Bose-Einstein Correlations in WW System at LEP

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Outline

- Introduction
- Theory
- Experimental Results
- Conclusions

Introduction

- Typical separation between W^+ and W^- at LEP2 energies is around 0.1 fm.

- One expects some coherence effects between identical bosons from different Ws due to the Bose Einstein Correlations.

- The effect due to BE is that the softest particles from each W are dragged closer to each other.

- This reduces the momentum of the Ws and thus increases the measured W mass.

- Number of estimates of this effect on W mass can be found in the literature ranging from 30 MeV to 100 MeV.

Theory

- Production of pions can be pictured as occurring at space-time points x inside some finite space-time volume during the hadronization of quarks and gluons.

- The distribution of these production points can be described by a function $f(x)$.

- Consider two pions with the same charge produced at points x_A and x_B. They are observed at detectors 1 and 2 with four-momenta p_1 and p_2 respectively.

- Due to the ambiguity in the origin of pions proper symmetrization is needed;

$$\psi = \frac{1}{\sqrt{2}}(\psi_{1A}\psi_{2B} + \psi_{1B}\psi_{2A})$$

Theory

- The probability density

$$I_{BE} \equiv |\psi|^2 = 1 + cos[(p_1 - p_2)(x_A - x_B)]$$

- Going from two point sources to the distribution of pion production points;

$$C_{BE}(p_1, p_2) = \frac{I_{BE}}{I_{ref}} = 1 + |G[f(x)]|^2$$

- Using Goldhaber-Goldhaber-Lee-Pais (GGLP) parameterisation and spherical shape for the source

$$C(Q) = 1 + \lambda\, exp(-R^2 Q^2)$$
$$Q^2 \equiv -(p_1 - p_2)^2 = M_{12}^2 - 4m_\pi^2$$

$M_{12} \rightarrow$ Invariant Mass of the Pion Pair
$R \rightarrow$ Radius of the pion emitting source
$\lambda \rightarrow$ is the measure of degree of source coherence

- To fit the data;

$$C(Q) = N[1 + \lambda\, exp(-R^2 Q^2)](1 + \delta Q)$$

Experimentally

Bose Einstein Correlations can be measured by taking the ratio of like-sign pion pairs to unlike-sign pion pairs;

$$R(Q) = \frac{N_{\pi}^{++,--}}{N_{\pi}^{+-}}$$

One can also form the double ratio i.e. the above ratio from data is divided by the same ratio from the Monte Carlo;

$$R(Q)^{*} = \frac{R(Q)^{data}}{R(Q)^{MC}}$$

Corrections due to Coulomb interactions are applied to data;

$$C_{cor}(Q) = \chi(Q) C_{uncor}(Q)$$

$$\chi(Q) = \frac{exp^{2\pi\eta} - 1}{1 - exp^{-2\pi\eta}}$$

Experimentally

At LEP2 we are interested to measure BE correlations between different Ws where both of them decaying hadronically;

To disentangle the contribution from BE correlations within the same W and different Ws;

1. The Q distribution for pion pairs was obtained for events where both Ws decay hadronically.
2. This distribution is the sum of pion pairs coming from the same W and that of the pion pairs from different Ws.
3. Contribution of pion pairs coming from the same W was subtracted statistically using the Q distribution from the semileptonic events.

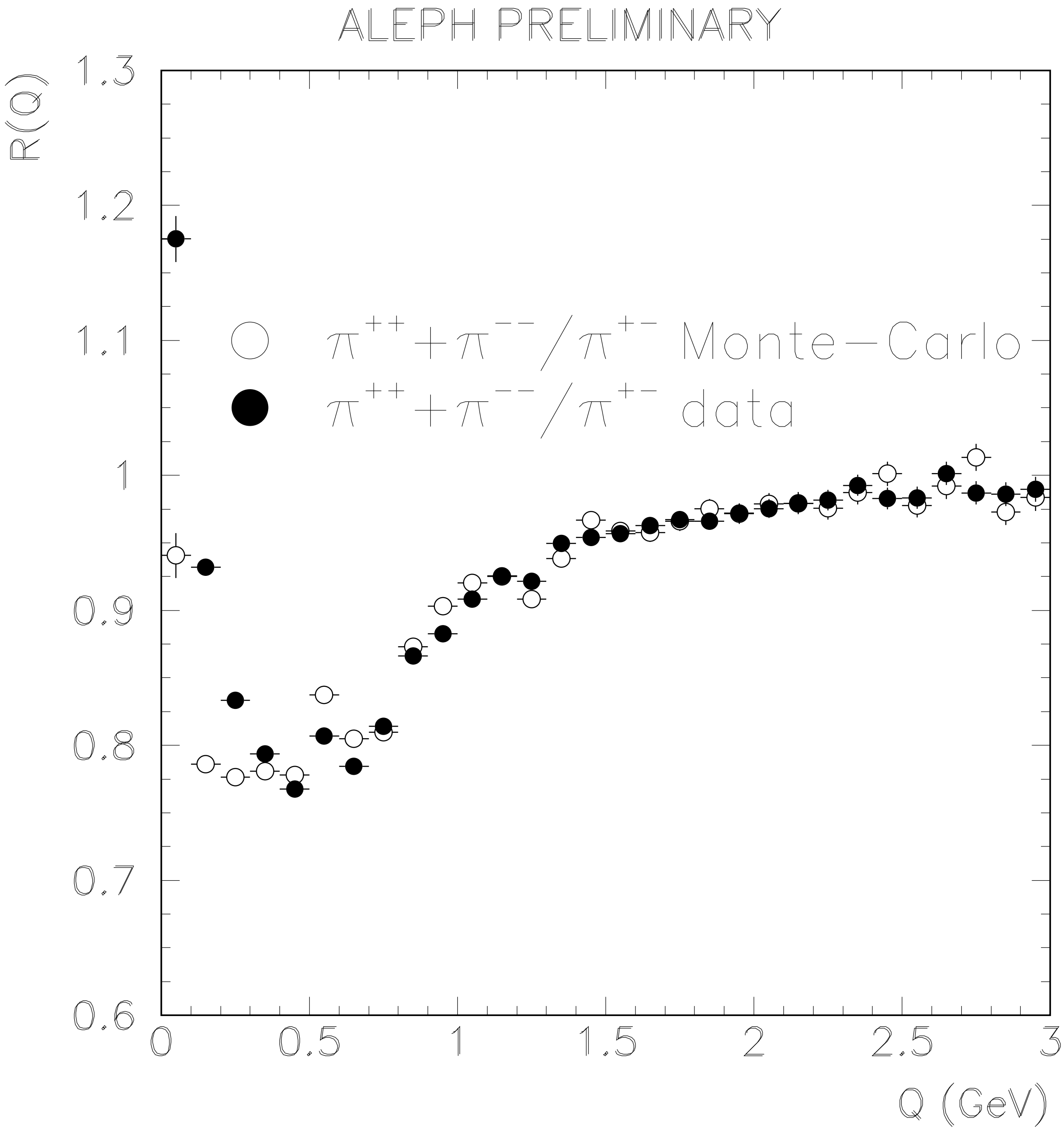
L3, OPAL:

Measured distributions can be unfolded using Monte Carlo.

ALEPH,DELPHI

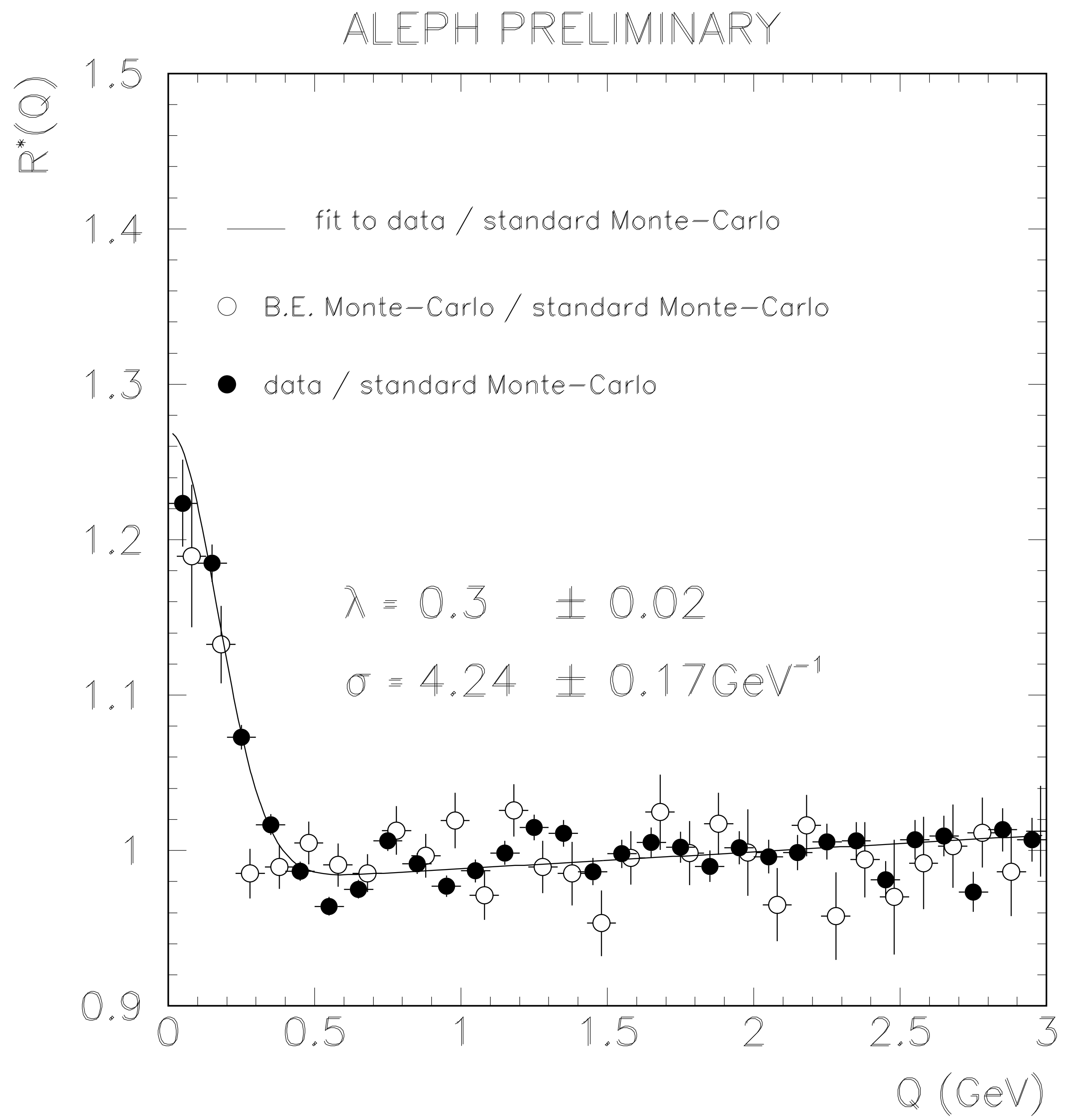
- W-pairs at $\sqrt{s}$ = 172 GeV with 10 pb^{-1}
- Contribution of the pion pairs coming from same W was subtracted statistically using semi-leptonic event.
- No corrections are applied due to Coulomb interactions.
- **ALEPH** in addition;
  1. Z calibration run data, Radiative Z events.
  2. Double ratios are used.
  3. Weighting scheme is used in MC.

