Monopoles, Anomalies, and Electroweak Symmetry Breaking

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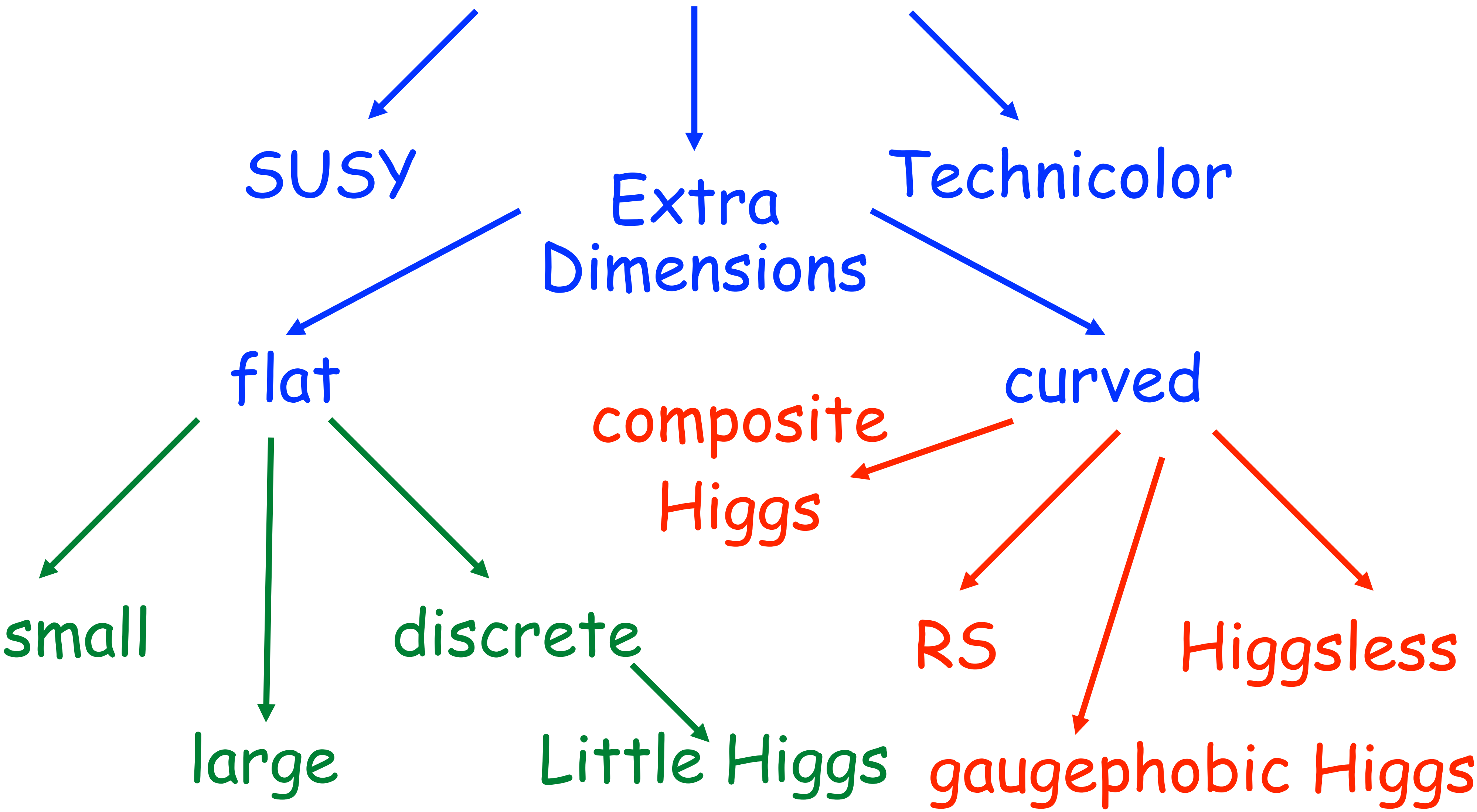
with Csaba Csaki, Yuri Shirman

hep-ph/1003.1718

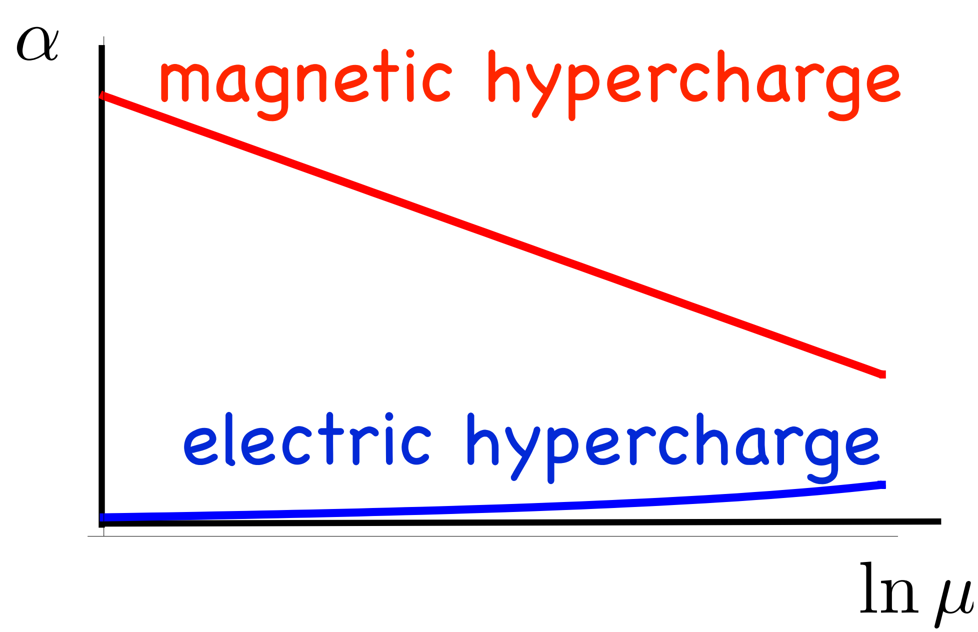
Outline

- Motivation
- A Brief History of Monopoles
- Anomalies
- Models
- LHC
- Conclusions

Hierarchy Problem Now



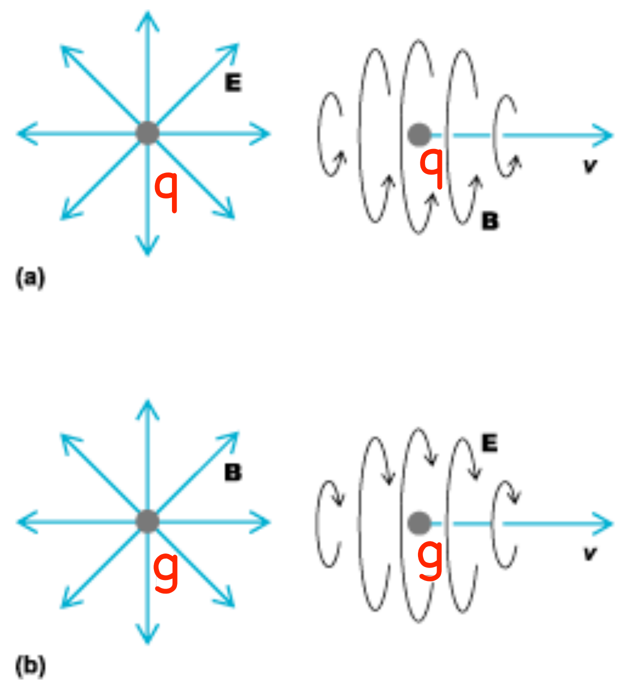
The Vision Thing



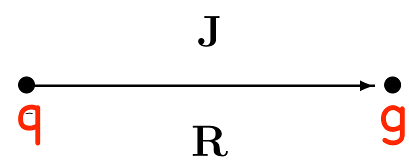
consistent theory of massless dyons?

chiral symmetry breaking -> EWSB?

