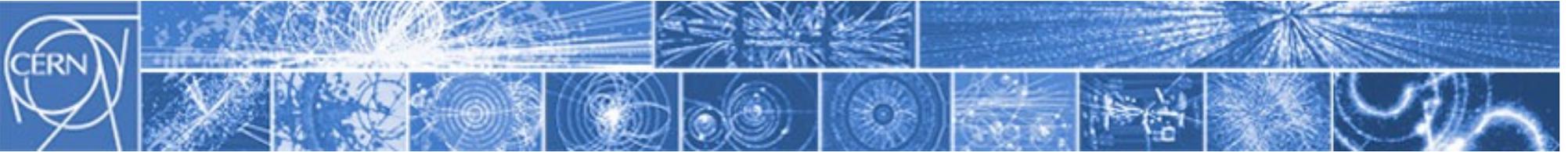


# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

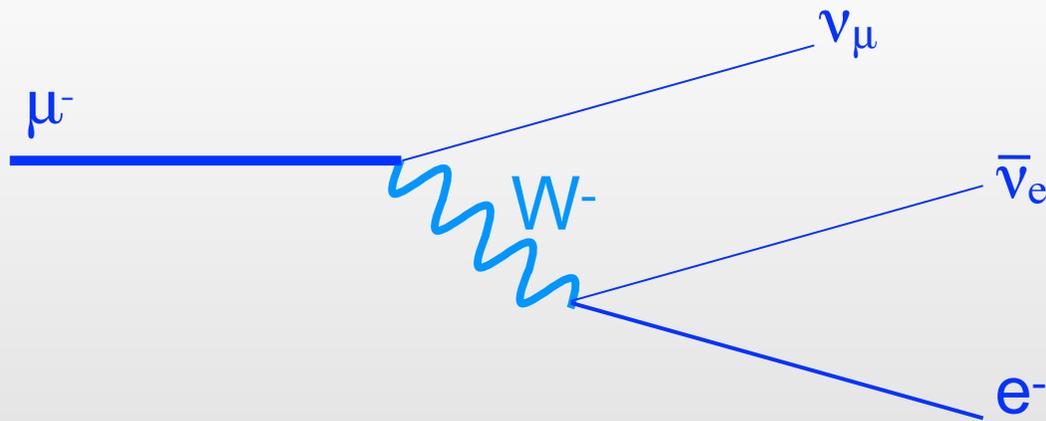
*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*

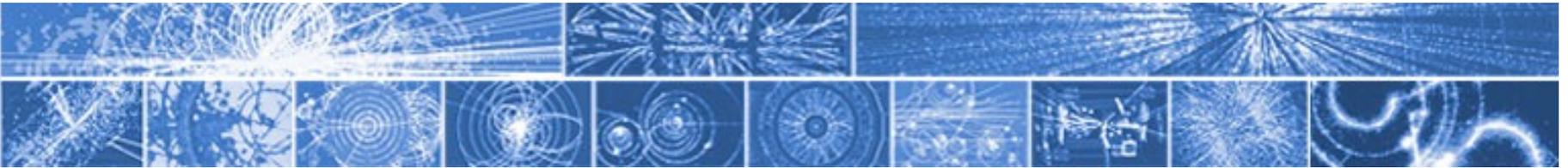


# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*

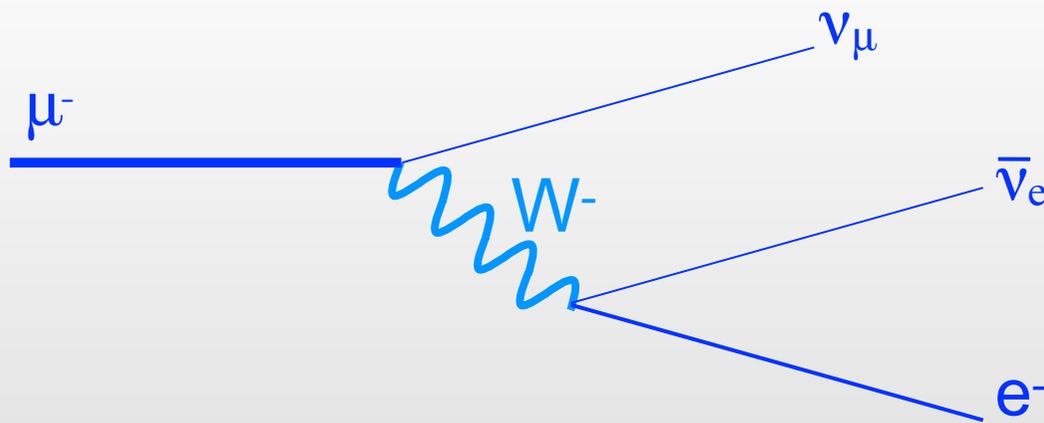




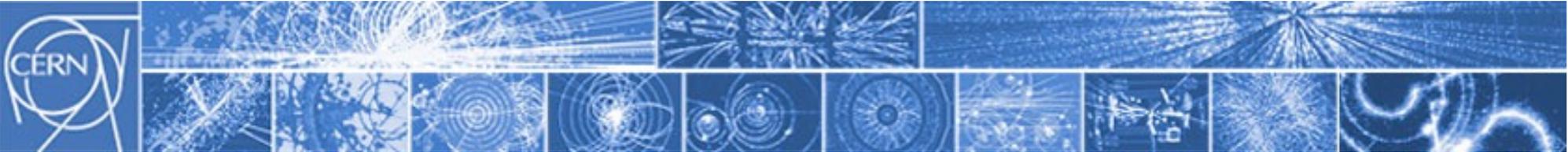
# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*



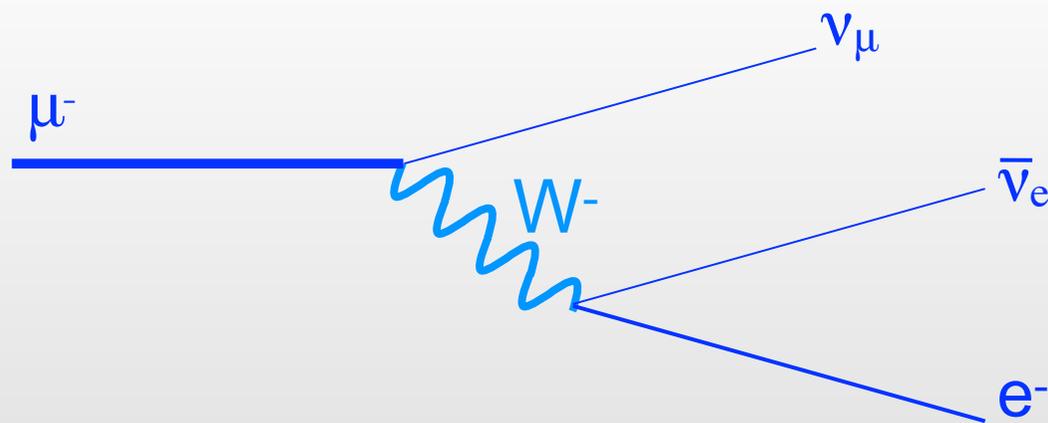
$$\mathcal{L} \simeq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi + y_{ij}\Psi_i\Psi_j\phi + |D_\mu\phi|^2 - V(\phi)$$



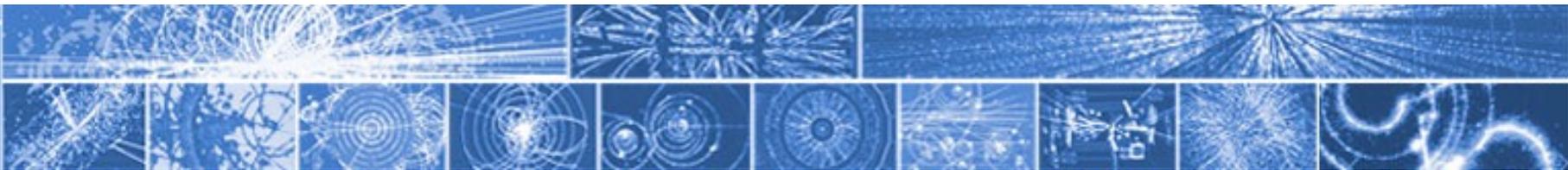
# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*



