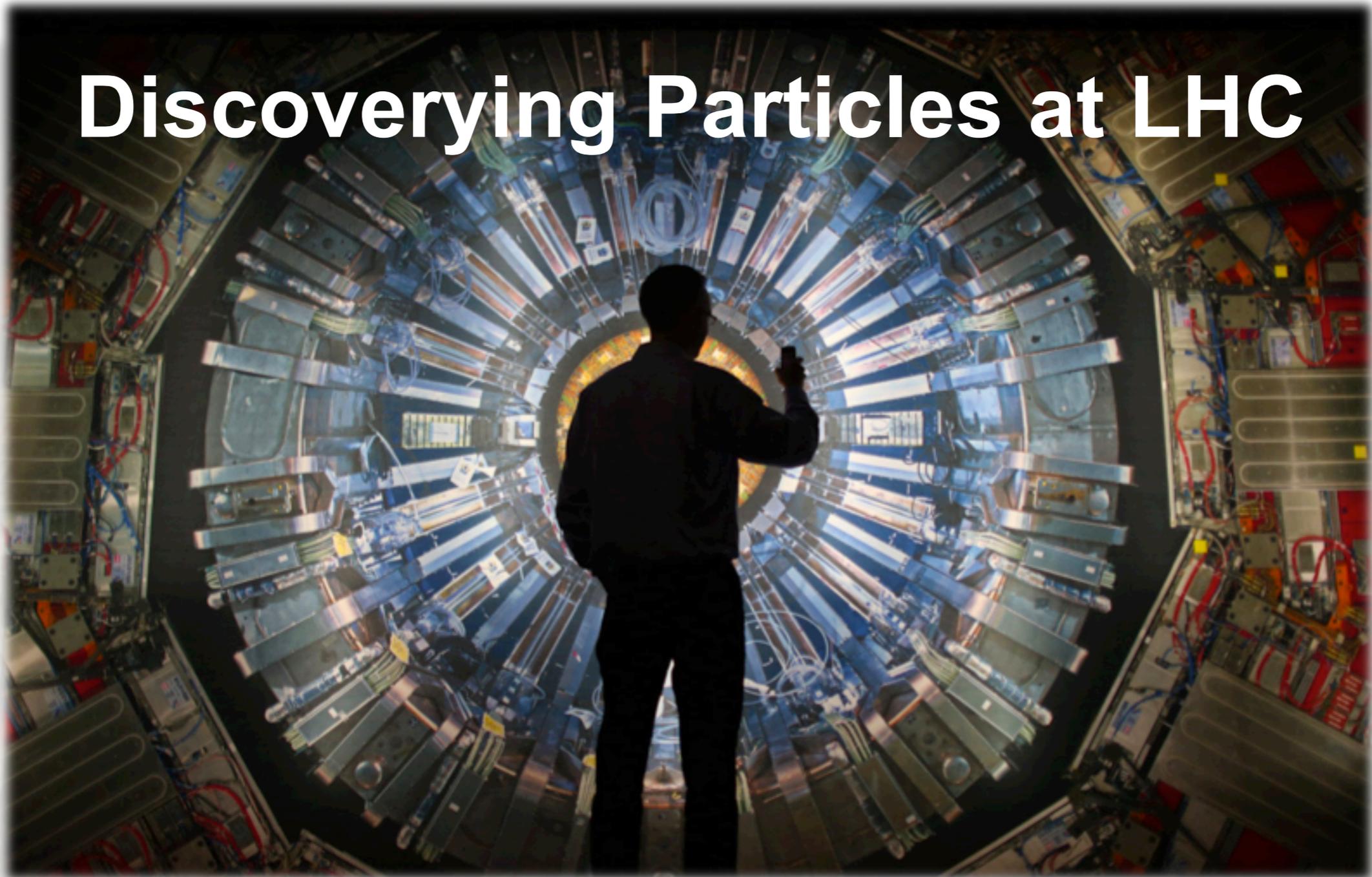


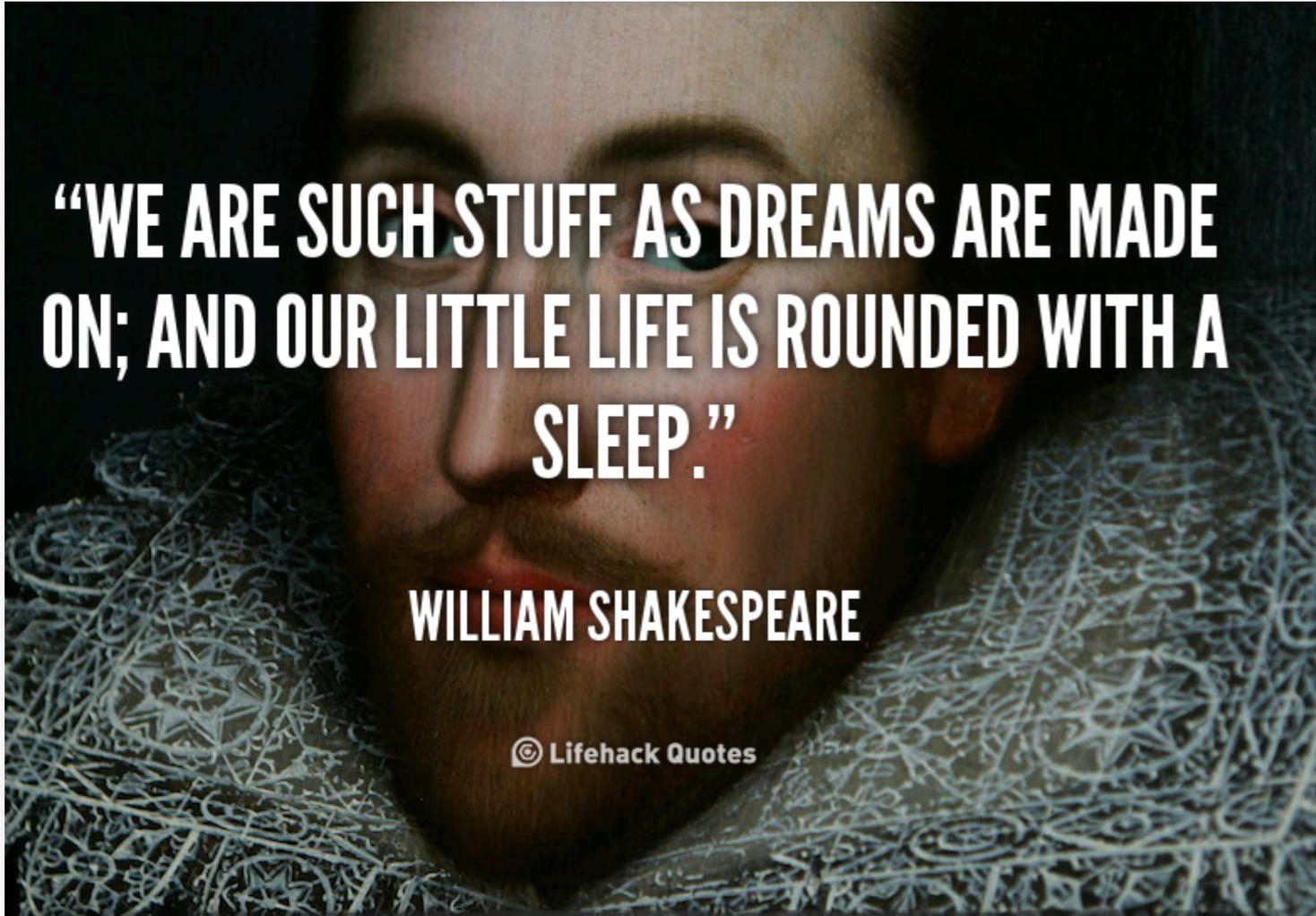
Discovering Particles at LHC



Livia Soffi - Postdoctoral Researcher
Cornell University , New York, USA

Viterbo, 17/02/2017

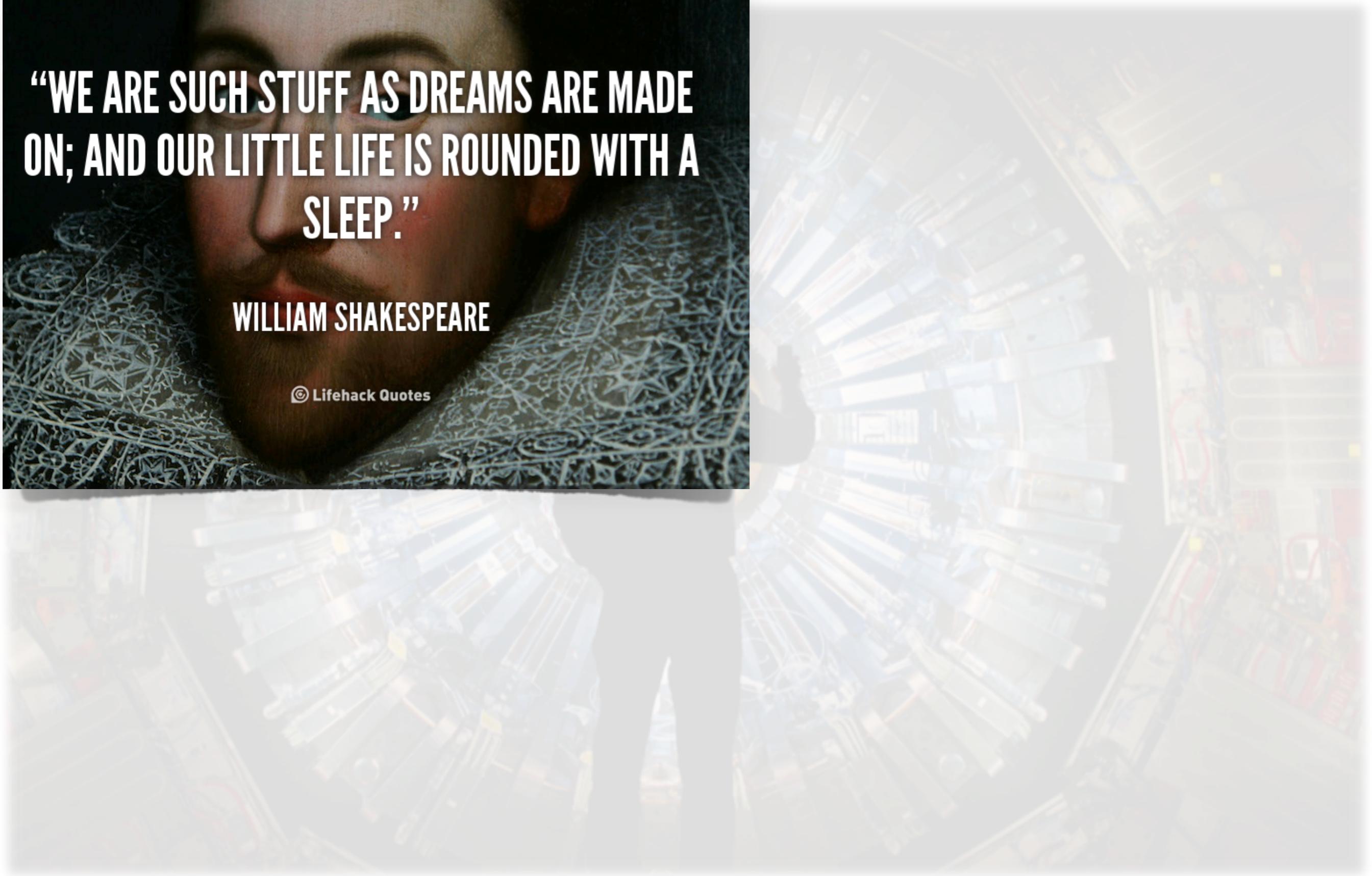
THE MACROSCOPIC WORLD



**“WE ARE SUCH STUFF AS DREAMS ARE MADE
ON; AND OUR LITTLE LIFE IS ROUNDED WITH A
SLEEP.”**

WILLIAM SHAKESPEARE

© Lifehack Quotes

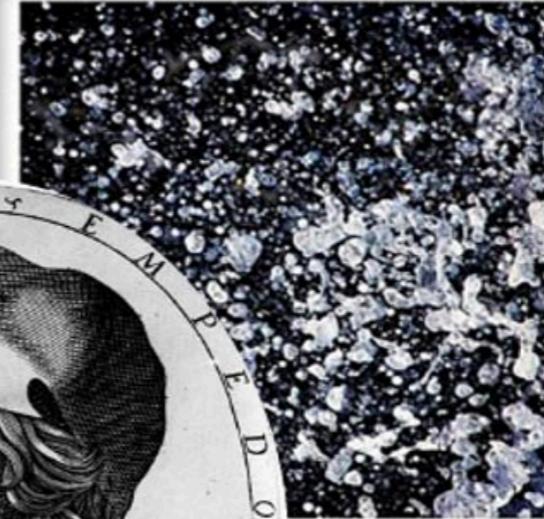


THE MACROSCOPIC WORLD

“WE ARE SUCH STUFF AS DREAMS ARE MADE ON; AND OUR LITTLE LIFE IS ROUNDED WITH A SLEEP.”

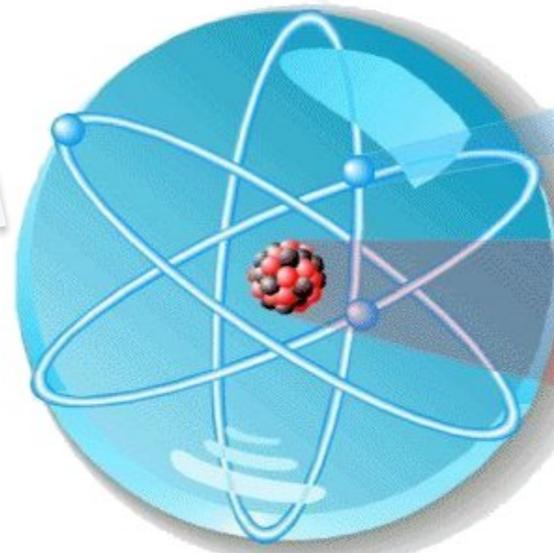
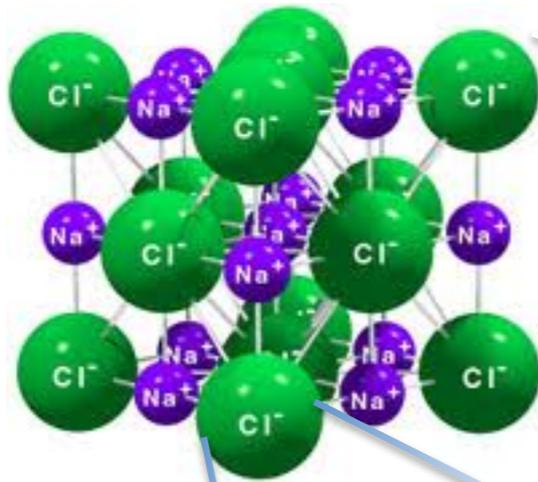
WILLIAM SHAKESPEARE

© Lifehack Quotes



THE MACROSCOPIC WORLD

“WE ARE SU
ON; AND OU



atom $\sim 10^{-8}$ cm

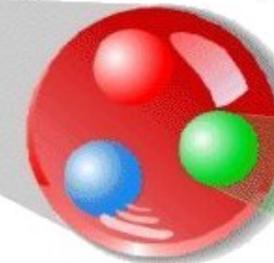


electron
 $< 10^{-16}$ cm



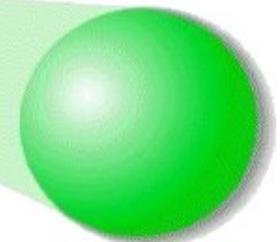
nucleus
 $\sim 10^{-12}$ cm

proton
(neutron)



$\sim 10^{-13}$ cm

