

# Compact Muon Solenoid

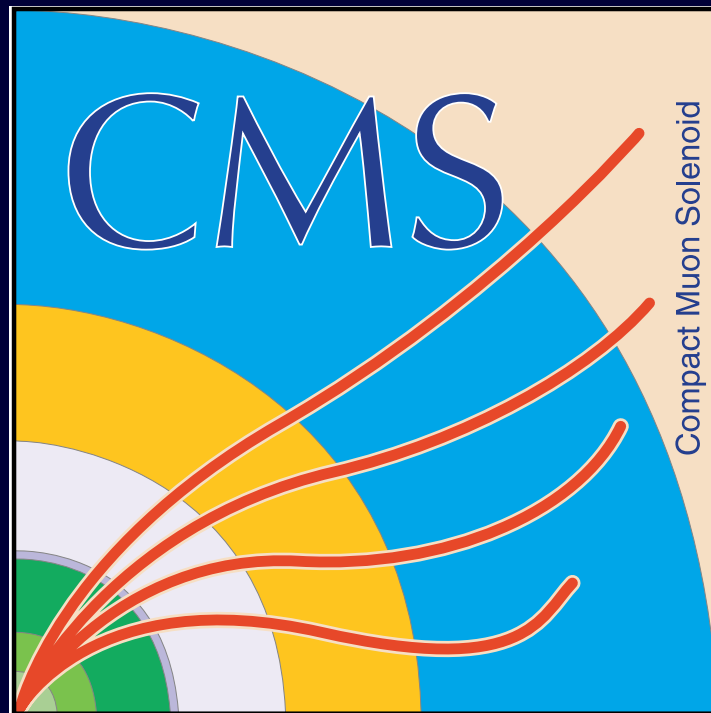
## Experimental challenge

*Grzegorz Wrochna*

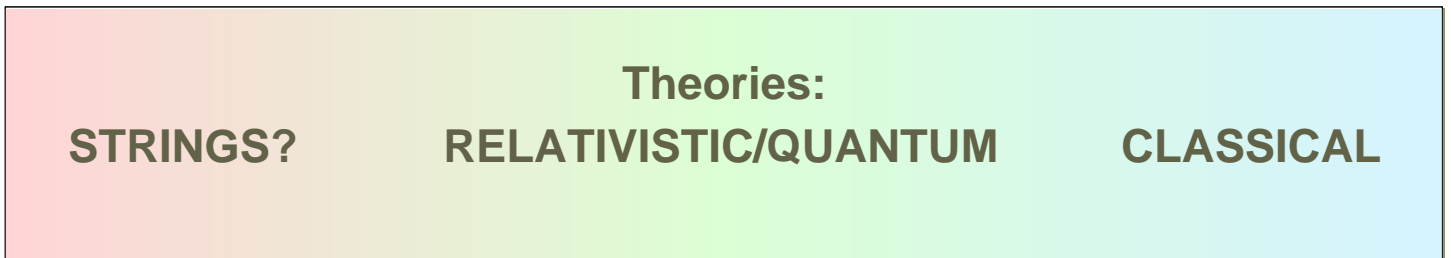
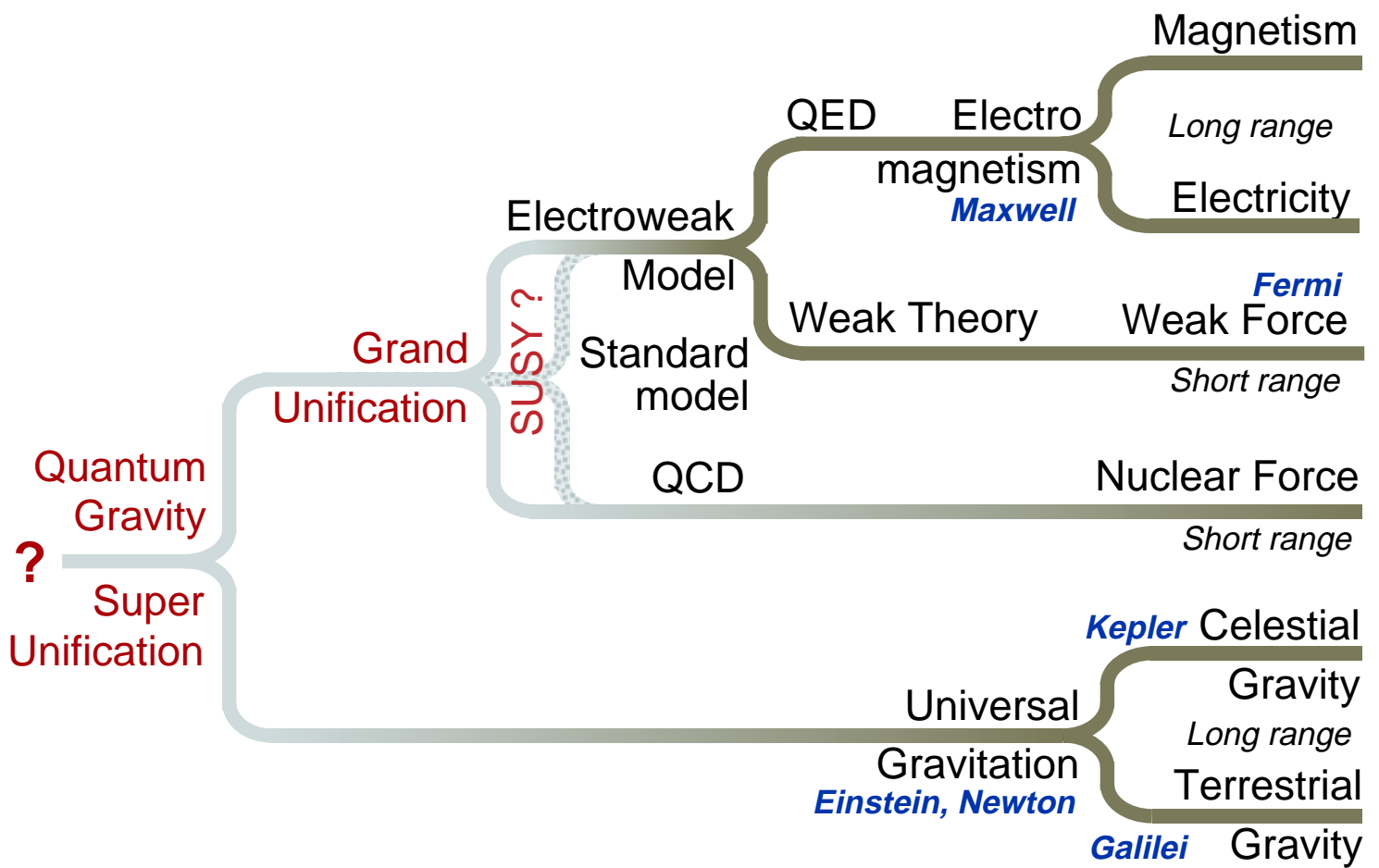
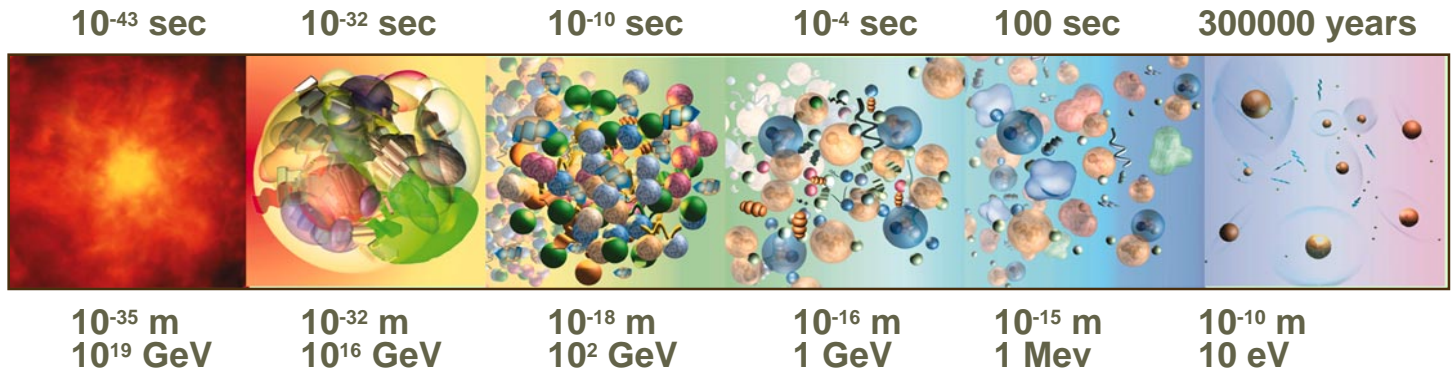
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- **Where to look for “New Physics”?**
  - femtobarns & teraelectronvolts
- **Required features of accelerators & detectors**
  - nanoseconds & microns
- **CMS trigger and data acquisition**
  - GIPS's, TIPS's & petabytes
- **Problems of designing and planning**
  - long, long years ...



