Rapidity gaps in gluon jets/ color reconnection at LEP

M. Giunta

University of California, Riverside

OPAL Collaboration

XXXVIIIth Recontres de Moriond

QCD And High Energy Hadronic Interactions

March 23rd 2003

Outline

- Rapidity gaps & color reconnection
  Why focus on rapidity gaps in gluon jets?
- Color reconnection models
  Rathsman-CR, Ariadne-CR, Herwig-CR
- Analysis strategy
- Results from OPAL
- Results from ALEPH
- Summary & conclusions

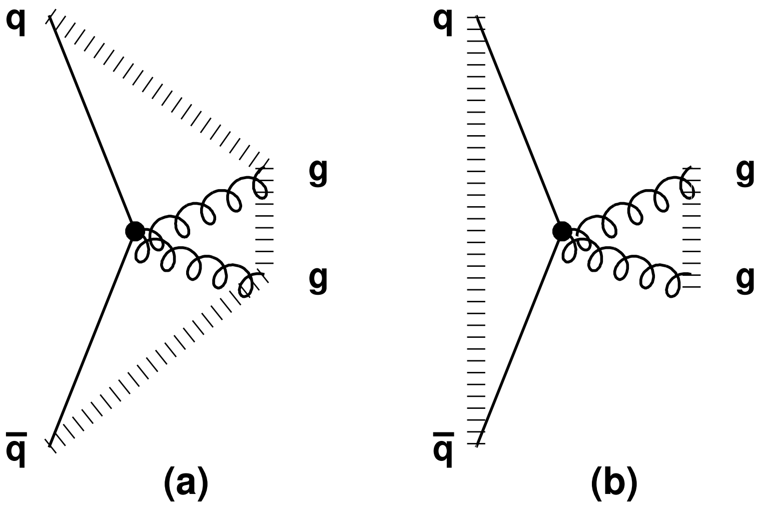
Rapidity gaps & CR

Rapidity : $y = \frac{1}{2} \ln \left(\frac{E+p_{\|}}{E-p_{\|}} \right)$

where:
$E =$ energy of the particle
$p_{\|} =$ 3-momentum component w.r.t. event, thrust or jet axis

Rapidity gap event: event in which two populated regions in rapidity are separated by an empty region

Color reconnection (CR): rearrangement of the color structure of an event from its simplest configuration



$\Rightarrow$ string segments can either cross or appear as disconnected entities whose endpoints are gluons ($1/N_C^2$ suppression; $N_C = 3$, number of colors)

$\Rightarrow$ in events with an isolated gluonic system a rapidity gap can form between particles coming from the isolated segment and the rest of the event

$\Rightarrow$ rapidity gaps in gluon jets provide a sensitive means to search for color reconnection effects

Color reconnection models

- ## Ariadne-CR model

  G. Gustafson,J. Häkkinen, Z. Phys. C64 (1994) 659
  L. Lönnblad, Z. Phys. C70 (1996) 107

  the three different existing implementations (Ar-1, Ar-2 and Ar-3) are equivalent at the Z^0

- ## Rathsman-CR model

  J. Rathsman, Phys. Lett. B452 (1999) 364

  implemented in the framework of Pythia 5.7.
  The color reconnection probability is proportional to the non-perturbative factor R_0 (fixed to 0.1)

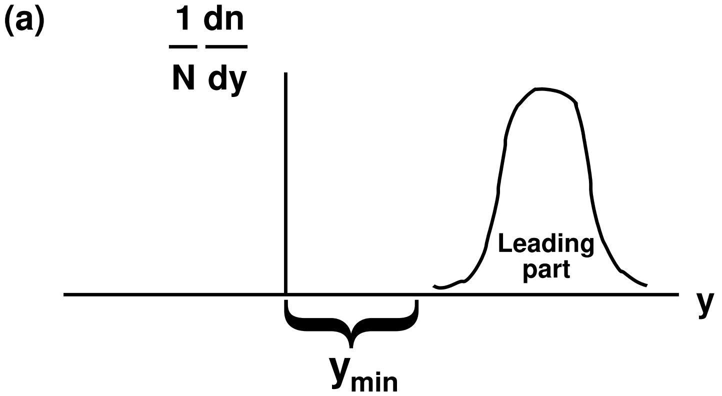
- ## Herwig-CR model

  G. Corcella et al., JHEP 0101 (2001) 010

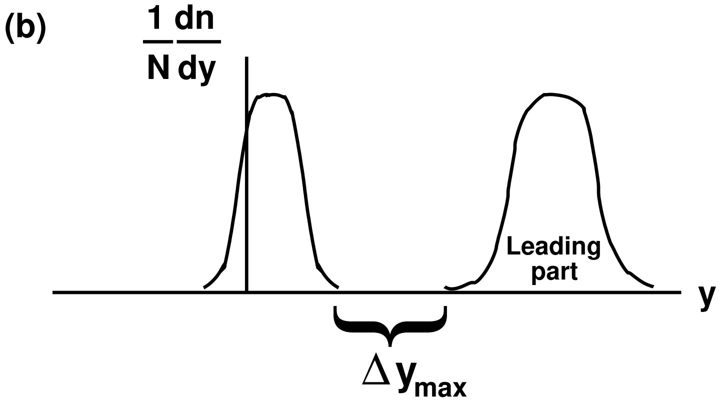
Analysis strategy

[first presented in OPAL-PN-515, Sep. 2002]

- verify that all the models (with and without CR) give a good description of the global features of hadronic events
- select gluon jets with a rapidity gap
  - cut on the smallest particle rapidity y_{min}



  - or on the largest rapidity difference Δy_{max}



- study the distribution of the charged particle multiplicity $n^{ch}_{leading}$ and total electric charge $Q_{leading}$ [a] of the leading part of the jet

---

[a] proposed for glueball searches by P. Minkowski, W. Ochs, Phys. Lett. B485 (2000) 139

OPAL selection (I)

