The BEH mechanism and its scalar boson

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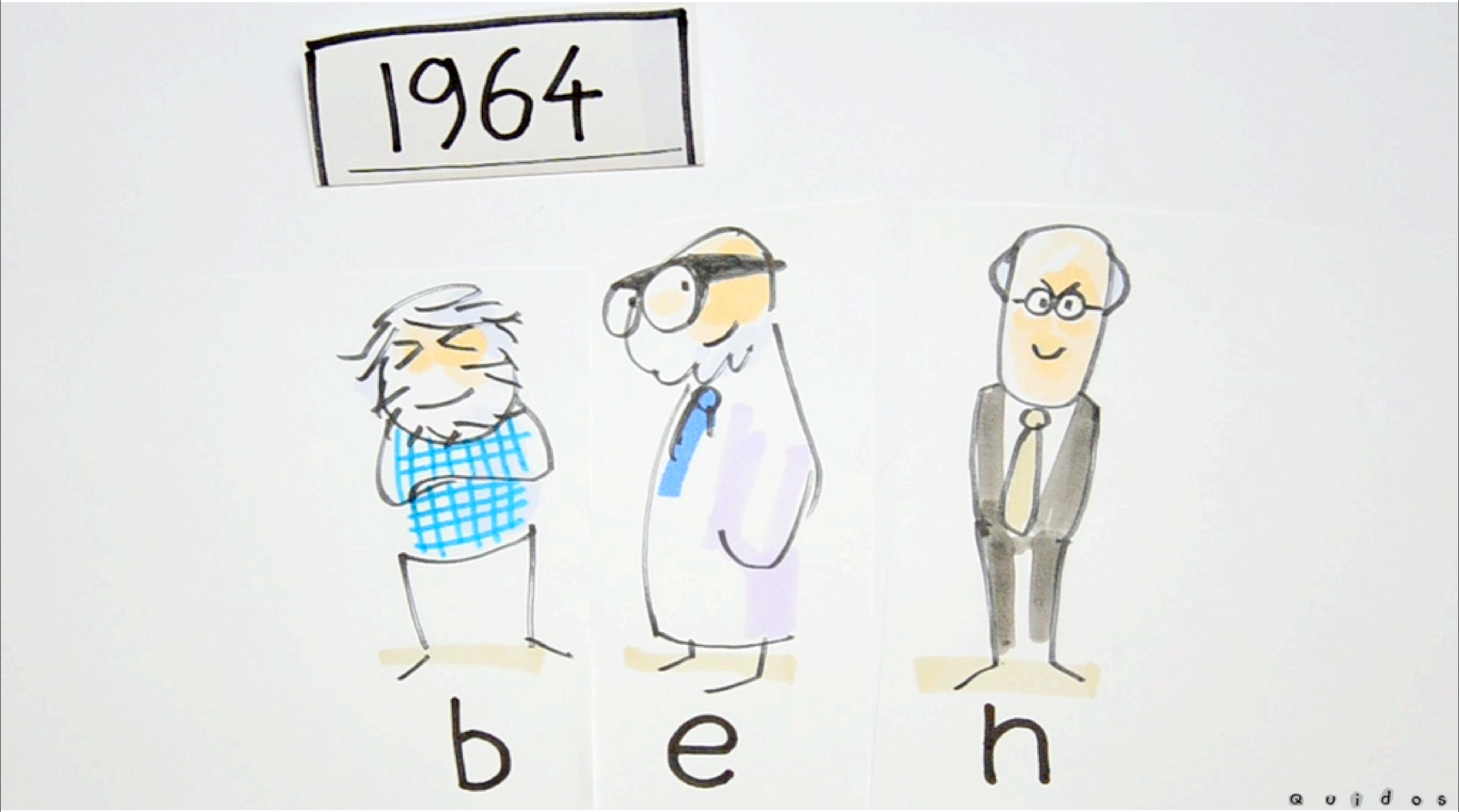


Nobel Lecture 2013

I. Introduction: short and long range interactions

long range interactions

general relativity

electromagnetism
(quantum electrodynamics)

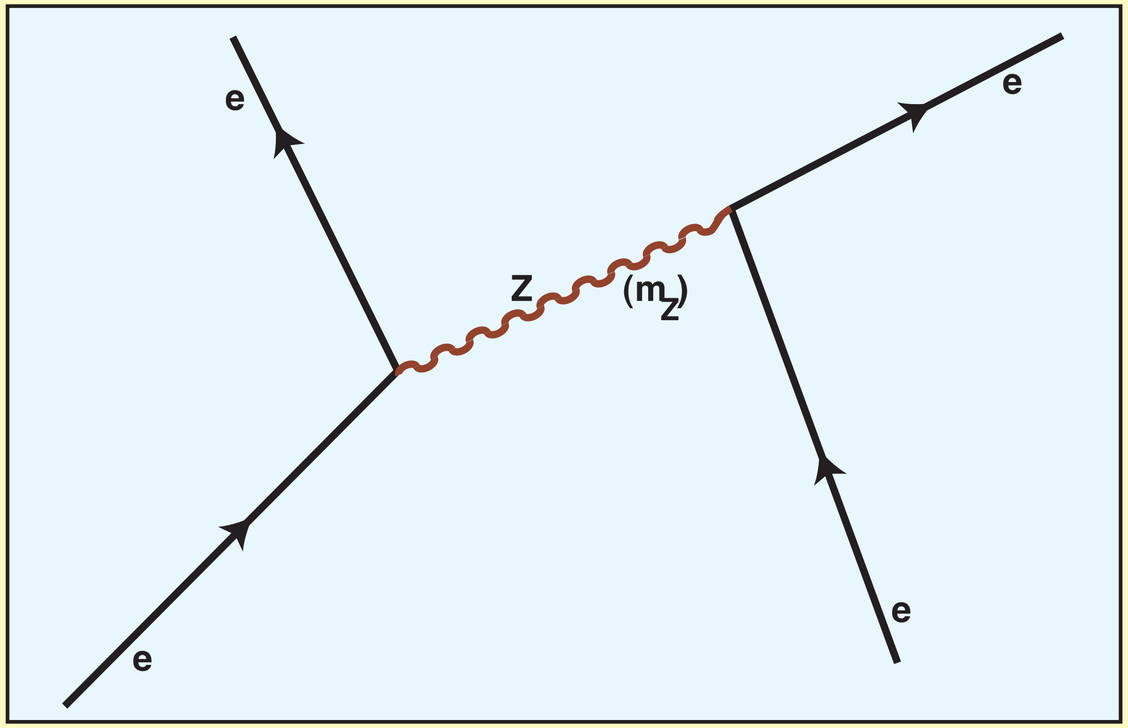
zero mass vector bosons

transverse polarization

local symmetry

Yang-Mills gauge fields

short range interactions



how to get vector boson masses ?