ALEPH



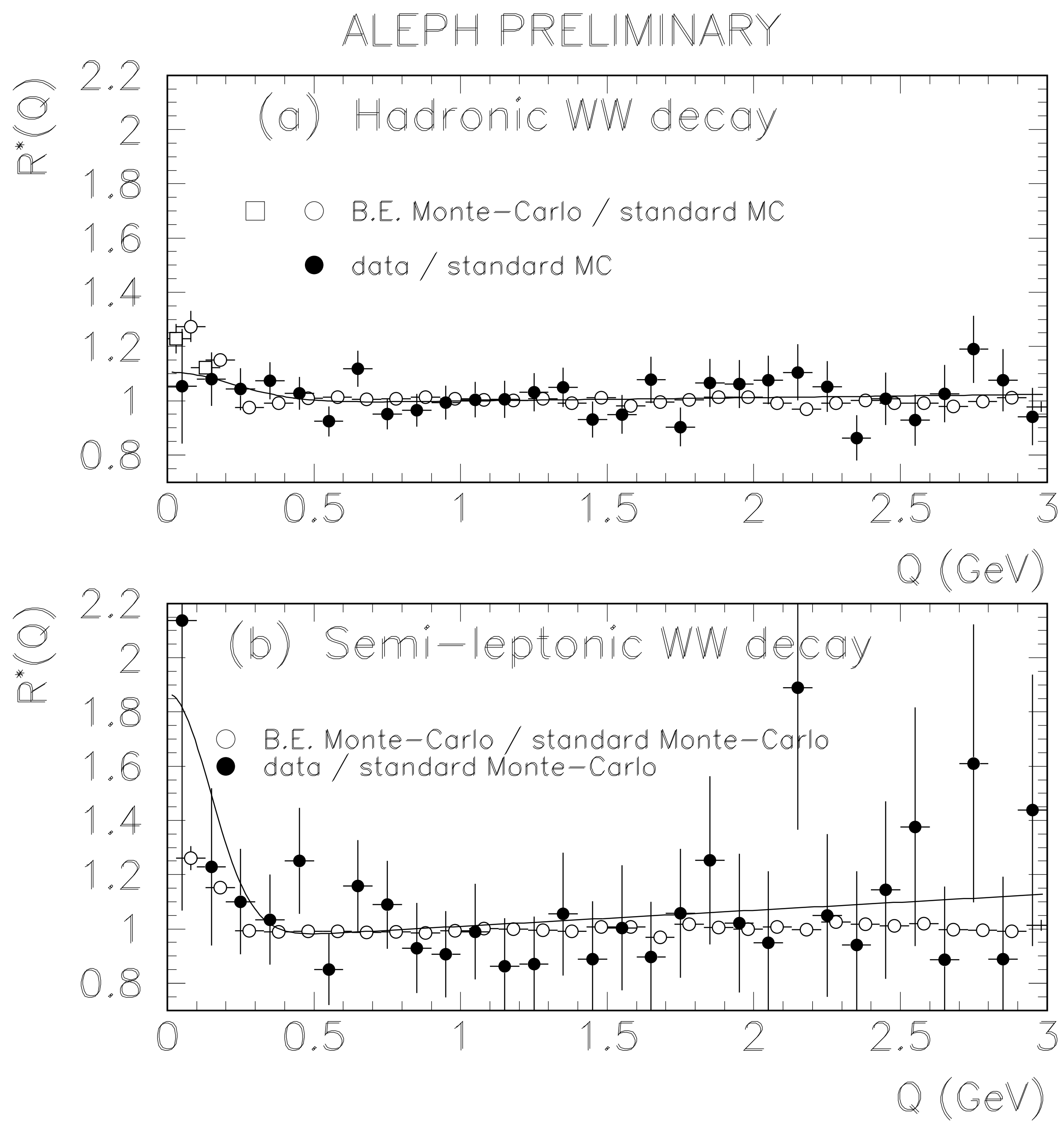
Data from Z Calibration run at $\sqrt{s} = 91$ GeV