J.J. Thomson

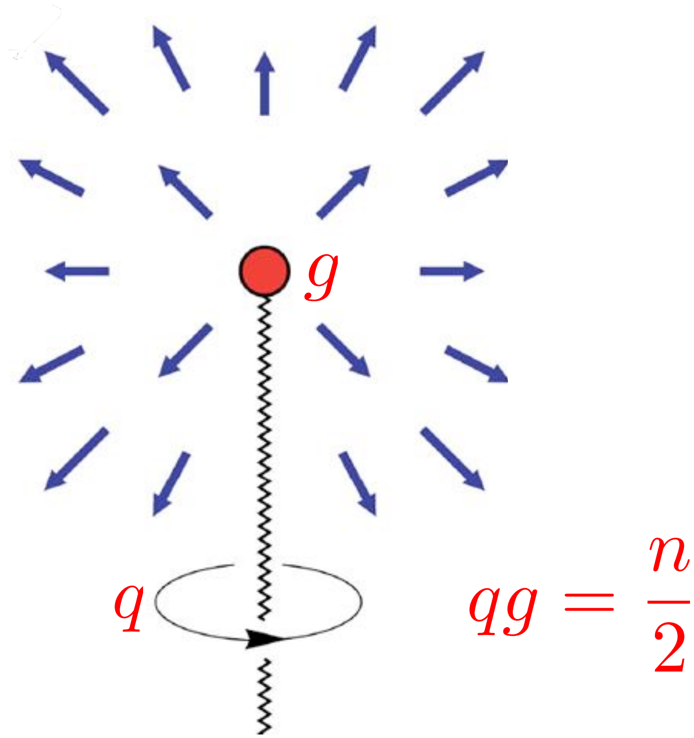


$J = q\,g$



Philos. Mag. 8 (1904) 331

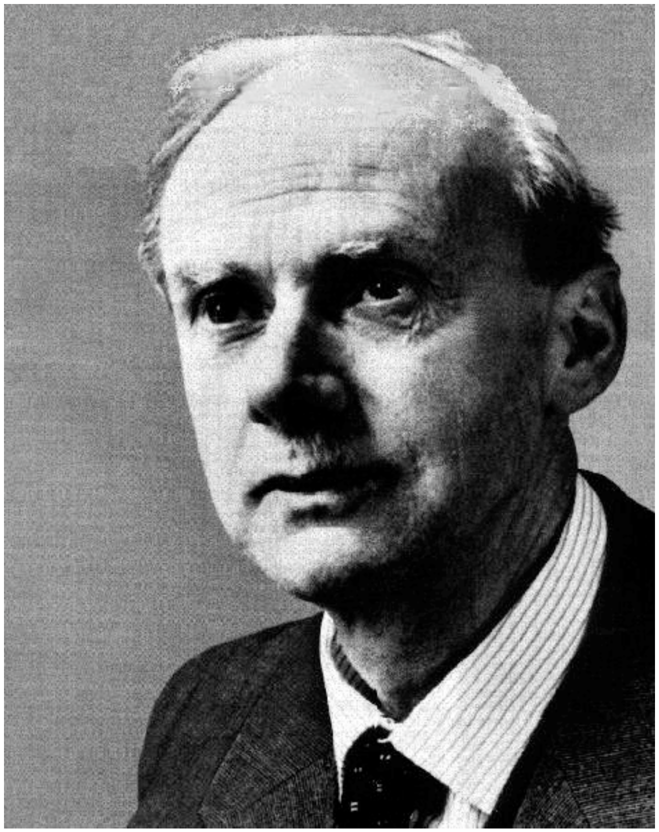
Dirac



charge quantization

Proc. Roy. Soc. Lond. A133 (1931) 60

Dirac



non-local action?

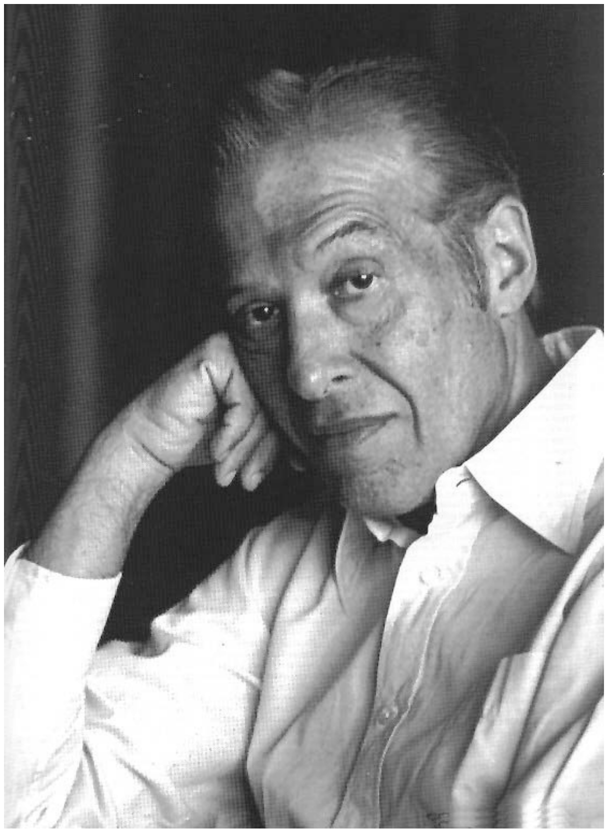
$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + {}^*G_{\mu\nu}$$

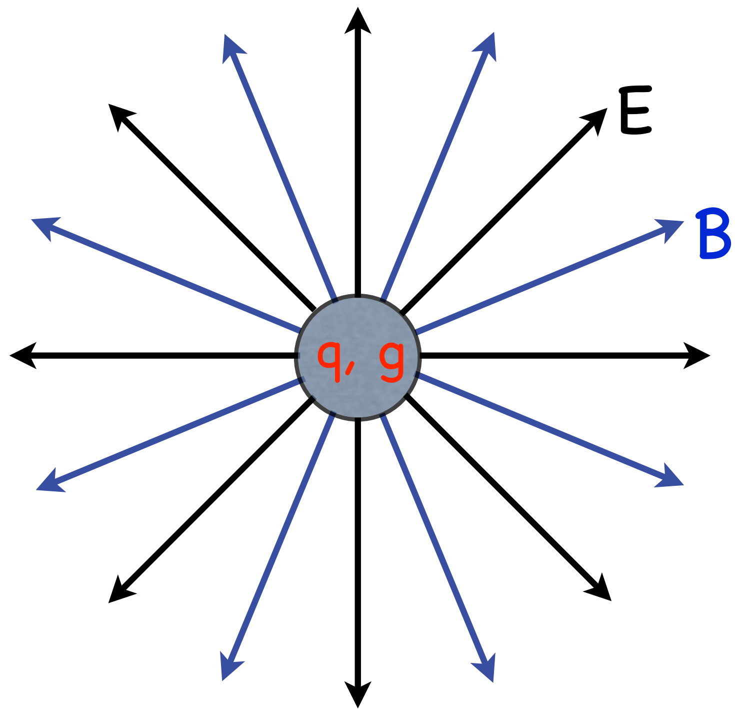
$$G_{\mu\nu}(x) = 4\pi\,(n\cdot\partial)^{-1}\left[n_\mu\,k_\nu(x) - n_\nu\,k_\mu(x)\right]$$
$$= \int (\mathrm{d}y)\left[f_\mu(x-y)\,k_\nu(y) - f_\nu(x-y)k_\mu(y)\right]$$

$$\partial_\mu f^\mu(x) = 4\pi\delta(x)$$
$$f^\mu(x) = 4\pi n^\mu\,(n\cdot\partial)^{-1}\,\delta(x)$$

Phys. Rev. 74 (1948) 817

Schwinger



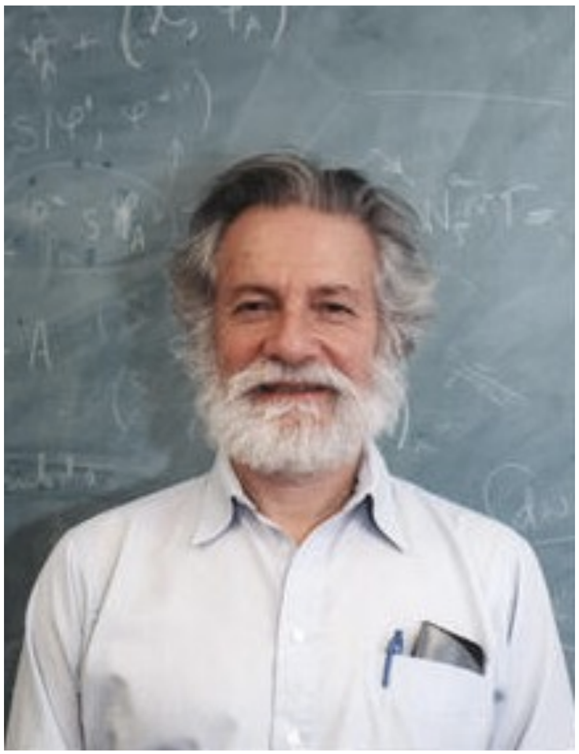


dyons

$$q_1 g_2 - q_2 g_1 = \frac{n}{2}$$

Science 165 (1969) 757

Zwanziger



non-Lorentz invariant, local action?

