Weak Bosons
Quarks - Leptons

Composite Particles

Harald Fritzsch

LMU Munich

QCD

1972

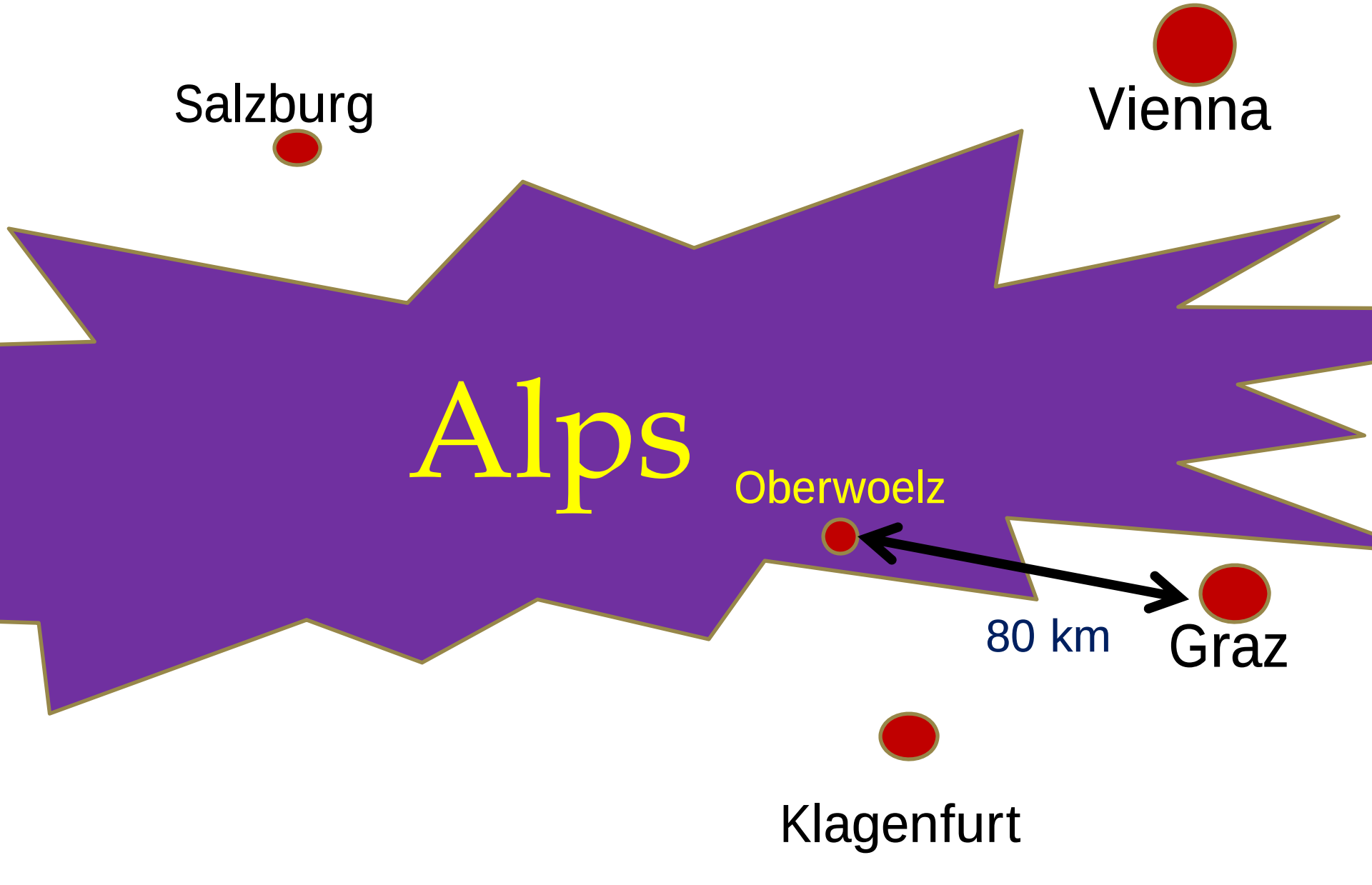
Fritzsch # Gell-Mann

2012:

QCD 40 years

conference in Oberwoelz, Austrian Alps

fritzsch@mppmu.mpg.de


Salzburg
Vienna
Alps
Oberwoelz
80 km
Graz
Klagenfurt

Weak Bosons
Quarks - Leptons

Composite Particles

Harald Fritzsch

LMU Munich

Standard Model:

quarks - leptons - weak bosons

==> pointlike

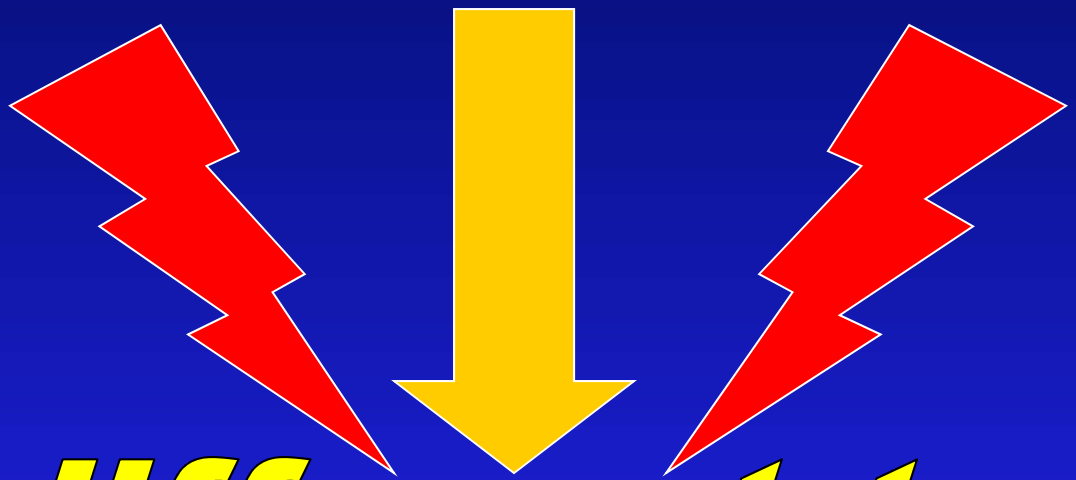
limits from experiment:

radius of electron:

radius of u/d-quark:

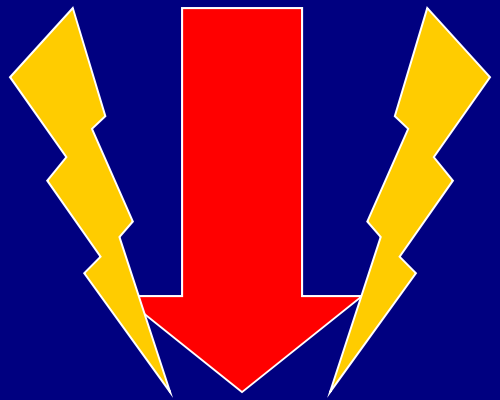
$$\leq 10^{-17}\, cm$$

Standard Model



two different types of mass generation

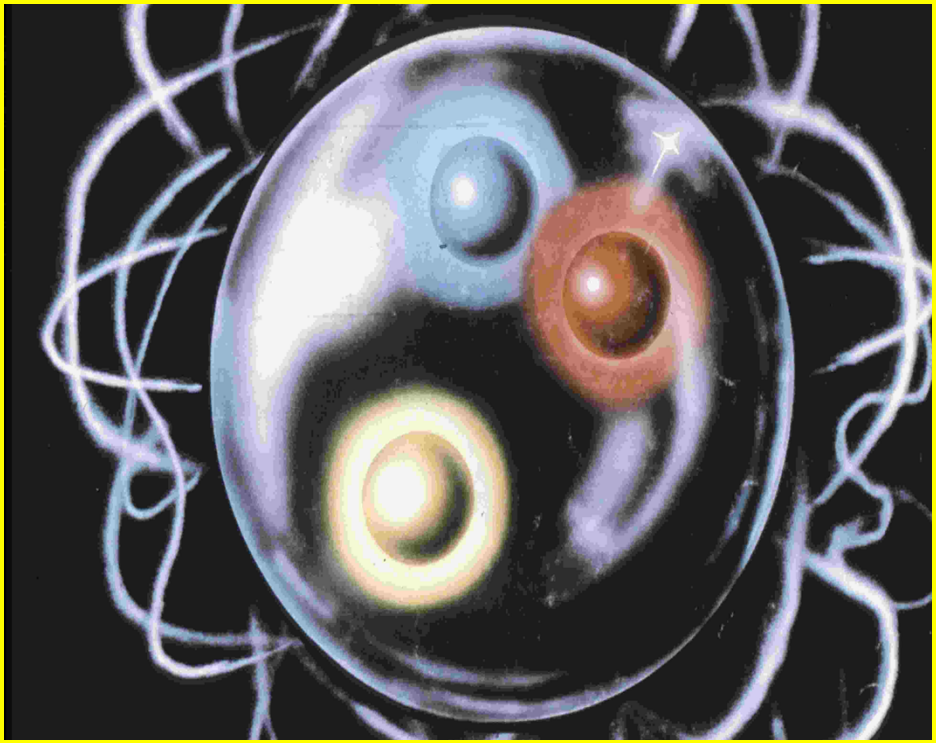
mass by confinement



QCD

proton mass

field energy of gluons and quarks



$$M_p = E(gluons, quarks) / c^2$$

electroweak theory

??? origin of masses of ???

leptons

quarks

W-bosons

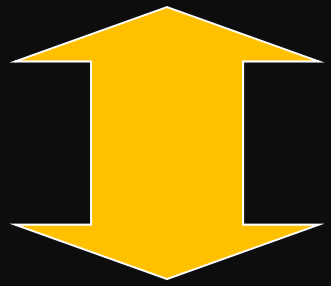
??????????????????????

mass generation

„Higgs“ mechanism

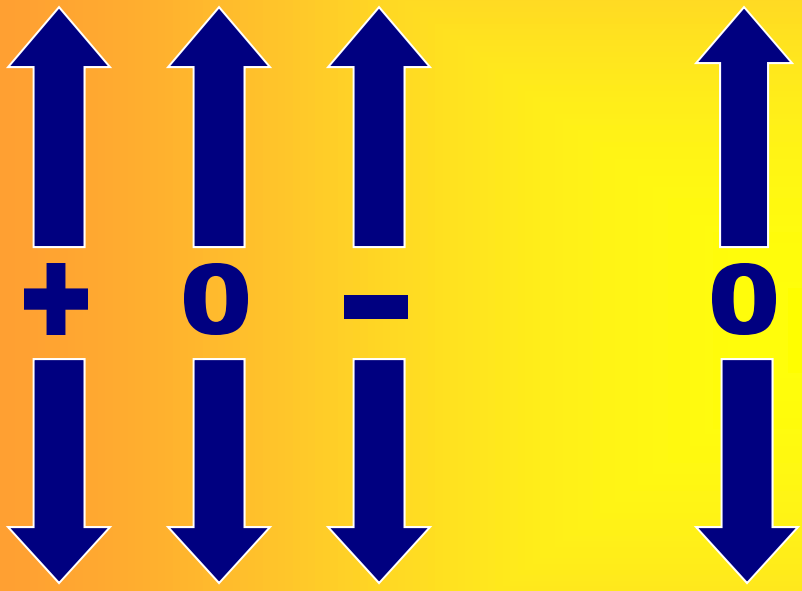
Brout, Englert;
Higgs;
Guralnik, Hagen, Kibble

spontaneous symmetry breaking

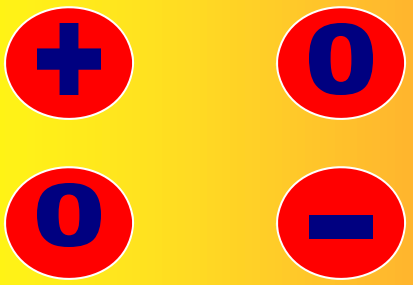


scalar fields

SU(2) x U(1)



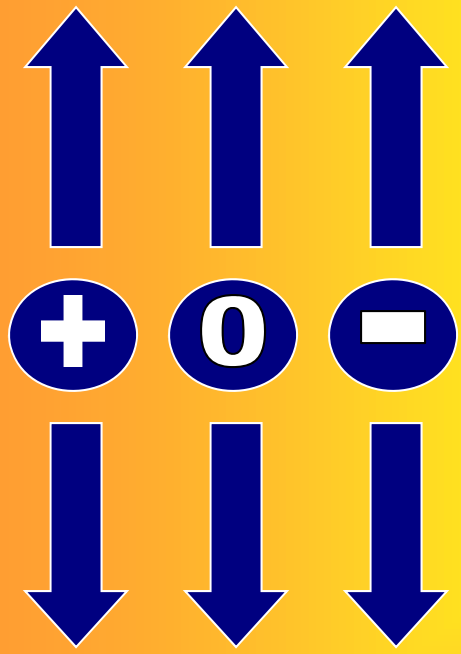
scalars

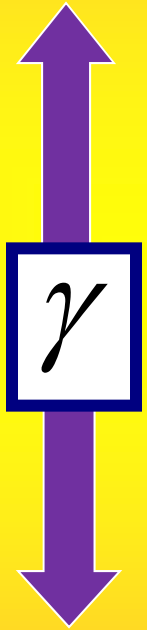


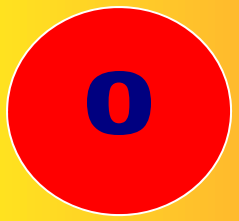
massless gauge bosons

mass M

SU(2) x U(1)







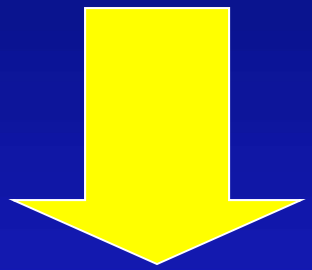
"Higgs" particle

massive

massless

alternative:

mass generation

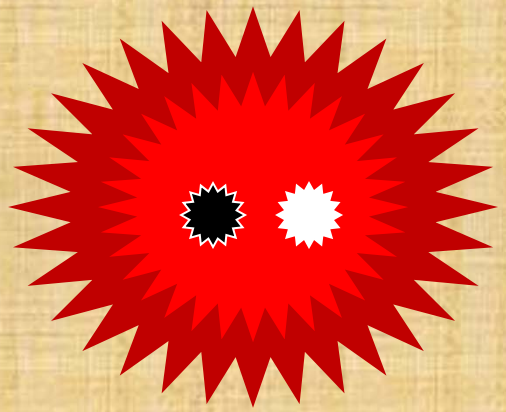


confinement

→ QCD

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

rho – mesons

quark– antiquark bound states

weak bosons

bound states of ???

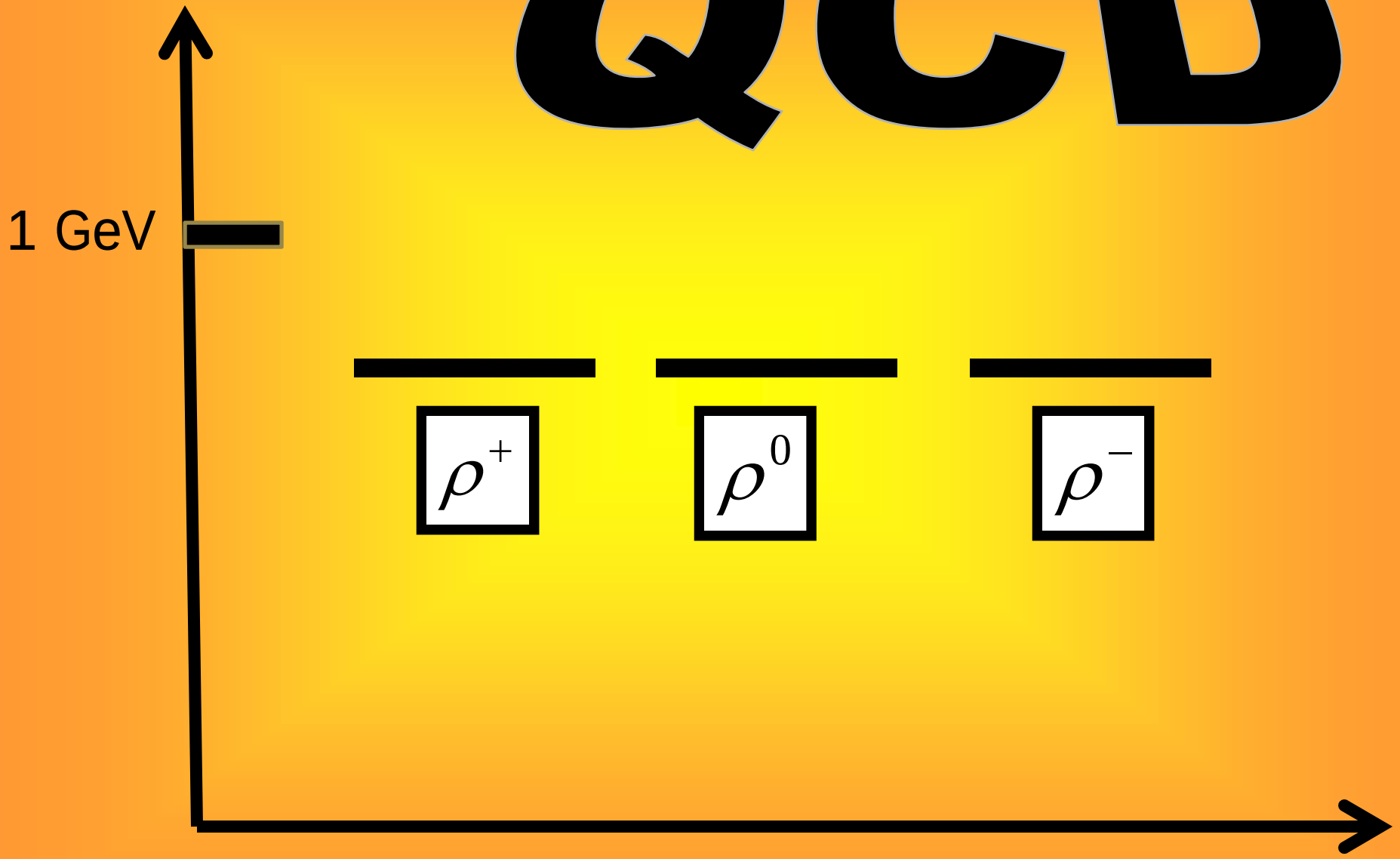
analogy

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

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

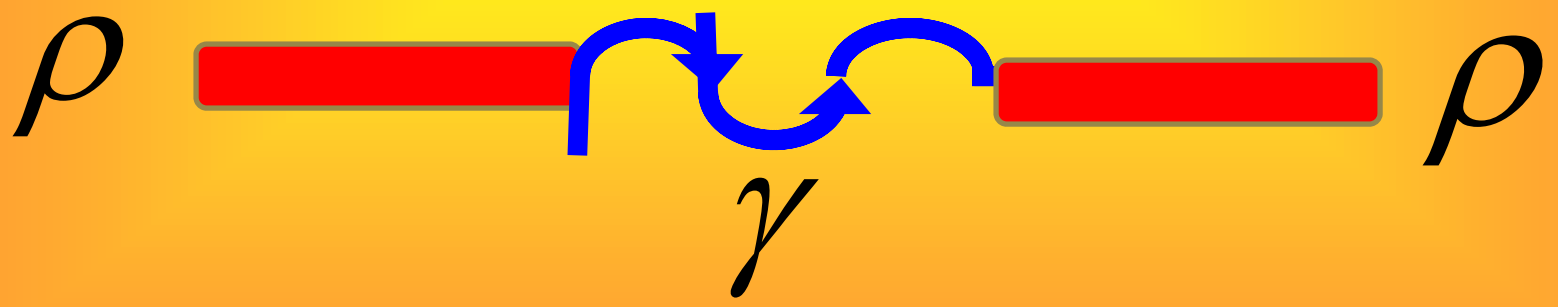
$$\rho^{-} \Leftrightarrow W^{-}$$

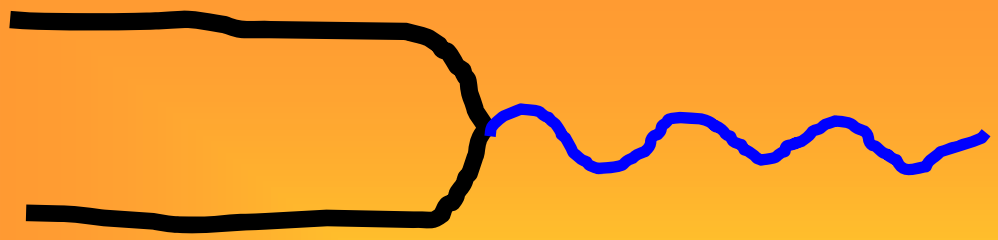
QCD



QCD + QED

Dynamical mixing of rho meson and photon:





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

F_ρ : decay constant

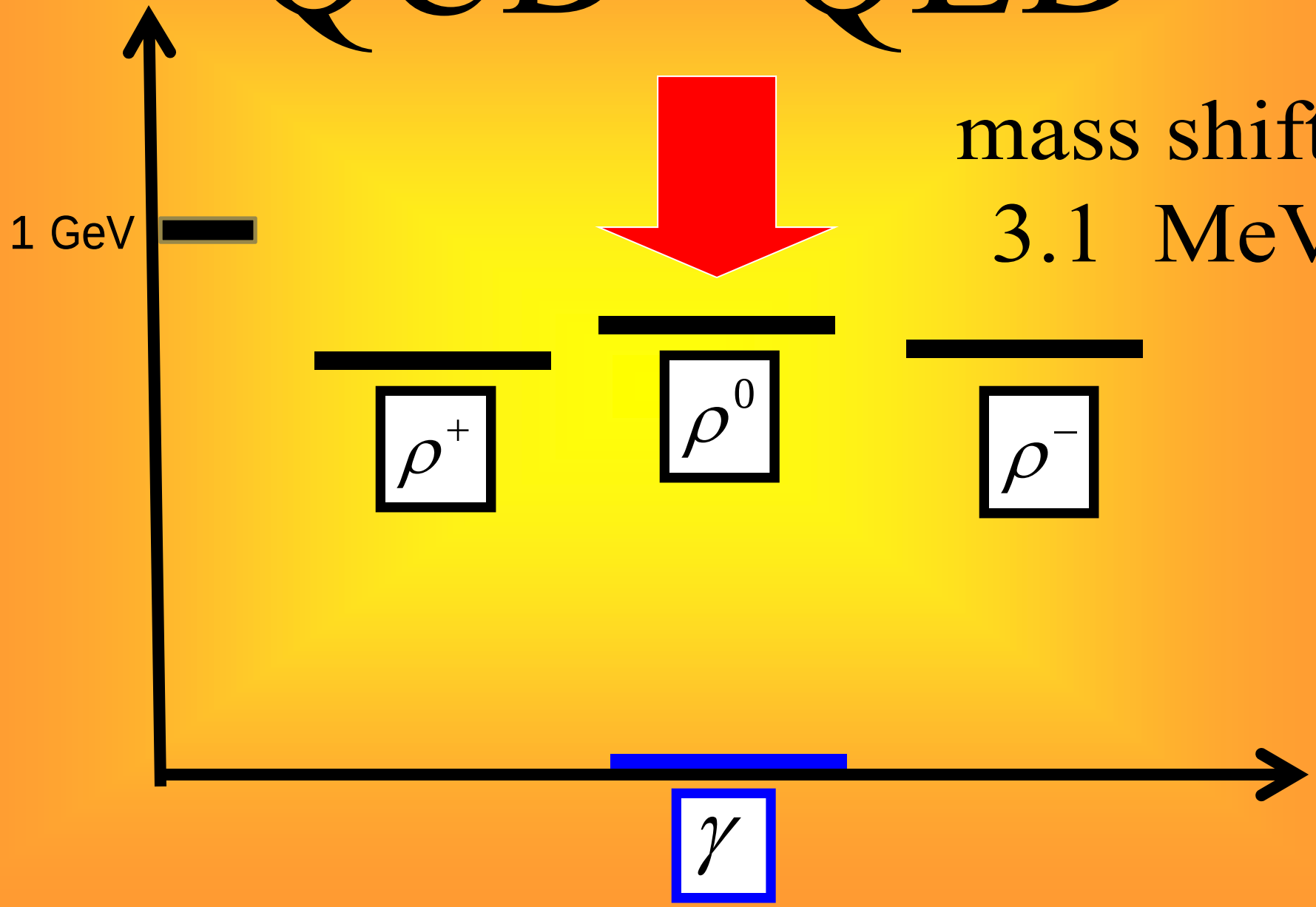
mixing parameter m

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

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

$$F_\rho \approx \Lambda_c$$

QCD +QED



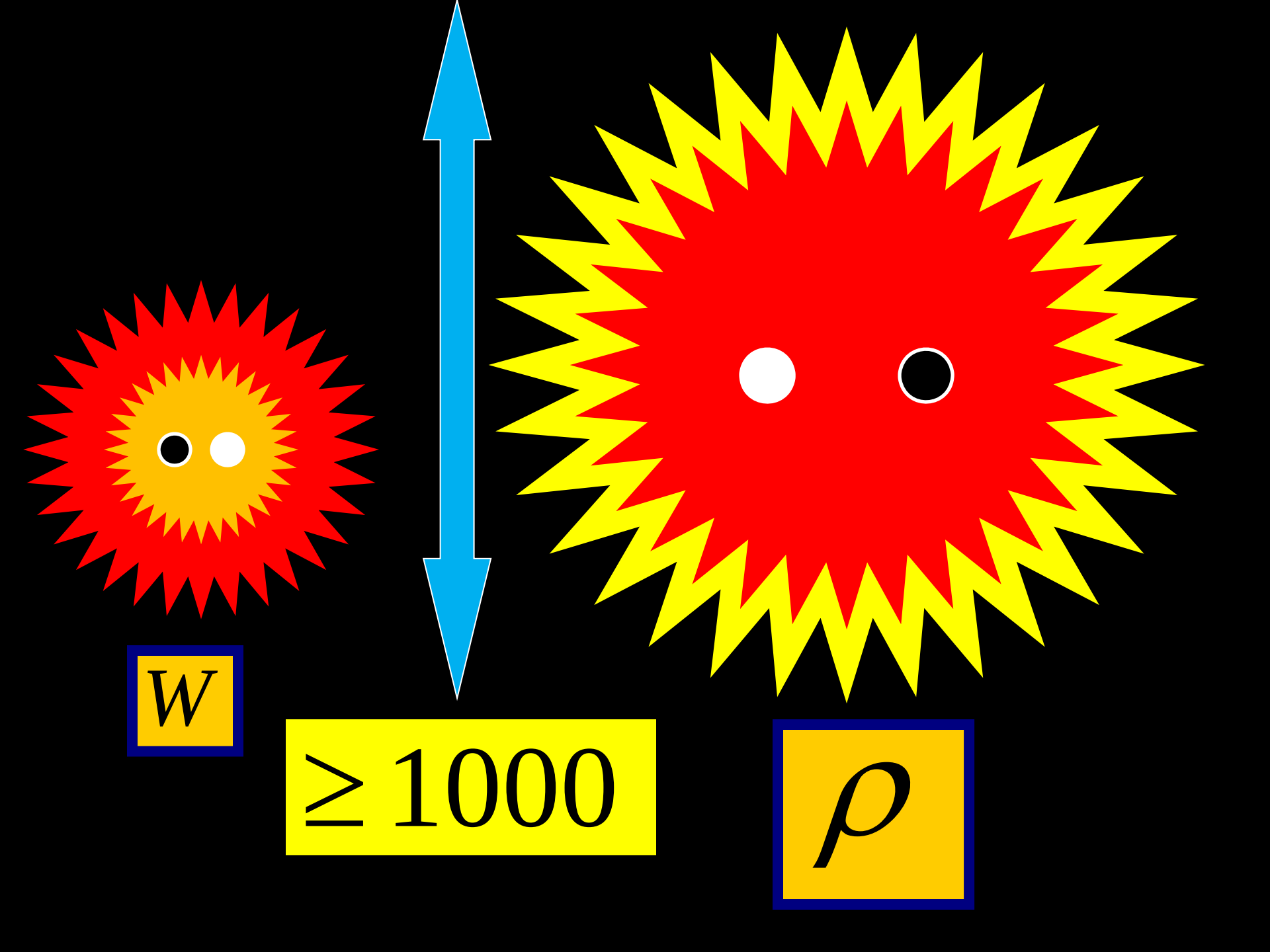
mass shift:
3.1 MeV

composite weak bosons ?

