α_{S} determination and test of QCD models

at various CM energies with L3

For the L3 Collaboration
Jorge Casaus
CIEMAT - Madrid

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Introduction

- $\sqrt{s} = 2 \cdot E_{beam}$ (Inclusive hadronic decays)

$$e^+e^- \to \gamma^*/Z \to \text{hadrons}$$

$\Rightarrow$ LEP1 Data sample ($\sqrt{s} \simeq 91$GeV)
$\Rightarrow$ LEP1.5 Data sample ($\sqrt{s} \simeq 133$GeV)

- $\sqrt{s'} < M_Z$ (Select hard radiated photon, ISR or FSR)

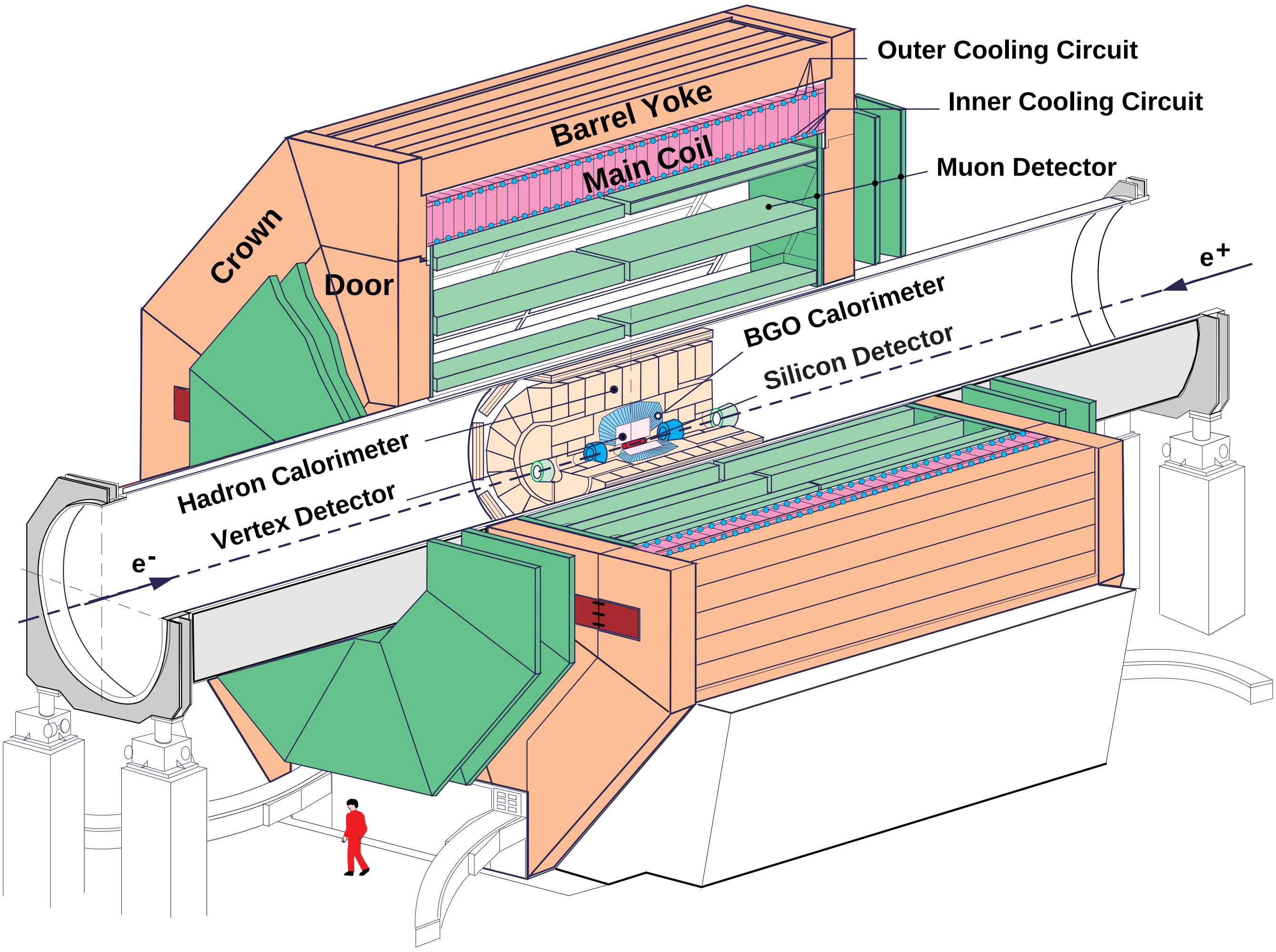
$$e^+e^- \to \gamma^*/Z \to \text{hadrons} + \gamma$$

$$\sqrt{s'} = \sqrt{s \cdot \left(1 - \frac{2E_\gamma}{\sqrt{s}}\right)}$$

$$30\text{GeV} < \sqrt{s'} < 86\text{GeV}$$

$\Rightarrow$ LEP1 Data sample ($\sqrt{s} \simeq 91$GeV)

