Monopoles and Electroweak Symmetry Breaking

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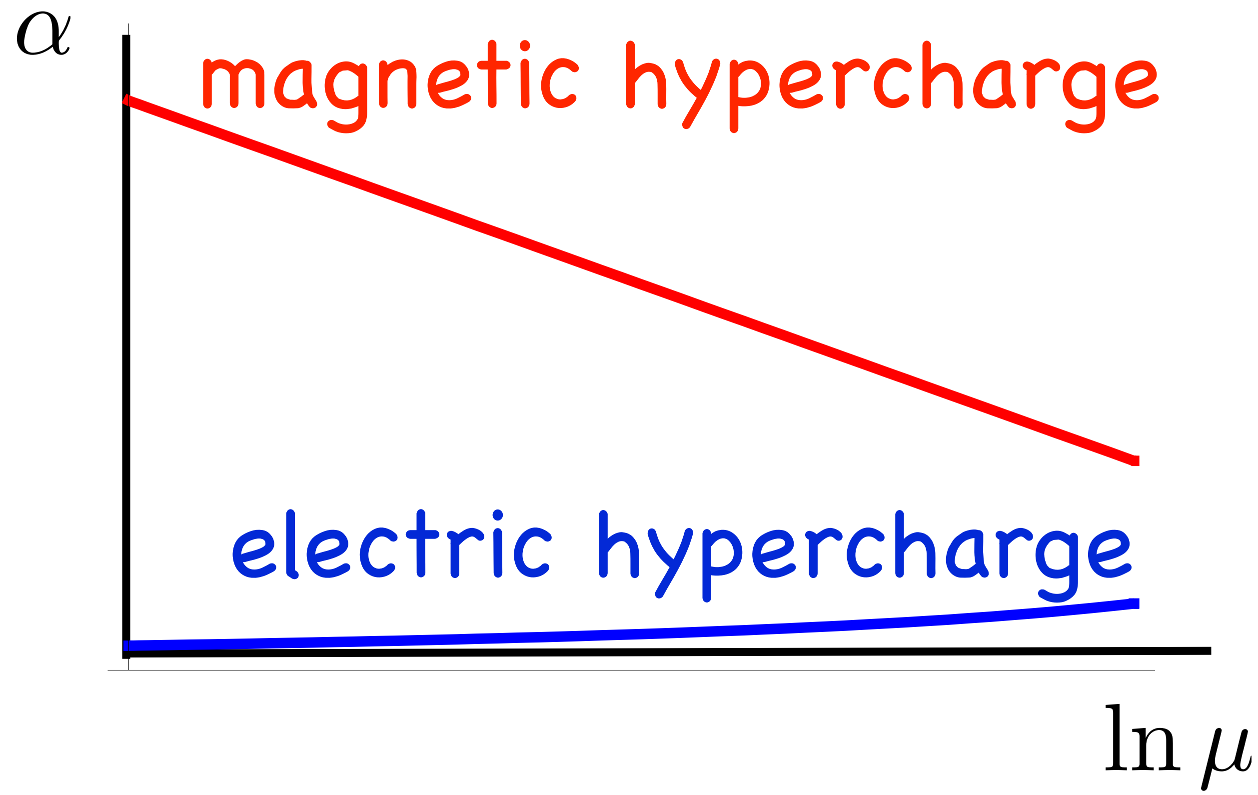
with Csaba Csáki, Yuri Shirman
hep-ph/1003.1718

Outline

* Motivation
* A Brief History of Monopoles
* Models
* LHC
* Conclusions

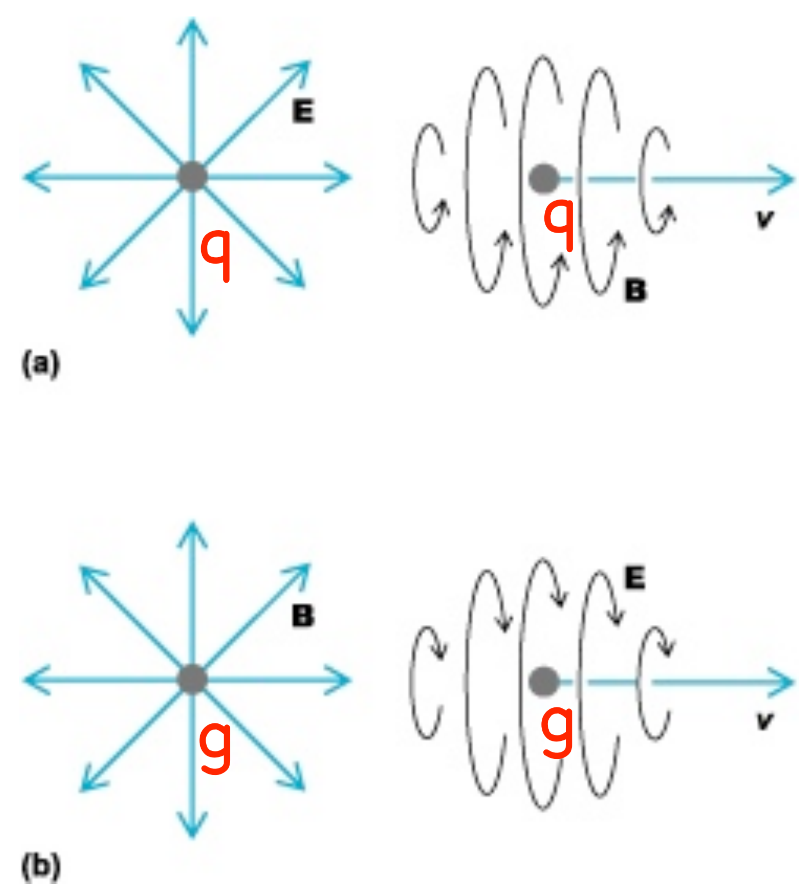
The Vision Thing

consistent theory of massless dyons?

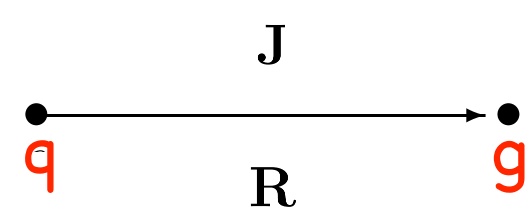


chiral symmetry breaking -> EWSB?

J.J. Thomson

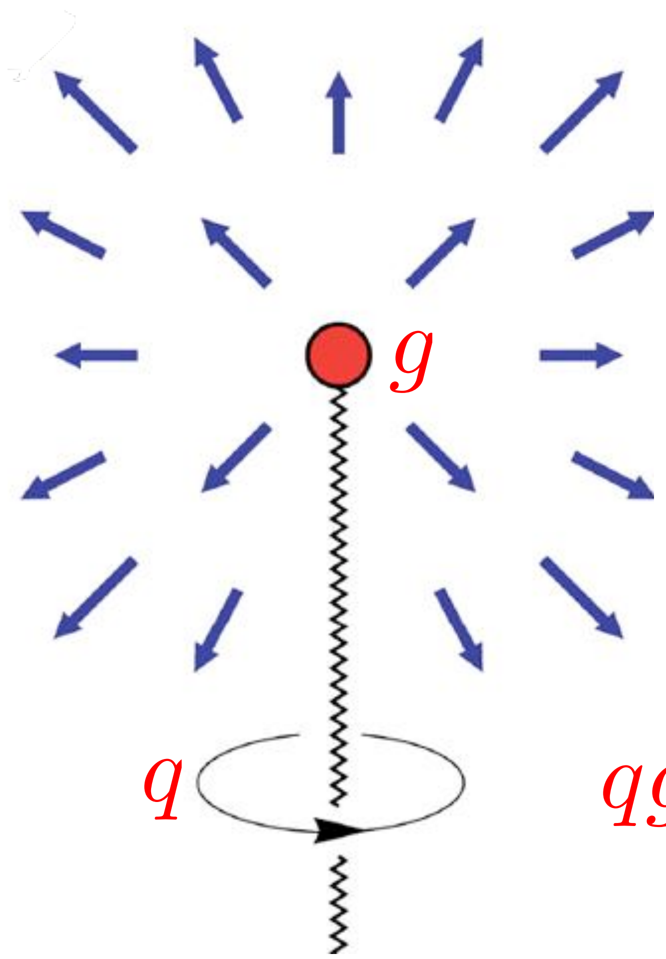


$$J = q\ g$$



Philos. Mag. 8 (1904) 331

Dirac

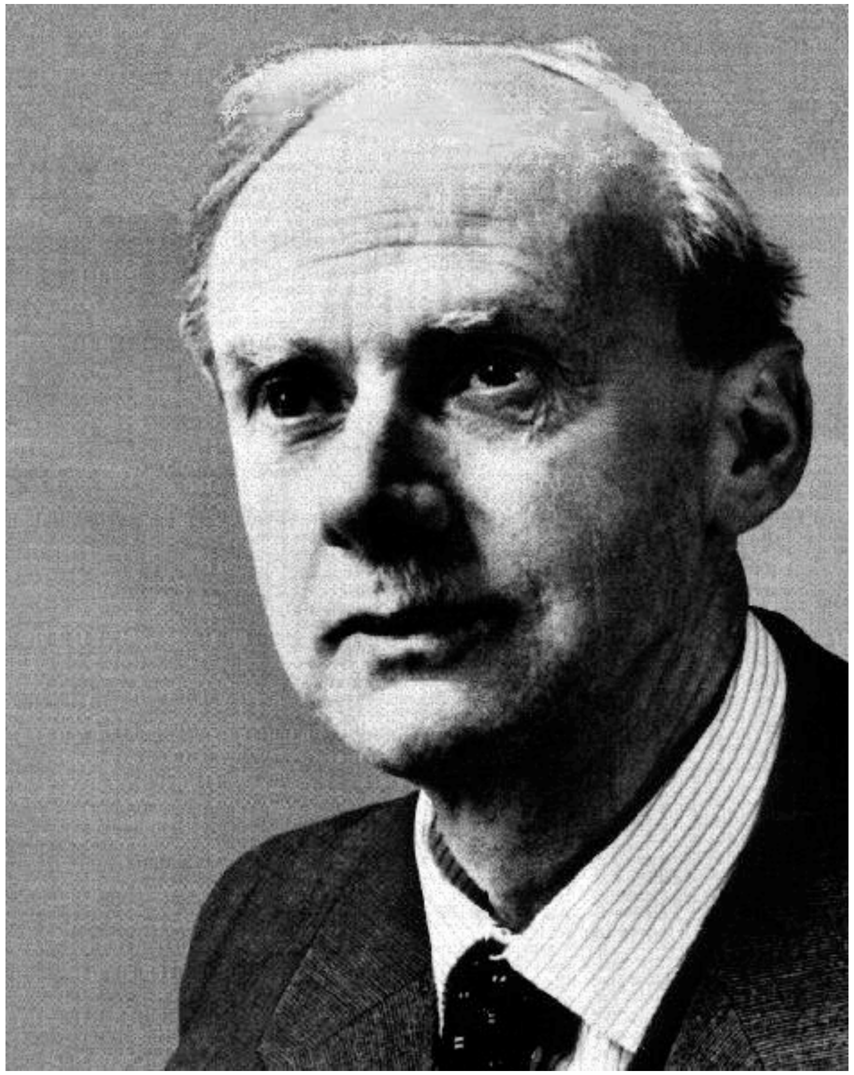


$$qg = \frac{n}{2}$$

charge quantization

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

Dirac



non-local action?

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

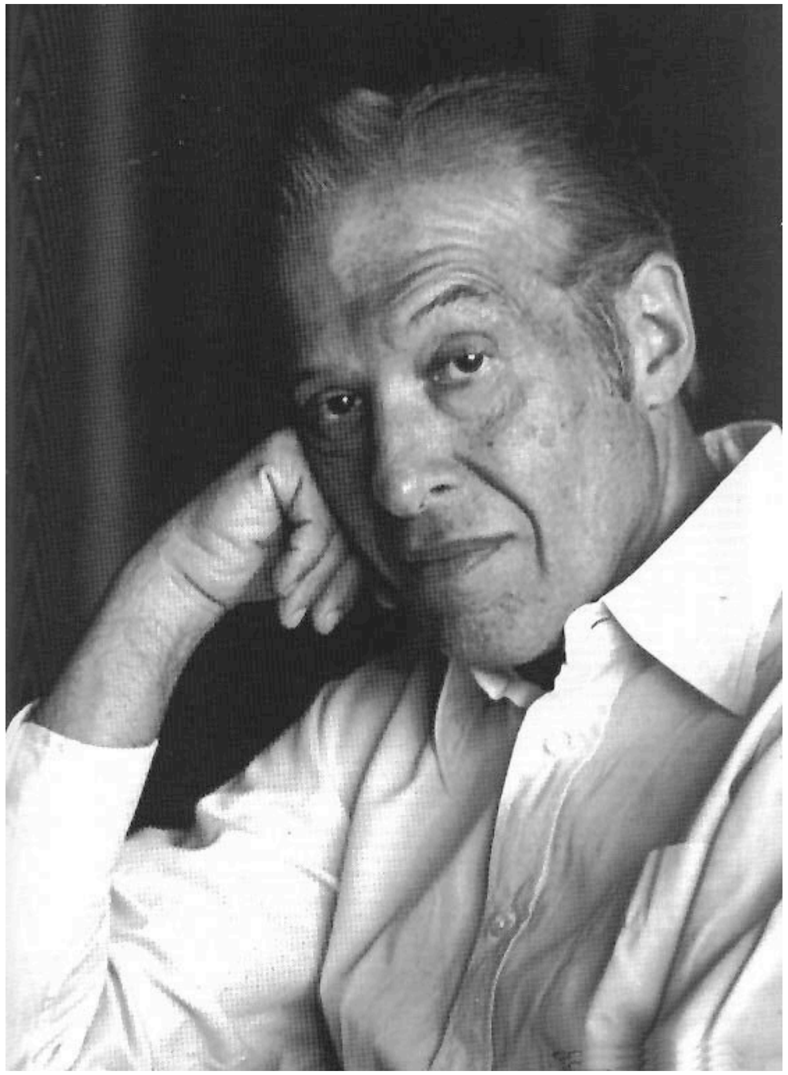
$$\begin{aligned} G_{\mu\nu}(x) &= 4\pi(n\cdot\partial)^{-1}\left[n_\mu K_\nu(x) - n_\nu K_\mu(x)\right] \\ &= \int d^4y\,\left[f_\mu(x-y)K_\nu(y) - f_\nu(x-y)K_\mu(y)\right] \end{aligned}$$