ALEPH



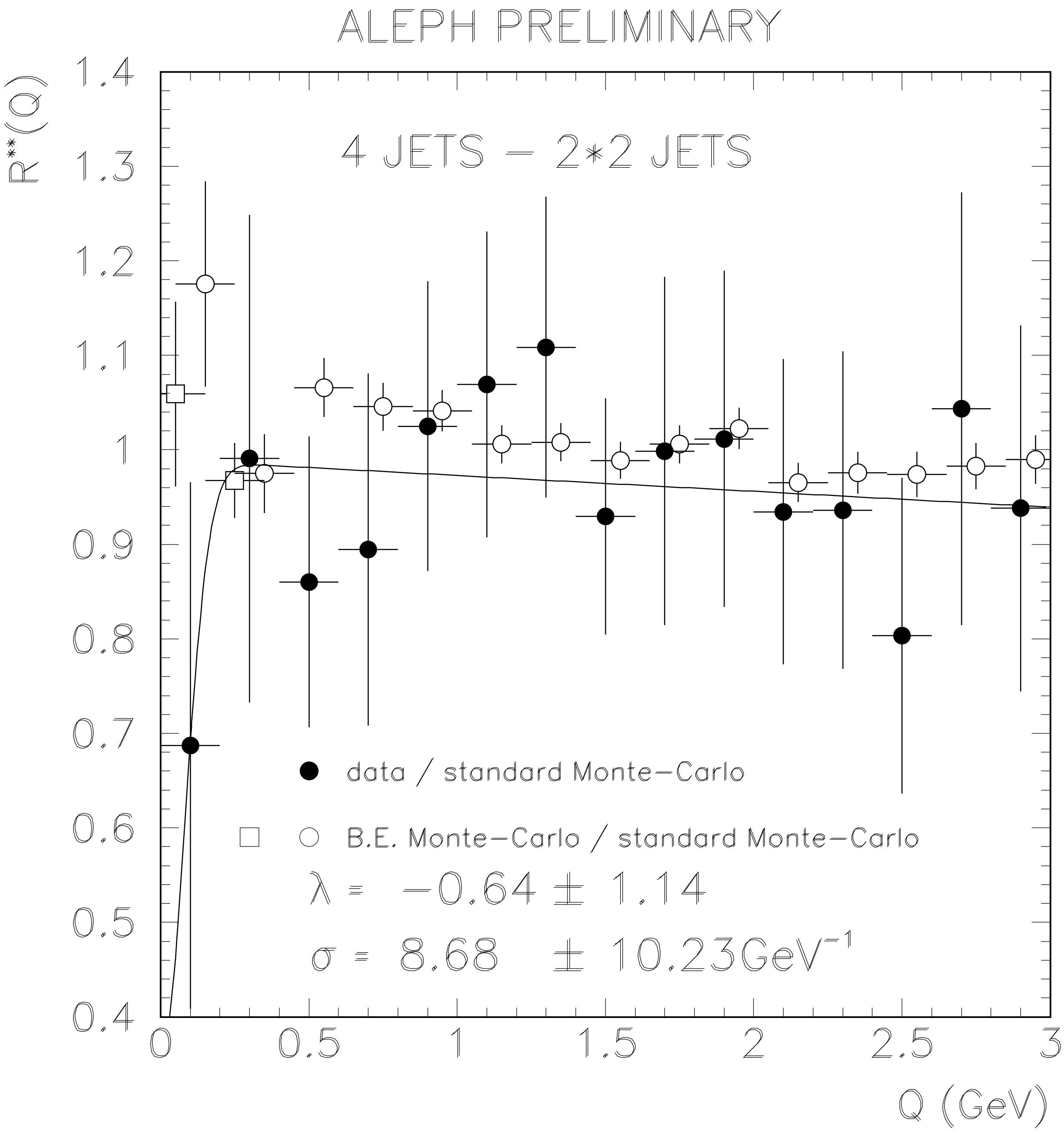
Data from Z Calibration run at $\sqrt{s} = 91$ GeV

ALEPH



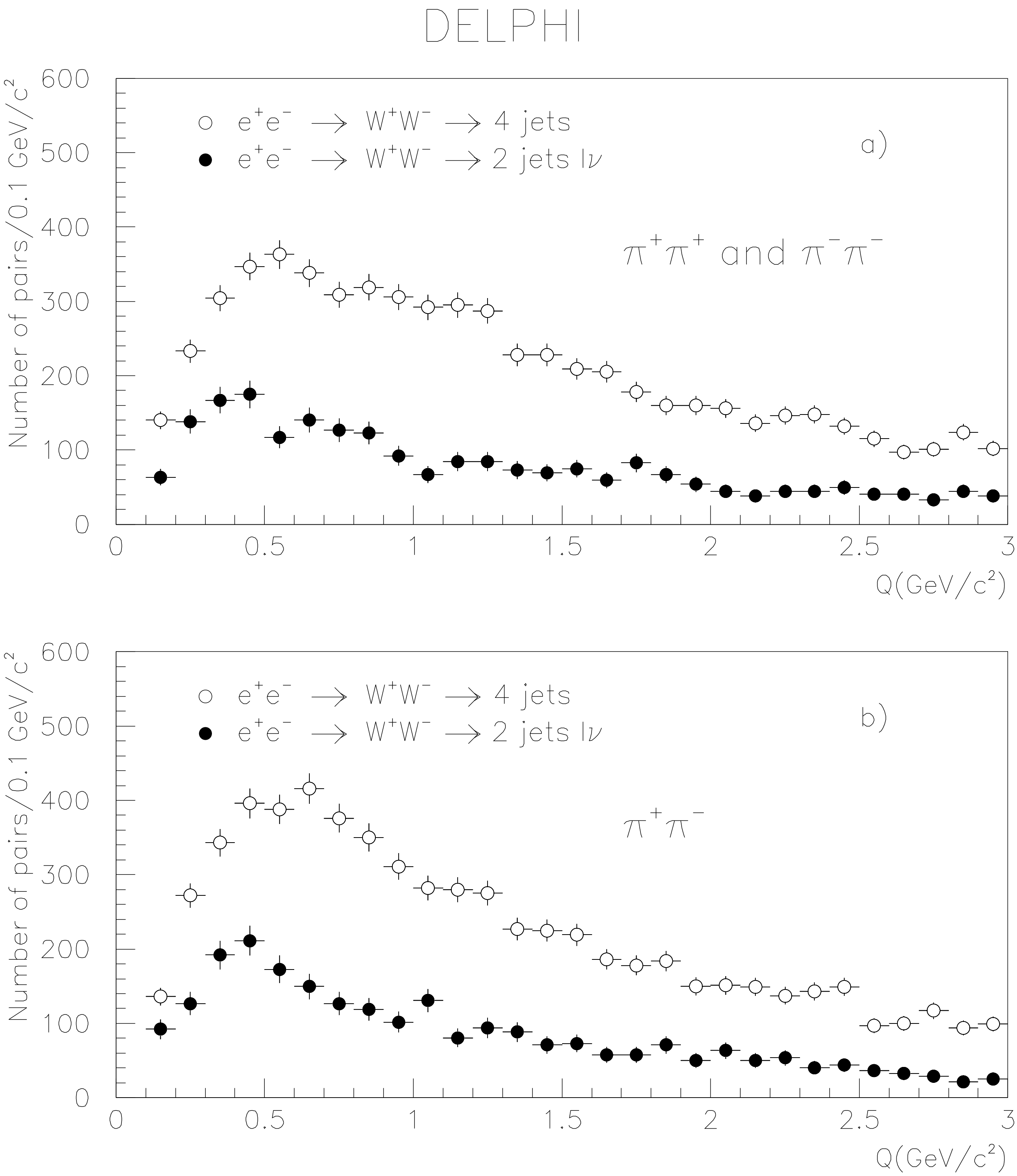
Data from LEP run at $\sqrt{s} = 172$ GeV

