

Looking for Higgs Boson beauty thanks to Machine Learning techniques

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Welcome to the zoology of particles

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As a natural science, the particle physics likes to **classify** (and therefore give funny names) to its **constituents**, hence creating a new **zoology**:

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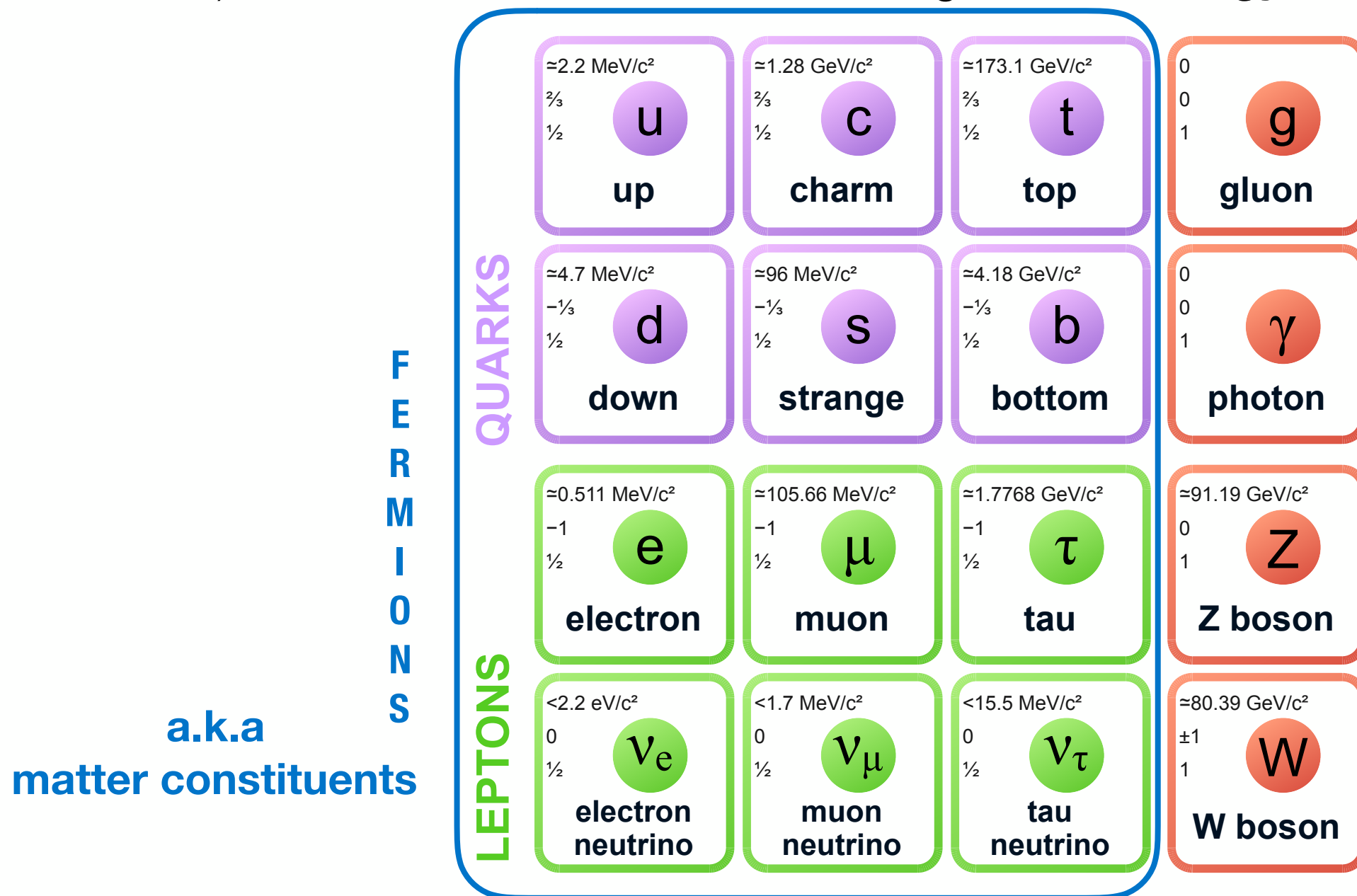
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QUARKS	$\approx 2.2 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.28 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 173.1 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluon
	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 96 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.18 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ photon
	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e electron	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muon	$\approx 1.7768 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	$\approx 91.19 \text{ GeV}/c^2$ 0 1 Z Z boson
	$< 2.2 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e electron neutrino	$< 1.7 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muon neutrino	$< 15.5 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutrino	$\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W boson
LEPTONS				

Contrary to biology families are defined by the nature of the objects and their functions.

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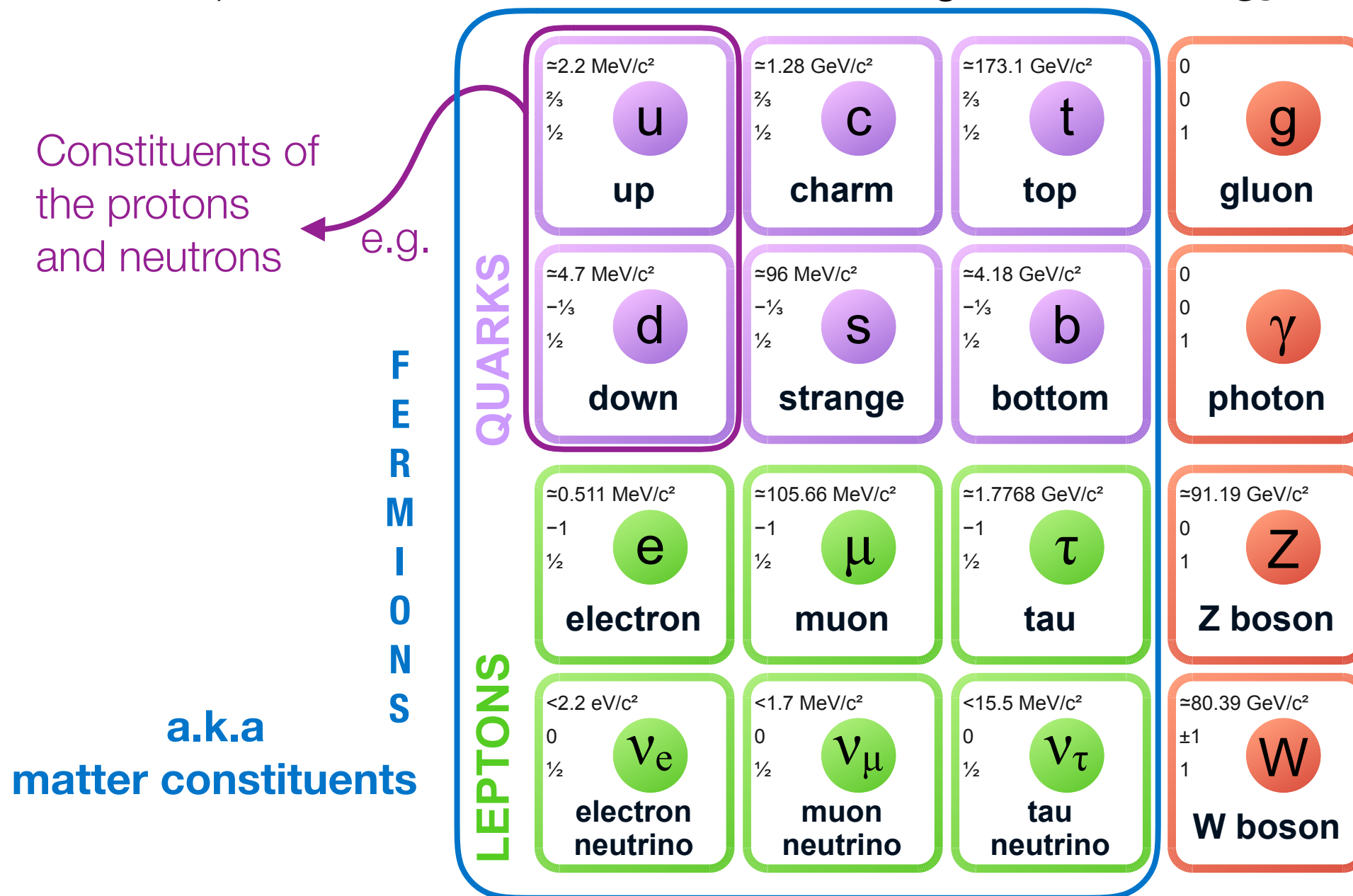
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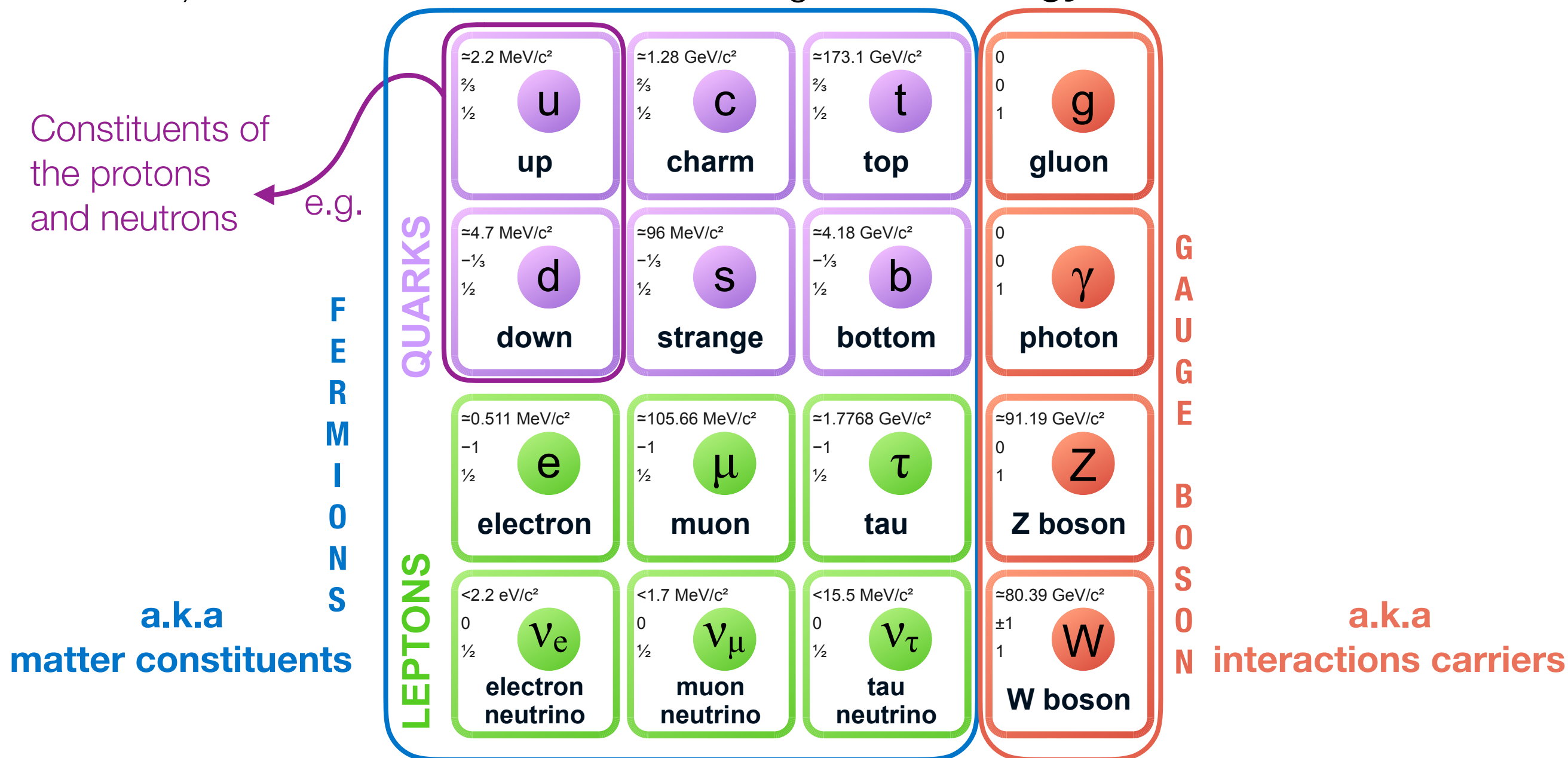
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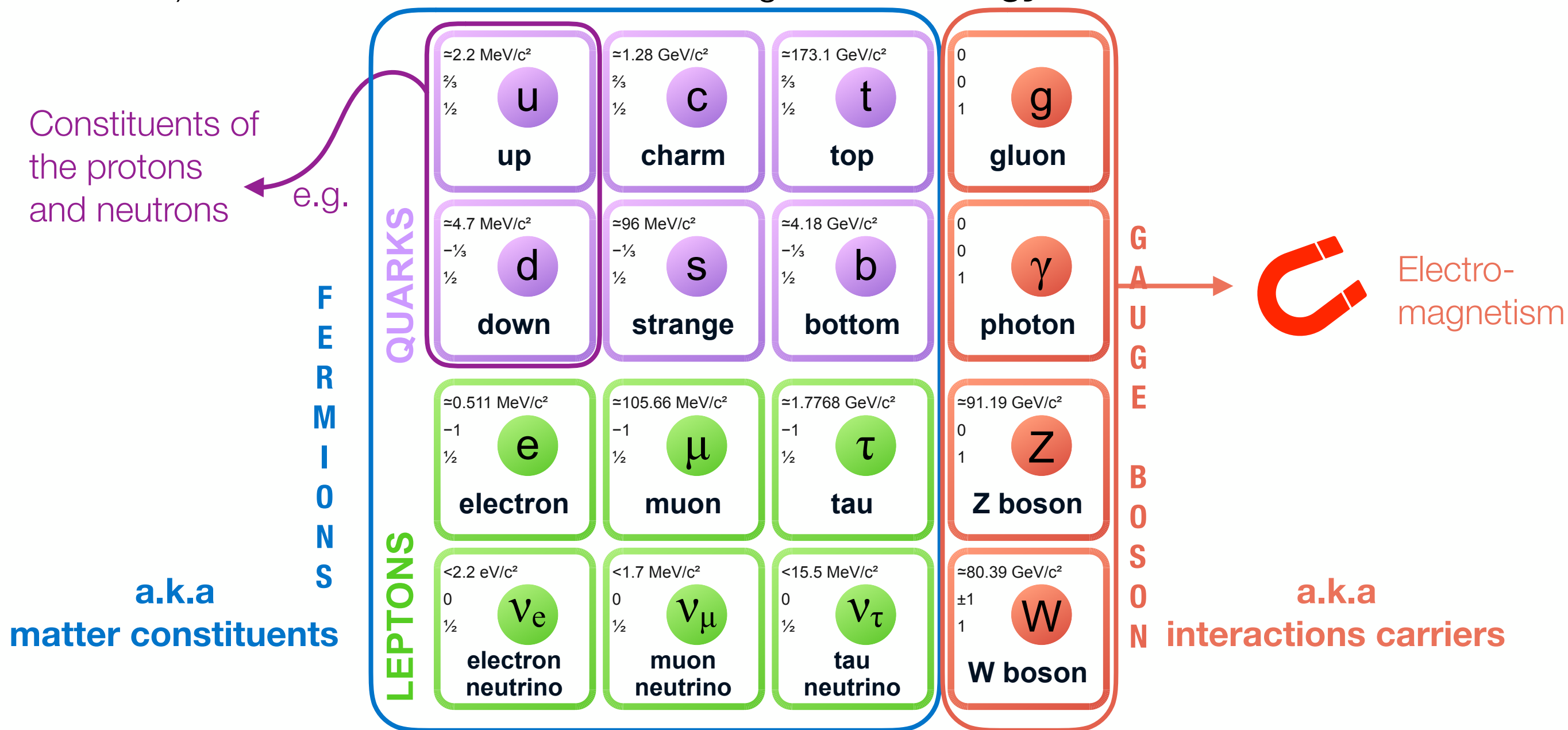
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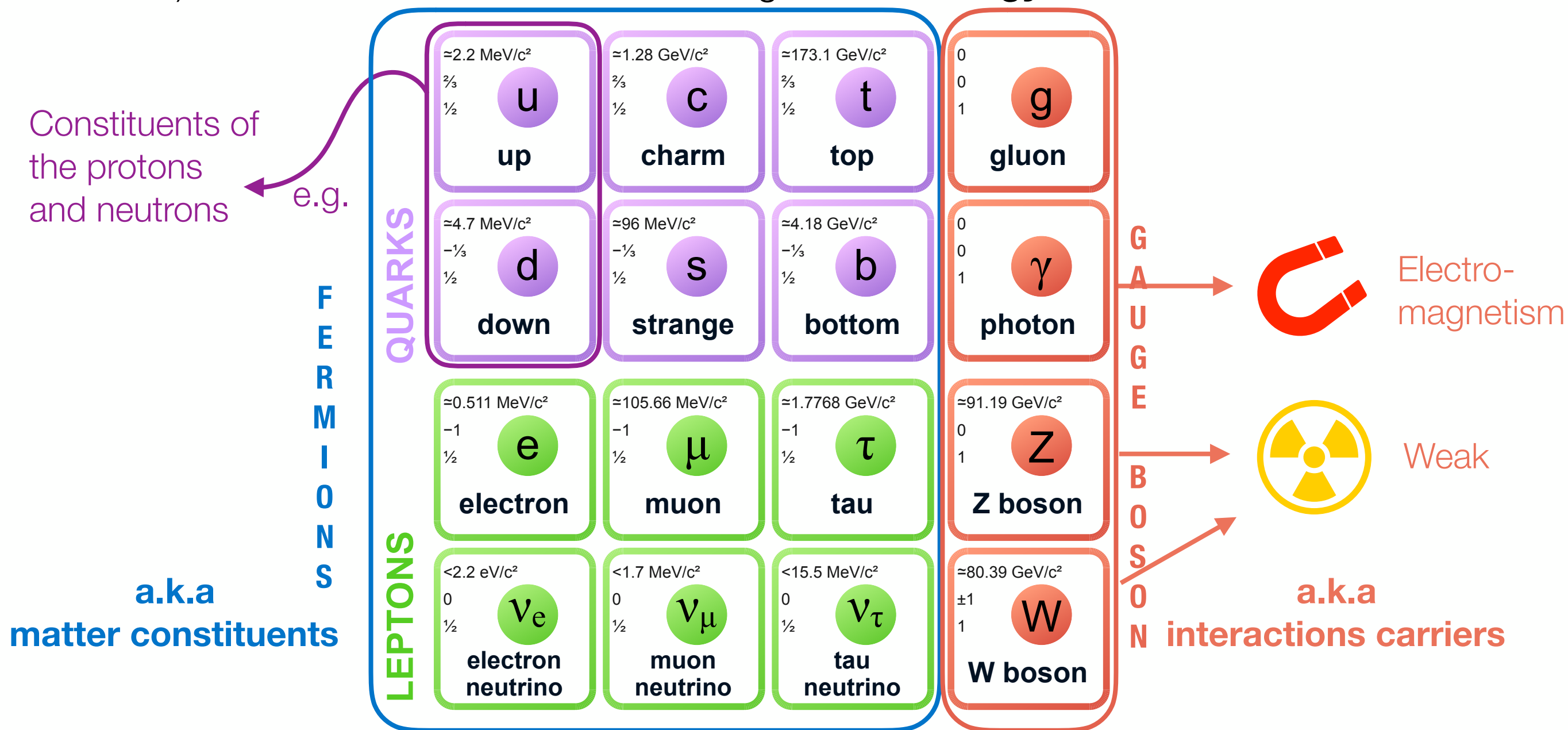
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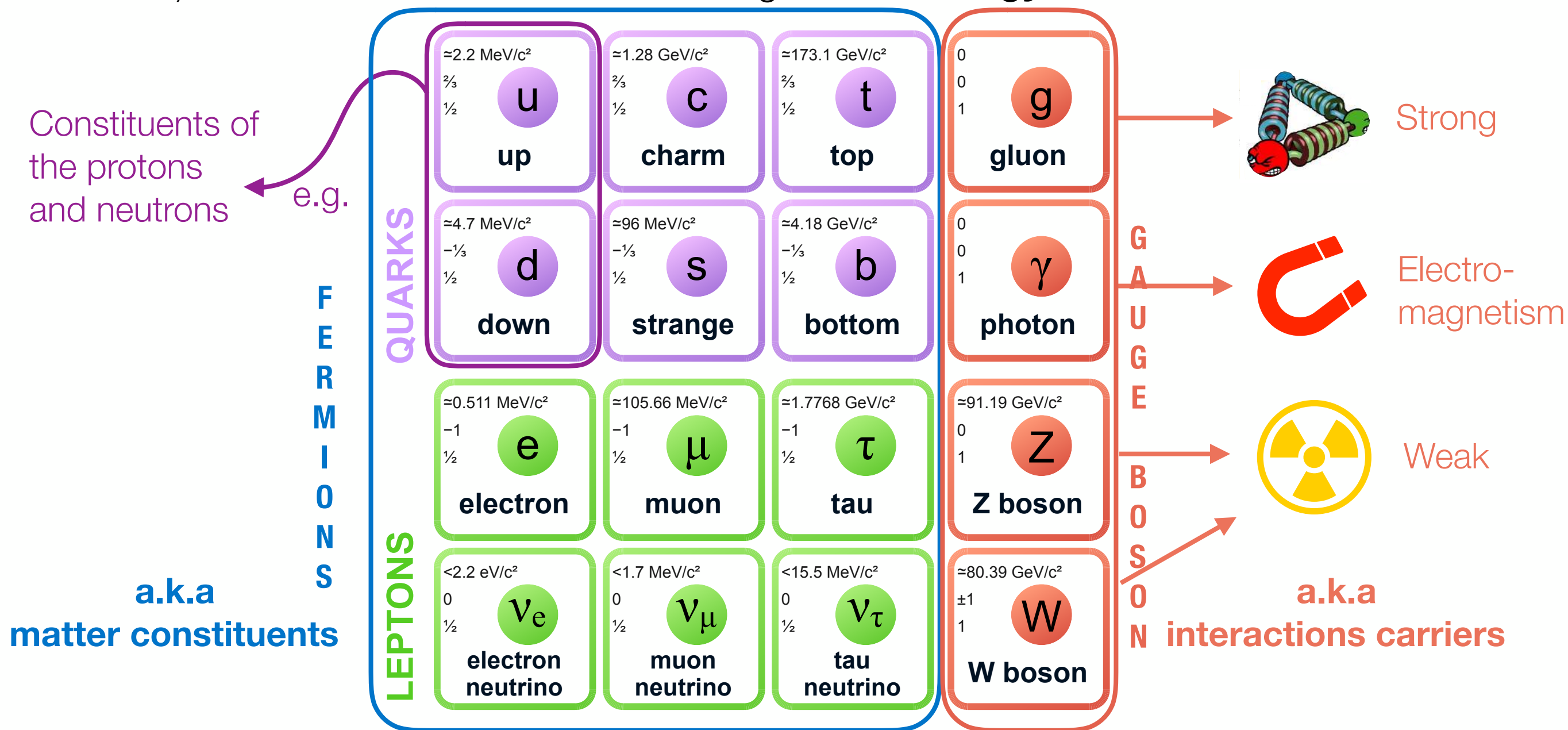
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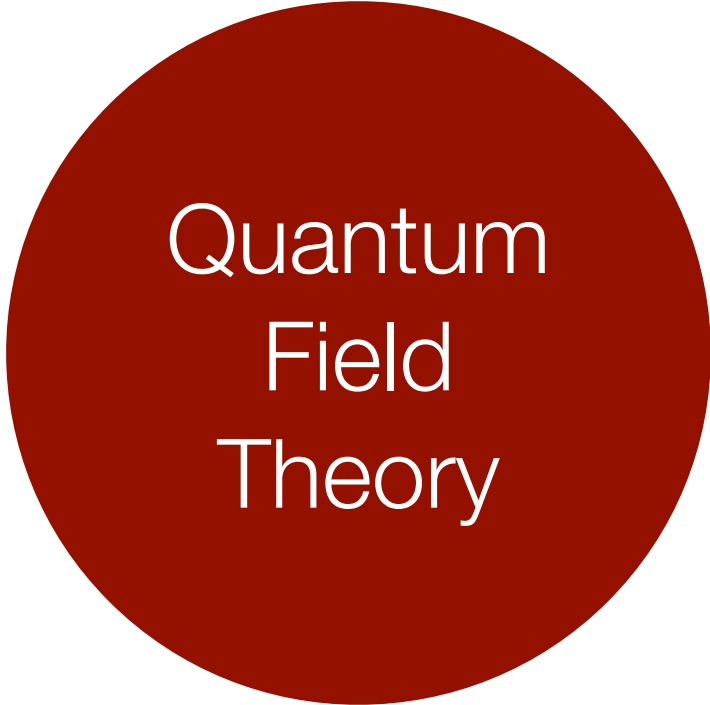


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Which theory to describe this?

