Comparing tuned event generators and resummed calculations for bottom-quark fragmentation

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G.C. and V. Drollinger, NPB 730 (2005) 82
G.C., NPB 705 (2005) 363; M. Cacciari, G.C. and A.D. Mitov, JHEP 0212 (2002) 015;
U. Aglietti, G.C. and G. Ferrera, hep-ph/0610035

Reliable description of b-quark fragmentation at LEP and SLD is fundamental to perform trustworthy measurements at the LHC

Monte Carlo event generators (HERWIG/PYTHIA) and resummed calculations to describe b-quark production, provided with non-perturbative hadronization models

Top quark physics:

b-fragmentation contributes to Monte Carlo systematics in m_t measurement

$J/\psi +$ lepton final states (10^3/year of high luminosity)

A. Kharchilava, PLB 476 (2000) 73 **(PYTHIA)**

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

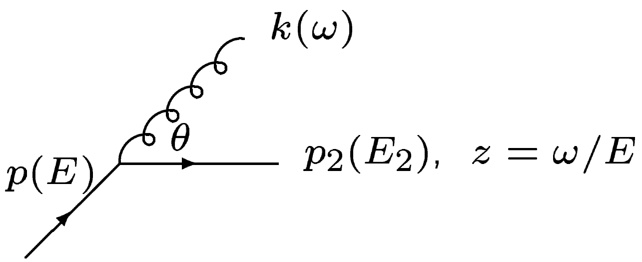
$m_{\ell J/\psi} = 0.51\ m_t - 23$ GeV

$\Delta m_{\ell J/\psi} \simeq 0.5$ GeV $\Rightarrow \Delta m_t \simeq 1$ GeV $\qquad \Delta m_t(\mathrm{frag}) \simeq 0.6$ GeV

$H \to b\bar{b}$ relevant at the LHC for $m_H \leq 135$ GeV for production in association with a vector boson or $t\bar{t}$ pairs

Monte Carlo event generators: parton shower algorithms

Multiple radiation in the soft or collinear approximation



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

Q^2: ordering variable

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

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

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

PYTHIA (up to 6.2 version): $Q^2 = p^2$

It includes angular ordering only by an additional veto

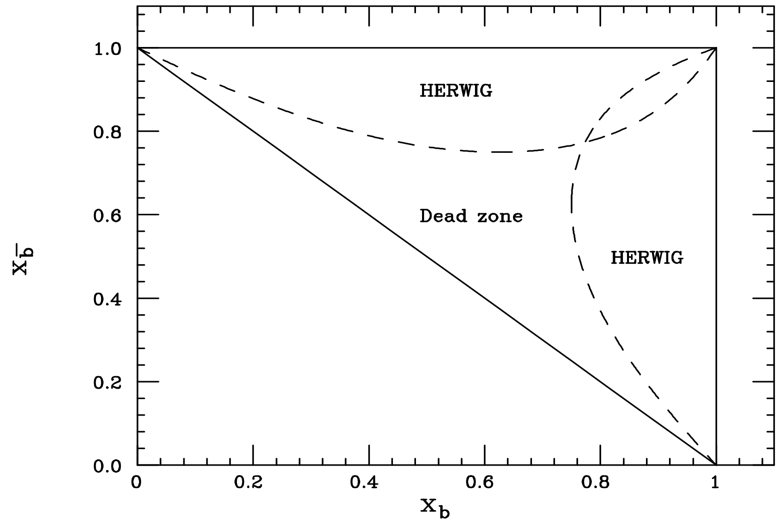
PYTHIA 6.3: $Q^2 = k_T^2$

Parton showers are equivalent to LL resummation including some NLLs

S. Catani, G. Marchesini and B.R. Webber, NPB 349 (1991) 635

Matrix-element corrections to simulate hard and large-angle emission

HERWIG: complementary phase spaces



$$\frac{1}{\sigma_0}\frac{d^2\sigma}{dx_b dx_{\bar{b}}} = \frac{C_F \alpha_S}{2\pi}\frac{x_b^2 + x_{\bar{b}}^2}{(1-x_b)(1-x_{\bar{b}})}$$