L3 Detector

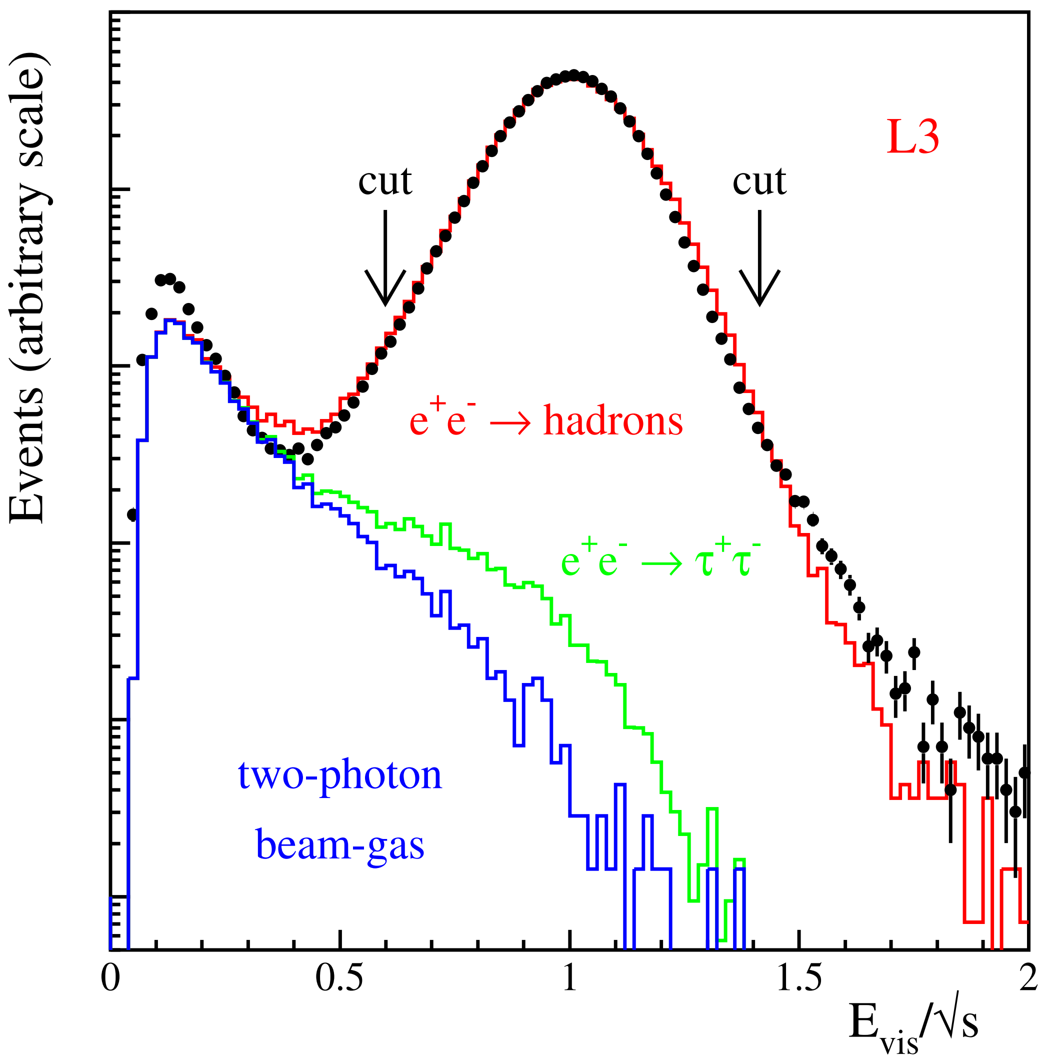

Outer Cooling Circuit
Inner Cooling Circuit
Muon Detector
Barrel Yoke
Main Coil
Crown
Door
e+
BGO Calorimeter
Silicon Detector
Hadron Calorimeter
Vertex Detector
e-

Event Selection

$q\bar{q}$ selection at $\sqrt{s} \simeq 91\text{GeV}$ ($\mathcal{L} = 8\text{pb}^{-1}$)

- $N_{clus} > 12$
- $0.6 < E_{vis}/\sqrt{s} < 1.4$
- $|E_{\parallel}|/E_{vis} < 0.4$ $E_{\perp}/E_{vis} < 0.4$

$\Rightarrow$ 240K hadronic events (BKG $< 0.2\%$)



Event Selection

$q\bar{q}$ selection at $\sqrt{s} \simeq 133\mathrm{GeV}$ $(130.3, 136.3\mathrm{GeV})$ $(\mathcal{L} = 5\mathrm{pb}^{-1})$

