Symmetry breaking and the Scalar boson - evolving perspectives

I. Spontaneous breaking of a global symmetry

II. The symmetry breaking mechanism for gauge fields

III. The electroweak theory

IV. Perspectives

Moriond 2012, 7 March

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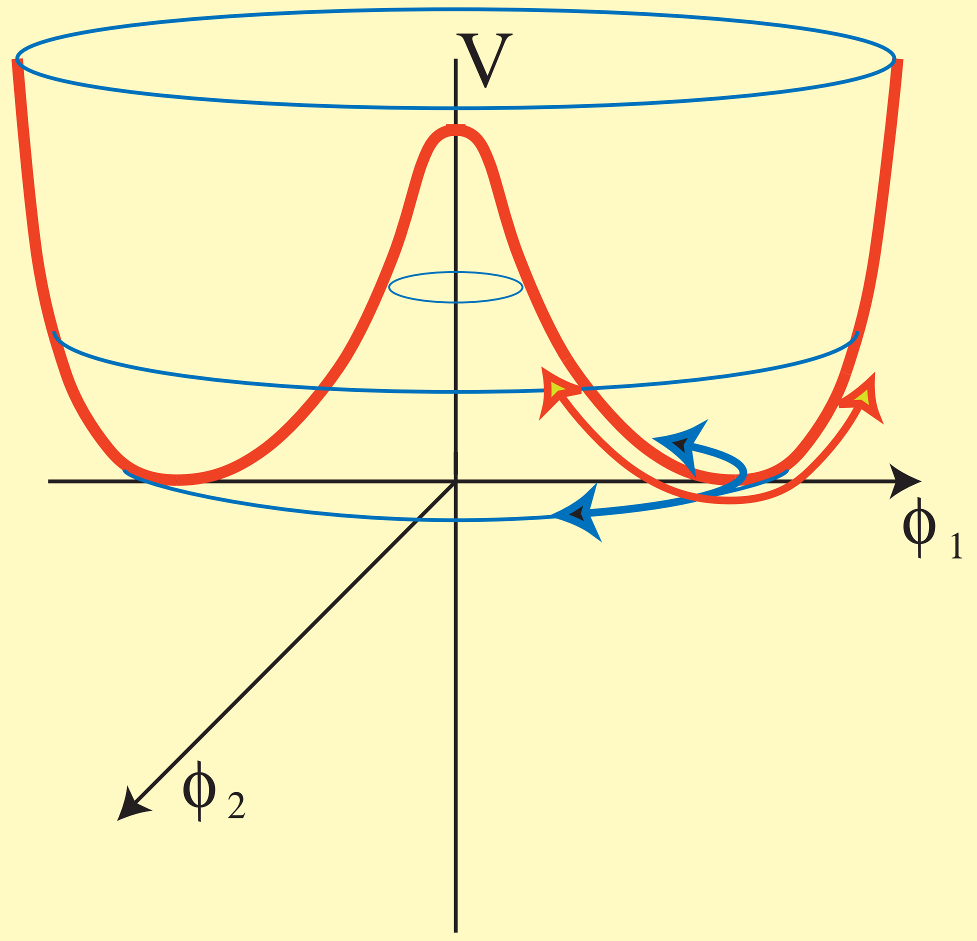

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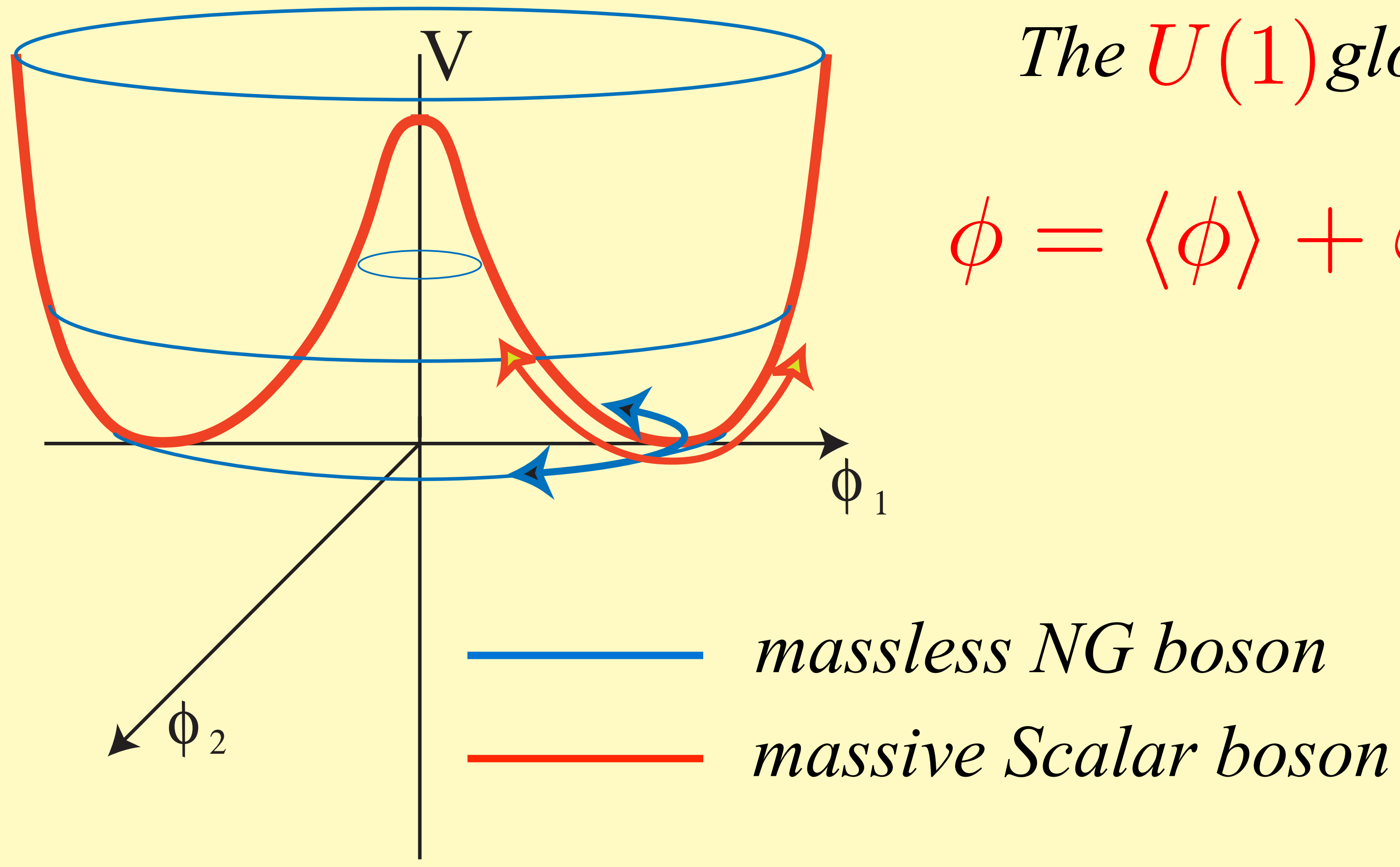

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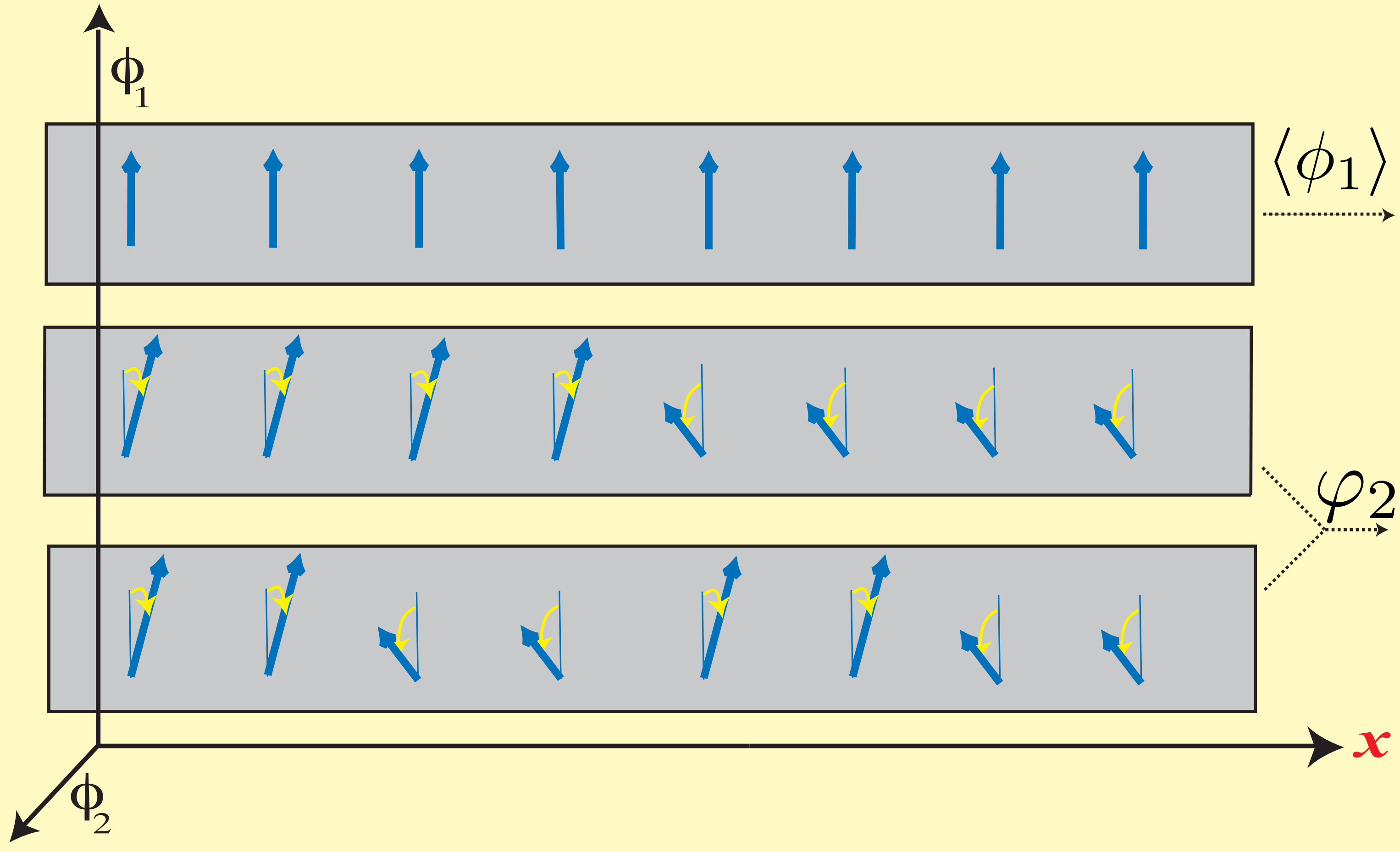
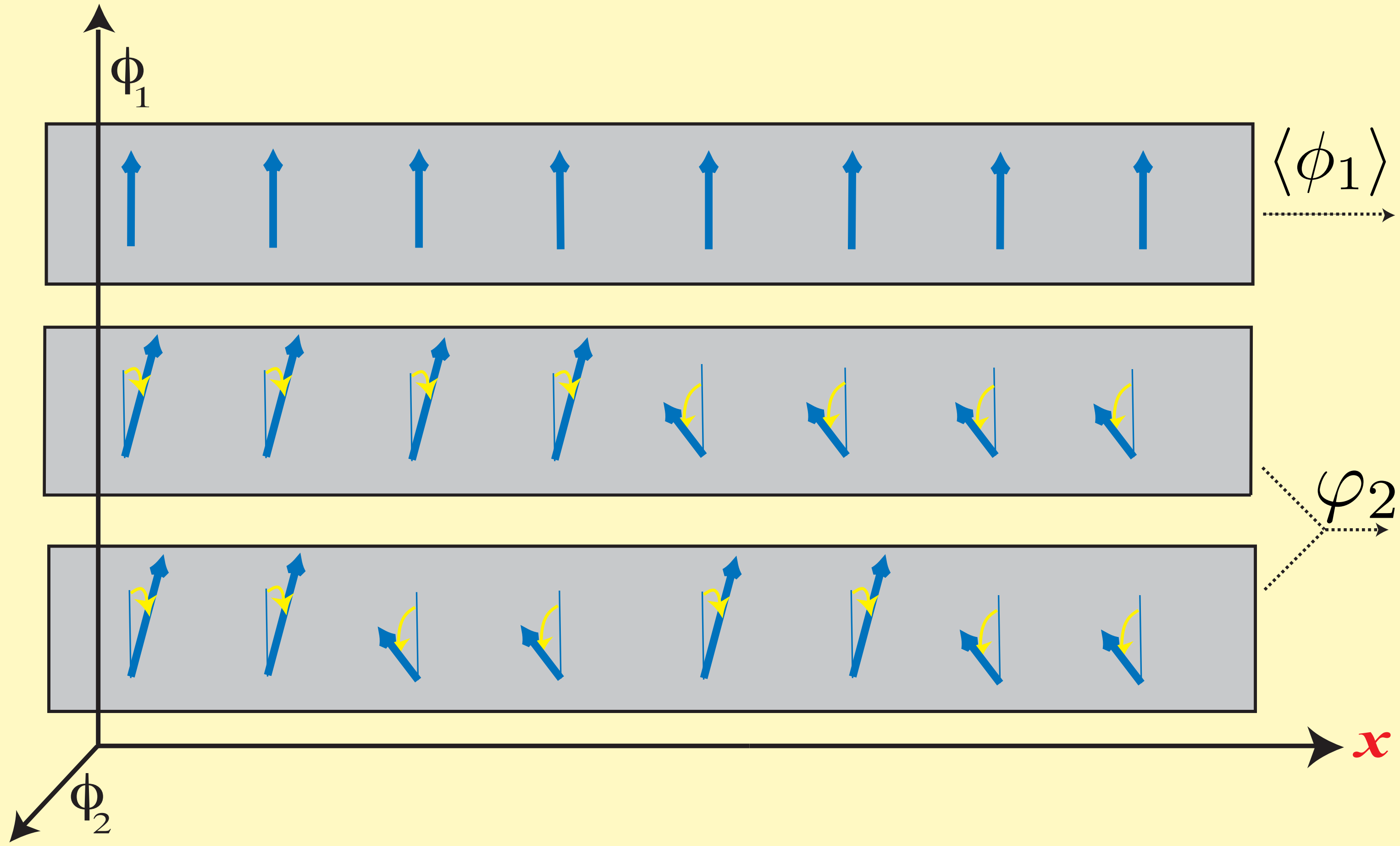