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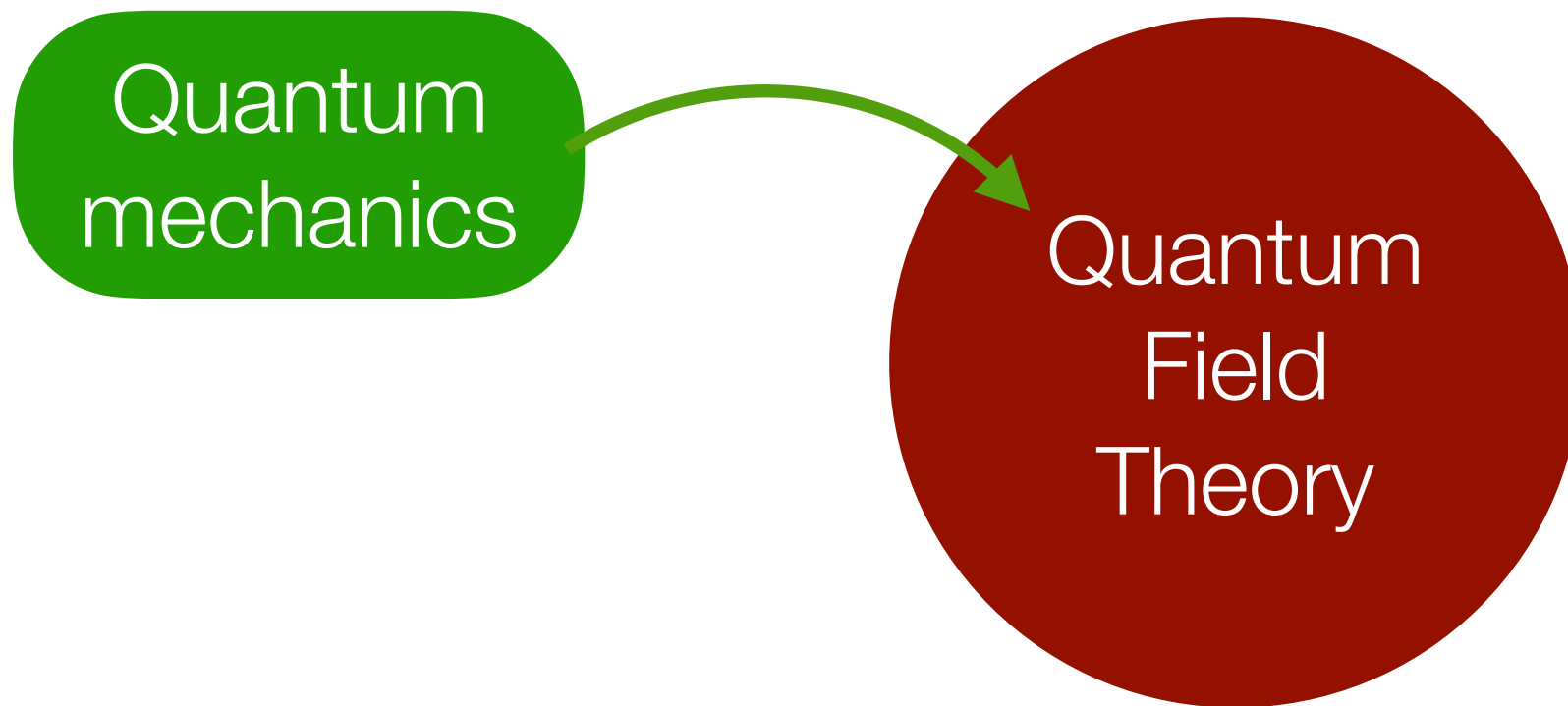
The theoretical background behind the zoology is composed of a few ingredients:



Quantum
Field
Theory

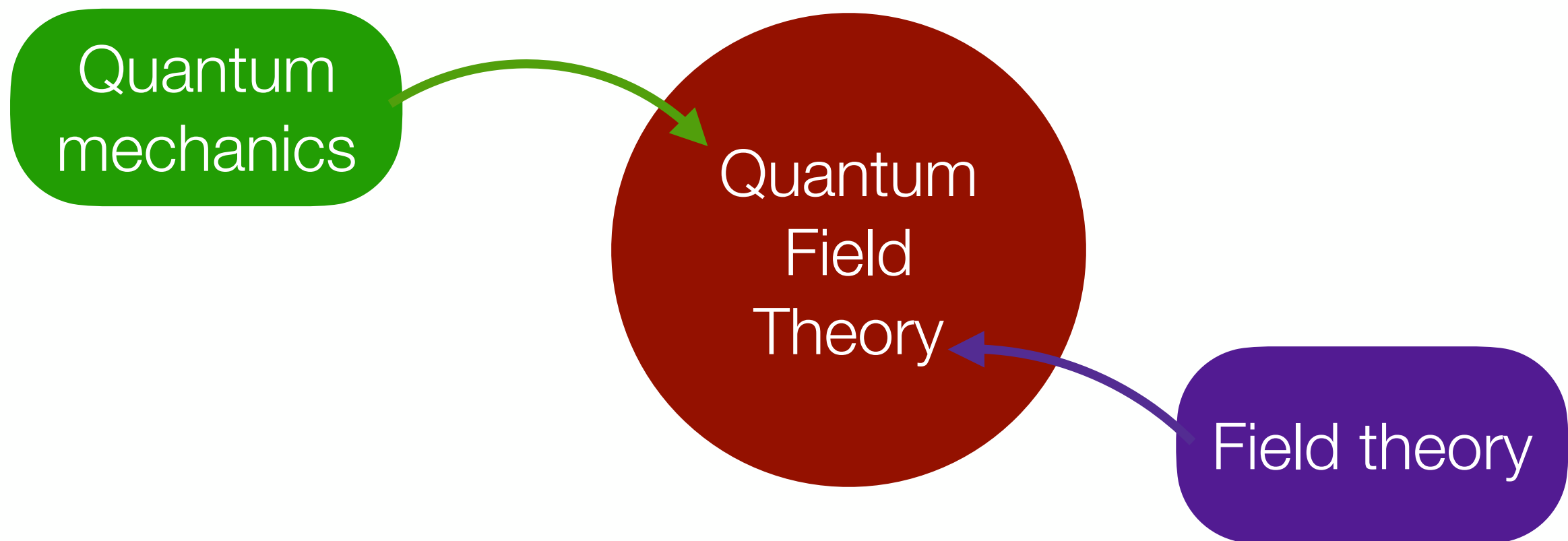
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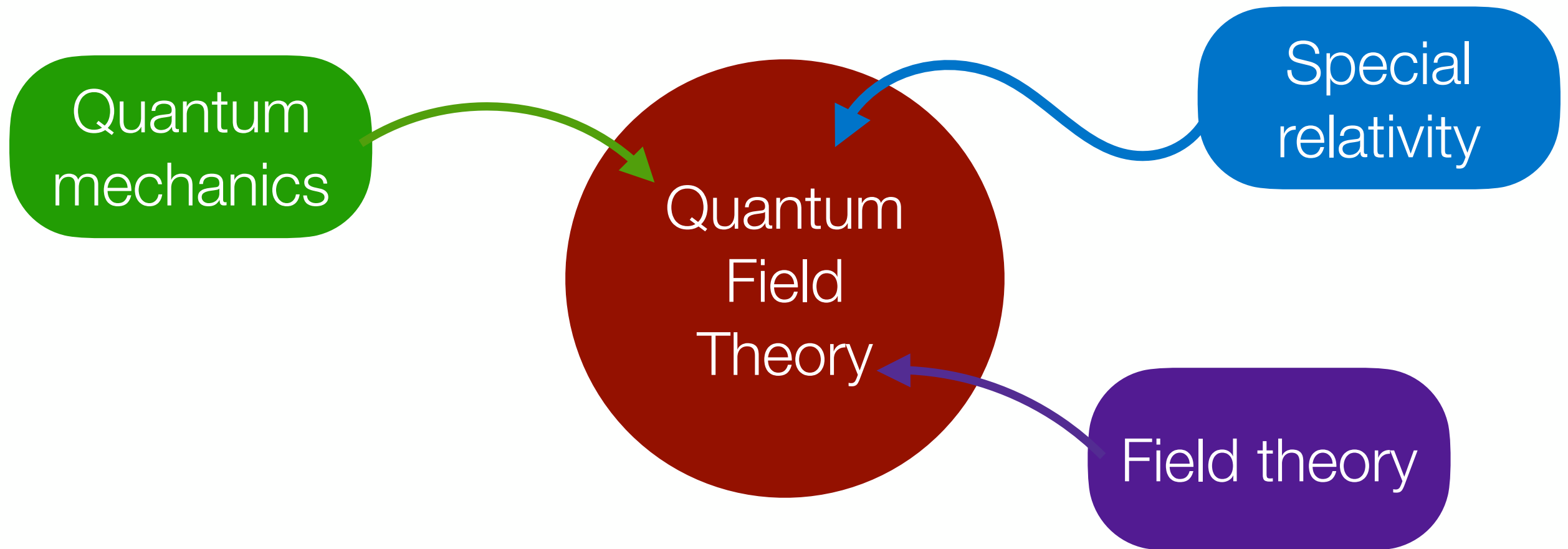
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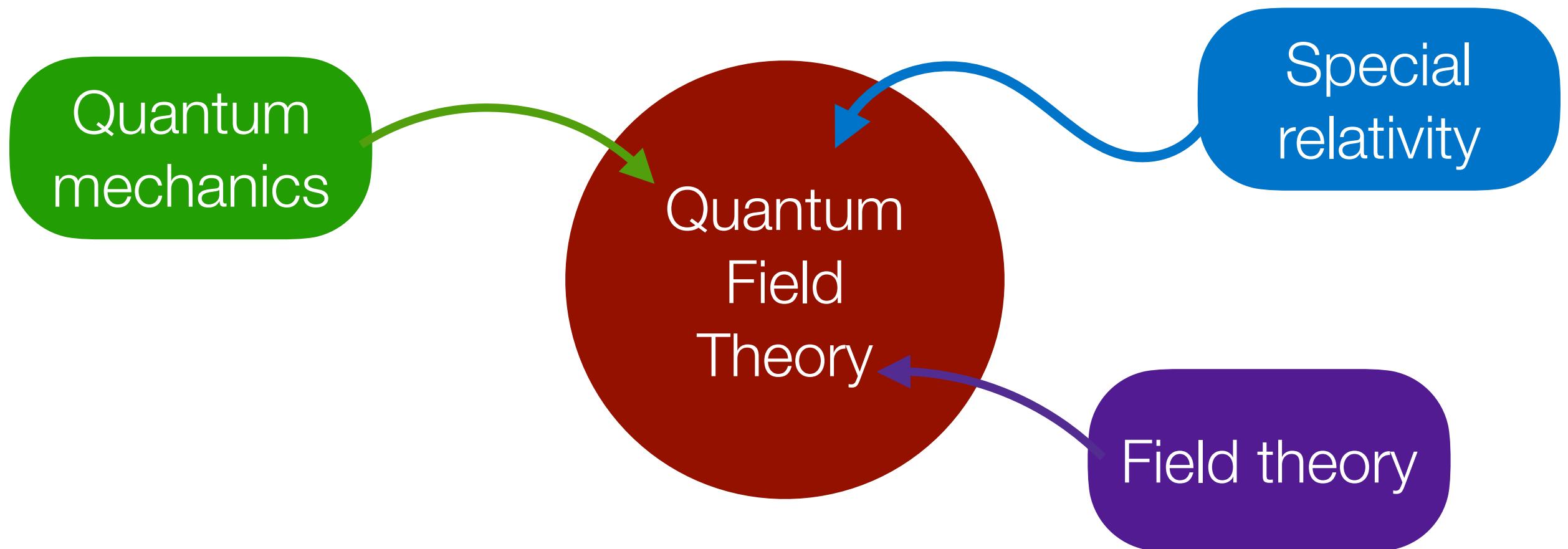
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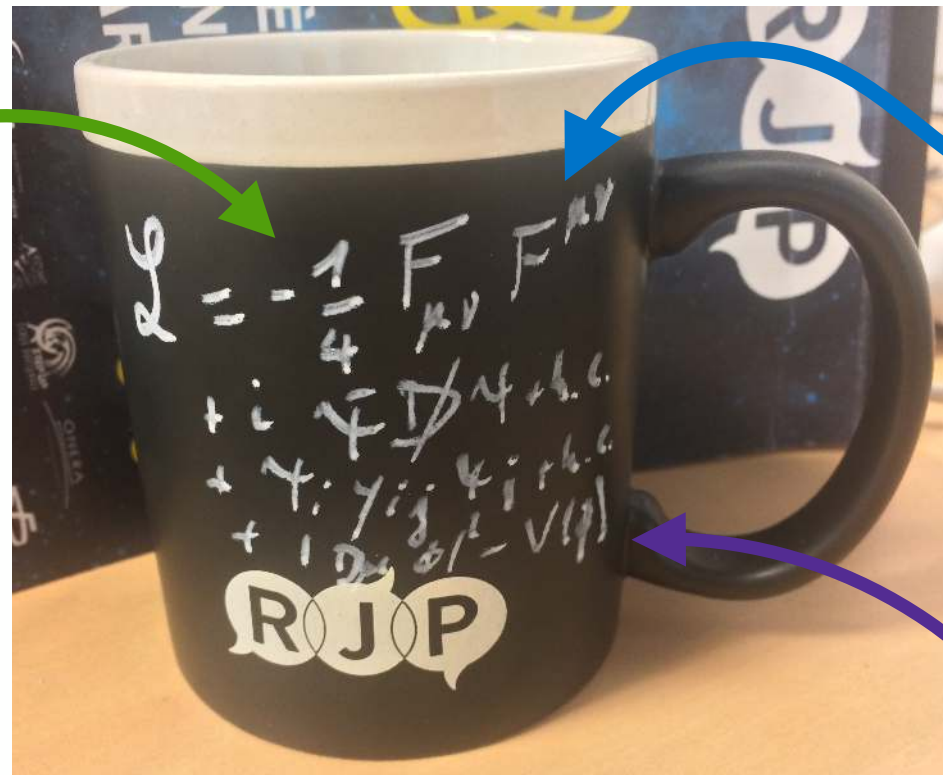


All that is condensed in a **Lagrangian** formalism that contains all the **kinematic properties** of the particles.

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Quantum
mechanics



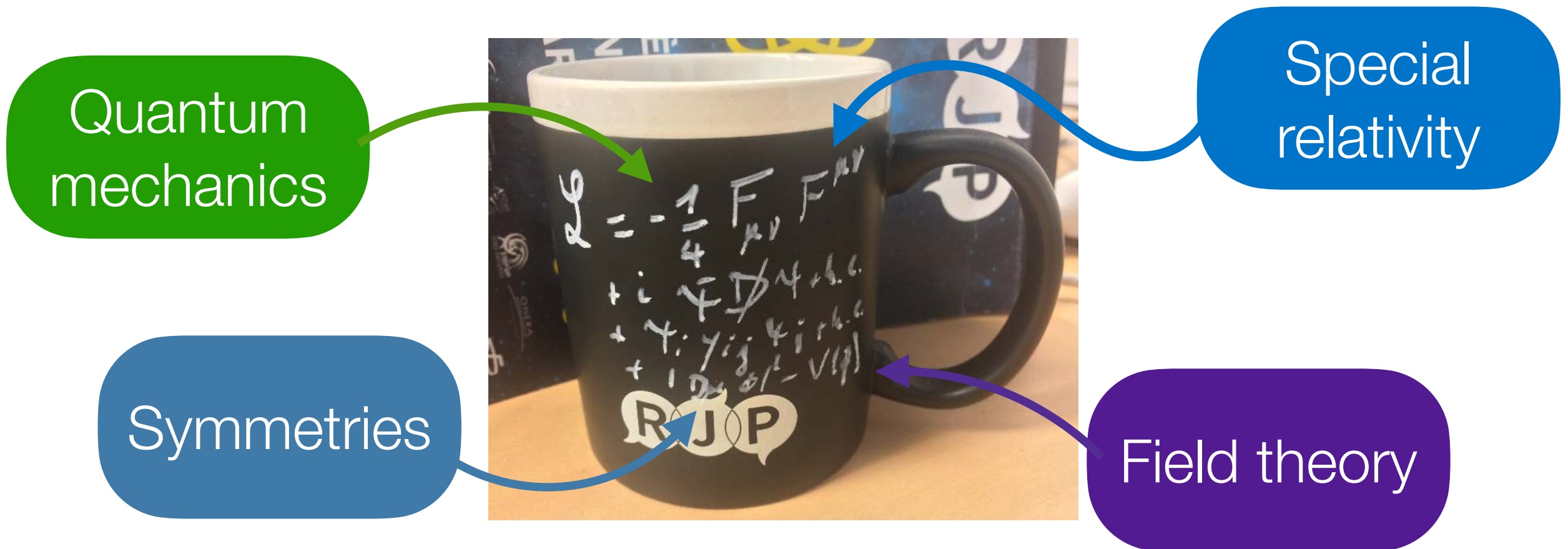
Special
relativity

Field theory

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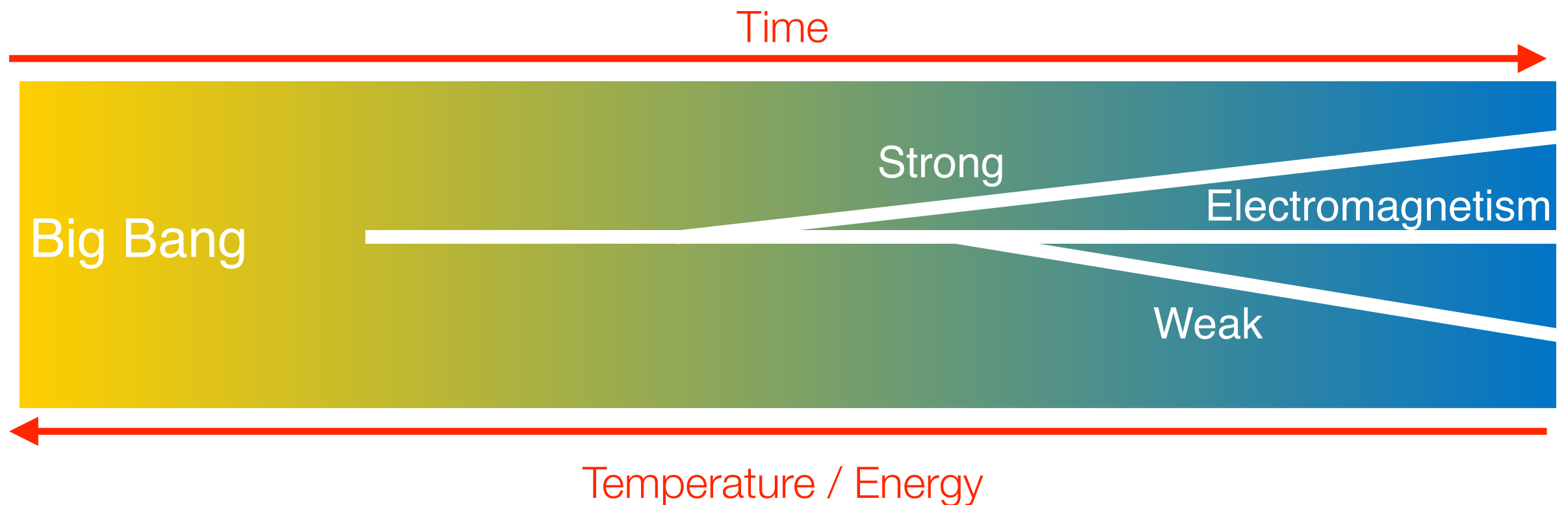


All that is condensed in a **Lagrangian** formalism that contains all the **kinematic properties** of the particles.

All the **interactions** arise from the consideration of **symmetries**. Really all?

Unifying the interactions

If we believe that all **interactions** arise from the **same mechanism**: there is a moment where they were **indistinguishable**.



Then how to explain that the **weak** force **mediators** (W/Z bosons) are **massive** when the **photon** is **massless**?

BELGIQUE

Why do we have massive mediators?
How to explain fermion mass ?

Mass

Electromagnetism

Strong

Weak

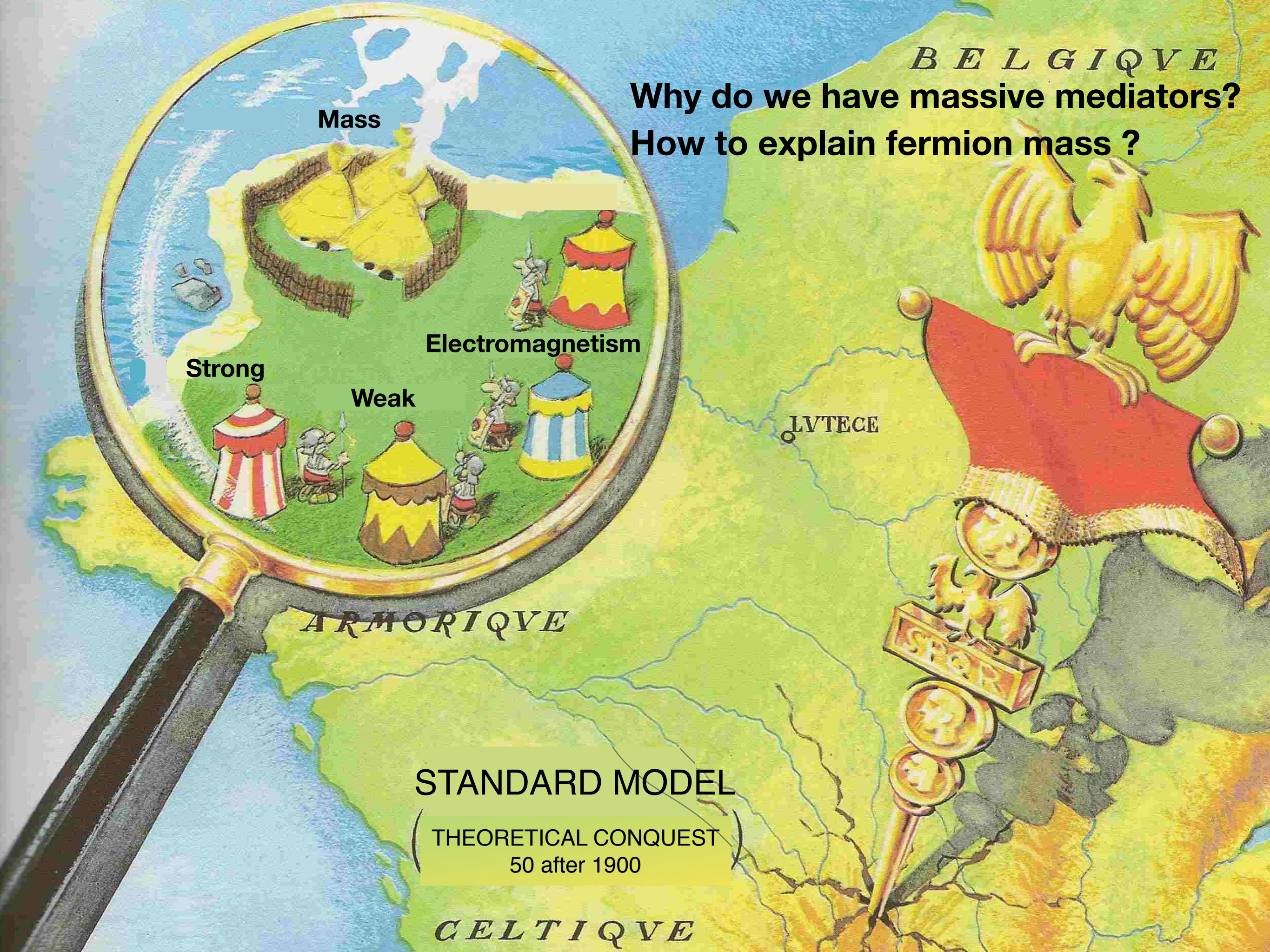
LYTECE

ARMORIQUE

STANDARD MODEL

(THEORETICAL CONQUEST
50 after 1900)

CELTIQUE

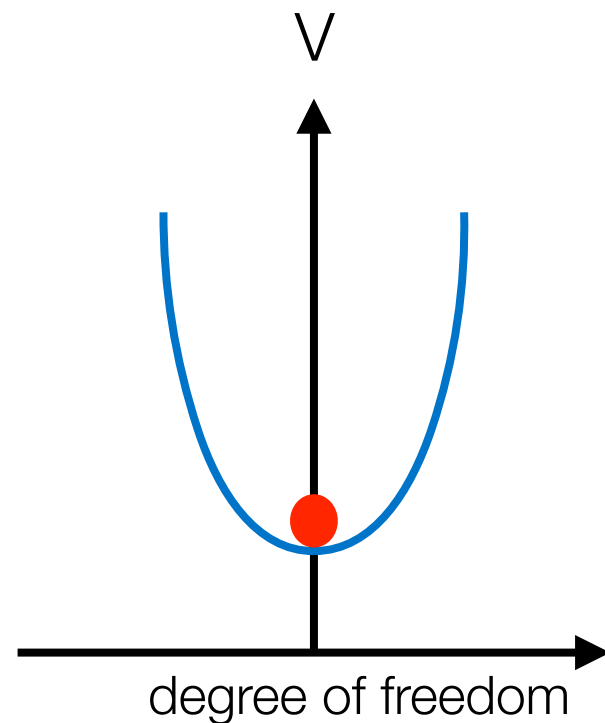


Here comes the Higgs

Inspired by **superconductivity** physics, two groups of physicists imagined that the answer could lie under the concept of **spontaneous symmetry breaking**.

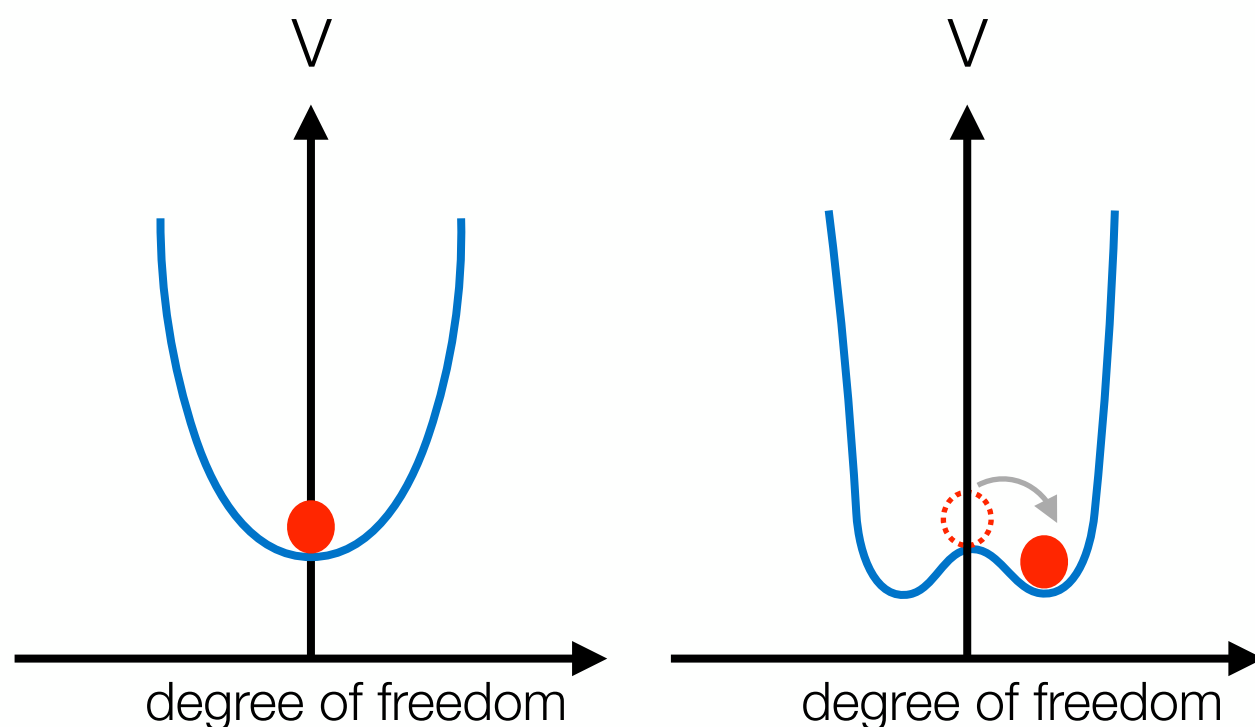
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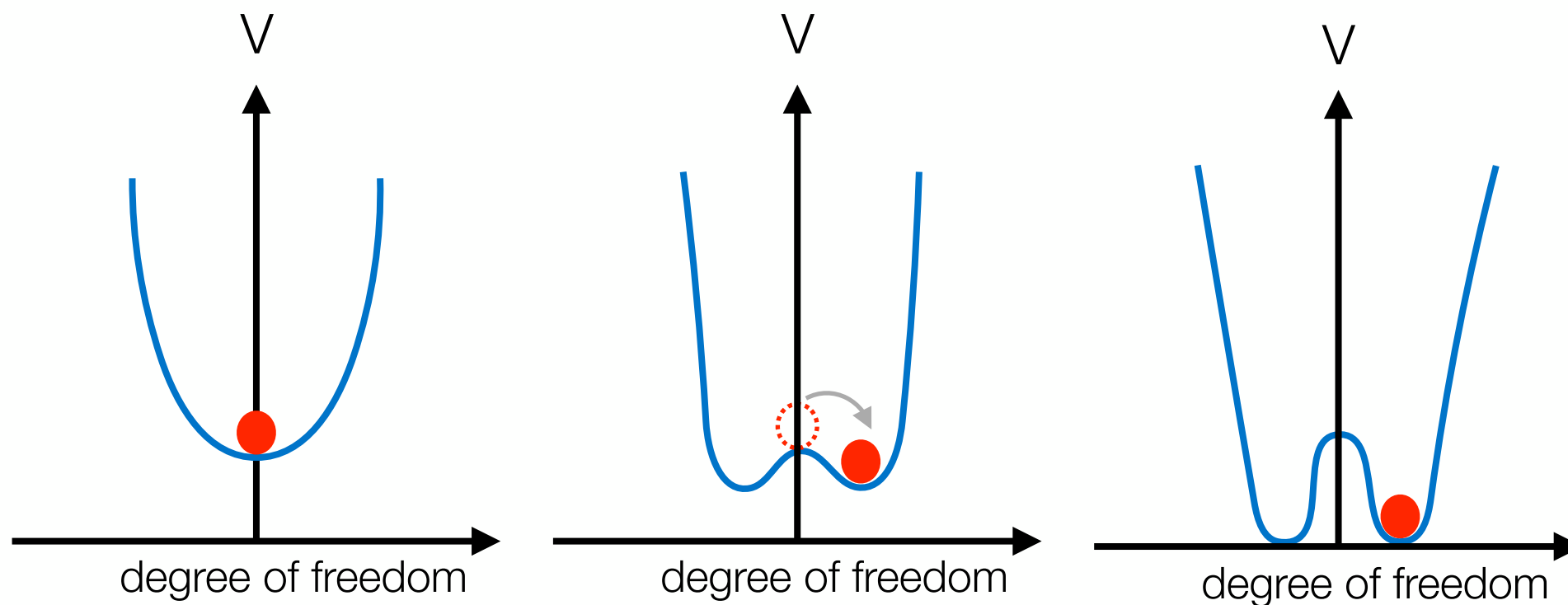
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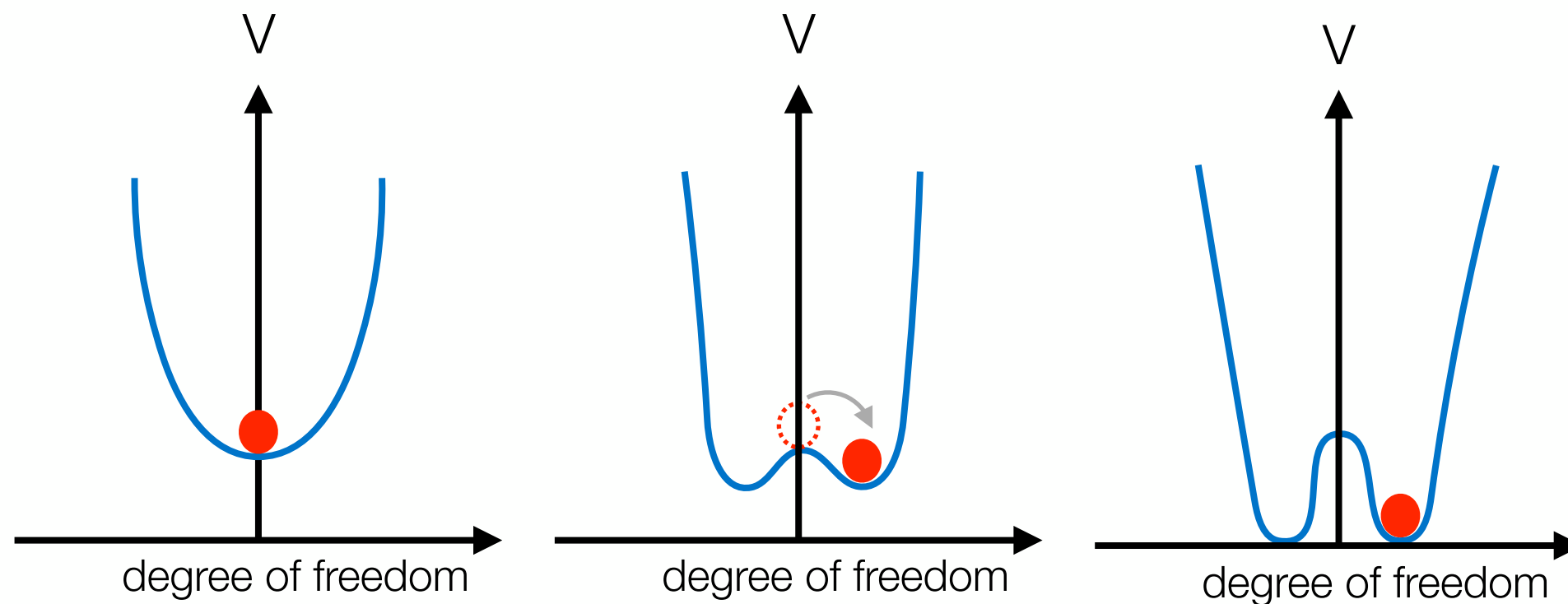
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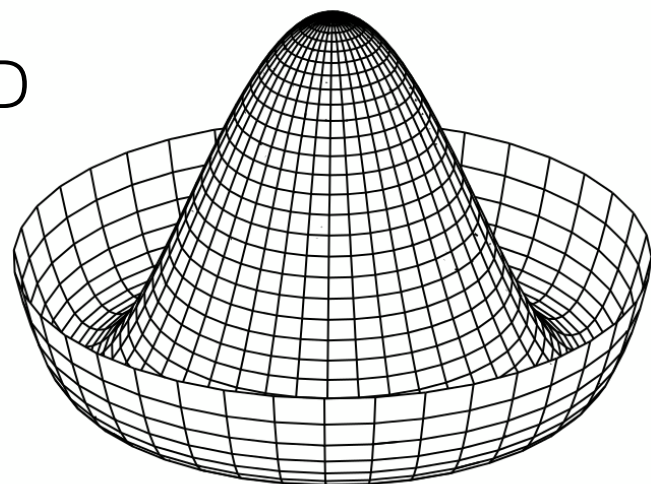


