

Title: 13/14 PSI - Standard Model Review - Lecture 7

Date: Jan 14, 2014 09:00 AM

URL: <http://pirsa.org/14010016>

Abstract:

⑦ Aspects of QCD

$$q_{br\alpha} \quad r=1, \dots, 6$$

$$\alpha=1, 2, 3$$

$$G^i \quad i=1, \dots, 8$$

$$g_3 = g_s, \quad \alpha_s = \frac{g_s^2}{4\pi}$$

$$\mathcal{L} = -\frac{1}{4} G_{\mu\nu}^i G^{\mu\nu i}$$

$$G_{\mu\nu}^i = \partial_\mu G_\nu^i - \partial_\nu G_\mu^i - g_s f_{abc} A_\mu^b A_\nu^c$$

$$D_\mu = \partial_\mu + ig_s L$$

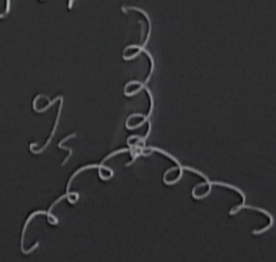
$$\mathcal{L} = -\frac{1}{4} G_{\mu\nu}^i G^{\mu\nu i} + \sum_r \bar{q}_r [i \not{D} - m_r] q_r$$

$$G_{\mu\nu}^i = \partial_\mu G_\nu^i - \partial_\nu G_\mu^i - g_s F_{ijk} G_\mu^j G_\nu^k$$

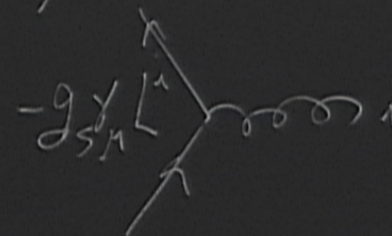
$$D_\mu = \partial_\mu + i g_s L^i G_\mu^i, \quad L^i = \frac{\lambda^i}{2}$$

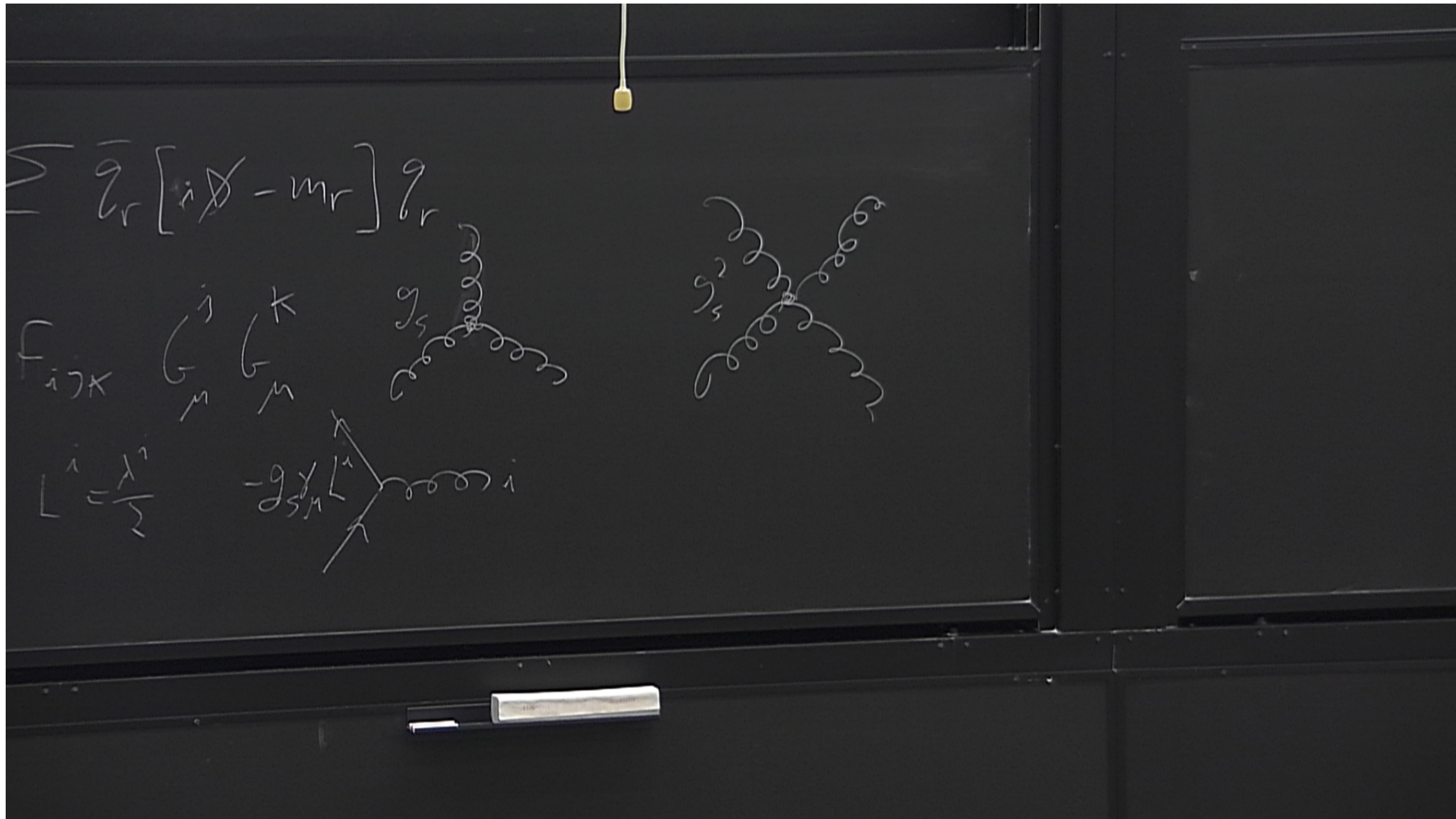
$$-g_s \gamma_\mu L^i$$

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Quarks, Gluons, Color

- quarks (1964): spectroscopy, currents

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 - spectroscopy, currents
 - Flavor sym/breaking

Quarks, Gluons, Color

- quarks (1964):
 - spectroscopy, currents
 - Flavor sym/breaking
- ~~isolated quarks~~
 - $q_u = \frac{2}{3}, \quad q_d = q_s = -\frac{1}{3}$
 - math. trick? Confinement
- 1970 SLAC

