Essentials of LHC

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Dimensions in Physics

We have already probed a distance scale of about 10^{-18} m

Big Bang

Proton
Atom

10^{-32} 10^{-28} 10^{-24} 10^{-20} 10^{-16} 10^{-12} 10^{-8} 10^{-4} 10^{4} 10^{8} 10^{12} 10^{16} 10^{20} 10^{24} 10^{28} cm

Radius of Earth

Earth to Sun

Radius of Galaxies

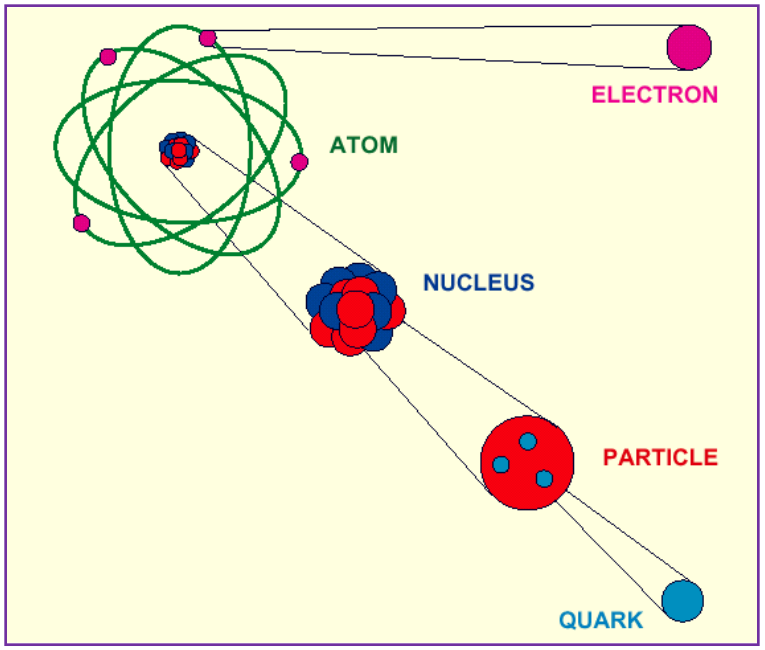
Universe

CERN

LHC

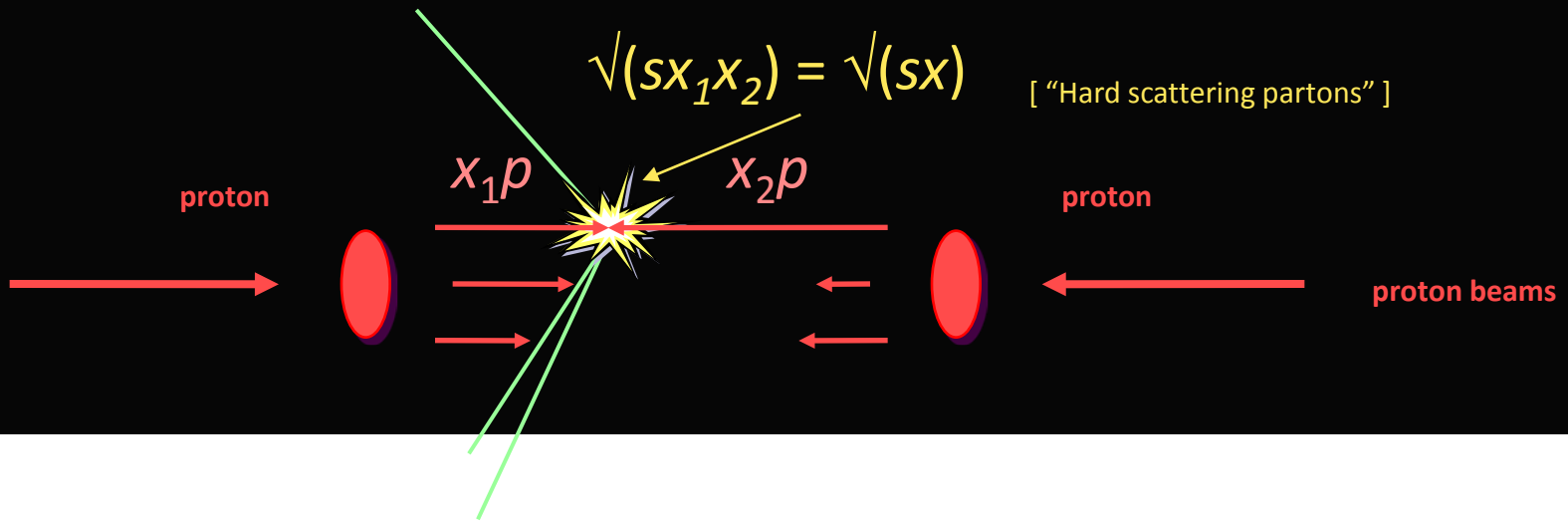
Super-Microscope

Study physics laws of first moments after Big Bang increasing Symbiosis between Particle Physics, Astrophysics and Cosmology



Is there more inside?

Proton-on-proton collision at LHC



Essential tool: Microscope

$$\Delta x \approx \frac{\hbar}{E}$$

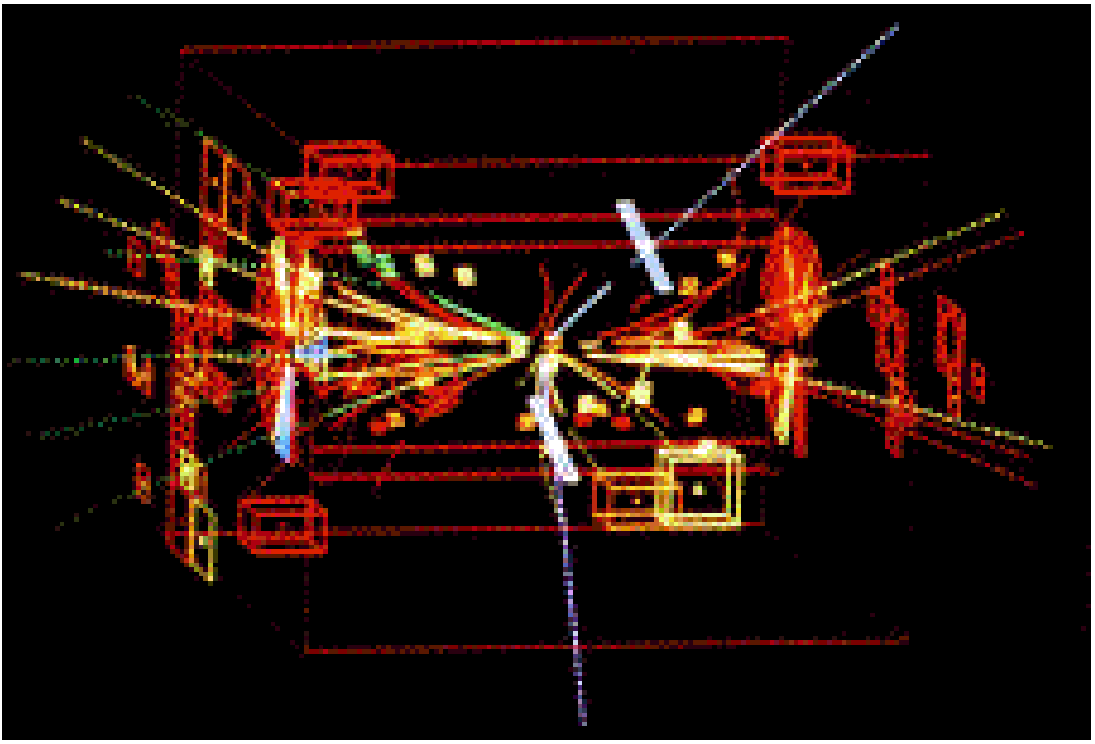
The probe wavelength should be smaller than the distance scale to be probed:

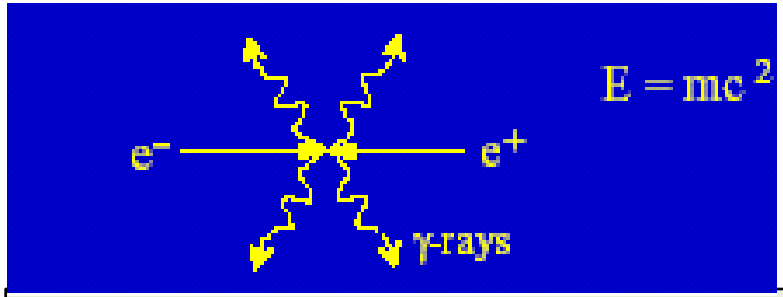
Object	Size	Energy of Radiation
Atom	10^{-10} m	0.00001 GeV (electrons)
Nucleus	10^{-14} m	0.01 GeV (alphas)
Nucleon	10^{-15}m	0.1 GeV (electrons)
Quarks	?	> 1 GeV (electrons?)

What lies within quarks and leptons…?

Need a higher energy probe

How do we go about it?

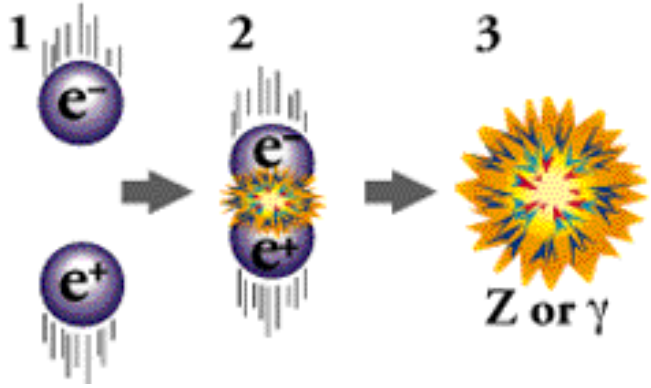


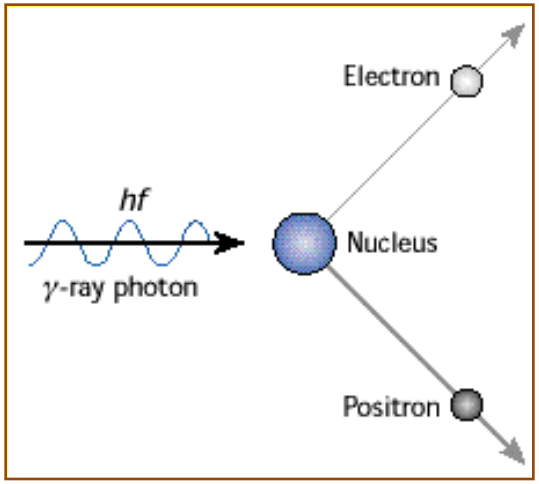


Mass of particles comes from energy of the reaction

The larger the energy the greater the variety of particles

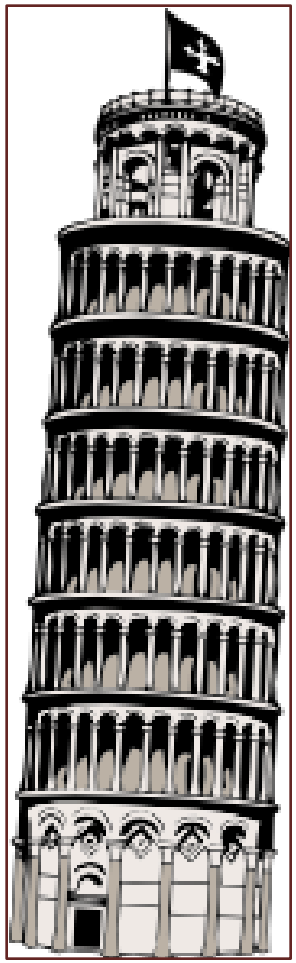
Equal amount of matter and antimatter is produced when energy is converted to matter.





