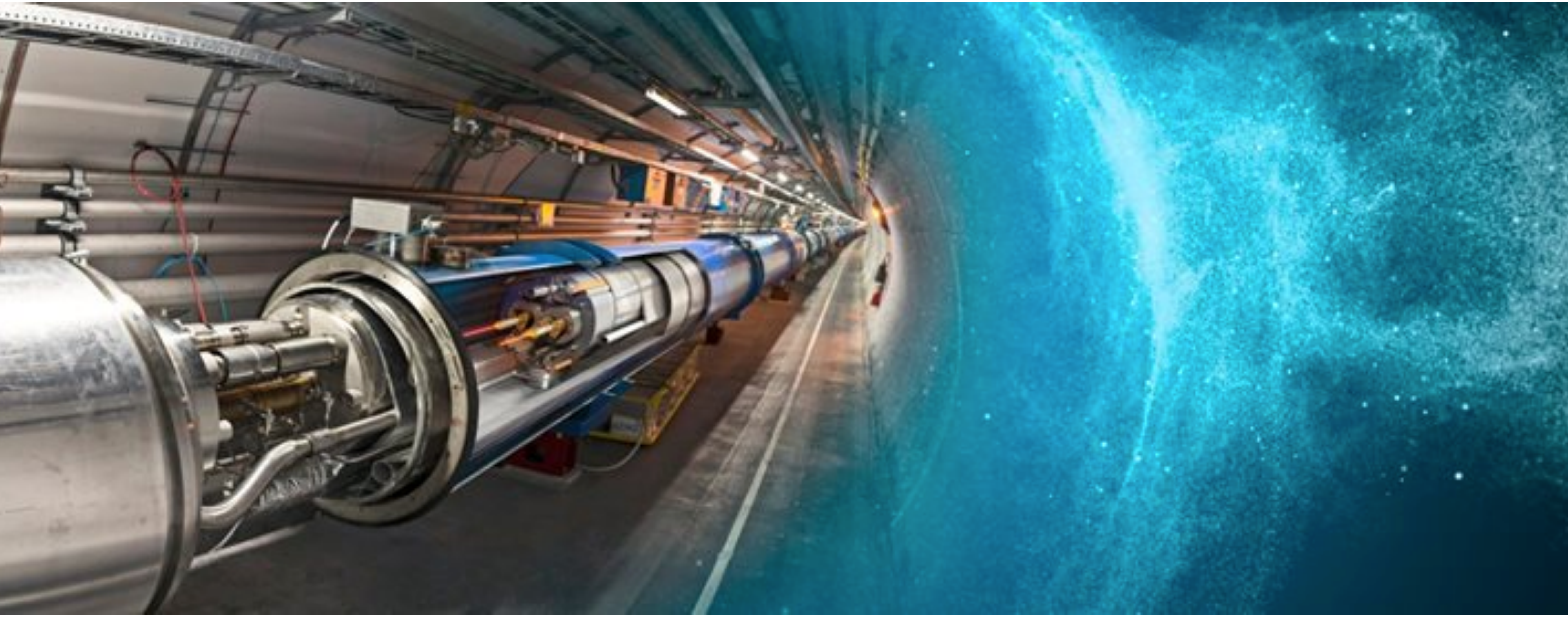
# Large Hadron Collider

## Science and Applications



**Norraphat SRIMANOBHAS**
(Chulalongkorn U., Thailand; CMS Collaboration, CERN, Switzerland)

Srinakharinwirot University
April 19, 2017

# How things work

**LHC**

- Accelerate protons
- Collide bunches of particles

**Theory**

- Theoretical particle physics

**Experiments**

- Detect particles coming from collisions
- Select events of interest
- Store RAW events, and transfer them around the world
- Do offline processing around the world
- Perform analyses

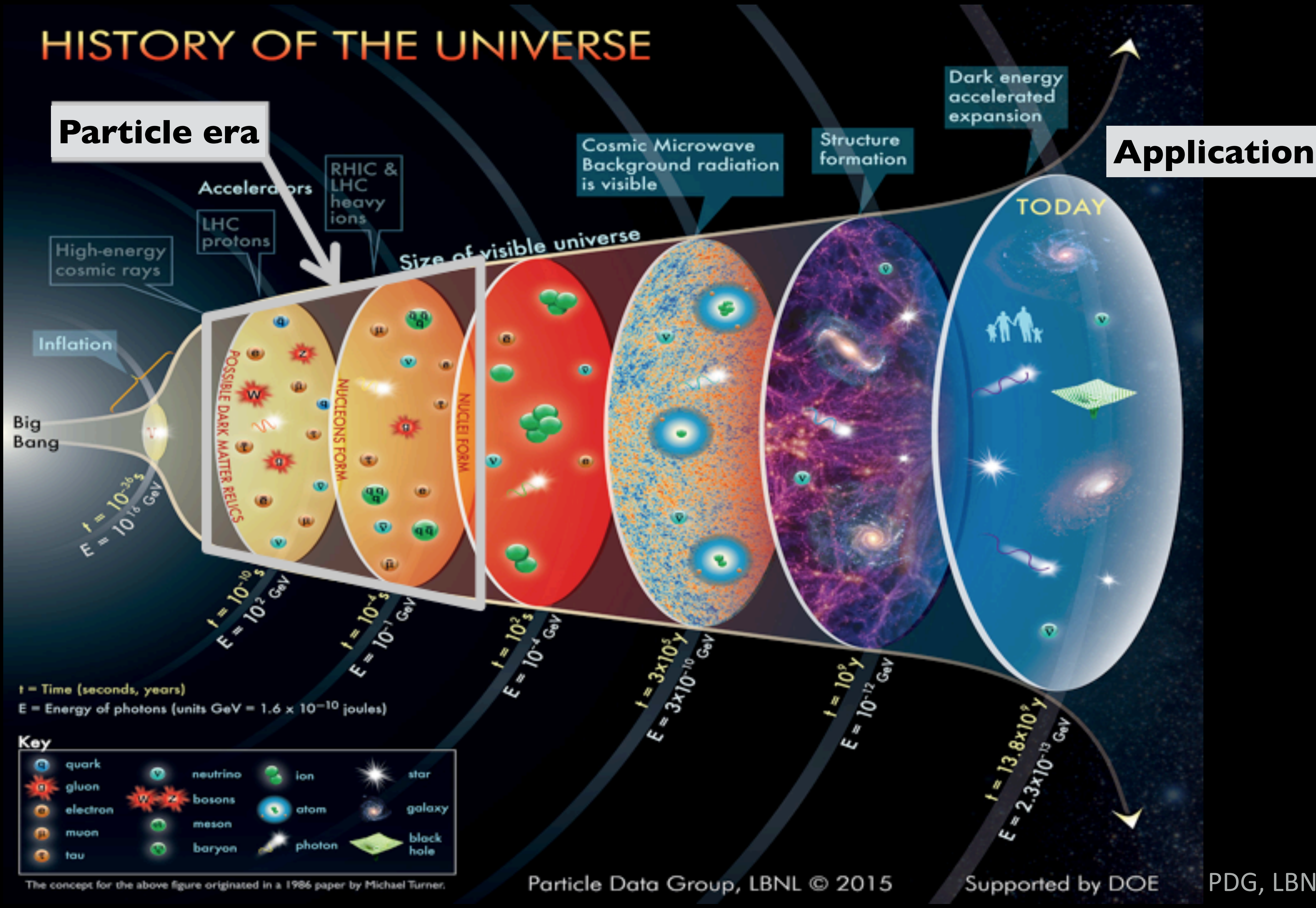
**Applications**

- Medical
- Space
- Materials
- Computing
- …

**Statistics**

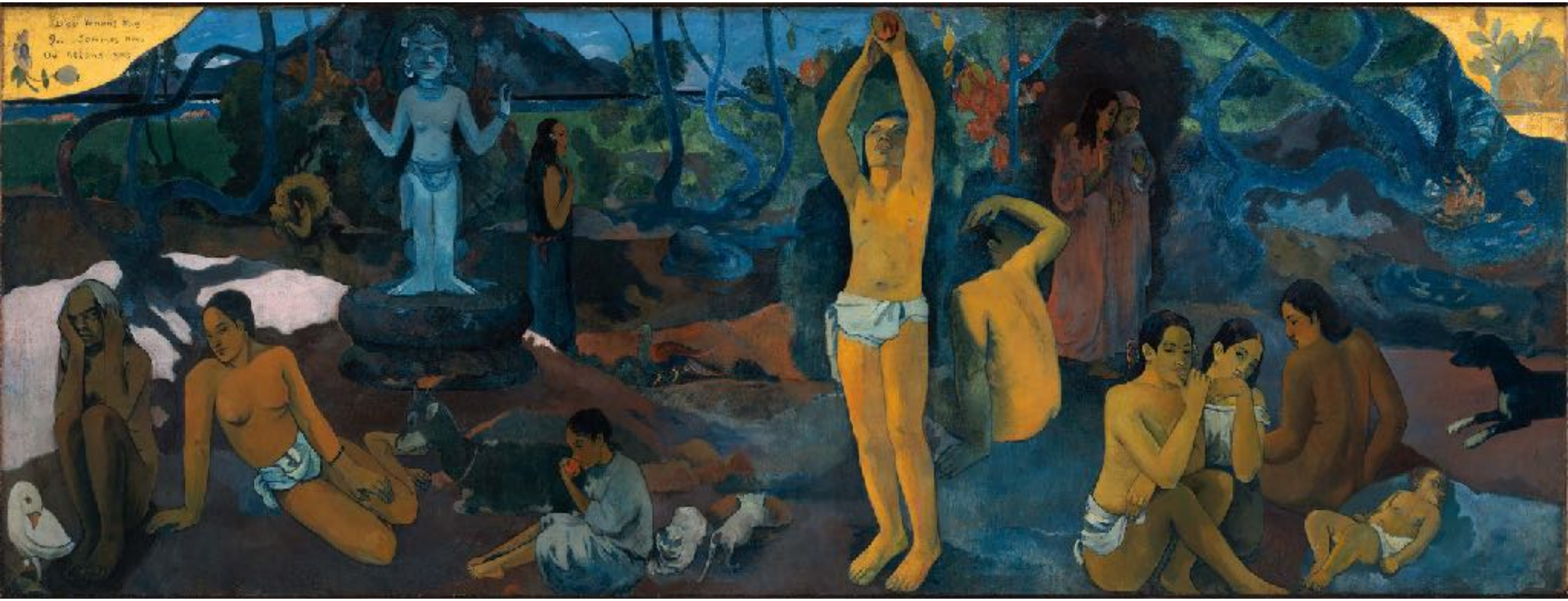
- Statistical method

# What will we talk about




PDG, LBNL

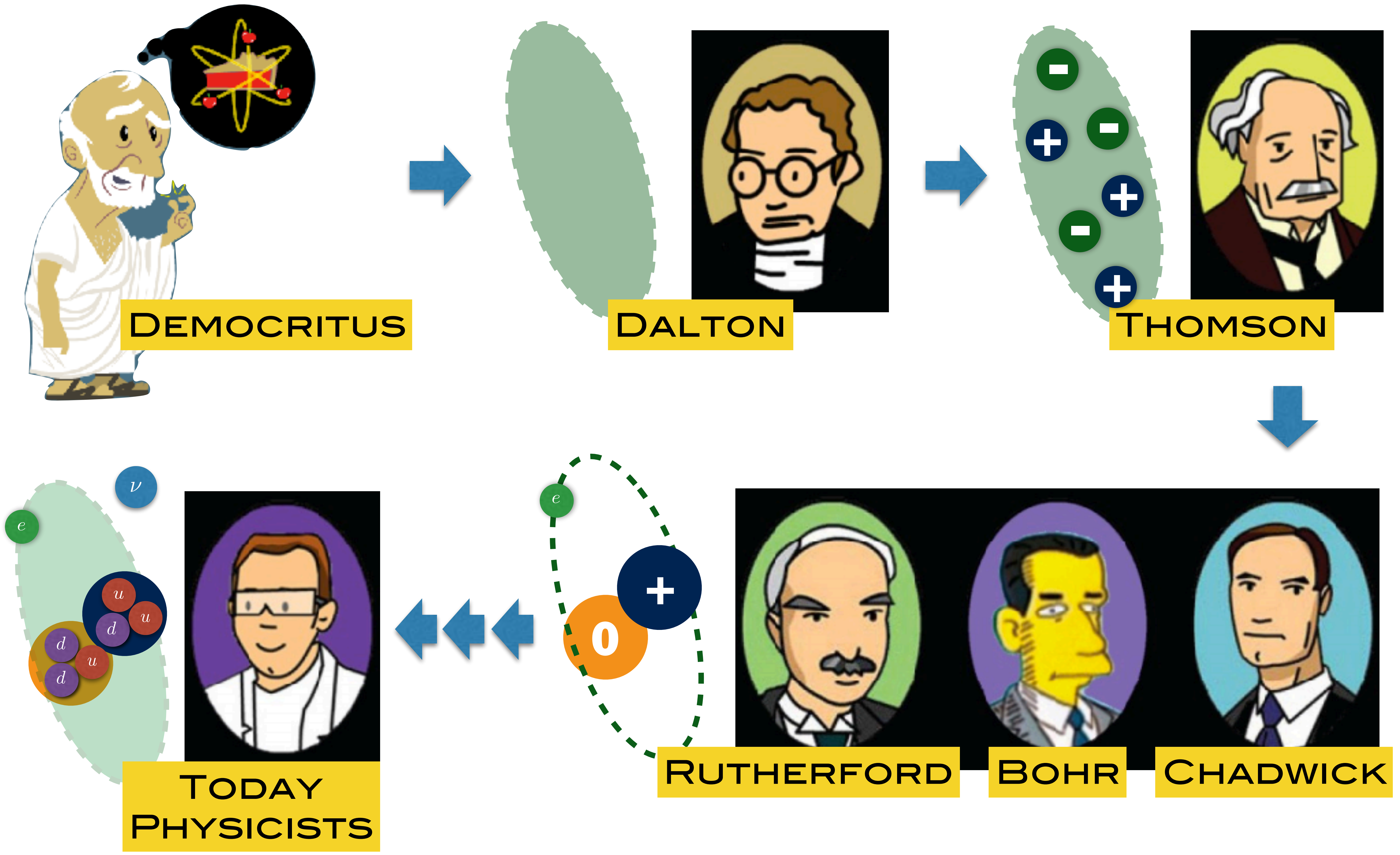
# Fundamental questions



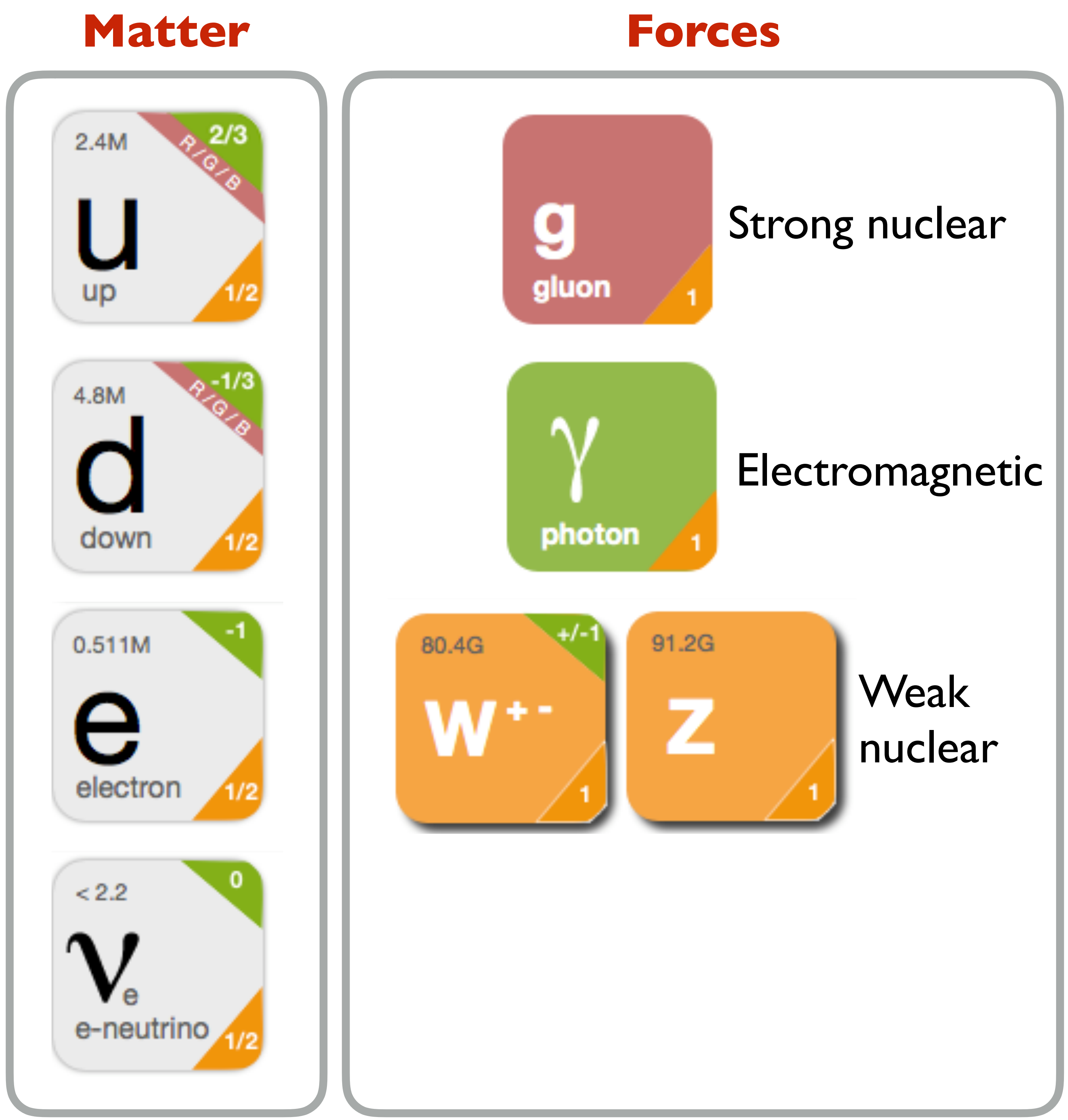
Painting by Paul Gauguin

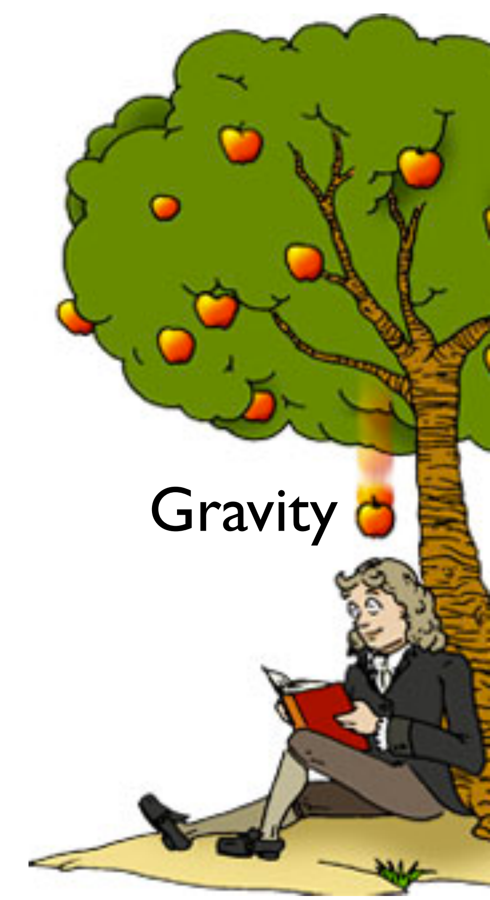
***Where Do We Come From? What Are We? Where Are We Going?***
*Note that this painting should be read from right to left.*