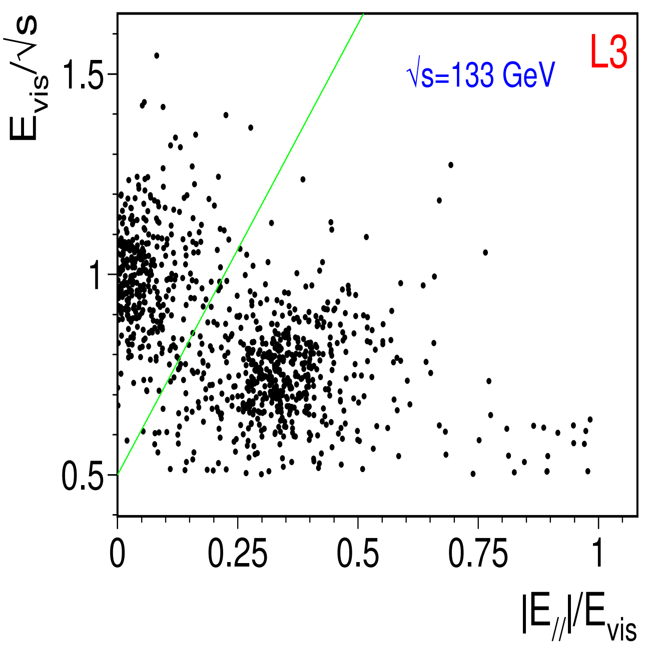
Hadronic Selection

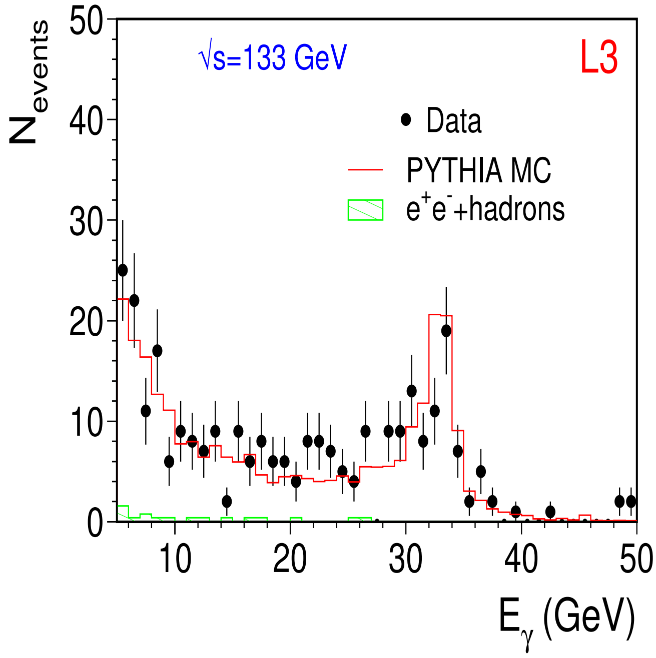
- $\mathrm{N_{clus}} > 13$
- $\mathrm{E_{vis}}/\sqrt{\mathrm{s}} > 0.5$
- $\mathrm{E_{\perp}}/\mathrm{E_{vis}} < 0.5$

Reject return to Z ($\sim 75\%$!!)

- $\mathrm{E_{vis}}/\sqrt{\mathrm{s}} > 2.5 \cdot (|\mathrm{E}_{\|}|/\mathrm{E_{vis}}) + 0.5$
- $\mathrm{E}_{\gamma}^{\max} < 15\mathrm{GeV}$

$\Rightarrow$ 402 events (241 and 161) $(\sim 20\%$ BKG return to Z)





Event Selection

$q\bar{q}\gamma$ selection at $\sqrt{s'} < M_Z$ $\qquad$ $(\mathcal{L} = 111\mathrm{pb}^{-1}$ at $\sqrt{s} \simeq M_Z)$

Hadronic Selection

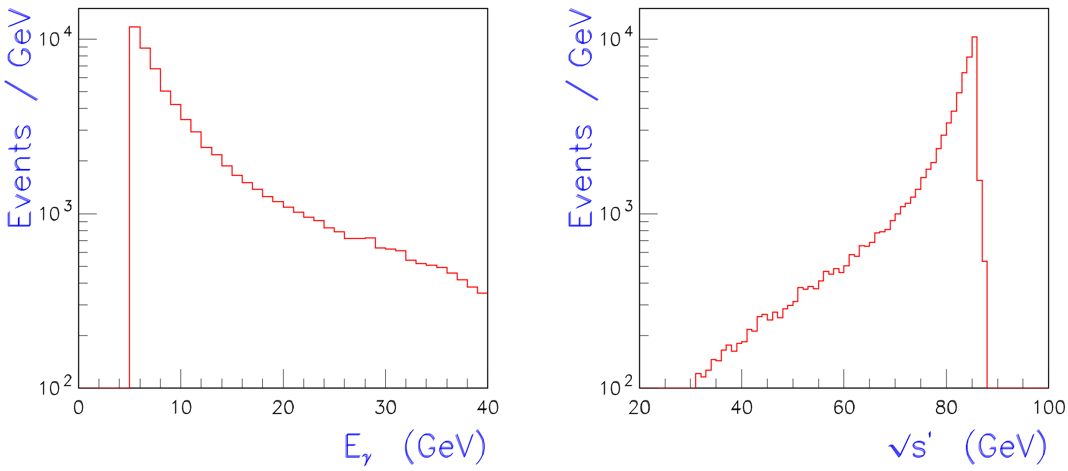
- $N_{clus} > 12$
- $0.6 < E_{vis}/\sqrt{s} < 1.4$
- $|E_{\parallel}|/E_{vis} < 0.4$ $\qquad$ $E_{\perp}/E_{vis} < 0.4$

$\Rightarrow$ 3M hadronic events selected

Hard photon preselection

- $E_{\gamma} > 5\mathrm{GeV}$
- No track associated
- Local Isolation $(E_{\alpha_{LI}} < 500\mathrm{MeV}\ ;\ \alpha_{LI} = 15°)$