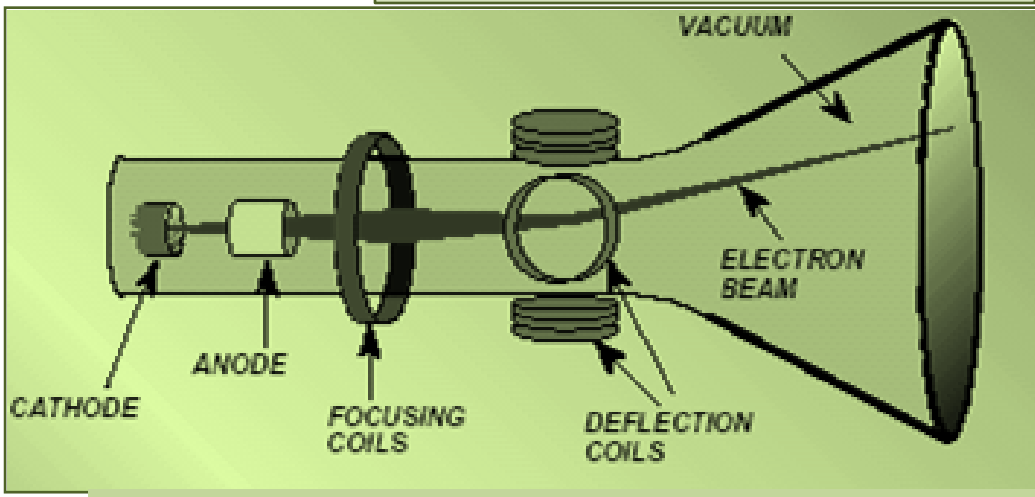
Pair production: γ rays → e+ e-

Accelerators

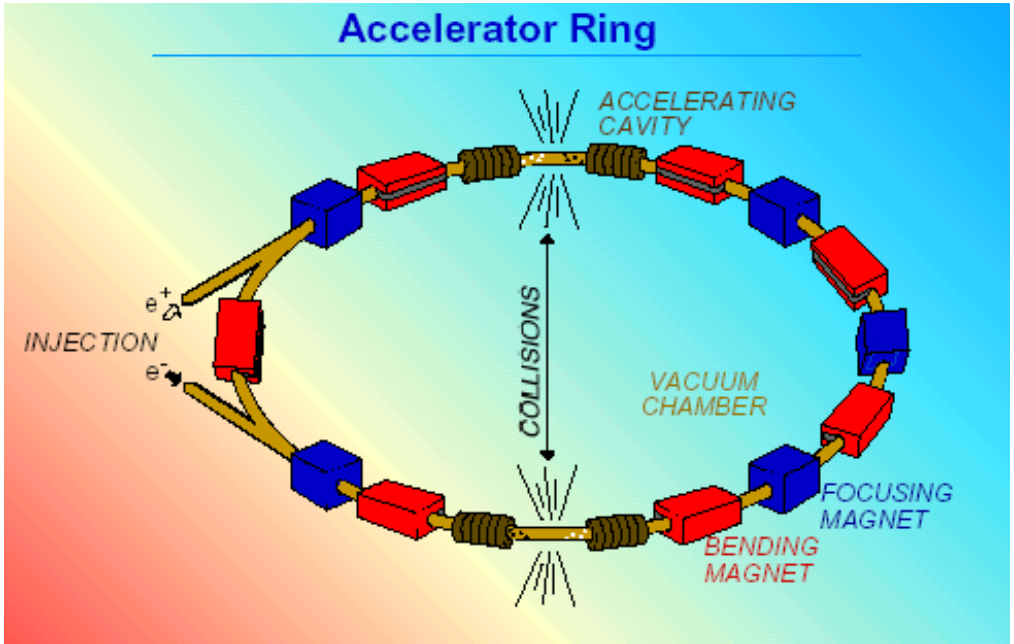


First accelerator made by humans

An accelerator at home



Voltage in a TV: 20 kV
➔Energy of each electron 20 keV
In LEP tunnel electron energy 50 billion eV



Probing shorter than ever length scales

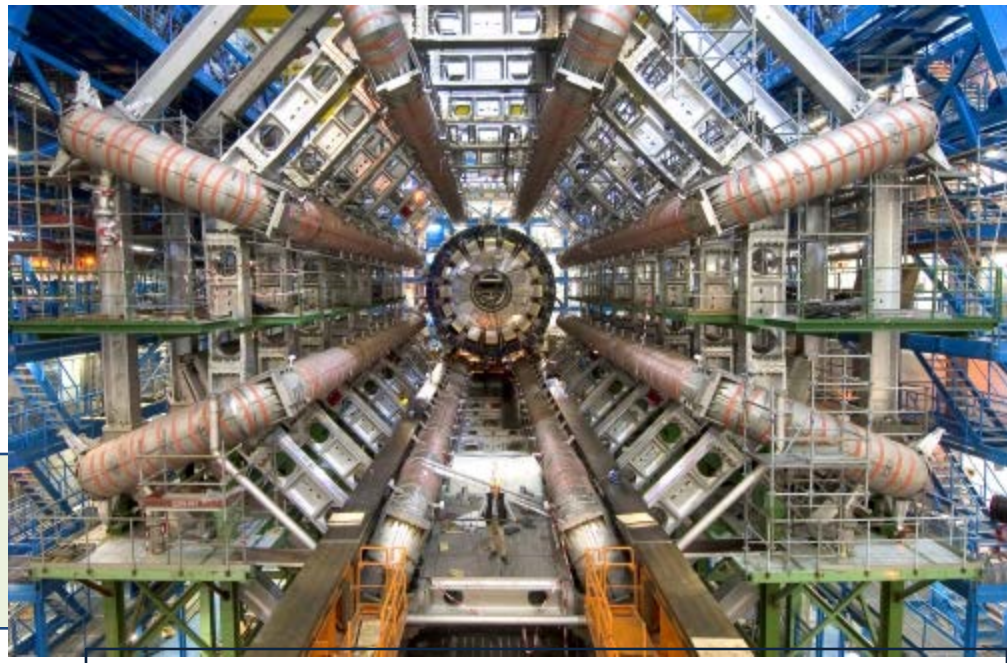
Electronic Eye

Required energy

$$10^{-20}\ \text{m} \approx 10^{+13}\ \text{eV}$$

$$= 10\ \text{TeV}$$

(1 TeV = 10^{12} electronVolt
= 1.6 * 10^{-7} Joule)



10 million electronic channels recording data every 25 nano sec.

LARGE HADRON COLLIDER

20 years to plan, build ,
20 more to work with
→ we need you!

Presently, LHC provides energy upto 7 TeV,

equivalent to the kinetic energy of a fly!

LHC motivations: explore, search, measure

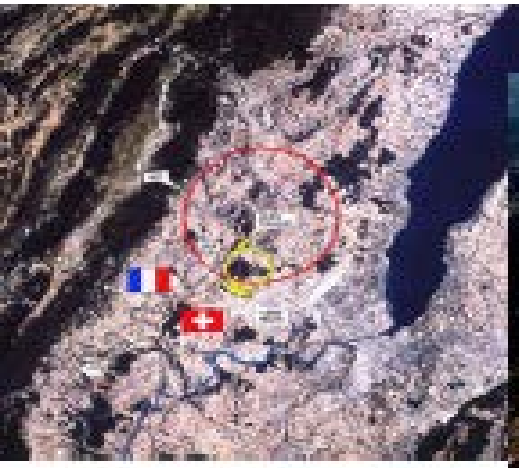
- LHC is world's most powerful microscope doing *nanonano* physicsc to
- Study how the universe was 13.7 billion years ago.

→ simulating the situation of the universe when it was as old as 10^{-12} s !!

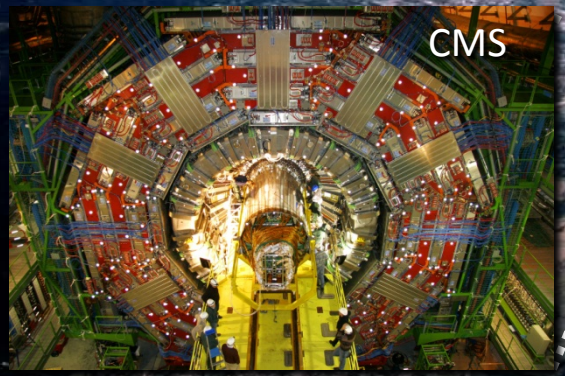
- LHC results is likely to change the way we consider the world.

Till now no Higgs boson and no departure from established physics!

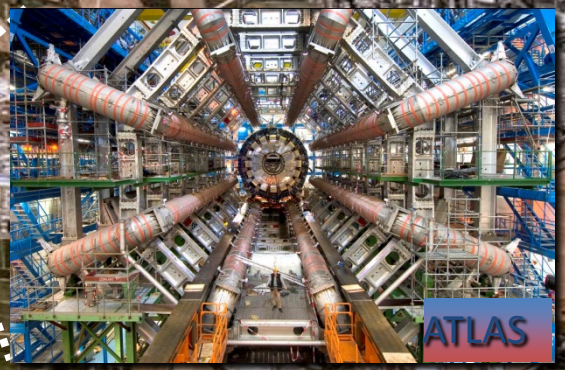
One of the fastest race tracks: protons zipping past with 99.999999% of velocity of light around 27 km of LGC ring 11000 times/sec.



Entering a New Era in Fundamental Science



Exploration of a new energy frontier



Is LHC a big deal?

6 experiments: 2 high luminosity (ATLAS, CMS)
+ 1 medium (LHCb)
+ 1 very low (ALICE),
+ 2 forward detectors (TOTEM, ALFA)

- **Great performance by the LHC operations team.**
- **Extremely vigilant with protection of the machine (100MJ of stored energy**

- **Matching performance by the experiments and computing.**

Main point for jubilation among physicists : lot of data accumulated,

Very fast turn around of physics harvest ➔ more than 100 published papers by big experiments in 2 years.

