Determination of α_s at LEP by L3 experiment

Simonetta Gentile

Università "La Sapienza"(Roma), INFN.

QCD 02

2-9th July 2002, Montpellier (France)

Outline

- Hadronic samples in e^+e^-collisions at $\sqrt{s}$ up to 208 GeV

- Analysis Methods:

- Jet algorithm

- Event shape variables

- Experimental data and QCD tests:

- Distribution of event shape variables

- Energy evolution of event shape variables

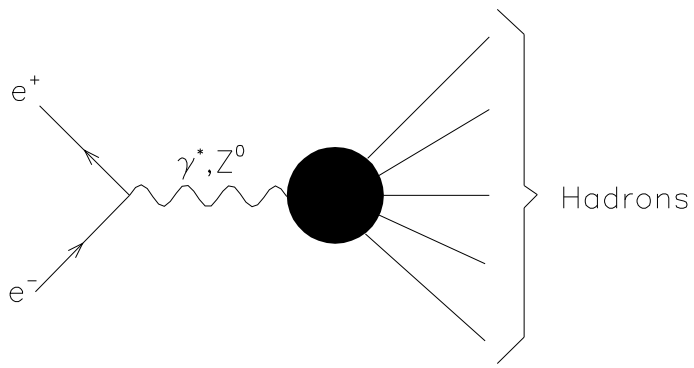
- α_s at LEP

- Conclusions

Over a decade of LEP running:

- $3.5 \cdot 10^6$ Z hadronic decays recorded at $\sqrt{s} \sim m_Z$ (1989-1995)
- Target luminosity at $\sqrt{s} > m_Z$ 500 pb^{-1} /expt

  Delivered luminosity (1995-2000) $\approx$ 700 pb^{-1} / exp



Precise measurements of QCD at LEP:

- Clean initial state (e^+e^-)
- Small hadronization corrections ($\propto 1/E$)

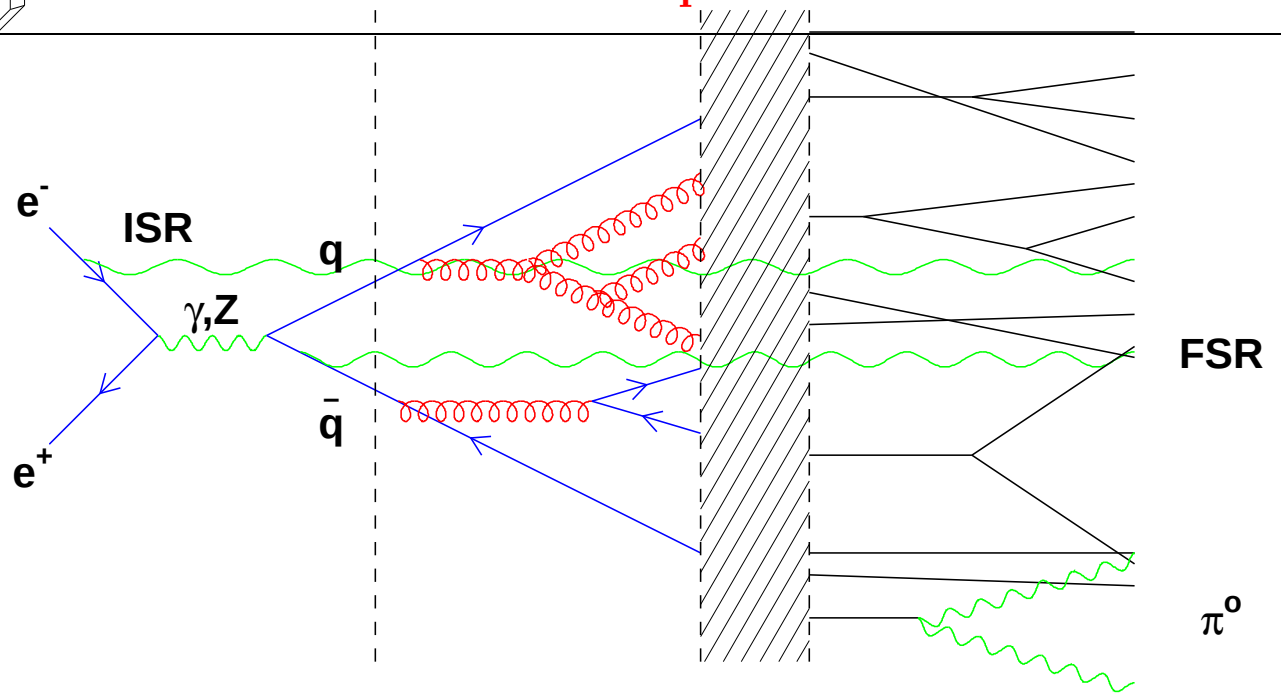
Study Hadronic events $30 \leq \sqrt{s} \leq 208$ GeV

- Hard Gluon Radiation:

Multi-jet topology, Event Shape Variables

Measurement of Strong coupling constant α_s

Event Samples



Electroweak pert.QCD Hadron Detector

- $\sqrt{s'} < m_Z$. Reduced $\sqrt{s'}$ from Z decay with isolated γ (FSR).

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

$$\sqrt{s'}(\text{GeV}) = \underbrace{40, 55, 65, 75, 82, 84}_{\text{L3}}$$

$\mathcal{O}(1000)$ events with purity $70 - 90$ %

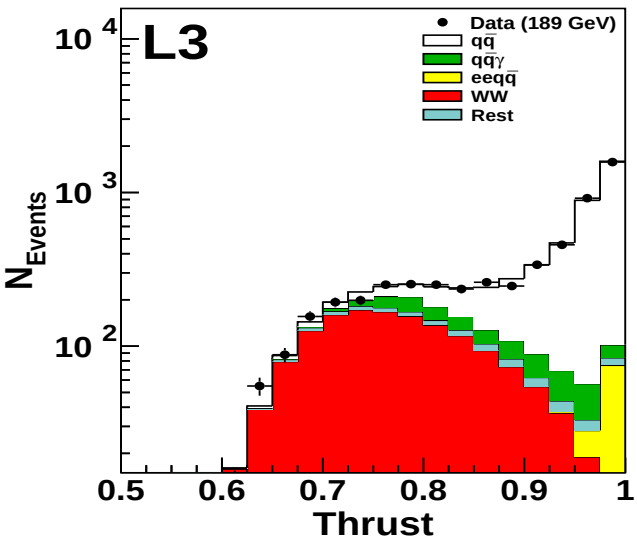
- $\sqrt{s} \sim m_Z$. Hadronic Z decays. Purity $\approx 99\%$

- $\sqrt{s} > m_Z$. Rejecting initial state radiation. Four fermion final state (WW,ZZ).
  Purity $\sim 78 - 90\%$:high selection efficiency $\sim 83 - 90\%$

