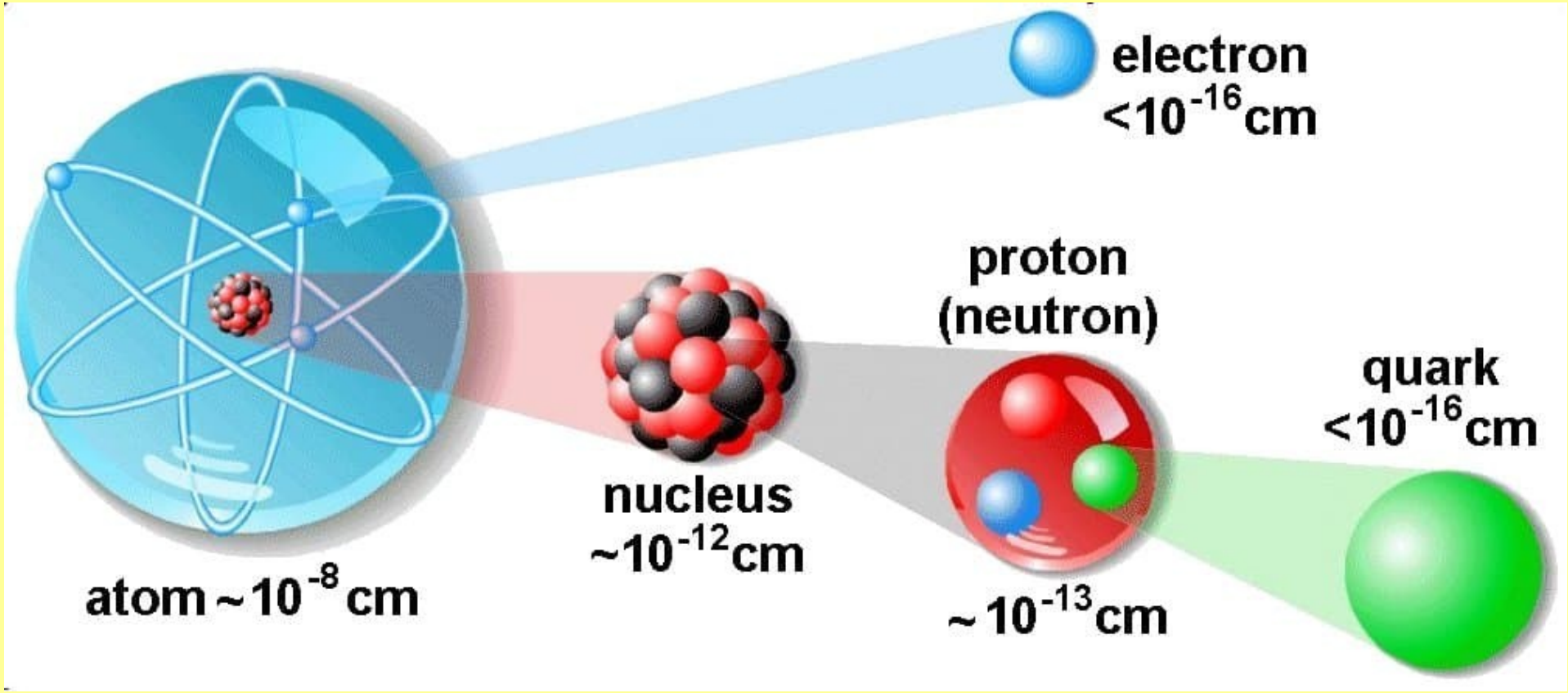
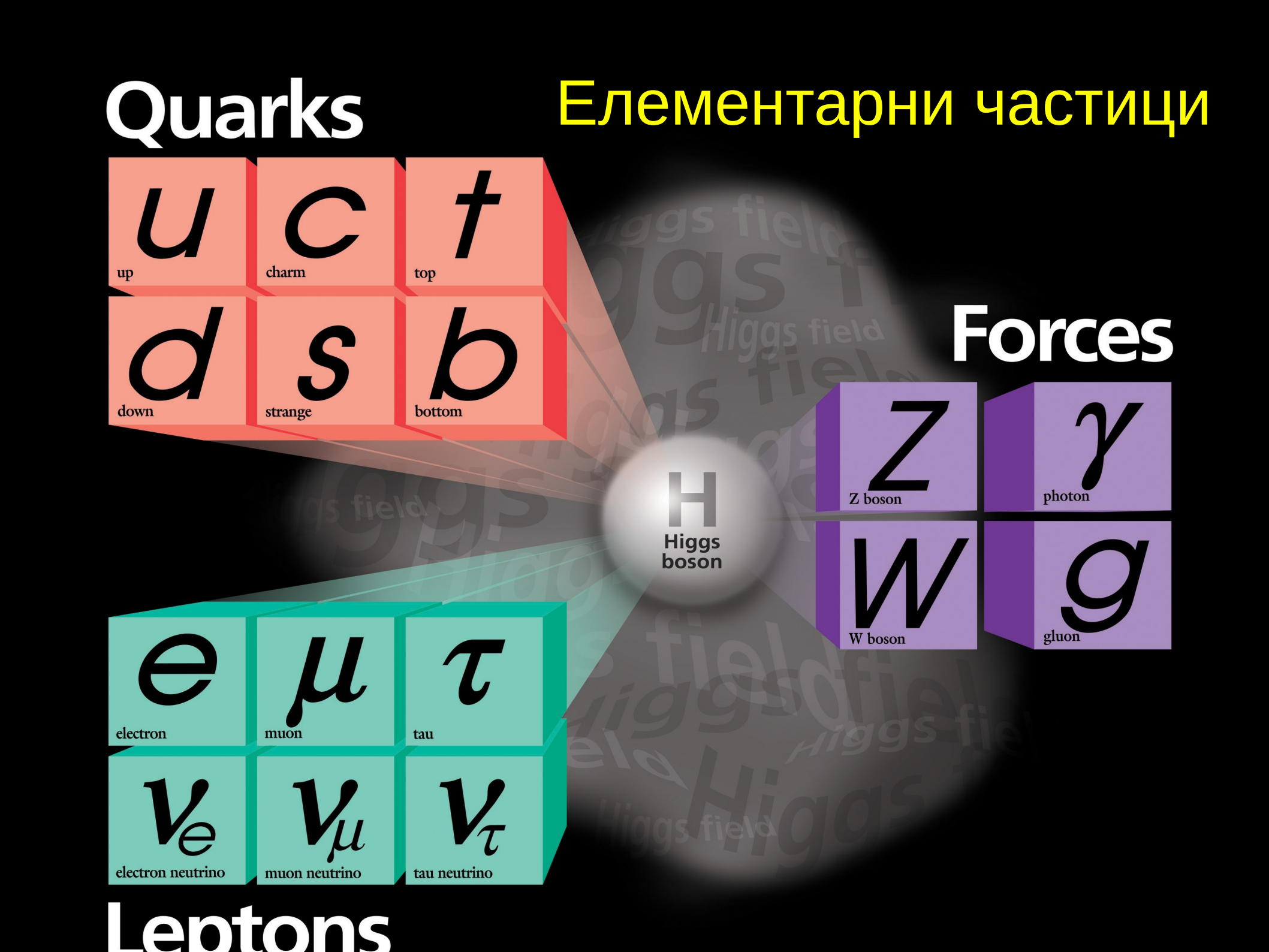
Въведение в детекторите на елементарни частици

„Малко“ физика ...

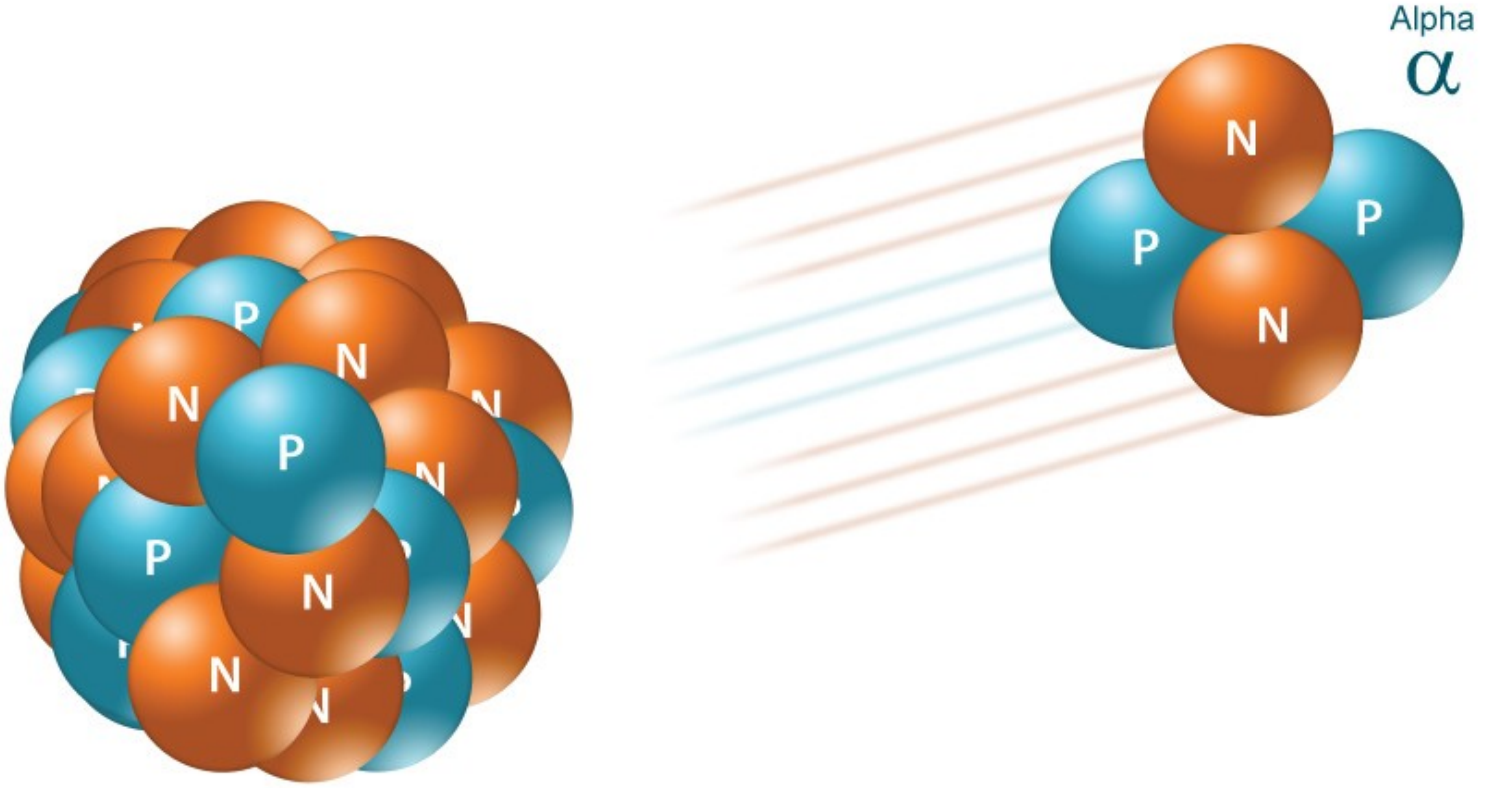
Веществото


electron
<10^-16 cm
proton
(neutron)
quark
<10^-16 cm
nucleus
~10^-12 cm
atom ~10^-8 cm
~10^-13 cm


Quarks
Елементарни частици
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Leptons

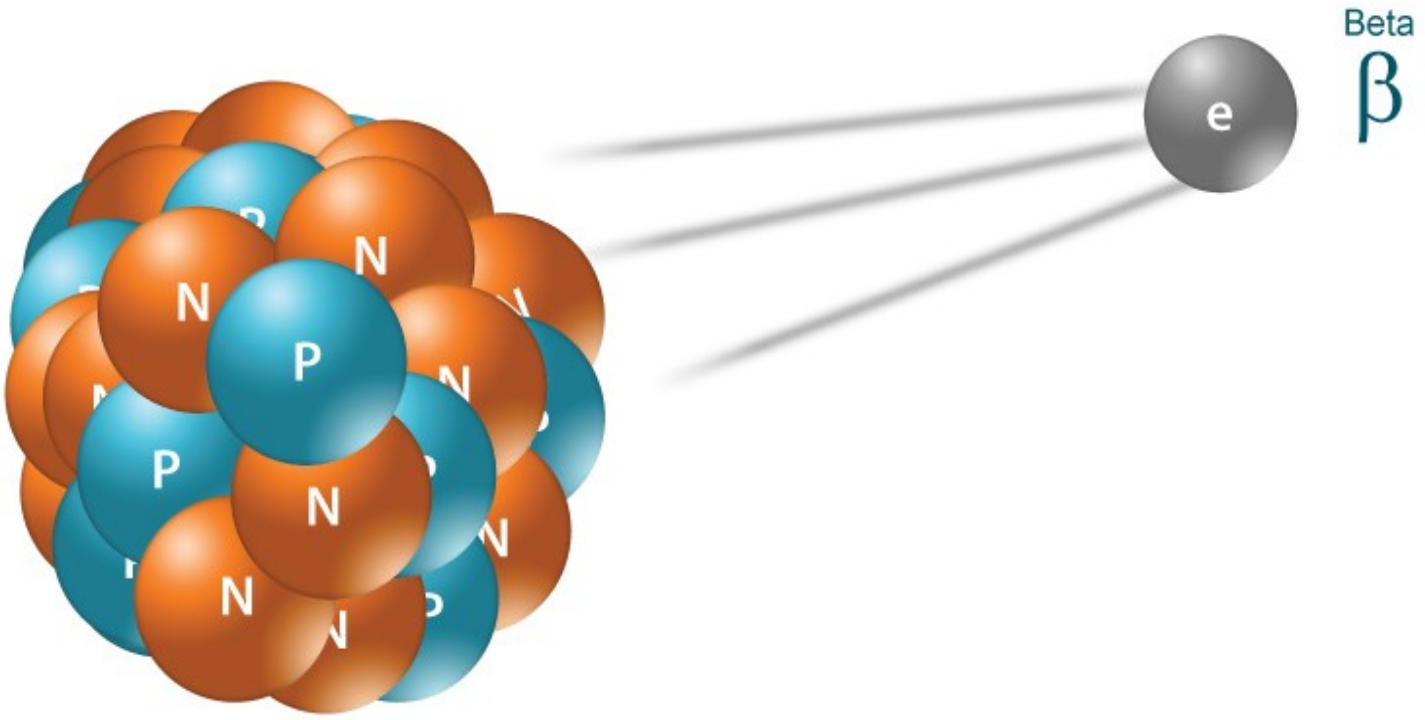
Йонизиращо лъчение

Йонизиращо лъчение:
α частици

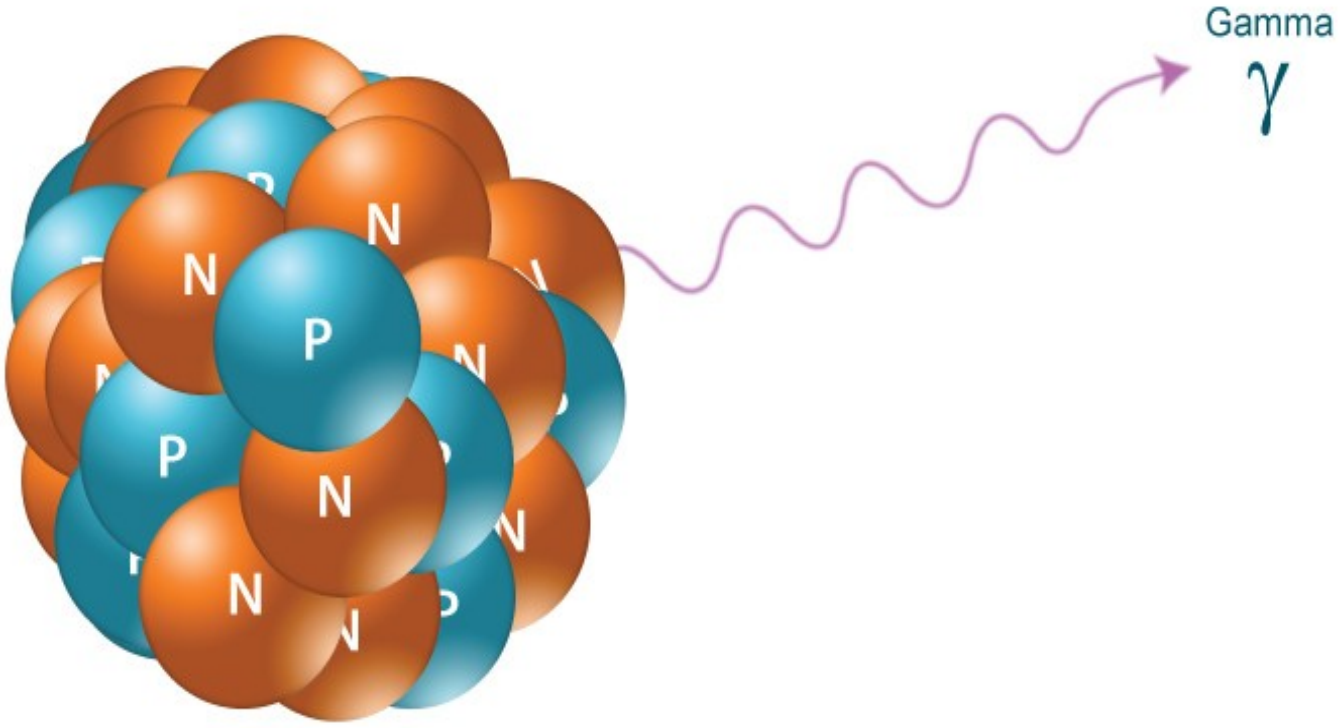


Йонизиращо лъчение:
β частици

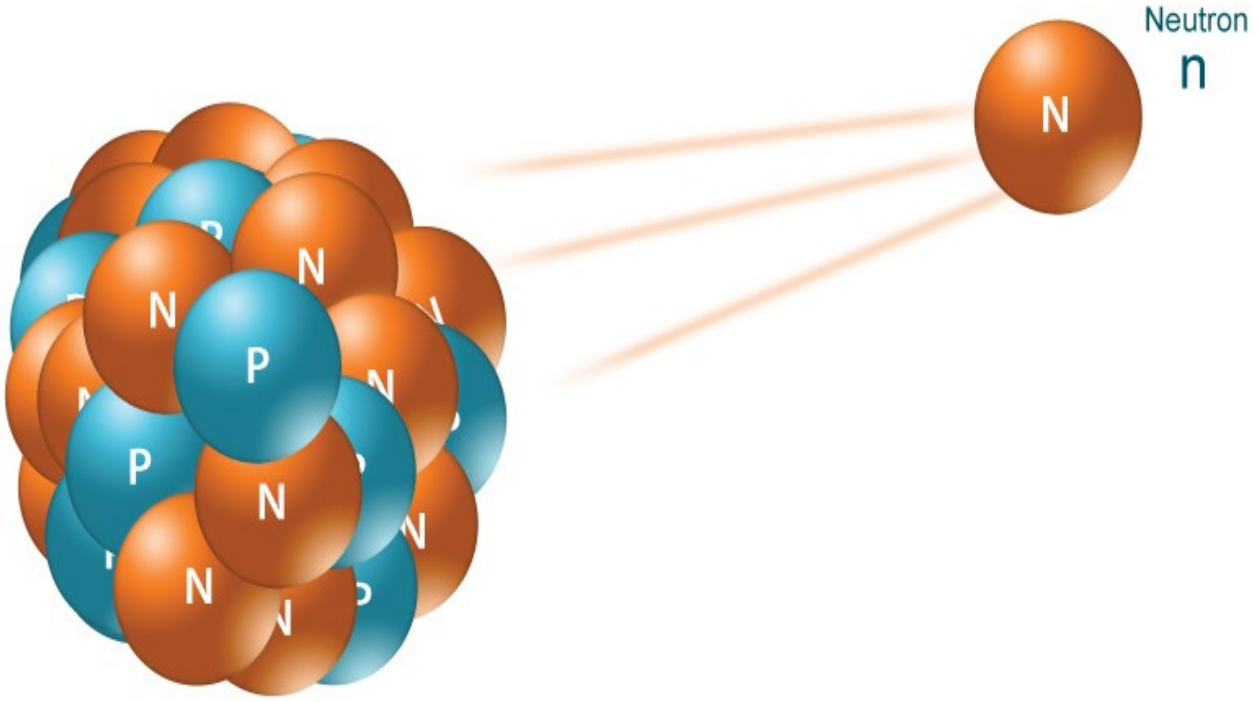
β+ / β-



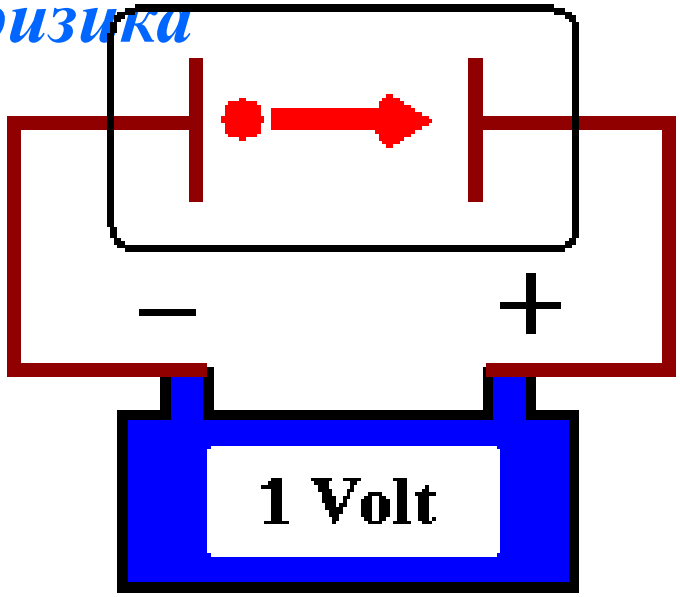
Йонизиращо лъчение:
γ



Йонизиращо лъчение: неутрони



Единици в субатомната физика



Енергия

1 electron-Volt (eV):

Енергията на частица със заряд = $|e|$,

Намираща се първоначално в покой и

Ускорена в електростатичен потенциал 1 V

(e = 1.60 x 10^{-19} C)

1 eV = 1.60 x 10^{-19} J

Производни:

1 keV = 10^3 eV ; 1 MeV = 10^6 eV

1 GeV = 10^9 eV; 1 TeV = 10^{12} eV

Енергията на протон в LHC:

7 TeV = 1.12 x 10^{-6} J

(енергията на тяло с маса = 1 mg движещо се със скорост = 1.5 m /s)

Експерименти във Физиката на елементарните частици

Експерименти на ускорители.
- Фиксирана мишена
- Колайдери

Космически лъчи
- На земята
- В космоса

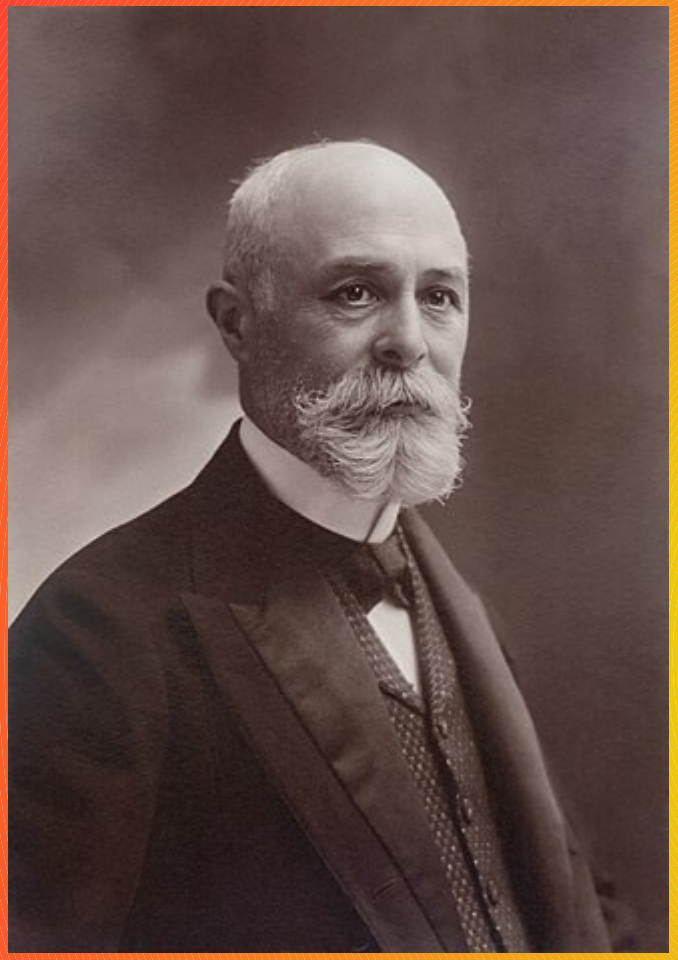
Реактори

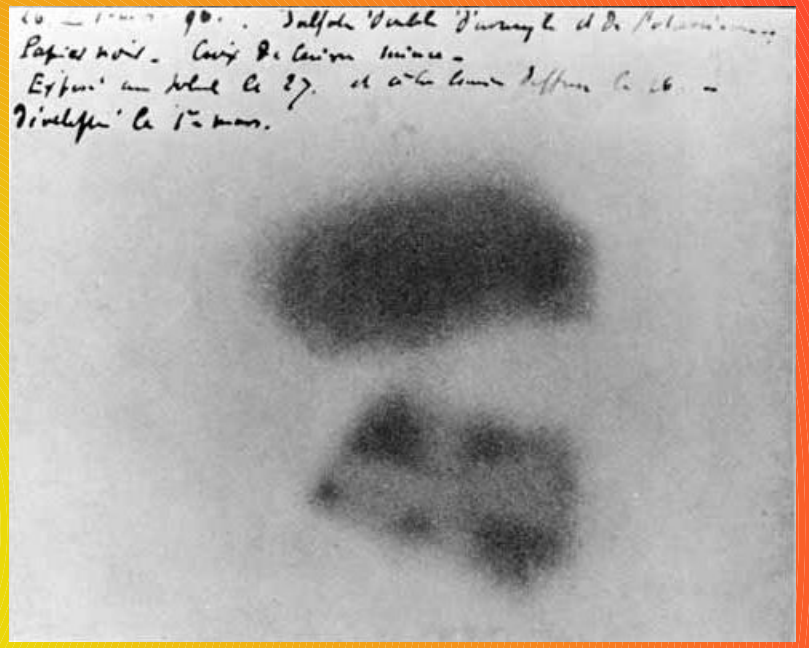
Други

Малко история ….