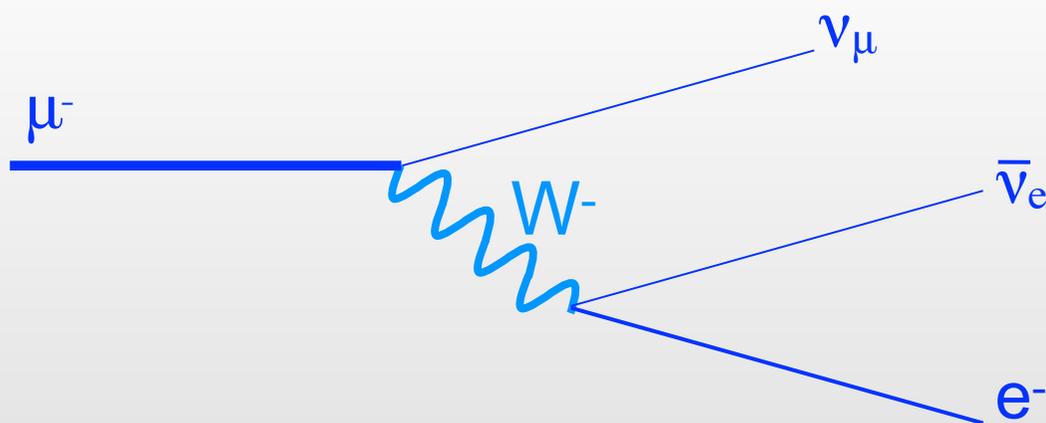
$$\mathcal{L} \simeq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi + y_{ij}\Psi_i\Psi_j\phi + |D_\mu\phi|^2 - V(\phi)$$



# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*



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

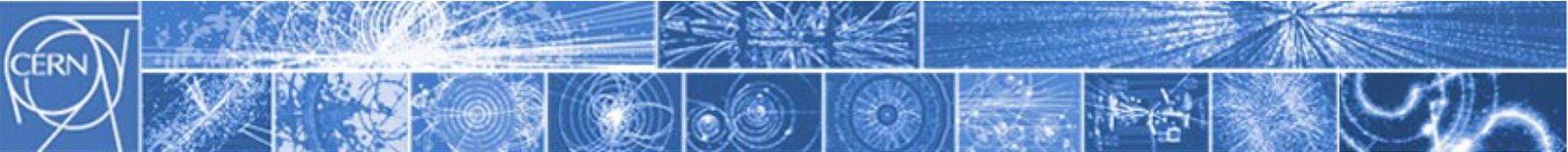
$$+ i \bar{\Psi} \not{D} \Psi$$

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

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

$$\Psi = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \frac{1 - \gamma_5}{2}$$

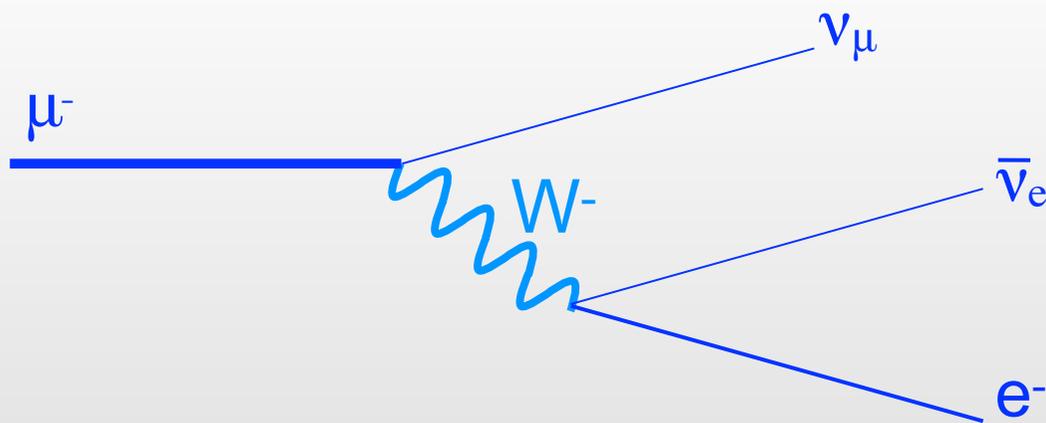
$$\not{D} = \gamma D \supset \gamma \left( -i \frac{g}{\sqrt{2}} W^- \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} \right)$$



# I diagrammi di Feynman al lavoro

## Esempio 4: decadimento del muone

(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)



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

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

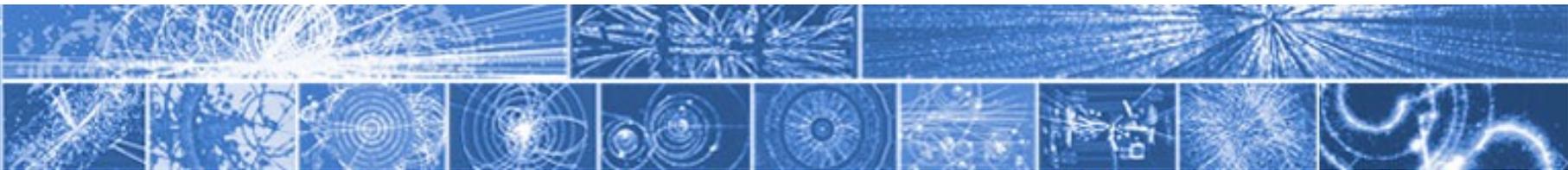
$$+y_{ij} \Psi_i \Psi_j \phi$$

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

$$\Psi = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \frac{1 - \gamma_5}{2}$$

$$\not{D} = \gamma D \supset \gamma \left( -i \frac{g}{\sqrt{2}} W^- \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} \right)$$

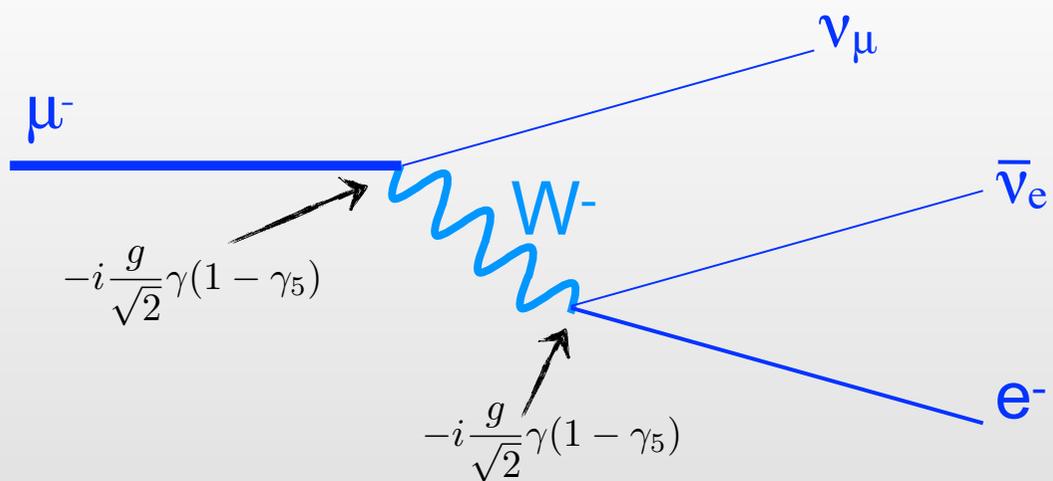
$$\simeq \nu_\mu \left( -i \frac{g}{\sqrt{2}} \right) \gamma (1 - \gamma_5) W^-_\mu$$



# I diagrammi di Feynman al lavoro

## Esempio 4: decadimento del muone

(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)



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

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

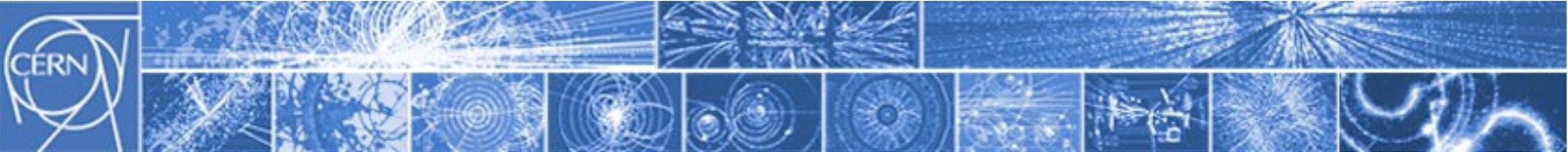
$$+y_{ij} \Psi_i \Psi_j \phi$$

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

$$\Psi = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \frac{1 - \gamma_5}{2}$$

$$\not{D} = \gamma D \supset \gamma \left( -i \frac{g}{\sqrt{2}} W^- \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} \right)$$

