QCD and Gluons

prepared by

Seonho Choi

Seoul National University

Topics in High Energy Physics

October 7, 2004

Asymptotic Freedom

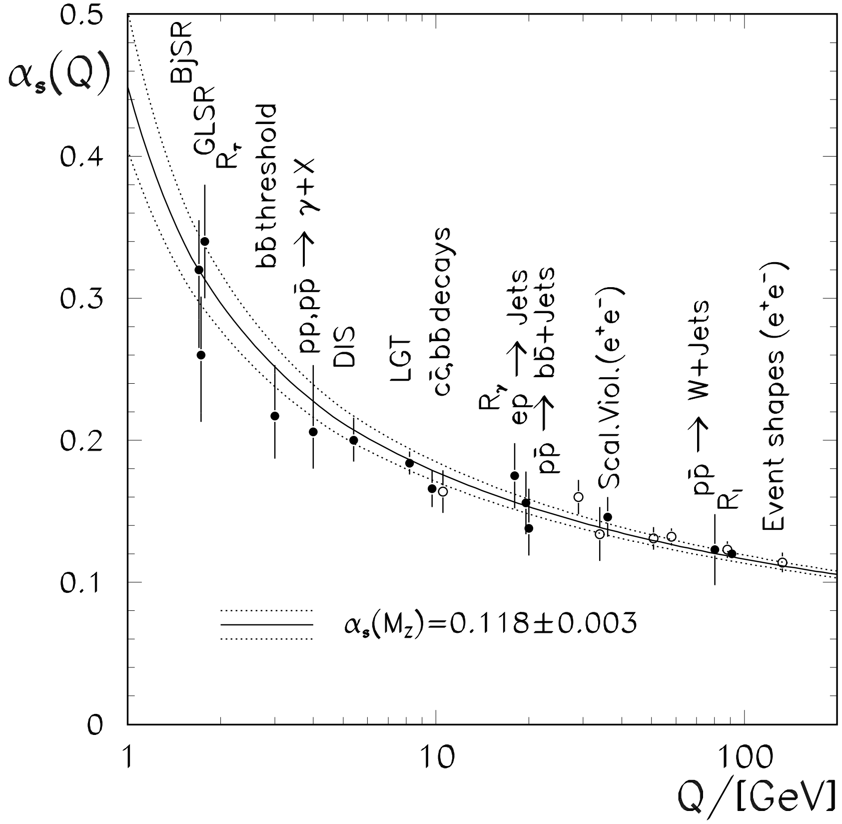
- Creation and annihilation of virtual particles $\rightarrow$ modification of propagators
- For Quantum Electro-Dynamics, slight decrease of α_{em} as Q^2 increases

$$\alpha(Q^2) = \frac{\alpha(\mu^2)}{1 - \frac{\alpha(\mu^2)}{3\pi} \log\left(\frac{Q^2}{\mu^2}\right)}$$

- For Quantum Chromo-Dynamics, dramatic decrease of α_S as Q^2 increases

$$\alpha_S(Q^2) = \frac{\alpha_S(\mu^2)}{1 + \frac{\alpha(\mu^2)}{12\pi}(33 - 2N_f) \log\left(\frac{Q^2}{\mu^2}\right)}$$

Variation of α_S vs. Q^2



- At large Q^2, interaction between quarks becomes weaker
- Perturbative calculation is possible at large Q^2
- At small Q^2, interaction becomes stronger - confinement (no isolated quarks)

