Recent results on particle production from OPAL.

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Studies of hadronisation properties in quark and gluon jets and in u,d,s jets.

All results are based on 4M hadronic Z^0 decay collected by OPAL between 1990 and 1995.

- π^0, η, K^0 and charged multiplicities in quark and gluon jets
- leading particle production in u,d,s jets
- charged multiplicities in u,d,s events

π^0, η, K^0 and charged multiplicities in quark and gluon jets

QCD predicts multiplicity enhancement in gluon jets independent of particle species.

Enhanced isoscalar meson (and possibly glueball) production is foreseen in gluon fragmentation models with octet colour neutralisation. (Peterson & Walsh)

L3 observed enhanced η production in 3-jet events.

Aleph: η/η' in 3-jet events, no confirmation.

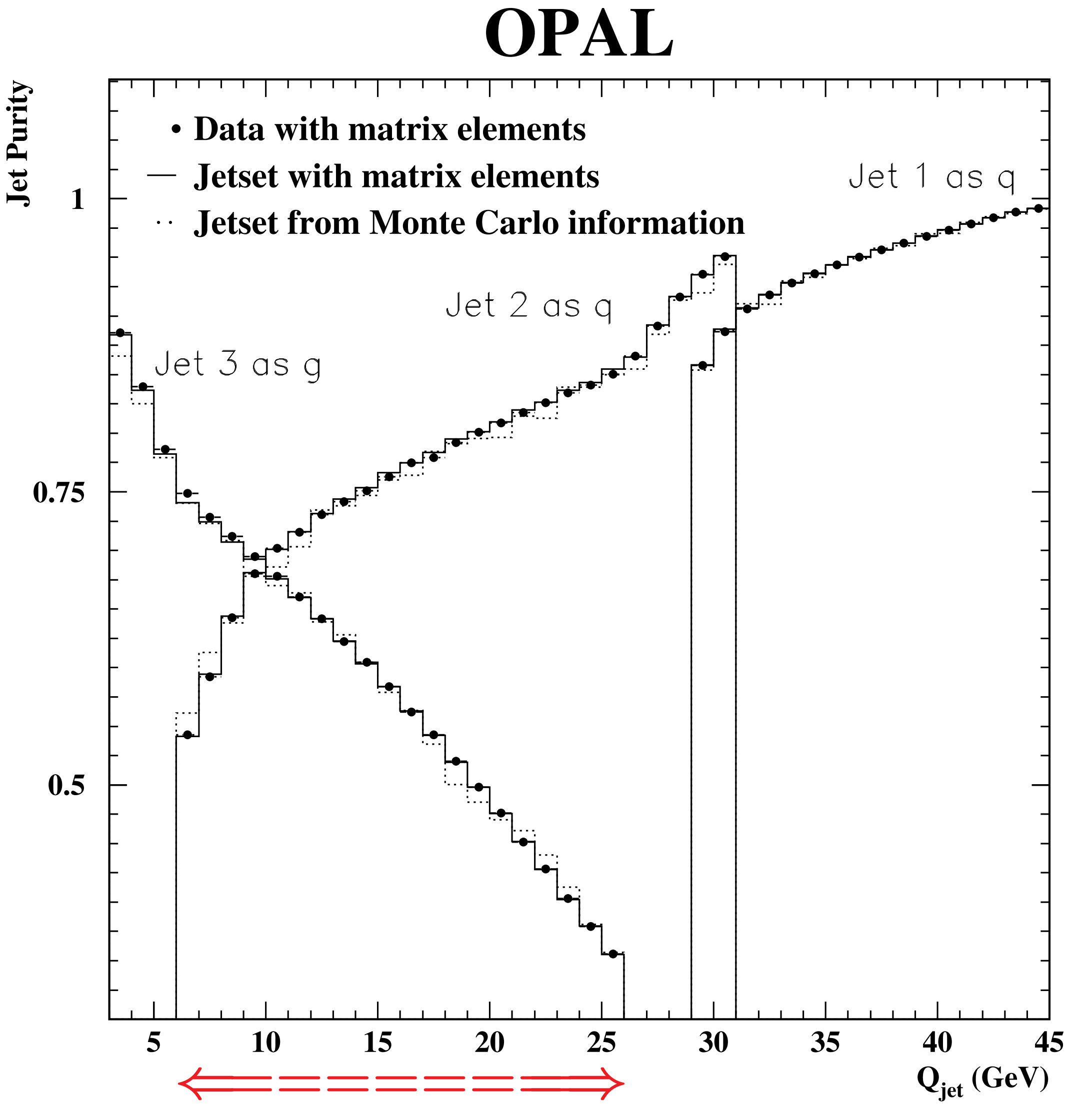
OPAL:
Use 493000 3-jet events to unfold multiplicity in pure quark and gluon jets

Particle selection:
$\pi^0 \longrightarrow \gamma\gamma$: invariant mass $\gamma\gamma$-pair,
$\eta \longrightarrow \gamma\gamma$: invariant mass $\gamma\gamma$-pair,
$K^0 \longrightarrow \pi^+\pi^-$: invariant mass oppositely charged tracks.