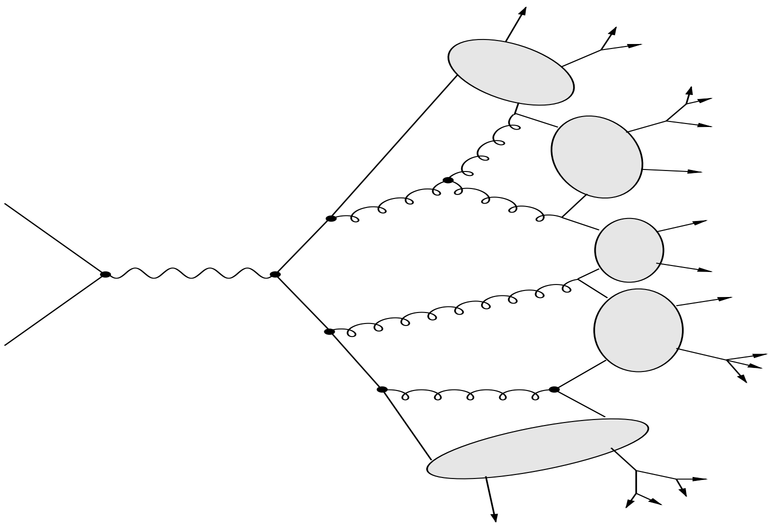
Exact matrix-element result in the dead zone and in the already-populated region any time an emission has the highest transverse momentum

Only one emission in the dead zone

PYTHIA: no dead zone, exact amplitude corrects the first emission

Implemented for $e^+e^- \to q\bar{q}$, top and Higgs decays, not for top production

Hadronization models



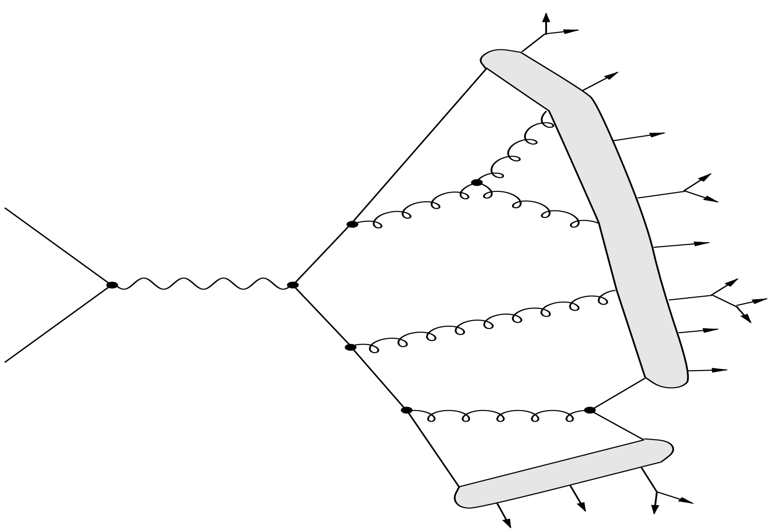
HERWIG: cluster model

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

Angular ordering $\Rightarrow$ colour preconfinement

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

Colour-singlet clusters decay into the observed hadrons



PYTHIA: string model

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 Ellis, Stirling and Webber, 'QCD and Collider Physics'

NLO calculation for the b-quark spectrum in $e^+e^- \to Z \to b\bar{b}(g)$:

$$x = \frac{2p_b \cdot p_Z}{m_Z^2} = \frac{2E_b}{m_Z}$$

$$\frac{1}{\sigma}\frac{d\sigma_b}{dx} = \delta(1-x) + \frac{\alpha_S C_F}{\pi}\left\{\frac{1}{2}\left[\frac{1+x^2}{1-x}\right]_+ \ln\frac{m_Z^2}{m_b^2} - \left[\frac{\ln(1-x)}{1-x}\right]_+ - \frac{7}{4}\frac{1}{(1-x)_+} + A(x)\right\}$$

NLO spectrum exhibits large contributions which need to be resummed:

$$\alpha_S \ln\frac{m_Z^2}{m_b^2} \quad ; \quad \frac{\alpha_S}{(1-x)_+} \quad ; \quad \alpha_S\left[\frac{\ln(1-x)}{1-x}\right]_+$$

Mass logarithms: LL $\alpha_S^n \ln^n(m_Z^2/m_b^2)$; NLL $\alpha_S^n \ln^{n-1}(m_Z^2/m_b^2)$ ...

NLL resummation using perturbative fragmentation approach and DGLAP evolution (B. Mele and P. Nason, NPB361 (1991) 626)

Large-x logarithms (soft/collinear emission) $\Rightarrow \sim \alpha_S^k \ln^m N$ in Mellin space
LL: $\alpha_S^n \ln^{n+1} N$; NLL: $\alpha_S^n \ln^n N$ NNLL: $\alpha_S^n \ln^{n-1} N$

NLL large-x resummation in M. Cacciari and S. Catani, NPB617 (2001);
NNLL in U. Aglietti, G.C. and G. Ferrera, hep-ph/0610035

