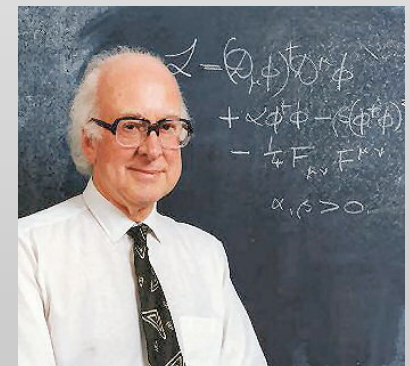
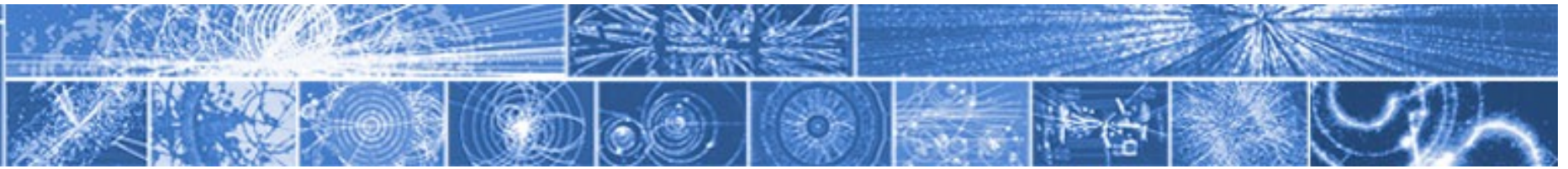


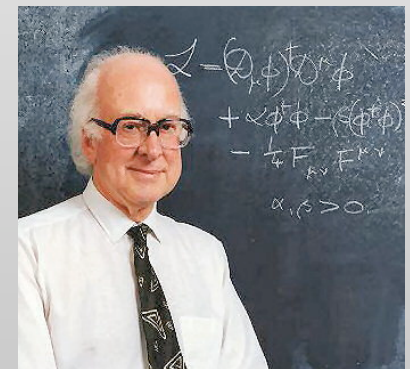
Il bosone di Higgs

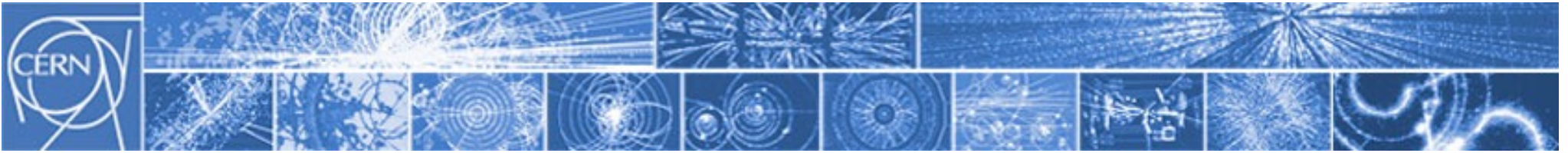




Il bosone di ~~Higgs~~

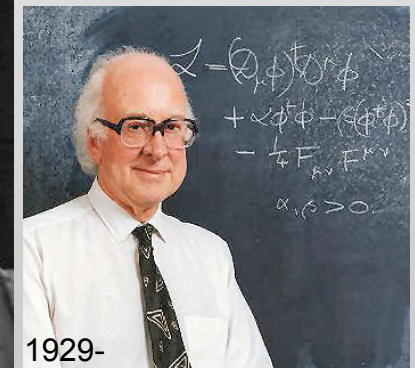
Englert-Brout-Higgs-Guralnik-Hagen-Kibble

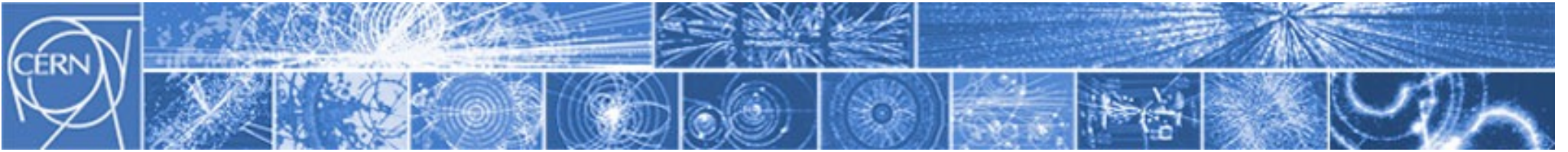




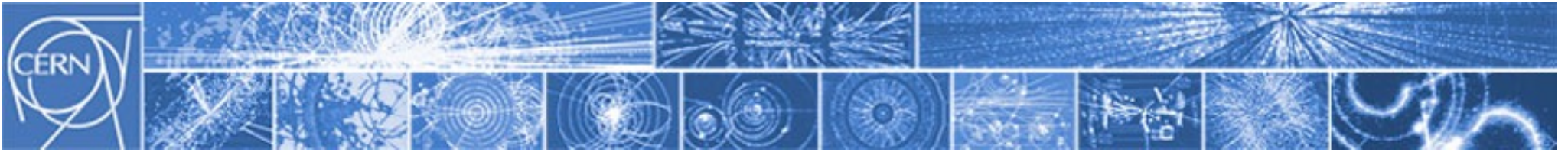
Il bosone di ~~Higgs~~

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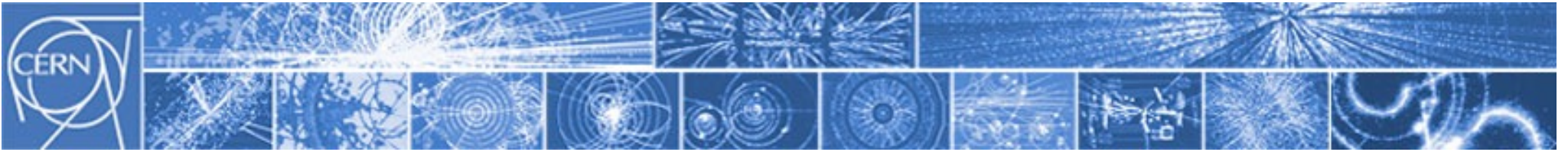


Q. Perché una particella ha massa m ?



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$$\begin{aligned}\mathcal{L} \simeq & -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\ & +i\bar{\Psi}\not{D}\Psi \\ & +y_{ij}\Psi_i\Psi_j\phi \\ & +|D_\mu\phi|^2 - V(\phi)\end{aligned}$$



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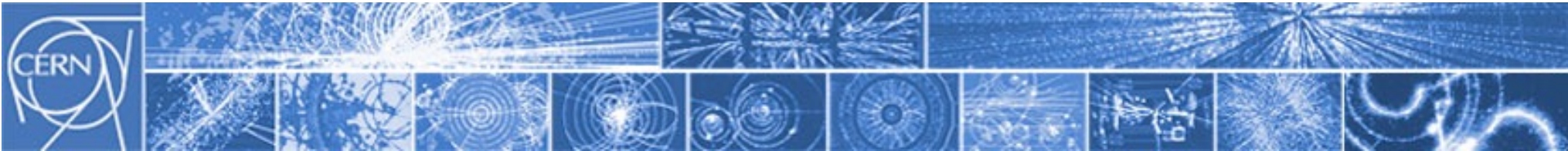
$$\mathcal{L} \simeq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