[new note OPAL-PN-518, Mar. 2003]

- use OPAL $Z^0 \rightarrow hadrons$ events collected from 1993 to 1995 ($\sim 2,722,000$ events)
- choose a relatively complete and uncorrelated set of distributions sensitive to the global features of hadronic events (Sphericity, Aplanarity, $-\ln(y_{34})$, y_T) and evaluate the global χ^2 (81 bins) for the different models

without CR	global χ^2	with CR	global χ^2
Ariadne 4.11	36.9	Ariadne-CR	32.4
Jetset 7.4	200.7	Rathsman-CR	243.5
Herwig 6.2	127.9	Herwig-CR	151.6

The uncertainties are dominated by systematics

These χ^2 are intended to be used only as a relative measure of the description of the data by the models

The χ^2 values for Ariadne are smaller because this model is used to correct the data

$\Rightarrow$ the models with color reconnection yield an equally good overall description of global event properties as the corresponding models without reconnection

- to select gluon jets
  - force three jets in all the events using *Durham*
  - identify gluon jet using anti b-tagging technique
  - to select well defined gluon jets require $K_{jet} = E_{jet} \sin(\theta_{min}/2) > 7$ GeV and to increase the purity $E_{jet} < 35$ GeV

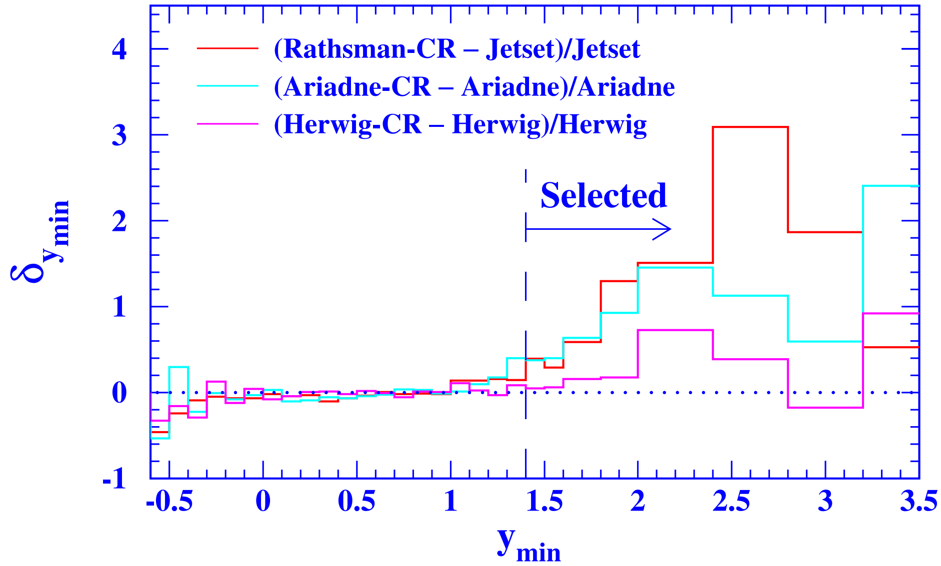
$\Rightarrow$ 12611 gluon jets selected with purity $\approx 95\%$ (energy range: $10 < E_g < 35$ GeV)

OPAL selection (II)

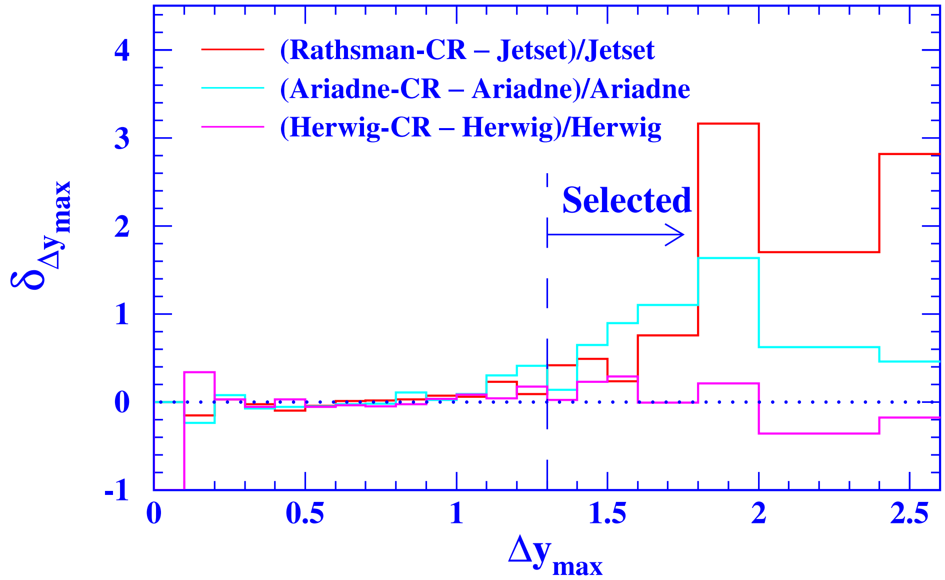
- choose the values to define a rapidity gap (using all particles) by looking at the ratio:

$$\delta_x = \frac{f(x)_{CR} - f(x)_{noCR}}{f(x)_{noCR}} \qquad x = y_{min}, \Delta y_{max}$$