Hadronization corrections

NLL calculation: Kartvelishvili model

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

NNLL computation: analytic effective coupling constant

Standard resummation **(D.Amati et al., NPB 173 (1980) 429)**:

$$\alpha_S \to \frac{i}{2\pi}\int_0^{k_T^2} ds\ {\rm Disc}_s\,\frac{\alpha_S(-s)}{s} \simeq \alpha_S(k_T^2)\quad ;\quad \left(\ln\frac{|s|}{\Lambda^2} \gg \pi\right)$$

Our model:

$$\tilde\alpha_S(k_T^2) = \frac{i}{2\pi}\int_0^{k_T^2} ds\ {\rm Disc}\frac{\alpha'_S(-s)}{s}\quad ;\quad \alpha'_S(q^2) = \frac{1}{2\pi i}\int_0^{\infty}\frac{ds}{q+k^2}{\rm Disc}[\alpha_S(-s)]$$

$\tilde\alpha_S(k_T^2)$ **does not exhibit the Landau pole and** $\to \alpha_S(k_T^2)$ **for** $k_T^2 \gg \Lambda^2$

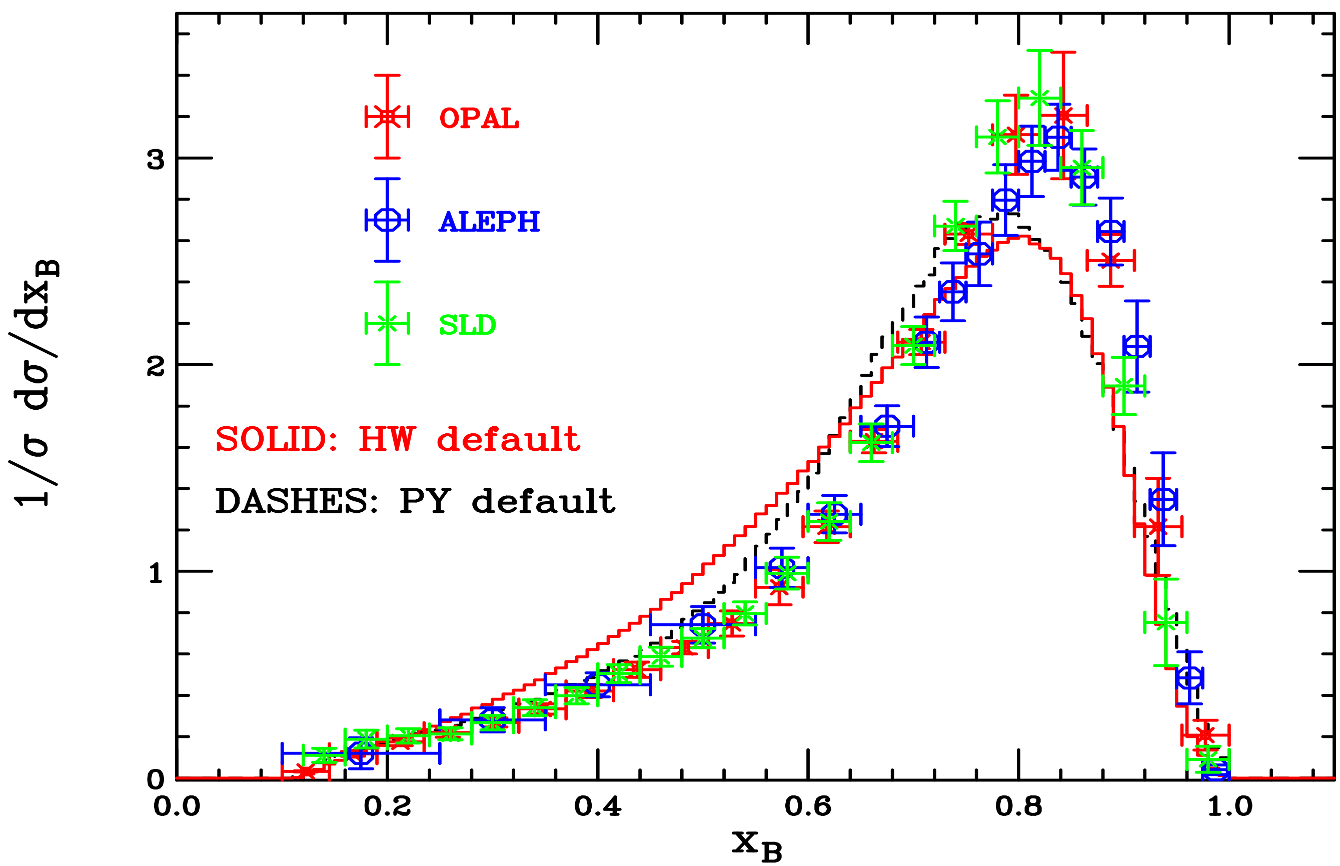
$$\mathrm{LO}:\ \tilde\alpha_S(k_T^2) = \frac{1}{2\pi i\beta_0}\left[\ln\left(\ln\frac{k_T^2}{\Lambda^2}+i\pi\right) - \ln\left(\ln\frac{k_T^2}{\Lambda^2}-i\pi\right)\right] = \frac{1}{\beta_0}\left\{\frac{1}{2}-\frac{1}{\pi}\arctan\left[\frac{\ln(k_T^2/\Lambda^2)}{\pi}\right]\right\}$$