$$+i\bar{\Psi}\not{D}\Psi$$

$$+y_{ij}\Psi_i\Psi_j\phi$$

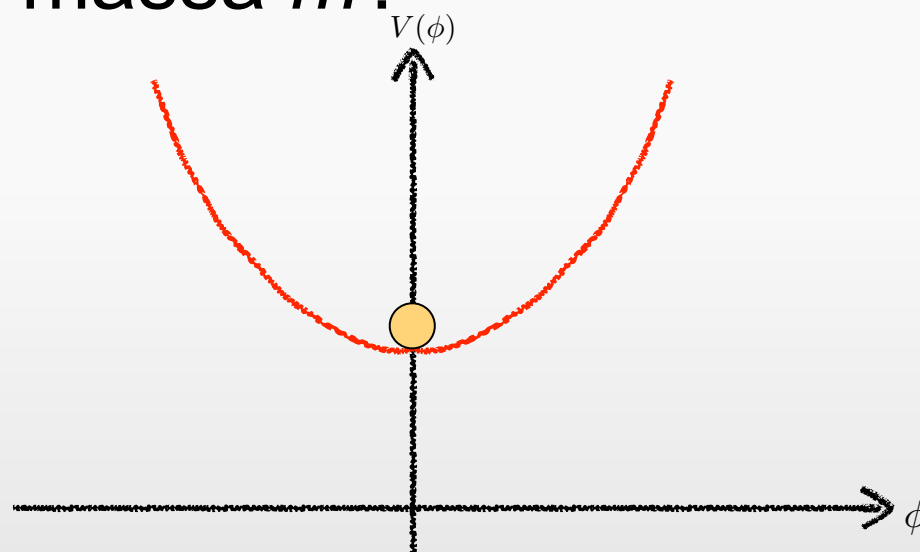
$$+|D_\mu\phi|^2 - V(\phi)$$

$$-m^2|\phi|^2 + \lambda|\phi|^4$$
An arrow points from the $V(\phi)$ term in the previous equation to this expanded form.



Q. Perché una particella ha massa m ?

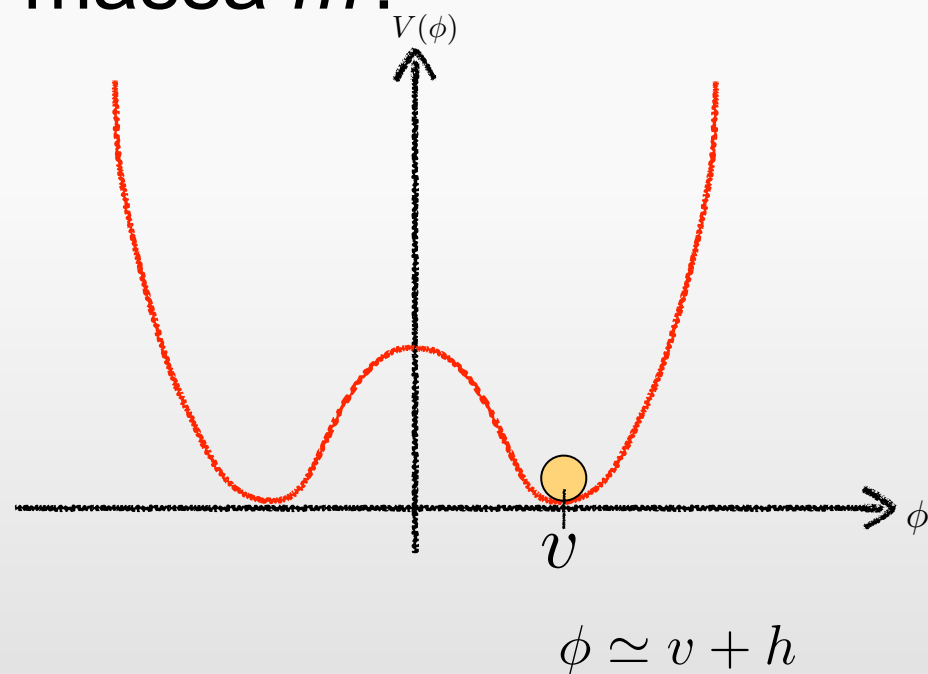
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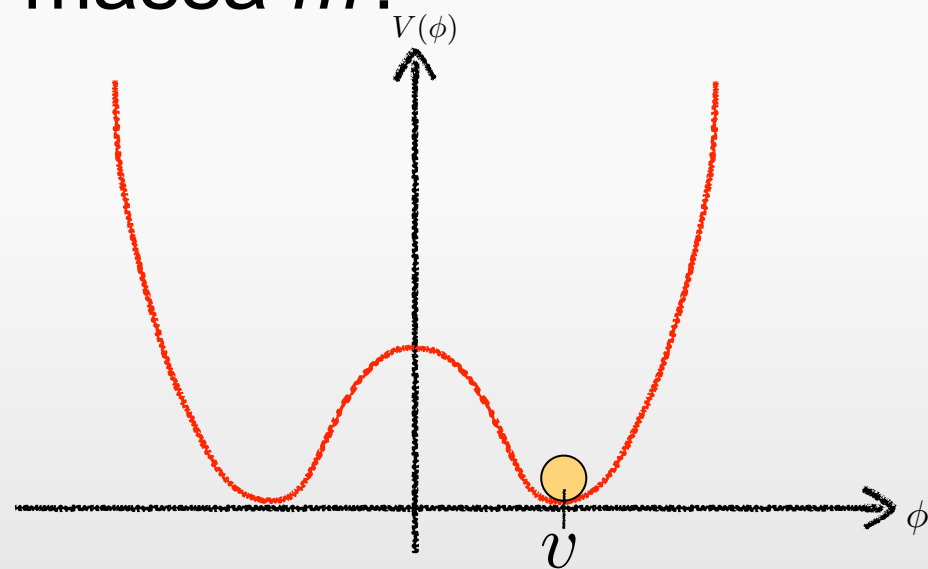
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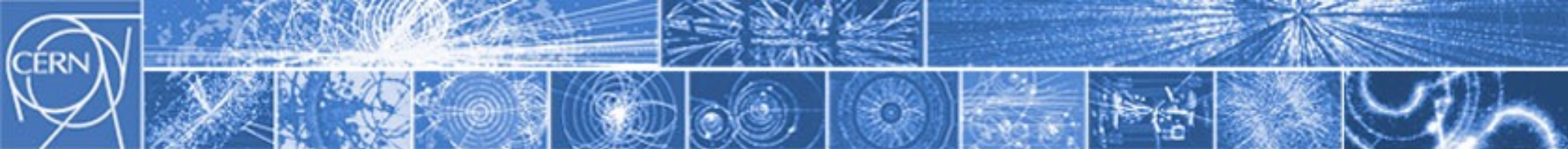


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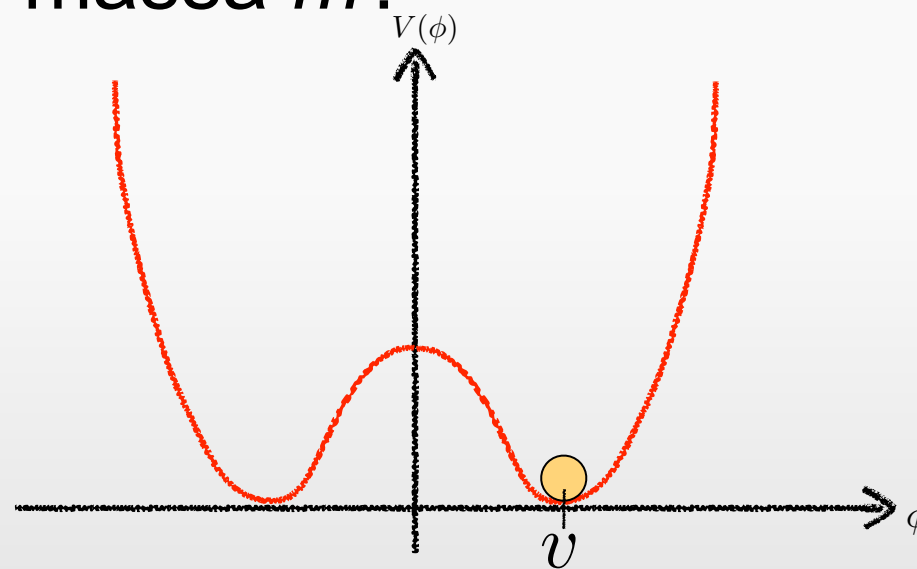


$$\phi = \frac{1}{\sqrt{2}}(v + h)$$



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$$\mathcal{L} \simeq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi + y_{ij}\Psi_i\Psi_j\phi + |D_\mu\phi|^2 - V(\phi)$$



