Bottom fragmentation in top quark decay: impact on the uncertainty on the top mass reconstruction

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1. b-quark fragmentation in top decay
2. Monte Carlo event generators (HERWIG and PYTHIA)
3. Fits of hadronization models to LEP and SLD B-hadron data
4. Top-decay spectra
5. Impact on the uncertainty on the top-mass reconstruction
6. Conclusions

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Reliable description of b-quark fragmentation in top decay $t \to bW$ is fundamental to perform accurate measurements of the top properties, e.g. m_t

Monte Carlo event generators widely used to simulate top production and decay, parton showers and $b \to B$ hadronization

Tevatron: b-fragmentation contributes to MC systematics in m_t measurement

LHC: $J/\psi+$ lepton final states

$t \to bW$ **;** $b \to B \to J/\psi\ X$ **;** $J/\psi \to \mu^+\mu^-$ **;** $W \to \ell\nu_\ell$

A. Kharchilava, PLB 476 (2000) 73 **(PYTHIA + Peterson fragmentation function)**

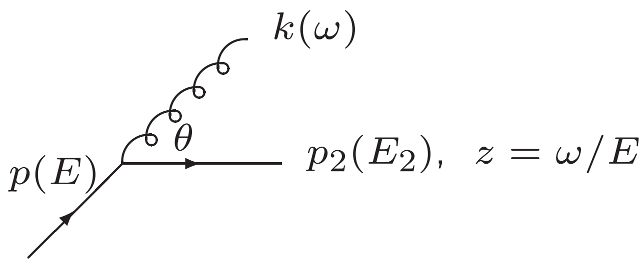
$m_{\ell J/\psi} = 0.51\ m_t - 23$ GeV

$\Delta m_{\ell J/\psi} \simeq 0.5$ GeV $\Rightarrow \Delta m_t \simeq 1$ GeV

Δm_t (b-frag)$\simeq 0.6$ GeV **obtained varying** $\epsilon = (5.0 \pm 0.5) \times 10^{-3}$ **in Peterson fragmentation function:** $D(x,\epsilon) = \frac{A}{x[1-1/x-\epsilon/(1-x)]^2}$

Reconsidering $b \to B$ transition and Δm_t estimate, fitting HERWIG/PYTHIA to LEP/SLD B-hadron data and using best fits in top decays

Monte Carlo event generators: multiple radiation soft or collinear approximation



$$dP = \frac{\alpha_S}{2\pi}\ P(z)dz\ \frac{dQ^2}{Q^2}\ \Delta_S(Q^2_{\rm max}, Q^2)$$

Q^2: **ordering variable**

$\Delta_S(Q^2_{\rm max}, Q^2)$ **Sudakov form factor: no radiation in** $[Q^2, Q^2_{\rm max}]$

$$\Delta_S(Q^2_{\rm max}, Q^2) = \exp\left[-\frac{\alpha_S}{2\pi}\int_{Q^2}^{Q^2_{\rm max}}\frac{dQ'^2}{Q'^2}\int_{z_{\rm min}}^{z_{\rm max}} dz P(z)\right]$$

HERWIG : $Q^2 = E^2(1-\cos\theta) \simeq E^2\theta^2/2$ **Soft approximation: angular ordering**

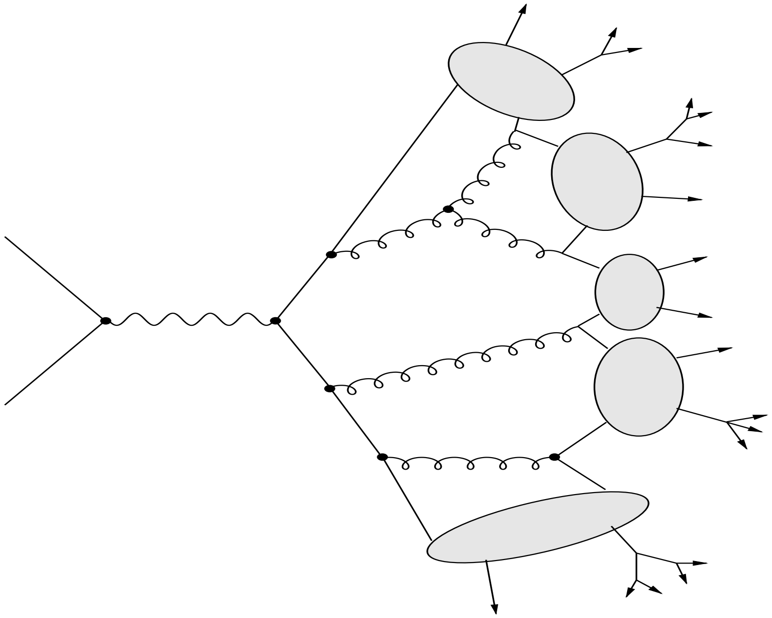
PYTHIA: $Q^2 = p^2$

It includes angular ordering by an additional veto

PYTHIA 6.3 and following: option $Q^2 = k_T^2$

Hard and large-angle radiation: matrix-element corrections (top decay)

Hadronization models



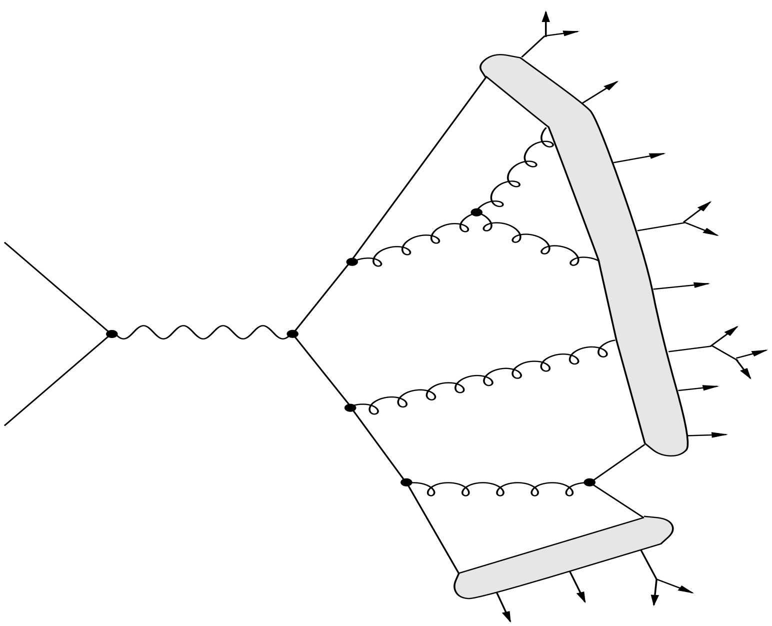
Cluster model (HERWIG)