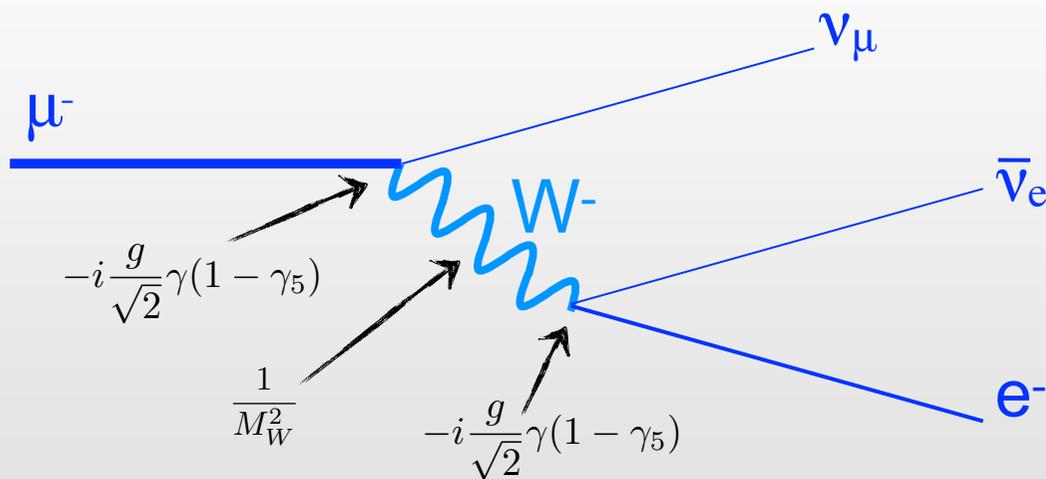
$$\simeq \nu_\mu \left( -i \frac{g}{\sqrt{2}} \right) \gamma (1 - \gamma_5) W^-_\mu$$



# I diagrammi di Feynman al lavoro

## Esempio 4: decadimento del muone

(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)



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

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

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

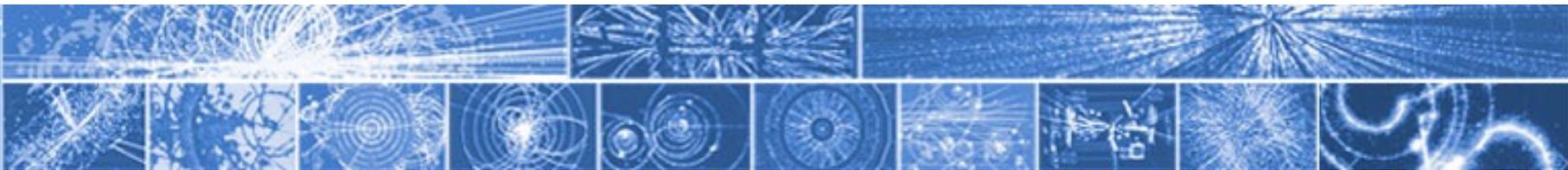
$$+|D_\mu \phi|^2 - V(\phi)$$

$$\Psi = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \frac{1-\gamma_5}{2}$$

$$\not{D} = \gamma D \supset \gamma \left( -i\frac{g}{\sqrt{2}} W^- \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} \right)$$

$$\text{[light blue box]} \simeq \nu_\mu \left( -i\frac{g}{\sqrt{2}} \right) \gamma(1-\gamma_5) W^- \mu$$

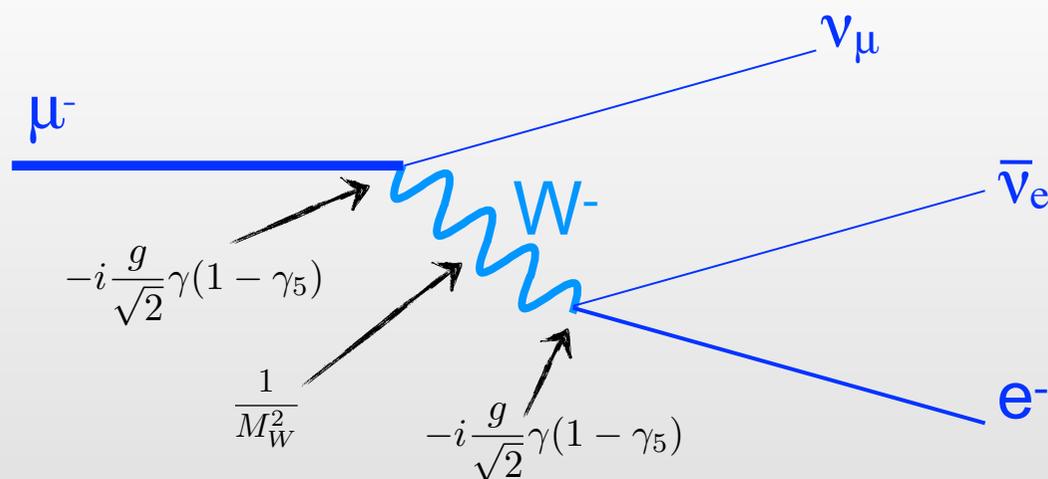
$$\text{[wavy line]} \propto \frac{1}{M_W^2 - p^2} \rightarrow \frac{1}{M_W^2}$$



# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*



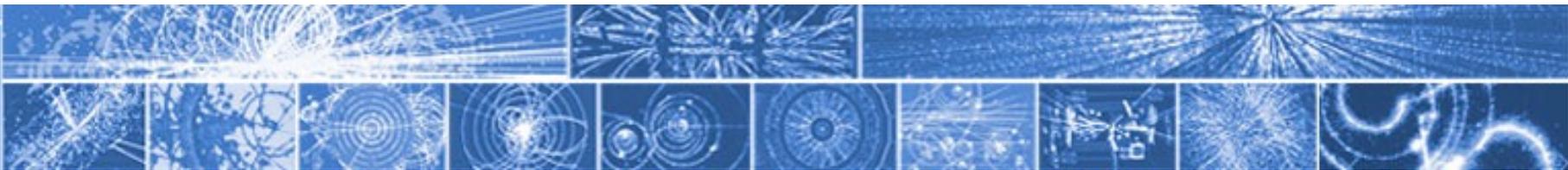
$$\mathcal{L} \simeq -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

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

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

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

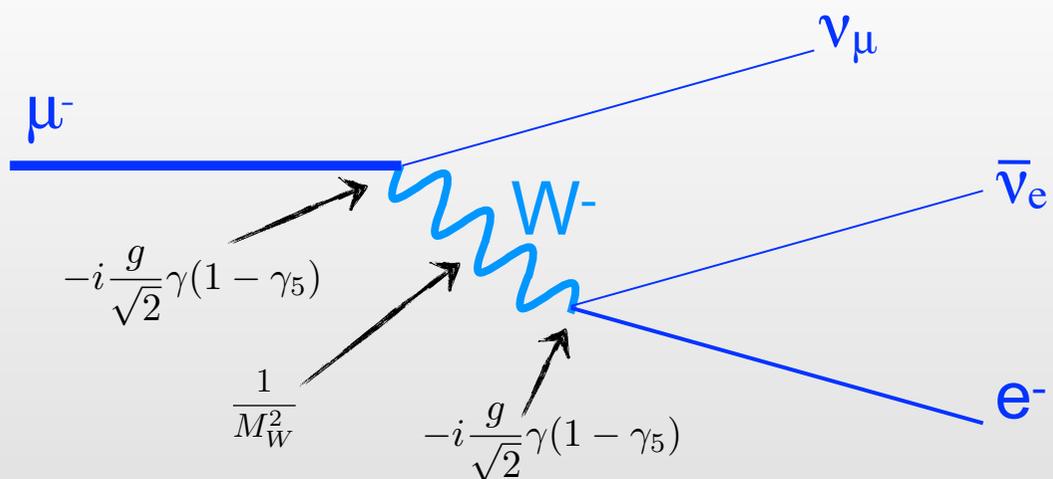
*ampiezza:*  $|\mathcal{M}| \propto \frac{g^2}{2} [\nu_\mu \gamma(1 - \gamma_5) \mu] \frac{1}{M_W^2} [e \gamma(1 - \gamma_5) \nu_e]$



# I diagrammi di Feynman al lavoro

## *Esempio 4: decadimento del muone*

*(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)*



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

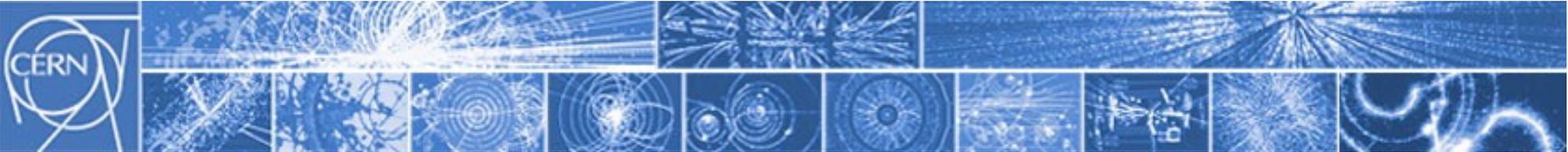
$$+ i \bar{\Psi} \not{D} \Psi$$

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

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

*ampiezza:*  $|\mathcal{M}| \propto \frac{g^2}{2} [\nu_\mu \gamma(1 - \gamma_5) \mu] \frac{1}{M_W^2} [e \gamma(1 - \gamma_5) \nu_e]$

