Problemas actuales en física de altas energias

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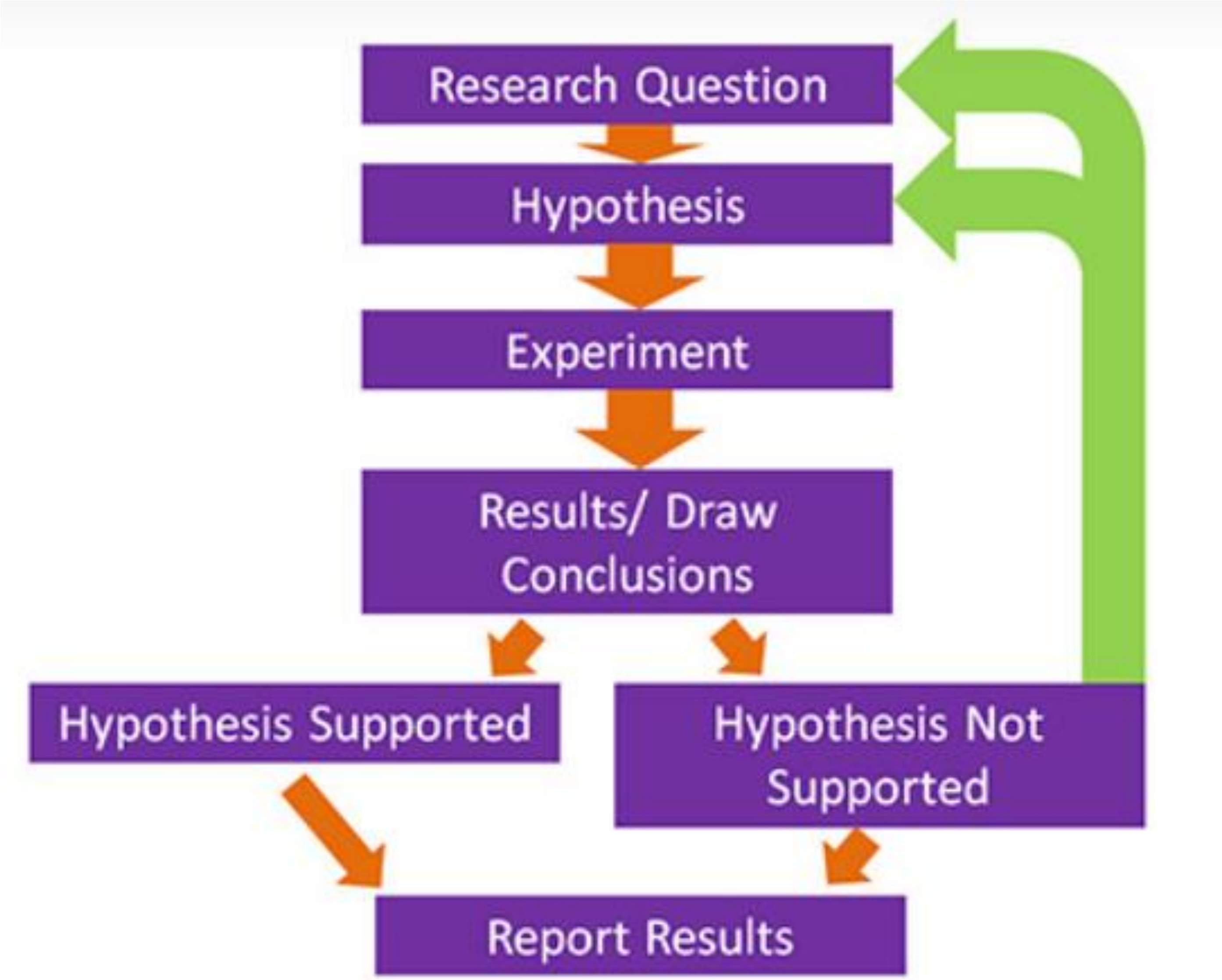