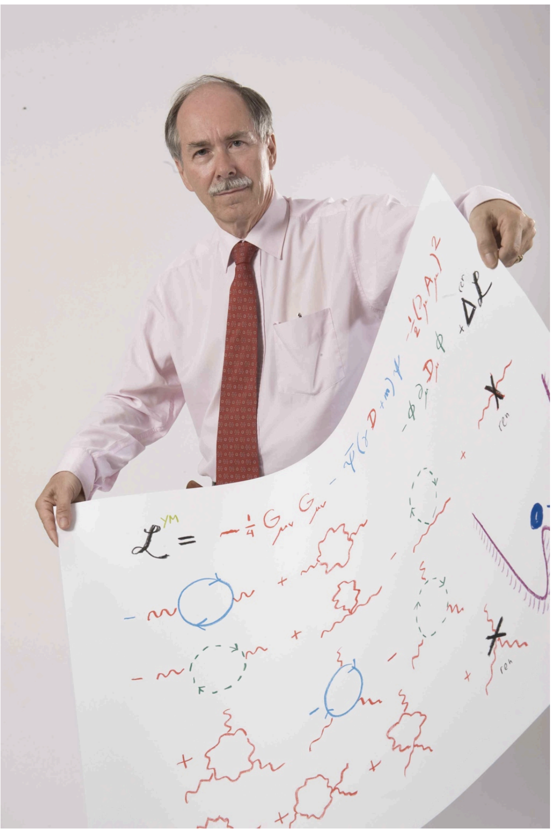
$$\mathcal{L} = -\frac{1}{2n^2e^2}\{[n\cdot(\partial\wedge A)]\cdot[n\cdot^*(\partial\wedge B)]-[n\cdot(\partial\wedge B)]\cdot[n\cdot^*(\partial\wedge A)] + [n\cdot(\partial\wedge A)]^2+[n\cdot(\partial\wedge B)]^2\} - J\cdot A - \frac{4\pi}{e^2}K\cdot B.$$

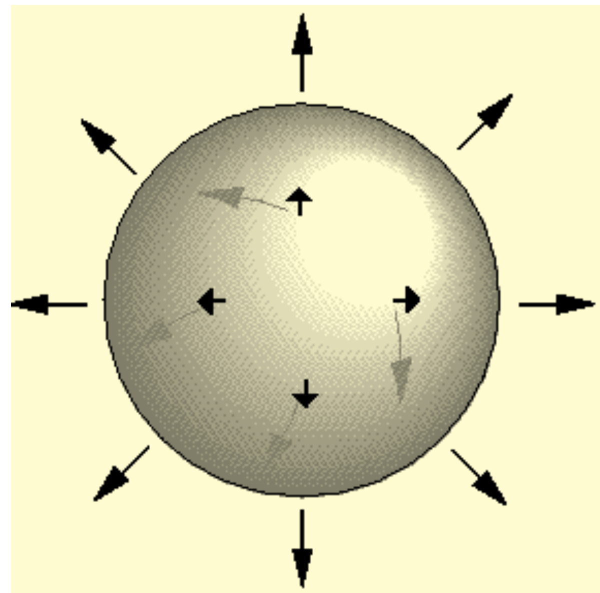
electric magnetic

$$F = \frac{1}{n^2}\left(\{n\wedge[n\cdot(\partial\wedge A)]\} - {}^*\{n\wedge[n\cdot(\partial\wedge B)]\}\right)$$

Phys. Rev. D3 (1971) 880

`t Hooft-Polyakov



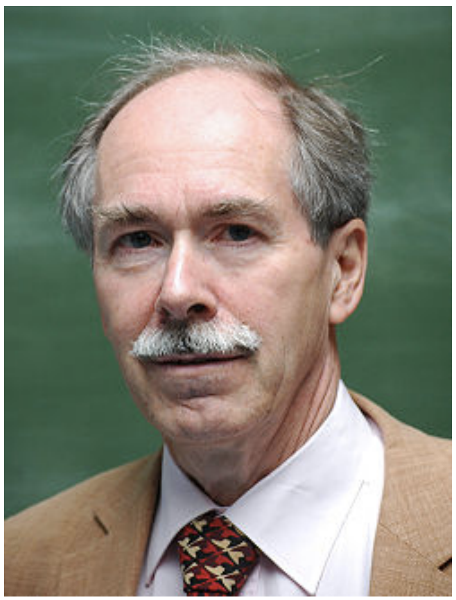


topological monopoles

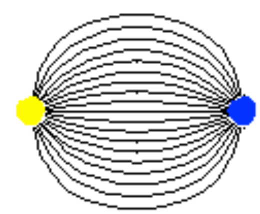
Nucl. Phys., B79 1974, 276

JETP Lett., 20 1974, 194

`t Hooft-Mandelstam

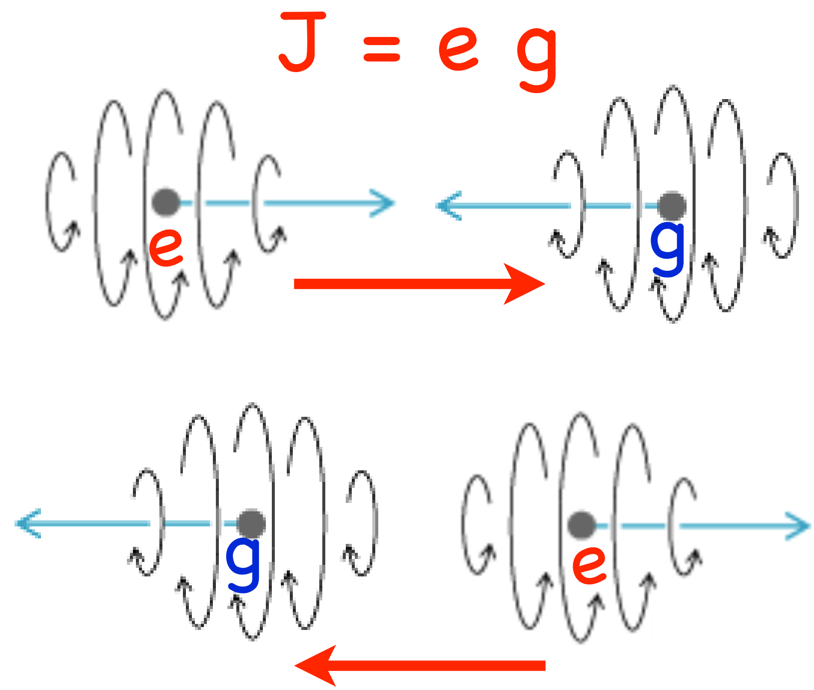


magnetic condensate
confines electric charge



High Energy Physics Ed. Zichichi, (1976) 1225
Phys. Rept. 23 (1976) 245

Rubakov-Callan

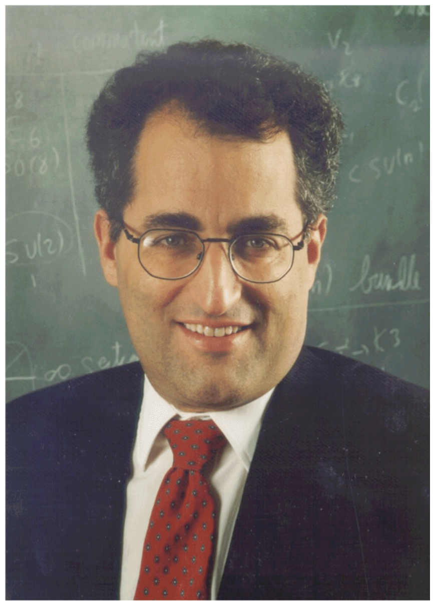


new unsuppressed contact interactions!

