Hadronization systematics and top mass: preliminary studies and thoughts

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1. **Introduction**
2. **Update of fragmentation studies in top decays**
3. **Simulation of events with hadronized top quarks**
4. **Conclusions**

Collaborators: F. Mescia and K. Tywoniuk (b-fragmentation)
See talk by M.L.Mangano at the first meeting of the TOP LHCWG (July '12)

Meeting of November '13: presented several studies on b-fragmentation in top decays, based on resummed calculations and Monte Carlo generators

Non-perturbative contributions taken from LEP and SLD data on B-hadron production in e^+e^- collisions

b-fragmentation contributes to the systematic error on the top mass measurement (b-jet energy scale and b-tagging efficiency)

$J/\psi +$ lepton final states: (Kharchilava, Chierici, Dierlamm): $\Delta m_t(\mathrm{syst}) \simeq 1.47$ GeV, with $\Delta m_t(\mathrm{frag}) \simeq 0.51$ GeV using $m_{3\ell}^{\max}$ with $J\psi \to \mu^+\mu^-$ and $W \to \ell\nu$

Best-fit parameters (PYTHIA) not the same, e.g. $\epsilon_b = 0.0033$ (ALEPH), 0.0055 (SLD); $\alpha_K = 11.9$ (OPAL), 13.7 (ALEPH), 10.0 (SLD)

Would be hopeful agreeing on a tuning which can be implemented in event generators

In the following, highlights of past presentation, along with criticism and updates

G. C. and V. Drollinger, NPB (2005): weakly-decaying B-hadron data from OPAL (mesons and baryons), ALEPH (only mesons) and SLD (mesons and baryons)

HERWIG	PYTHIA
CLSMR(2) = 0.3 (0.0)	PARJ(41) = 0.85 (0.30) $[a]$
DECWT = 0.7 (1.0)	PARJ(42) = 1.03 (0.58) $[b]$
CLPOW = 2.1 (2.0)	PARJ(46) = 0.85 (1.00) $[r]$
PSPLT(2) = 0.33 (1.00)	
$\chi^2/\mathrm{dof} = 222.4/61\ (739.4/61)$	$\chi^2/\mathrm{dof} = 45.7/61\ (467.9/61)$