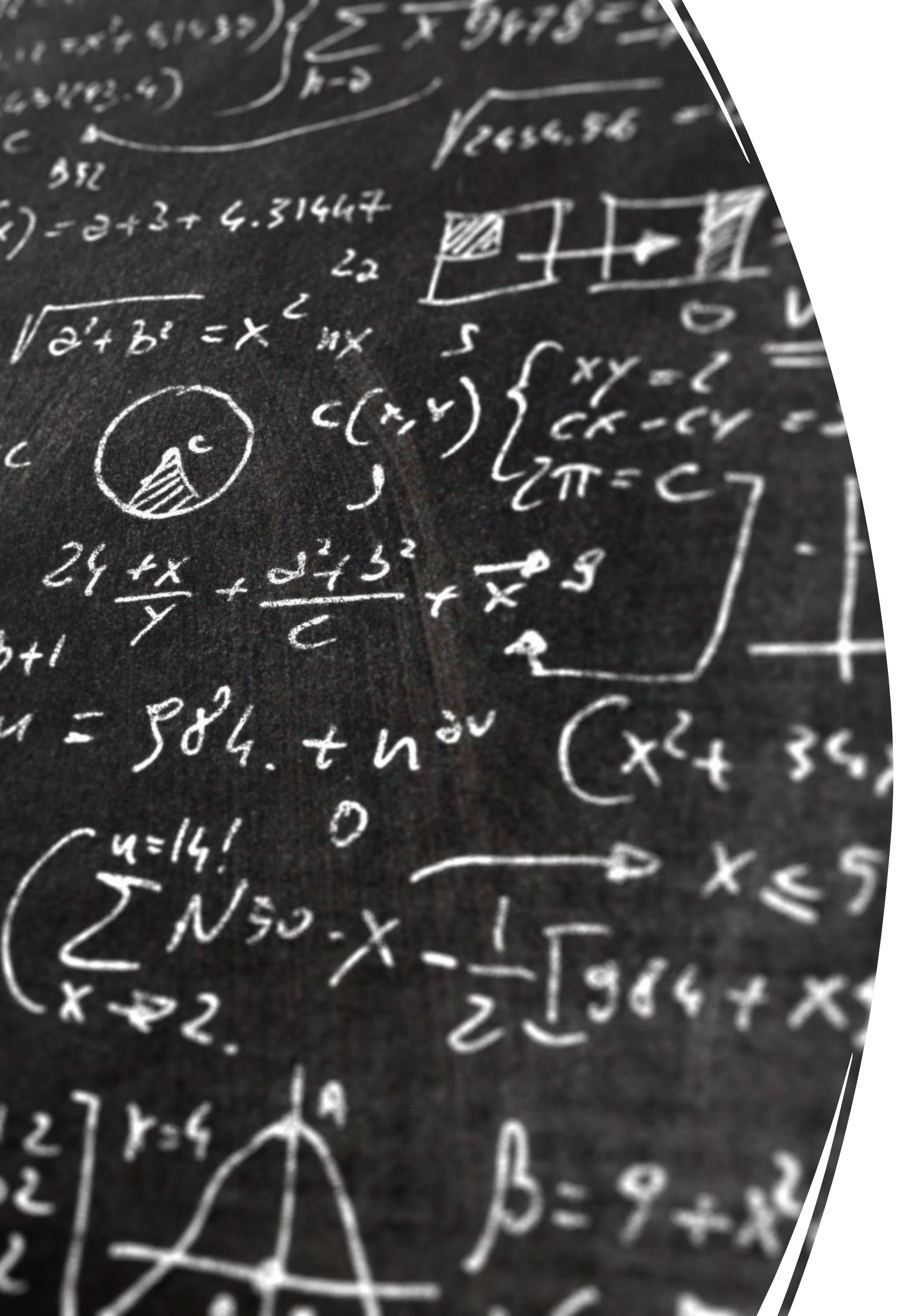
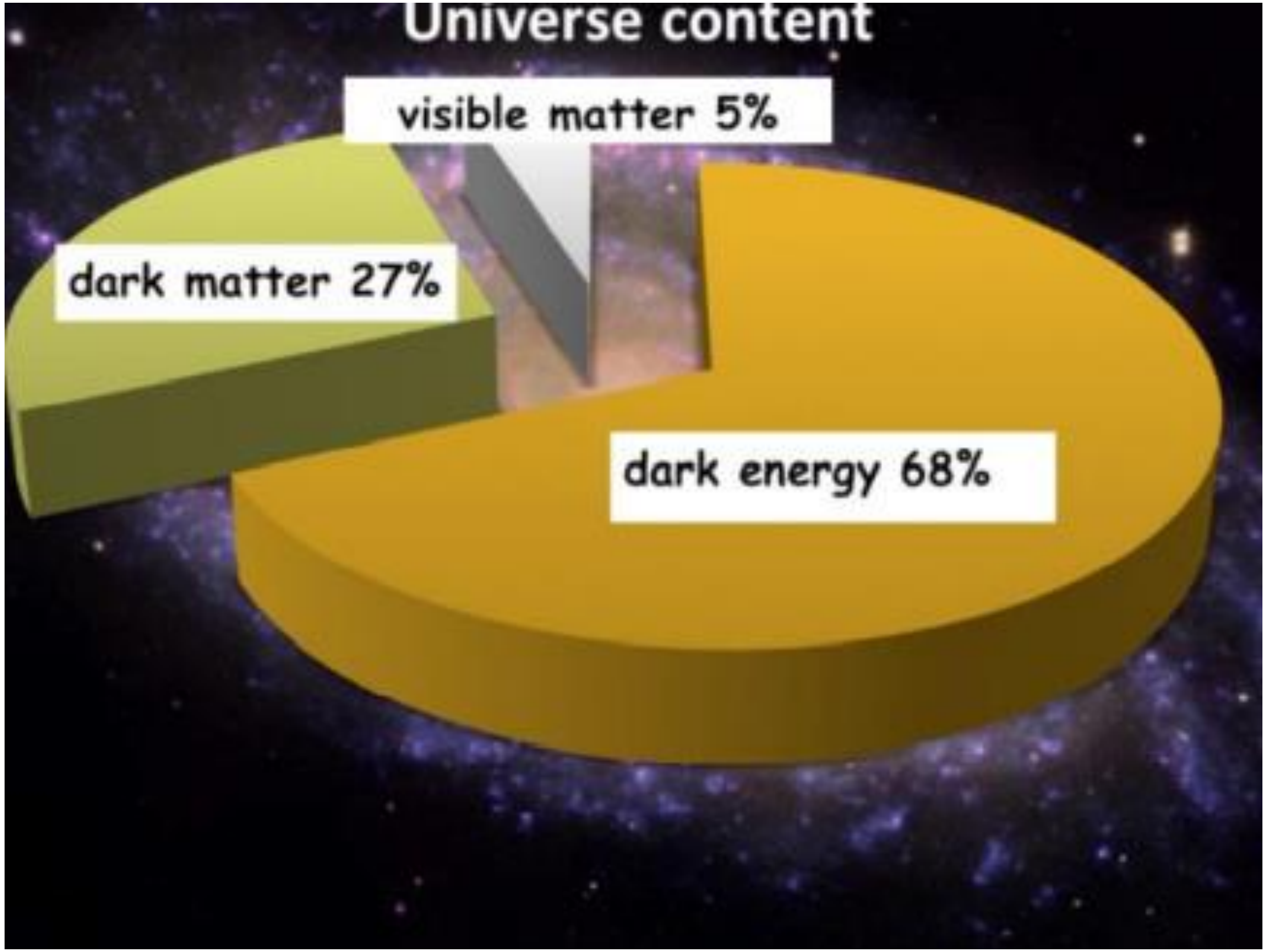
The steps of scientific investigation