W

====>>>

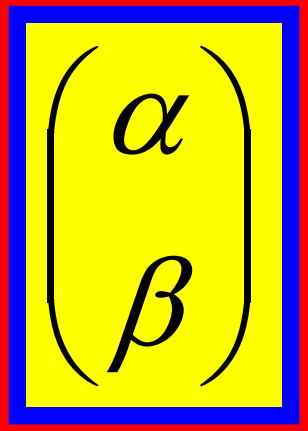
constituents


w
≥ 1000
ρ

Constituents of W-bosons

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

lefthanded fermions



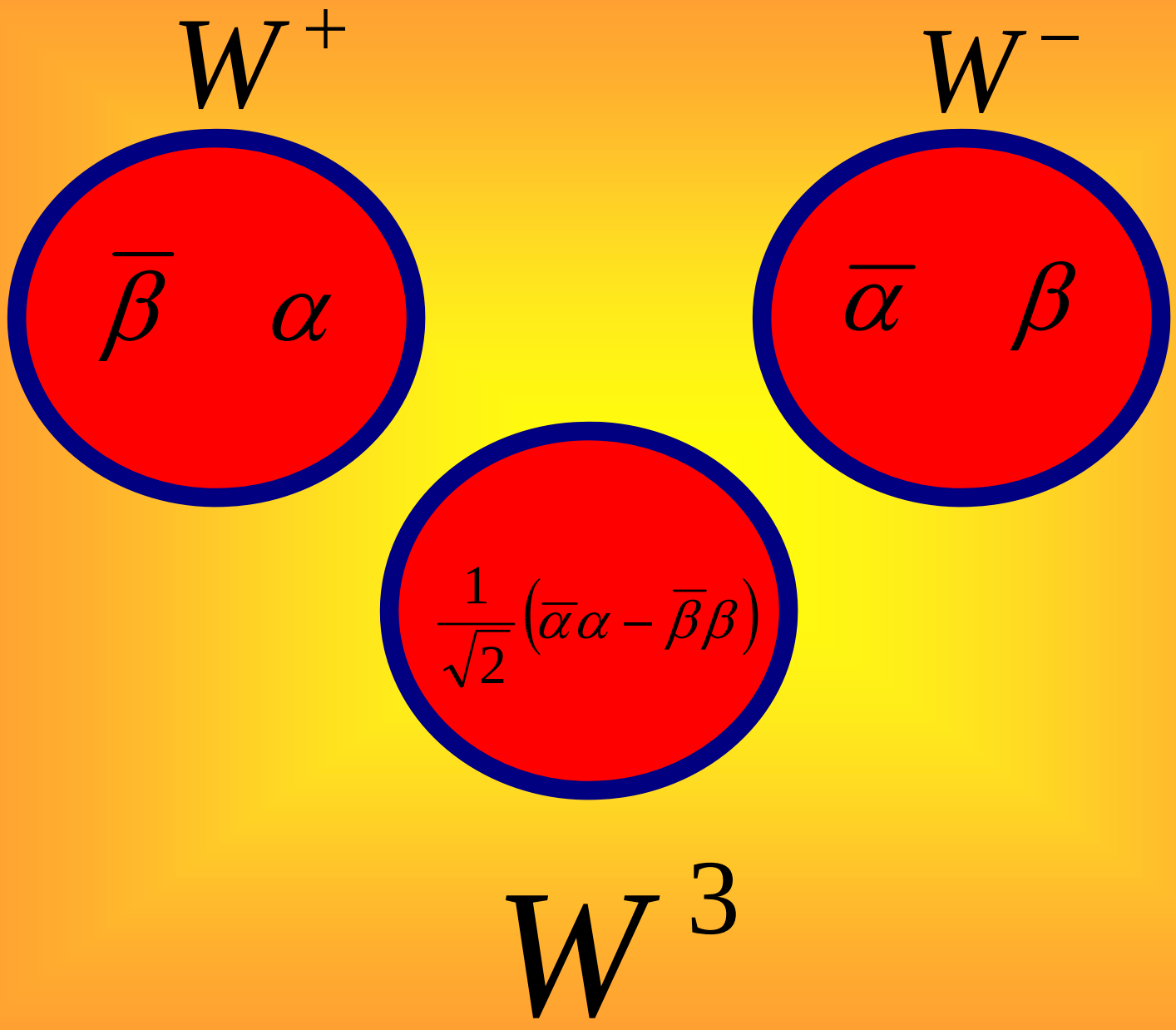
haplons

haplos ⇔ simple

electric charges

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

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


W^+
W^-
$\overline{\beta}\quad\alpha$
$\overline{\alpha}\quad\beta$
$\frac{1}{\sqrt{2}}\left(\overline{\alpha}\alpha-\overline{\beta}\beta\right)$
W^3

haplons confined by gauge force

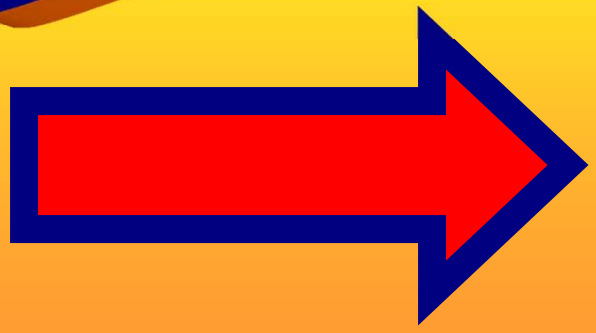
QHD

Gauge group of QHD:

SU(n)

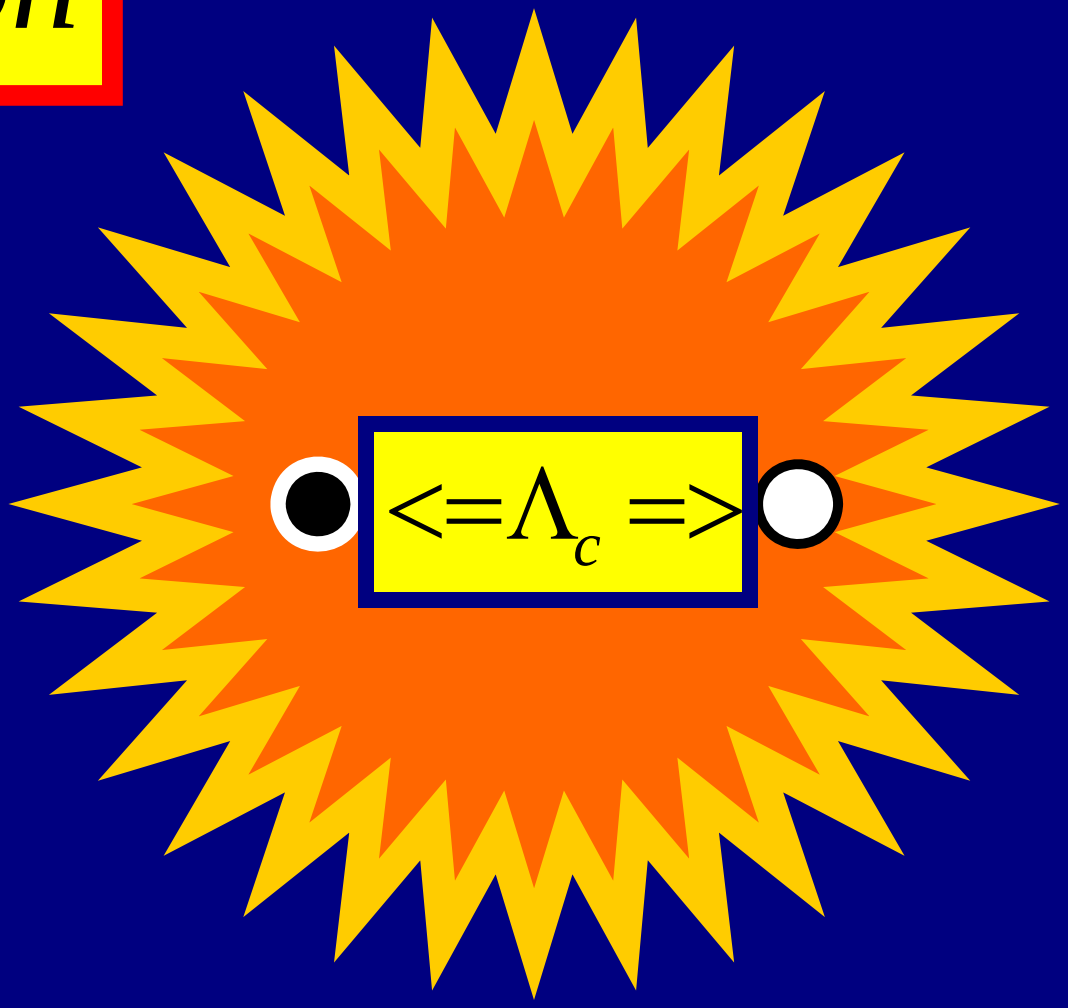
(e.g. SU(3))

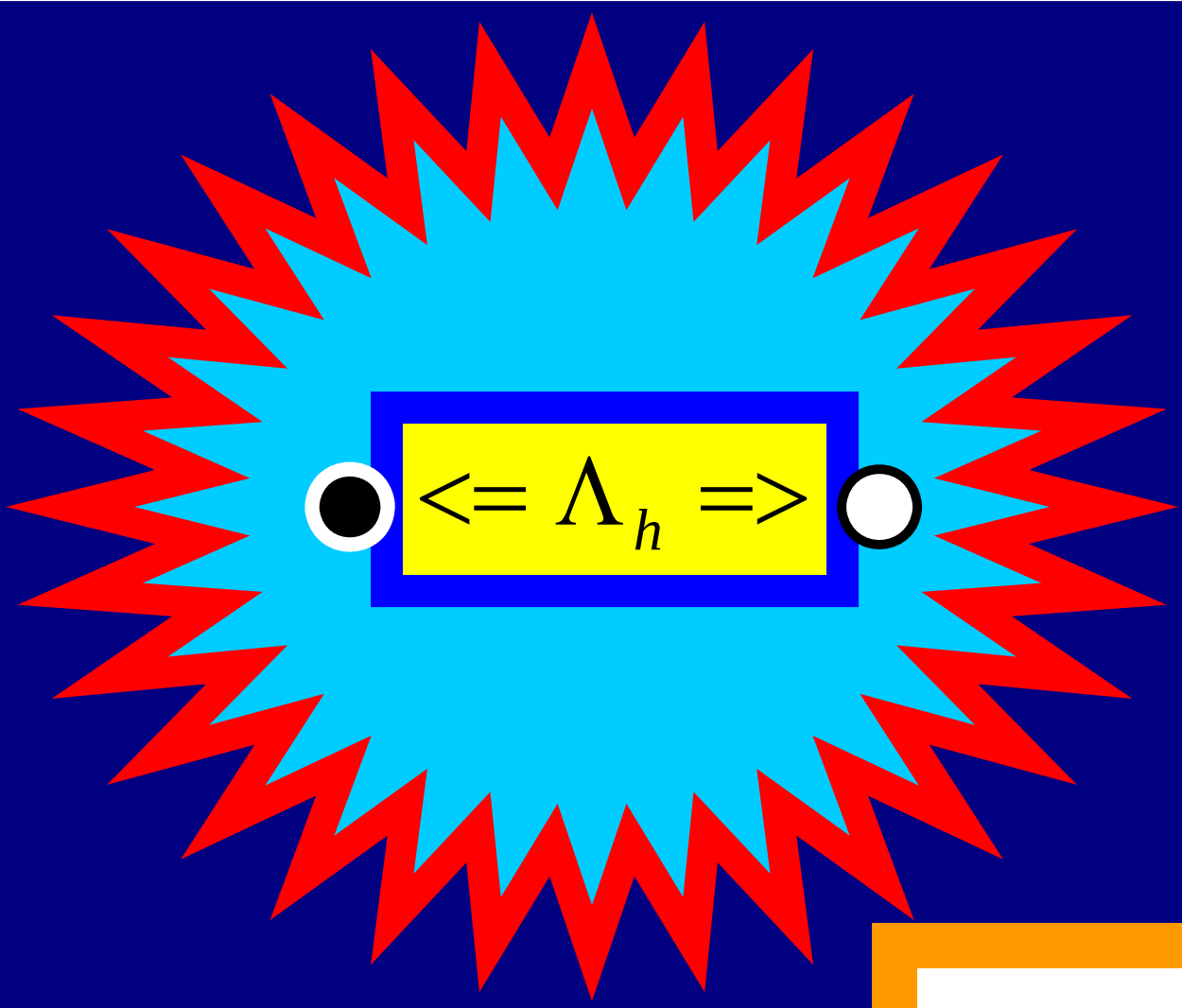
mass scale of QHD



Λ_h

$\rho - meson$



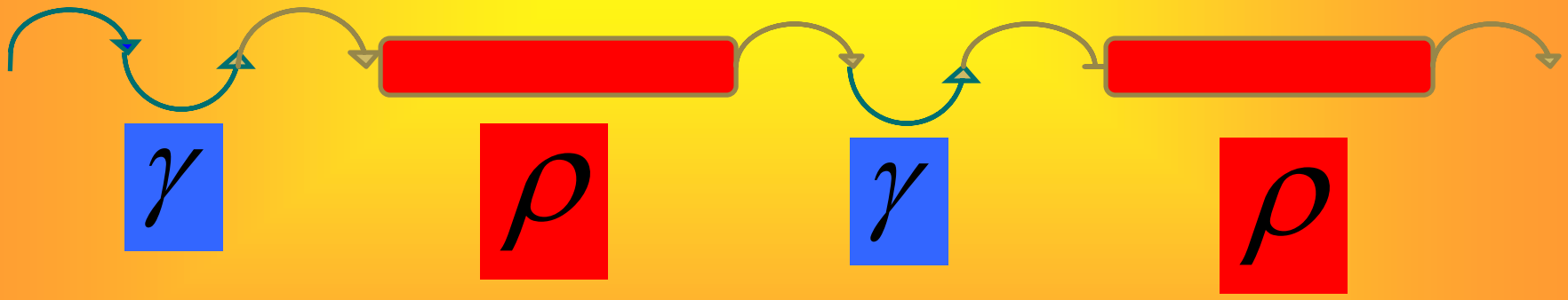


$W-boson$

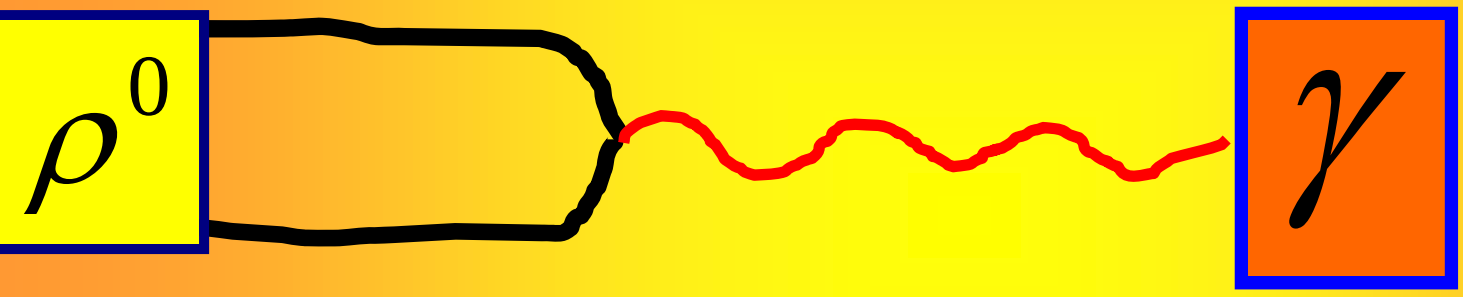
Λ_h ?

→ QCD

Dynamical mixing of meson and photon



mixing with photon



m: mixing parameter

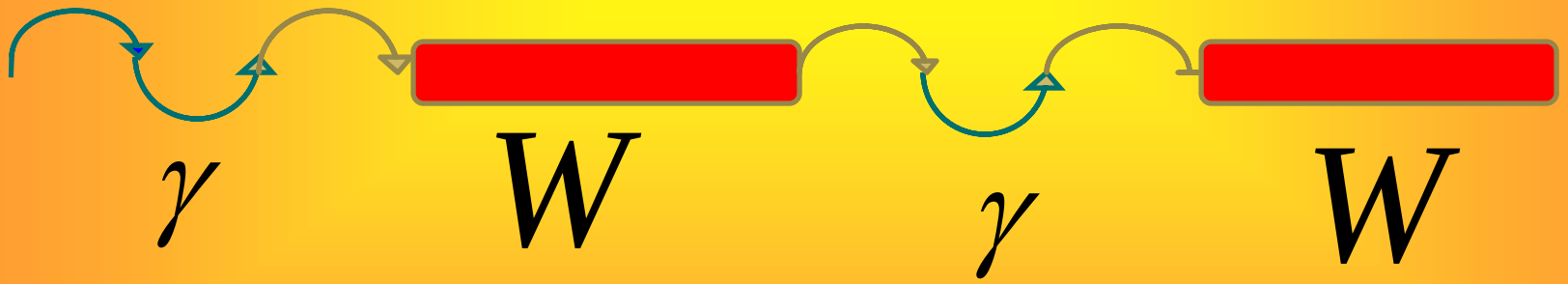
$$M_{\rho^0}^{\ 2} = \frac{M_{\rho^+}^{\ 2}}{1-m^2}$$

~ 3.1 MeV

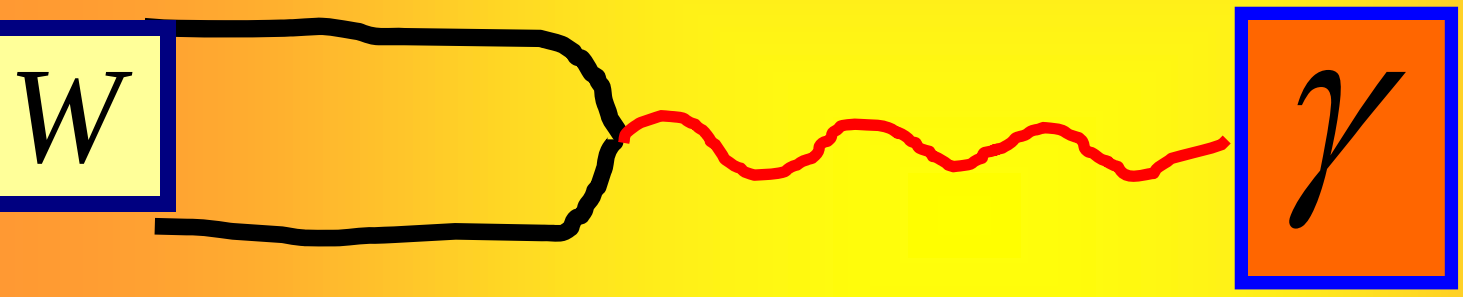
m = 0.09

QHD

Dynamical mixing of W-boson and photon



mixing of W with photon



m: mixing parameter

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

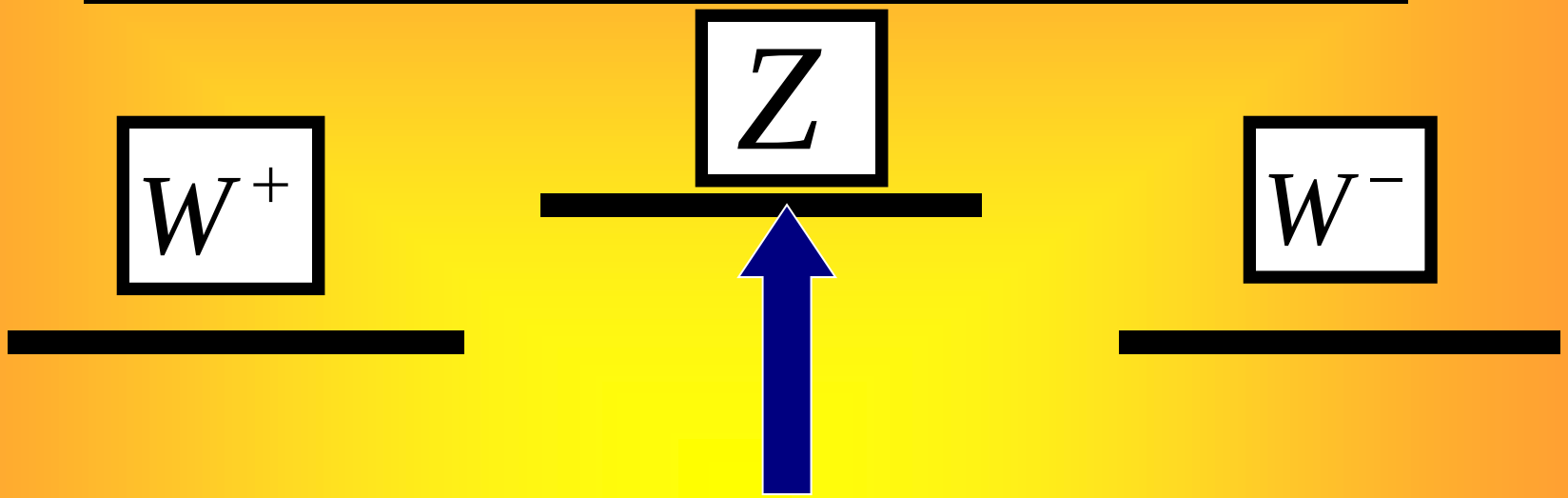
$$M_Z^{\,2} = \frac{M_W^{\,2}}{1 - m^2}$$

Standard Model

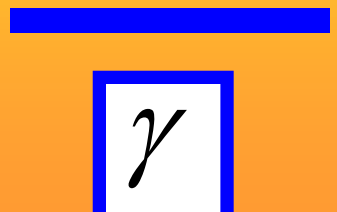
$$M_Z^{\,2} = \frac{M_W^{\,2}}{1 - \sin^2\theta_w}$$

