Atoms of the Modern World

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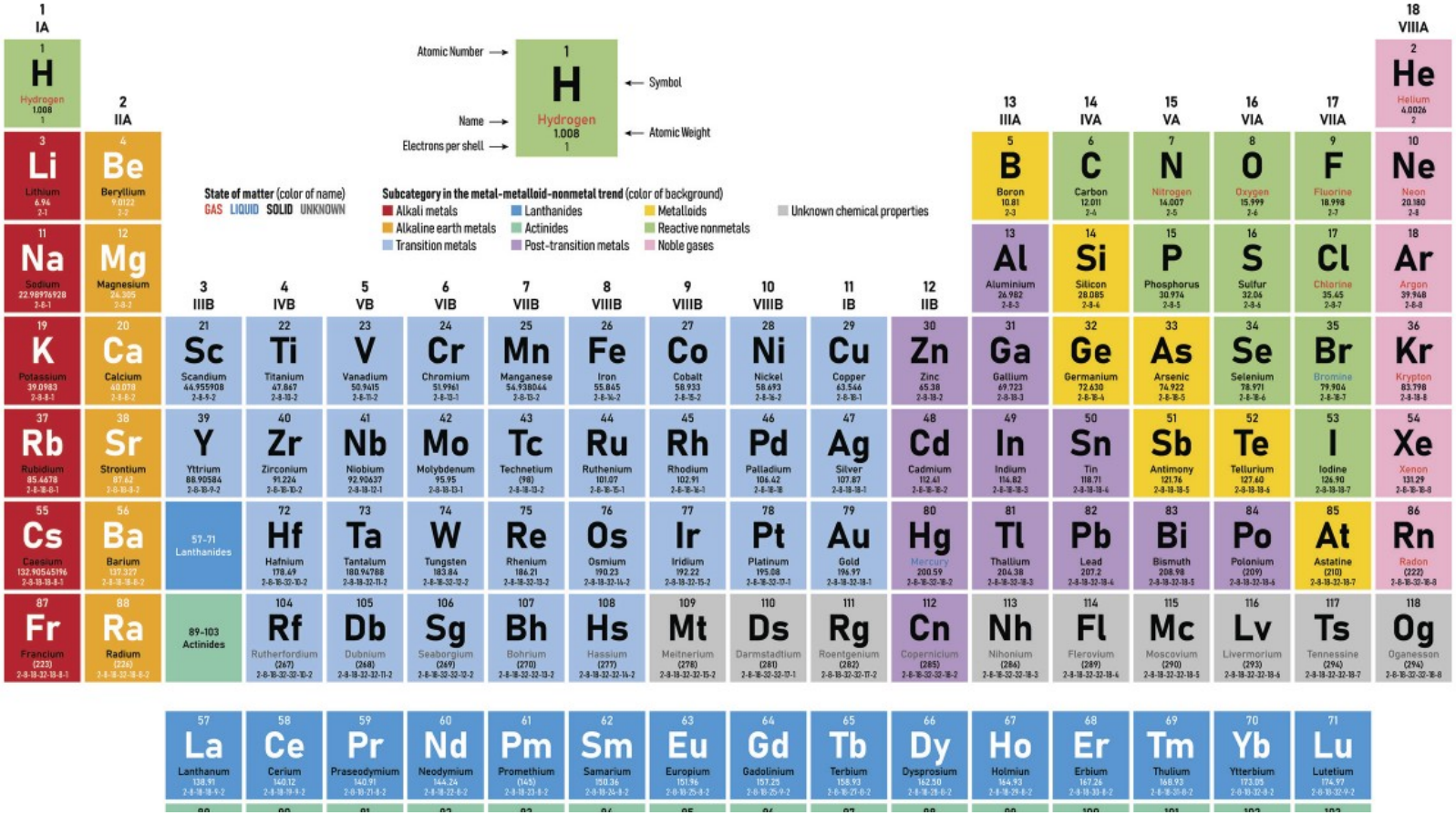
Our Universe

High Energy Particle Physics

High energy particle physics or simply particle physics addresses the following key questions:

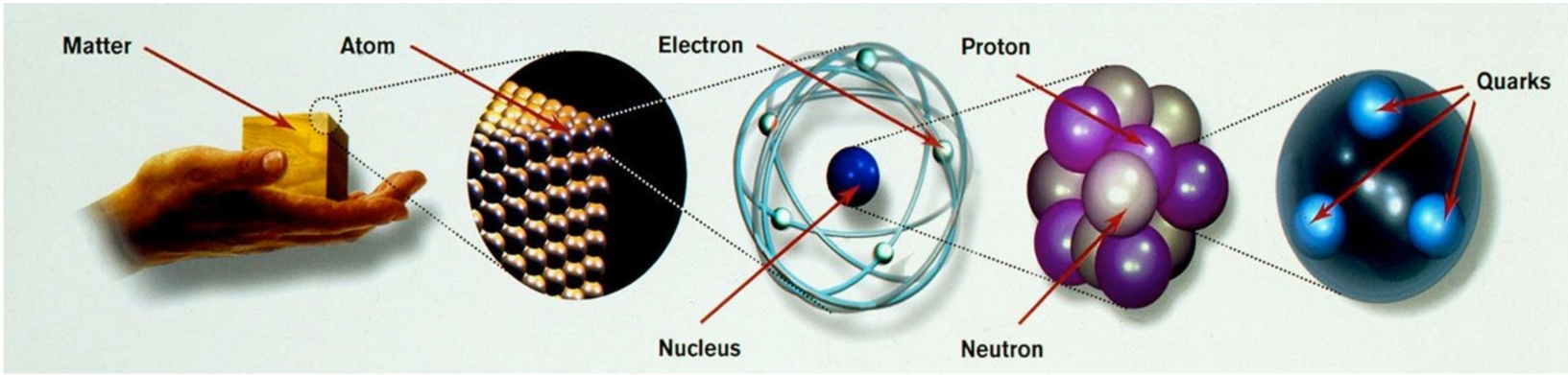
- What is the Universe made of ?
- Are there fundamental building blocks?
- If so what are they?
- How do they interact?

What is stuff made of?



- What ever we see in this world and universe is made of these elements (atoms)

Fundamental Building Blocks of Matter

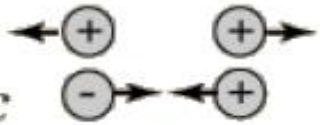


	~10 cm	~0.00000001 cm	$\sim 10^{-12}$ cm	$\sim 10^{-13}$ cm	$< 10^{-16}$ cm
ALL ORDINARY MATTER BELONGS TO THIS GROUP.	**LEPTONS**		**QUARKS**		
	Electron Electric charge −1 Responsible for electricity and chemical reactions	**Electron neutrino** Electric charge 0. Rarely interacts with other matter	**Up (u)** Electric charge + 2/3 Protons have 2 Up quarks, Neutrons 1	**Down (d)** Electric charge −1/3 Protons have 1 Down quark, Neutrons 2	
FOR THE MOST PART, THESE PARTICLES EXISTED IN THE EARLY MOMENTS AFTER THE BIG BANG.	**Muon** A heavier relative of the Electron	**Muon neutrino** Created with muons when some particles decay	**Charm (c)** A heavier relative of the Up	**Strange (s)** A heavier relative of the Down	
	Tau Heavier still	**Tau neutrino**	**Top (t)** Heavier still	**Bottom (b)** Heavier still	

ANTIMATTER Each particle also has an antimatter counterpart ... sort of a mirror image.