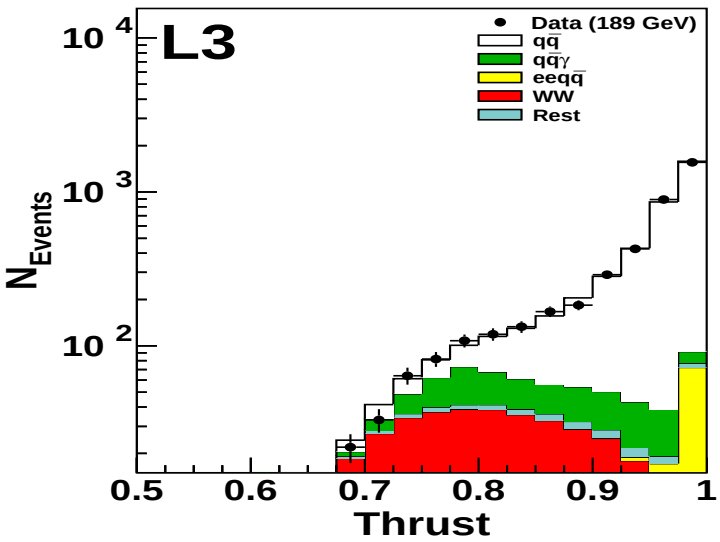
Distribution of event shapes from total hadronic event sample → precise determination of α_s

$\sqrt{s} > m_Z$: Large contamination from WW events

BEFORE WW rejection

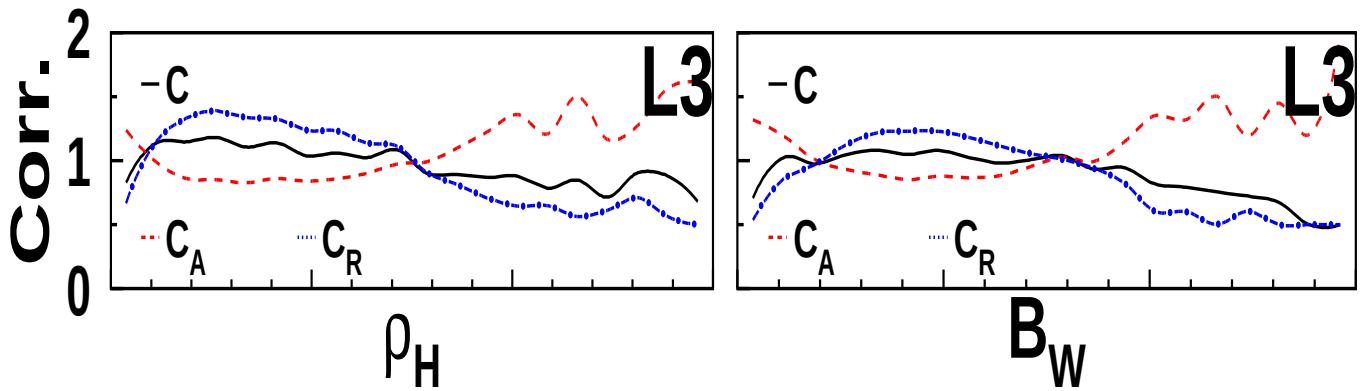


ATFER WW rejection



Detector level distributions corrected *bin-by-bin* for:

- Remaining Background
- Detector Resolution
- Acceptance
- Initial/Final State Radiation



Event Samples. Jet algorithm

$\sqrt{s}$ (GeV)	$\int \mathcal{L}\, dt$ (pb^{-1})	Events
130	6.1	556
136	5.9	414
161	10.8	424
172	10.2	325
183	55.3	1500
189	176.8	4479
194.4	112.2	2403
200.2	117.0	2456
206.2	207.6	4146

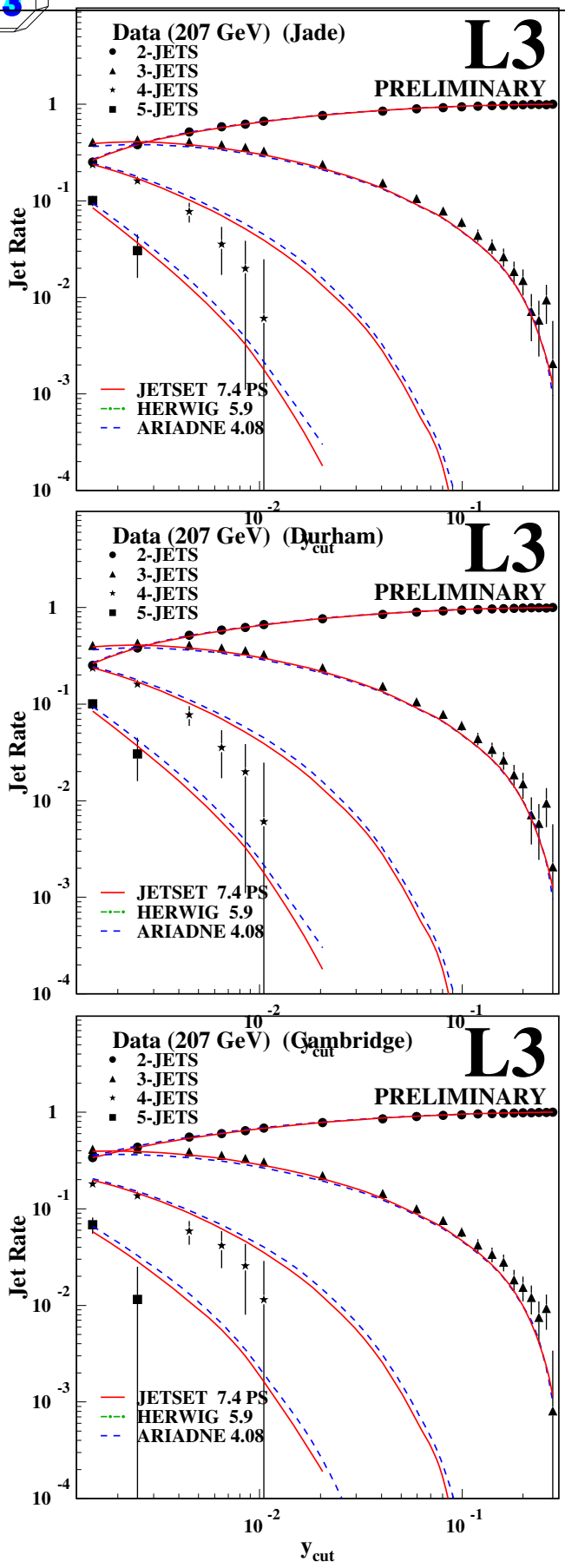
- High energy sample. $192 \leq \sqrt{s} \leq 208$ GeV

Comparison with QCD Event Generators

QCD Model	Shower Development	Fragmentation
JETSET/PYTHIA	Parton Shower	String
HERWIG	Parton Shower	Cluster
ARIADNE	Color Dipole	String
COJETS	Incoherent	Independent

