Charged particle multiplicity and hadronization properties of b quarks compared to light quarks in e^+e^- annihilations at $\sqrt{s} = 206$ GeV

Pavel Chliapnikov

Institute for High Energy Physics, Protvino

DELPHI Collaboration

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Detector simulation

In DELSIM, the full DELPHI simulation program, signal $q\bar{q}(\gamma)$ events were generated with KK2F for the primary quarks that were then fragmented with JETSET 7.4 Parton Shower and hadronization program, with parameters tuned to DELPHI data

Background events, dominated by WW and ZZ processes, were generated with WPHACT for the electroweak part, separately for WW (charged currents) and ZZ (neutral currents), to which then applied the PS and fragmentation as implemented in JETSET

The hadronic cross-section at 206 GeV is dominated by radiative $q\bar{q}(\gamma)$ events. ISR photons are generally aligned along the beam and not detected. In order to evaluate the hadronic c.m. energy, $\sqrt{s'}$, considering ISR, an algorithm is used that is based on a constrained fit method using four-momenta of jets and taking energy and momentum conservation into account. To remove the radiative return to the Z, it was required that $\sqrt{s'}/\sqrt{s} \geq 0.9$

Layout

The DELPHI detector at LEP has collected 164 pb^{-1} of data from 203 up to 208 GeV or at luminosity weighted average centre-of-mass energy $\sqrt{s} = 206$ GeV.

The cross section at $\sqrt{s} = 206$ GeV is dominated by radiative $q\bar{q}(\gamma)$ events. Event selection used to remove the radiative return to the Z and to reduce the background from WW and ZZ events is discussed.

Distribution of the multiplicity of charged particles, their average multiplicity, $\langle n_{ch} \rangle$, and dispersion, D, and their evolution with the centre-of-mass energy are discussed.

Average multiplicity in $b\bar{b}$ events, $\langle n_{ch} \rangle_{bb}$, the difference, δ_{bl}, between $\langle n_{ch} \rangle_{bb}$ and the average multiplicity, $\langle n_{ch} \rangle_{uds}$, in generic light quark events is presented.

Evolution of δ_{bl} with the centre-of-mass energy allows to test the consistency of QCD predictions, and of models assuming that multiplicity accompanying the decay of a heavy quark is independent of the mass of the quark itself.

Charged particle selection

p[GeV]	$0.1 \leq p$
$\Delta p/p$	≤ 1
θ	$20^\circ \leq \theta \leq 160^\circ$
track length	$\geq$ 30cm
$\Delta_{r\phi}$	$\leq$ 4cm
Δ_z	$\leq$ 10cm

