

Frammentazione di b in eventi $H \rightarrow b\bar{b}$

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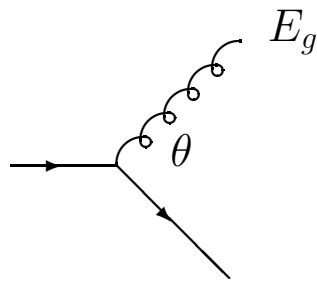
1. $H \rightarrow b\bar{b}$ a NLO
2. Risommazione collineare e soffice
3. Spettro di energia del quark b
4. Produzione di adroni B
5. Conclusioni

G.C., Nucl. Phys. B705 (2005) 363

For Higgs searches at Tevatron and LHC, precise QCD calculations are necessary

Fixed-order calculations (NLO) are reliable to predict inclusive observables

Differential distributions present large terms $\alpha_S^n L^m$ corresponding to collinear ($\theta \rightarrow 0$) or soft ($E_g \rightarrow 0$) parton radiation, which need to be resummed



Recent calculation implemented soft and collinear resummation in $H \rightarrow b\bar{b}$ processes

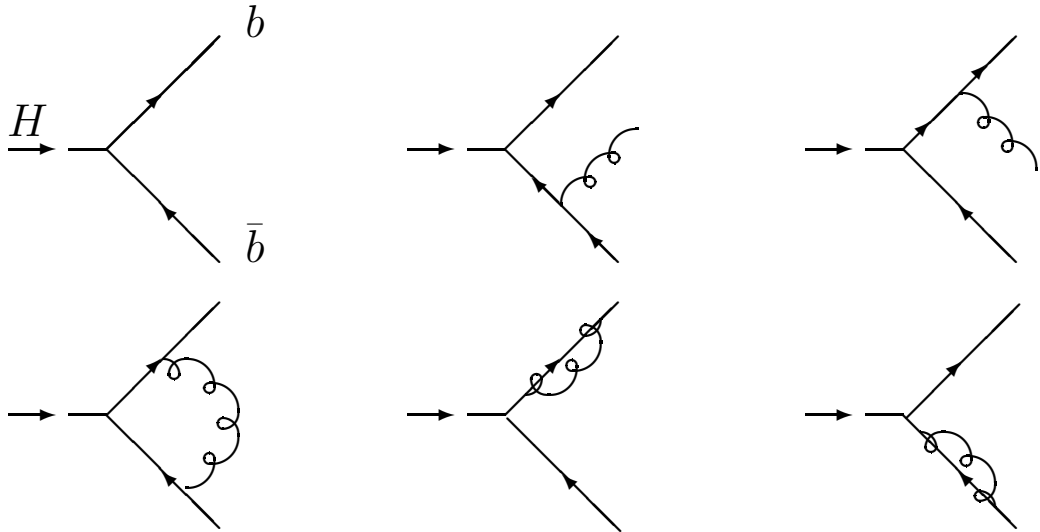
At the Tevatron ($m_H \leq 130$ GeV), the favourite Higgs discovery channel is: $p\bar{p} \rightarrow VH$, $H \rightarrow b\bar{b}$, $V \rightarrow \ell_1\ell_2$

At the LHC, larger QCD backgrounds

$H \rightarrow b\bar{b}$ is still relevant for $m_H \leq 140$ GeV and $pp \rightarrow t\bar{t}H$, $pp \rightarrow WH$, vector boson fusion $W^+W^-(ZZ) \rightarrow H$

Bottom quark production in Higgs decay at NLO

$$H(q) \rightarrow b(p_b)\bar{b}(p_{\bar{b}})(g(p_g)) \quad x_b = \frac{2p_b \cdot q}{q^2} = \frac{2E_b}{m_H}$$



$$\frac{1}{\Gamma_0} \frac{d\Gamma}{dx_b} = \delta(1-x_b) + \frac{\alpha_S(\mu)}{2\pi} \left[P_{qq}(x_b) \ln \frac{m_H^2}{m_b^2} + A(x_b) \right] + \mathcal{O} \left[\left(\frac{m_b}{m_H} \right)^p \right]$$

Altarelli–Parisi splitting function:

$$P_{qq}(x_b) = C_F \left[\frac{1+x_b^2}{(1-x_b)_+} + \frac{3}{2} \delta(1-x_b) \right] = C_F \left(\frac{1+x_b^2}{1-x_b} \right)_+$$

