The CMS Experiment at CERN

Claudia-Elisabeth Wulz

Institute for High Energy Physics of the Austrian Academy of Sciences Vienna

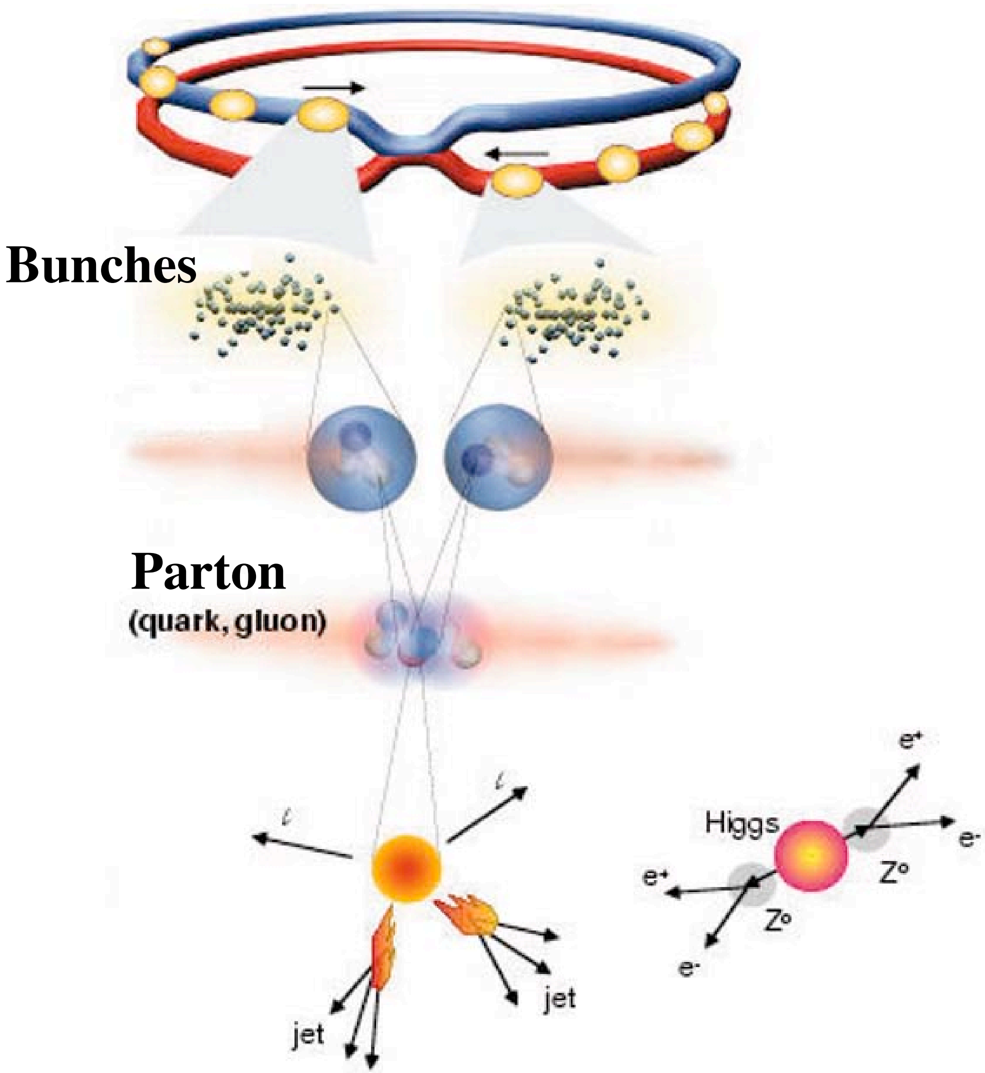
SPIE Conference

Warsaw, 31 August 2005

Some important open physics questions

Where do particle masses come from ?
Does the Higgs boson exist ?
What comes after the Standard Model (Supersymmetry, …) ?
Are there more than 3 generations of quarks and leptons ?
What role do massive neutrinos play ?
Is there a quark-gluon plasma ?
What is dark matter (heavy SUSY-particles, axions, …) ?
Can all forces be unified?
How can gravity be accommodated ?
What is dark energy ?
Are there extra dimensions ?
How did the universe emerge ?
Why is there so much more matter than antimatter?
-> The Large Hadron Collider (LHC) will shed light on most questions!

Properties of the Large Hadron Collider



Proton-Proton

Circumference: 27 km
Number of bunches: 3564 + 3564
Protons per bunch: 10^{11}
Beam energy: 2 x 7 TeV
Luminosity: 10^{34} $cm^{-2}s^{-1}$
Bunch crossing interval: 25 ns
Collision rate: 10^7 … 10^9 Hz
Flux density of dipole magnets: 8.33 T
Number of dipole magnets: 1232

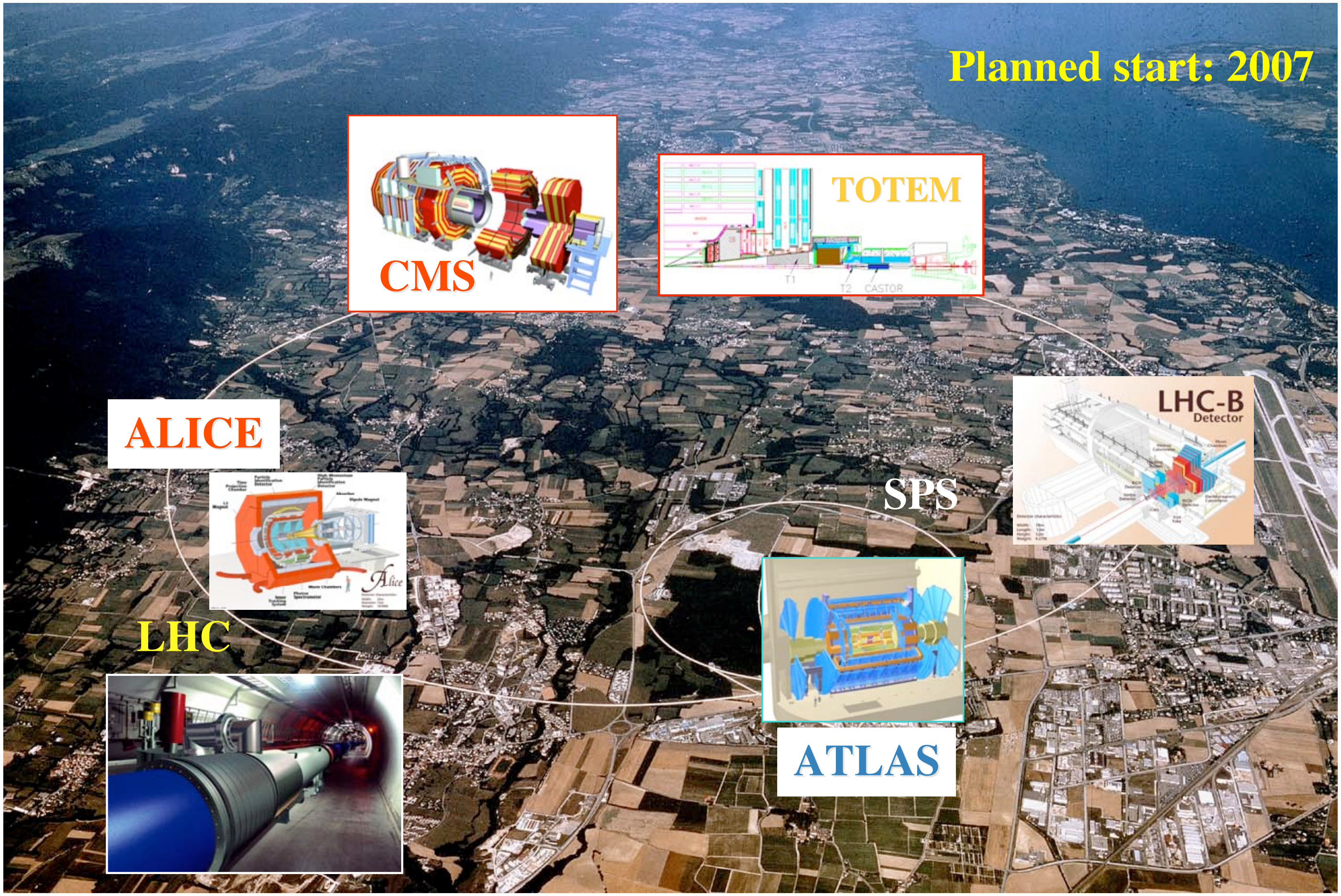
Heavy ions (Pb-Pb, S-S, etc.)
Beam energy: 5.5 TeV per nucleon pair
Luminosity:
10^{27} $cm^{-2}s^{-1}$ for lead
$3 \cdot 10^{31}$ $cm^{-2}s^{-1}$ for oxygen
Bunch crossing interval : 125 ns