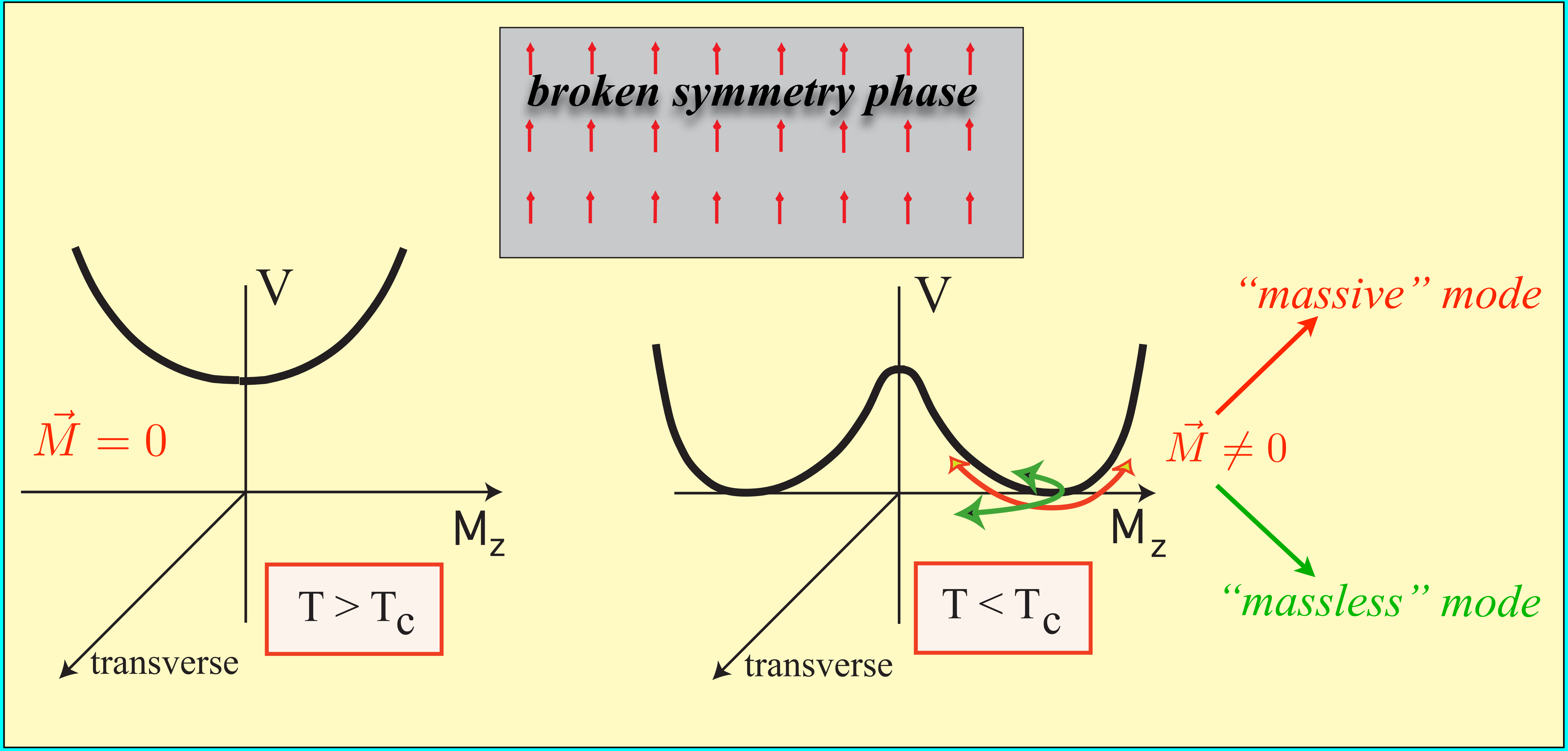
Spontaneous Symmetry Breaking ?

II. Spontaneous symmetry breaking

1. Spontaneous symmetry breaking in phase transitions

L.D. Landau, Phys. Z. Sowjet. **11** (1937) 26 [JETP **7** (1937) 19].

Ferromagnetism



Superconductivity

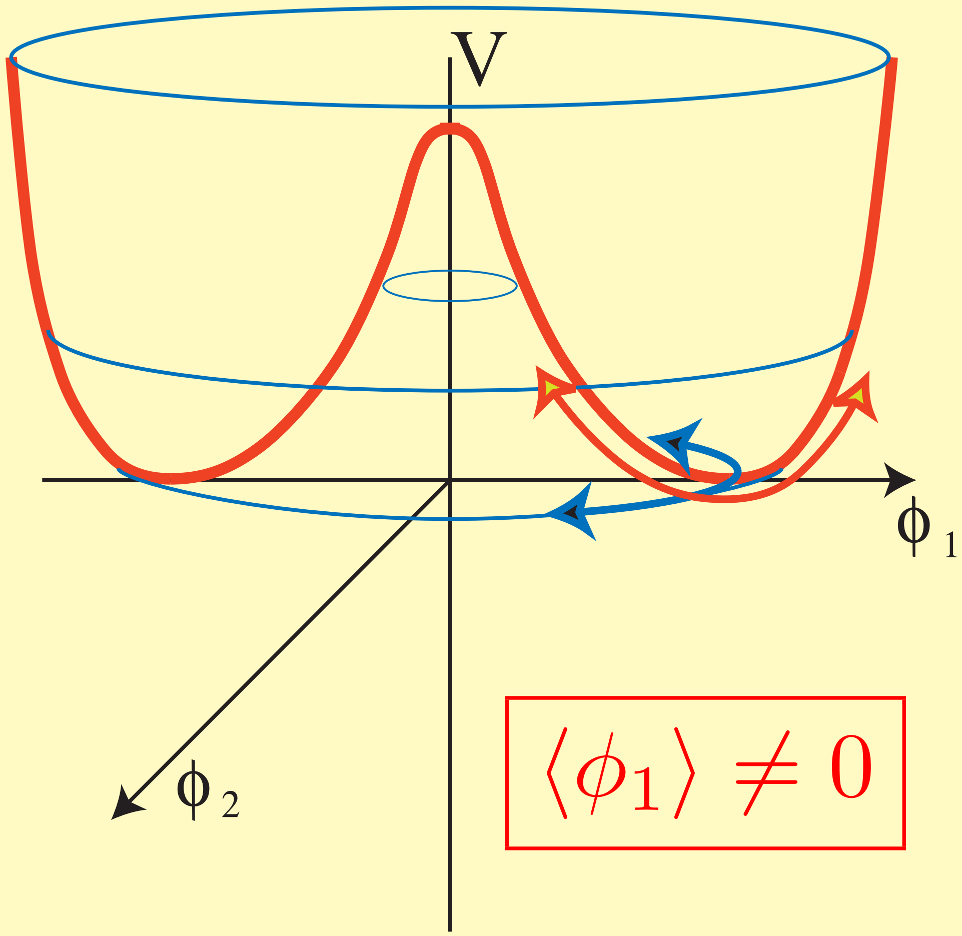
P.W. Anderson, Phys. Rev. **112** (1958) 1900; Y. Nambu, Phys.Rev. **117** (1960) 648; P.W. Anderson, Phys. Rev. **130** (1962) 439.

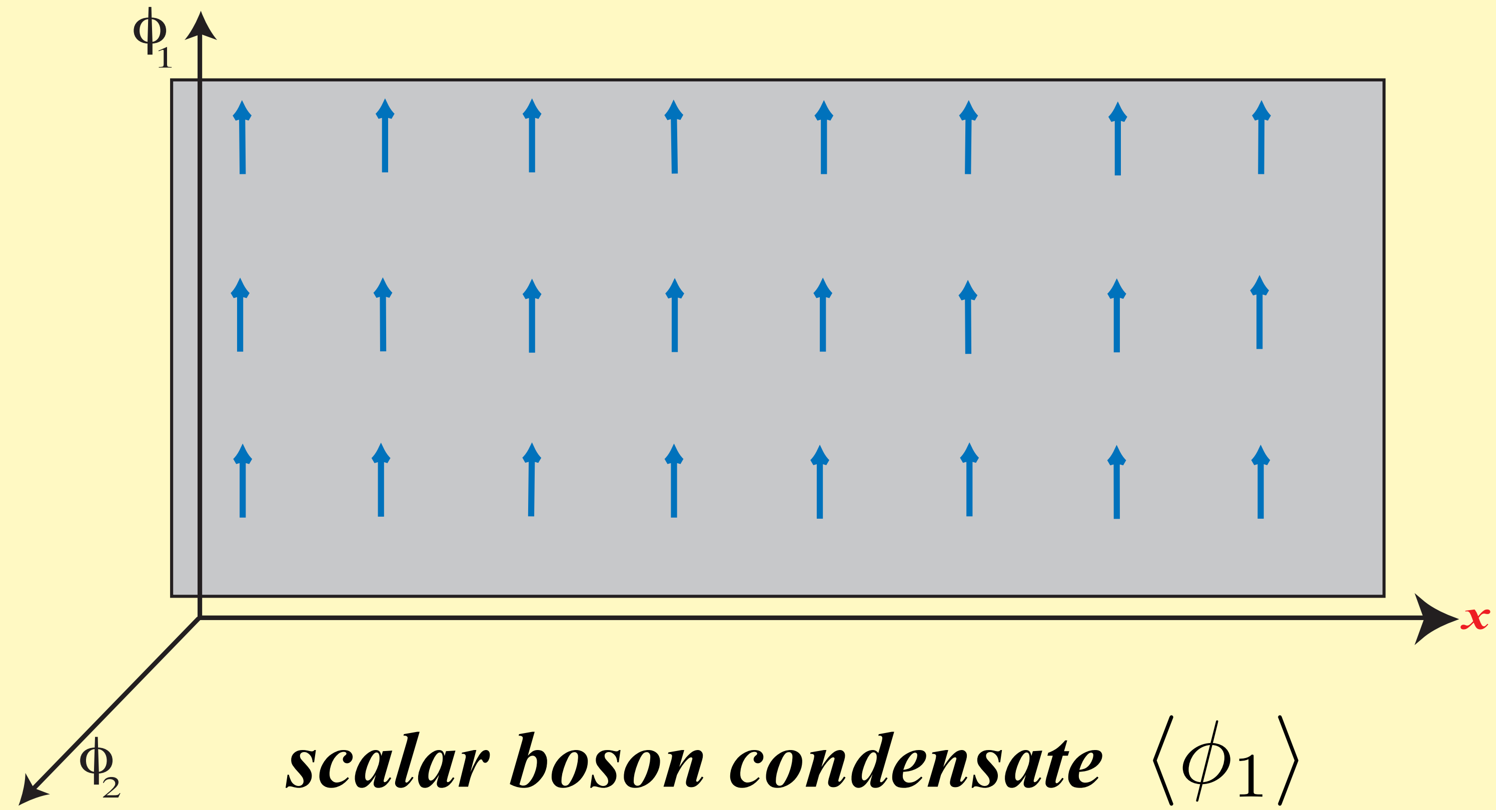
2. Spontaneous symmetry breaking in field theory