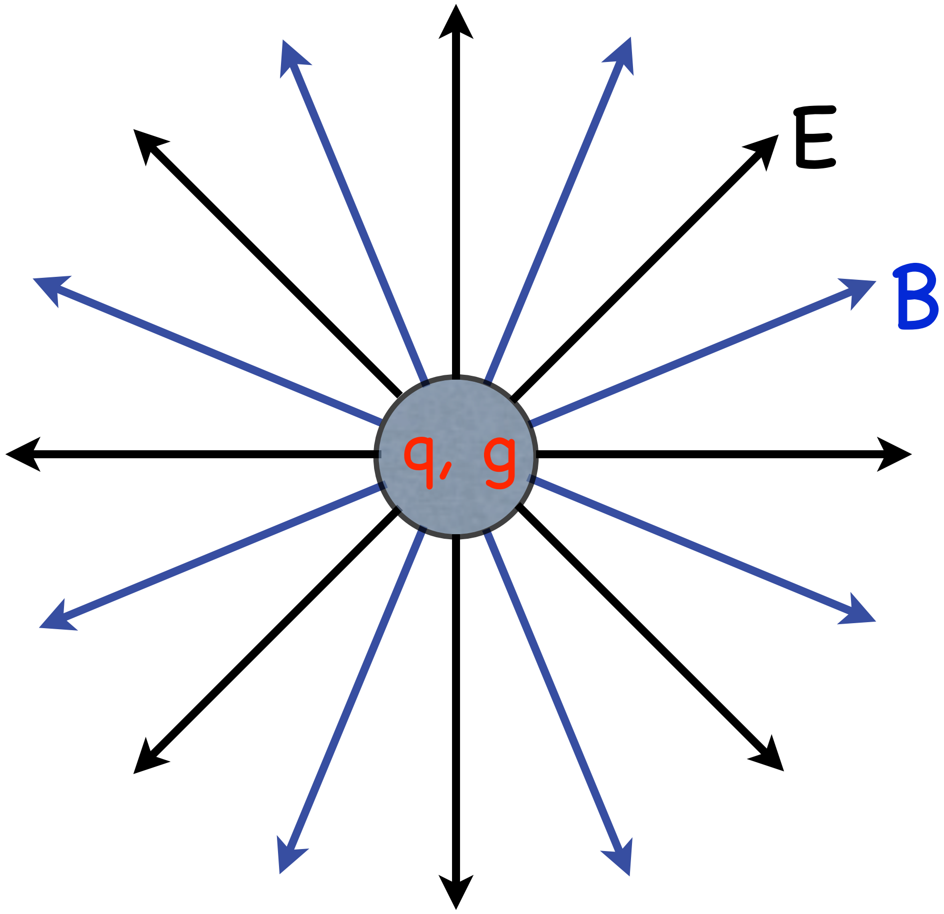
$$\partial_\mu f^\mu(x) = 4\pi\delta(x)$$

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

Phys. Rev. 74 (1948) 817

Schwinger



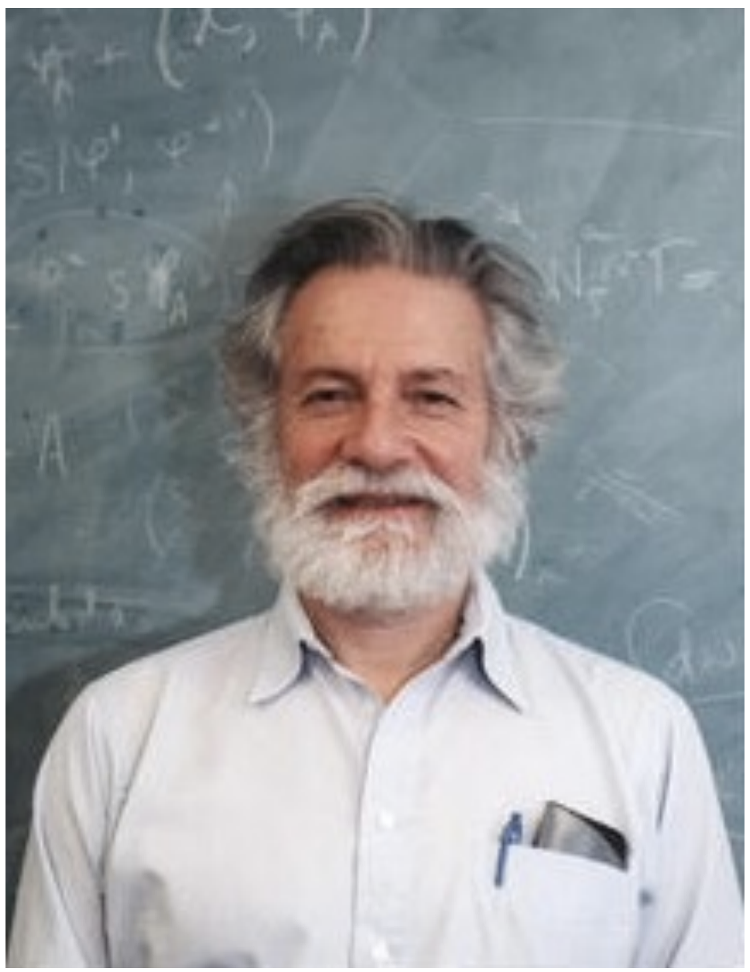


dyons

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

Science 165 (1969) 757

Zwanziger



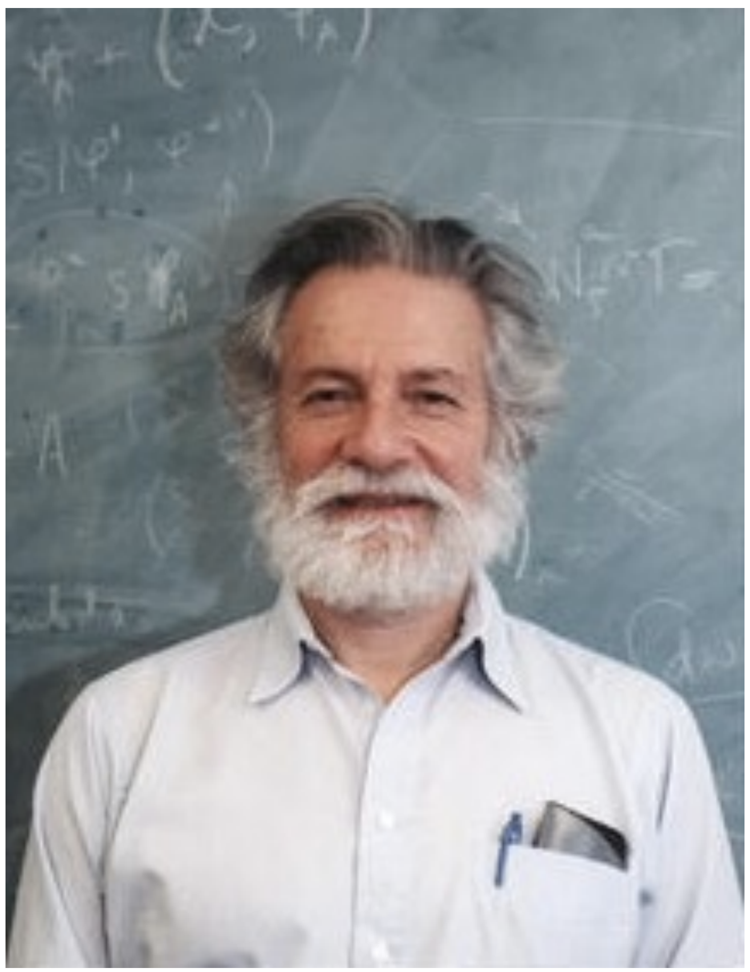
non-Lorentz invariant, local action?

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

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

Phys. Rev. D3 (1971) 880

Zwanziger



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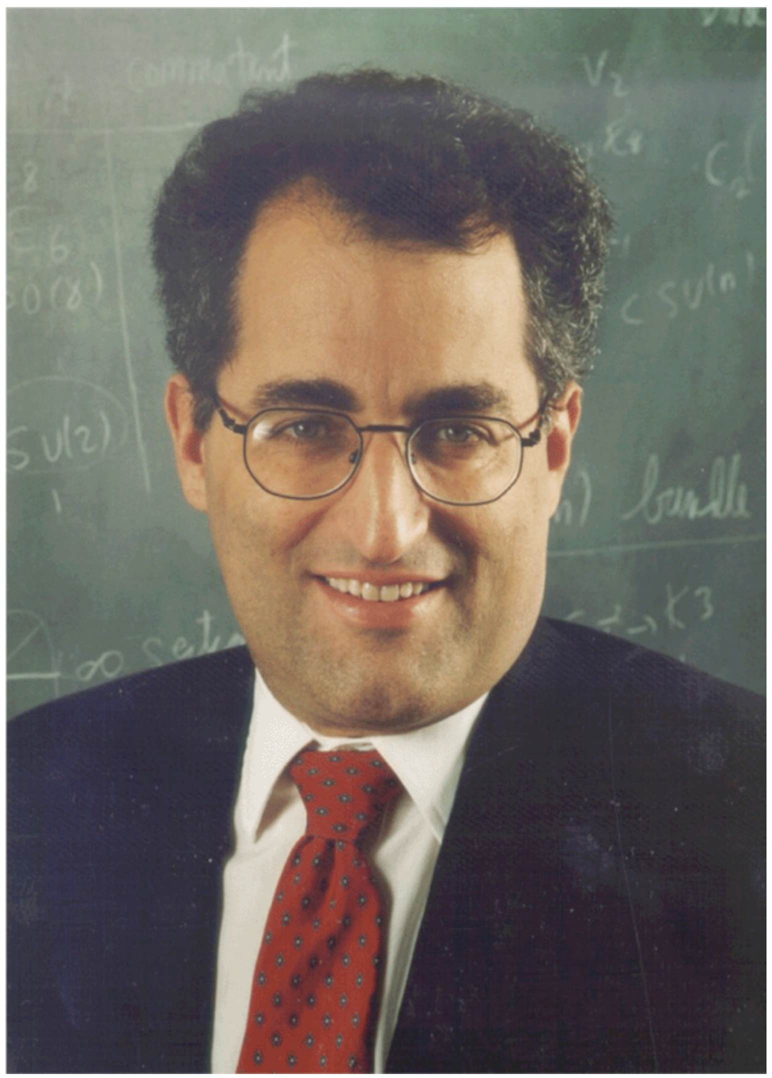
electric magnetic