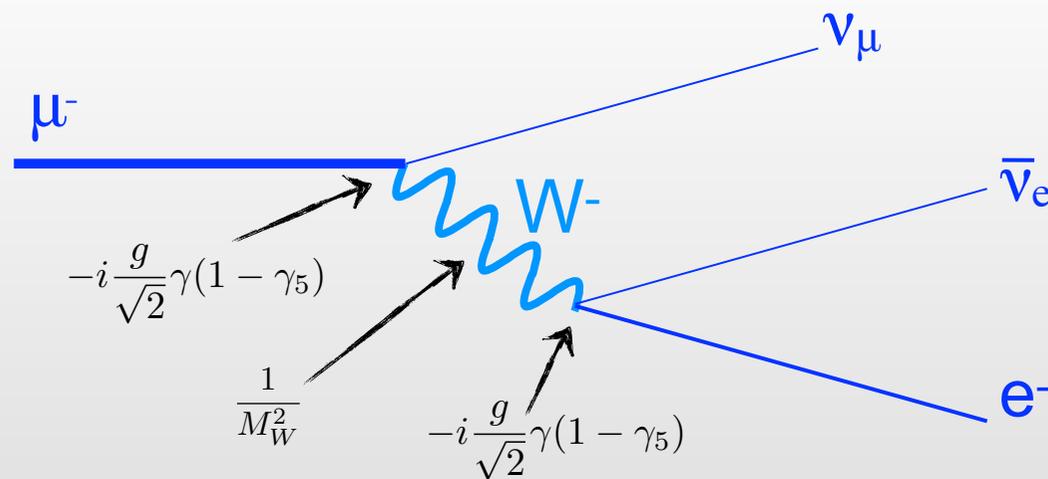
*tasso di decadimento:*  $\Gamma \propto |\mathcal{M}|^2$



# I diagrammi di Feynman al lavoro

## Esempio 4: decadimento del muone

(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)



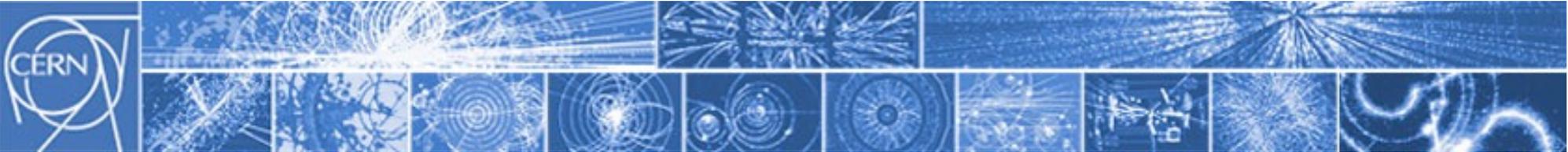
$$\mathcal{L} \simeq -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\Psi} \not{D} \Psi + y_{ij} \Psi_i \Psi_j \phi + |D_\mu \phi|^2 - V(\phi)$$

ampiezza:  $|\mathcal{M}| \propto \frac{g^2}{2} [\nu_\mu \gamma(1 - \gamma_5) \mu] \frac{1}{M_W^2} [e \gamma(1 - \gamma_5) \nu_e]$

“...dopo una serie di facili passaggi, si può facilmente dimostrare che...”

$$G_F = \frac{\sqrt{2} g^2}{8 M_W^2}$$

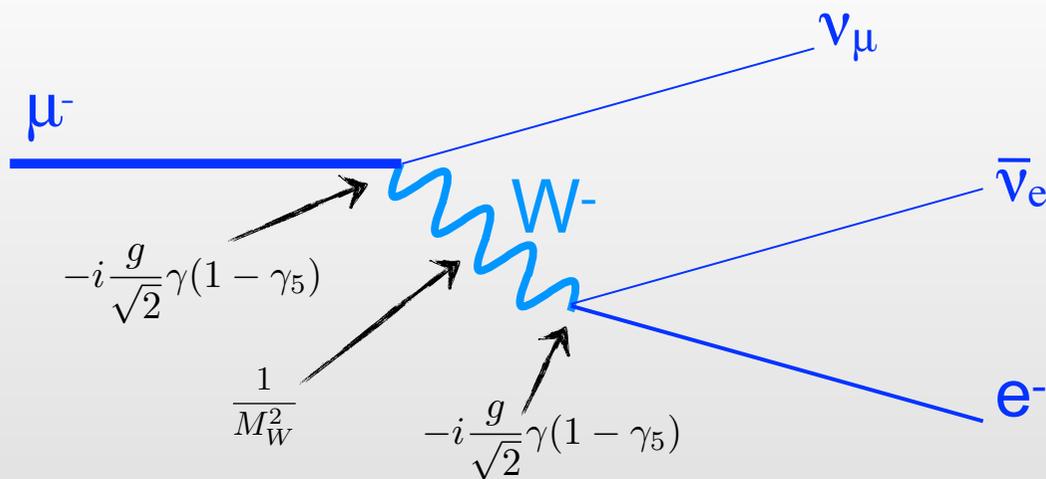
tasso di decadimento:  $\Gamma = \frac{1}{192 \pi^3} G_F^2 m_\mu^5$



# I diagrammi di Feynman al lavoro

## Esempio 4: decadimento del muone

(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)



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

ampiezza:  $|\mathcal{M}| \propto \frac{g^2}{2} [\nu_\mu \gamma(1 - \gamma_5) \mu] \frac{1}{M_W^2} [e \gamma(1 - \gamma_5) \nu_e]$

“...dopo una serie di facili passaggi, si può facilmente dimostrare che...”

$$G_F = \frac{\sqrt{2} g^2}{8 M_W^2}$$

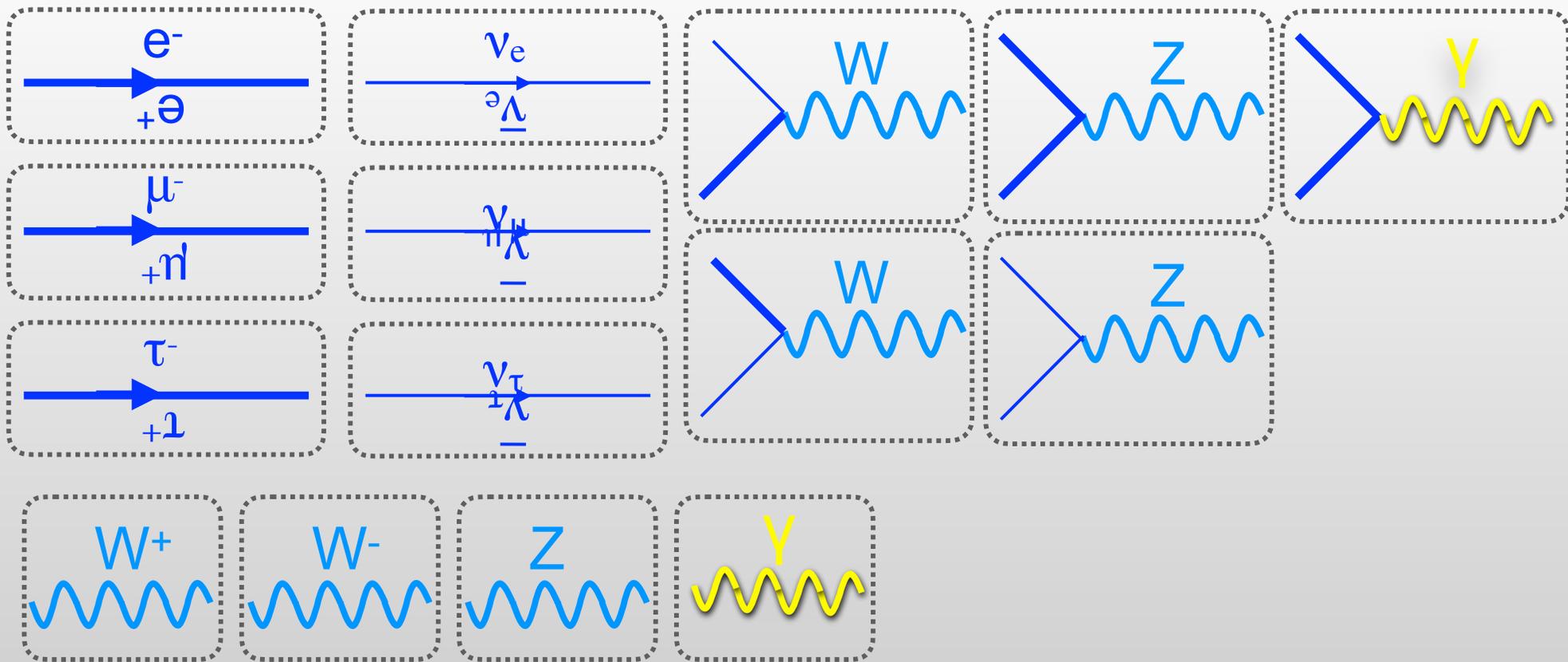
tasso di decadimento:  $\Gamma = \frac{1}{192 \pi^3} G_F^2 m_\mu^5$