  - require $y_{min} > 1.4$



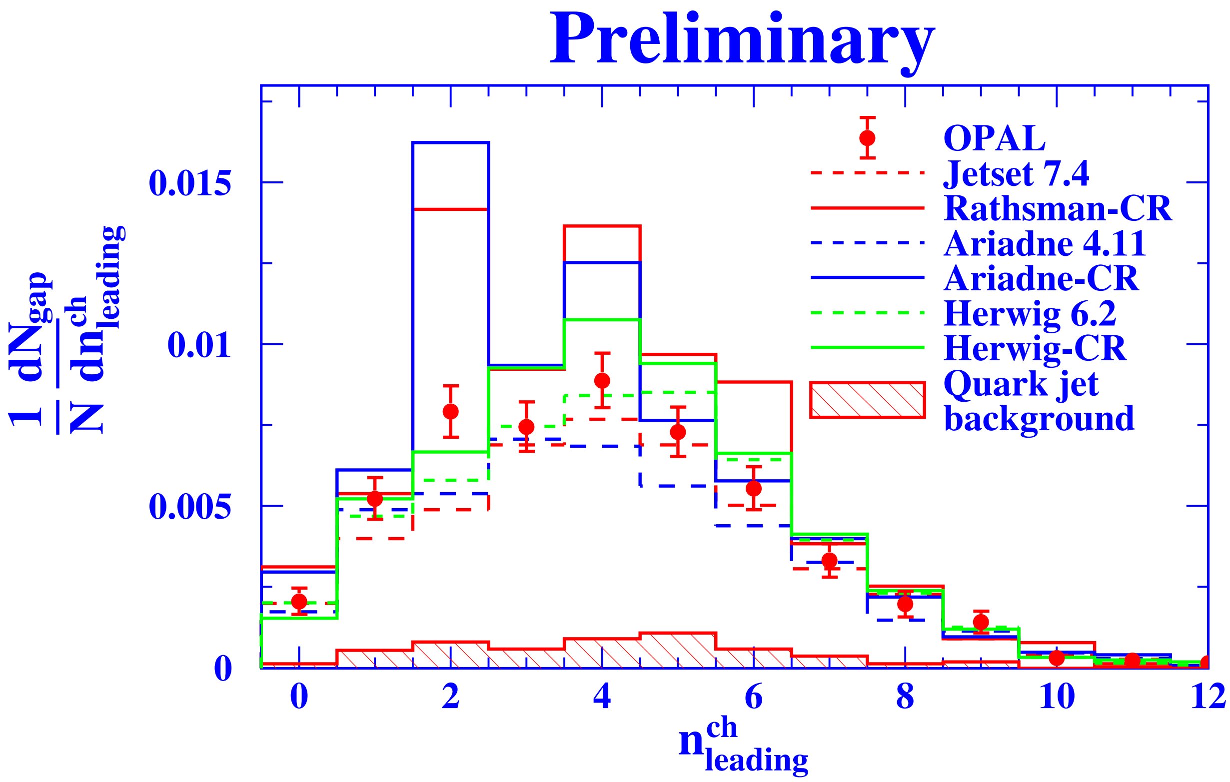
  - for jets with $y_{min} < 1.4$ require $\Delta y_{max} > 1.3$



$\Rightarrow$ purity of the final sample (655 events): $\approx 86\%$

OPAL detector level results (I)

- distributions normalized to the total number of selected gluon jets before the rapidity gap requirement

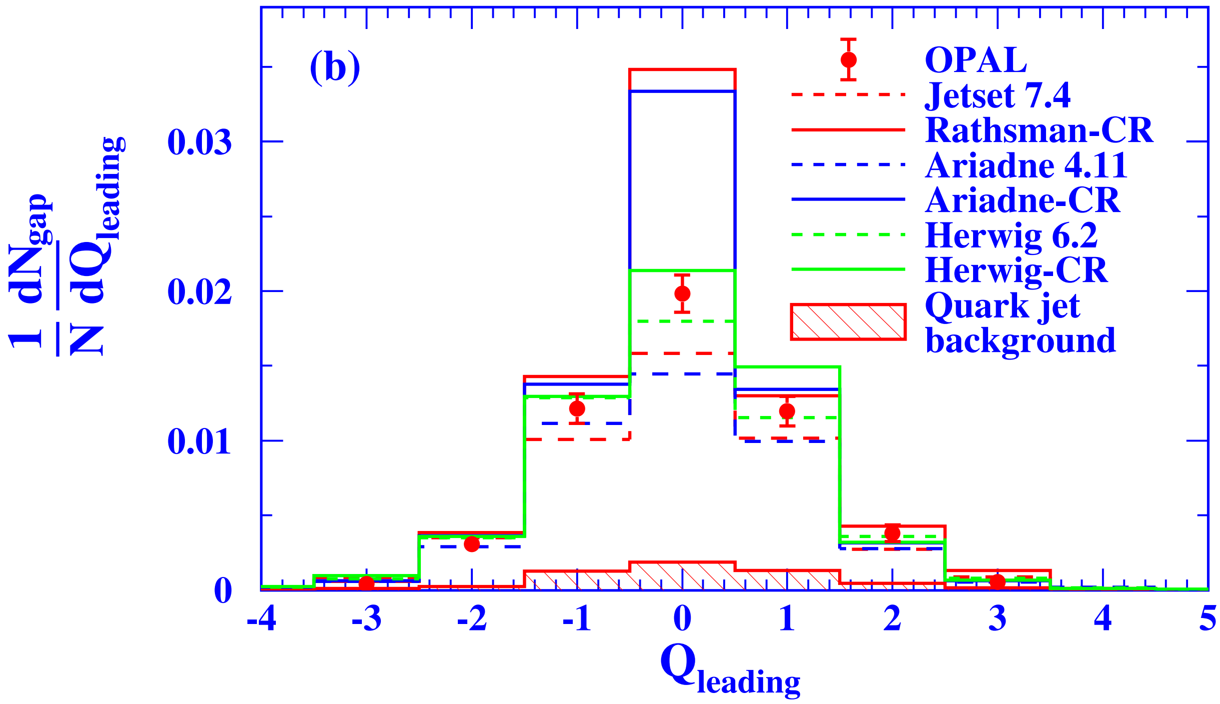


$\Rightarrow$ Rathsman-CR, Ariadne-CR: large excess of entries at $n^{ch}_{leading} = 2, 4$

$\Rightarrow$ a consequence of events with an isolated gluonic system in the leading part of the gluon jets

$\Rightarrow$ Herwig-CR: less striking excess for $3 \leq n^{ch}_{leading} \leq 5$

OPAL detector level results (II)



$\Rightarrow$ Rathsman-CR, Ariadne-CR: large excess of entries at $Q_{leading} = 0$

$\Rightarrow$ **AGAIN** a consequence of events with an isolated gluonic system in the leading part of the gluon jets

$\Rightarrow$ Jetset and Ariadne: predictions 15-20 % low for the $Q_{leading} = 0$ bin

BUT

there is no spiking behaviour in the data for the $n^{ch}_{leading}$ distribution, i.e. no clear color reconnection signal
$\longrightarrow$ we cannot conclude this is due to color reconnection

(? some other problem in Jetset and Ariadne not related to color reconnection?)

