Final State Interactions in Hadronic WW decay at LEP

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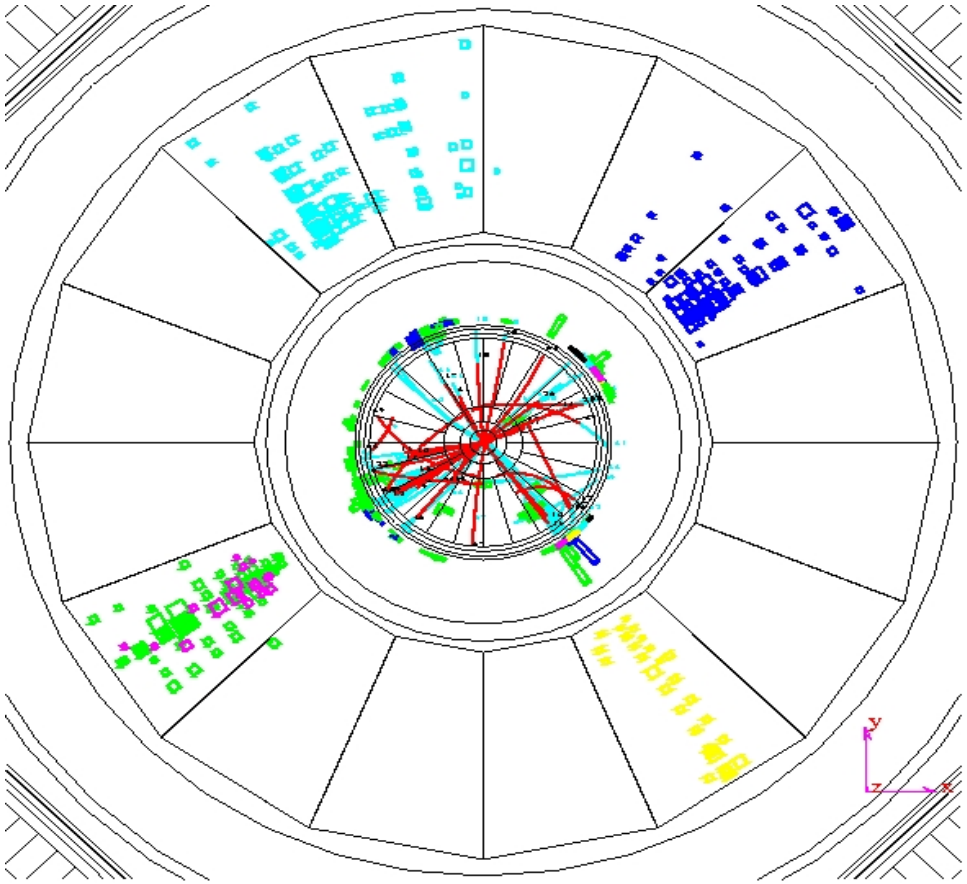
XXXVIIth Rencontres de Moriond
March 9−16, 2001

Introduction

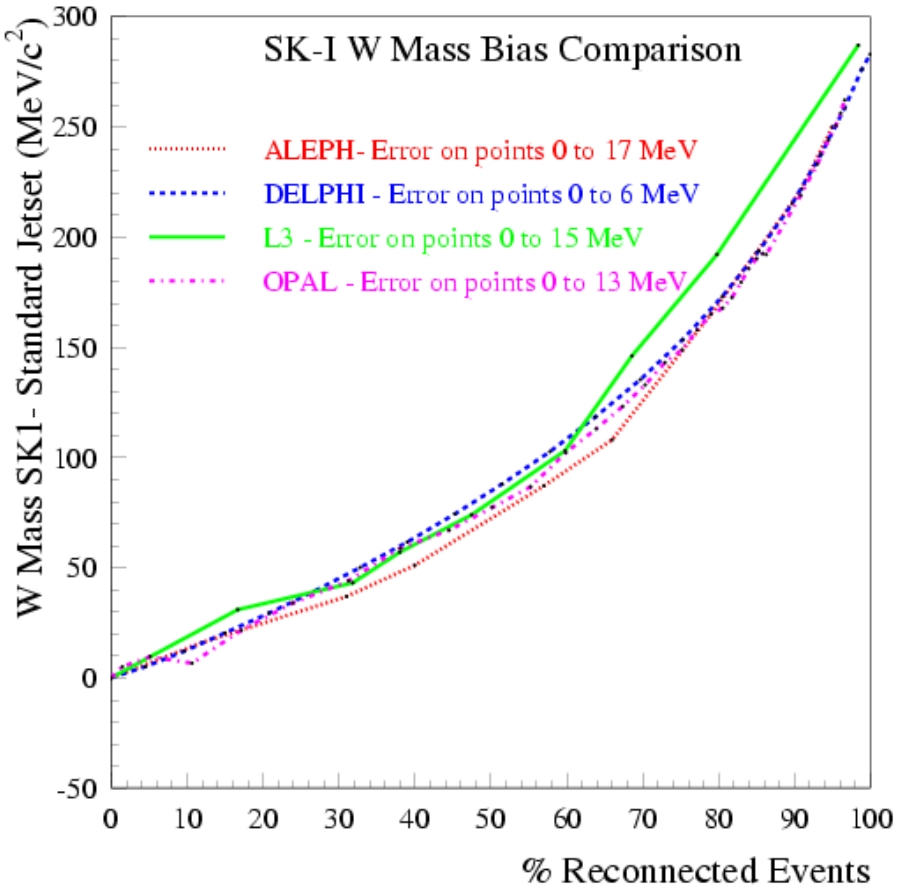
- LEP2: $\sqrt{s}$ > W−pair threshold
- 46% of the W−pairs decay into 4 quarks
- WW decay vertices ~ 0.1 fm
  hadronisation scale ~ 1 fm
  Correlations between W's might occur:
  - Colour Reconnection
  - Bose−Einstein Correlations