Perturbative evolution ends at $Q^2 = Q_0^2$

Angular ordering $\Rightarrow$ colour preconfinement

Forced gluon splitting $(g \rightarrow q\bar{q})$

Colour-singlet clusters decay into the observed hadrons



String model (PYTHIA)

q **and** $\bar{q}$ **move in opposite direction**

The colour field collapses into a string, with uniform energy density

$q\bar{q}$ **pairs are produced**

The string breaks into the observed hadrons

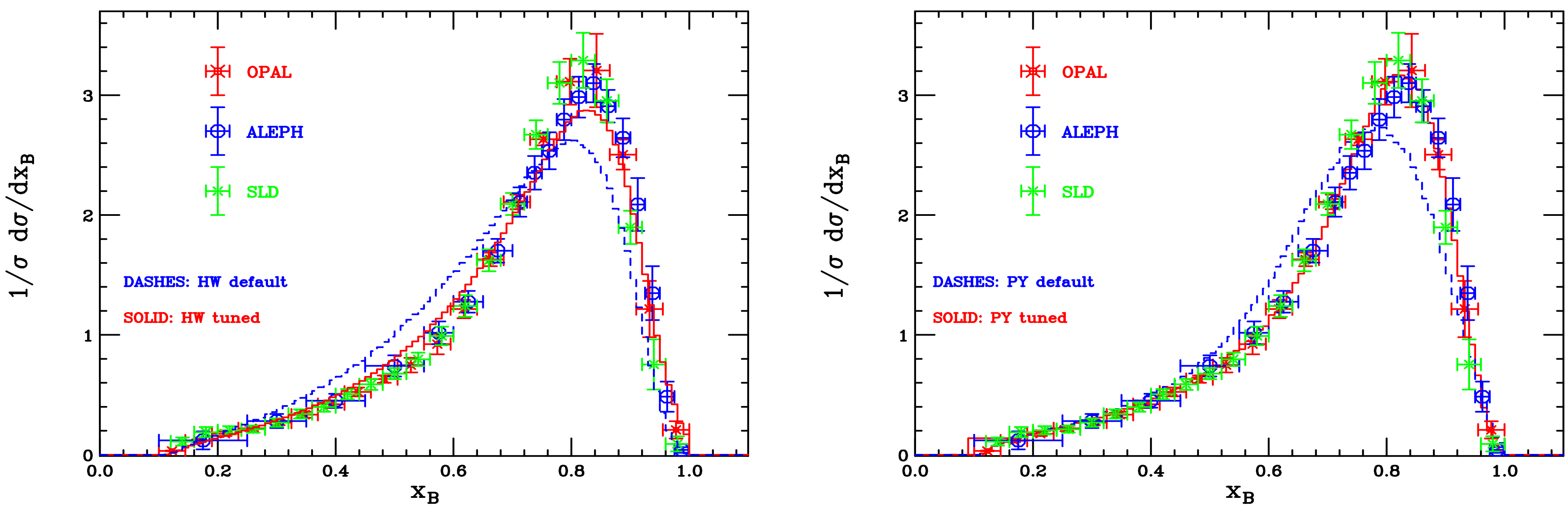
Figures from R.K. Ellis, W.J. Stirling and B.R. Webber, QCD and Collider Physics

Monte Carlo tuning: $e^+e^- \to Z^0 \to b\bar{b} \to BX_{\bar{b}}$ $\quad x_B = 2E_B/m_Z$

