Lecture:

Standard Model of Particle Physics

Heidelberg SS 2016

QCD Tests

Contents

- General Concepts
- QCD jets & jet algorithm
- Measurement of alpha$_s$
- Measurement of Quark and Gluon Spins
- Measurement of Color Factors

Intermezzo QCD

QCD Lagrangian (physical fields)

$$L_{phys} = -\frac{1}{4}F^{\alpha}{}_{\mu\nu}(x)F_{\alpha}{}^{\mu\nu}(x) + \sum_k \frac{i}{2}(\bar{q}_k(x)\gamma^{\mu}\nabla_{\mu}q_k(x) - \nabla_{\mu}\bar{q}_k(x)\gamma^{\mu}q_k(x)) \ .$$

vector coupling

Covariant derivative:

$$\nabla_{\mu}q(x) = \partial_{\mu}q(x) - i\,g\,G^{\alpha}_{\mu}(x)\hat{t}_{\alpha}q(x) \ ;$$

SU(3) group generators

Gluon field: non-abelian coupling

$$F^{\alpha}_{\mu\nu}(x) = \partial_{\mu}G^{\alpha}_{\nu}(x) - \partial_{\nu}G^{\alpha}_{\mu}(x) + g\,f^{\alpha}_{\beta\gamma}G^{\beta}_{\mu}(x)G^{\gamma}_{\nu}(x) \ ;$$

SU(3) structure constants

self coupling

SU(3) Group Representation

color states $r = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ $g = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$ $b = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