$\Rightarrow$ 80K events selected



$\sqrt{s'}$ (GeV)	30−50	50−60	60−70	70−80	80−84	84−86
events after preselection	3800	4114	7035	16791	18758	18931

π^o, η background reduction

- Neural Network probability, $0.10 < \epsilon_\gamma < 0.95$
- Energy of individual clusters within the cone < 50MeV
- Local Isolation cone, α_{LI} $(15° - 24°)$
- Angle to nearest jet, α_{JI} $(20° - 24°)$

$\Rightarrow$ ~1000 events selected / $\sqrt{s'}$ bin (BKG from neutral hadrons < 25%)

$\sqrt{s'}$ (GeV)	30–50	50–60	60–70	70–80	80–84	84–86
STATISTICS						
events after final selection	913	815	1193	2326	1792	1440
Selection Efficiency	0.63	0.55	0.51	0.46	0.40	0.35
ISOLATION CUTS						
Local isolation angle (α_{LI})	15°	15°	15°	15°	21°	24°
Jet isolation angle (α_{JI})	20°	20°	20°	20°	21°	24°
BACKGROUND						
Scale factor for hadronic BKG (JETSET)	1.5	1.1	1.0	1.6	2.0	2.4
BKG due to hadrons (%) (rescaled)	23.0 %	12.0 %	8.0 %	9.0 %	9.5 %	14.0 %
total BKG (%)	24.0 %	14.0 %	10.0 %	11.0 %	11.5 %	16.0 %

Test of QCD models

Event Shape variable definition

- AIM: Define observables sensitive to multijet events

$$N_{3-\mathrm{jet}}/N_{2-\mathrm{jet}} \sim \alpha_s$$

- REQUIREMENT: Infrared and Collinear safe

- EVENT SHAPE VARIABLES USED IN L3 ANALYSES

  – THRUST:

$$T = \max \frac{\Sigma|\vec{p}_i \cdot \vec{n}_T|}{\Sigma|\vec{p}_i|}$$

  The perpendicular plane to the thrust axis divides the event in two hemispheres (+ and -)

  – HEAVY JET MASS:

$$M_H = \max\left[M_+(\vec{n}_T), M_-(\vec{n}_T)\right] \quad ; \quad \rho = M_H^2/E_{vis}^2$$

  where $M_\pm$ are the invariant masses of the two hemispheres

  – JET BROADENING VARIABLES:

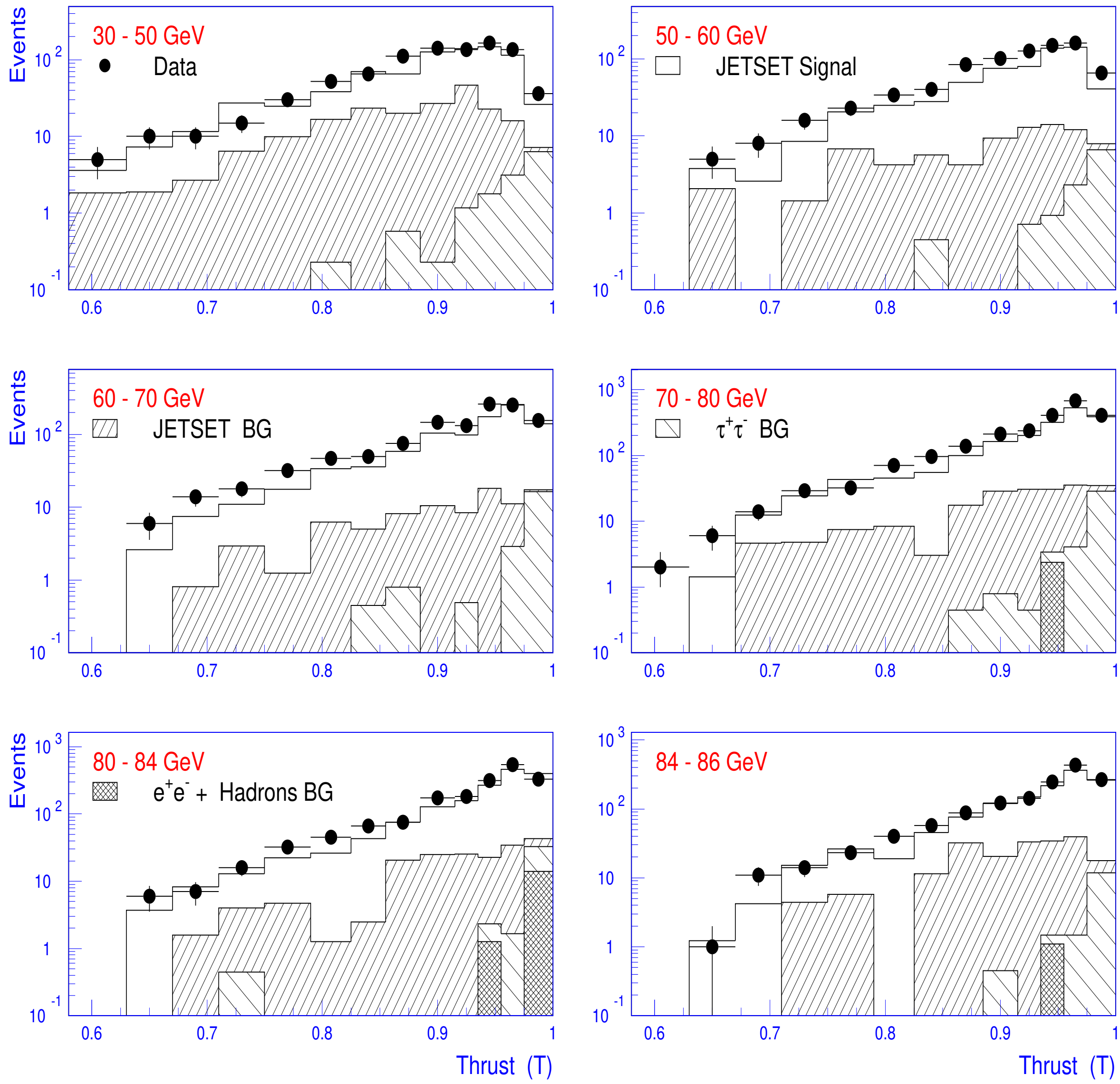
$$B_\pm = \frac{\Sigma_\pm|\vec{p}_i \times \vec{n}_T|}{2\Sigma|\vec{p}_i|}$$