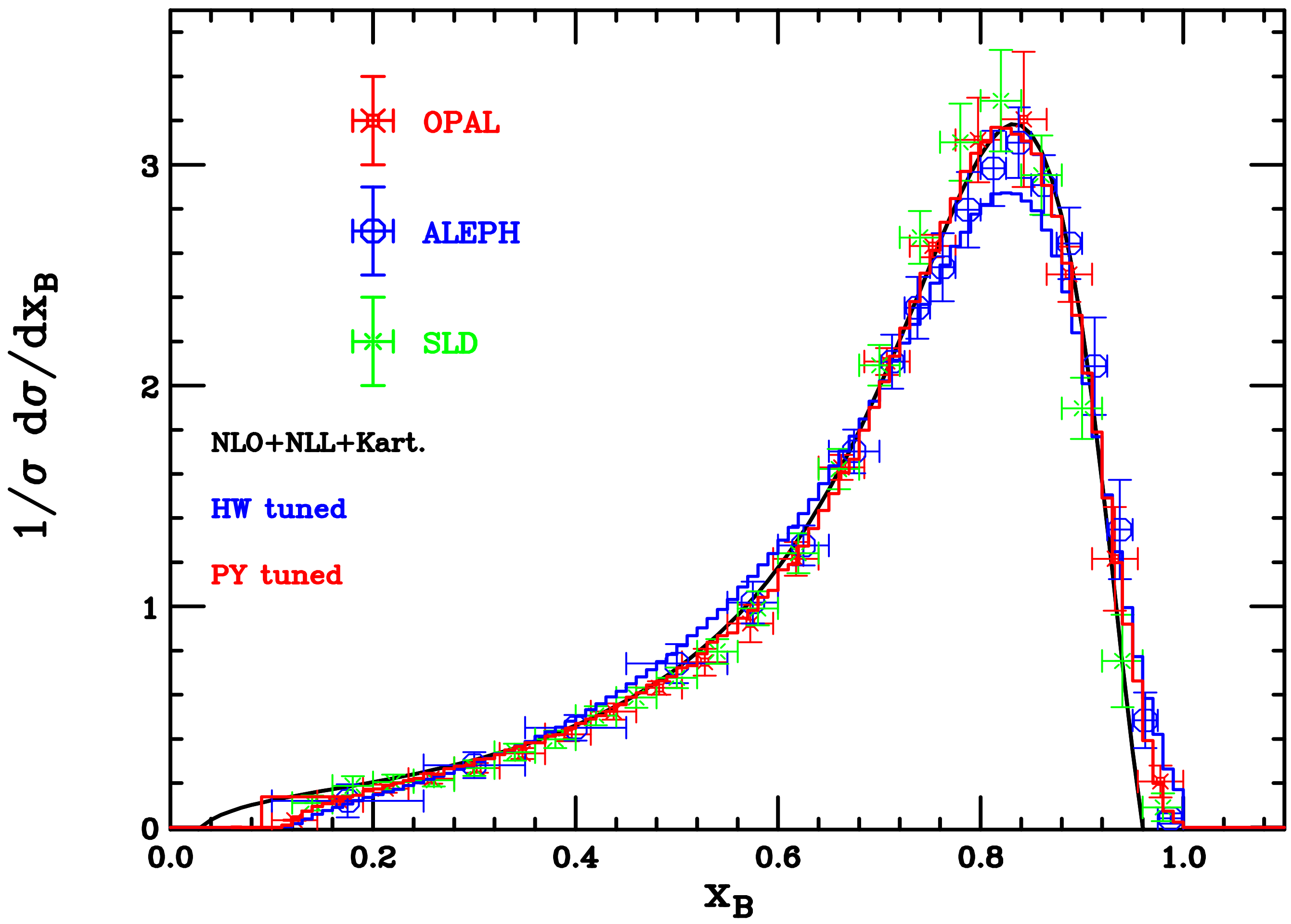
$$f_B(z) \propto \frac{1}{z^{1+brm_b^2}}(1-z)^a \exp(-bm_T^2/z)$$

HERWIG tuned parameters describe B-hadron gaussian smearing (CLSMR), baryon/meson (CLPOW) and decuplet/octet (DECWT) ratios, mass spectrum of b-like clusters (PSPLT)

Tuning mostly driven by PSPLT, i.e. b-cluster mass spectrum $\sim M^{PSPLT}$

Our PYTHIA tuning in ATLAS jet-energy measurement (EPJ C73 (2013) 2304) and as a cross-check for top analyses

Comparing tuned HERWIG and PYTHIA



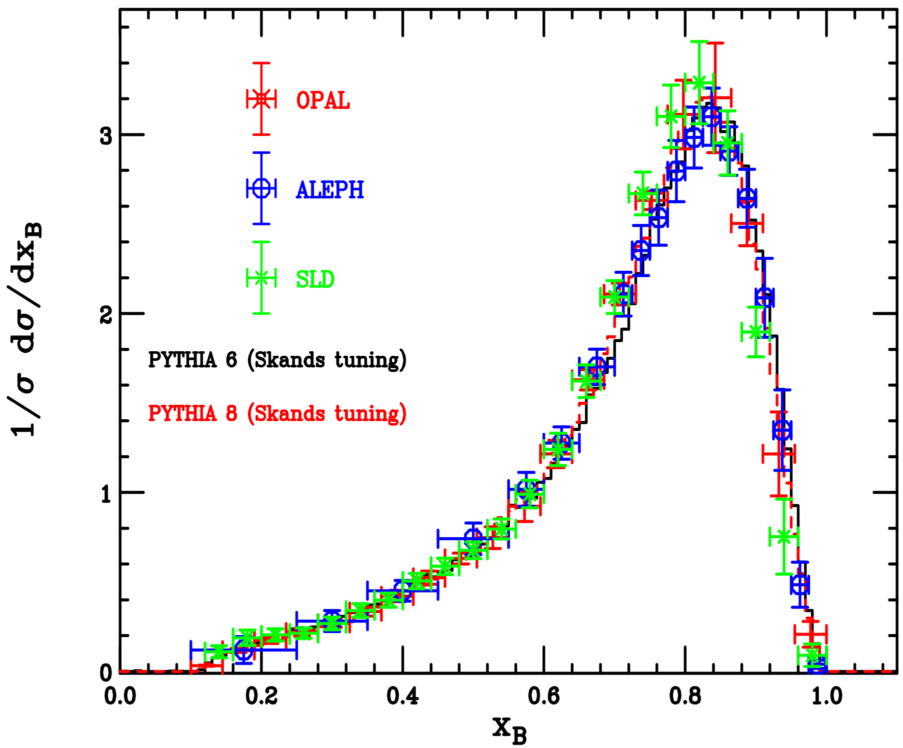
NLO+NLL calculation with Kartvelishvili model: M.Cacciari and S.Catani '01