8 generators (N*N-1)

$$t_1 = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad t_2 = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad t_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$t_4 = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \quad t_5 = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix} \quad t_6 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$$t_7 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix} \quad t_8 = \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

Three-Jet Event at PETRA

Reaction:

$$e^+ e^- \rightarrow q \bar{q} g$$

- Hard gluon emission
  - calculable in pQCD
  - event topology
- Soft gluon emissions
  - parton showers (non-pQCD)
  - high particle multiplicities
  - collinear emissions makes “jet” structure
- Hadronisation
  - long distance scale
  - formation of hadrons from quarks and gluons

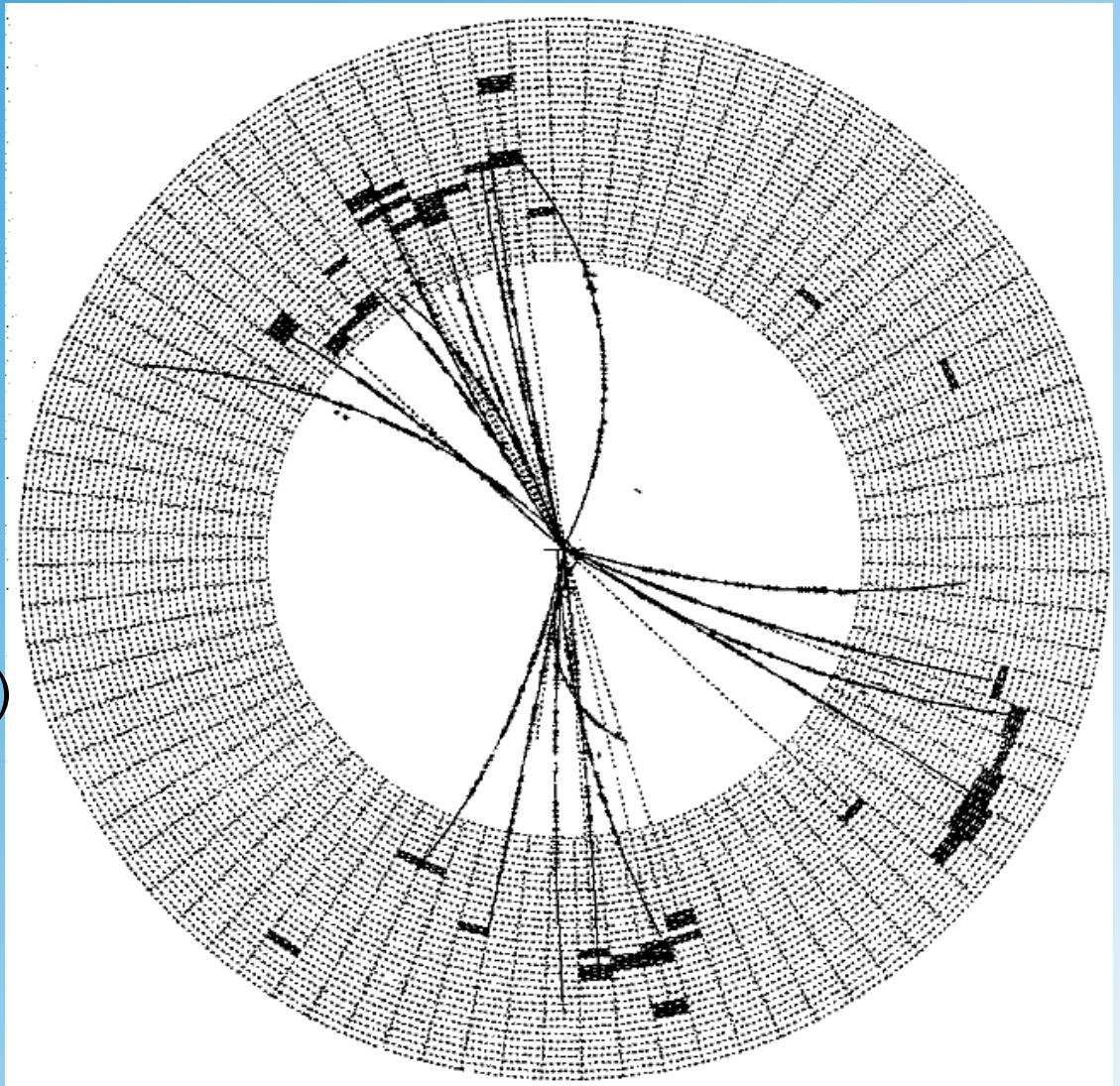
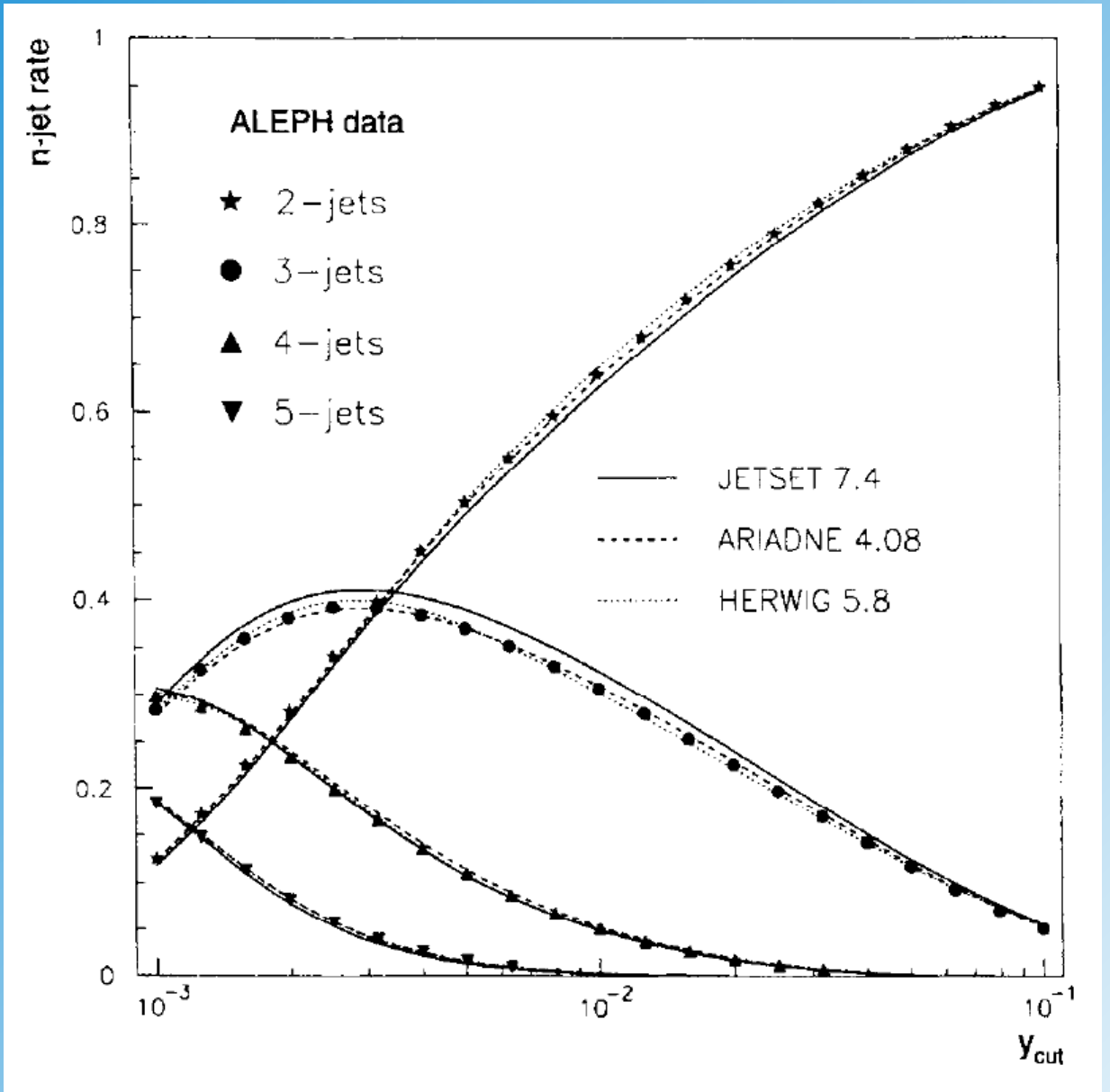


