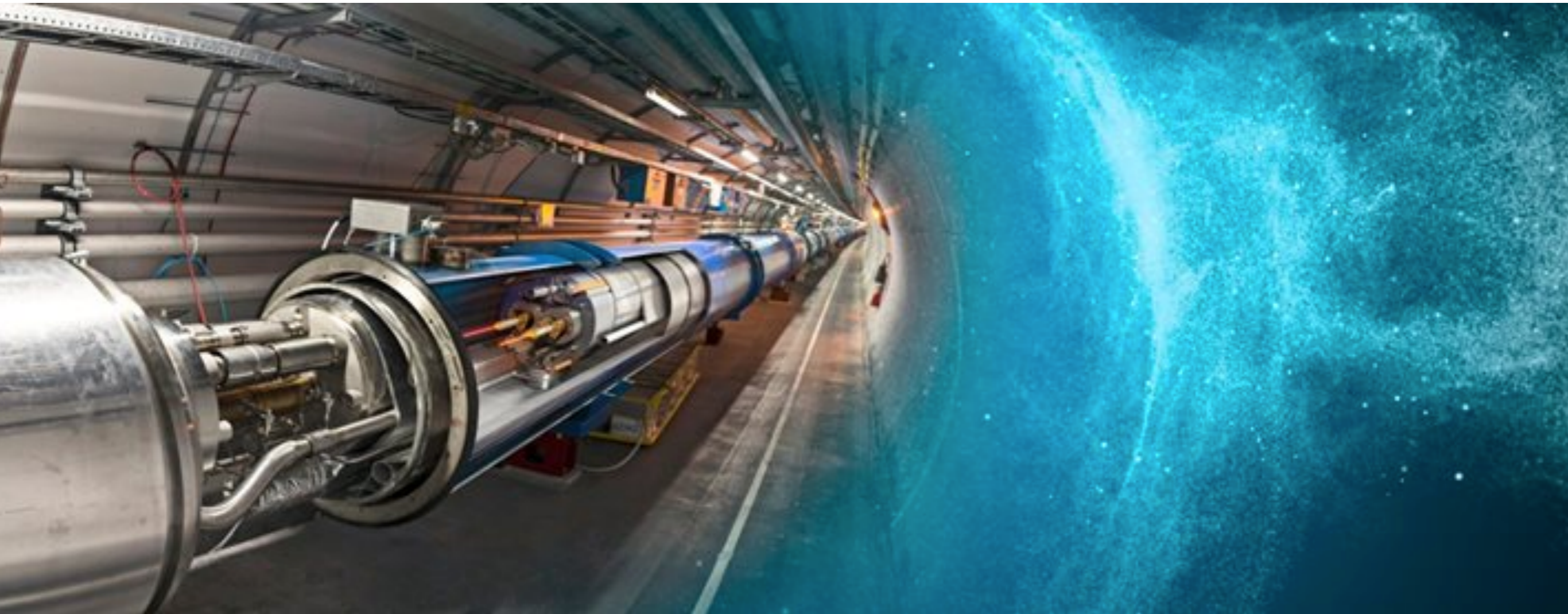




Large Hadron Collider

Science and Applications



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

Srinakharinwirot University
April 19, 2017

How things work

- Accelerate protons
- Collide bunches of particles

LHC

- Theoretical particle physics

Theory

- Medical
- Space
- Materials
- Computing
- ...

Applications

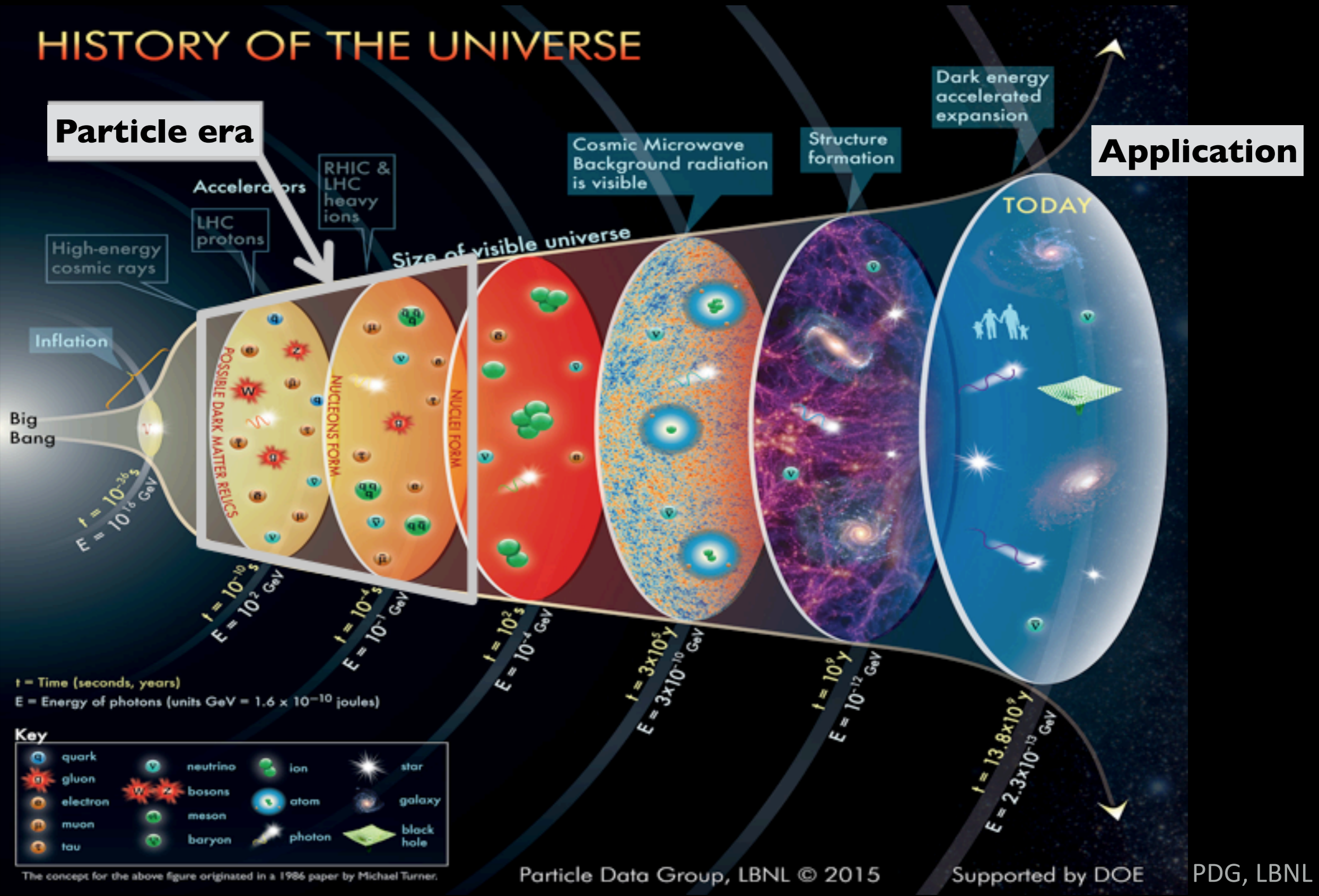
- Detect particles coming from collisions
- Select events of interest
- Store RAW events, and transfer them around the world
- Do offline processing around the world
- Perform analyses

Experiments

- Statistical method

Statistics

What will we talk about



Fundamental questions



Painting by Paul Gauguin

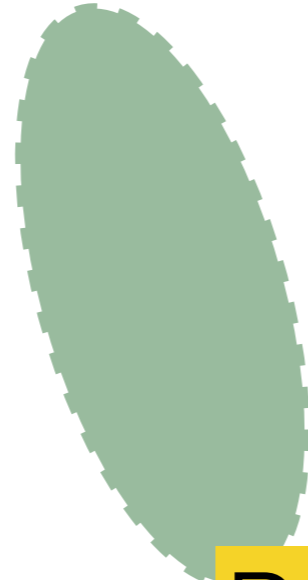
Where Do We Come From? What Are We? Where Are We Going?

Note that this painting should be read from right to left.

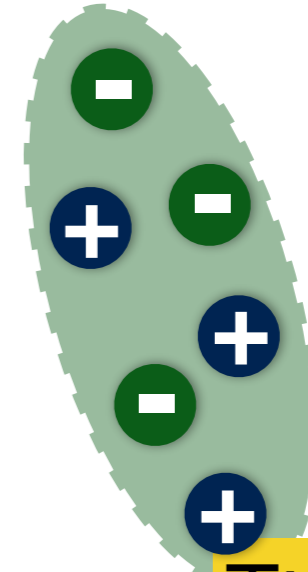
Building blocks of known universe



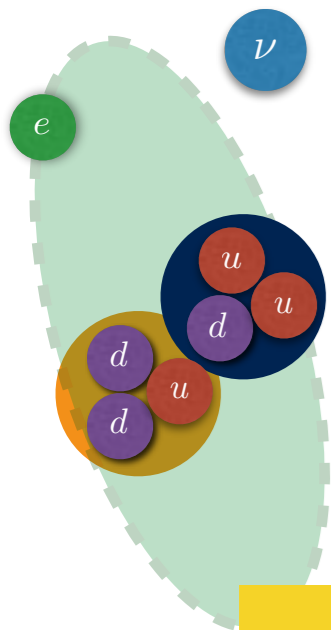
DEMOCRITUS



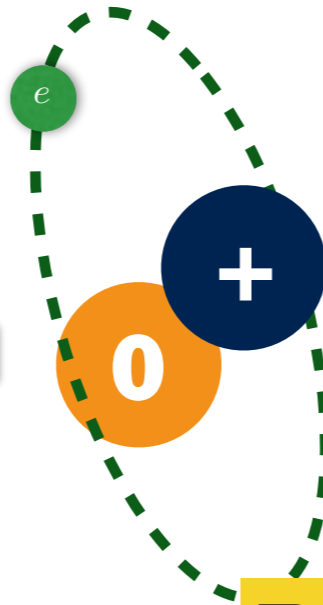
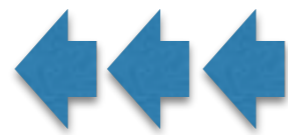
DALTON