All models tuned at $\sqrt{s} = m_Z$ using LEP I data

Jet Rates

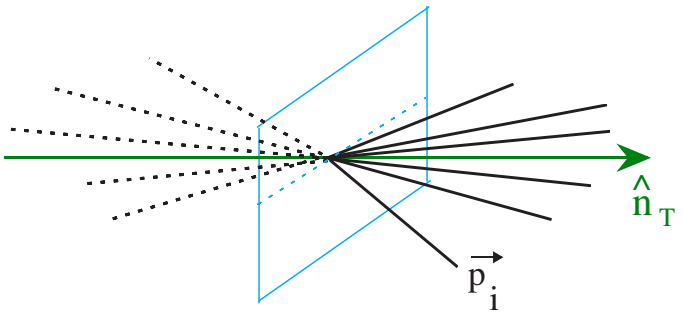


$$y_{ab}^{Jade} = \frac{2E_aE_b}{E_{vis}^2}(1-\cos\theta_{ab})$$

$$y_{ab}^{Durham} = 2\,\frac{(E_a^2,E_b^2)_{min}}{E_{vis}^2}(1-\cos\theta_{ab})$$

$$y_{ab}^{Cambridge} = 2\,\frac{(E_a^2,E_b^2)_{min}}{E_{vis}^2}(1-\cos\theta_{ab})$$

- Collinear and infrared safe variables analytically calculable.
- Perturbative calculations more complete than in jet rate.



Thrust

$$T = \left(\frac{\Sigma_i |\vec{p}_i \cdot \hat{n}_T|}{\Sigma_i |\vec{p}_i|}\right)_{max}$$

Heavy jet mass

$$\rho_H = (\Sigma_i p_i)^2_{max} / s$$

$$(i \text{ in } S_\pm)$$

Jet broadenings

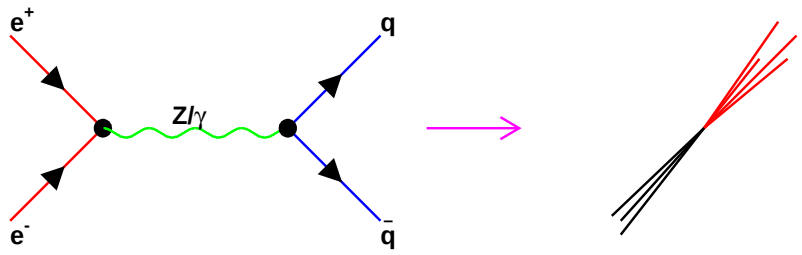
$$B_\pm = \left(\frac{\Sigma_i |\vec{p}_i \times \hat{n}_T|}{2\Sigma_i |\vec{p}_i|}\right)$$

$$B_T = B_+ + B_-, \quad B_W = \max(B_+, B_-)$$

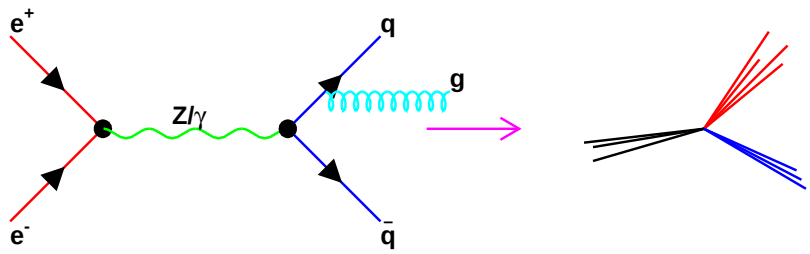
C-parameter

$$C = \left(\frac{3}{s}\right) \Sigma_{i<j} |\vec{p}_i| * |\vec{p}_j| * \sin^2(\theta_{ij})$$

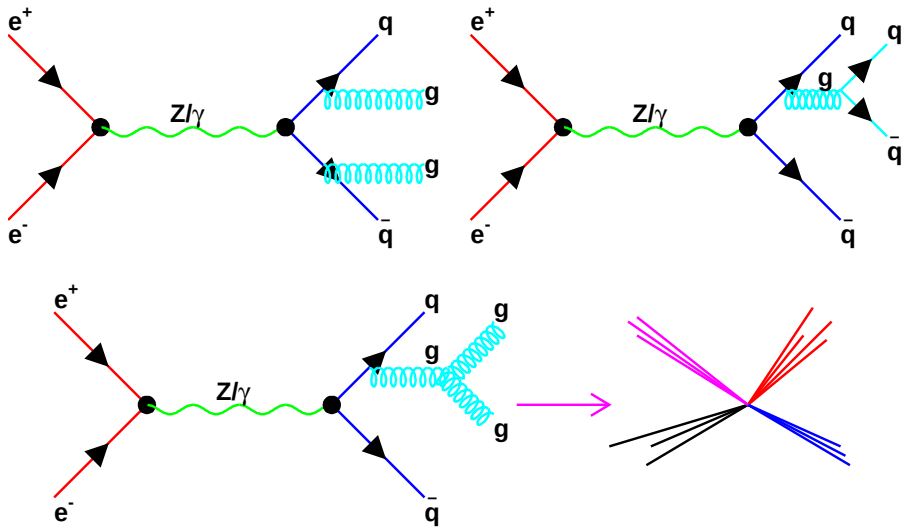
Event Shapes: relative contributions from n-jet configuration