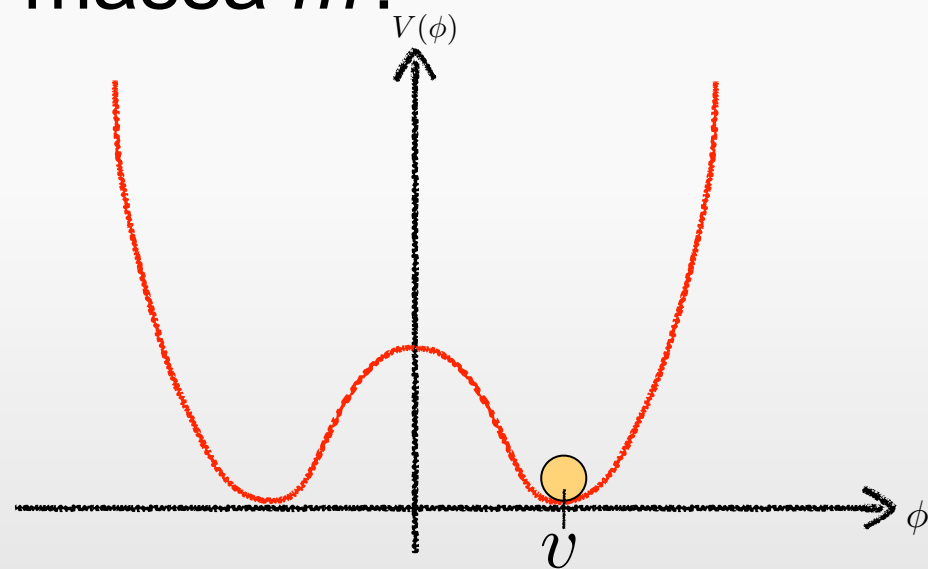
$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h) \rightsquigarrow \frac{y_\mu v}{\sqrt{2}}\mu\mu + \frac{y_\mu}{\sqrt{2}}\mu\mu h = \mu\mu + \mu\mu h$$

$\phi = \frac{1}{\sqrt{2}}(v+h)$



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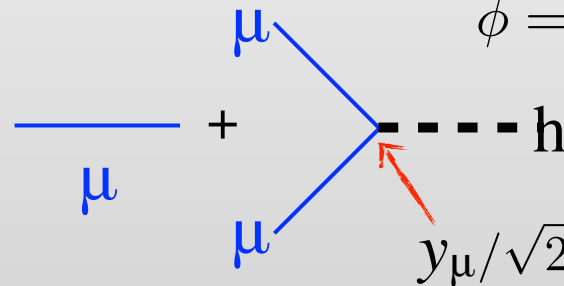


$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h)$$

$$\frac{y_\mu v}{\sqrt{2}} \mu\mu$$

\downarrow
 m_μ

$$+ \frac{y_\mu}{\sqrt{2}} \mu\mu h$$

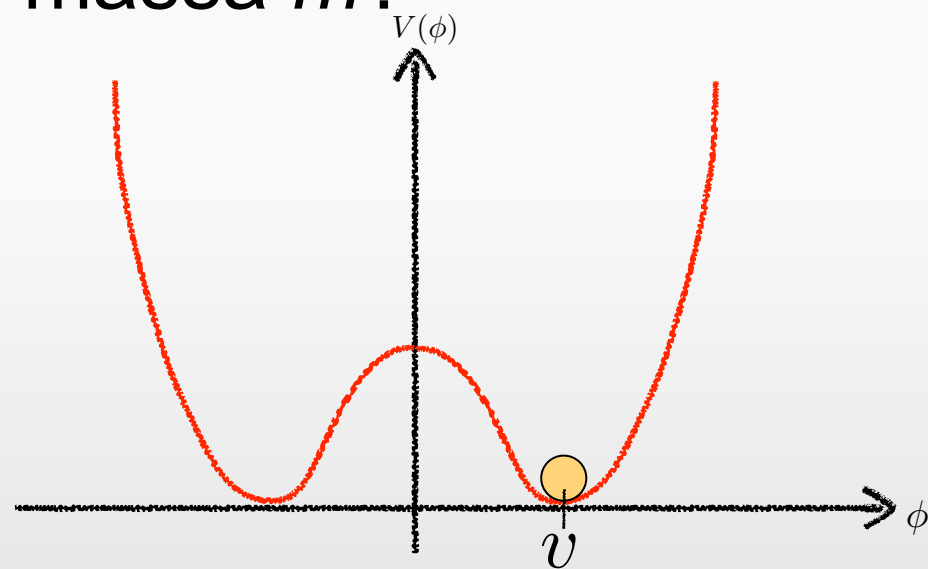


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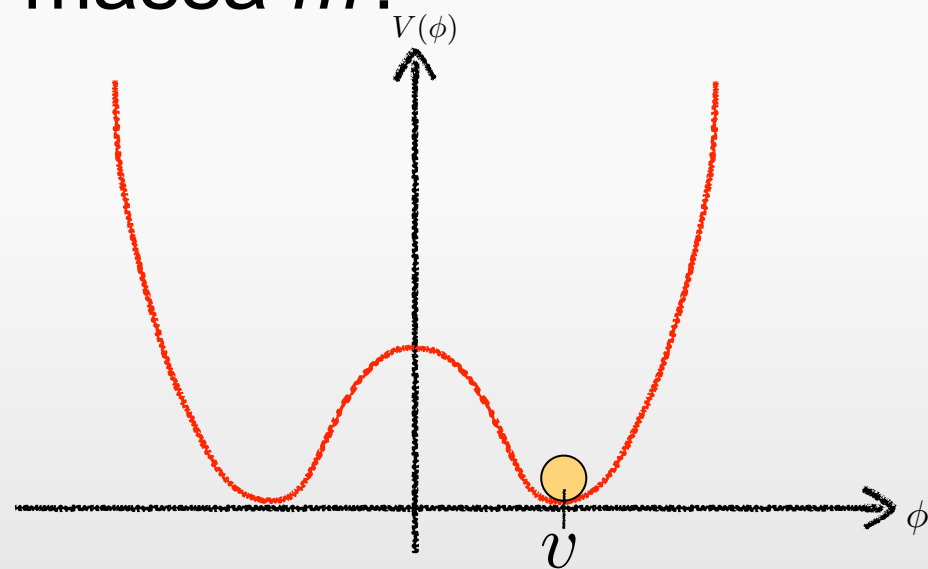
$\phi = \frac{1}{\sqrt{2}}(v+h)$

$$|D_\mu\phi|^2 \rightsquigarrow \frac{g v}{2}W^+W^-$$



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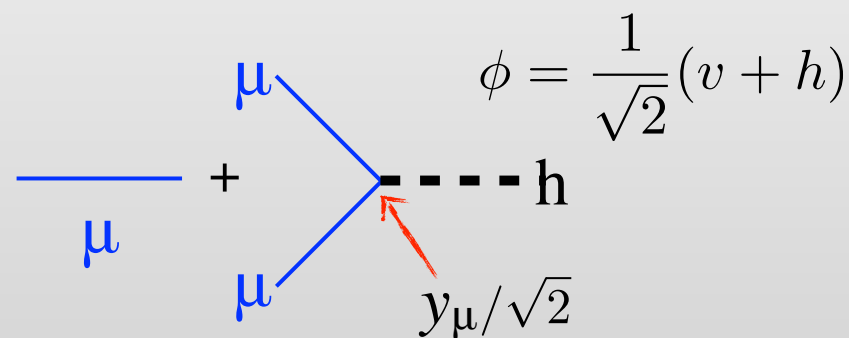