Unfolding of quark and gluon multiplicities

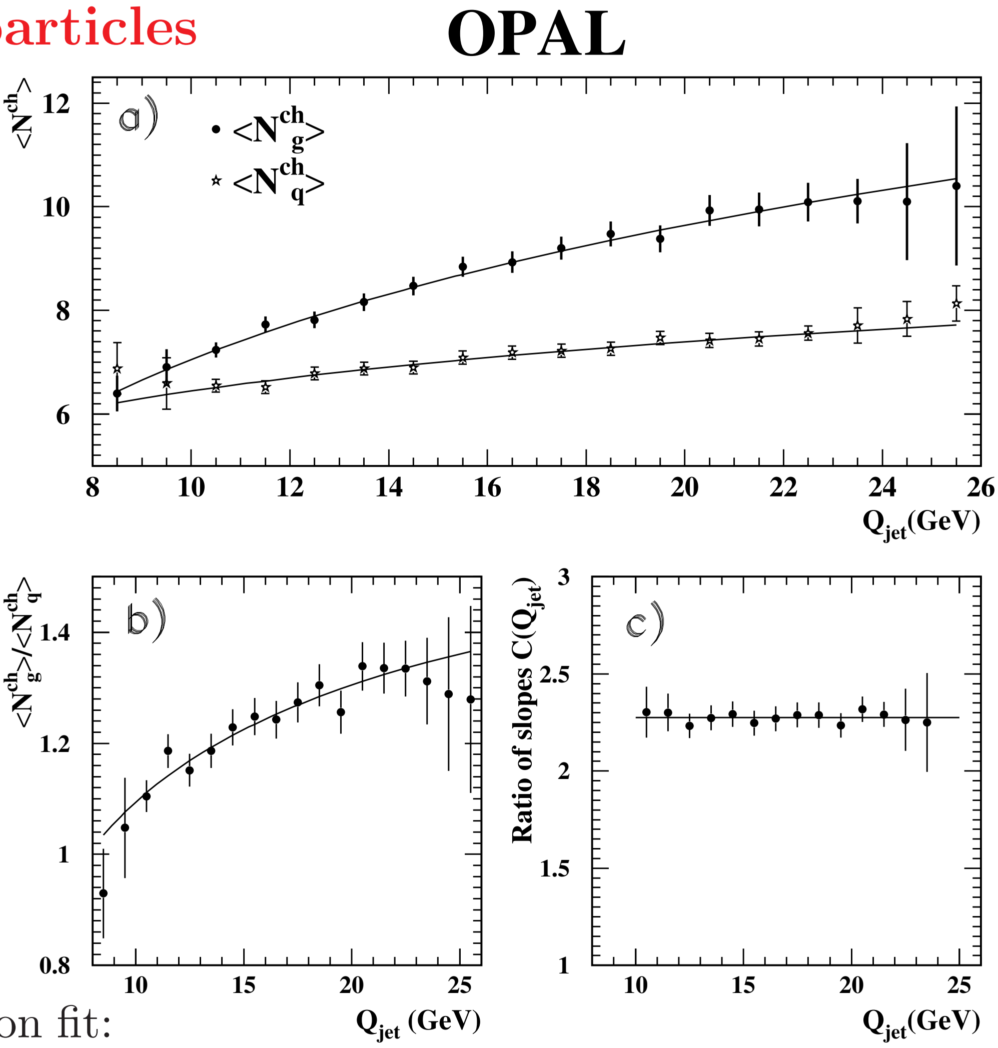
The jets are energy ordered: $\mathbf{E_{jet1} > E_{jet2} > E_{jet3}}$

Define hardness scale: $\mathbf{Q_{jet} \equiv E_{jet} \sin\frac{\theta}{2}}$ (θ w.r.t nearest jet) (Dokshitzer et al.)



For $\mathbf{6\,GeV} < \mathbf{Q_{jet}} < \mathbf{26\,GeV}$ the jet 2 and jet 3 samples have different quark/gluon purities.

Charged particles



Parametrisation fit:

$$\langle N_q(Q_{jet})\rangle = a_0 + a_1 \ln Q_{jet} + a_2(\ln Q_{jet})^2$$

$$\langle N_g(Q_{jet})\rangle = R_0 + R_1\langle N_q(Q_{jet})\rangle$$

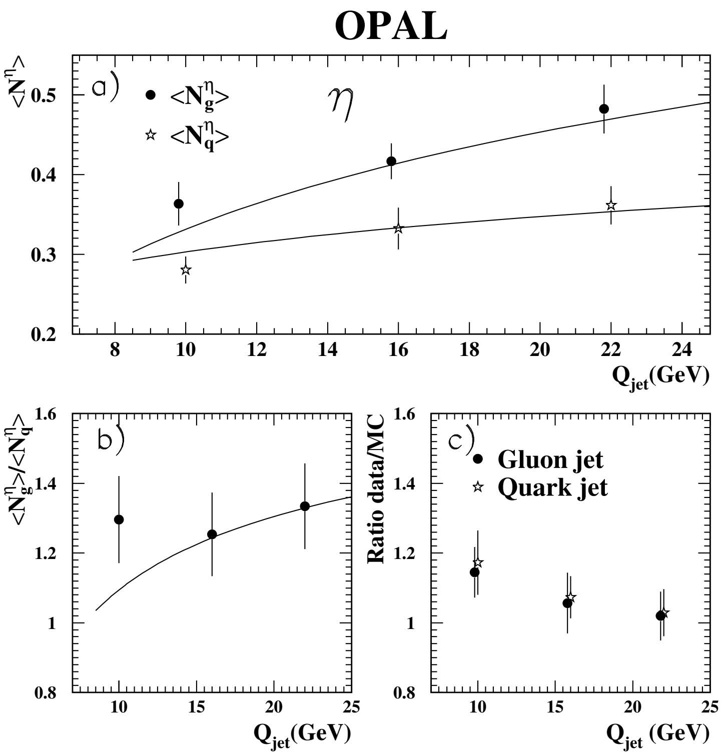
Theory: $\frac{\langle N_g\rangle}{\langle N_q\rangle} \rightarrow C_A/C_F = 2.25$ at large Q_{jet}

