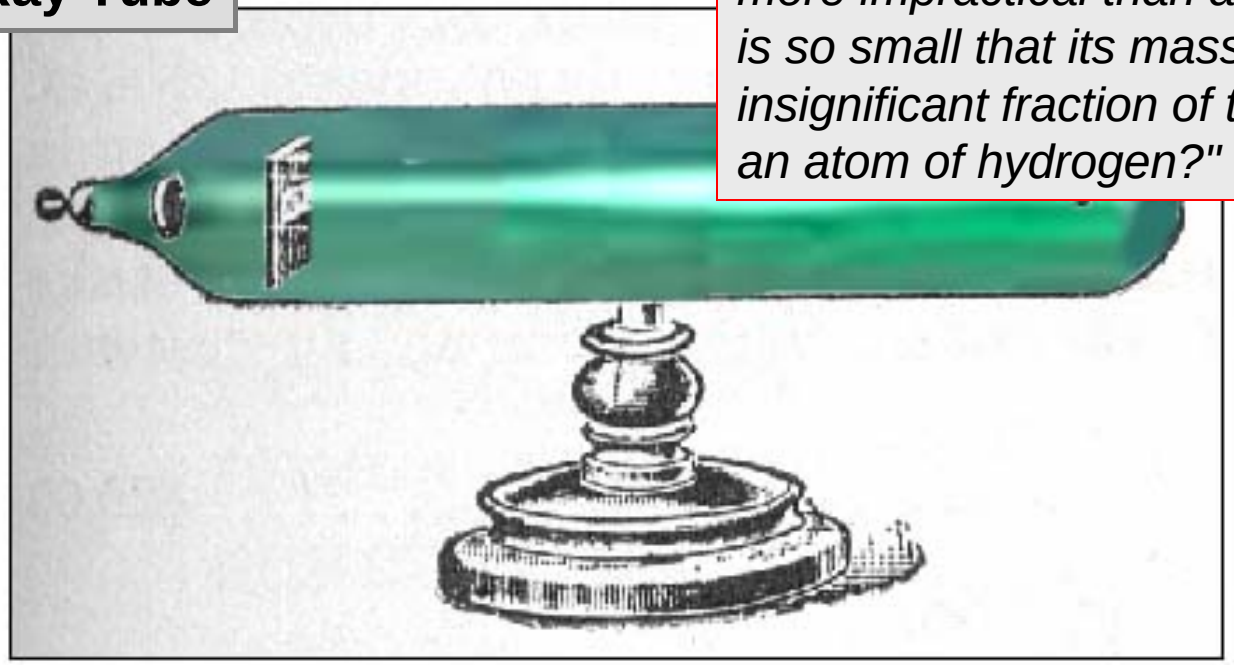
A Trip to the Beginning to the Universe with the Large Hadron Collider

Stefan Spanier
University of Tennessee, Knoxville

Experiments 111 years ago …

Cathode Ray Tube



"Could anything at first sight seem more impractical than a body which is so small that its mass is an insignificant fraction of the mass of an atom of hydrogen?"

J.J. Thompson: *Cathode rays are material constituents of atoms! bend in electric and magnetic field*

Nobel Prize 1906

➔ **electron** *fundamental building block of matter*

G.P. Thompson: *electrons have wave character*

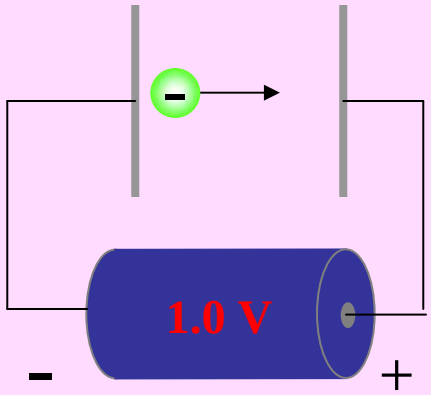
Nobel Prize 1937

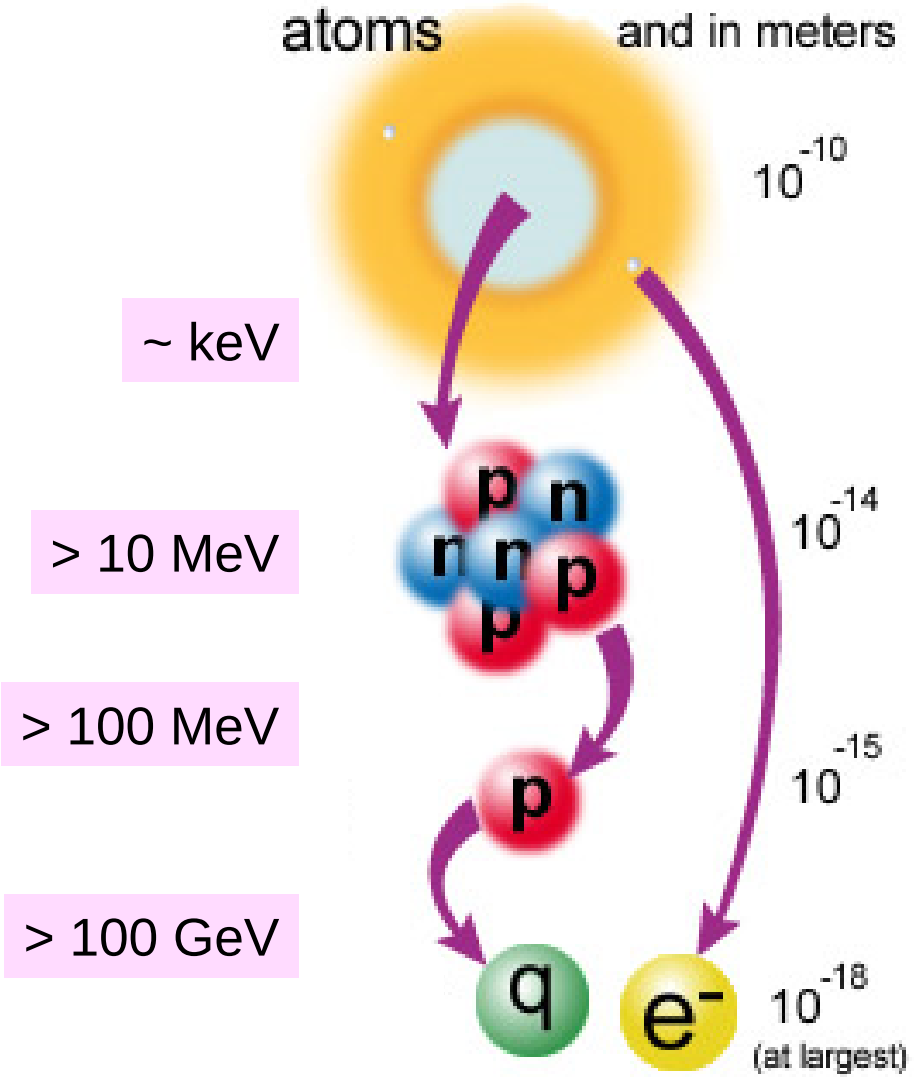
Particle Accelerator as Microscope

Length to be resolved L

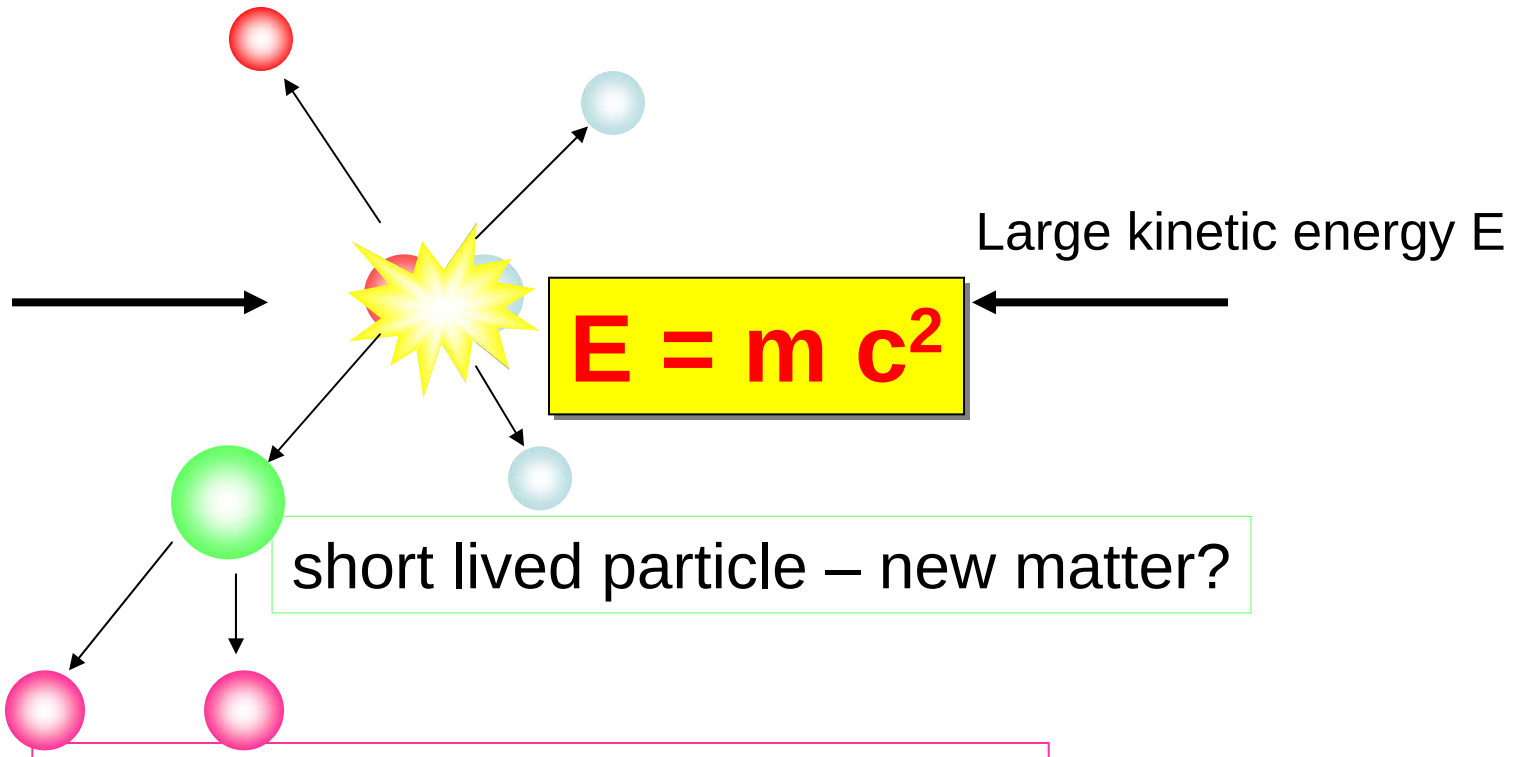
L $\propto$ 1/Particle Energy

1eV = kinetic energy an electron gains in a electric field of 1 Volt





Particle Collider Experiment



Particles live long enough to make signals in a detector (material)
- light
- new charges