$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h) \rightsquigarrow \frac{y_\mu v}{\sqrt{2}}\mu\mu + \frac{y_\mu}{\sqrt{2}}\mu\mu h = \mu \text{---} \mu + \mu \text{---} \mu \text{---} h$$

\downarrow m_μ

$$|D_\mu\phi|^2 \rightsquigarrow \frac{g v}{2} W^+ W^-$$

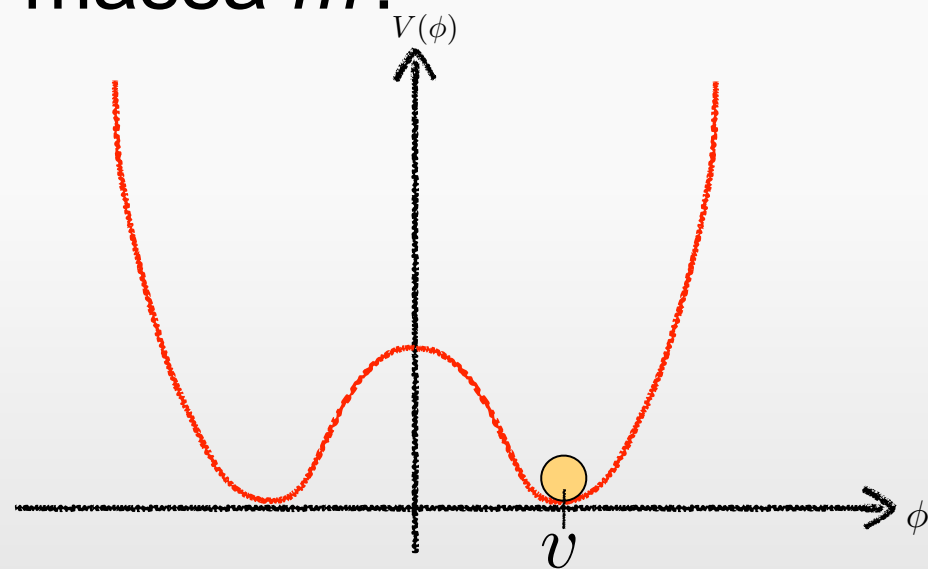
\uparrow M_W





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$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h) \rightsquigarrow \frac{y_\mu v}{\sqrt{2}}\mu\mu + \frac{y_\mu}{\sqrt{2}}\mu\mu h = \mu + h$$

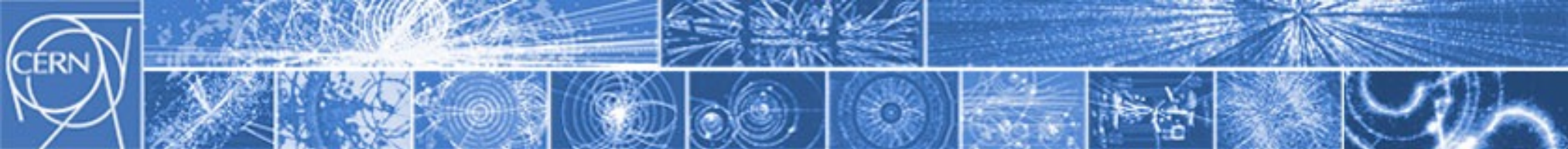
$\phi = \frac{1}{\sqrt{2}}(v+h)$

A Feynman diagram showing a muon (μ) line on the left and a higgs boson (h) line on the right, meeting at a vertex. A red arrow points to the vertex with the label $y_\mu/\sqrt{2}$.

$$|D_\mu\phi|^2 \rightsquigarrow \frac{g v}{2} W^+ W^-$$

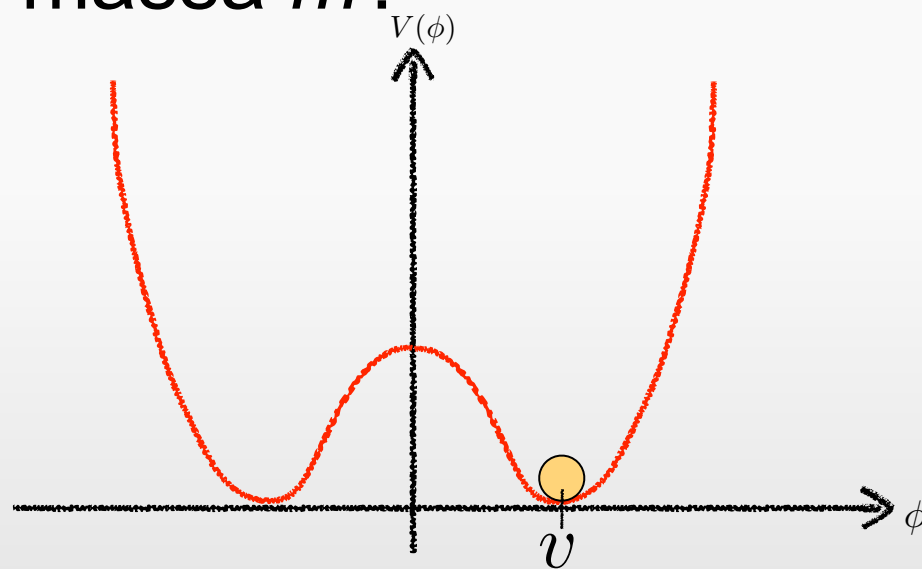
M_W

$$V(\phi) \rightsquigarrow \frac{1}{2}(2\lambda v^2)hh$$



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$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h) \rightsquigarrow \frac{y_\mu v}{\sqrt{2}}\mu\mu + \frac{y_\mu}{\sqrt{2}}\mu\mu h = \mu + h$$

$\phi = \frac{1}{\sqrt{2}}(v+h)$

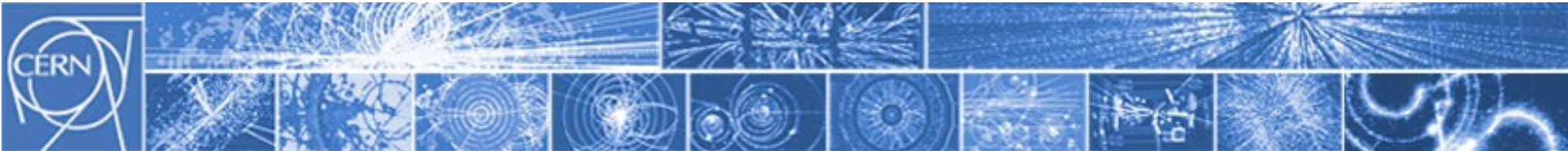
A Feynman diagram showing two muons (μ) interacting via a Higgs boson (h). The muons are represented by blue lines, and the Higgs boson is represented by a dashed line. A red arrow points to the vertex with the label $y_\mu/\sqrt{2}$.