THOMSON



TODAY
PHYSICISTS



RUTHERFORD



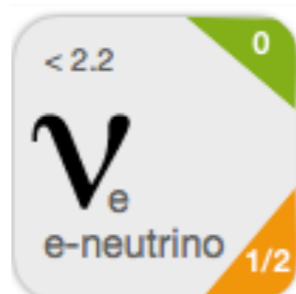
BOHR



CHADWICK

Building blocks of known universe

Matter



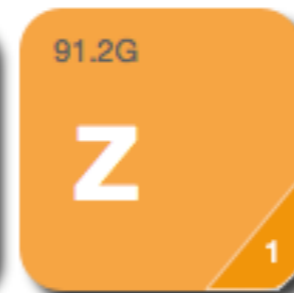
Forces



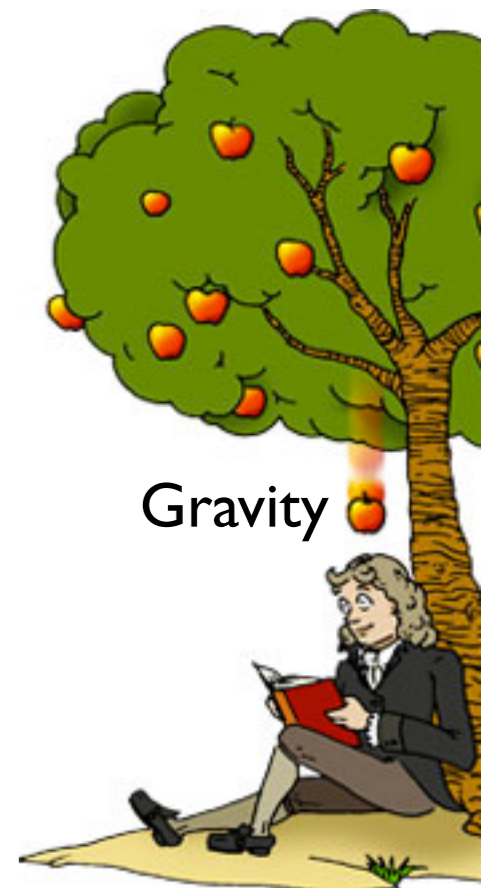
Strong nuclear



Electromagnetic



Weak nuclear

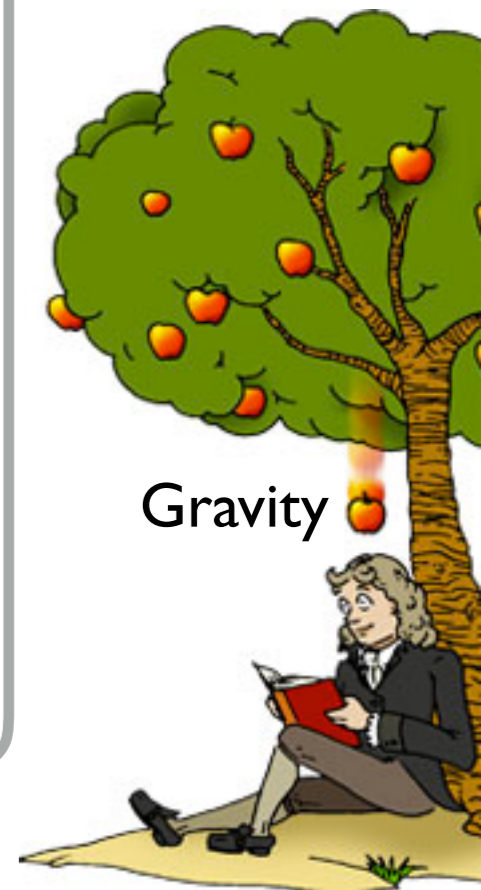


Building blocks of known universe

Matter

Forces

	Strong nuclear
	Electromagnetic
	Weak nuclear



Building blocks of known universe

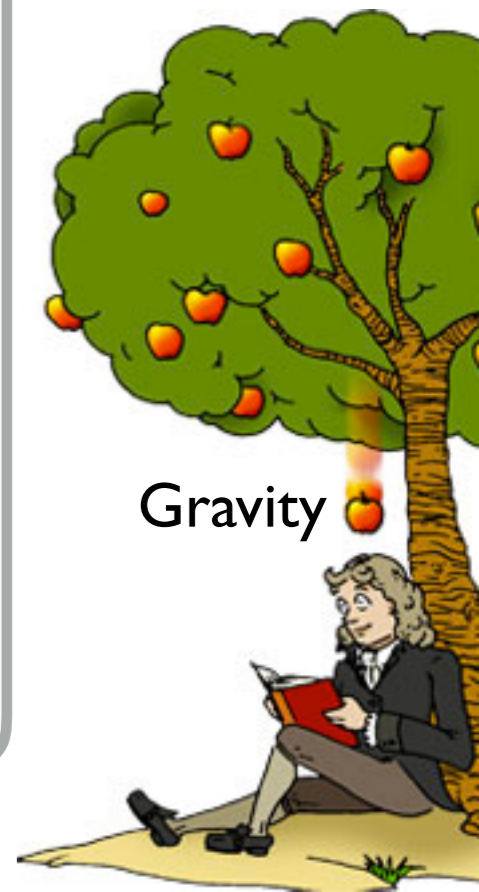
Matter



Forces



Standard model

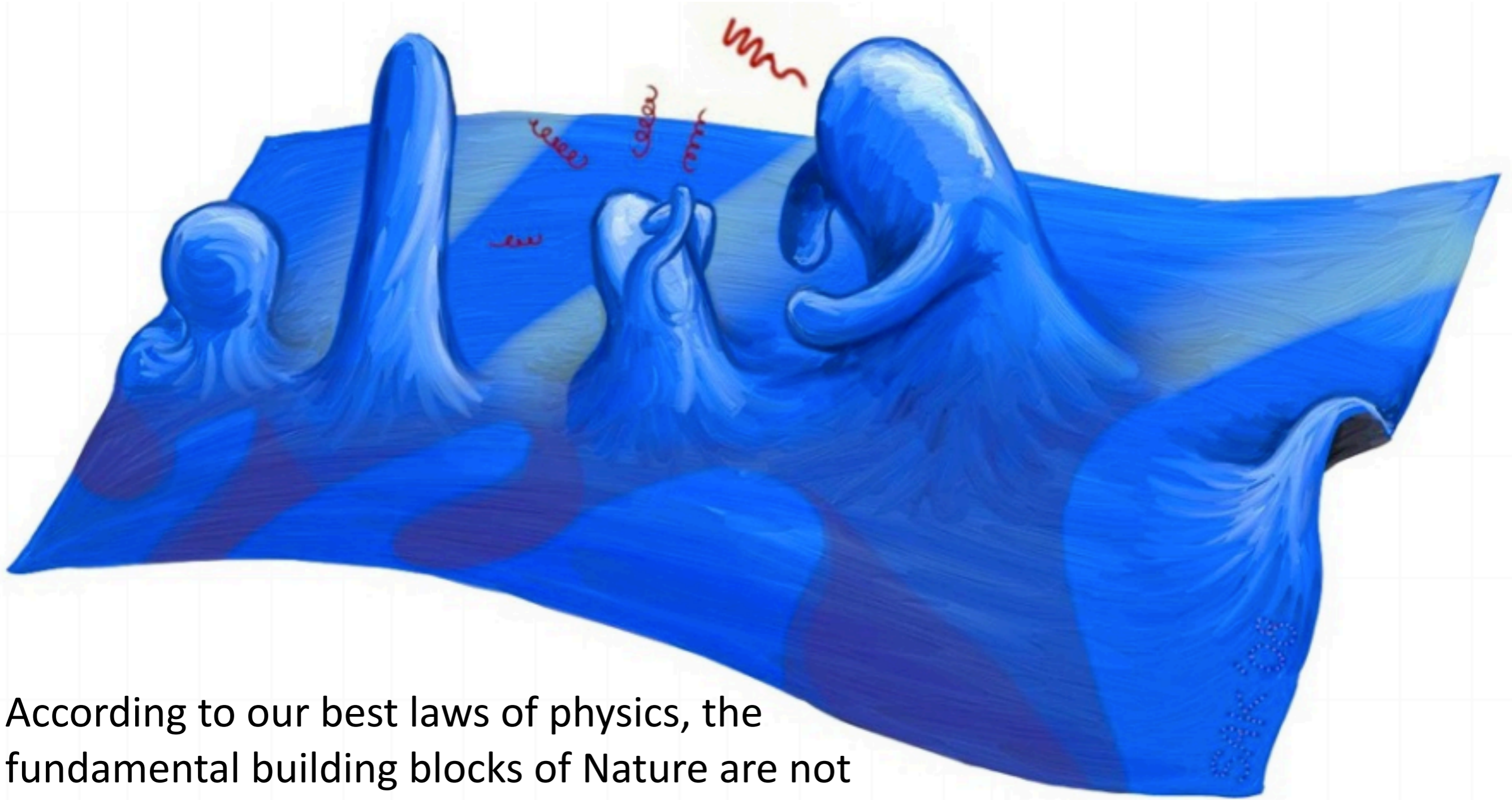


Particles-Fields



<http://www.publicdomainpictures.net/pictures/140000/velka/green-field-and-blue-sky-1446458468c5i.jpg> 9

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.



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

Elementary particle physics

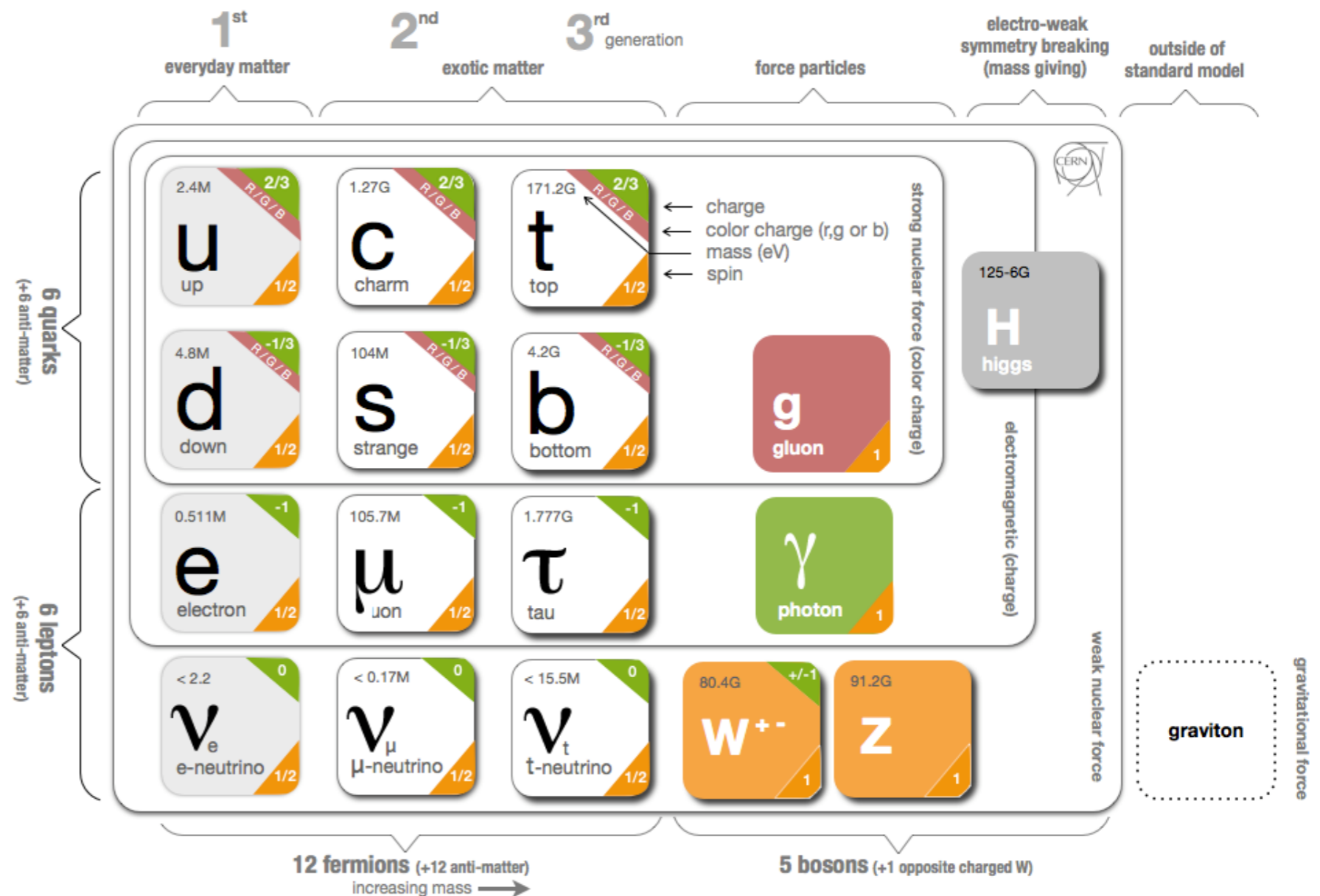
The **Standard Model** of particle physics is a theory concerning the electromagnetic, weak, and strong nuclear interactions, as well as classifying all the subatomic particles known.

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

So far so good, but

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

<https://cds.cern.ch/journal/CERNBulletin/2012/35/News%20Articles/I473657>



Standard model

$$\begin{aligned}
 & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^b g_\mu^c g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \\
 & \frac{1}{2}i g_s^2 (\bar{q}_i^c \gamma^\mu q_i^c) g_\mu^a - \bar{G}^a \partial^2 G^a + g_s j^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
 & M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \\
 & \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^c \phi^0 - \beta_h \left[\frac{2M^2}{\Lambda^2} + \right. \\
 & \left. \frac{2M}{g} \Pi + \frac{1}{2}(\Pi^2 + \eta^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{g^2} \alpha_h - igc_w [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\nu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - \\
 & W_\nu^- \partial_\nu W_\mu^+) - ig s_w \partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - A_\nu (W_\mu^- \partial_\nu W_\mu^+ - \\
 & W_\mu^+ \partial_\nu W_\mu^-) - A_\mu (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+) - \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\nu^+ W_\mu^- + \\
 & \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\nu^+ W_\mu^- + g^2 c_w^2 (Z_\mu^0 W_\nu^+ Z_\nu^0 W_\mu^- - Z_\mu^0 Z_\nu^0 W_\nu^+ W_\mu^-) + \\
 & g^2 s_w^2 (A_\mu W_\nu^+ A_\nu W_\mu^- - A_\mu A_\nu W_\nu^+ W_\mu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - y \alpha [H^3 + H \phi^c \phi^0 + 2H \phi^+ \phi^-] - \\
 & \frac{1}{2}g^2 c_w [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^c)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^c)^2 H^2] - \\
 & y M W_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^0 Z_\mu^0 H - \frac{1}{2}ig [W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - \\
 & W_\mu^- (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \frac{1}{2}g [W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W_\mu^- (H \partial_\mu \phi^+ - \\
 & \phi^+ \partial_\mu H)] + \frac{1}{2}g \frac{1}{c_w} (Z_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig \frac{M}{c_w} Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
 & ig s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2s_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
 & ig s_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \frac{1}{4}g^2 W_\mu^+ W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \\
 & \frac{1}{4}g^2 \frac{1}{c_w} Z_\mu^0 Z_\mu^0 [H^2 - (\phi^0)^2 + 2(2s_w^2 - 1)\phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - \\
 & g^2 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma^\partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma^\partial \nu^\lambda - \bar{u}_j^\lambda (\gamma^\partial + m_u^\lambda) u_j^\lambda - \\
 & \bar{d}_j^\lambda (\gamma^\partial + m_d^\lambda) d_j^\lambda - ig s_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) - \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \\
 & \frac{ig}{4c_w} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{1}{3}s_w^2 - \\
 & 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + \\
 & (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda e} d_j^\lambda) + \frac{ig}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\lambda C_{\lambda e} \gamma^\mu (1 + \\
 & \gamma^5) u_j^\lambda)] + \frac{ig}{2\sqrt{2}} \frac{m_\lambda^2}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \\
 & \frac{g m_\lambda^2}{2M} [H (\bar{e}^\lambda e^\lambda) + i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda e} (1 - \gamma^5) d_j^\lambda) + \\
 & m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda e} (1 - \gamma^5) u_j^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^- [m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda e}^\dagger (1 + \gamma^5) u_j^\lambda) - m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda e}^\dagger (1 - \\
 & \gamma^5) d_j^\lambda) - \frac{g m_\lambda^2}{2M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g m_\lambda^2}{2M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \\
 & \frac{ig}{2M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + X^+ (\partial^2 - M^2) X^- + X^- (\partial^2 - M^2) X^+ + X^0 (\partial^2 - \\
 & \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + igc_w W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + ig s_w W_\mu^+ (\partial_\mu \bar{Y} X^- - \\
 & \partial_\mu \bar{X}^+ Y) + igc_w W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + ig s_w W_\mu^- (\partial_\mu \bar{X}^- Y - \\
 & \partial_\mu \bar{Y} X^+) + igc_w Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + ig s_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \\
 & \partial_\mu \bar{X}^- X^-) - \frac{1}{2}qM [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w} \bar{X}^0 X^0 H] + \\
 & \frac{1-2c_w^2}{2c_w} igM [\bar{X}^- X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \frac{1}{2}igM [\bar{X}^0 X^- \phi^- - \bar{X}^0 X^+ \phi^-] + \\
 & igMs_w [\bar{X}^+ X^+ \phi^- - \bar{X}^0 X^+ \phi^-] + \frac{1}{2}igM [\bar{X}^- X^- \phi^c - \bar{X}^- X^- \phi^0]
 \end{aligned}$$

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



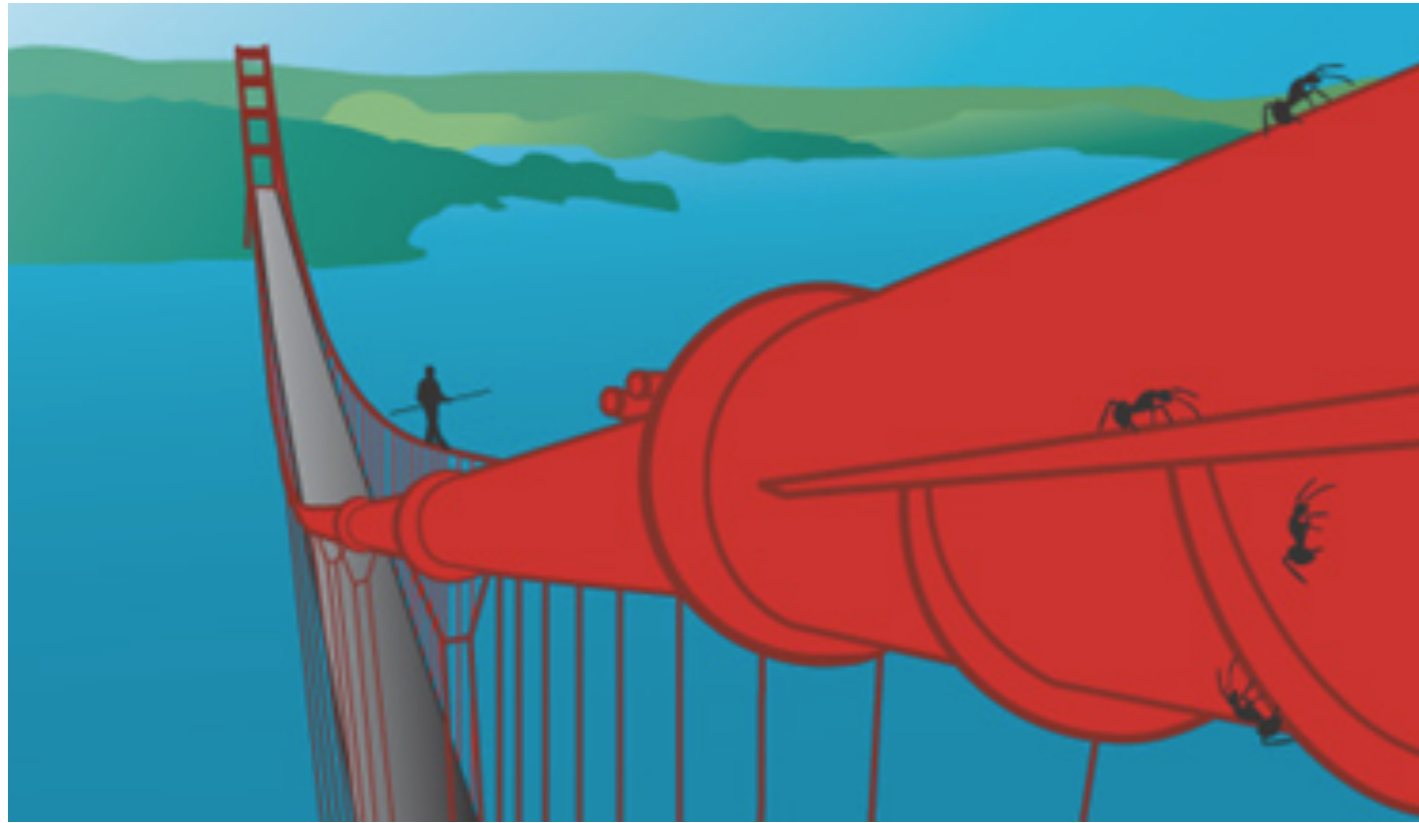
If you try to write the full SM Lagrangian, it will look like

