

De rendijas a dibujos

La física mágica de Feynman



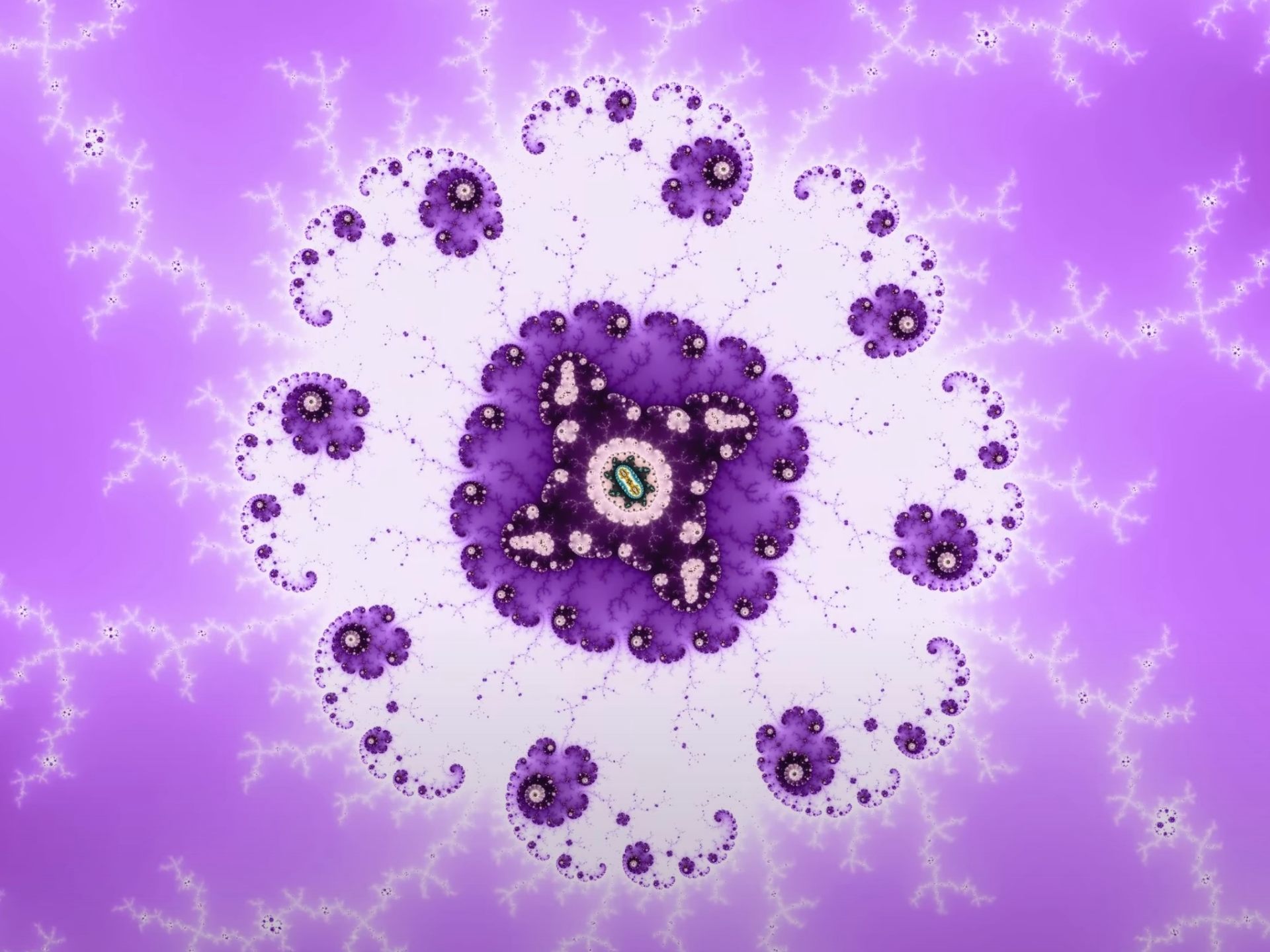
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CERN Spanish Teacher Program
26 de Julio de 2023

¿Qué son los
diagramas de Feynman?

Preliminares ...



Ancecedentes

Demostración ...