$$|D_\mu\phi|^2 \rightsquigarrow \frac{g v}{2} W^+ W^-$$

M_W

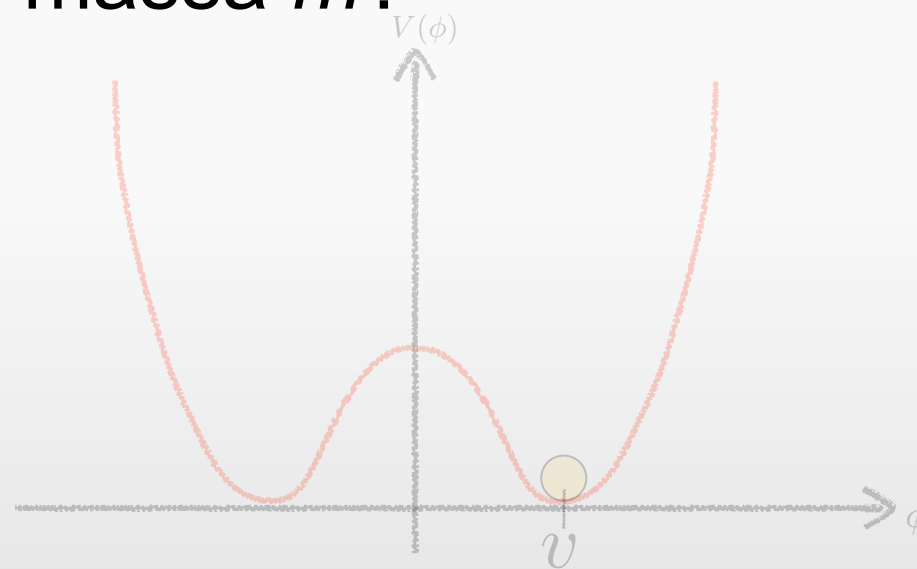
$$V(\phi) \rightsquigarrow \frac{1}{2}(2\lambda v^2) h h$$

m_h^2



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$$\mathcal{L} \simeq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi + y_{ij}\Psi_i\Psi_j\phi + |D_\mu\phi|^2 - V(\phi)$$



$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h) \rightsquigarrow \frac{y_\mu v}{\sqrt{2}}\mu\mu + \frac{y_\mu}{\sqrt{2}}\mu\mu h = \mu + h$$

$\phi = \frac{1}{\sqrt{2}}(v+h)$

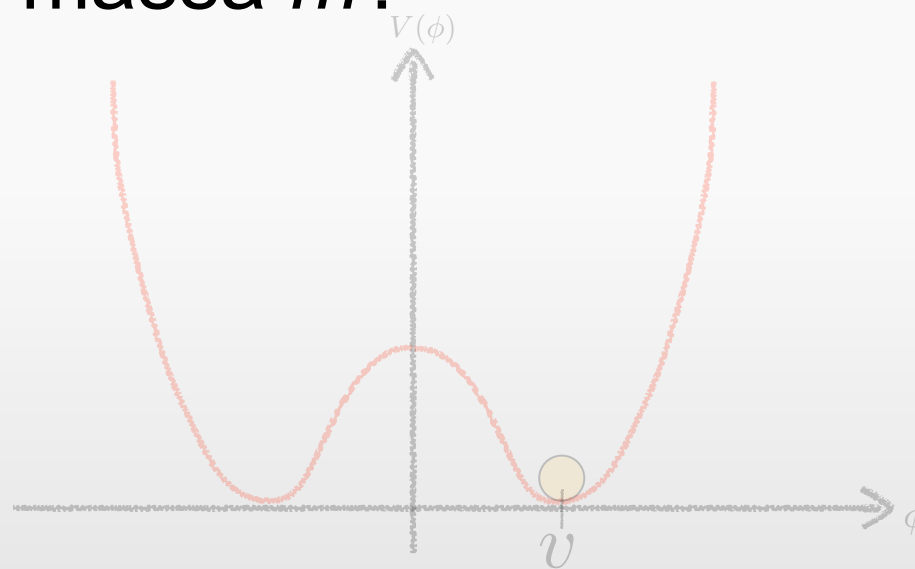
$$|D_\mu\phi|^2 \rightsquigarrow \frac{g v}{2}W^+W^- \quad V(\phi) \rightsquigarrow \frac{1}{2}(2\lambda v^2)hh$$

A. Perché interagisce con l'higgs con intensità $y = \sqrt{2}m/v$!



Q. Perché una particella ha massa m ?

$$\mathcal{L} \simeq -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\Psi} \not{D} \Psi + y_{ij} \Psi_i \Psi_j \phi + |D_\mu \phi|^2 - V(\phi)$$

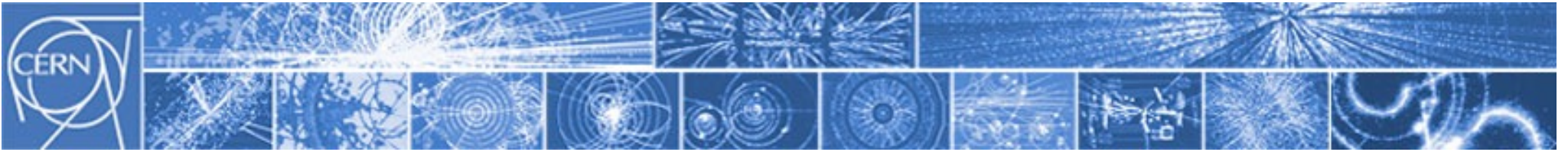


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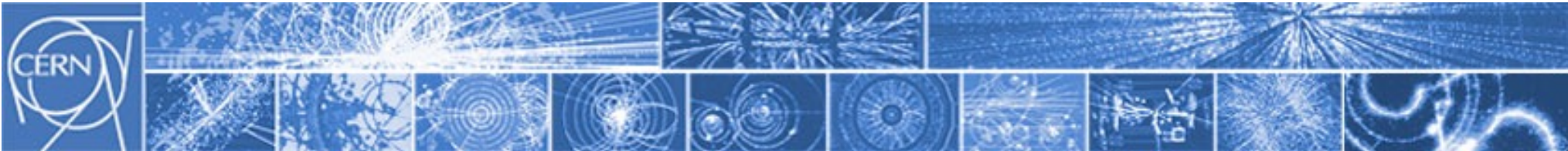
$$|D_\mu \phi|^2 \rightsquigarrow \frac{g v}{2} W^+ W^- \quad V(\phi) \rightsquigarrow \frac{1}{2} (2\lambda v^2) h h$$

Q. E se il campo scalare non esistesse?



Q. Perché una particella ha massa m ?

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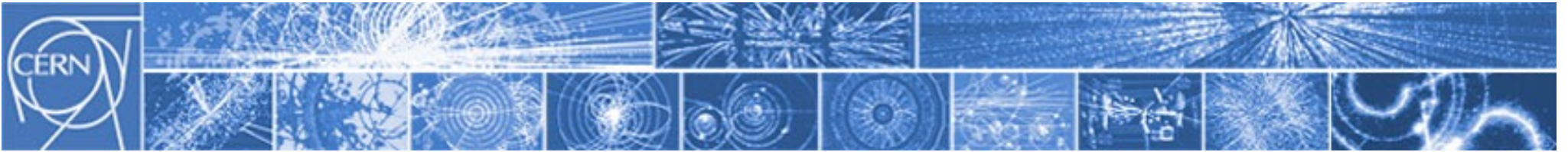
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$$\mathcal{L} \simeq -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\Psi} \not{D} \Psi$$

$$+ y_{ij} \Psi_i \Psi_j \phi + |D_\mu \phi|^2 - V(\phi)$$

$$F_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$$

$$F_{\mu\nu} F^{\mu\nu} \rightsquigarrow \partial_\mu W_\nu \partial_\nu W_\mu + \dots$$



Q. Perché una particella ha massa m ?

$$\mathcal{L} \simeq -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\Psi} \not{D} \Psi$$

