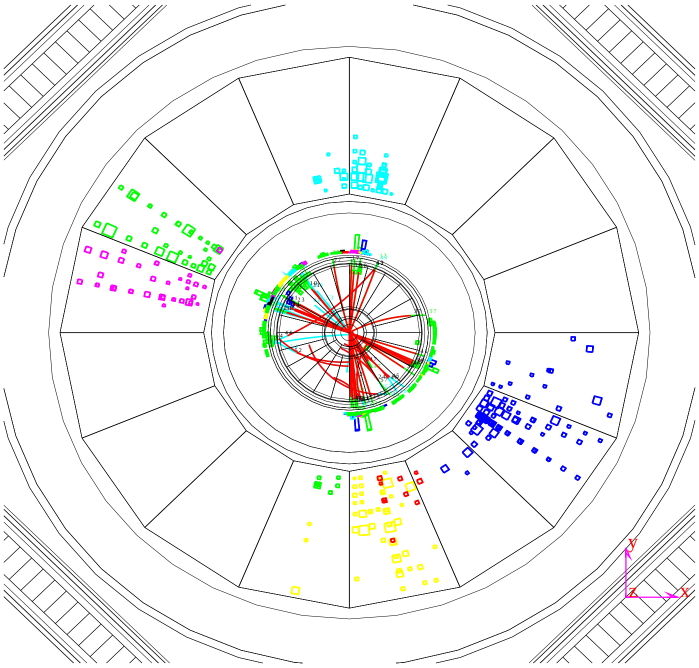
Bose-Einstein Correlations in W^+W^- Events at LEP

Jorn van Dalen
University of Nijmegen
The Netherlands

Introduction



$$W^+W^- \rightarrow q_1\bar{q}_2q_3\bar{q}_4$$

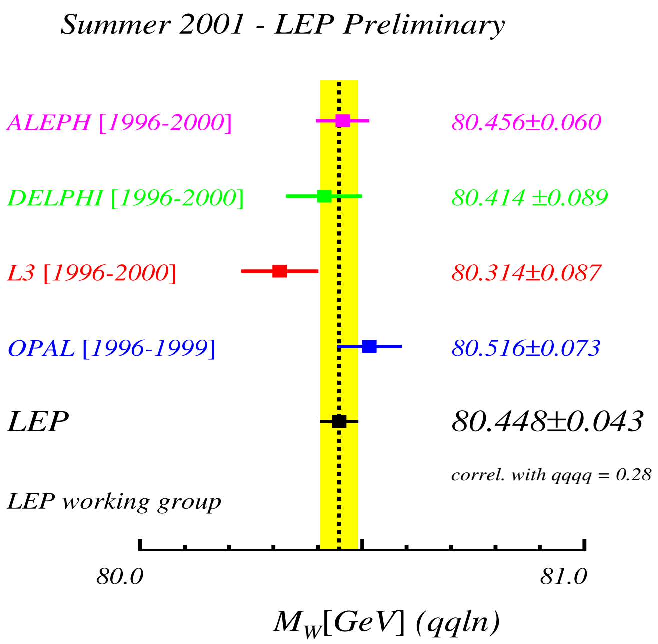
Distance between W decay vertices ~ 0.1 fm, whereas the hadronic scale ~ 1 fm.
$\Rightarrow$ There may be inter-W correlations:

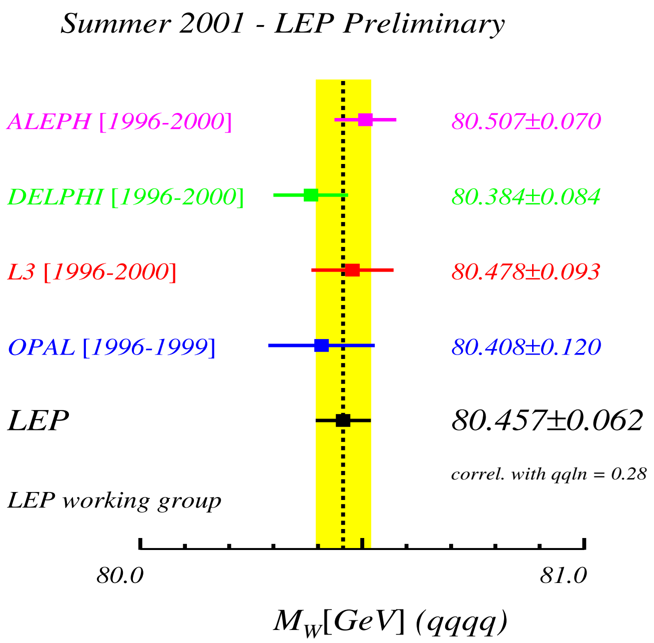
- Colour Rearrangement
- Inter-W Bose-Einstein Correlations (BEC)

LEP2

- 2^{nd} phase of the Large e^+e^- collider
- Major aim of LEP2: Precision M_W measurement.
- $\mathcal{L} \simeq 700\ pb^{-1}$/exp.; $\sqrt{s} \simeq$160-209 GeV;
  data are collected in 1996-2000
- $\sim$10k W^+W^- events/exp.; most at $\sqrt{s} \geq$189 GeV

Results for the $q_1\bar{q}_2\ell\nu$ and $q_1\bar{q}_2q_3\bar{q}_4$ channel:



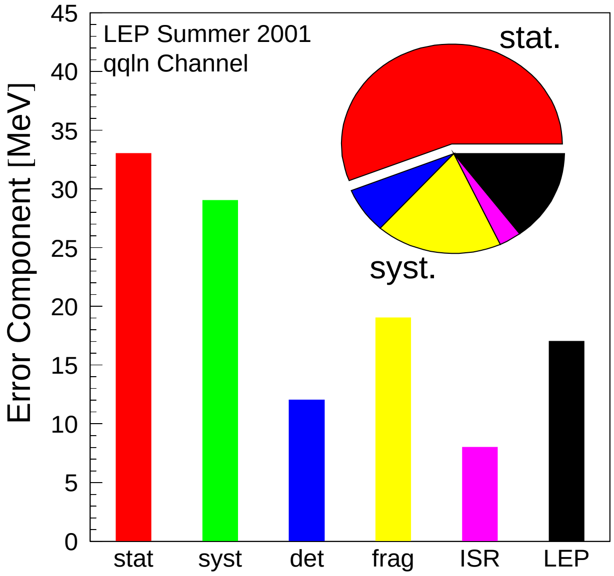


Both Channels COMBINED:

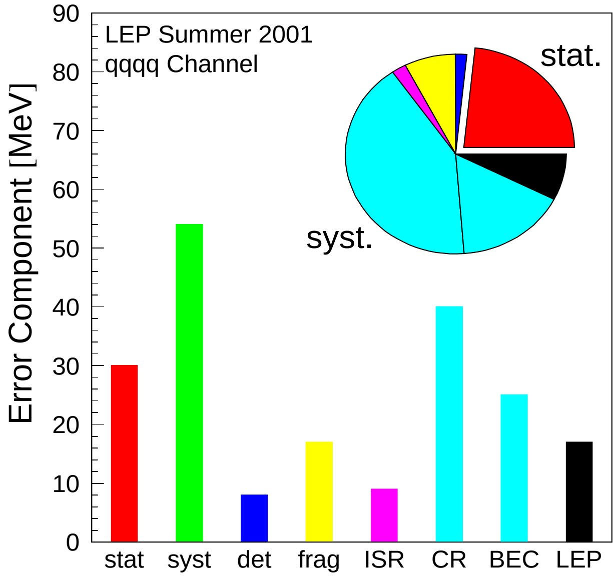
$$\boxed{M_W = 80.450 \pm 0.039 \text{ GeV (stat.}\oplus\text{syst.)}}$$

Weight of the $q_1\bar{q}_2q_3\bar{q}_4$ channel is only 27%.

Status Error on M_W



$W^+W^- \rightarrow q_1\bar{q}_2\ell\nu$



$W^+W^- \rightarrow q_1\bar{q}_2q_3\bar{q}_4$

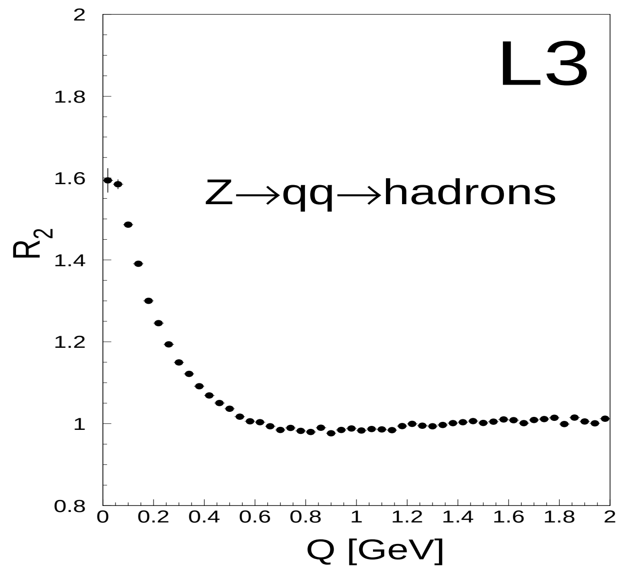
$\Rightarrow$ Systematic errors from BEC and CR are important.

$\Rightarrow$ Large differences between the 4 experiments:

For BEC: 20-67 MeV
For CR: 30-66 MeV

$\Rightarrow$ A better understanding of BEC and CR in the $q_1\bar{q}_2q_3\bar{q}_4$ channel is needed.

Bose-Einstein correlations?



where $\quad Q \equiv \sqrt{-(p_1 - p_2)^2} \quad$ and $\quad R_2 = \dfrac{\rho(Q)}{\rho_0(Q)}$

→ A well established effect at LEP I.

At LEP II, BEC in $e^+e^- \to W^+W^- \to q_1\bar{q}_2q_3\bar{q}_4$ can be divided into two types:

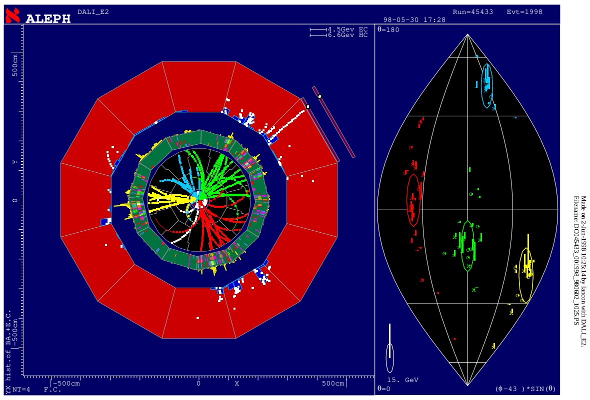
intra-W BEC: BEC between particles coming from the same W (do exist).
inter-W BEC: BEC between particles originating from different W's (may exist).

Inter-W BEC form a potential bias in the determination of the W-mass. The main question is therefore:

$\boxed{\text{DO INTER-W BEC EXIST ?}}$

WW decay channels:

- $WW \to q_1\bar{q}_2q_3\bar{q}_4$: 46% (fully hadronic channel)
- $WW \to q_1\bar{q}_2\ell\bar{\nu}_\ell$: 44% (semi-hadronic channel)
- $WW \to \ell\bar{\nu}_\ell\ell'\bar{\nu}_{\ell'}$: 11% (fully leptonic channel)