“Simplificando” el mundo



Periodic Table of Elements
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| | | Group 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 | | | | | | | | | | | | | | | | | | |
|----------------|-------------------|--|----|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|----------------|-----|-----|-----|-----|-------|----|
| Period | 1 | IA | | | | | | | | | | | | | | | | | VIIIA | |
| | 1 | 1 | H | | | | | | | | | | | | | | | | | 2 |
| | 2 | 3 | 4 | | | | | | | | | | | | | | | | | 10 |
| | 3 | 11 | 12 | | | | | | | | | | | | | | | | | 18 |
| | 4 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | |
| | 5 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | |
| | 6 | 55 | 56 | 57 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | |
| | 7 | 87 | 88 | 89 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | |
| | | <i>s-block</i> | | <i>d-block</i> | | | | | | | | | | <i>p-block</i> | | | | | | |
| <i>f-block</i> | Lanthanide Series | | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | | | |
| | Actinide Series | | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | | | |

H - Gas



Non-Metals



Alkali Metals

Li - Solid



Transition Metals



Alkali Earth Metals

Br - Liquid



Rare Earth Metals



Other Metals

Tc - Synthetic

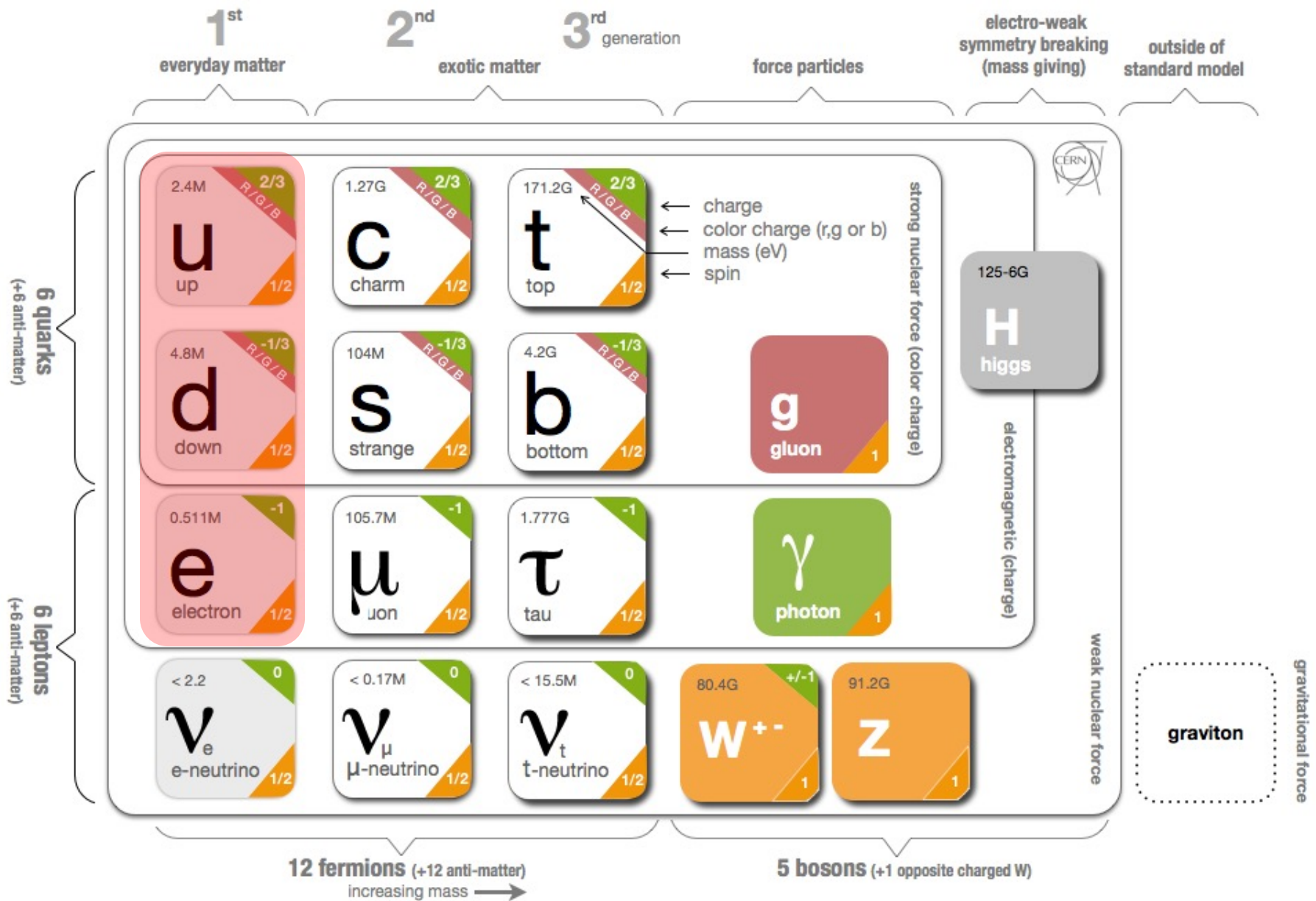


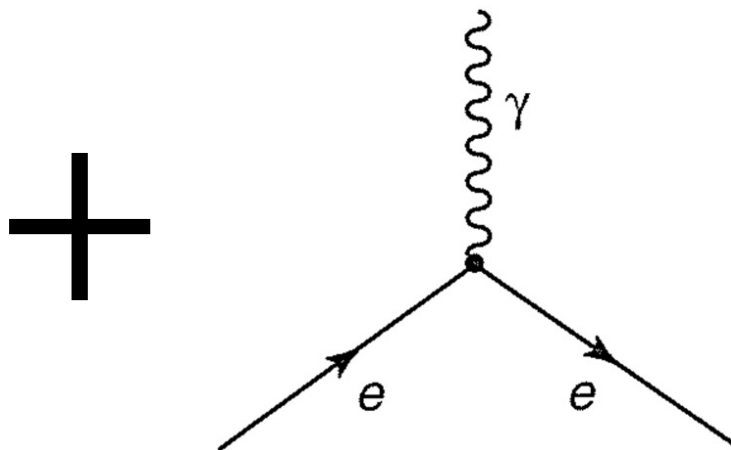
Halogens



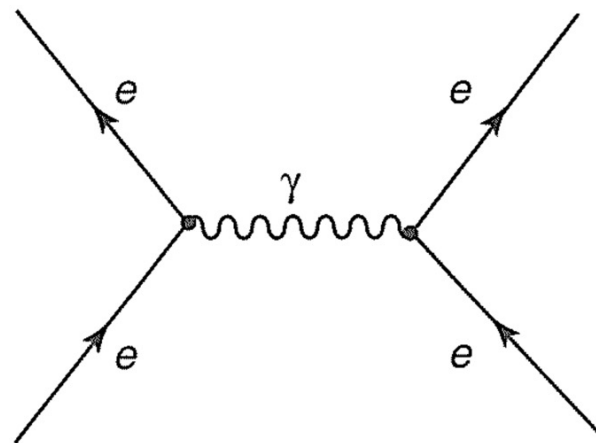
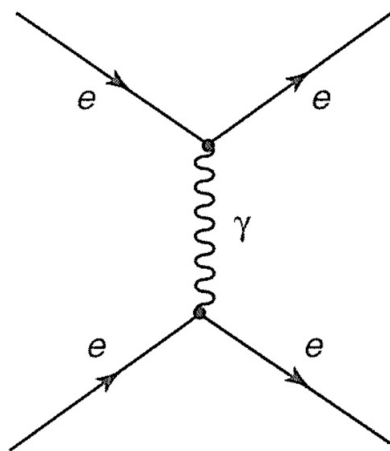
Inert Elements





