BE and CR effects in W decays

results from LEP experiments

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- Motivation
- BE correlations
- Colour reconnection
- Conclusions

W mass measurement

Major topic of study at LEP 2

$e^+e^- \rightarrow W^+W^-$

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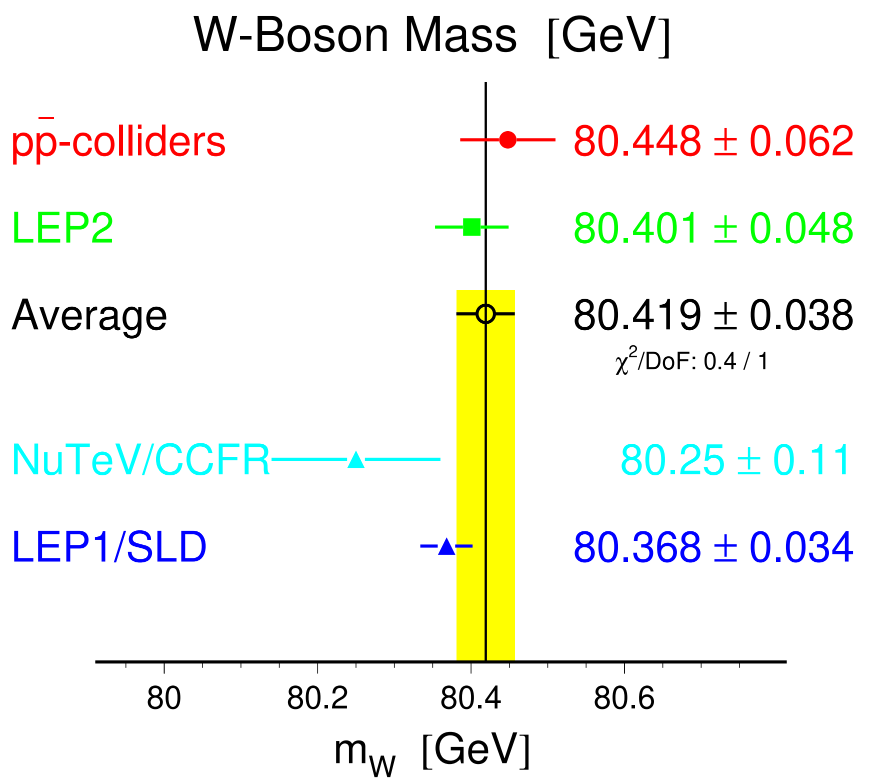
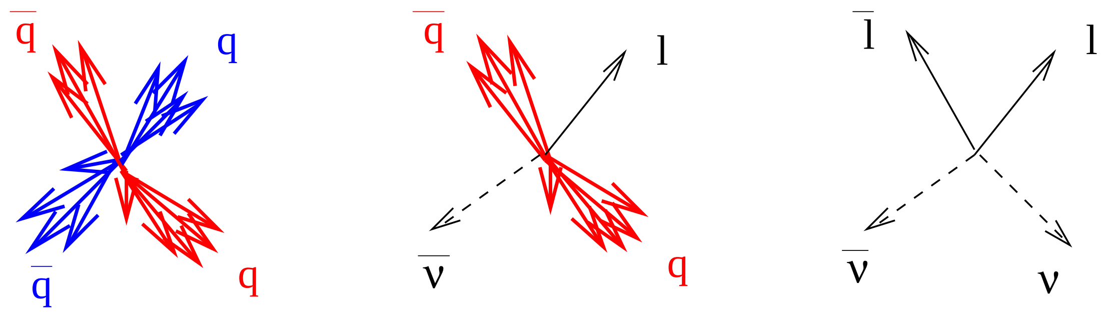
direct measurement of W mass, independent of SM assumptions.

Status for Moriond 2000



Aim for LEP 2: measure W mass with 20-30 MeV accuracy.

W mass measurement

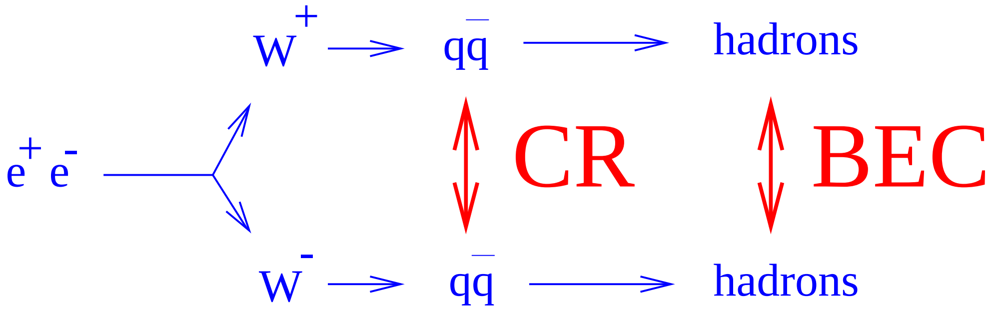


BR 45%, 44%, 11% respectively

W mass obtained from kinematic fit, after reconstruction of W decay products.