quark
 $< 10^{-16}$ cm



"ELEMENTARY WATSON"!!

- In particle physics we study the **origin of matter and its composition**
- We will discover that there are **forces that keep together the element of the ordinary matter**
- We call "**elementary**" **particles** the smallest and indivisible unit of matter
- Composite particles (like atoms) may "look" elementary just because we are not looking at them with an enough **powerful instrument!!**



BUT THEN.. WHY DO WE NEED THE LHC?

- In life, in general, we should **always use the right instrument**. In any situation :)



- **LHC is the most powerful “instrument”** we have to determine whether the particles are elementary or not!
- The dimension I can “see” is proportional to $1/E$ where E is the energy of my “probe”

→ **PROBING THE INFINITELY SMALL I NEED “A LOT” OF ENERGY**

IS THE ATOM "ELEMENTARY"?

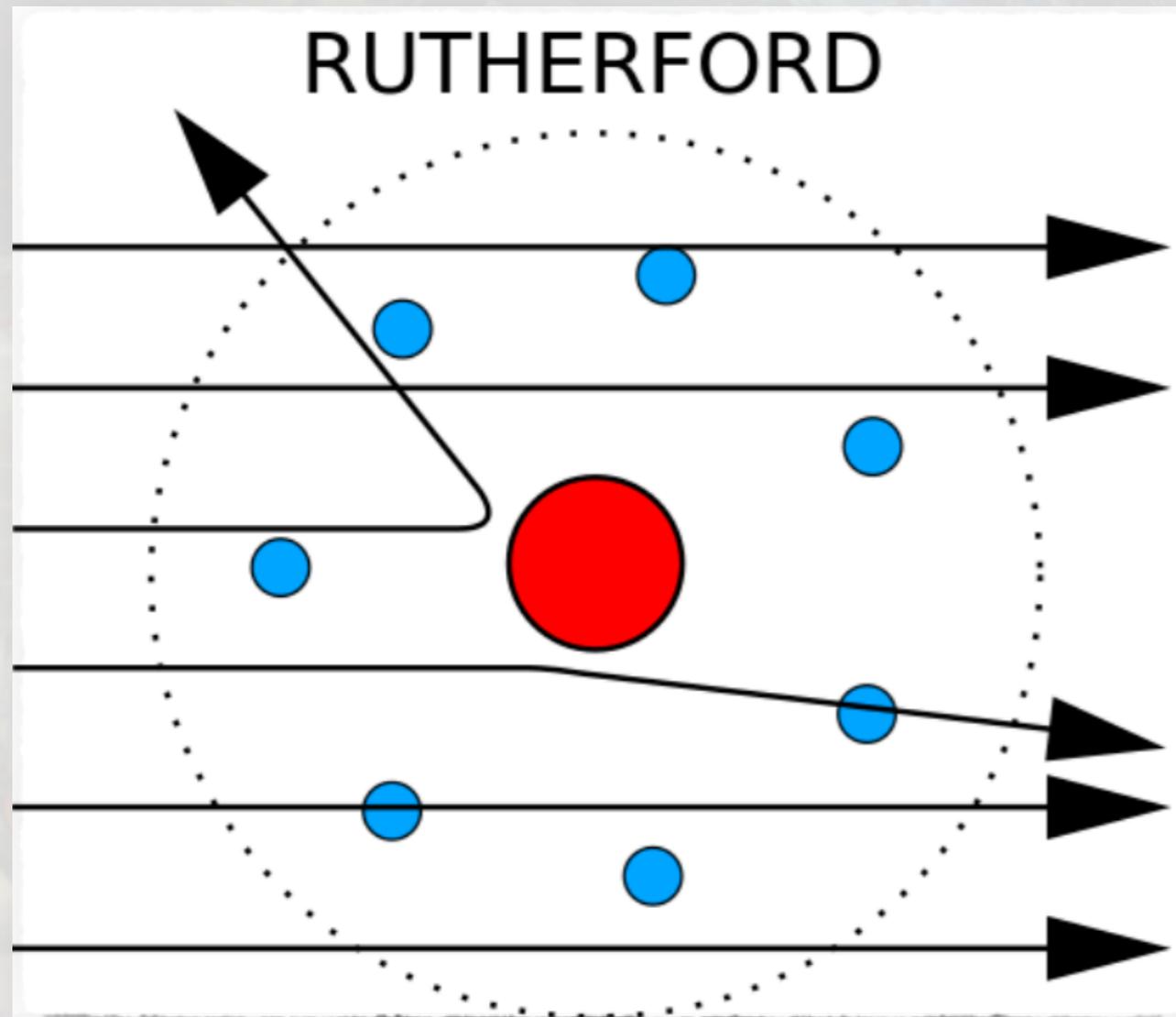
- The "Tex Willer" method can answer!