$D_{\rm np}(x_B, \alpha) = (1+\alpha)(2+\alpha)x_B(1-x_B)^\alpha$

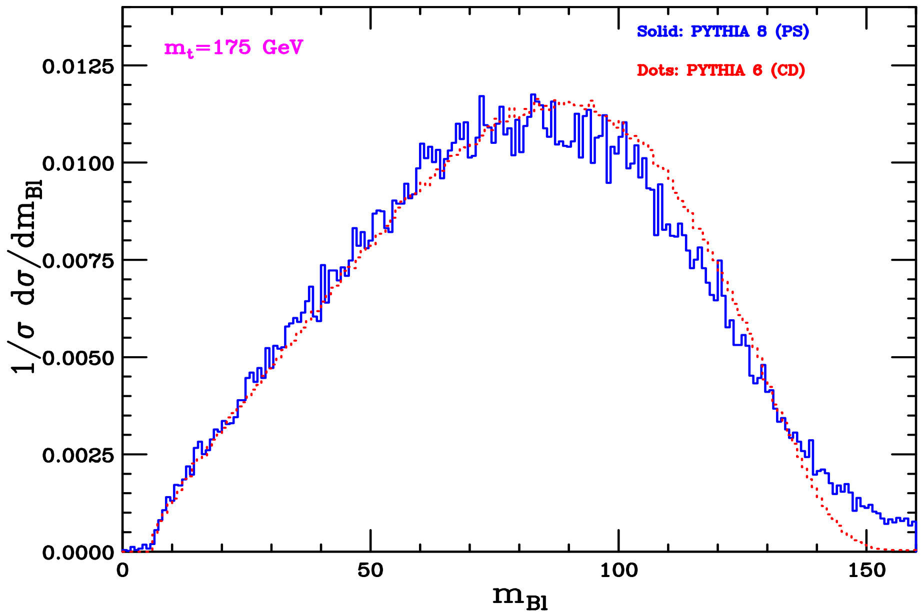
Best fit $(0.18 \le x_B \le 0.94)$: $\alpha = 17.178 \pm 0.303$, $\chi^2/\mathrm{dof} = 46.2/53$

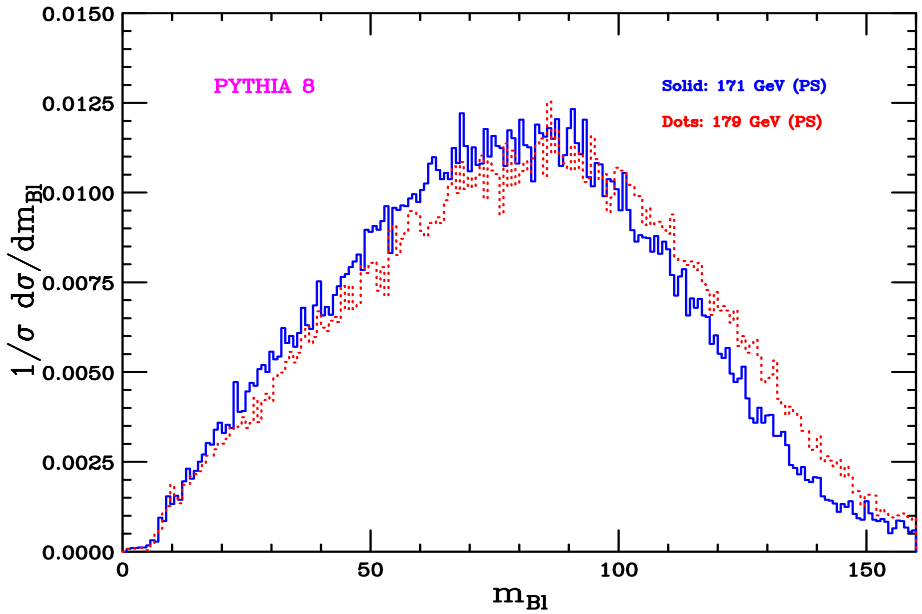
Drawbacks of CD tuning: a and b should be universal for all flavours, although a may be flavour-dependent (PYTHIA 8), r can vary up to 10% from default value - Suggested tuning (P.Skands):