2 jets: $1 - \mathrm{T} \simeq 0$ ρ_H, B_T, B_W, $\mathrm{C} \simeq 0$

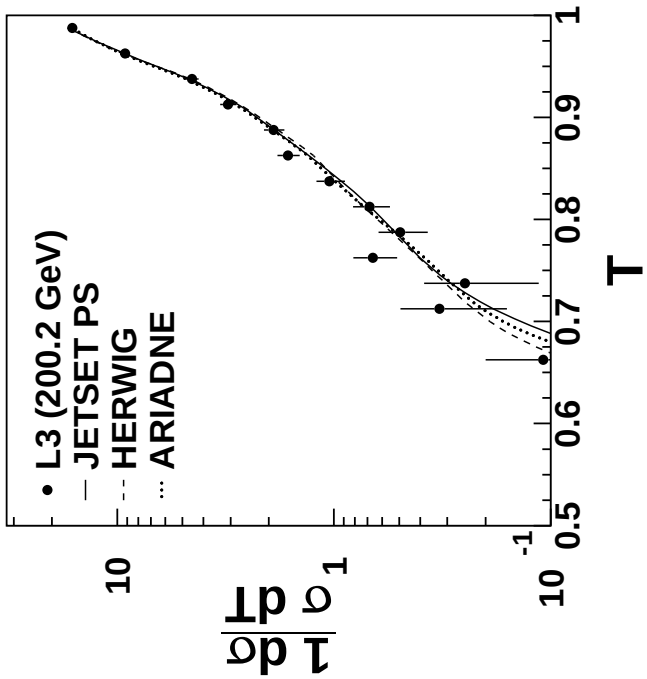


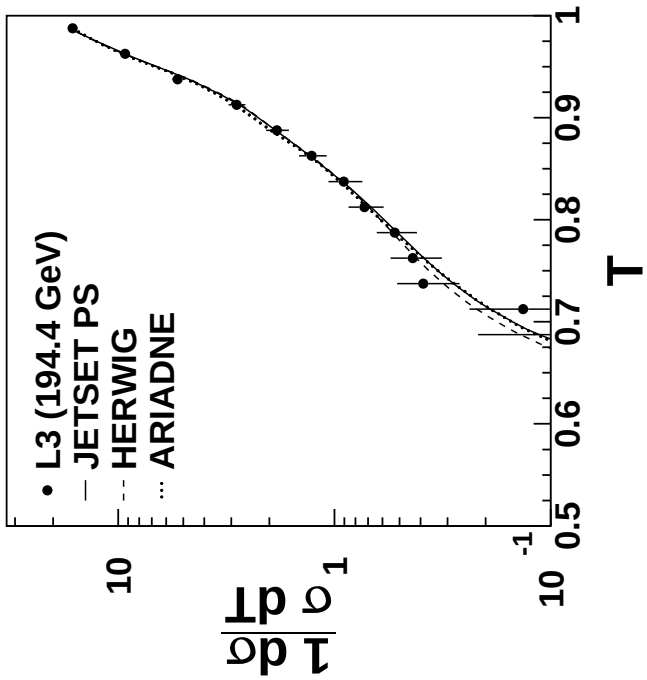
3 jets: T $[\frac{2}{3}, 1]$, $\rho_H \approx 1 - \mathrm{T}$, B_T $[0, \frac{1}{2\sqrt{3}}]$, C $[0, \frac{3}{4}]$

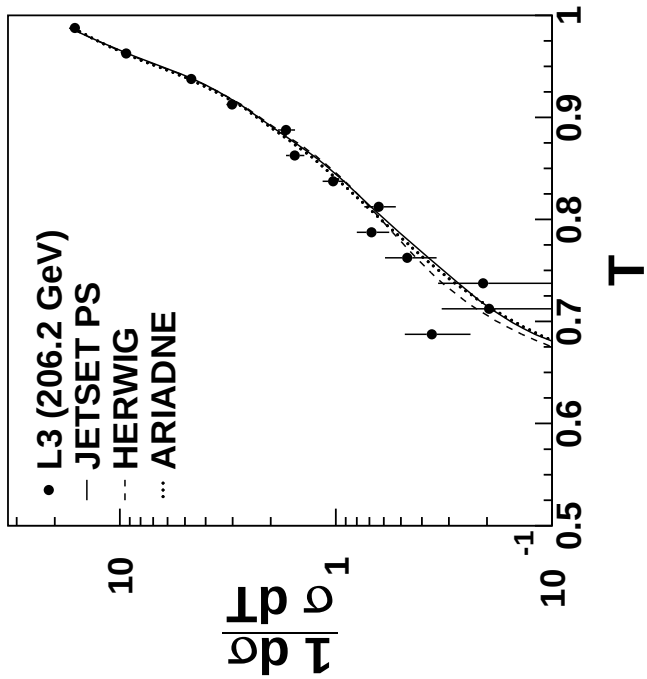


4 jets: T $[\frac{1}{\sqrt{3}}, 1]$, Planar Topology $(\mathrm{C})_{max} = 1$.
Spherical Topology, $(B_T)_{max} = \frac{\pi}{8}$, $(B_W)_{max} = \frac{\pi}{16}$