The Higgs Field / Particle



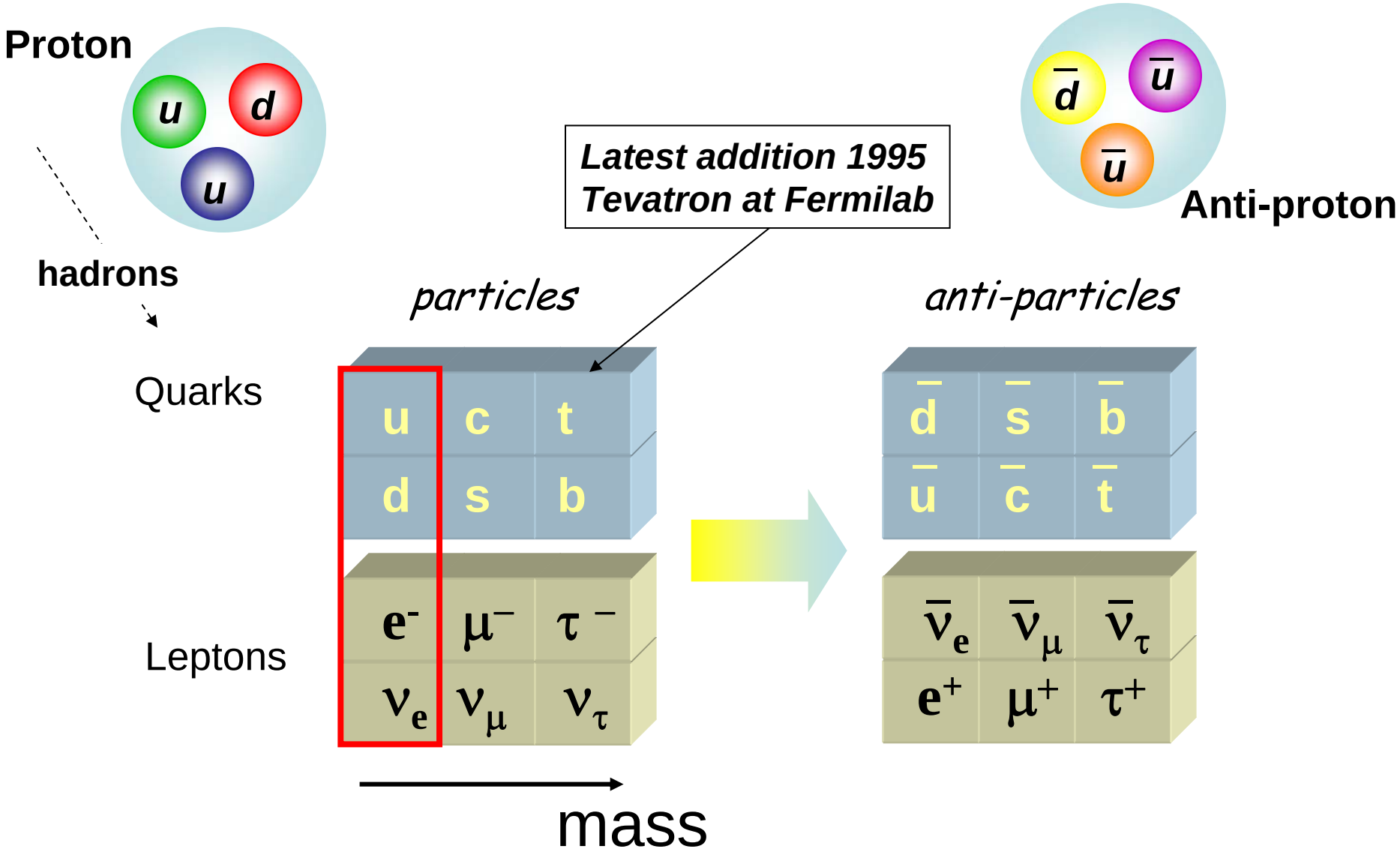
How particles acquire masses …


The Higgs particle mass generation

Expected mass: 100 GeV … 1 TeV

The Standard Model

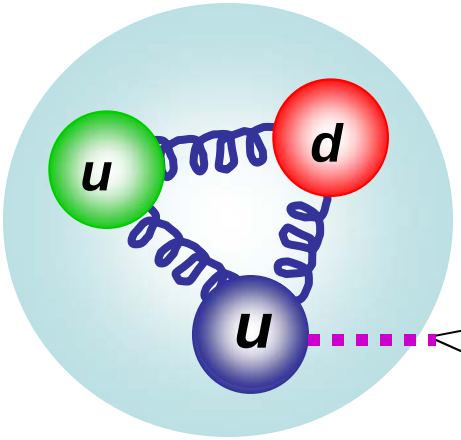
Building Blocks



Standard Model does not 'predict' any of the masses (parameters);
How do masses come about?

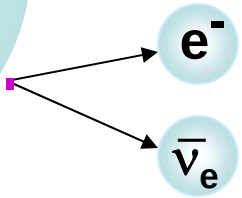
Fundamental Forces

Neutron → Proton



Photon binds electron in Hydrogen atom

Gluons bind quarks in hadrons

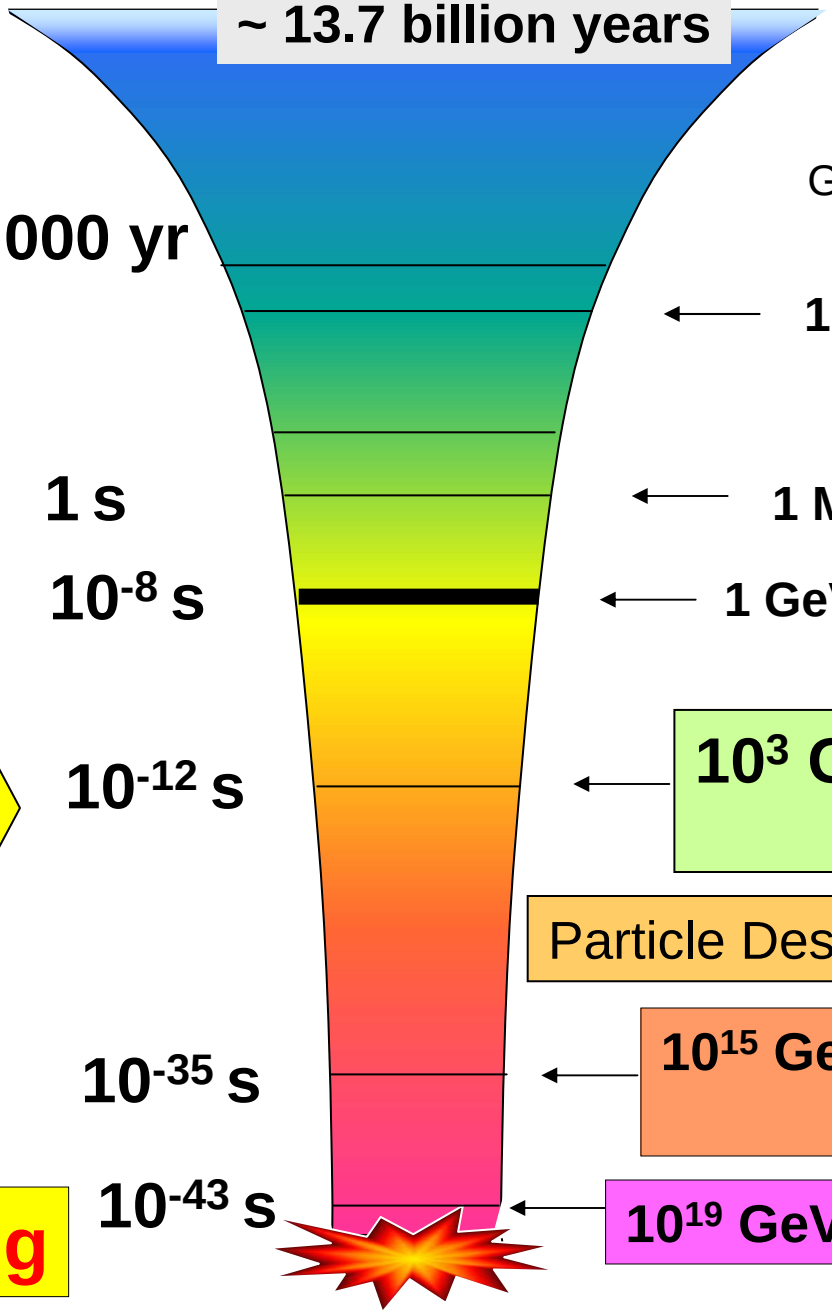


W^- transforms *d* to *u* quark

Force	relative strength	mediators	
Strong	1 → 0.12	gluons	
Electromagnetic	1/137 → 1/128	photons	Unify in Standard Model
Weak	10^{-6}	W^+, W^-, Z^0	
Gravity	10^{-39}	graviton	Least understood

- Electromagnetic and weak force unify in Standard Model – 'Symmetry breaks' at about 1 TeV: How? → Higgs mechanism
- Do all forces unify at some energy?

Evolution of the Universe Theory



~ 13.7 billion years

1 meV Today (T= -270ºC)

Solar system

Galaxy formation

400,000 yr

1 eV Matter domination

onset of gravitational instability

1 s

1 MeV Nucleosynthesis (D, He, Li)

10^{-8} s

1 GeV Quark → Hadron

protons, neutrons form

LHC

10^{-12} s

10^{3} GeV **Electroweak Symmetry Breaks**

Particle Desert: Supersymmetric particles ?

10^{-35} s

10^{15} GeV Unification of electroweak and strong force

Big Bang

10^{-43} s

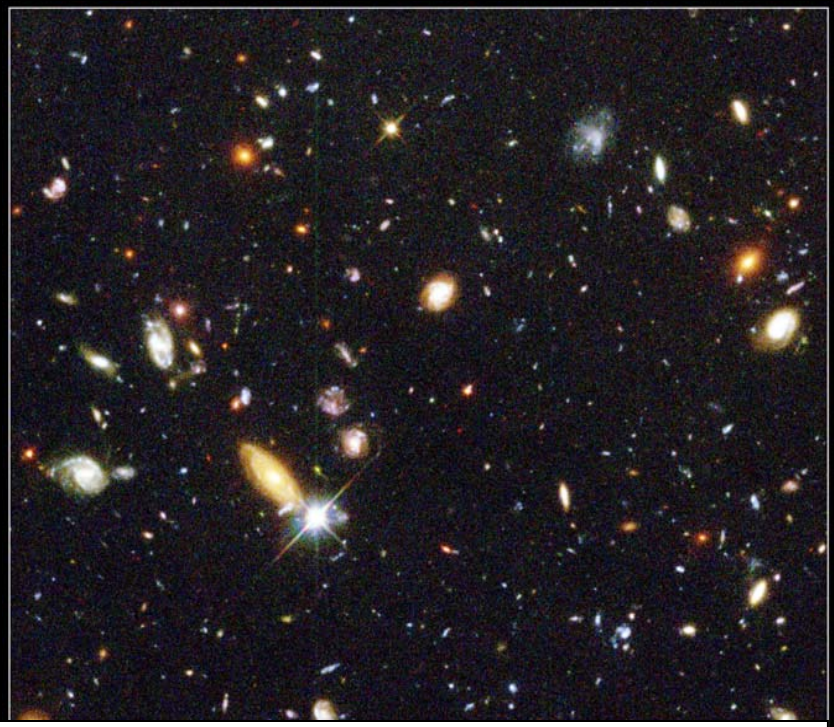
10^{19} GeV *Planck Epoch*

(T~10^{32} ºC)

