Fragmentation of Quarks and Gluons

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Contents:

- 1) Multiplicity
- 2) Quark and Gluon Jets
- 3) Properties of Identified Particles

Contributed Abstracts

- DELPHI-Collaboration :
 - ABS231** Charged particle multiplicity in e^+e^- annihilations into $q\bar{q}$ at $\sqrt{s} = 206$ GeV
 - ABS232** Hadronization properties of b quarks compared to light quarks in e^+e^- annihilations into $q\bar{q}$ at $\sqrt{s} = 206$ GeV
 - ABS247** Topology dependence of the charged multiplicity in hadronic three jet events
 - ABS233** Study of the charge of leading hadrons in gluon and quark fragmentation
- CDF-Collaboration :
 - ABS359** Gluon and quark jet fragmentation at CDF
- OPAL-Collaboration :
 - ABS577** Measurement of the scaling violations of the quark and gluon fragmentation functions
- SLD-Collaboration :
 - ABS970** Production of charged $\pi^\pm$, $K^\pm$ and $p/\bar{p}$ in hadronic Z^0 decays
 - ABS971** A study of correlations between identified charged hadrons in hadronic Z^0 decays
- H1-Collaboration :
 - ABS1002** The photoproduction of Protons at HERA
 - ABS1015** Inclusive D -meson production in DIS at HERA

The most obvious result of fragmentation:
A final state
with a large number
of hadronic particles

N_{ch} in e^+e^- -annihilation at 206GeV (DELPHI)

- In 2000 DELPHI collected 164pb^{-1} with $\langle\sqrt{s}\rangle = 206\text{GeV}$
- DELPHI: measurement of N_{ch} from integrated ξ_E -distribution $\xi_E = -\log\left(\frac{E}{\sqrt{s}/2}\right)$
 - Main BG: ISR $\longrightarrow \sqrt{s'} > 0.9 \cdot \sqrt{s}$
 - ZZ, WW $\longrightarrow$ Narrow Jet Broadening < 0.065
 - $\longrightarrow$ **3047 events** (BG: 682 expected, mainly WW)
- Results:
 - $N_{ch}(206\text{GeV}) = 28.03 \pm 0.22 \pm 0.27$
 - $D(206\text{GeV}) = 8.97 \pm 0.16 \pm 0.13$
 - $\xi_p^*(206\text{GeV}) = 4.21 \pm 0.04 \pm 0.02$
- Main sources for systematic errors: Calibration factor , acceptance correction

N_{ch} in e^+e^- -annihilation at 206 GeV (DELPHI)

Energy development

KNO-scaling

Koba-Nielsen-Olesen scaling:

$$\frac{\langle N_{ch} \rangle}{D} = \text{const.}$$

Expectations fulfilled up to 206 GeV

NLLA:

$$N_{ch}(\sqrt{s}) = a[\alpha_s(\sqrt{s})]^b \cdot e^{c/\sqrt{\alpha_s(\sqrt{s})}} (1 + \mathcal{O}(\sqrt{\alpha_s}))$$

3 jet Events in e^+e^- annihilation (DELPHI)

- N_{ch} in dependence of **event-topology** at $\sqrt{s} = M_Z$
- Variation in energy scales of **quark** and **gluon** jets due to variation in topology
- Prediction for 3 jet multiplicity (P.Eden et al.)

$$N_{q\bar{q}g} = N_{q\bar{q}}(L, \kappa) + \frac{1}{2}N_{gg}(\kappa)$$

L : **Quark** scale, κ : **Gluon** (p_t -like) scale

- **Coherence effects** are taken into account by choice of scales
- Phase-space restriction in $q\bar{q}$ -system due to **gluon** jet $\rightarrow N_{q\bar{q}}$ depends on κ

$$\frac{dN_{gg}}{dL}(L + c_g - c_q) = \frac{C_A}{C_F} \frac{dN_{q\bar{q}}}{dL}(L) \quad \left(1 + \frac{\alpha_0 c_r}{L}\right)$$

