Colour Reconnection at LEP2

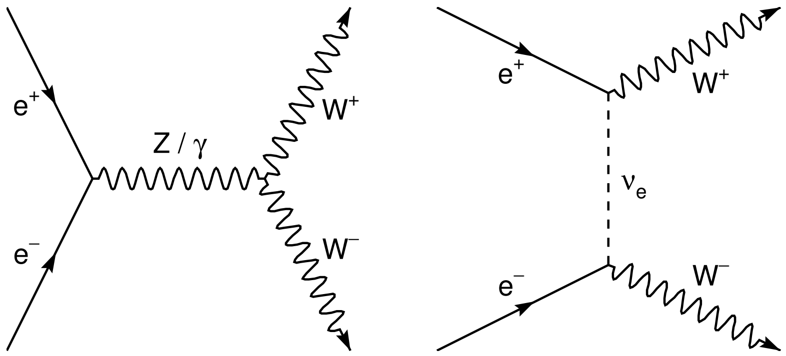
Nandakumar Raja

TIFR
MUMBAI

- Introduction
- Multiplicity based method
- Particle flow analysis
- Summary

LEP 2 :

- 2^{nd} phase of the the Large e^+e^- collider
- $\mathcal{L} \approx 470\ \mathrm{pb}^{-1}$ / expt; $\sqrt{s} > 160$ GeV
  (WW production threshold)



- ≈ 7700 WW events per experiment
- Major aim of LEP2 : Precision M_W measurement
  (35 MeV statistical accuracy)

This talk :

Data taken in 1997, 1998 and 1999

Most results are preliminary

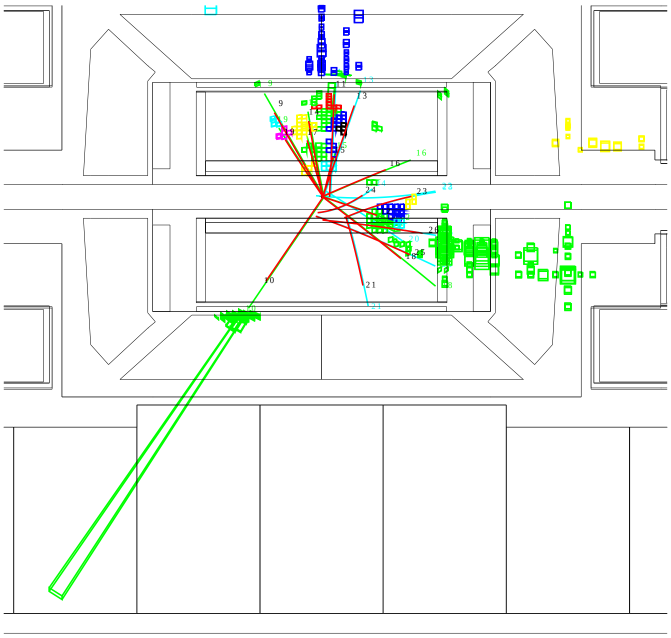
Unchanged since Osaka

WW Decays :

$WW \longrightarrow l\nu l\nu$ 11%

$WW \longrightarrow q\bar{q}l\bar{\nu}_l$ 44% (Semi–leptonic)

$WW \longrightarrow q\bar{q}q\bar{q}$ 46% (Hadronic)

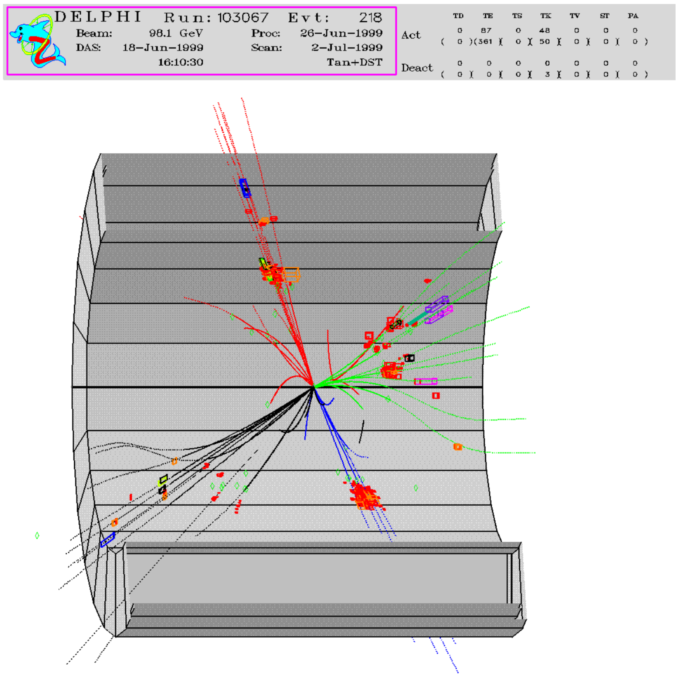


$q\bar{q}e\bar{\nu}_e$

Note in $q\bar{q}q\bar{q}$ channel :

