Bose-Einstein Correlations

The legacy of LEP and SLC

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On behalf of the LEP collaborations

Introduction

Identical bosons obey Bose-Einstein statistics

- Constructive interference between identical bosons in multi-hadronic final states
- Enhancement of number of identical bosons over number of non identical bosons close in phase space
- First observed in like-sign charged pion pairs in $p\bar{p}$ annihilations

BEC may influence the properties of multi-hadronic final states:

LEPI: ee→Z→qq→hadrons

LEPII: ee→WW→qqqq→hadrons

Bose Einstein Correlations (BEC)

- Studied as a function of Q:

$$Q^2 = -(p_1 - p_2)^2 \qquad p_{1,2} = 4 - \text{momentum}$$

- Using the two-particle correlation function

$$R(Q) = \frac{r(Q)}{r_0(Q)} \qquad r(p_1, p_2) = \frac{1}{N_{ev}} \frac{dn_{pairs}}{dQ}$$

$$R(Q) = 1$$

In the absence of BEC

ρ : two particle density

$\rho_0 = \rho_{\text{no BE}}$ (reference sample)

- Unlike sign charged particle pairs
- 'mixed events'
- MC without BEC

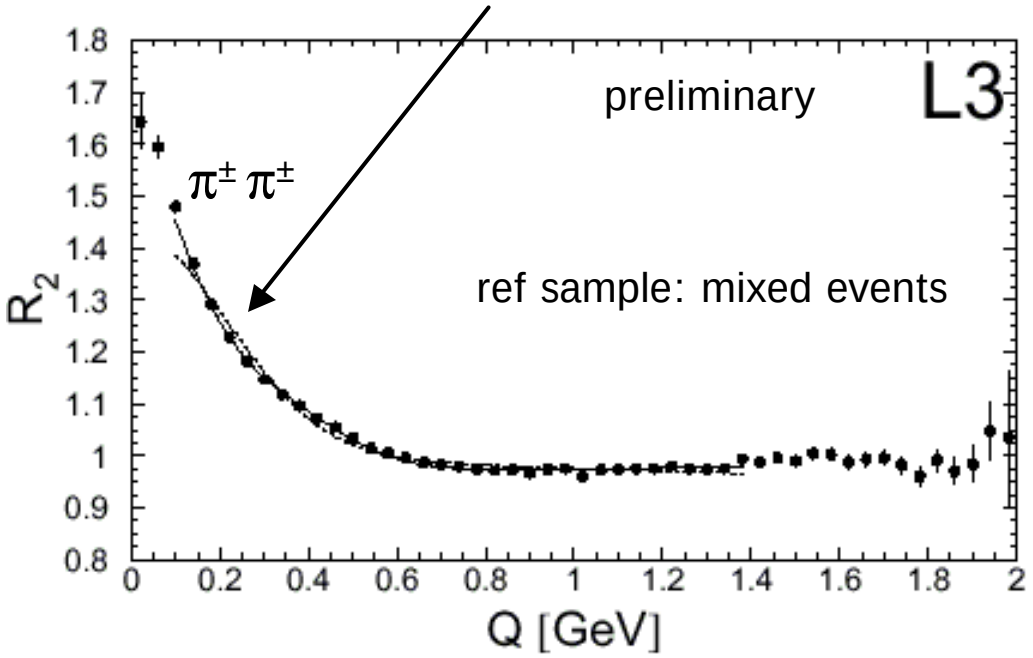
} Double ratio: $R_{data}/R_{\text{MC no BE}}$

LEP I

Z →qq→hadrons

$\pi^{\pm}\pi^{\pm}$

Enhancement at low values of Q



Fit assuming a spherical source of BEC with gaussian density:

$$R(Q) \approx 1 + l \exp(-r^2 Q^2)$$

λ : strength of the correlation

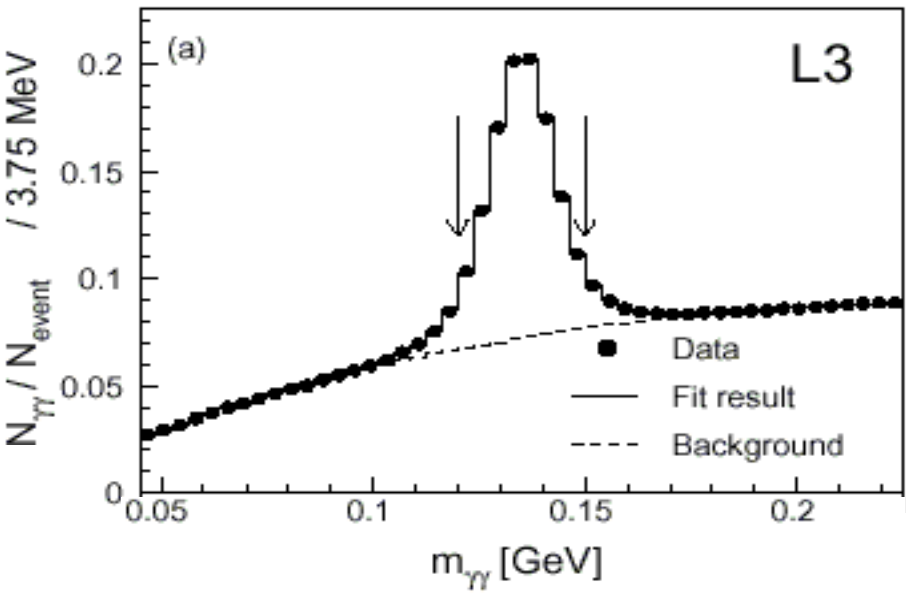
r : source size

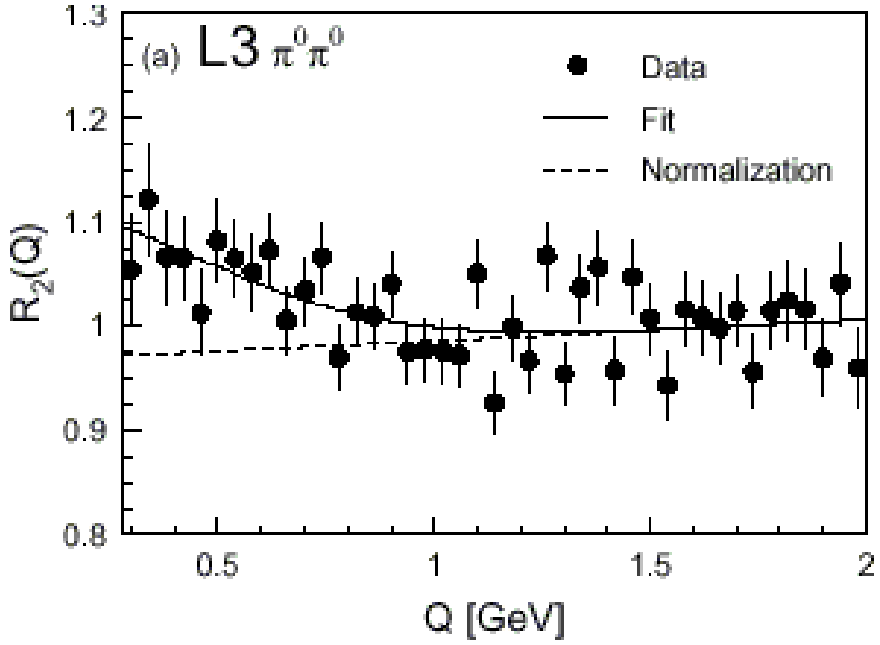
λ significantly different from zero (also measured by A,D,O)

r ~0.5-1.0 fm

A,D,L,O { different reference samples
different fragmentation parameters (JETSET)

