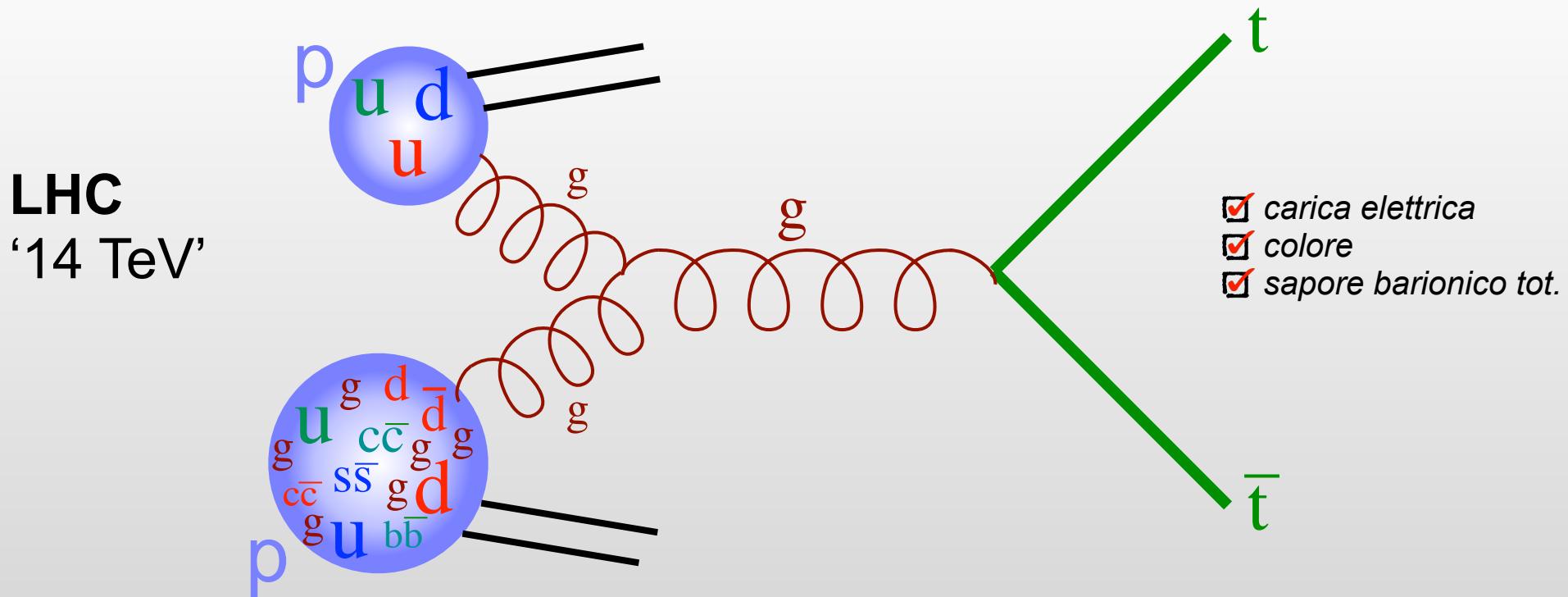
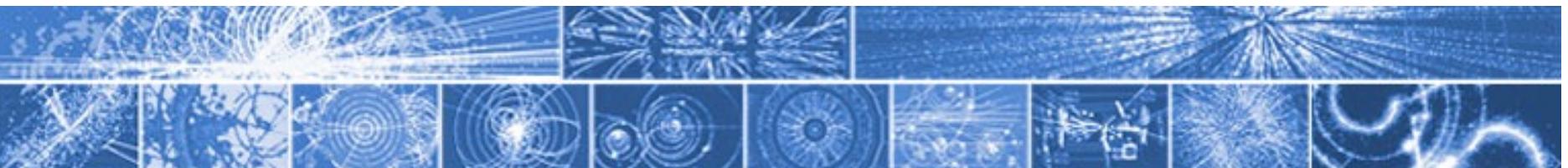


I diagrammi di Feynman al lavoro

Esempio 2b: collisione $pp \rightarrow$ produzione di quark top
(semirigoroso)



Un protone ‘contiene’ quarks, antiquarks di tutti i sapori (del mare, vs valenza), e gluoni, secondo una certa *distribuzione di probabilità*, funzione dell’energia.

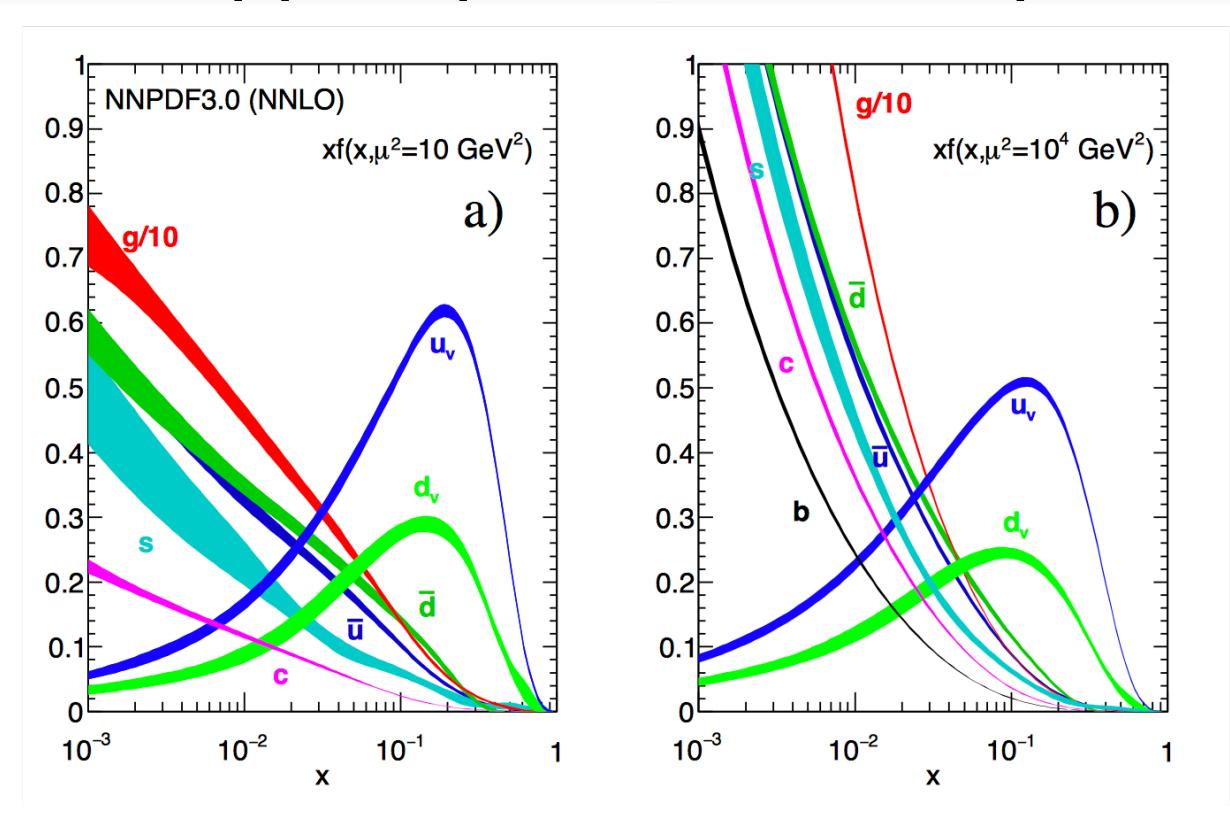
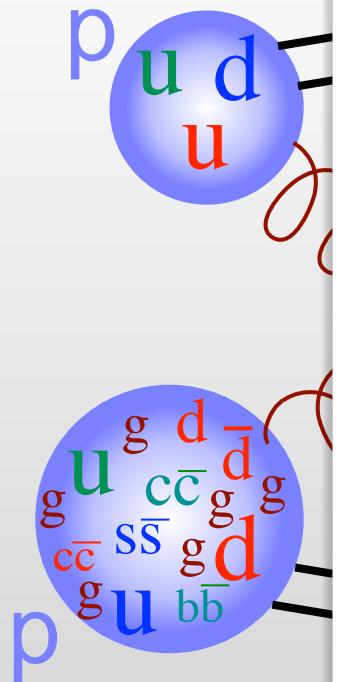


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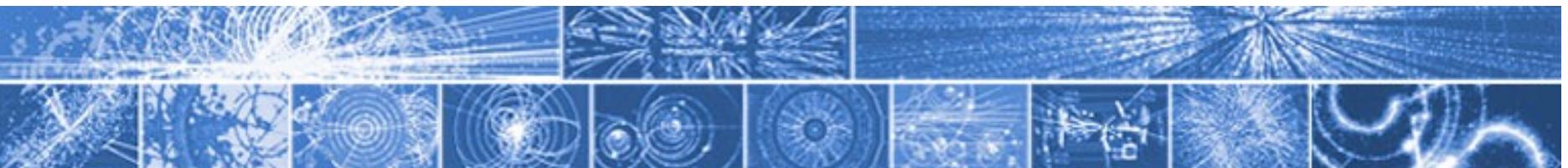
LHC
'14 TeV'



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Spiegazione divulgativa ma rigorosa:

[Quanta Magazine Oct 2022](#), C. Wood and M. Sherman ‘Inside the Proton, the ‘Most Complicated Thing You Could Possibly Imagine’

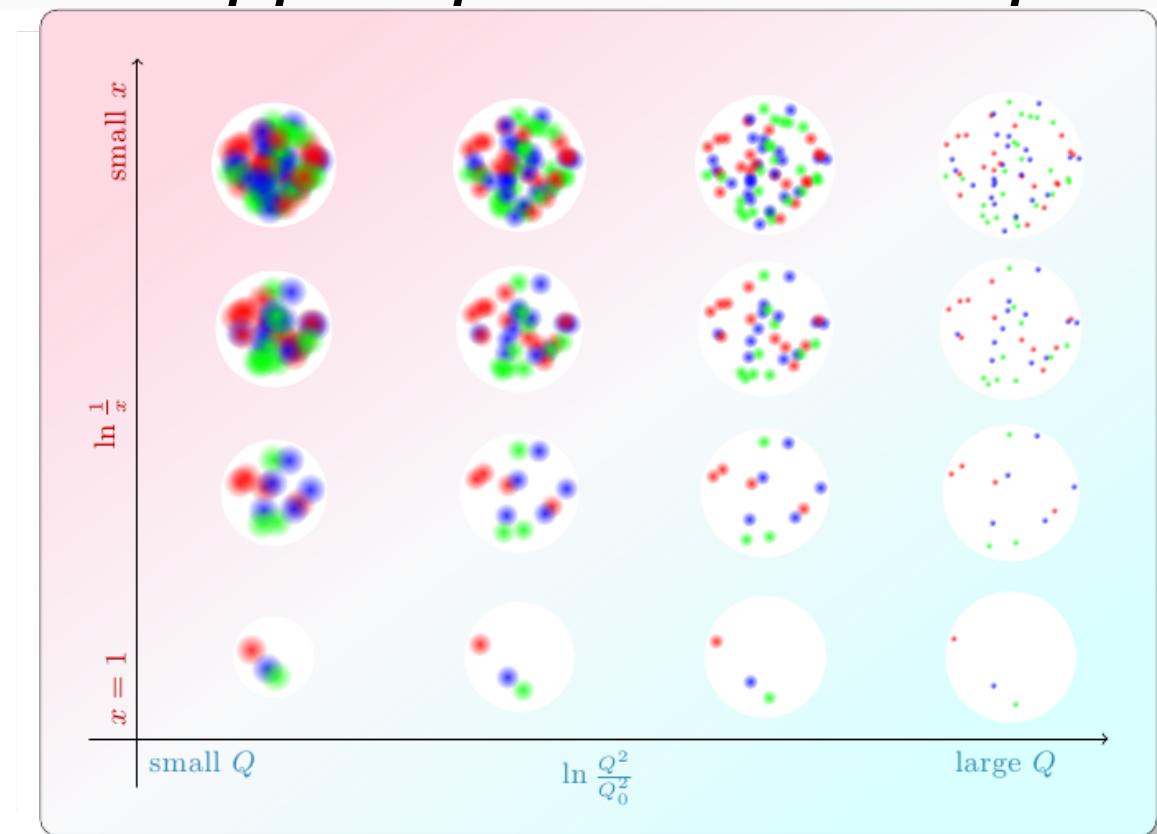
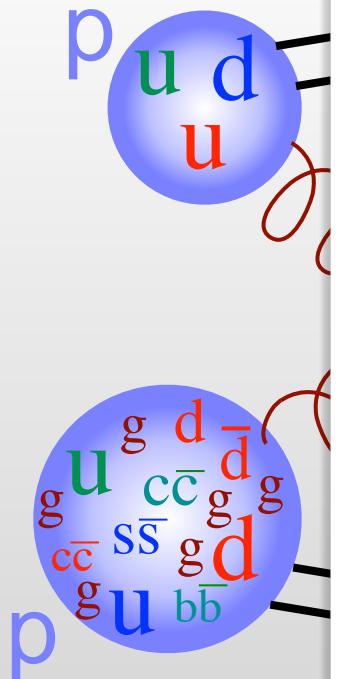