- **Shooting** to a sack and observing the deviation of the bullets I can understand if the sack contains sand or gold :D

IS THE ATOM "ELEMENTARY"?

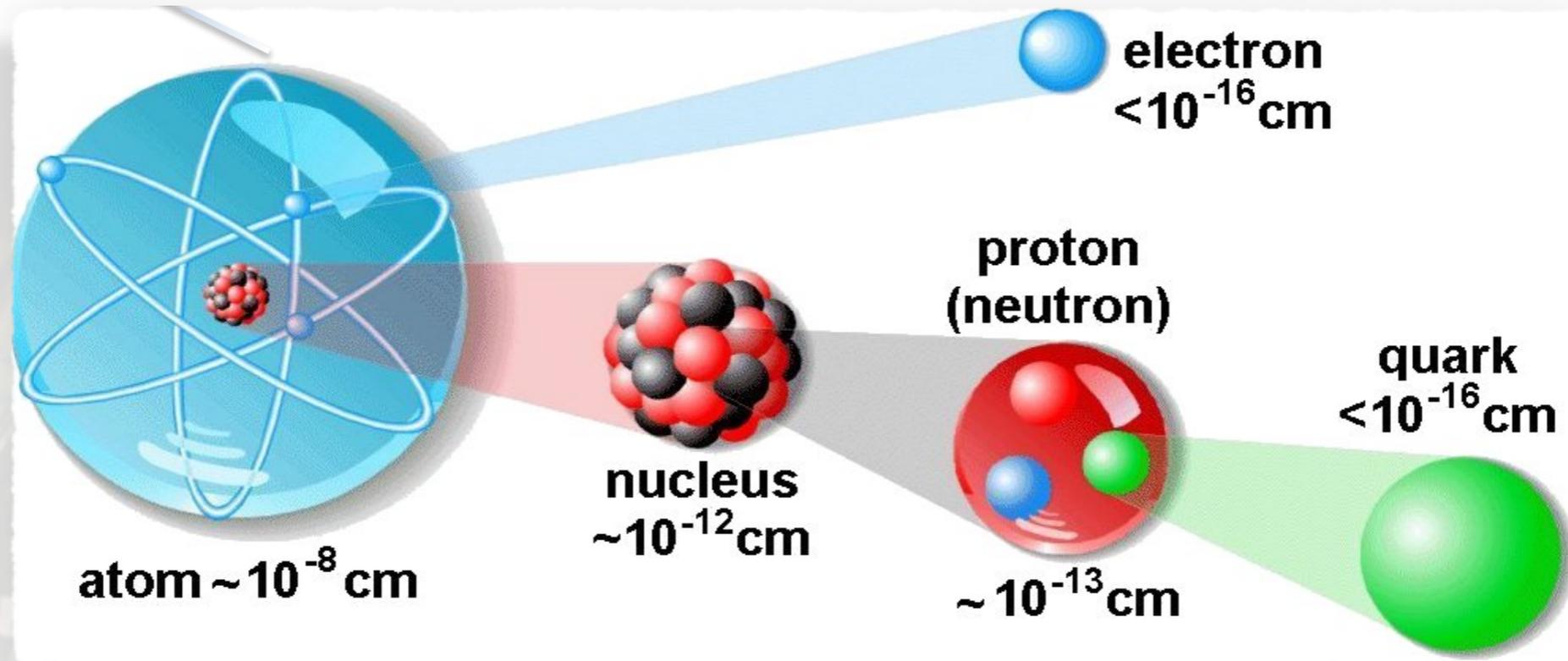
- 1909: The Rutherford Experiment



- Shoot "alpha" particles to the atoms and observe their deviation

→ DISCOVERY: THE ATOM IS "EMPTY" AND CONTAINS A CENTRAL STRUCTURE CALLED **NUCLEUS** WHICH HAS A RADIUS OF 10^{-15} M

IS THE NUCLEUS "ELEMENTARY"?



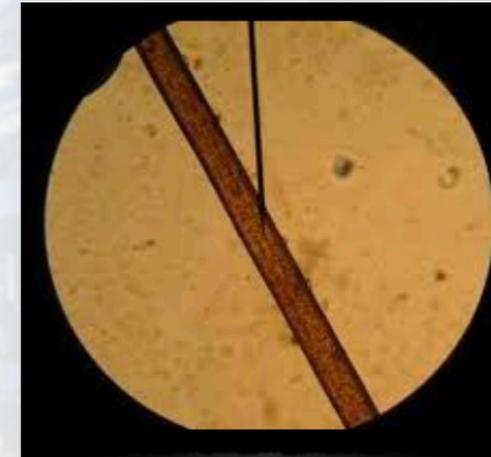
- 1909: The nucleus is composed by **protons (positive charge)** and **neutrons (neutral charge)**
- 1932: Protons and Neutrons are composed by elementary particles called **quarks**
- To understand this much more energetic "bullets" have been used: **cosmic rays and accelerators**

THE MICROSCOPIC WORLD

#1: If the electron weights like a 5cents coin, the proton would weight like 4 liters of milk