# Building blocks of known universe

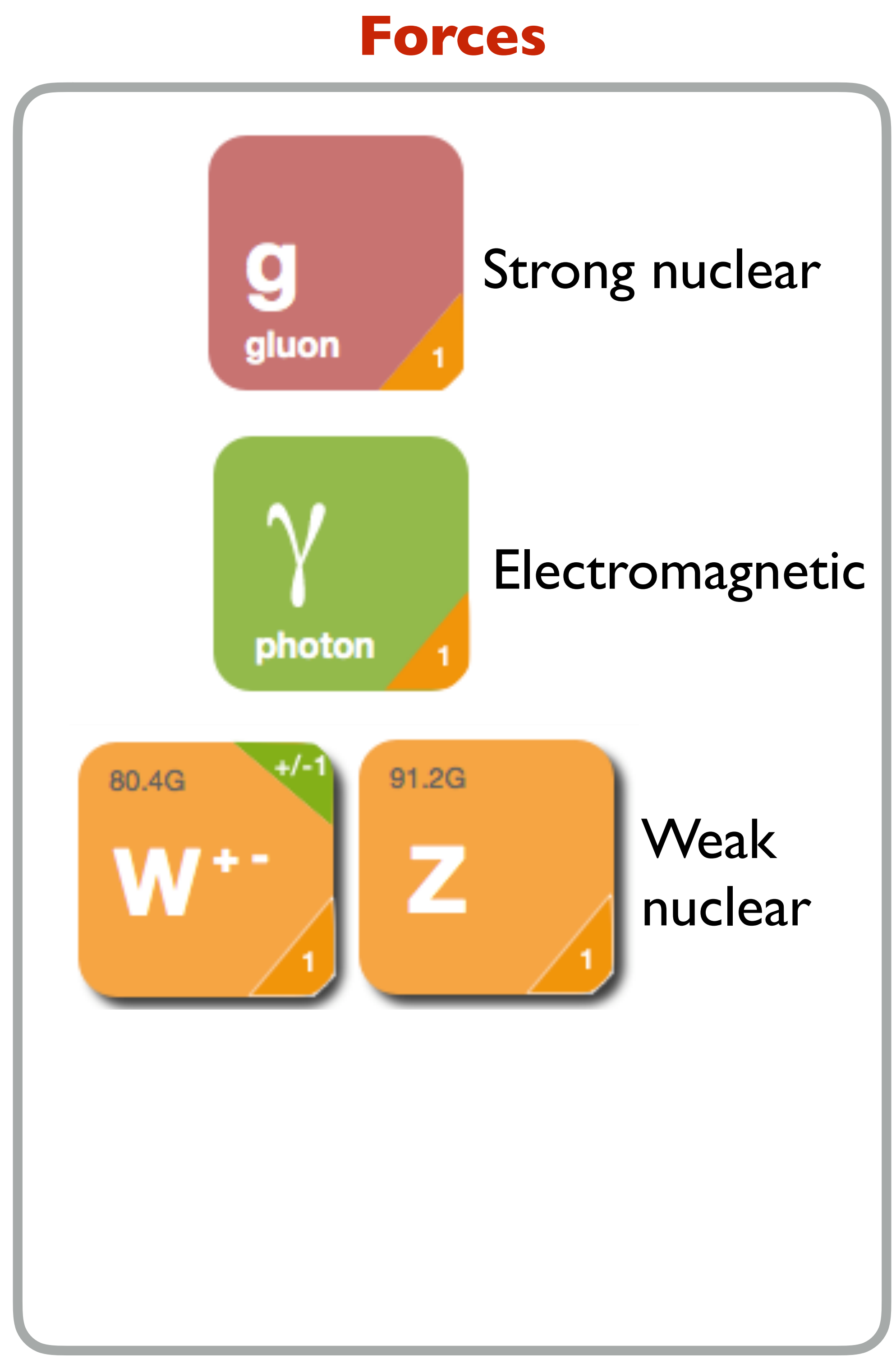


# Building blocks of known universe

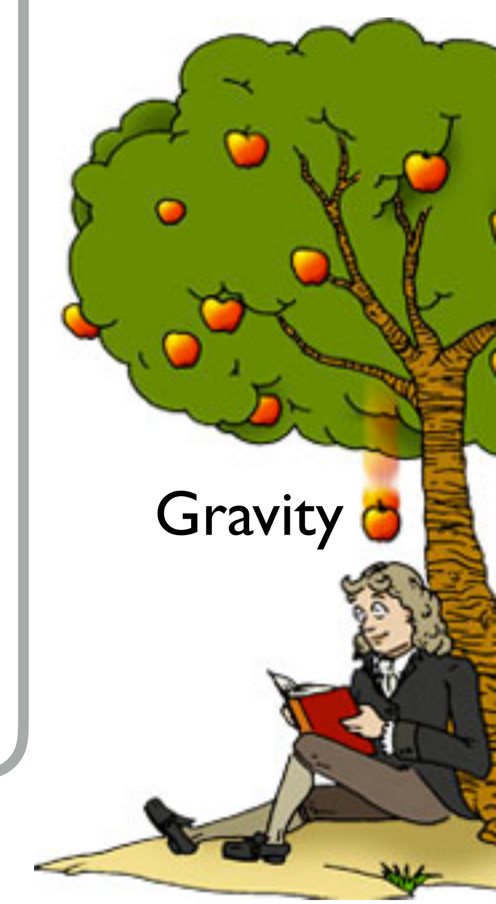


# Building blocks of known universe

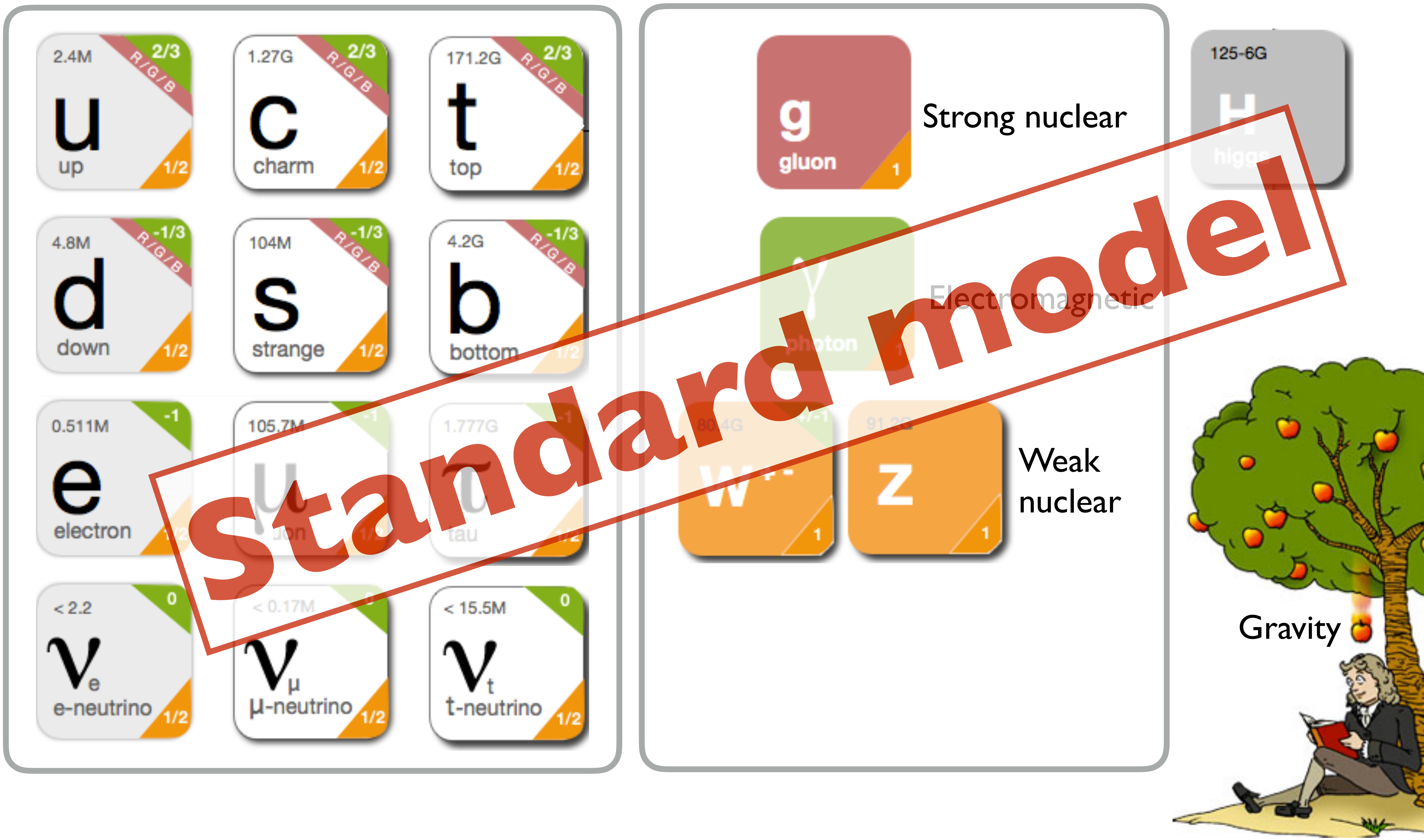







# Building blocks of known universe

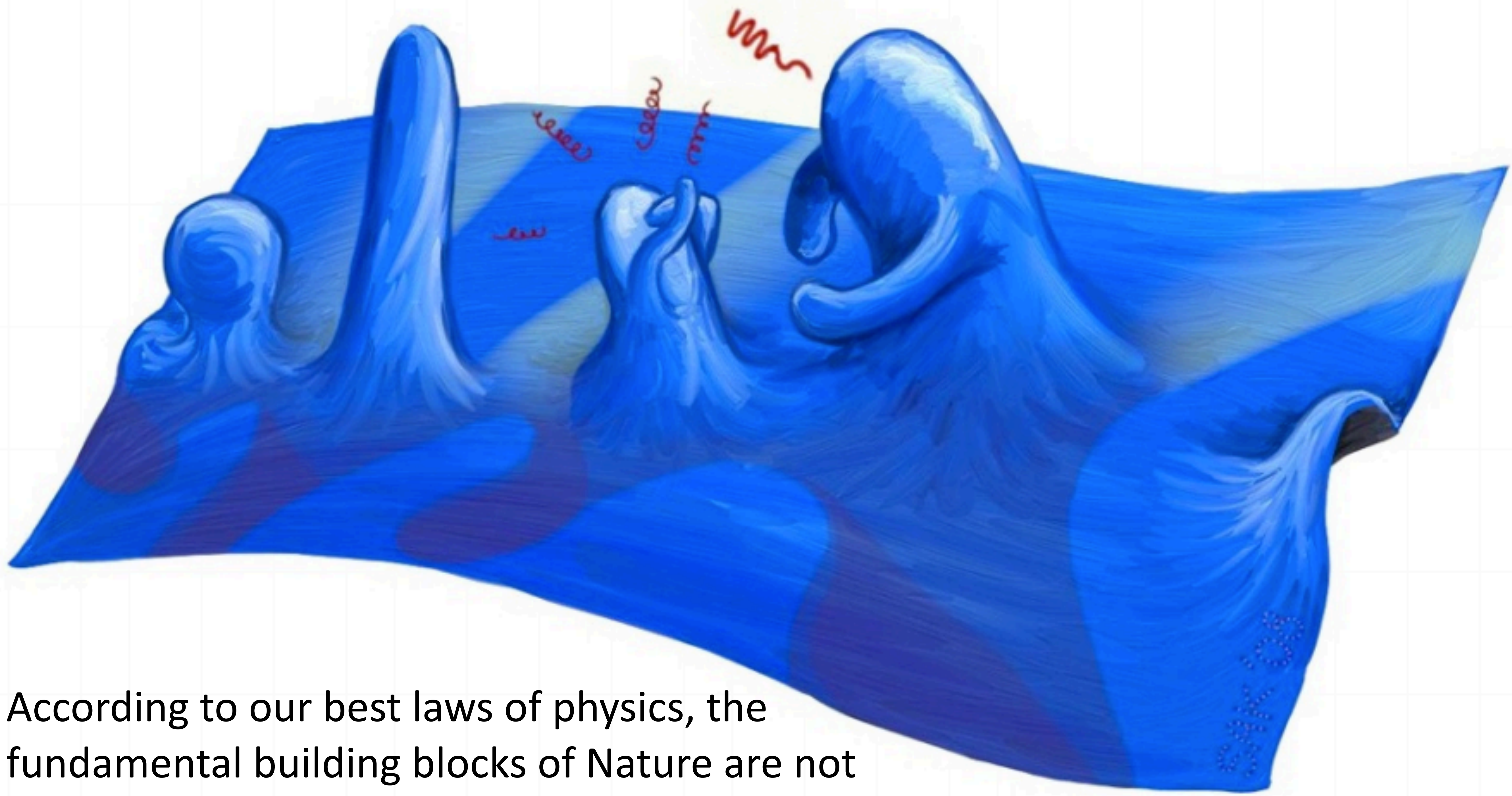
**Matter** **Forces**



# Particles-Fields

http://www.publicdomainpictures.net/pictures/140000/velka/green-field-and-blue-sky-1446458468c5i.jpg

# Particles-Fields (Quantum Field Theory)



According to our best laws of physics, the fundamental building blocks of Nature are not discrete particles at all. Instead they are continuous fluid-like substances, spread throughout all of space. We call these objects *fields*.

http://www.damtp.cam.ac.uk/user/tong/whatisqft.html

# What are physicists doing at CERN

**Basic research** in the field of experimental and theoretical particle physics, finding out what the Universe is made of and how it works. At CERN, the world's largest and most complex scientific instruments are used to study the basic constituents of matter — the fundamental particles. By studying what happens when these particles collide, physicists learn about the laws of Nature.

http://acceleratingnews.web.cern.ch/content/accelerators-celebrating-international-year-light

# Theoretical particle physics

**Basic research** in the field of experimental and theoretical particle physics, finding out what the Universe is made of and how it works. At CERN, the world's largest and most complex scientific instruments are used to study the basic constituents of matter — the fundamental particles. By studying what happens when these particles collide, physicists learn about the laws of Nature.

