Introdução à Física de Partículas

Introduction to particle Physics

(1/3)

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De que trata a Física de Partículas?

A Física de partículas é um ramo da Física que estuda os constituintes elementares da matéria e da radiação, e a interação entre eles e suas aplicações. É também chamada de Física de altas energias, porque muitas partículas elementares só podem ser criadas a energias elevadas, logo a detecção destas também é possível apenas a altas energias de aceleração. O elétron e o próton foram as únicas partículas aceleradas até os dias de hoje, outras nunca foram detectadas (como o gráviton) e as restantes foram detectadas através da radiação cósmica (como o méson pi e o méson mu).

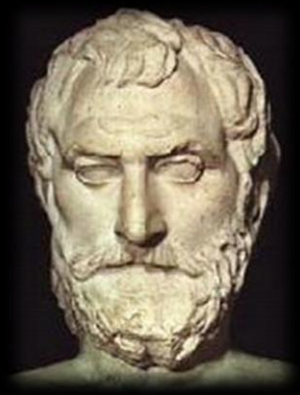
A Física de partículas, estudada pela Mecânica Quântica (parte da Física Moderna), busca o fundamental, o nível mais básico da matéria e da Natureza. Todo o nosso mundo visível se fundamenta nesse nível invisível das partículas elementares.

"Todo o nosso mundo visível se fundamenta nesse nível invisível das partículas elementares."

- Partículas e interacções
- As revoluções da Física no sec. XX
- A teoria do "quase-tudo"...
- Porquê "quase-tudo" ?

IMPOSSÍVEL SER RIGOROSO E PROFUNDO

MAIS DE 100 ANOS DE IDEIAS, TEORIAS, DESCOBERTAS …



Tales de Mileto (624-547 A.C.)

Tales de Mileto foi pioneiro no que respeita à procura da origem das substâncias e suas transformações sem recorrer a entidades divinas (mitologia).

ἄτομος Átomo

Indivisível

A matéria é composta por algumas espécies de átomos fundamentais, que diferem na sua forma e tamanho, e por espaço vazio.

Leucipo e Demócrito (500-400 A.C.)

A complexidade da Natureza é o resultado das inúmeras combinações destes átomos e das suas posições no espaço vazio.

Atomismo baseado no raciocínio abstrato e filosófico. Mas...

A ideia de que a matéria é constituída por unidades discretas está na base da Física moderna.

1-2 Matter is made of atoms

If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* (or the atomic *fact*, or whatever you wish to call it) that *all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another*. In that one sentence, you will see, there is an *enormous* amount of information about the world, if just a little imagination and thinking are applied.

In "Feynman lectures on Physics", R. Feynman, 1964.

Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

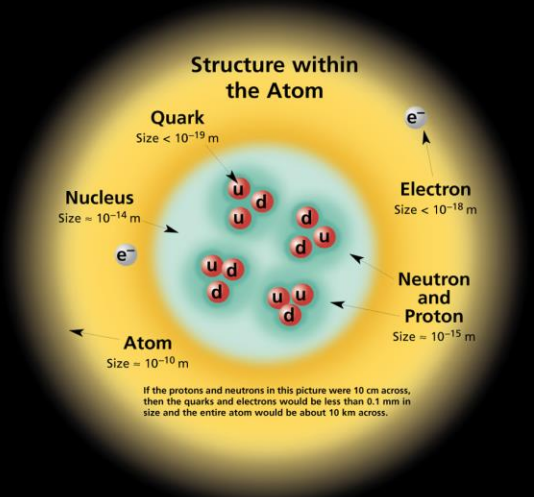
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$
Baryons are fermionic hadrons.
There are about 120 types of baryons.