[1960] Y. Nambu (Nobel Prize 2008)

Y. Nambu, Phys. Rev. Lett. **4** (1960) 380; Y. Nambu and G. Jona-Lasinio, Phys. Rev. **122** (1961) 345, Phys. Rev. **124** (1961) 246;
J. Goldstone, Il Nuovo Cimento **19** (1961) 154; J. Goldstone, A. Salam and S. Weinberg, Phys. Rev. **127** (1962) 965.

The Goldstone Model

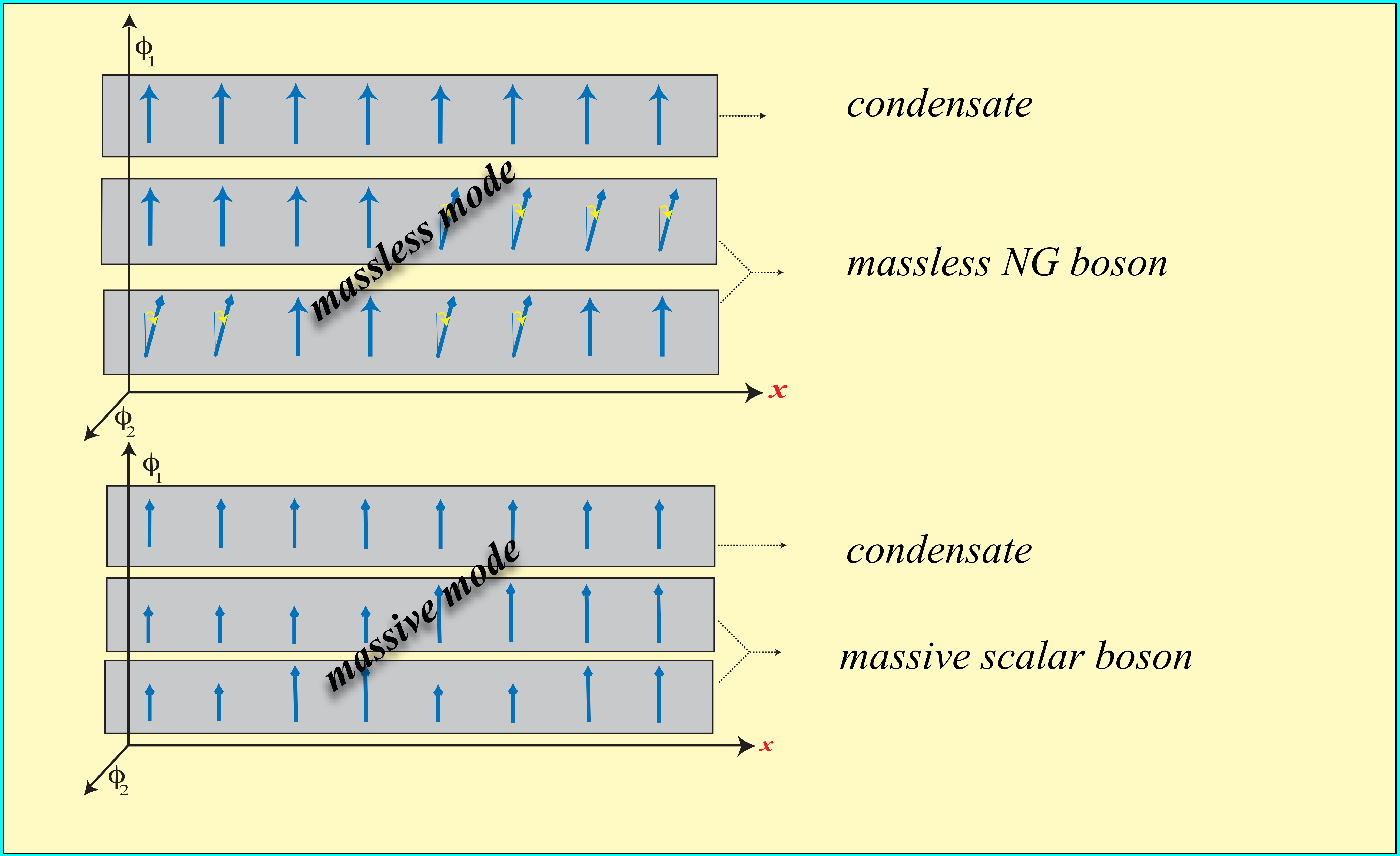




scalar boson condensate $\langle \phi_1 \rangle$

massive scalar boson $\phi_1 = \langle \phi_1 \rangle + \varphi_1$

massless NG boson $\phi_2 = \varphi_2$

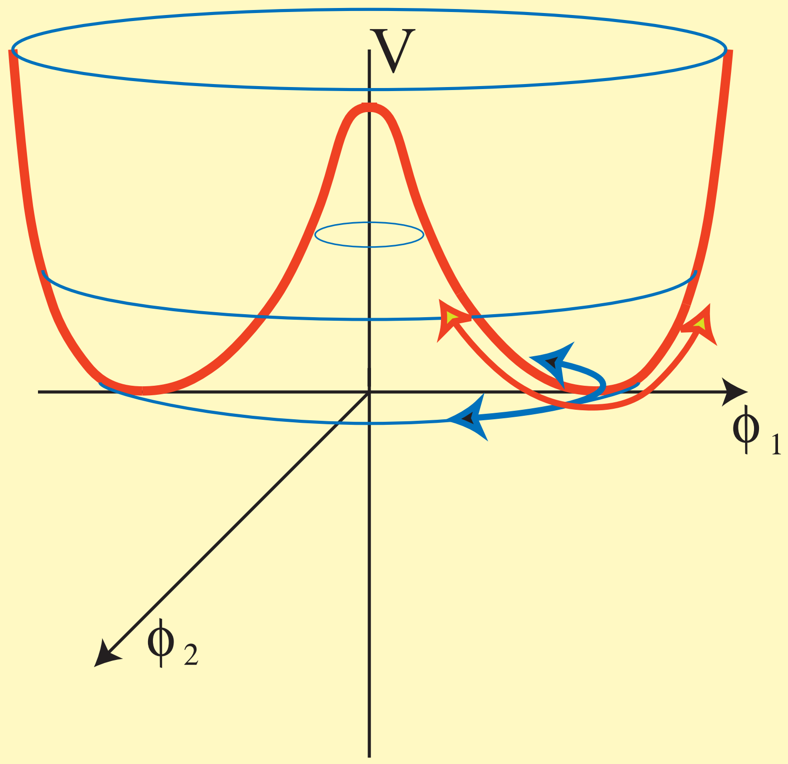

φ1
condensate
massless mode
massless NG boson
x
φ2
φ1
condensate
massive mode
massive scalar boson
x
φ2