LHC: The Giant Marvel of Technology

- 100-150 m under the surface
- 27 km at 1.9 K (superfluid He)
- Vaccuum ~ 10^{-13} Atm.
- SuperConducting coils: 12000 tonnes/7600

- Temperature generated at LHC due to proton-proton collision ~10^{16} ^{0}c, compare with sun: 5506 ^{0}c, a matchstick: 250 ^{0}c

LHC machine to be maintained at -271 ^{0}c vs. Home freezer: -8 ^{0}c
Boomerang nebula: -272 ^{0}c, antarctica: -89.2 ^{0}c,

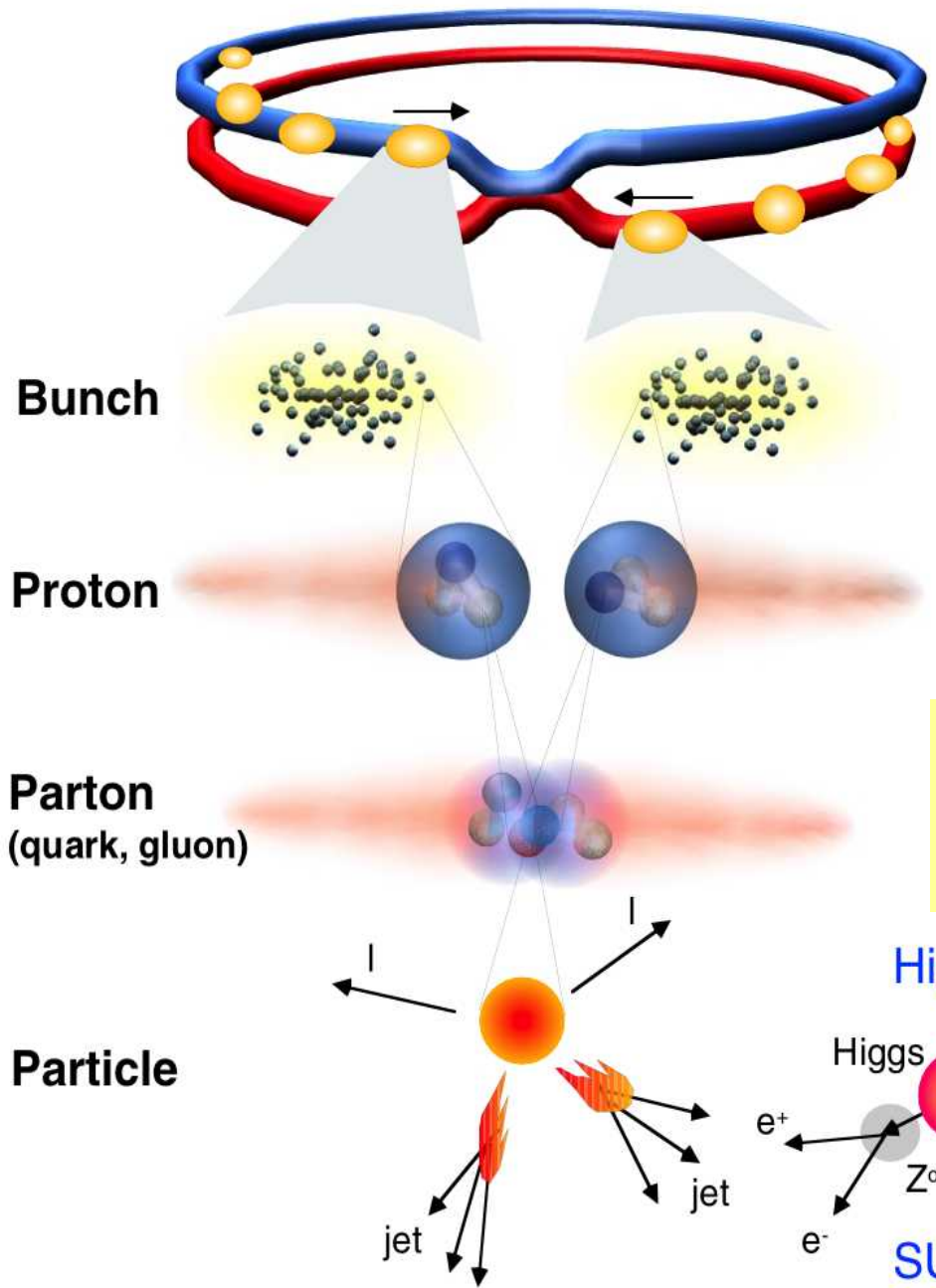
Indian contributions in LHC magnet components

Largest ever human endeavour, require huge resources to be put in.
To be passed on to younger generations of today and tomorrow: YOU!

What happens in LHC experiment

2011

Proton-Proton	1400 bunch/beam
Protons/bunch	$2.\ 10^{11}$
Beam energy	3.5 TeV ($1TeV = 10^{12}$ eV)
Luminosity	3.10^{33} /cm ^{2}/s
Crossing rate	20 MHz
Collisions	10^8 Hz

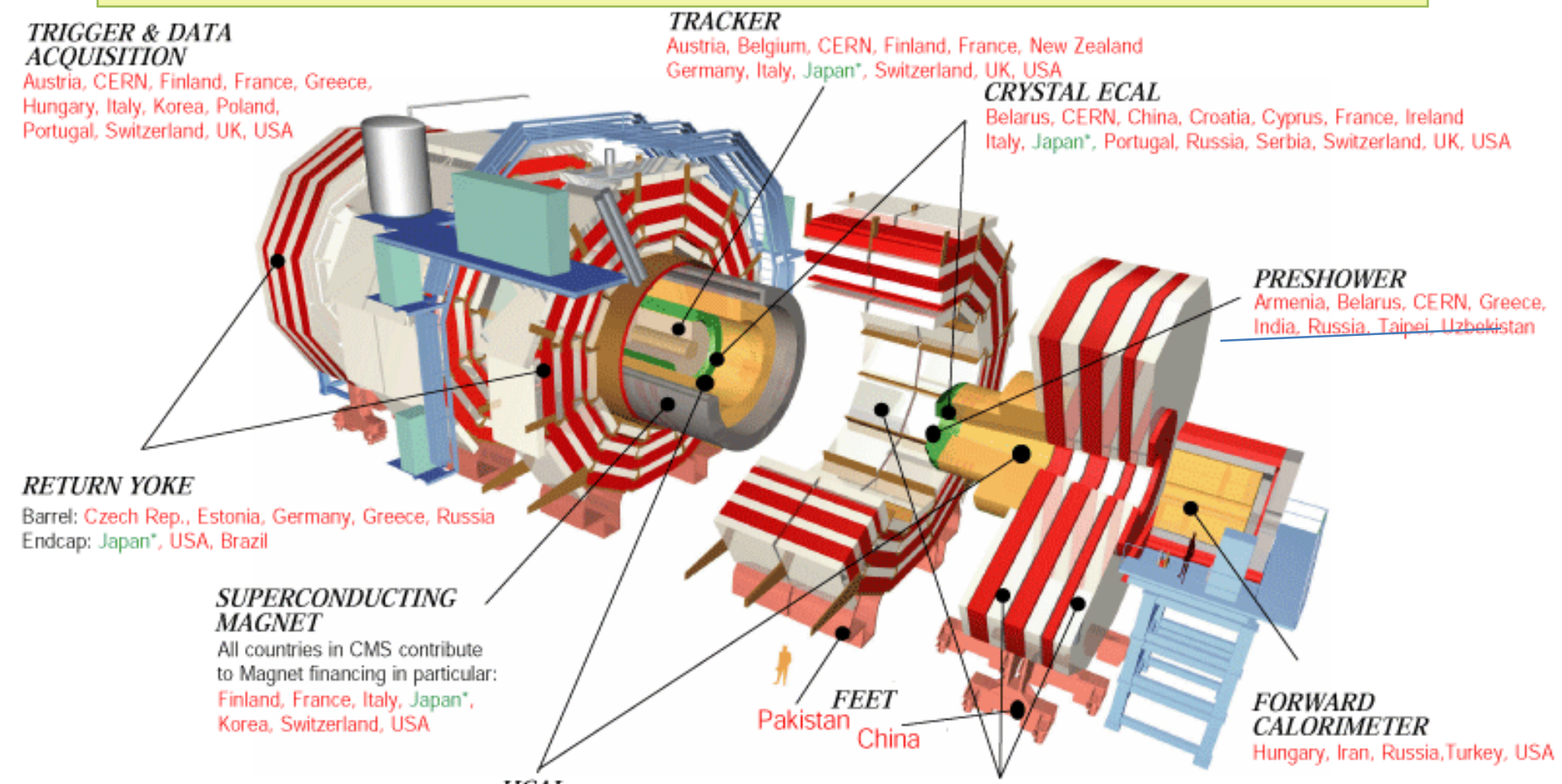


Mammoth detectors register signals for Energetic, mostly (hard) inelastic collisions involving large momentum transfer.

Selection of 1 in 10,000,000,000,000

CMS Collaboration

~190 Institutions with about 3500 scientists and engineers.



TRIGGER & DATA ACQUISITION
Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER
Austria, Belgium, CERN, Finland, France, New Zealand Germany, Italy, Japan*, Switzerland, UK, USA

CRYSTAL ECAL
Belarus, CERN, China, Croatia, Cyprus, France, Ireland Italy, Japan*, Portugal, Russia, Serbia, Switzerland, UK, USA

PRESHOWER
Armenia, Belarus, CERN, Greece, India, Russia, Taipei, Uzbekistan

RETURN YOKE
Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA, Brazil

SUPERCONDUCTING MAGNET
All countries in CMS contribute to Magnet financing in particular: Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan
China

FORWARD CALORIMETER
Hungary, Iran, Russia,Turkey, USA

HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HO: India

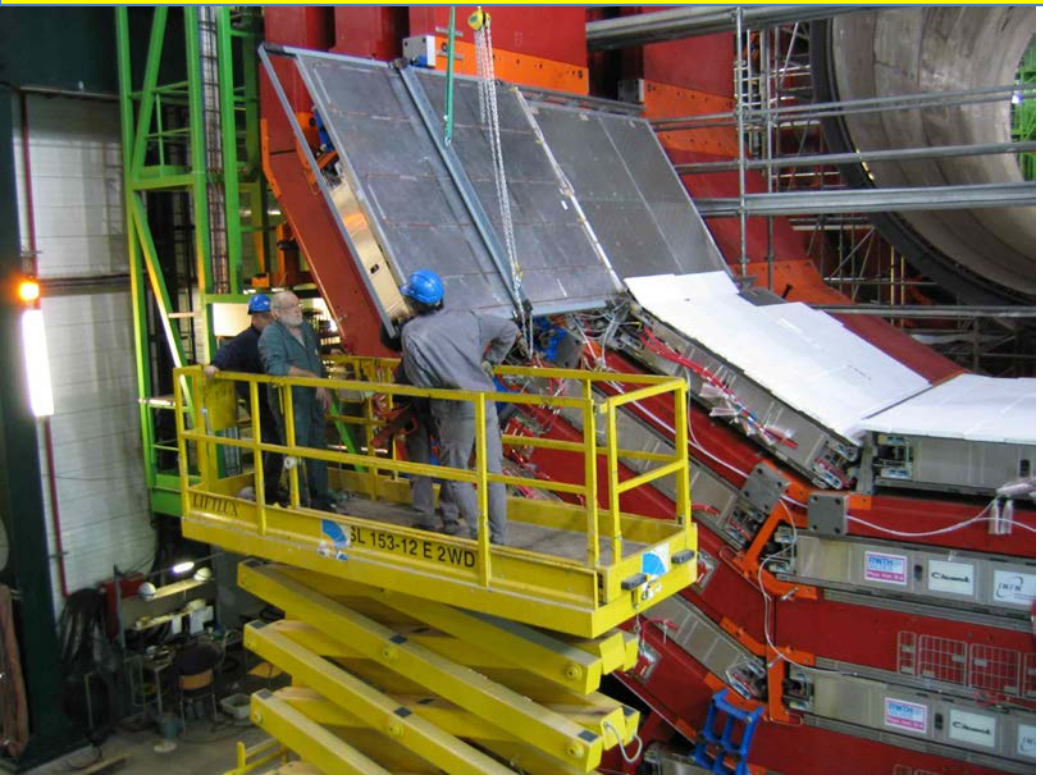
MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Korea, Pakistan, Russia, USA