I diagrammi di Feynman al lavoro

Esempio 2b: collisione $pp \rightarrow$ produzione di quark top

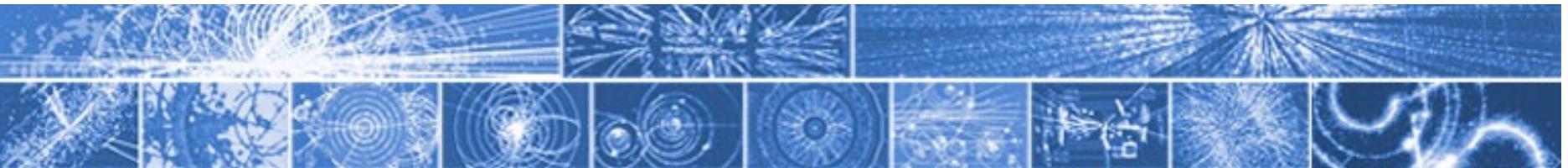
(semirigoroso)

LHC
'14 TeV'



Credit: David Zaslavsky
Also: JCLab 2022

Un protone ‘contiene’ quarks, antiquarks di tutti i sapori (del *mare*, vs *valenza*), e gluoni, secondo una certa *distribuzione di probabilità*, funzione dell’energia.

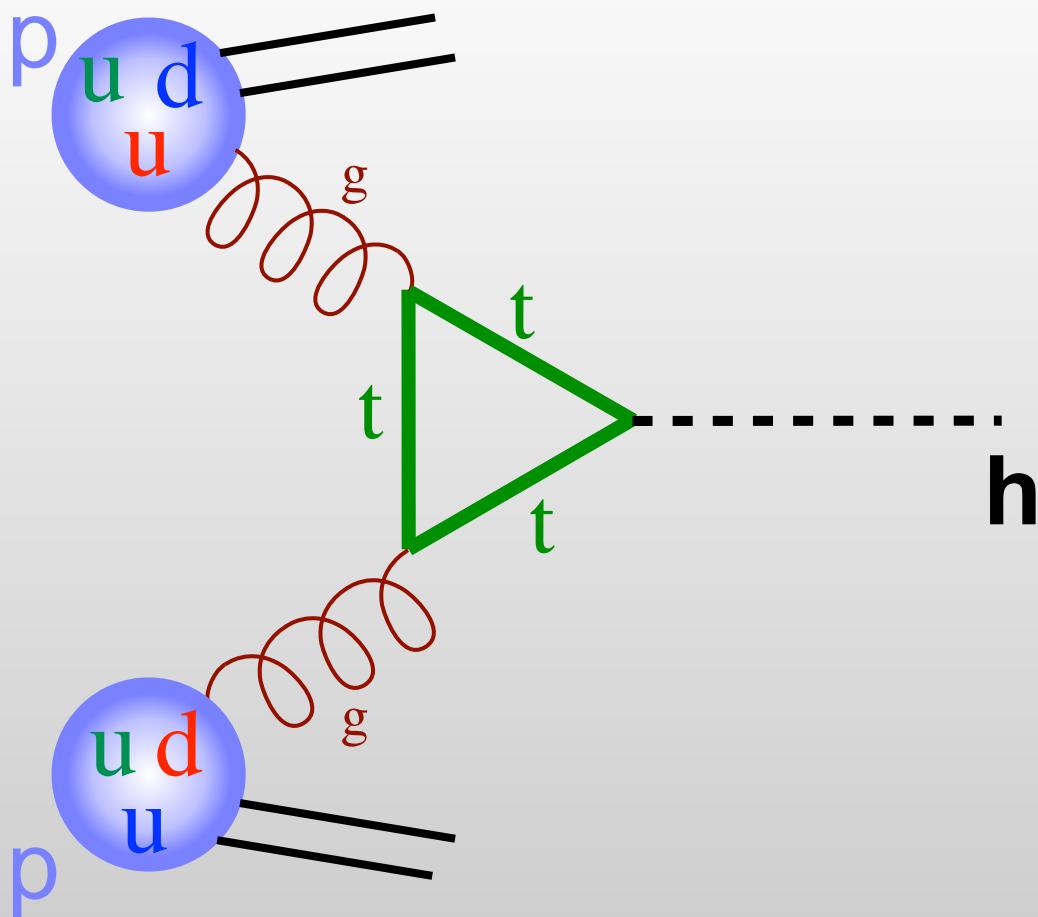


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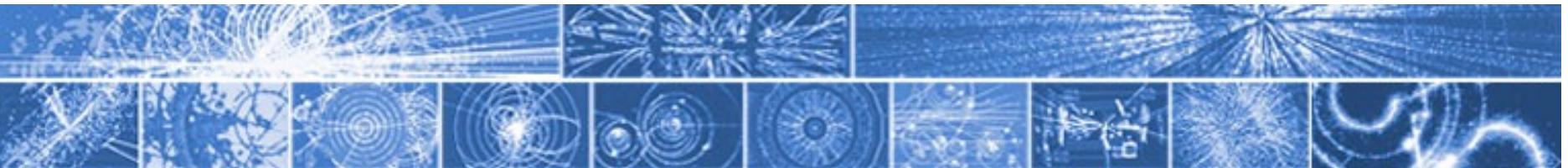
Esempio 3: collisione $pp \rightarrow$ produzione di higgs

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LHC
‘14 TeV’



- carica elettrica
- colore
- sapore barionico tot.

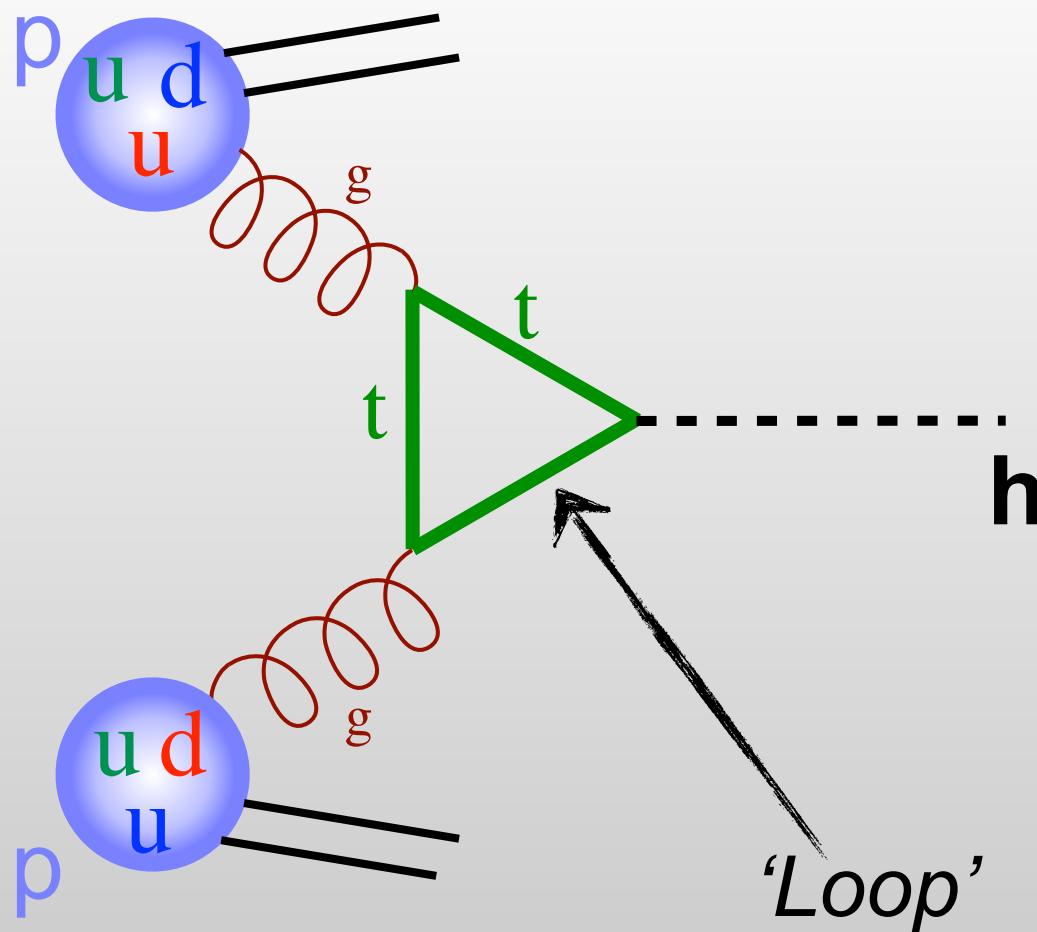


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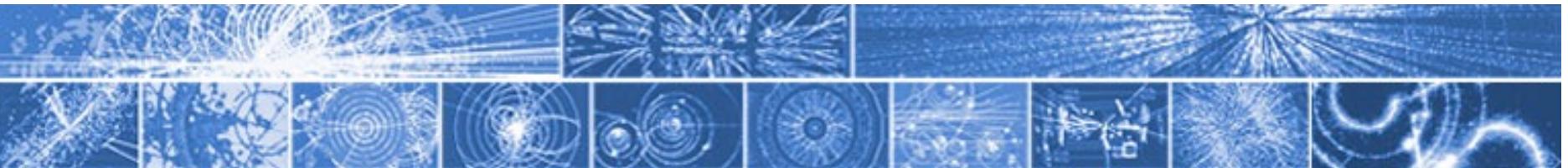
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LHC
‘14 TeV’



- carica elettrica
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‘Loop’