Deep inelastic Scattering

$$\bar{e}P \rightarrow \bar{e} + \underbrace{X}_{\text{hadrons}}$$

Deep inelastic Scattering

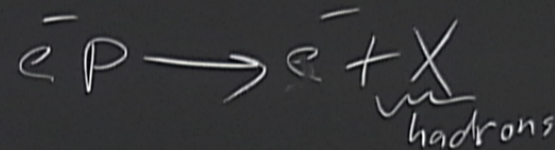
$$e^- p \rightarrow e^- + \underbrace{X}_{\text{hadrons}}$$

Deep inelastic Scattering

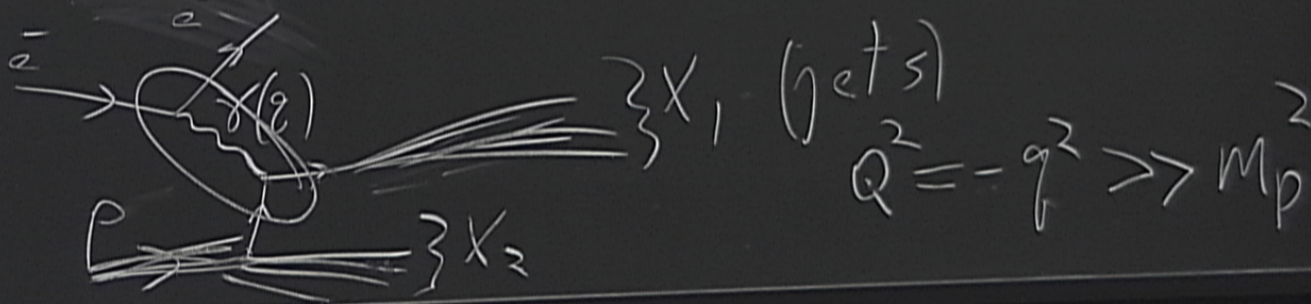
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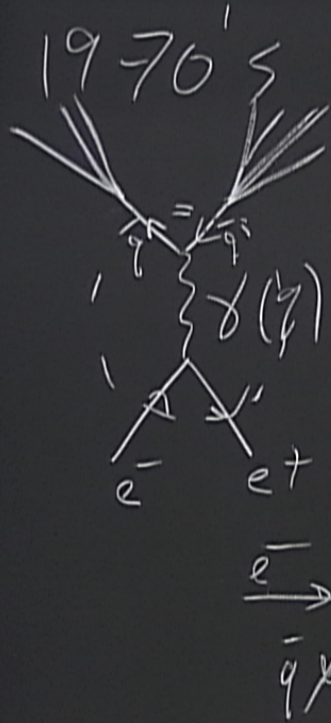
$\Rightarrow$ proton has point-like constituents

Deep inelastic scattering



$\Rightarrow$ proton has point-like constituents





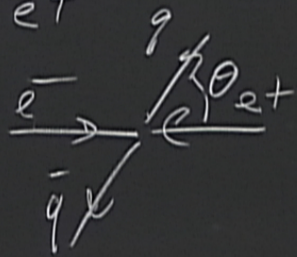
$e^+e^- \rightarrow \text{hadrons}$

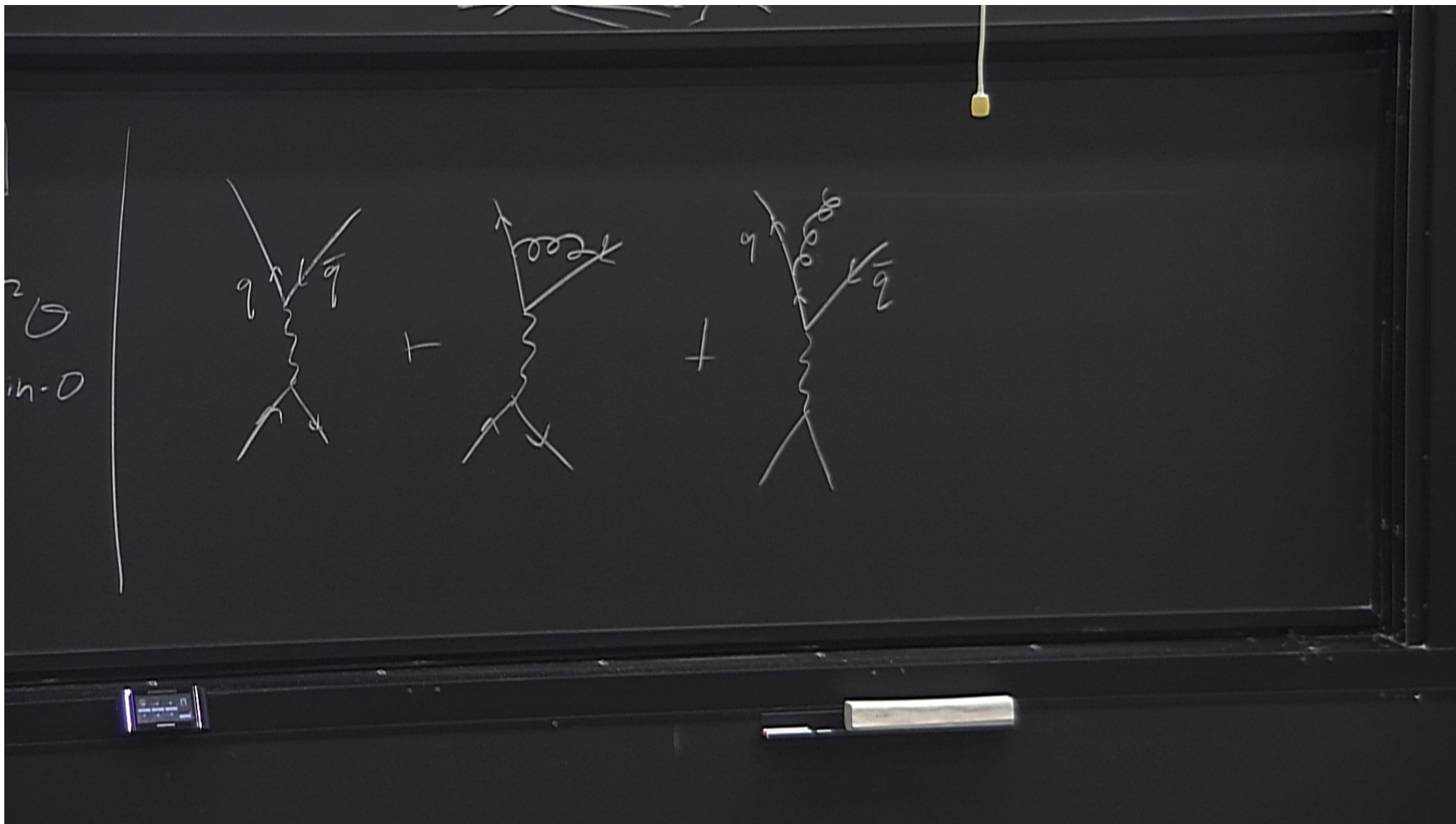
[SLAC, DESY]