The Cosmic Connection

Furthermore …

- What is dark matter?
- What is dark energy?
- Where did the anti-matter go (CP Violation)

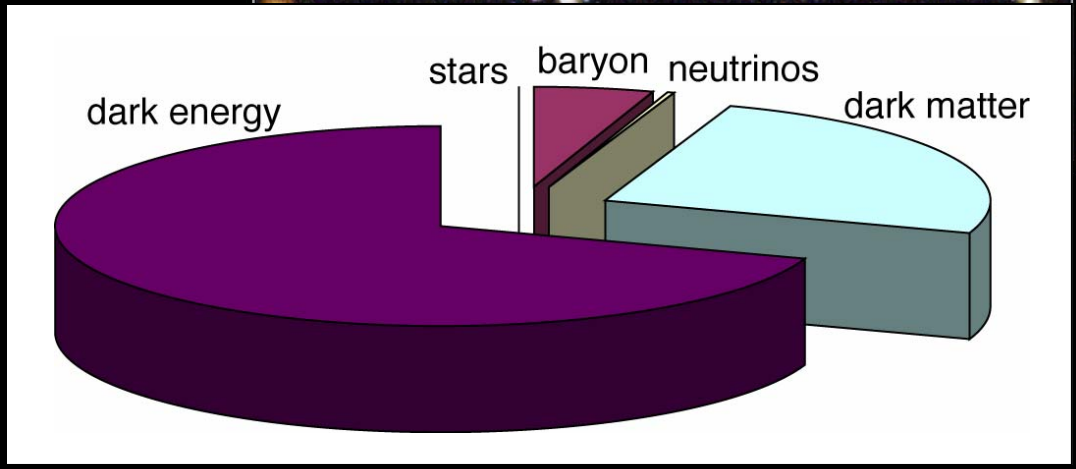


Neutrinos are ~0.1–10%

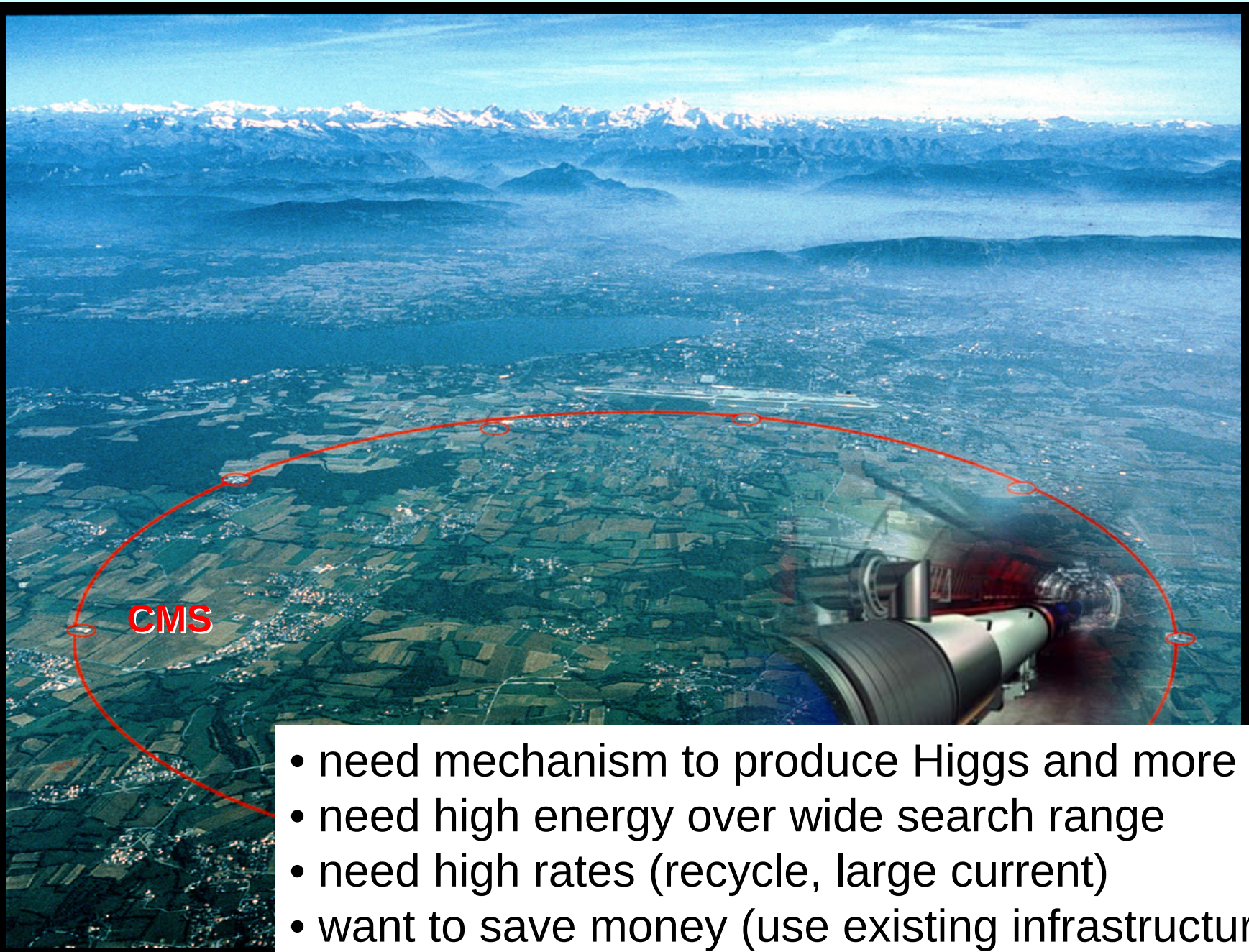
Electrons and protons are ~5%

Dark Matter ~25%

Dark Energy ~70%

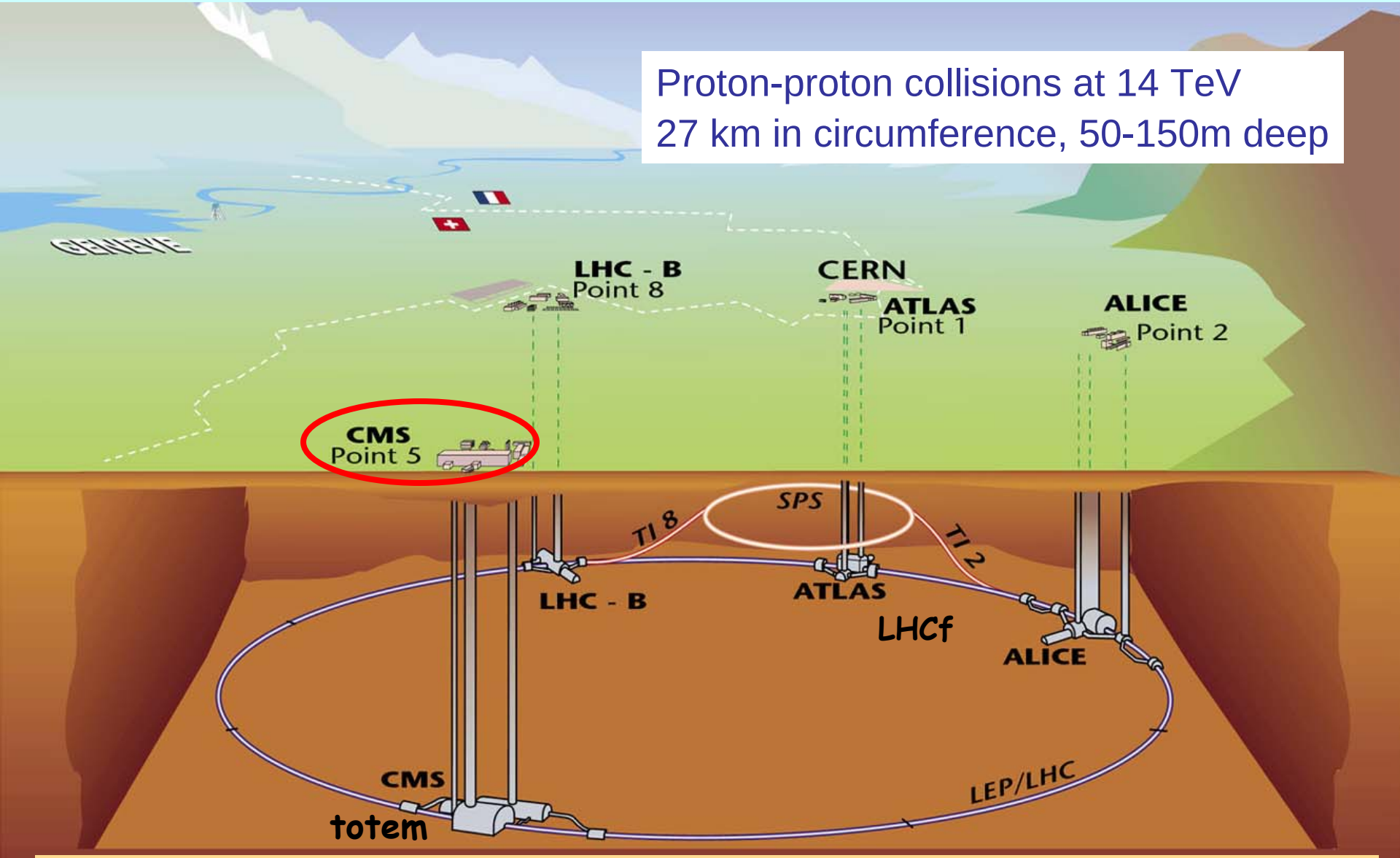


The Large Hadron Collider at CERN in Geneva, CH



- need mechanism to produce Higgs and more
- need high energy over wide search range
- need high rates (recycle, large current)
- want to save money (use existing infrastructure)

The LHC Machine and Experiments



- High Energy — factor 7 increase w.r.t. present accelerators
- High Intensity — (# events/reaction/time) ⇒ factor 100 increase

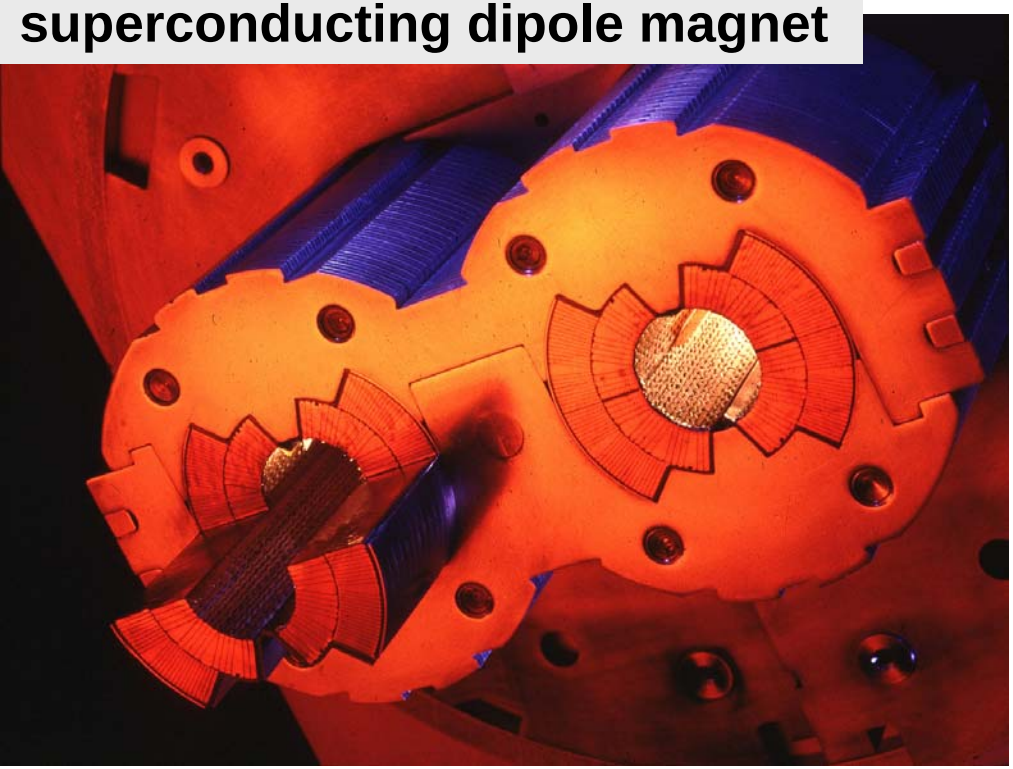
LHC

Superconducting magnets:

- 1232 dipole magnets (bending)
  - T = -271°C (superfluid Helium)
  - 100,000 x earth magnetic field
- 386 quadrupole magnets (focus)
- Thousands of correcting magnets

LHC in LEP tunnel

superconducting dipole magnet



Each beam

- 2808 bunches of protons
- ~100 billion protons/bunch
- Circulation time: 89 μs
- Current: 0.584 Ampere
- Time between collisions: 25 ns

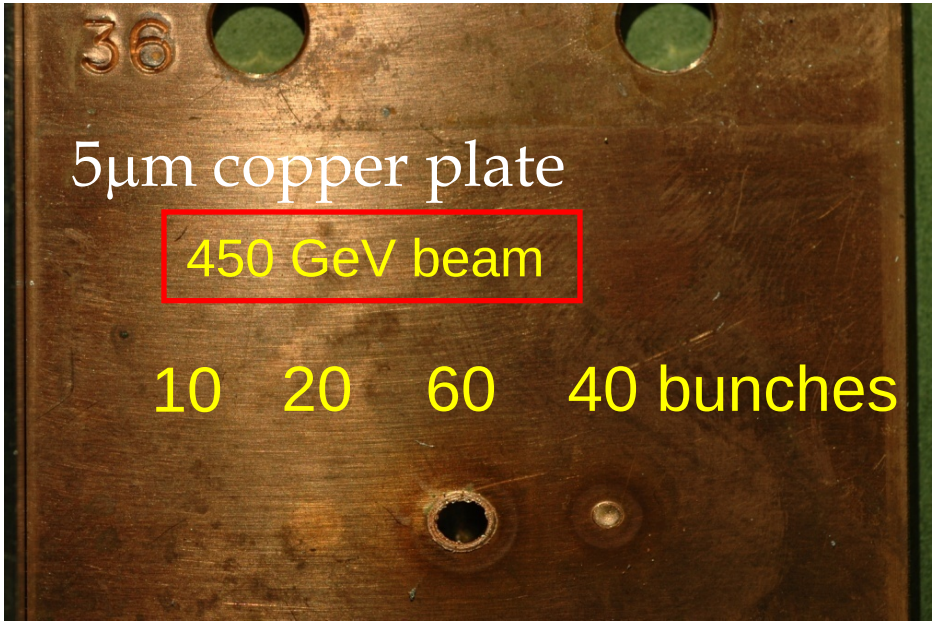
- Fill time (450 GeV): 7.5 min
- Acceleration time : 20 min
- Beam lifetime : ~15 hours

Beam Accidents

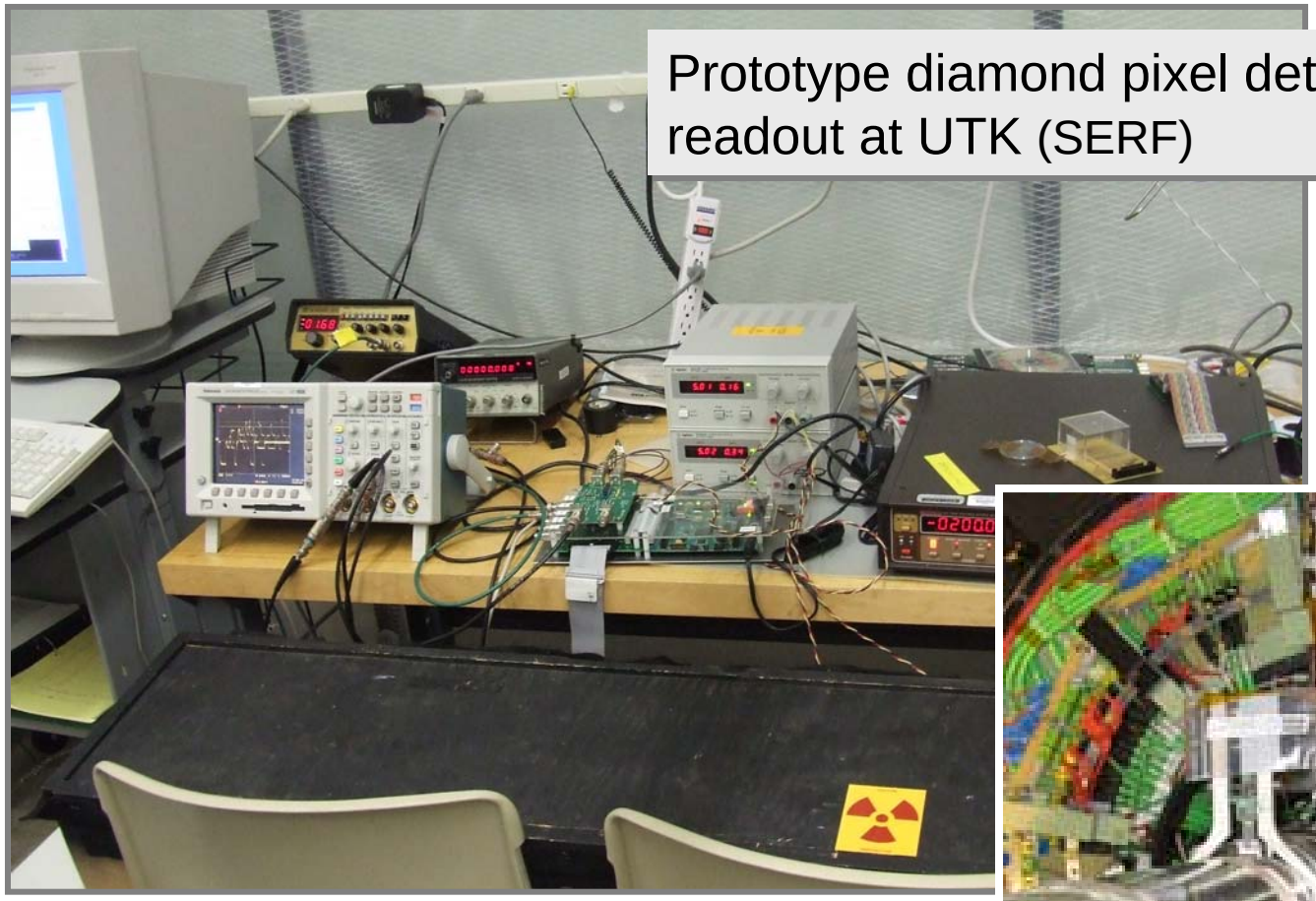
Energy stored/beam: 360 MJ
Energy stored in magnets: 700 GJ

- The energy per proton is equivalent to using ~70,000 Hiroshima bombs ('Little Boy') to accelerate a 22 caliber bullet.
- The energy stored in the beam is equivalent to a small aircraft carrier of mass 10,000 tons traveling at 20 miles/hour
- Dumping this energy over 1s can lighten up about 400 Million light bulbs

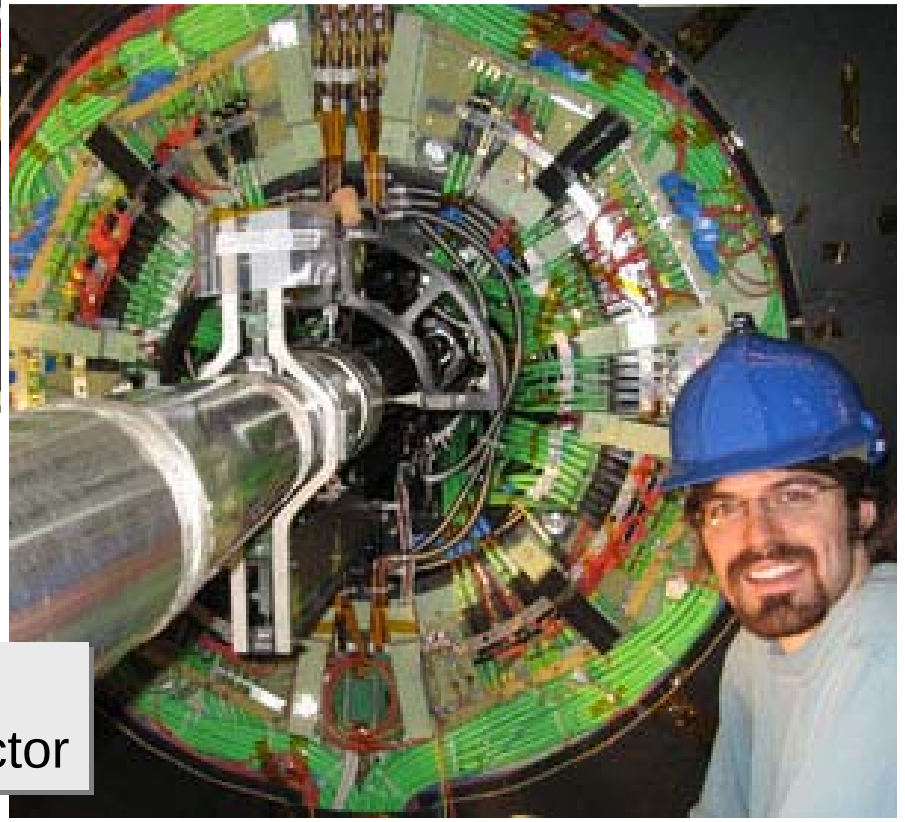
Beam loss is fatal:



Pixel Diamond Detector – New Technology



Prototype diamond pixel detector readout at UTK (SERF)

