weak bosons

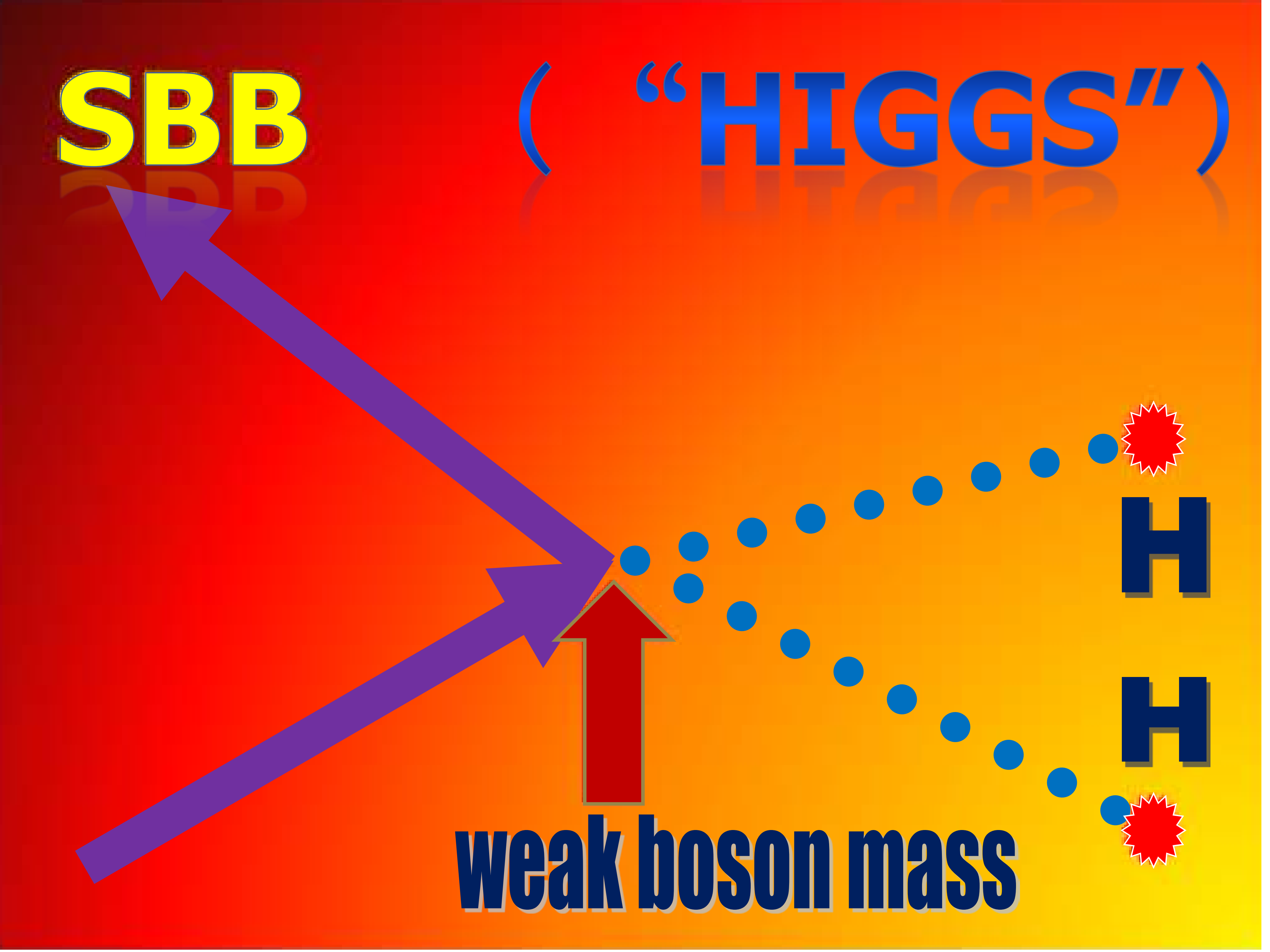
? composite ?

H. Fritzsch

LMU Munich

Standard Model

masses
of
? leptons ?
quarks
weak bosons


SBB
(“HIGGS”)
H
H
weak boson mass

???

Proton

0.94 GeV

W-boson

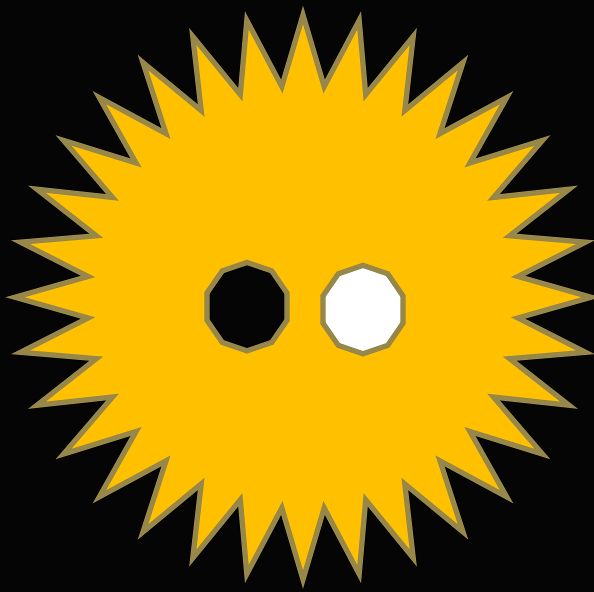
81 GeV

!!!

Proton

0.94 GeV

W-boson



81 GeV

weak bosons

composite

old references:

Bjorken (1977)

Fritzsch - Mandelbaum (1981)

Abbott - Farhi (1981)

Barbieri - Mohapatra (1981)

Fritzsch – Kogerler - Schildknecht (1982)

Kugo – Uehara - Yanagida (1984/5)

Calmet - Fritzsch (2000)

new:

H. Fritzsch

2010 - arXiv: 1010.1428

2011 - arXiv: 1105.3354

2012 - arXiv: 1203.5600

masses of composite weak bosons ?

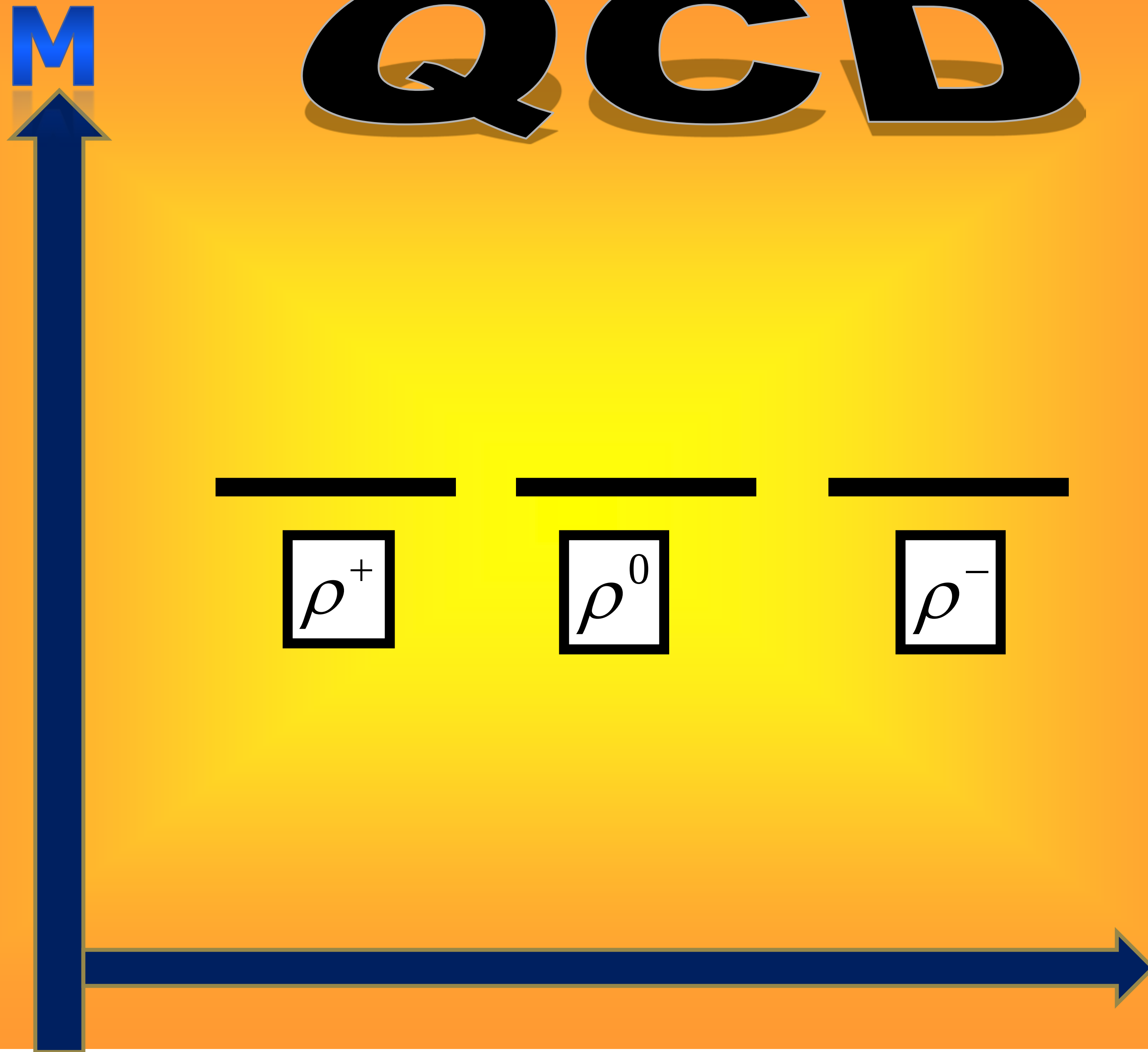
a n a l o g y

$$\rho^{+} \Leftrightarrow W^{+}$$

$$\rho^{0} \Leftrightarrow W^{0}$$

$$\rho^{-} \Leftrightarrow W^{-}$$

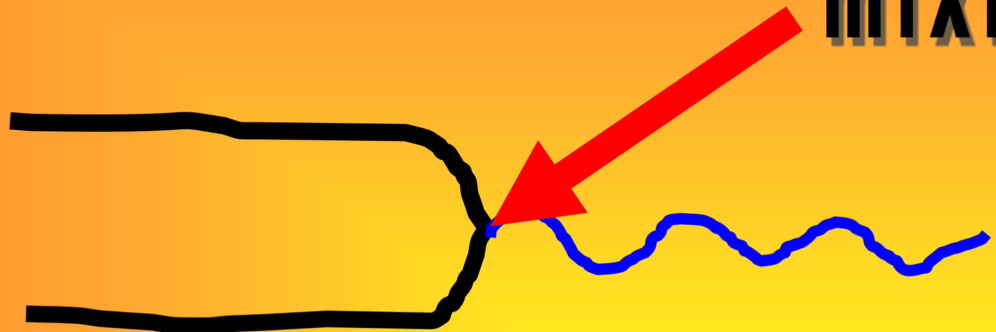
QCD



QCD + QED

Dynamical mixing of rho meson and photon:

mixing parameter m



$$m = e\frac{F_\rho}{M_\rho}$$

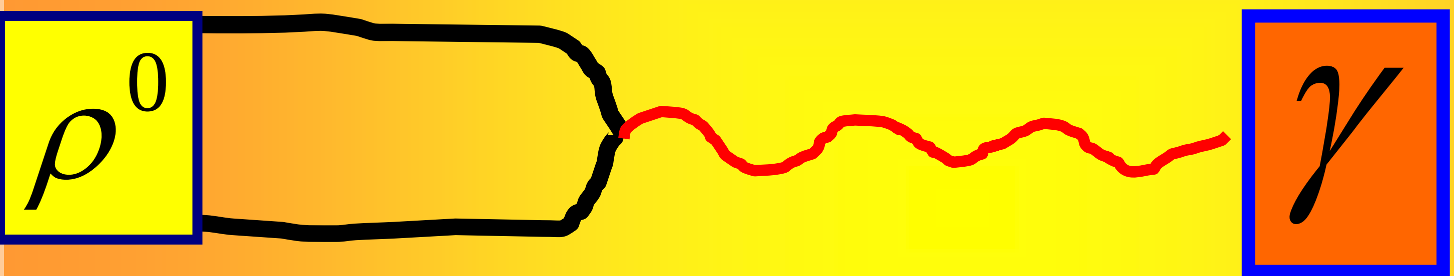
$$\langle 0 | \frac{1}{2}(\bar{u}\gamma_\mu u - \bar{d}\gamma_\mu d) | \rho_0 \rangle = \varepsilon_\mu M_\rho F_\rho$$

F_ρ : decay constant

$$F_\rho \approx 220 \quad MeV$$

$$F_\rho \approx \Lambda_c$$

mixing with photon



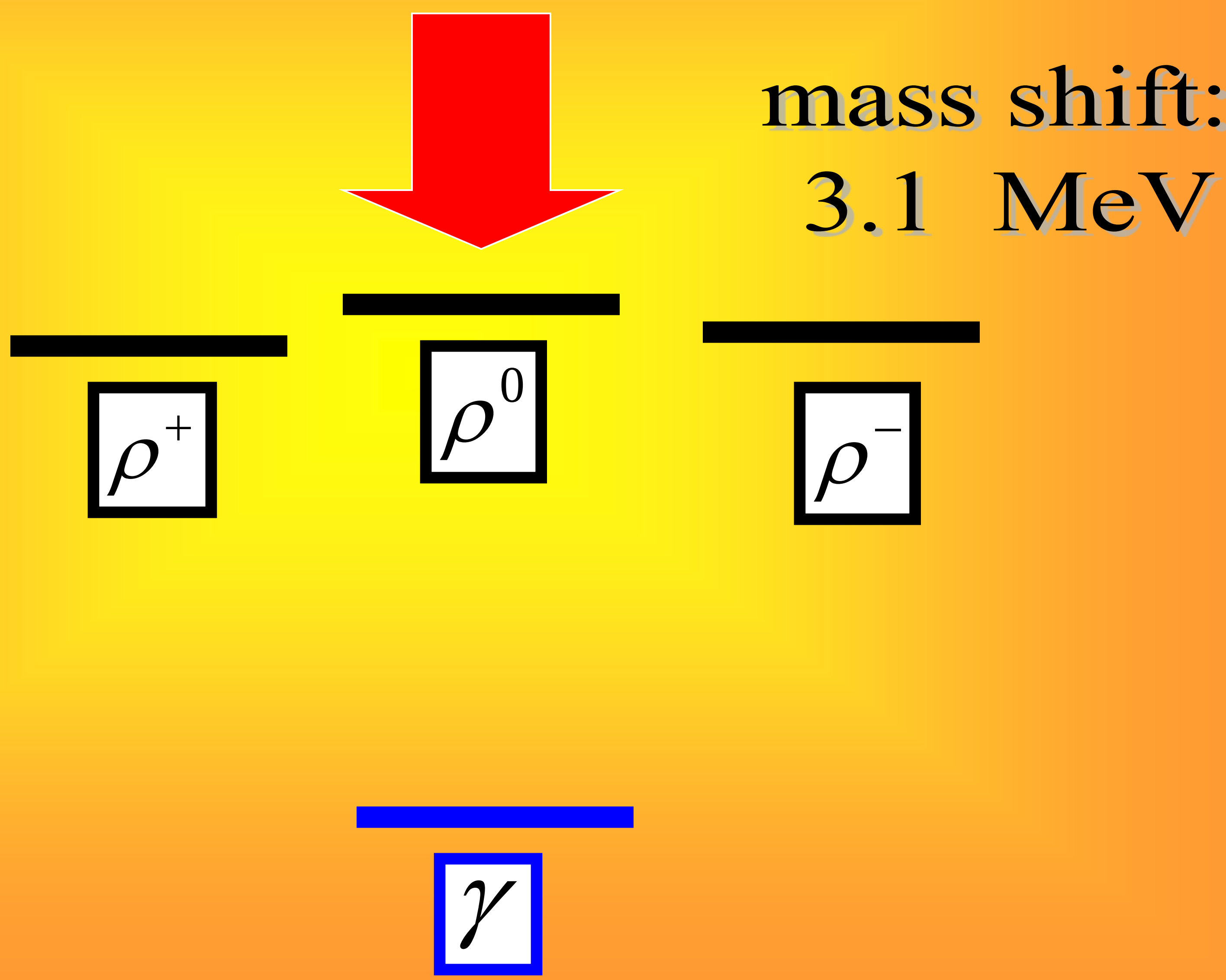
m: mixing parameter

$$M_{\rho^0}^{\ 2} = \frac{M_{\rho^+}^{\ 2}}{1-m^2}$$

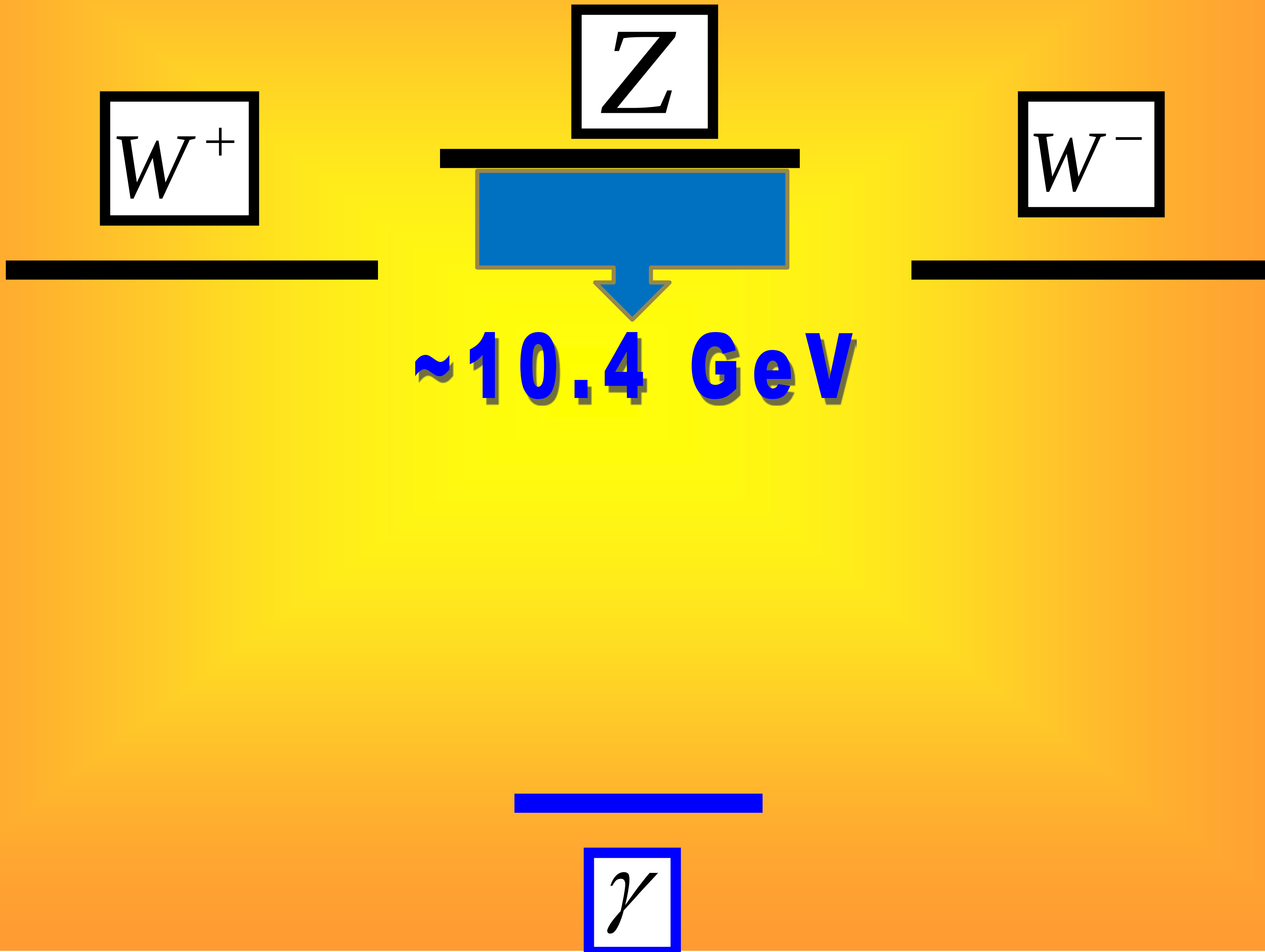
~ 3.1 MeV

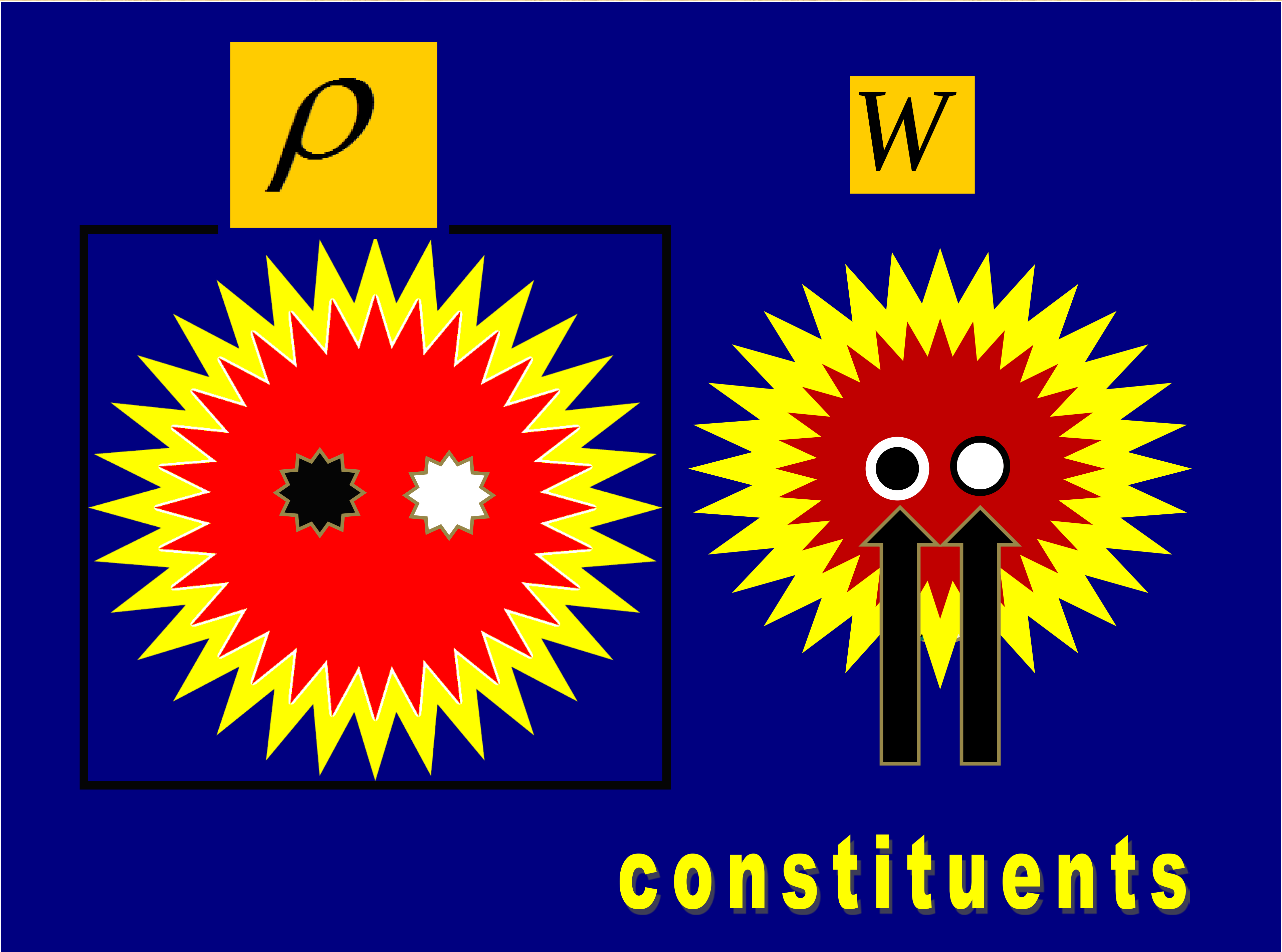
m = 0.09

QCD +QED



Standard Model





ρ
W
constituents

Constituents of W-bosons

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

⇓

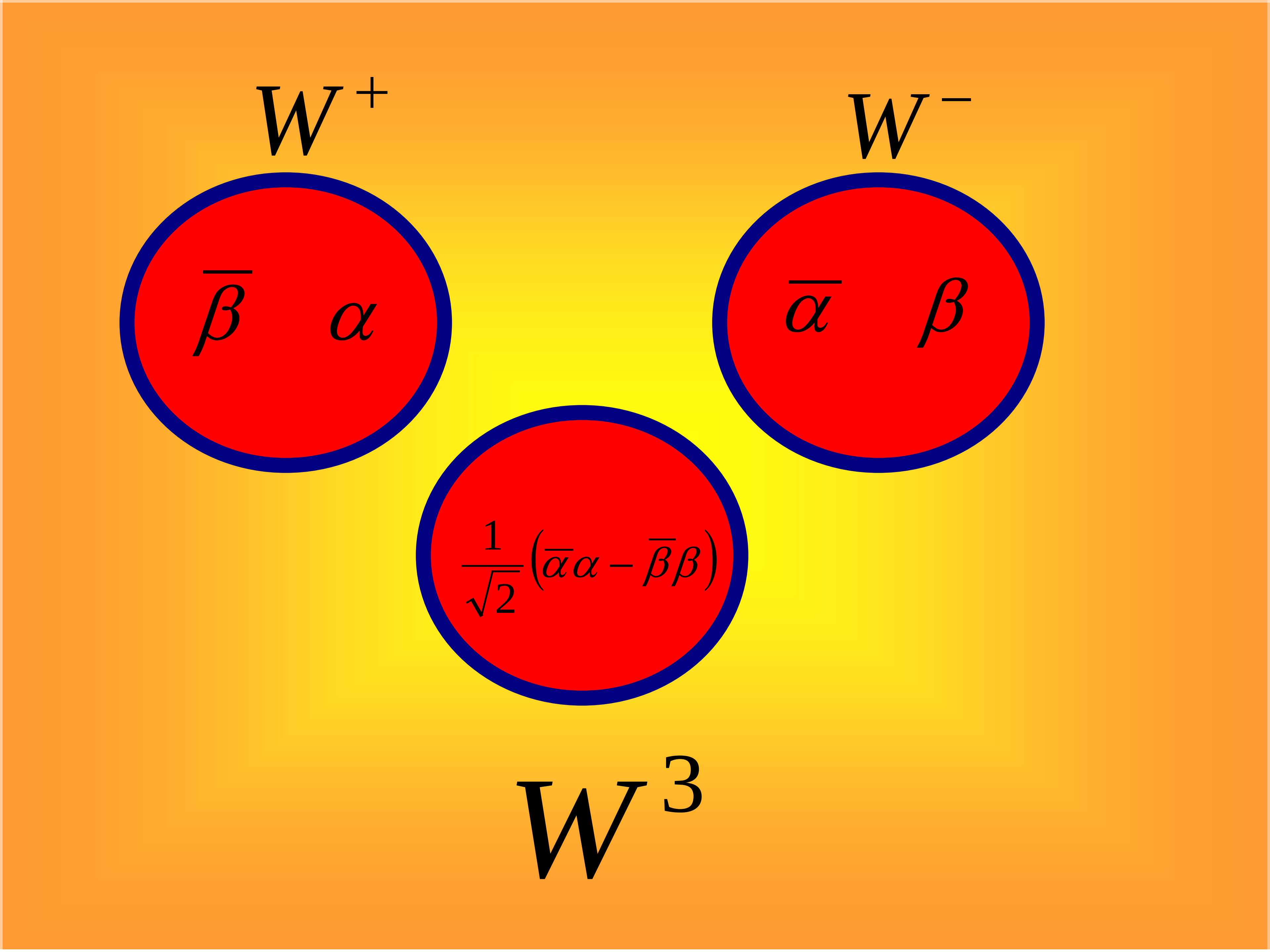
haplons

haplos ⇔ simple

electric charges

$$\alpha \Rightarrow +1/2$$

$$\beta \Rightarrow -1/2$$


W^+
$\bar{\beta}\ \alpha$
W^-
$\bar{\alpha}\ \beta$
$\frac{1}{\sqrt{2}}(\bar{\alpha}\alpha - \bar{\beta}\beta)$
W^3

haplons confined by gauge force

QHD

gauge bosons

glutinos

glue → gluten

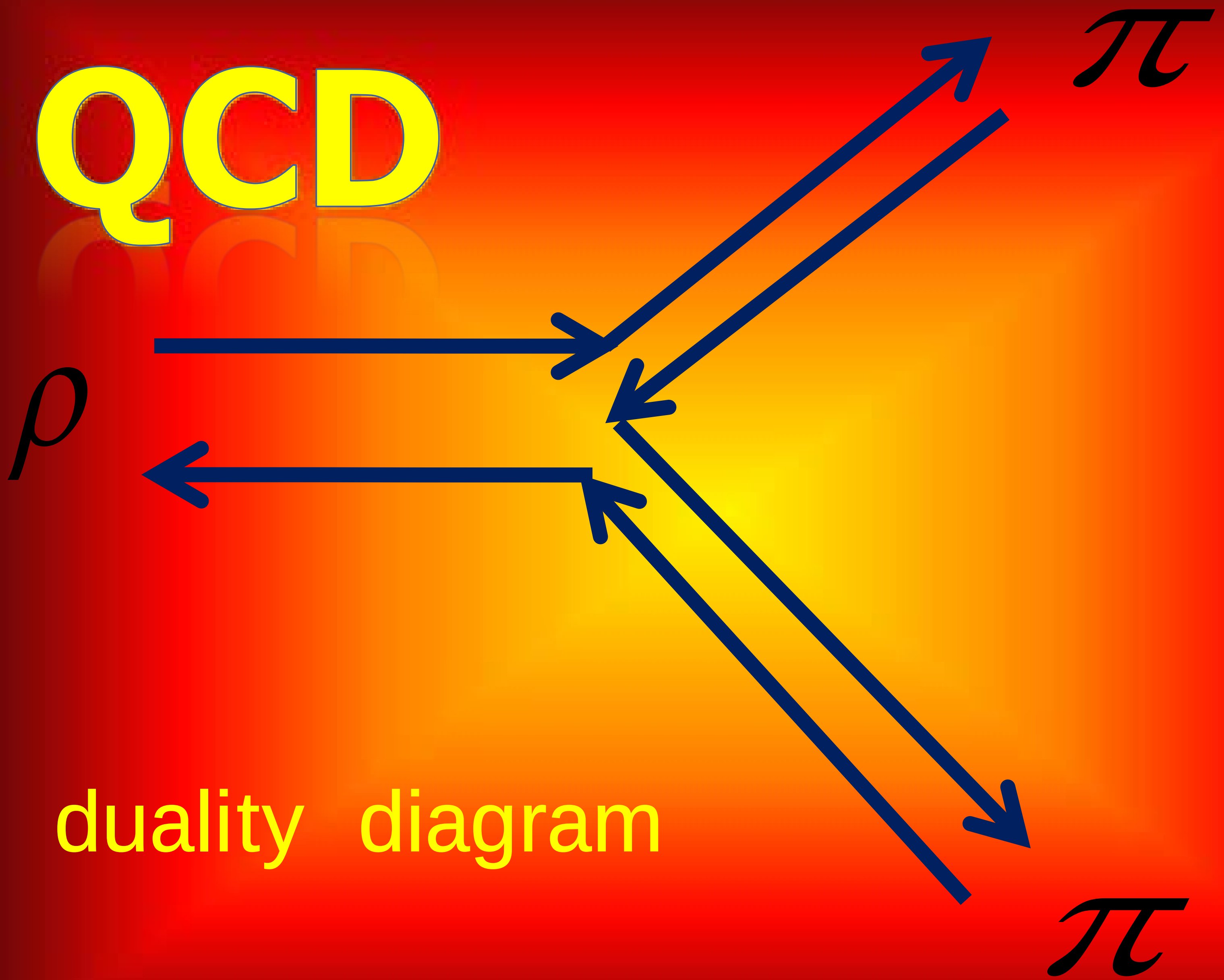
QHD

gauge group

SU(*n*)