FSI and M_W

- Statistical uncertainty on $M_W(4q)$ is 30 MeV
- Large systematic uncertainty from Final State Interactions:

  e.g. CR: ΔM_W = 0–300 MeV



Bose−Einstein Correlations

- Bosons obey Bose−Einstein statistics
  - Amplitude symmetrisation: enhancement of identical bosons close in phase space

- BEC observed in $Z \rightarrow qq$ at LEP1
  - Does it exist between particles from different W's?

- Study inter−W BEC in $e^+e^- \rightarrow W^+W^-$

	$\sqrt{s}$ [GeV]	L [pb^{-1}]
ALEPH	183 – 209	683
DELPHI	189 – 209	531
L3	189 – 209	627
OPAL	172 – 189	250

All results are preliminary!

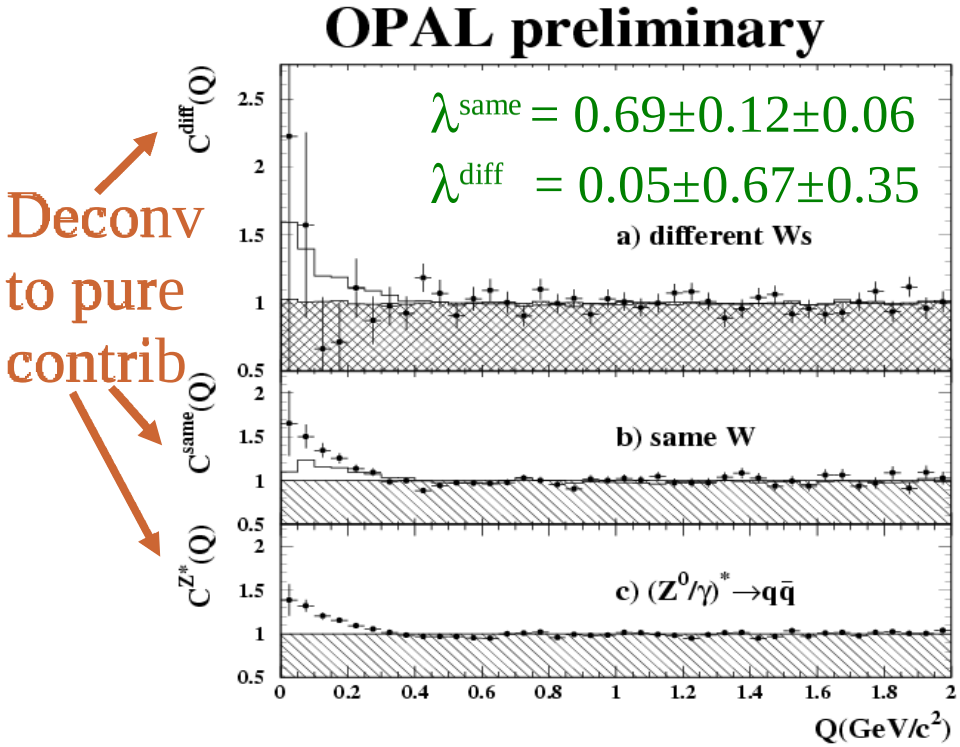
BEC methods

- Two-particle density: $\rho(p_1, p_2) = \frac{1}{N_{ev}} \frac{d\, n_{pairs}}{d\, Q}$
- Effect largest at small 4-momentum diff $Q^2 = -(p_1 - p_2)^2$
- Unlike-sign pair analysis: compare with refence sample without inter-W BEC
- Mixed events analysis: build 4q event from hadronic part of qqlν events
- $\rho \approx (1 + \lambda \exp(-r^2 Q^2))$ source of radius r and strength λ