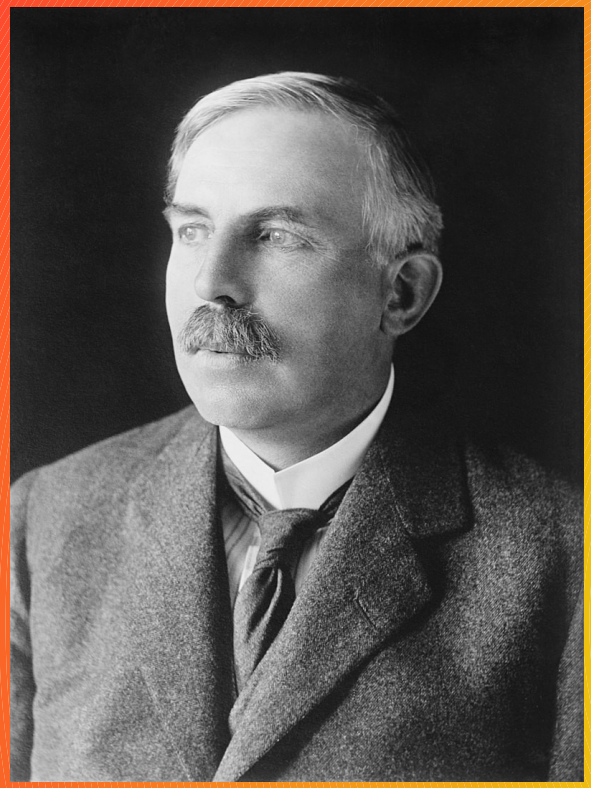
Вилхелм Конрад Рьонтген

Анри Бекерел





Ърнст Ръдърфорд



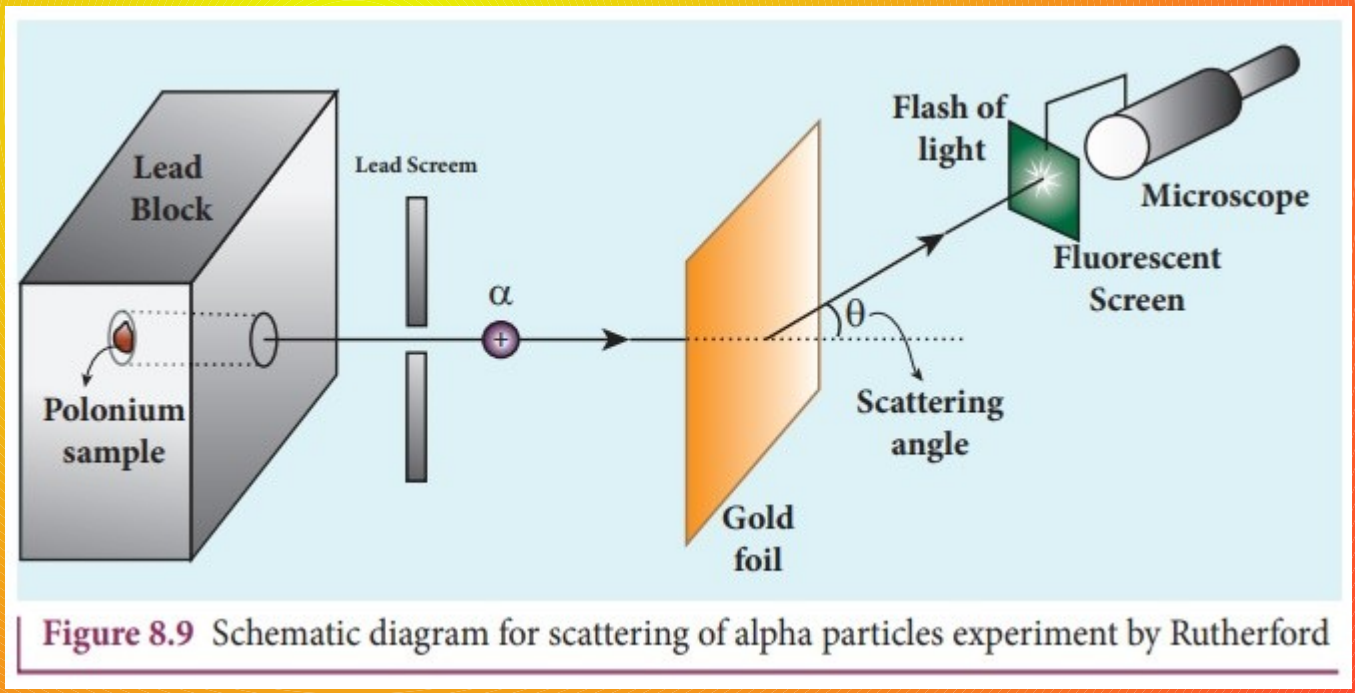
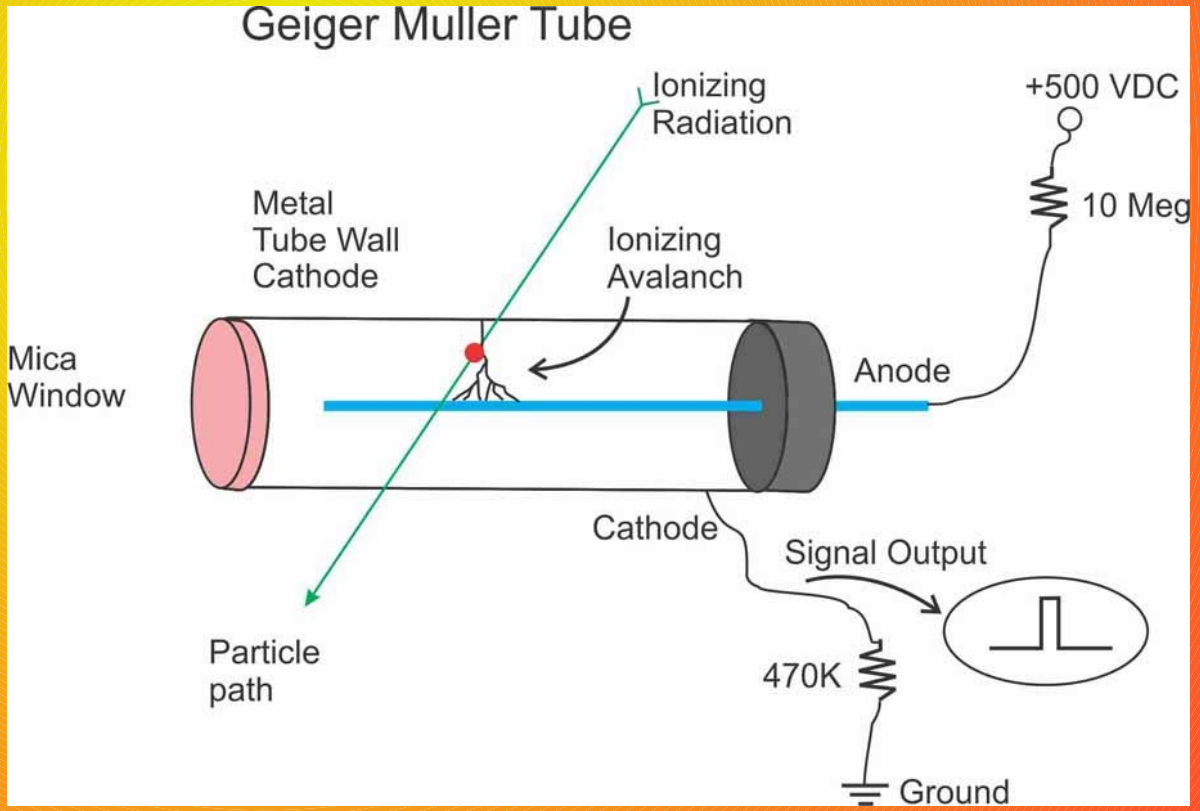
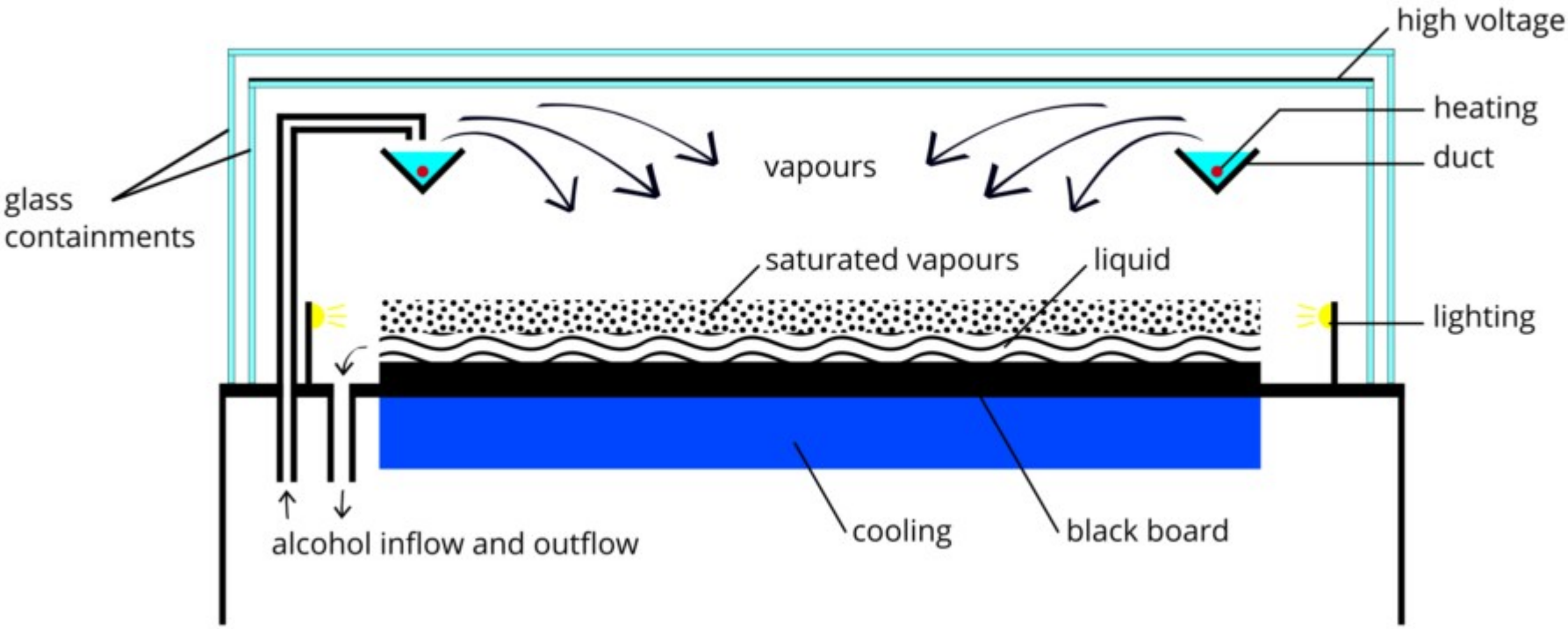


Figure 8.9 Schematic diagram for scattering of alpha particles experiment by Rutherford

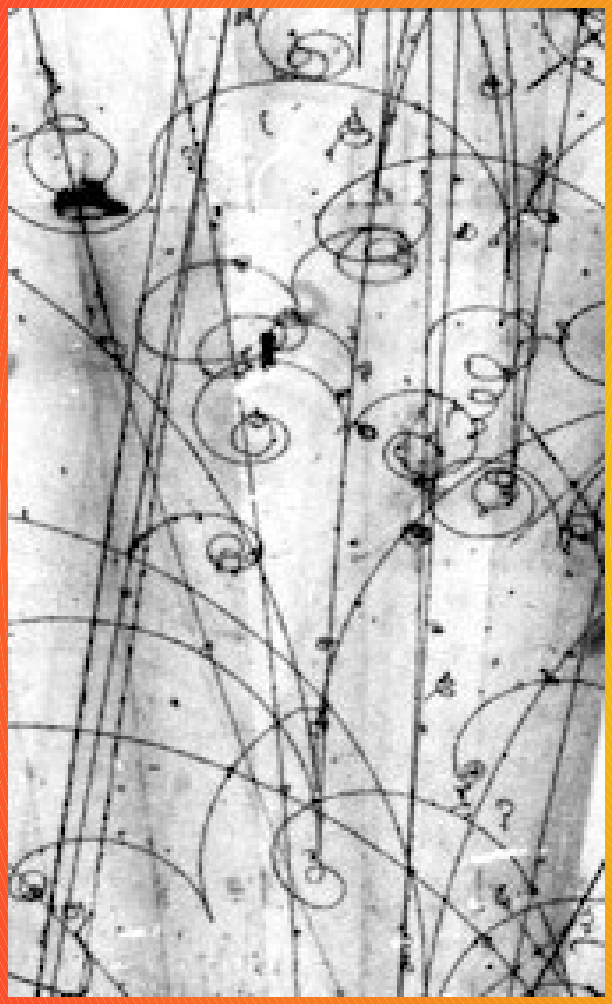
Ханс Гайгер


Geiger Muller Tube
Ionizing
Radiation
+500 VDC
10 Meg
Metal
Tube Wall
Cathode
Ionizing
Avalanch
Mica
Window
Anode
Cathode
Signal Output
Particle
path
470K
Ground

Cloud chamber

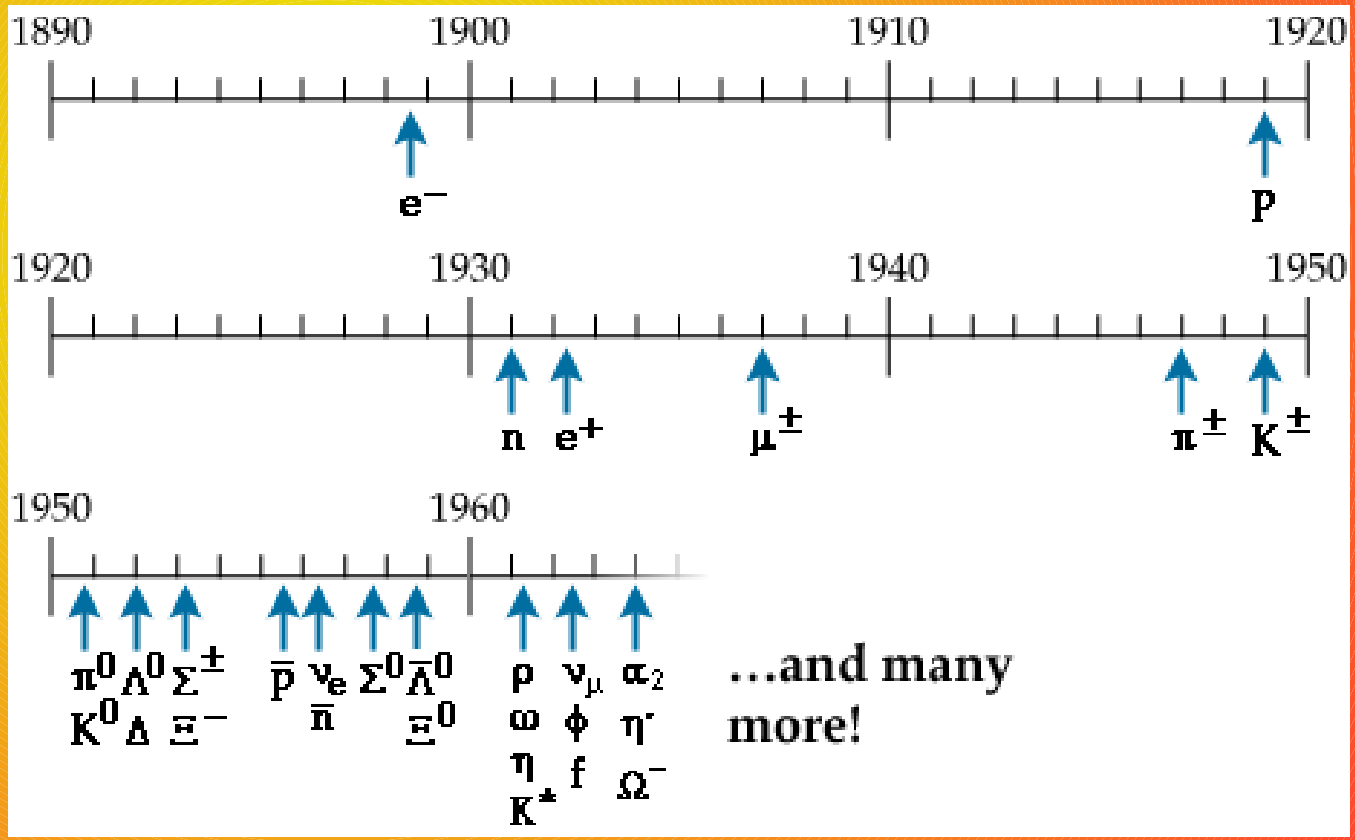


New Types of Matter!

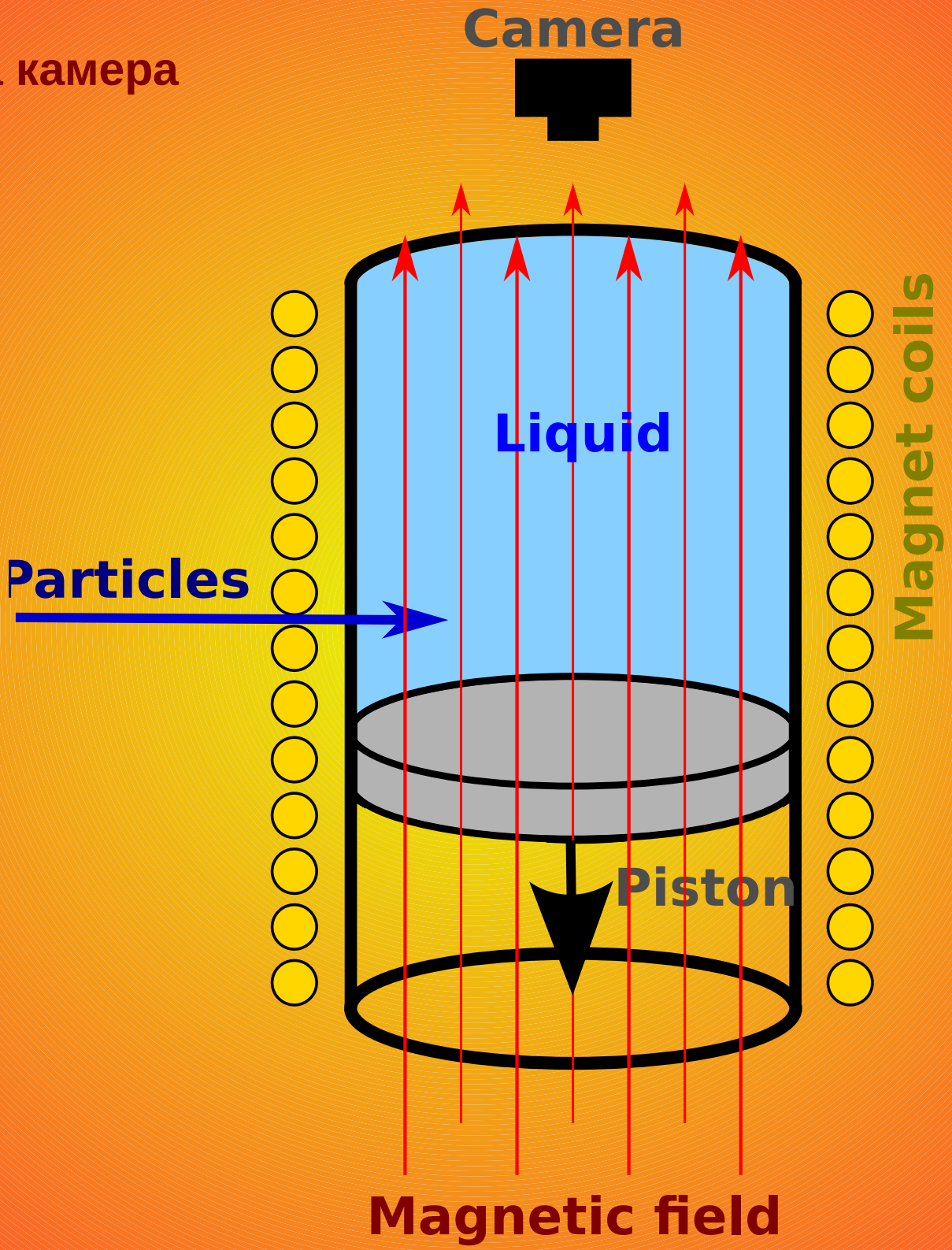


Fermilab:
Мехурчеста камера

More and More Mystery particles



Мехурчеста камера



Мехурчеста камера

И в днешно време ...

CERN – European Centre for Nuclear Research

CERN – European Centre for Nuclear Research

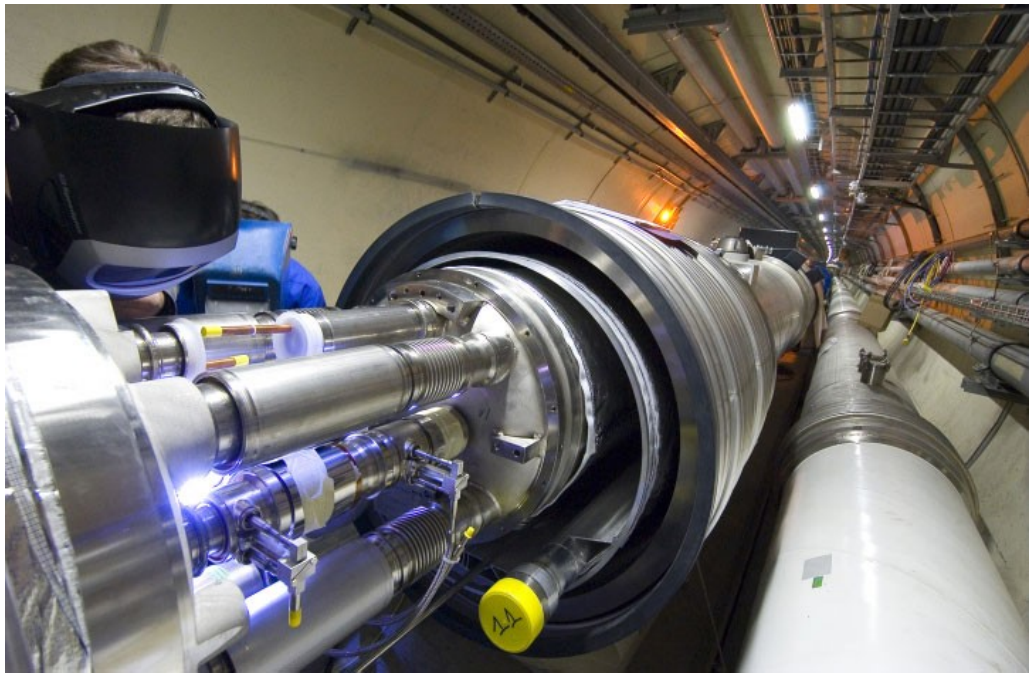
lies the world's **fastest** and most **brutal** racetrack…

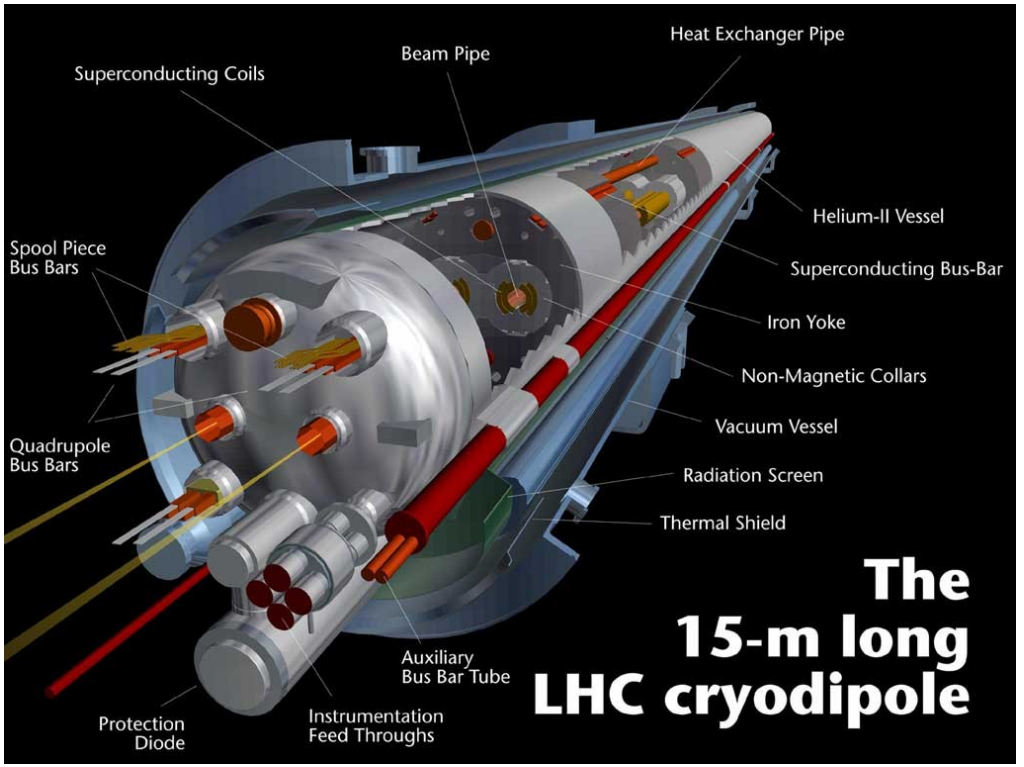
Protons race around a 27 km circuit at **99.999999%** the speed of light,

crashing head on into each other **40,000,000** times a second.

CERN – European Centre for Nuclear Research

in the **emptiest** space in our solar system…





The beam pipe is evacuated to the same vacuum as interplanetary space
The pressure is about 1/10th that of the surface of the moon.

CERN – European Centre for Nuclear Research

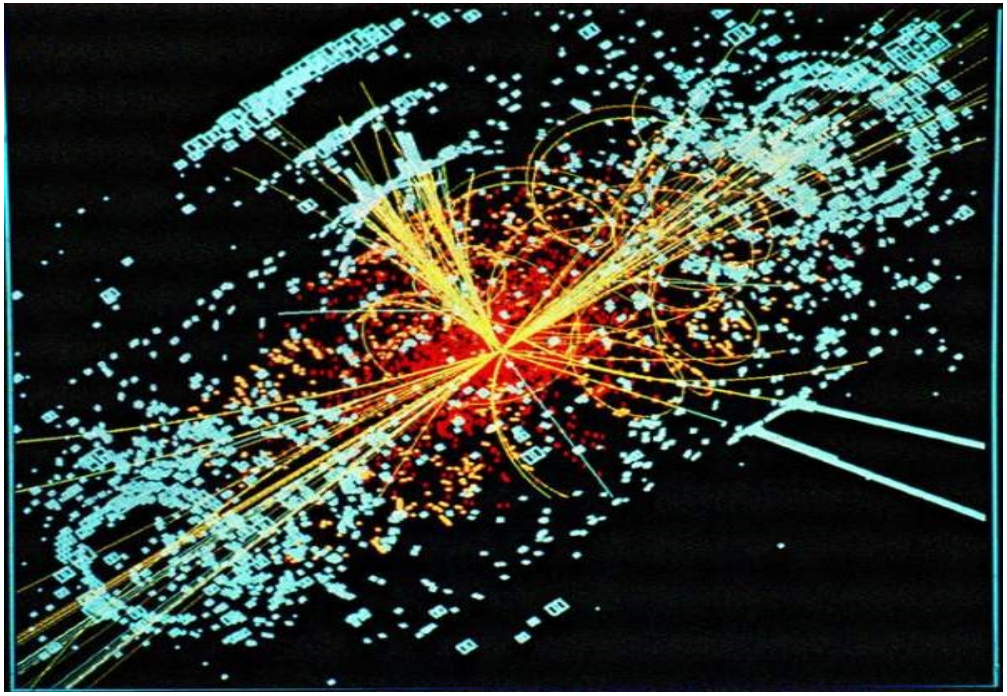
in one of the **coldest** regions in the universe…

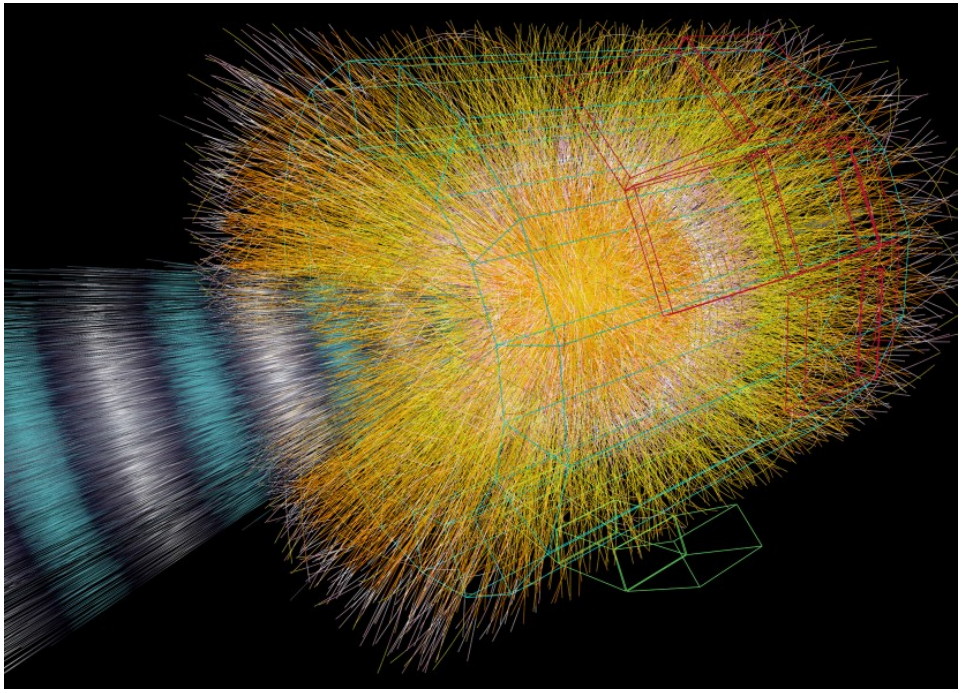
Superconducting and superfluid liquid helium is maintained at -271.3 C or 1.9 K.

