Compact Muon Solenoid

Experimental challange

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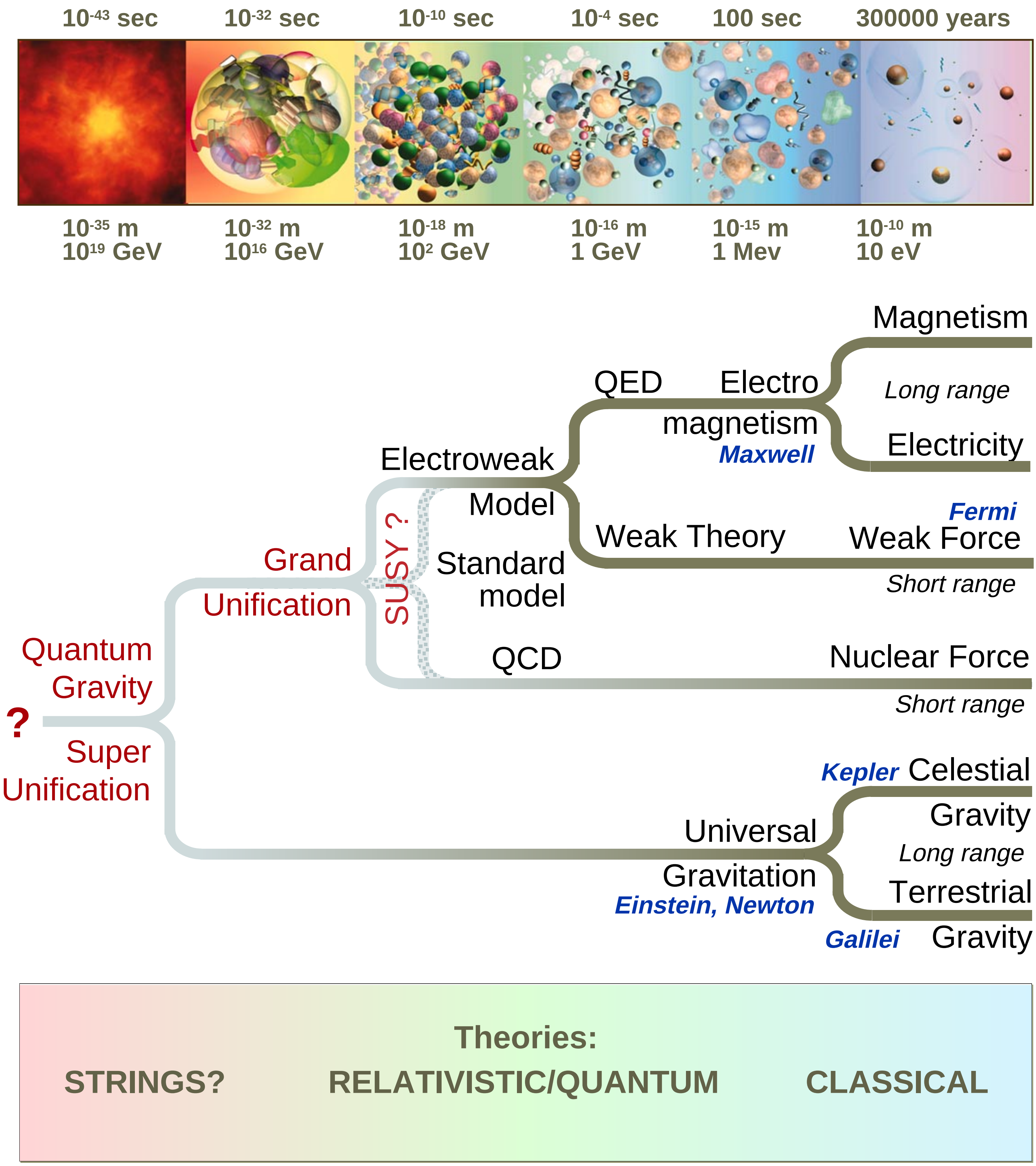
- **Where to look for “New Physics”?**
  – femtobarns & teraelectronovolts
- **Requied features of accelerators & detectors**
  – nanoseconds & microns
- **CMS trigger and data acquisition**
  – GIPS’s, TIPS’s & petabytes
- **Problems of designing and planning**
  – long, long years ...



10-43 sec
10-32 sec
10-10 sec
10-4 sec
100 sec
300000 years
10-35 m
1019 GeV
10-32 m
1016 GeV
10-18 m
102 GeV
10-16 m
1 GeV
10-15 m
1 Mev
10-10 m
10 eV
Magnetism
QED
Electro
magnetism
Maxwell
Long range
Electricity
Electroweak
Model
SUSY ?
Fermi
Weak Theory
Weak Force
Short range
Grand
Unification
Standard
model
Quantum
Gravity
QCD
Nuclear Force
Short range
?
Super
Unification
Kepler Celestial
Gravity
Long range
Universal
Gravitation
Einstein, Newton
Terrestrial
Galilei Gravity
Theories:
STRINGS?
RELATIVISTIC/QUANTUM
CLASSICAL

Particle physics today

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:

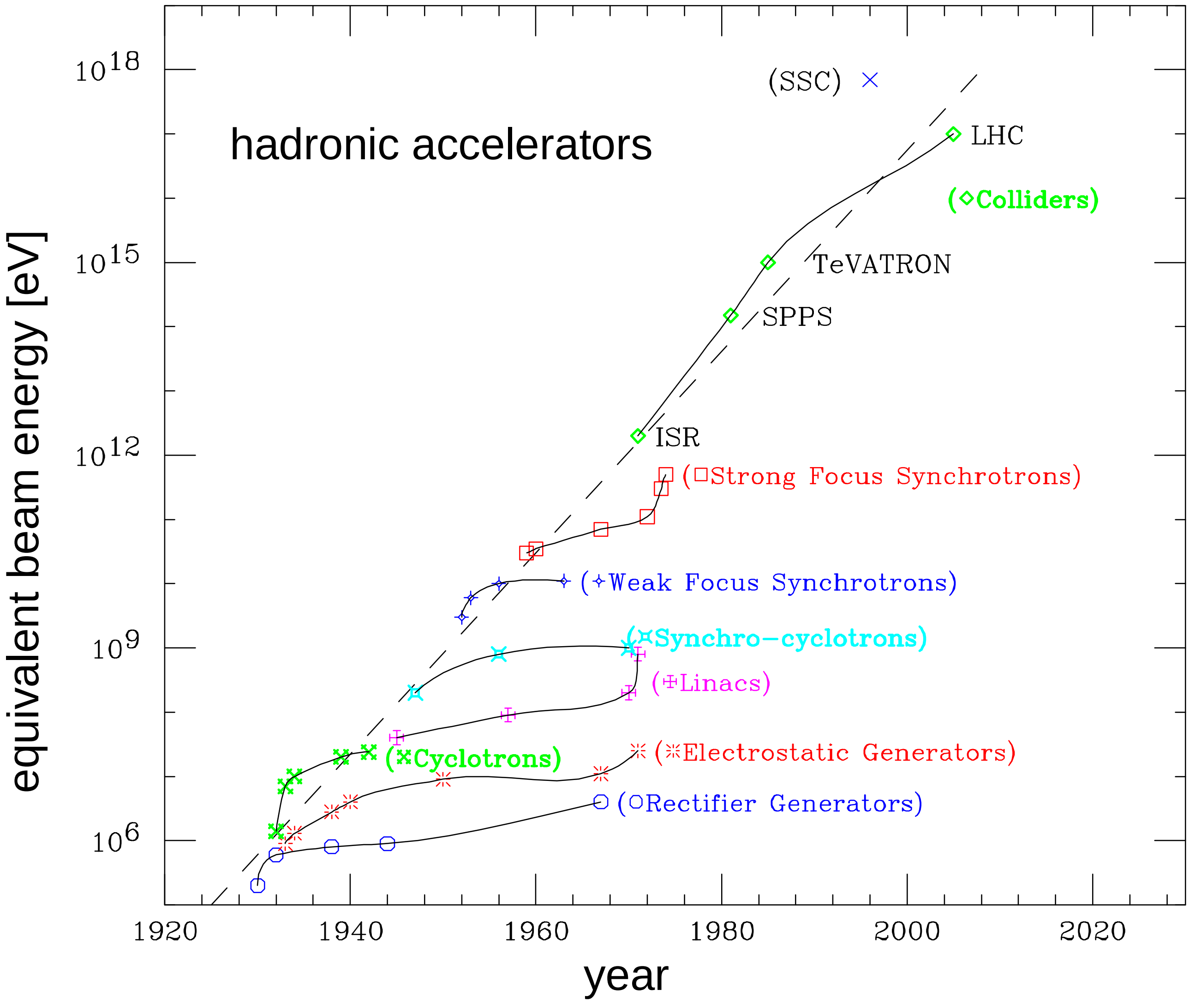
- **find Higgs particle or exclude its existence in the region allowed by theory (~1 TeV)**
- **look for deviations from the Standard Model**
- **search for new particles (~50 GeV — ~5 TeV)**

