glueballs from gluon jets at the LHC

Wolfgang Ochs
Max-Planck-Institut für Physik, München

- status of glueballs: theory, experimental scenarios
- leading systems in gluon jets, LEP results
- proposals for LHC

with Peter Minkowski (Univ. Bern)

hadron2011, Munich, June 13, 2011

QCD expectations for glueballs

- early prediction: bound states of self-interacting gluons
  scenarios for glueball phenomenology
  Fritzsch-Minkowski '75
- Lattice QCD
  - quenched approximation (only gluons)
    lightest state $J^{PC} = 0^{++}$: mass $\sim$ 1600 $\pm$ 200 MeV
  - unquenched results (including $q\bar{q}$)
    lightest gluonic flavour singlet:
    mass $\sim$ 1000 MeV — UKQCD '06: Hart et al.
    mass $\sim$ 1500 MeV — UKQCD '10: Richards et al.
    some problems:
    extrapolation to small lattice spacing, small m_q; decay to $\pi\pi$

- QCD sum rules
  - 2 gluonic resonances to satisfy sum rules for 0^{++}
    $M_{gb1} \simeq 1$ GeV, $M_{gb2} \simeq 1.5$ GeV

    either 2 gb states (NV) or a mixed gb-$q\bar{q}$ system (HKMS)

    Narison-Veneziano '89 (broad M_{gb1})
    Harnett-Kleiv-Moats-Steele '08-'11

- Experimental searches
  - extra state in spectrum besides flavour nonets
  - enhanced production in "gluon rich" processes
  - suppression in $\gamma\gamma$ processes

glueball in scalar meson spectrum

possible solution:

$f_0(1710)$
$f_0(1500)$ 3 isoscalars: 2 nonet $q\bar{q}$ states
$f_0(1370)$ one extra state: $\rightarrow$ glueball $M \sim 1.5$ GeV

Amsler, Close '96 $\ldots$

$f_0(980)$
$f_0(600)/\sigma$ could be from light nonet: $q\bar{q},\ 4q,\ K\bar{K}$

problem:
$f_0(1370)$ not seen in energy-independent analyses ($\pi\pi$)

alternative possibility:

$f_0(1500)$
$f_0(980)$ $q\bar{q}$ nonet (no $f_0(1370)$)

Minkowski, W.O. '98

$f_0(600)/\sigma$ glueball $M_{BW} \sim 1$ GeV

Narison

gluon rich processes produce $gb = (gg)\ldots$

1. central production in pp collisions:
   double Pomeron exchange: $pp \to p_f\ gb\ p_f$
2. $J/\psi \to \gamma\ gb$
3. $p\bar{p} \to \pi\ gb$
4. $b \to sg$: $B \to K\ gb$
5. gluon jet at high energy: $e^+e^- \to q\bar{q}g$, $pp \to g + X$: $g \to gb + X$

reactions 1-4 proceed at low energies, role of gluon not obvious

example:

ALICE @ LHC: (double Pomeron): excess of $f_0(980)$ and $f_2(1270)$ ($q\bar{q}$)!

Pomeron structure at HERA:

large $q\bar{q}$ singlet component at z=1.

$\Rightarrow$ only in reaction 5 a gluon can be identified

leading systems in gluon jets

Quark fragmentation,
color triplet field

Color octet fragmentation
of the gluon (hypothetical)

$u \to \pi^+(u\bar{d}) + X$: leading meson at large x carries initial quark

in analogy:

$g \to gb(gg) + X$: leading meson is a glueball, carries initial gluon (?)

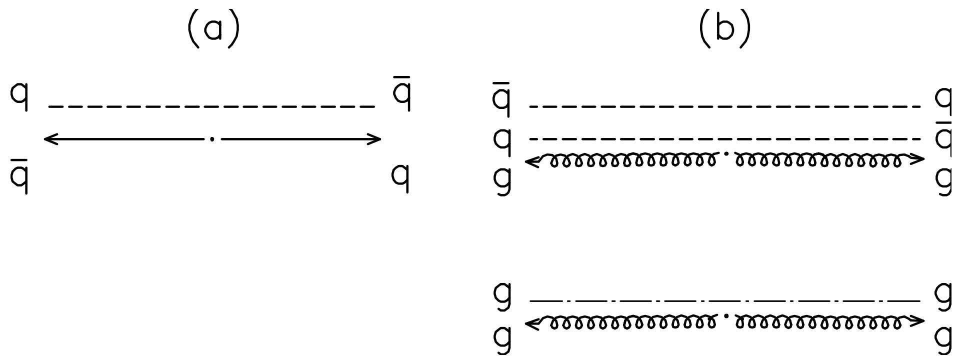
- nonperturbative jet model for flavour singlet object $(\eta, \eta', \omega, gb)$
  (analogy to Field Feynman model) C.Peterson, T.F.Walsh, '80
- fragmentation functions $g \to gb$ at large x P. Roy, K. Sridhar '97
  H. Spiesberger, P.M. Zerwas '00
- rapidity gap analysis, study charge and mass of leading cluster
  W. O., P. Minkowski '00