Correction & systematics

Question :
can the Rathsman-CR or Ariadne-CR model be tuned to describe our data while continuing to provide a reasonable description of inclusive Z^0 decays?

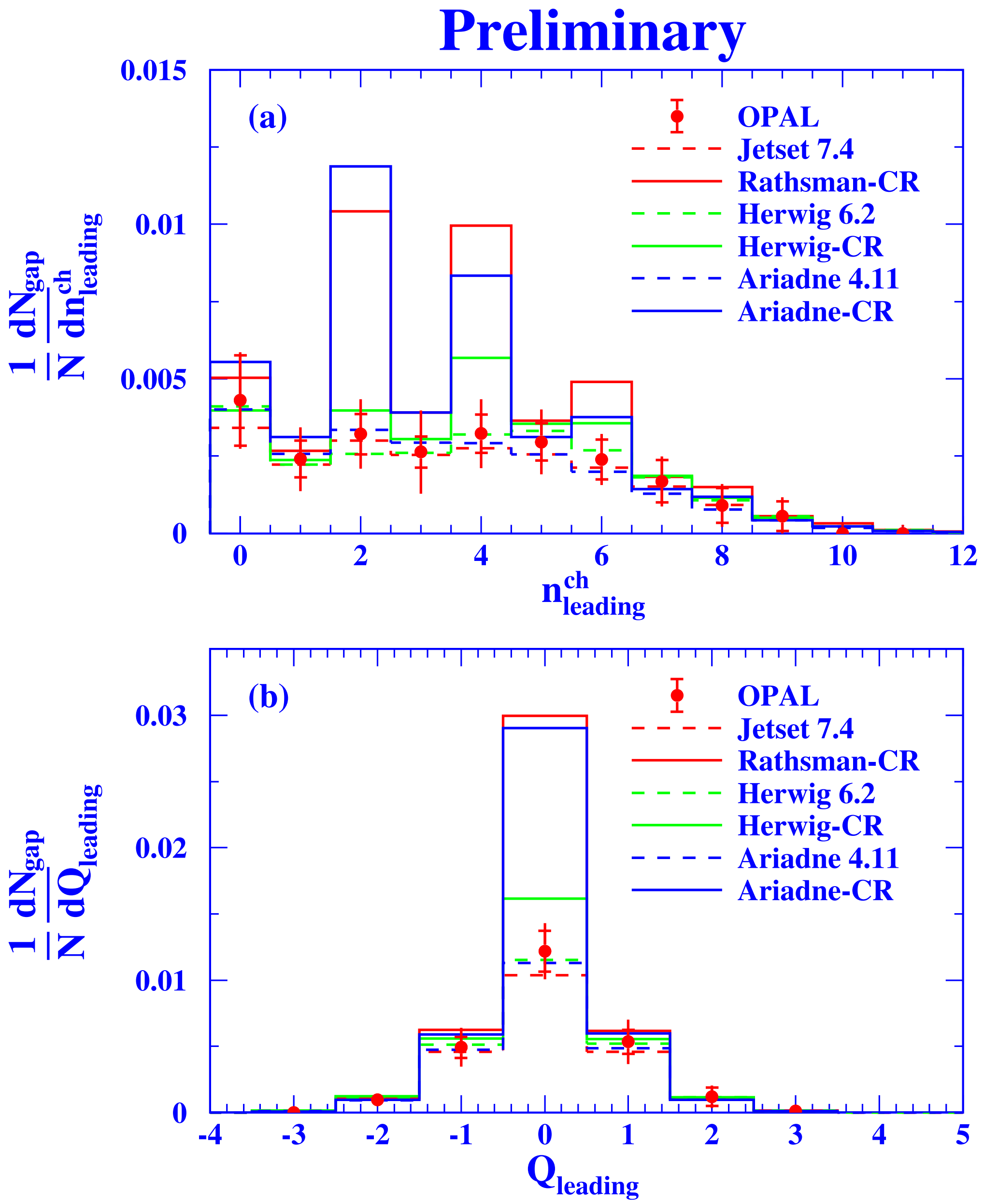
$\Rightarrow$ correct the distributions to the hadron level

- define $\Delta Q^{MC-data}_{leading}$: difference between MC prediction and data for the $Q_{leading} = 0$ bin
- vary the principal parameters of the models to try to obtain simultaneously $\Delta Q^{MC-data}_{leading} \approx 0$ and the correct result $\langle n_{ch.} \rangle = 21.15$ for inclusive Z^0 decays
- check if the global shape variables are still well described ($\longrightarrow$ global χ^2)

Systematics :

- model dependence
  - Jetset, Ariadne and Herwig-CR used to determine the correction factors
- Charged tracks alone used for the data and MC detector level samples
- particle selection
- gluon jet identification