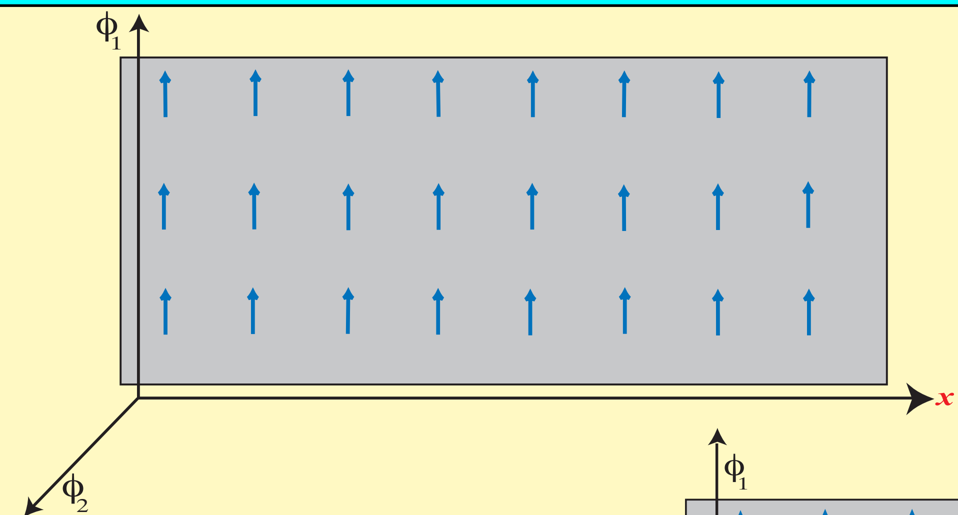
III. The BEH mechanism

F. Englert and R. Brout, Phys. Rev. Lett. **13** (1964) 321, P.W. Higgs, Phys. Rev. Lett. **13** (1964) 508.

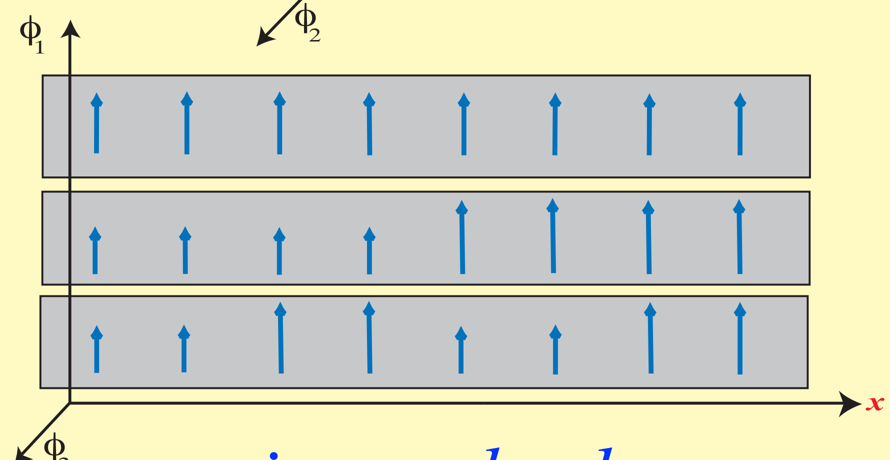
1. The fate of the Nambu-Goldstone boson