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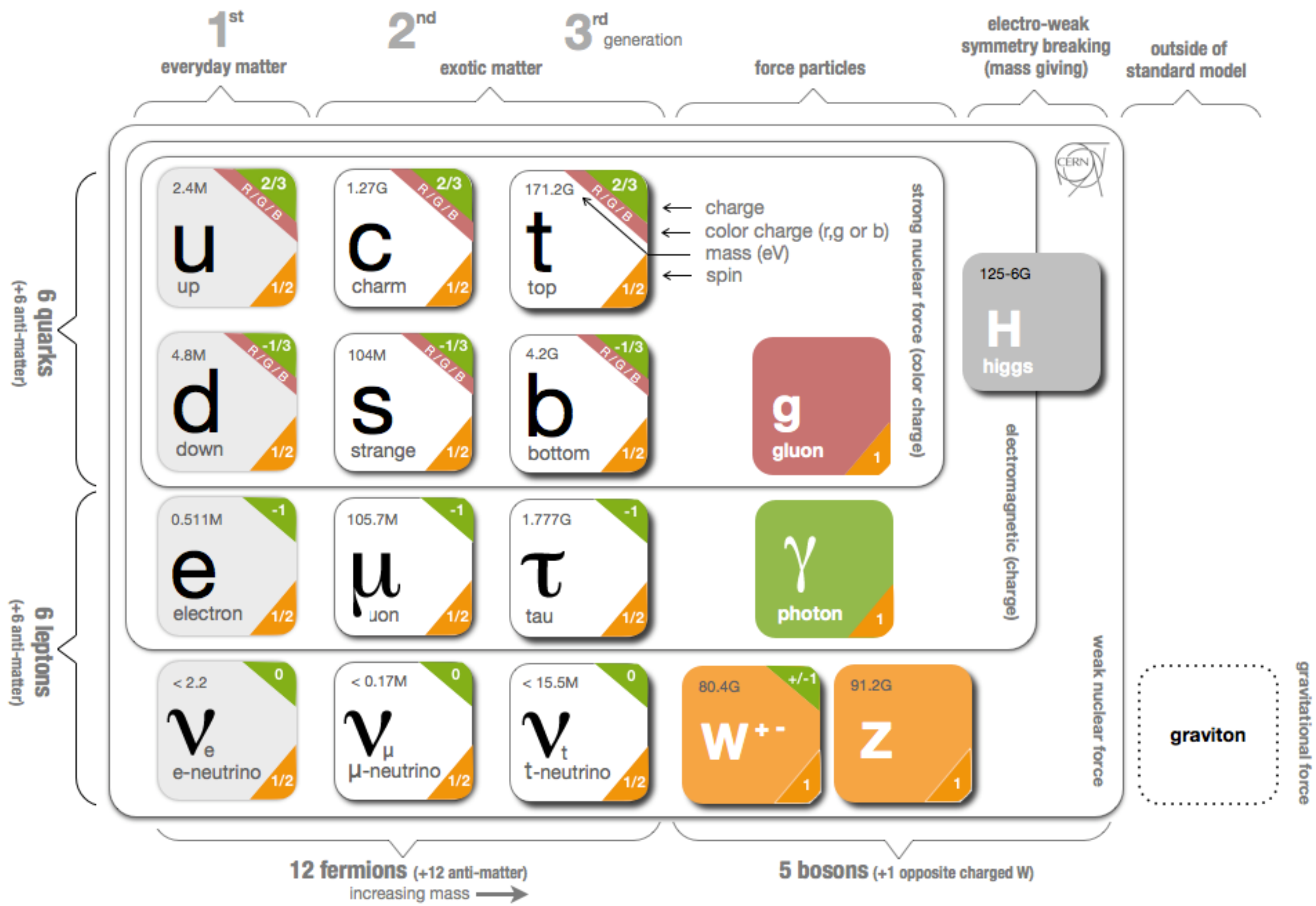
# Elementary particle physics

The **Standard Model** of particle physics is a theory concerning the electromagnetic, weak, and strong nuclear interactions, as well as classifying all the subatomic particles known.

https://en.wikipedia.org/wiki/Standard_Model

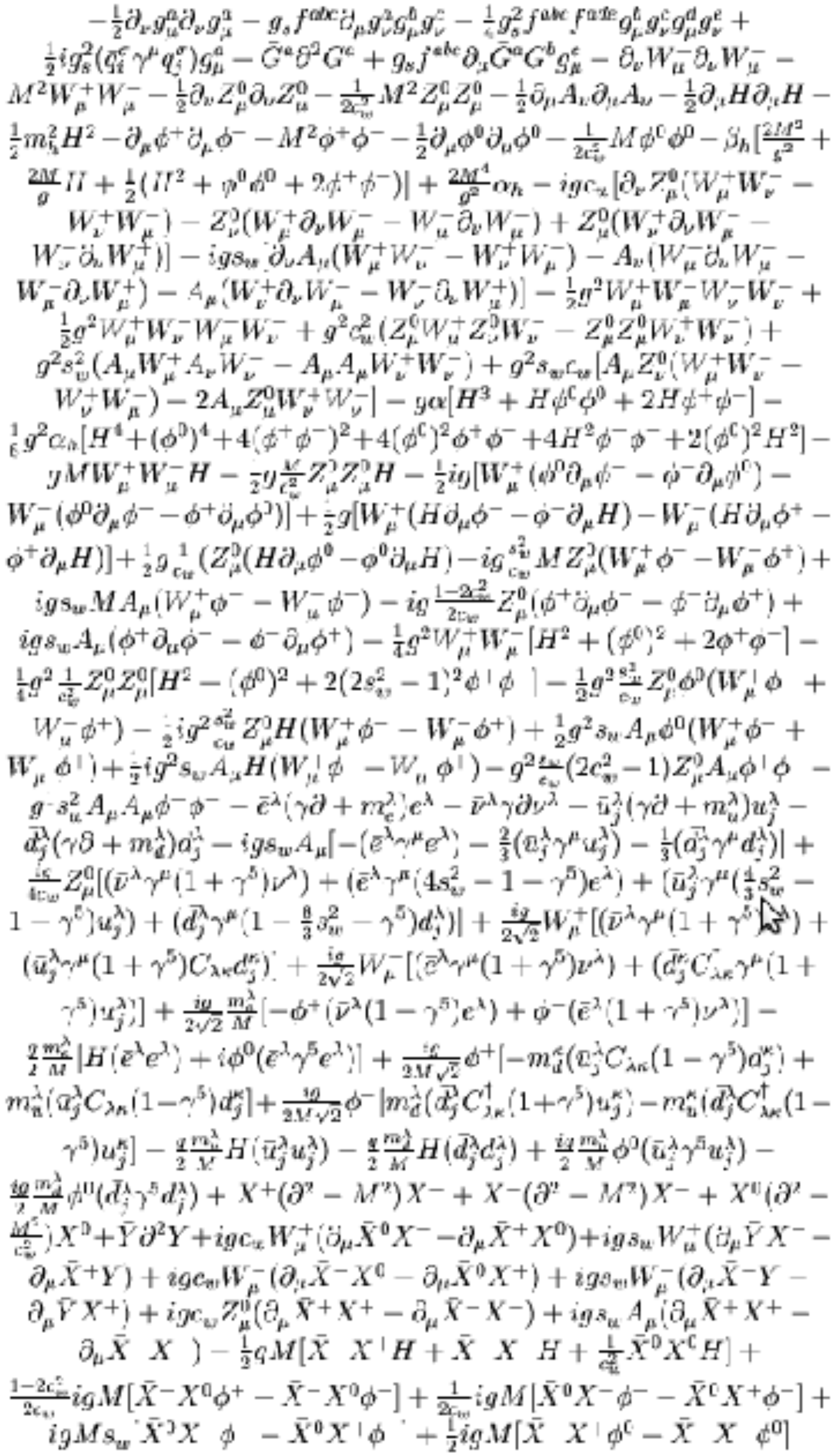
https://cds.cern.ch/journal/CERNBulletin/2012/35/News%20Articles/1473657




So far so good, but

- Is there new physics beyond, i.e. Dark Matter, Antimatter after big bang?
- Unification with gravity?

# Standard model



Standard model does a very good job. It explains how things work (except gravity):

- How you can see things around?
- Radiation from everything around you

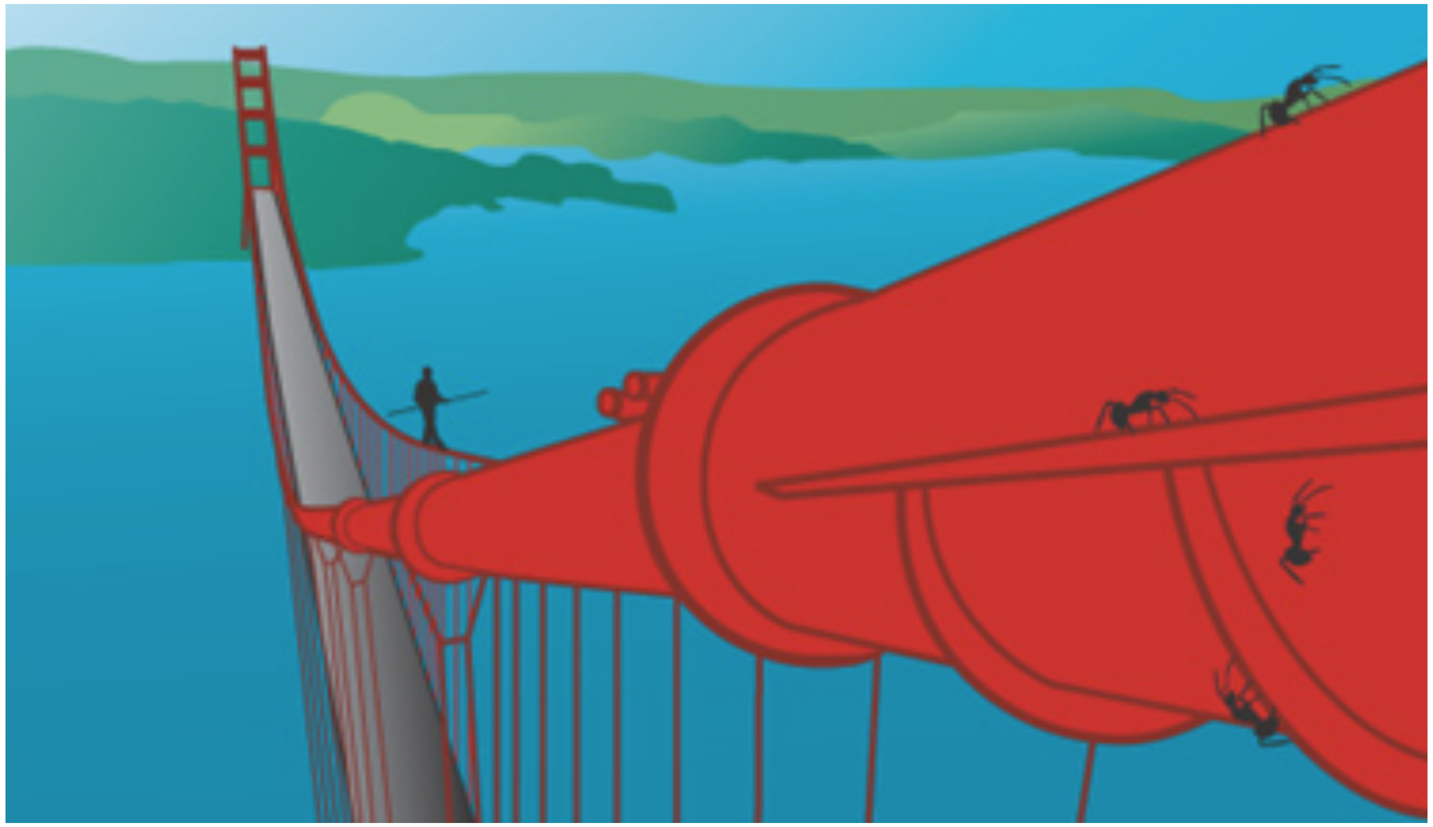
If you try to write the full SM Lagrangian, it will look like

http://www.quantumdiaries.org/2012/09/13/higgs-problems/

With the SM Lagrangian, we need to

- Understand it (Is there a simple principle behind?)
- Perform calculations which can predict results of events that can be seen in accelerators

# Examples of mathematics in theory



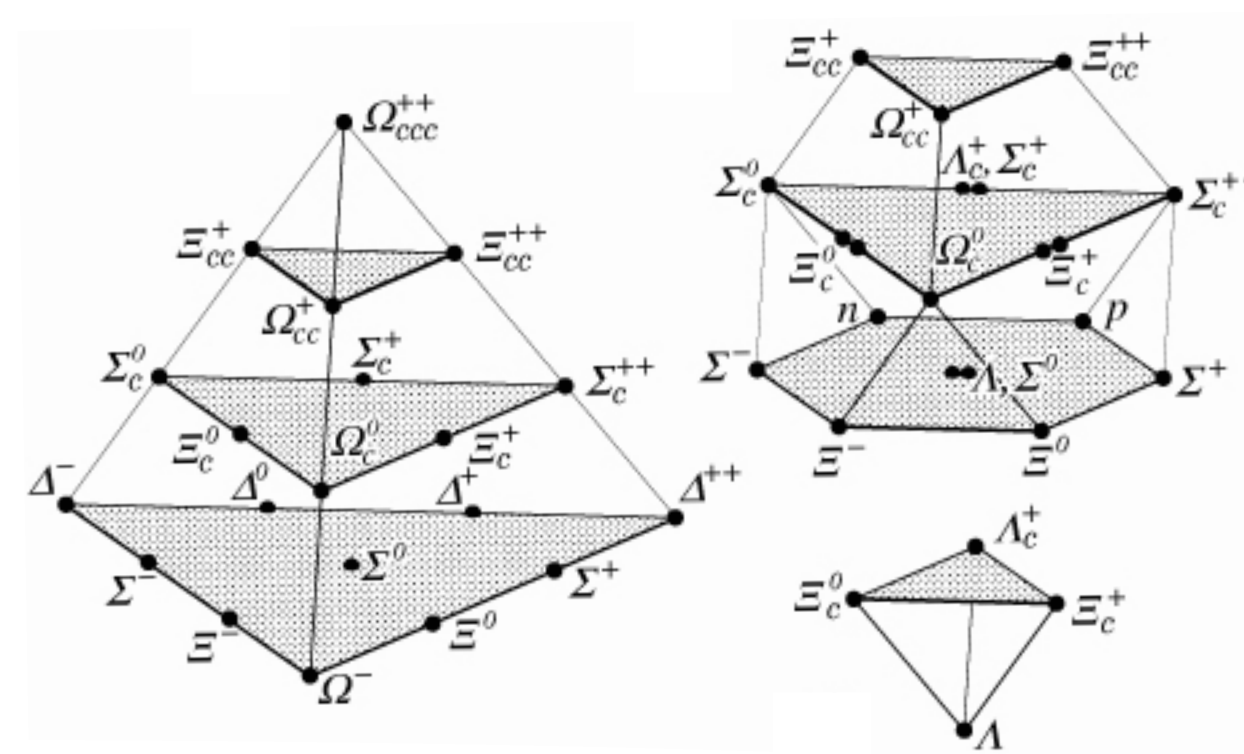
http://www.thephysicsmill.com/2013/04/28/stuff-from-shape-kaluza-klein-theory/

**Geometry**

- Kaluza–Klein theory
  - ➡Unifies gravity with electromagnetic force by introducing fifth dimension beyond the usual four of space and time.
- String theory

**Mathematical model**

- Composite particles - Eightfold Way, SU(3)
- Quantum gauge symmetry, SU(3) x SU(2) x U(1)
  - ➡Follow by spontaneous symmetry breaking



# Ex. of BSM: Extra-Dimensions

**Hierarchy problem**

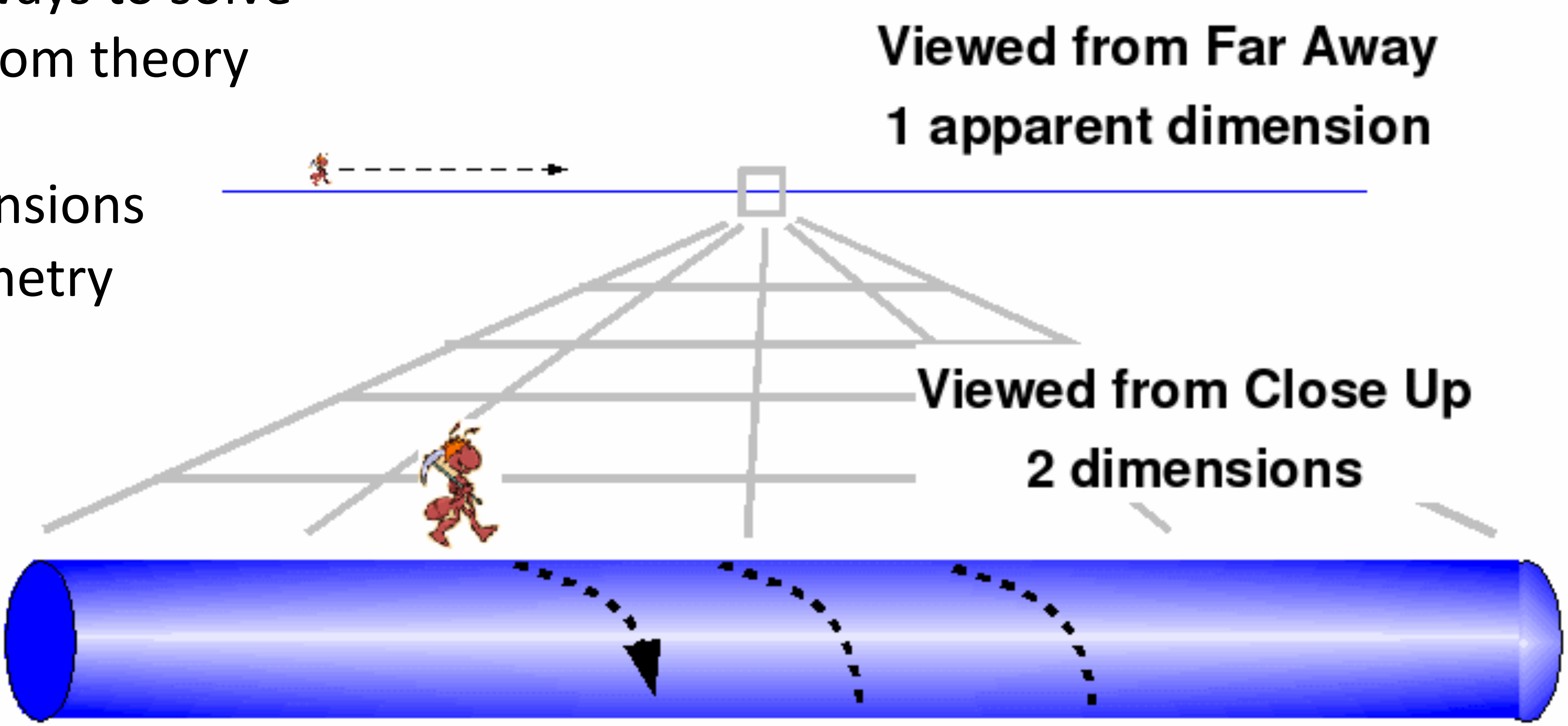
- $M_{Pl}$ ~$10^{19}$ GeV
- $M_{EW}$ ~100 GeV
- $M_{QCD}$ ~100 MeV
- Why gravity is so weak?
- Few different ways to solve this problems (from theory point of view)
    - ➡ Extra dimensions
    - ➡ Supersymmetry