LHC components

String tests of LHC magnets

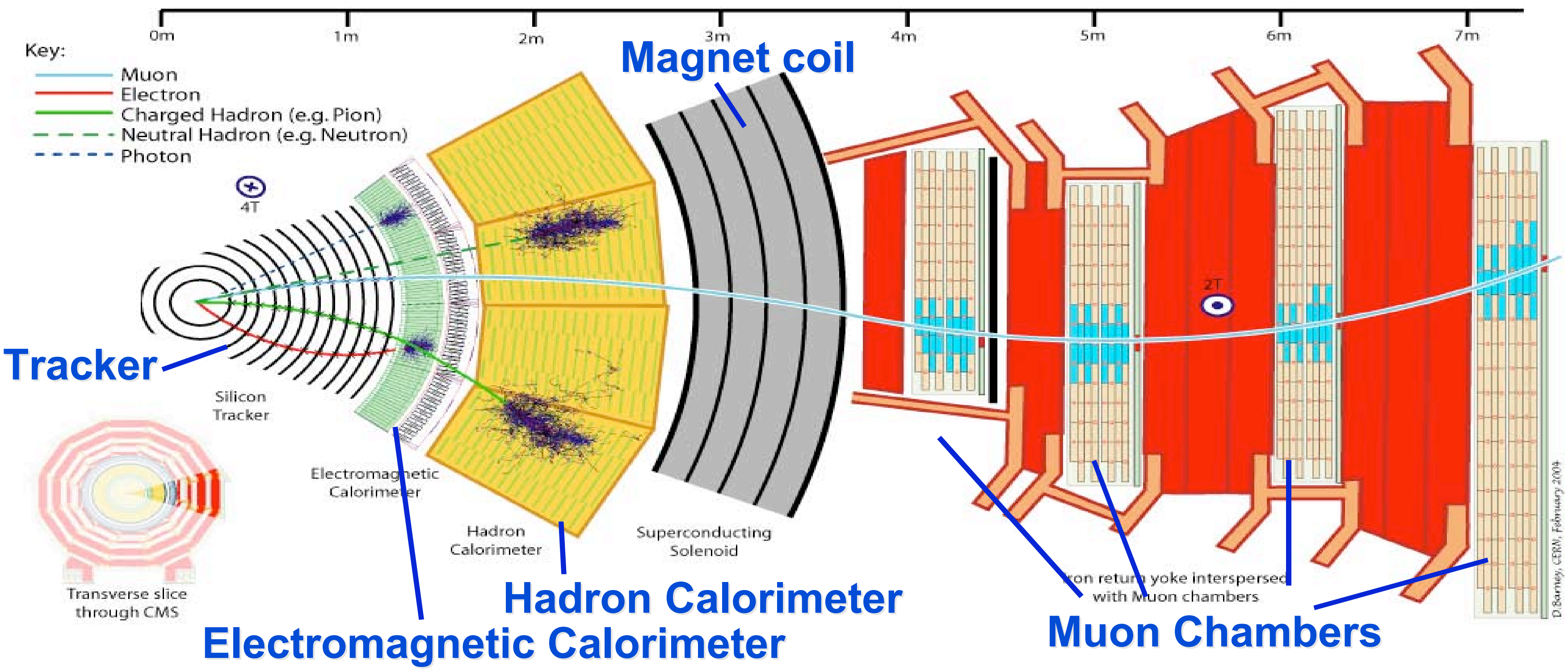
Superconducting RF cavity

Experiments at the Large Hadron Collider

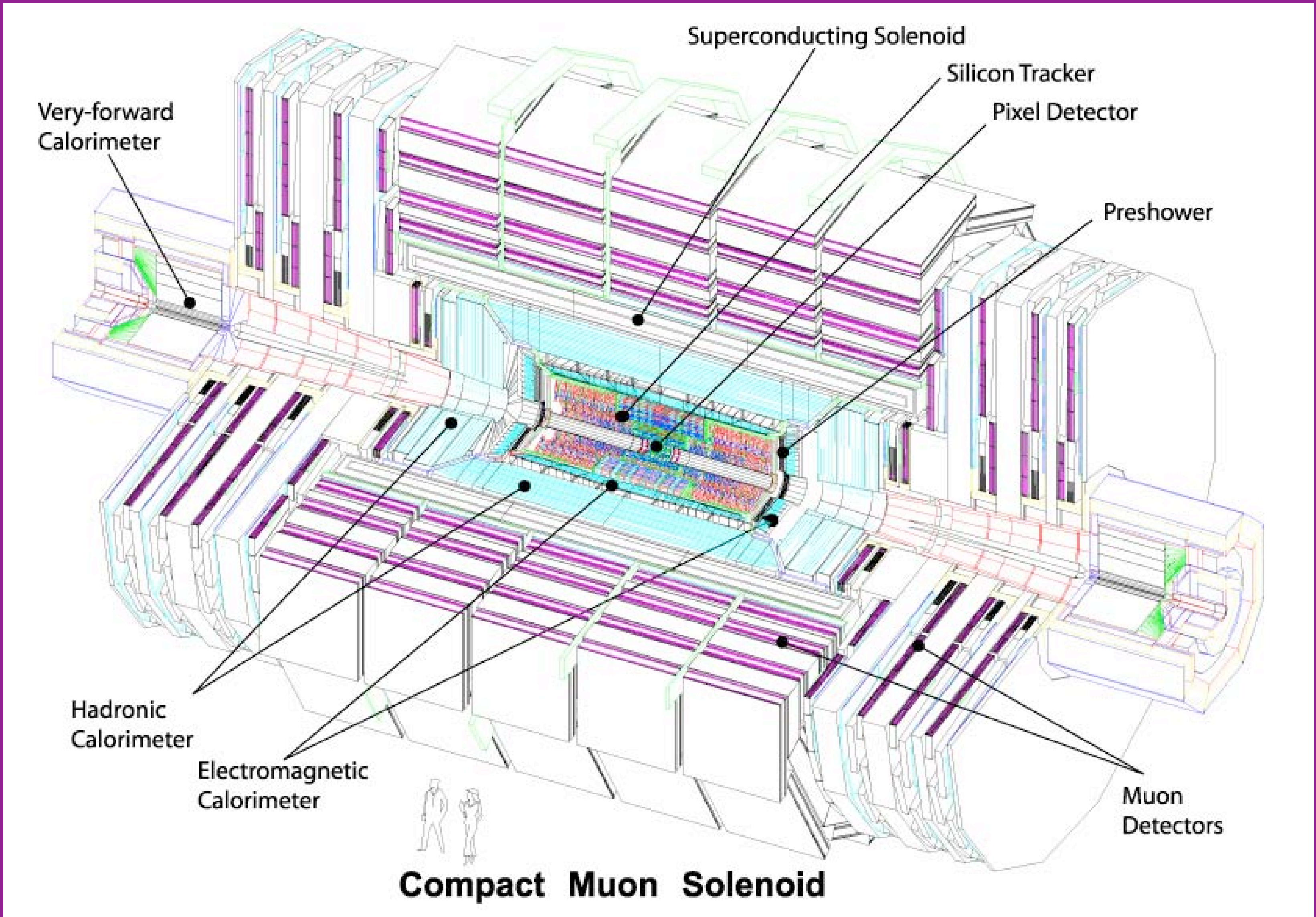


CMS - a typical high energy physics experiment

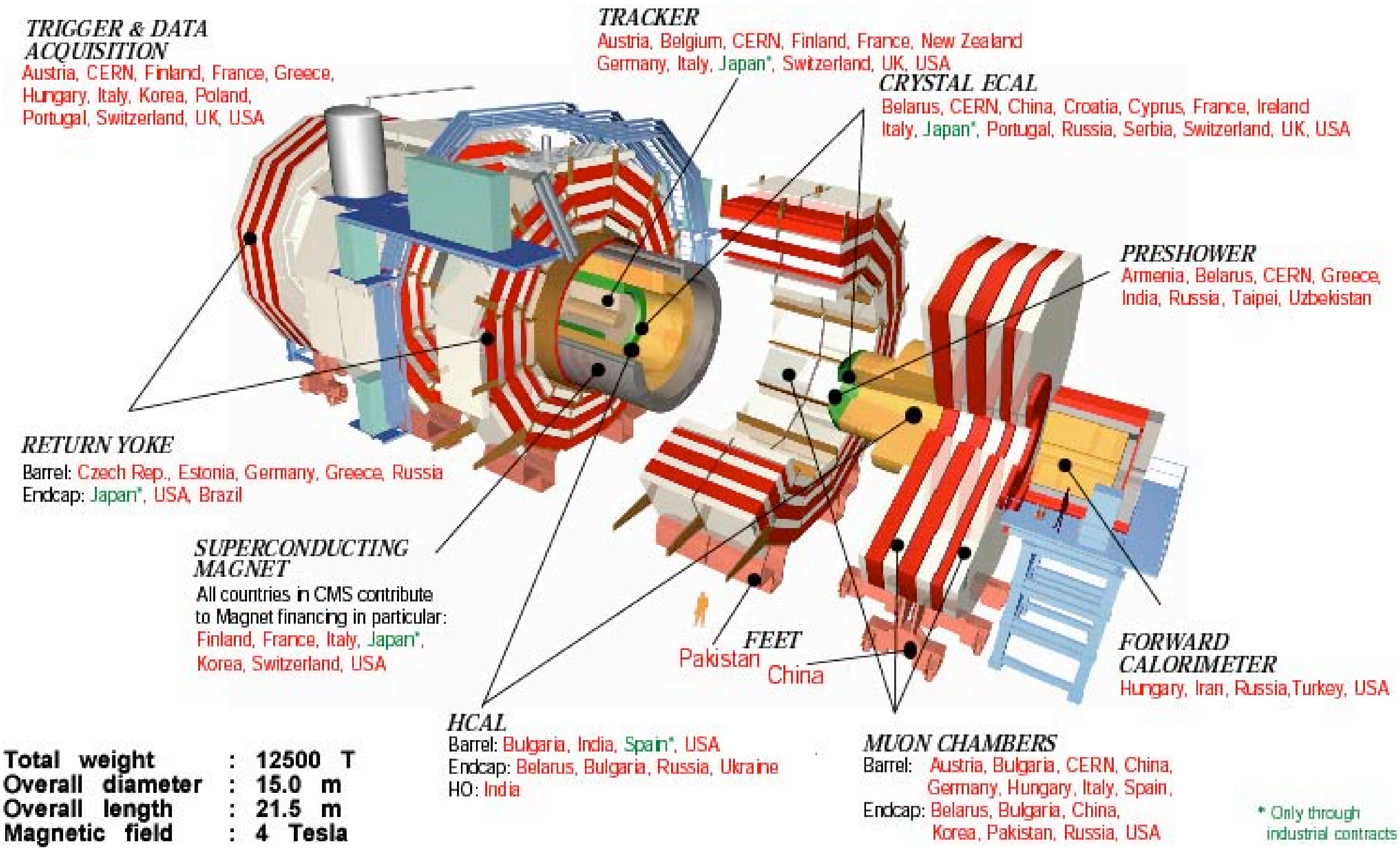
No single detector can identify particles and measure their location, momentum, energy and timing -> need multiple detectors, whch are interrelated in the analysis.



CMS Detector



CMS Collaboration

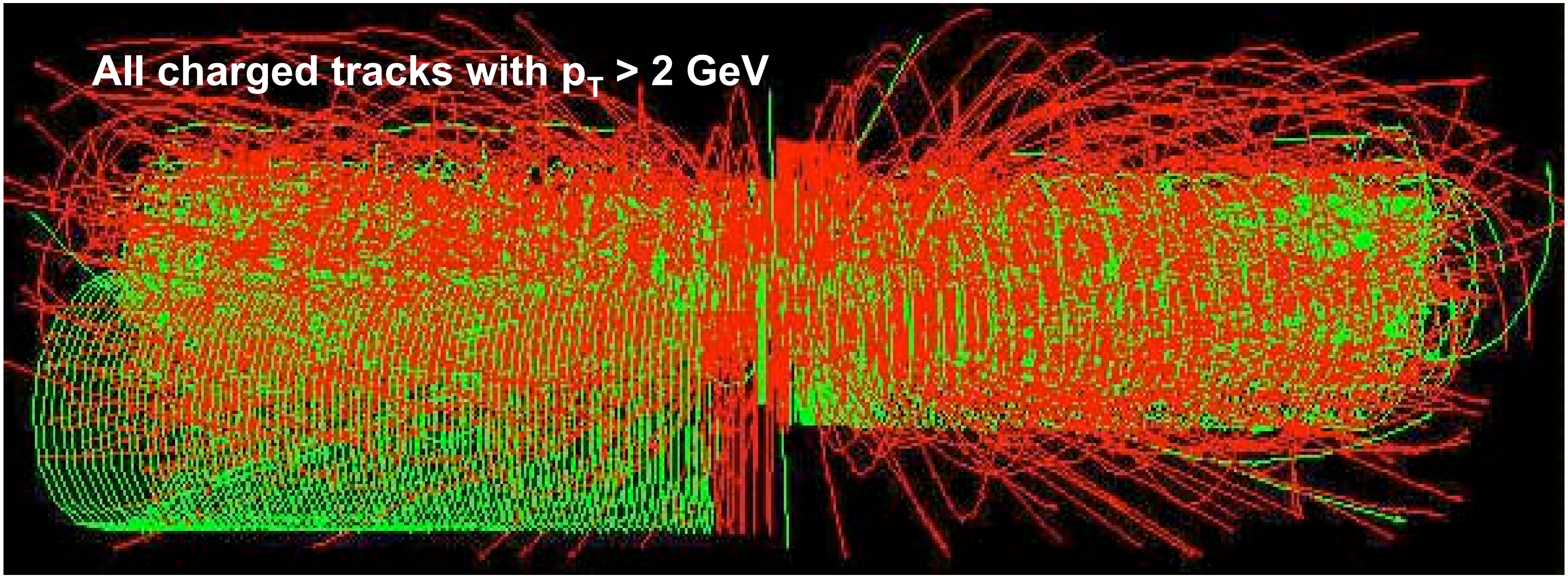


Total weight	**:**	**12500 T**
Overall diameter	**:**	**15.0 m**
Overall length	**:**	**21.5 m**
Magnetic field	**:**	**4 Tesla**

Tracks in CMS

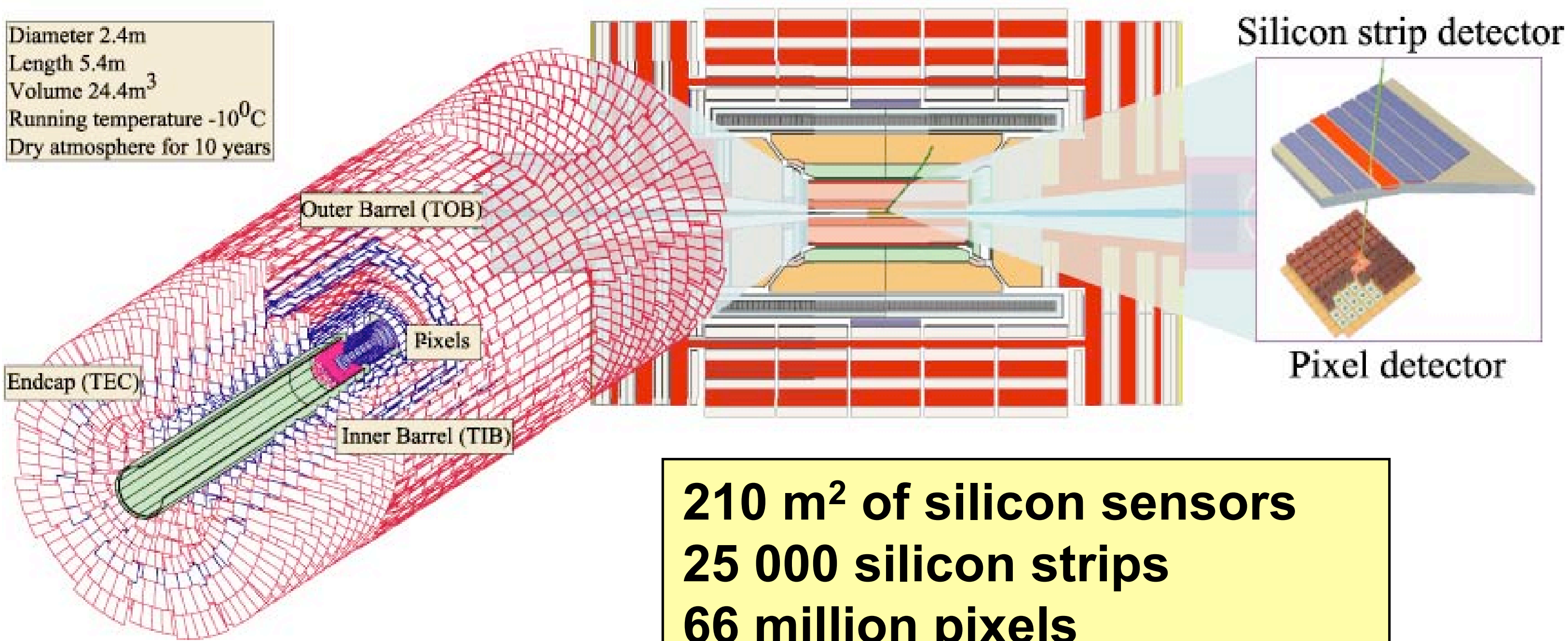
On average ~ 20 proton-proton interactions are superimposed, giving rise to a large number of particles.

Is there a Higgs particle ?



Silicon Tracker

The Tracker records trajectories of charged particles and measures their spatial coordinates, transverse momenta and electric charges. The innermost part is the Pixel Detector, whose main purpose is to identify vertices. It is surrounded by the Inner Tracker (TIB, TOB, TEC).



