QCD

1972

Fritzsch / Gell-Mann

2012

40 years

QCD conference Oberwölz, Austria

September 2 – 8, 2012

Weak Bosons

Quarks - Leptons

Composite Particles

Harald Fritzsch

LMU Munich

Example:

rho – mesons

„Higgs“ mechanism

↕

QCD

~ 1960: J. J. Sakurai

rho mesons

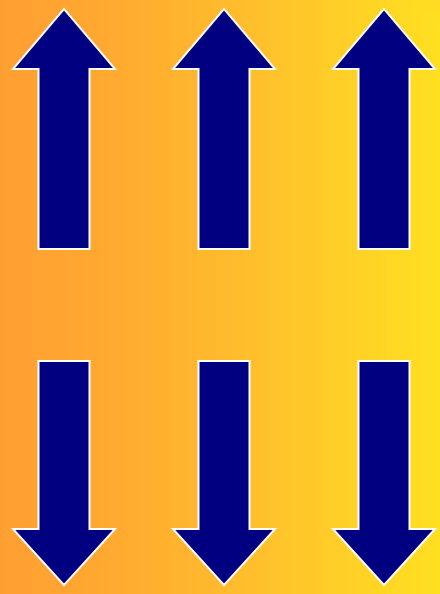
→

elementary gauge bosons

~ 1964
mass generation
for rho mesons

„Higgs“
mechanism

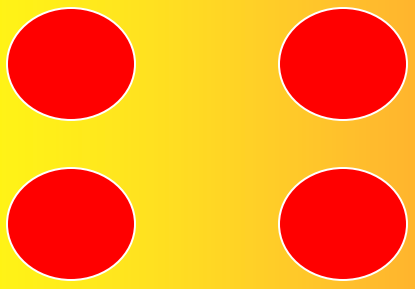
SU(2)



massless

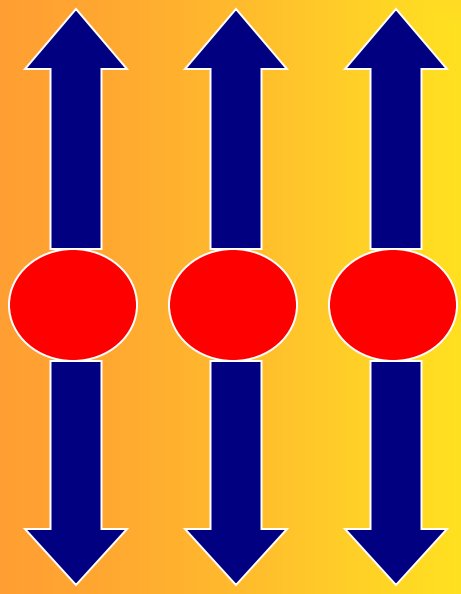
rho - mesons

2 x 2 scalars



mass M

“Higgs“ - mechanism



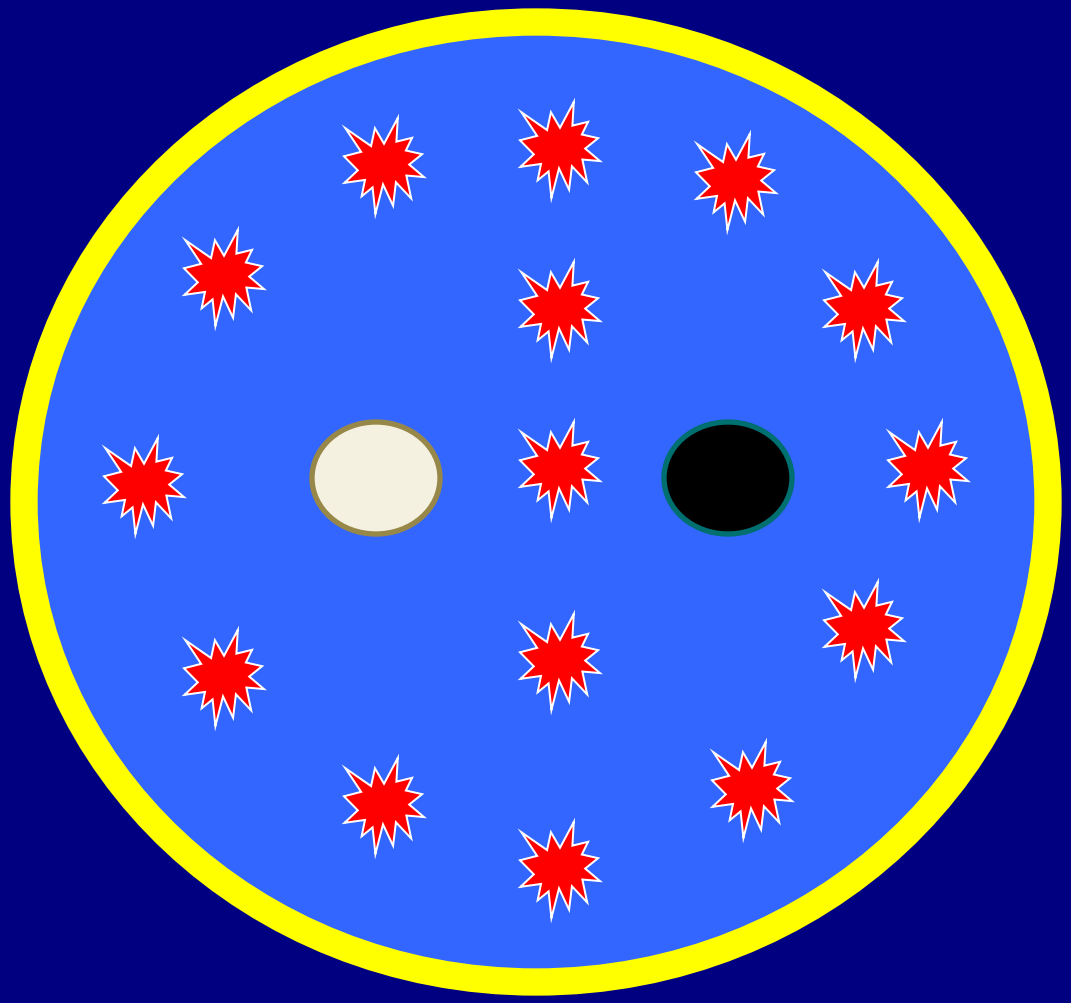
„Higgs“ - scalar

mass M

massive

rho - mesons

ρ - meson in QCD :



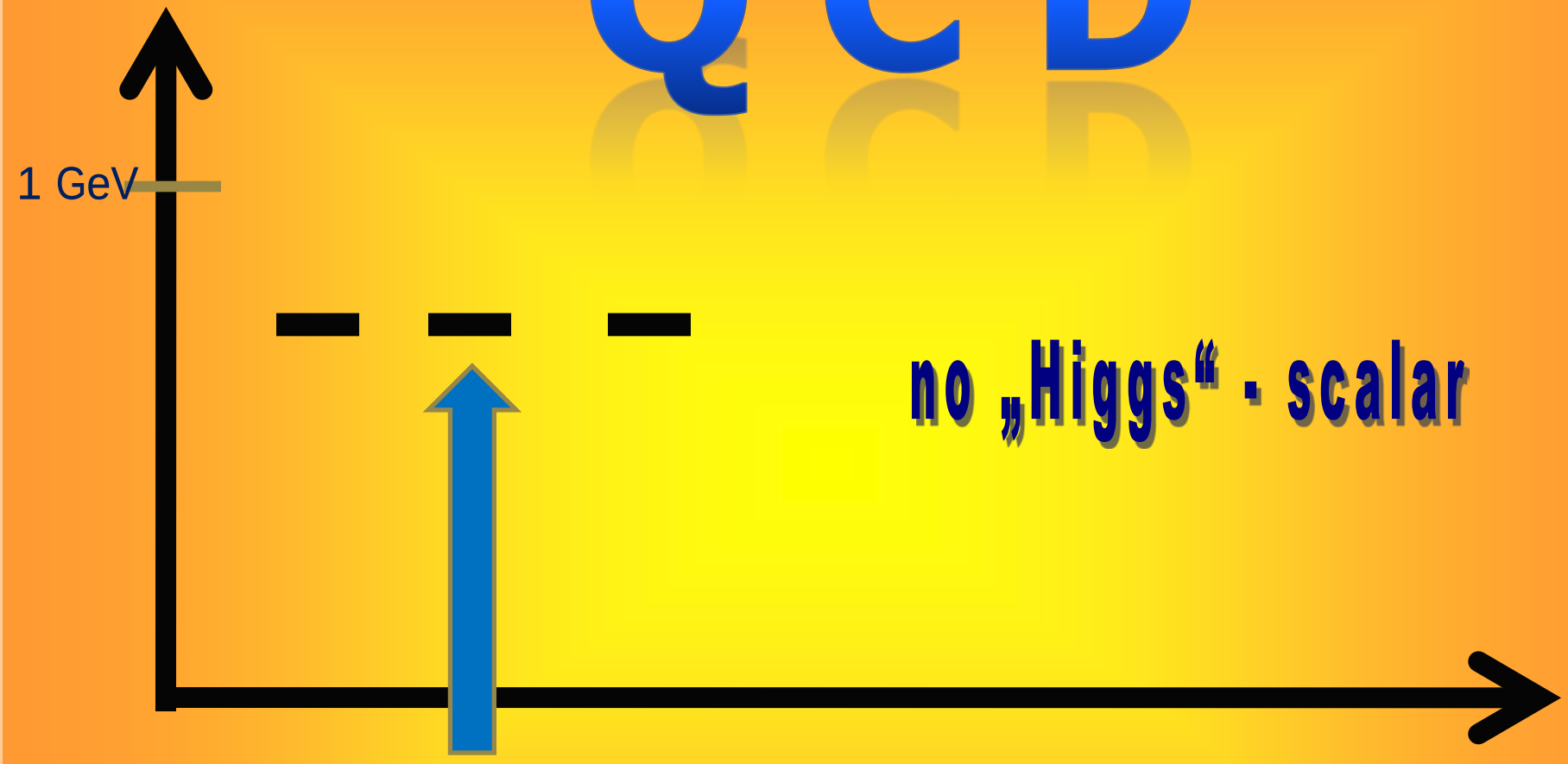
quark - antiquark - gluons

$$\rho = \left(\bar{q}q\right)$$

$$M_{\rho} \approx 760 \quad MeV$$

$$= const. \bullet \Lambda_{c}$$

QCD



no „Higgs“ - scalar

3 massive

rho - mesons

weak bosons

composite

old references:

Bjorken (1977)

Fritzsch and Mandelbaum (1981)

Abbott and Farhi (1981)

Barbieri and Mohapatra (1981)

Fritzsch, Kogerler and Schildknecht (1982)

Lüst (1985)

Calmet and Fritzsch (2000)

new:

H. Fritzsch

2010 - arXiv: 1010.1428

2011 - arXiv: 1105.3354

masses of composite weak bosons ?

analogy

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

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

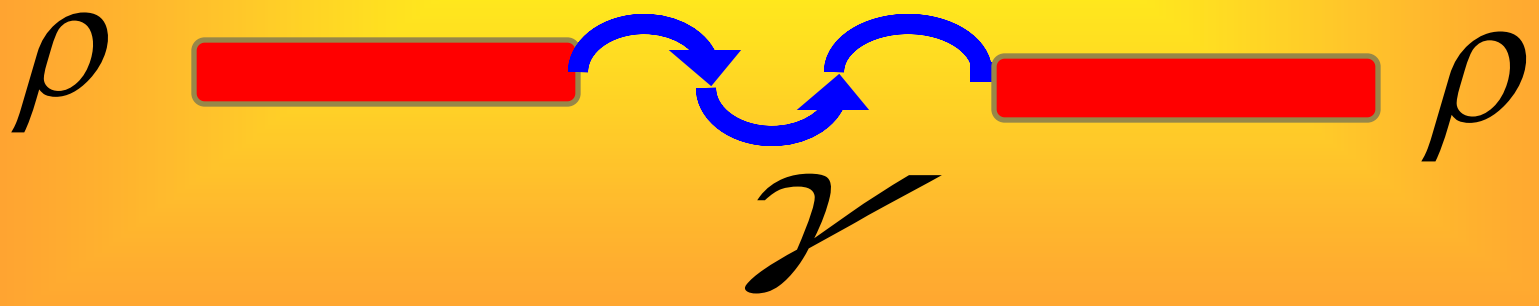
$$\rho^{-} \Leftrightarrow W^{-}$$

QCD

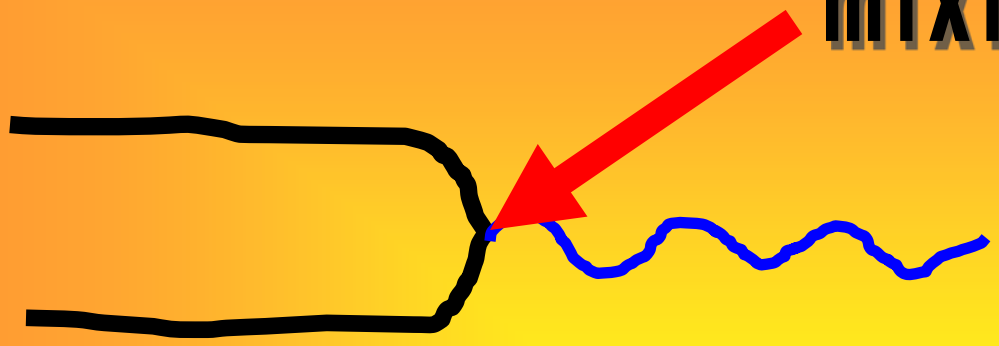
ρ^+ ρ^0 ρ^-

QCD + QED

Dynamical mixing of rho meson and photon:



mixing parameter m



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

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

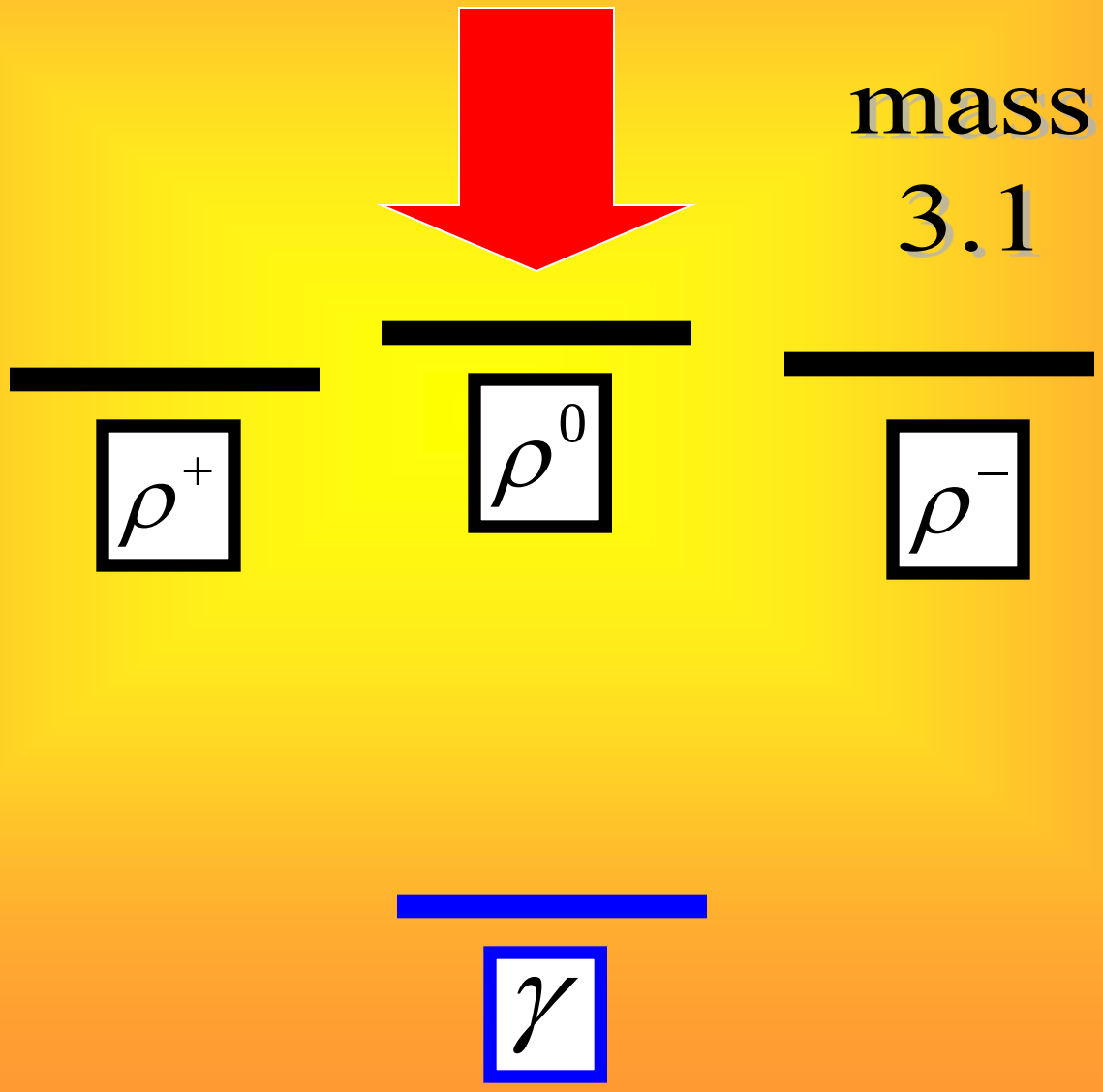
F_ρ : decay constant

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

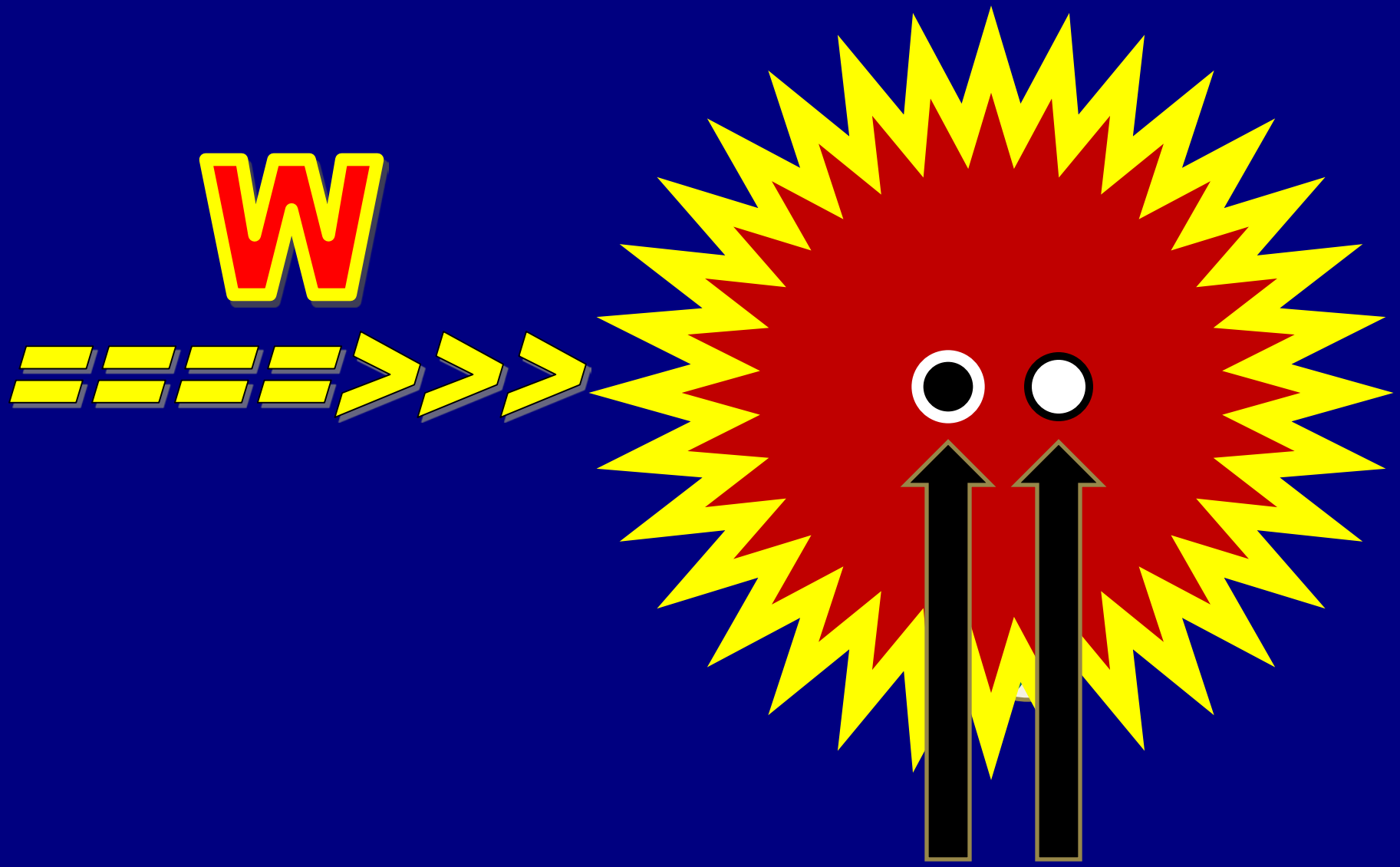
$$\boxed{F_\rho \approx \Lambda_c}$$

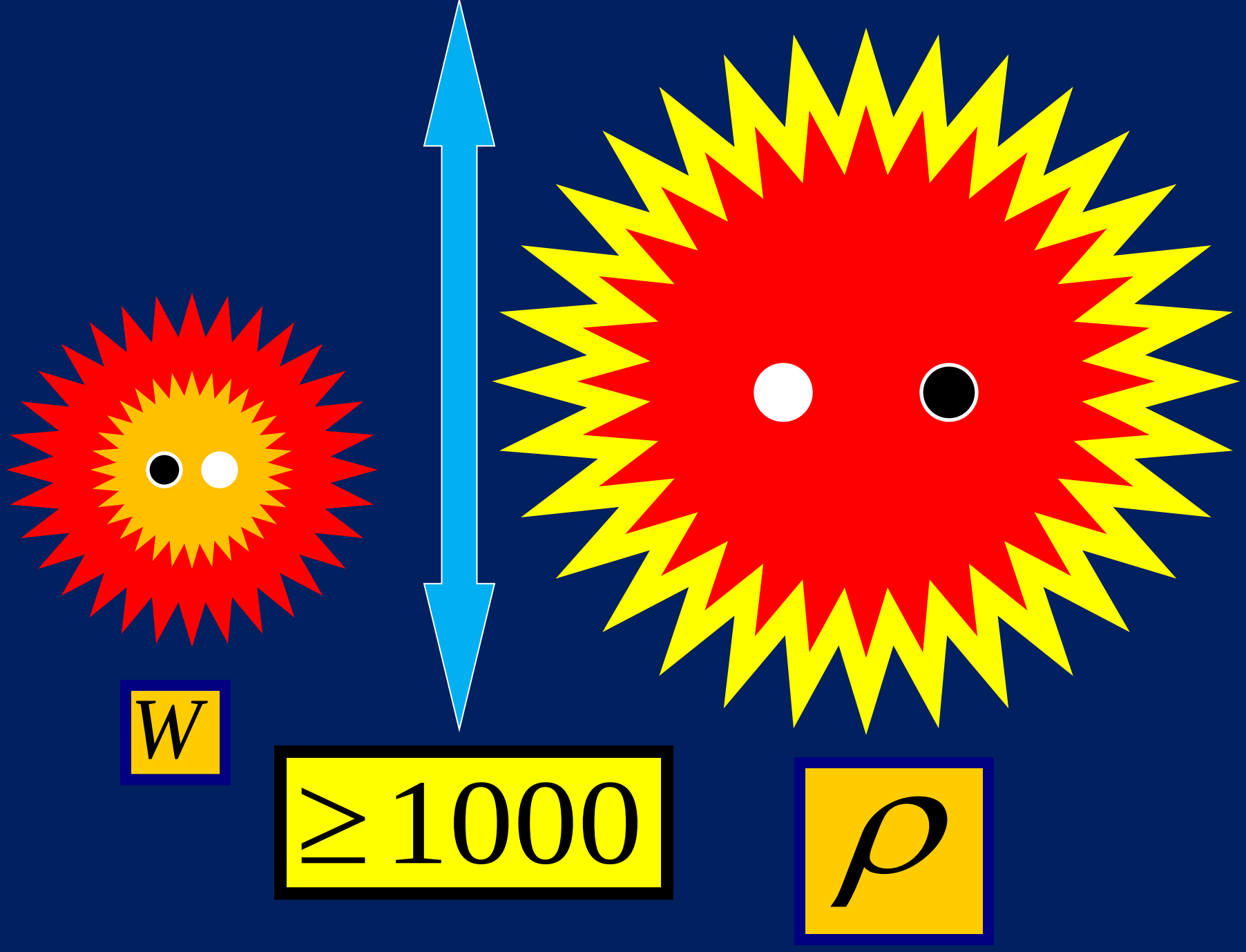
QCD +QED

mass shift:
3.1 MeV



masses of composite weak bosons ?