February 1, 2008

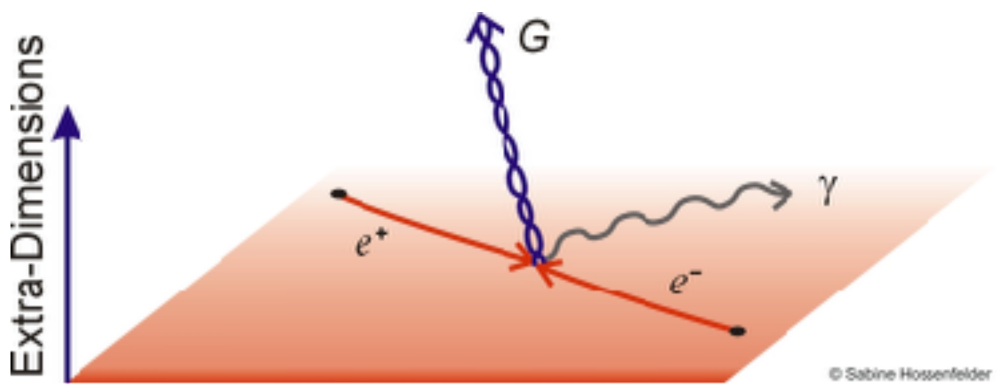
SLAC-PUB-7769
SU-ITP-98/13

**The Hierarchy Problem and New Dimensions at a Millimeter**


Nima Arkani–Hamed*, Savas Dimopoulos** and Gia Dvali†
* SLAC, Stanford University, Stanford, California 94309, USA
** Physics Department, Stanford University, Stanford, CA 94305, USA
† ICTP, Trieste, 34100, Italy

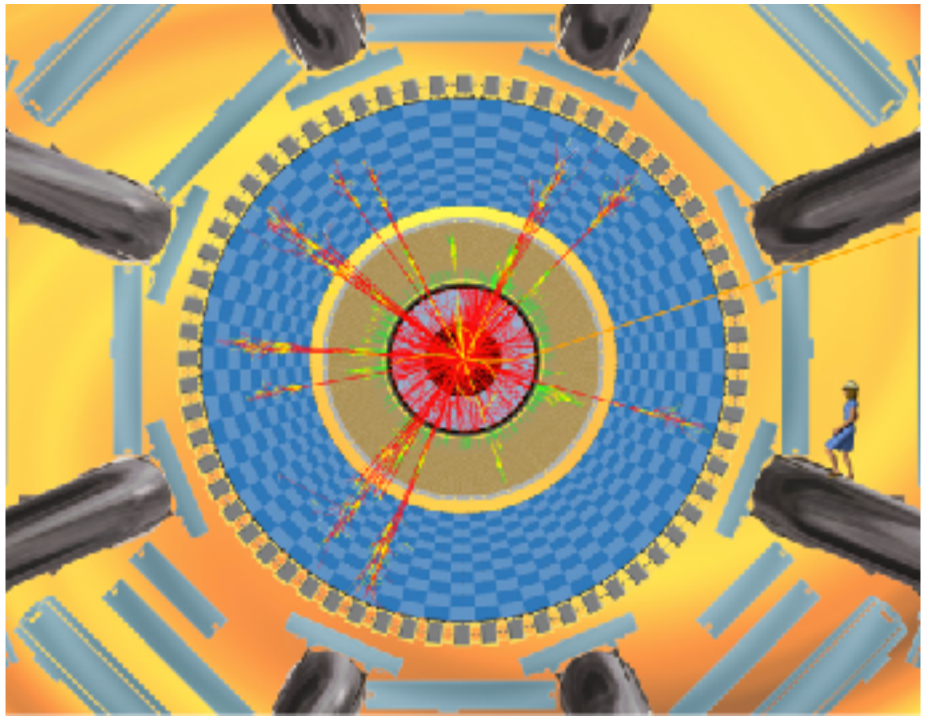



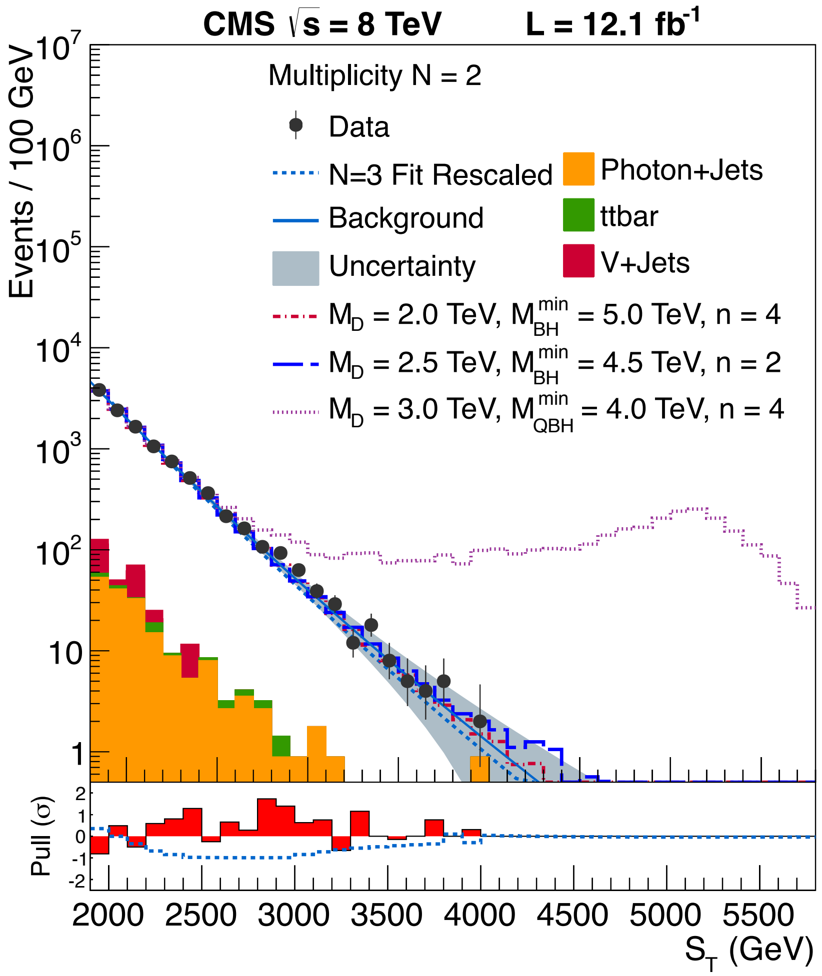
# Ex. of BSM: Black Hole



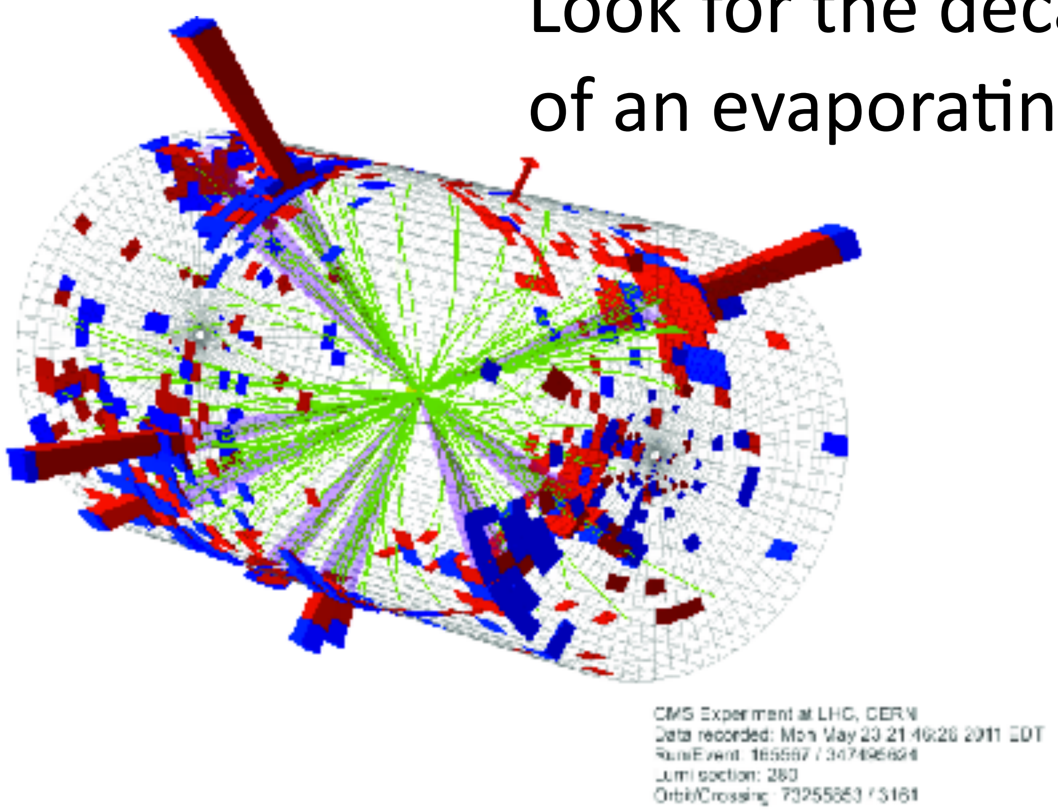

Extra Dimensions

Planck scale
a few TeV?

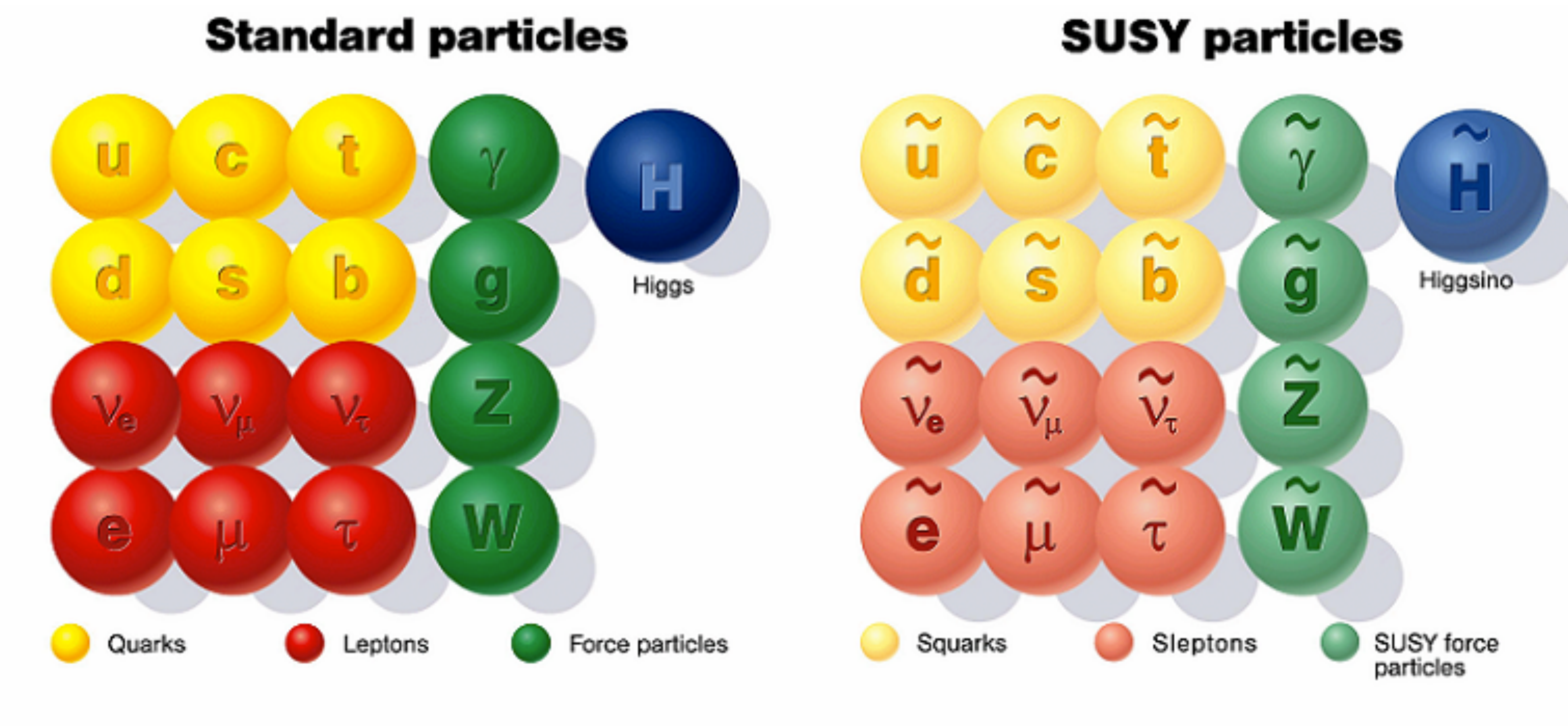





Look for the decay products of an evaporating **black hole**



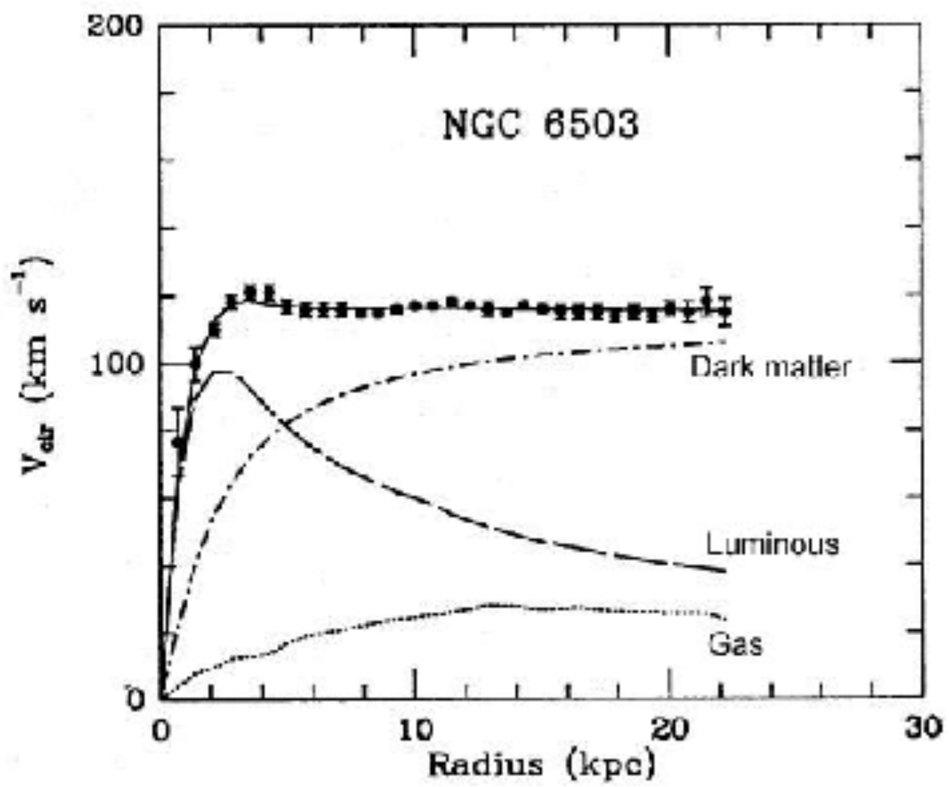
# Ex. of BSM: Supersymmetry




- Bridges between particle and space; New type symmetry
- Provides the good candidate of Dark Matter (WIMP)
- Higgs mass becomes light & E scale naturally is provided.
- Unifies 3 Forces (EM, Weak and strong)