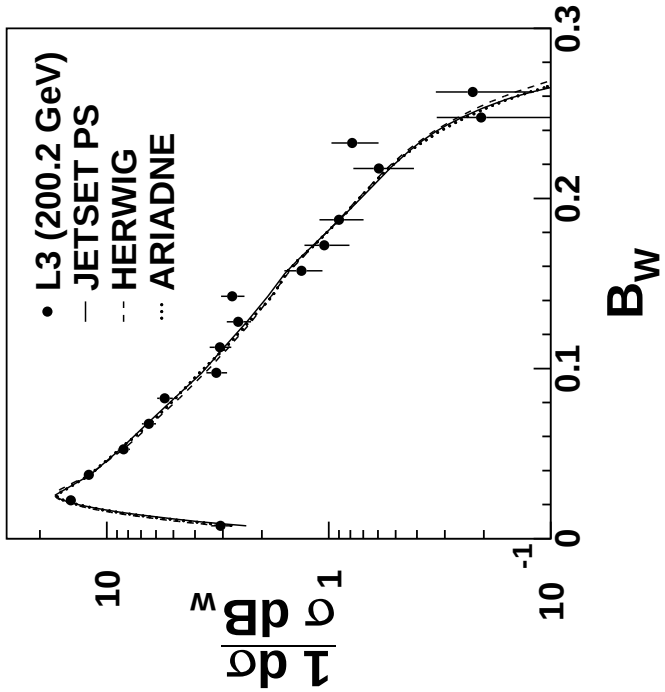
Distributions: Trust

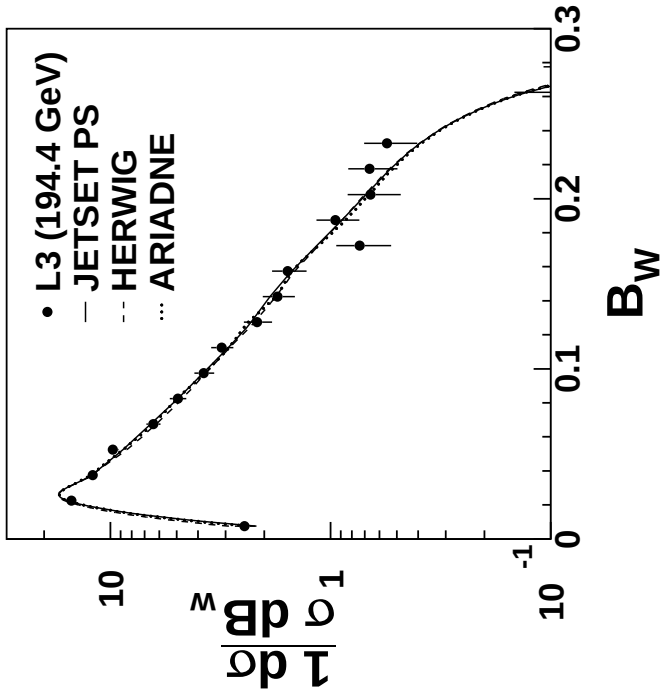


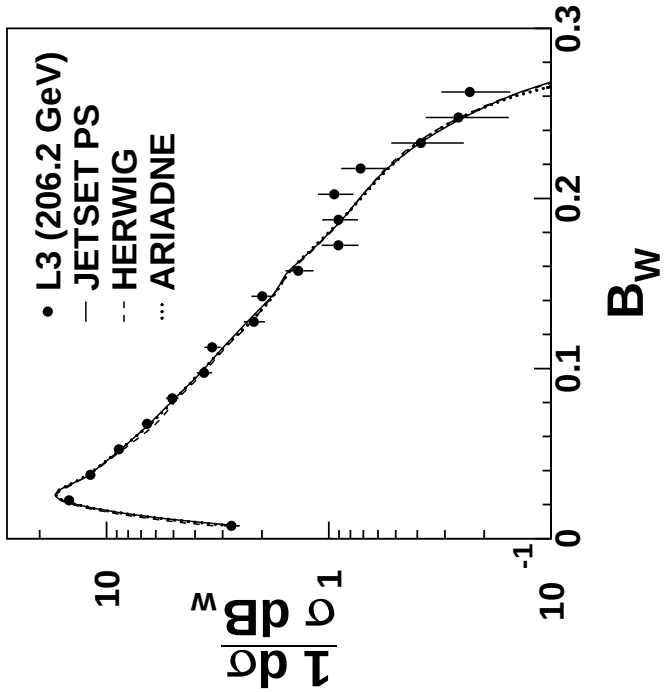




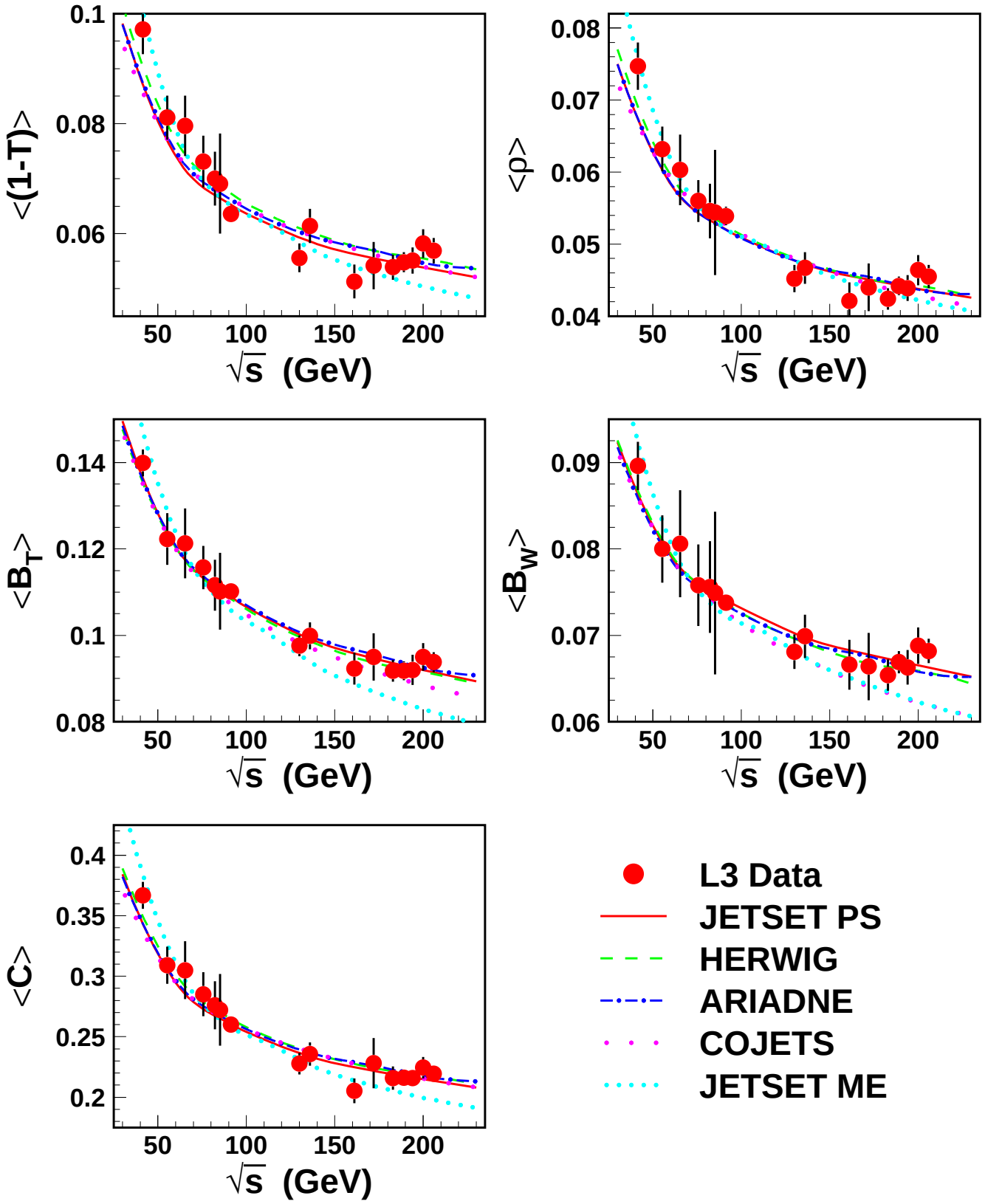
Distributions: Bw







Energy Evolutions



⇒ QCD Models with parton shower describe data well

Methods to extract α_s

Complete analytical QCD calculations are available for event shape variables up to second order and leading logharithmic terms have been resummed up all orders for certain variables:

• Complete calculation to $\mathcal{O}(\alpha_s^2)$ for the event shape variable y:

$$\frac{1}{\sigma}\frac{d\sigma}{dy} = \mathrm{A(y)}\frac{\alpha_s(\mu)}{2\pi} + \left(\mathrm{B(y)} + 2\mathrm{A(y)}\beta_0 \ln\frac{\mu^2}{Q^2}\right)\left(\frac{\alpha_s(\mu)}{2\pi}\right)^2$$

μ is the renormalization scale used for α_s calculations.A(y), B(y) computed.

the event shape variables distributions $\propto \alpha_s$

$\Rightarrow$ great sensitivity to coupling constant.

• Resummation: Leading order terms $(\Sigma\overline{\alpha_s}^n L^{n+1})$ and next-to-leading logarithmic terms $(\Sigma\overline{\alpha_s}^n L^n)$, with $\mathrm{L} = \ln(\frac{1}{y})$

	LL	NLL
$\mathcal{O}(\alpha_s)$	$\overline{\alpha_s}L^2$	$\overline{\alpha_s}\mathrm{L}$
$\mathcal{O}(\alpha_s^2)$	$\overline{\alpha_s^2}L^3$	$\overline{\alpha_s^2}L^2$
$\mathcal{O}(\alpha_s^3)$	$\overline{\alpha_s^3}L^4$	$\overline{\alpha_s^3}L^3$
.	.	
.	.	

• Combination of fixed order calculations with resummed calculations (avoiding double counting of terms).

Modified Log R Replacing in the resummed terms by L' = ln $(y^{-1} - y_{max}^{-1} + 1)$, take log fixed order, expand in power series and match.

This calculations are performed at parton level and do not include heavy quarks mass effect.

• Compare the analytical calculations with the experimental distributions. The effect of hadronization and decays incorporated with MonteCarlo.