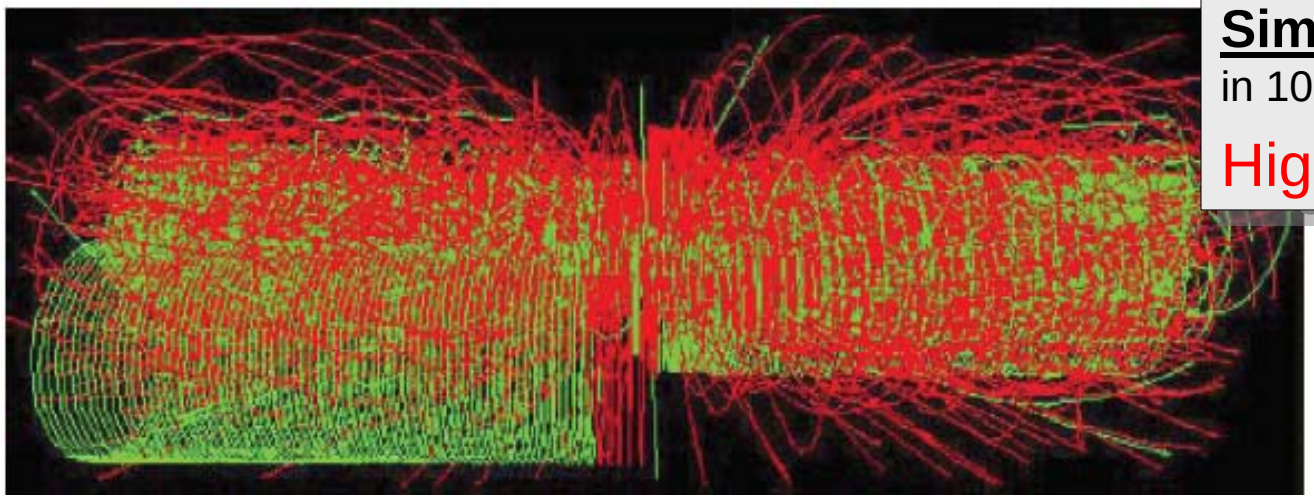


Installation of diamond detectors
Near the beam pipe in the CMS detector

How to detect the Higgs

Every 25ns protons in bunches collide

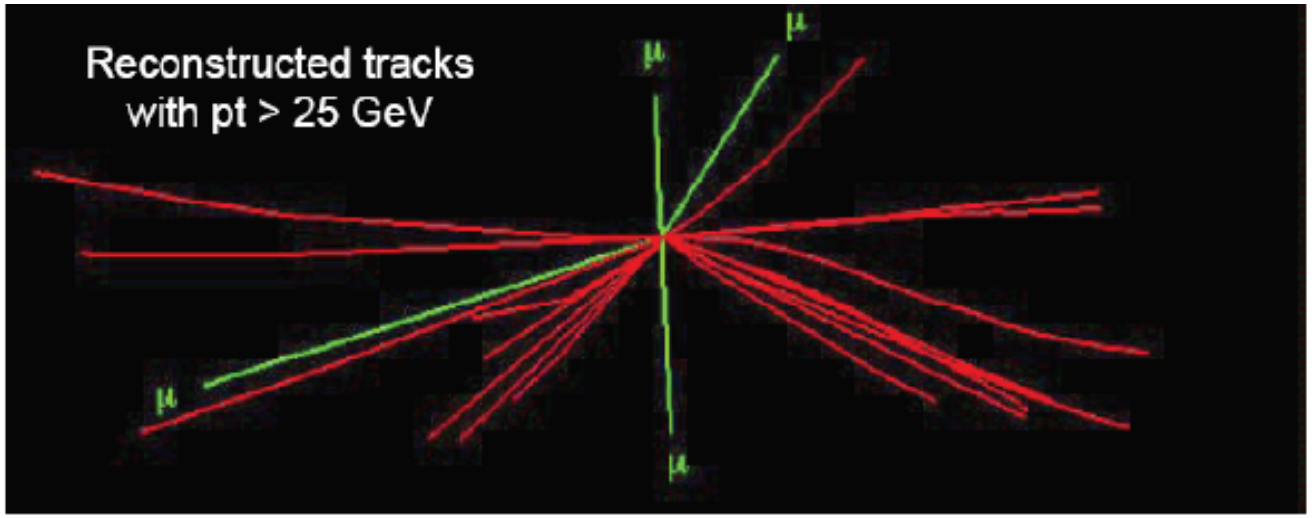
Interactions/crossing = 25 (~1000 charged particles)

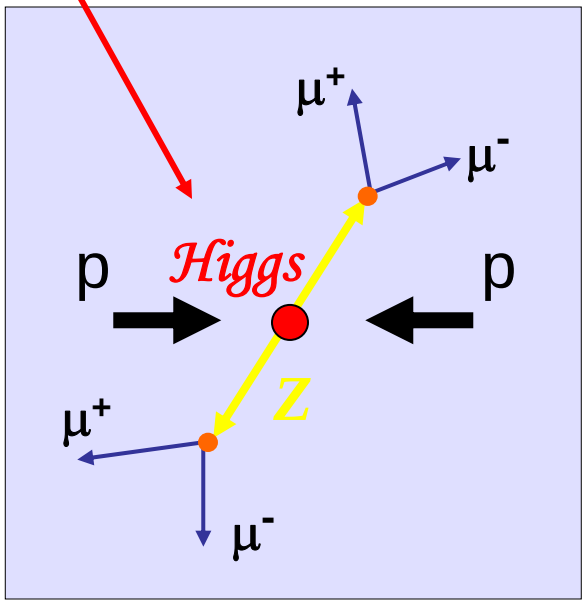


Simulation

in 100,000x earth magnetic field

Higgs + 25 other events



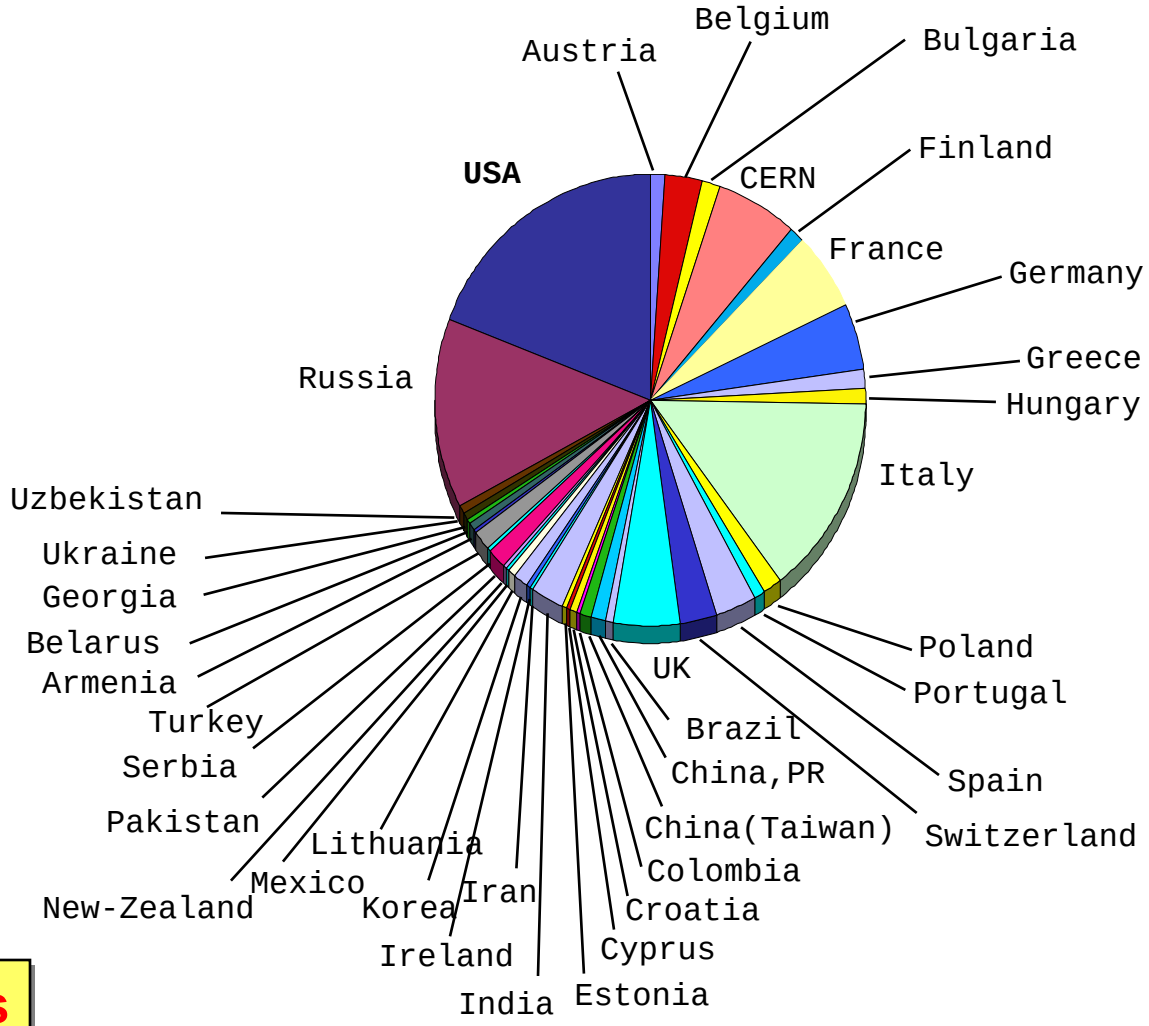


In CMS collision information corresponds to 100 billion phone calls per second.

The Compact Muon Solenoid (CMS) Collaboration

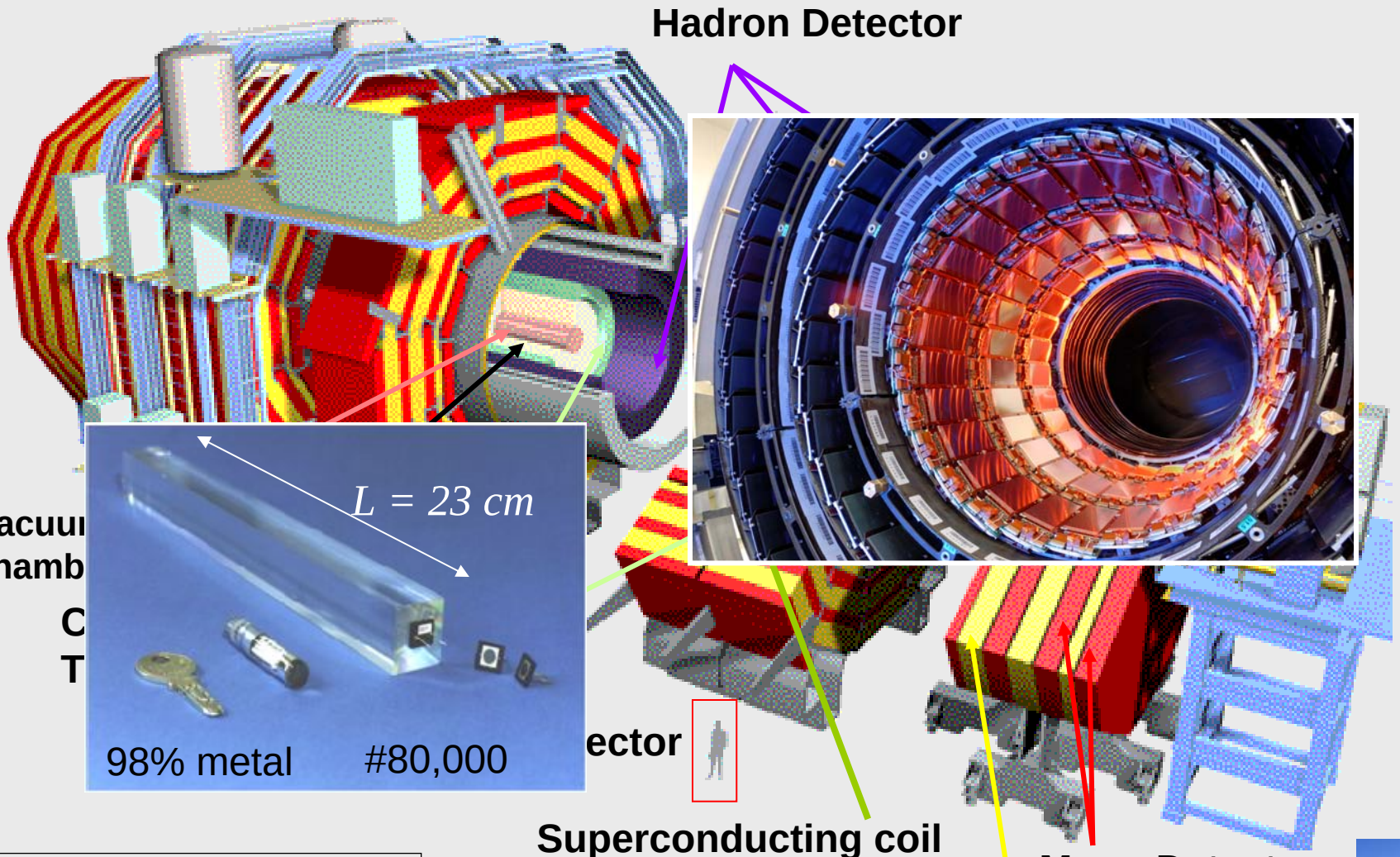
	Number of Laboratories
Member States	59
Non-Member States	67
USA	50
Total	176