From the question to the answer(s)

- Questions are usually of the following type: What, Why, How, When
- Observation →actively acquiring information through sight
- Formulation of a (or more) hypothesis/prediction
- Experimentation - the testing of the hypothesis on the basis of an experiment.
  - it implies taking to the practical field the previous steps (initial question, hypothesis…), studying the phenomenon in question (which is usually reproduced in a laboratory through artificial and experimental techniques).
- Data analysis
  - Data are analysed and compared to the hypothesis


Universe content
visible matter 5%
dark matter 27%
dark energy 68%

Our knowledge will continue to grow!

- Despite the continuing absence of any direct evidence for the new physics beyond the Standard Model at the LHC, one should not become disheartened.
- History abounds with examples of people who thought they knew it all, but did not. In 1894, just before the discoveries of radioactivity and the electron, Albert Michelson declared that **“The more important fundamental laws and facts of physical science have all been discovered**".
- Stephen Hawking asked **“Is the End in Sight for Theoretical Physics?".** However, my favourite example of a lack of ability to think outside the box
- he Spanish Royal Commission rejected a proposal by Christopher Columbus to sail west before 1492: **“So many centuries after the Creation, it is unlikely that anyone could find hitherto unknown lands of any value**" .

The Standard Model explains a lot about our world But there is still MUCH work to do

- The model which describes the world around us is called “The Standard Model” of particle physics.
- It includes many particles like the very well know electron, the photon, the Higgs particle (sometimes called The God Particle), the quarks and many more.
- The standard model explains many things which happen in nature. Some of the most astonishing scientific measurements in the world are predicted with extreme accuracy within the framework of this model. **Nevertheless, there are a lot of things in our universe that The Standard Model cannot explain.**

7 reasons for anticipating physics beyond the Standard Model

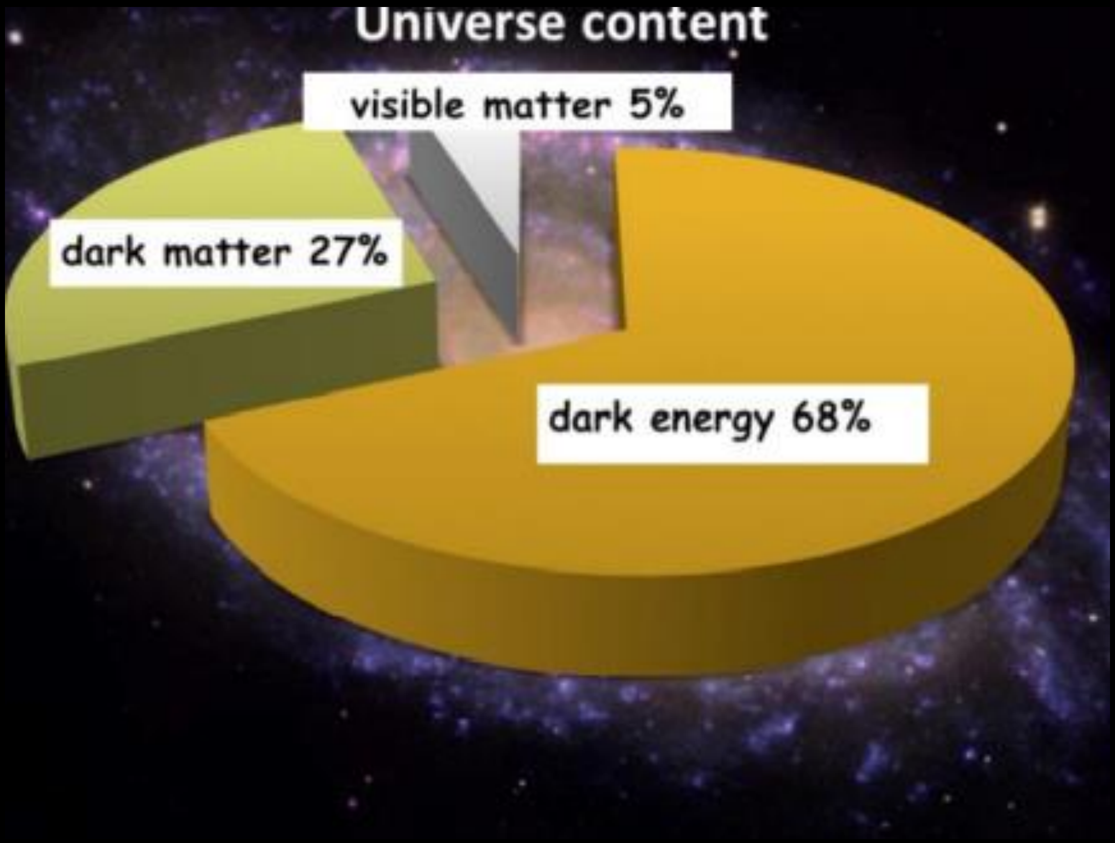
- The Standard Model has no candidate for the astrophysical dark matter.
- The SM does not explain the origin of the matter in the universe.
- The SM does not have a satisfactory mechanism for generating neutrino masses.
- The SM does not explain or stabilize the hierarchy of mass scales in physics.
- The Standard Model does not have a satisfactory mechanism for cosmological inflation.
- We need a quantum theory of gravity.
- The world of matter