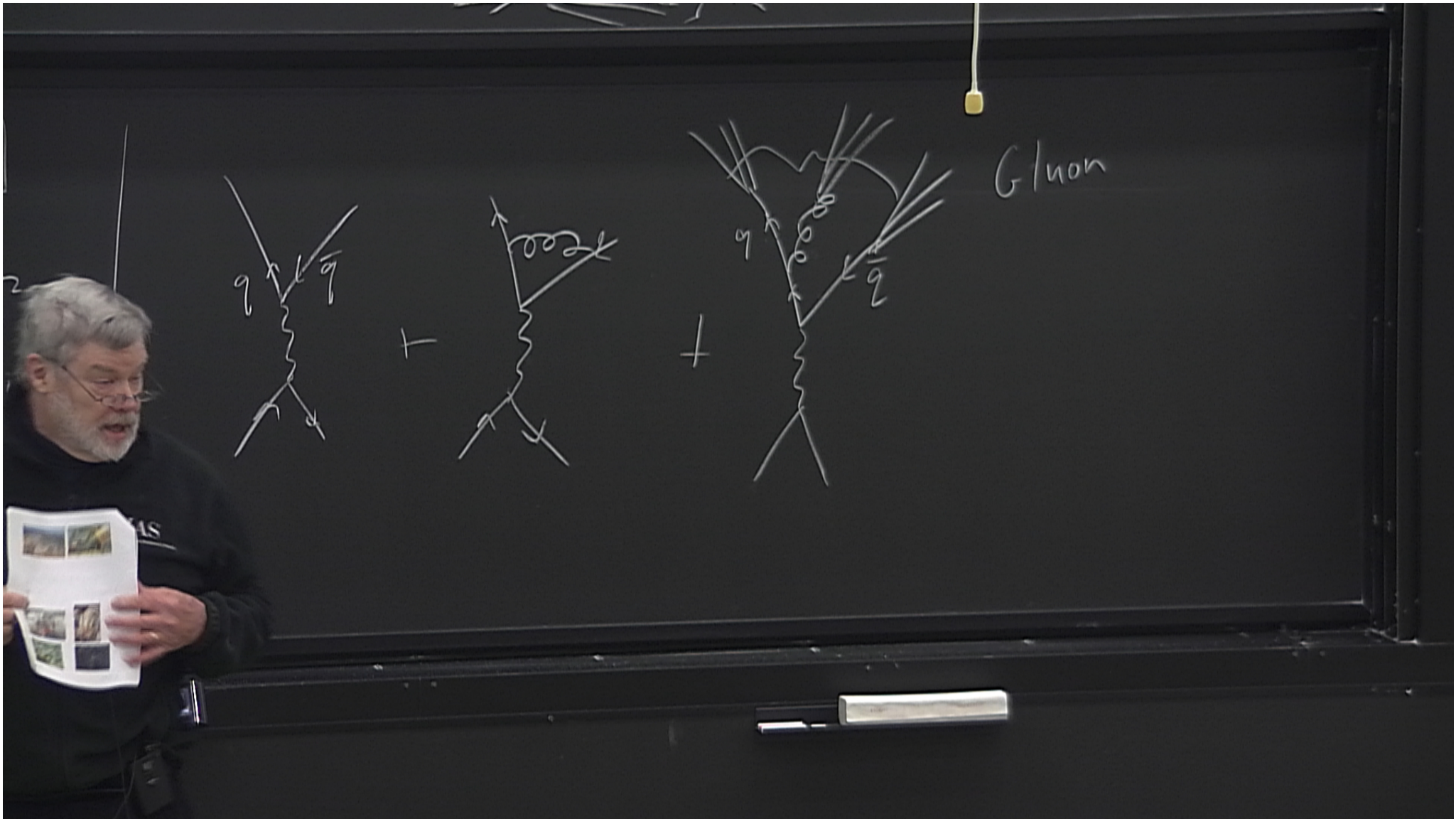
$\Rightarrow$ point-like

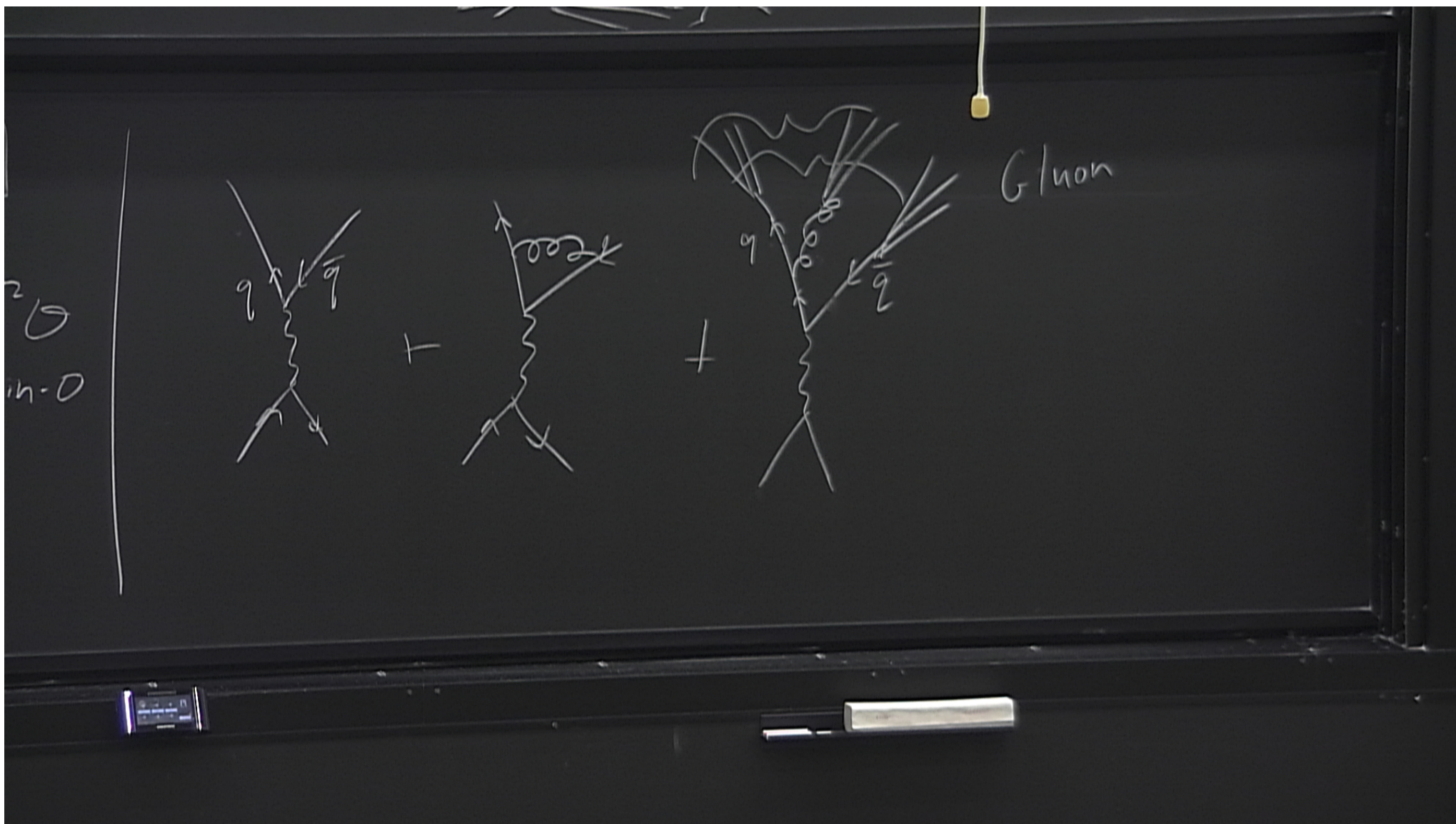
ang dist: $1 + \cos^2 \theta$
spin- $\frac{1}{2}$

vs $\sin^2 \theta$
spin-0









$N_c = 3$ colors

$$|\Omega^-\rangle = |s^\uparrow s^\uparrow s^\uparrow\rangle$$

spin $\frac{3}{2}$

$S = -\frac{3}{2}$

symmetric in sp- ψ
pure s-wave

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add color

$$\frac{1}{\sqrt{6}} \sum_{\alpha\beta\gamma} |\alpha\beta\gamma\rangle$$

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spin $\frac{3}{2}$

$S = -3$

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pure s -wave

add color