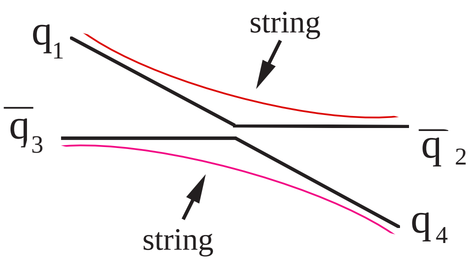
3 different ways of pairing up 4 jets into 2 Ws

Use some algorithm to obtain good pairing efficiency

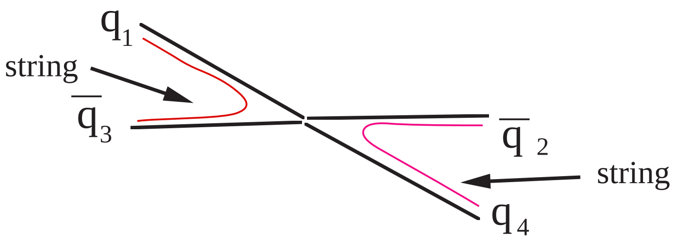


$q\bar{q}q\bar{q}$

- Interaction between independent colour singlets
  eg. quarks of different Ws (WW$\rightarrow q\bar{q}q\bar{q}$ channel)
- W^+W^- decay vertex separation $\lessapprox 0.1$ fm
  ($\ll$ Hadronisation scale ~ 1 fm)



No Reconnection



Immediate Reconnection

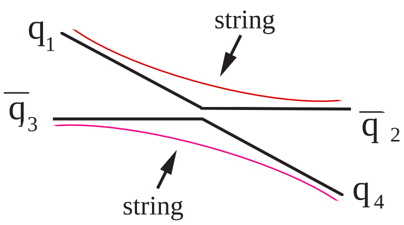
- ▷ Energy – momentum exchange between all quarks
- ▷ Change in string configuration
- ▷ Affects reconstructed p_μ of Ws (M_W is affected)

$\rightarrow$ No CR in $q\bar{q}l\bar{\nu}_l$ events
(quark system is source of CR free Ws)

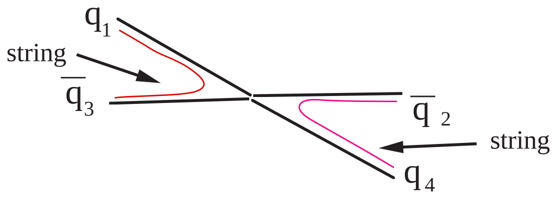
$\rightarrow$ Simulate different models, compare with data
(Popular : SK1, SK2, GH, CR in HERWIG)

CR causes reduction in string length

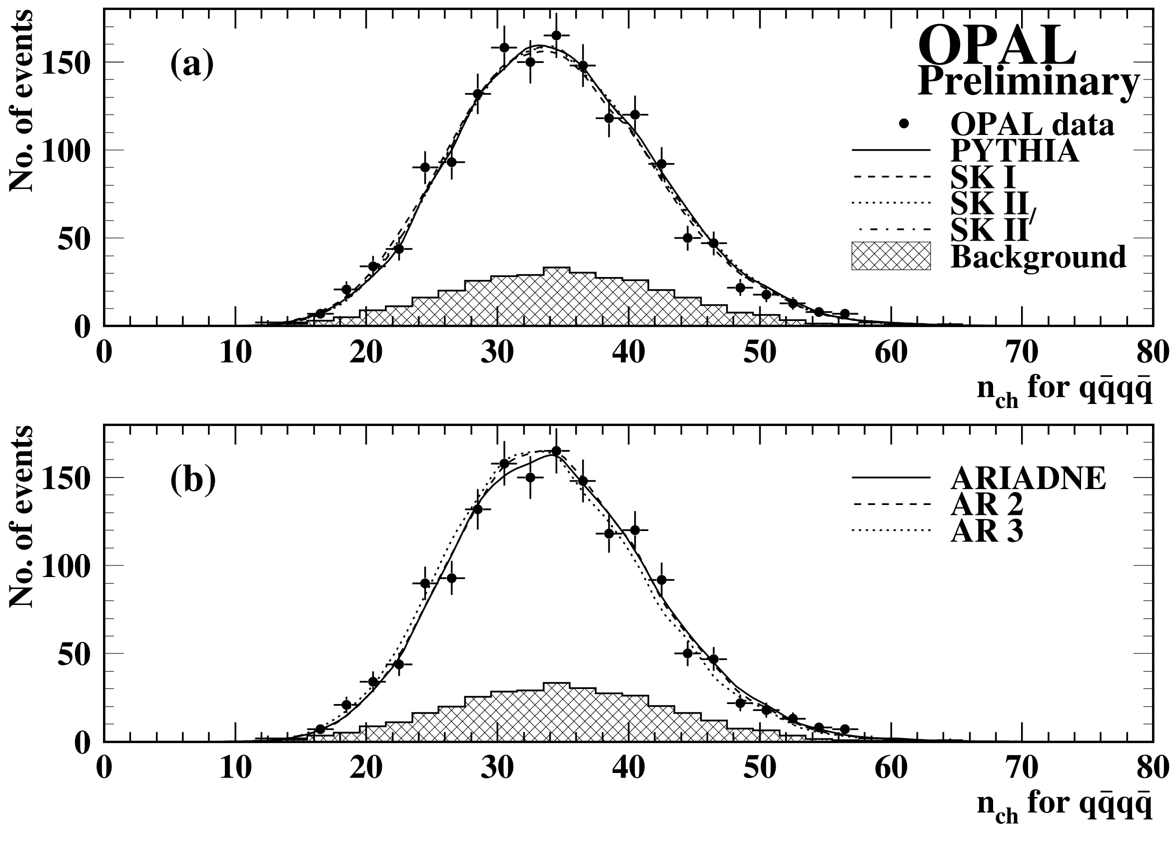
☞ Charged particle multiplicity (N_{CH}) is reduced