different colour neutralization processes

colour charges separated beyond confinement radius $r \gtrsim R_c$:

$\Rightarrow$ colour neutralization by pair production

a) initial $q\bar{q}$: b) initial gg



colour triplet neutralization

electric charge $Q = 0, \pm 1$

(P_3) colour triplet neutralization $Q = 0, \pm 1$

(P_8) colour octet neutralization $Q = 0$

colour octet mechanism is precondition for leading glueballs

rapidity gap analysis

rapidity gap isolates leading cluster (charge Q_{lead}, mass M_{lead})

$|| \quad | \qquad\qquad\qquad\qquad | \quad ||$

$- - - - - - - - - - - - - - - -> y$ rapidity: $y = \frac{1}{2} \ln \frac{E+p_{\|}}{E-p_{\|}}$

Δy

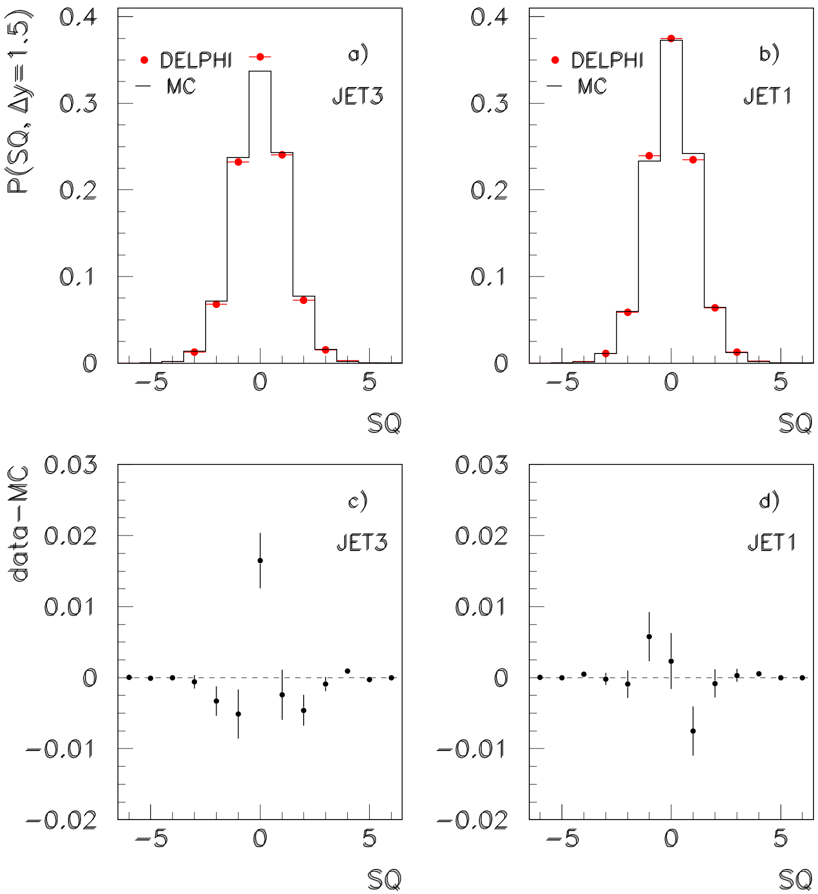
for large rapidity gaps Δy :

