ALEPH results on Quark- and Gluon Fragmentation

Gerald RUDOLPH
Inst.f.Astro- u Teilchenphysik, University Innsbruck

Workshop on parton fragmentation processes : in the vacuum and in the medium
ECT, Trento, 25-29 Feb 2008

Content

Parton fragmentation is studied in the annihilation process

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

in the energy region 91 – 207 GeV using the ALEPH detector at LEP.

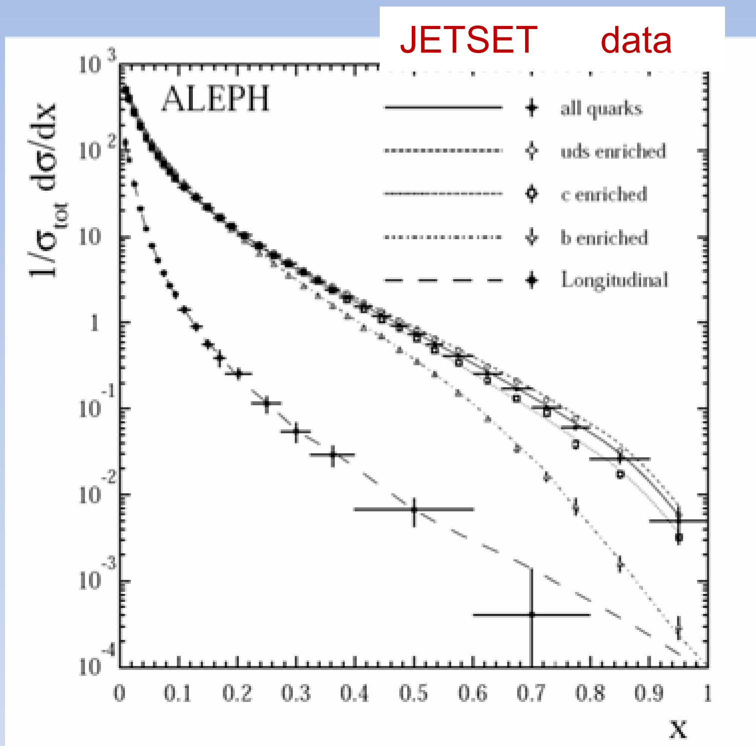
- Quark fragmentation functions and their evolution with energy scale
- Identified light and heavy hadrons
- QCD-Monte Carlo parameter fits
- Bose-Einstein correlations
- Gluon fragmentation

Not covered in this talk :

- Colour coherence
- $g \rightarrow cc$, $g \rightarrow bb$
- Photon FSR from quarks

Scaled energy x=E/Q of charged particles

At LO: Quark fragmentation function at scale $Q=E_{cm}/2$



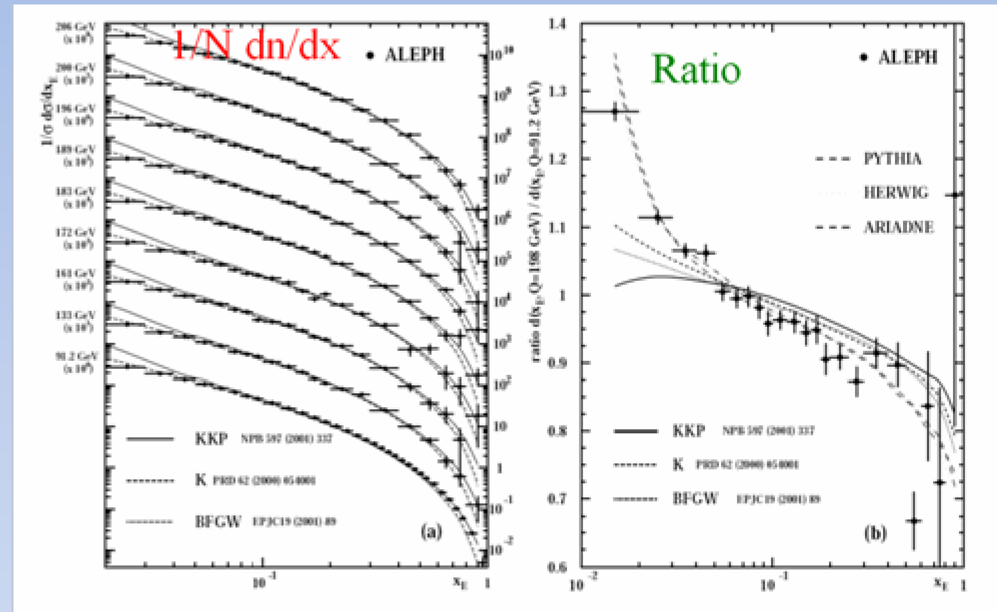


Figure 6: The inclusive scaled energy distributions compared to three different global NLO parametrisations of fragmentation functions (a). The ratio of the luminosity-weighted distribution at LEP2 (189-206 GeV, $\langle E_{cm}\rangle$ =198 GeV) and 91.2 GeV, whereby the latter is taken from [21] (b).

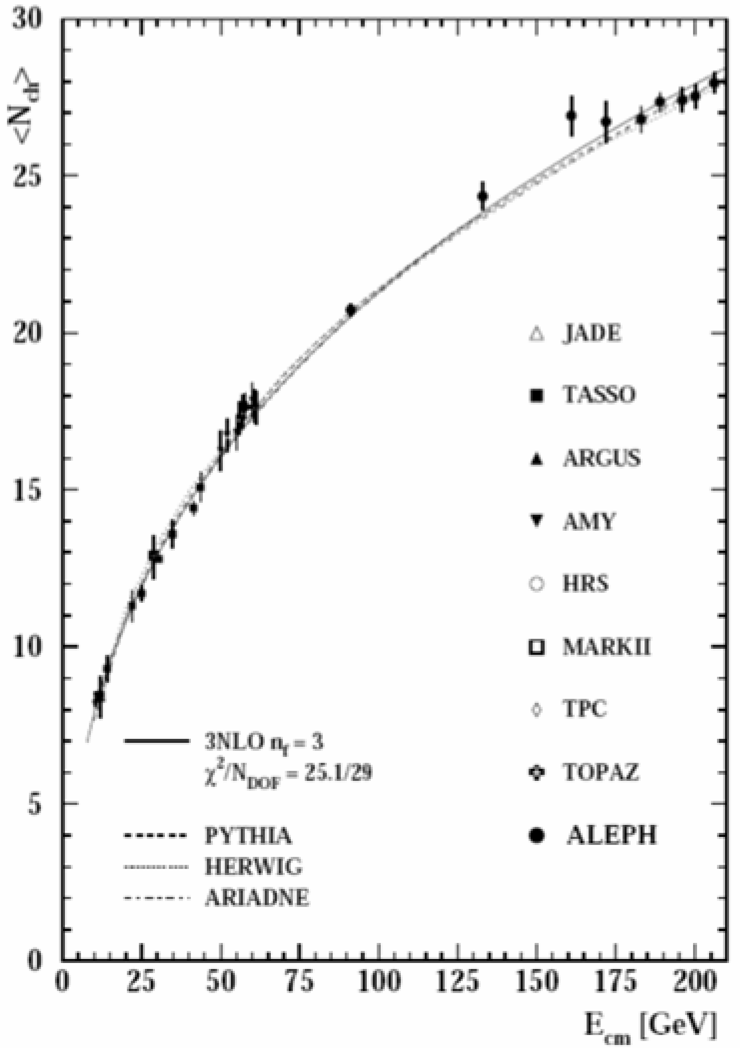
Z data + lower E_{cm} (PETRA,PEP)
Incl. flavour dependence
Scale depend. at NLO → $\alpha_S(M_Z)$
(1) Phys.Lett.B 357(1995)487