Event selection

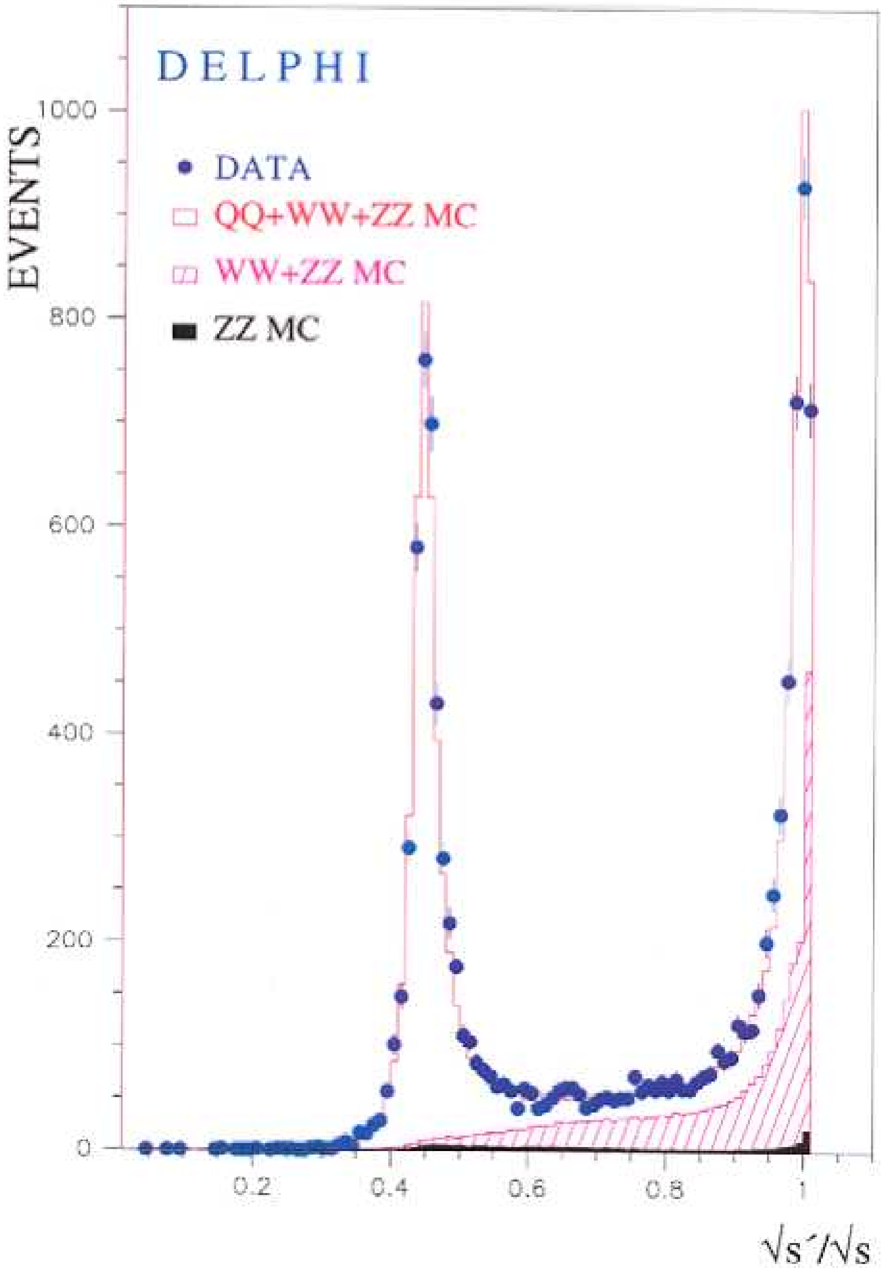
θ_{Thrust}	$30^\circ \leq \theta \leq 150^\circ$
E_{tot}	$\geq 20\%\ E_{CM}$
$\sqrt{s'}$	$\geq 90\%\ E_{CM}$
N_{ch}	$9 \leq N_{\mathrm{ch}}$
B_{N}	≤ 0.065