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

Phys. Rev. D3 (1971) 880

Witten



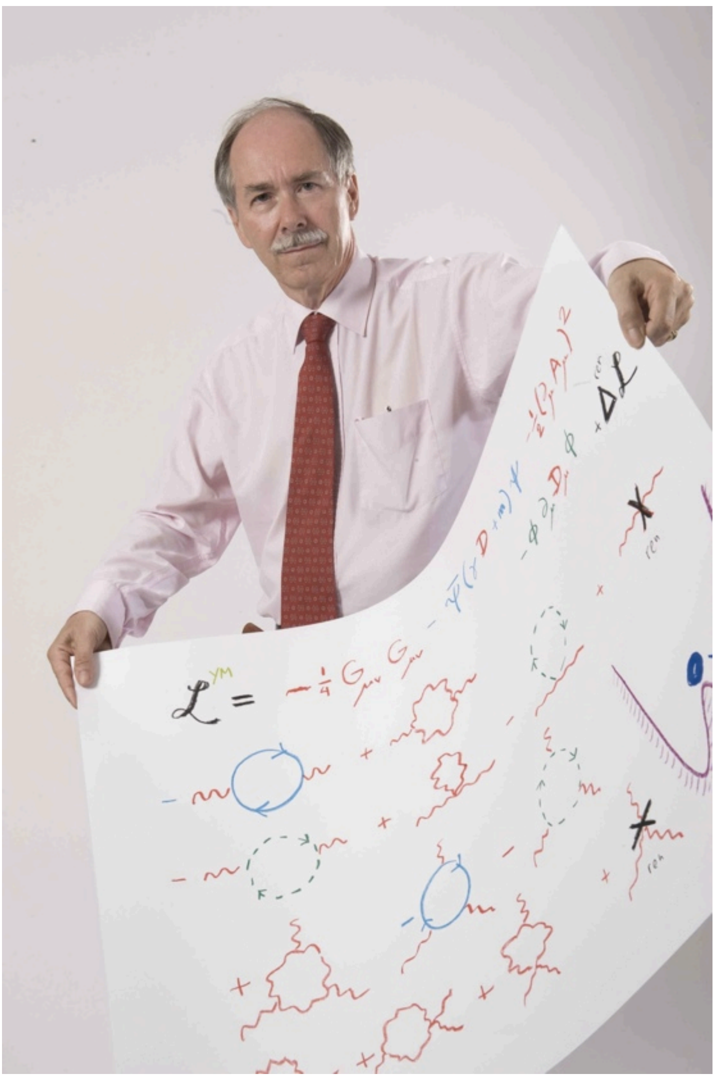
effective charge shifted

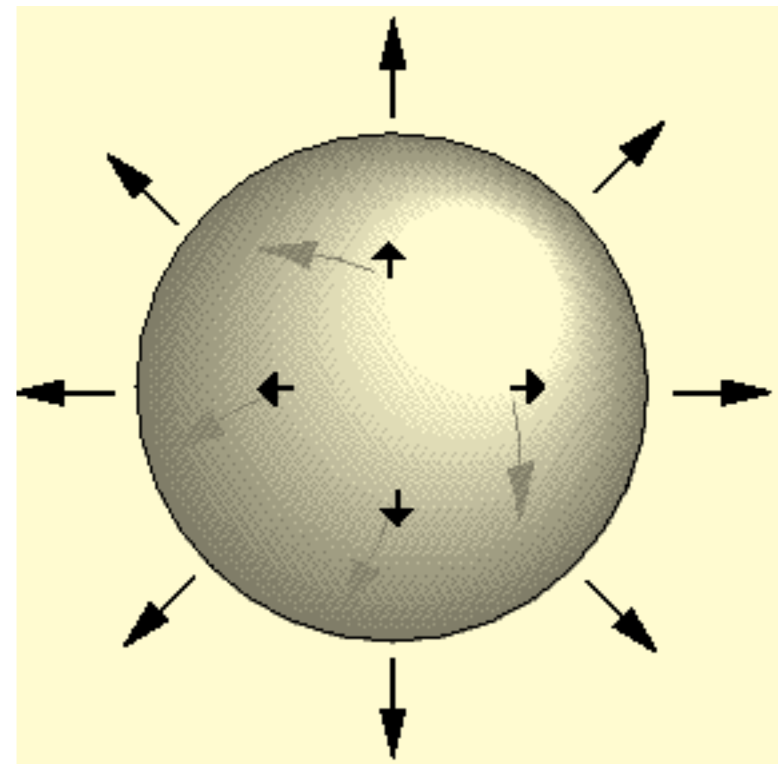
$$\mathcal{L}_{\rm free} = -\frac{1}{4e^2}F^{\mu\nu}F_{\mu\nu} - \frac{\theta}{32\pi^2}F^{\mu\nu}\,{}^*F_{\mu\nu}$$

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

Phys. Lett. B86 (1979) 283

`t Hooft-Polyakov

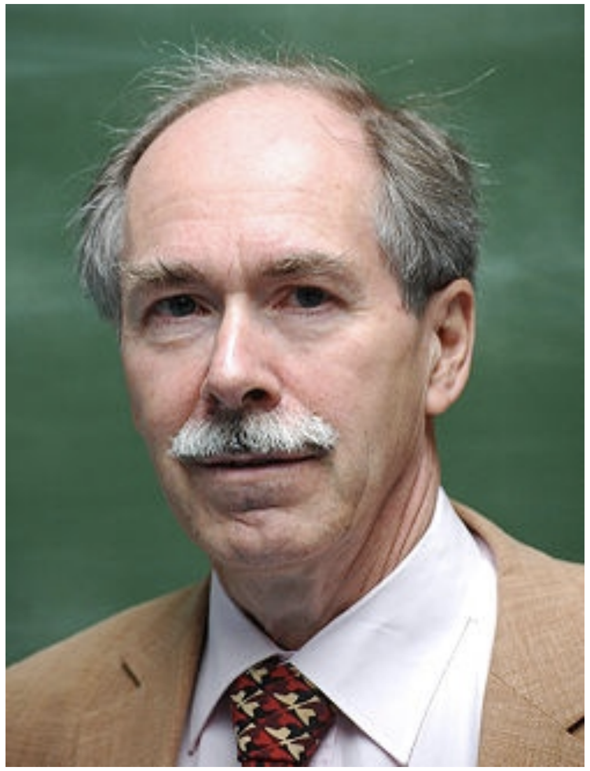




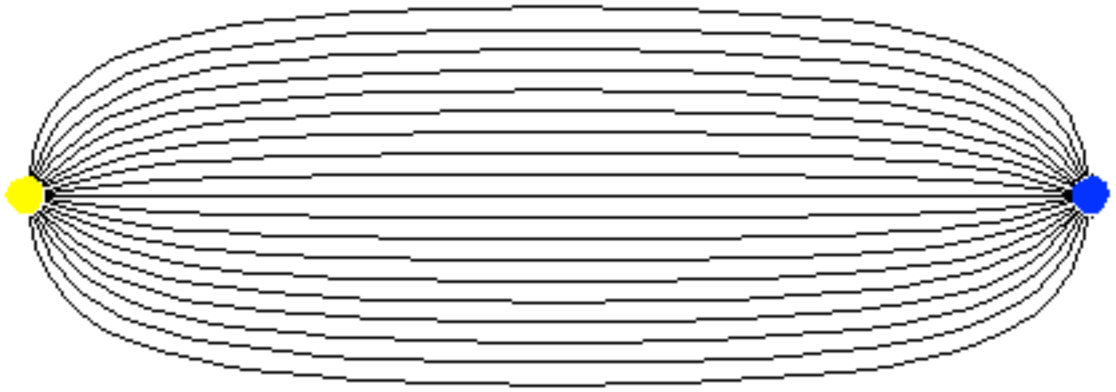
topological monopoles

Nucl. Phys., B79 1974, 276
JETP Lett., 20 1974, 194

`t Hooft-Mandelstam

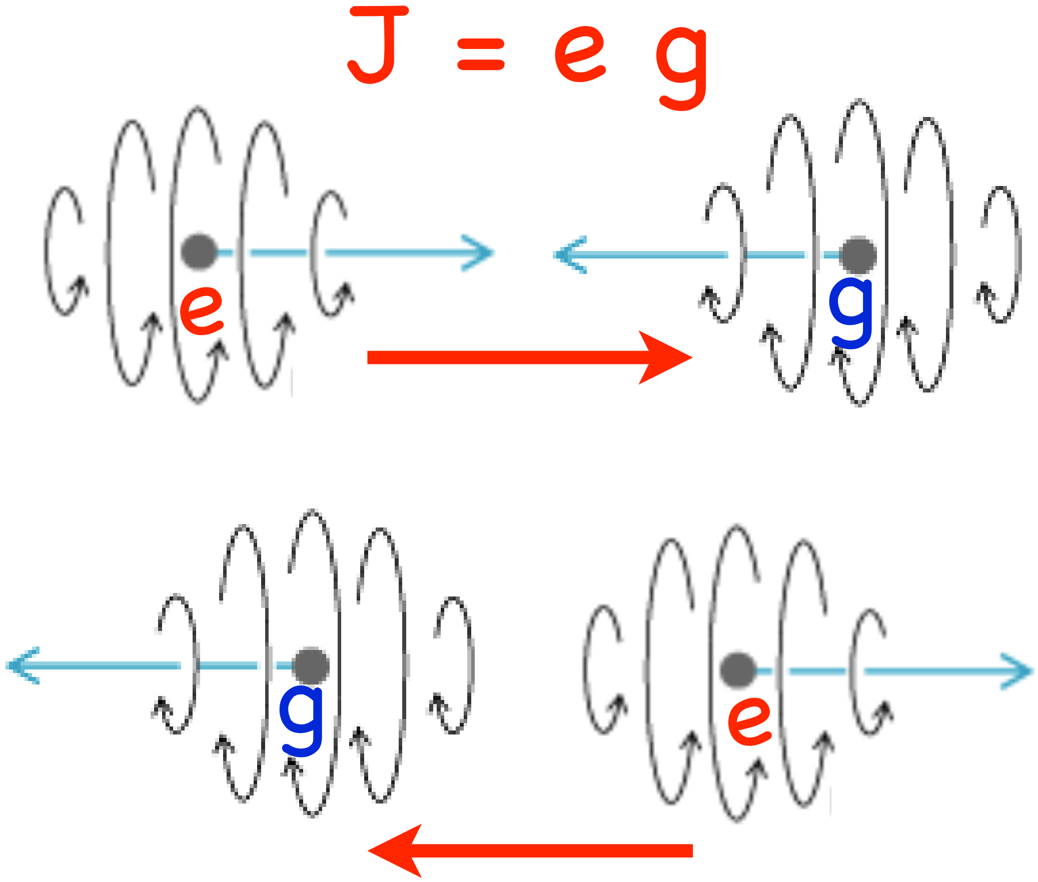


magnetic condensate
confines electric charge



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

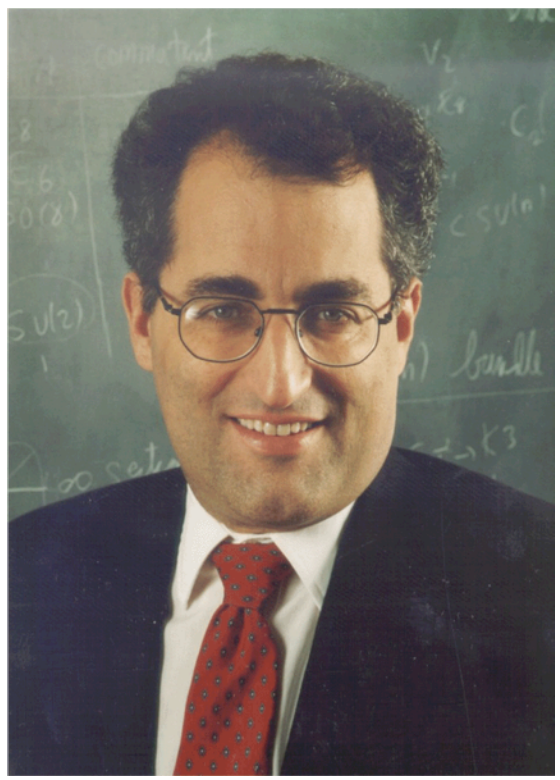
Rubakov-Callan



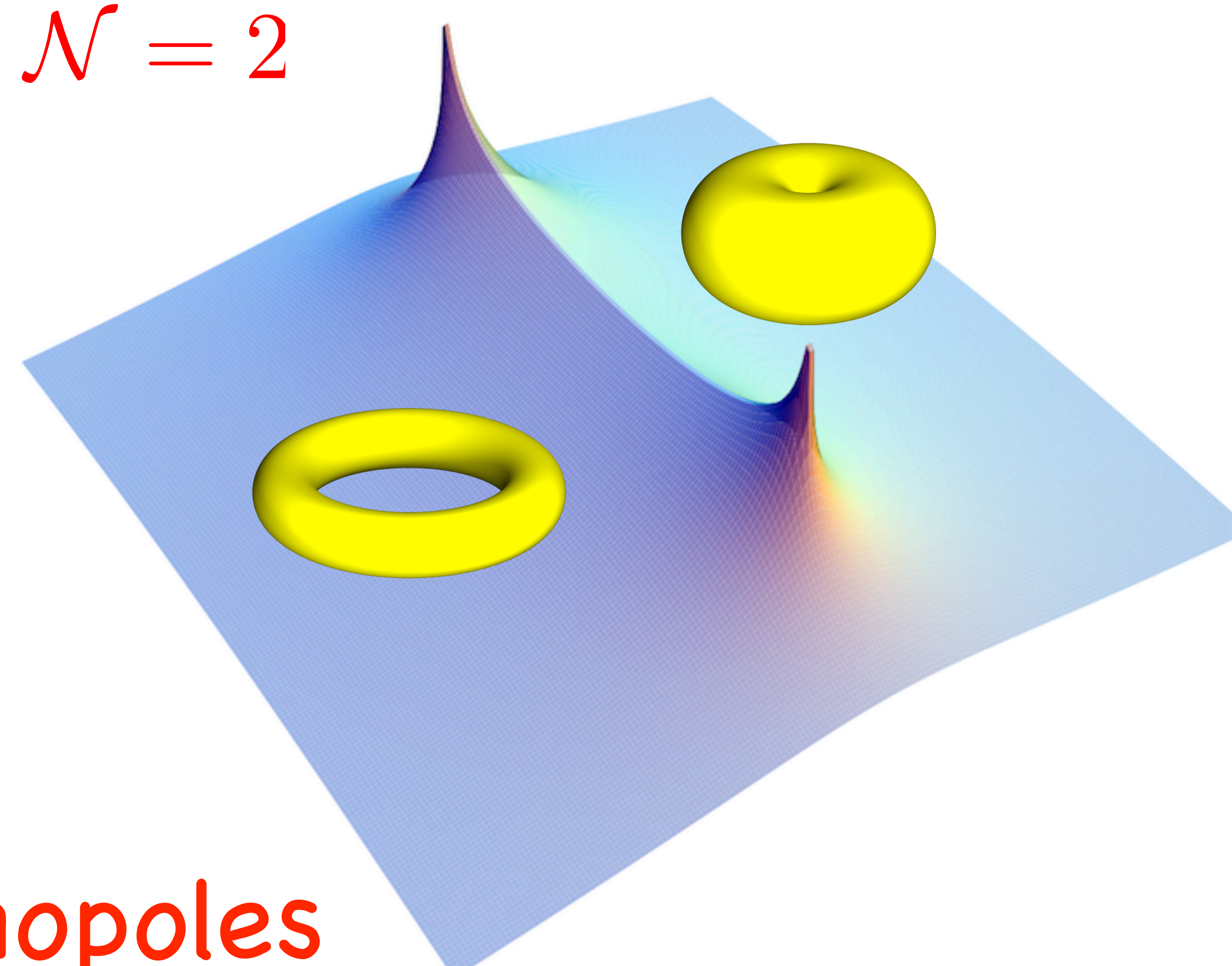
new unsuppressed contact interactions!

