b quark fragmentation

Massimo Corradi (INFN Bologna)

- **Motivation**
- **First look at available data / theories**
- **Plans**

Factorization for light quarks/hadrons

Light hadron production in e^+e^-:

$$e^+e^- \to hX$$

The light hadron cross section can be written as

$$\sigma_h(x,E) = \sum_i \int \frac{dz}{z} \sigma_i(z,E) D_{i\to h}\left(\frac{x}{z}, E\right) + \mathcal{O}\left(\frac{\Lambda}{E}\right)$$

where $E = \sqrt{s}$, $x = 2E_h/E$, $\sigma_i(z,E)$ is the i$^{\text{th}}$ parton cross-section and $D_{i\to h}(z,E)$ is the fragmentation function

- **$D_{i\to h}(z,E)$ is needed to cure collinear divergence,**
- **depedends on the factorization scheme,**
- **evolves in E with GDLAP, initial condition fixed by expt. data,**
- **is process independent: take from e^+e^-, use for ep, pp.**

Non Perturbative (NP) corrections are small: $\mathcal{O}(\frac{\Lambda}{E}) \sim 0.2\%$ at the Z.

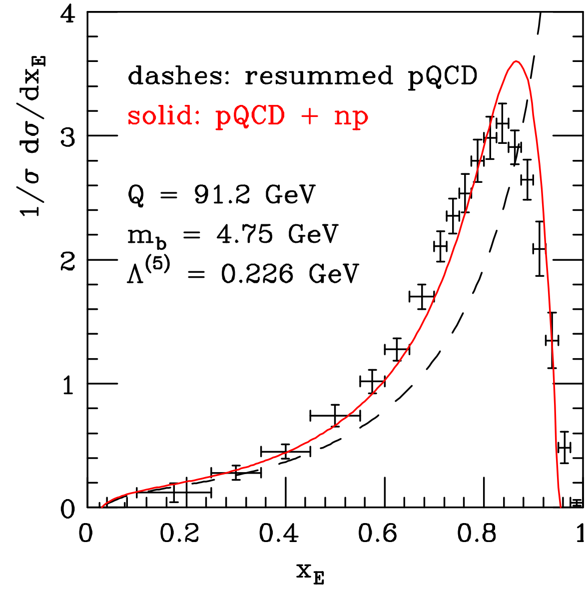
Factorization for Heavy Quarks ?

The HQ mass m_Q ia a cutoff for collinear divergence: <u>no need for factorization</u>
Perturbative cross section:

$$\sigma_h(x, E, m_Q) = \sigma_Q(x, E, m_Q) + \mathcal{O}\left(\frac{\Lambda}{m_Q}\right)$$

NP corrections may be large: $\mathcal{O}(\Lambda/m_Q) \sim 5\%$ for b and 15% for c

Convolute quark cross section with a NP fragmentation function $D^{\rm NP}_{Q\to H}(z)$:



$$\sigma_H(x, E) = \sum_i \int \frac{dz}{z}\, \sigma_Q(z, m_Q, E)\, D^{\rm NP}_{Q\to H}\left(\frac{x}{z}\right)$$

Is $D^{\rm NP}_{Q\to H}(z)$ process independent ?

Test the portability of $D^{\rm NP}_{Q\to H}(z)$ from e^+e^- to ep, pp

What can be done for the Workshop

- **Fit** $D^{NP}(z)$ **on** e^+e^- **data**
- **Evaluate uncertainty from** $D^{NP}(z)$ **on** ep, pp **cross sections**
- **Study how to measure** $D^{NP}(z)$ **directly in** ep **or** pp

Before starting two points need to be understood:

1. **which data ?**
2. **which theory ?**

Which data ?