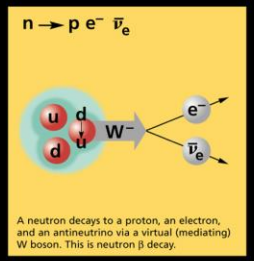
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

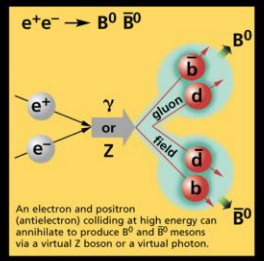
Mesons $q\bar{q}$
Mesons are bosonic hadrons.
There are about 140 types of mesons.

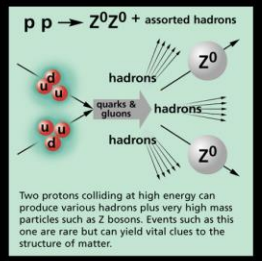
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or − charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures
These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.







The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

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American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

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Spin = 0

h^0 Higgs	~125	0

HADRÕES

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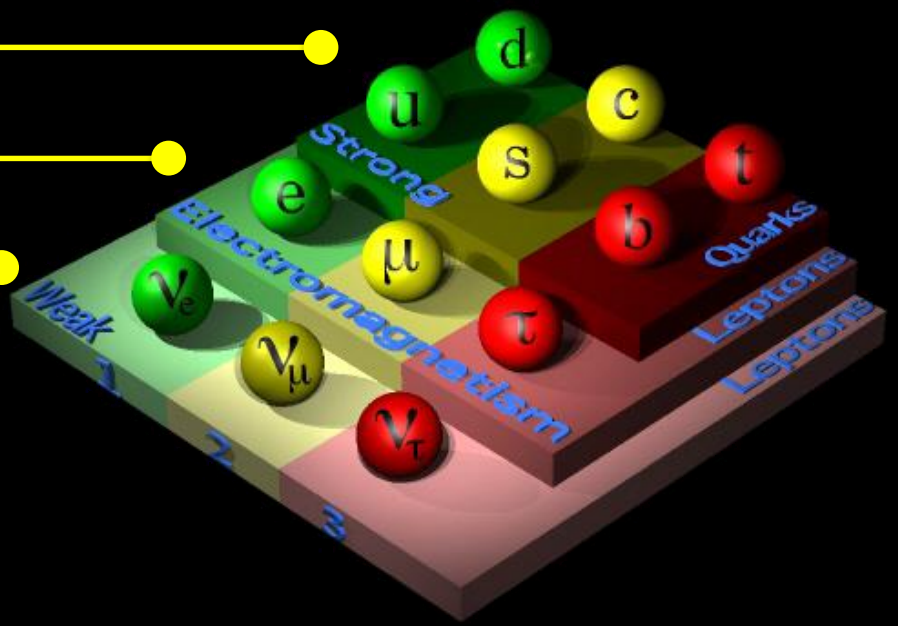
Força Forte (g)