$$\frac{1}{\sqrt{6}} \sum_{\alpha\beta\gamma} \epsilon^{\alpha\beta\gamma} |s_\alpha^\uparrow s_\beta^\uparrow s_\gamma^\uparrow\rangle$$

spin $\frac{3}{2}$
 $S = -3$

symmetric in $sp.4$
pure S -wave

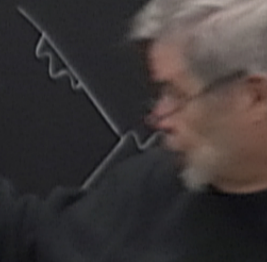
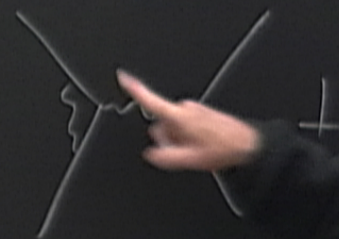
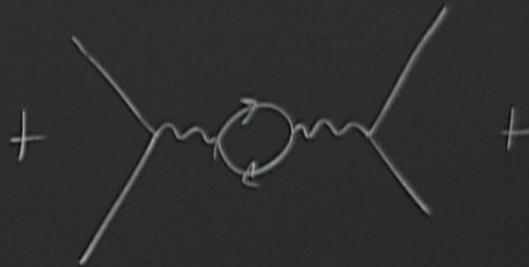
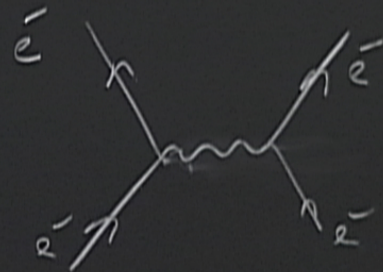
$$R(s) = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

- QCD was unique. $\left\{ \begin{array}{l} \text{asymptotic Freedom} \\ \text{infrared slavery} \end{array} \right.$

QCD was unique.

{ asymptotic Freedom
infrared slavery

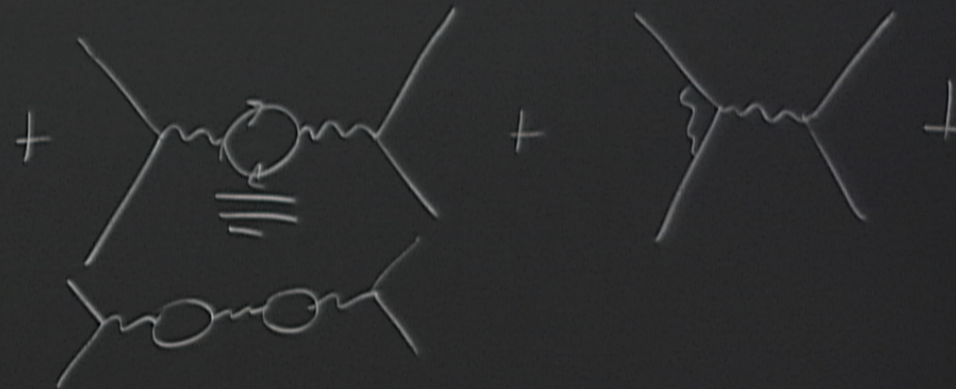
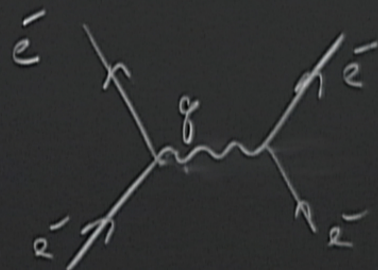
QED