Local symmetry and gauge vector fields A_b^ν

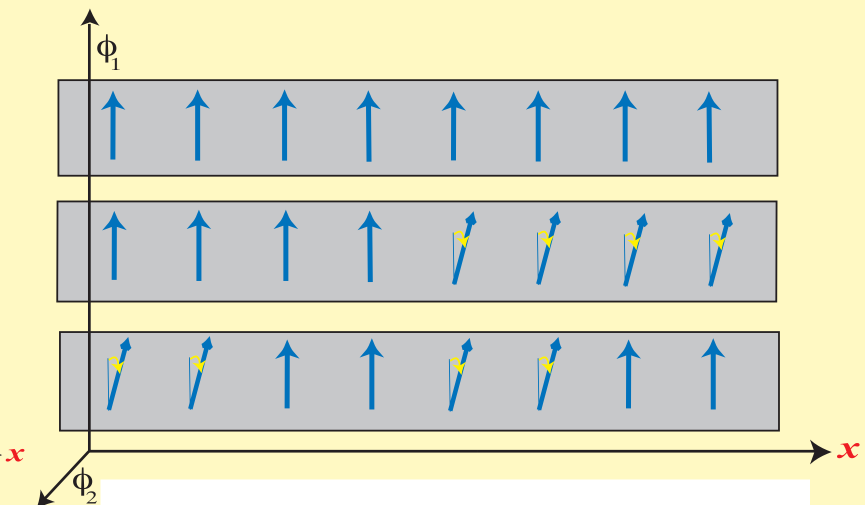




condensate



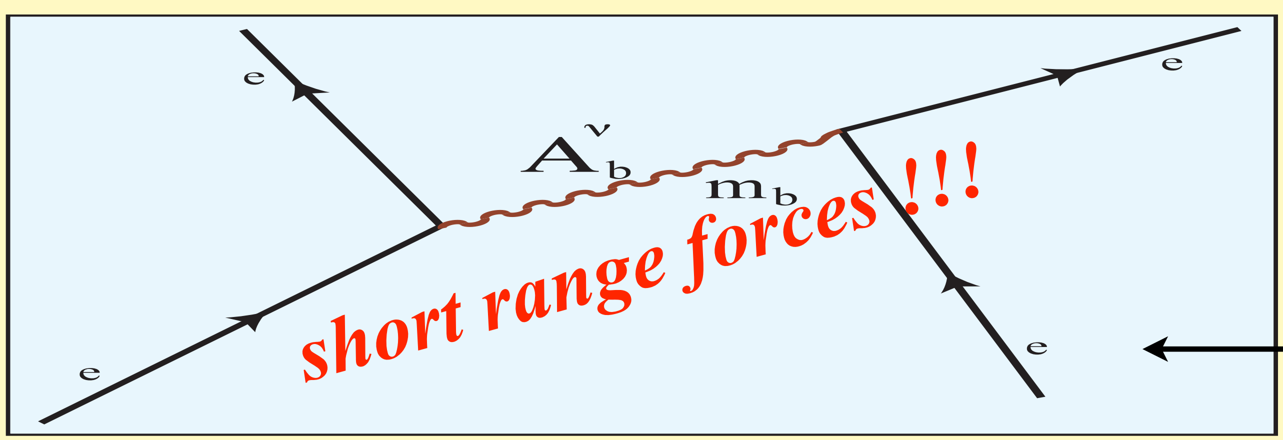
massive scalar bosons



fictitious NG bosons

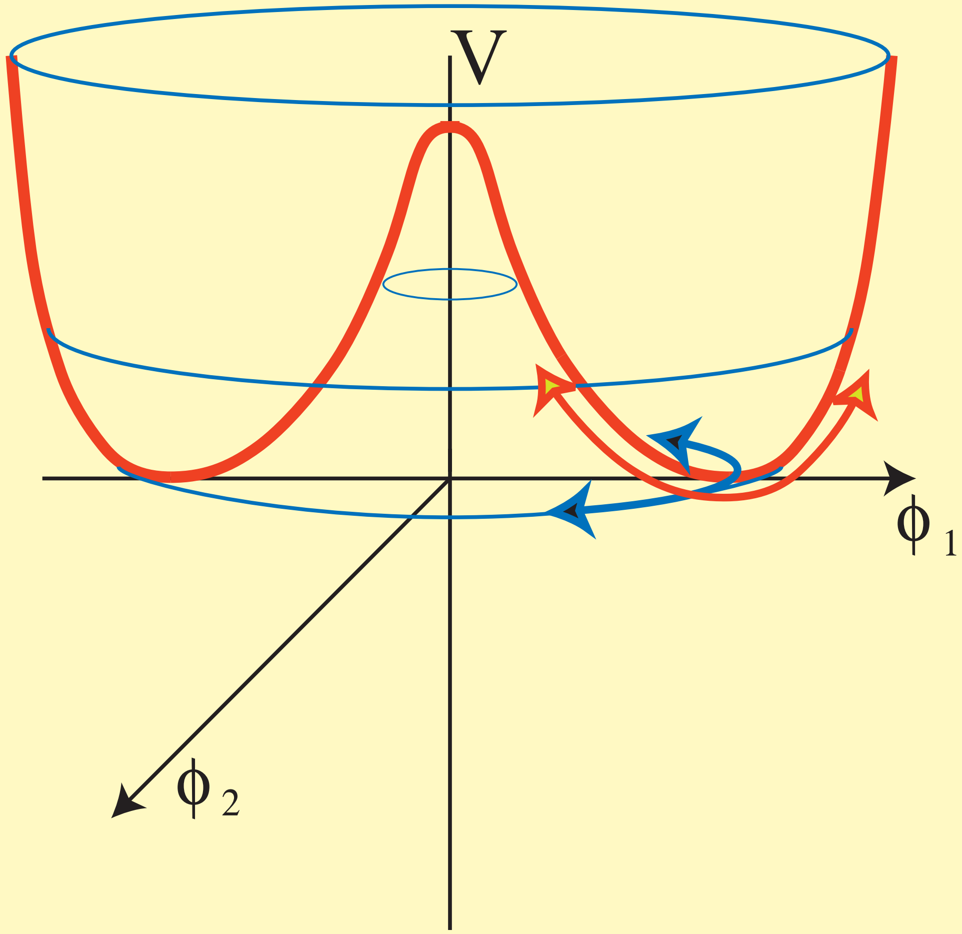
cf. P.W. Higgs, Phys. Letters **12** (1964) 132; G.S. Guralnik, C.R. Hagen and T.W.B. Kibble, Phys. Rev. Lett. **13** (1964) 585.
S. Elitzur, Phys. Rev. **D12** (1975) 3978.

absorbed by the gauge field



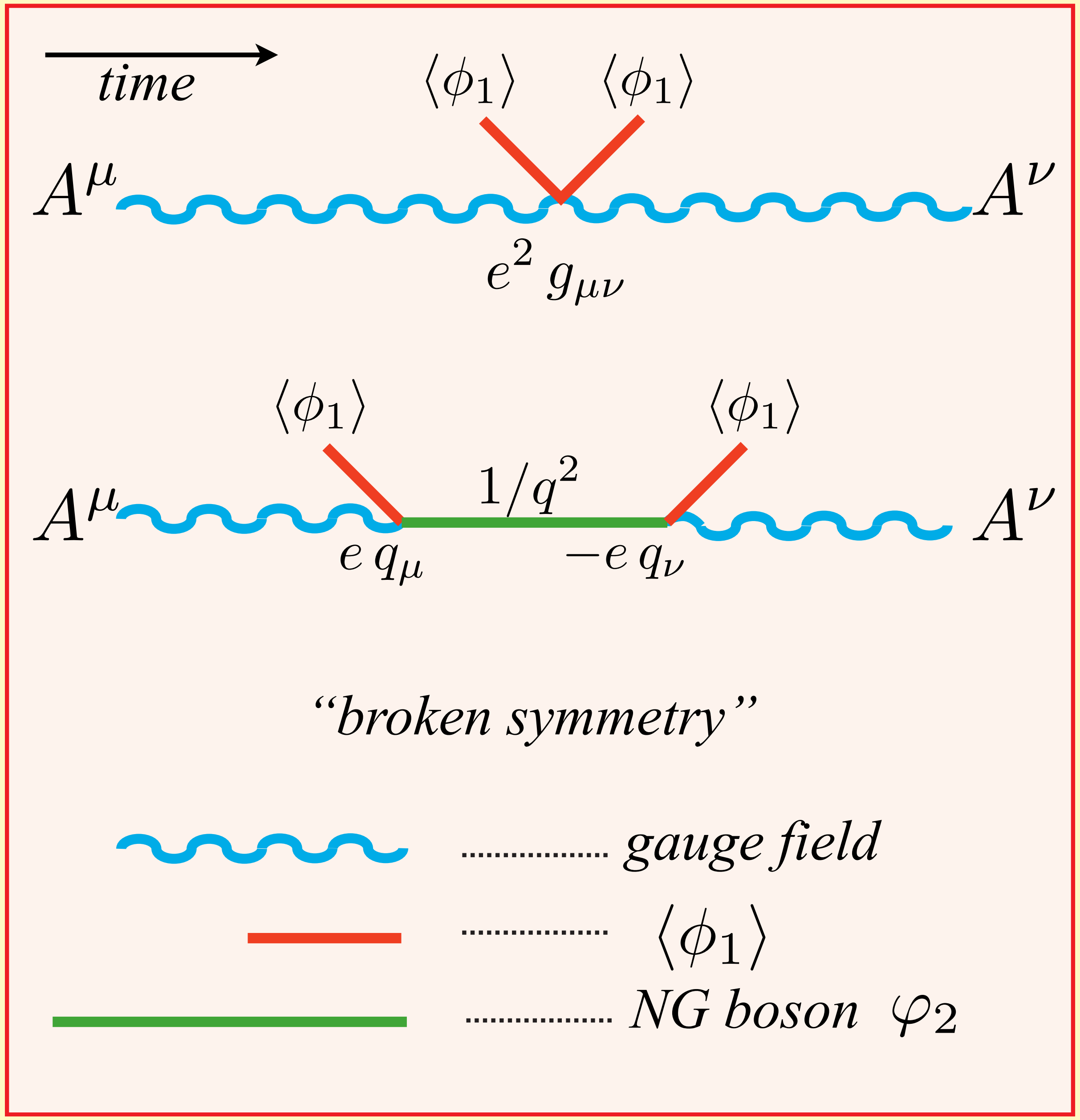
NG provides the 3rd polarization

Quantitatively



$$\Pi_{\mu\nu} = (g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2})\, e^2 \langle\phi_1\rangle^2$$