$\Delta_{r\phi}$ and Δ_z are the distances to the interaction point in $r\phi$ plane and z axis

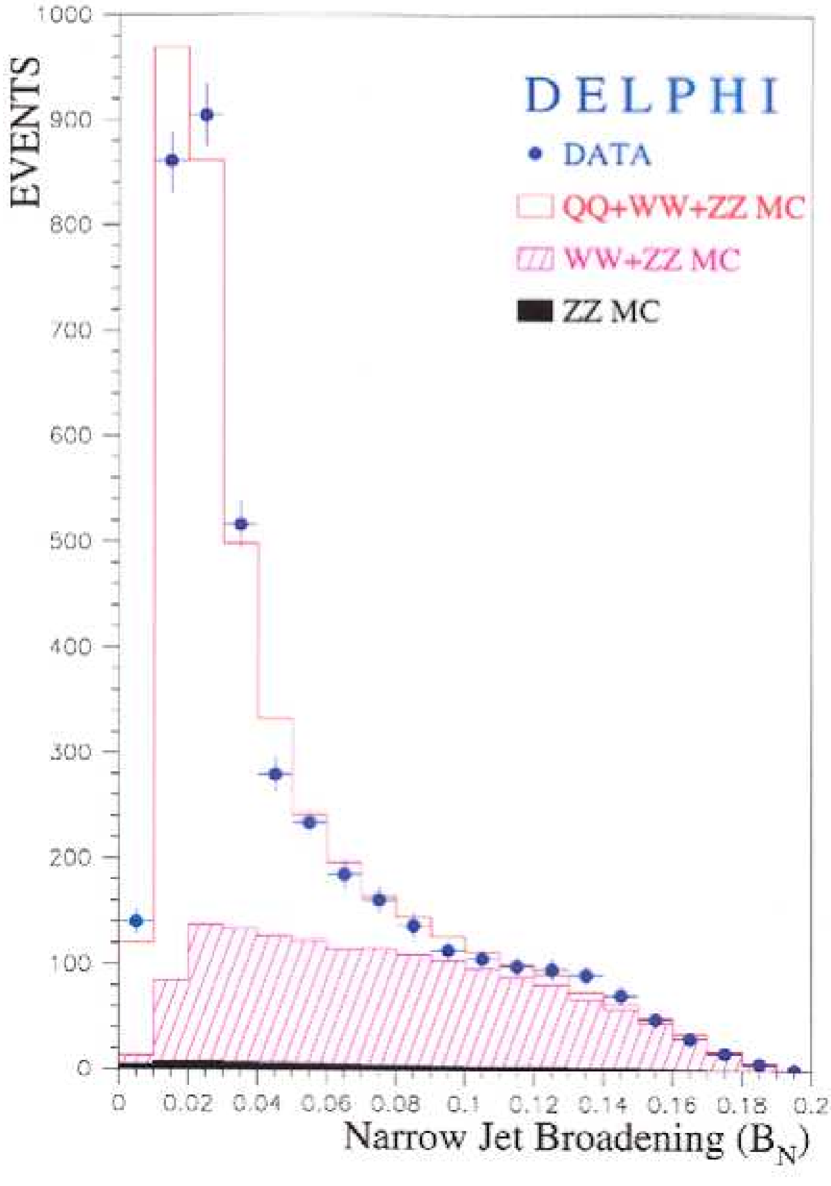
E_{tot} the total transverse energy carried by all selected particles and E_{CM} the nominal LEP energy