PYTHIA 6 (8)	
PARJ(41) (StringZ:aLund) $=$ 1.08	$[a]$
PARJ(42) (StringZ:bLund) $=$ 0.55	$[b]$
PARJ(46) (StringZ:rFactB) $=$ 0.85	$[r]$
χ^2/dof $=$ 109.5/61 (45.91/56)	



Preliminary results with PYTHIA 8 vs. PYTHIA 6 on $m_{B\ell}$ invariant mass (K. Tywoniuk)





Mellin moments PYTHIA 8 (PS) and PYTHIA 6 (CD)

PYTHIA 8 (PS):

m_t (GeV)	$\langle m_{B\ell} \rangle$ (GeV)	$\langle m_{B\ell}^2 \rangle$ (GeV^2)	$\langle m_{B\ell}^3 \rangle$ (GeV^3)	$\langle m_{B\ell}^4 \rangle$ (GeV^4)
171	77.33	6.97×10^3	6.92×10^5	7.39×10^8
173	78.49	7.18×10^3	7.23×10^5	7.82×10^8
175	79.30	7.32×10^3	7.44×10^5	8.10×10^8
177	80.67	7.56×10^3	7.79×10^5	8.58×10^8
179	81.36	7.68×10^3	7.97×10^5	8.83×10^8

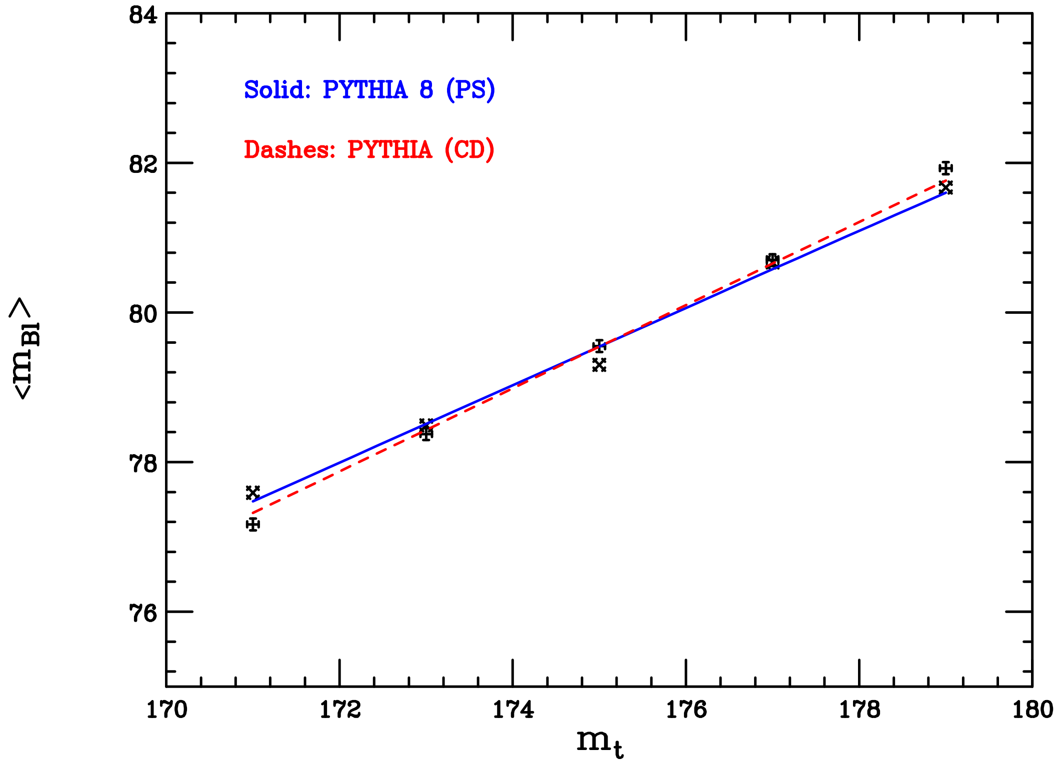
PYTHIA 6 (CD):