$\pi^0\pi^0$



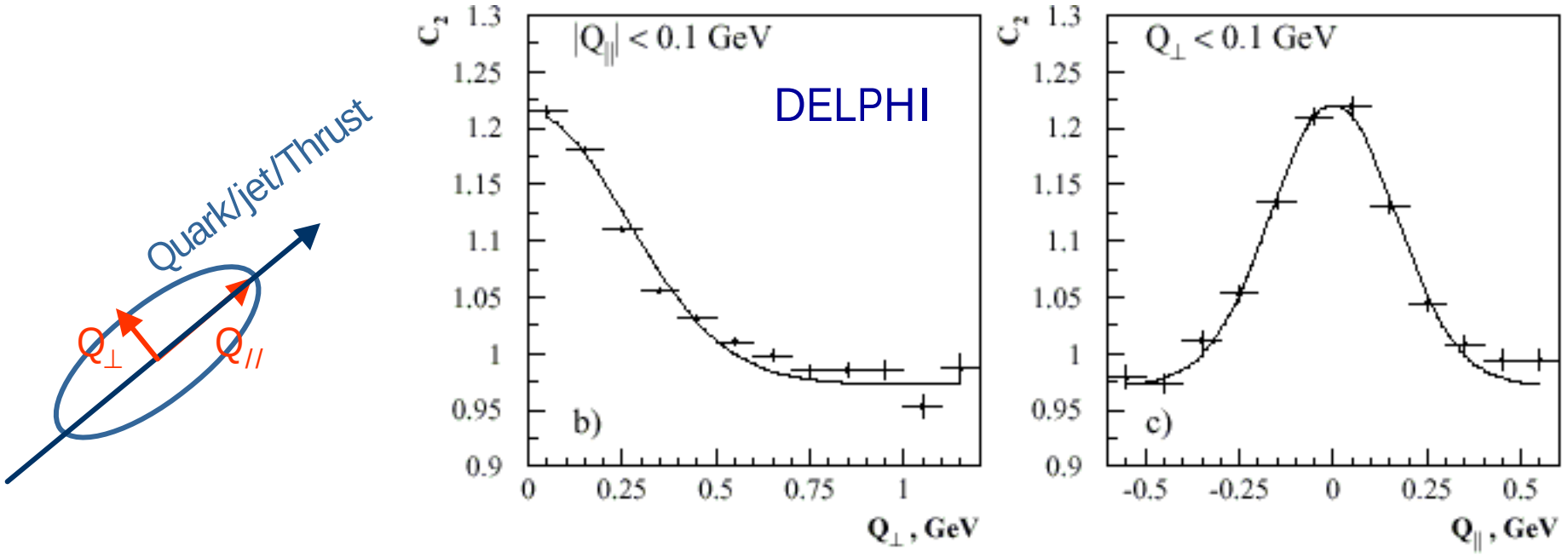


$$r_{\pm\pm} - r_{00} = 0.150 \pm 0.075(st) \pm 0.068(sys) \ \ [fm]$$

same reference sample for $\pi^0\pi^0$ and $\pi^\pm\pi^\pm$

indication of smaller radius for the neutral pion source

2-Dim analysis of the source



	$r_\wedge / r_{//}$	Method
DELPHI	**0.62 ± 0.02 ±0.05**	**Mixed events**
OPAL	**0.73 ± 0.02 ±0.07**	**Unlike-Charge**
L3	**0.81 $\pm 0.02^{+0.03}_{-0.19}$**	**Mixed events**

- evidence for the elongation of the pion source
- implications for modeling of BEC in hadronic final states

Three particle correlations

- Studied as a function of Q_3:

$$Q_3^2 = Q_{12}^2 + Q_{13}^2 + Q_{23}^2$$

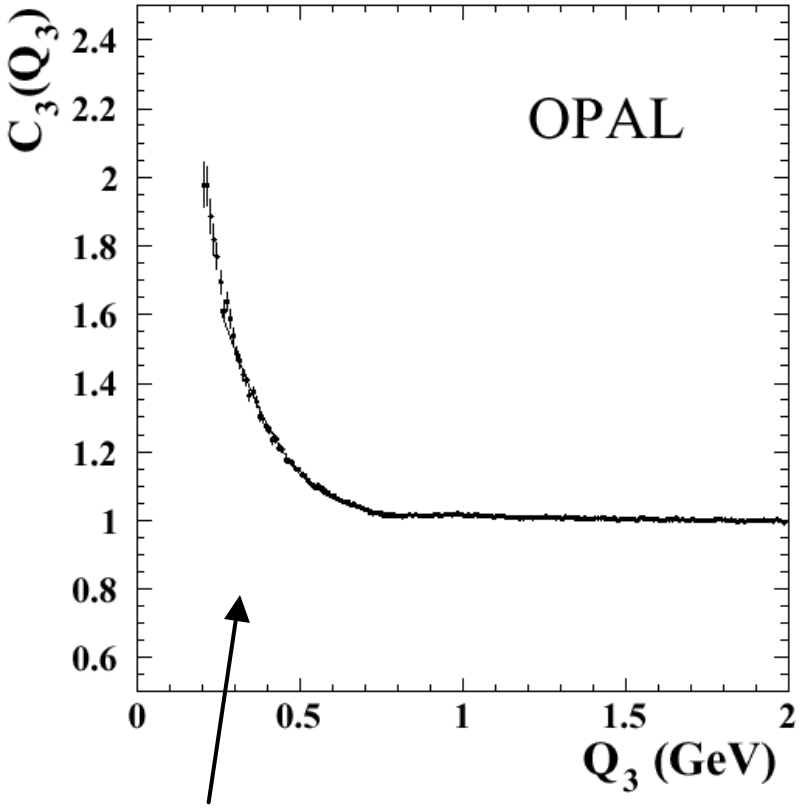
- Using the three particle correlation function:

$$R_3(Q) = \frac{r_3(p_1, p_2, p_3)}{r_0(p_1, p_2, p_3)}$$

- C_3 : genuine 3 boson correlation

$$C_3(Q_3) = R_3 - R_{1,2}$$

Two-boson correlation contribution



Enhancement at low values of Q_3

(also observed by D,L)