That is a little colder than interstellar space.

CERN – European Centre for Nuclear Research

will occur some of the **hottest** reactions in our galaxy…



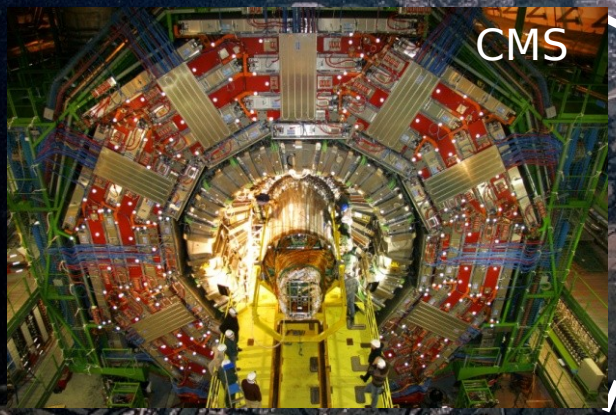


Violent collisions corresponding to temperatures a billion times higher than the core of the sun will be produced.

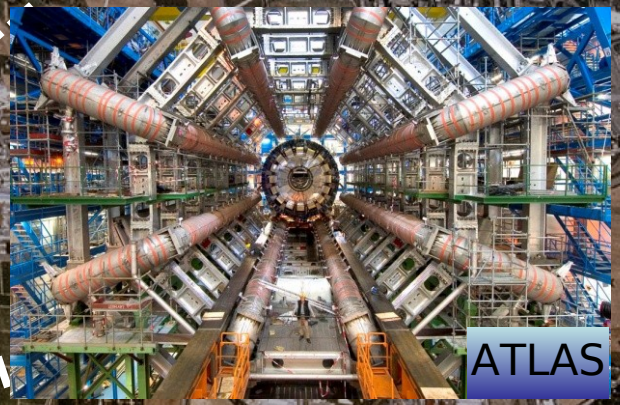
That is roughly 160,000,000,000,000,000 C

Нова ера във фундаменталната наука

Пуска на Големия Адронен Колайдер (LHC), един от най-големите и глобални научни проекти, е най-вълнуващата повратна точка във физиката на елементарните частици.



Изследване на нова енергийна граница
p-p и Pb-Pb сблъсъци



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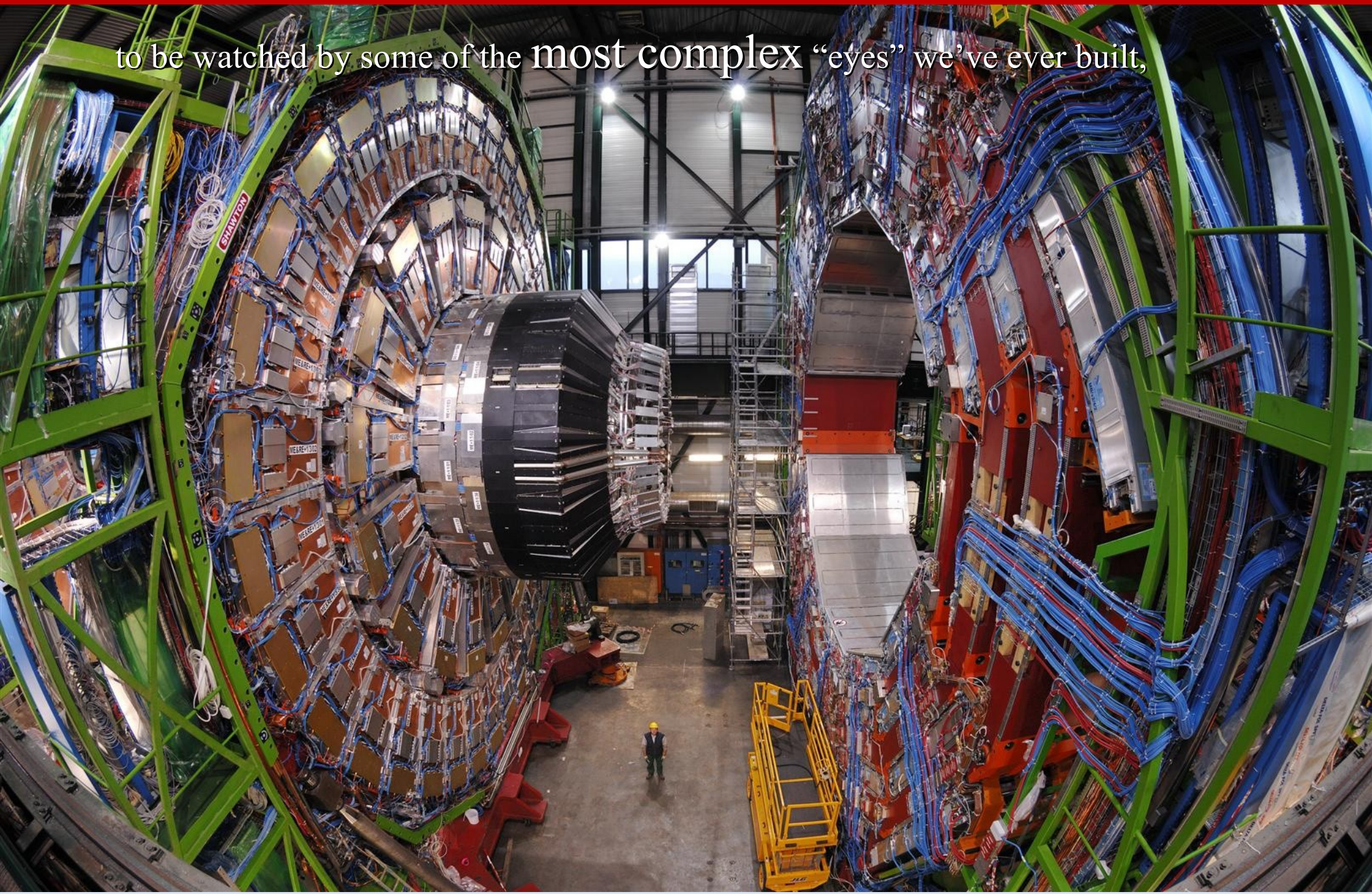

The detectors together have 140 million data channels observing at 40 million times a second.

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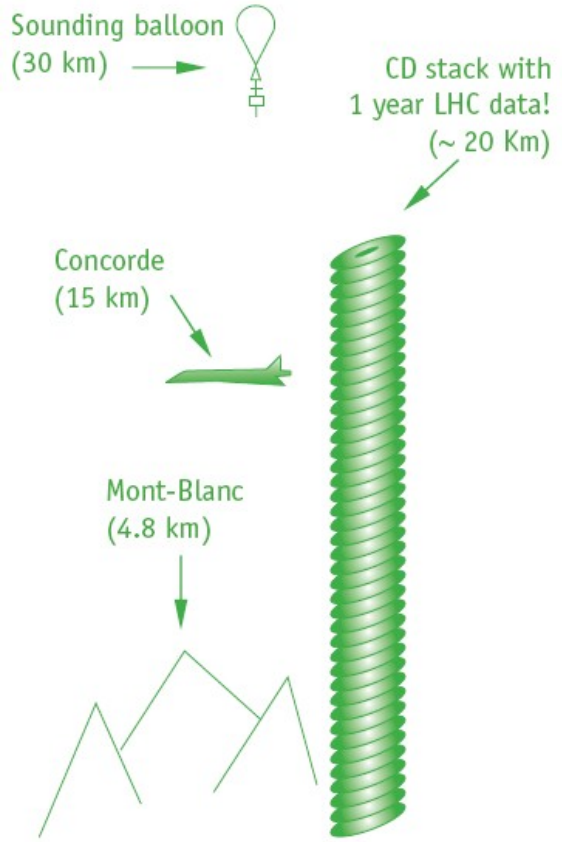
and analyzed by the most powerful computing system in the world.

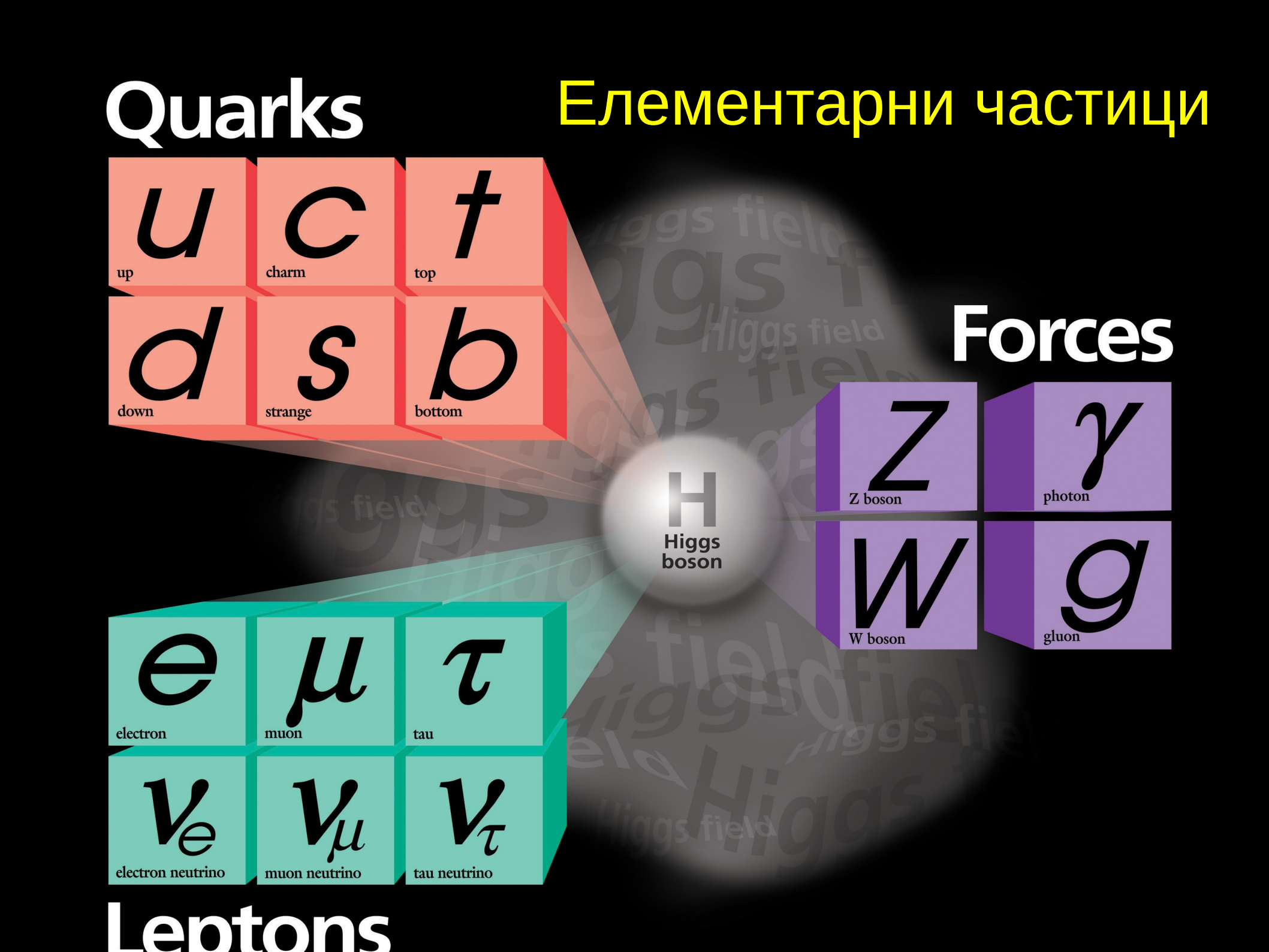


The detectors will spew out analyzed data at **700 MB/sec.**

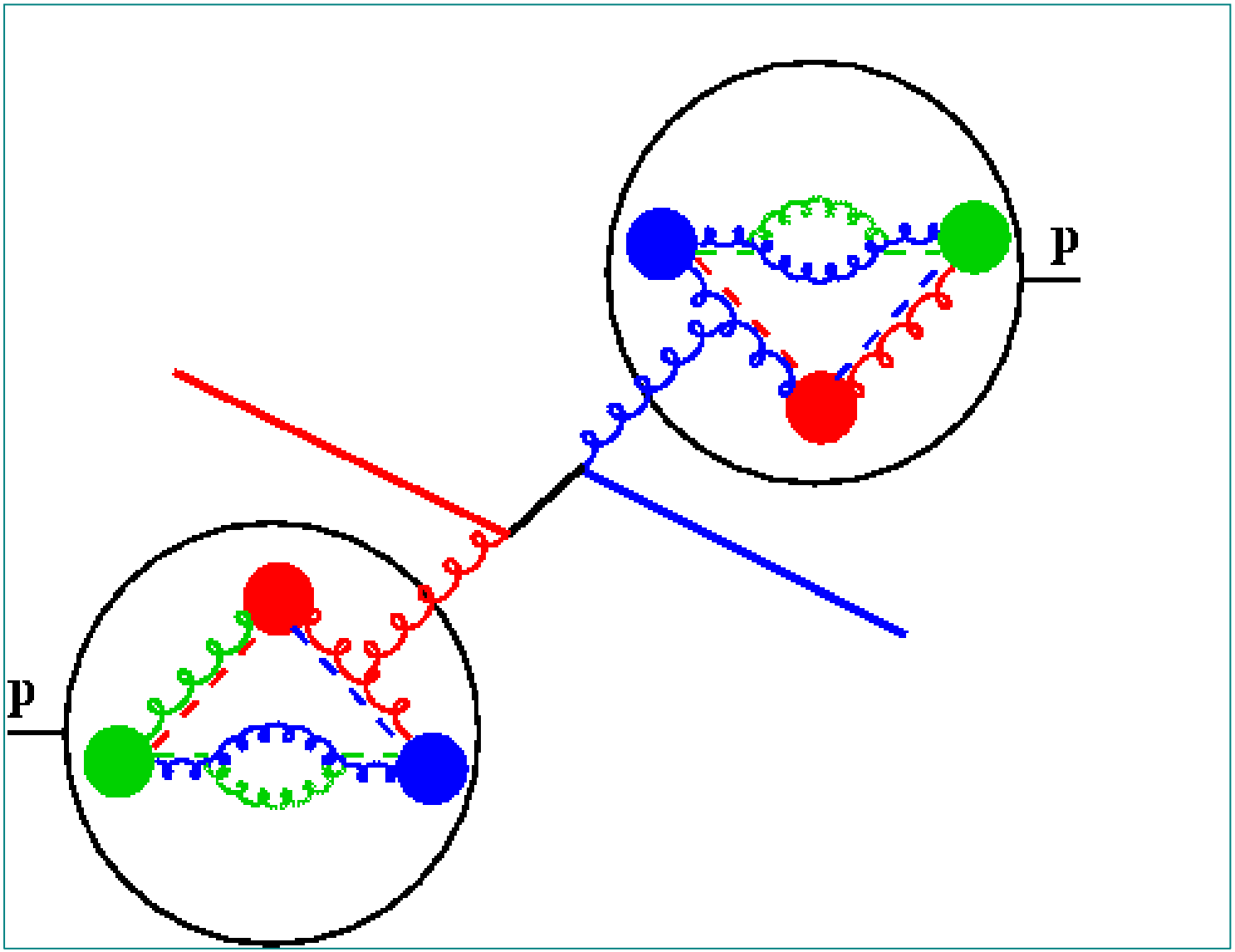
That is ~30,000 Encyclopedia Britannicas *every second*!

That is 15,000,000 GB (15 PB) per year

20 km stack of average CDs per year.

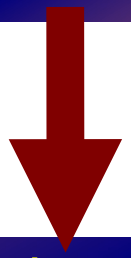

Quarks
Елементарни частици
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Leptons

Протон-протонни сблъсъци

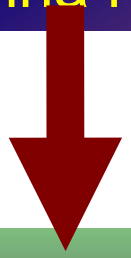


Резултати от взаимодействието

Протон-протон
Оловно ядро – оловно ядро



Б-мезони, Извстни частици, Хиггс бозох, суперсиметрични частици,
Екзотични частици и т.н.
Кварк-глуонна плазма



Кварки
Глуони
Адрони (бариони и мезони)
Лептони
Фотони

Регистрирани частици

* Кварките и глуоните адронизират в струи

* Адрони (бариони и мезони)

* Лептони

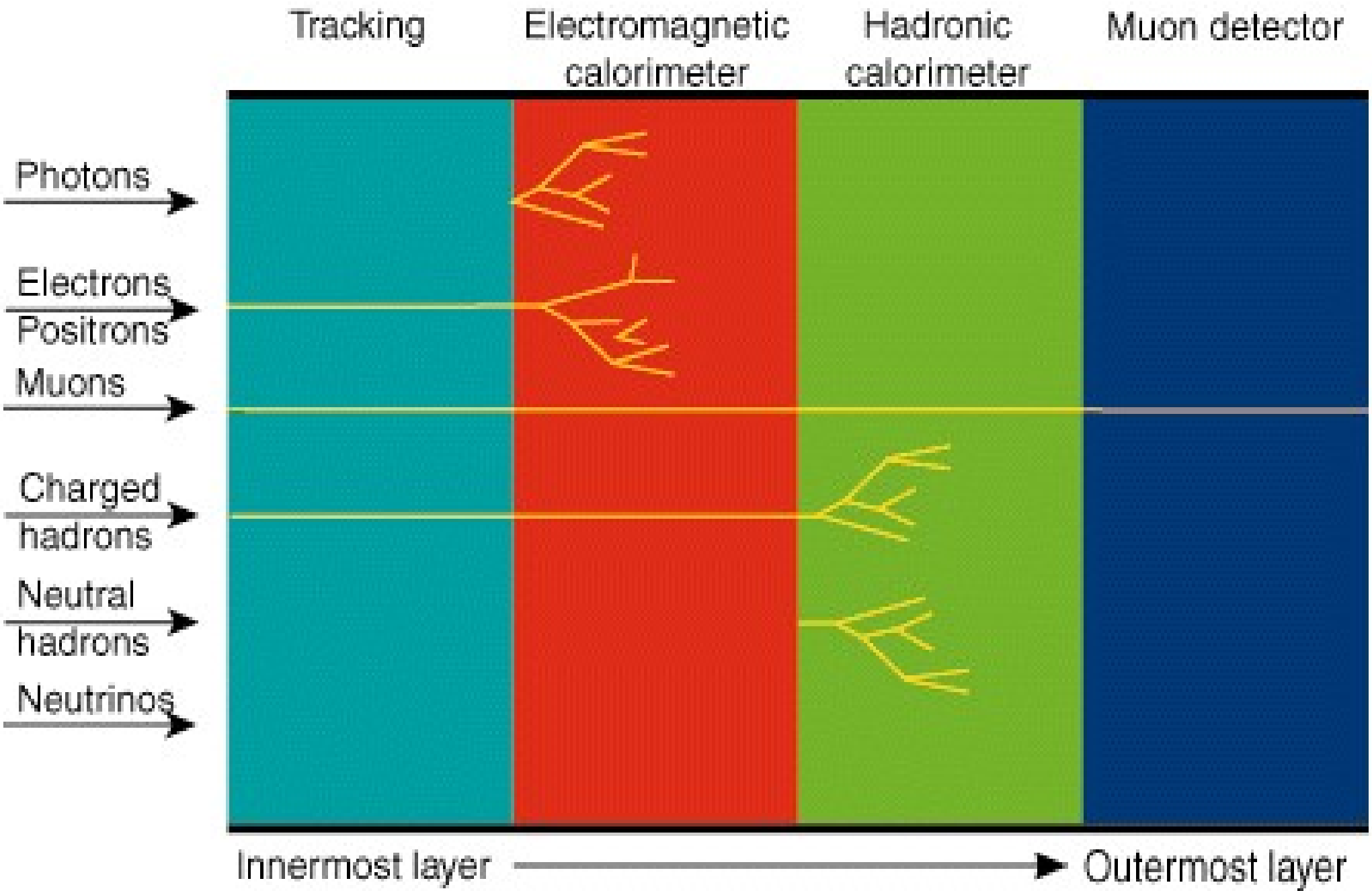
    * електрон, мюон, тау (разпада се и се регистрират разпадните му продукти)

    * неутрина (не могат да се регистрират в CMS и ATLAS,

Но може да се оцени каква енергия са отнесли)

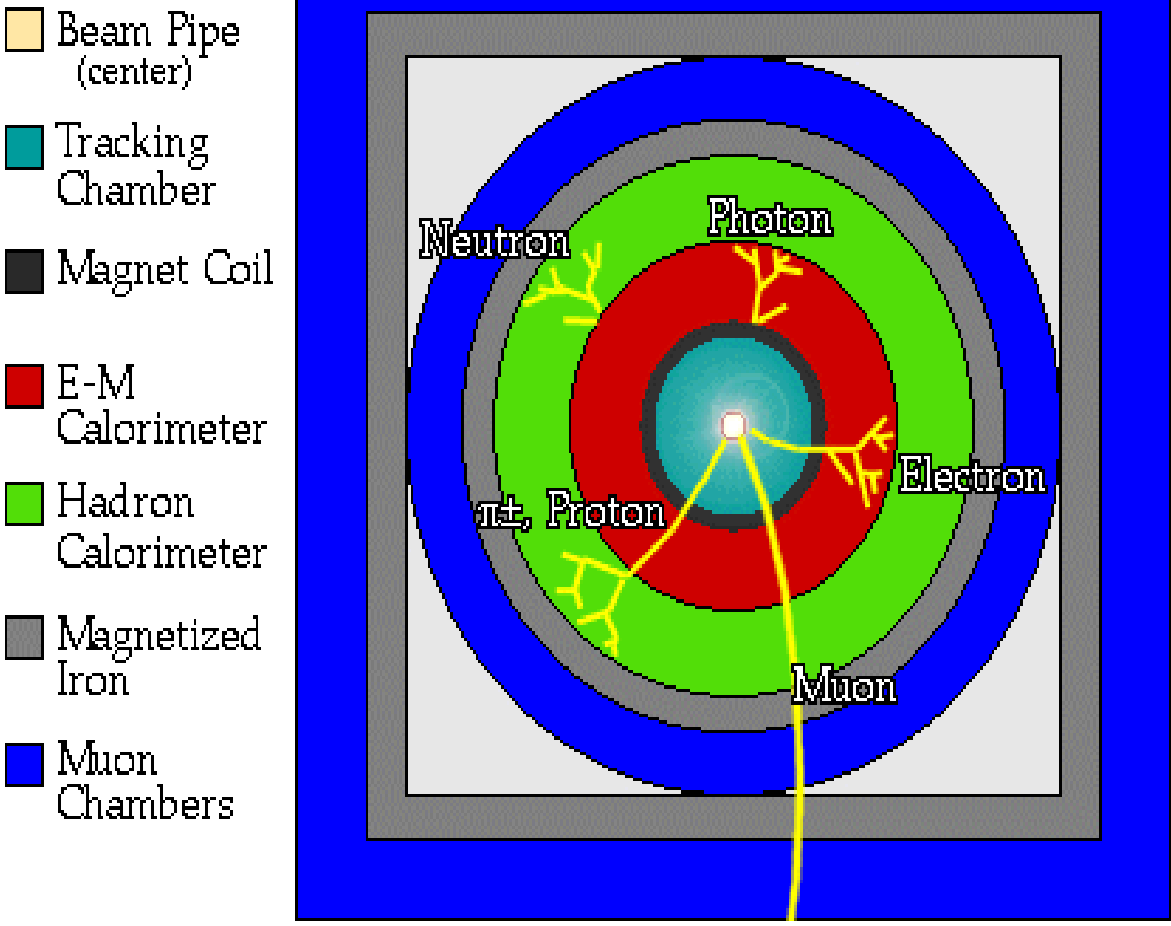
* Фотони

Обща структура



Обща структура

A detector cross-section, showing particle paths



Основни системи

Трeков детектор

Електромагнитен калориметър (ECAL)

Адронен калориметър (HCAL)

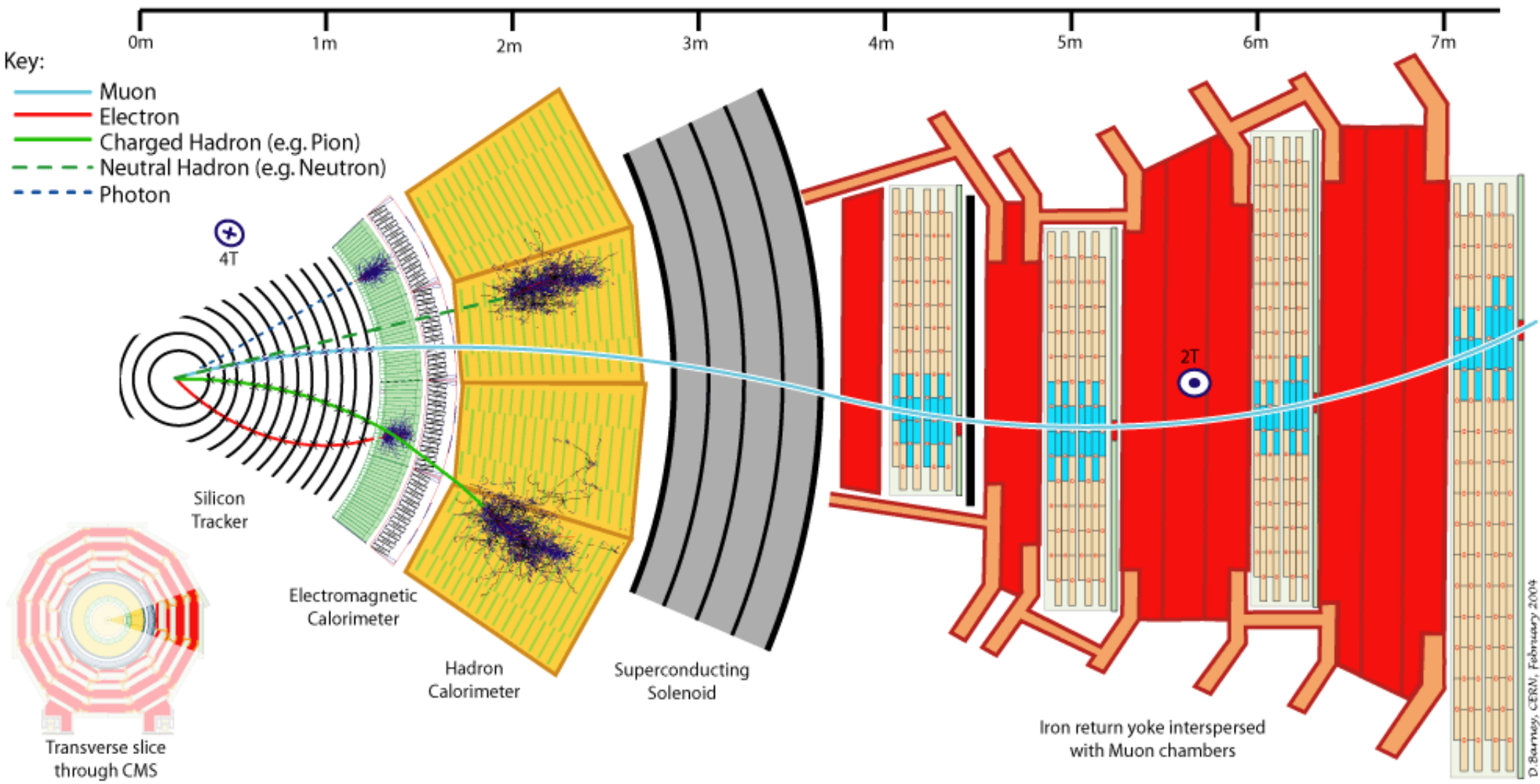
Предни калориметри (FH)