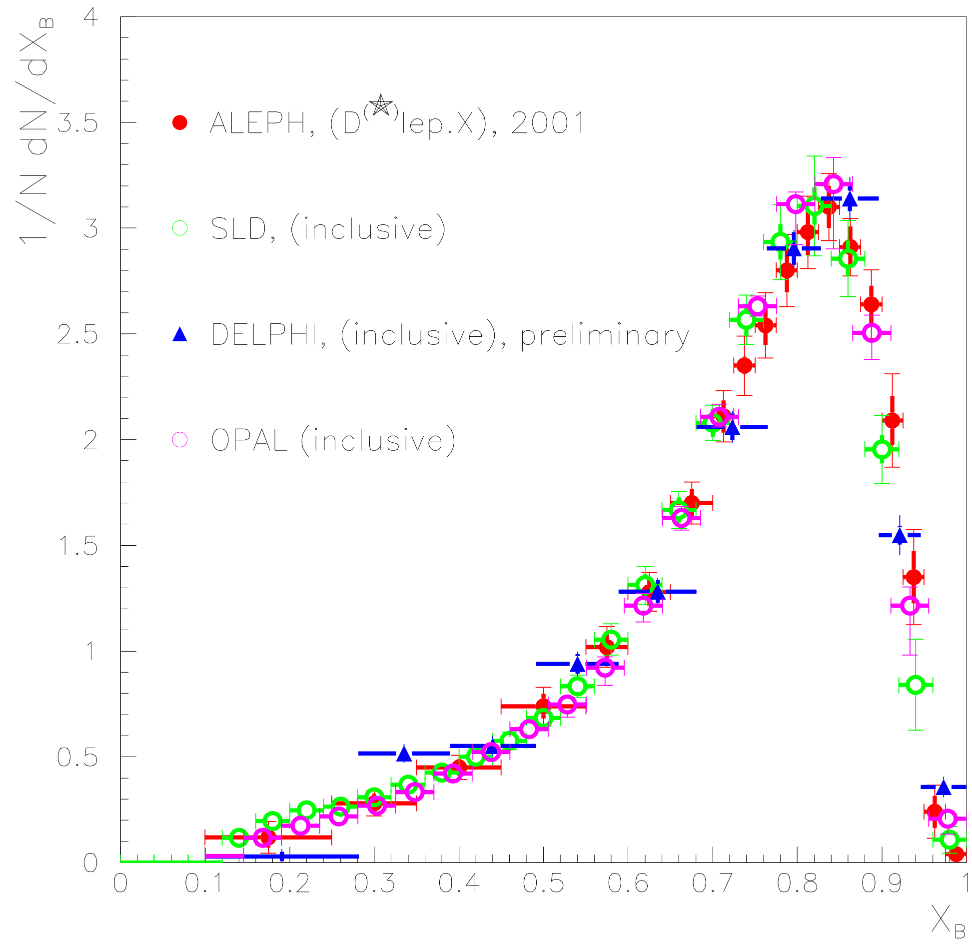
All the available measurements are from e^+e^-

Observable: $x_E = E_H/E_{\rm beam}$ (H is the weakly decaying hadron)