Fig. 11.12 A three-jet event observed by the JADE detector at PETRA.

Jet Rates (ALEPH)



Running alpha$_s$

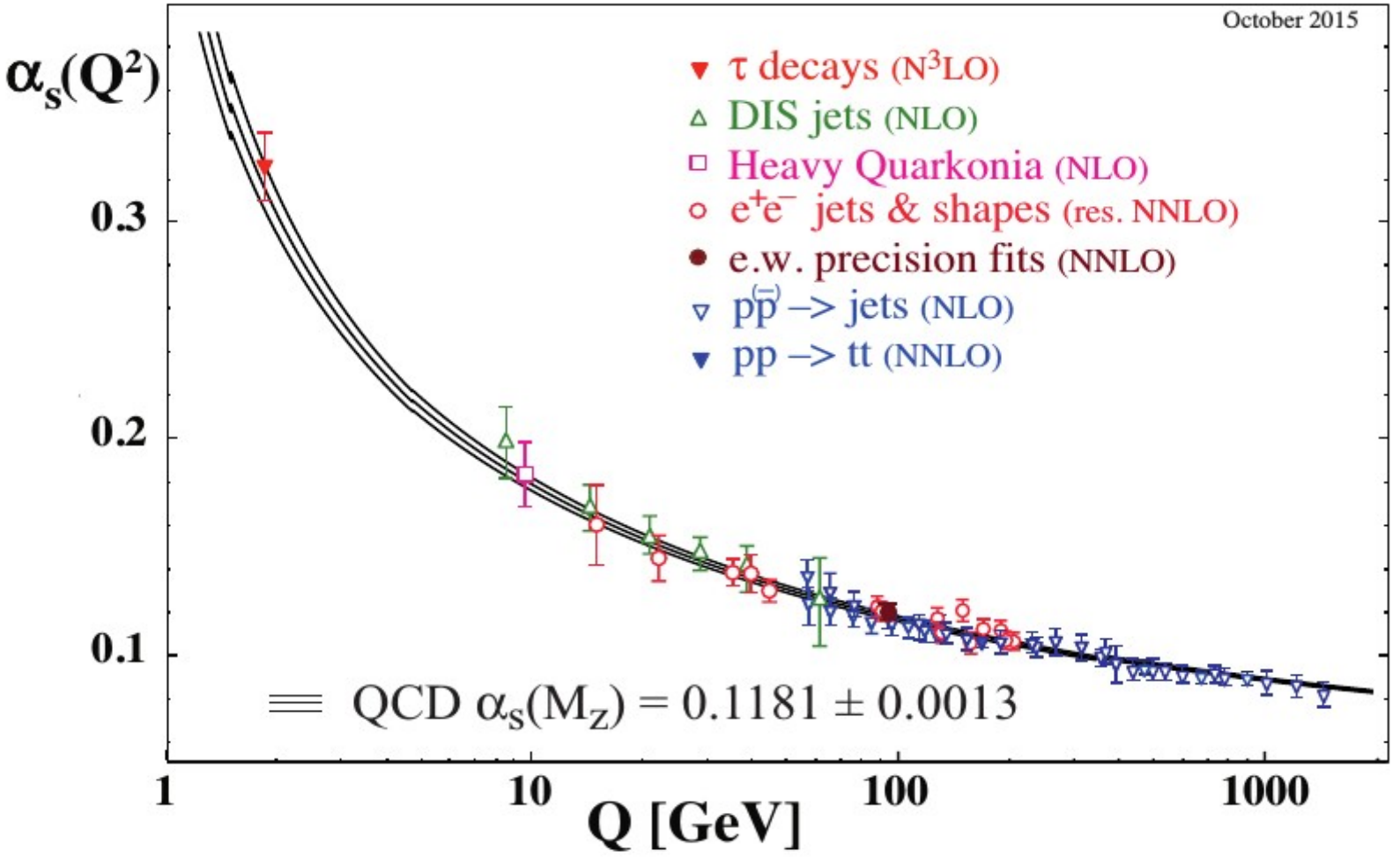
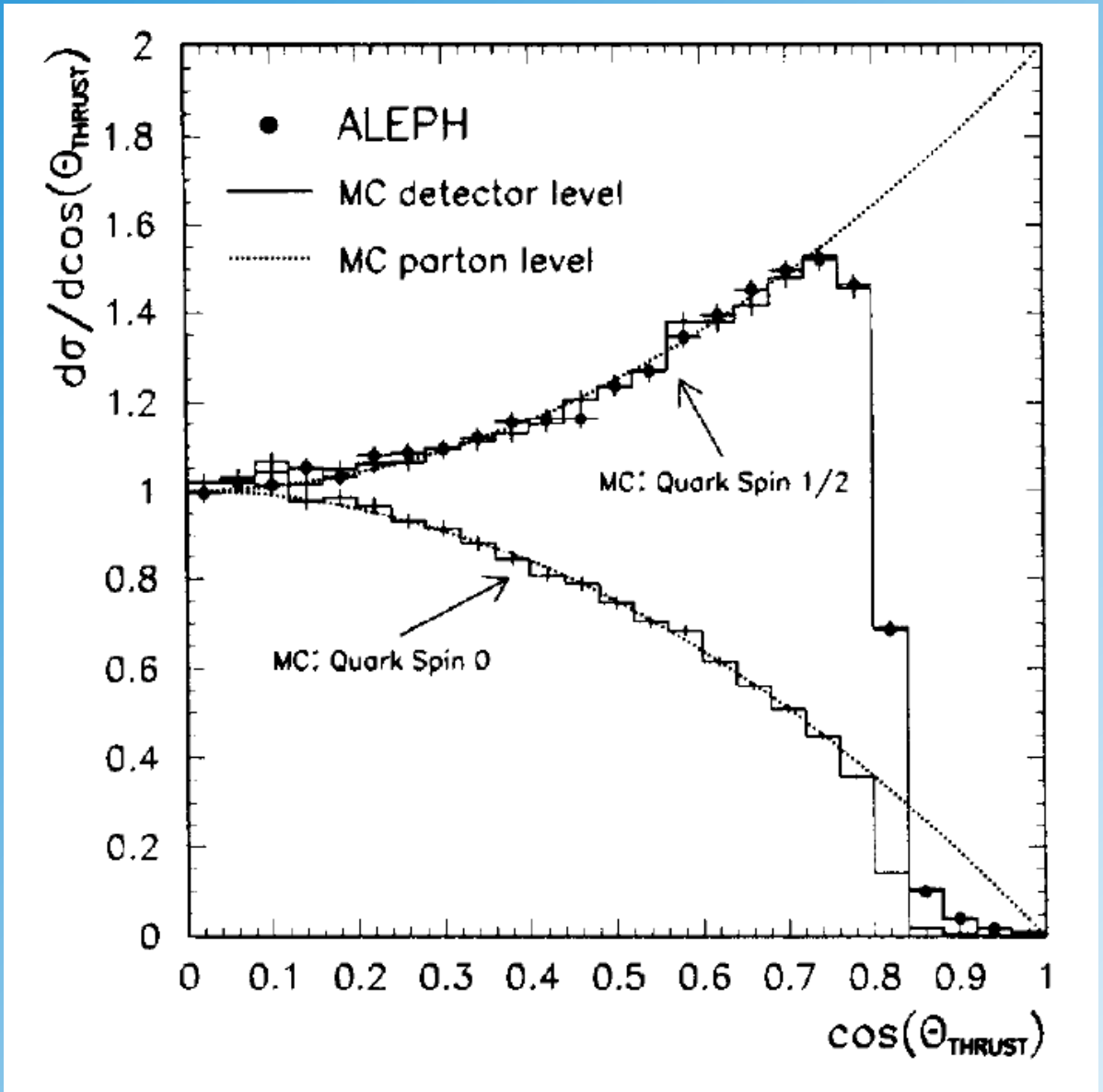
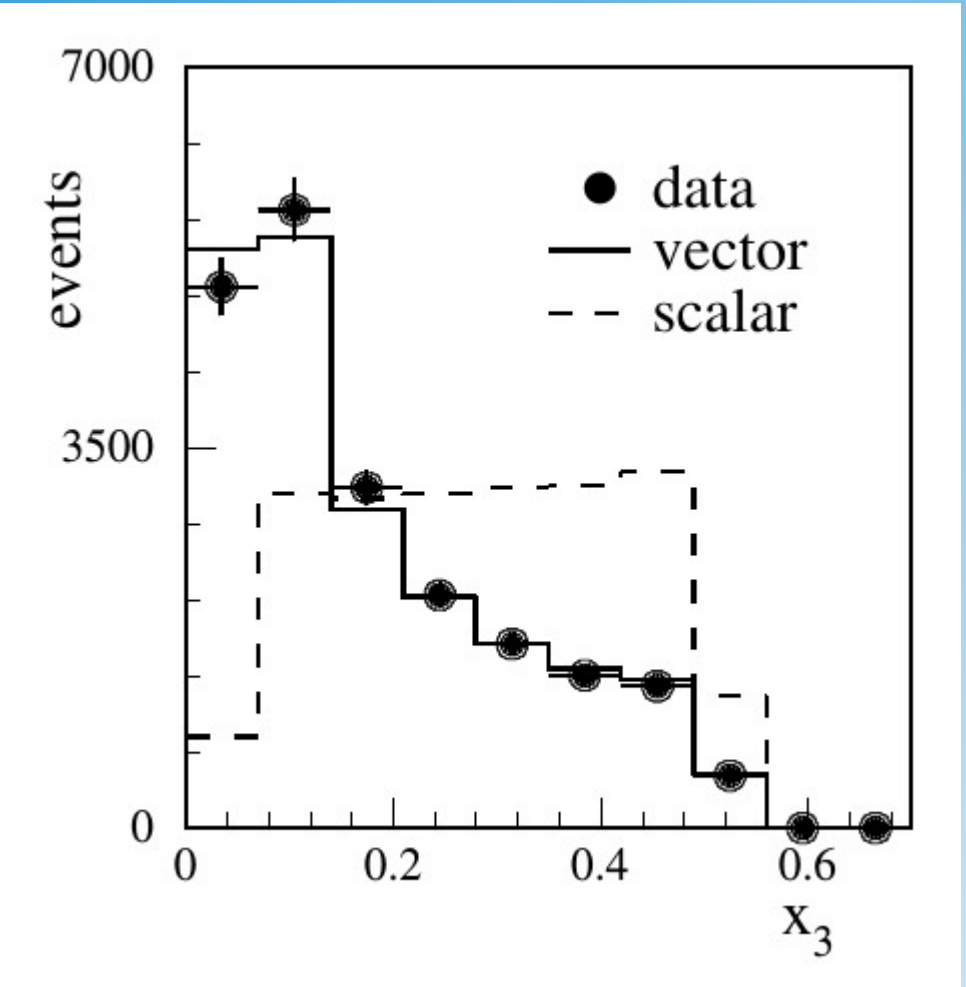