* Only through industrial contracts

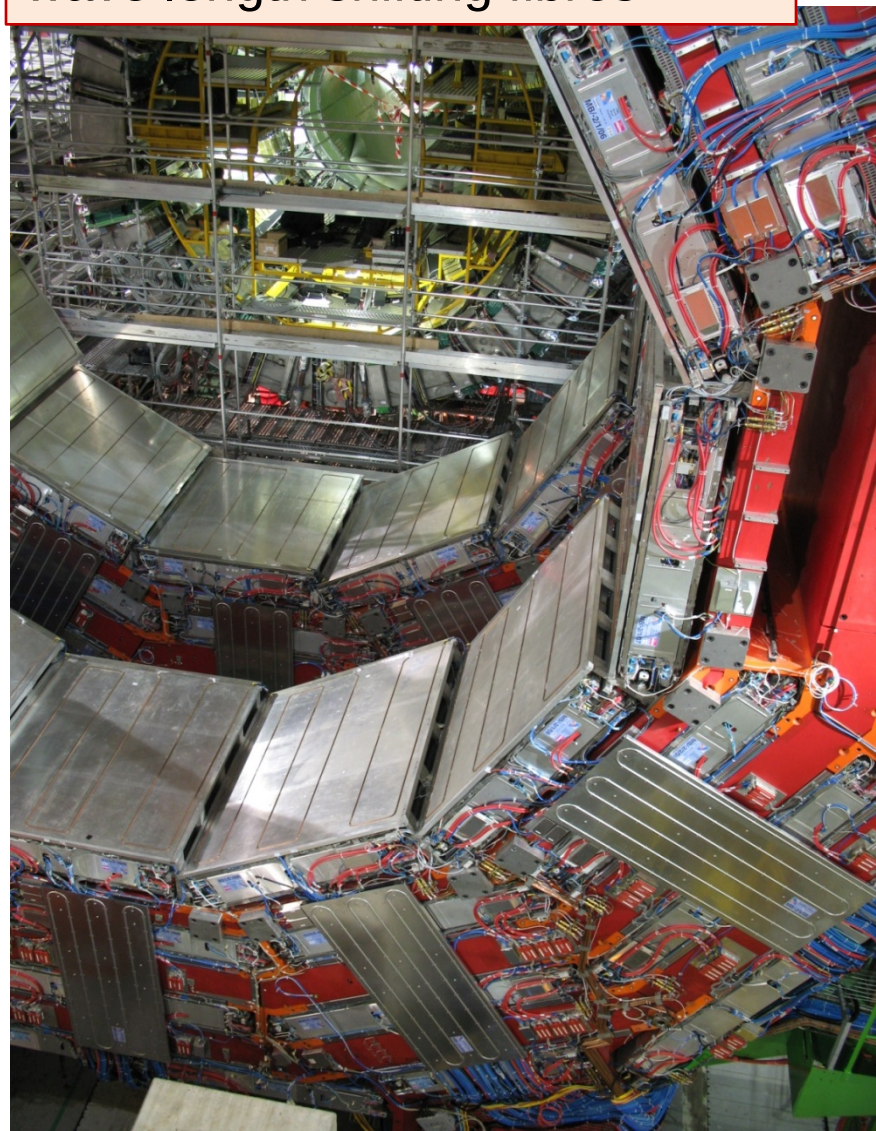
Total weight	**:**	**12500 T**
Overall diameter	**:**	**15.0 m**
Overall length	**:**	**21.5 m**
Magnetic field	**:**	**4 Tesla**

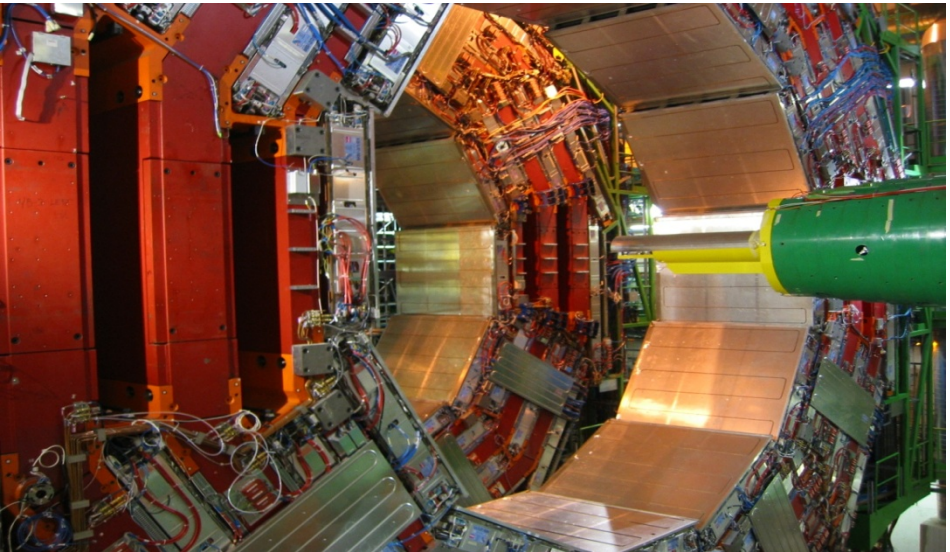
Indian contributions in HO and Si-preshower detectors

Hadron Outer Calorimeter installation



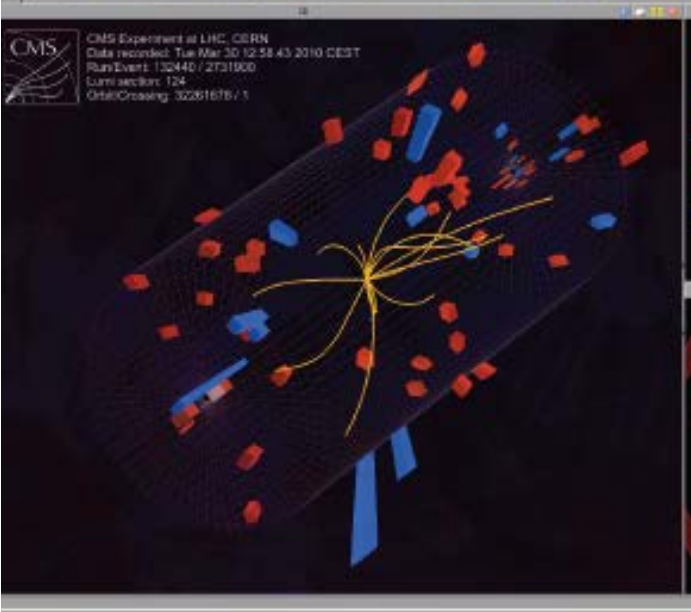
432 trays consisting of plastic scintillators (40 cm X 30 cm) + wave length shifting fibres