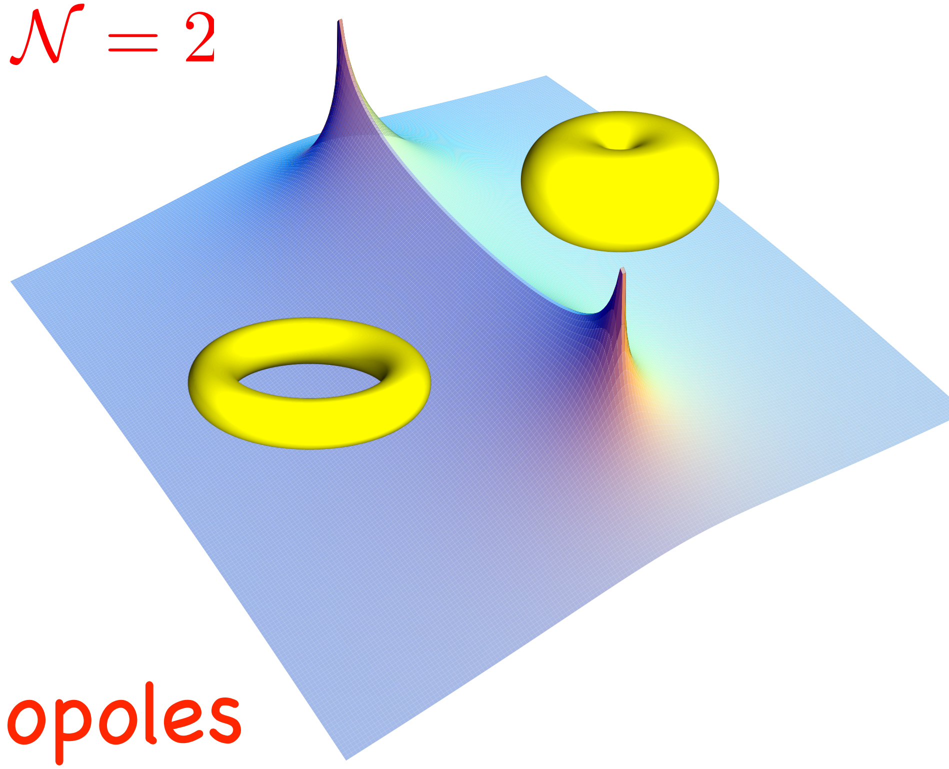
JETP Lett. 33 (1981) 644

Phys. Rev. D25 (1982) 2141

Seiberg-Witten



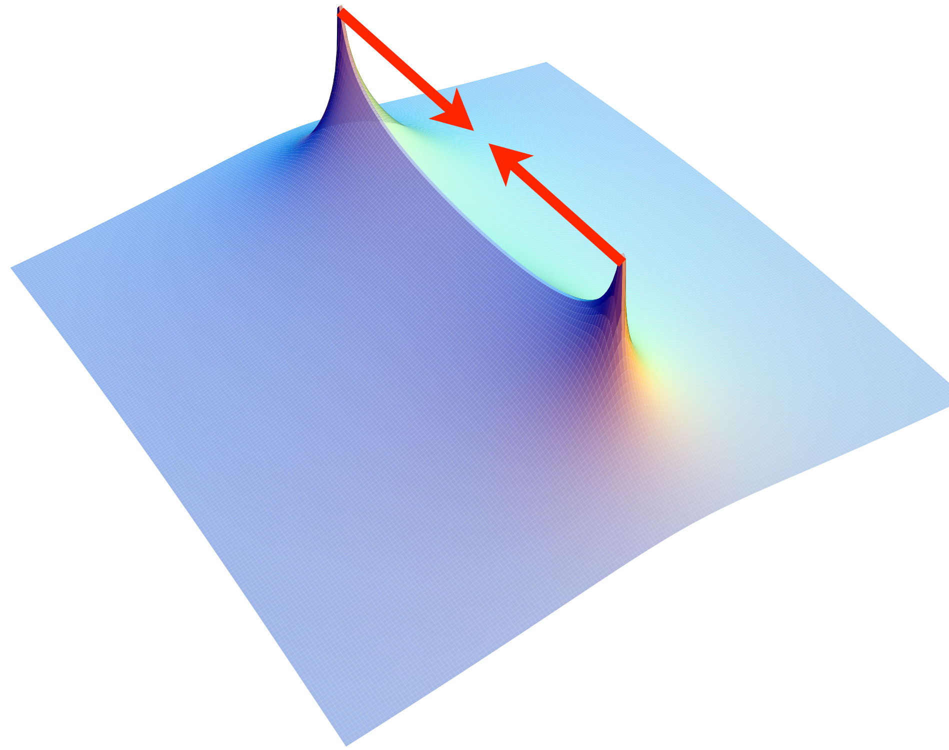
$\mathcal{N} = 2$



massless fermionic monopoles

hep-th/9407087

Argyres-Douglas



CFT with massless electric and magnetic charges

hep-th/9505062

Toy Model

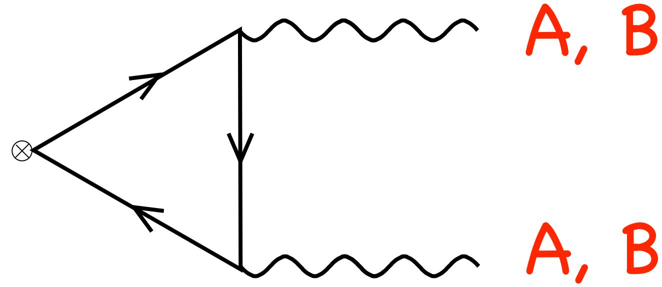
	$SU(3)_c$	$SU(2)_L$	$U(1)_Y : q$	$U(1)_Y : g$
Q	$\square$	$\square$	$\frac{1}{6}$	3
L	1	$\square$	$-\frac{1}{2}$	-9
$\bar{U}$	$\bar{\square}$	1	$-\frac{2}{3}$	-3
$\bar{D}$	$\bar{\square}$	1	$\frac{1}{3}$	-3
$\bar{N}$	1	1	0	9
$\bar{E}$	1	1	1	9

$$q_i g_j - q_j g_i = \frac{n}{2}$$

is this anomaly free?

Anomalies

$$\mathcal{L} = -\frac{1}{2n^2e^2}\{[n\cdot(\partial\wedge A)]\cdot[n\cdot^*(\partial\wedge B)]-[n\cdot(\partial\wedge B)]\cdot[n\cdot^*(\partial\wedge A)]$$
$$+[n\cdot(\partial\wedge A)]^2+[n\cdot(\partial\wedge B)]^2\}-J\cdot A-\frac{4\pi}{e^2}K\cdot B.$$



Toy Model

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y : q$	$U(1)_Y : g$
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$$\sum_j q_j^3 = 0\ , \quad \sum_j g_j^3 = 0\ , \quad \sum_j g_j^2 q_j = 0\ , \quad \sum_j q_j^2 g_j = 0\ , \quad \sum_j q_j = 0\ , \quad \sum_j g_j = 0\ ,$$

$$\sum_j \mathrm{Tr}\, T^a_{r_j} T^b_{r_j} q_j = 0\ , \quad \sum_j \mathrm{Tr}\, \tau^a_{r_j} \tau^b_{r_j} q_j = 0\ , \quad \sum_j \mathrm{Tr}\, T^a_{r_j} T^b_{r_j} g_j = 0\ , \quad \sum_j \mathrm{Tr}\, \tau^a_{r_j} \tau^b_{r_j} g_j = 0$$

Dynamics

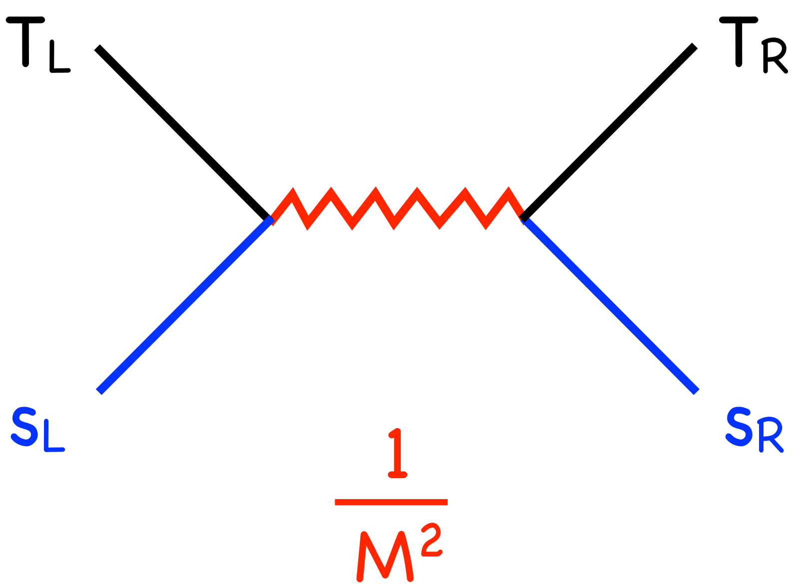
	$SU(3)_c$	$SU(2)_L$	$U(1)_Y : q$	$U(1)_Y : g$
Q	$\square$	$\square$	$\frac{1}{6}$	3
L	1	$\square$	$-\frac{1}{2}$	-9
$\bar{U}$	$\bar{\square}$	1	$-\frac{2}{3}$	-3
$\bar{D}$	$\bar{\square}$	1	$\frac{1}{3}$	-3
$\bar{N}$	1	1	0	9
$\bar{E}$	1	1	1	9