# ***Particle physics today***

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The Standard Model precisely describes both electroweak and strong interactions. No significant deviation from its predictions was observed so far.

## **But:**

- it has ~20 free parameters
- particle masses are generated by Higgs mechanism, not explained within the Standard Model
- Higgs particle was not observed so far
- Standard Model does not explain
  - existence of 3 generations of fermions
  - mixing between different generations

## **Strategy for the near future:**

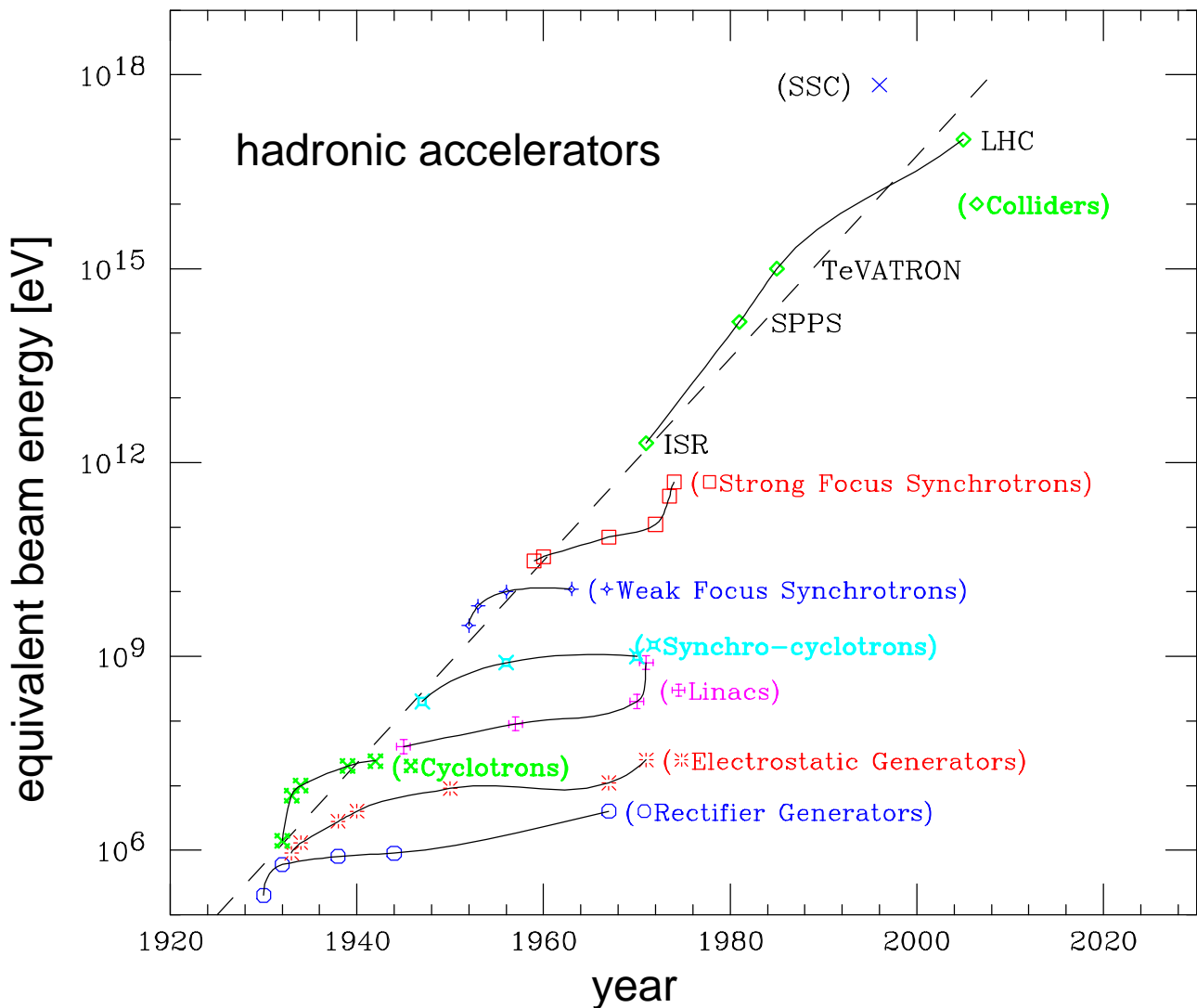
- find Higgs particle or exclude its existence in the region allowed by theory (~1 TeV)
- look for deviations from the Standard Model
- search for new particles (~50 GeV — ~5 TeV)

## **Needed tools**

- **accelerator**
  - high energy
  - wide energy range
  - high luminosity
- **detectors**
  - universality (e,  $\gamma$ ,  $\mu$ , jets, missing energy)
  - granularity (large number of particles)
  - speed (high luminosity)