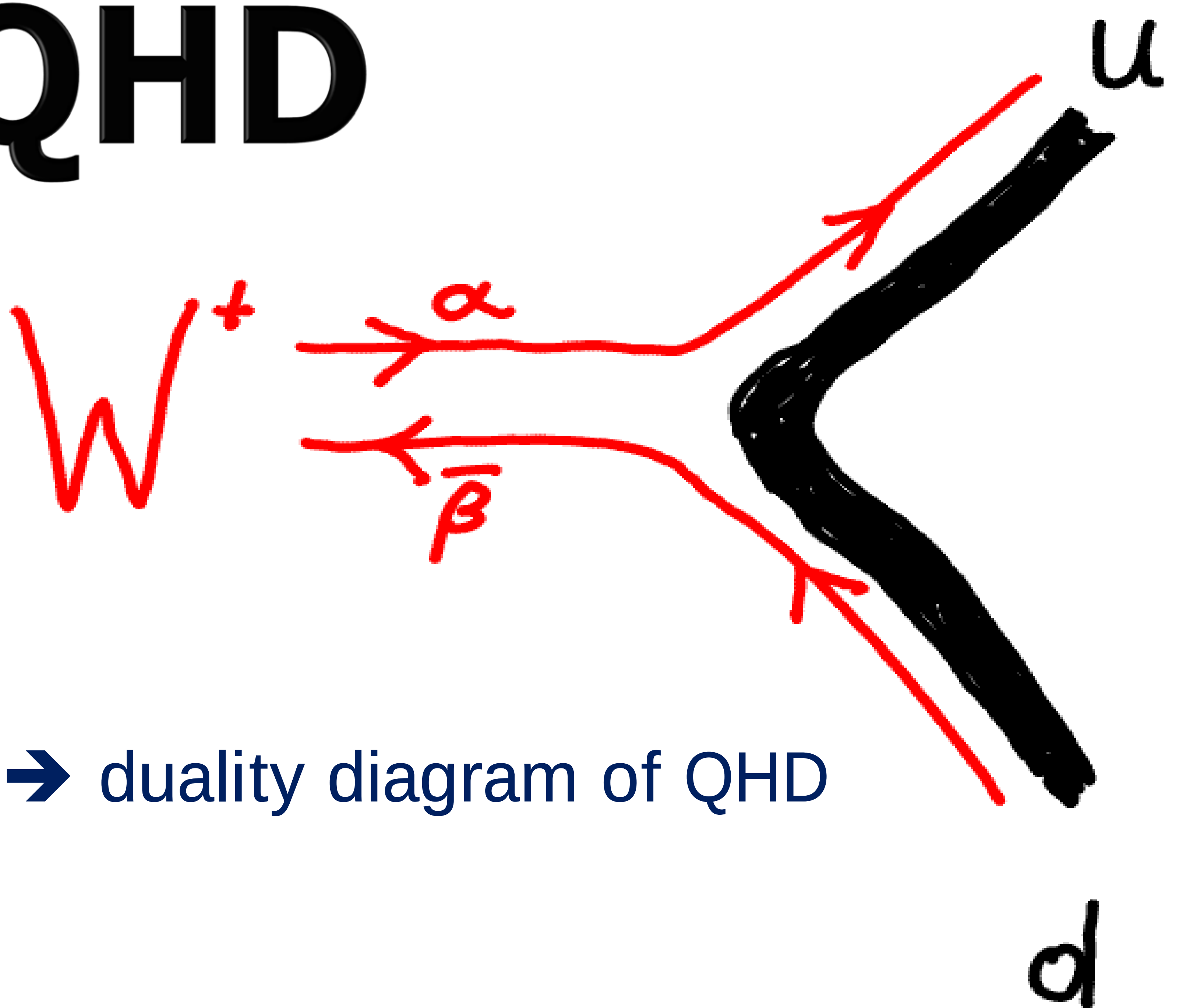
? SU(3) ?

QCD



duality diagram

QHD



➔ duality diagram of QHD

Standard Model

$$SU(3)_c \otimes SU(2)_L \otimes U(1)$$

problem

maximal parity violation

$$SU(2)_L \otimes SU(2)_R \otimes U(1)$$

LEFT-RIGHT SYMMETRIC ELECTROWEAK THEORY

$$SU(2)_L \otimes U(1)$$

$$SU(2)_L \otimes SU(2)_R \otimes U(1)$$

$$SU(2)_L \otimes SU(2)_R \otimes U(1)$$

$$mass \quad of \quad W_R : \ \succ 1 \quad TeV$$

Standard Model

$$SU(3)_c \otimes SU(2)_L \otimes U(1)$$

$$\left(SU(3)_c \otimes U(1)\right) \otimes SU(2)_L \otimes SU(2)_R$$

$$SU(3)_c \otimes SU(2)_L \otimes U(1)$$

$$\big(SU(3)_c \otimes U(1)\big) \otimes SU(2)_L \otimes SU(2)_R$$

$$SU(4)_{c,l} \otimes SU(2)_L \otimes SU(2)_R$$

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

$$SU(2)_L \otimes SU(2)_R$$

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

$$SU(4)_{c,l} \succ SU(3)_c \otimes U(1)$$

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

4th color

J. Pati – A. Salam

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

$$\{SU(2)$$

$$SU(4) \Rightarrow U(1) \otimes SU(3)_c$$

$$\longrightarrow \begin{bmatrix} \alpha \\ \beta \end{bmatrix} \quad \text{2 fermions}$$

$$\Rightarrow SU(2)_L$$

$$SU(4)_{c,l} \otimes SU(2)_L \otimes SU(2)_R$$

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix}_L$$

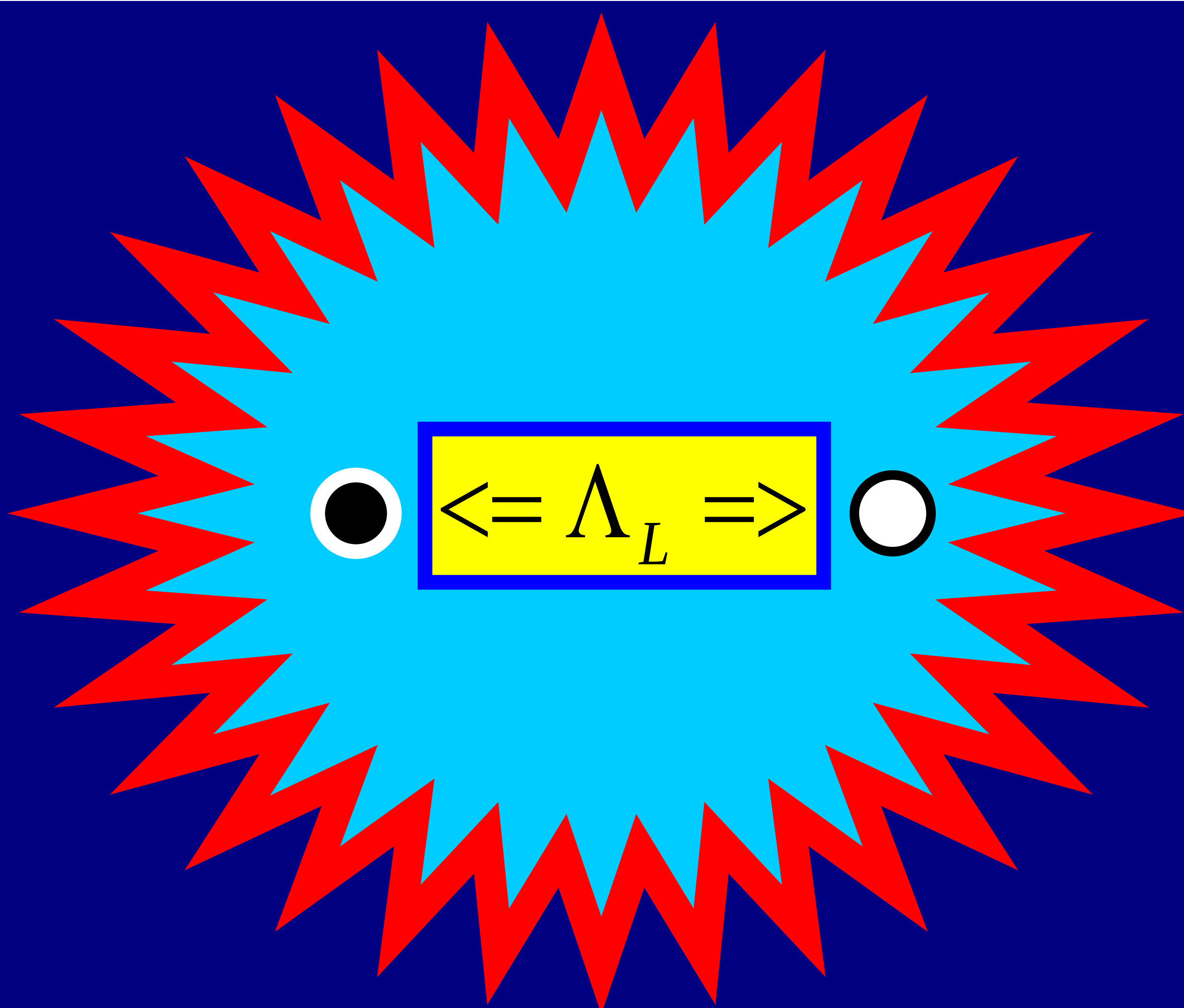
$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix}_R$$

gauge group of QHD

$$SU(n)_L \otimes SU(n)_R$$

mass scale of QHD

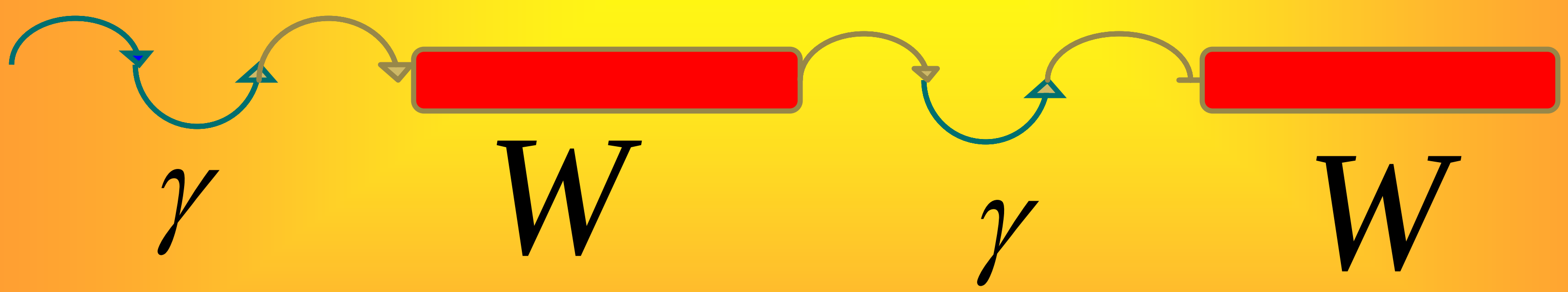
$$\left[\Lambda_L * \Lambda_R\right]$$



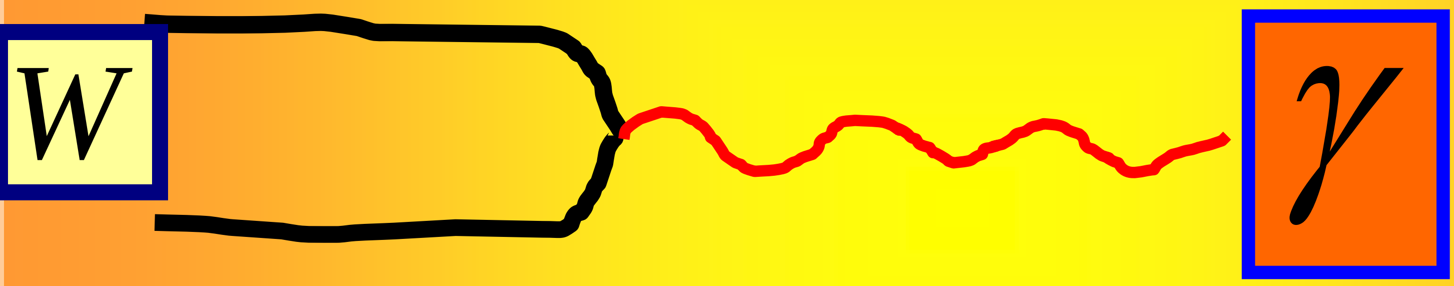
$W - boson$

➔ QHD

Dynamical mixing of W-boson and photon



mixing of W with photon



m: mixing parameter

$$M_Z^2 = \frac{M_W^2}{1-m^2}$$

Standard Model

$$M_Z^{\,2} = \frac{M_W^{\,2}}{1 - \sin^2\theta_w}$$

$$M_Z{}^2 = \frac{M_W{}^2}{1 - m^2}$$

Standard Model

$$M_Z{}^2 = \frac{M_W{}^2}{1 - \sin^2 \theta_w}$$

$$M_Z{}^2 = \frac{M_W{}^2}{1 - \sin^2\theta_w}$$

$$M_Z{}^2 = \frac{M_W{}^2}{1 - m^2}$$

$$\sin\theta_w = m \approx 0.485$$

W decay constant

$$\langle 0 | \frac{1}{2}(\overline{\alpha}\gamma_{\mu L}\alpha - \overline{\beta}\gamma_{\mu L}\beta) | Z \rangle = \varepsilon_{\mu} M_W F_W$$

$$m = e\frac{F_W}{M_W}$$

$$m \approx 0.485$$

$$\Rightarrow F_W \approx 125 \quad GeV$$

experimental data:

$$M_W = 80.4 \ldots GeV$$

$$M_Z = 91.19 \ldots GeV$$

$$F_W = 124.6 \ldots GeV$$

$$\sin^2 \theta_W = 0.2315$$

$$\alpha = \frac{e^2}{4\pi} \cong \frac{1}{128.9}$$

$$e \cong 0.3122$$

$$F_\rho \approx \Lambda_c \approx 220 \quad MeV$$

$$F_W \approx 0.125\_TeV$$

$\Rightarrow$

$$\Lambda_L$$

$$F_W \approx 0.130\_TeV$$

$$\Lambda_L \approx 0.13 \Leftrightarrow 1.0\_TeV$$

uncertainty: gauge group of QHD

$$SU(n) \Rightarrow SU(3)$$

$$\Updownarrow$$

$$F_W \approx 0.13 \quad TeV$$

$$\Lambda_L \approx 0.13 \quad TeV$$

$$\left[\Lambda_L * \Lambda_R\right]$$

$$\Lambda_R > 1 \quad TeV$$

NEW BOSONS

$$\frac{1}{\sqrt{2}}\left(\overline{\alpha}\alpha - \overline{\beta}\beta\right)$$

Z

New:
isoscalar

$$\frac{1}{\sqrt{2}}\left(\overline{\alpha}\alpha + \overline{\beta}\beta\right)$$

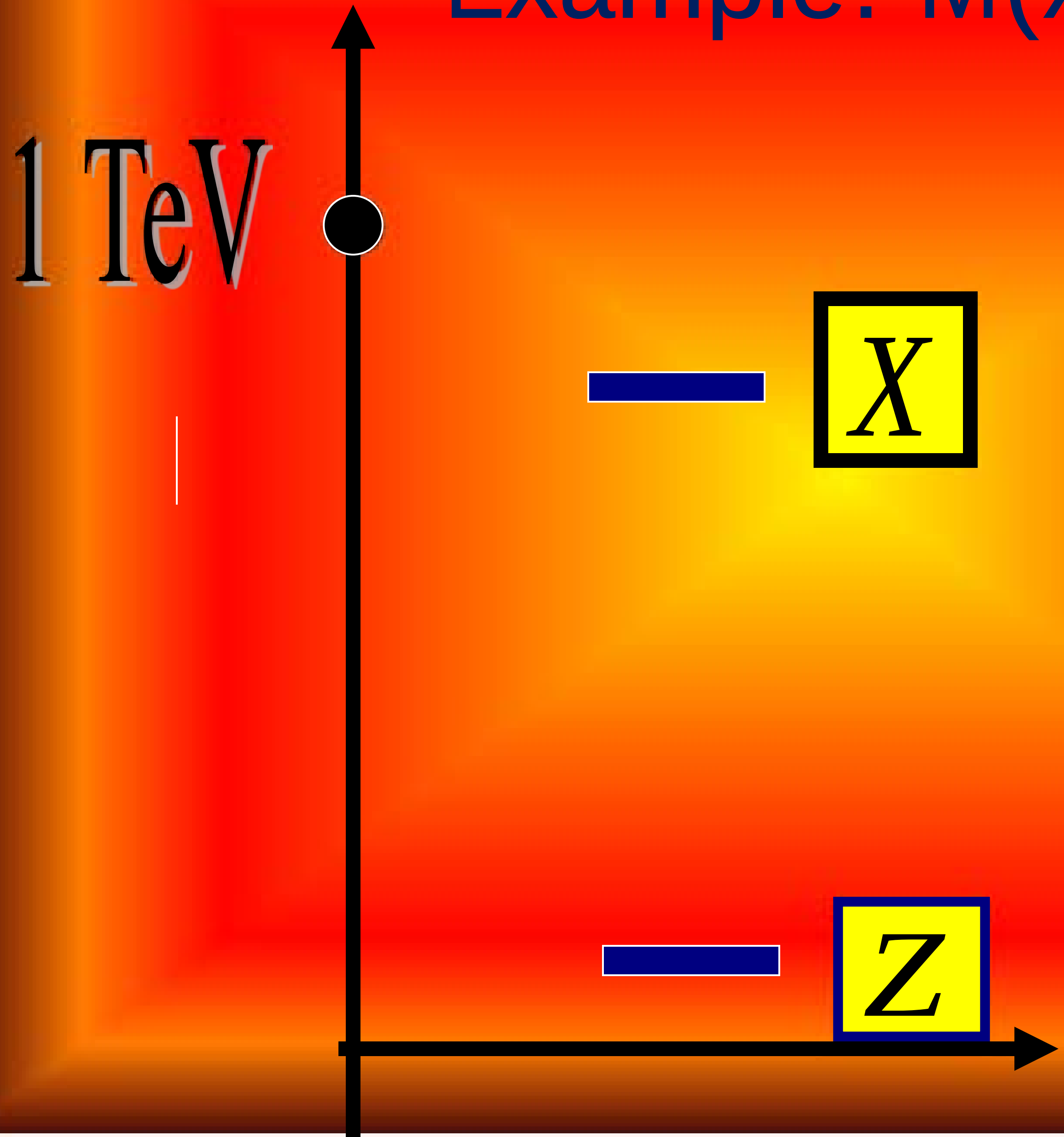
X

Experiment

M(X)

4 0 0 **GEV**

Example: M(X)=0.8 TeV



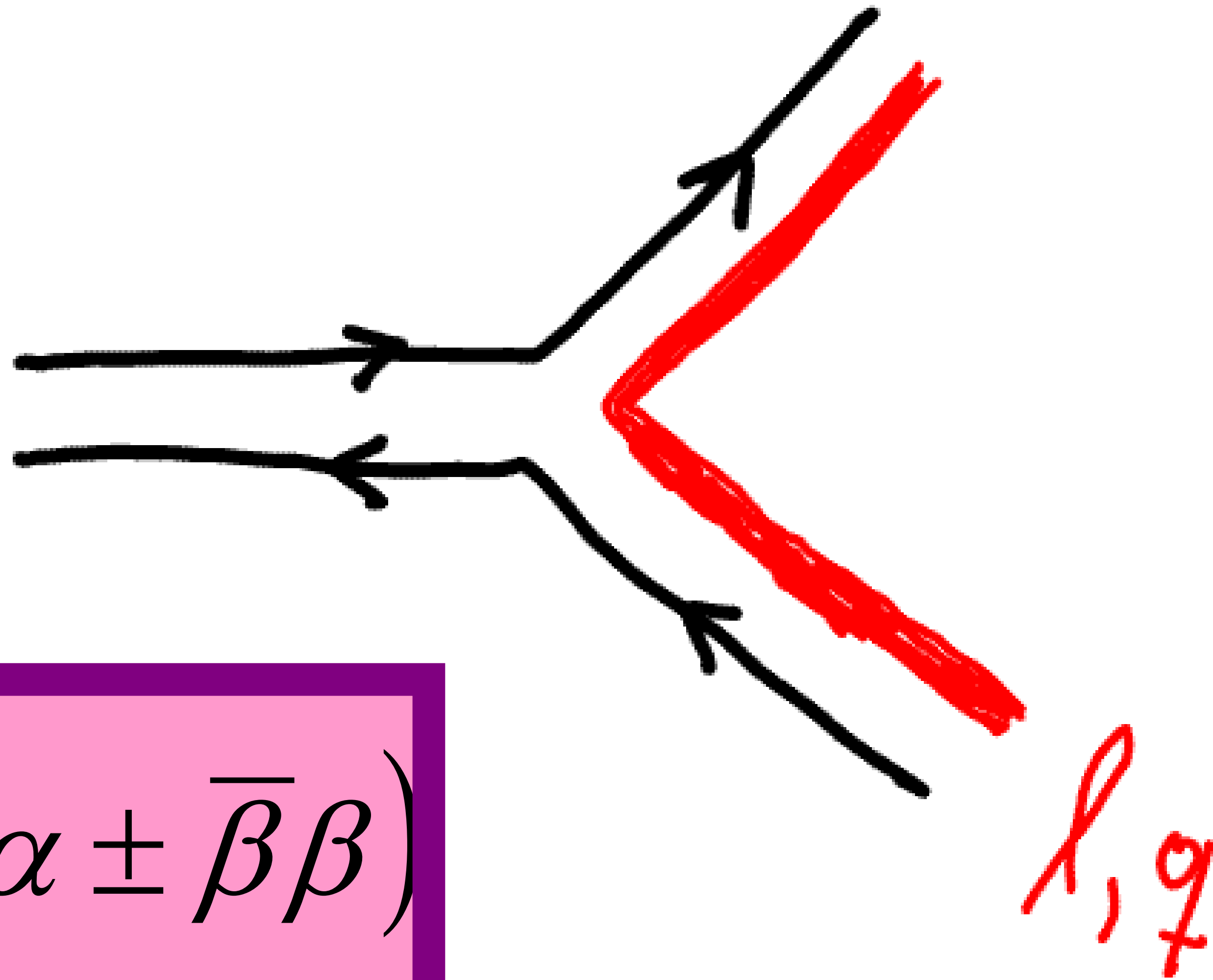
cross section of Z-production at LHC: ~ 60 nb

➔ cross section for X-production: ~0.5 nb

Coupling of X to leptons and quarks:

→ coupling of Z - boson

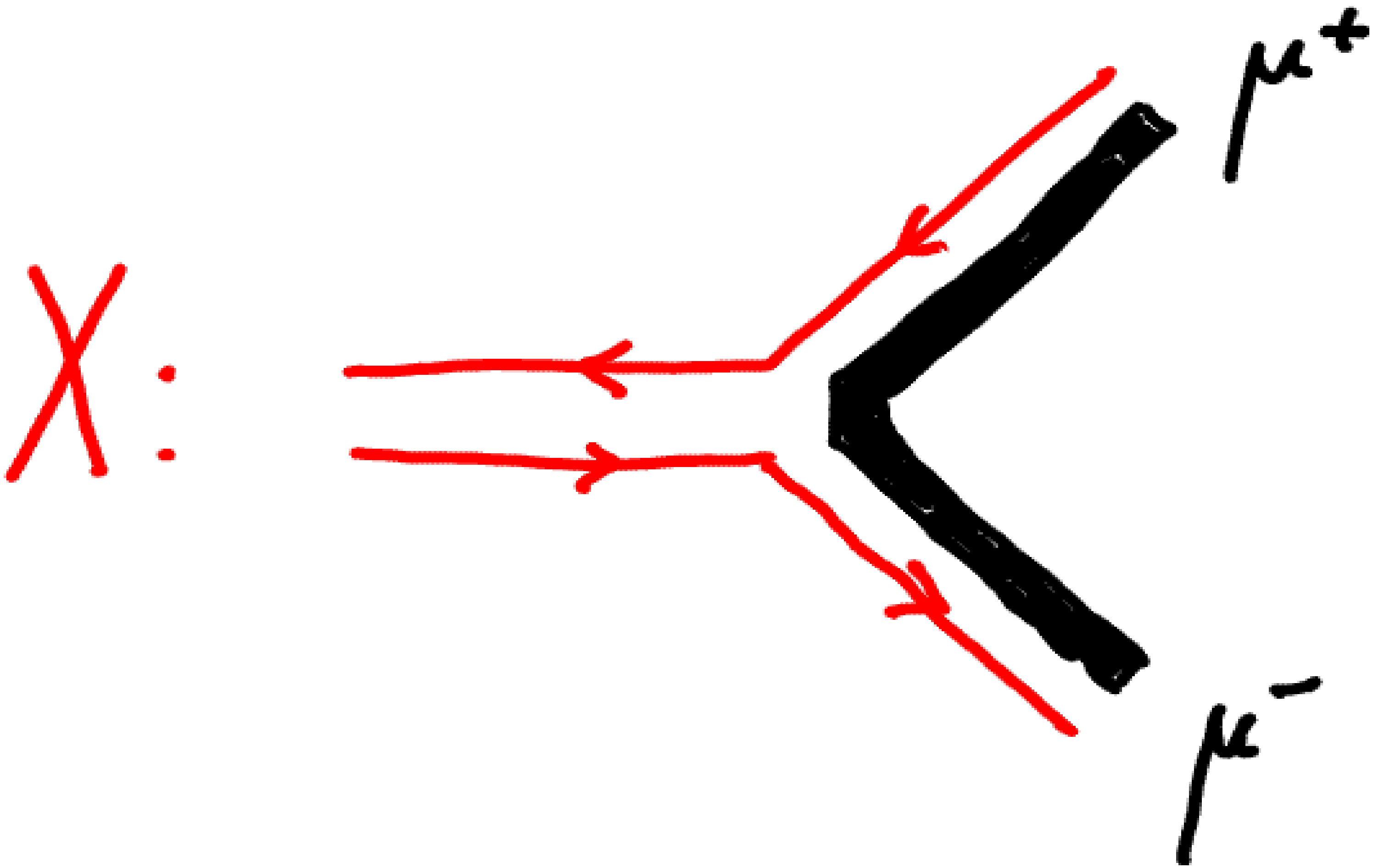
Z → X



$$\frac{1}{\sqrt{2}}\left(\overline{\alpha}\alpha \pm \overline{\beta}\beta\right)$$

X – decay into muons

➔ Z – decay into muons:



$$\Gamma(Z \Rightarrow \mu^+ \mu^-) \cong 84 \quad MeV$$

$$\Gamma(X \Rightarrow \mu^+ \mu^-) \cong 3.6 \quad GeV$$

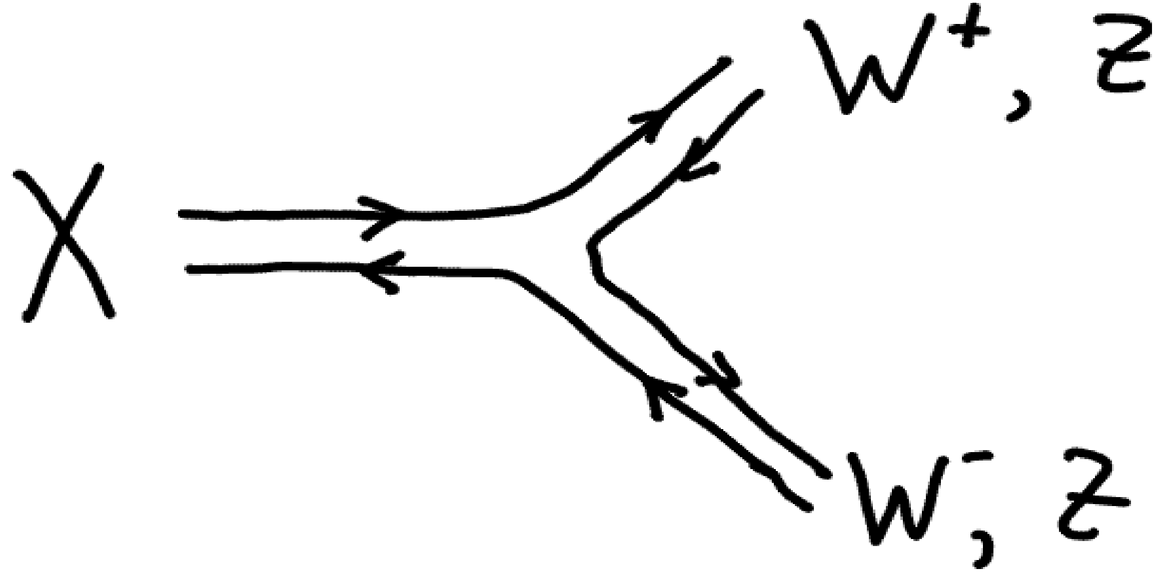
X - decays → leptons, quarks

$$\Gamma(X \to \mu^+\mu^-) \cong \Gamma(X \to e^+e^-)$$

$$\cong \Gamma(X \to \bar{\nu}_e \nu_e)$$

$$\Gamma(X \to \bar{u}u) \cong \Gamma(X \to \bar{d}d)$$

$$\cong 3 \times \Gamma(X \to \mu^+\mu^-)$$



Expected:

$$\Gamma(X \to W^+W^-) \geq$$
$$\Gamma(X \to ZZ)$$
$$\Gamma(X \to \mu^+\mu^-)$$

other decays:

$$X \Rightarrow W^+W^-Z$$

$$X \Rightarrow W^+W^-\gamma$$

$$X \Rightarrow ZZZ$$

$$X \Rightarrow ZZ\gamma$$

$$X \Rightarrow Z\gamma\gamma$$

$$X \Rightarrow W^+W^-W^+W^-$$

$$X \Rightarrow W^+W^-ZZ$$

$$X \Rightarrow W^+W^-Z\gamma$$

$$X \Rightarrow W^+W^-\gamma\gamma$$

$$X \Rightarrow \ldots$$

Summation

Total width of X:

≥ 200 GeV

Total width of Z:

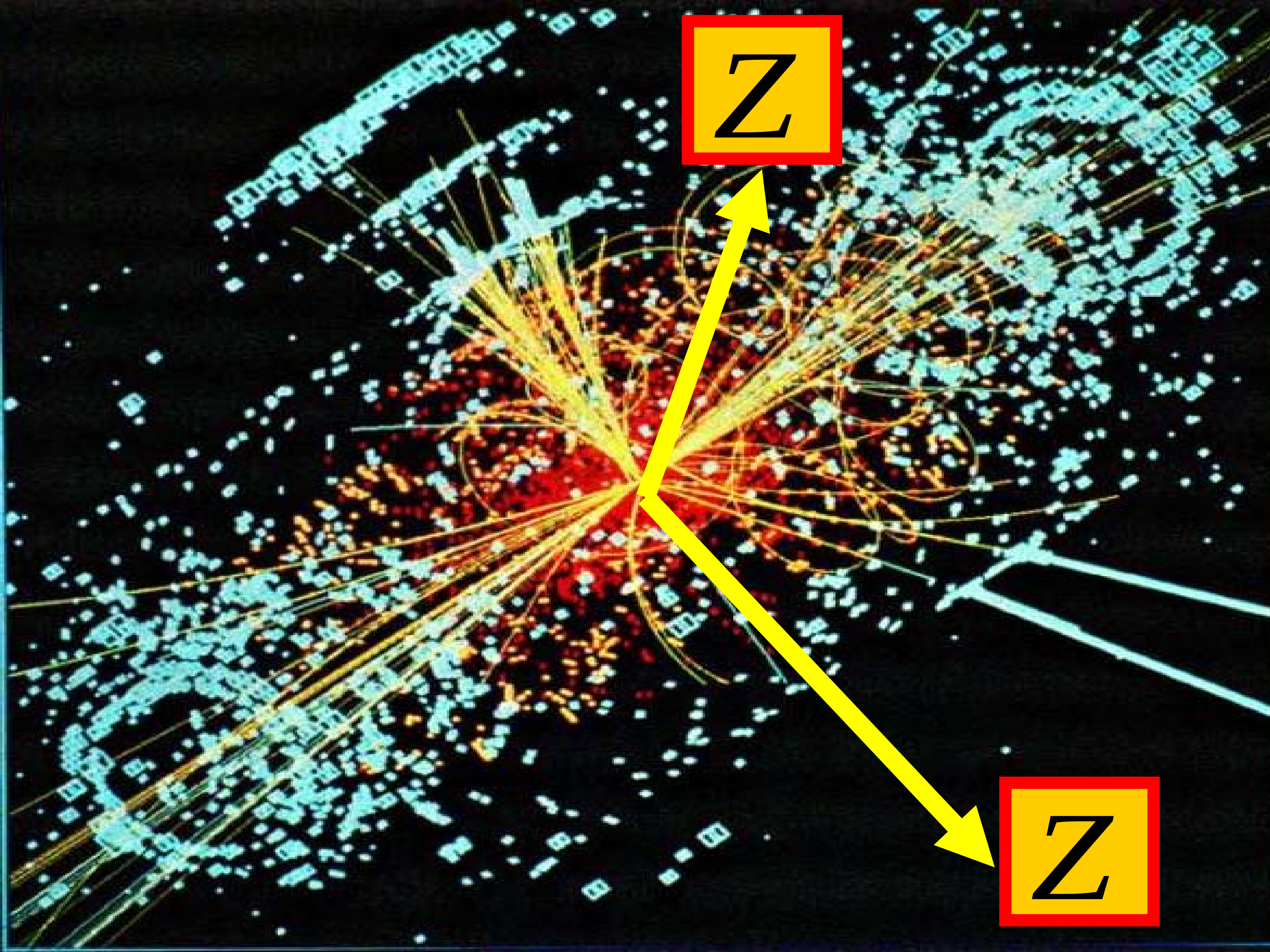
2.5 GeV

branching ratio
for decays
into lepton pairs,
e.g. muon pairs,
might be less than
0.001.

Discovery of X-boson:

search for decay into weak bosons

$$X \Rightarrow Z + Z$$


Z
Z

$$\Lambda_c \approx 0.3 \ldots GeV$$

complexities

of

strong interactions

~ 1 GeV

$$\Lambda_h \propto 0.3\_TeV$$
$$= 1000 \cdot \Lambda_c$$

complexities

of

QHD interactions

~ 1 TeV

EXCITED WEAK BOSONS

$$I(J)$$

$$I : SU(2)$$

$$J : \quad angular \quad momentum$$

p-wave bosons

three SU(2) singlets

$$S = \frac{1}{\sqrt{2}}\left(\overline{\alpha}\alpha + \overline{\beta}\beta\right)$$

S(0) = 0 (0)

S(1) = 0 (1)

S(2) = 0 (2)

p-wave bosons

three SU(2) triplets

$$T^{+} = \bar{\beta}\alpha \qquad T^{-} = \bar{\alpha}\beta \qquad T^{0} = \frac{1}{\sqrt{2}}\left(\bar{\alpha}\alpha - \bar{\beta}\beta\right)$$

T(0) = 1 (0)
T(1) = 1 (1)
T(2) = 1 (2)

p-wave mesons
(QCD)

$$scalar: \qquad \sigma(\sim 700)$$

$$vector: \qquad h_1(1170)$$

$$tensor: \qquad f_2(1270)$$

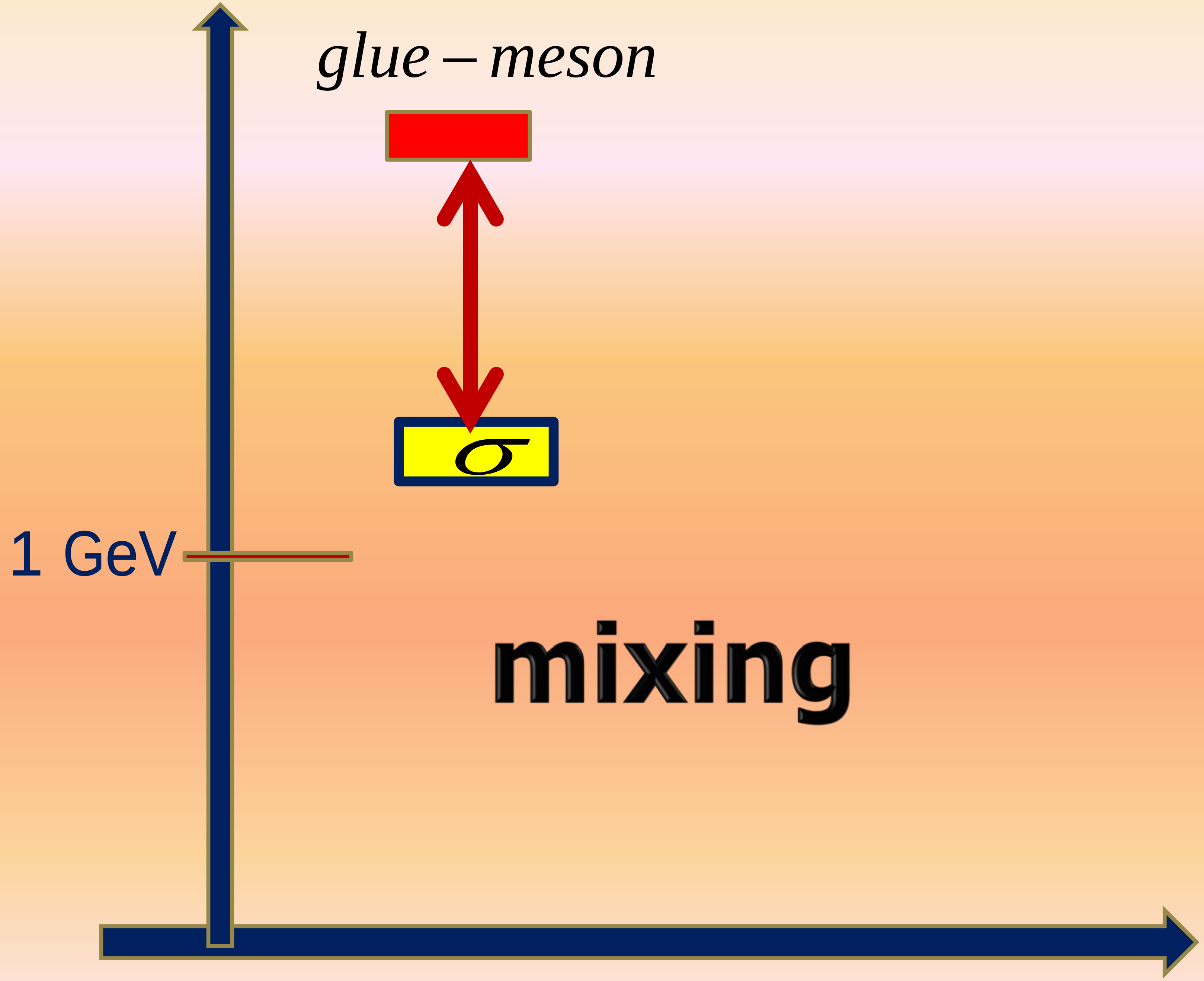
$\sigma \Longrightarrow$

strong mixing

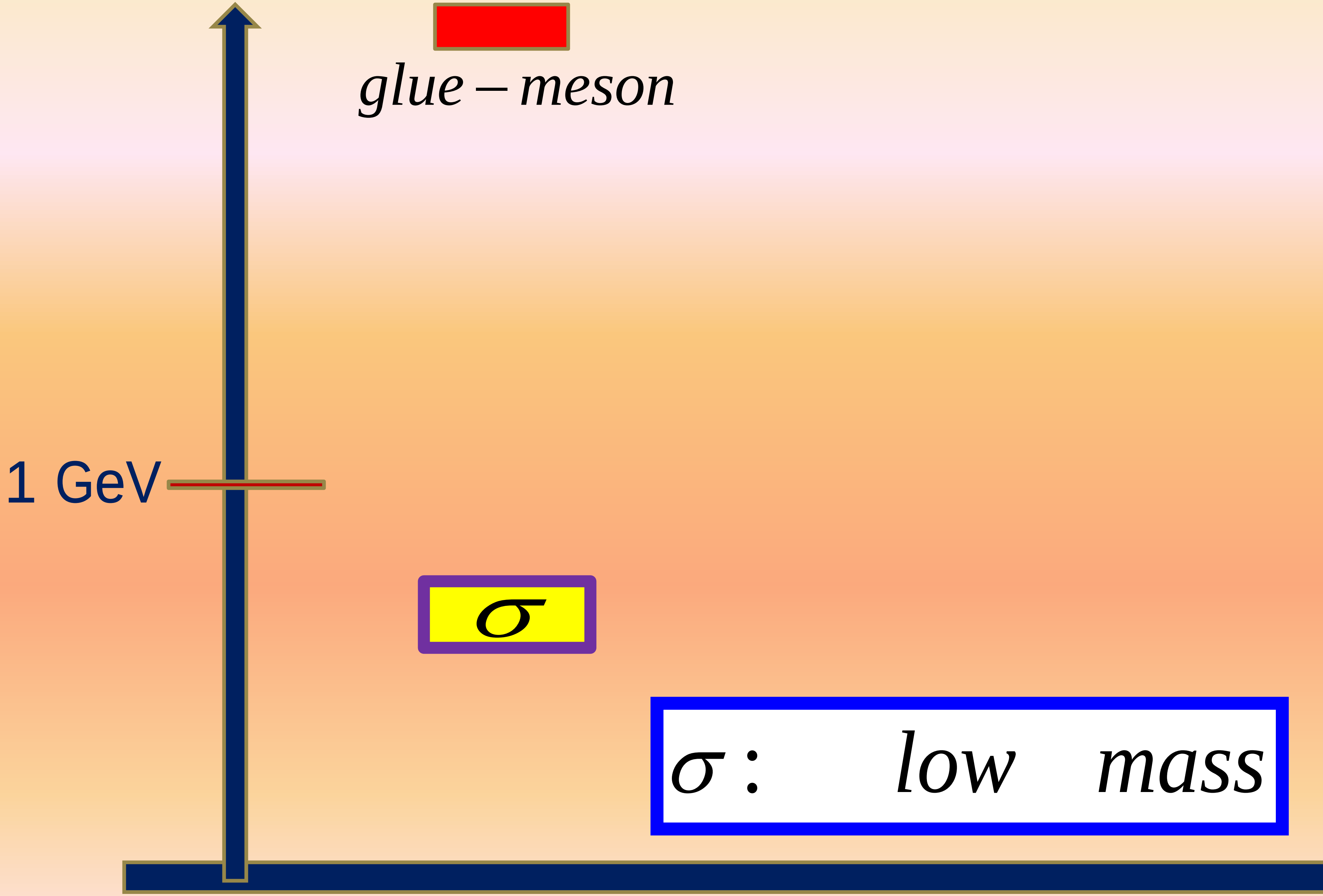
with

glue mesons

=> low mass



$glue - meson$
σ
1 GeV
mixing

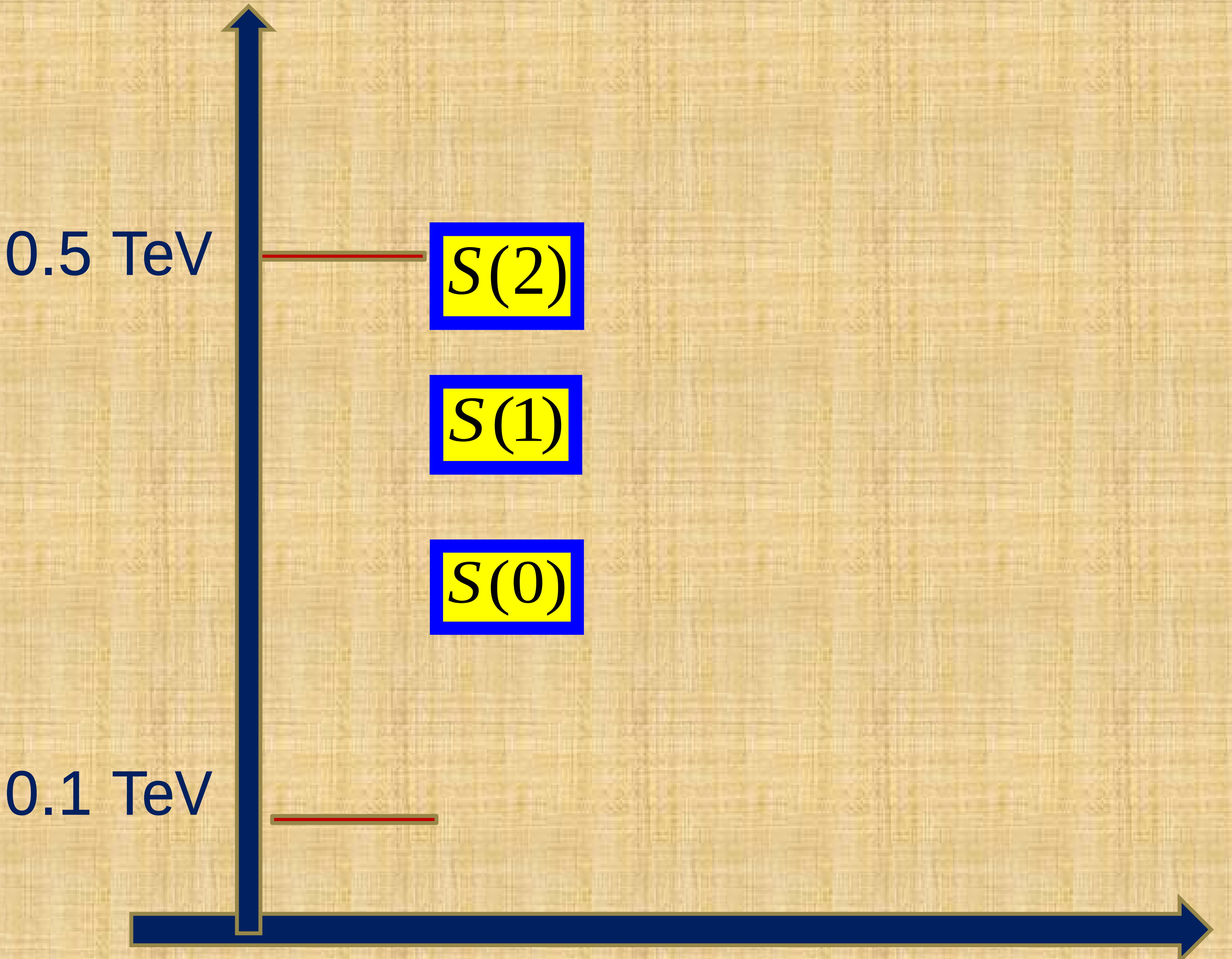

glue – meson
1 GeV
σ
σ : low mass

analogy

$$\sigma(\sim 700) \quad \Rightarrow \quad S(0)$$

$$h_1(1170) \quad \Rightarrow \quad S(1)$$

$$f_2(1270) \quad \Rightarrow \quad S(2)$$


0.5 TeV
0.1 TeV
S(2)
S(1)
S(0)

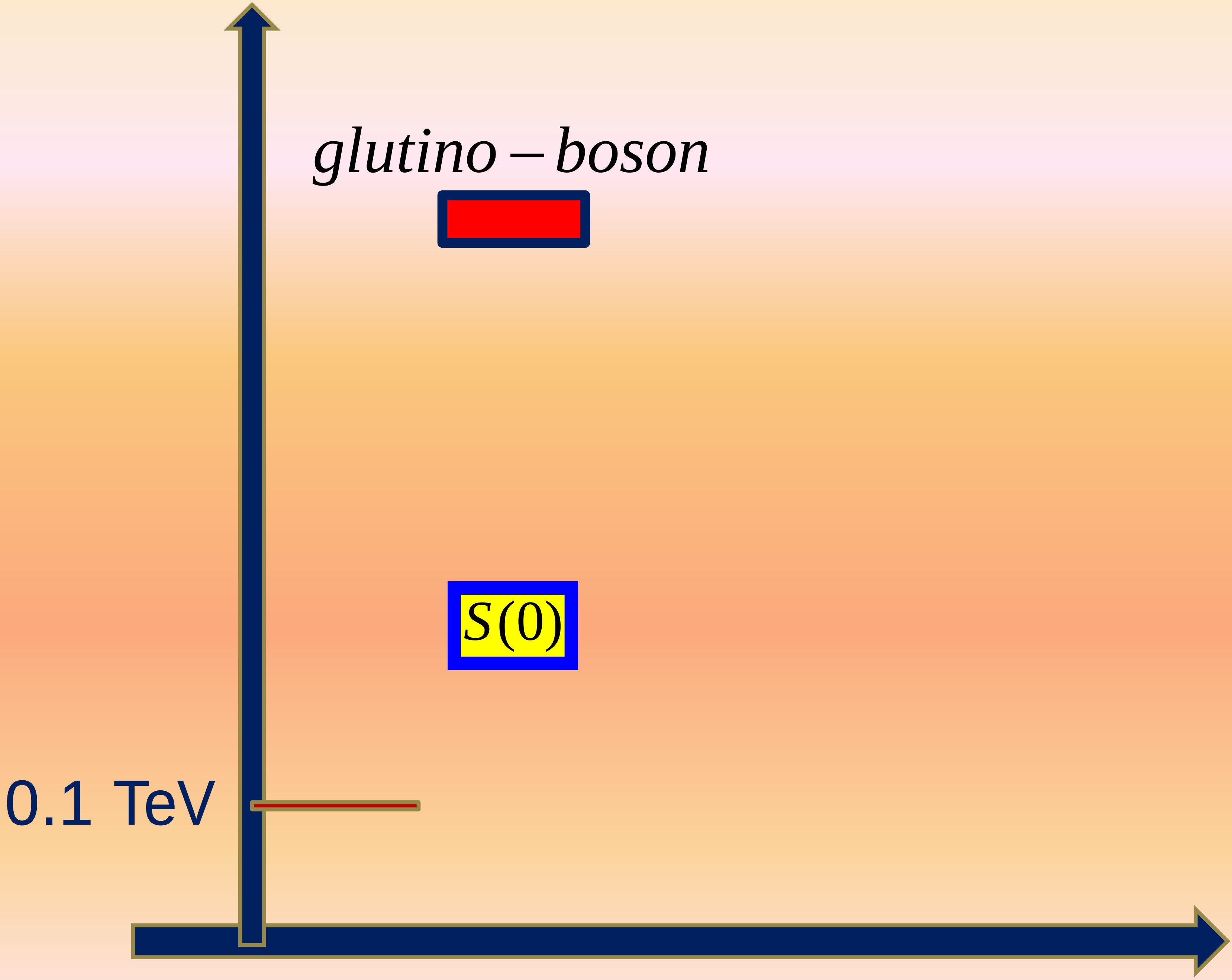
S(0)

