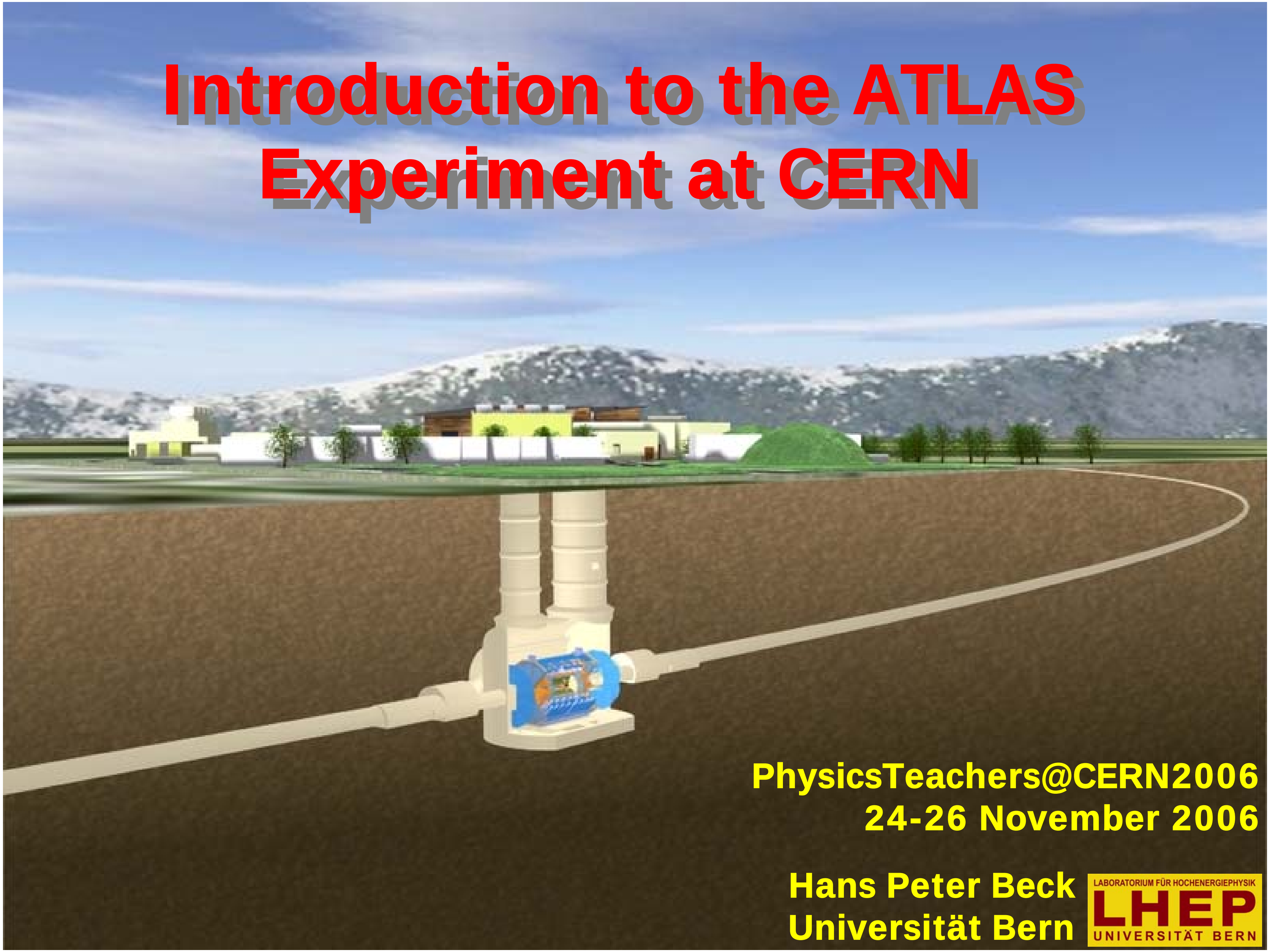
Introduction to the ATLAS Experiment at CERN

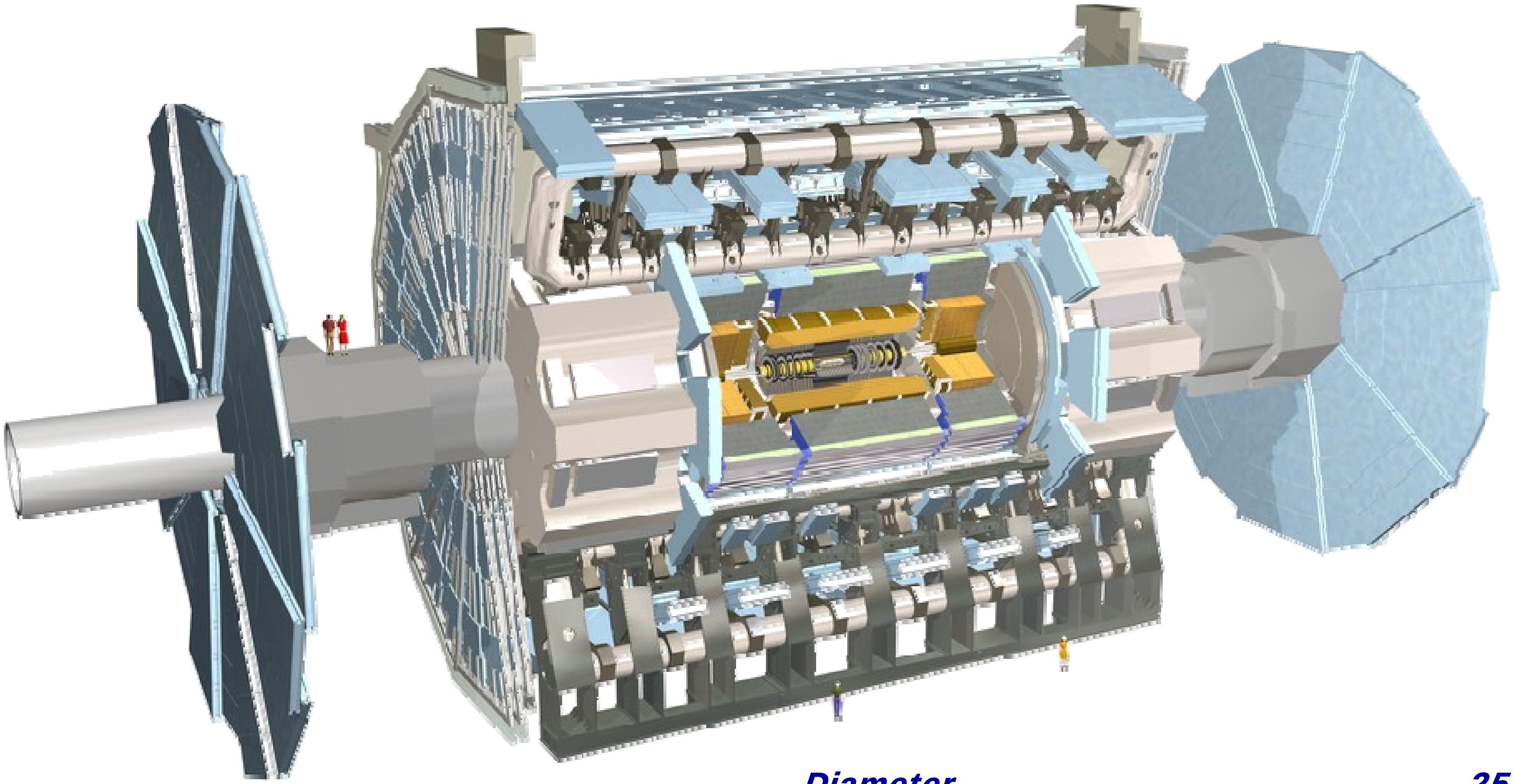


PhysicsTeachers@CERN2006
24-26 November 2006

Hans Peter Beck
Universität Bern

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

The ATLAS Detector



Diameter	***25 m***
Barrel toroid length	***26 m***
End-cap end-wall chamber span	***46 m***
Overall weight	***7000 tons***

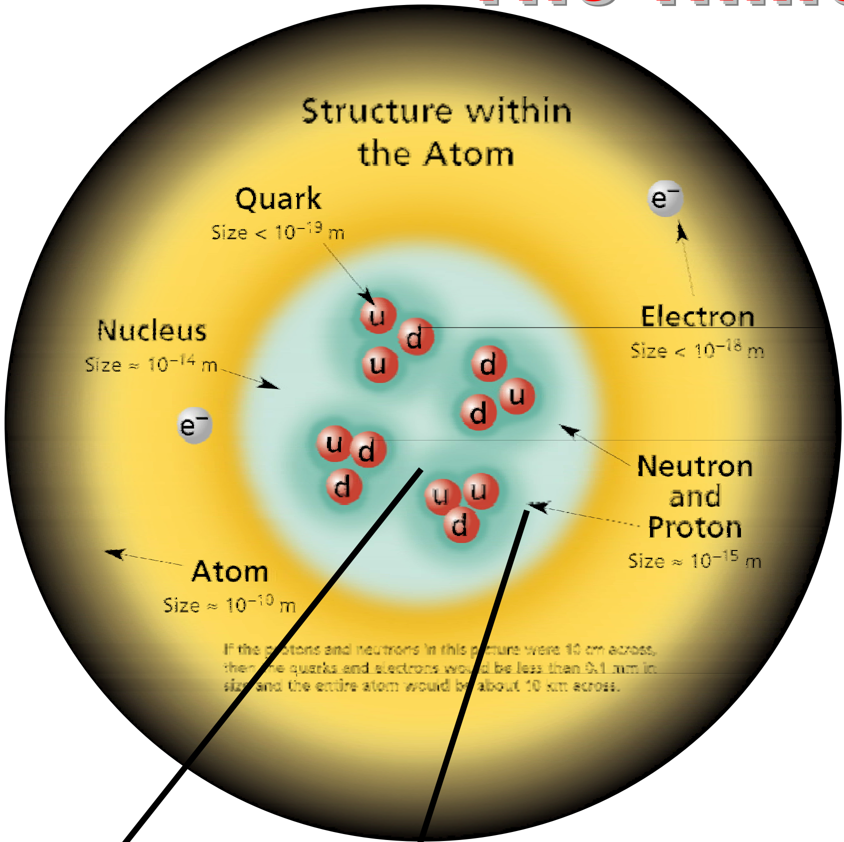
Particle Physics

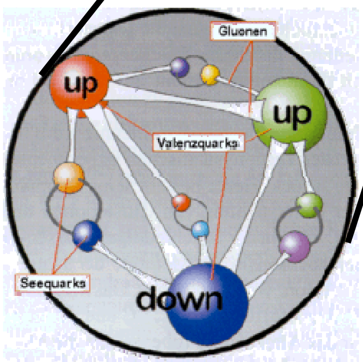
Dass ich erkenne, was die Welt im Innersten zusammenhält

Goethe's Faust

That ATLAS the force may recognise
That binds creation's inmost energies…

The Inmost...





Matters inmost consists of Atoms.

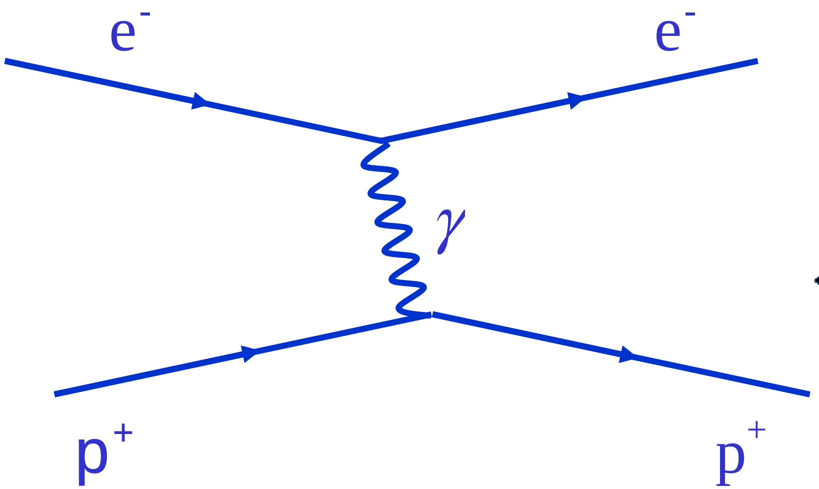
An atom is composed out of electrons, neutrons and protons. The rest is empty space (vacuum).