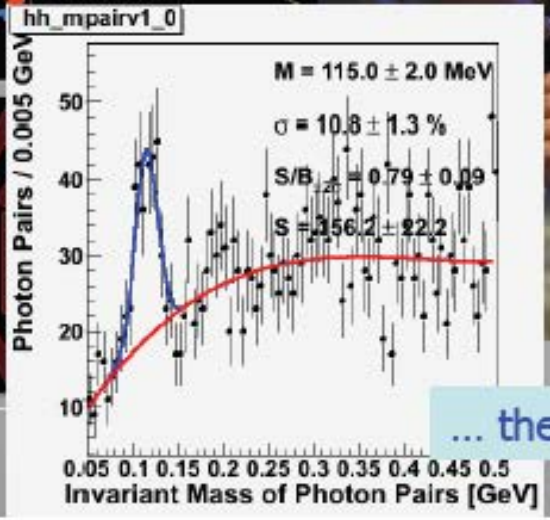




30/3: 7 TeV Collisions…

12:58





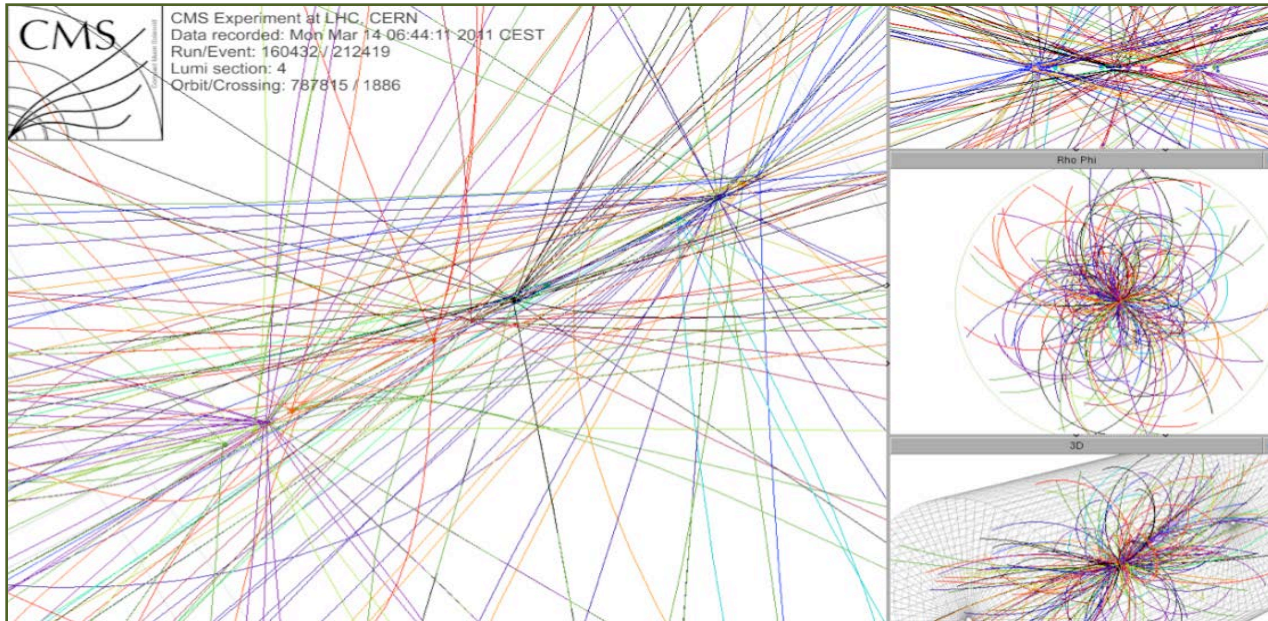
… the first 5 min

Brief history of collisions at LHC

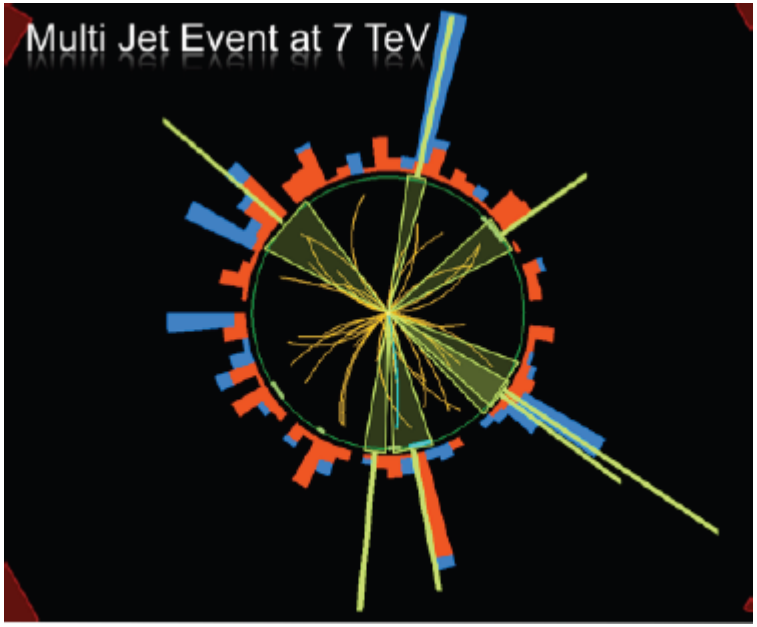
- Protons circulated in maiden LHC tunnel on August 2008
- Accident occurs soon → implications on our spending
- LHC operation restarted after machine consolidation in September 2009
- Collisions at 7 TeV from April 2010, lead ion collisions for several weeks
- Very good operation in 2011
- **LHC operation to continue in 2012.**

$$R = \sigma L$$

➔Very few interesting events corresponding to rare processes .

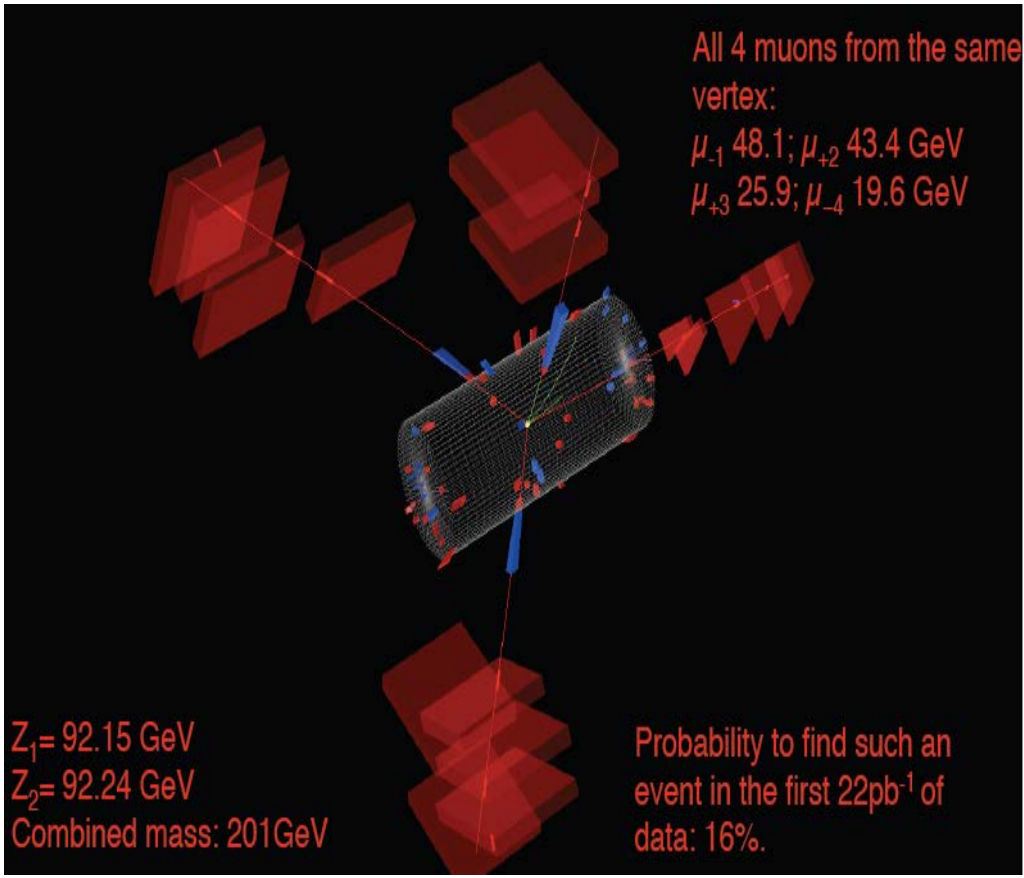


Multijet event in CMS detector



Mostly cause background in analyses.

First ZZ → 4μ event

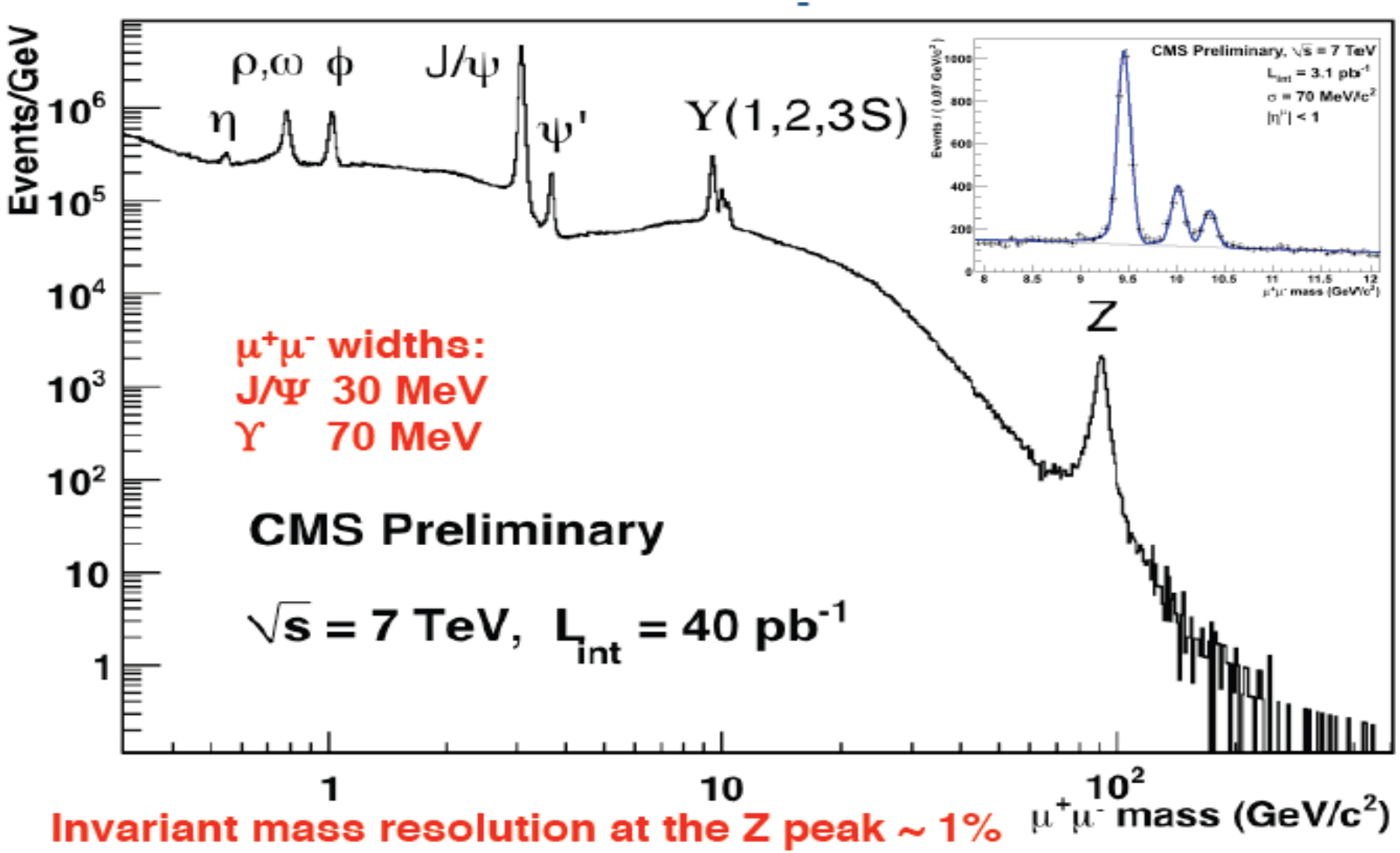


Background to search for Higgs in decay mode H → ZZ → 4μ

Data recording rate:	300 Hz
Electronics channel:	$8*10^7$
Data volume (2011):	several petabytes

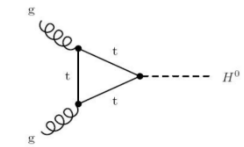
Nobel prize winning particle physics of last century

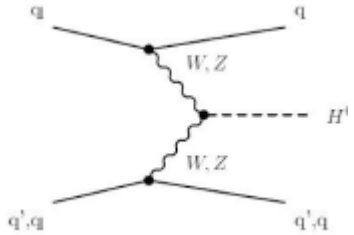
being utilized at LHC for detector calibration

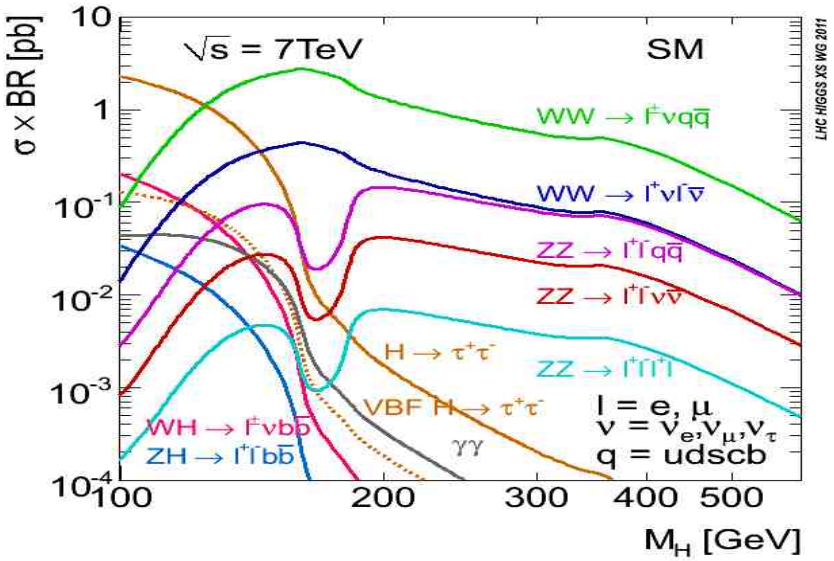


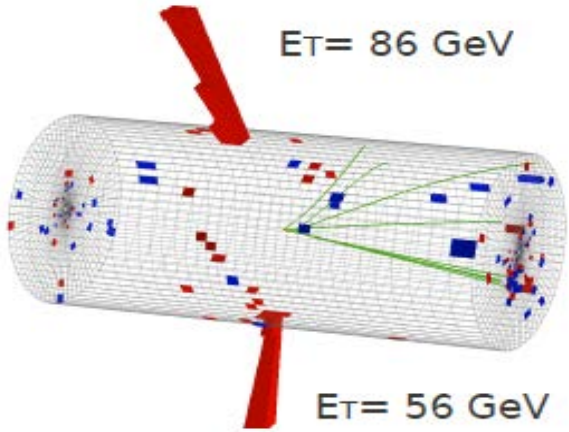
Invariant mass resolution at the Z peak ~ 1%

Most important physics harvest from LHC









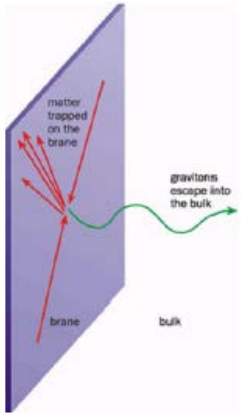
Higgs production/total interaction:10^{-9}

Search for standard model Higgs boson exclusion as of January 2012: 127 -600 GeV/c^2

- excess at ~125 GeV
- need more data to conclude about existence of Higgs boson
- absence of Higgs will also be a discovery!