vita media:  $\tau = 1/\Gamma = (2.19703 \pm 0.0004) \times 10^{-6}$  secondi



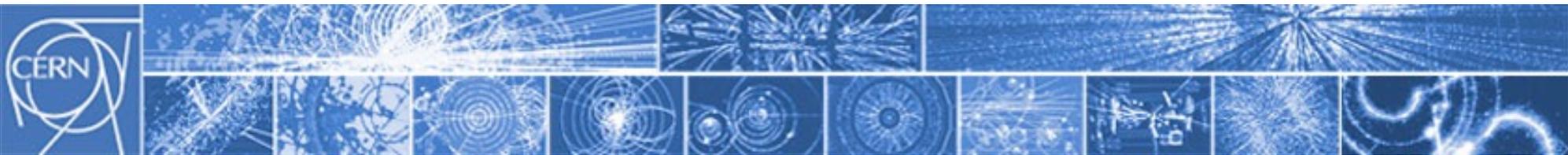
# I diagrammi di Feynman al lavoro: gioco del domino *(un'idea di presentazione/masterclass?)*

EW Feynman rules



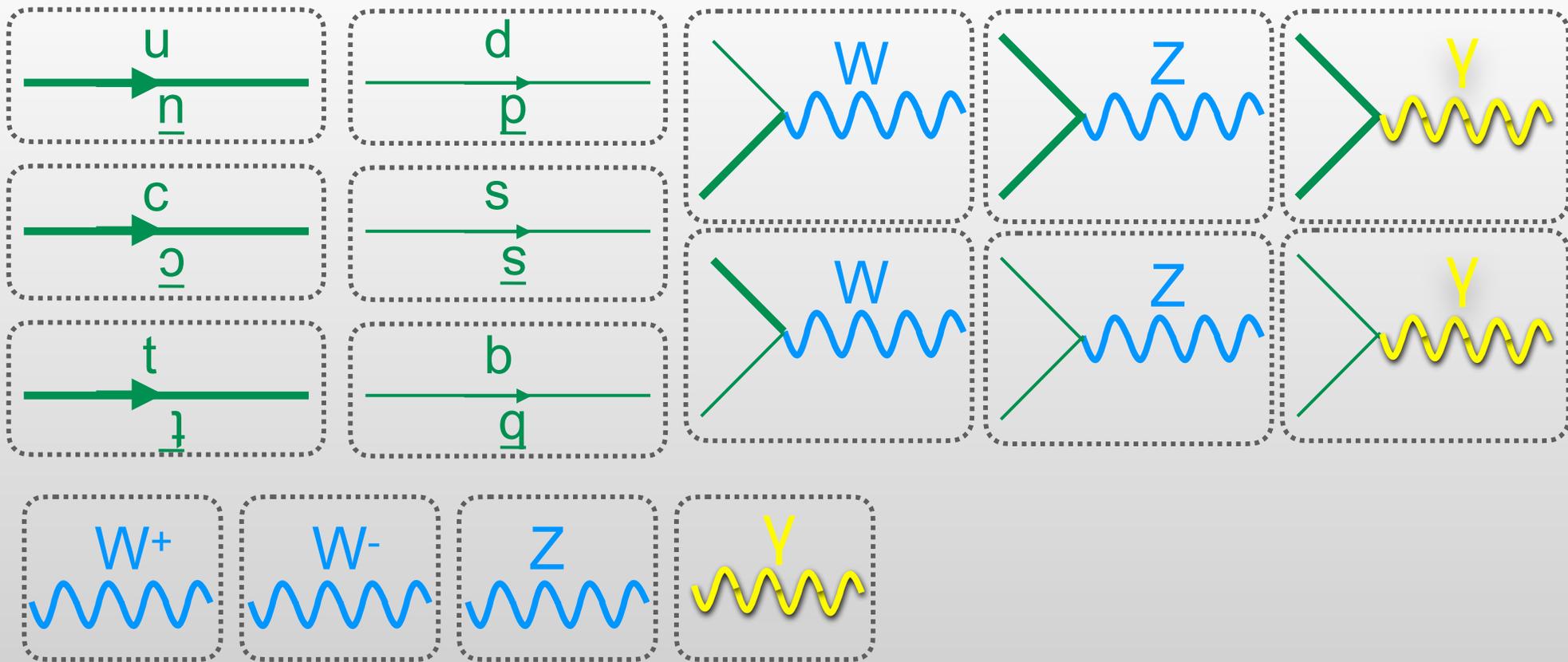
idea ripresa in:

J. Woithe, J. Wiener, F. Van der Veken, *Let's have a coffee with the Standard Model of particle physics!*, Phys. Educ. 52 (2017) 034001



# I diagrammi di Feynman al lavoro: *gioco del domino* (un'idea di presentazione/masterclass?)

EW Feynman rules



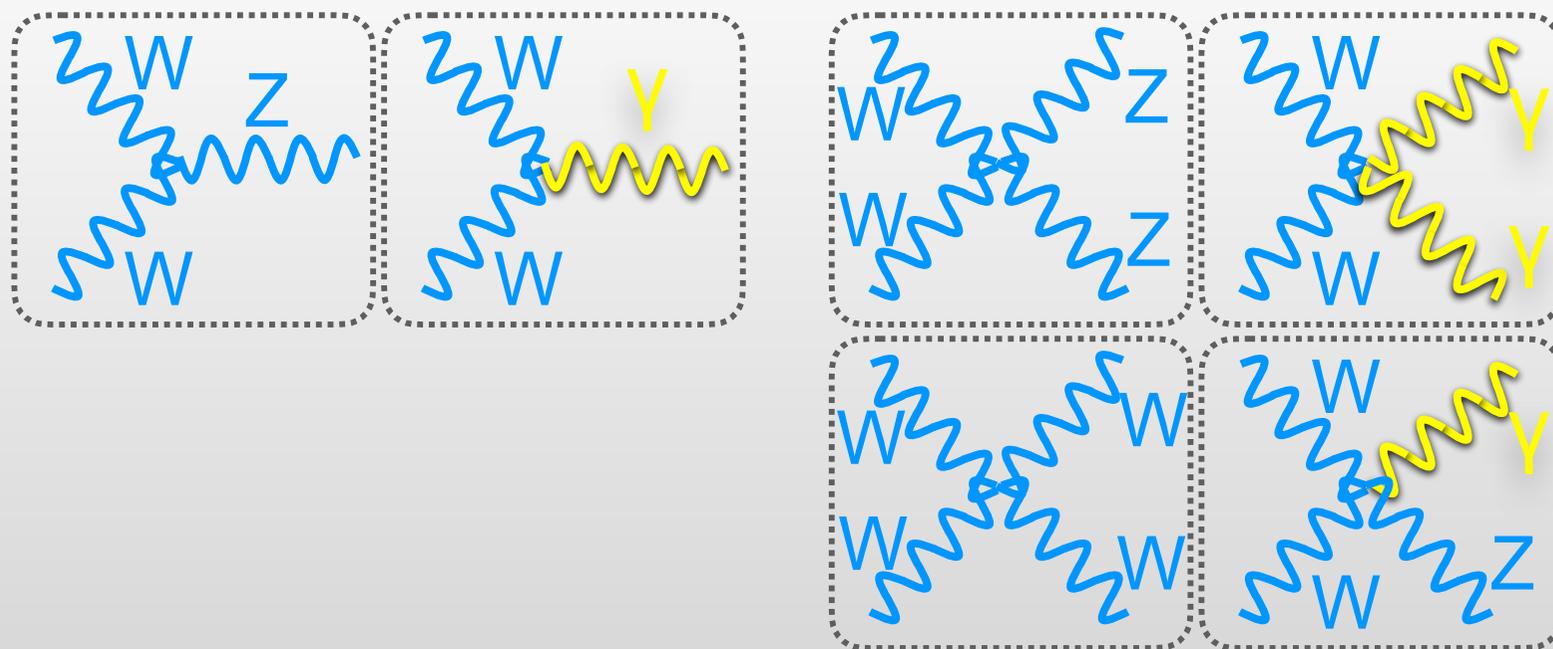
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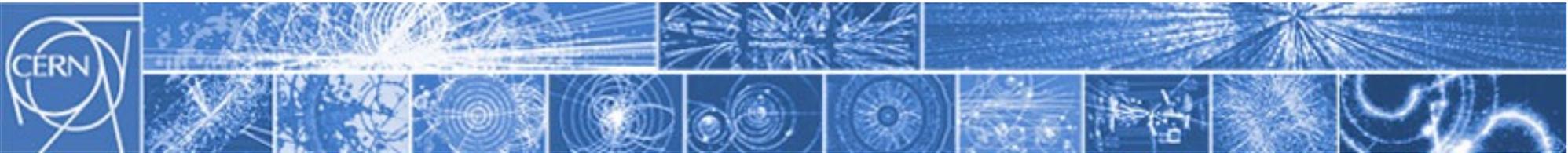
# I diagrammi di Feynman al lavoro: *gioco del domino* (un'idea di presentazione/masterclass?)