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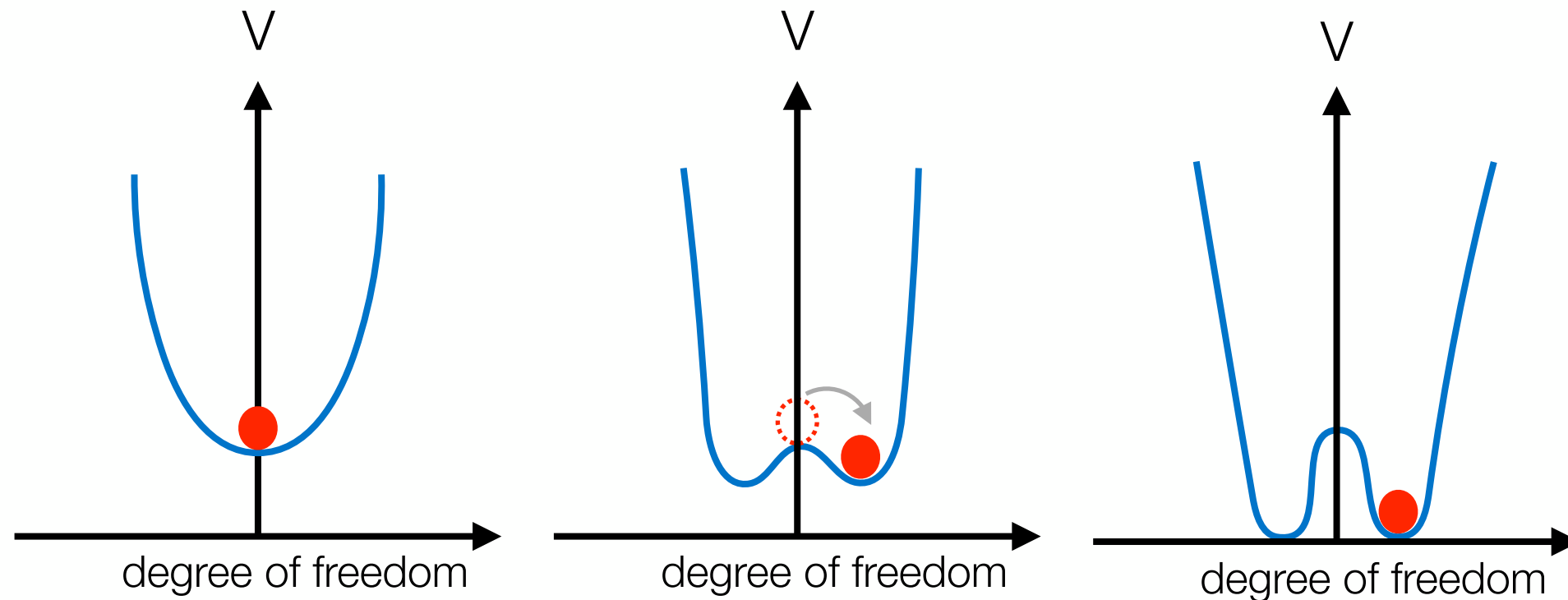


Or in 2D

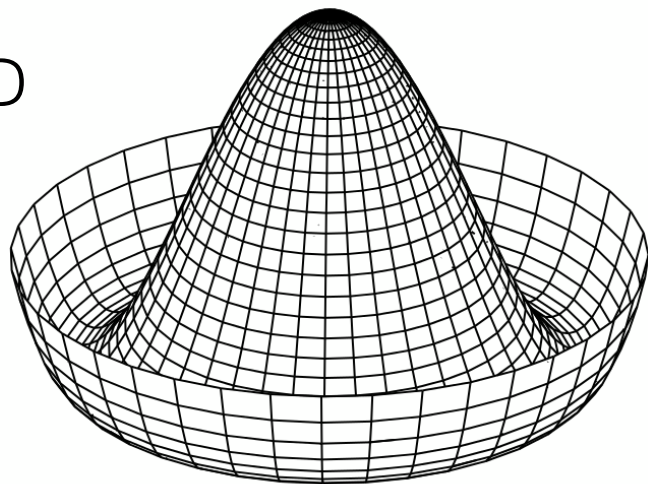


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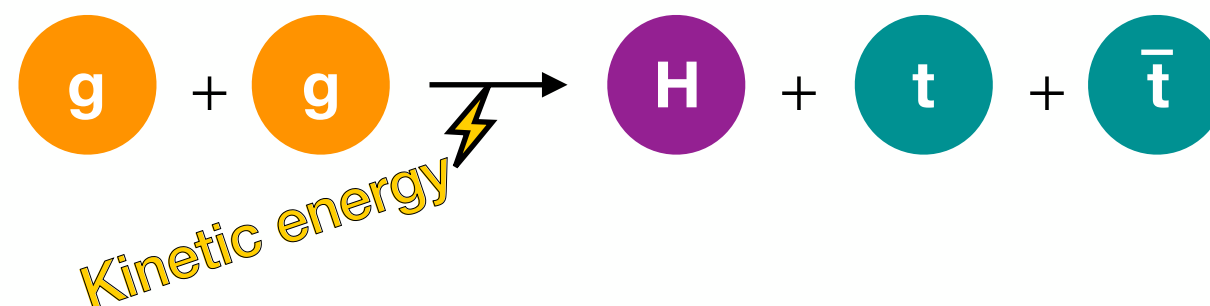
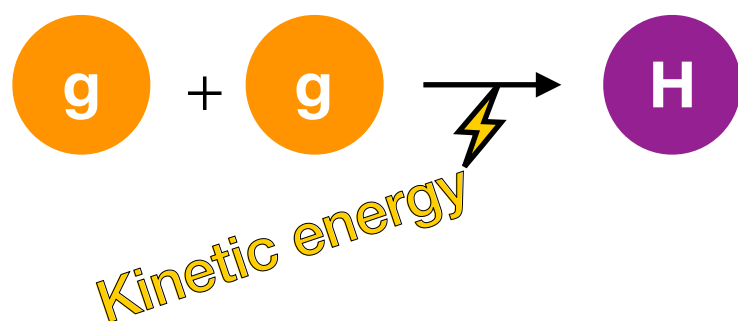
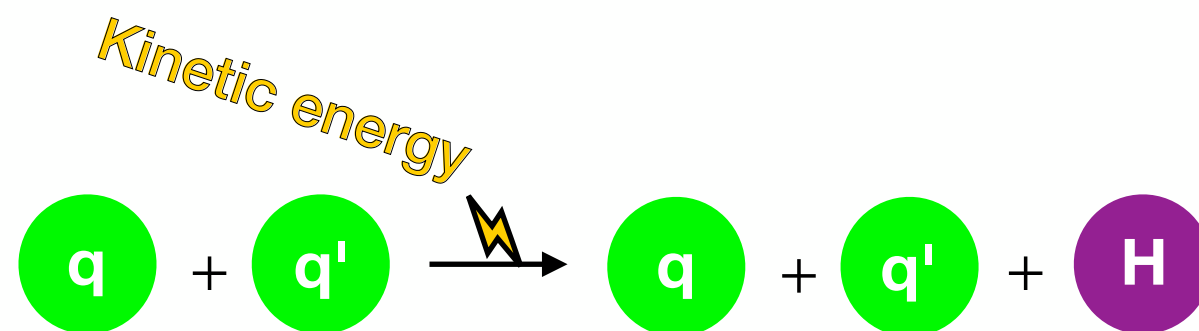
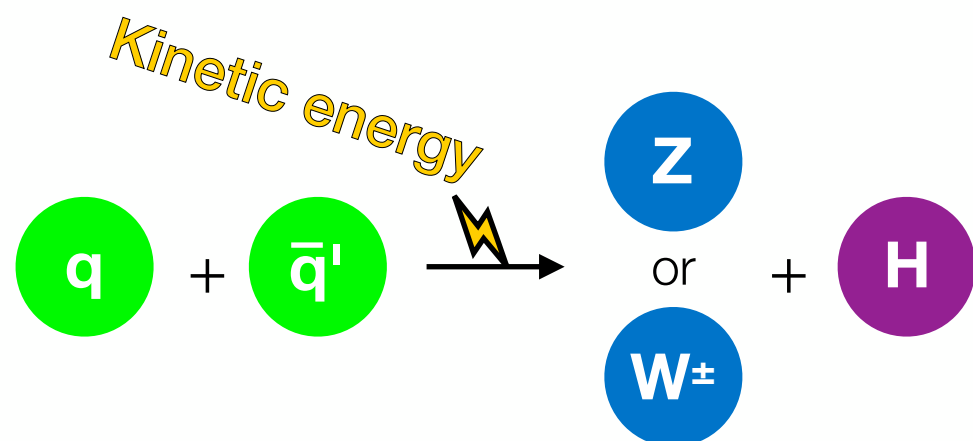


Therefore **some particles** feel a **quadratic potential** (i.e. like a mass term) while **other** can "**move**" freely.

The localised **excitation** of the **field** associated to this potential is the famous **Higgs boson**.

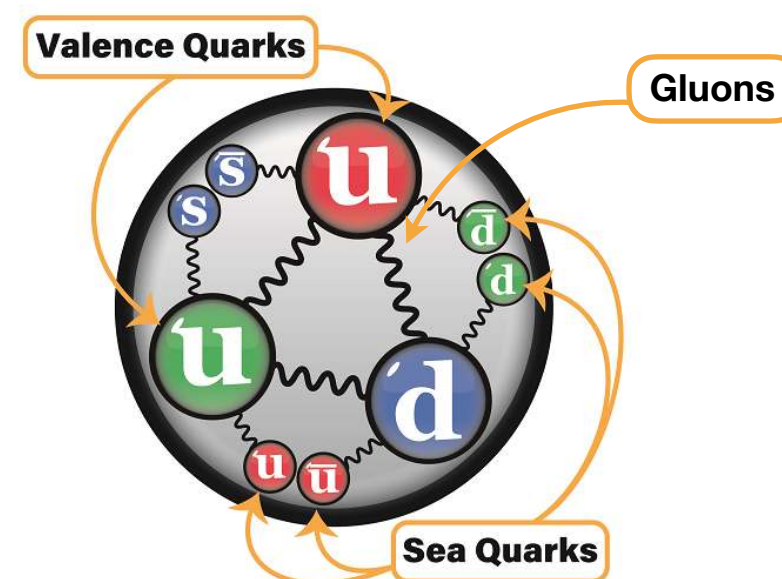
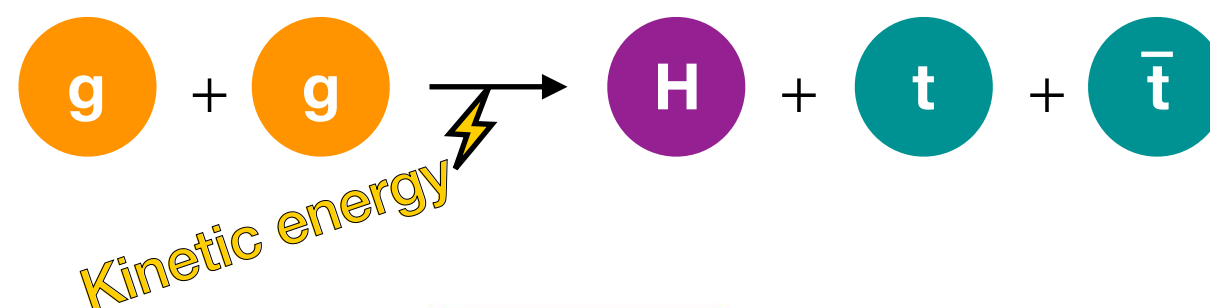
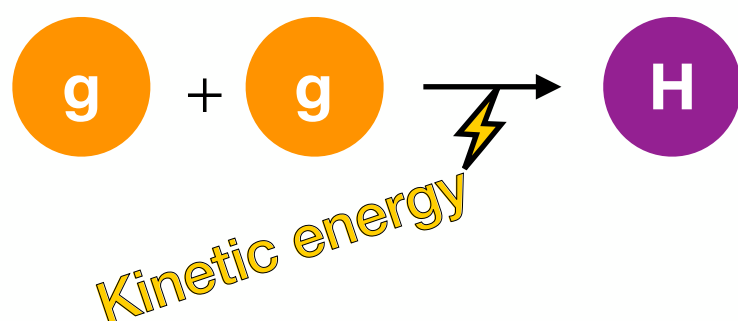
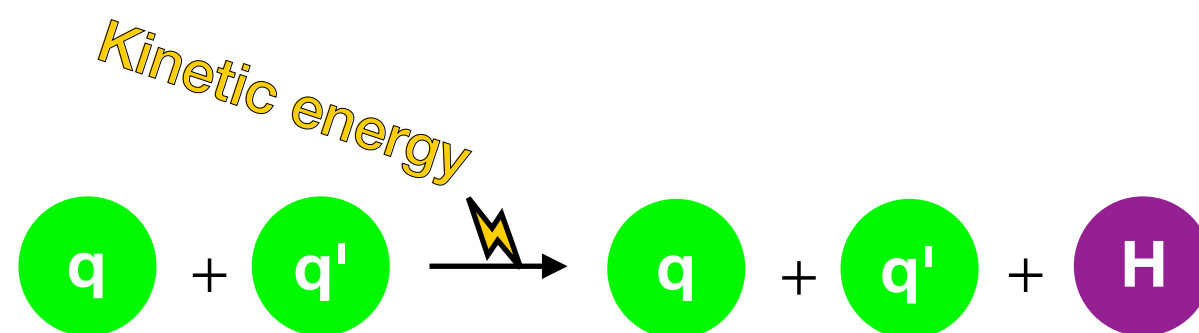
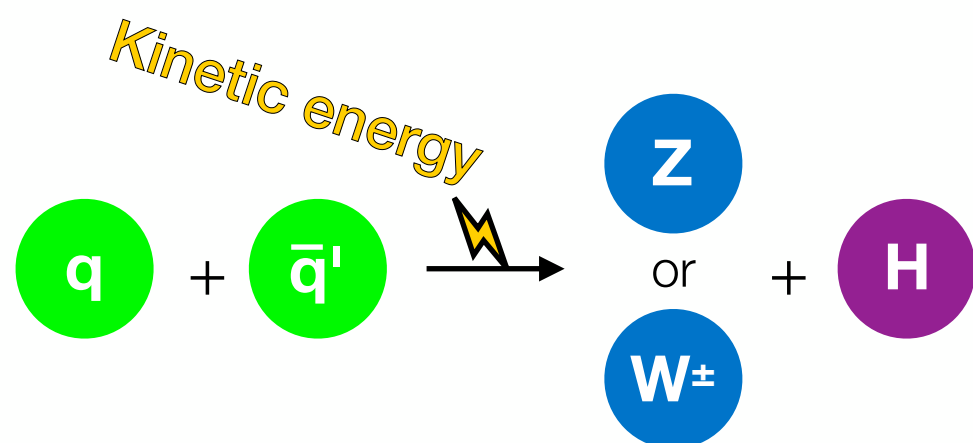
How to look for the Higgs boson

How to create an Higgs boson



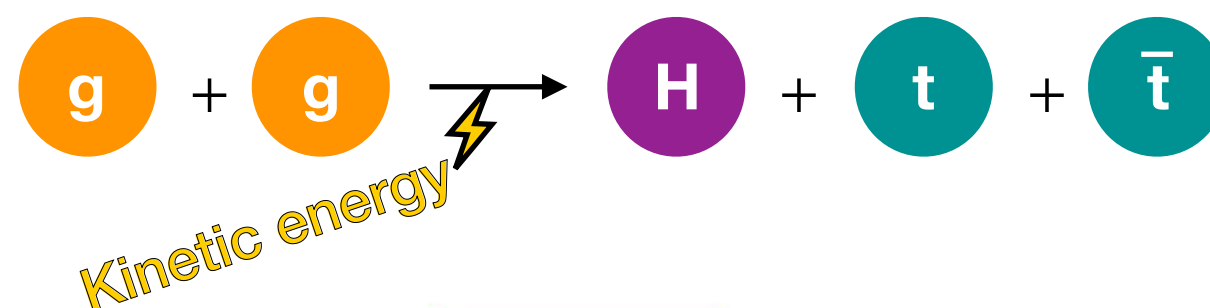
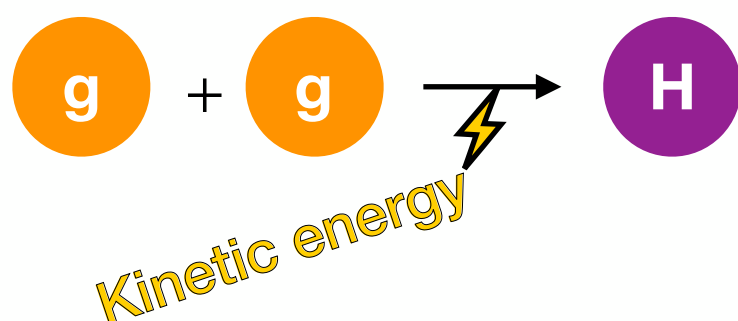
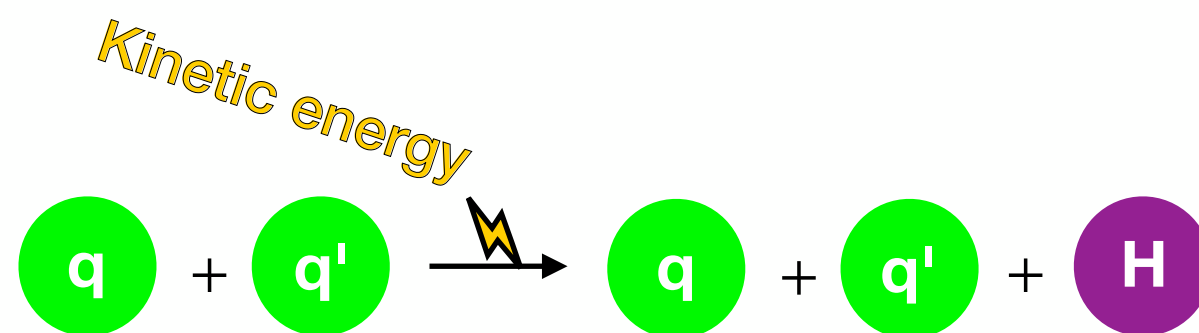
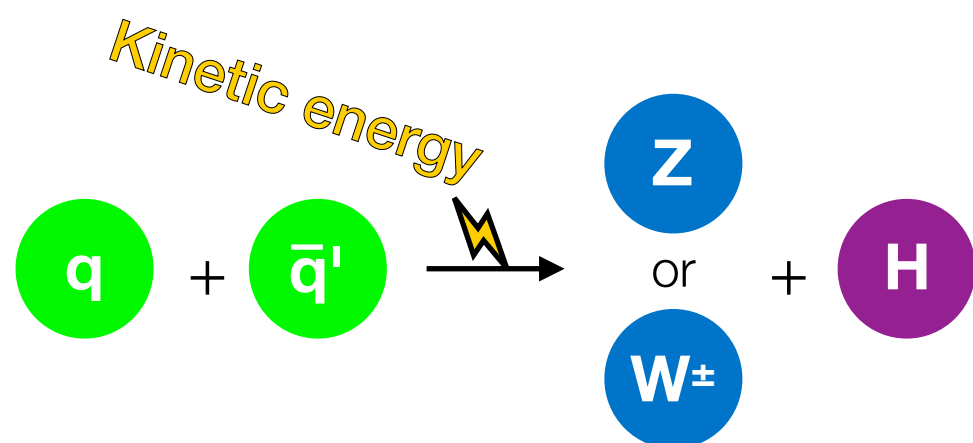
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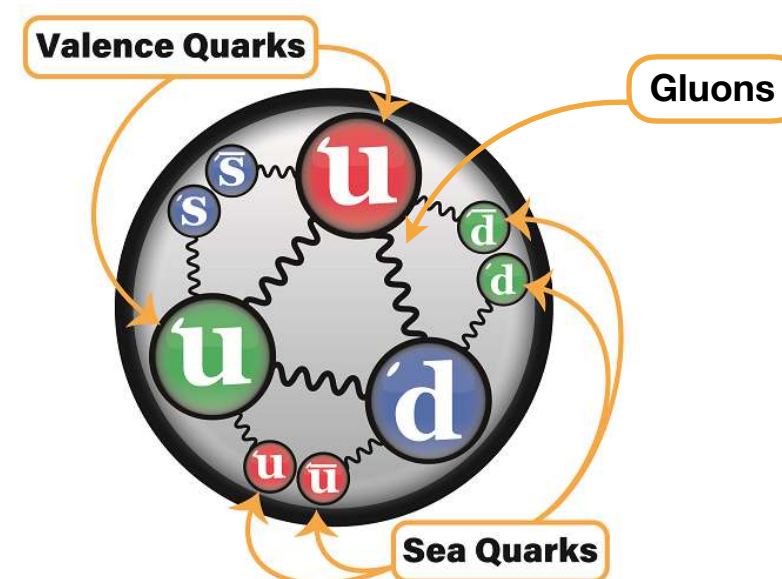


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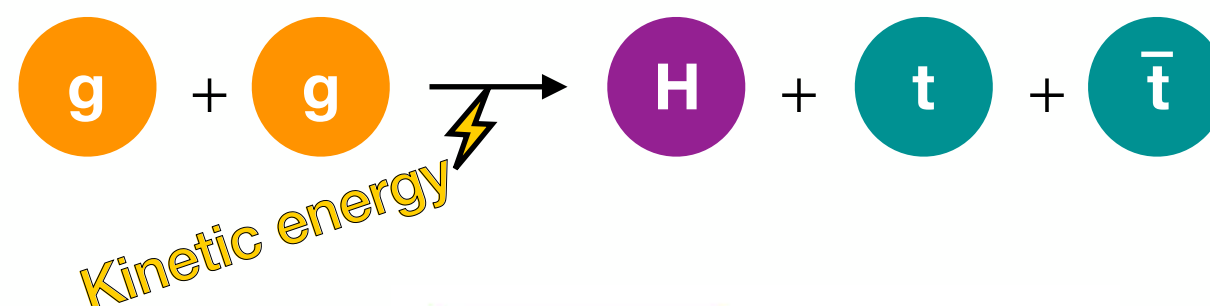
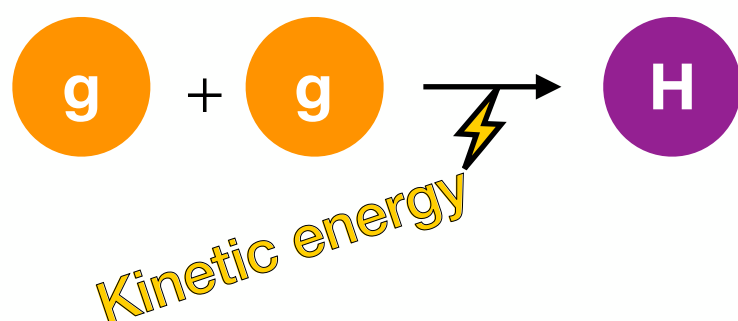
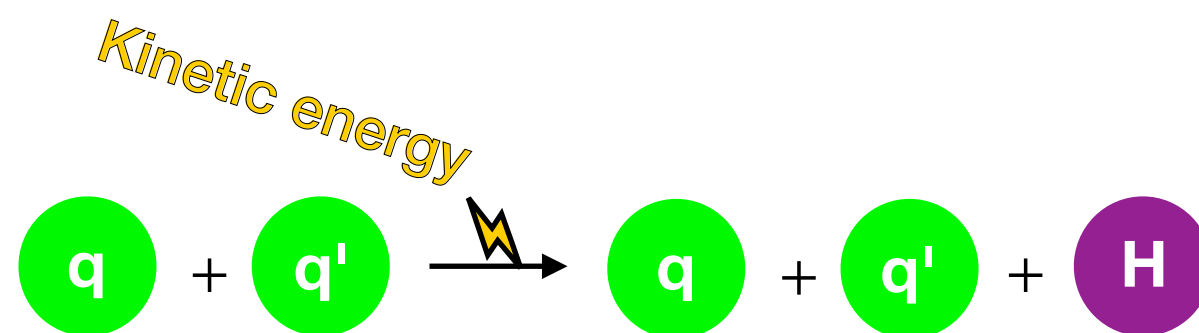
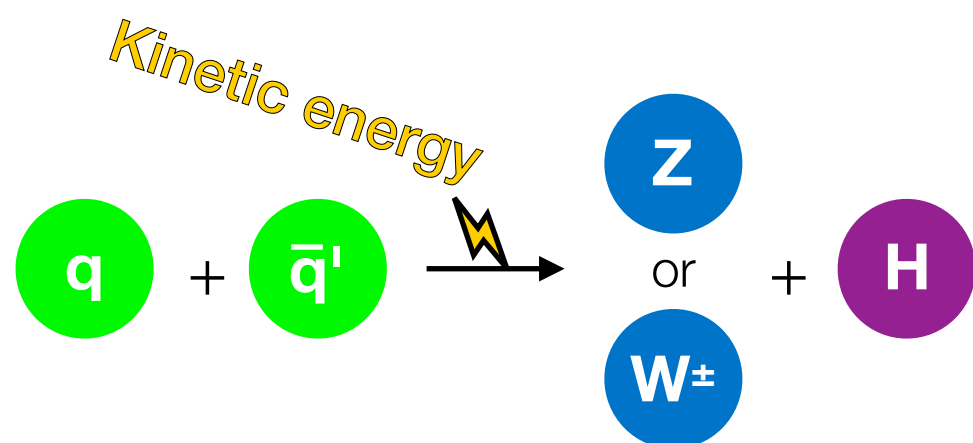


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Fortunately they are all contained **inside protons**.