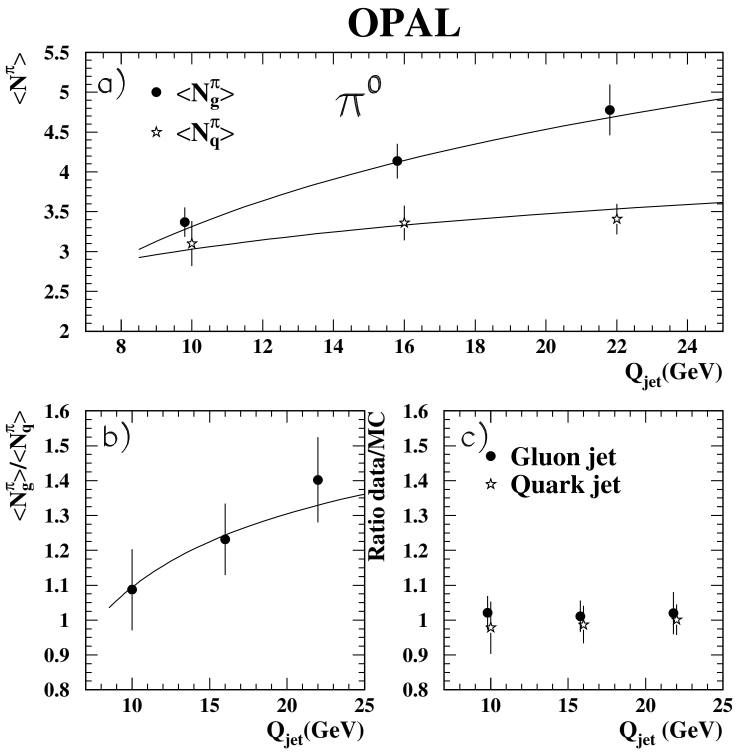
$C(Q_{jet}) = \frac{\mathrm{d}\langle N_g\rangle/\mathrm{d}Q_{jet}}{\mathrm{d}\langle N_q\rangle/\mathrm{d}Q_{jet}} \simeq 1.92$ (3NLO: Capella et al.)

OPAL: $\boldsymbol{C(Q_{jet}) = 2.27 \pm 0.07}$**(stat.)** $\boldsymbol{\pm\, 0.19}$**(syst.)**

π^0, η and K^0 results

Curves: fit to $\langle N^{ch}_{q,g} \rangle$ scaled by a single number



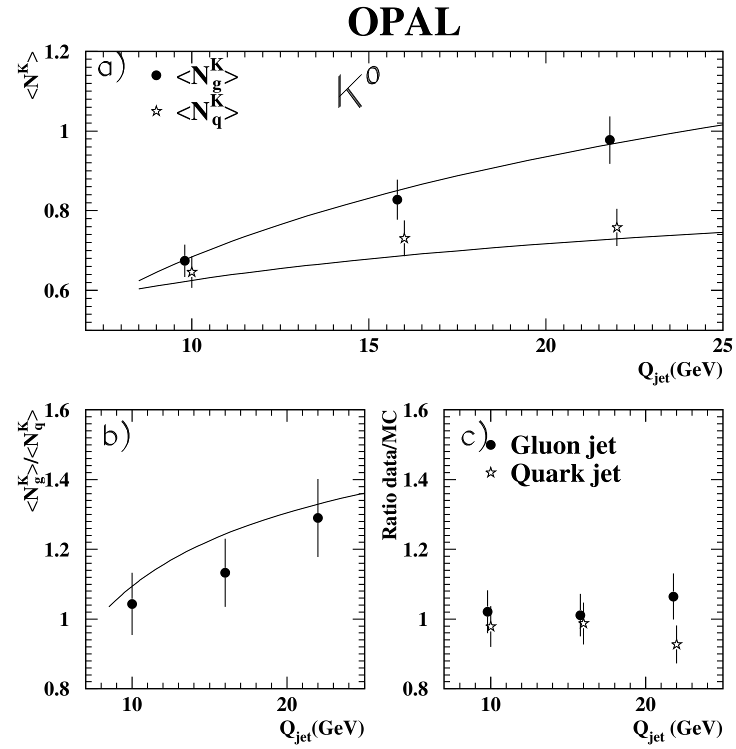


$$R'_i = \frac{N^i_g/N^i_q}{N^{ch}_g/N^{ch}_q}$$

$$R'_{\pi^0} = 1.013 \pm 0.017 \pm 0.040$$

$$R'_{\eta} = 1.088 \pm 0.079 \pm 0.086$$

$$R'_{K^0} = 0.947 \pm 0.014 \pm 0.039$$



Leading particle production in u,d,s jets

Leading particle effect: leading particles carry the flavour of the initial state quark. (Feynmann & Field)

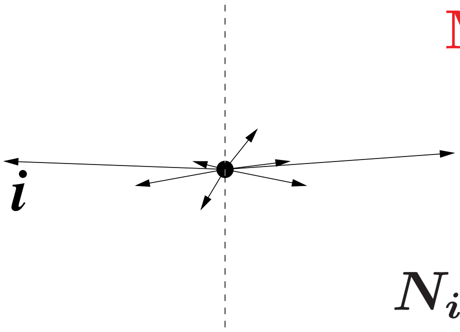
Well known from D and B meson production in heavy quark events.

Little experimental evidence for light quarks.

OPAL measurement of the rates $\eta_q^i(x_p > x_p^{min})$ for leading: $\pi^{\pm}, K^{\pm}, K_S^0, p(\bar{p})$ and $\Lambda(\bar{\Lambda})$ in u, d, s flavoured jets.

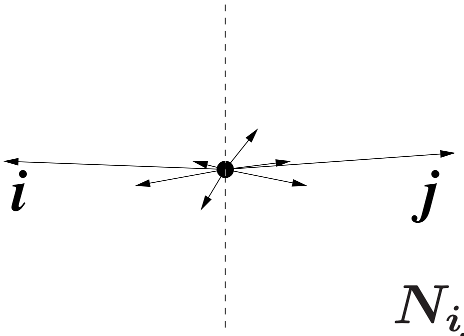
Detailed information on the hadronisation process.