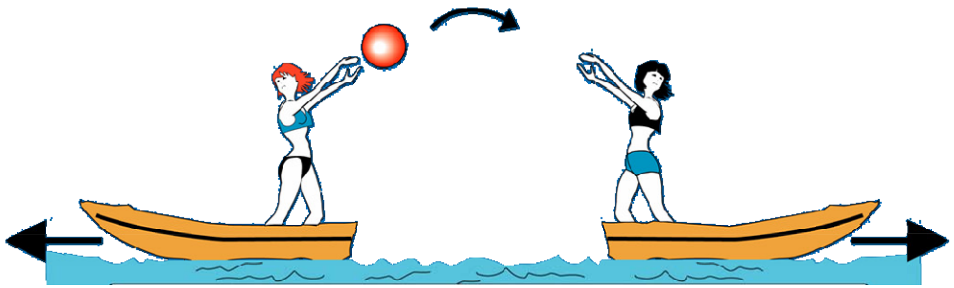
A proton is made out of two up-quarks and own down-quark

A neutron is made out of one up-quark and two down-quarks

Looking deeper into protons and neutrons one finds a sea of quark and anti-quark pairs and gluons

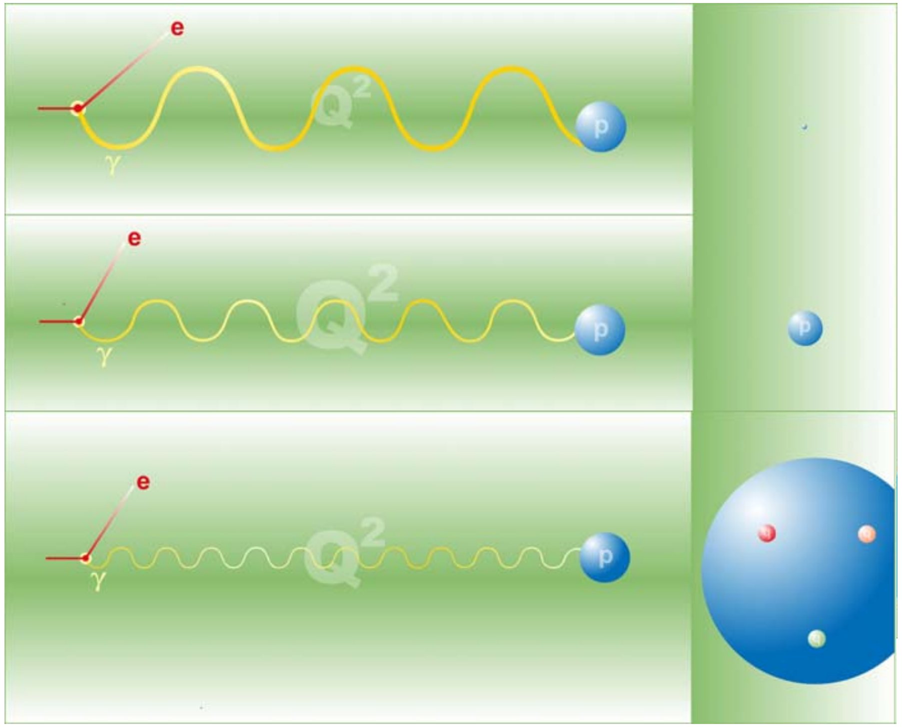
Forces

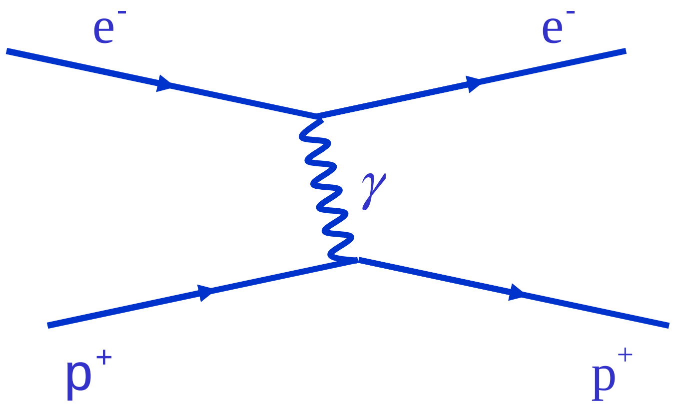




Forces are conveyed by means of particle exchange

Looking deep into Protons: Electron-Proton Scattering

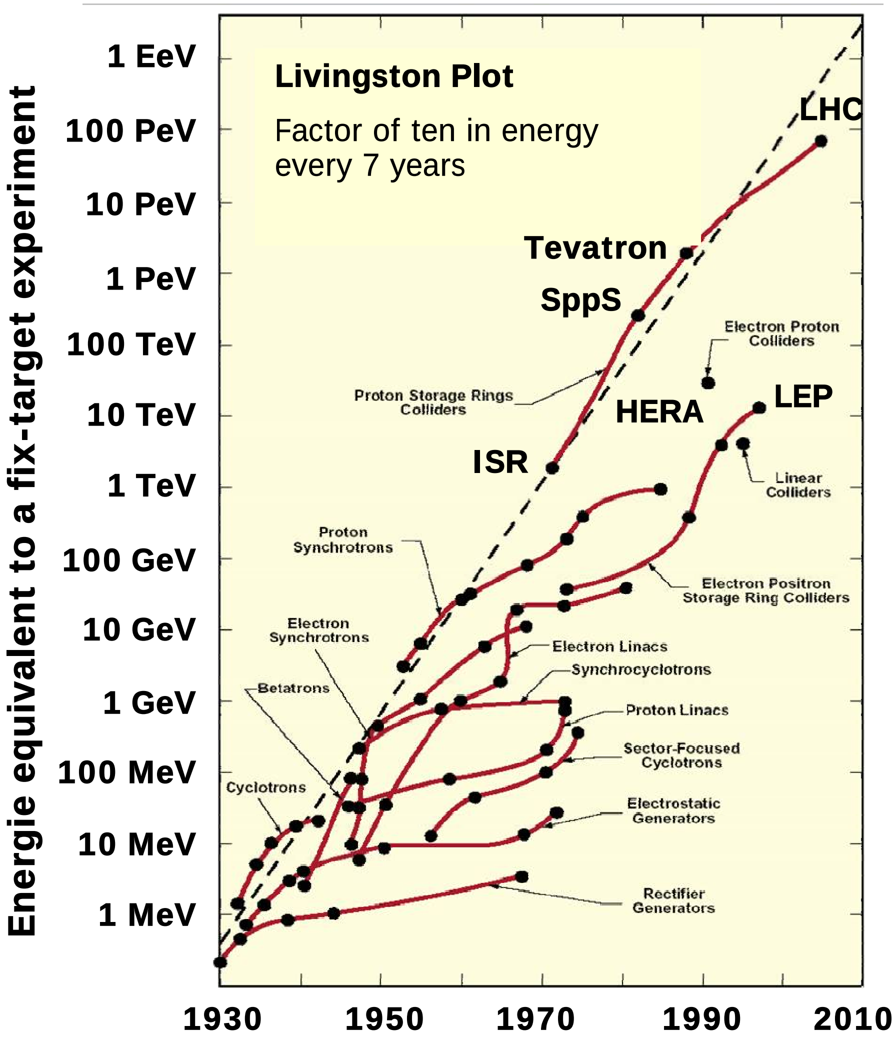




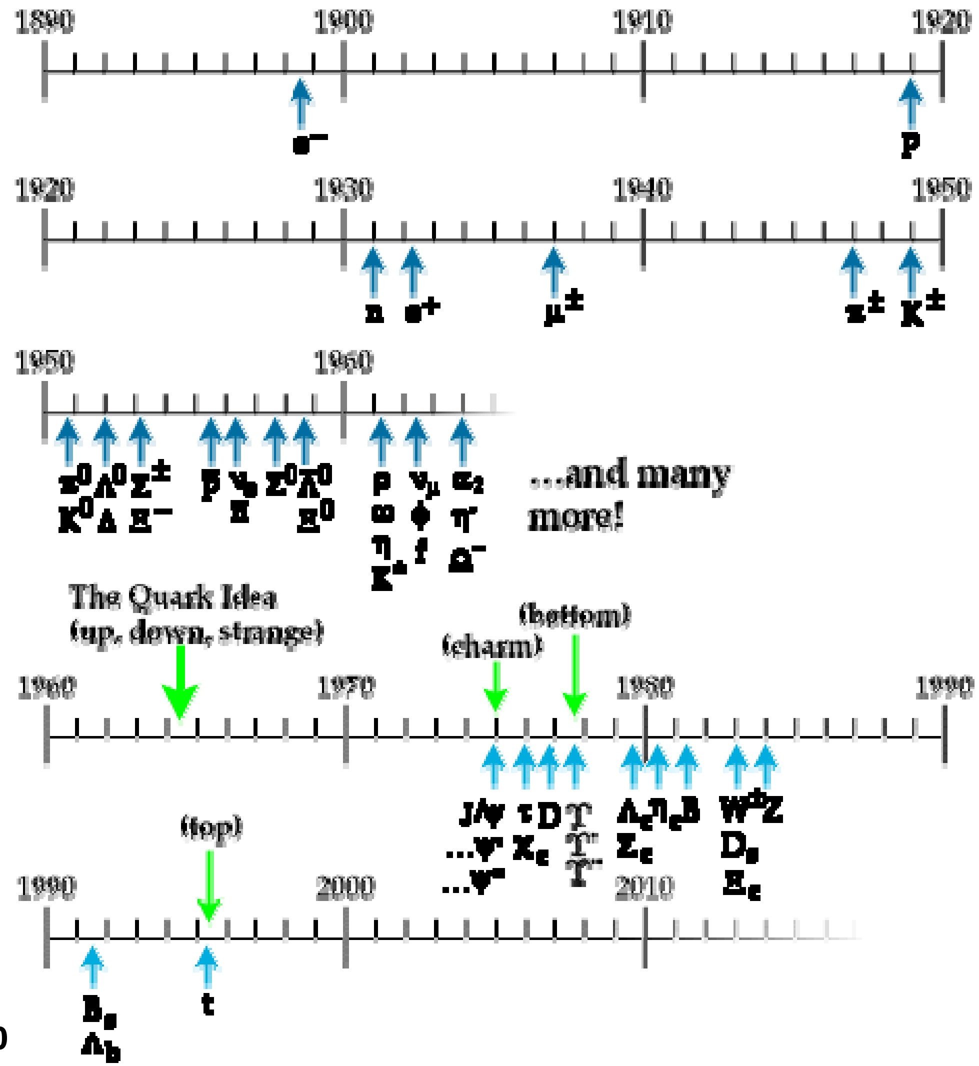
Elektronen are **back scattered** when they **hit a hard inner core**
Protons are not elementary particles.

- **Protonen** (and **Neutronen**) consist of **quarks** and **gluons.**
  - **Proton:** (uud) up-quark + up-quark + down-quark
  - **Neutron:** (udd) up-quark + down-quark + down-quark

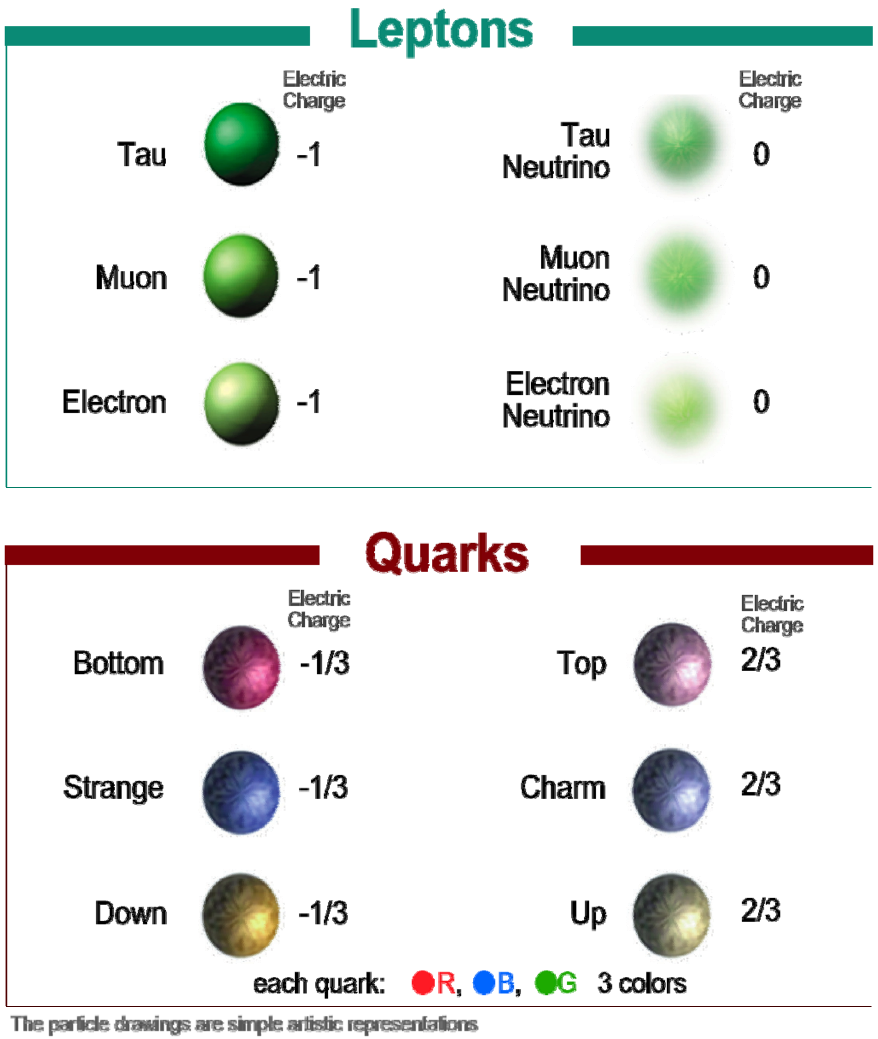
Bigger Accelerators – More Particles detected