JETP Lett. 33 (1981) 644
Phys. Rev. D25 (1982) 2141

Seiberg-Witten



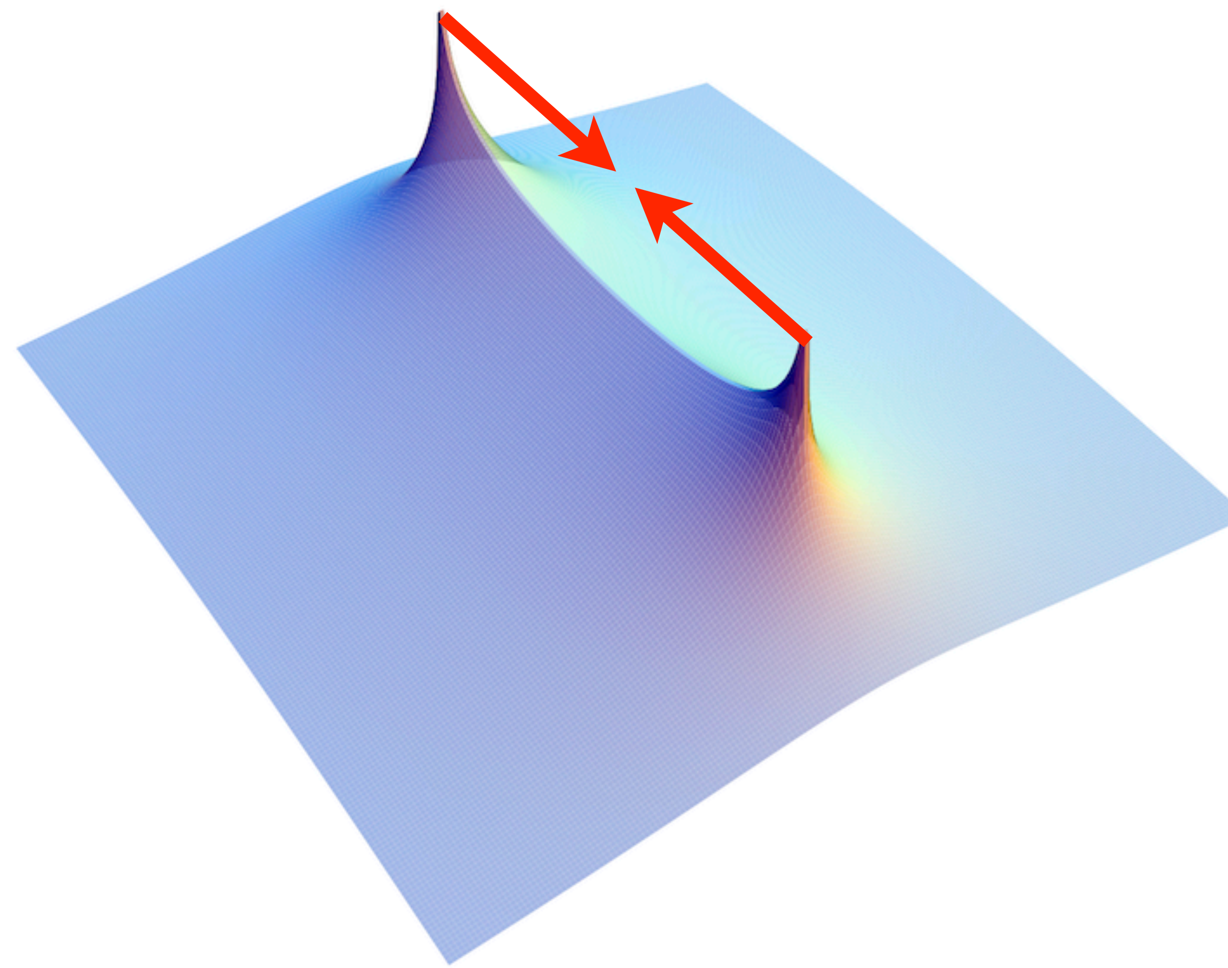
$\mathcal{N} = 2$



massless fermionic monopoles

hep-th/9407087

Argyres-Douglas



CFT with massless electric and magnetic charges

hep-th/9505062

Toy Model

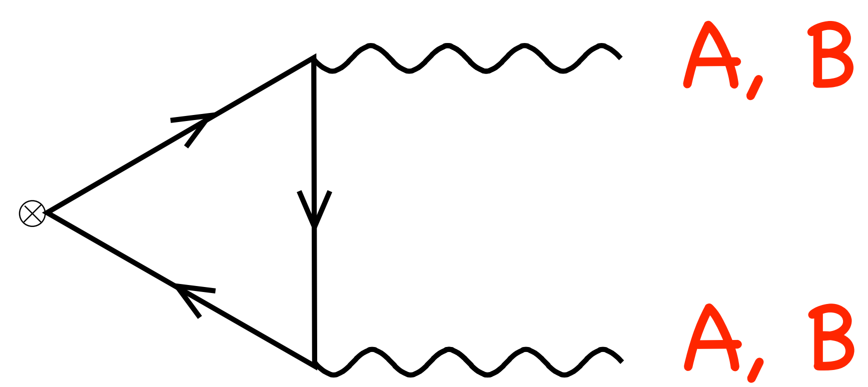
	$SU(3)_c$	$SU(2)_L$	$U(1)_Y : q$	$U(1)_Y : g$
Q	$\square$	$\square$	$\frac{1}{6}$	3
L	1	$\square$	$-\frac{1}{2}$	-9
$\bar{U}$	$\bar{\square}$	1	$-\frac{2}{3}$	-3
$\bar{D}$	$\bar{\square}$	1	$\frac{1}{3}$	-3
$\bar{N}$	1	1	0	9
$\bar{E}$	1	1	1	9

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

is this anomaly free?

Anomalies

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



$U(1)^3$ Anomaly

$$\sum_j q_j^3 = 0$$

$$\sum_j q_j\, g_j^2 = 0$$

$$\sum_j q_j^2\, g_j = 0$$

$$\sum_j g_j^3 = 0$$

Csáki, Shirman, JT hep-th/1003.0448

Toy Model

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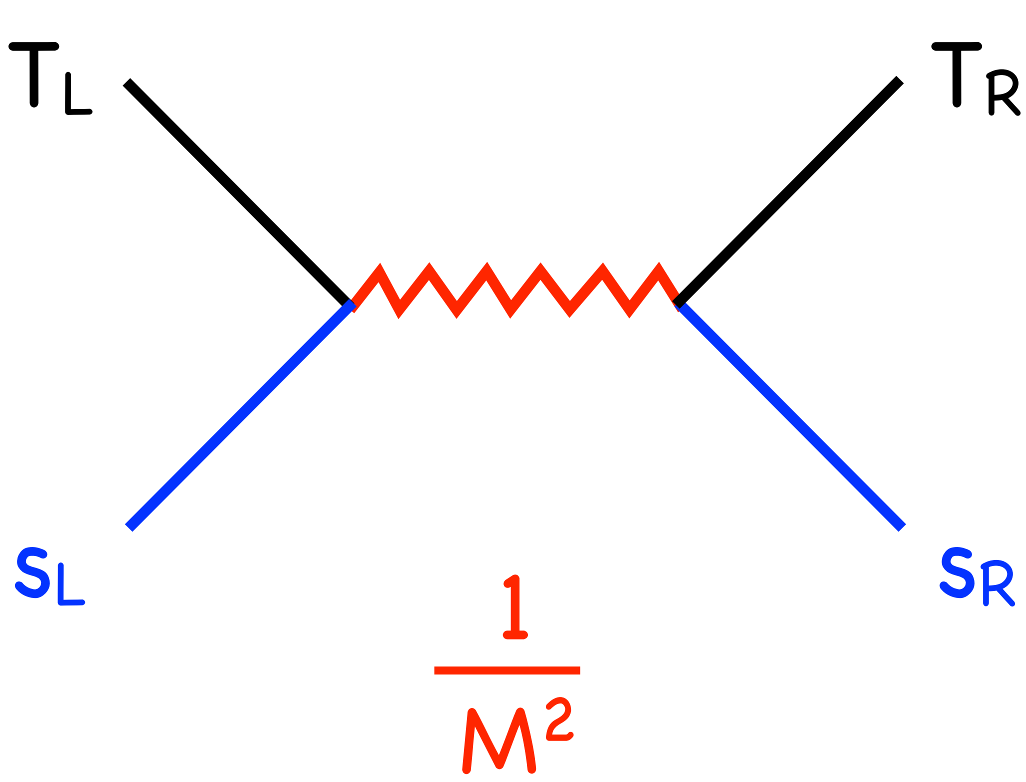
$\bar{D}$	$\bar{\square}$	1	$\frac{1}{3}$	-3
$\bar{N}$	1	1	0	9
$\bar{E}$	1	1	1	9

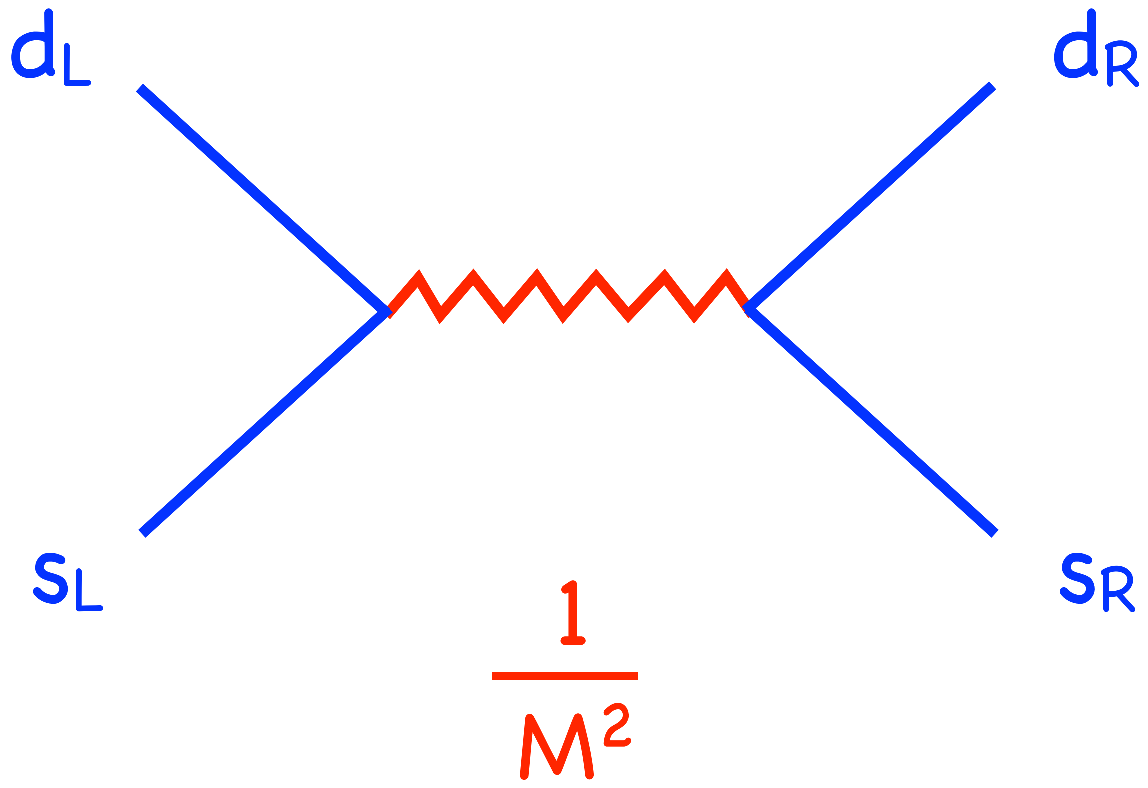
$$\sum_j q_j^3 = 0 \ , \quad \sum_j g_j^3 = 0 \ , \quad \sum_j g_j^2 q_j = 0 \ , \quad \sum_j q_j^2 g_j = 0 \ , \quad \sum_j q_j = 0 \ , \quad \sum_j g_j = 0 \ ,$$