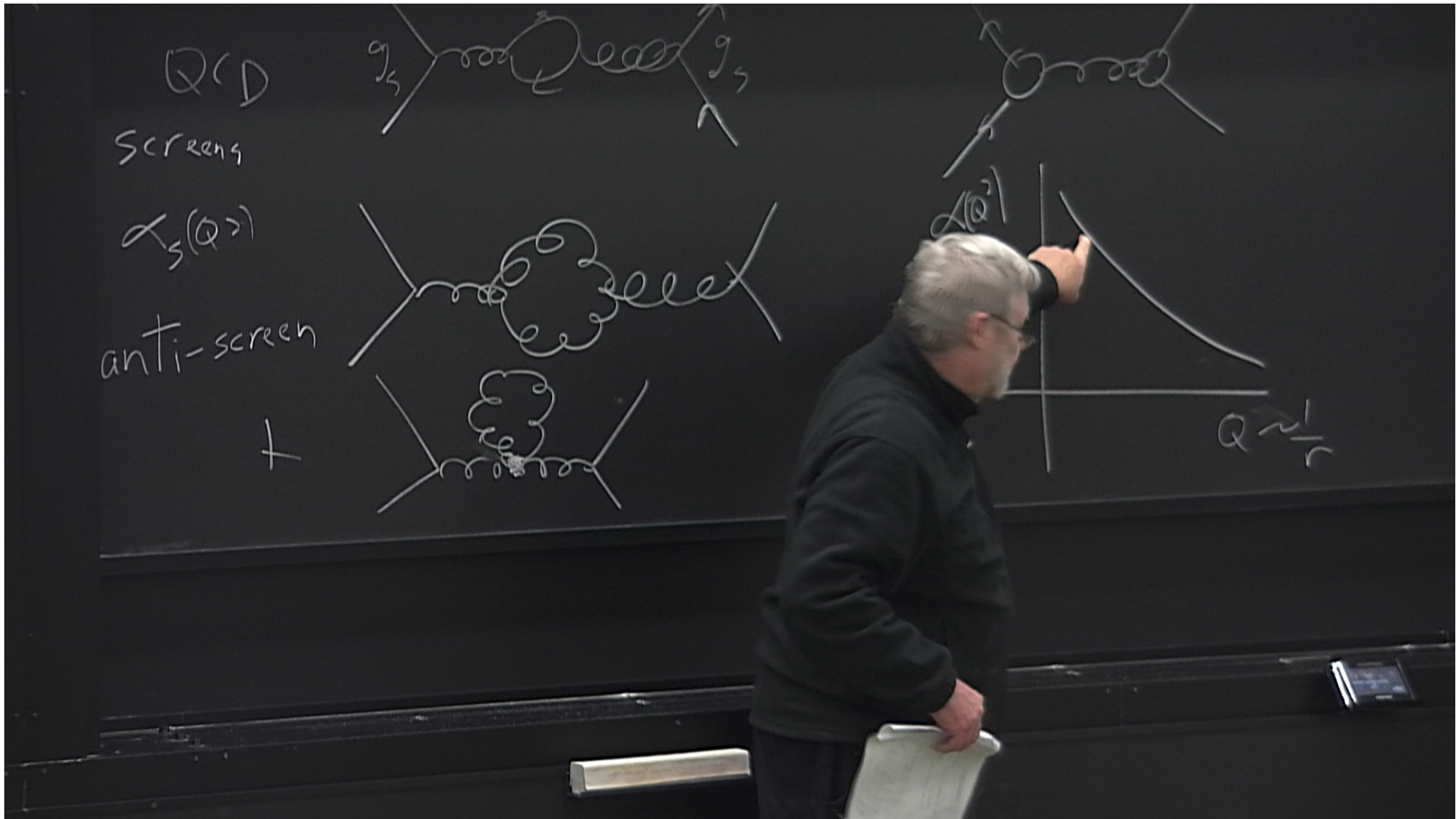


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large Q , $\alpha_s^{(0)}$ is small
quarks are "Free"

$$Q \sim \frac{1}{r}$$

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quarks are "Free" } q, G

small Q
(large r) α_s is large
- confinement
- strong interactions
- bound states } p, n, π, K

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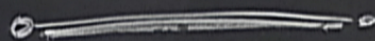
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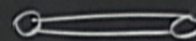


flux tube



q

$\bar{q}$



q

$\bar{q}$



q

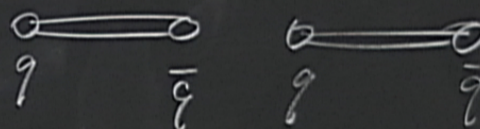
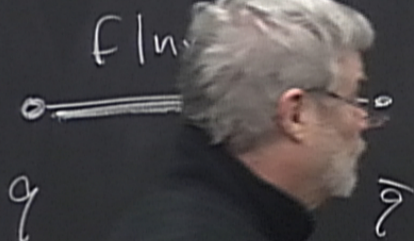
$\bar{q}$



$$|N\rangle = |q_\alpha \bar{q}_\alpha\rangle$$

singlet

$$\epsilon^{\alpha\beta\gamma} |q_\alpha q_\beta q_\gamma\rangle$$



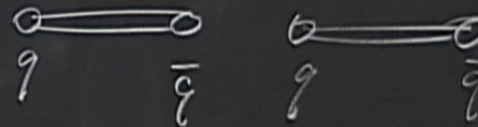
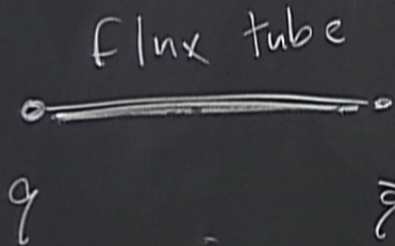