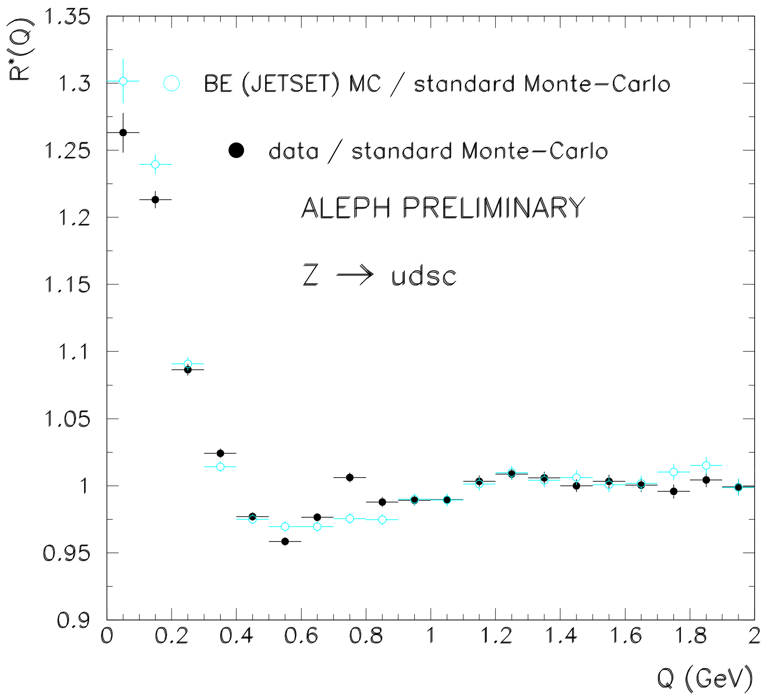
For the qqqq final state

WW decay vertices ~ 0.1 fm
hadronization scale ~ 1 fm $\Rightarrow$ spacetime overlap interconnections



Bose-Einstein correlations

Bose-Einstein correlations are well established at LEP 1.



where $Q^2 = -(p_1 - p_2)^2$ and $R_2 = \frac{\rho(Q)}{\rho_o(Q)}$.

At LEP 2, BEC should be present also in hadronic W decays:

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

If sizeable BEC between decay products of different W's

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potential bias in the determination of the W mass

LEP data samples in analysis for BEC

ALEPH

- ➢ 172, 183, 189 GeV data (publ.), 192, 196, 200, 202 GeV data (prel.)

DELPHI

- ➢ 172 GeV data (publ.), 183, 189, 192, 196, 200, 202 GeV data (prel.)

L3

- ➢ 189 GeV data (publ.)

OPAL

- ➢ 172, 183 GeV data (publ.), 189 GeV data (prel.)

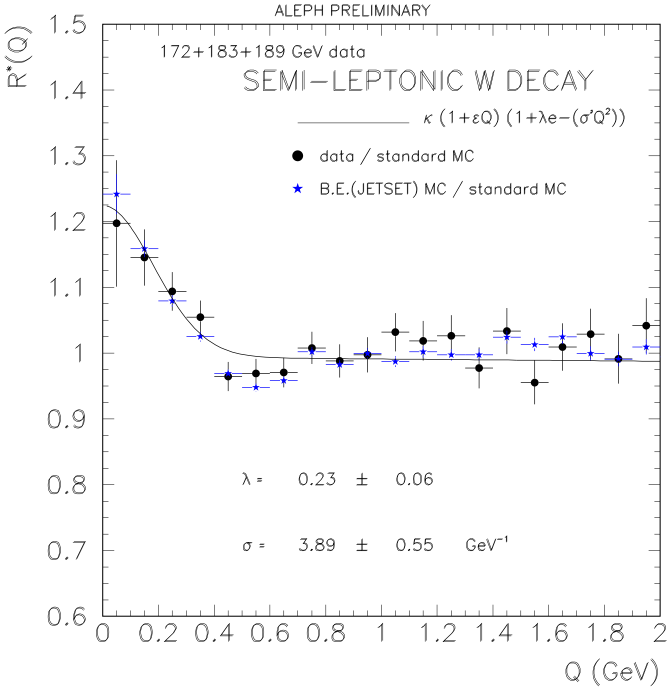
Typical number of W-pairs per experiment

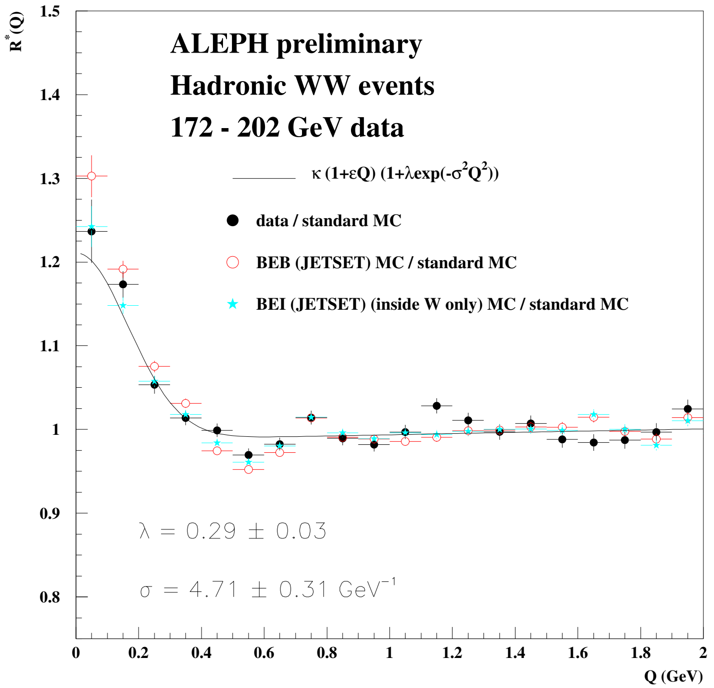
$\sqrt{s}$ (GeV)	$q\bar{q}q\bar{q}$	$q\bar{q}l\nu_l$	Lum(pb^{-1})
172	60	40	10
183	450	300	55
189	1500	1000	180
192	270	180	28
196	660	440	77
200	750	500	83
202	330	220	40
total	4000	2700	480