Z data + LEP2 data
For theor. prediction, LEP2 data not used
Data better described by MC models
(2) Eur.Phys.J. C35(2004)457

Flavour-inclusive x distributions
archived as computer-readable tables

For $E_{cm}=M_Z$ at //durpdg.dur.ac.uk/hepdata/
For 133-206 GeV at //cern.ch/aleph/QCD/

Mean charged particle multiplicity



3NLO prediction :
expansion parameter Y=ln(Q/Λ)
E_{cm}-dependent flavour composition
fitted parameters :
Λ=0.20±0.03 GeV
K_{LPHD}=0.19±0.01

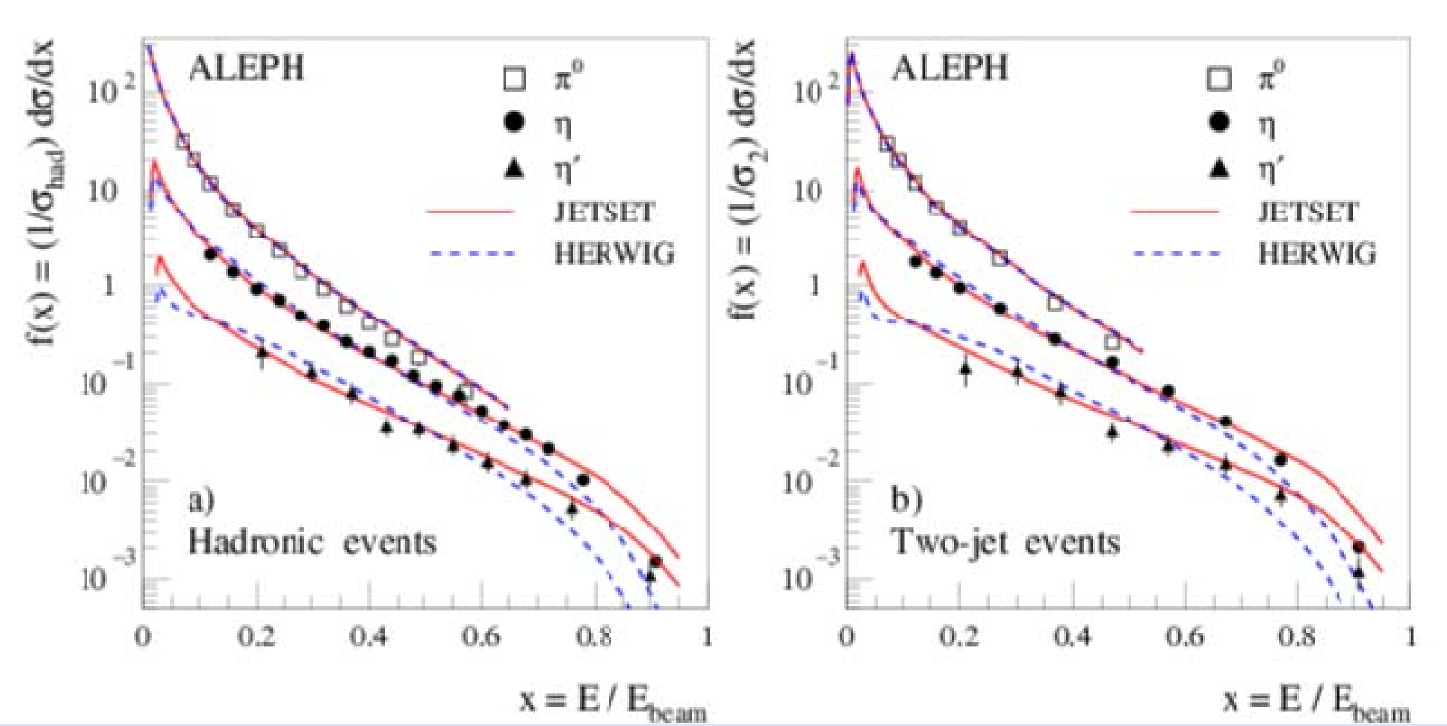
Figure 3: The mean charged particle multiplicity $\langle N_{ch} \rangle$ as a function of centre-of-mass energy E_{cm}. The measurements are compared to Monte Carlo predictions and to a fit of the QCD 3NLO evolution.

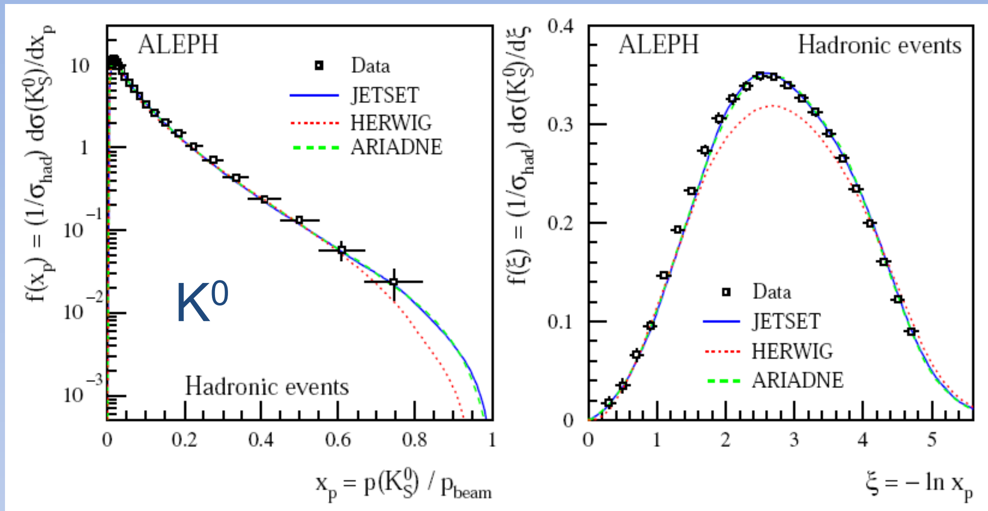
Inclusive x-distributions of identified light hadrons

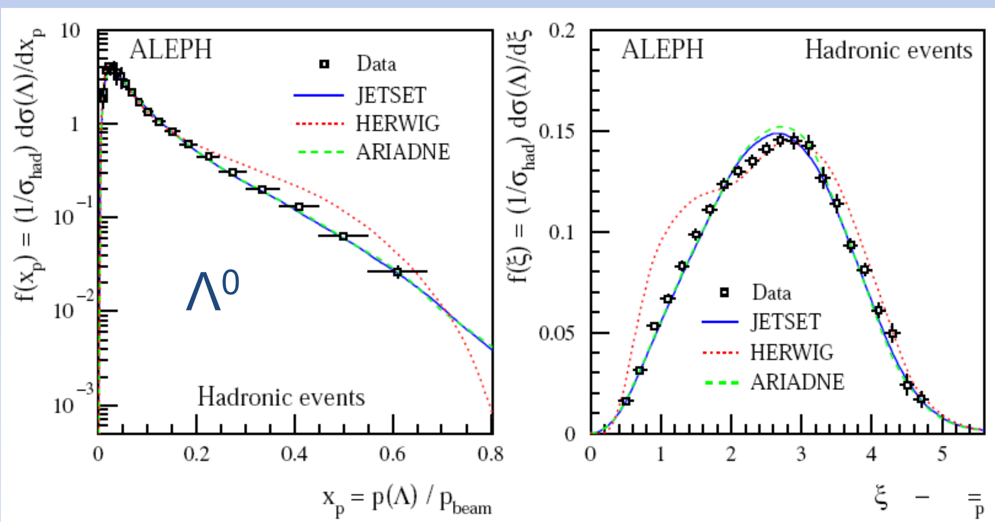
Measured at $E_{cm}=M_Z$ (high statistics) :
Mesons : pi+, K+, pi0, eta, eta‘, K0, rho0, omega, phi,K*0, K*+
Baryons : p, Lambda0, Sigma(1385), Xi-, Xi0(1530), Omega-