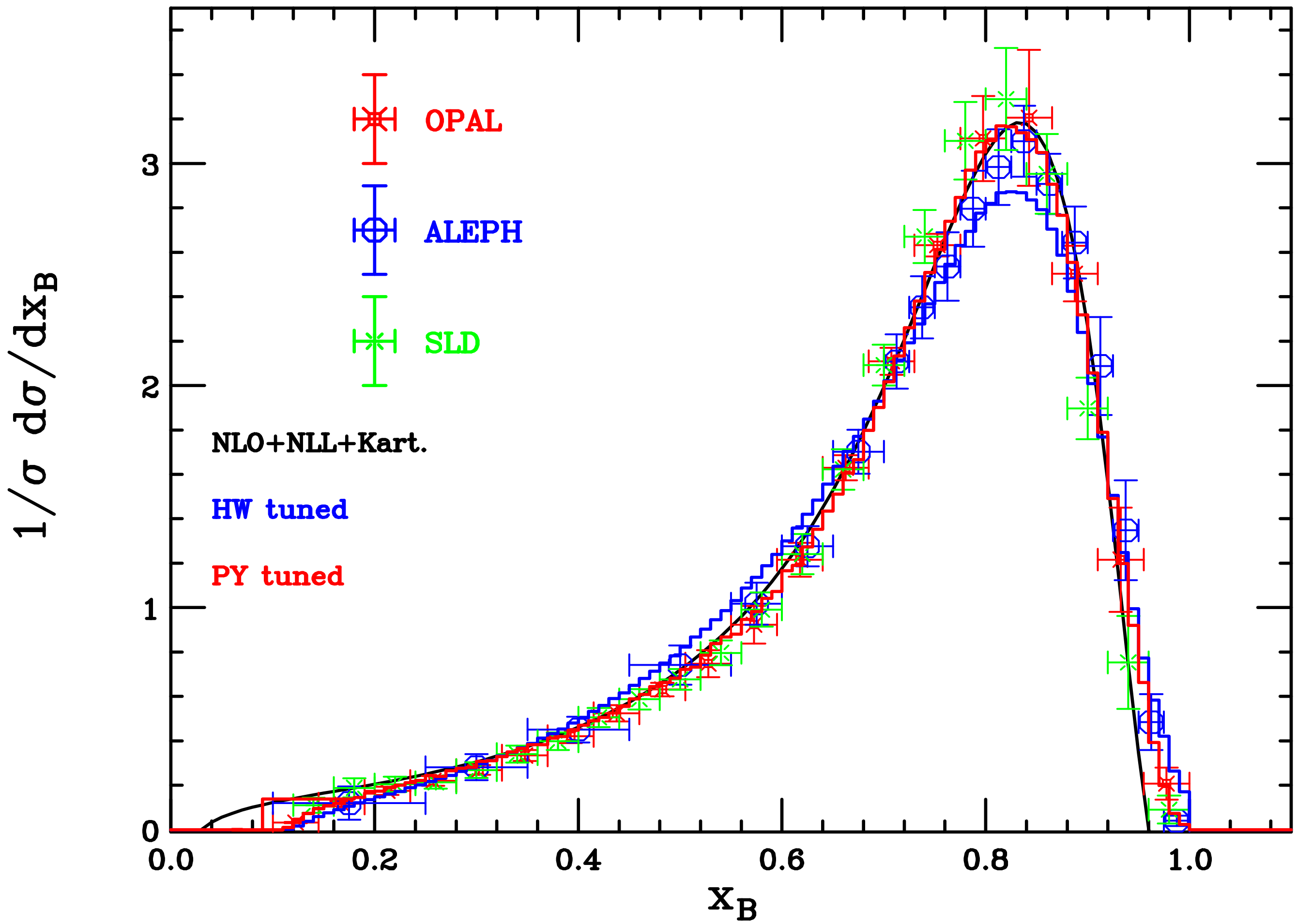
(G. C. and V. Drollinger, NPB 730 (2005) 82)

HERWIG	PYTHIA
CLSMR(1) = 0.4 (0.0)	
CLSMR(2) = 0.3 (0.0)	PARJ(41) = 0.85 (0.30)
DECWT = 0.7 (1.0)	PARJ(42) = 1.03 (0.58)
CLPOW = 2.1 (2.0)	PARJ(46) = 0.85 (1.00)
PSPLT(2) = 0.33 (1.00)	
χ^2/dof = 222.4/61 (739.4/61)	χ^2/dof = 45.7/61 (467.9/61)

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



Comparing tuned HERWIG and PYTHIA

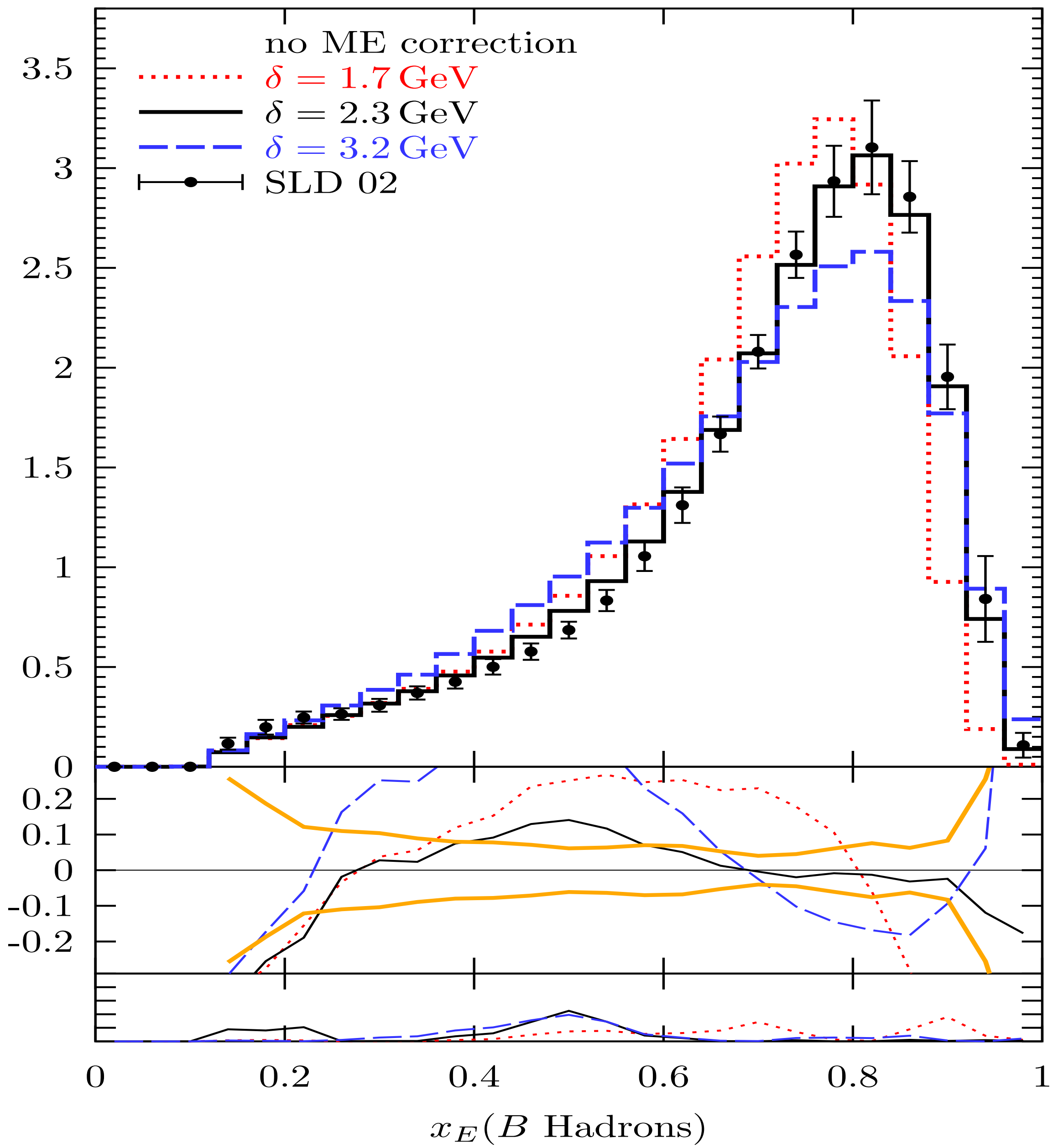


NLL calculation (Cacciari–Catani) with Kartvelishvili model:

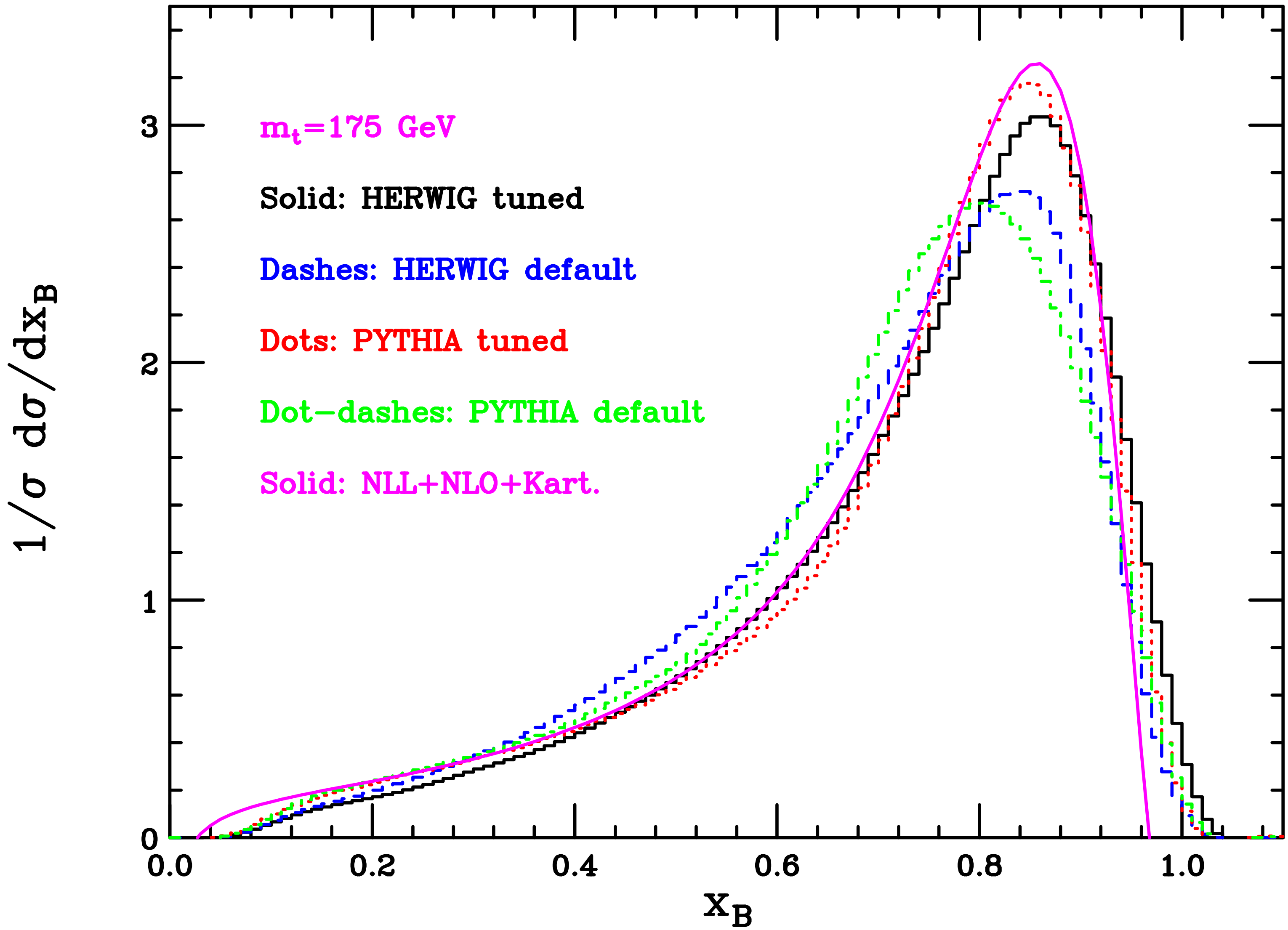
$D_{\rm np}(x_B,\gamma) = (1+\gamma)(2+\gamma)x_B(1-x_B)^\gamma$

Best fit ($0.18 \leq x_B \leq 0.94$): $\gamma = 17.178 \pm 0.303, \quad \chi^2/{\rm dof} = 46.2/53$

HERWIG ++: improved fragmentation model $(\chi^2/\mathrm{dof} \simeq \mathcal{O}(1))$



B-hadron spectrum in top decay : $x_B = \frac{1}{1-m_W^2/m_t^2}\frac{2p_B\cdot p_t}{m_t^2}$



NLL/NLO resummed calculation (M.Cacciari, G.C. and A.Mitov) along with Kartvelishvili model