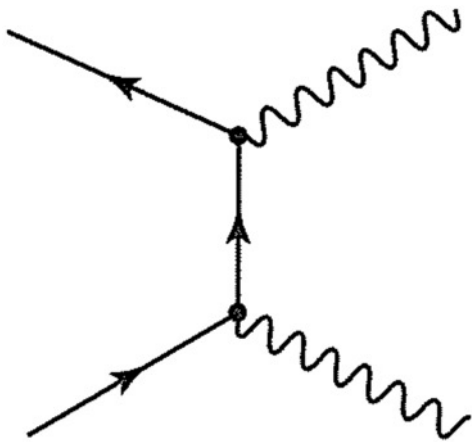


tiempo →

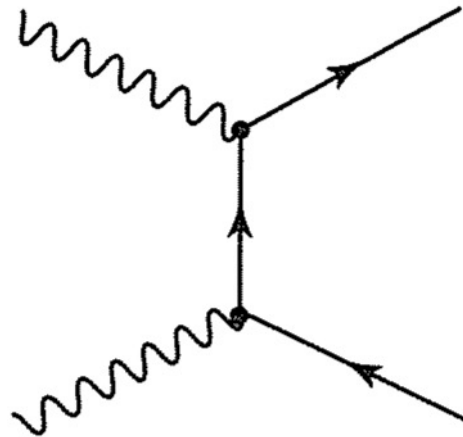


Otras combinaciones:

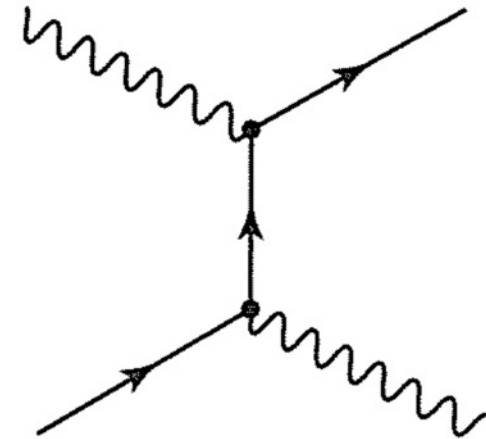
tiempo \longrightarrow



Aniquilación de pares
 $e^+ + e^- \rightarrow \gamma + \gamma$



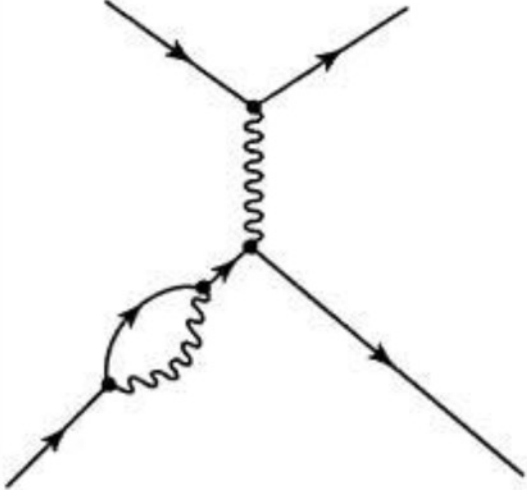
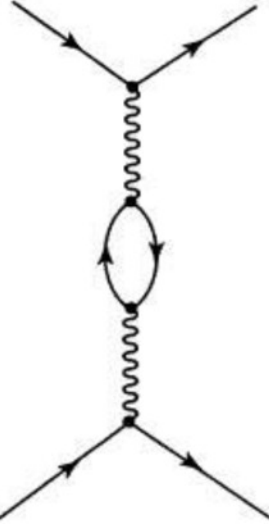
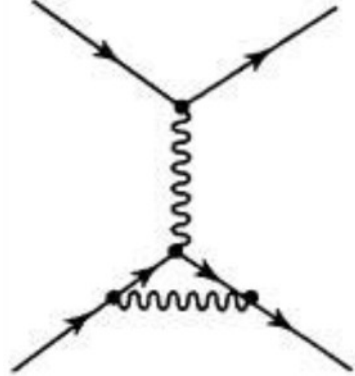
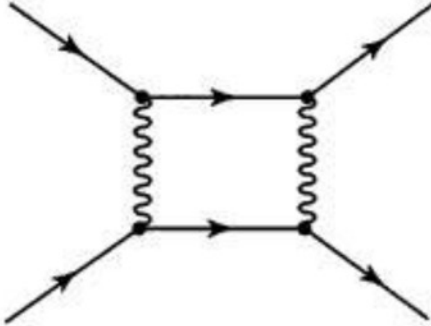
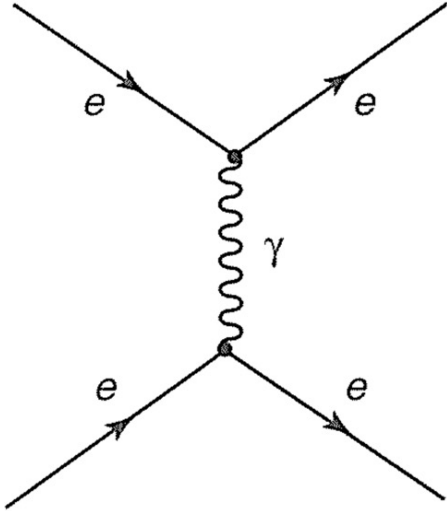
Producción de pares
 $\gamma + \gamma \rightarrow e^+ + e^-$