$$k_T^2 \gg \Lambda^2:\quad \tilde\alpha_S(k_T^2) = \alpha_S(k_T^2) - \frac{(\pi\beta_0)^2}{3}\alpha_S^3(k_T^2) + \mathcal{O}(\alpha_S^4)$$

Comparison with e^+e^- data

B-hadrons from SLD, OPAL (mesons and baryons) and ALEPH (only mesons)

Default HERWIG: $\chi^2/\mathrm{dof} = 739.4/61$; default PYTHIA: $\chi^2/\mathrm{dof} = 467.9/61$



Fits of hadronization models to $e^+e^- \to b\bar{b}$ data

HERWIG 6.506	PYTHIA 6.202
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	χ^2/dof $=$ 45.7/61

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

$$\frac{d\sigma_{\mathrm{had}}}{dx_B}(e^+e^- \to B) = \frac{d\sigma_{\mathrm{part}}}{dx_b}(e^+e^- \to b\bar{b}) \otimes D_{np}(b \to B)$$

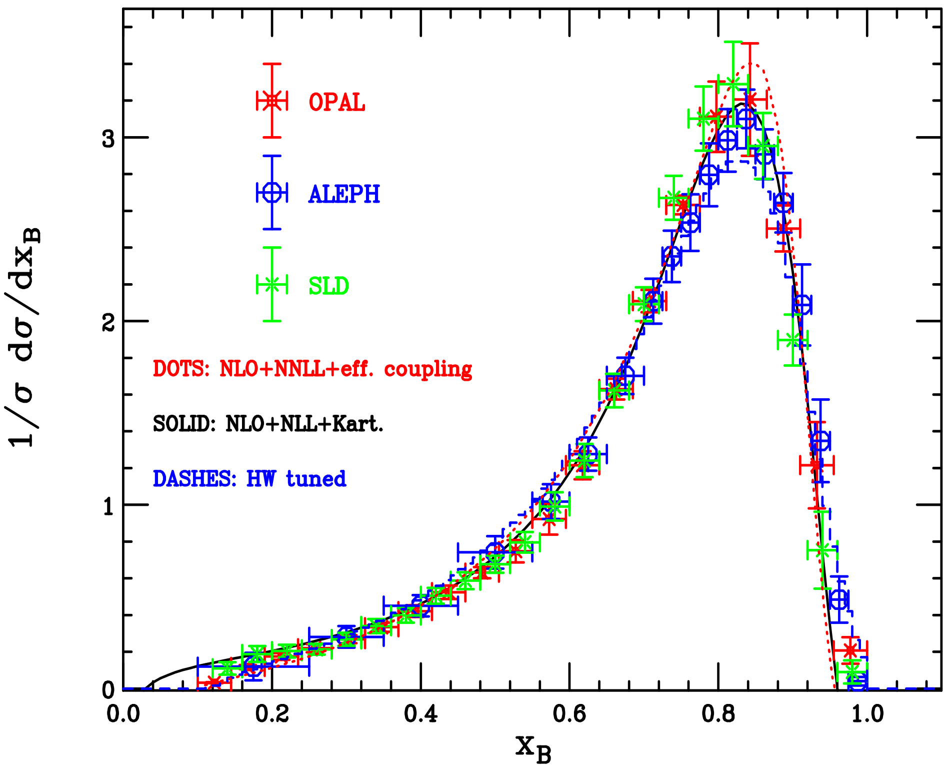
Kartvelishvili model ($0.18 \leq x_B \leq 0.94$): $\gamma = 17.178 \pm 0.303$, $\chi^2/\mathrm{dof} = 46.2/53$