structured
vacuum



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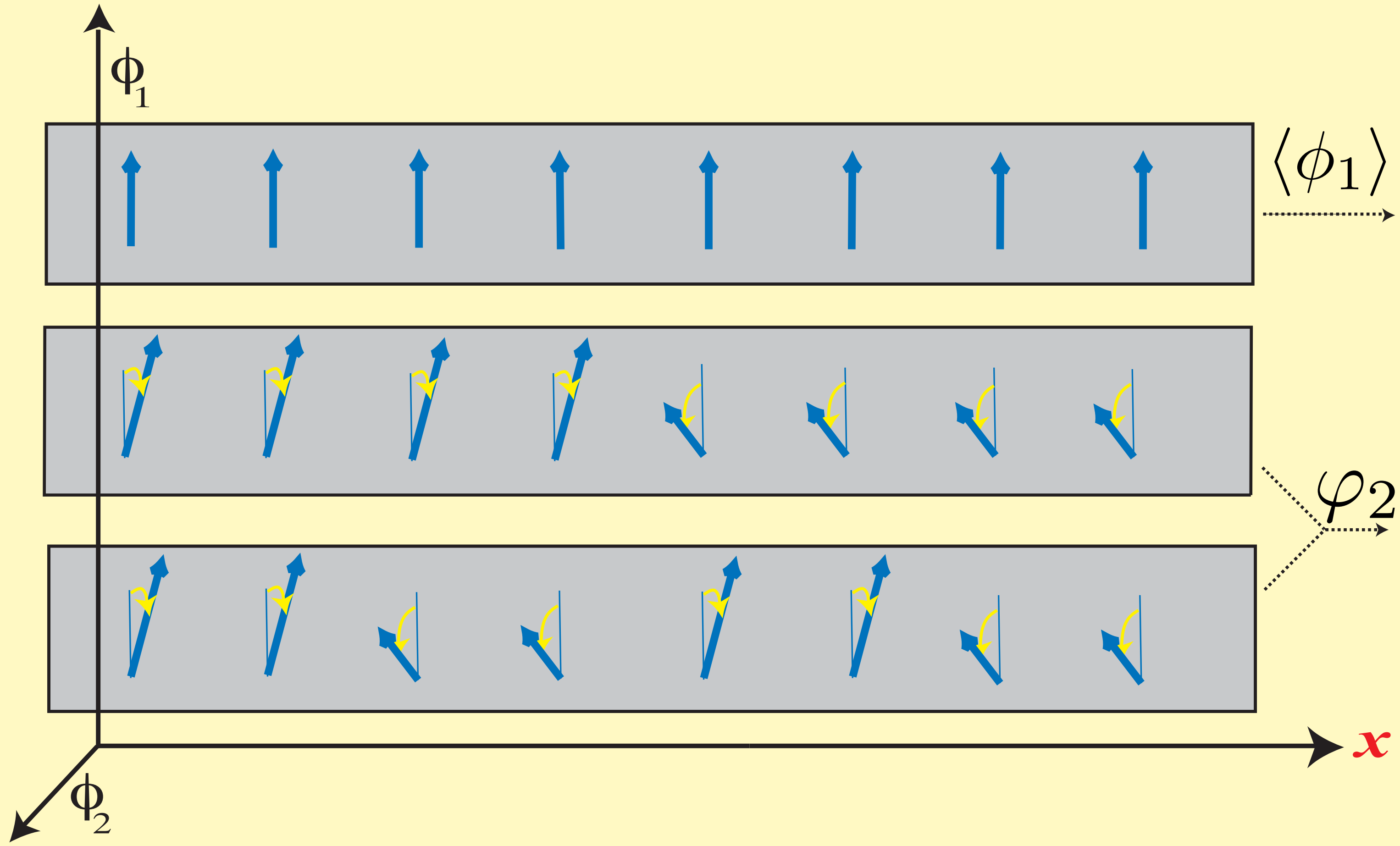

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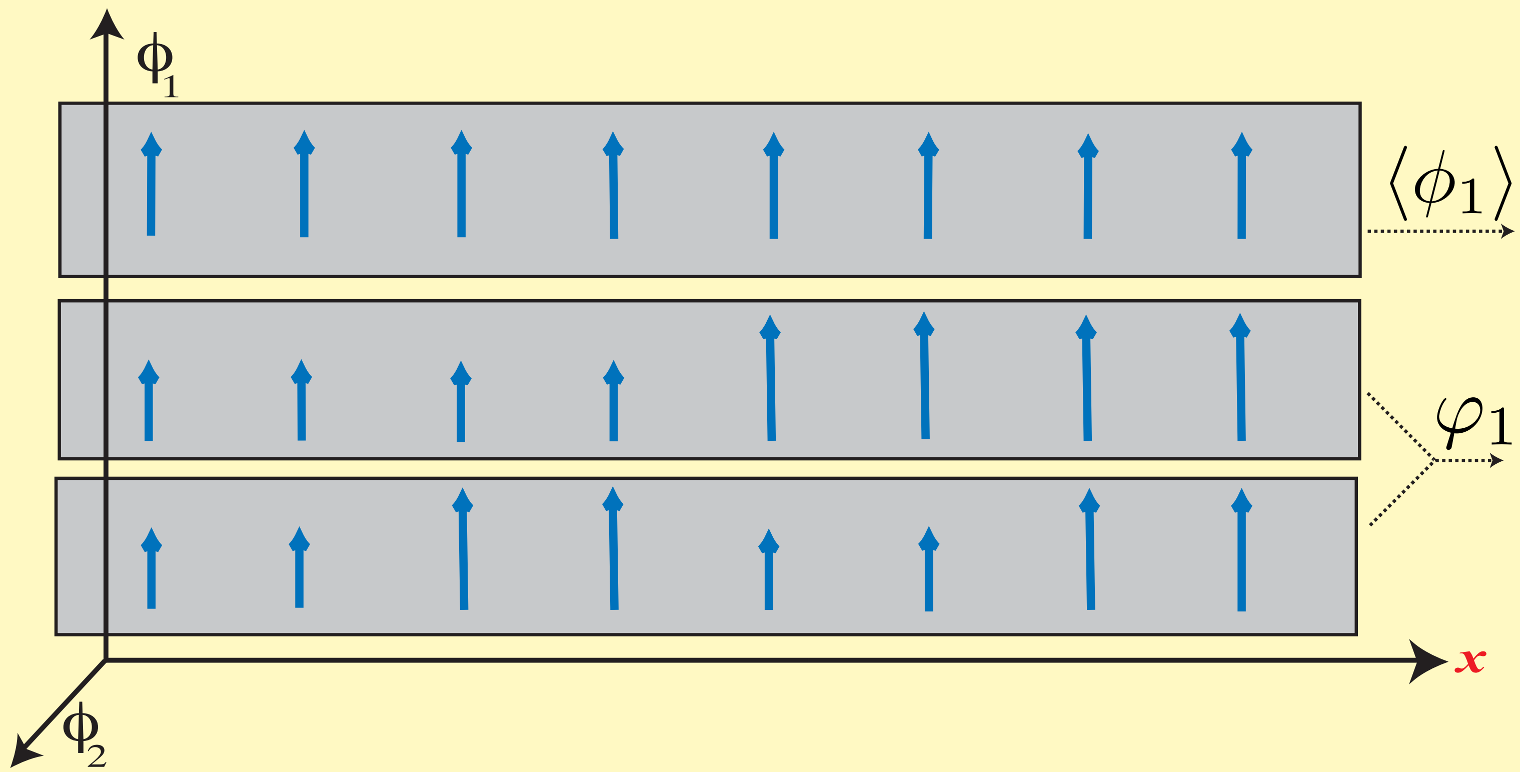

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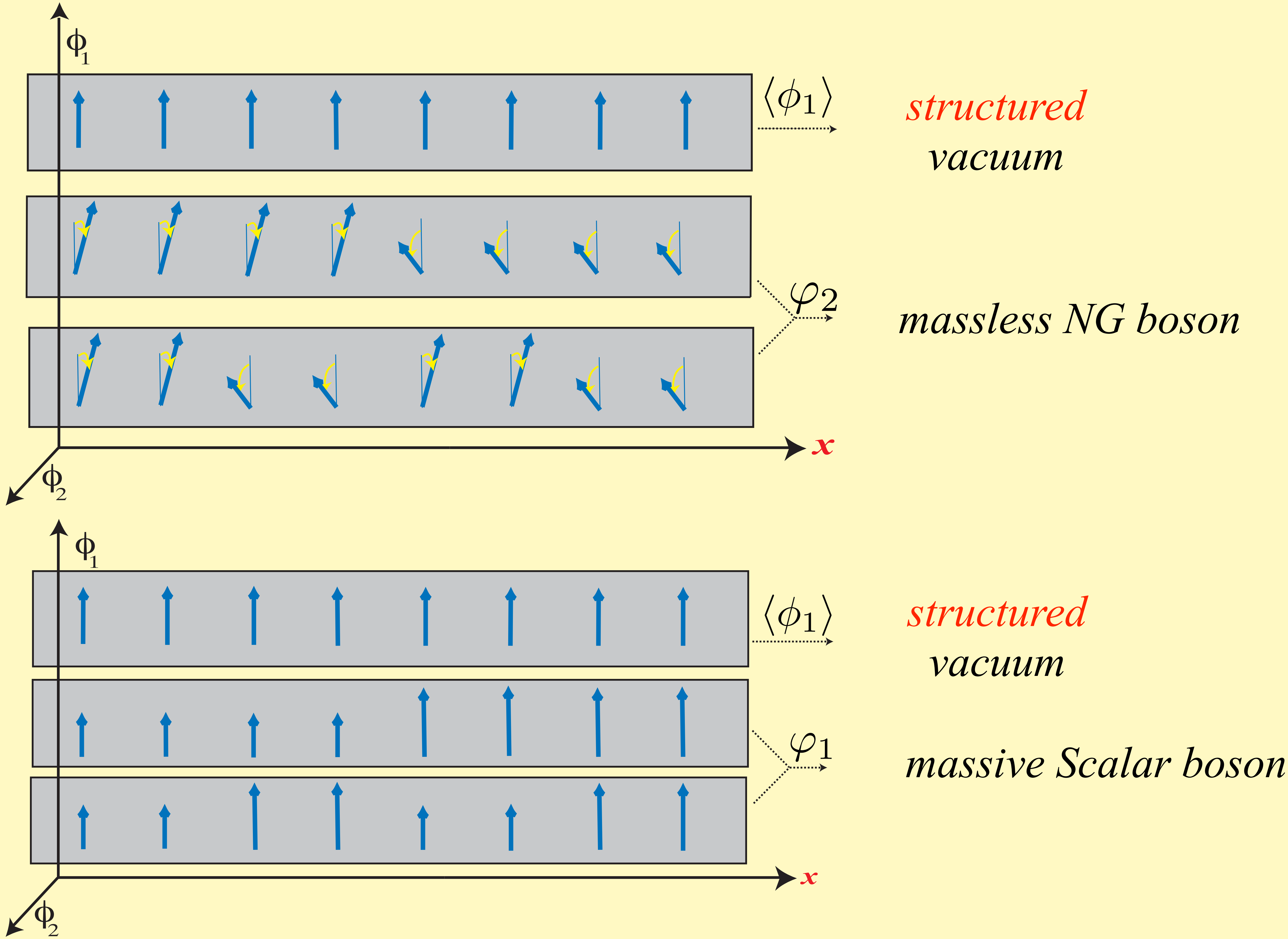

ϕ_1
$\langle\phi_1\rangle$
structured
vacuum
φ_2
massless NG boson
x
ϕ_2
ϕ_1
$\langle\phi_1\rangle$
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vacuum
φ_1
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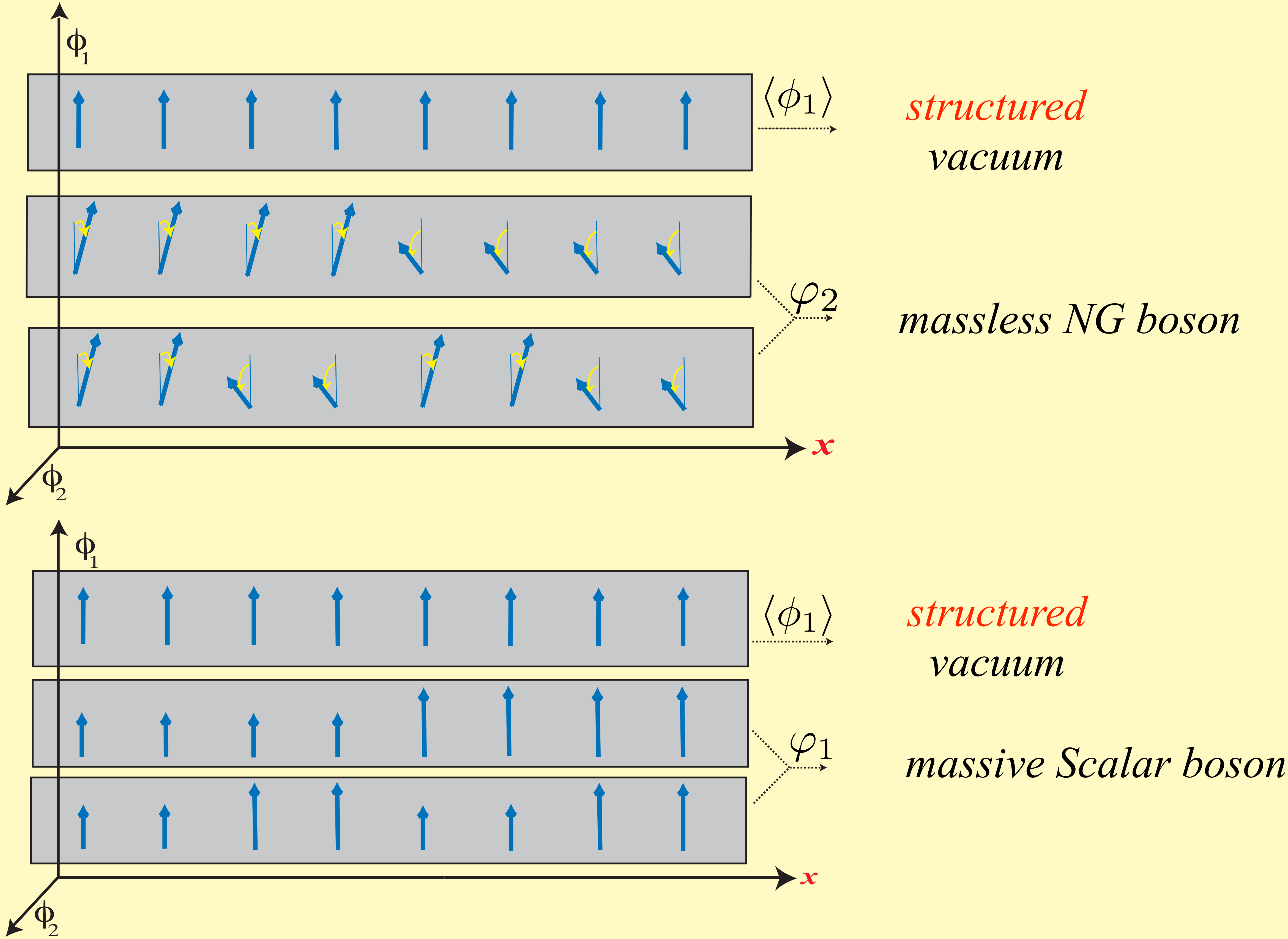
x
ϕ_2



The massless NG boson characterizes a continuous SSB

The massive Scalar boson measures the rigidity of the vacuum

II. The symmetry breaking mechanism for gauge fields

1. From global to local symmetry

Local abelian symmetry

$$\phi \to \phi e^{i\alpha(x)} \qquad A_\mu \to A_\mu + \frac{1}{e}\partial_\mu \alpha$$

$$D_\mu \phi = \partial_\mu \phi - ieA_\mu \phi \qquad F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

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Local non-abelian symmetry

$$\begin{aligned} (D_\mu \phi)^A &= \partial_\mu \phi^A - eA_\mu^a T^{a\,AB} \phi^B \\ F_{\mu\nu}^a &= \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + ef^{abc} A_\mu^b A_\nu^c \end{aligned}$$