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

Quark Masses

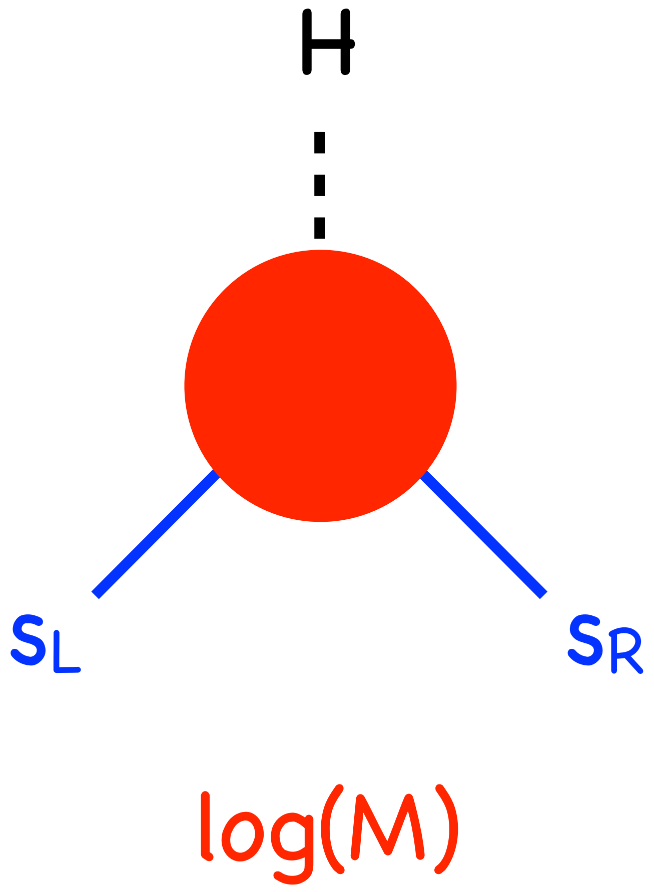
technicolor: fail

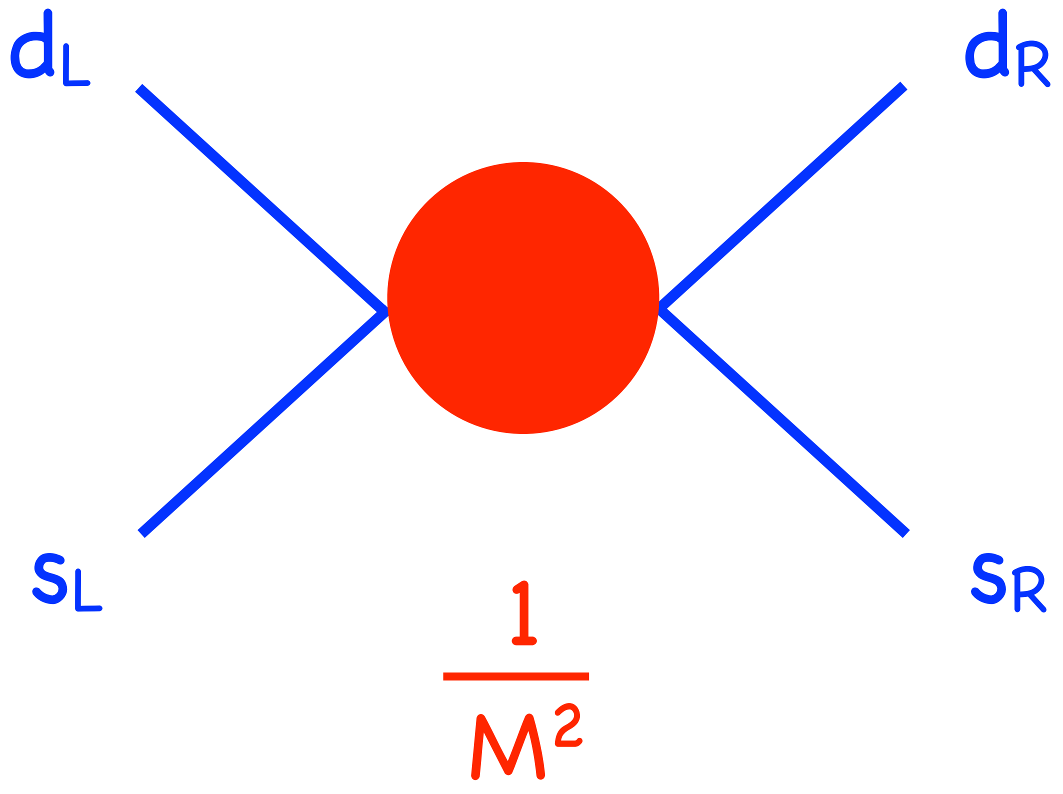




Quark Masses

Standard Model

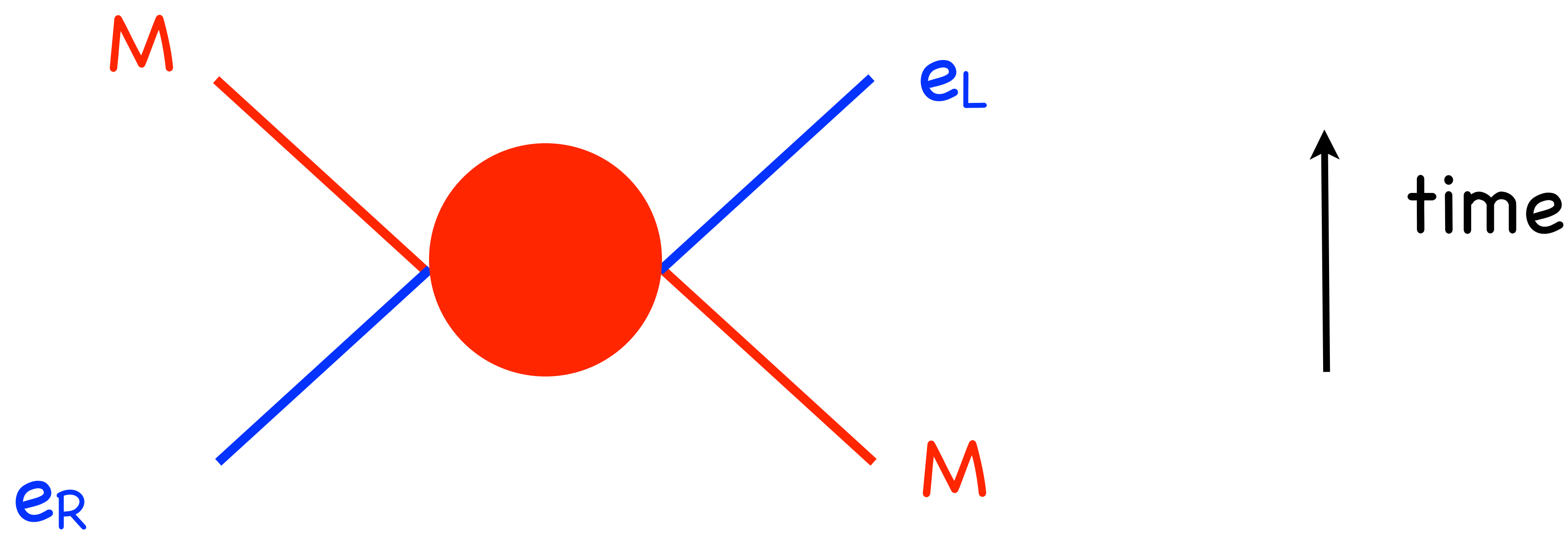




Rubakov-Callan

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

$S_f = -1/2$



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

$S_i = 1/2$

New dimension 4, four particle operator

Angular Momentum

Classical: $\vec{L} = \vec{r} \times \vec{p} - q\, g\, \hat{r}$

$$L^2 = |\vec{r} \times \vec{p}|^2 + q^2\, g^2$$

Quantum: $[L_i, L_j] = i\, \epsilon_{ijk} L_k$

$$L^2 Y^{qg}_{\ell,m} = \ell(\ell+1) Y^{qg}_{\ell,m} \ , \quad \ell \geq |qg|$$

Wu, Yang Nucl. Phys. B107, (1976) 365

Quantum Mechanics

$$\left[(\partial_\mu - iqA_\mu)^2 - \frac{q}{2}\sigma^{\mu\nu}F_{\mu\nu} - m^2\right]\Psi = 0$$

$$\left[-\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\frac{\partial}{\partial r}) + \frac{1}{r^2}(\vec{L}^2 - q^2g^2) - q\,\vec{\sigma}\cdot\vec{B} - (E^2 - m^2)\right]\Psi = 0$$

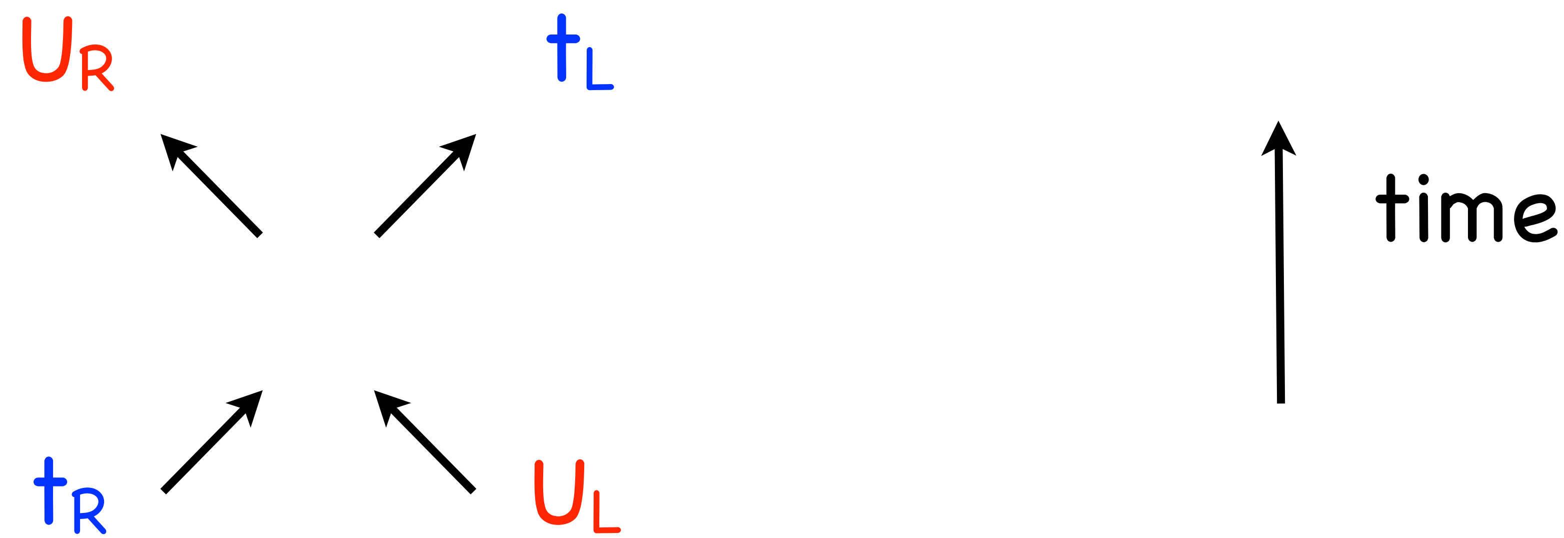
$$\frac{1}{r^2}(\ell(\ell+1) - q^2g^2) - q\,g\frac{\vec{\sigma}\cdot\hat{r}}{r^2}$$