$p^{pert}(y')$ is convoluted with the probability of finding a value y after fragmentation and decays for a parton level y'.

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

$p^{non-pert}$ is evaluted using Montecarlo: JETSET (as default), HERWIG/ARIADNE (for-cross-check).

α_s from Event Shape Distributions

Errors considered:

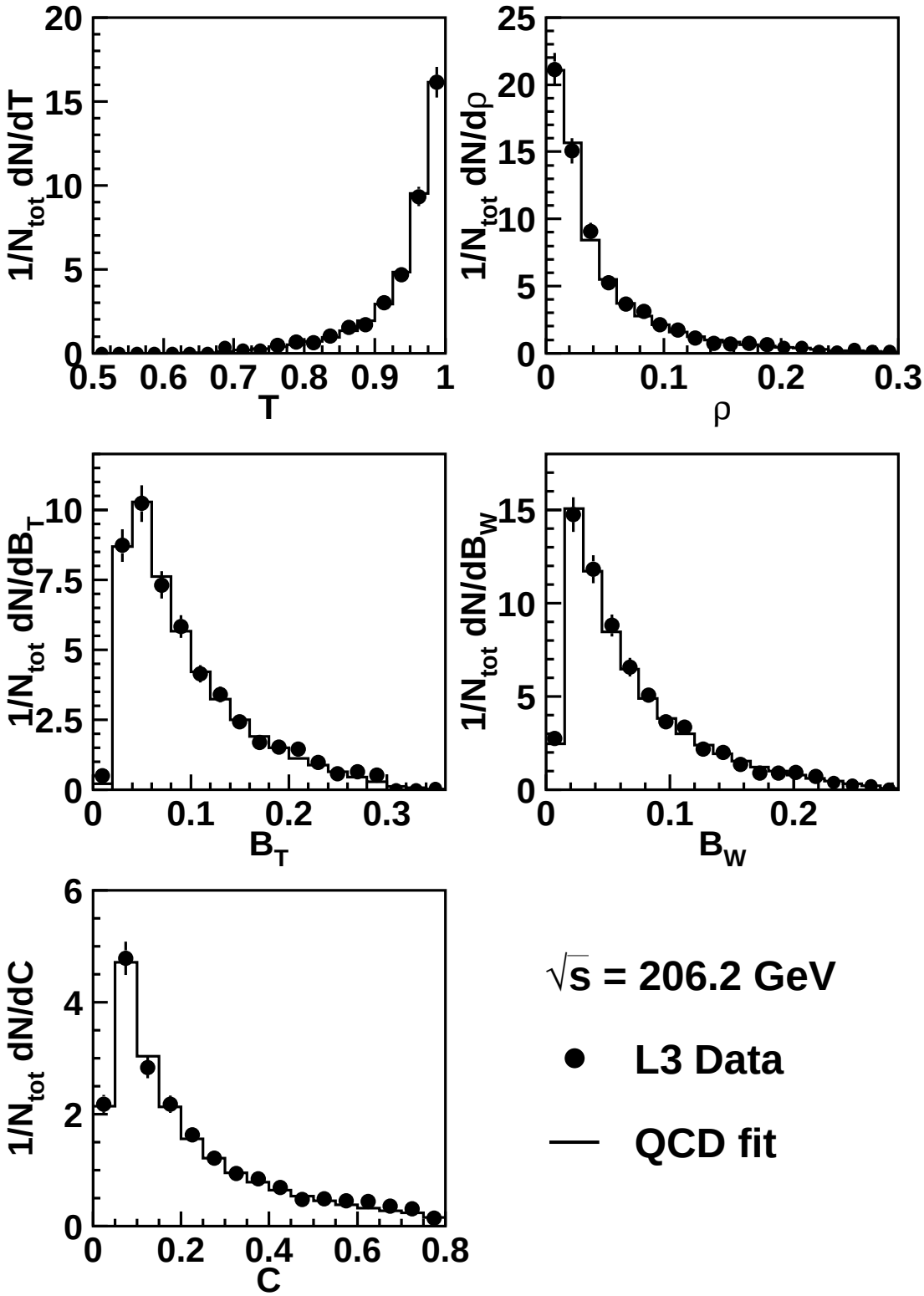
- Statistical
- Experimental systematics. Variation:
  - Detector effect
  - Background modelling
- Hadronization. Variation:
  - Fragmentation models
  - Fragmentation parameters
- Uncalculated High order. Variation:
  - Matching schemes
  - Scale 0.5 $\sqrt{s}$ to 2 $\sqrt{s}$

α_s value at $\sqrt{s}$= 206 GeV

α_s(1-T)	= 0.1173	$\pm$ 0.0021 (exp)	$\pm$ 0.0057 (theo)
$\alpha_s(\rho)$	= 0.119	$\pm$ 0.0019 (exp)	$\pm$ 0.0034 (theo)
$\alpha_s(B_T)$	= 0.1163	$\pm$ 0.0021 (exp)	$\pm$ 0.0065 (theo)
$\alpha_s(B_W)$	= 0.1077	$\pm$ 0.0019 (exp)	$\pm$ 0.0062 (theo)
α_s(C)	= 0.1077	$\pm$ 0.0019 (exp)	$\pm$ 0.0062 (theo)

- α_s is the average of α_s(1-T) $\alpha_s(\rho)$ $\alpha_s(B_T)$ $\alpha_s(B_W)$ α_s(C)

Measured distributions of event shape variables in comparison with QCD predictions.



