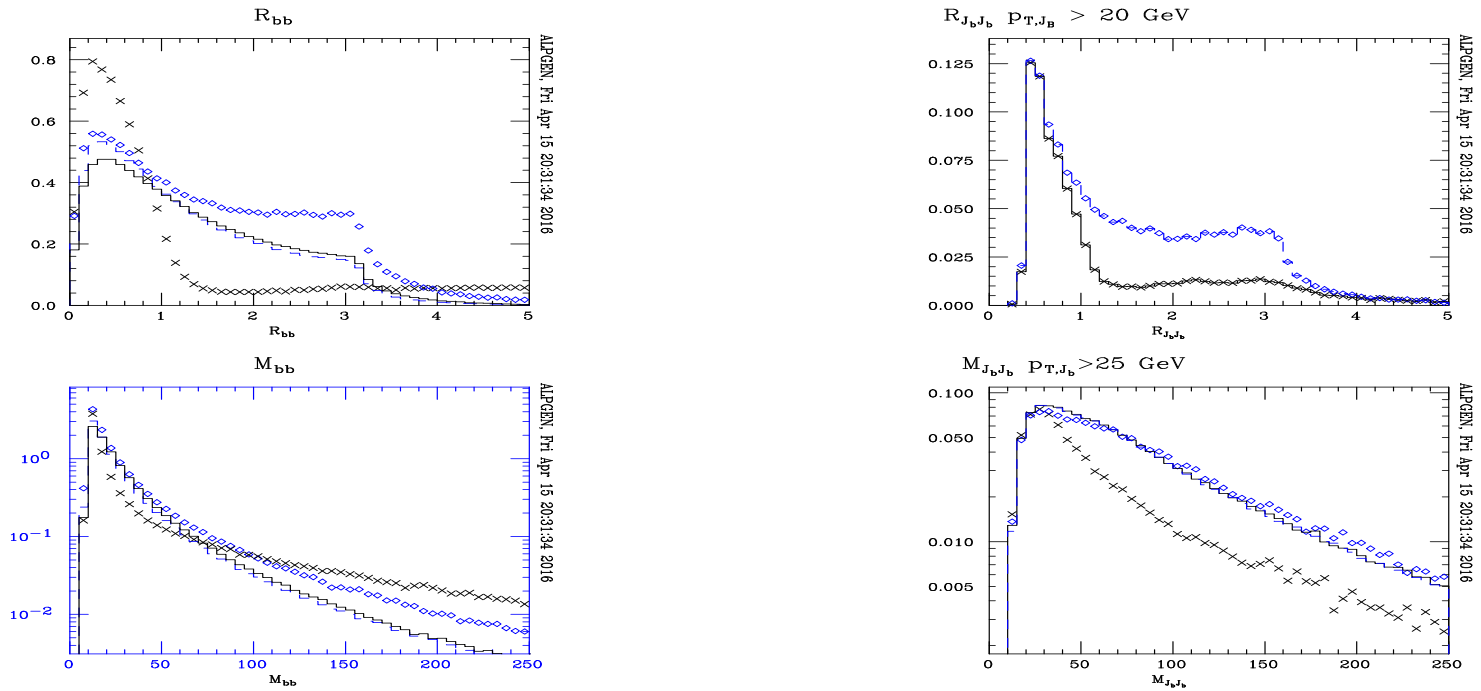


Figure: R_{bb} upper left, $R_{J_bJ_b}$ upper right, m_{bb} lower left and $m_{J_bJ_b}$ lower right. $P_{TJ_b} > 25GeV$, $|\eta_b| < 2.5$ and $|\eta_{J_b}| < 2.5$ Continuos Herwig 4Q, dashed Pythia 4Q, crosses Herwig (2Q), diamonds PYTHIA(2Q).

Conclusions: our current best solution.

Avaliable with the next release

- $b\bar{b}$ from ME everywhere with CKKW-like ME reweighting
- option to veto $b\bar{b}$ from PS
- caveats: we have a preliminary study of $t\bar{t}b\bar{b}$ only, more channels needed as well as comparison with data when avaliable. A similar study for charm needed