Plus prescription:

$$\int_0^1 dx_b \frac{f(x_b)}{(1-x_b)_+} = \int_0^1 dx_b \frac{f(x_b) - f(1)}{1-x_b}$$

$$\alpha_S(\mu) \ln \frac{m_H^2}{m_b^2} \simeq \mathcal{O}(1)$$

Perturbative fragmentation functions

B. Mele and P. Nason, NPB 361 (1991) 626

$$\frac{1}{\Gamma_0} \frac{d\Gamma}{dx_b}(x_b, m_b \neq 0) = \frac{1}{\Gamma_0} \sum_i \int_{x_b}^1 \frac{dz}{z} \frac{d\hat{\Gamma}_i}{dz}(z, m_i = 0, \mu_F) D_i\left(\frac{x_b}{z}, \mu_F, m_b\right) + \mathcal{O}\left[\left(\frac{m_b}{m_H}\right)^p\right]$$

$D_i(x_b, \mu_F, m_b)$: perturbative fragmentation function (PFF)

$$\frac{1}{\Gamma_0} \frac{d\hat{\Gamma}_b}{dz} = \delta(1-z) + \frac{\alpha_S(\mu)}{2\pi} \left[P_{qq}(z) \left(-\frac{1}{\epsilon} + \gamma_E - \ln 4\pi \right) + \hat{A}(z) \right]$$

$$\begin{aligned} \hat{A}(z) = & C_F \left[\left(\frac{1+z^2}{1-z} \right)_+ \ln \frac{m_H^2}{\mu_F^2} + \left(\frac{2}{3}\pi^2 - \frac{5}{2} \right) \delta(1-z) + 5 - z - \frac{3}{2} \frac{z^2}{(1-z)_+} \right. \\ & - (1+z)[\ln(1-z) + 2 \ln z] + 6 \frac{\ln z}{(1-z)_+} \\ & \left. - 2 \frac{\ln z}{1-z} + 2 \left(\frac{\ln(1-z)}{1-z} \right)_+ \right] \end{aligned}$$

$z \rightarrow 1$: soft-gluon emission

$\overline{\text{MS}}$ coefficient function:

$$\left(\frac{1}{\Gamma_0} \frac{d\hat{\Gamma}_b}{dz} \right)^{\overline{\text{MS}}} = \delta(1-z) + \frac{\alpha_S(\mu)}{2\pi} \hat{A}_1(z)$$

$$\frac{1}{\Gamma_0} \frac{d\Gamma}{dx_b}(m_b) = \left(\frac{1}{\Gamma_0} \frac{d\hat{\Gamma}_b}{dx_b}(m_b = 0) \right)^{\overline{\text{MS}}} \otimes D_b^{\overline{\text{MS}}}(m_b)$$

DGLAP equations for PFF's:

$$\frac{d}{d \ln \mu_F^2} D_i(x_b, \mu_F, m_b) = \sum_j \int_{x_b}^1 \frac{dz}{z} P_{ij} \left(\frac{x_b}{z}, \alpha_S(\mu_F) \right) D_j(z, \mu_F, m_b)$$

Initial condition $D(x_b, \mu_{0F})$:

$$D_b(x_b, \mu_{0F}, m_b) = \delta(1-x_b) + \frac{\alpha_S(\mu_0) C_F}{2\pi} \left[\frac{1+x_b^2}{1-x_b} \left(\ln \frac{\mu_{0F}^2}{m_b^2} - 2 \ln(1-x_b) - 1 \right) \right]_+$$

$$D_N(\mu_F, m_b) = \int_0^1 dx x_b^{N-1} D(x_b, \mu_F, m_b)$$

$$\frac{dD_N(\mu_F, m_b)}{d \ln \mu_F^2} = \frac{\alpha_S(\mu_F)}{2\pi} \left[P_N^{(0)} + \frac{\alpha_S(\mu_F)}{2\pi} P_N^{(1)} \right] D_N(\mu_F, m_b)$$

$$D_N(\mu_F, m_b) = D_N(\mu_{0F}, m_b) \exp \left\{ \frac{P_N^{(0)}}{2\pi b_0} \ln \frac{\alpha_S(\mu_{0F})}{\alpha_S(\mu_F)} + \frac{\alpha_S(\mu_{0F}) - \alpha_S(\mu_F)}{4\pi^2 b_0} \left[P_N^{(1)} - \frac{2\pi b_1}{b_0} P_N^{(0)} \right] \right\}$$

$$D_N(\mu_F, m_b) = D_N(\mu_{0F}, m_b) \exp \left\{ C_{1,0} \alpha_S(\mu_F) + C_{1,1} \alpha_S(\mu_F) \ln(\mu_F^2/\mu_{0F}^2) \dots + C_{n,n-1} \alpha_S^n(\mu_F) \ln^{n-1}(\mu_F^2/\mu_{0F}^2) + C_{n,n} \alpha_S^n(\mu_F) \ln^n(\mu_F^2/\mu_{0F}^2) + \dots \right\}$$