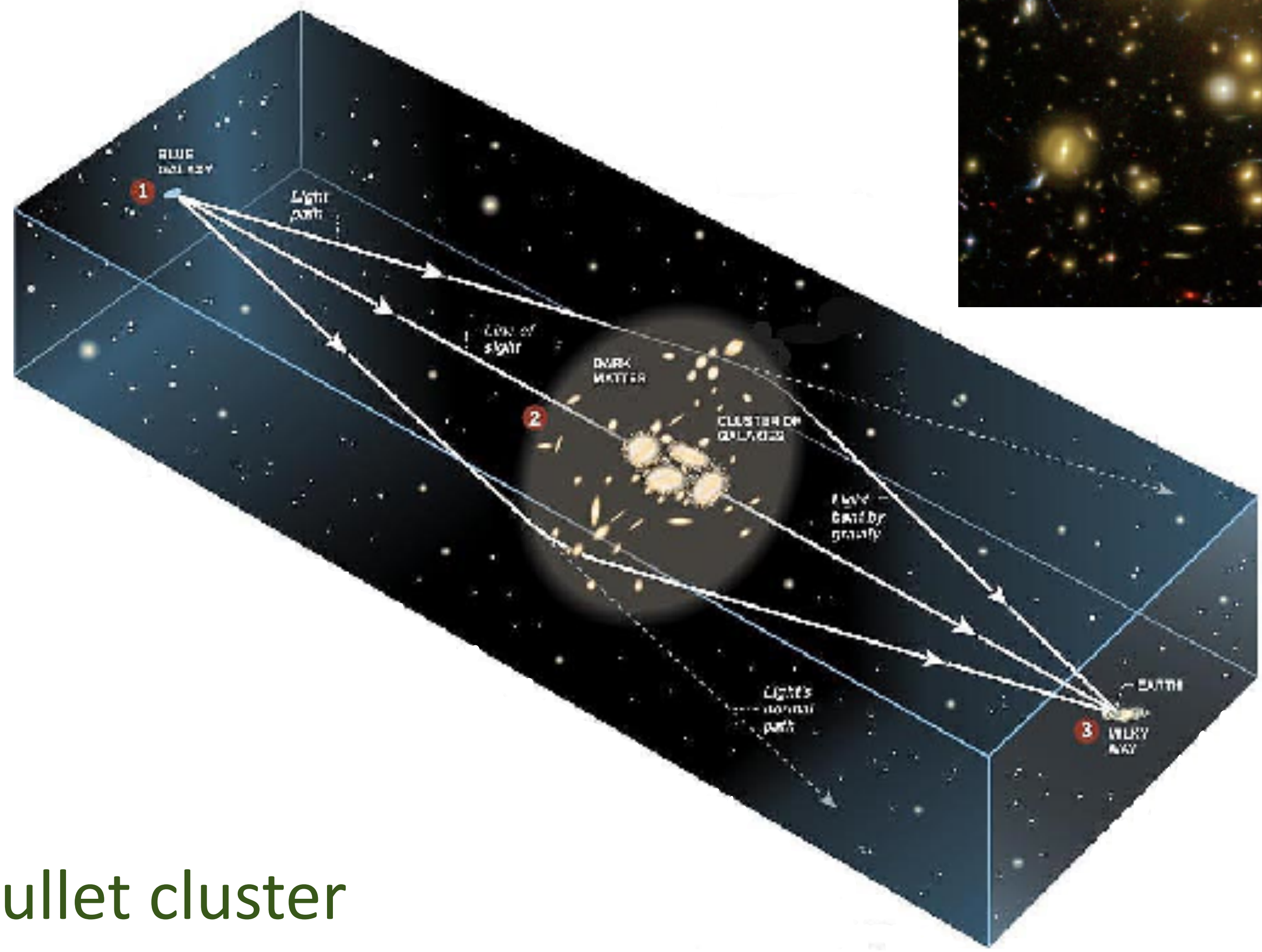
# Ex. of BSM: Dark matter

Strong evidences for the existence of dark matter, i.e. :



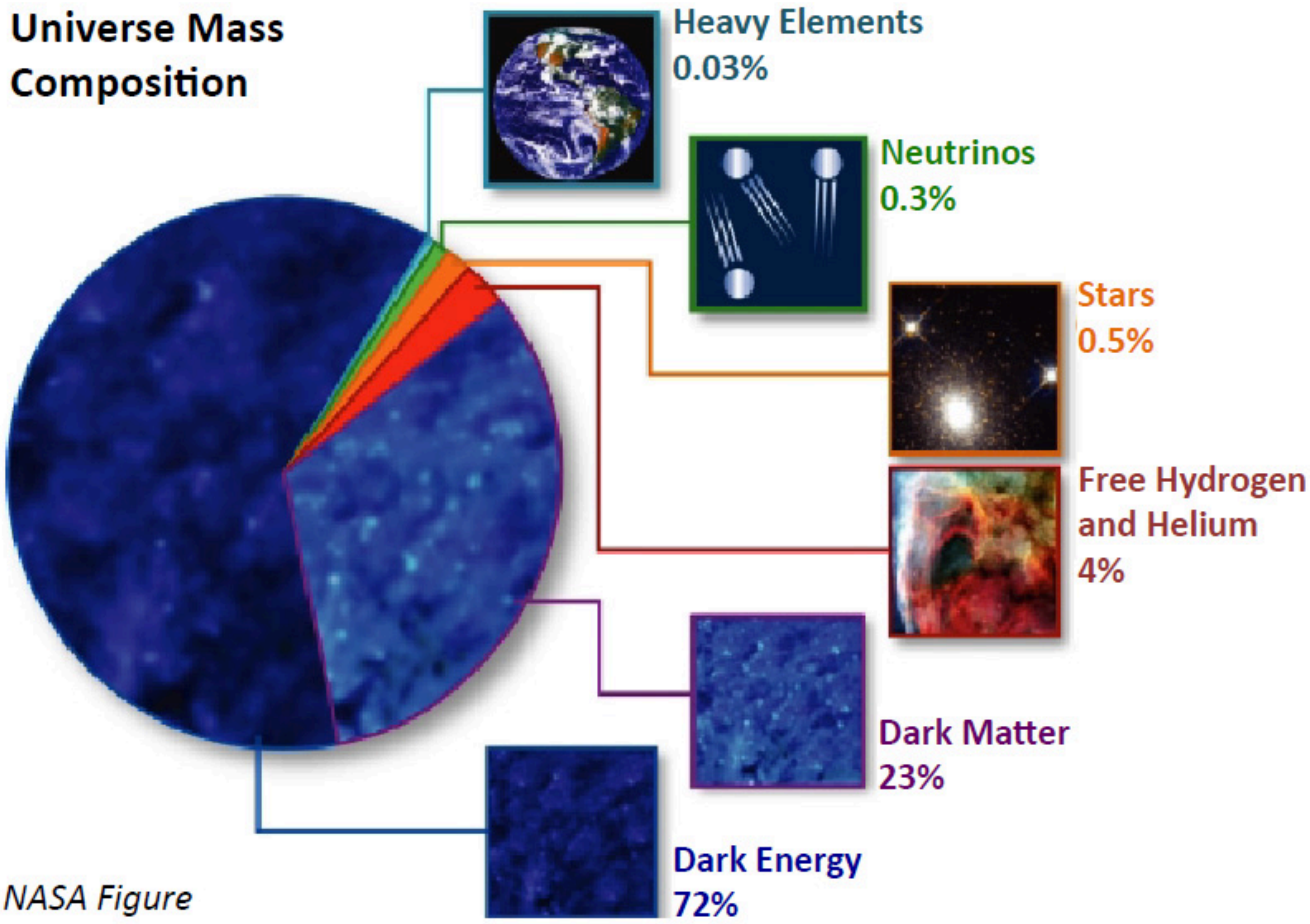

Galactic rotation curves

Strong Gravitational Lensing



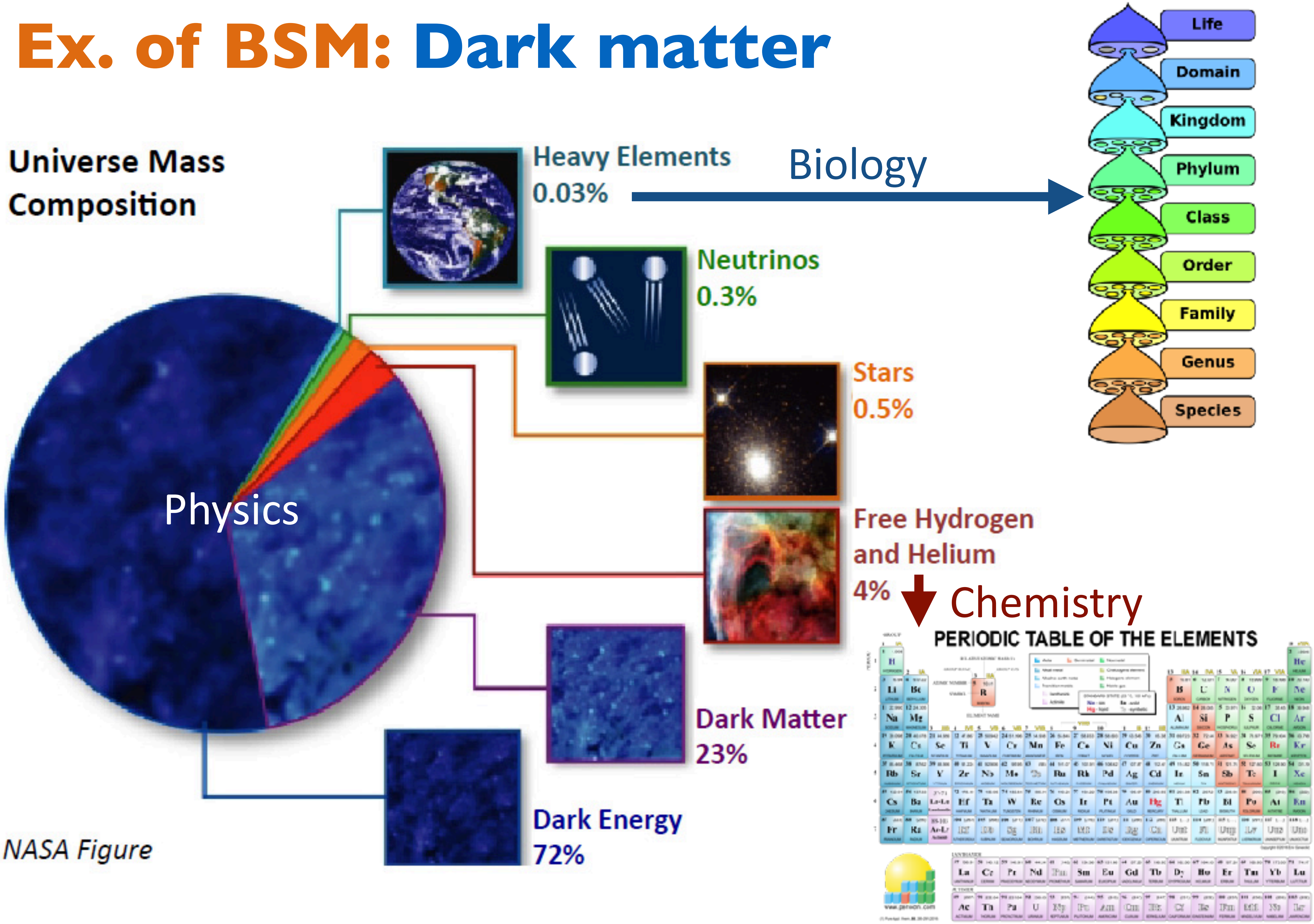
Bullet cluster

# Ex. of BSM: Dark matter




*NASA Figure*

# Ex. of BSM: Dark matter



# Experimental particle physics

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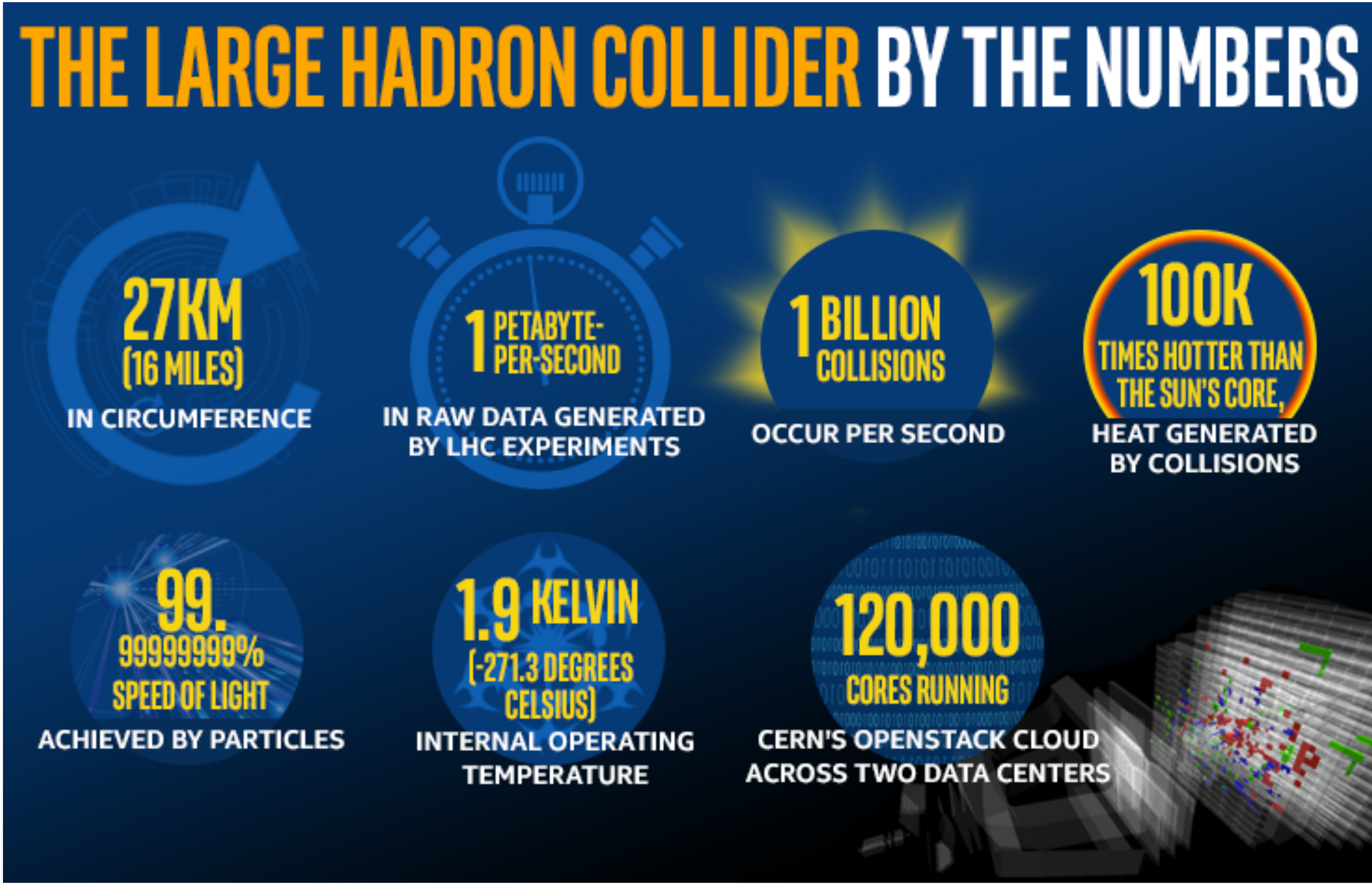
# Large Hadron Collider

# Large Hadron Collider

# LHC by numbers




http://www.intelfreepress.com/news/cern-upgrades-data-center-and-restarts-large-hadron-collider/9819/

# Looking closer to LHC with PHYS101

**Ideal gas**: Estimate the number of air molecules at the interaction point at room temperature.

- $P = 10^{-9}$ Pa
- $T = 293K$
- $V = 2x10^{-11}$ $m^3$
- $R = 8.31$ J $mol^{-1}$ $K^{-1}$

# Looking closer to LHC with PHYS101

**Kinematics**: Estimate the strength of magnetic field needed to control proton at LHC.

- Beam Energy = 7 TeV
- Bending radius = 2804 m
- Proton charge = $1.6 \times 10^{-19}$ C