Dark matter

- **Dark Matter Galaxies speeding up** When we look at galaxies in our universe, we notice something really peculiar: **they are rotating too fast.**
    - The rotational velocity of a star in a galaxy is determined, following Newton laws, by the mass enclosed in the region between the star itself and the center of the observed galaxy. We infer this mass from astronomical observation, using electromagnetic interactions. Matter in stars and galaxies absorb, reflect or emit light that we are able to detect letting us to do estimations of the mass. However, if we use this value to compute the rotational velocity of stars with our current theory of gravitation, we get a result which does not agree with data.
  - Data in fact seem to tell us that there is **extra matter in those regions**, and actually that this matter should be much more abundant than the matter we observe. This new kind of "unknown" matter is the so called Dark Matter.
    - Why Dark? First of all because, as stated above, it doesn't interact with the electromagnetic force, otherwise

We just understand around 4% of our universe!

- Why Dark?
- it doesn’t interact with the electromagnetic force, otherwise we should have seen it (as we see a normal star that emits its own light or the planets that simply reflect it) and **there seems not to be a particle of the Standard Model with the required properties to be a candidate for this new kind of matter.**
    - The only thing we know for sure is that Dark Matter has to interact gravitationally (to modify the rotational speeds of galaxies through its mass) and weakly enough in order to be so difficult to detect. Moreover, it turns out that apparently only 4% of our universe is made of the matter we know and “see”, which we call “baryonic matter” (the stuff of which atoms are made); other 21% of the universe is made of this unknown dark matter and the rest is what is called dark energy



Dark energy

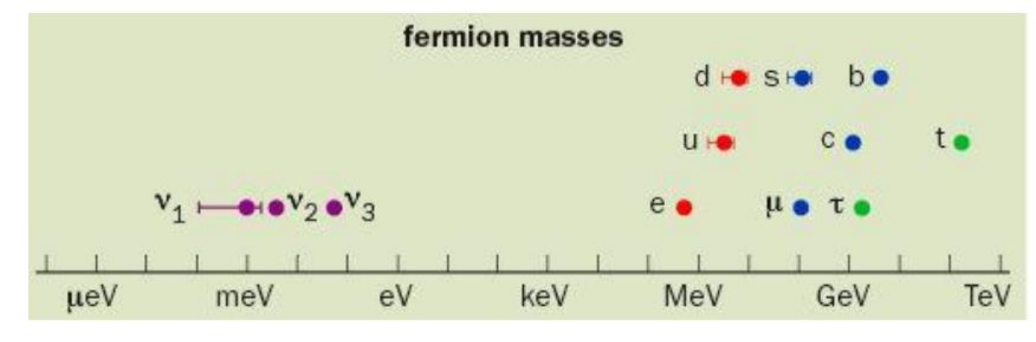
- In 1998 astronomers found, observing the exploding stars in different galaxies, that the expansion of the universe **is speeding up**! The fact that the universe is expanding was known decades ago, but physicists always thought that the expansion was decelerating; in fact, using the laws of general relativity, and even just the common sense derived from Newtonian Gravitation, one expects that the mass enclosed in the universe slows down the expansion, through gravitational attraction.
- The observation that the expansion of the universe was accelerating was like looking at a bullet which comes back once discharged. If we accept the validity of the general theory of relativity, this can only be explained by an energy that is not contained within standard particle masses, but it is instead inherent to space itself.
- "Dark Energy" produces a sort of antigravity which pushes the galaxies apart.

“I have done something very bad today by proposing a particle that cannot be detected ” W. Pauli. – the neutrino

- Massive or not massive, that is the question
- In the Standard Model neutrinos are massless particles which have no electric charge and interact very weakly.
- Neutrinos exist in three different flavors: electron, muon and tau neutrinos.
- They were detected in not even in one but in 3 flavors!
- A fundamental piece of the Standard Model puzzle!.
- However, the Standard Model neutrinos **do not have a mass**, but experiments have shown that they actually DO have a mass; it is really tiny, more than a million times smaller than electron mass, but it is very existence gives rise to important physical phenomena like neutrino oscillations. .
- Neutrinos have most of the properties to convert them into a good candidate and, in fact, many physicists have proposed them as the main source for dark matter. Unfortunately, their mass seems to be insufficient and moreover we could get conflicting predictions regarding galactic structures.
- In fact, the lighter is the dark matter particle the more relativistic it will be, leading to small inhomogeneities on galaxy-scale. Why so small? But why neutrino masses are so small?
- This is another open question in particle physics!

But why neutrino masses are so small?

- This is another open question in particle physics there are many proposed solutions but the most appealing and generally accepted one is that there is a kind of new very massive particles, called sterile neutrinos.
- The sterile neutrinos are even more elusive than “normal” or active neutrinos, because they do not interact neither through weak interactions. However, with a mechanism called “seesaw” it is possible to explain the tiny mass of active neutrinos: the larger is the mass of sterile neutrinos, the smaller will be the one of the active. Therefore very massive (therefore very difficult to produce at colliders) sterile neutrinos imply very light active neutrinos



Matter vs antimatter in the Universe

- There are different models for Baryogenesis. One of them involves the decay or the oscillations of the sterile neutrinos discussed above. None of them is definitive, and all of them involve physics beyond the standard model: new particles, new interactions.