	Number of Authors
Member States	1084
Non-Member States	503
USA	723
Total	2310



~2300 Scientific Authors
38 Countries
176 Institutions

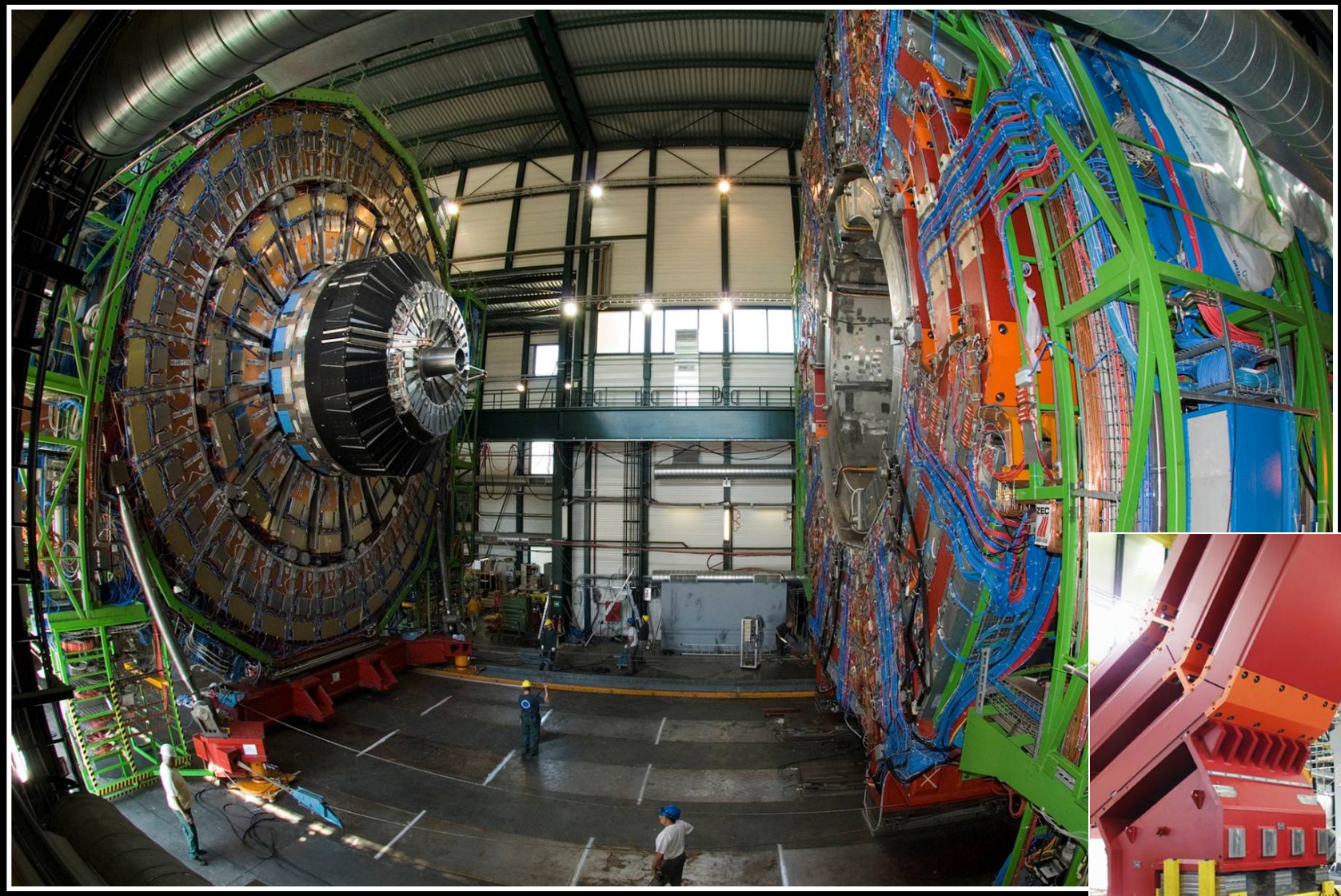
The CMS Detector

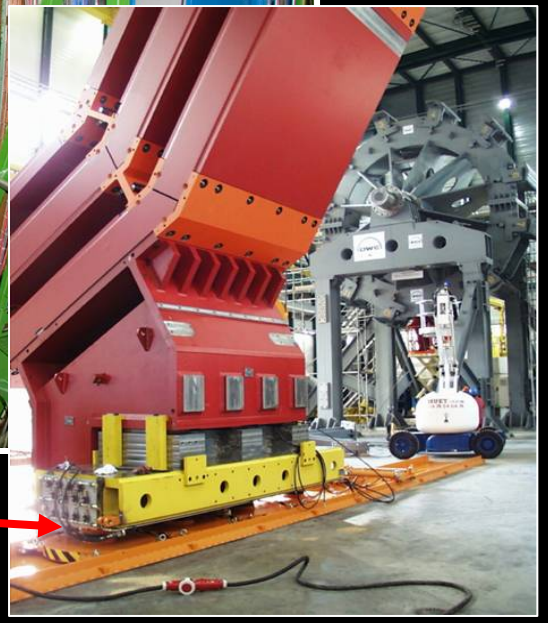


Width:	**22m**
Diameter:	**15m**
Weight:	**13,000 tons**

Weighs ~25% more than the Eiffel Tower in Paris

Pre-assembly above Ground



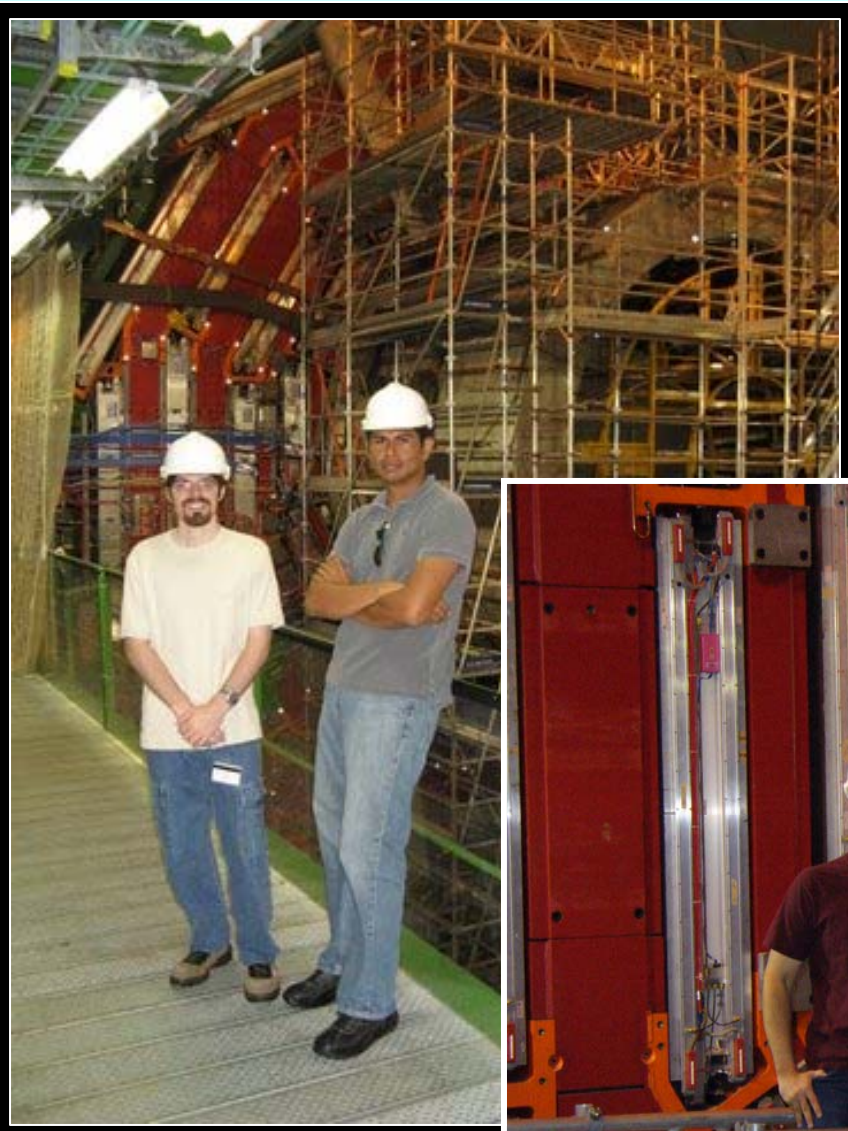


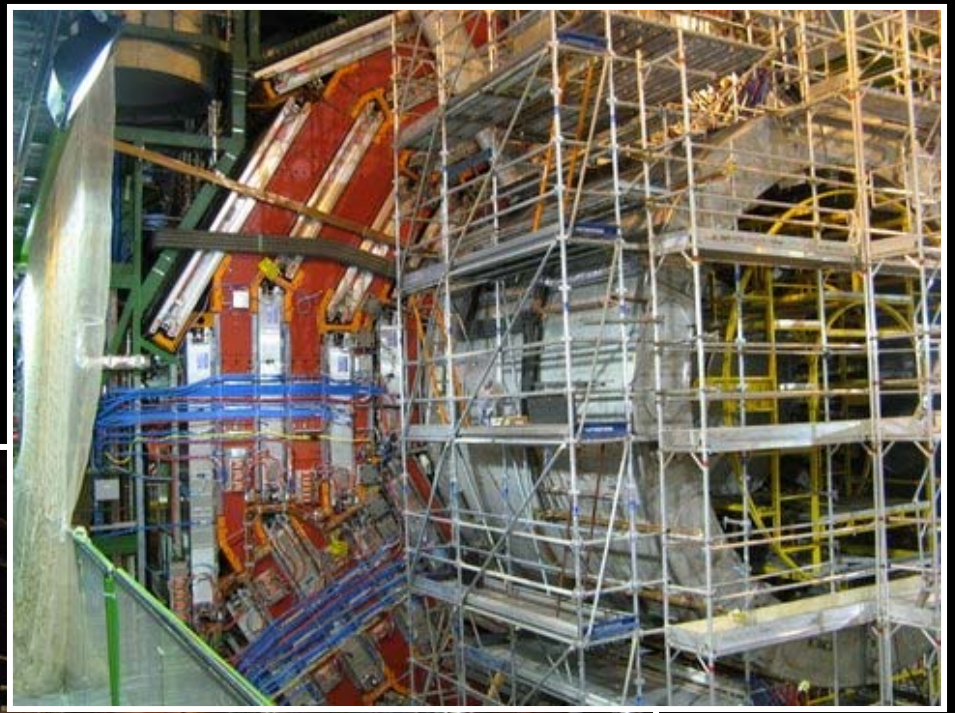
Air pads used to move the 11 CMS elements