Conclusions from LEPI analyses

- Bose-Einstein Correlations are observed in hadronic Z decays
- Indication of smaller radius for $\pi^0\pi^0$ than $\pi^\pm\pi^\pm$
- Evidence for the elongation of the BEC source
- Three particle correlations also observed

Other analyses done at LEPI

- Dependence of source size on hadron mass
- BEC in $K^\pm K^\pm$ and $K_s^0 K_s^0$
- Multiplicity dependence of BEC

LEP II

WW→qqlv

WW→qqqq

BEC in e^+e^- →WW

- BEC inside W in hadronic W decays (inter-W)
- BEC between two W's in fully hadronic decays (intra-W)
  - Distance between the two W decay vertices: 0.1 fm
  - Hadronization scale: 0.5-1 fm

  } Space-time overlap

If intra-W BEC exist:

momentum transfer between the two W's can affect the W mass measurement in qqqq channel

Systematic error on the W mass

$$\Delta M_W^{BEC} = 20 - 67 MeV$$

} Summer 2001 A,D,L,O

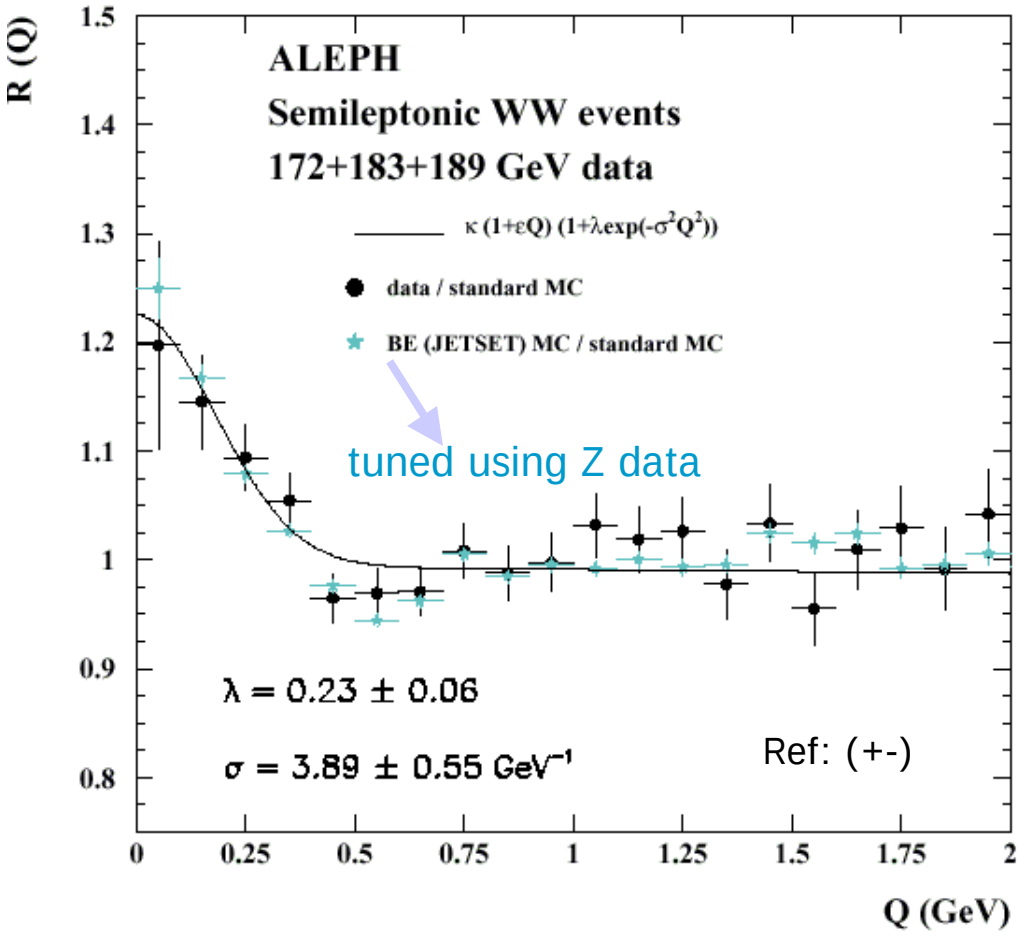
BE Models

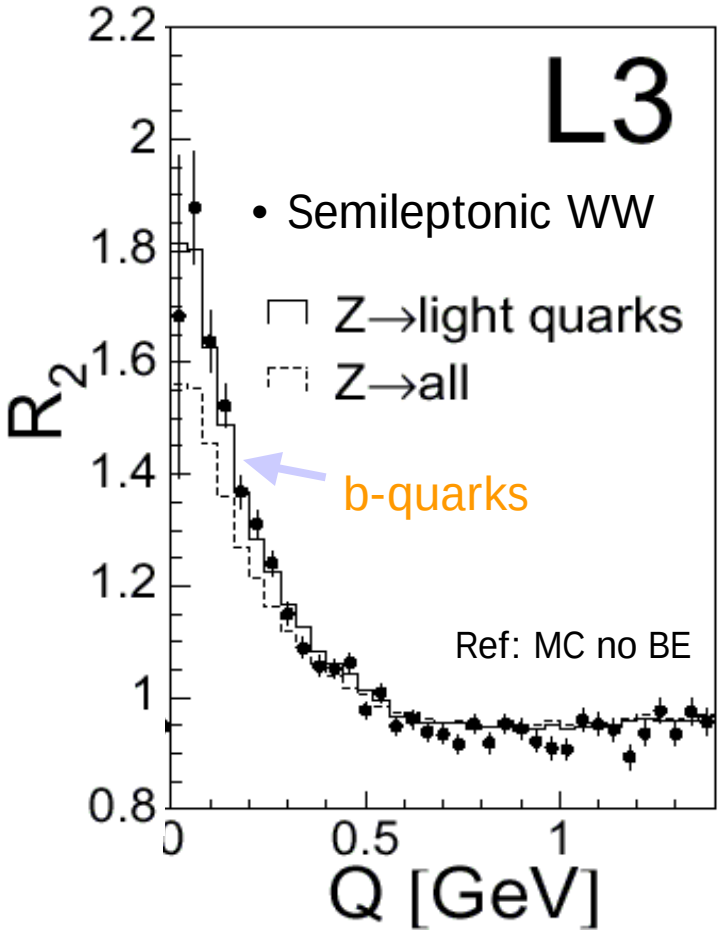
- Models of Sjöstrand/Lönnblad (LUBOEI)
  - 2 particle correlations introduced artificially by reshuffling momenta of final hadrons
  - E/P transfer between Ws to ensure global E/P conservation
  - Models are tuned using hadronic Z decays

- Reweighting models
  - conserve E/P and include QM calculations
  - But... very difficult to implementation (negative and large weights) – not used for the time being.

Intra W correlations

WW→qqlν





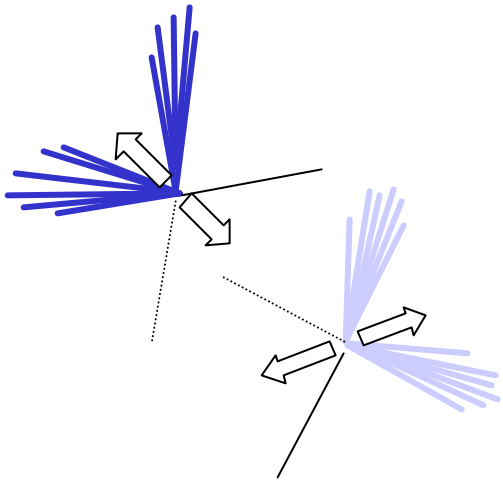
Evidence for BEC inside W's

Inter-W BEC

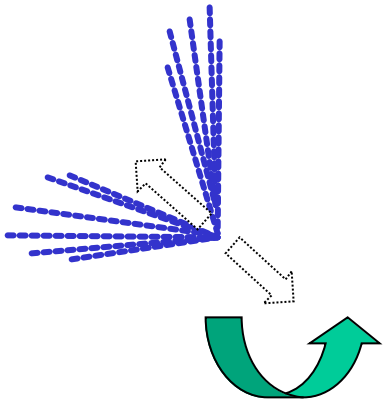
Analysis à la Chekanov, De Wolf, Kittel (Eur.Phys.J.C6 (1999) 403)

$$\Delta r = r^{\mathrm{WW}\to 4\mathrm{q}} - (2\,r^{\mathrm{W}\to 2\mathrm{q}} + r^{\mathrm{WW_{mix}}})$$