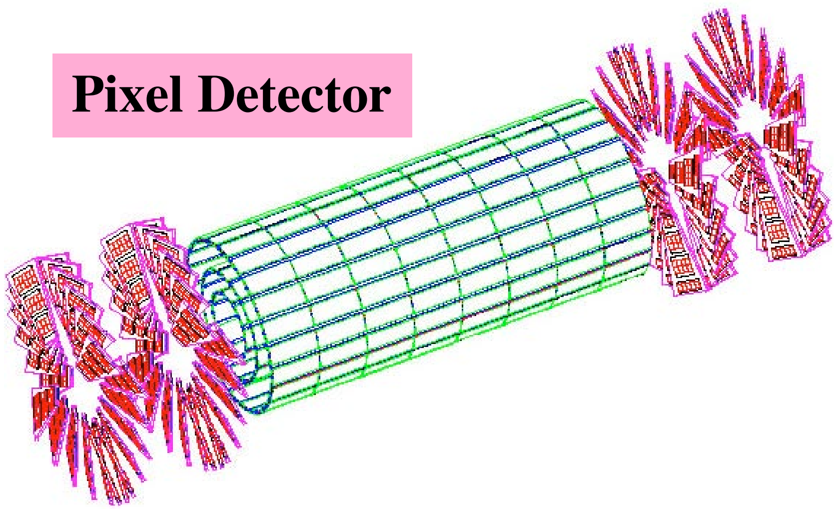
210 m^2 of silicon sensors
25 000 silicon strips
66 million pixels

10 million readout channels

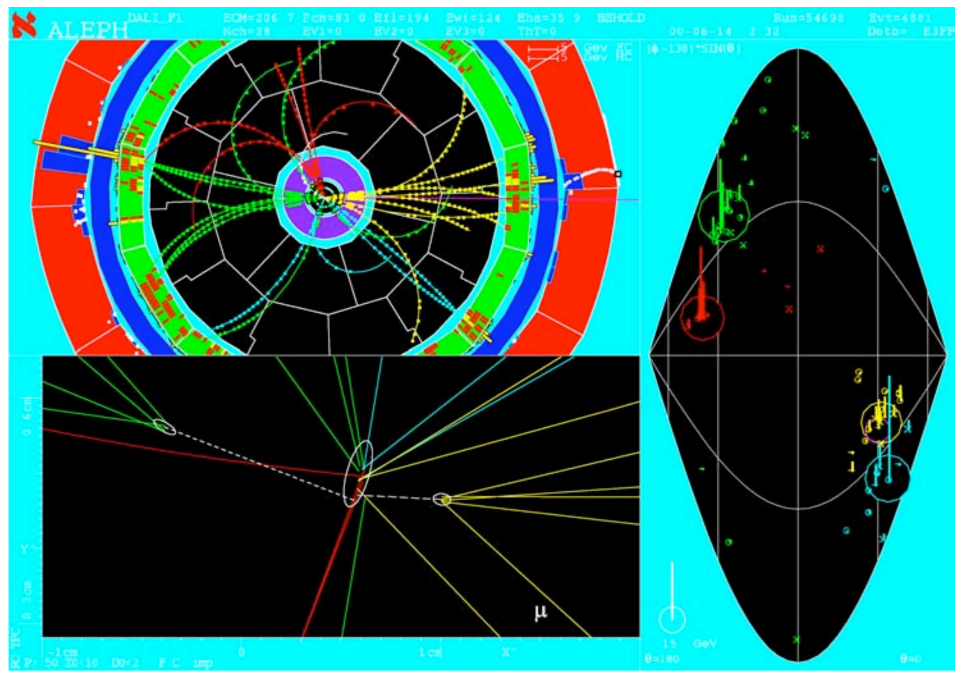
Pixel Detector Purpose and Layout

It surrounds the interaction point. Barrel layers are at radii 4, 7, and 11 cm. Forward layers are at ±34 and ±46 cm from interaction point. Its silicon pads provide high-resolution (10 to 20 μm) patterns of space points. Secondary vertices, which may arise from particles containing Beauty-Quarks, are identified. Such particles are especially important in the search for the Higg particle or for Supersymmetry.

Pixel Detector

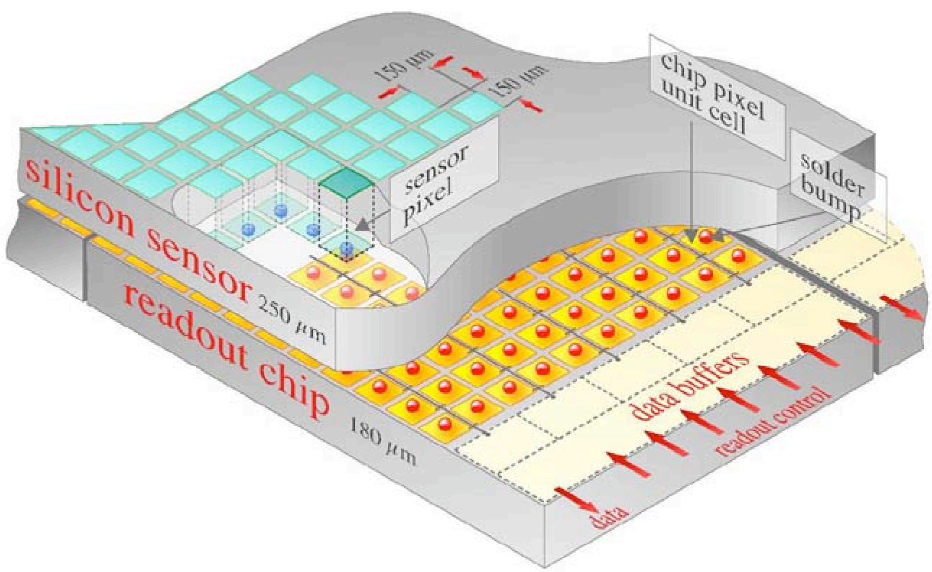


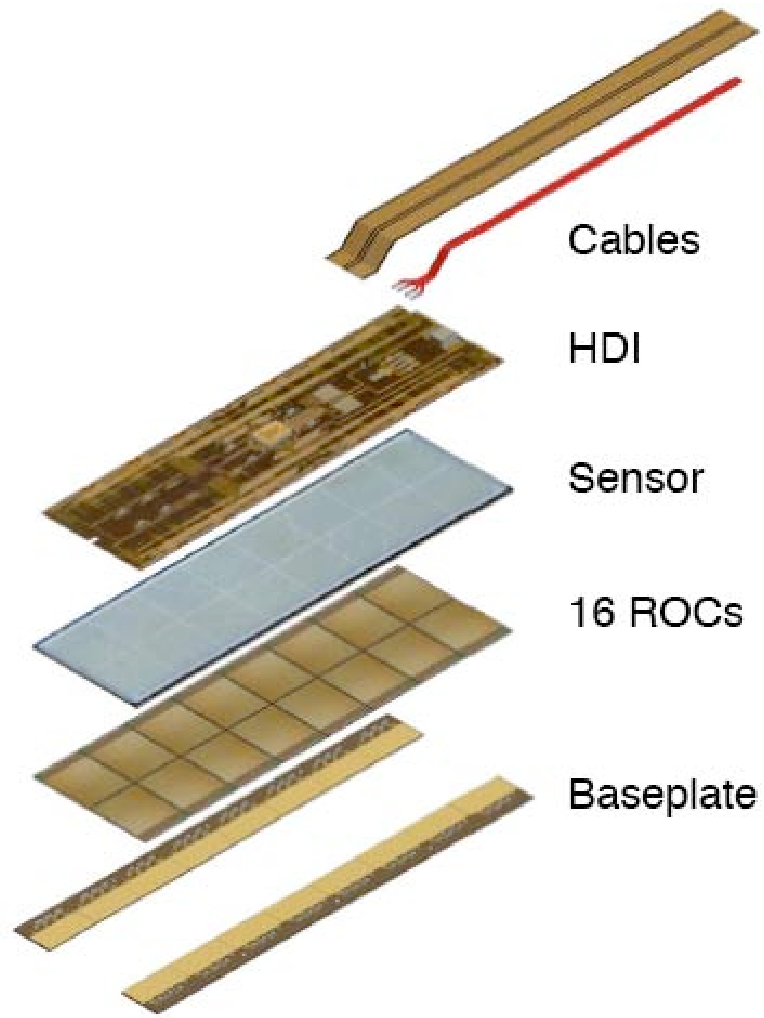
Possible Higgs event seen by ALEPH at LEP



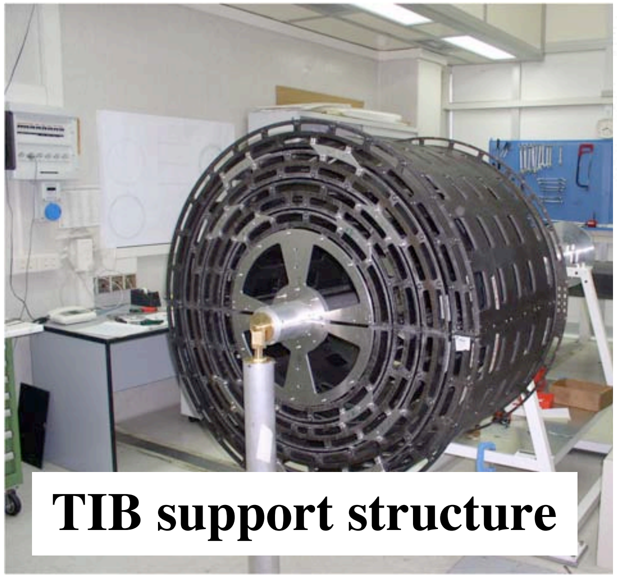
Pixel Detector Components

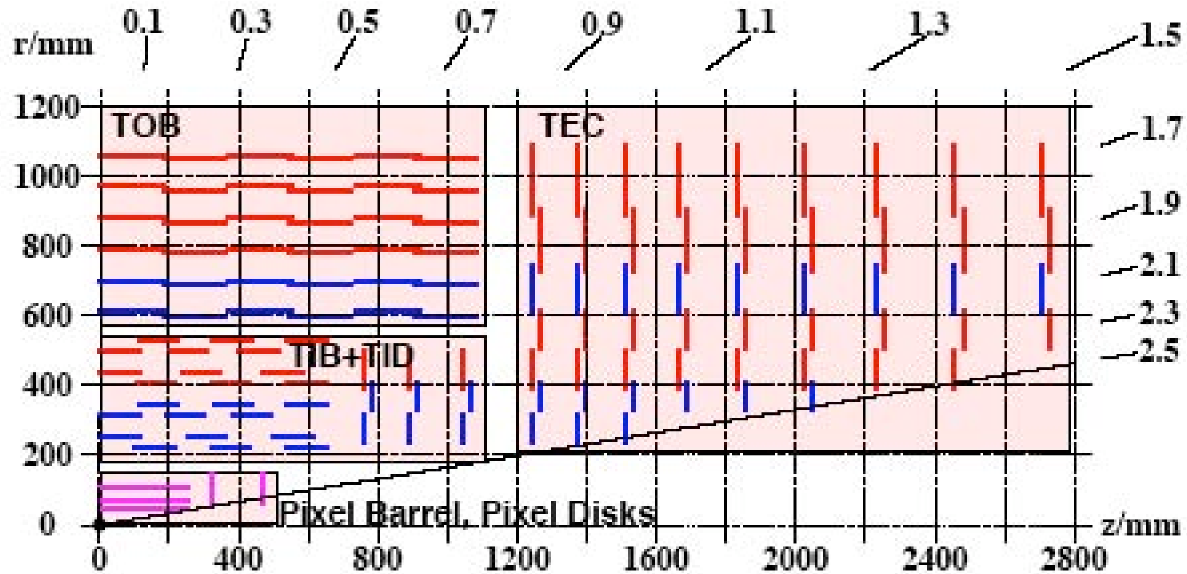
Pixel size 100 μm x 150 μm;
16000 readout chips (ROC) in 0.25 μm CMOS technology, bump-bonded to the silicon sensors;
Capton high-density interconnect boards (HDI) distribute signal and power lines;
Challenging radiation environment (100 Mrad in 10 years).