The ratio $R(Q) = N^{++}(Q)/N^{+-}(Q)$ is corrected with MC without BEC:

$$R^*(Q) = (\frac{N_\pi^{++,--}(Q)}{N_\pi^{+-}(Q)})^{data} / (\frac{N_\pi^{++,--}(Q)}{N_\pi^{+-}(Q)})^{MC}_{noBEC}$$

$$R^*(Q) = k(1+\epsilon Q)(1+\lambda e^{-\sigma^2 Q^2})$$





Data compatible with BEI and not with BEA

DELPHI analysis

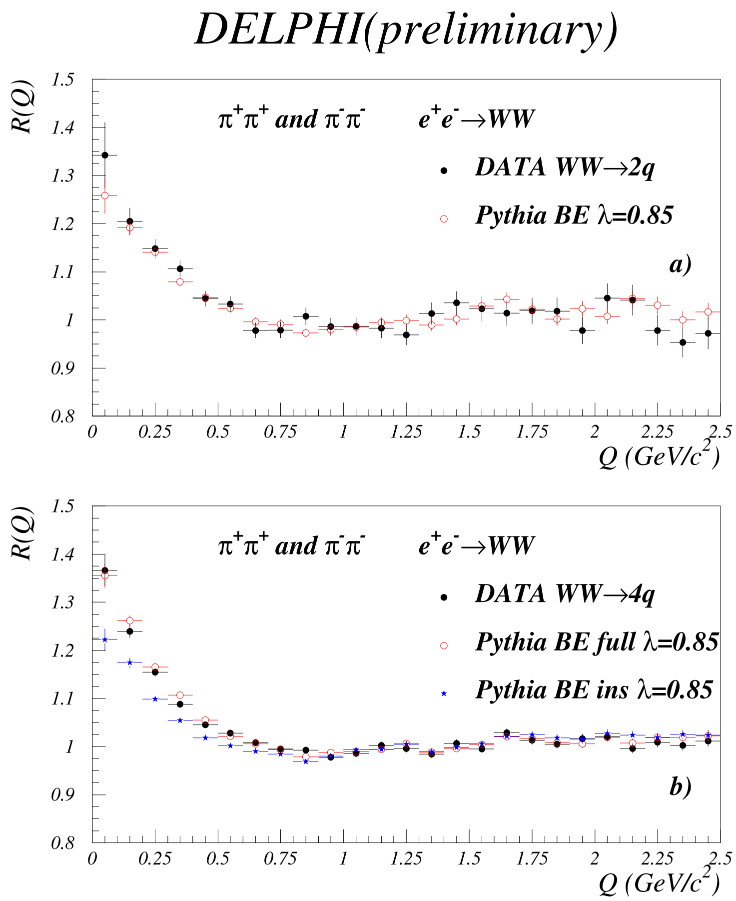
Reference sample corrected for detectors effects:

$$R_2(Q) = \frac{N^{\pm\pm}_{data}(Q)}{N^{\pm\pm}_{MC,noBEC}(Q)}$$

BEA describes data better than BEI

BEI is disfavoured

$\lambda_{2q} = 0.288 \pm ..038$
$\lambda_{4q} = 0.281 \pm .020$
$\lambda_{Z\to udsc} = .306 \pm .009$



This indication is confirmed by:

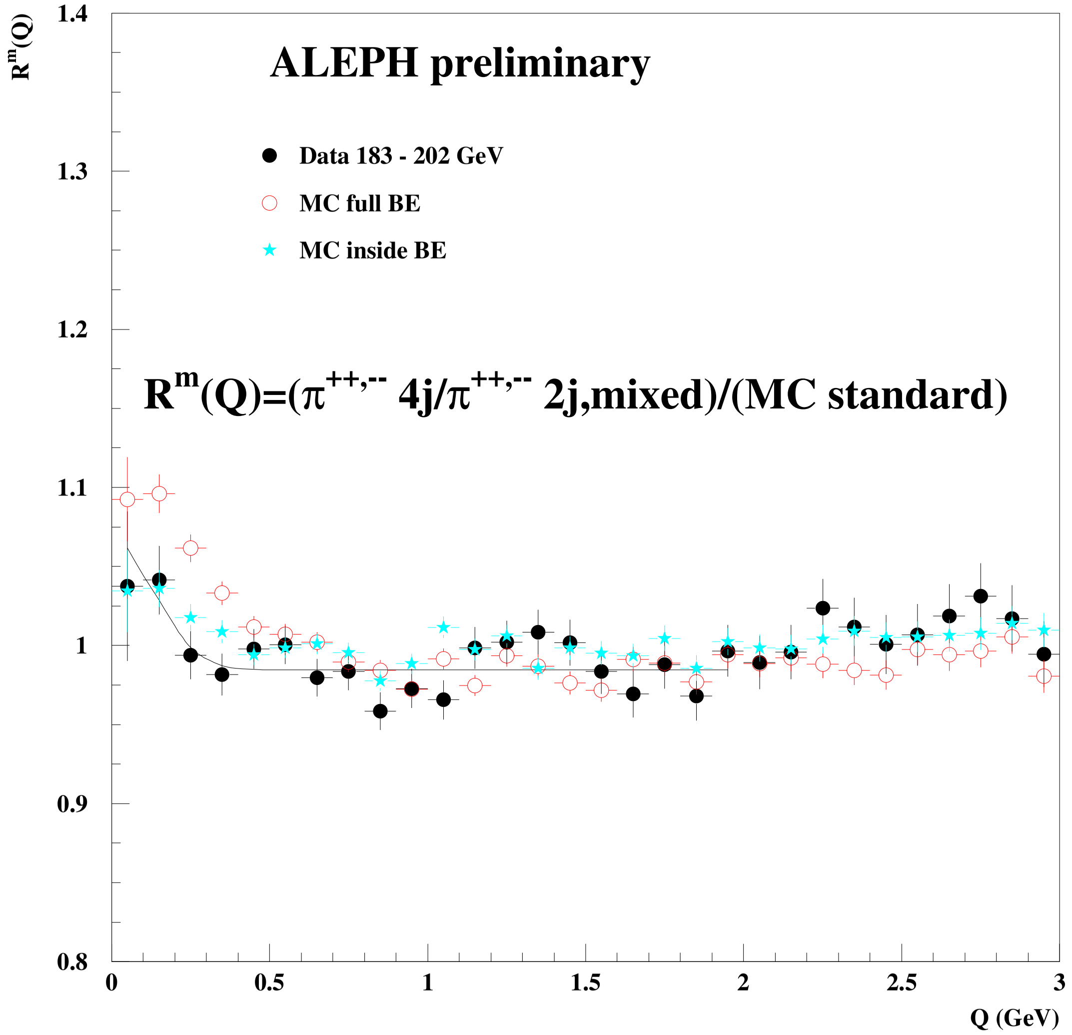
$$R(Q)^{constr} = \frac{(N^{\pm\pm}_{semi} + N^{\pm\pm}_{mix})_{data}}{(N^{\pm\pm}_{semi} + N^{\pm\pm}_{mix})_{MC,noBEC}}$$

$$\lambda_{constr} = 0.214 \pm .029 \pm .008$$
$$\Delta\lambda = 0.062 \pm .025 \pm .021 \Rightarrow 2.4\sigma \text{ effect.}$$