Method: (Letts & Mättig)



$\boldsymbol{N_i}$: Single hemisphere tags

$$\boldsymbol{N_i/N_{had} = 2\sum_{flav.} \eta_q^i \, \mathrm{R}_q}$$



$\boldsymbol{N_{ij}}$: Double hemisphere tags

$$\boldsymbol{N_{ij}/N_{had} = (2-\delta_{ij})\sum_{flav.} \rho_{ij} \, \eta_q^i \, \eta_q^j \, \mathrm{R}_q}$$

$i, j = \pi^\pm, K^\pm, K_S^0, p(\bar{p}), \Lambda(\bar{\Lambda}), (e^\pm, \mu^\pm, D^{*\pm})$

R_q: Z^0 branching fraction q

ρ_{ij}: correction for hemisphere correlation (close to 1)

Extra constraints:
(isospin symmetry & flavour independence)

$$\boldsymbol{\eta_d^{\pi^\pm} = \eta_u^{\pi^\pm}, \; \eta_d^{e^\pm} = \eta_u^{e^\pm}, \; \eta_d^{\Lambda(\bar{\Lambda})} = \eta_u^{\Lambda(\bar{\Lambda})}, \; \eta_s^{K^\pm} = \eta_s^{K^0}}$$

54 equations, 41 unknowns

particle identification

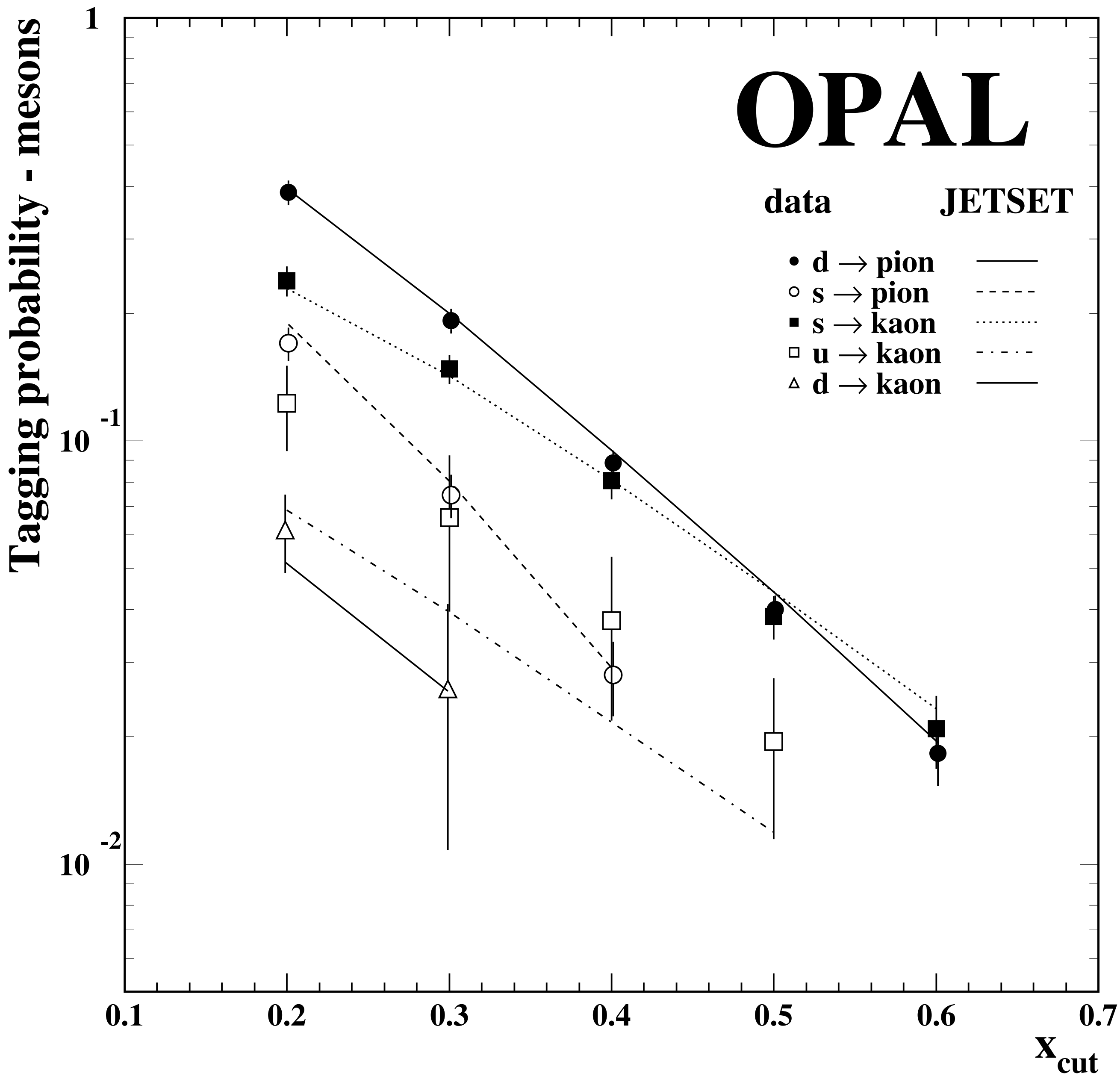
- $\pi^\pm$, $K^\pm$, p: $\mathrm{d}E/\mathrm{d}x$
- $e^\pm$, $\mu^\pm$: $\mathrm{d}E/\mathrm{d}x$, EM calorimeter and μ-chambers.
- $K^0_s \to \pi^+\pi^-$, $\Lambda \to p\pi^-$: Invariant mass oppositely charged tracks
- $D^* \to D^0\,\pi^+\ (D^0 \to K\pi, K\pi\pi\pi, Ke\nu_e, K\mu\nu_\mu)$
- b events are tagged by a secondary vertex

$\eta^{\mu}_{u,d,s}$, $\eta^{D^*}_{u,d,s}$ and $\eta^{b-\mathrm{tag}}_{u,d,s}$ are set to JETSET values.