W
constituents


w
≥ 1000
ρ

Constituents of W-bosons

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

lefthanded fermions

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

$$\Downarrow$$

haplons

haplos ⇔ simple

electric charges

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

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

W^+

$\bar{\beta} \quad \alpha$

W^-

$\bar{\alpha} \quad \beta$

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

W^3

haplons confined
by gauge force

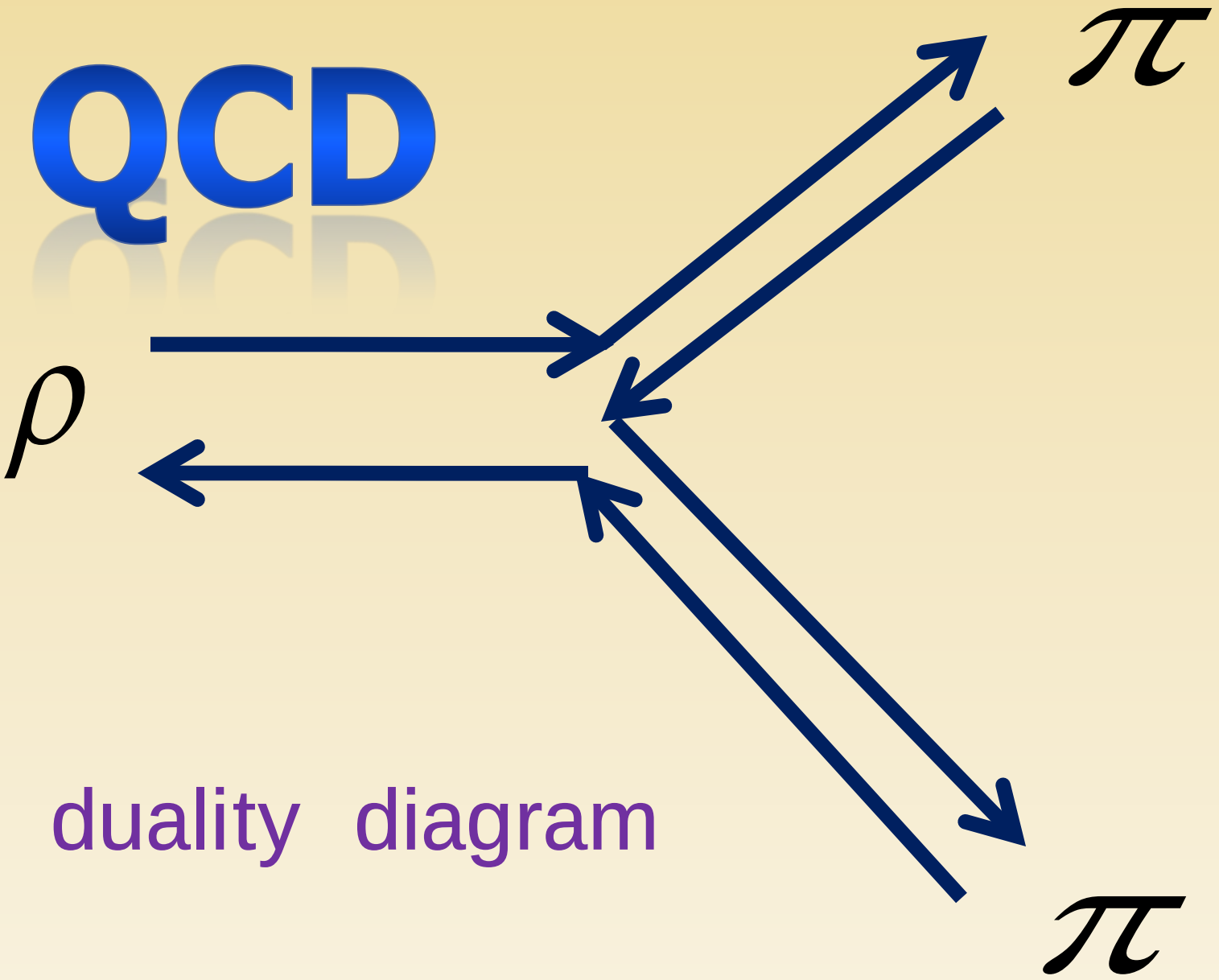
QHD

Gauge group of QHD:

SU(n)

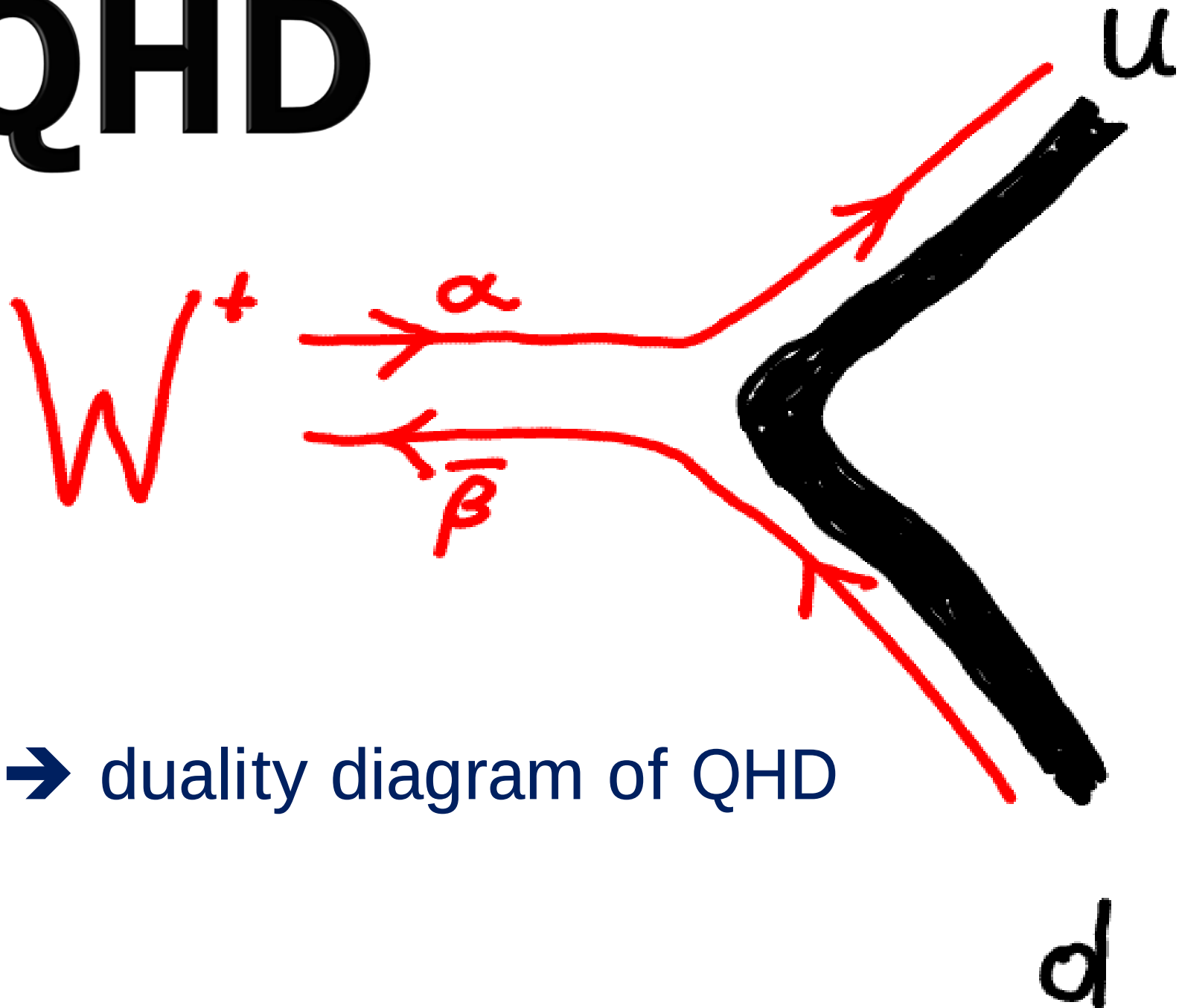
(e.g. SU(3))

QCD



duality diagram

QHD



➔ duality diagram of QHD

→

constituents

of

weak bosons

are also

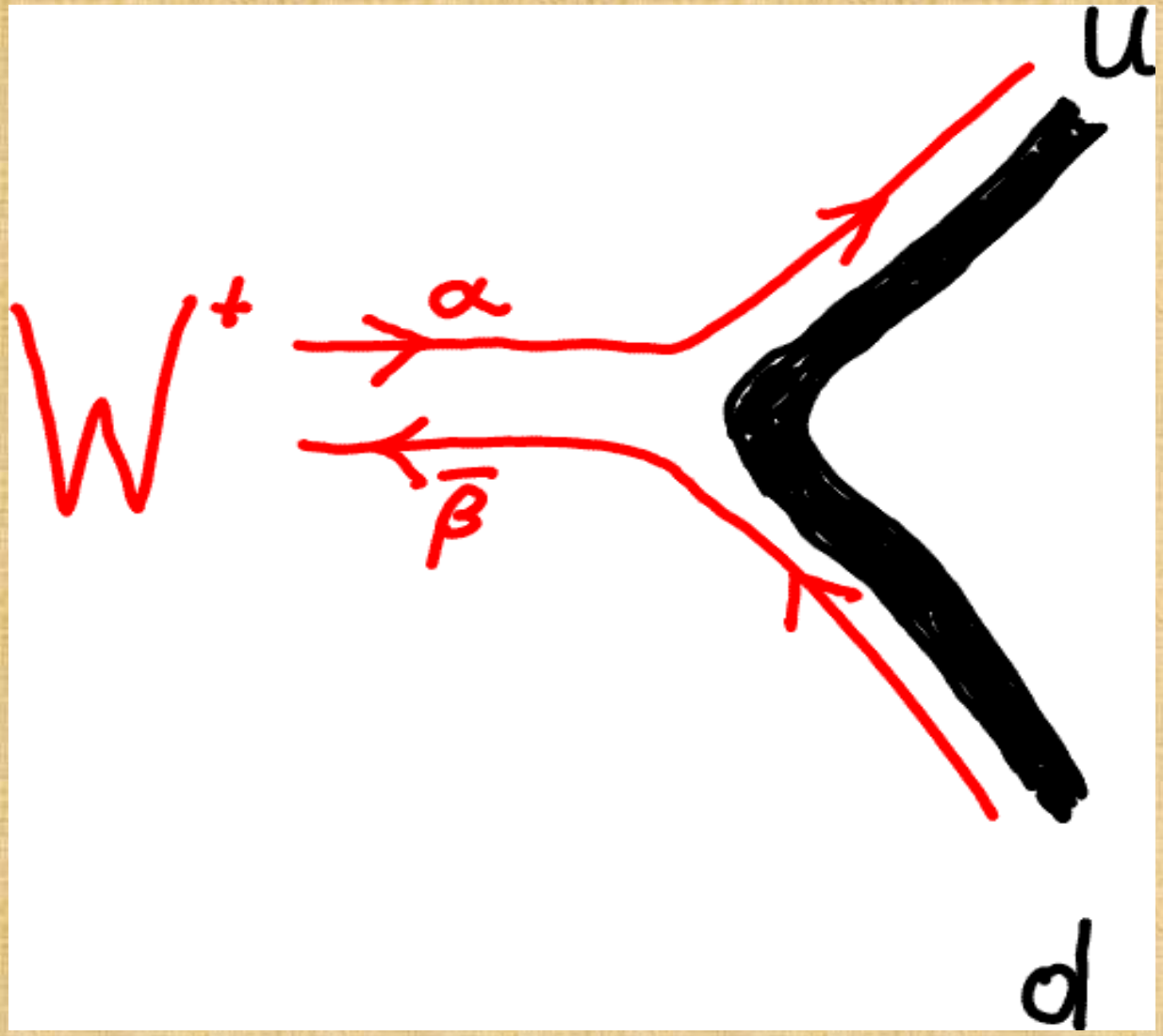
constituents

of

leptons

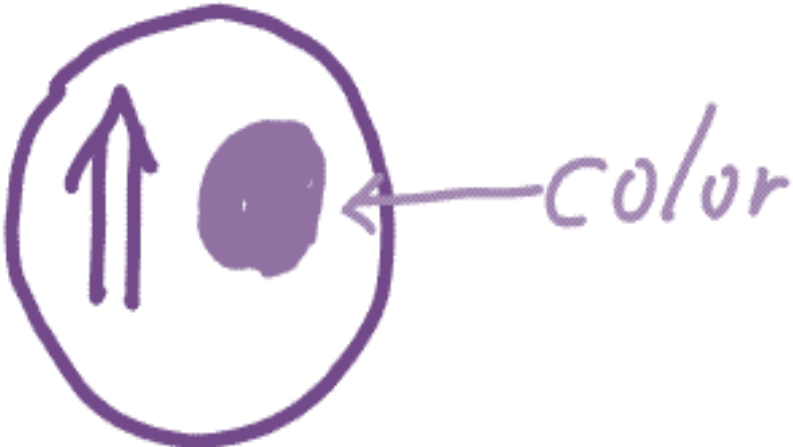
and

quarks



lepton:

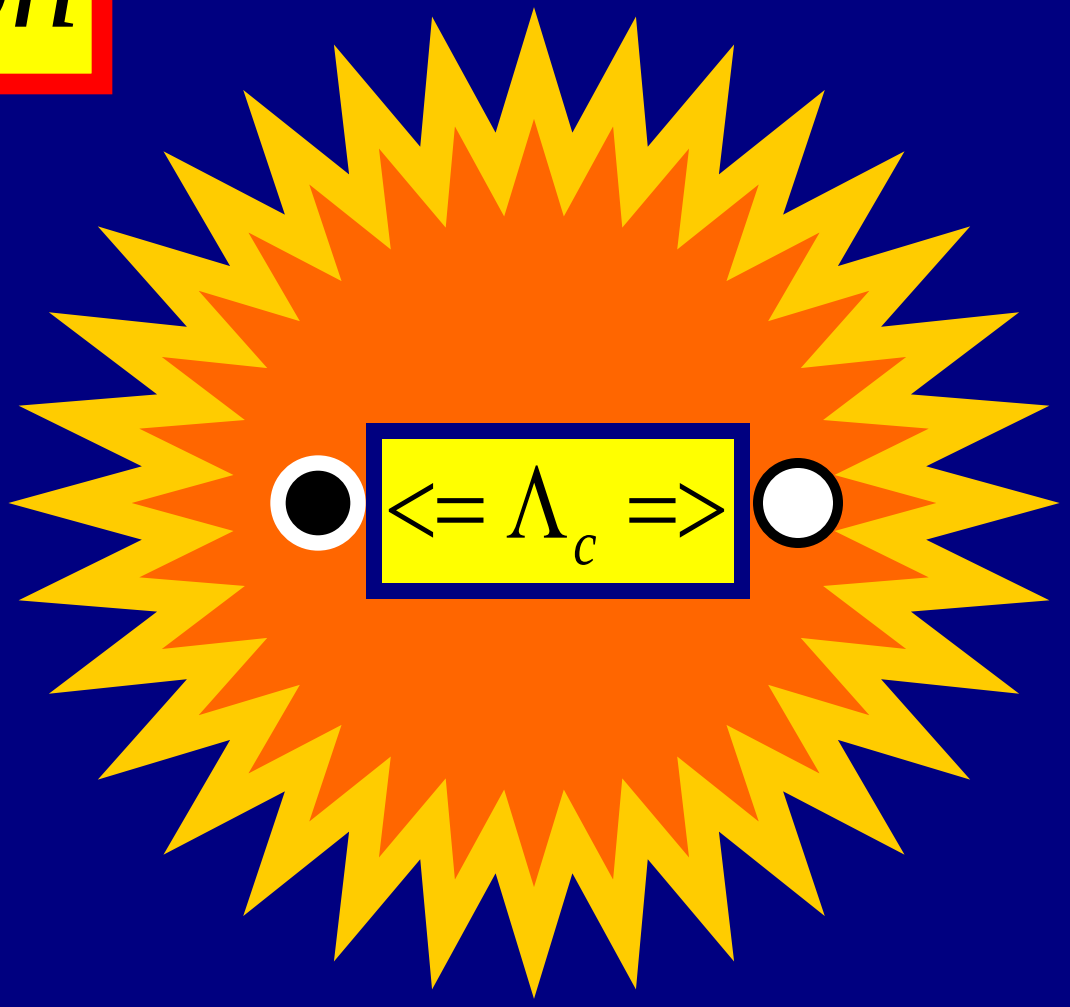
quark:

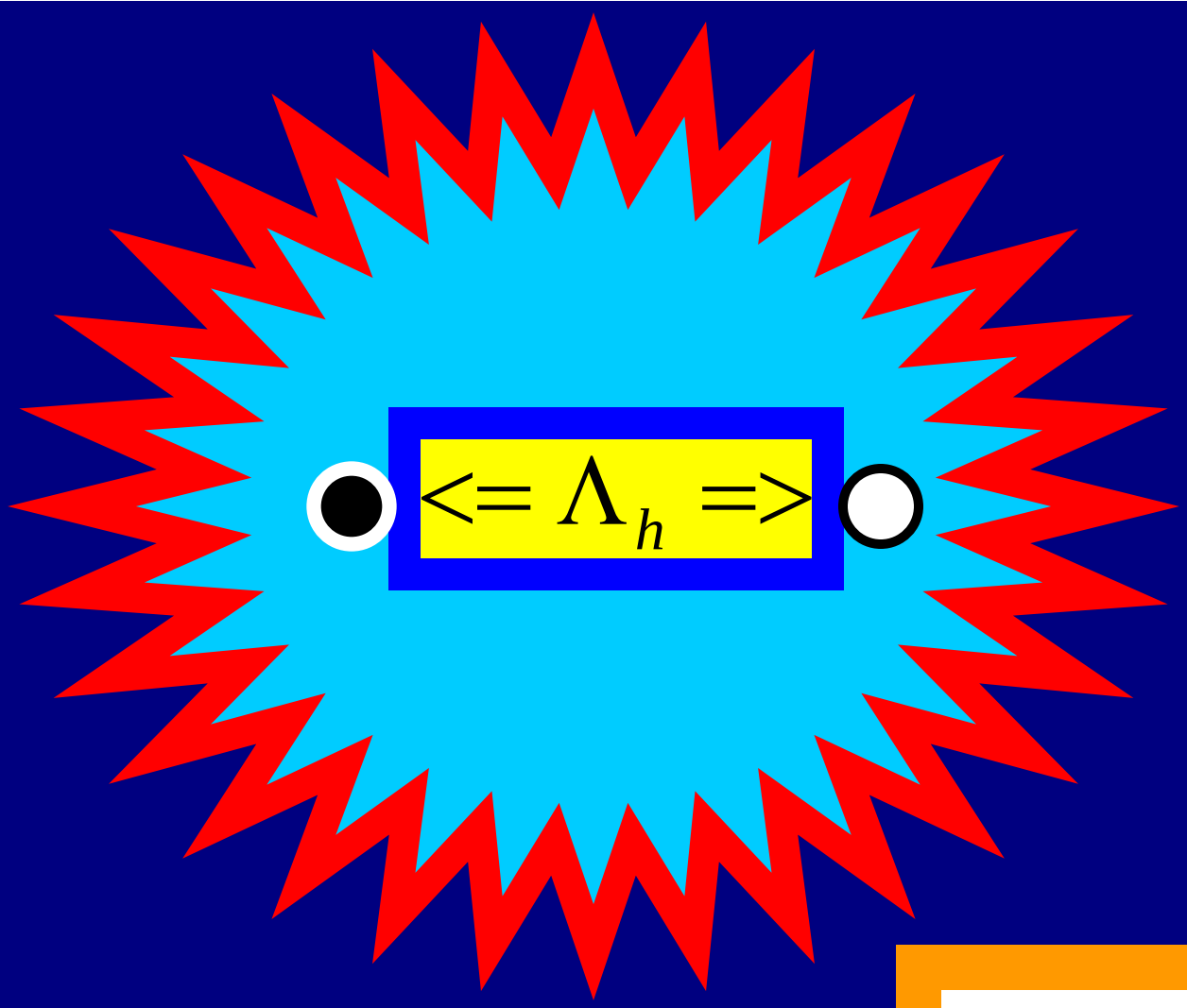


mass scale of QHD

$$\Lambda_h$$

$\rho - meson$



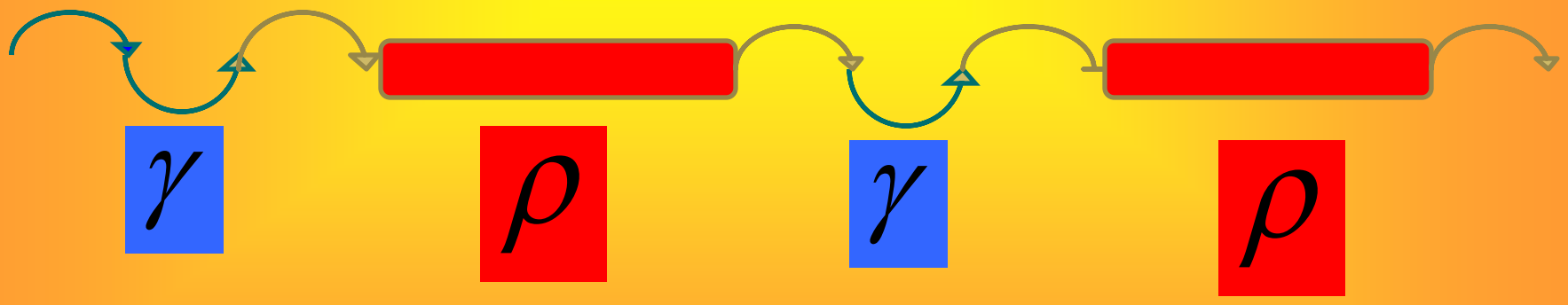


$W - boson$

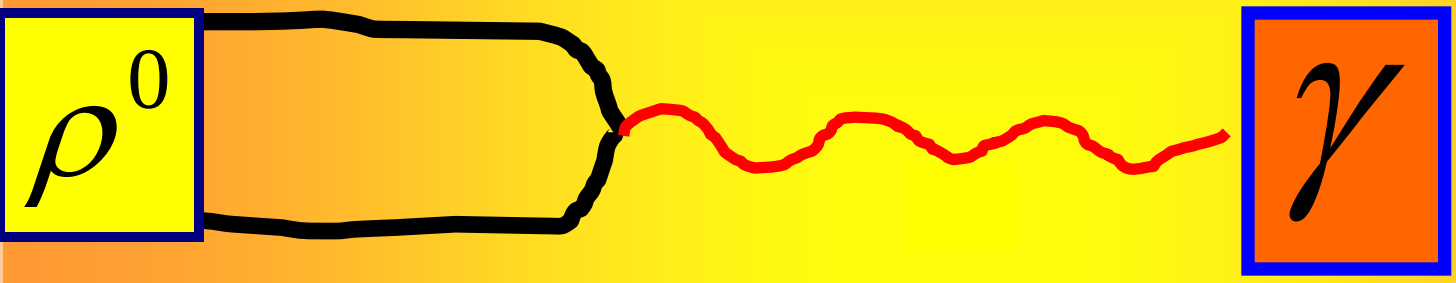
Λ_h ?