ALEPH



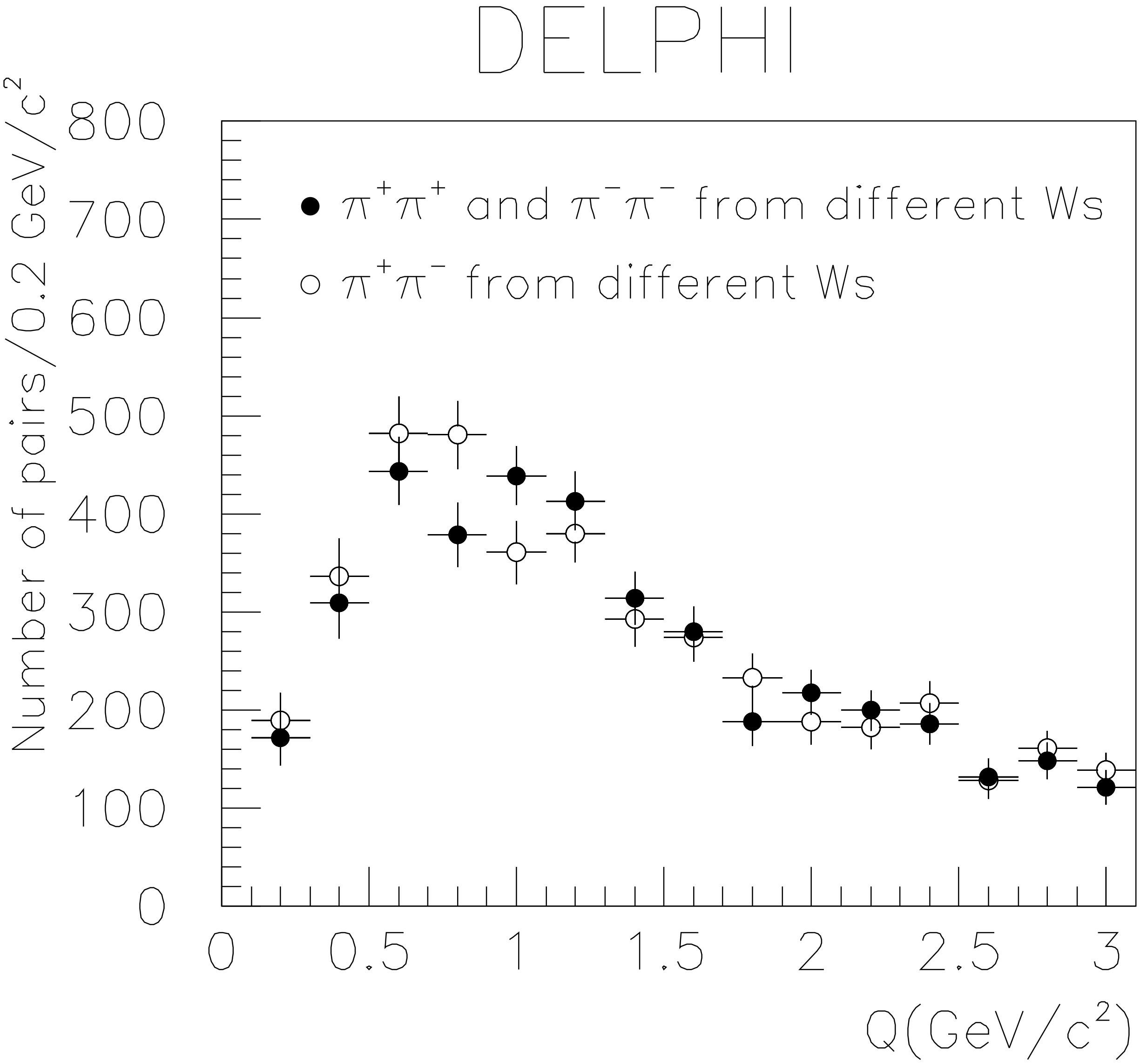
ALEPH PRELIMINARY
4 JETS − 2*2 JETS
R**(Q)
Q (GeV)
data / standard Monte−Carlo
B.E. Monte−Carlo / standard Monte−Carlo
λ = −0.64 ± 1.14
σ = 8.68 ± 10.23GeV⁻¹