Results ($x_p^{min} = 0.2$) $\Rightarrow$ more than 3σ off

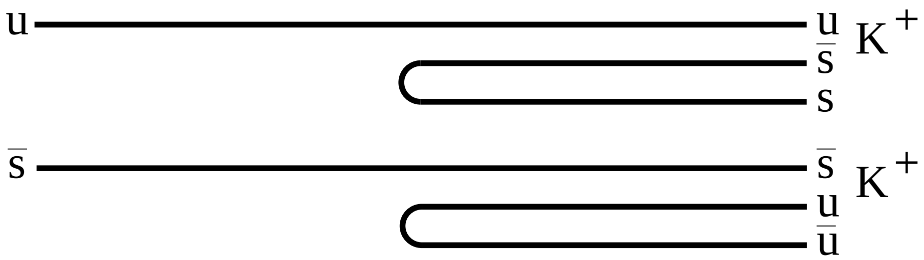
	OPAL data	JETSET	HERWIG
$\eta_d^{\pi^\pm}$	0.3866 ± 0.0027 ± 0.0257	0.3926	0.3558
$\eta_u^{\pi^\pm}$	0.3831 ± 0.0026 ± 0.0256	0.3891	0.3558
$\eta_s^{\pi^\pm}$	0.1701 ± 0.0062 ± 0.0139	0.1884	$\Rightarrow$0.1367
$\eta_c^{\pi^\pm}$	0.1728 ± 0.0097 ± 0.0186	0.1508	0.1480
$\eta_b^{\pi^\pm}$	0.1350 ± 0.0020 ± 0.0093	0.1226	$\Rightarrow$0.1129
$\eta_d^{K^\pm}$	0.0617 ± 0.0102 ± 0.0080	0.0517	0.0451
$\eta_u^{K^\pm}$	0.1227 ± 0.0136 ± 0.0244	0.0687	0.0703
$\eta_s^{K^\pm}$	0.2390 ± 0.0056 ± 0.0187	0.2294	0.2300
$\eta_c^{K^\pm}$	0.0952 ± 0.0100 ± 0.0208	0.1123	0.1107
$\eta_b^{K^\pm}$	0.0623 ± 0.0017 ± 0.0066	0.0530	$\Rightarrow$0.0464
η_d^{p}	0.0362 ± 0.0063 ± 0.0075	0.0356	$\Rightarrow$0.0795
η_u^{p}	0.0569 ± 0.0086 ± 0.0109	0.0666	$\Rightarrow$0.0913
η_s^{p}	0.0328 ± 0.0042 ± 0.0084	0.0232	0.0319
η_c^{p}	0.0246 ± 0.0058 ± 0.0071	0.0266	0.0334
η_b^{p}	0.0232 ± 0.0010 ± 0.0045	0.0253	0.0199
$\eta_d^{K_S^0}$	0.0461 ± 0.0087 ± 0.0061	0.0350	0.0345
$\eta_u^{K_S^0}$	0.0228 ± 0.0107 ± 0.0100	0.0251	0.0229
$\eta_s^{K_S^0}$	0.1210 ± 0.0028 ± 0.0096	0.1161	0.1160
$\eta_c^{K_S^0}$	0.0586 ± 0.0072 ± 0.0132	0.0457	0.0505
$\eta_b^{K_S^0}$	0.0273 ± 0.0012 ± 0.0022	0.0226	$\Rightarrow$0.0195
η_d^{Λ}	0.0231 ± 0.0025 ± 0.0020	0.0172	$\Rightarrow$0.0566
η_u^{Λ}	0.0211 ± 0.0023 ± 0.0020	0.0158	$\Rightarrow$0.0542
η_s^{Λ}	0.0493 ± 0.0046 ± 0.0041	0.0607	$\Rightarrow$0.1325
η_c^{Λ}	0.0295 ± 0.0075 ± 0.0063	0.0251	0.0480
η_b^{Λ}	0.0180 ± 0.0009 ± 0.0014	0.0182	0.0170