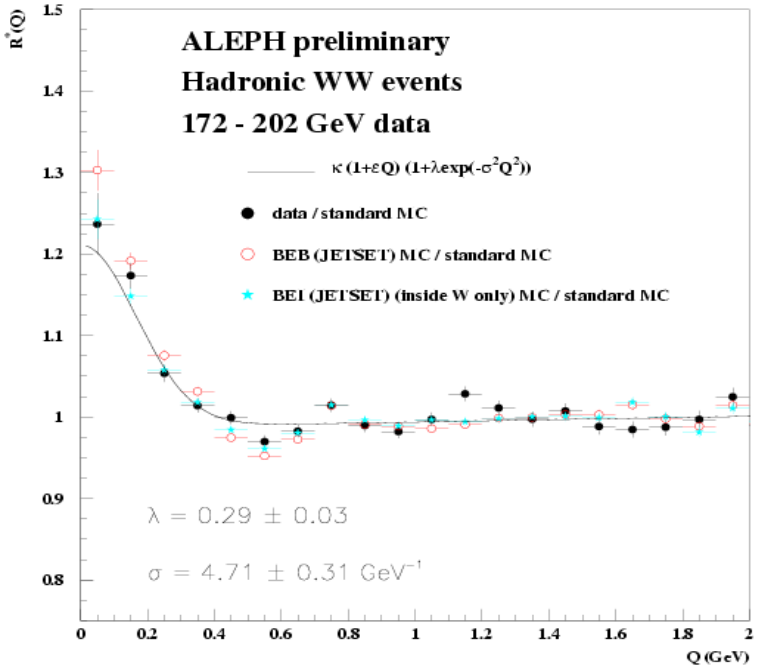
BEC unlike−sign pairs

- Double ratio between like− and unlike−signed pions:

$$R(Q) = \left(\frac{N^{++,--}(Q)}{N^{+,-}(Q)}\right)^{data} \Big/ \left(\frac{N^{++,--}(Q)}{N^{+,-}(Q)}\right)^{MC,noBEC}$$



Deconv to pure contrib



Compatible with both inter−W and no inter−W BEC

Inter−W BEC MC disfavoured by 2.2σ

BEC mixed events (1)

- If 2 W's decay independently:

$$\rho^{WW\to 4q} = 2\cdot\rho^{W\to 2q} + \rho^{WW_{mix}}$$

4q sample — from qqlν — from mixing hadronic part qqlν events

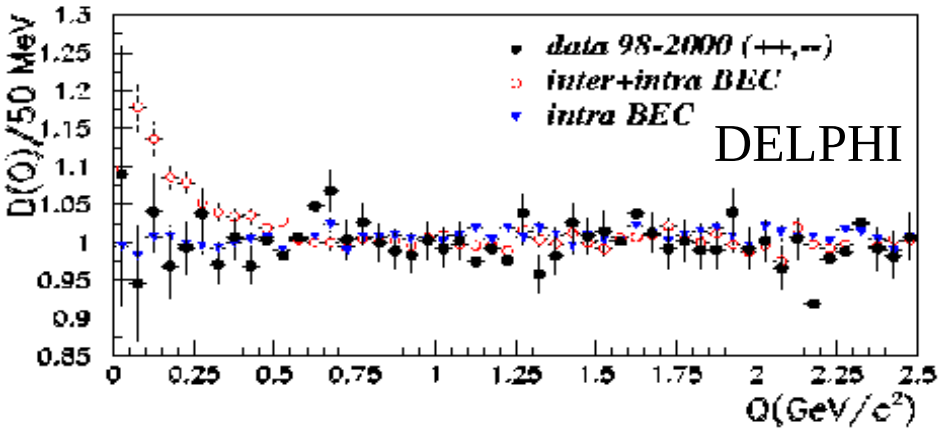
⇒ direct acces to inter−W BEC from data

- Sensitive distributions:

$$\Delta\rho = \rho^{WW\to 4q} - 2\cdot\rho^{W\to 2q} - \rho^{WW_{mix}}$$

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

If no inter−W BEC exist:
$\Delta\rho \equiv 0$, $D \equiv 1$

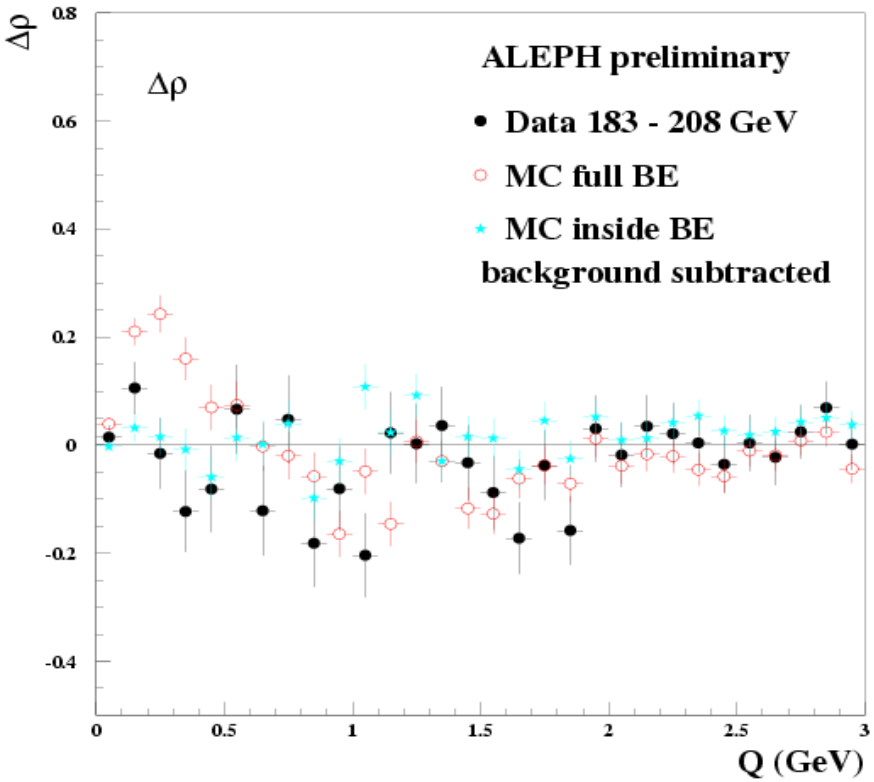


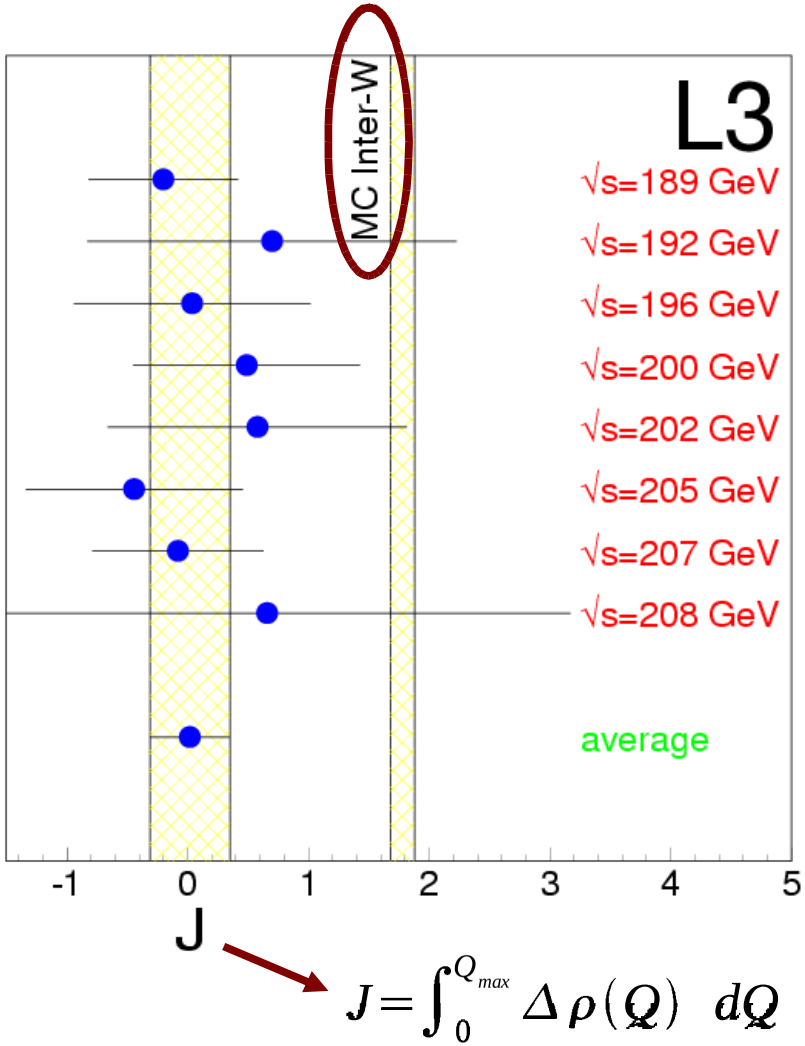
$\Lambda^{\text{intra+inter BEC}} \equiv 0.24 \pm 0.03$