<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



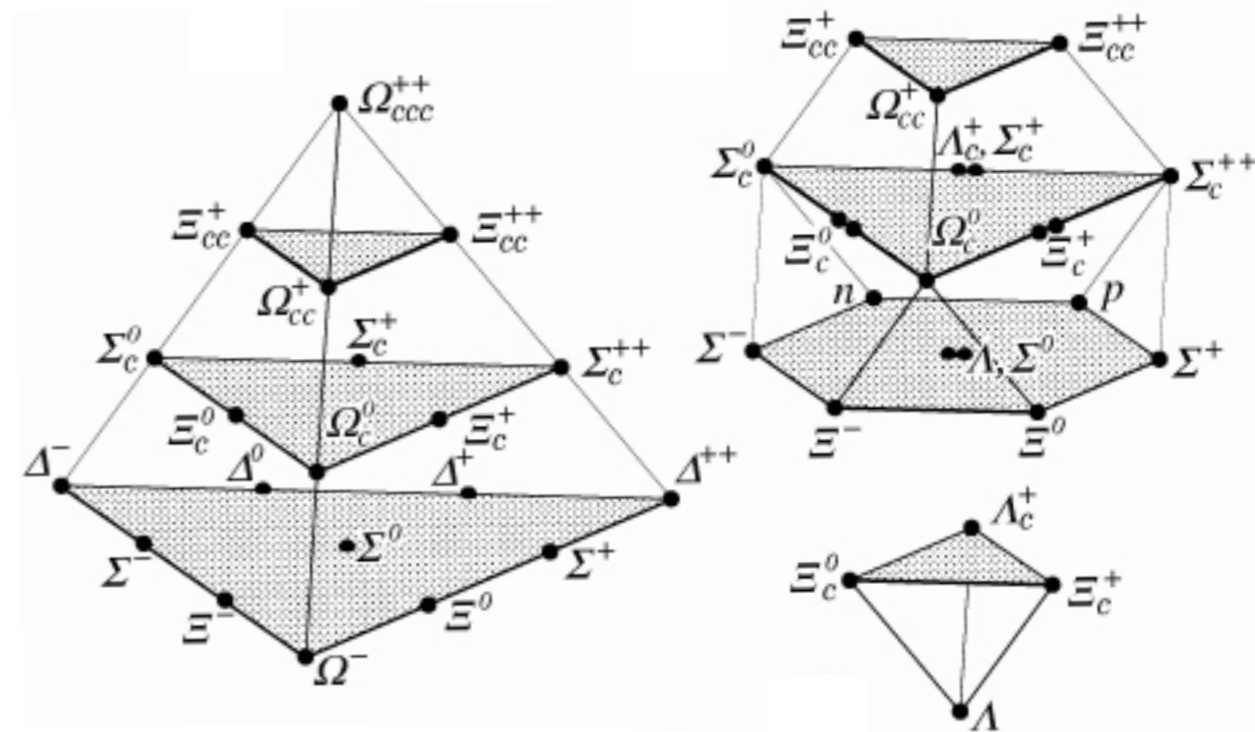
Geometry

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

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

Mathematical model

- Composite particles - Eightfold Way, $SU(3)$
- Quantum gauge symmetry, $SU(3) \times SU(2) \times U(1)$
 - ➔ Follow by spontaneous symmetry breaking



Ex. of BSM: Extra-Dimensions

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†

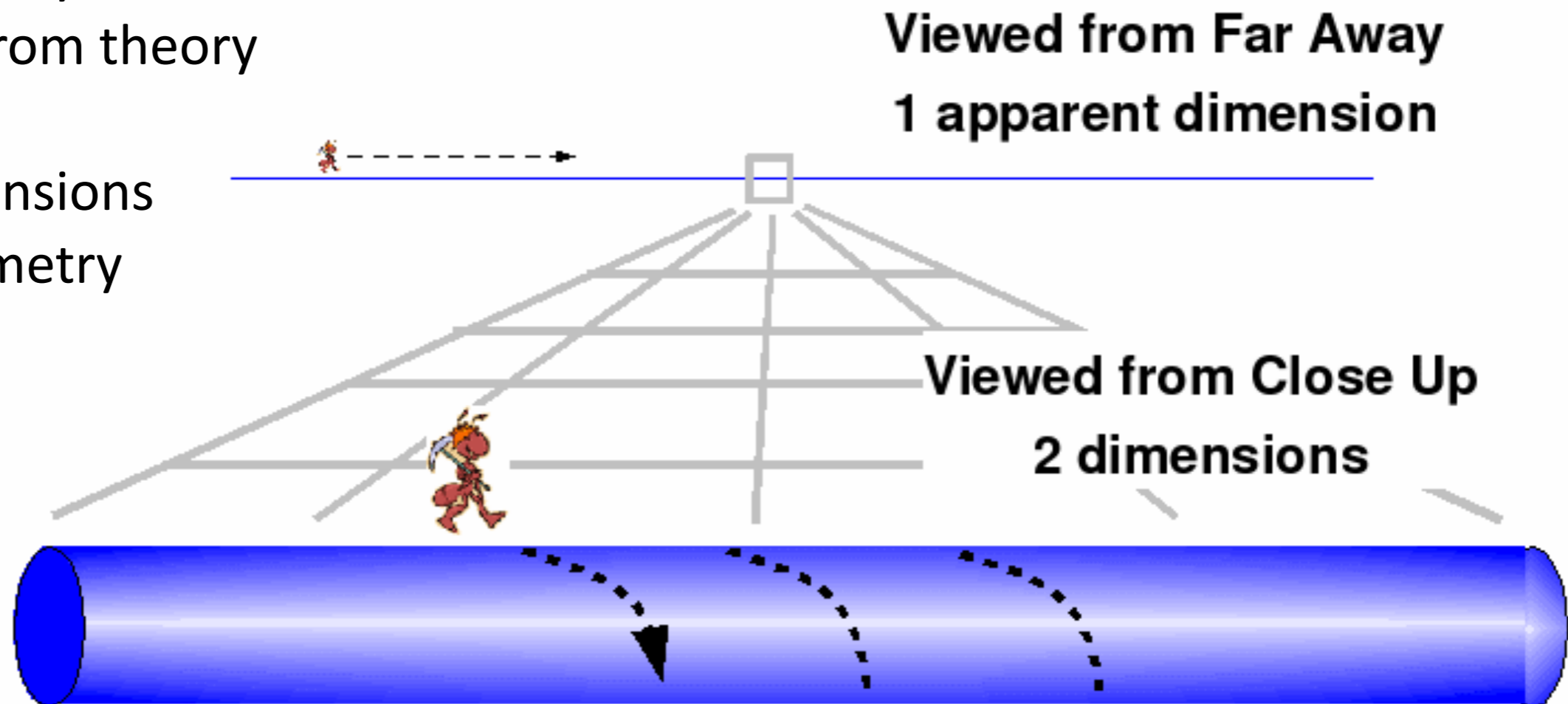
* SLAC, Stanford University, Stanford, California 94309, USA

** Physics Department, Stanford University, Stanford, CA 94305, USA

† ICTP, Trieste, 34100, Italy

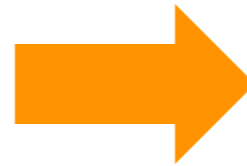
Hierarchy problem

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

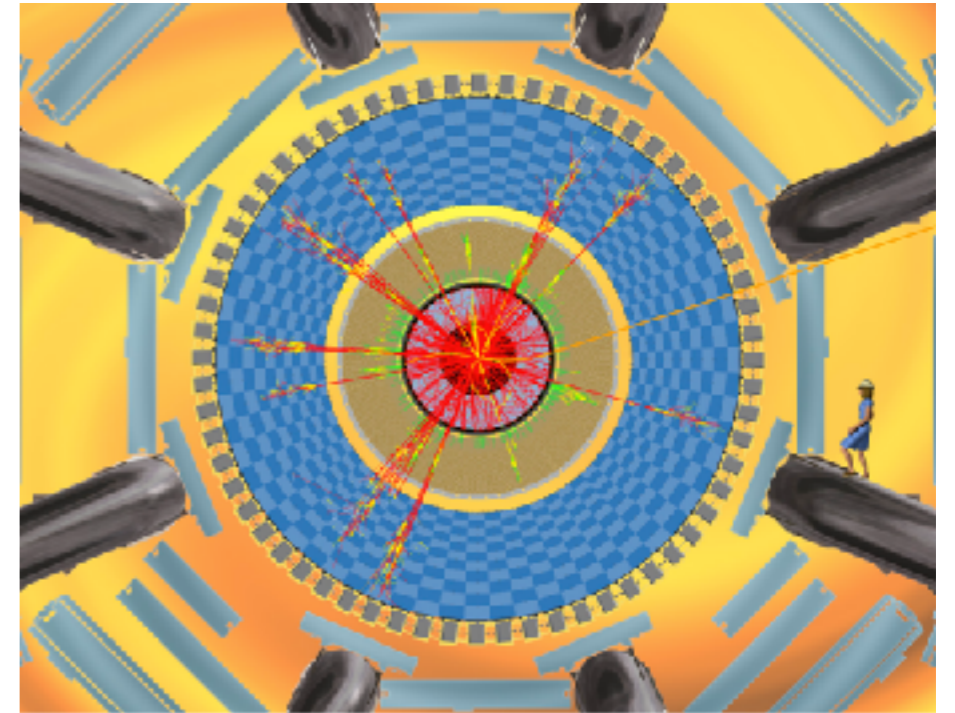


Ex. of BSM: Black Hole

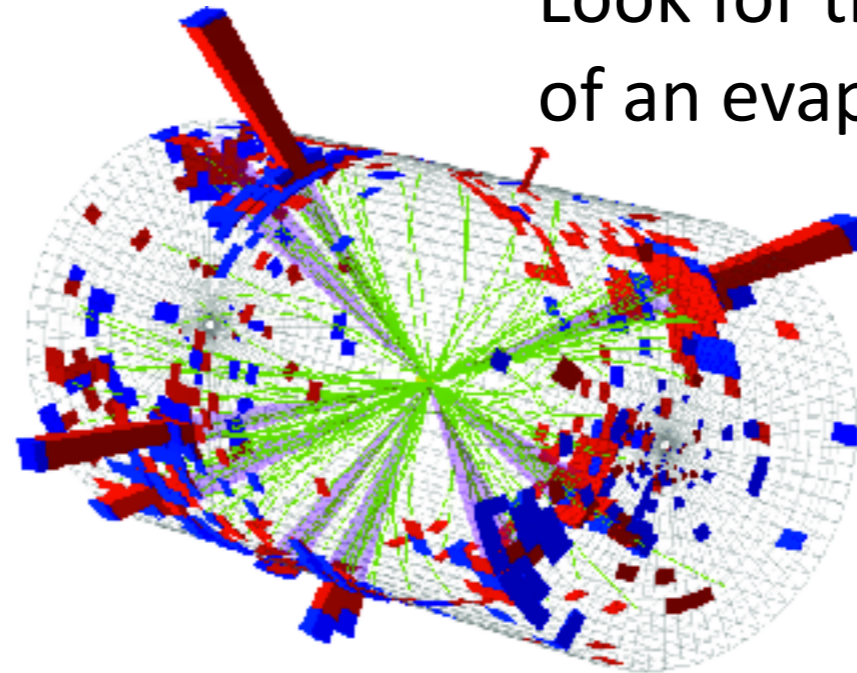
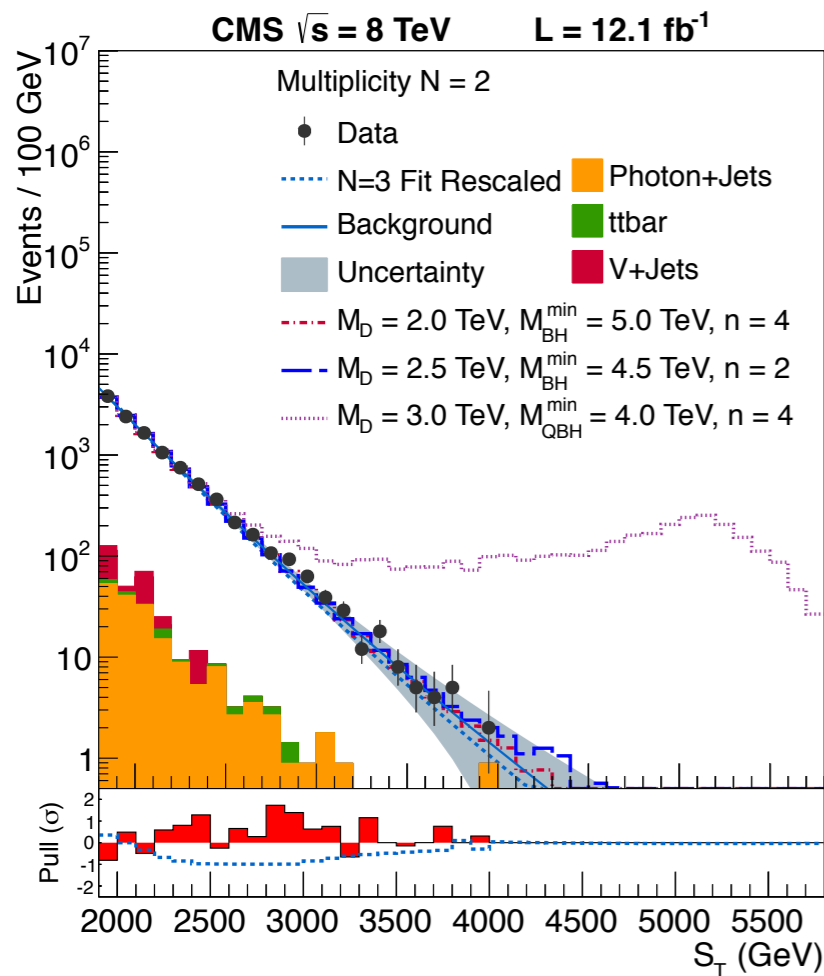
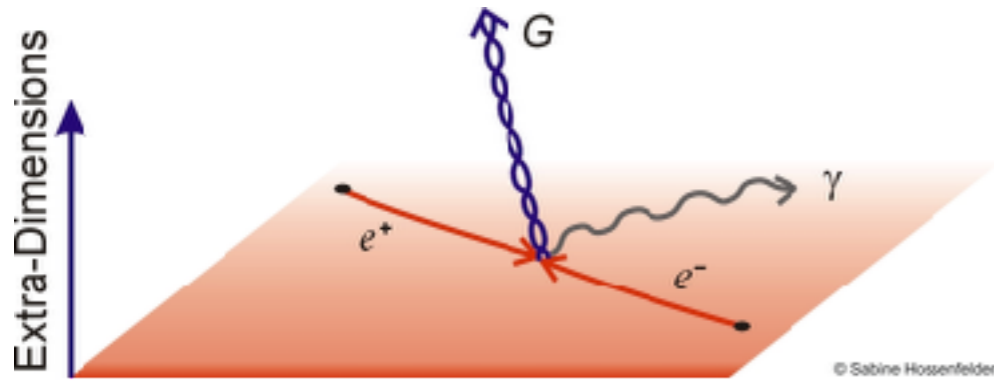
Extra Dimensions



Planck scale
a few TeV?