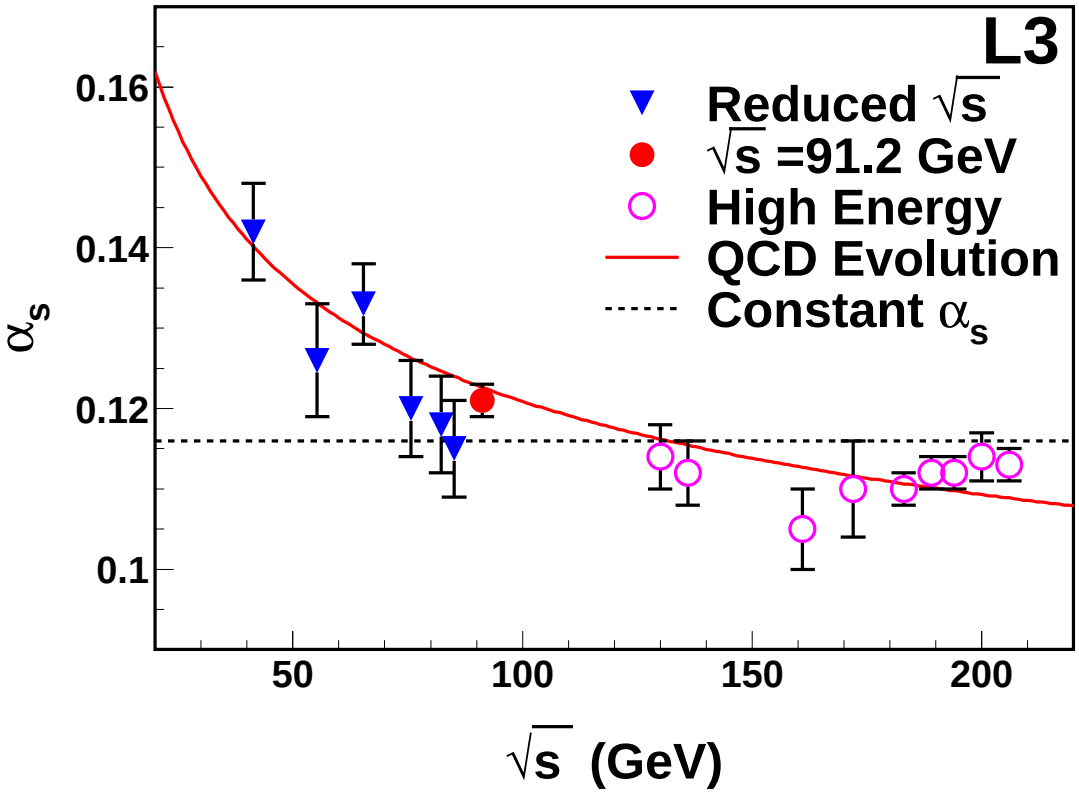
$\alpha_s(\text{thrust}) = 0.1173$, $\alpha_s(\rho) = 0.1119$, $\alpha_s(B_T) = 0.1163$, $\alpha_s(B_W) = 0.1077$, $\alpha_s(B_W) = 0.1130$

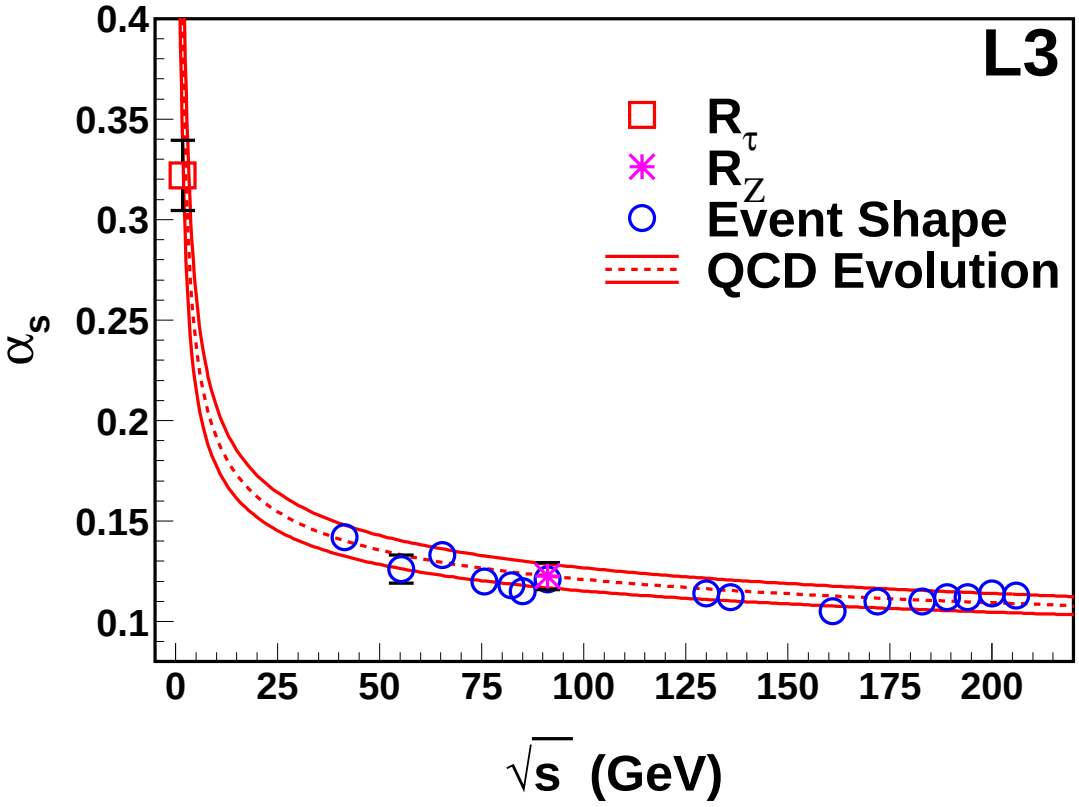
The α_s *running* is the solution of renormalization equation.
From the experimental data is possible to derive:

- **Energy dependence of α_s compared with QCD prediction.**
- **Fit to QCD evolution equation with $\alpha_s(m_Z)$ free parameter.**

Running α_s from 30 to 208 GeV

From event shape





α_s values

Combined α_s values from the five event shape variables.

$< \sqrt{s} >$ (GeV)	α_s measurement from T, ρ, B_T, B_w, C				
	α_s	stat	syst	hadr.	hi. order
41.4	0.1418	$\pm$0.0053	$\pm$0.0030	$\pm$0.0055	$\pm$0.0085
55.3	0.1260	$\pm$0.0047	$\pm$0.0056	$\pm$0.0066	$\pm$0.0062
65.4	0.1331	$\pm$0.0032	$\pm$0.0042	$\pm$0.0059	$\pm$0.0064
75.7	0.1204	$\pm$0.0024	$\pm$0.0059	$\pm$0.0060	$\pm$0.0053
82.3	0.1184	$\pm$0.0028	$\pm$0.0053	$\pm$0.0060	$\pm$0.0051
85.1	0.1152	$\pm$0.0037	$\pm$0.0051	$\pm$0.0060	$\pm$0.0055
91.2	0.1210	$\pm$0.0008	$\pm$0.0017	$\pm$0.0040	$\pm$0.0052
130.1	0.1138	$\pm$0.0033	$\pm$0.0021	$\pm$0.0031	$\pm$0.0046
136.1	0.1121	$\pm$0.0039	$\pm$0.0019	$\pm$0.0038	$\pm$0.0045
161.3	0.1051	$\pm$0.0048	$\pm$0.0026	$\pm$0.0026	$\pm$0.0044
172.3	0.1099	$\pm$0.0052	$\pm$0.0026	$\pm$0.0024	$\pm$0.0048
182.8	0.1096	$\pm$0.0022	$\pm$0.0010	$\pm$0.0023	$\pm$0.0044
188.6	0.1122	$\pm$0.0014	$\pm$0.0012	$\pm$0.0022	$\pm$0.0045
194.4	0.1123	$\pm$0.0018	$\pm$0.0016	$\pm$0.0020	$\pm$0.0047
200.2	0.1138	$\pm$0.0018	$\pm$0.0021	$\pm$0.0020	$\pm$0.0046
206.2	0.1132	$\pm$0.0014	$\pm$0.0016	$\pm$0.0019	$\pm$0.0047