- **LEP/SLD: precise measurements of**

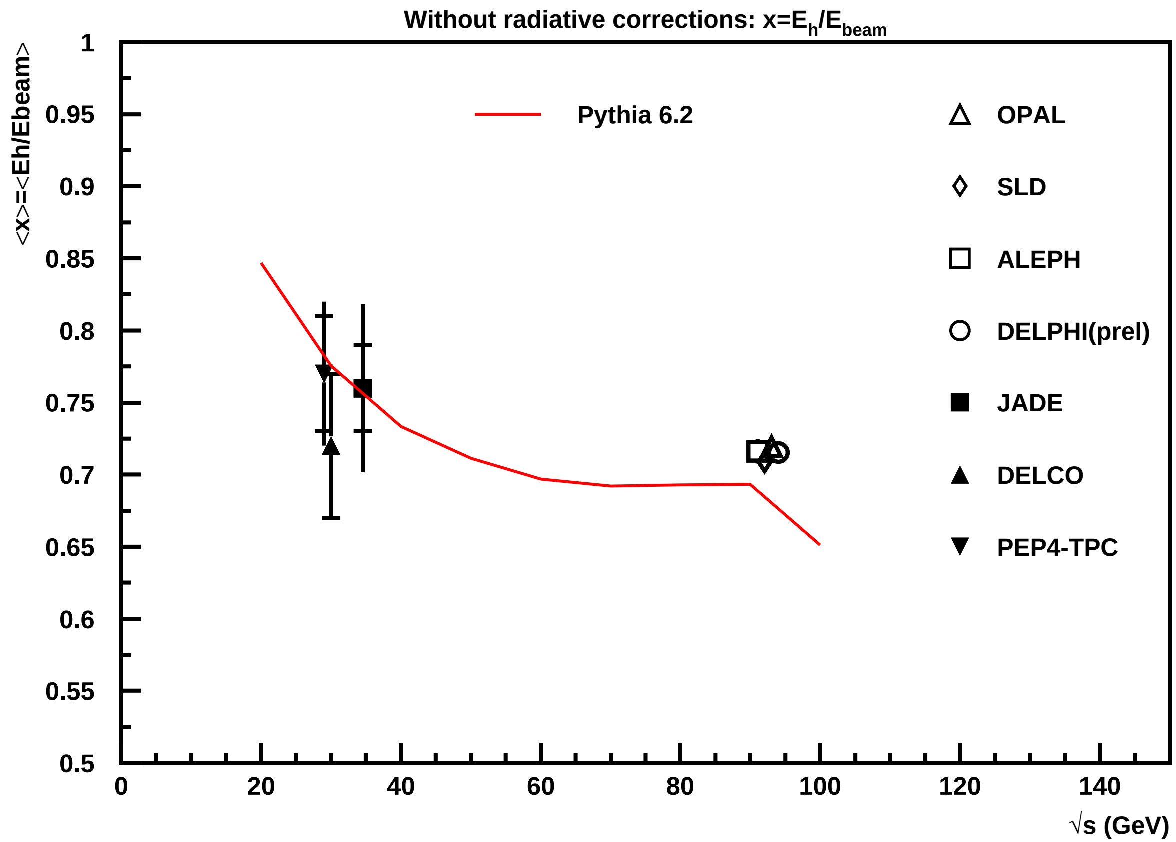
$$\frac{1}{\sigma}\frac{d\sigma}{dx_E}$$

- **Full error matrix available**
- **$\langle x_E \rangle$ available**
- **data in agreement (at first sight)**



Which data (2)

Measurement of $\langle x_E \rangle$ also from PEP, PETRA, TOPAZ



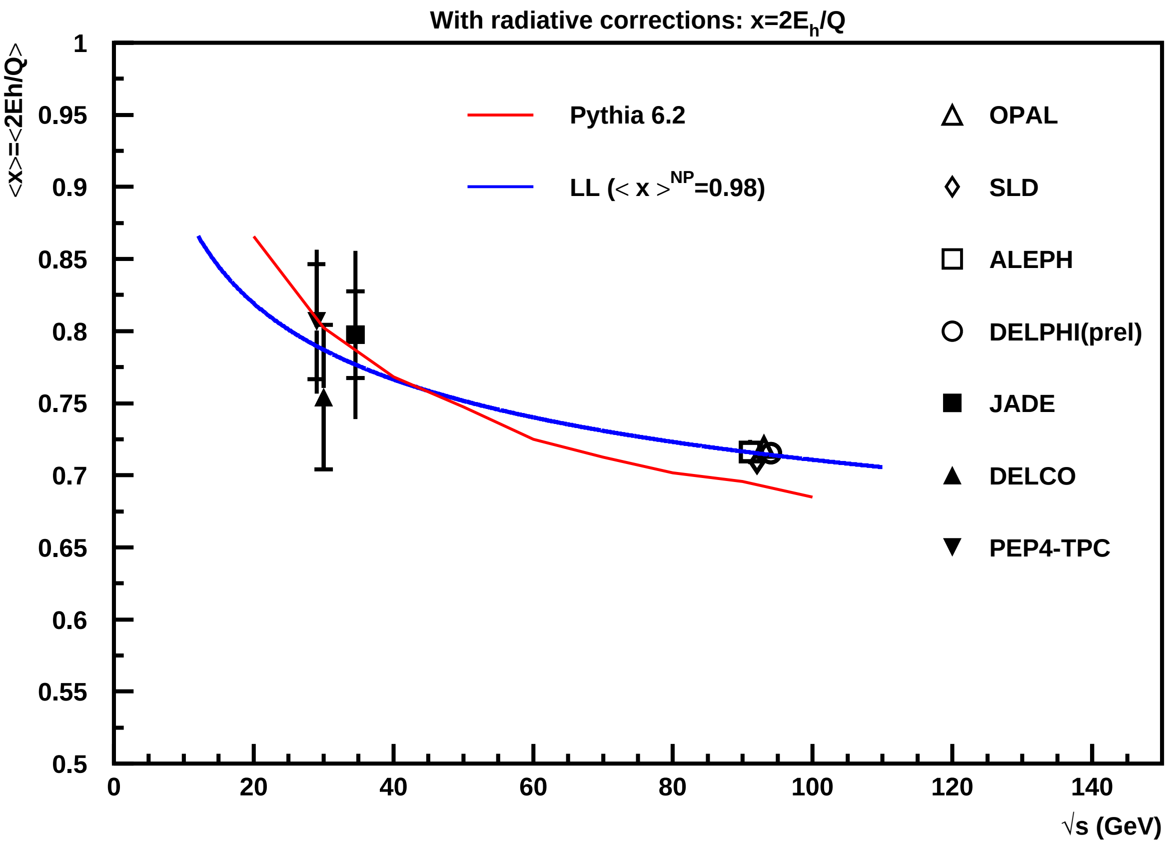
•Measurements that don't provide an direct observable such as $\langle x_E \rangle$ but a fragmentation parameter of some MC model are not considered