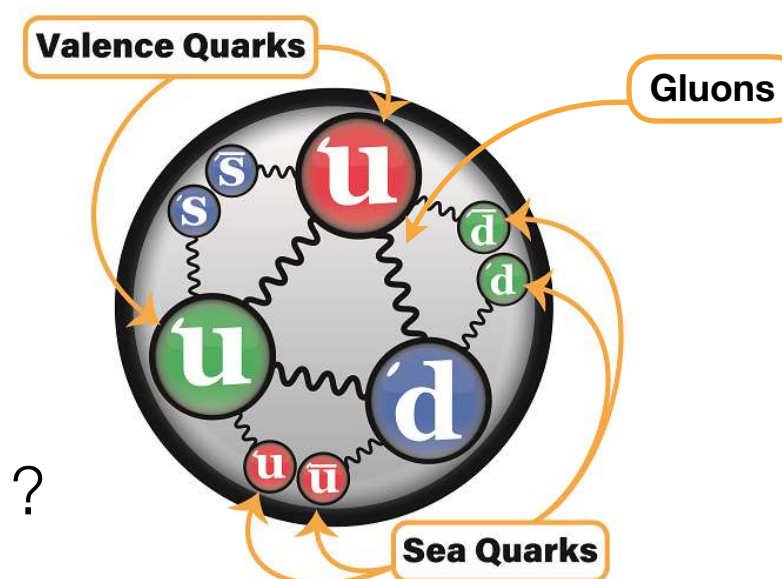
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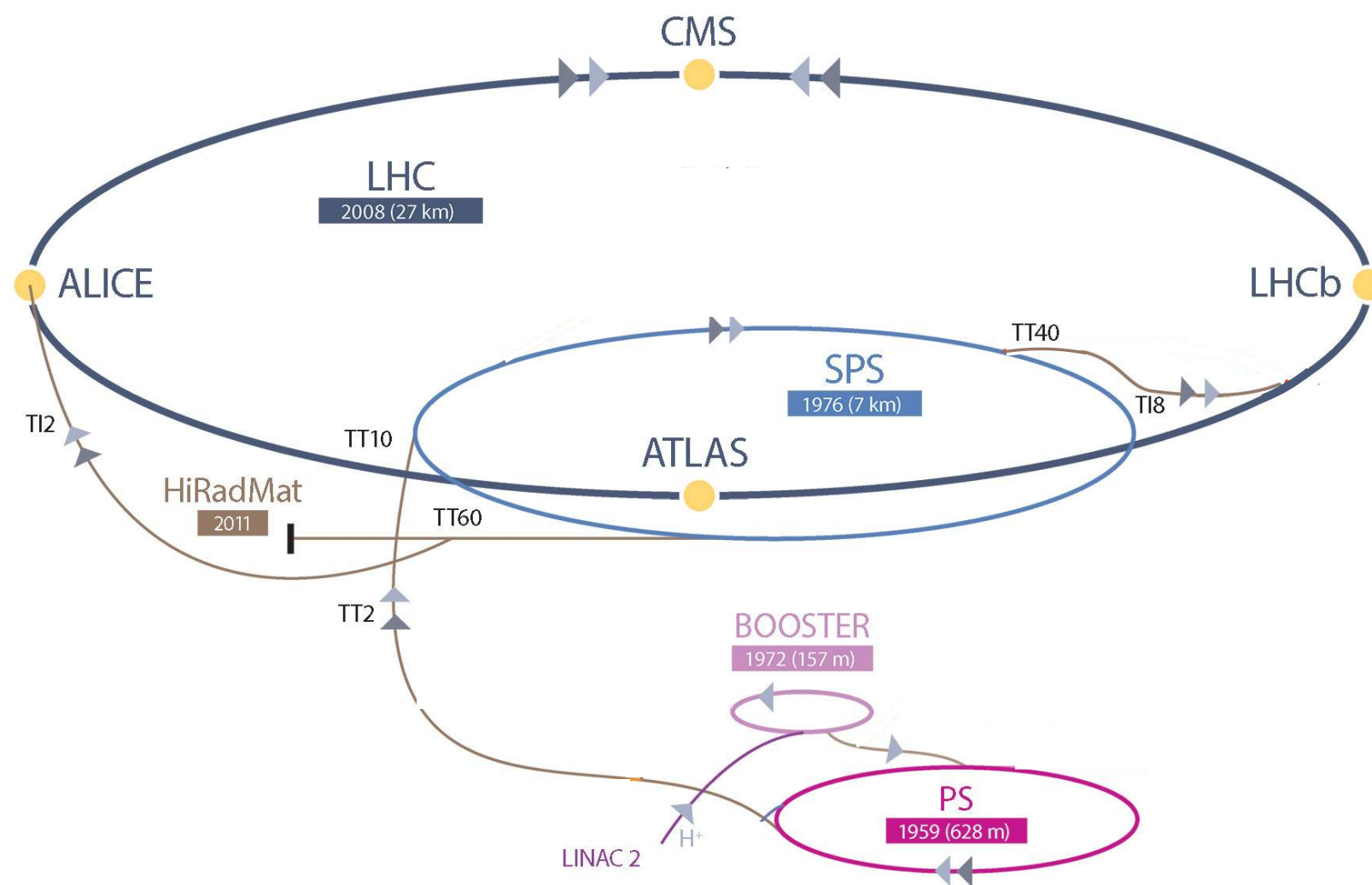


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But to get them close enough so that they **could interact** ?



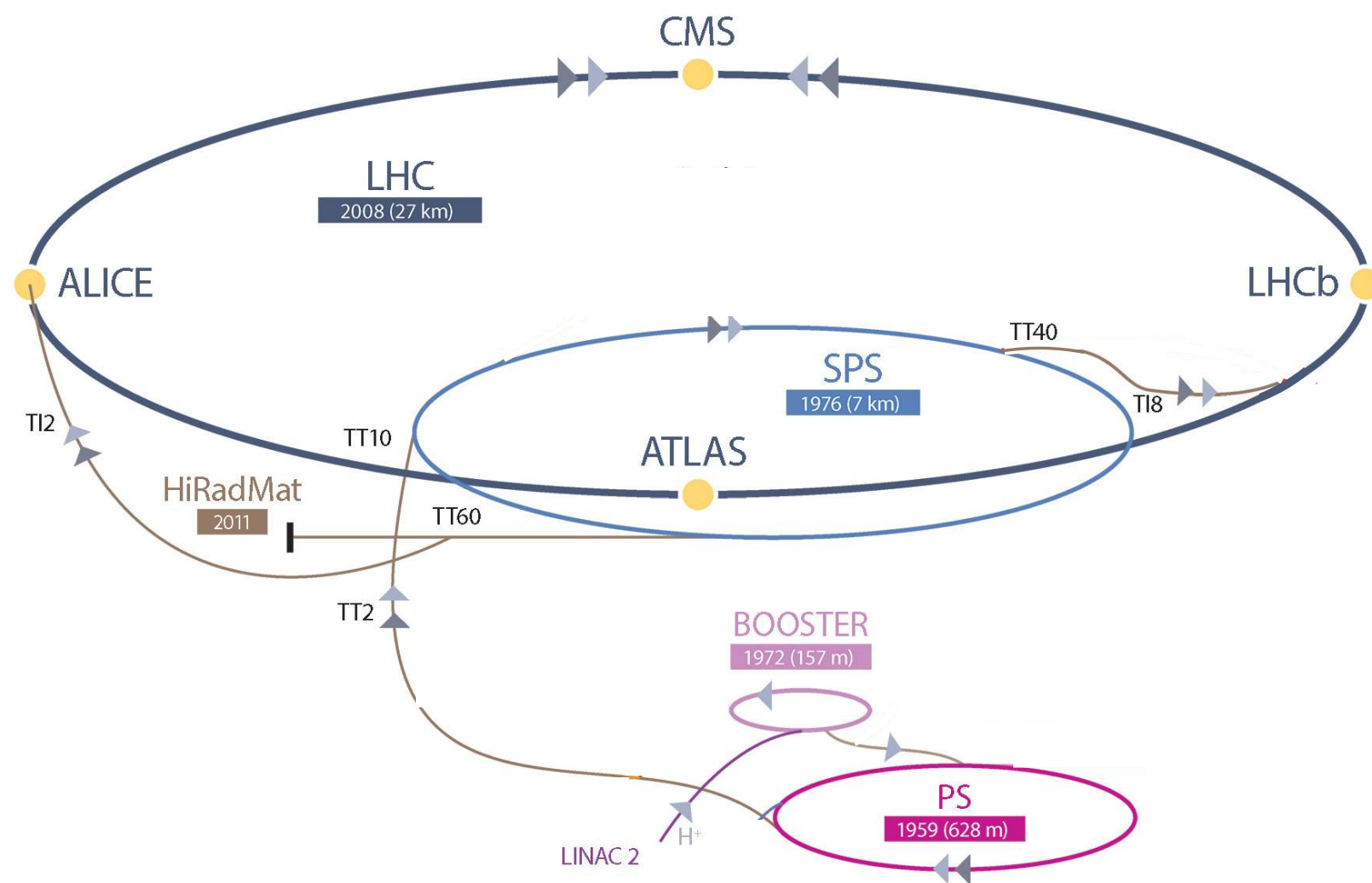
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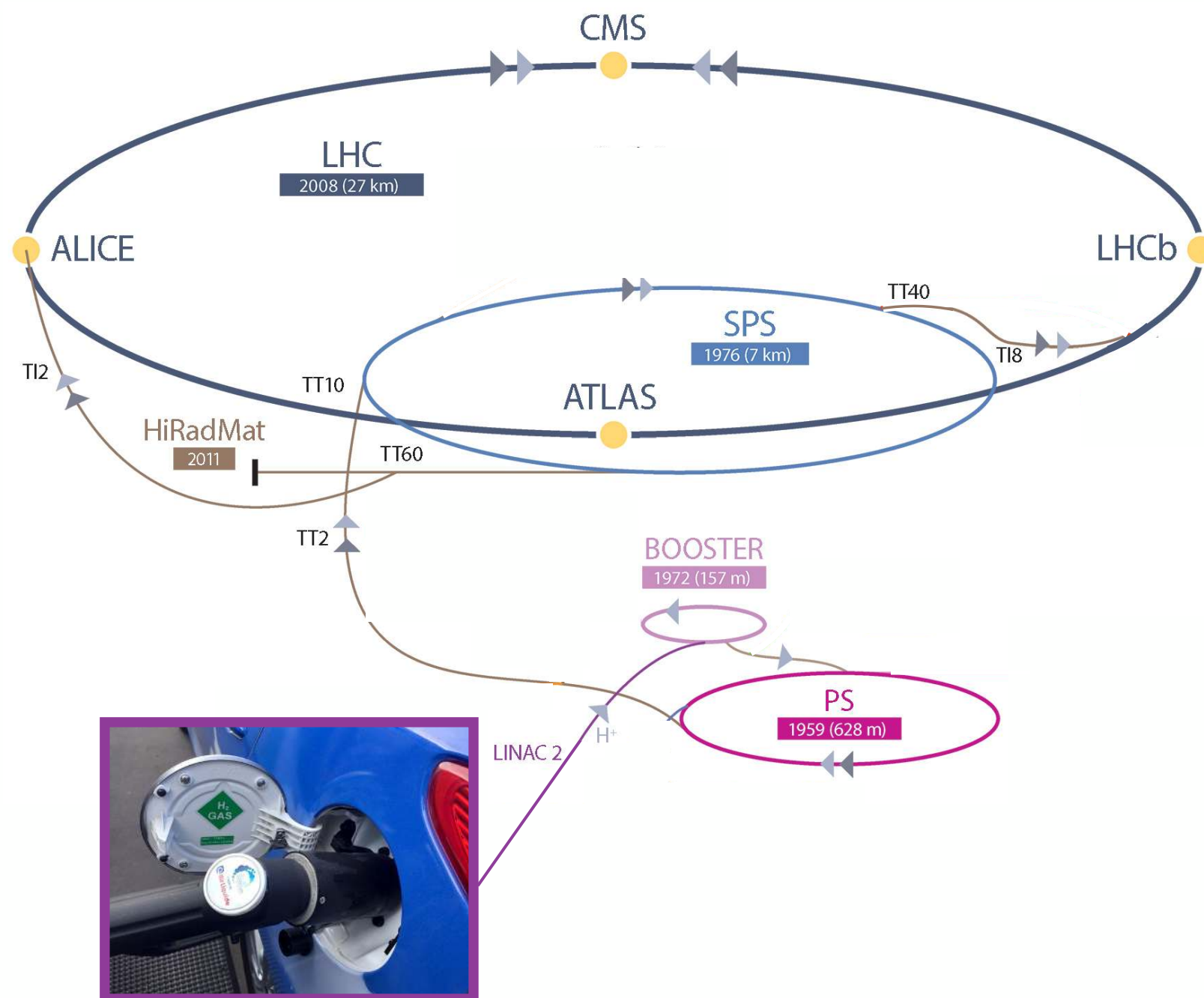
- a source of protons



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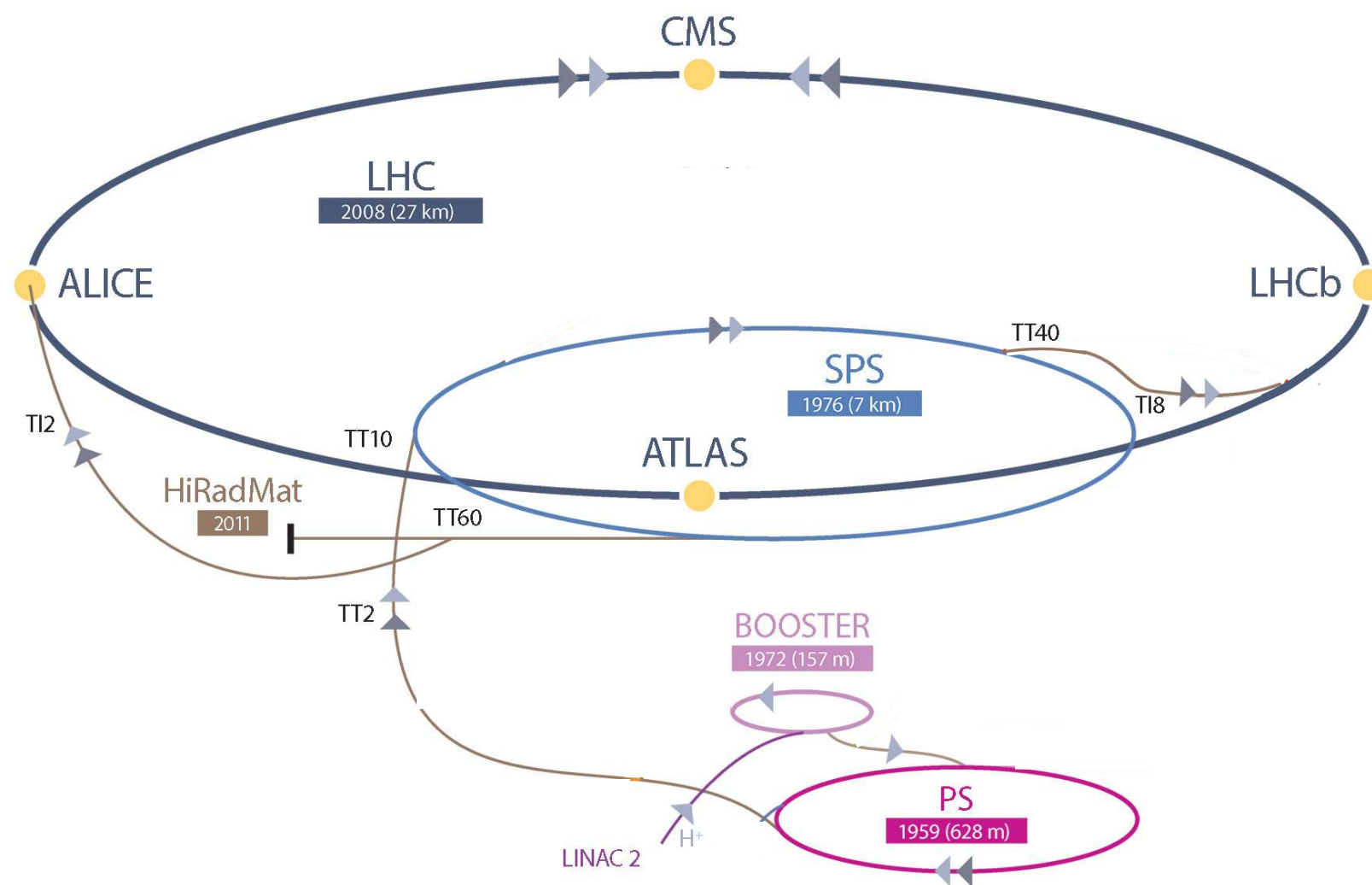
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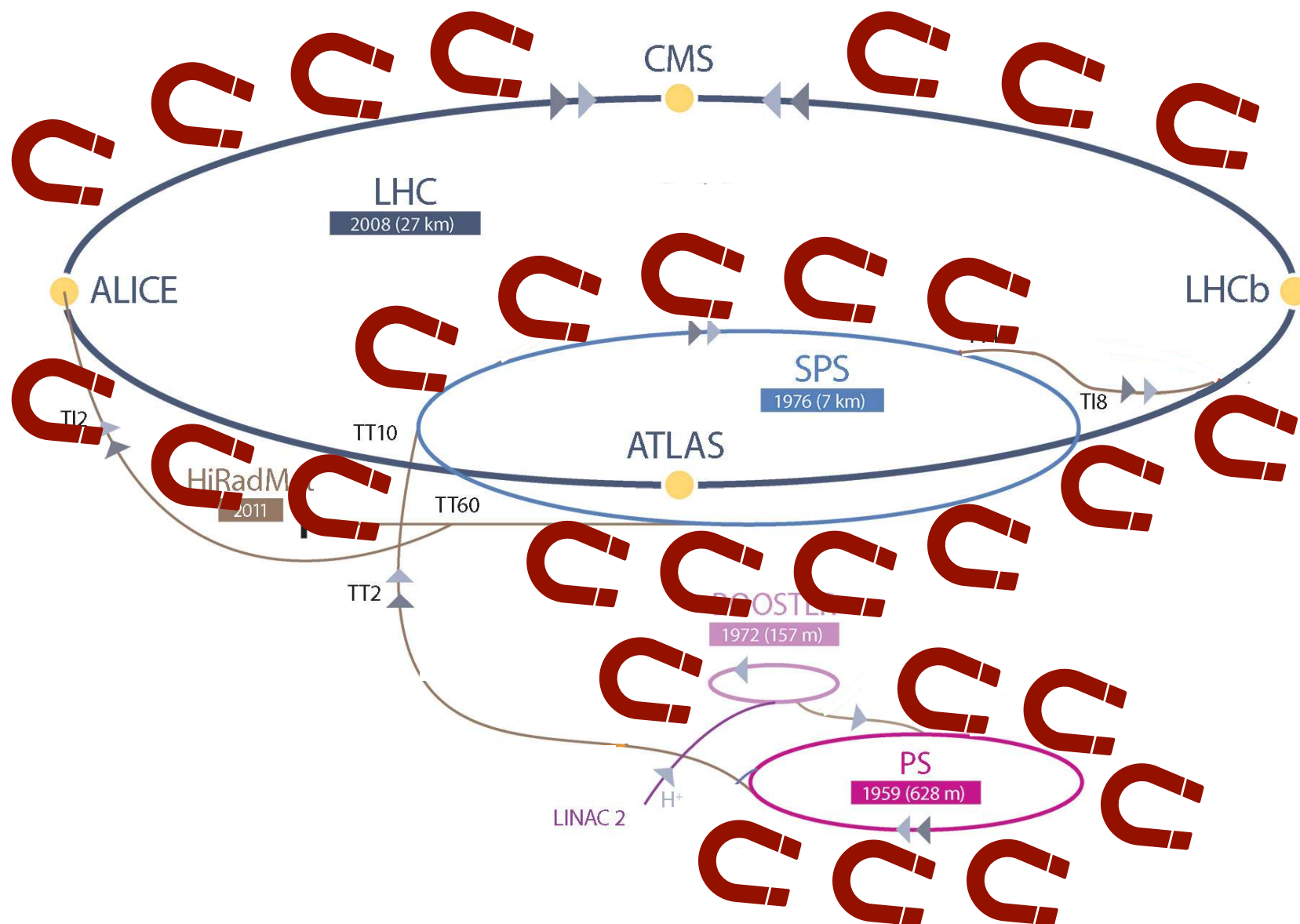
- a source of protons
- a way to accelerate them



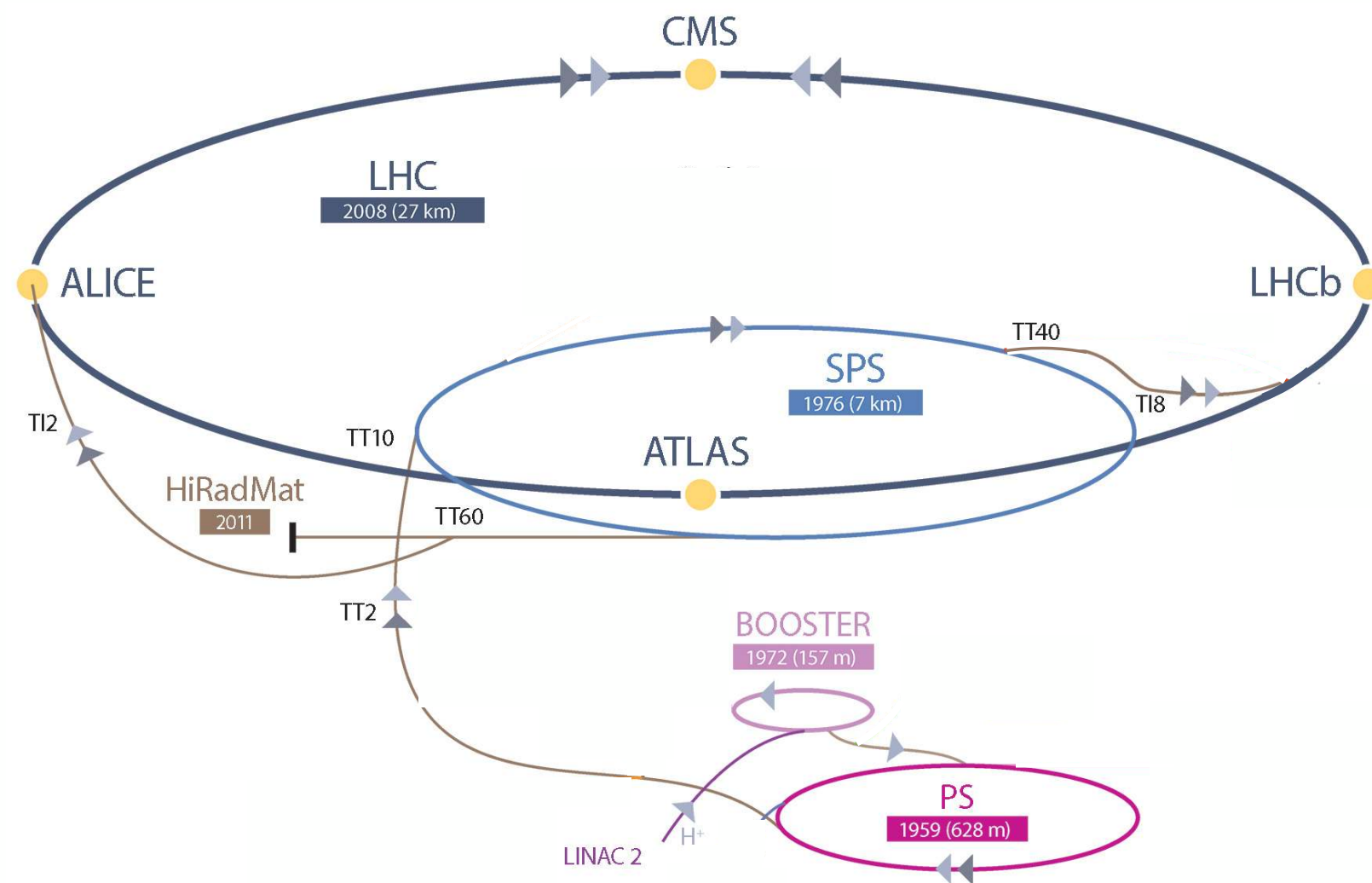
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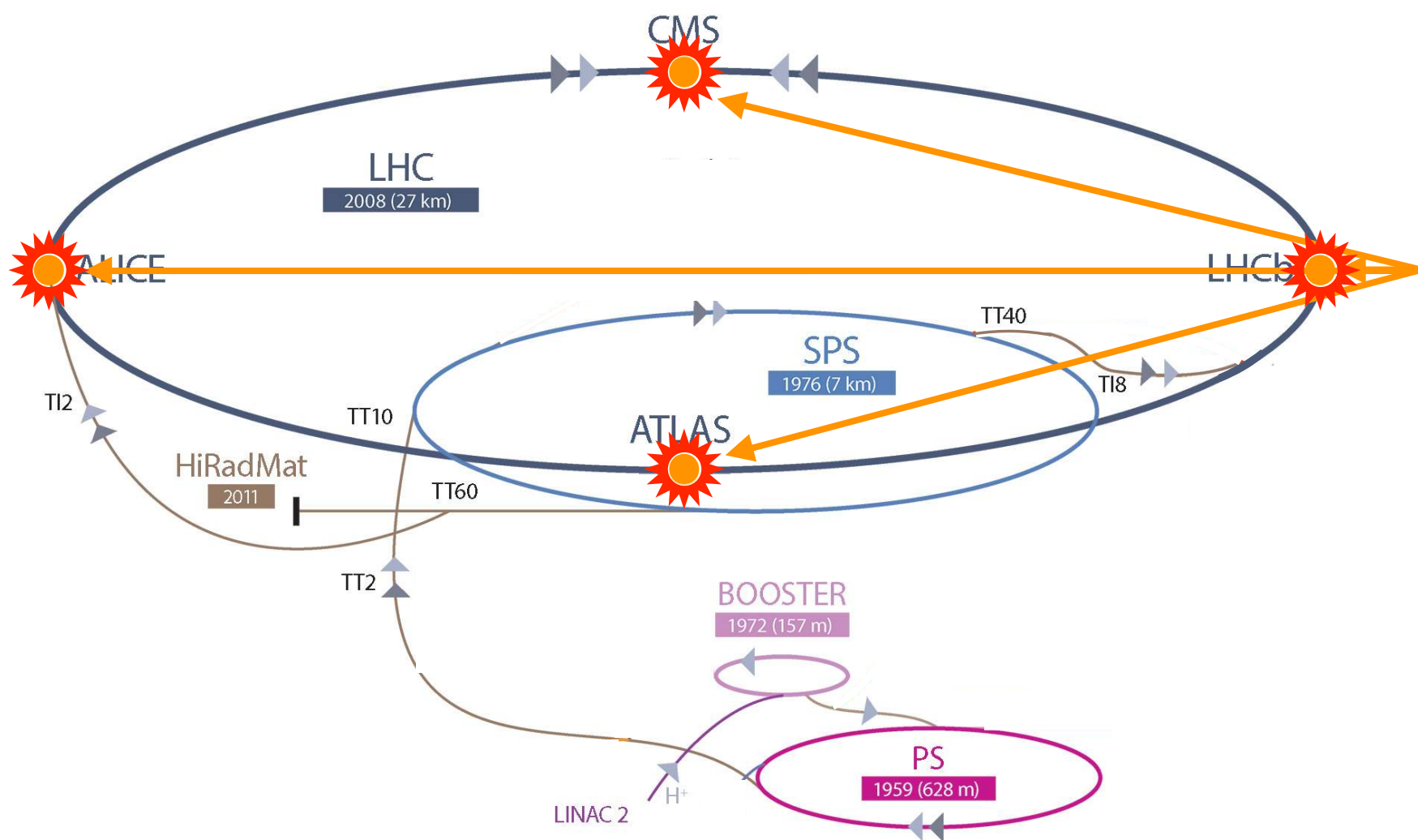
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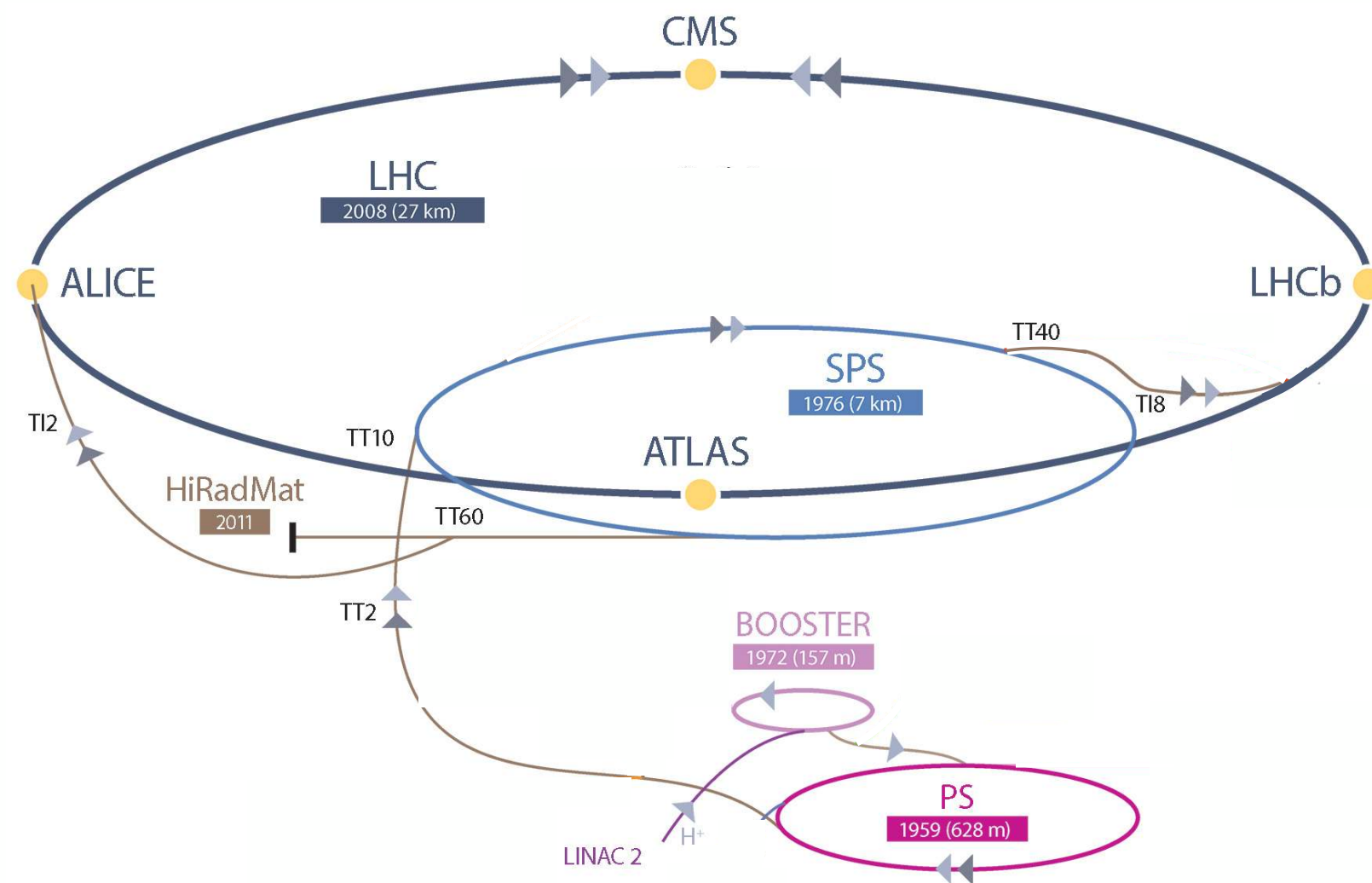
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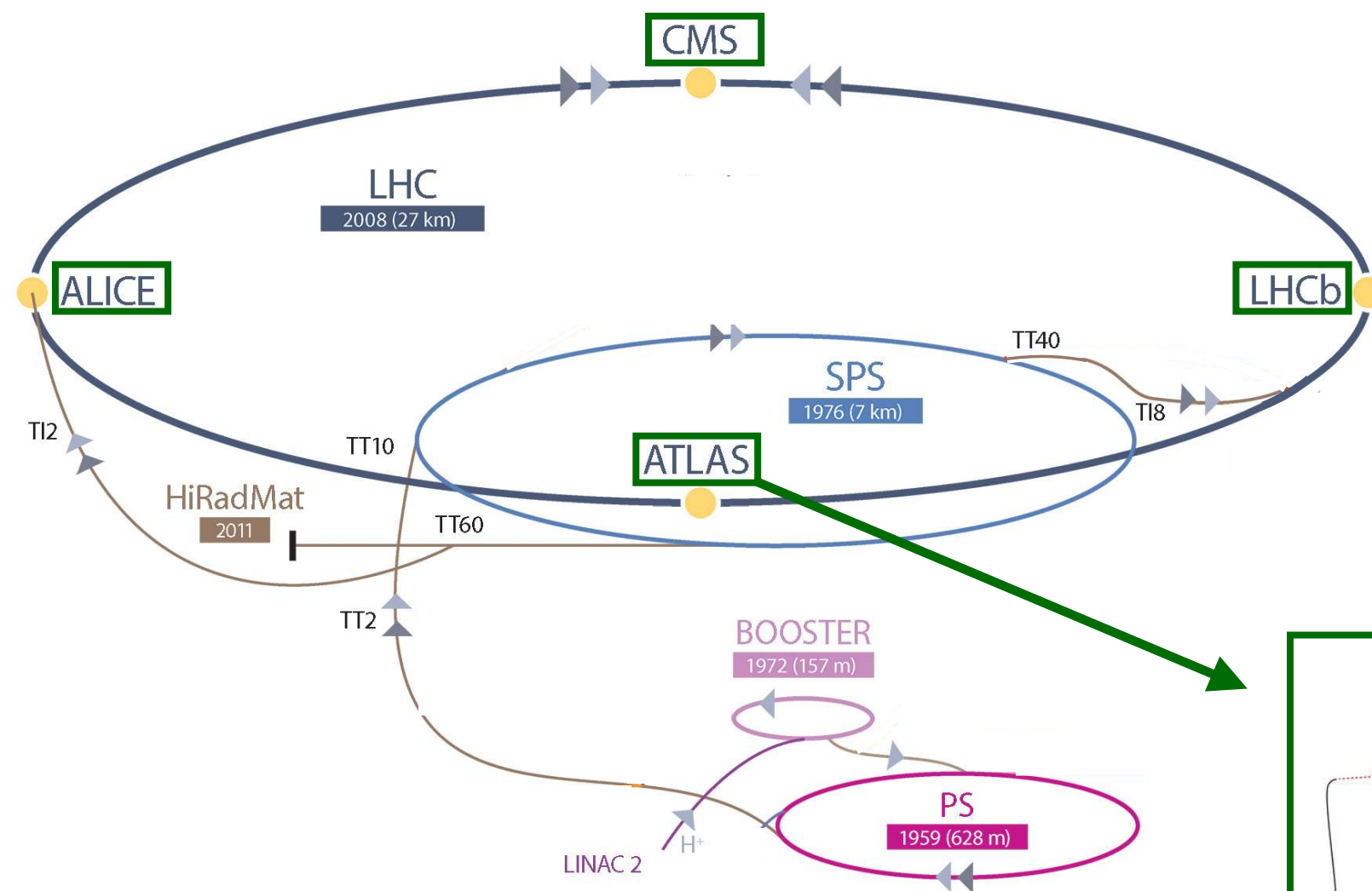
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- a source of protons
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- Something to detect the outgoing particles