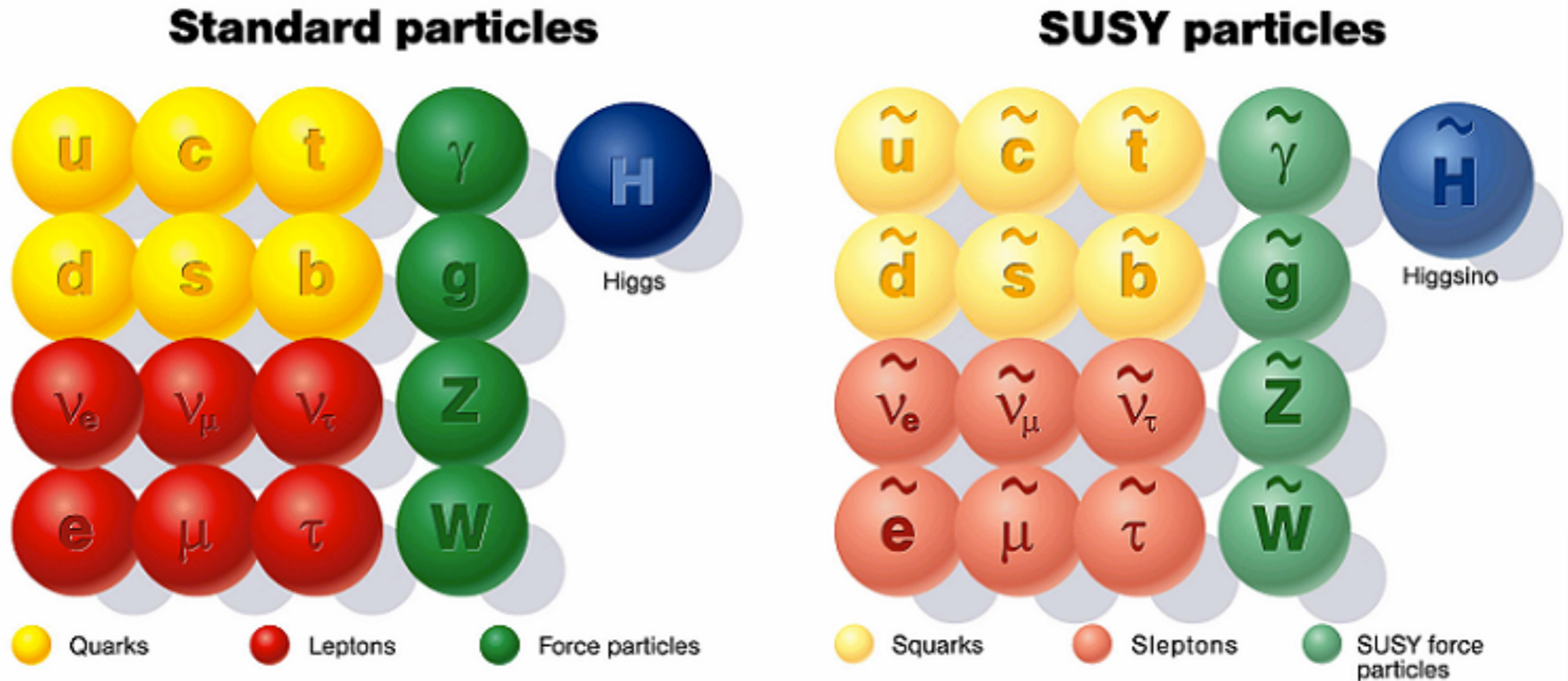


Look for the decay products
of an evaporating **black hole**



CMS Experiment at LHC, CERN
Data recorded: Mon May 23 21:46:26 2011 EDT
Run/Event: 165567 / 347495694
Lumi section: 260
Orbit/Crossing: 70255853 / 5161

Ex. of BSM: Supersymmetry

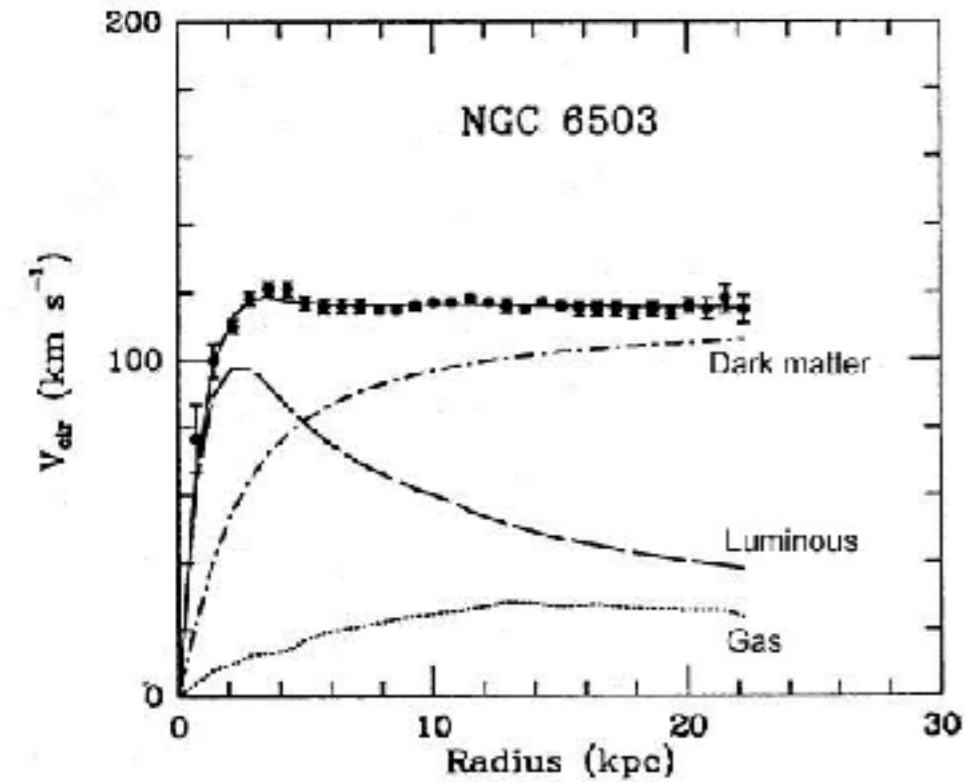


- ▶ Bridges between particle and space; New type symmetry
- ▶ Provides the good candidate of Dark Matter (WIMP)
- ▶ Higgs mass becomes light & E scale naturally is provided.
- ▶ Unifies 3 Forces (EM, Weak and strong)

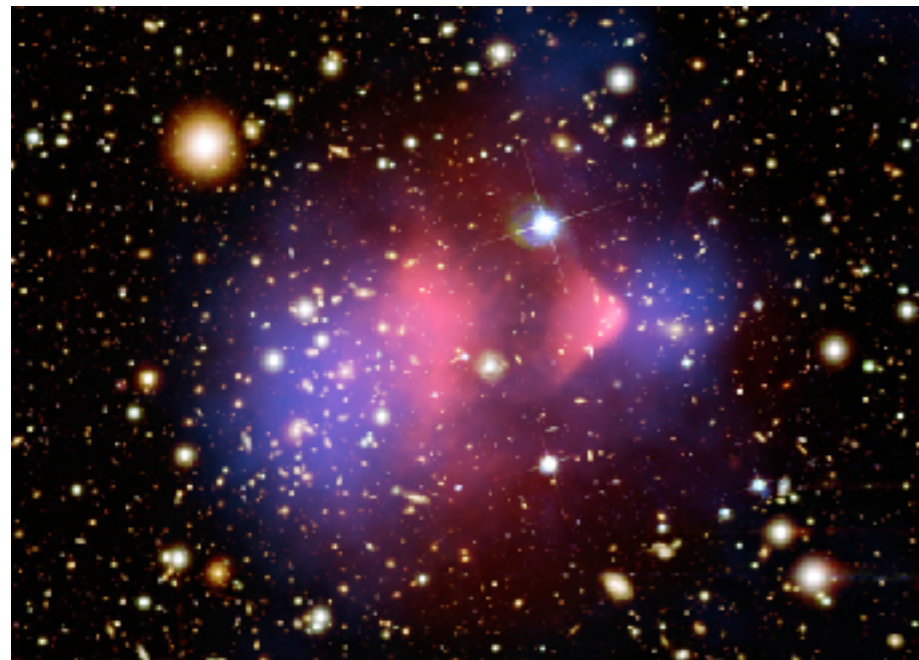
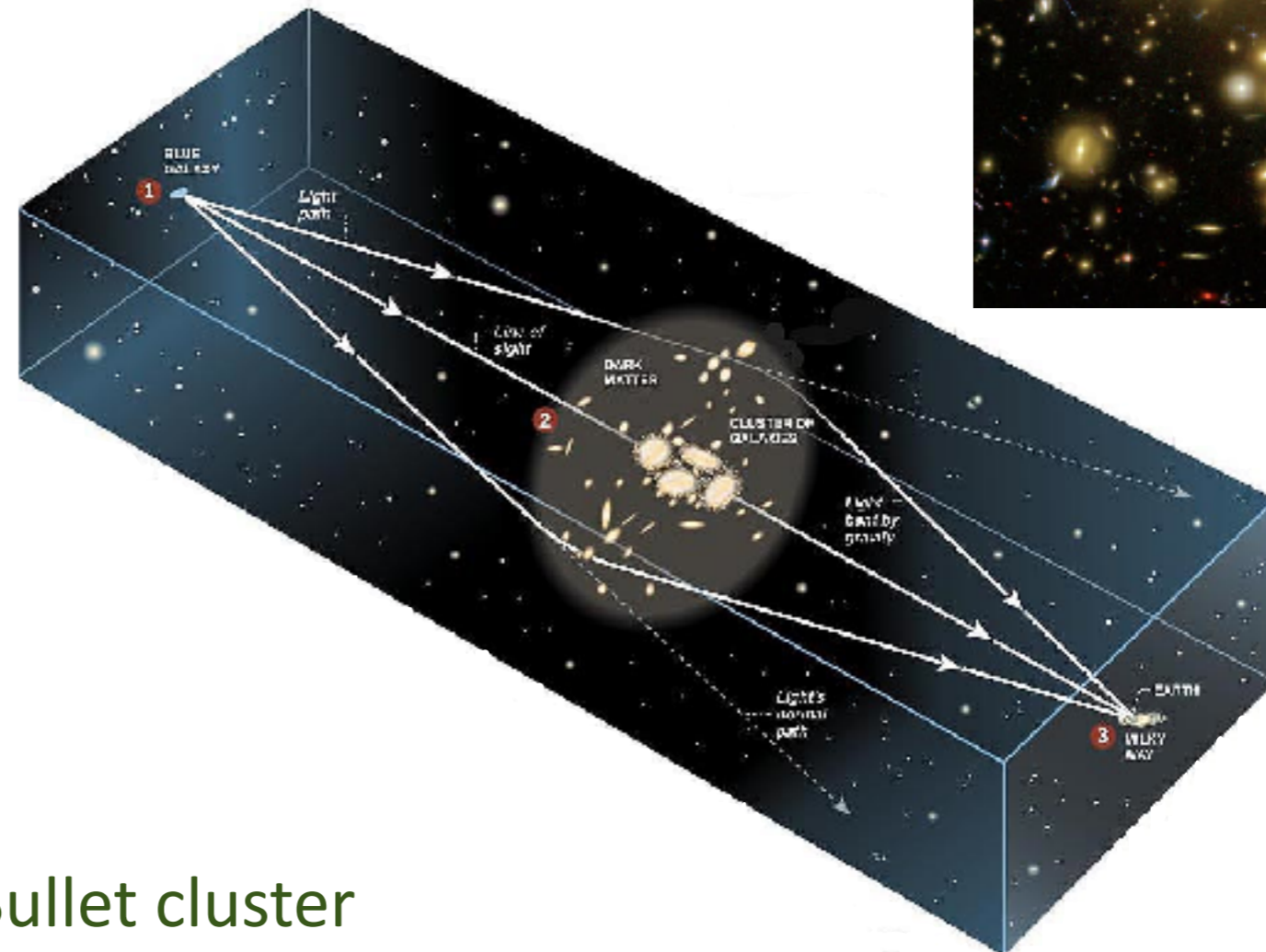
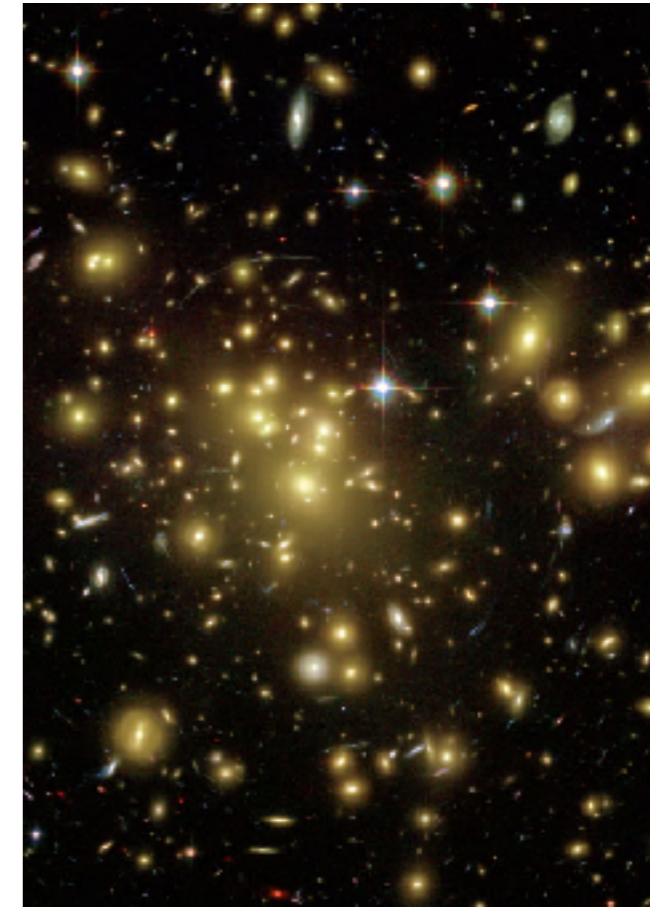
Ex. of BSM: Dark matter

