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$F = 4$ s-confining
$\to F = 5$ approach weak coupling

# Deconfinement

odd

| | $SU(N)$ | $SU(F)$ | $SU(N+F-4)$ |
|---|---|---|---|
| $A$ | $\boxminus$ | 1 | 1 |
| $Q$ | $\square$ | $\square$ | 1 |
| $\bar{Q}$ | $\bar{\square}$ | 1 | $\square$ |

$W=0$

$\hat{F} = \hat{N}+2$
$2\hat{F} = N+1 = 2\hat{N}+4$
$2\hat{N} = N-3$
$m$ $\bar{p}$'s $A(\boxminus) = N-4$
$= N-3+-m$
$m=1$

| | $SU(N)$ | $Sp(N-3)$ | $SU(F)$ | $SU(N+F-4)$ |
|---|---|---|---|---|
| $Y$ | $\square$ | $\square$ | 1 | 1 |
| $Z$ | 1 | $\square$ | 1 | 1 |
| $\bar{P}$ | $\bar{\square}$ | 1 | 1 | 1 |
| $Q$ | $\square$ | 1 | $\square$ | 1 |
| $\bar{Q}$ | $\bar{\square}$ | 1 | 1 | $\square$ |

$$W = YZ\bar{P} + \mathrm{Pf}(\quad) \to YZ = 0$$

$(YY) \sim A \qquad (YZ) \sim \square$

$SU(N)$ duality $\to \tilde{N} = \tilde{F} - N = N+F-3-N = F-3$

| | $SU(F-3)$ | $Sp(N-3)$ | $SU(F)$ | $SU(N+F-4)$ |
|---|---|---|---|---|
| $y$ | $\square$ | $\square$ | 1 | 1 |
| $\bar{p}$ | $\bar{\square}$ | 1 | 1 | 1 |
| $q$ | $\square$ | 1 | $\bar{\square}$ | 1 |
| $\bar{q}$ | $\bar{\square}$ | 1 | 1 | $\bar{\square}$ |
| $(Q\bar{Q}) \sim M$ | 1 | 1 | $\square$ | $\square$ |
| $(Y\bar{Q}) \sim L$ | 1 | $\square$ | 1 | $\square$ |
| $(Q\bar{P}) \sim B$ | 1 | 1 | $\square$ | 1 |
| $(Y\bar{P})$ | 1 | $\square$ | 1 | 1 |
| $Z$ | 1 | $\square$ | 1 | 1 |

$$W = Mq\bar{q} + Bq\bar{p} + Ly\bar{q} + (Y\bar{P})y\bar{p} + (Y\bar{P})\sim$$

$$\frac{\partial W}{\partial Z} = (Y\bar{P}) = 0$$

$2\tilde{N} = N-3$

$2\tilde{F} = F-3 + N+F-4 = 2F+N-7$

$Sp(2\tilde{F}-2\tilde{N}-4) = Sp(2F+N-7-N+3-4)$

$= Sp(2F-8)$

| | $SU(F-3)$ | $Sp(2F-8)$ | $SU(F)$ | $SU(N+F-4)$ |
|---|---|---|---|---|
| $\tilde{y}$ | $\square$ | $\square$ | 1 | 1 |
| $\bar{p}$ | $\bar{\square}$ | 1 | 1 | 1 |
| $q$ | $\square$ | 1 | $\bar{\square}$ | 1 |
| $\bar{q}$ | $\bar{\square}$ | 1 | 1 | $\bar{\square}$ |
| $M$ | 1 | 1 | $\square$ | $\square$ |
| $l$ | 1 | $\square$ | 1 | $\bar{\square}$ |
| $B$ | 1 | 1 | $\square$ | 1 |
| $(yy) \sim a$ | $\boxminus$ | 1 | 1 | 1 |
| $H$ | 1 | 1 | 1 | $\boxminus$ |
| $(Ly)$ | $\square$ | 1 | 1 | $\square$ |

$W = a\tilde{y}\tilde{y} + Hll + (Ly)l\tilde{y}$

$+ Mq\bar{q} + Bq\bar{p} + (Ly)\bar{q}$

integrate out $(Ly)$ and $\bar{q}$

$W = a\tilde{y}\tilde{y} + Hll + Mql\tilde{y} + Bq\bar{p}$

$D(Op) \geq 1 \Rightarrow$ IRFP $N > 11$
some fields are free

$F=5$ $SU(2) \times SU(2)$
integrate out a flavor $\Delta W = M$ $= \cancel{\text{Just}}$

$\downarrow \langle ql\tilde{y} \rangle \neq 0$

s-confined description

~~SUSY~~ Rule of Thumb

No flat direction

S. Break Global continuos symmetry

$\downarrow$

Goldstone (no interactions in pot)

SUSY $\downarrow$ scalar "

$\downarrow$

flat direction

unless scalar partner is also a Goldstone

people looked models with
no flat directions
(assuming that quant. corr.
don't cancel potential)
tried arrange SSB in perturbative v. ne

found a handful of model

with duality we can find many models

also see how quantum corrections
can lift classical flat directions

3-2 model

| | SU(3) | SU(2) | U(1) | $U(1)_R$ |
|---|---|---|---|---|
| $Q$ | $\square$ | $\square$ | $1/3$ | $1$ |
| $L$ | $1$ | $\square$ | $-1$ | $-3$ |
| $\bar{Q}\left\{\bar{U}\right.$ | $\bar{\square}$ | $1$ | $-4/3$ | $-8$ |
| $\bar{D}$ | $\bar{\square}$ | $1$ | $2/3$ | $4$ |

flat directions: $Q^T = Q = \begin{pmatrix} a & 0 \\ 0 & b \\ 0 & 0 \end{pmatrix}$