•TOPAZ (VENUS) data have too low precision, not considered

•EW radiative corrections are needed to compare with QCD models

Which data (3)

e^+e^- data with EW correction (taken from Pythia)



Red: Pythia 6.2 with ISR radiation from e off

Blue: Leading Log formula (Nason, Mele, PLB 245 (1990) 635)

- Evidence for scaling violation of $\langle x_E \rangle$
- Low energy data consistent with LEP/SLD within (large) uncertainties
- Default Pythia a bit low at LEP/SLD energy

Which theory ? (1)

$D^{\mathrm{NP}}(z)$ is not an observable, depends on the theoretical model
Need to use consistent theory for e^+e^- and for ep, pp

Possible theories:

- **MC (Pythia)**
  - + NP fragmentation is tunable
  - + fits to e^+e^- data already done by LEP/SLD experiments
  - + usable for any observable in ep, pp
  - + detailed model for fragmentation
  - – cross sections accurate to LO
- **Fixed Order (NLO) calculations**
  - – fits to recent e^+e^- to be done (fit to old ALEPH data in Nason, Oleari Nuc.Phys.B 565 (2000) 245)
  - + programs for ep, pp available for any observable
  - + cross sections accurate to NLO
  - – large log resummation missing, important at LEP/SLD, LHC, not at HERA

Which theory ? (2)

- Fixed Order plus resummation of Leading Logs (FONLL)

  + some fit to e^+e^- already available (Corcella, Mitov Nucl. Phys. B 565 (2000) 245)

  – calculation for ep, pp only for single differential distributions

  + accurate to NLO and NLL

  would be very good if a simple program for any observable was available

- MC⊚NLO

  ? NP fragmentation partially tunable (Herwig)

  – missing for e^+e^-, use Herwig ?

  + available for pp

  – missing for ep

  + accurate to NLO and LL

  + detailed model for fragmentation

  would be ideal if ep (and ee) implemented

- mixed solution (for the moment):
  take $D^{\mathrm{NP}}(z)$ from FONLL fit to LEP/SLD and apply to FO

  + FO∼FONLL for b at HERA, should be OK at HERA

  – not good for LHC

Available Fits to e^+e^-

Fits to Single Parameter functions:

Kartvelishvili	$f(x) = (1-x)x^{\alpha}$
Peterson	$f(x) = \frac{1}{x}\left(1 - \frac{1}{x} - \frac{\epsilon}{(1-z)}\right)^{-2}$

FONLL

Corcella, Mitov Nucl. Phys. B 565 (2000) 245

(without soft log resummation)

Parameter	**ALEPH**	**SLD**
α	15.0 ± 0.4	14.6 ± 0.4
ϵ	0.0029 ± 0.0002	0.0023 ± 0.0002

FO and FONLL

Nason, Oleari Nuc.Phys.B 565 (2000) 245

Theory	**Parameter**	**ALEPH (old)**
FO(LO)	ϵ	0.0069
FO(NLO)	ϵ	0.0033
FONLL	ϵ	0.0023

Fits within Pythia

Parameter	**ALEPH**	**SLD**	**OPAL**
ϵ	0.0031 ± 0.0006	0.0055	0.0041 ± 0.0004
α	13.7 ± 1.3	10.0	11.9 ± 0.5