Needed tools

- **accelerator**
  – high energy
  – wide energy range
  – high luminosity
- **detectors**
  – universality (e, γ, μ, jets, missing energy)
  – granularity (large number of particles)
  – speed (high luminosity)

Large Hadron Collider

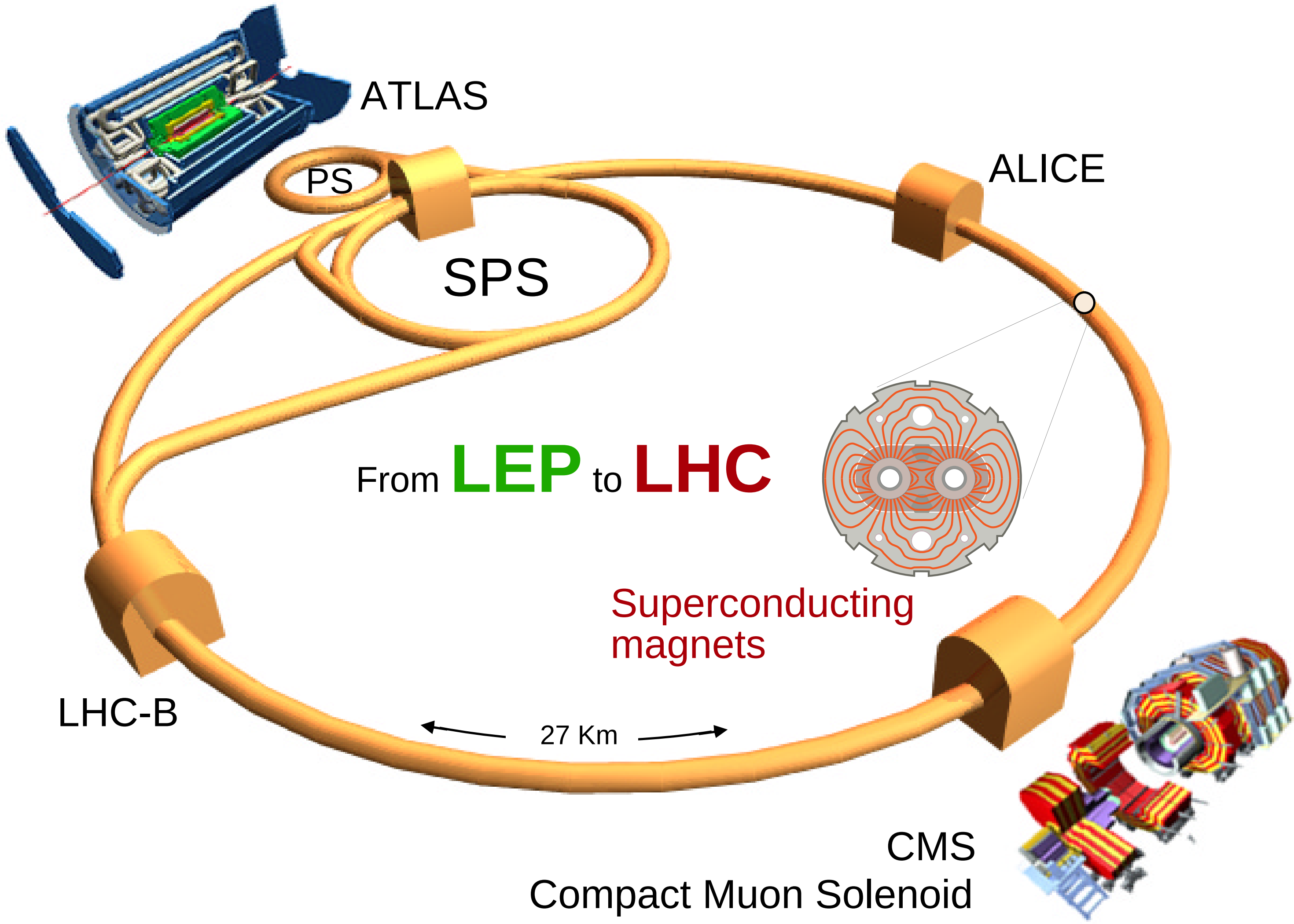
Livingston plot



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)

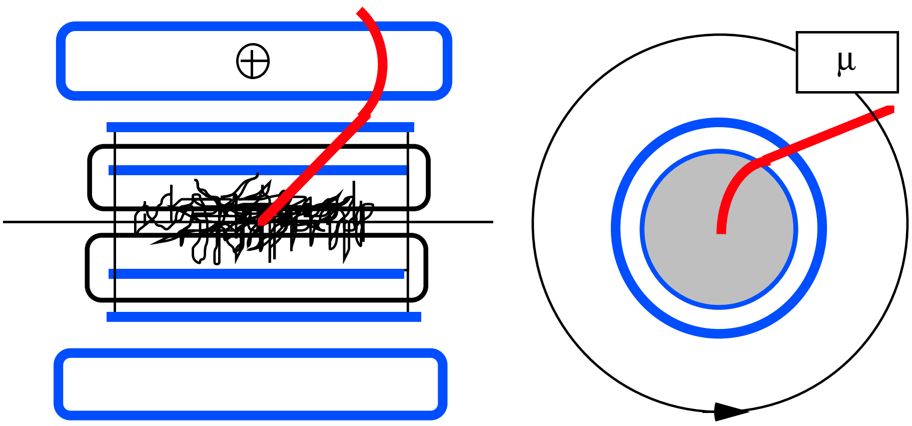


	Beams	Energy		Luminosity
LEP	e^+ e^-	200	GeV	10^{32} $cm^{-2}s^{-1}$
LHC	p p	14	TeV	10^{34}
	Pb Pb	1312	TeV	10^{27}