# Looking closer to LHC with PHYS101

## Ideal gas

**Energy**

**Momentum**

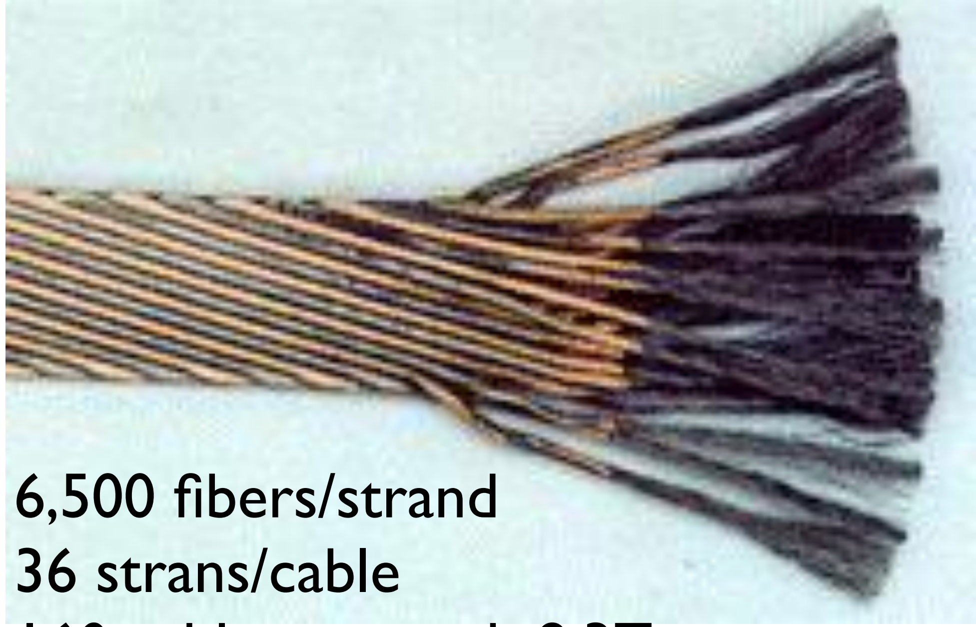
**Coulomb law, Lorentz force**

**Special relativity**

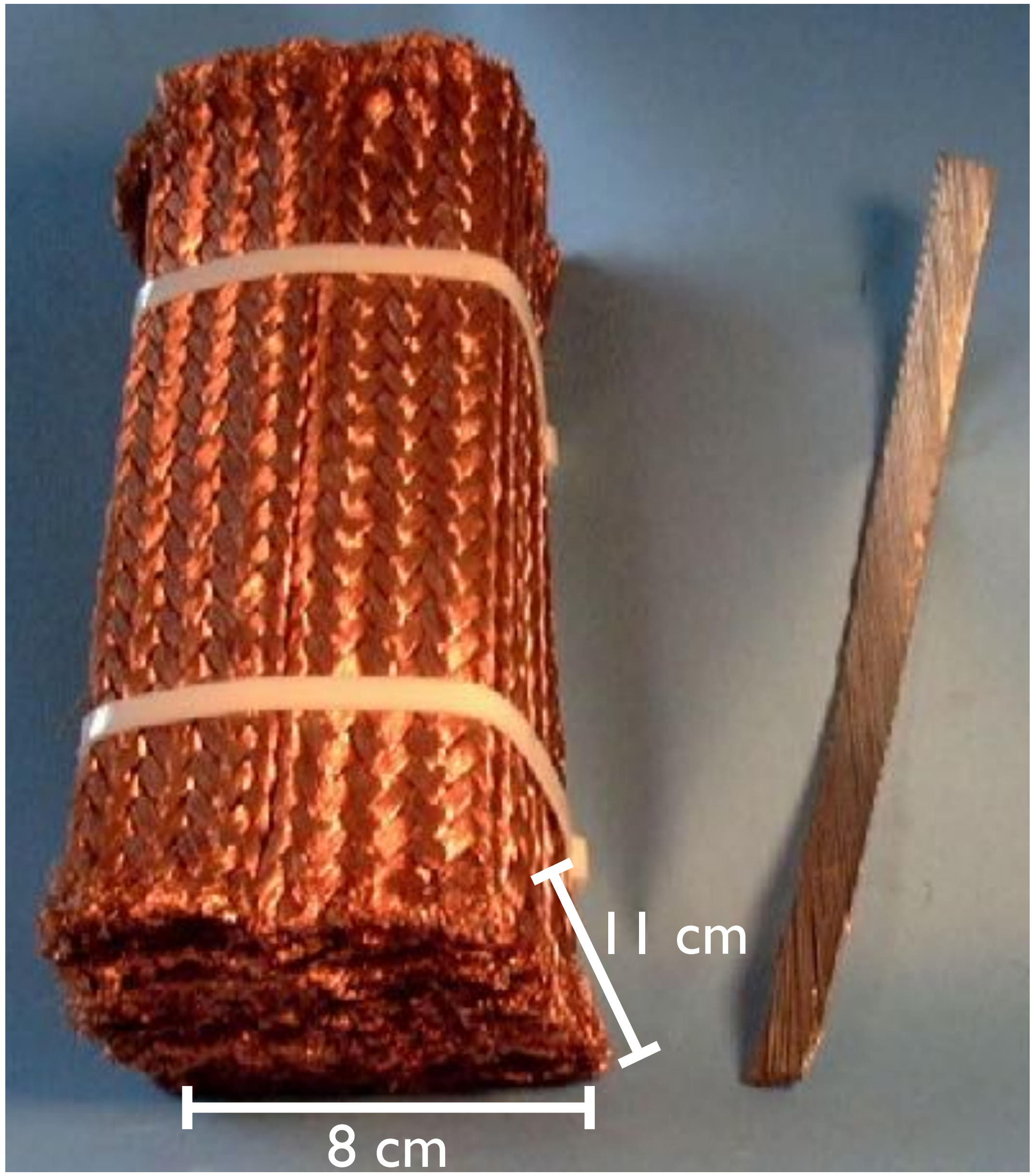
**Superconductivity**

**…**

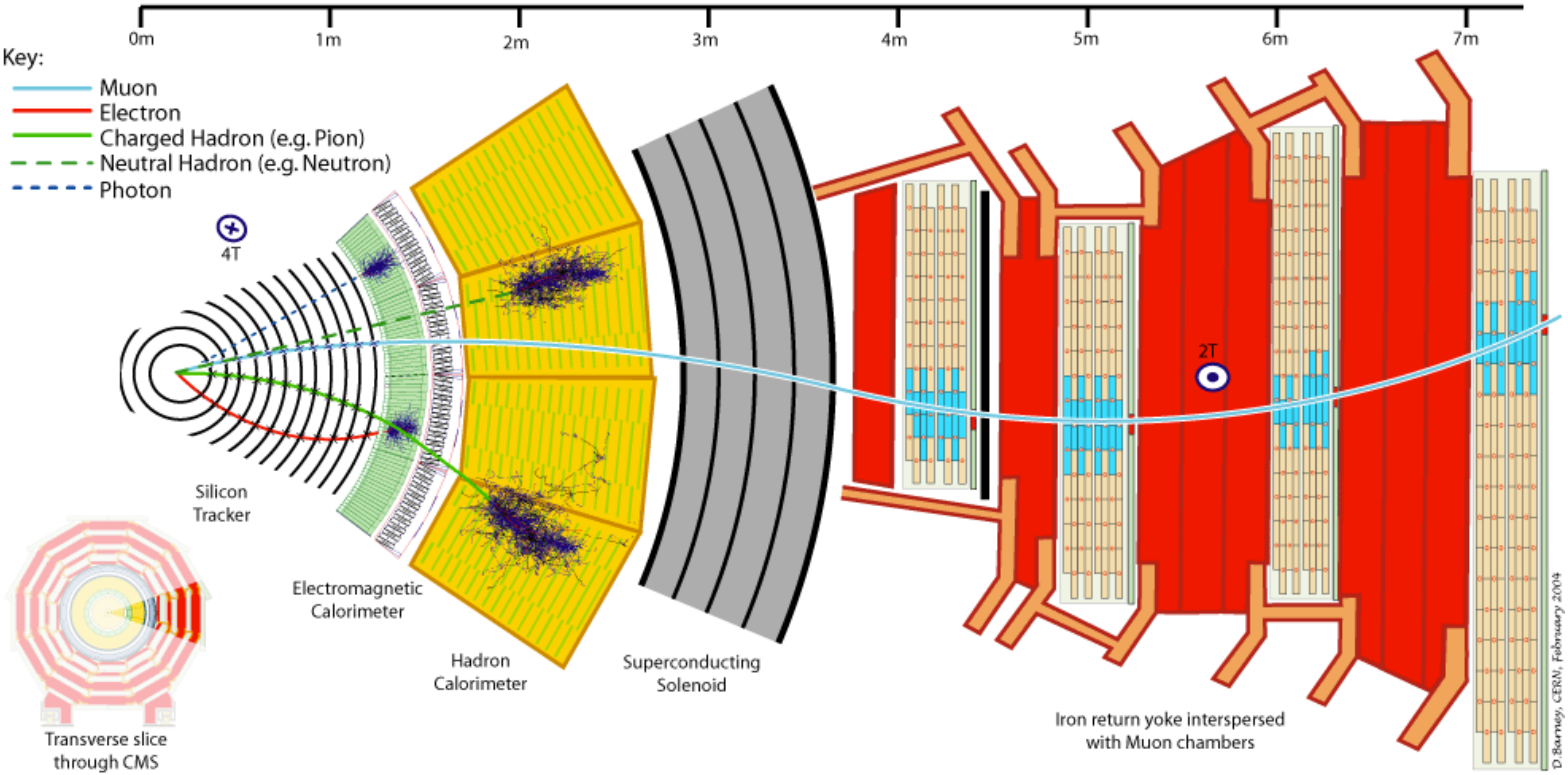
# LHC display objects



6,500 fibers/strand
36 strans/cable
160 cables to reach 8.3T

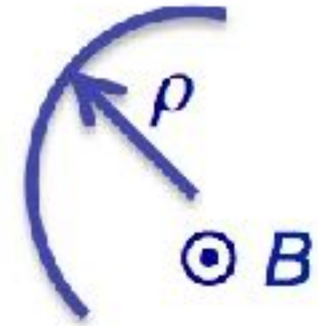


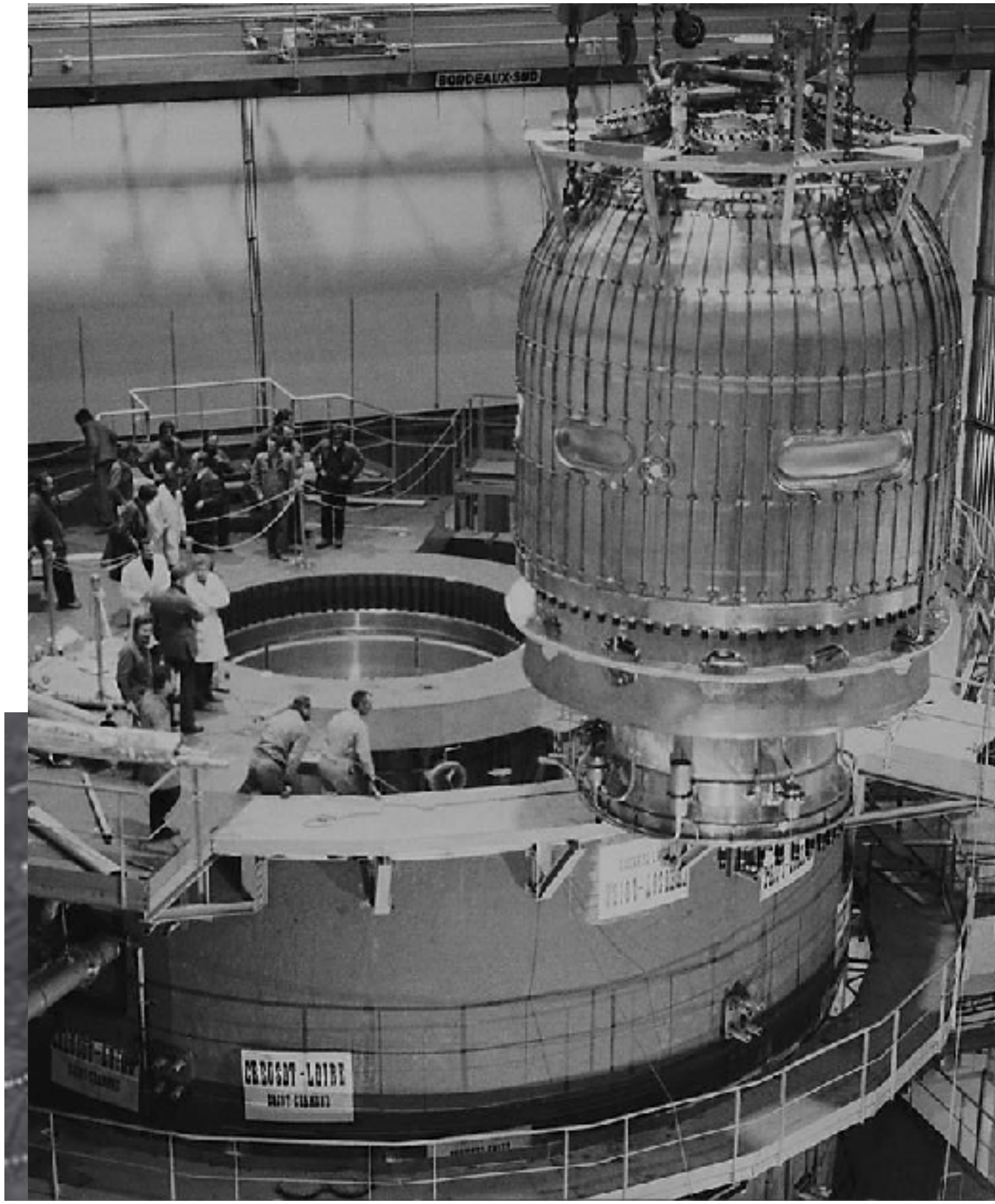
# Particle detector: Very complex camera



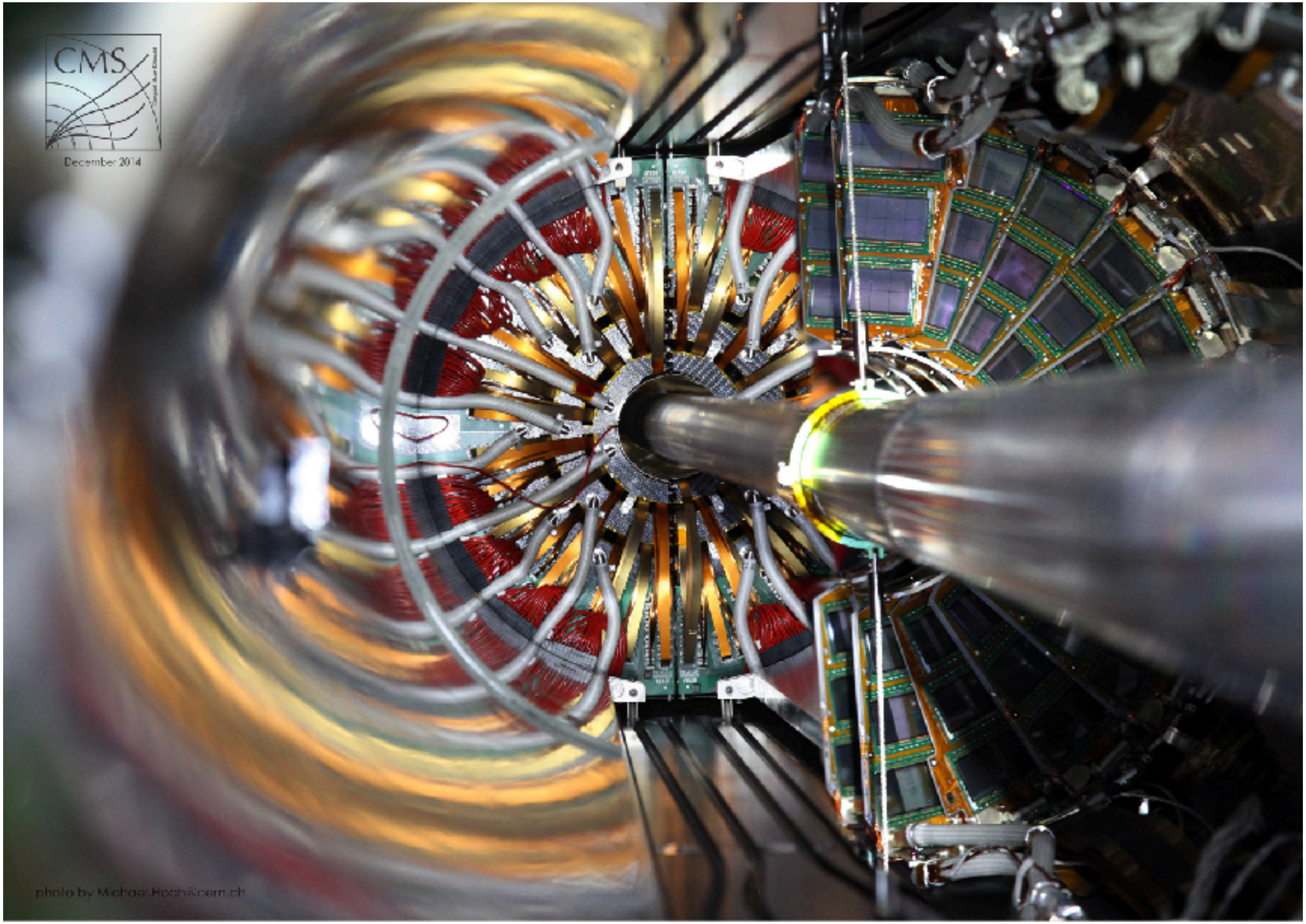
# Particle detector: Momentum & Charge

Charged particles are deflected by magnetic field



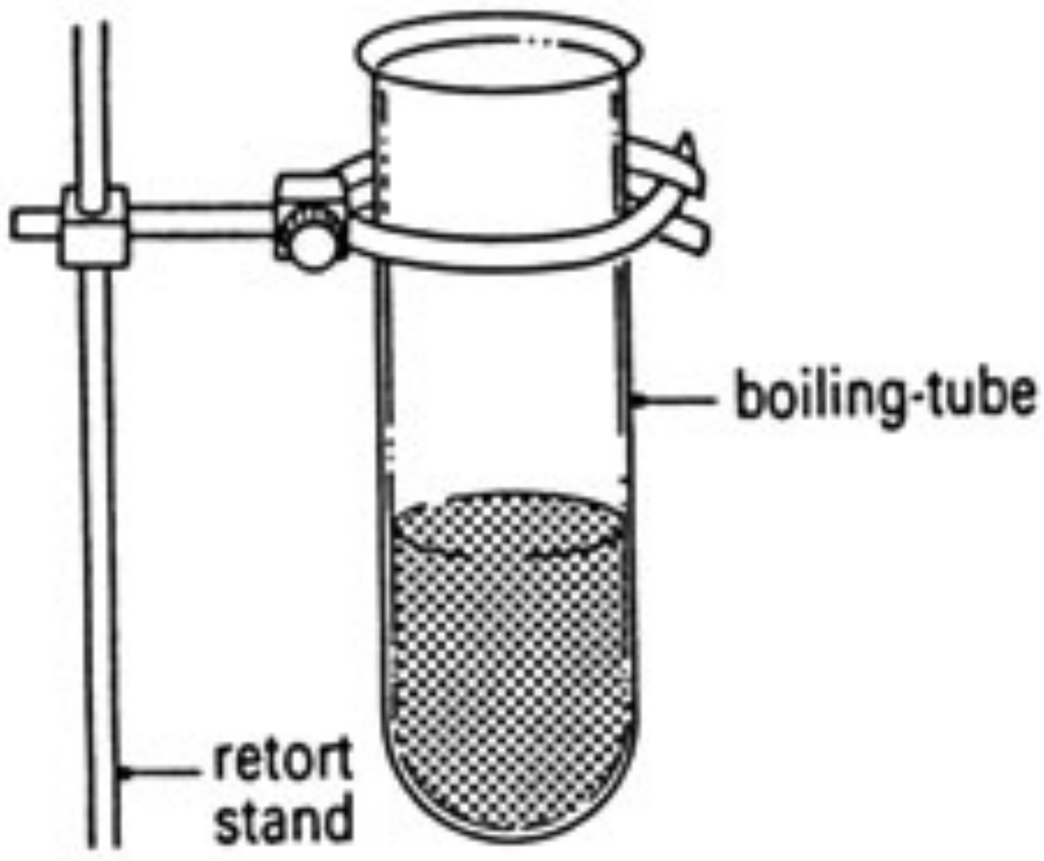
# Particle detector: Momentum & Charge



# Particle detector: Energy

How do we measure the energy in food?