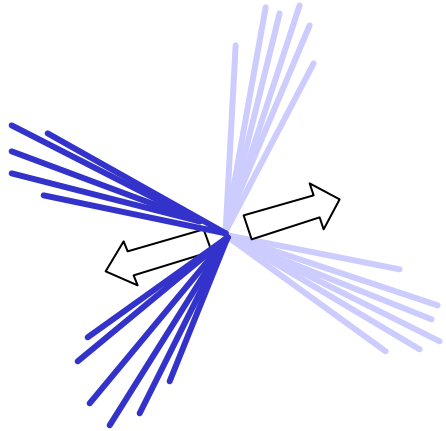
$\Delta\rho=0$ in the absence of inter BEC



hadronic parts of two lνqq evts



rotate/boost to balance momenta



mix => uncorrelated 'WW' event

- Experimentally robust (data compared with data)
- Model independent (except for background subtraction)

ABSOLUTE MEASUREMENT OF INTER-W CORRELATIONS

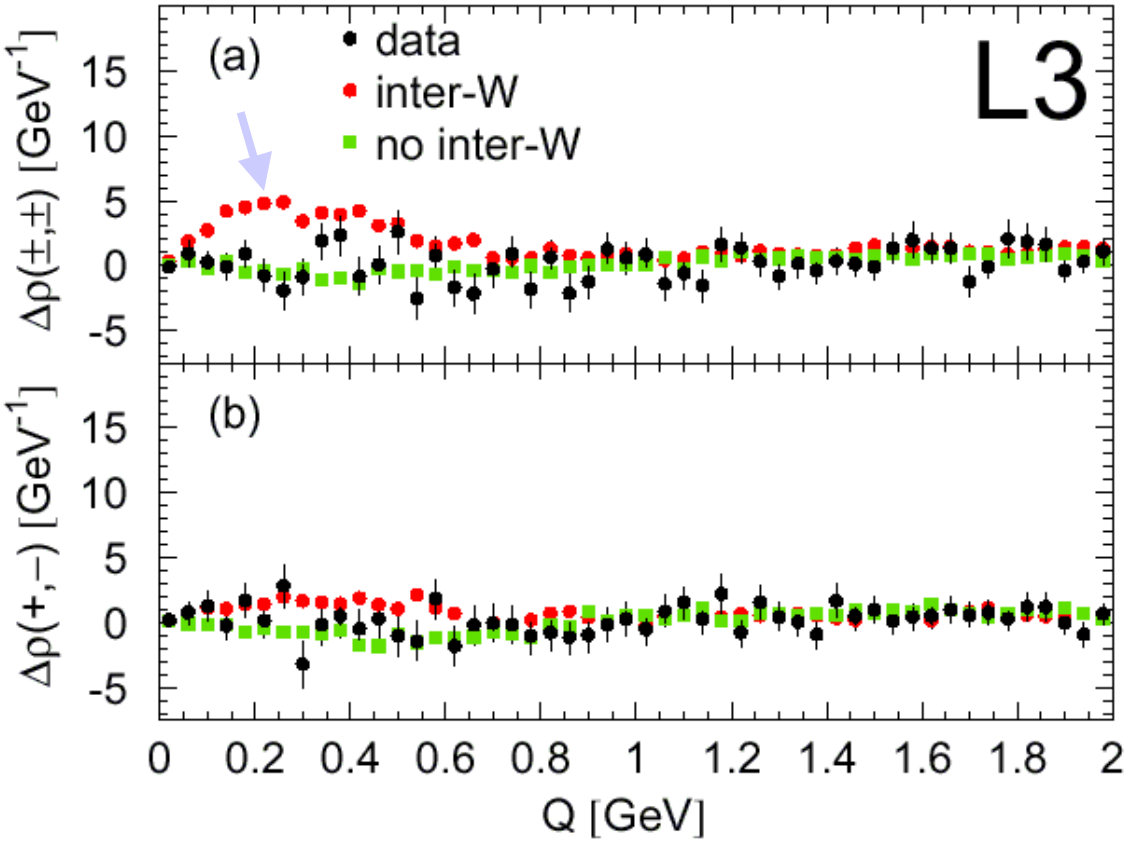
Inter W BEC

Data compatible with NO inter W BEC

Small artificial enhancement for