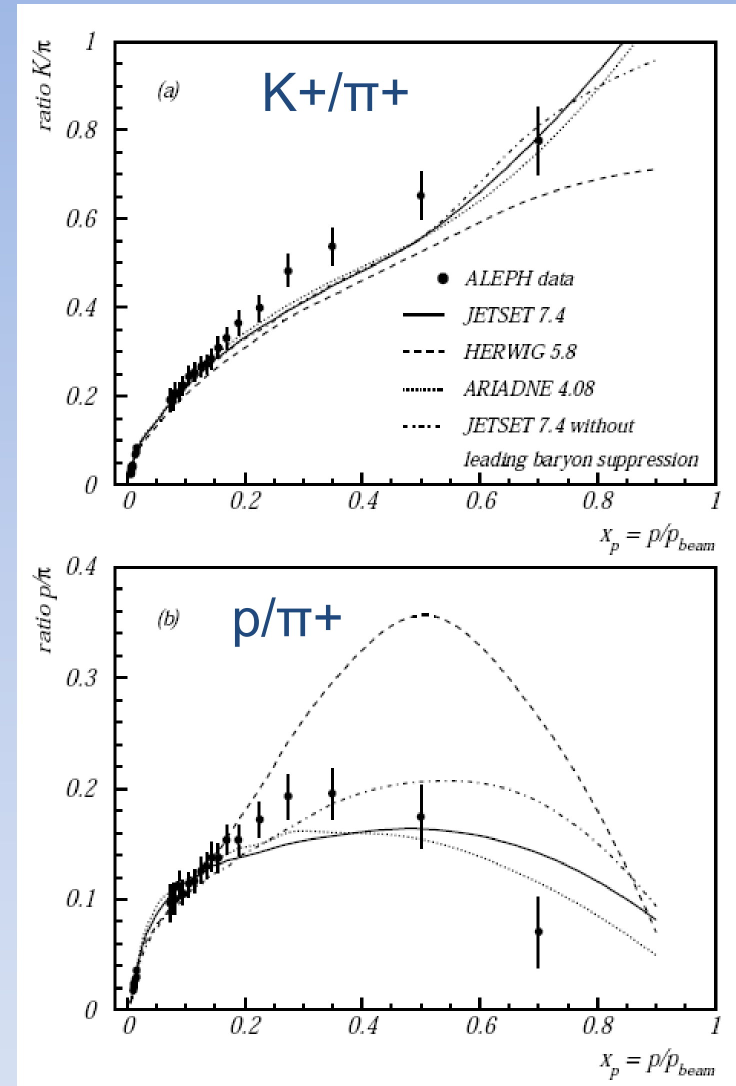
(3) Physics Reports 294(1998)1 (4) Eur.Phys.J. C16(2000)613

Examples :









HERWIG has problems with baryons !

The x and pT and event shape distributions at the Z were used to

Fit the QCD-MC fragmentation parameters

JETSET 7.4

parameter	name in program	default value	range generated	fit result value	error	syst.
Λ_{QCD} (GeV)	PARJ(81)	0.29	0.21 - 0.37	0.292	$\pm$ 0.003	$\pm$ 0.006
M_{min} (GeV)	PARJ(82)	1.0	1.0 - 2.0	1.57	$\pm$ 0.04	$\pm$ 0.13
σ_q (GeV)	PARJ(21)	0.36	0.28 - 0.44	0.370	$\pm$ 0.002	$\pm$ 0.008
a	PARJ(41)	0.30	0.20 - 0.60	0.40	(fixed)	
b (GeV^{-2})	PARJ(42)	0.58	0.60 - 1.00	0.796	$\pm$ 0.012	$\pm$ 0.033
ϵ_c	–PARJ(54)	0.050	0.015 - 0.065	0.040	adjusted	
ϵ_b	–PARJ(55)	0.005	0.0005 - 0.0075	0.0035	adjusted	
$p(S=1)_{d,u}$	PARJ(11)	0.50	0.40 - 0.70	0.55	$\pm$ 0.02	$\pm$ 0.06
$p(S=1)_s$	PARJ(12)	0.60	0.35 - 0.65	0.47	$\pm$ 0.02	$\pm$ 0.06
$p(S=1)_{c,b}$	PARJ(13)	0.75	0.50 - 0.80	0.65	adjusted	
$p(J^P=2^+; L=1, S=1)$	PARJ(17)	0.0	0.10 - 0.30	0.20	adjusted	
extra η' suppression	PARJ(26)	0.40	0.05 - 0.55	0.27	$\pm$ 0.03	$\pm$ 0.09
s/u	PARJ(2)	0.30	0.19 - 0.39	0.285	$\pm$ 0.004	$\pm$ 0.014
qq/q	PARJ(1)	0.10	0.05 - 0.15	0.106	$\pm$ 0.002	$\pm$ 0.003
$(su/du)/(s/u)$	PARJ(3)	0.40	0.4 - 1.0	0.71	$\pm$ 0.04	$\pm$ 0.07
leading baryon suppr.	PARJ(19)	1.0	0.2 - 1.0	0.57	$\pm$ 0.03	$\pm$ 0.10
switch				setting		
fragmentation function	MSTJ(11)	4		3		
baryon model	MSTJ(12)	2		3		
azimuthal distrib. in PS	MSTJ(46)	3		3		