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

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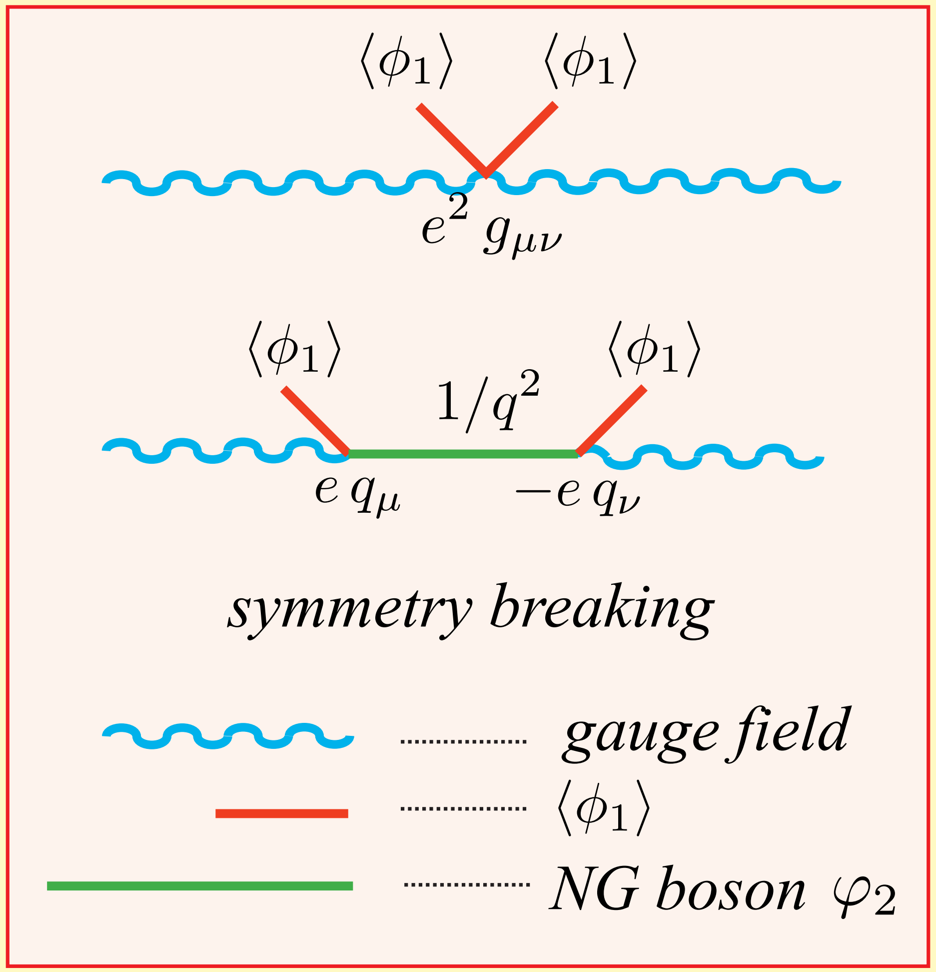

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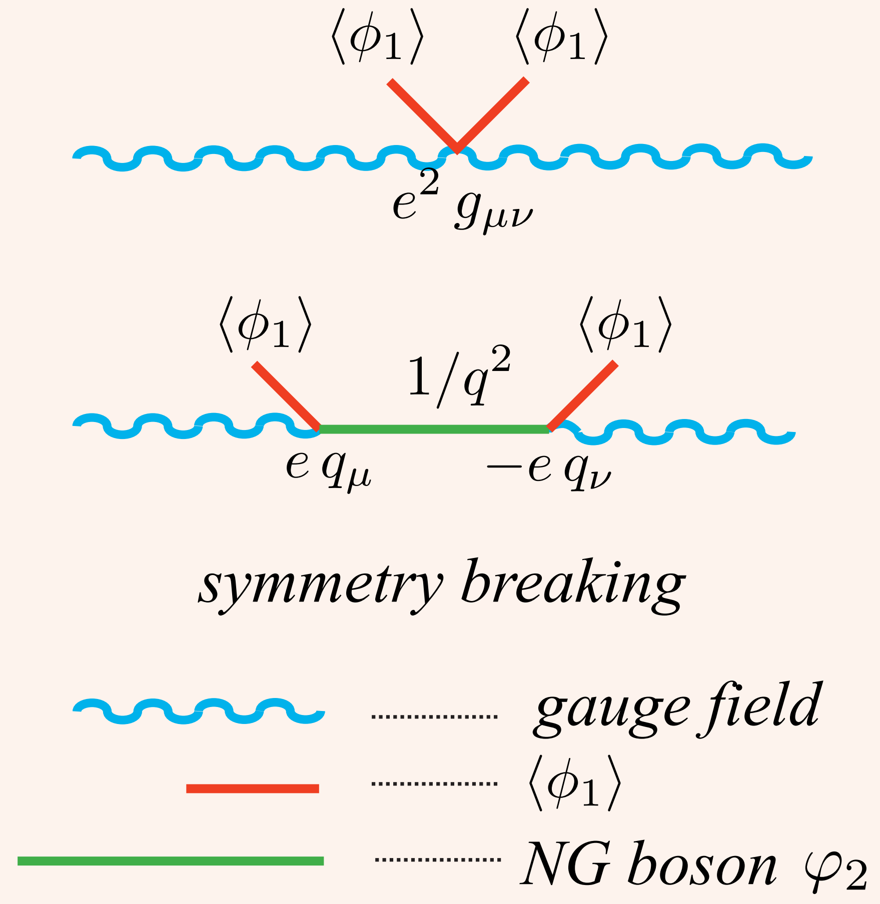

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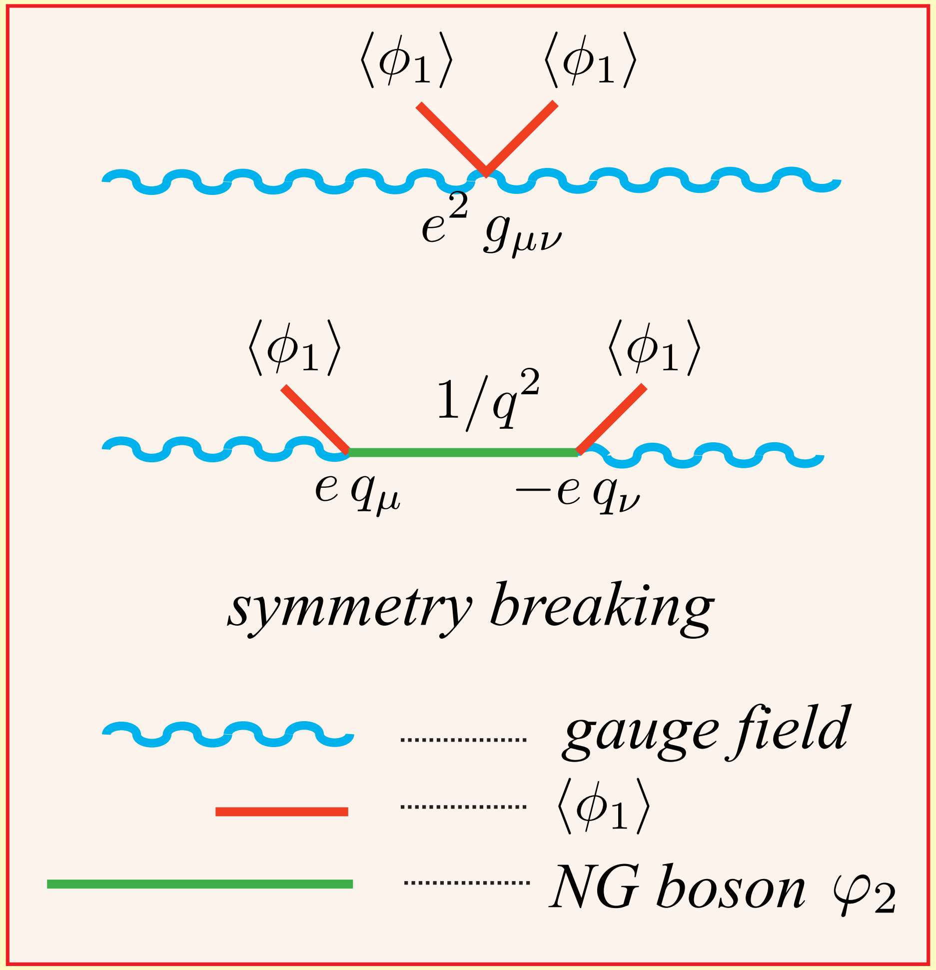

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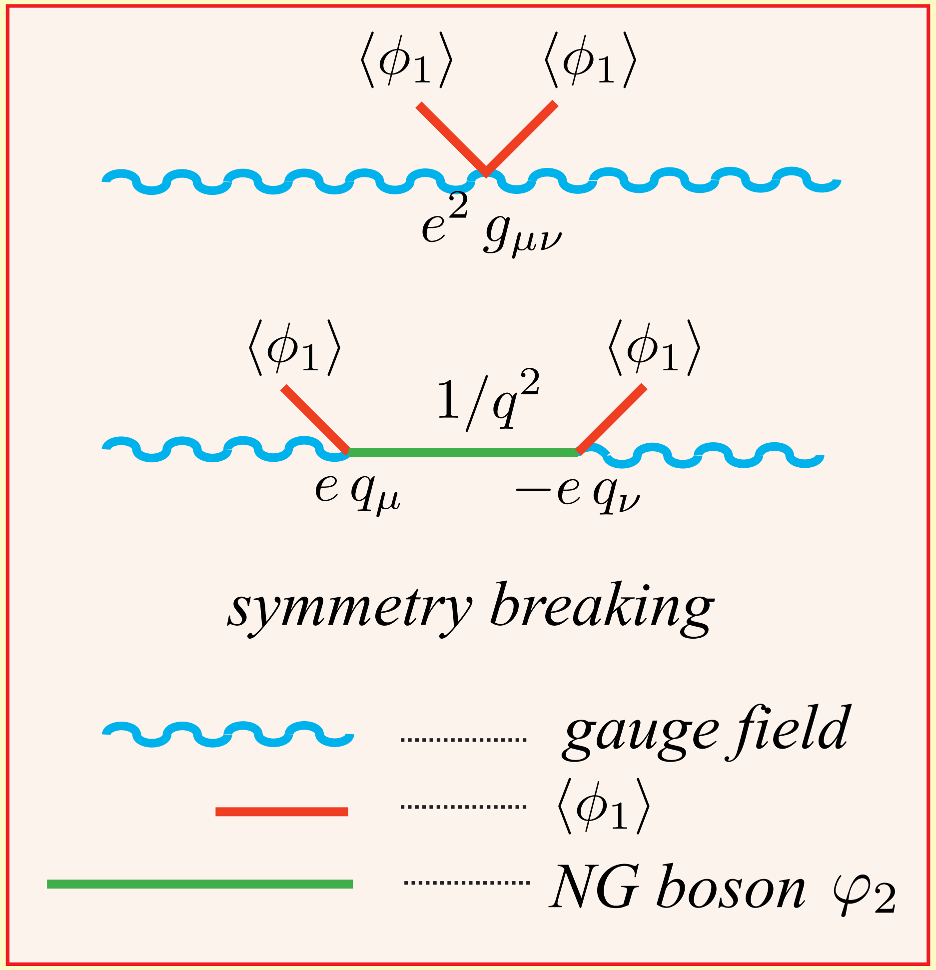

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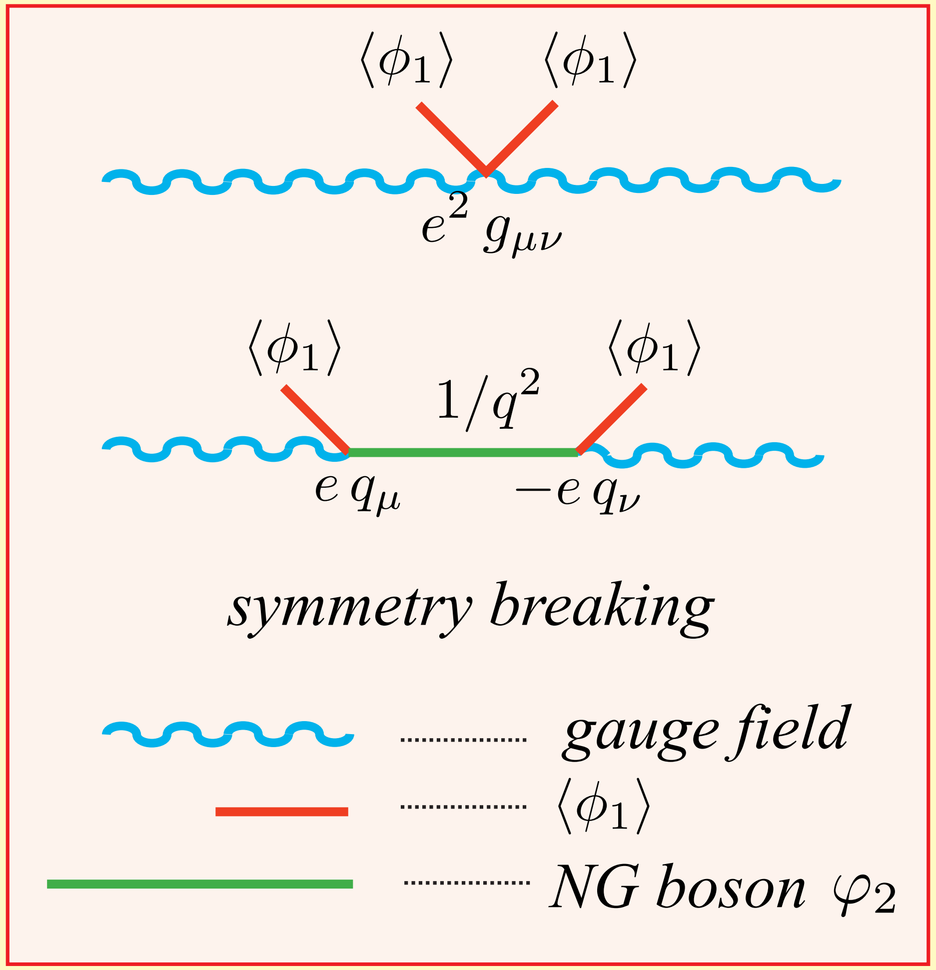

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Global symmetry breaking from condensate $\longrightarrow$ *NG boson* $\longrightarrow$ ***Local symmetry***