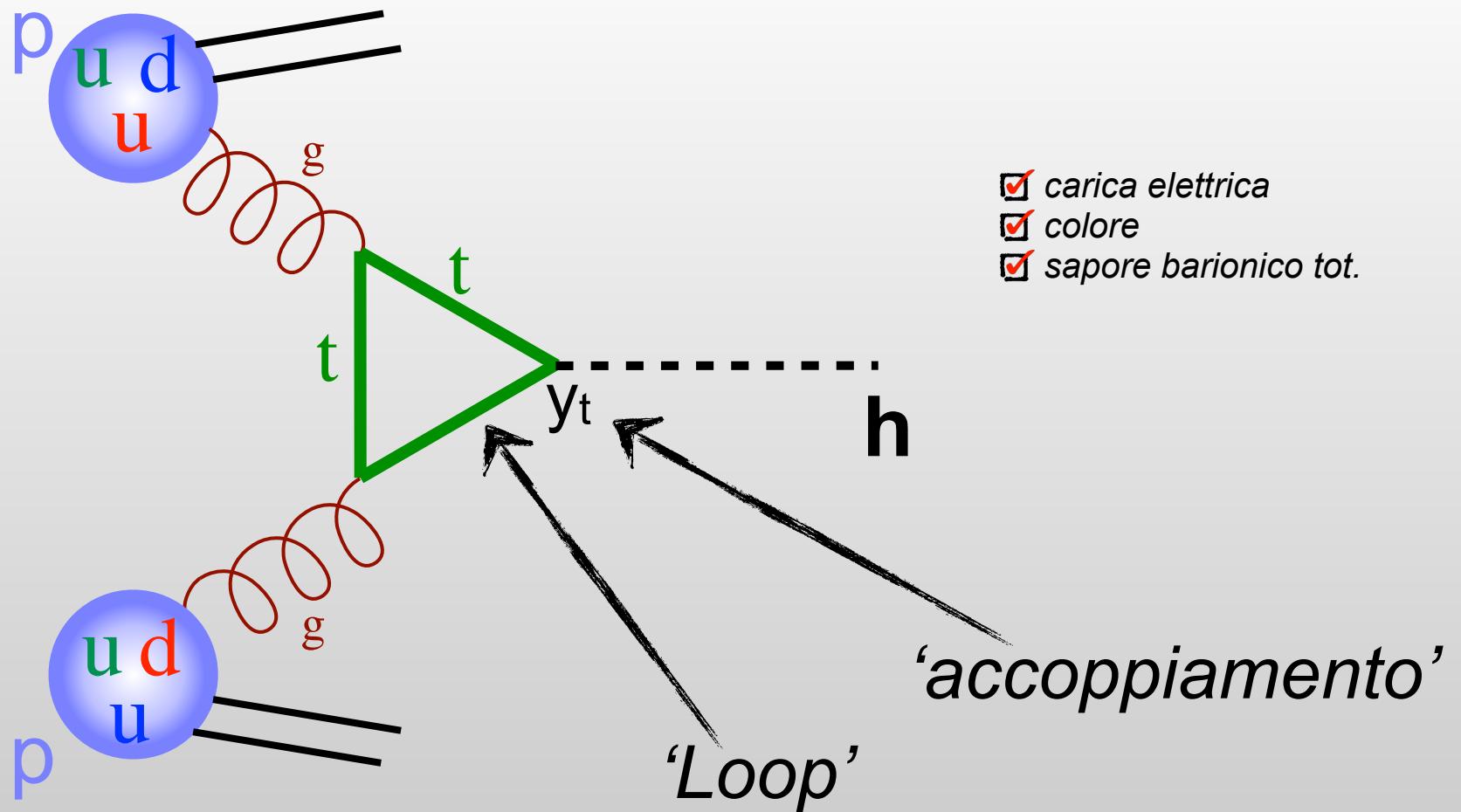


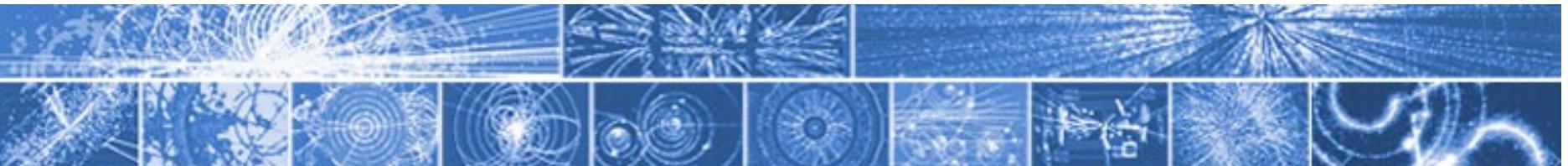
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LHC
'14 TeV'





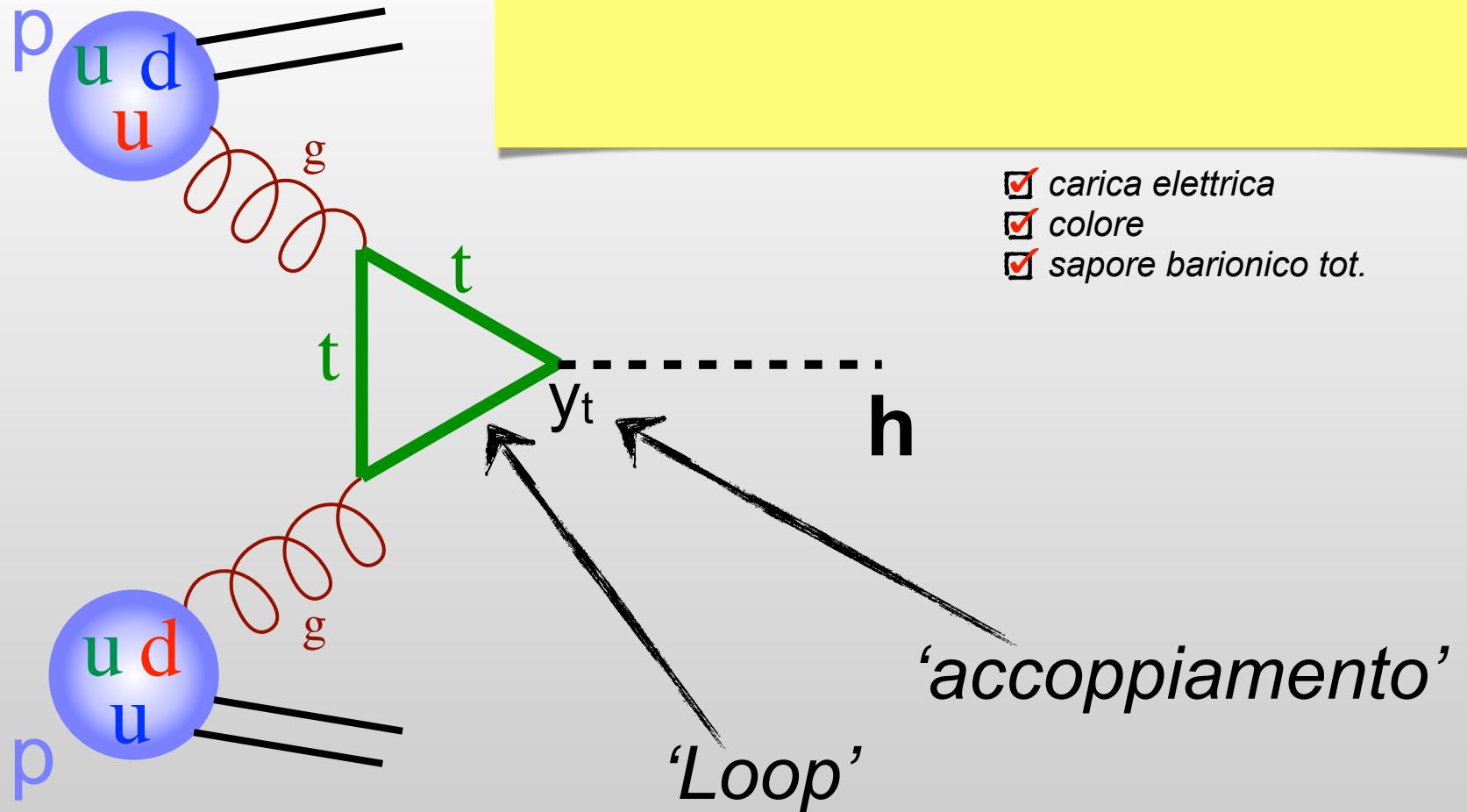
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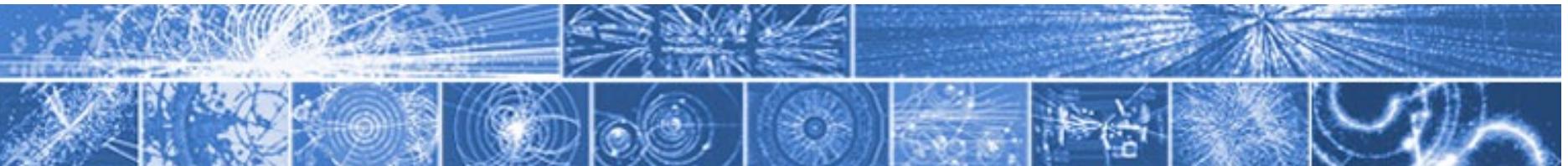
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Q: Ma quindi alla fin fine si può fare un po' tutto?

LHC
'14 TeV'