Магнит

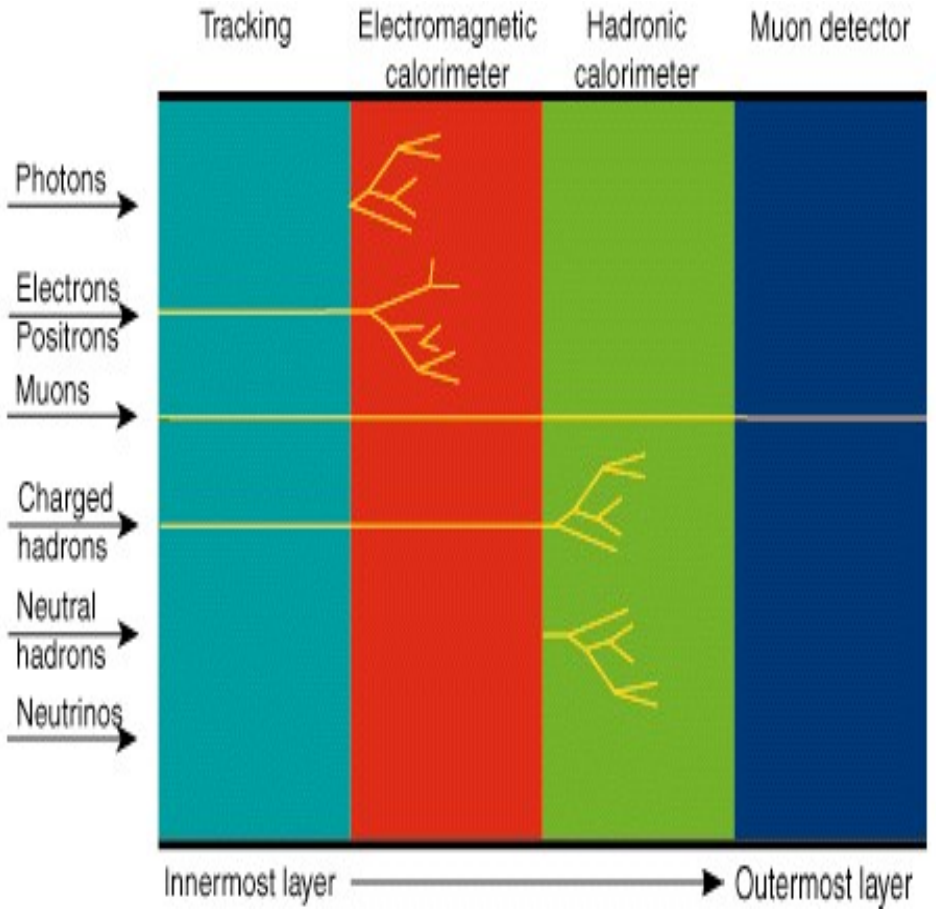
Мюонна система

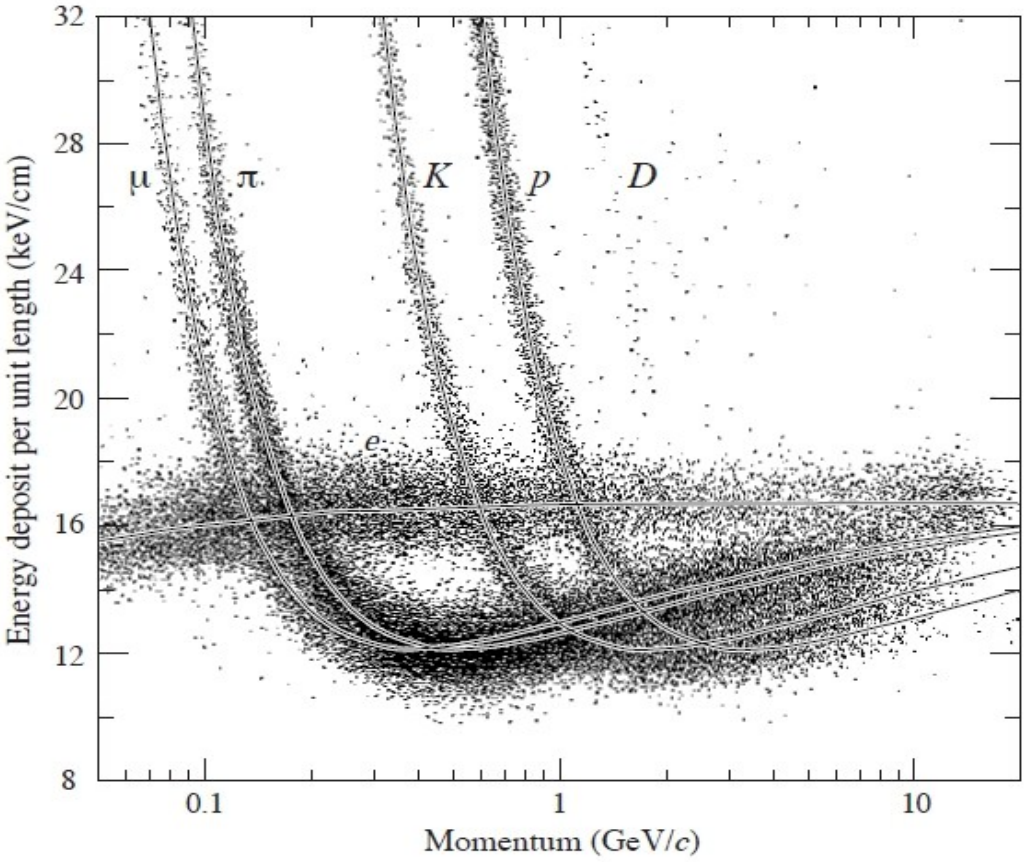
Тригерна и много други системи

Регистриране на частици в CMS

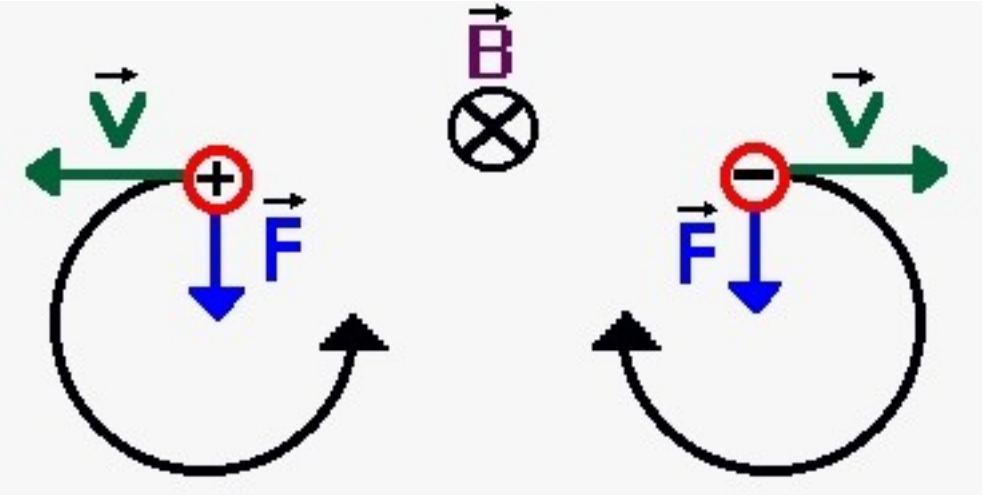


Идентификация на частици





Измерване на импулс



$\mathbf{P} = M\mathbf{V}$

$\mathbf{F}_L = Q\mathbf{V}x\mathbf{B}$

$\mathbf{F}_c = MV^2/R$

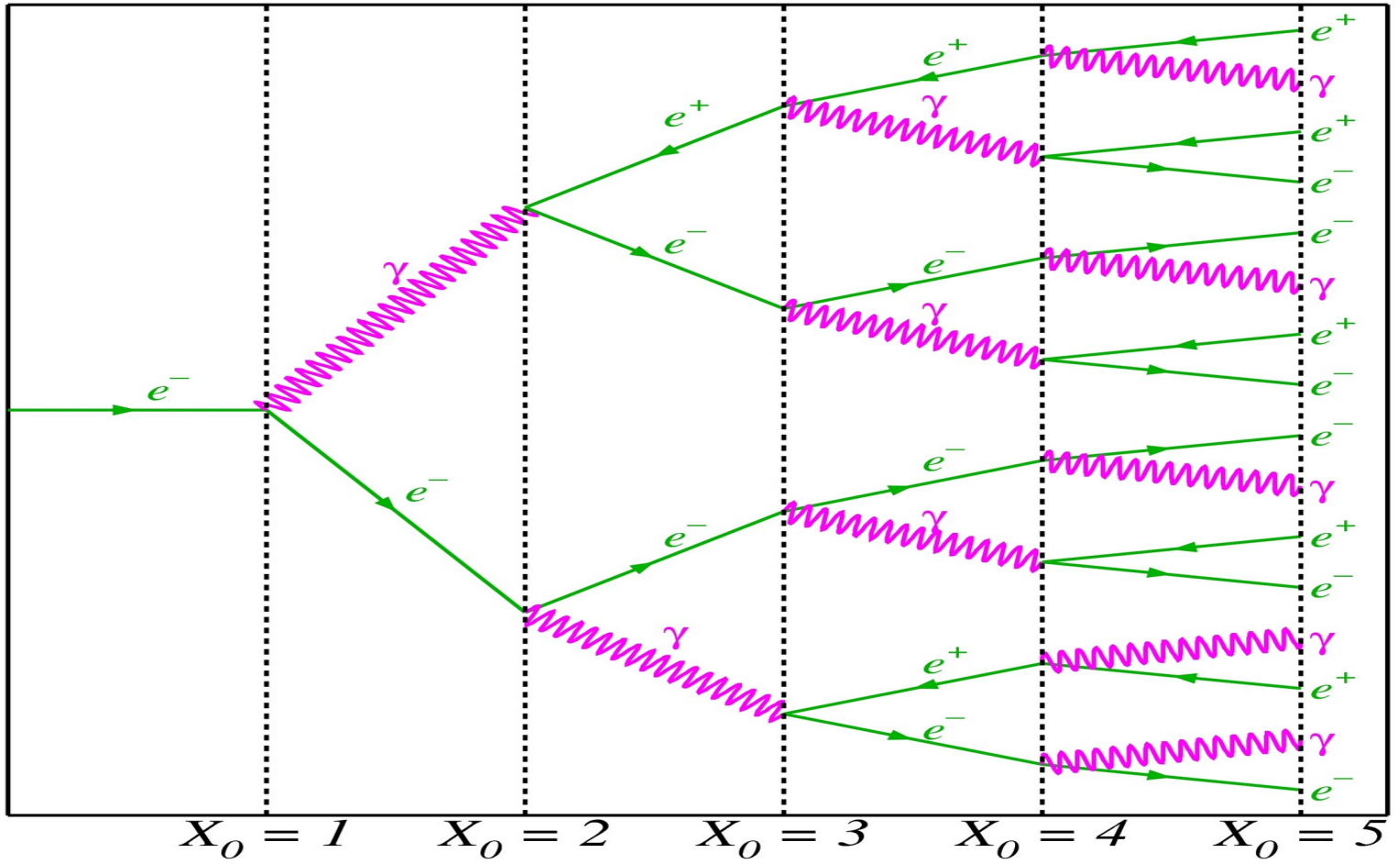
$MV^2/R = QVB$

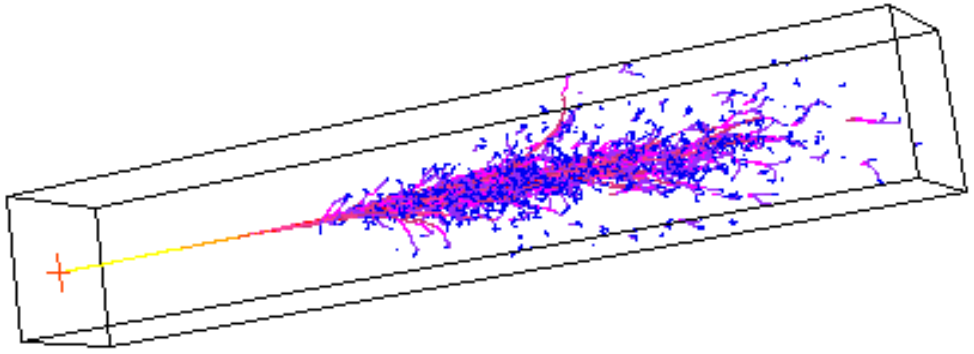
$=> |\mathbf{P}|/Q = BR$

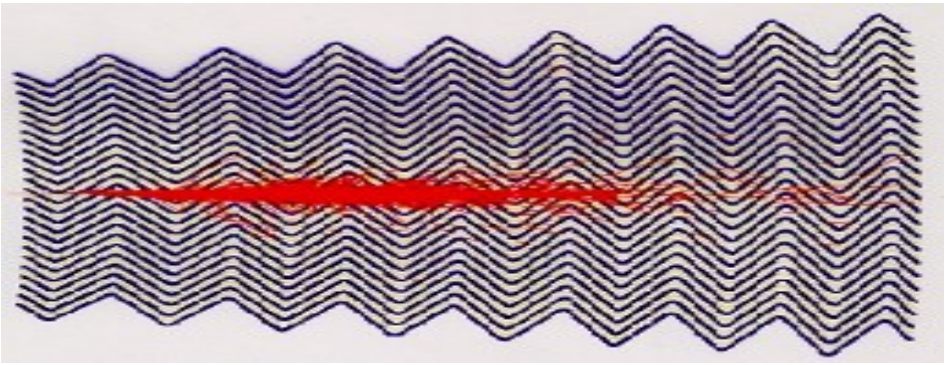
$Q = \pm e$

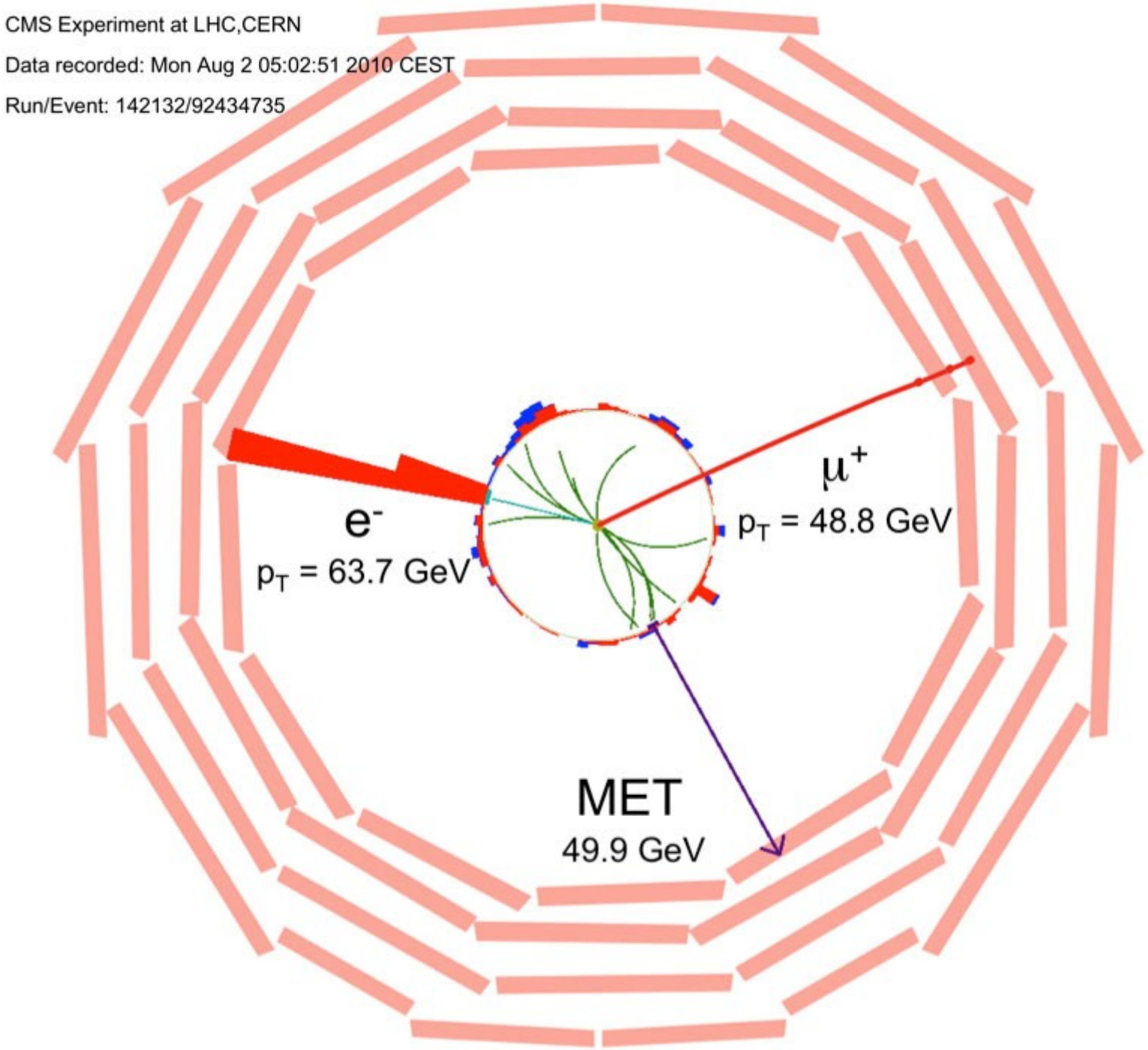
$=> |\mathbf{P}| = eBR$

Измерване на енергия

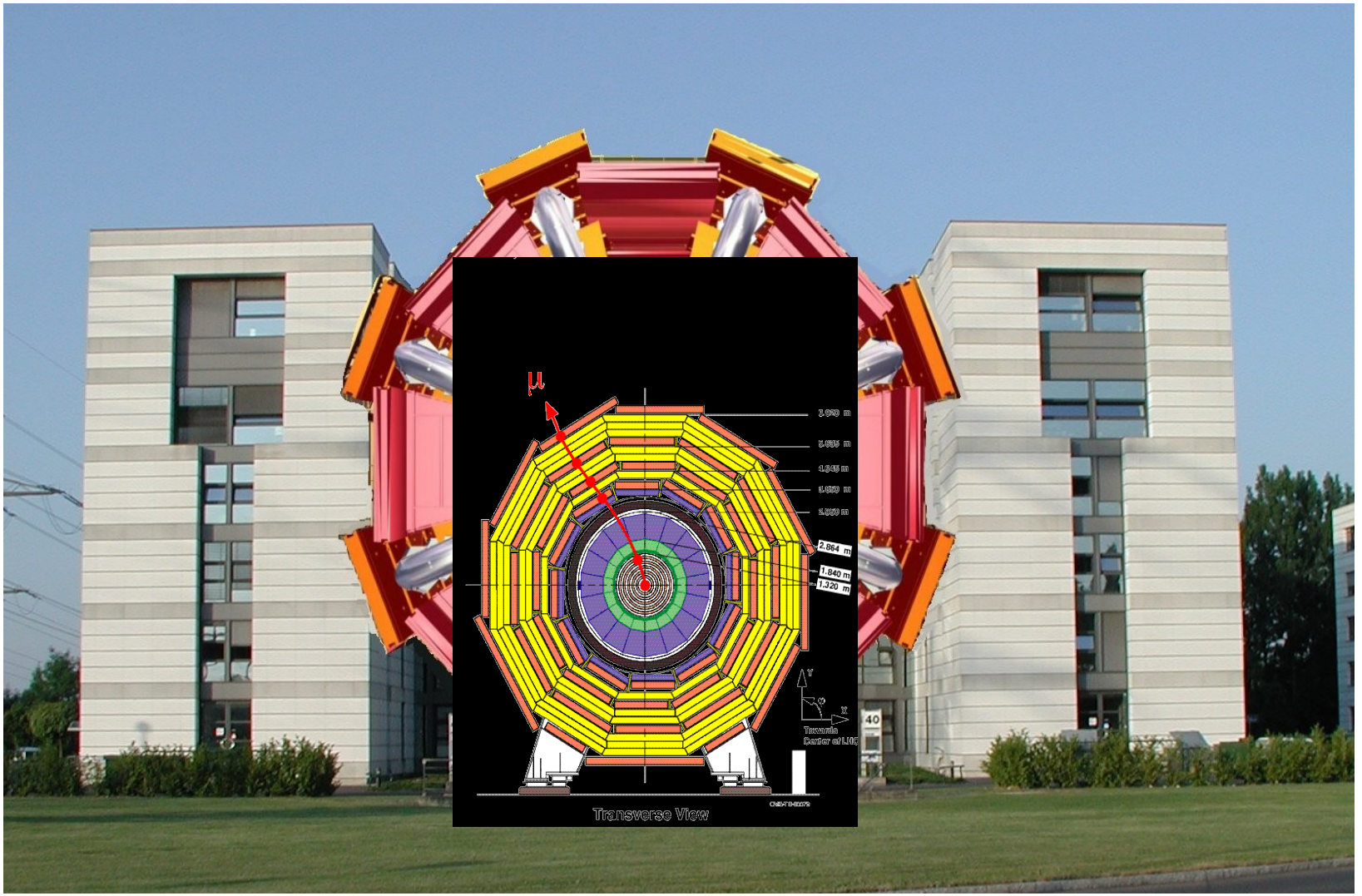


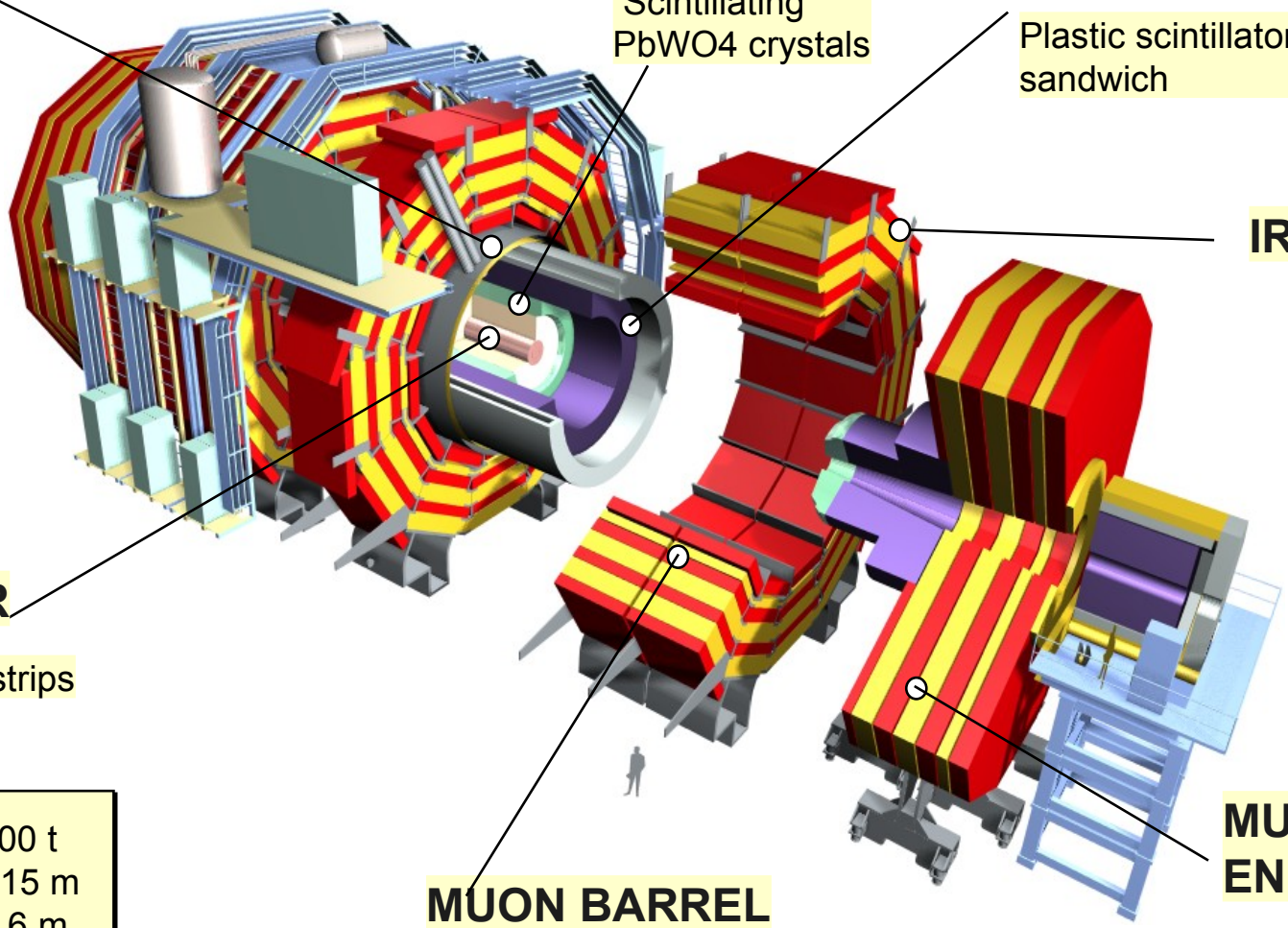





CMS Experiment at LHC,CERN
Data recorded: Mon Aug 2 05:02:51 2010 CEST
Run/Event: 142132/92434735
e-
pT = 63.7 GeV
μ+
pT = 48.8 GeV
MET
49.9 GeV

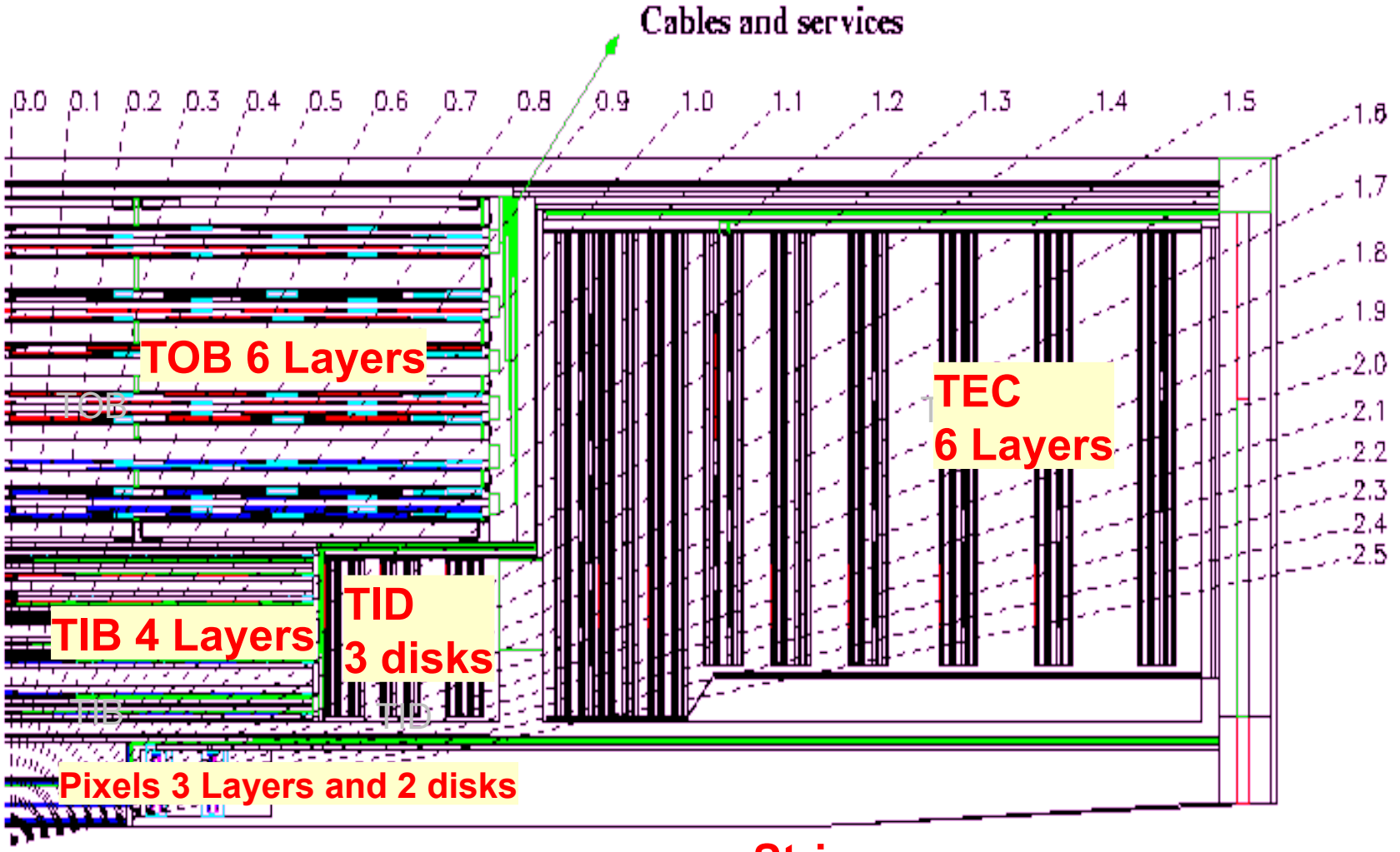
Building 40 at CERN





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

Inner Tracker



Pixels:

100 μm x 150μm

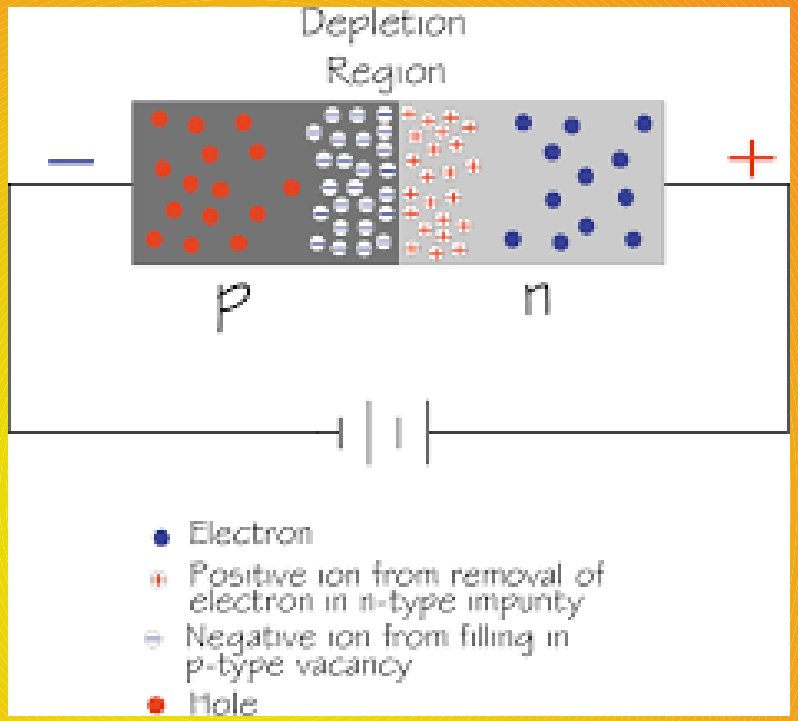
rφ and z resolution: 15-20 μm

Strips:

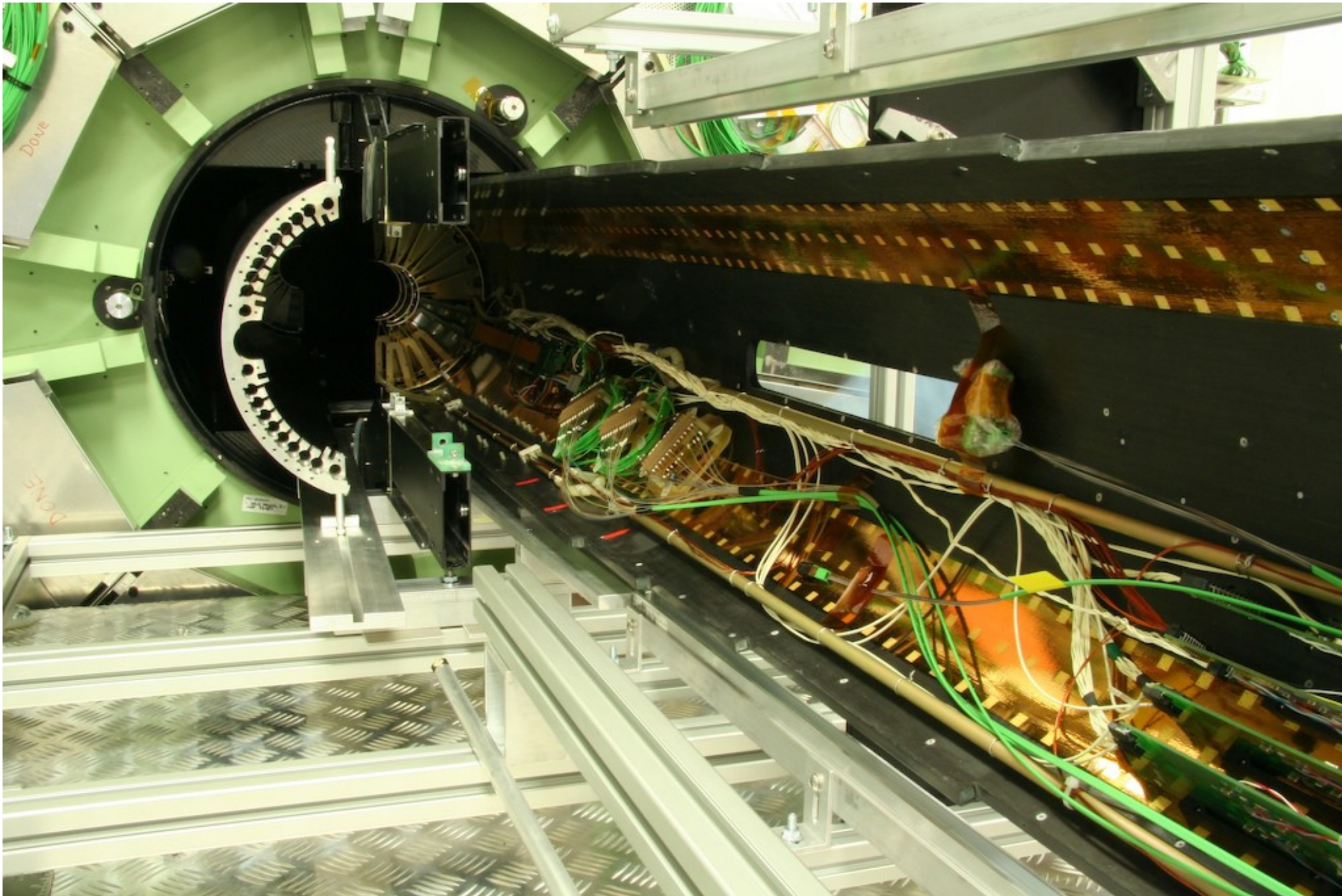
Pitch: 80 μm to 180μm

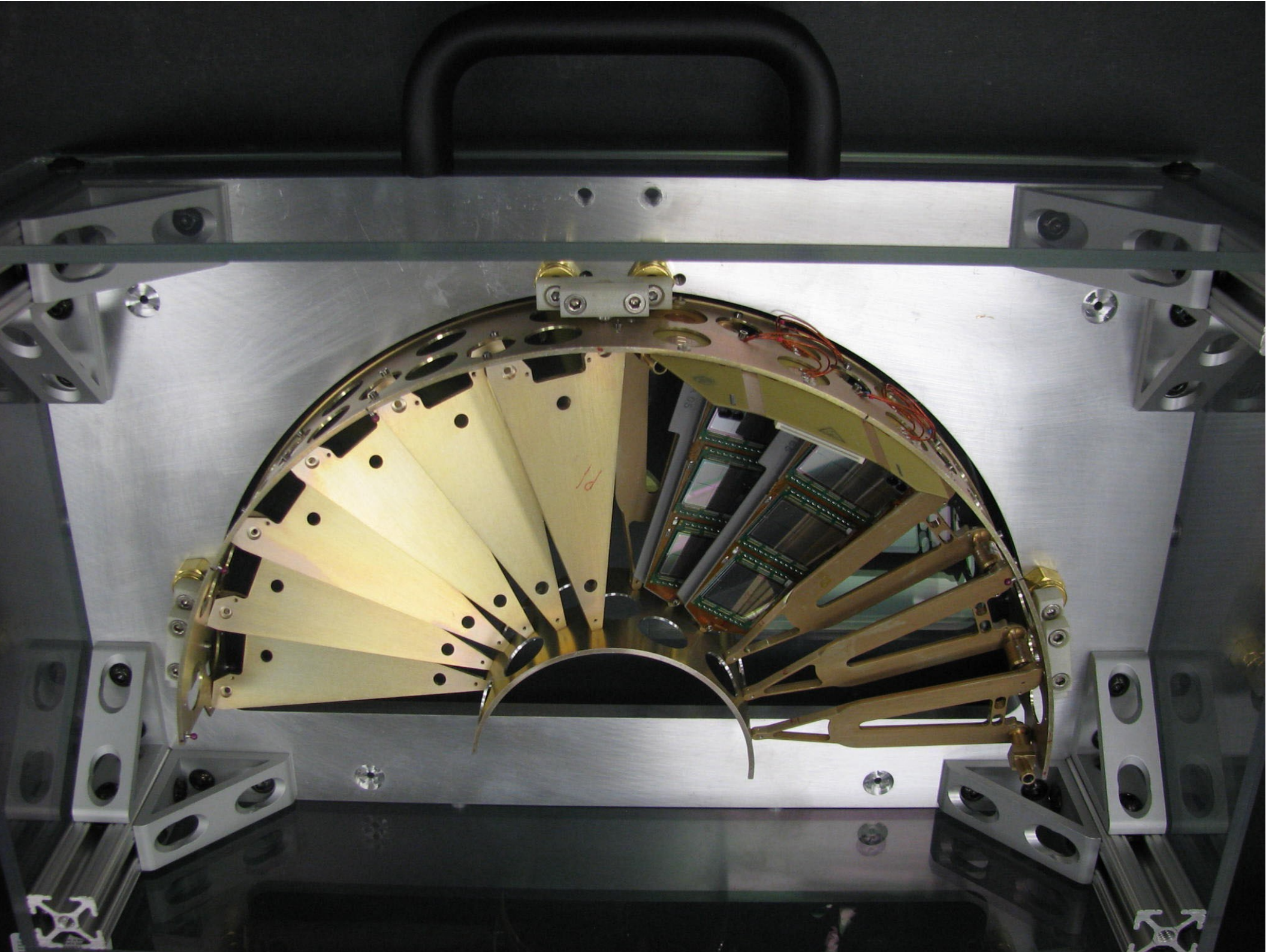
Hit Resolution: 20 μm to 50μm

Полупроводников детектор

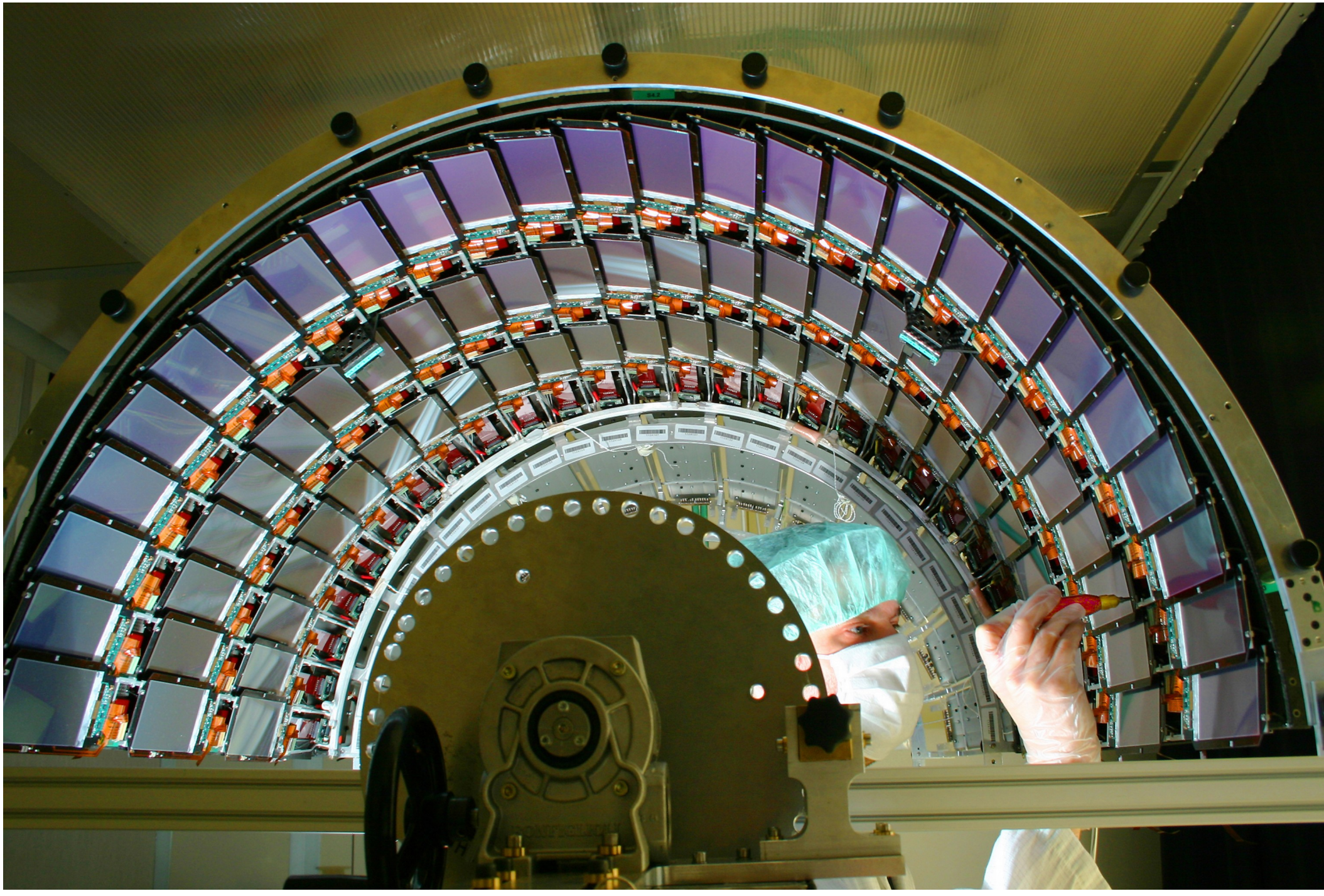


PIXEL

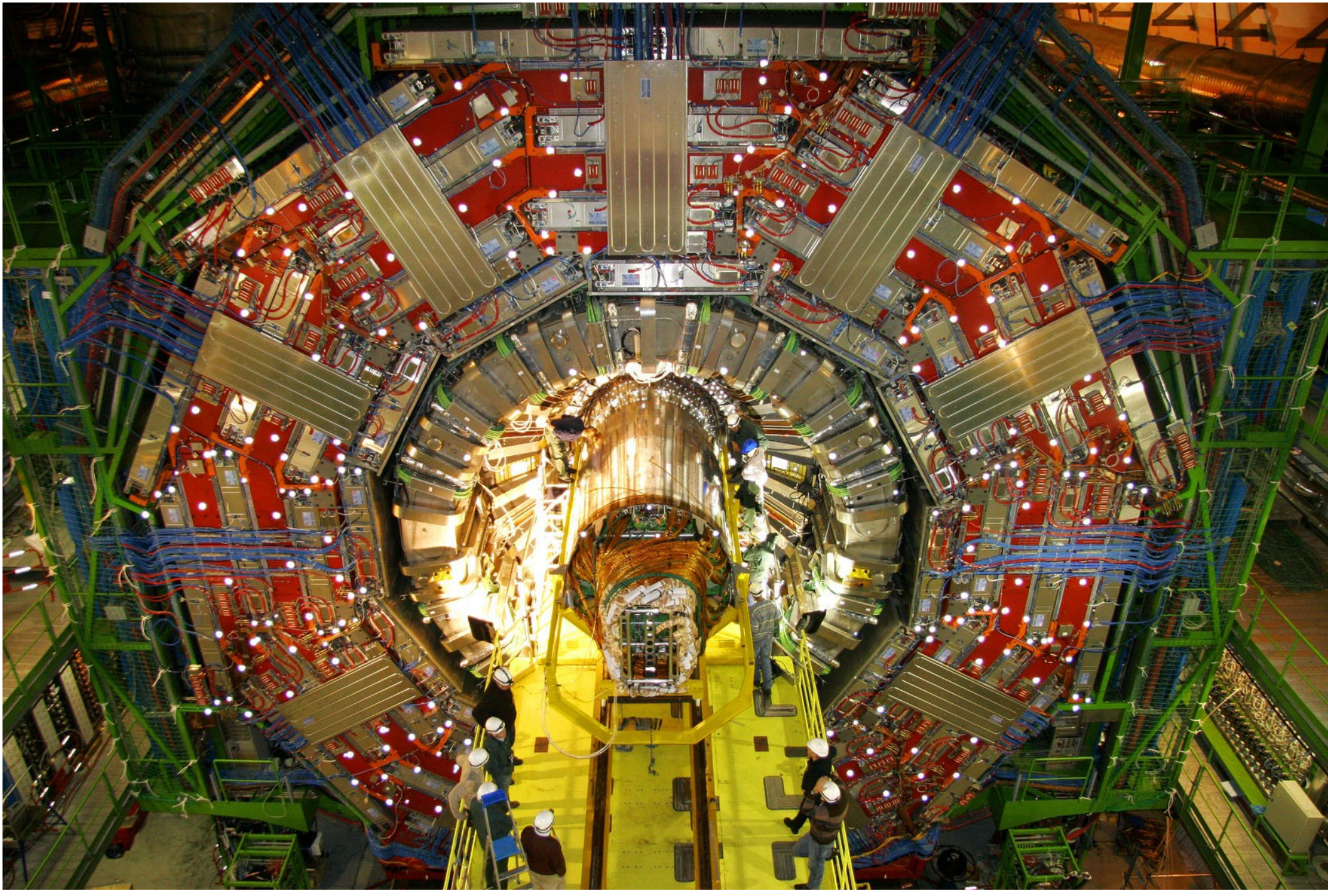




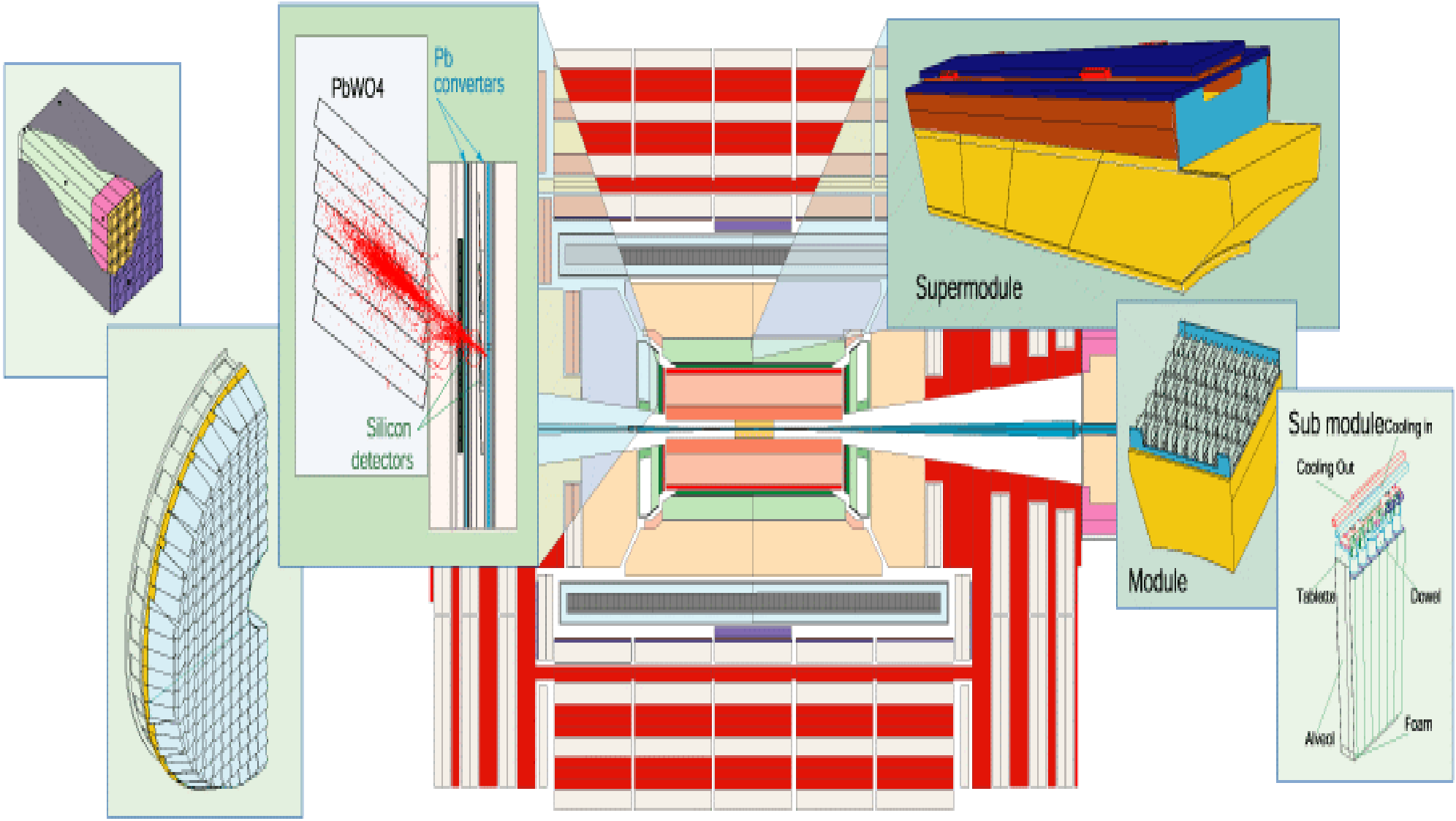
Si Strip

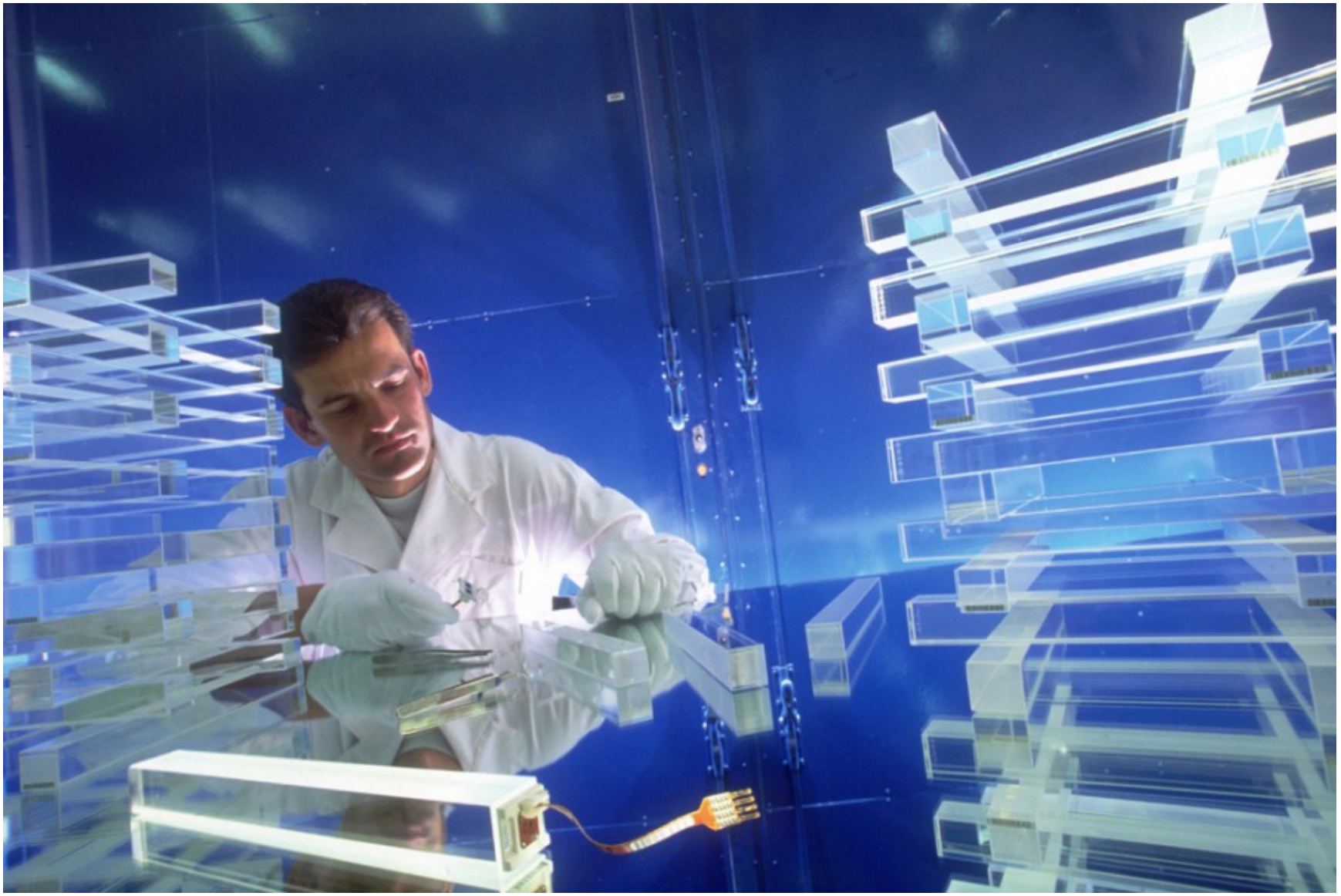


Инсталиране на тракера

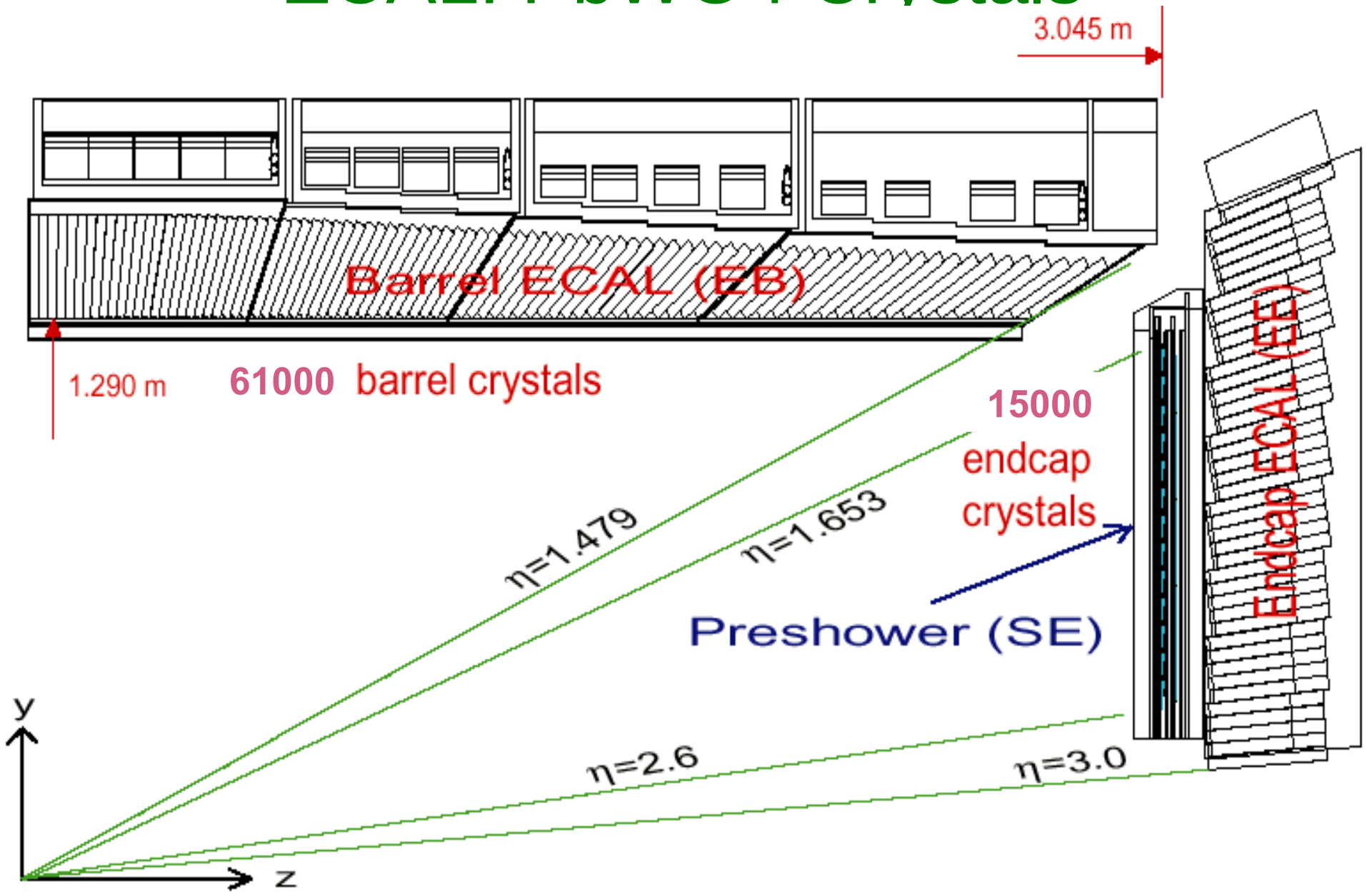


ECAL Overview

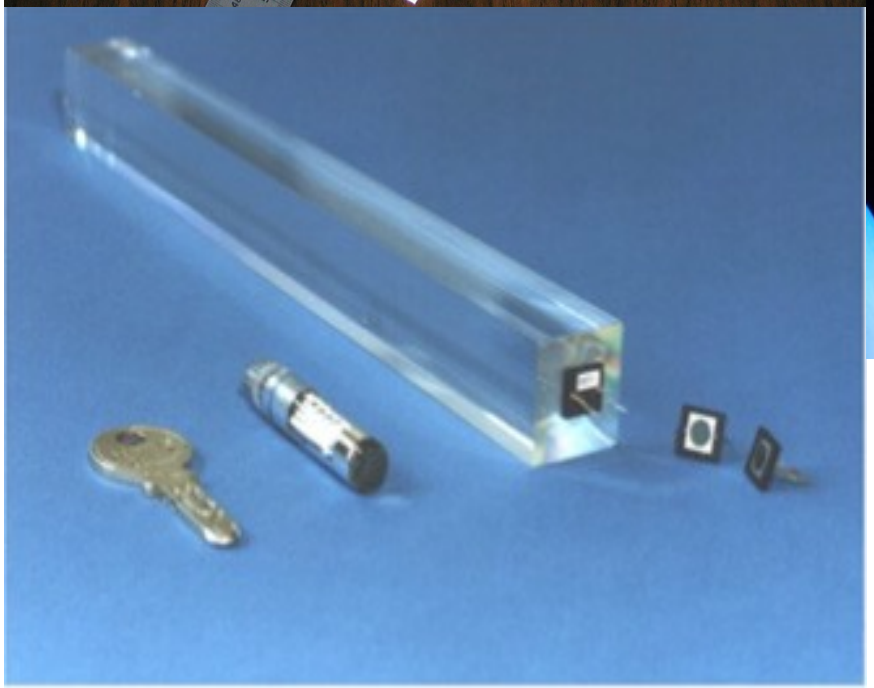


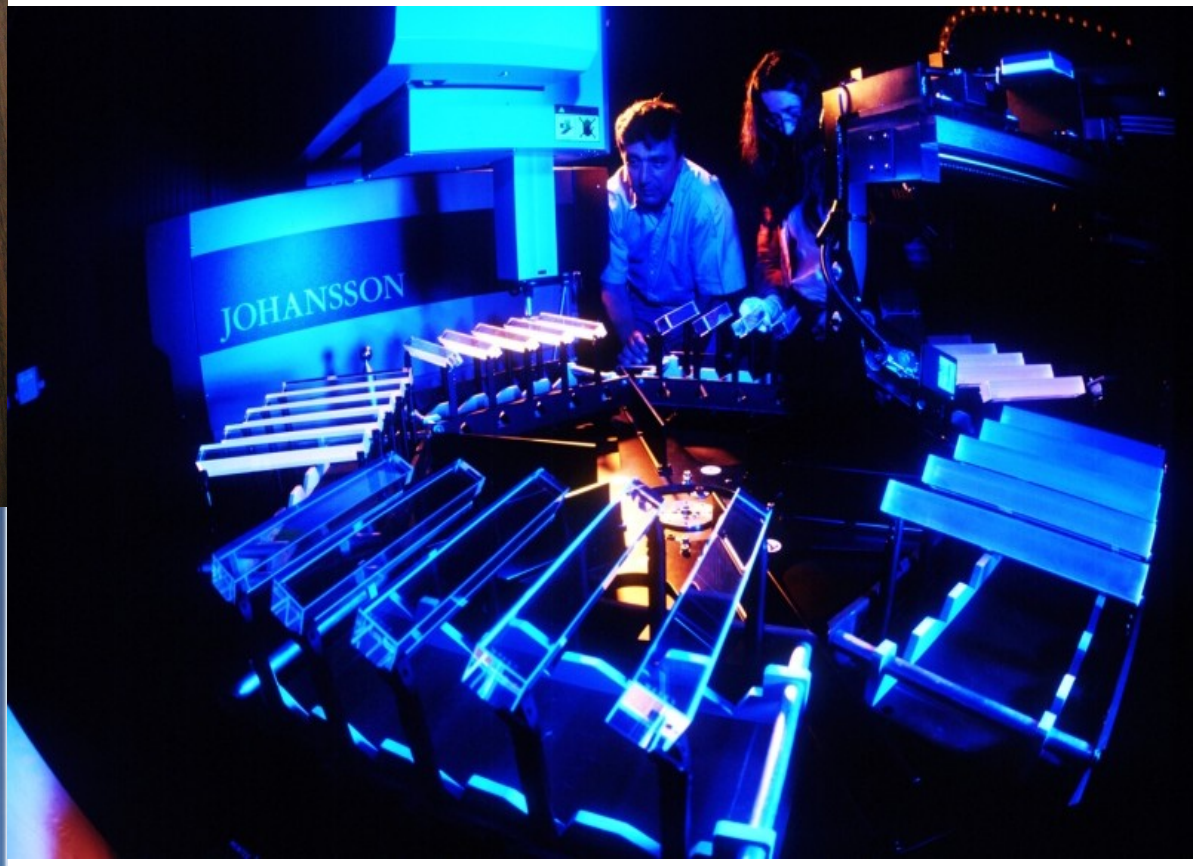


ECAL: PbWO4 Crystals

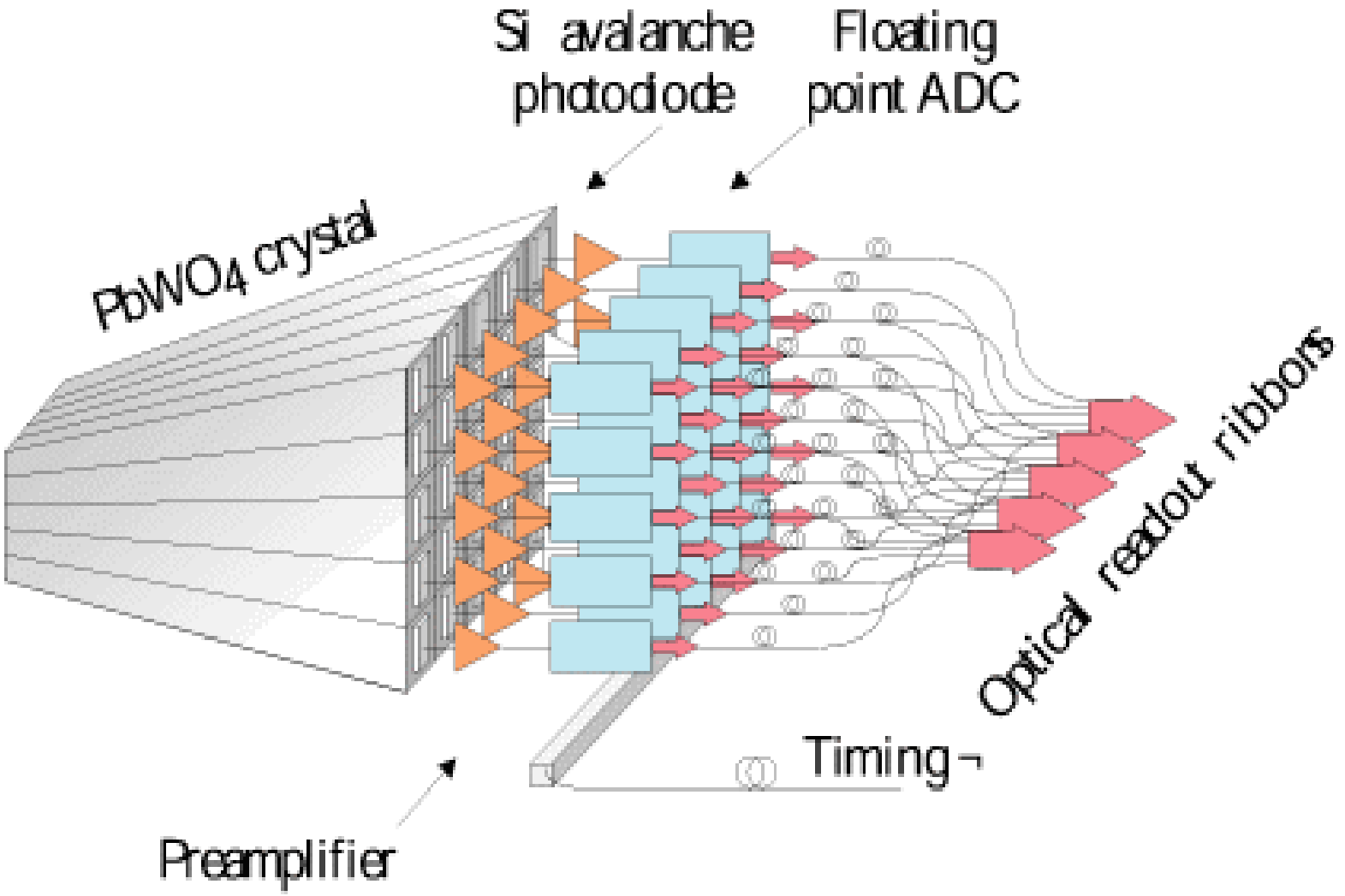


$PbWO_4$ crystals

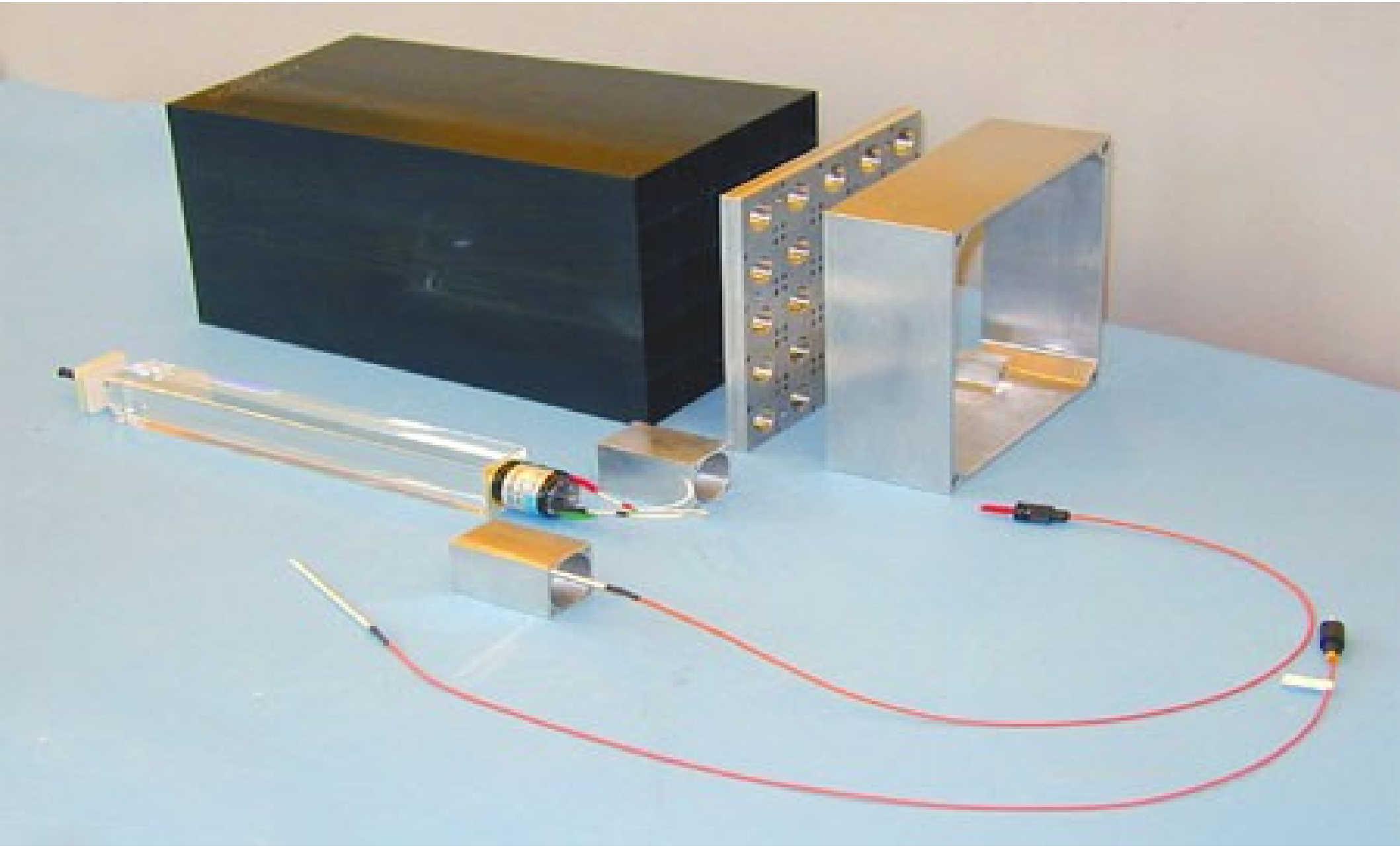


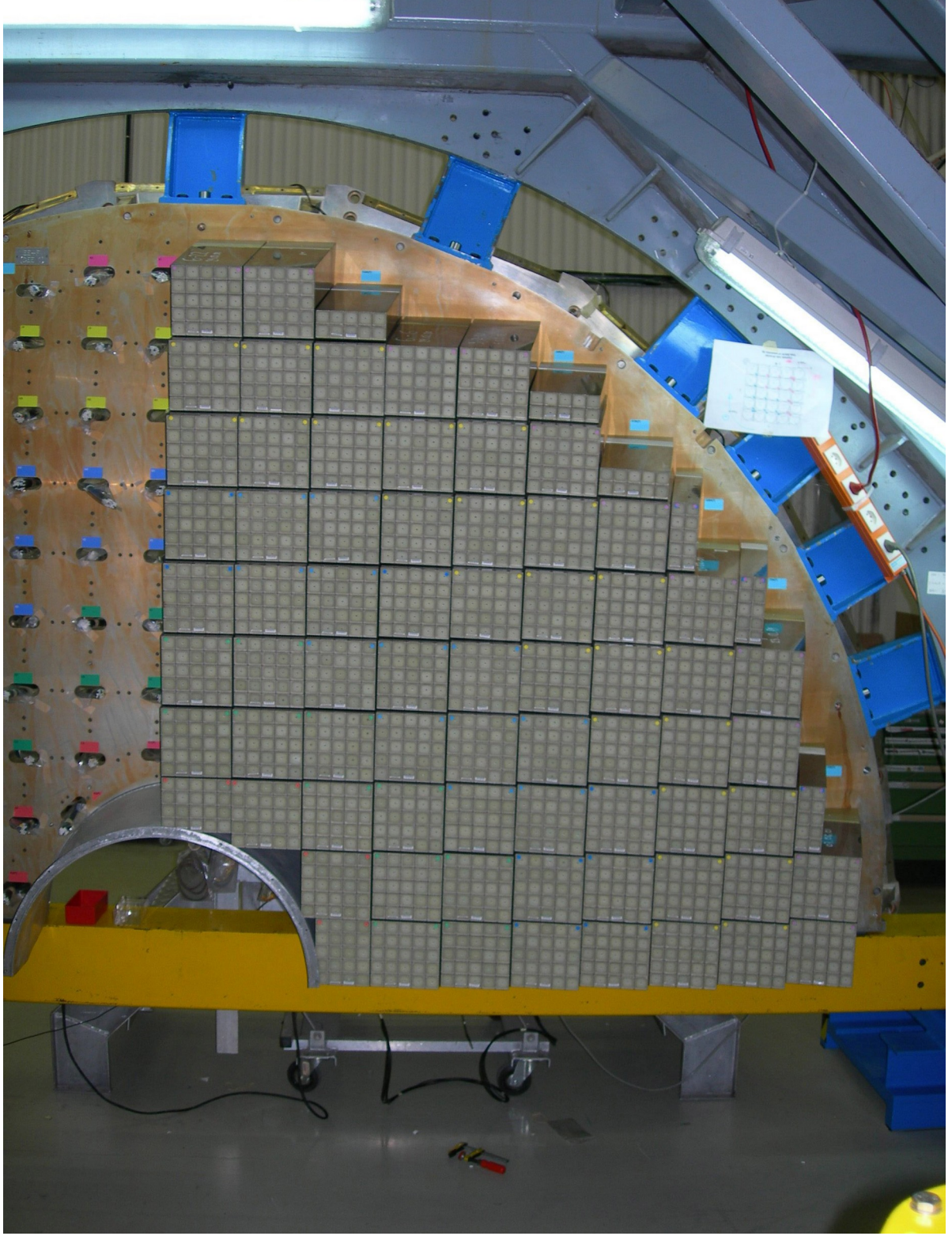


ECAL

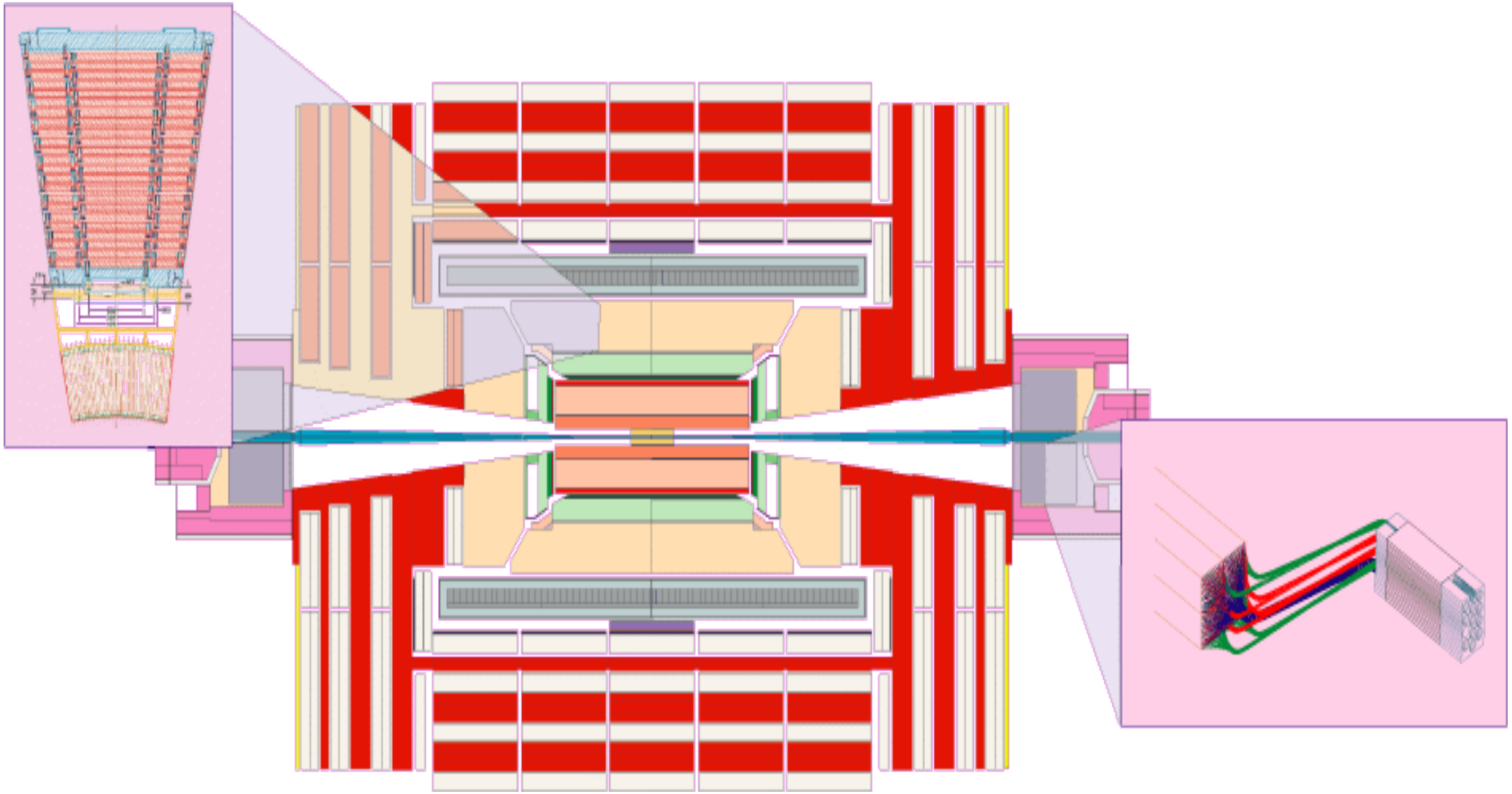

Si avalanche photodiode
Floating point ADC
PbWO4 crystal
Optical readout ribbons
Timing
Preamplifier