Fundamental Forces of Nature

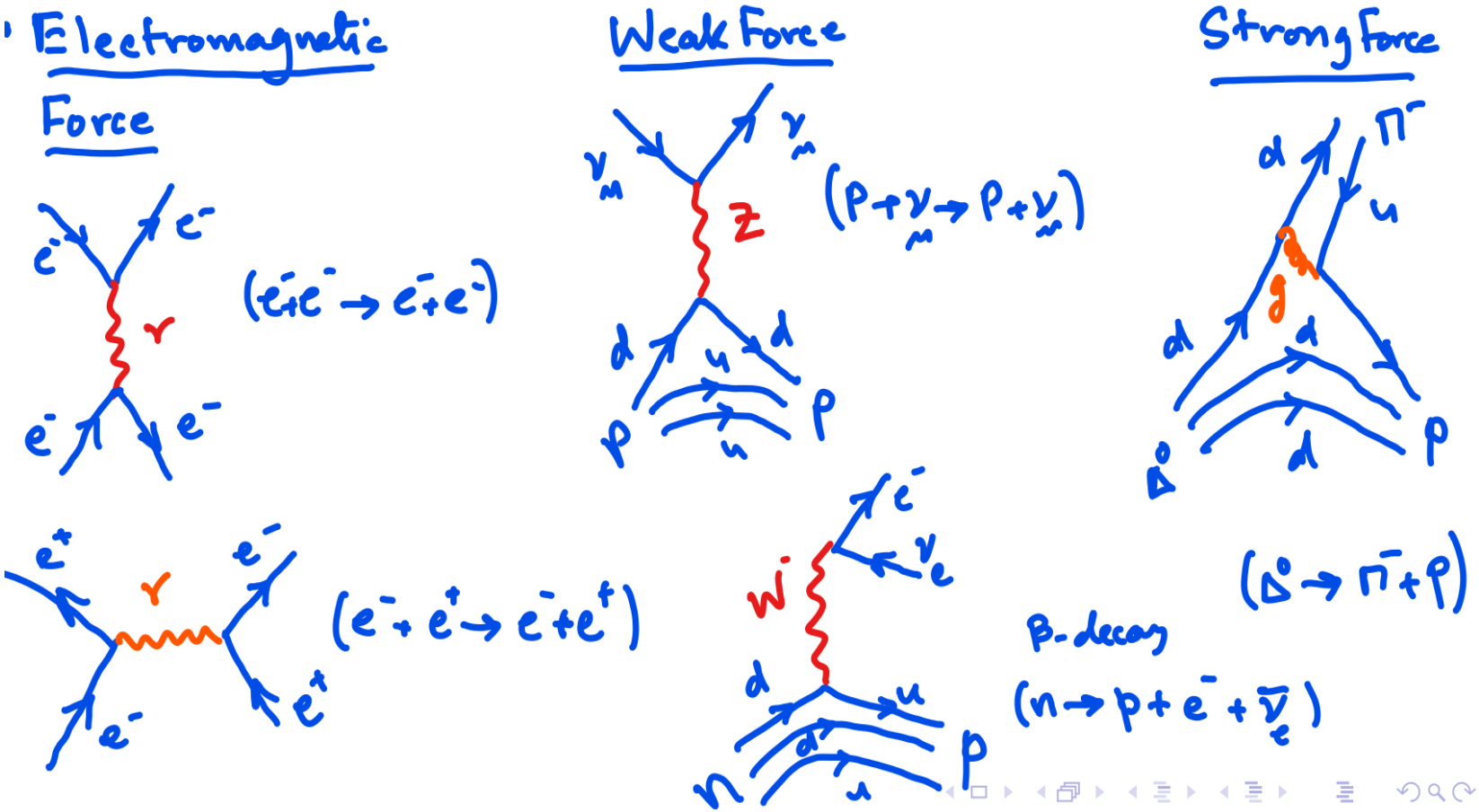
4 Fundamental Forces in the Universe

		Strength	Range (m)	Particle
Strong	 Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Electro-magnetic		$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	 neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity		6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

These forces generally considered manifestations of the same force.→ Unified.

http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html#c4

How Do Fundamental Particles Interact via Fundamental Forces?



What are Hadrons?

Hadrons are composite particles made up of quarks (bound states of quarks and gluons). They are of following two types :

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

Mesons $q\bar{q}$

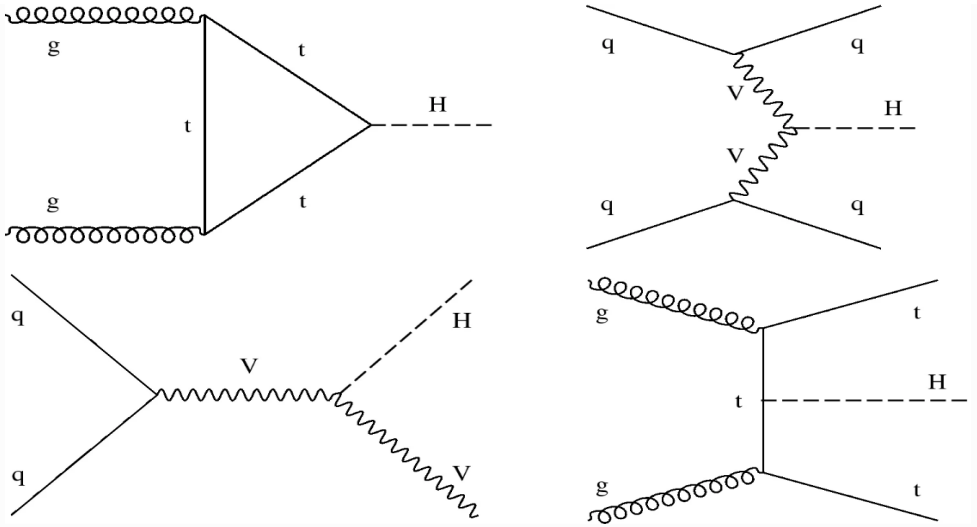
Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

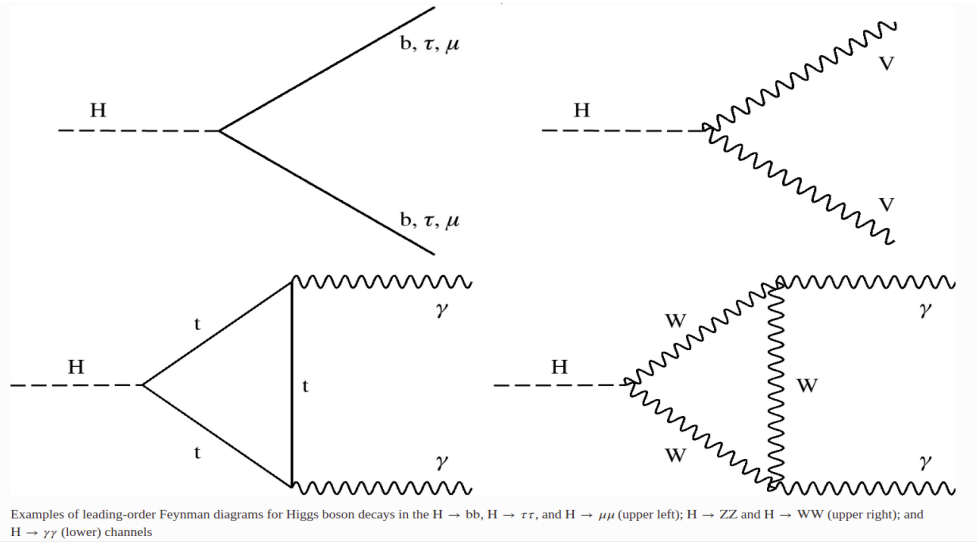
What is a Higgs Boson?