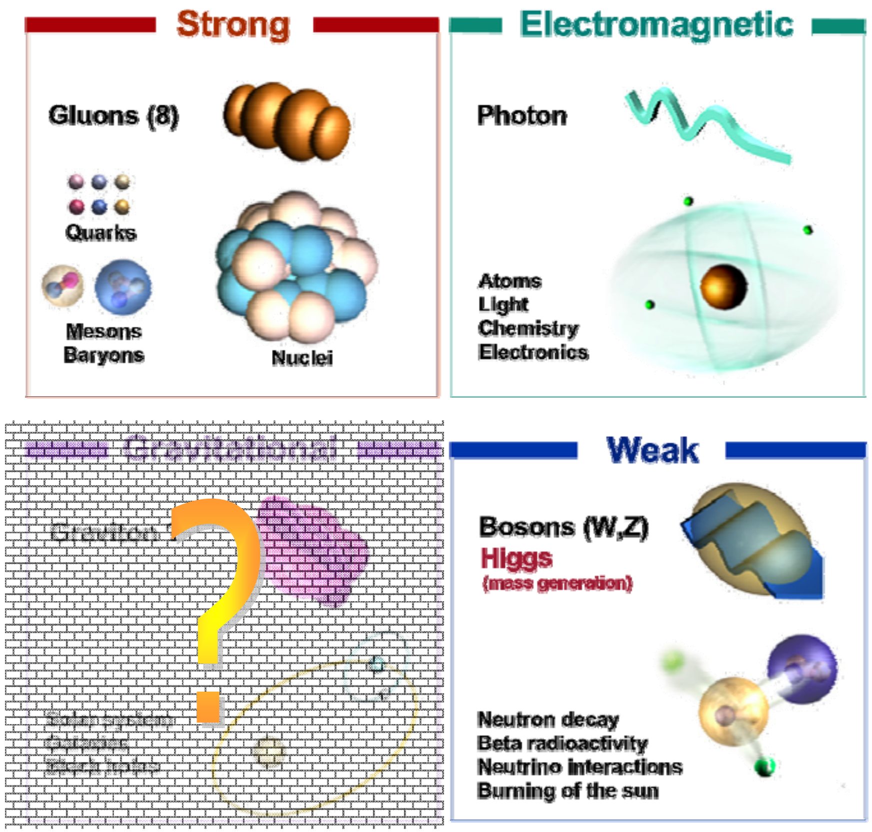


$$E^{FT}_{Lab} = E^{2}_{cm} / 2m_p$$



The Standard Modell of Particle Physics





4 fundamental forces

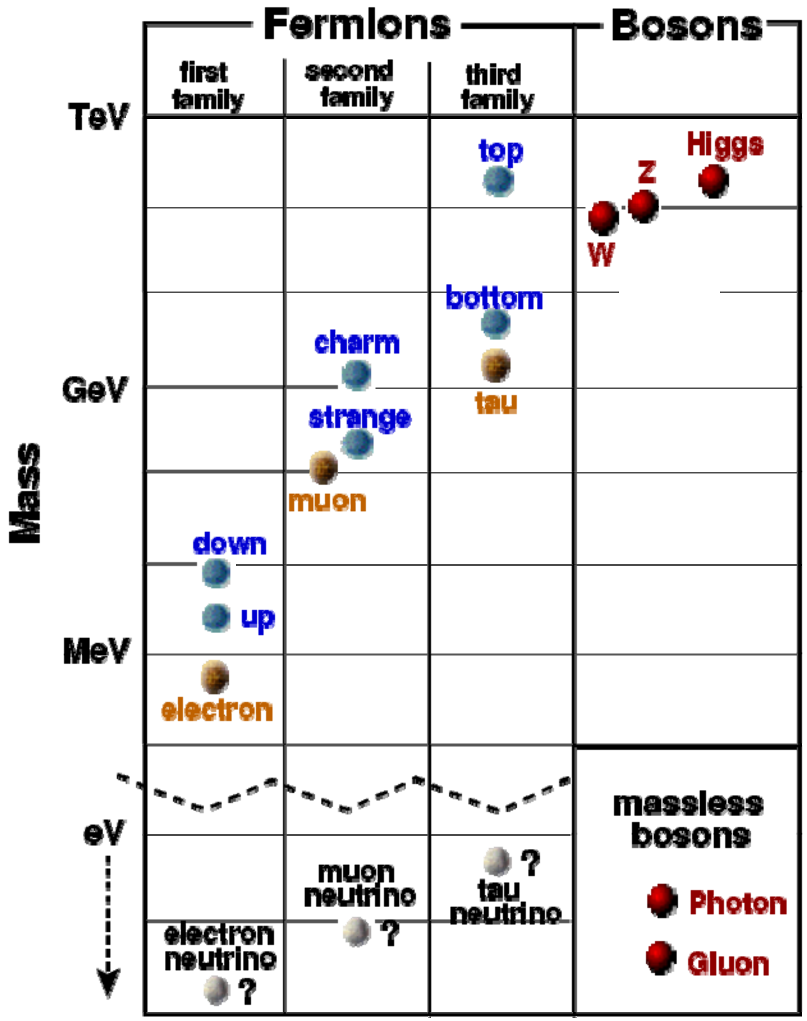
Leptons & Quarks: 3 families

Where are the Masses in the Standard Model?

Perfect Symmetry: $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \Rightarrow$

$$m_\gamma = m_g = 0$$
$$m_{W^\pm} = m_{Z^0} = 0$$

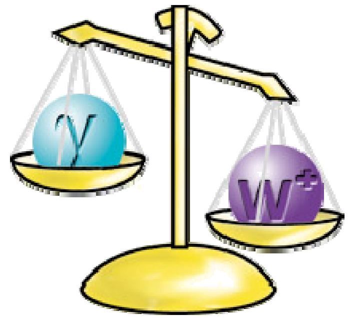
All masses should vanish



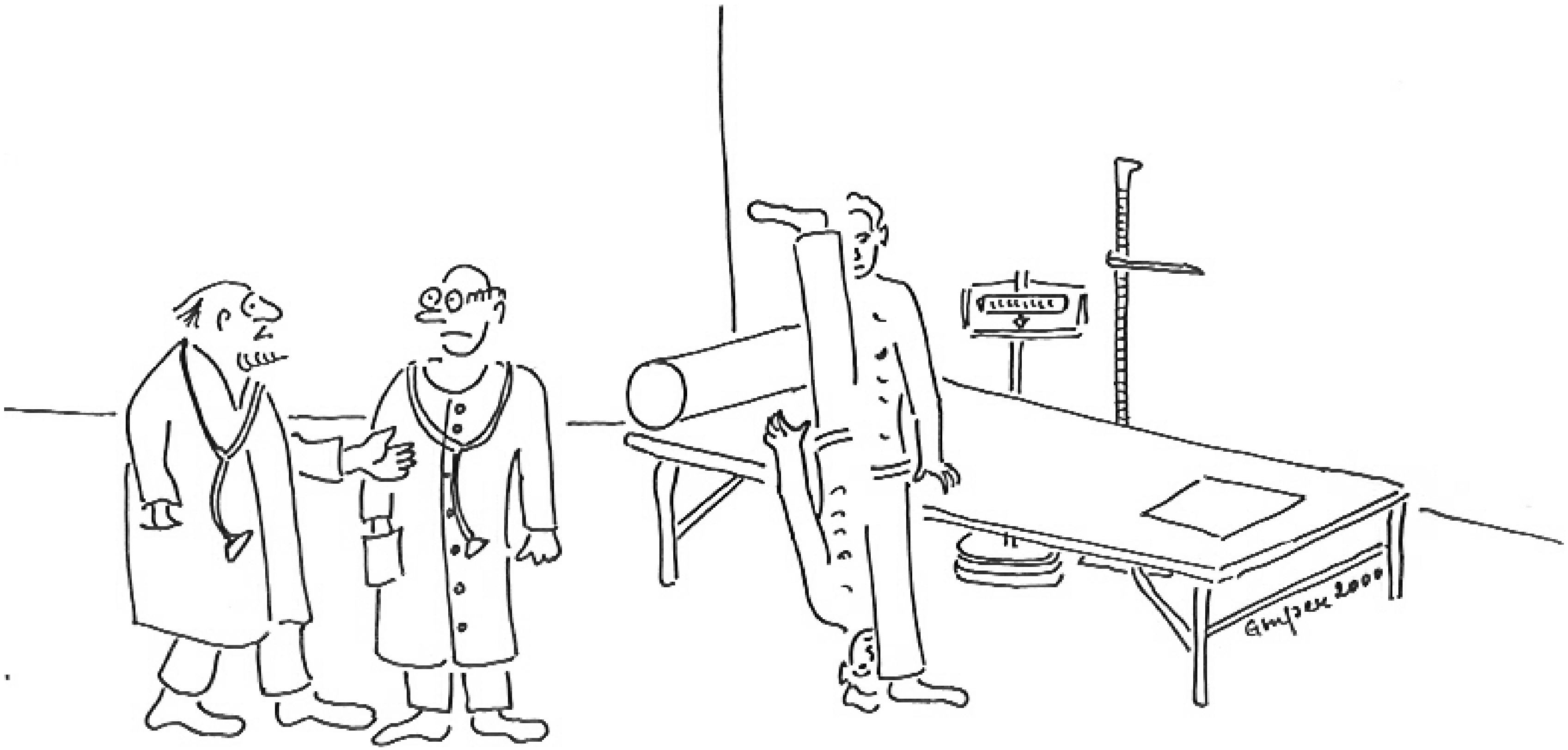
But we have measured a wide spectrum of particle masses

Thus, something is missing in our theory

$$m_\gamma = 0 \quad i.e. < 6 \times 10^{-26}\ \text{GeV}$$
$$m_{W^\pm} = 80.425 \pm 0.038\ \text{GeV}$$
$$m_{Z^0} = 91.1876 \pm 0.0021\ \text{GeV}$$



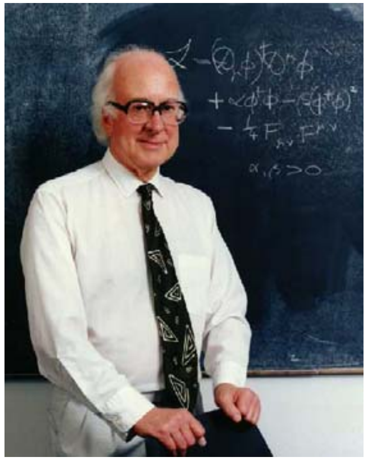
Something must break this perfect symmetry

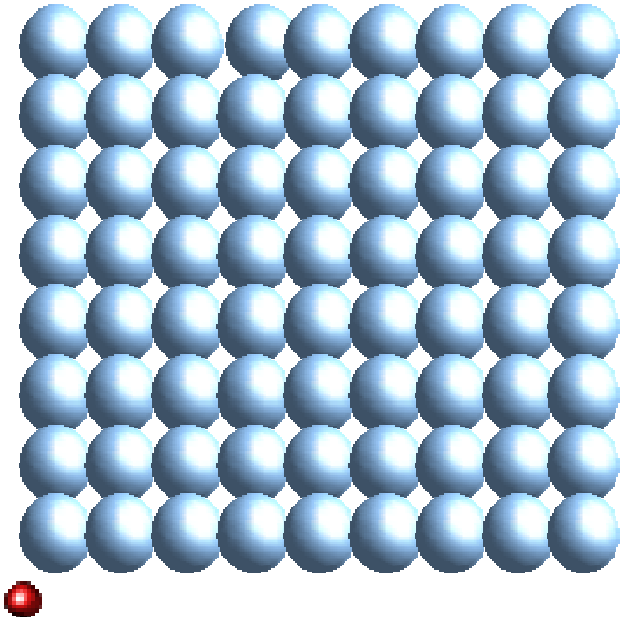


"A severe case of symmetry breaking!"

1964-1965 The Idea of Prof. Higgs

Prof Peter Higgs
*1929





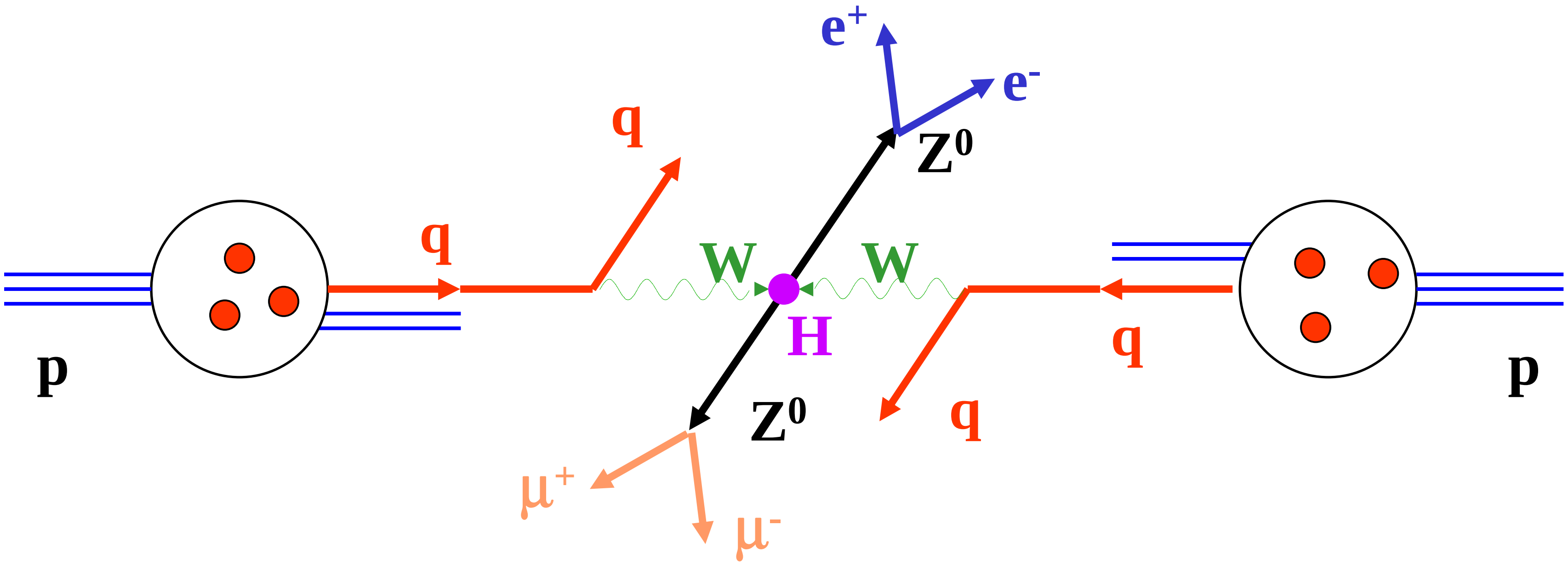
- The vacuum is not empty!
- The vacuum is filled up with a neutral, so far undiscovered scalar particle, the Higgs boson
- When particles travel through space, they interact with a sea of virtual Higgs bosons and thus move at a speed slower than the speed of light
- Thus, particle behave as if they would have a mass
  - effective mass