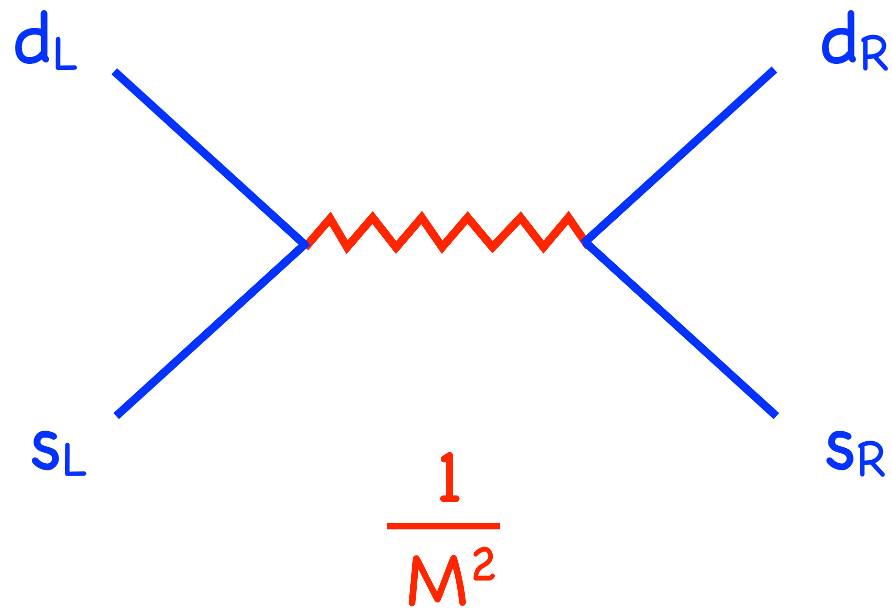
$$\left(\frac{1}{6}\right)^2 \alpha_Y 3^2 \alpha_m = \frac{1}{4}$$

$$\alpha_m \sim 98$$

Quark Masses

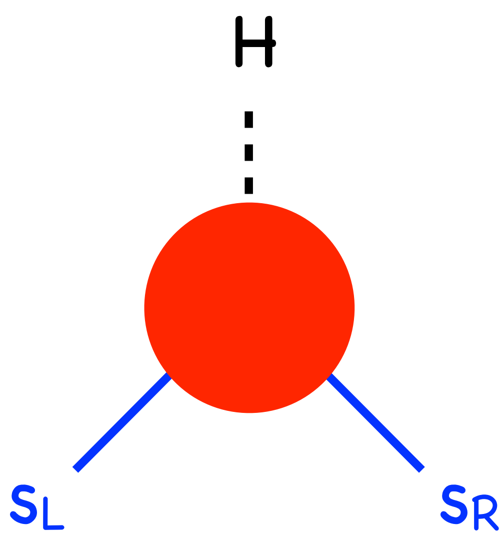
technicolor: fail



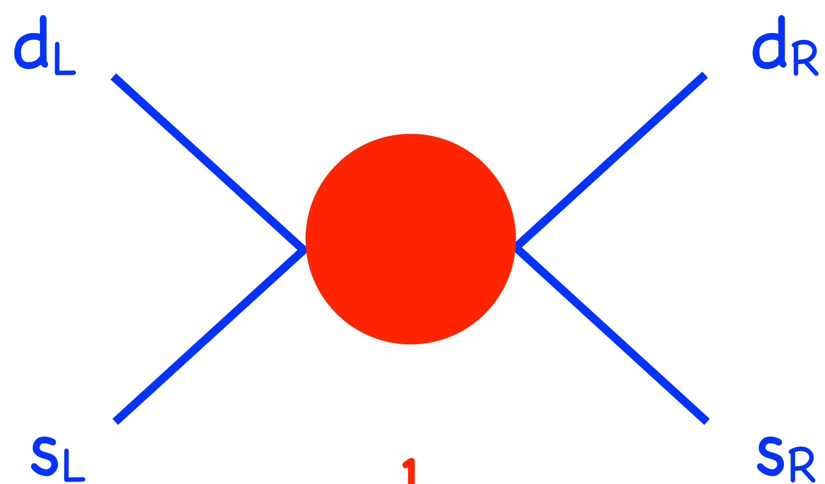


Quark Masses

Standard Model



$\log(M)$

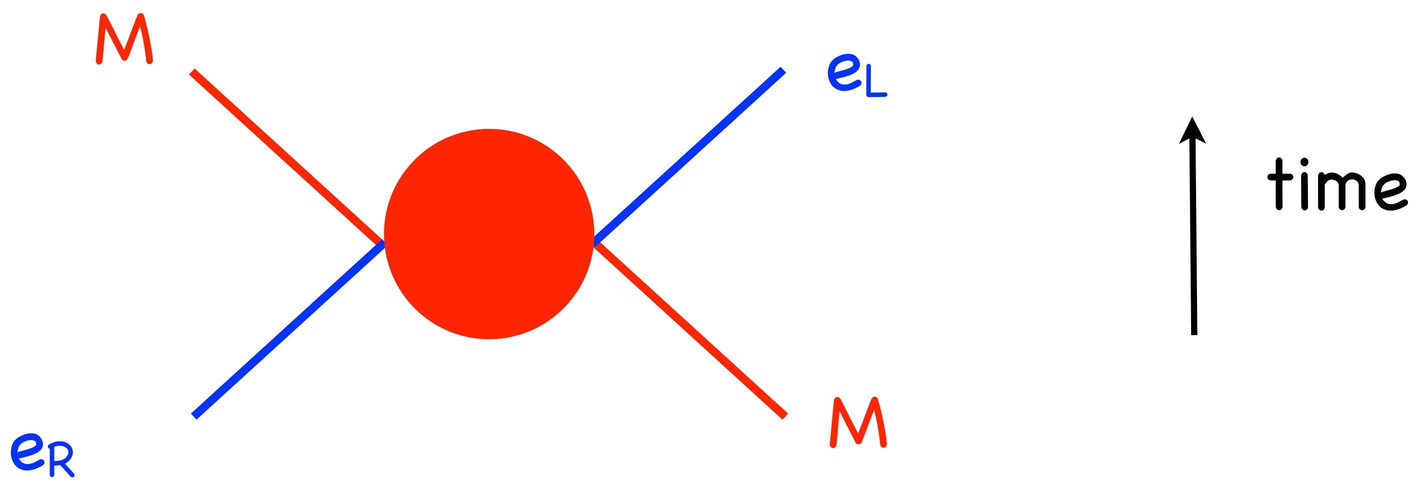


$\frac{1}{M^2}$

Rubakov-Callan

$J_f = -q\ g = 1/2$

$S_f = -1/2$



$J_i = q\ g = -1/2$

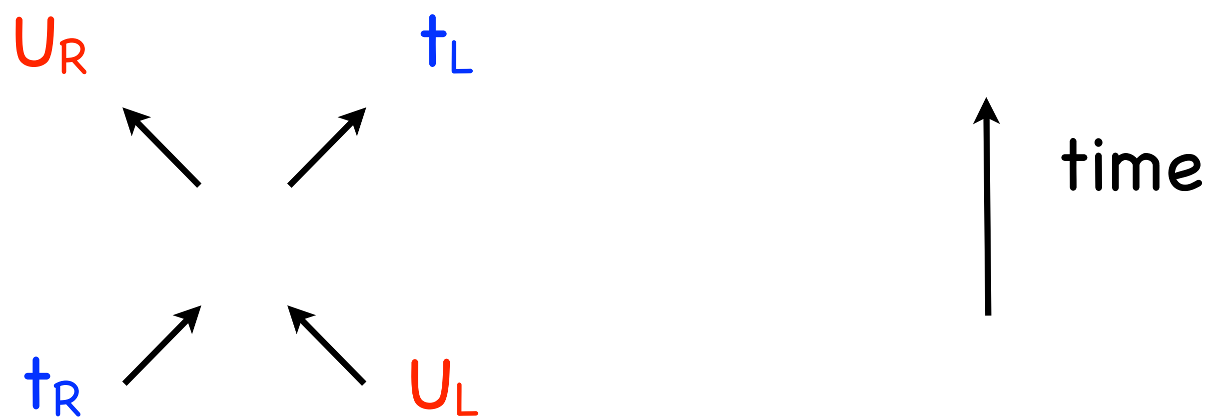
$S_i = 1/2$

New dimension 4, four particle operator

Four Fermion Ops

$J_f = -q\ g = -1/2$

$S_f = -1$



$J_i = q\ g = 2$

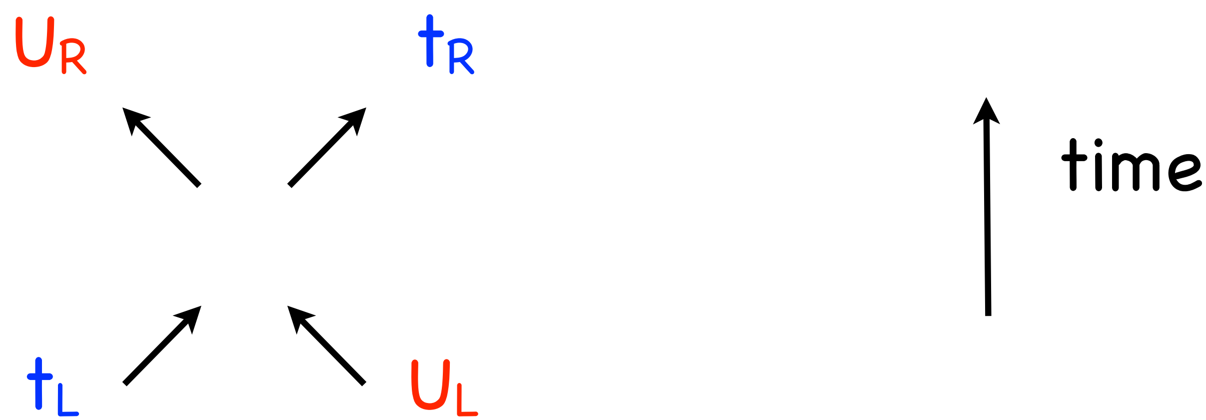
$S_i = 1$

fail!