#2: You need to allineate 100000 atoms to cover the diameter of a hair



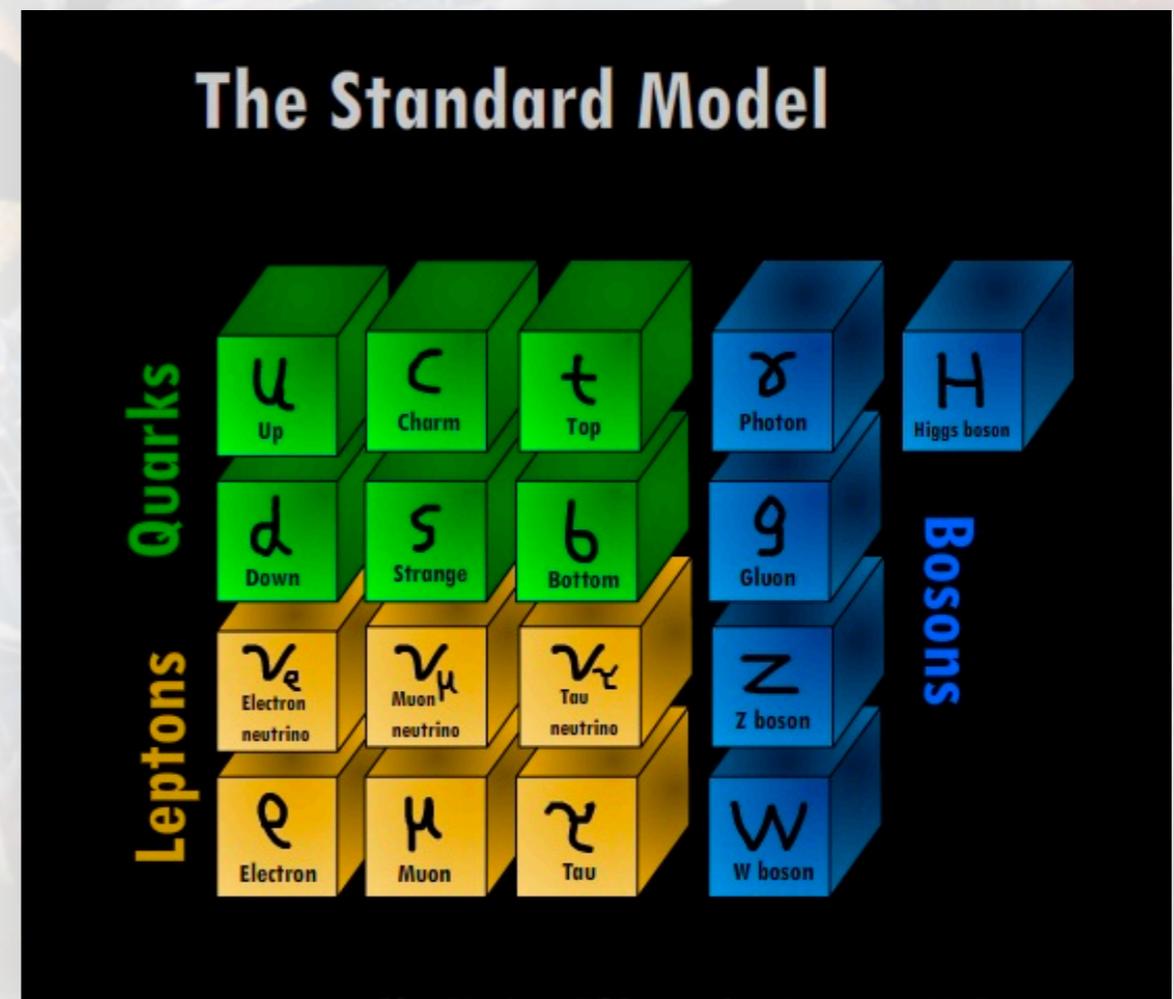
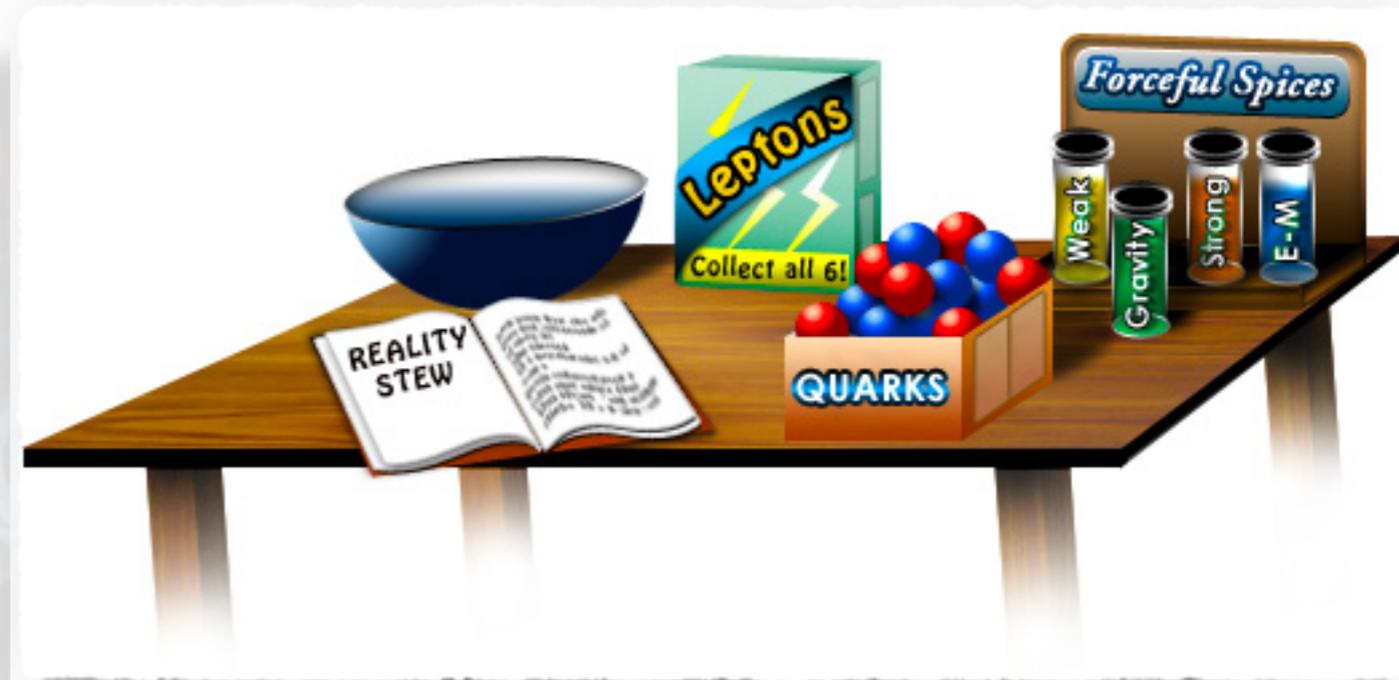
#3: The proportion between a nucleus and an electron is the same as the one between a football pitch and a tennis ball



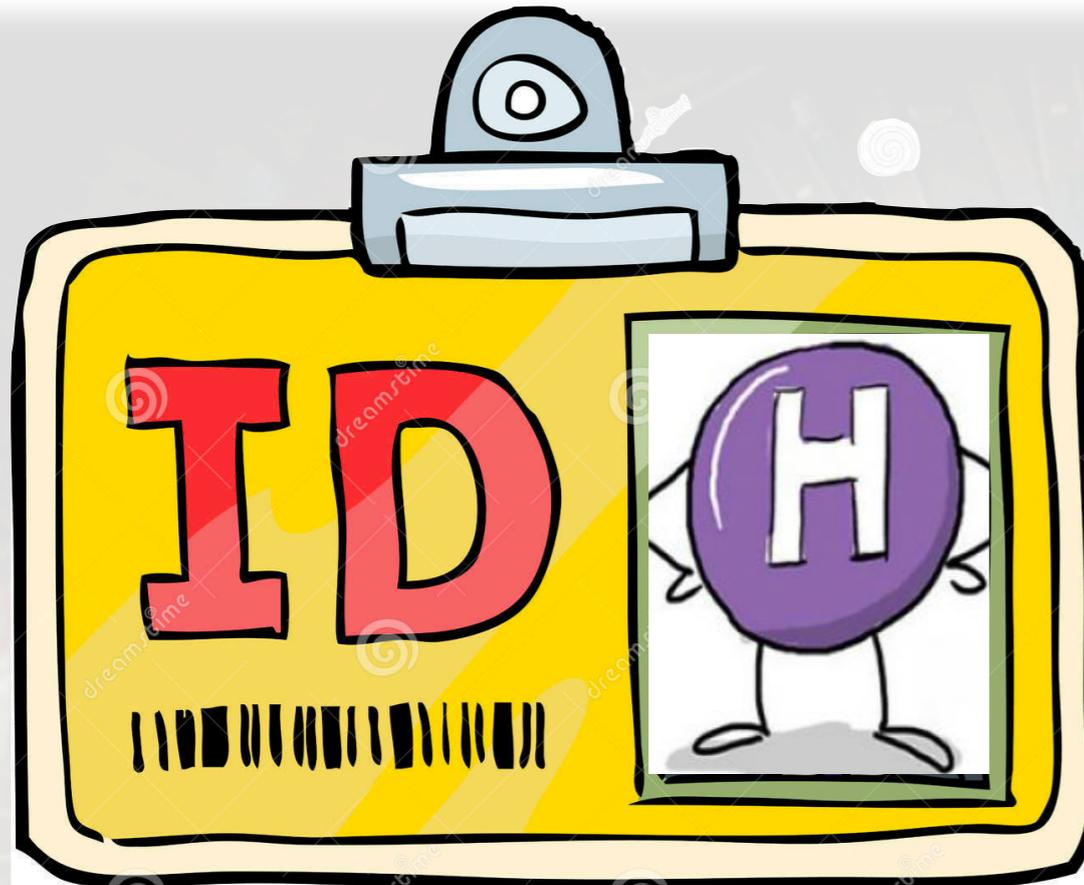
THE STANDARD MODEL OF PARTICLES

- Considers **all the known particles and their interactions**
- It provides **all the ingredients** needed to build the world where we live
- It describes with **high accuracy many experimental data** but..

.. there are still **unsolved questions** which motivate the **“Search for Physics Beyond the Standard Model”**



PARTICLE IDENTIKIT



- The properties that describe univocally a particle include:

#1: Charge

#2: Mass

Mass = Amount of matter (Newton 1687)