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

Galactic rotation curves



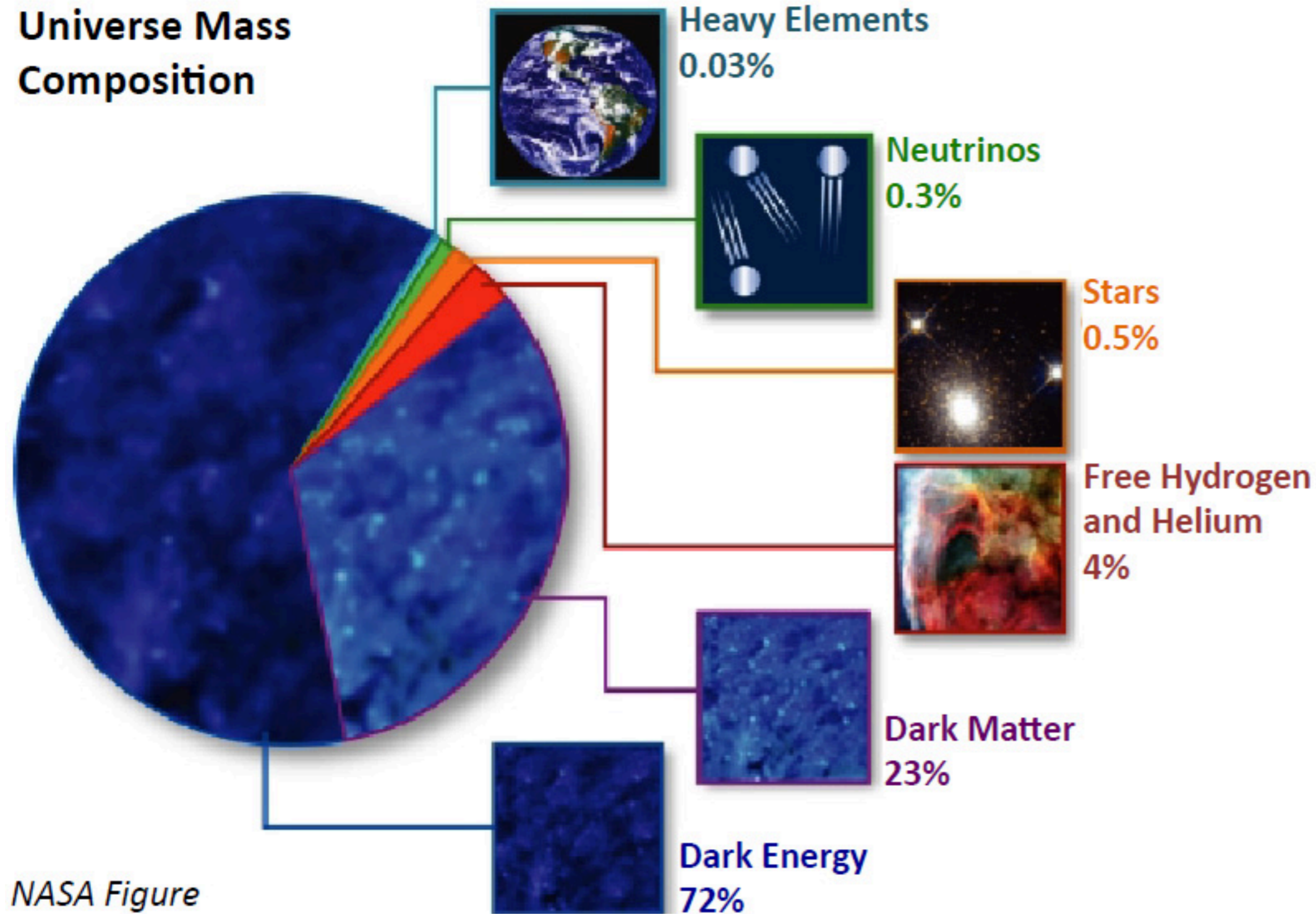
Strong Gravitational Lensing



Bullet cluster

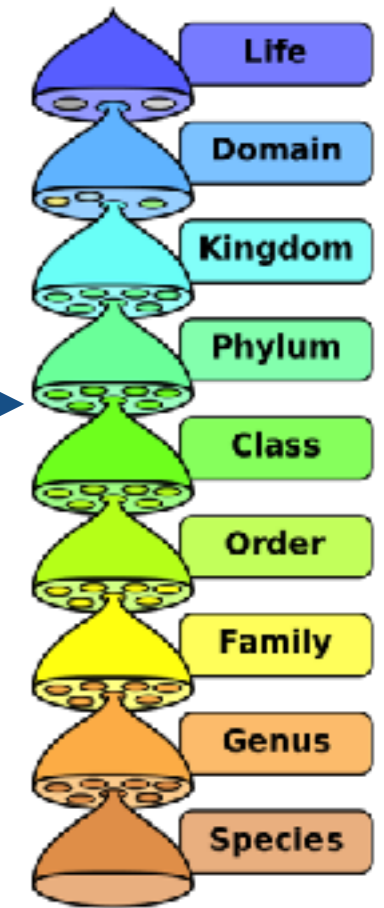
Ex. of BSM: Dark matter

Universe Mass Composition

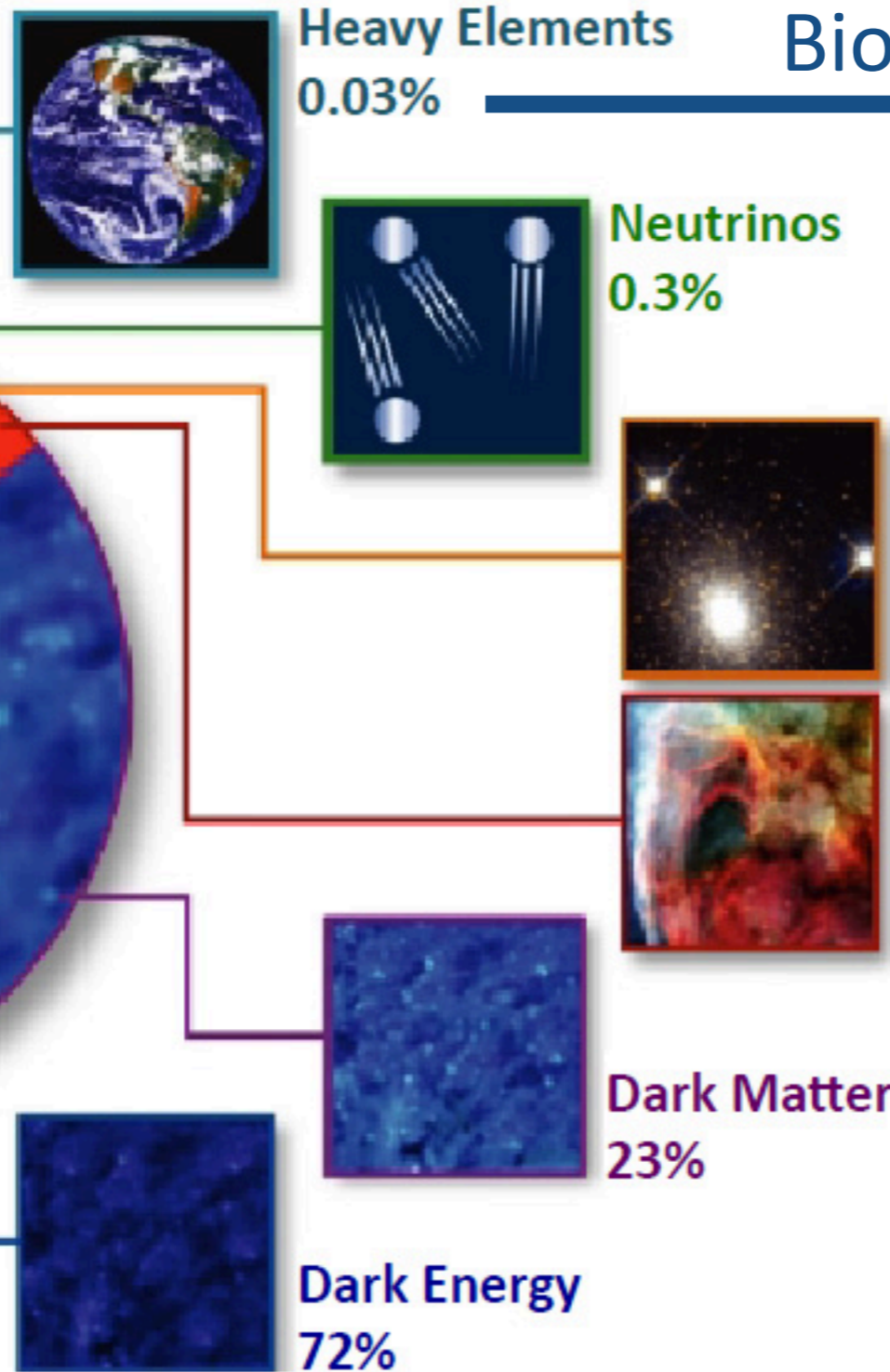
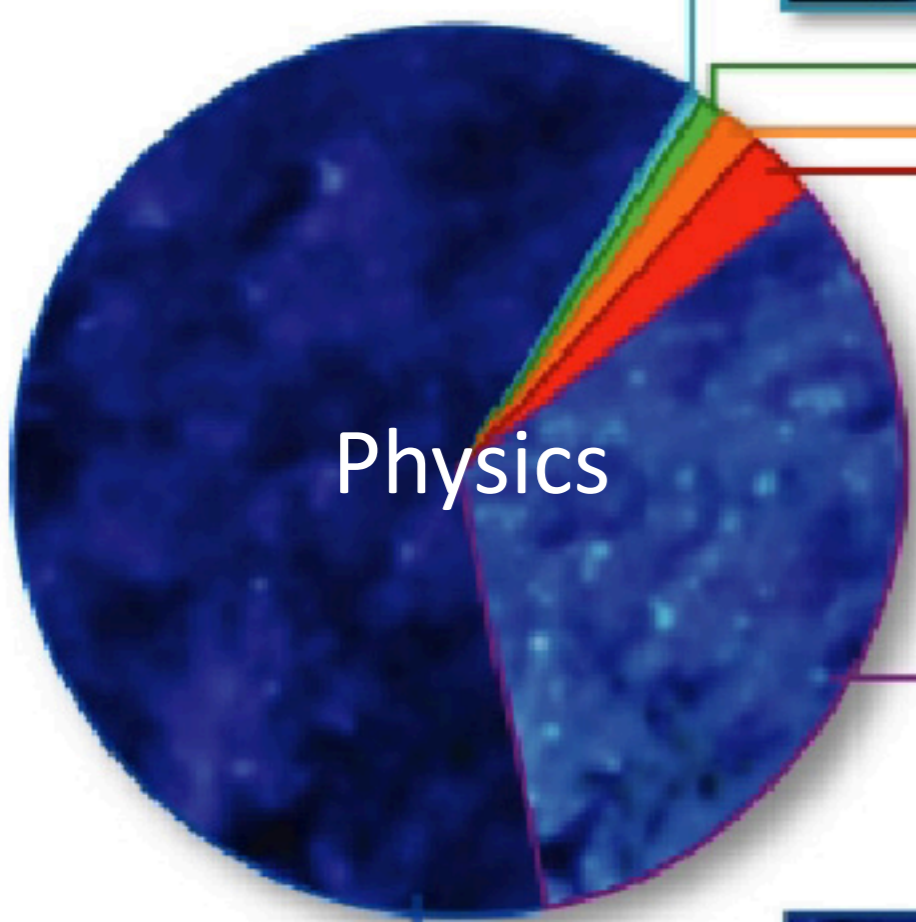


NASA Figure

Ex. of BSM: Dark matter



Universe Mass Composition



Biology

Chemistry

PERIODIC TABLE OF THE ELEMENTS

A detailed periodic table of elements, color-coded by groups. It includes labels for groups like 'ALKALI METALS', 'TRANSITION METALS', 'NONMETALS', 'METALLOIDS', 'HALOGENS', and 'NOBLE GASES'. It also includes a legend for element types and a small diagram of a periodic table structure.

NASA Figure

Experimental 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.



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

Large Hadron Collider



Large Hadron Collider



LHC by numbers

THE LARGE HADRON COLLIDER BY THE NUMBERS

27KM
(16 MILES)

IN CIRCUMFERENCE

1 PETABYTE-
PER-SECOND

IN RAW DATA GENERATED
BY LHC EXPERIMENTS

1 BILLION
COLLISIONS

OCCUR PER SECOND

100K
TIMES HOTTER THAN
THE SUN'S CORE,

HEAT GENERATED
BY COLLISIONS

99.
99999999%
SPEED OF LIGHT

ACHIEVED BY PARTICLES

1.9 KELVIN
(-271.3 DEGREES
CELSIUS)

INTERNAL OPERATING
TEMPERATURE

120,000
CORES RUNNING

CERN'S OPENSTACK CLOUD
ACROSS TWO DATA CENTERS

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

Looking closer to LHC with PHYSIOI

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

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

Looking closer to LHC with PHYSIO I

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

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

Looking closer to LHC with PHYS101

Ideal gas

Energy

Momentum

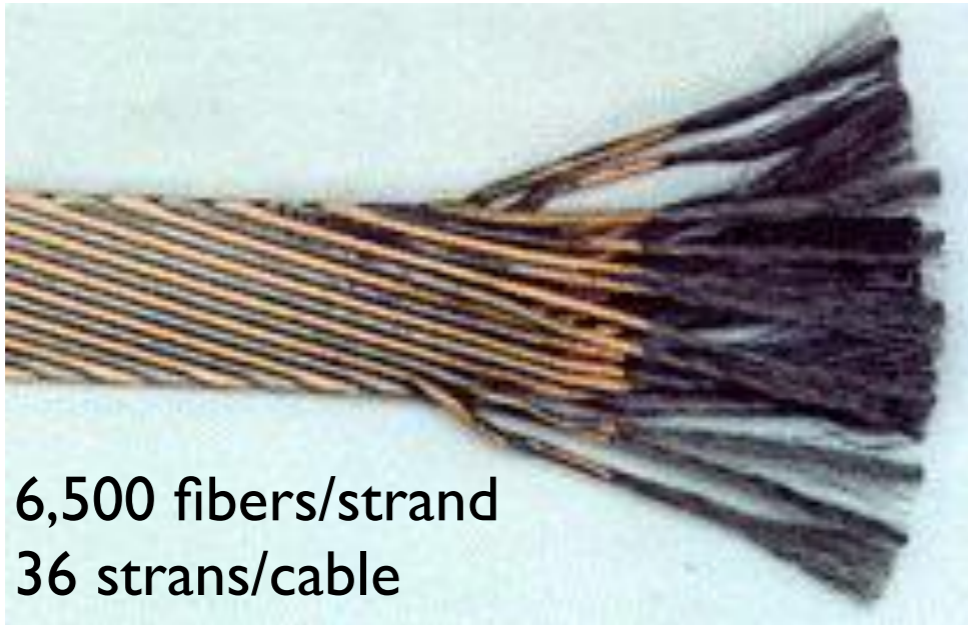
Coulomb law, Lorentz force

Special relativity

Superconductivity

...