OPAL hadron level results



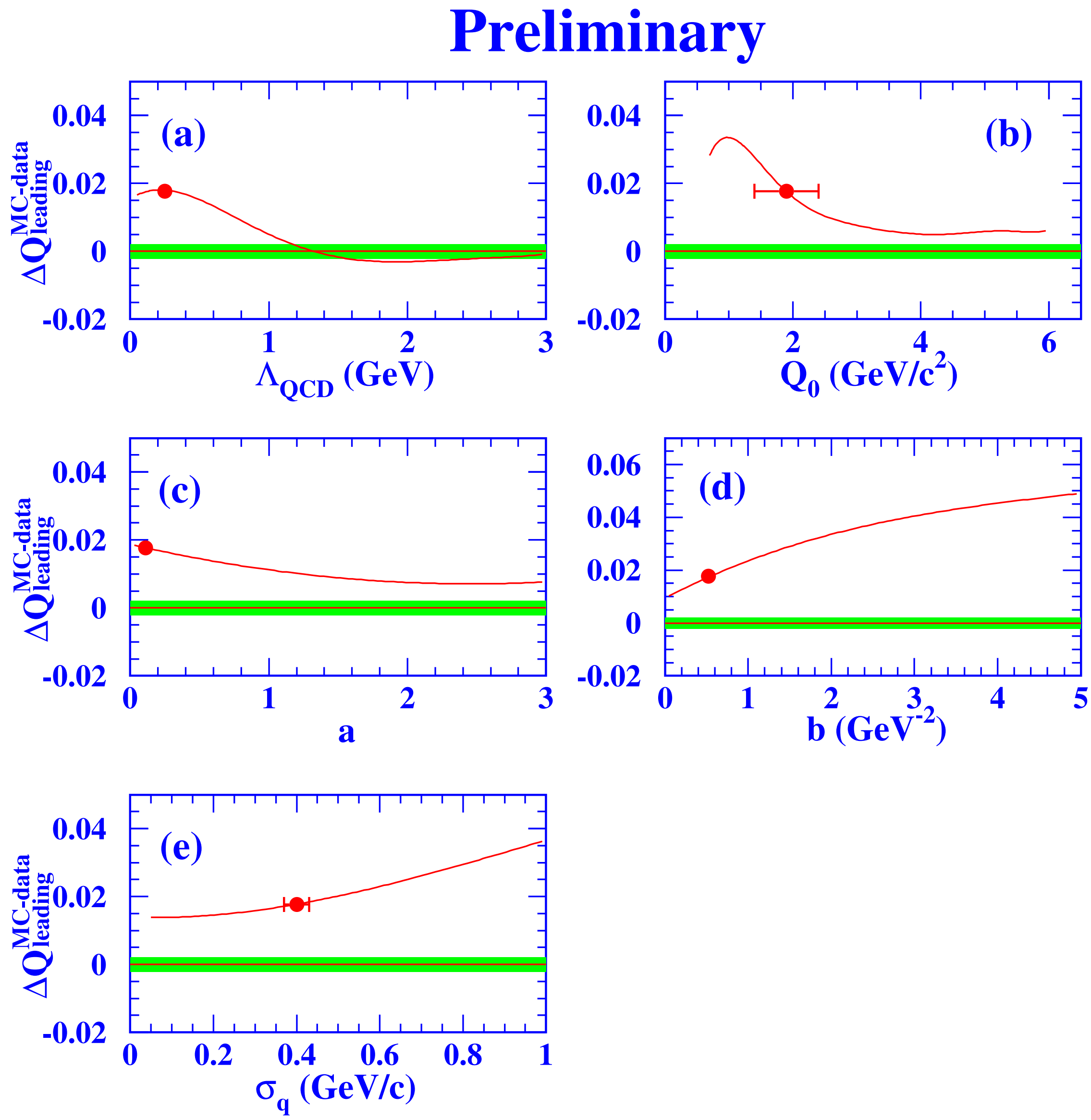
- results qualitatively similar to the detector level ones
- a clear spike is predicted at $n^{ch}_{leading} = 4$ by Herwig-CR

Rathsman-CR: try variation of the CR suppression factor. For

$$R_0 = 0.0085 \pm 0.0075(stat.) \pm 0.0087(syst.)$$

describes the data. Result consistent with zero ($\rightarrow$ no CR)

OPAL: Rathsman-CR re-tuning



Results of the re-tuning:

- $Q_0 = 5.5\, GeV/c^2$ $b = 0.27 \longrightarrow \Delta Q^{MC-data}_{leading} = 6.7 \times 10^{-7}$