Resummation of leading logarithms $\alpha_S^n \ln^n(\mu_F^2/\mu_{0F}^2)$
and next-to-leading logarithms $\alpha_S^n \ln^{n-1}(\mu_F^2/\mu_{0F}^2)$

$\mu_{0F} \simeq m_b$ and $\mu_F \simeq m_H$

Resummation of NLL $\ln(m_H^2/m_b^2)$
(Collinear resummation)

Soft-gluon radiation

Region $x_b \rightarrow 1$ **corresponds to soft-gluon radiation**

Bottom quark spectrum presents terms behaving like
 $1/(1-x_b)_+$ **or** $[\ln(1-x_b)/(1-x_b)]_+$ **for** $x_b \rightarrow 1$

$$\frac{1}{(1-x_b)_+} \rightarrow \ln N \quad \left[\frac{1}{1-x_b} \ln(1-x_b) \right]_+ \rightarrow \ln^2 N$$

$$\hat{\Gamma}_N(m_H, \mu, \mu_F) = 1 + \frac{\alpha_S(\mu) C_F}{2\pi} \left[\ln^2 N + \left(\frac{3}{2} + 2\gamma - 2 \ln \frac{m_H^2}{\mu_F^2} \right) \ln N \right. \\ \left. + K(m_H, \mu_F) + \mathcal{O}\left(\frac{1}{N}\right) \right]$$

$$z = 1 - x_b, \quad k^2 = (p_b + p_g)^2 (1 - z) = 2E_g^2 (1 - \cos \theta_{bg}) \simeq E_g^2 \sin^2 \theta_{bg}$$

$$\Delta_N = \exp \left\{ \int_0^1 dz \frac{z^{N-1} - 1}{1-z} \int_{\mu_F^2}^{m_H^2(1-z)} \left[\frac{dk^2}{k^2} A[\alpha_S(k^2)] \right. \right. \\ \left. \left. + \frac{1}{2} B[\alpha_S(m_H^2(1-z))] \right] \right\} = \exp [\ln N g_1 + g_2]$$

S. Catani and L. Trentadue, NPB 327 (1989) 323

$$A(\alpha_S) = \sum_{n=1}^{\infty} \left(\frac{\alpha_S}{\pi} \right)^n A^{(n)} \quad ; \quad B(\alpha_S) = \sum_{n=1}^{\infty} \left(\frac{\alpha_S}{\pi} \right)^n B^{(n)}$$

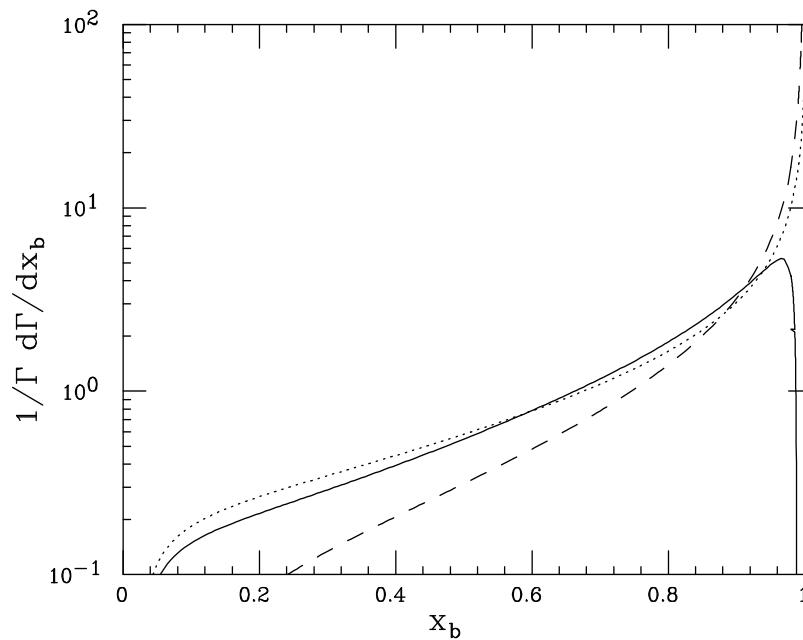
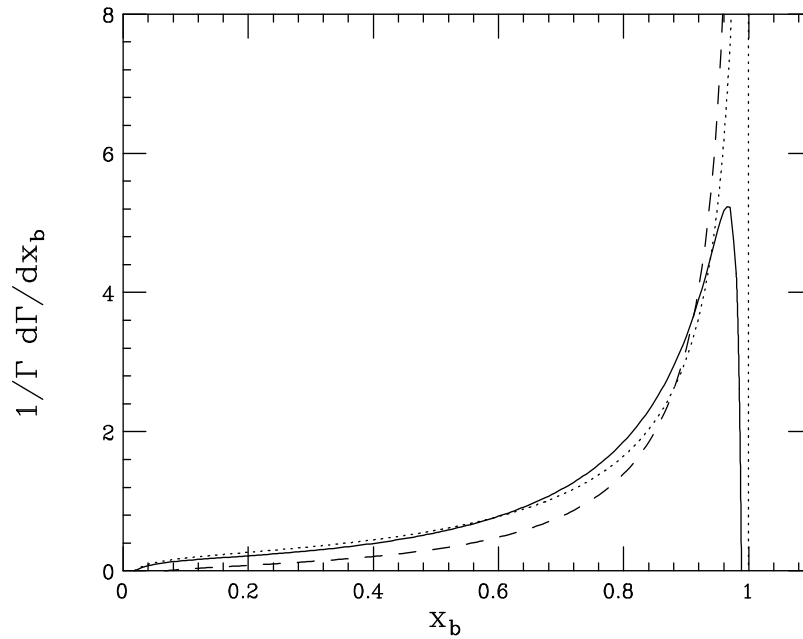
$g_1 \ln N$ **resums LL** $A^{(1)}$: $\alpha_S \ln^2 N, \alpha_S^2 \ln^4 N \dots \alpha_S^n \ln^{n+1} N$