Google said “Burn food samples under a boiling tube containing a measured amount of water. Measure the temperature increase in the water. Calculate the amount of energy needed to cause that temperature increase. This gives an estimate of the amount of energy stored in the food.”



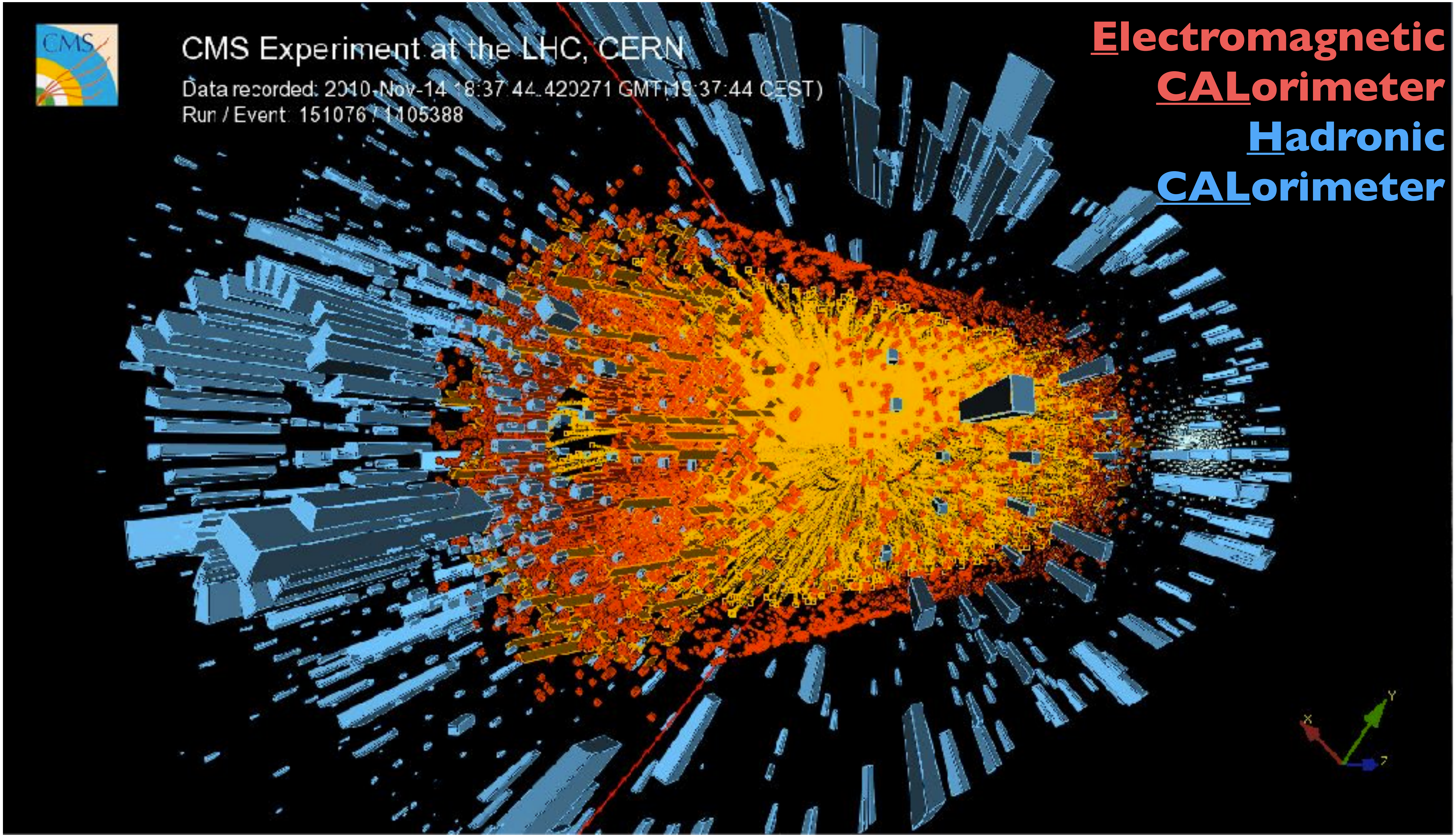

Food, burn it!

What is the concept behind this experiment?

Release the food energy to boil water until the food is gone.

# Particle detector: Energy

Kinetic energy determined via a calorimetric measurement



# LHC experiments

**ALICE**

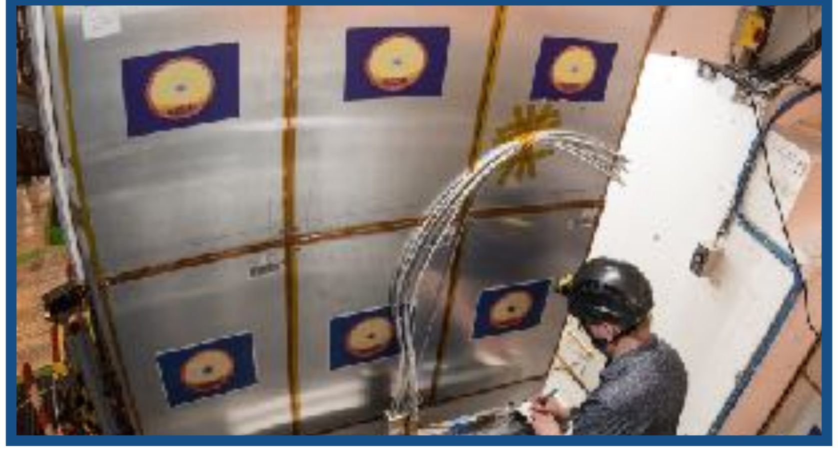
**ATLAS**

**CMS**

**LHCb**

**LHCf**

**MoEDAL**



**TOTEM**

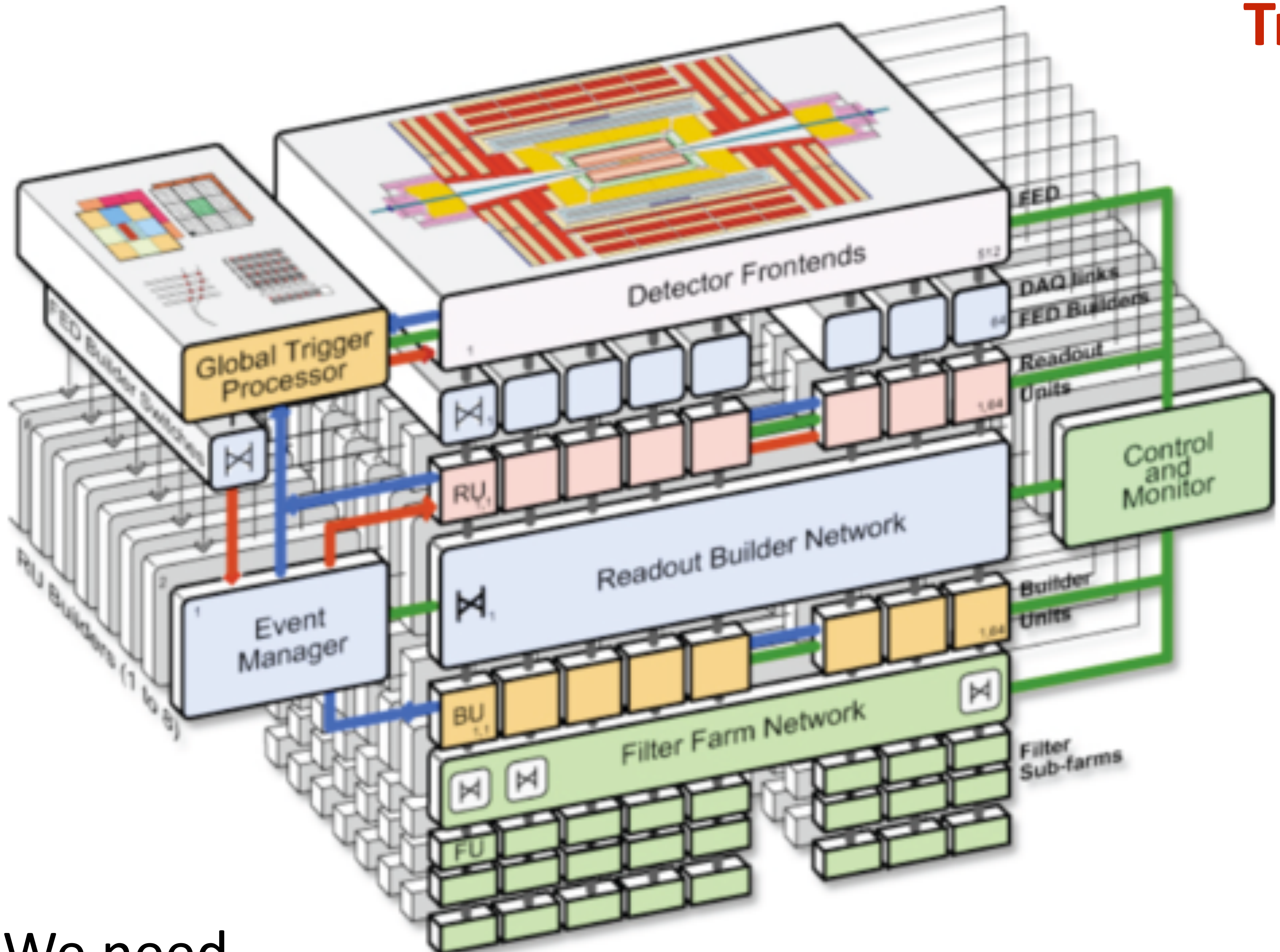
# Experimental particle physics


http://www.symmetrymagazine.org/article/august-2012/particle-physics-tames-big-data

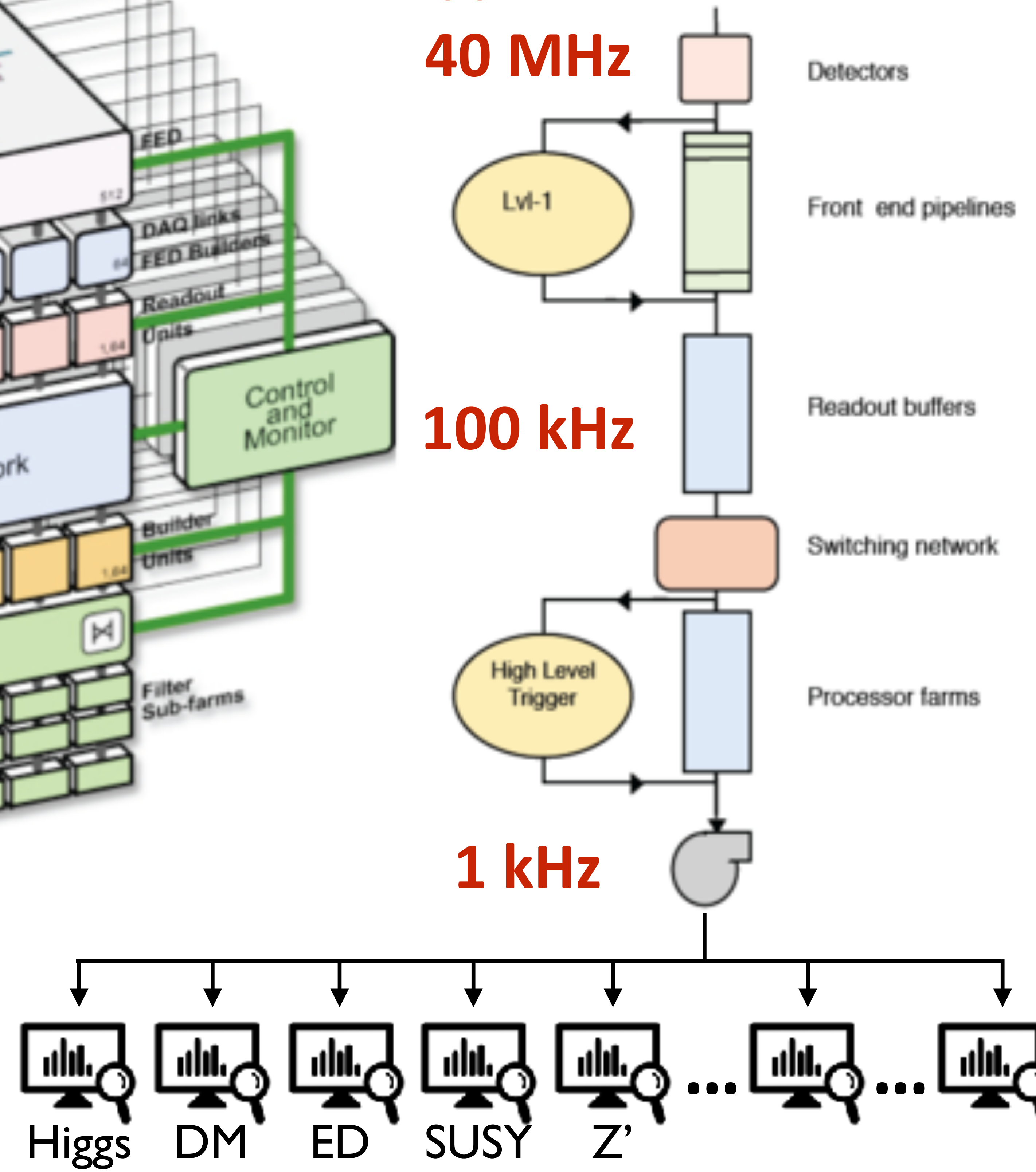
**High Energy Physics is a statistical science:**
**Processes have a probability to happen.**

The smaller it is, the more data (collisions) are needed for an observation, discovery or finally precision measurement.