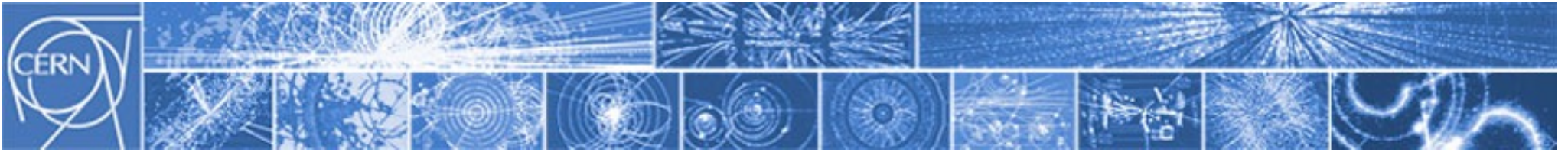
$$+ y_{ij} \Psi_i \Psi_j \phi + |D_\mu \phi|^2 - V(\phi)$$

$$F_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$$

$$D \simeq \partial - igW$$

$$F_{\mu\nu} F^{\mu\nu} \rightsquigarrow \partial_\mu W_\nu \partial_\nu W_\mu + \dots$$

$$i\bar{\Psi} \not{D} \Psi \rightsquigarrow \mu \partial \mu - ig \mu W \mu$$



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$$\mathcal{L} \simeq -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\Psi} \not{D} \Psi$$

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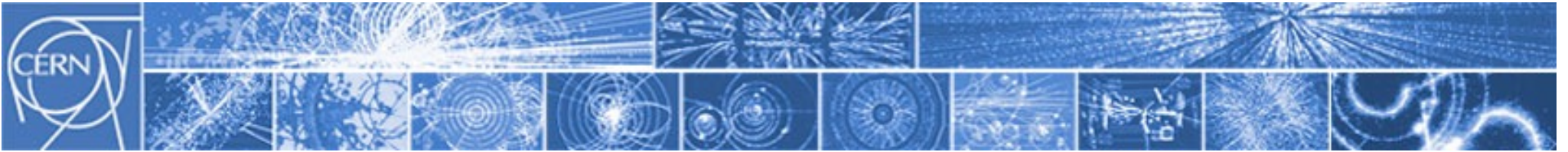
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niente termini di massa!



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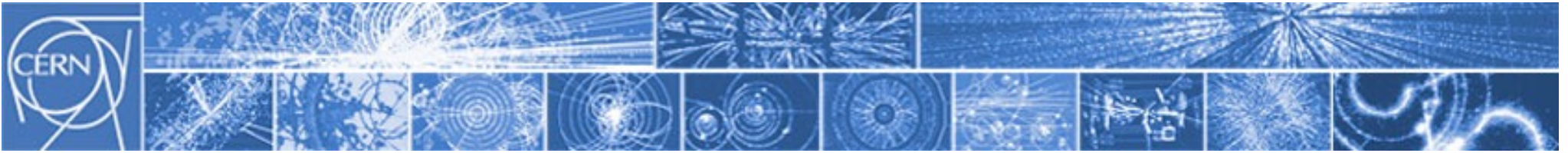
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niente termini di massa!

E se li mettessimo *a mano*?

$$+M W W \dots \quad +m \mu \mu \dots$$



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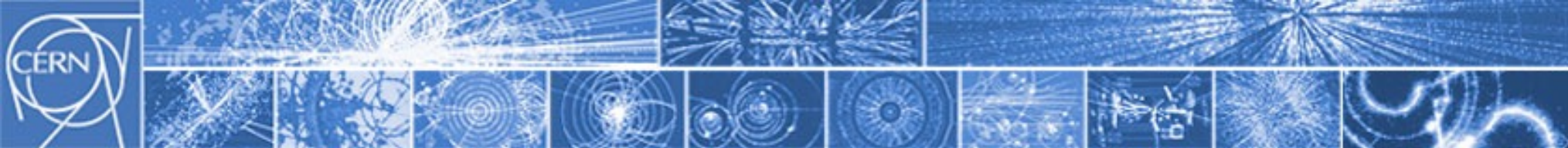
$$i\bar{\Psi} \not{D} \Psi \rightsquigarrow \mu \partial_\mu - ig \mu W_\mu$$

E se li mettessimo *a mano*?

$$+ M W W \dots + m \mu \mu \dots$$



rottura esplicita della simmetria di gauge



Q. Derive the Lagrangian for the Higgs boson

$$\mathcal{L} = \bar{\psi} (i \not{\partial} - m) \psi - \frac{1}{4} F_{\mu\nu}^2 - \partial_\nu W_\mu$$

W

$$F_{\mu\nu}^2$$

$$i\bar{\Psi} \not{D} \Psi$$

E_s

$$+ M$$

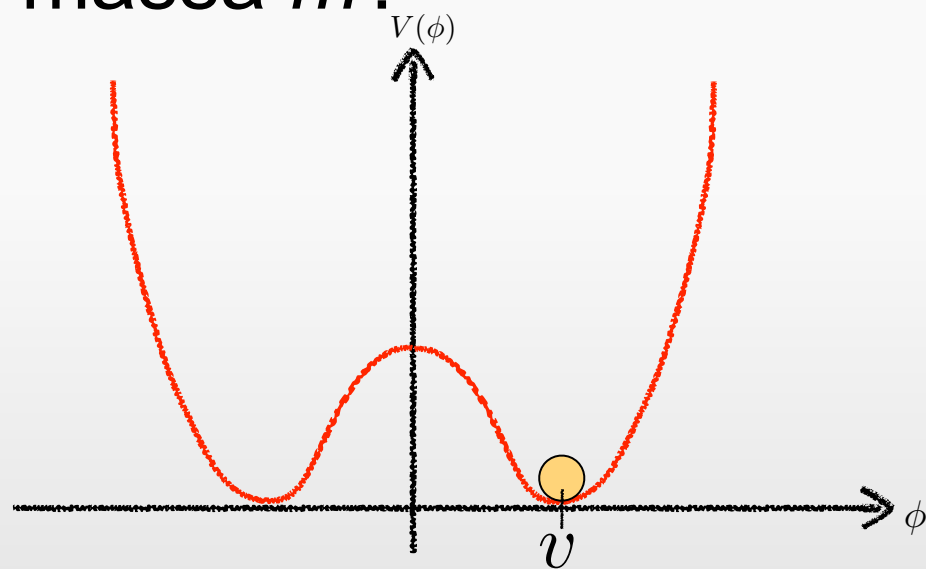


di gauge



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$$y_{ij}\Psi_i\Psi_j \frac{1}{\sqrt{2}}(v+h) \rightsquigarrow \frac{y_\mu v}{\sqrt{2}}\mu\mu + \frac{y_\mu}{\sqrt{2}}\mu\mu h = \mu + h$$

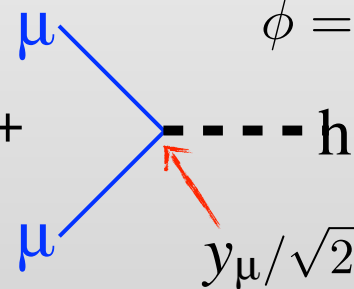
$\phi = \frac{1}{\sqrt{2}}(v+h)$

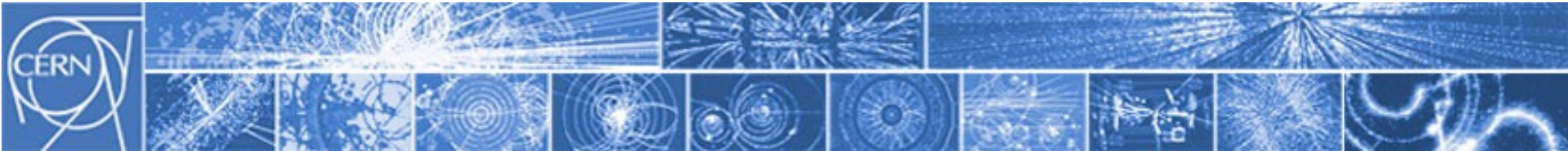
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M_W