No Reconnection



Immediate Reconnection



Limited sensitivity of this method

Define average charged multiplicities :

$\langle N_{ch}^{4q} \rangle$: from $q\bar{q}q\bar{q}$

$\langle N_{ch}^{2q} \rangle$: from $q\bar{q}$ system of $q\bar{q}l\bar{\nu}_l$

N_{ch} obtained from tracks, bkg subtraction, unfolding

	$\sqrt{s}$ (GeV)	$\langle N_{ch}^{4q} \rangle$	$\langle N_{ch}^{2q} \rangle$
ALEPH	183–202	$35.75 \pm 0.13 \pm 0.52$	$17.41 \pm 0.12 \pm 0.15$
DELPHI	183	$38.11 \pm 0.57 \pm 0.44$	$19.78 \pm 0.49 \pm 0.43$
	189	$39.12 \pm 0.33 \pm 0.36$	$19.49 \pm 0.31 \pm 0.27$
L3	183–202	$37.90 \pm 0.14 \pm 0.41$	$19.09 \pm 0.11 \pm 0.21$
OPAL	183	$39.4 \pm 0.5 \pm 0.6$	$19.3 \pm 0.3 \pm 0.3$
	189	$38.31 \pm 0.24 \pm 0.37$	$19.23 \pm 0.19 \pm 0.19$

Define : $\Delta\langle N_{ch} \rangle = \langle N_{ch}^{4q} \rangle - 2\langle N_{ch}^{2q} \rangle$ ($\neq 0$ for CR)

Unofficial combined value :