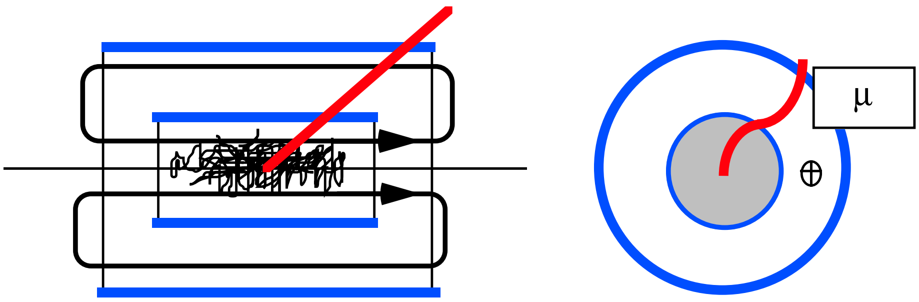
The LHC machine and the experiments are under design and construction. The observation of first collisions is expected in 2005

Magnets

ATLAS A Toroidal LHC ApparatuS



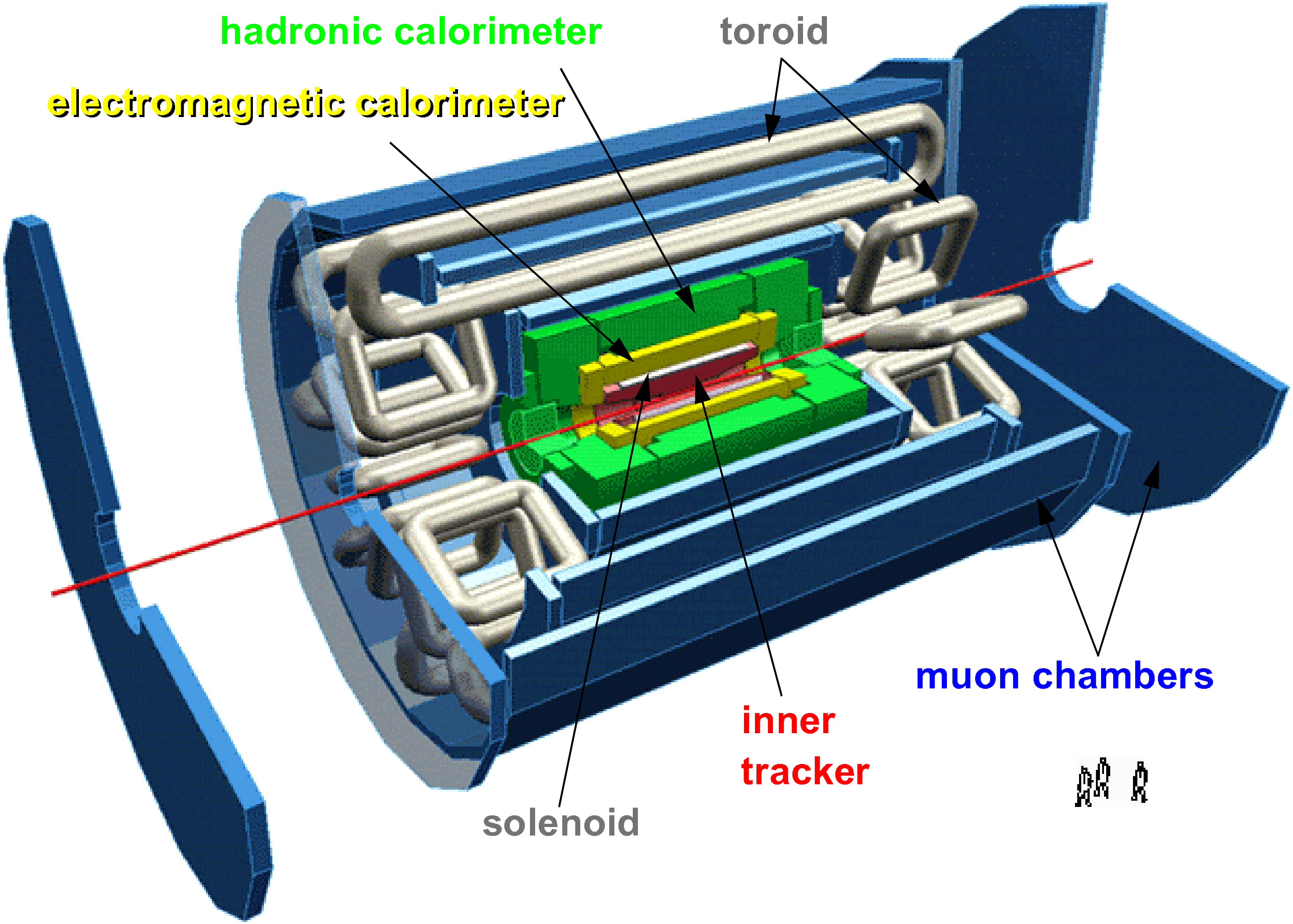
CMS Compact Muon Solenoid



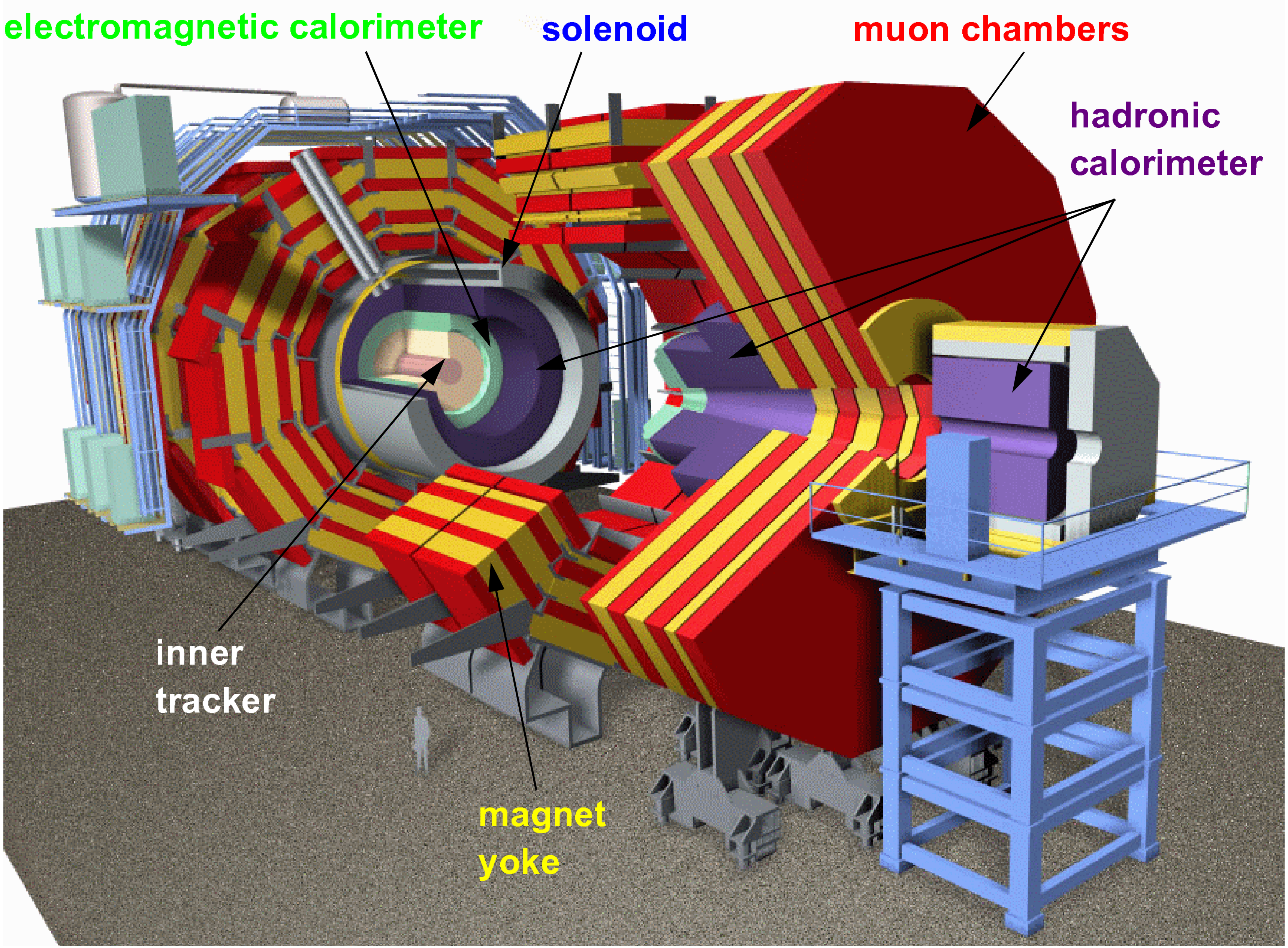
experiment	cost	magnet	cost
ATLAS	475 M CHF	toroid	200 M CHF
CMS	475 M CHF	solenoid	120 M CHF