$$V(\phi) \rightsquigarrow \frac{1}{2}(2\lambda v^2) h h$$

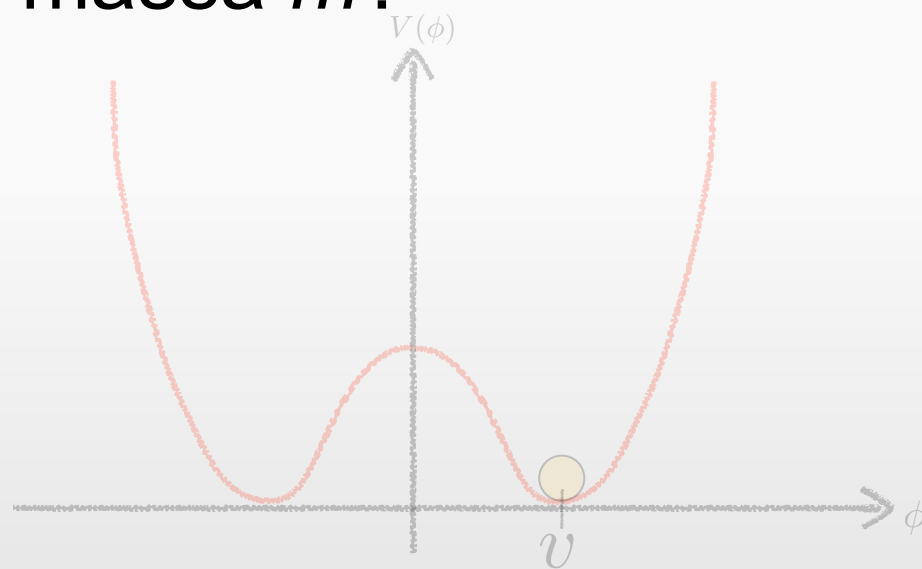
m_h^2





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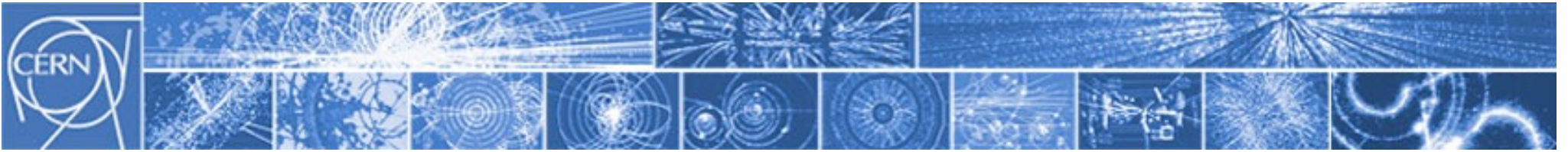


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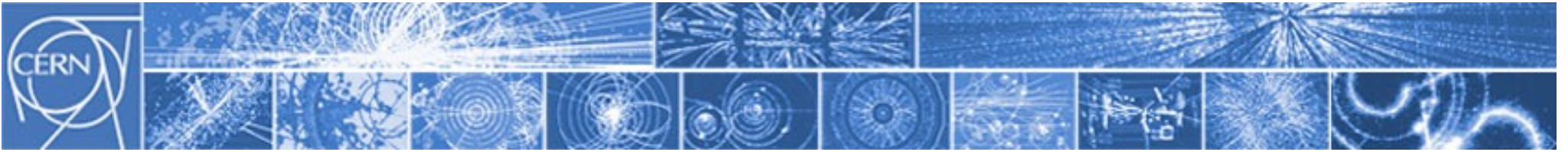
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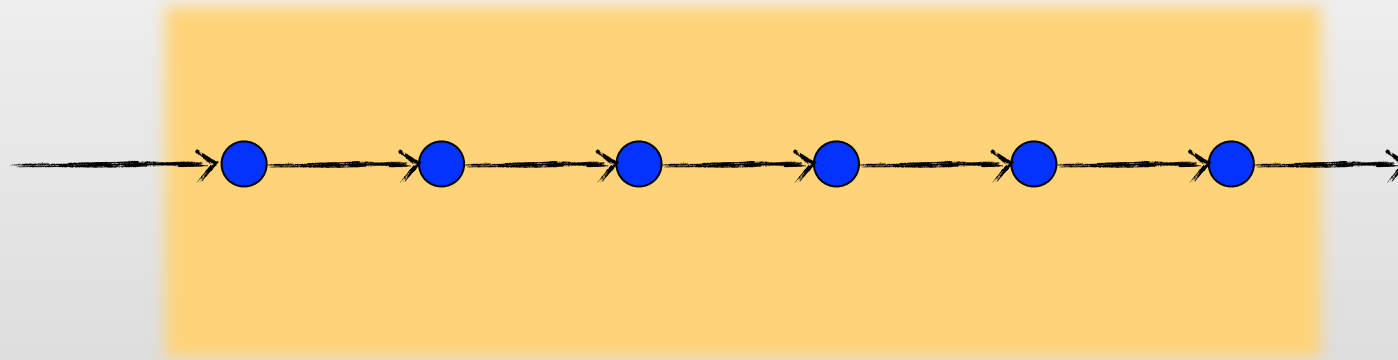
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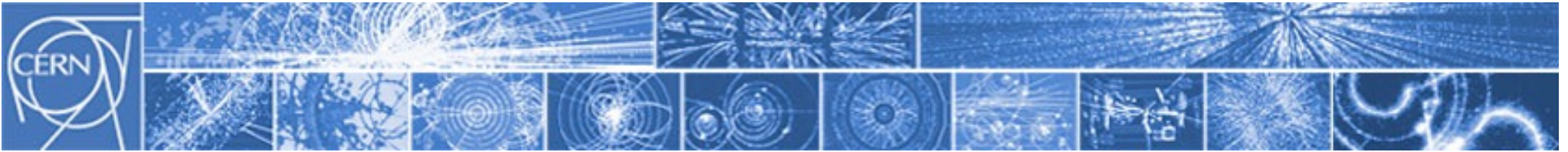


Q. Perché una particella ha massa m ?

A. Perché interagisce con l'higgs con intensità $y=\sqrt{2}m/v!$

Il *campo di higgs* è un mezzo continuo che permea l'universo.
Le particelle, interagendo col campo, acquistano un'inerzia/massa.