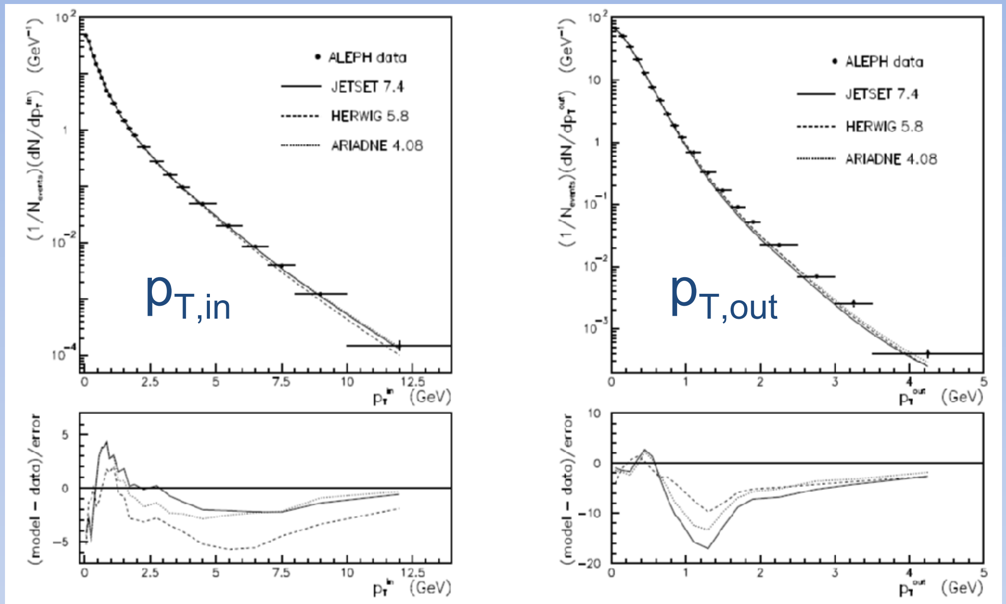
Phys.Rep. 294(1998)1

HERWIG 6.1

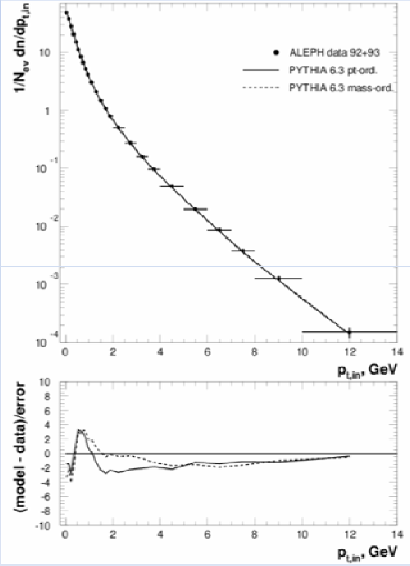
parameter	MC name	HW0	HW-CR
$P_{\rm reco}$	PRECO	0	1/9
min. virtuality (GeV^2)	VMIN2	-	0.1
Λ (GeV)	QCDLAM	0.190 ± 0.005	0.187 ± 0.005
gluon mass (GeV)	RMASS(13)	0.77 ± 0.01	0.79 ± 0.01
max. cluster mass (GeV)	CLMAX	3.39 ± 0.08	3.40 ± 0.08
angular smearing, dusc	CLSMR(1)	0.59 ± 0.03	0.66 ± 0.04
angular smearing, b	CLSMR(2)	0	0
power in cluster splitting, dusc	PSPLT(1)	0.945 ± 0.018	0.886 ± 0.017
power in cluster splitting, b	PSPLT(2)	0.33	0.32
decuplet baryon weight	DECWT	0.71 ± 0.06	0.70 ± 0.06
$\langle n_{\rm ch} \rangle$		20.96	20.98
f(reco)		-	0.08

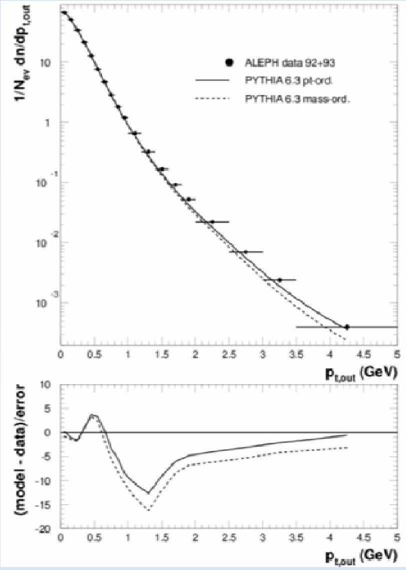
Eur.Phys.J. C48(2006)685

Transverse momentum distributions



$p_{T,out}$ > 1 GeV
largest MC-data discrepancy



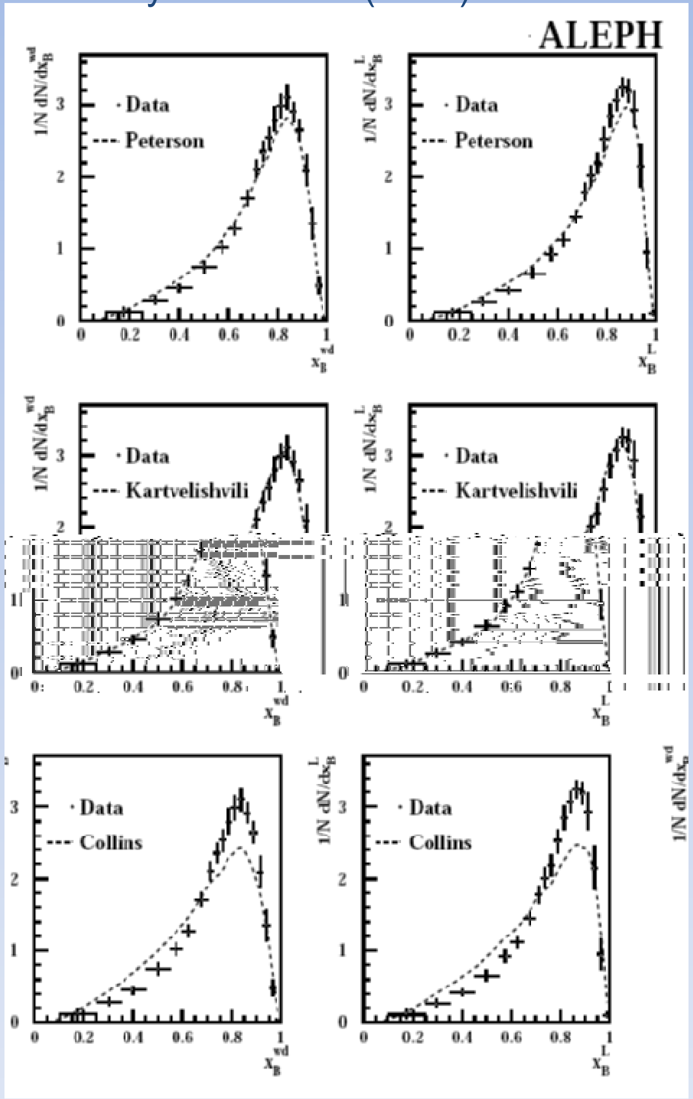


Slight improvement using pT-ordered PS
(now PYTHIA standard for pp
Eur.Phys.J. C39(2005)129)
as compared to
Mass-ordered PS