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

A Toroidal LHC ApparatuS (ATLAS)



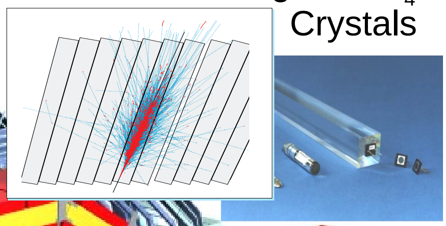
Compact Muon Solenoid



CMS layout and detectors

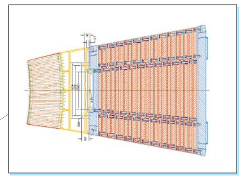
SUPERCONDUCTING COIL

ECAL Scintillating $PbWO_4$ Crystals

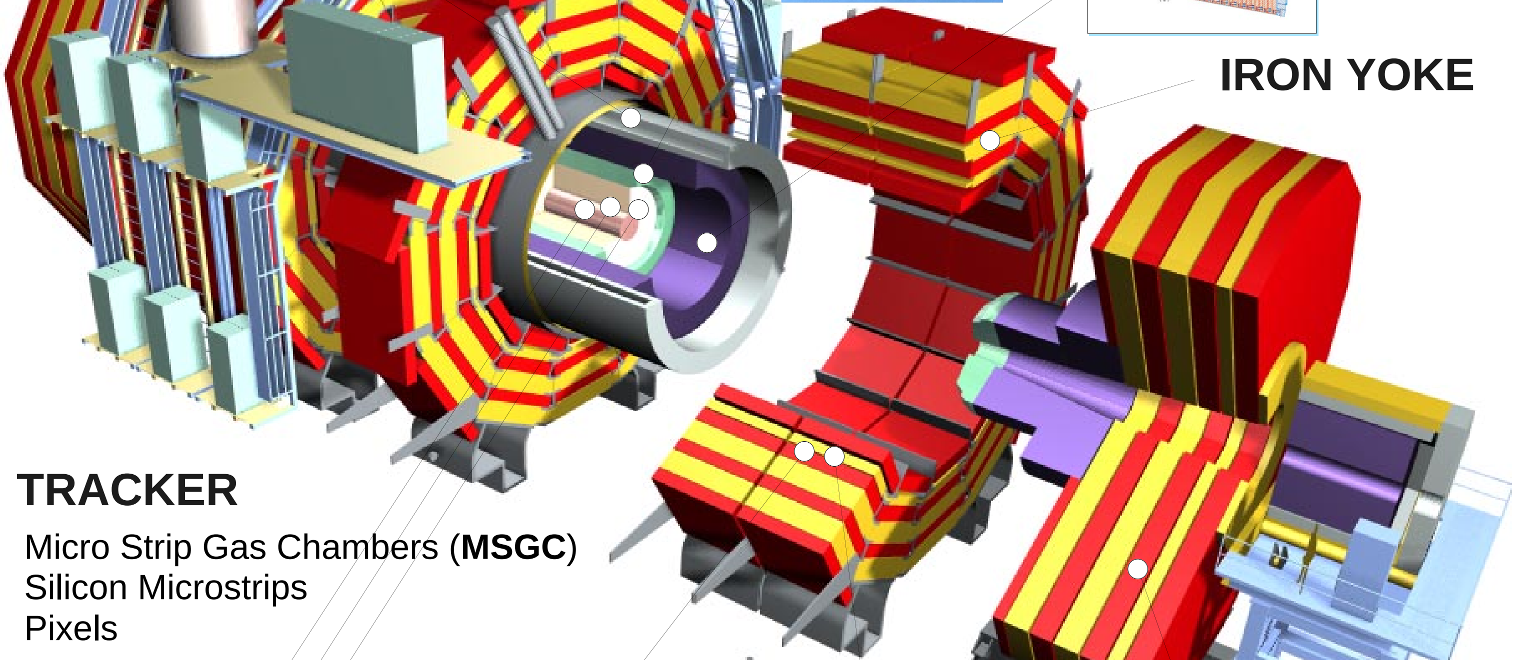


CALORIMETERS

HCAL Plastic scintillator copper sandwich

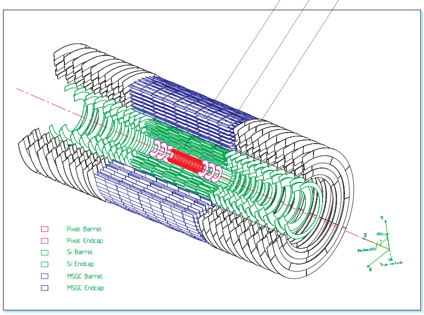


IRON YOKE

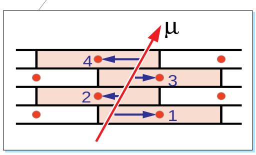


TRACKER

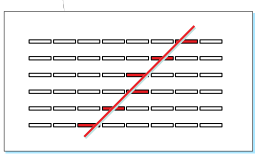
Micro Strip Gas Chambers (**MSGC**)
Silicon Microstrips
Pixels



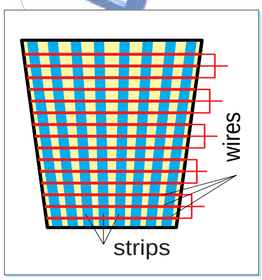
MUON BARREL



Drift Tube Chambers (**DT**)



Resistive Plate Chambers (**RPC**)