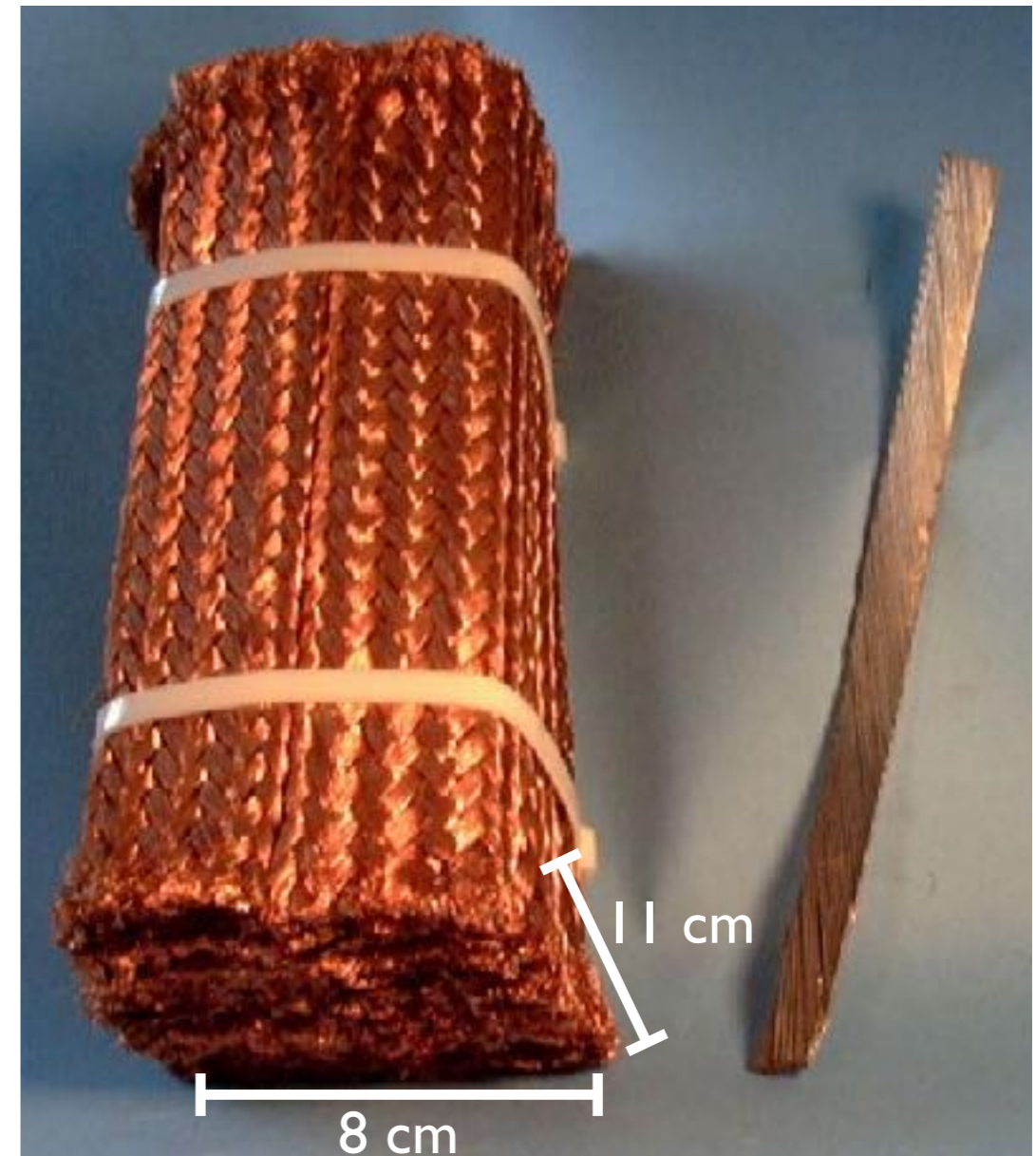
LHC display objects



6,500 fibers/strand

36 strans/cable

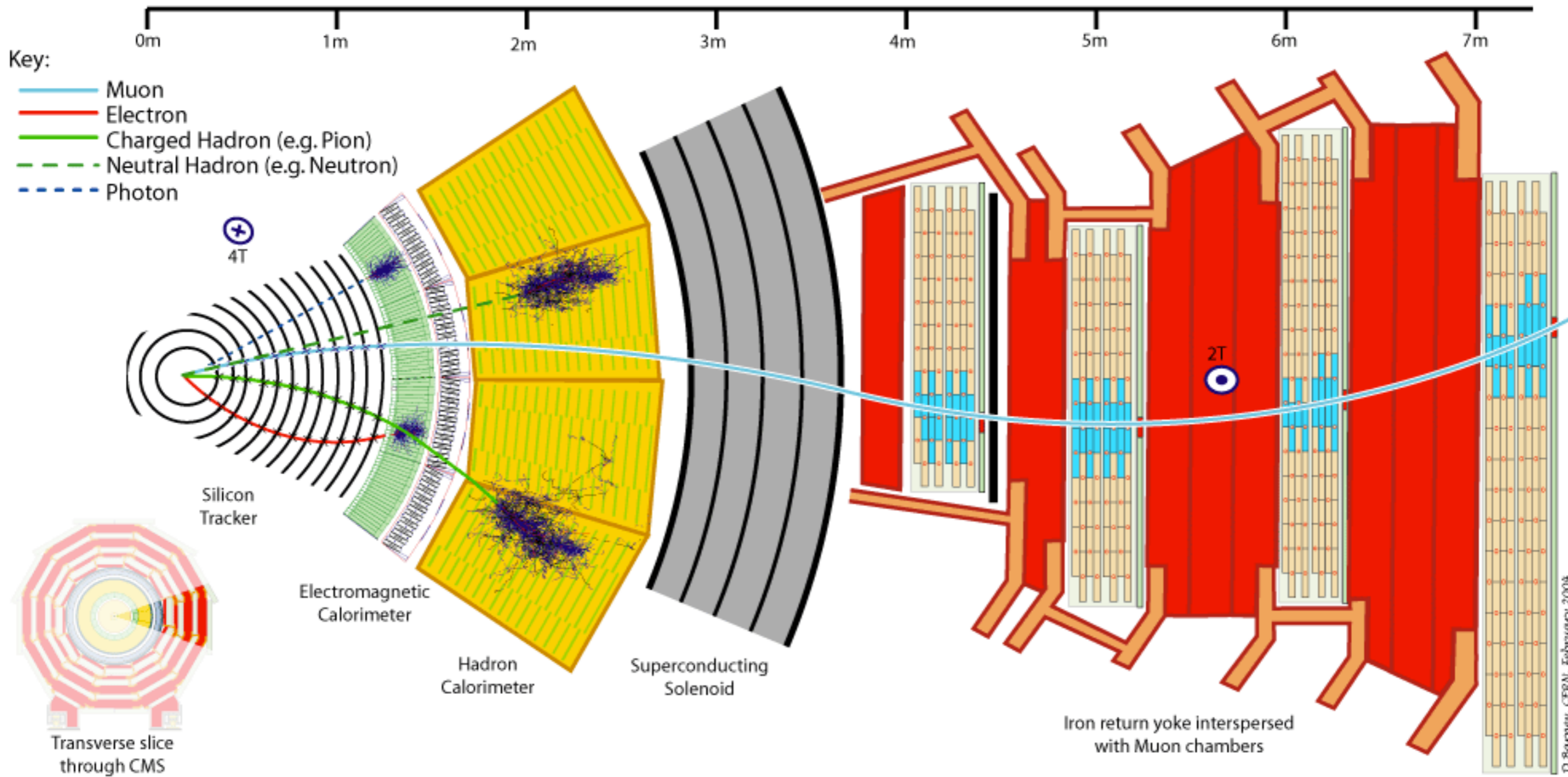
160 cables to reach 8.3T



8 cm

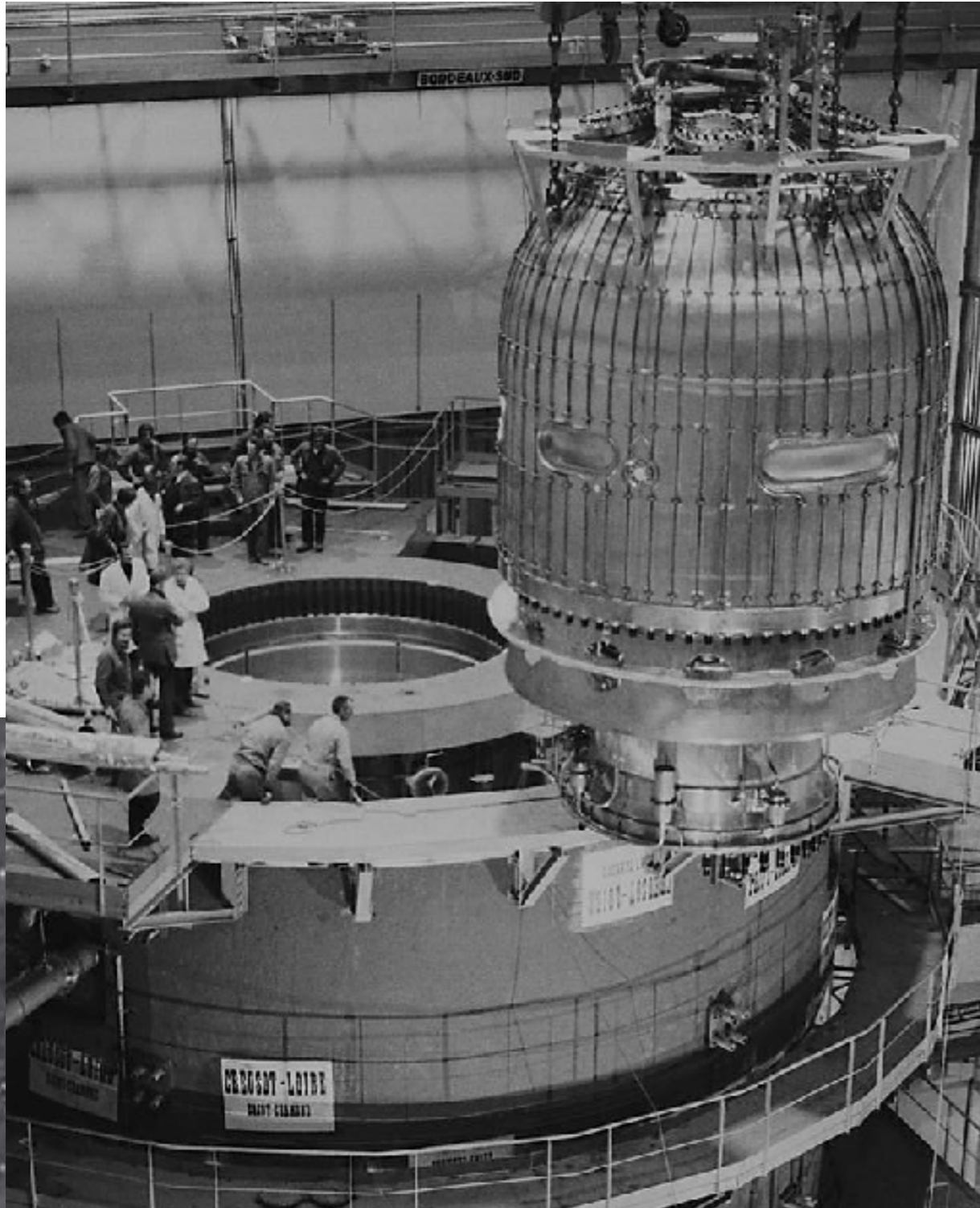
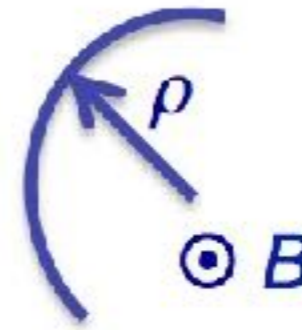
11 cm