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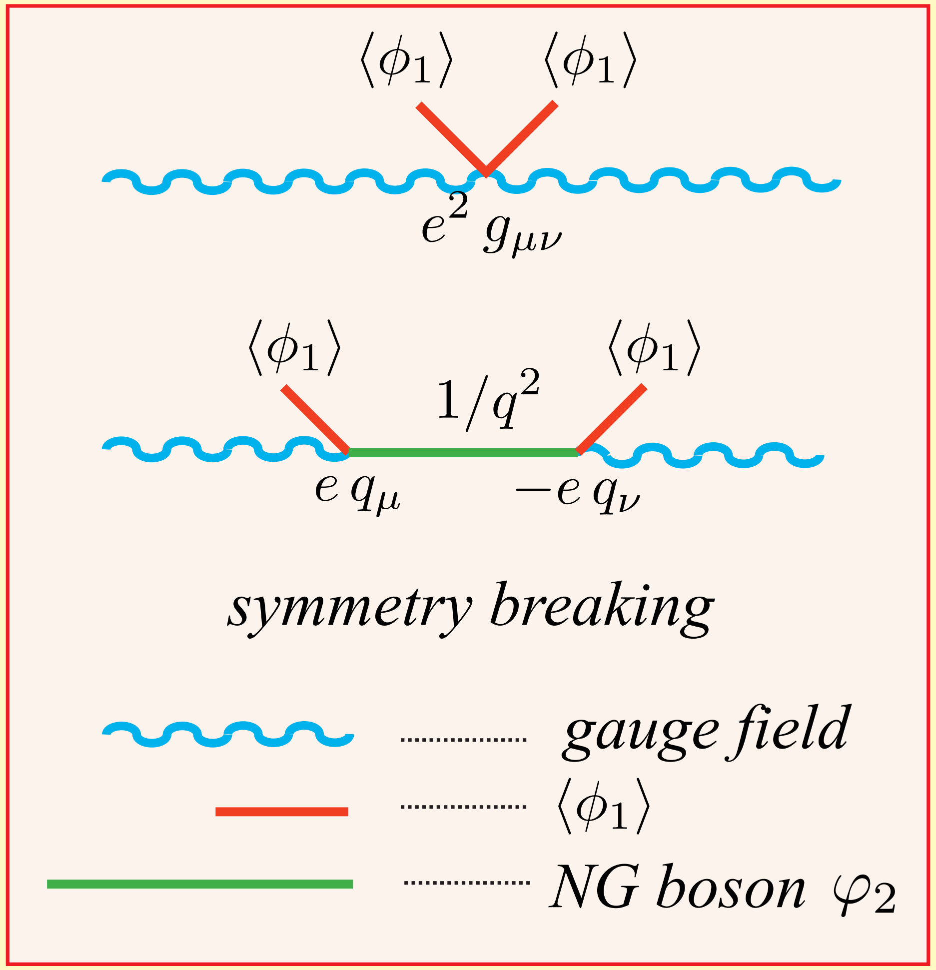

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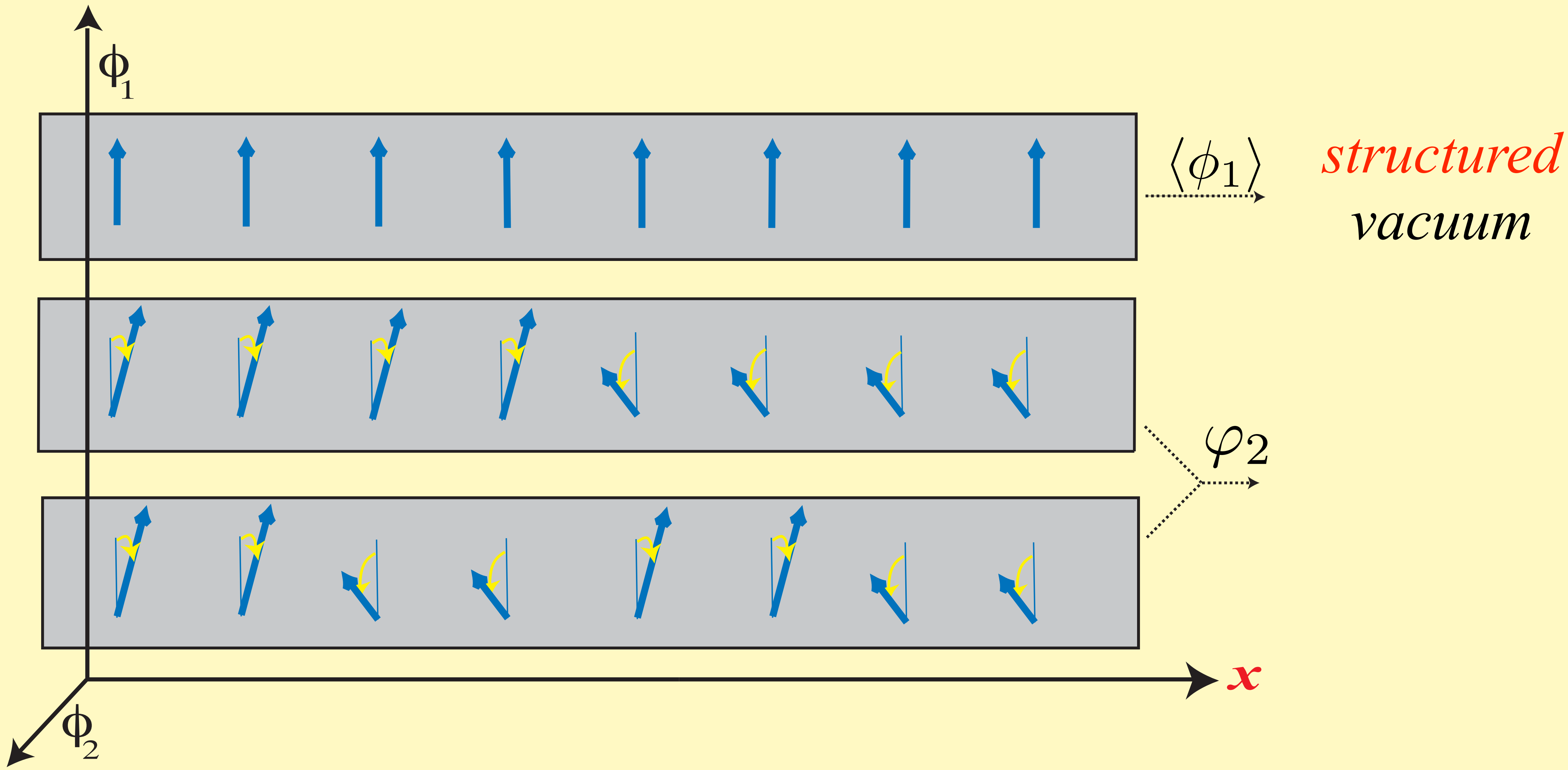

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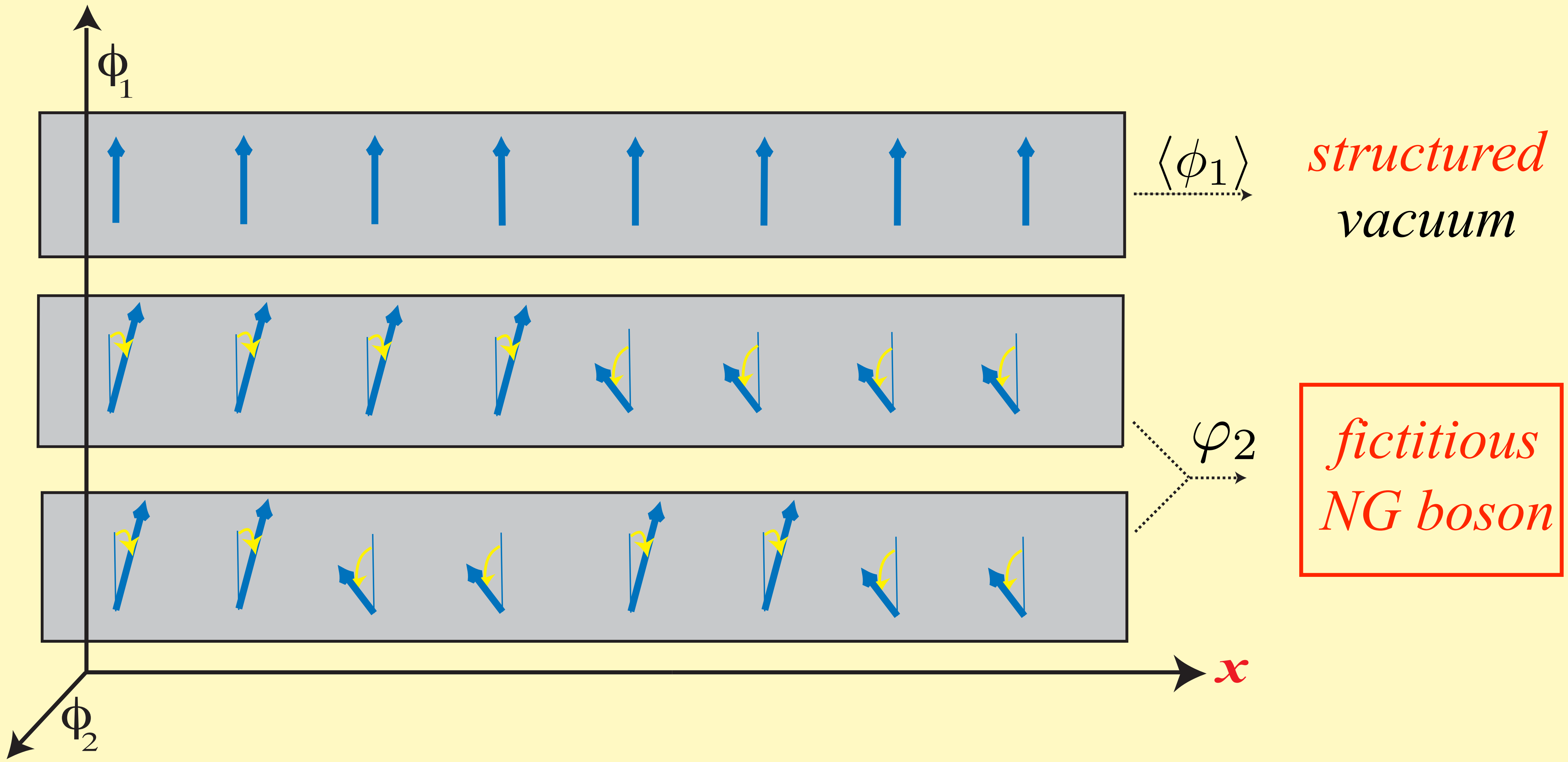

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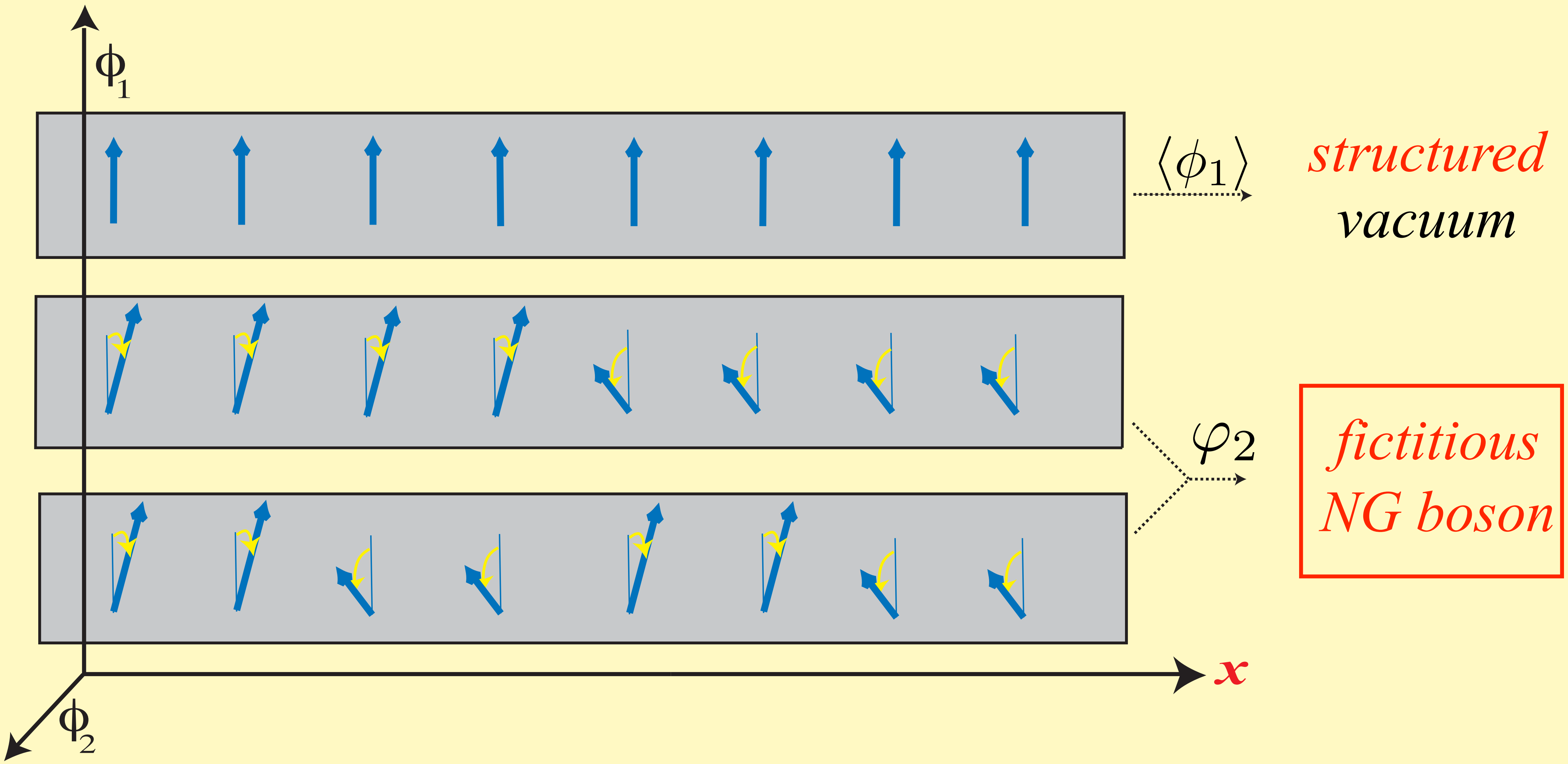

There is no degeneracy but a redundant description of the vacuum

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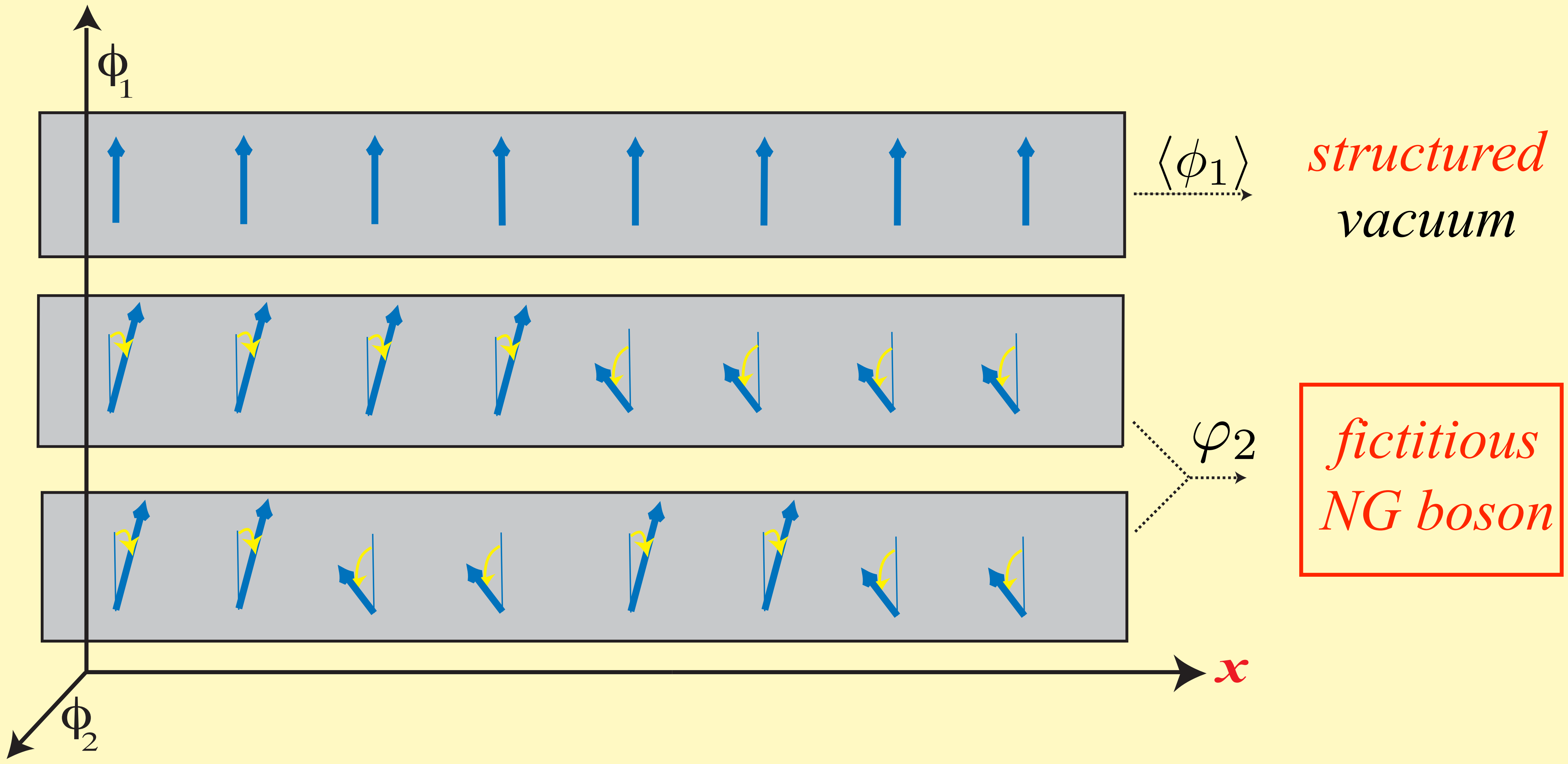