Four Fermion Ops

$J_f = -q\ g = -2$

$S_f = 0$



$J_i = q\ g = 1/2$

$S_i = 0$

fail!

non-Abelian magnetic charge

$$Q = T^3 + Y$$

$$Q_m = T^3_m + Y_m$$

explicit examples known in GUT models

EWSB is forced to align with the monopole charge

non-Abelian magnetic charge

$$\vec{B}^a_Y = \frac{g}{g_Y}\,\frac{\hat{r}}{r^2}$$

$$\vec{B}^a_L = \delta^{a3}_L\,\frac{g\,\beta_L}{g_L}\,\frac{\hat{r}}{r^2}$$

$$\vec{B}^a_c = \delta^{a8}_c\,\frac{g\,\beta_c}{g_c}\,\frac{\hat{r}}{r^2}$$

$$4\pi\left(T^8_c\,g\,\beta_c + T^3_L\,g\,\beta_L + Y g\right) = 2\pi n$$

non-Abelian magnetic charge

$$4\pi\left(T_c^8\, g\, \beta_c + T_L^3\, g\, \beta_L + Y g\right) = 2\pi n$$

$$eA^\mu = g_L A_L^{3\mu} + g_Y A_Y^\mu$$

$$\beta_L = 1$$

$$T_c^8\, g\, \beta_c + q\, g = \frac{n}{2}$$

The Model

$$(SU(3)_c \times SU(2)_L \times U(1)_Y)/Z_6$$

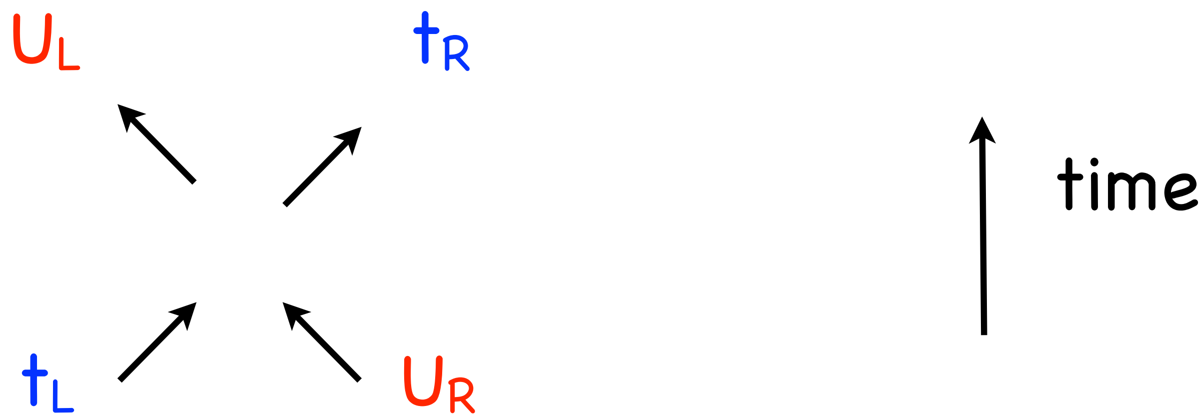
	$SU(3)_c$	$SU(2)_L$	$U(1)^{el}_Y$	$U(1)^{mag}_Y$
Q_L	$\Box^m$	$\Box^m$	$\frac{1}{6}$	$\frac{1}{2}$
L_L	1	$\Box^m$	$-\frac{1}{2}$	$-\frac{3}{2}$
U_R	$\Box^m$	1^m	$\frac{2}{3}$	$\frac{1}{2}$
D_R	$\Box^m$	1^m	$-\frac{1}{3}$	$\frac{1}{2}$
N_R	1	1^m	0	$-\frac{3}{2}$
E_R	1	1^m	-1	$-\frac{3}{2}$

$$\alpha_m = \frac{1}{4\alpha} \approx 32$$

Four Fermion Ops

$$J_f = -\left(\frac{1}{3}\cdot 1 + \frac{2}{3}\cdot 1\right)$$

$$S_f = +1$$



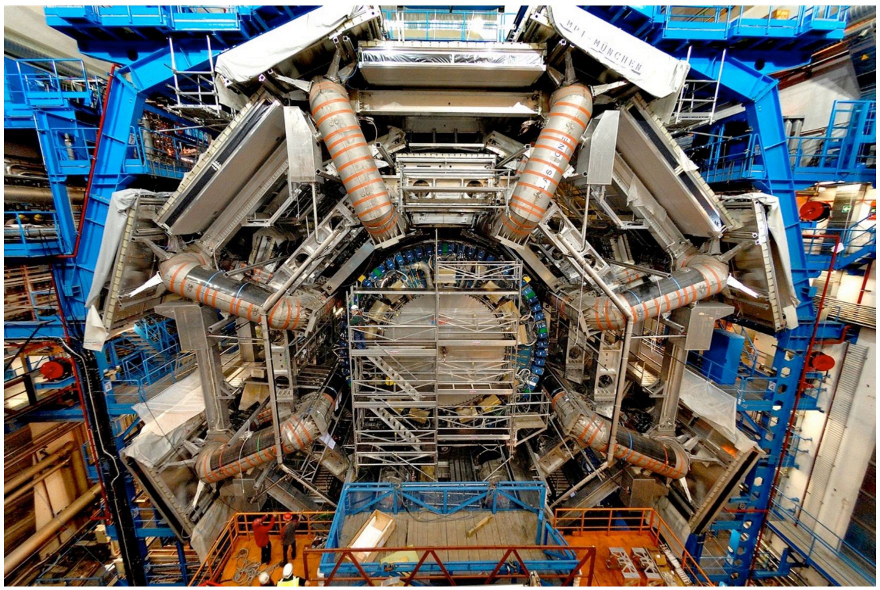
$$J_i = \frac{1}{3} + \left(\frac{1}{2} + \frac{1}{6}\right)\cdot 1$$

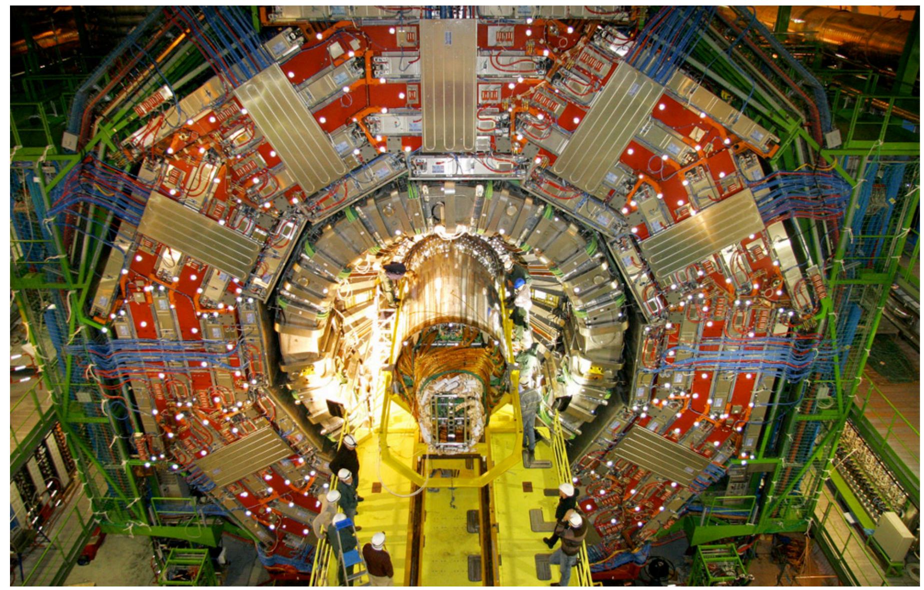
$$S_i = -1$$

hooray!