g_2 **resums NLL** $A^{(2)}, B^{(1)}$: $\alpha_S \ln N, \alpha_S^2 \ln^2 N \dots \alpha_S^n \ln^n N$

b -quark spectrum in Higgs decay

$$m_H = 120 \text{ GeV} \quad m_b = 5 \text{ GeV} \quad \Lambda_{\overline{\text{MS}}} = 200 \text{ MeV}$$

$$\mu = \mu_F = m_H \quad \mu_0 = \mu_{0F} = m_b$$

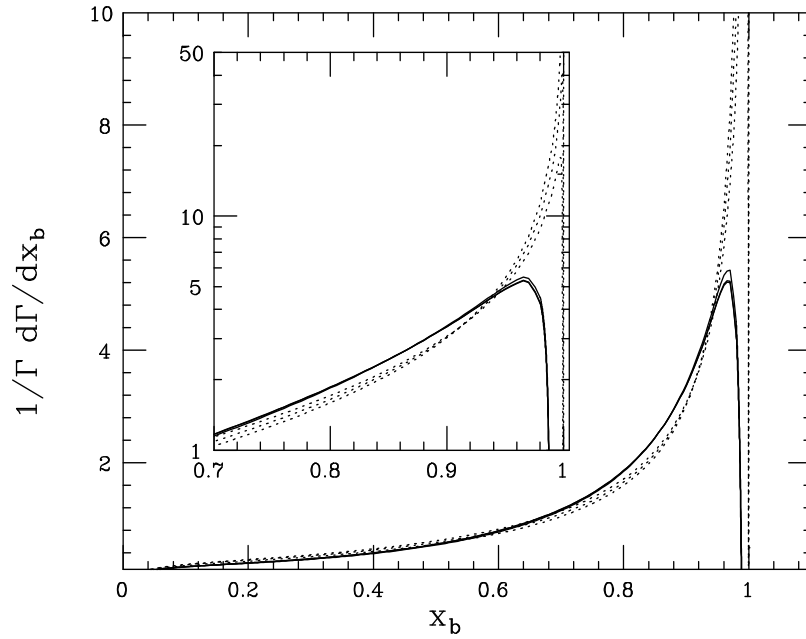


Solid: soft and collinear resummation **Dots:** only collinear resummation