Matter antimatter Asymmetry

- for every particle in nature there is a corresponding anti-particle, which has the same mass, spin, type of interactions, but opposite charge. It is somehow the particle equivalent to the algebraic equation x 2 = 1, which has the two solutions ±1.
- The anti-particle of the electron, for example, is called positron, the one of the muon, anti-muon, the one of the tau anti-tau and so on
- . When a particle and an anti-particle meet they annihilate each other emitting energy and disappearing.
- Therefore, it is intuitive to understand that if there is in the universe the same number of particles and anti-particles they would have with time annihilated each other and we wouldn't be here. Fortunately for us, it turns out that in the universe there seems to be many more particles than antiparticles; for example, looking at cosmic rays we found evidence of protons and anti-protons, but anti-protons constitute only 1%.
- Baryogenesis This particle-antiparticle asymmetry cannot be explained with the Standard Model. One, in fact, would expect that at the beginning of everything, after the big bang, particles and anti-particles were equally distributed and after that some kind of dynamical mechanism would have generated the asymmetry we observe today.

Too close this part message to you!

- One of the main builder of the Standard Model, Nobel prize laureate Steven Weinberg, says:
- **“I still hold the hope that one day a paper posted in the arXiv preprint server by some previously unknown graduate student will turn the SM on its head – a 21st century model of particles that incorporates dark matter and dark energy and has all the hallmarks of being a correct theory, using ideas no one had thought of before”**

The slow march of science – an illustration

- the slow march of science has many reasons :
- Ideology
- Disbelief
- …..

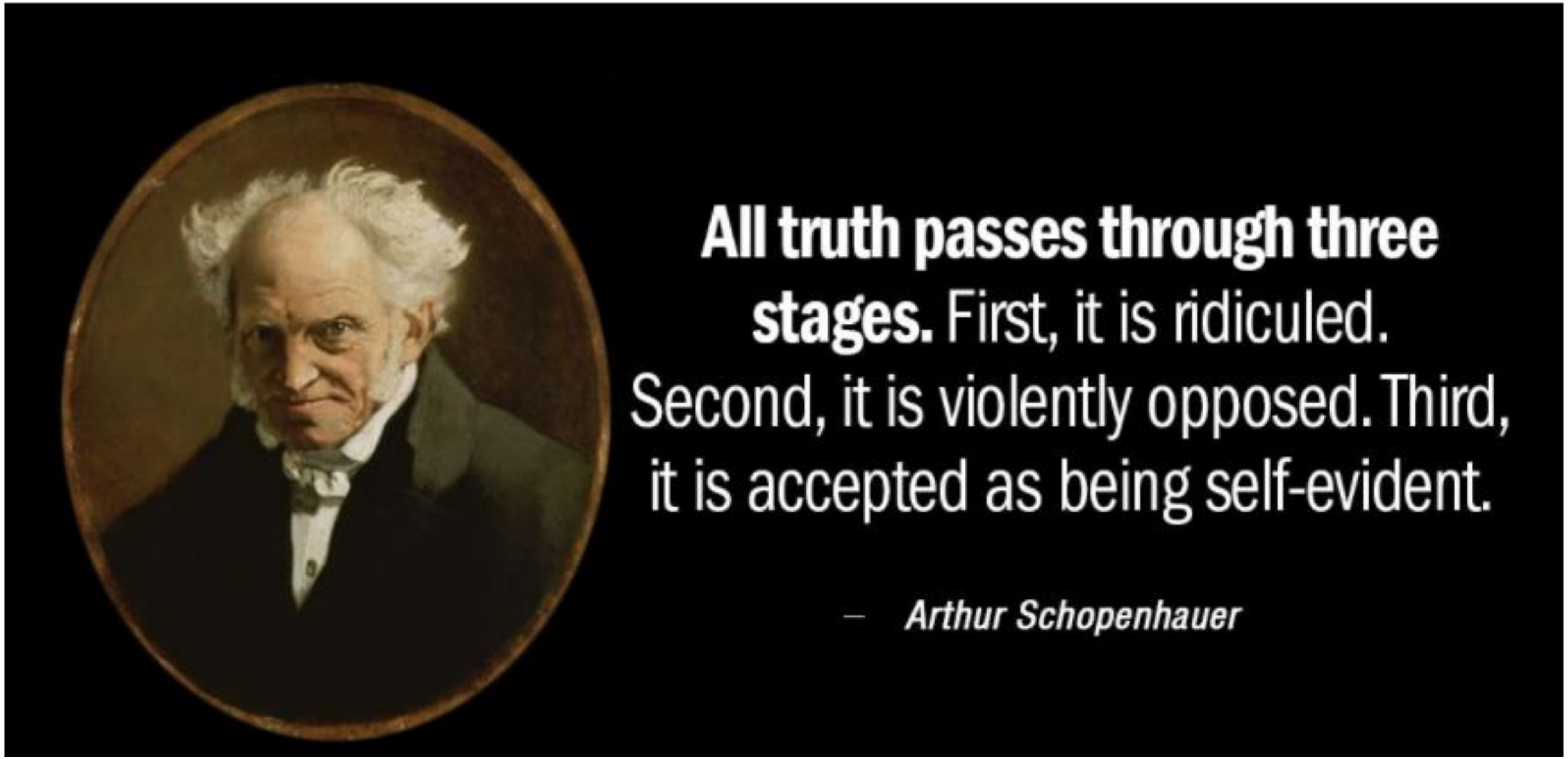
The long history of tectonic plates

- **[1490 – Leonardo Da Vinci]** • Noticed on early charts that the continents would fit together like a jigsaw puzzle
- **[1620 - Francis Bacon]** • Also noticed the “fit” of the continents
- **[1885 – Edward Suess]** • Thought that there was once a single large land mass. Source: www.usgs.gov
- **[1912 – Alfred Wegener]** • German meteorologist and polar explorer • Proposed the continental drift theory • He suggested that all earth’s land had once been joined into a single supercontinent called Pangaea. • Wegener thought Pangaea had broken into pieces about 200 million years ago
  - But his ideas challenged scientists in geology, geophysics, zoogeography and paleontology to such a degree that any discussion was virtually stopped! o.