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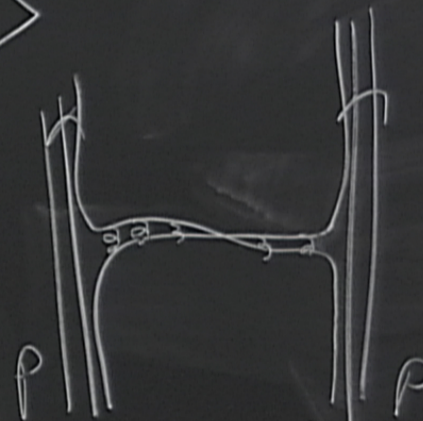
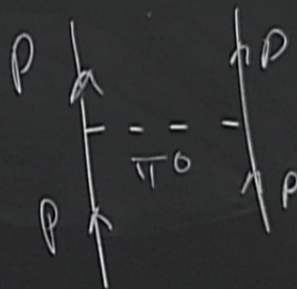
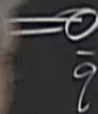


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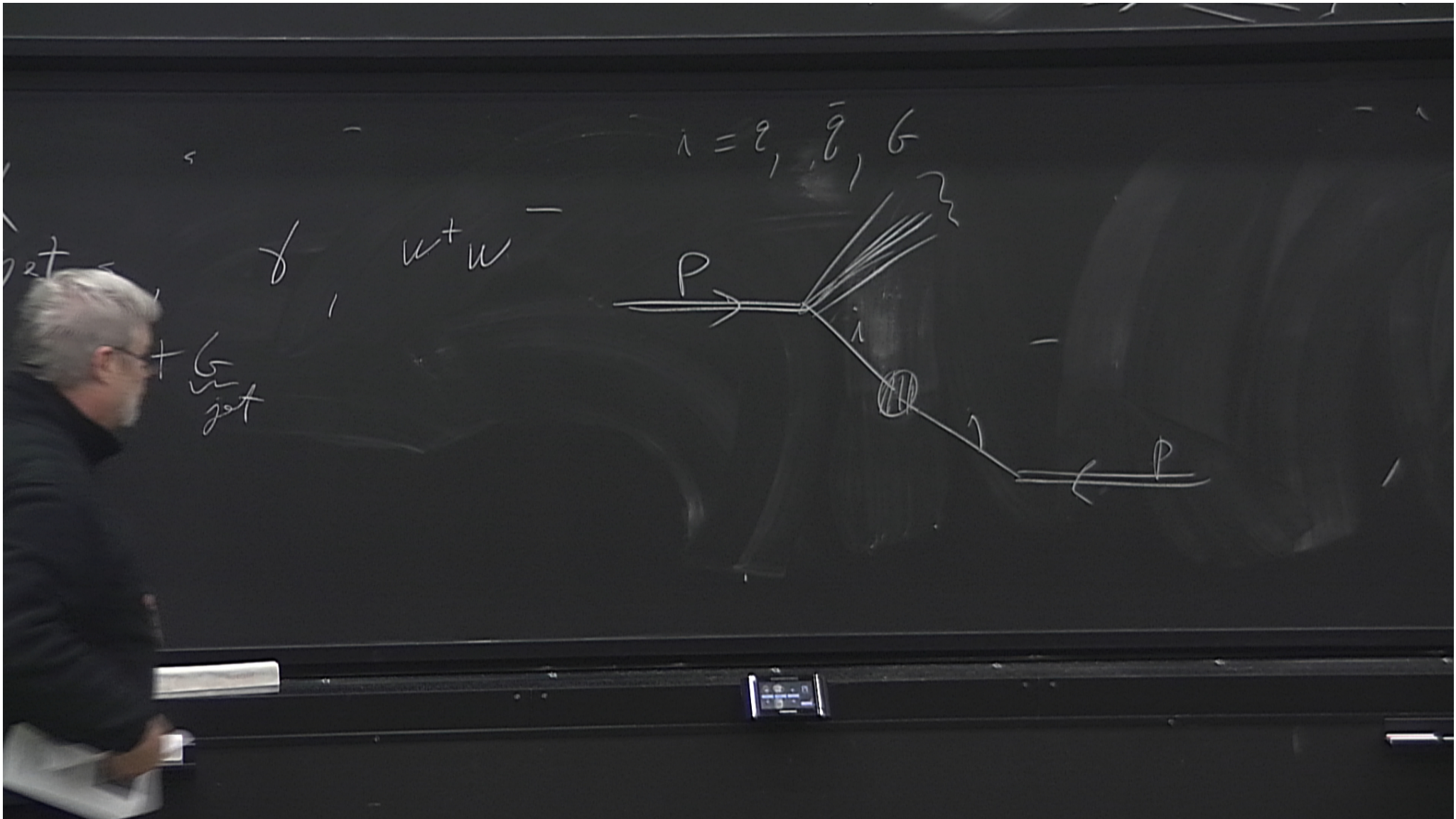
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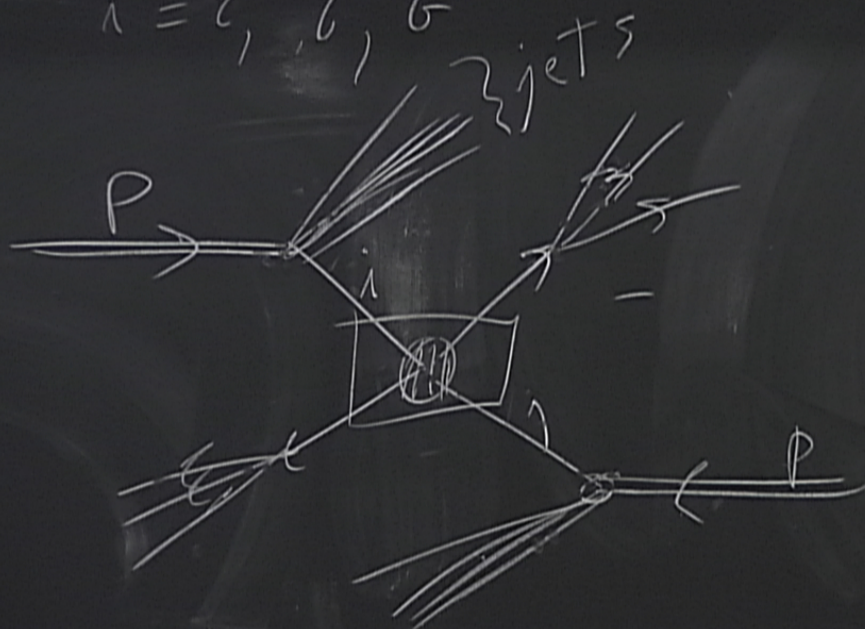