- After the big bang to about 10^{-12}s, all fundamental particles were massless.
- Since the universe was expanding, temperature dropped and phase transition took place.
- This phase transition broke electroweak symmetry and produced the Higgs field with non-zero average value everywhere in the universe.
- Leptons (except neutrinos), quarks, $W^{\pm}$ and Z^0 get mass by interacting with the Higgs field.
- The excitation in the Higgs field is the Higgs boson.
- In fact all fundamental particles are excitation of their respective fields.

Production and Decays of the Higgs Boson



Examples of leading-order Feynman diagrams for the ggH (upper left), VBF (upper right), VH (lower left), and ttH (lower right) production modes



Examples of leading-order Feynman diagrams for Higgs boson decays in the H → bb, H → ττ, and H → μμ (upper left); H → ZZ and H → WW (upper right); and H → γγ (lower) channels

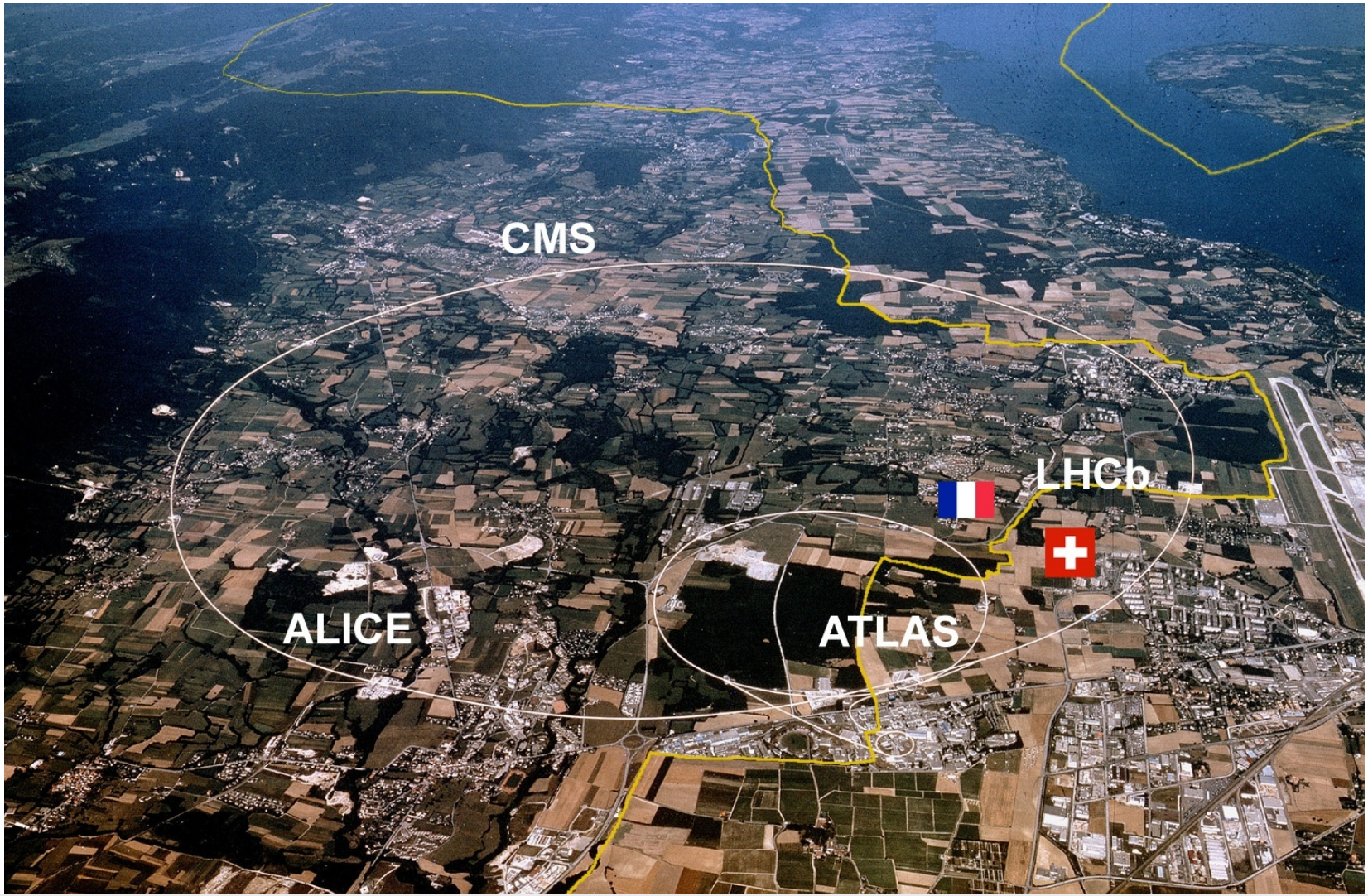
How to look for Fundamental Particles?

- Ordinary objects $\rightarrow$ naked eye
- Relatively small objects $\rightarrow$ magnifying glass
- For objects as small as $\sim 10^{-6}$m (bacteria etc.) $\rightarrow$ microscope.
- For objects as small as $\sim 10^{-10}$m (atoms etc.)$\rightarrow$ electron microscope.
- Recall the Planck energy relation $E = \frac{hc}{\lambda}$ and de Broglie wavelength of a matter particle $\lambda = \frac{h}{p}$.
- To *see* nuclei ($\sim 10^{-15}$m) and fundamental particles ($\sim 10^{-18}$m), we need to have comparable wavelength which implies high energy and hence the name of the subject high energy particle physics.