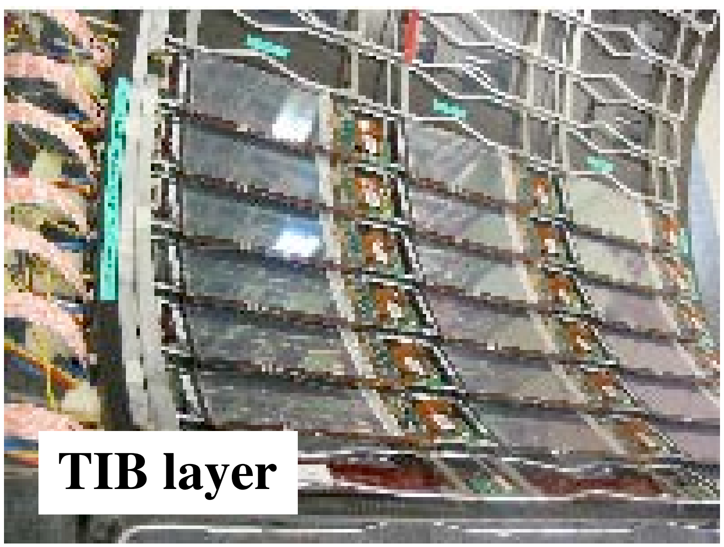


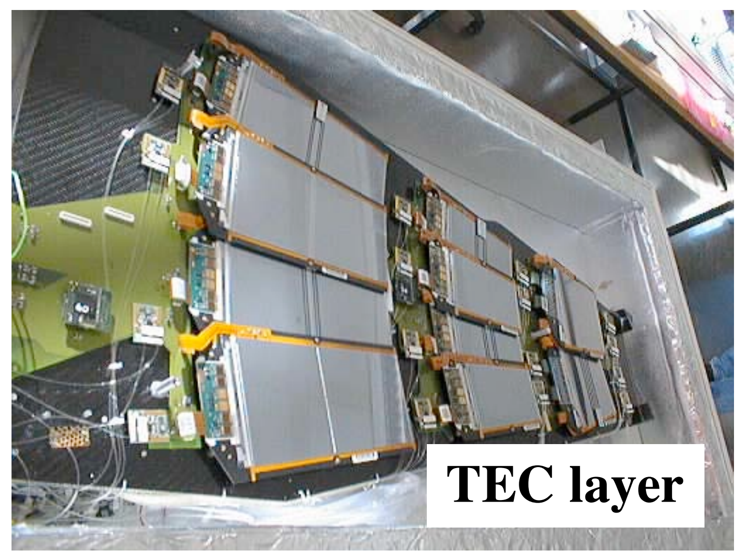


Inner Tracker Mechanics


TIB support structure

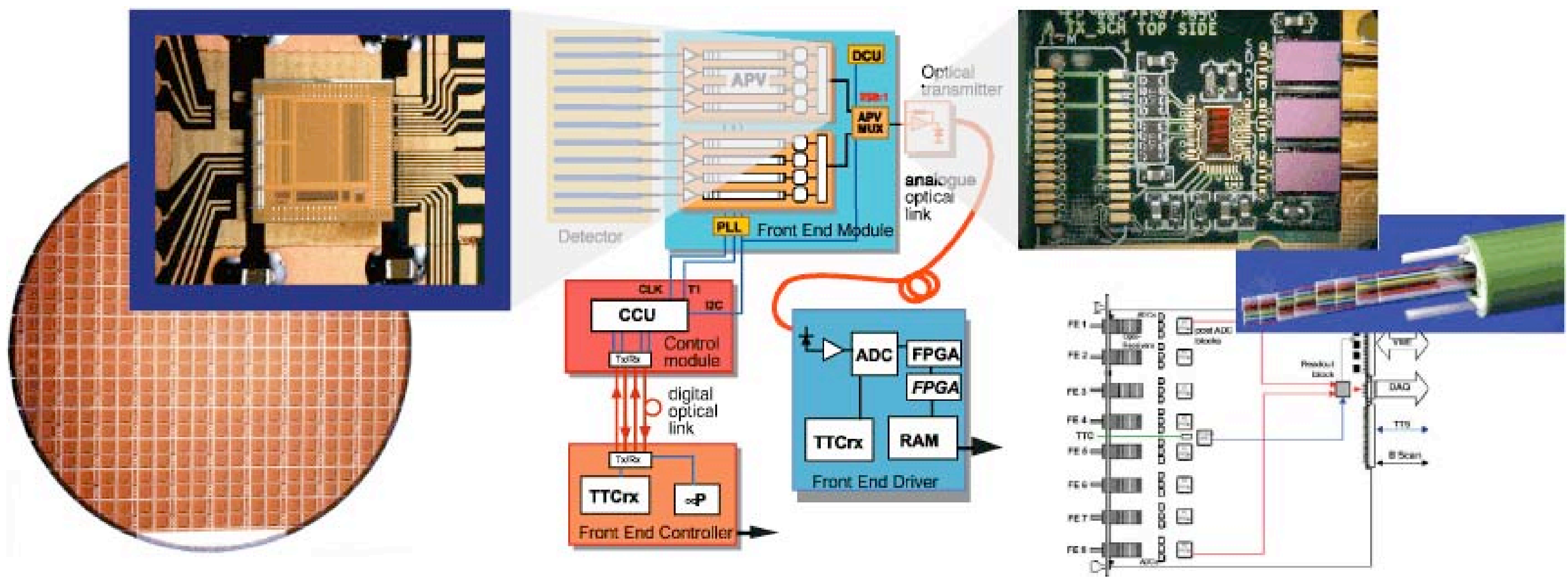



TIB layer


TEC layer

Inner Tracker Electronics

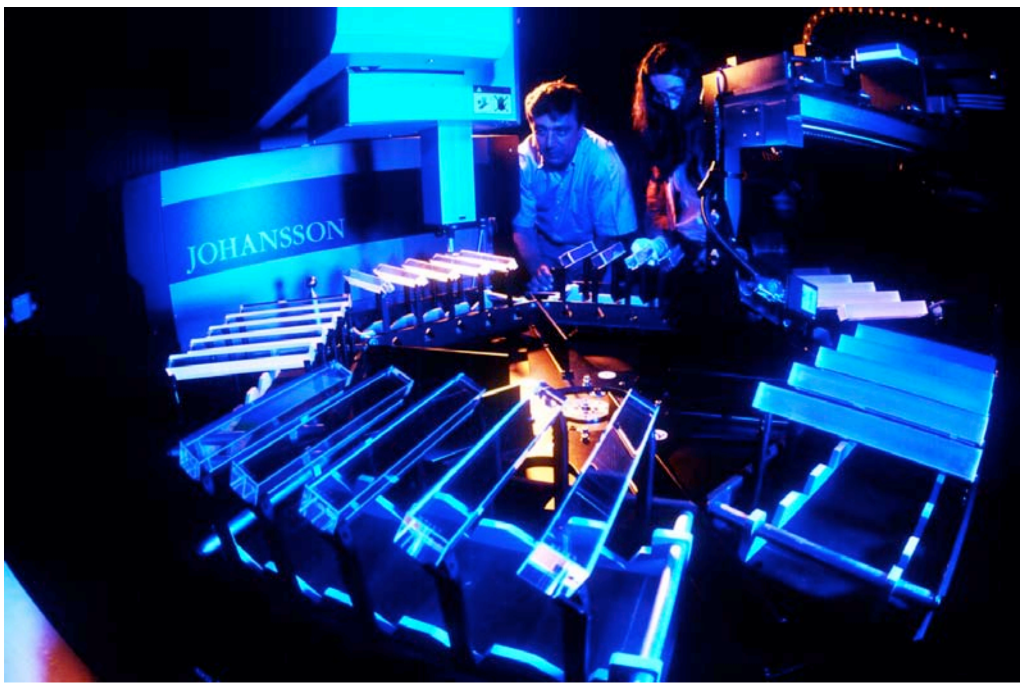
There are 15000 silicon microstrip detector modules, consisting of sensors with pitch of ~ 100 µm, a mechanical support structure and a frontend readout hybrid bonded to the sensors. 50000 optical fibes extract readout data through laser-driven opto-hybrids connected to the readout hybrids. Each APV chip is made in 0.25 µm CMOS technology and contains 128 channels.



Electromagnetic Calorimeter

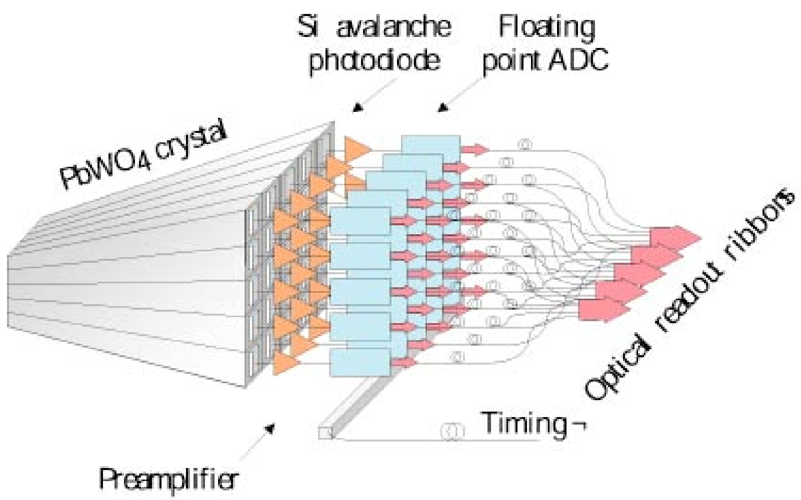
The energy of photons, electrons and positrons is deposited entirely in the lead tungstate ($PbWO_4$) crystal calorimeter. Scintillation light is produced and captured with photodetectors.

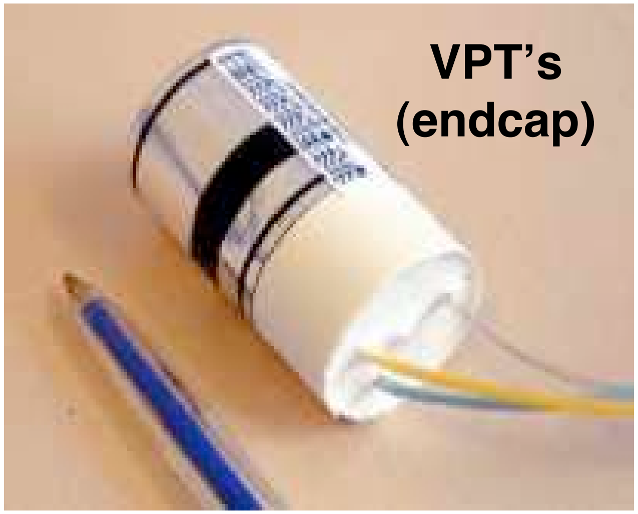
ECAL crystals and qualification machine

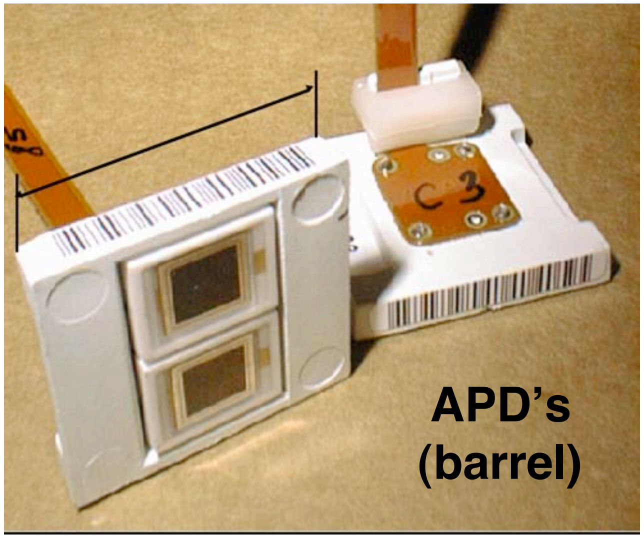


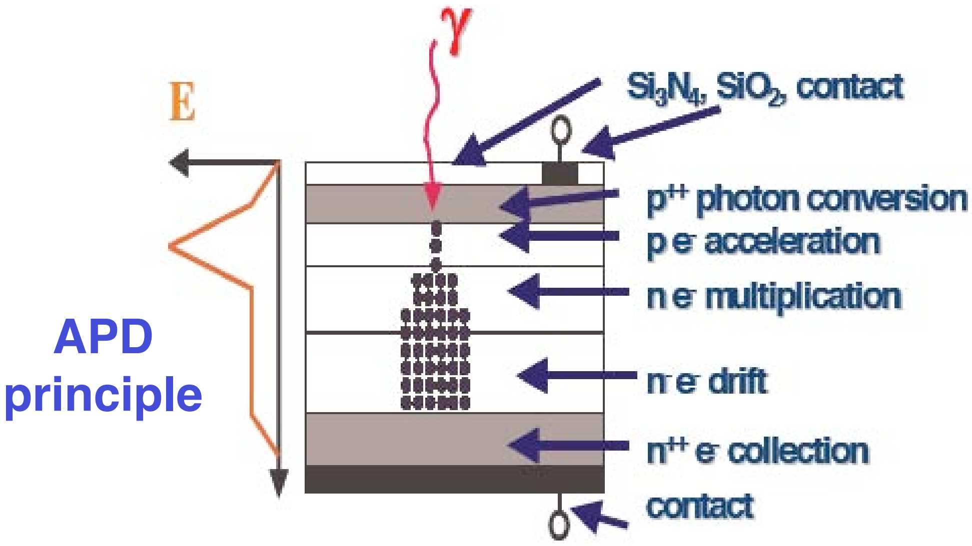
ECAL Supermodule production

Electromagnetic Calorimeter Readout



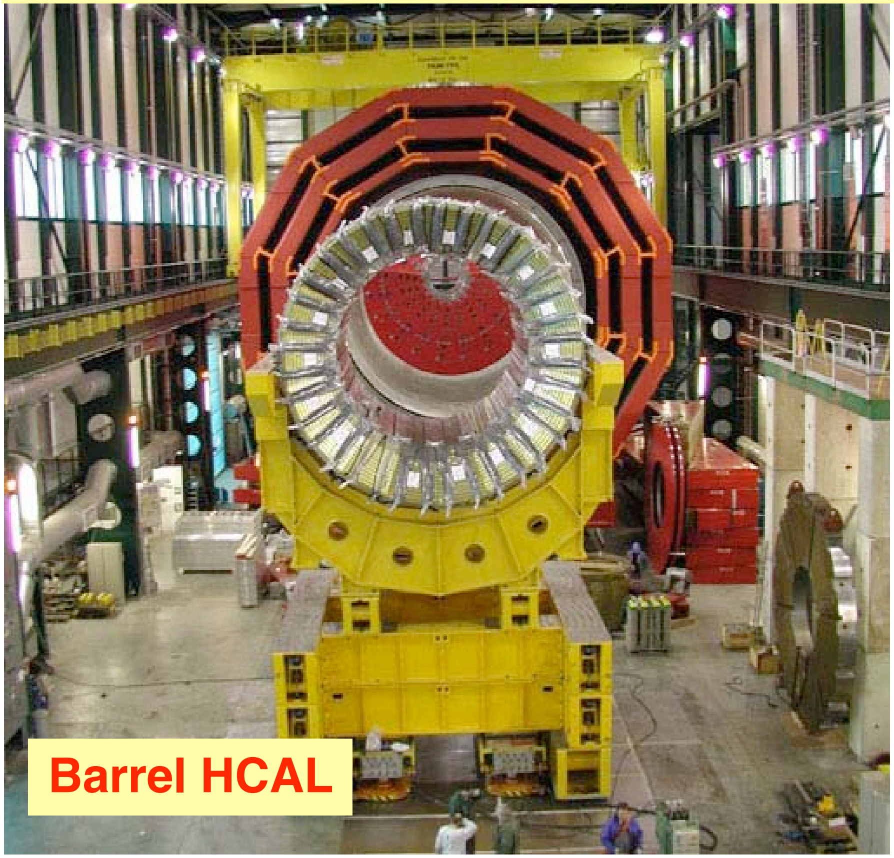




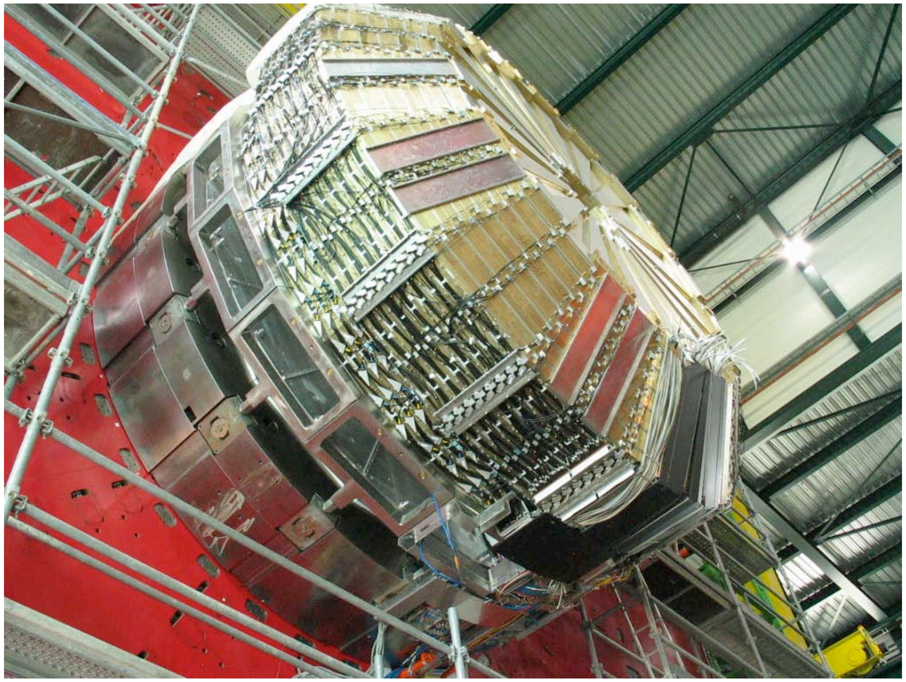


Hadron Calorimeter

Hadrons are particles that feel the strong interaction which binds nuclei together. They deposit practically all their energy in the HCAL. The central part (barrel + endcaps) consists of alternating plates of brass and plastic scintillator read out by photodiodes through wavelength shifting optical fibres.