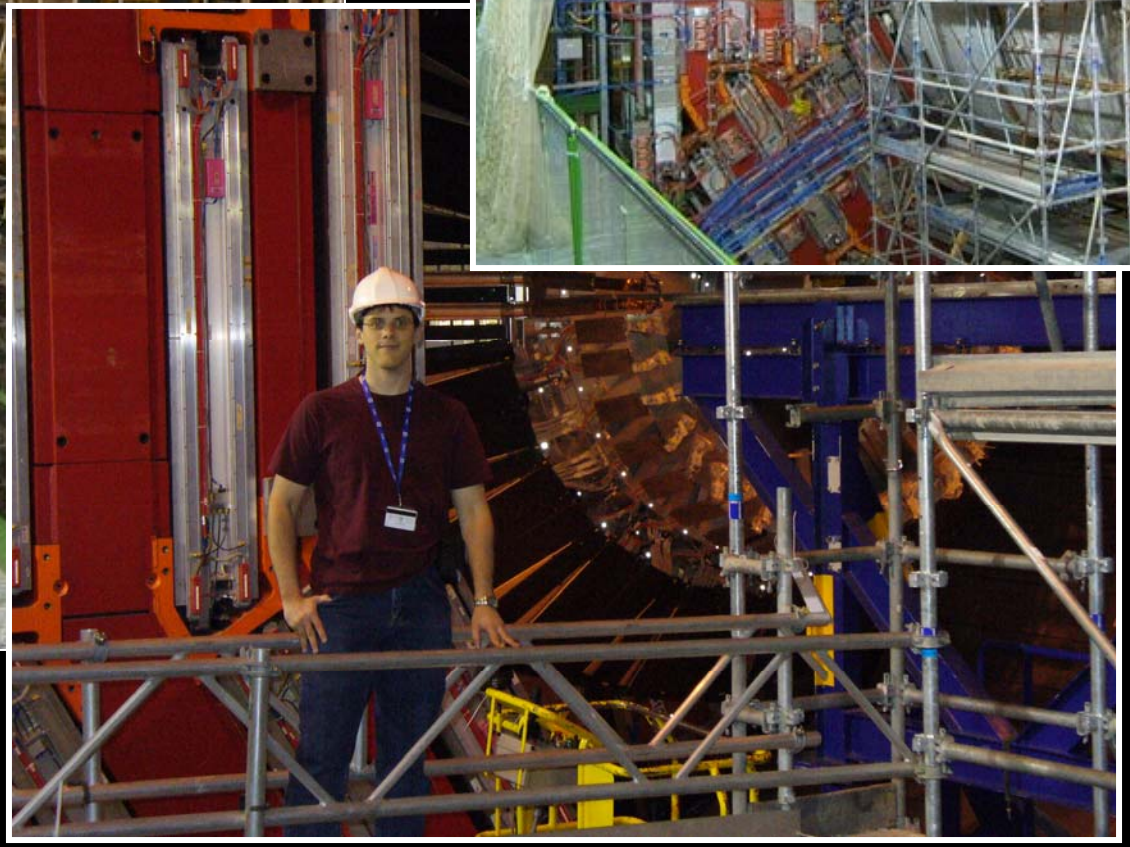
Lowering of Detector Modules

The first force studied carefully by CMS was Gravity …

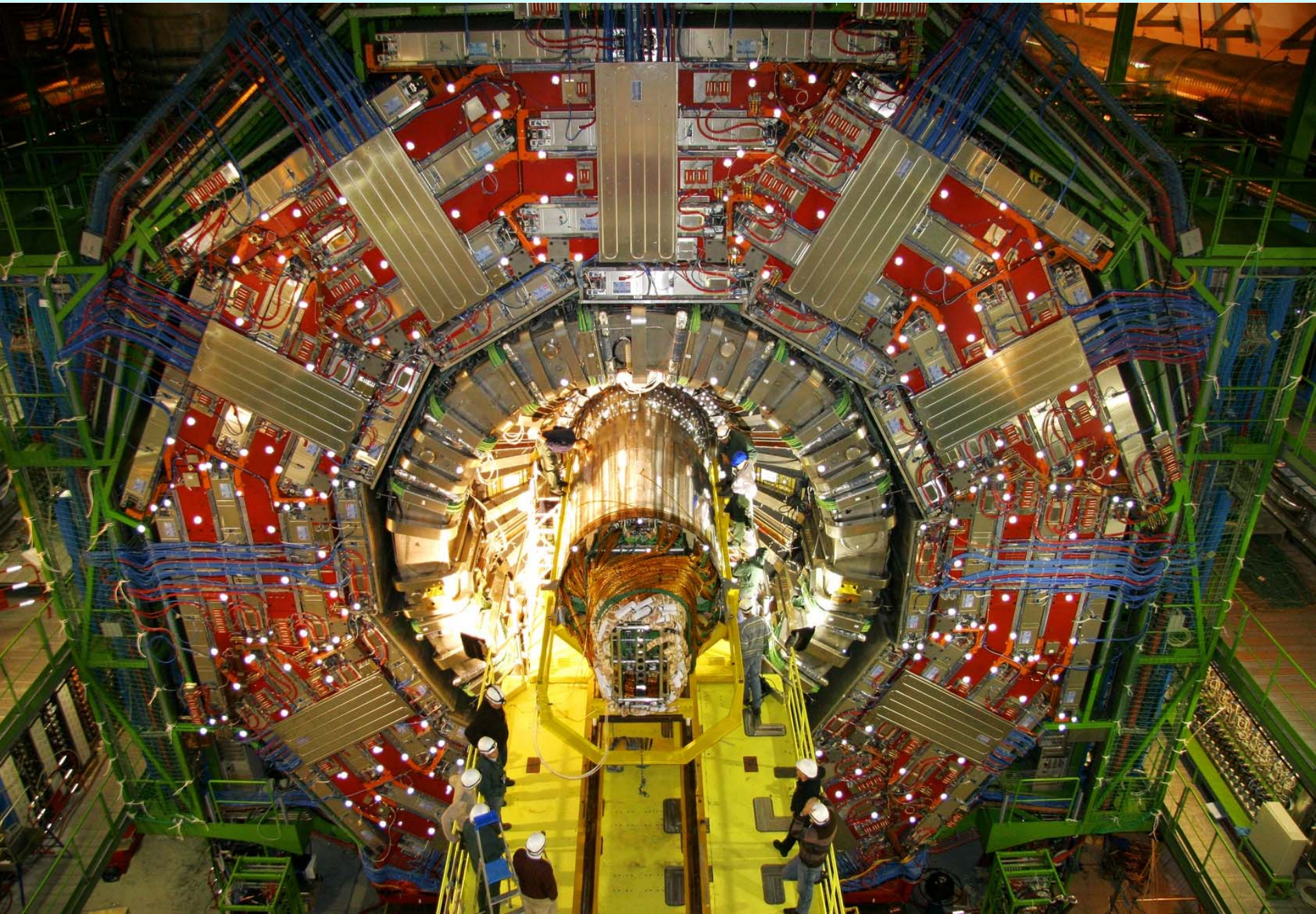
Students/Postdoc from UTK at CERN





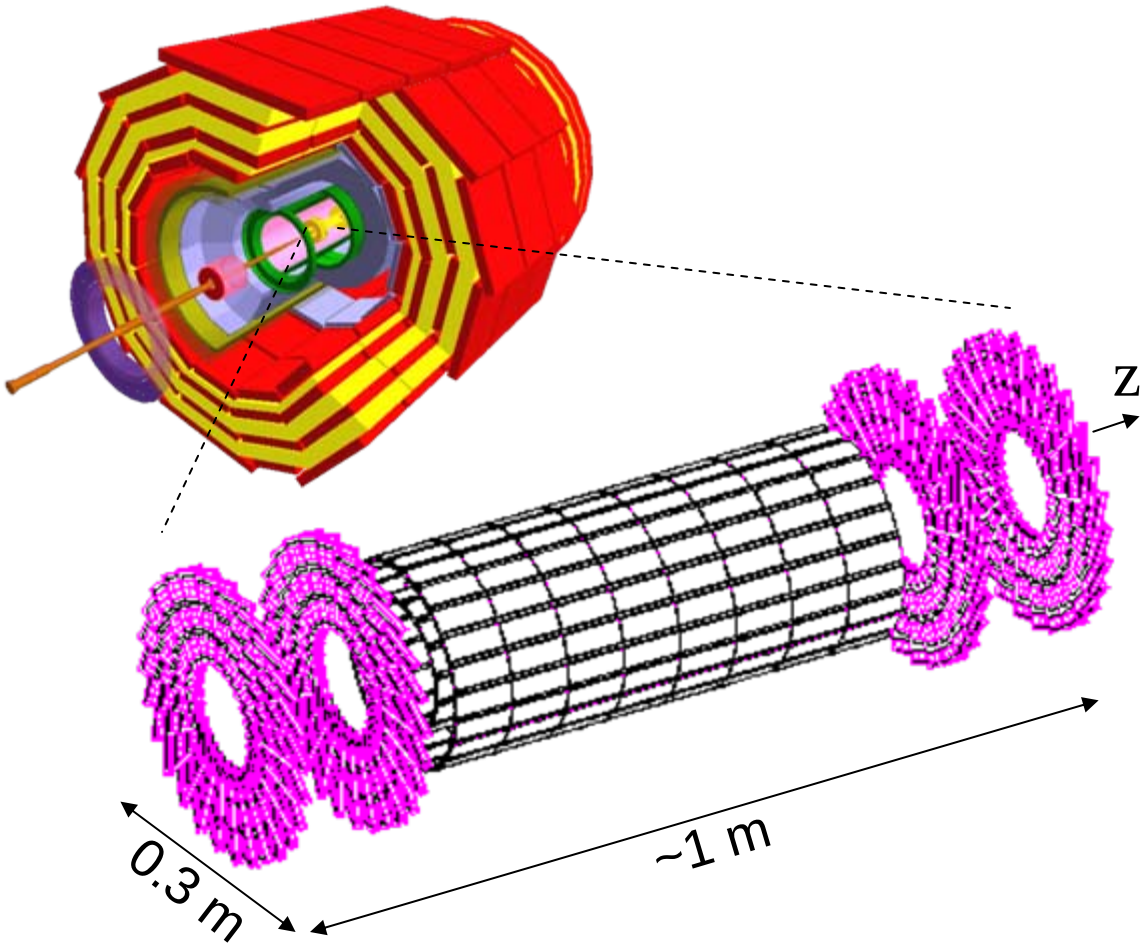


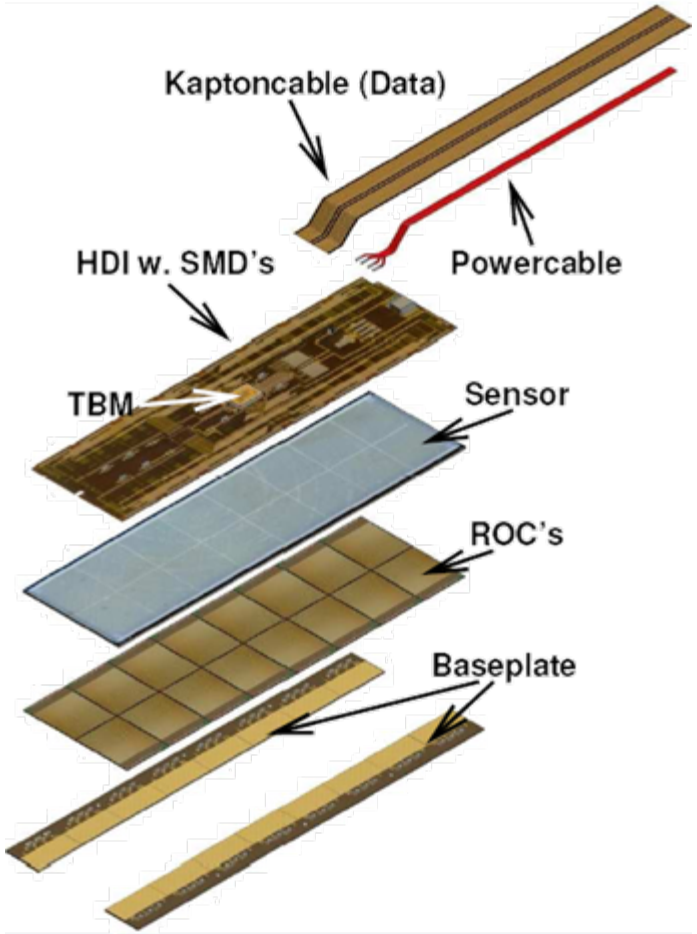
Insertion of Silicon Tracker Detectors



The Pixel Detector

- Barrel layers at radii = 4.3cm, 7.3cm and 10.2cm
- 2 Disks at +/- side
- Pixel cell size = 100x150 μm^2 → ~1m^2 of silicon / 66 Million pixels
- ~15k front-end chips





Computing

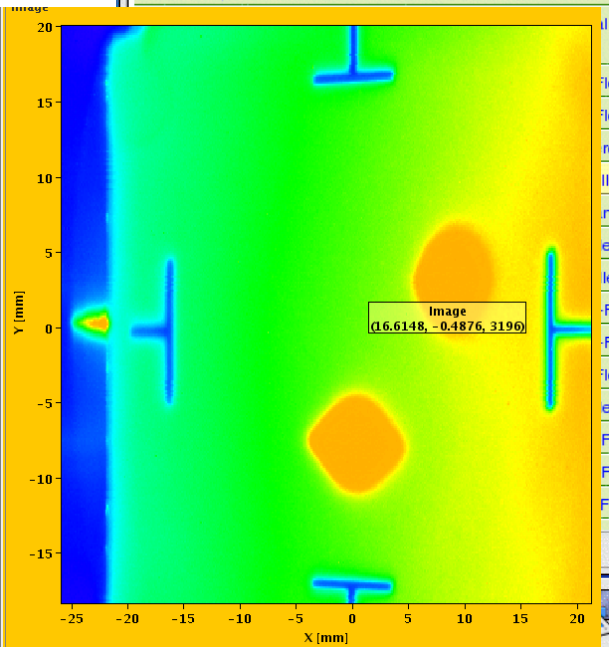
15 Million Gigabytes of data each year (about 20 million CDs!)

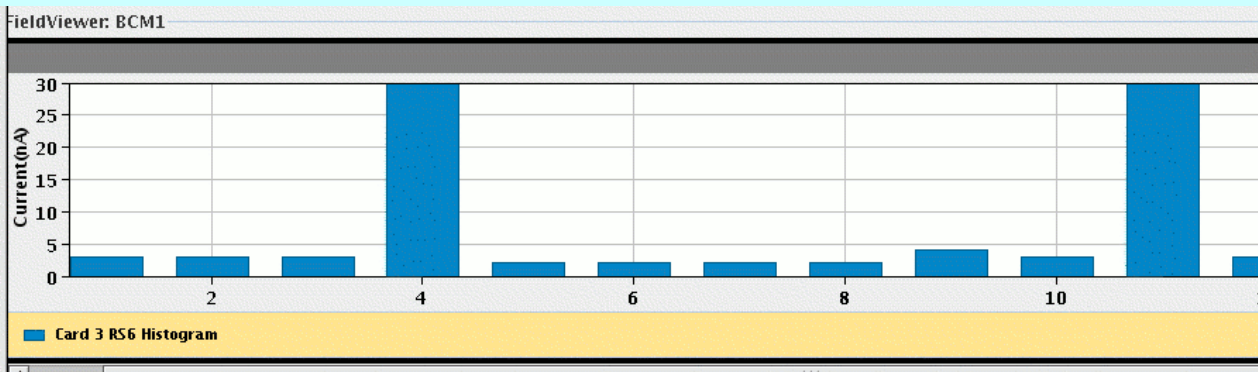
GRID Node at UTK

10 GBit/s connection; 250 processors + 50TByte storage

First Beam in LHC

9 September 2008





Tue Sep 9 21:59:05 2008, Steffen Mueller, Steffen.Mueller@cern.ch, BCM2_operation, Restart of BCM2
Tue Sep 9 21:55:42 2008, Steffen Mueller, Steffen.Mueller@cern.ch, Data Quality Management, BCM1L