Figure 9.3: Summary of measurements of α_s as a function of the energy scale Q. The respective degree of QCD perturbation theory used in the extraction of α_s is indicated in brackets (NLO: next-to-leading order; NNLO: next-to-next-to leading order; res. NNLO: NNLO matched with resummed next-to-leading logs; N^{3}LO: next-to-NNLO).

Quark Spin

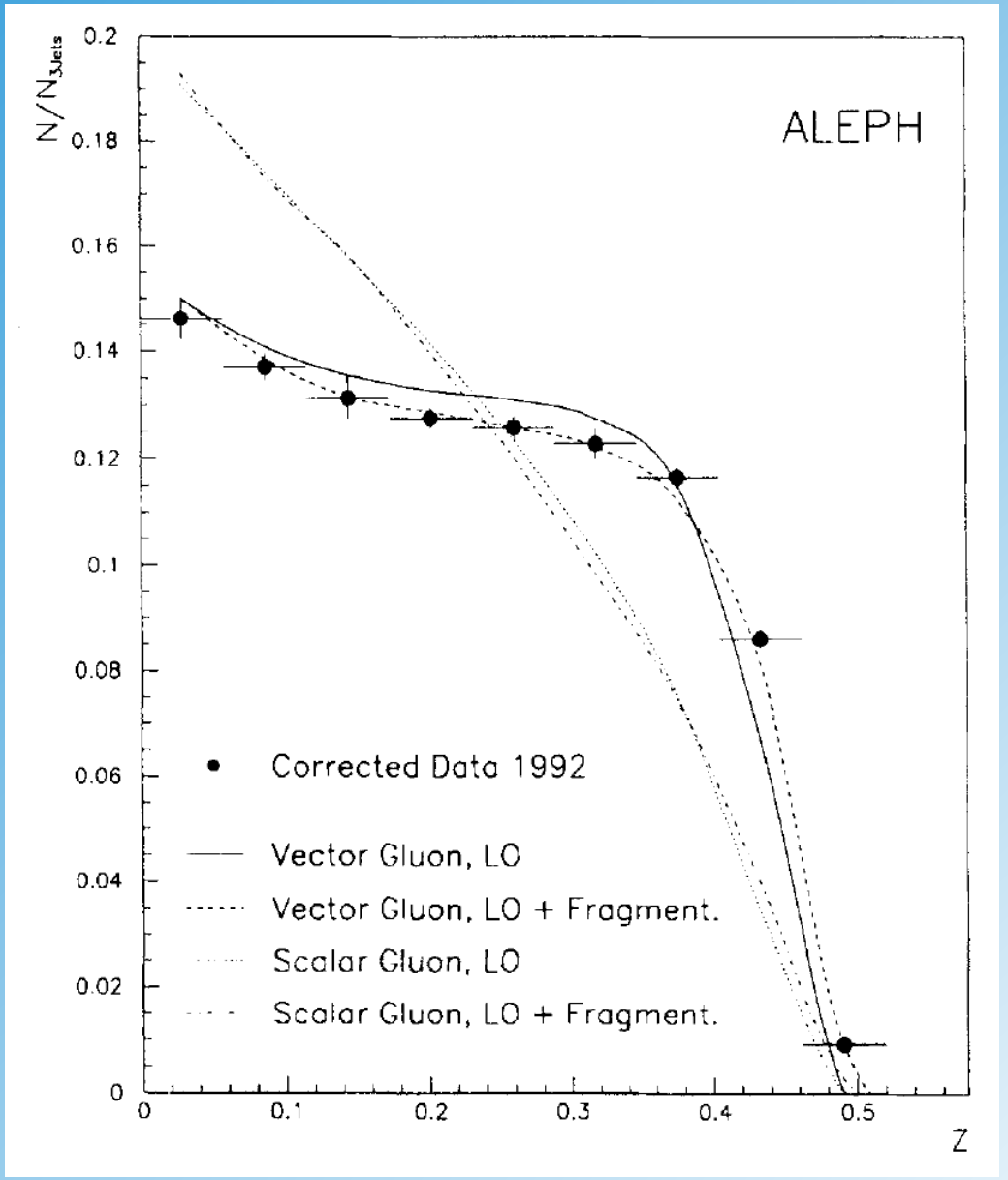

ALEPH
MC detector level
MC parton level
MC: Quark Spin 1/2
MC: Quark Spin 0
dσ/dcos(Θ_THRUST)
cos(Θ_THRUST)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.1
0.3
0.5
0.7
0.9

Gluon Spin



Fragmentation Effect

$Z=(x_2-x_3) / \sqrt{3}$

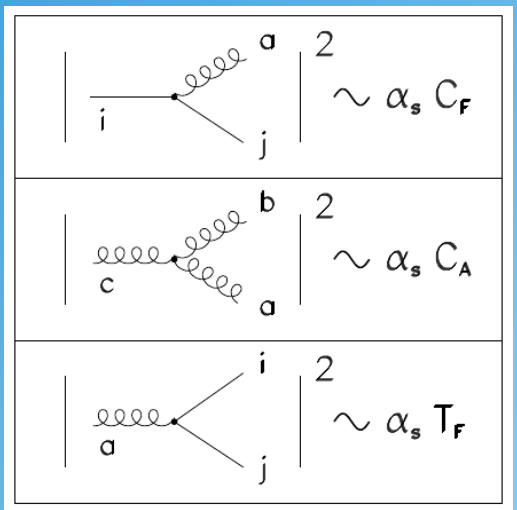


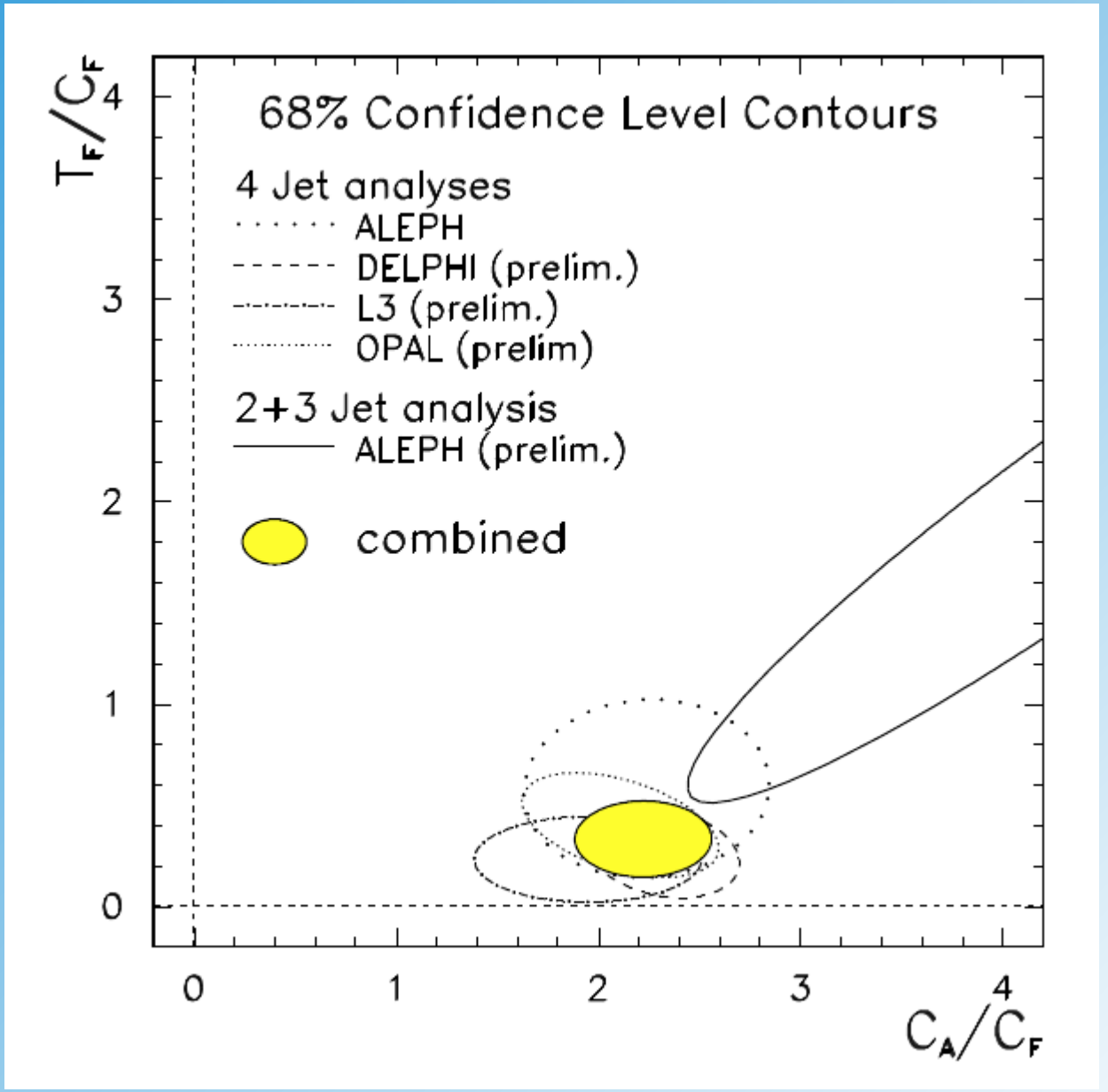
QCD Color Factors

Theory:

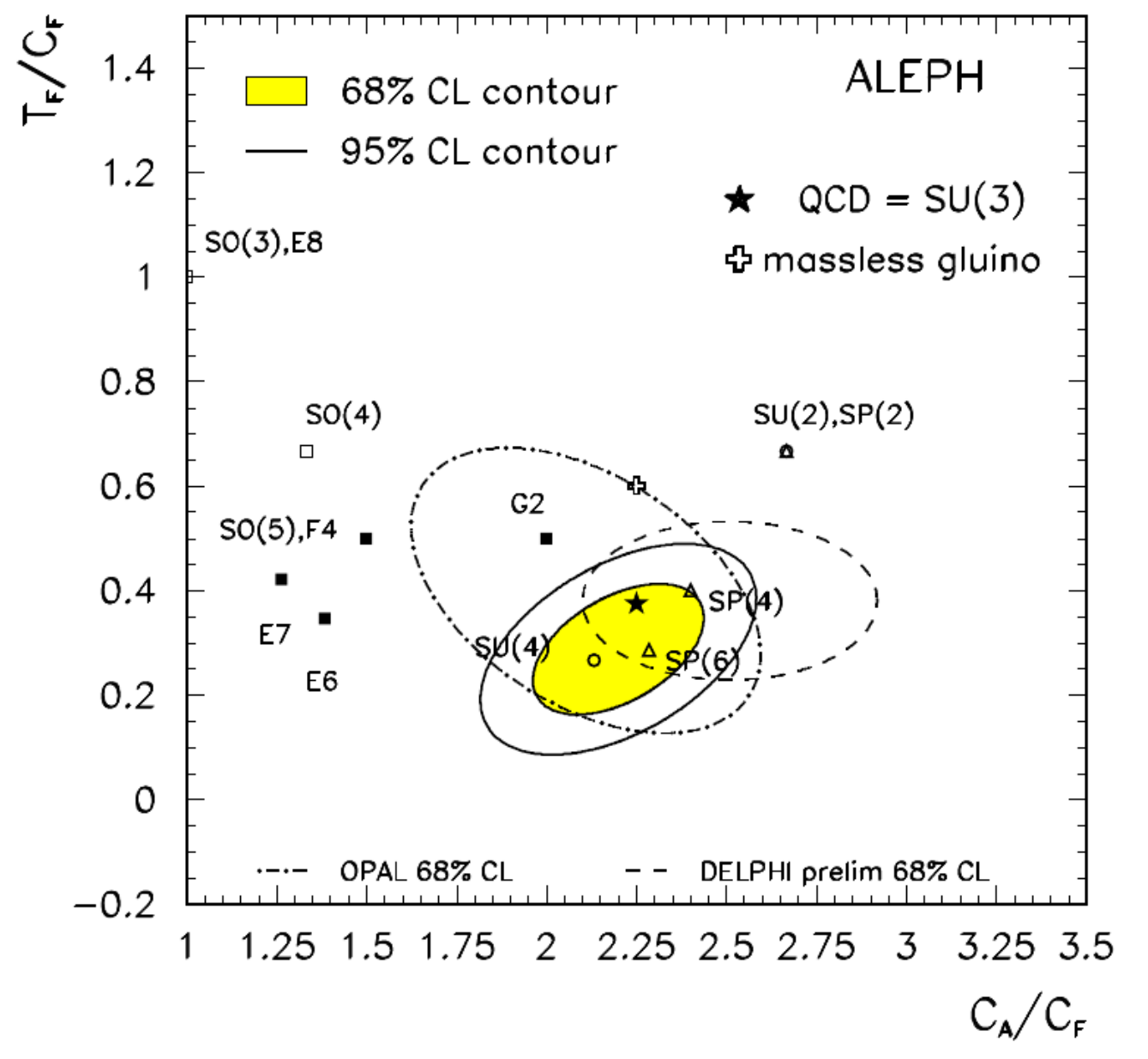
$C_A/C_F = 9/4$

$T_F/C_F = 3/8$



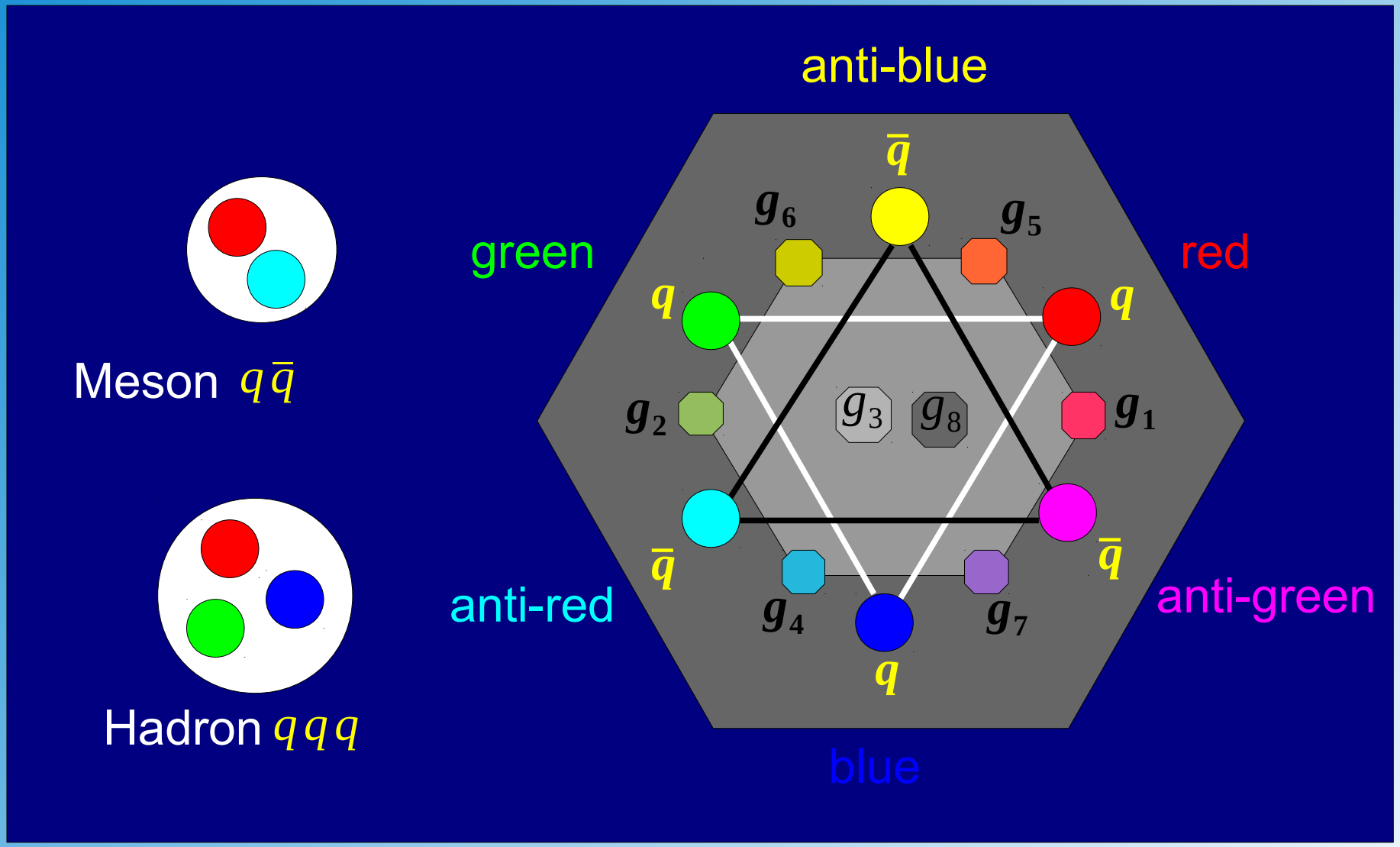


QCD Color Factors

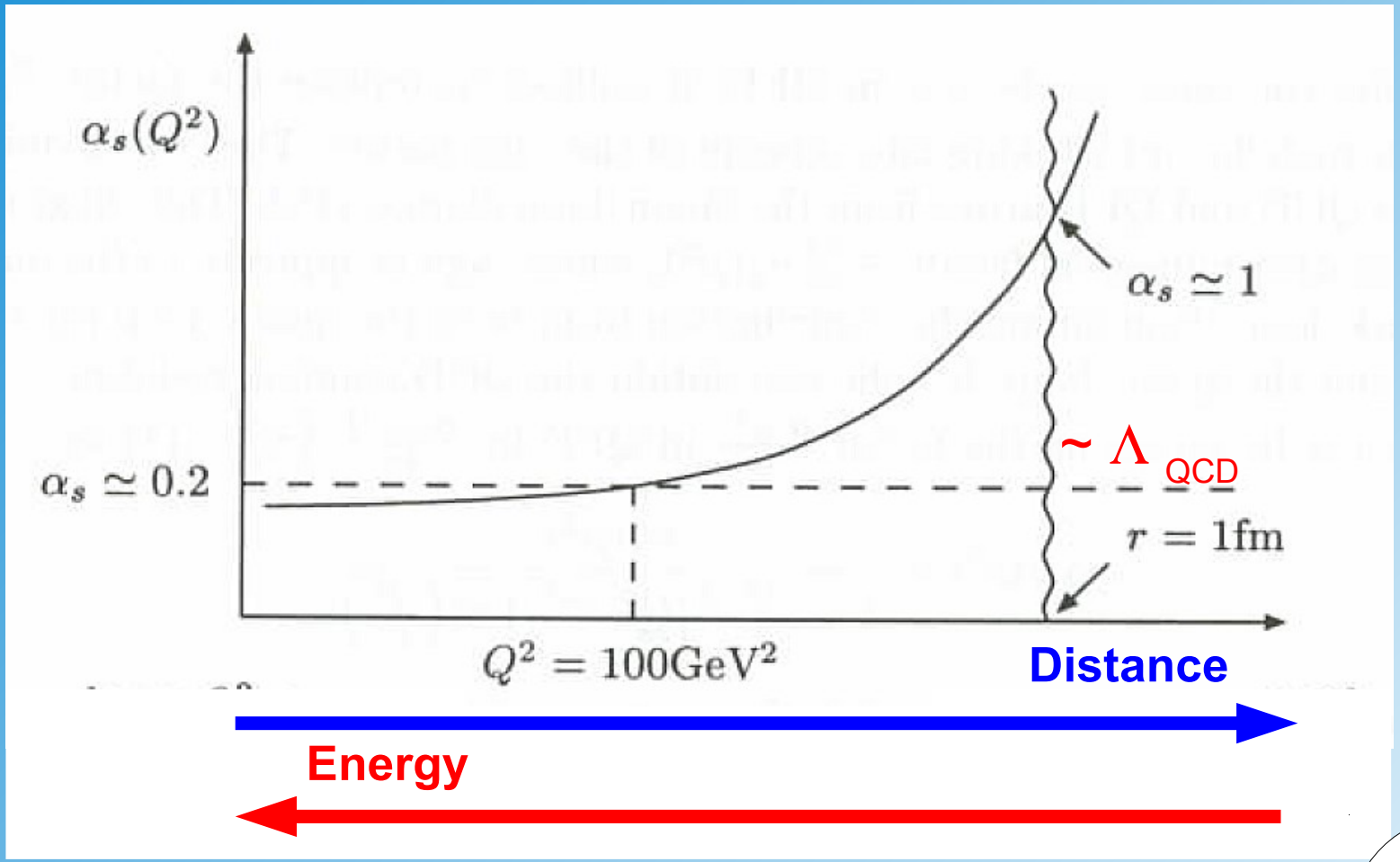