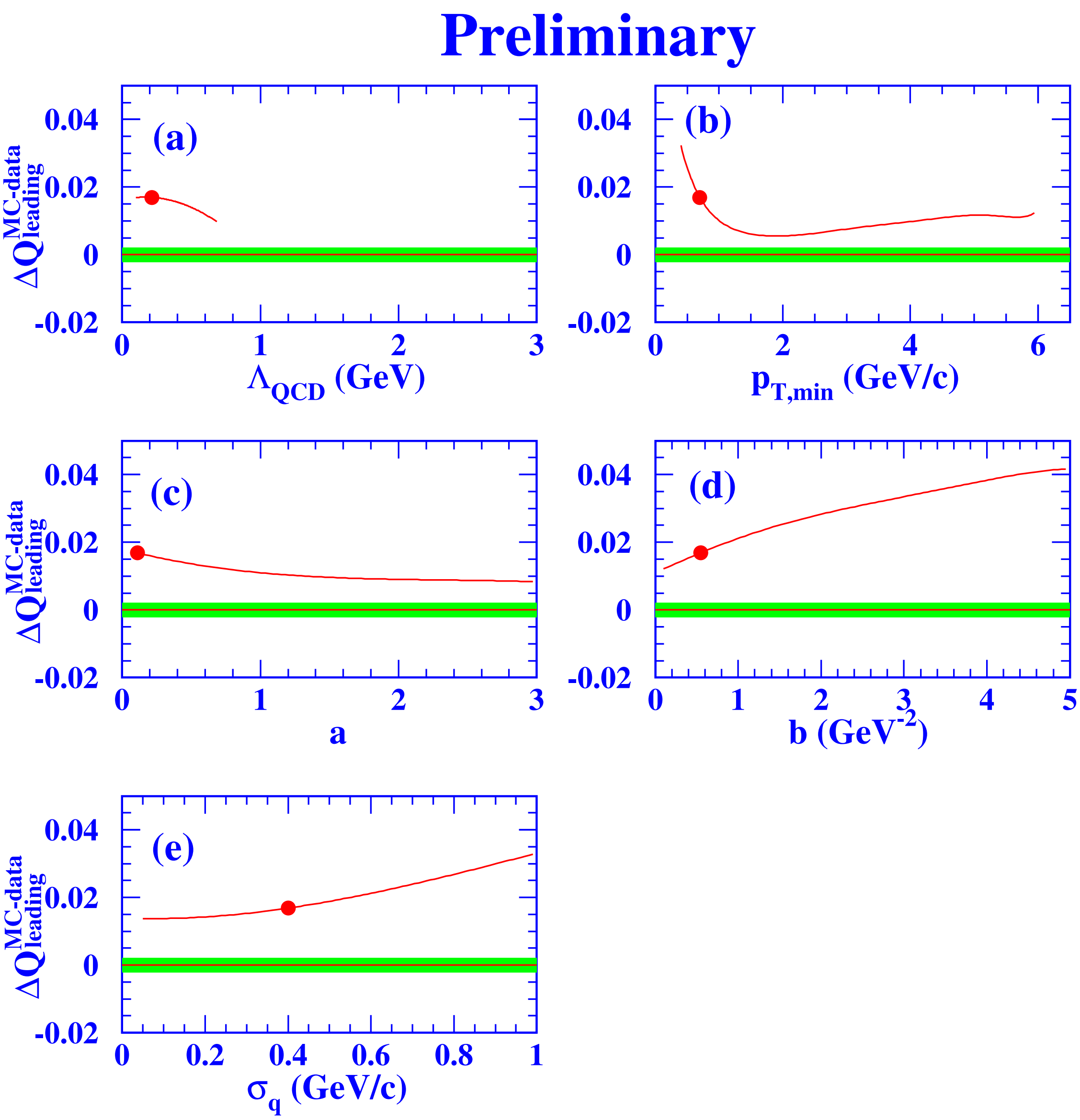
  BUT

  the global χ^2 increases from 244 to 1118

- $\Lambda = 1.3\, GeV$ $b = 4.9 \longrightarrow \Delta Q^{MC-data}_{leading} = 0.012$,
  $\chi^2 = 2.1 \times 10^4$

- $\Lambda = 0.6\, GeV$ $Q_0 = 4.9\, GeV/c^2 \longrightarrow \Delta Q^{MC-data}_{leading} = 0.004$,
  $\chi^2 = 1606$

OPAL: Ariadne-CR re-tuning



Results of the re-tuning:

- $p_{T,min} = 4.7\, GeV/c\; b = 0.17 \longrightarrow \Delta Q^{MC-data}_{leading} = -4.1 \times 10^{-5}$