Results in moment space

$$\sigma_N = \int_0^1 dz\ z^{N-1} \frac{1}{\sigma}\frac{d\sigma}{dz}(z)$$

e^+e^- **annihilation** $\sigma_N^B = \sigma_N^b D_N^{np}$

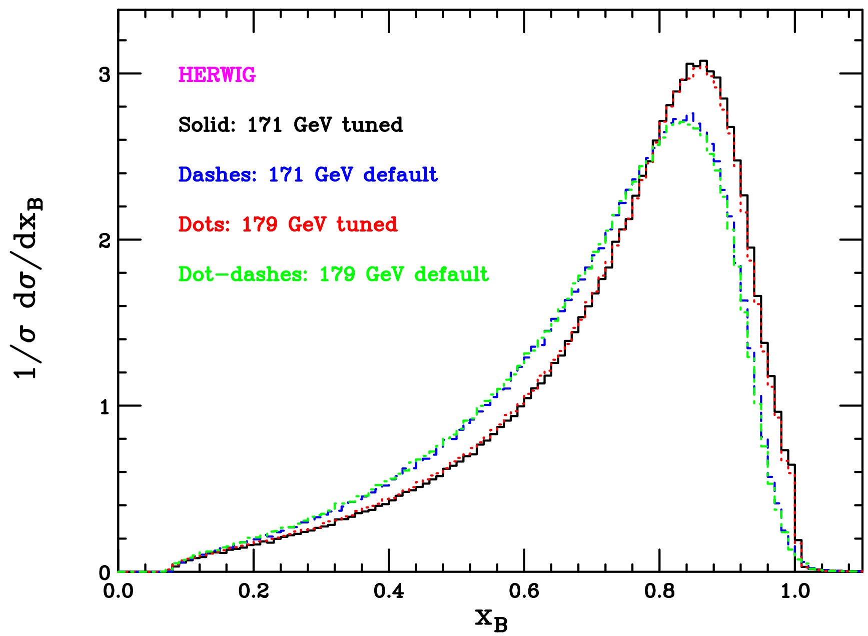
σ_N^B **measured ;** σ_N^b **calculated ;** D_N^{np} **fitted**

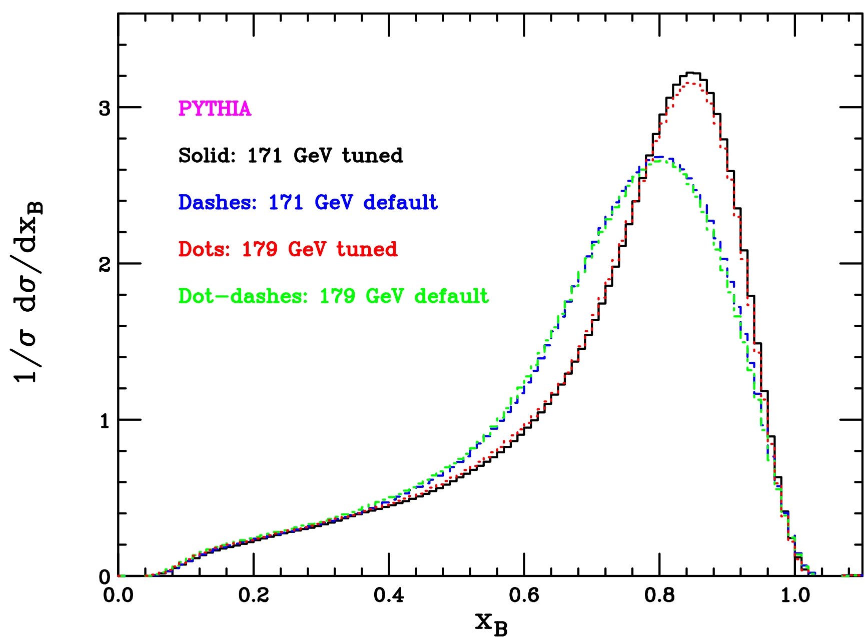
top decay: $\Gamma_N^B = \Gamma_N^b D_N^{np} = \Gamma_N^b \sigma_N^B / \sigma_N^b$

Fits to DELPHI data (ICHEP 2002 Note, DELPHI 2002-069 CONF 603)

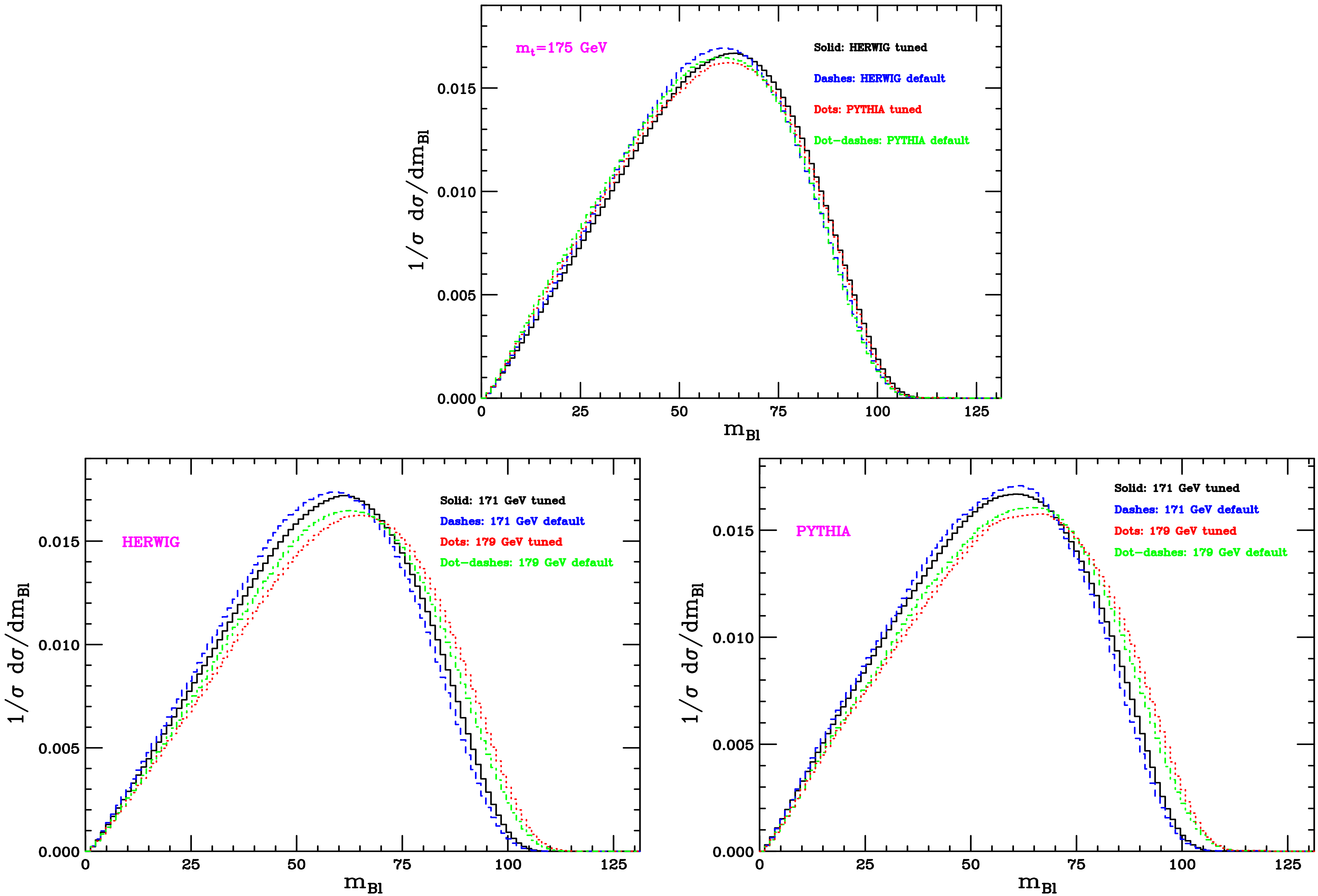
	$\langle x \rangle$	$\langle x^2 \rangle$	$\langle x^3 \rangle$	$\langle x^4 \rangle$
e^+e^- data σ_N^B	0.7153$\pm$0.0052	0.5401$\pm$0.0064	0.4236$\pm$0.0065	0.3406$\pm$0.0064
e^+e^- NLL σ_N^b	0.7801	0.6436	0.5479	0.4755
$D_N^{\rm np}$	0.9169	0.8392	0.7731	0.7163
e^+e^- HW σ_N^B	0.7113	0.5354	0.4181	0.3353
e^+e^- PY σ_N^B	0.7162	0.5412	0.4237	0.3400
t-dec. NLL Γ_N^b	0.7883	0.6615	0.5735	0.5071
t-dec. NLL $\Gamma_N^B = \Gamma_N^b D_N^{\rm np}$	0.7228	0.5551	0.4434	0.3632
t-dec. HW Γ_N^B	0.7325	0.5703	0.4606	0.3814
t-dec. PY Γ_N^B	0.7225	0.5588	0.4486	0.3688