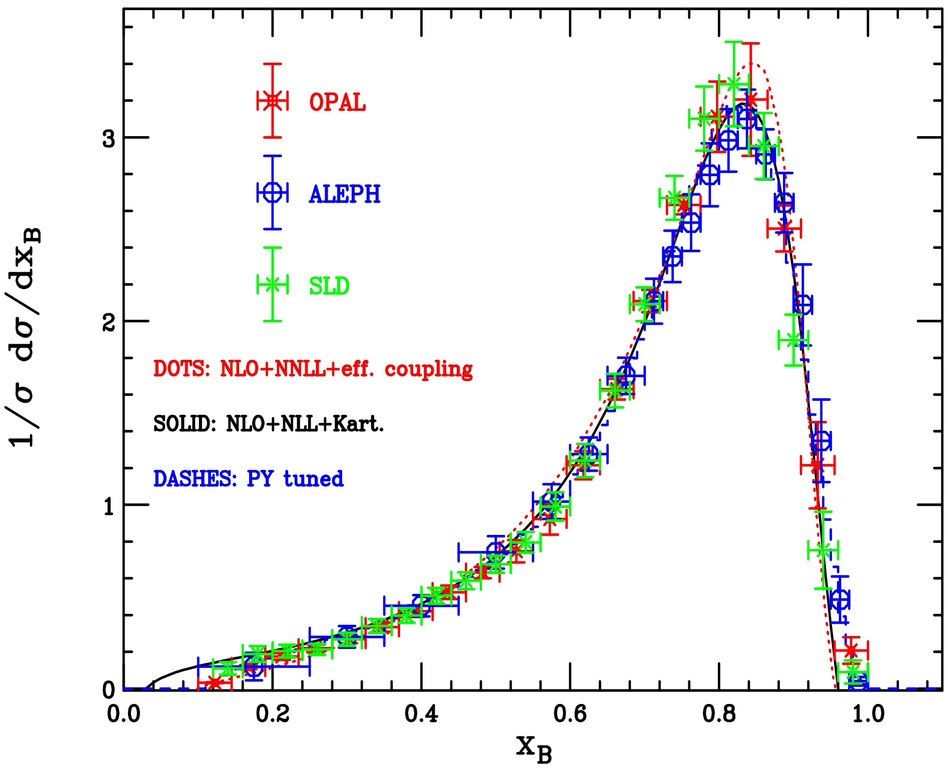
NNLL with $\tilde{\alpha}_S(k_T^2)$: $(x_b, \alpha_S) \to (x_B, \tilde{\alpha}_S)$; $x_B \leq 0.92$

No parameter fit, only varying ren./fact. scales ($\mu_R = \mu_F = m_Z$, $\mu_{0R} = m_b$, $\mu_{0F} = m_b/2$):

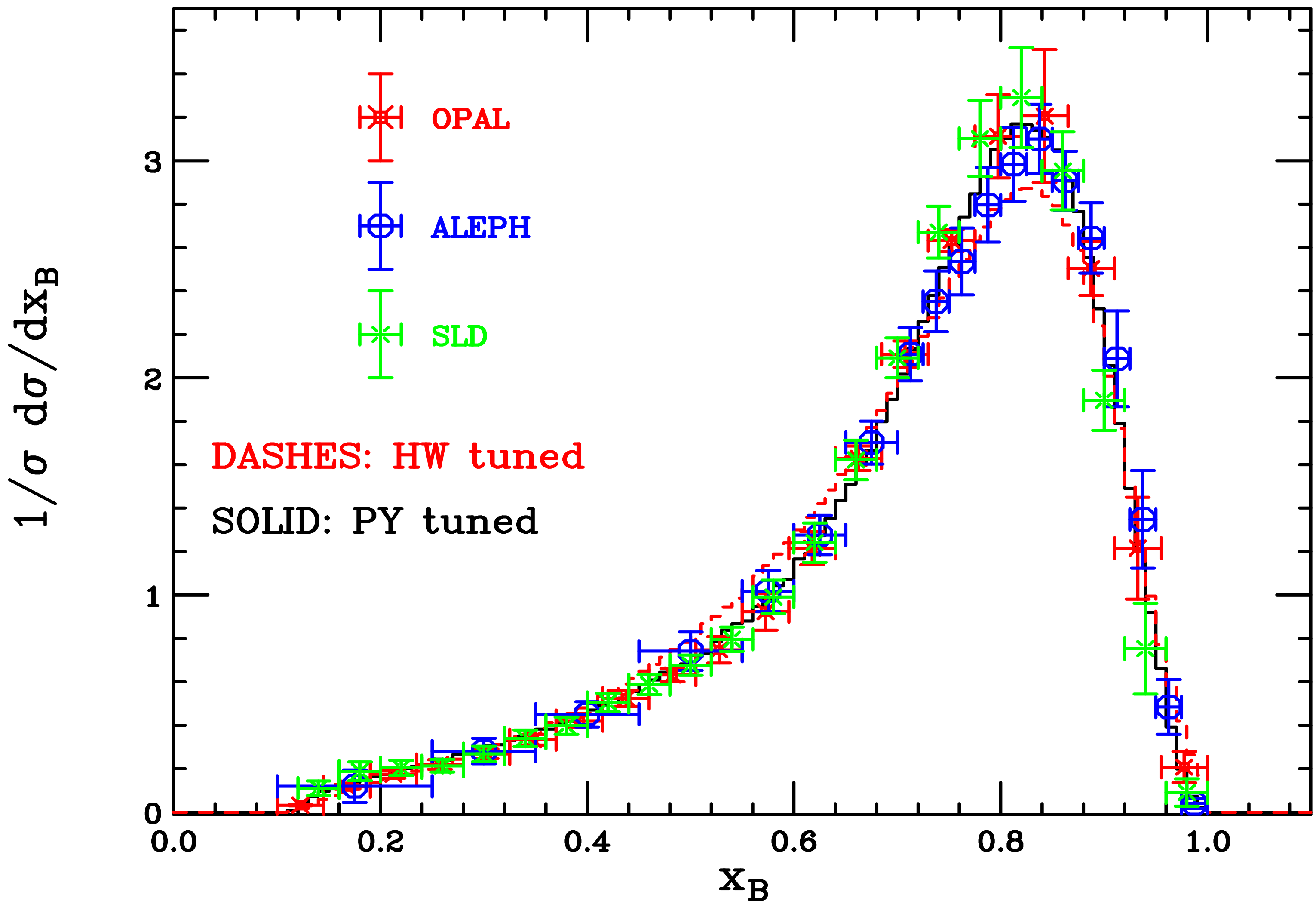
$\chi^2/\mathrm{dof} = 103.4/54$ (overall) 24.8/16 (ALEPH), 30.4/18 (OPAL) 47.8/20 (SLD)