$\sqrt{s'}$ the reconstructed centre-of-mass energy, as reduced by ISR radiation

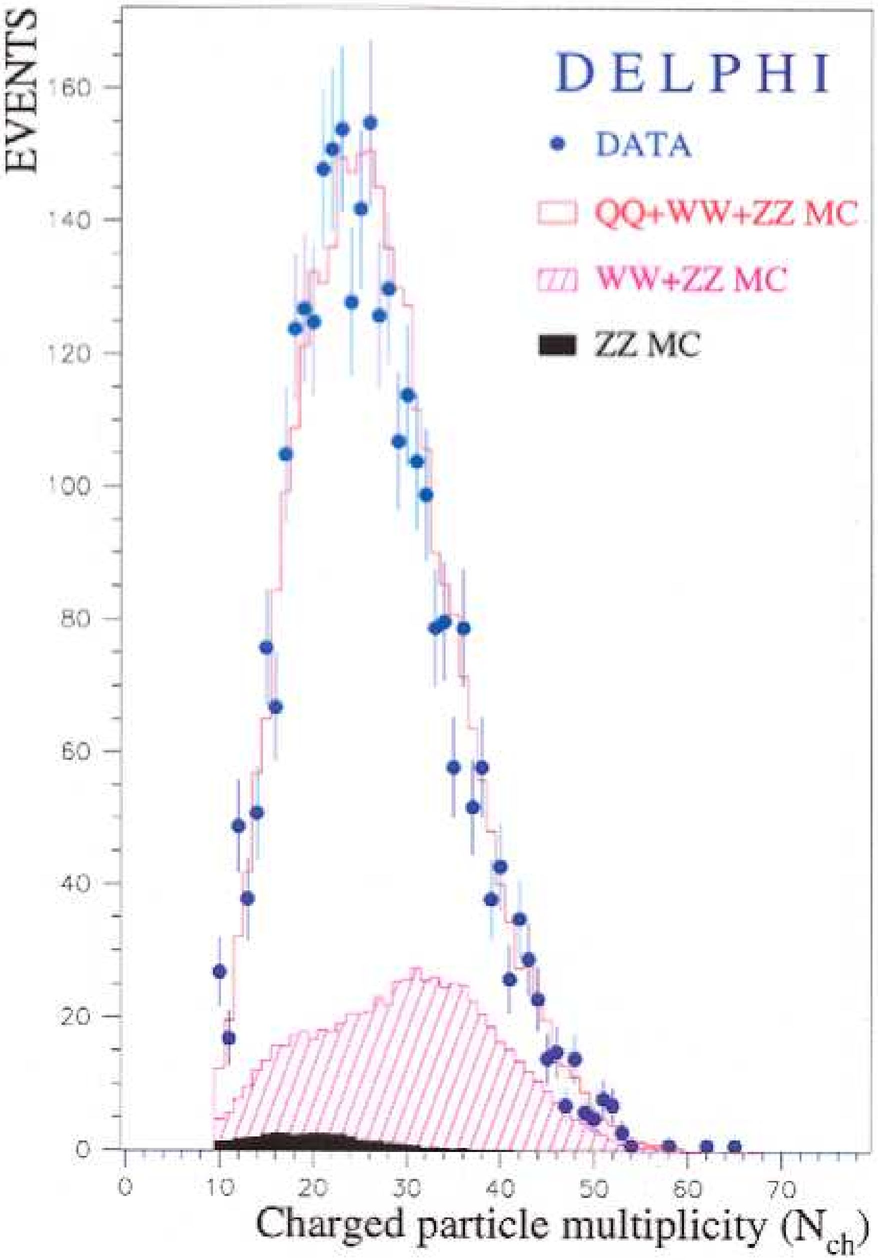
B_{N} the narrow jet broadening