$\Delta r\,(+,-)$

due to BE simulation



Strength of the inter W BEC

$$D = \frac{r^{WW\to 4q}}{2\,r^{W\to 2q} + r^{WW_{mix}}}$$

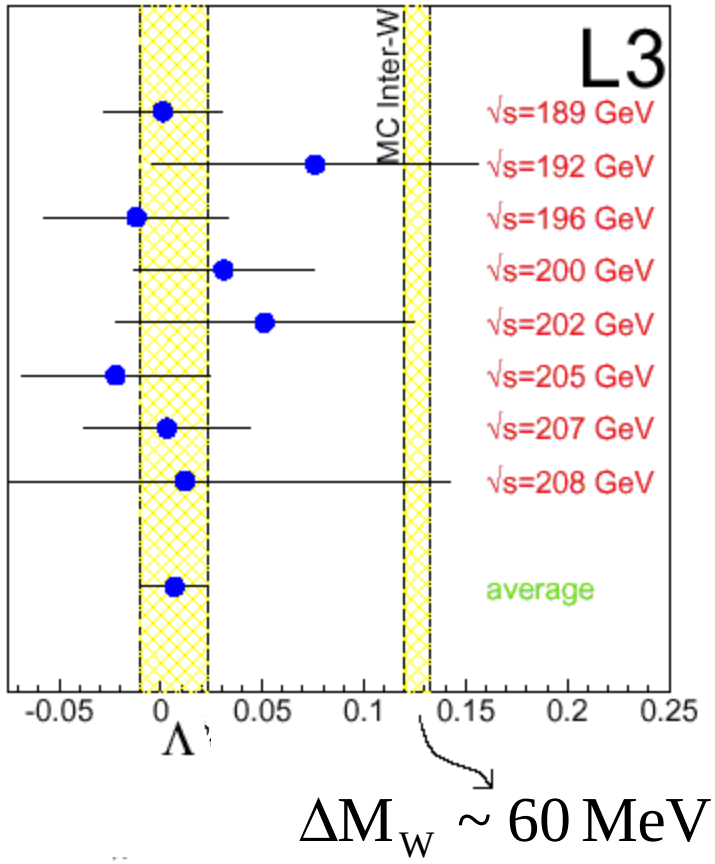
$$D' = \frac{D^{data}}{D^{MC}_{no\ BE}}$$

D'=D=1 in the absence in inter-W BEC

Fit: $D'(Q) \approx 1 + \Lambda \exp(-k^2 Q^2)$

$$\Lambda^{data} = 0.008 \pm 0.018(st.) \pm 0.016(sy.)$$

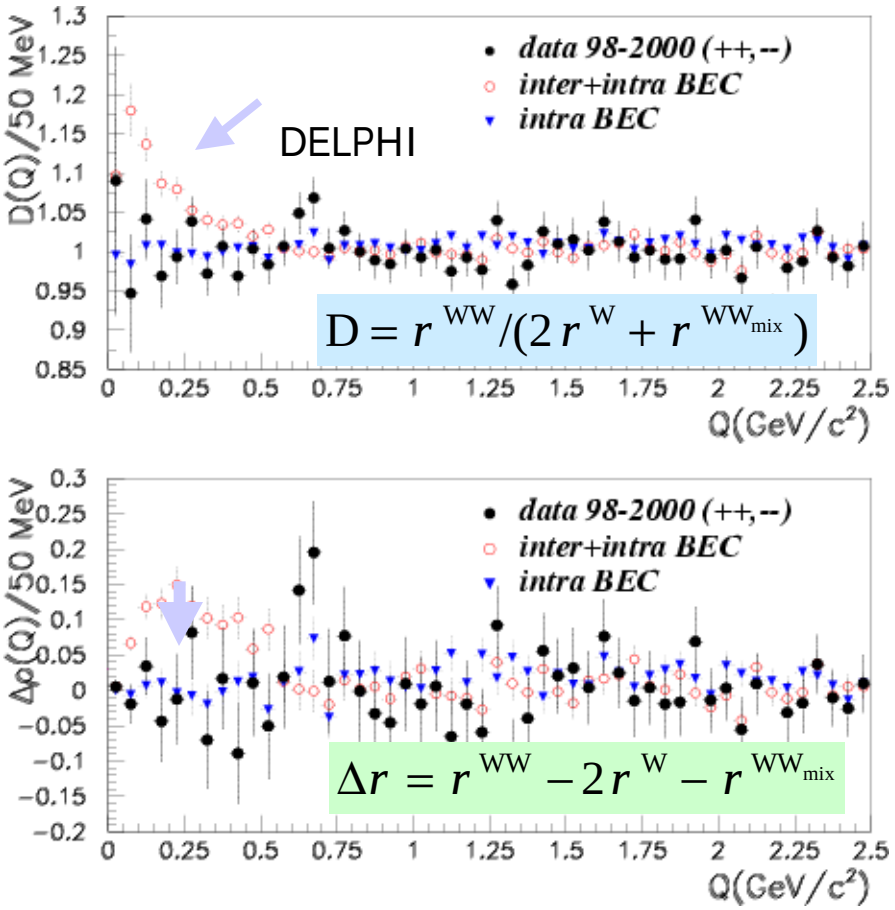
$$\Lambda^{MC}(interWW) = 0.126 \pm 0.008(st.)$$