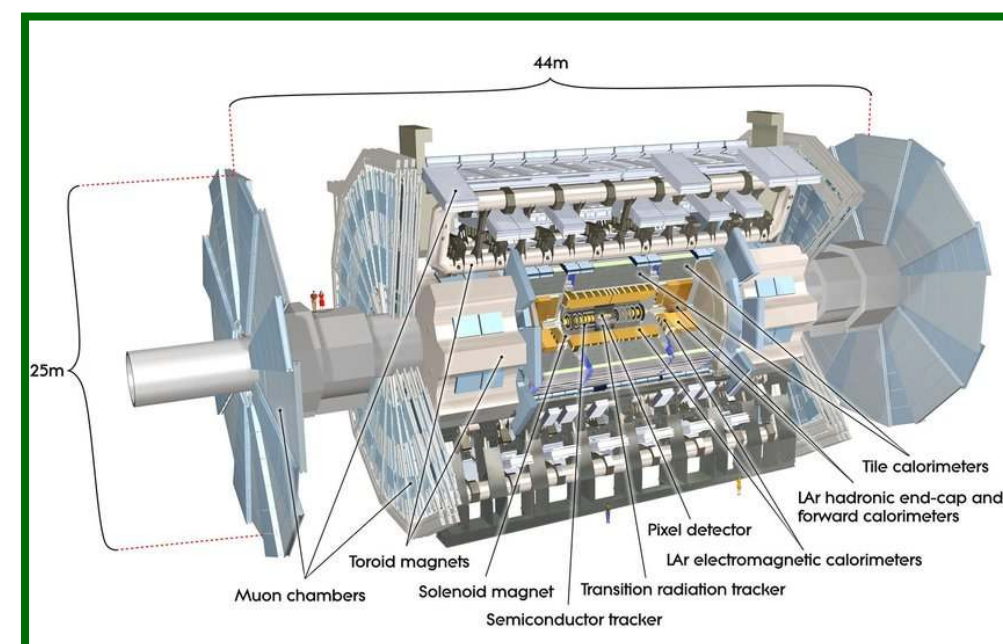
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Measurements to interpret

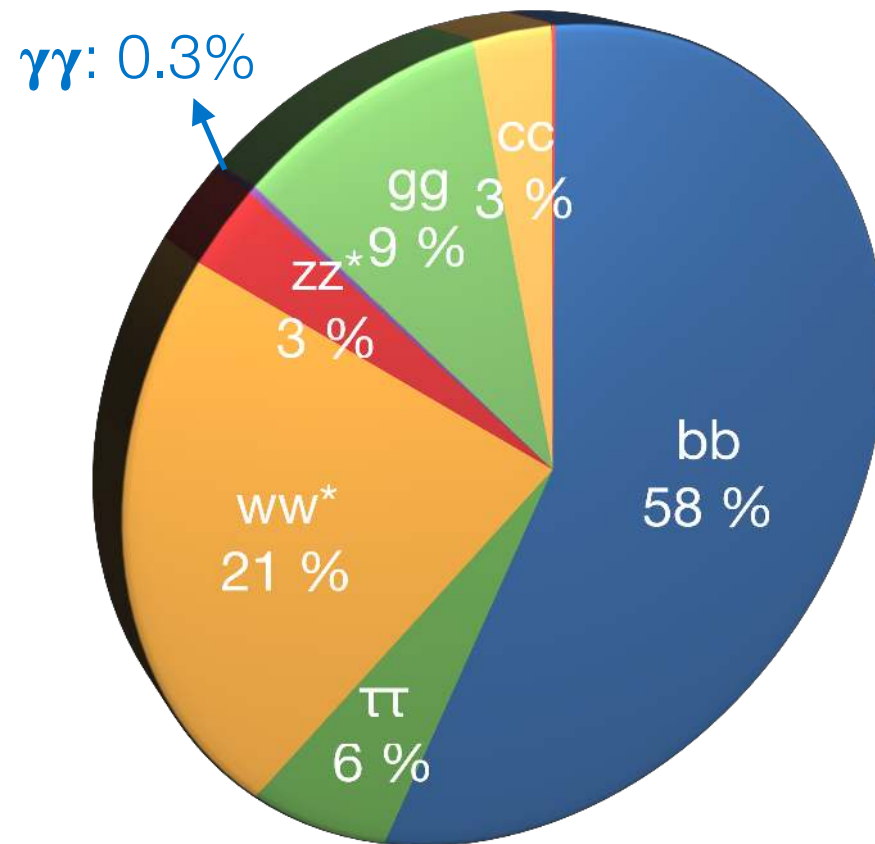
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Why looking for the Higgs boson beauty?

Higgs bosons have a very, very **short life**: 10^{-22} s.
But they love to **decay** into b quarks :

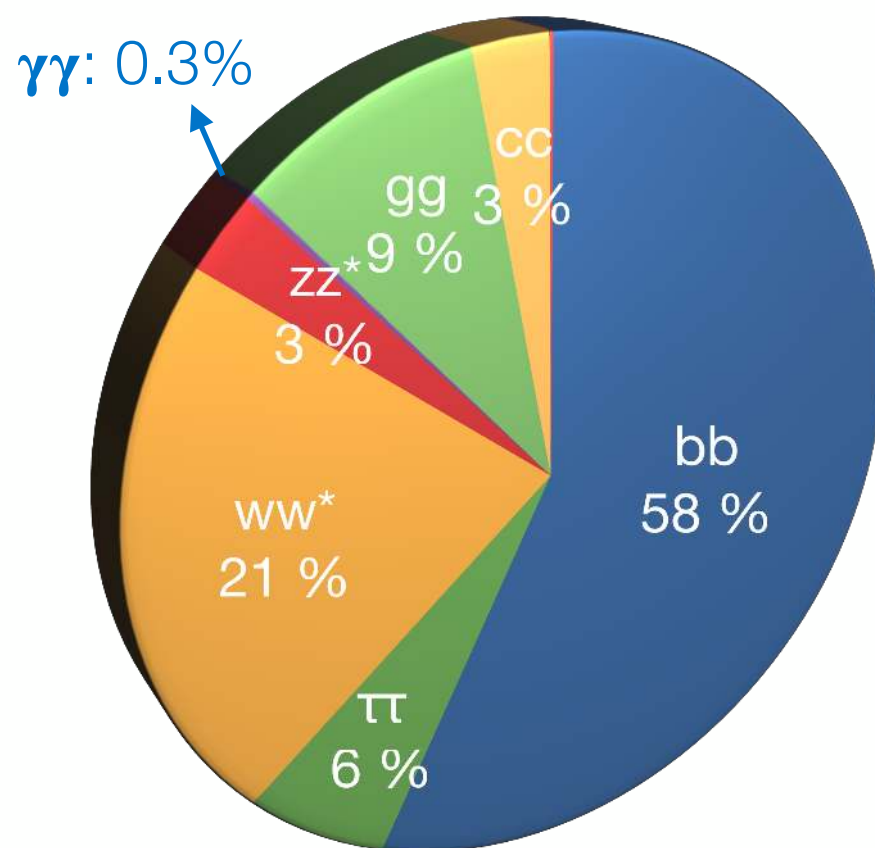


Branching ratio of Higgs decay

So why not having discovered the Higgs already with that???

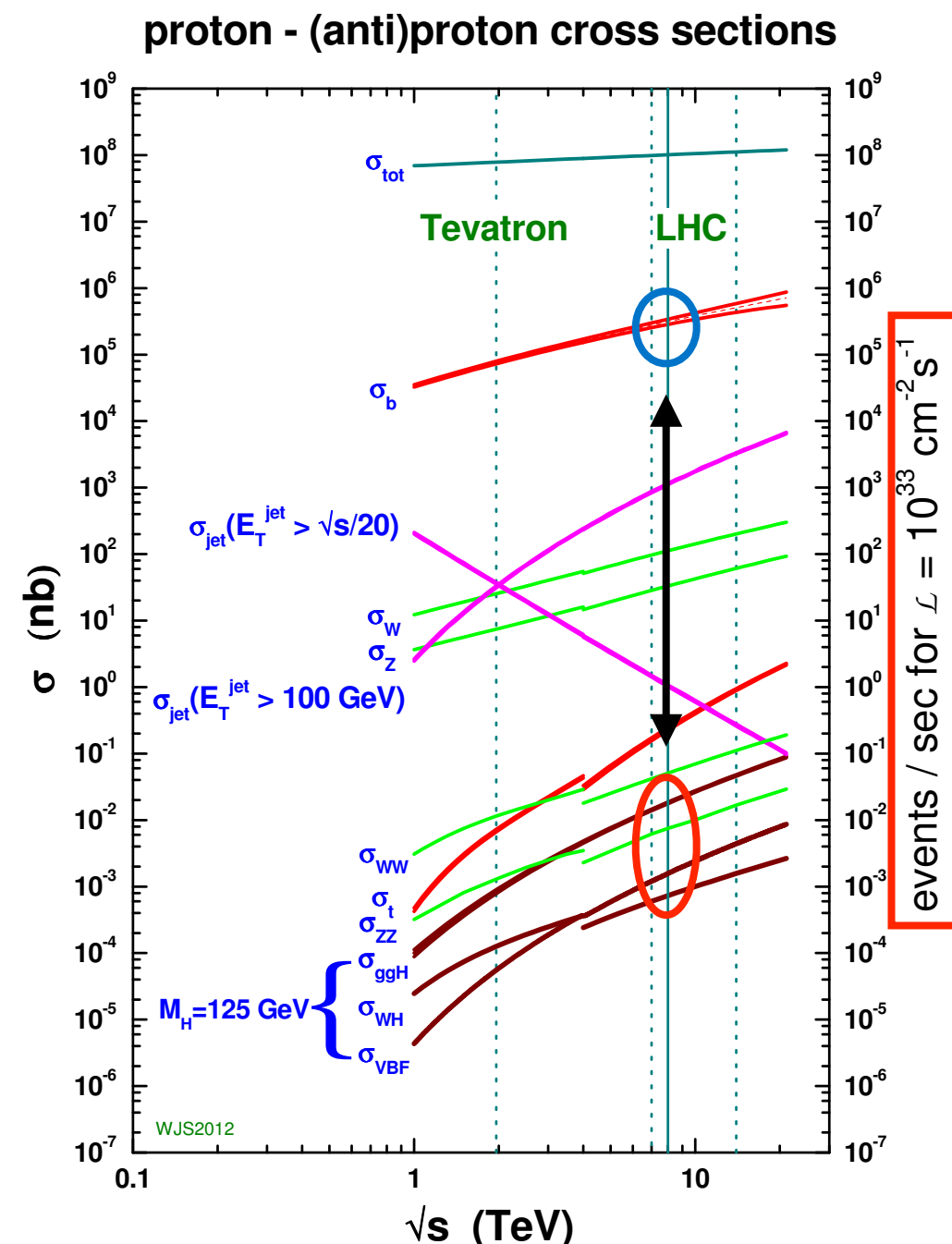
Why looking for the Higgs boson beauty?

Higgs bosons have a very, very **short life**: 10^{-22} s. Well, in a p-p collision, a lot of **b quarks** are also **produced** by **other mechanism**. But they love to **decay** into b quarks :



Branching ratio of Higgs decay

So why not having discovered the Higgs already with that???



Ok, but why machine learning?

So looking for ~~a needle~~ 2 b quarks coming from a Higgs boson in ~~an haystack~~ a dataset from the ATLAS detector....



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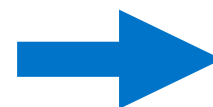


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Ok but this raise a lot of questions.

- Are the variable the most **sensitive** ones?
- How to **define** the **cuts**?
- What about **correlations** between variables?
- What if some signal can **fail** a **cut**?



Let the **machine** deal with that!!!!

Constructing a decision tree



The goal is to **classify** an event in 2 categories : **Signal** / **Background**.

Simulated samples are used to construct this decision tree.

Constructing a decision tree

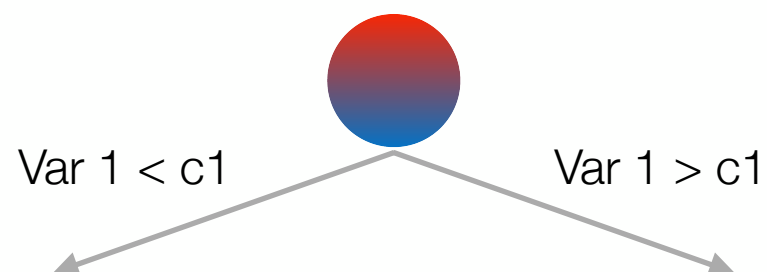


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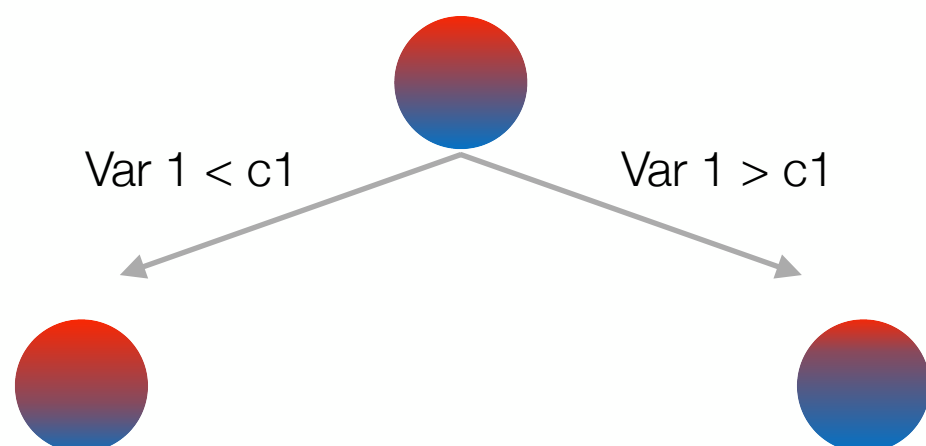


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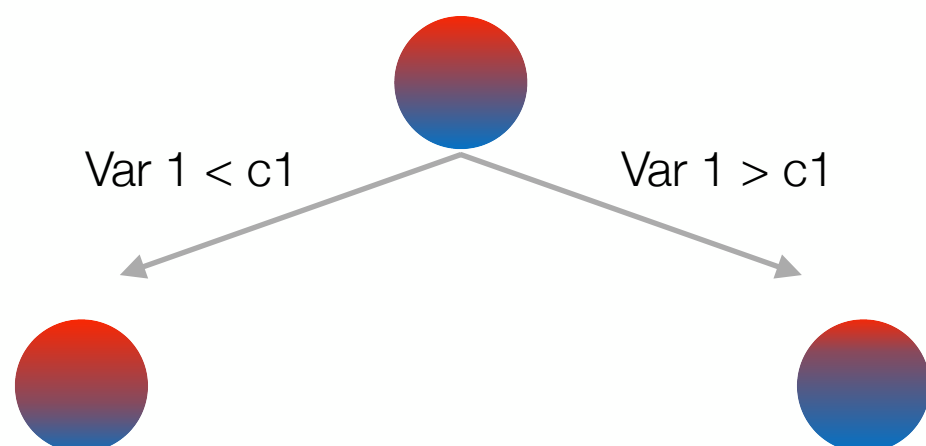


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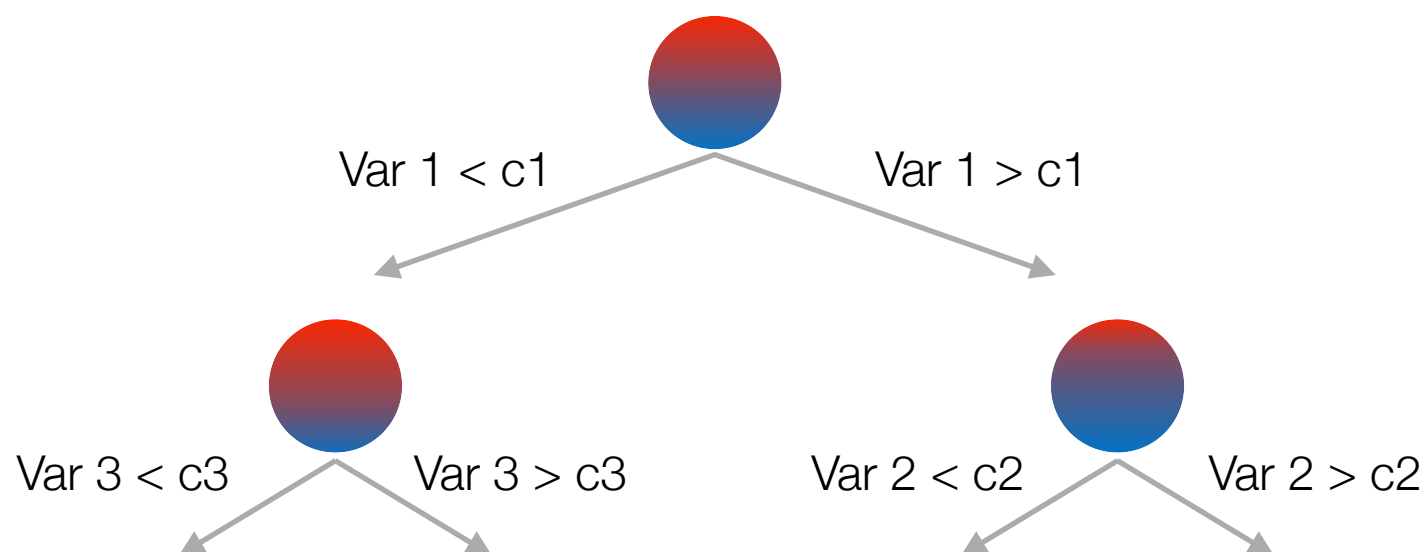
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Events passing/failing are set to two **leaves** and we **repeat** the operation to find the optimal cut on the new optimal variable.

Constructing a decision tree



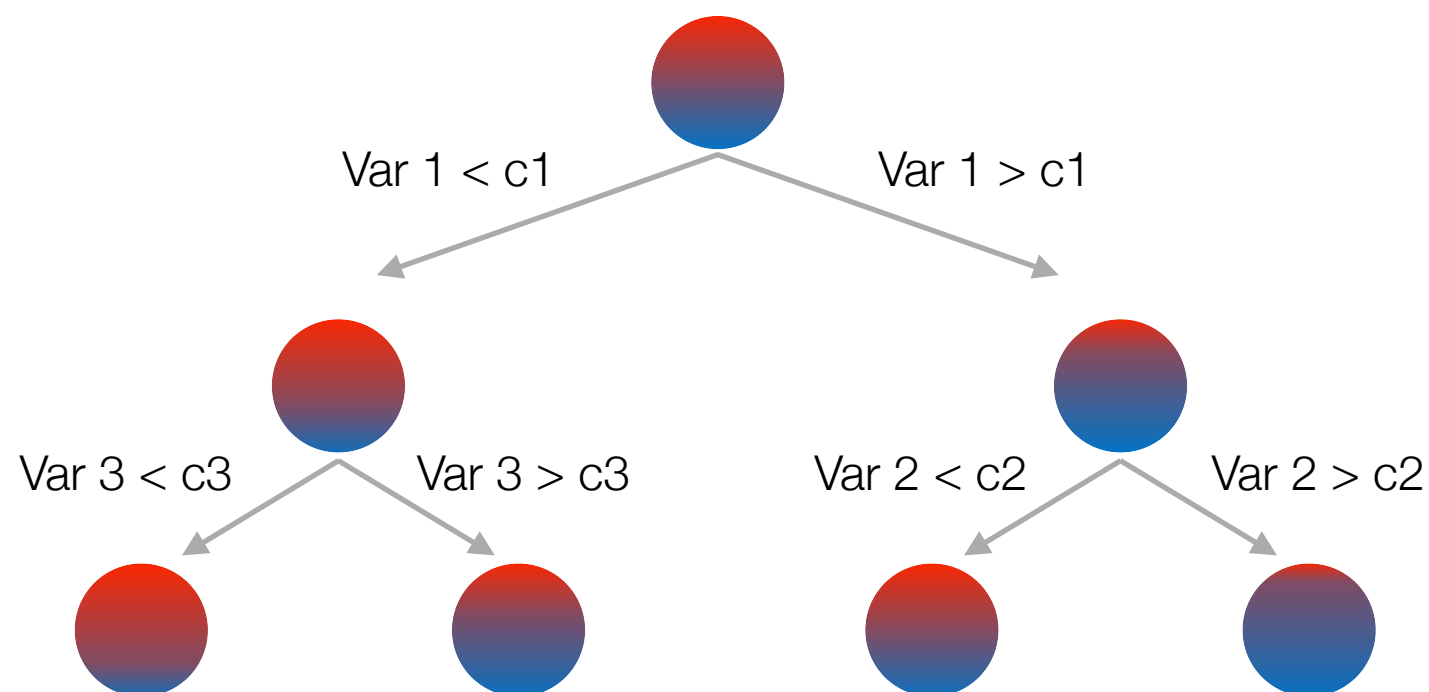
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Events passing/failing are set to two **leaves** and we **repeat** the operation to find the optimal cut on the new optimal variable.