$\Lambda^{\text{data}} \equiv -0.037 \pm 0.055 \pm 0.055$

inter−W BEC MC disfavoured 3.2σ

BEC mixed events (2)

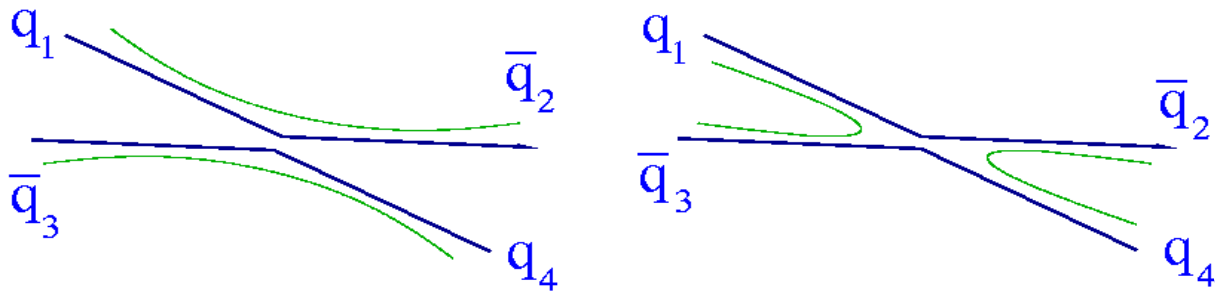




Good agreement data and
MC with only intra−W BEC

Colour Reconnection

- Change of initial colour flow pattern :



- Created hadrons cannot be assigned to either W

- Affects – multiplicities of soft and heavy particles (not sensitive)
  – particle and energy flow between jets

- Different phenomenological models exist:
  - PYTHIA: reconfiguration of string topology (Sjöstrand–Khoze)
    SKI: flux tubes

$$P_{reco} = (1 - e^{-f(\sqrt{s}) \cdot k_I})$$

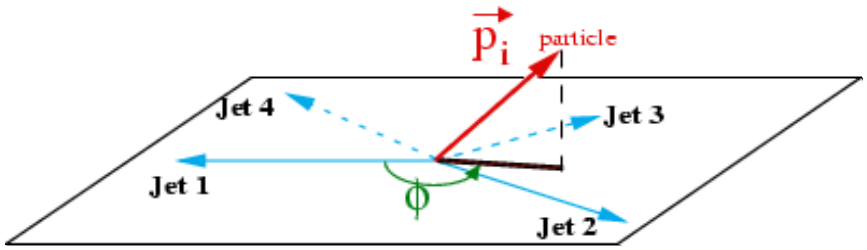
free parameter

volume of string overlap

  - ARIADNE, HERWIG, Rathsman, ...

CR particle flow (1)

- Compare particle rates between jets of same and diff W's
- project particle momenta in plane of jets
- particle flow $f_p = \frac{1}{N_{evt}} \frac{\Delta n}{\Delta \phi}$