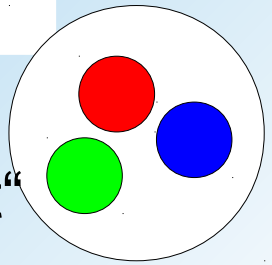
G.Dissertori

Quantum Chromodynamics



Running of alpha$_s$

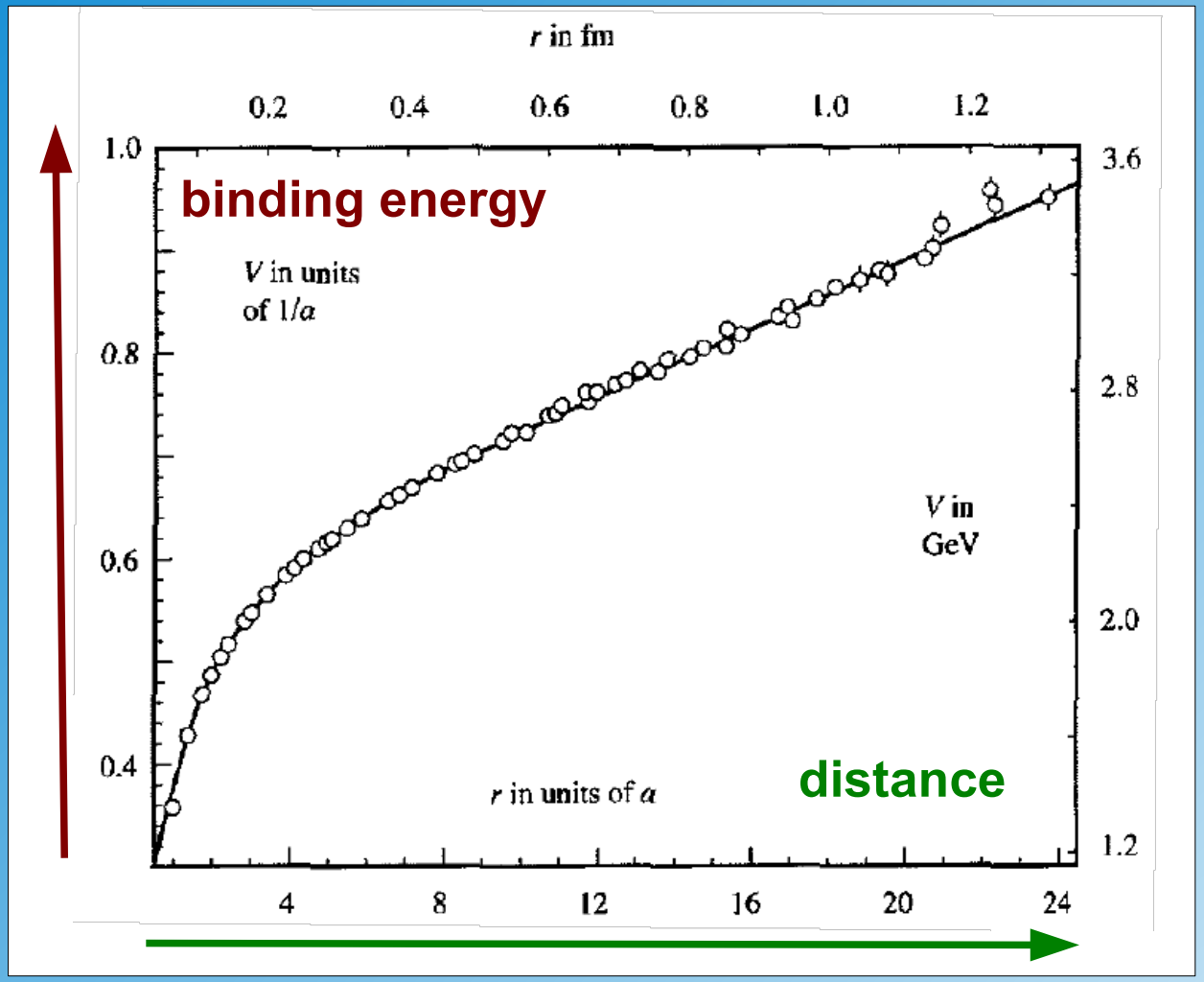