DELPHI



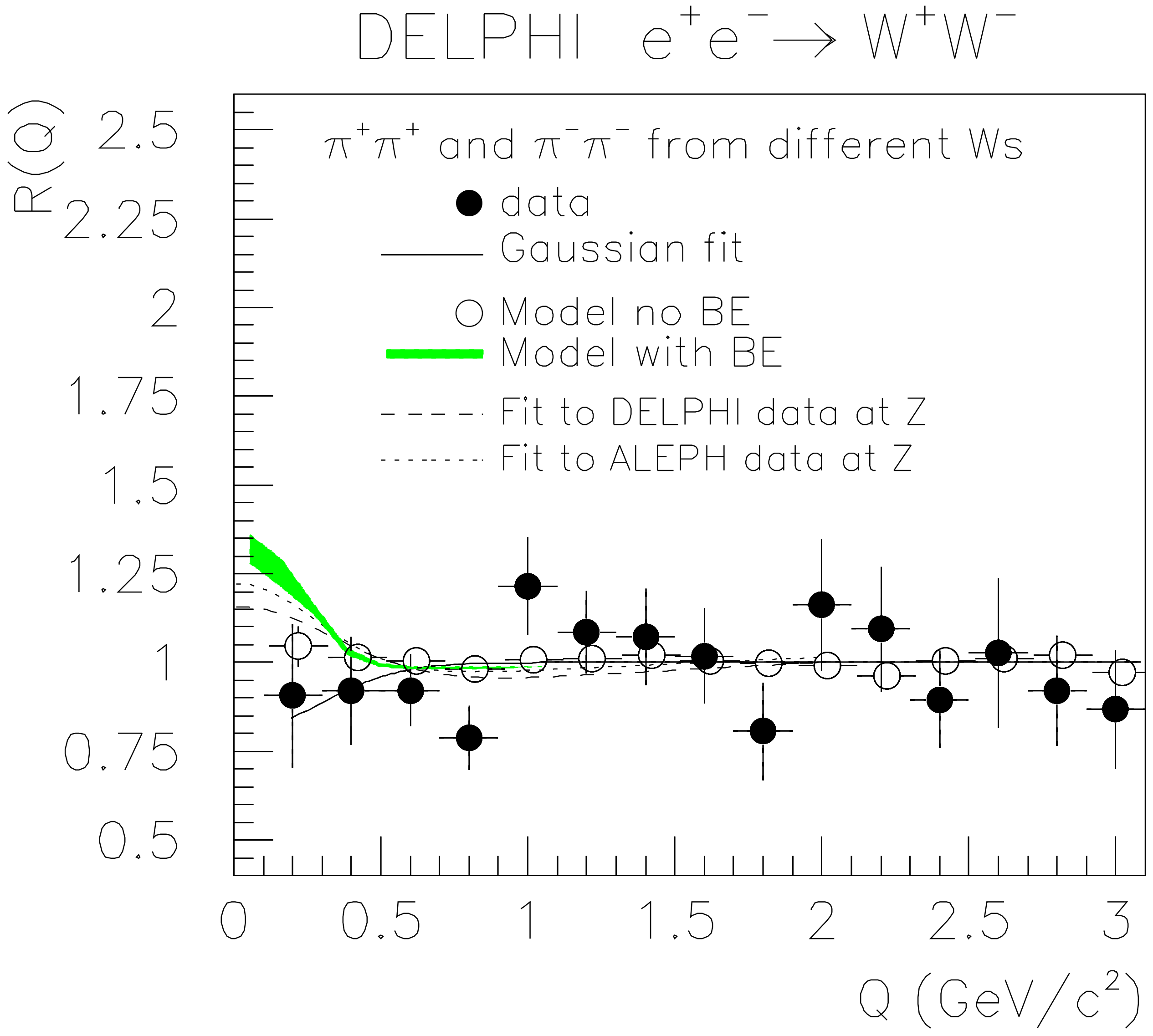
Data from LEP run at $\sqrt{s} = 172$ GeV