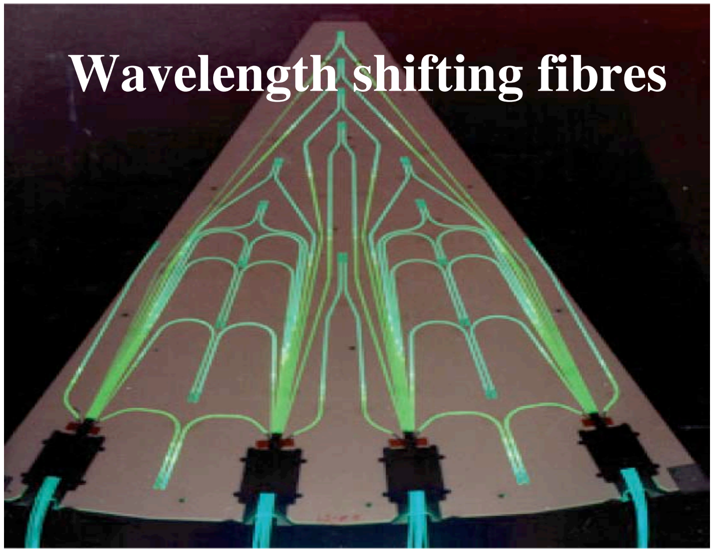


Barrel HCAL



Endcap HCAL

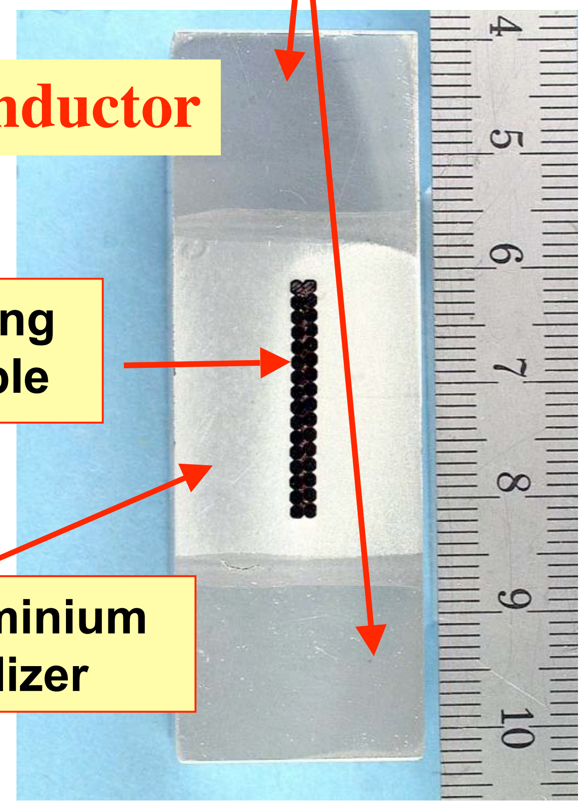
Hadron Calorimeter



In the very forward regions calorimetry is completed by the Very Forward HCAL made of steel absorber plates sampled by quartz fibres due to their good radiation tolerance. They are read out by conventional photomultipliers, since the magnetic flux density is much lower than in the central region.

Magnet Coil

The superconducting solenoid coil is the central piece of CMS. It provides a flux density of 4 T with a current of 19.5 kA and a precision of 10^{-6}. The flux returns through an iron yoke (1.8 T).

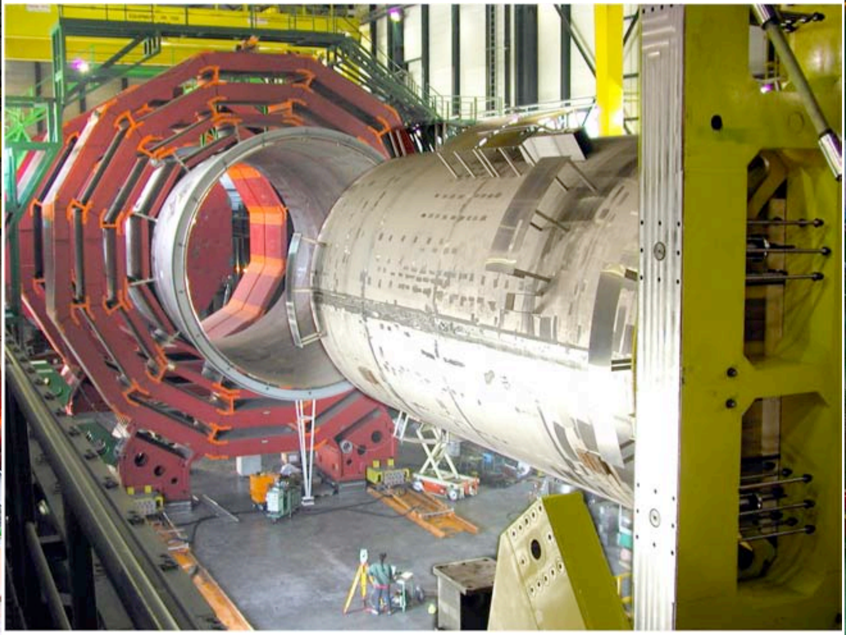


Magnet Coil and Yoke

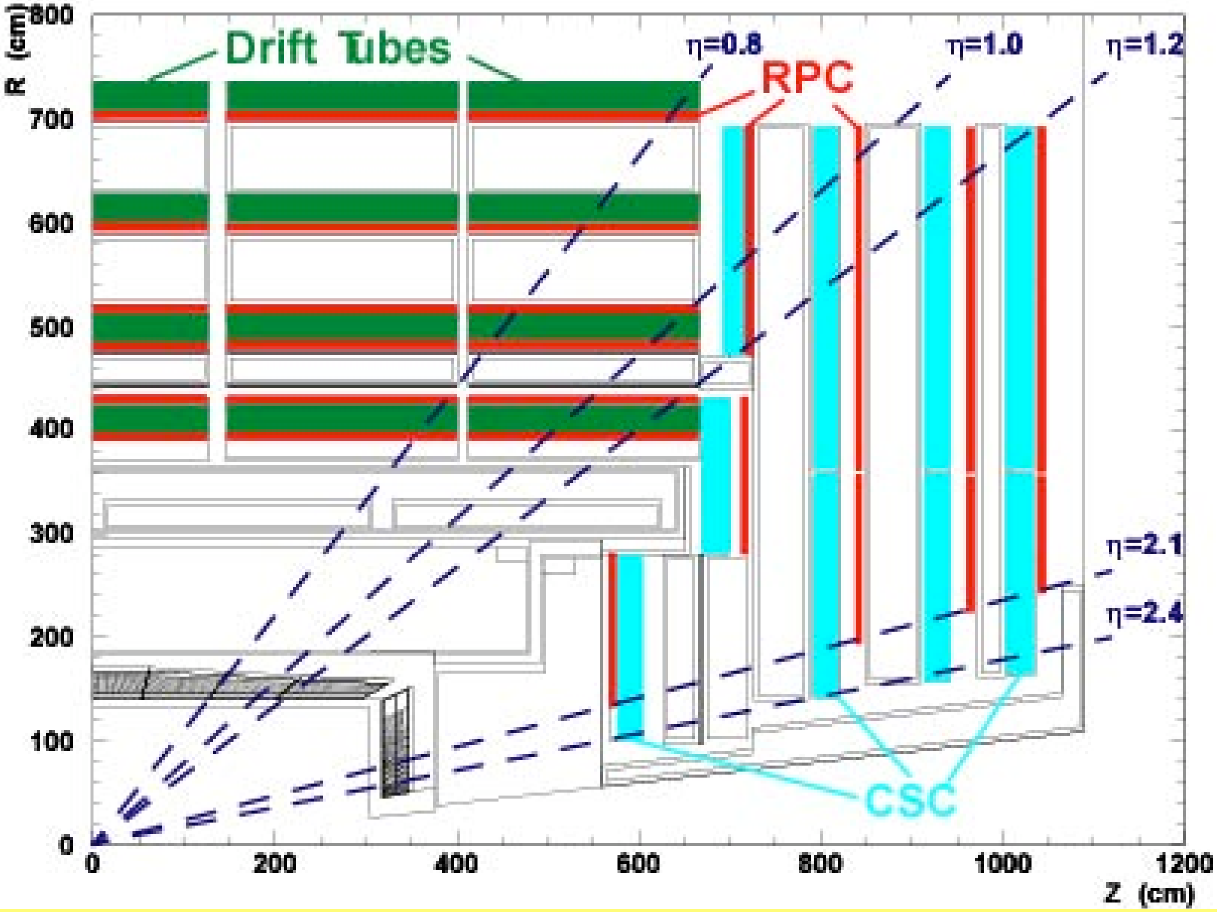
The coil, which has 3 safety systems to remove the 2.67 GJ energy if needed, is inserted into a vacuum vessel consisting of two concentric steel cylinders.

Return yoke (11000 tons of steel) controls the field outside of the coil, and acts as a filter for muons. It is built in sections: 5 barrel "rings" and 3+3 endcap "disks".

Barrel rings are divided into layers, interspersed with muon chambers; muon chambers are also placed on each endcap disk.



Muon System

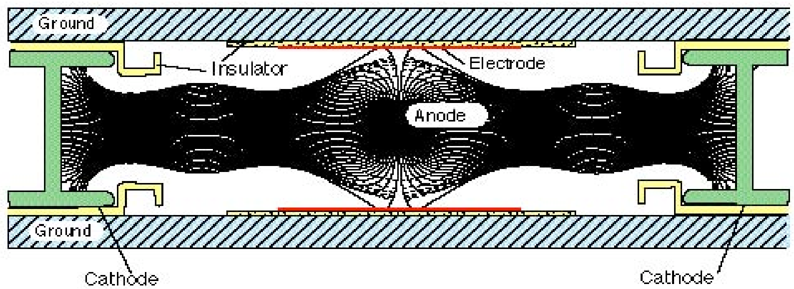


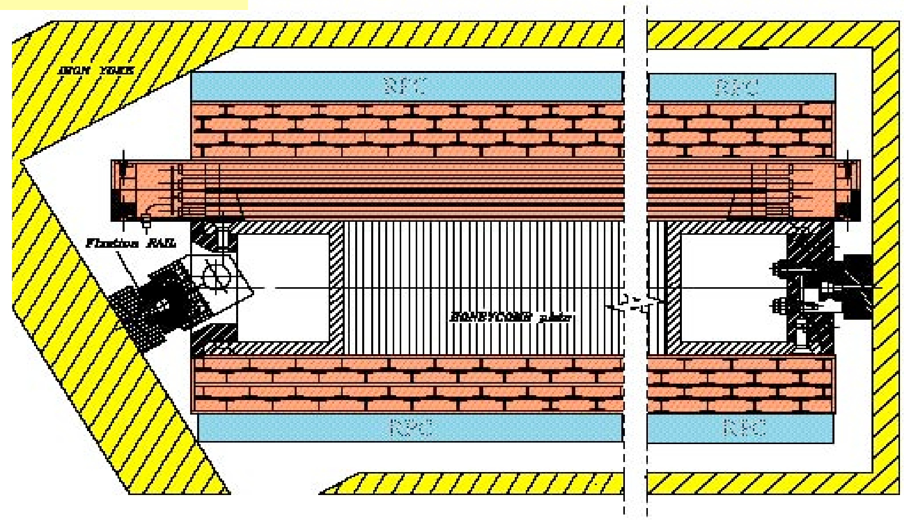
Drift Tube Chambers (DT) and Cathode Strip Chambers (CSC) are used for precision measurements and for triggering.

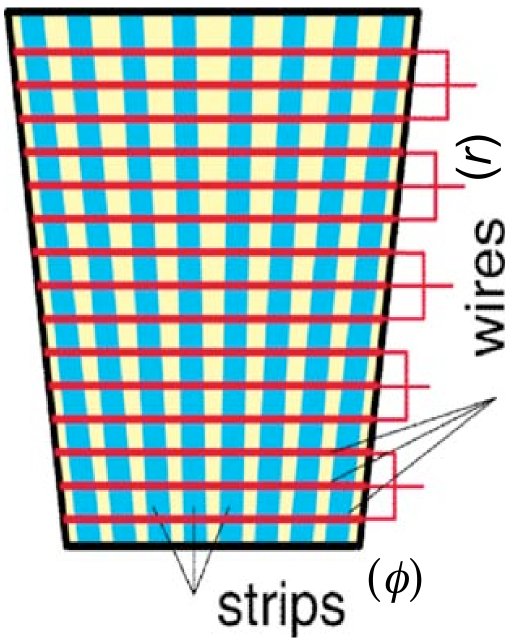
Resistive Plate Chambers (RPC's) are dedicated trigger chambers.