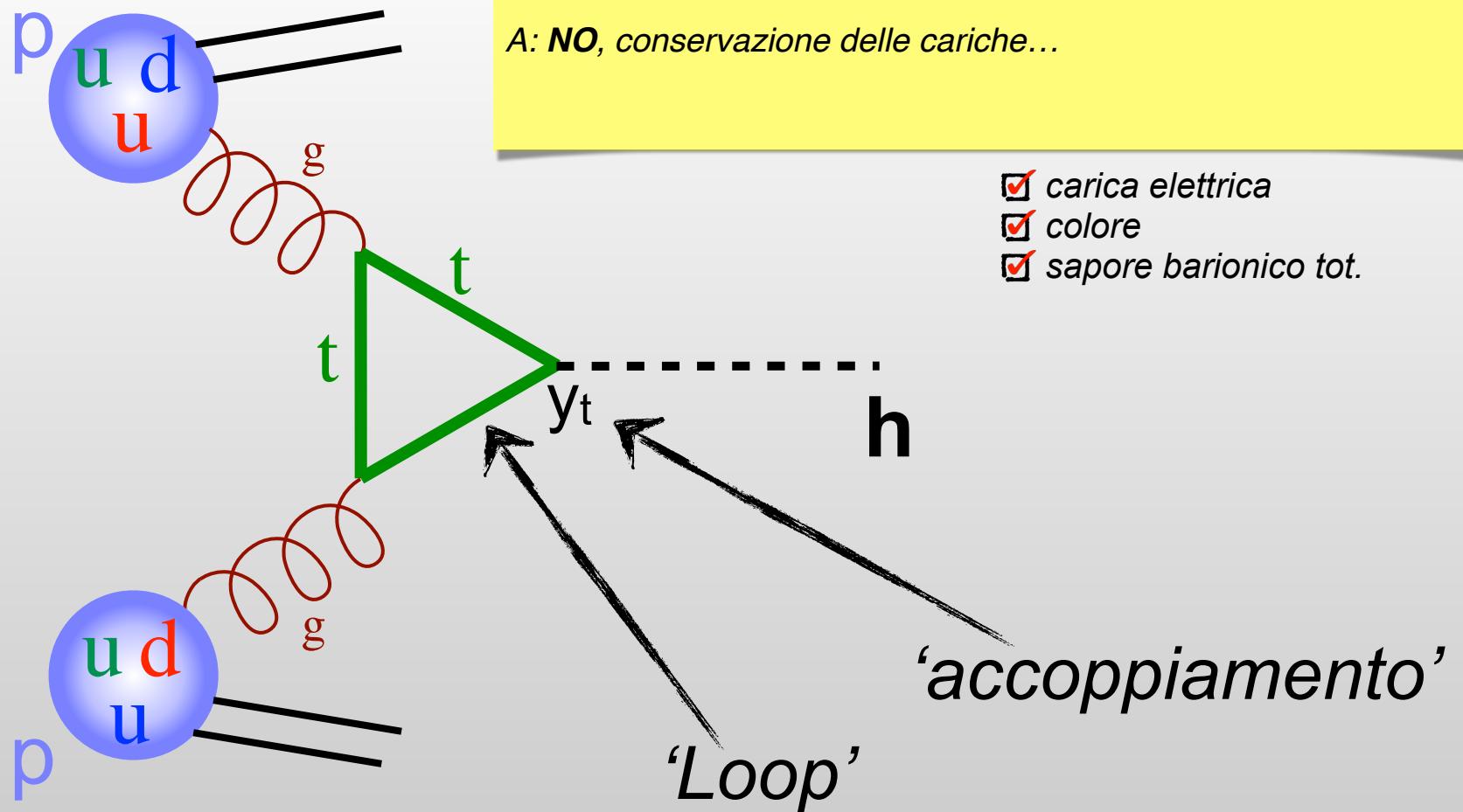


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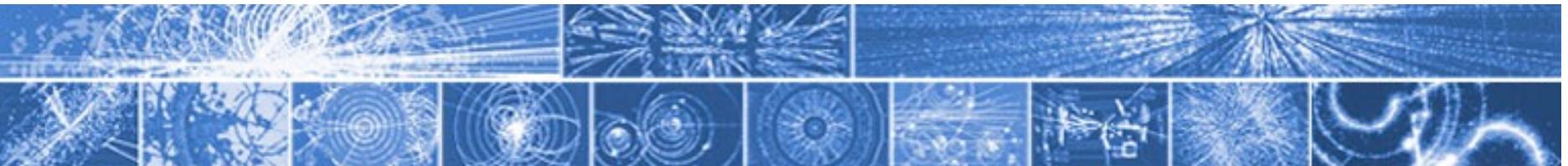
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LHC
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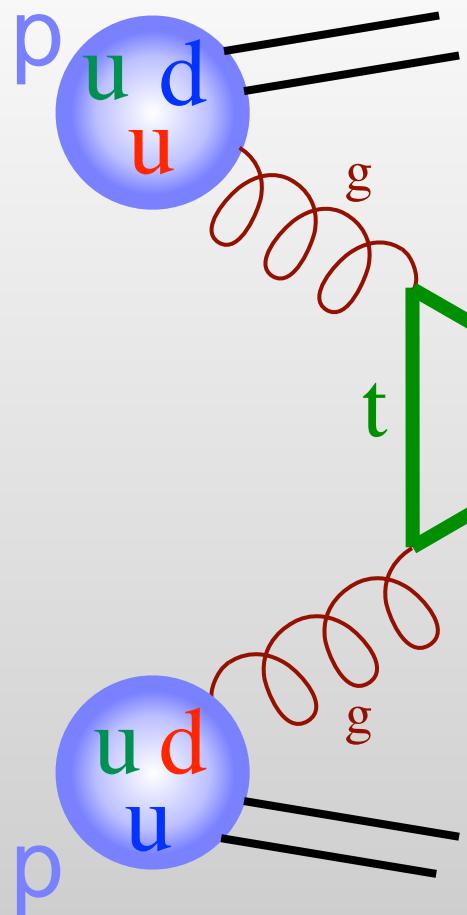


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LHC
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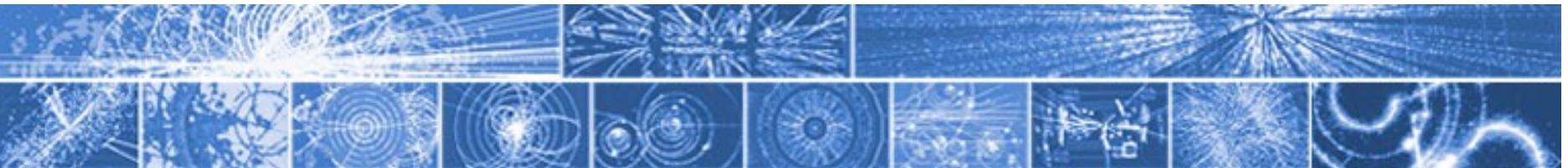


Q: Ma quindi alla fin fine si può fare un po' tutto?

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Sì, ma pagando il prezzo della rarità (processo 'soppresso')...
Il punto è saper calcolare i vari processi.

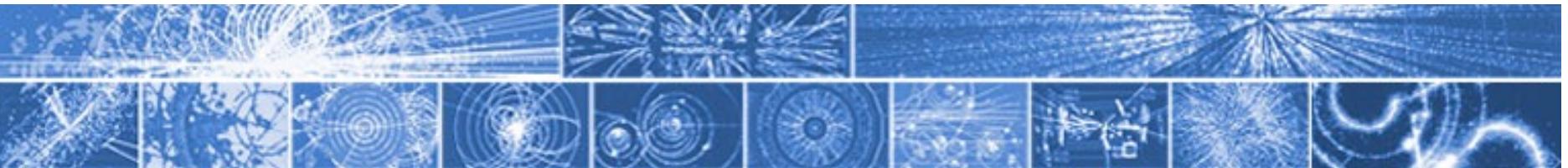
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I diagrammi di Feynman al lavoro

Esempio 4: decadimento del muone

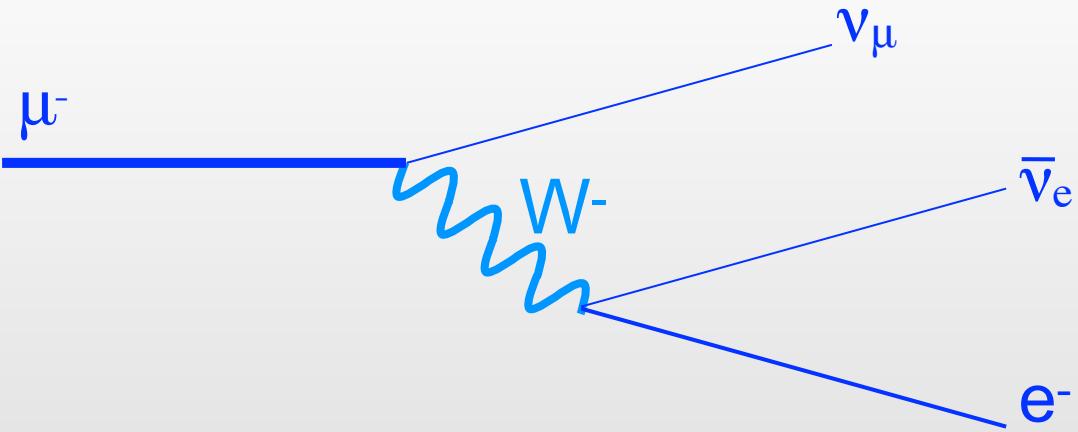
(piuttosto rigoroso: ma per i dettagli ci vorrebbe un intero corso di QFT!)

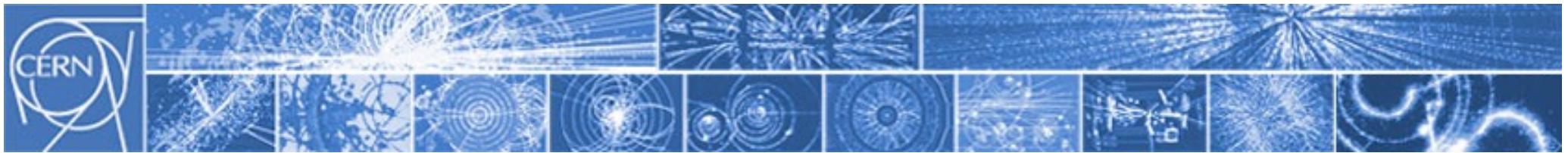


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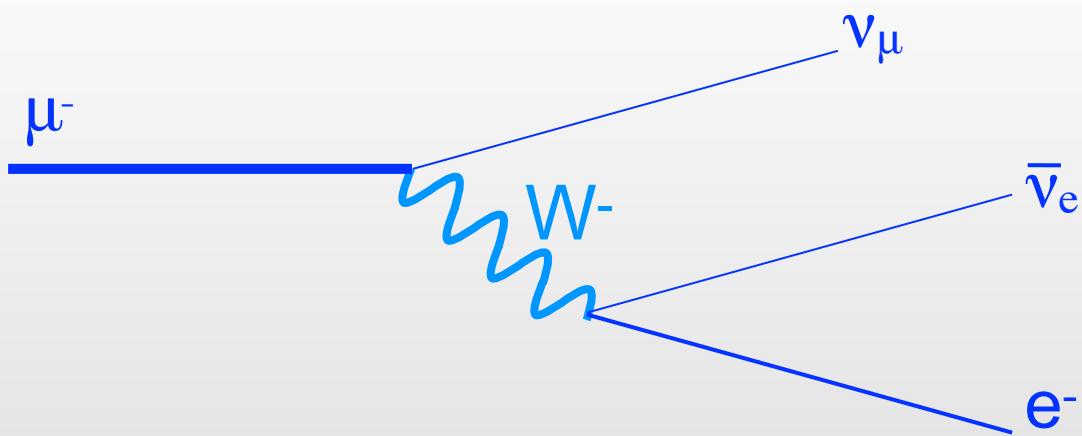




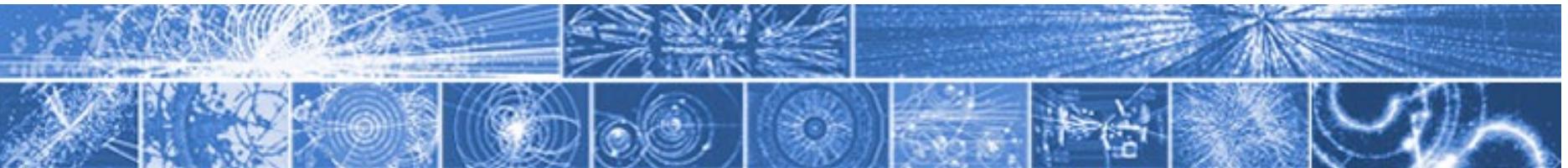
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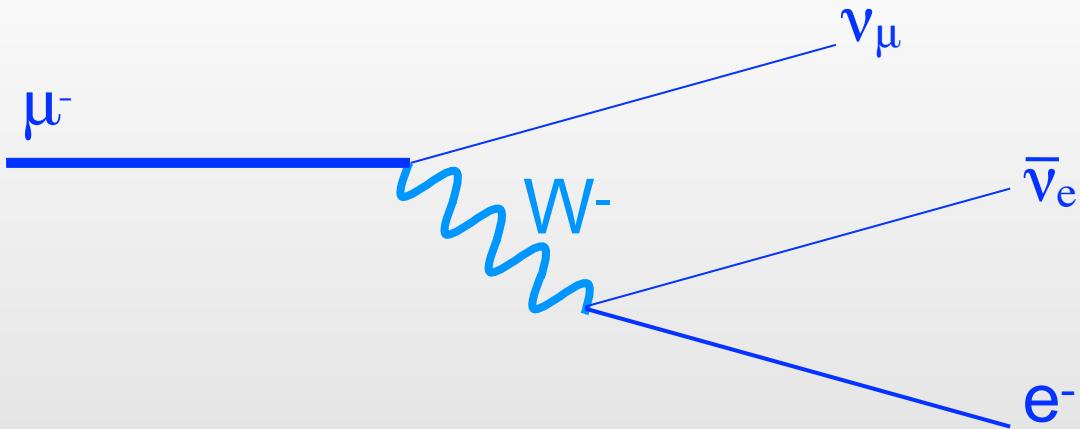
$$\begin{aligned}\mathcal{L} \simeq & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i \bar{\Psi} D\Psi \\ & + y_{ij} \Psi_i \Psi_j \phi \\ & + |D_\mu \phi|^2 - V(\phi)\end{aligned}$$