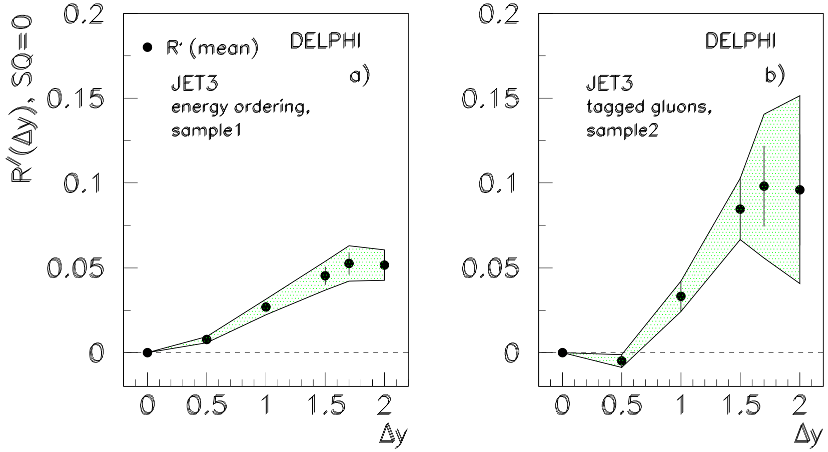
- limiting distribution of charge Q_{lead}
  $Q_{lead} = 0, \pm 1$ for $(q\bar{q})$, probabilities from fragmentation models
  $Q_{lead} = 0$ for (gg)
- charges $|Q_{lead}| > 1$ are suppressed (multiquark exchanges)