$W^+W^- \to q_1\bar{q}_2q_3\bar{q}_4$

Selection Performance

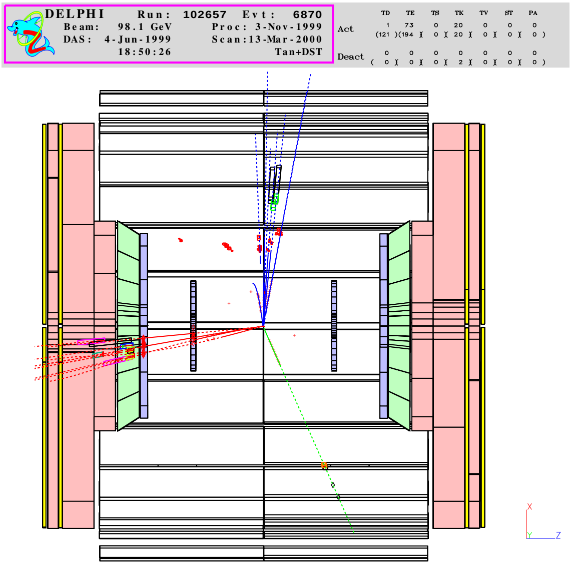
	$q\bar{q}q\bar{q}$	$q\bar{q}\ell\nu$
ε	83%	70%
π	80%	92%

Background events are mainly:

$e^+e^- \to Z/\gamma \to q\bar{q}(\gamma)$

and

$e^+e^- \to ZZ$

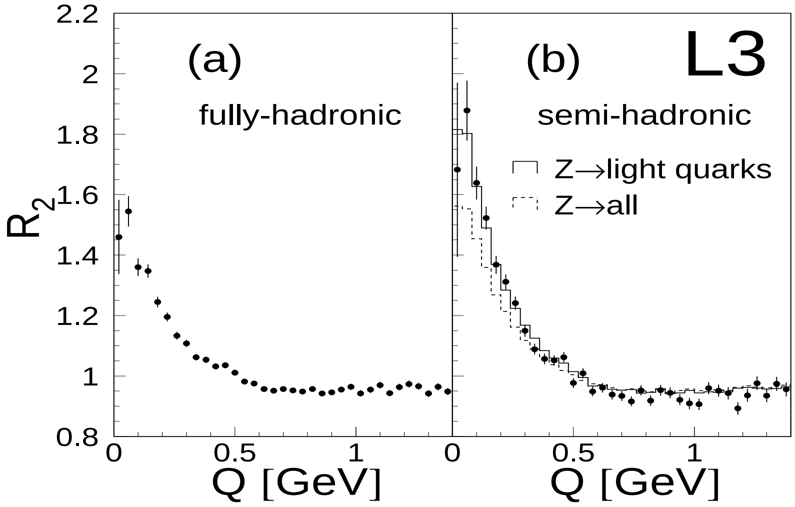


$W^+W^- \to q_1\bar{q}_2\mu\bar{\nu}_\mu$

NOTE: Results in this talk are PRELIMINARY !

Define the two-particle density: $\rho(p_1, p_2) = \frac{1}{N_{\mathrm{ev}}} \frac{\mathrm{d}n_{\mathrm{pairs}}}{\mathrm{d}Q}$

Intra-W BEC exist:

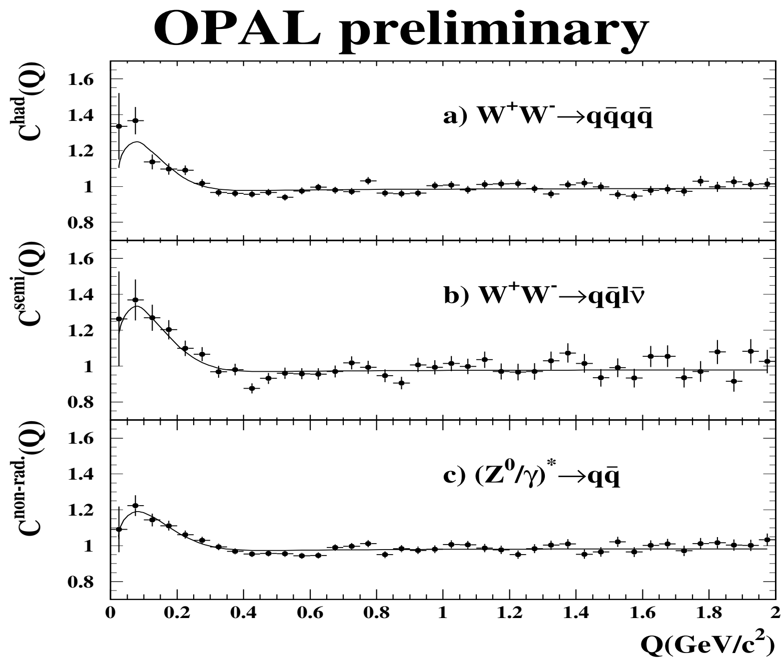


$$R_2 \equiv \frac{\rho(\pm,\pm)_{\mathrm{data}}}{\rho(\pm,\pm)_{\mathrm{MC,\,noBE}}}$$

and corrected for detector effects.

$\Rightarrow \lambda_{\mathrm{fully}} < \lambda_{\mathrm{semi}} \simeq \lambda_{\mathrm{Zudsc}}$
$\Rightarrow$ In agreement with no or weak inter-W BEC.

Existence of INTRA-W BEC is also confirmed by ALEPH, DELPHI and OPAL; E.g.



WHAT ABOUT INTER-W BEC?

Study the (non-)existence of inter-W BEC directly: When the two W's decay independently, then

$$\rho^{\mathrm{WW}}(1,2) = \rho^{\mathrm{W}^+}(1,2) + \rho^{\mathrm{W}^-}(1,2) + \underbrace{2\rho^{\mathrm{W}^+}(1)\rho^{\mathrm{W}^-}(2)}_{\downarrow\; 2\rho_{\mathrm{mix}}^{\mathrm{W}^+\mathrm{W}^-}}$$

$\rho_{\mathrm{mix}}^{\mathrm{W}^+\mathrm{W}^-}$ is obtained by pairing particles originating from two *different* semi-hadronic WW events.