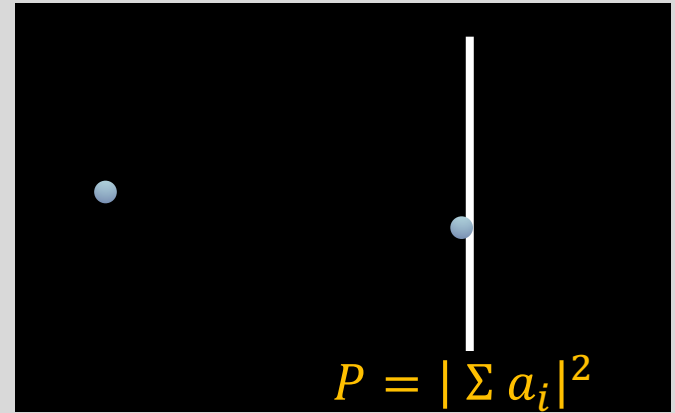
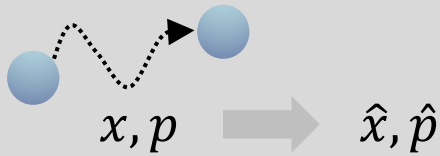
Dispersión Compton
 $e^- + \gamma \rightarrow e^- + \gamma$

... pero, y las demás posibilidades?

tiempo \longrightarrow

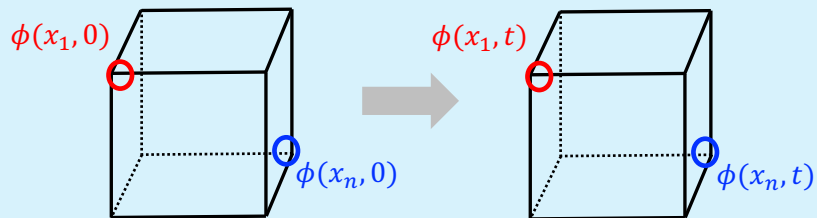


MECÁNICA CLÁSICA:



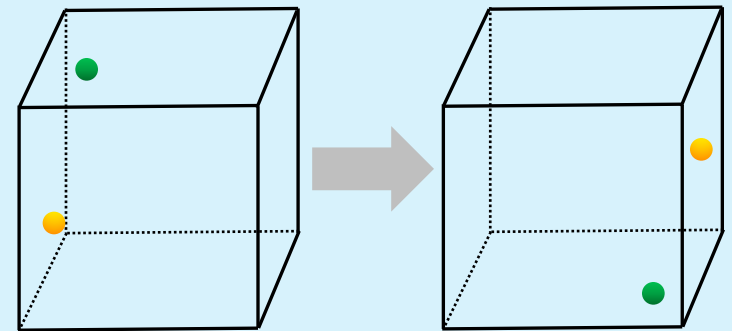
A ALTAS ENERGÍAS (DISTANCIAS CORTAS)