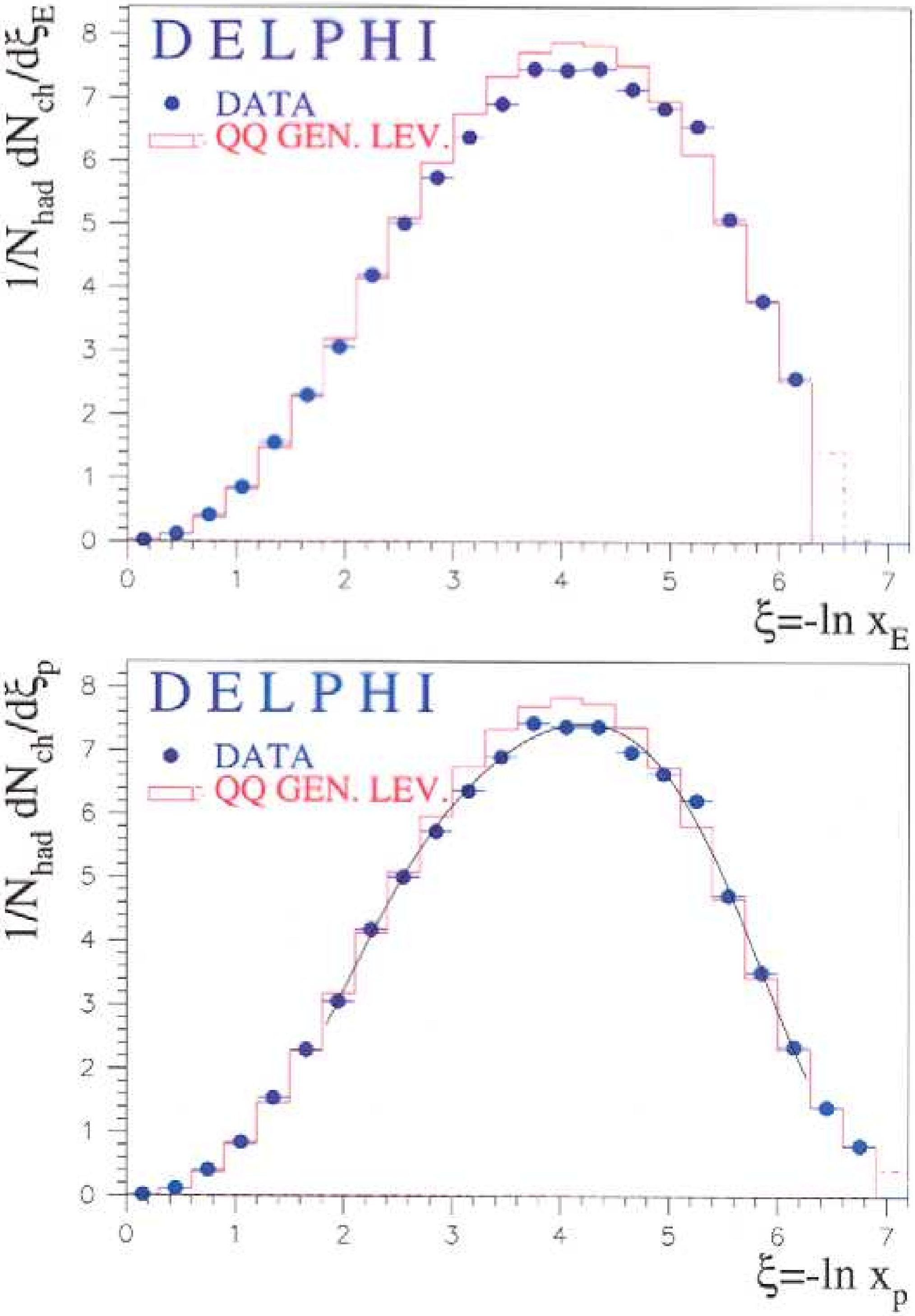


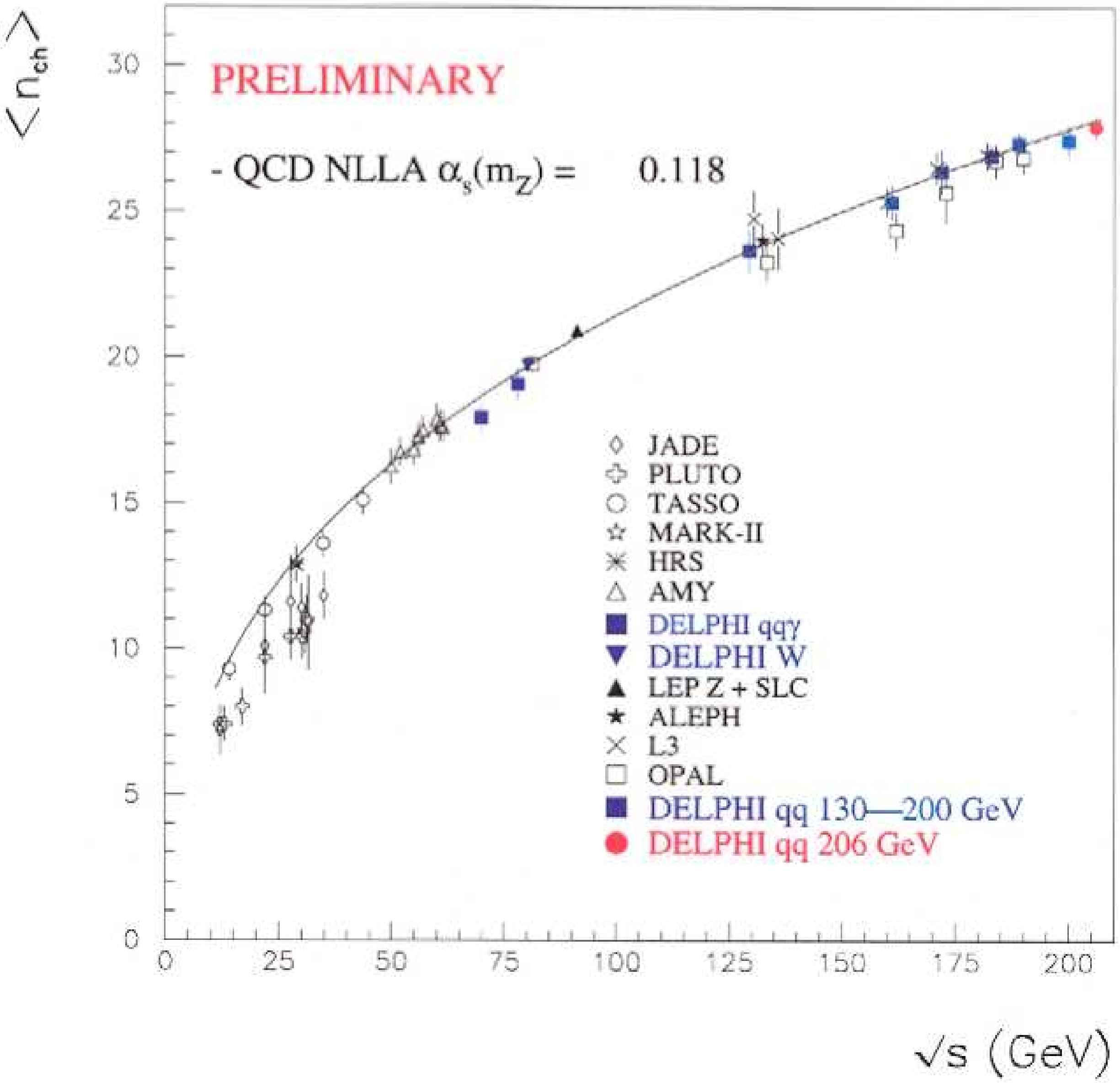
DELPHI
EVENTS
1000
800
600
400
200
0
DATA
QQ+WW+ZZ MC
WW+ZZ MC
ZZ MC
0.2
0.4
0.6
0.8
1
√s′/√s