The following test statistics are used to test the validity of this equation:

Difference

$$\Delta\rho = \rho^{\mathrm{WW}} - 2\rho^{\mathrm{W}} - 2\rho_{\mathrm{mix}}^{\mathrm{W}^+\mathrm{W}^-}$$

Ratio

$$D = \frac{\rho^{\mathrm{WW}}}{2\rho^{\mathrm{W}} + 2\rho_{\mathrm{mix}}^{\mathrm{W}^+\mathrm{W}^-}} \quad \text{and} \quad D' = \frac{D_{\mathrm{data}}}{D_{\mathrm{MC,no\ BE}}}$$

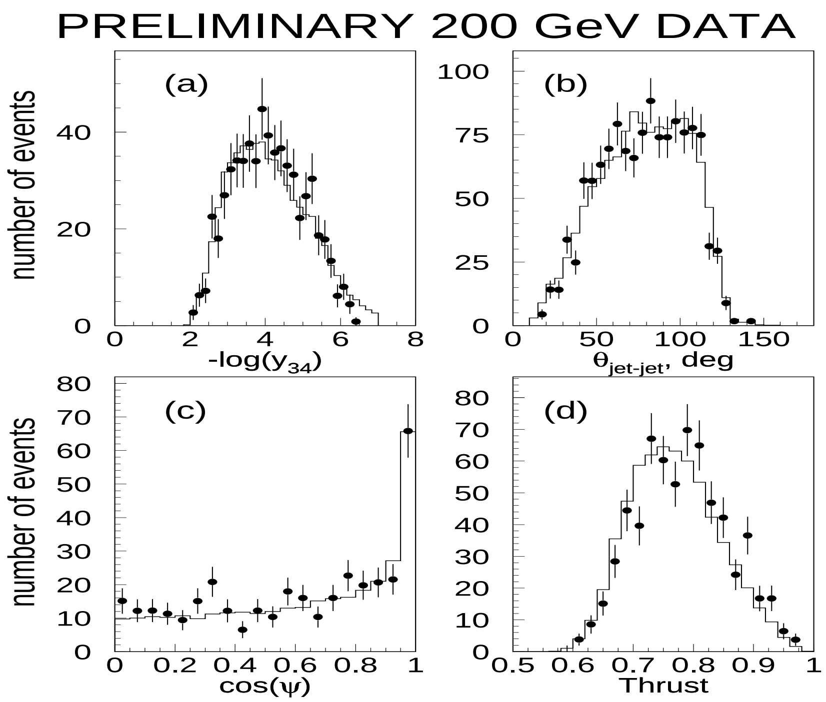
$2\rho^{\mathrm{W}} + 2\rho_{\mathrm{mix}}^{\mathrm{W}^+\mathrm{W}^-}$: two-particle density in fully-hadronic events that would occur if inter-W BEC did not exist.

$\Rightarrow$ look for a deviation from $\Delta\rho$=0 and $D, D' = 1$

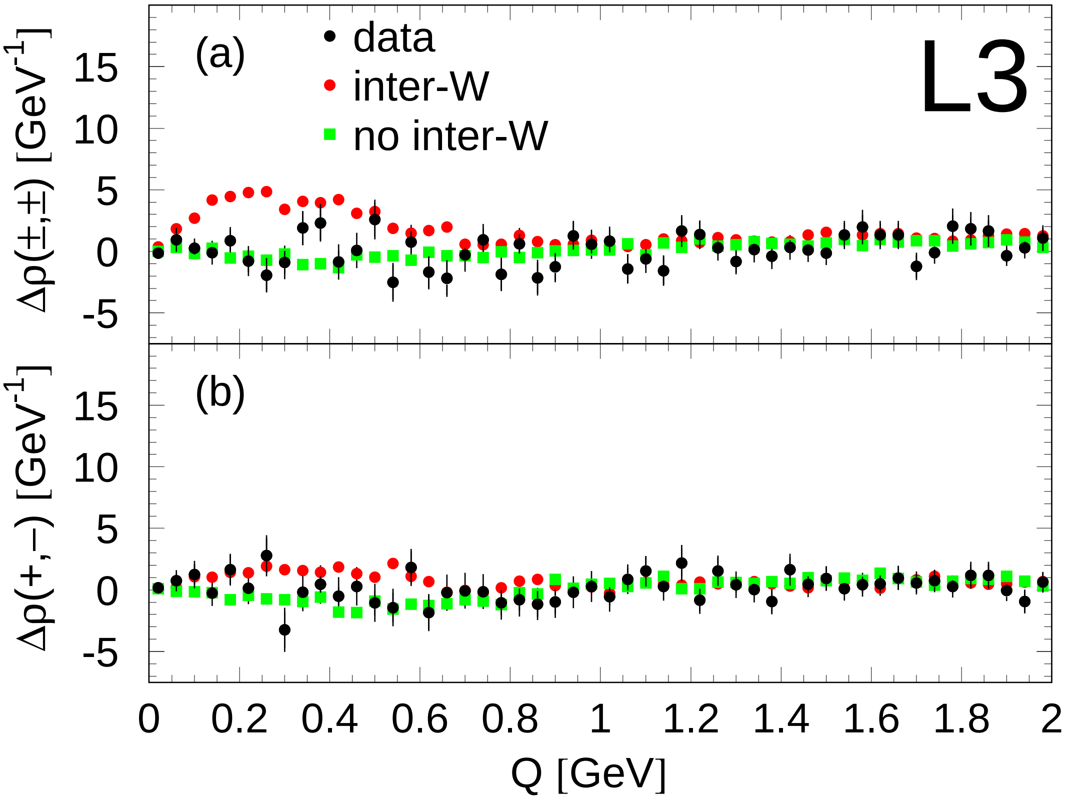
MIXING PROCEDURE

- take two different semi-hadronic WW events
- discard the leptonic decays
- determine direction of W by adding all remaining momenta
- rotate one W such that $\vec{W}_1 \simeq -\vec{W}_2$
- only combine opposite charged W's
- impose the same selection criteria on the mixed events as on the real qqqq events

What is left over generally agrees well with the real qqqq events for a lot of variables. E.g.