2012: L = 3.5- 3.7 X 10^{33} /cm^2/s
Expect 10-15 fb^{-1} @ 8TeV

Black holes at LHC?



• If there are extra spatial dimensions in addition to usual 3, it is possible that gravitational force is being shared by all ➔ explains the weakness

• LHC could to allow particles to move between the normal 3D world and other dimensions, manifesting itself in the sudden disappearance of a particle.

•Or, LHC may produce with very, very small probability, a completely harmless Micro Quantum Black Hole!

➔In large extra dimensions Schwarzchild radius of proton increases from 10^{-33} to 10^{-17} cm.

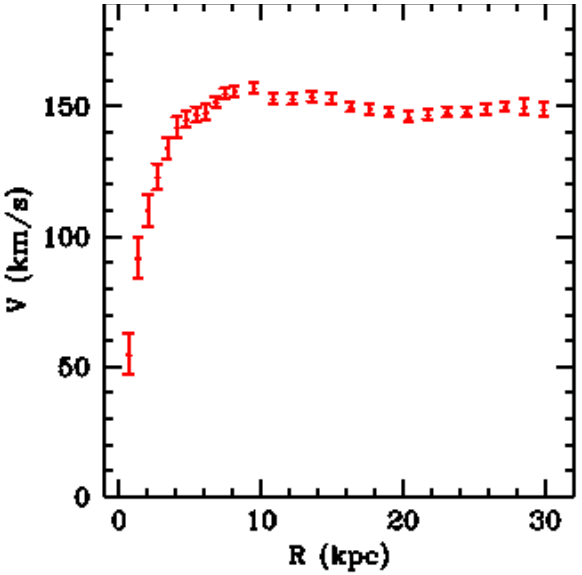
➔ If the impact parameter of two colliding protons is smaller than this distance, they coalesce into a micro blackhole .

➔ It evaporates, via Hawking radiation, within 10^{-25} s spewing out many particles isotropically in the detector.

Not yet observed in collision data!

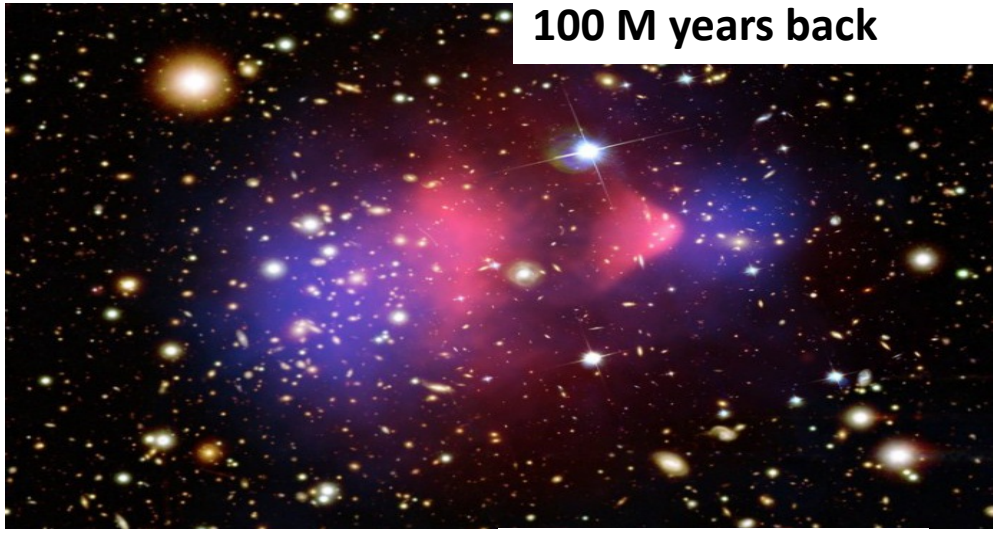
Seeing the dark

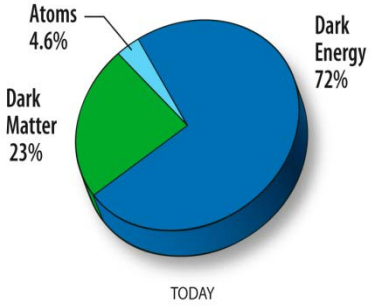
Rotation curve of a galaxy (1989)

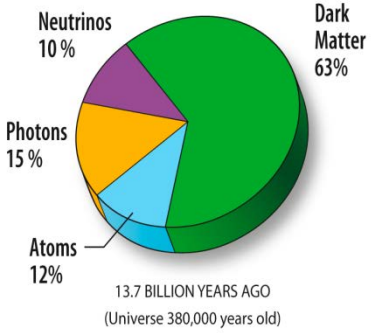


60 years to confirm via observation

Passage of 2 galaxies 100 M years back





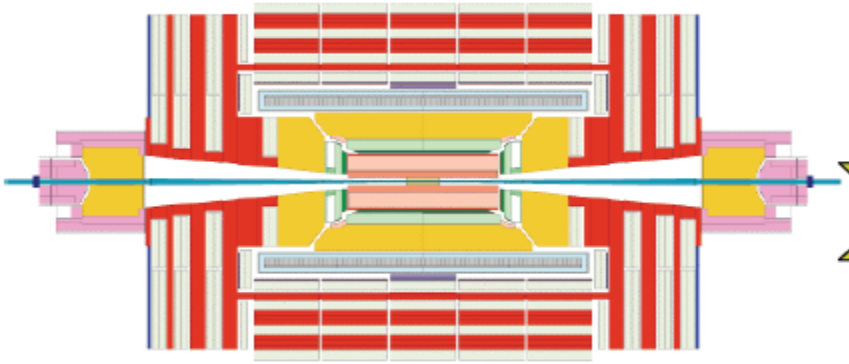


LHC can shed light on the nature of thedark matter

- Lightest SuperSymmetric particle is a very good candidate of the dark matter
- SUSY is the most favourite model for physics beyond Standard model.

LHC will discover SUSY if it is relevant at EWSB scale (rescues divergence of the physical mass of the Higgs boson)

Data rates @ CMS as foreseen for design parameters



Collision Rate: ~ 40 MHz

~ 60 TB/sec

Reduction with ASICs

Level 1

Trigger

~ 150 GB/sec

Event size: ~1.5 MB

High Level

Trigger

Software Data Reduction

(PC Farm)

~ 225 MB/sec

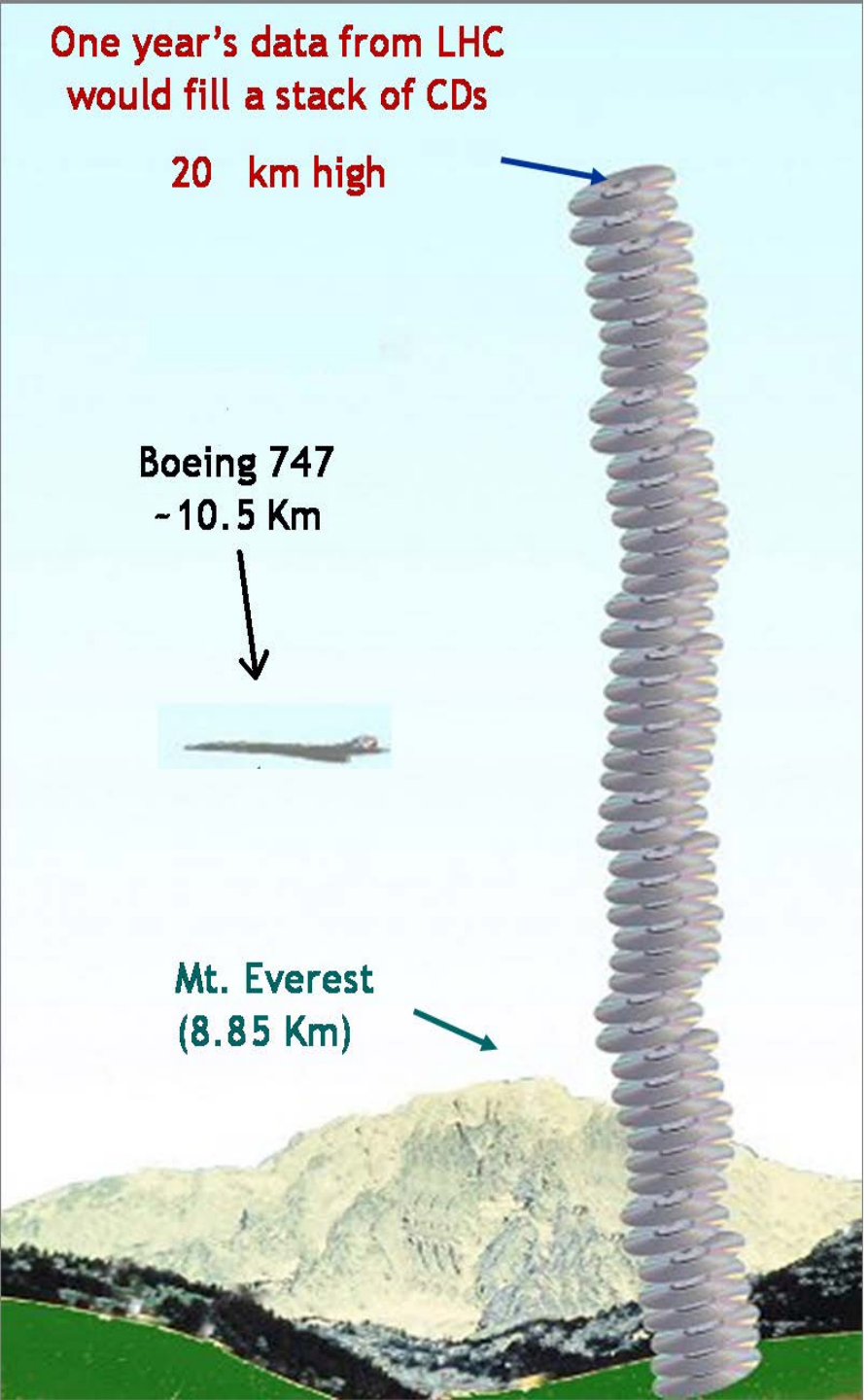
for Offline-

Analysis

Tape & HDD

Storage

Presently event size ~ 1MB (beam flux lower than design)
data collection rate ~ 300 Hz



In hard numbers

LHC will collide 6-8 hundred million proton-on-proton per second for several years.