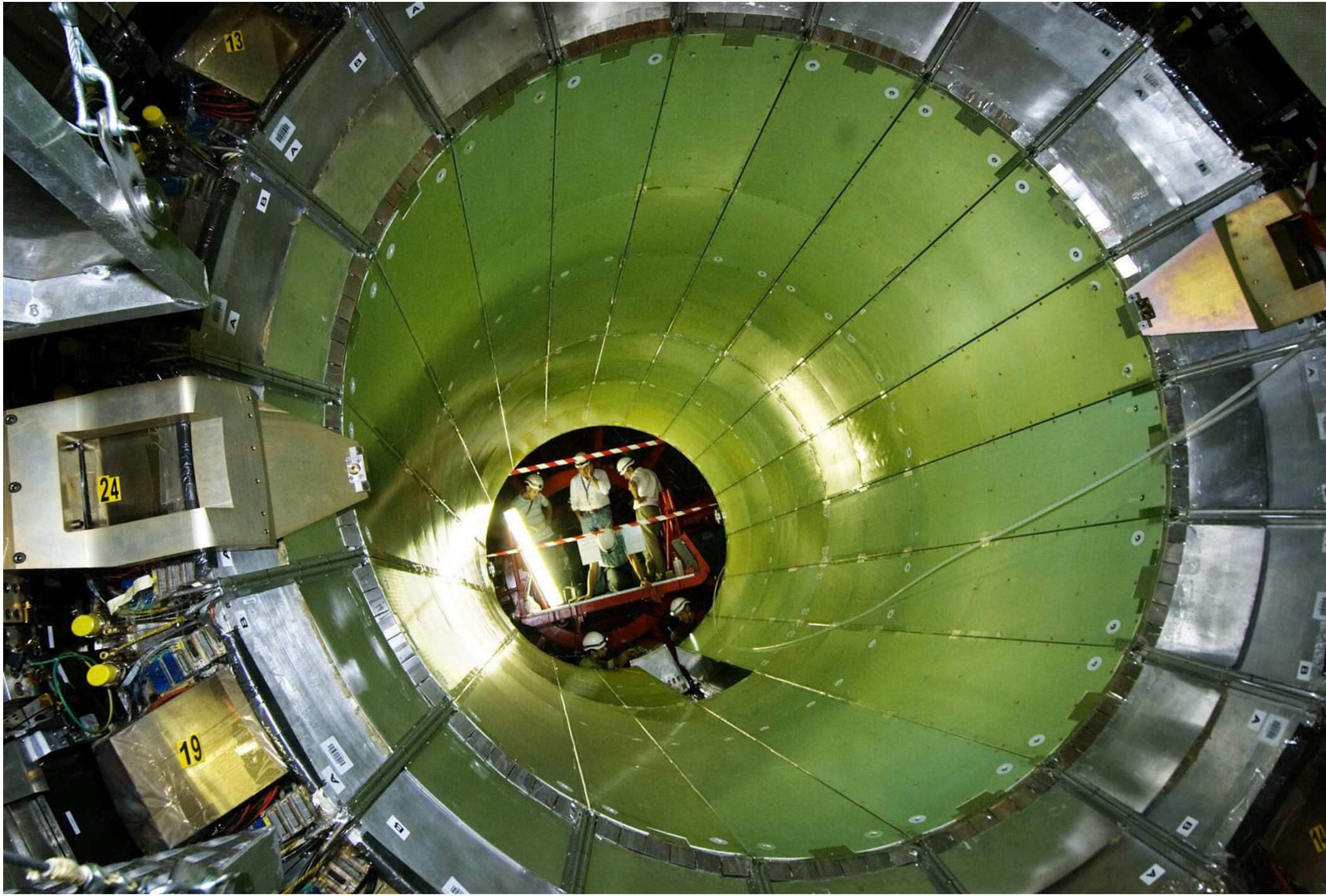
Електромагнитен калориметър



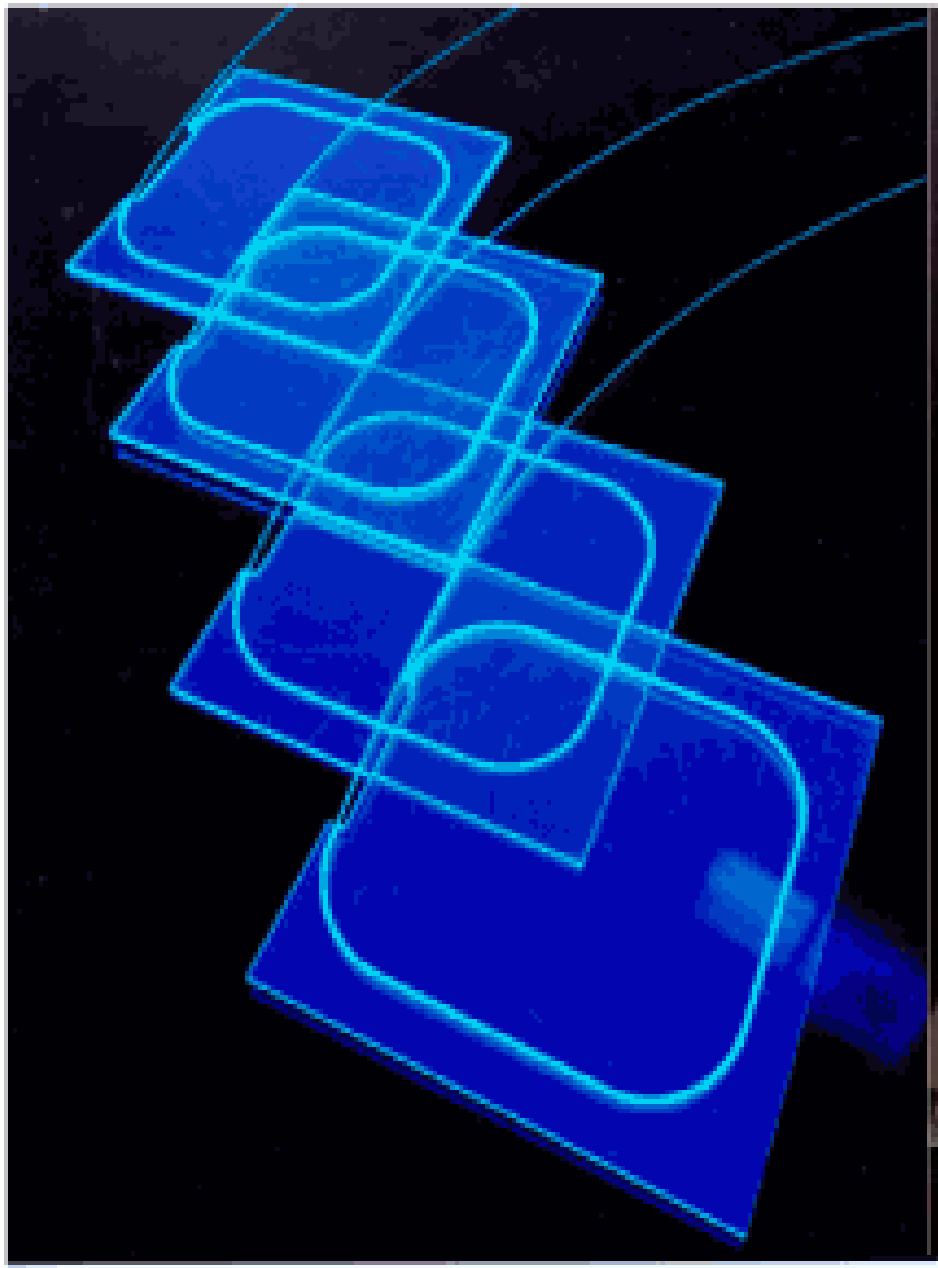


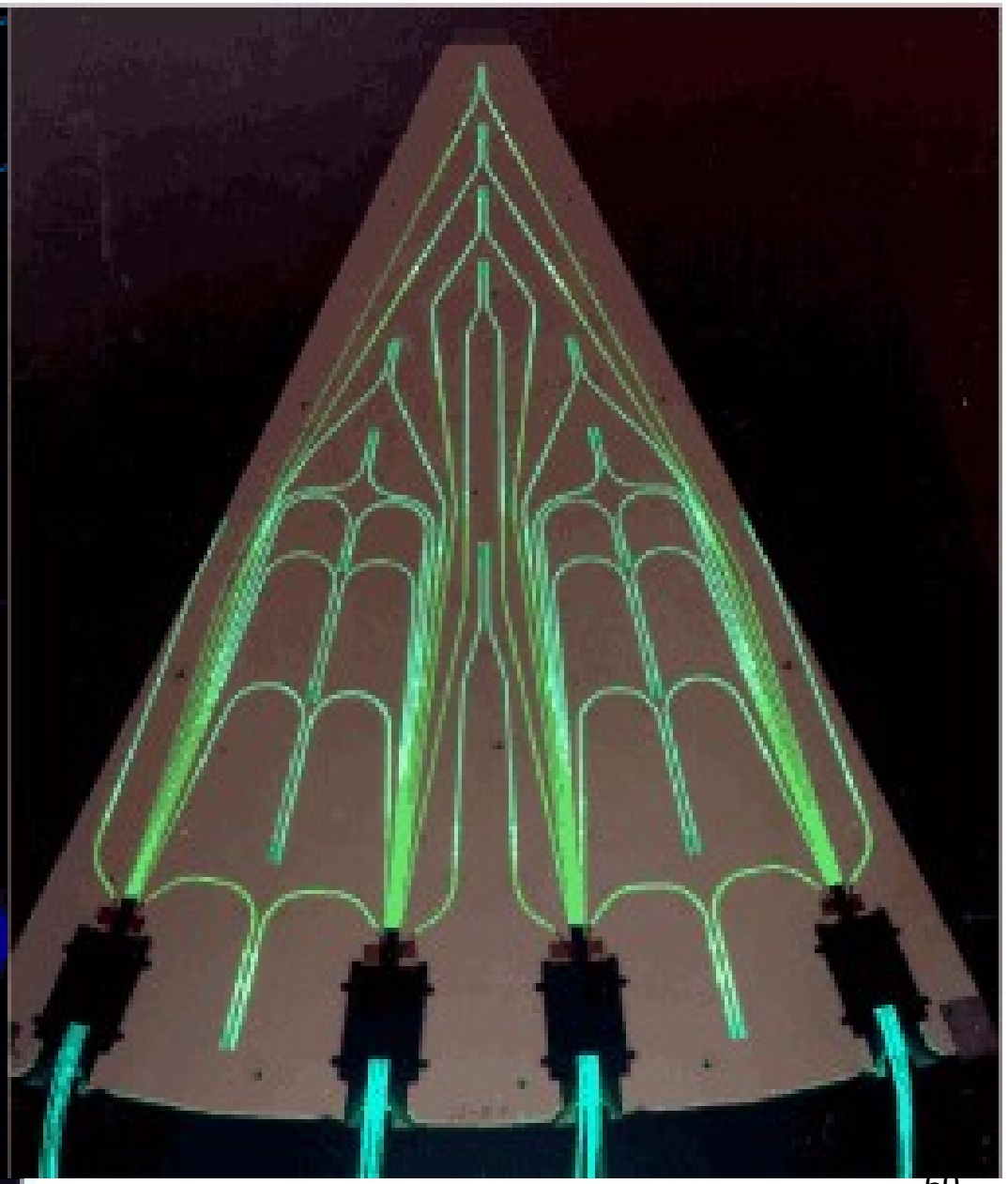
HCAL overview

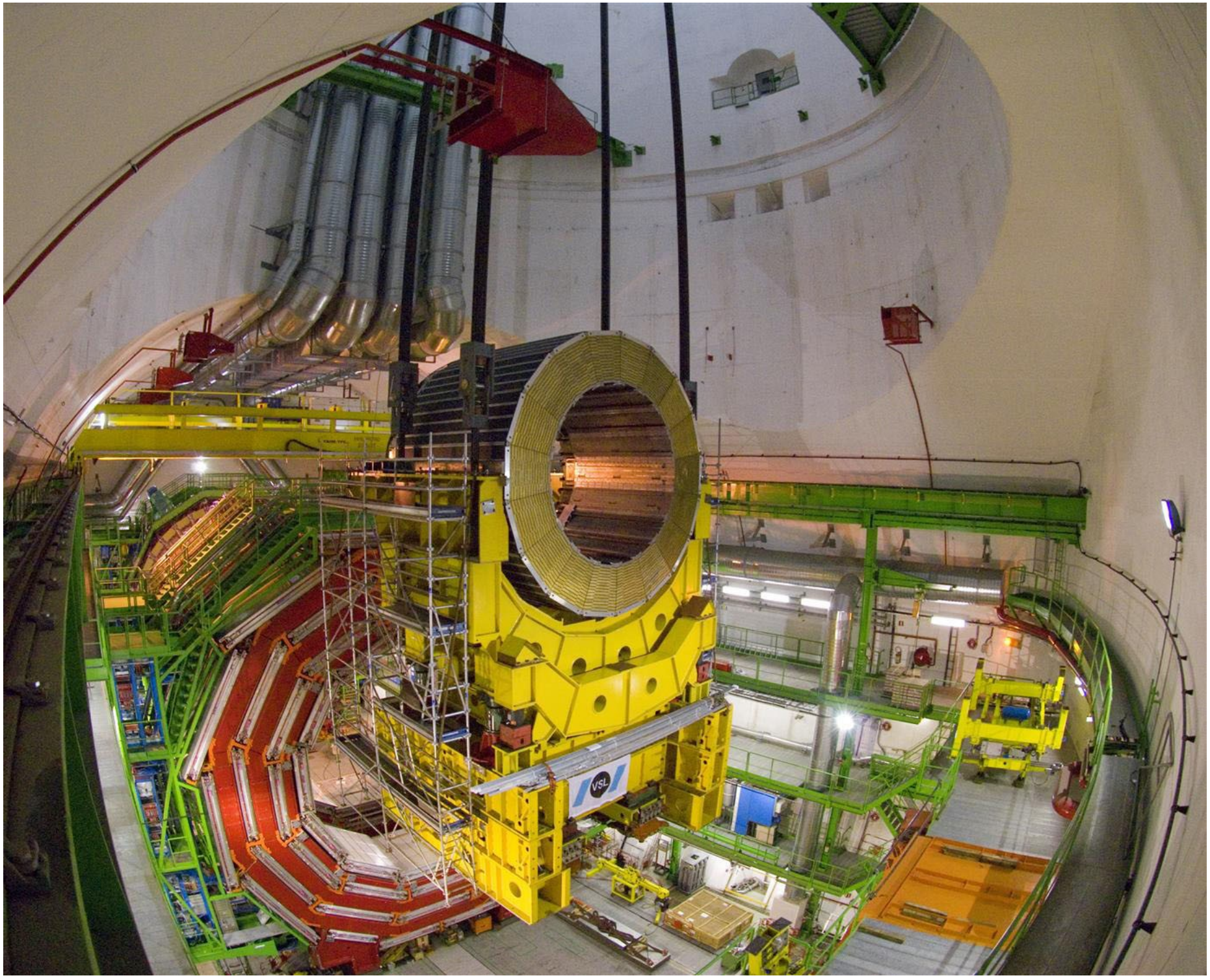



13
24
19

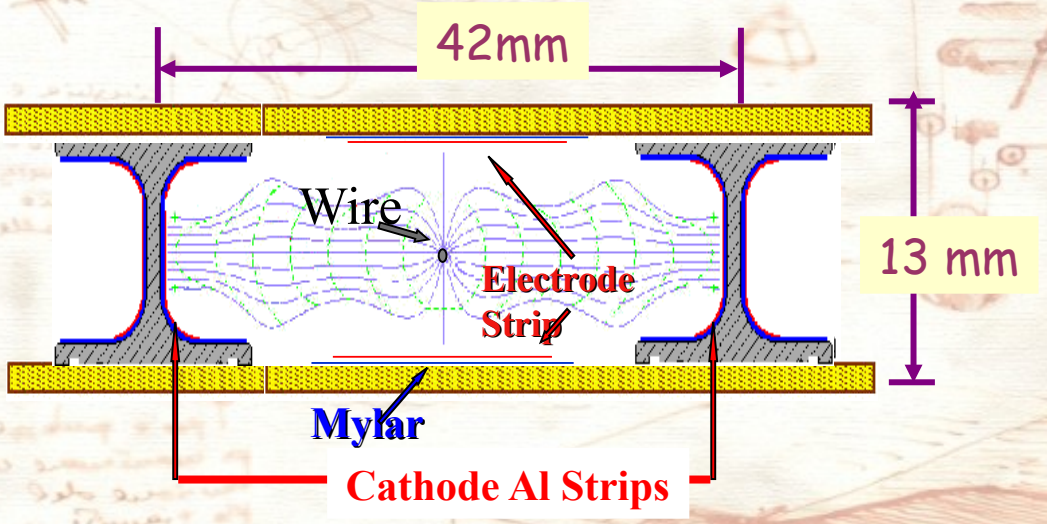
HCAL Scintillators



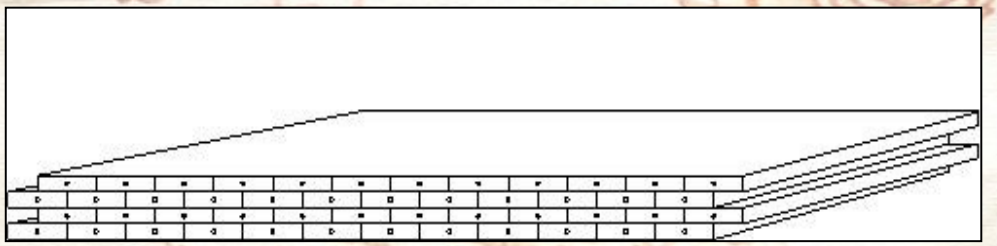



VSL

Drift Tube Chambers



4 Layers = 1 *Superlayer* (SL)



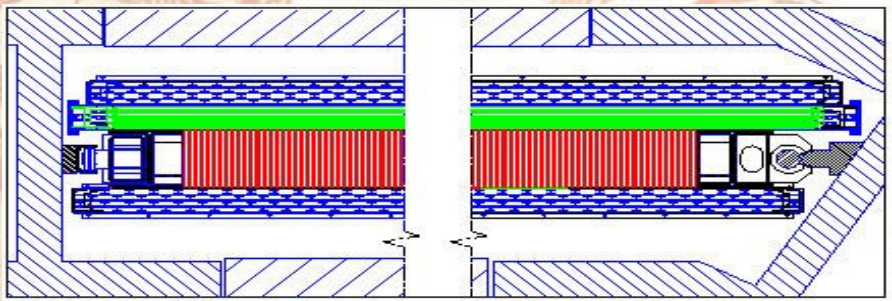
Independent Subunit

(Gas tightness, HV, Front End)

GAS: Ar/CO_2 (85/15)

HV: Wires 3600 V
Strips 1800 V
I-beams -1200 V

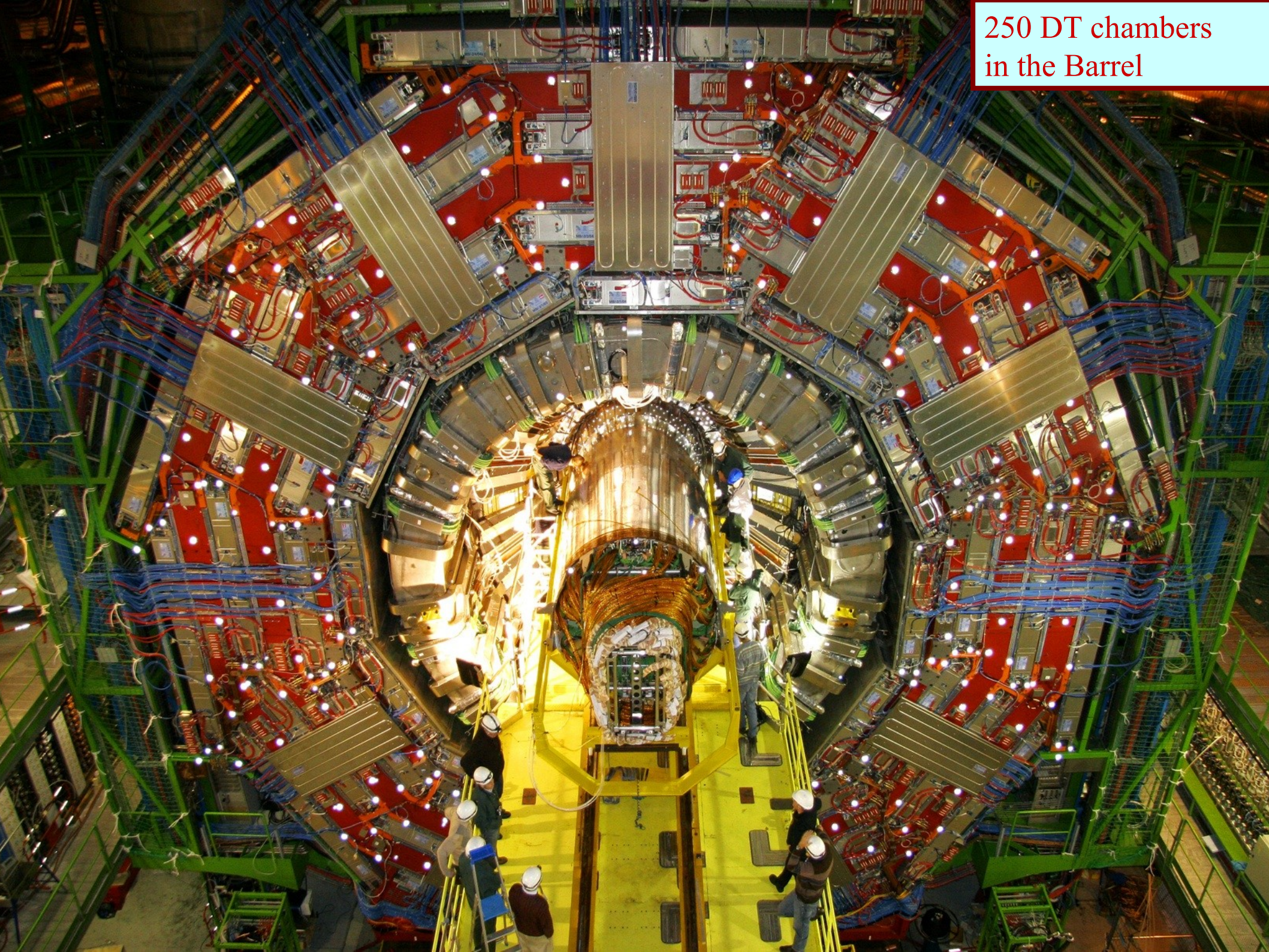
Φ SL
θ SL
Honeycomb
Φ SL



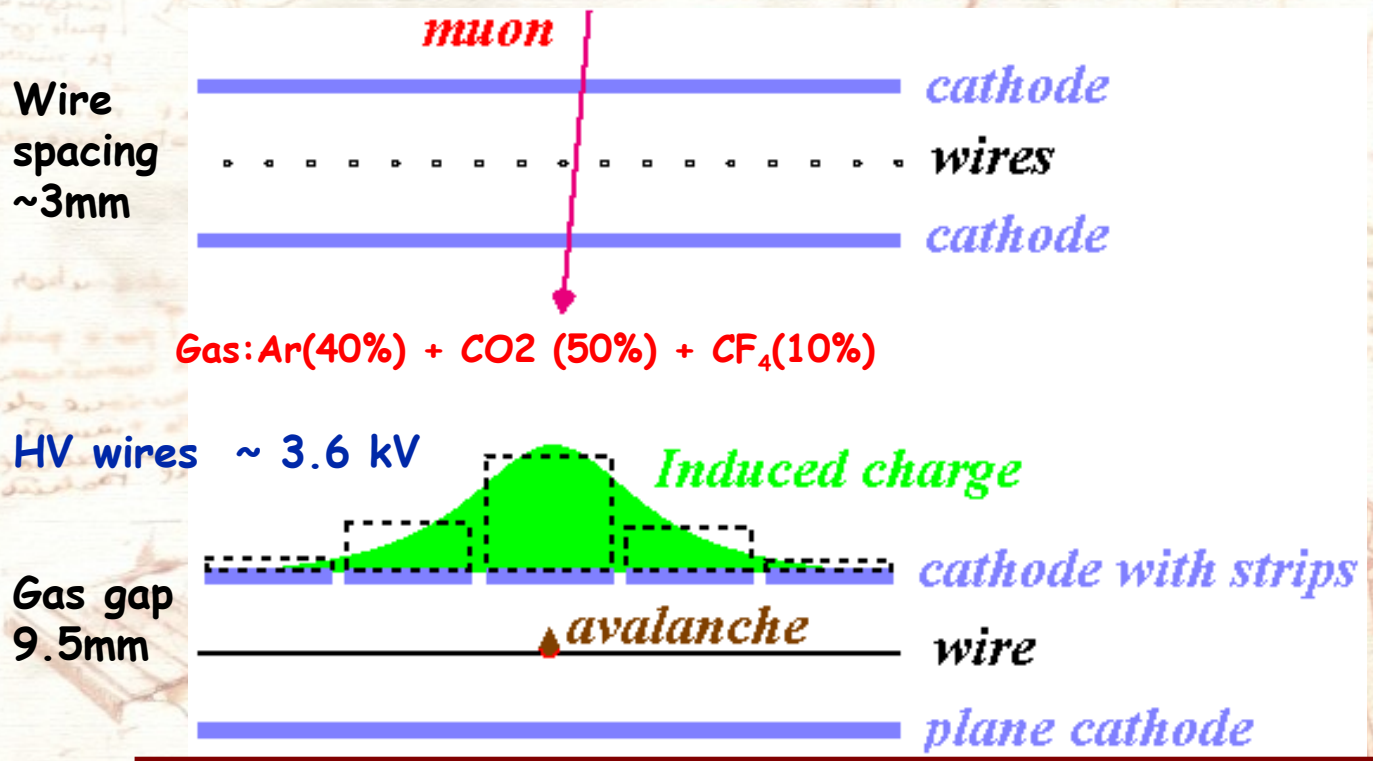
Tmax: 380 ns
Drift Velocity : ~ 55μm/ns

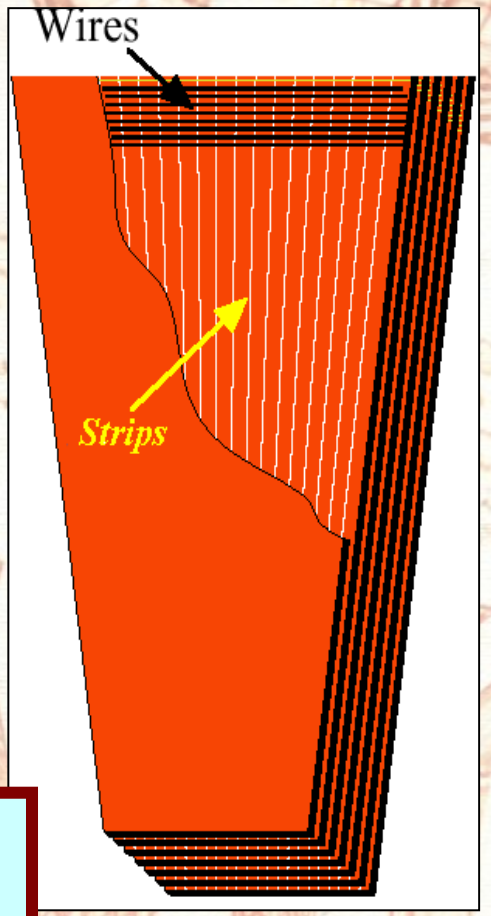
Single Wire Resolution : < 300 μm

100μm Φ
150μm θ


250 DT chambers
in the Barrel

Cathode Strip Chambers (CSC)





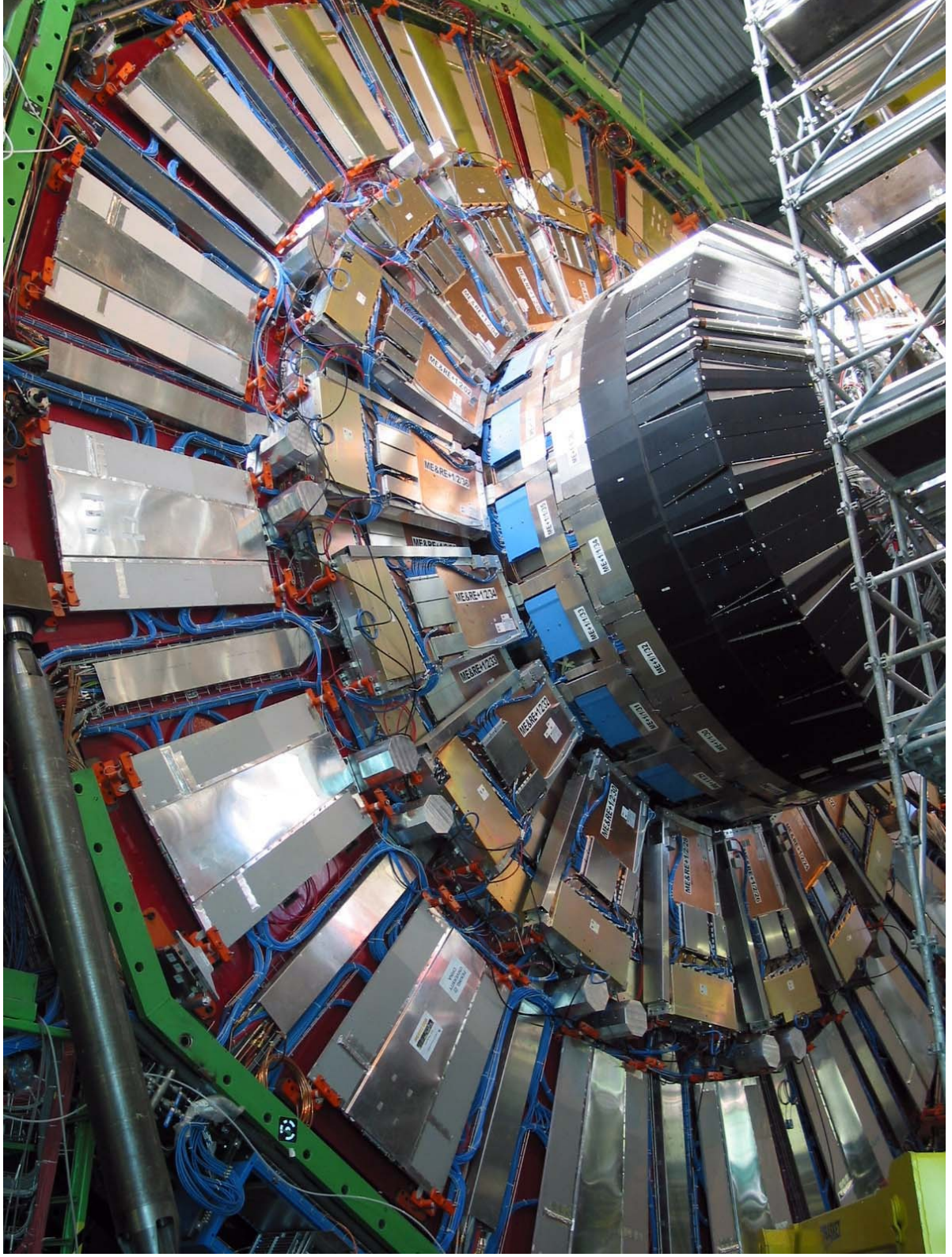
Trapezoidal Chambers (10^0 or 20^0 in Φ), 6 layers

Radial cathode strips – measure Φ (75-150 μm)

Wires orthogonal to strips

Precise timing measurement (BX) - ~4.5 ns

Coarse measurement of the radial position (16-54 mm)



CSC

Resistive Plate Chambers

Resistive Plates – bakelite with bulk resistivity $(2 \pm 1).10^{10}\Omega$cm

Gas gap (2mm ± 20μm wide)

Gas mixture, containing

96% $C_2H_2F_4$(Freon),

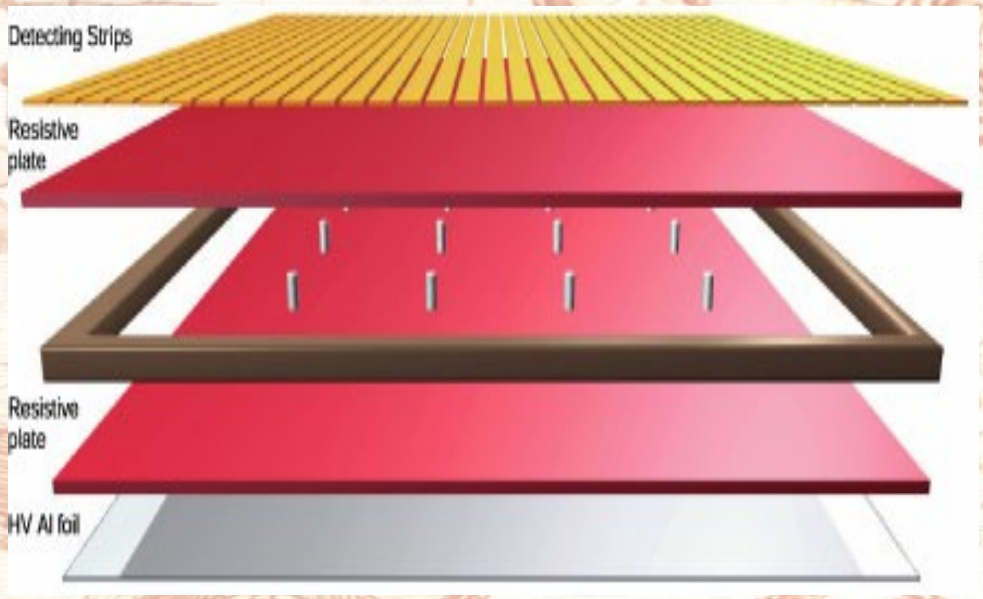
3,5 % isobutan, SF_6 – 0,5 %

Graphite electrodes with resistivity 300 kΩ / cm

Insulating PET film (0.3 mm thick)