α_s at m_Z

$$\alpha_s(m_Z) = 0.1227 \pm 0.0012\ (\mathrm{exp}) \pm 0.0058\ (\mathrm{theo})$$

($\chi^2 = 17.9$ n.d.f $= 15$ c.l. $=0.27$)

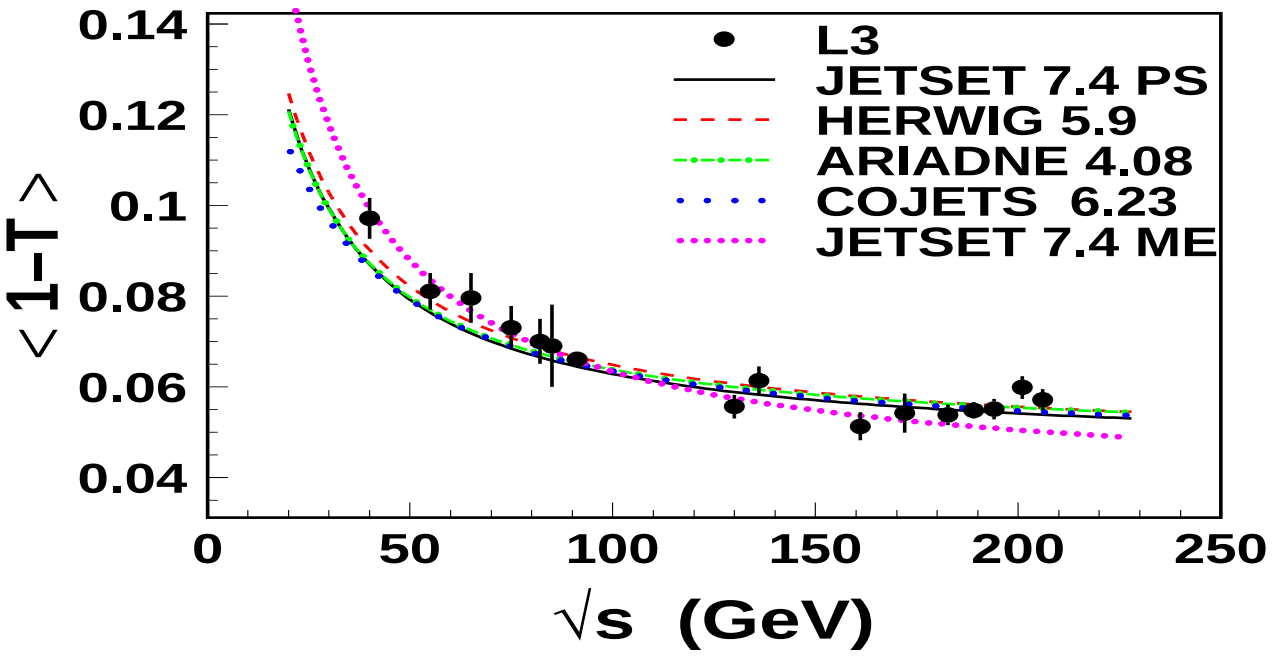
Conclusions

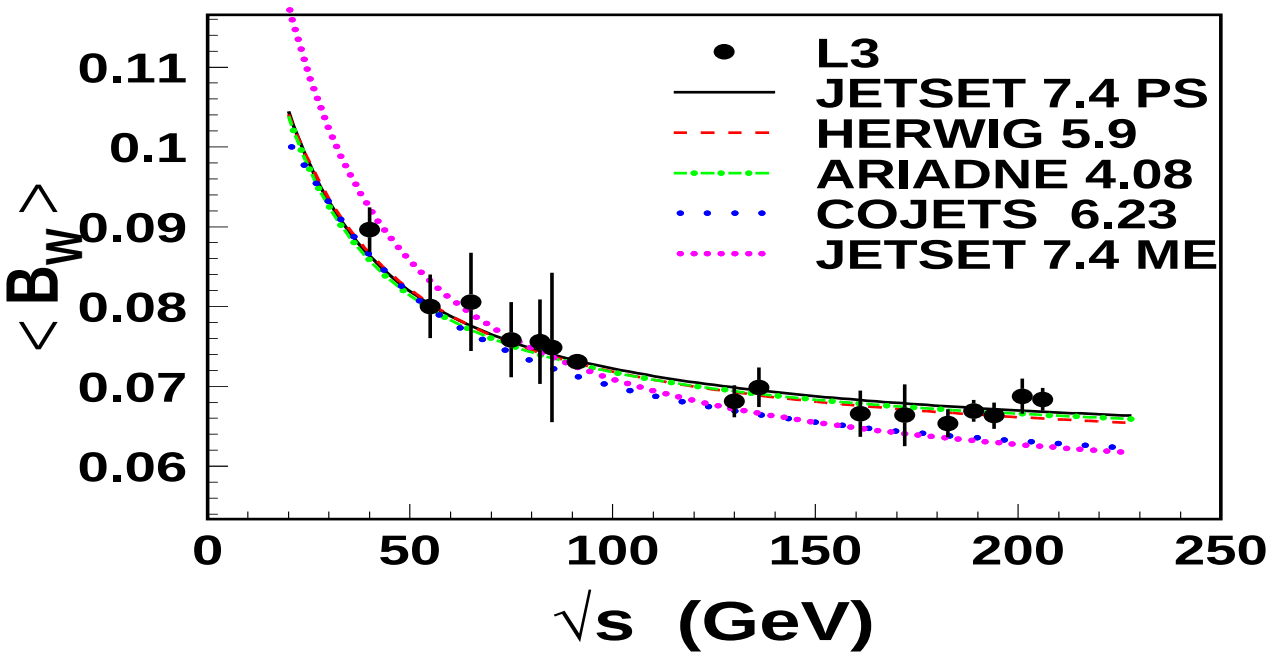
- Event shape variables have been studied over a large energy range: 30 to 208 GeV in e^+e^- collisions by L3 experiment. Good agreement is seen between data and coherent models tuned at $\sqrt{s} = m_Z$.
- Runinng of α_s is clearly demonstrated. In agreement with QCD predictions.
- A fit to QCD evolutions gives:

$$\alpha_s(m_Z) = 0.1227 \pm 0.0012\ (\text{exp}) \pm 0.0058\ (\text{theo})$$

- Theoretical uncertainty from unknown higher orders dominate.
- Very consistent result with other α_s measurements performed.

Energy Evolutions





Error bars include experimental systematic uncertanties

spage Energy evolution of α_s

The *running* of α_s can be expressed as:

$$\alpha_s(\mu) = \frac{\alpha_s(\mu_o)}{1 + \beta_o \alpha_s(\mu_o) ln \frac{(}{\mu^2} \mu_o^2)}$$

$$\beta_o = \frac{33 - 2n_f}{12\pi}$$

assumption: $\alpha_s(\mu_o) = \alpha_s(m_Z)$

- **Energy dependence of α_s compared with QCD prediction.**
- **Fit to QCD evolution equation with $\alpha_s(m_Z)$ free parameter.**