strong mixing

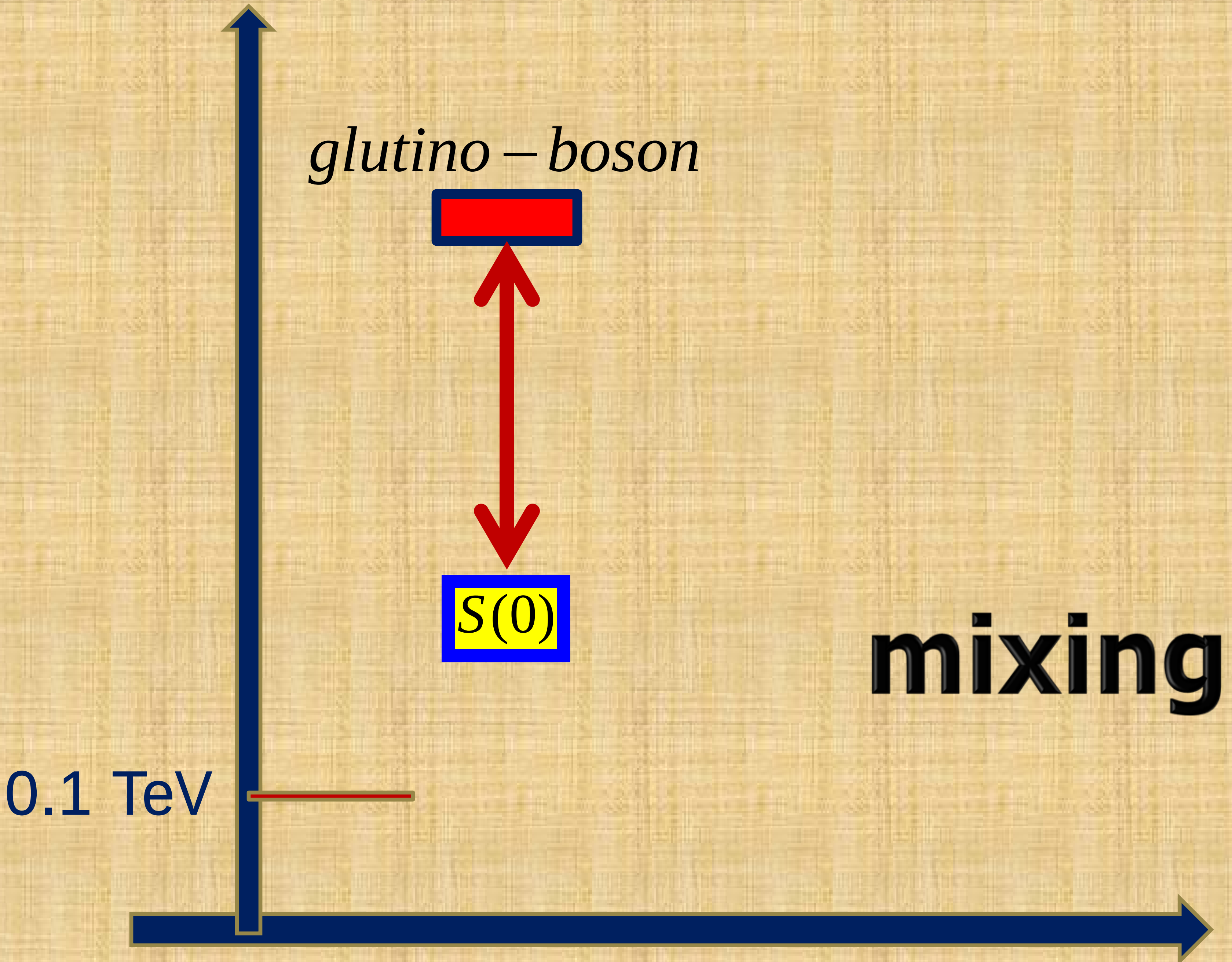
with

glutino bosons

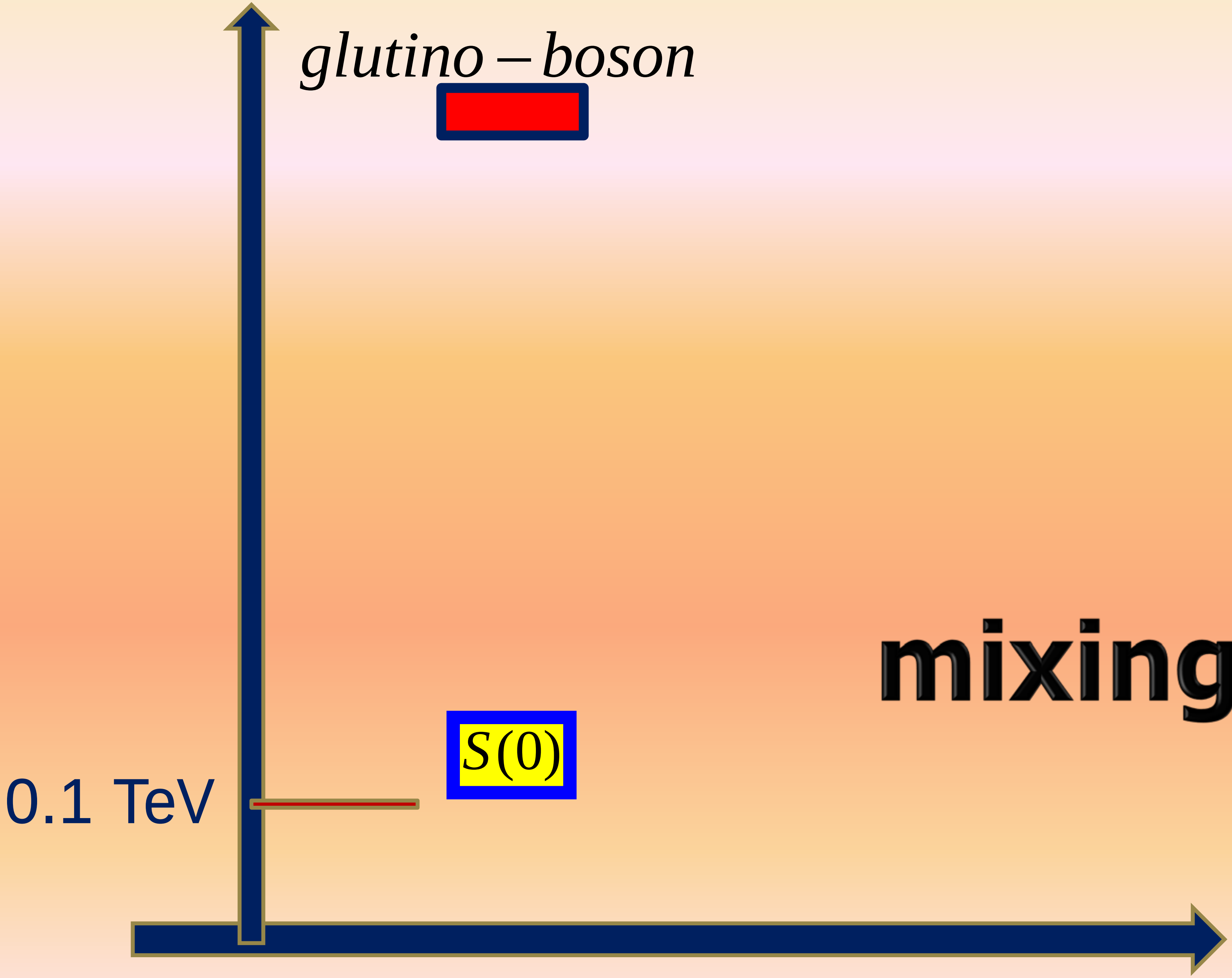
=> low mass



$glutino - boson$
$S(0)$
0.1 TeV



$glutino-boson$
$S(0)$
mixing
0.1 TeV

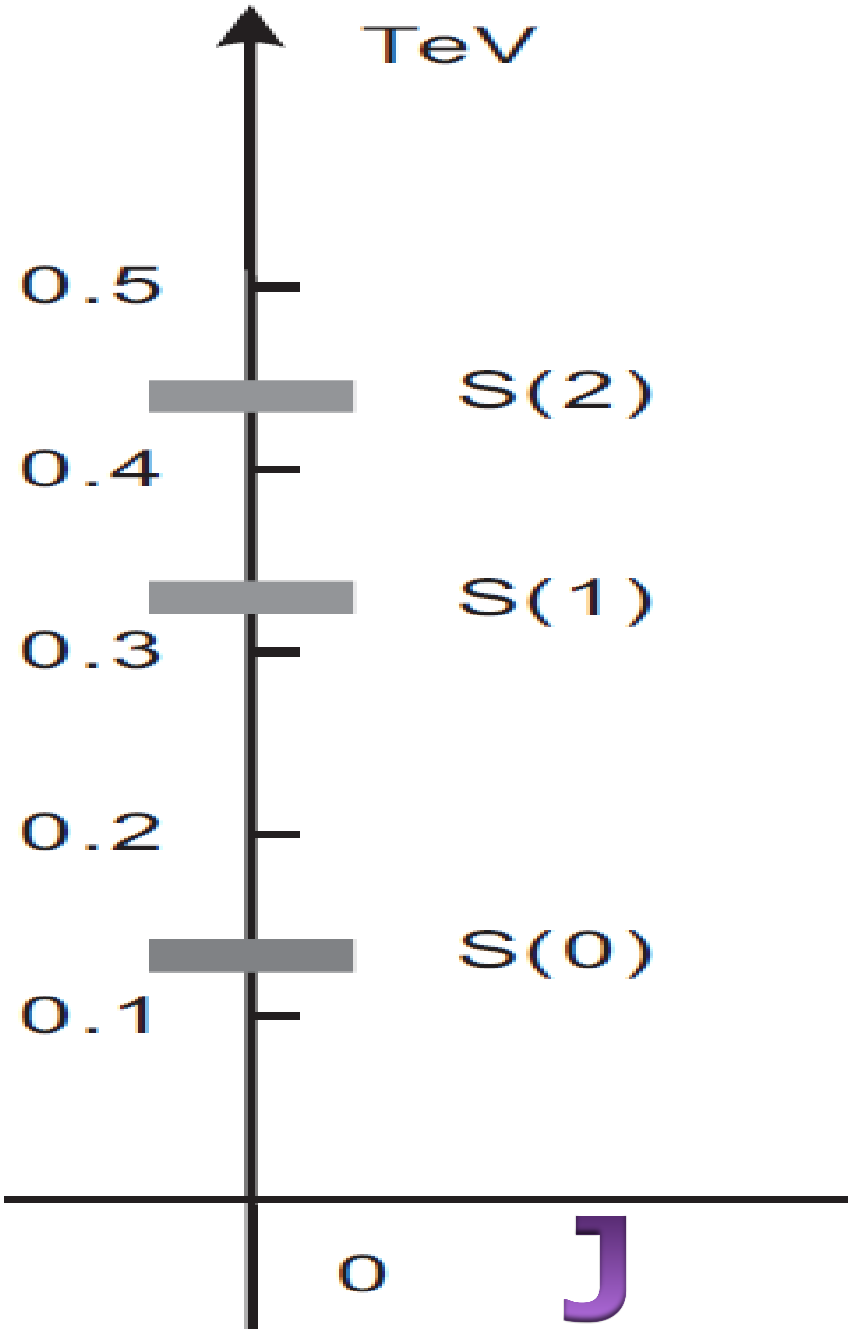

glutino – boson
mixing
S(0)
0.1 TeV

S(0)

LHC

? 125 GeV ?

possible mass spectrum



isospin triplets in QCD

$$scalar: \quad a_0(980)$$

$$vector: \quad b_1(1235)$$

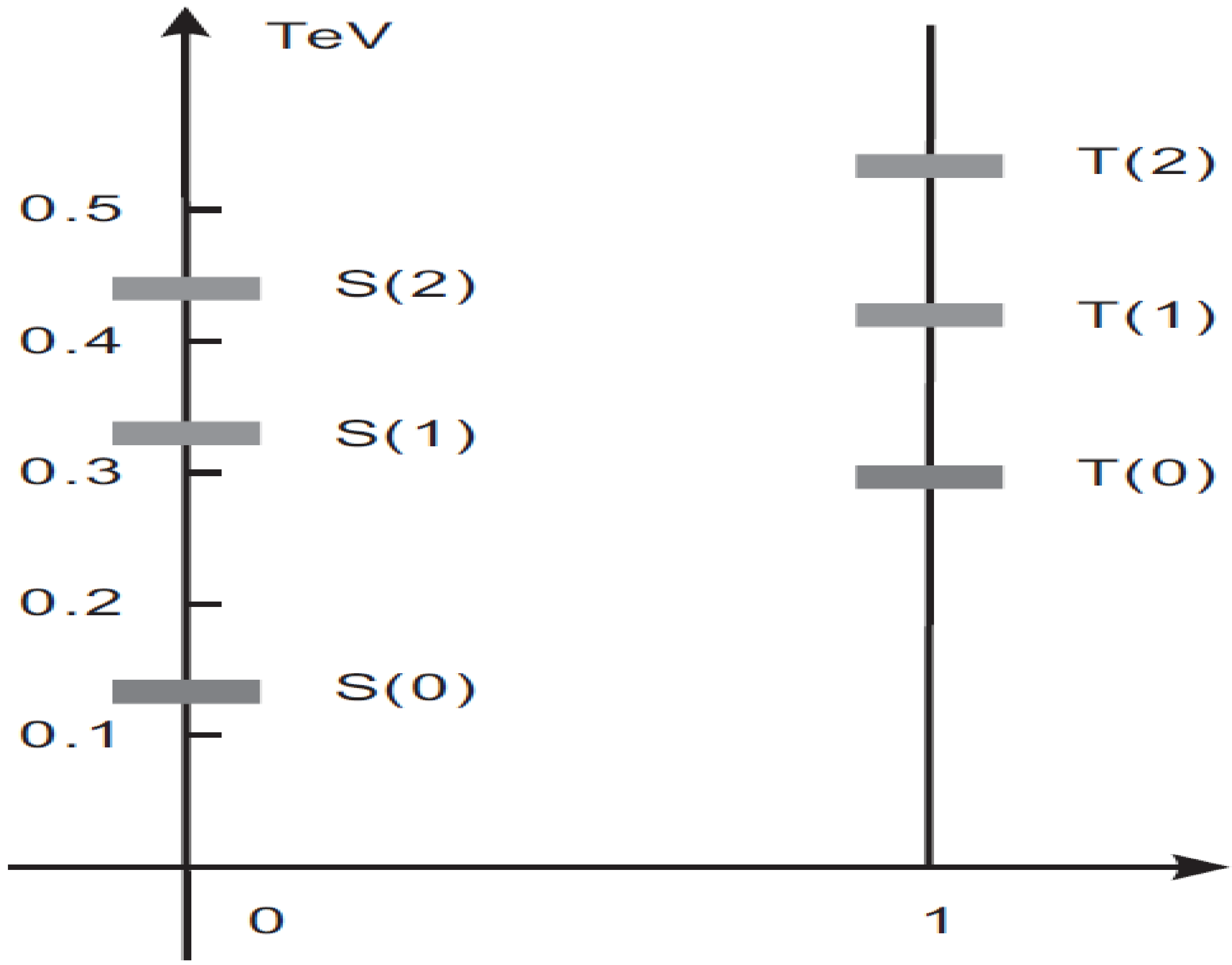
$$tensor: \quad f_2(1270)$$

analogy

$$a_0(980) \Rightarrow T(0)$$

$$b_1(1235) \Rightarrow T(1)$$

$$f_2(1270 \Rightarrow T(2)$$


TeV
0.5
0.4
0.3
0.2
0.1
S(2)
S(1)
S(0)
T(2)
T(1)
T(0)
0
1

decays

$$S(0) \Rightarrow "W^{+}" + W^{-}$$

$$S(0) \Rightarrow W^{+} + "W^{-}"$$

$$S(0) \Rightarrow "Z" + Z$$

$$"Z" \Rightarrow \quad virtual \quad Z$$

$$S(0) \Rightarrow W^{+} + W^{-}$$

$$S(0) \Rightarrow W^{-} + W^{+}$$

$$S(0) \Rightarrow W^{3} + W^{3}$$

$$W^{3} = \cos\theta_{w} Z + \sin\theta_{w} \gamma$$

$$W^3 \Rightarrow 0.77..Z + 0.23..\gamma$$

$$S(0) \Rightarrow W^+ + W^- \quad 100\%$$

$$S(0) \Rightarrow Z + Z \quad 59\%$$

$$S(0) \Rightarrow Z + \gamma \quad 36\%$$

$$S(0) \Rightarrow \gamma + \gamma \quad 5\%$$

$$S(0) \Rightarrow e^{+} + e^{-}$$

$$S(0) \Rightarrow \mu^{+} + \mu^{-}$$

$$S(0) \Rightarrow \ldots\ldots\ldots\ldots$$

$$S(0) \Rightarrow \overline{u} + u$$

$$S(0) \Rightarrow \ldots\ldots\ldots\ldots$$

weak boson decay / leptonic decay

$$\frac{rate\left[S(0) \Rightarrow \mu^{+}\mu^{-}\right]}{rate\left[S(0) \Rightarrow WW\right]} = ?$$

If this ratio is 1:

decay into muons

rate as large as rate for decay into weak bosons - not observed at LHC.

$$\frac{rate\left[S(0) \Rightarrow \mu^{+}\mu^{-}\right]}{rate\left[S(0) \Rightarrow WW\right]} = \varepsilon$$

$$\varepsilon \prec 1$$

$$e.g. \qquad \varepsilon \leq 0.001$$

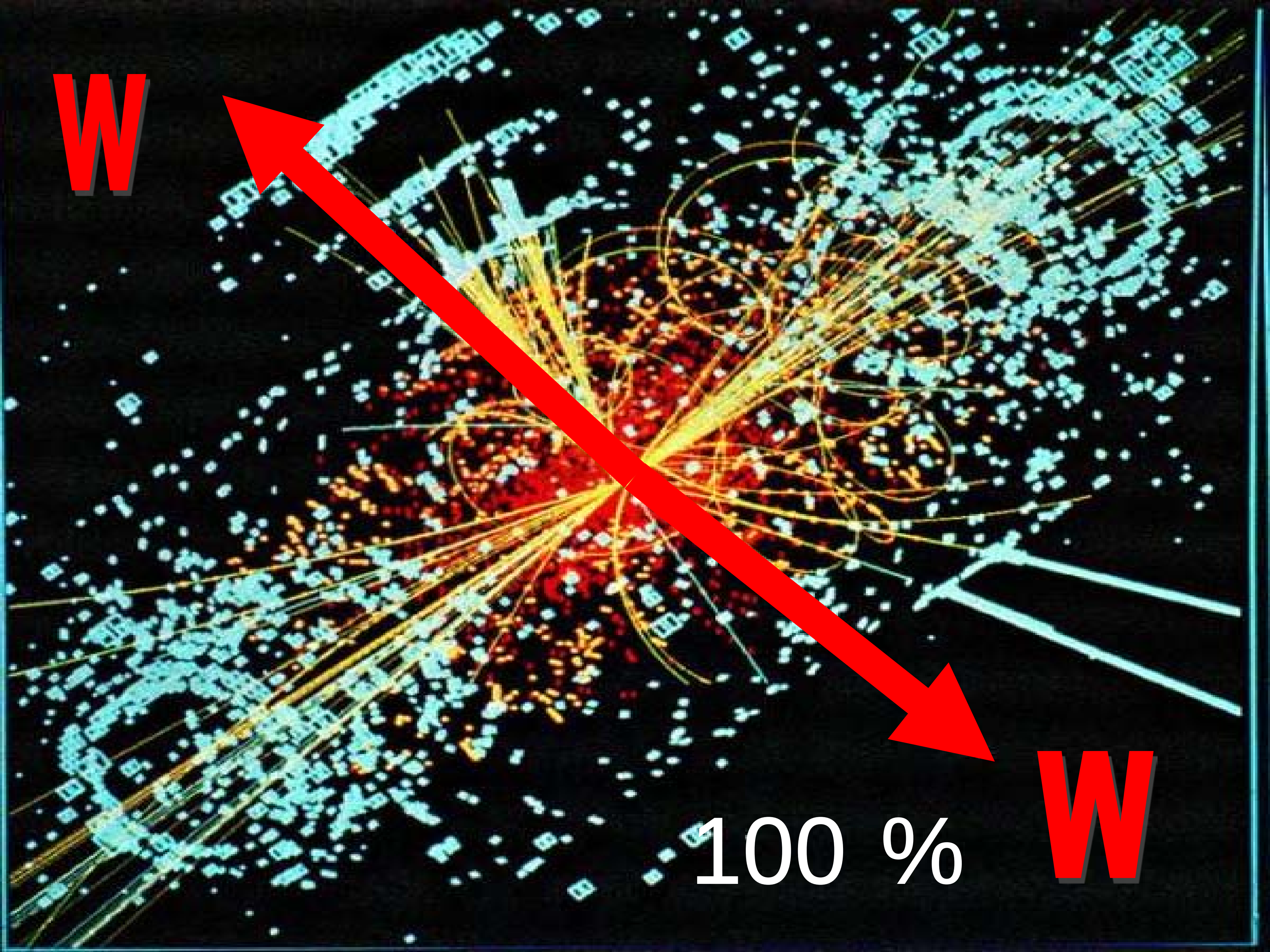
➔ leading decay modes

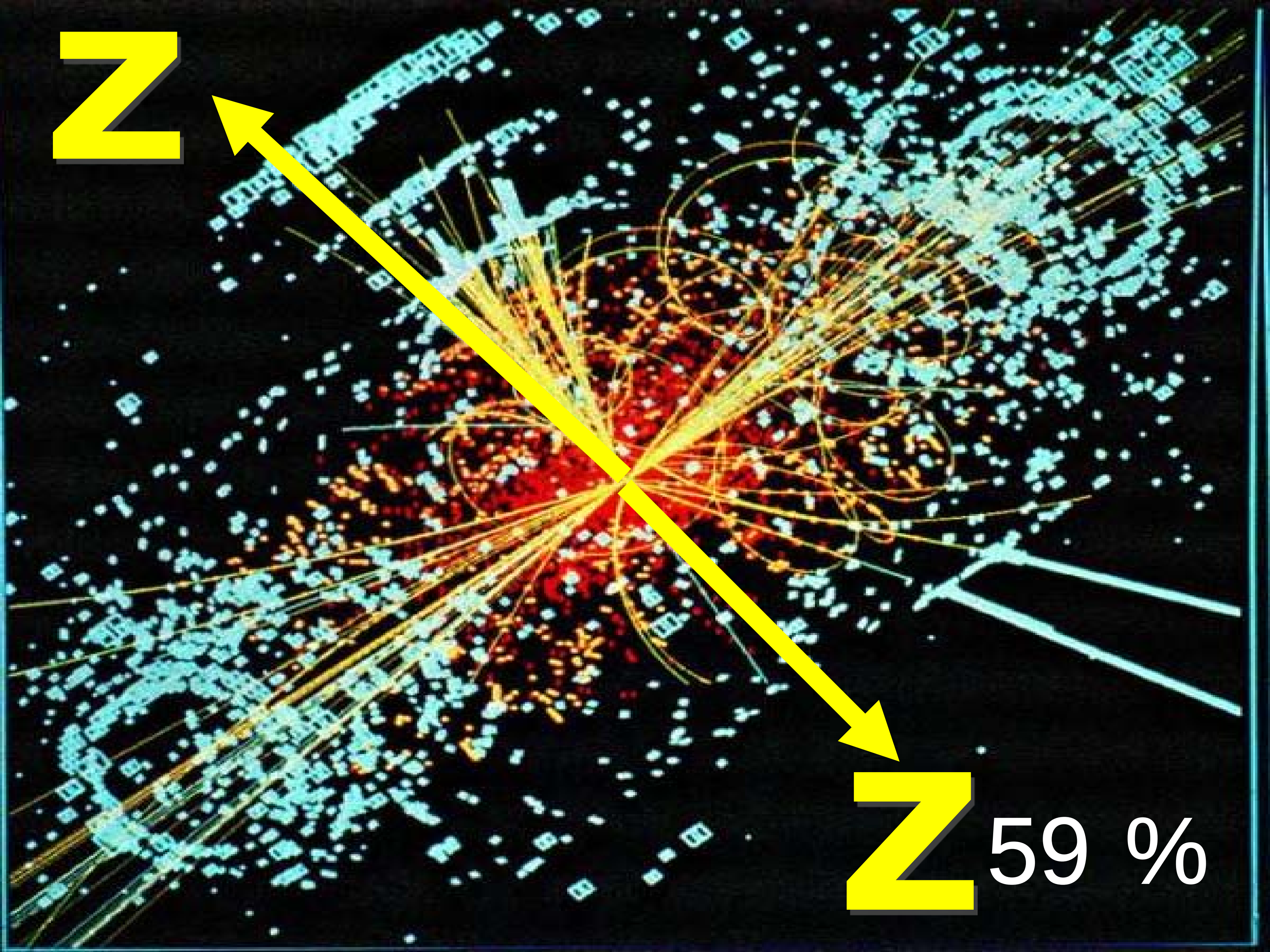
$$S(0) \Rightarrow W + W$$

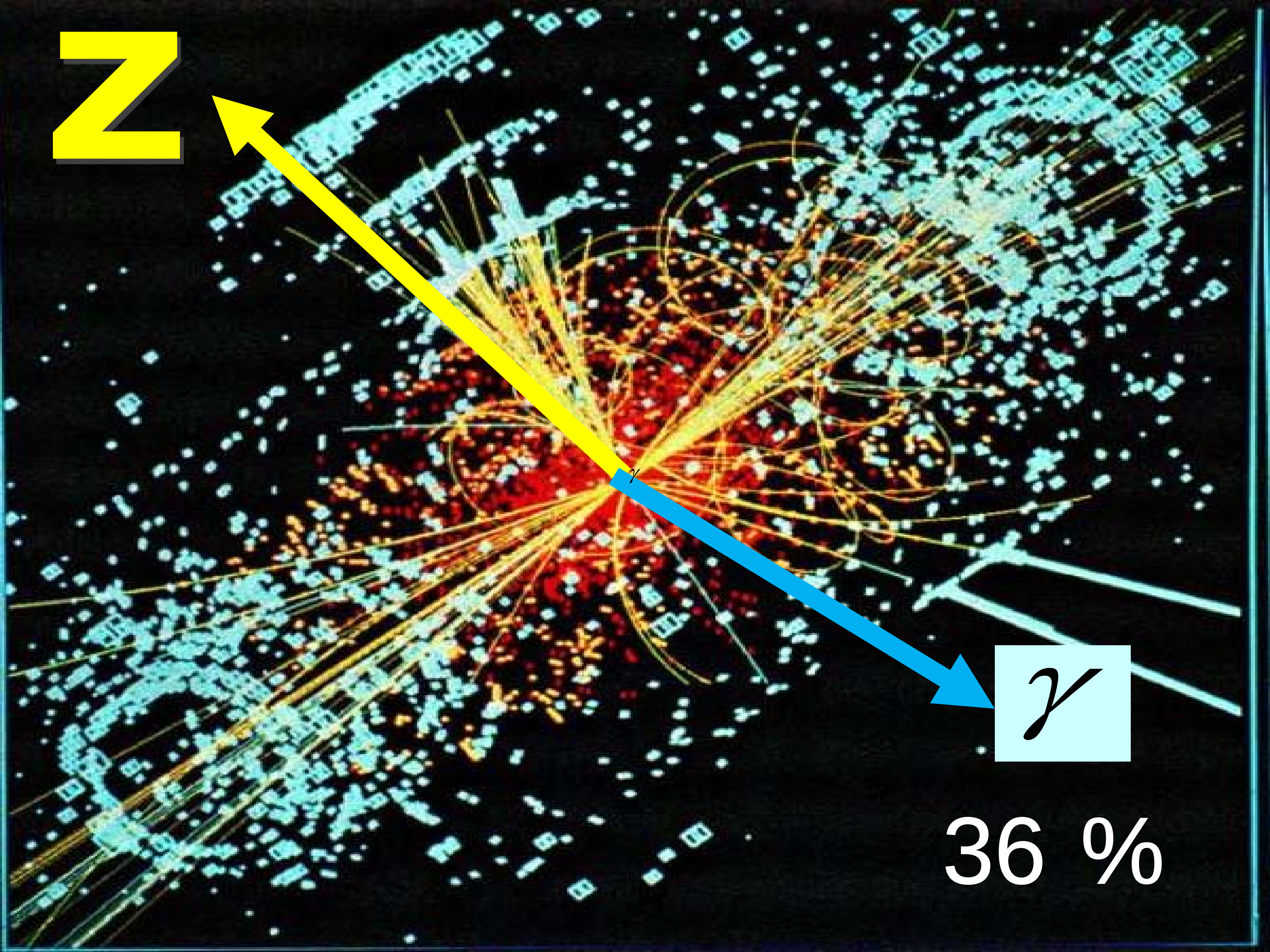
$$S(0) \Rightarrow Z + Z$$

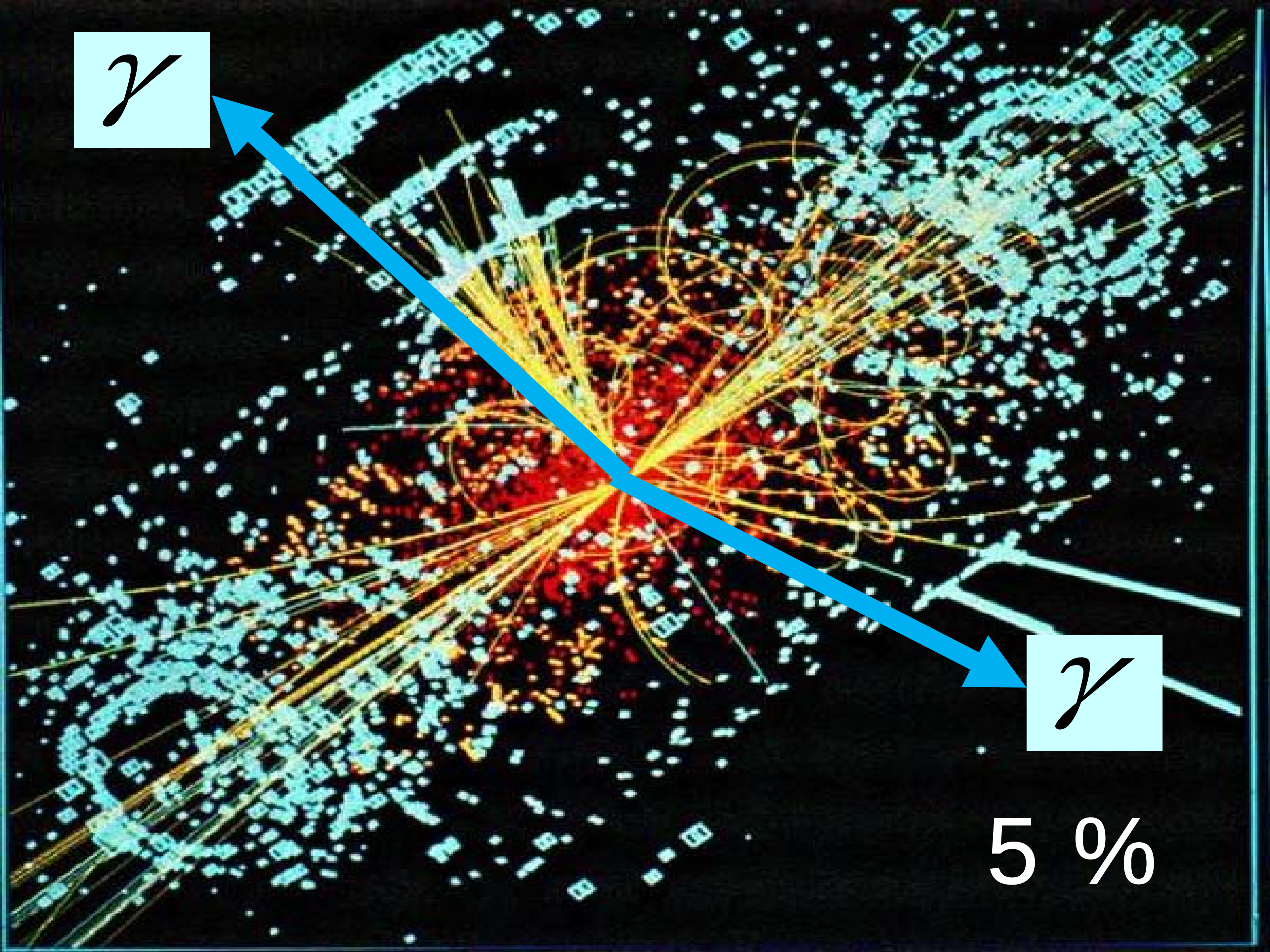
$$S(0) \Rightarrow Z + \gamma$$

$$S(0) \Rightarrow \gamma + \gamma$$


W
W
100 %


Z
Z
59 %


Z
γ
36 %



γ
γ
5 %

Experiment

$$\frac{S(0) \Rightarrow \gamma + \gamma}{S(0) \Rightarrow W^{+} + W^{-}} \approx 0.04 \pm 0.015$$