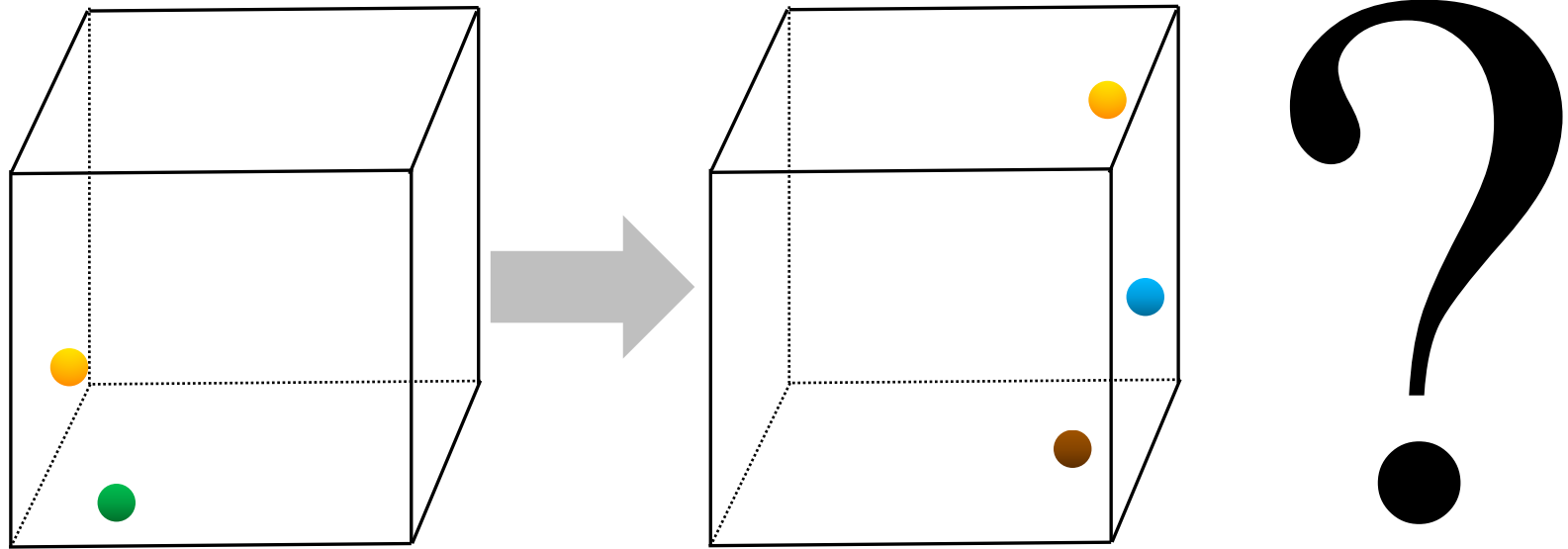
- No podemos ignorar la posible producción de partículas



Each $\phi(x) \rightarrow \hat{\phi}(x)$

Excitations at each point: **quanta of that field**





“Todas las historias posibles” son aquellas que se pueden construir combinando los “vértices básicos” que representan las interacciones fundamentales.

¿Cuánto es $\frac{1}{1.03}$?

$$\begin{aligned}\frac{1}{1 + 0.03} &\approx 1 - 0.03 \\ &\approx 1 - 0.03 + 0.03^2 \\ &\approx 1 - 0.03 + 0.03^2 - 0.03^3 \\ &\quad \dots\end{aligned}$$