continental drift

continued

- !958 Hapgood published “The Earth's Shifting Crust” which denied the existence of continental drift and featured a foreword by Albert Einstein!
  - I frequently receive communications from people who wish to consult me concerning their unpublished ideas. It goes without saying that these ideas are very seldom possessed of scientific validity. The very first communication, however, that I received from Mr. Hapgood electrified me. His idea is original, of great simplicity, and—if it continues to prove itself—of great importance to everything that is related to the history of the earth’s surface. (Einstein, 18th of May 1954, courtesy of the Einstein Archives Online
- 1968 Jack Oliver provides seismologic evidence for the plate tectonics



Do not be discouraged!

It is normal for the interpretation phase to have a tortuous path, but this does accentuate the importance of the confrontation of different viewpoints and open channels of communication.

From prediction to reality

- The last 60 years have been marked by a tremendous revolution that has revolutionized our understanding of the fundamental particles of our Universe.
- The quarks, the new particles and the Standard model, the neutrino masses and finally the discovery of the Higgs boson has crowned the triumphant march of the theory and experiment
- the quarks and gluons are kept together in strict confinement within the rules of the quantum chromodynamics.
- However J. Friedman and F. Wilczek. Predicted that, at sufficiently high temperature and/ or density the quarks and gluons reach a state of "asymptotic" freedom permitting them for a fleeting moment to move freely within a piece of matter.
- This stirred an enthusiastic echo in the experimental community of nuclear and high energy physicists opening the tantalizing possibility of a new state of matter the "quark gluon plasma" appearing in collisions of heavy ion accelerated at ultrarelativistic energies. According the theoretical predictions we should have encountered a new phase of matter - the plasma consisting of non-interacting quarks and gluons.
- **This was the prediction**. However, after the first experiments at the Relativistic heavy ion collider RHIC at Brookhaven the data could not be interpreted otherwise than assuming that the collision system created in the collisions is a liquid of strongly interacting quarks and gluons named strong -sQGP

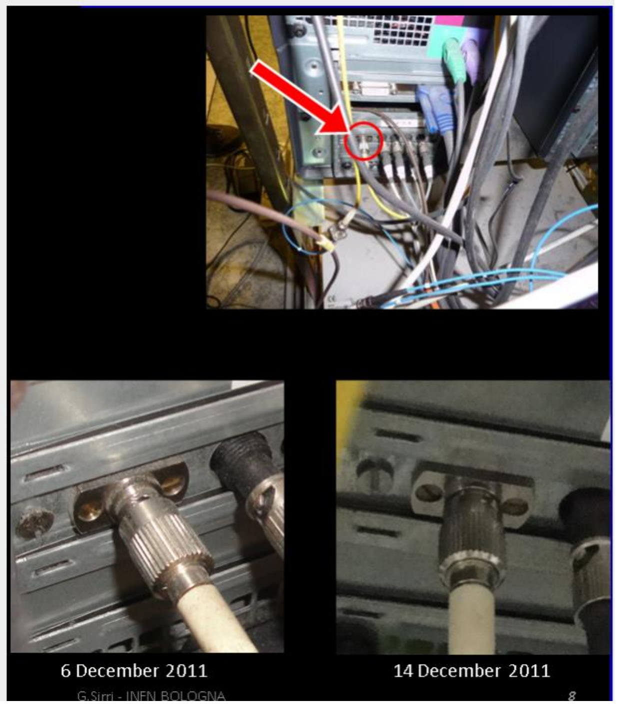
How a wrongly connected connector can change the world for a couple of months

In the early 1980 , first measurements of neutrino speed were consistent with the speed of light

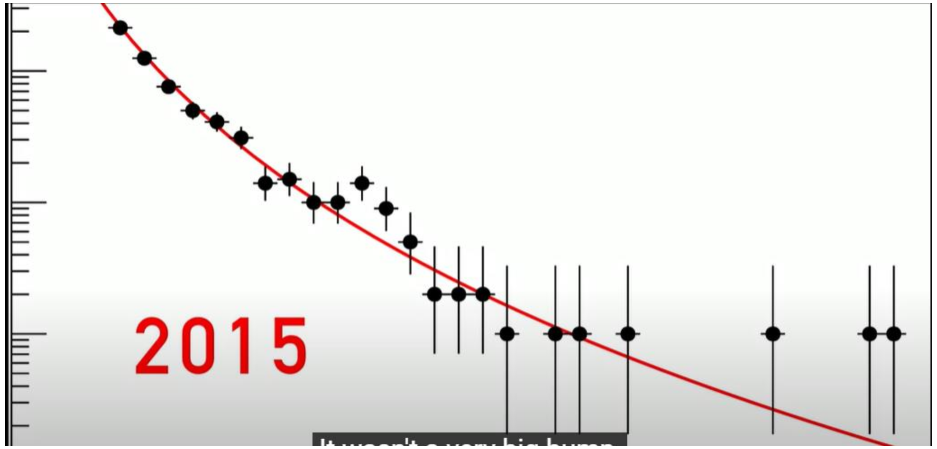
In 2010 surprise!