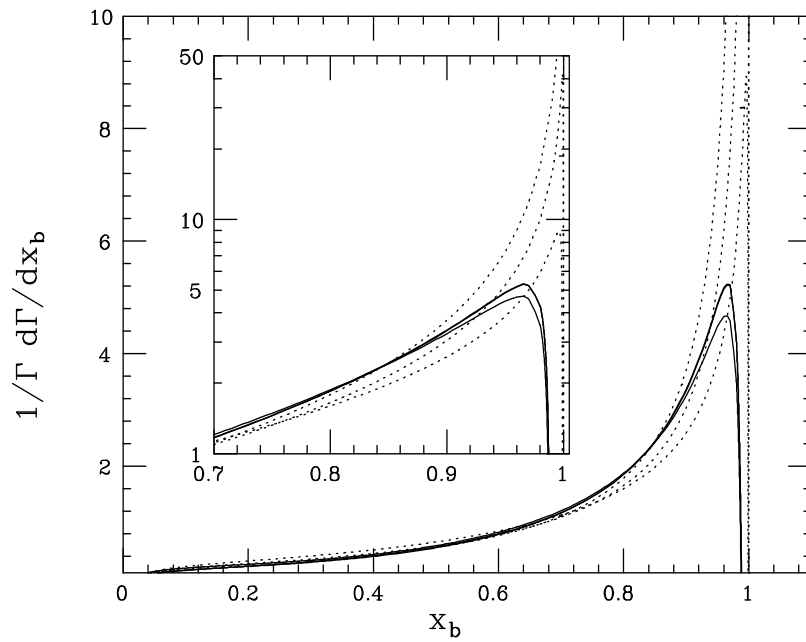
Dashes: massive NLO without resummation

Dependence on the factorization scales

Solid: collinear and soft resummation; dots: only collinear

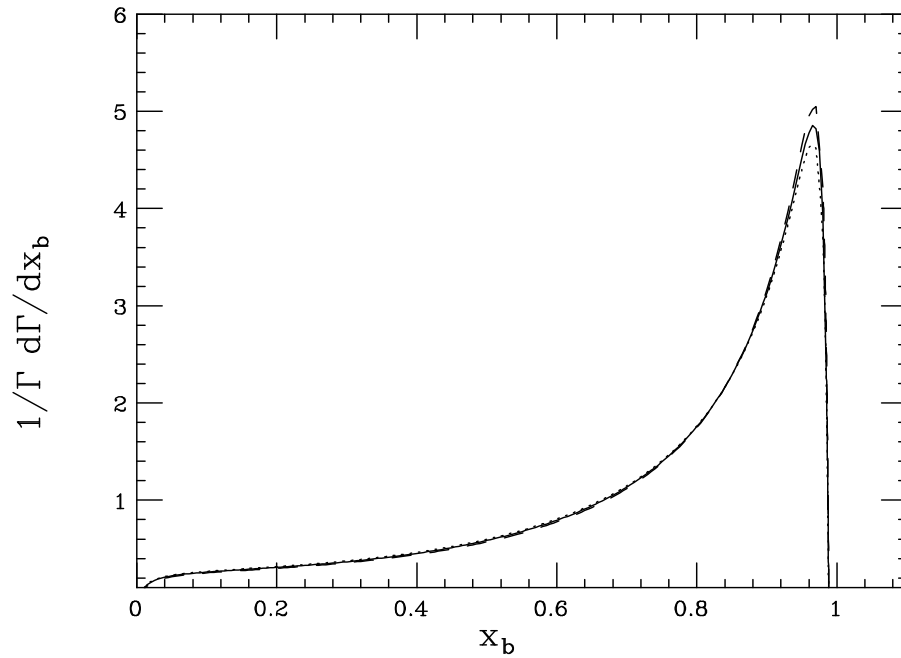


$$\mu_F = m_H/2, m_H, 2m_H \quad \mu_0 = \mu_{0F} = m_b, \mu = m_H$$



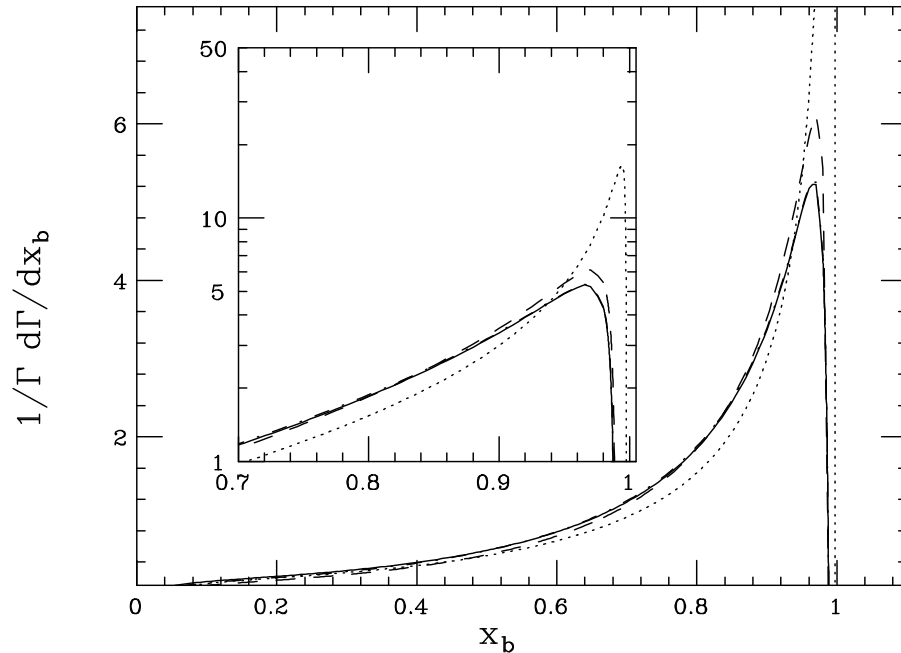
$$\mu_{0F} = m_b/2, m_b, 2m_b \quad \mu_0 = m_b, \mu = \mu_F = m_H$$