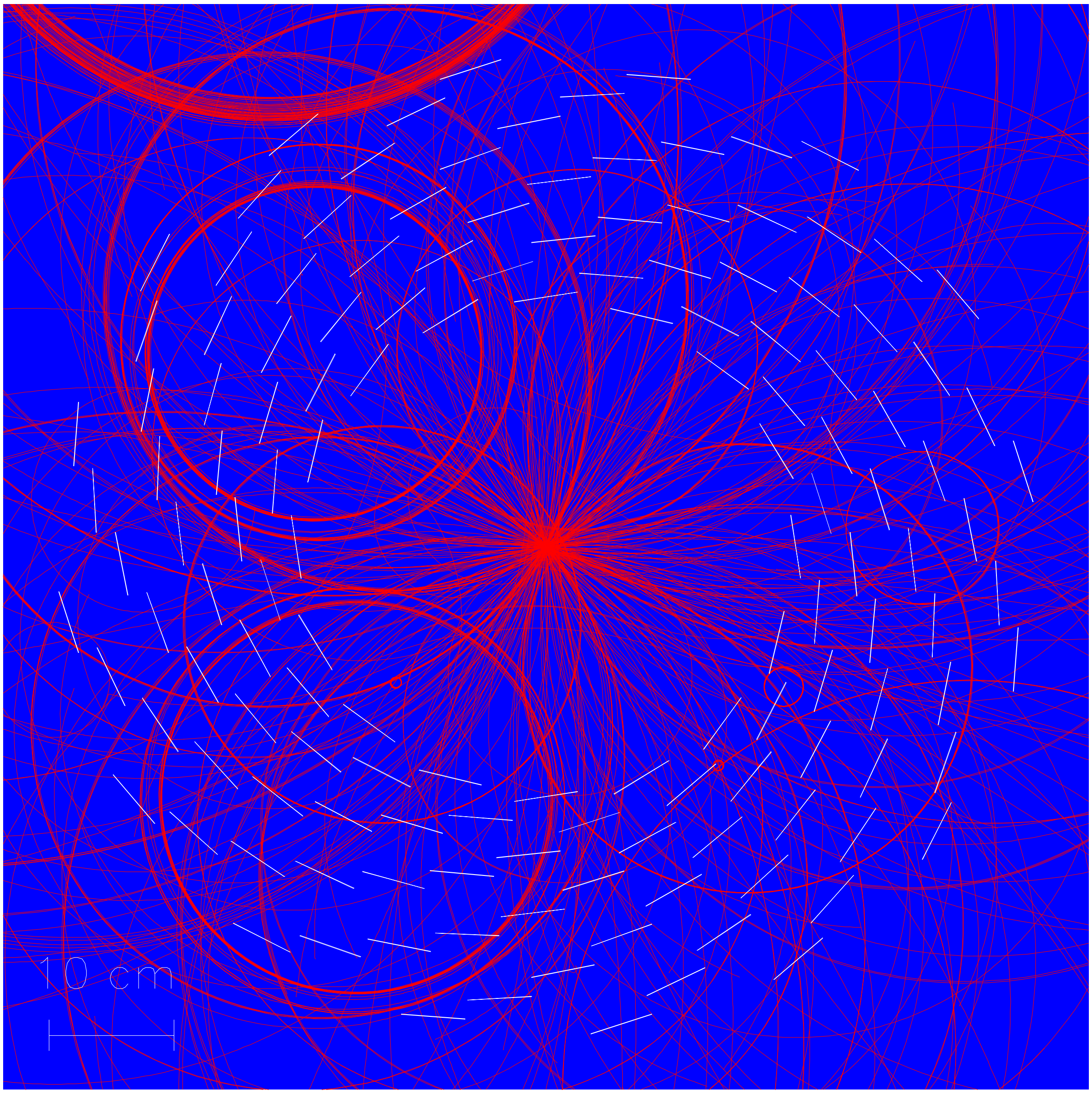
MUON ENDCAPS

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

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

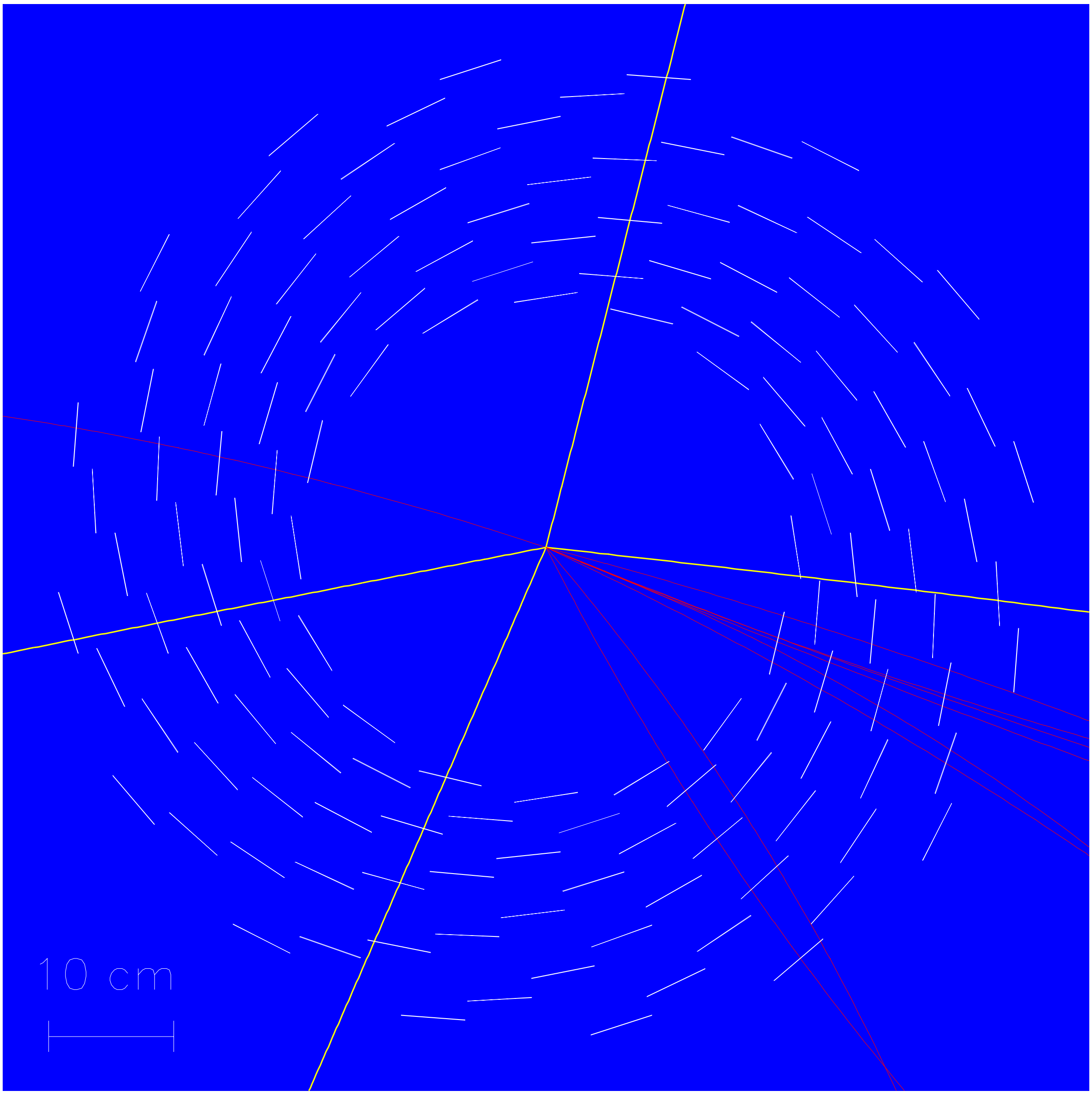


Find 4 straight tracks.

Solution

Reconstructed tracks of p_t > 2 GeV.

Among them well visible 4 muons from the higgs decay.