x_B exhibits very mild dependence on top mass in both HERWIG and PYTHIA:

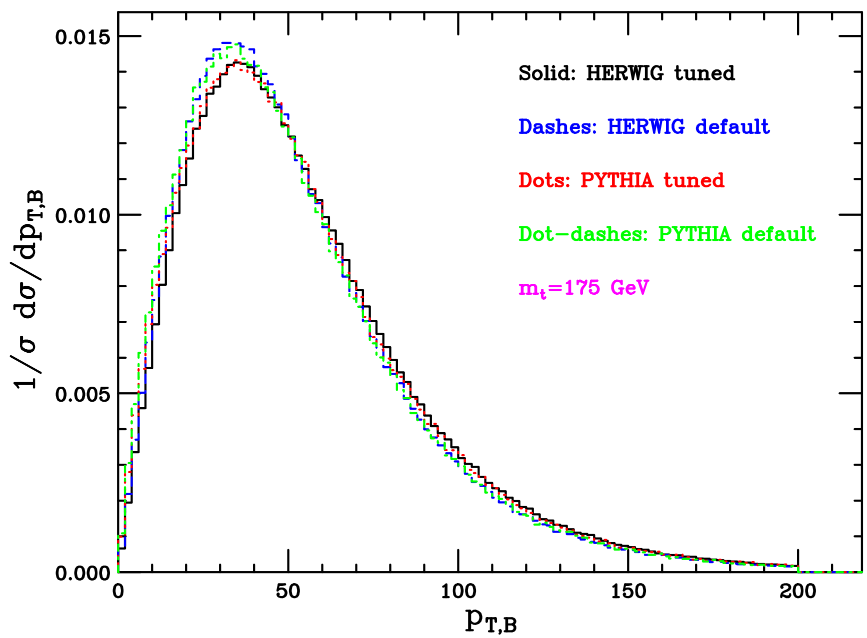


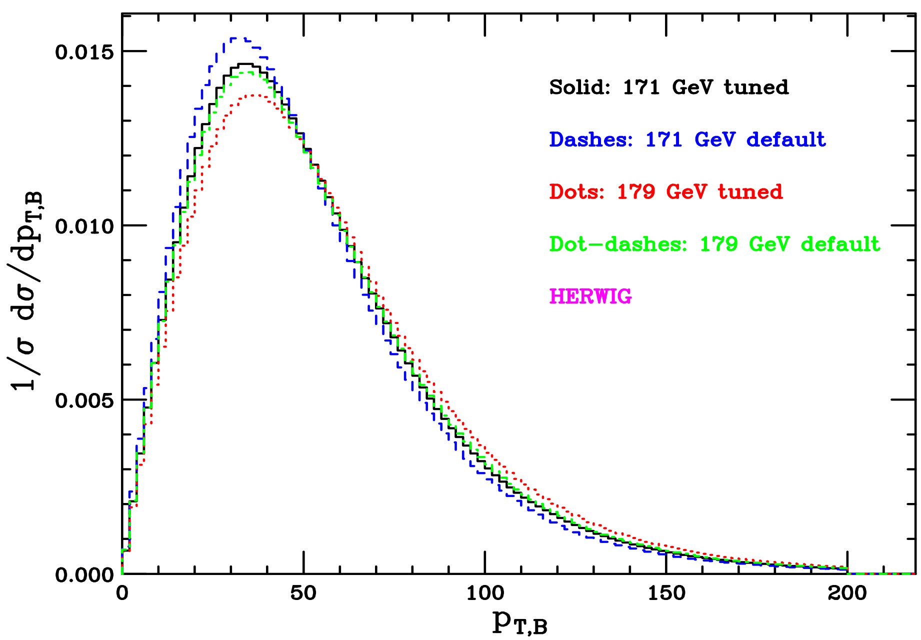


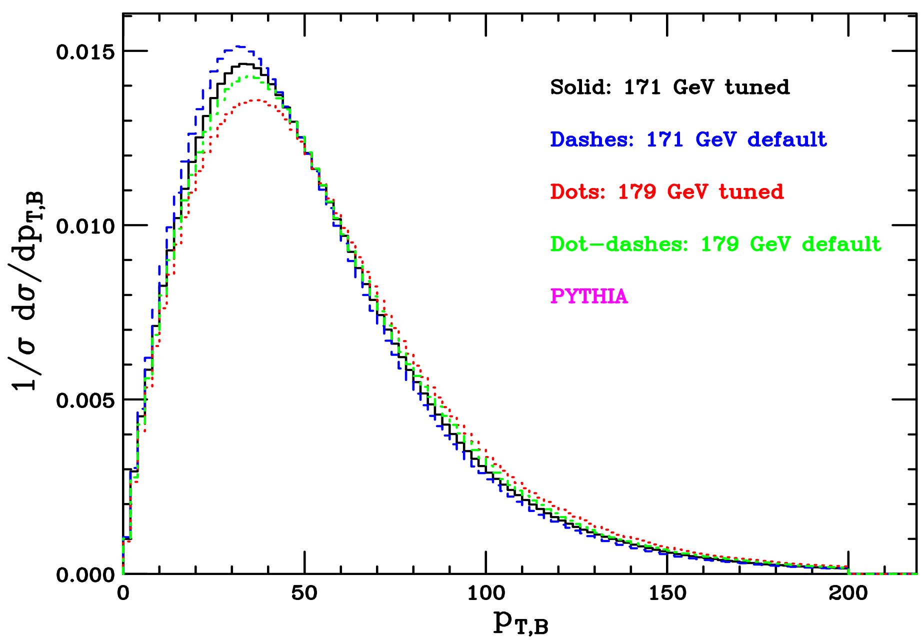
Investigating other observables: invariant mass $m_{B\ell}$ (see G.C., M. Mangano and M. Seymour)



B-hadron transverse momentum spectrum at LHC







Summary of the results

B-lepton invariant mass:

m_t	$\langle m_{B\ell}\rangle_{H,t}$	$\langle m_{B\ell}\rangle_{H,d}$	$\langle m_{B\ell}\rangle_{P,t}$	$\langle m_{B\ell}\rangle_{P,d}$	$\Delta\langle m_{B\ell}\rangle_{H,H}$	$\Delta\langle m_{B\ell}\rangle_{P,P}$	$\Delta\langle m_{B\ell}\rangle_{H,P}$
171	55.23	53.91	54.38	53.52	1.32	0.86	0.85
173	56.11	54.77	55.23	54.29	1.34	0.94	0.88
175	56.94	55.63	56.08	55.15	1.31	0.93	0.86
177	57.85	56.45	56.89	55.95	1.40	0.94	0.96
179	58.68	57.30	57.76	56.83	1.38	0.93	0.92

$\Delta\langle m_{B\ell}\rangle_{H,H} \simeq 1.3$ **GeV ;** $\Delta\langle m_{B\ell}\rangle_{P,P} \simeq 0.9$ **GeV ;** $\Delta\langle m_{B\ell}\rangle_{H,P} \simeq 0.9$ **GeV**