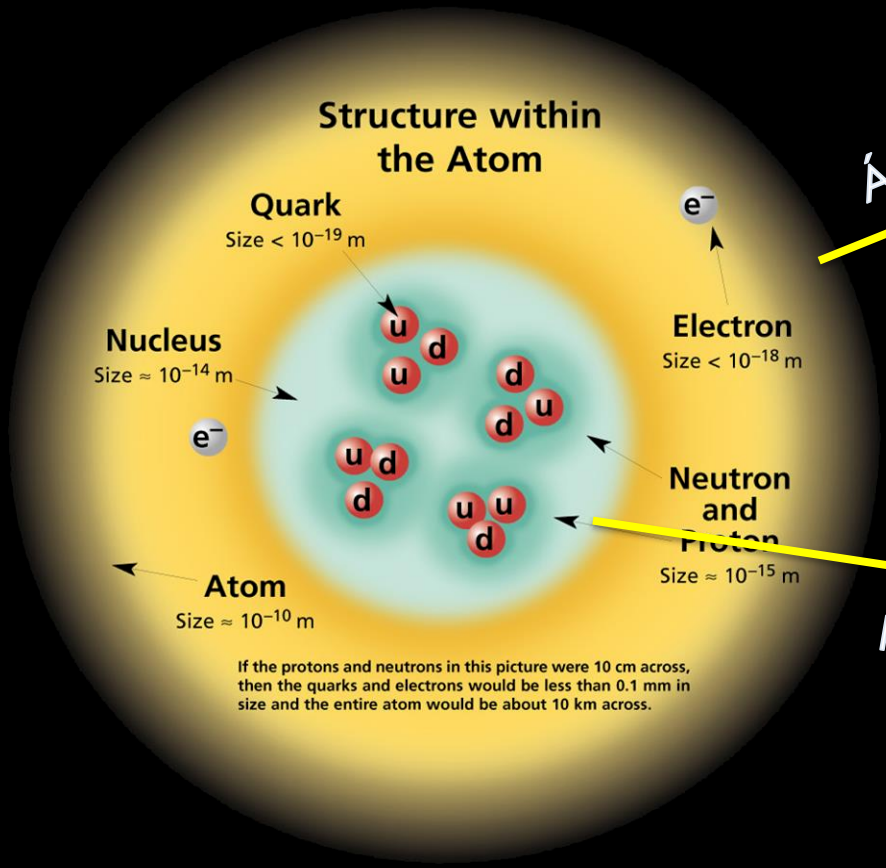
Força Electromagnética (γ)

Força fraca (W^+, W^-, Z^0)



W^+, W^- - Correntes carregadas

γ, Z^0 - Correntes neutras



Átomo

Núcleo

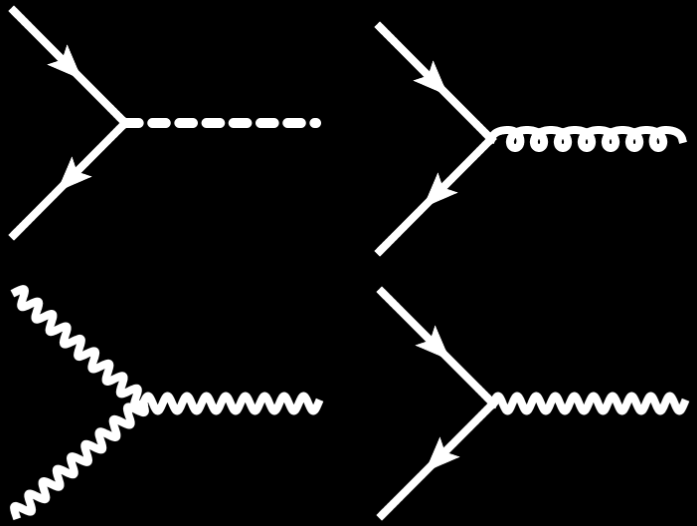

Fermiões e anti-fermiões (leptões e quarks)


Bosões de gauge ($W^{\pm}$, Z^0, γ)

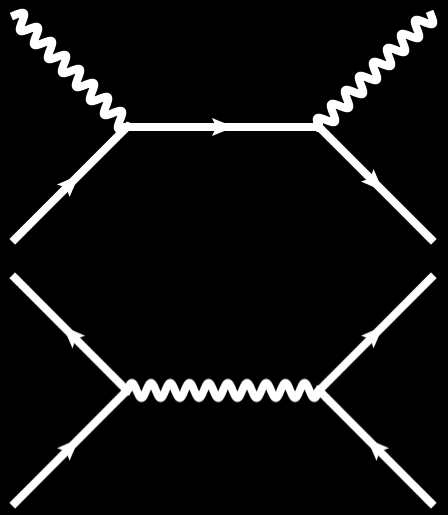

Partículas escalares (h^0)


Gluões (g)