# Triggering events




Trigger Rate

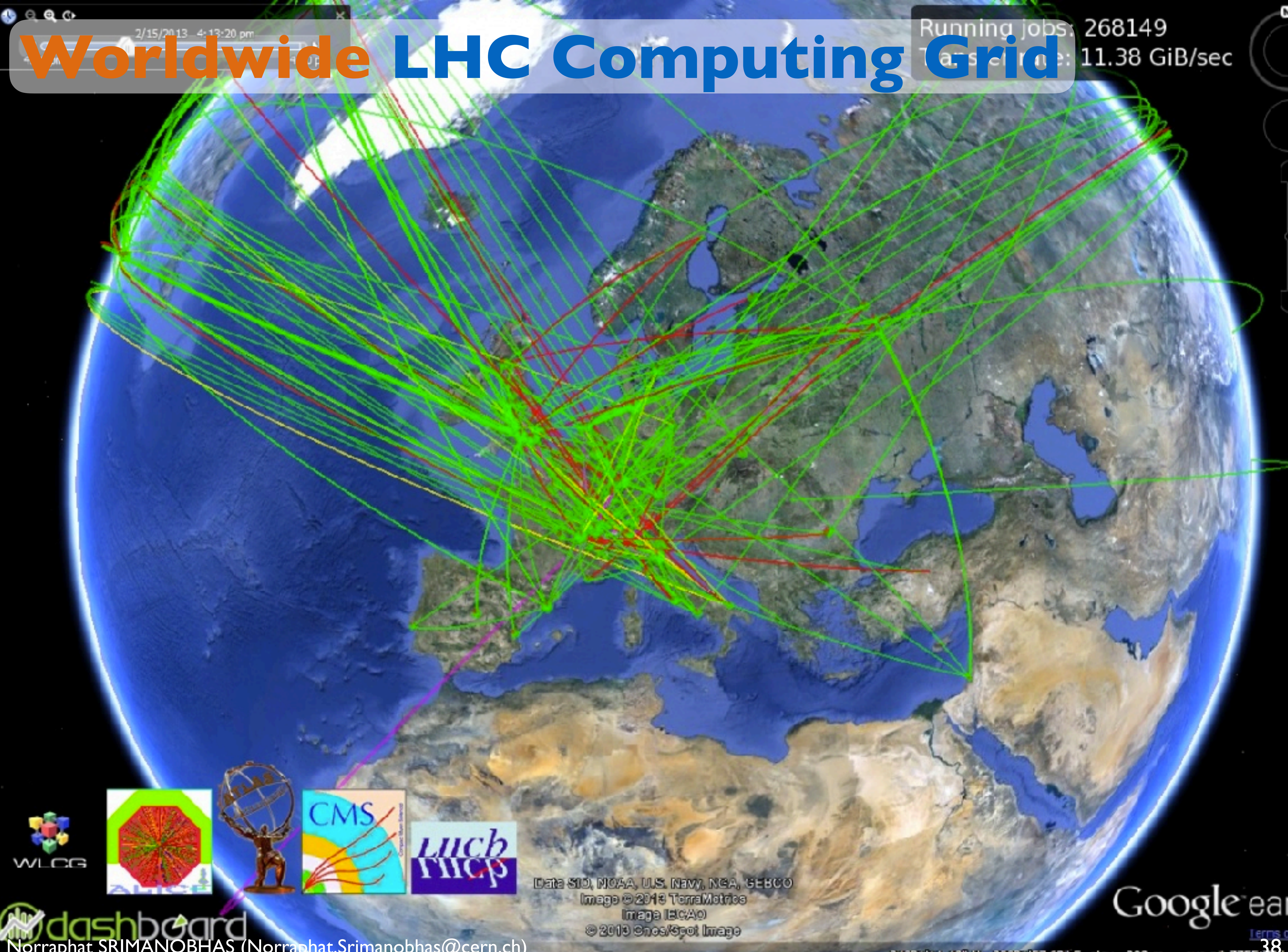



We need

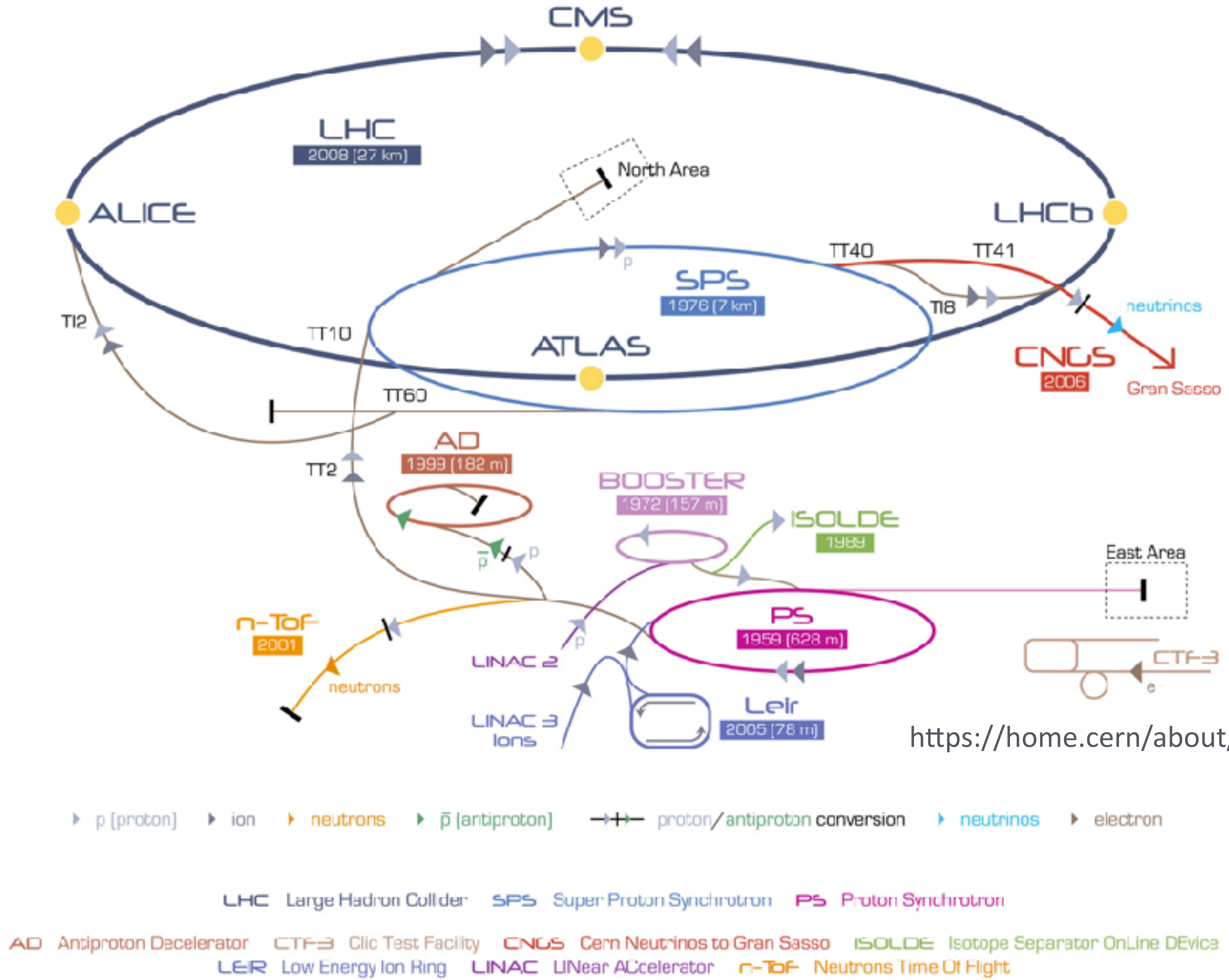
- ➡Fast electronic devices
- ➡Fast computing algorithms

to make a trigger system

# Worldwide LHC Computing Grid



# None LHC programs




https://home.cern/about/experiments

# Examples of non LHC programs

**AEGIS**

AEGIS uses a beam of antiprotons from the Antiproton Decelerator to measure the value of Earth's gravitational acceleration.


**DIRAC**

A collaboration of CERN physicists are studying the decay of unstable “pionium atoms” to gain insight into the strong force.

**AMS**

The Alpha Magnetic Spectrometer looks for dark matter, antimatter and missing matter from a module on the International Space Station.

https://home.cern/about/experiments

# Examples of non LHC programs

**AWAKE**

AWAKE explores the use of plasma to accelerate particles to high energies over short distances.

**CLOUD**

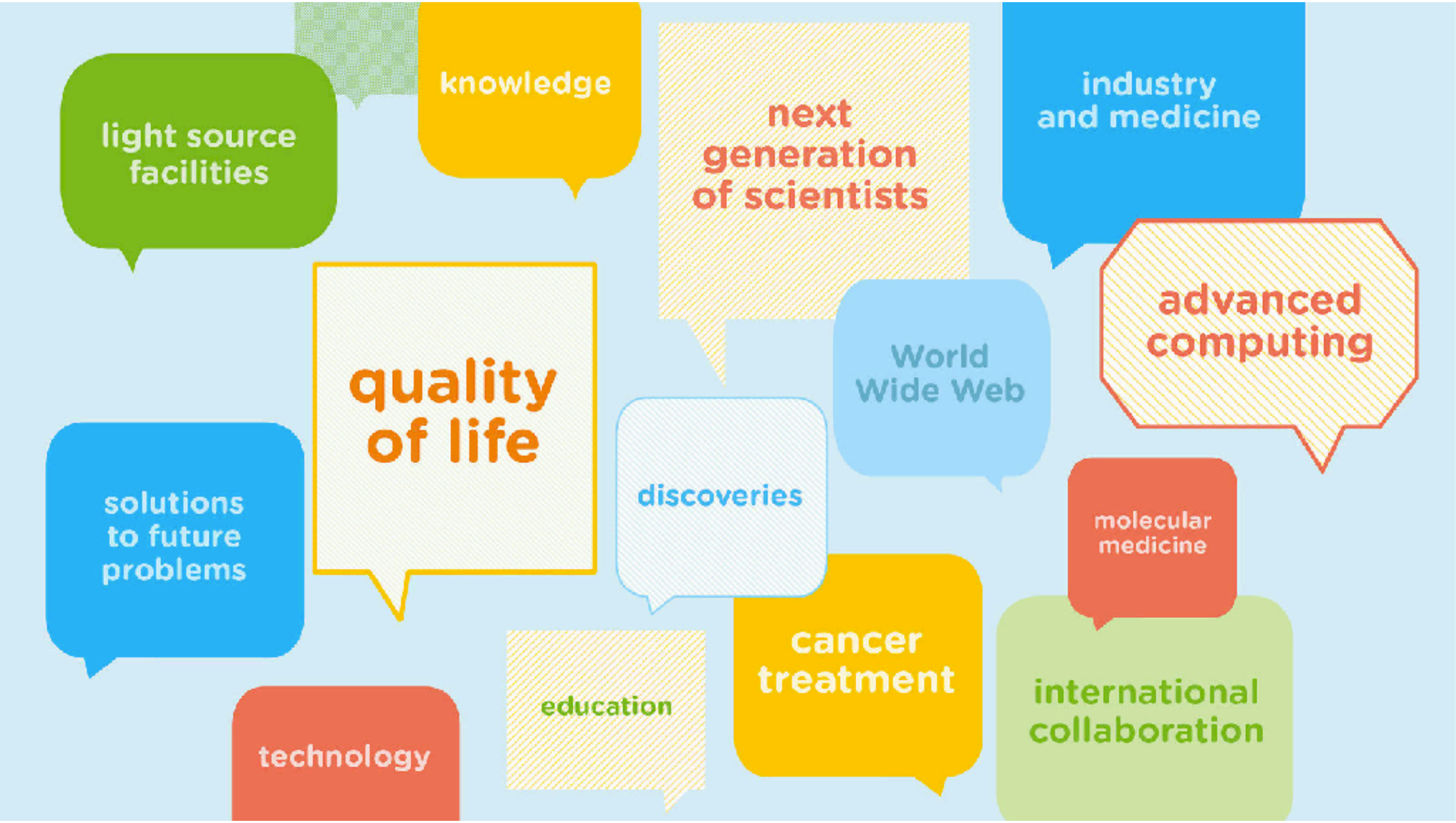
Could there be a link between galactic cosmic rays and cloud formation? An experiment at CERN is using the cleanest box in the world to find out.

**ISOLDE**

ISOLDE studies the properties of atomic nuclei, with further applications in fundamental studies, astrophysics, material and life sciences.

https://home.cern/about/experiments

# Why particle physics matters




http://www.symmetrymagazine.org/article/october-2013/why-particle-physics-matters

# How particle physics improves your life

## Diaper

Using X-ray microscopy at ALS Berkeley, chemists were able to see the detailed structure of the superabsorbent polymer material while wet. This help them tp adjust and improve the formula for the superabsorbent polymers until they had the perfect diaper.

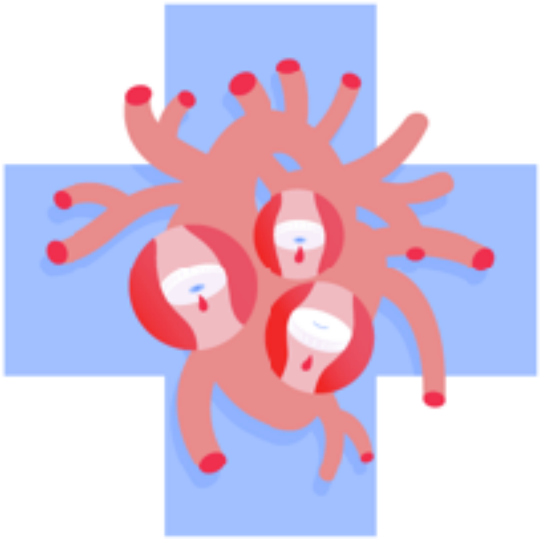
http://www.symmetrymagazine.org/article/may-2011/accelerator-apps-diapers

## Shrink wrap

Particle accelerators, electron beam, tie the molecules of plastic together by knocking hydrogen atoms off the polymer chains. If conditions are right, the carbon atoms in one chain bond with carbons in neighboring chains — and make the film tougher mechanically

http://www.symmetrymagazine.org/article/october-2009/accelerator-application-shrink-wrap

# How particle physics improves your life



## Heart valves

Physicists and biologists are improving the safety of artificial heart valves by designing a new material bombarded with silver ions from a particle accelerator using the Alabama A&M.

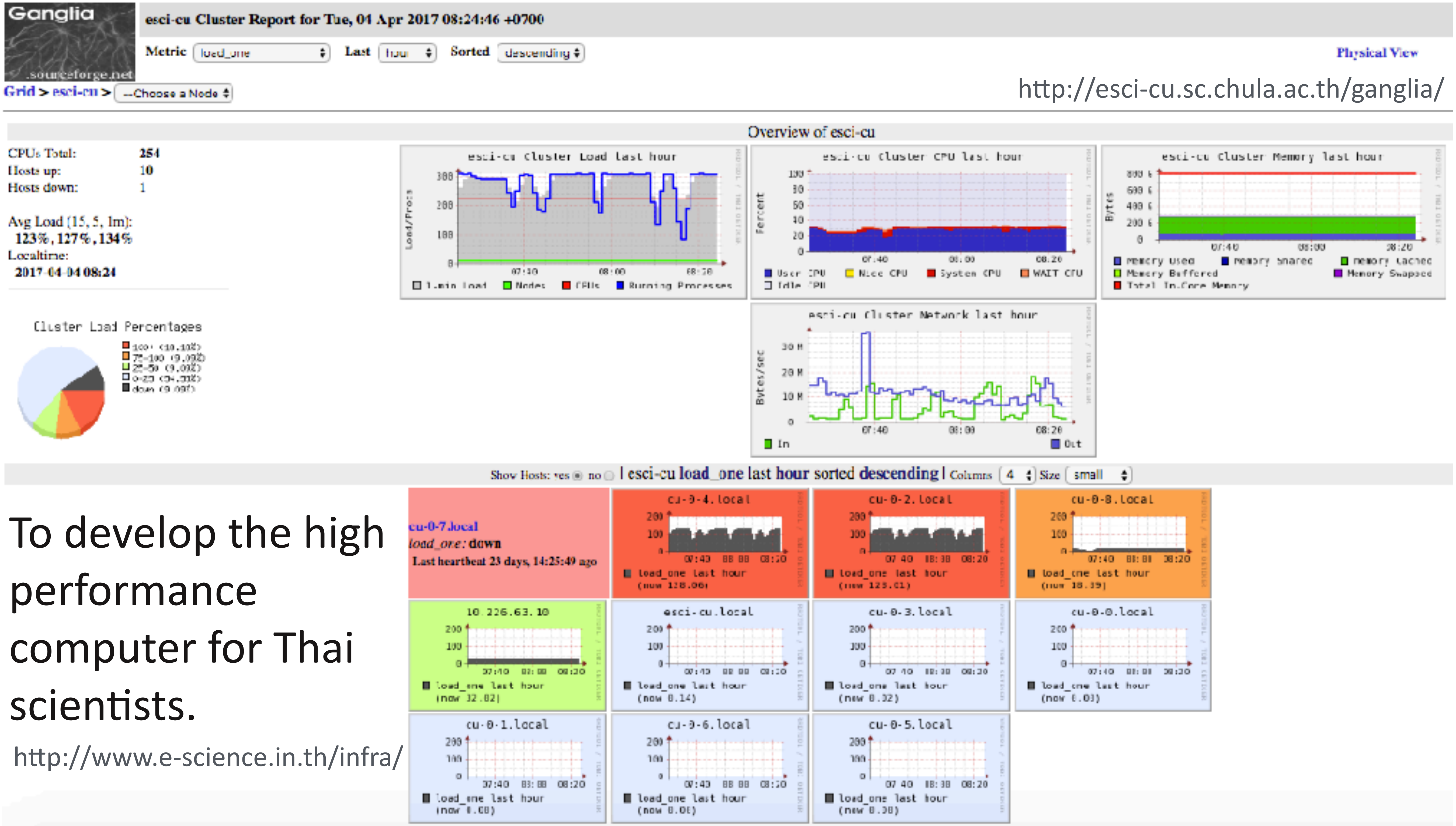
http://www.symmetrymagazine.org/article/august-2009/accelerator-applications-heart-valves

## Grid computing

The World Wide Web isn't the only computing advancement to come out of particle physics. To deal with the computing demands of the LHC experiments, particle physicists have created the world's largest Grid computing system, pushing the boundaries of global networking and distributed computing.

http://www.symmetrymagazine.org/article/march-2013/how-particle-physics-improves-your-life

# National eScience Infrastructure Consortium



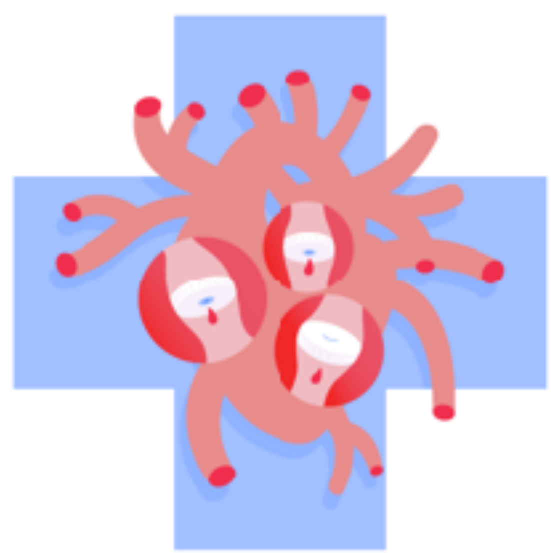

http://esci-cu.sc.chula.ac.th/ganglia/

To develop the high performance computer for Thai scientists.

http://www.e-science.in.th/infra/

# How particle physics improves your life



http://www.symmetrymagazine.org/article/march-2013/how-particle-physics-improves-your-life

# Summary

**Space**: the final frontier. These are the voyages of the starship Enterprise. Its five-year mission: to explore strange new worlds, to seek out new life and new civilizations, to boldly go where no man has gone before.

**Big Bang**: the final frontier. These are the voyages of the accelerator LHC. Its thirty-year mission: to explore strange new particles, to seek out new knowledge and new technology, to boldly run where no machine has been done before.

# **We** choose to go to the Moon

"We choose to go to the Moon, we choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills"

*John F. Kennedy, Rice University, Sept. 12, 1962*

https://www.nasa.gov/content/president-john-f-kennedy-at-rice-university