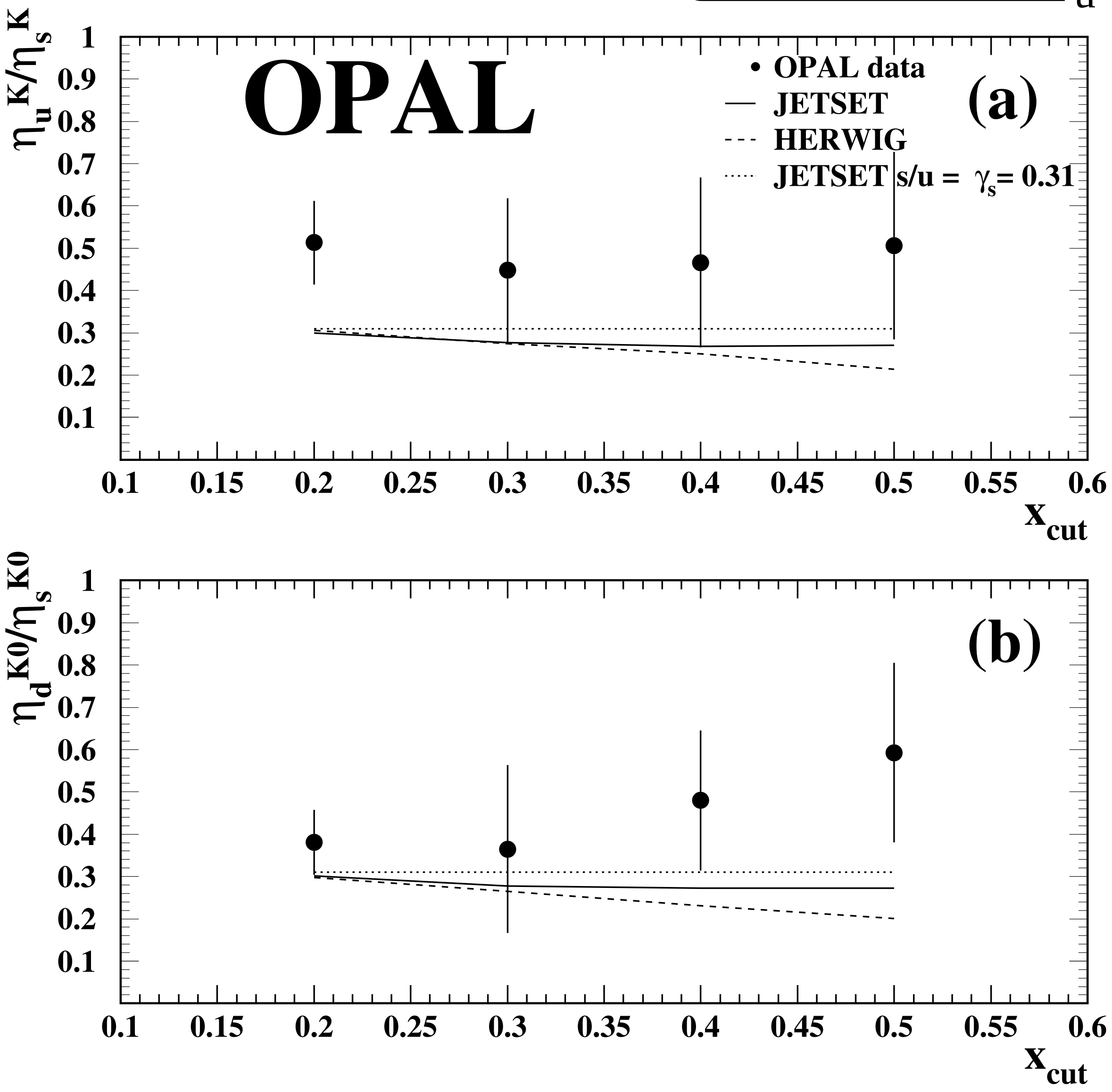
$\pi^{\pm}$ and $K^{\pm}$ rates in u,d,s jets



The leading particle effect is clearly observed.

Strangeness suppression factor



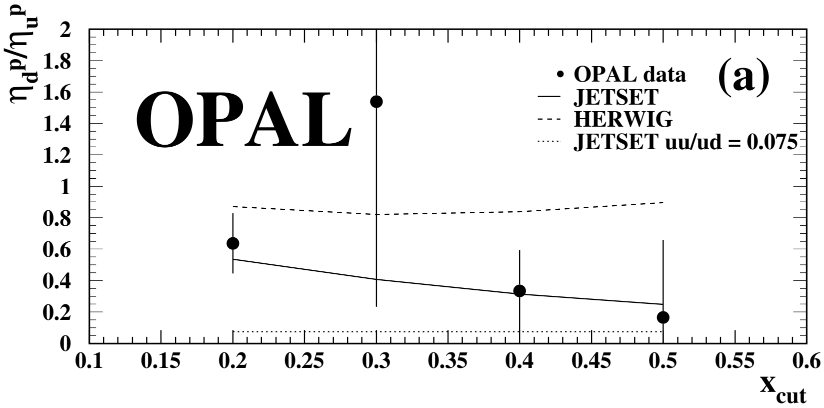


OPAL: $\gamma_s = 0.422 \pm 0.049$(stat.) $\pm\, 0.059$(syst.)

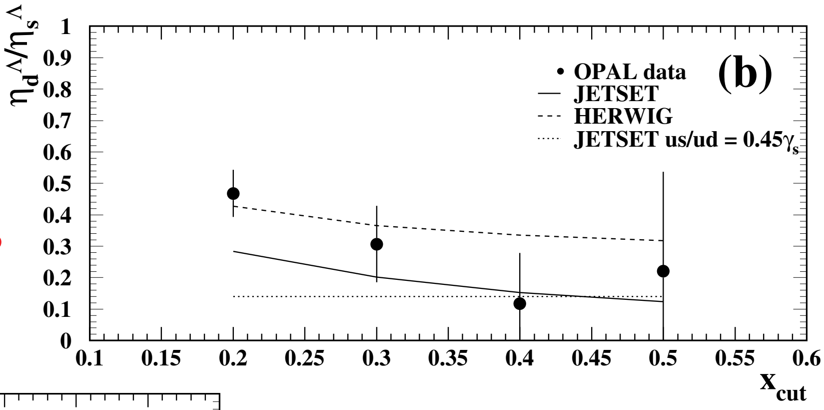
(SLD: $\gamma_s = 0.26 \pm 0.12$, indirect measurements: ~ 0.3)