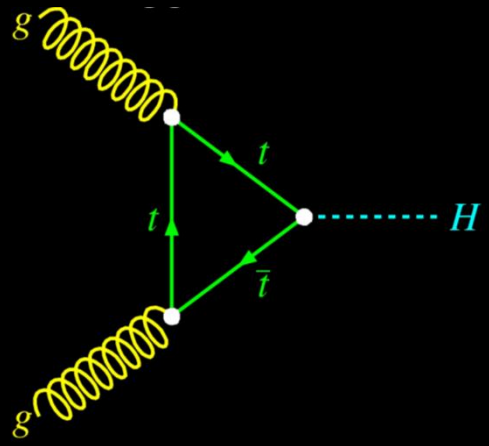
Exemplos de acoplamentos

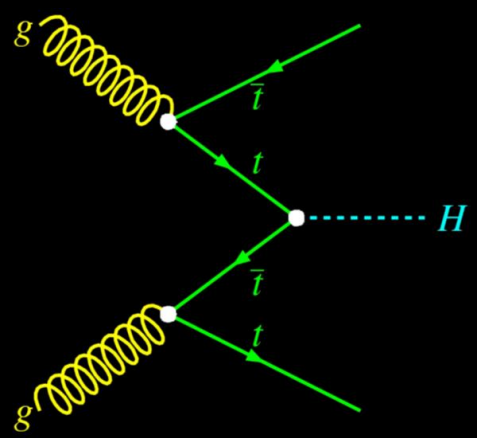


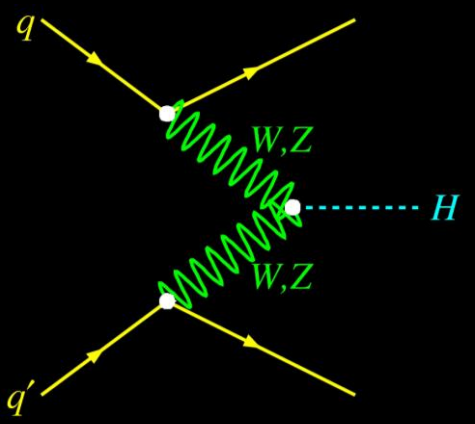
Exemplos de processos

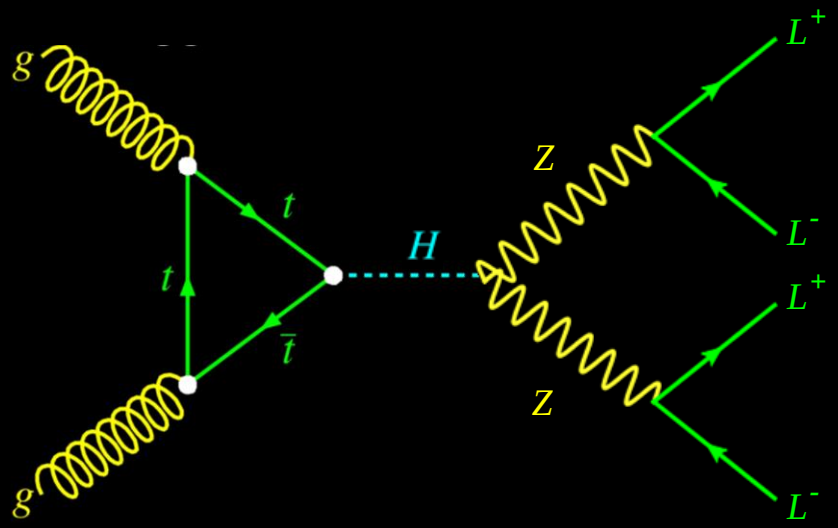


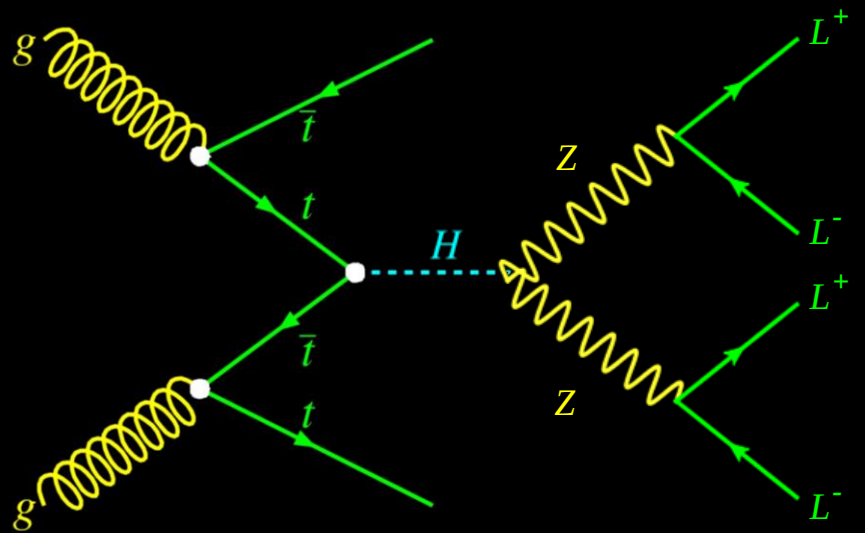
Mais exemplos...