m_t (GeV)	$\langle m_{B\ell} \rangle$ (GeV)	$\langle m_{B\ell}^2 \rangle$ (GeV^2)	$\langle m_{B\ell}^3 \rangle$ (GeV^3)	$\langle m_{B\ell}^4 \rangle$ (GeV^4)
171	77.17	6.85×10^3	6.62×10^5	6.81×10^8
173	78.37	7.06×10^3	6.94×10^5	7.23×10^8
175	79.55	7.27×10^3	7.25×10^5	7.67×10^8
177	80.70	7.48×10^3	7.56×10^5	8.12×10^8
179	81.93	7.71×10^3	7.91×10^5	8.61×10^8

Linear fits to extract m_t from $m_{B\ell}$

PYTHIA 8: $\langle m_{B\ell}\rangle \simeq -10.93\ \mathrm{GeV} + 0.52\ m_t$; $\delta = 0.168\ \mathrm{GeV}$

PYTHIA 6: $\langle m_{B\ell}\rangle \simeq -24.11\ \mathrm{GeV} + 0.59\ m_t$; $\delta = 0.022\ \mathrm{GeV}$



Higher statistics should shed light on the comparison

Reconstructed Monte Carlo mass m_t and top mass definitions: $m_{\rm pole}$, $m_{\overline{\rm MS}}$?

Following M.Mangano's talk at start-up meeting:

Top quarks hadronize ($T^{\pm,0}$, etc.) and then decay, e.g., by means of the spectator model

From a given observable R extract the Monte Carlo mass $m_T^{\rm MC}$

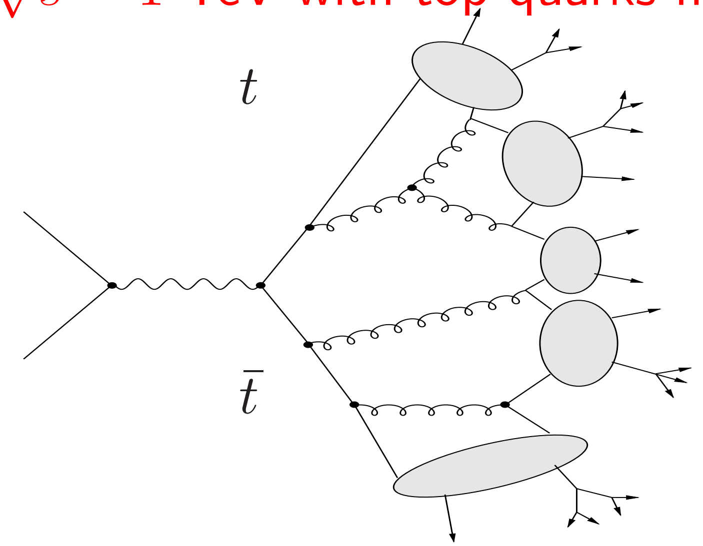
Study the same observable R with standard top samples, get $m_t^{\rm MC}$ and compare the extracted masses $m_T^{\rm MC} = m_t^{\rm MC} + \Delta m$

In the hadronized samples, the Monte Carlo mass can be related to the T-meson mass M_T and ultimately to the pole or $\overline{\rm MS}$ top-quark masses by using lattice, potential models, NRQCD, etc.