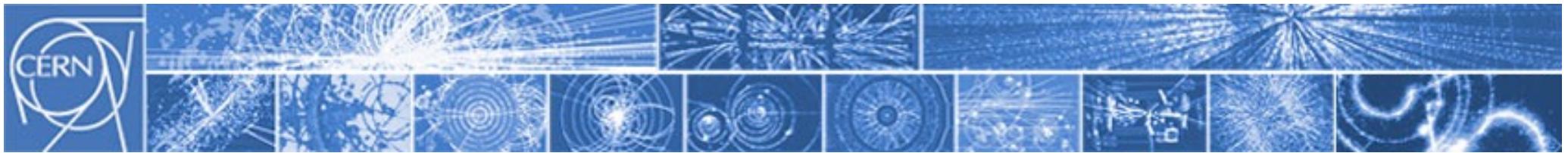
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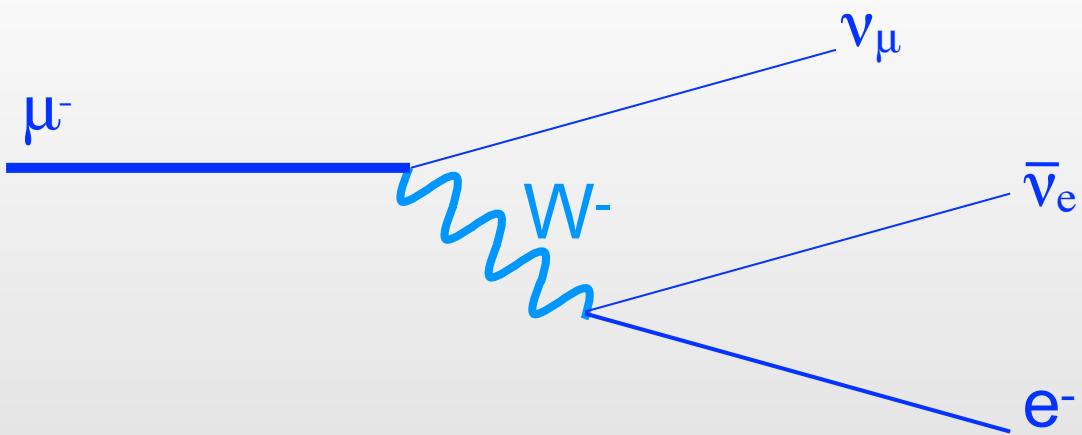
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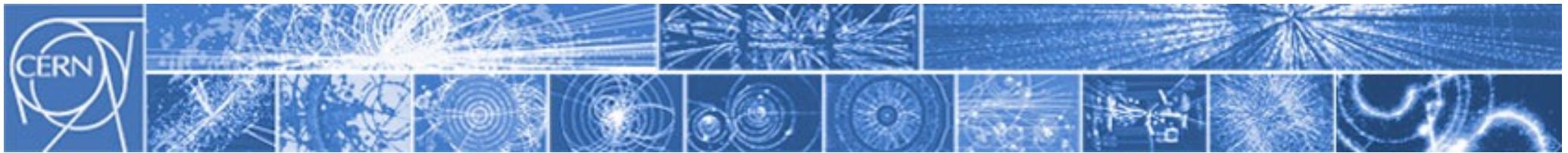
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$$\Psi = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L = \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \frac{1 - \gamma_5}{2}$$

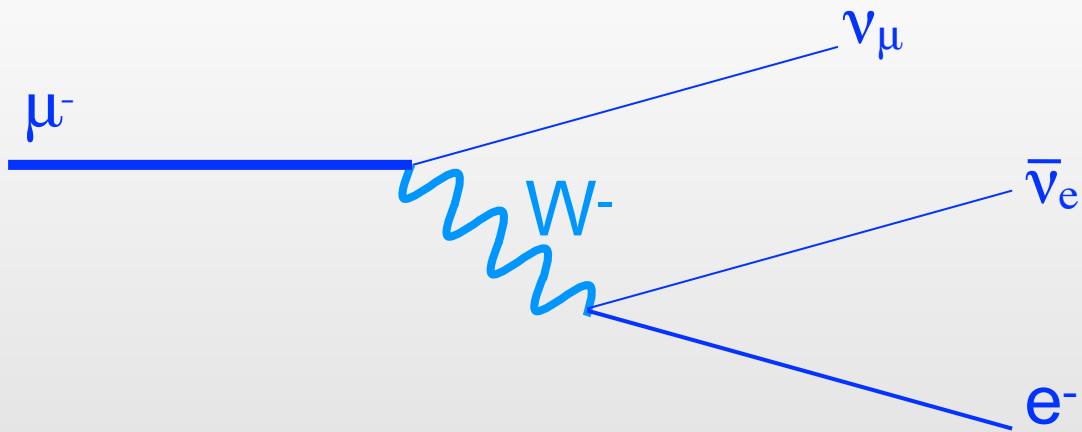
$$\not{D} = \gamma D \supset \gamma \left(-i \frac{g}{\sqrt{2}} W^- \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix} \right)$$



I diagrammi di Feynman al lavoro

Esempio 4: decadimento del muone

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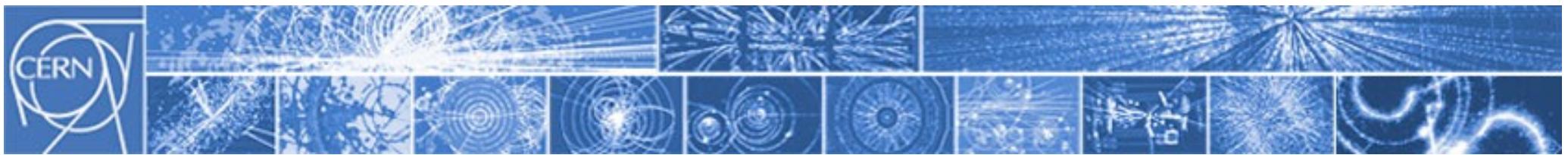


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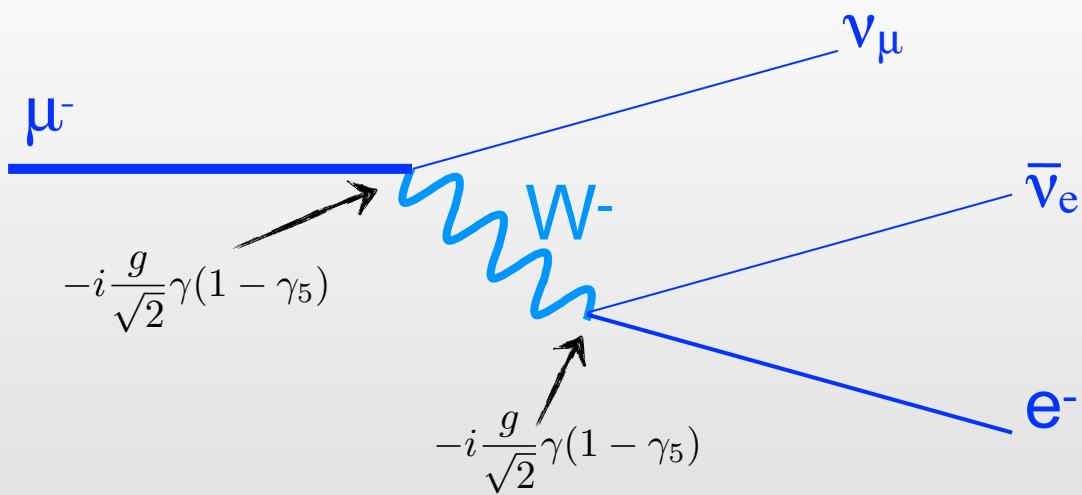
$$\simeq \nu_\mu \left(-i \frac{g}{\sqrt{2}} \right) \gamma (1 - \gamma_5) W^- \mu$$



I diagrammi di Feynman al lavoro

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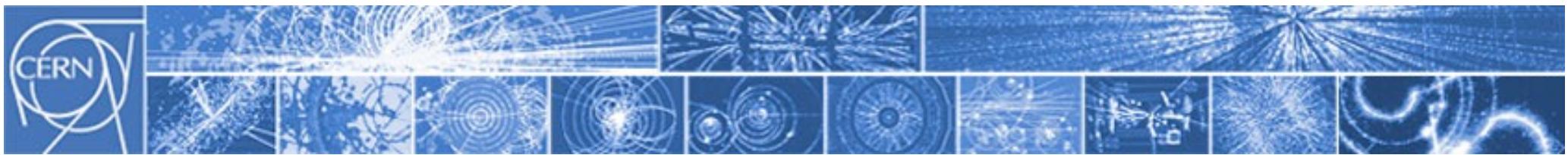


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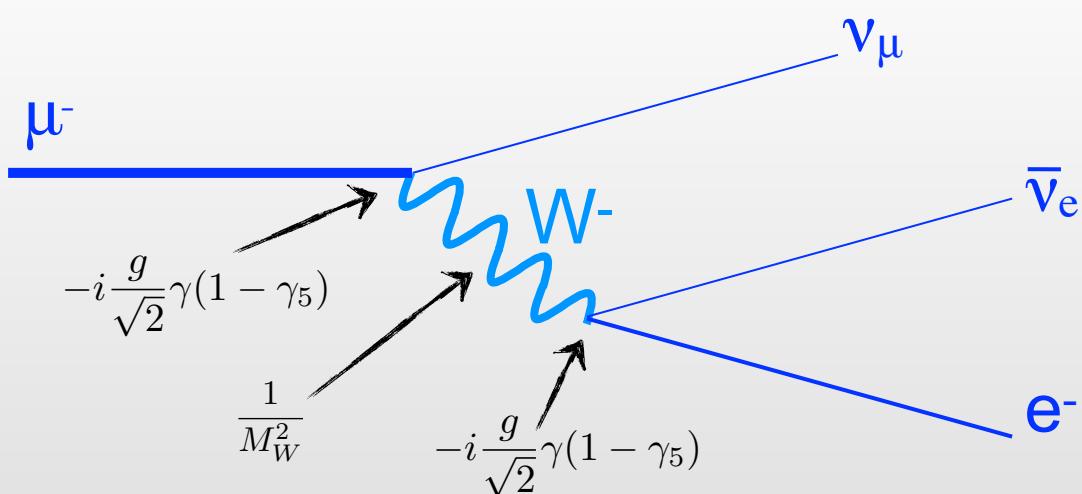
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I diagrammi di Feynman al lavoro

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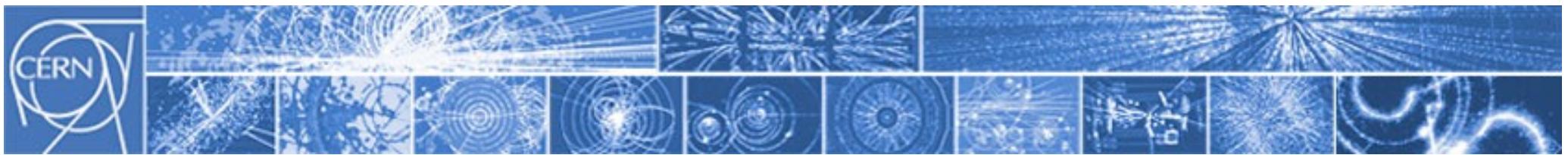
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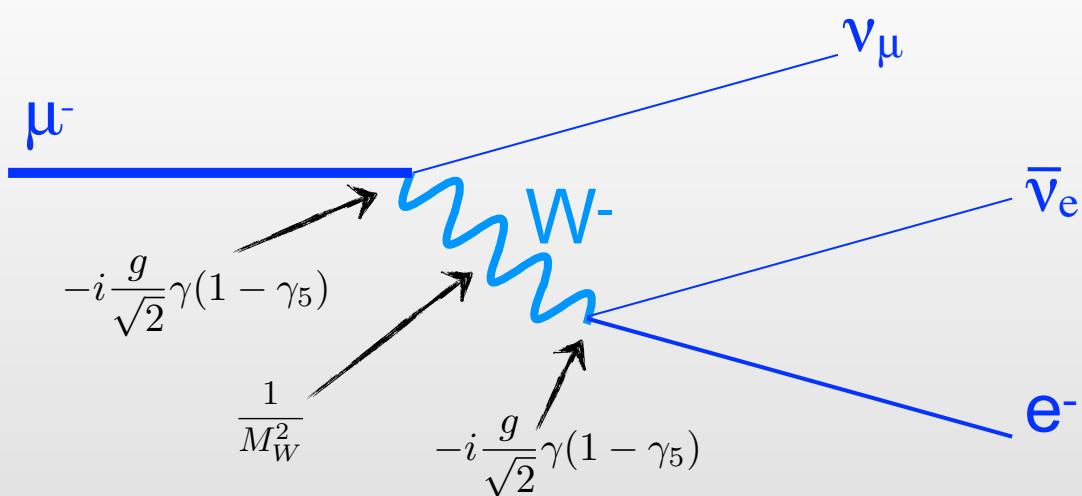
$$\text{Wavy line} \propto \frac{1}{M_W^2 - p^2} \rightarrow \frac{1}{M_W^2}$$