Expected < **S(0): 0.05**

„Higgs“ -boson

$$\frac{H \Rightarrow \gamma + \gamma}{H \Rightarrow W^{+} + W^{-}} \approx 0.015$$

S(0) production cross section at the LHC

(from two photon decay)

~ 10 pb

125 GeV „Higgs“ boson

decay into leptons

electrons : muon : tauons

0.00002 : 1 : 286

125 GeV

S(0)

electrons : muon : tauons

1 : 1 : 1

decays of S(1)
M= 320 Gev

$$S(1) \Longrightarrow W^{+} + W^{-}$$

$$S(1) \Longrightarrow Z + Z$$

$$S(1) \Longrightarrow Z + Z + \gamma$$

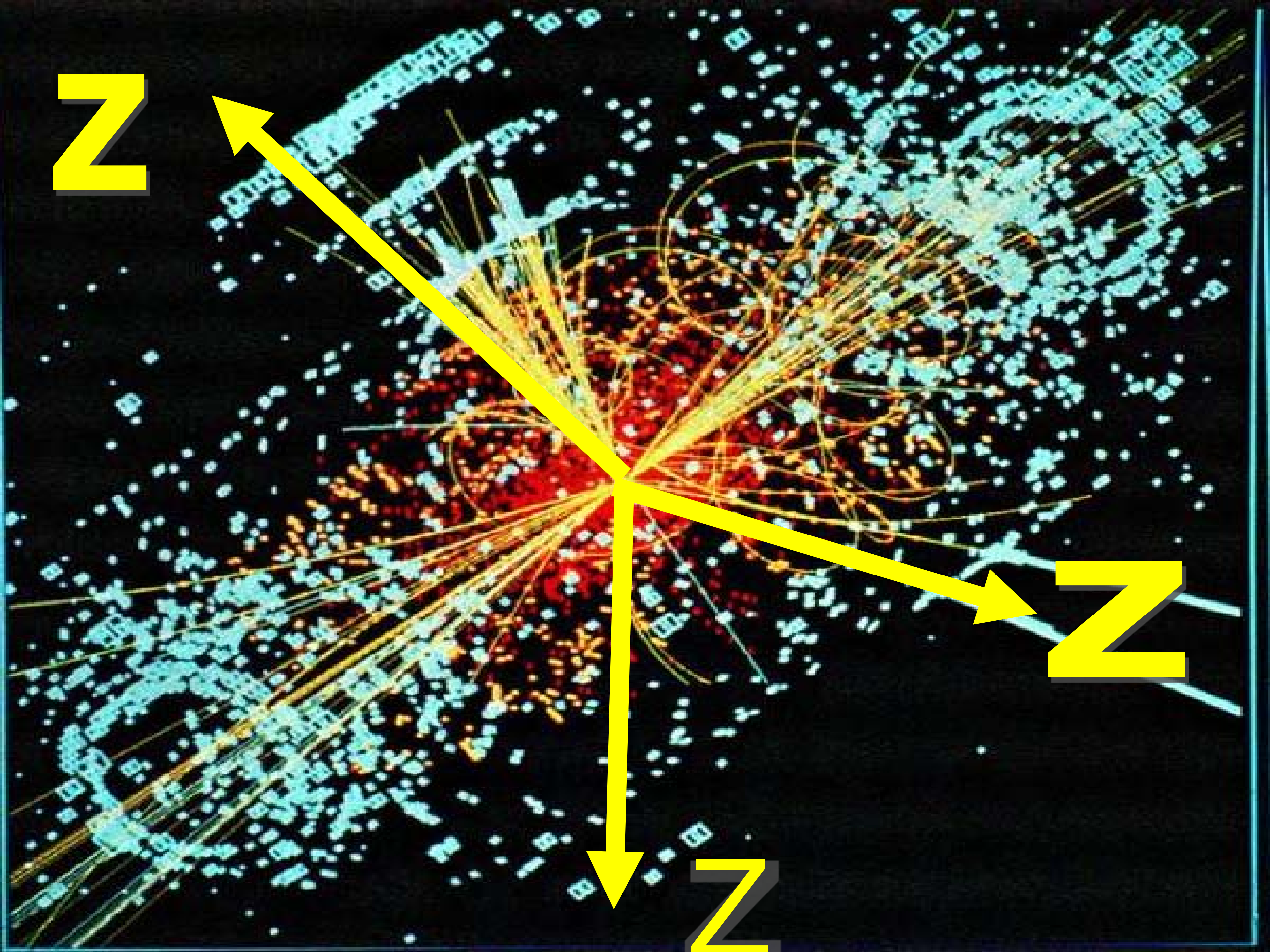
$$S(1) \Longrightarrow Z + Z + Z$$

$$S(1) \Longrightarrow Z + \gamma + \gamma$$

$$S(1) \Longrightarrow \gamma + \gamma + \gamma$$

$$S(1) \Rightarrow \gamma + \gamma$$

Landau-Yang-Theorem


Z
Z
Z

decays of T-bosons

M= 290 GeV

$$T(0)^{+} \Rightarrow W^{+} + Z$$

$$T(0)^{+} \Rightarrow W^{+} + \gamma$$

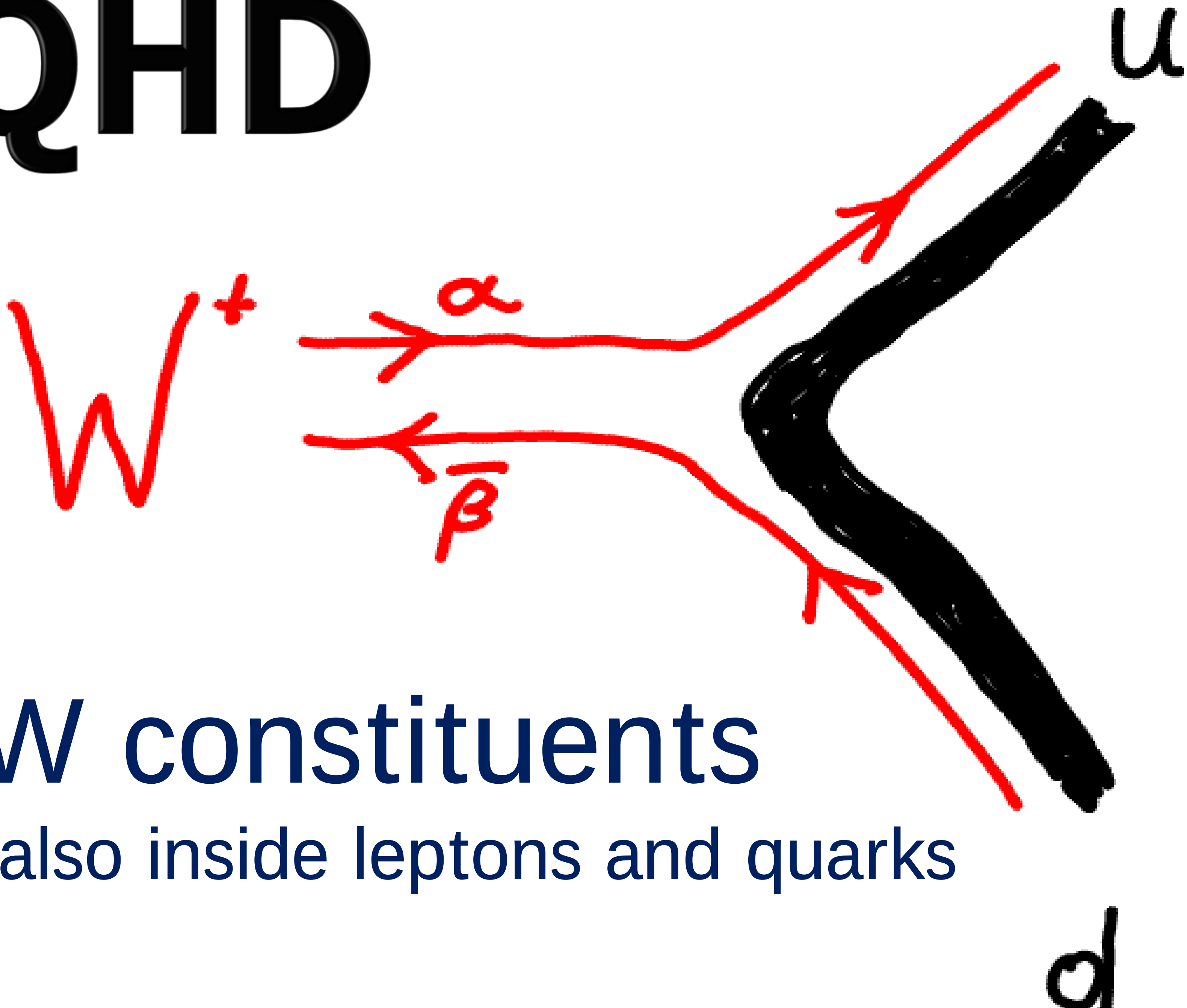
$$T(0)^{+} \Rightarrow W^{+} + \gamma + \gamma$$

$$T(0)^{+} \Rightarrow W^{+} + Z + \gamma$$

$$T(0)^{+} \Rightarrow W^{+} + Z + Z$$

$$T(0)^{+} \Rightarrow W^{+} + \ldots + \ldots + \ldots \therefore \ldots$$

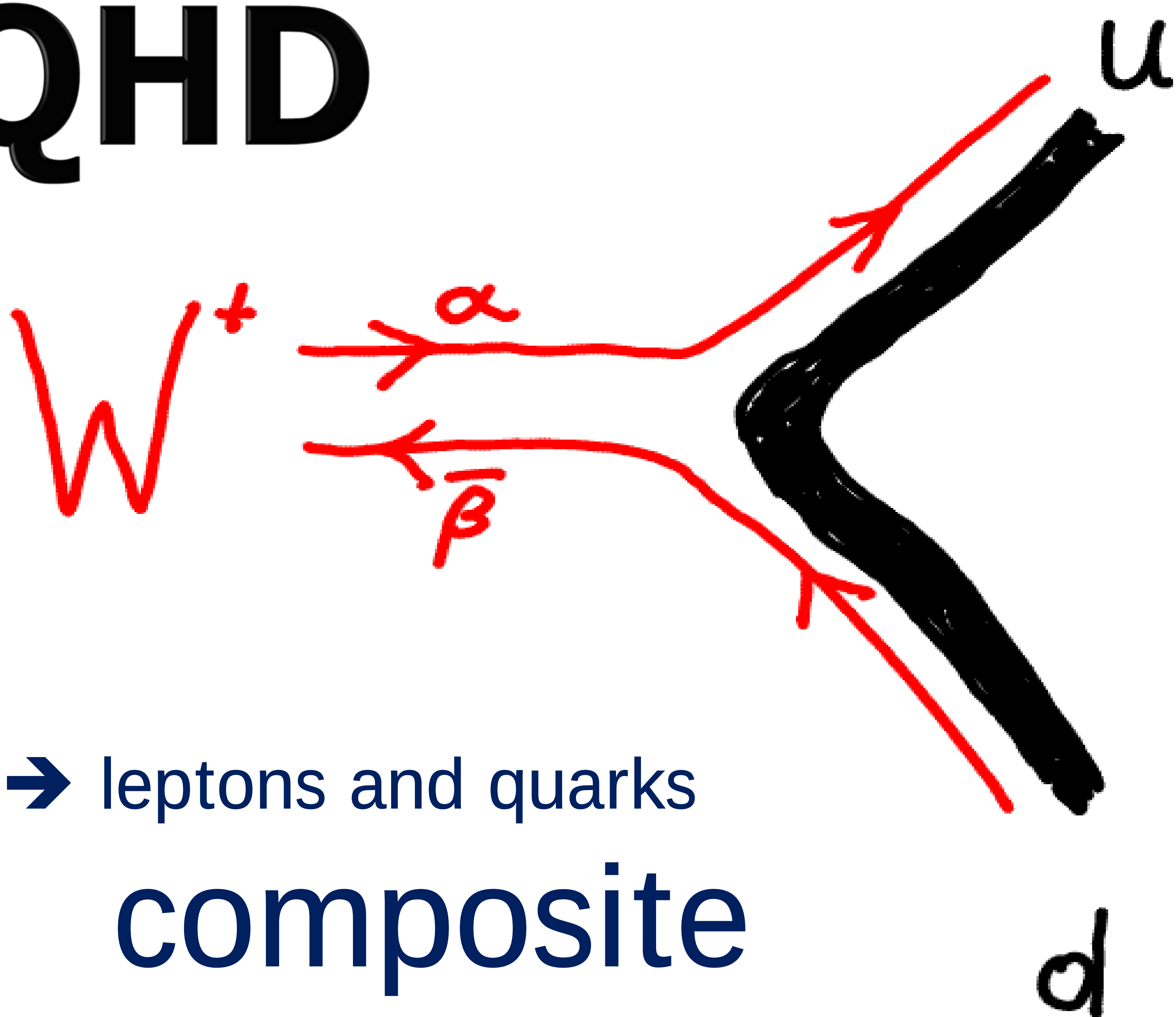
QHD



W constituents

also inside leptons and quarks

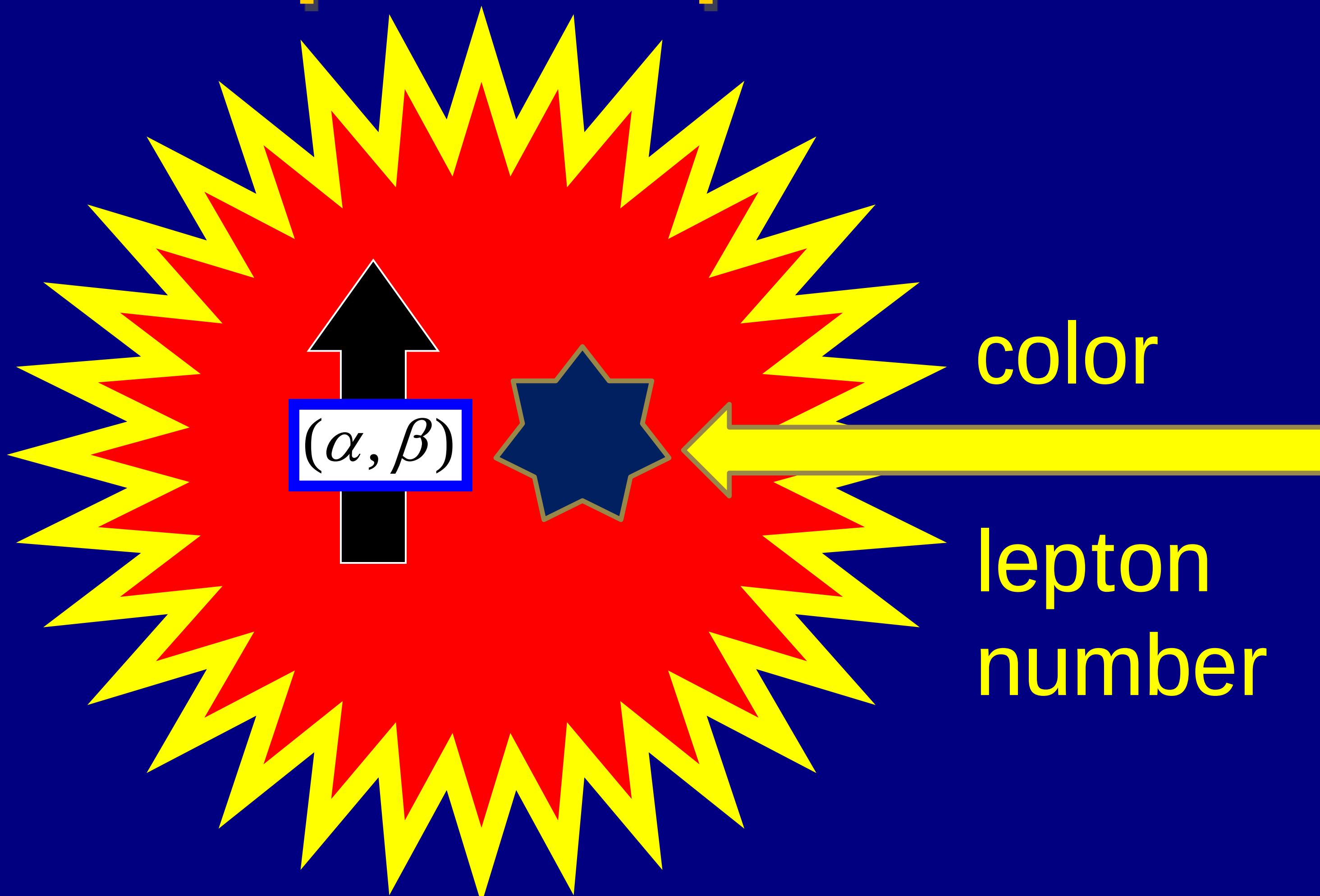
QHD



➔ leptons and quarks

composite

leptons - quarks



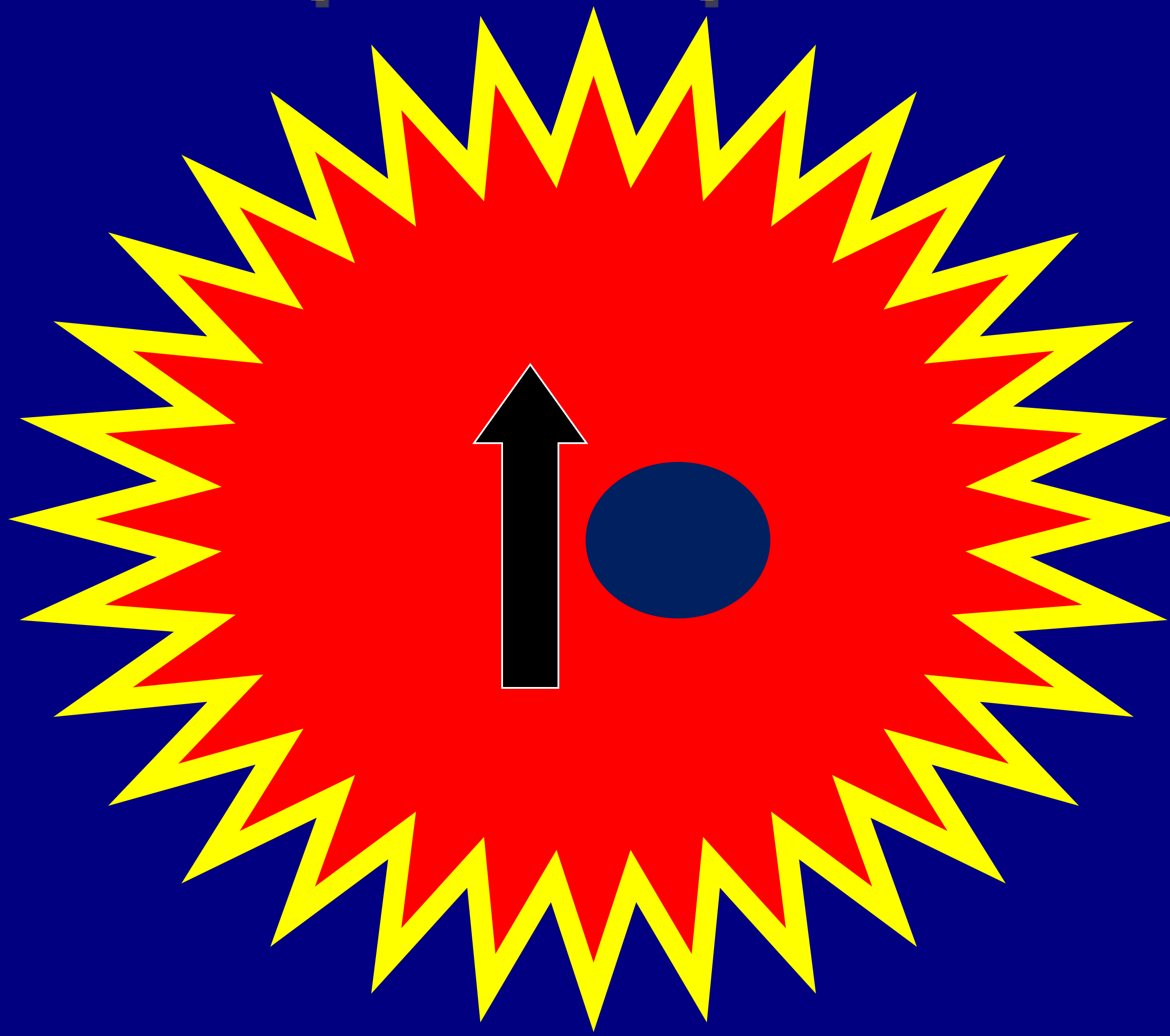
simplest theory:

leptons - quarks

↕

(fermion + scalar)

leptons - quarks



Fritzsch - Mandelbaum (1981)

Abbott - Farhi (1981)