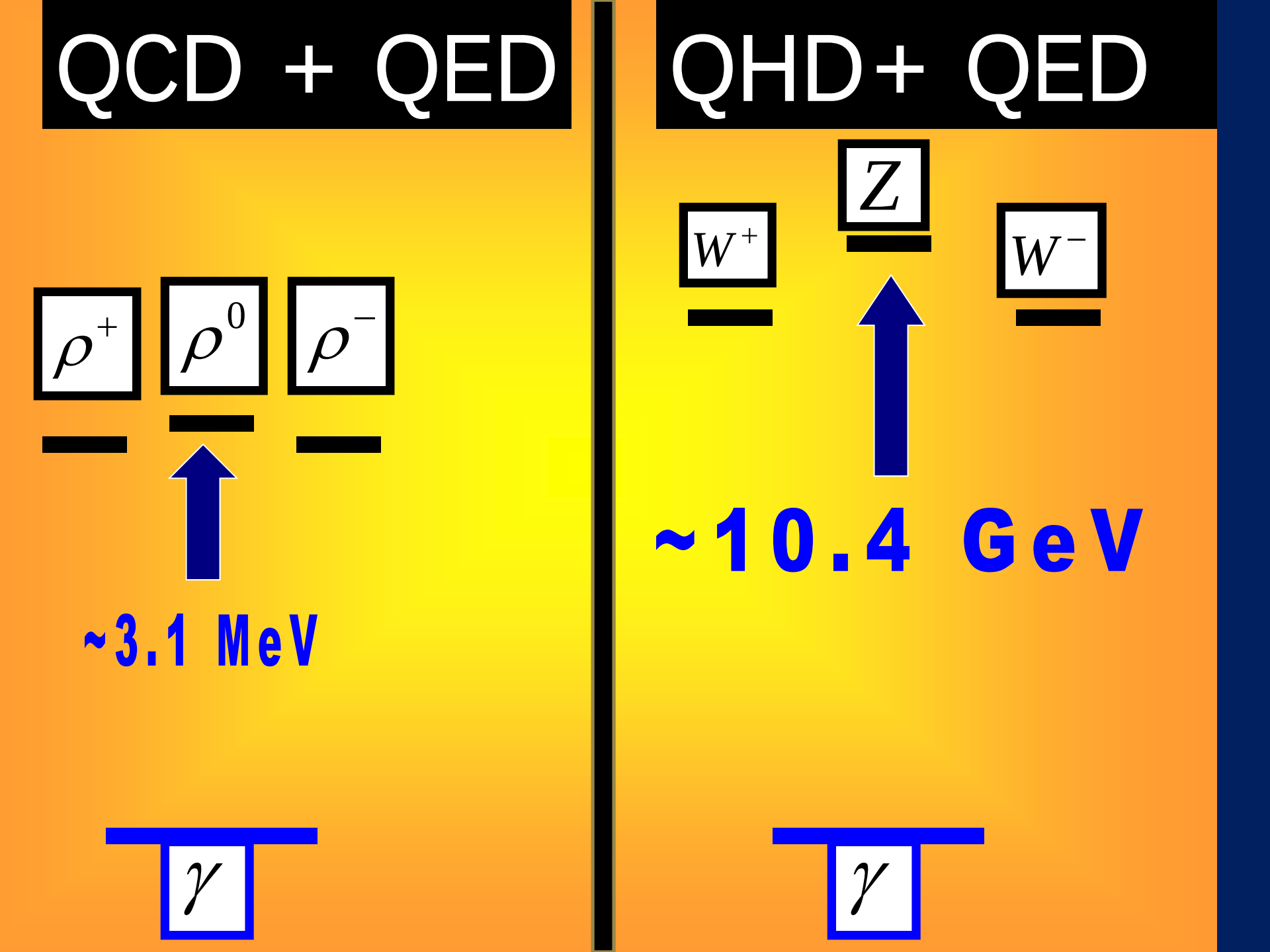
$$\sin\theta_w = m \approx 0.485$$

Standard Model



~10.4 GeV




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

W decay constant

$$\langle 0|\frac{1}{2}(\bar{\alpha}\gamma_{\mu L}\alpha-\bar{\beta}\gamma_{\mu L}\beta)|Z\rangle=\varepsilon_{\mu}M_{W}F_{W}$$

experimental data:

$$M_W = 80.4...GeV$$

$$M_Z = 91.19...GeV$$

$$F_W \cong 125....GeV$$

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

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

$$e \cong 0.3122$$

$$m = e \frac{F_w}{M_w}$$

$$m \approx 0.485$$

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

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

$$F_W \approx 0.130\_TeV$$

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

uncertainty:

gauge group of QHD

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

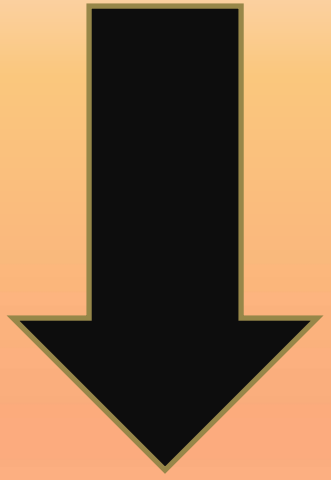
$$F_W \approx 0.13 \quad TeV$$

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

$ low energy $

Standard Model

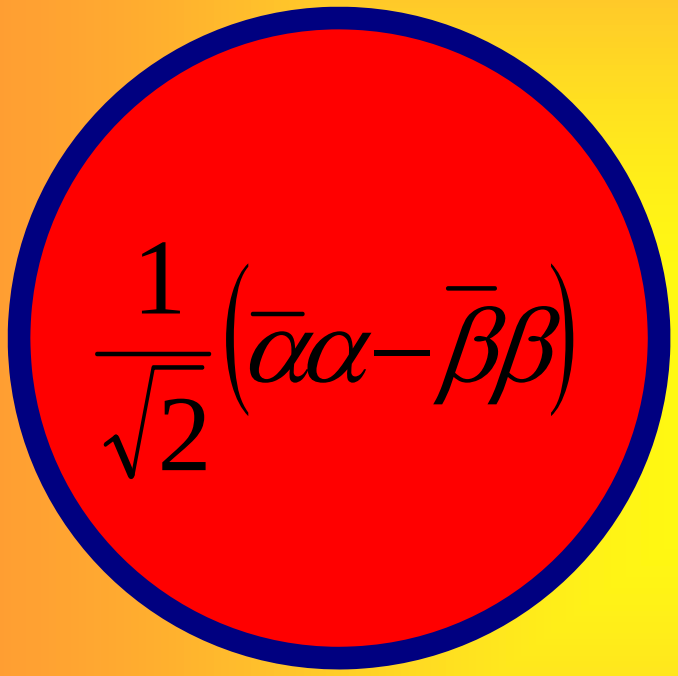
$ high energy $

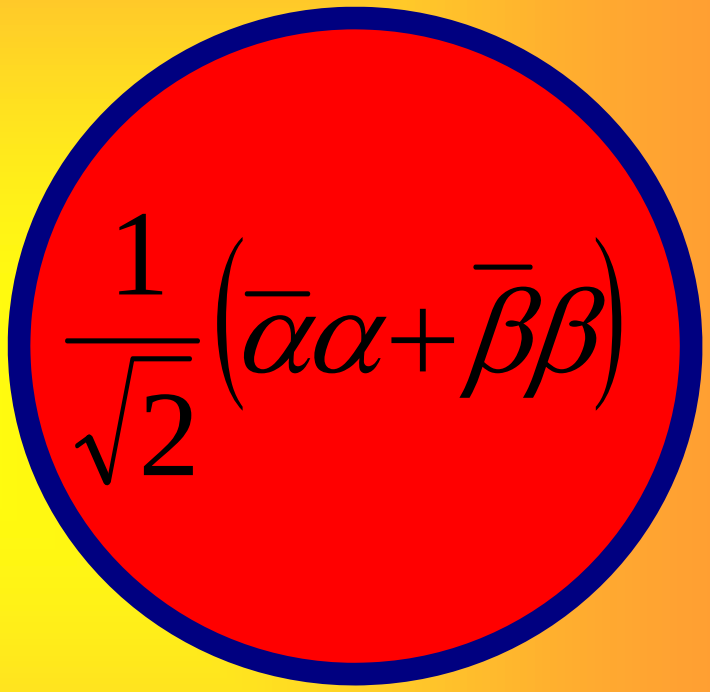


many new states

~~Standard Model~~

New:
isoscalar



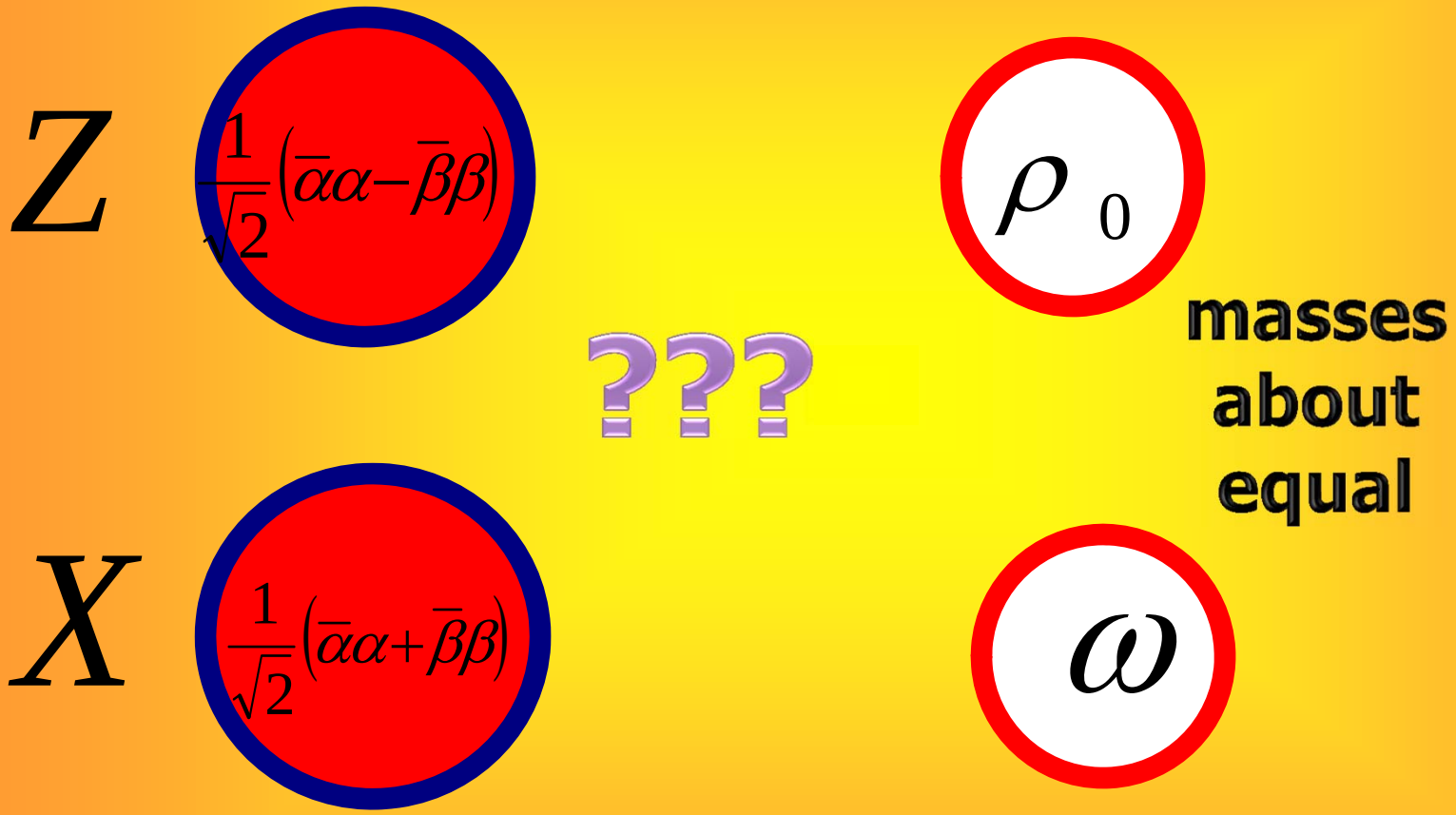


Z

X

Present lower limit on X-mass:

~700 GeV


Z
$\frac{1}{\sqrt{2}}(\bar{\alpha}\alpha - \bar{\beta}\beta)$
ρ_0
???
masses about equal
X
$\frac{1}{\sqrt{2}}(\bar{\alpha}\alpha + \bar{\beta}\beta)$
ω

QCD - anomaly

↓

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

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

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

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

(quark masses $\longrightarrow 0$)

QHD - anomaly

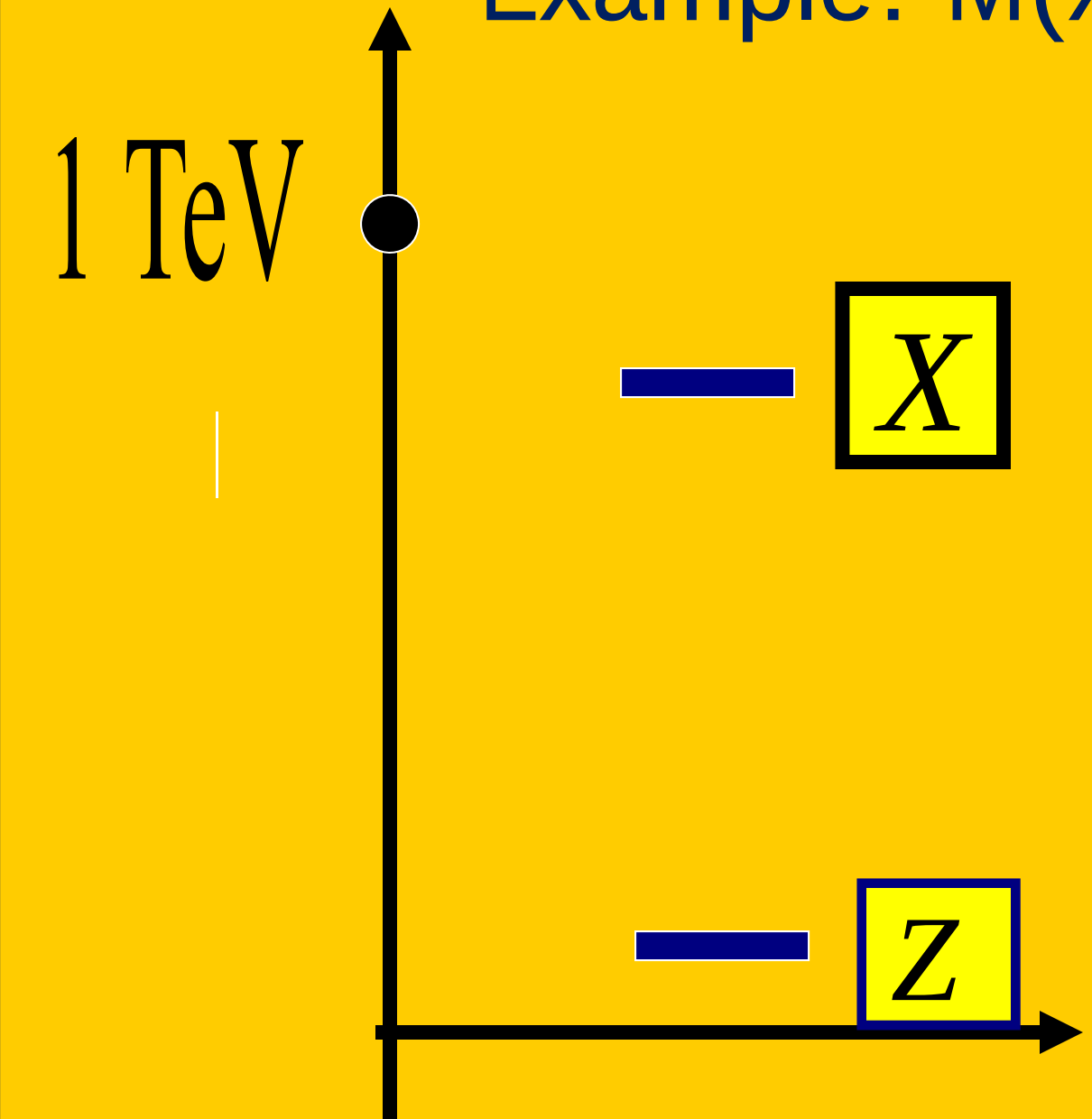
$$\partial_\mu (\bar{h} \gamma^\mu \gamma^5 h) \sim g_h^2 H_{\mu\nu} \tilde{H}^{\mu\nu}$$

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

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

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

Example: M(X)=0.8 TeV

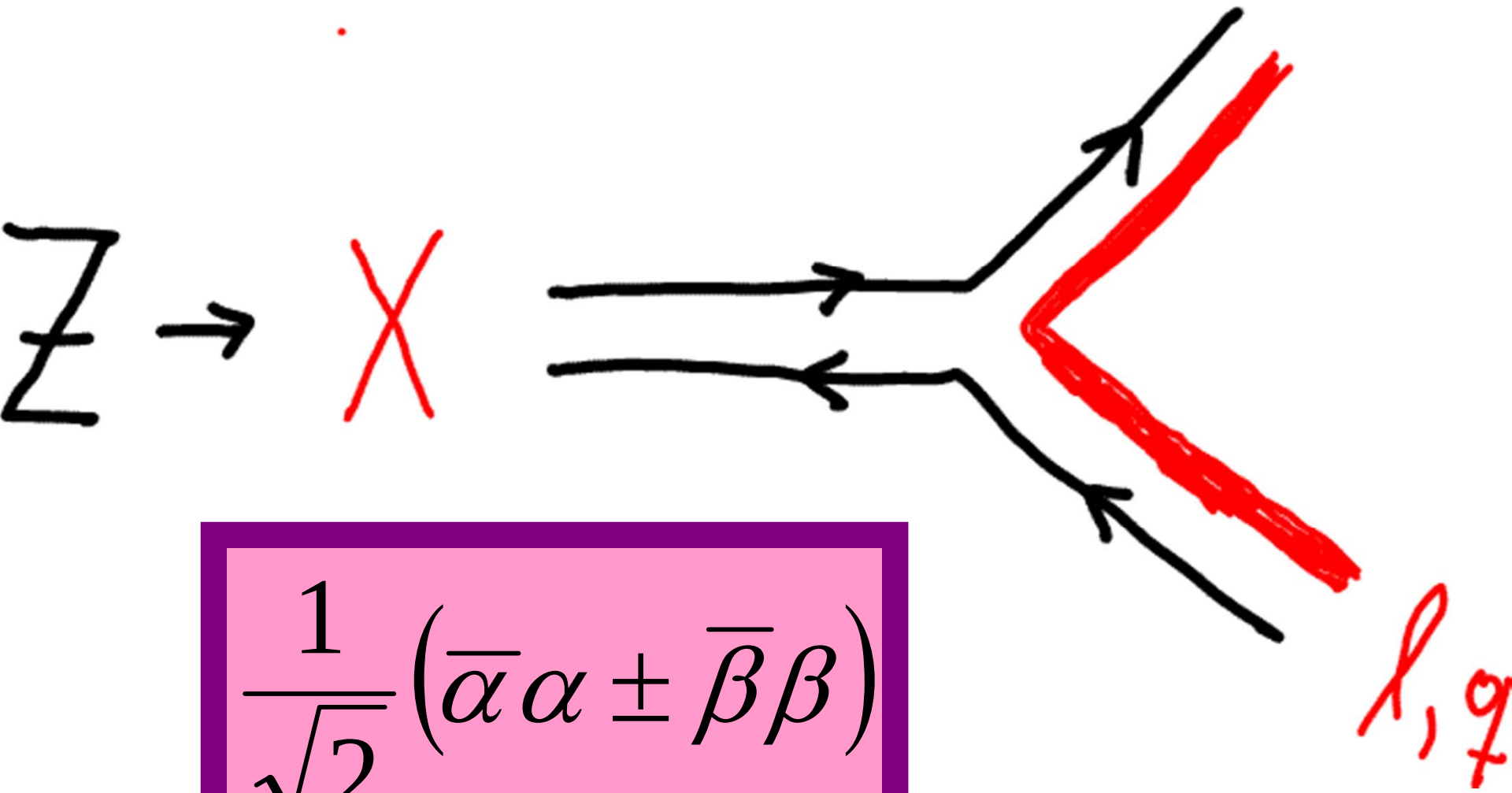


cross section of Z-production at LHC: ~ 60 nb

➔ cross section for X-production: ~0.8 nb

Coupling of X to leptons and quarks:

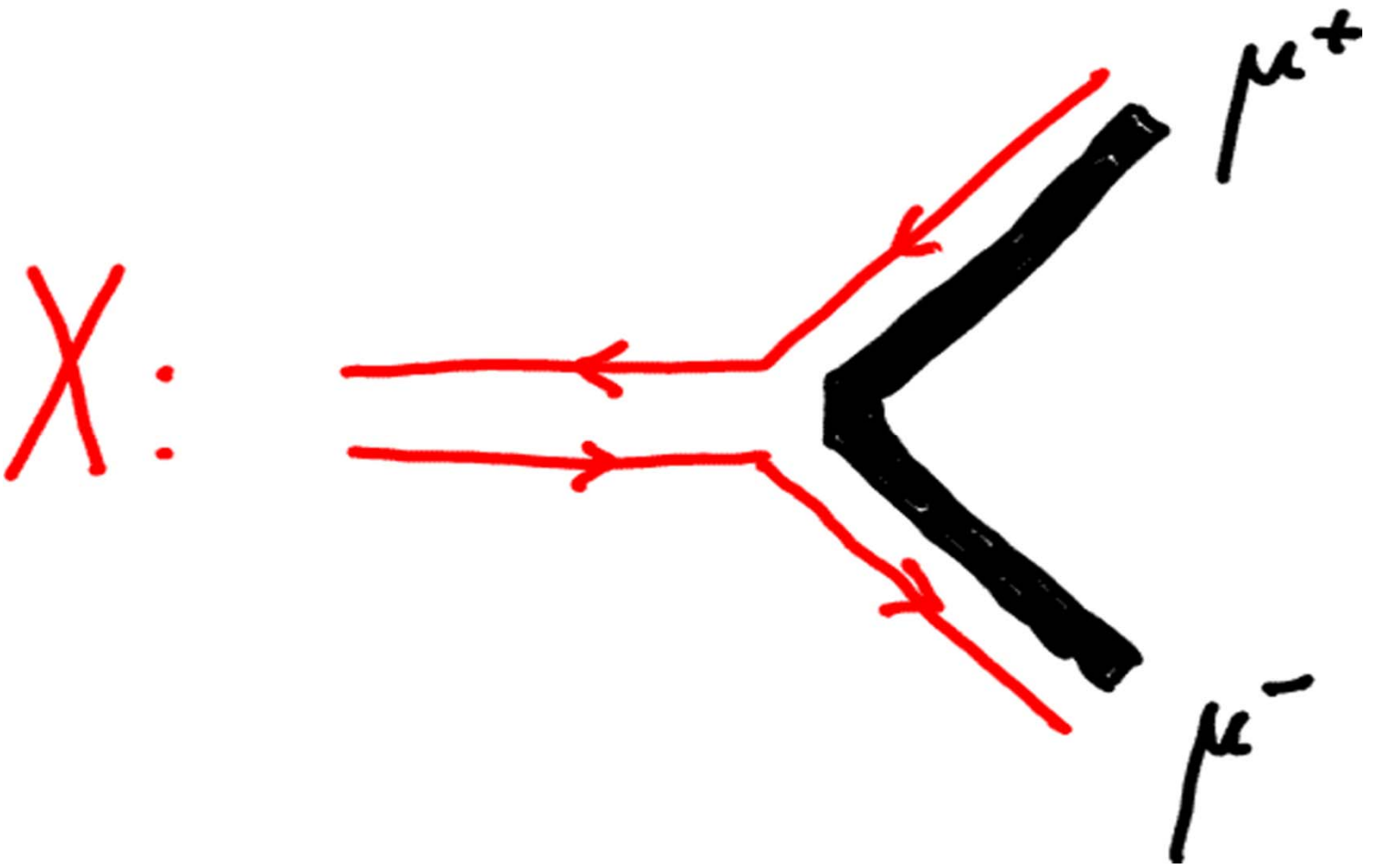
➔coupling of Z - boson



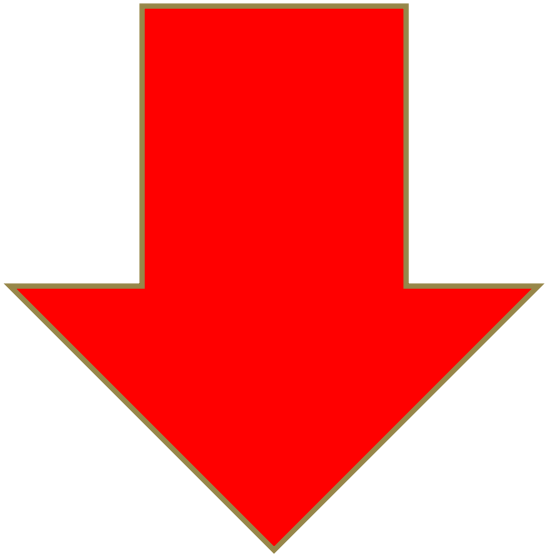
$$\frac{1}{\sqrt{2}}\left(\bar{\alpha}\alpha \pm \bar{\beta}\beta\right)$$

X – decay into muons

➔ Z – decay into muons:



$$\Gamma(W^+ \Rightarrow \mu^+ \nu_\mu) \cong 226 \ \ MeV$$



$$\Gamma(X \Rightarrow \mu^+ \mu^-) \cong 2.2 \ \ GeV$$

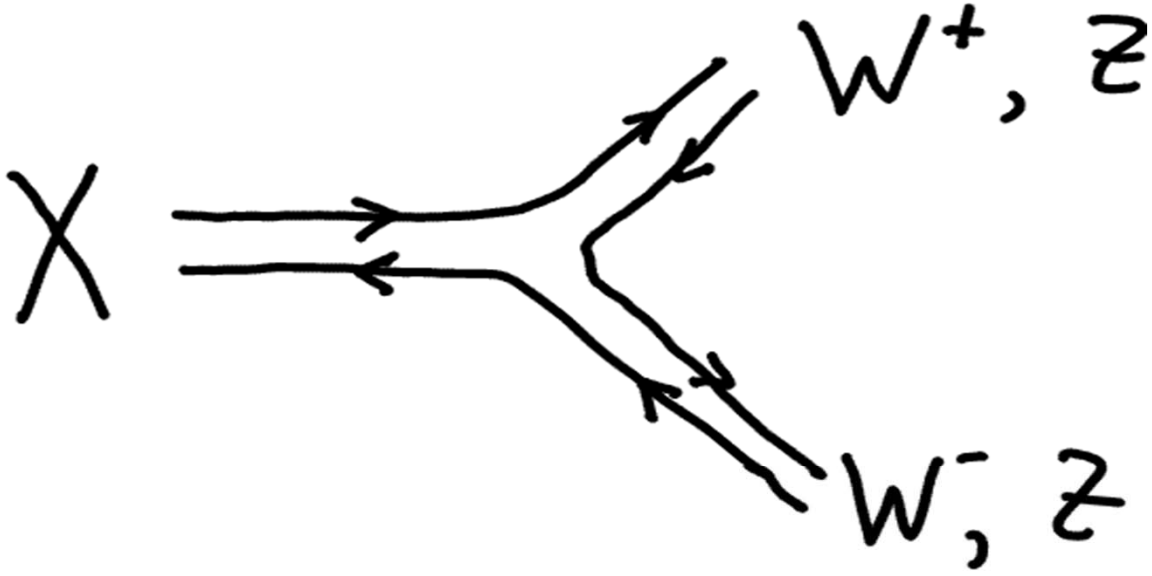
X - decays → leptons, quarks

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

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

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

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



Expected:

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

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

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

X →

leptons

quarks

WW

ZZ

WWZ

ZZZ

Summation

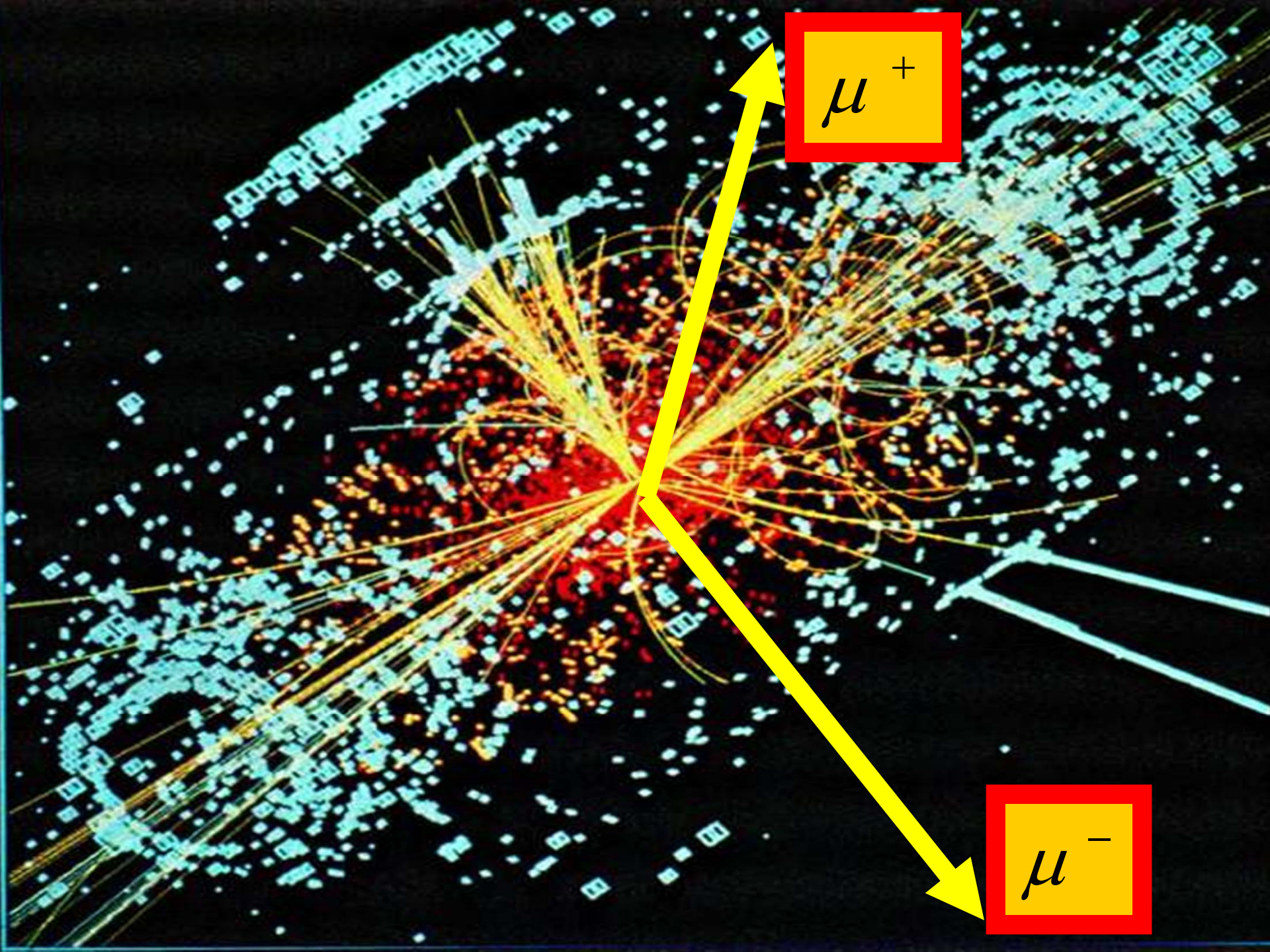
Total width of X:
~62 GeV

Total width of Z:
2.5 GeV

Discovery of X-boson:

search for decay into muon pairs

$$X \Rightarrow \mu^+ \mu$$


μ^+
μ^-

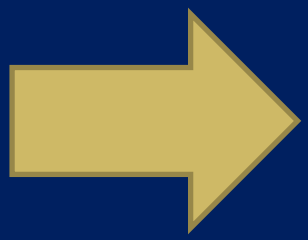
$$\Lambda_c \approx 0.3...GeV$$

complexities

of

strong interactions

~ 1 GeV



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

complexities

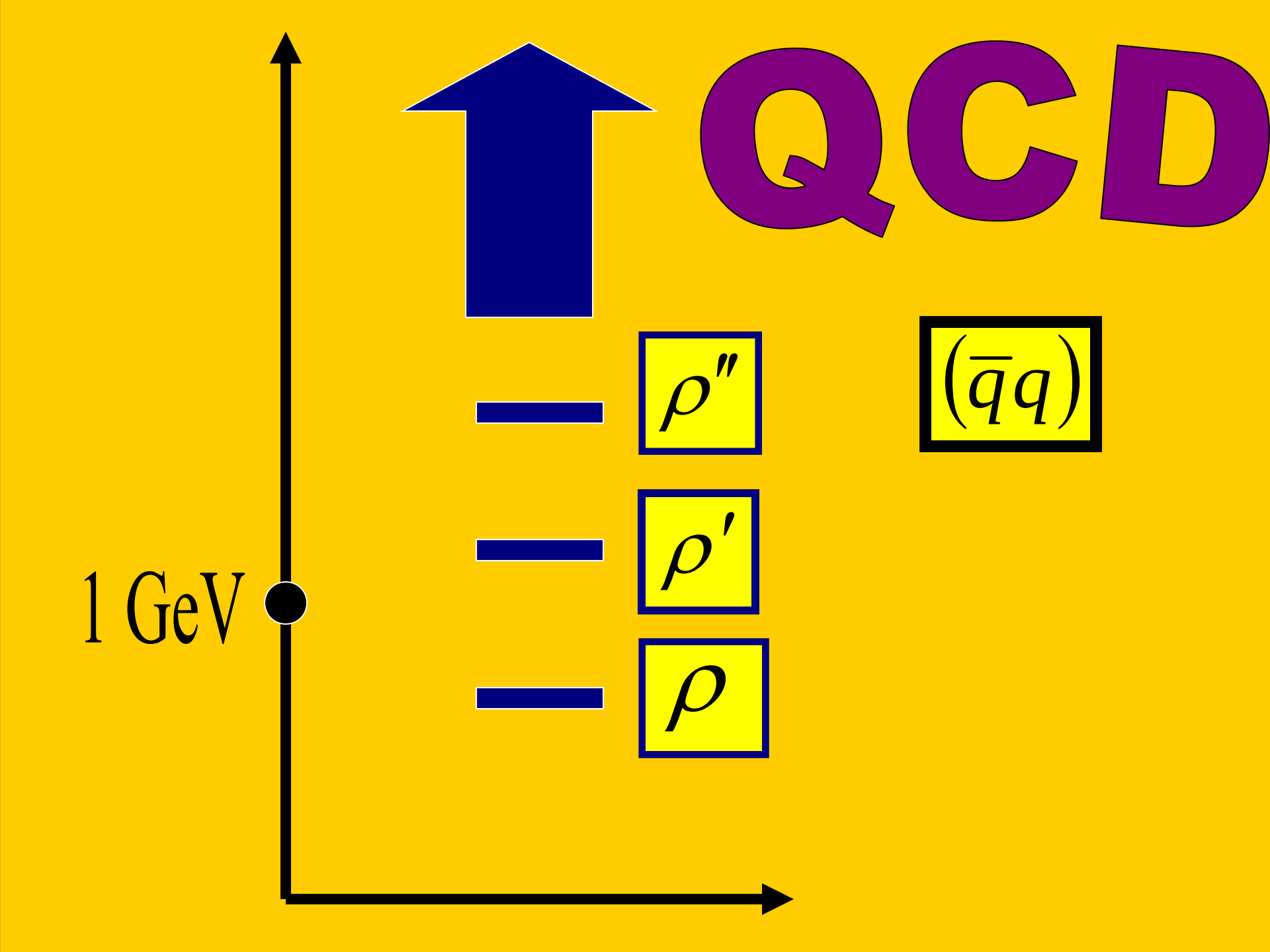
of

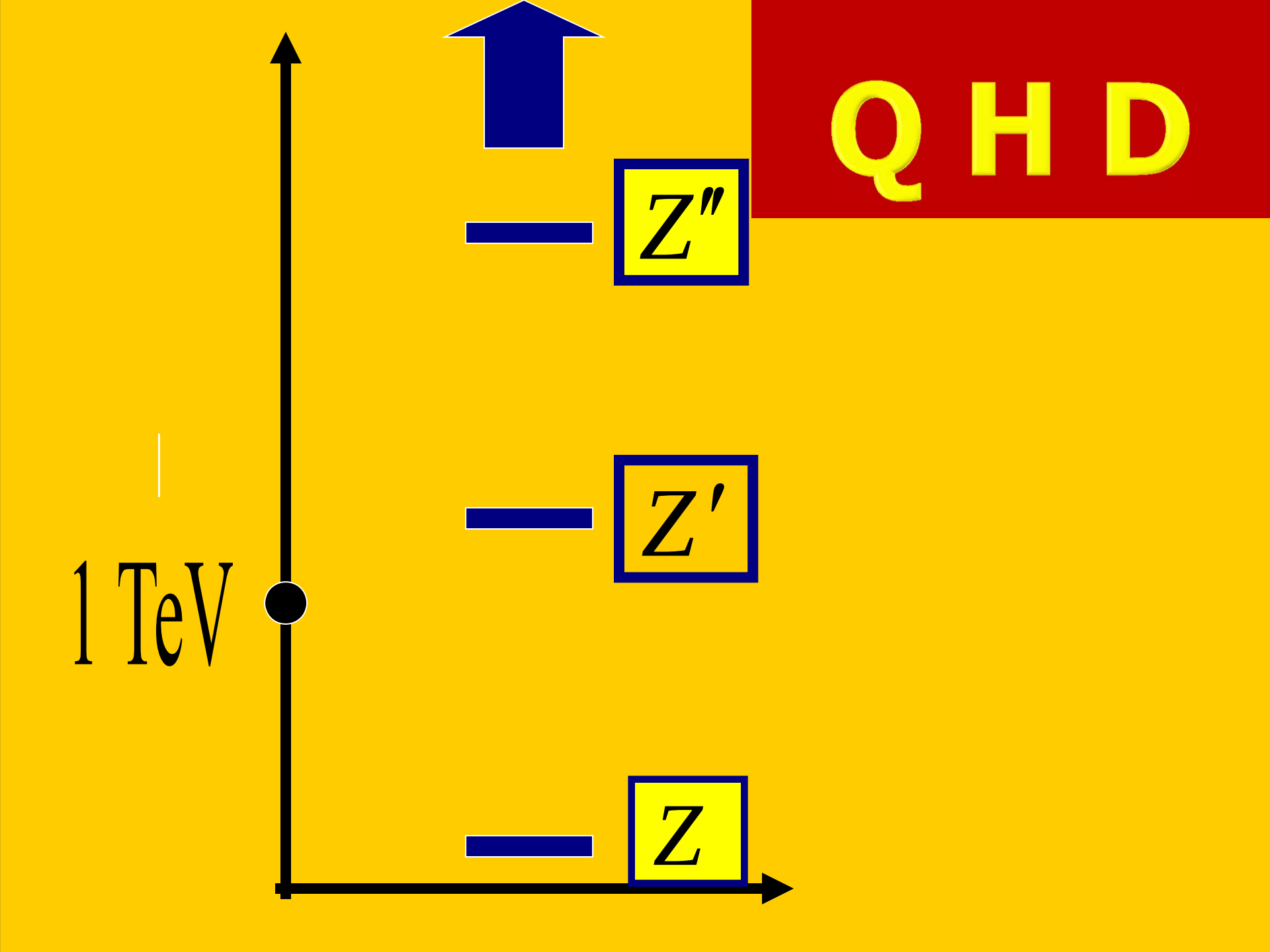
QHD interactions

~ 1 TeV

EXCITED WEAK BOSONS

above 1 TeV

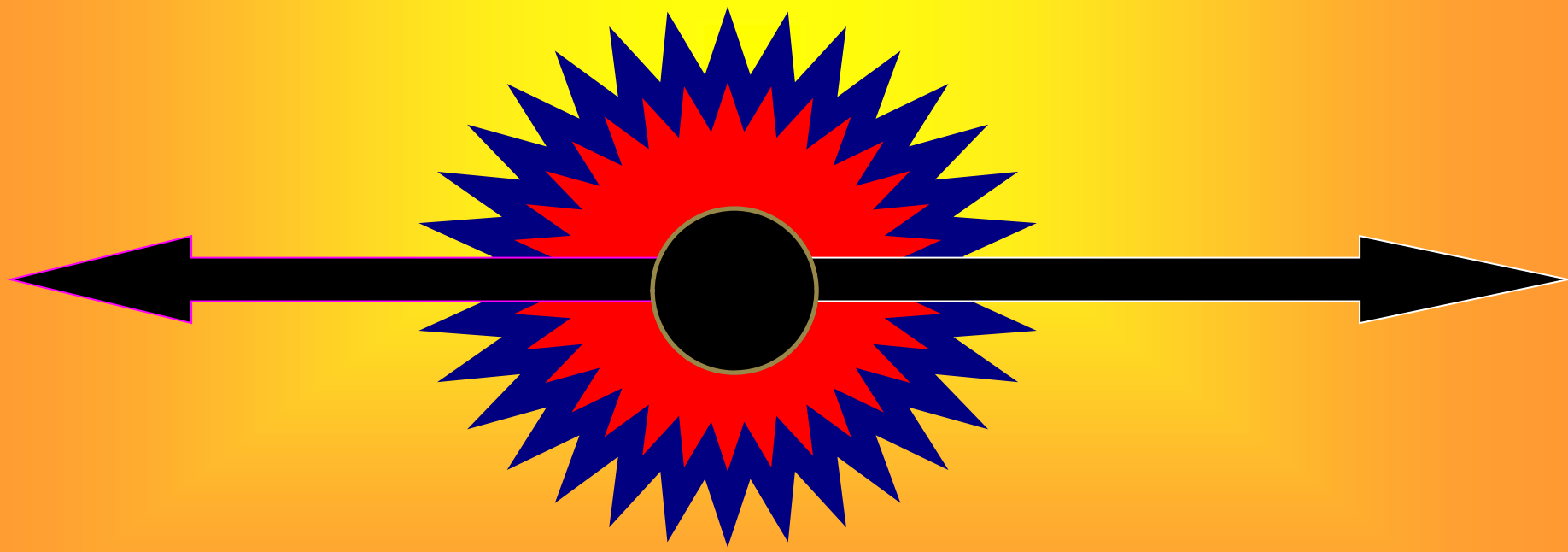

QCD
$(\bar{q}q)$
ρ''
ρ'
ρ
1 GeV

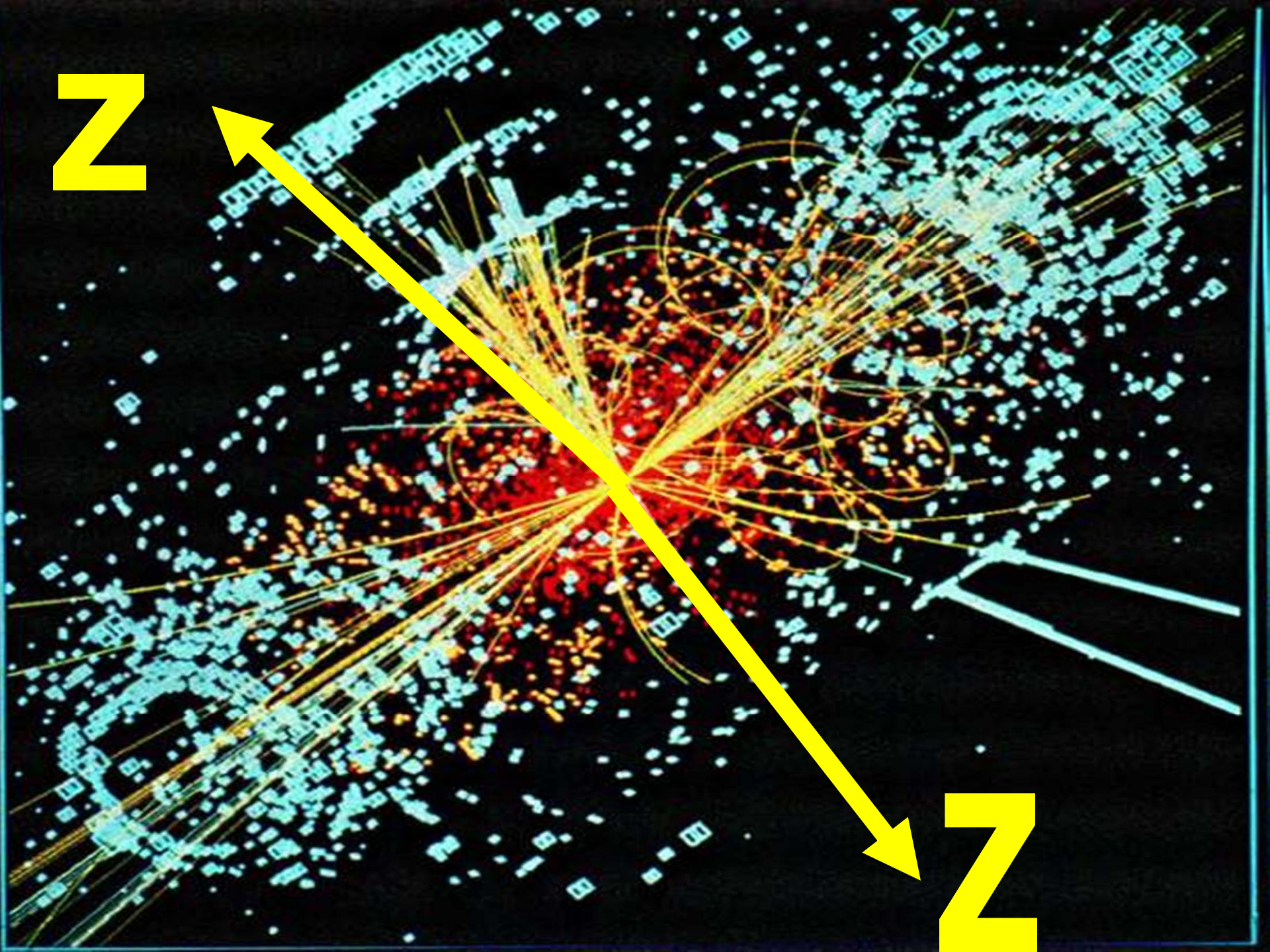

QHD
Z″
Z′
1 TeV
Z

Limit from Tevatron and from LHC:

M(Z`) > 0.8 TeV

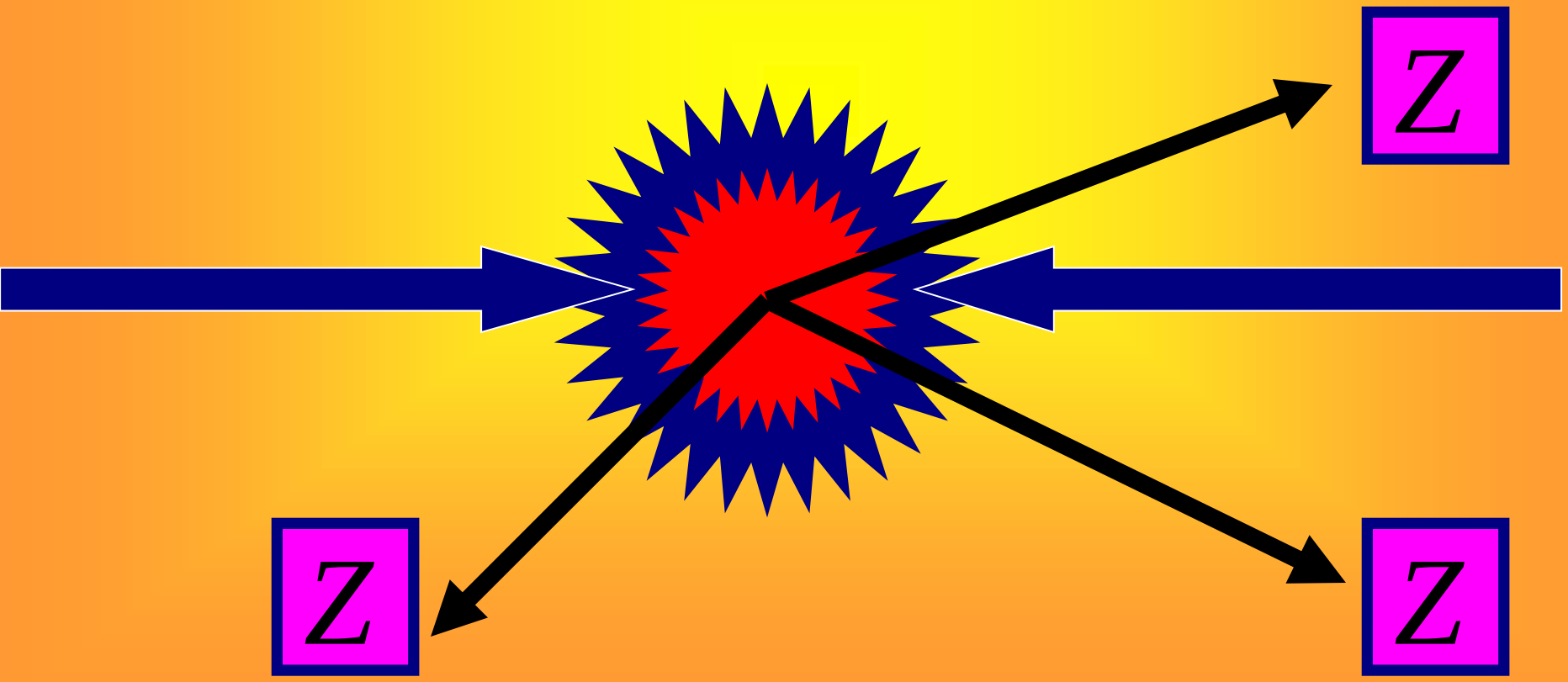
$$Z' \Rightarrow Z + Z$$



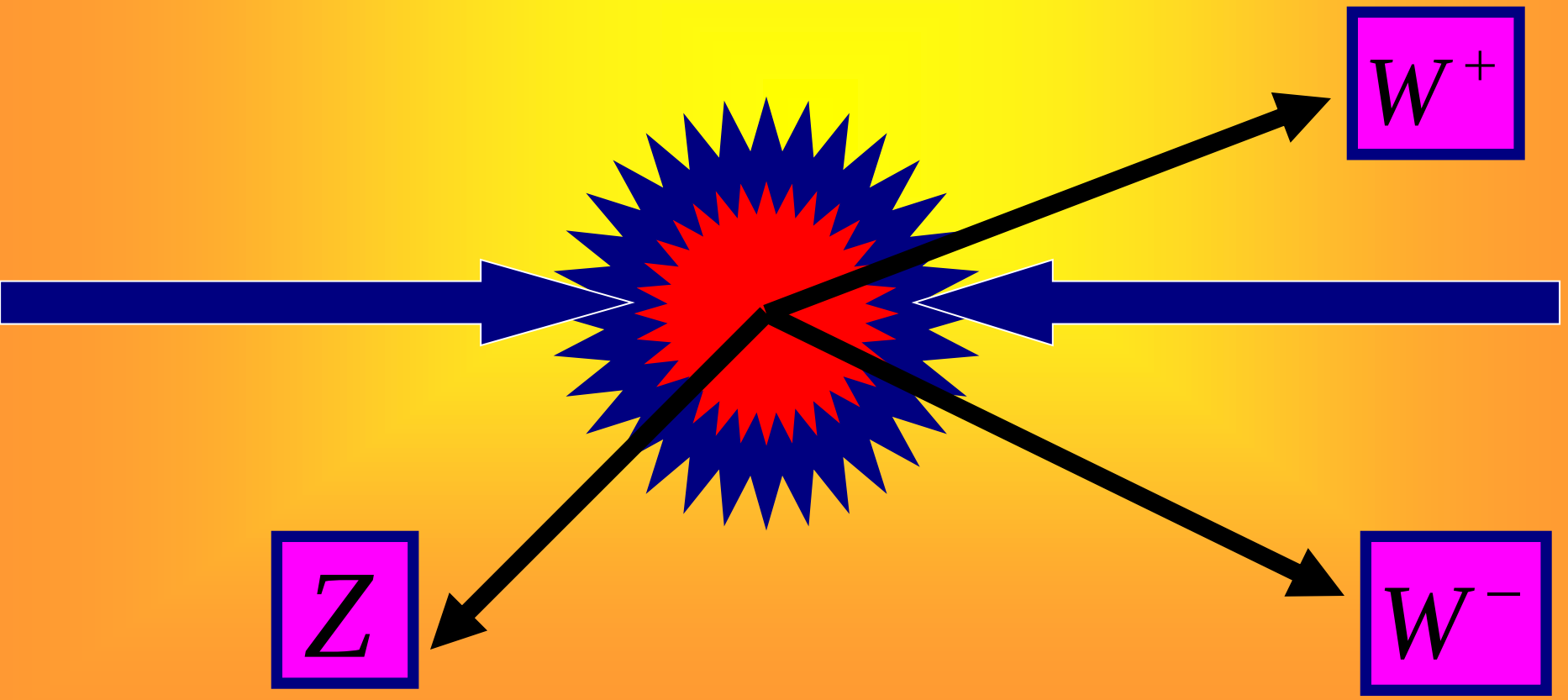

Z
Z

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

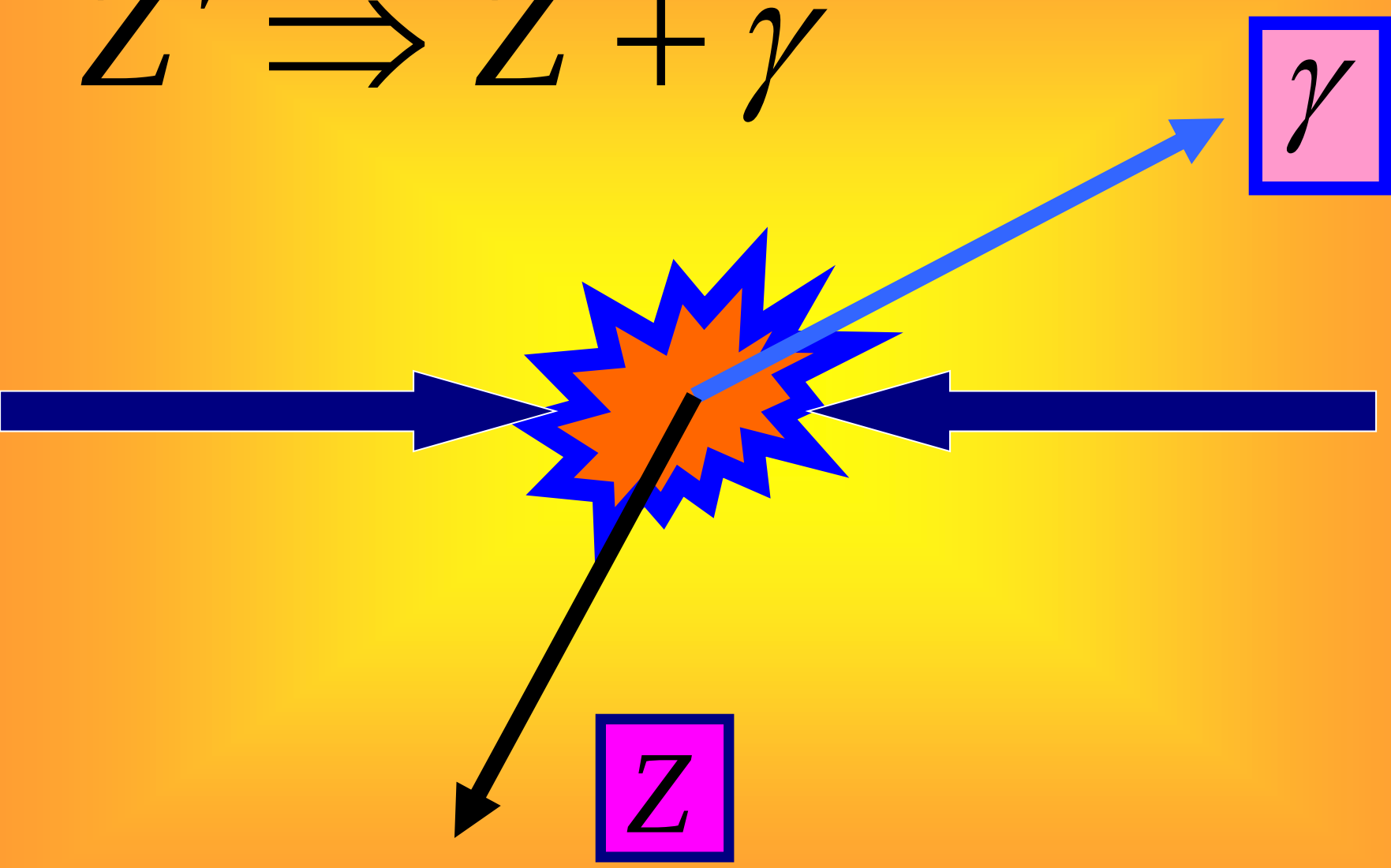
$$Z' \Rightarrow Z + Z + Z$$



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



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



QCD

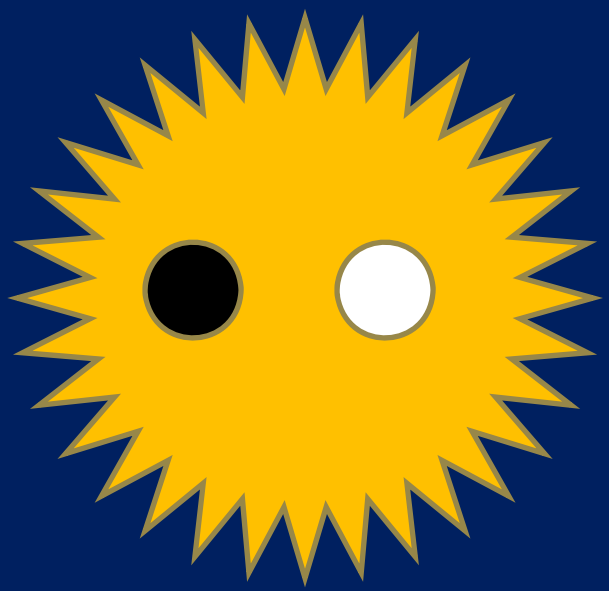
$$\rho \Rightarrow a_2(1320) \Rightarrow \ldots$$

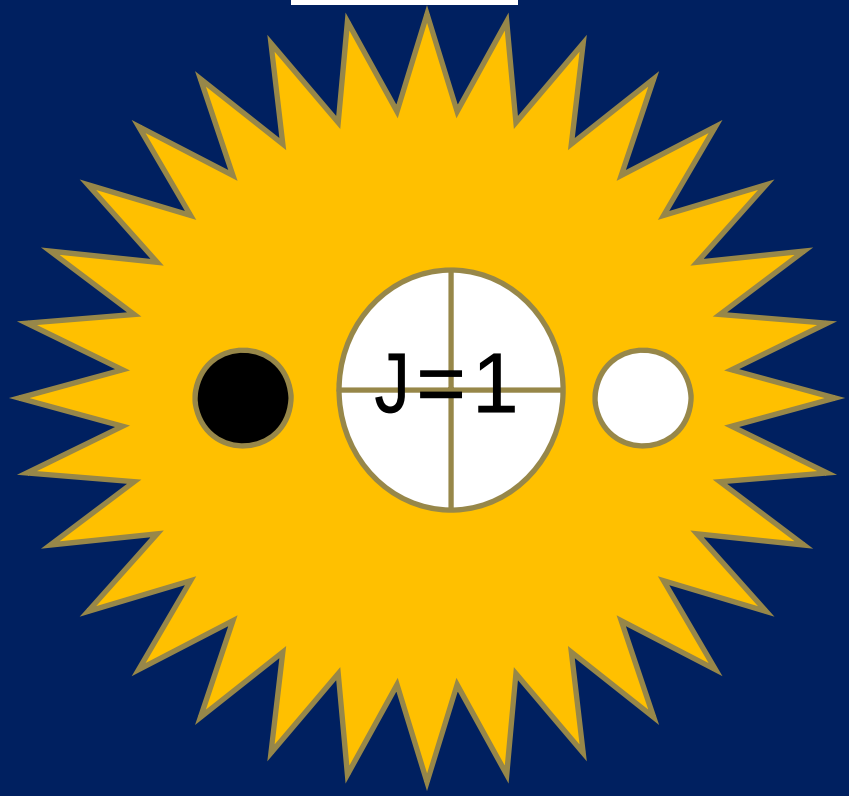
tensor mesons...

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

ρ

a_2

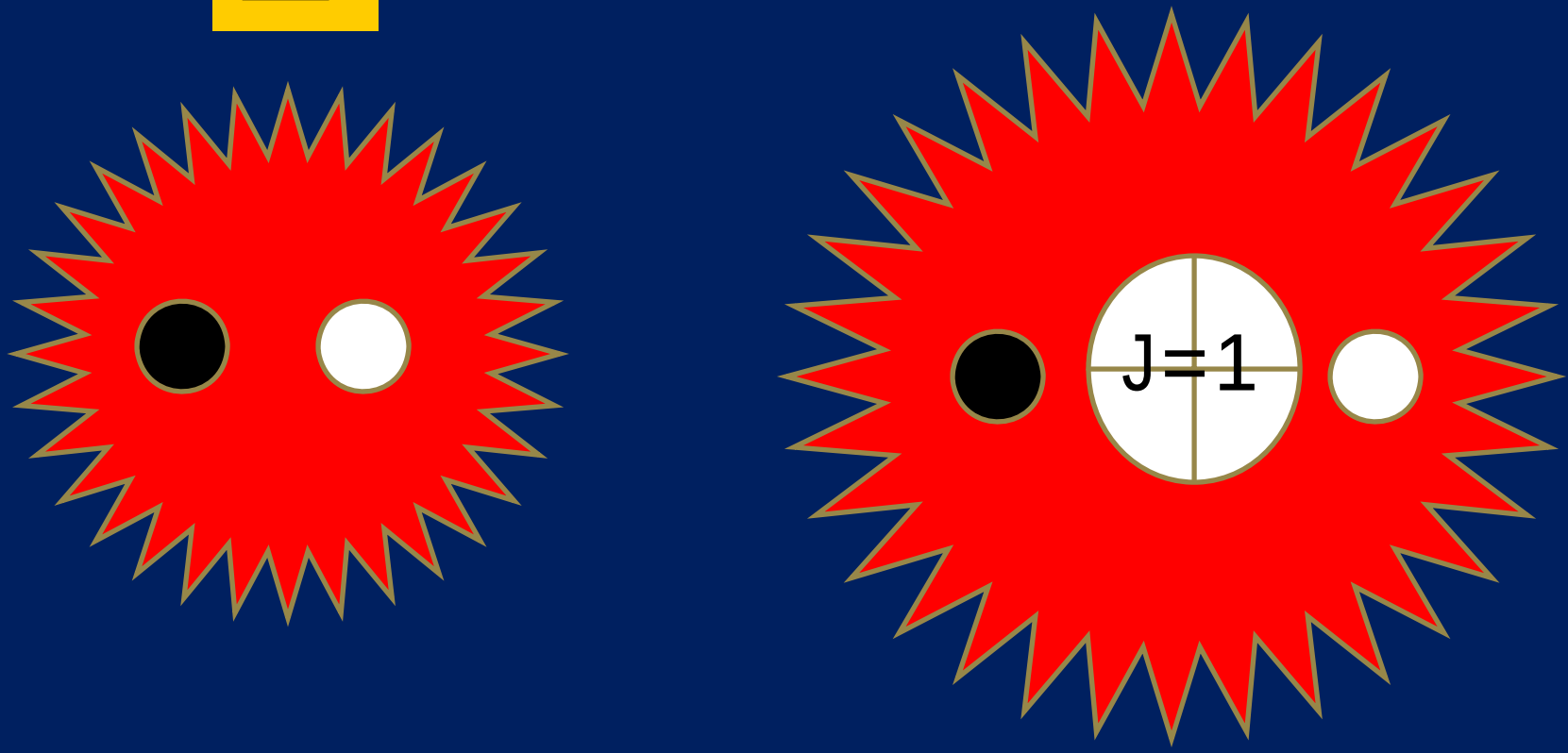




$$Z \Rightarrow Z_2 \Rightarrow Z_3 \Rightarrow \ldots$$

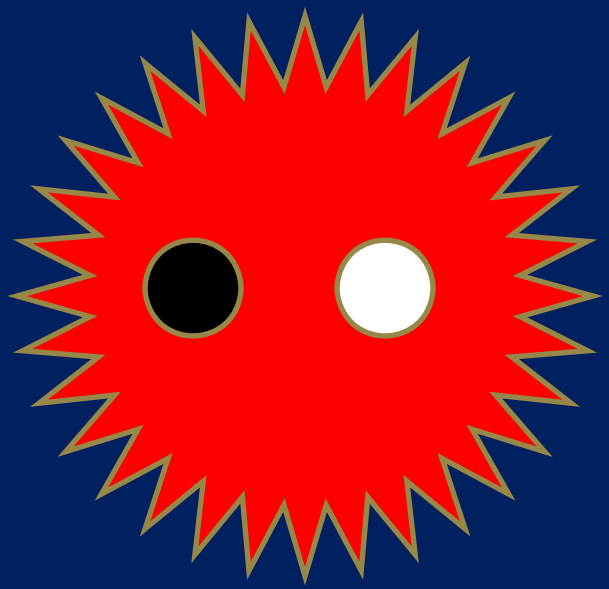
Z

Z_2

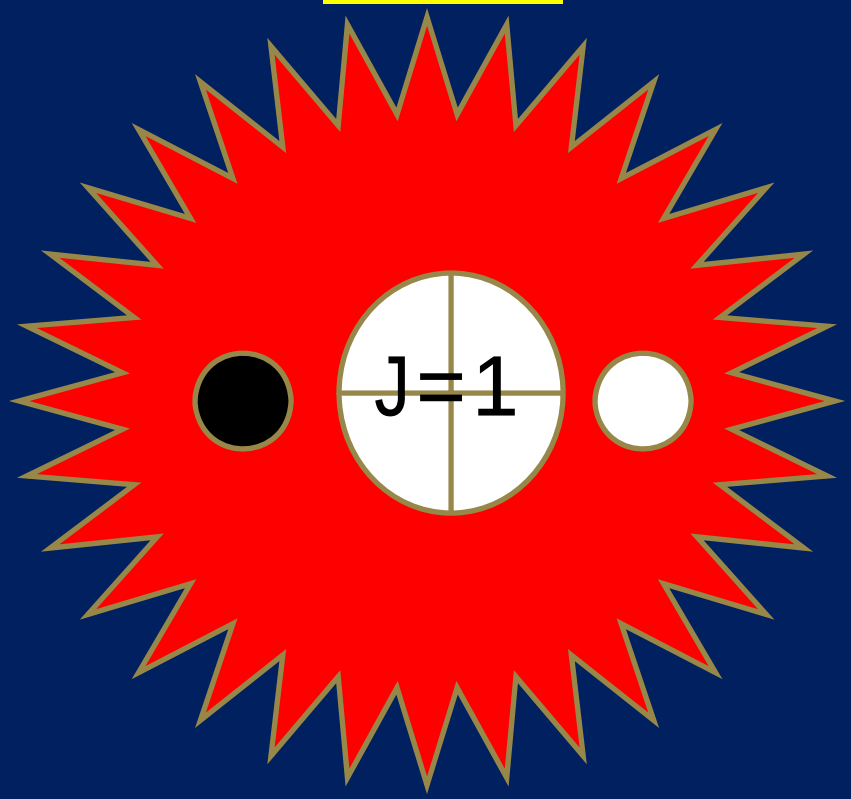


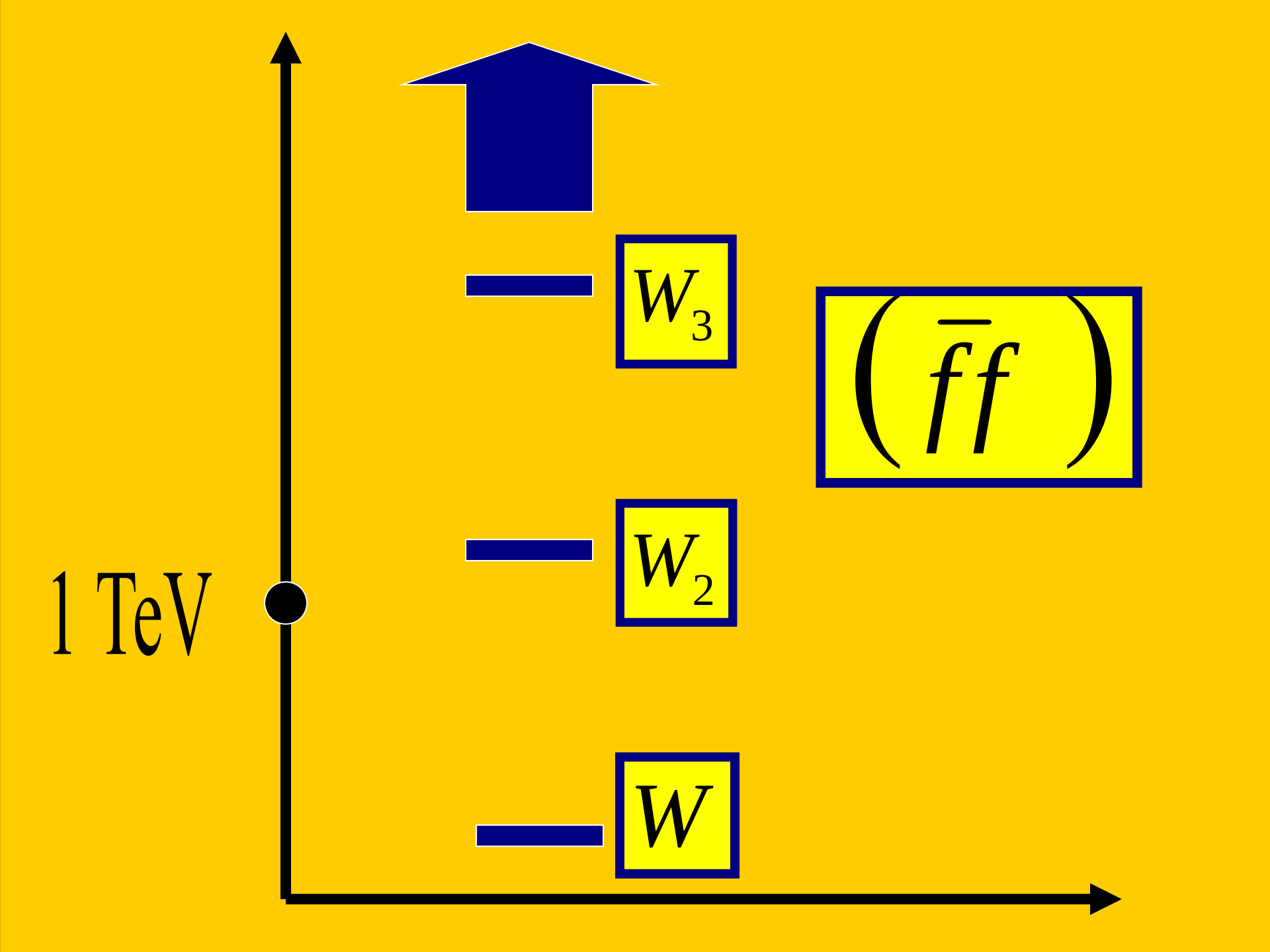
$$W \Rightarrow W_2 \Rightarrow W_3 \Rightarrow \ldots$$