Heavy Quark Fragmentation

B

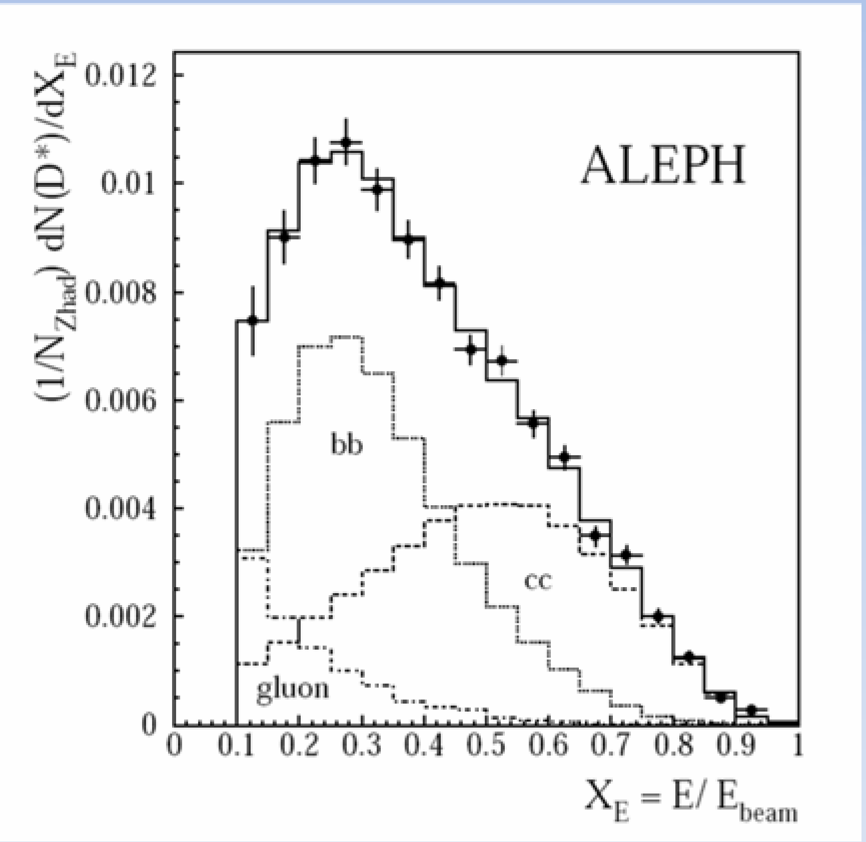
Phys.Lett. B512(2001)30



Scaled energy distributions of

D*+

Eur.Phys.J. C16(2000)597



compared to tuned JETSET MC

Production of HF meson spin states

	Measured
Charm : from D, D*	V/(P+V) = 0.595 ± 0.045
Bottom: from B, B*	V/(P+V) = 0.77 ± 0.07

Standard JETSET only allows one common value V_c,b
HVFL (not public): improved HF spin selection and decay tables

Higher spin states : N(B**)/N(B) = 0.28 ± 0.08

Parametrisation of Bose-Einstein correlations

$Q = \sqrt{-(p_1-p_2)^2}$ distribution of same-sign charged particle pairs

Fitted BE_{32} model (PYTHIA 6) parameters

$\lambda = 1.1$ $\sigma = 0.33$ GeV

Needed to describe BEC's in WW → 4q decays
Phys.Lett. B606(2005)265

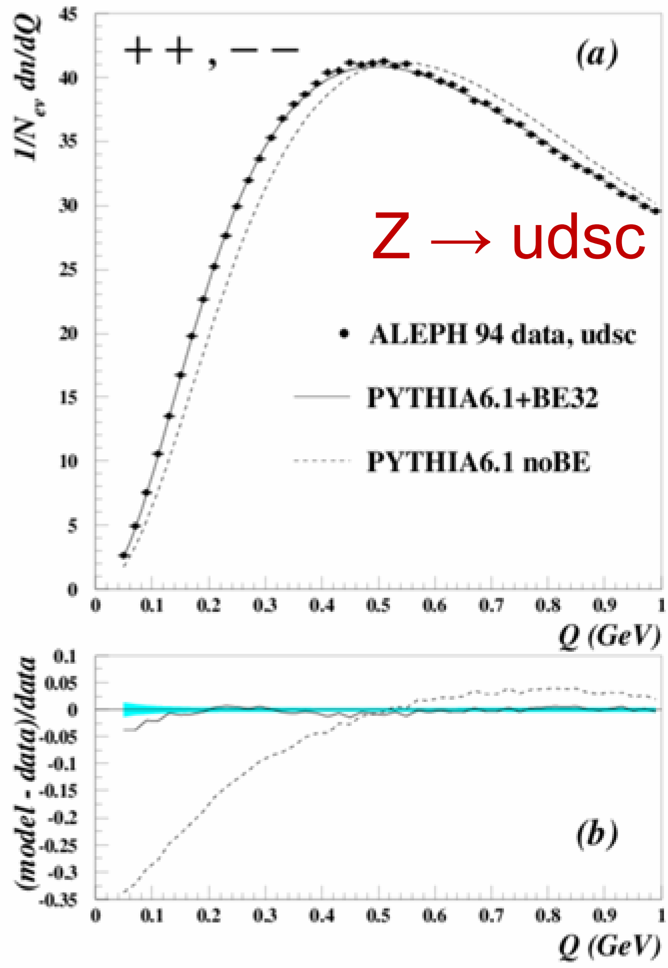
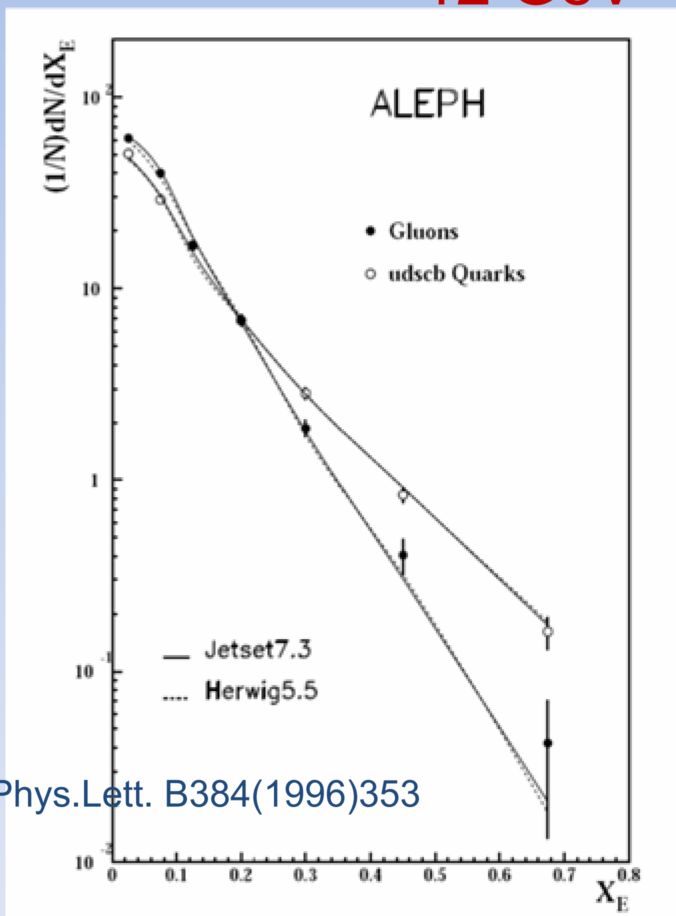


Figure 1: The normalized and corrected Q distribution of same-sign charged particle pairs in b-depleted Z decays, compared to model predictions (a). The relative deviation of the model predictions from the data is shown in (b). The grey band indicates the statistical errors.