I diagrammi di Feynman al lavoro

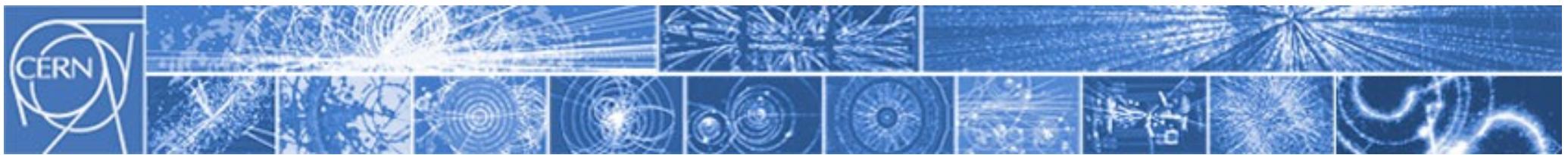
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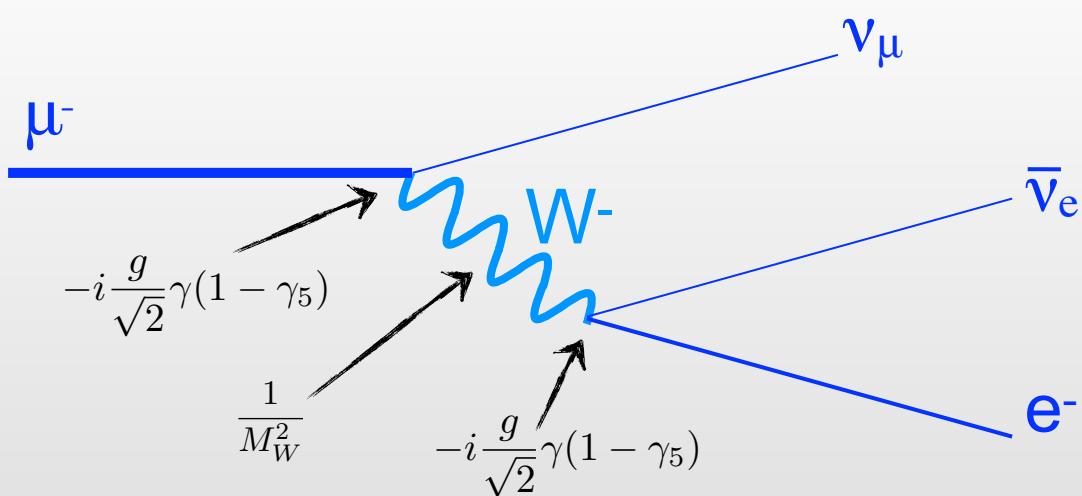
ampiezza: $|\mathcal{M}| \propto \frac{g^2}{2} [\nu_\mu \gamma(1 - \gamma_5) \mu] \frac{1}{M_W^2} [e \gamma(1 - \gamma_5) \nu_e]$



I diagrammi di Feynman al lavoro

Esempio 4: decadimento del muone

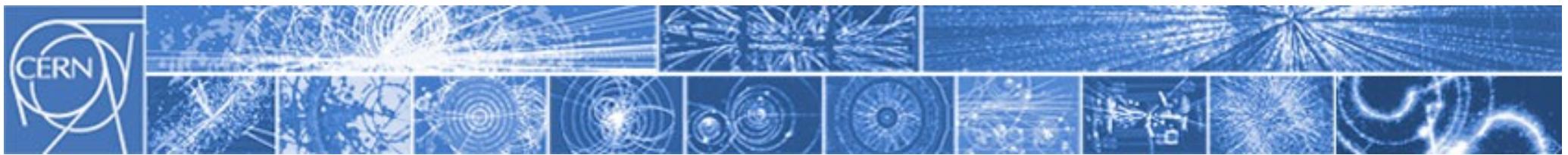
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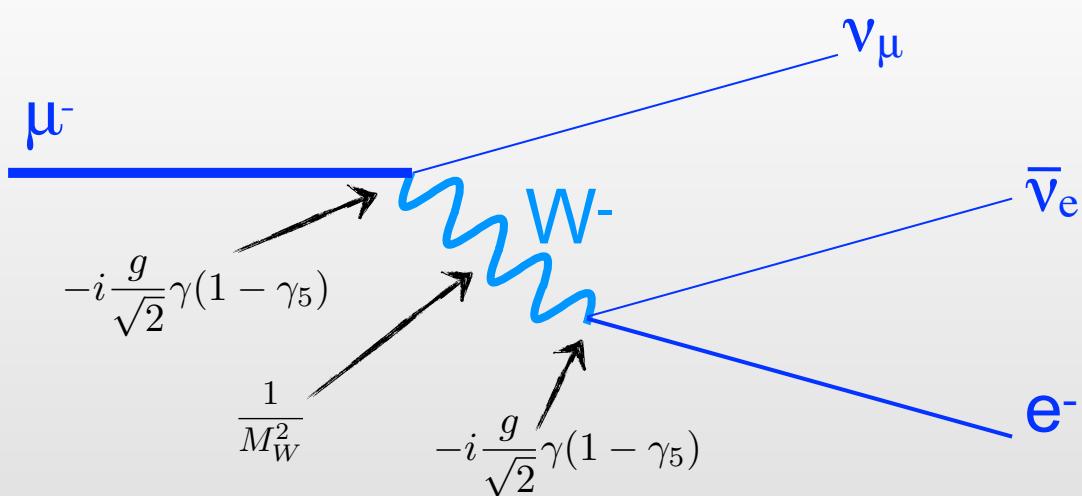
*tasso di
decadimento:* $\Gamma \propto |\mathcal{M}|^2$



I diagrammi di Feynman al lavoro

Esempio 4: decadimento del muone

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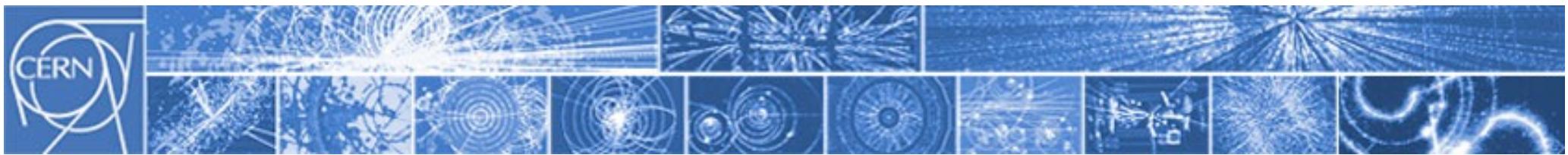
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“...dopo una serie di facili passaggi, si può facilmente dimostrare che...”

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

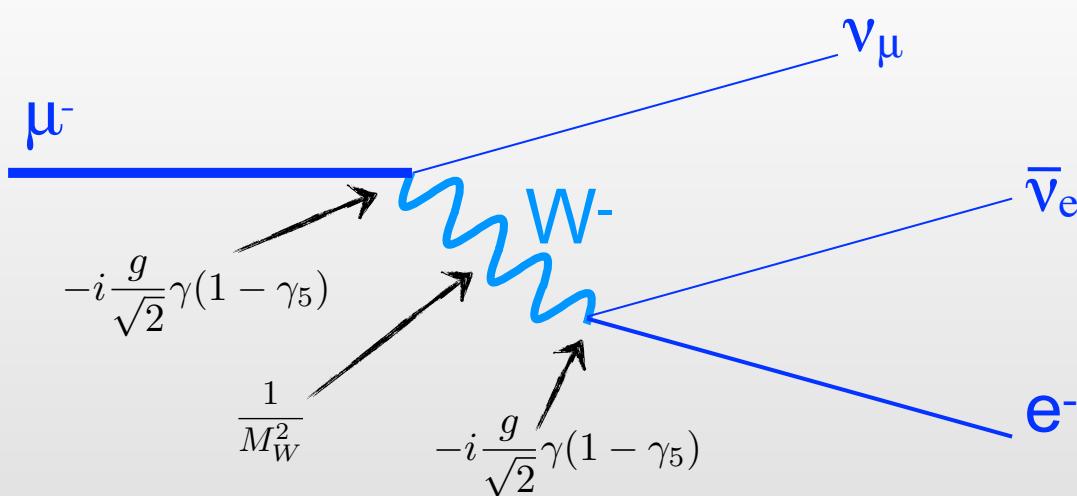
$$G_F = \frac{\sqrt{2} g^2}{8 M_W^2}$$



I diagrammi di Feynman al lavoro

Esempio 4: decadimento del muone

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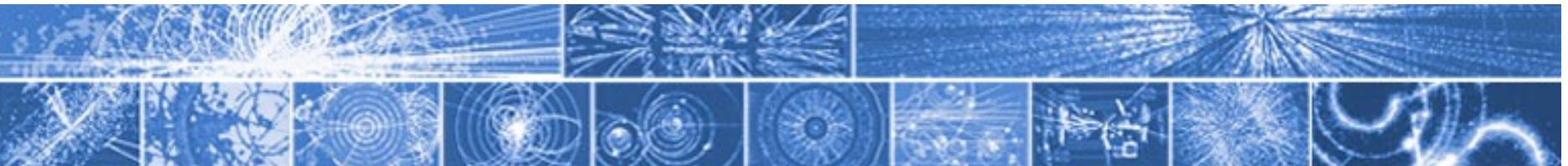
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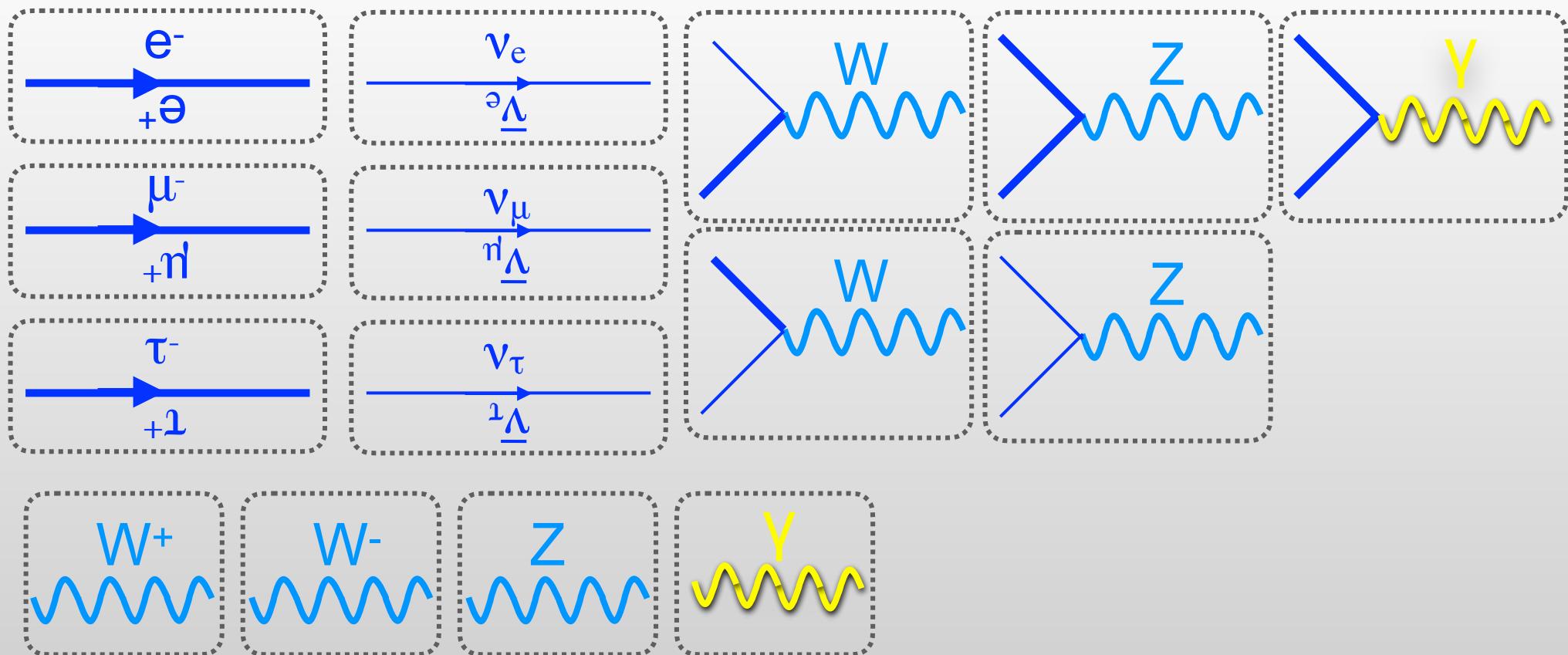
tasso di decadimento: $\Gamma = \frac{1}{192 \pi^3} G_F^2 m_\mu^5$