Effects at HERA

First look using FO calculation for HERA (FMNR)

Use $D^{\mathrm{NP}}(z)$ to rescale quark momentum and obtain B hadron differential cross-sections

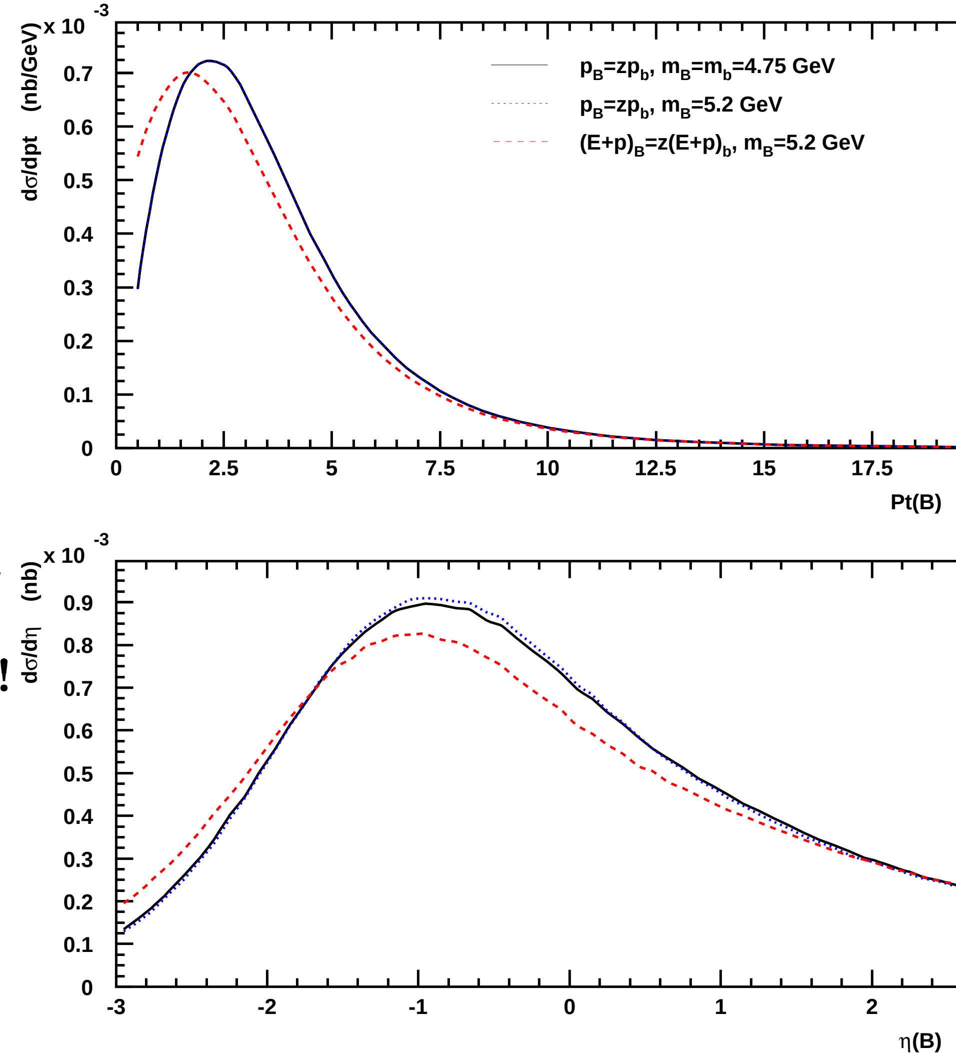
- **Peterson with $\epsilon = 0.0035$**
- **B-hadron momentum obtained by:**

Black: rescaling $\vec{p}^{\,b}$ in the frame $p_Z^b = p_Z^{\bar{b}}$ (FMNR default)