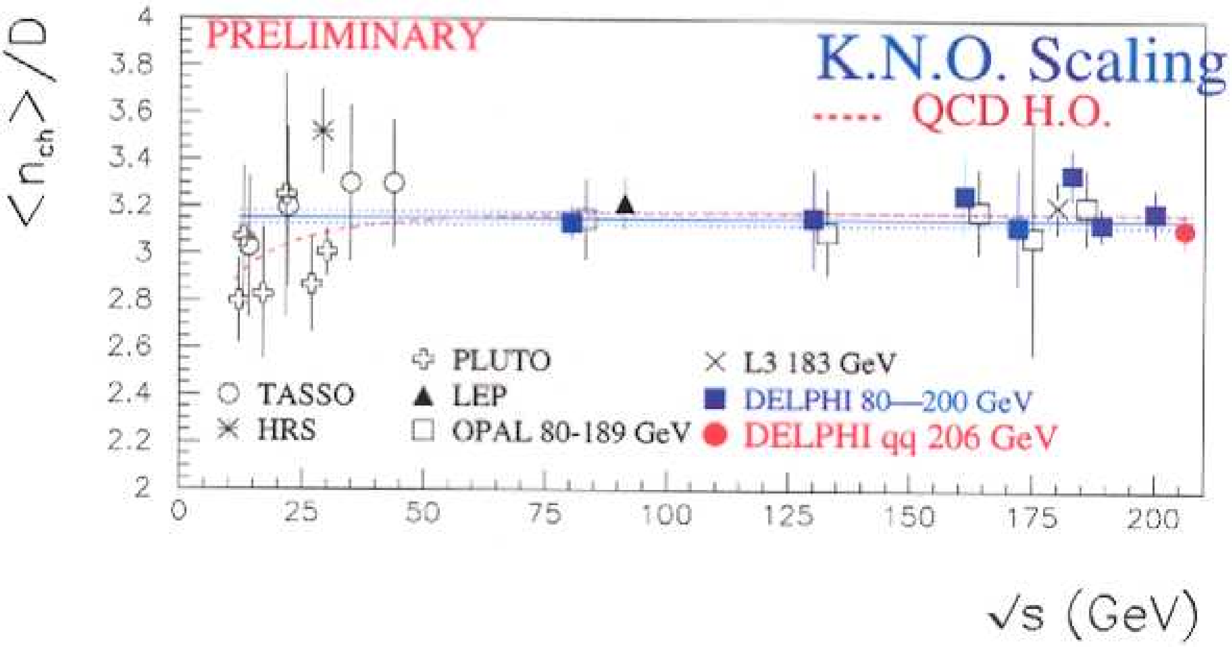
DELPHI
DATA
QQ+WW+ZZ MC
WW+ZZ MC
ZZ MC
EVENTS
1000
900
800
700
600
500
400
300
200
100
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Narrow Jet Broadening (B_N)


DELPHI
DATA
QQ+WW+ZZ MC
WW+ZZ MC
ZZ MC
EVENTS
Charged particle multiplicity (N_ch)


DELPHI
DATA
QQ GEN. LEV.
$1/N_{had}\ dN_{ch}/d\xi_E$
$\xi=-\ln x_E$
DELPHI
DATA
QQ GEN. LEV.
$1/N_{had}\ dN_{ch}/d\xi_p$
$\xi=-\ln x_p$



PRELIMINARY
- QCD NLLA $\alpha_s(m_Z)$ = 0.118
JADE
PLUTO
TASSO
MARK-II
HRS
AMY
DELPHI qqγ
DELPHI W
LEP Z + SLC
ALEPH
L3
OPAL
DELPHI qq 130—200 GeV
DELPHI qq 206 GeV
⟨n_{ch}⟩
√s (GeV)



PRELIMINARY
K.N.O. Scaling
----- QCD H.O.
PLUTO
TASSO
LEP
HRS
OPAL 80-189 GeV
L3 183 GeV
DELPHI 80—200 GeV
DELPHI qq 206 GeV
$\langle n_{ch} \rangle / D$
$\sqrt{s}$ (GeV)

Models and QCD predictions

In a model in which the hadronization is independent of the mass of the quarks (Kisselev, Petrov, Yushchenko, 1988), one assumes that the non-leading multiplicity in an event, i.e., the light quark multiplicity which accompanies the decay products of the primary hadrons, is governed by the effective energy available to the fragmentation system following the production of the primary hadrons

In QCD, the large mass of the b quark, in comparison to the scale of the strong interaction, $\Lambda \simeq 0.2$ GeV, results in a natural cut off for the emission of gluon bremsstrahlung. For c.m. energy greatly exceeding the scale of the b quark mass, the inclusive spectrum of heavy quark production is expected to be well described by perturbative QCD in MLLA. The value of δ_{bl} calculated in perturbative QCD:

$$\begin{aligned}\delta_{bl} &= 2\langle n_B^{(decay)}\rangle - \langle n_{l\bar{l}}\rangle(\sqrt{s} = e^{1/2} m_b) \\ &+ O(\alpha_s(m_b))\langle n_{l\bar{l}}\rangle(\sqrt{s} = m_b)\end{aligned}$$

(Schumm, Dokshitzer, Khoze, Koetke 1992)
(Petrov, Kisselev, 1995)

Results for charged multiplicity

The average charged particle multiplicity and dispersion of the charged particle multiplicity distribution, together with the peak position of the ξ_p distribution, in e^+e^- annihilations at 206 GeV were measured as

$$\begin{aligned} \langle n_{ch} \rangle &= 28.03 \pm 0.22 \pm 0.27 \\ D_{ch} &= 8.97 \pm 0.16 \pm 0.13 \\ \xi_p^* &= 4.21 \pm 0.04 \pm 0.02 \end{aligned}$$

b- and uds-event selection

Two samples enriched in (1) $b-$ events and in (2) $uds-$ events were selected from the b tagging variable, representing the probability that none of the tracks in the event comes from a vertex separated from the primary one. A third sample (3) consisted of all events.