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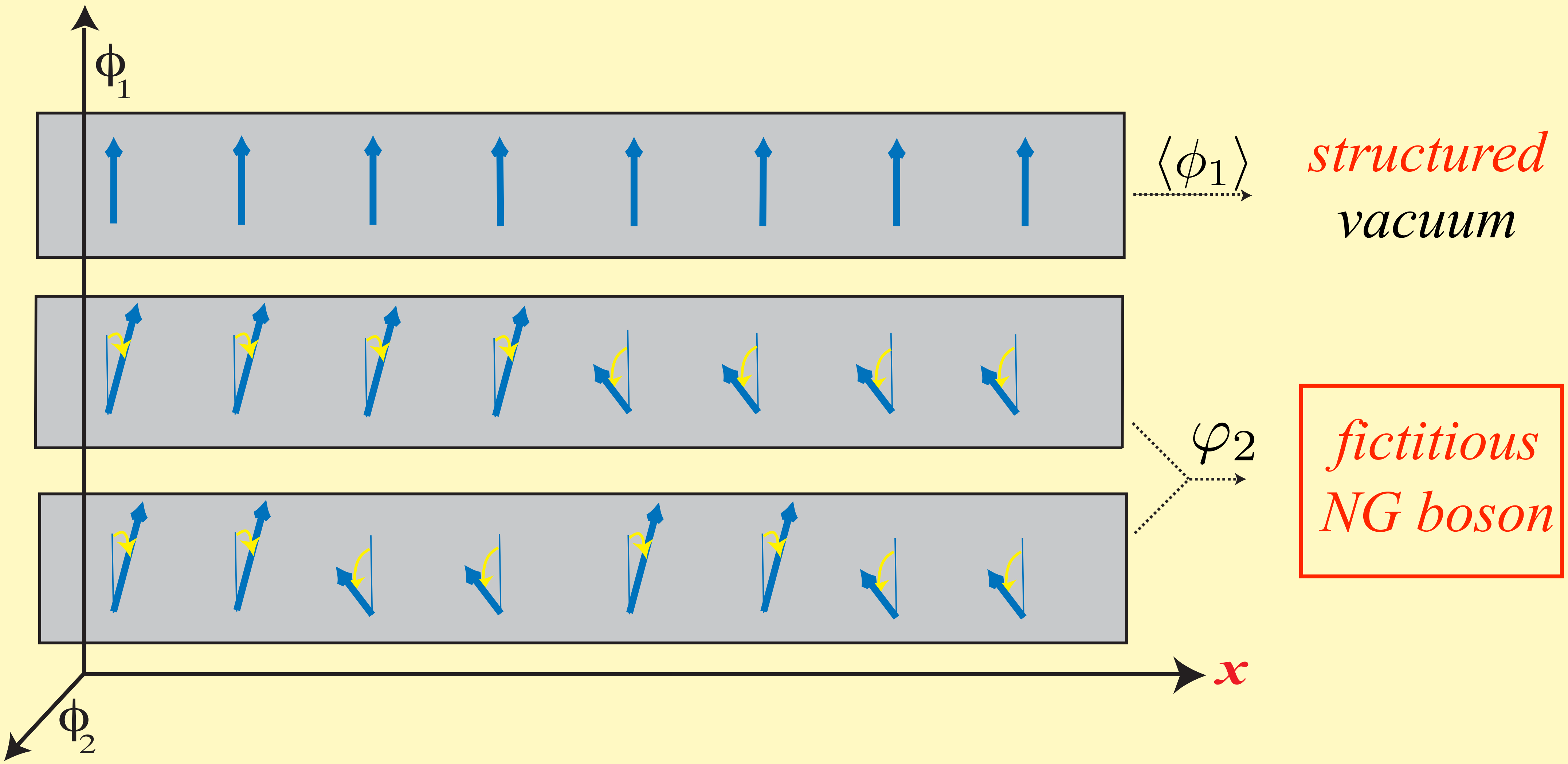

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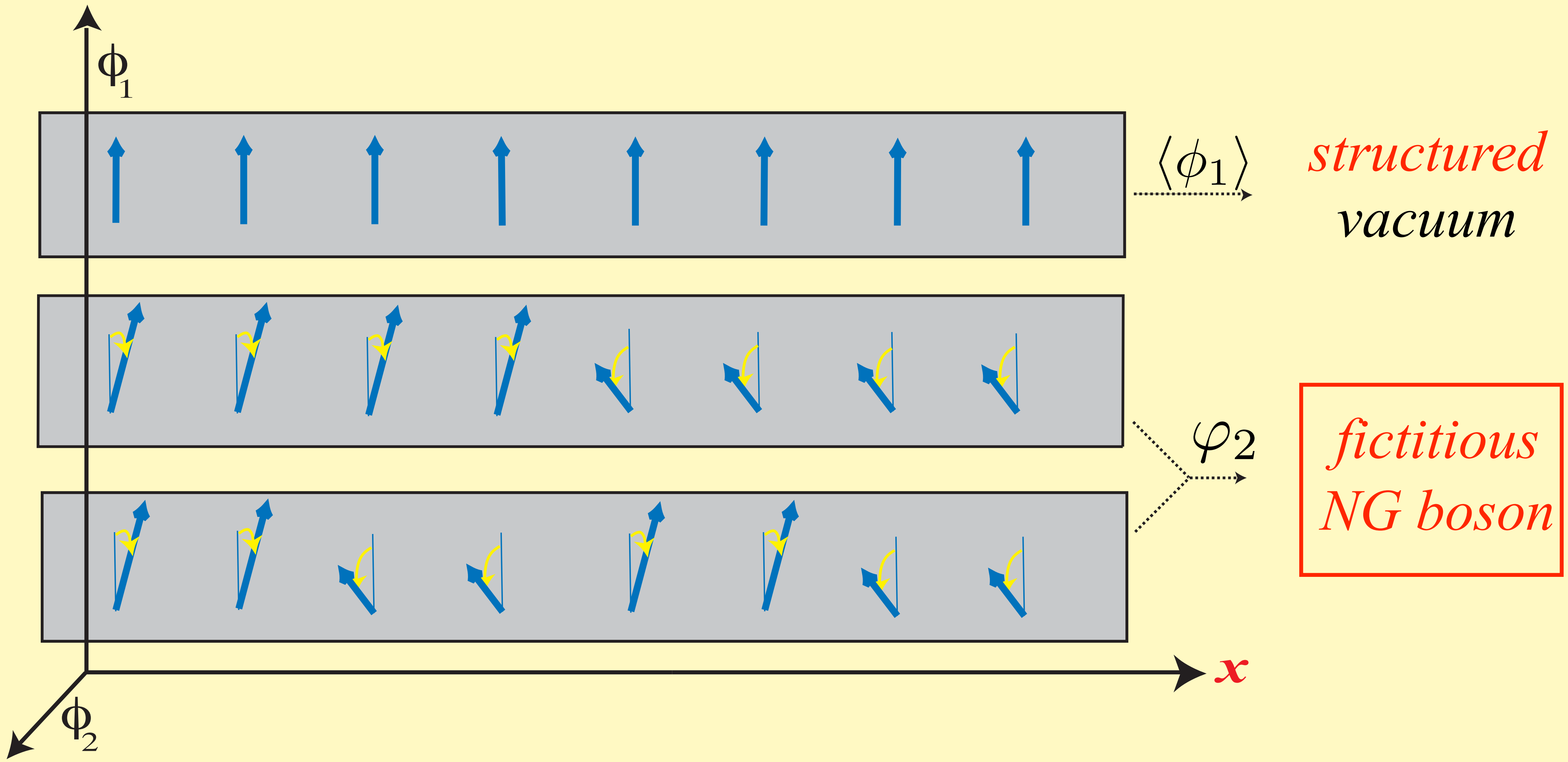

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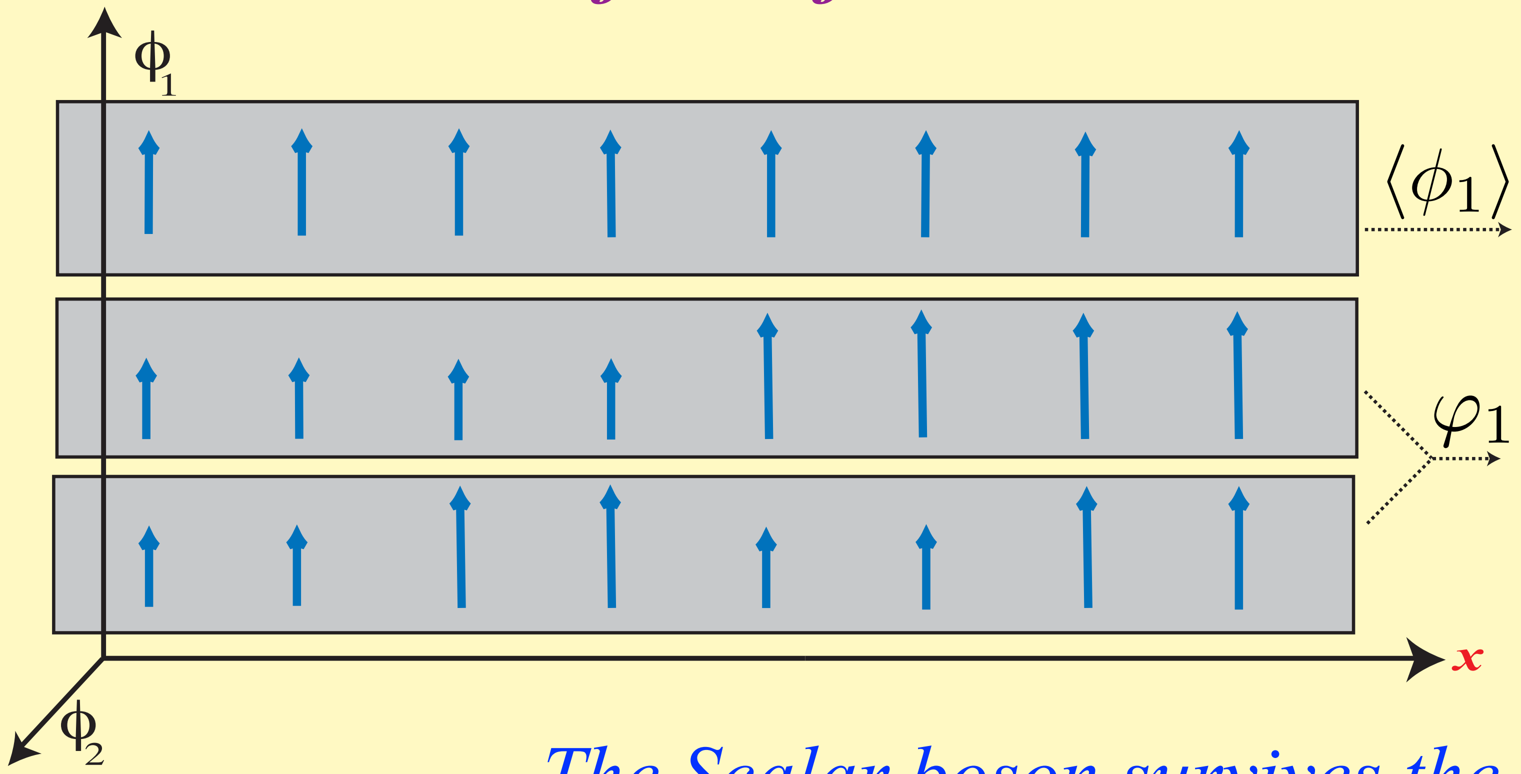
Apparent breaking is with respect to a preferred vacuum orientation