B-hadron transverse momentum:

m_t	$\langle p_{T,B}\rangle_{H,t}$	$\langle p_{T,B}\rangle_{H,d}$	$\langle p_{T,B}\rangle_{P,t}$	$\langle p_{T,B}\rangle_{P,d}$	$\Delta\langle p_{T,B}\rangle_{H,H}$	$\Delta\langle p_{T,B}\rangle_{P,P}$	$\Delta\langle p_{T,B}\rangle_{H,P}$
171	53.01	50.66	52.20	50.59	2.35	1.61	0.81
173	53.79	51.40	52.96	51.33	2.39	1.63	0.83
175	54.46	52.19	53.65	52.05	2.27	1.60	0.81
177	55.24	52.84	54.38	52.67	2.40	1.71	0.86
179	55.94	53.58	55.15	53.39	2.36	1.76	0.79

$\Delta\langle p_{T,B}\rangle_{H,H} \simeq 2.3$ **GeV ;** $\Delta\langle p_{T,B}\rangle_{P,P} \simeq 1.7$ **GeV ;** $\Delta\langle p_{T,B}\rangle_{H,P} \simeq 0.8$ **GeV**

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

Tuned HERWIG: $\langle m_{B\ell}\rangle \simeq -18.41\ \mathrm{GeV} + 0.42\ m_t$; $\epsilon = 0.013$ GeV

Default HERWIG: $\langle m_{B\ell}\rangle \simeq -18.64\ \mathrm{GeV} + 0.43\ m_t$; $\epsilon = 0.021$ GeV

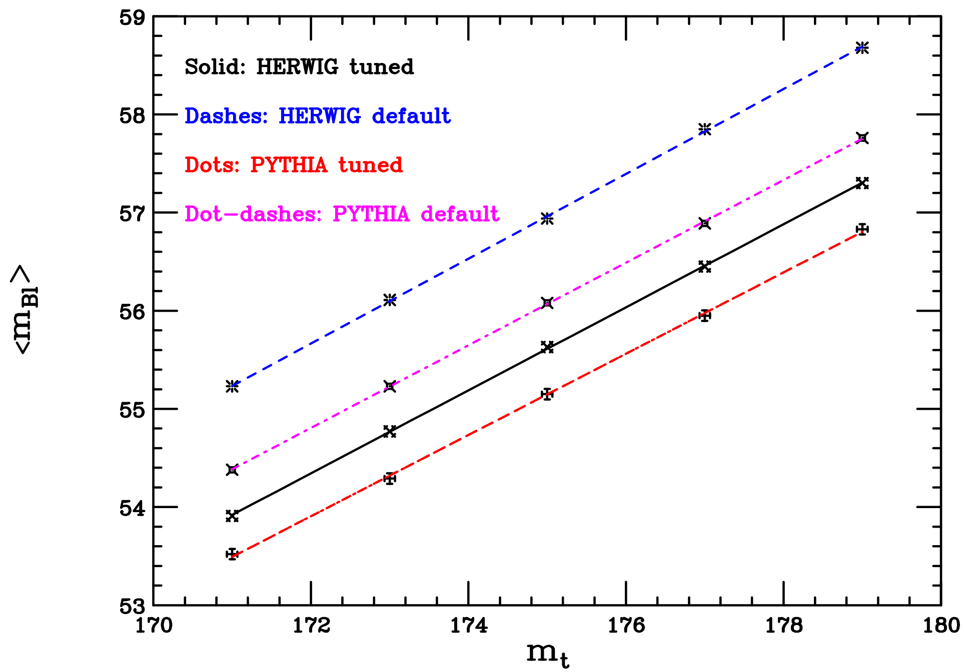
Tuned PYTHIA: $\langle m_{B\ell}\rangle \simeq -17.30\ \mathrm{GeV} + 0.41\ m_t$; $\epsilon = 0.032$ GeV