Particle detector: Very complex camera

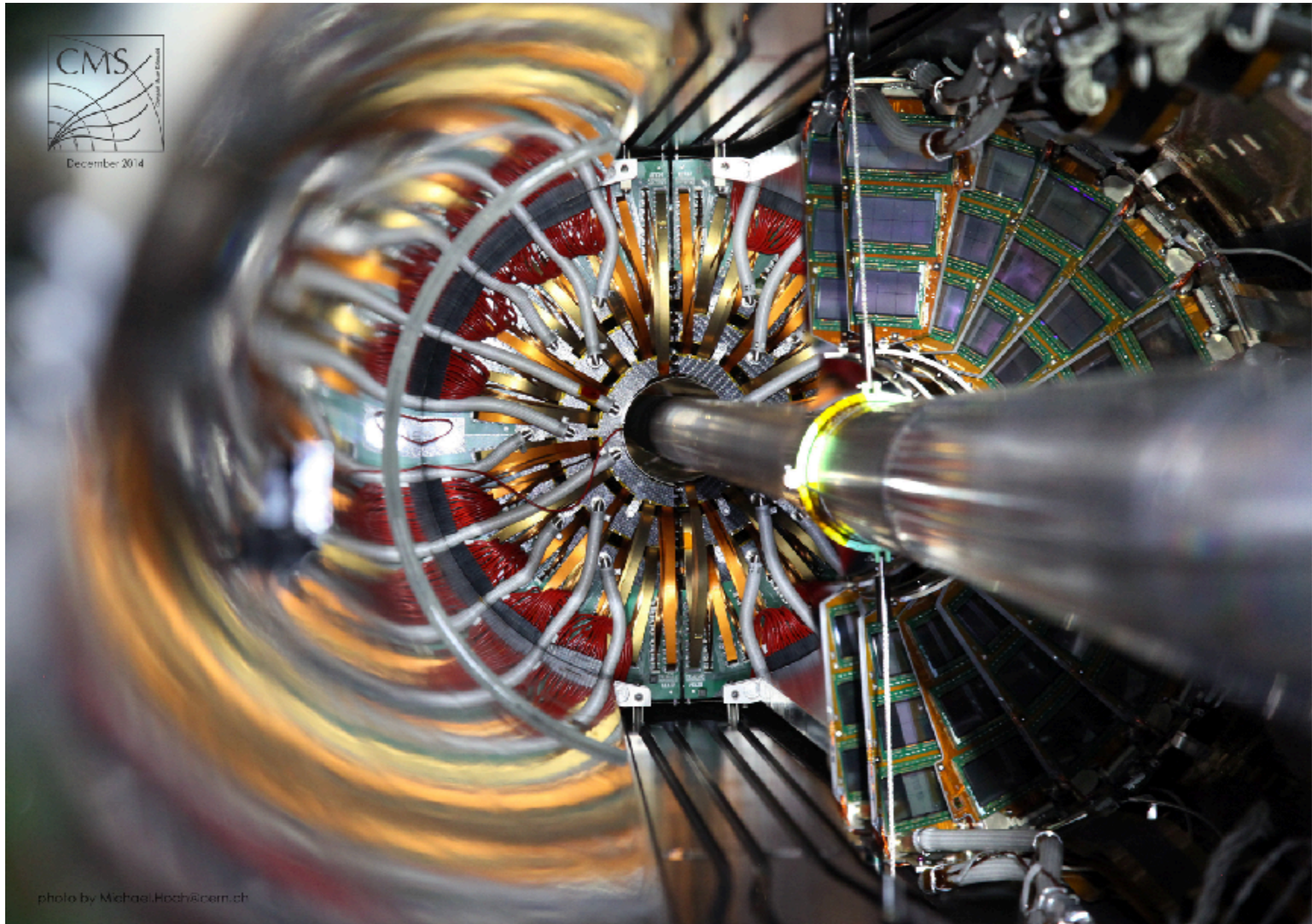


Particle detector: Momentum & Charge

Charged particles are deflected by magnetic field



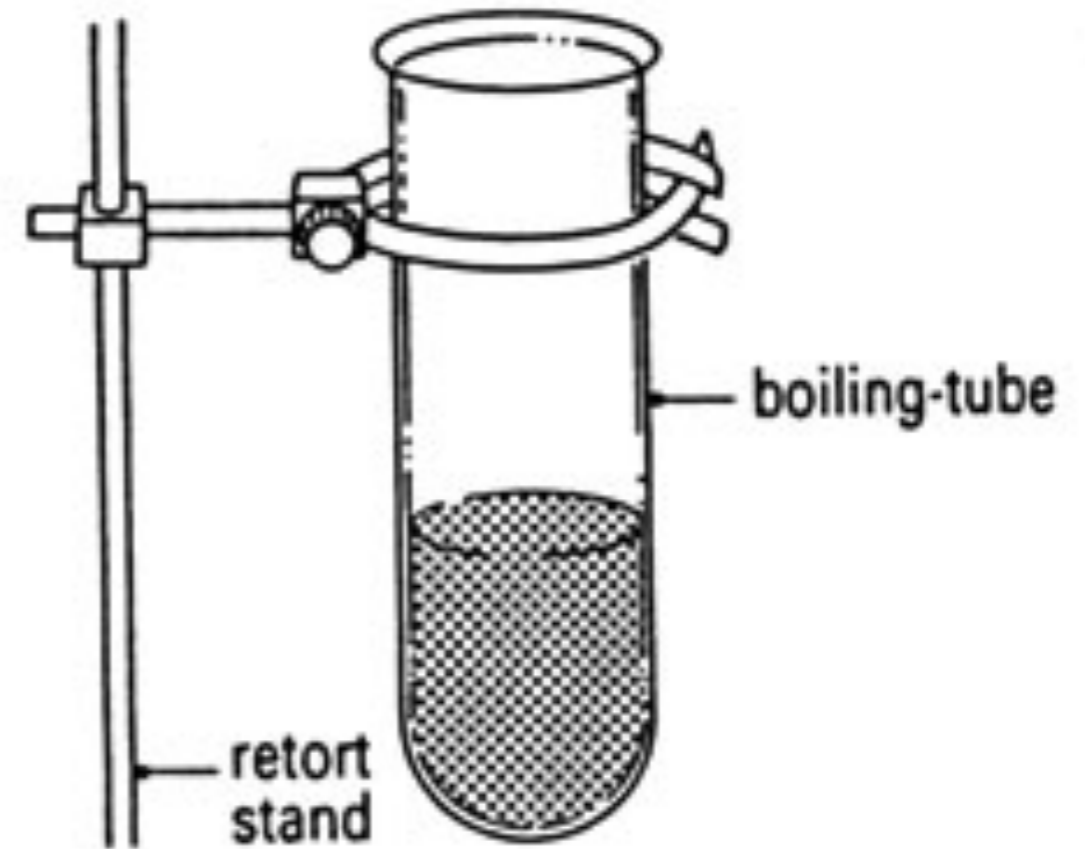
Particle detector: Momentum & Charge



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

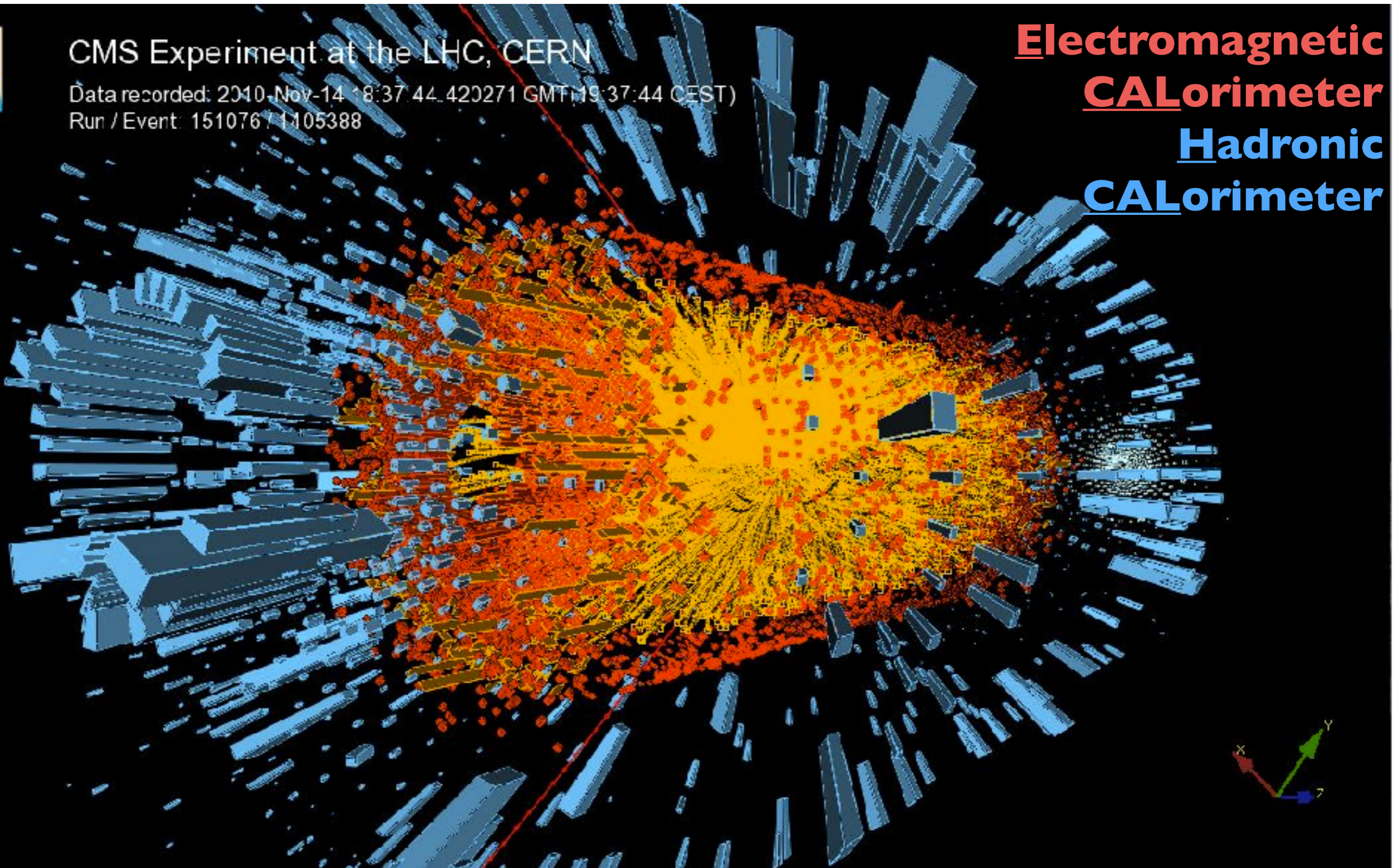


CMS Experiment at the LHC, CERN

Data recorded: 2010-Nov-14 18:37:44.420271 GMT (19:37:44 CEST)

Run / Event: 151076 / 1105388

**Electromagnetic
CALorimeter
**Hadronic
CALorimeter****



LHC experiments

ALICE



ATLAS



CMS



LHCb



LHCf



MoEDAL



TOTEM



Experimental particle physics

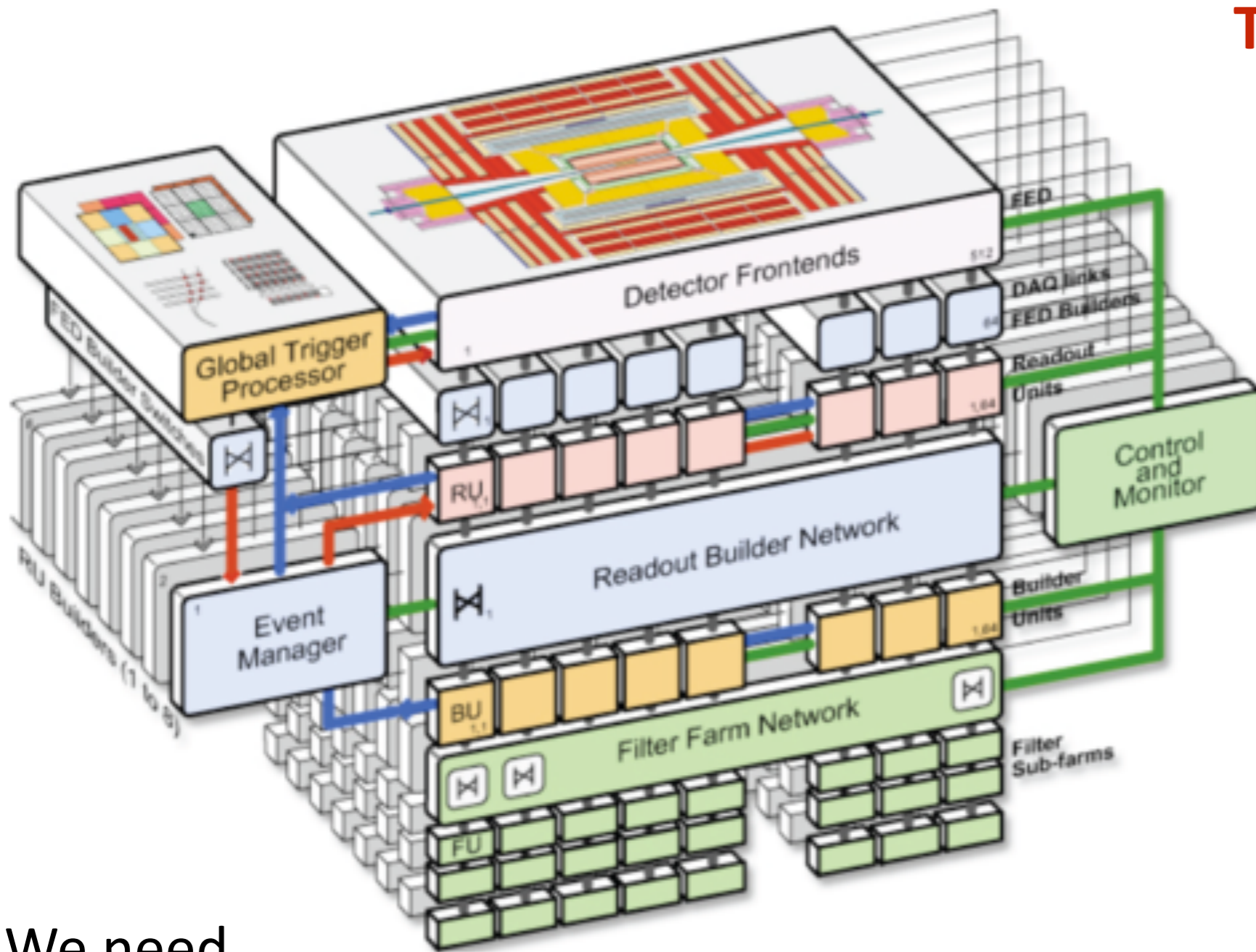


High Energy Physics is a statistical science:

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

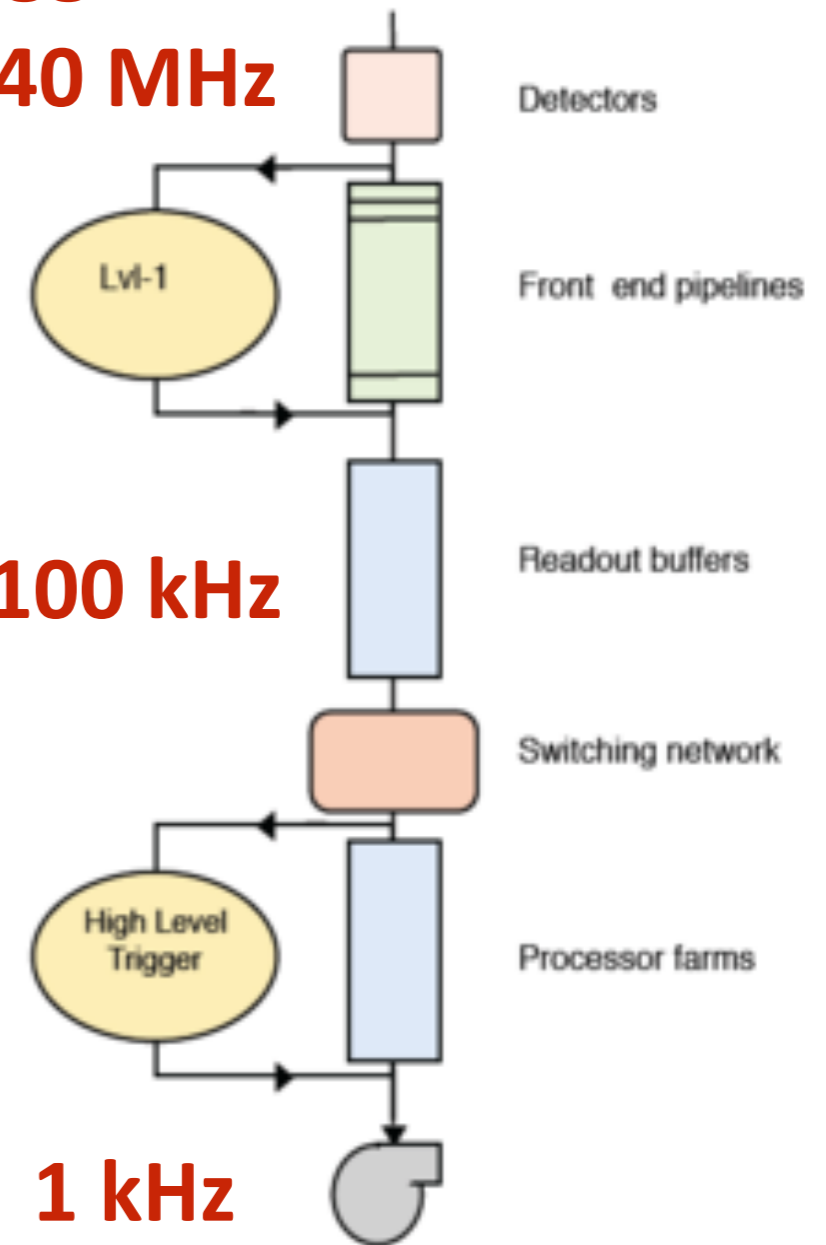


Trigger Rate

40 MHz

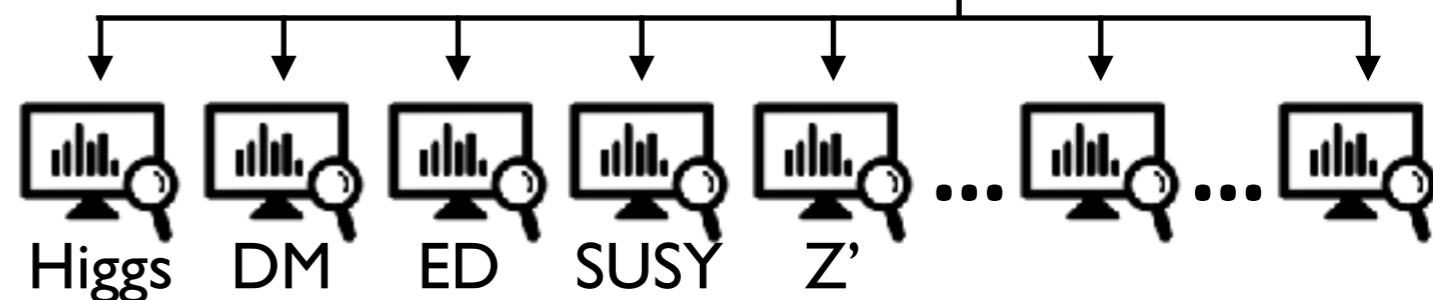
100 kHz

1 kHz



We need

- ➔ Fast electronic devices
- ➔ Fast computing algorithms to make a trigger system