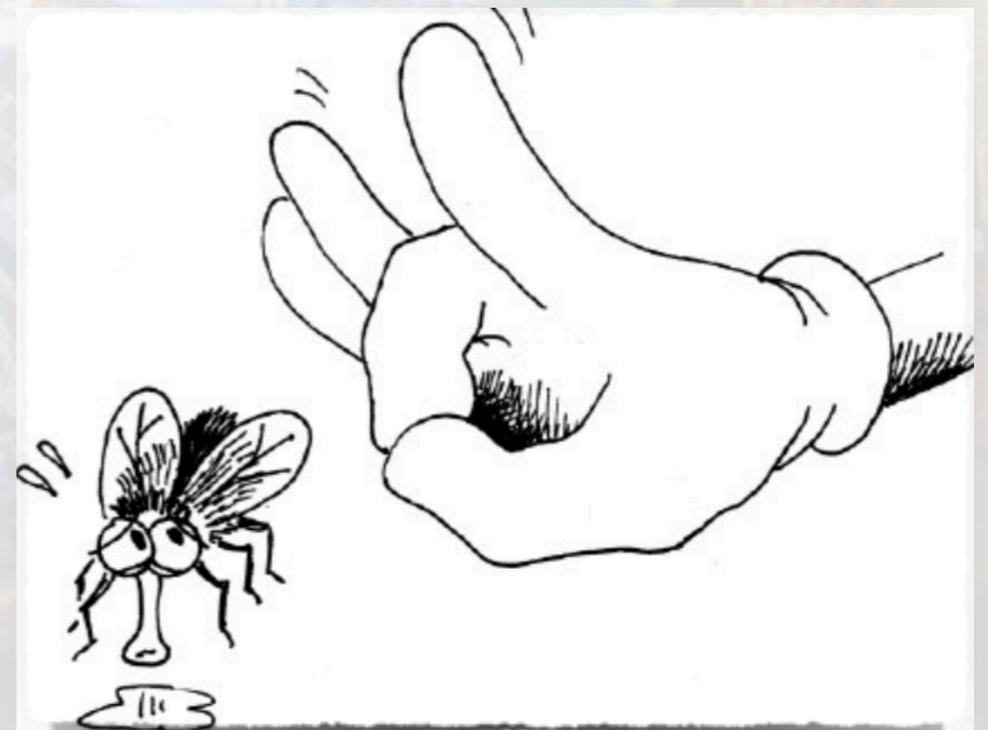
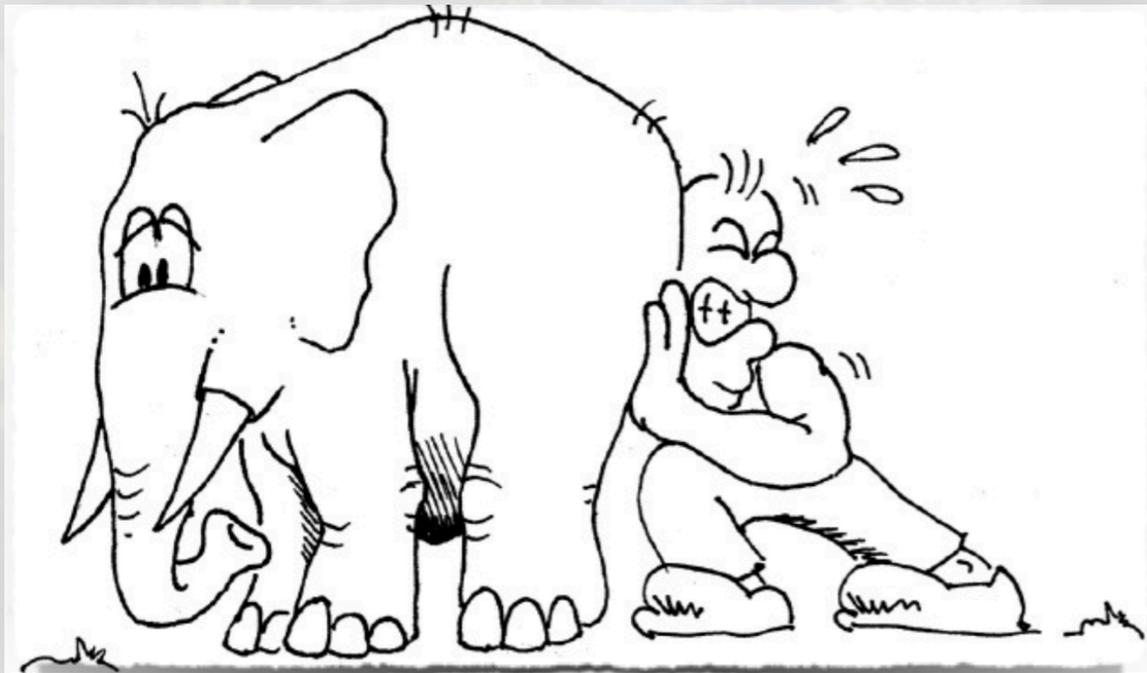


Mass = Amount of energy (Einstein 1905)



FORCES AND INTERACTIONS

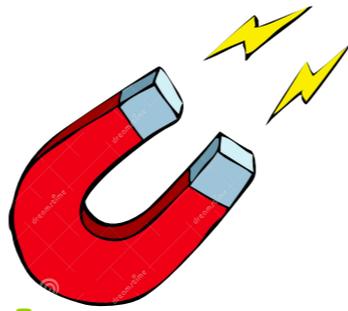
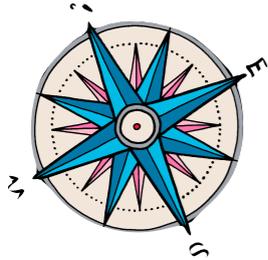
- The particles, and matter in general, **interact thanks to what we call forces**
- When we apply a force to an object, we **change its status of motion**
- **The lower the mass the easier to change is motion**



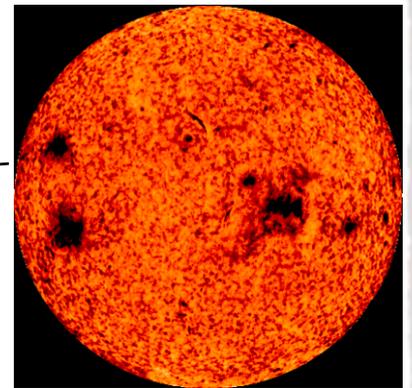
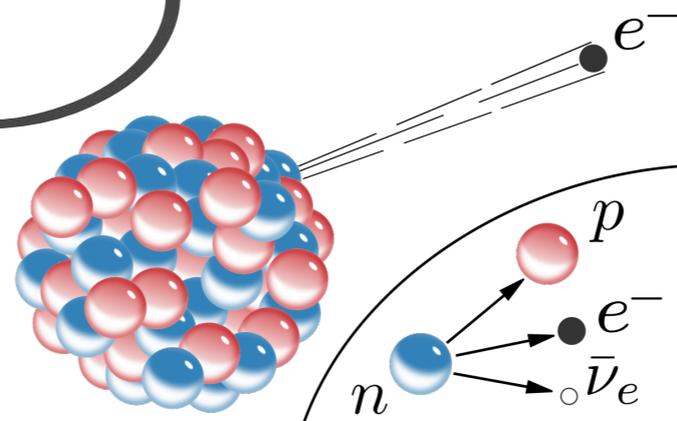
FANTASTIC FOUR



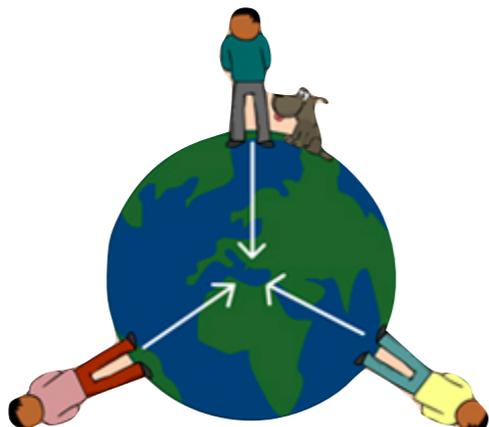
ELECTROMAGNETIC ($I=1$)



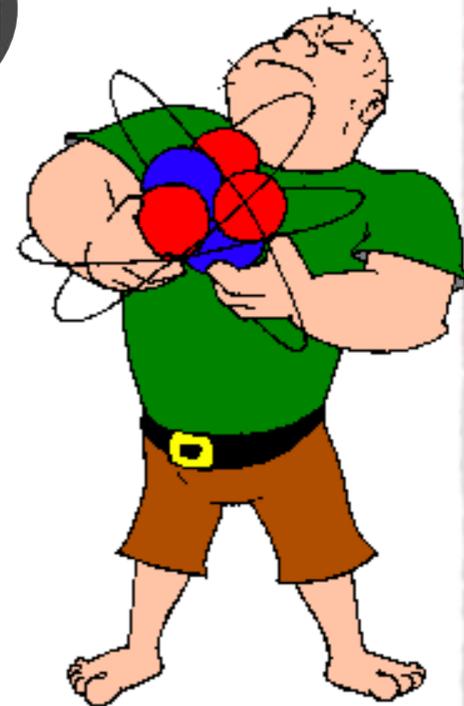
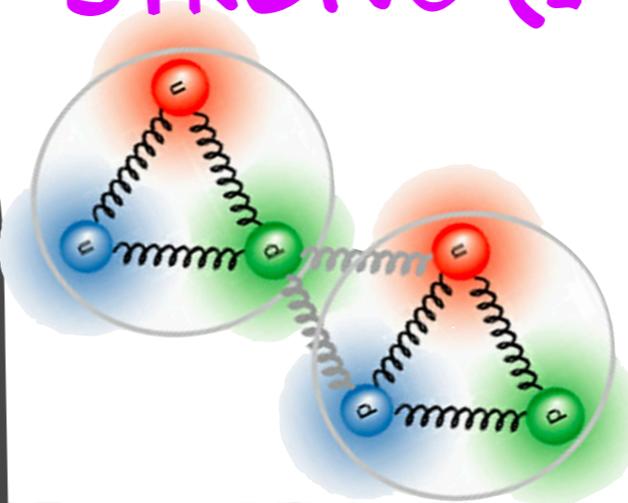
WEAK ($I=10^{-4}$)



GRAVITATIONAL ($I=10^{-41}$)



STRONG ($I=60$)



FORCES AS EXCHANGE OF PARTICLES

- Interactions which affect matter particles are due to an **exchange of force carrier particles**
- These particles are **like basketballs tossed between matter particles**