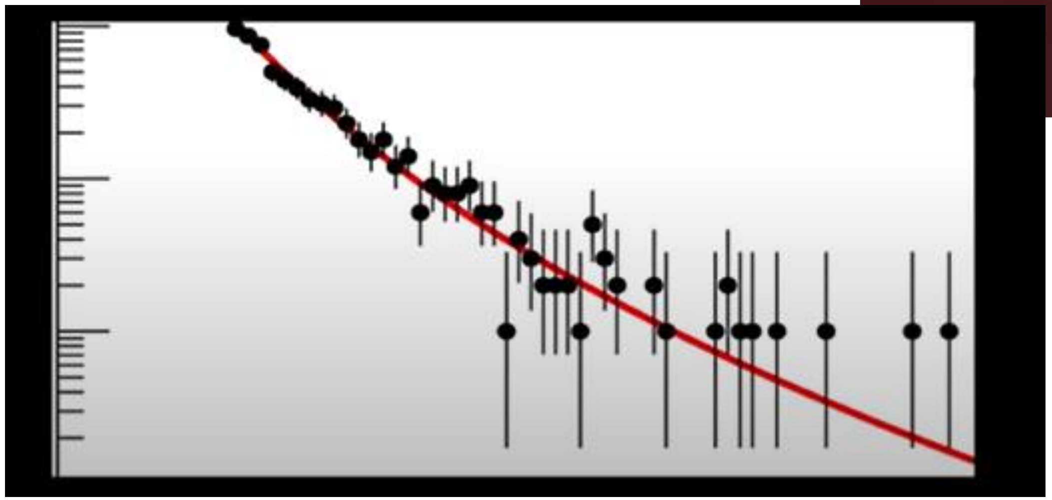
The experiment OPERA measures the velocity greater than the velocity of light!?

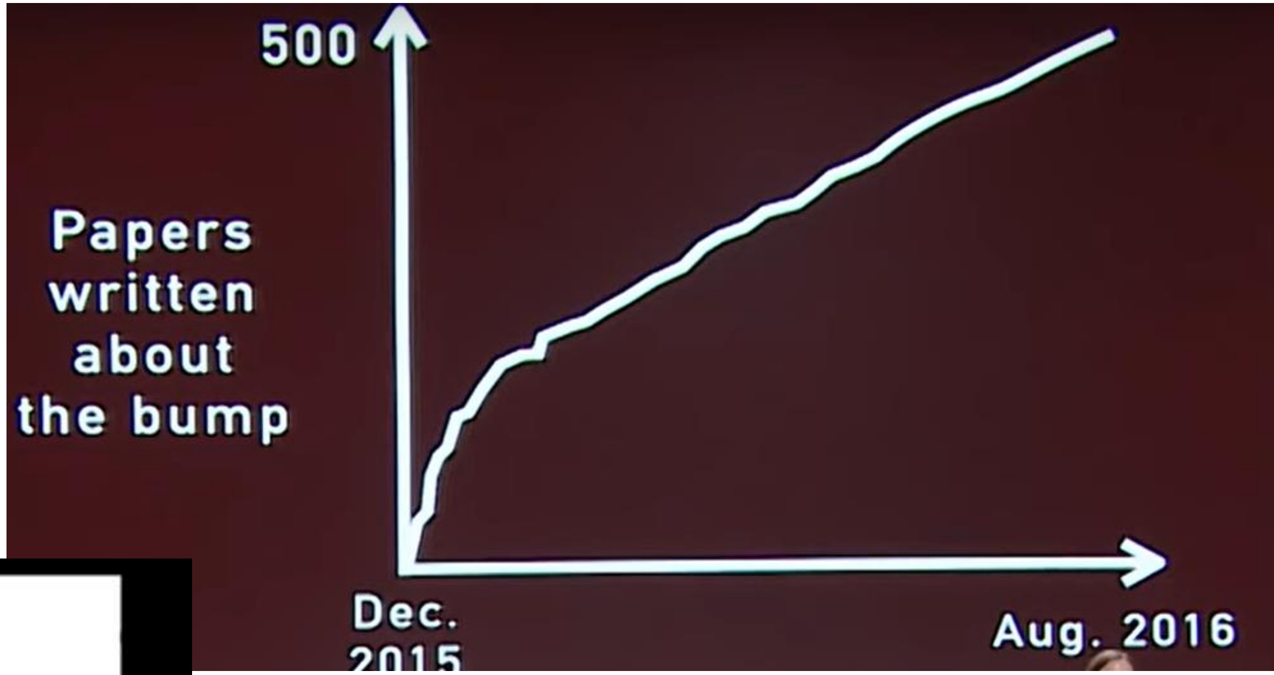
- You do not go full-speed ahead with a big public presentation and a press conference if you haven't, in fact, done all the basic internal checks of your equipment.