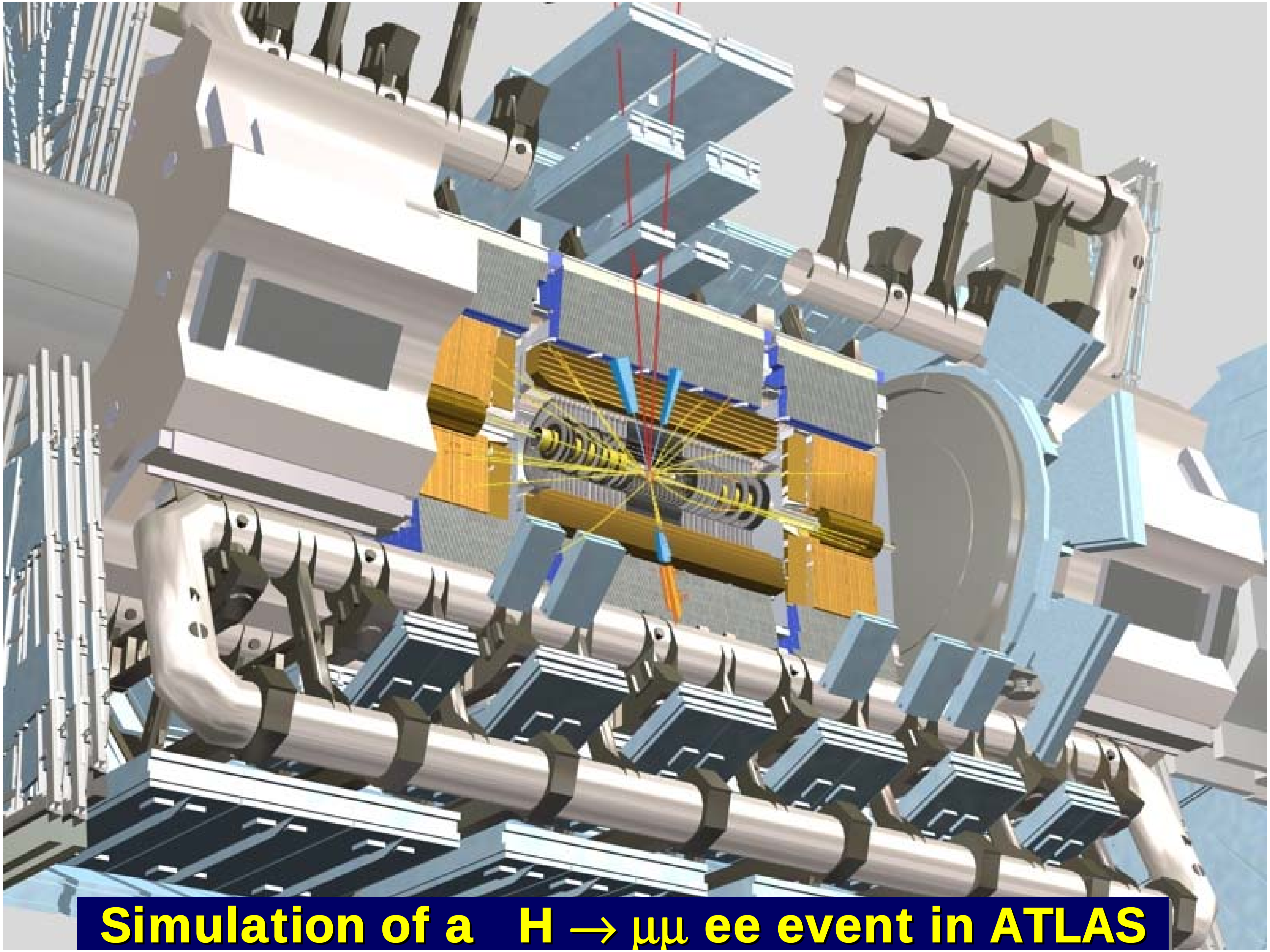
Higgs Boson Production

- **Standard Model recipe:**
  - **Squeeze the vacuum with enough energy until a Higgs boson pops out**
    - The vacuum is filled up with a sea of Higgs bosons but in there they are invisible
  - **Best way is to shoot two particles head-on on each other**
    - **You need a big accelerator-collider for this**
  - **You need enough collision energy**
    - concentrated into a small spot
    - above the Higgs Mass itself

– **Existing colliders were not strong enough**
  - **The LHC can measure a Higgs in the range 100 GeV – 1000 GeV**
    - 114 GeV < M_{Higgs} < 194 GeV

Higgs Production in Proton-Proton Collisions





Simulation of a $H \rightarrow \mu\mu\ ee$ event in ATLAS

There are more fundamental questions where ATLAS will shed light on

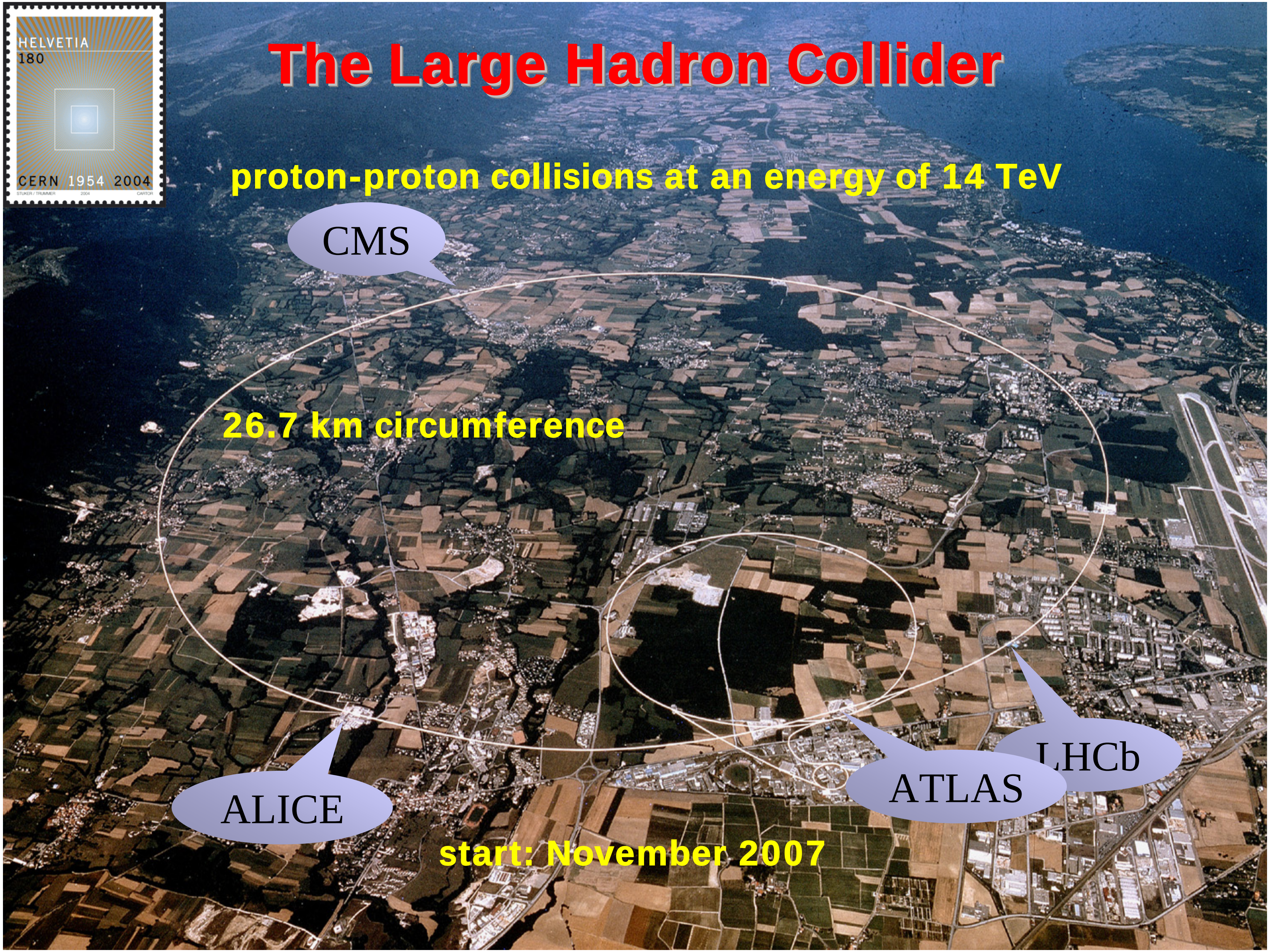
- Higgs mechanism
  - is it really the Higgs mechanism that gives mass to particles?
  - Why are the masses of particles so grossly different from each other?
- Are Quarks and Leptons really fundamental or is there something more fundamental inside?
  - Why is the electron charge and the proton charge exactly mirrored?
- Why are there three families of particles?
- Why are particles and anti-particles not exactly mirrored?
- Are there more symmetries and even more particles in nature?
  - Great Unification
  - Super Symmetrie
- What is dark matter and what is dark energy?
- Is there a theroy consistent with particle physics and with gravity?
  - Why is gravity so much weaker than any other force?
- In how many dimensions do we live in?
  - Other than the 3 space and 1 time dimension
  - Any attempt to describe particle physics and gravity in a unified theory leads to the conclusion that there must be more dimensions

ATLAS and the LHC

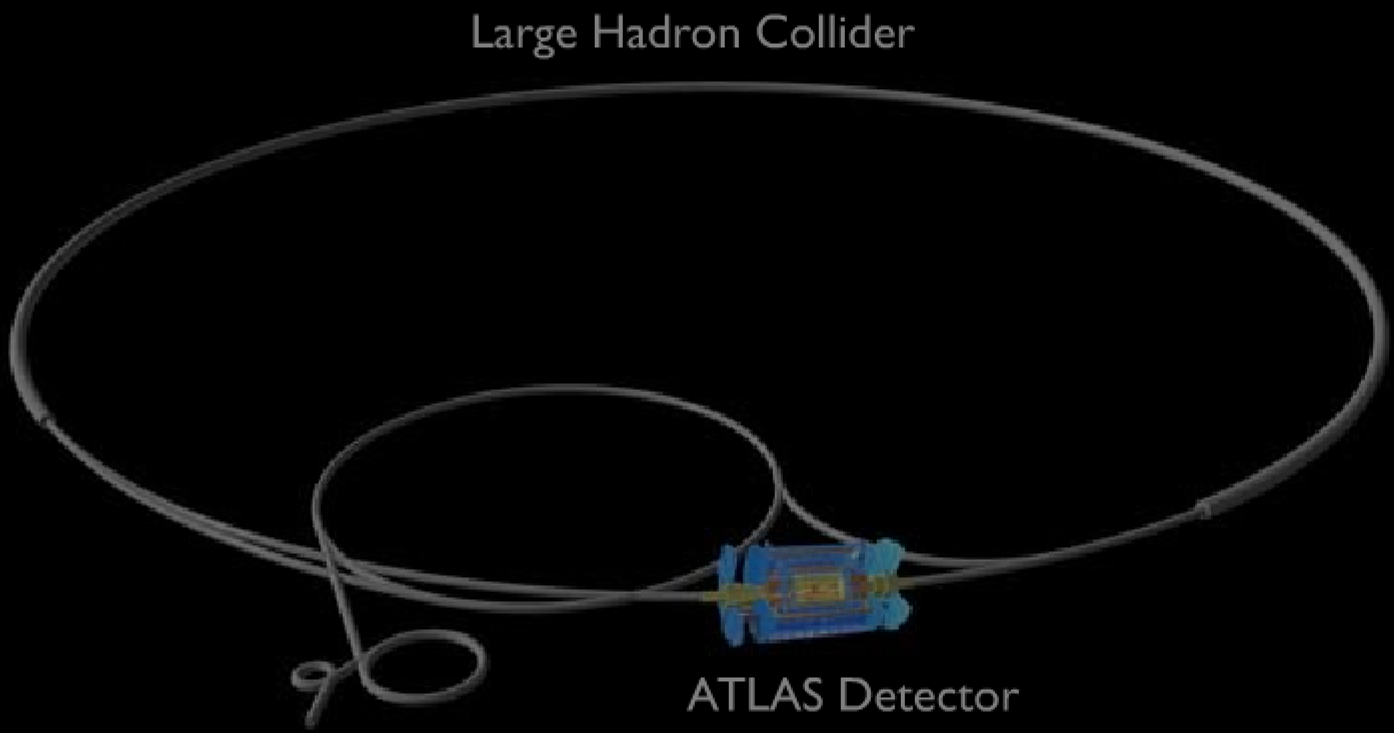
ATLAS	**“A Toroidal LHC ApparatuS“**
LHC	**“Large Hadron Collider”**

Hadrons are strongly interacting particles
Protons belong to the family of hadrons