The fate of the massive Scalar boson

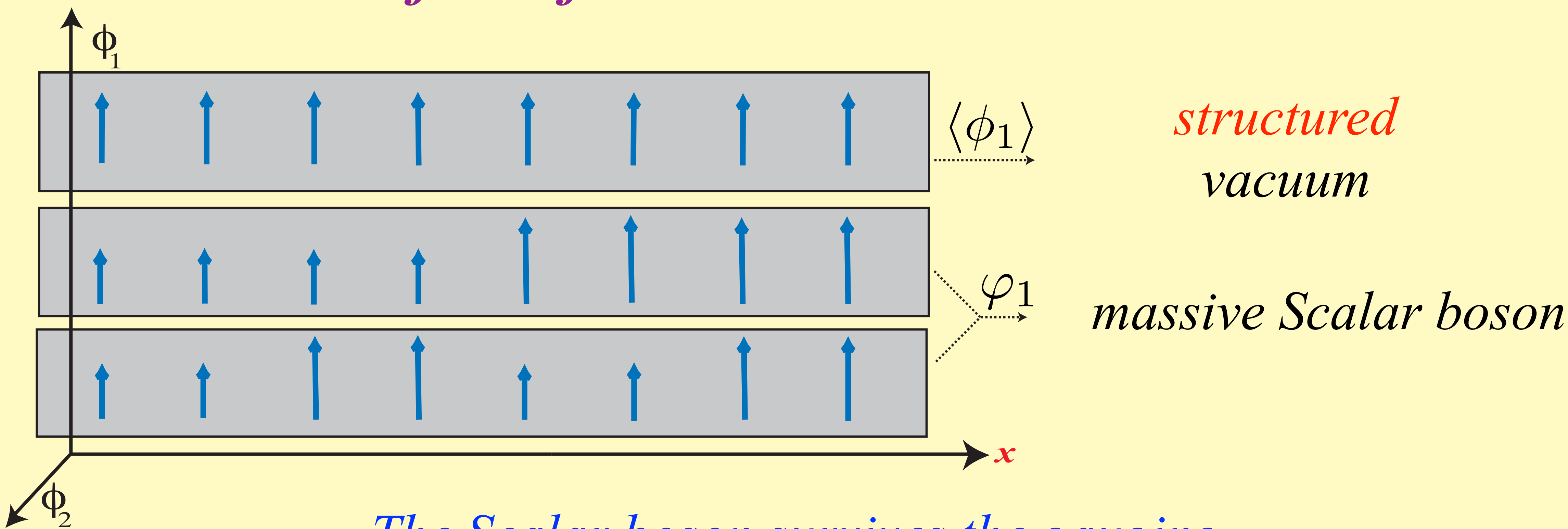


structured *vacuum*

massive Scalar boson

The Scalar boson survives the gauging

The fate of the massive Scalar boson



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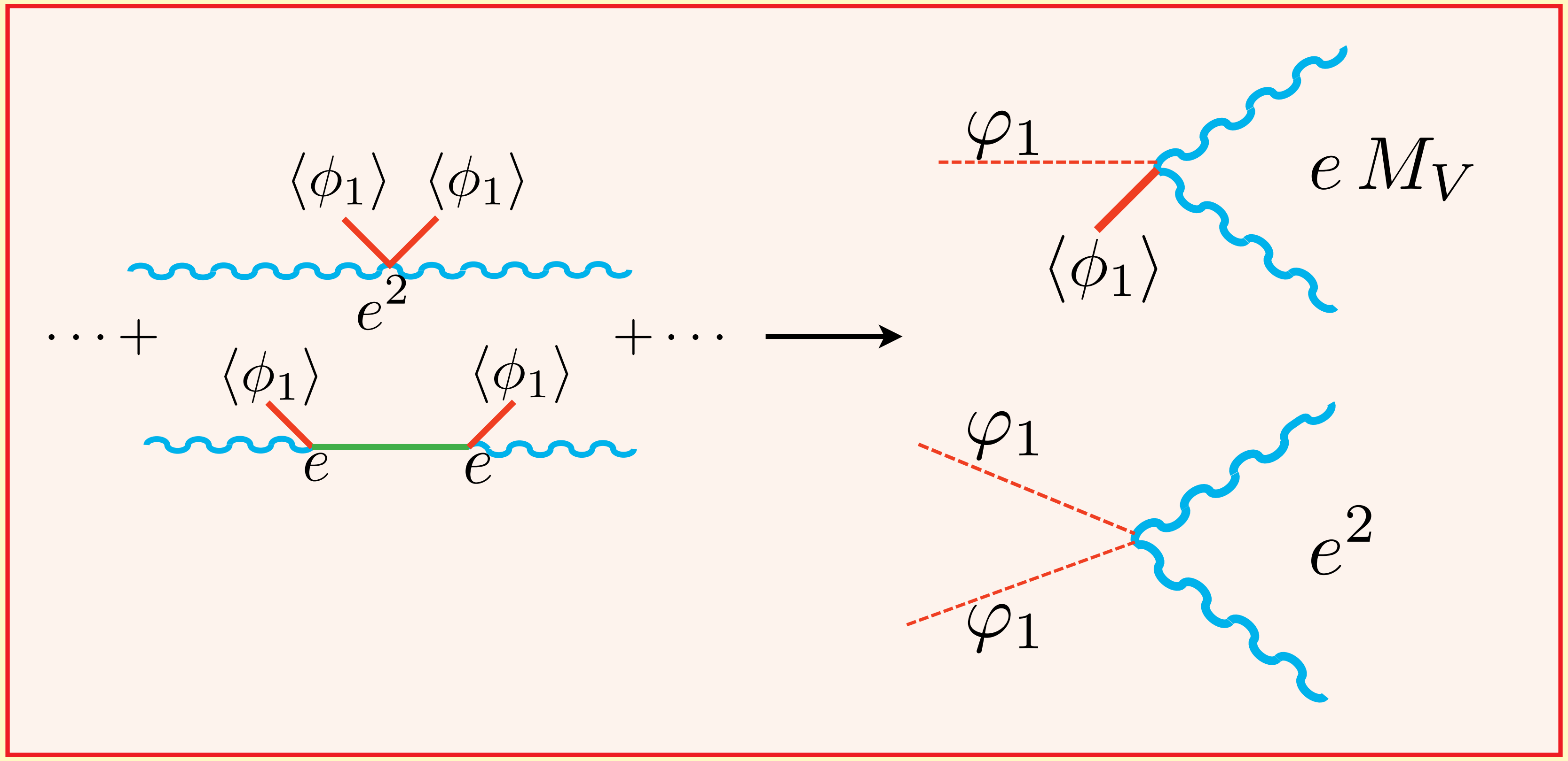

The Scalar boson couples at tree-level to two massive gauge bosons

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Brout - Englert

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renormalizable gauge Brout - Englert

unitary gauge Higgs

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Consistent quantum theory

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

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P.W. Higgs, Phys. Rev. Lett. **13** (1964) 508.

$$\frac{g_{\mu\nu} - q_\mu q_\nu / q^2}{q^2 - M_V^2} - \frac{1}{M_V^2}\frac{q_\mu q_\nu}{q^2} = \frac{g_{\mu\nu} - q_\mu q_\nu / \mu^2}{q^2 - M_V^2}$$

↑ *renormalizable gauge* Brout - Englert

↑ *unitary gauge* Higgs

↓

Consistent quantum theory ⟶ **Precision measurements**

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

III. The electroweak theory

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

gauge group

$$SU(2) \times U(1) \to U'(1)$$

$$g A_\mu^a T^a \qquad\qquad g' B_\mu \frac{Y}{2}$$

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3 fictitious NG bosons

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3 massive and 1 massless gauge boson

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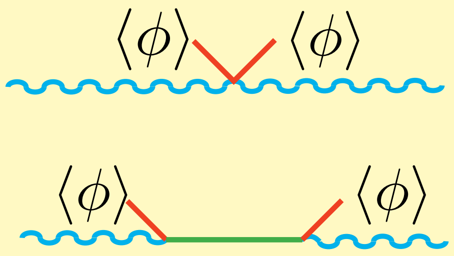
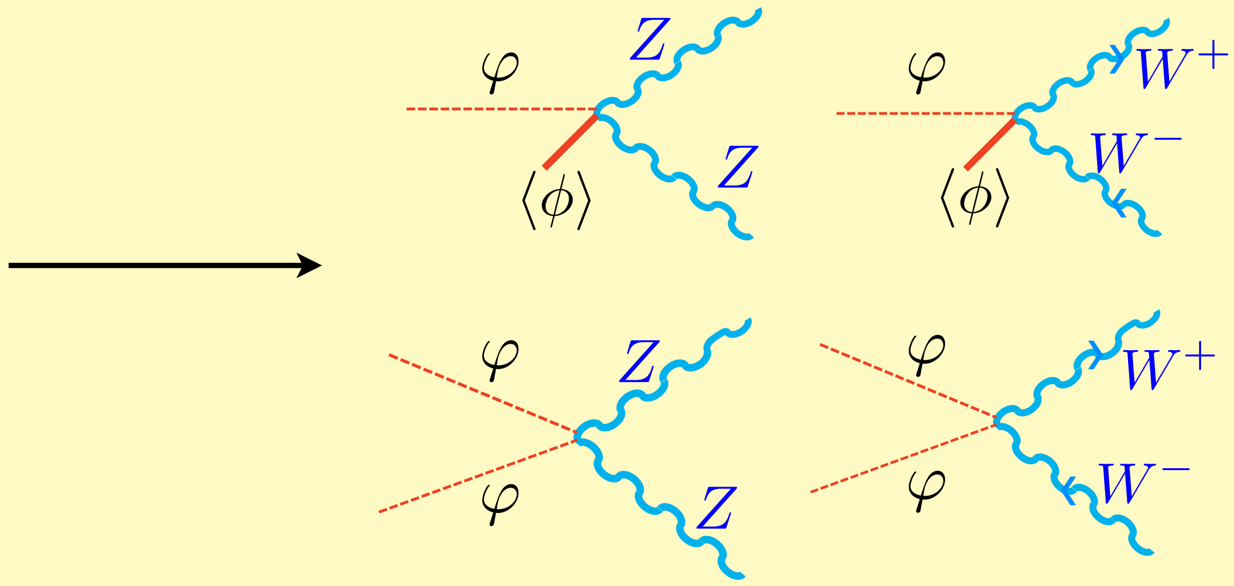
The mechanism should be considered as verified !

The Scalar boson coupling to gauge and fermionic sectors

massive gauge bosons





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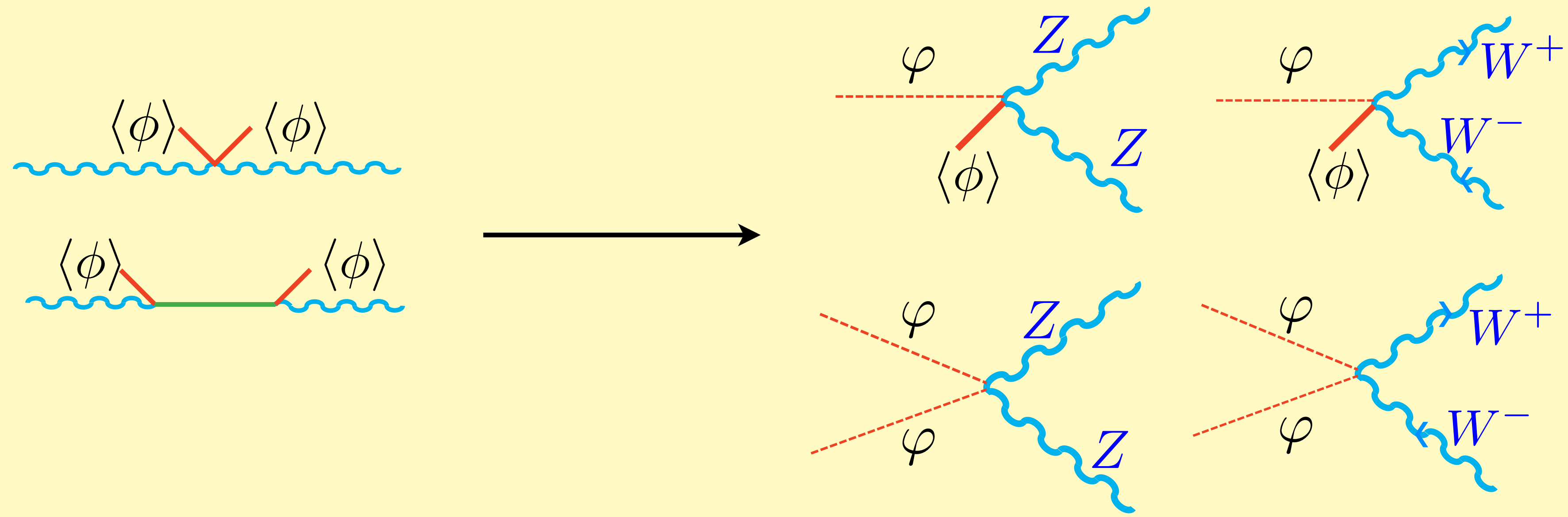
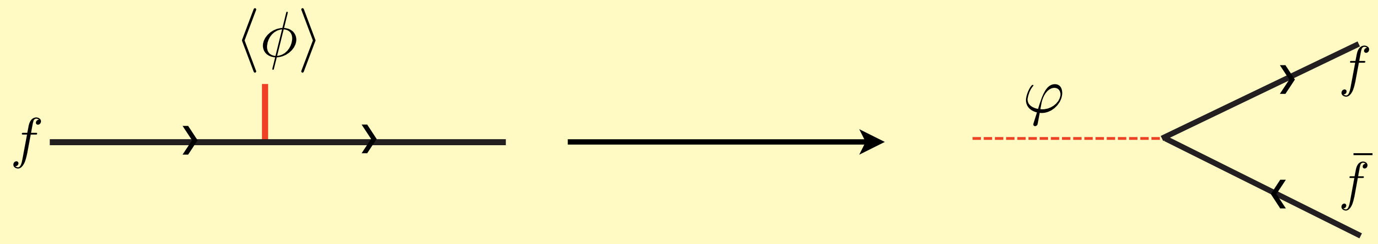


fermion masses



$$\propto \frac{m_f}{M_V}$$

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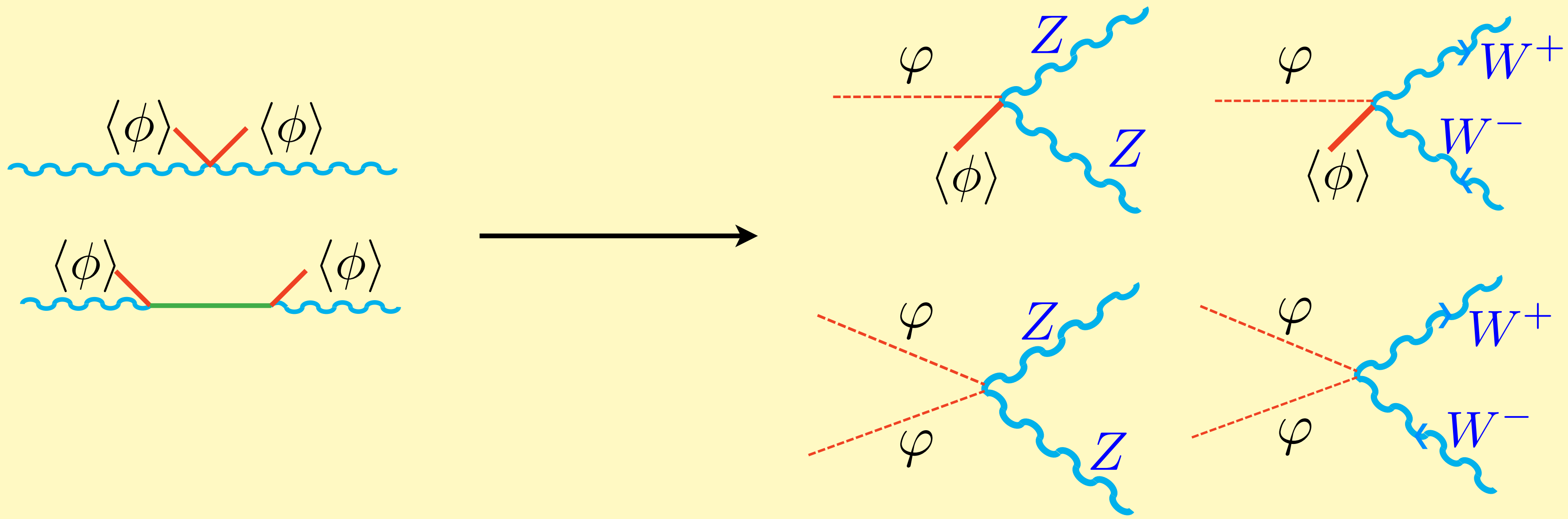

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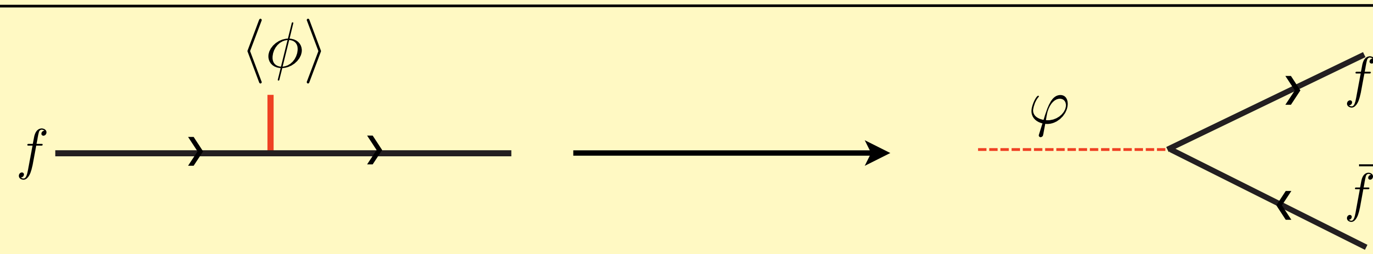