Statistics: the killer of dreams



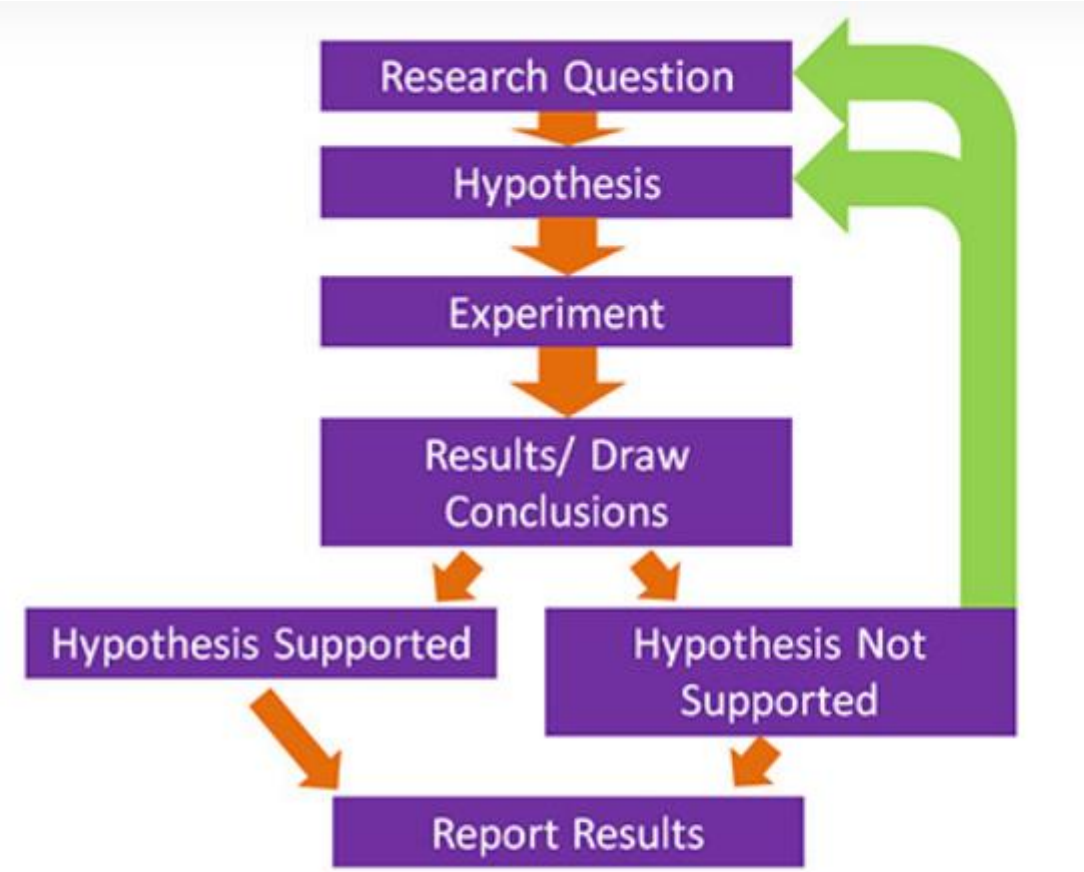




More data less signal!

The march of science is slow and tortuous!

At every step one can have problems but this is the essence of science and the fun to search



Serendipity in science

- **Penicillin**
- Perhaps the most famous accidental discovery of all is penicillin, a group of antibiotics used to combat bacterial infections. In 1928, Scottish biologist Alexander Fleming took a break from his lab work investigating staphylococci and went on holiday. When he returned, he found that one Petri dish had been left open, and a blue-green mould had formed. This fungus had killed off all surrounding bacteria in the culture. The mould contained a powerful antibiotic, penicillin, that could kill harmful bacteria without having a toxic effect on the human body.
- At the time, Fleming's findings didn't garner much scientific attention. In fact, it took another decade before this drug was available for use in humans. Retrospectively, Fleming's chance discovery has been credited as the moment when modern medicine was born.
- **Pulsars**
- In 1967, astronomy graduate student Jocelyn Bell noticed a strange "bit of scruff" coming from her radio telescope. It was a regular signal coming from the same patch of sky, of a type that no known natural sources would produce. Bell and her supervisor, Anthony Hewish, ruled out sources of human interference – other researchers, television signals, satellites. None explained the signal, and the scientists wondered if they had detected a sign from aliens. This was ruled out when another was located in a different part of the sky: it seemed unlikely that two sets of aliens would simultaneously be trying to communicate with Earth.
- In fact, it was the first discovery of a pulsar (pulsating radio star), a highly magnetised, rotating neutron star that emits a beam of electromagnetic radiation. Pulsars, which had been predicted three decades earlier but had never been actually observed, indirectly confirm the existence of gravitational radiation.
- **Radioactivity**
- French scientist Henri Becquerel was working on phosphorescent materials, which glow in the dark after exposure to light. The chance discovery came during an experiment involving a uranium-enriched crystal. He believed sunlight was the reason that the crystal would burn its image on a photographic plate.
- One stormy day in 1896, he decided to leave it for the day and resume his experiments when the weather was better. A few days later, he took his crystal out of a darkened drawer. The image burned on the plate was "fogged" – the crystal had still emitted rays, despite the lack of sunlight. It was clear that there was a form of invisible radiation that could pass through

- X-rays
- In 1895, German physicist Wilhelm Roentgen was working with a cathode ray tube. The tube was covered, but a fluorescent screen nearby would still glow when the tube was on and the room was dark. The rays were illuminating the screen. Roentgen tried blocking the rays, but most things he placed in front made no difference. However, when he placed his hand in front of the tube, he noticed he could see his bones in the image projected onto the screen. The tube was replaced with a photographic plate, and the first x-ray images produced.
- Atomic nucleus
- Ernest Rutherford was a physics professor at Manchester University, already well known for his studies of radiation. In 1911, under his supervision, German physicist Hans Geiger and physics undergraduate student Ernest Marsden observed how alpha particles scattered from a gold foil. Rutherford didn't like to neglect any aspect of an experiment, no matter how unpromising, and told Marsden to check if any particles scattered backwards. He did so, writing later that he felt it was a test of his experimental skills, if nothing else.
  But there was a highly unexpected result: some of the particles scattered backwards, rather than passing through the foil with little deviation from their existing path. Rutherford's analysis was that the scattering was caused by a hard, dense core at the centre of the atom – the nucleus, where its positive charge and most of its mass are concentrated.
- And many others

- “Chance favors the prepared mind.” (louis Pasteur)