$$\langle\phi_1\rangle \neq 0$$



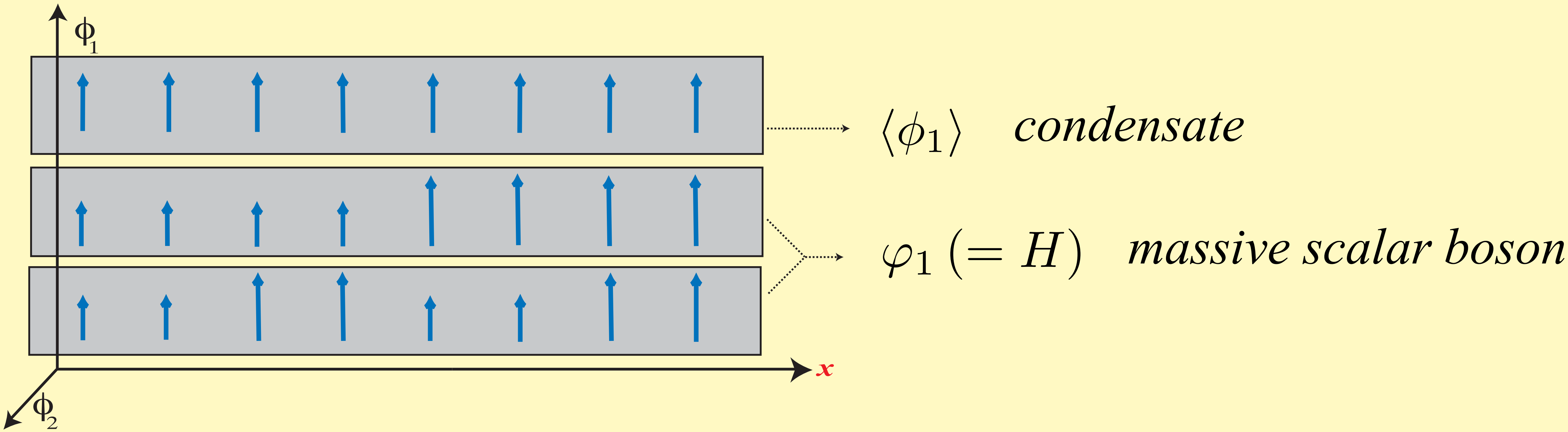
$$M_V^2 = e^2\langle\phi_1\rangle^2$$

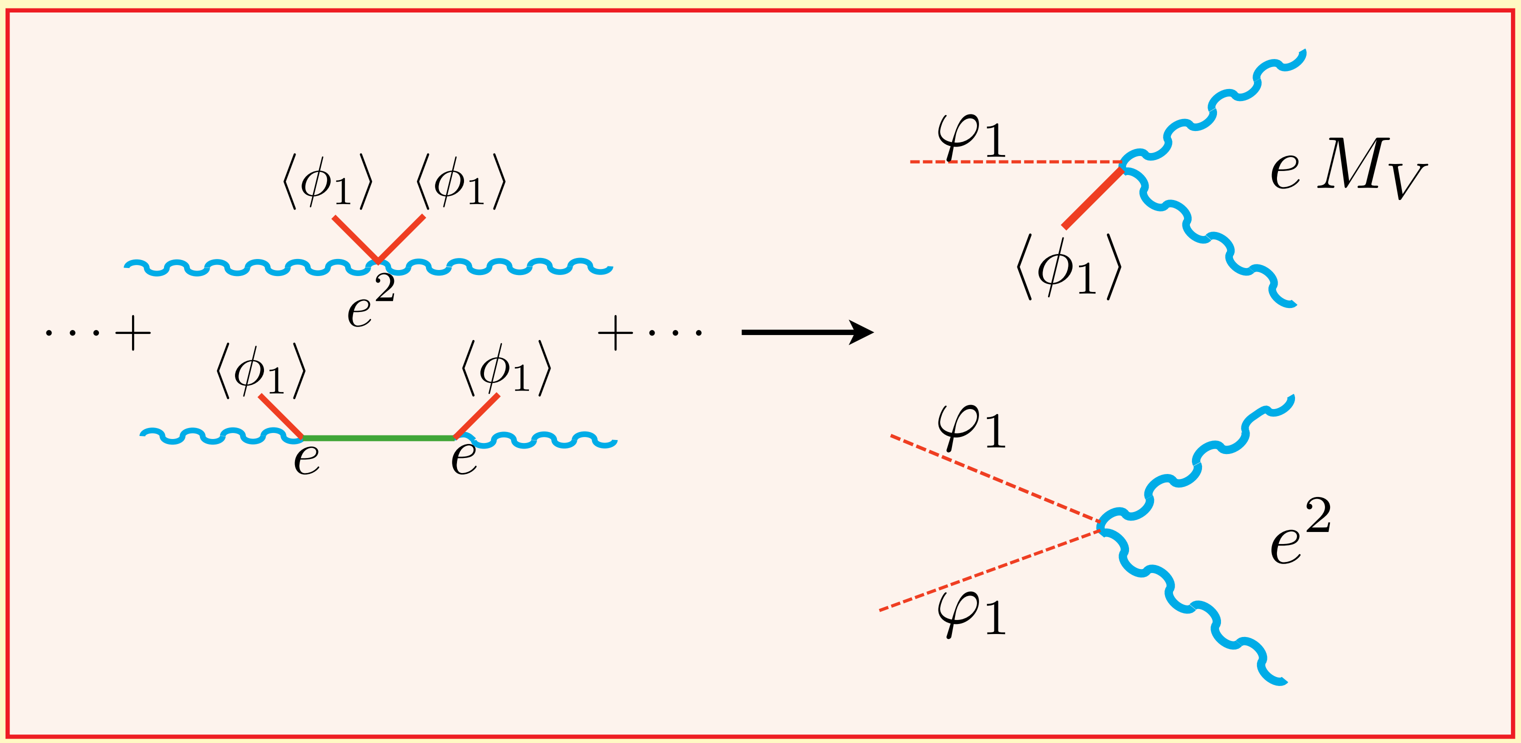
$$(M_V^2)^{ab} = -e^2\langle\phi_B\rangle T^{aBA} T^{bAC}\langle\phi_C\rangle$$

Dynamical symmetry breaking

Composite condensate: SSB ⟶ *NG boson* ***Local symmetry: BEH mechanism***

2. The fate of the massive scalar boson





The scalar boson couples to the massive gauge bosons

3. Why is the mechanism needed ?

F. Englert, Proceedings of the 1967 Solvay Conference, p.18.

The theory is valid quantum mechanically

[1971] G.'t Hooft, M. Veltman (Nobel Prize 1999)

4. The electroweak theory and the Standard Model

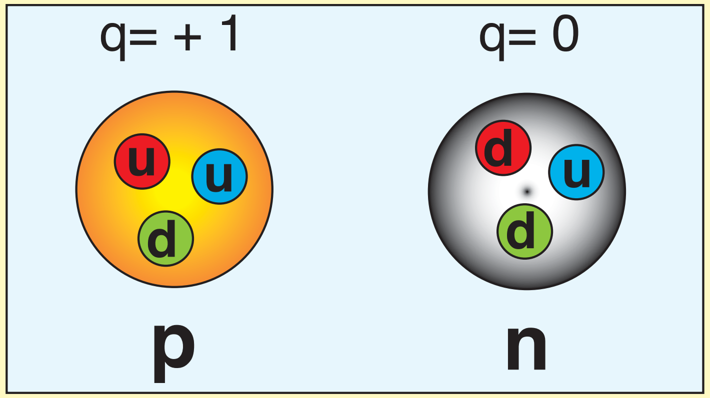
[1967] S. L. Glashow, A. Salam, S. Weinberg (Nobel Prize 1979)

particles (charge)

$e\ (-1)$	$\nu_e\ (0)$	$u\,u\,u\ (\frac{2}{3})$	$d\,d\,d\ (-\frac{1}{3})$
$\mu\ (-1)$	$\nu_\mu\ (0)$	$c\,c\,c\ (\frac{2}{3})$	$s\,s\,s\ (-\frac{1}{3})$
$\tau\ (-1)$	$\nu_\tau\ (0)$	$t\,t\,t\ (\frac{2}{3})$	$b\,b\,b\ (-\frac{1}{3})$

S.L. Glashow, J. Iliopoulos and L. Maiani, Phys.Rev. **D2** (1970) 1285.

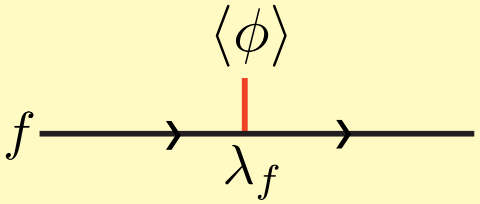
(Nobel Prize 2008) M. Kobayashi and T. Maskawa, Prog.Theor.Phys. **49** (1973) 652.