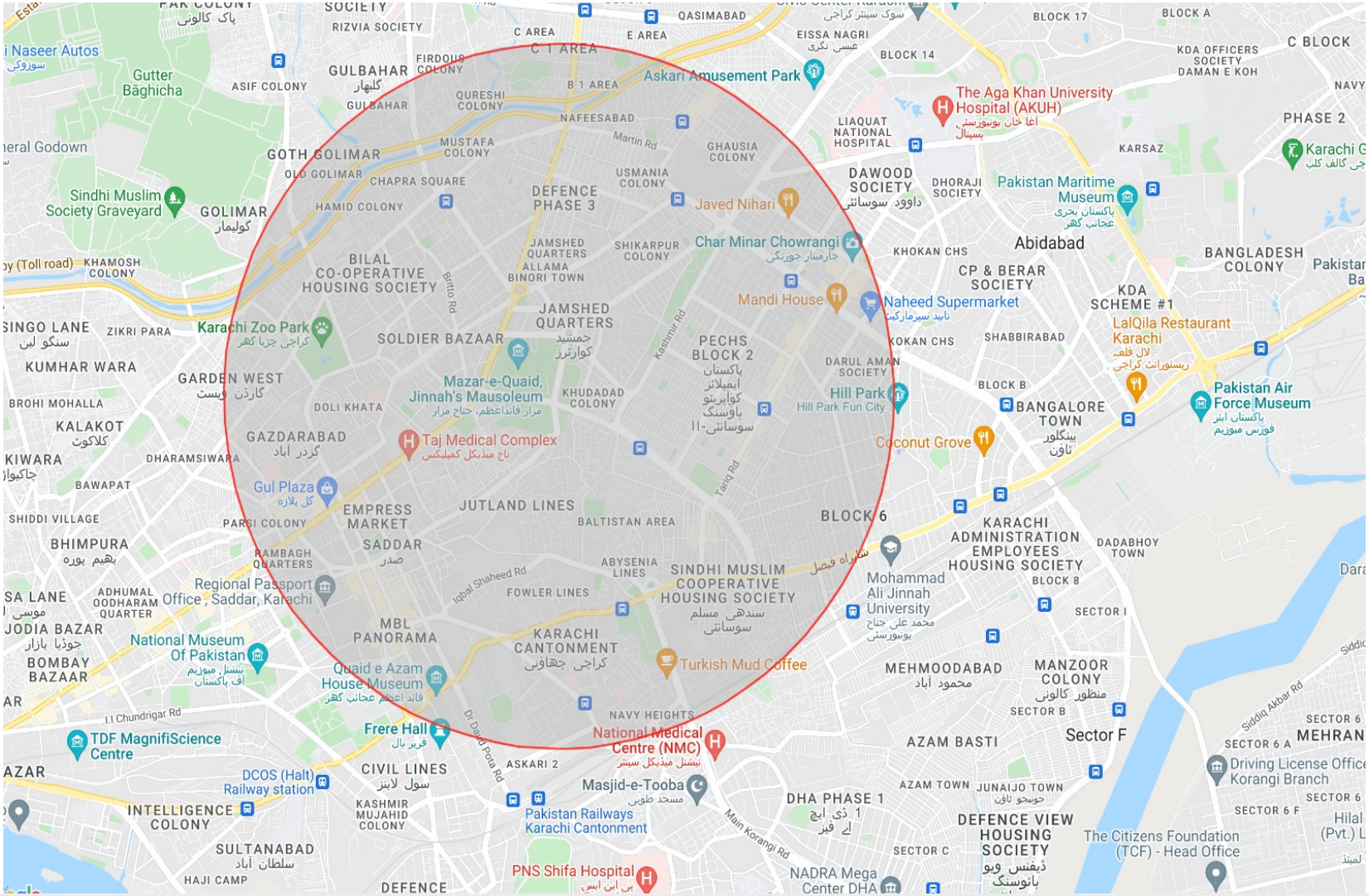
High Energy Particle Colliders

- High energy particle colliders are the microscopes for fundamental particles.
- When particles collide at high energies, the available energies can be converted into new particles due to $E = mc^2$.
- The largest and most powerful collider is the Large Hadron Collider (LHC) at European Laboratory for Nuclear Research (CERN).
- The LHC tunnel has a circumference of 27 km and worth more than \$13 billion.
- It consists of four detectors, ATLAS, CMS, ALICE and LHCb.
- It gives us glimpse of our universe at about $\sim 10^{-12}$s after the big bang and probe nature (particles) at the scale $\lesssim 10^{-18}$m.