EW Feynman: triple and quartic gauge interactions



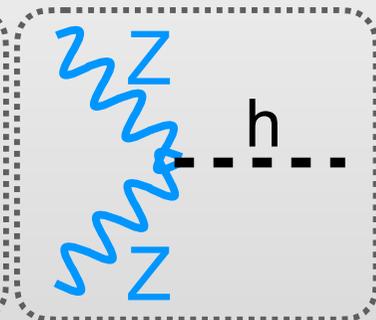
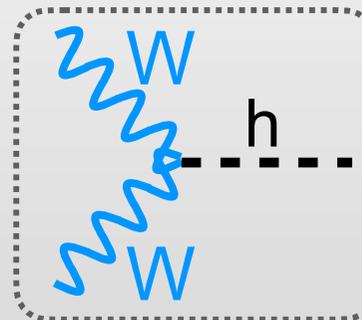
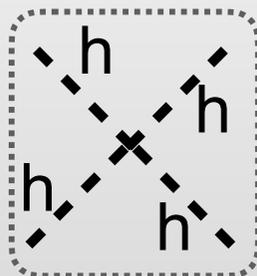
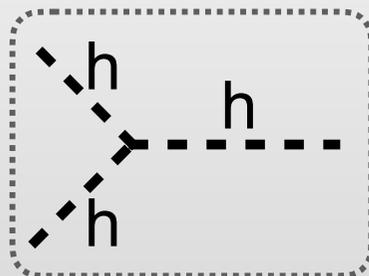
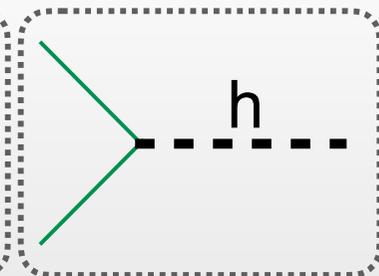
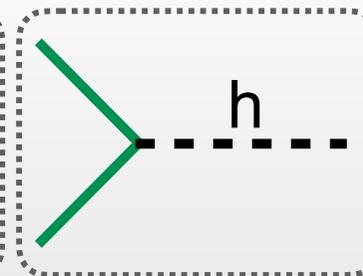
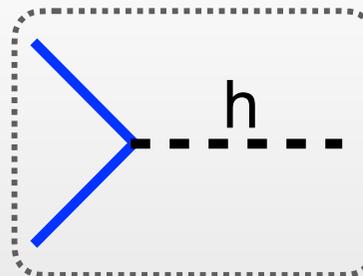
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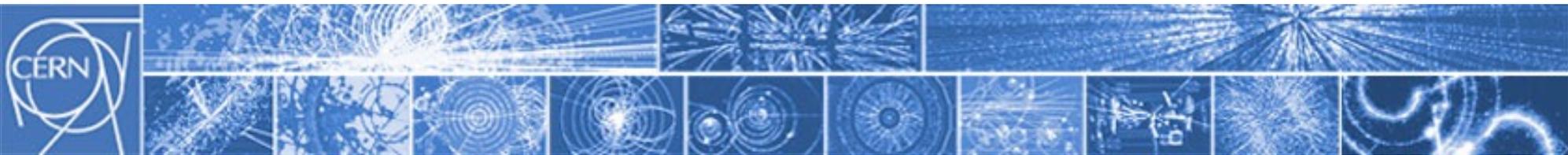
# I diagrammi di Feynman al lavoro: *gioco del domino* (un'idea di presentazione/masterclass?)

Feynman rules higgs sector



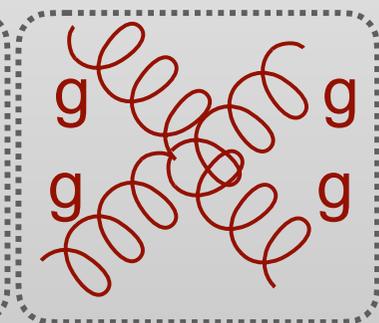
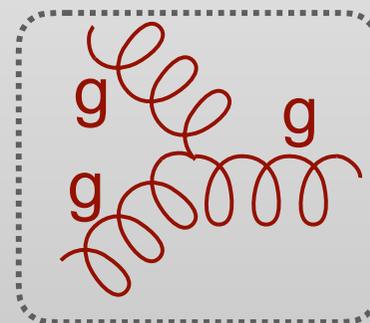
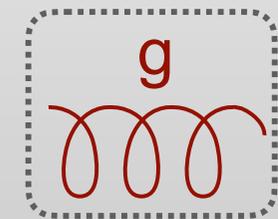
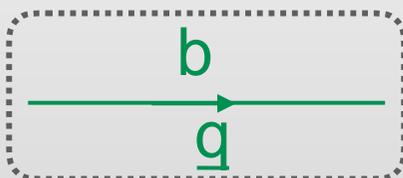
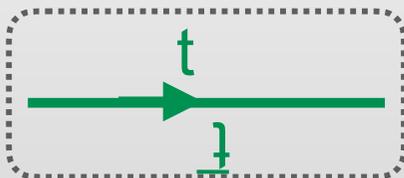
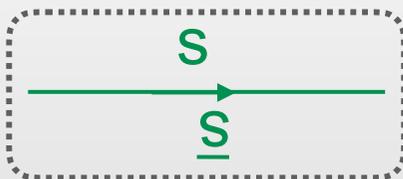
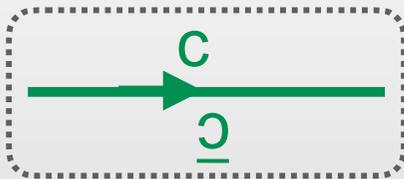
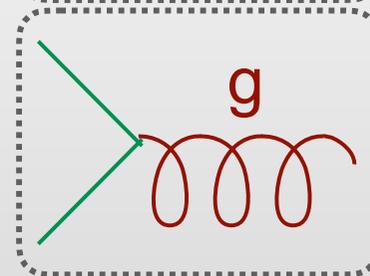
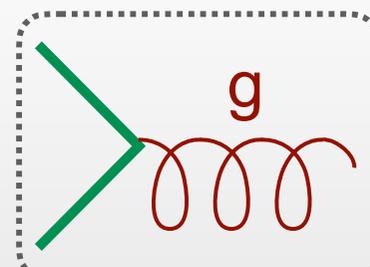
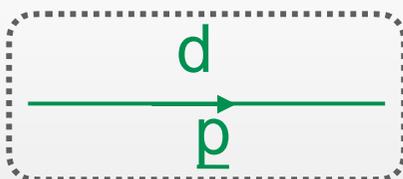
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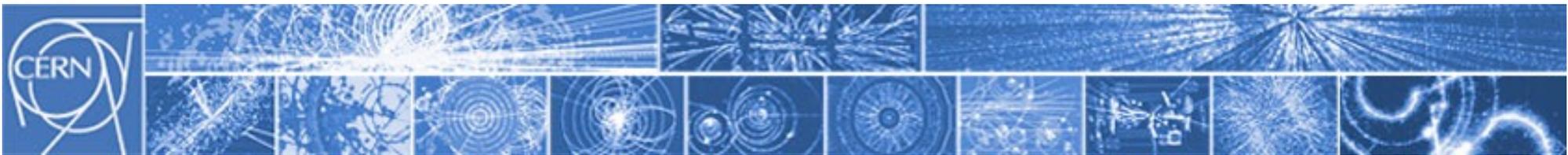
# I diagrammi di Feynman al lavoro: *gioco del domino* (un'idea di presentazione/masterclass?)