for $\ell = |qg|$ one helicity can reach the origin

Four Fermions

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

$S_f = -1$



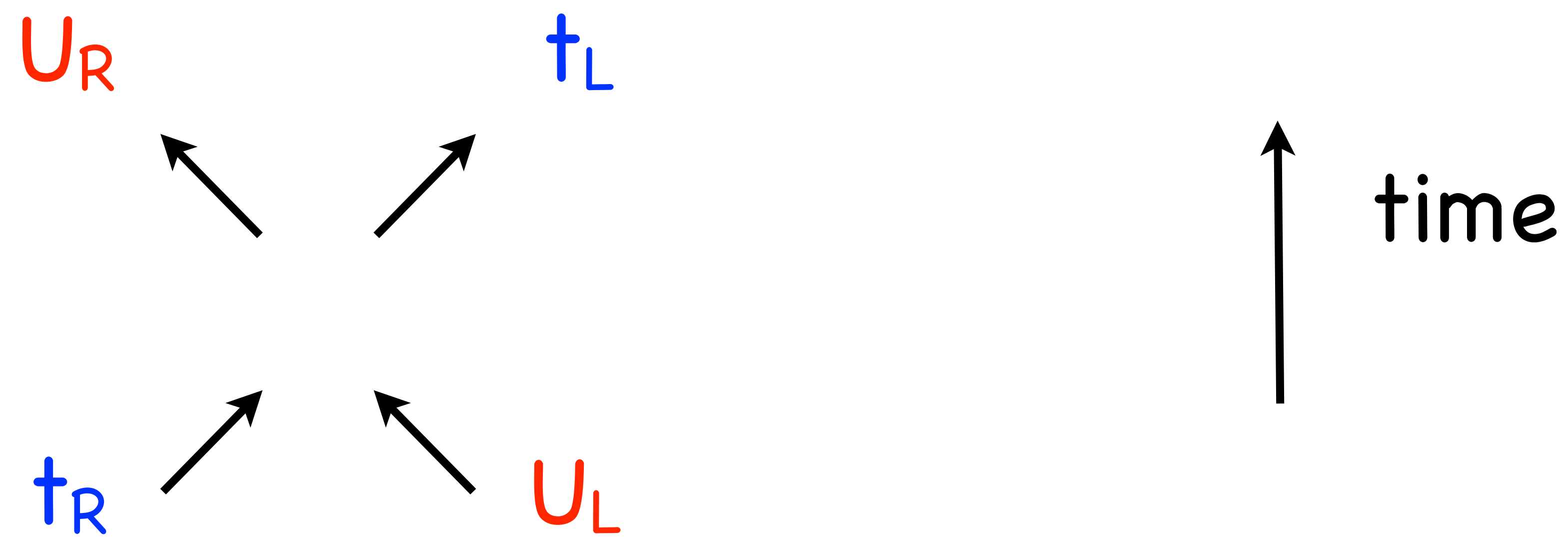
$J_i = q\ g = 2$

$S_i = 1$

Four Fermions

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

$S_f = -1$



$J_i = q\ g = 2$

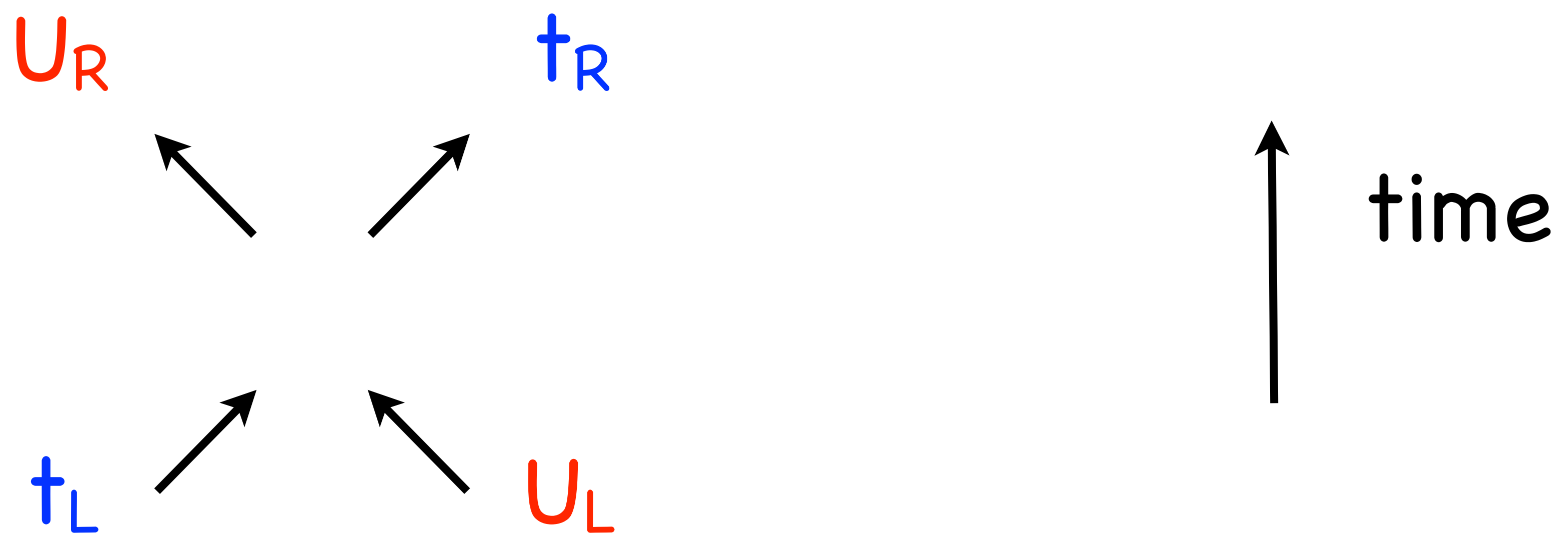
$S_i = 1$

fail!

Four Fermions

$J_f = -q\ g = -2$

$S_f = 0$



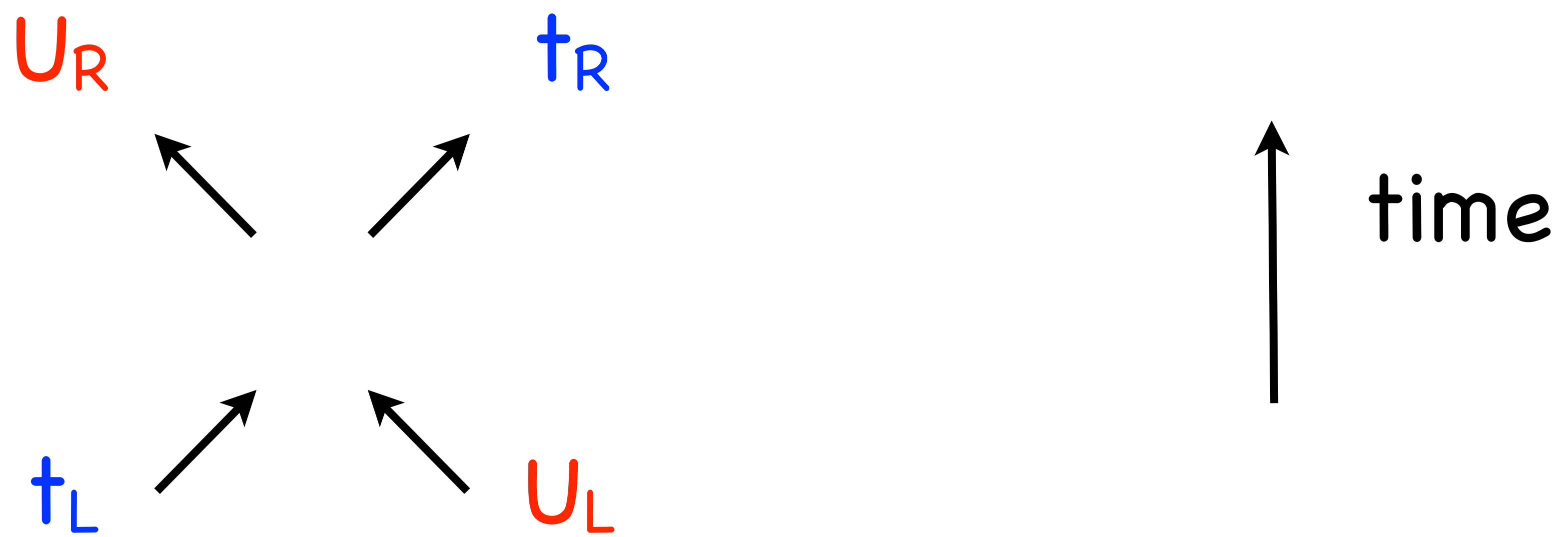
$J_i = q\ g = 1/2$

$S_i = 0$

Four Fermions

$J_f = -q\ g = -2$ ←

$S_f = 0$



$J_i = q\ g = 1/2$ →

$S_i = 0$

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

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

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

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

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

$\beta_L = 1$

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

The Model

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

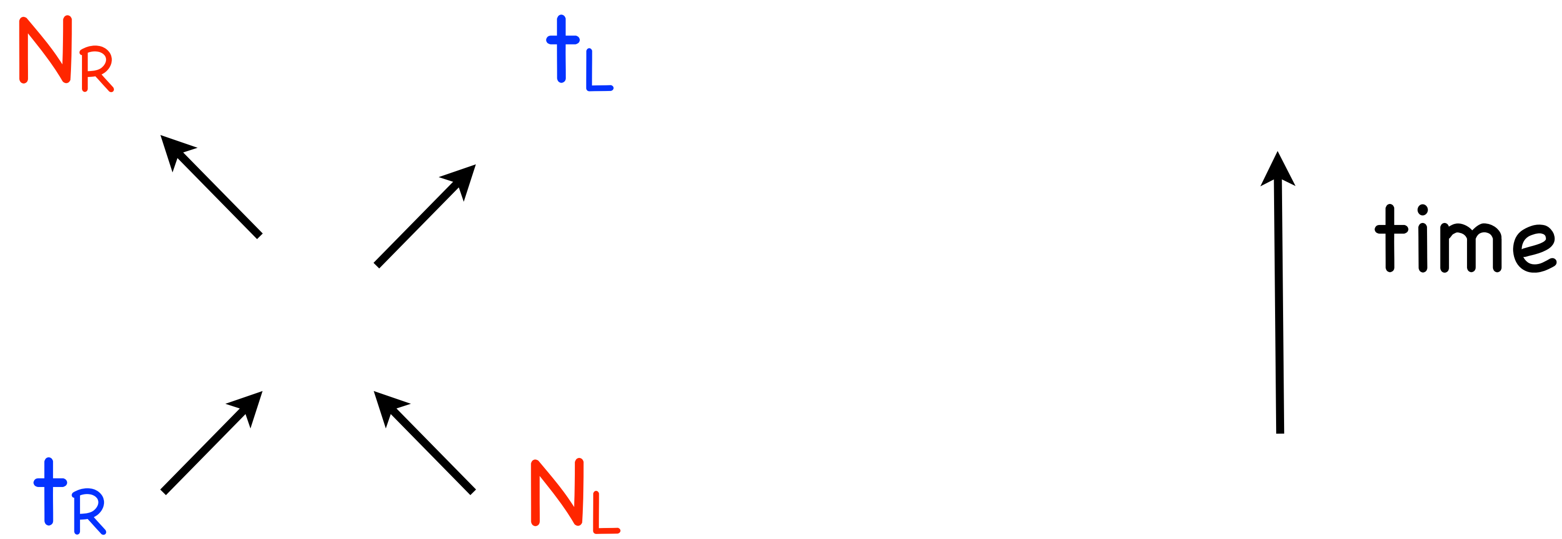
	$SU(3)_c$	$SU(2)_L$	$U(1)_Y^{el}$	$U(1)_Y^{mag}$
Q_L	$\square^m$	$\square^m$	$\frac{1}{6}$	$\frac{1}{2}$
L_L	1	$\square^m$	$-\frac{1}{2}$	$-\frac{3}{2}$
U_R	$\square^m$	1^m	$\frac{2}{3}$	$\frac{1}{2}$
D_R	$\square^m$	1^m	$-\frac{1}{3}$	$\frac{1}{2}$
N_R	1	1^m	0	$-\frac{3}{2}$
E_R	1	1^m	-1	$-\frac{3}{2}$

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

Four Fermions

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

$$S_f = -1$$



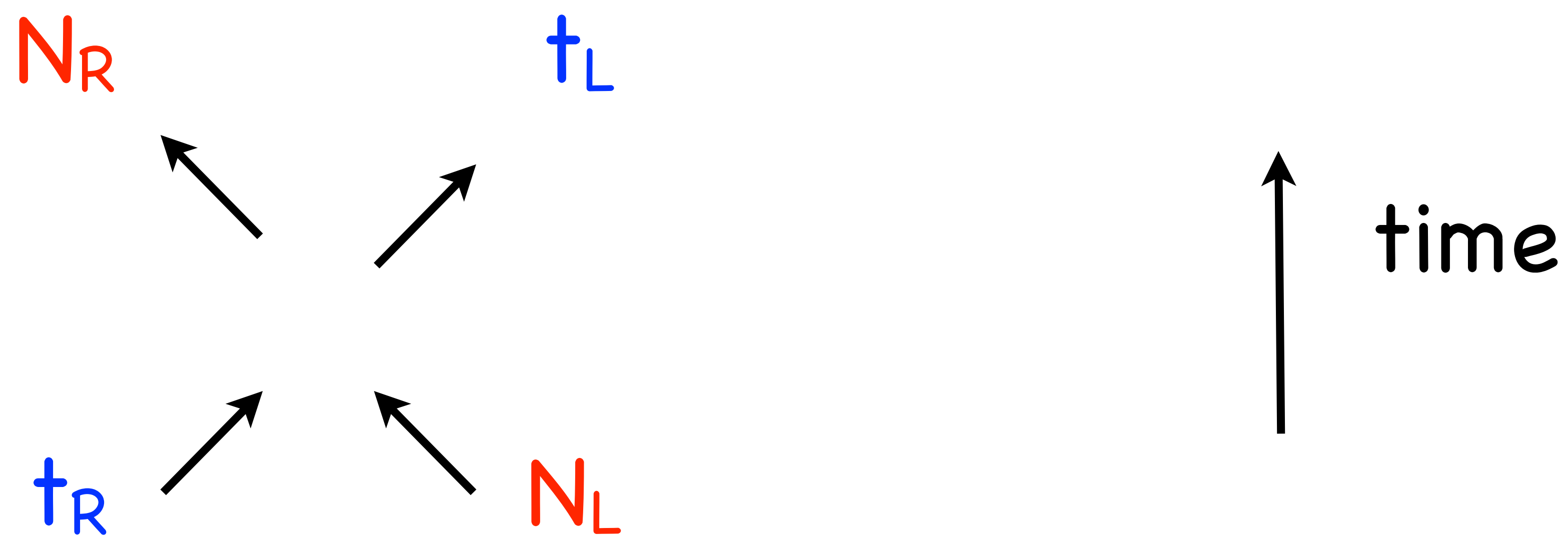
$$J_i = \frac{2}{3}\left(\frac{-3}{2}\right)$$