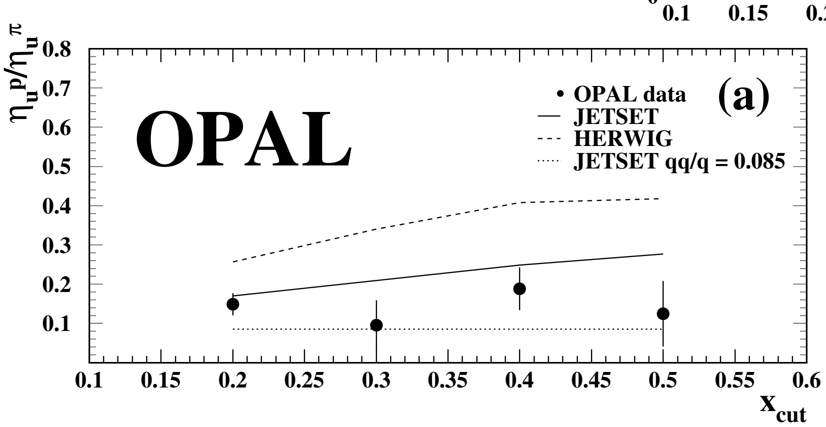
Other results

$\eta_d^p/\eta_u^p \;\rightarrow\; uu/ud$
relative rate of
spin 1 diquarks

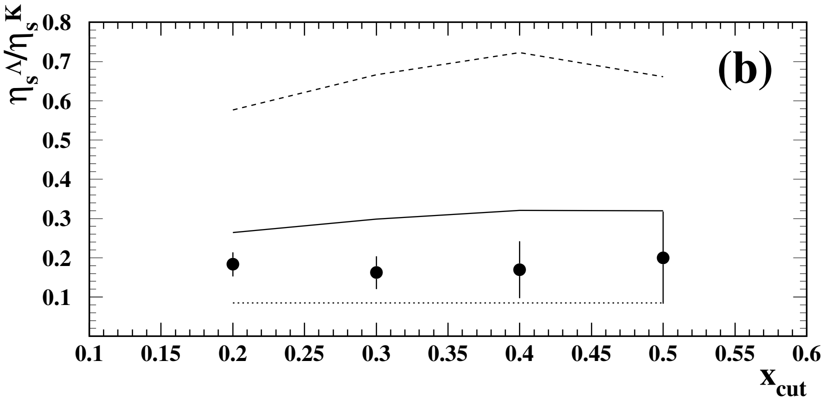


$\eta_d^\Lambda/\eta_s^\Lambda \;\rightarrow\; us/ud$
extra strangeness
suppression diquarks





$\eta_u^p/\eta_u^\pi \;\rightarrow\; qq/q$
relative diquark rate



$\eta_s^\Lambda/\eta_s^K \;\rightarrow\; qq/q$
relative diquark rate

Charged particle multiplicity in u,d,s events

Test the flavour independence of the strong interaction.

Multiplicities in light quarks are expected to be identical, with only small corrections due to hadronic decays.

JETSET prediction:
$\langle n_u \rangle = 20.097 \pm 0.005$
$\langle n_d \rangle = 19.987 \pm 0.005$
$\langle n_s \rangle = 19.897 \pm 0.005$
$\langle n_c \rangle = 21.387 \pm 0.005$
$\langle n_b \rangle = 23.725 \pm 0.005$

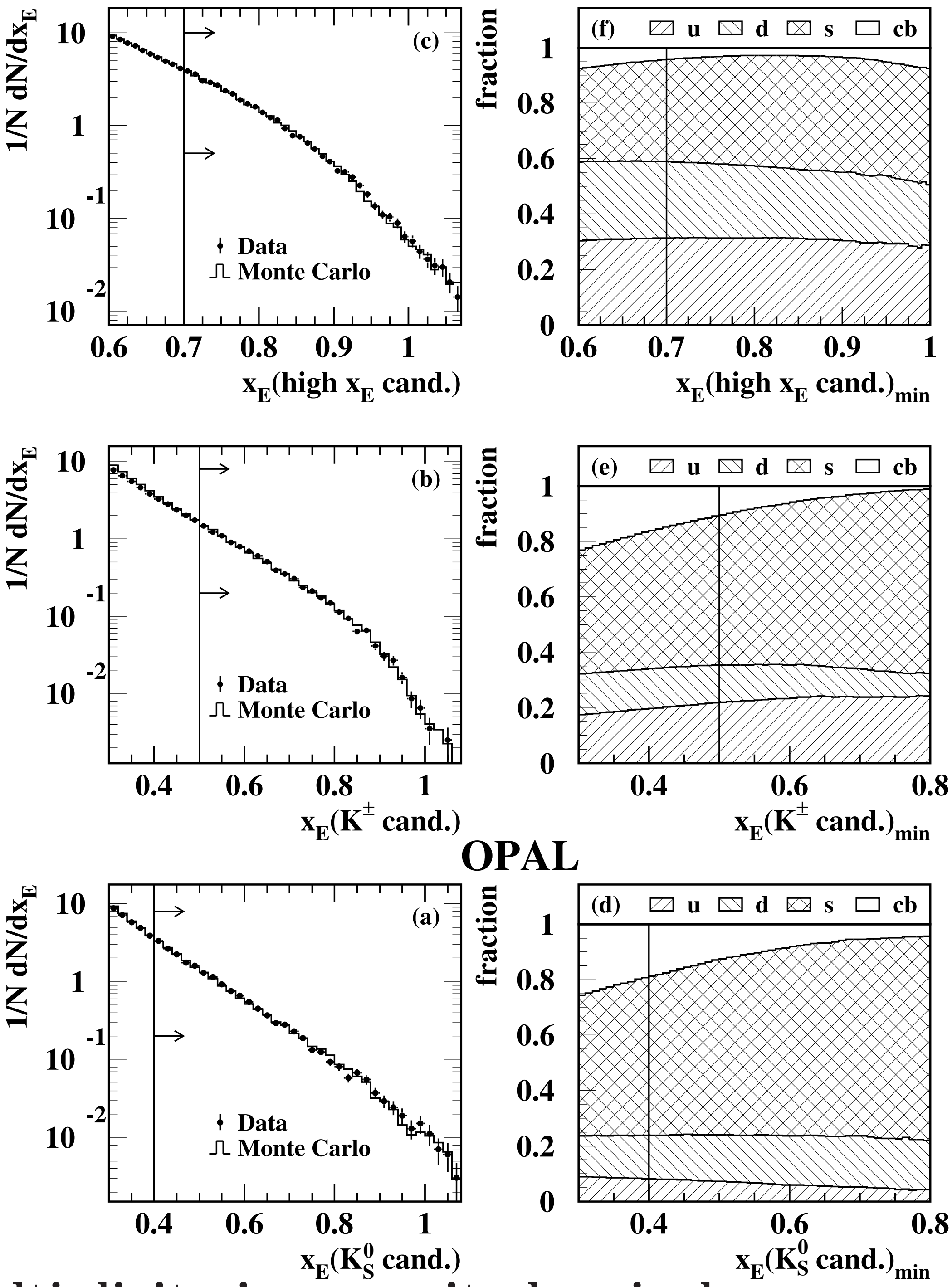
We exploit the leading particle effect to unfold multiplicity for u,d,s jets