Dependence on the Higgs mass m_H



Dashes: $m_H = 110$ GeV; solid: $m_H = 120$ GeV; dots: $m_H = 130$ GeV

Comparison of $e^+e^- \rightarrow b\bar{b}$, Higgs and top decay



Solid: Higgs decay; dots: top decay; dashes: e^+e^- at $\sqrt{s} = 91.2$ GeV; dot-dashes: e^+e^- at $\sqrt{s} = m_H = 120$ GeV

$e^+e^- \rightarrow b\bar{b}$: M. Cacciari and S. Catani, NPB 617 (2001) 167;

top decay: M. Cacciari, G.C. and A.D. Mitov, JHEP 0212 (2002) 015

Hadron-level results

$$\frac{d\Gamma_{\text{had}}}{dx_B}(B) = \frac{d\Gamma_{\text{part}}}{dx_b}(b) \otimes D_{np}(b \rightarrow B)$$

$d\Gamma_{\text{part}}/dx_b$ according to PFF approach

Non-perturbative fragmentation functions:

Power law with two tunable parameters:

$$D_{np}(x; \alpha, \beta) = \frac{1}{B(\beta + 1, \alpha + 1)}(1 - x)^\alpha x^\beta$$

Model of Kartvelishvili et al.:

$$D_{np}(x; \delta) = (1 + \delta)(2 + \delta)(1 - x)x^\delta$$

Model of Peterson et al.:

$$D_{np}(x; \epsilon) = \frac{A}{x[1 - 1/x - \epsilon/(1 - x)]^2}$$

Parameters $\alpha, \beta, \delta, \epsilon$ from fits to $e^+e^- \rightarrow b\bar{b}$ data

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

$d\sigma_{\text{part}}/dx_b$ must be computed within the same framework as $d\Gamma_{\text{part}}/dx_b$

Results of fits of fragmentation models to e^+e^- data

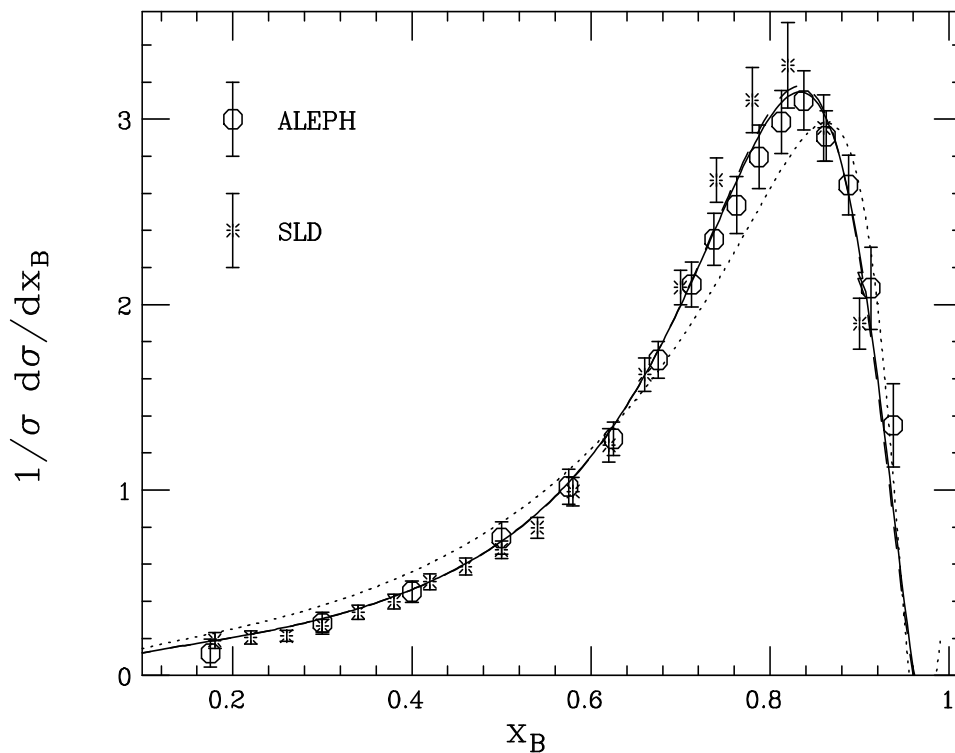
Preliminary: correlations between data points are neglected