$$pp \rightarrow F + X$$

$$F \Rightarrow \text{jet}_5, 3 \text{ jet}_5, \gamma, W^+W^-, W + \underset{\text{jet}}{G}$$



$$i = q, \bar{q}, G$$



$$q\bar{q} \rightarrow q\bar{q}$$

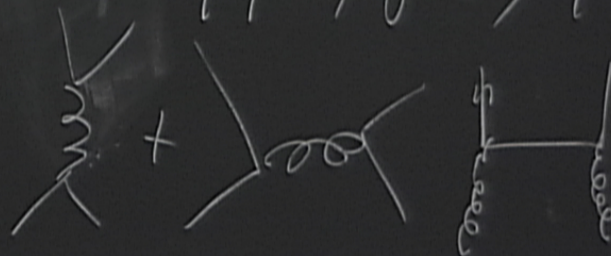
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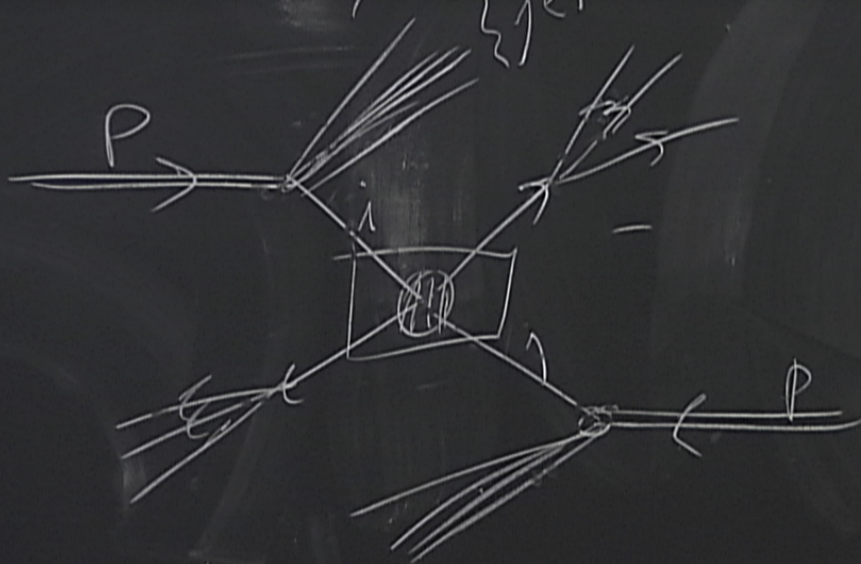
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$$i = q, \bar{q}, G$$

{jets}



$$q\bar{q} \rightarrow q\bar{q}$$

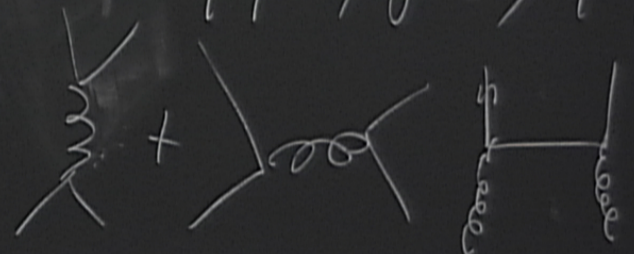
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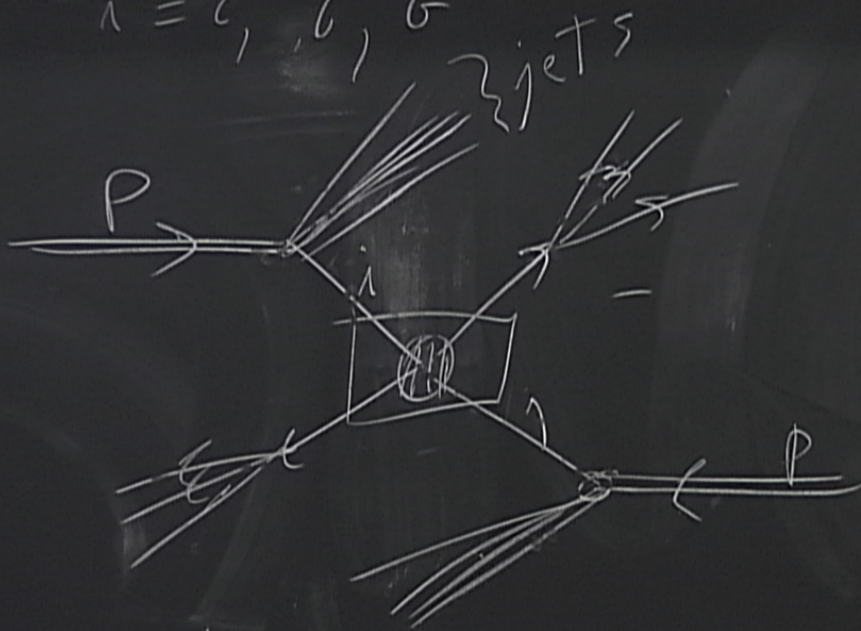
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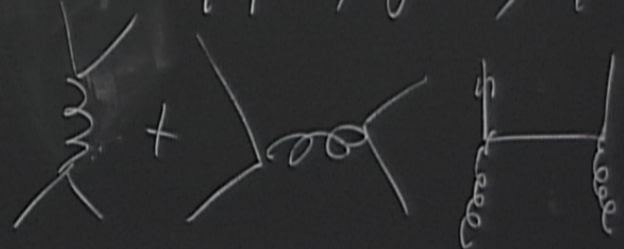
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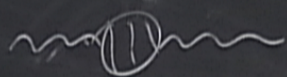
$$GG \rightarrow q\bar{q}$$