e^+e^- Annihilation and QCD

- Cross section for $e^-e^+ \to \mu^+\mu^-$

$$\sigma(e^-e^+ \to \mu^-\mu^+) = \frac{4\pi\alpha_{em}^2}{3s}$$

- Cross section for $e^-e^+ \to q\bar{q}$

$$\sigma(e^-e^+ \to q\bar{q}) = 3e_q^2\sigma(e^-e^+ \to \mu^-\mu^+)$$

- Cross section for $e^-e^+ \to$ hadrons

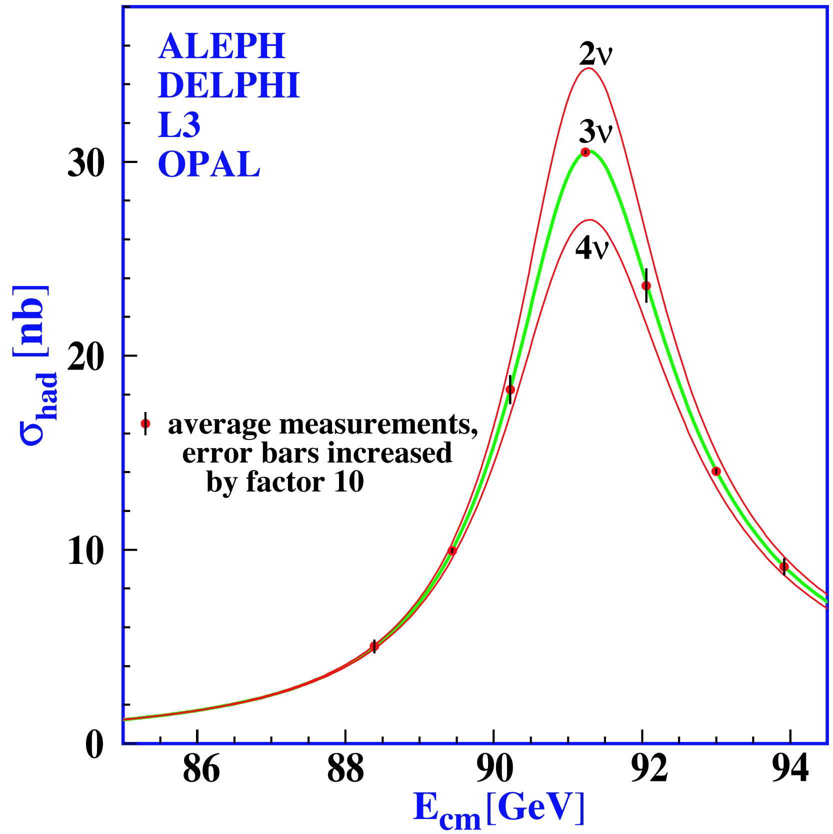
$$\begin{aligned}\sigma(e^-e^+ \to \text{hadrons}) &= \sum_q \sigma(e^-e^+ \to q\bar{q}) \\ &= 3\sum_q e_q^2\sigma(e^-e^+ \to \mu^-\mu^+)\end{aligned}$$

➜ Finally, the ratio,

$$R \equiv= \frac{\sigma(e^- e^+ \rightarrow \text{hadrons})}{\sigma(e^- e^+ \rightarrow \mu^- \mu^+)} = 3 \sum_q e_q^2$$

$$\begin{aligned}
R &= 3\left[\left(\frac{2}{3}\right)^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)^2\right] = 2 \quad \text{for u,d,s} \\
&= 2 + 3\left(\frac{2}{3}\right)^2 = \frac{10}{3} \quad \text{for u,d,s,c} \\
&= \frac{10}{3} + 3\left(\frac{1}{3}\right)^2 = \frac{11}{3} \quad \text{for u,d,s,c,b}
\end{aligned}$$

Width of Z^0 Resonance



- ➜ Z^0s are produced from e^+e^- annihilation at $\sqrt{s} \simeq 91$GeV
- ➜ Width of the resonance peak is related to number of *avialable* decay channels
- ➜ Comparison with calculation can reveal *yet-unknown* channels

From quarks to hadrons

- Quarks inside the nucleons - parton distribution function $q(x)$
- How an individual quark becomes hadrons - fragmentation function $D_q^h(z)$

$$\frac{d\sigma}{dz}(e^-e^+ \to hX) = \sum_q \sigma(e^-e^+ \to q\bar{q}) \left[D_q^h(z) + D_{\bar{q}}^h(z)\right]$$

- Taking the ratio,

$$\frac{1}{\sigma}\frac{d\sigma}{dz}(e^-e^+ \to hX) = \frac{\sum_q \sigma(e^-e^+ \to q\bar{q}) \left[D_q^h(z) + D_{\bar{q}}^h(z)\right]}{\sum_q e_q^2}$$

Frangmentaion Functions

- $D_q^h(z)$ function is universal, for example, for *semi*-inclusive reaction

$$\frac{1}{\sigma}\frac{d\sigma}{dz}(ep \to hX) = \frac{\sum_q e_q^2 f_q(x) D_q^h(z)}{\sum_q e_q^2 f_q(x)}$$

- From symmetry arguments

$$\begin{aligned}
D_u^{\pi^+} &= D_{\bar{u}}^{\pi^-} = D_d^{\pi^-} = D_{\bar{d}}^{\pi^+} \\
D_u^{\pi^-} &= D_{\bar{u}}^{\pi^+} = D_d^{\pi^+} = D_{\bar{d}}^{\pi^-} \\
D_s^{\pi^+} &= D_s^{\pi^-}
\end{aligned}$$