Comparing HERWIG, PYTHIA and resummed calculations after fits

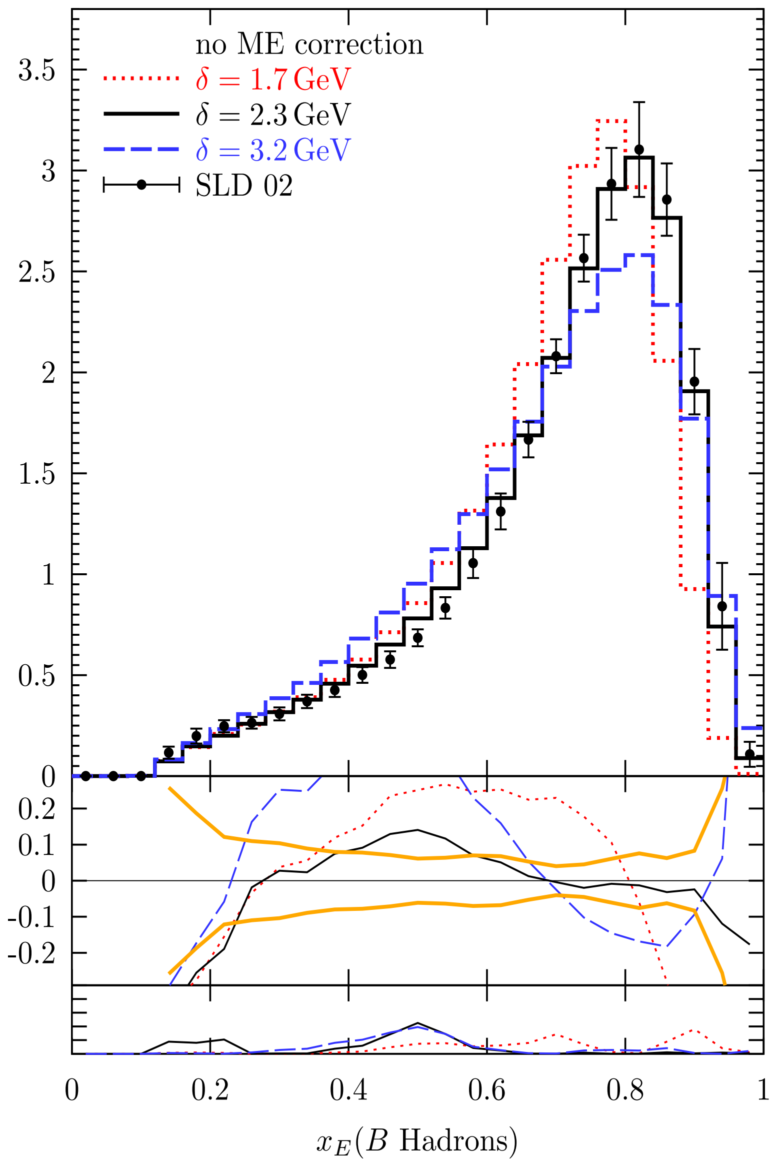




Comparing tuned HERWIG and PYTHIA



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

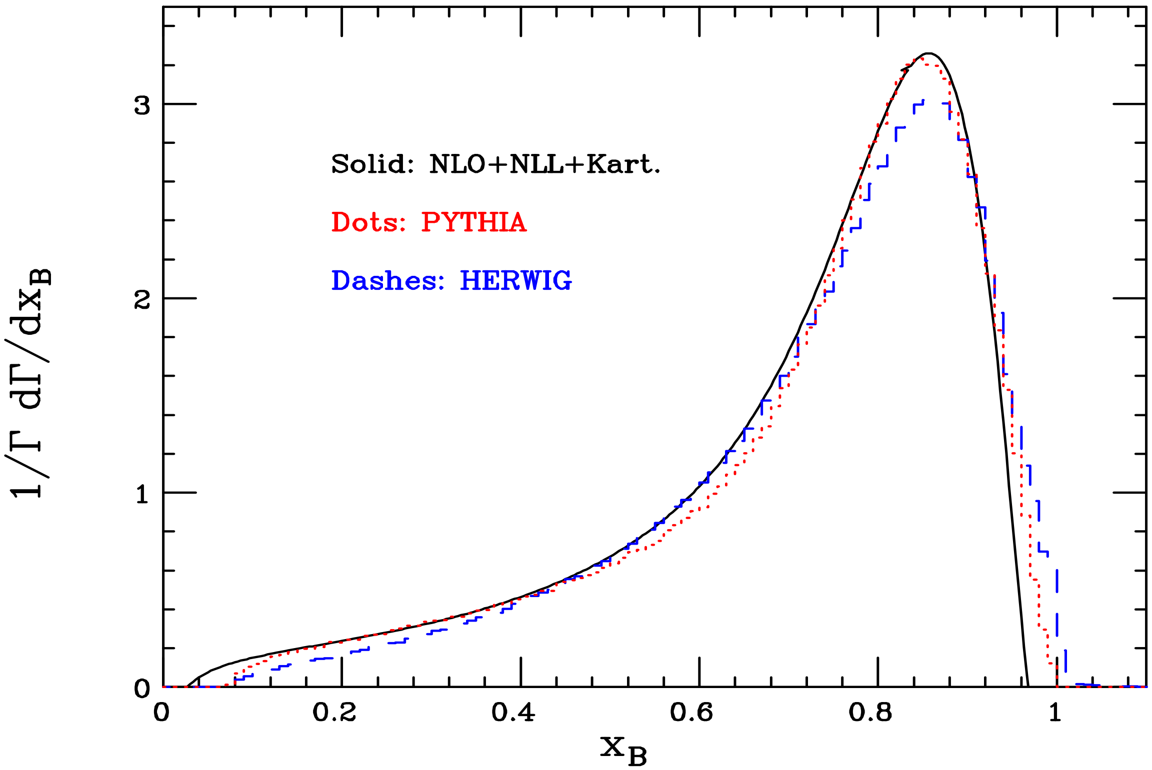


Plot by S. Gieseke

B-hadron spectrum in top decay

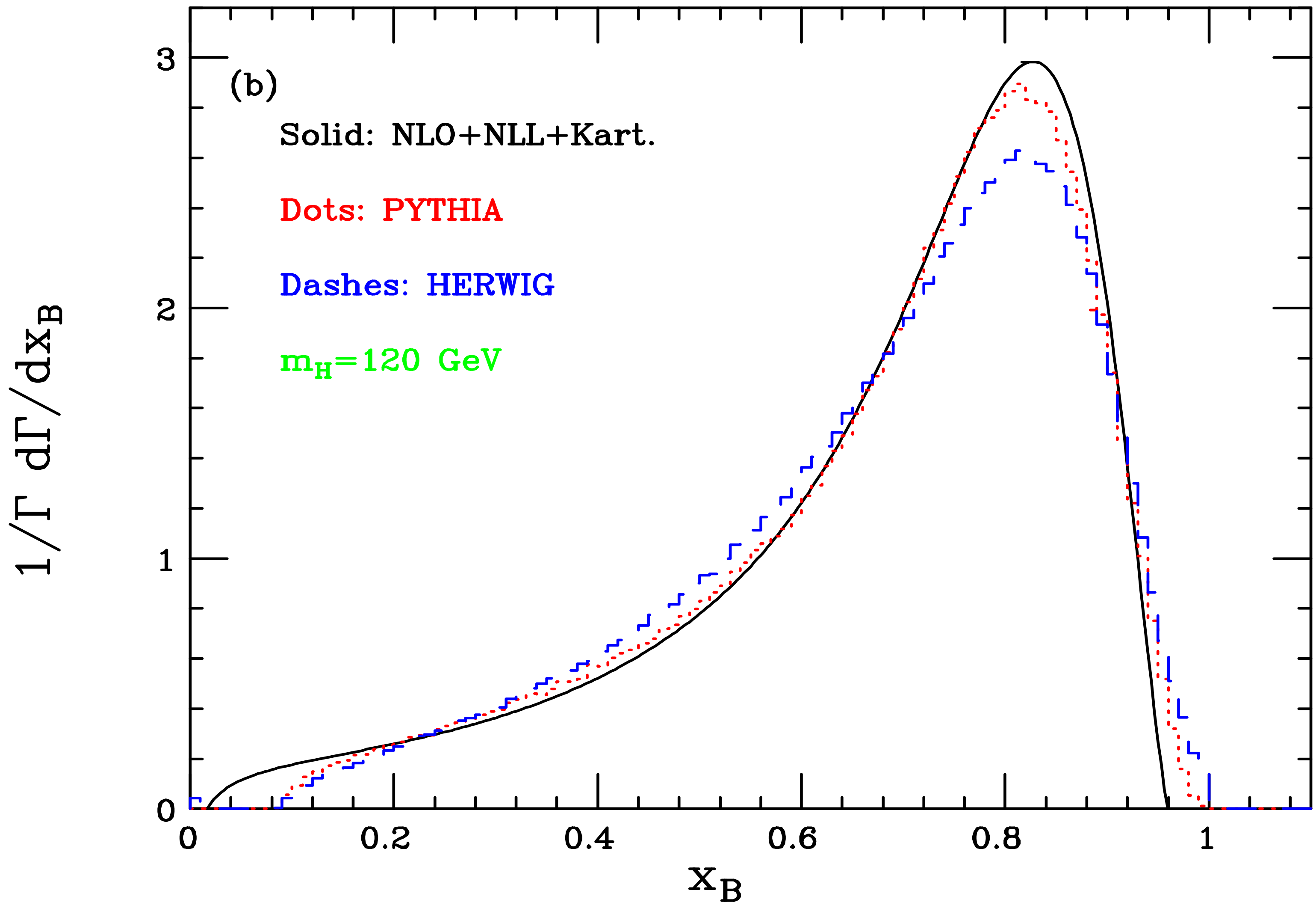
Neglecting production/decay interference effects:

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_b} = \frac{1}{\sigma}\frac{d\sigma}{dx_b}$$



NLO+NLL calculation for top decay: G.C. and A.D. Mitov, NPB623 (2002) 247,
M. Cacciari, G.C. and A.D. Mitov, JHEP 0212 (2002) 015

B-hadron spectrum in Higgs decay $H \to b\bar{b}$:



NLO+NLL calculation for Higgs decay: G.C. NPB 705 (2005) 363

Results in moment space