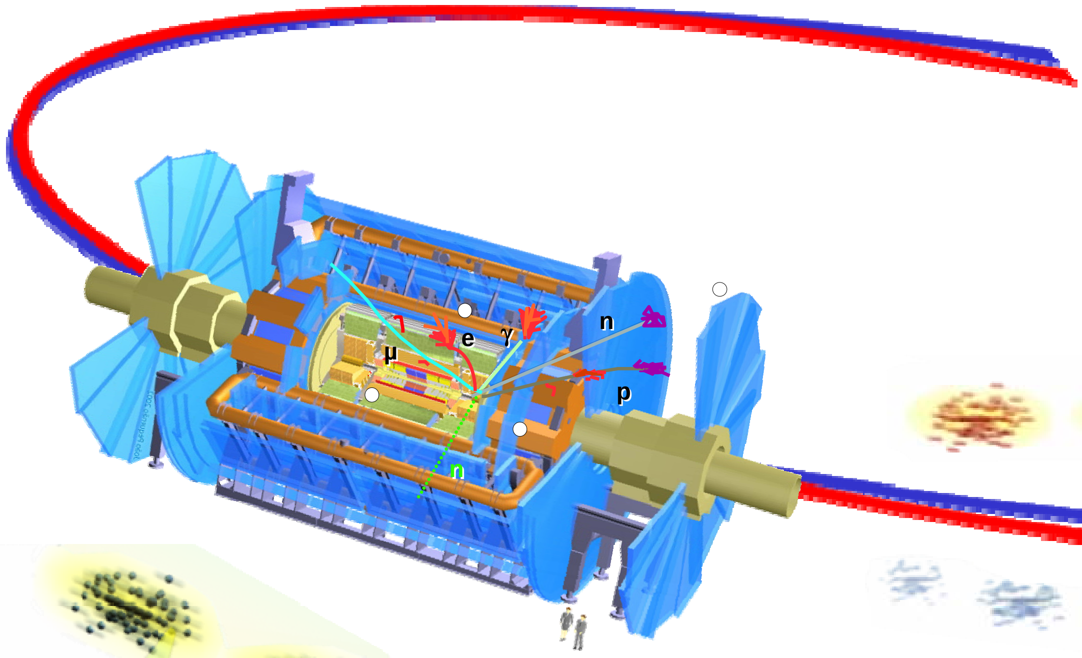
(greek hadros αδρος = strong)


HELVETIA
180
CERN 1954 2004
The Large Hadron Collider
proton-proton collisions at an energy of 14 TeV
CMS
26.7 km circumference
LHCb
ATLAS
ALICE
start: November 2007

PLAY▶

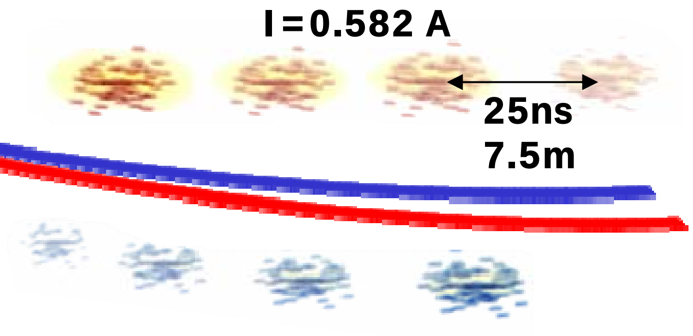


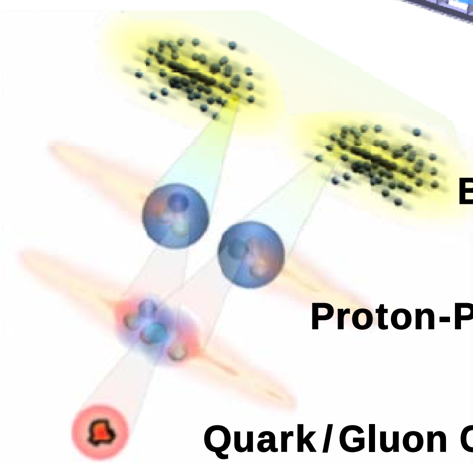
Proton-Proton Collisions @ LHC



Nominal LHC Parameters:

7 TeV	Proton Energy
$10^{34} cm^{-2}s^{-1}$	Luminosity
2808	Bunches per Beam
10^{11}	Protons per Bunch

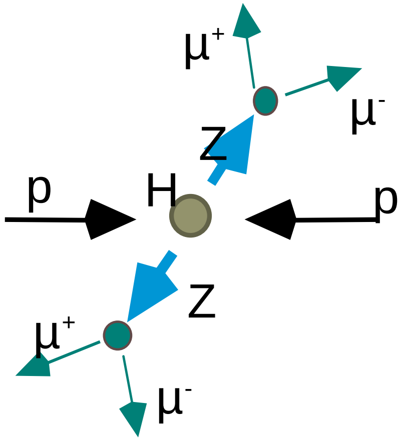


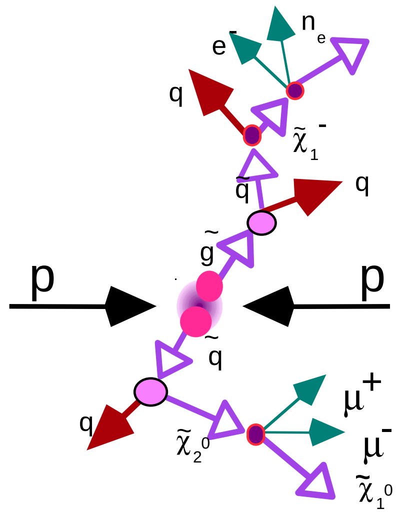


Bunch Crossings $4x10^7$ Hz

Proton-Proton Collisions 10^9 Hz

Quark/Gluon Collisions





Heavy particle production $10^{+3...-6}$ Hz
(W, Z, t, Higgs, SUSY,...)

Detecting particles in ATLAS...

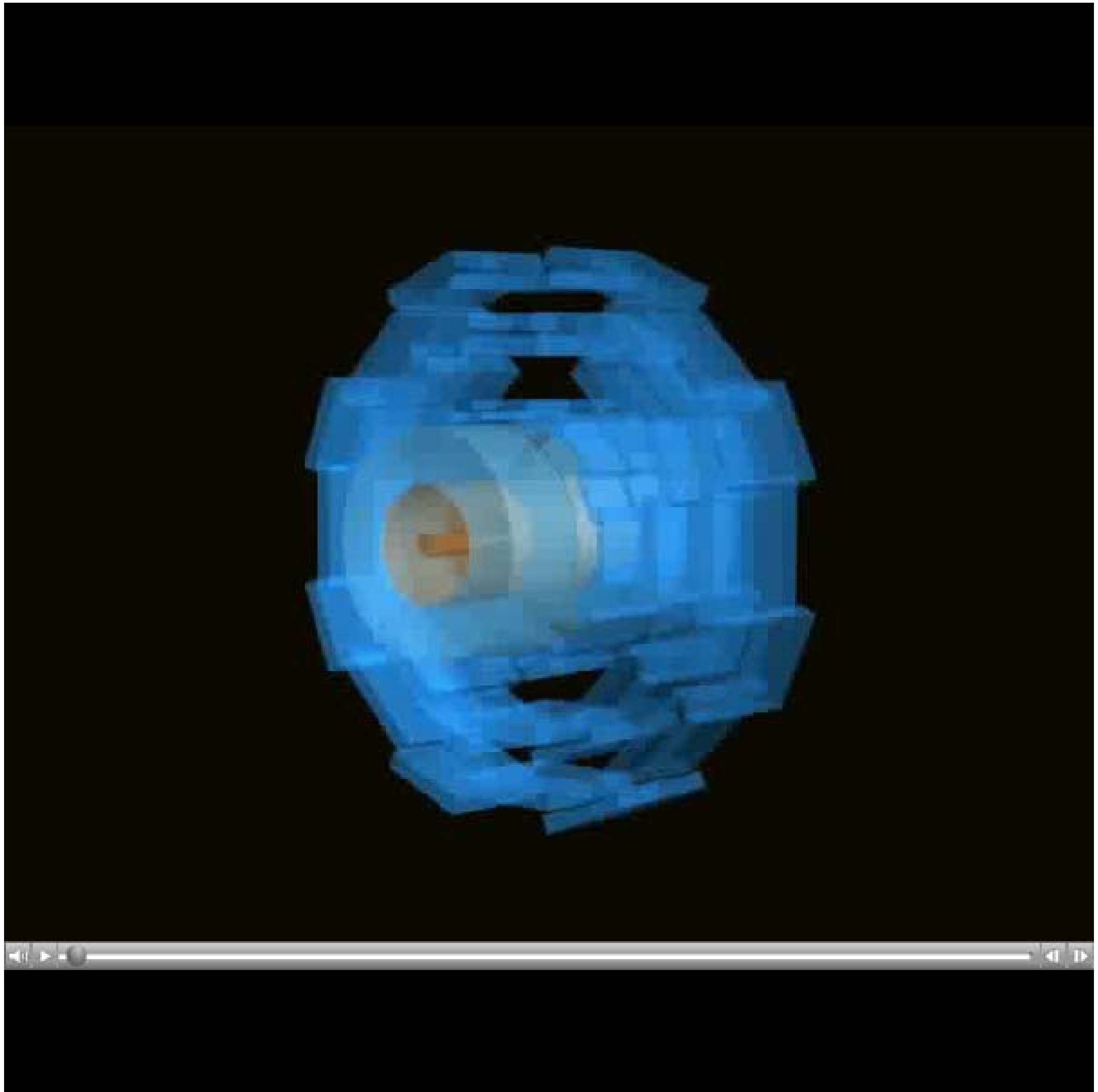
ATLAS detects
long lived particles only:

Electrons
Photons
charged hadrons - Proton
neutral hadrons - Neutron
Muons

Short lived particles:

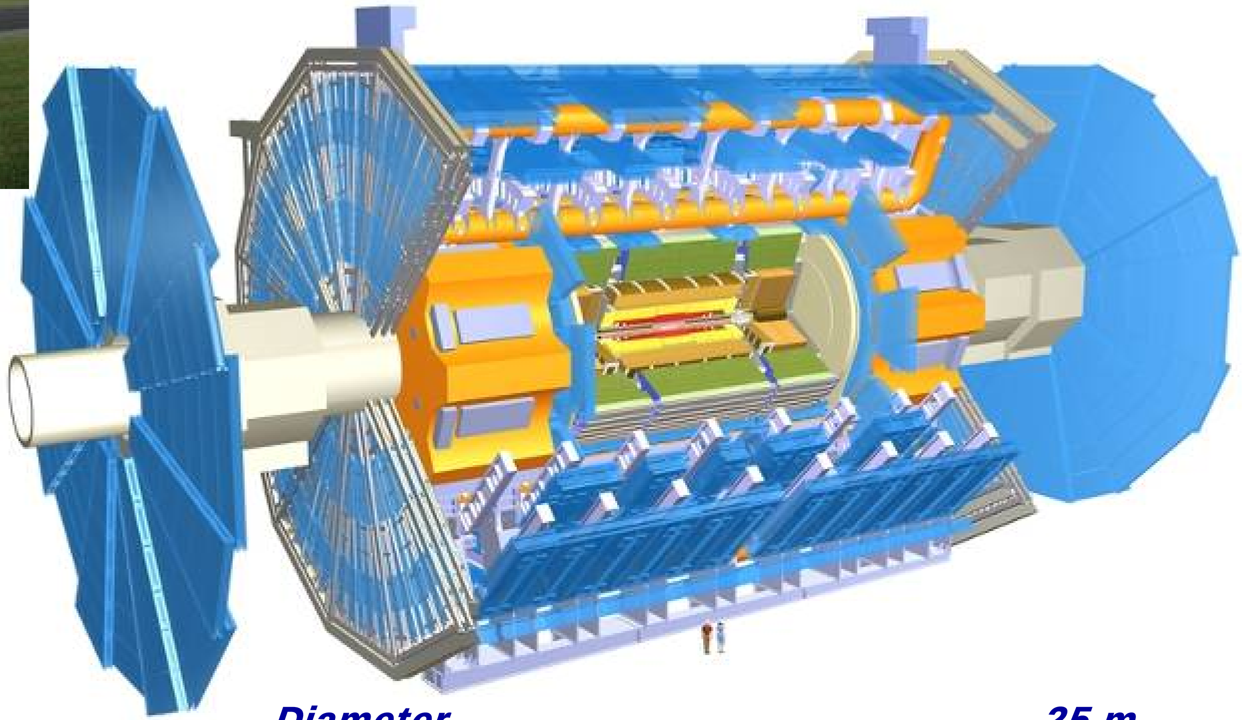
decay into long lived particles that are measured with ATLAS.