ALEPH Collaboration, A. Heister et al., PLB 512 (2001) 30: only B mesons

SLD Collaboration, K. Abe et al., PRL 84 (2000) 4300: both b -flavoured mesons and baryons

$$0.18 \lesssim x_B \lesssim 0.94$$

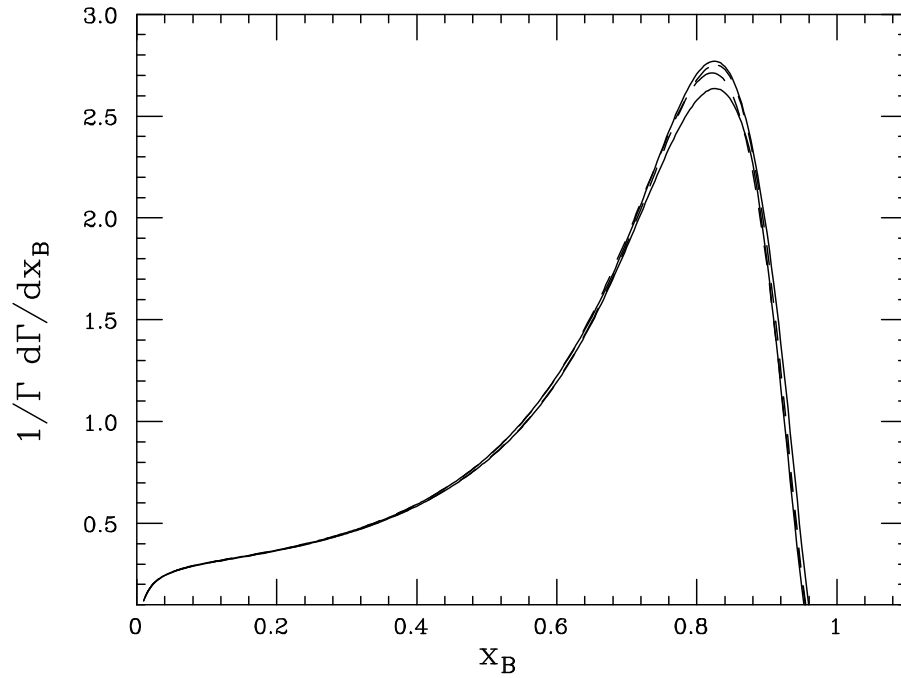
α	0.90 ± 0.15
β	16.23 ± 1.37
$\chi^2(\alpha, \beta)/\text{dof}$	$33.42/32$
δ	17.07 ± 0.39
$\chi^2(\delta)/\text{dof}$	$33.80/32$
ϵ	$(1.71 \pm 0.09) \times 10^{-3}$
$\chi^2(\epsilon)/\text{dof}$	$166.36/32$



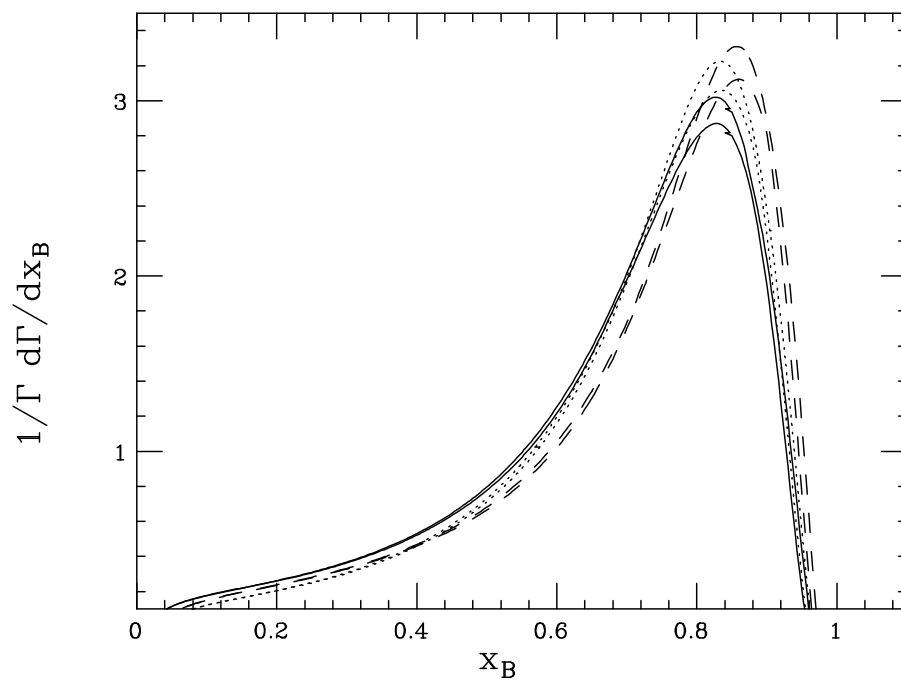
Solid: power law; dashes: Kartvelishvili; dots: Peterson

b -flavoured hadron spectrum in Higgs decay

Solid: power law; Dashes: Kartvelishvili



B spectrum in Higgs decay (solid), top decay (dashes) and e^+e^- annihilation (dots) at $\sqrt{s} = m_Z$