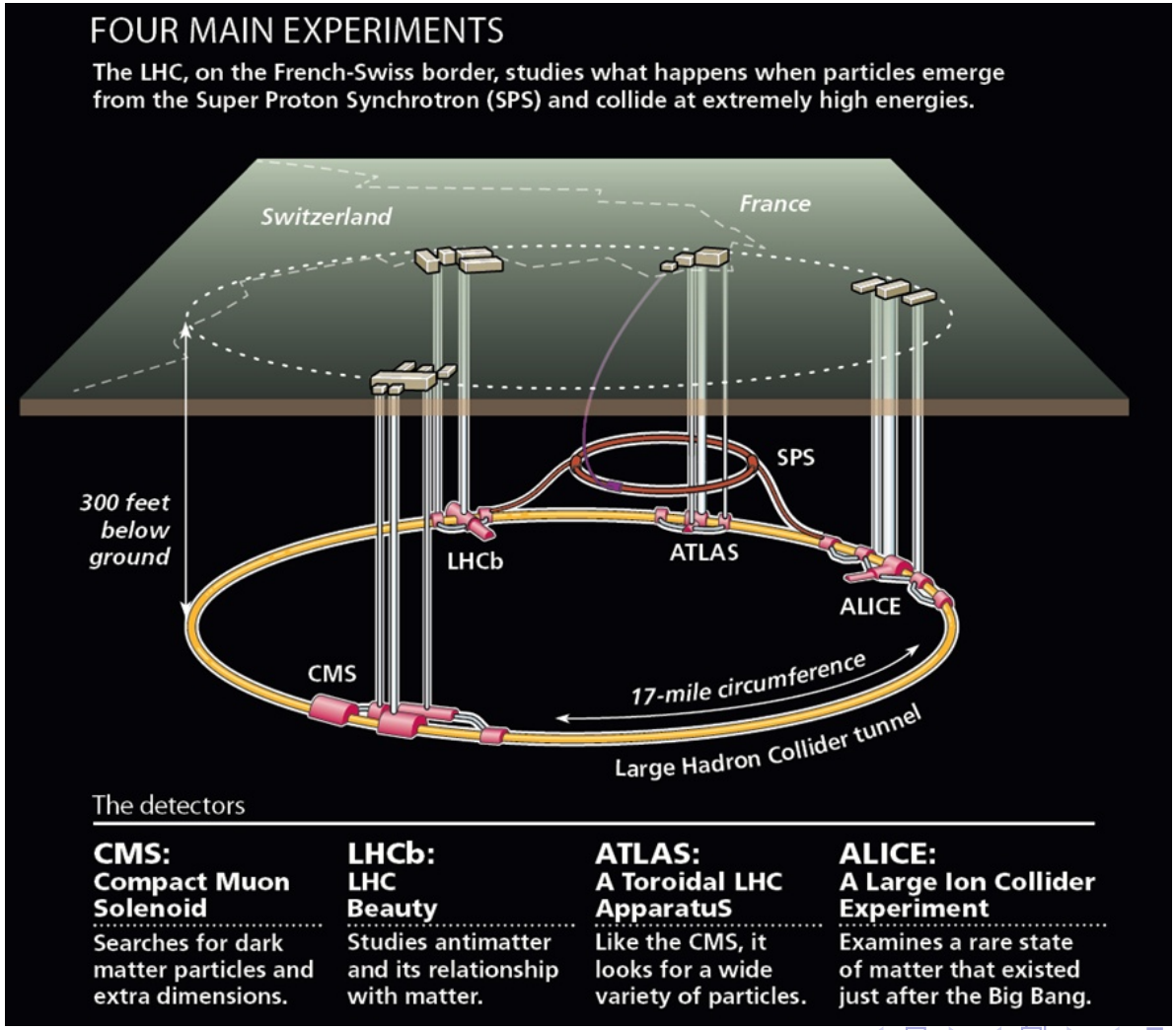
LHC Aerial View



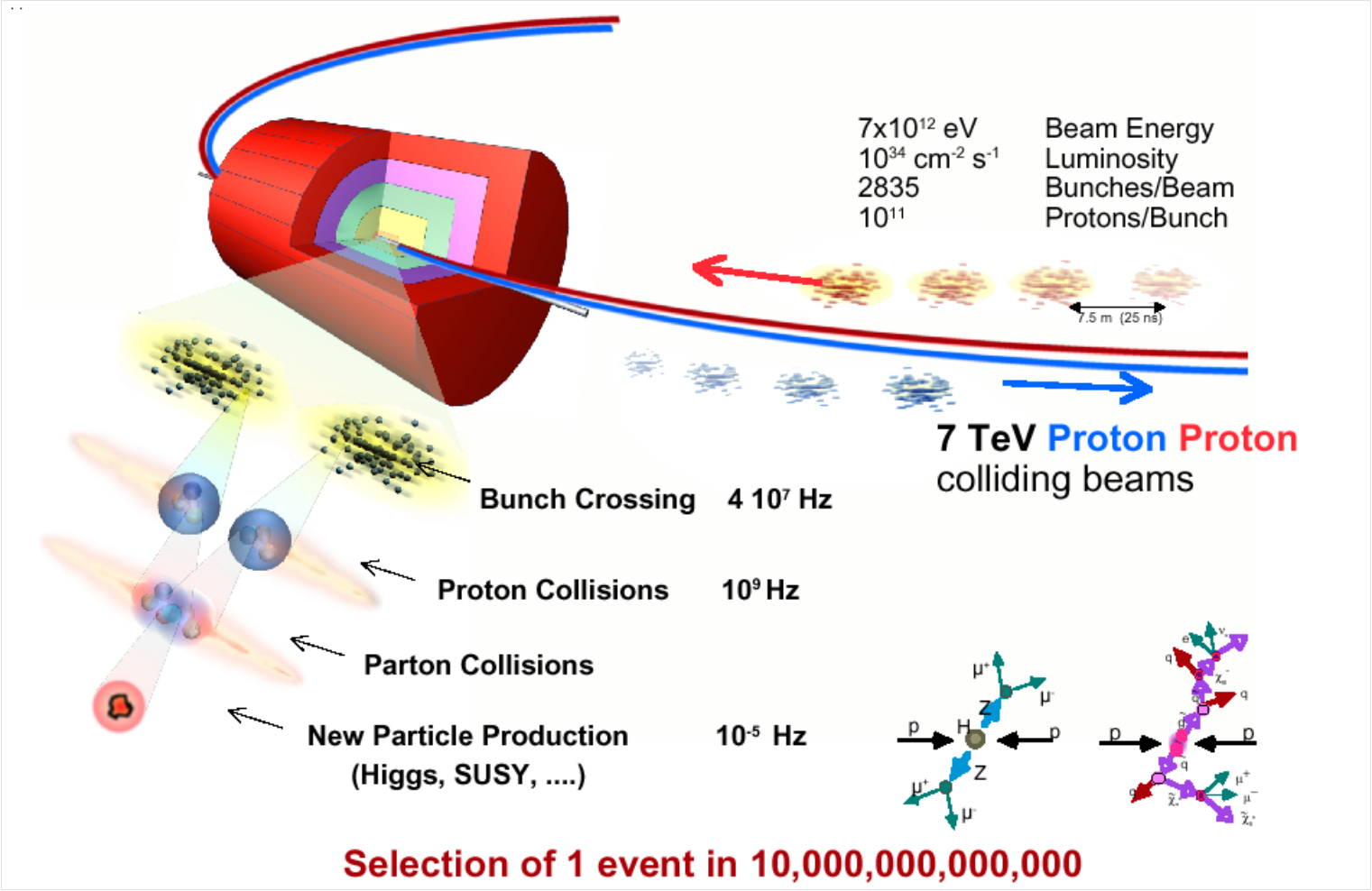
Comparison If LHC is in Karachi



Four LHC Detectors

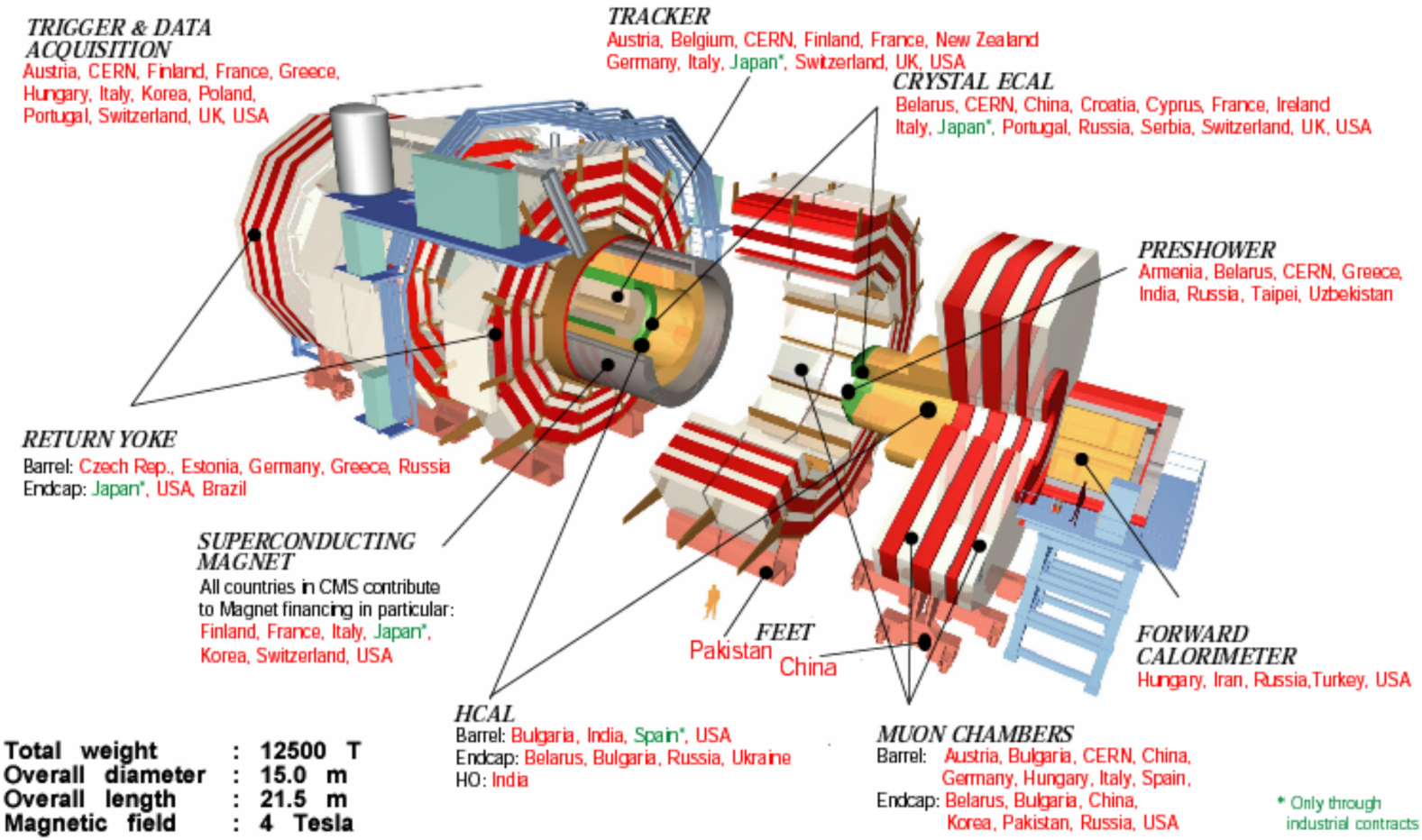


Particle Collision in a LHC Detector