$\Rightarrow$ Results from LEP on Q_{lead} and M_{lead} from DELPHI, OPAL, ALEPH

rapidity gap analysis: leading charge Q_{lead}

gluon jet quark jet $\Delta y = 1.5$ DELPHI





excess $Q_{lead} = 0$ in gluon jet

vs. MC (JETSET), excess 5-10%

dependence on Δy

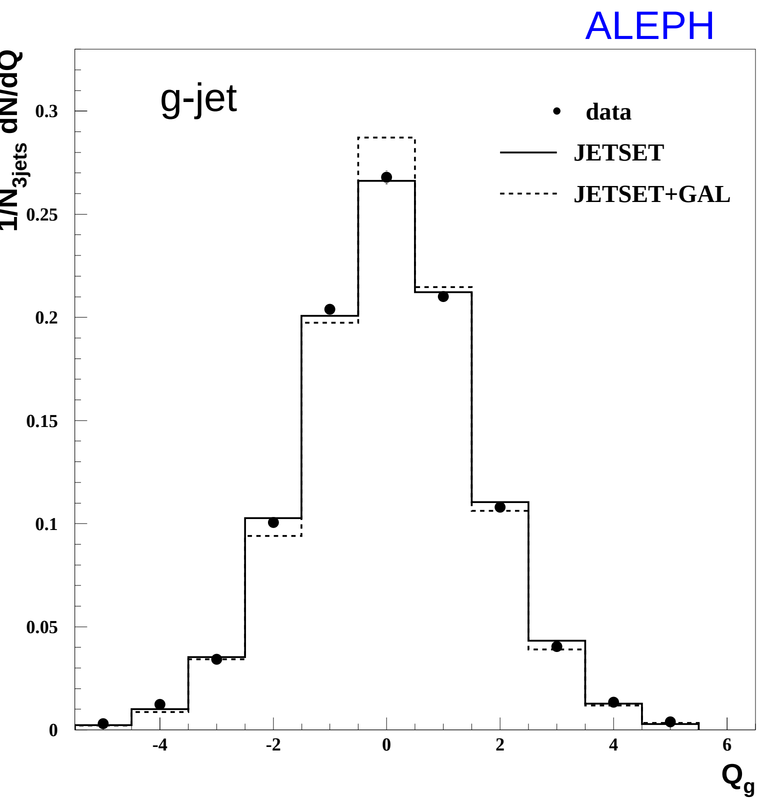
leading charge Q_{lead} in gluon jets

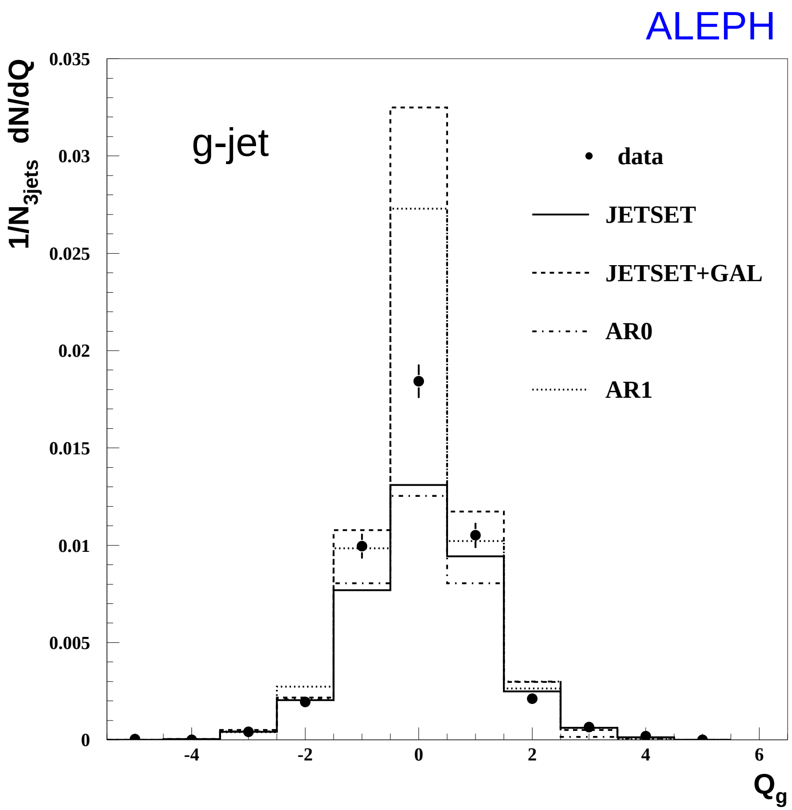
identified $b\bar{b}g$ events

ALEPH

gluon jet, no gap

gluon jet, with gap





JETSET ok

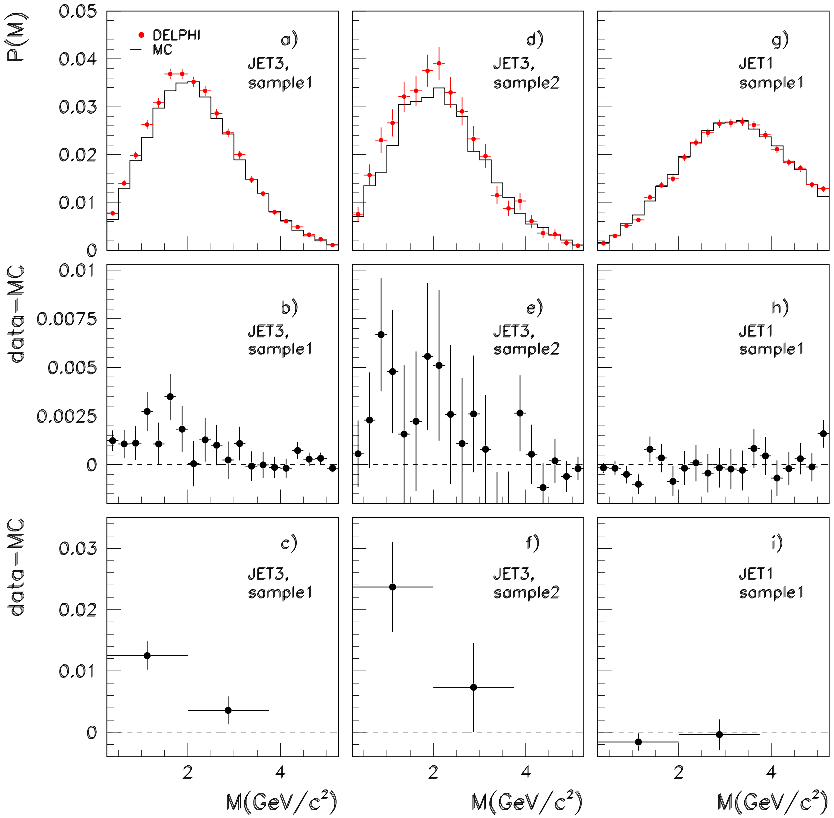
$Q_{lead} = 0$ excess of $\sim 40\%$ (JETSET)

(GAL, AR refer to color reconnection models)