Only 1 in 20 thousand collisions will have an important tale to tell, *but we do not know which one!*

➔ so we have to search through all of them!

➔ Huge task!

- **15 PBytes (10^{15} bytes) of data a year**
- **Analysis requires ~100,000 computers to get results in reasonable time.**

GRID computing is essential

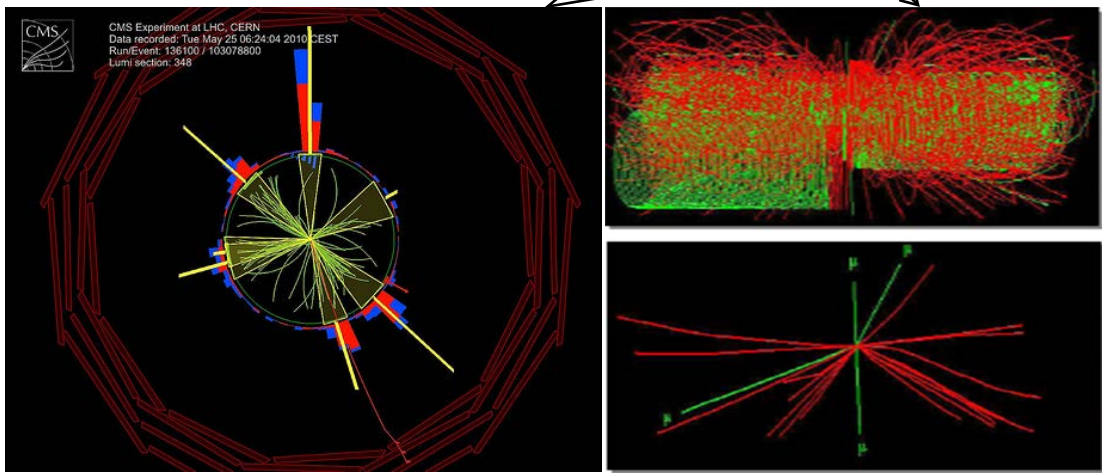
e-Science and e-Research

- Collaborative research that is made possible by sharing resources across the internet (data, computation, people's expertise...)
  - Crosses organisational , national and International boundaries
  - Often very compute intensive and/or data intensive
  - CERN-LHC project is an excellent example of all the above
  - HEP-LHC has been a driving force for GRID technology
  - Worldwide LHC Computing GRID (WLCG) is a natural evolution of internet technology

WWW was born in CERN to satisfy the needs of previous generation HEP experiments.

The GRID Computing Goal

- Science without borders
- Provide Resources and Services to store/serve O(10) PB data/year
- Provide access to all interesting physics events to O(4000) collaborators



- Minimize constraints due to user localisation and resource variety
- Decentralize control and costs of computing infrastructure
- Share resources with other LHC experiments

➔ Solution through Worldwide LHC Computing GRID
➔ Delivery of physics should be fast
➔ Workhorse for production data handling

- Today >140 sites
- ~250k CPU cores
- ~100 PB disk

From Web to Grid Computing

1. Share more than information

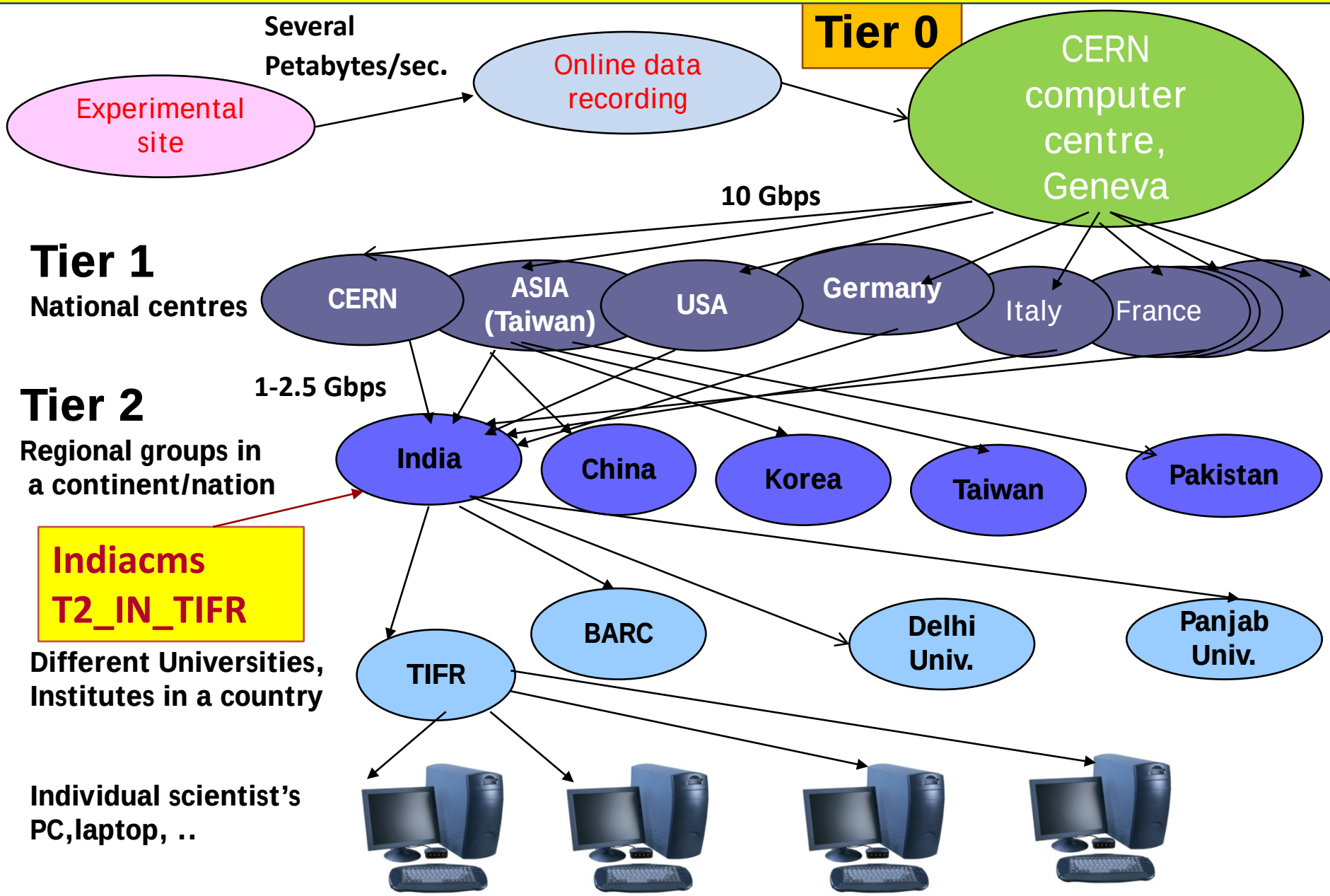
Data, computing power, applications in dynamic, multi-institutional, virtual organizations (Ian Foster: Anatomy of Grid)

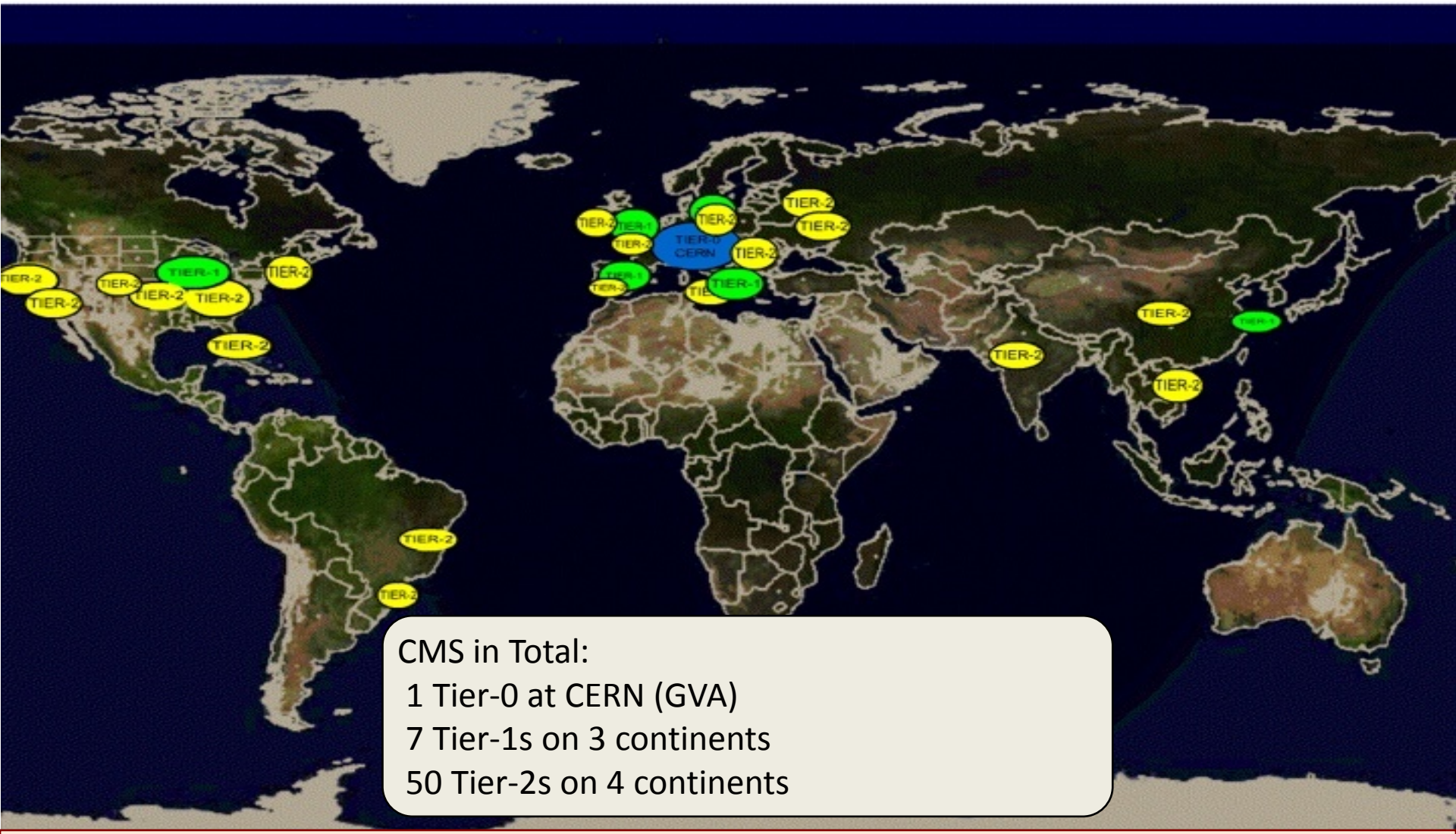
2. Efficient use of resources at many institutes. People from many institutions working to solve a common problem (virtual organisation).