Gluon fragmentation

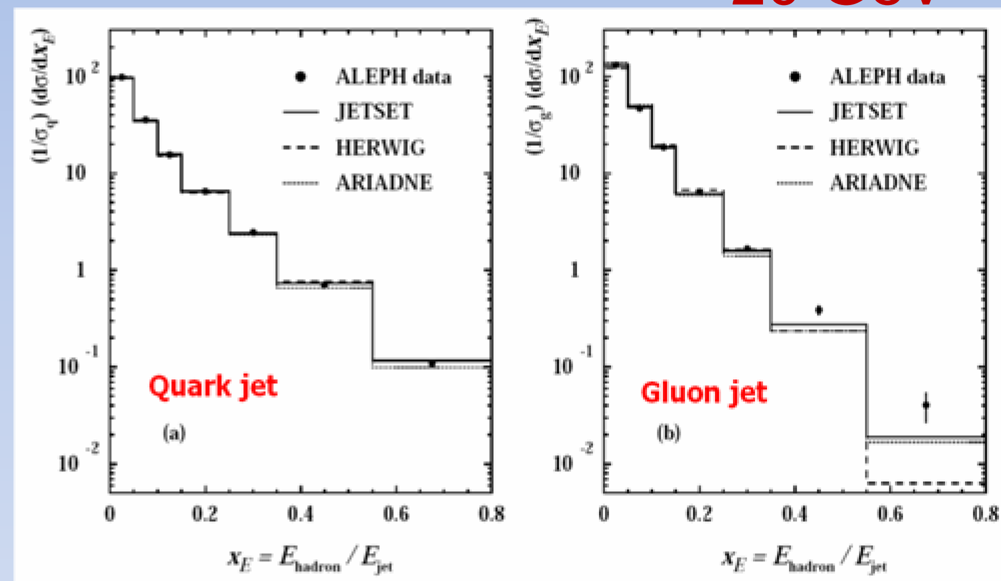
Charged particle $x = E/E_{jet}$ distributions measured from symmetric 3-jet events at scale $Q = E_{jet} \sin \theta/2$

≈12 GeV



Phys.Lett. B384(1996)353

≈ 20 GeV

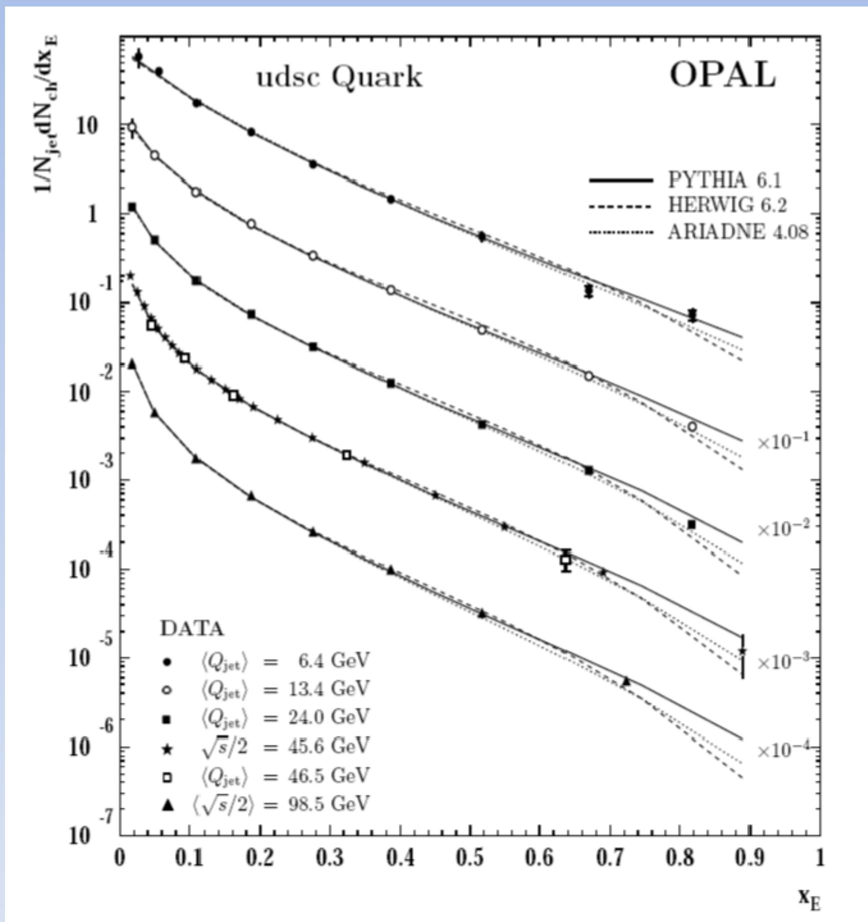


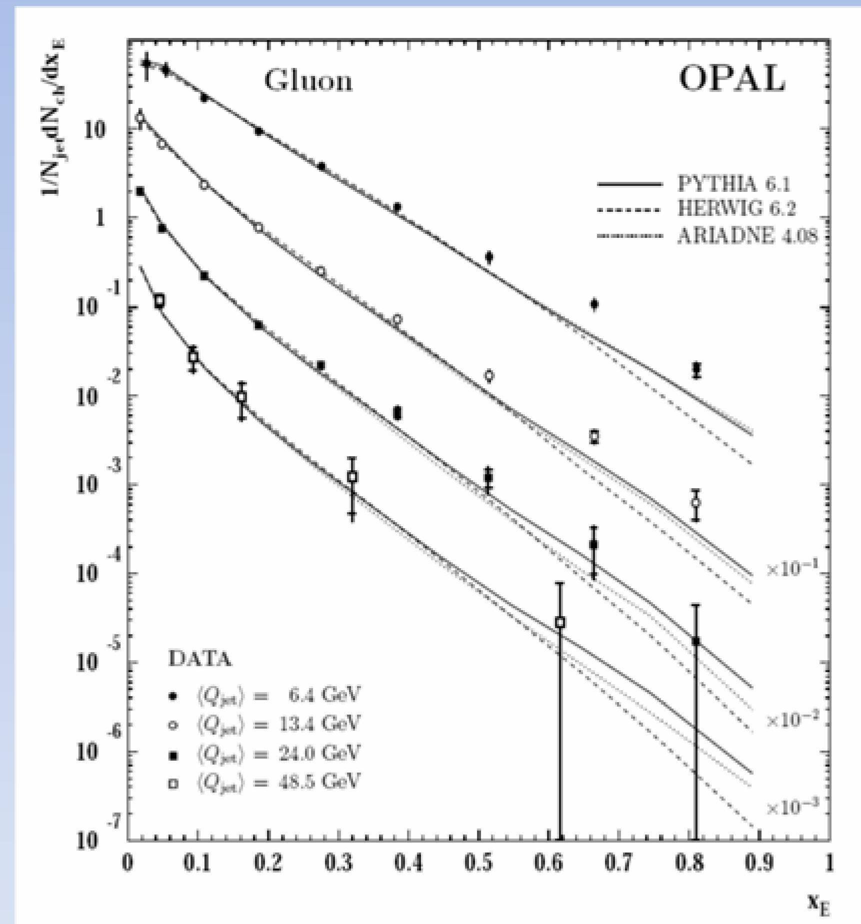
Eur.Phys.J. C17(2000)1

→ gluon steeper than quark

More extended analyses as a function of scale performed by DELPHI & OPAL

Eur.Phys.J. C37(2004)25



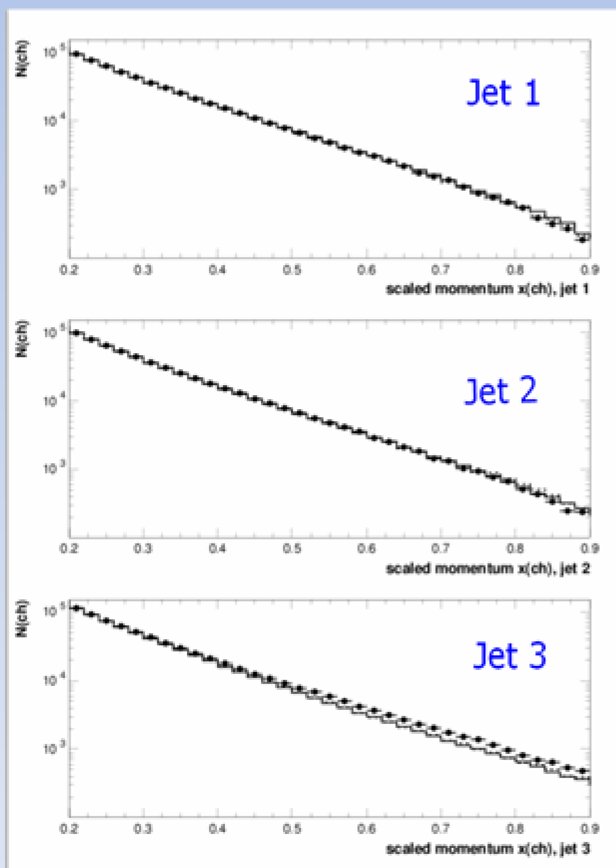


→ MC models low at x > 0.4 in gluon jet

ALEPH, preliminary :