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Renormalization Group Equations (RGE)

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 fermions
 gauge bosons
 scalars

$$\frac{dg^2}{d \ln Q^2} = 4\pi \beta(g^2) = \underbrace{b g^4}_{1 \text{ loop}} + \underbrace{O(g^6)}_{2 \text{ loops}}$$

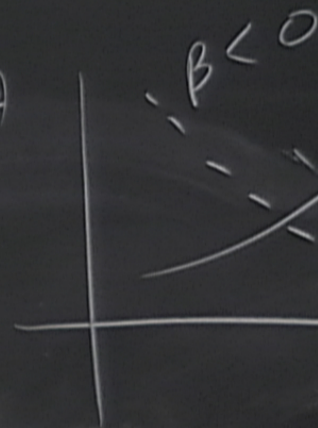
$$\overline{T_F \delta_{ij}} = \text{Tr}[\overline{L_\psi^i} L_\psi^j] = T(L_\psi) \delta^{ij}$$

[non chiral]

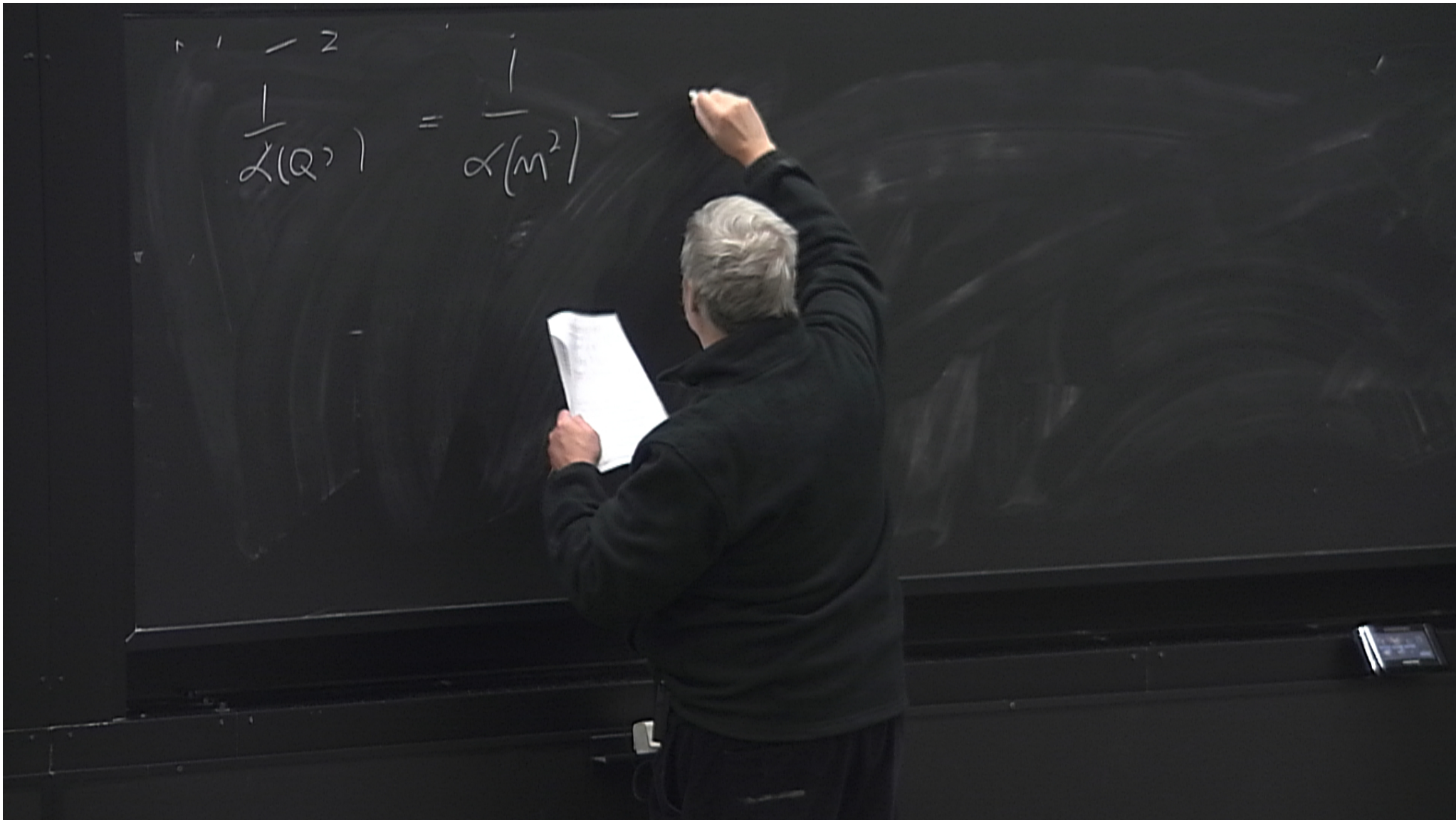
$$\stackrel{\text{chiral}}{=} \frac{1}{2} \text{Tr}[\overline{L_L^i} L_L^j] + \frac{1}{2} \text{Tr}[\overline{L_R^i} L_R^j]$$

$$\overbrace{T_F \delta_{ij}}^{\text{[non chiral]}} = \text{Tr}[\tilde{L}_\psi^i L_\psi^j] = T(L_\psi) \delta^{ij}$$

$\propto Q^2$



$$\underset{\text{chiral}}{=} \frac{1}{2} \text{Tr}[\tilde{L}_L^i L_L^j] + \frac{1}{2} \text{Tr}[\tilde{L}_R^i L_R^j]$$



$$\frac{1}{\alpha(Q^2)} = \frac{1}{\alpha(m^2)} - 4\pi b \ln \frac{Q^2}{m^2}$$

QCD: n_f flavors

$$\frac{1}{\alpha_s(Q^2)} = \frac{1}{\alpha_s(m^2)} + \frac{33 - 2n_f}{12\pi}$$

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A.F. = For $n_f \leq$