- $N_{q\bar{q}}$ measured before, constant of integration fixed by measurement of N_{gg}
- **Prediction of $N_{q\bar{q}g}$ dependent on $\frac{C_A}{C_F}$**

3 jet Events in e^+e^- annihilation (DELPHI)

- Scales function of θ_1, θ_3
- **Two formulations** of prediction
- Different definitions of **gluon**-contribution

A :

$$s_{q\bar{q}} \rightarrow L$$

$$\frac{s_{qg}s_{\bar{q}g}}{s_{q\bar{q}}} \rightarrow \kappa$$

B :

$$s \rightarrow L$$

$$\frac{s_{qg}s_{\bar{q}g}}{s} \rightarrow \kappa$$

3 jet Events in e^+e^- annihilation (DELPHI)

- $N_{q\bar{q}g}$ as function of (θ_1, θ_3)
- Fit of C_A/C_F to data
- No b -tagging applied, δ_{lb} constant, **additional offset** N_0 fitted.
- Two formulations of prediction, different choice of scales
- (prel.) Result:

$$\frac{C_A}{C_F} = 2.277 \pm 0.02 \pm 0.05 \quad (a)$$

$$\frac{C_A}{C_F} = 2.093 \pm 0.05 \pm 0.08 \quad (b)$$

in agreement with $SU(3)_C$

3 jet Events in e^+e^- annihilation (DELPHI)

- Measurement of N_{gg} possible:

$$N_{gg} = 2 [N_{q\bar{q}g} - N_{q\bar{q}} - N_0]$$

- N_{gg} extracted for effective $E_{cm} = 16 \dots 52 \text{ GeV}$
- Two used formulations of the prediction with different gluon scale
→ different energy ranges
- Good agreement with previous measurement and prediction (line)

II A Closer Look at the Final State

Leading Systems and Identified Particles

Colour Octet Neutralisation (DELPHI)

- Colour blanching in **gluon** jets possible via triplet and **octet neutralisation**
- Colour octet neutralisation necessary for **bound gluonic states** (glueballs)
- Signature: Surplus on neutral leading particles in **gluon** jets
- DELPHI: analysis of 3 jet events:
 - Most energetic jet $\rightarrow$ **quark** jet ($\sim 90\%$)
 - Least energetic jet $\rightarrow$ **gluon** jet ($\sim 70\%$)
- Leading system of a jet defined by particles with $y > 2$ and no particles with $0 < y < 2$
- Summed charges of leadings systems: Comparison with MC-Model **without octett neutralisation**

Colour Octet Neutralisation (DELPHI)

Leading systems: Sum of charges

Gluon enriched
Surplus of neutral leading systems

Quark enriched
Agreement with simulation

Mass Spectra of Leading Systems (DELPHI)

Quark sample:
no deviations from simulation

Gluon sample:
only deviations with little
significance
But: Surplus concentrated at
small masses

Identified π , K and p in e^+e^- Annihilation (SLD)

- Identified π , K and p in hadronic Z -decays
- Identification via SLD's RICH detector (CRID)
- Measured positions ξ^* of the maxima of the ξ -distributions:

$$\xi_{\pi}^* = 3.77 \pm 0.01 \pm 0.02$$

$$\xi_K^* = 2.63 \pm 0.01 \pm 0.03$$

$$\xi_p^* = 2.94 \pm 0.02 \pm 0.06$$

- Only $Z \rightarrow u\bar{u}/d\bar{d}/s\bar{s}$ due to veto against secondary vertices
- Polarized e^- beams and a large asymmetry of the Z :
 - Determination of the direction of the quark and the anti-quark possible
 - Hemisphere purity 73%

Identified π , K and p in e^+e^- Annihilation (SLD)