rapidity gap analysis: cluster mass for $Q_{lead} = 0$

DELPHI

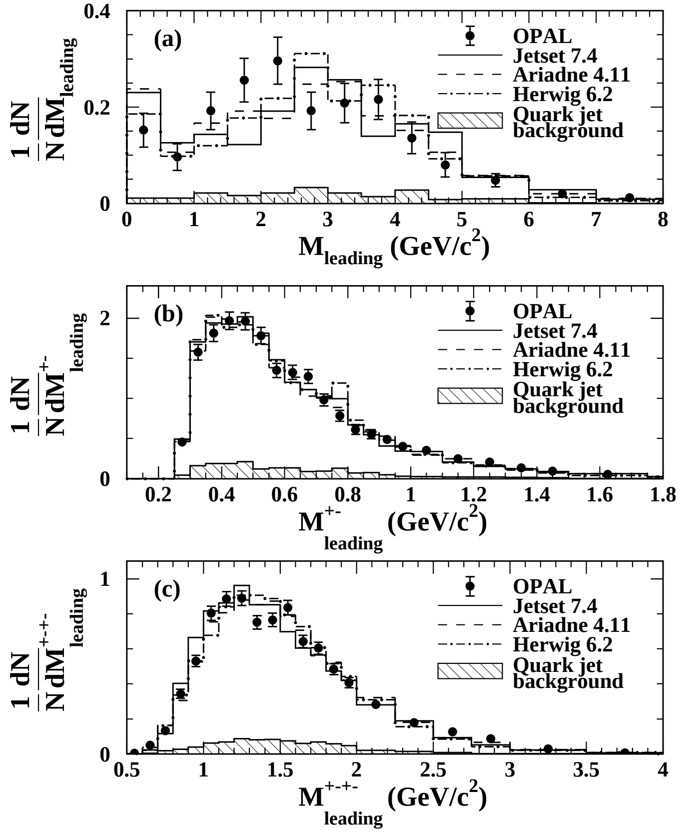
gluon jet   gluon jet   quark jet



charged + neutrals

OPAL

gluon jet



excess at mass < 2.5 GeV (2σ)

gluon jets: excess of low mass $M_{lead} < 3$ GeV

no ρ in $\pi^+\pi^-$, $f_0(1500)$ in 4π?

Advantages at LHC

- higher energy of gluon jets $\rightarrow$ larger rapidity gaps
- quark and gluon jets at comparable energies in the same experiment
- higher statistics

separation of gluon and quark jets at LHC

1. leading order processes

quark jets in γ + jet events ($qg \to \gamma q$)

gluon jets in di-jet events (at small x_T)

rates from pdf's and parton parton cross sections

		p_T	x_T	g in di-jet	q in $\gamma +$ jet
Tevatron (CDF)	1.8 TeV	50	0.056	60%	75 %
LHC (G& S)	7 TeV	200	0.057	60%	80 %
		50	0.014	75%	90 %
		800	0.229	25%	75%

J. Gallicchio and M.D. Schwartz, 4/2011

quark jets: an 80% purity is ok for the study of leading systems
(quarks fragment harder than gluons)

2. gluon bremsstrahlung

gluon jets: from 3 jet events with high purity (> 90 %)

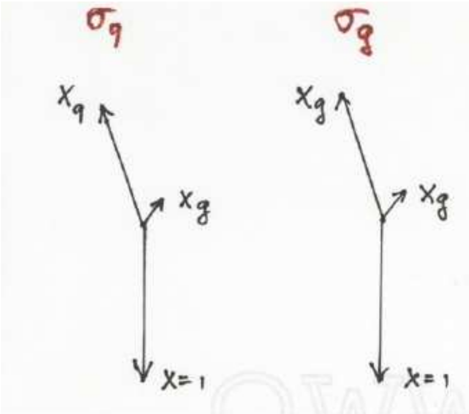
selection of gluon jets

⇒ trigger on total transverse energy

select 3 jet events: soft gluon jet from bremsstrahlung: qqg or ggg

production of low energy jet:

$$\frac{d\sigma}{dx_g dp_T^2} = \sigma_q \frac{\alpha_s}{2\pi p_T^2} P_{gq}(x_g) + \sigma_g \frac{\alpha_s}{2\pi p_T^2} P_{gg}(x_g)$$



fraction of gluon jets:

$$F_g(x_g) = \frac{\sigma_q P_{gq}(x_g) + \sigma_g P_{gg}(x_g)}{\sigma_q (P_{gq}(x_g) + P_{qq}(x_g)) + \sigma_g P_{gg}(x_g)} \qquad \left(P_{gq}(x_g) = \frac{4}{3}\frac{1+(1-x_g)^2}{x_g}, \ldots\right)$$

for $x_g \to 0$:

$$F_g(x_g) = \frac{1}{1+4x_g/(8+18R_g)}; \qquad R_g = \frac{\sigma_g}{\sigma_q}$$

examples: $x_g = 0.2;\ R_g = 1 \quad \Rightarrow F_g \approx 95\%$

$x_g = 0.5;\ R_g = 1 \quad \Rightarrow F_g \approx 85\%$

studies at LHC

1. Repeat rapidity gap studies at LEP in new environment:

   $\Rightarrow$ larger rapidity gaps ($\Delta y \sim 4$) (factor 10 in energy, $\ln 10 = 2.3$);
   $Q = 0, \pm 1$ closer to asymptotics;
   learn more about colour neutralization of gluon $P_3, \; P_8$