Blue: as above but on B hadron mass shell

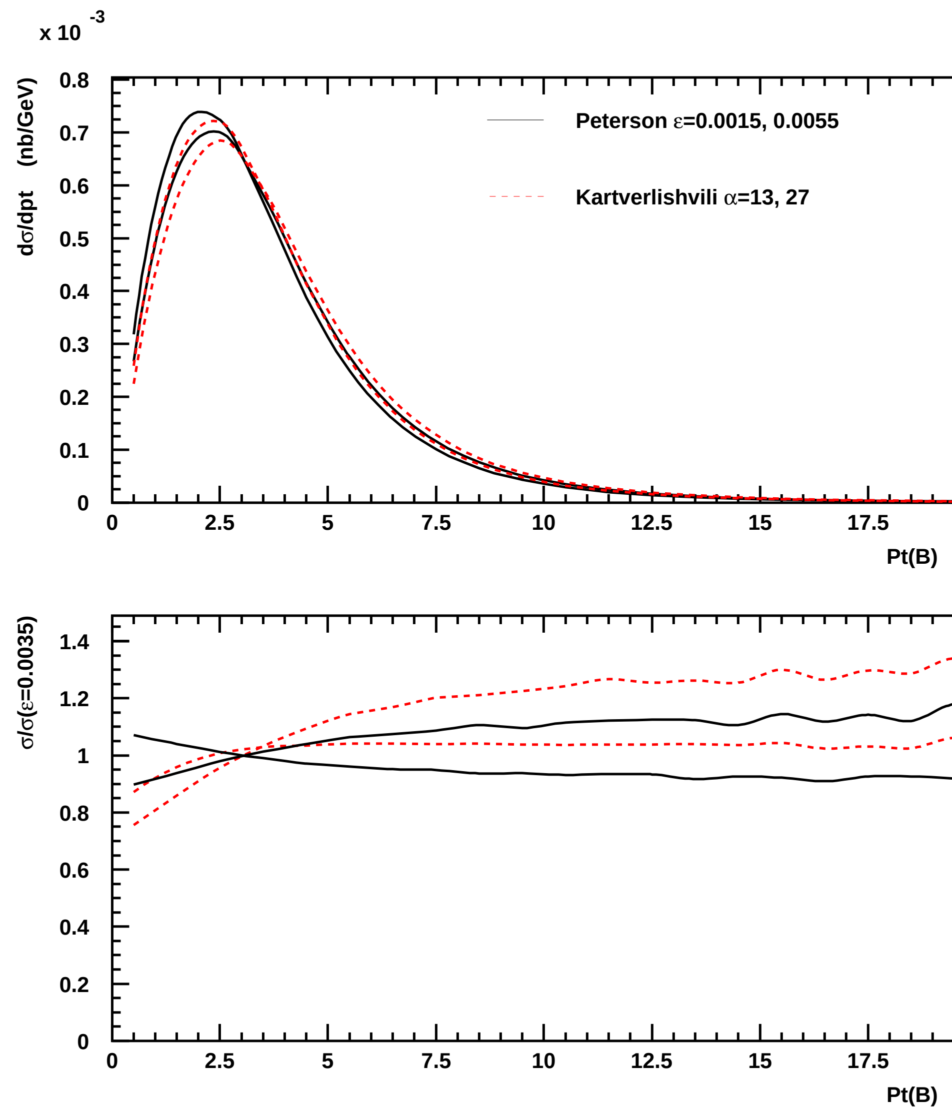
Red: rescaling $(E+P)^b$

- **Dependence on scaling variable at low p_T!**



Effects at HERA (2)