  TOTAL JET BROADENING: $B_T = B_+ + B_-$

  WIDE JET BROADENING: $B_W = \max\left(B_+, B_-\right)$

- Histograms containing the measured distributions

  ⇒ bin width > 1.5 experimental resolution



Measured Thrust distributions from the $q\bar{q}\gamma$ analysis after boosting the events in the CM of the hadronic system

Event Shape variable correction

- Background Subtraction

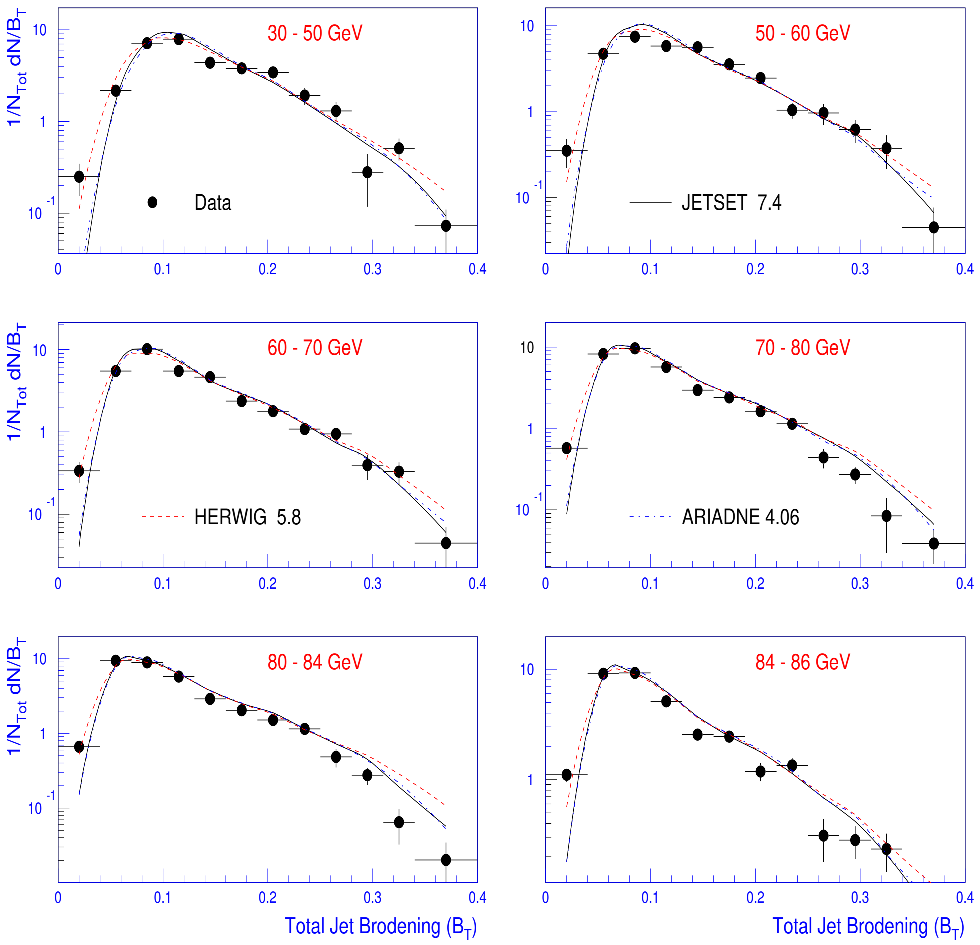
  $\Rightarrow$ bin-by-bin

  ($q\bar{q}$ at $\sqrt{\mathrm{s}} \simeq 133\mathrm{GeV}$ and $q\bar{q}\gamma$ at $\sqrt{\mathrm{s}'} < \mathrm{M_Z}$)

- Detector Unfolding

  $\Rightarrow$ JETSET / PYTHIA , HERWIG

  – Regularized unfolding ($q\bar{q}$ at $\sqrt{\mathrm{s}} \simeq 91\mathrm{GeV}$)
  – Bin-by-bin correction ($q\bar{q}$ at $\sqrt{\mathrm{s}} \simeq 133\mathrm{GeV}$, $q\bar{q}\gamma$ at $\sqrt{\mathrm{s}'} < \mathrm{M_Z}$)