W



W_2




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

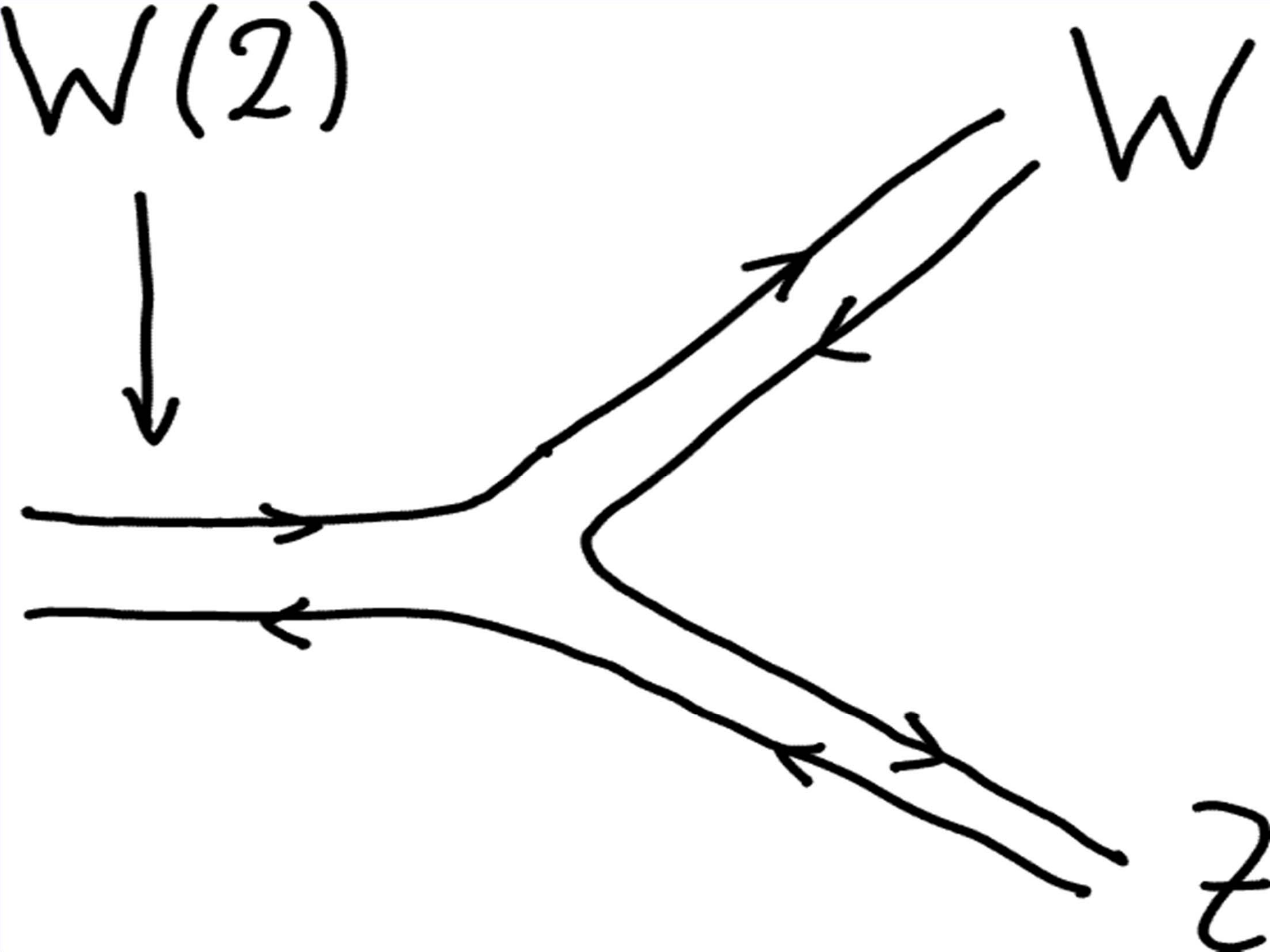
decays

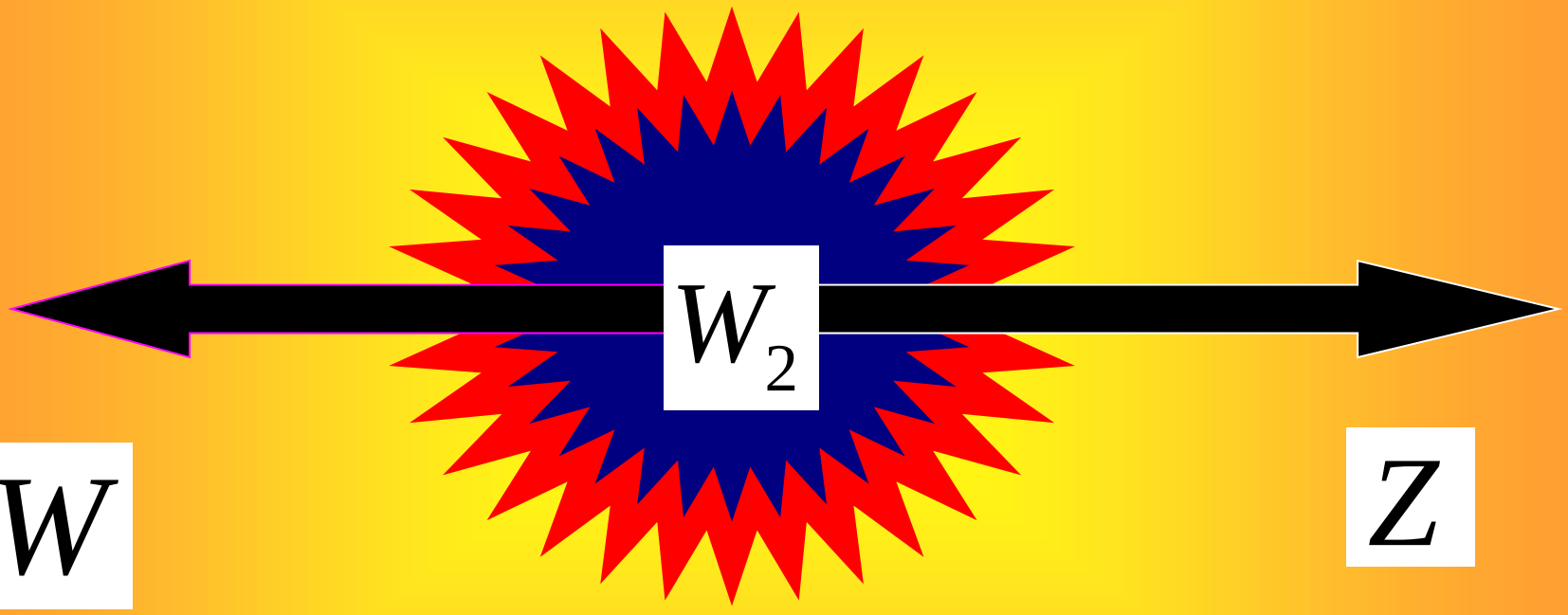
W(2) → W Z

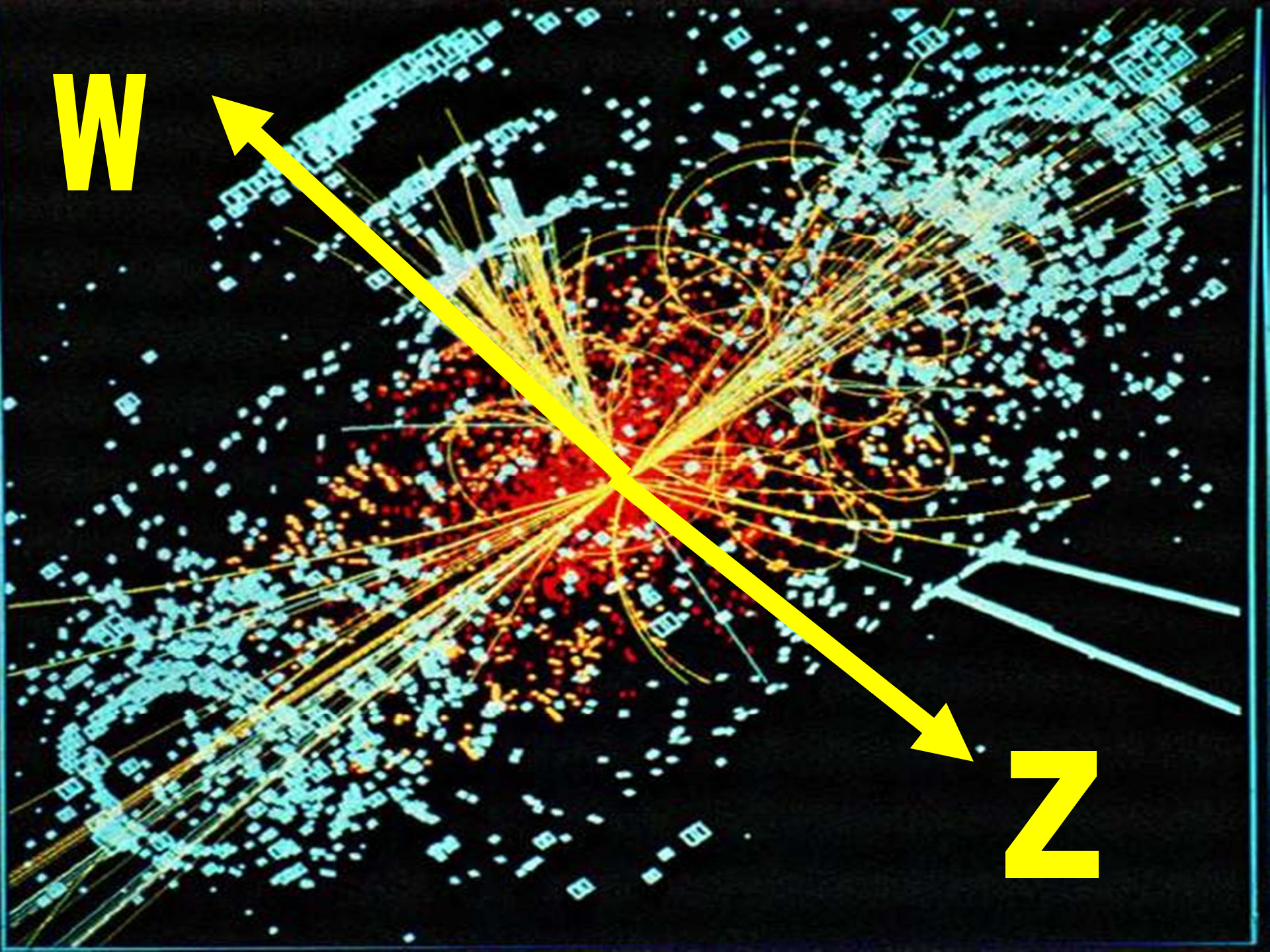
W(2) → W Z Z

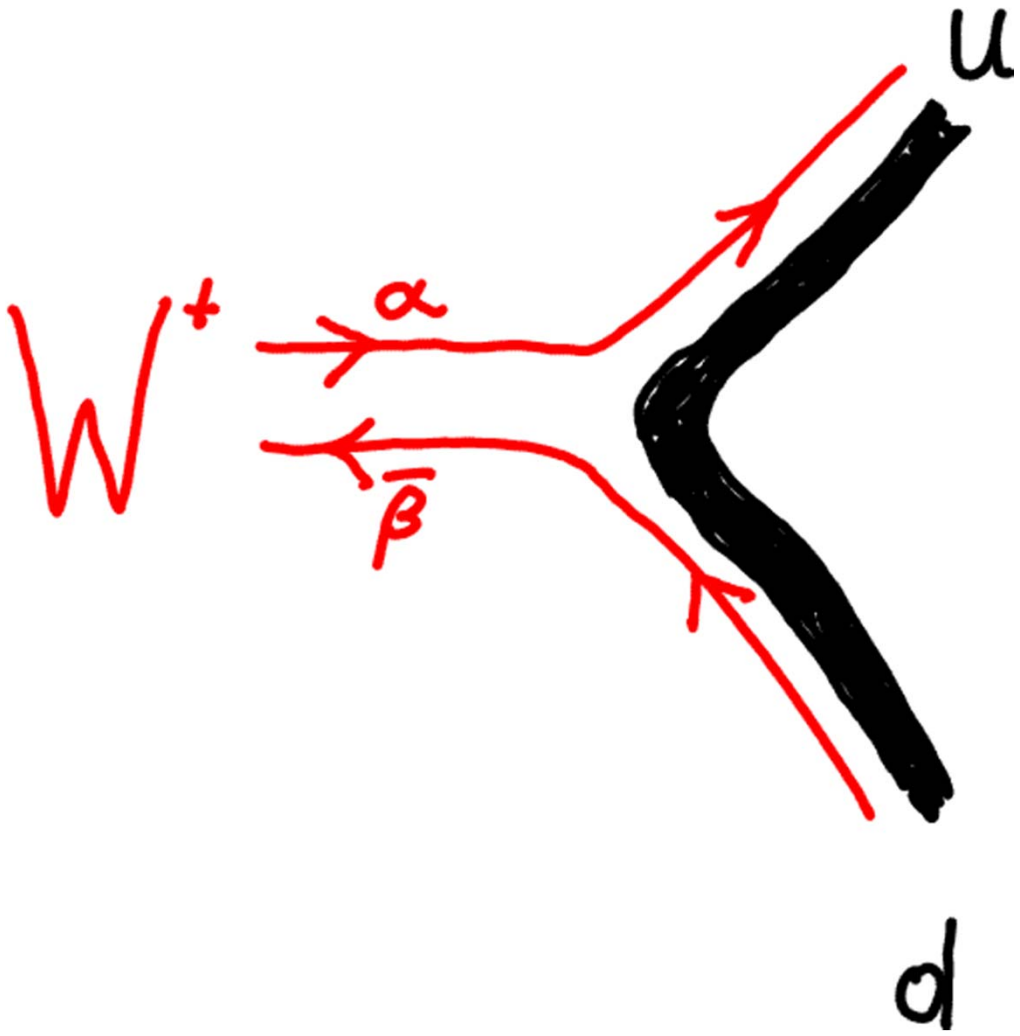
W(2) → W W W

decays into lepton and quark pairs suppressed


W(2)
W
Z


W_2
W
Z


W
Z

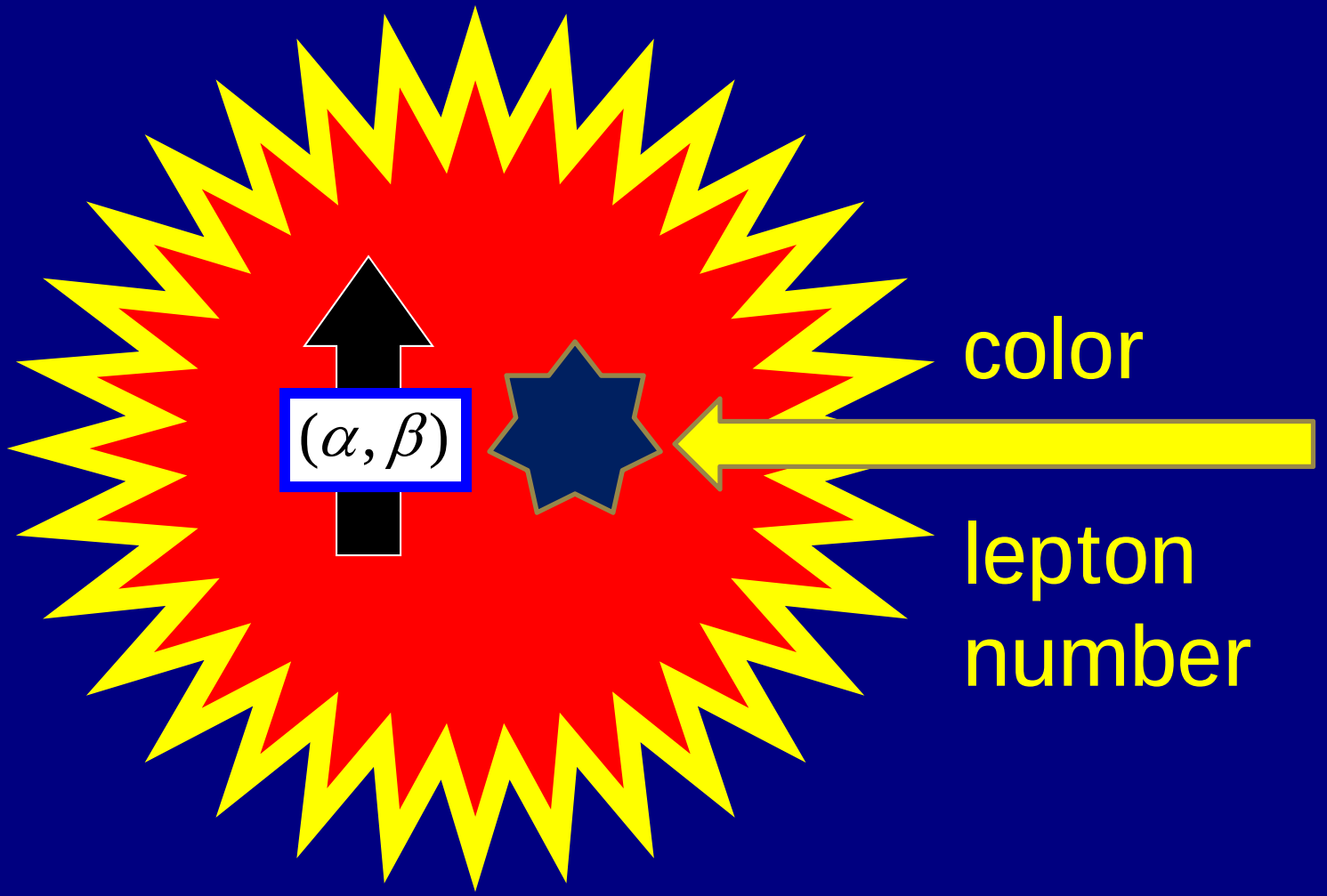

u
W+
α
β̄
d

weak bosons composite

weak interactions

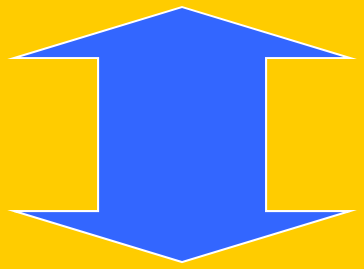
leptons and quarks → composite

leptons - quarks



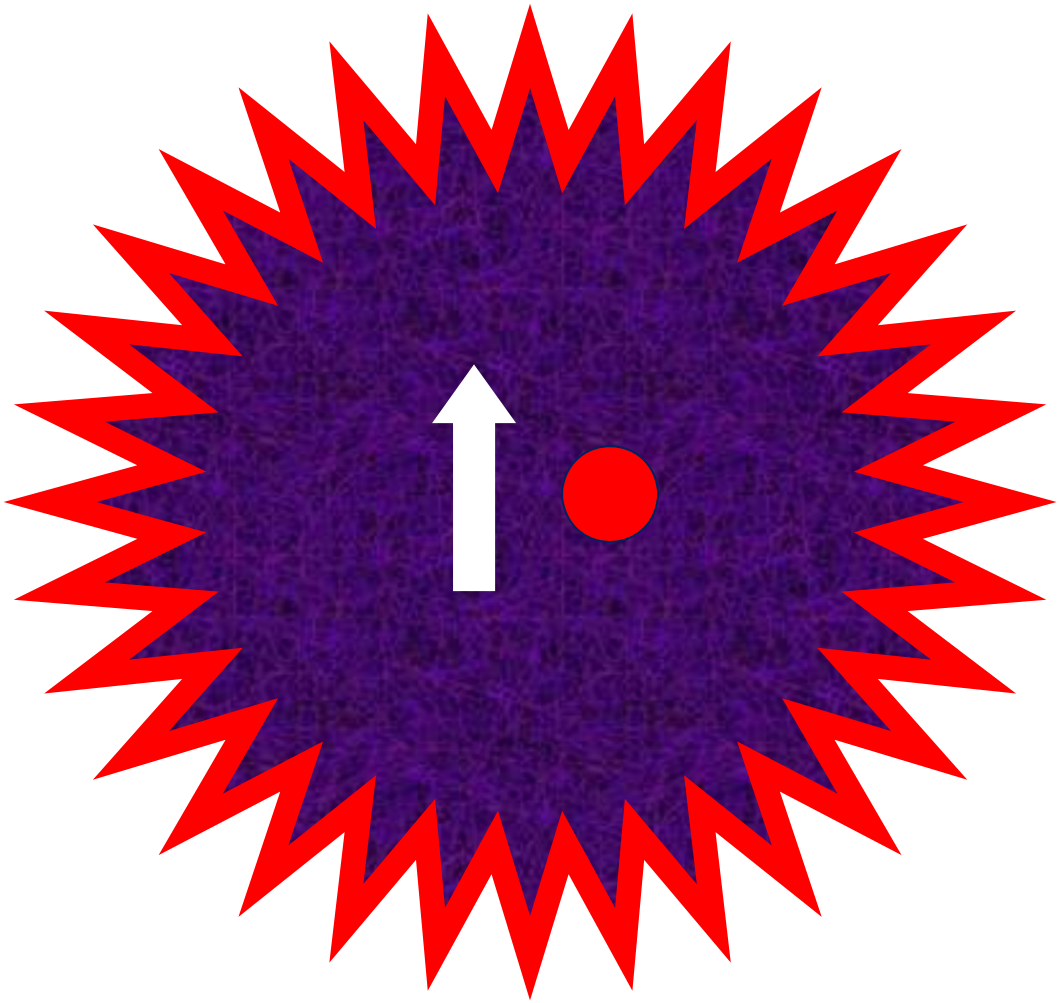
simplest theory:

leptons - quarks



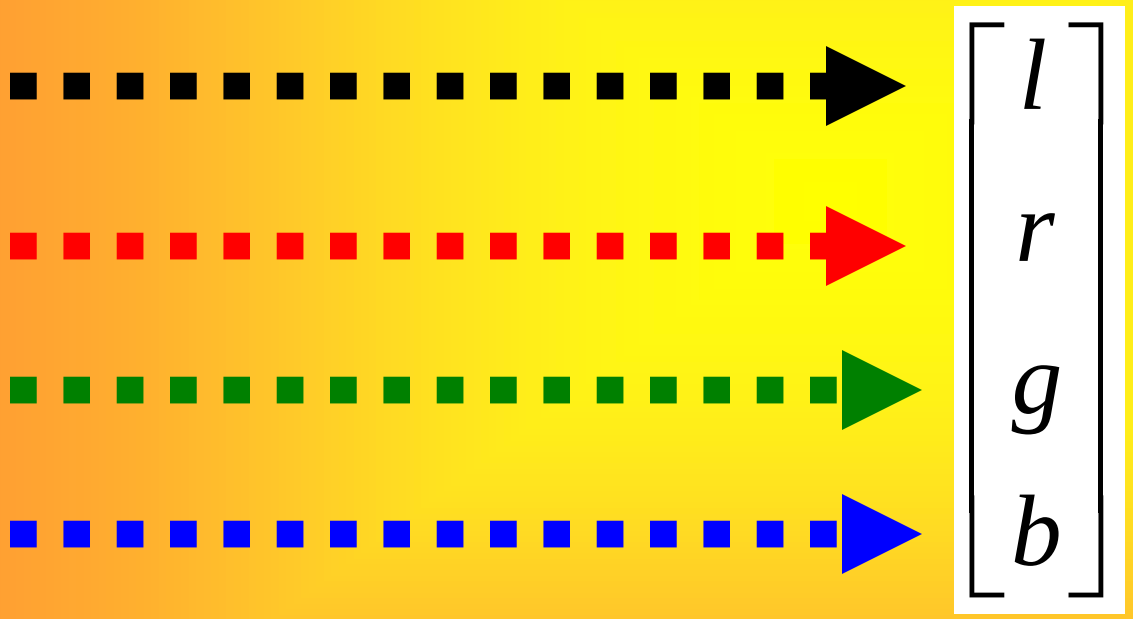
(fermion + scalar)

leptons - quarks




10^{-17} cm

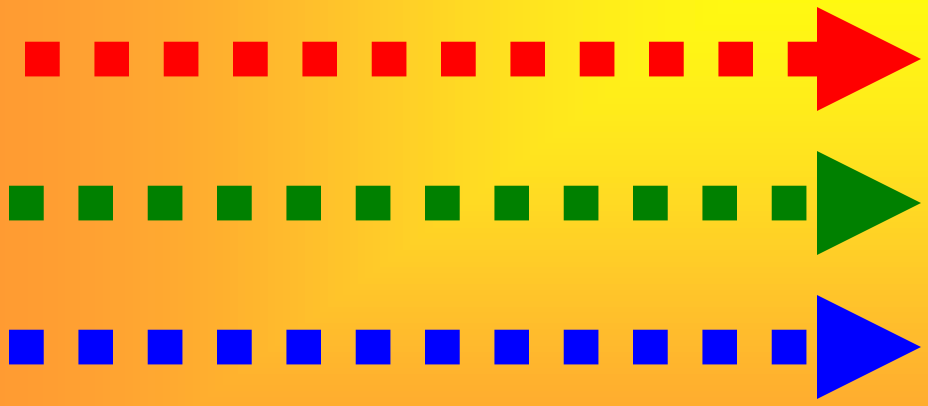
2 fermions



4 scalars

4 scalars

inside leptons

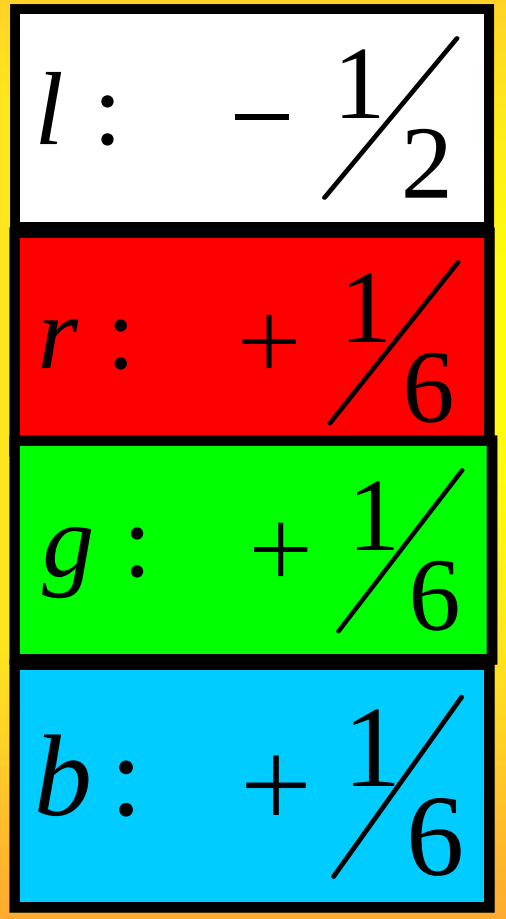


inside quarks

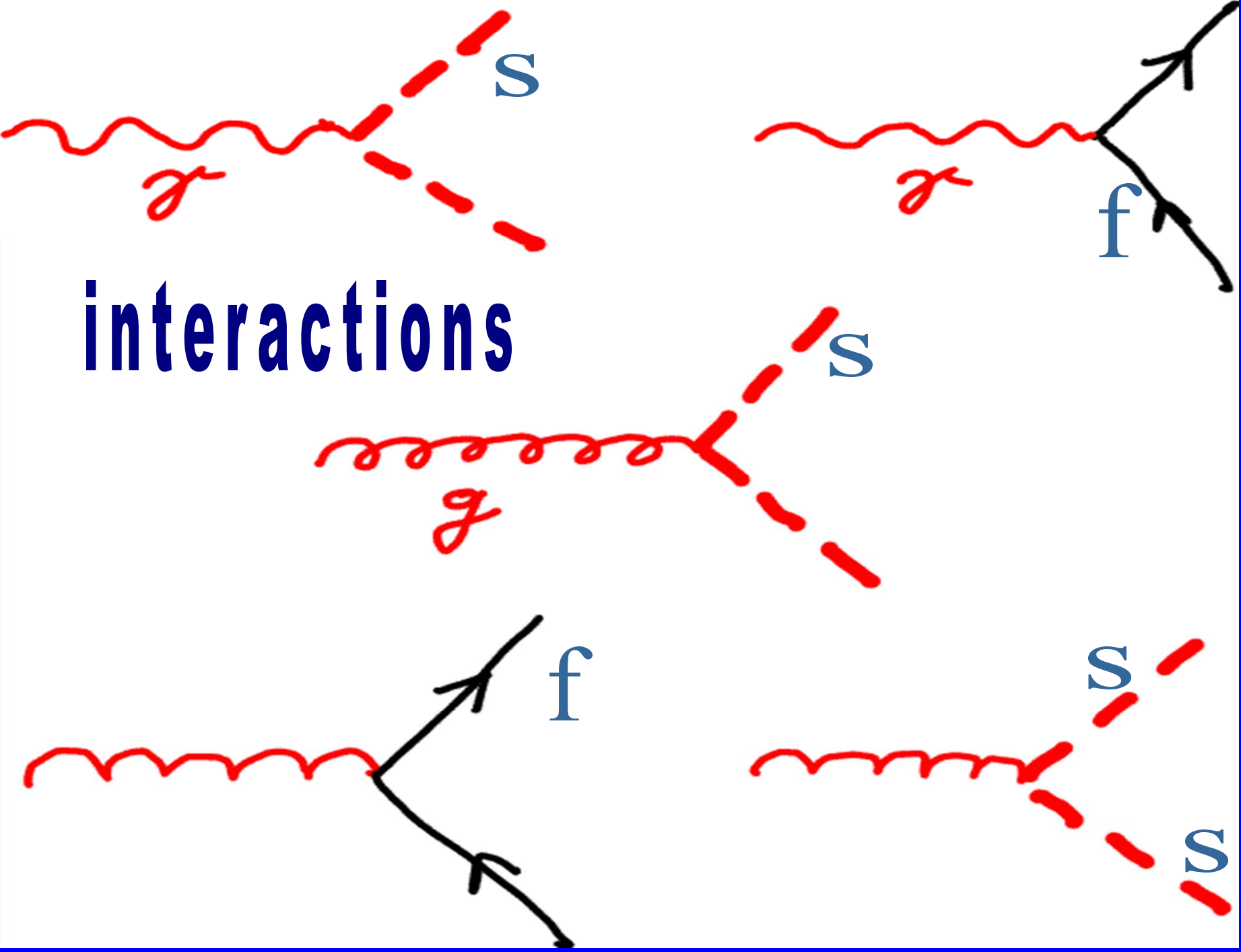
electric charges

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

electric charges



interactions



leptons

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

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

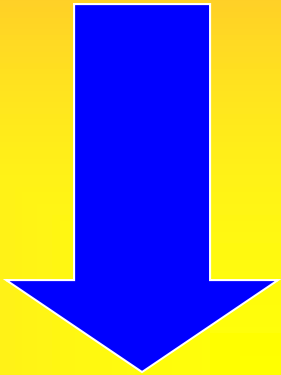
$$(\alpha r): u_r, c_r, t_r$$

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

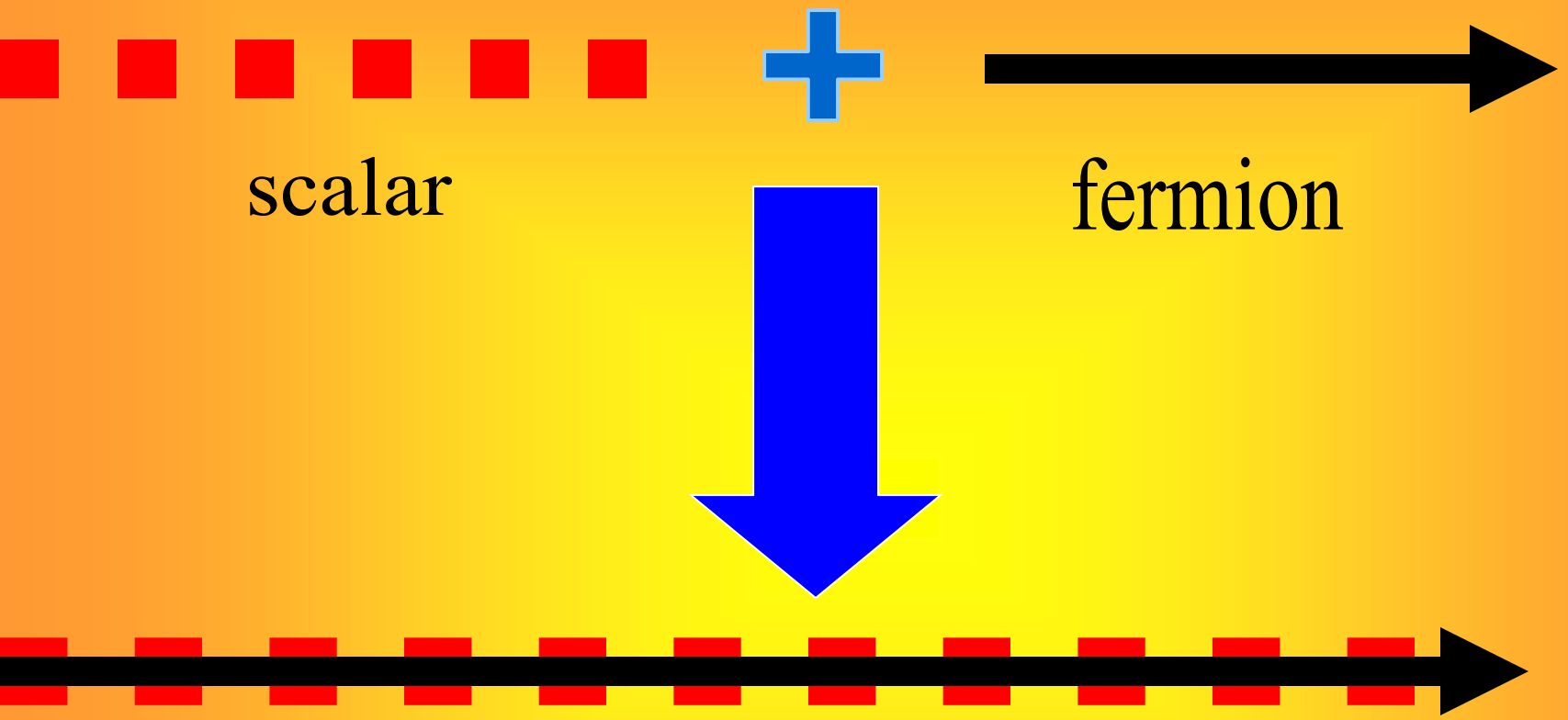
red quarks

scalar

fermion



electron



red quark

resonances above 1 TeV:

$(\bar{f}f)$ boson

$(\bar{s}s)$ boson

$(\bar{s}f)$ fermion

cross section for QHD interaction?

comparison with proton - proton inelastic scattering:

size:

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

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

comparison with proton - proton inelastic scattering:

size:

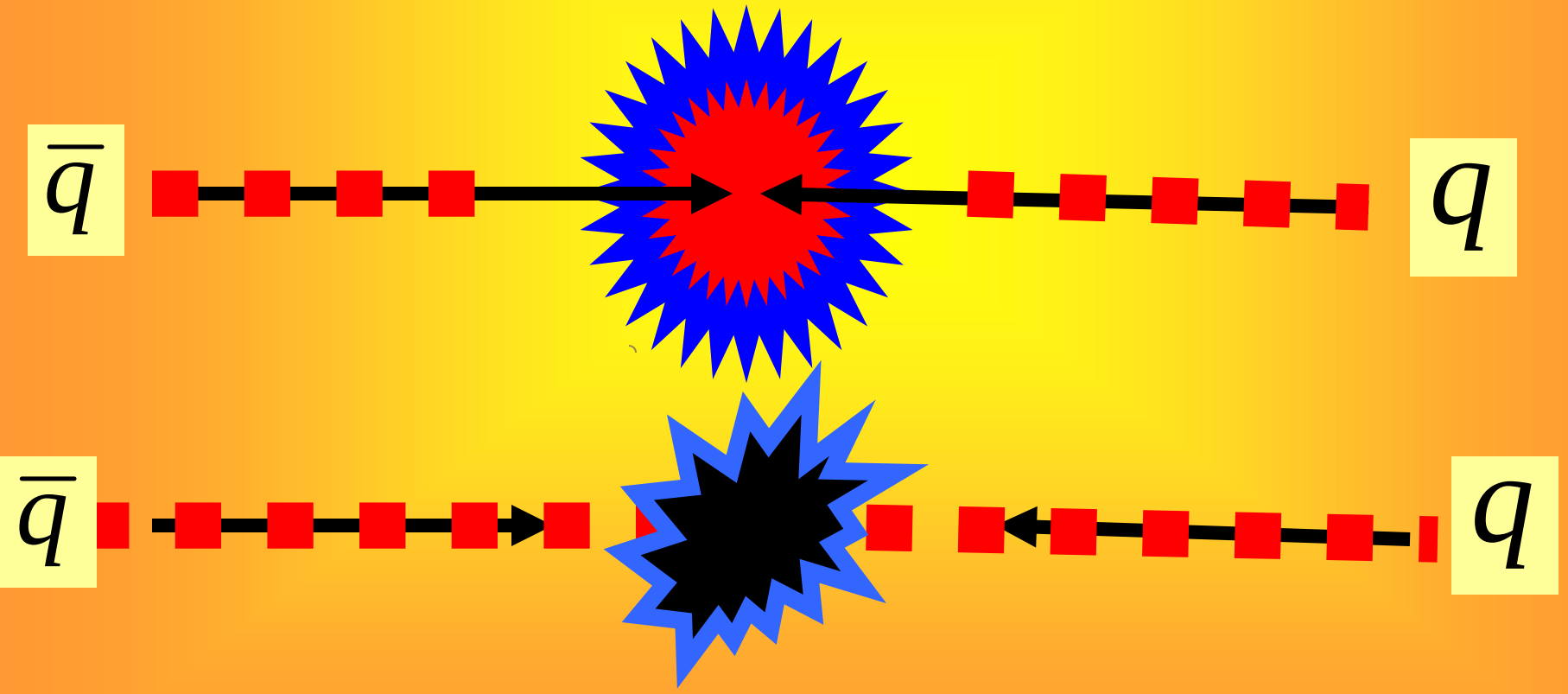
$$quark: 10^{-17}\, cm$$

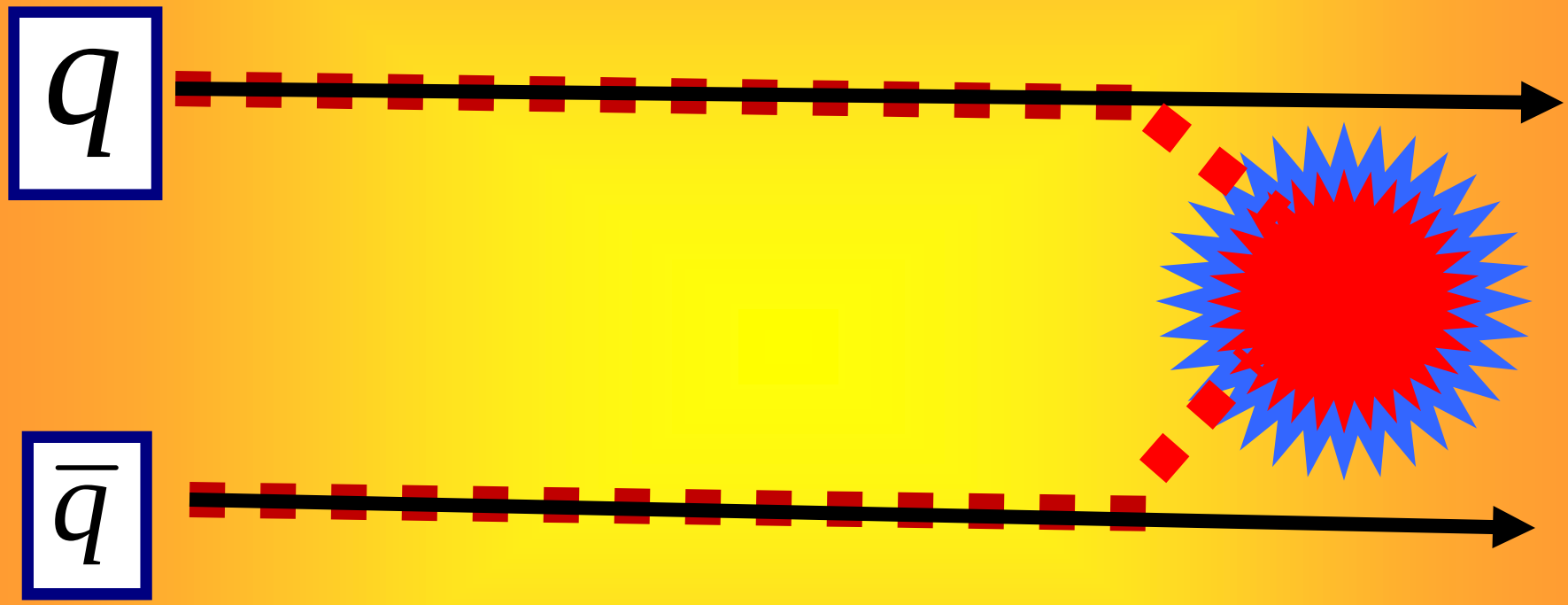
$$\sigma(qq) \approx 10^{-6} 60 \quad mb = 60 \quad nb$$

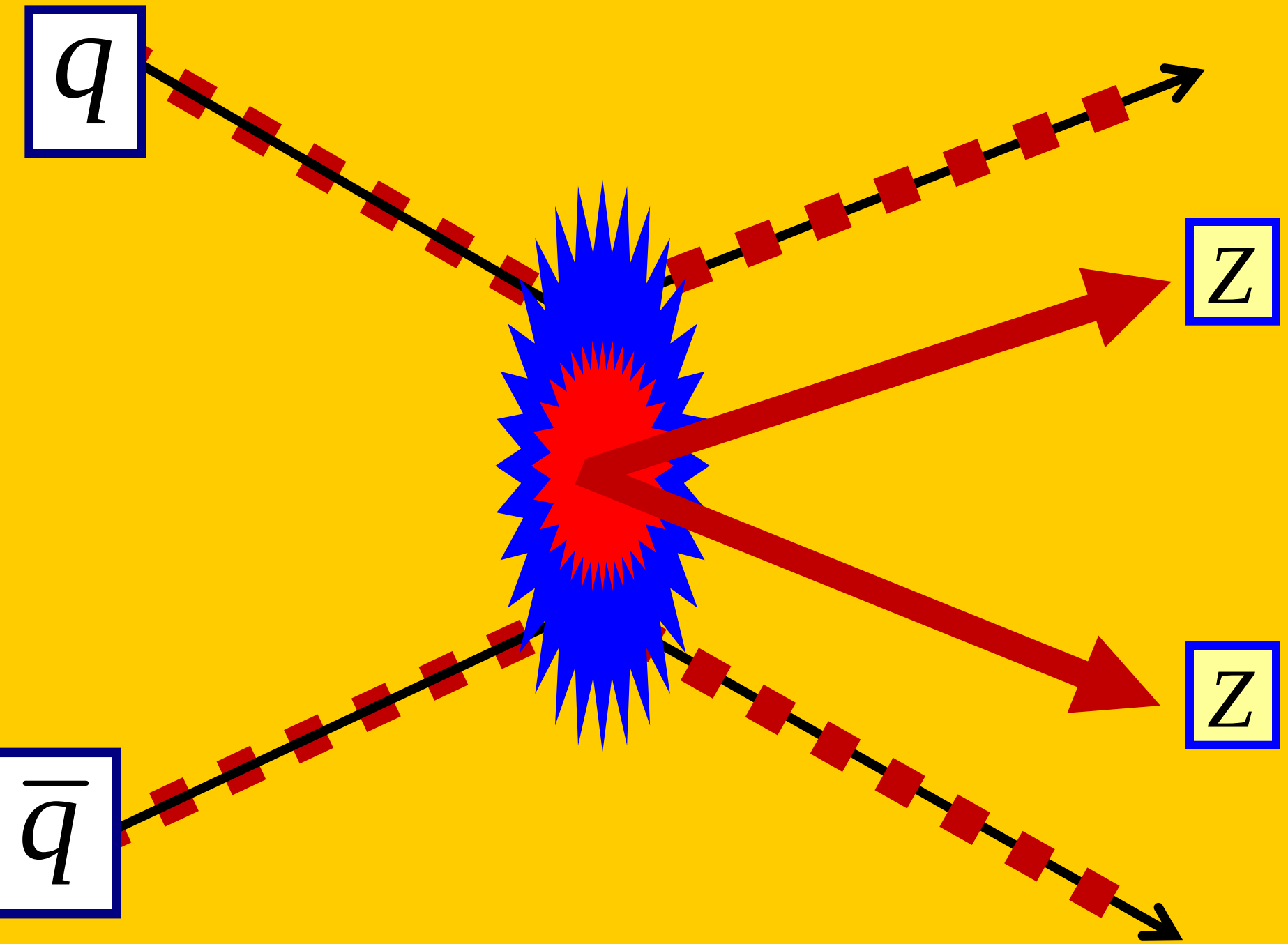
$$\sigma(qq - gq - gg)$$

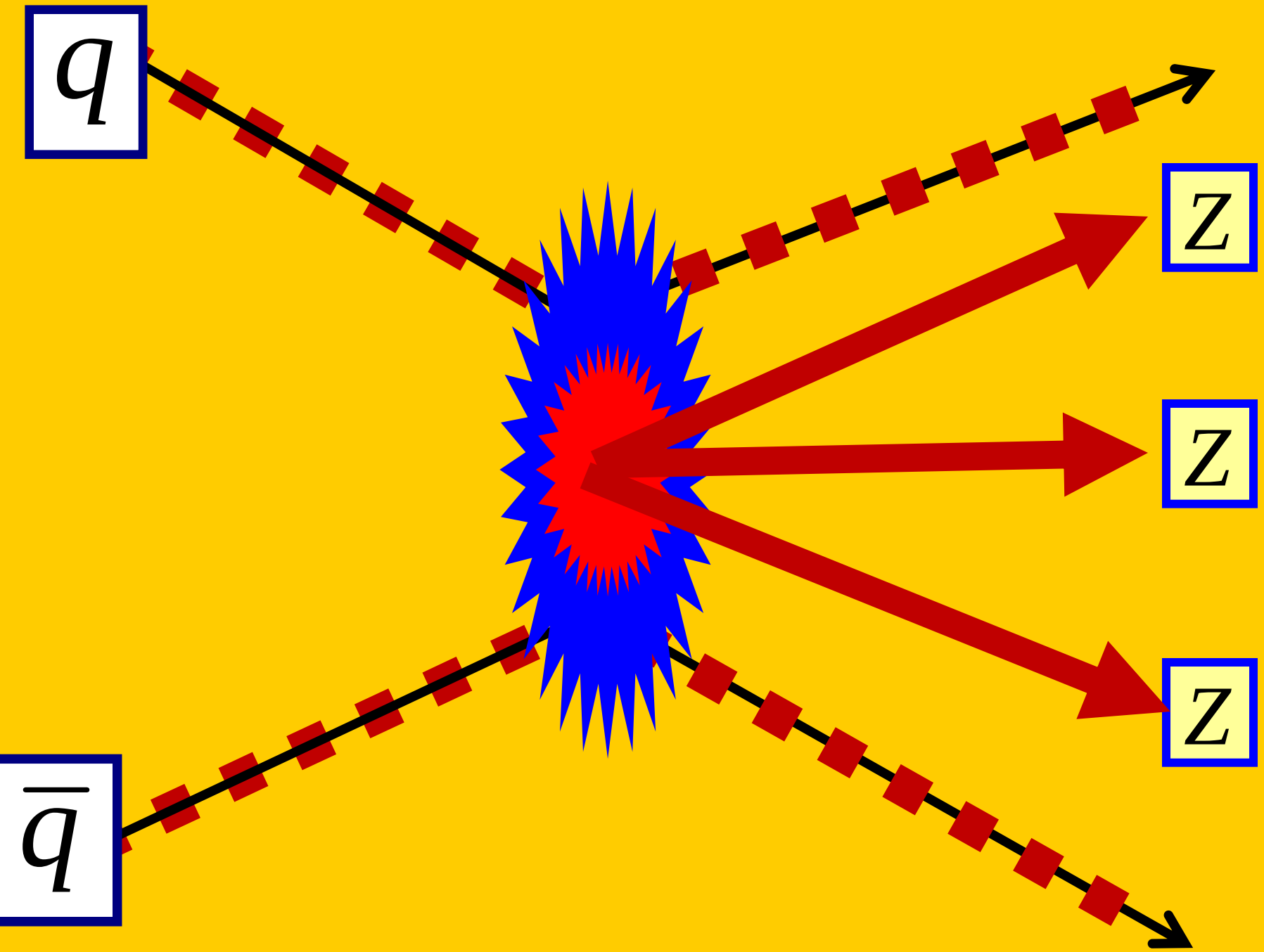
$$\propto 10 \bullet 60 \quad nb \approx 600 \quad nb$$

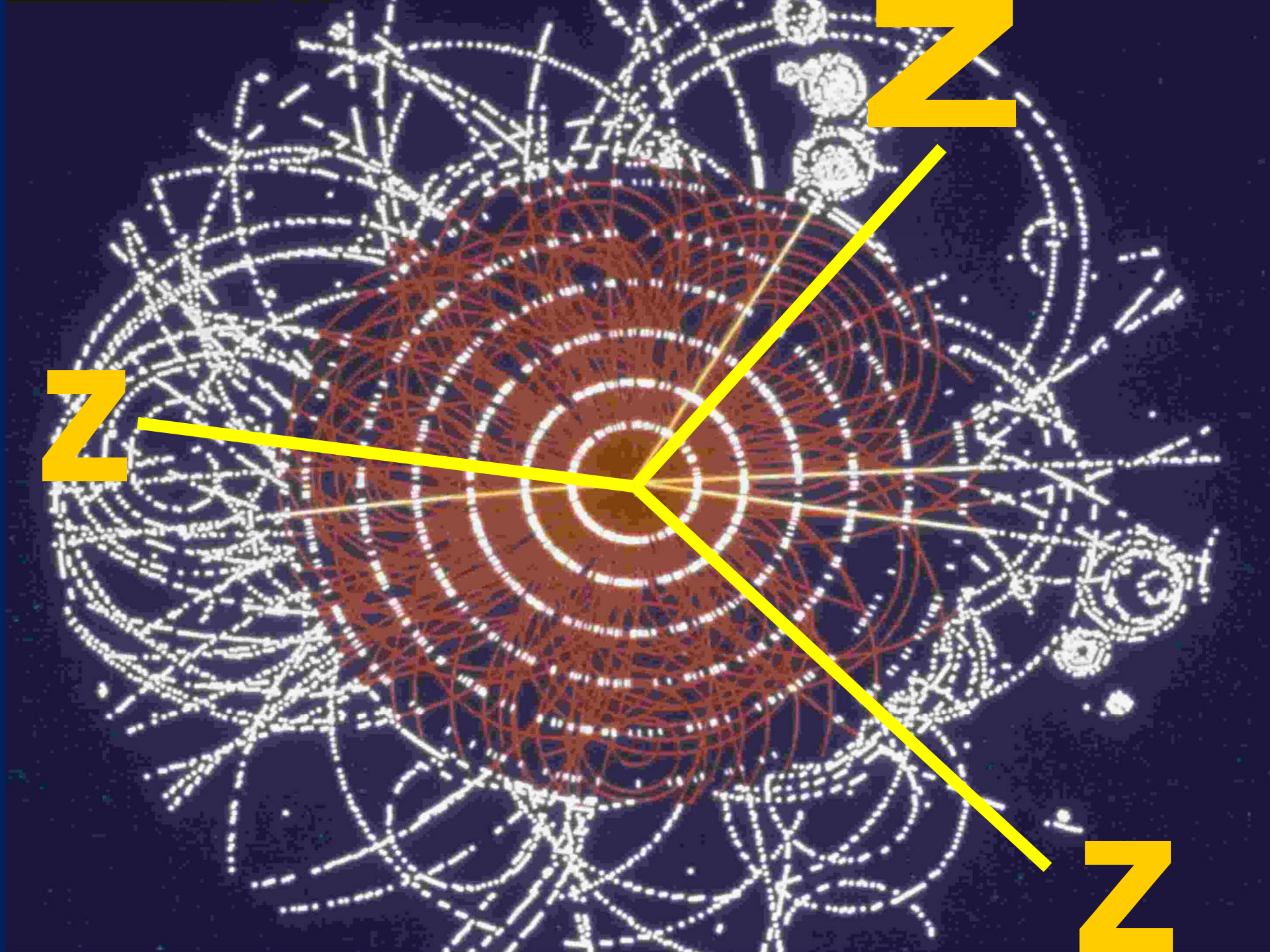
quark – antiquark scattering:

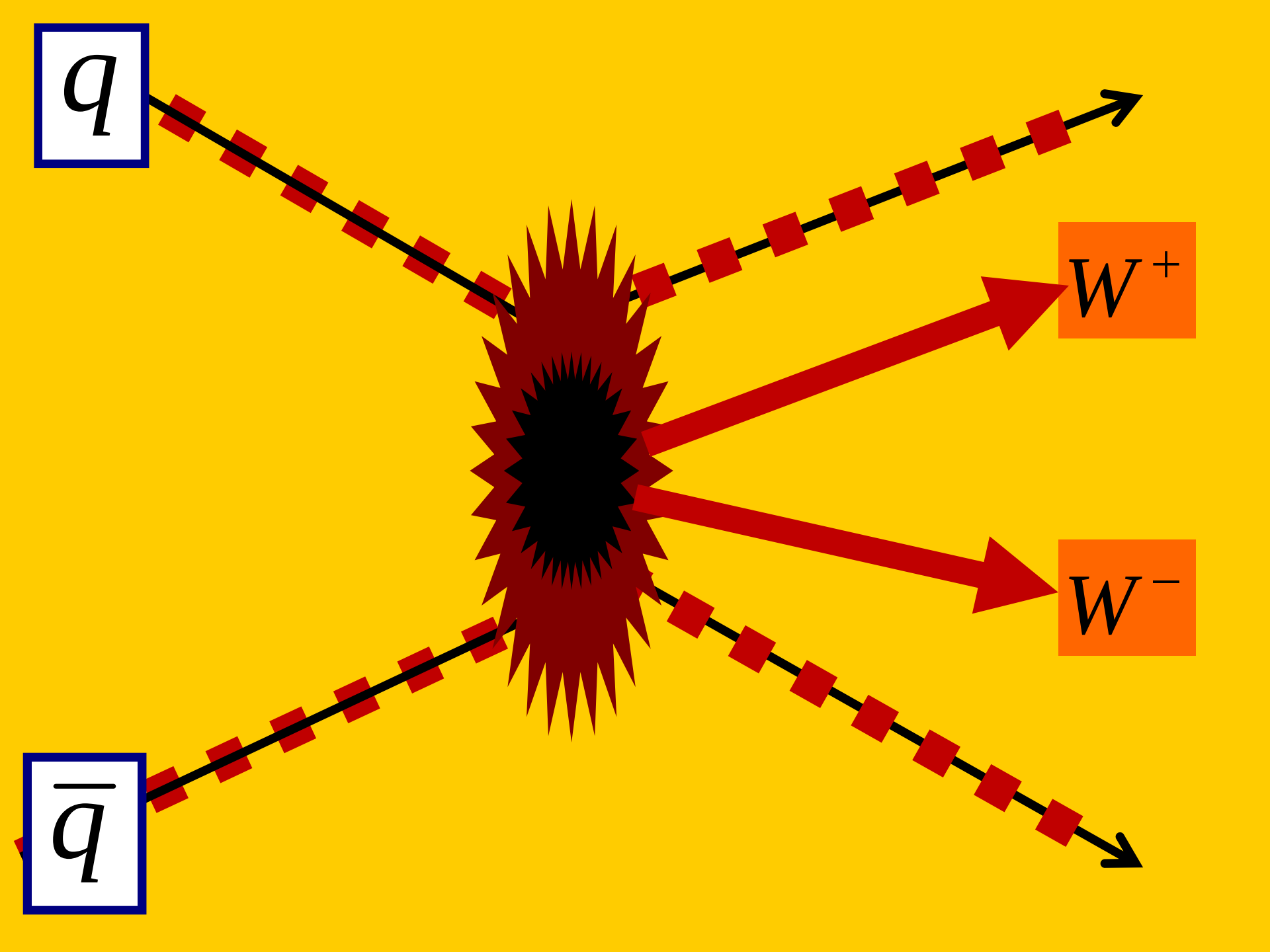


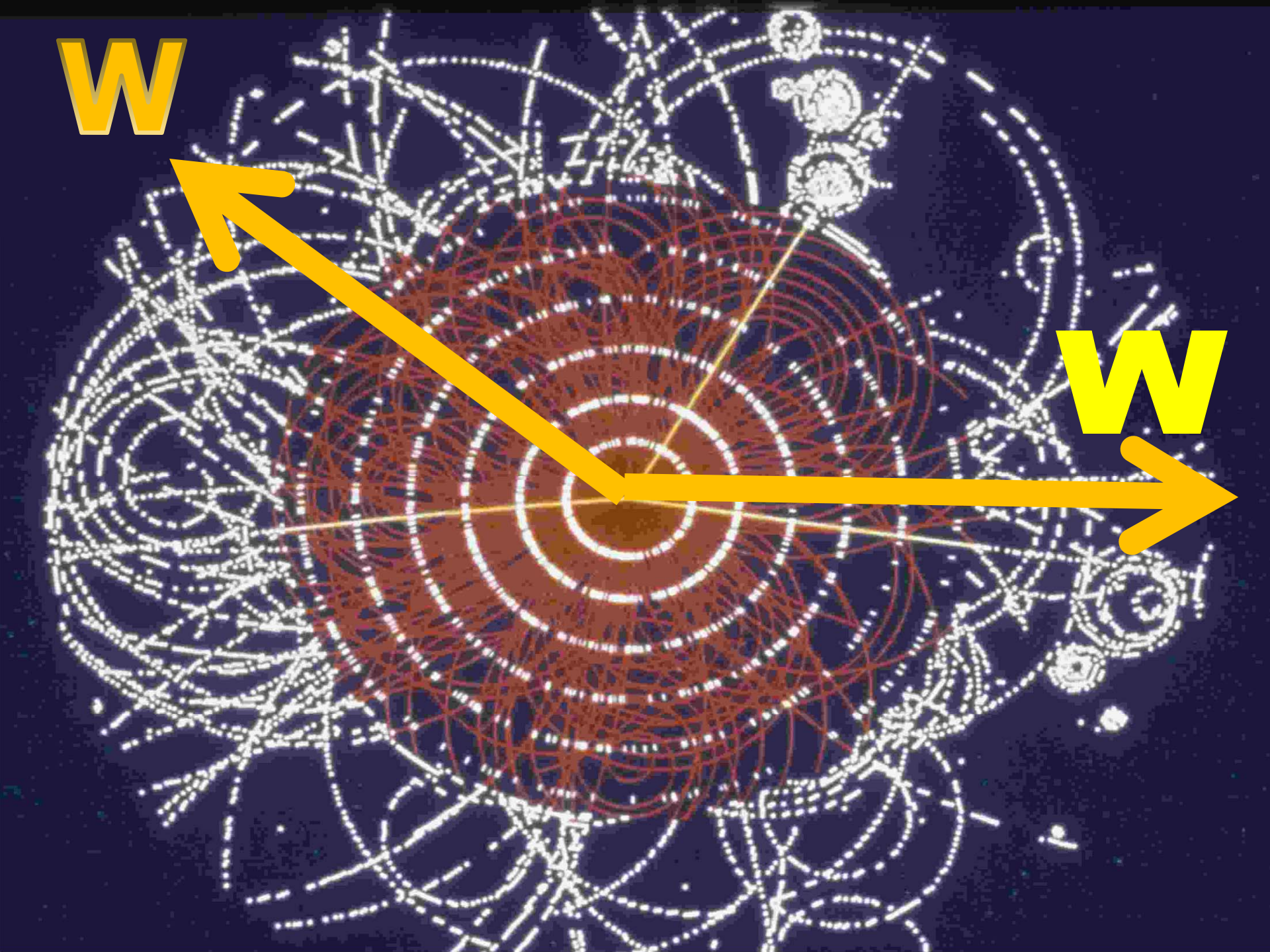

q
$\overline{q}$

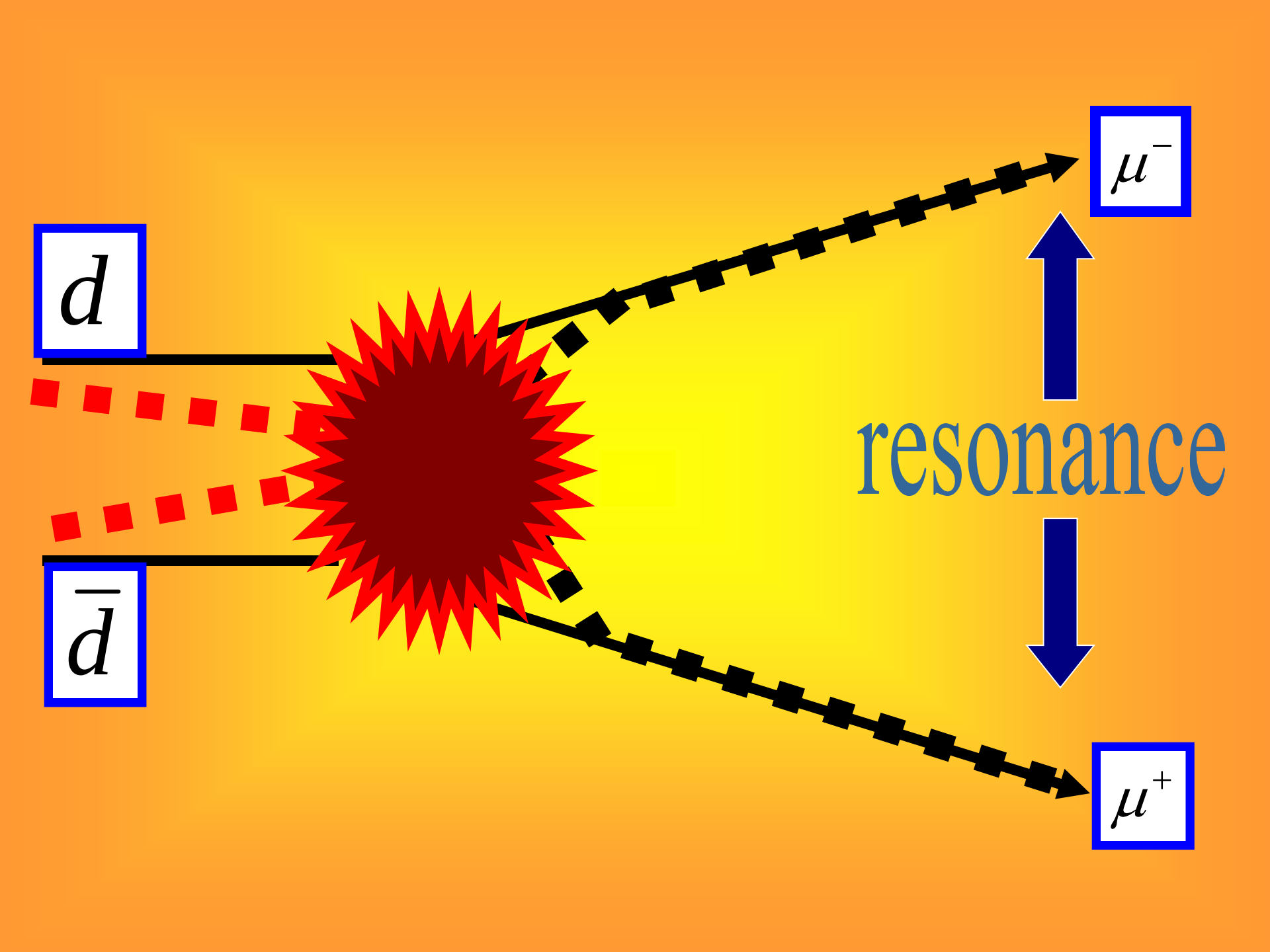

q
$\bar{q}$
Z
Z

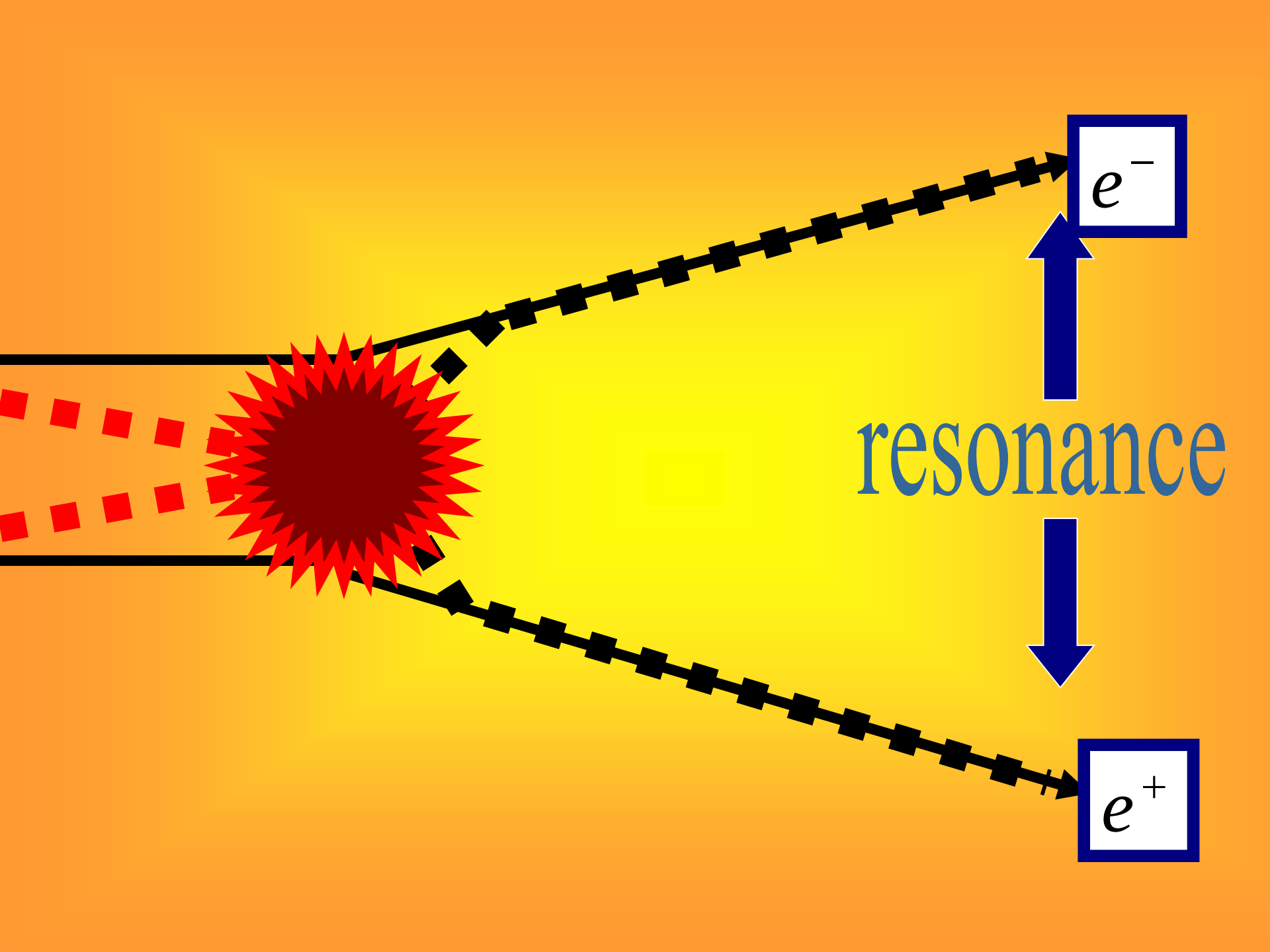

q
$\bar{q}$
Z
Z
Z

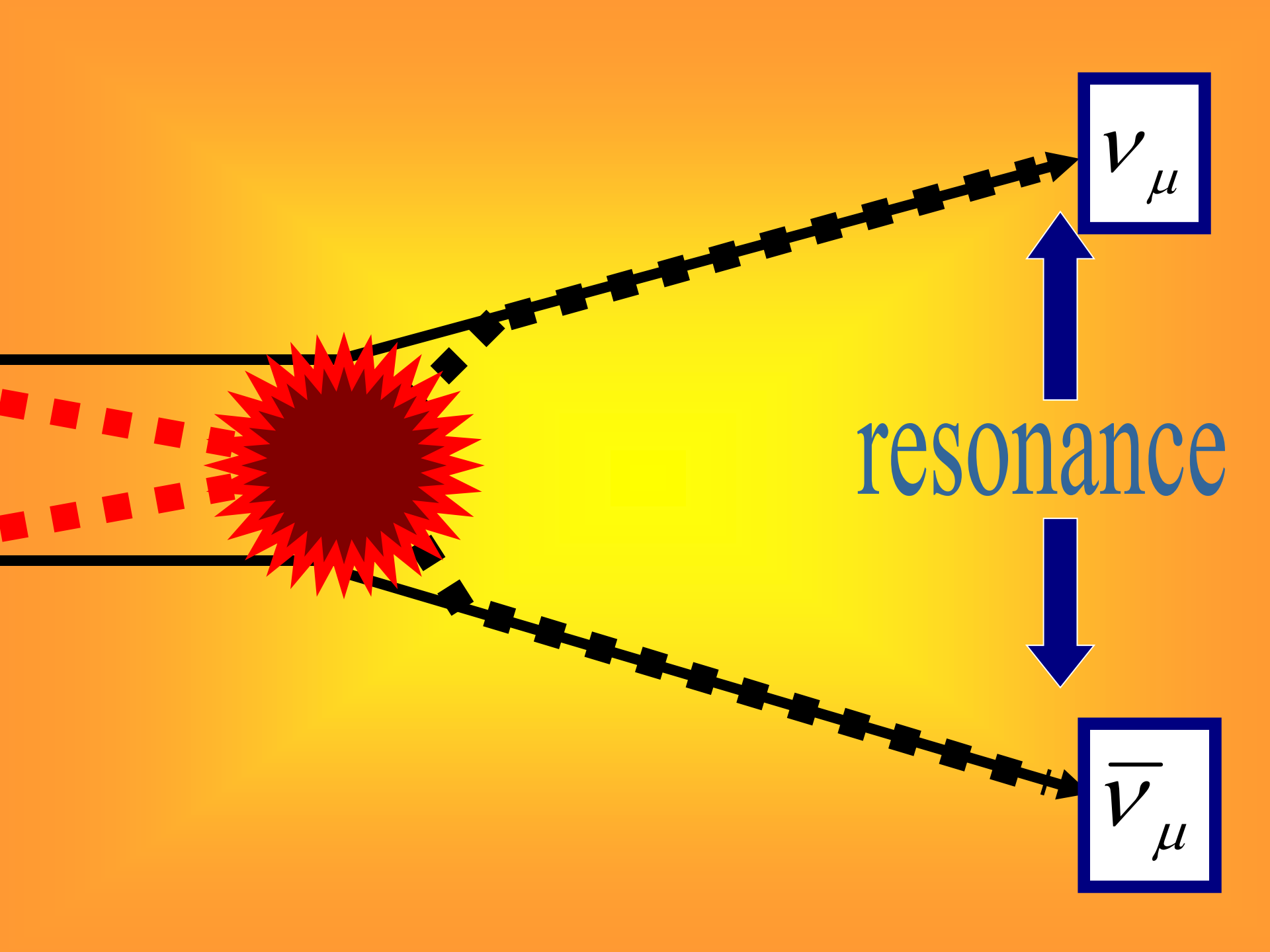

Z
Z
Z

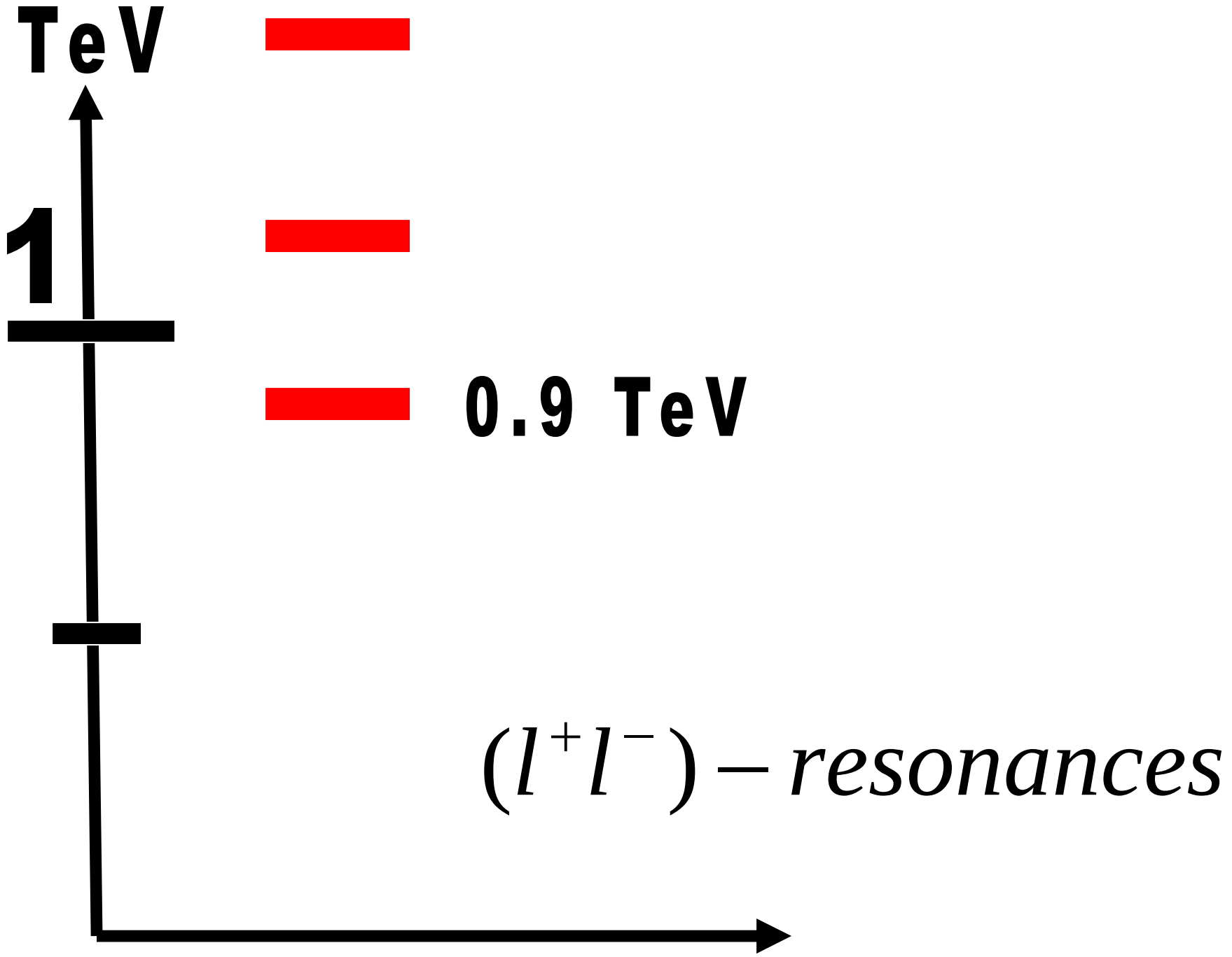

q
$\bar{q}$
W^+
W^-

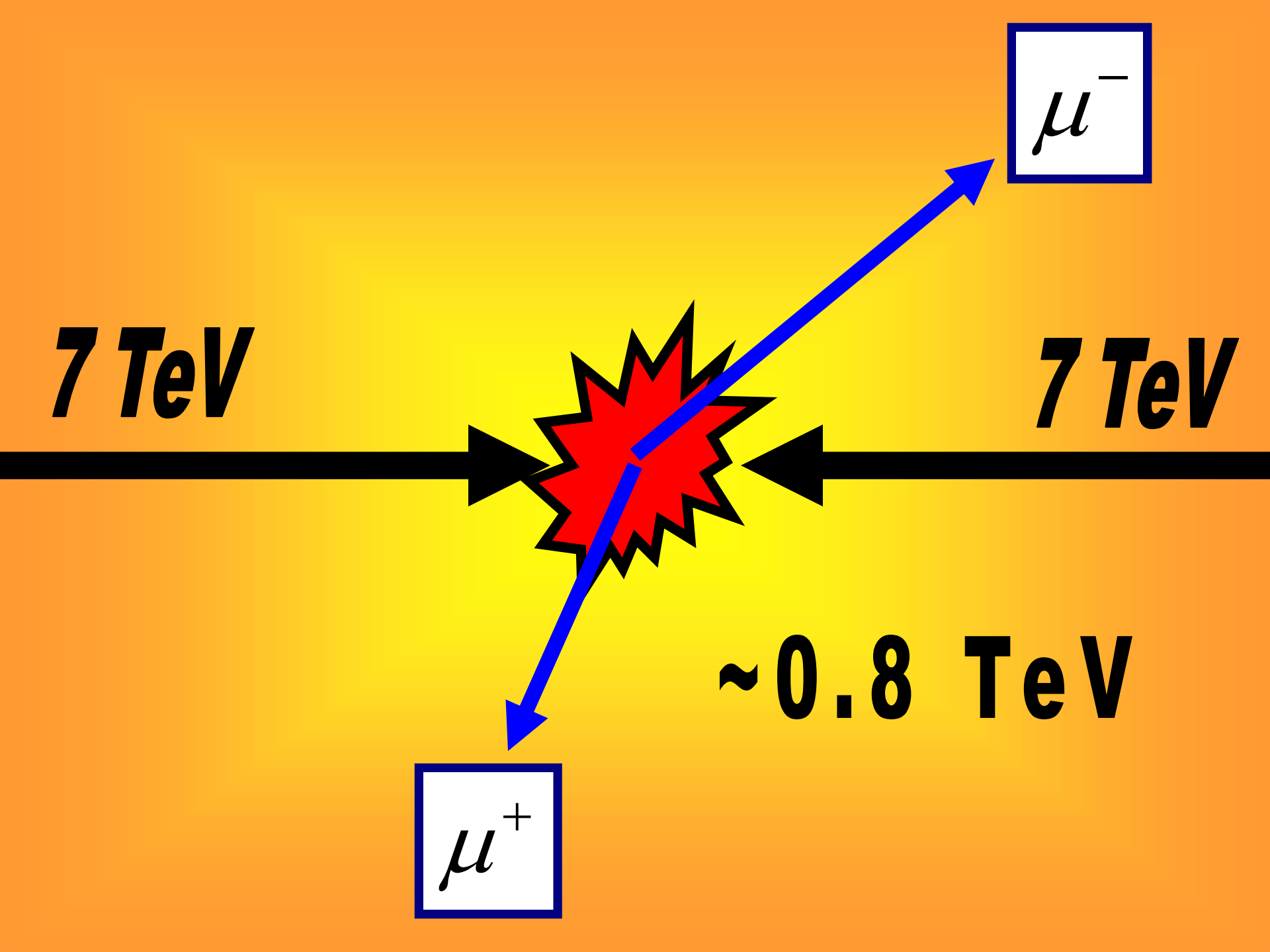

W
W

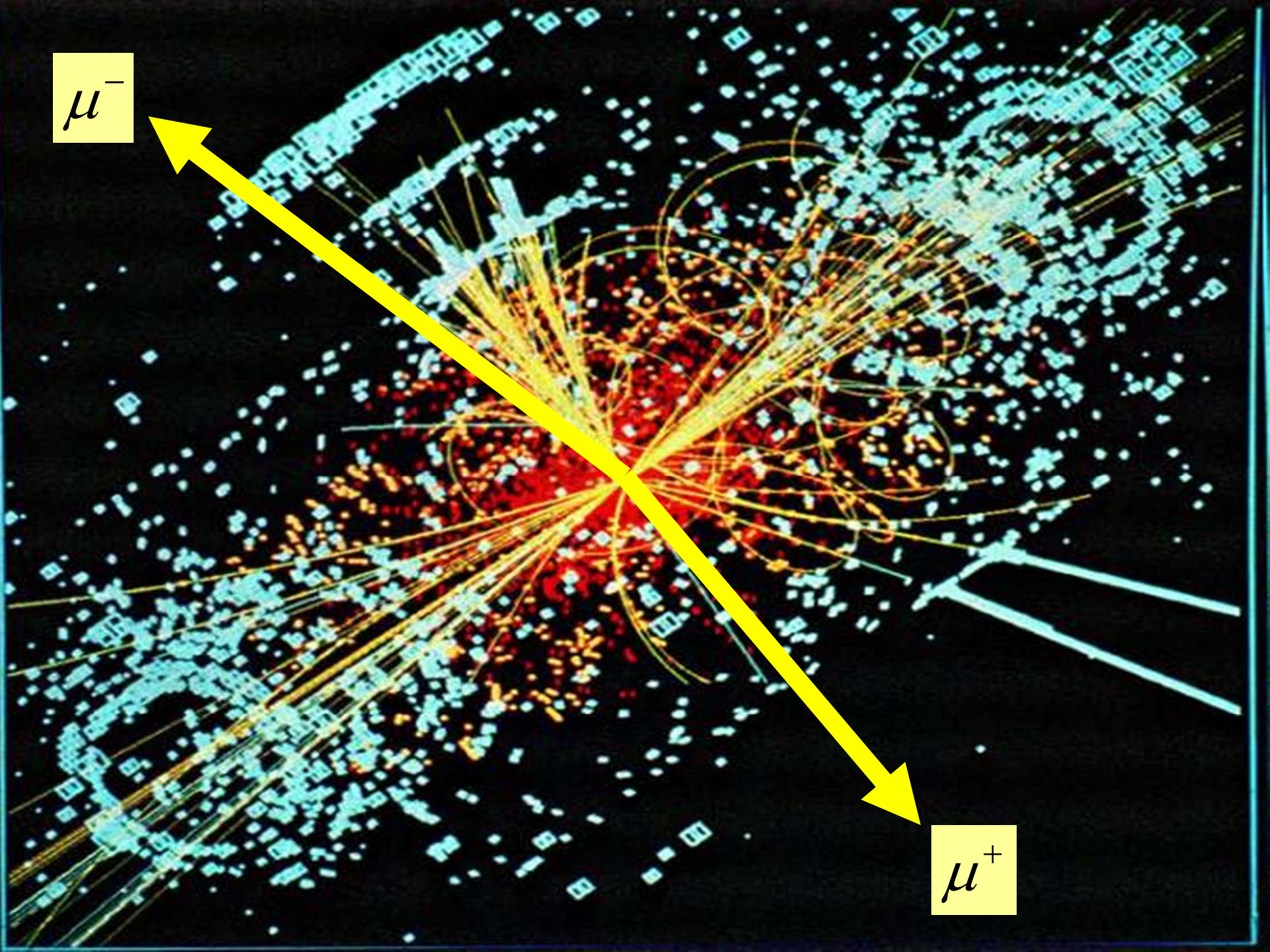

d
$\bar{d}$
μ^-
μ^+
resonance


e^-
resonance
e^+


ν_μ
resonance
$\bar{\nu}_\mu$


TeV
1
0.9 TeV
$(l^+l^-) - resonances$


μ^-
7 TeV
7 TeV
~0.8 TeV
μ^+


μ^-
μ^+

lepton–antilepton resonances

quark – antiquark resonances

Conclusions

weak bosons,
leptons and quarks
are composite systems

weak boson =>
fermion + antifermion

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lepton, quark =>
fermion + scalar

Z - boson

X-boson

QHD resonances