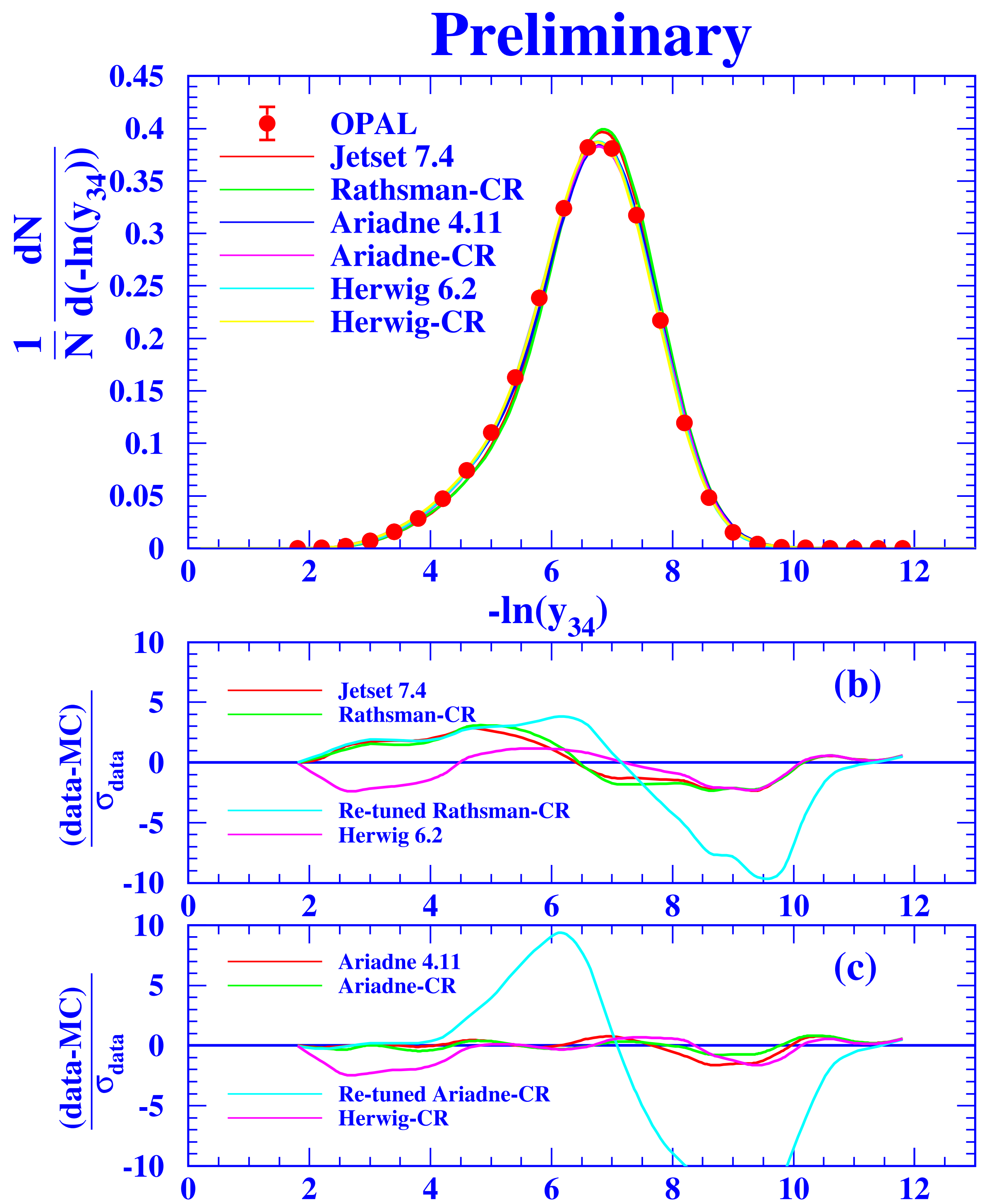
  BUT

  the global χ^2 increases from 32 to 3019

- $\Lambda = 0.5\, GeV\; p_{T,min} = 2.4\, GeV/c \longrightarrow \Delta Q^{MC-data}_{leading} = 0.0041, \chi^2 = 2095$
- Λ & b: couldn't adjust because of the constraint $\Lambda < p_{T,min}$

Rathsman-CR and Ariadne-CR models are both DISFAVORED

Example of effects of the retuning



Due to the large values of Q_0 or $p_{T,min}$ in the re-tuned models, there is a severe truncation of events with multi-jet structure in disagreement with the data

ALEPH selection

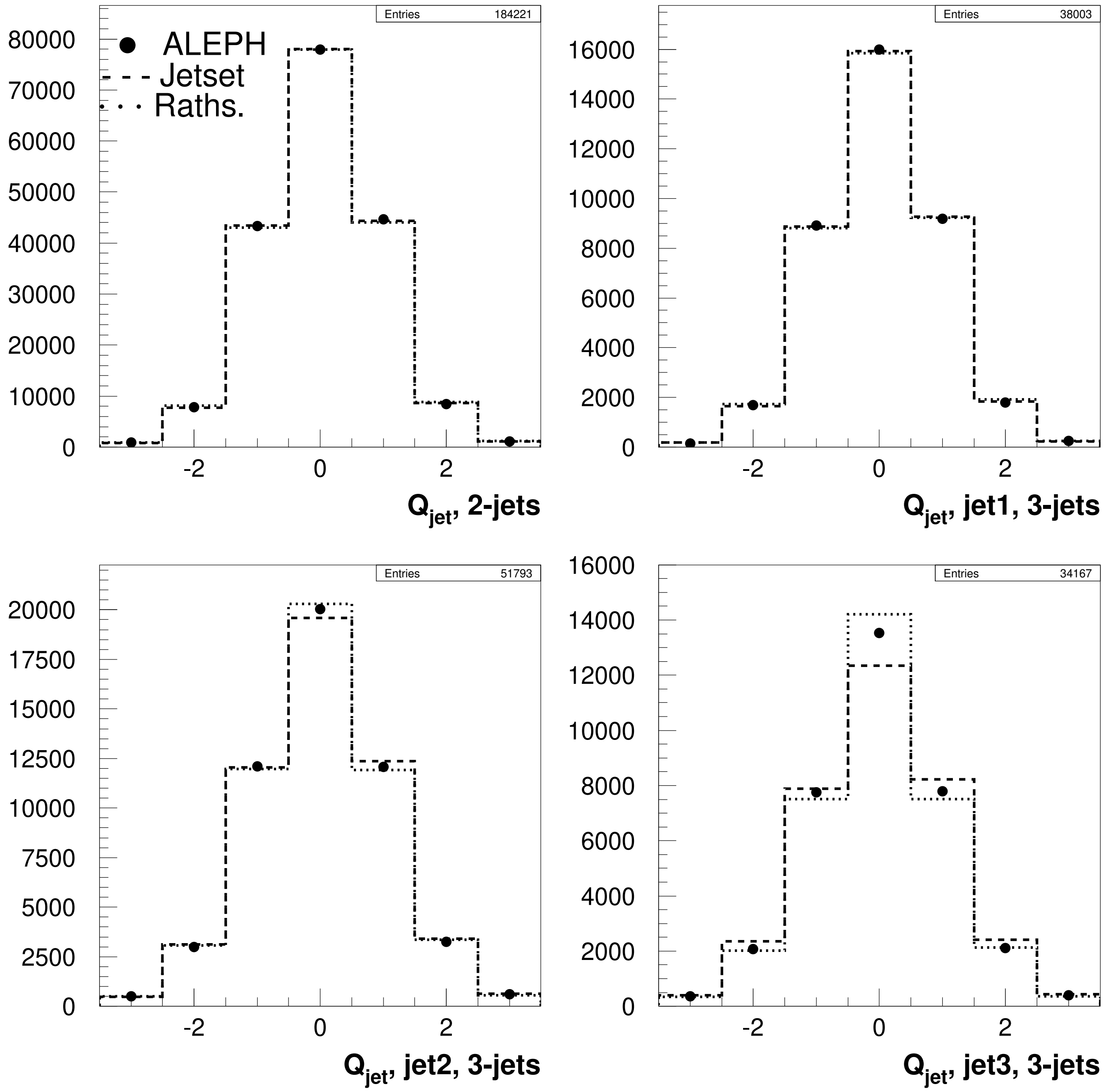
- use ALEPH $Z^0 \rightarrow hadrons$ events collected in 1994 ($\sim 1,660,000$ events)
- parameter values used for the different Monte Carlos (Jetset, Rathsman, Ariadne and Ariadne-CR) obtained from fits to global quantities
- to select gluon jets
  - find 3 jet events using *Durham* with fixed $y_{cut} = 0.01$
  - identify gluon jet using energy ordering : $x_1 > x_2 > x_3$
    (x_i = jet energies re-calculated using massless kinematics)
  - to increase purity require $z = \frac{1}{\sqrt{3}}(x_2 - x_3) > 0.15$