# Large Hadron Collider

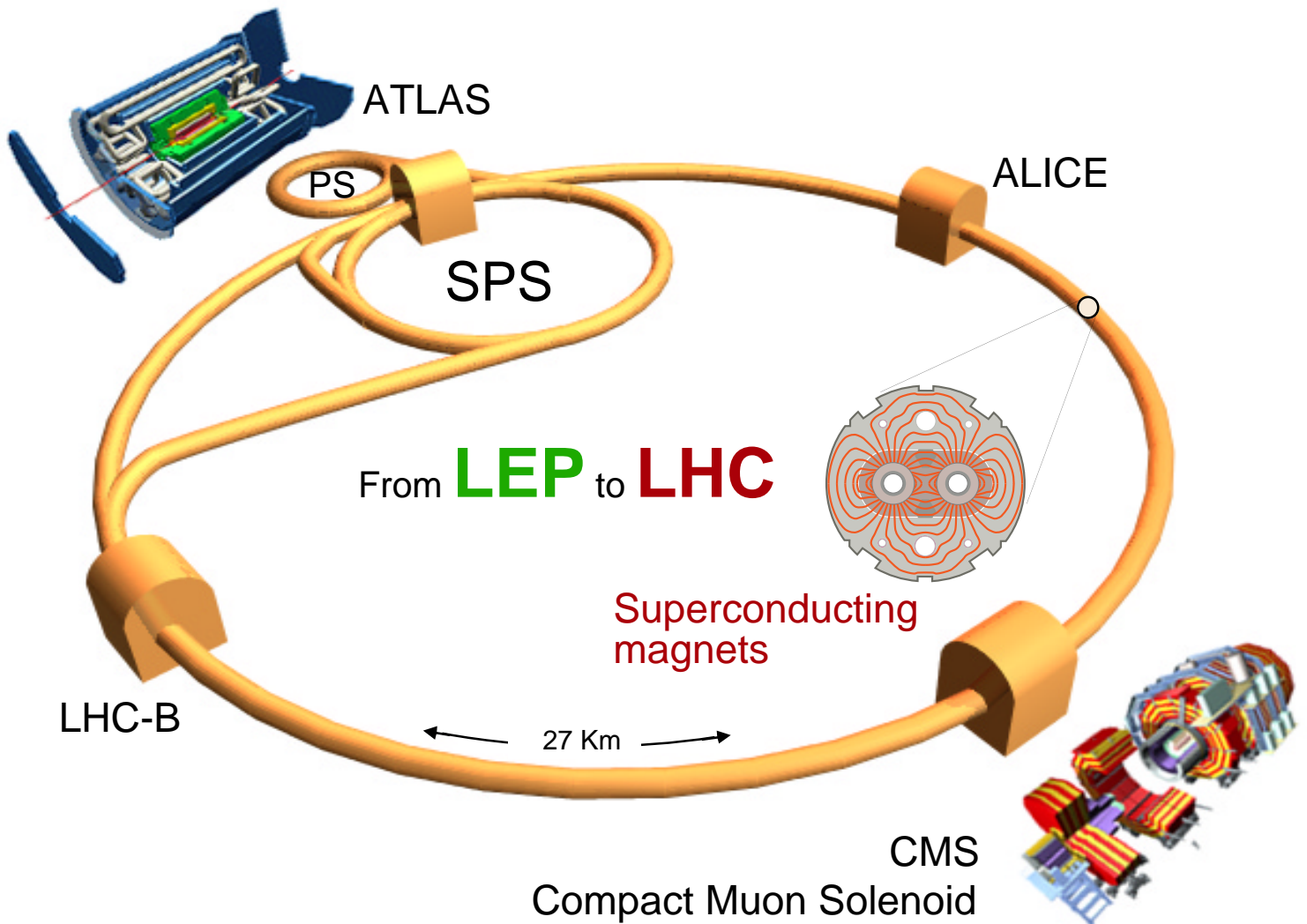
Livingston plot



**Fast increase in performance of accelerators is possible because of ever new technologies.**

**Superconducting magnets installed in the existing LEP tunnel will make possible proton-proton collisions with the energy  $\sqrt{s}=14$  TeV.**

# The Large Hadron Collider (LHC)

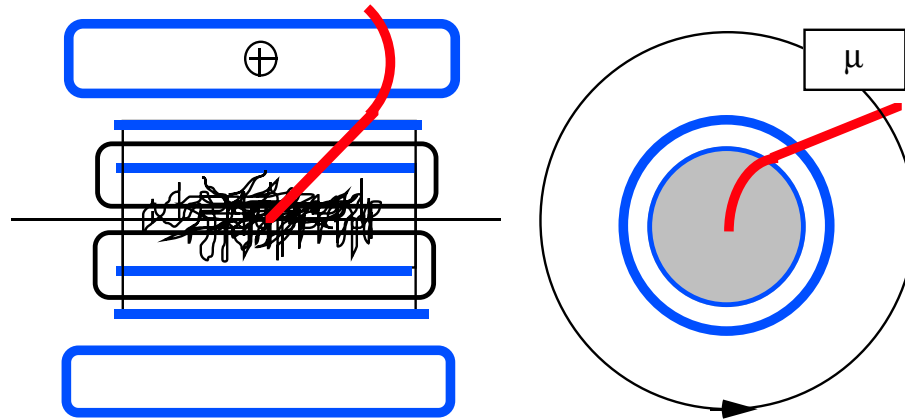


	Beams	Energy	Luminosity
<b>LEP</b>	$e^+ e^-$	200 GeV	$10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
<b>LHC</b>	p p	14 TeV	$10^{34}$
	Pb Pb	1312 TeV	$10^{27}$

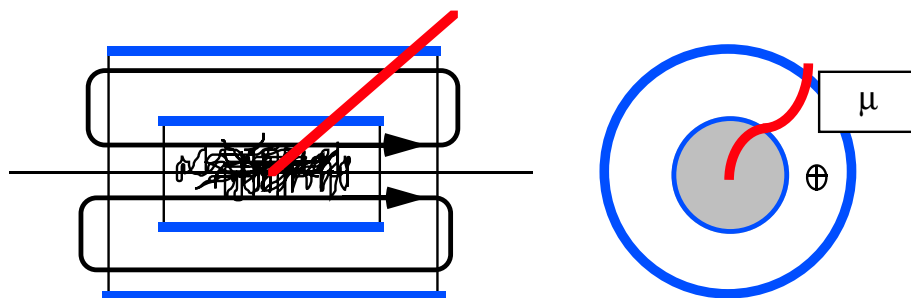
The LHC machine and the experiments are under design and construction. The observation of first collisions is expected in 2005

# Magnets

## ATLAS A Toroidal LHC ApparatuS



## CMS Compact Muon Solenoid



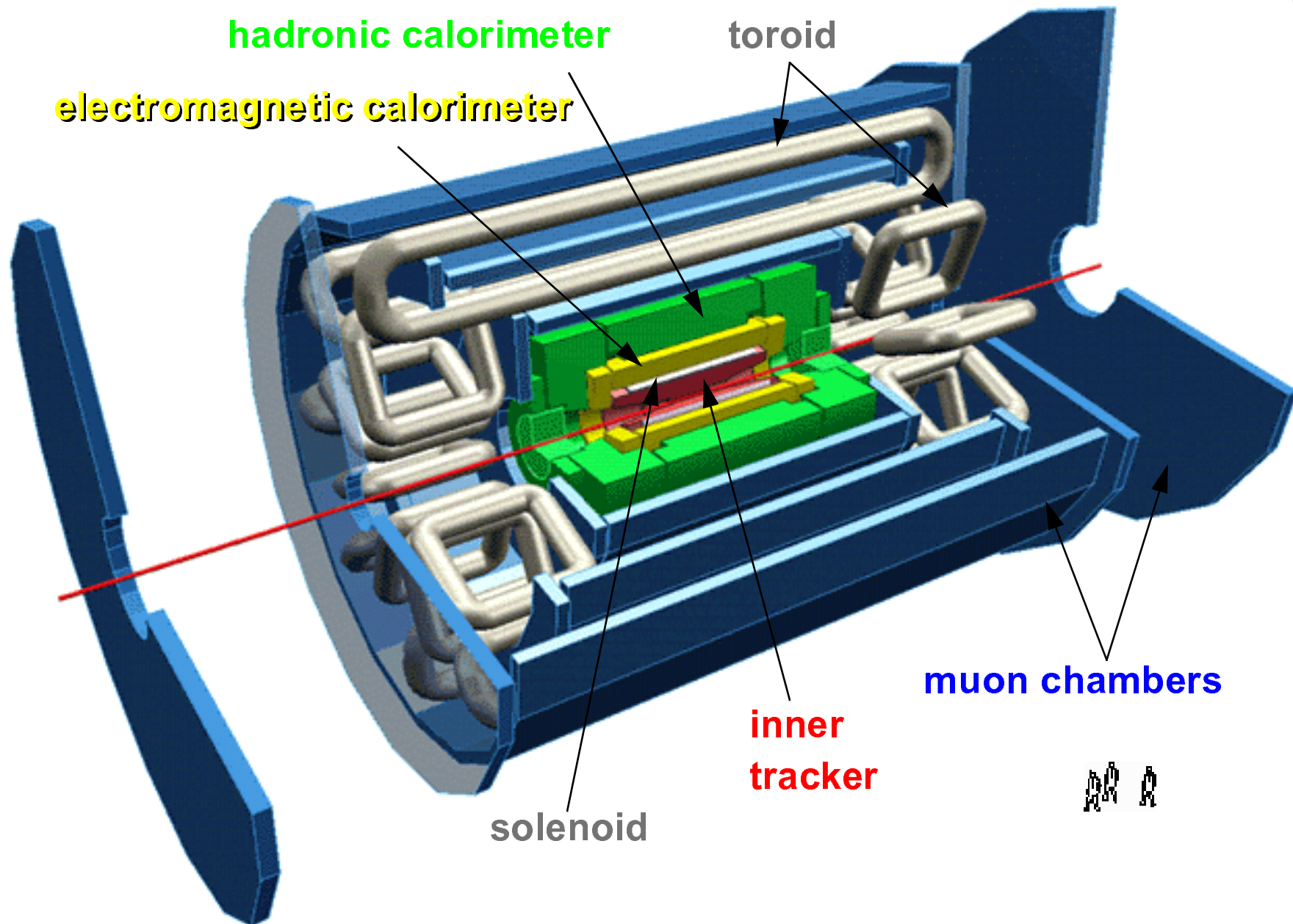
experiment	cost	magnet	cost
ATLAS	475 M CHF	toroid	200 M CHF
CMS	475 M CHF	solenoid	120 M CHF

The choice of magnetic field configuration determines the characteristic of the experiment.