	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]
L3	189 – 209	627
DELPHI	183 – 209	601
ALEPH	189 – 209	628
OPAL	189	183

tight cuts on angles between jets: clean topology but low efficiency

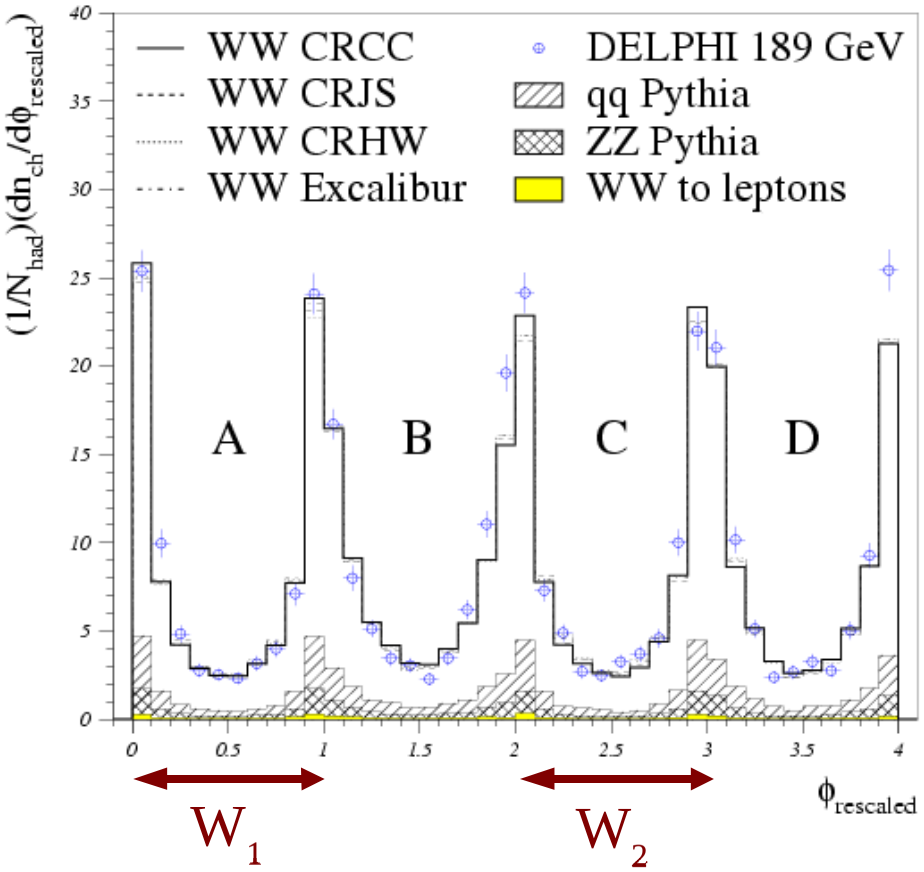
based on standard W analysis higher efficiency but less planar events

All results are preliminary!

CR particle flow (2)

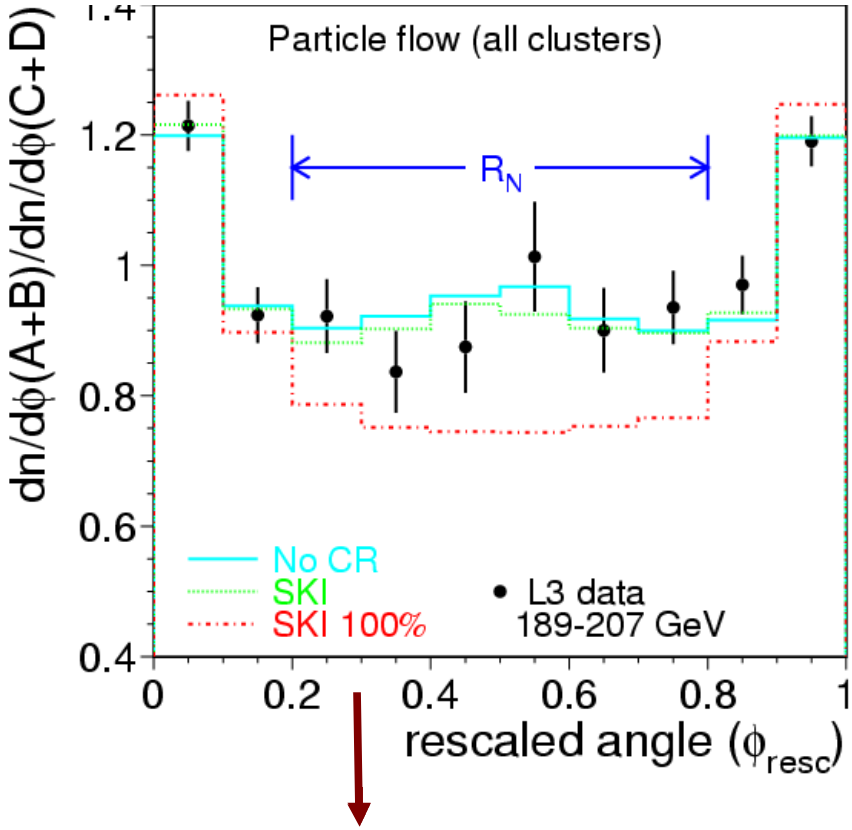
rescale angles:

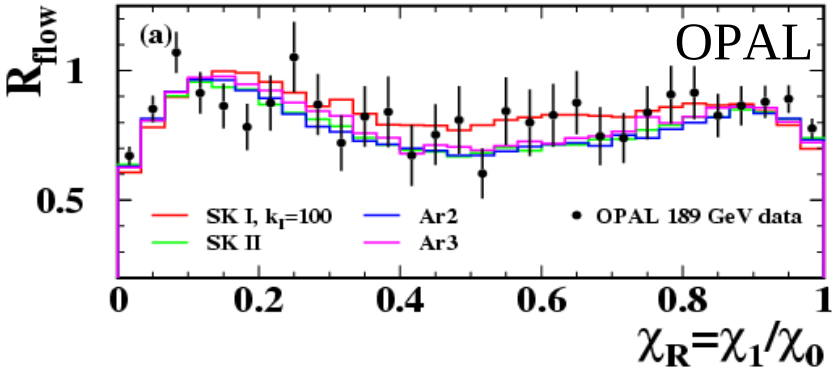
$$\phi^{resc} = \phi / \phi_{jet-jet}$$



- combine region inside W's (A+C) and between W's (B+D)
- take ratio of particle flows R ≡ (A+C)/(B+D)

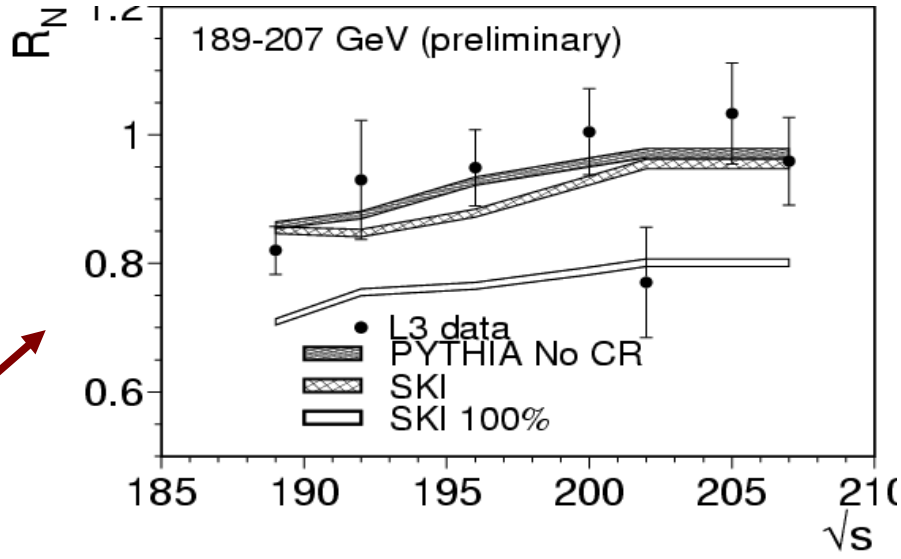
CR particle flow (3)





Ratio R in restricted interval:

$$R_N = \frac{\int_{0.2}^{0.8} f_p(inside\ W)}{\int_{0.2}^{0.8} f_p(between\ W's)}$$



CR particle flow (4)

- Compare experiments: take ratio of R between data and MC with and without CR (SKI model)

	$\langle R_R(\text{noCR})\rangle$	$\langle R_R(\text{CR})\rangle$
ALEPH	0.961±0.012±0.007 −2.8σ	1.041±0.013±0.008 +2.7σ
DELPHI[1]	1.009±0.030±0.019 +0.3σ	1.110±0.033±0.029 +2.5σ
L3	0.990±0.025±0.023 −0.3σ	1.194±0.039±0.028 +4.7σ
OPAL[2]	0.906±0.033±0.011 0.996±0.051±0.011 −2.7σ / −0.1σ	1.050±0.038±0.013 1.193±0.061±0.014 +1.2σ / +3.1σ

prefers some CR, P≡100% too much

no effect seen

inconsistent between different selections

↓

under study in all exp, due to selection, background, ... ?