Thus, properties of short lived particles need to be calculated backwards from their long lived decay products



The ATLAS Detector

ATLAS is as large as a 5 story building



Diameter	***25 m***
Barrel toroid length	***26 m***
End-cap end-wall chamber span	***46 m***
Overall weight	***7000 tons***

ATLAS Collaboration

35 Countries
164 Institutions
1700 Scientific Authors total

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, **Bern**, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Ritsumeikan, UFRJ Rio de Janeiro, Rochester, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, Wisconsin, Wuppertal, Yale, Yerevan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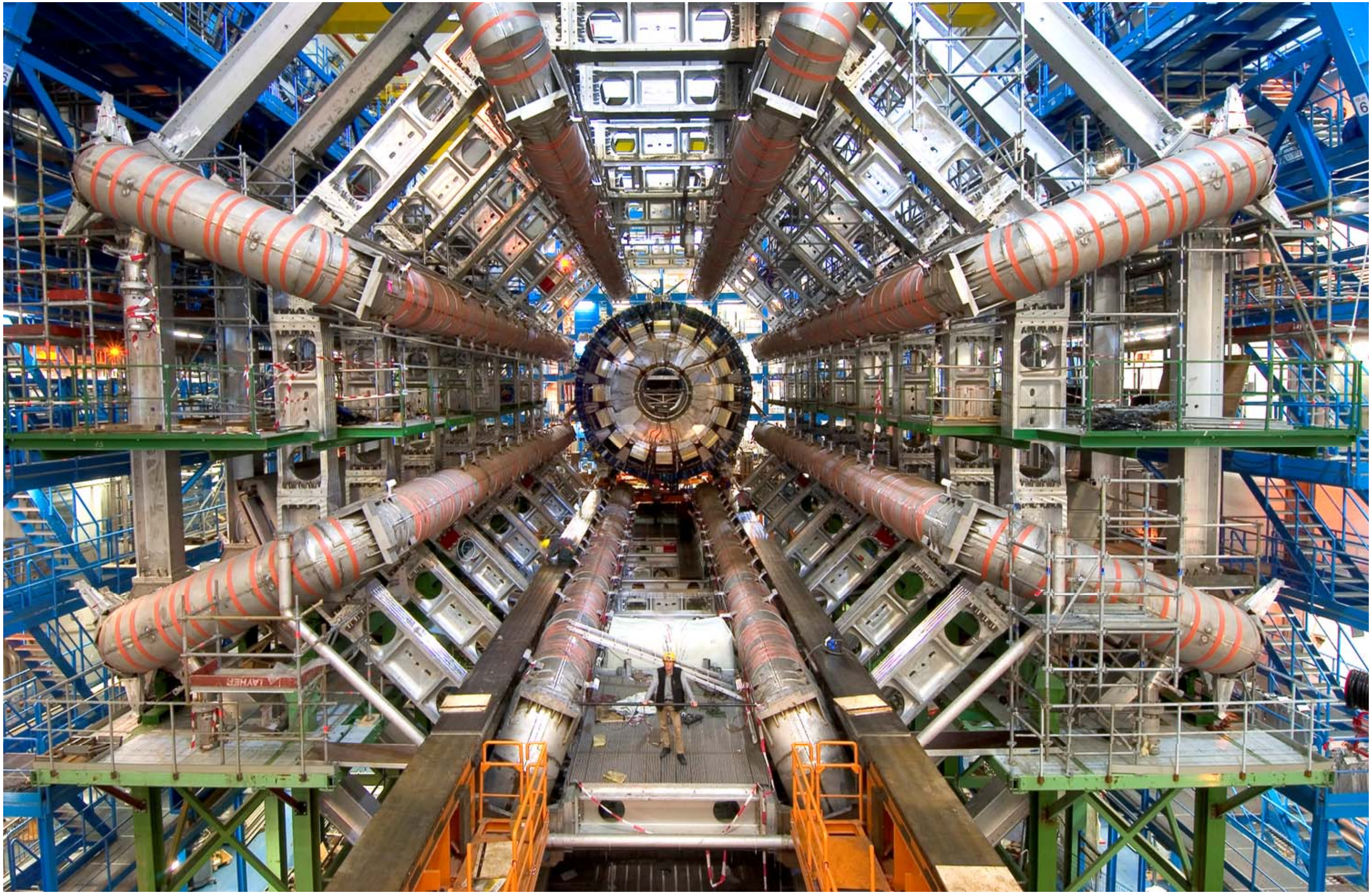
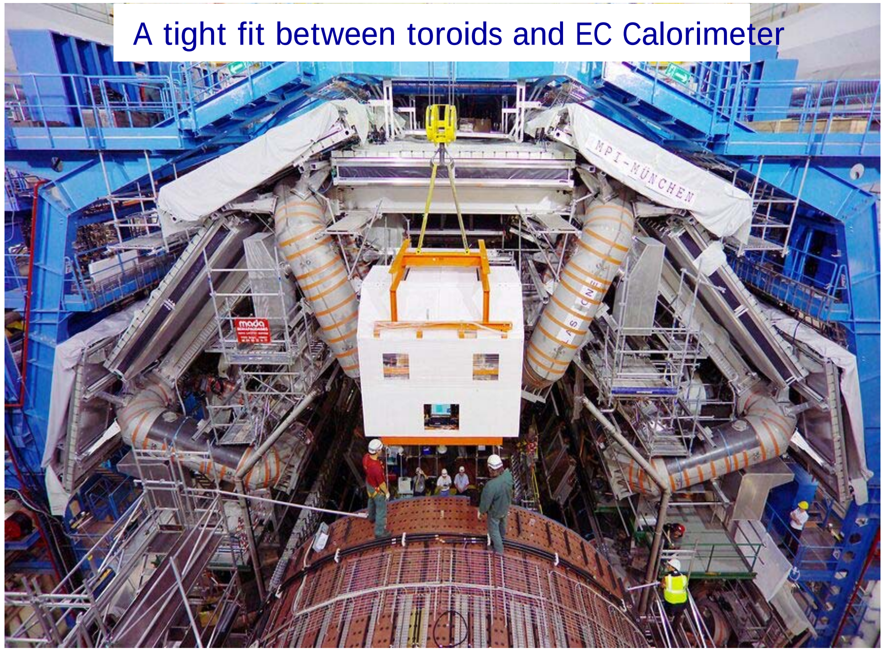
Not just small particles…

October 2005



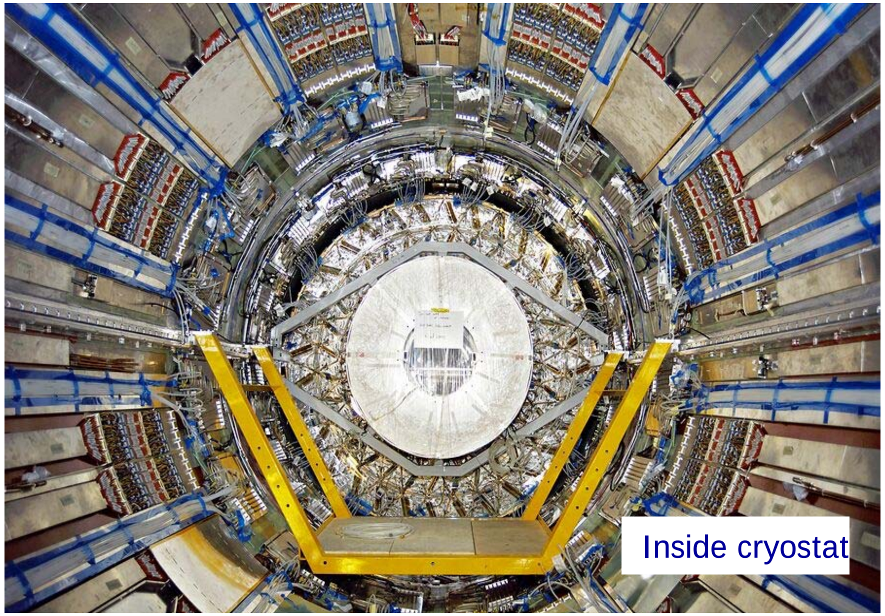
Preparing the Bore for the Inner Detector

August 2006: Inner Detector Installation



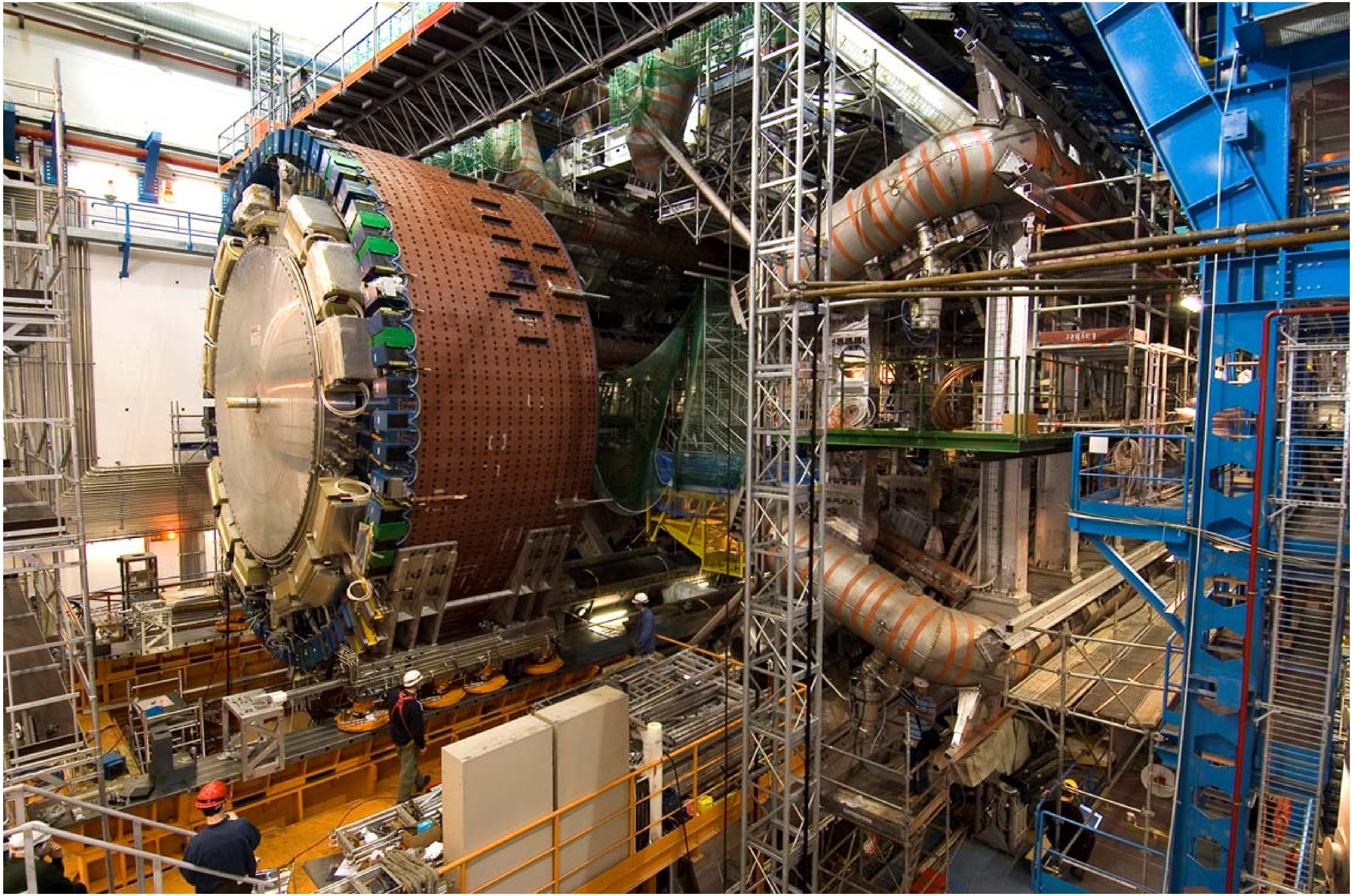
A tight fit between toroids and EC Calorimeter