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These masses could result from a global SSB but consistency requires local SSB

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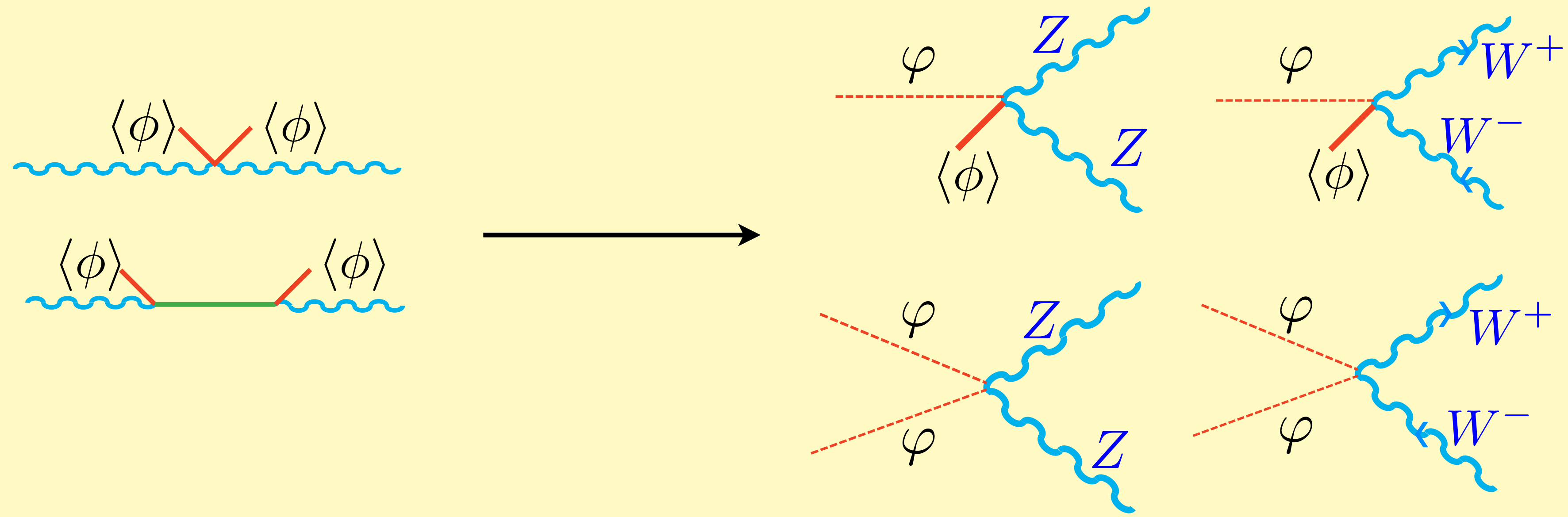

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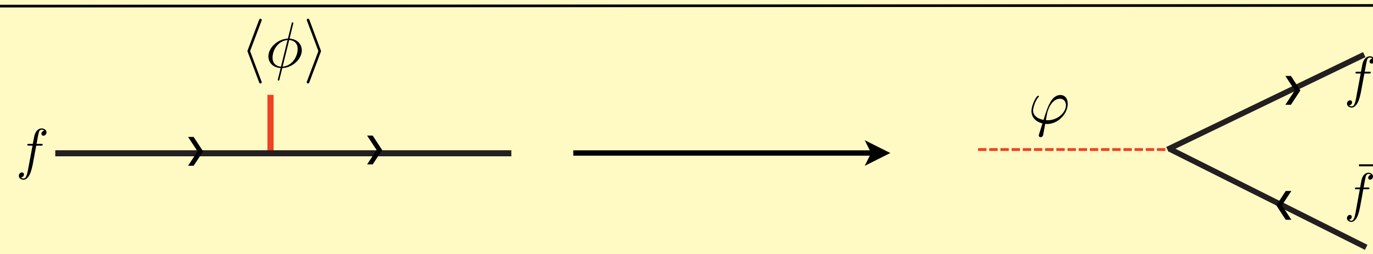

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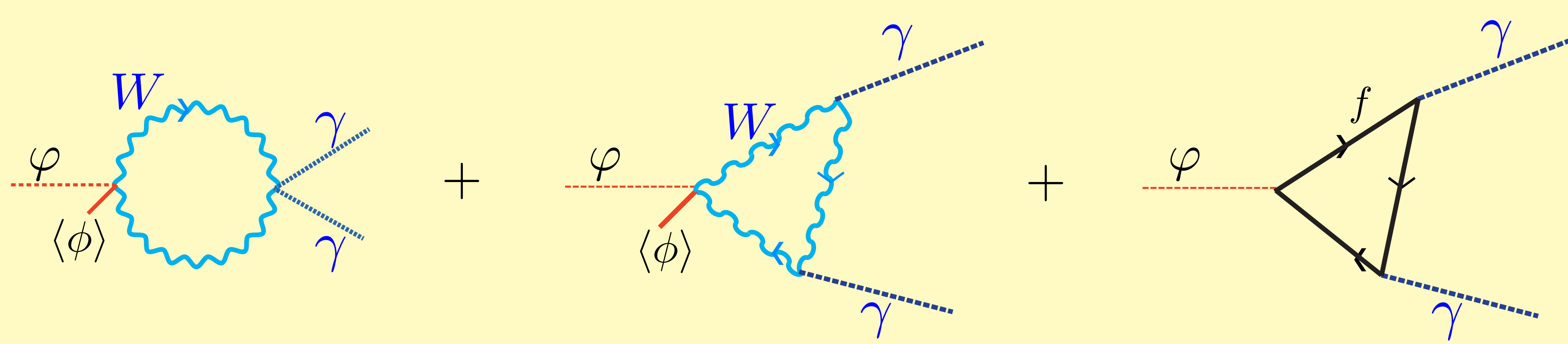
$\varphi \to \gamma\gamma$



IV. Perspectives

"Historic" and "logic" perspectives on SSB and on the Scalar boson

Local symmetry "breaking"
Gauge fields acquire mass

Fermions acquire mass
in a chiral group

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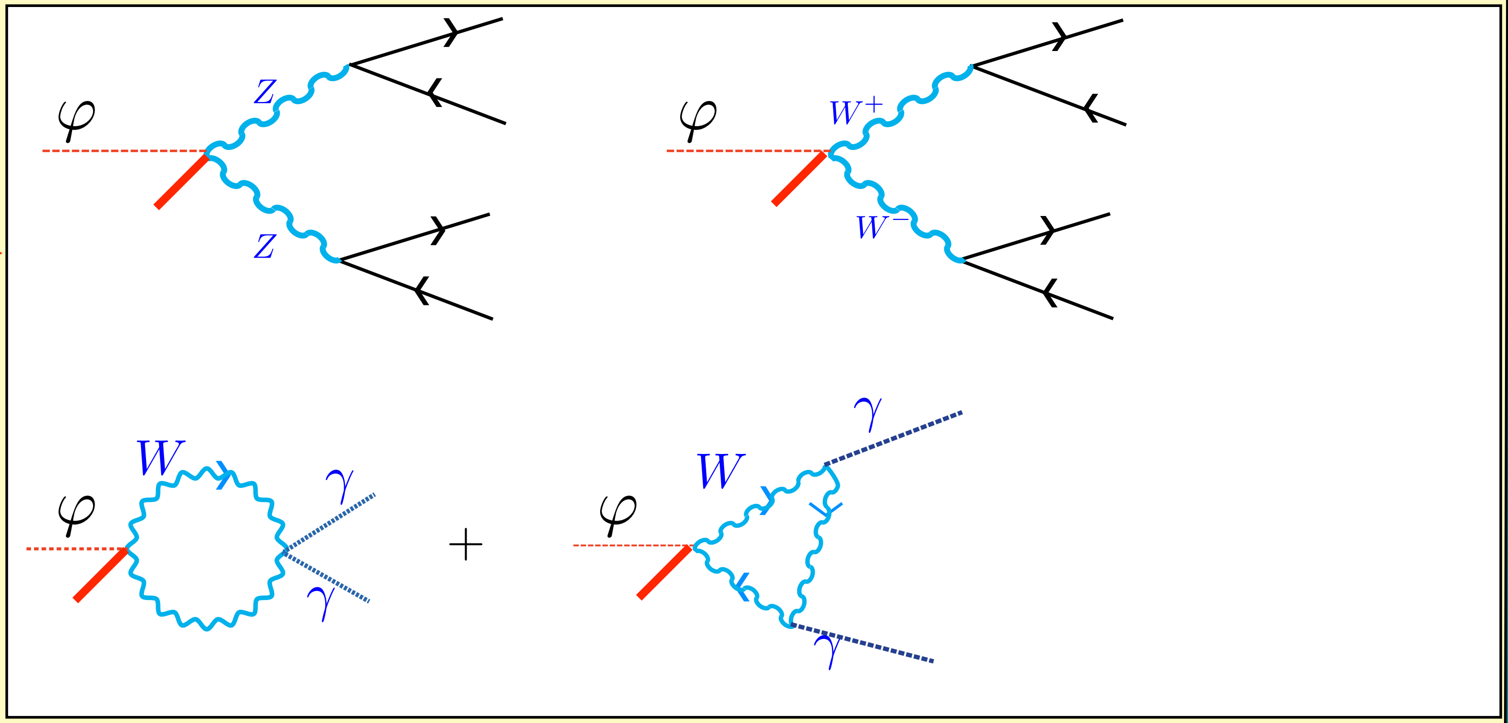

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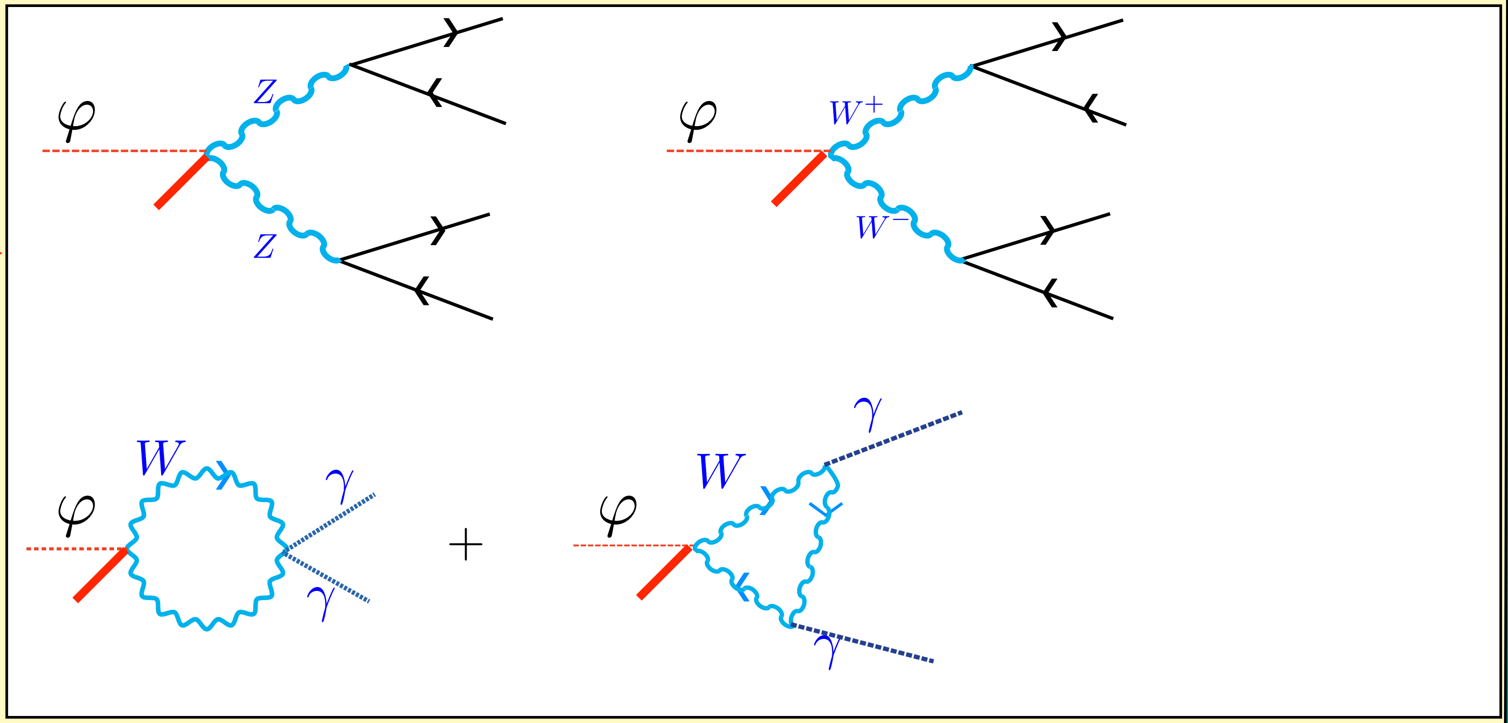

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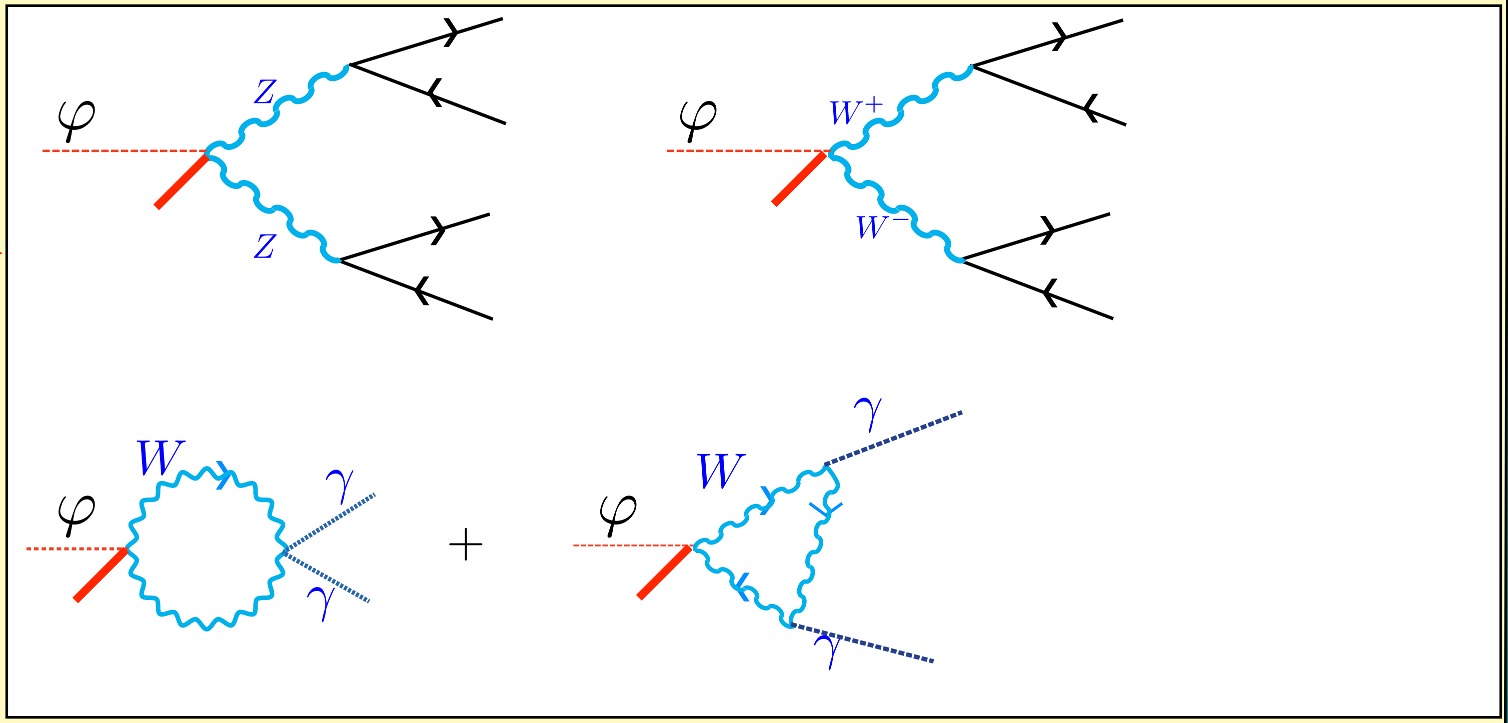