$$S_i = 1$$

Four Fermions

$$J_f = -\frac{2}{3}\left(\frac{-3}{2}\right) \longrightarrow$$

$$S_f = -1 \longleftarrow$$



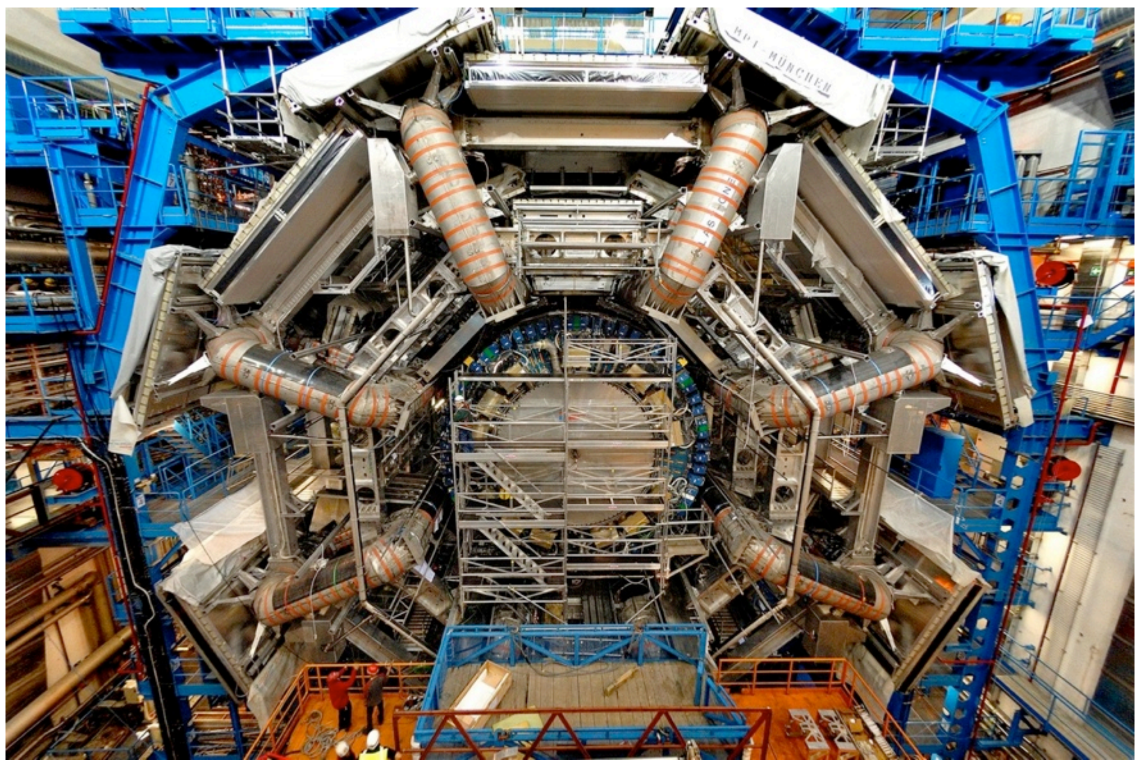
$$J_i = \frac{2}{3}\left(\frac{-3}{2}\right) \longleftarrow$$

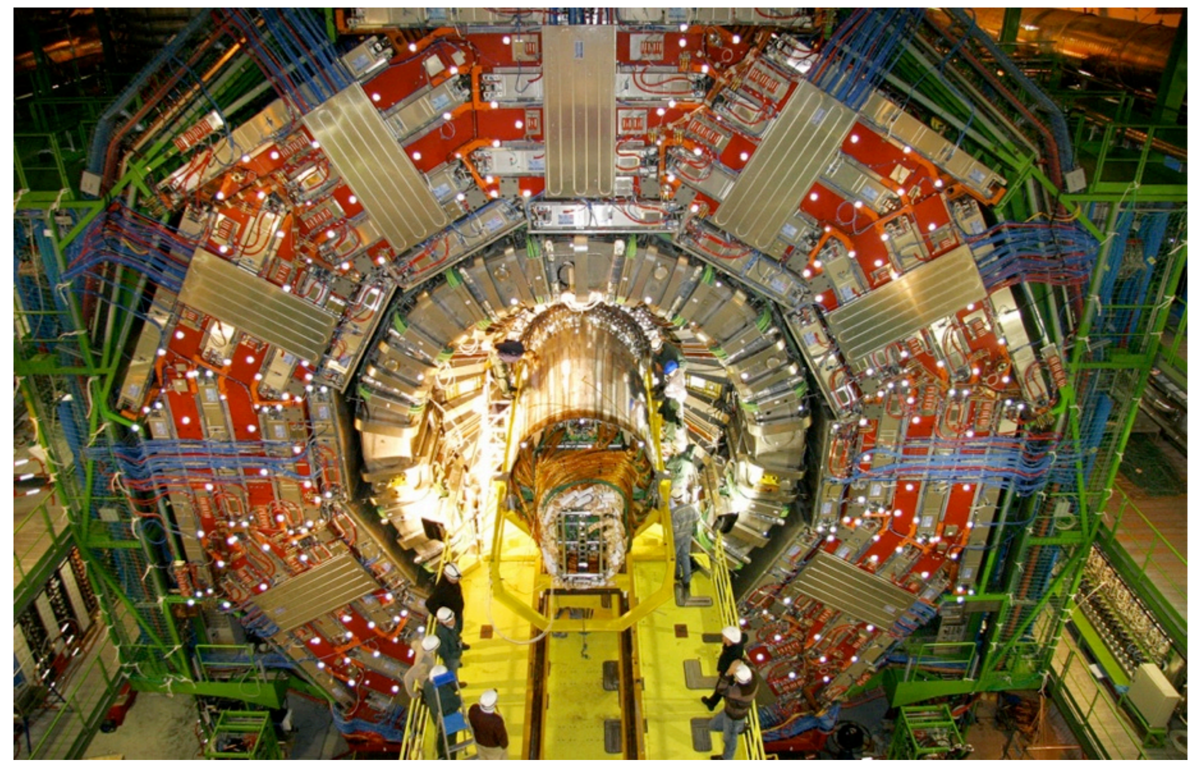
$$S_i = 1 \longrightarrow$$

hooray!