Tue Sep 9 16:52:54 2008, Jose Lazo-Flores, Jose.Lazo-Flores@cern.ch, Displays, BPTX Screen configu
Tue Sep 9 16:36:49 2008, Jose Lazo-Flores, Jose.Lazo-Flores@cern.ch, Configuration, Channel connec
ll-wilton@cern.ch, BCM2_operation, BCM2 Rea
lores@cern.ch, DQM Interface, how to reach the
lores@cern.ch, Data Quality Management, BCM
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nd@cern.ch, Installation, Installation of BCM1L
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ler@cern.ch, Other, BCM2 operations: Zm turne
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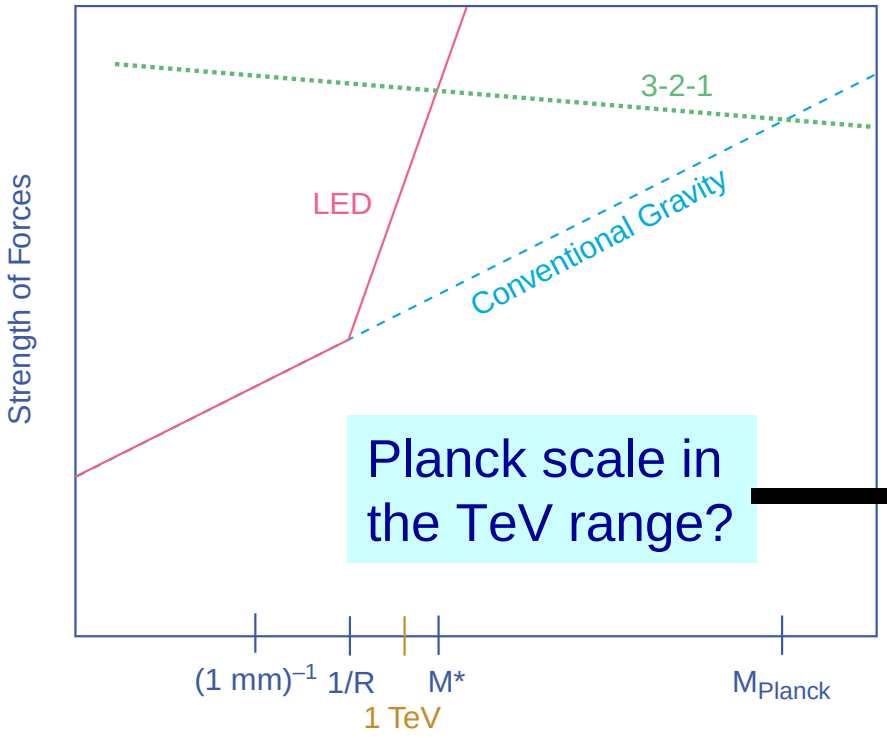
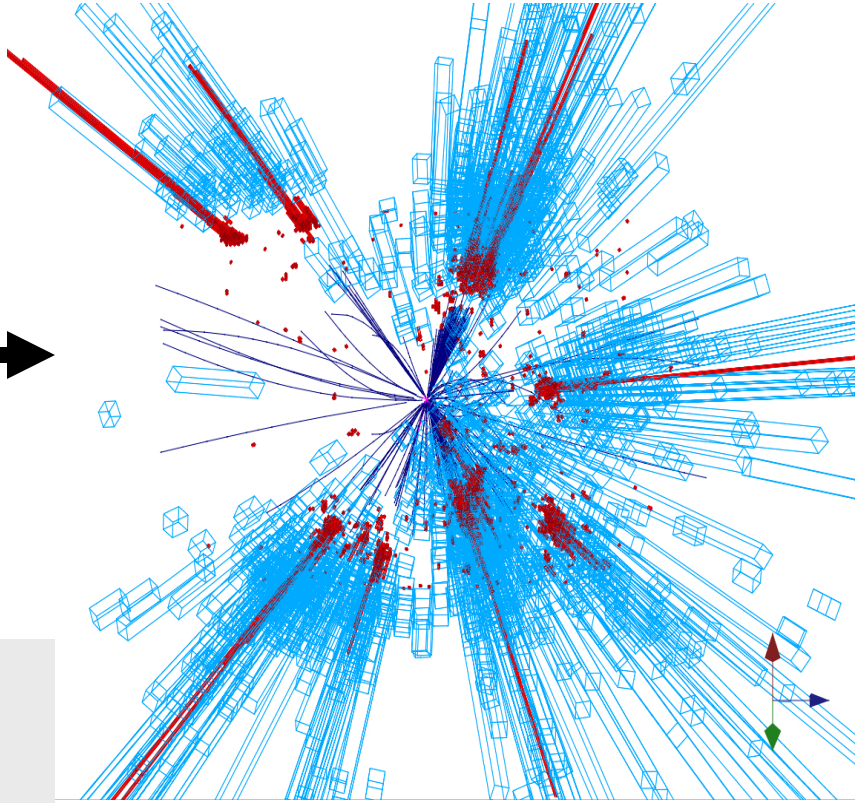
Flores@cern.ch, Installation, BRMBCMCTRL1

Black Hole Generation in LHC



Simulation of a black hole event with M_{BH} ~ 8 TeV in CMS



BH's will decay within ~ 10^{-27} secs

Detectors, electronics (and rest of the world) are safe!!

Decay properties
➔ Extra dimensions

http://www.youtube.com/watch?v=BXzugu39pKM