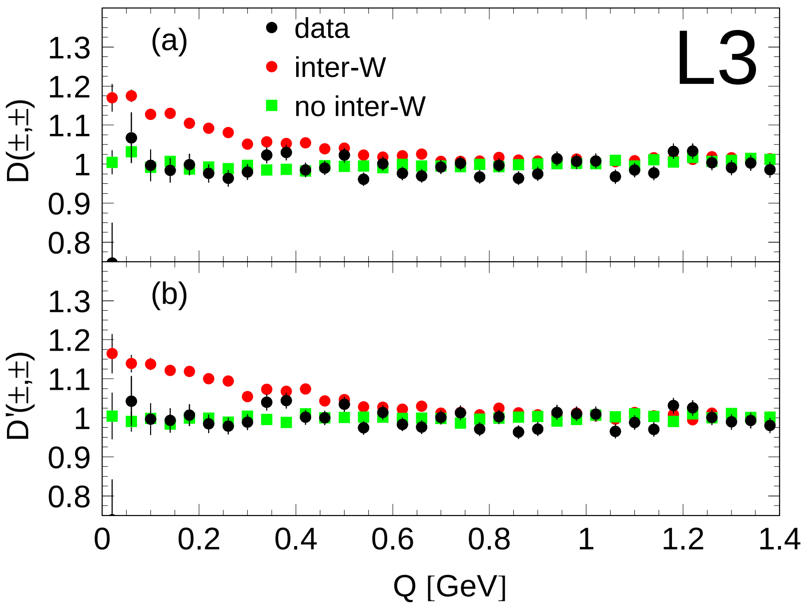


Preliminary L3 Results



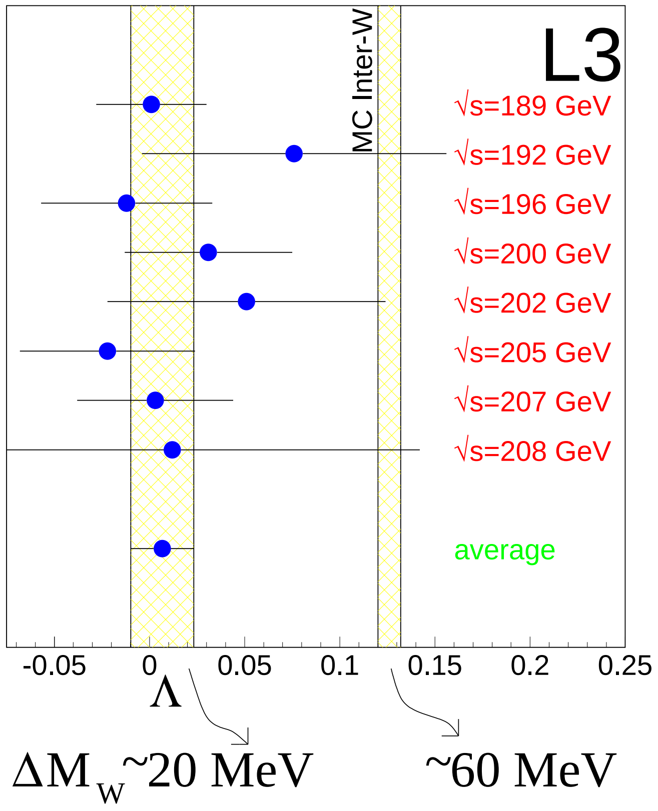
$\Rightarrow$ The MC with inter-W BEC is disfavoured, the MC without inter-W BEC (so only intra-W BEC) describes the data.

$\Rightarrow$ Enhancement in $\Delta\rho(+,-)$ for inter-W MC due to the 'ad hoc' BE implementation of the LUBOEI algorithm.



Again: Inter-W BEC are disfavoured

In particular: Fit $D'(Q) = (1+\epsilon Q)(1+\Lambda \exp(-k^2 Q^2))$, where Λ measures the strength of the inter-W BEC.