LHC

naively expect pair production,
unconfined, highly ionizing



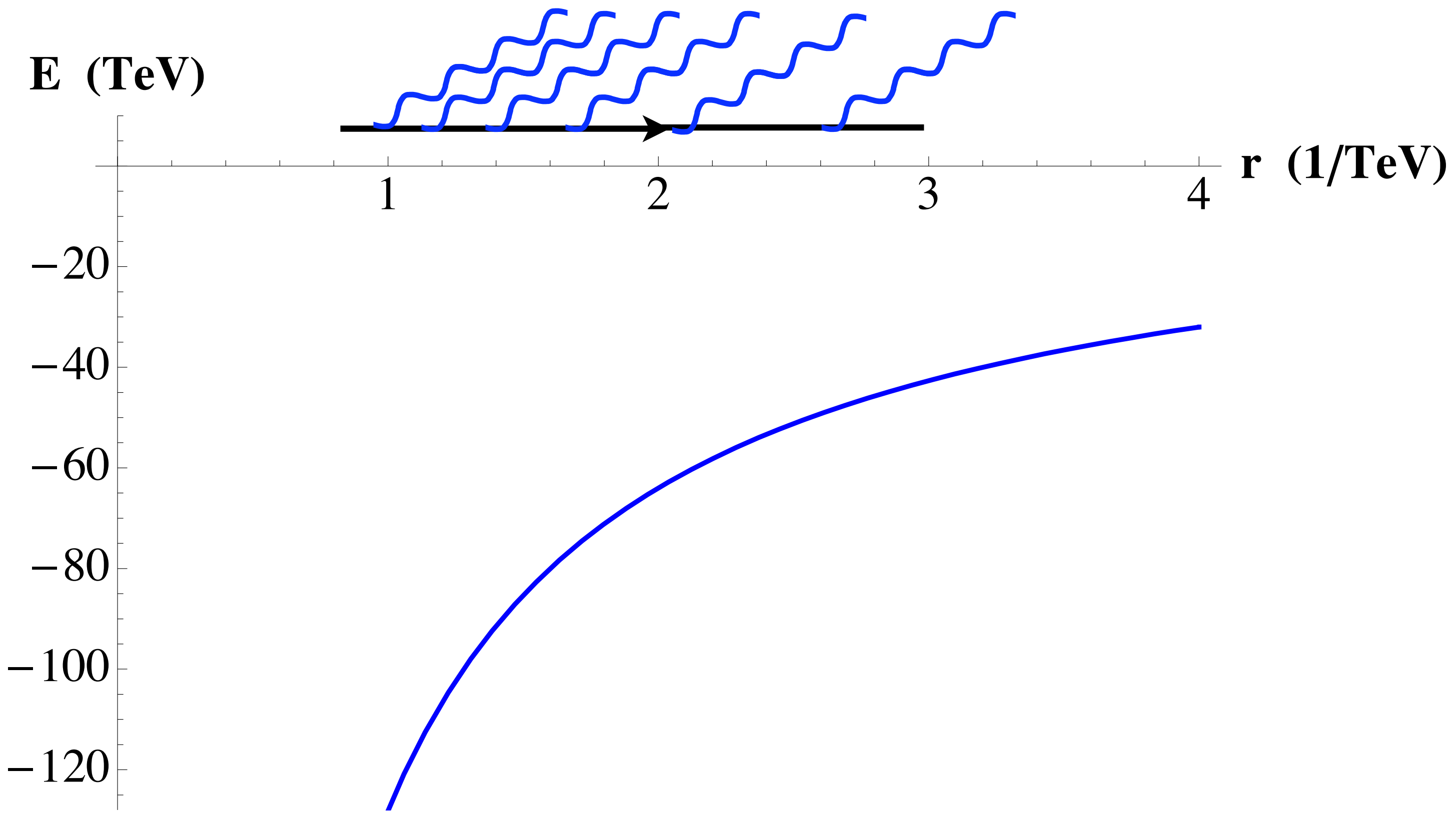


ATLAS has a trigger for monopoles

CMS does not

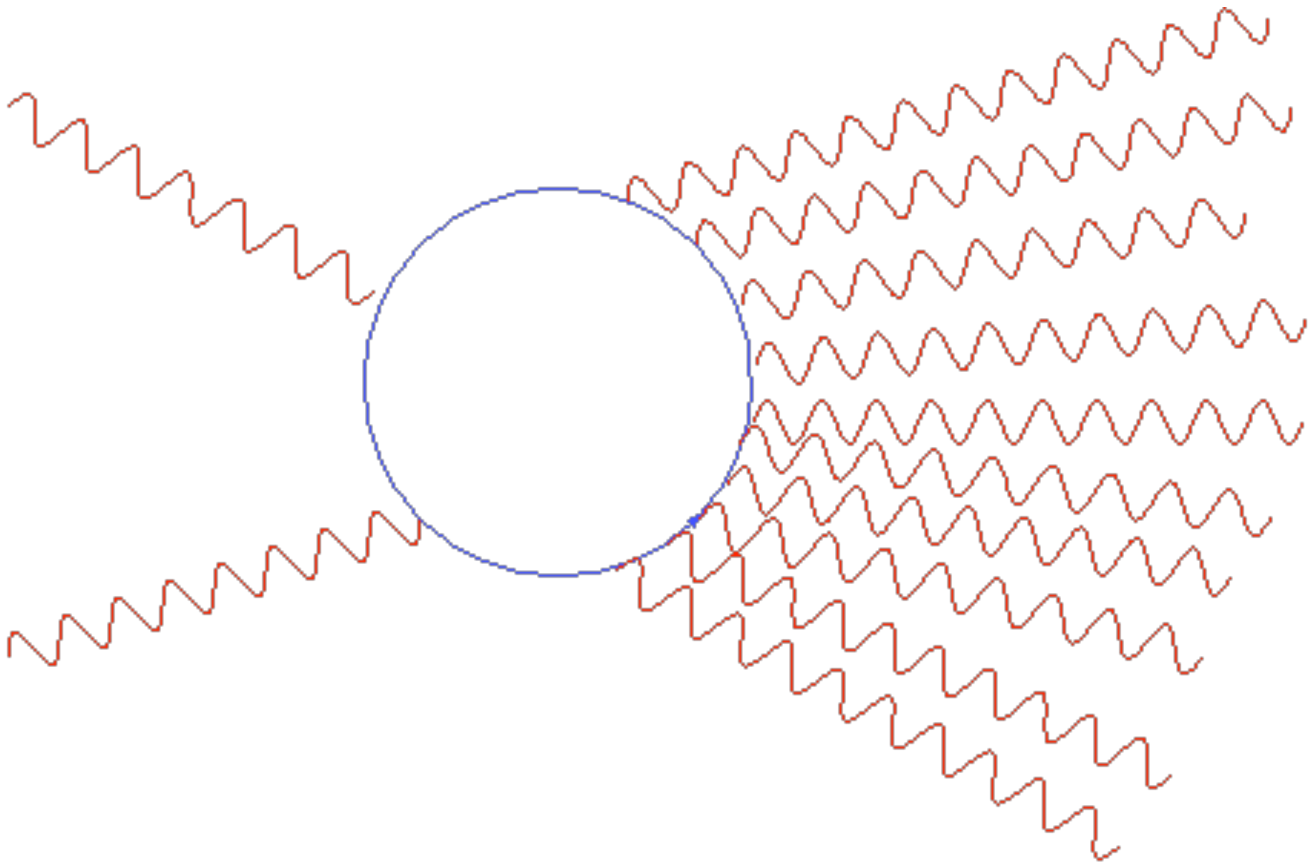
but it won't work

Bremstrahlung



Andersen, Grojean, Weiler, JT

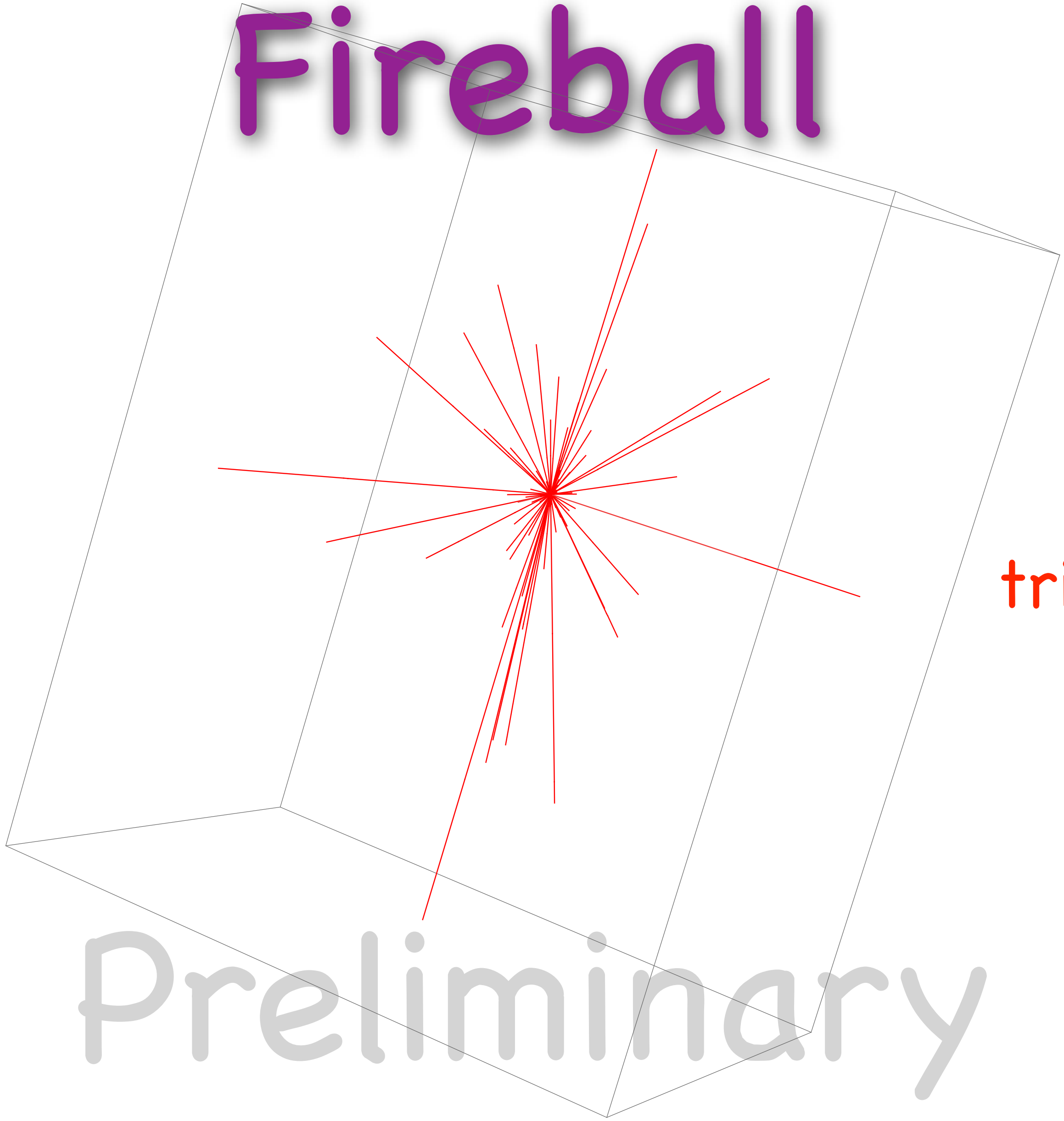
Annihilation



Heisenberg and Euler,

Z. Phys. **98**, 714 (1936) arXiv:physics/0605038

Fireball



CMS has a trigger for this

Andersen, Grojean, Weiler, JT

Conclusions

Monopoles are still fascinating
after all these years

monopoles can break EWS and give the
top quark a large mass

monopole phenomenolgy is pushing
at the boundaries of MC4BSM

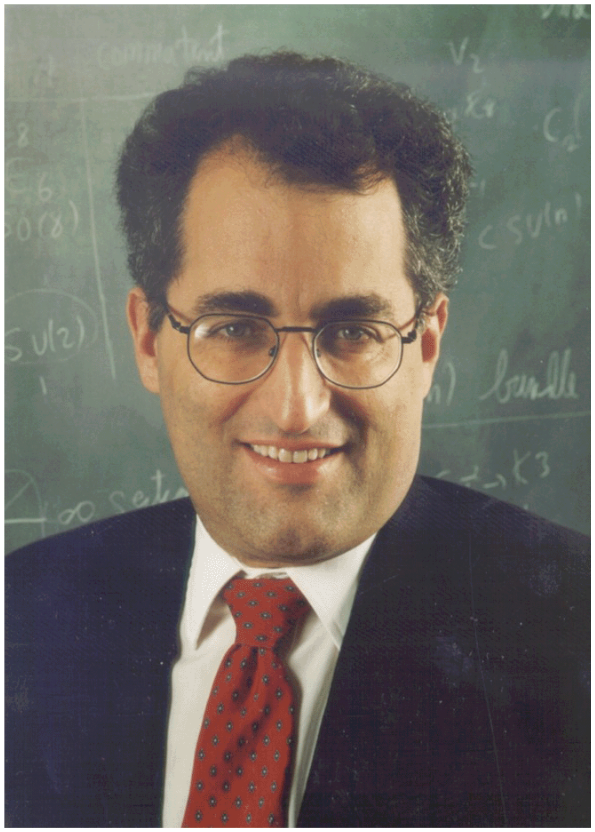
CP

$$e_\alpha \to \sigma^2_{\alpha\dot{\alpha}} e^{\dagger\dot{\alpha}}$$

$$\begin{aligned} (q, g) &\quad\to\quad (-q, g) \\ (q, -g) &\quad\to\quad (-q, -g) \end{aligned}$$