ALEPH analysis à la DELPHI

Reference sample obtained with *event mixing*:

$$R^m(Q) = \frac{(N^{++,--}_{WW\to 4q}/N^{++,--}_{W\,mixed})^{data}}{(N^{++,--}_{WW\to 4q}/N^{++,--}_{W\,mixed})^{MC,noBEC}}$$



Good agreement between DATA and JETSET BEI.

Note: enhancement in BEI is caused by $q\bar{q}$ background.

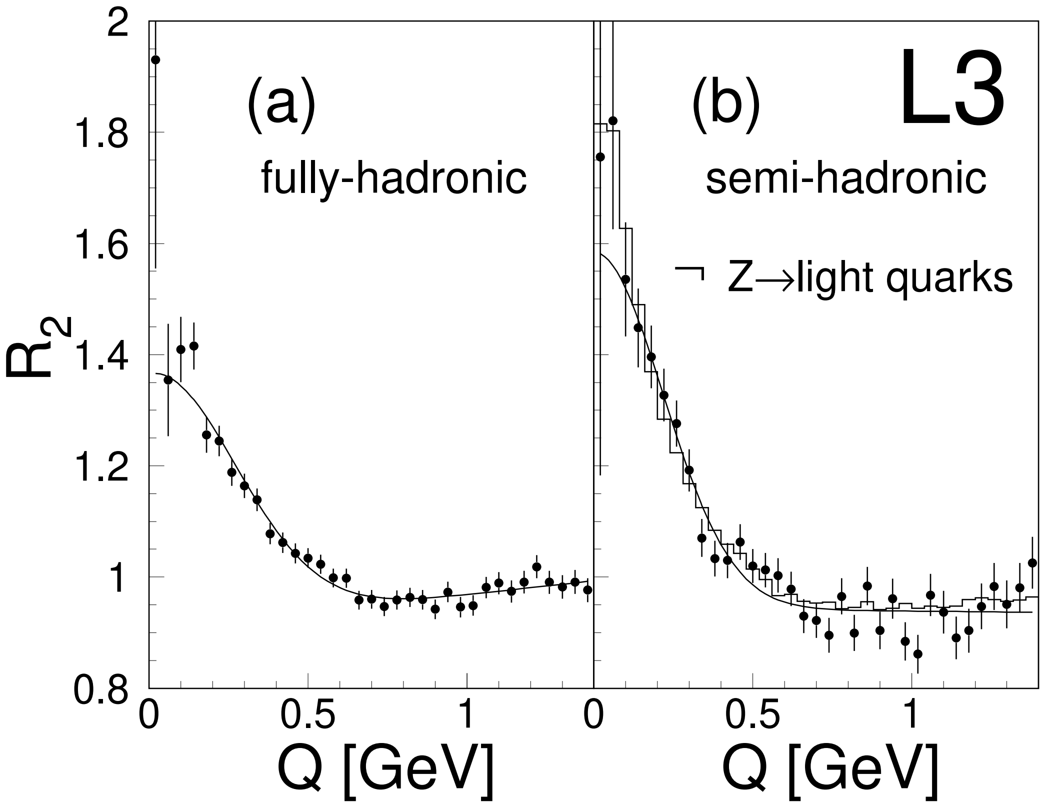
L3 analysis

Reference sample: Monte Carlo without BEC.

$$R_2 = \frac{\rho(\pm,\pm)_{data}}{\rho(\pm,\pm)_{MC_noBEC}}$$

Fit:

$$R_2(Q) = \gamma(1+\delta Q)(1+\lambda e^{-R^2Q^2})$$



$$\lambda_{fully} < \lambda_{semi} \sim \lambda_{Z\to udsc}$$

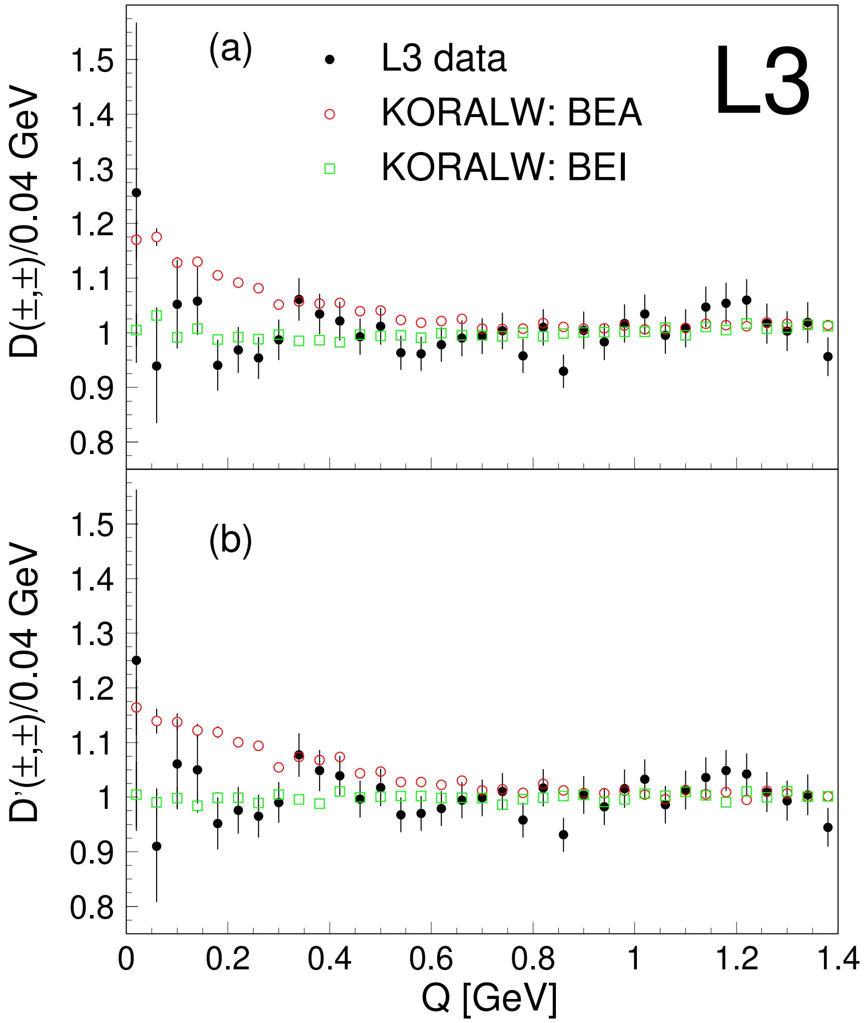
Agreement with no or weak inter-W BEC

L3 analysis

Study inter-W BEC directly (event mixing technique).

$$D = \frac{\rho^{WW}}{2\rho^{W} + 2\rho^{W^+W^-}_{mix}} \quad \text{and} \quad D' = \frac{D_{data}}{D_{MC,noBEC}}$$

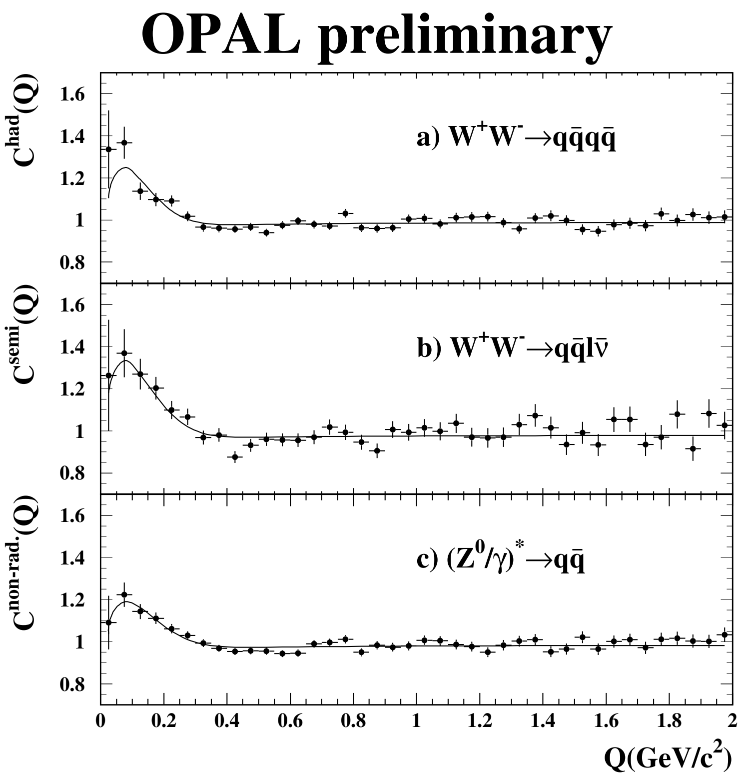
Look for deviation from $D, D' = 1$

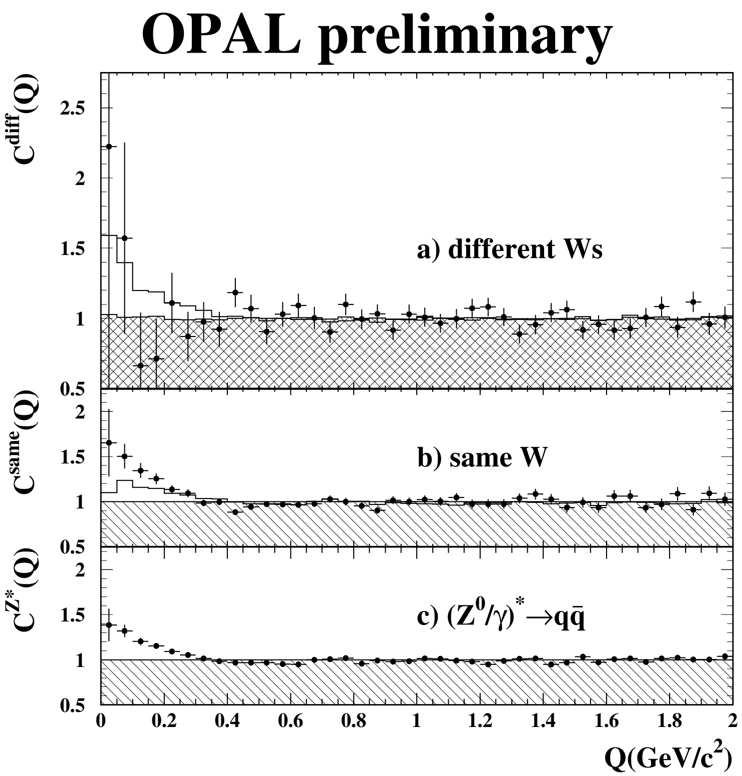


BEA is excluded with $\sim 5.0\sigma$
BEI describes the data

Reference sample: double ratio (like ALEPH).
Different processes may have different BEC. E.g. $W^+W^- \to q\bar{q}q\bar{q}$:

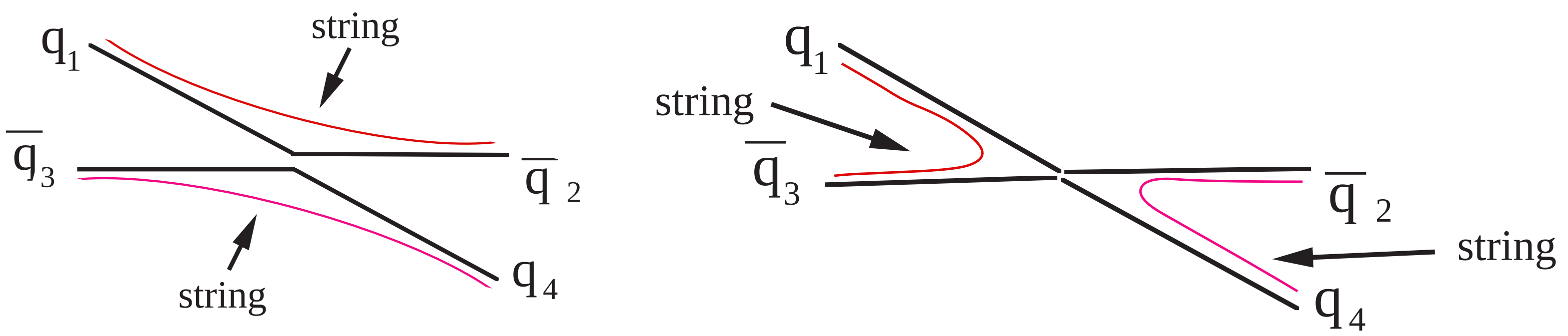
$$C^{had}(Q) = P^{same}_{had}(Q)C^{same}(Q) + P^{Z^*}_{had}(Q)C^{Z^*}(Q) + (1 - P^{same}_{had}(Q) - P^{Z^*}_{had})C^{diff}(Q)$$





Background is fitted simultaneously and there are no assumptions on it, but the method is less sensitive.

QCD interaction between different W's can be expected:



In a colour reconnected event, the event topology is changed with respect to the original event.

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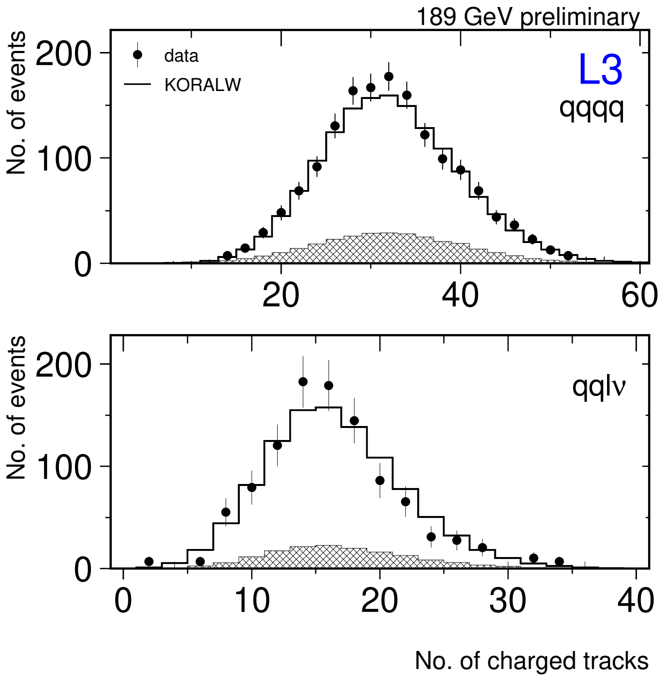
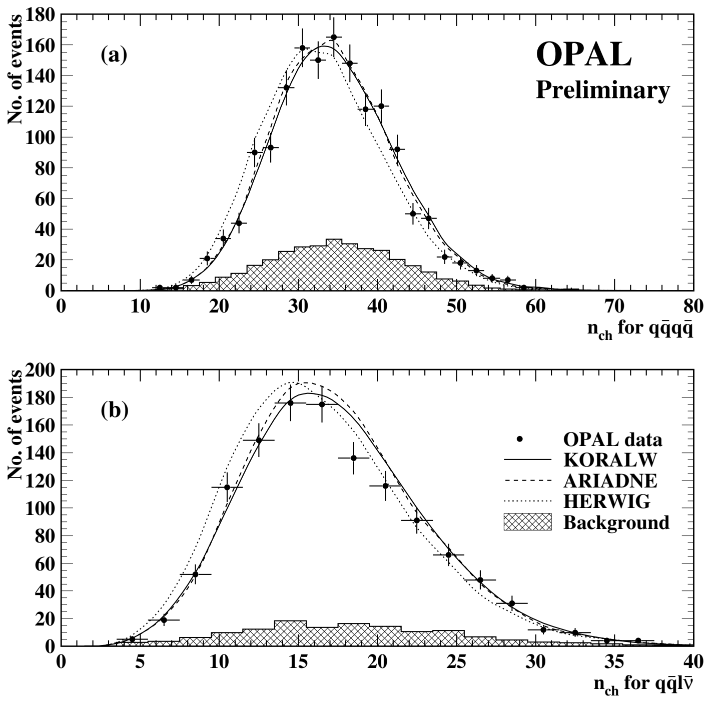
Search for colour reconnection effects by studying event topologies.

Various models predict:

$$< n_{ch}^{qqqq} > \neq 2 < n_{ch}^{qq} >$$

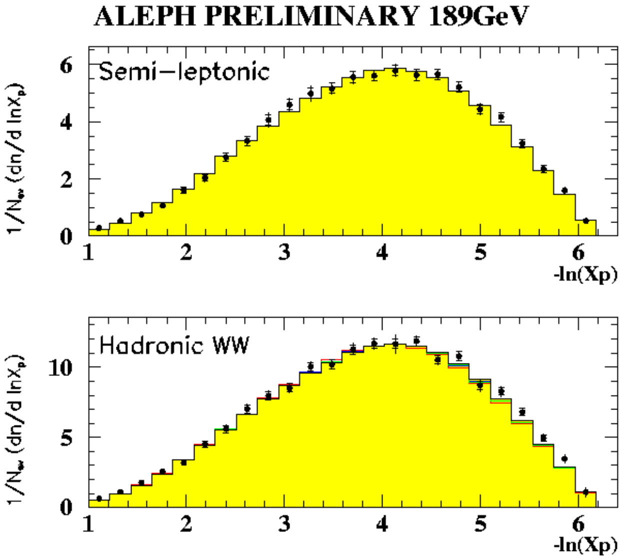
when hadronization of two W's are not independent





The charged multiplicity is investigated from multiplicity distribution, or from integrated fragmentation function.