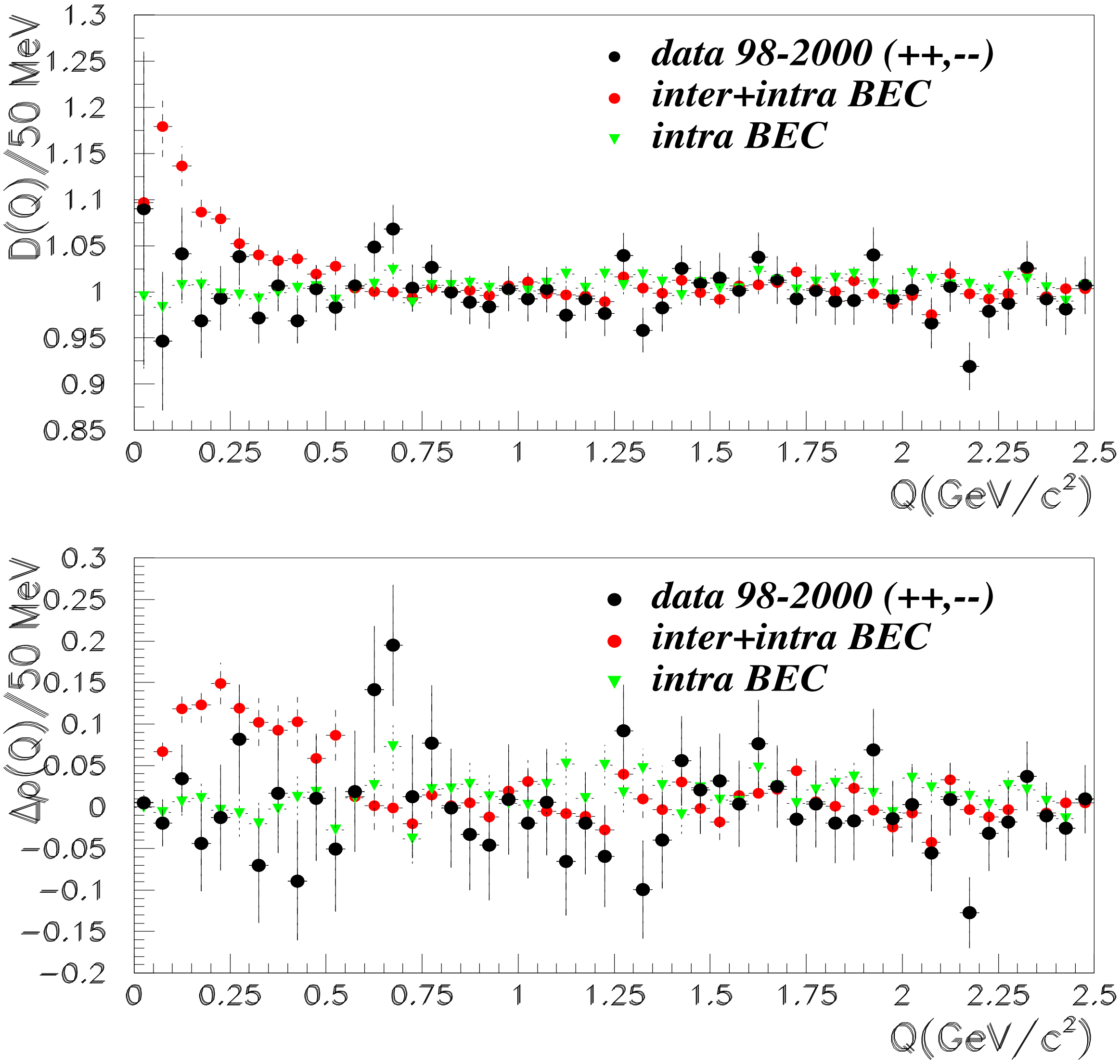


$\Lambda = 0.008 \pm 0.018 \pm 0.016$

MC inter-W disfavoured by 4.7σ

$\Rightarrow$ Effect on W mass measurement is small

Preliminary DELPHI Results

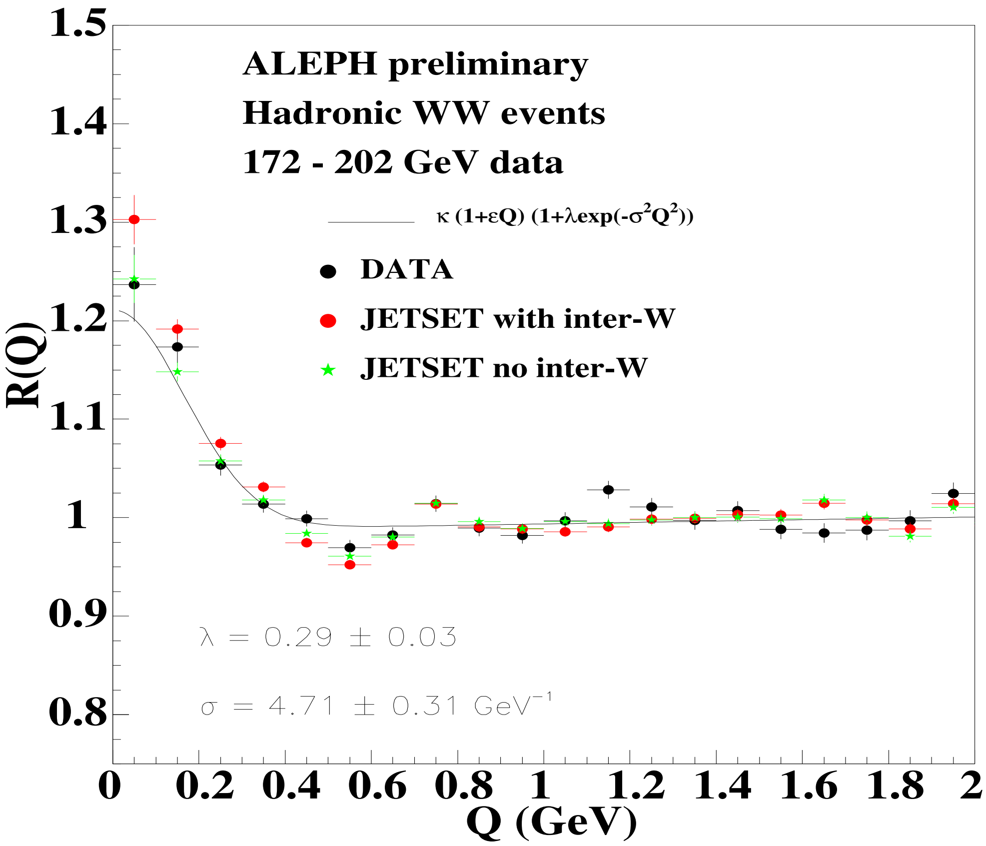


⇒ Like L3: NO evidence for inter-W BEC

⇒ MC with inter-W BEC is disfavoured by 3.2σ

Preliminary ALEPH Results

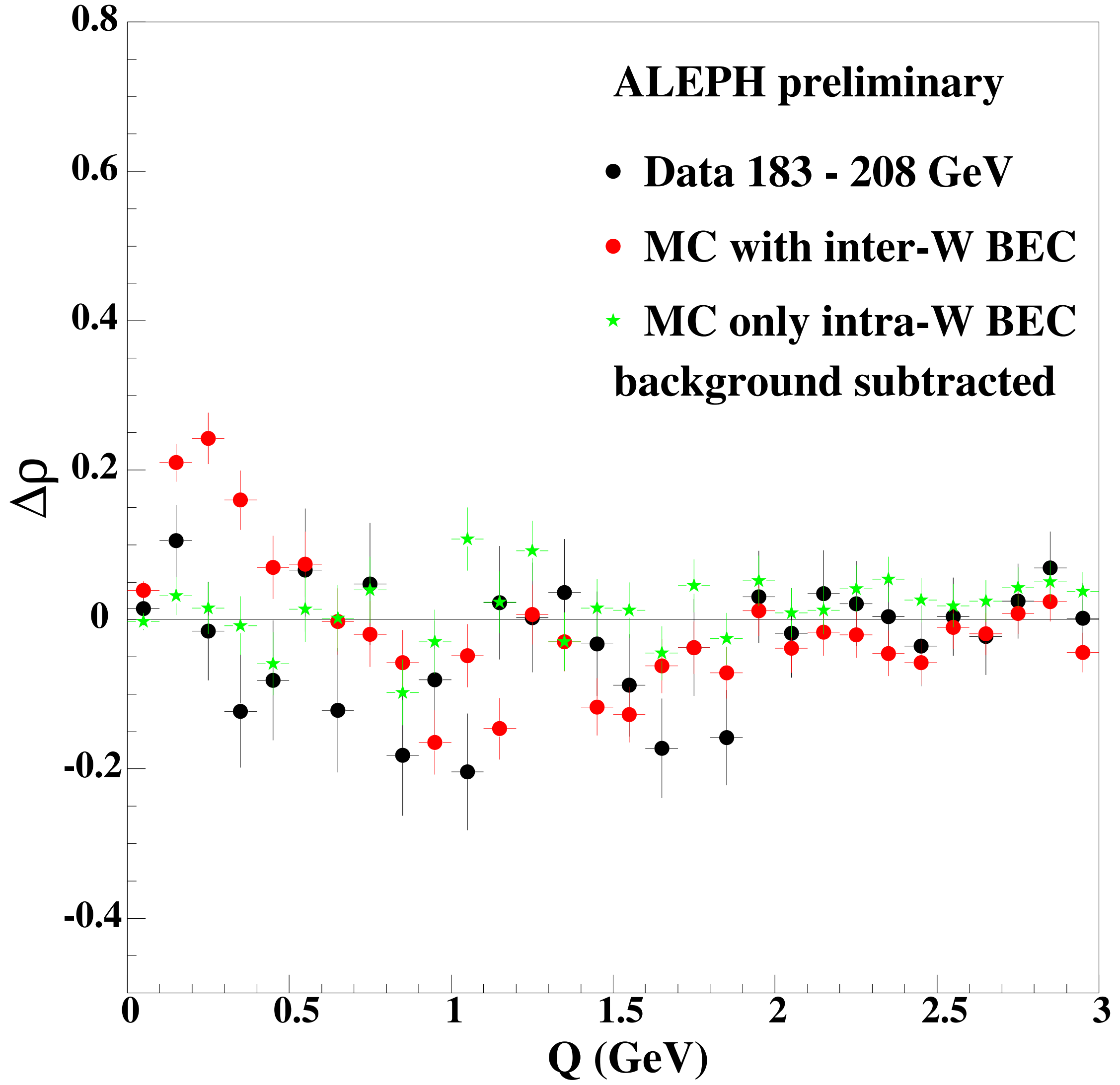
$$R_2(Q) = \left(\frac{N^{\pm\pm}(Q)}{N^{+-}(Q)}\right)^{\text{data}} \Big/ \left(\frac{N^{\pm\pm}(Q)}{N^{+-}(Q)}\right)^{\text{MC, noBE}}$$



The MC without inter-W BEC describes the data;

A model allowing inter-W BEC is disfavoured by 2.2σ