From the trolley to the support rails

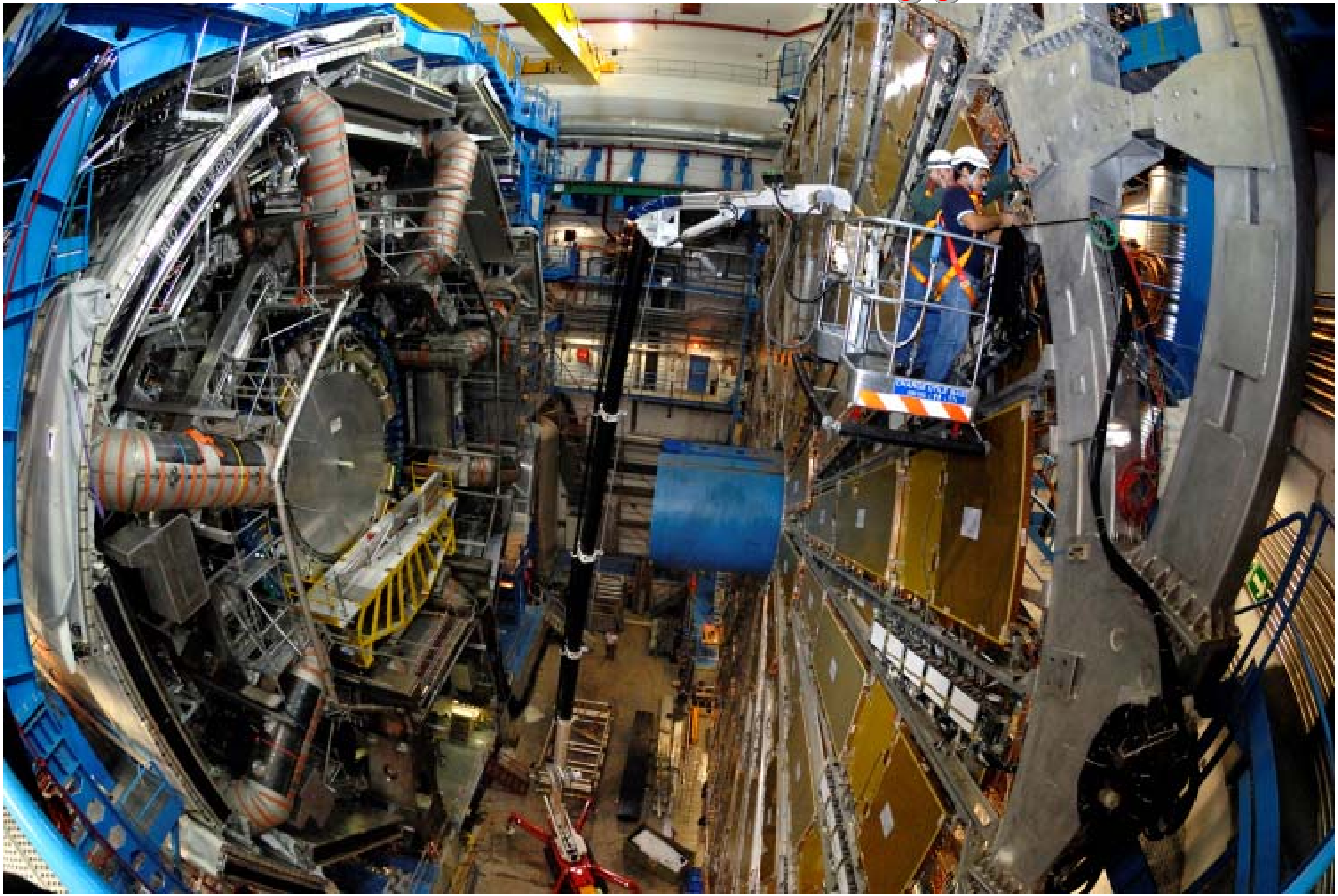


Inside cryostat

Aug 2006: Electromagnetic Endcap Calorimeter



November 2006: Muon Trigger Wheel



Online Event Selection

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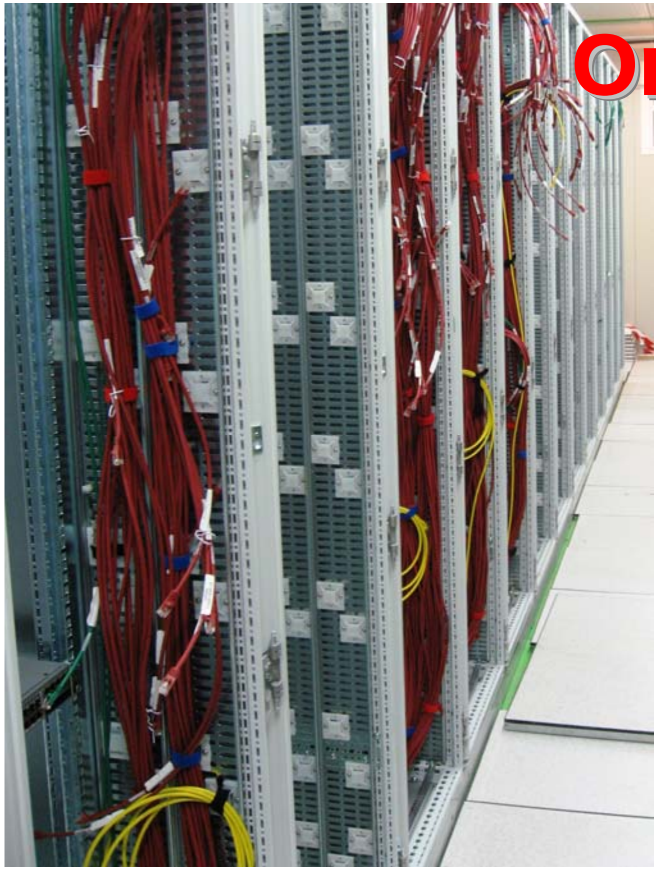
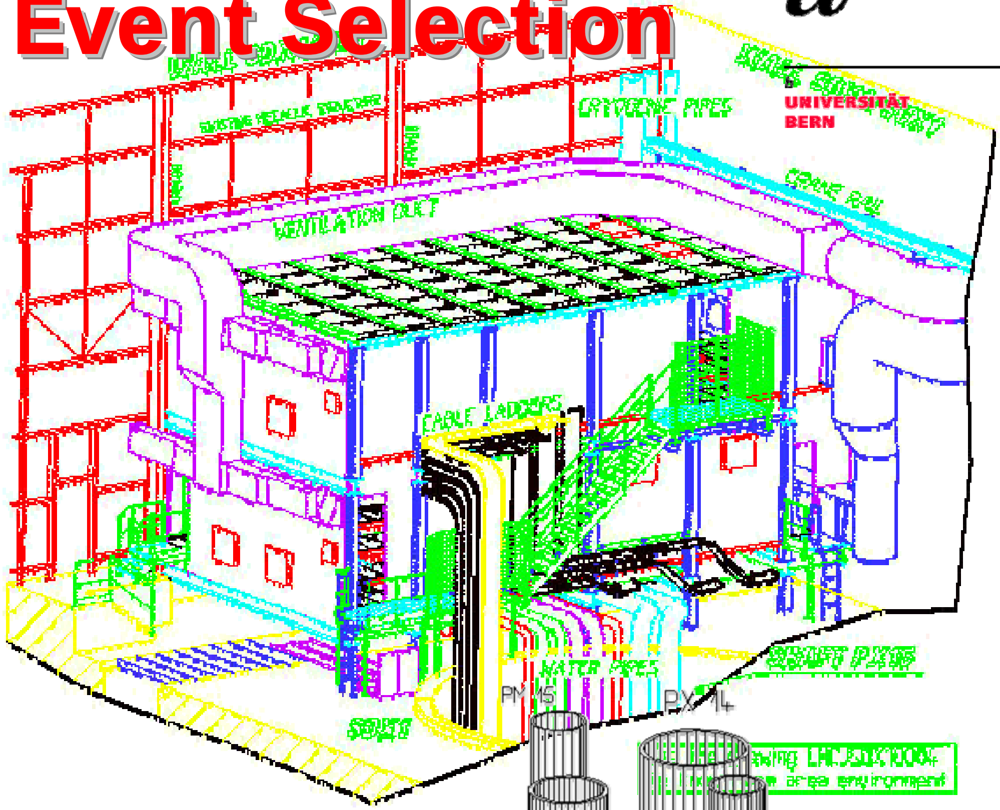
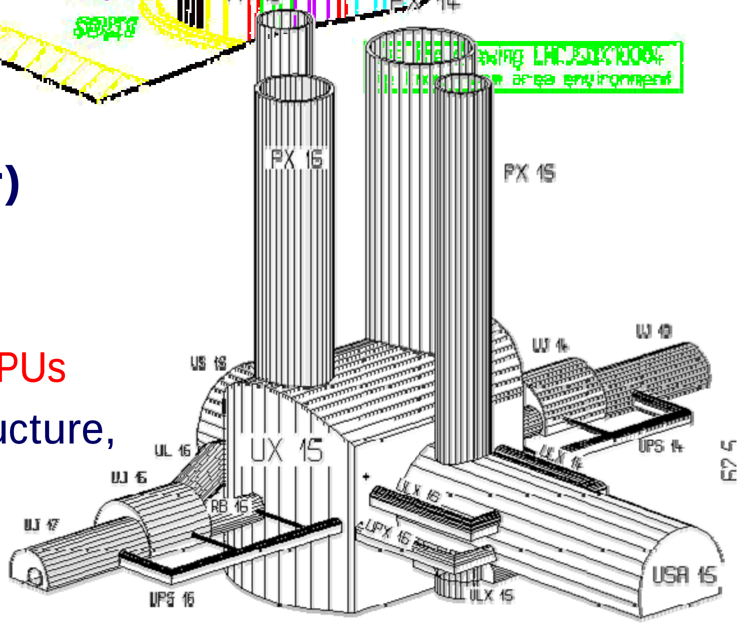




Online dataacquisition and event selection (Trigger)

- 1 billion proton-proton collisions every second
- Select one out of 10’000’000 events
- ATLAS event data is analyzed in real time using 6000 CPUs
- 101 racks for ca. 3000 computers, networking, infrastructure, ATLAS detector control,…



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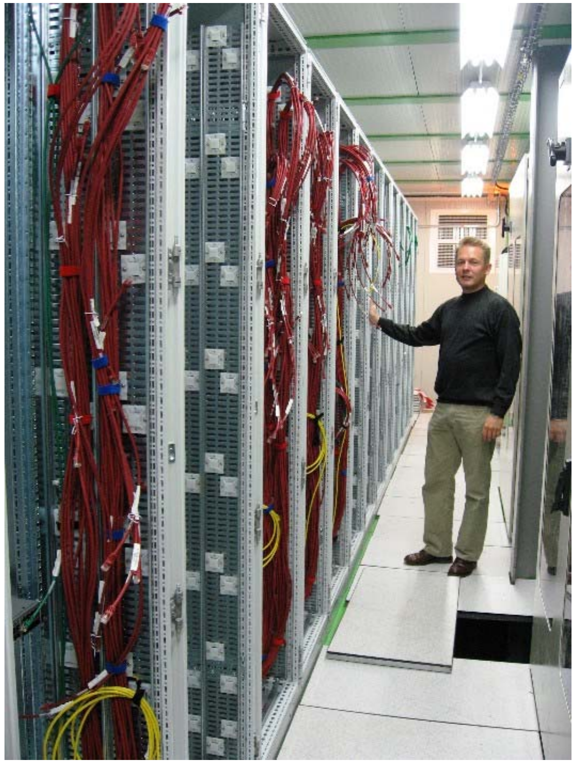
SDX1 – TDAQ Room @ Point 1



"pre-series" system
~100 PCs

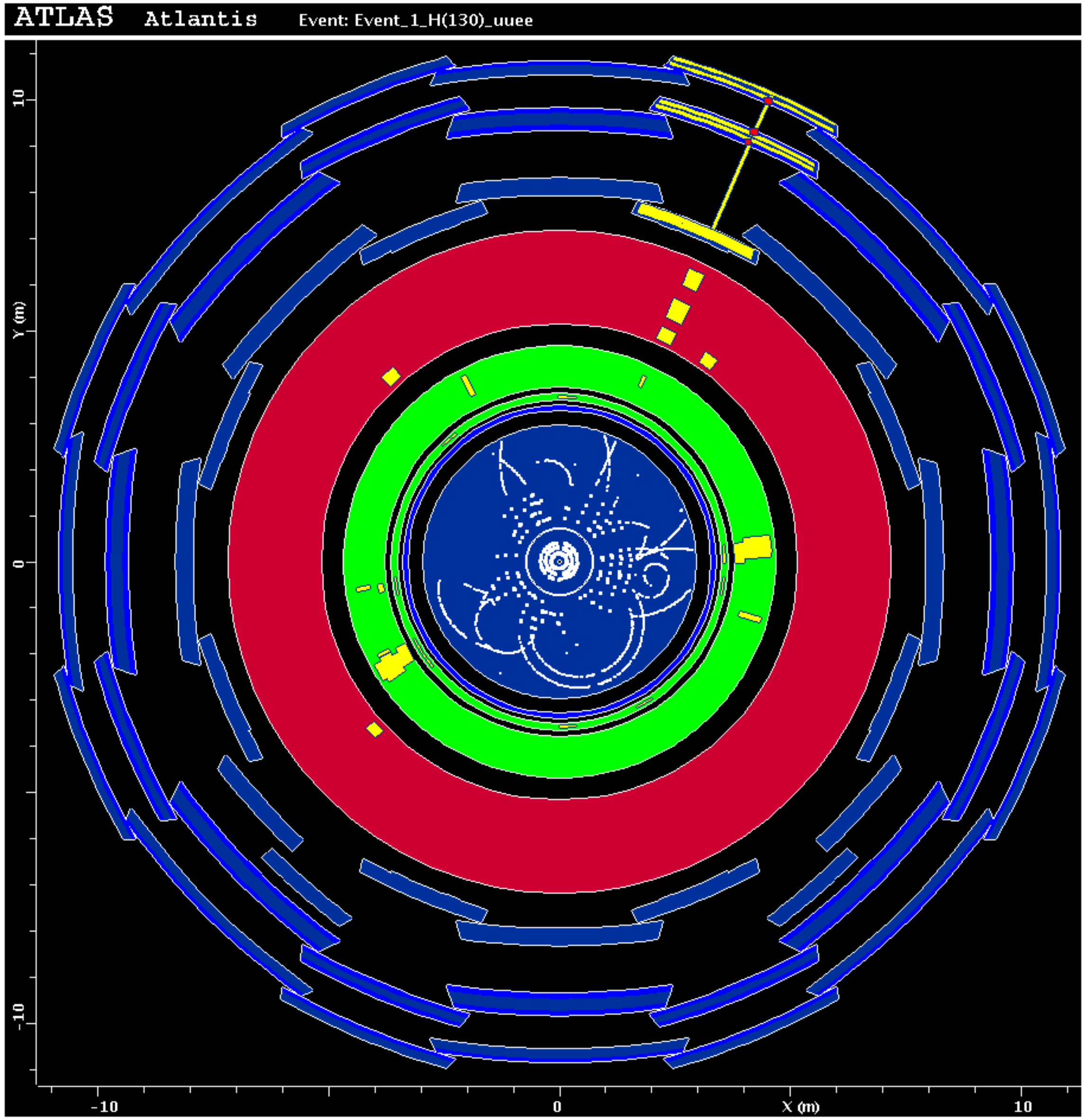
racks being prepared

air and water for cooling
(1 Mega Watt)

Summary

- The LHC will provide unprecedented energy and luminosity in high energy p-p collisions
  - allowing to enter new undiscovered territories in nature
- Atlas is being designed and constructed to take advantage of the vast physics potential the LHC will offer
  - The Higgs boson
  - SuperSymmetry
  - Quark and Lepton sub-structre
  - SuperGravity
  - Extra Dimensions
  - the totally unexpected…
- By the end of this decade we will definitely know more
  - ATLAS will take data for ~15 years to discover all that is possible
- An international community with highly motivated people from 35 countries is in charge of a program that took 15 years to set up and will take another 15 years to operate