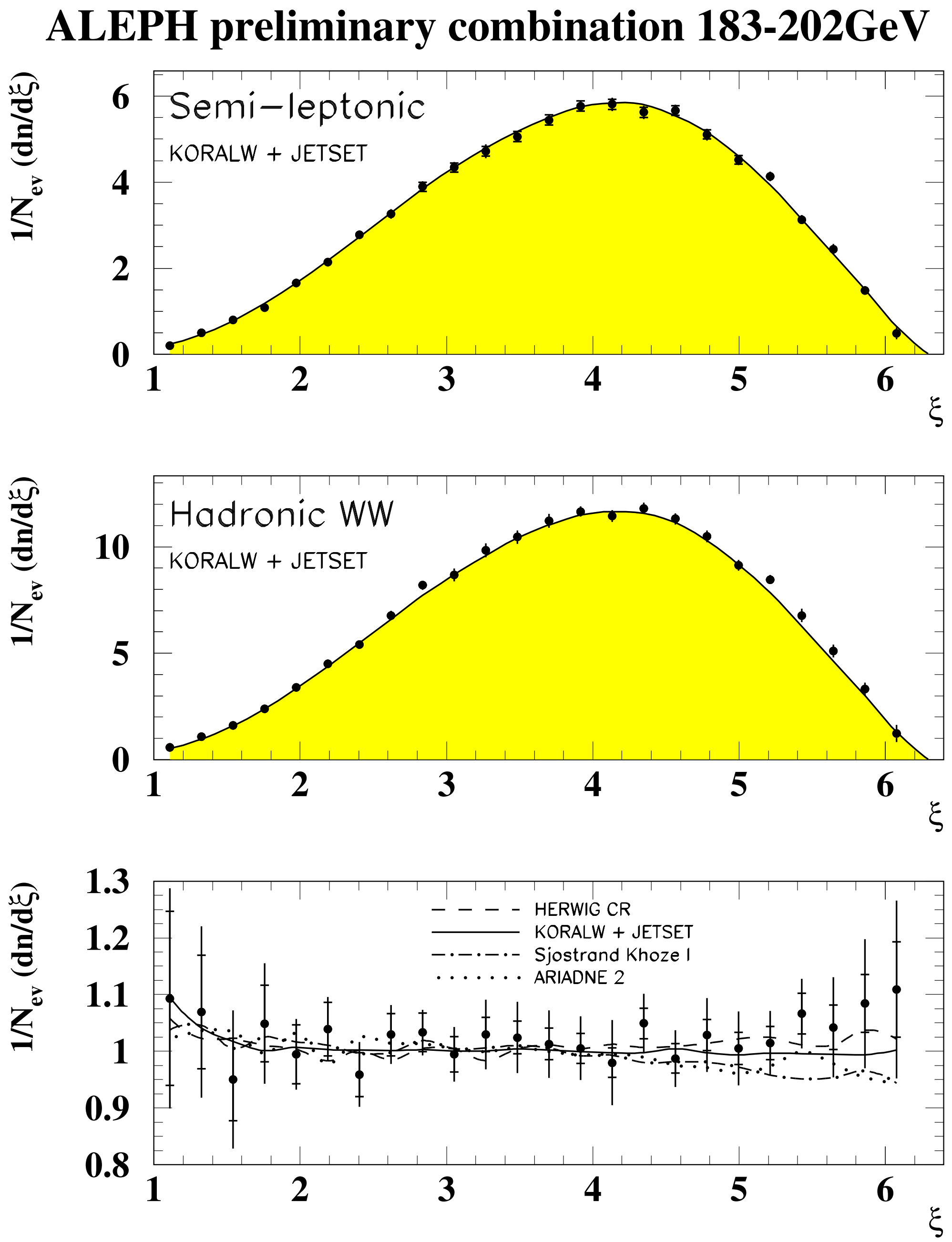
$$\Delta\langle N_{ch} \rangle = 0.22 \pm 0.20 \pm 0.35$$

Result consistent with 0

No significant effect seen

Similar result for Dispersions

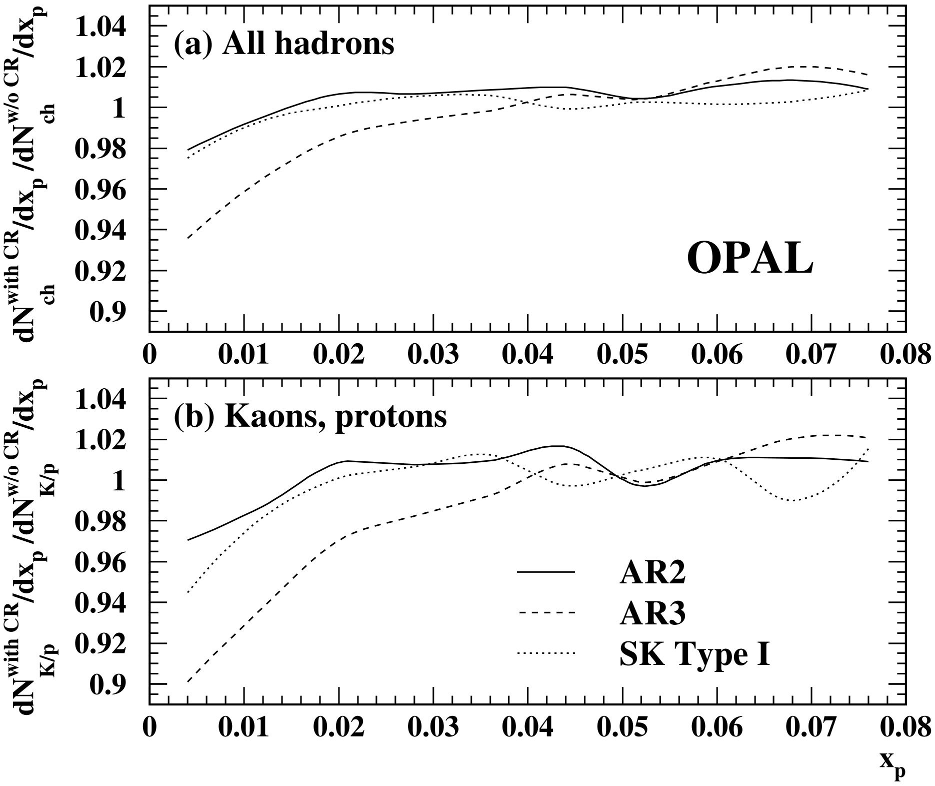
Define $x_p = \frac{2p}{\sqrt{s}}$ and $\xi = -\log x_p$