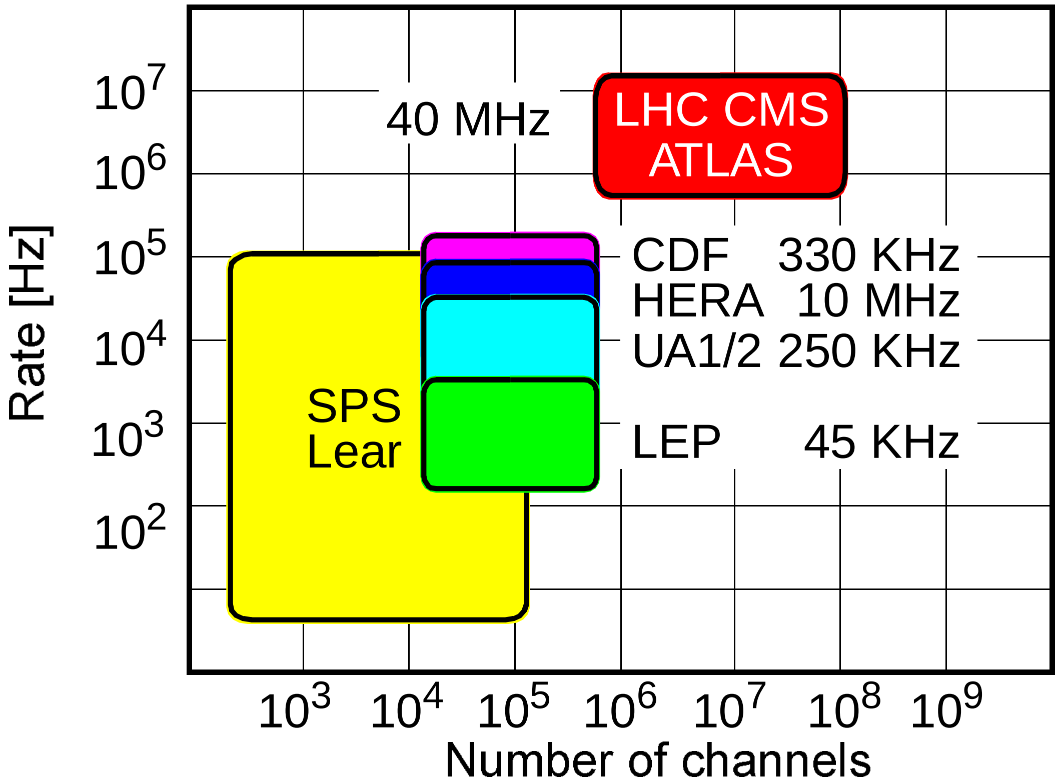
The solution is possible if detector occupancy ~1%

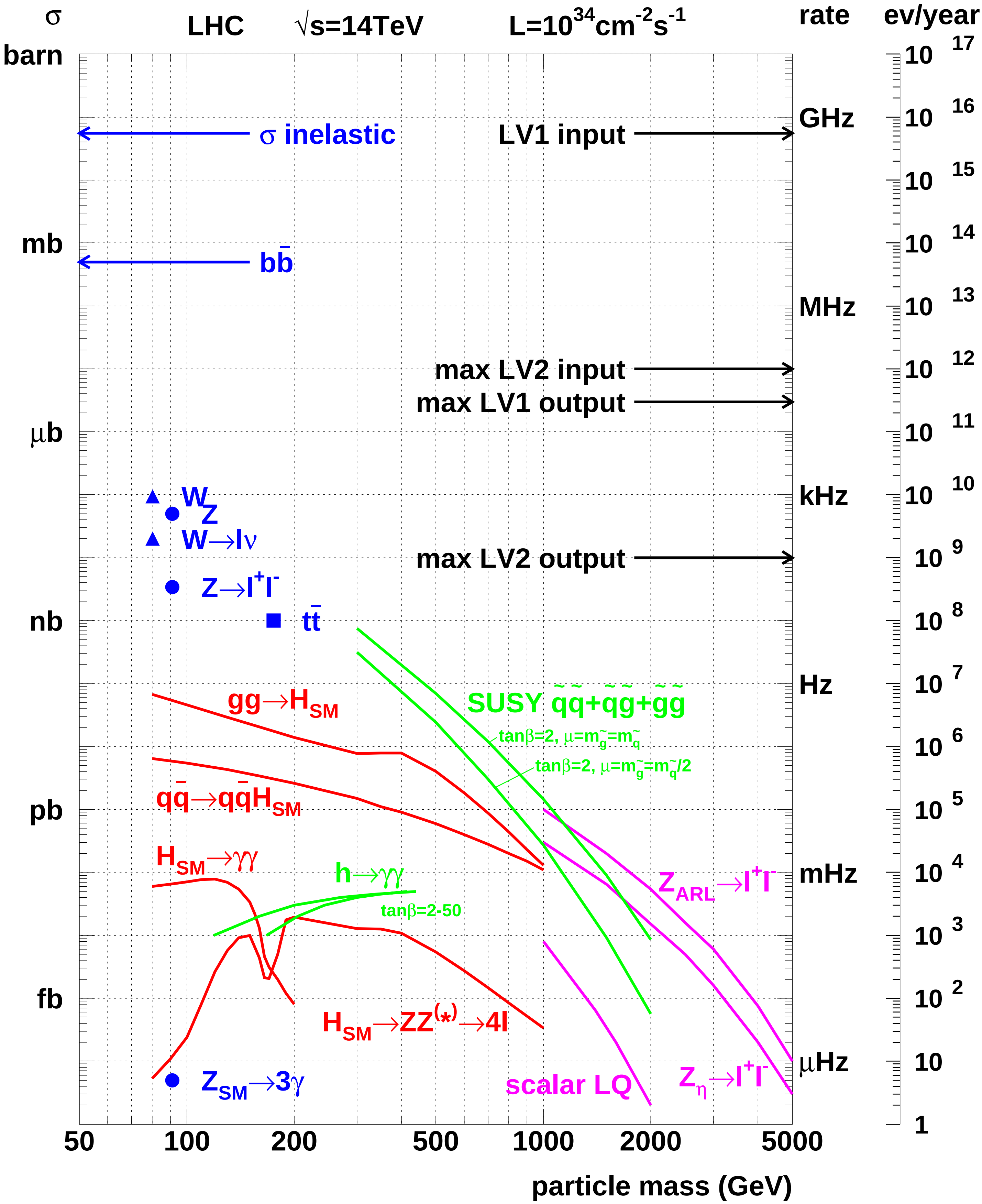
⟶ microstrip area ~1mm^2

⟶ >10^7 readout channels

CMS and other experiments

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




σ
barn
mb
μb
nb
pb
fb
LHC
√s=14TeV
L=10^34 cm^-2 s^-1
rate
ev/year
σ inelastic
LV1 input
GHz
bb̄
MHz
max LV2 input
max LV1 output
kHz
W
Z
W→lν
Z→l+l-
max LV2 output
tt̄
Hz
gg→H_SM
SUSY q̃q̃+q̃g̃+g̃g̃
tanβ=2, μ=m_g̃=m_q̃
tanβ=2, μ=m_g̃=m_q̃/2
qq̄→qq̄H_SM
H_SM→γγ
h→γγ
tanβ=2-50
Z_ARL→l+l-
mHz
H_SM→ZZ(*)→4l
Z_SM→3γ
scalar LQ
Z_η→l+l-
μHz
10 17
10 16
10 15
10 14
10 13
10 12
10 11
10 10
10 9
10 8
10 7
10 6
10 5
10 4
10 3
10 2
10
1
50
100
200
500
1000
2000
5000
particle mass (GeV)

Event selection

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

An observation of ~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.