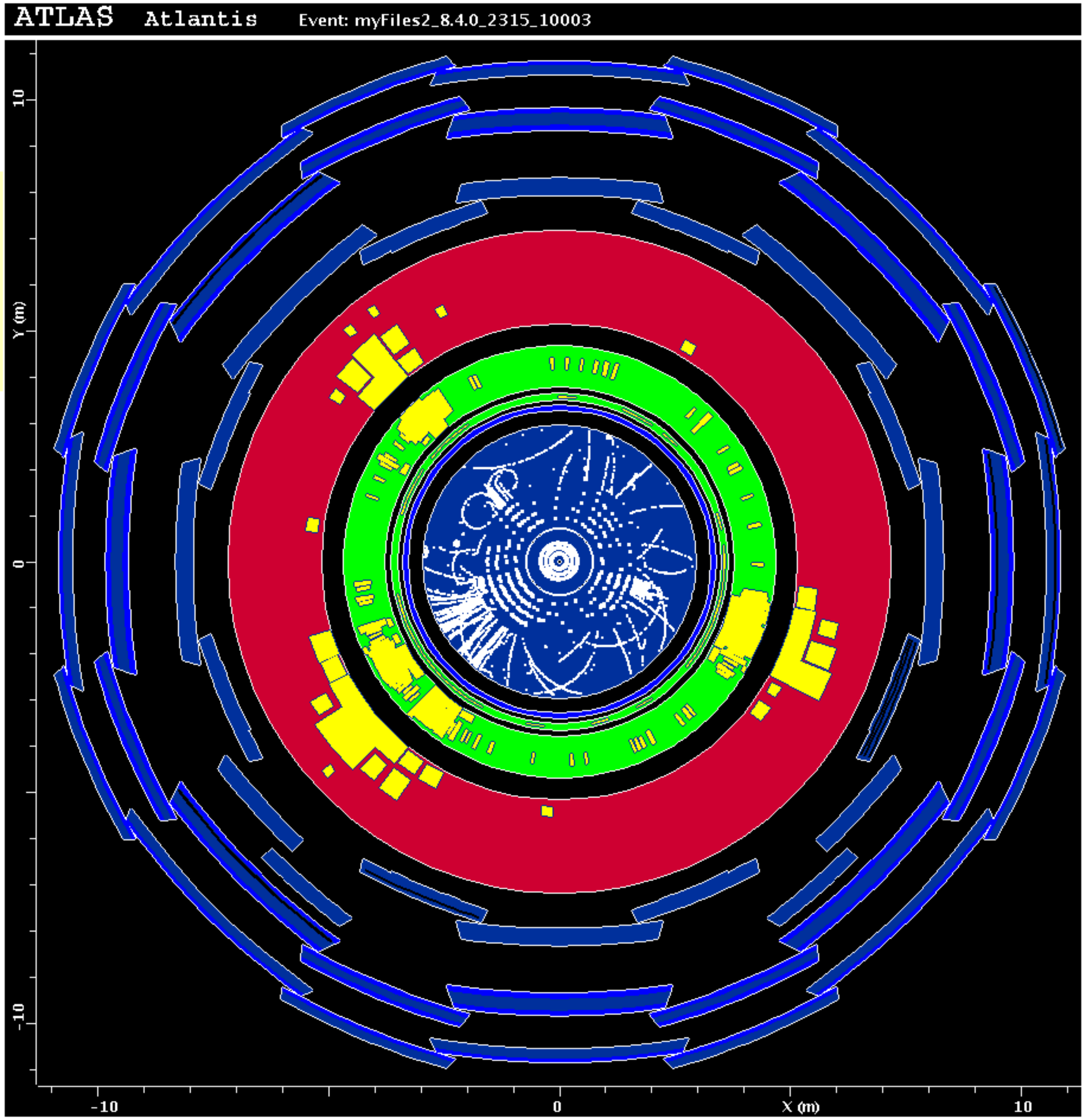
H ® Z^0Z^{0*} ® $m^+m^- e^+e^-$



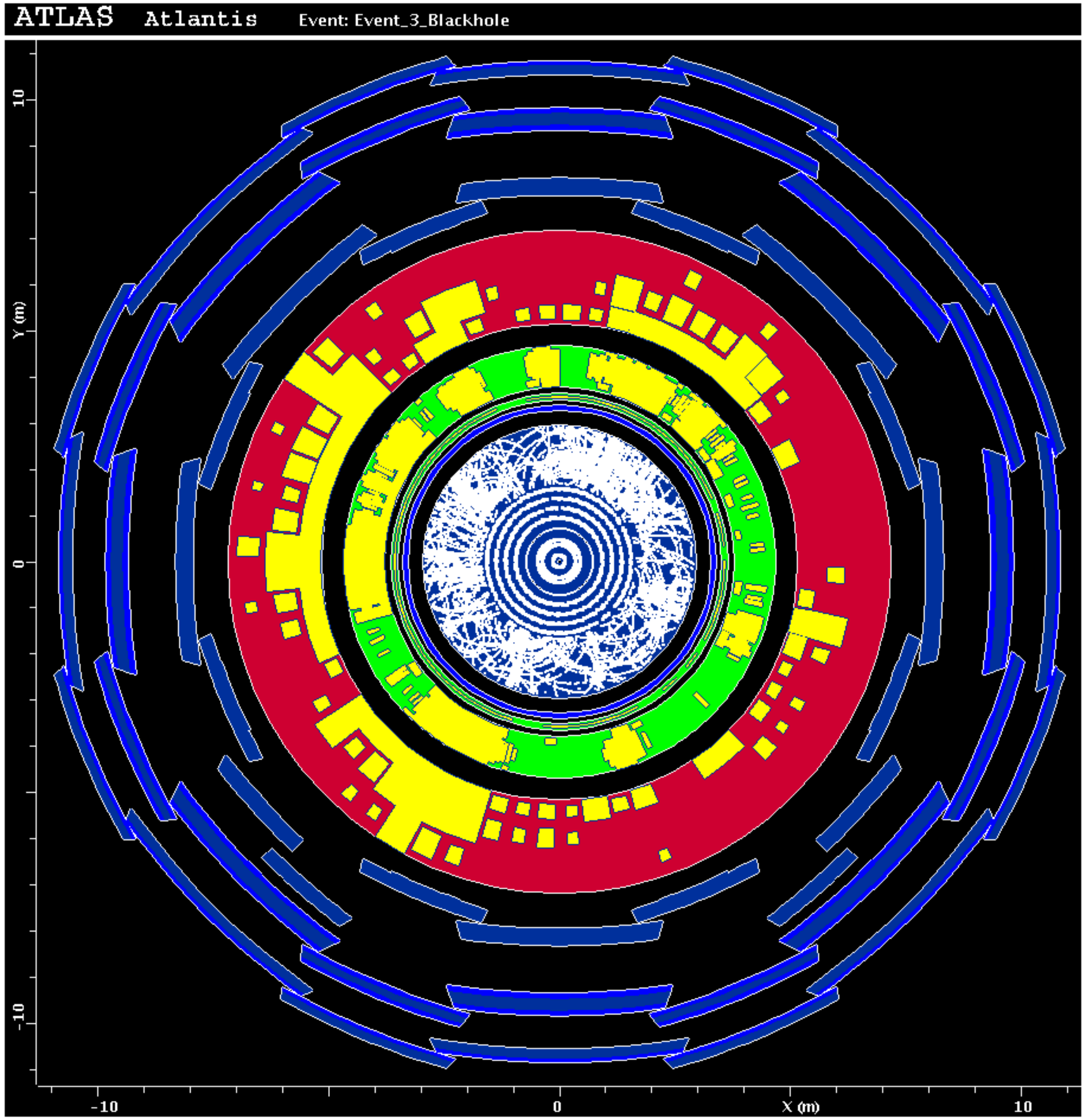
Super Symmetry (SUSY)

$$\tilde{u}_R \rightarrow u + \tilde{\chi}_1^0$$

$$\bar{\tilde{u}}_R \rightarrow \bar{u} + \tilde{\chi}_1^0$$

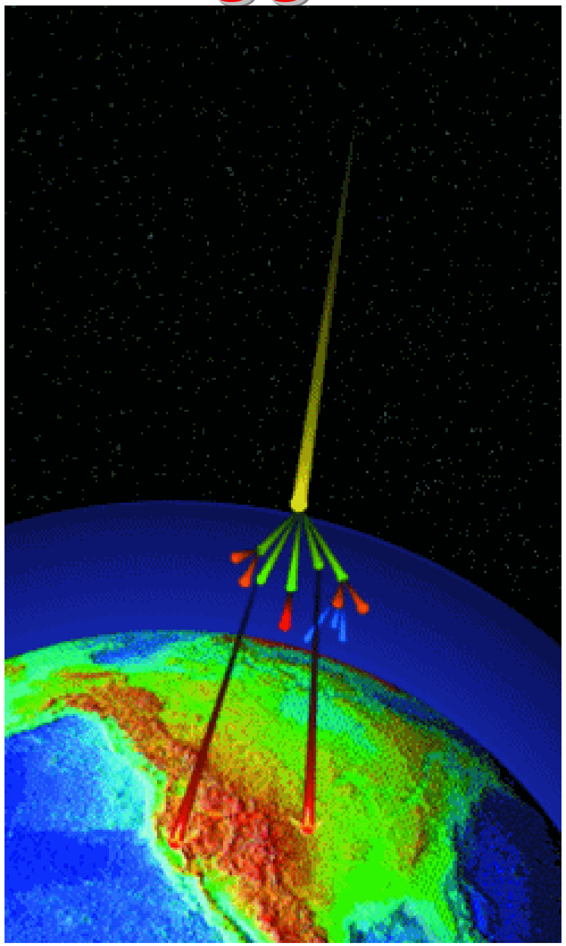


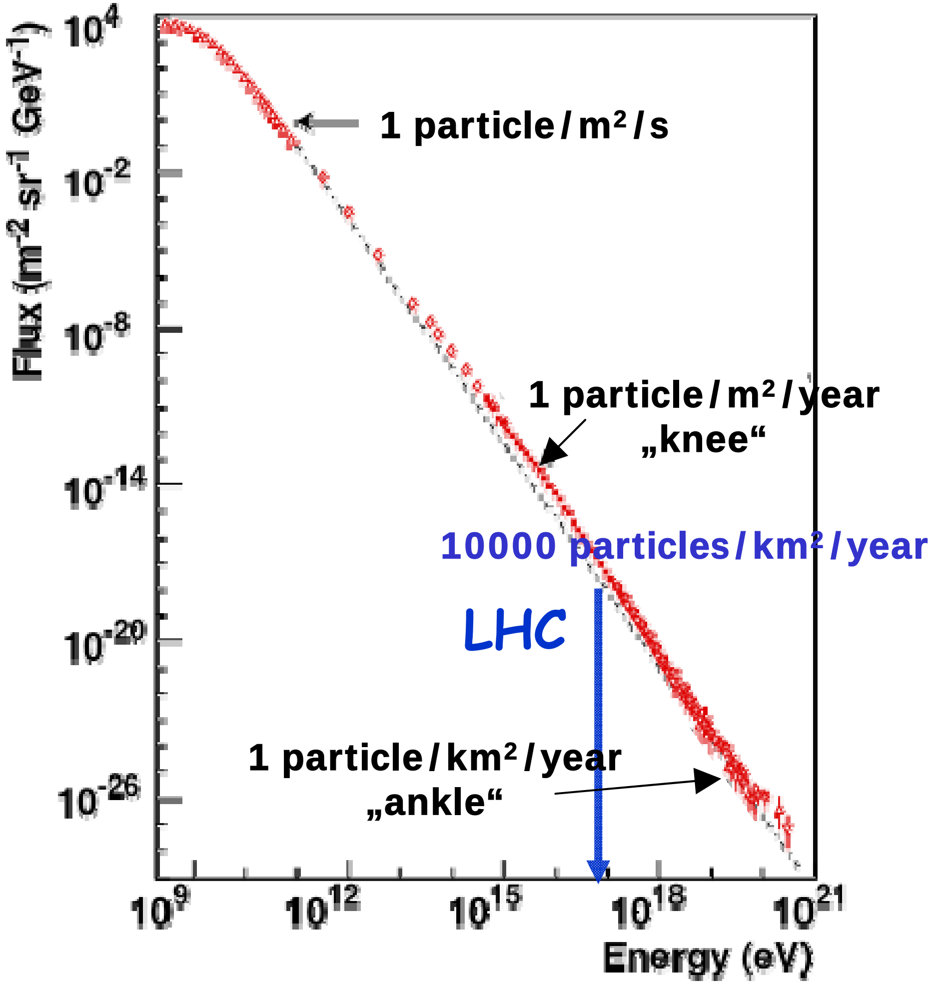
Black Hole



BackUp

The biggest accelerator is the Universe





Cosmic ray particles bang on the higher atmosphere at energies far higher than the LHC can provide – but at low rates and unknown directions

- **At the LHC 10^9 collisions take – place every second**

The Mass of the Higgs Particle

- **The Standard Model says (almost) nothing about the mass of the Higgs boson:**
  - **"Mass" is a real riddle in particle physics**
  - **From experiments (LEP) we know: M_{Higgs} > 114 GeV (122 M_{Proton})**
  - **Theoretical considerations: M_{Higgs} < 195 GeV (210 M_{Proton})**
  - **The Higgs boson is either found within these bounds…**
  - **… or, we physicists, need to find a better explanation for why particles have mass**
    - **some physicists have proposals**
      - not favoured by many
      - but no conclusion possible without experimental facts
    - **One needs to ask nature; i.e. to make an experiment and to measure whether there is such a thing as the Higgs boson**