Purities for $b-$ and $uds-$ events over the total $q\bar{q}$ in samples (1) and (2) were approximately 91% and 83%, respectively.

The average multiplicity for a given flavour q in each sample is equal to $C_q^{(i)} \times \langle n \rangle_{q\bar{q}}$, with $C_q^{(i)} \neq 1$ in general. The factors $C_q^{(i)}$ account for biases introduced by the application of the b probability and the jet broadening cuts, as well as for detector effects. These factors and the fractions of q-type quarks in the (i)-th sample, $f_q^{(i)}$, were determined from the simulation.

Average multiplicities

In each of the three samples, the average multiplicity $\langle n \rangle$ is a linear combination of the unknowns $\langle n \rangle_{b\bar{b}}$, $\langle n \rangle_{l\bar{l}}$ and $\langle n \rangle_{c\bar{c}}$. One can thus formulate a set of three simultaneous equations to compute these unknowns:

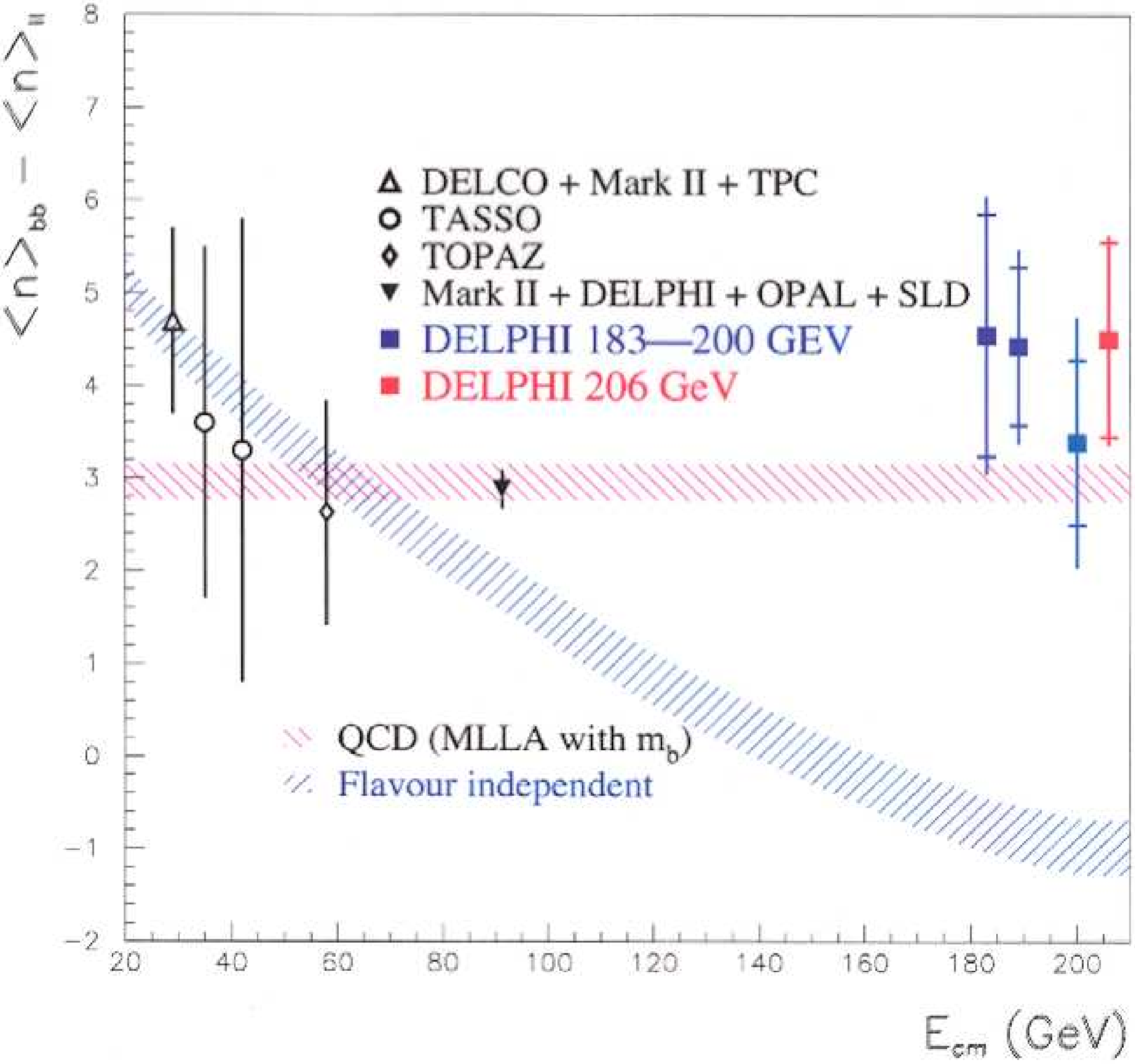
$$\begin{aligned}
\langle n \rangle^{(1)} &= f_b^{(1)} C_b^{(1)} \langle n \rangle_{b\bar{b}} + f_{uds}^{(1)} C_{uds}^{(1)} \langle n \rangle_{l\bar{l}} + f_c^{(1)} C_c^{(1)} \langle n \rangle_{c\bar{c}} \\
\langle n \rangle^{(2)} &= f_b^{(2)} C_b^{(2)} \langle n \rangle_{b\bar{b}} + f_{uds}^{(2)} C_{uds}^{(2)} \langle n \rangle_{l\bar{l}} + f_c^{(2)} C_c^{(2)} \langle n \rangle_{c\bar{c}} \\
\langle n \rangle^{(3)} &= f_b^{(3)} \langle n \rangle_{b\bar{b}} + f_{uds}^{(3)} \langle n \rangle_{l\bar{l}} + f_c^{(3)} \langle n \rangle_{c\bar{c}}
\end{aligned}$$