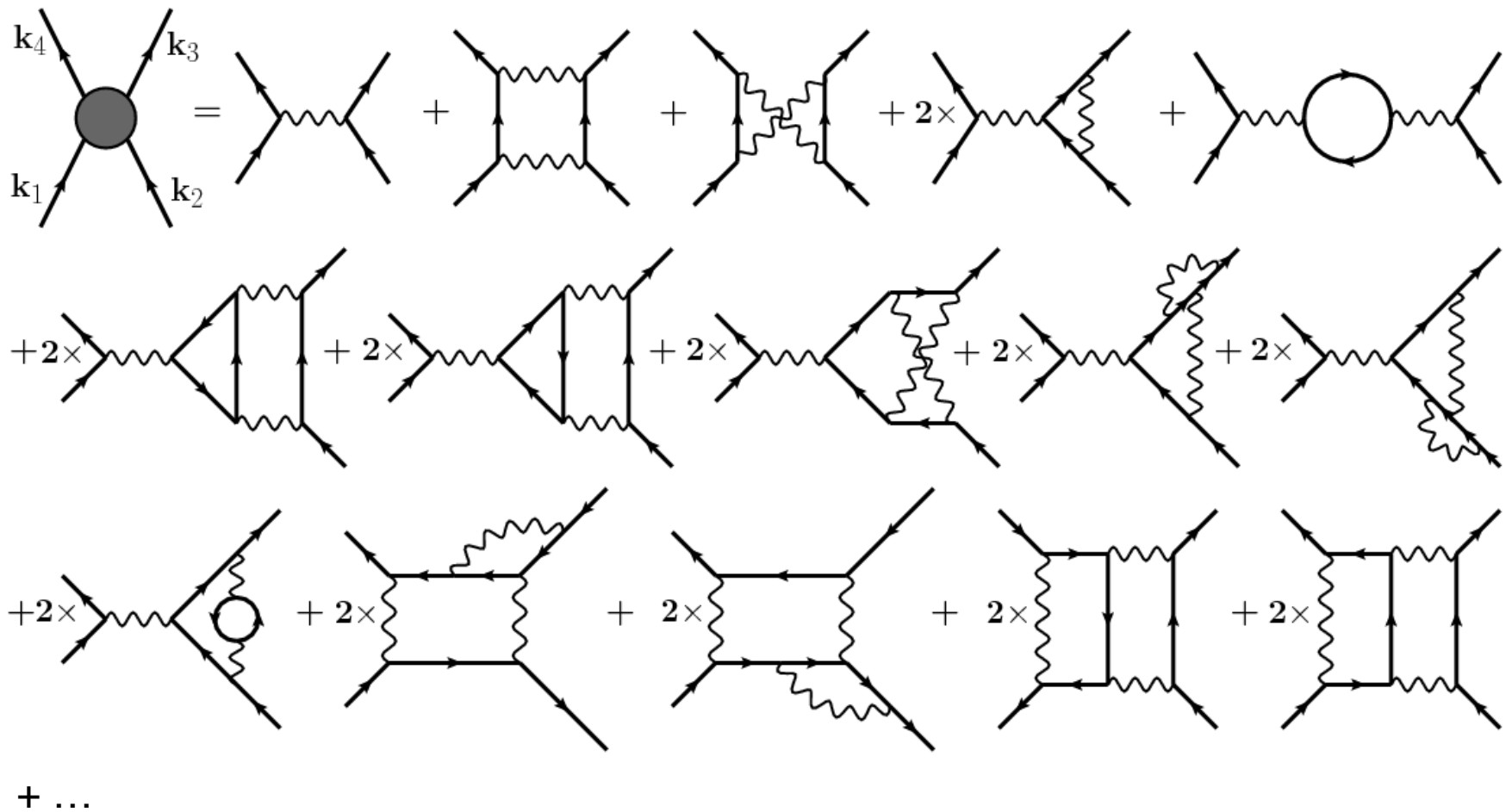
$$\frac{1}{1 + x} = 1 - x + x^2 - x^3 + \dots$$

Sabemos cómo obtener la serie, pero no “por inspección”.

Por otro lado, *cada diagrama de Feynman* tiene una traducción *única* en una expresión que da un número complejo.

Conociendo los vértices válidos y qué partículas entran y salen del proceso, *podemos escribir 'por inspección' las expresiones a calcular!!!*

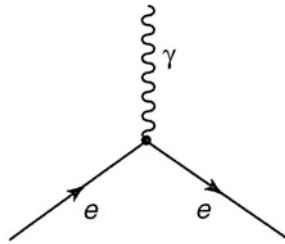
La suma de esas expresiones es la amplitud de probabilidad del proceso.



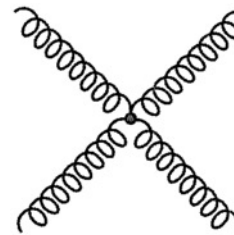
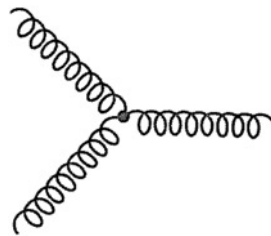
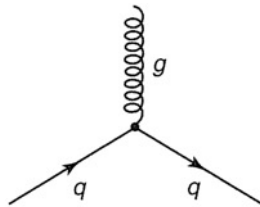
- En QED, mientras más vértices, menor valor
- Para alta precisión, hasta miles de términos

Resumen de interacciones (sin el bosón de Higgs)