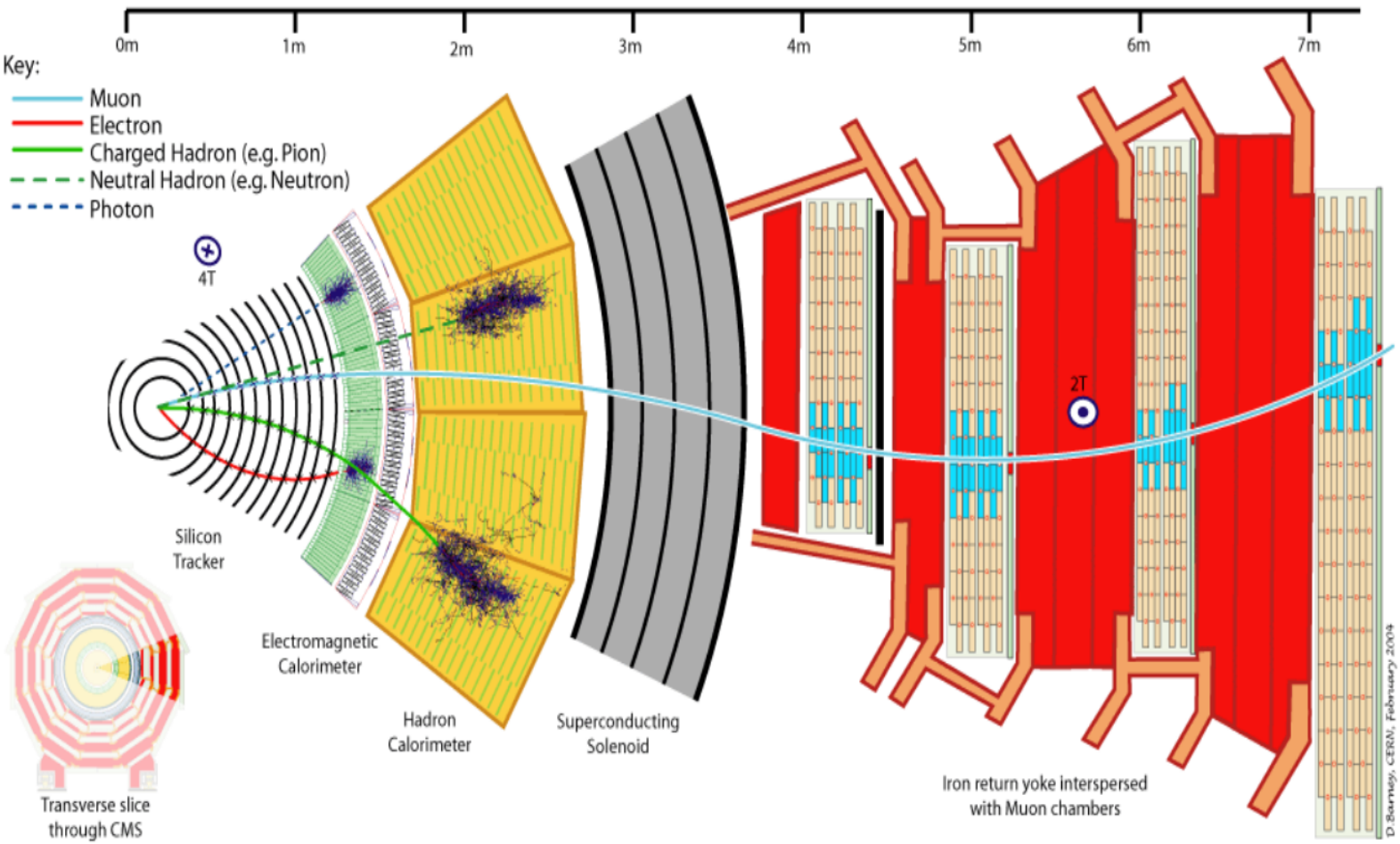


The Compact Muon Solenoid (CMS) Detector

The figure below summarizes the involvement in CMS by country. Details of each country can be found on the CMS Outreach web site.