QCD Feynman rules



idea ripresa in:

J. Woithe, J. Wiener, F. Van der Veken, *Let's have a coffee with the Standard Model of particle physics!*, Phys. Educ. 52 (2017) 034001



# I diagrammi di Feynman al lavoro: *FeynGame* (un'idea di presentazione/masterclass?)

arXiv.org > physics > arXiv:2003.00896

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## FeynGame

R.V. Harlander, S.Y. Klein, M. Lipp

(Submitted on 28 Feb 2020)

A java-based graphical tool for drawing Feynman diagrams is presented. It differs from similar existing tools in various respects. For example, it is based on models, consisting of particles (lines) and (optionally) vertices, each of which can be given their individual properties (line style, color, arrows, label, etc.). The diagrams can be exported in any standard image format, or as PDF. Aside from its plain graphical aspect, the goal of FeynGame is also educative, as it can check a Feynman diagrams validity. This provides the basis to play games with diagrams, for example. Here we describe on such game where a given set of initial and final states must be connected through a Feynman diagram within a given interaction model.

Comments: 26 pages, several figures and screenshots. FeynGame is available from [this https URL](https://arxiv.org/abs/2003.00896)

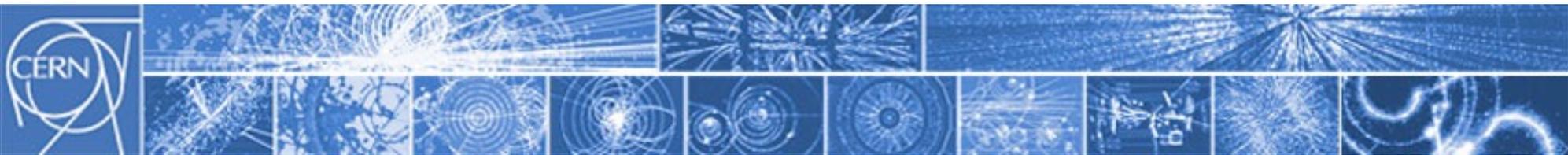
Subjects: **Physics Education (physics.ed-ph)**; High Energy Physics – Phenomenology (hep-ph)

Report number: TTK-20-04

Cite as: [arXiv:2003.00896](https://arxiv.org/abs/2003.00896) [physics.ed-ph]  
(or [arXiv:2003.00896v1](https://arxiv.org/abs/2003.00896v1) [physics.ed-ph] for this version)

<https://arxiv.org/abs/2003.00896>

<https://gitlab.com/feyngame/FeynGame>



# I diagrammi di Feynman al lavoro: *FeynGame* (un'idea di presentazione/masterclass?)

Terminal window output:

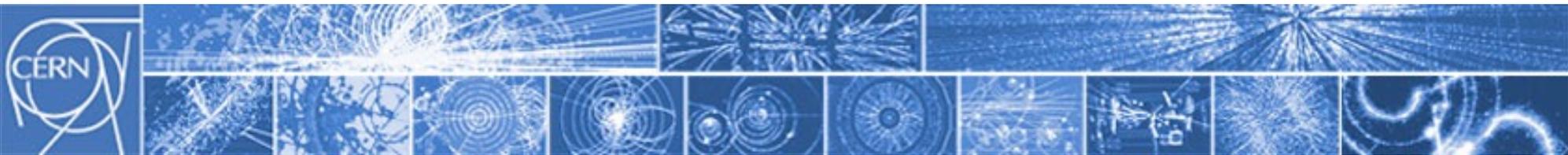
```
adding: resources/helppages/Philosophy.html(in = 1346) (out= 697)(deflated 48%)
adding: resources/helppages/Labels.html(in = 1406) (out= 675)(deflated 51%)
adding: resources/Star.png(in = 6879) (out= 6857)(deflated 0%)
adding: resources/grab.png(in = 30118) (out= 29533)(deflated 1%)
adding: resources/License.txt(in = 32472) (out= 11182)(deflated 65%)
adding: resources/GetResources.class(in = 3198) (out= 1613)(deflated 49%)
adding: resources/NoPattern.png(in = 395) (out= 148)(deflated 62%)
adding: javafx/(in = 0) (out= 0)(stored 0%)
adding: javafx/crosshatched.fx(in = 25847) (out= 2171)(deflated 91%)
adding: javafx/JavaFXToJavaVectorGraphic.class(in = 7222) (out= 3697)(deflated 48%)
adding: javafx/star.fx(in = 3327) (out= 958)(deflated 71%)
adding: javafx/cross.fx(in = 4316) (out= 893)(deflated 79%)
adding: javafx/hatched.fx(in = 14144) (out= 1535)(deflated 89%)
Now run 'java -jar build/out/FeynGame.jar game.model'
[base] [mcirelli@011 ~/Desktop/FeynGame-master/FeynGameJava]$ cd build/out/
[base] [mcirelli@011 ~/Desktop/FeynGame-master/FeynGameJava/build/out]$ java -jar FeynGame.jar game.model
```

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by Robert Harlander, Sven Yannick Klein, and Maximilian Lipp.  
This program comes with ABSOLUTELY NO WARRANTY.  
This is free software, and you are welcome  
to redistribute it under certain conditions.  
For details, see Licence.  
Running on Mac OS X  
Working directory: /Users/mcirelli/Desktop/FeynGame-master/FeynGameJava/build/out  
Found 4 line configurations  
Found 6 vertex rules  
Found 3 vertex style definitions  
Found 1 image definitions

The graphical interface shows a Feynman diagram on a grid. It consists of two vertices connected by a red wavy line (photon). Each vertex has two black lines with arrows (fermions) entering and exiting. The toolbar includes icons for a plus sign, a fermion line (t), a gluon line (g), a photon line (γ), a Higgs boson line (H), a black dot, a red dot, a cross, and a star.

<https://arxiv.org/abs/2003.00896>

<https://gitlab.com/feyngame/FeynGame>



# I diagrammi di Feynman al lavoro: *FeynGame* (un'idea di presentazione/masterclass?)

```
adding: resources/helppages/Philosophy.html(in = 1346) (out= 697)(deflated 48%)
adding: resources/helppages/Labels.html(in = 1406) (out= 675)(deflated 51%)
adding: resources/Star.png(in = 6879) (out= 6857)(deflated 0%)
adding: resources/grab.png(in = 30118) (out= 29533)(deflated 1%)
adding: resources/License.txt(in = 32472) (out= 11182)(deflated 65%)
adding: resources/GetResources.class(in = 3198) (out= 1613)(deflated 49%)
adding: resources/NoPattern.png(in = 395) (out= 148)(deflated 62%)
adding: javafx/(in = 0) (out= 0)(stored 0%)
adding: javafx/crosshatched.fx(in = 25847) (out= 2171)(deflated 91%)
adding: javafx/JavaFXToJavaVectorGraphic.class(in = 7222) (out= 3697)(deflated 48%)
adding: javafx/star.fx(in = 3327) (out= 958)(deflated 71%)
adding: javafx/cross.fx(in = 4316) (out= 893)(deflated 79%)
adding: javafx/hatched.fx(in = 14144) (out= 1535)(deflated 89%)
Now run 'java -jar build/out/FeynGame.jar game.model'
[base] [mcirelli@dl ~/Desktop/FeynGame-master/FeynGameJava]$ cd build/out/
[base] [mcirelli@dl ~/Desktop/FeynGame-master/FeynGameJava/build/out]$ java -jar FeynGame.jar game.model
```

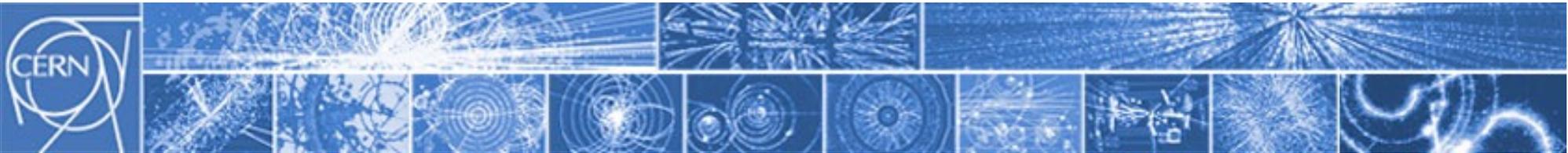
**FeynGame**

Copyright (C) 2019  
by Robert Harlander, Sven Yannick Klein, and Maximilian Lipp.  
This program comes with ABSOLUTELY NO WARRANTY.  
This is free software, and you are welcome  
to redistribute it under certain conditions.  
For details, see Licence.  
Running on Mac OS X  
Working directory: /Users/mcirelli/Desktop/FeynGame-master/FeynGameJava/build/out  
Found 4 line configurations  
Found 6 vertex rules  
Found 3 vertex style definitions  
Found 1 image definitions

Found 1 Error  
Checking 5 Lines and 2 Vertices:  
- Vertex {gluon, higgs, higgs} is not in model file.