Fits in moment space

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

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

Higgs and 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 ± 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} [B]	0.9169	0.8392	0.7731	0.7163
t -decay NLL Γ_N^b	0.7884	0.6617	0.5737	0.5072
t -decay Γ_N^B	0.7228	0.5553	0.4435	0.3633
H -decay NLL Γ_N^b	0.7578	0.6162	0.5193	0.4473
H -decay Γ_N^B	0.6948	0.5171	0.4015	0.3204

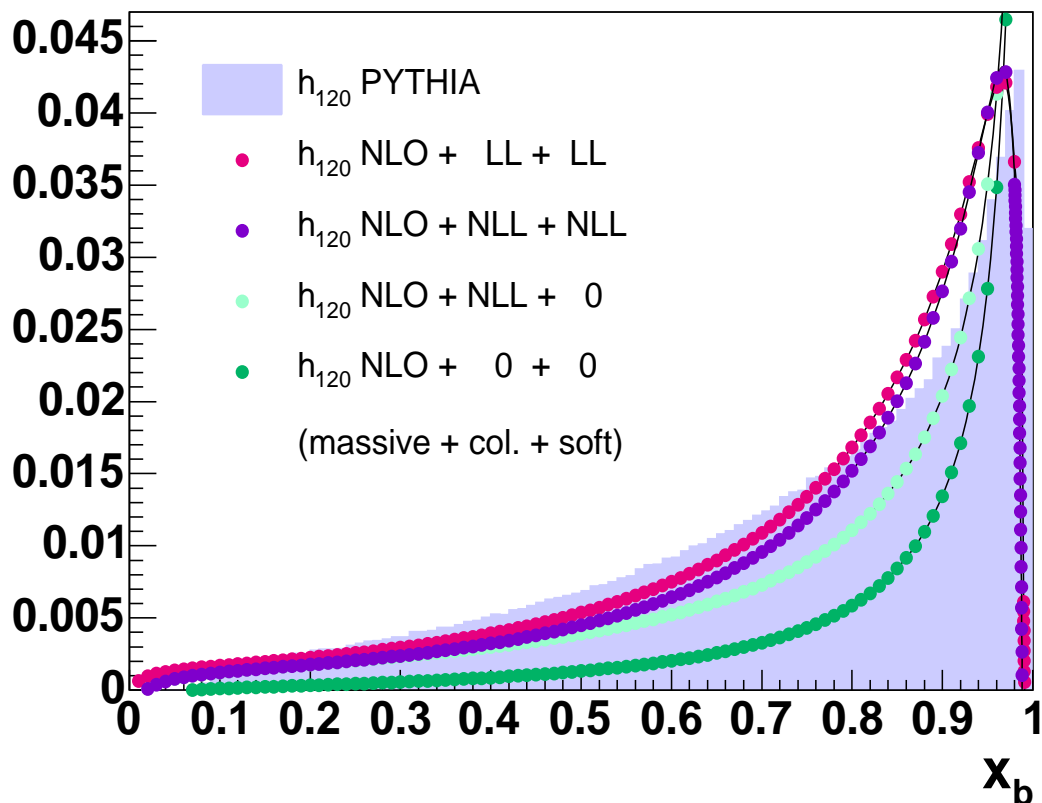
Comparison with Monte Carlo event generators (with V.Drollinger, CMS)

MC generators like HERWIG or PYTHIA are LO+LL programs, with some NLL terms and, after matrix-element corrections, hard real-gluon radiation

No matrix-element corrections for $H \rightarrow b\bar{b}$

Input parameters need to be tuned: gluon effective mass, Λ_{QCD} , cutoff Q_0 for parton shower evolution, hadronization parameters, etc.

Comparison with default PYTHIA



In progress (Les Houches): tuning of parameters and comparison with HERWIG

Conclusions and outlook

NLO b spectrum in $H \rightarrow b\bar{b}$ presents large collinear- and soft-enhanced terms

Collinear and soft resummation

Big effect of resummation on b energy distribution

Fits of hadronization models to ALEPH and SLD data in x_B space and to DELPHI in N space

B -hadron spectrum in x_B and N spaces

Comparison of $e^+e^- \rightarrow b\bar{b}$, Higgs and top decay

In progress:

Application to Higgs and top physics at Tevatron and LHC

Studies of other observables, e.g. transverse momentum of b quarks or B hadrons

Comparison with Monte Carlo event generators

Matrix-element corrections to $H \rightarrow b\bar{b}$ in HERWIG