Try different $D^{\mathrm{NP}}(z)$



- **Large variation range:**

Black: Peterson with $\epsilon = 0.0015 - 0.0055$

Red: Kartvelishvili with $\alpha = 13 - 27$

- **Effect of** $\pm 10\%$ **at large** p_T

Conclusions

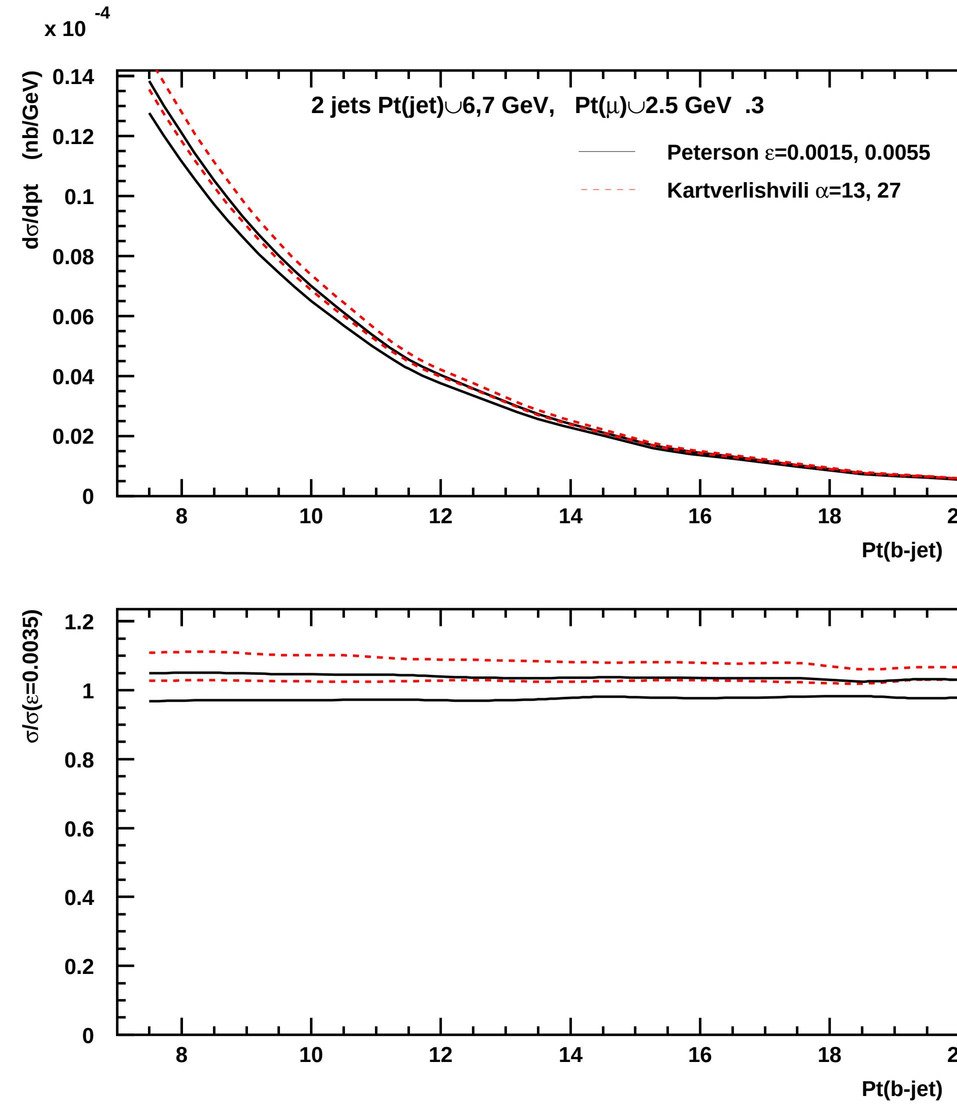
- **Universality of NP Fragm. Function needs to be tested**
- **Precise data available from LEP/SLD**
- **No perfect theoretical framework:**
  - **Try FONLL for** ee/pp **and** FO **for HERA**
  - **MC⊚NLO would be ideal if** ep **available**
- **effects of different choices of fragmentation at HERA** $\sim 10\%$

Possible Developments (Plans)

- **Fit LEP/SLD data using FONLL**
- **see effect on HERA observables (use HZTOOL ?)**
- **study how to measure fragmentation at HERA**

Effects at HERA (3)

Much reduced dependence on fragmentation when using jets



Black: Peterson with $\epsilon = 0.0015 - 0.0055$
Red: Kartvelishvili with $\alpha = 13 - 27$
Effect of $\pm 3\%$ **at large** p_T

HQ Perturbative Fragmentation Functions

HQ perturbative FF are introduced to resum large logs:
When $E \gg m_Q$ the cross section is finite but large terms like $\alpha_S^n \log^n(E^2/m_Q^2)$ appear.
Large logarithms can be resummed to all orders using perturbative FF:

$$\sigma_h(x, E, m_Q) = \int \frac{dz}{z} \sigma_Q^{\text{massless}}(z, Q) D_{Q \to H}^{\text{pert}}(x/z, E, m_Q) + O\left(\frac{m_Q}{E}\right) + O\left(\frac{\Lambda}{m_Q}\right)$$

So this is not related to the universality of $D^{NP}(z)$!