Moreover, mixing events analysis ('a là' L3) gives:

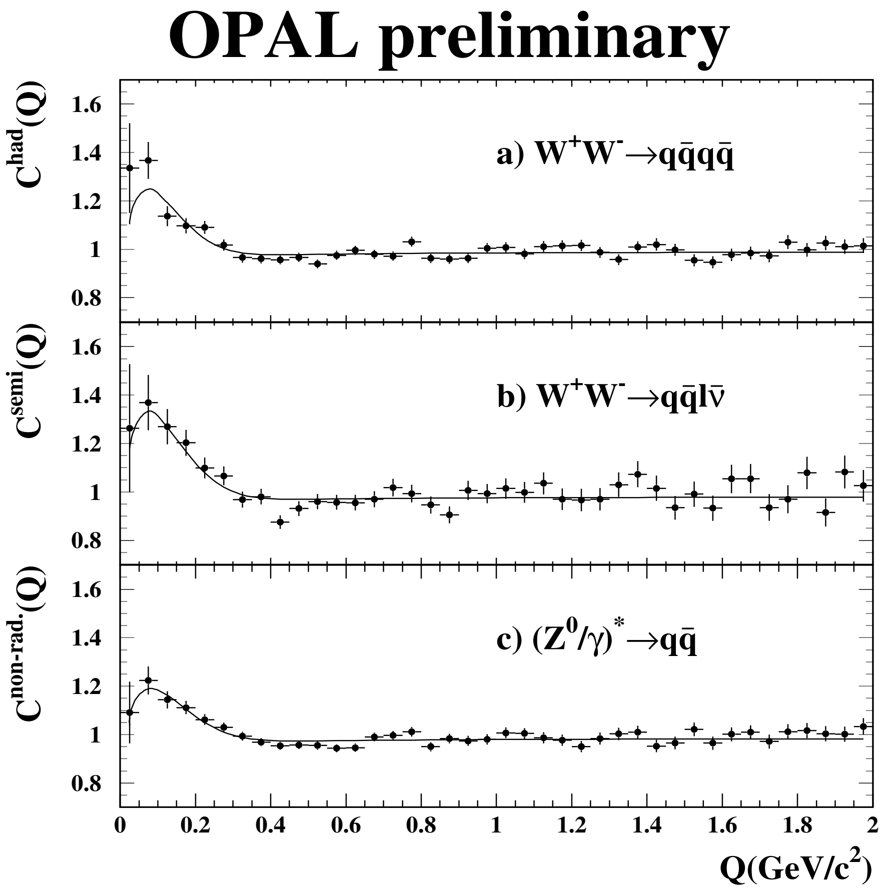


$$\Delta\rho \equiv \Delta\rho(\pm,\pm)_{\rm data} - \Delta\rho(\pm,\pm)_{\rm MC,\, noBE}$$

$\Rightarrow$ Good agreement between DATA and MC with only intra-W BEC

$\Rightarrow$ MC with inter-W BEC is disfavoured

Preliminary Opal Results



The different processes: $(\mathrm{Z}/\gamma)^* \rightarrow \mathrm{q}\bar{\mathrm{q}}$, $\mathrm{W}^+\mathrm{W}^- \rightarrow \mathrm{q}_1\bar{\mathrm{q}}_2\mathrm{q}_3\bar{\mathrm{q}}_4$ and $\mathrm{W}^+\mathrm{W}^- \rightarrow \mathrm{q}_1\bar{\mathrm{q}}_2\ell\nu_\ell$ may have different BEC.