Charged particle multiplicity



Predictions of various models for $\Delta < N_{had} >$:

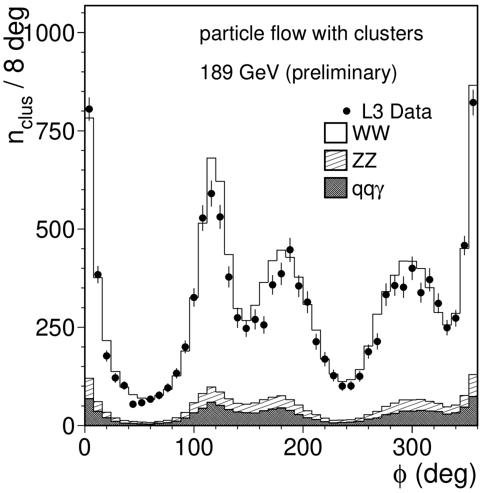
- PYTHIA toy model: ∼-3
- ARIADNE Model II: ∼-1
- others: ∼-0.1–0.3

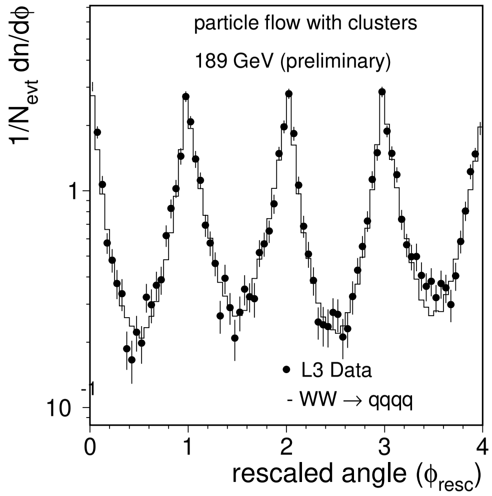
$\mathrm{Exp}(\sqrt{(s)})$	$< N^{qqqq}_{had} >$	$< N^{qq}_{had} >$	$\Delta < N_{had} >$
A 189	35.52±.22±.43	17.53±.19±.24	0.47±.44±.26
D 183-189	38.80±.29±.38	19.57±.26±.32	-0.34±.60±.34
L 183-202	37.90±.14±.41	19.09±.11±.21	-0.29±.26±.30
O 189	38.31±.24±.37	19.23±.19±.19	-0.15±.44±.38

It's difficult to be sensitive using those variables.

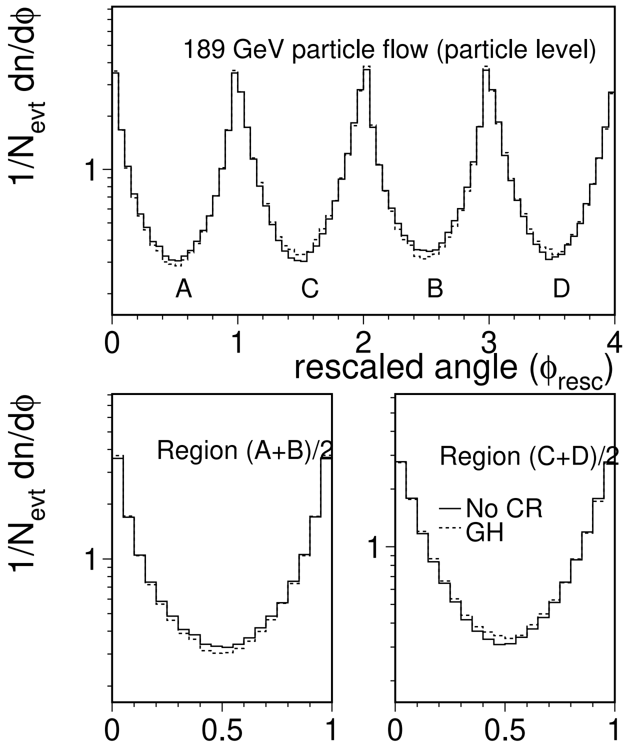
Energy and particle flow (L3)

In order to study inter-jet regions, angles are rescaled:





Regions between jets from the same/different W are combined:

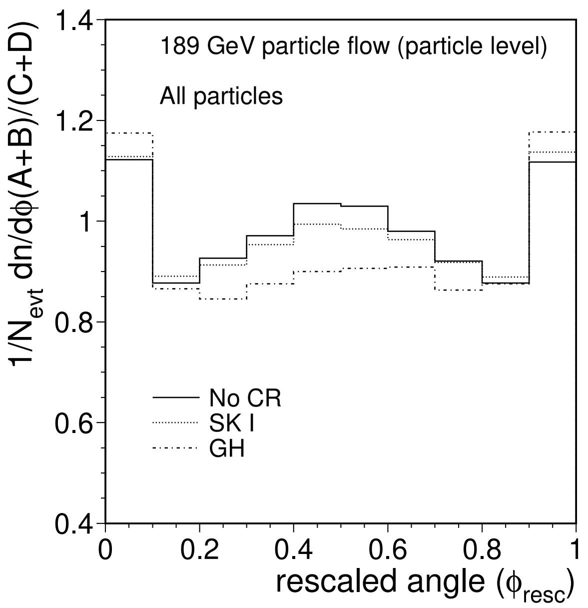


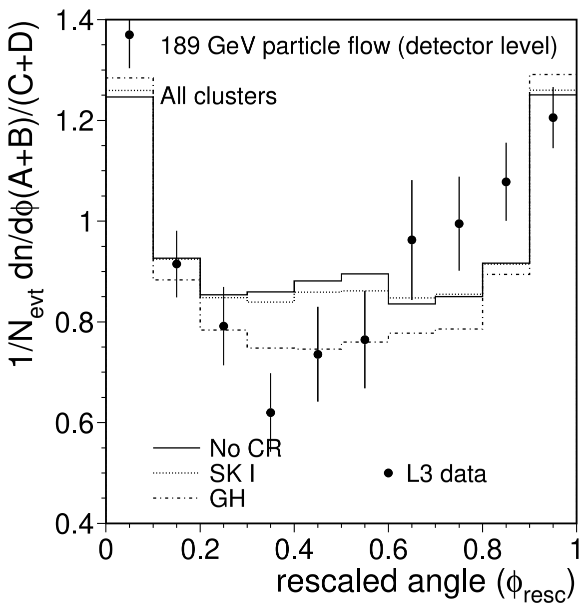
colour reconnection effects could appear as depletion and/or enhancement in inter-jet regions.

Energy and particle flow (L3)

The following quantities are sensitive observables to the cross-talk effects:

$$R_N = \frac{\int \frac{1}{N}\frac{dn}{d\phi}(regions A+B)}{\int \frac{1}{N}\frac{dn}{d\phi}(regions C+D)} \qquad R_E = \frac{\int \frac{1}{E}\frac{dE}{d\phi}(regions A+B)}{\int \frac{1}{E}\frac{dE}{d\phi}(regions C+D)}$$





Integrating from 0.3 to 0.7 give:

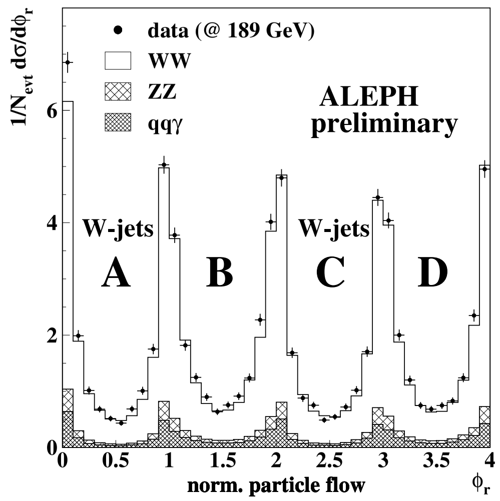
$$R_N = 0.771 \pm 0.049 \pm 0.029$$
$$R_E = 0.593 \pm 0.058 \pm 0.020$$

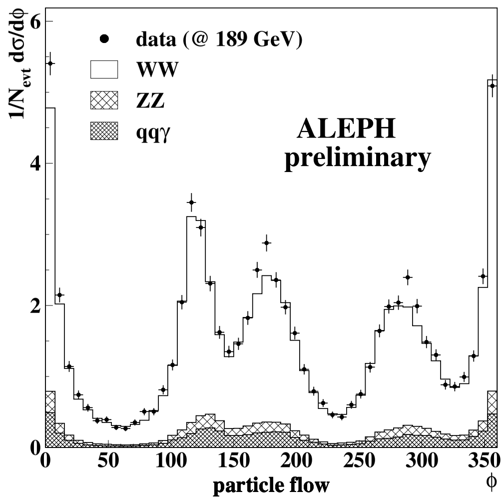
Model	R_N	R_E
No CR	0.868 ± 0.007	0.696 ± 0.009
SK II	0.855 ± 0.007	0.680 ± 0.009
SK I	0.852 ± 0.007	0.675 ± 0.009
GH	0.758 ± 0.006	0.615 ± 0.008

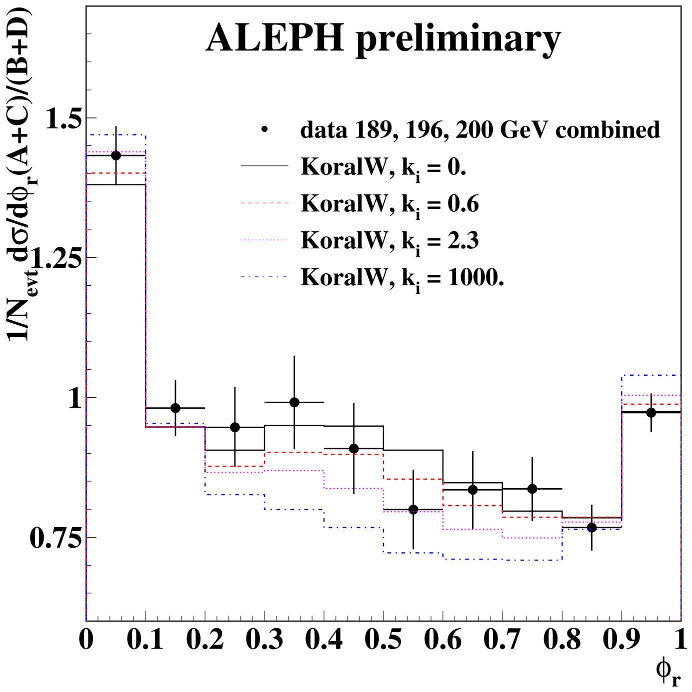
Data show 1.7σ deviation from noCR model predictions
Data are compatible with a 40% reconnection probability

Energy and particle flow (ALEPH)

Similar analysis is now performed by most of LEP experiments.







Aleph set a 1σ limit of $k < 1.4$, corresponding to 45% reconnection probability in SK I model.

Limit of 40 MeV of W mass shift.

Conclusions

- L3 and ALEPH data prefer no BEC between different W's; DELPHI data are in agreement with inter-W BEC; OPAL data are inconclusive.

- The particle multiplicity of $qqqq$ events are compatible, both with models without CR, and with models with *realistic* CR. Only the most extreme colour reconnections models can be excluded.

- The particle and energy flows method is more sensitive and preliminary limits on W mass shift are possible.

- By combining particle and energy flows for all experiments and for all luminosity, we will be able to discriminate between CR models at the end of LEP 2.

... STILL A LOT OF WORK TO BE DONE ...