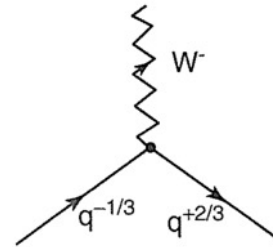
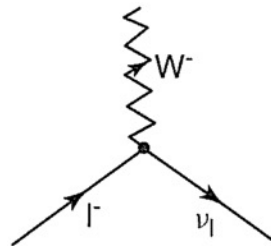
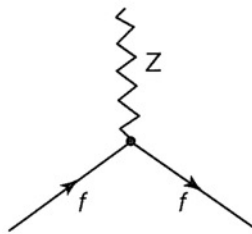
QED:



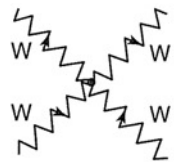
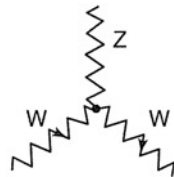
QCD:



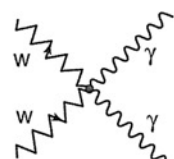
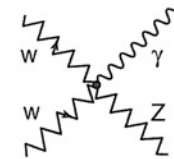
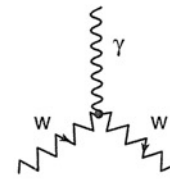
Débil:



W/Z:



(W|Z)/γ:

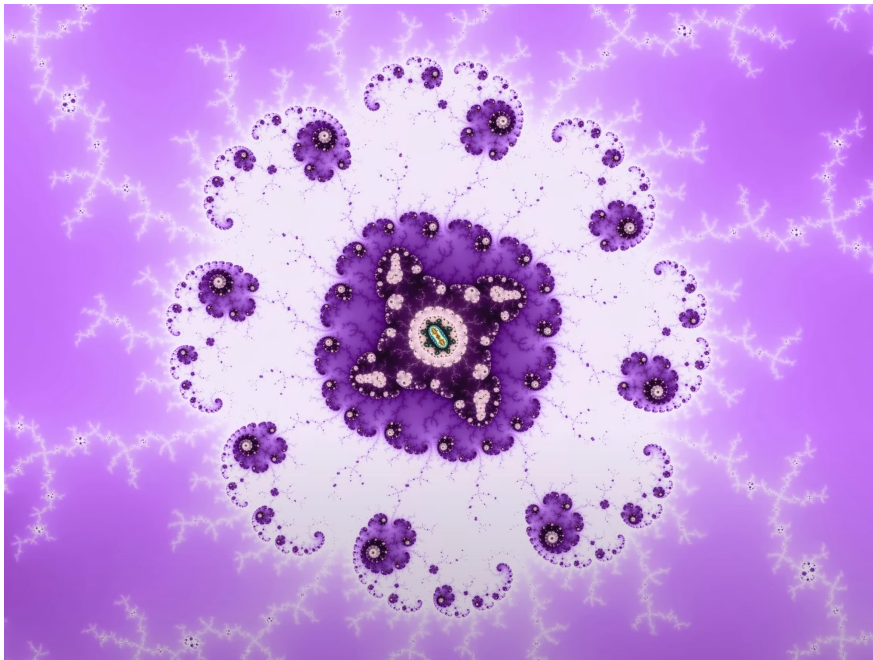


| | Fermions | | | Bosons | Force carriers |
|---------|---|---------------------------------------|--------------------------------------|---------------------|----------------|
| Quarks | <i>u</i> up | <i>c</i> charm | <i>t</i> top | <i>γ</i> photon | |
| | <i>d</i> down | <i>s</i> strange | <i>b</i> bottom | <i>Z</i> Z boson | |
| Leptons | <i>ν_e</i> electron neutrino | <i>ν_μ</i> muon neutrino | <i>ν_τ</i> tau neutrino | <i>W</i> W boson | |
| | <i>e</i> electron | <i>μ</i> muon | <i>τ</i> tau | <i>g</i> gluon | |

Cabibbo-Kobayashi-Maskawa

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Cada **vertice válido** corresponde a un **término** en el Lagrangiano del modelo estándar.
- i.e., los diagramas de Feynman son términos la expansión perturbativa de la amplitud de probabilidad de un proceso.



$$z \leftarrow z^2 + c$$