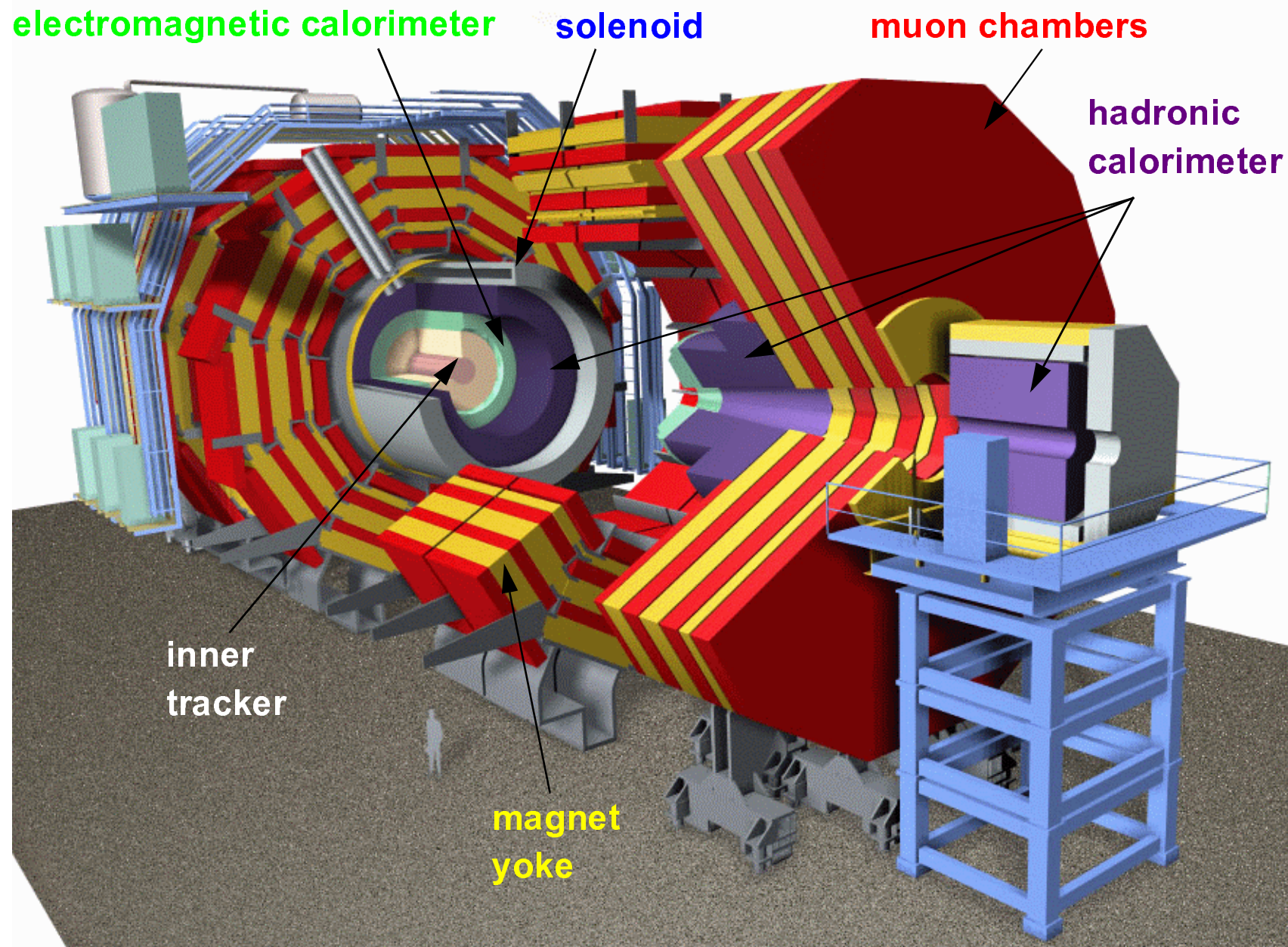


# *A Toroidal LHC ApparatuS (ATLAS)*

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# *Compact Muon Solenoid*





# CMS layout and detectors

## SUPERCONDUCTING COIL

## ECAL Scintillating $\text{PbWO}_4$ Crystals

## CALORIMETERS

### HCAL Plastic scintillator copper sandwich

## IRON YOKE

## TRACKER

Micro Strip Gas Chambers (MSGC)  
Silicon Microstrips  
Pixels

## MUON BARREL

Drift Tube Chambers (DT)

Resistive Plate Chambers (RPC)

## MUON ENDCAPS

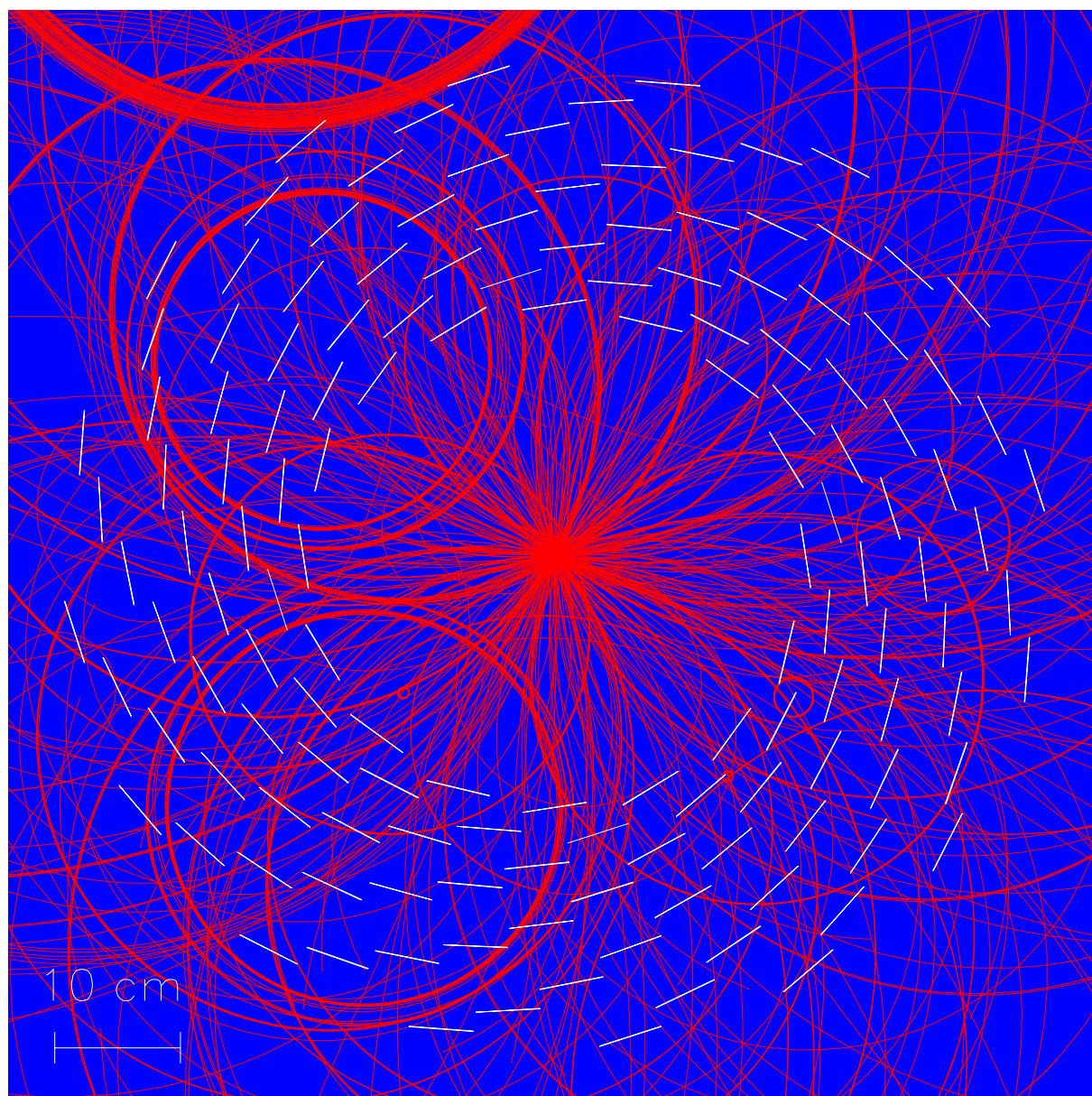
Cathode Strip Chambers (CSC)  
Resistive Plate Chambers (RPC)