   $\Rightarrow$ mass peaks in $Q = 0$ system?
   problem: limited angular acceptance due to rapidity gap

2. alternative approach: resonance production directly

   $\Rightarrow$ mass spectra $M(\pi\pi), \; M(K\bar{K}), \; M(4\pi) \ldots$ in jets
   study their x-dependence in quark and gluon jets

   $\Rightarrow$ define reference x-distributions:
   "leading" (like $u \to \pi^+$) and "suppressed" (like $u \to \pi^-, \; g \to \pi$)

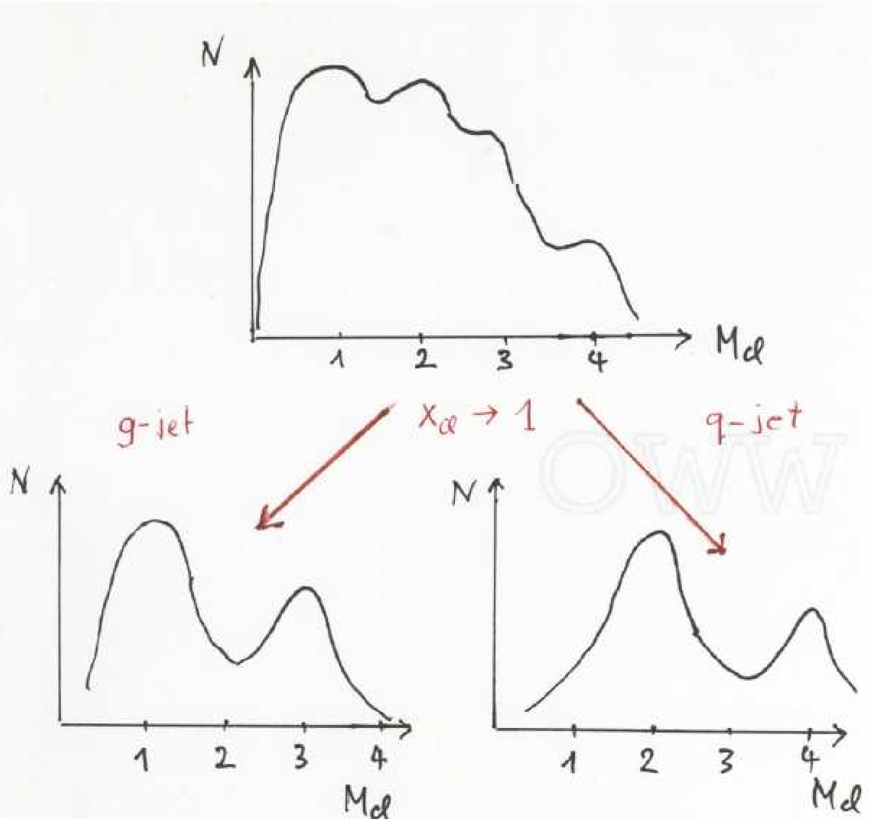
large x fragmentation

meson	quark jet	gluon jet	
		triplet neutr.	octet neutr.
$q\bar{q}: \{ref: \rho, f_2\}, f_0$	leading	suppressed	suppressed
$gb: f_0$	suppressed	suppressed	leading
$q\bar{q}: f_0$, strongly mixed	leading	suppressed	leading (?)
$4q: \sigma, f_0(980)$ (?)	suppressed	suppressed	suppressed

$x-$ dependent mass spectrum

cluster mass spectrum for

$x_{cluster}$ small (many combinations)



$x_{cluster}$ large (one or few combinations)

glueballs among isoscalars

cluster	scalar meson
$(\pi\pi)^0$	$f_0(600)/\sigma,\ f_0(980),\ f_0(1500)$
$(4\pi)^0$	$f_0(1370)(?),\ f_0(1500)$
$(K\bar{K})^0$	$f_0(980),\ f_0(1500)\ f_0(1710)$

Summary

- glueballs predicted in QCD since the very beginning
  no clear evidence yet

- new chance finding glueballs in gluon jets at LHC
  - large rapidity gaps - increased $Q_{lead} = 0$ excess
  - x-dependence of mass spectra in q and g jets

- important hints from LEP
  $\Rightarrow$ new fragmentation component beyond JETSET
  clear excess of $Q_{lead} = 0$ jets (up to 40%)
  not enough ρ?
  gluon jets may not be built from quark strings only