  $\Rightarrow$ 264000 gluon jets selected with purity $\approx 79\%$
  (energy range: $5 < E_3 < 18$ GeV)
- to define the rapidity gap
  - use charged particles only
  - require $y_{min} = 1.5$

  $\Rightarrow$ purity of the final 34167 gluon jets $\approx 62\%$
- for comparison, the following are also analysed:
  - quark jets from 2-jet events
  - jets 1 and 2 from 3-jet events

ALEPH Rathsman results

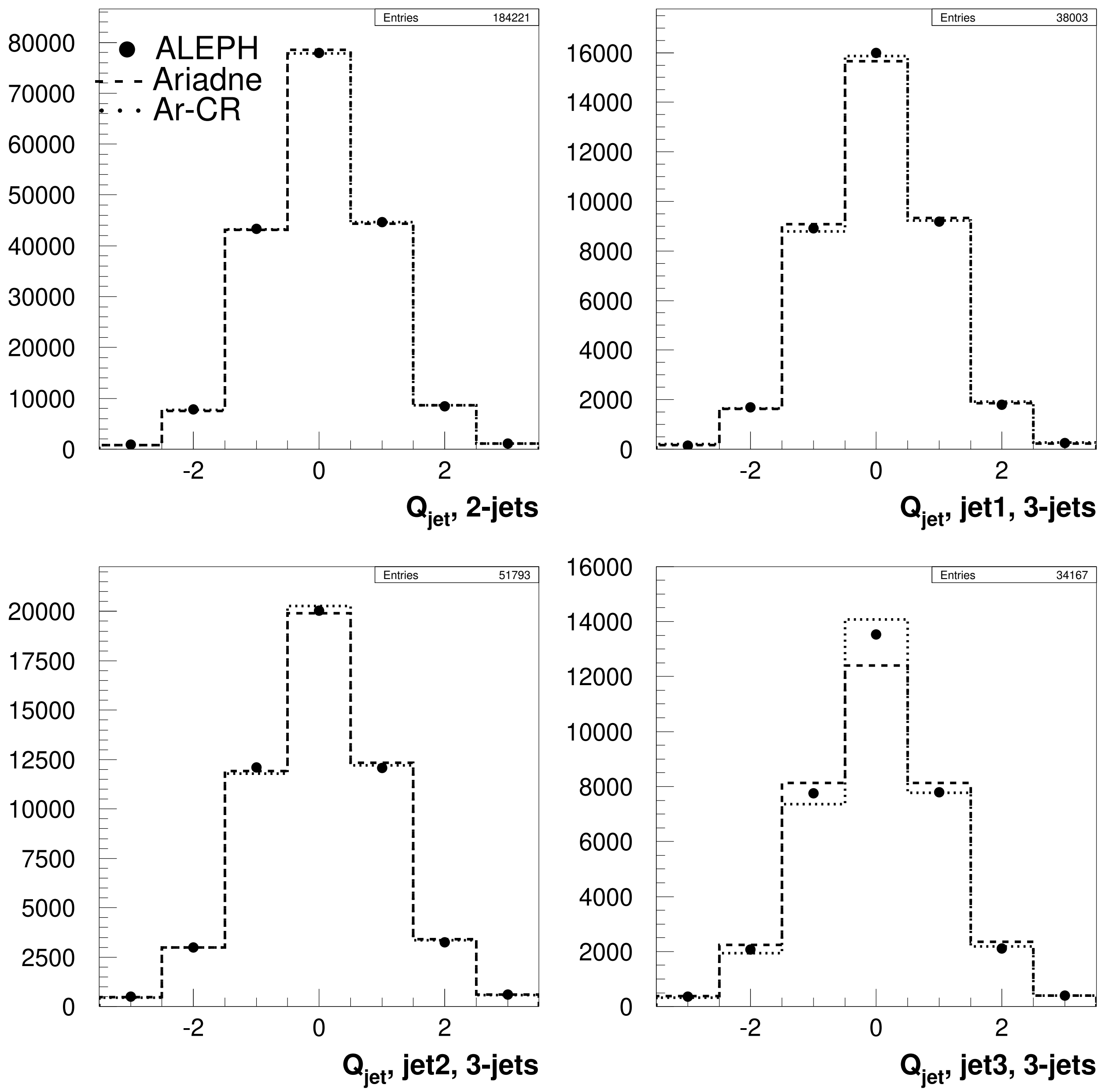
- results shown at the detector level
- distributions normalized to the number of jets with a rapidity gap



- excellent description of quark jets
- gluon jets: Rathsman gives a too strong effect; Jetset predicts too few ($\approx 10\%$) neutral jets

consistent with the OPAL result for Jetset

ALEPH Ariadne results



- similar results for Ariadne

Further checks

1. different values for $y_{min} = 1.7, 2.0$
2. gap defined using charged+neutral particles
3. require $z < 0.15$ in the 3-jet sample

$\Rightarrow$ qualitatively same conclusions

Summary & conclusions

- results by the OPAL and ALEPH collaborations have been presented
- models with color reconnection predict a large excess of gluon jets with a rapidity gap
- $n^{ch}_{leading}$ and $Q_{leading}$ gluon jet distributions are very sensitive to CR effects (first presented in OPAL-PN515)
- the Rathsman-CR and Ariadne-CR models predict large spikes at $n^{ch}_{leading} = 2, 4$ and $Q_{leading} = 0$ compared to the data
- the Jetset 7.4 and Ariadne 4.11 predictions for $Q_{leading} = 0$ are too low. This may be a problem in these models not related to CR since the data do not exhibit spiking at $n^{ch}_{leading} = even$, which is the most unambiguous signal for reconnection
- a tuning of the models with color reconnection in order to describe the $n^{ch}_{leading}$ and $Q_{leading}$ distributions results in a severe degradation of the description of the global features of the event

$\Rightarrow$ Color reconnection as currently implemented in Rathsman-CR and Ariadne-CR is strongly disfavored

$\Rightarrow$ no definite conclusion concerning Herwig-CR