vita media: $\tau = 1/\Gamma = (2.19703 \pm 0.00004) \times 10^{-6}$ secondi



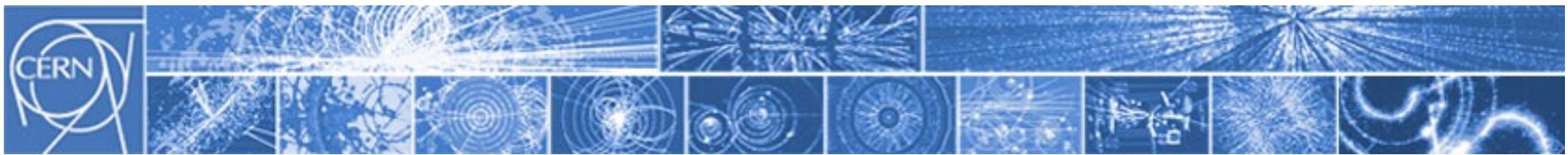
I diagrammi di Feynman al lavoro: *gioco del domino* (*un'idea di presentazione/masterclass?*)

EW Feynman rules



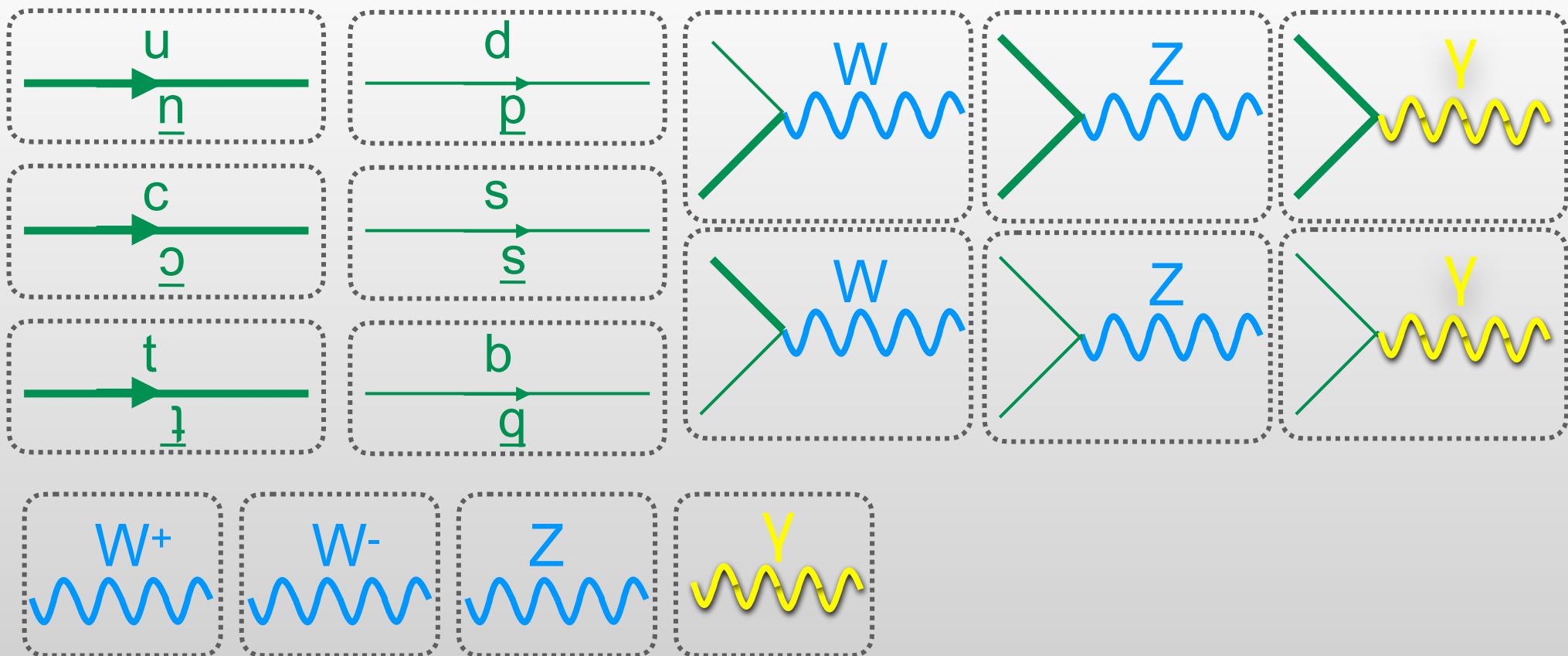
idea ripresa in:

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



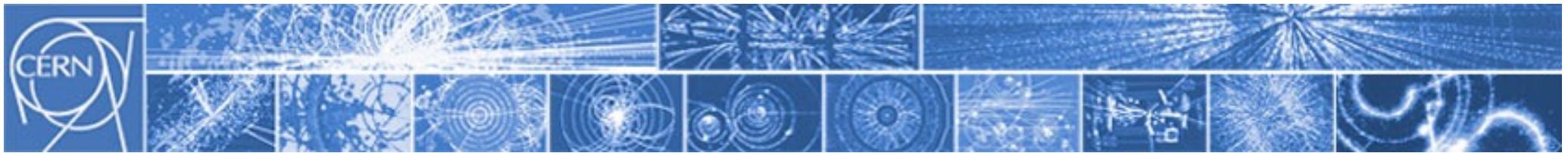
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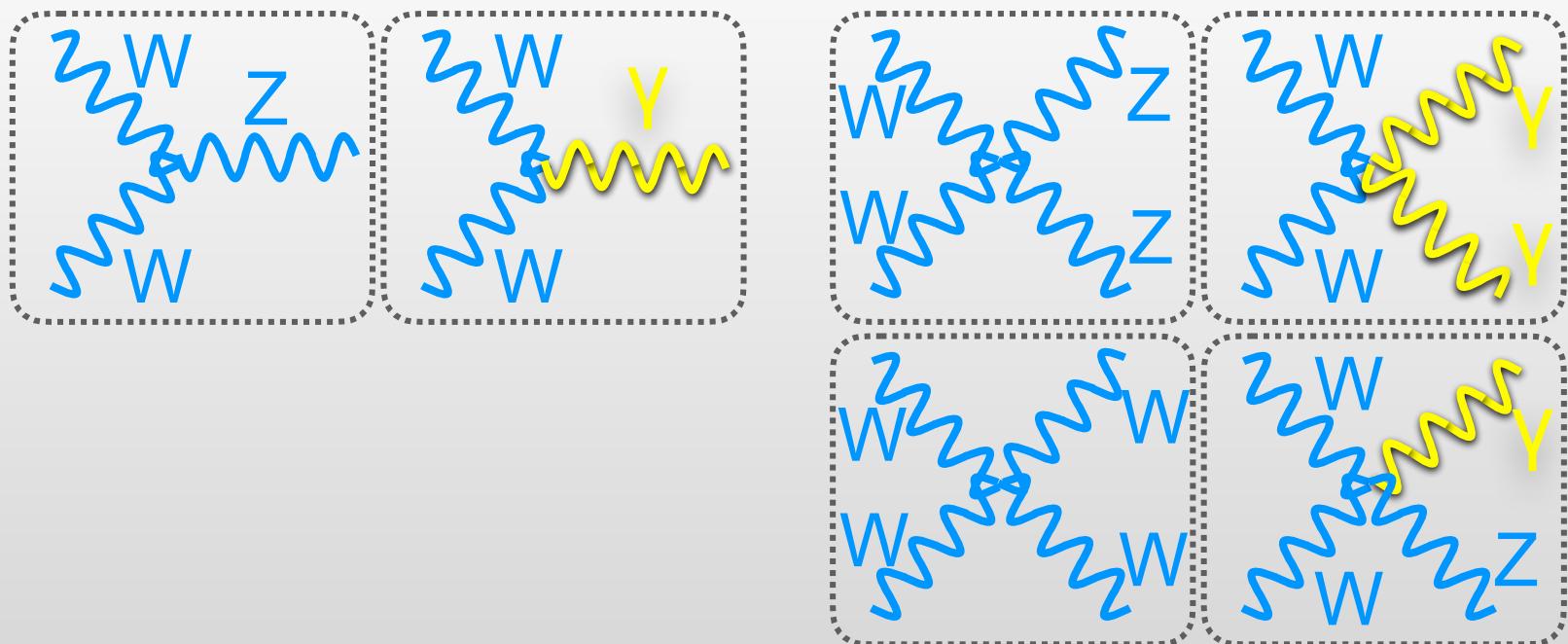
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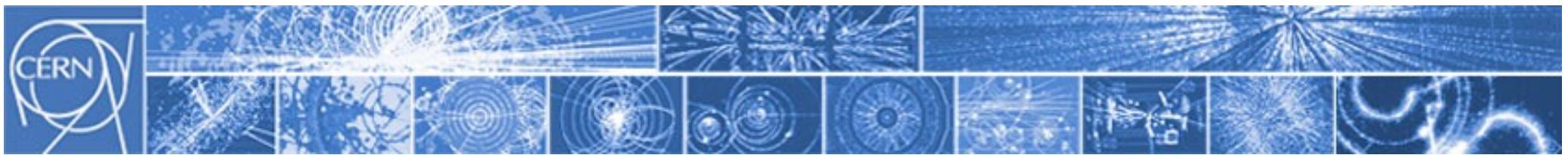
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EW Feynman: triple and quartic gauge interactions