- Scaled momentum distribution in **quark direction**
- Charge conjugate in anti-**quark** direction included
- **Leading particle effect** in p and K distribution
- More protons and K^- at high x_p than c.c.
- Smaller surplus of π^- w.r.t. π^+

Identified π , K and p in e^+e^- Annihilation (SLD)

- Protons: $D_p > 0$ for high x , **leading particle** with only valence **quarks**
- π : $D_\pi \sim 0.27$ expected for uniform π -production
- instead: compatible with $0.27 \cdot D_p$
- $D_K > 0$ for high x
- **Evidence for leading particle production**

π , K and p : Correlations (SLD)

- Correlation studies
- Rapidity y signed due to **quark** direction
- $\Delta y^{+-} = y(h^+) - y(h^-)$
- Asymmetries in Δy^{+-} -distribution:
→ **particle ordering** along event-axis
- Proton: Positive asymmetry at low Δy^{+-}
→ **leading baryon** with **local** N_B -conservation (baryon number ordering)
- Kaon: Negative asymmetry at high Δy^{+-}
→ **leading Kaon production** in $s\bar{s}$ -events

π , K and p : Correlations (SLD)

- Correlations between unlike particles
- Kaon-related asymmetries probably due to leading Kaons
- **Discrepancy** between data and simulation for $p - \pi$ pairs

Reconstructed D -Mesons in DIS (H1)

- Production of D -Mesons in DIS $\rightarrow$ Test of the **universality of fragmentation**
- H1: reconstruction of (charge conj. incl.)
 - $D^+ \rightarrow K^- \pi^+ \pi^+$
 - $D^0 \rightarrow K^- \pi^+$
 - $D_s^+ \rightarrow \phi \pi^+ \rightarrow (K^+ K^-) \pi^+$
 - $D^{*+} \rightarrow D^0 \pi^+ \rightarrow (K^- \pi^+) \pi^+$
- Kinematic range given by $2\text{GeV}^2 \leq Q^2 \leq 100\text{GeV}^2$, $0.05 \leq y \leq 0.7$,
 $p_t(D) \geq 2.5\text{GeV}/c$ and $|\eta(D)| \leq 1.5$

	D^+	D^0	D_s^+	D^{*+}
$\sigma_{\text{vis}}(ep \rightarrow eDX)(nb)$	2.16	6.53	1.67	2.90
stat. error	± 0.19	± 0.49	± 0.41	± 0.20
syst. error	+0.46 -0.35	+1.06 -1.30	+0.54 -0.54	+0.58 -0.44

Reconstructed D -Mesons in DIS (H1)

- Differential cross-sections for D^+
- **Good agreement** with LO simulation
- Fragmentation factors of c have been deduced
- The fraction of produced vector mesons (VM) has been deduced

$$P_V = \frac{VM}{PS + VM}$$

- $P_V = 0.693 \pm 0.045 \pm 0.004 \pm 0.009$
 $P_V = 0.613 \pm 0.061 \pm 0.033 \pm 0.008$
 (two approaches)
- In **agreement** with w.a. (e^+e^-)-value
 0.601 ± 0.032

Photoproduction of protons in ep (H1)

- **Photoproduction**: quasi-real photon ($Q^2 < 0.01 \text{ GeV}^2$)
- $0.3 < y < 0.7$
- **Proton ID** by specific energy loss dE/dx
- Good agreement with simulation for $P(qq/q) = 0.05$
- $P(qq/q) = 0.1$ found in e^+e^- analyses

Summary

- The charged multiplicity in e^+e^- has been measured at 206GeV
- The **quark** and **gluon** contributions in 3 jet multiplicities have been studied, C_A/C_F and N_{gg} have been determined.
- Surplus of neutral leading systems of **gluon** jets indicate possible colour octet neutralisation
- Identified particles in Z -decays show leading particle effects and local baryon number conservation
- Cross section for D -production in DIS have been measured and the fragmentation factors and P_V have been derived
- The photoproduction of protons in DIS prefers a low di**quark** production fraction