$+$ antiparticles

4 massless vector bosons and 4 scalar bosons (3NG) $\langle\phi\rangle \neq 0 \qquad \varphi \equiv H$

fermion masses



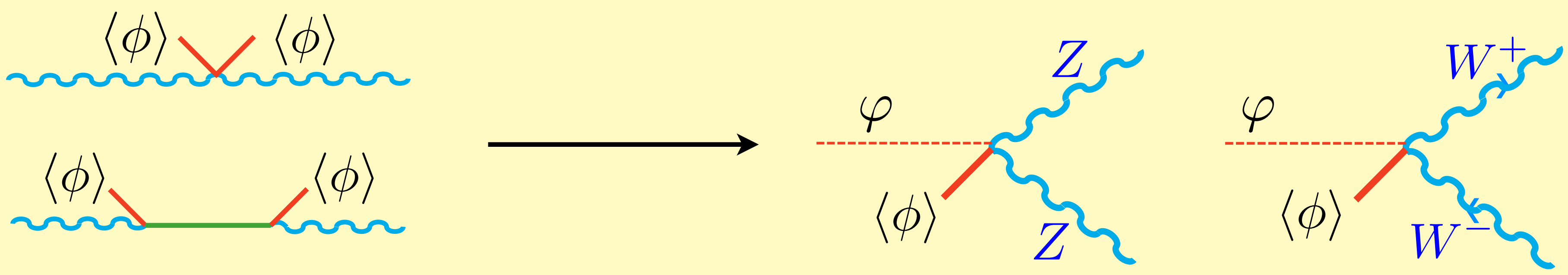
γ	$W^+\ W^-\ Z$	*8 gluons*

[1983] C. Rubbia, S. van der Meer (Nobel Prize 1984)