SU(2) $L = (0, \sqrt{a^2 - b^2})$

gauge invariants: $\det \bar{Q}Q$, $Q\bar{D}L$, $Q\bar{U}L$

$Q^3 L = 0$ classically

$\Lambda_3 \gg \Lambda_2$ SU(2) weak coupling

$$W_{int} = \frac{\Lambda_3^{3\cdot 3-2}}{\det \bar{Q}Q} \Rightarrow \text{SSB}$$

runaway vacuum

$$W = \frac{\Lambda^7}{\det \bar{Q}Q} + \lambda Q \bar{D} L$$

↑ add

$$\frac{\partial W}{\partial L_\alpha} = \epsilon^{\alpha\beta} \lambda Q_{n\alpha} \bar{D}^n = 0$$

$$\det \bar{Q}Q = \det \begin{pmatrix} \bar{U}Q_1 & \bar{U}Q_2 \\ \bar{D}Q_1 & \bar{D}Q_2 \end{pmatrix} = \bar{U}Q_1 \bar{D}Q_2 - \bar{U}Q_2 \bar{D}Q_1$$

$$= \bar{U}^m Q_{m1} \bar{D}^n Q_{n2} - \bar{U}^m Q_{m2} \bar{D}^n Q_{n2}$$

$$= \bar{U}^m \bar{D}^n Q_{m\alpha} Q_{n\alpha} \epsilon^{\alpha\beta}$$

$$\frac{dW}{\partial \bar{D}^n} = \frac{-\Lambda^7}{(\det \bar{Q}Q)^2} \bar{U}^m Q_{m\alpha} Q_{n\beta} \epsilon^{\alpha\beta} + \lambda Q_{m\alpha} L_\beta \epsilon^{\alpha\beta}$$

$$V = \left|\frac{\partial W}{\partial Q_{max}}\right|^2 + \left|\frac{\partial W}{\partial \bar{u}}\right|^2 + \left|\frac{\partial W}{\partial \bar{D}}\right|^2 + \left|\frac{\partial W}{\partial L}\right|^2$$

$\langle\ \rangle \sim \phi$

$$= \left|\frac{\Lambda_3^7}{\phi^5} + \lambda\phi^2\right|^2 + \left|\frac{\Lambda_3^7}{\phi^5}\right|^2 + \left|\frac{\Lambda_3^7}{\phi^5} + \lambda\phi^2\right| + |\lambda\phi^2|$$

$$\geq \left|\frac{\Lambda_3^7}{\phi^5}\right|^2 + |\lambda\phi^2|^2 \qquad \lambda \ll 1$$

$$V \simeq \frac{\Lambda_3^{14}}{\phi^{10}} + \lambda^2\phi^4$$

$$\frac{\partial V}{\partial \phi} \simeq -\frac{\Lambda^{14}}{\phi^{11}} + \lambda^2\phi^3$$

$$\langle\phi^{14}\rangle \simeq \frac{\Lambda_3^{14}}{\lambda^2}$$

$$\langle\phi\rangle \sim \frac{\Lambda_3}{\lambda^{1/7}} \gg \Lambda_3 \quad \text{for } \lambda \ll 1$$

weak coupling

$$V \simeq \Lambda_3^4 \lambda^{10/7} + \lambda^2 \Lambda_3^4 \lambda^{-4/7}$$

$$\simeq \lambda^{10/7}\Lambda_3^4 + \lambda^{10/7}\Lambda_3^4$$

$$\to 0 \quad \text{as } \lambda \to 0 \text{ or } \Lambda_3 \to 0$$

$\Lambda_2 \gg \Lambda_3$ $\quad SU(3)$ weak

$SU(2)$ with $4\,\Box = 2$ flavors

confinement with $\chi SB$

$$B = Q_1 Q_2 \qquad M_{ij} = \begin{pmatrix} L\,Q_1 & L\,Q_2 \\ Q_3\,Q_1 & Q_3\,Q_2 \end{pmatrix}$$
$$\bar{B} = Q_3 L$$

$$W = \cancel{X}\left(\det M - B\bar{B} - \Lambda_2^4\right) + \lambda\left(M_{1i}\bar{D}^i + \bar{B}\bar{D}^3\right)$$

$$\frac{\partial W}{\partial \bar{D}^n} = \lambda\left(M_{1j}\delta^{nj} + \bar{B}\delta^{n3}\right)$$

constraint means that at least one of $M_{11}$, $M_{12}$ or $\bar{B}$ is nonzero

$V = \lambda^2 \Lambda_2^4$ comparing with previous

$SU(3)$ domanates $\lambda^{\frac{10}{28}}\Lambda_3 \gg \lambda^{1/2}\Lambda_2$

$$\Lambda_3 \gg \lambda^{1/7}\Lambda_2$$

full analysis

$$W = \frac{\Lambda_3^7}{\det \bar{Q}Q} + X\left(\det M - B\bar{B} - \Lambda_2^4\right) + \lambda Q\bar{D}L$$