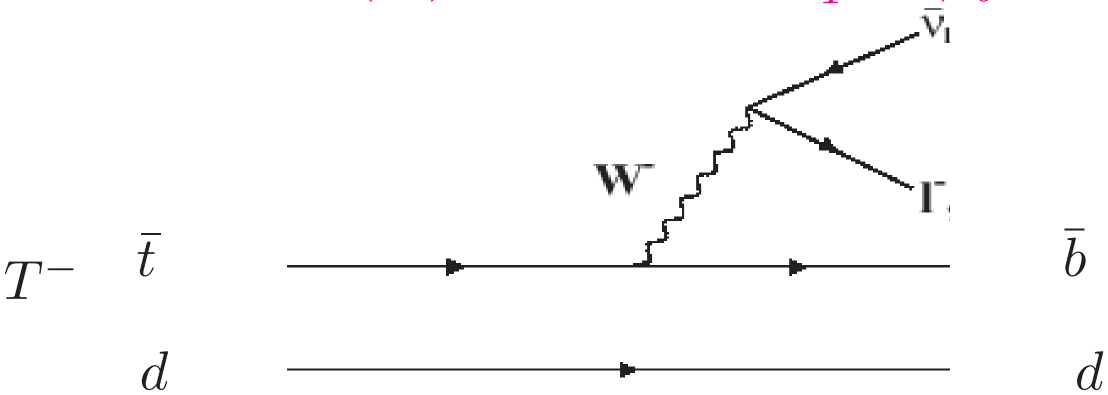
Connection between the so-obtained pole/$\overline{\rm MS}$ mass and the Monte Carlo mass in standard analyses

Investigate the dependence of the results on the specific analysis/observable and contributions to Δm (colour flow, gluon radiation, hadron decay models)

HERWIG for $e^+e^- \to t\bar{t}$ at $\sqrt{s} = 1$ TeV with top quarks hadronizing before decaying