3. Join local communities.

4. Interactions with the underneath layers must be transparent and seemless to the user.

Layered Structure of CMS GRID → connecting computers across globe





CMS in Total:
1 Tier-0 at CERN (GVA)
7 Tier-1s on 3 continents
50 Tier-2s on 4 continents

CMS T2 in India : one of the 5 in Asia-Pacific region

Today : 6 collaborating institutes in CMS , ~ 50 scientists +students

Contributing to computing resource of CMS

Comparatively large hardware resources with high speed connectivity

Conclusion

Today, the LHC is attracting immense attention, it is possibly THE most watched science project → CERN is in the spotlight.

The journey of thousand miles have already started though what awaits at the end is not known.

- Fascinating science, the curiosity provides the sustenance over time
- Addresses long standing questions of mankind
- Forefront technologies in accelerator, detector, computing
- Sociological experiment

LHC is poised to tackle some of the most profound questions very soon.

Stay Tuned!

Backup

Unknowns in Today's High Energy Physics

- Explanation of mass of elementary particles.
- Existence of new particles, novel interactions?
- What is the structure of space-time?
- Nature of *dark* matter filling most of the universe.
- Cause of tiny difference in the amount of matter and antimatter in the present universe.

⇒ issues to be addressed at LHC!

Primary Motivation of research: curiosity

- Results of Research:
  - Fundamental Research ↔ Applied Research
  - Knowledge / Know-how ↔ Application / Use
  - Culture ↔ Technology
- Primary aim of fundamental research KNOWLEDGE
- → also leads to applications: from applications in the research itself
- AND applications from the tools and methods
- Primary aim of applied research – APPLICATIONS
- Fundamental and applied research are inseparably connected

Fundamental research

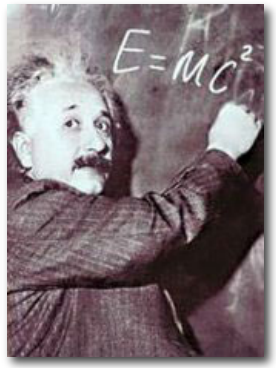
Is innovation: Needs innovation → Drives innovation requires competence, openness, training and education

Innovations at LHC: accelerators, detector, computing

Large-scale Science Projects - Summary

- address fundamental science questions
- stimulate general interest
- fascinate and inspire
- stimulate fantasy
- increase knowledge
- educate
- train scientists and engineers for tomorrow
- drive innovation and technology
- are global by nature
- need international collaboration and understanding
- need giving and sharing

Unusal Funs in HEP



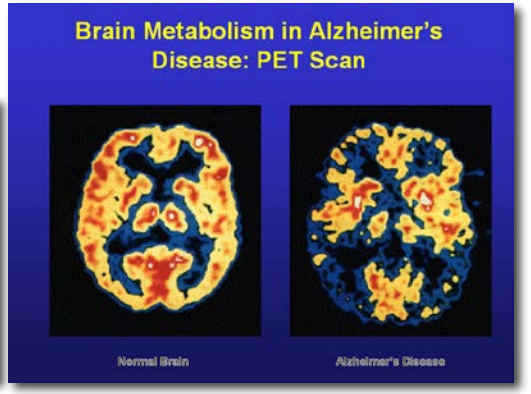
- Push back the frontiers of knowledge

  E.g. the secrets of the Big Bang …what was matter like within the first moments of the Universe's existence?

- Develop new technologies for accelerators and detectors

  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy

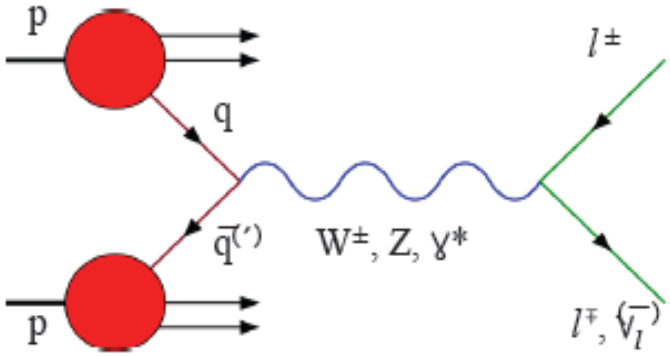


- Train scientists and engineers of tomorrow

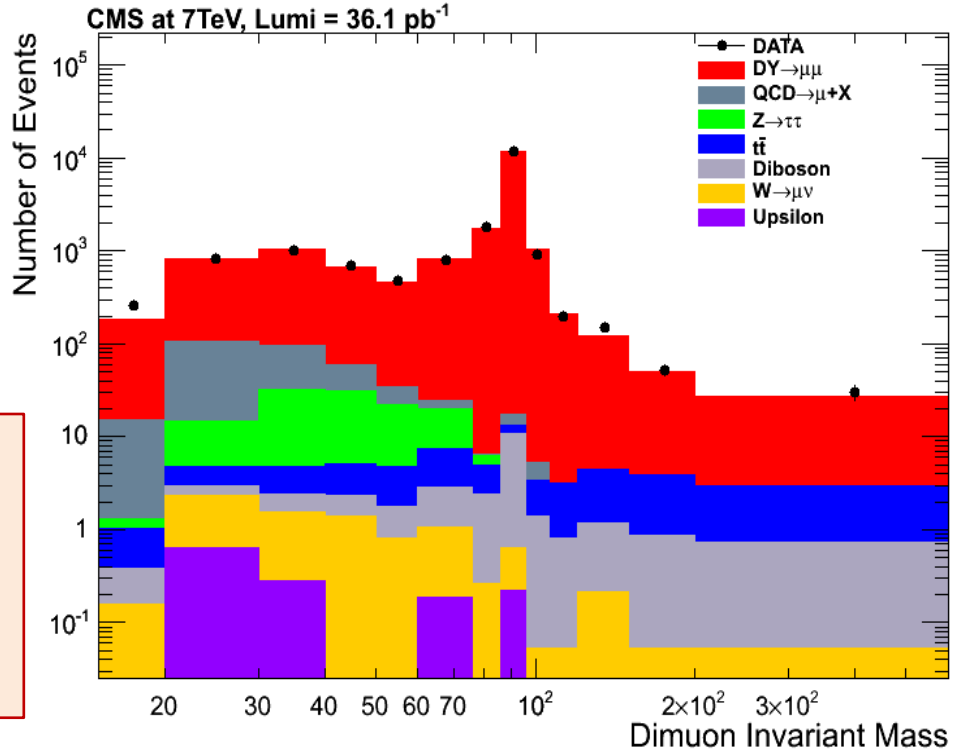
- Unite people from different countries and cultures: science without frontiers.

Simplest example of physics analyses: Drell-Yan process

- Standard Model benchmark process, not spoilt by QCD!
- Background process to Higgs boson and New Physics searches



- Look for events with 2 muons
- Make invariance mass.
- The spectrum indicates existence of resonance



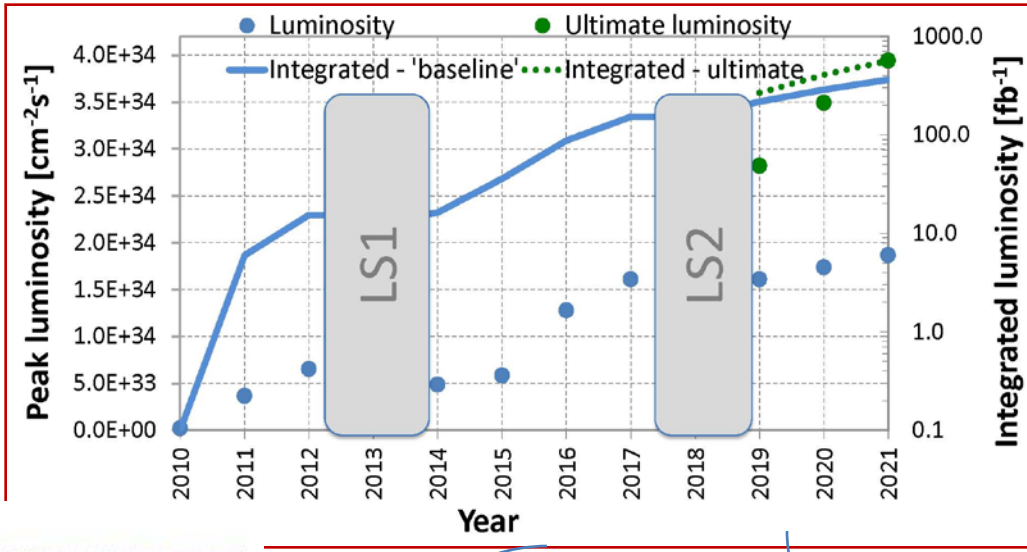
Large rate of production of vector bosons have been utilized for validation of standard model at LHC as a preparation for discovery.

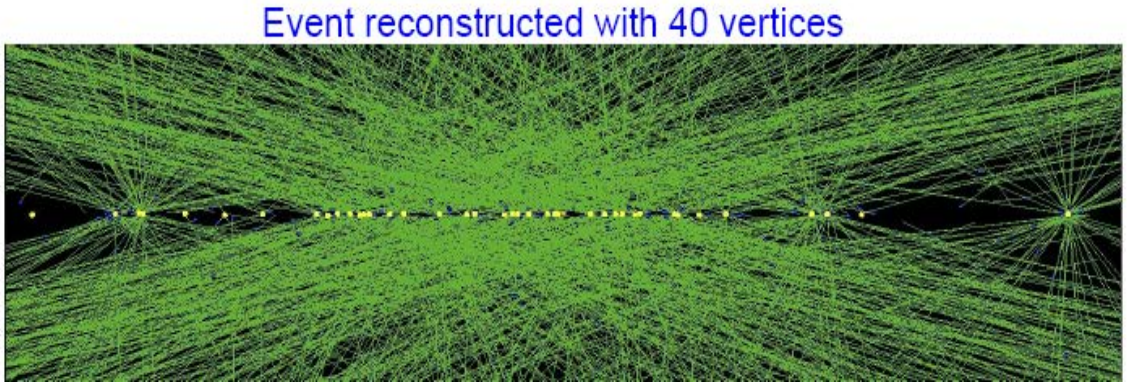
➔ cross-sections to be measured well since they are backgrounds to searches

Near future

Upgradation of LHC experiments connected with evolving timeline of LHC machine ➔ continue proton collisions in 2013 if needed.

➔ Funding profile need to be flexible





Pile up could be ~ 100

Upgradation of CMS detector needed for improvement in physics capabilities

→ measurement of Higgs coupling after discovery

→ measurement of rare top decays with very good b-tagging

→measurement of exclusive processes of beyond standard model physics