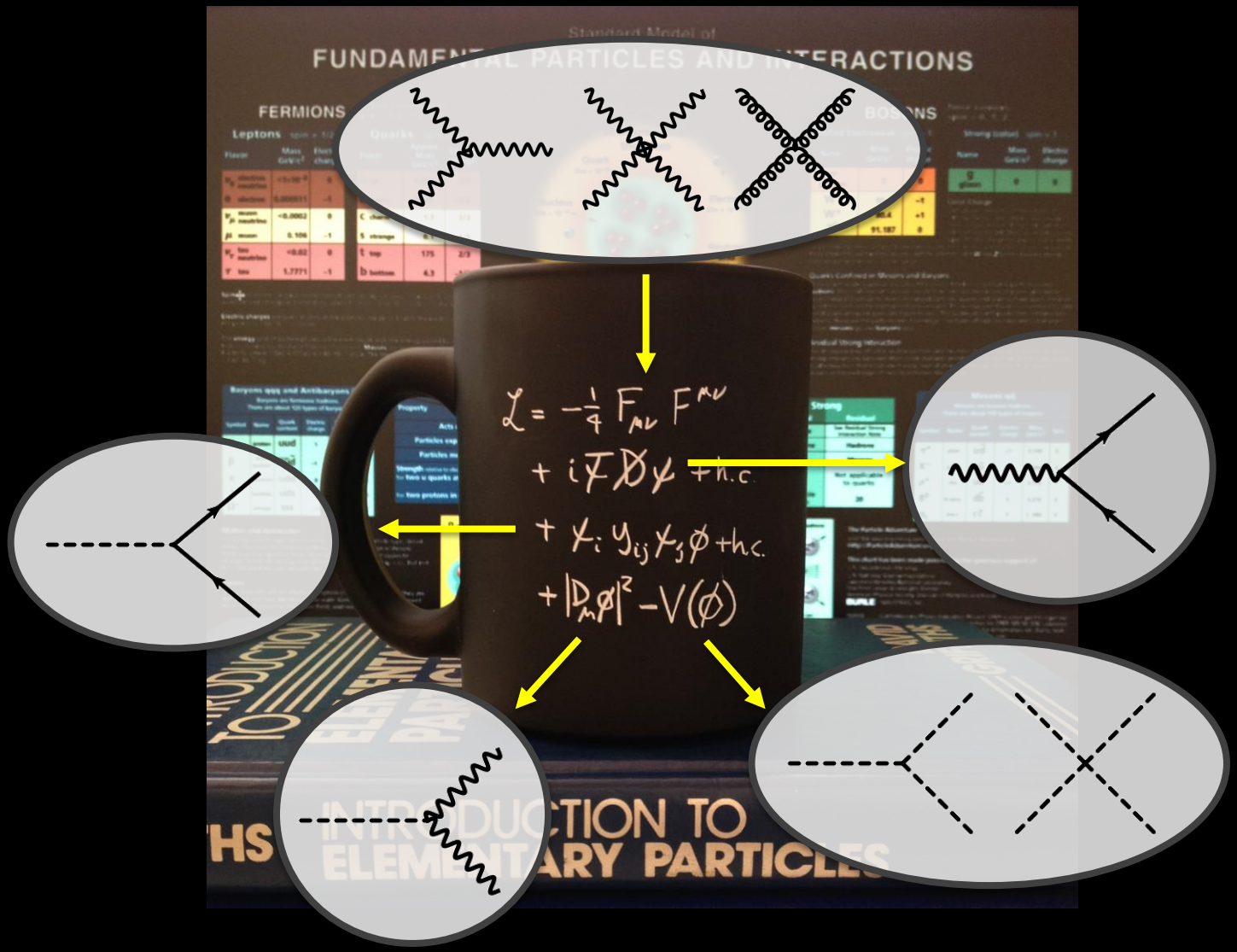


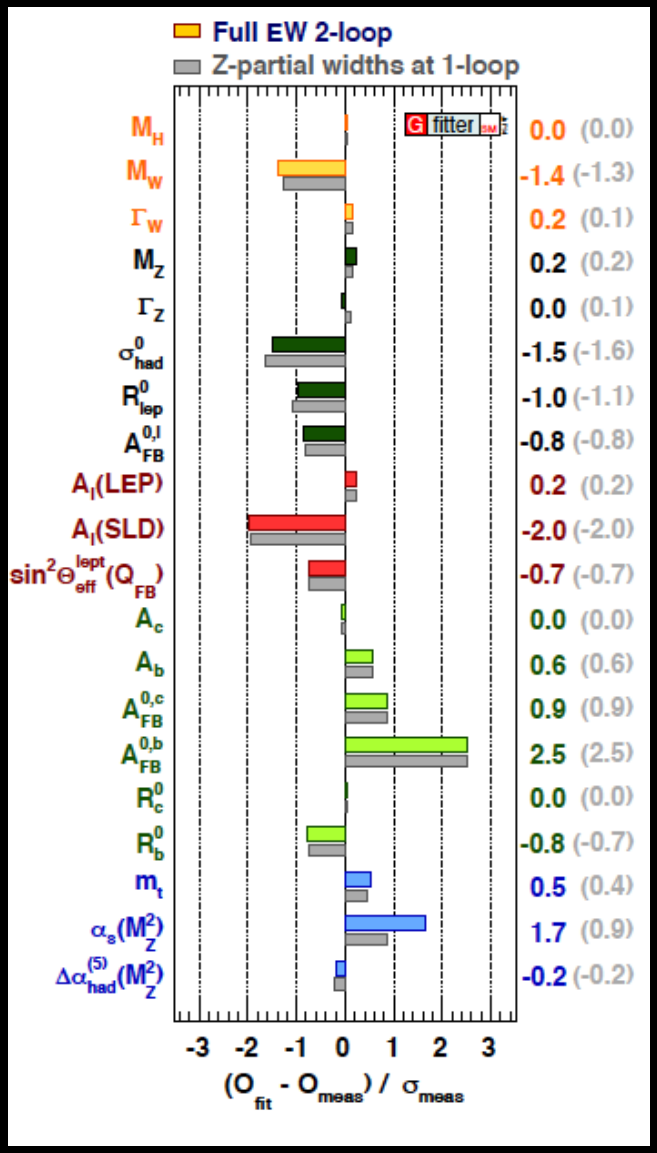









FERMIONS
Leptons
$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$+ i \not{D} \psi + h.c.$
$+ Y_i y_{ij} Y_j \phi + h.c.$
$+ |D_\mu \phi|^2 - V(\phi)$
INTRODUCTION TO
ELEMENTARY PARTICLES



O MODELO PADRÃO ESTÁ DE ACORDO COM (QUASE TODOS) OS RESULTADOS EXPERIMENTAIS A

$\sim 2.5\sigma$