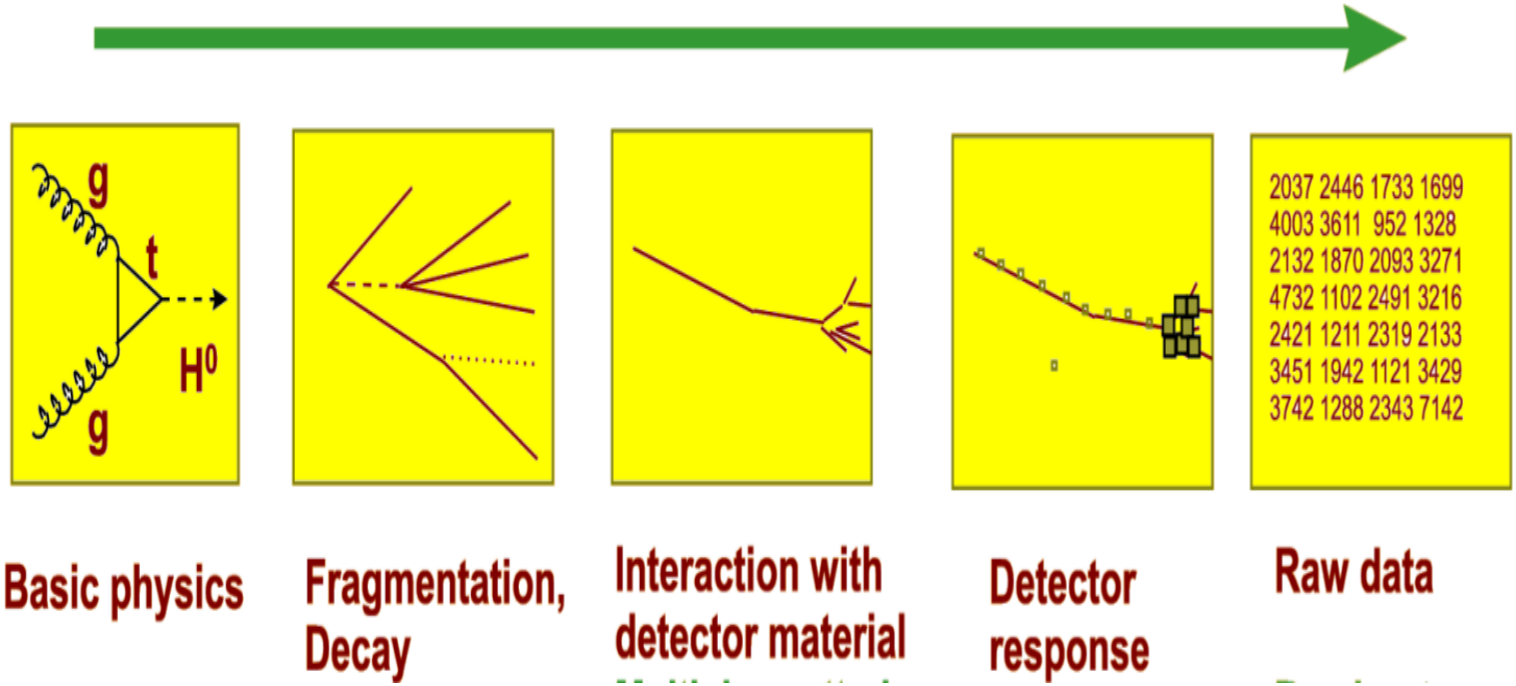


Inside a LHC Detector



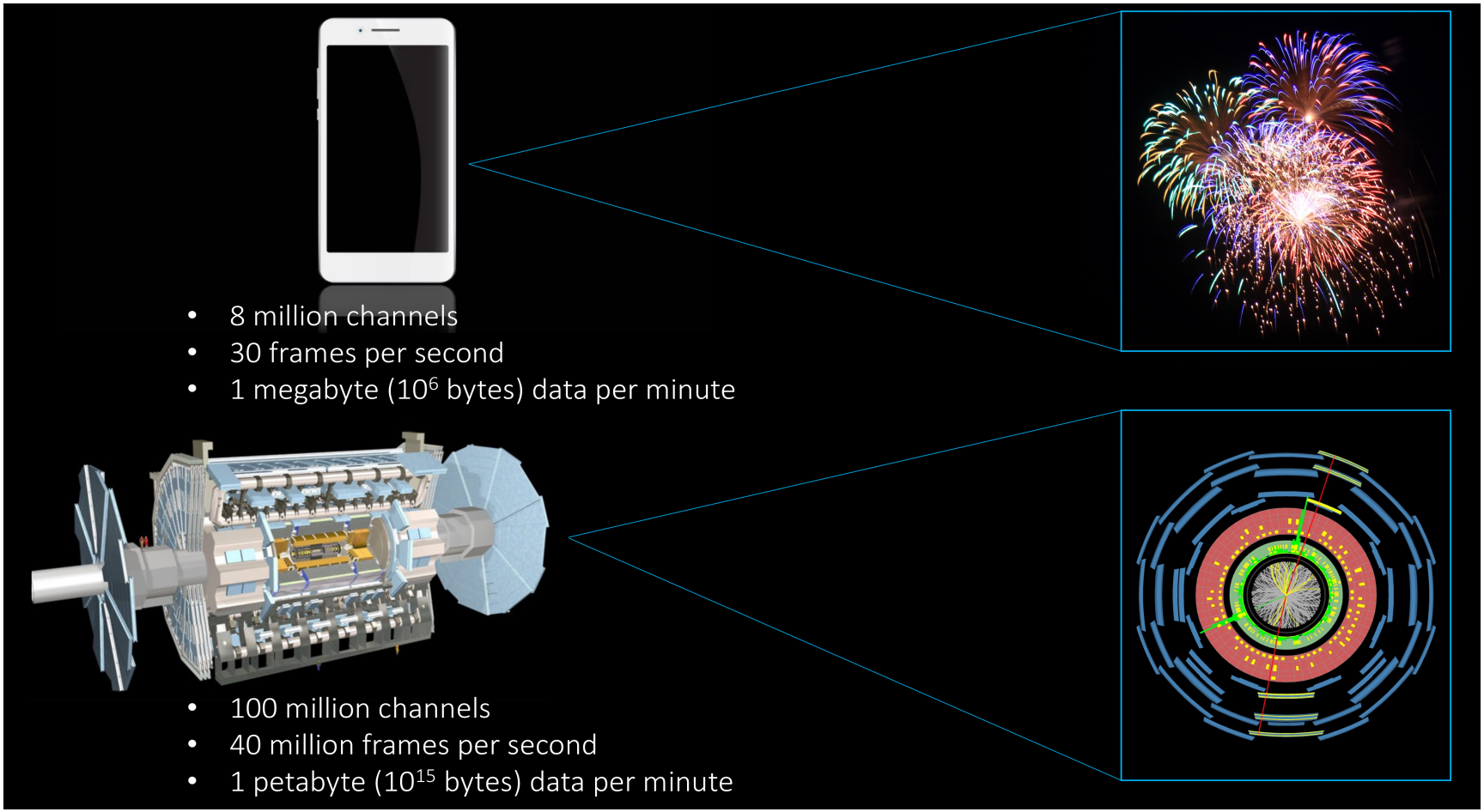
From Collision to Raw Data

From slides of Aurelijus Rinkevicius.



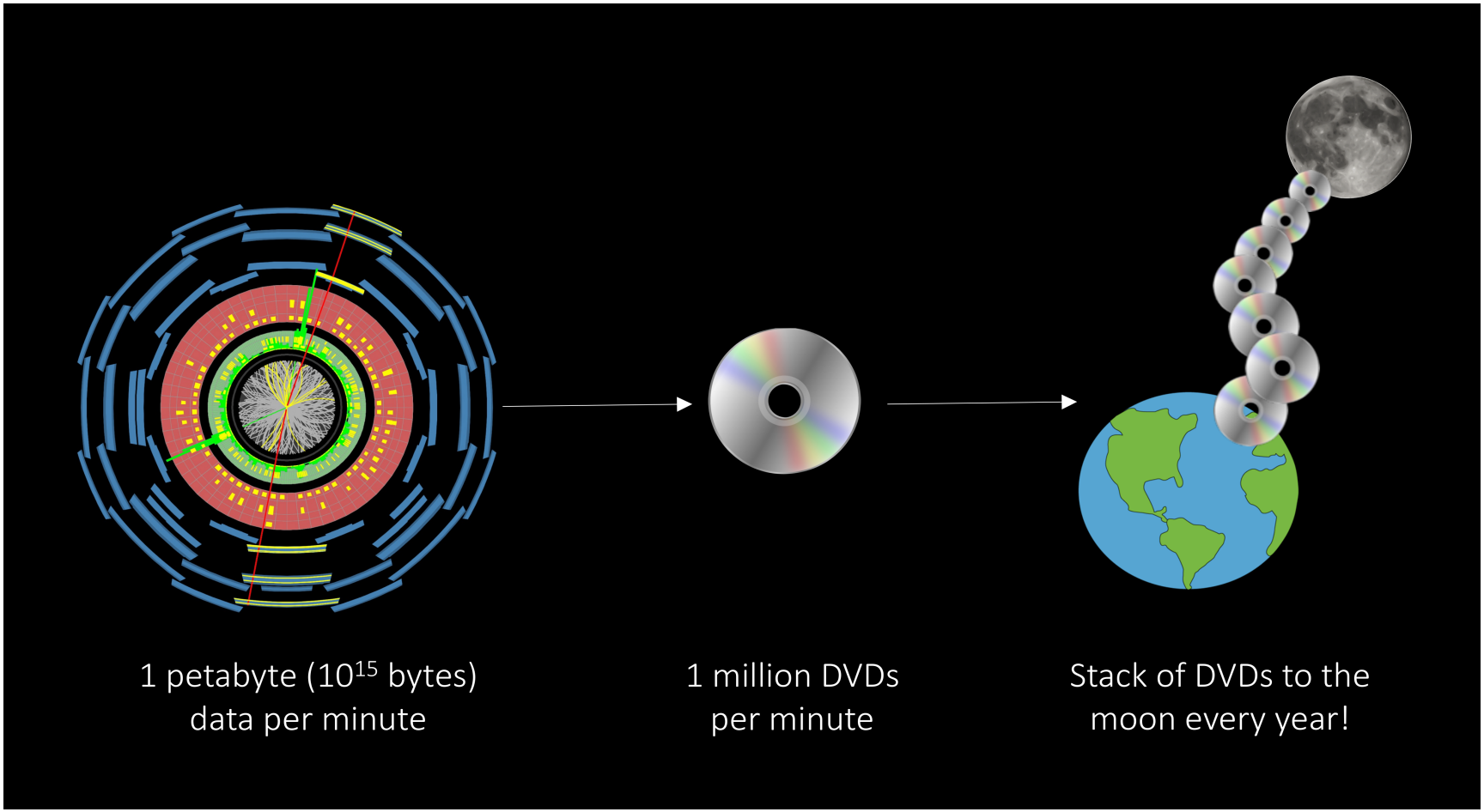
Amount of Data Produce in Collisions

From Slides of Robin Hayes, Masterclass 2021.



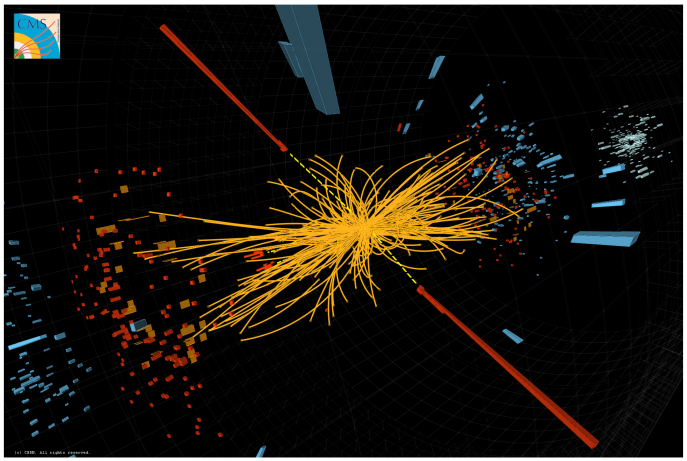
Amount of Data Produce in Collisions-continues

From Slides of Robin Hayes, Masterclass 2021.