Constructing a decision tree



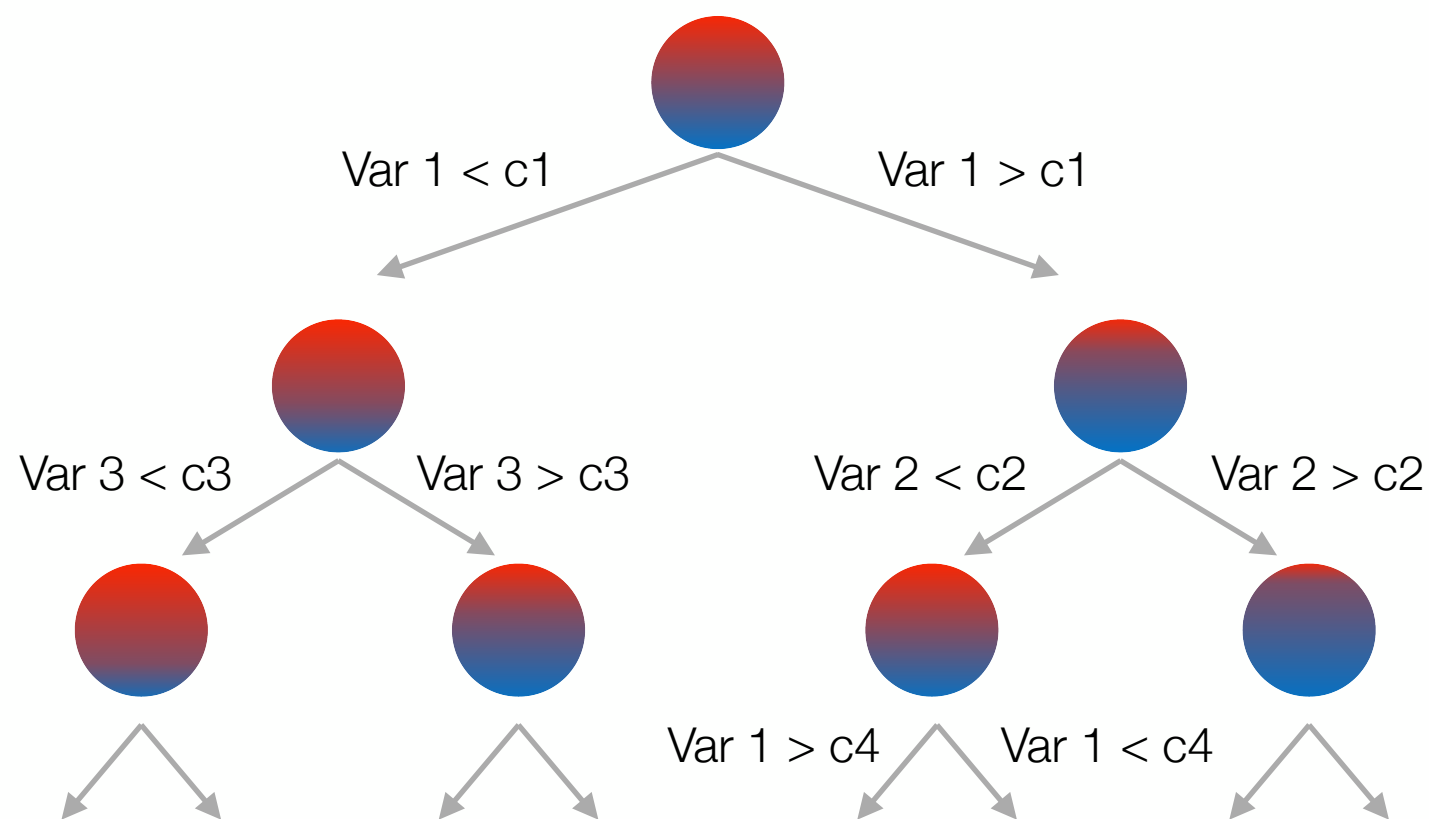
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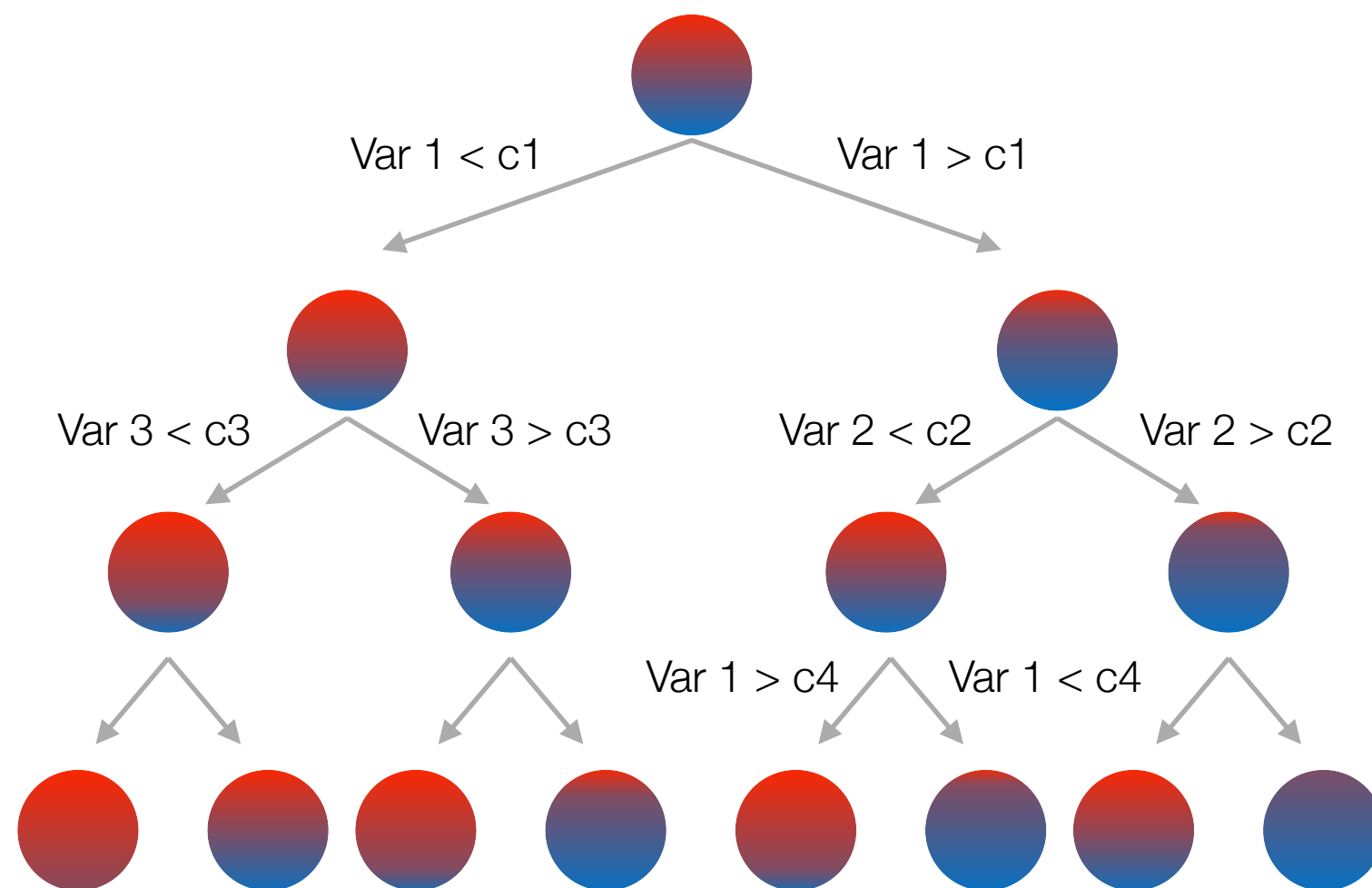
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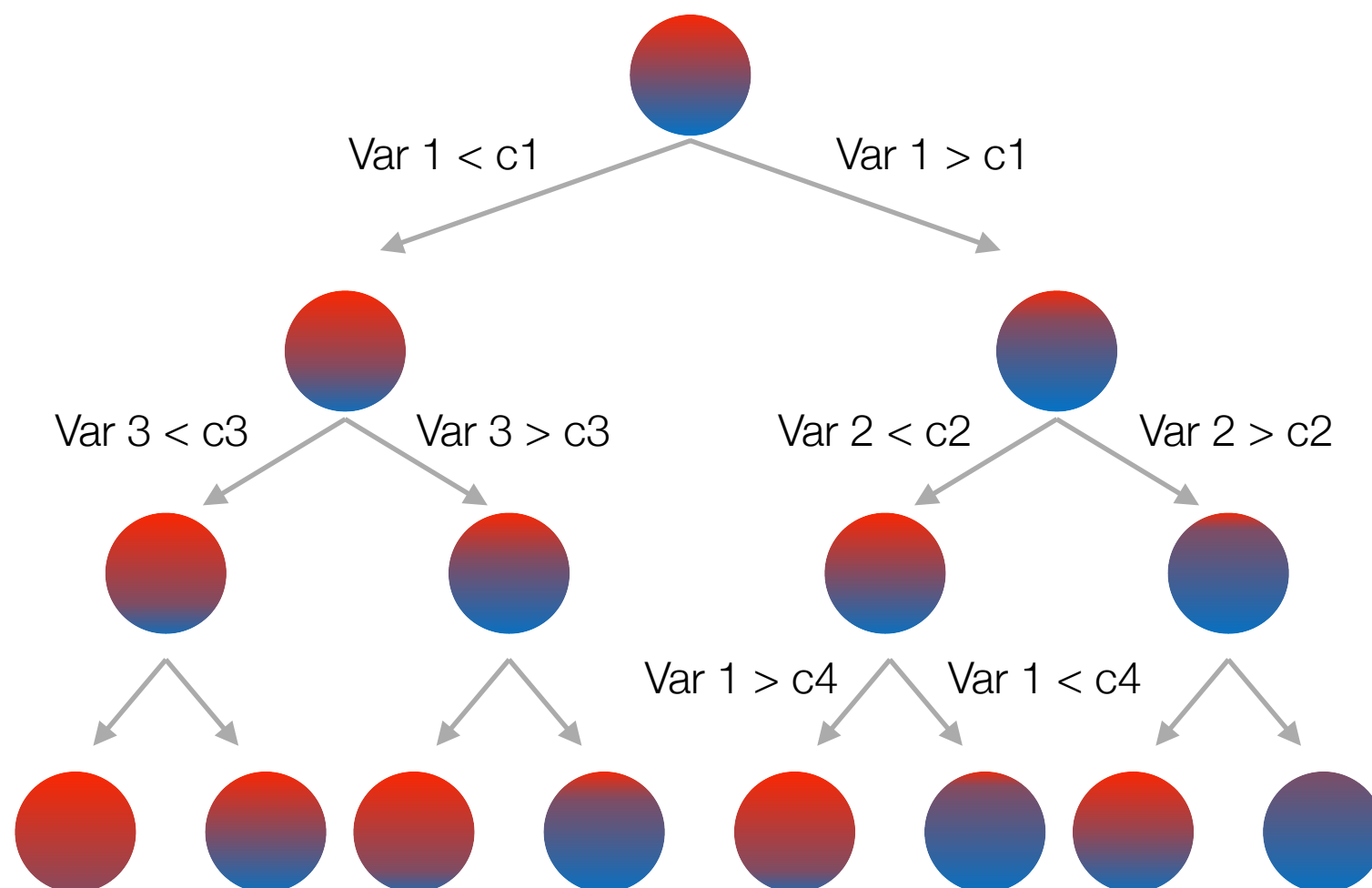
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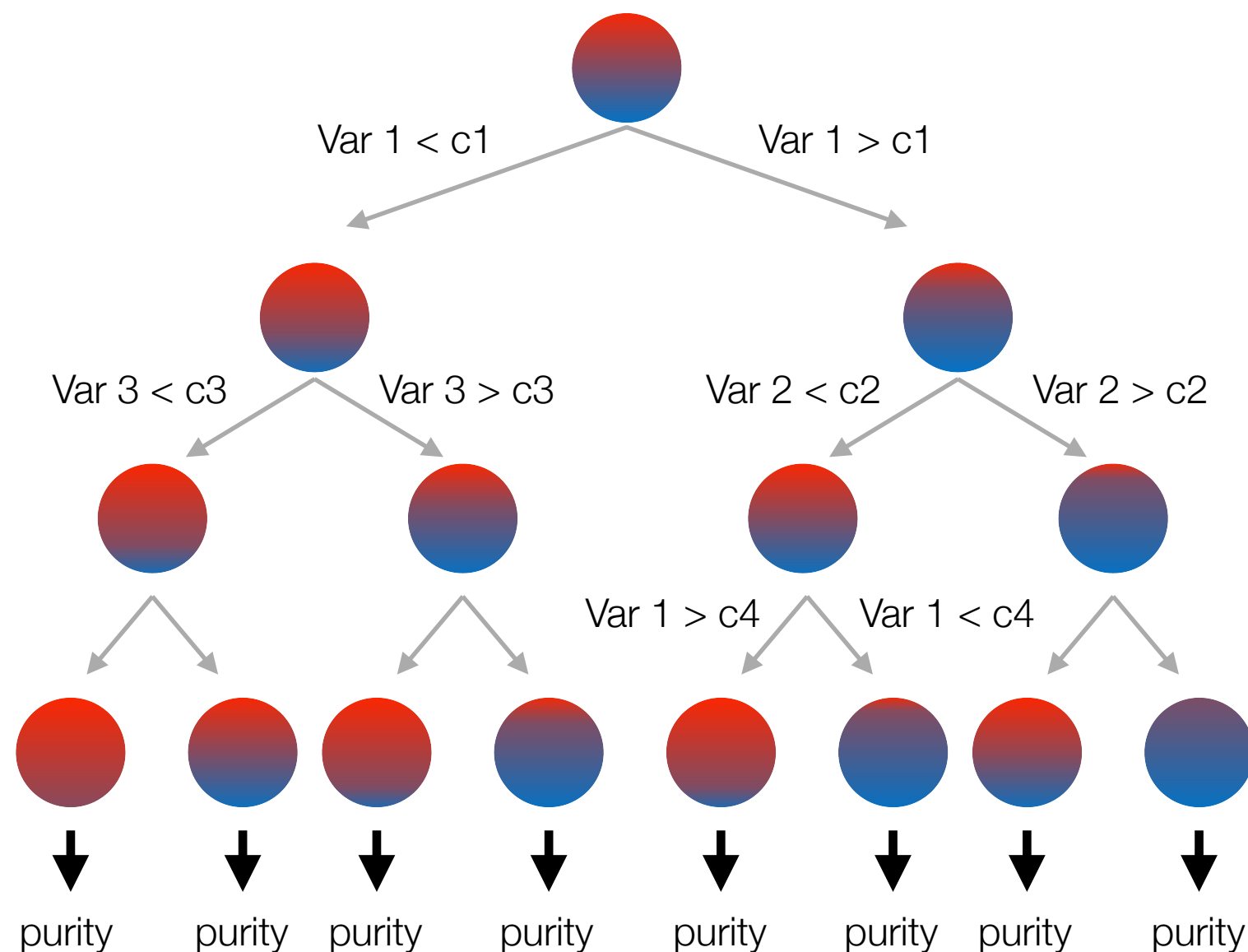
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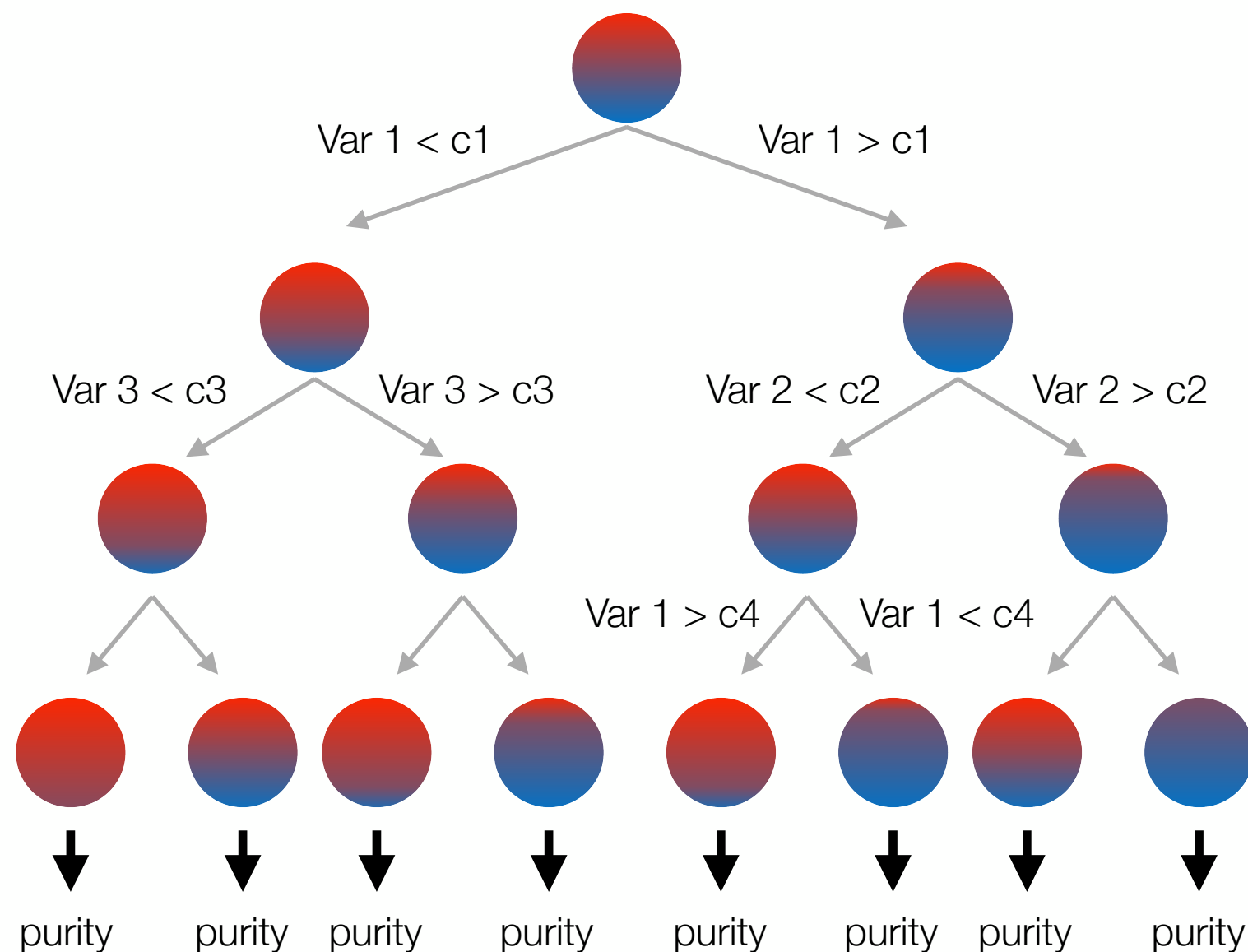
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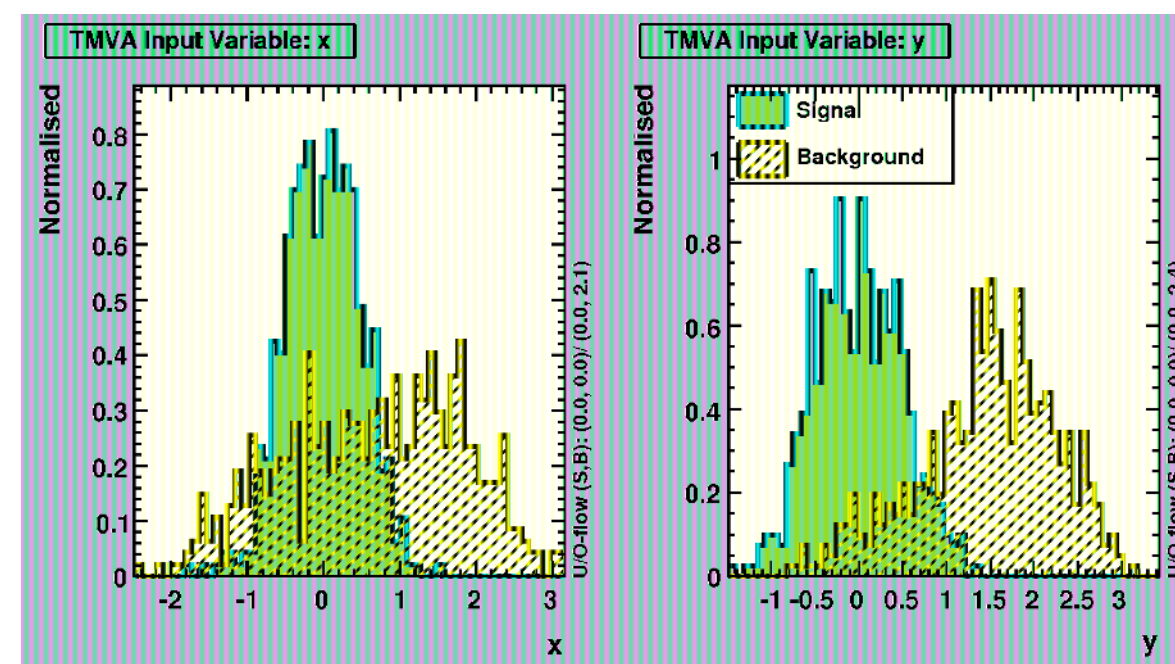
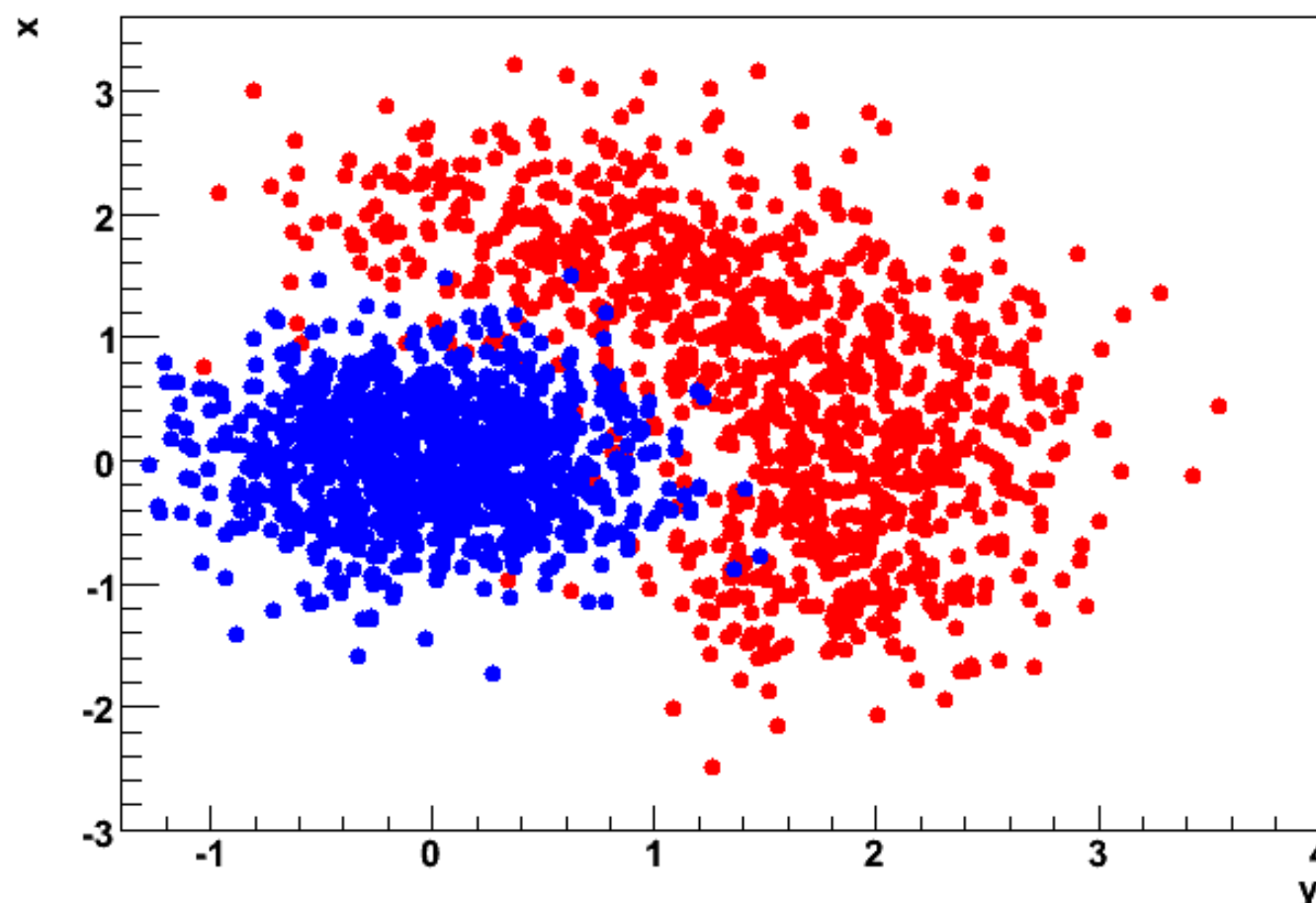
A **purity** is then computed depending on the **number** of **Signal/Background events** that are in the final leaf.

Example of Decision Tree

From the two **1-D distributions** it is **not clear** how to **distinguish** signal from background.

The **2-D plot** reveals better the **disentanglement**.

Let the **decision tree** know how to **separate** the two.

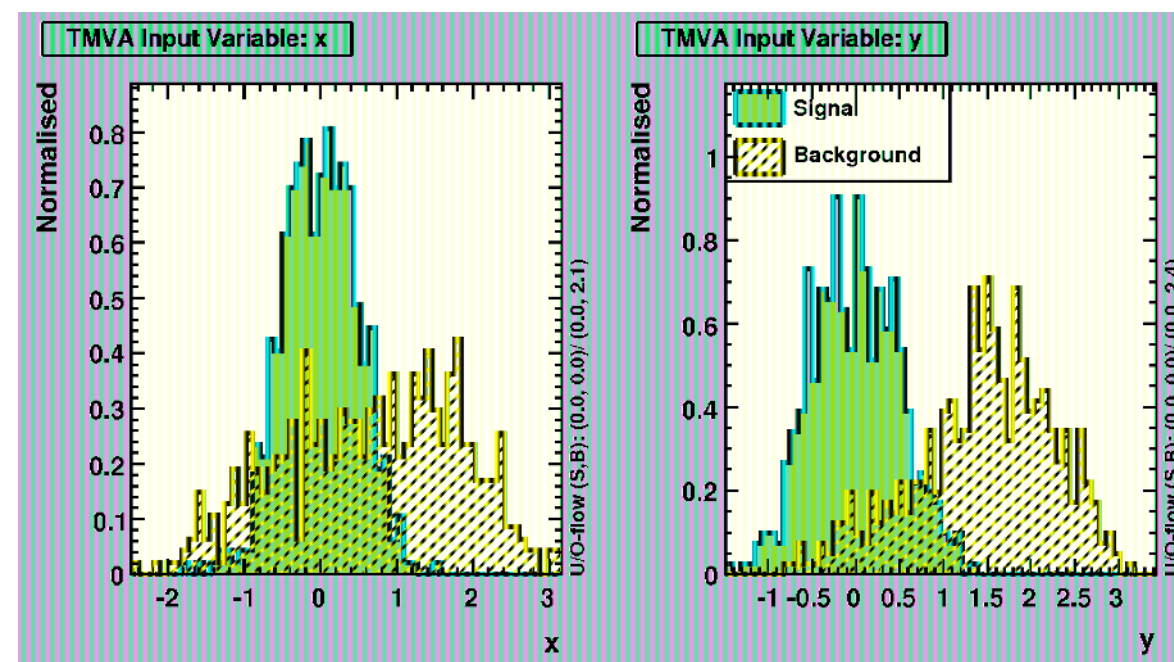
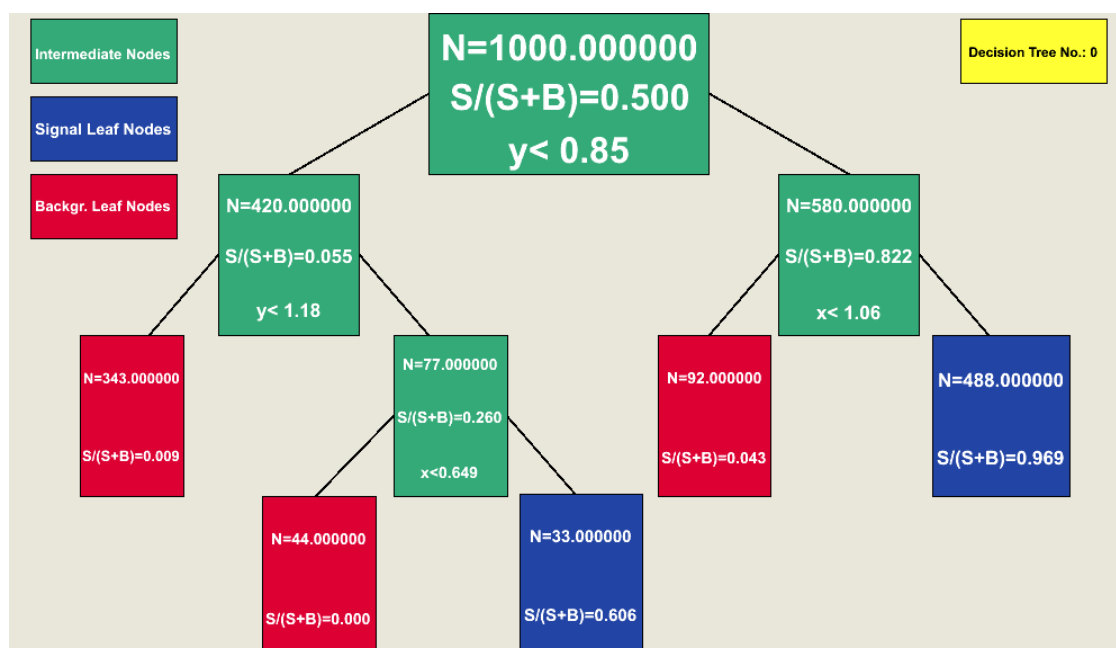
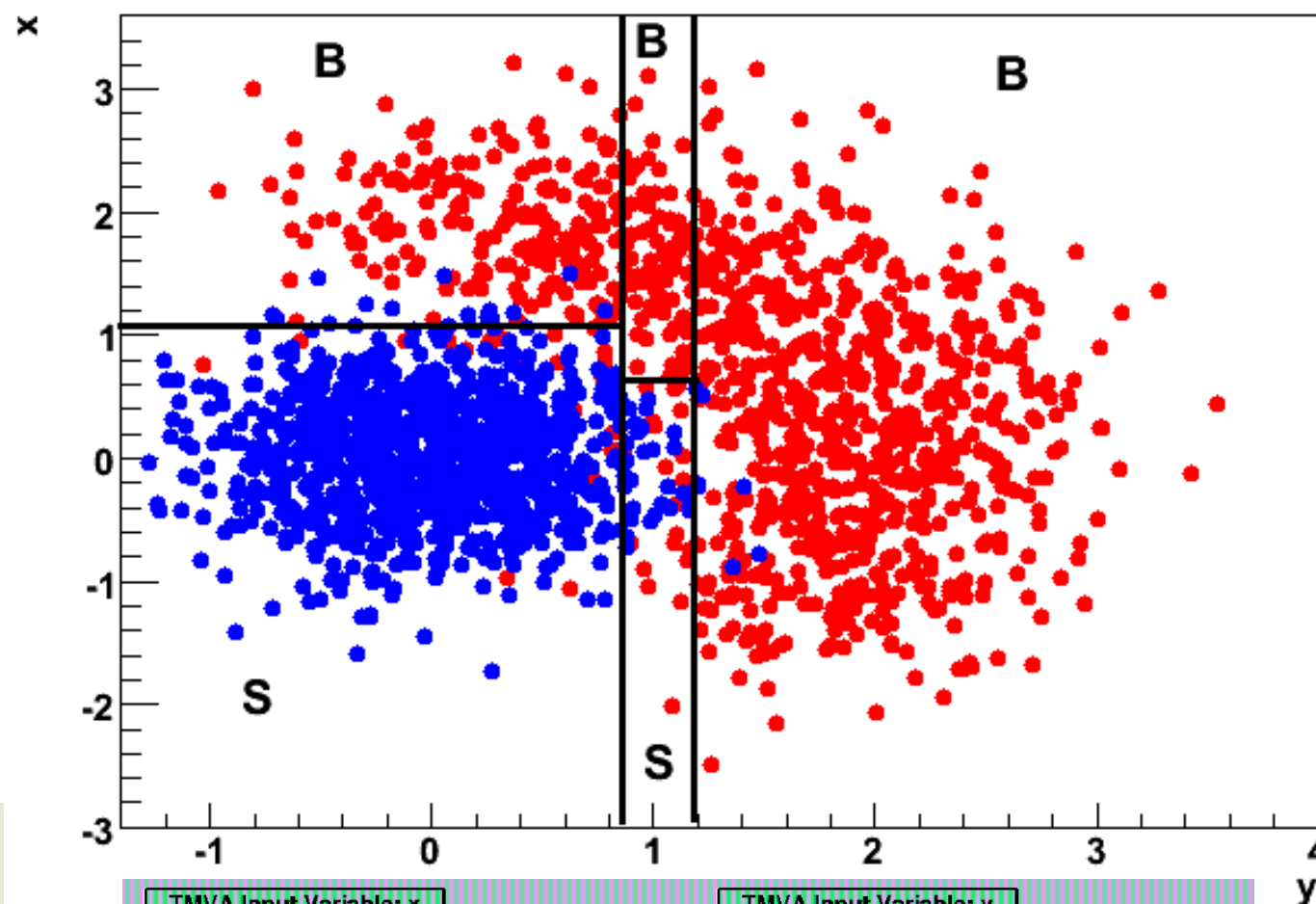