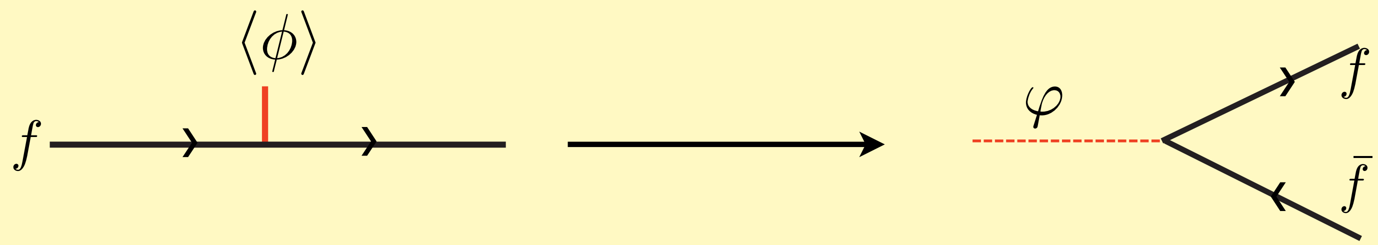
IV. The discovery

Decays of the scalar boson

massive gauge bosons

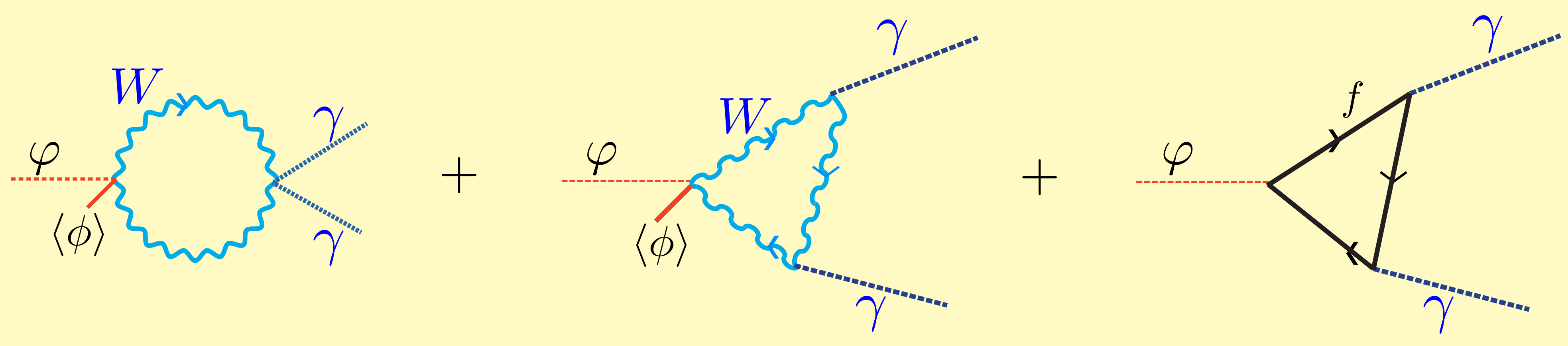


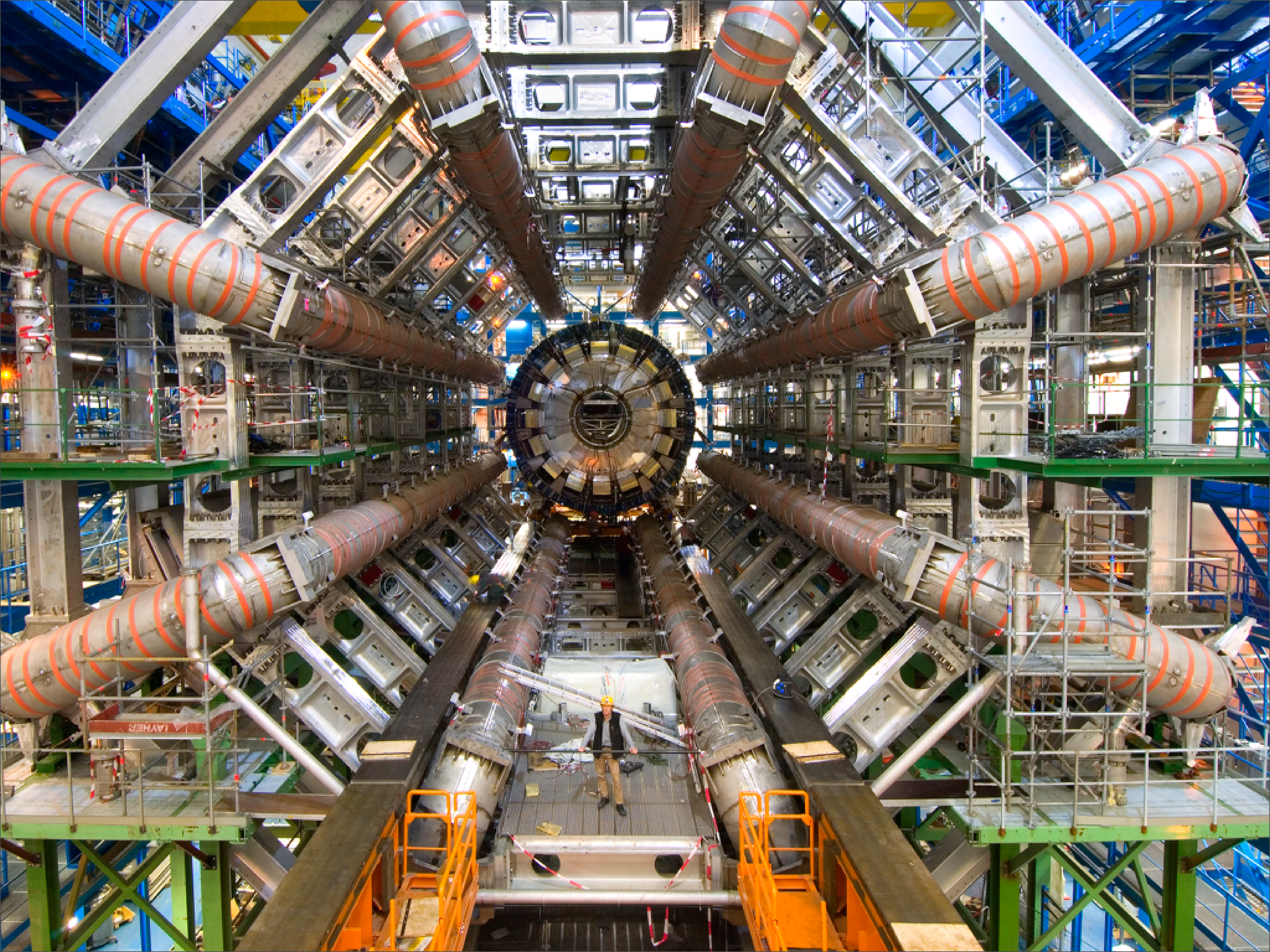
fermion masses

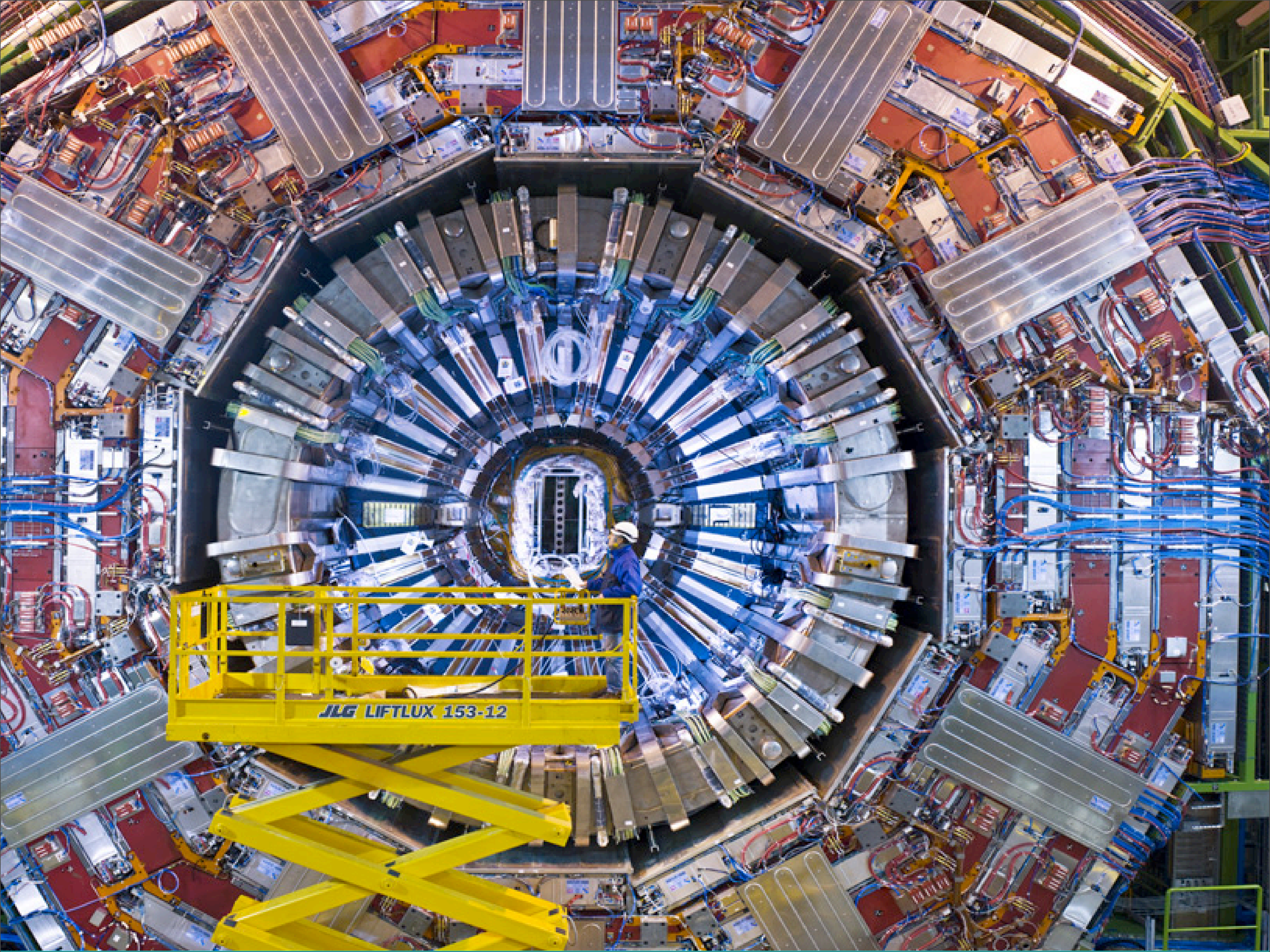


$$\propto \frac{m_f}{M_W}$$

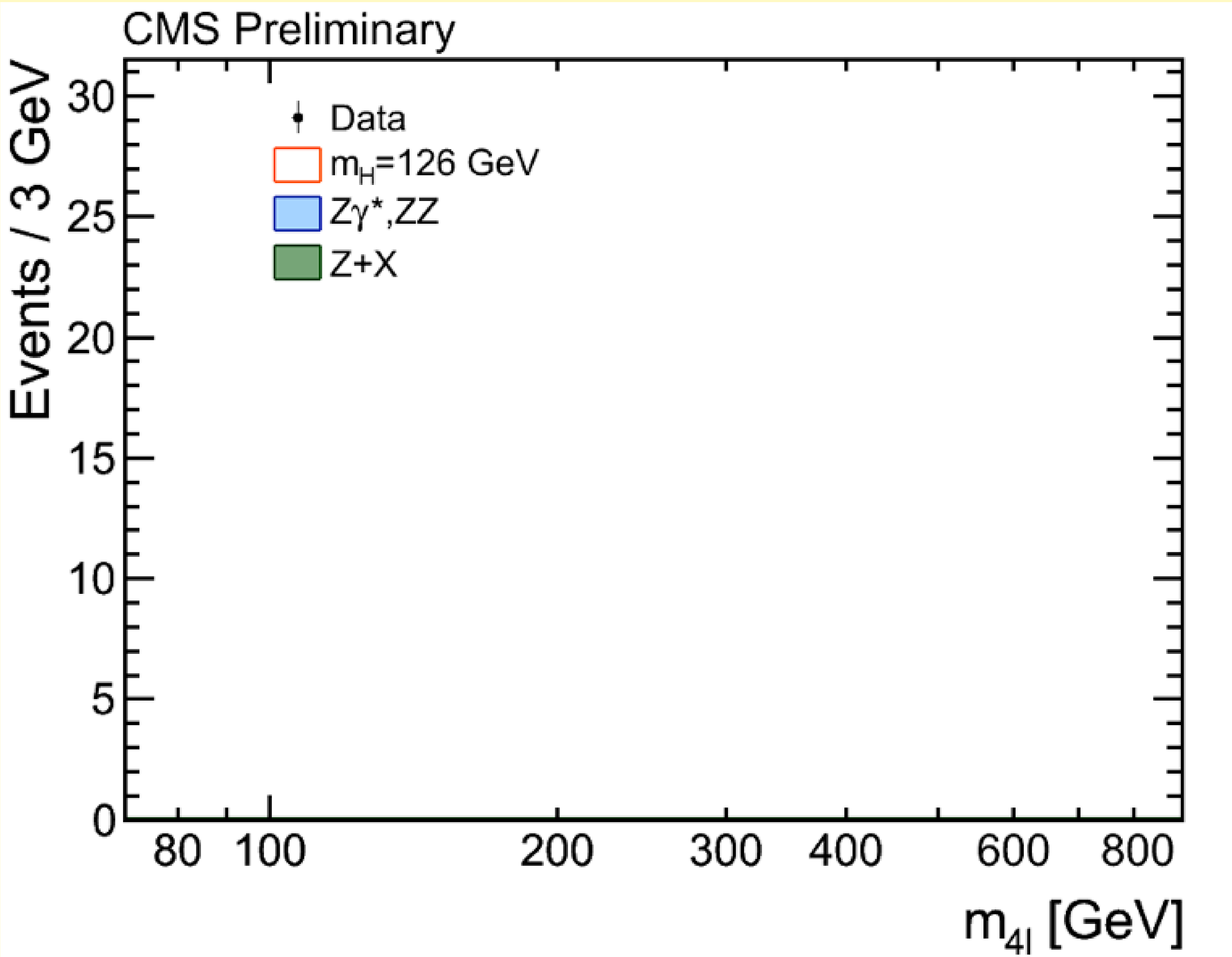
$\varphi \to \gamma\gamma$






JLG LIFTLUX 153-12

Example: decay of the scalar boson into ZZ^*



$H \to ZZ$

$H \to \gamma\gamma$

$H \to W^+W^-$

$H \to \tau\bar{\tau}$

$H \to b\bar{b}$

$\sigma/\sigma_{SM} = 0.88 \pm 0.21$

The scalar boson appears to be an elementary particle !!!