Muon Chambers

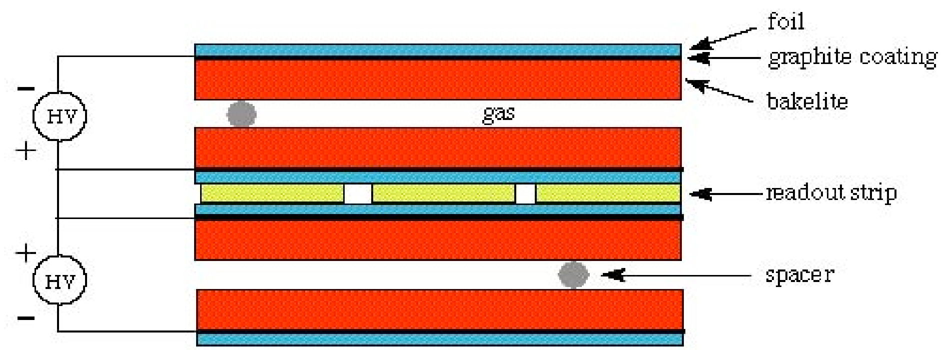
Drift cell and DT Chamber







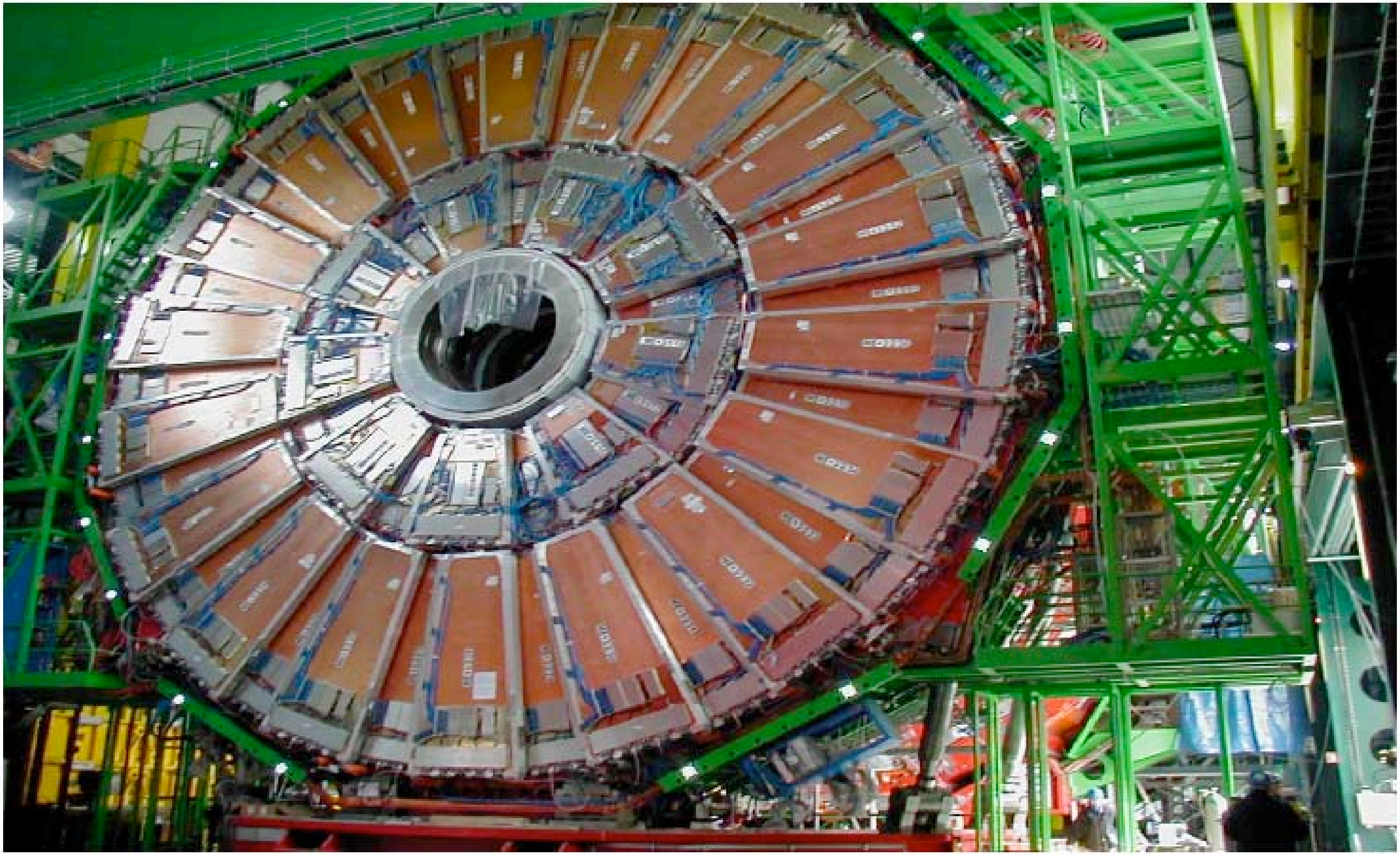
CSC chamber (1 of 6 planes)



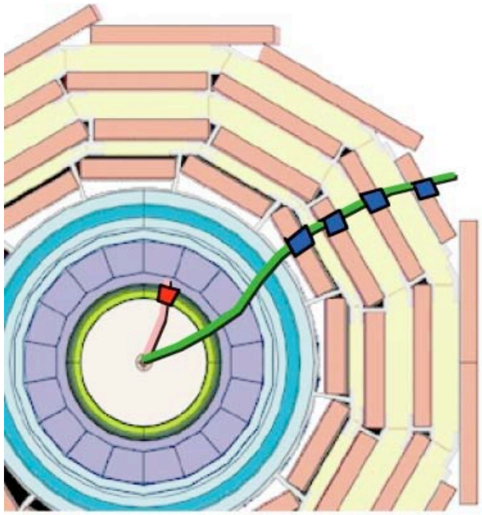
Double-gap RPC chamber

Barrel Yoke with Drift Tube Muon Chambers

Cathode Strip Endcap Muon Chambers

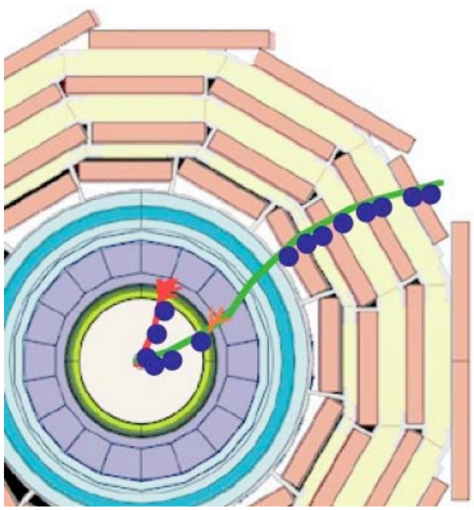


Trigger System



Level-1 Trigger

Macrogranular information from Calorimeters and Muon System (e, μ, jets, $E_T^{missing}$, E_T^{total})
Threshold and topology conditions possible
Latency: 3.2 μs
Input rate: 40 MHz
Output rate: up to 100 kHz (50 kHz at startup)
Custom designed electronics system

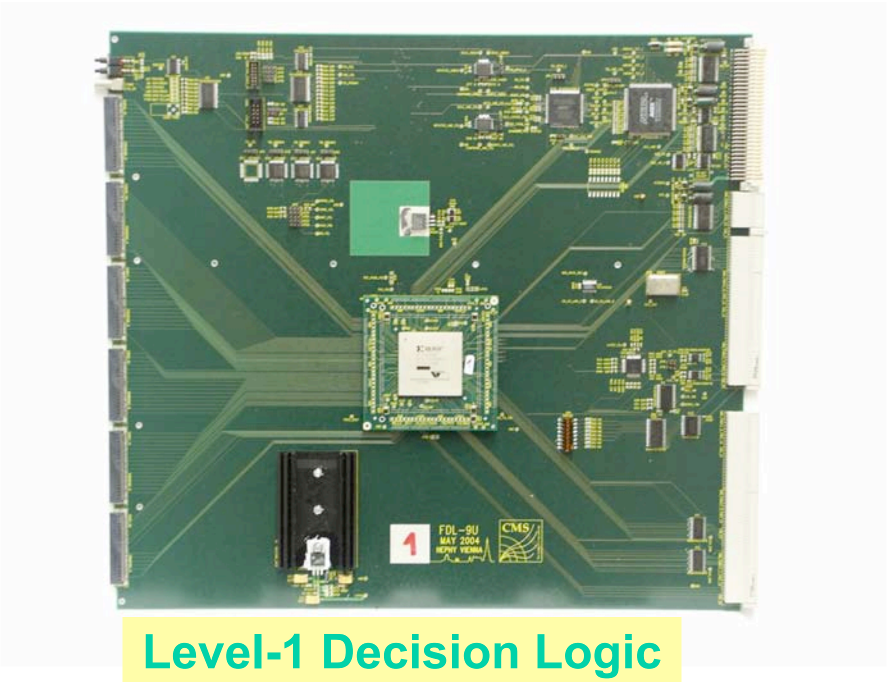


High Level Trigger (several steps)

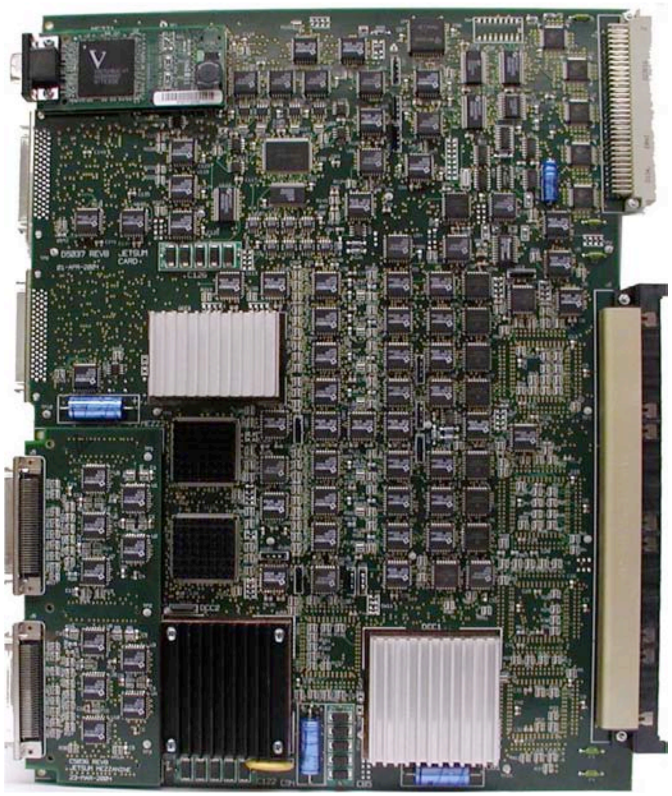
Precise information from Calorimeters, Muon System, Pixel Detector and Inner Tracker
Threshold, topology, mass, … criteria possible as well as matching with other detectors
Latency: between 10 ms and 1 s
Input rate: up to 100 kHz
Ouput (data acquisition) rate: approx. 100 Hz
Industrial processors and switching network

Level-1 Trigger Hardware

Fast electronics (40 MHz and more) is needed for the Level-1 Trigger.



Level-1 Decision Logic (FPGA)



Level-1 Calorimeter Trigger Board (ASIC)

RPC Trigger Boards: See Warsaw contribution to this Conference

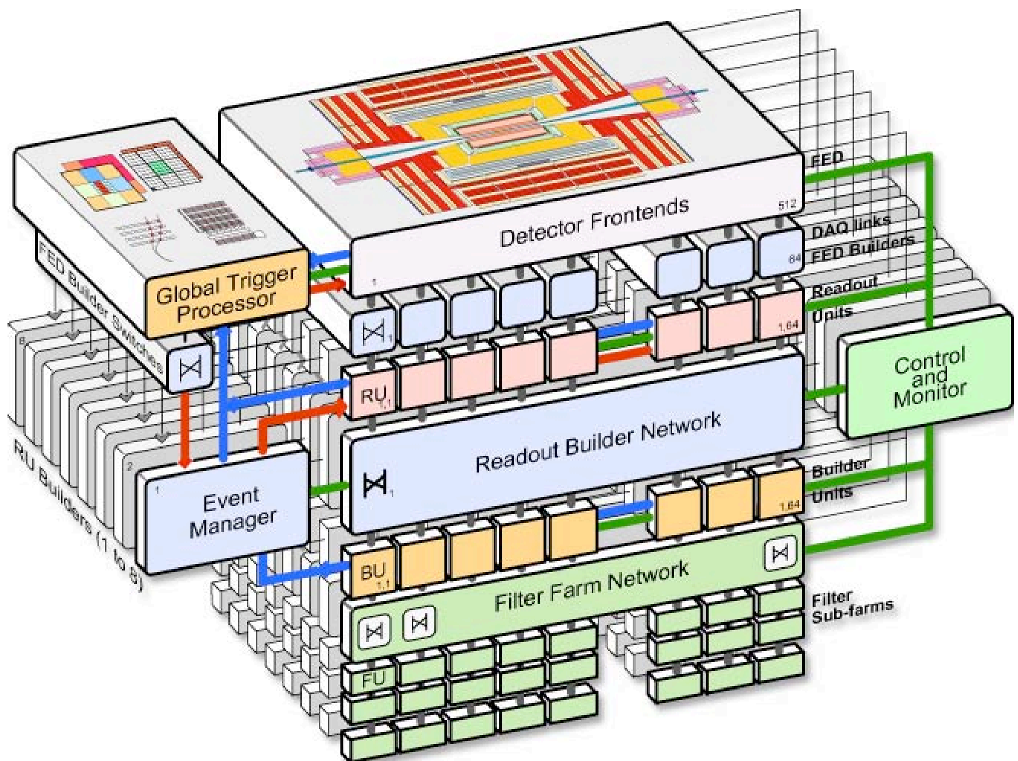
Trigger and Data Acquisition Architecture

Interconnection of processors and frontend

Frontend has O(1000) modules -> necessity for large switching network.