Solving the above equations gave the following mean charge multiplicities:

$$\begin{aligned}
\langle n \rangle_{b\bar{b}}(206\,\mathrm{GeV}) &= 28.72 \pm 0.70 \\
\langle n \rangle_{c\bar{c}}(206\,\mathrm{GeV}) &= 36.32 \pm 3.08 \\
\langle n \rangle_{l\bar{l}}(206\,\mathrm{GeV}) &= 24.22 \pm 1.09 \\
\delta_{bl}(206\,\mathrm{GeV}) &= 4.50 \pm 1.05
\end{aligned}$$

with correlation coefficient of -0.38 between $\langle n \rangle_{b\bar{b}}$ and $\langle n \rangle_{l\bar{l}}$. With the systematic errors included, the final numbers are:

$$\begin{aligned}
\langle n \rangle_{b\bar{b}}(206\,\mathrm{GeV}) &= 28.72 \pm 0.70 \pm 0.32 \\
\delta_{bl}(206\,\mathrm{GeV}) &= 4.50 \pm 1.05 \pm 0.52
\end{aligned}$$



$\langle n \rangle_{bb} - \langle n \rangle_{ll}$
8
7
6
5
4
3
2
1
0
−1
−2
DELCO + Mark II + TPC
TASSO
TOPAZ
Mark II + DELPHI + OPAL + SLD
DELPHI 183—200 GEV
DELPHI 206 GeV
QCD (MLLA with m_b)
Flavour independent
20
40
60
80
100
120
140
160
180
200
E_{cm} (GeV)

Summary

The average charged particle multiplicity and dispersion of the charged particle multiplicity distribution, together with the peak position of the ξ_p distribution, were measured at the highest c.m. energy in e^+e^- annihilations at 206 GeV:

$$\begin{aligned} \langle n_{ch} \rangle &= 28.03 \pm 0.22 \pm 0.27 \\ D_{ch} &= 8.97 \pm 0.16 \pm 0.13 \\ \xi_p^* &= 4.21 \pm 0.04 \pm 0.02 \end{aligned}$$

in agreement with the expected energy evolution predicted by QCD and KNO hypothesis

The difference between the average charged particle multiplicity $\langle n \rangle_{b\bar{b}}$ in $e^+e^- \to b\bar{b}$ events and the multiplicity in generic light quark $l = u, d, s$ events was measured at 206 GeV:

$$\delta_{bl} = 4.50 \pm 1.05 \pm 0.52 \qquad (1)$$

This difference, when compared to equivalent values at other c.m. energies, is in agreement with QCD predictions, while it is inconsistent with calculations assuming that the multiplicity accompanying the decay of a heavy quark is independent of the mass of the quark itself