1. average of ratios over energies
2. W−selection/topological selection

CR SKI k_I parameter

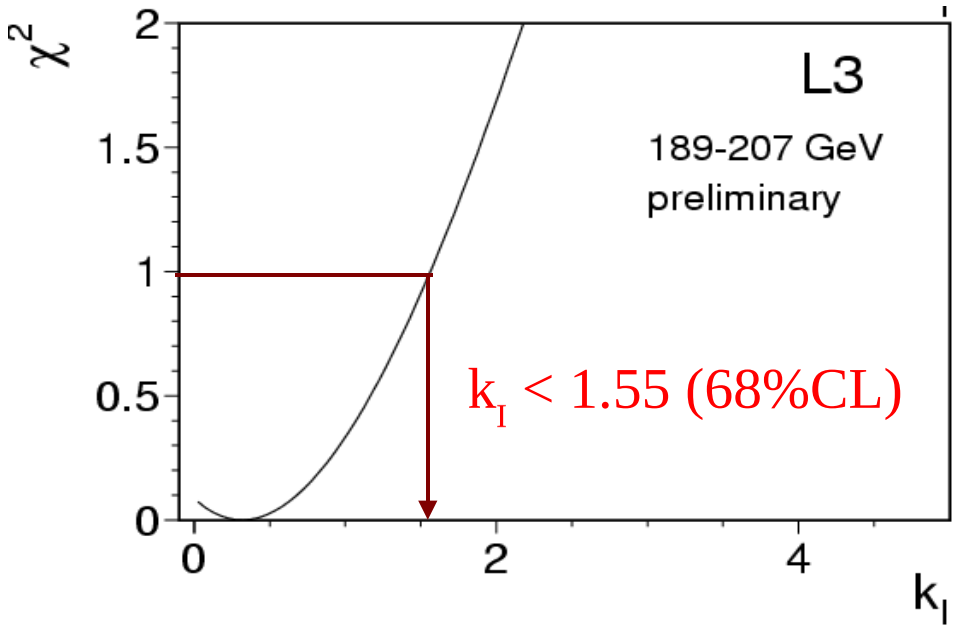
- Sjöstrand–Khoze model (SK): recon. if strings cross or overlap
  - → SKI: flux tubes

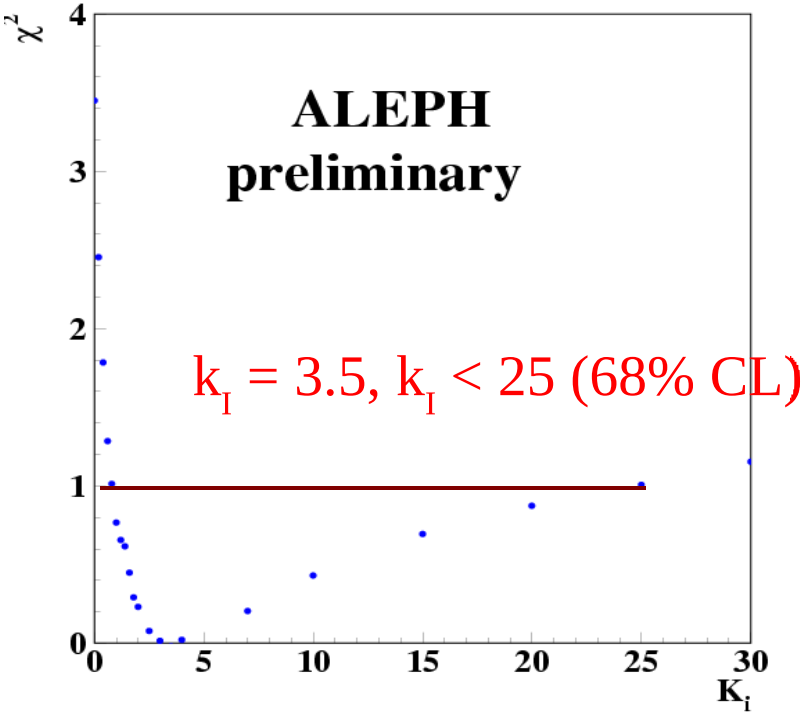
$$P_{reco} = (1 - e^{-f(\sqrt{s})\,k_I})$$

free parameter

volume of string overlap

- Extract k_I from R_N: vary P_{reco} => χ^2 data–MC





Conclusions and Outlook

- No inter−W BEC observed at LEP
  MC with inter−W BEC strongly disfavoured

- Different results on CR using particle flow method
  Systematics still under study
  Experiments working on new methods (cone algorithm, rapidity gaps)

- LEP combination in progress for BEC and CR
  −> pin down systematic uncertainty on M_W