➔ QCD

Dynamical mixing of meson and photon



mixing with photon



m: mixing parameter

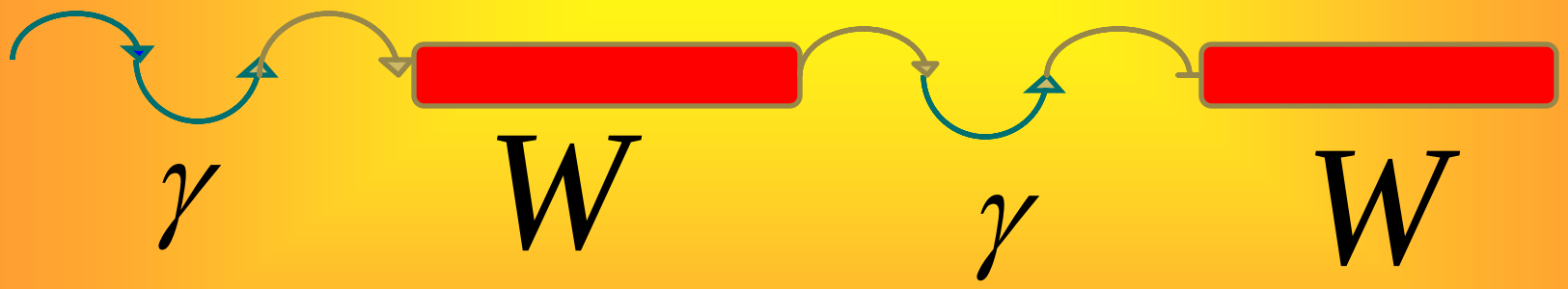
$$M_{\rho^0}^{\ 2} = \frac{M_{\rho^+}^{\ 2}}{1-m^2}$$

~ 3.1 MeV

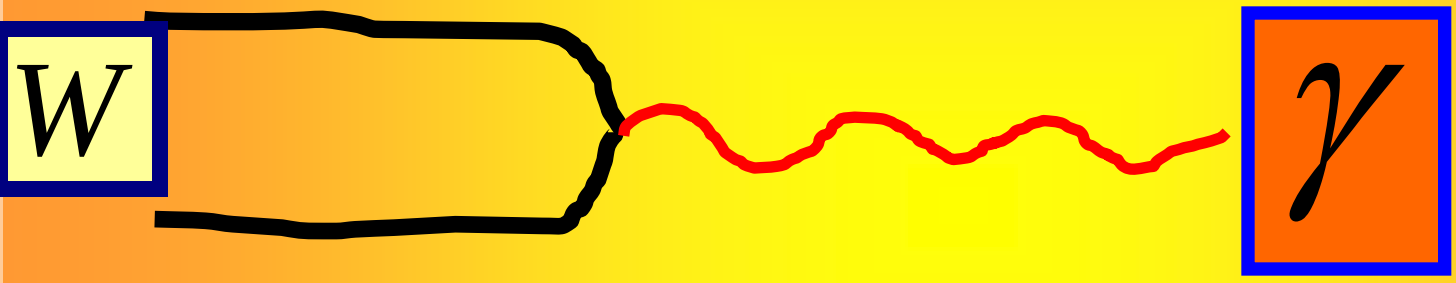
m = 0.09

→ QHD

Dynamical mixing of W-boson and photon



mixing of W with photon



m: mixing parameter

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

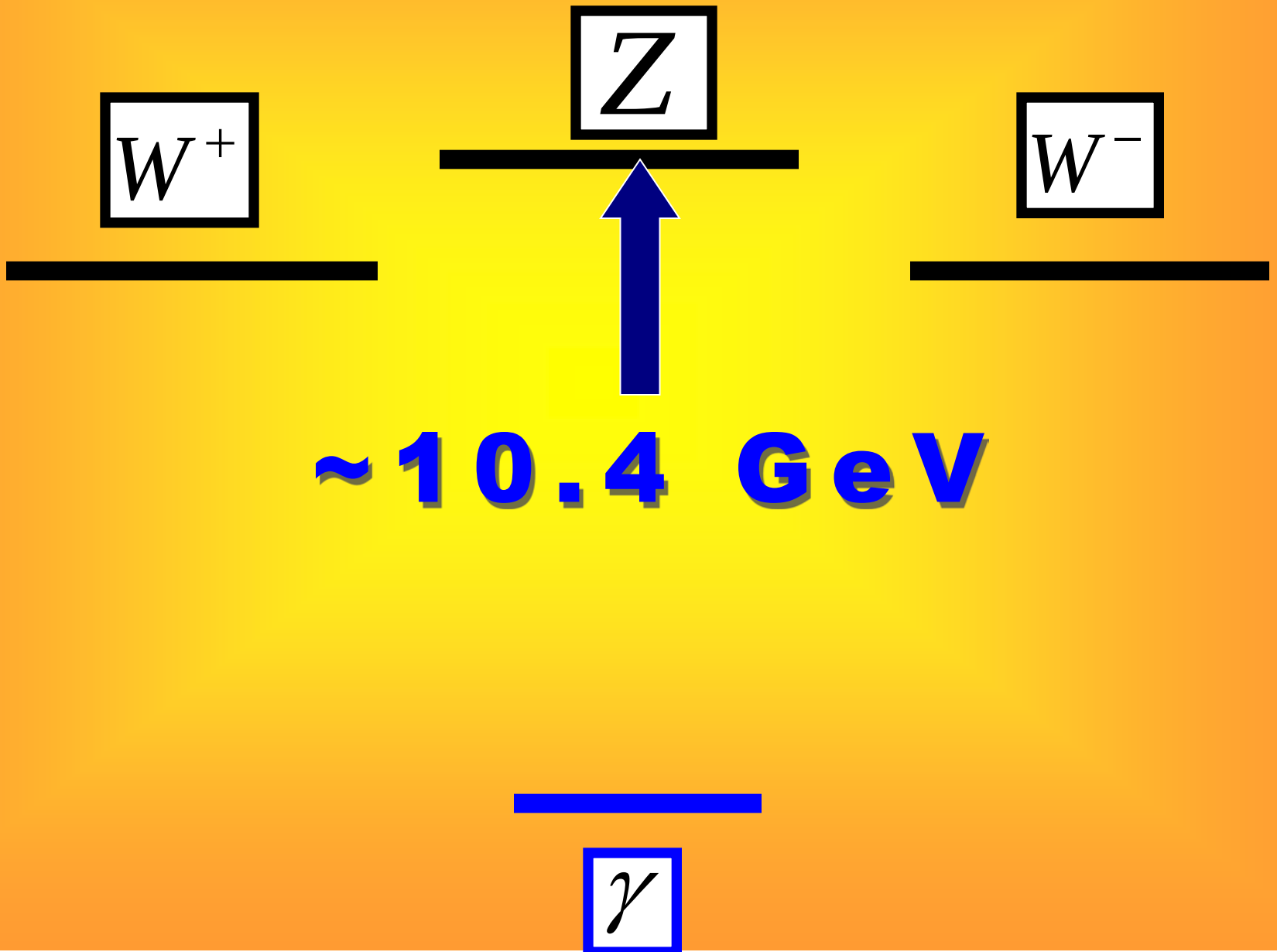
$$M_Z^{\ 2} = \frac{M_W^{\ 2}}{1 - m^2}$$

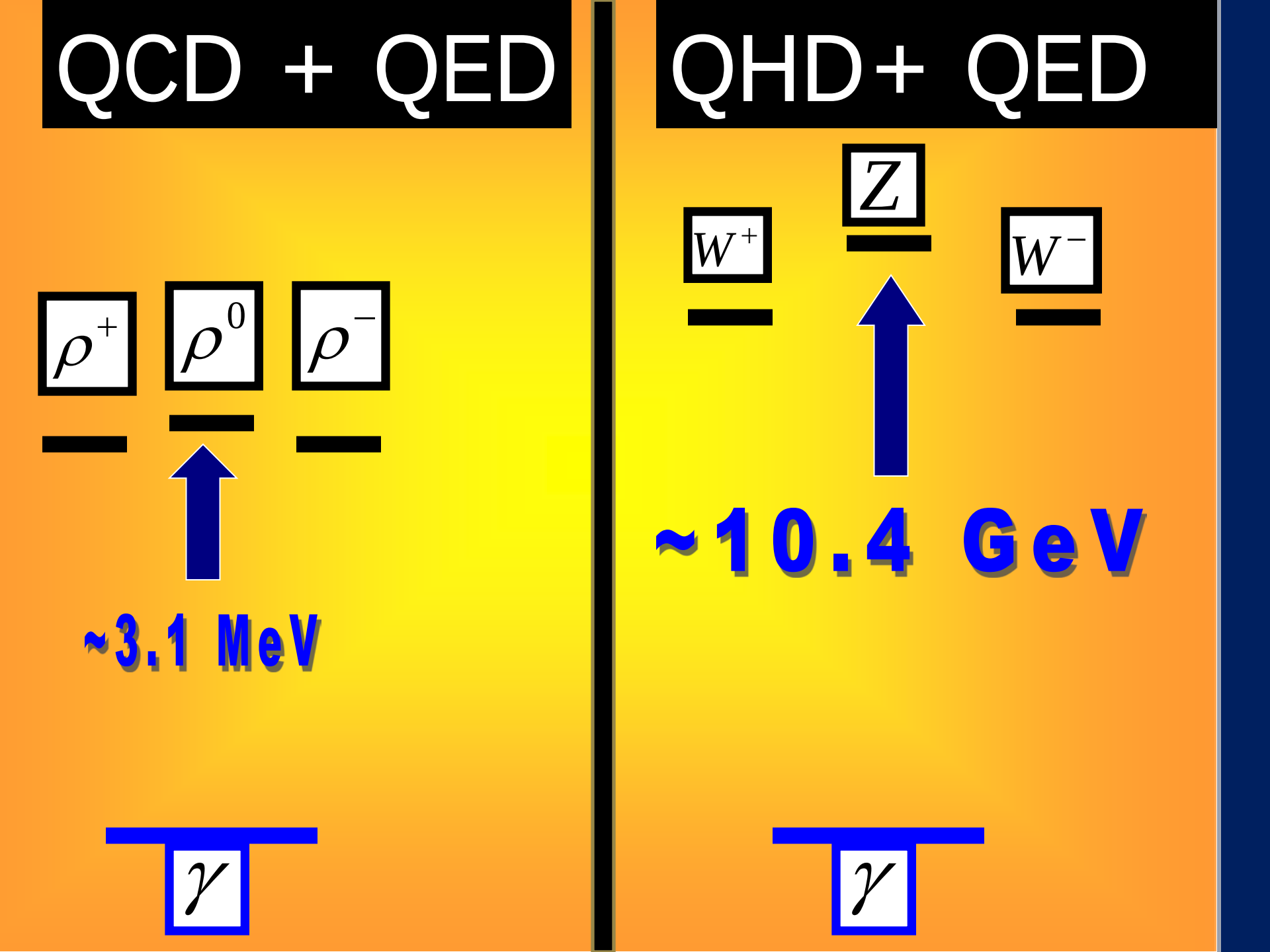
Standard Model

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

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

Standard Model




QCD + QED
ρ^+
ρ^0
ρ^-
~3.1 MeV
γ
QHD+ QED
Z
W^+
W^-
~10.4 GeV
γ

W decay constant

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

experimental data:

$$M_W = 80.4...GeV$$

$$M_Z = 91.19...GeV$$

$$F_W = 124.6...GeV$$

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

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

$$e \cong 0.3122$$

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

$$m \approx 0.485$$

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

$$F_W \approx 0.125\_TeV \Rightarrow \Lambda_h$$

$$F_W \approx 0.130\_TeV$$

$$\Lambda_h \approx 0.13 \Leftrightarrow 1.0\_TeV$$

uncertainty:
gauge group of
QHD

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

$$\Updownarrow$$

$$F_W \approx 0.13 \quad TeV$$

$$\Lambda_h \approx 0.13 \quad TeV$$

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

$$Z$$

New:
isoscalar

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

$$X$$

Present lower limit on X-mass:

~700 GeV

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

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

???

ρ_0

ω

masses about equal

QCD - anomaly

$\downarrow$

$$m(\eta') \gg m(\pi^0)$$

$$\partial_\mu (\bar{q}\gamma^\mu\gamma^5 q) \sim g^2 \cdot G_{\mu\nu}\hat{G}^{\mu\nu}$$

π^0: $\partial_\mu (\bar{u}\gamma^\mu\gamma_5 u - \bar{d}\gamma^\mu\gamma^5 d) = 0$

η': $\partial_\mu (\sim \quad + \quad \sim) \neq 0$

(quark masses $\longrightarrow 0$)

QHD - anomaly

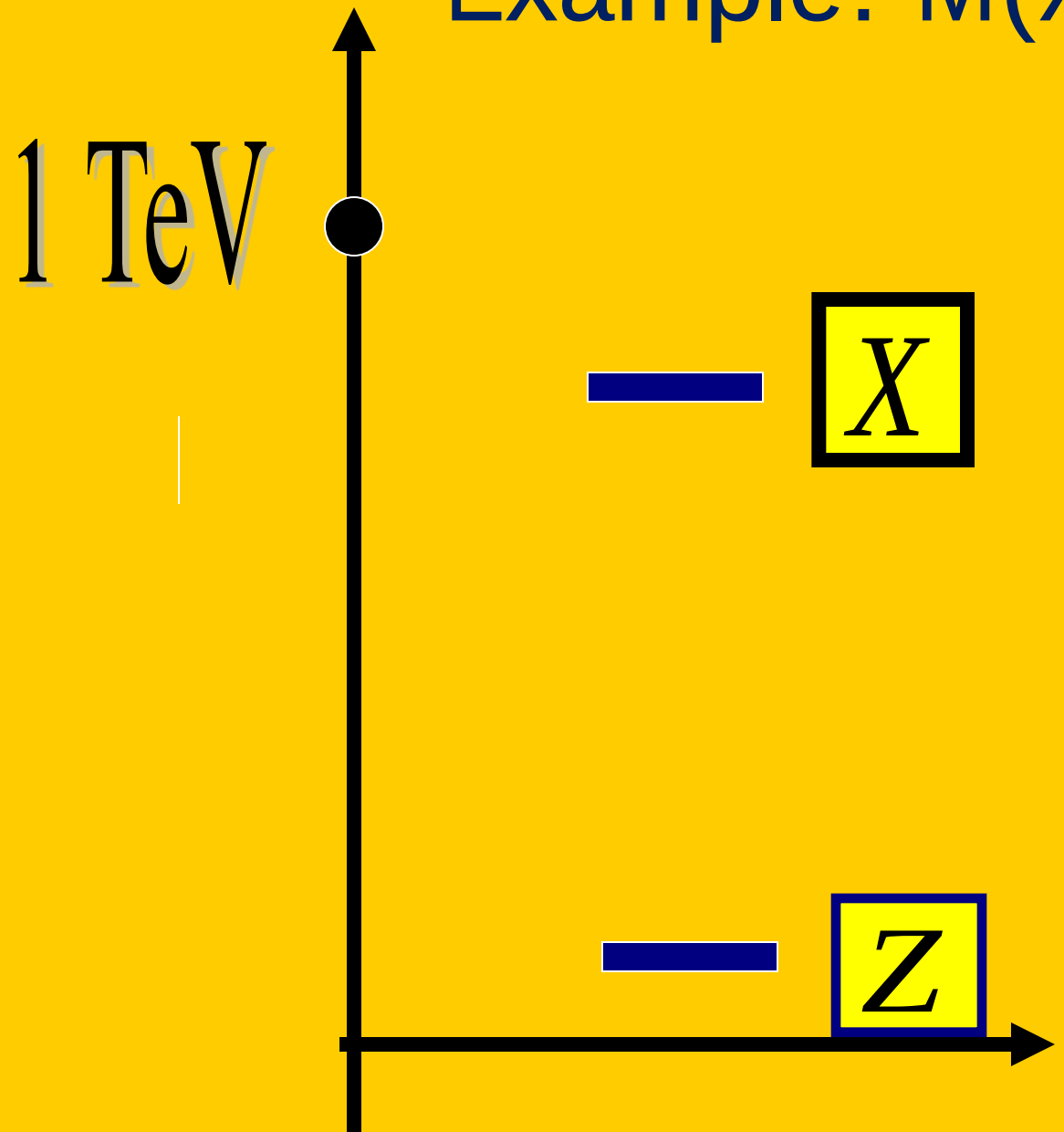
$$\partial_\mu (\bar{h} \gamma^\mu \gamma^5 h) \sim g_h^2 H_{\mu\nu} \hat{H}^{\mu\nu}$$

$$Z: \quad \partial_\mu (\bar{\alpha} \gamma^\mu \gamma^5 \alpha - \bar{\beta} \gamma^\mu \gamma^5 \beta) = 0$$

$$X: \quad \partial_\mu (\sim \quad + \sim) \neq 0$$

QHD: chiral theory
(no 0^{-+} - states)
$m(X) \gg m(Z)$

Example: M(X)=0.8 TeV



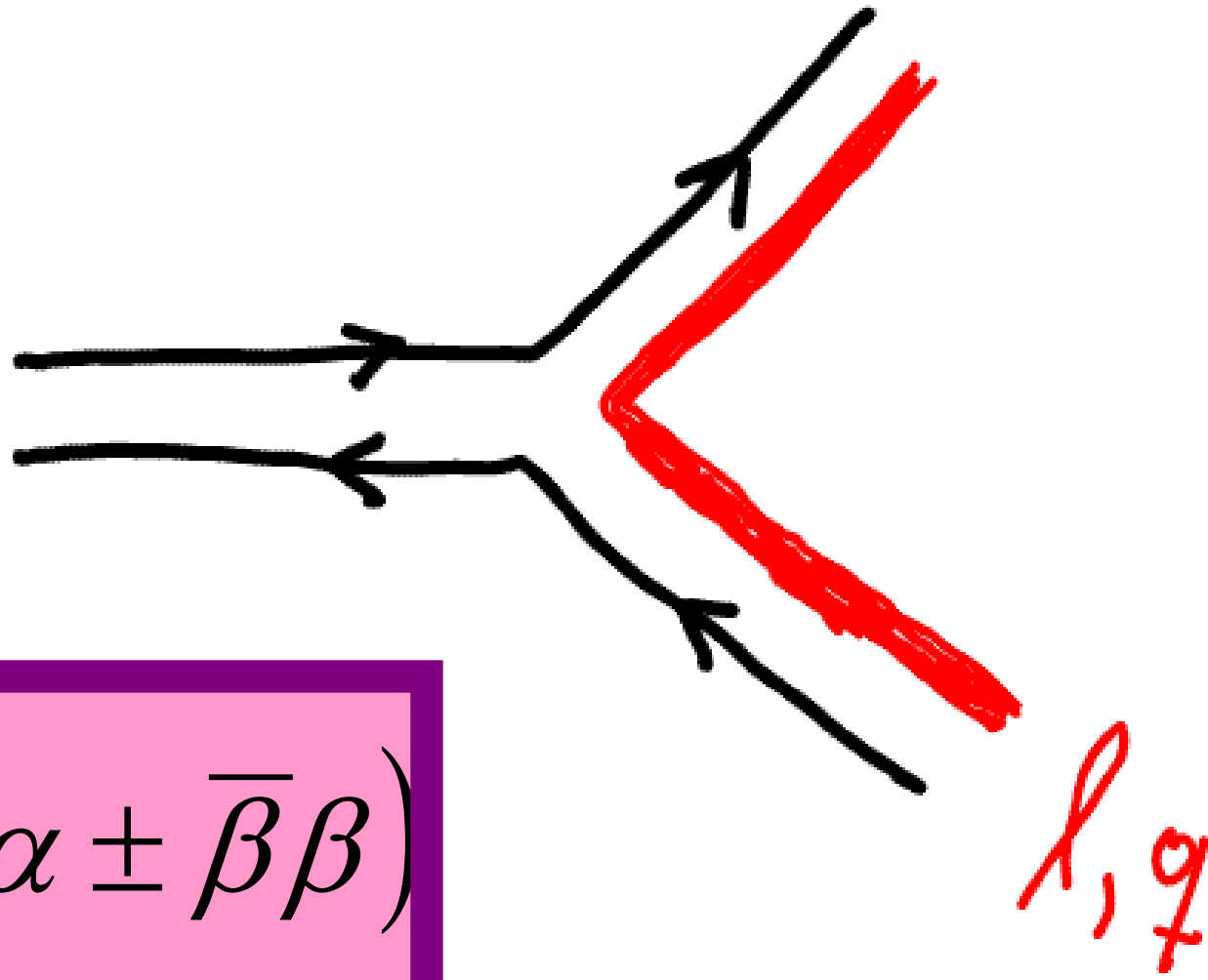
cross section of Z-production at LHC: ~ 60 nb

➔ cross section for X-production: ~0.8 nb

Coupling of X to leptons and quarks:

➔coupling of Z - boson

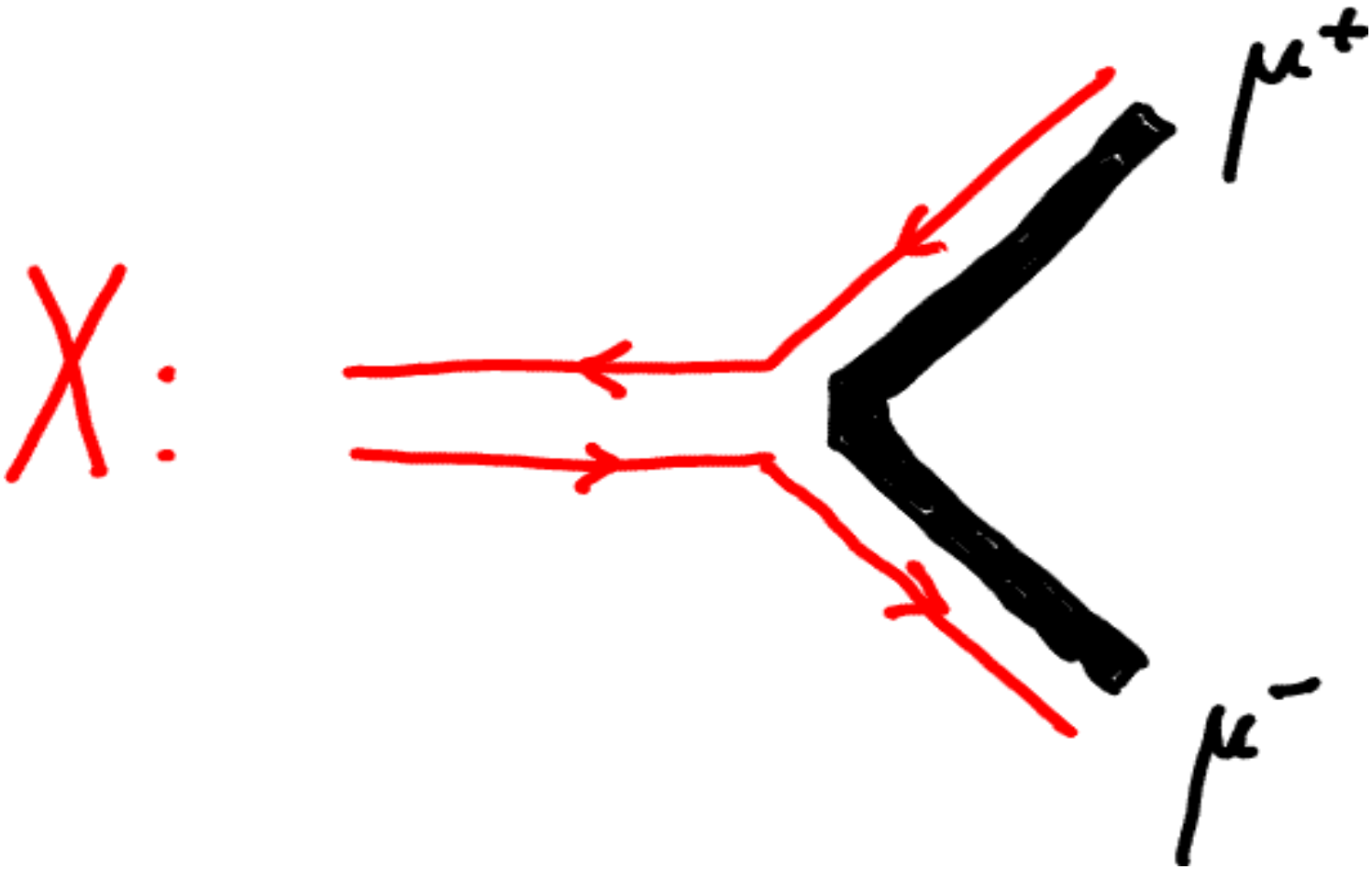
$Z \to X$



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

X – decay into muons

➔ Z – decay into muons:



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

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

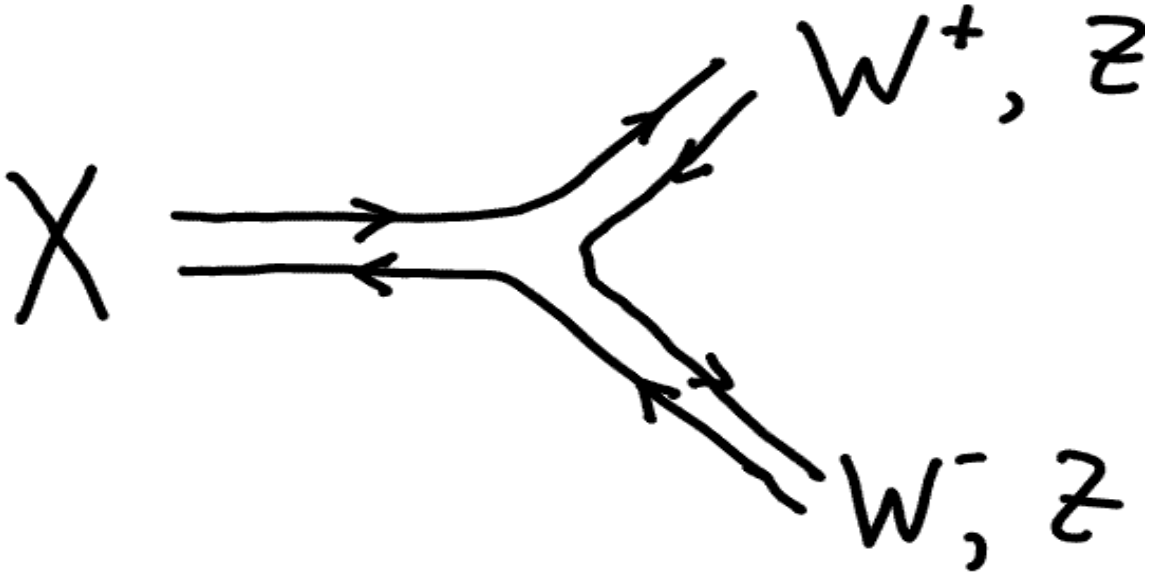
X - decays → leptons / quarks

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

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

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

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



Expected:

$$\Gamma(X \to W^+W^-) =$$

$$\Gamma(X \to ZZ) \approx$$

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

X →

leptons

quarks

WW

ZZ

WWZ

ZZZ

Summation

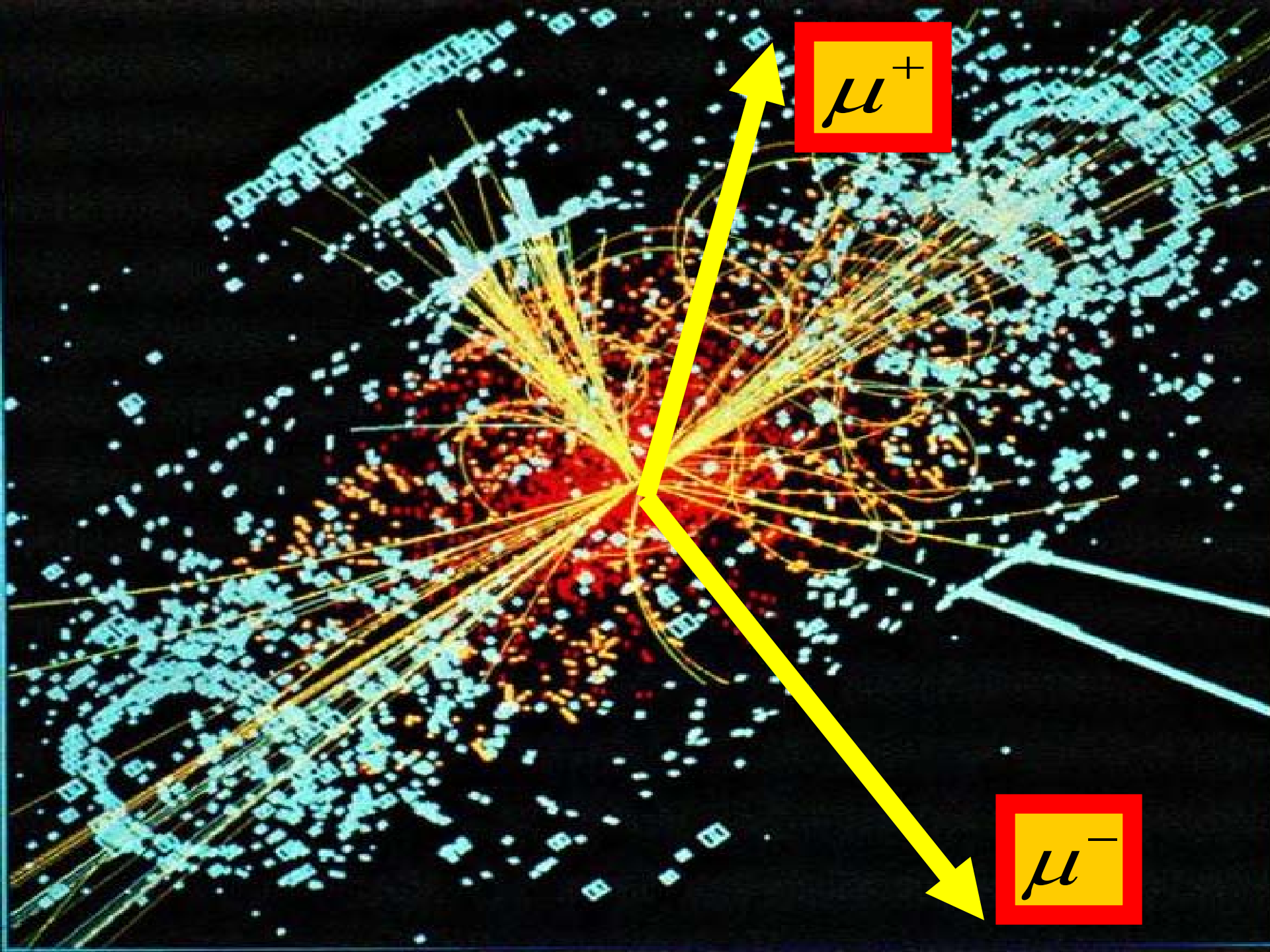
Total width of X:
~ 95 GeV

Total width of Z:
84 MeV

Discovery of X-boson:

search for decay into muon pairs

$$X \Longrightarrow \mu^+ \mu$$


μ^+
μ^-

$$\Lambda_c \approx 0.3...GeV$$

complexities

of

strong interactions

~ 1 GeV

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

complexities

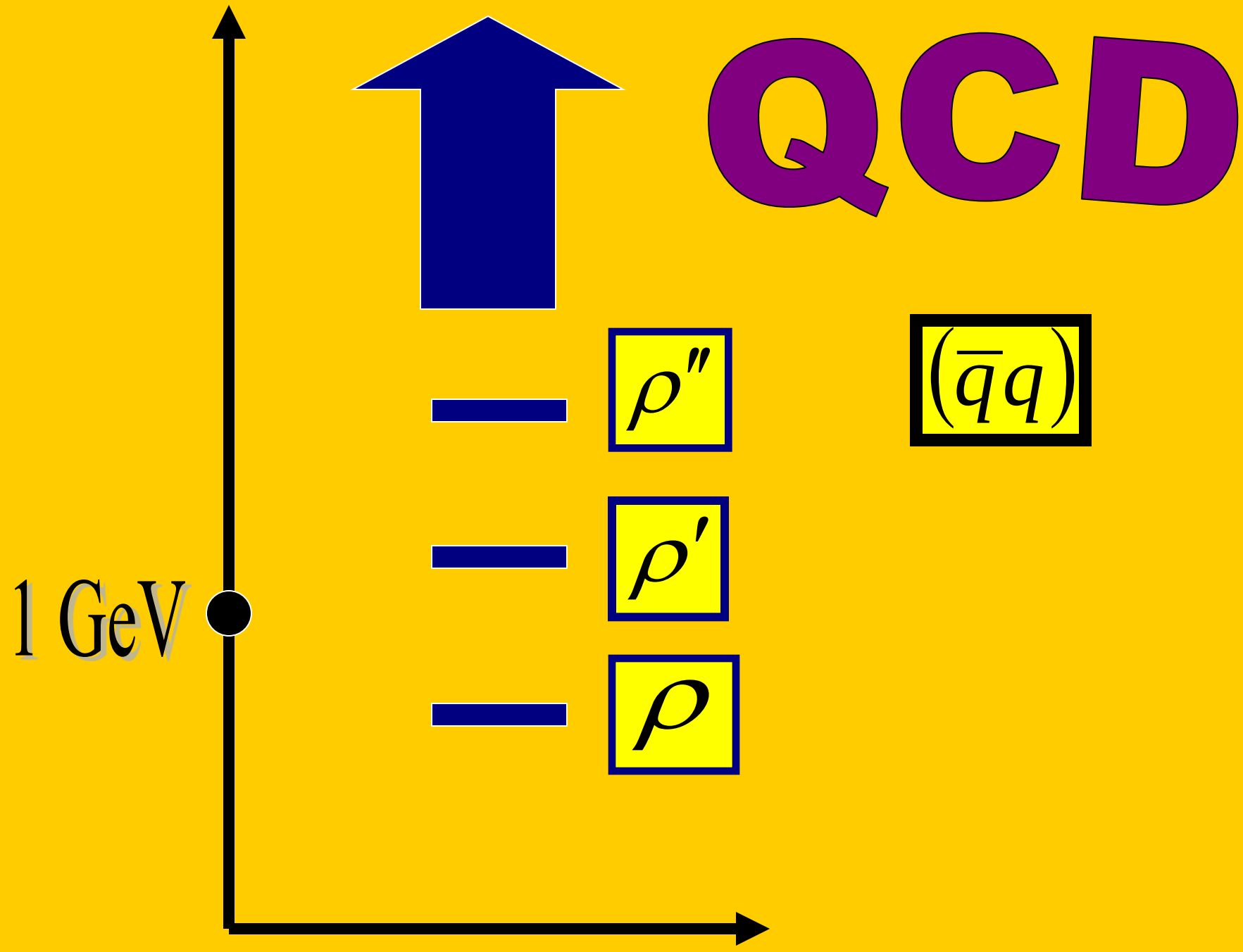
of

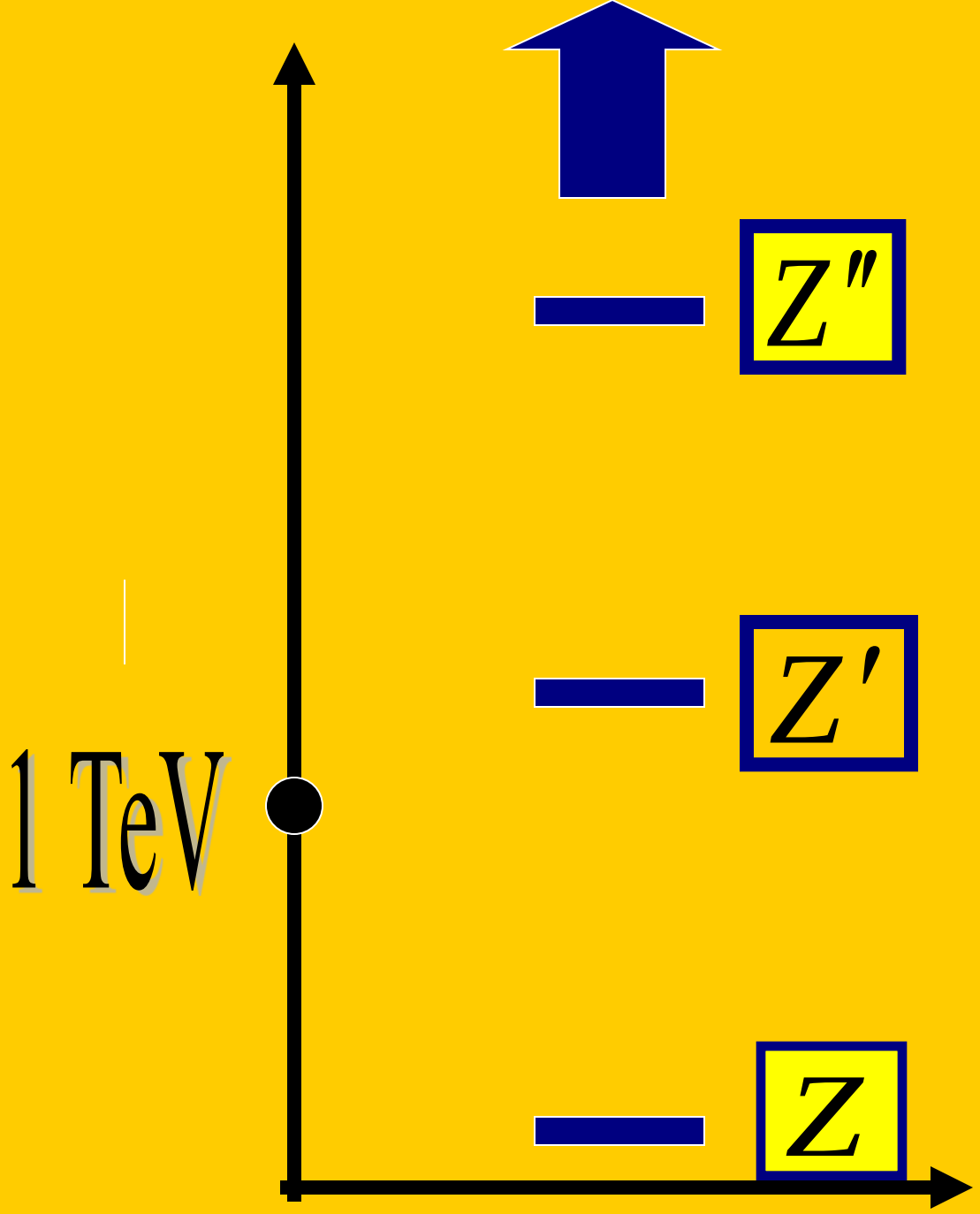
QHD interactions

~ 1 TeV

EXCITED WEAK BOSONS

above 1 TeV


QCD
$(\bar{q}q)$
ρ''
ρ'
ρ
1 GeV

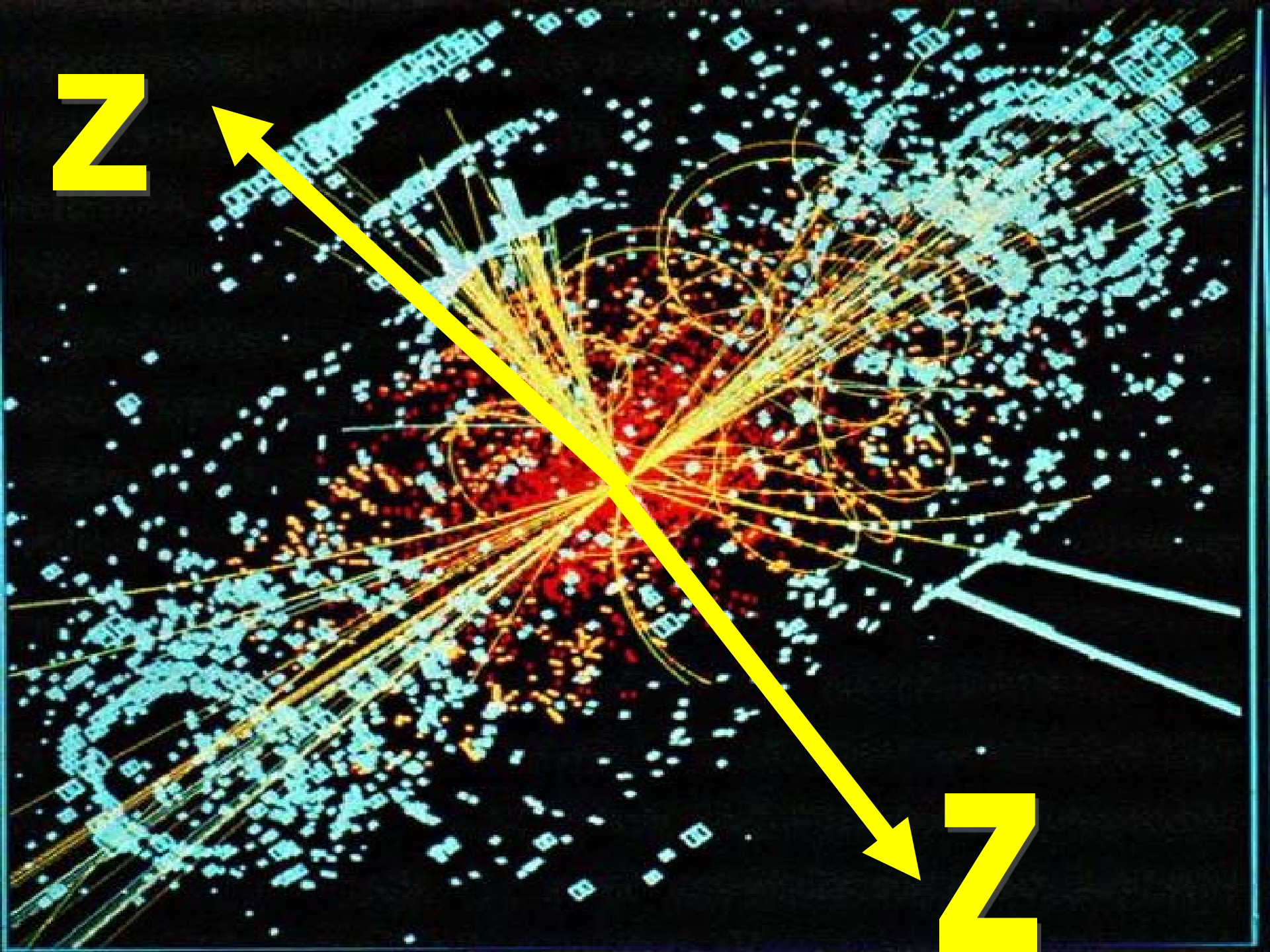


QHD

Limit from Tevatron and from LHC:

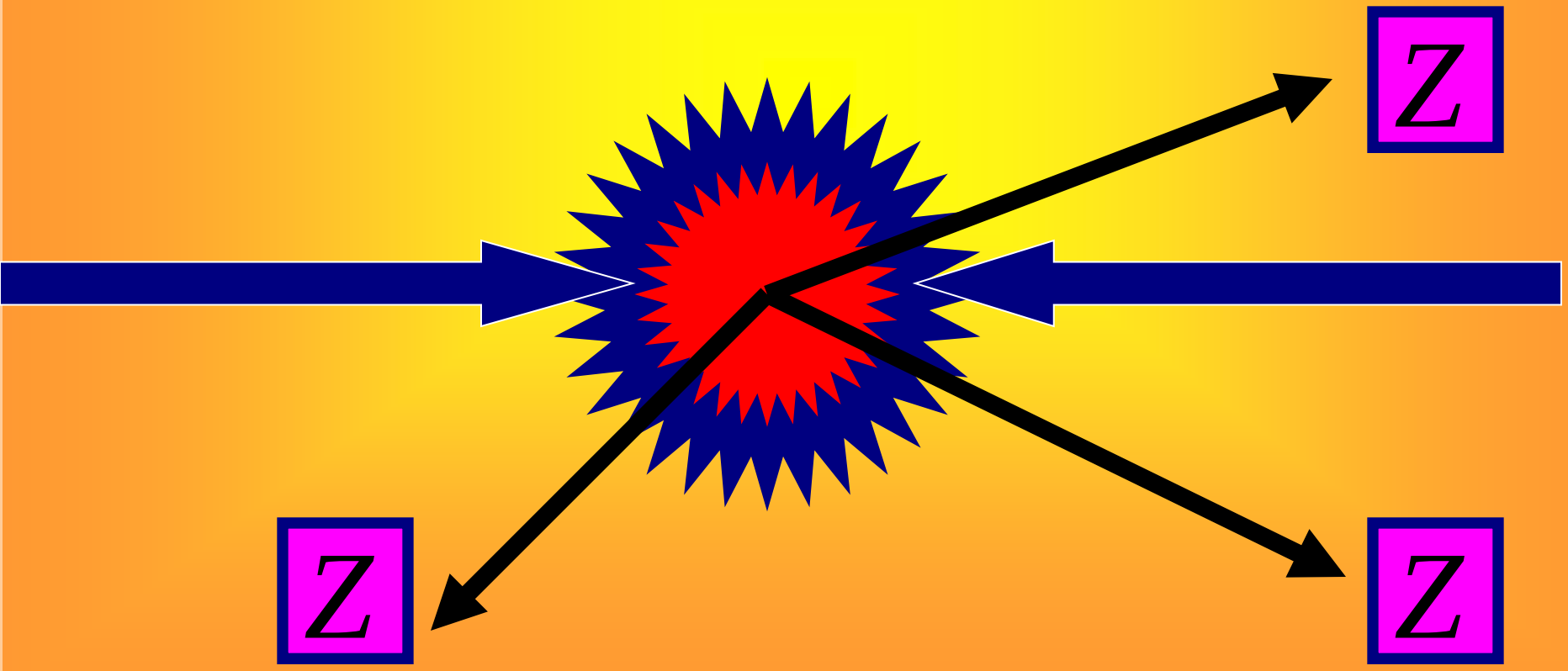
$M(Z`) > 0.8$ TeV

$$Z' \Rightarrow Z + Z$$

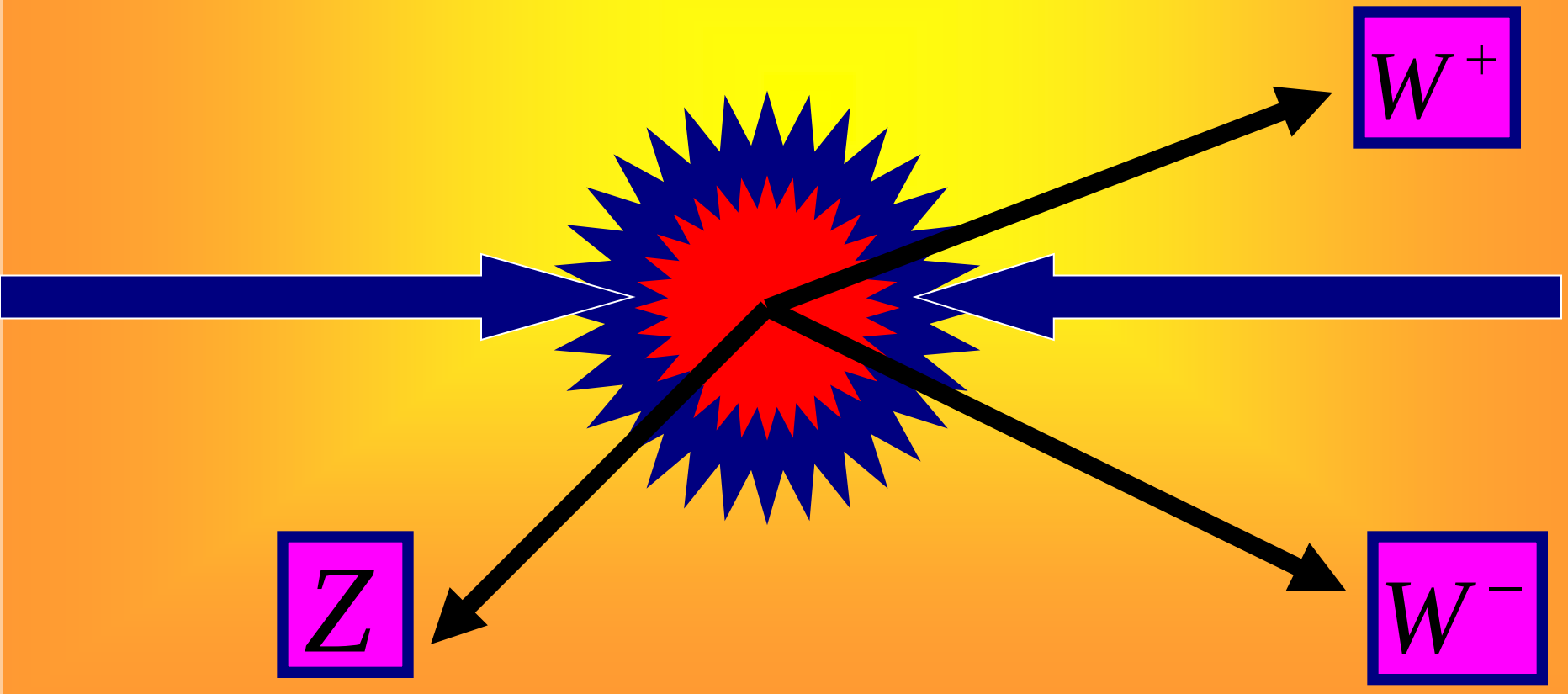

Z
Z

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

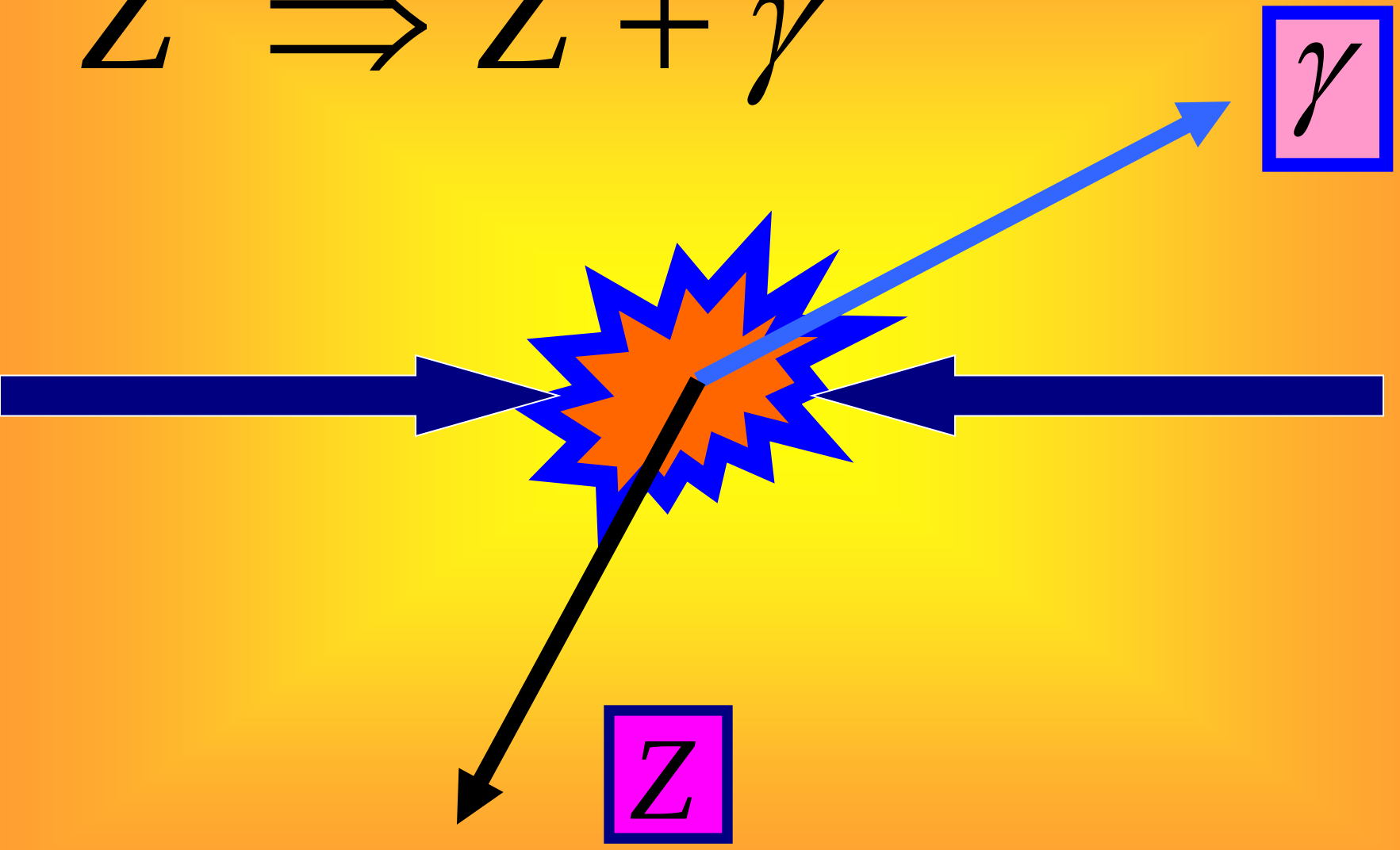
$$Z' \Rightarrow Z + Z + Z$$



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



$$Z' \Rightarrow Z + \gamma$$

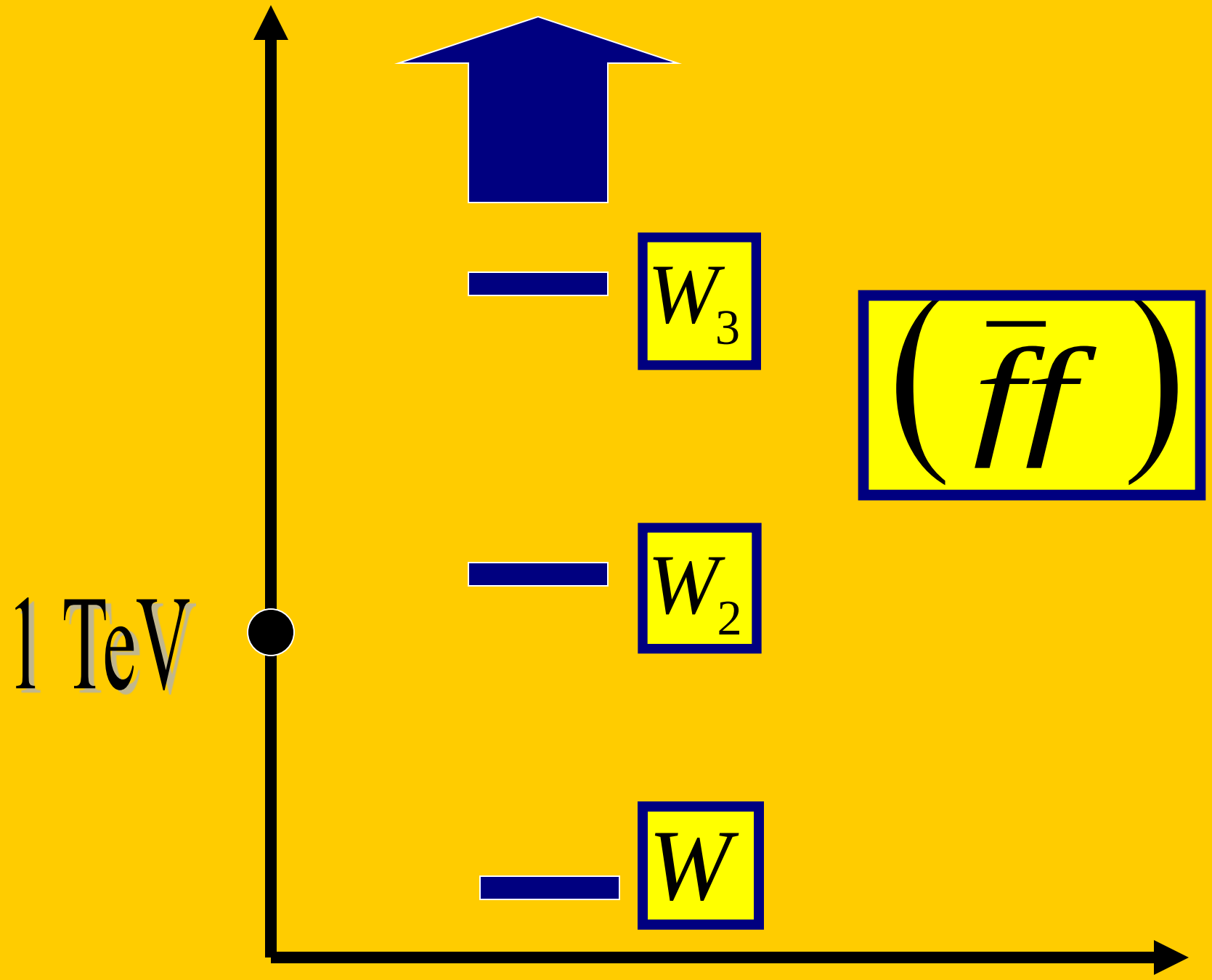


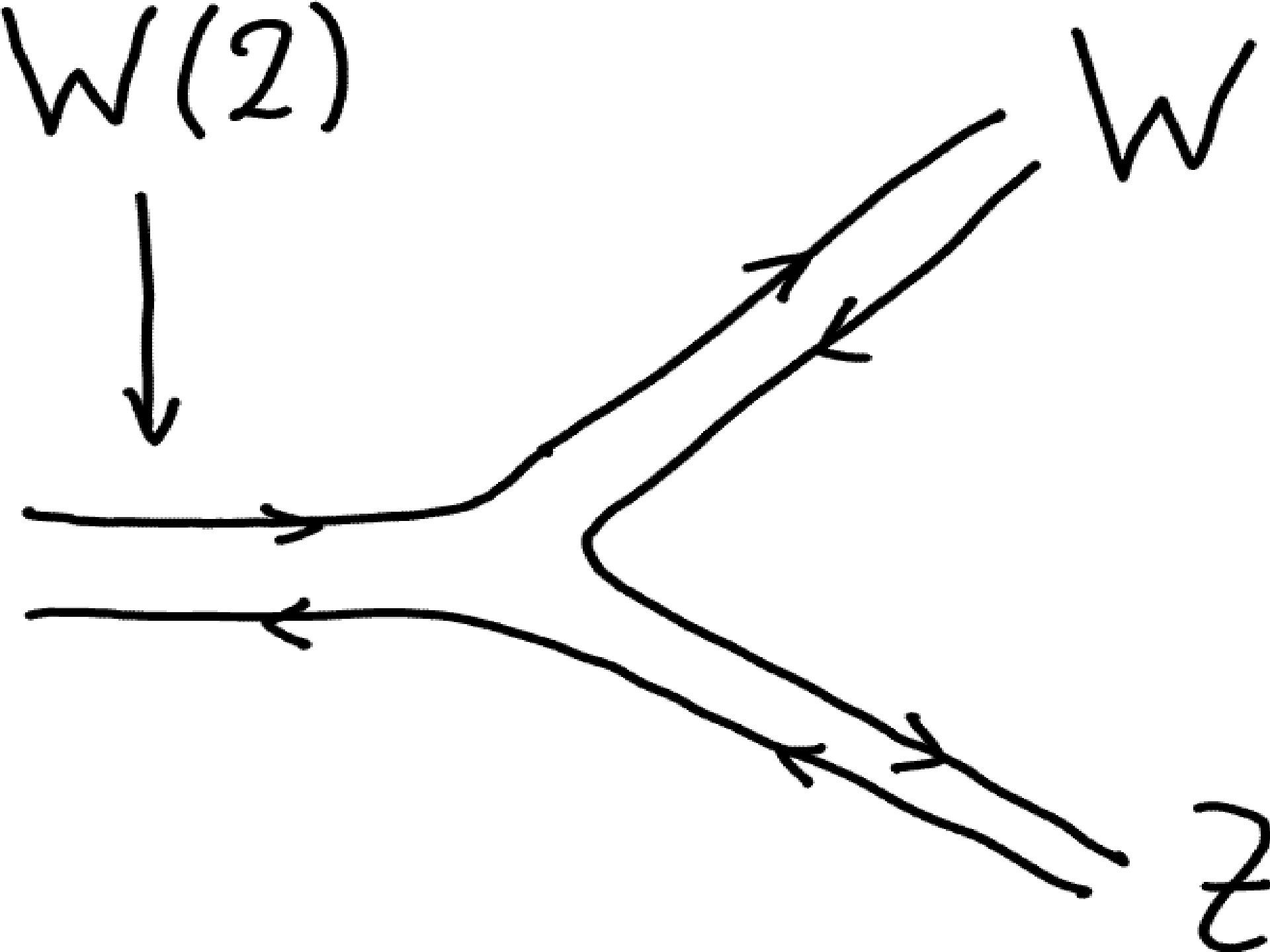
QCD

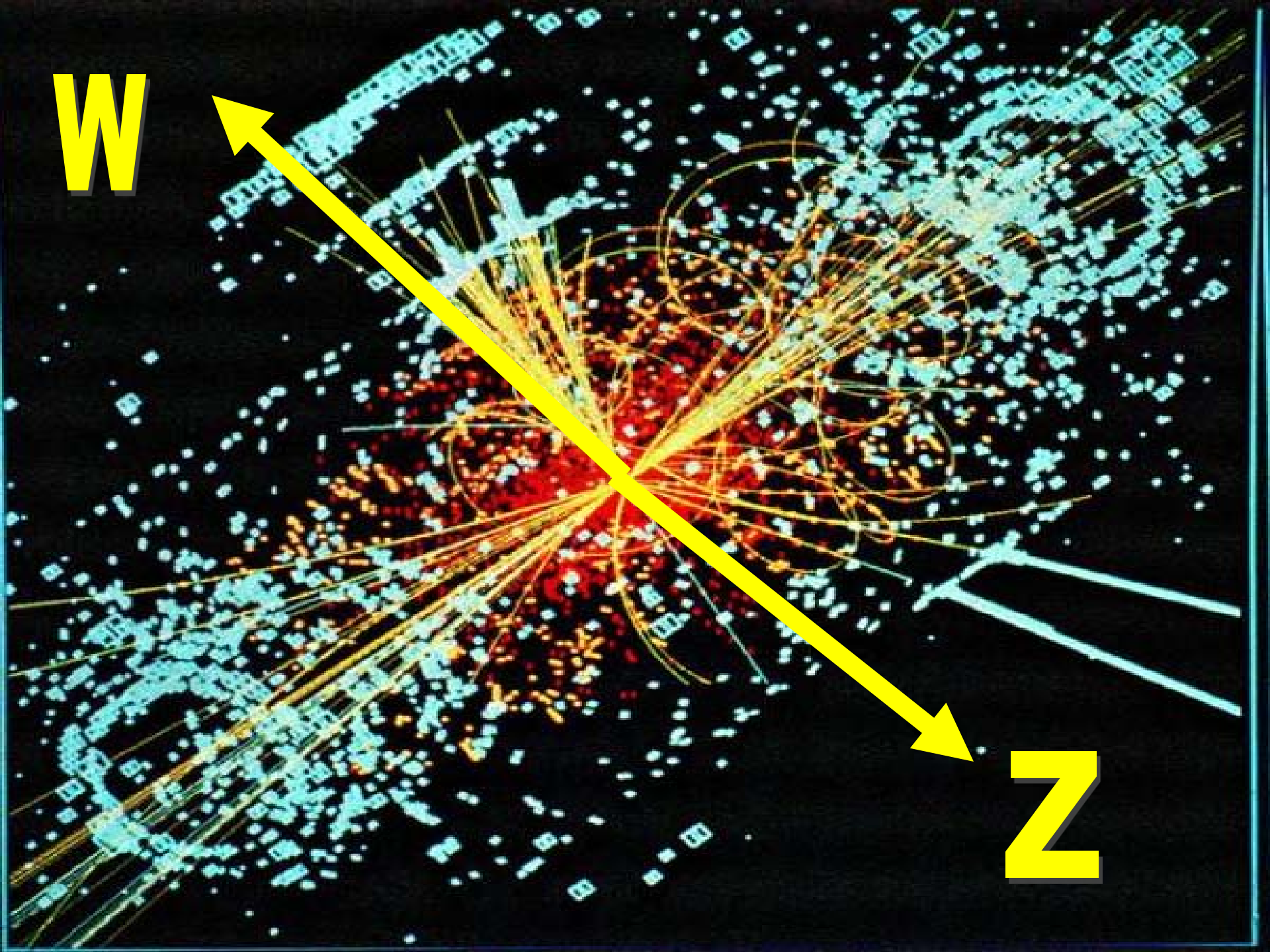
$$\rho \Rightarrow a_2(1320) \Rightarrow \ldots$$

QHD

$$W \Rightarrow W_2(1.2 \quad TeV\,?) \Rightarrow \ldots$$


1 TeV
W_3
W_2
W
$(\bar{f}f)$


W(2)
W
Z


W
Z

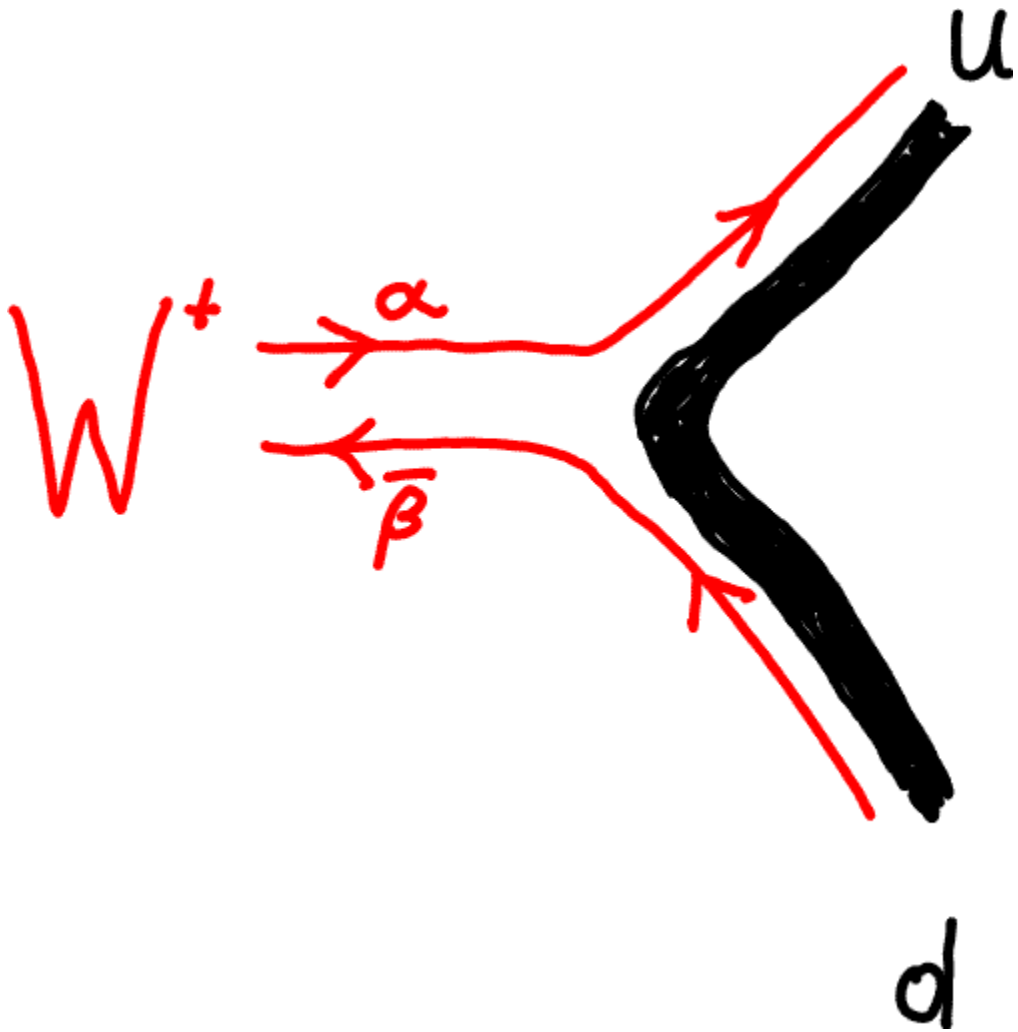
weak bosons composite

↓

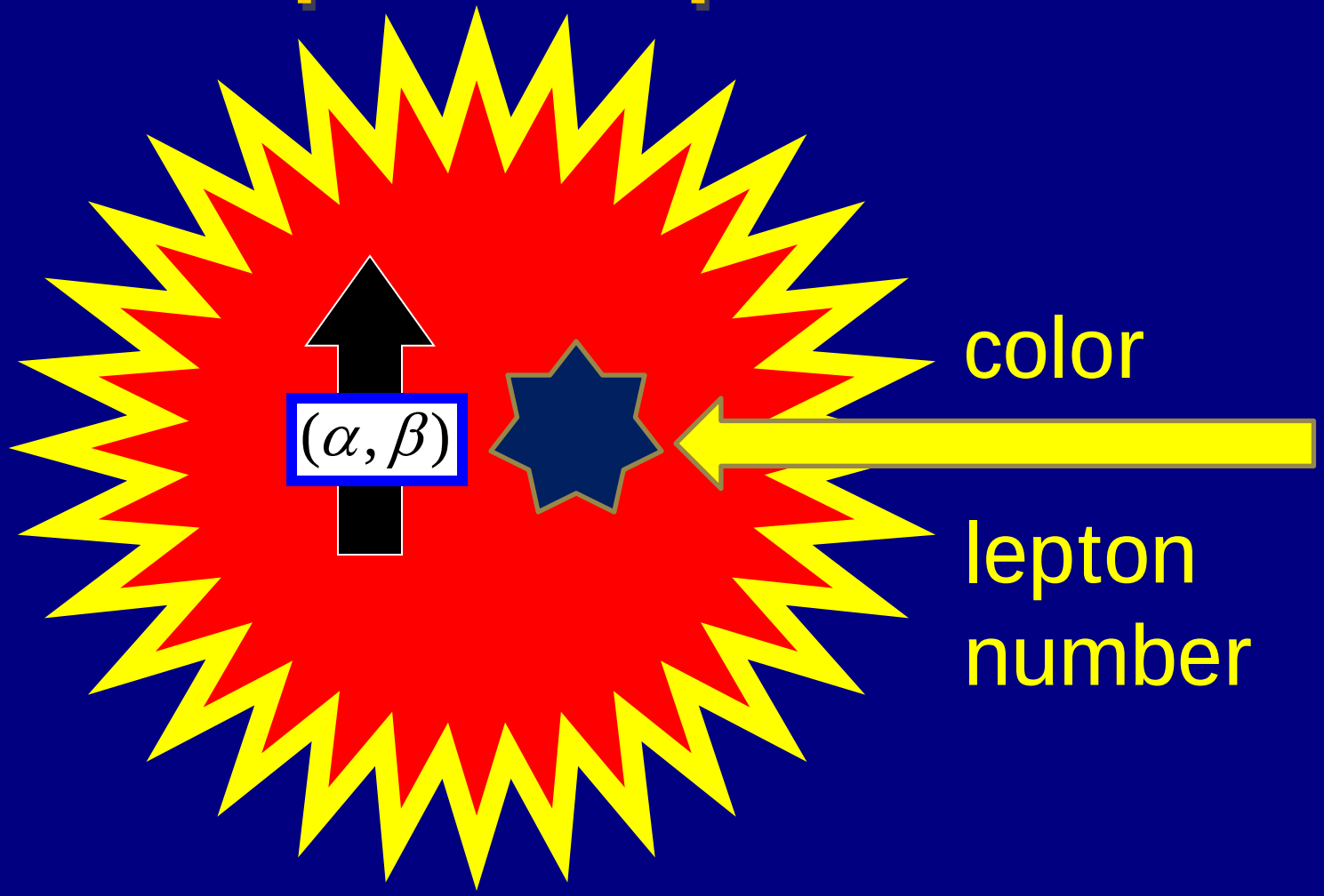
weak interactions

↓

leptons and quarks → composite


u
W+
α
β̄
d

leptons - quarks

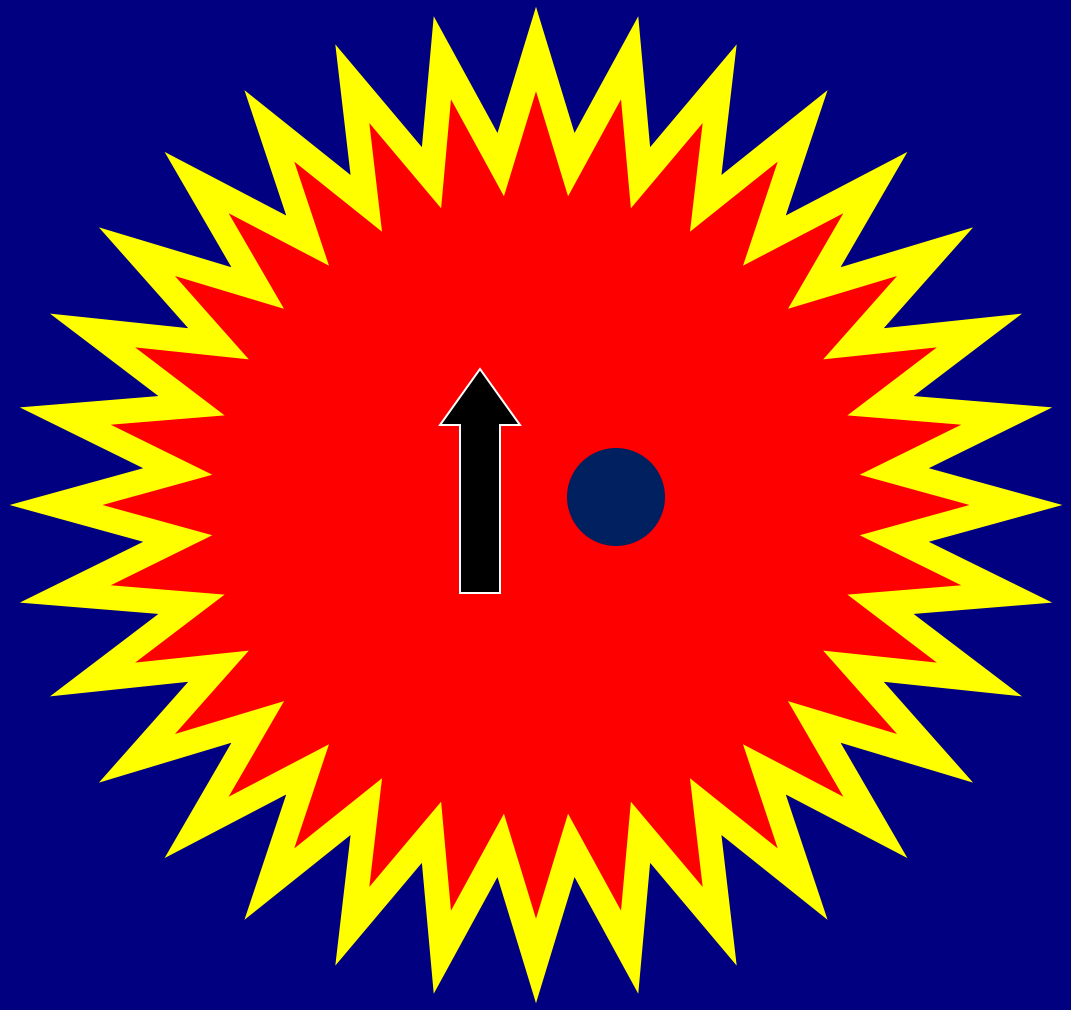


simplest theory:

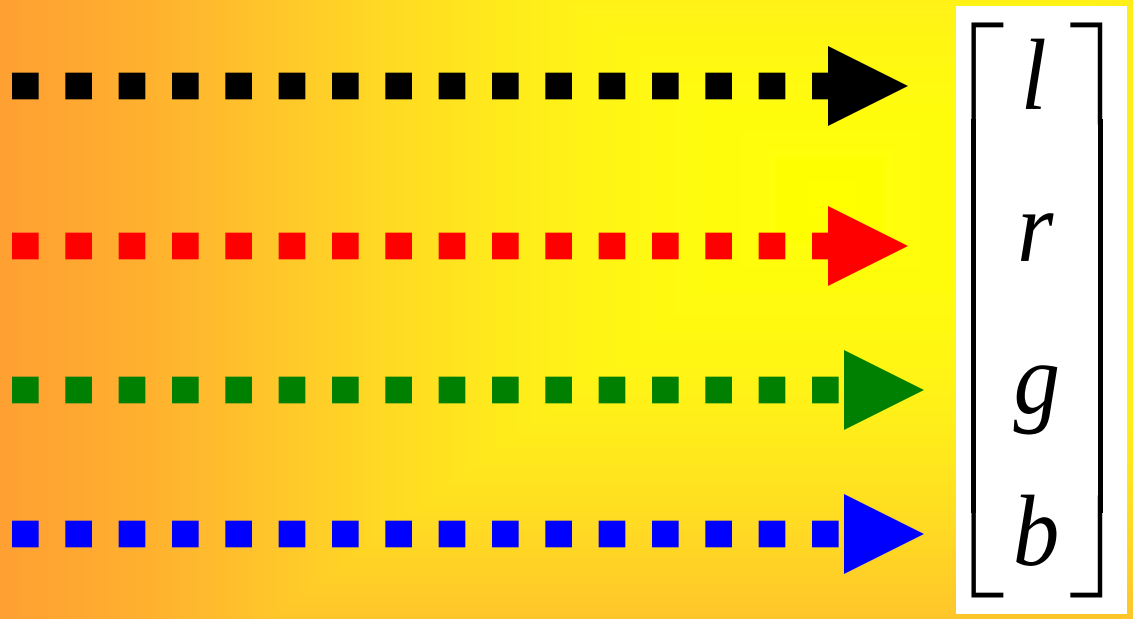
leptons - quarks

(fermion + scalar)