Barbieri - Mohapatra (1981)

lepton-quark-family

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

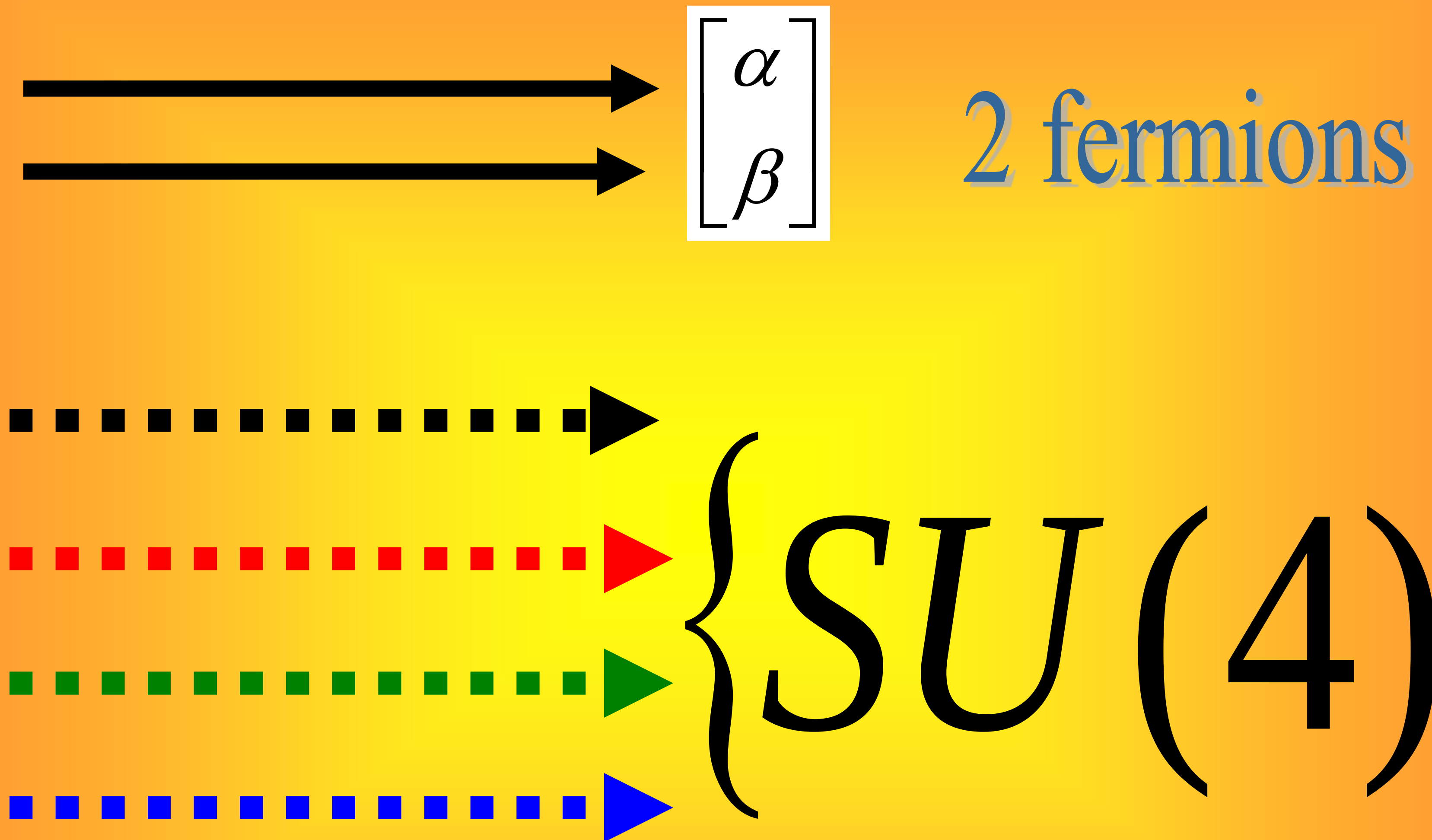
$$SU(2)_L \otimes U(1)$$

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

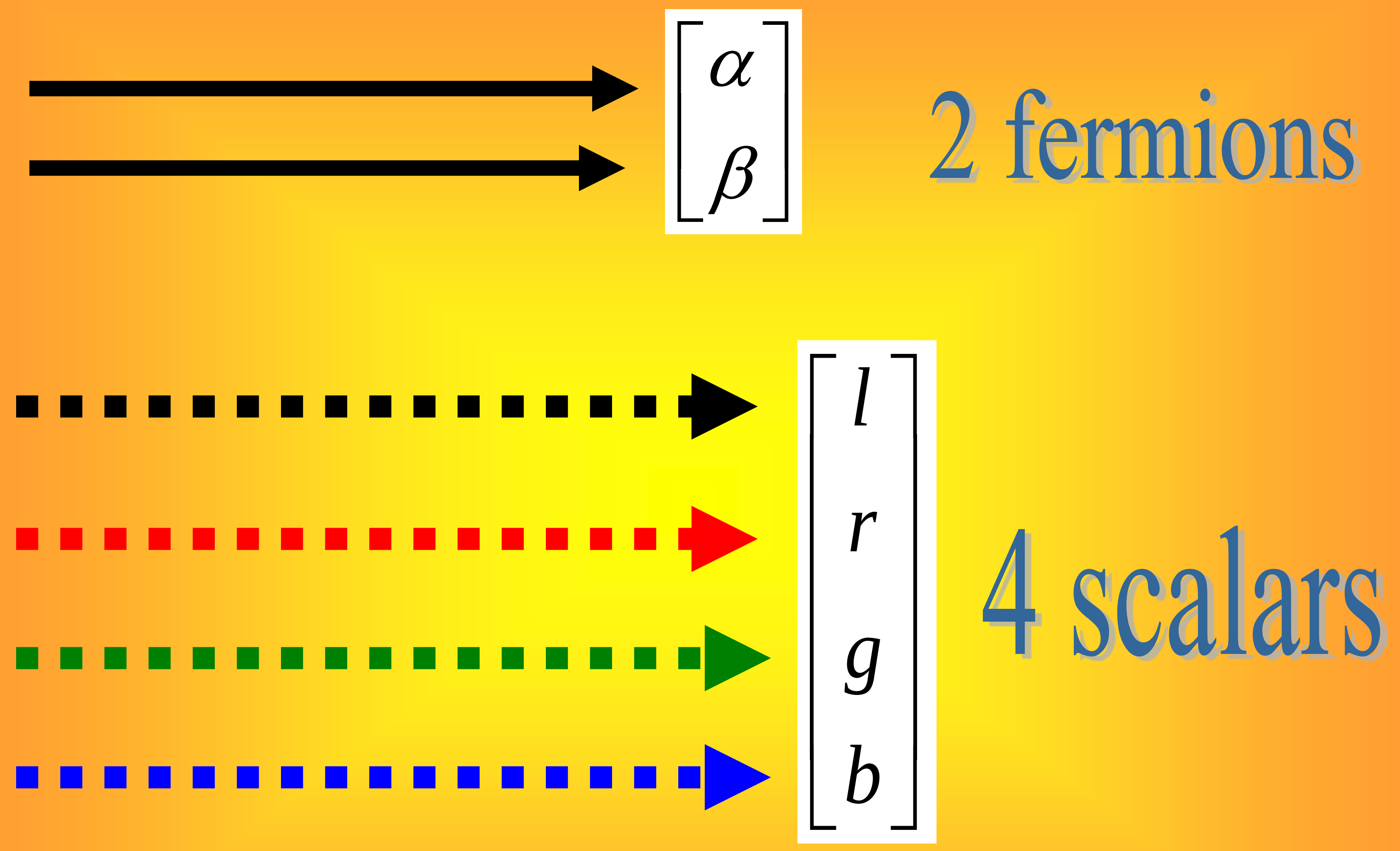
$$SU(2)_L \otimes SU(2)_R$$

$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix} \left\{ SU(2) \right.$$

$$SU(4) \Rightarrow U(1) \otimes SU(3)_c$$

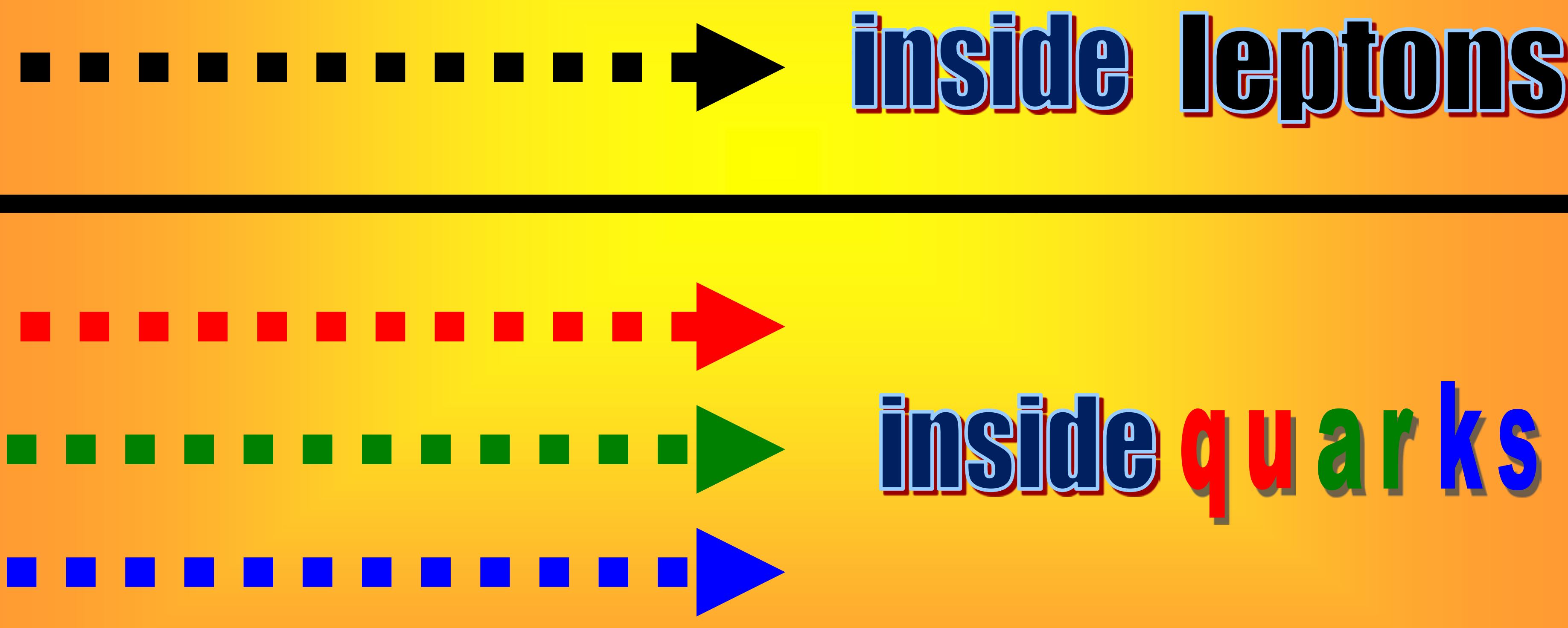


α
β
2 fermions
SU(4)



$\begin{bmatrix} \alpha \\ \beta \end{bmatrix}$
2 fermions
$\begin{bmatrix} l \\ r \\ g \\ b \end{bmatrix}$
4 scalars

4 scalars



$$\begin{pmatrix} \nu & U_r & U_g & U_b \\ L & D_r & D_g & D_b \end{pmatrix}$$

$$\Downarrow$$

$$\begin{pmatrix} (\alpha l) & (\alpha r) & (\alpha g) & (\alpha b) \\ (\beta l) & (\beta r) & (\beta g) & (\beta b) \end{pmatrix}$$

electric charges

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} \Rightarrow \begin{pmatrix} 1/2 \\ -1/2 \end{pmatrix} \bullet e$$