Default PYTHIA: $\langle m_{B\ell}\rangle \simeq -17.61\ \mathrm{GeV} + 0.42\ m_t$; $\epsilon = 0.021$ GeV

$\Delta\langle m_{B\ell}\rangle_{H,H} \simeq 1.3$ **GeV** $\Rightarrow \Delta m_{t,HH} \simeq 3.1$ **GeV**

$\Delta\langle m_{B\ell}\rangle_{P,P} \simeq 0.9$ **GeV** $\Rightarrow \Delta m_{t,PP} \simeq 2.2$ **GeV**

$\Delta\langle m_{B\ell}\rangle_{H,P} \simeq 0.9$ **GeV** $\Rightarrow \Delta m_{t,HP} \simeq 2.1$ **GeV**



Linear fits to extract m_t from $p_{T,B}$

Tuned HERWIG: $\langle p_{T,B}\rangle \simeq -9.47\ \mathrm{GeV} + 0.36\ m_t$; $\epsilon = 0.037\ \mathrm{GeV}$

Default HERWIG: $\langle p_{T,B}\rangle \simeq -11.57\ \mathrm{GeV} + 0.36\ m_t$; $\epsilon = 0.030\ \mathrm{GeV}$

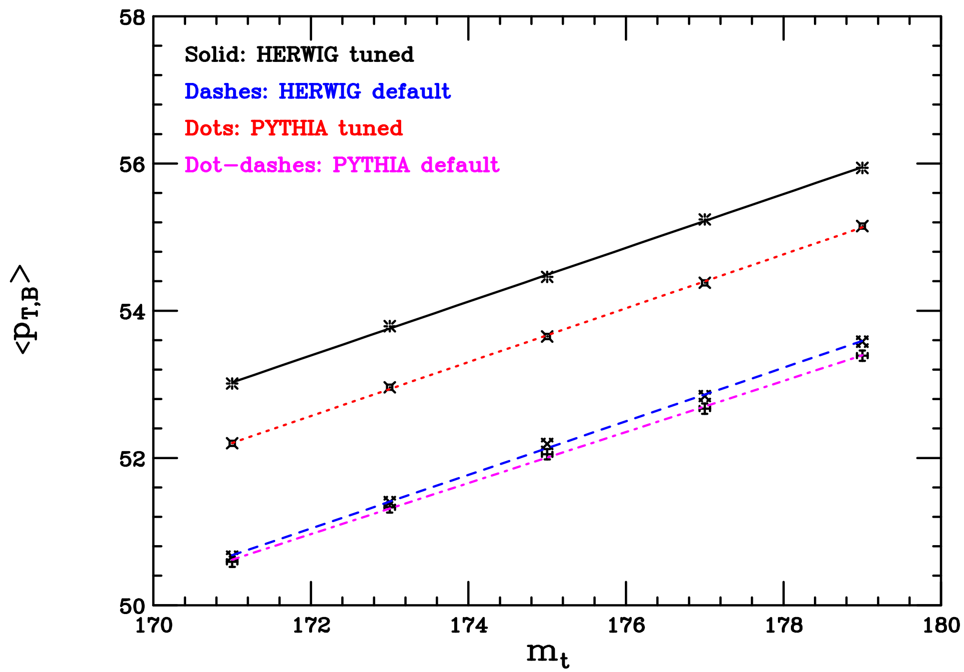
Tuned PYTHIA: $\langle p_{T,B}\rangle \simeq -10.38\ \mathrm{GeV} + 0.36\ m_t$; $\epsilon = 0.036\ \mathrm{GeV}$

Default PYTHIA: $\langle p_{T,B}\rangle \simeq -8.72\ \mathrm{GeV} + 0.35\ m_t$; $\epsilon = 0.023\ \mathrm{GeV}$

$\Delta\langle p_{T,B}\rangle_{H,H} \simeq 2.3$ **GeV** $\Rightarrow \Delta m_{t,HH} \simeq 6.4$ **GeV**

$\Delta\langle p_{T,B}\rangle_{P,P} \simeq 1.7$ **GeV** $\Rightarrow \Delta m_{t,PP} \simeq 4.3$ **GeV**

$\Delta\langle p_{T,B}\rangle_{H,P} \simeq 0.8$ **GeV** $\Rightarrow \Delta m_{t,HP} \simeq 2.2$ **GeV**



Conclusions and outlook

Bottom fragmentation in top decay as a source of Monte Carlo systematics on top-mass measurement, especially for $J/\psi\ell$ final states

Fitting HERWIG and PYTHIA to b-fragmentation LEP/SLD data

Studies of energy, transverse momentum and $B\ell$ invariant-mass distributions

Extracting m_t from linear fits of $m_{B\ell}$ and $p_{T,B}$

Estimate of b-fragmentation impact on Δm_t

In progress:

Studies of other observables, such as transverse momentum of charged hadrons and leptons from B decays in top events

Investigating higher moments of top-decay distributions

Using C++ versions of HERWIG and PYTHIA and determination of Δm_t due to b-fragmentation

Applying advanced tools for generator tuning (Professor) and estimate of statistical error on Monte Carlo predictions