leptons - quarks



2 fermions



4 scalars

4 scalars

inside leptons

inside quarks

electric charges

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

electric charges

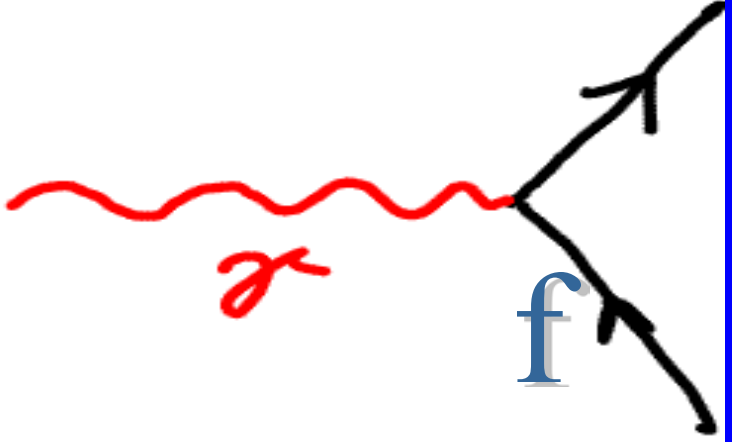
$l: \quad -\frac{1}{2}$

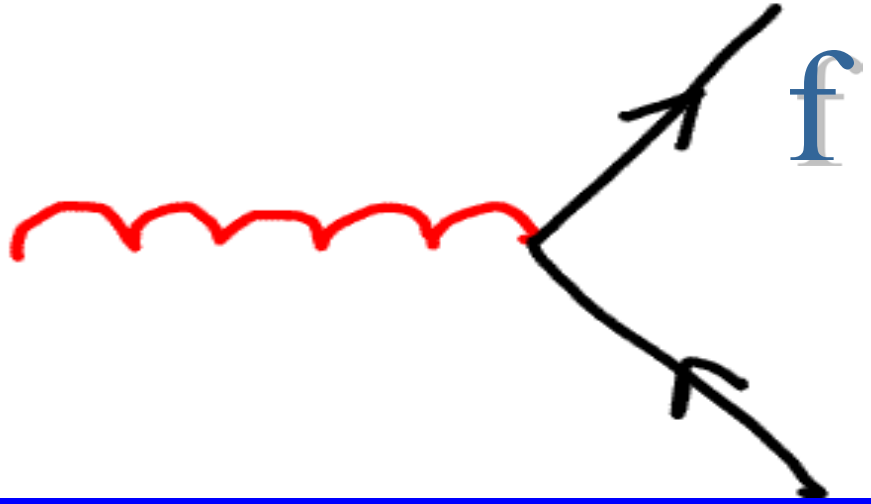
$r: \quad +\frac{1}{6}$

$g: \quad +\frac{1}{6}$

$b: \quad +\frac{1}{6}$

interactions





leptons

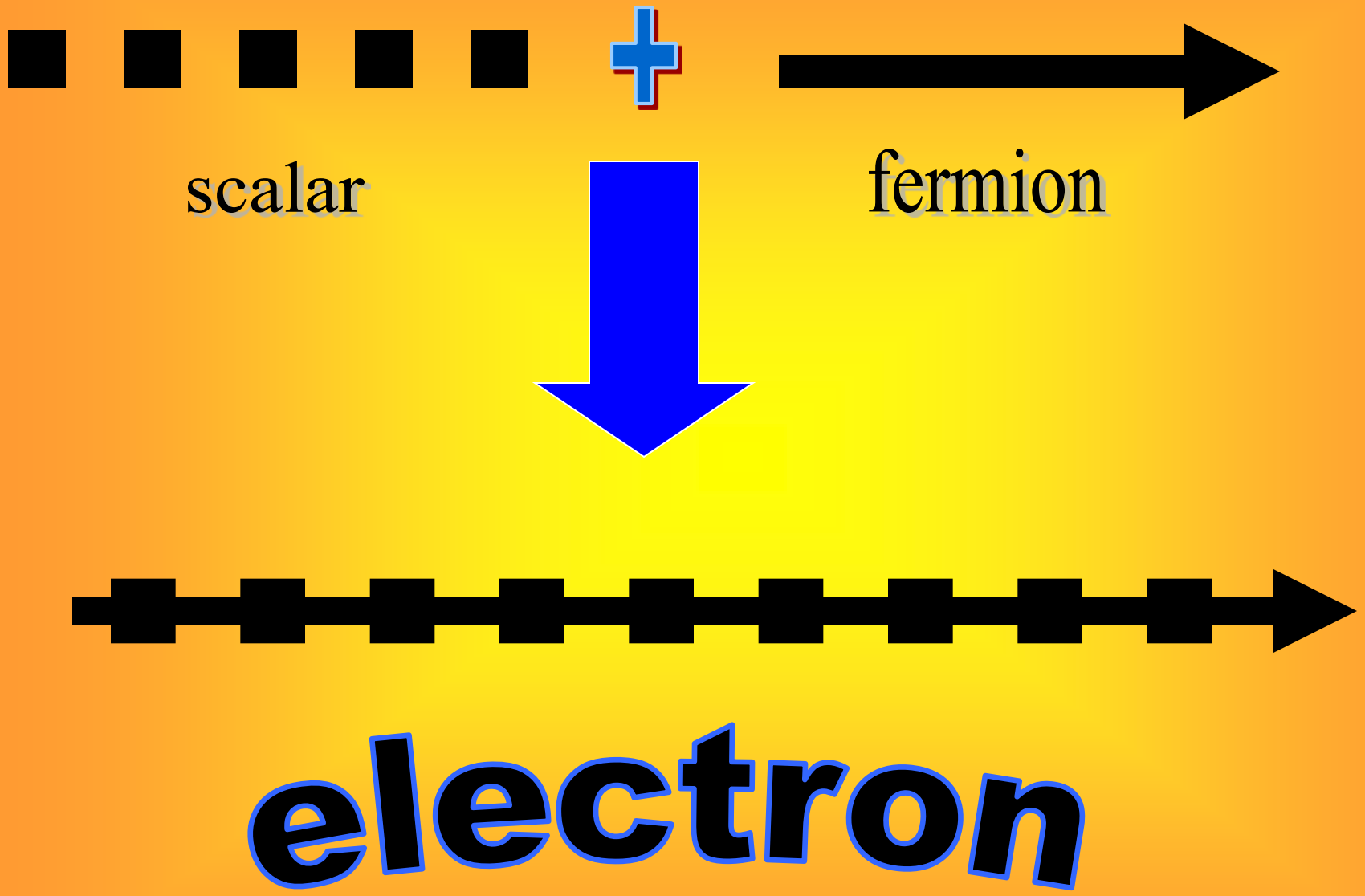
$$(\alpha l): \nu_e - \nu_\mu - \nu_\tau$$

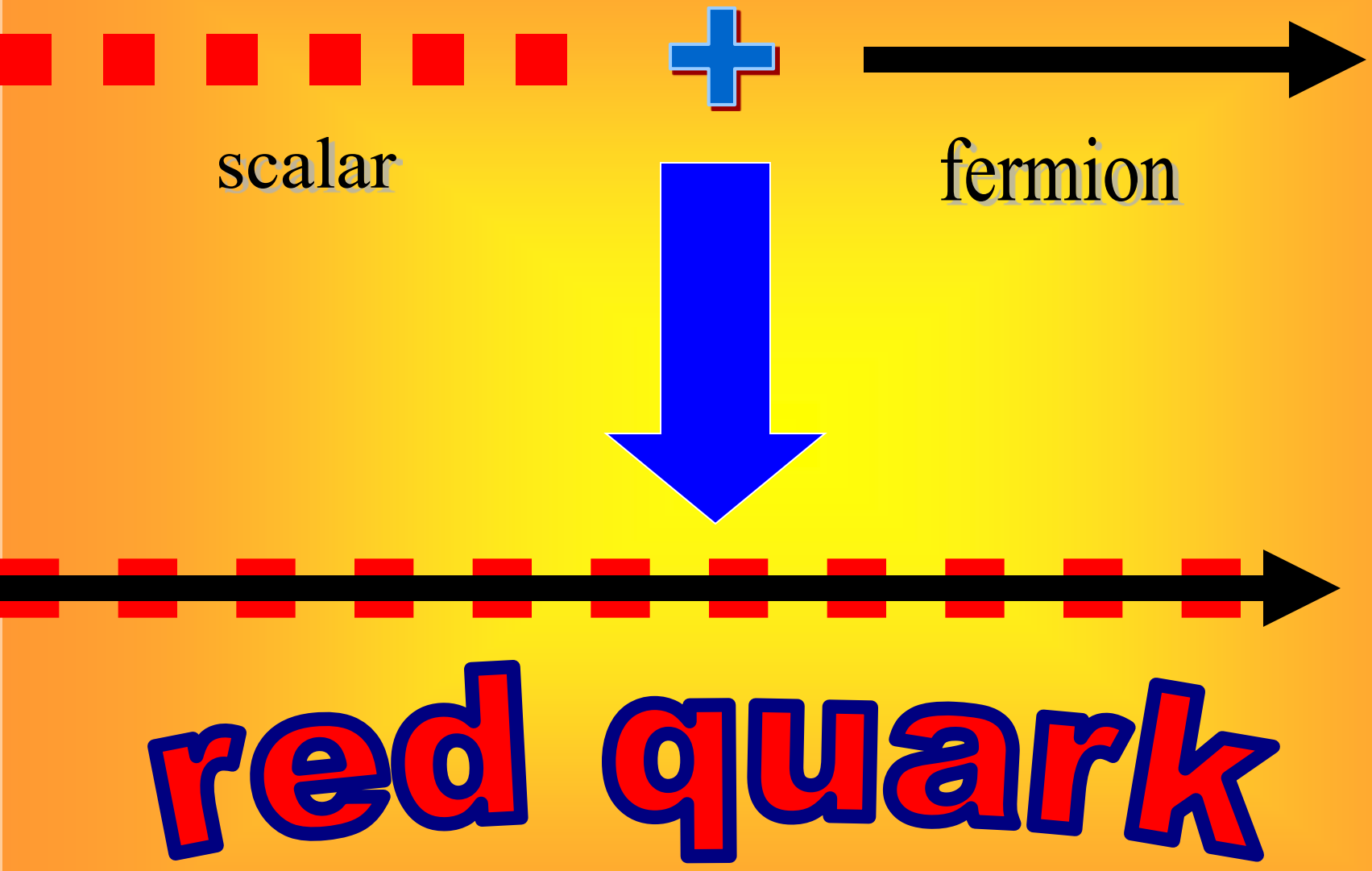
$$(\beta l): e - \mu - \tau$$

$$(\alpha r): u_r, c_r, t_r$$

$$(\beta r): d_r, s_r, b_r$$

red quarks


scalar
fermion
electron


scalar
fermion
red quark

cross section for QHD interaction?

comparison with proton - proton inelastic scattering:

size:

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

$$\Updownarrow$$

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

comparison with proton - proton inelastic scattering:

size:

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

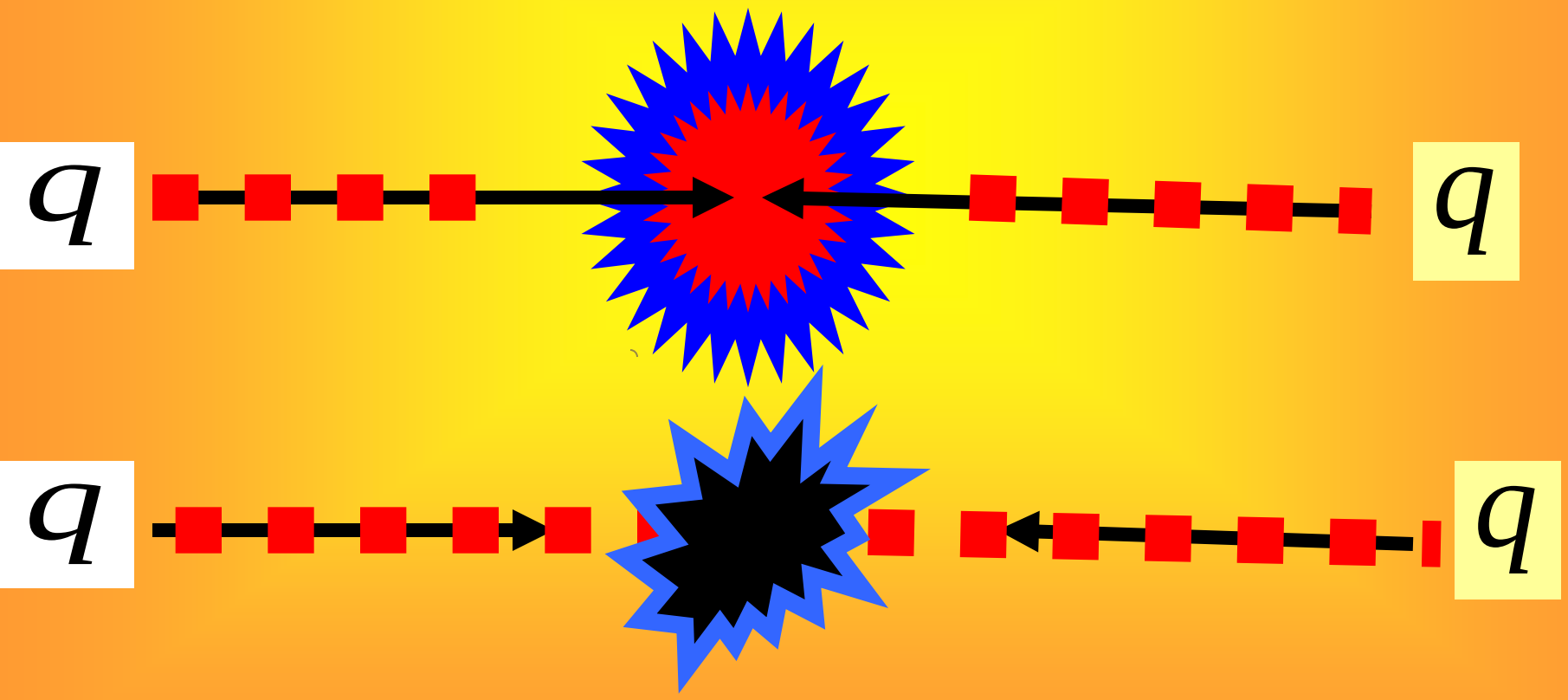
$$\Updownarrow$$

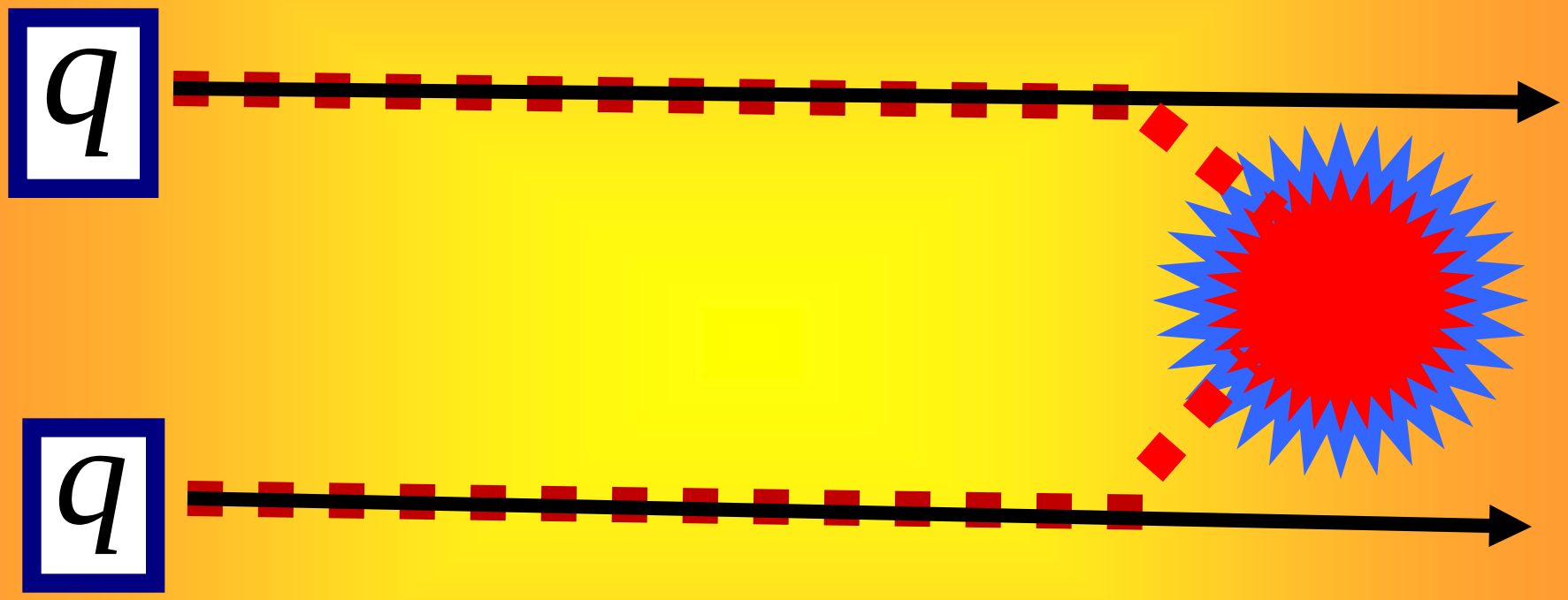
$$\sigma(qq) \approx 10^{-6} 60 \quad mb = 60 \quad nb$$

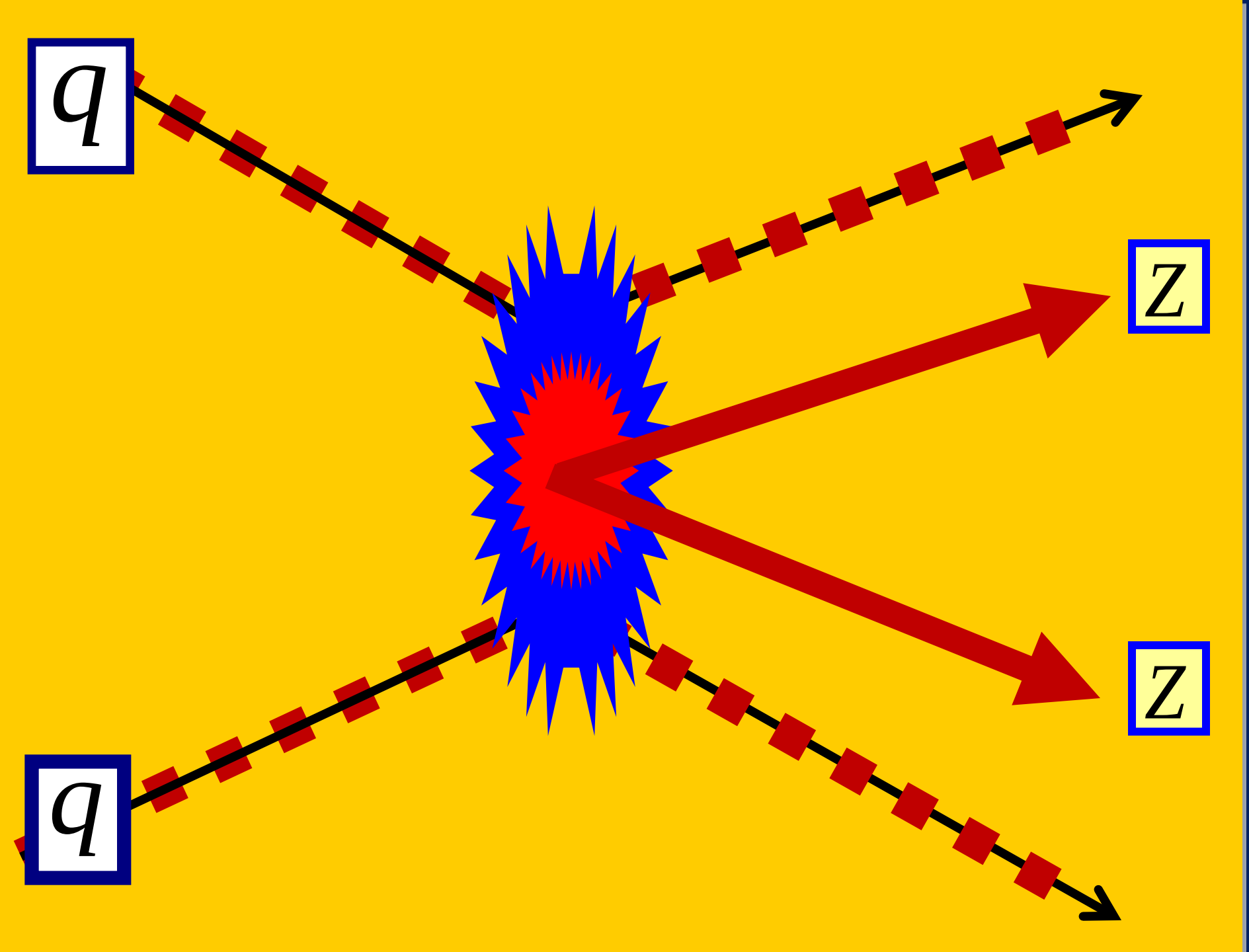
$$\sigma(qq - gq - gg)$$

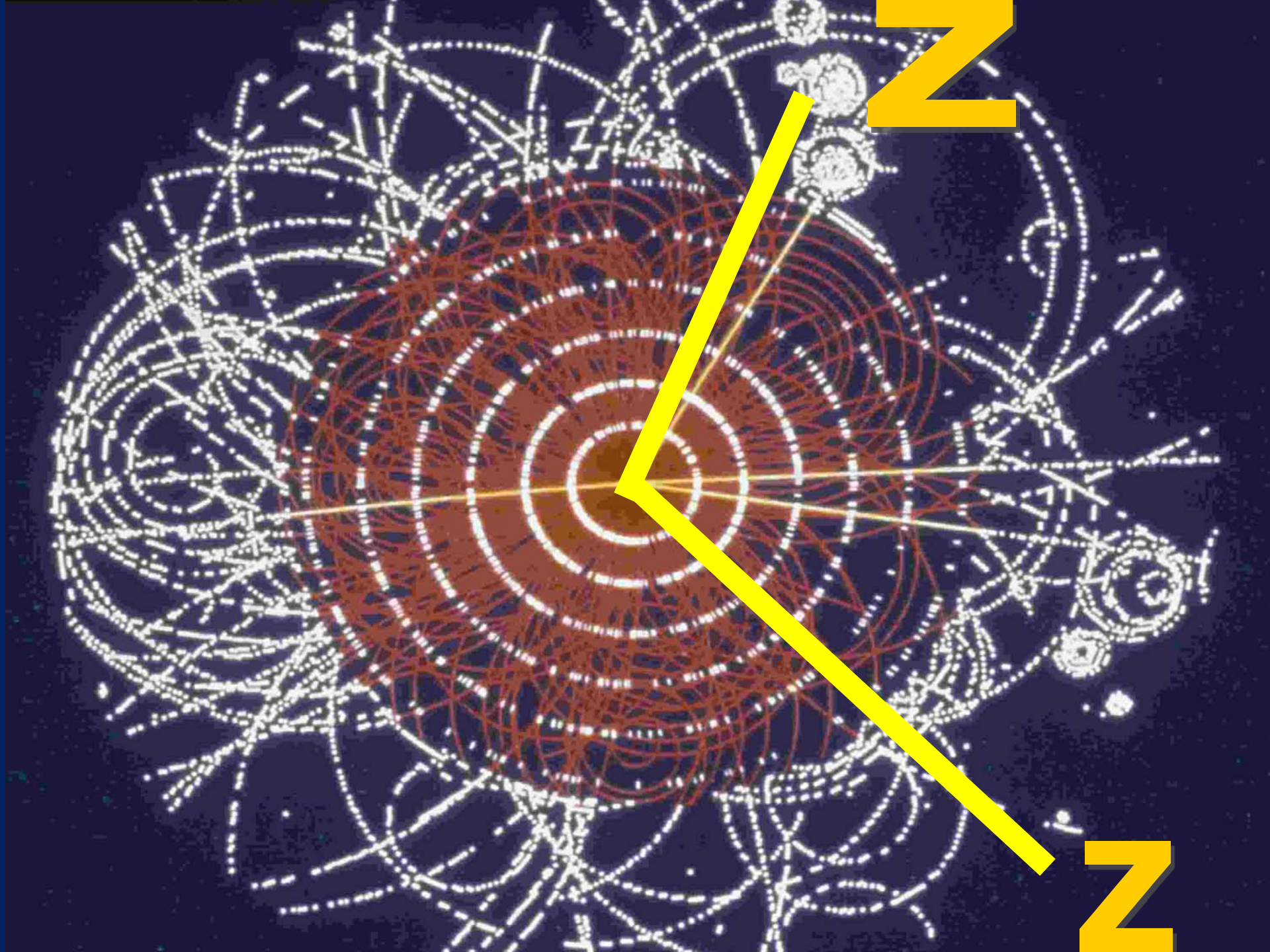
$$\propto 10 \bullet 60 \quad nb \approx 600 \quad nb$$

quark – quark scattering:

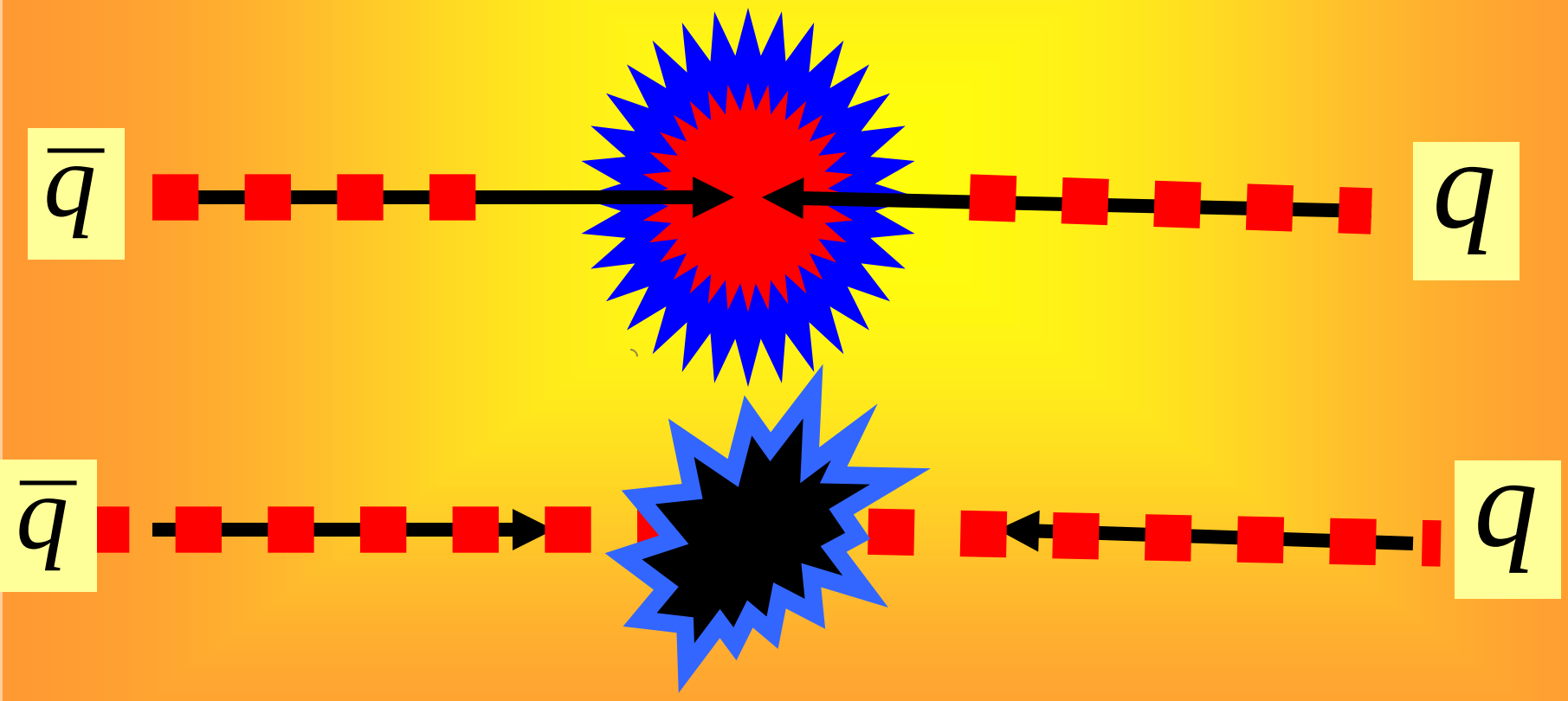


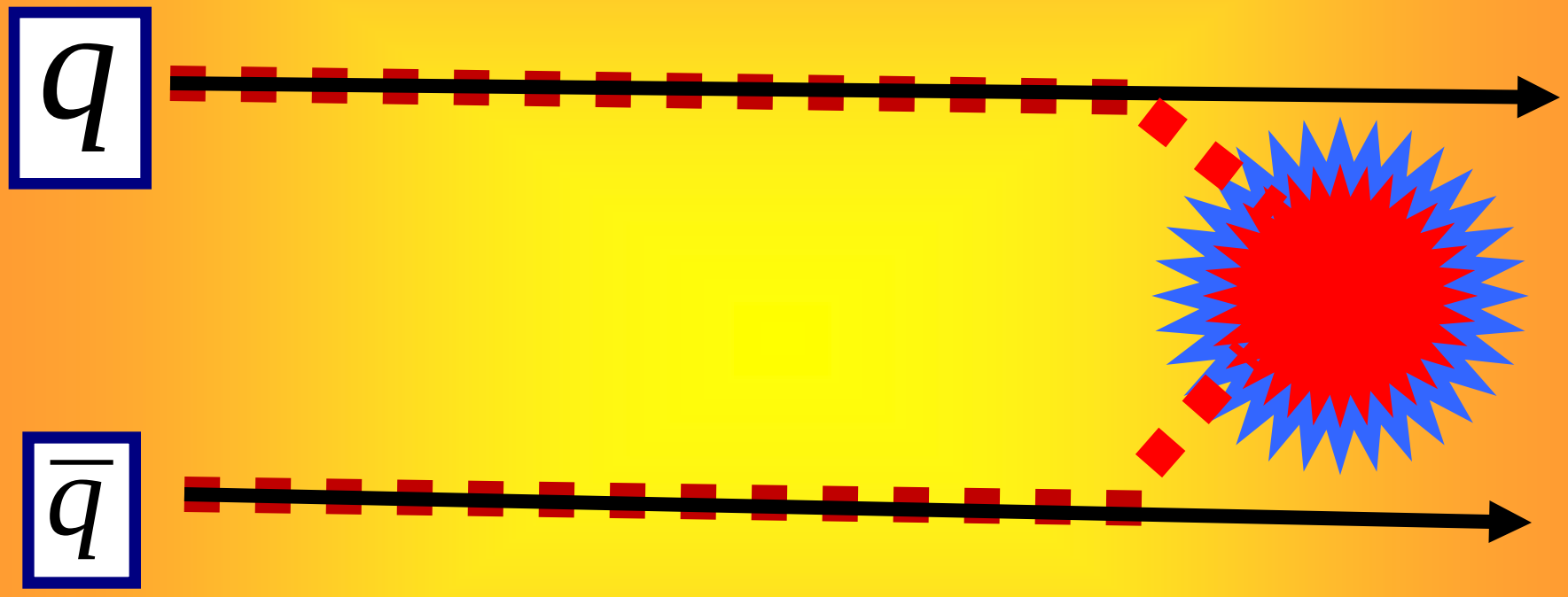

q
q

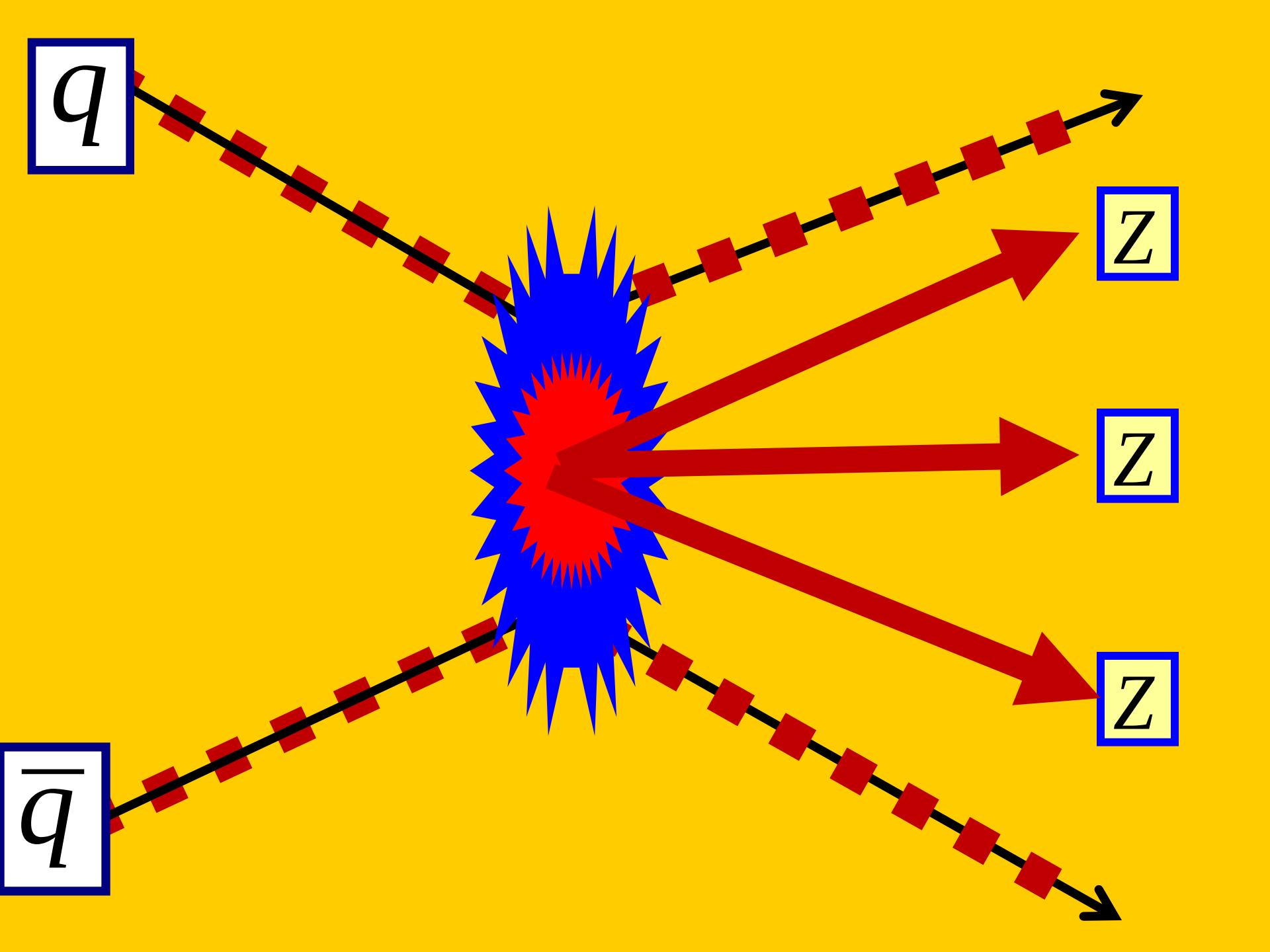

q
Z
Z
q

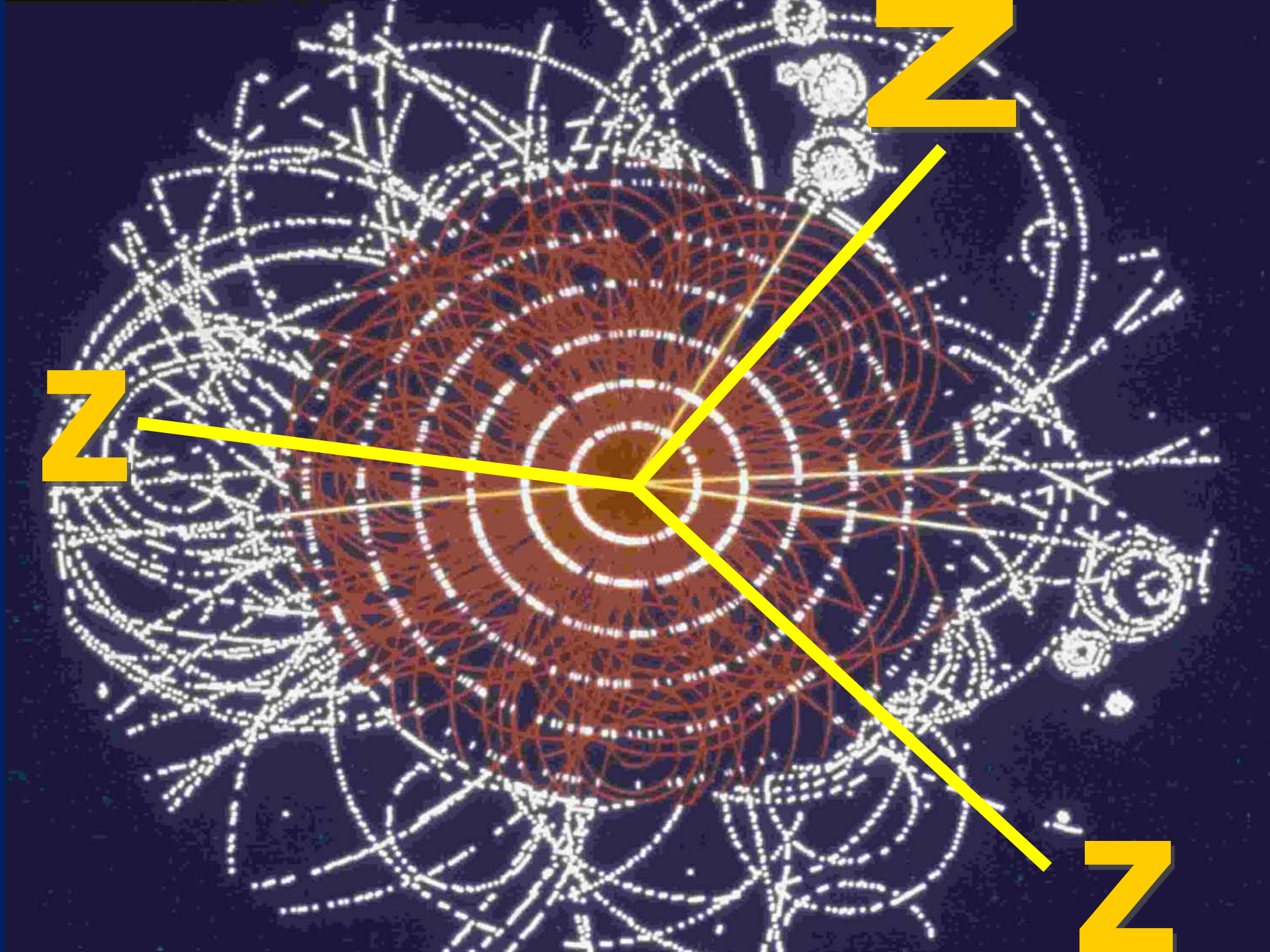

Z
Z

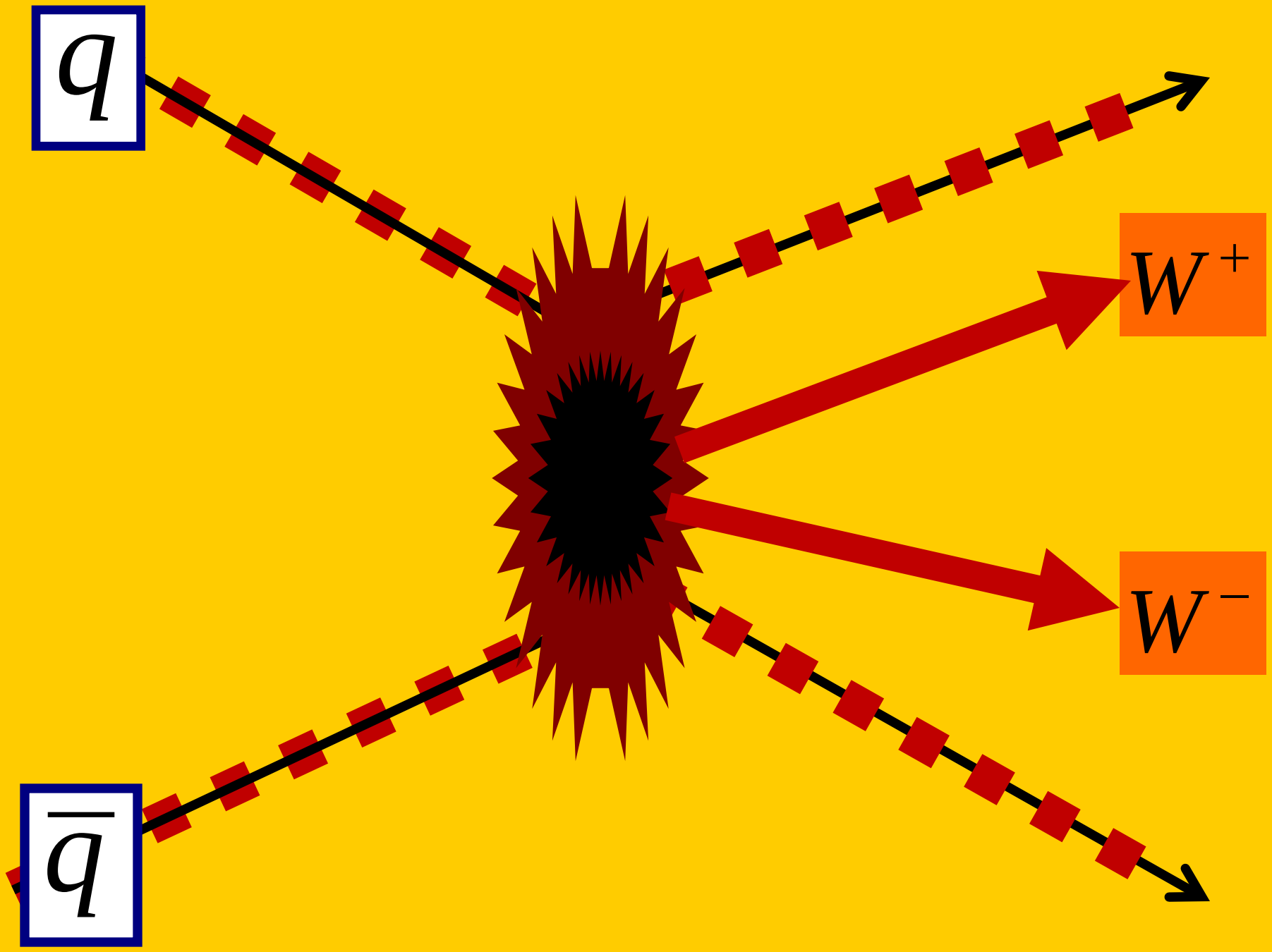
quark – antiquark scattering:

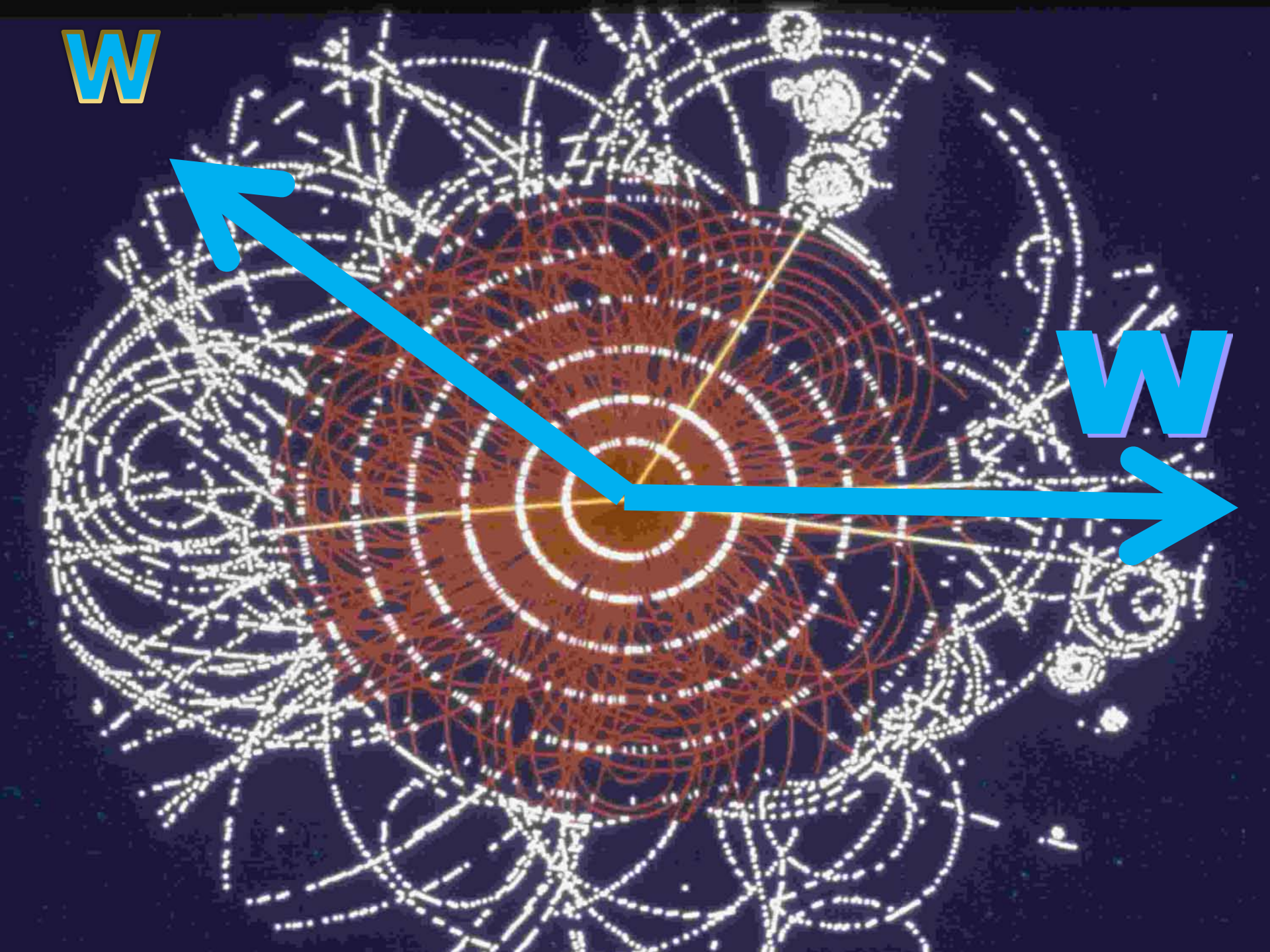


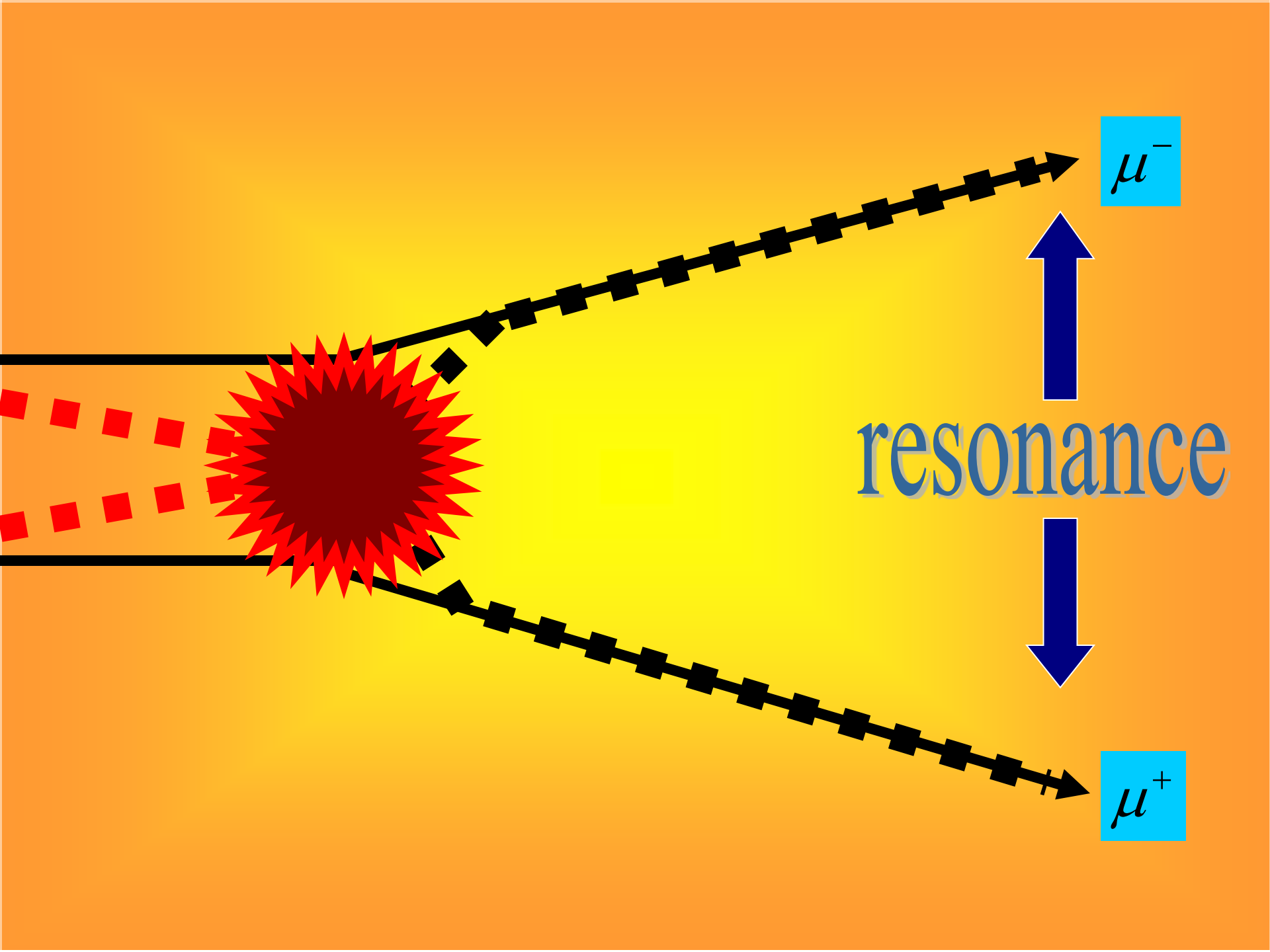

q
$\overline{q}$

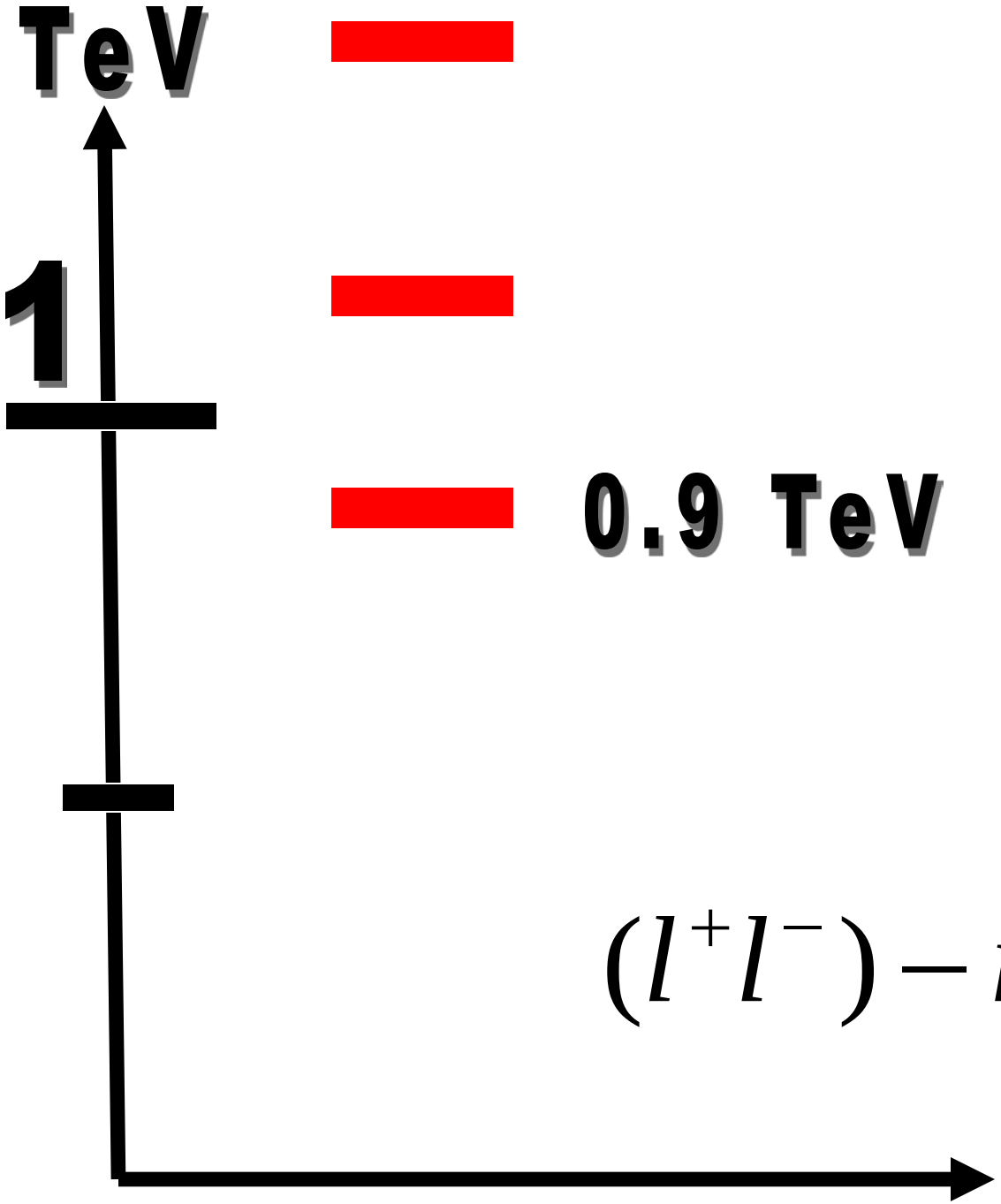

q
Z
Z
Z
$\overline{q}$


Z
Z
Z

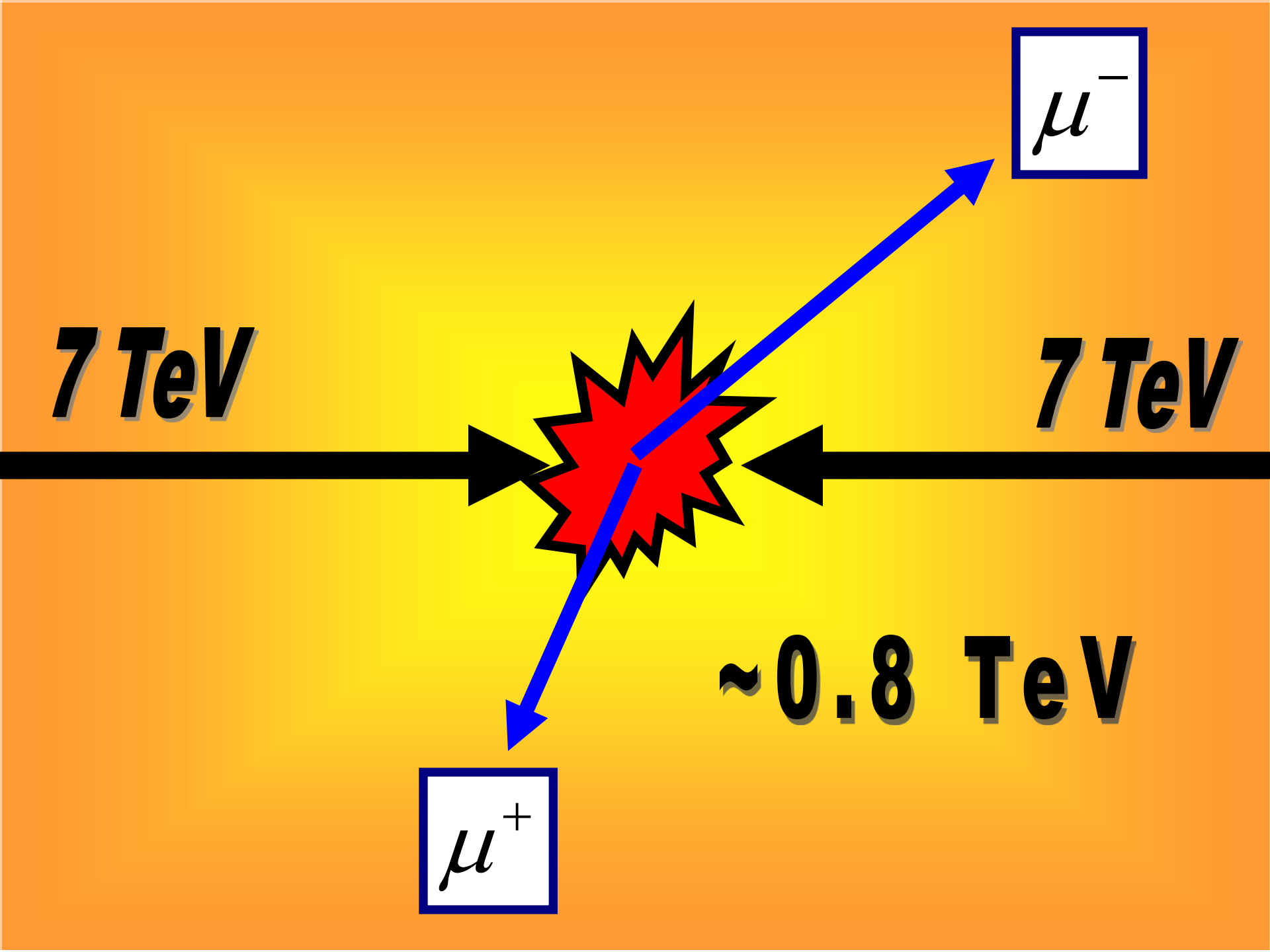

q
$\bar{q}$
W^+
W^-

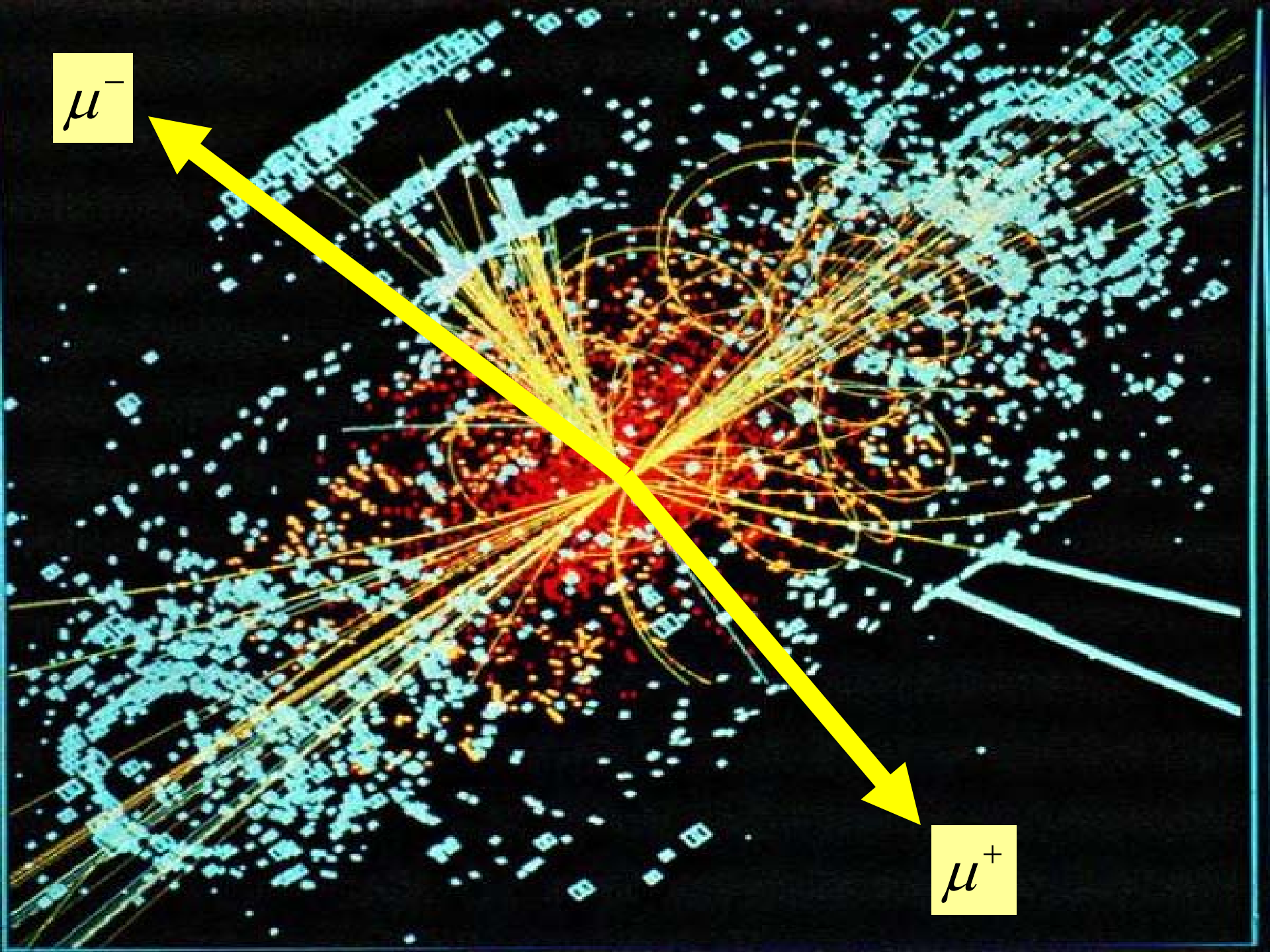

W
W


μ^-
resonance
μ^+



$(l^+l^-) - resonances$


μ^-
7 TeV
7 TeV
~0.8 TeV
μ^+


μ^-
μ^+

non-zero
angular momentum

p-wave, d-wave, ...

p-wave

e

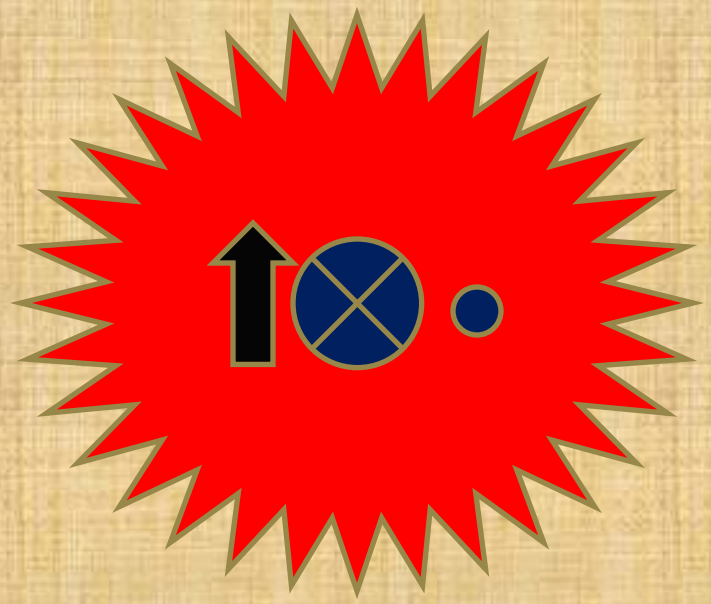
$e^*(3/2)$

p-wave

u

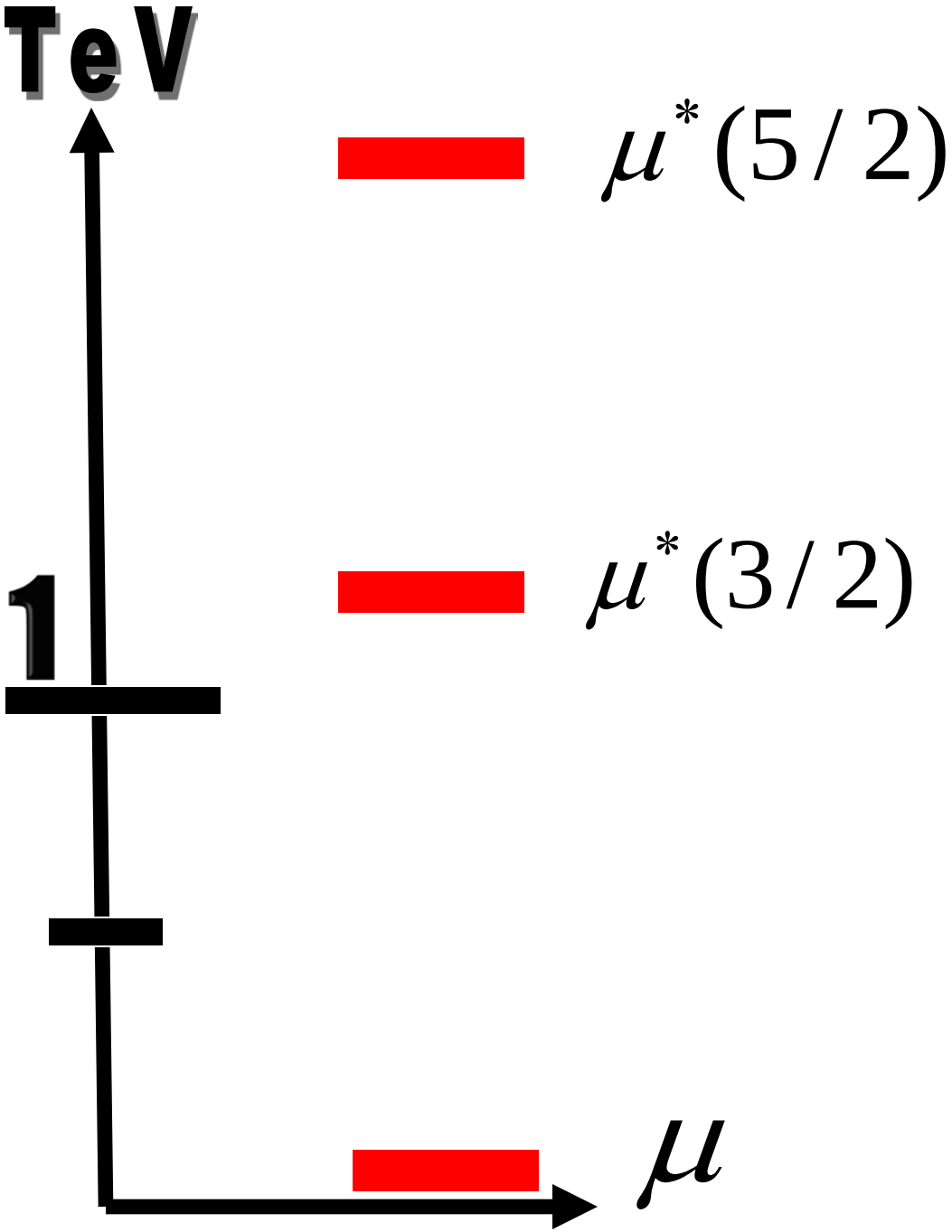
$u^*(3/2)$

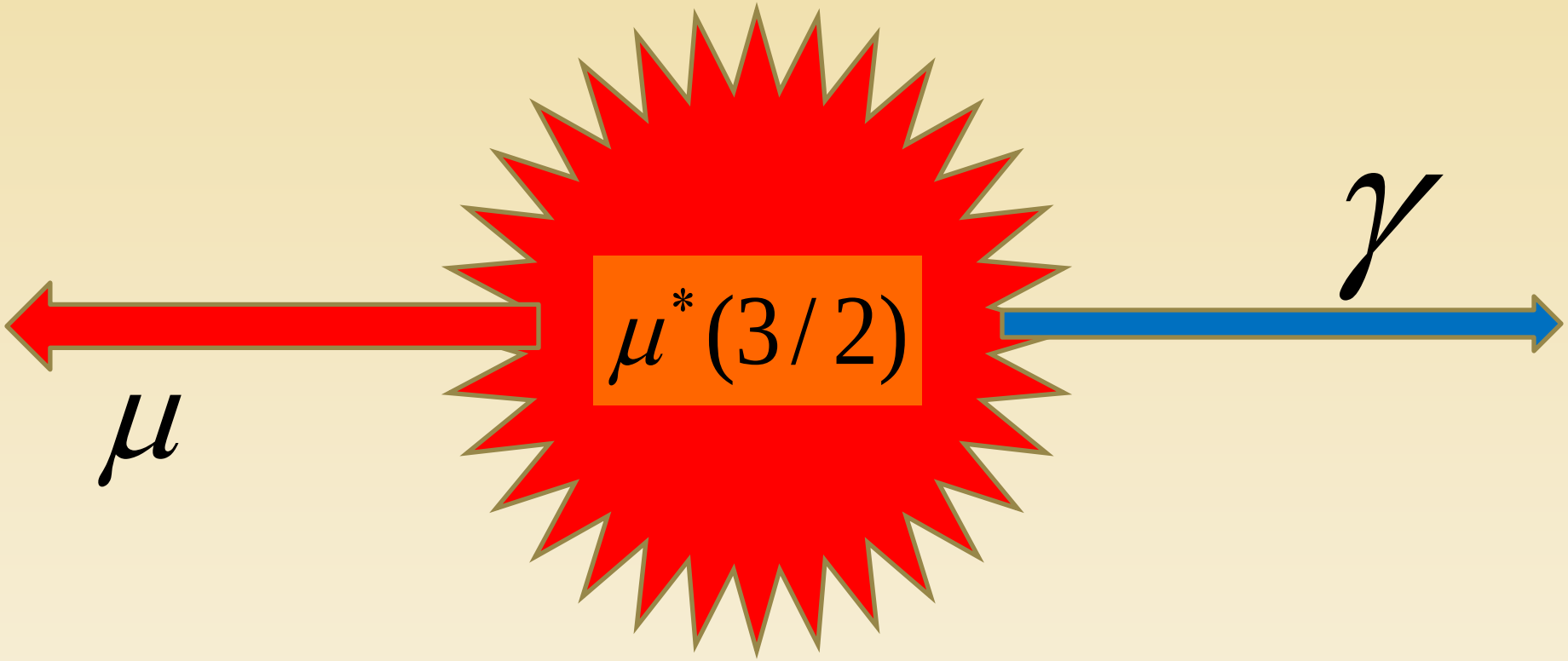
p-wave

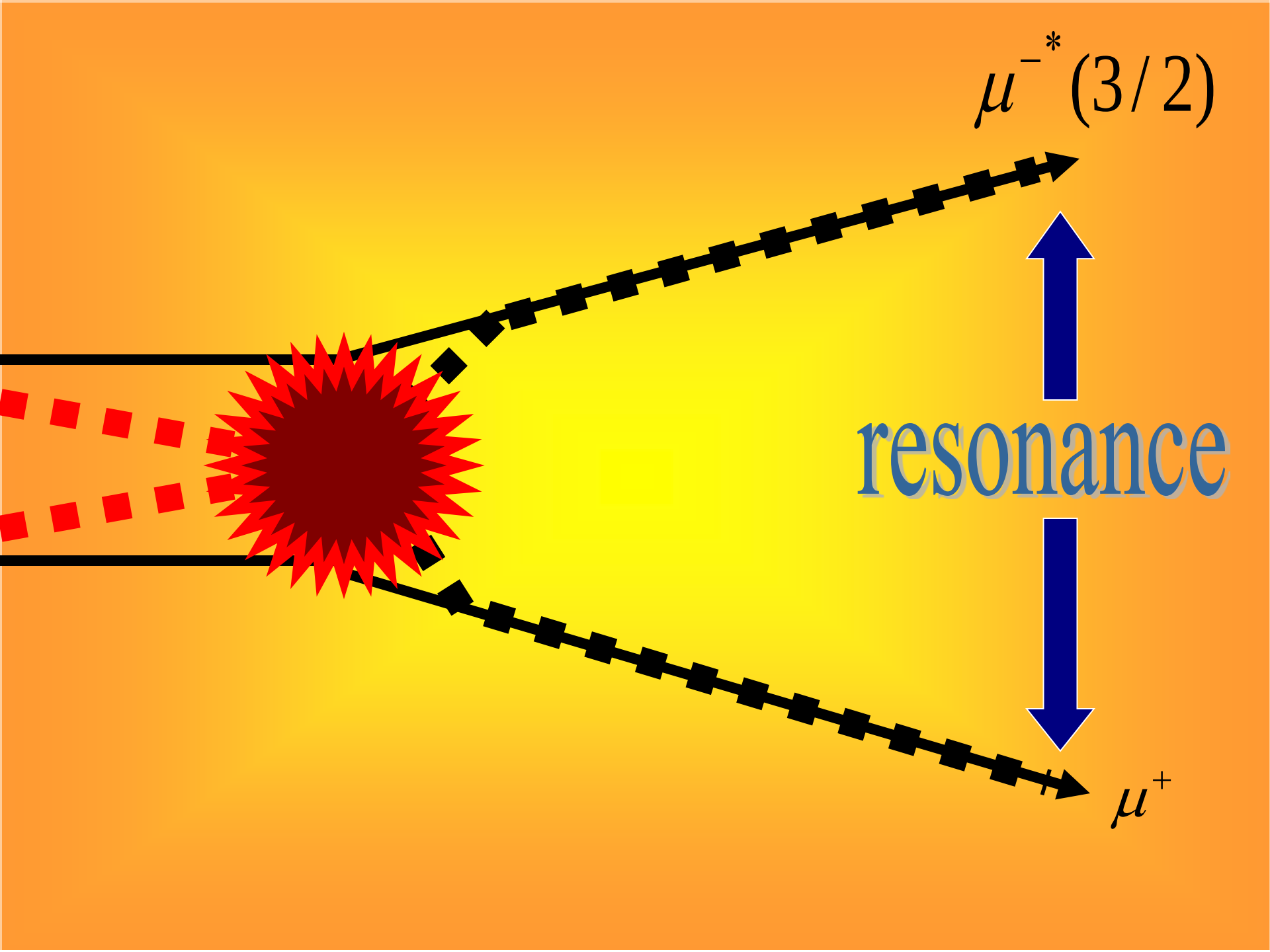


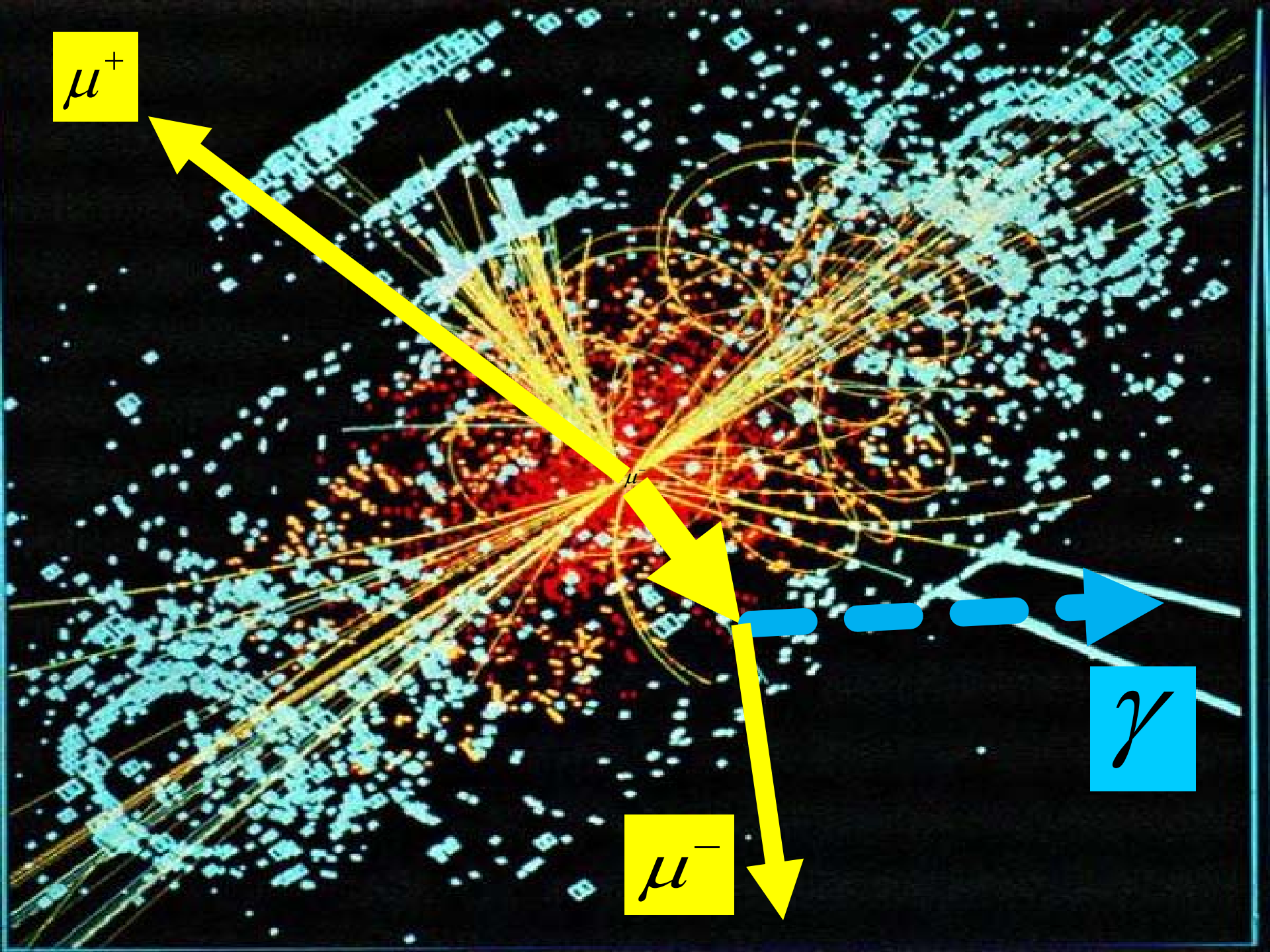
μ

$\mu^*(3/2)$


TeV
1
$\mu^*(5/2)$
$\mu^*(3/2)$
μ


$\mu^*(3/2)$
γ
μ


$\mu^{-*}(3/2)$
resonance
μ^{+}


μ^+
μ^-
γ

conclusions

weak bosons,
leptons and quarks
are composite systems

weak boson =>
fermion + antifermion

lepton, quark =>
fermion + scalar

X - boson: isosclar partner of Z-boson

QHD resonances :

$\sim$ 1 TeV

leptons and quarks

↓

excited fermions

(spin1/2, 3/2, ...)

QHD resonances