Maximum sensitivity (at 189 GeV)

$$4.5 \leq \xi \leq 6.1 \quad \Rightarrow \quad 0.001 \leq x_p \leq 0.005$$

Heavy hadrons (eg. Kaons, protons) more sensitive to CR



MC $q\bar{q}q\bar{q}$ events at $\sqrt{s} = 189$ GeV

Define : $R = \frac{\langle N_{ch}^{4q} \rangle}{2\langle N_{ch}^{2q} \rangle}$

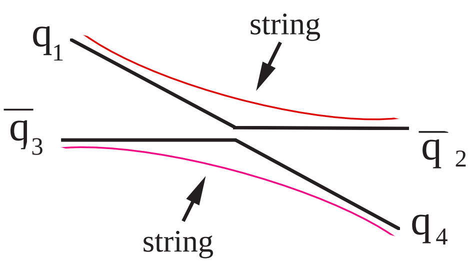
DELPHI : Particle ID using TPC, RICH

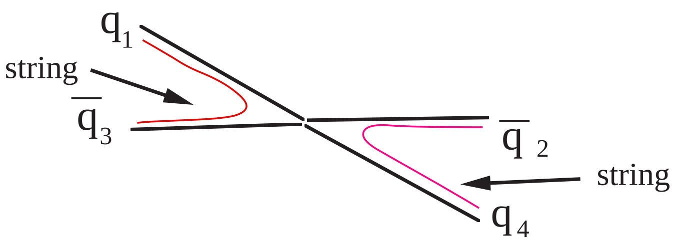
	All p	$0.002 \leq x_p \leq 0.007$ GeV
$\pi^{\pm}$	$1.02 \pm 0.03 \pm 0.04$	$1.03 \pm 0.03 \pm 0.01$
$K^{\pm}$	$0.98 \pm 0.17 \pm 0.08$	$0.96 \pm 0.38 \pm 0.08$
$p, \bar{p}$	$0.97 \pm 0.28 \pm 0.11$	$0.72 \pm 0.57 \pm 0.08$

Similar results from OPAL

No effects seen

Study the "string" topology across jets in $q\bar{q}q\bar{q}$ events





Require :