$$\mathcal{L}_{\text{int}} = -\chi^\dagger \left(q\, A_\mu + \tilde{g}\, B_\mu\right) \bar{\sigma}^\mu \chi - \psi^\dagger \left(q\, A_\mu - \tilde{g}\, B_\mu\right) \bar{\sigma}^\mu \psi$$

Witten



effective charge shifted

$$\mathcal{L}_{\text{free}} = -\frac{1}{4e^2}F^{\mu\nu}F_{\mu\nu} - \frac{\theta}{32\pi^2}F^{\mu\nu}\,{}^*F_{\mu\nu}$$

$$q_{\text{eff},j} = q_j + g_j\frac{\theta}{2\pi}$$

Phys. Lett. B86 (1979) 283

non-Abelian magnetic charge

$$(SU(2)_L \times U(1)_Y)/Z_2$$

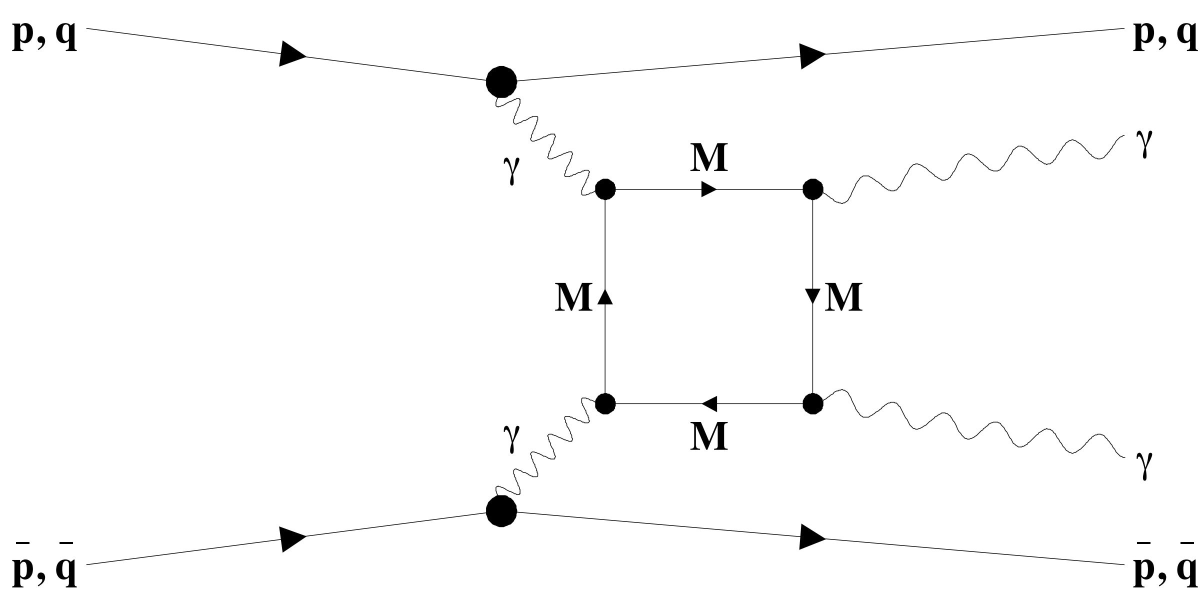
$$Q = T^3 + Y$$

Y integer

$$\begin{aligned} e^{2\pi i Q} &= e^{2\pi i T^3} e^{2\pi i Y} \\ &= \text{diag}(e^{i\frac{1}{2}2\pi}, e^{-i\frac{1}{2}2\pi}) \\ &= Z \end{aligned}$$

Z element of center of $SU(2)$

Phenomenology



uncontrolled perturbation theory

Ginzburg, Schiller hep-th/9802310