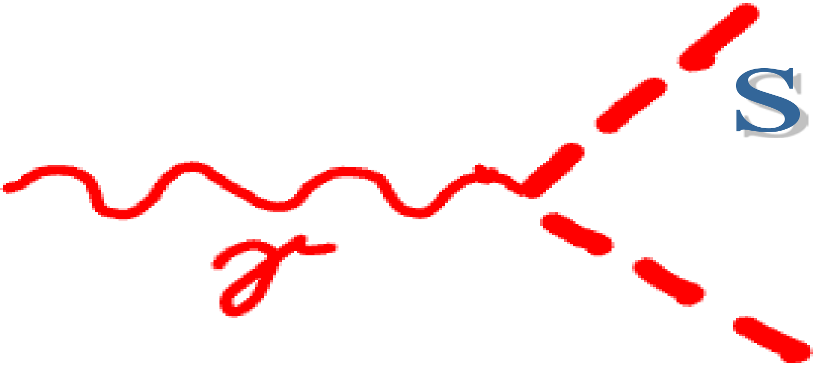
electric charges

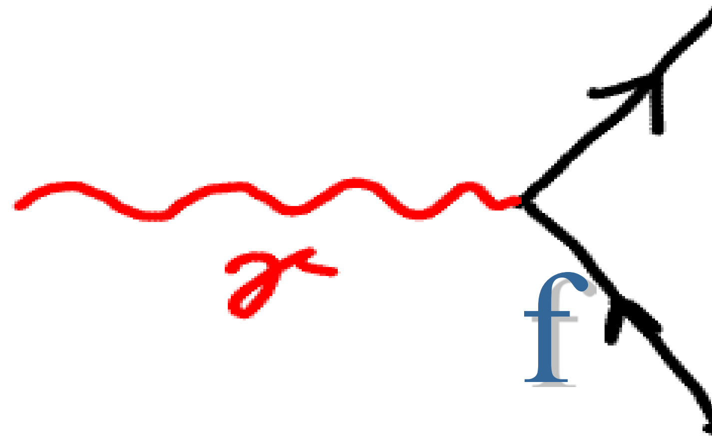
$$l: \ -\tfrac{1}{2}$$

$$r: \ +\tfrac{1}{6}$$

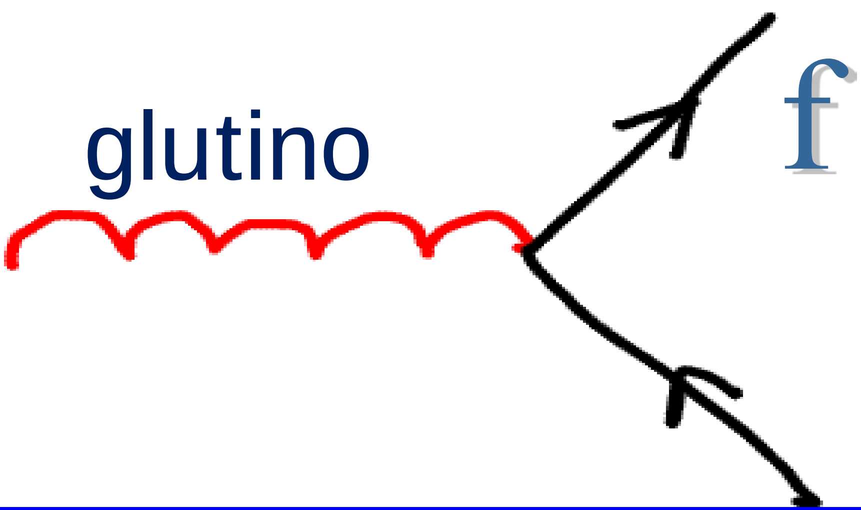
$$g: \ +\tfrac{1}{6}$$

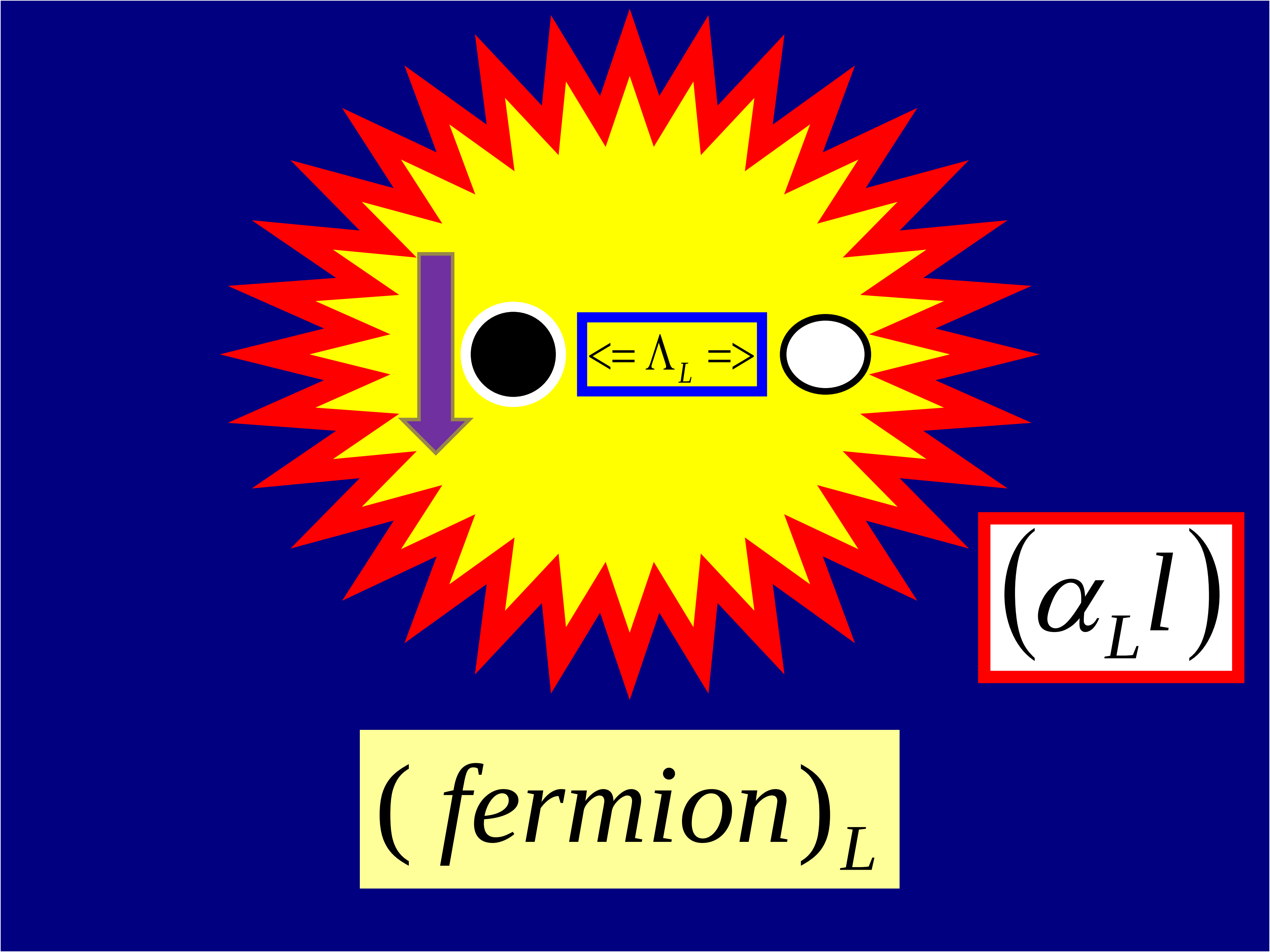
$$b: \ +\tfrac{1}{6}$$

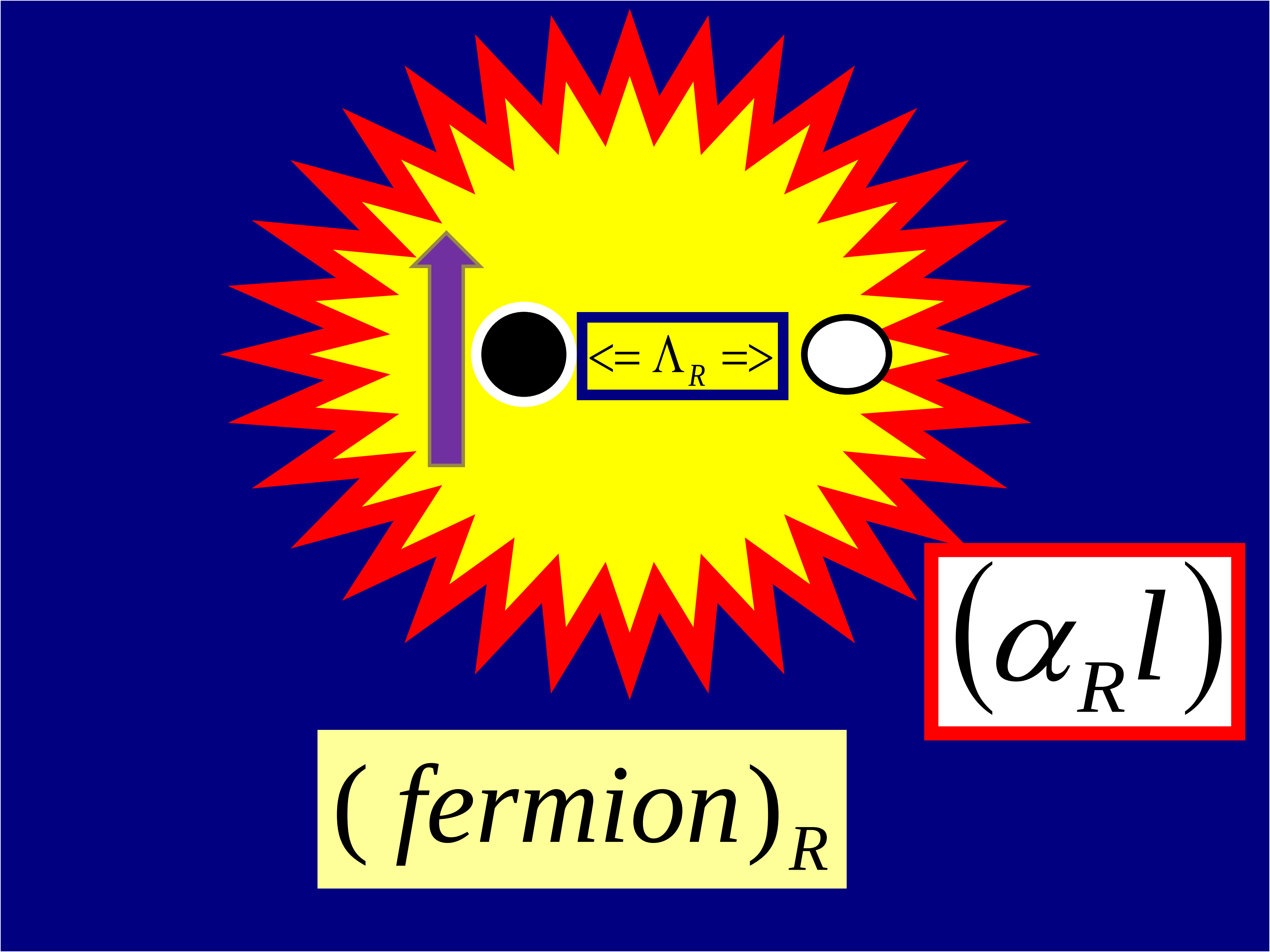


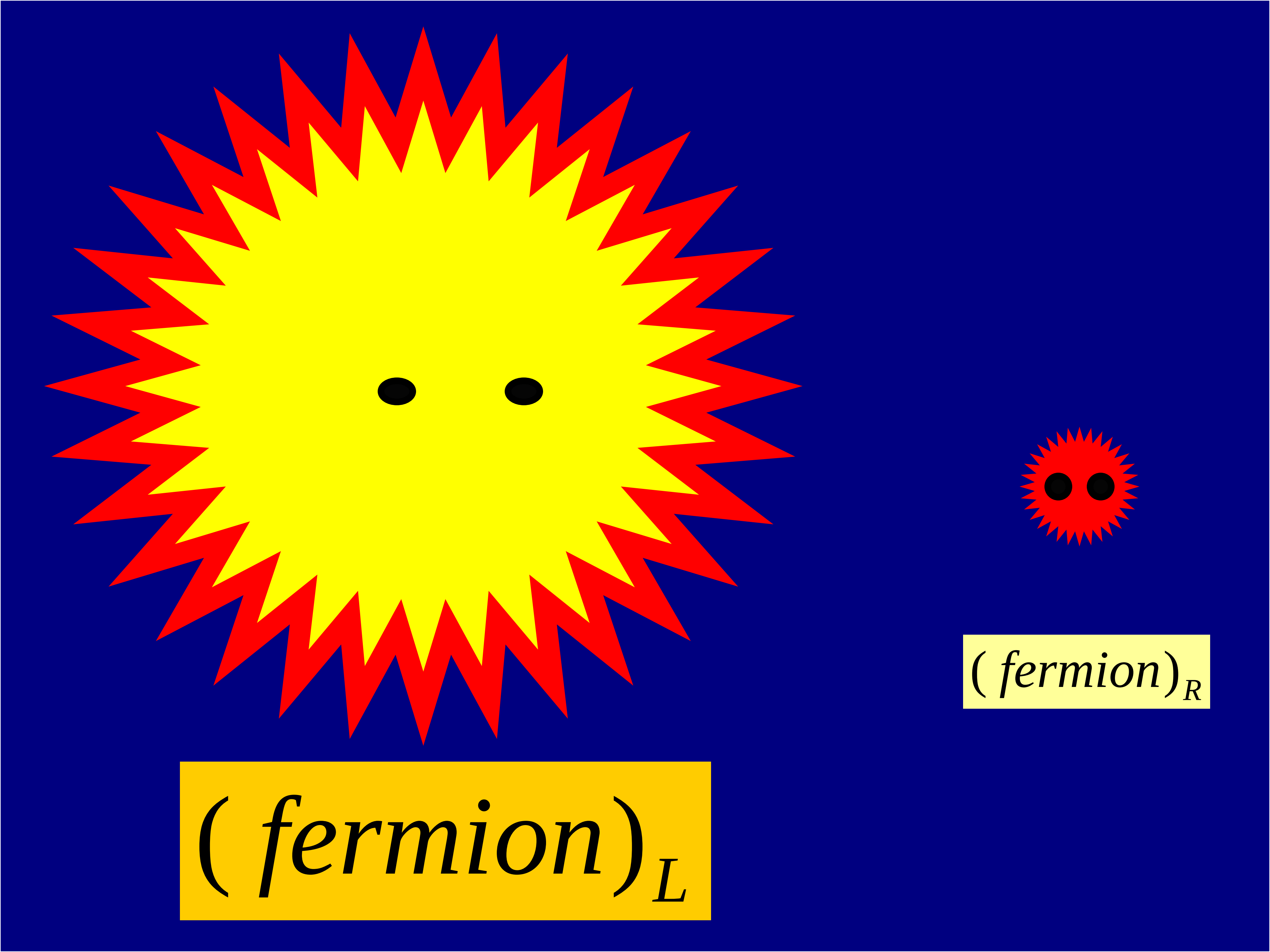


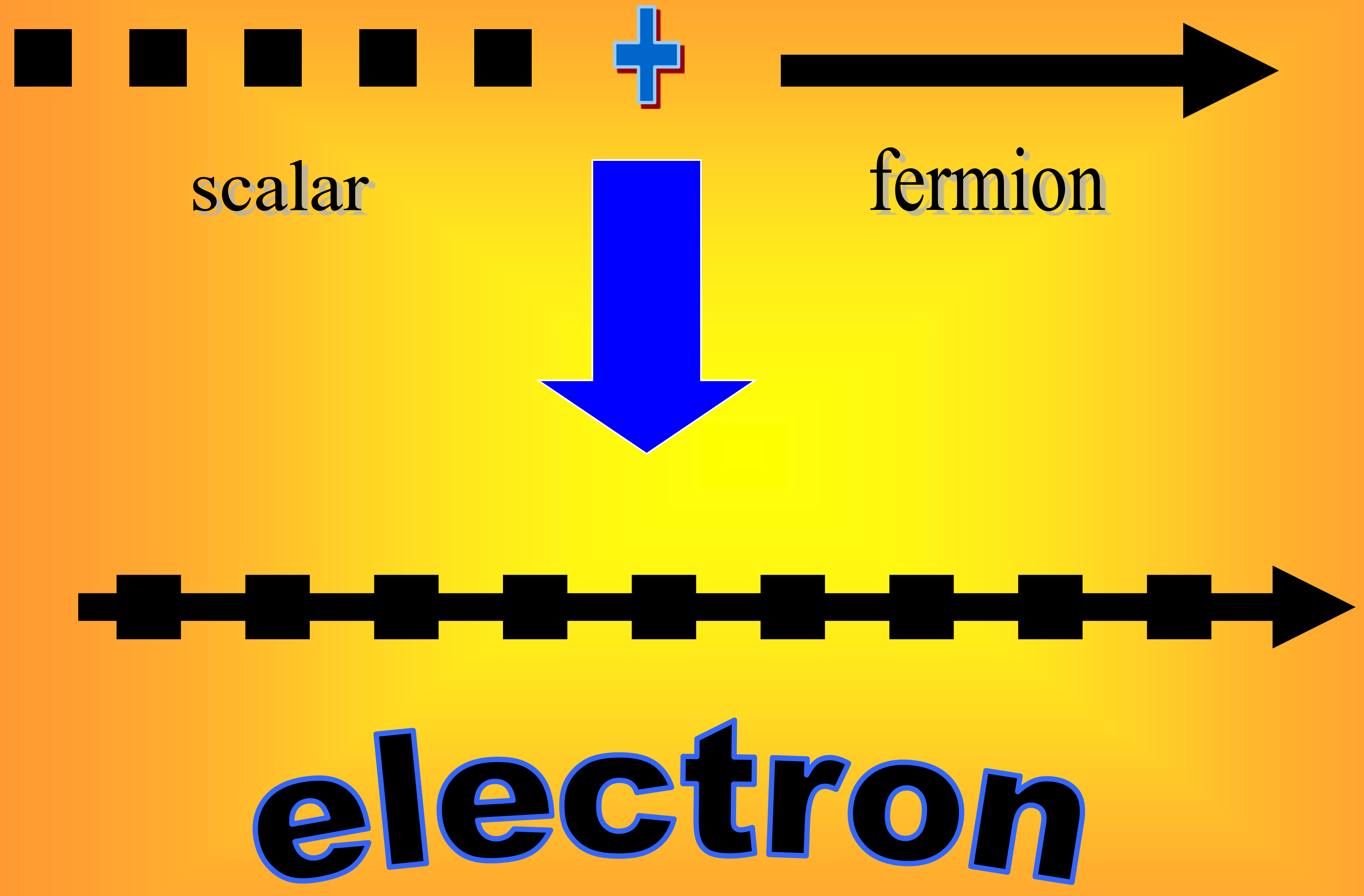
interactions

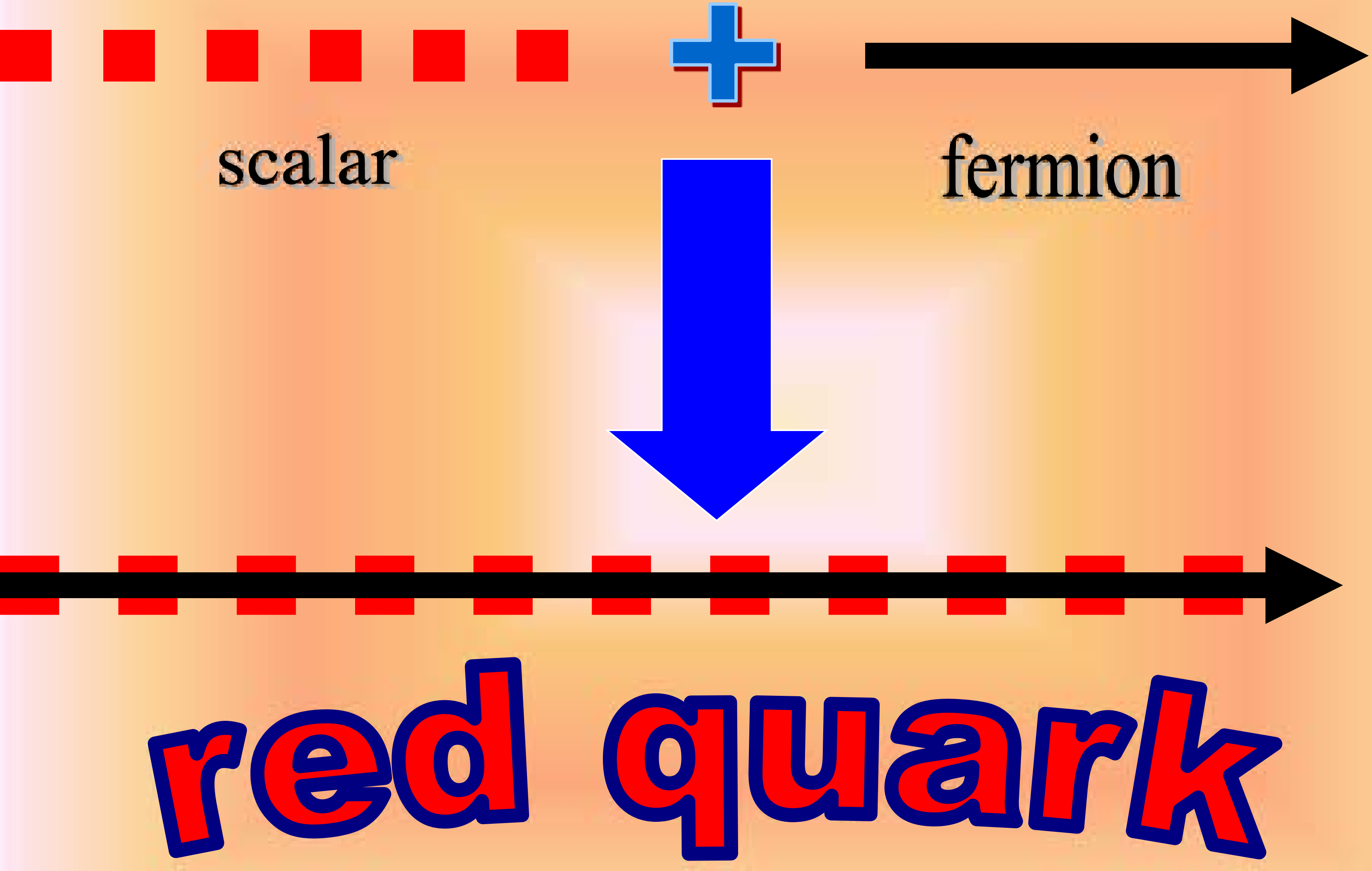



<= Λ_L =>
$(\alpha_L l)$
$(fermion)_L$


<= Λ_R =>
$(\alpha_R l)$
$(fermion)_R$


(fermion)L
(fermion)R


+
scalar
fermion
electron


scalar
fermion
red quark

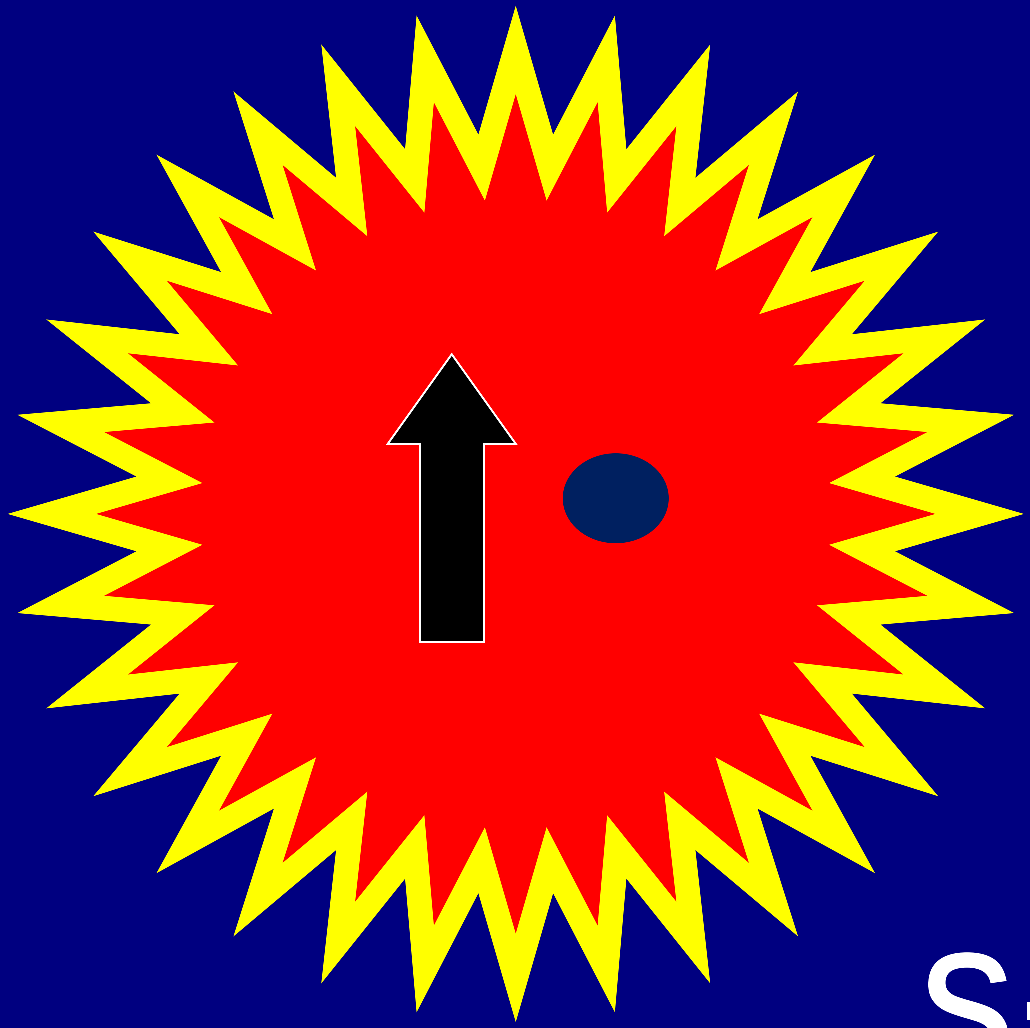
How many lepton-quark families?

→rank of

QHD group

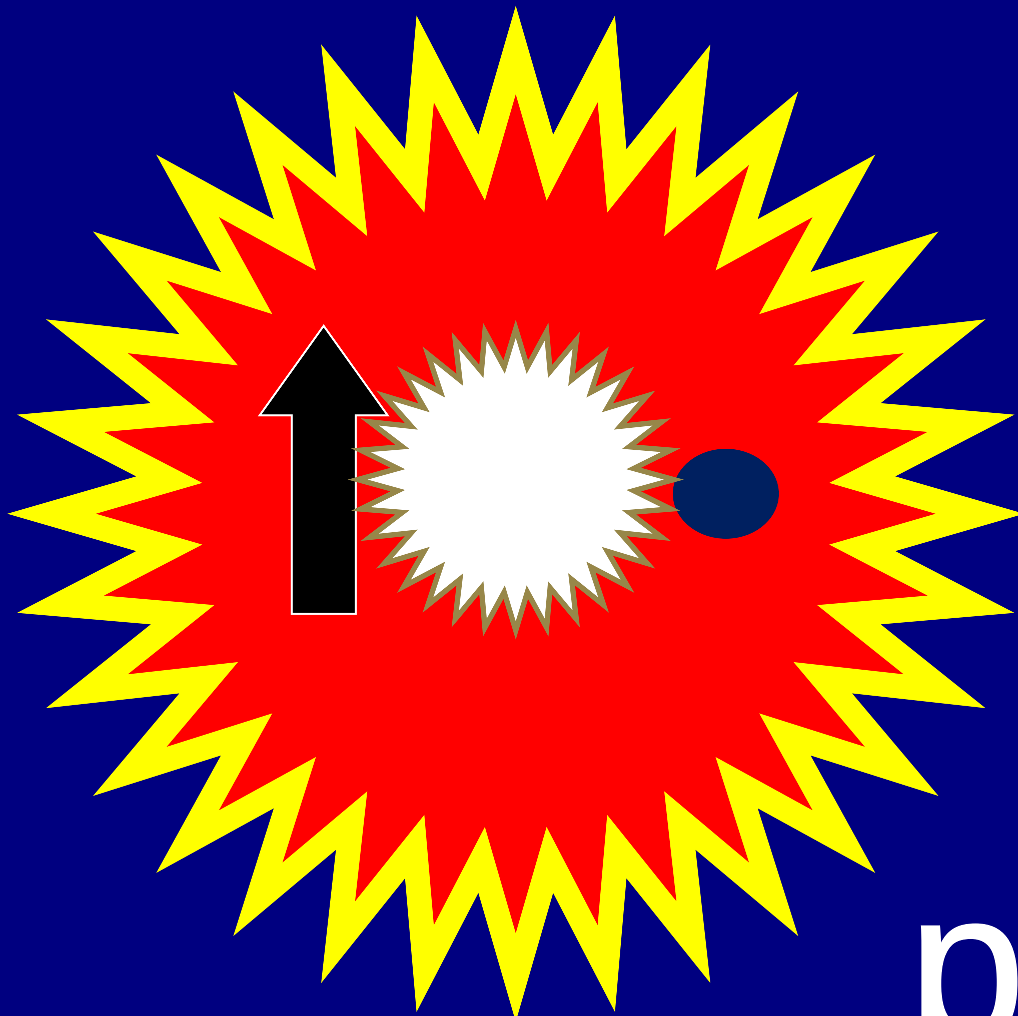
SU(3) => 3

leptons – quarks



s-wave

excited leptons – quarks



p-wave

$$J = \frac{3}{2} \qquad \mu^{**}$$

$$J = \frac{1}{2} \qquad \mu^{*}$$

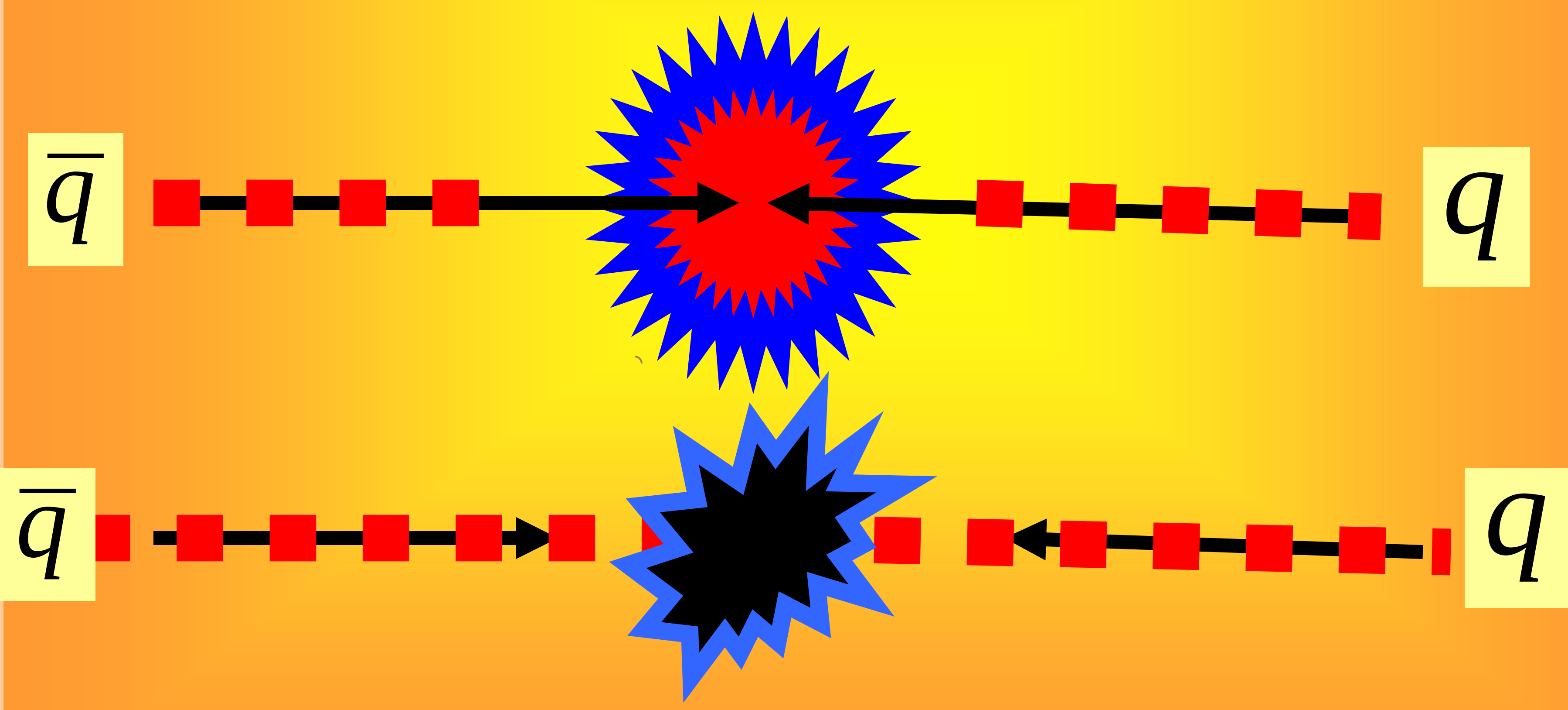
? m~1.5 TeV ?

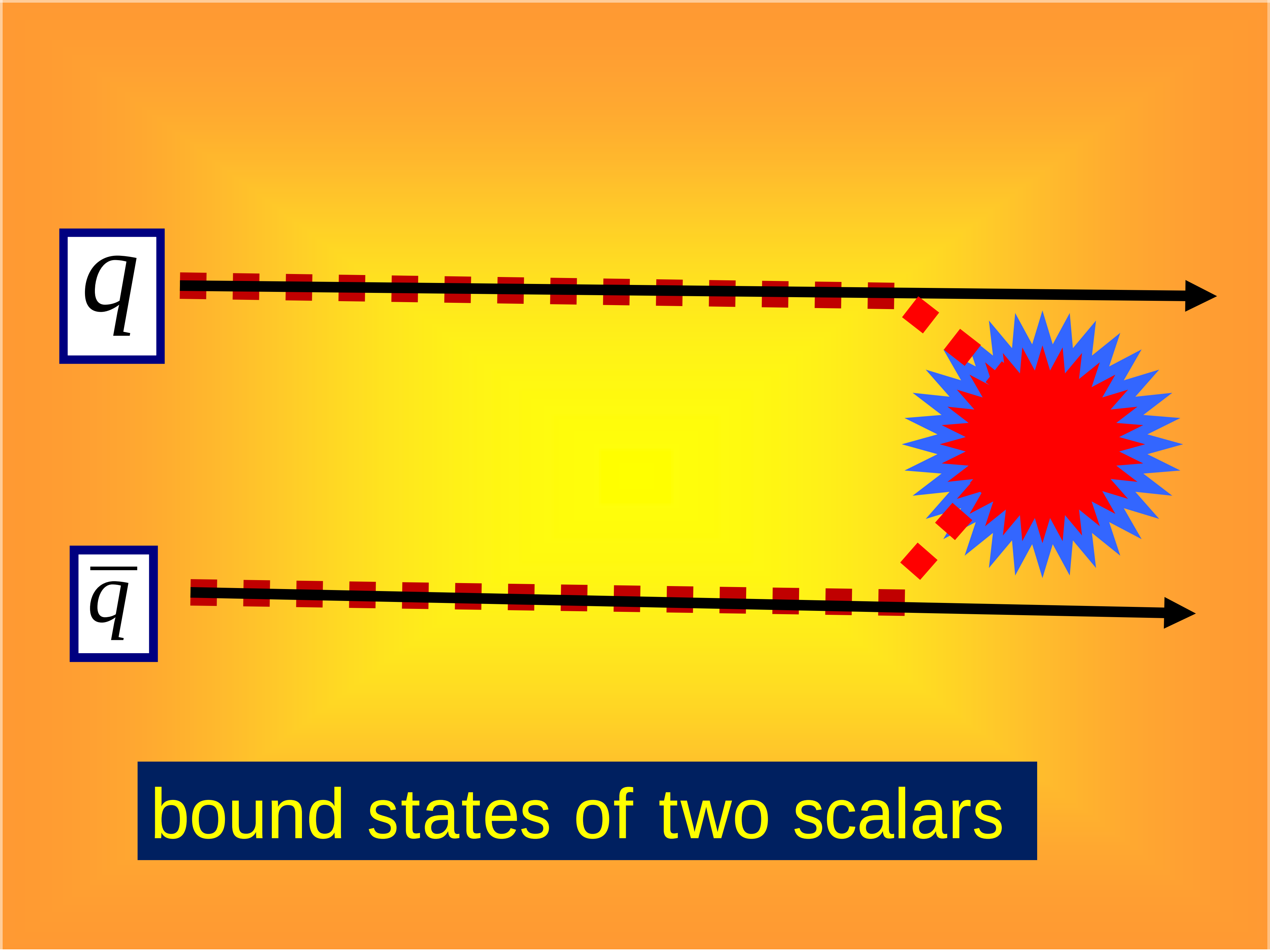
Decay

$$\mu^* \Rightarrow \mu + \gamma$$

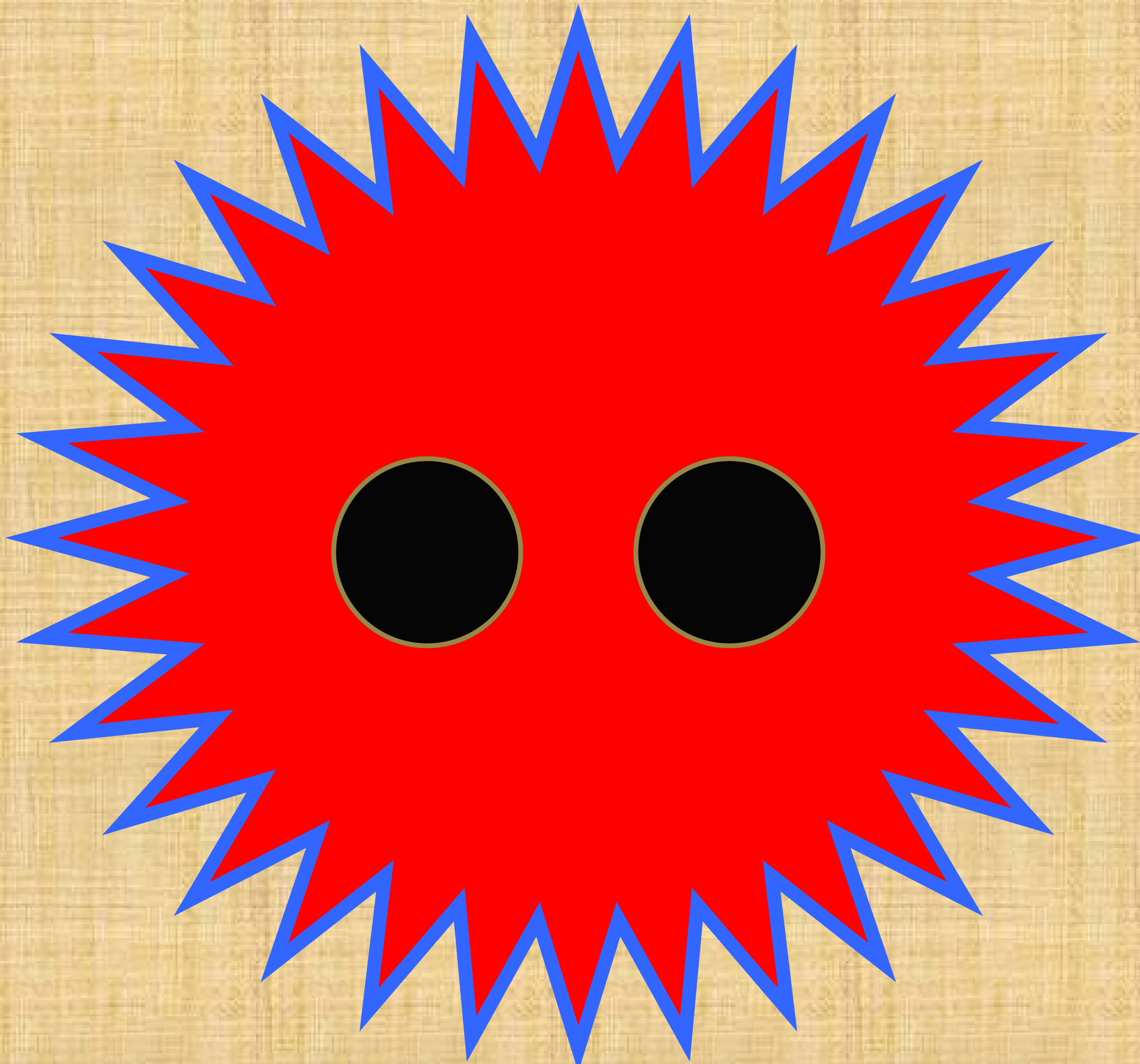
$$\mu^* \Rightarrow \mu + Z$$

quark – antiquark scattering:



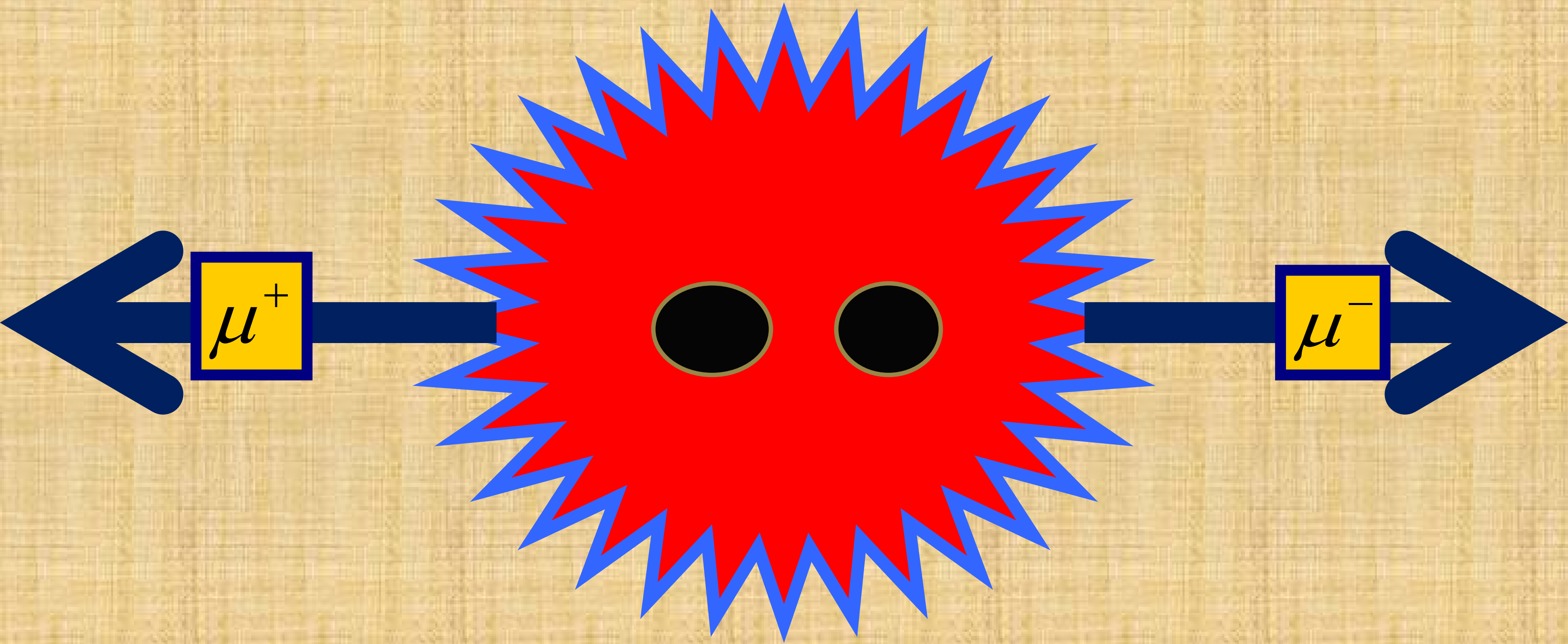


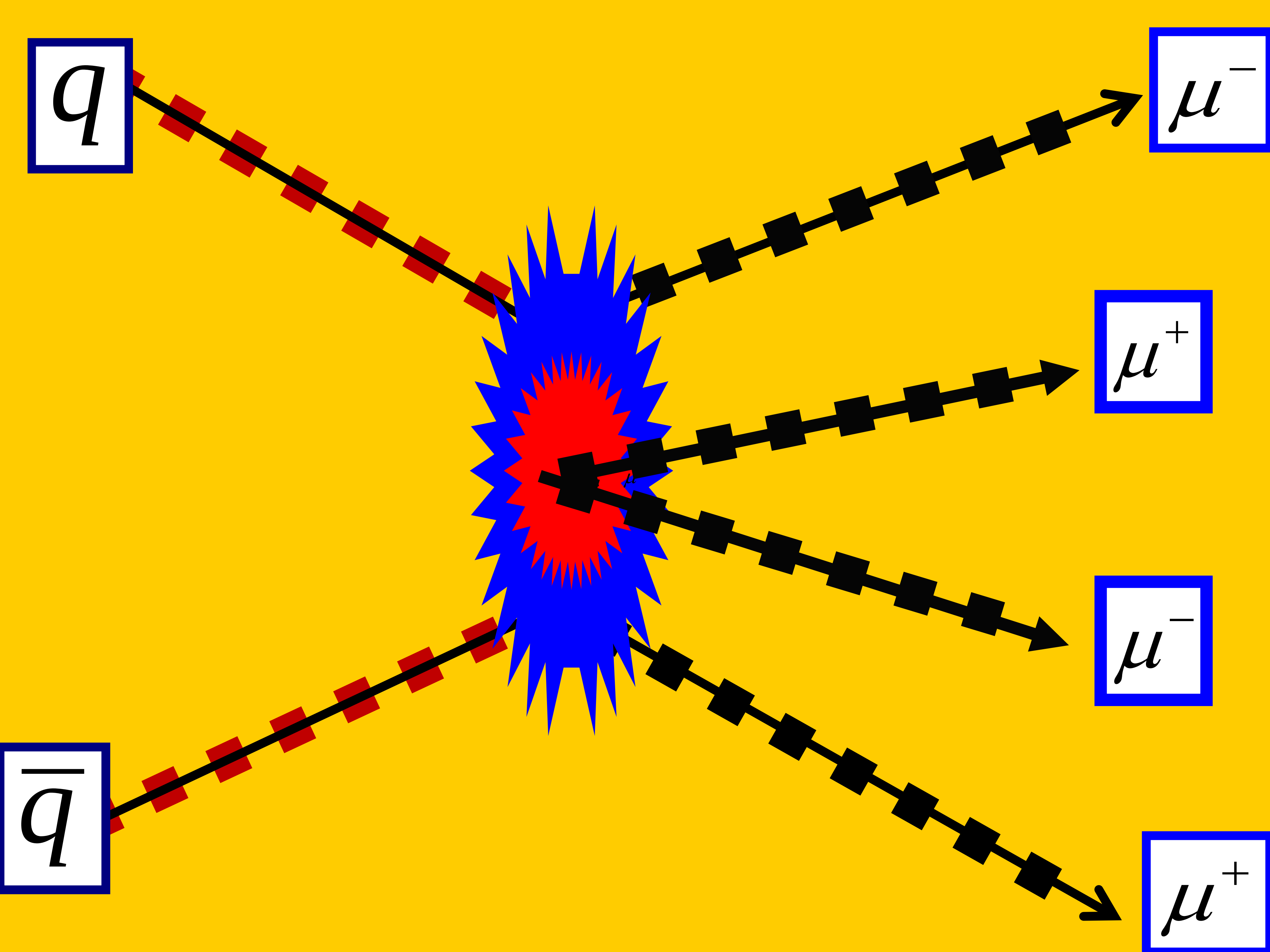
q
q̄
bound states of two scalars

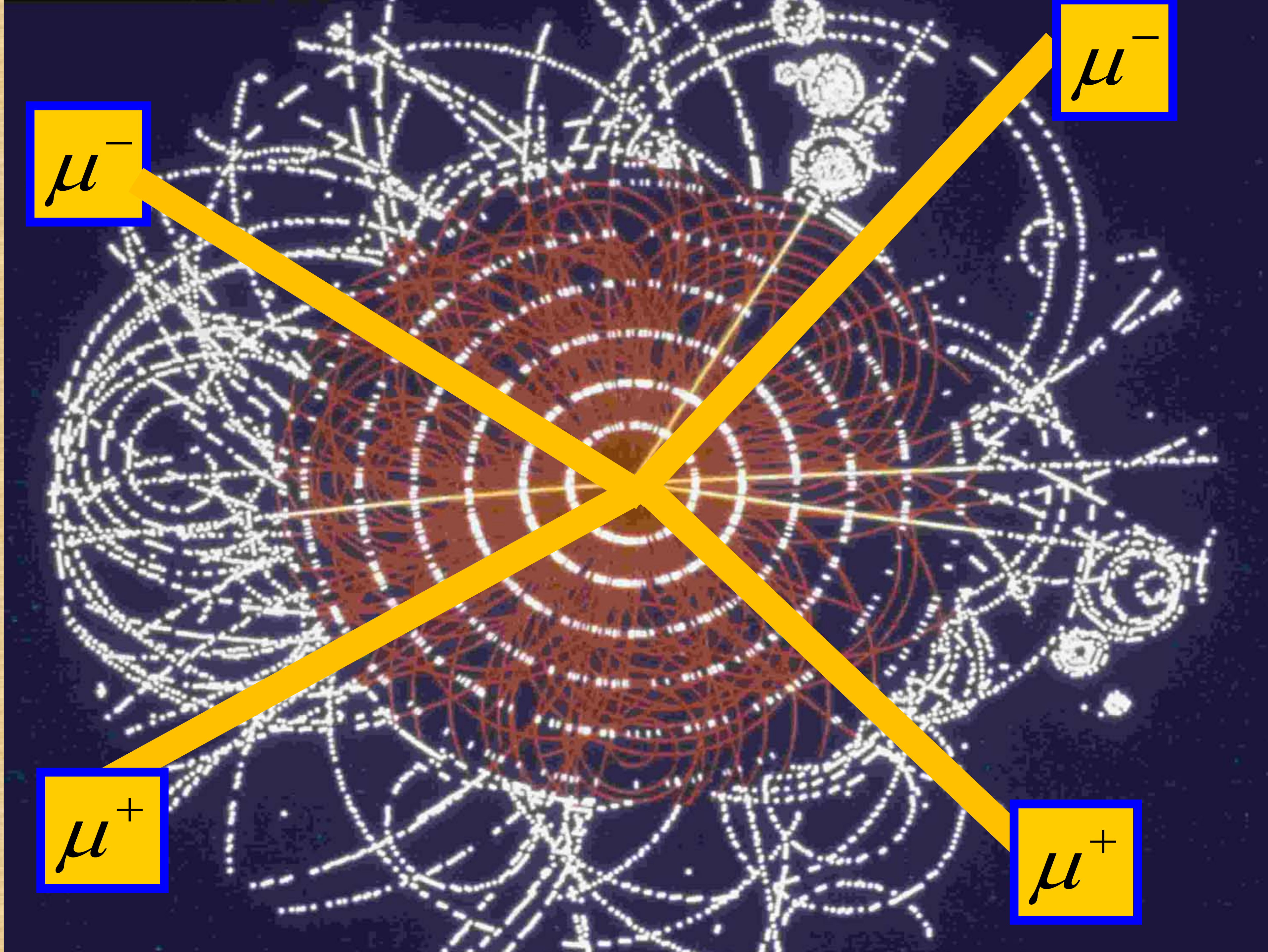


M>0.5 TeV ?