DELPHI



Data from LEP run at $\sqrt{s} = 172$ GeV

DELPHI

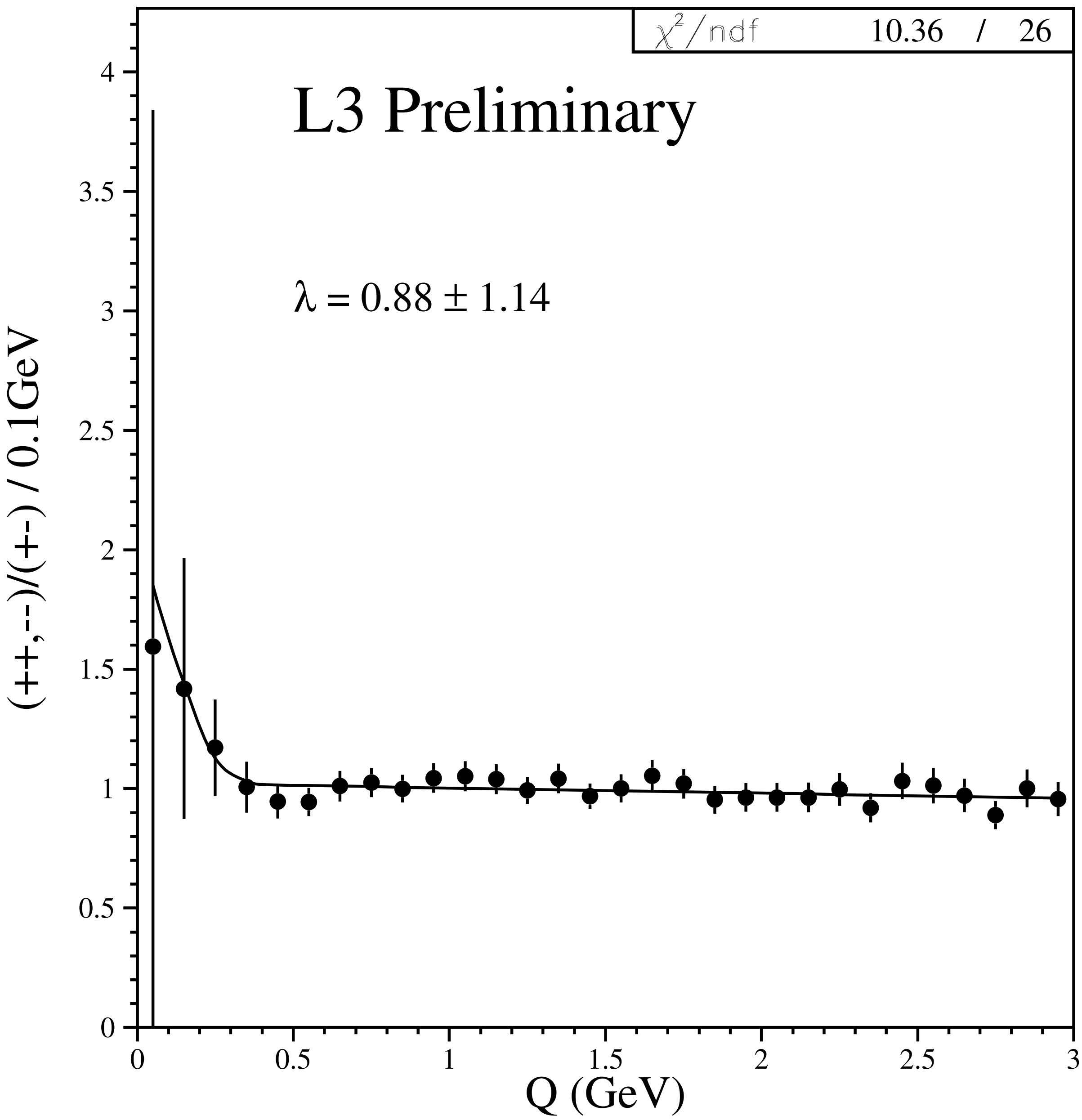


DELPHI $e^+e^- \to W^+W^-$
$\pi^+\pi^+$ and $\pi^-\pi^-$ from different Ws
data
Gaussian fit
Model no BE
Model with BE
Fit to DELPHI data at Z
Fit to ALEPH data at Z
R(Q)
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0
0.5
1
1.5
2
2.5
3
Q (GeV/c^2)