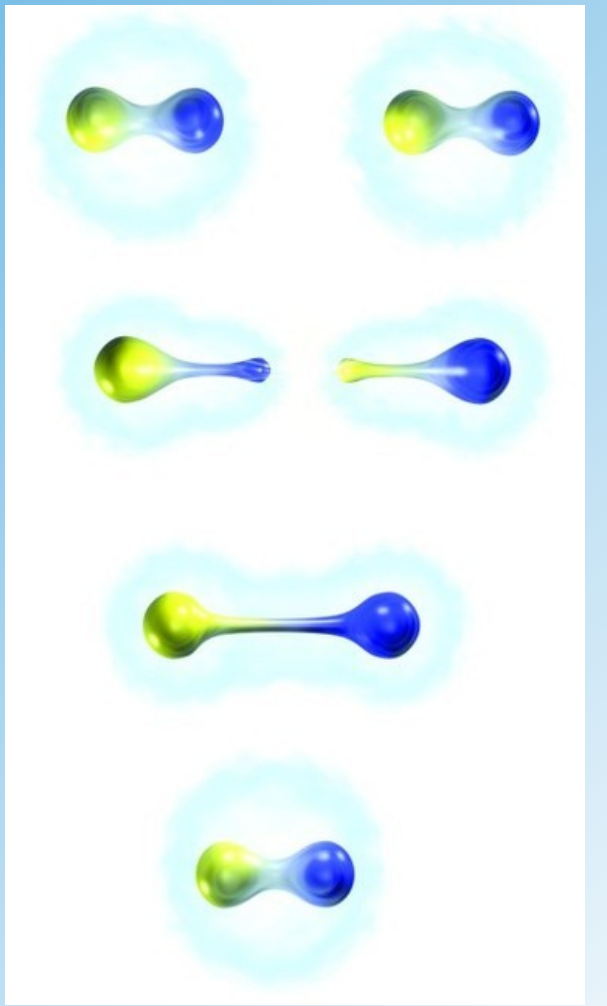


„Asymptotic Freedom“ „Confinement“

Confinement

The force between two quarks is 50000 N !!!





consequence: free quarks or gluons are not observable