From Raw data to Physics

- The huge amount of data is hard to keep at one place.
- After some initial cuts, CERN distributes data to Grid Computing points located in various countries.
- At those Grid points data may further be shared with other institution for the analysis.
- After doing a lot of hard work of dedicated physicists:



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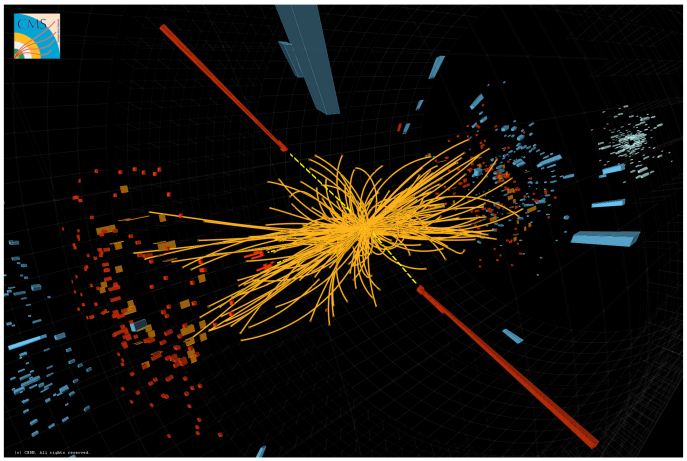
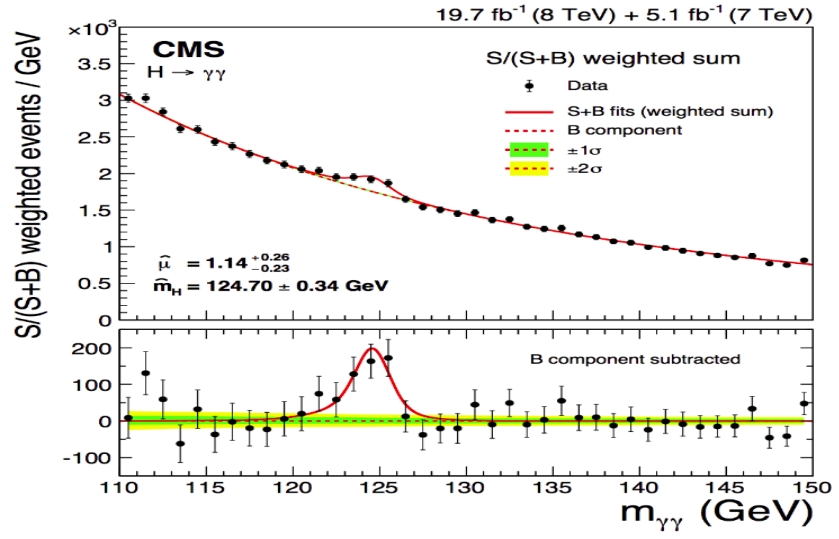
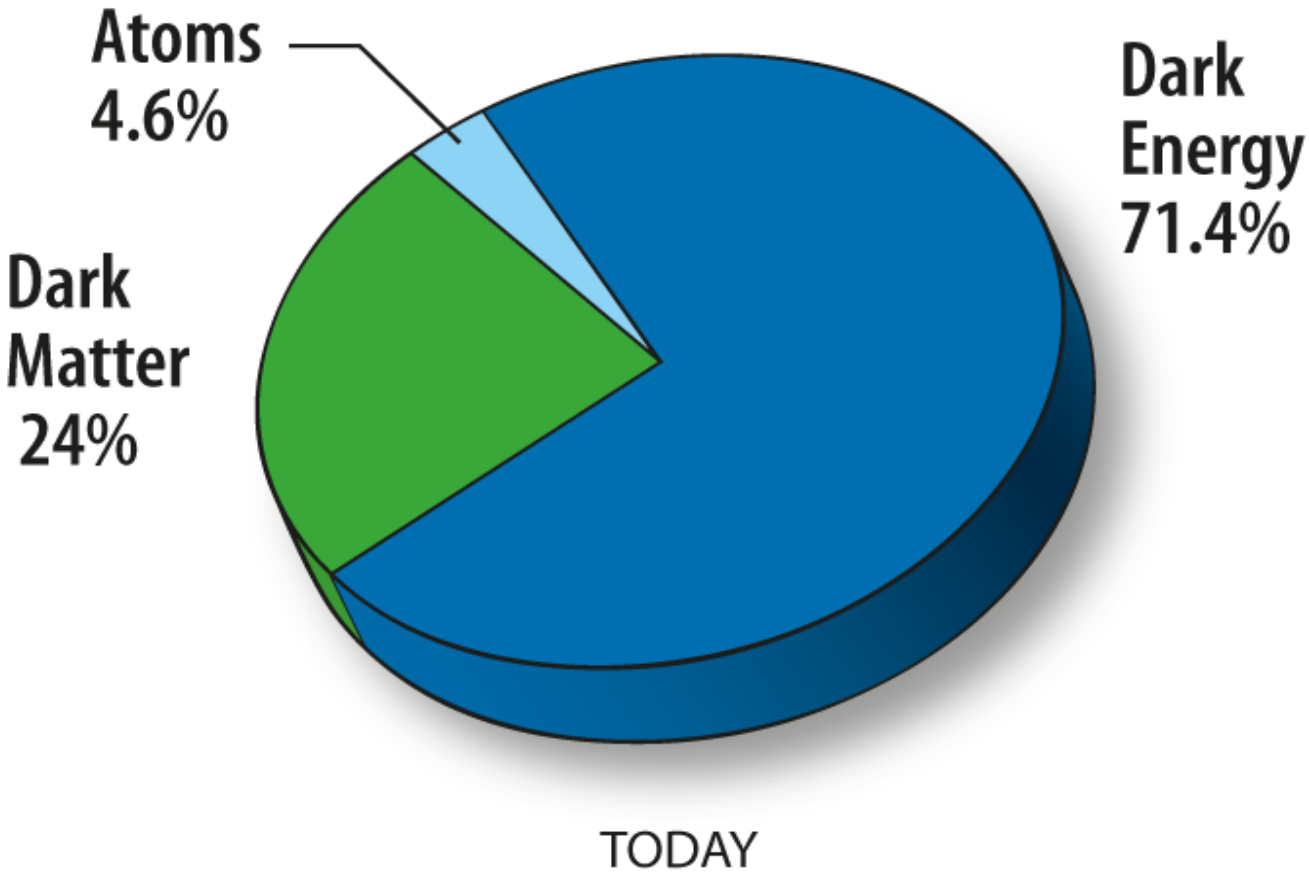




Pakistan-CERN Collaboration

- National Center for Physics (NCP) at Quaid-i-Azam University, Islamabad became full member of CMS in 2000.
- NCP has been involved in (i) detector assembly and testing (ii)physics analysis (iii) Grid computing.
- It also helped in the development, testing and fabrication of 432 Resistive Plate Chambers (RPC) required for the CMS muon detector.
- Pakistan became associate member state of CERN in 2015.
- The Associate Membership of Pakistan opens a new era of cooperation that will strengthen the long-term partnership between CERN and the Pakistani scientific community.
- It allows Pakistani scientists to become members of the CERN staff, and to participate in CERN's training and career-development programmes.

Back to Physics: Dark Side of the Universe!



Future Targets of the LHC

- The LHC (CMS) is going to restart after a maintenance/improvement shutdown in 2022. It may address the following issues:
- One Higgs boson found – could there be more?
- What is the Universe made of?
- Do we really live in only three dimensions?.
- How did matter form?
- What and where is antimatter?
- Are there more particles left to find?

Any Questions?

Very exciting future a head.
Be a Particle Physicist. Come join us.

Thank you very much