3 samples with tagged leading particle

high x_E charged particle

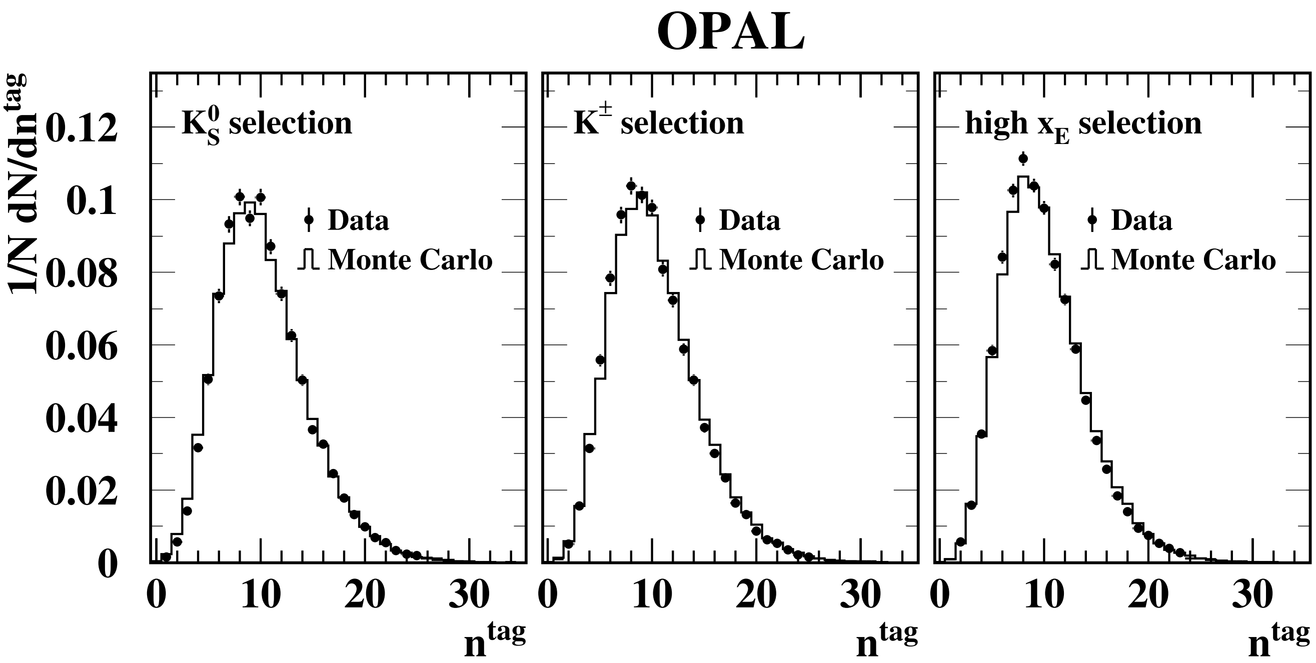
$K^\pm$ (dE/dx)

$K_s^0 \to \pi^+\pi^-$



Measure multiplicity in opposite hemisphere.

Results



$$\langle n_u \rangle = 17.77 \pm 0.51\,(\text{stat.})\,^{+0.86}_{-1.20}\,(\text{syst.})$$

$$\langle n_d \rangle = 21.44 \pm 0.63\,(\text{stat.})\,^{+1.46}_{-1.17}\,(\text{syst.})$$

$$\langle n_s \rangle = 20.02 \pm 0.13\,(\text{stat.})\,^{+0.39}_{-0.37}\,(\text{syst.})$$

Note: $\langle n_u \rangle$ **and** $\langle n_d \rangle$ **strongly anti-correlated.**

$$\frac{\langle n_u \rangle}{\langle n_d \rangle} = 0.829 \pm 0.047\,(\text{stat.})\,^{+0.081}_{-0.109}\,(\text{syst.})$$

$$\frac{\langle n_s \rangle}{\langle n_d \rangle} = 0.934 \pm 0.030\,(\text{stat.})\,^{+0.062}_{-0.089}\,(\text{syst.})$$

$$\frac{\langle n_s \rangle}{\langle n_u \rangle} = 1.127 \pm 0.033\,(\text{stat.})\,^{+0.057}_{-0.077}\,(\text{syst.})$$

Agrees with expectation flavour independence.

Summary results

π^0, η and K^0 in quark & gluon jets:

- confirm multiplicity ratios are independent of studied particle species,
- no confirmation of (extra) η enhancement observed by L3.

Leading particles in u,d,s jets:

- leading particle effect confirmed in light quarks,
- $\gamma_s = 0.422 \pm 0.049(\text{stat.}) \pm 0.059(\text{syst.})$,
- direct check on other hadronisation properties, JETSET ok, HERWIG problem with baryon yields,
- measured η_q^i can be used to determine flavour composition in decays other than Z_0.

Charged particle multiplicity in u,d,s events:

- results agree with expectation from flavour independence.