Total weight : 12,500 t  
Overall diameter : 15 m  
Overall length : 21.6 m  
Magnetic field : 4 Tesla

# ***Puzzle***

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**18 superimposed pp collisions,**  
as seen by internal part of CMS silicon central tracker.  
**Among them 4 muons from a higgs decay.**



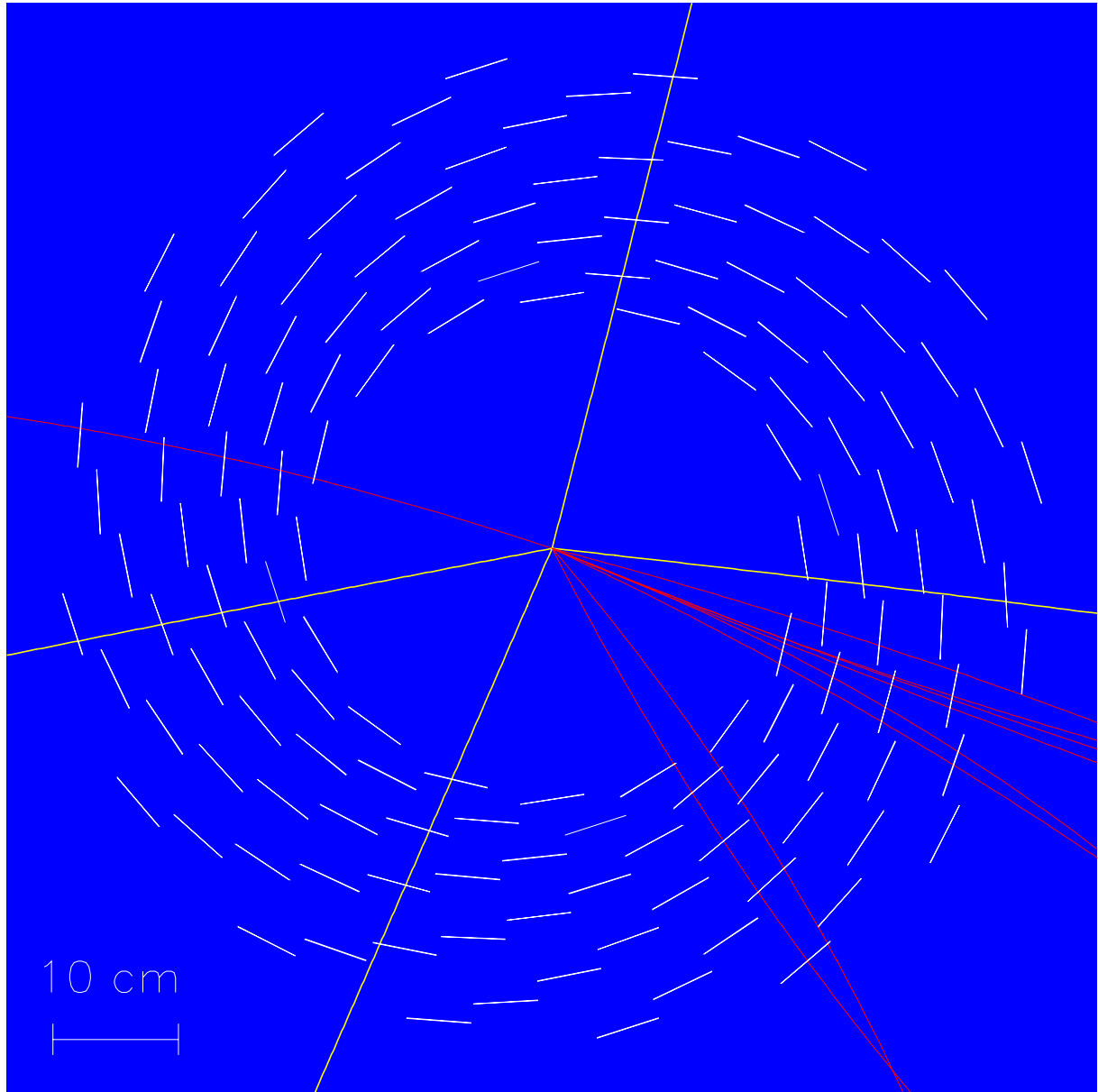
**Find 4 straight tracks.**

# Solution

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Reconstructed tracks of  $p_t > 2 \text{ GeV}$ .

Among them well visible 4 muons from the higgs decay.