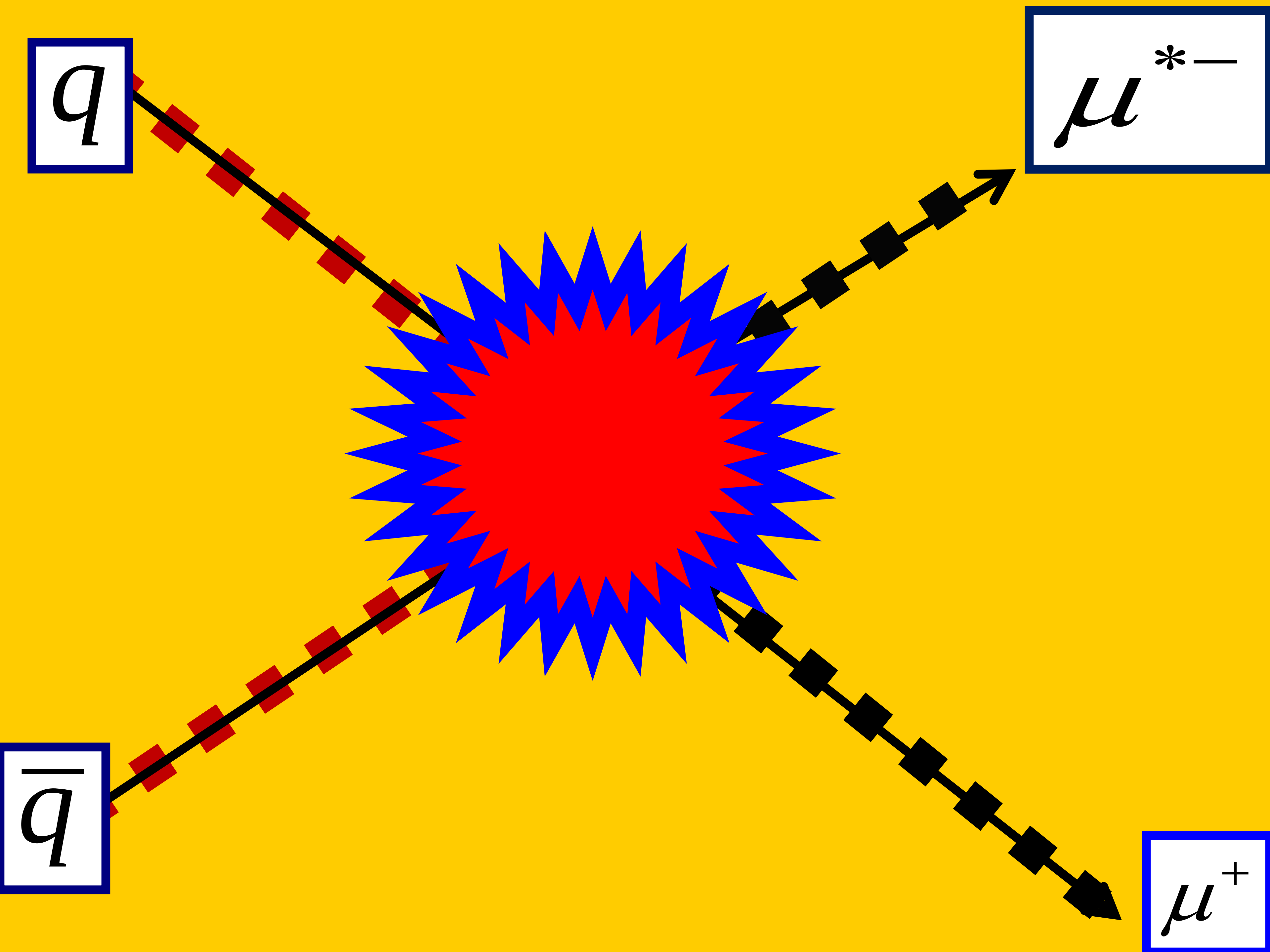
decay into leptons and quarks



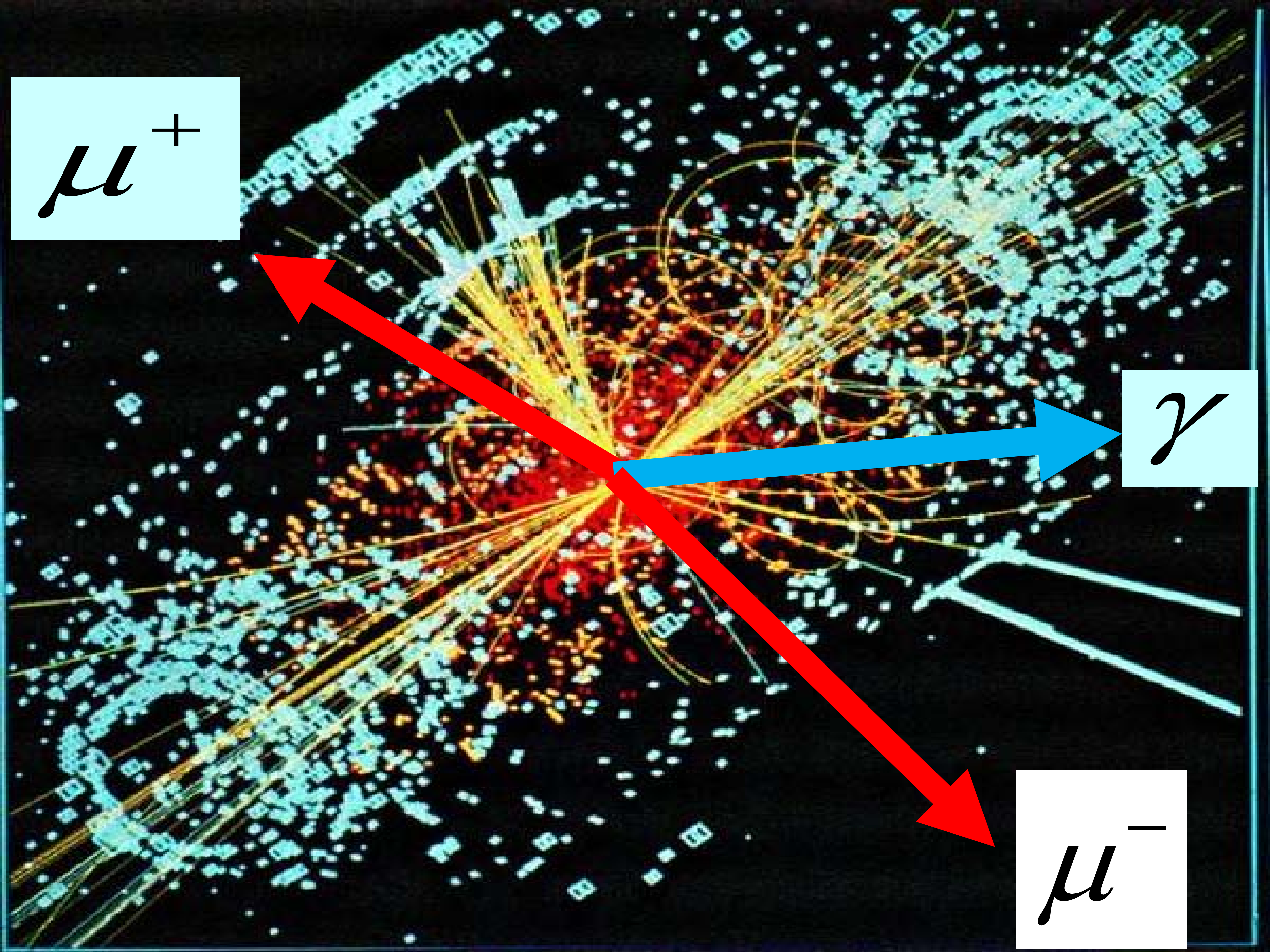

q
$\bar{q}$
μ^-
μ^+
μ^-
μ^+



μ^-
μ^-
μ^+
μ^+



q
μ^{*-}
$\overline{q}$
μ^{+}



μ^+
γ
μ^-

cross section for QHD interaction?

comparison with proton - proton inelastic scattering:

size:

$$proton: 10^{-14}\,cm$$

$$\Updownarrow$$

$$\sigma(pp)_{inel} \approx 60mb$$

comparison with proton - proton inelastic scattering:

size:

$$quark : 10^{-17}\, cm$$

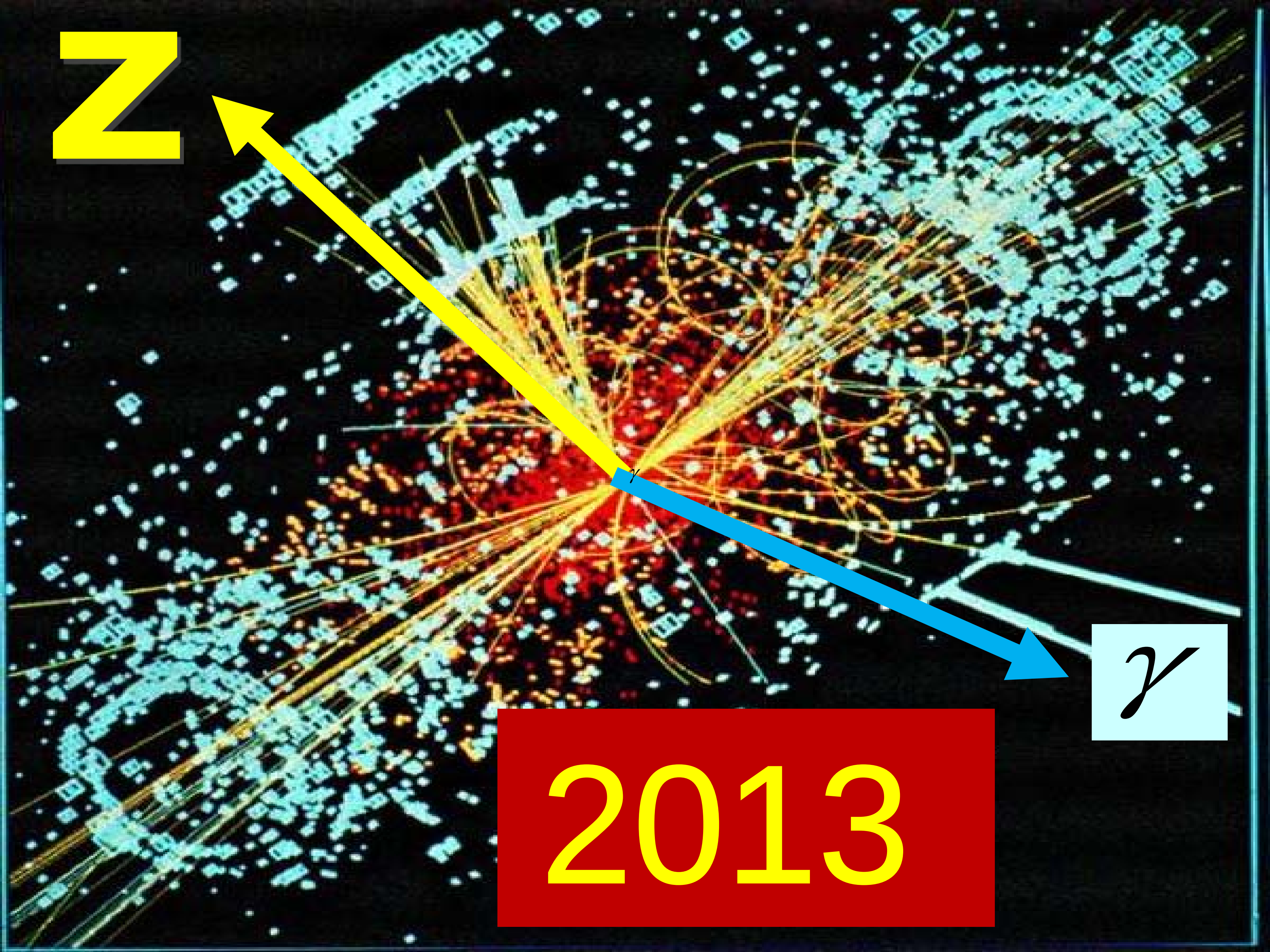
↕

$$\sigma(qq) \approx 10^{-6} 60 \quad mb = 60 \quad nb$$

LHC

2013

$$S(0) \Rightarrow Z + \gamma$$


Z
γ
2013

2014

S(1)

0.33 TeV

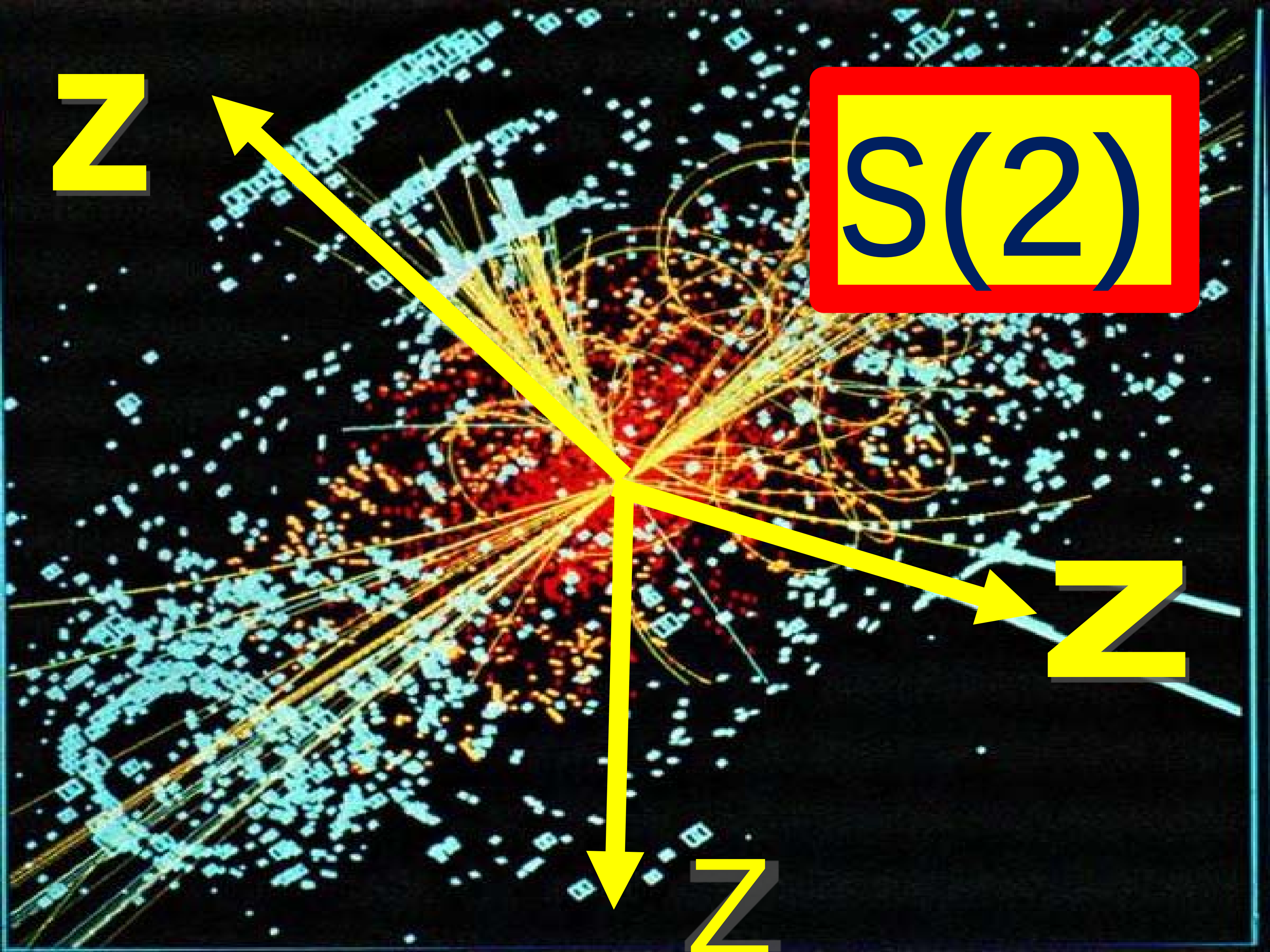
S(1) => Z Z

2014

S(2)

0.47 TeV

S(2) => Z Z Z


Z
S(2)
Z
Z

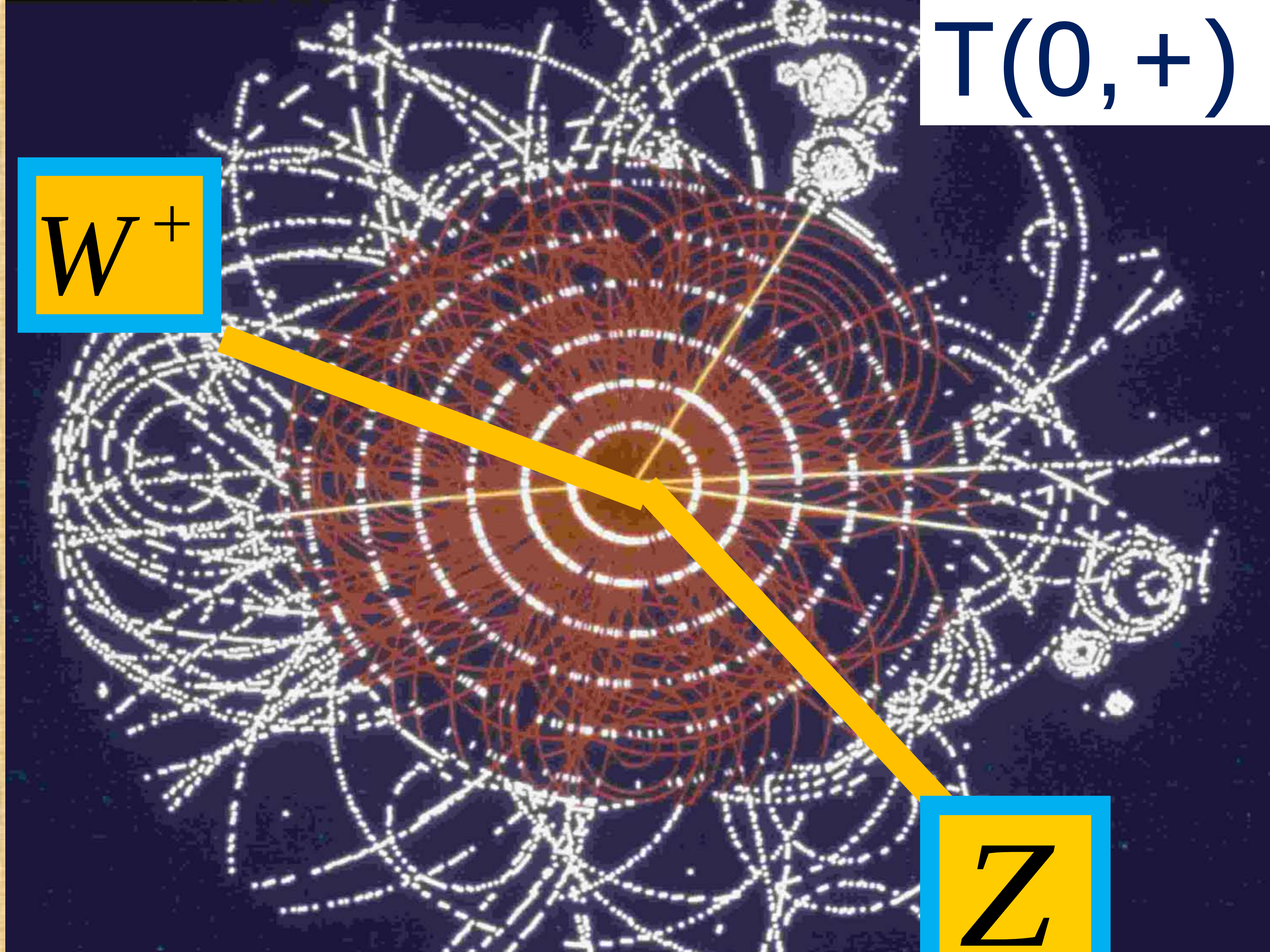
2015

T(0): 0.33 TeV

T(0,+) => W(+) Z

T(1): 0.46 TeV

T(1,0) => ZZZ

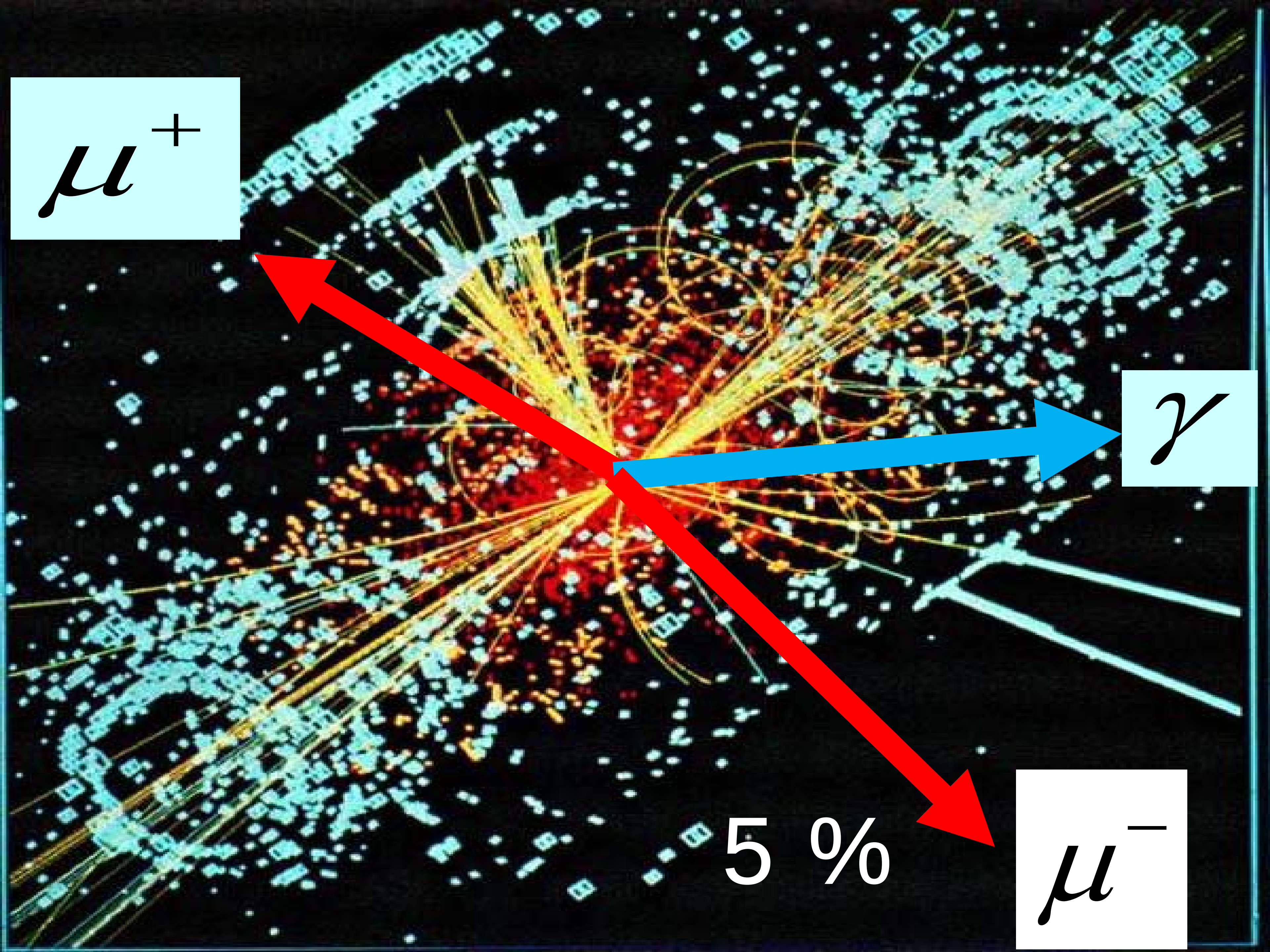

T(0,+)
W^+
Z

2016

μ^*

e^*

1.48 TeV


μ^+
γ
5 %
μ^-


LHC
QHD