Estimated processing time

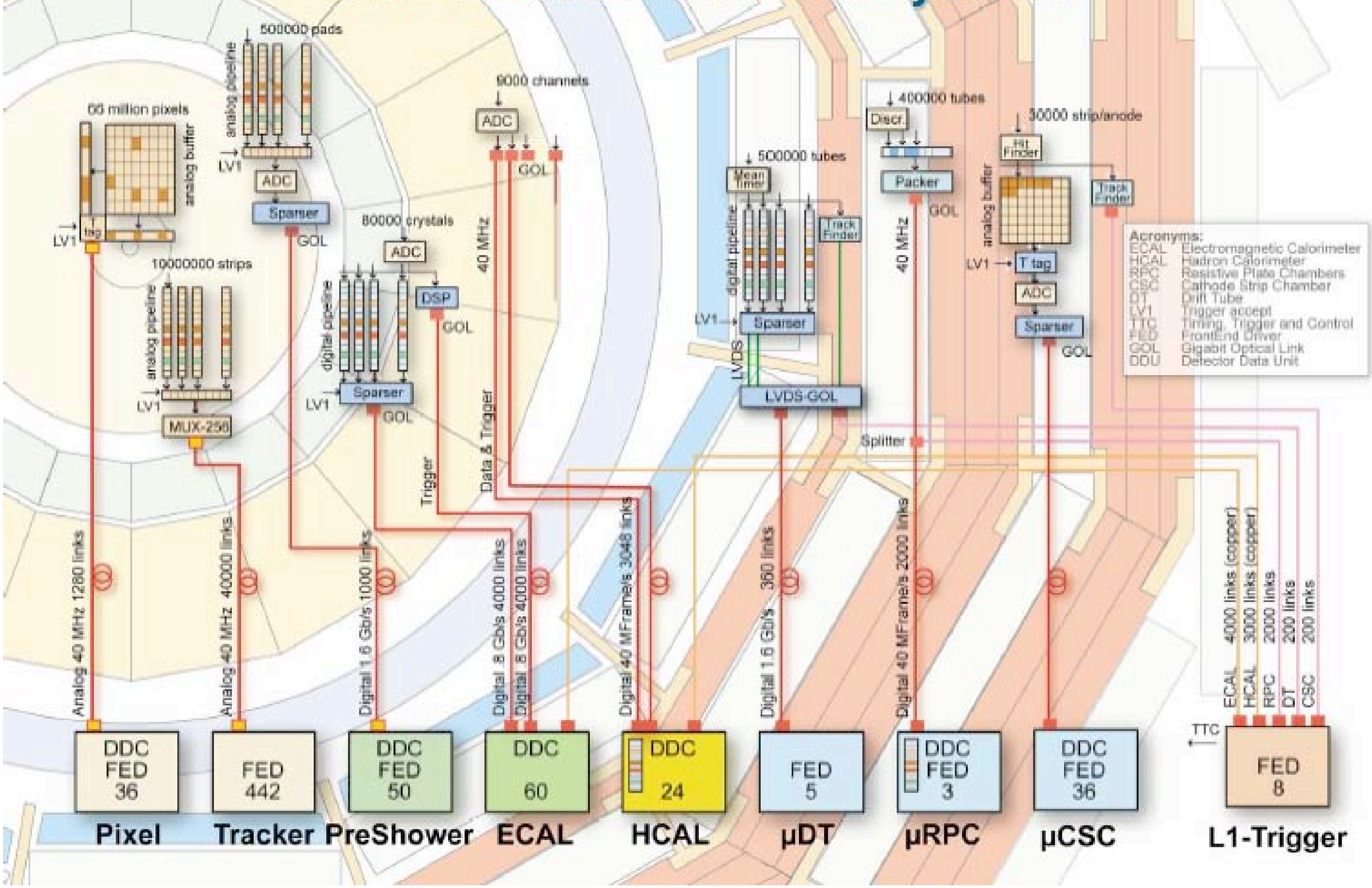
Up to 1 second for certain events, average 50 ms.



Bandwidth and mass storage

Average event size 1 MB -> For maximum level-1 rate need 100 GByte/s capacity. For 1 LHC year (10^7 s) ~ 1 Petabyte of data needs to be stored.

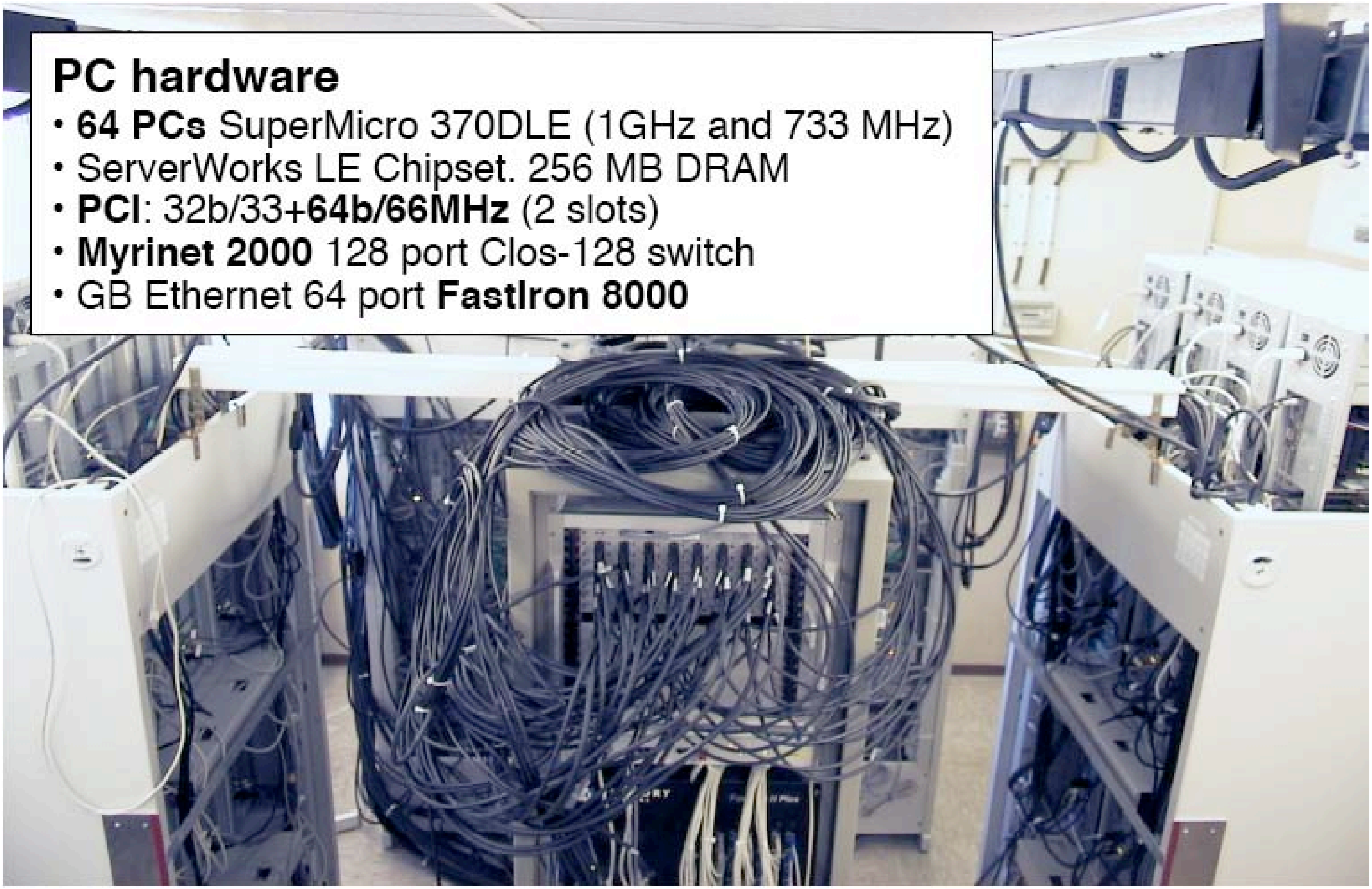
CMS frontend readout systems



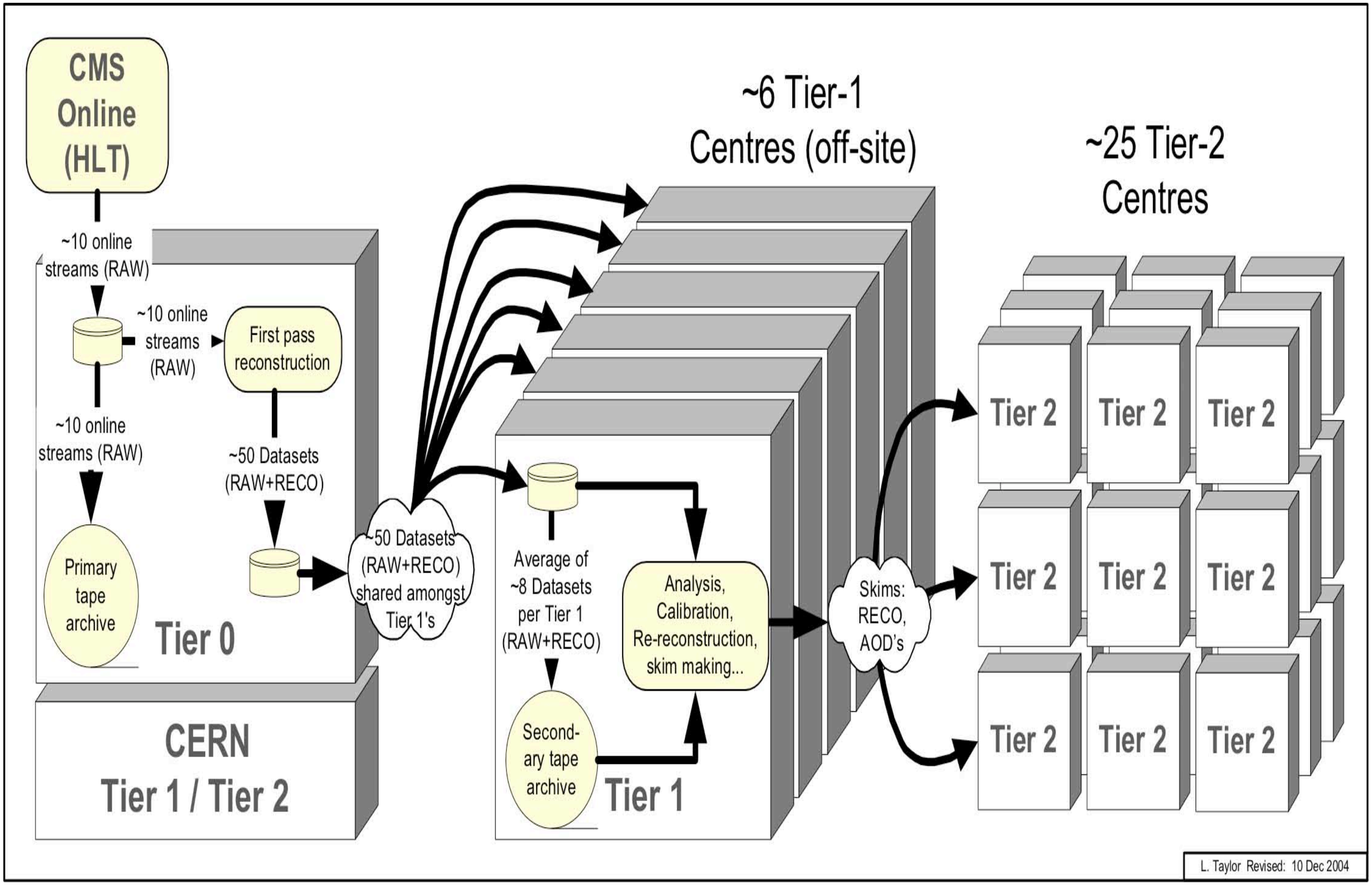
Event Builder Test Bench

PC hardware

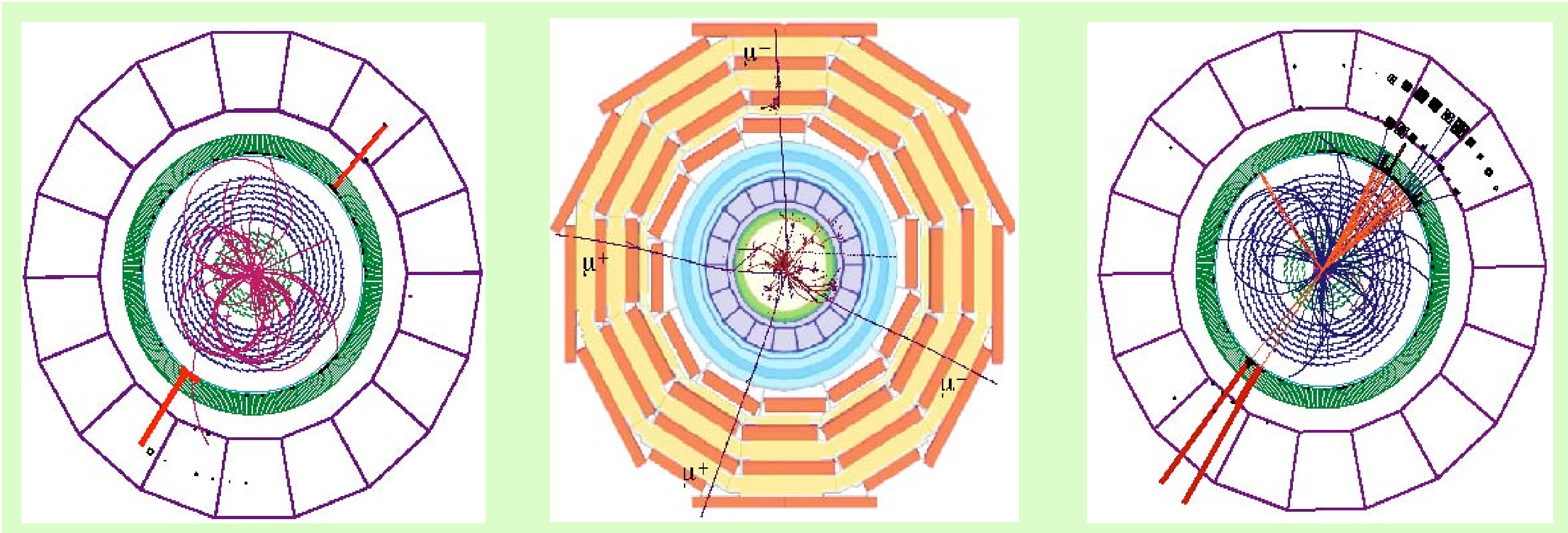
- **64 PCs** SuperMicro 370DLE (1GHz and 733 MHz)
- ServerWorks LE Chipset. 256 MB DRAM
- **PCI**: 32b/33+**64b/66MHz** (2 slots)
- **Myrinet 2000** 128 port Clos-128 switch
- GB Ethernet 64 port **FastIron 8000**