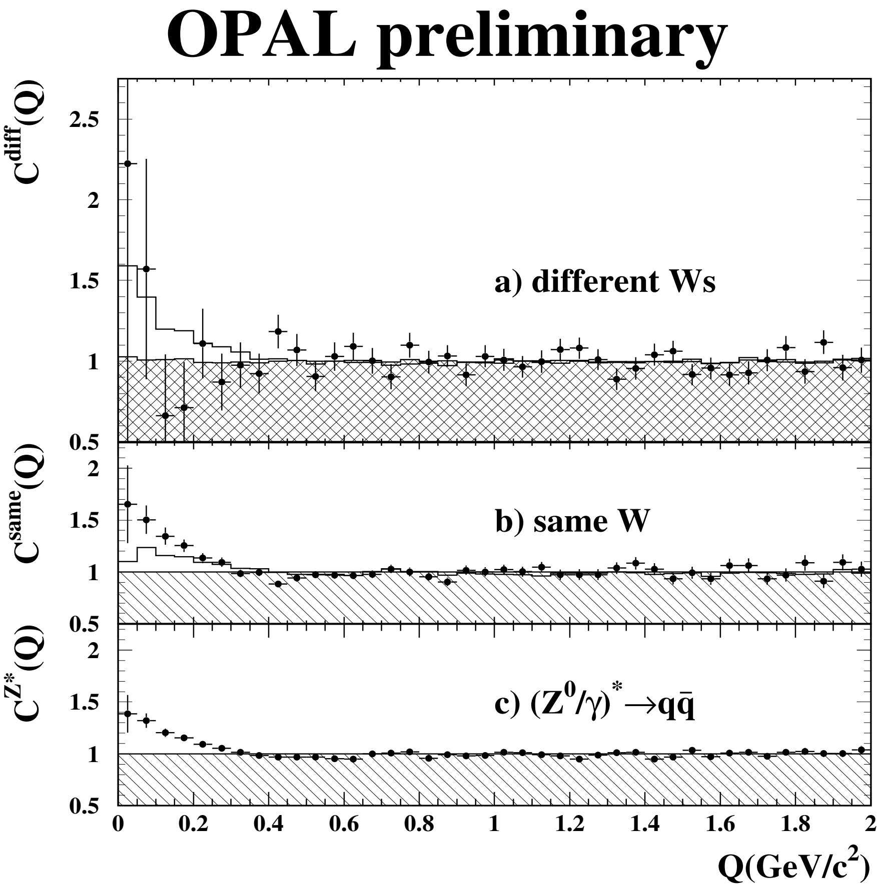
$\Rightarrow$ Rewrite the BEC-function,

$$C(Q) \equiv \left(\frac{N^{\pm\pm}(Q)}{N^{+-}(Q)}\right)^{\text{data}} \Bigg/ \left(\frac{N^{\pm\pm}(Q)}{N^{+-}(Q)}\right)^{\text{MC, noBE}},$$

as a combination of contributions from the various pure pion classes.

E.g. for $\mathrm{W}^+\mathrm{W}^- \rightarrow \mathrm{q}_1\bar{\mathrm{q}}_2\mathrm{q}_3\bar{\mathrm{q}}_4$:

$$\begin{aligned} C^{\text{had}}(Q) = {} & P^{\text{same}}_{\text{had}}(Q) C^{\text{same}}(Q) + P^{\mathrm{Z}^*}_{\text{had}}(Q) C^{\mathrm{Z}^*}(Q) \\ & + \left(1 - P^{\text{same}}_{\text{had}}(Q) - P^{\mathrm{Z}^*}_{\text{had}}(Q)\right) C^{\text{diff}}(Q) \end{aligned}$$



Results simultaneous fit: "3×" $N(1+f_\pi(Q)\lambda\exp(-Q^2R^2))$

- common source size R

$\lambda^{same} = 0.70 \pm 0.10$; $R^{same} = 1.04 \pm 0.05$ fm

$\lambda^{diff} = -0.14 \pm 0.36$; $R^{diff} = 1.04 \pm 0.05$ fm

- R is allowed to vary for each class

$\lambda^{same} = 0.62 \pm 0.10$; $R^{same} = 1.03 \pm 0.07$ fm

$\lambda^{diff} = 2.85 \pm 1.70$; $R^{diff} = 3.24 \pm 1.18$ fm

- Impose $(R^{diff})^2 = (R^{same})^2 + 4\beta^2\gamma^2\tau^2$

$\lambda^{same} = 0.69 \pm 0.12 \pm 0.06$; $R^{same} = 1.07 \pm 0.07 \pm 0.12$ fm

$\lambda^{diff} = 0.05 \pm 0.67 \pm 0.35$; $R^{diff} = 1.51 \pm 0.05 \pm 0.09$ fm

$\Rightarrow$ No evidence for the existence of inter-W BEC.

Conclusions & Outlook

- ★ NO evidence for the existence of inter-W BEC
- ★ MC with inter-W BEC disfavoured by several σ's
- ★ Now a consistent picture compared to the results of last year
- ★ Result consistent with the Lund string model: the strings from the two W's are independent
- ★ Effect on W mass measurement is small
  Latest LEP W mass combination:
  $\Delta M_{\mathrm{W}}^{\mathrm{BEC}}(\mathrm{q\bar{q}q\bar{q}}) = 25$ MeV
- ★ ADLO combination in progress
  $\Rightarrow \Delta M_{\mathrm{W}}^{\mathrm{BEC}}(\mathrm{q\bar{q}q\bar{q}}) \lesssim 10$ MeV
  (in case no inter-W will be observed).