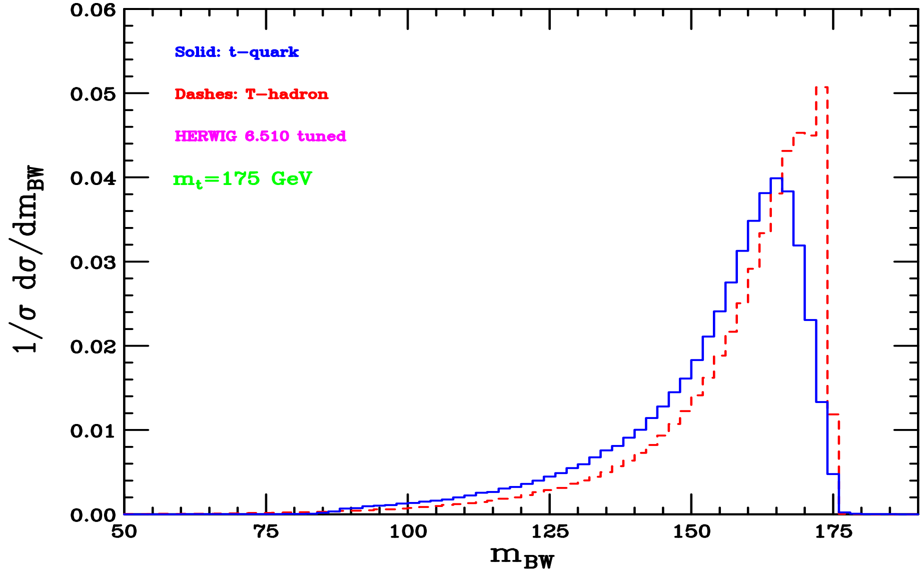


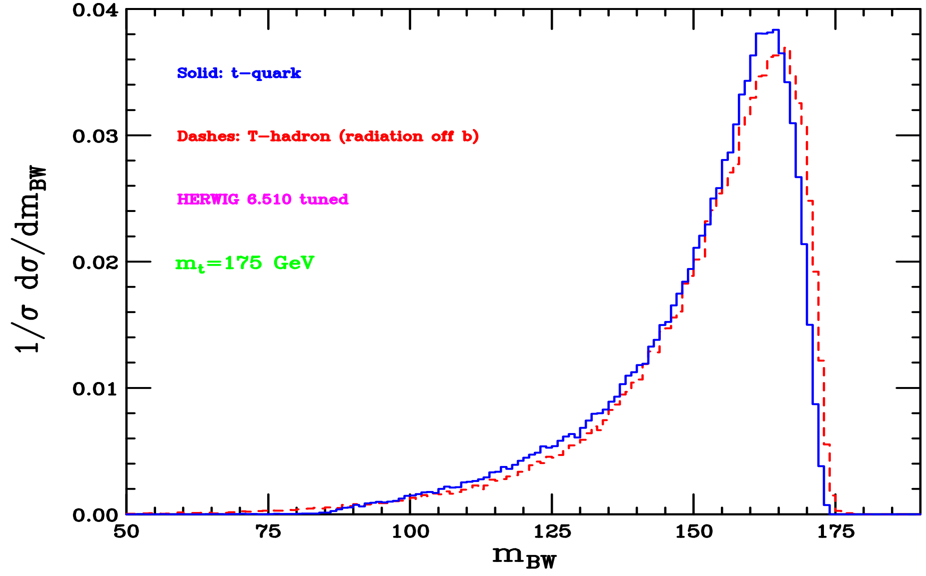
t-flavoured mesons in the dilepton channel, i.e. $T^+ = (t\bar{d})$, $T^0 = (t\bar{u})$, $T^- = (\bar{t}d)$, etc.
Spectator model decays: $T^- \to (\bar{b}d)\ell^-\bar{\nu}_\ell + X \ldots \quad p_T^2 = (p_{\bar{b}} + p_W + p_q + p_X)^2$