LHC

naively expect pair production,
unconfined, highly ionizing



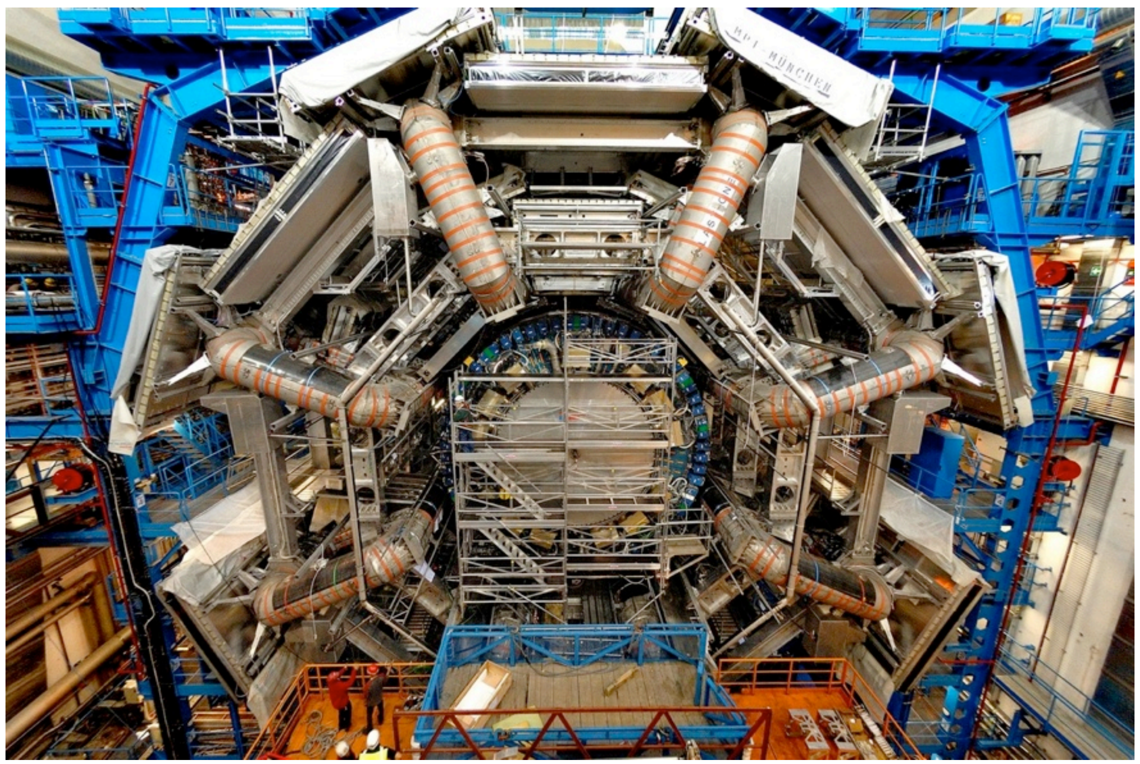


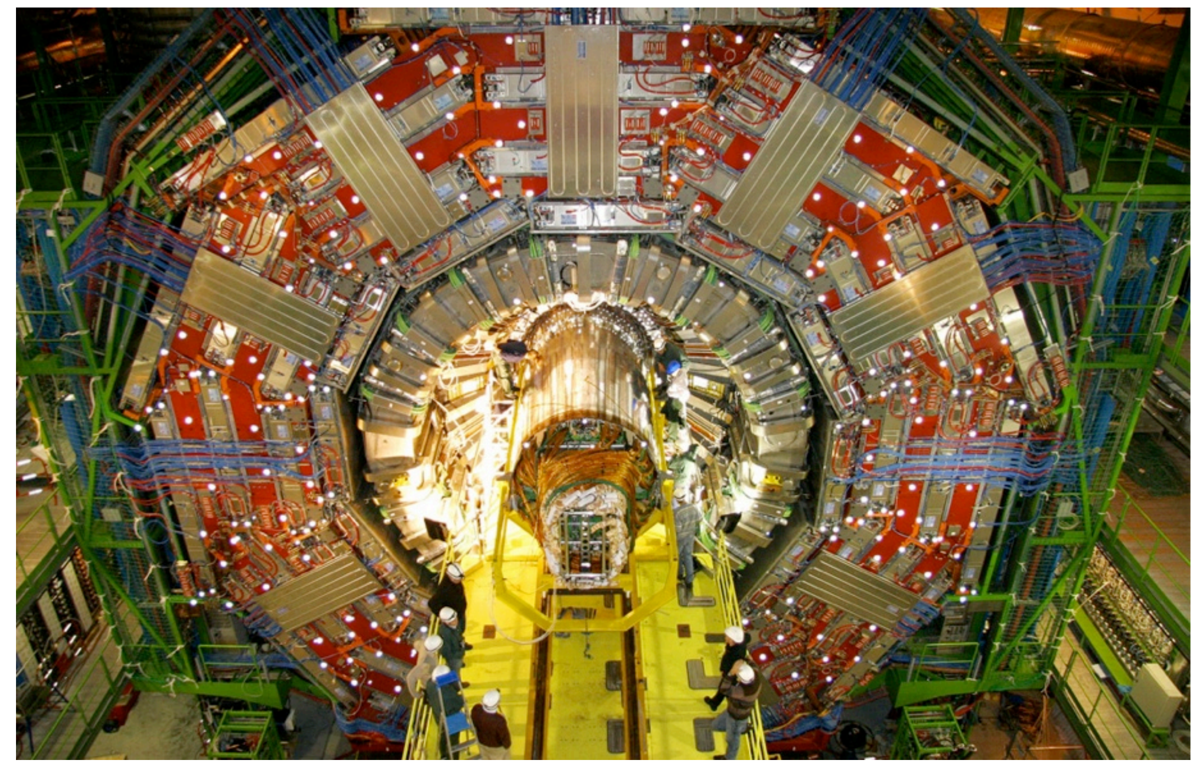
ATLAS has a trigger
for monopoles

CMS does not

LHC

naively expect pair production,
unconfined, highly ionizing



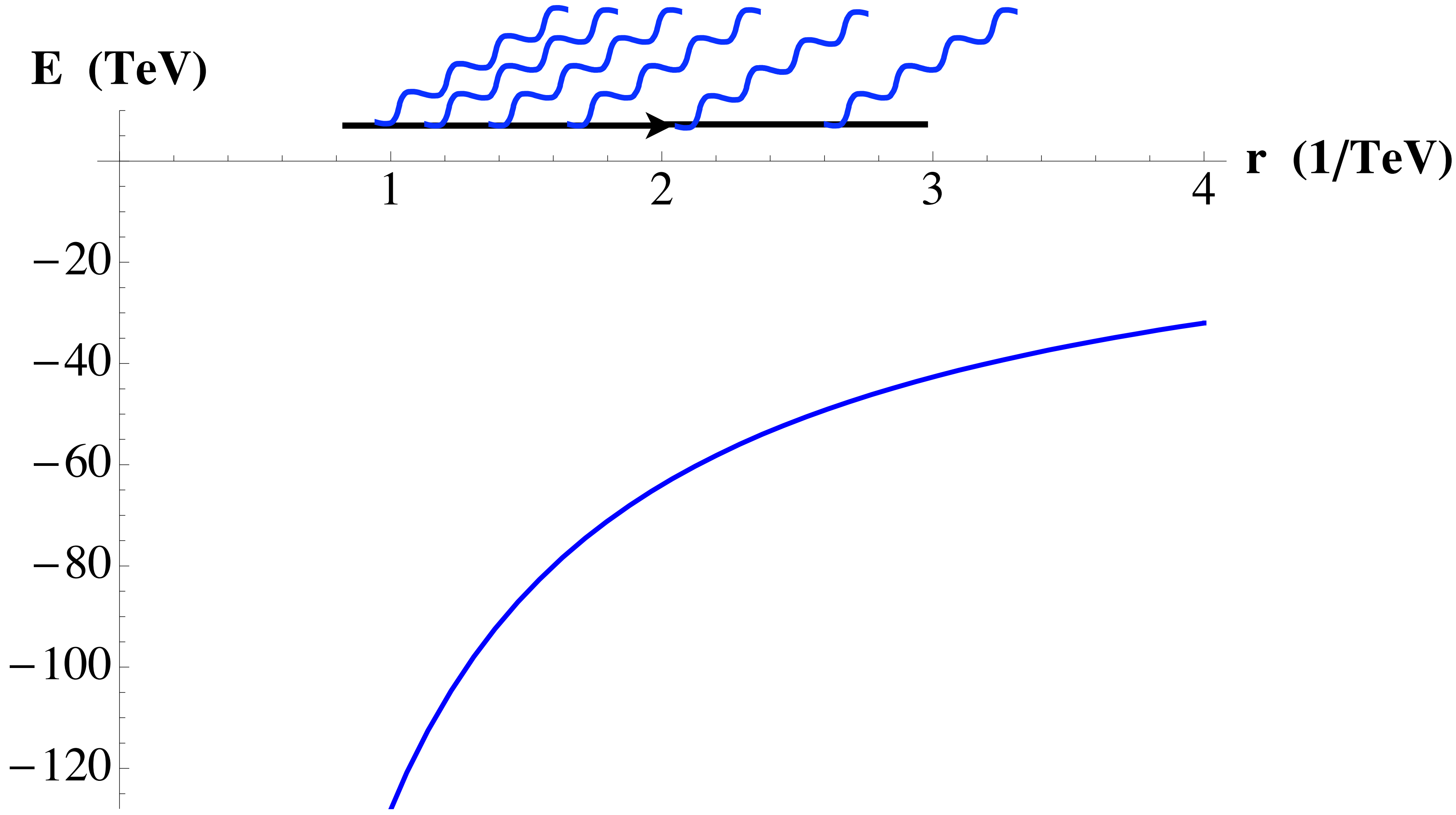


ATLAS has a trigger for monopoles

CMS does not

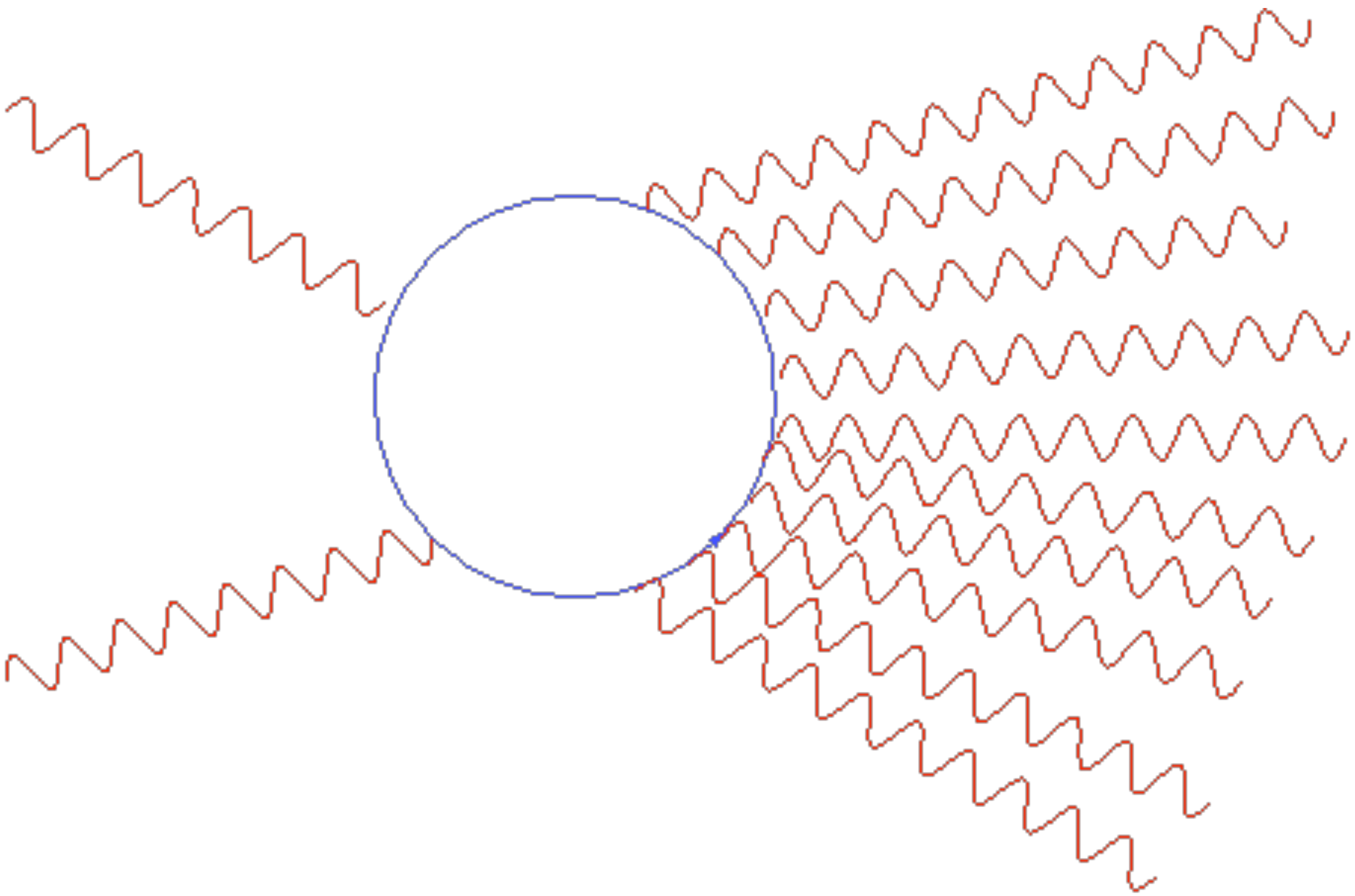
but it won't work

Bremstrahlung



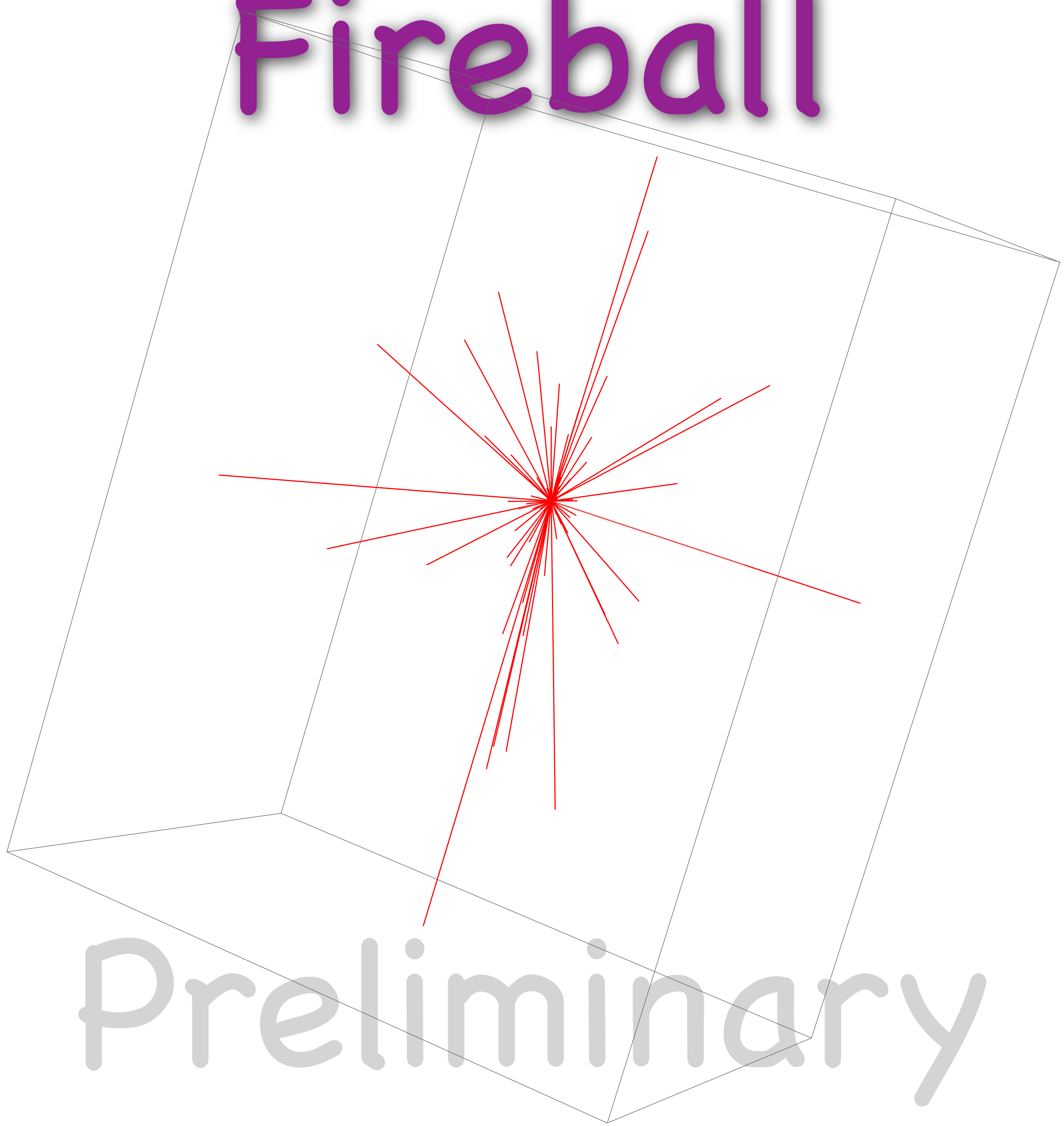
Andersen, Grojean, Weiler, JT

Annihilation



Andersen, Grojean, Weiler, JT

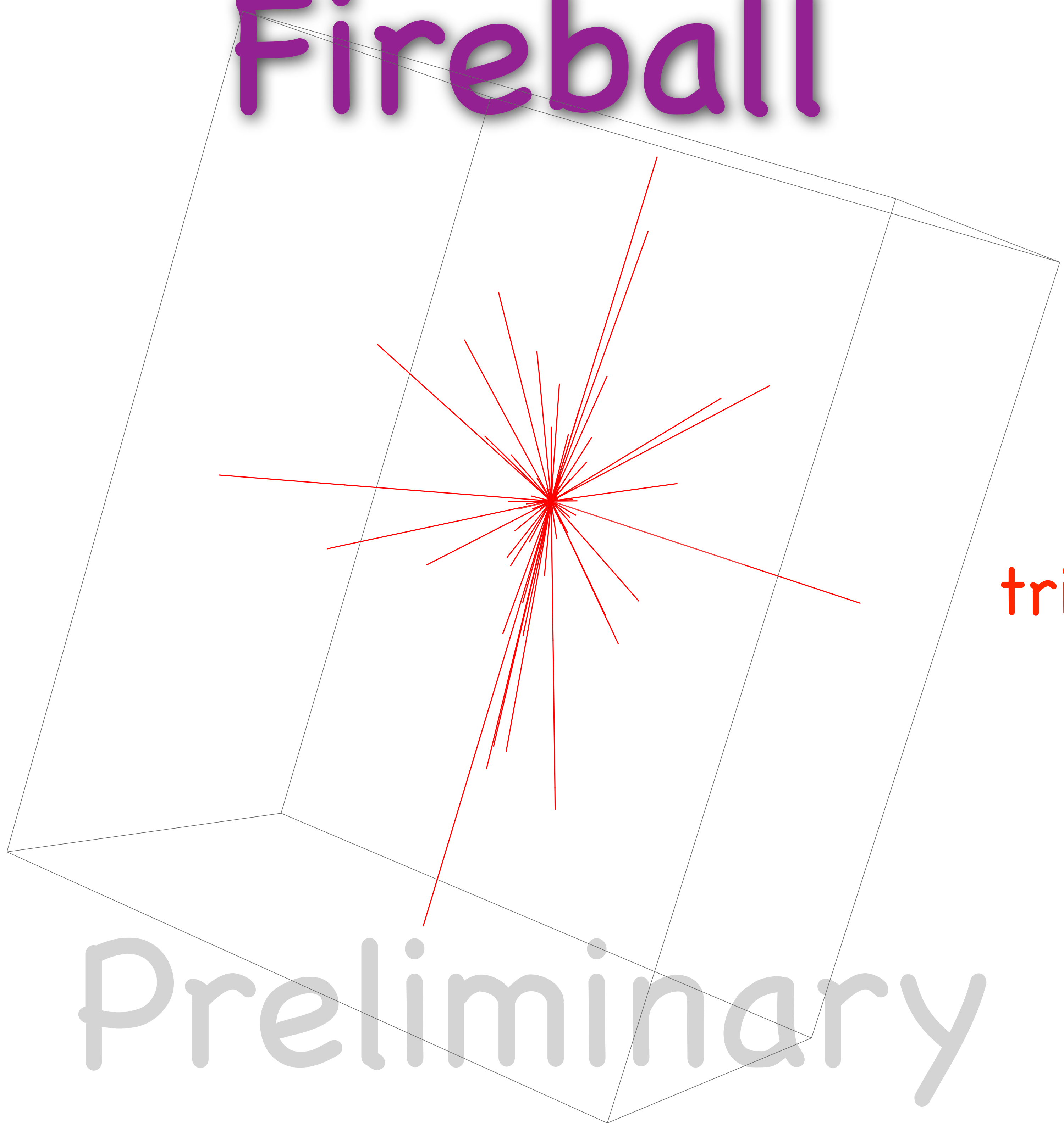
Fireball



Preliminary

Andersen, Grojean, Weiler, JT

Fireball



Preliminary

CMS has a trigger for this

Andersen, Grojean, Weiler, JT

Conclusions

Monopoles are still fascinating
after all these years

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

the LHC could be very exciting