<https://arxiv.org/abs/2003.00896>

<https://gitlab.com/feyngame/FeynGame>



# I diagrammi di Feynman al lavoro: *gioco del domino* (un'idea di presentazione/masterclass?)

## Processi da riprodurre:

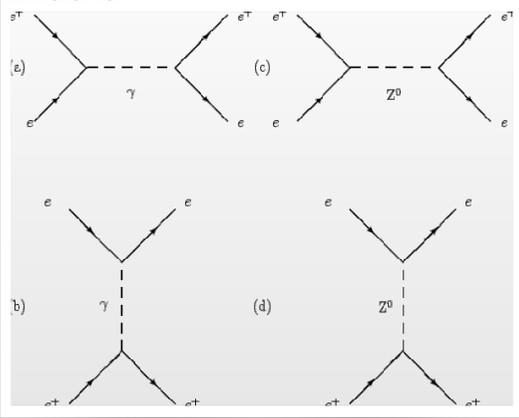
- Bhabha scattering:  $e^+e^- \rightarrow e^+e^-$  [hint: 4 diagrammi possibili (tree-level)]
- Decadimento beta:  $(A,Z) \rightarrow (A,Z+1) e^- \bar{\nu}$
- Decadimento beta<sup>+</sup>:  $(A,Z) \rightarrow (A,Z-1) e^+ \nu$
- Cattura K:  $(A,Z) e^- \rightarrow (A,Z-1) \nu$
- Decadimento del muone
- Decadimento del top (semi-leptonico, hadronico)
- Scattering  $e^+e^- \rightarrow W^+W^-$  [hint: 3 diagrammi possibili (tree-level)]
- Decadimento  $K^+ \rightarrow \pi^+ \pi^+ \pi^-$  [hint: implica sia interazioni deboli che forti]
- ...



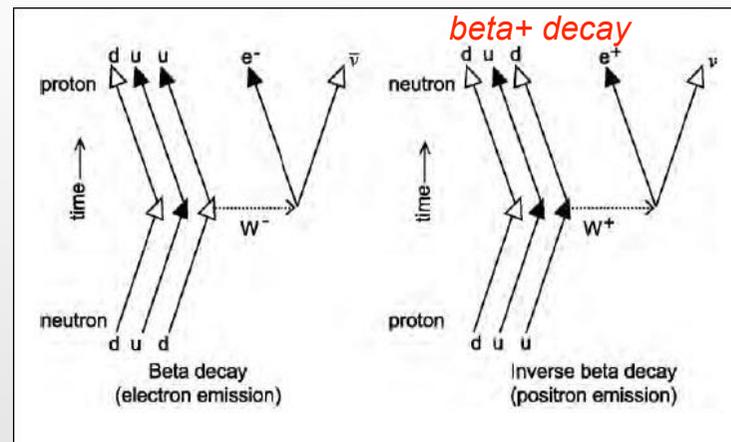
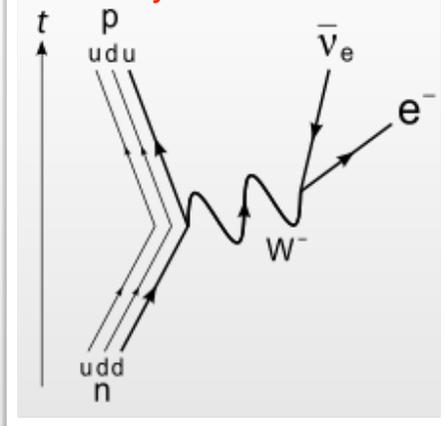
# I diagrammi di Feynman al lavoro: *gioco del domino*

*“Soluzioni”*

*Bhabha*



*beta decay*



*ee -> WW*

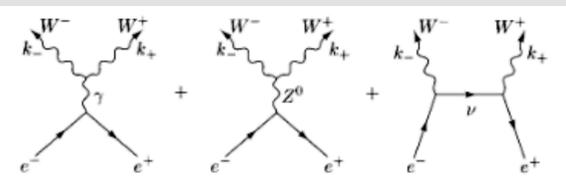
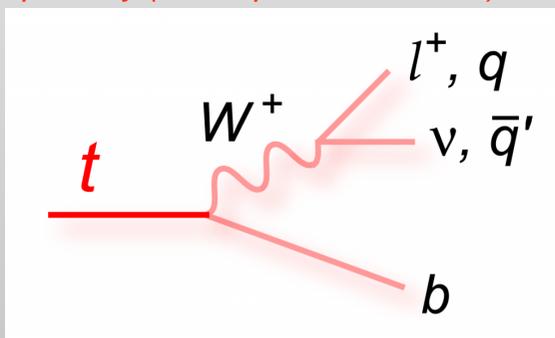
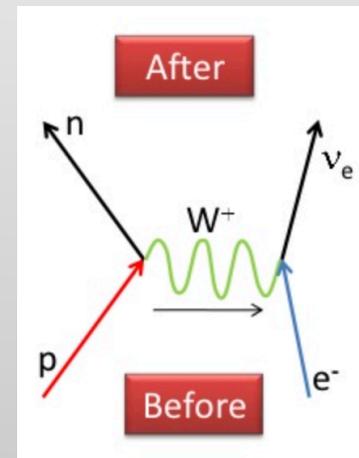


Figure 21.7. Diagrams contributing to  $e^+e^- \rightarrow W^+W^-$  in the weak interaction gauge theory.

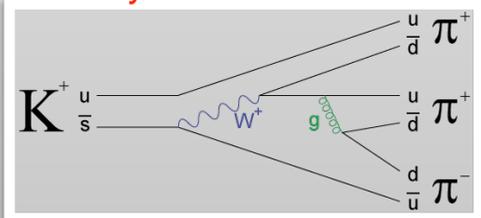
*top decay (semileptonic, hadronic)*



*cattura K*



*K+ decay*





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ALUNNI

## Valeria Fedeli: "Compiti a casa? Sistema che va superato, più attività a scuola"

Di **Andrea Carlino** - 19/11/2017



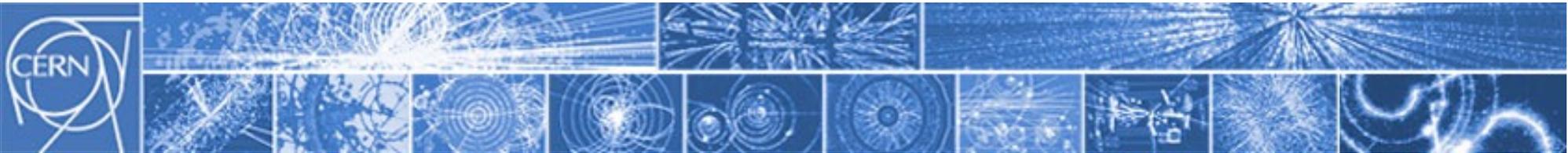
La ministra dell'Istruzione, **Valeria Fedeli**, a margine della quarta giornata delle Olimpiadi di Debate, interpellata dall'Agenzia Dire, affronta il tema dell'abolizione dei compiti a casa, misura **recentemente introdotta** in Francia.

Ci sono "tesi a favore e tesi contro – dice Fedeli – e questo è ovviamente espressione

*del dibattito che ci sarebbe in tutta Italia qualora questo diventasse un tema della politica. Credo che ci debba essere un atteggiamento sicuramente migliorativo rispetto a quello tradizionale 'Ti faccio la lezione frontale, poi tu approfondisci a casa da solo'. Credo che questo non sia più il tempo né della sola lezione frontale né dei singoli compiti a casa".*

La ministra osserva che "i ragazzi hanno bisogno **non di schemi rigidi**. Ci sono...

Cerca



# I diagrammi di Feynman al lavoro: *gioco del domino* (un'idea di presentazione/masterclass?)

## Processi da riprodurre:

- Bhabha scattering:  $e^+e^- \rightarrow e^+e^-$  [hint: 4 diagrammi possibili (tree-level)]
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- ...