<u>Searching for a needle in a hay stack?</u>

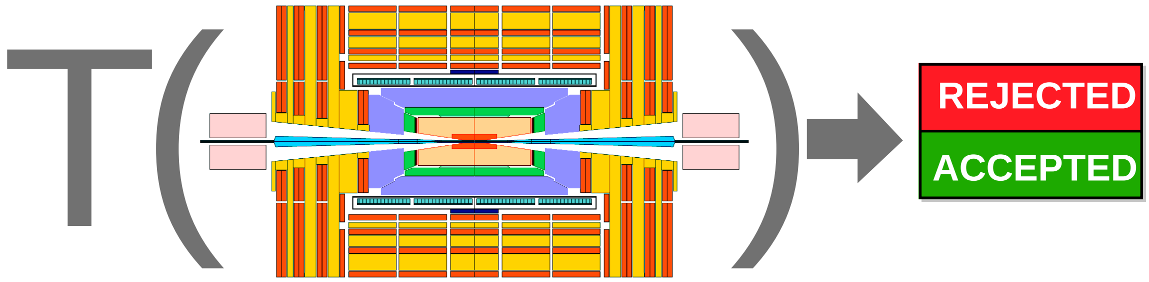
- typical needle — 5 mm^3
- typical hay stack — 50 m^3

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

The trigger is a function of :



Event data & Apparatus
Physics channels & Parameters

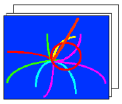
Since the detector data are not all promptly available and the function is highly complex, T(...) is evaluated by successive approximations called :

TRIGGER LEVELS

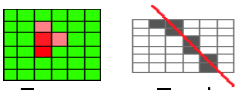
(possibly with zero dead time)