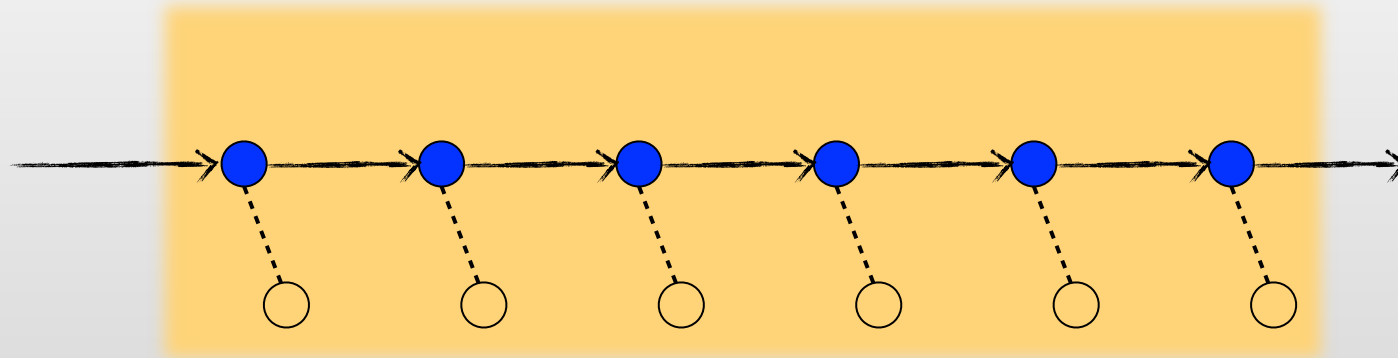


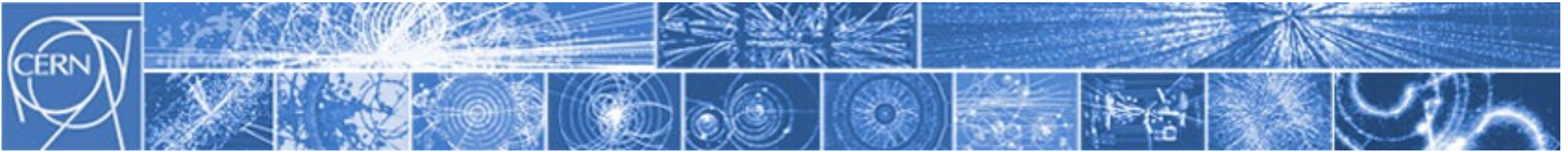


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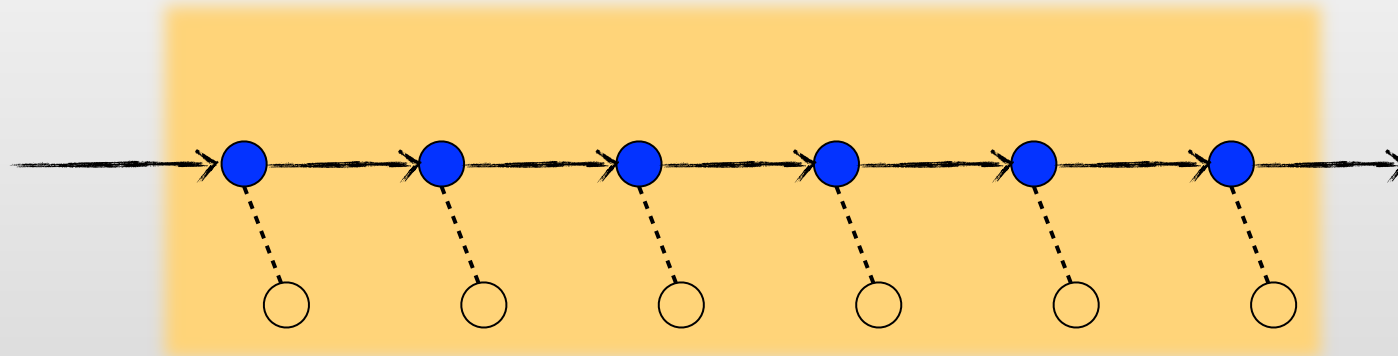




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Le 'onde' del *campo* di Higgs sono una *particella*:
la particella di Higgs (bosone).

Equation (2b) describes waves whose quanta have
(bare) mass $2\phi_0\{V''(\phi_0^2)\}^{1/2}$

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BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

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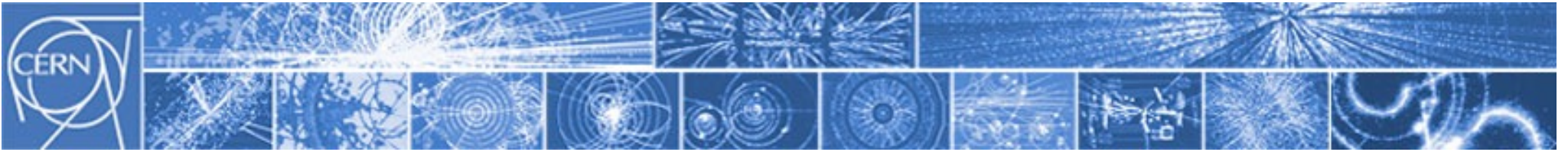
19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

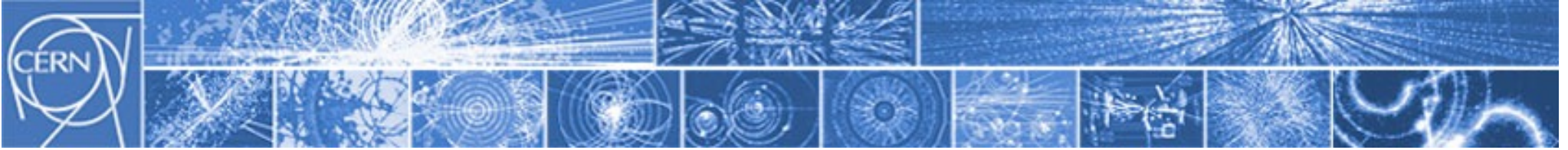
Peter W. Higgs

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Migliore analogia per il meccanismo e il bosone di higgs?



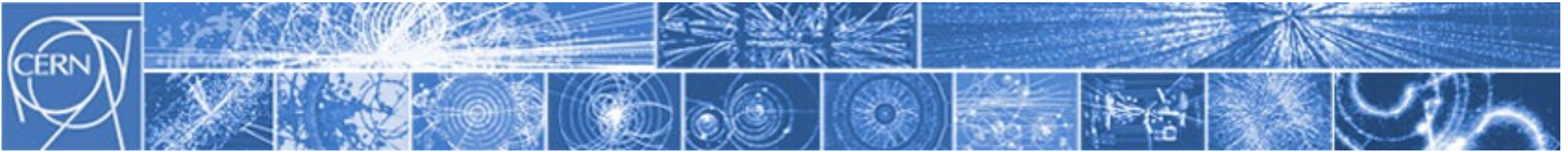
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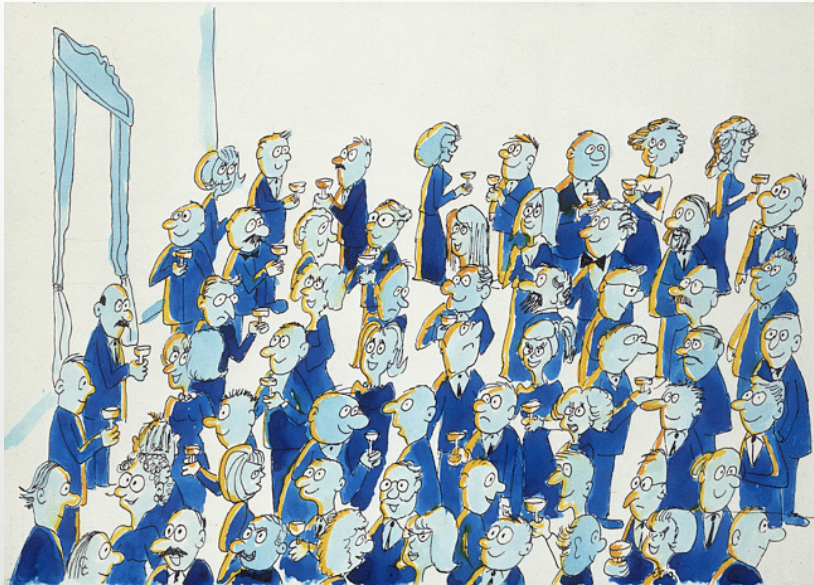


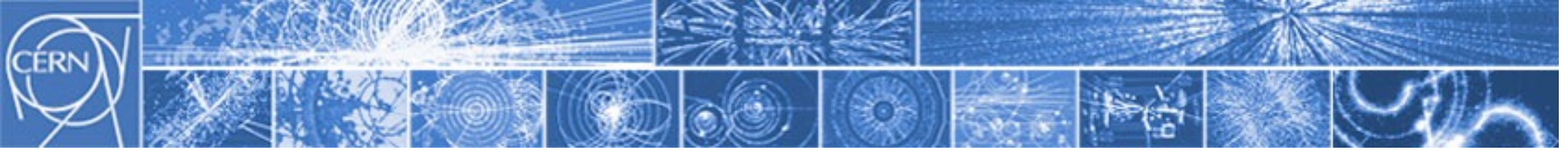
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