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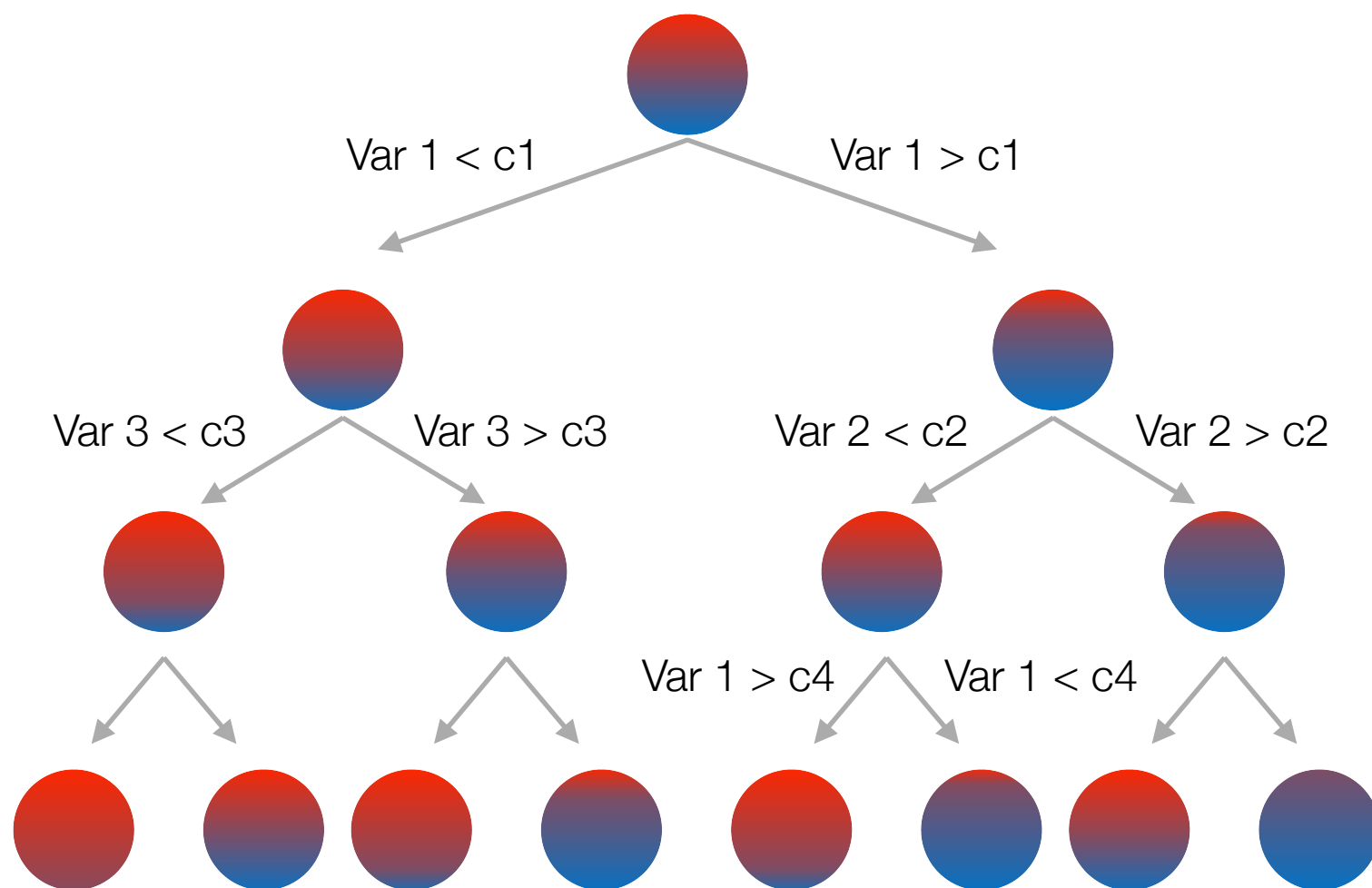
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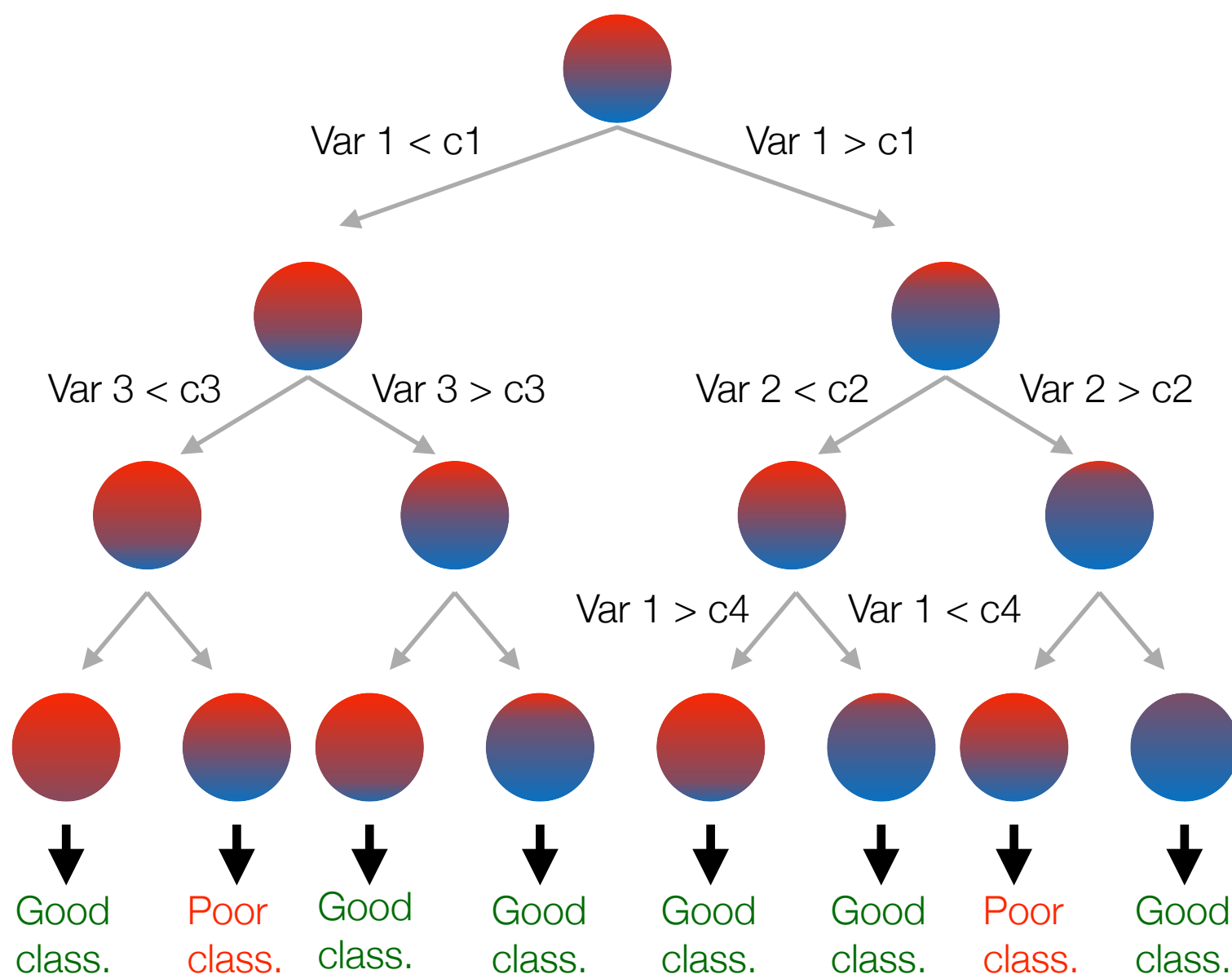
Boosting the Decision Tree

After the classification, some **leaves** are **not pure**.