- Clean, 4–jet topology
- Jet pairing with high efficiency

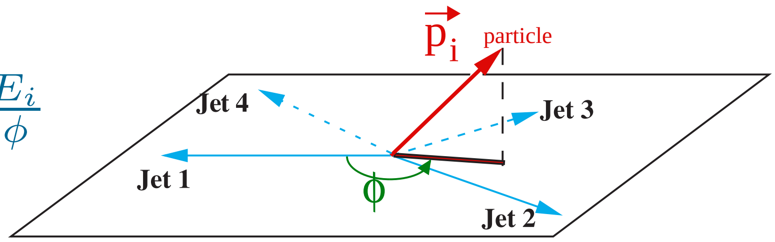
▷ Use strong cuts for event selection

▷ Selection eff $\approx 15\%$, Jet pairing eff $\approx 87\%$

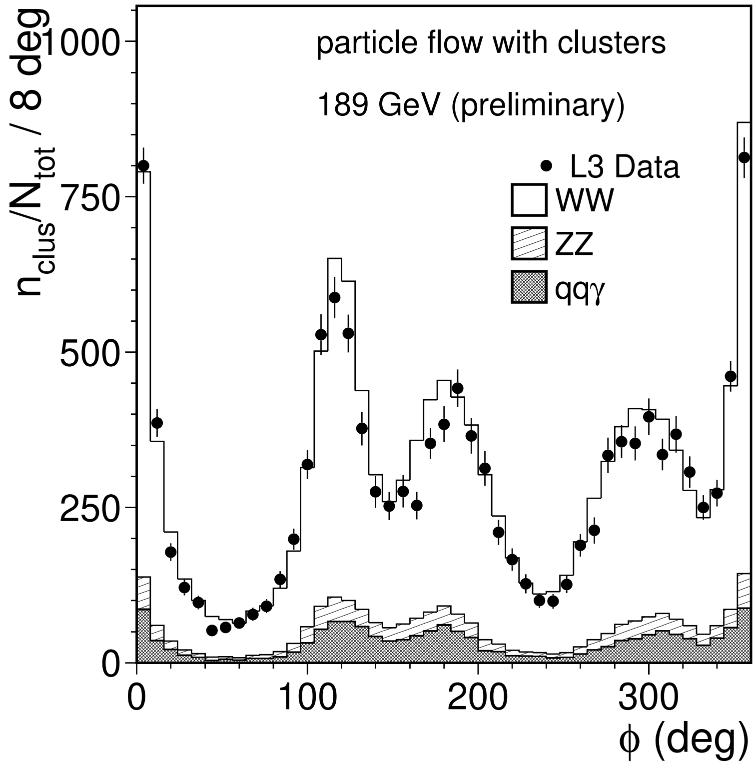
Project particles onto jet–jet plane

Particle flow : $\frac{1}{N_{evt}} \frac{\Delta N}{\Delta \phi}$

Energy flow : $\frac{1}{E_{vis}} \frac{1}{N_{evt}} \frac{\Delta E_i}{\Delta \phi}$