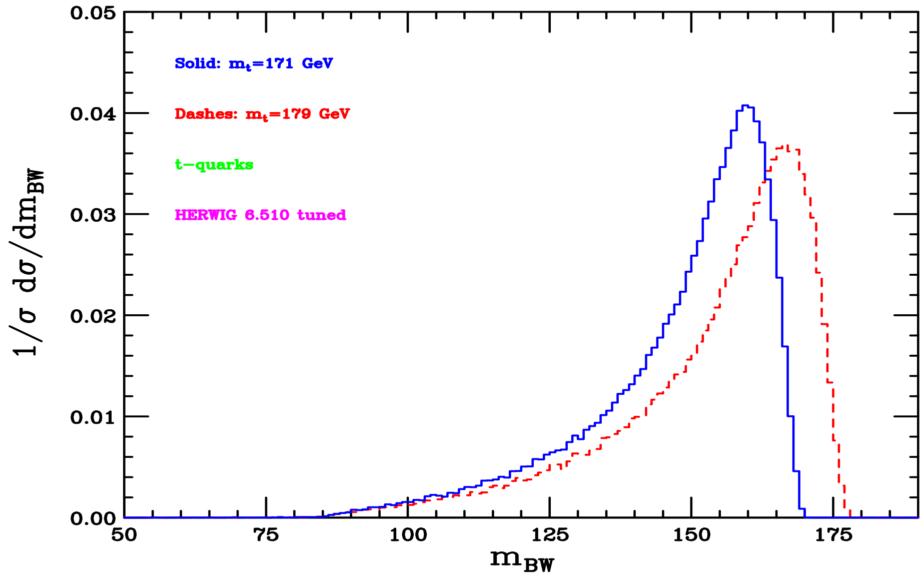


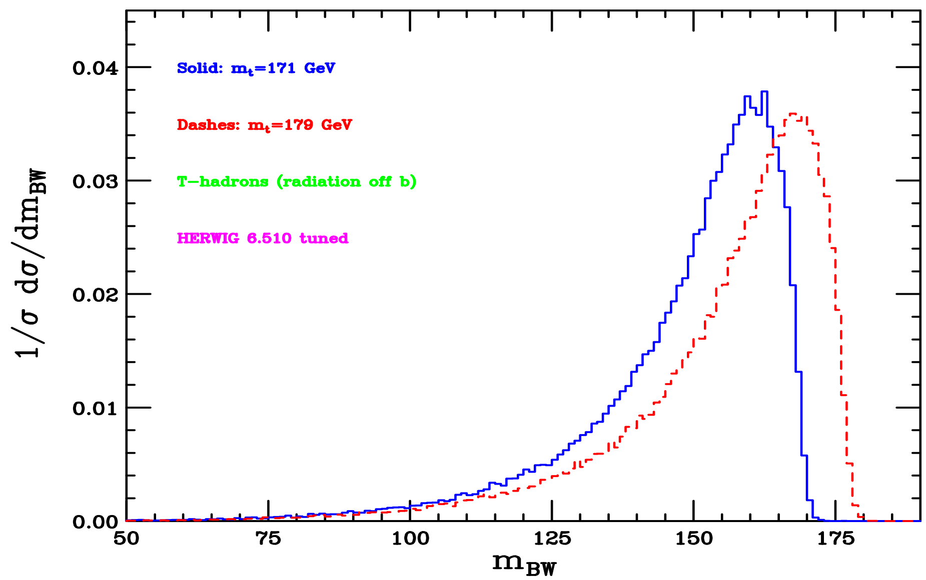
In some event fractions, proportional to $\Delta(Q_b^2, Q_0^2)$, the b quarks in T decays do not radiate gluons: the $(\bar{b}q)$ cluster yields a B meson plus a soft hadron, e.g. pions
Spectator quarks likely do not radiate

Results with hadronized top quarks for BW invariant mass for fixed $m_t^{\rm MC}$ with and possibly without gluon radiation off the b (top plots) and varying $m_t^{\rm MC}$ (bottom)









Mellin moments - m_{BW} spectrum, allowing gluon emissions off the b quarks

T-hadrons:

m_t (GeV)	$\langle m_{BW} \rangle$ (GeV)	$\langle m_{BW}^2 \rangle$ (GeV^2)	$\langle m_{BW}^3 \rangle$ (GeV^3)	$\langle m_{BW}^4 \rangle$ (GeV^4)
171	148.76	2.24×10^4	3.41×10^6	5.24×10^8
173	150.44	2.29×10^4	3.53×10^6	5.48×10^8
175	152.18	2.35×10^4	3.66×10^6	5.74×10^8
177	153.80	2.40×10^4	3.77×10^6	5.99×10^8
179	155.61	2.45×10^4	3.91×10^6	6.28×10^8

t-quarks:

m_t (GeV)	$\langle m_{BW} \rangle$ (GeV)	$\langle m_{BW}^2 \rangle$ (GeV^2)	$\langle m_{BW}^3 \rangle$ (GeV^3)	$\langle m_{BW}^4 \rangle$ (GeV^4)
171	148.08	2.21×10^4	3.35×10^6	5.11×10^8
173	149.56	2.26×10^4	3.46×10^6	5.32×10^8
175	151.00	2.30×10^4	3.56×10^6	5.54×10^8
177	152.60	2.36×10^4	3.67×10^6	5.78×10^8
179	153.97	2.40×10^3	3.78×10^6	6.00×10^8

Conclusions and outlook

Updates on b-fragmentation using PYTHIA 8 and comparison with PYTHIA 6, consistently tuned to LEP/SLD data

Preliminary studies of event simulations with hadronized top quarks

Perspectives:

Comparing PYTHIA 8 and HERWIG++ to estimate b-hadronization systematics

Extending the analysis to NLO+showers tools (POWHEG and aMC@NLO) and ultimately NNLO calculations

Tuning fragmentation parameters directly to LHC data on b-fragmentation in top decays to test factorization and quality of hadronization models

Extending analysis with hadronized top quarks, e.g. b-jets vs. B-mesons, turning spectator-quark radiation on, studying dependence on shower cutoff, to shed light on current discrepancies and possibly make a statement on the nature of the reconstructed top mass

Comparing HERWIG and PYTHIA with hadronized top quarks to test hadronization models