Corrected Total Jet Broadening distributions from the $q\bar{q}\gamma$ analysis

Experimental uncertainties

- $q\bar{q}$ at $\sqrt{\mathrm{s}} \simeq 91\mathrm{GeV}$

  $\Rightarrow$ variation of energy response of calorimeters

  $\Rightarrow$ JETSET vs HERWIG

  $\Rightarrow$ compare calorimetric and track distributions

- $q\bar{q}$ at $\sqrt{\mathrm{s}} \simeq 133\mathrm{GeV}$

  $\Rightarrow$ variation of the ISR background
  (removing cut on $\mathrm{E}_{\gamma}^{\mathrm{max}}$)

- $q\bar{q}\gamma$ at $\sqrt{\mathrm{s}'} < \mathrm{M_Z}$

  $\Rightarrow$ variation of background scale factors

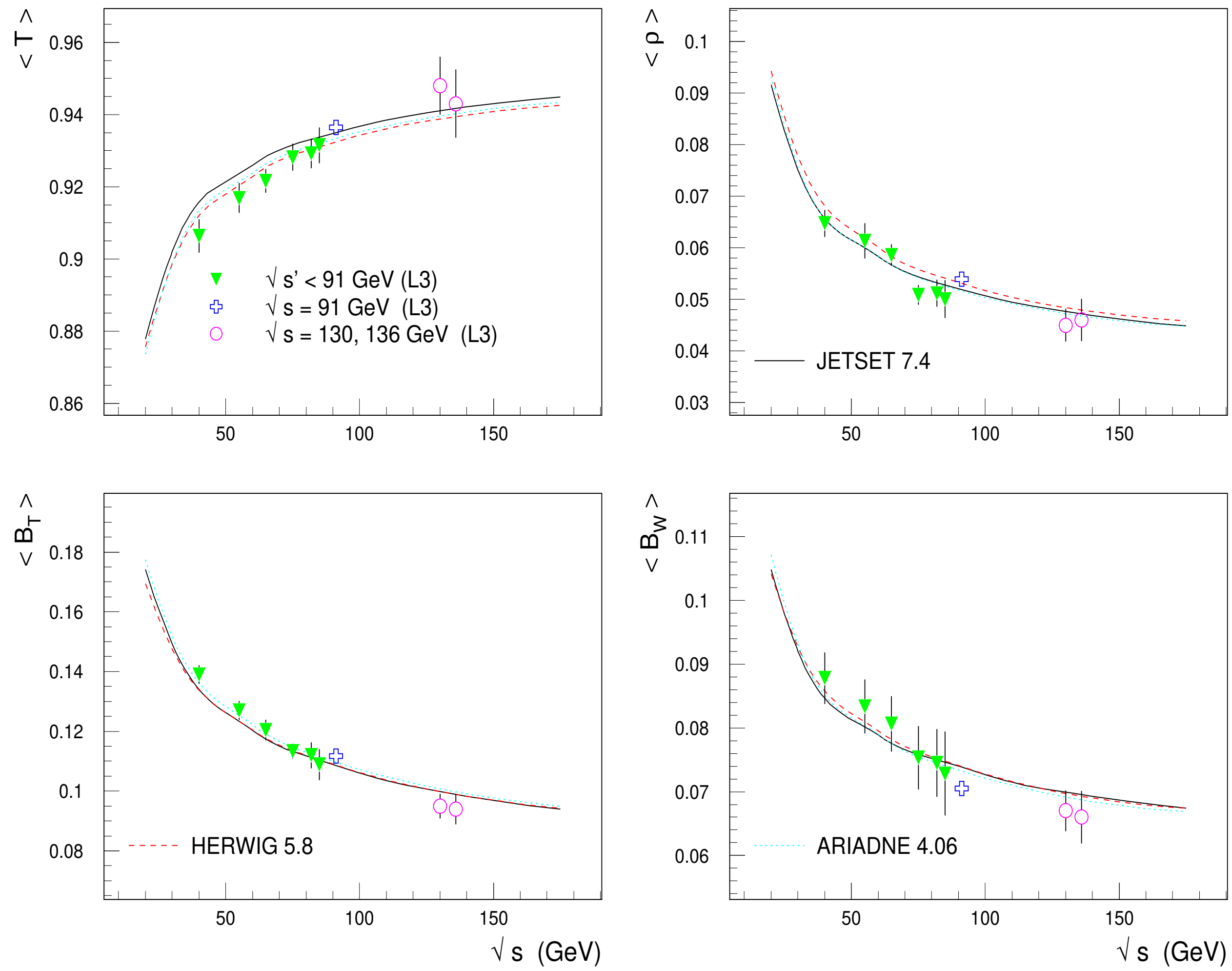
  $\Rightarrow$ variation of selection cuts
  ($\epsilon_{\gamma}, \mathrm{E}_{\alpha_{\mathrm{LI}}}, \alpha_{\mathrm{LI}}, \alpha_{\mathrm{JI}}$)

  $\Rightarrow$ correction method
  (JETSET vs HERWIG, correction factors, $\cos\theta_{\gamma} < 0.7$)