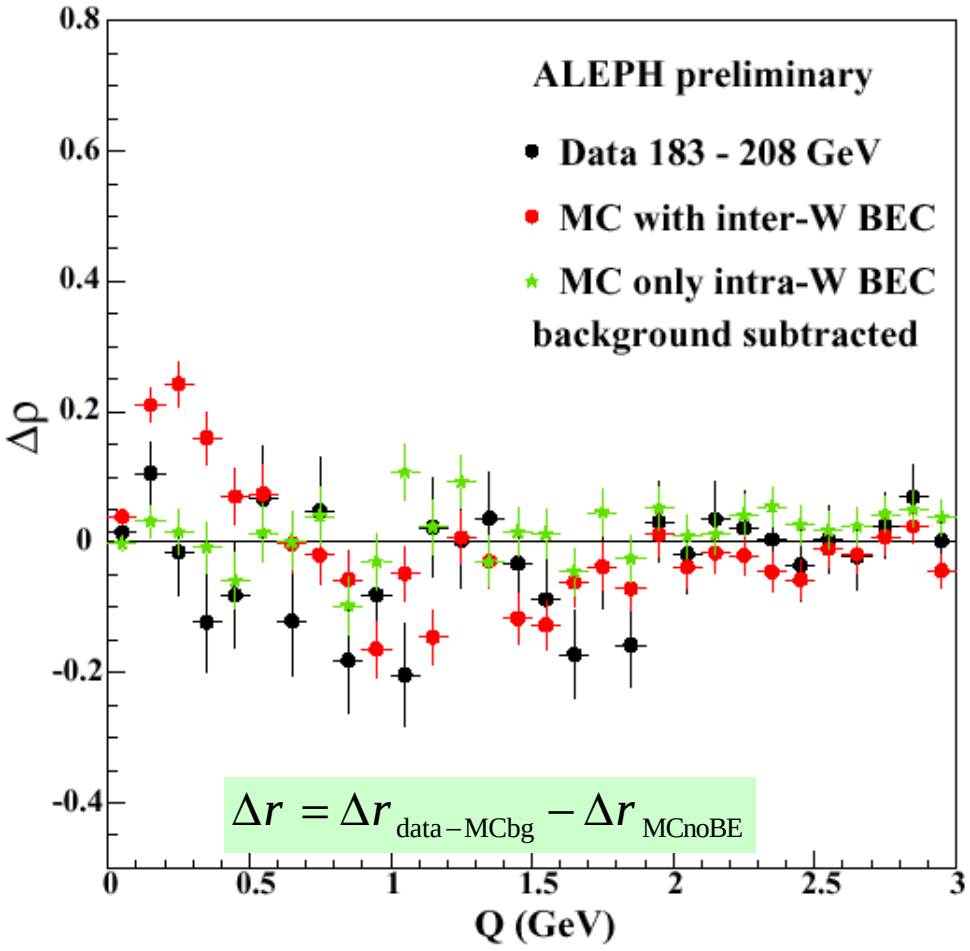


$\Delta M_W \sim 60$ MeV

Inter WW BEC are disfavored

Inter W BEC





NO correlations between different Ws observed

OPAL analysis with mixing method in progress

Conclusions from LEPII analyses

- BEC exist inside W's
- Similar effect in Z and W decays
- No evidence for the existence of inter-W correlations
  - Not taken into account yet for ΔM_W^{BEC}