CMS trigger and data acquisition

COMMUNICATION



40 MHz
COLLISION RATE



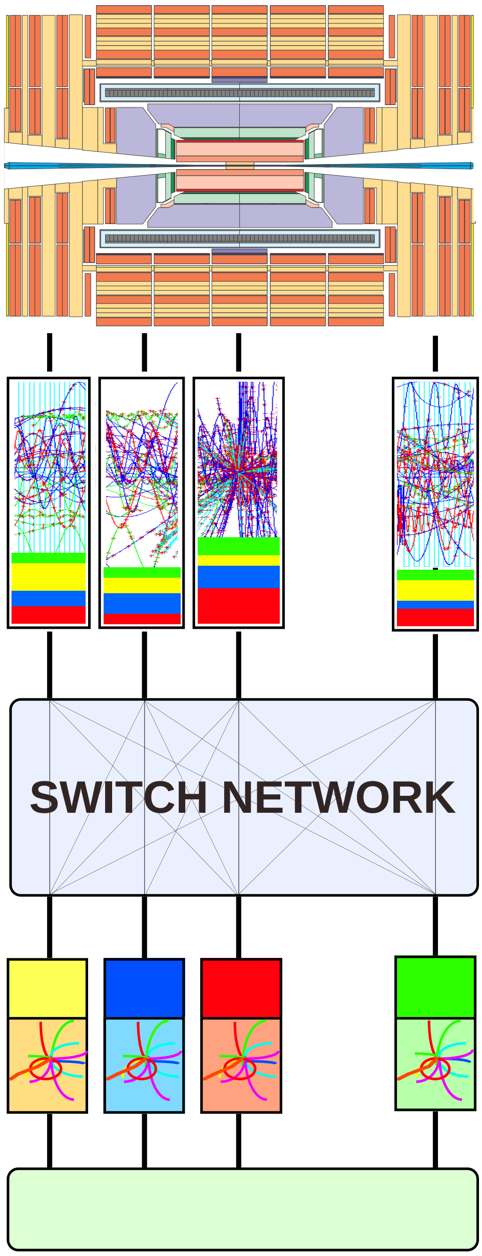
100 kHz
LEVEL-1 TRIGGER

1 Terabit/s
(50000 DATA CHANNELS)

500 Gigabit/s

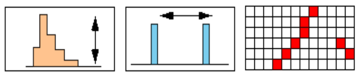
100 Hz
FILTERED EVENT

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

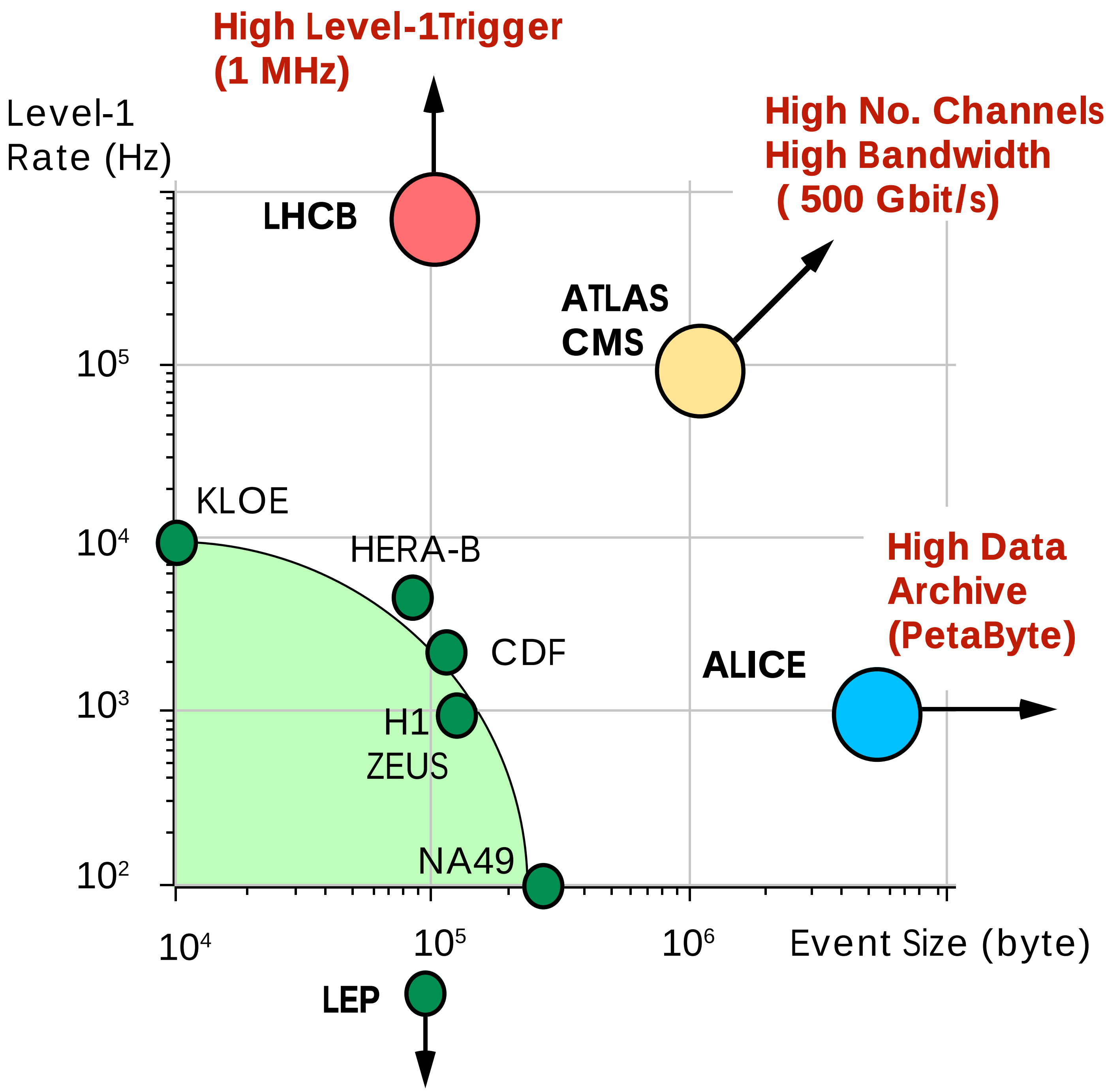
5 TeraIPS

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

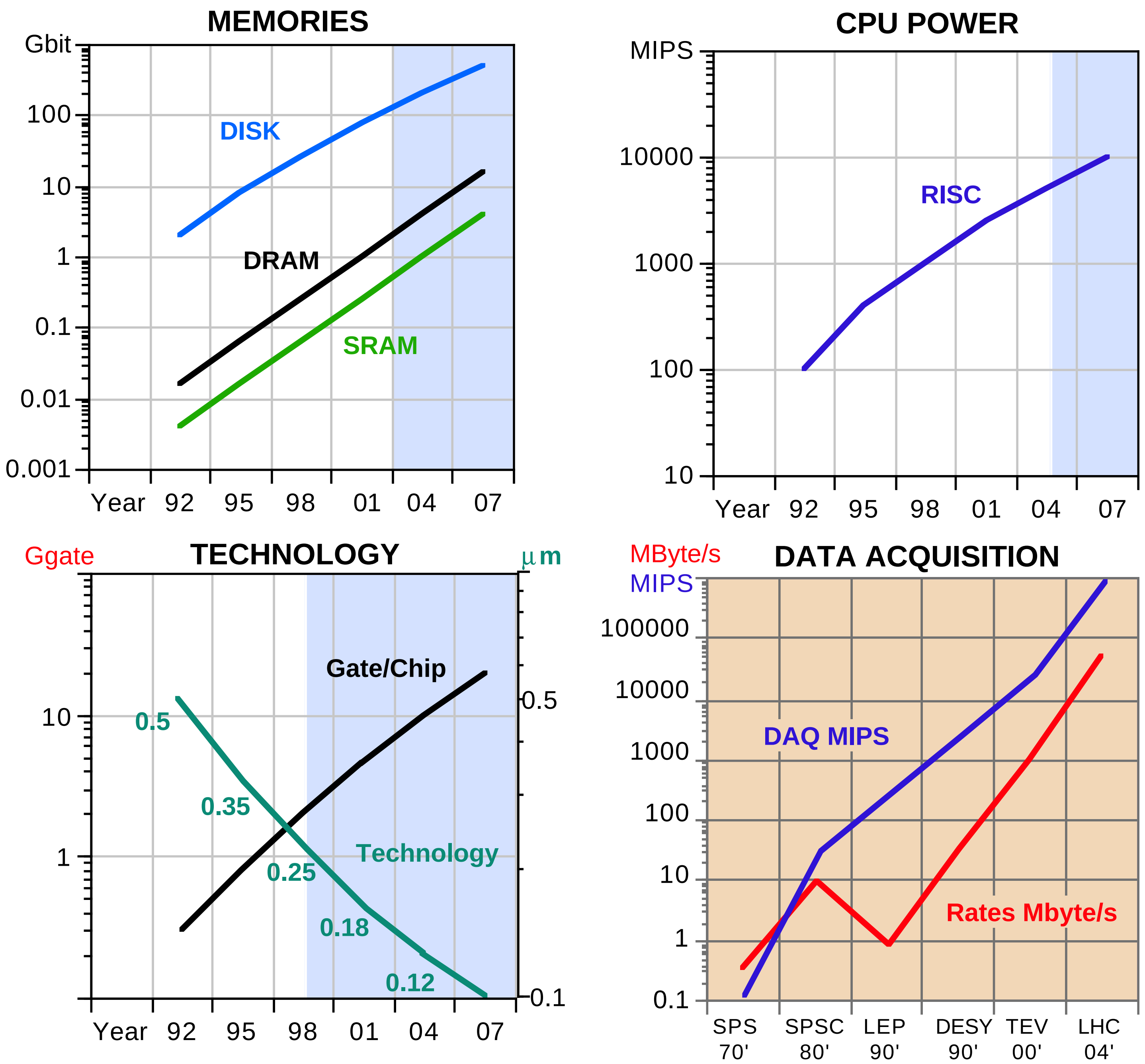
Petabyte ARCHIVE

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

Trigger and DAQ trends

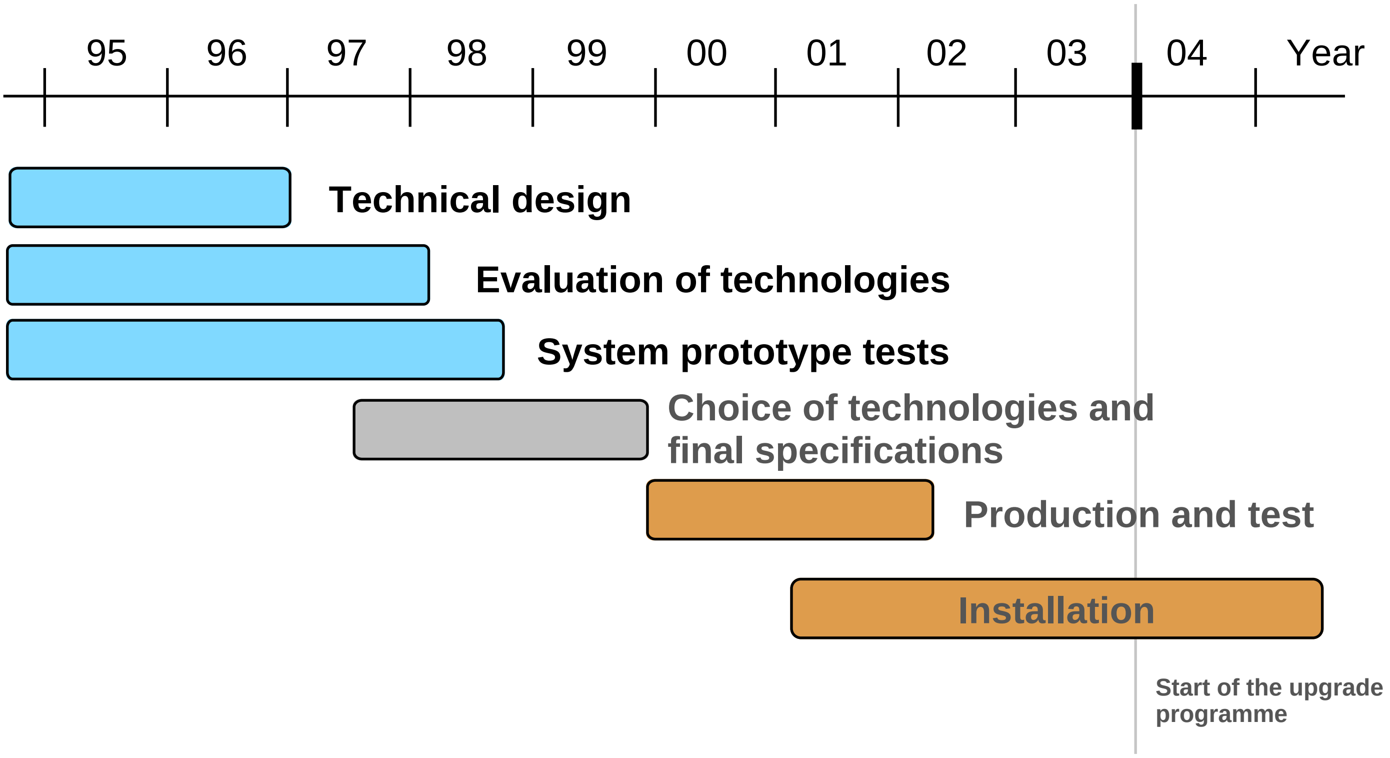


Technology & DAQ trends



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

CMS trigger and data acquisition schedule



Summary

"New Physics" searches require reaching
very high energies 14 TeV
and searching for extremaly rare phenomena σ~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** ~100μ/10m

searching for new phenomena:

- **very high frequency of interactions** ~1 GHz
- **pile-up of many interations** 10-20
- **small signal to background ratio** $1:10^{11}$ - $1:10^{16}$

resulting technological requirements:

- **steering of large volume data flow** 500 Gbits/s
- **event analysis in real time** selection $1:10^{7}$
- **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

- 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 (≈ 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 (≈ 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?