Comparison with QCD models

We compare the mean values of the event shape distributions with the predictions of different QCD models

JETSET 7.4, HERWIG 5.8 and ARIADNE 4.06



Data agree with the energy evolution of the QCD models

α_s measurement

QCD predictions

- Event shape variable y $\quad$ ($y \to 0$ on 2-jet events)

$$\Rightarrow \qquad \text{(1-T)} \, , \, \rho \, , \, \mathrm{B_T} \, , \, \mathrm{B_W}$$

- Define cummulative cross section

$$R(y) = \int_0^y dz \, \frac{1}{\sigma} \frac{d\sigma}{dz}$$

- The perturbative expansion of $\ln R$ leads to the following terms

	LL	NLL	subleading			
1st order	$\alpha_s \mathrm{L}^2$	$\alpha_s \mathrm{L}$	α_s	$\alpha_s O\left(\frac{1}{\mathrm{L}}\right)$		
2nd order	$\alpha_s^2 \mathrm{L}^3$	$\alpha_s^2 \mathrm{L}^2$	$\alpha_s^2 \mathrm{L}$	α_s^2	$\alpha_s^2 O\left(\frac{1}{\mathrm{L}}\right)$	
3rd order	$\alpha_s^3 \mathrm{L}^4$	$\alpha_s^3 \mathrm{L}^3$	$\alpha_s^3 \mathrm{L}^2$	$\alpha_s^3 \mathrm{L}$	α_s^3	$\alpha_s^3 O\left(\frac{1}{\mathrm{L}}\right)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

where $\mathrm{L} = \ln\left(\frac{1}{\mathrm{y}}\right)$

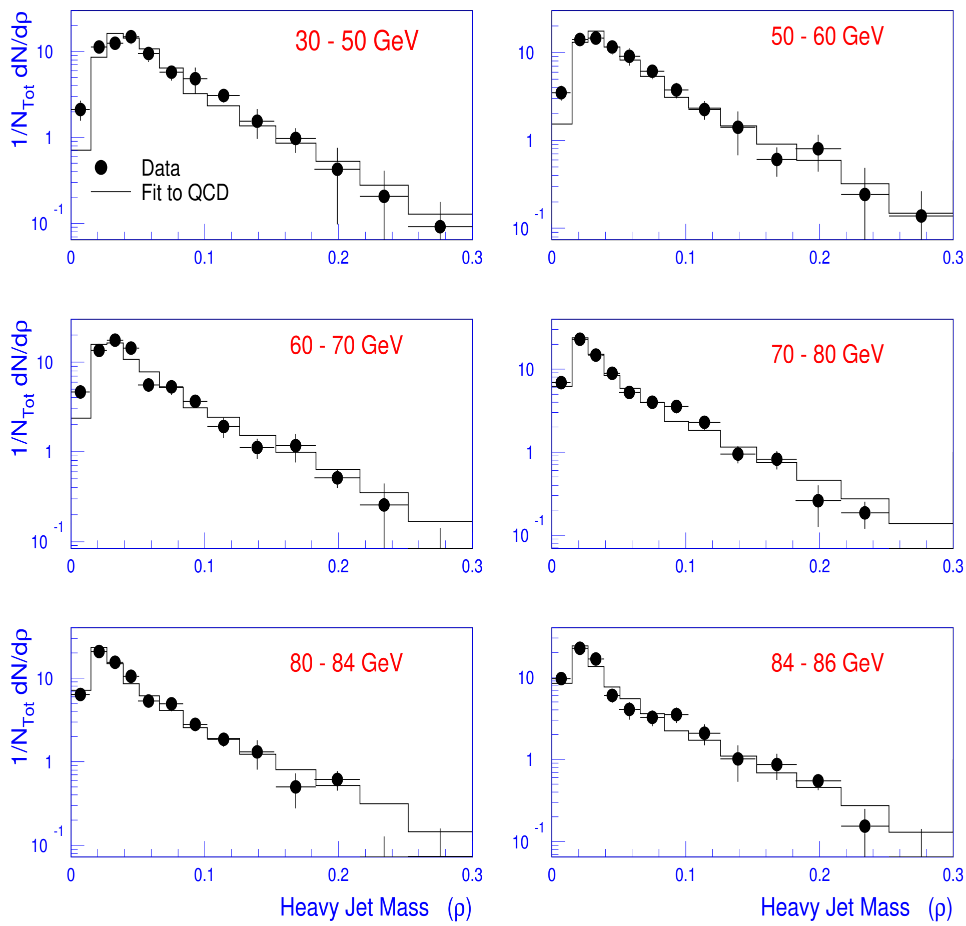
- $O(\alpha_s^2)$ known from ERT-matrix elements
- LL+NLL terms have been resummed for some Event Shape variables

- Several prescriptions relate fixed order and resummed predictions

- Hadronization effects

$$f(y) = \int f^{\text{pert}}(y') \cdot p^{\text{non-pert}}(y', y)\, dy'$$

- Fit range
  - Reliable theoretical calculation
  - Detector and hadronization corrections small
  - Sufficient statistics