The solution is possible if detector occupancy  $\sim 1\%$

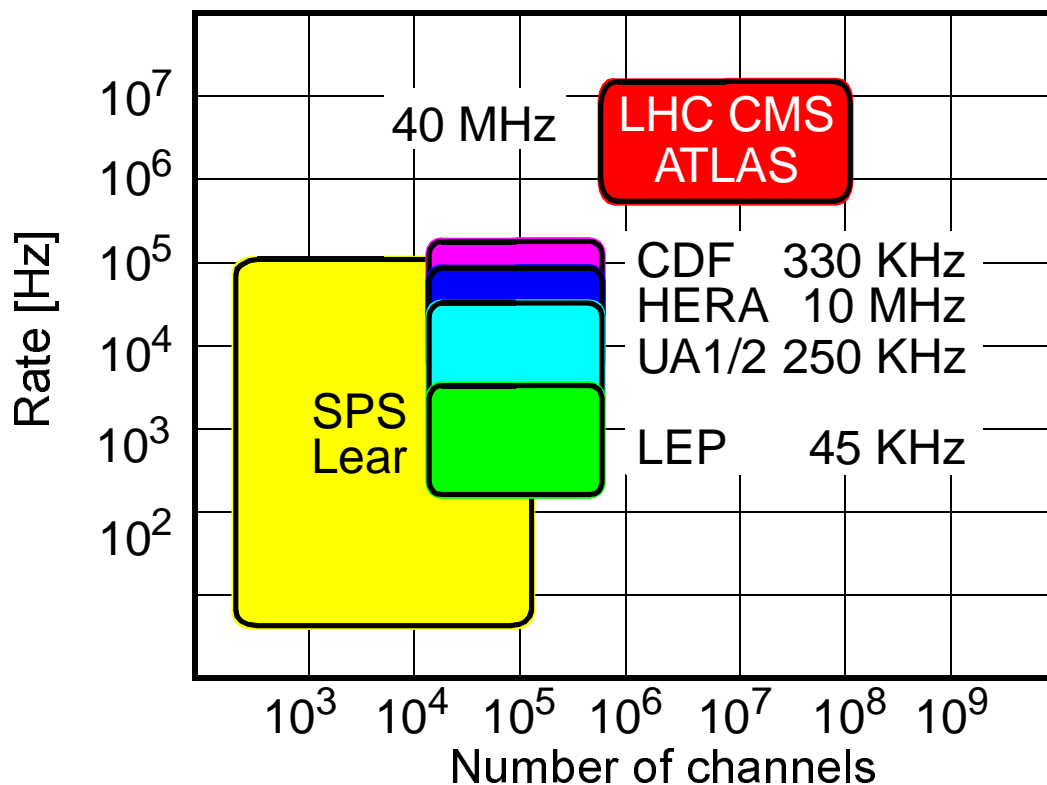
→ microstrip area  $\sim 1\text{mm}^2$

→  $>10^7$  readout channels

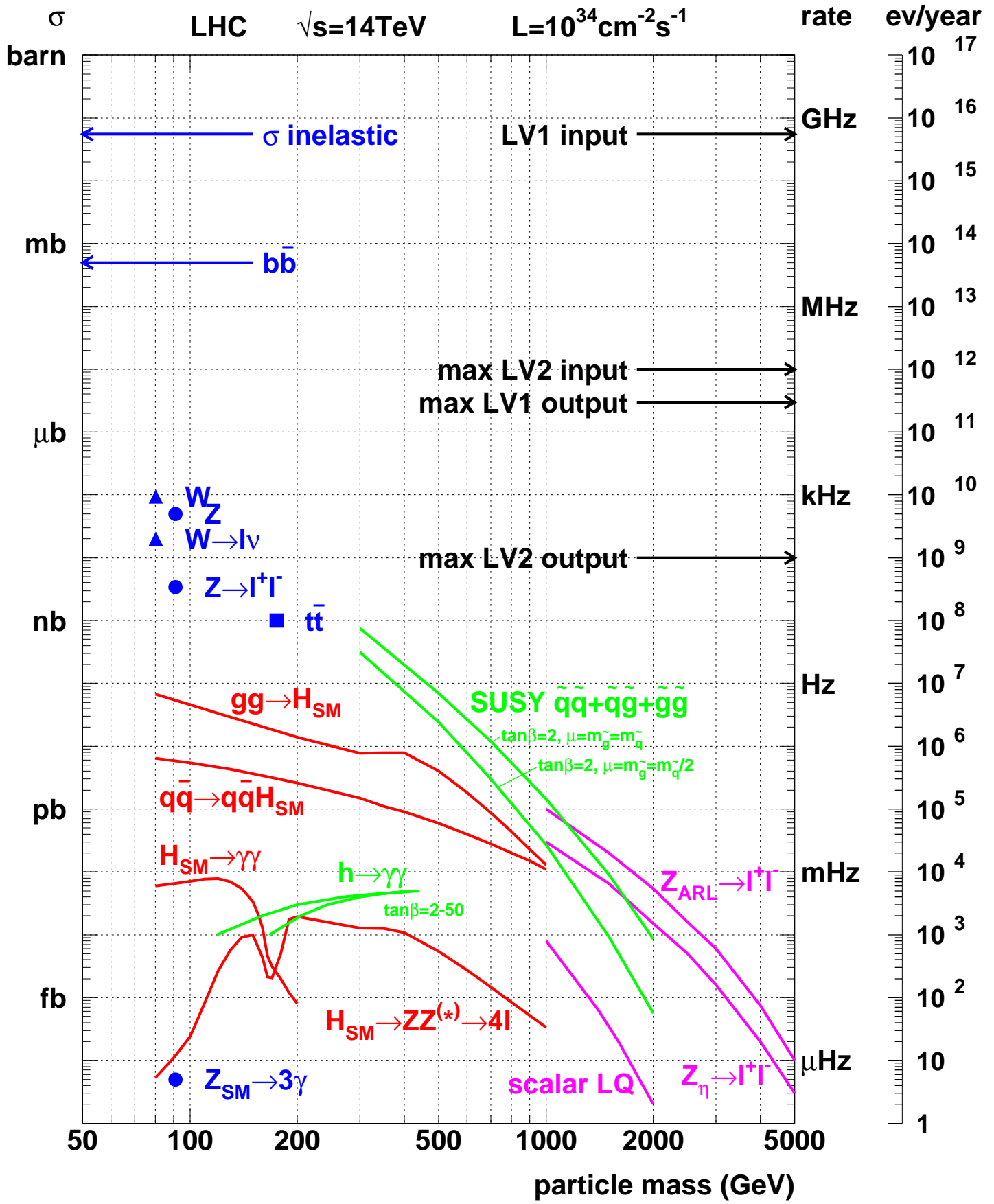
# ***CMS and other experiments***

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detector	channels	occupancy	event size
pixels	80 000 000	0.01 %	100 kB
microstrips	16 000 000	3 %	700 kB
preshower	512 000	10 %	50 kB
calorimeter	125 000	5 %	50 kB
muon detector	1 000 000	0.1 %	10 kB
Total event size			1 MB







# ***Event selection***

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During 10 years of LHC running about  $10^{17}$  pp collisions will be produced.

An observation of  $\sim 10$  “exotic” events could be a discovery of “New Physics”.

**However, one has to find these 10 events among  $10^{17}$  of non interesting ones.**

**Searching for a needle in a hay stack?**

- typical needle —  $5 \text{ mm}^3$
- typical hay stack —  $50 \text{ m}^3$

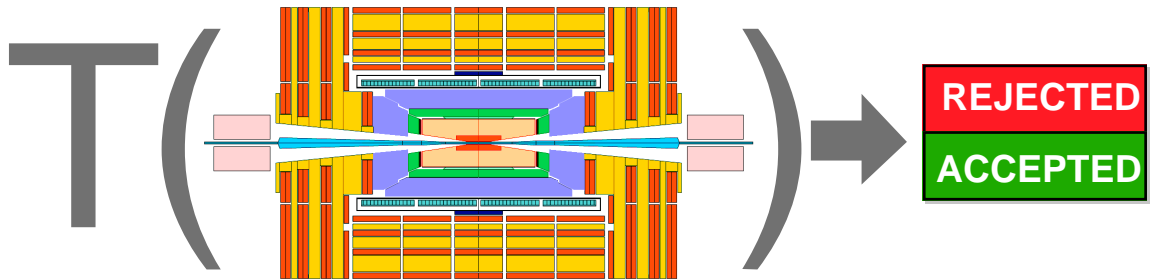
**needle : hay stack = 1 :  $10^{10}$**

**Searching for “New Physics” at LHC is like searching for a needle in one million of hay stacks.**

# The trigger system

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The trigger is a function of :



Event data & Apparatus  
Physics channels & Parameters

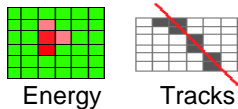
Since the detector data are not all promptly available and the function is highly complex,  $T(\dots)$  is evaluated by successive approximations called :

**TRIGGER LEVELS**  
(possibly with zero dead time)

# CMS trigger and data acquisition

## COMMUNICATION

**40 MHz**  
**COLLISION RATE**



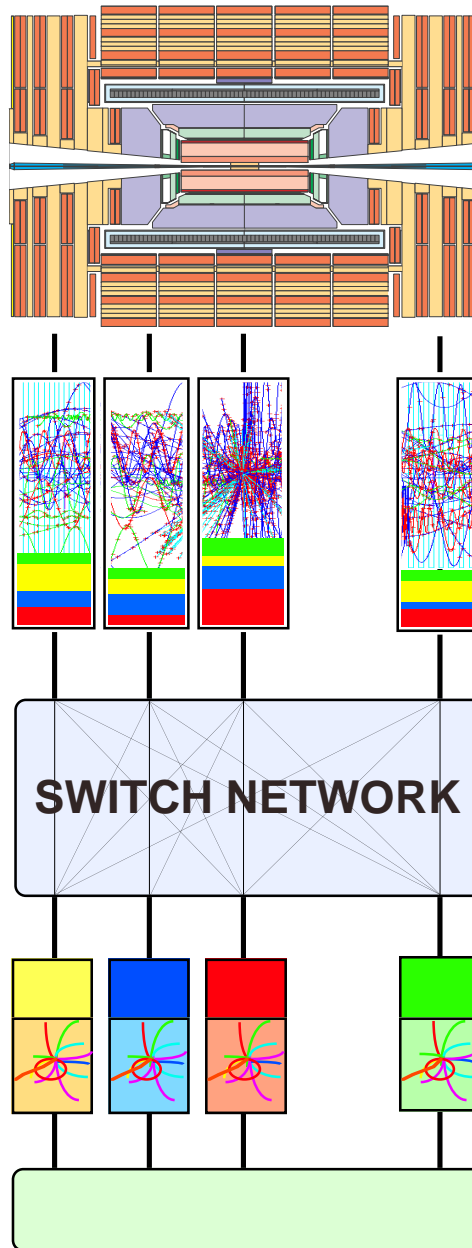
**100 kHz**  
**LEVEL-1 TRIGGER**

**1 Terabit/s**  
**(50000 DATA CHANNELS)**

**500 Gigabit/s**

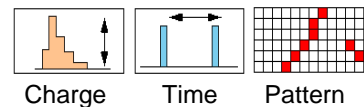
**100 Hz**  
**FILTERED EVENT**

**Gigabit/s**  
**SERVICE LAN**



## PROCESSING

**16 Million channels**  
**3 Gigacell buffers**



**1 Megabyte EVENT DATA**

**200 Gigabyte BUFFERS**  
**500 Readout memories**

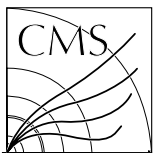
**EVENT BUILDER.** A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs

**5 TeraIPS**  
**EVENT FILTER.** It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event

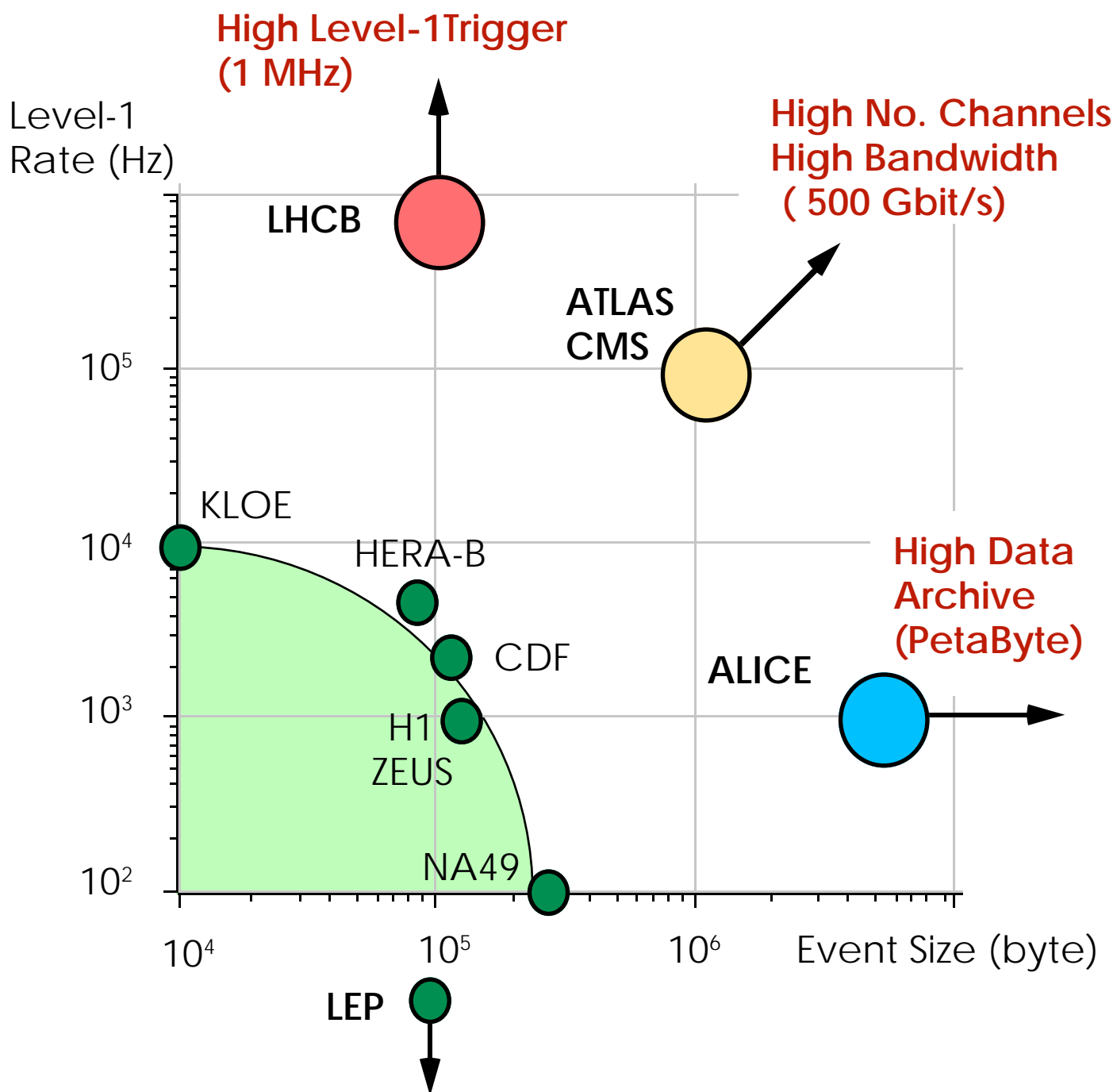
**Petabyte ARCHIVE**

Tera :  $10^{12}$ ; Peta  $10^{15}$ ; IPS : Instruction Per Second; LAN : Local Area Network

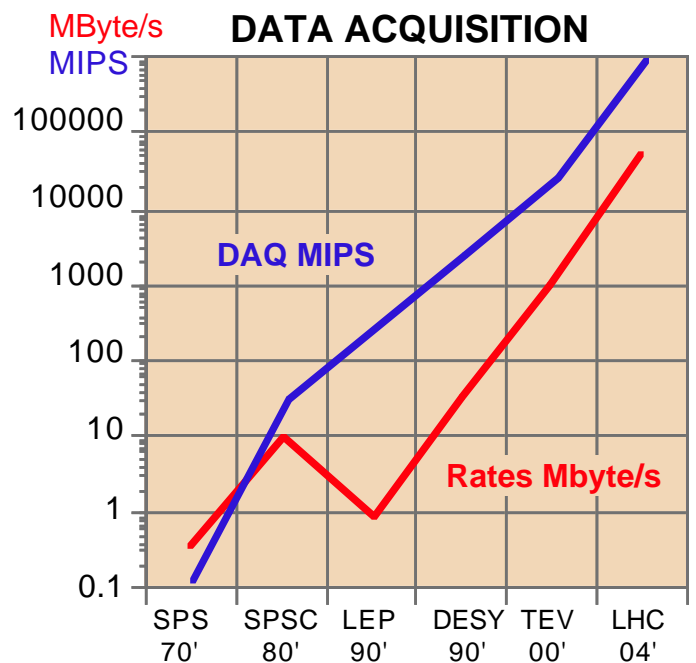
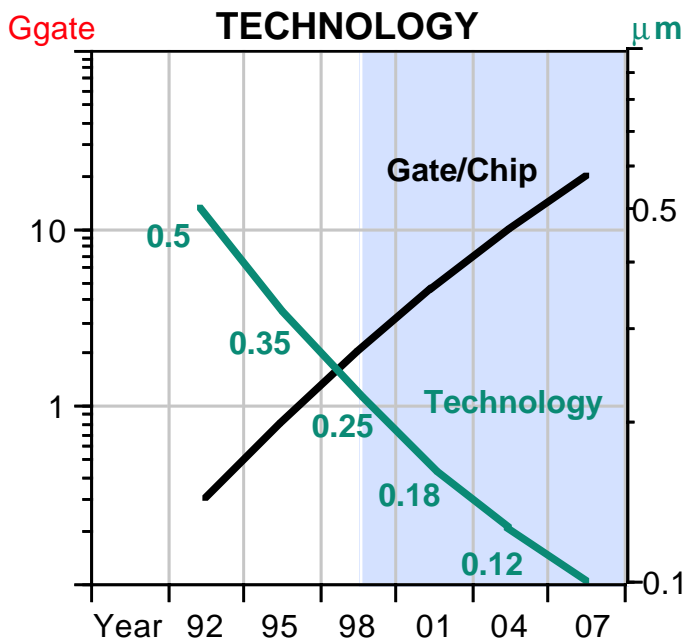
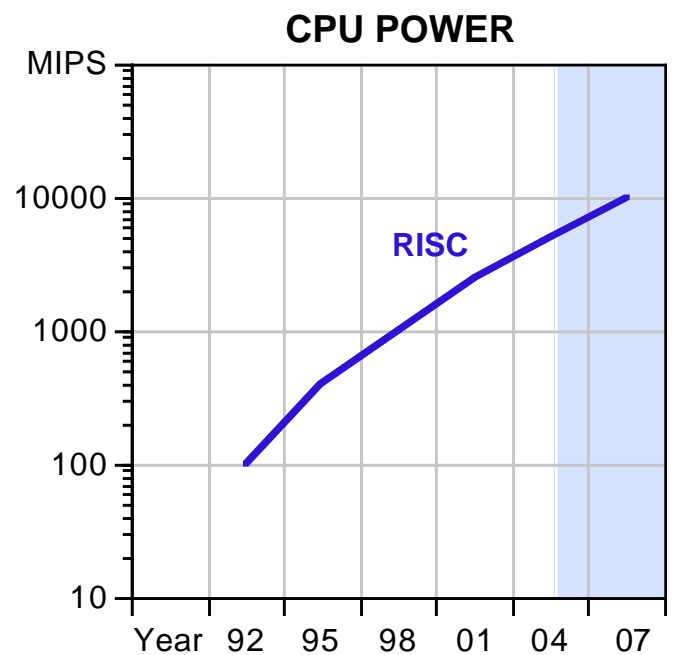
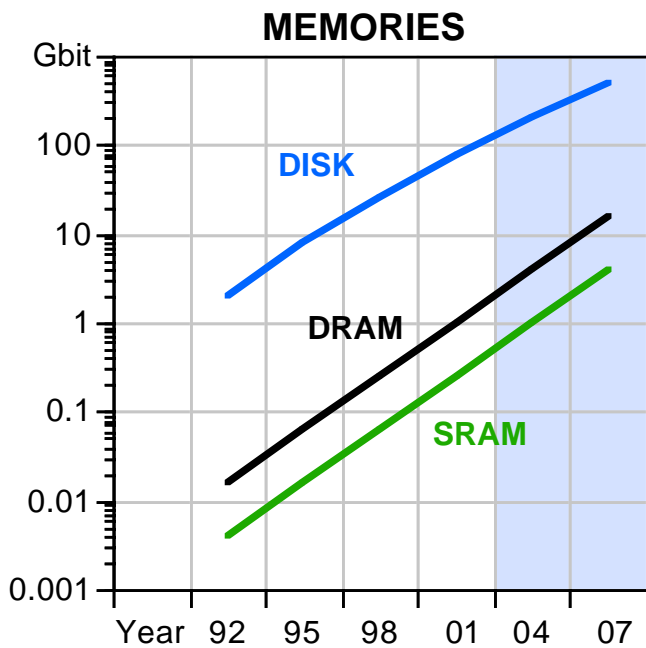