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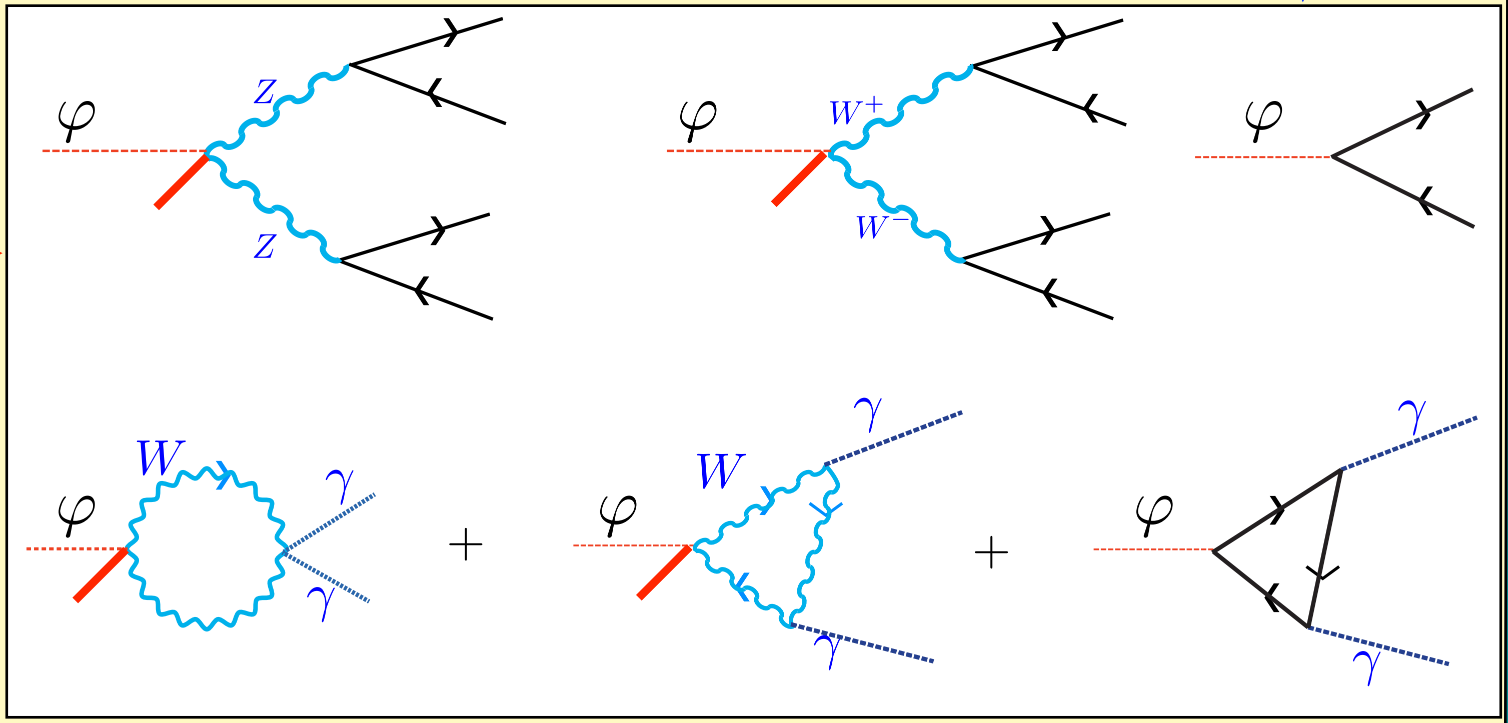

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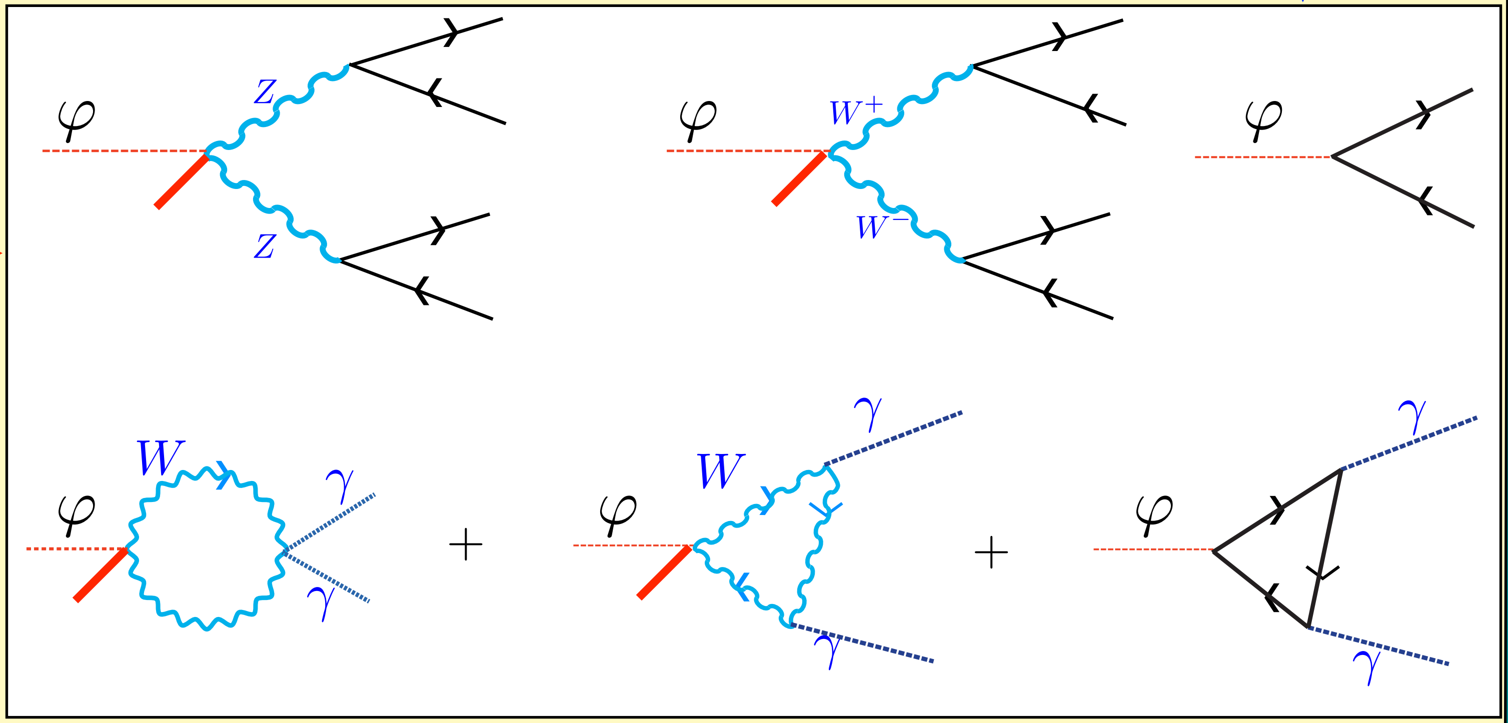

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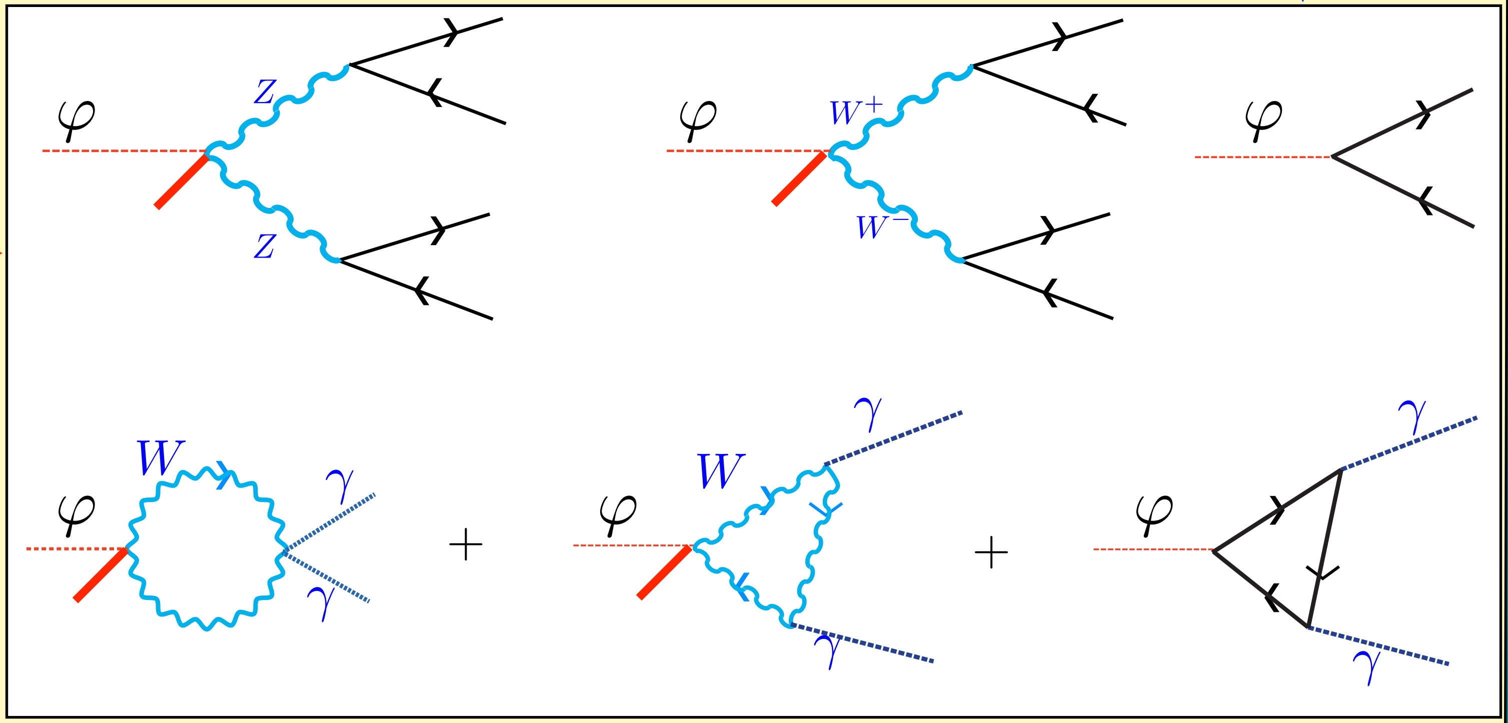

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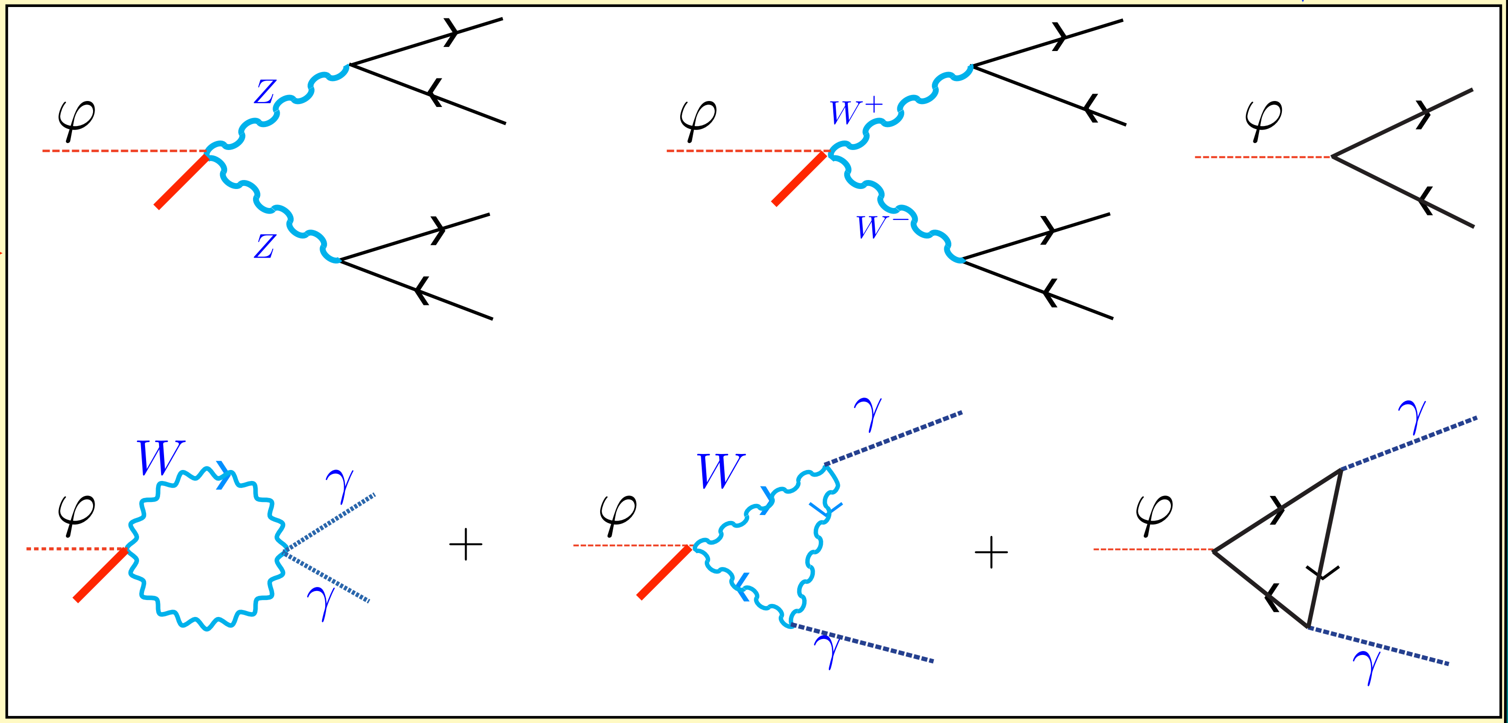

fermion contributions are critical for assessing perspectives

	Article	Reception date	Publication date
1	F. Englert and R. Brout Phys. Rev. Letters **13-[9]** (1964) 321	26/06/1964	31/08/1964
2	P.W. Higgs Phys. Letters **12** (1964) 132	27/07/1964	15/09/1964
3	P.W. Higgs Phys. Rev. Letters **13-[16]** (1964) 508	31/08/1964	19/10/1964
4	G.S. Guralnik, C.R. Hagen and T.W.B. Kibble Phys. Rev. Letters **13-[20]** (1964) 585	12/10/1964	16/11/1964