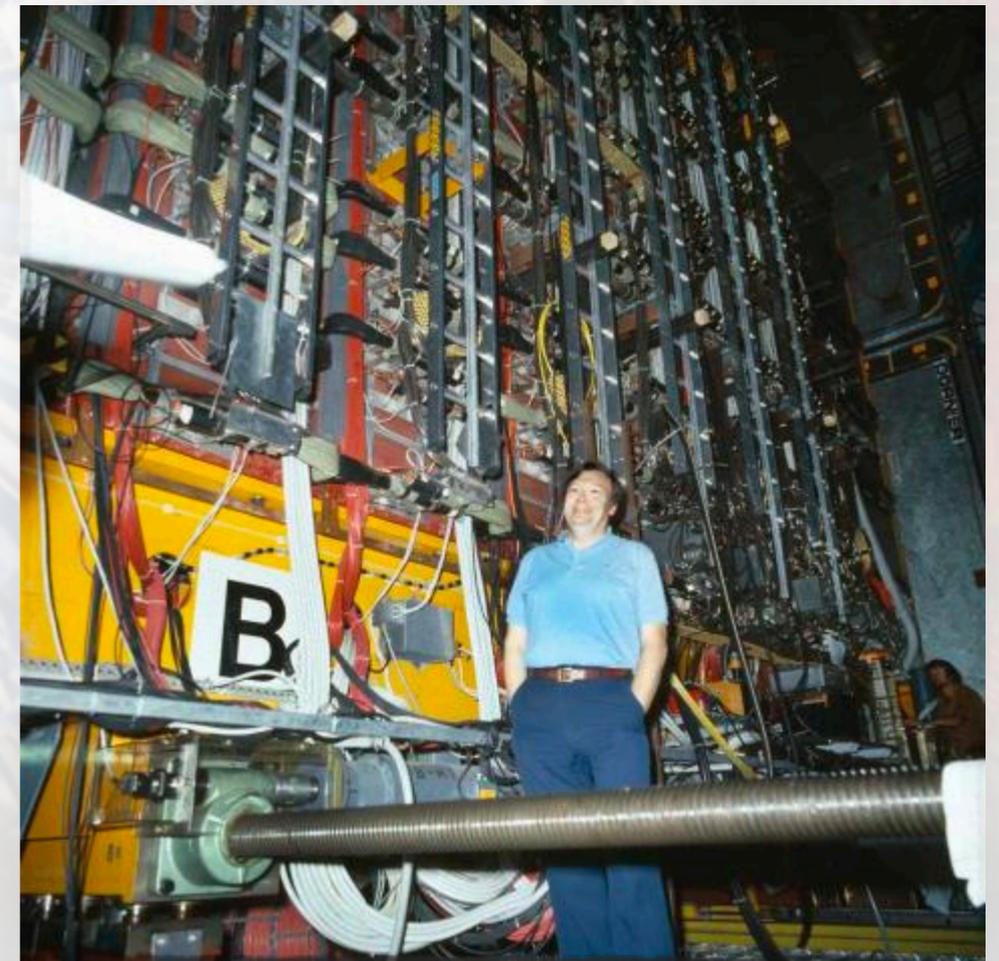


THE W AND Z BOSONS

→ W AND Z BOSONS ARE THE PARTICLES MEDIATOR OF THE WEAK FORCE

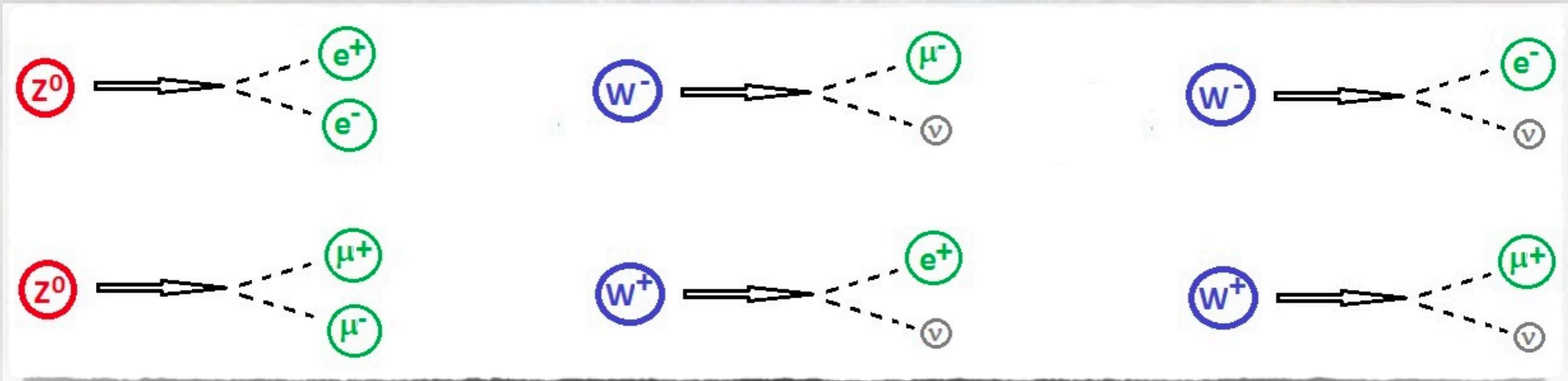
- They have been **predicted in the 1960`s** to explain the “beta” decays observed well before by Fermi.

- Theory predicted **W and Z masses around 100 GeV** and physicists at CERN built in early 1980`s the first most powerful collider able to reach such high energies: the SpPpS



DISCOVERY OF A NEW PARTICLE

- The **Z and W bosons** produced at LHC do not live long, but **decay immediately to other elementary particles that can be measured by the CMS and ATLAS detectors**



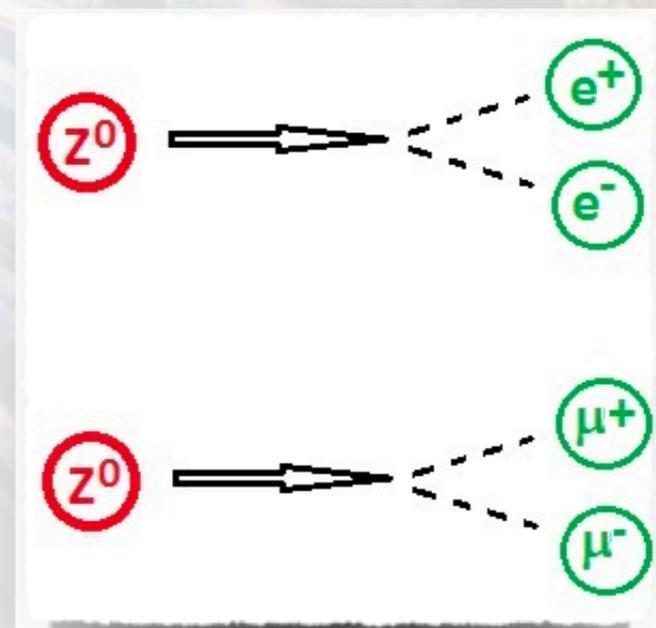
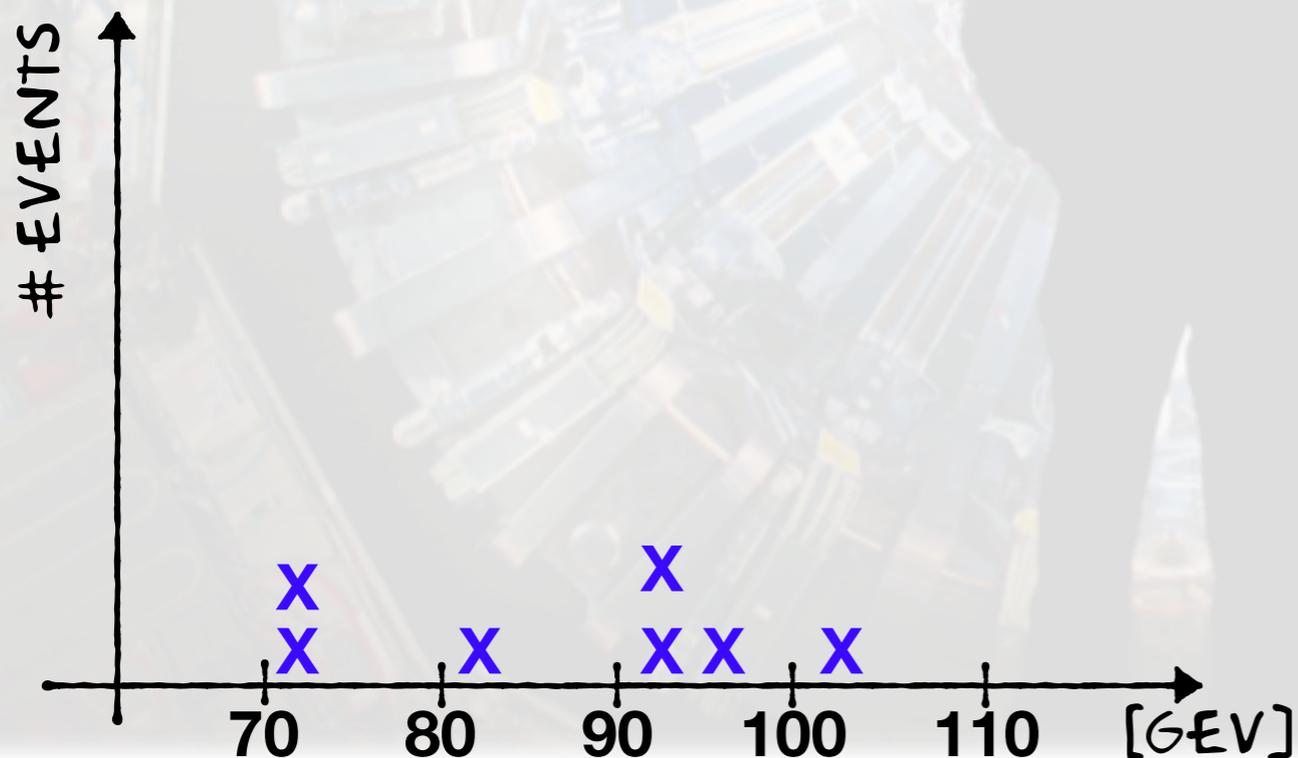
- So when in an LHC collision we produce a Z or W particle, **what we detect in the our experiments are only electrons and muons!**

THE Z BOSON MASS RECONSTRUCTION

- Measuring the **energies** and the **direction of production** of the two electrons or muons, we can compute the mass of the particle that have produced them in its decays:

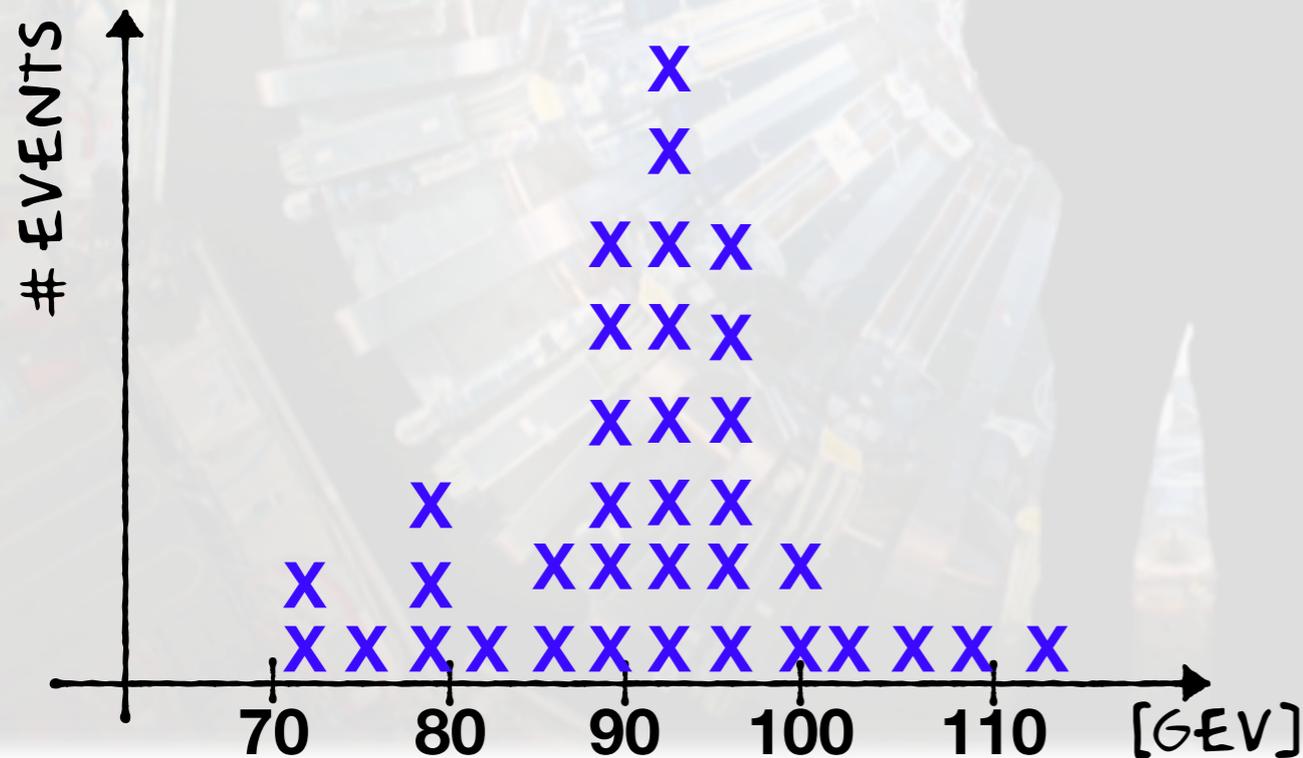
$$m_X = \sqrt{2E_1E_2(1 - \cos\theta)}$$

- In each **event** where we have two electrons/or muons we compute the Z mass with this formula and we fill an histogram of events:



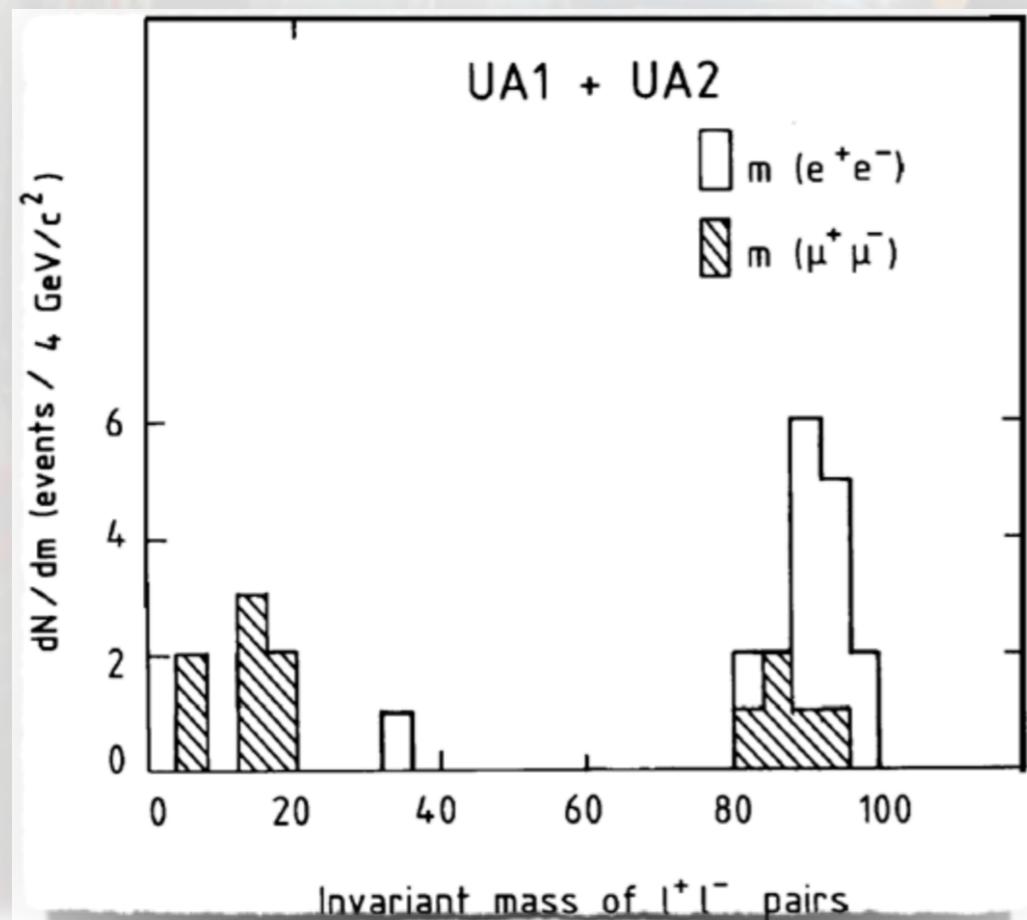
THE Z BOSON MASS RECONSTRUCTION

- A PEAK OF EVENTS WILL APPEAR CLOSE TO THE TRUE VALUE OF THE MASS OF THE Z BOSON IF THE Z EXISTS
- IF THE "EXCESS" OF EVENTS IS SIGNIFICANTLY BIG., WE DISCOVERED A NEW PARTICLE"



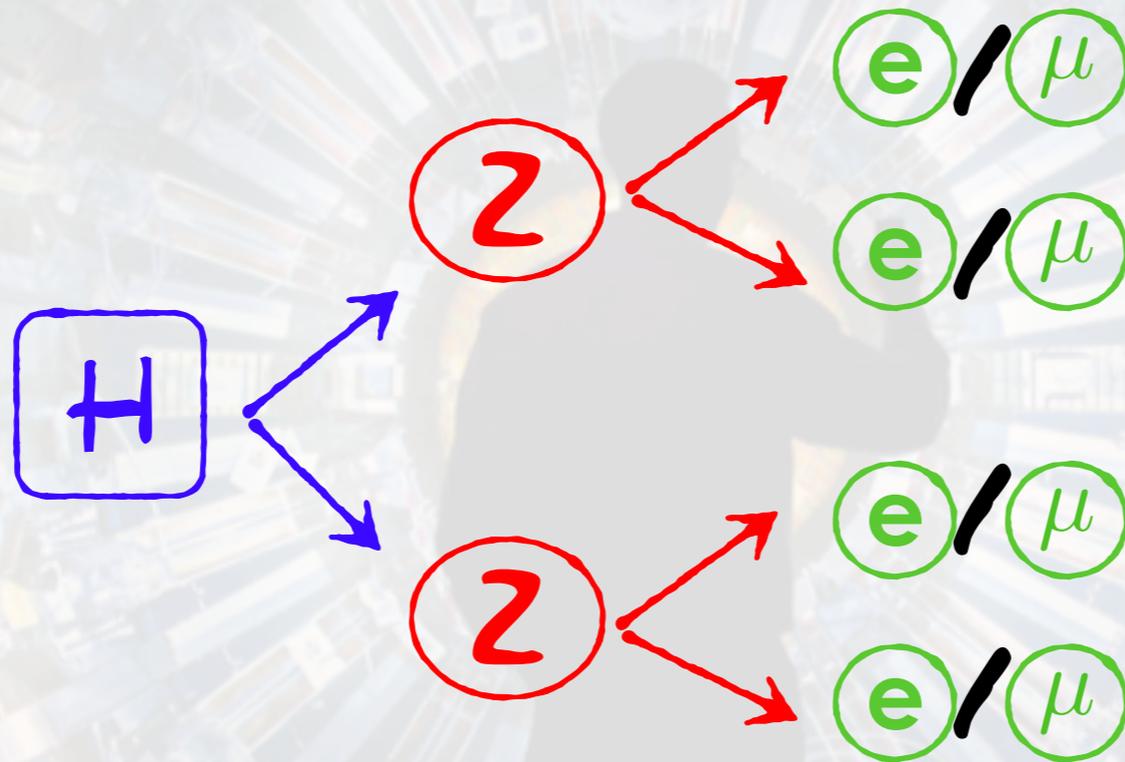
THE Z BOSON MASS RECONSTRUCTION

- A PEAK OF EVENTS WILL APPEAR CLOSE TO THE TRUE VALUE OF THE MASS OF THE Z BOSON IF THE Z EXISTS
- IF THE "EXCESS" OF EVENTS IS SIGNIFICANTLY BIG.. WE DISCOVERED A NEW PARTICLE"
- IN 1983 THE UA1 AND UA2 EXPERIMENTS AT CERN: DISCOVERY OF THE W AND Z BOSON