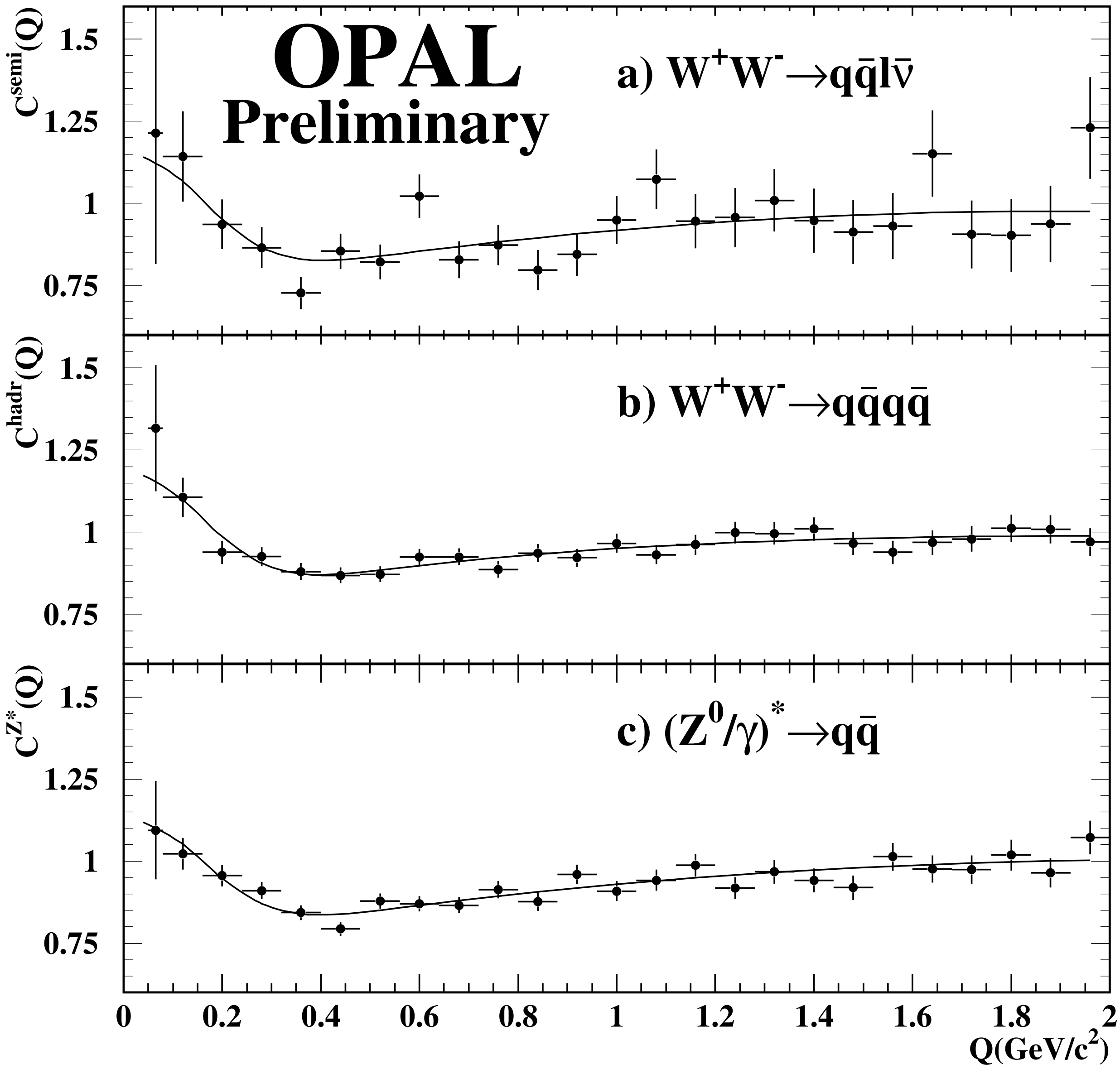
L3,OPAL

- Experimental distributions are unfolded using Monte Carlo.
- **L3:** Fraction of pion pairs coming from same W are estimated bin-by-bin in Q.
- **OPAL:**
  1. Select $\mathrm{WW} \to \mathrm{q\bar{q}}\ell\bar{\nu}$, $\mathrm{WW} \to \mathrm{q\bar{q}q\bar{q}}$ and $(\mathrm{Z}^*/\gamma) \to \mathrm{q\bar{q}}$ samples.
  2. Fit simultaneously for $\lambda^{\mathrm{same\,W}}$, $\lambda^{\mathrm{diff\,W}}$ and λ^{Z^*}.
  3. Taking into account cross-feed between channels.
- Data at $\sqrt{s} = 183$ GeV is used with total integrated luminosity of 55 pb^{-1}.
- Corrections due to Coulomb interactions are applied.

L3

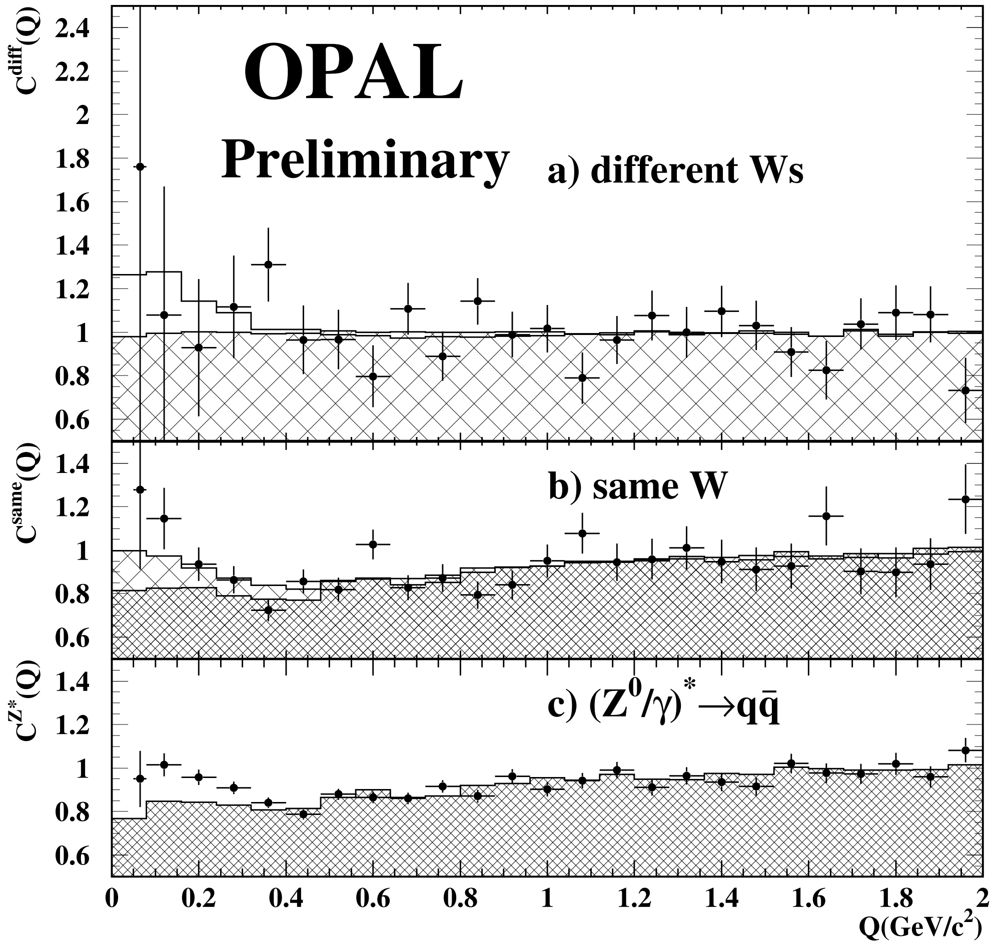


χ^2/ndf 10.36 / 26
L3 Preliminary
$\lambda = 0.88 \pm 1.14$
(++,--)/(+-) / 0.1GeV
Q (GeV)
0
0.5
1
1.5
2
2.5
3
3.5
4



Data from LEP run at $\sqrt{s}$ = 172 GeV and 183 GeV

Unfolded



Data at $\sqrt{s}$ = 172 GeV and 183 GeV.

Open histogram: BEC different W's only.

Wide hatched histogram: BEC same W's only.

Fine hatched histogram: no BEC.

Conclusions

LEP experiments have measured the following values of parameter λ which in turn measures the strength of Bose Einstein Correlations;

Experiment	λ
ALEPH	**-0.64 $\pm$ 1.14**
DELPHI	**-0.20 $\pm$ 0.22 $\pm$ 0.08**
L3	**0.88 $\pm$ 1.14**
OPAL	**0.40 $\pm$ 0.50 $\pm$ 0.39**

At the present level of statistics, no Bose Einstein correlations are observed between different Ws decaying hadronically in the same event.