Corrected scaled heavy jet mass distributions from the $q\bar{q}\gamma$ analysis

α_s results

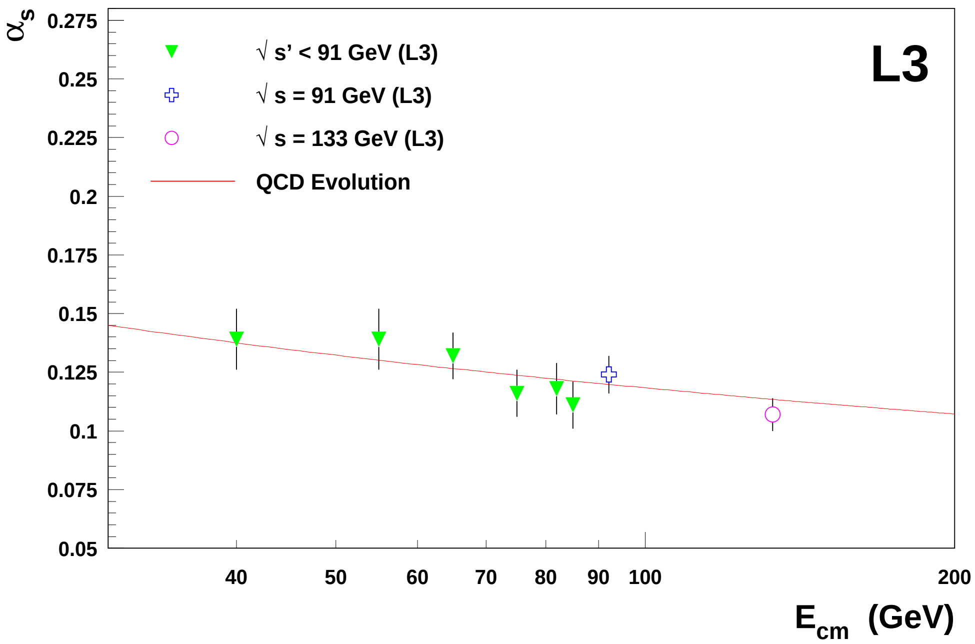
We perform fits to $O(\alpha_s^2)$ + resummed calculations

$\sqrt{s}$ (GeV)	$(1-T)$	ρ	B_T	B_W
30–50	$0.143 \pm 0.008 \pm 0.012$	$0.126 \pm 0.007 \pm 0.006$	$0.147 \pm 0.011 \pm 0.013$	$0.140 \pm 0.015 \pm 0.005$
50–60	$0.146 \pm 0.017 \pm 0.010$	$0.136 \pm 0.008 \pm 0.005$	$0.146 \pm 0.009 \pm 0.008$	$0.127 \pm 0.010 \pm 0.004$
60–70	$0.144 \pm 0.009 \pm 0.009$	$0.138 \pm 0.007 \pm 0.004$	$0.132 \pm 0.006 \pm 0.007$	$0.115 \pm 0.011 \pm 0.004$
70–80	$0.123 \pm 0.010 \pm 0.008$	$0.113 \pm 0.004 \pm 0.005$	$0.126 \pm 0.007 \pm 0.006$	$0.102 \pm 0.012 \pm 0.004$
80–84	$0.125 \pm 0.013 \pm 0.007$	$0.118 \pm 0.005 \pm 0.007$	$0.125 \pm 0.010 \pm 0.007$	$0.104 \pm 0.010 \pm 0.007$
84–86	$0.116 \pm 0.014 \pm 0.006$	$0.111 \pm 0.006 \pm 0.004$	$0.117 \pm 0.006 \pm 0.006$	$0.099 \pm 0.012 \pm 0.004$
91	$0.123 \pm 0.003 \pm 0.008$	$0.123 \pm 0.001 \pm 0.005$	$0.126 \pm 0.002 \pm 0.008$	$0.117 \pm 0.002 \pm 0.006$
133	$0.109 \pm 0.005 \pm 0.007$	$0.108 \pm 0.005 \pm 0.003$	$0.107 \pm 0.004 \pm 0.008$	$0.103 \pm 0.004 \pm 0.006$

- Theoretical uncertainties
  - Hadronization uncertainties
    $\Rightarrow$ compare different hadronization models
    $\Rightarrow$ variation of fragmentation parameters
  - Scale uncertainties
    $\Rightarrow$ repeat the fit for different values of μ
  - Matching uncertainties (Resummed)
    $\Rightarrow$ change the matching scheme.

From the unweighted average of the four distributions we obtain

$\sqrt{s}$ (GeV)	α_s ($\sqrt{s}$)	$\Delta\alpha_s$ (experimental)	$\Delta\alpha_s$ (theoretical)
30 – 50	0.139	± 0.010	± 0.009
50 – 60	0.139	± 0.011	± 0.007
60 – 70	0.132	± 0.008	± 0.006
70 – 80	0.116	± 0.008	± 0.006
80 – 84	0.118	± 0.010	± 0.007
84 – 86	0.111	± 0.010	± 0.005
91	0.122	± 0.002	± 0.007
133	0.107	± 0.005	± 0.006



The energy dependence of α_s is consistent with QCD expectations

Conclusions

Conclusions

We have studied hadronic events collected by the L3 experiment at LEP at various CM energies

- Data agree with the energy evolution of the QCD models JETSET 7.4, HERWIG 5.8 and ARIADNE 4.06.

- The energy dependence of α_s is consistent with QCD expectations