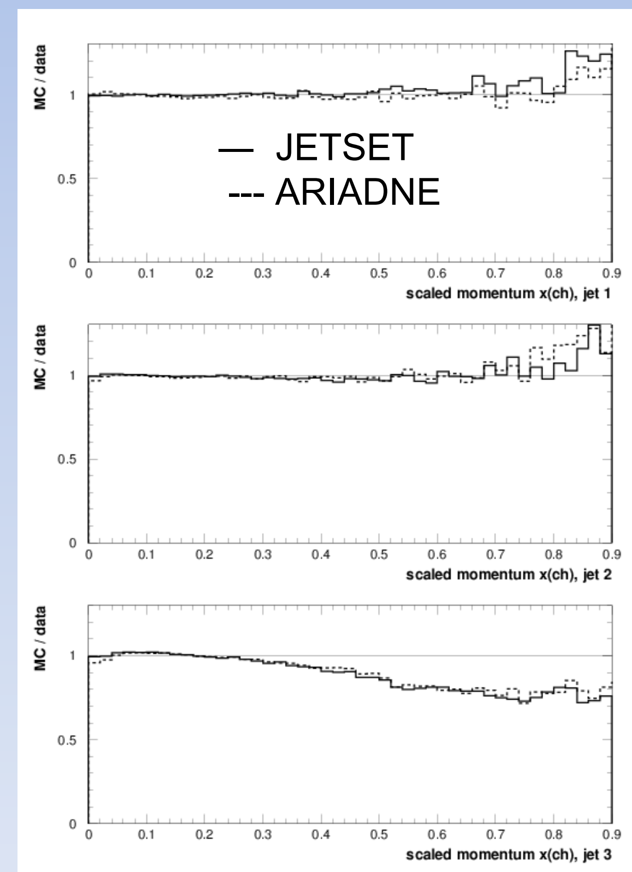
3-jet events (D,0.01) at $E_{cm}=M_Z$ of all topologies, photonic jets removed, 890 000 events selected,

energy-ordering $E_{jet1} > E_{jet2} > E_{jet3}$, Jet 3 is 71% gluon



MC low
at x > 0.4
why ?

Ratio MC/data



Discussion on large-x discrepancy :
(assuming it is related to hadronisation)

Within the colour string model,

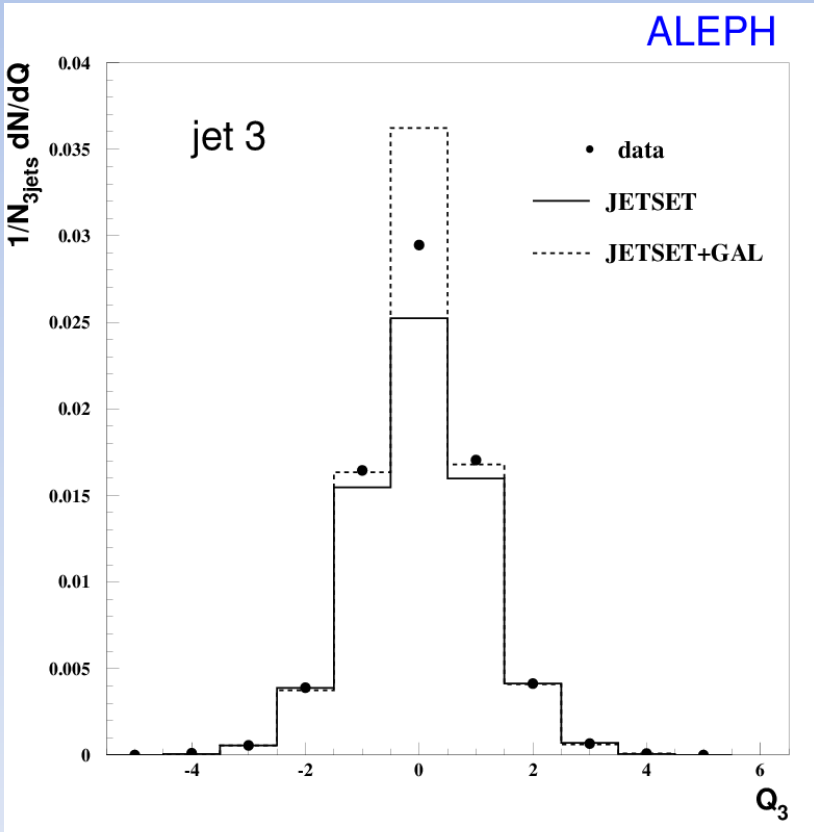
parameters are determined by the dominant 2-jet events (quark jets).
Gluon jet properties are predicted.

Technical problem of treating the hadron at the gluon kink,
or physics ?

3-jet events : neutral jets with a central rapidity gap

Jet 3 is sensitive to colour-reconnection (Eur.Phys.J. C48(2006)685)

Jet charge distribution
of the lowest energy jet
if no particles in $0 < y < 1.5$
are required

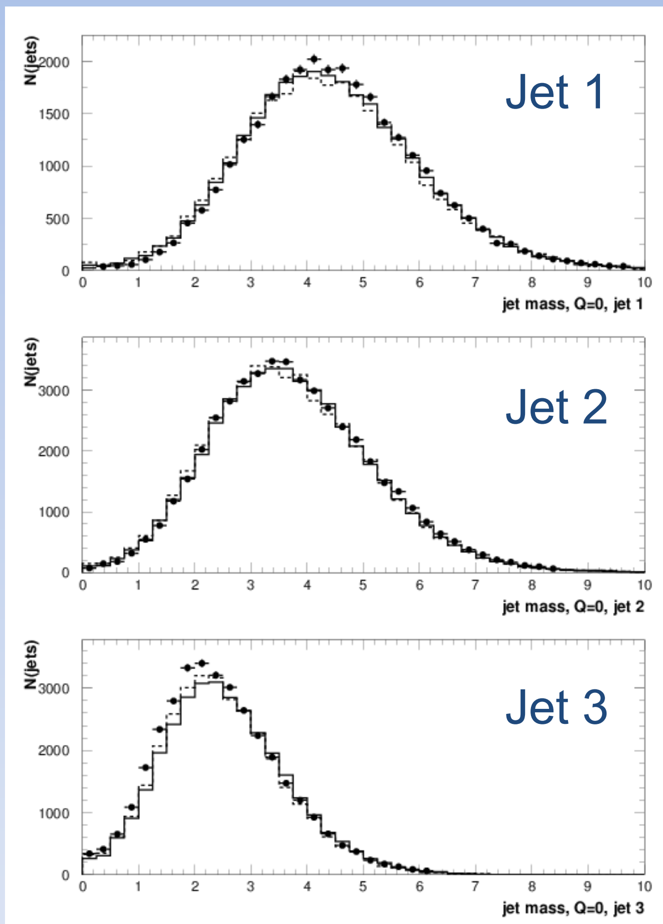


→ CR too high (excluded)

→ no-CR too low (why?)