Jet 1 : Maximum energy

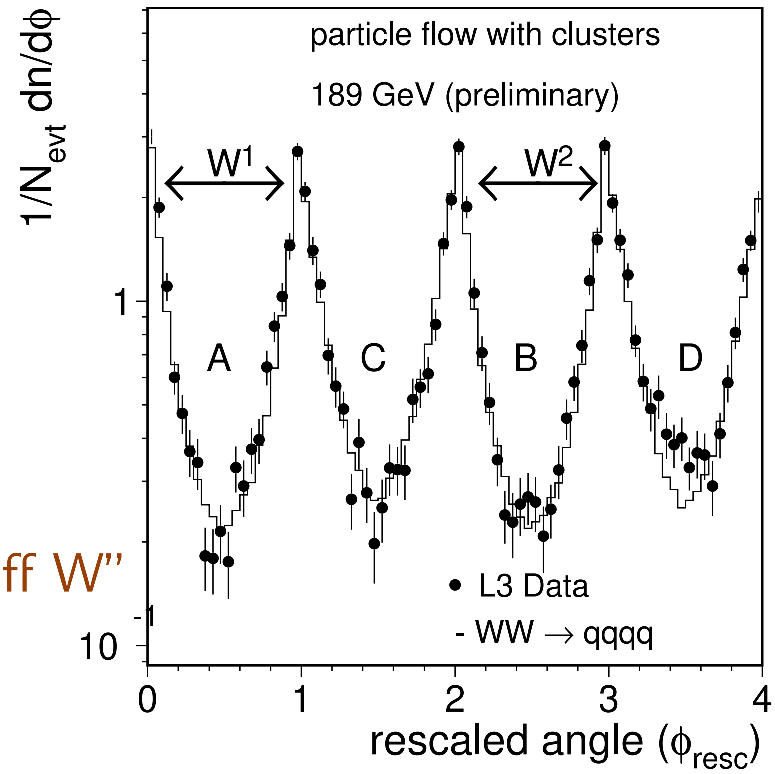


Subtract background

Symmetrize using 4 planes

Define $\phi_{resc} = \frac{\phi}{\phi_{jj}}$

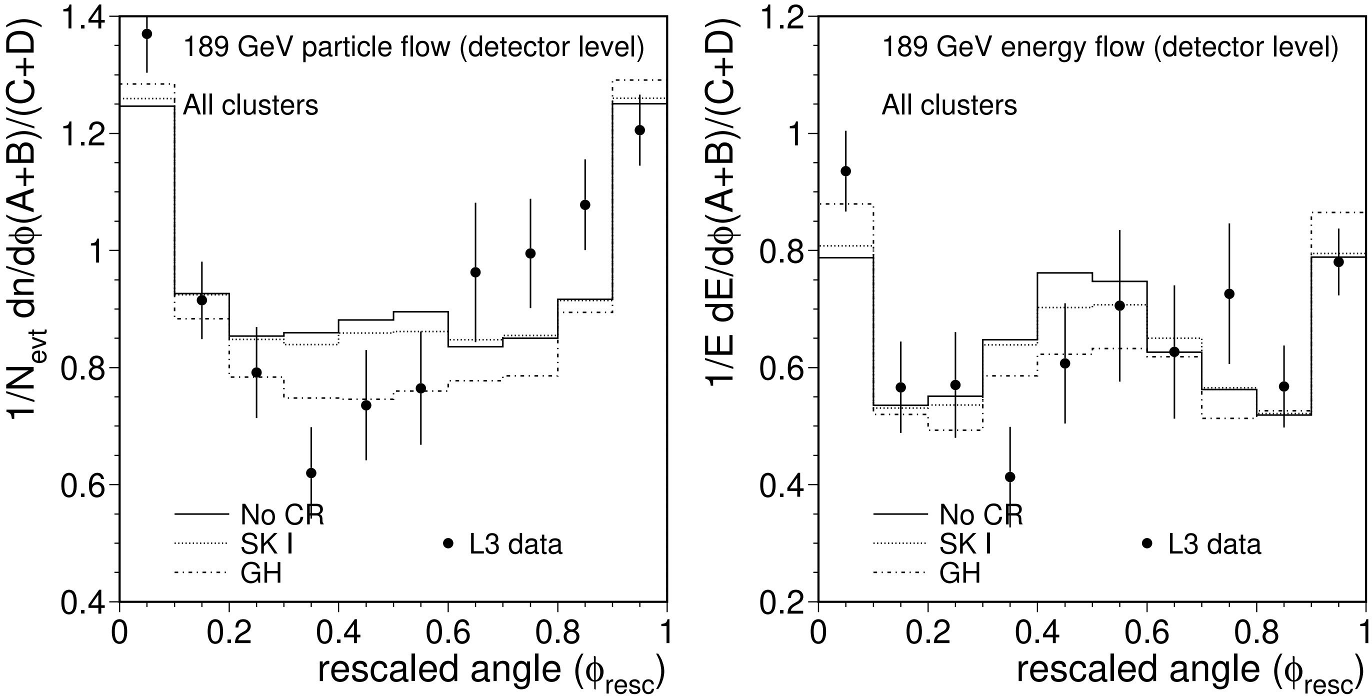
$(0 \leq \phi_{resc} \leq 4)$



Take Ratio : $\frac{A+B}{C+D}$

Ratio of “Same W” vs “Diff W”