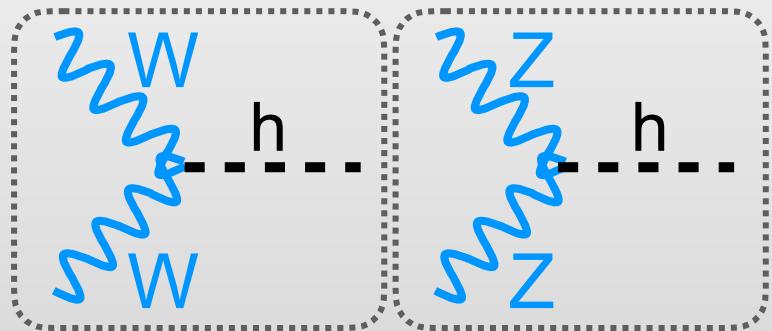
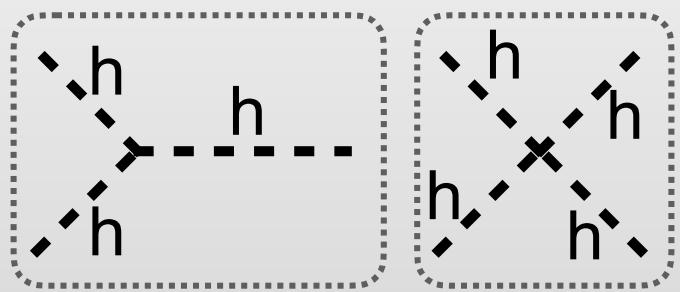
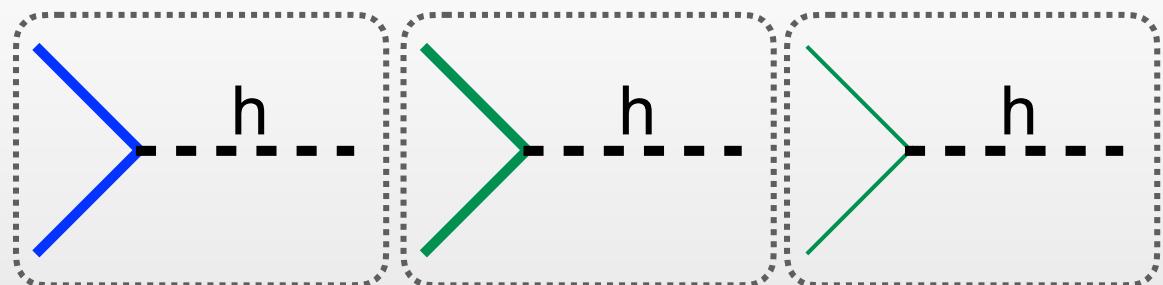
idea ripresa in:

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



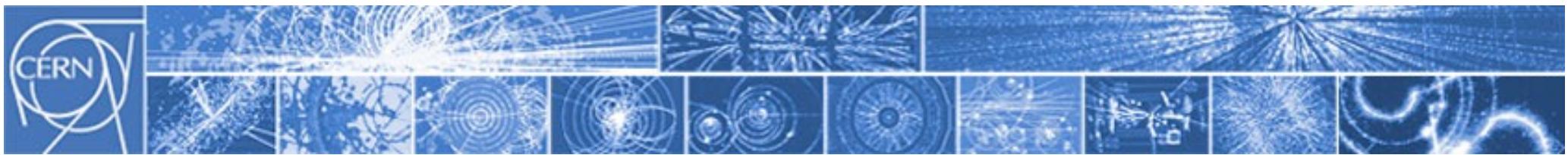
I diagrammi di Feynman al lavoro: *gioco del domino* (*un'idea di presentazione/masterclass?*)

Feynman rules higgs sector



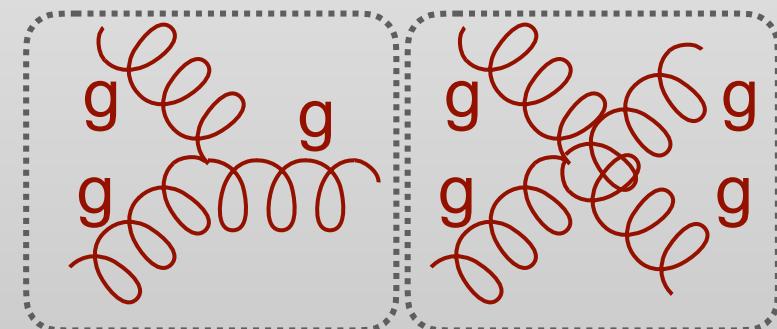
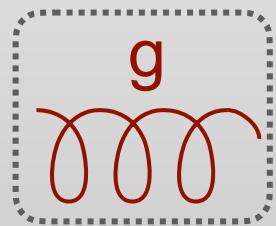
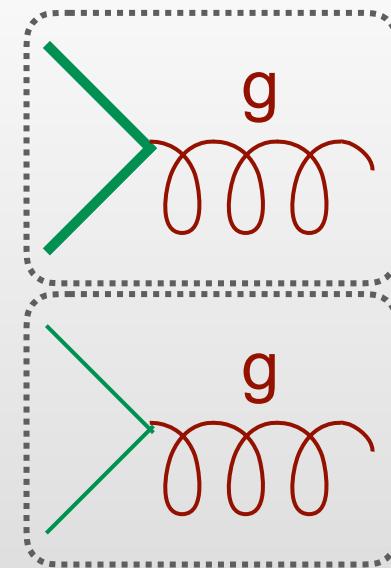
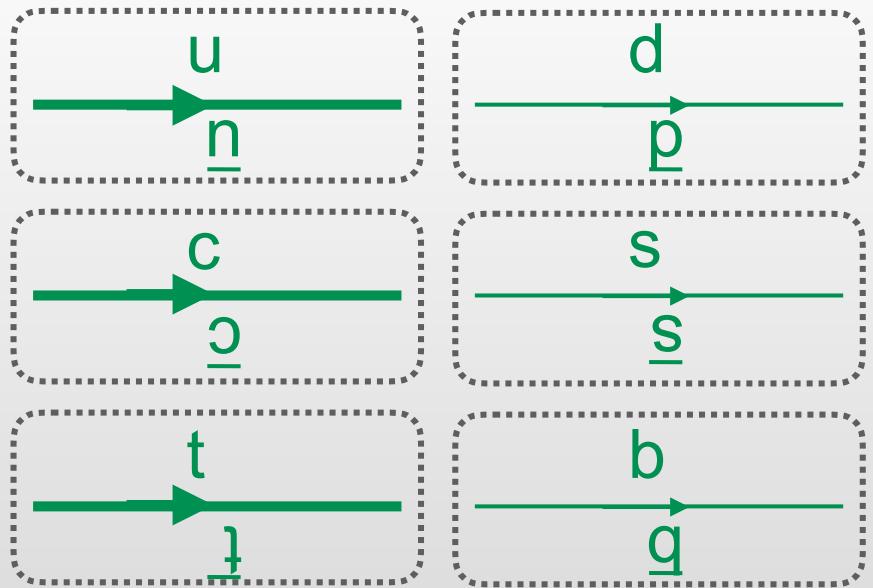
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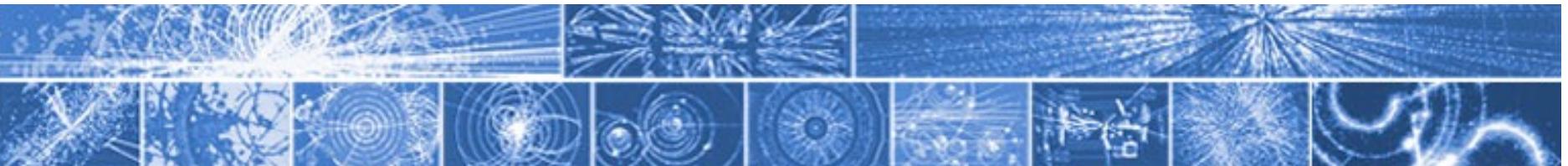
I diagrammi di Feynman al lavoro: *gioco del domino* (*un'idea di presentazione/masterclass?*)

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](#)

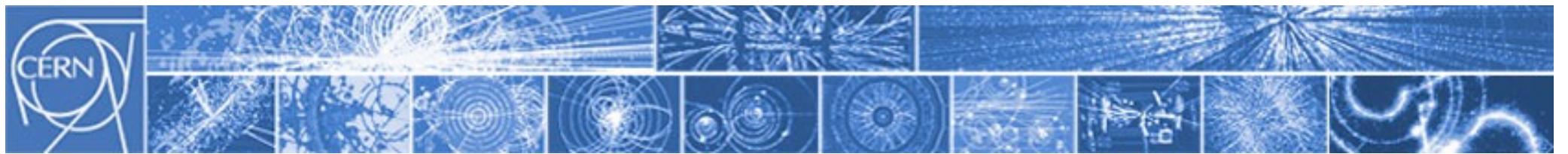
Subjects: Physics Education (physics.ed-ph); High Energy Physics – Phenomenology (hep-ph)

Report number: TTK-20-04

Cite as: [arXiv:2003.00896](#) [physics.ed-ph]
(or [arXiv: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?*)

The screenshot displays two windows. On the left is a terminal window showing the command-line build process for FeynGame:

```
out — java -jar FeynGame.jar game.model — 122x39
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@O1 ~] cd build/out/
(base) [mcirelli@O1 ~] java -jar FeynGame.jar game.model
```

Below the terminal is a dark-themed window showing the text "FeynGame" repeated in a grid pattern. At the bottom, there is a copyright notice and build information:

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

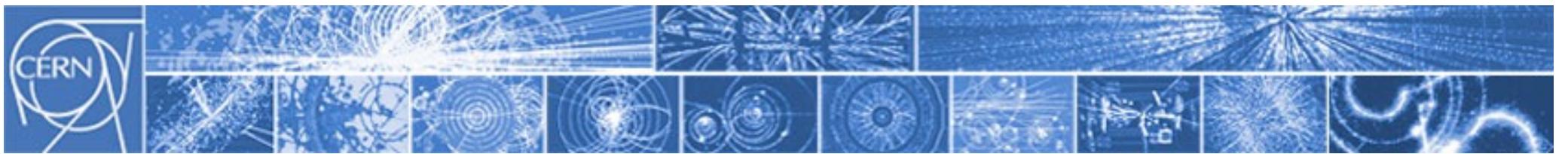
On the right is the main FeynGame application window titled "FeynGame v1.0.0". It shows a Feynman diagram consisting of two external lines meeting at a central vertex, which then splits into two internal lines that loop back to form a horizontal chain of five vertices. The diagram is set against a dotted grid background. Below the diagram is a toolbar with various icons:

- +
- t
- g
- γ
- - -
- H
-
-
- Cross

Below the toolbar is a "Star" icon.

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

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



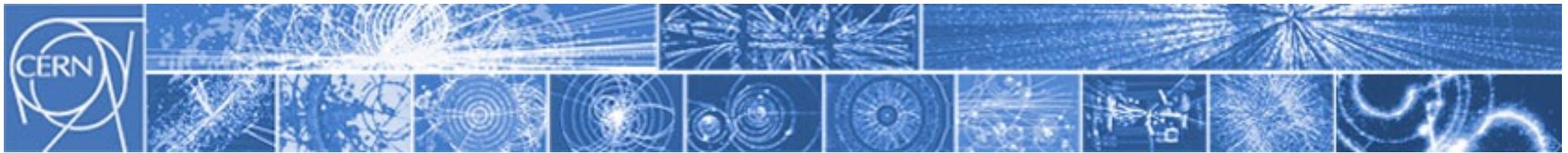
I diagrammi di Feynman al lavoro: *FeynGame* (*un'idea di presentazione/masterclass?*)

The screenshot displays two windows related to the FeynGame project:

- Terminal Window:** Shows the command-line interface for building and running the application. It includes the Java command to run the jar file and the resulting output of the build process, which lists various files being added to the jar.
- FeynGame v1.0.0 Application:** A graphical interface for creating Feynman diagrams. It features a grid-based workspace where a diagram is being constructed. The diagram consists of a central black vertex connected to several red circular vertices, which are further connected by red lines. A dashed blue line extends from one of the red vertices. Below the workspace are tool buttons for creating lines, arrows, gluons (curly lines), and vertices. An error dialog box is open, stating "Found 1 Error" and "Checking 5 Lines and 2 Vertices: - Vertex {gluon, higgs, higgs} is not in model file.", with an "OK" button.

<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⁺: $(A,Z) \rightarrow (A,Z-1) e^+ \nu$
- 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]
- ...