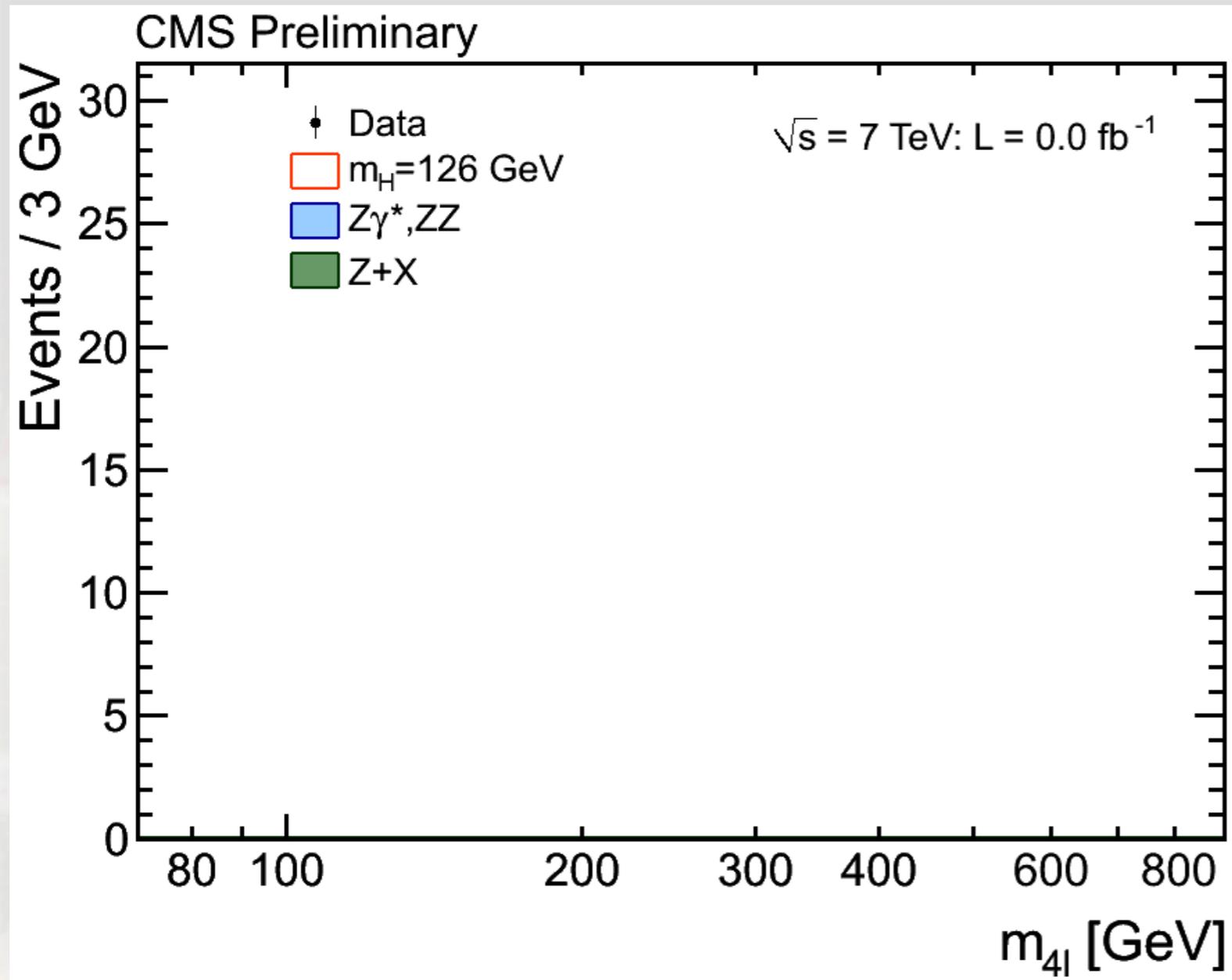
HOW WE USE THE Z BOSON TO DISCOVER THE HIGGS

- The discovery of the Z boson opened the opportunity to “use” the recently discovered particle for the quest of the Higgs boson:



- Either decays of the **Z** to **electrons or muons** are considered

2012: THE DISCOVERY OF THE HIGGS BOSON



IS THE HIGGS THE END OF THE STORY?

- The answer is: **NO!**
- There is a wide panorama of **physics beyond the standard model** that we can explore
- We have seen that there are **many questions** about nature that the standard model of particle physics cannot explain
- The **origin and properties of Dark Matter** are our priorities and..
- .. we can now **“use” the Higgs boson to probe the existence of Dark Matter!**

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High Energy Physics - Experiment

Search for associated production of dark matter with a Higgs boson decaying to $b\text{-}\bar{b}$ or $\gamma\text{-}\gamma$ at $\sqrt{s} = 13$ TeV

CMS Collaboration

(Submitted on 15 Mar 2017)

Download:

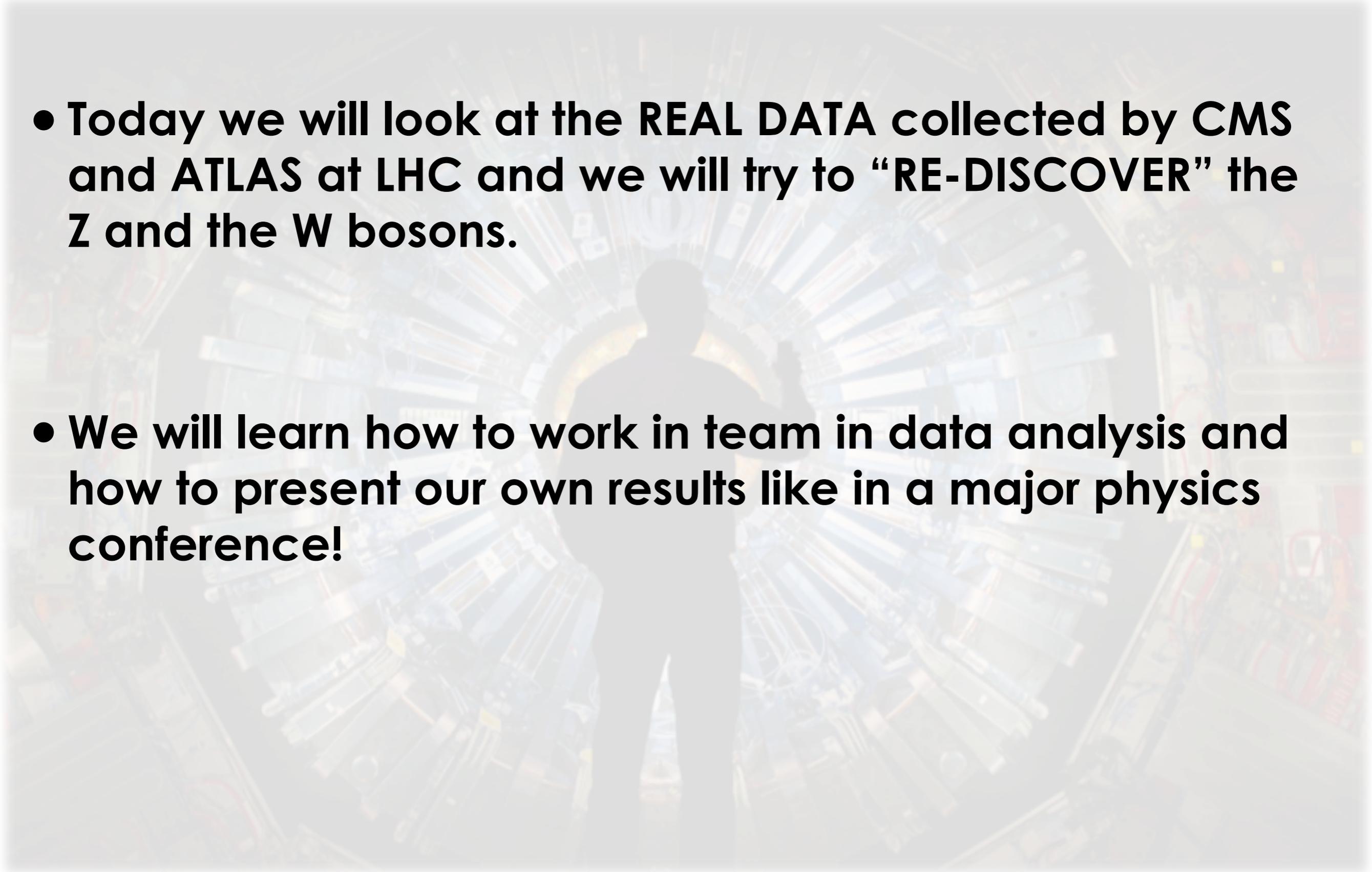
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LHC: A PARTICLE FACTORY!

- IN ONE HOUR OF DATA TAKING LHC PRODUCE, AT CMS COLLISION POINT:
 - 180000 Z BOSONS
 - 1500 HIGGS BOSONS
 - 13 EVENTS WITH HIGGS BOSON AND DARK MATTER PARTICLES (IF THEY EXIST)

NOW IT'S YOUR TURN!!

- **Today we will look at the REAL DATA collected by CMS and ATLAS at LHC and we will try to “RE-DISCOVER” the Z and the W bosons.**
 - **We will learn how to work in team in data analysis and how to present our own results like in a major physics conference!**
- 

CMS MASTERCLASSES

<https://quarknet.i2u2.org/page/cms-masterclass-2017-documentation>

<https://www.i2u2.org/elab/cms/ispy-webgl/#>

<https://www.i2u2.org/elab/cms/cima/index.php>