Worldwide LHC Computing Grid

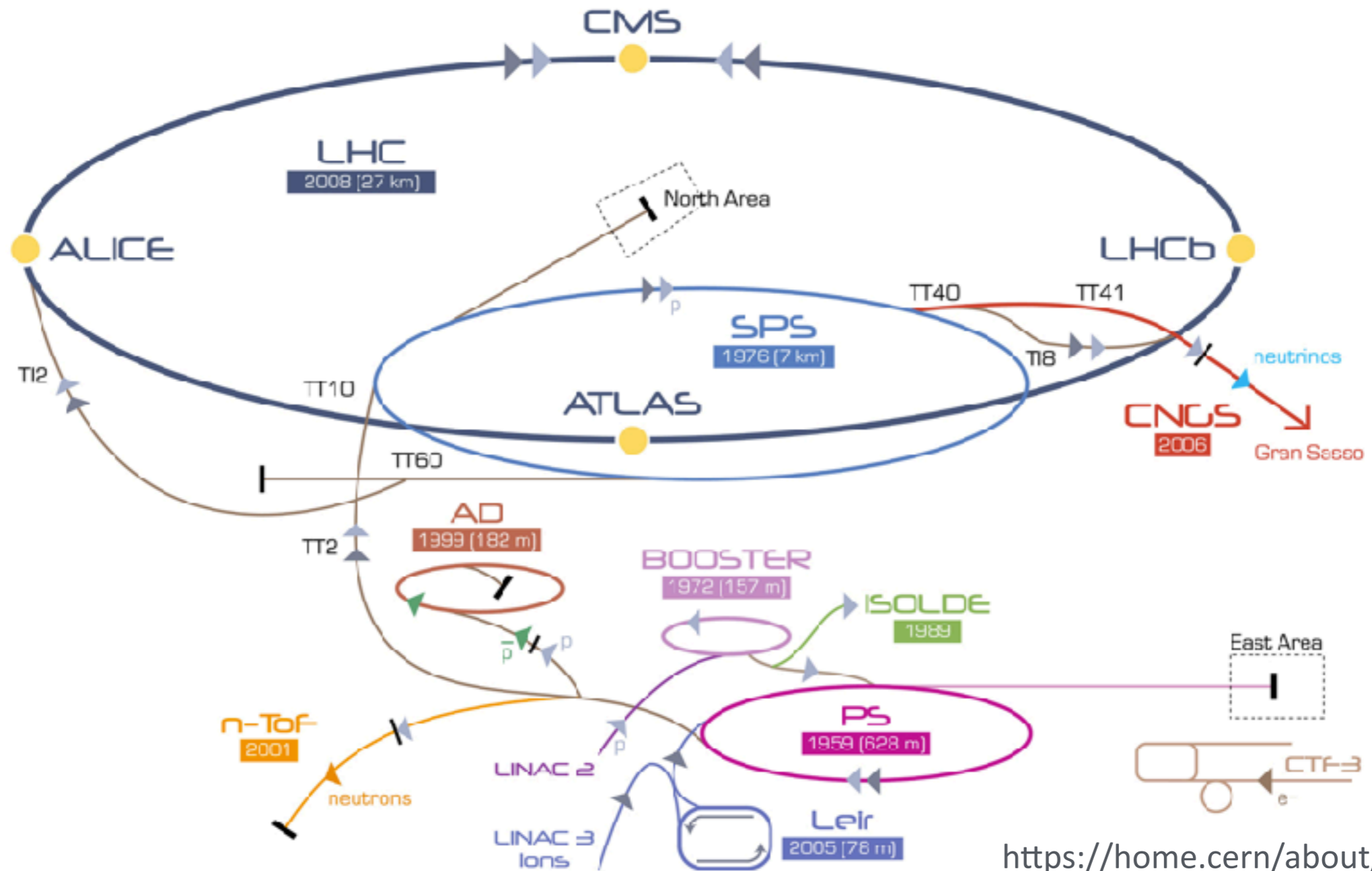
Running jobs: 268149
Transfer rate: 11.38 GiB/sec



Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2013 TerraMetrics
Image IBCAO
© 2013 Gncs/Spot Image

Google earth

None LHC programs



<https://home.cern/about/experiments>

▶ p [proton] ▶ ion ▶ neutrons ▶ \bar{p} [antiproton] \leftrightarrow proton/antiproton conversion ▶ neutrinos ▶ electron

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF-3 Clic Test Facility CNUS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
 LEIR Low Energy Ion Ring LINAC LINEar ACcelerator n-ToF Neutrons Time Of Flight

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



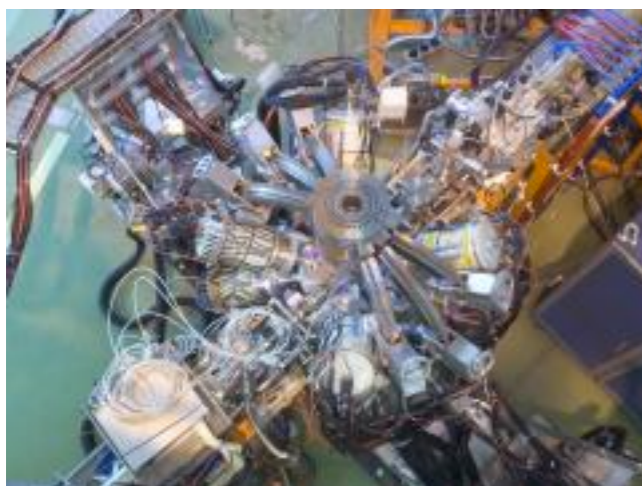
AWAKE

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.symmetrismagazine.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>

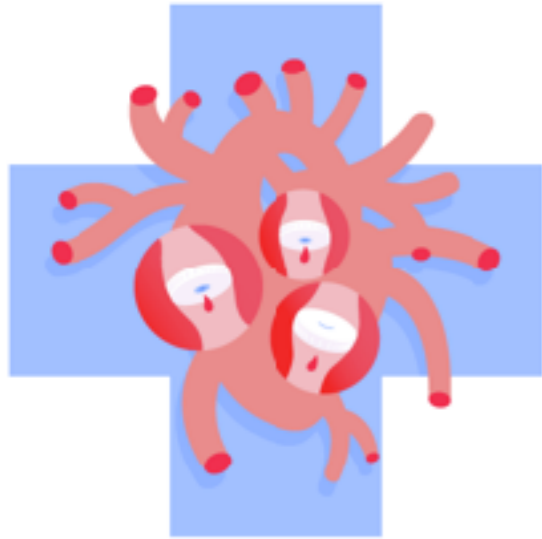
Shrink wrap

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

Ganglia **esci-cu Cluster Report for Tue, 04 Apr 2017 08:24:46 +0700** Physical View

Metric: **load_one** Last: **hour** Sorted: **descending**

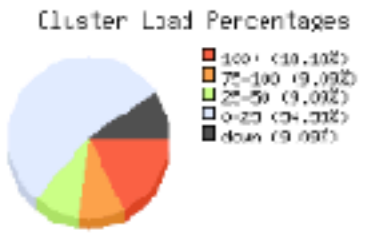
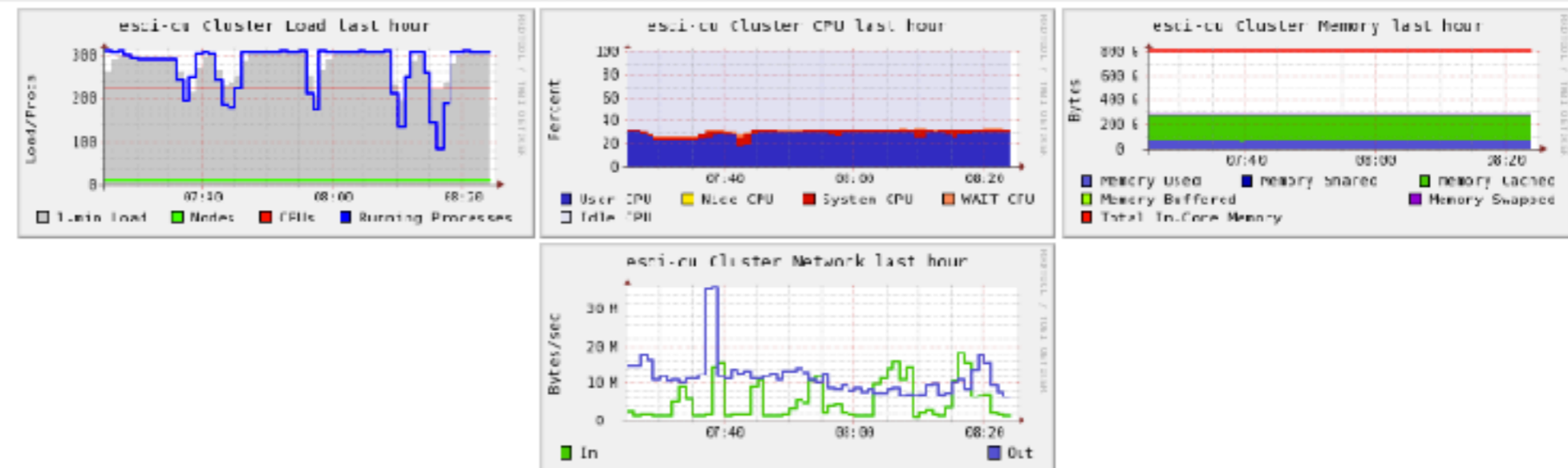
Grid > **esci-cu** > --Choose a Node

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

CPU's Total: **254**
 Hosts up: **10**
 Hosts down: **1**

Avg Load (15, 5, 1m):
123%, 127%, 134%

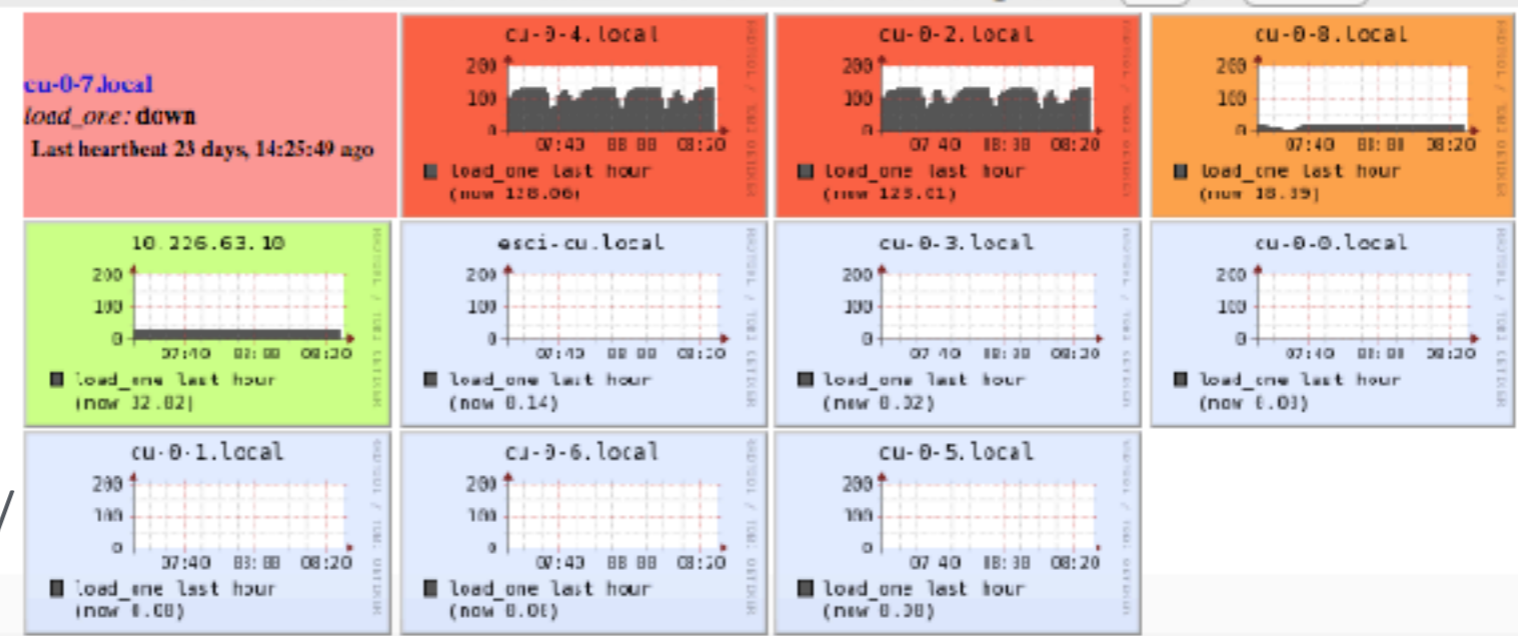
Localtime:
2017-04-04 08:24



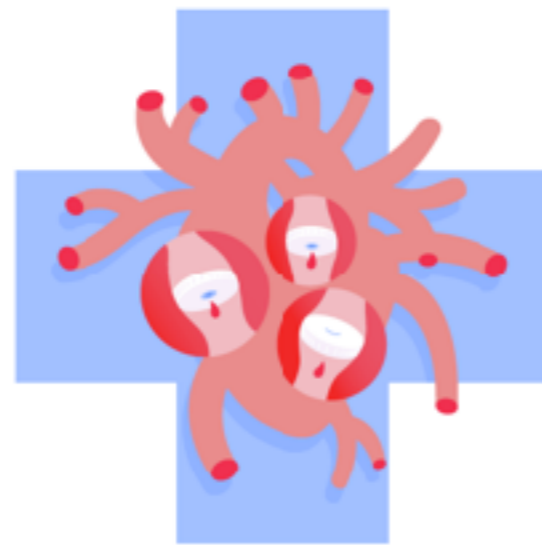
Show Hosts: yes no | **esci-cu load_one last hour sorted descending** | Columns: **4** | Size: **small**

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>