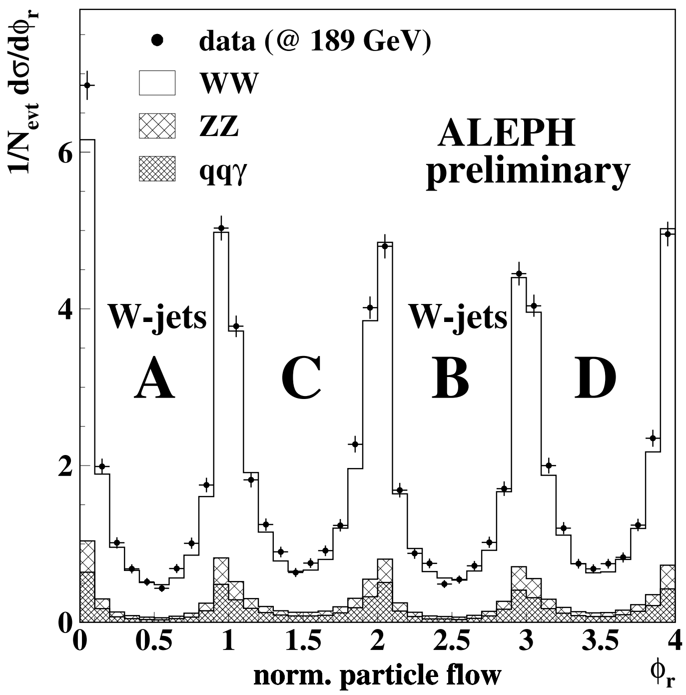
Some systematics cancel

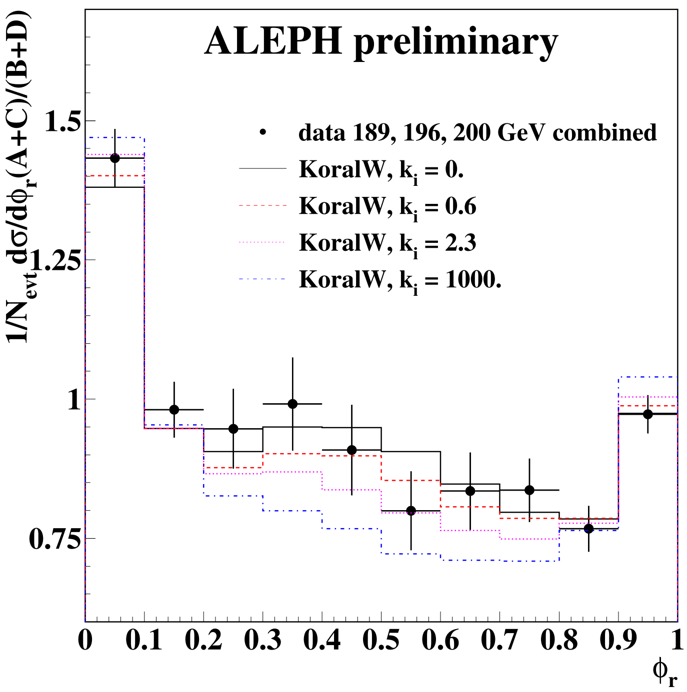


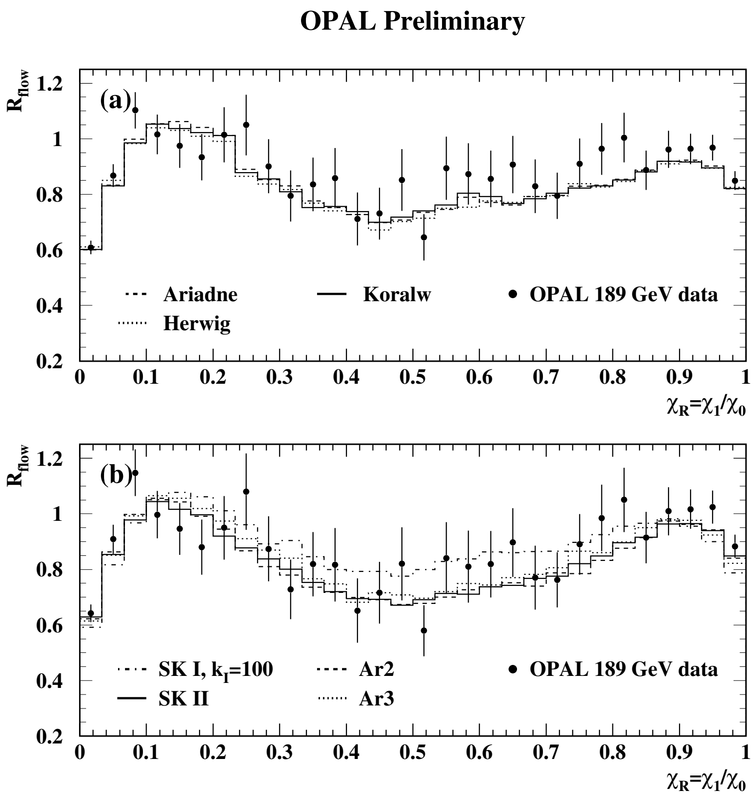
Define : $R = \int_{0.3}^{0.7} \frac{A+B}{C+D}\, d\phi_{resc}$

for particle and energy flow distributions

	Particle flow	Energy flow
No CR	0.868 ± 0.007	0.696 ± 0.009
SK I	0.852 ± 0.007	0.675 ± 0.009
SK II	0.855 ± 0.007	0.680 ± 0.009
GH	0.758 ± 0.006	0.615 ± 0.008
Data	$0.771 \pm 0.049 \pm 0.029$	$0.593 \pm 0.058 \pm 0.020$


data (@ 189 GeV)
WW
ZZ
qqγ
ALEPH
preliminary
W-jets
A
C
W-jets
B
D
$1/N_{evt}\, d\sigma/d\phi_r$
norm. particle flow
ϕ_r


ALEPH preliminary
data 189, 196, 200 GeV combined
KoralW, k_i = 0.
KoralW, k_i = 0.6
KoralW, k_i = 2.3
KoralW, k_i = 1000.
$1/N_{evt}\, d\sigma/d\phi_r\,(A+C)/(B+D)$
ϕ_r


OPAL Preliminary
R_{flow}
(a)
Ariadne
Herwig
Koralw
OPAL 189 GeV data
$\chi_R=\chi_1/\chi_0$
(b)
SK I, k_I=100
SK II
Ar2
Ar3
OPAL 189 GeV data
$\chi_R=\chi_1/\chi_0$

Test SK I (scan over CR probability)

L3 :

- Data prefers 40 % CR (SK I model)
- Difference with No CR : 1.7σ

Aleph :

- Data prefers 15 % CR (SK I model)
- 1σ upper limit : 45 % CR

Opal :

- Default analysis : $\simeq$ 60 % CR (SK I model)
  (1.3σ for $\approx 30\%$, -1.5σ for $\approx 95\%$)
- Cross check analysis : best agreement with no CR

Outlook :

☞ Combination of experiments in progress : large gain

☞ Most sensitive method, limited statistics

☞ Systematics are small

☞ $e^+e^- \to W^+W^-$ at LEP2 allows studies of CR

▷ Multiplicity based analyses :

- ▶ Limited sensitivity
- ▶ No significant results

▷ Particle flow analyses :

- ▶ Most sensitive method, limited statistics
- ▶ Some indication of CR

$\longrightarrow$ M_W, Γ_W: Affected due to change in p_μ of reconstructed Ws

$\longrightarrow$ CR Systematic error :

- ▷ M_W: 50 MeV fully correlated across experiments
- ▷ Γ_W: 40 MeV – 70 MeV

$\longrightarrow$ Aim to use particle flow analysis to improve these numbers