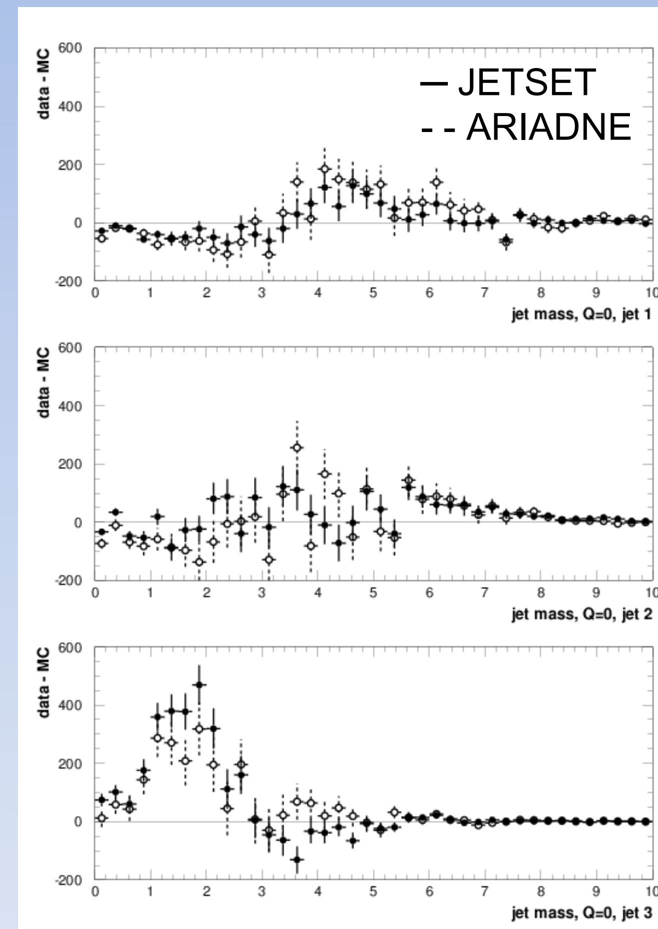
ALEPH, preliminary :

3-jet events: effective mass of neutral (Q=0) particle system beyond rapidity gap (charged + neutral particles)



Data excess in 0.8-2.2 GeV

Gluonium state(s) ?



Conclusions

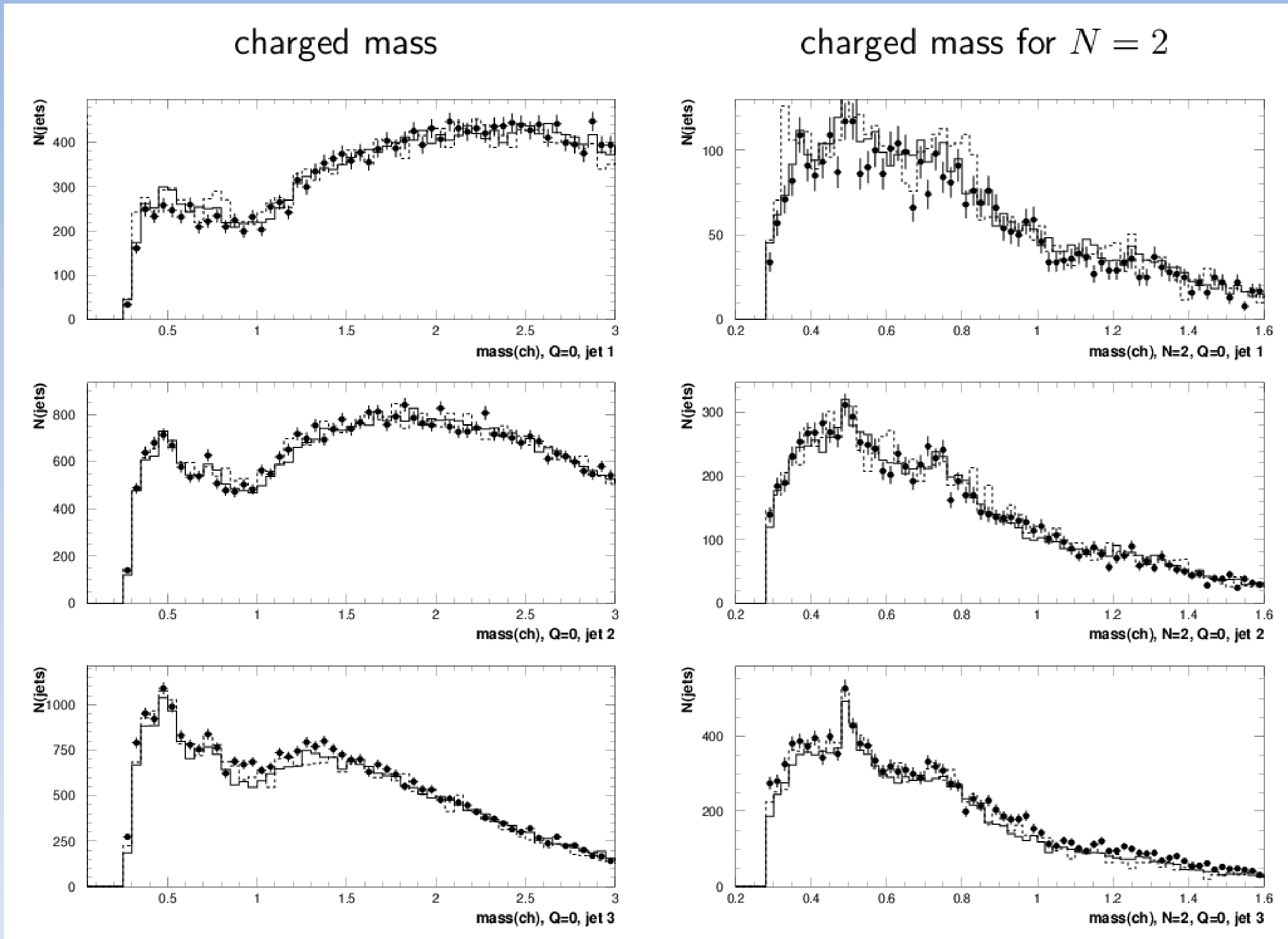
Quark fragmentation functions :
scale dependence qualitatively reproduced by global NLO parametrisations

Differential distributions of
charged particles and many identified light and heavy hadrons
are quite well reproduced by QCD-MC programs,
with parameters tuned to Z $\rightarrow$ hadrons data.
persistent problem areas : large $p_{T,out}$, baryons in HERWIG

BEC's can be parametrised

Gluon jet vs Quark jet differences are qualitatively as expected,
but , gluon jet not fully understood in terms of QCD-MC programs :
large x
low-mass enhancement in case of rapidity gap

More…


charged mass
charged mass for $N = 2$
N(jets)
mass(ch), Q=0, jet 1
mass(ch), N=2, Q=0, jet 1
mass(ch), Q=0, jet 2
mass(ch), N=2, Q=0, jet 2
mass(ch), Q=0, jet 3
mass(ch), N=2, Q=0, jet 3