# Trigger and DAQ trends



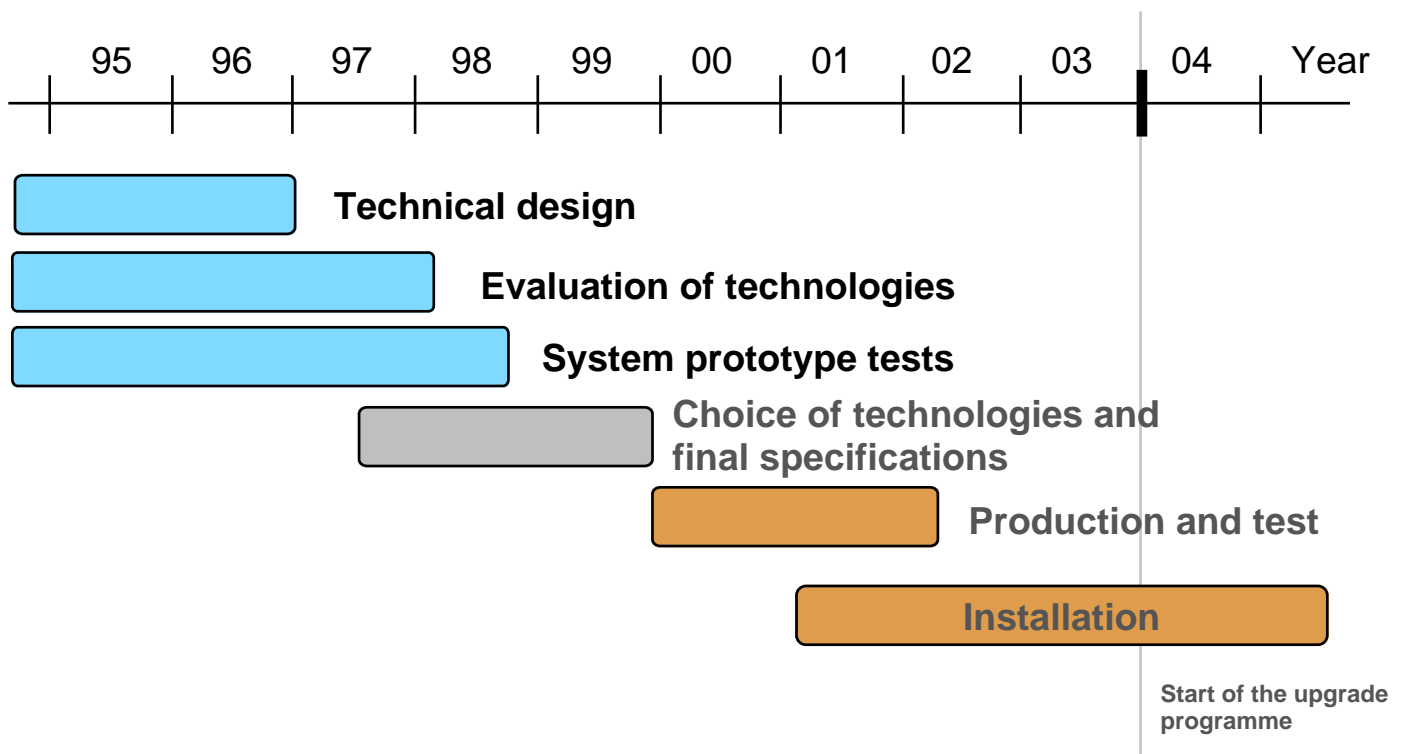
# Technology & DAQ trends



from Semiconductor Industry Association -Semiconductor Technology Workshop Conclusions - March '93

# CMS trigger and data acquisition schedule

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# Summary

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“New Physics” searches require reaching very **high energies** and searching for extremally **rare phenomena**

14 TeV  
 $\sigma \sim \text{fb}$

Coincidence of these two requirements creates a challenge for modern technologies in **computing** and **telecommunication**

## high energy:

- large number of produced ~100/event
- precise measurement in large dynamic range ~100 $\mu$ /10m

## searching for new phenomena:

- very high frequency of interactions ~1 GHz
- pile-up of many interactions 10-20
- small signal to background ratio 1:10<sup>11</sup> - 1:10<sup>16</sup>

## resulting technological requirements:

- steering of large volume data flow 500 Gbits/s
- event analysis in real time selection 1:10<sup>7</sup>
- gigantic computing power 5 TIPS
- huge mass storage 1 PB/year

**Those requirements are fulfilled by ATLAS and CMS experiments. This give us a hope for discovery of “something new” at LHC.**



# LHC perspectives

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- The number of institutions participating to a LHC experiment is of the order of the number of authors in the UA1 experiment
- The 'Slow Control' data rate of an LHC experiment (temperature, voltages, status etc.) is comparable the current LEP experiment readout rate
- During one second of CMS running, the data volume transmitted through the readout network is equivalent to the amount of data that is moved in one day by the present CERN network system (FDDI, ethernet, local nets)
- The data rate handled by the CMS event builder ( $\approx 500$  Gbit/s) is equivalent to the amount of data exchanged by world telecoms (today)
- The total number of processors in the CMS event filter equals the number of workstations and personal computers running today at CERN ( $\approx 4000$ . How many failures per day?).
- The laboratory computing power available to UA1 in 1980 was comparable to that of a modern desktop computer.
- The physicists and engineers who will lead and run the experiment in 200x are now students.  
Maybe some of them are here today listening to this lecture?