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

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

Top/Higgs 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±0.0052	0.5401±0.0064	0.4236±0.0065	0.3406±0.0064
e^+e^- **NLL** σ_N^b	0.7801	0.6436	0.5479	0.4755
D_N^{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
e^+e^- **NNLL+**$\tilde{\alpha}_S$ σ_N^B	0.7230	0.5433	0.4213	0.3341
t**-dec. NLL** Γ_N^b	0.7883	0.6615	0.5735	0.5071
t**-dec. NLL** $\Gamma_N^B = \Gamma_N^b D_N^{\mathrm{np}}$	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
H**-dec. NLL** Γ_N^b	0.7580	0.6166	0.5197	0.4477
H**-dec.** $\Gamma_N^B = \Gamma_N^b D_N^{\mathrm{np}}$	0.6950	0.5175	0.4018	0.3207
H**-dec. HW** Γ_N^B	0.6842	0.5036	0.3877	0.3076
H**-dec. PY** Γ_N^B	0.6876	0.5080	0.3913	0.3099

Conclusions

Bottom fragmentation in e^+e^- annihilation, top and Higgs decay

Use of HERWIG, PYTHIA and resummed calculations implementing the Kartvelishvili hadronization model and an effective coupling constant

Default HERWIG and PYTHIA unable to fit x_B data from LEP and SLD

Fits of Kartvelishvili, cluster and string models

PYTHIA describes well the data, the resummed calculations for $x_B \leq 0.92$, HERWIG is marginally consistent but improvements in the C++ version

Predictions for B-hadron spectrum in top decay in x_B and moment spaces

Good description of the first five DELPHI moments

In progress:

Study of other observables and impact on the top/Higgs mass reconstruction

Further inclusion of NNLO/NNLL corrections in the resummations and extension to top and Higgs decays