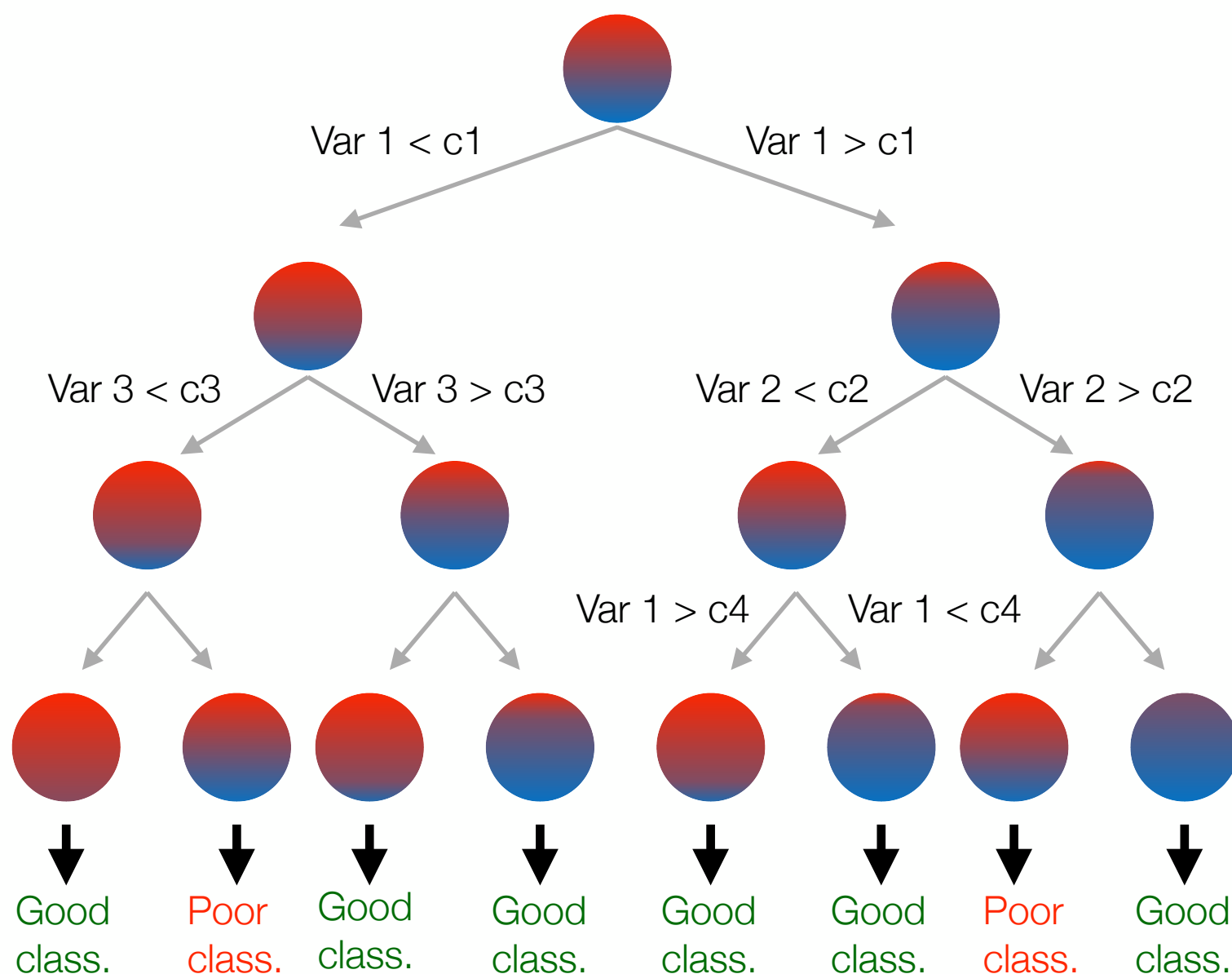


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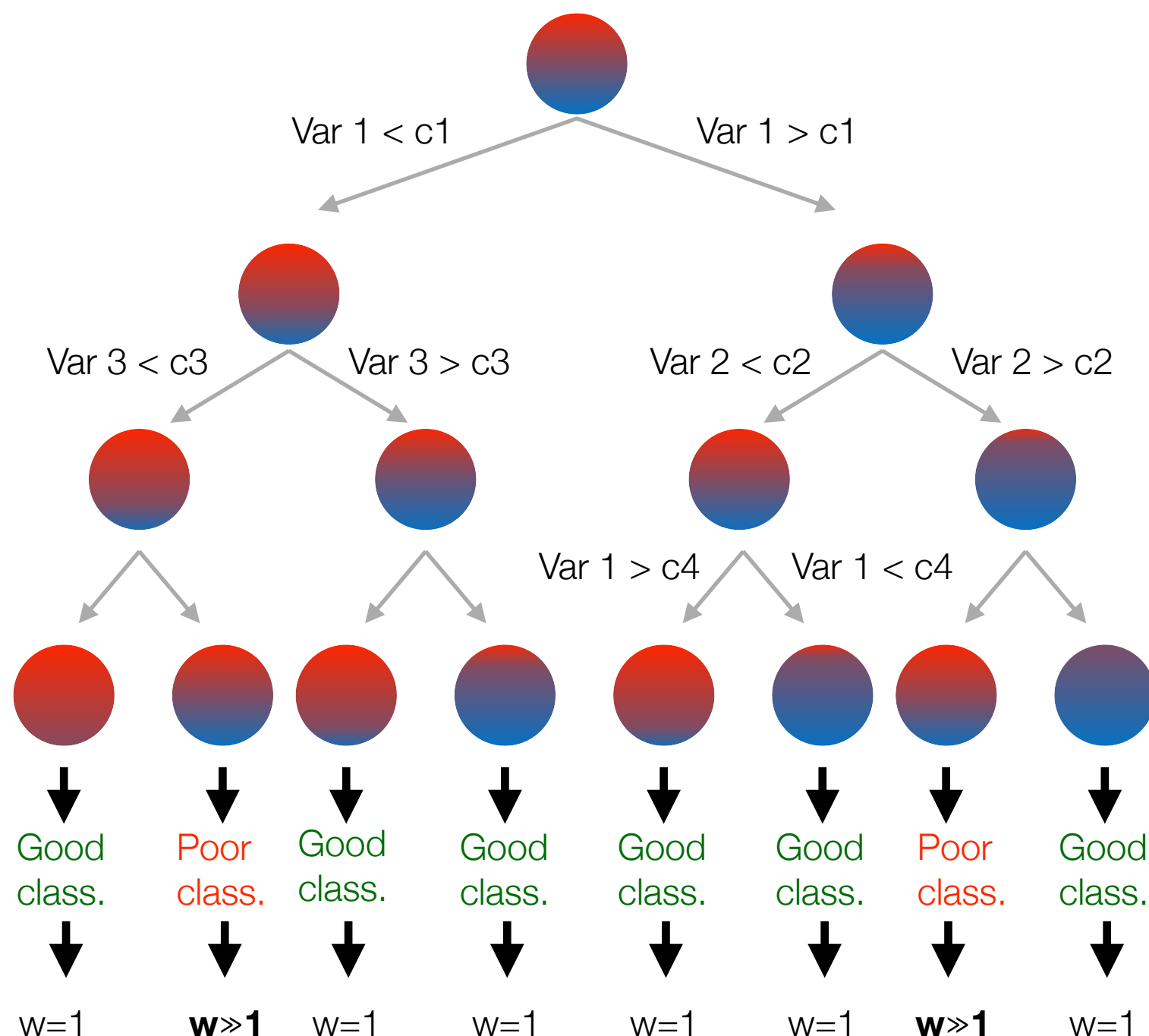
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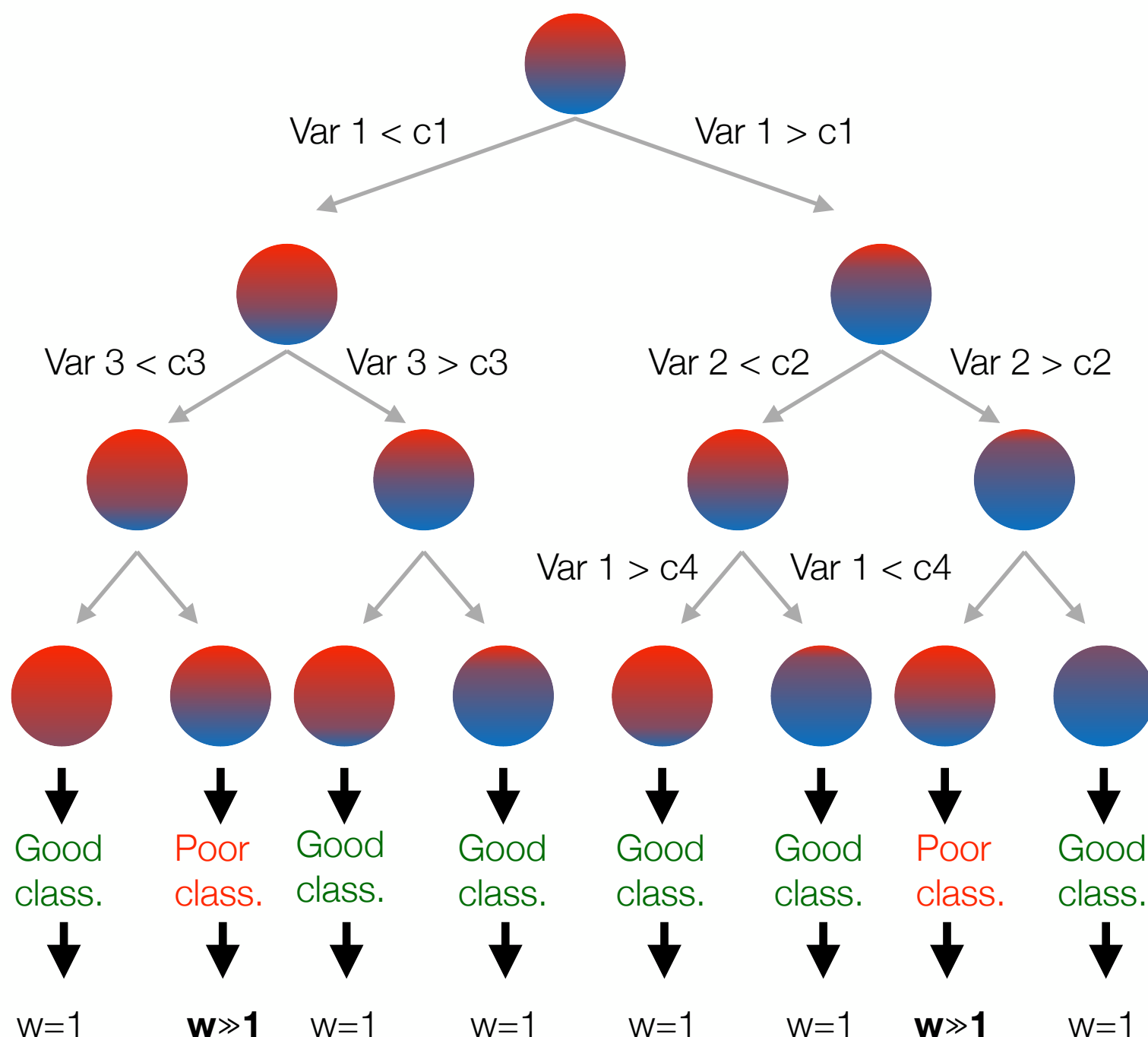
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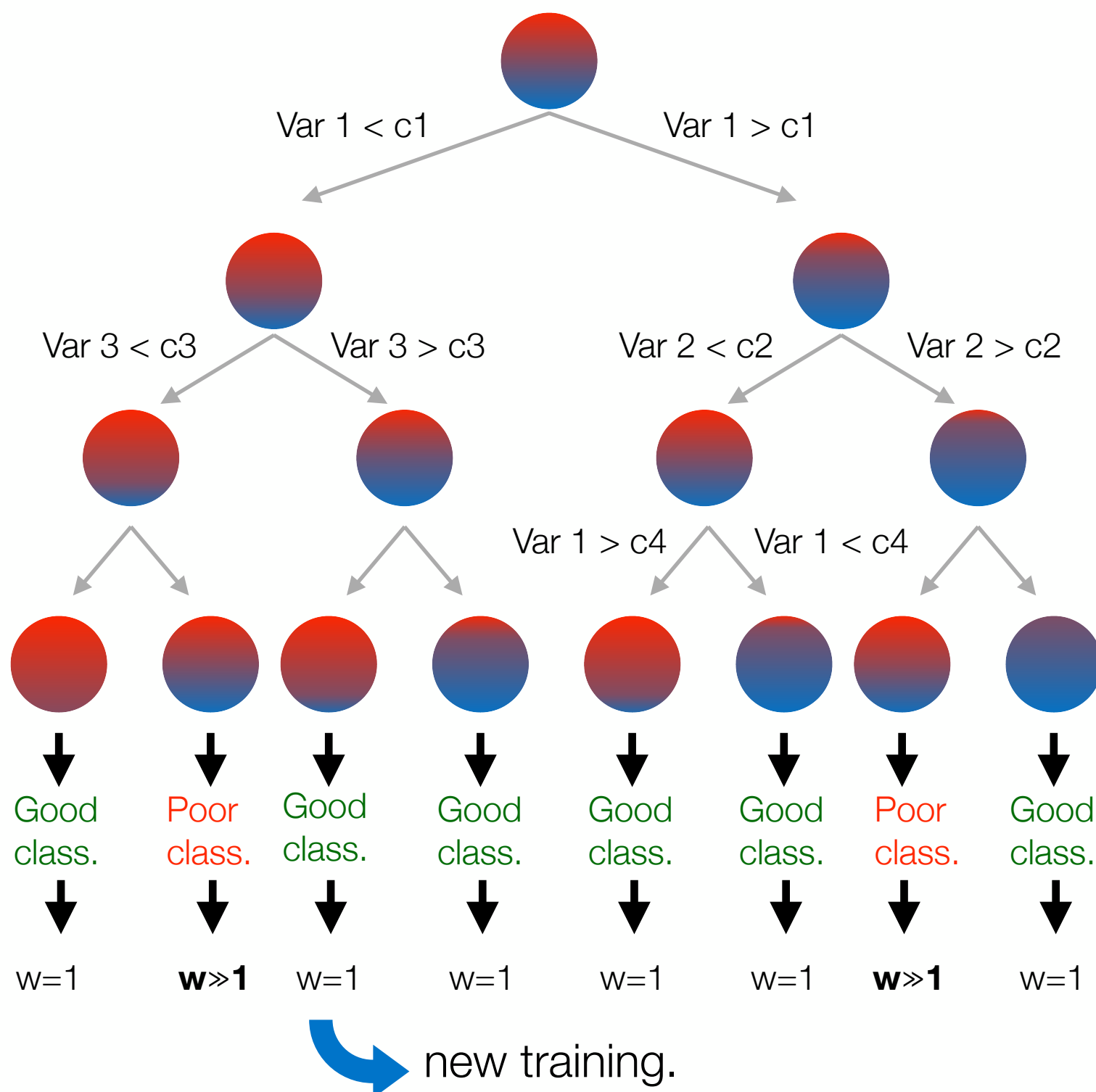
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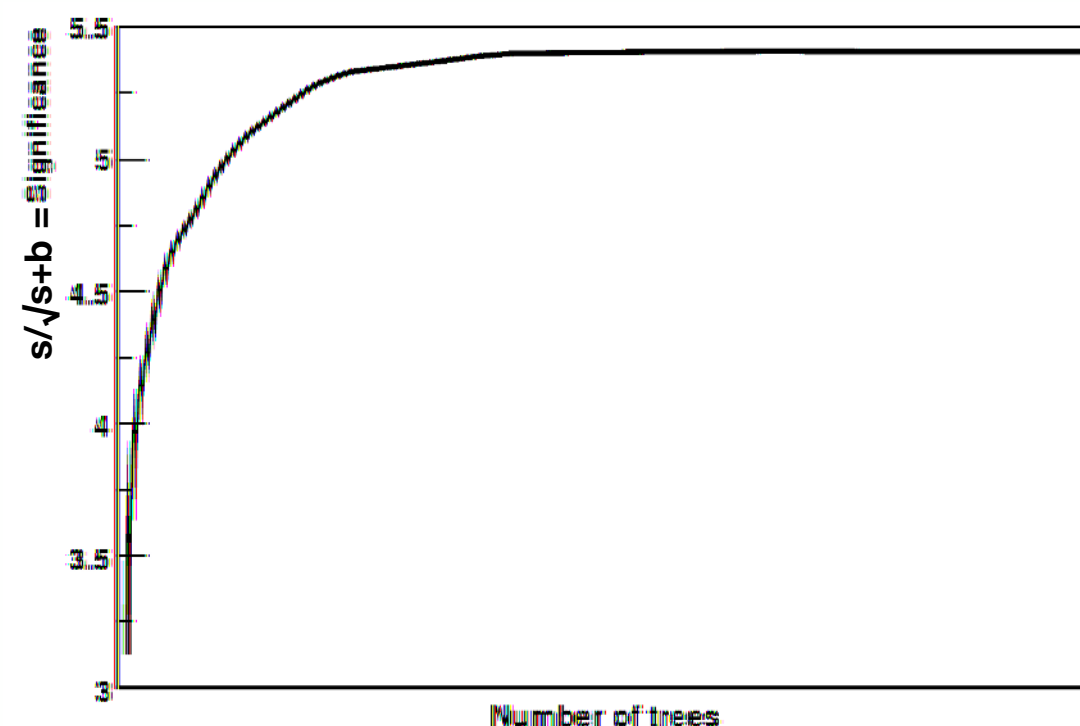
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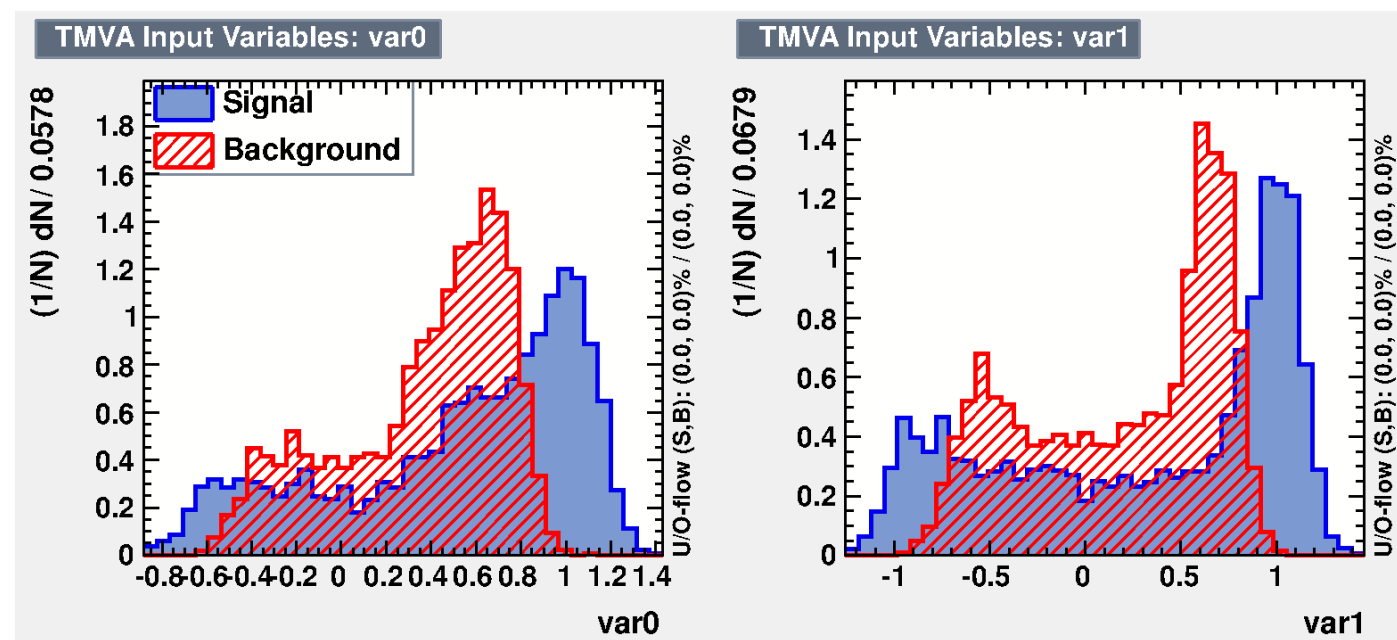
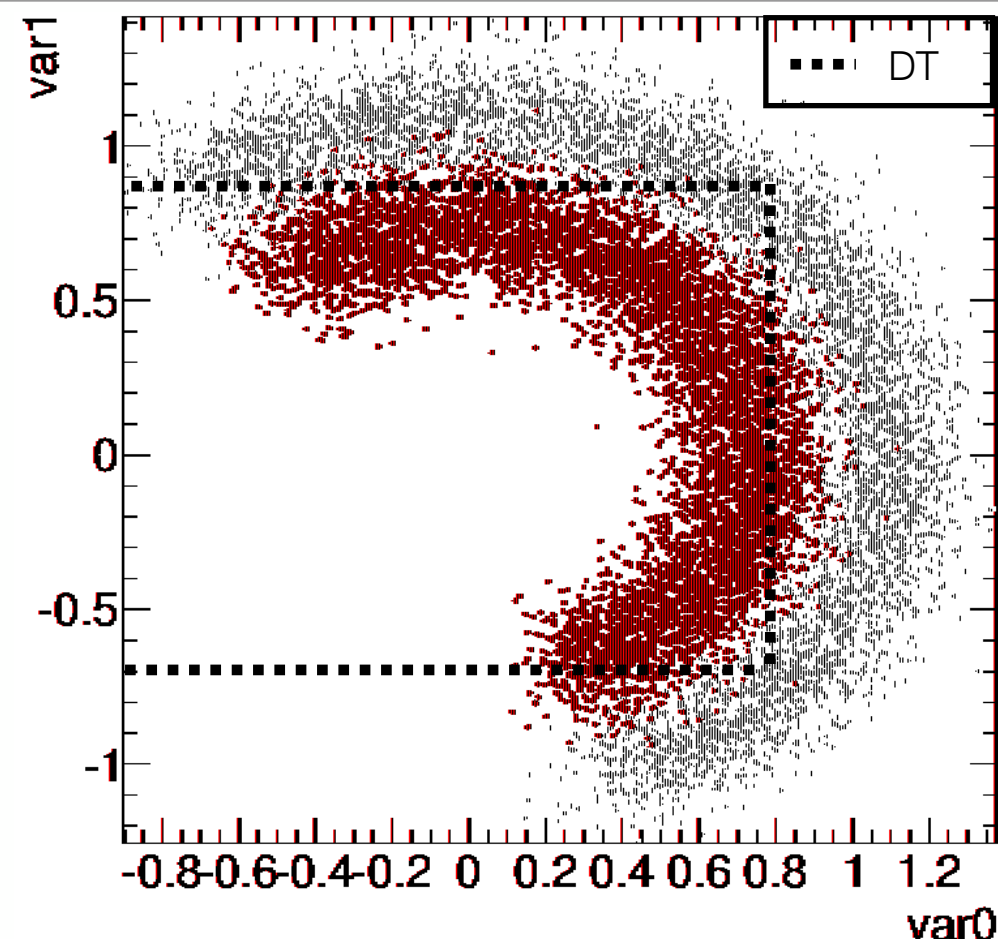
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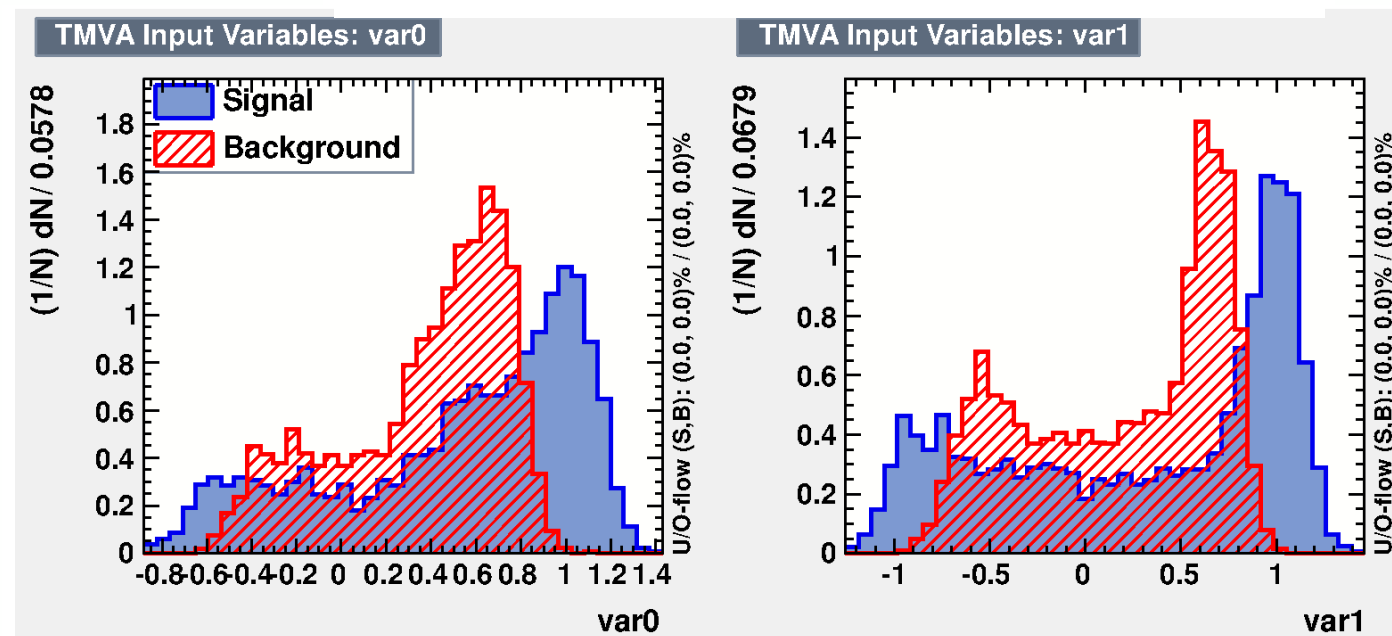
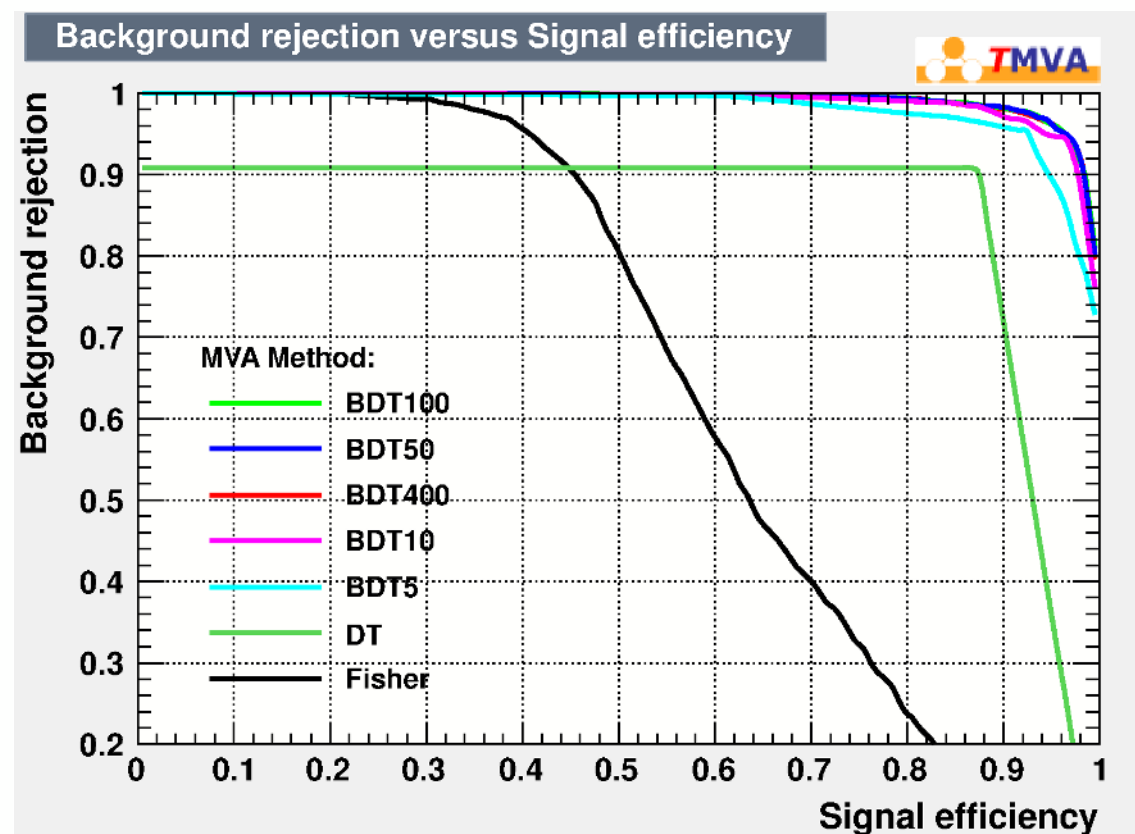
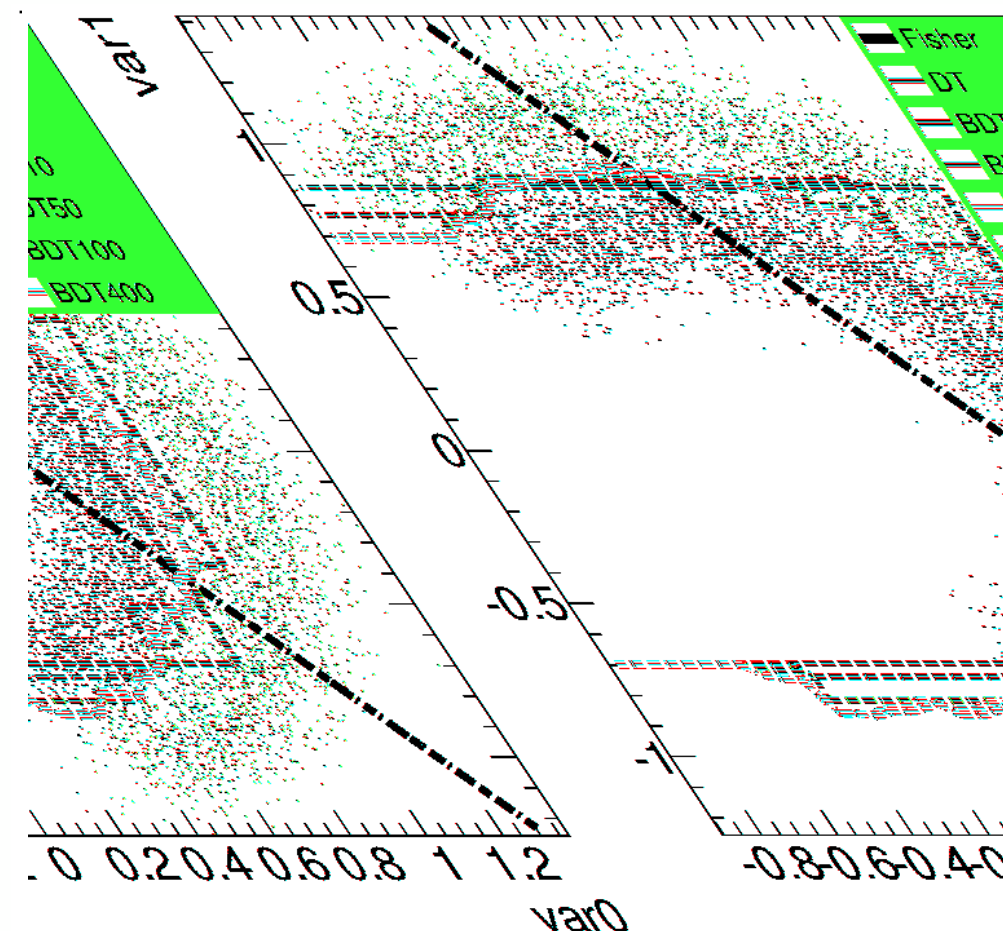
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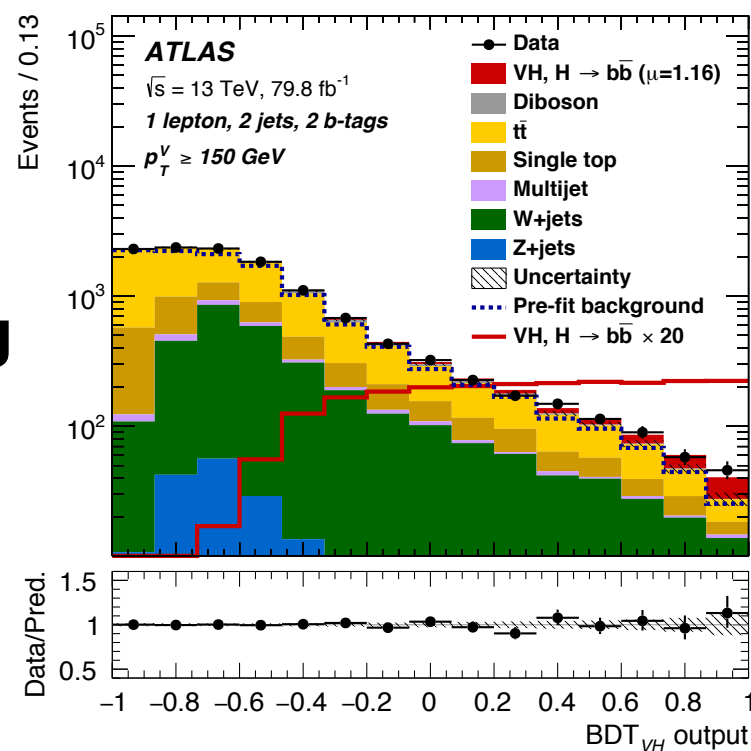
However **performances** are **similar** for more than **50 trees** → just a waste of CPU.



Application to $H \rightarrow b\bar{b}$ observation

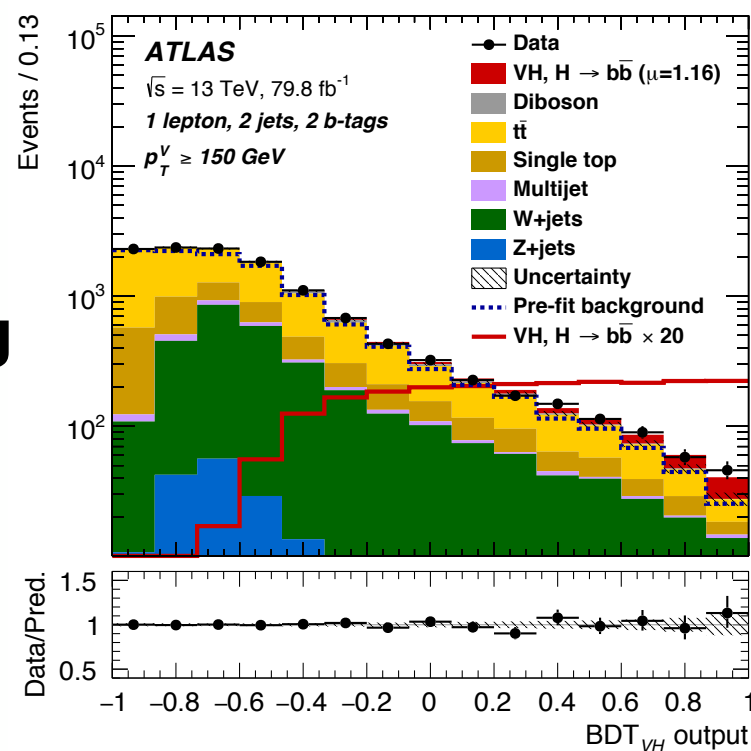
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Machine learning
technique

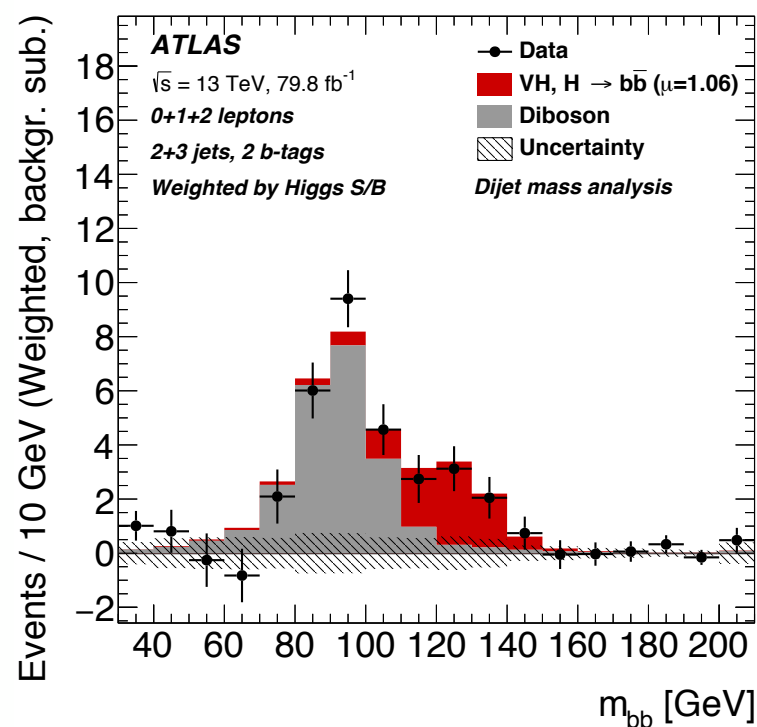


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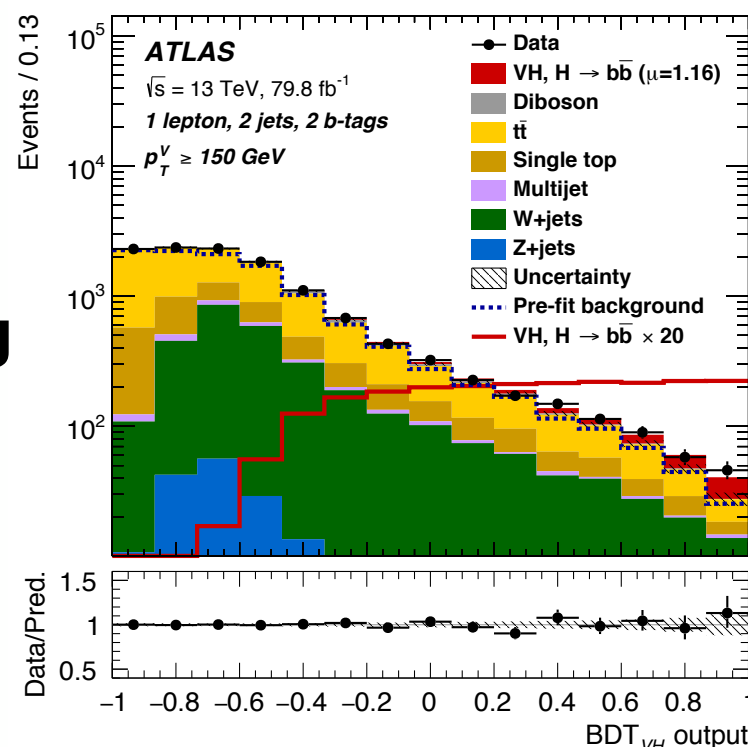


Cut and count
technique



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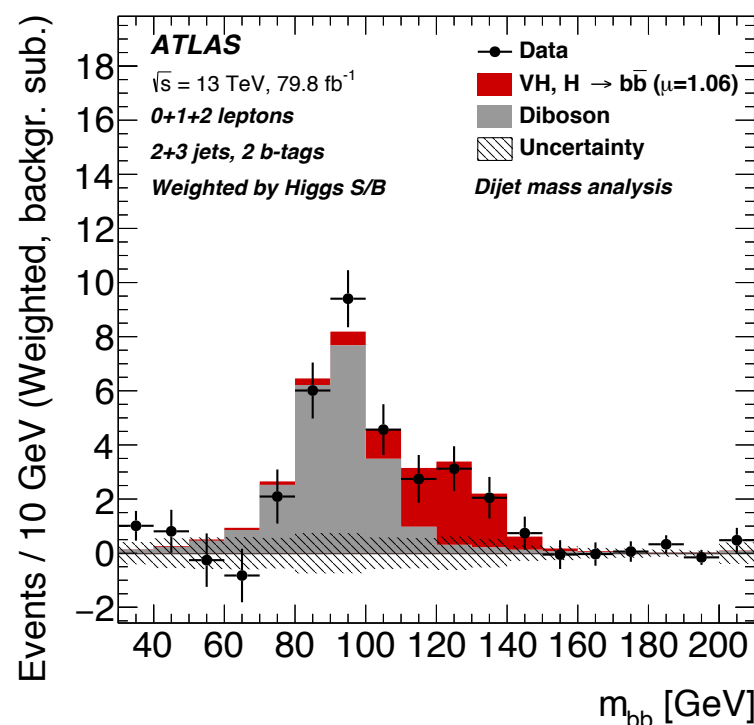


→ statistical **significance**: 4.9σ **observation**

Confidence taking
into account all
possible source of
errors (experimental,
statistical,
modelisation...)

Gain of 27%

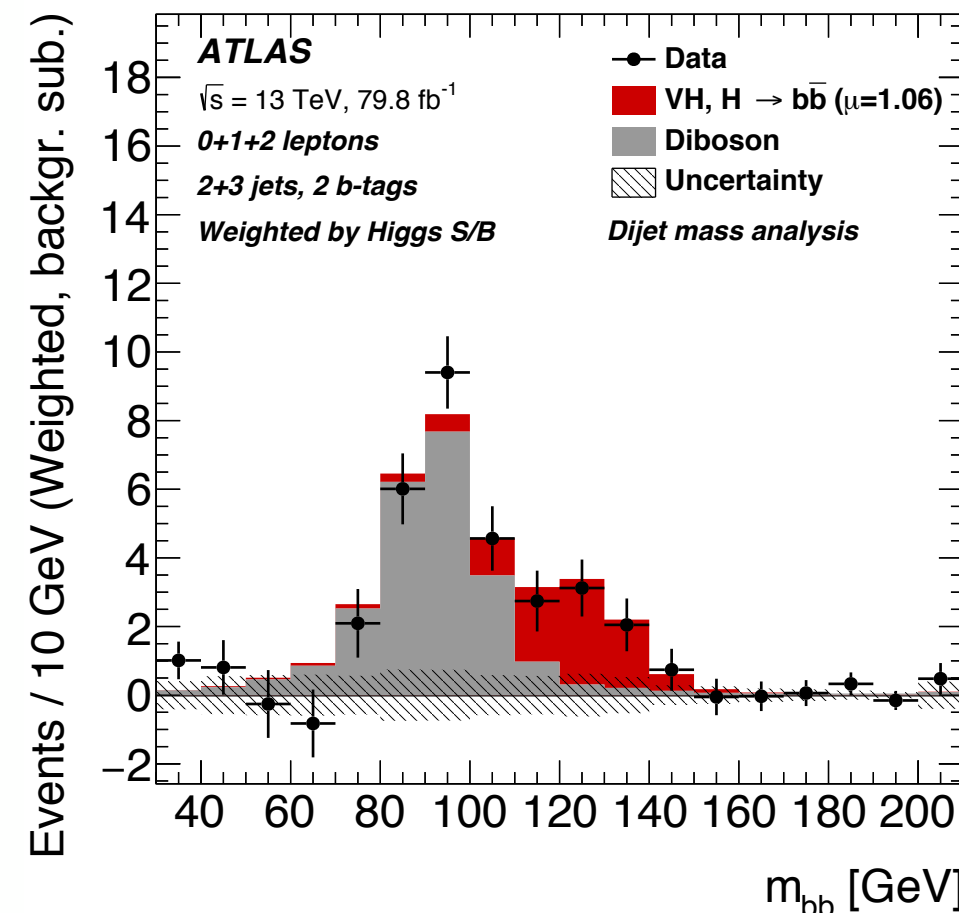
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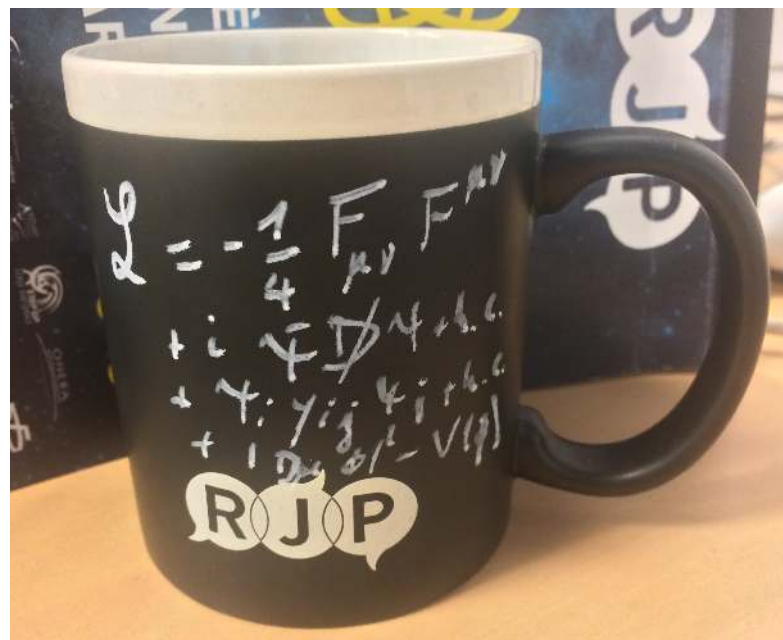
→ statistical **significance**: 3.6σ **evidence...**

Conclusion

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- In order to explain the **mass** of the **weak force mediators**, a spontaneously broken field has to be involved, and requires a new particle: the **Higgs Boson**
- Its **coupling** to the **b quarks** is a rather experimental **complex** but **fascinating** question.
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