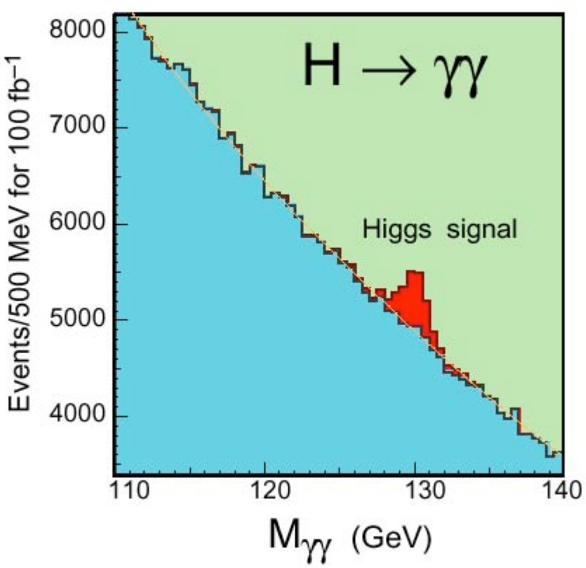


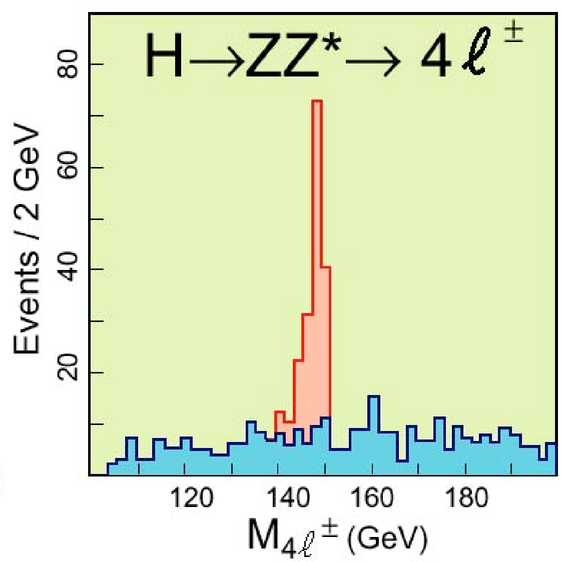
Computing Model

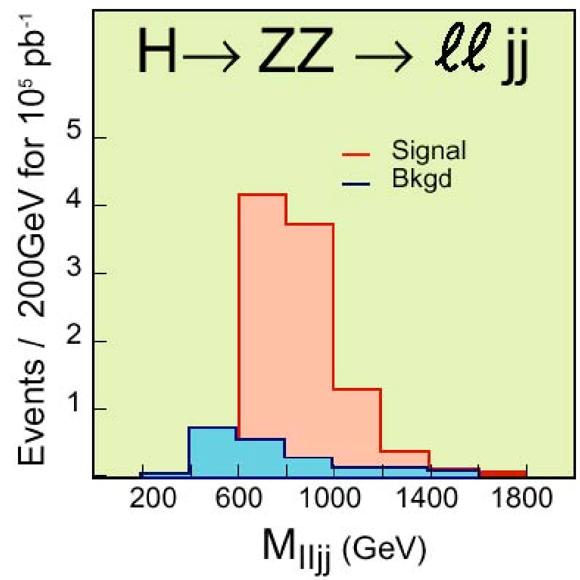


Higgs Search Stategies



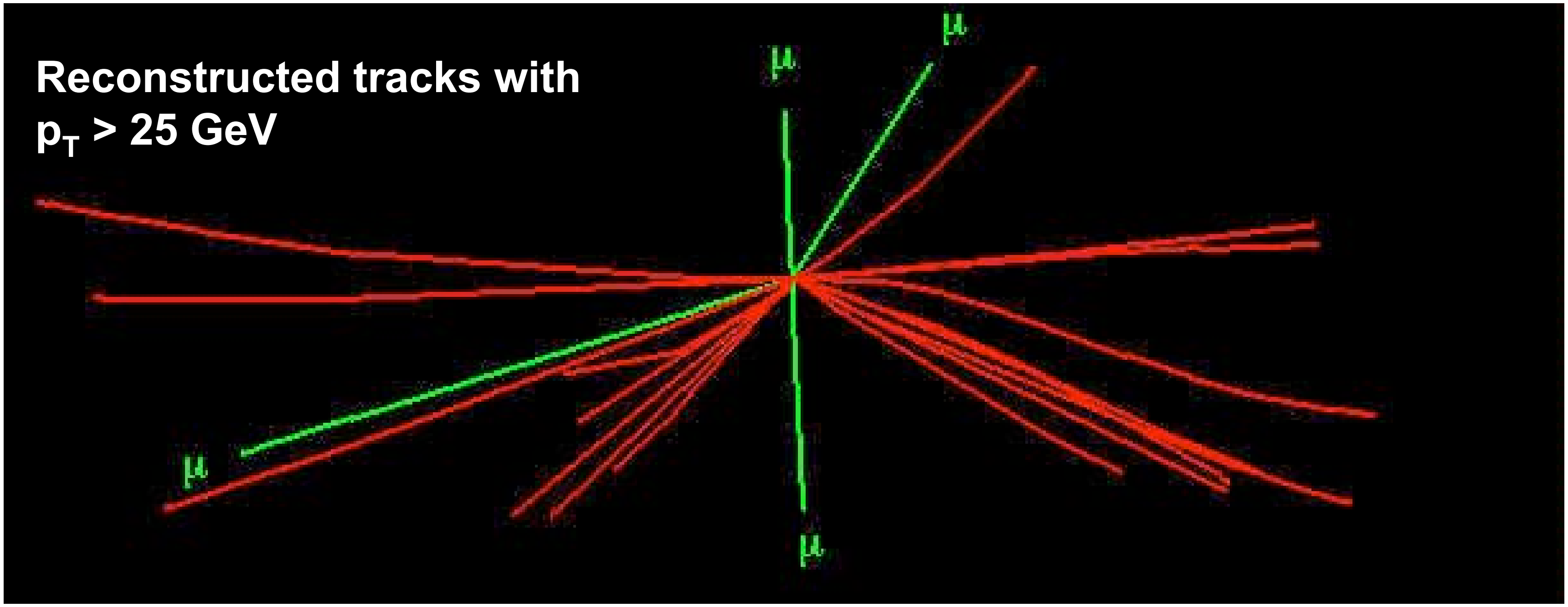


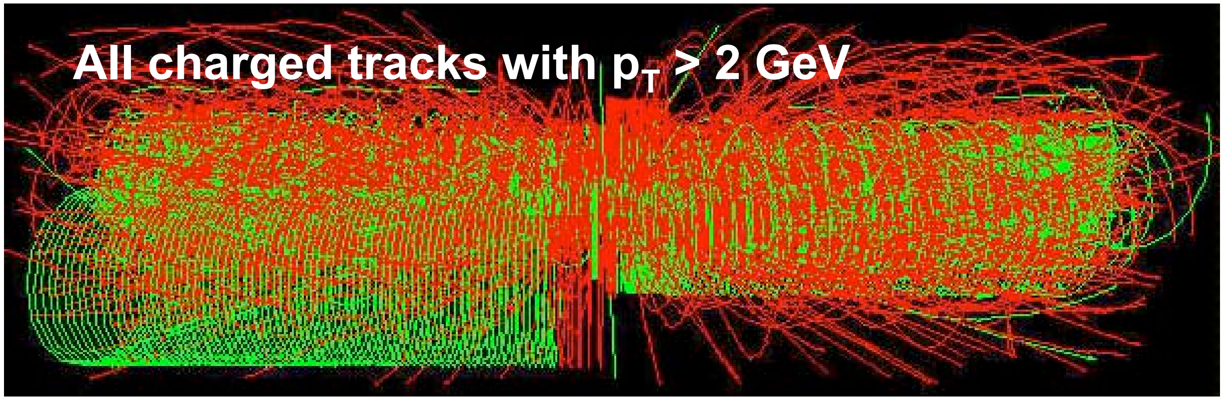




Higgs

The Higgs particle is here !





Supersymmetry

Supersymmetric particles can have spectacular signatures through cascade decays, which lead to final states with leptons, jets and missing energy. Supersymmetry can be discovered within a few weeks of LHC running.

Example for a Squark-Gluino event:

$\tilde{q} \to \tilde{\chi}_2^0\, q$

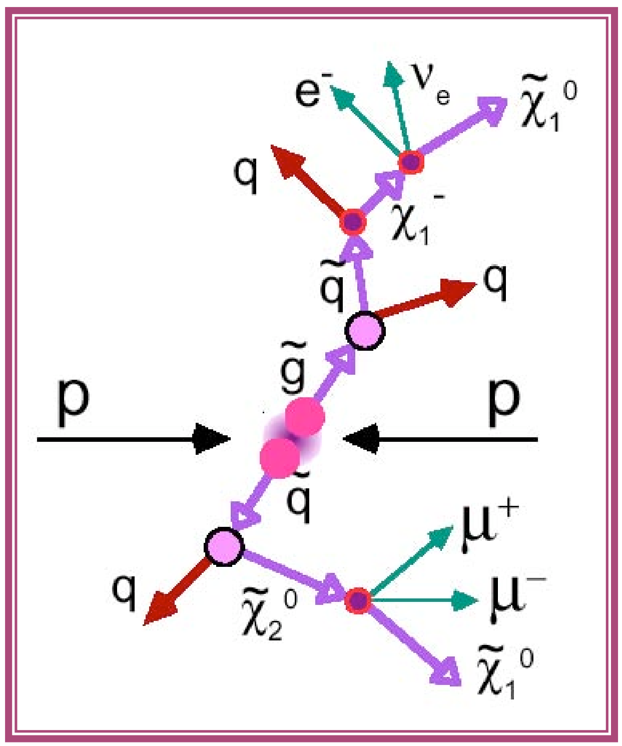
$\quad \hookrightarrow \tilde{\mu}\, \mu$

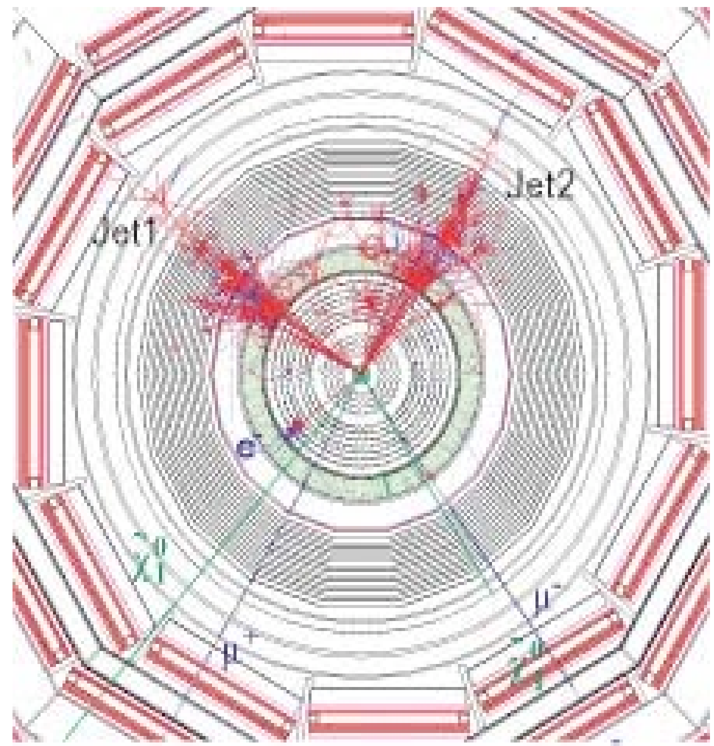
$\quad\quad \hookrightarrow \tilde{\chi}_1^0\, \mu$

$\tilde{g} \to \tilde{q} q$

$\quad \hookrightarrow \tilde{\chi}_1^{\pm}\, q$

$\quad\quad \hookrightarrow e\, \nu\, \tilde{\chi}_1^0$





Conclusions

CMS is a multi-purpose detector designed to answer fundamental questions in physics.

The detector design is technologically challenging.

Construction of the experiment is approaching completion.

The startup of LHC is eagerly awaited!

WE LIVE IN INTERESTING TIMES!

Many thanks to the CMS Collaboration members and especially to R. Romaniuk for the invitation!