Detecting copper strips

40μm thick,2–4 cm wide and 1250 mm long

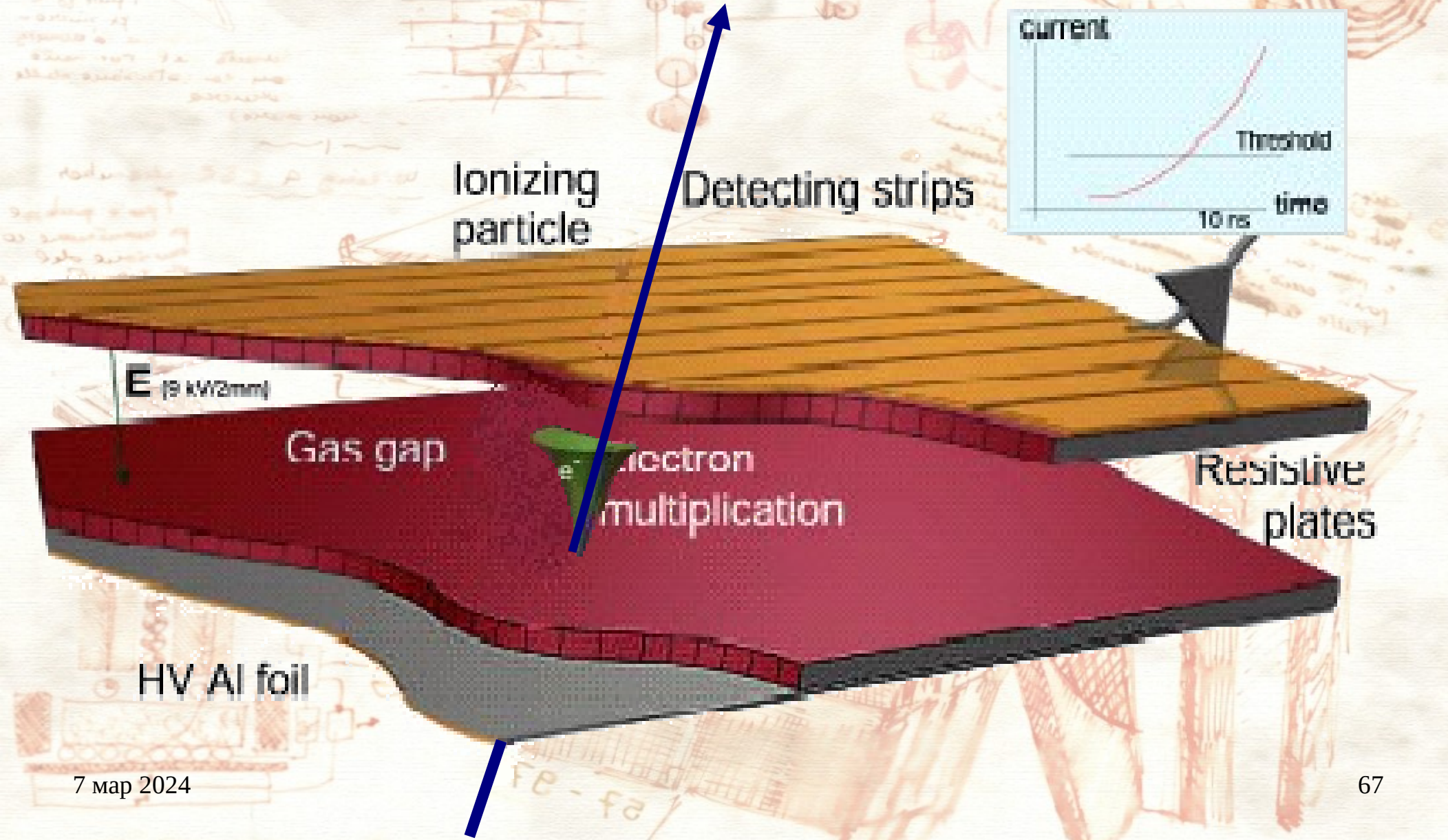


Spacers (cylinders with diameter 10 mm and height 2mm)

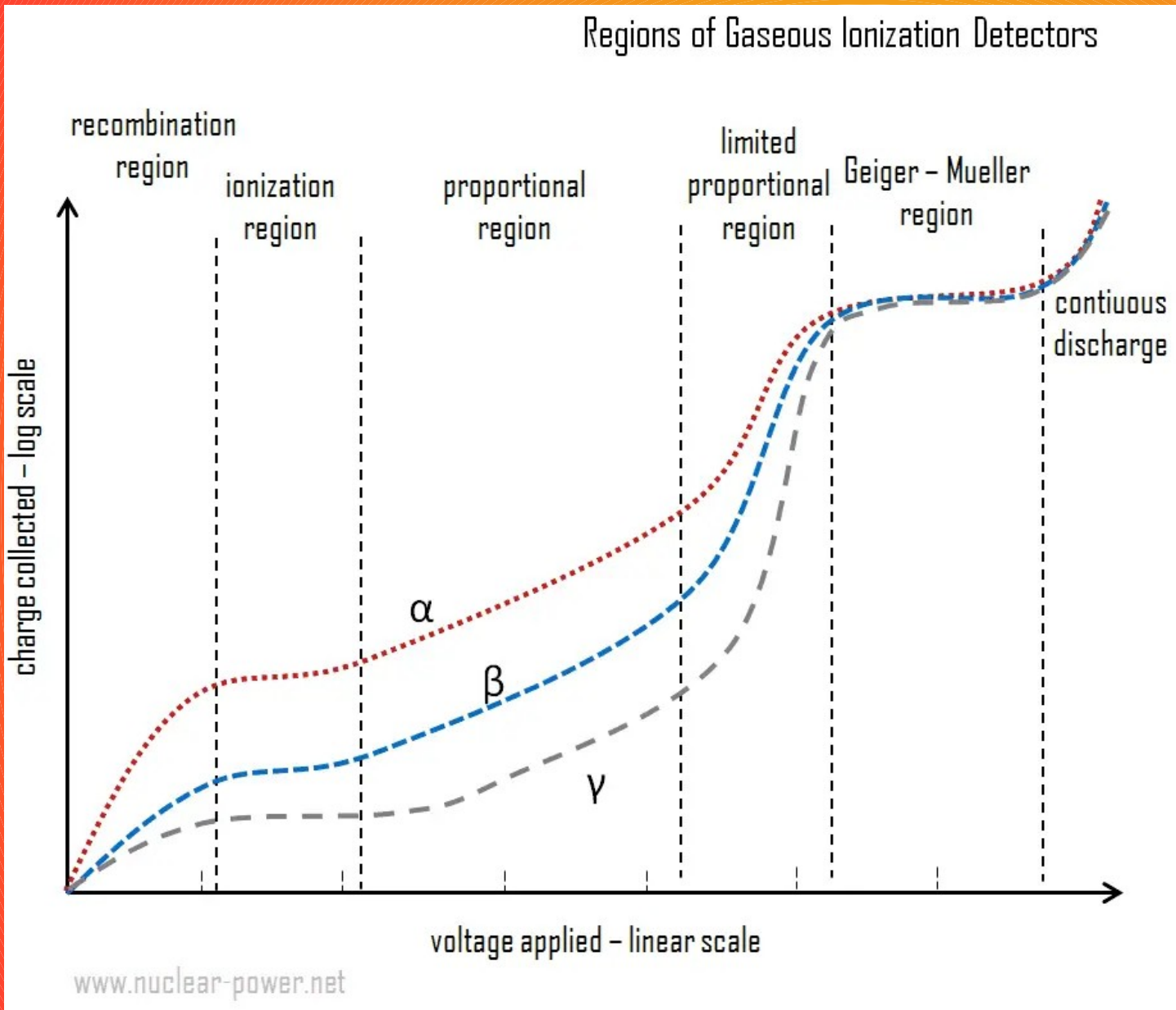
Copper shielding

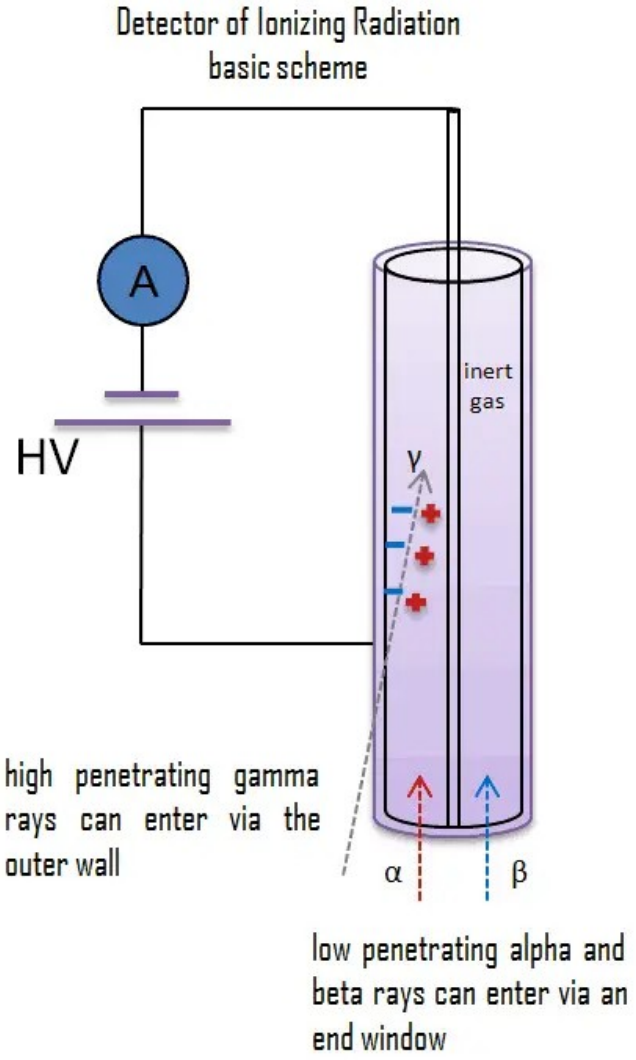
Linseed oil treatment

RPC - Principle of Action

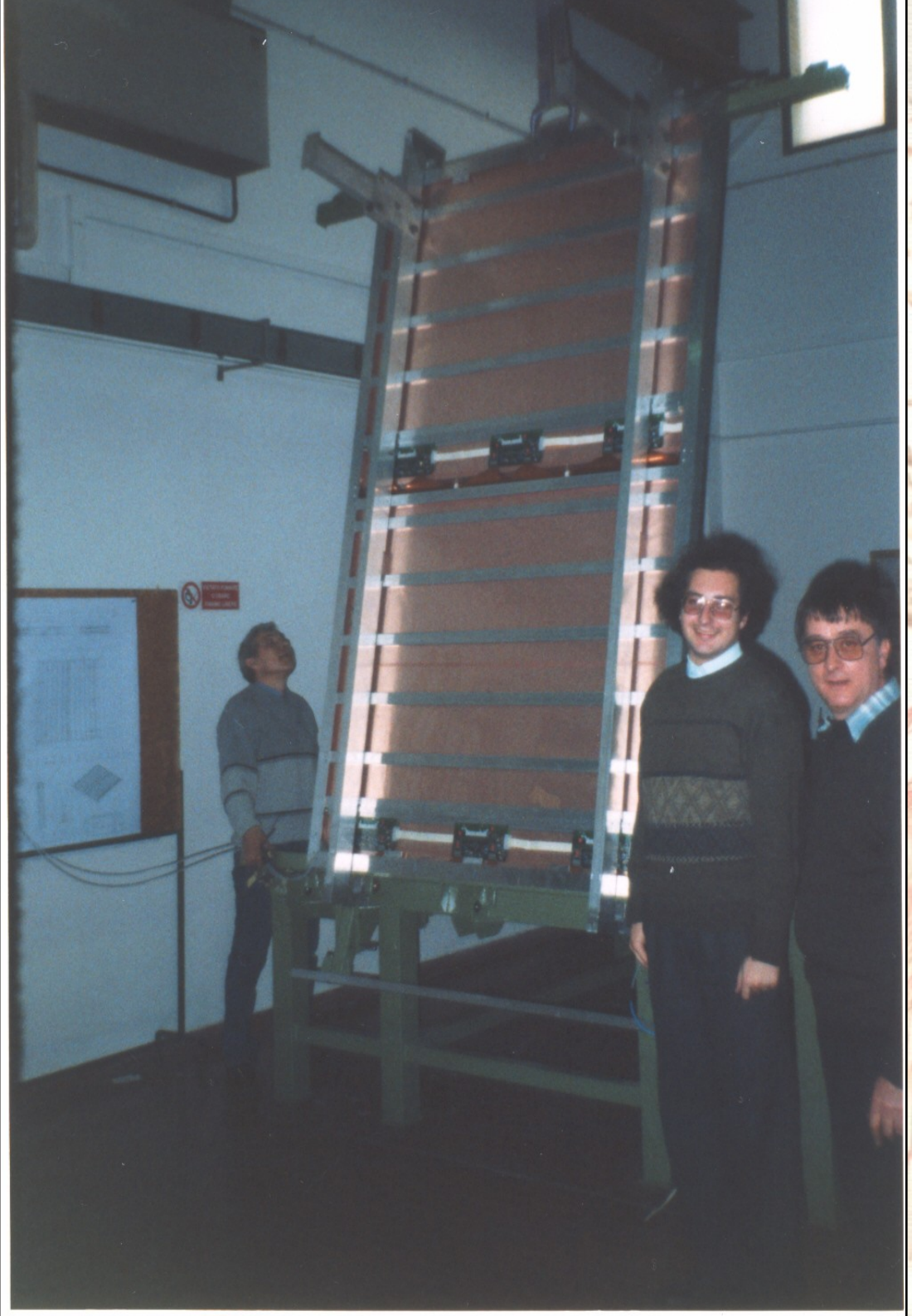


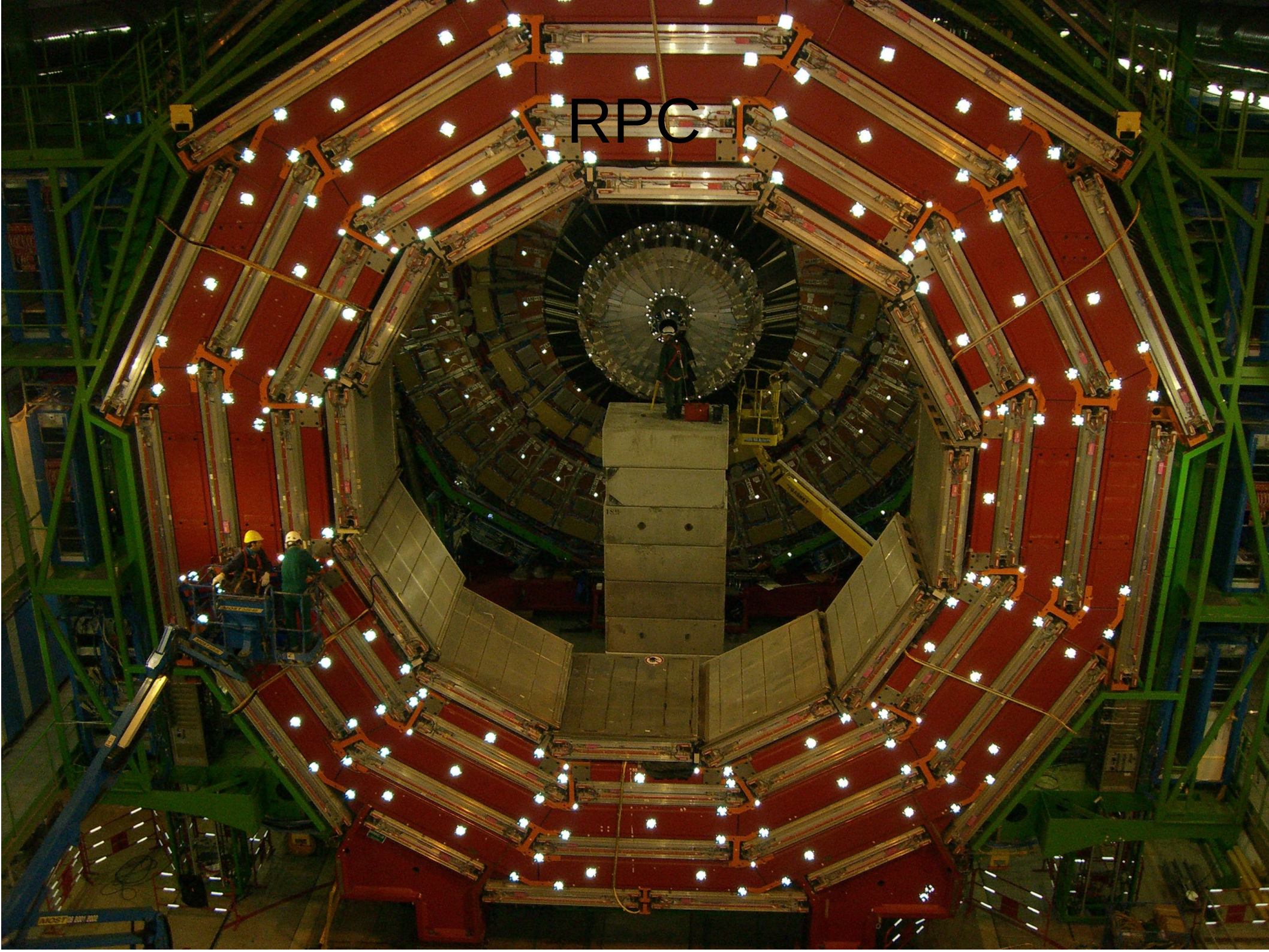
Газови детектори – режими на работа



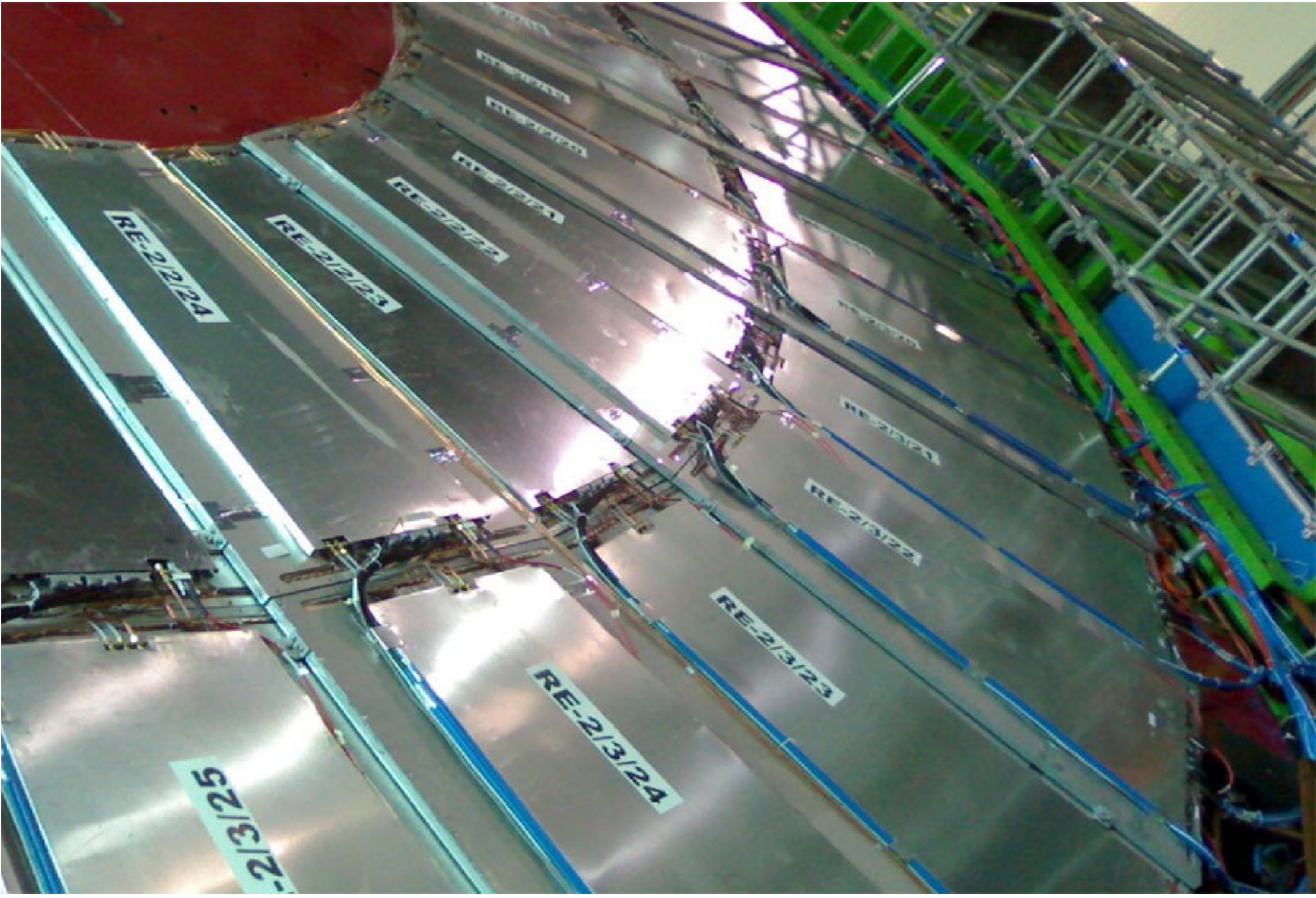


Първата RPC камера за CMS 14 февруари 2002 г.

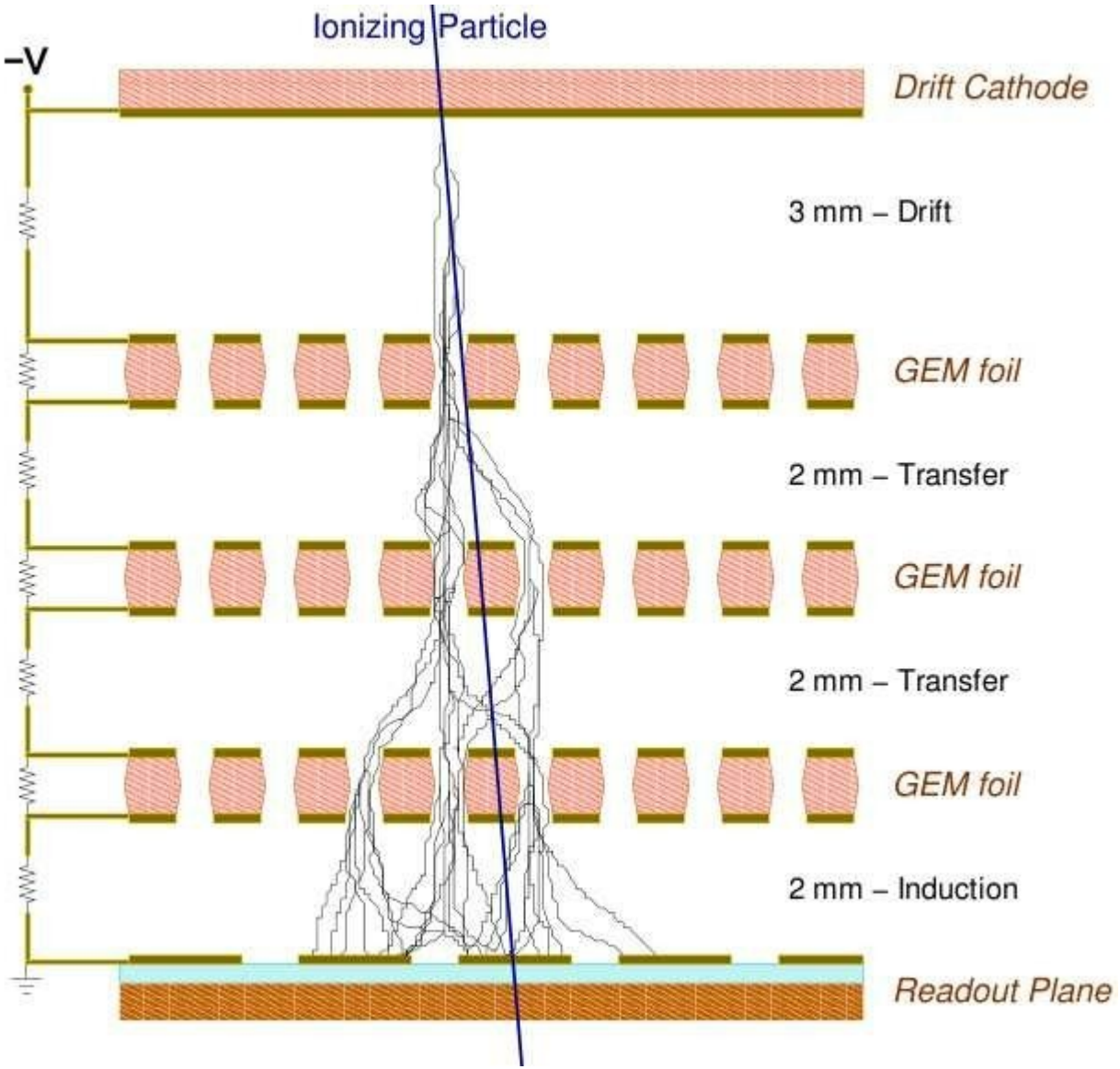



RPC

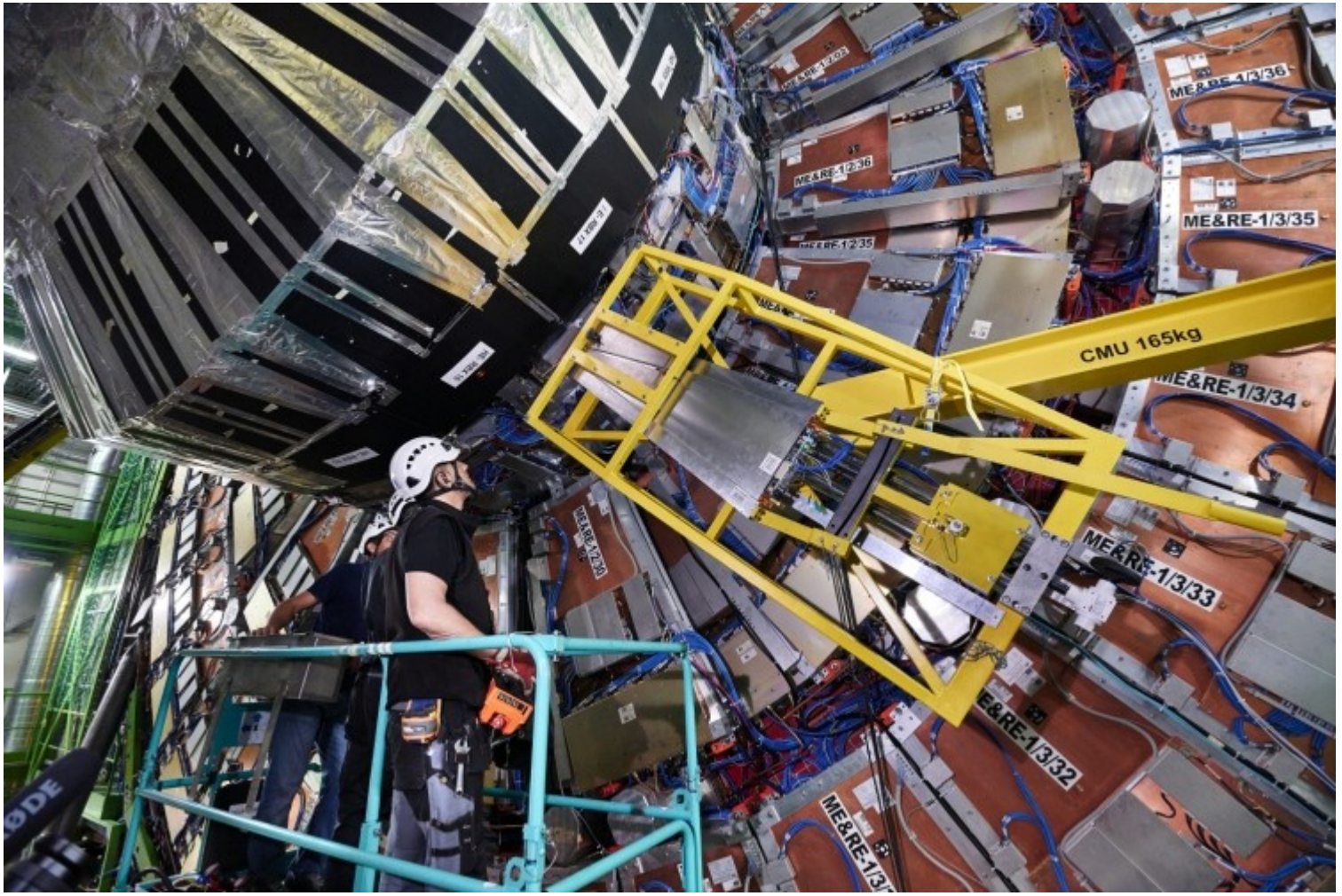
RPC

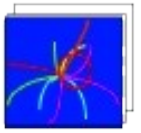


GEM


Ionizing Particle
-V
Drift Cathode
3 mm – Drift
GEM foil
2 mm – Transfer
GEM foil
2 mm – Transfer
GEM foil
2 mm – Induction
Readout Plane

GEM





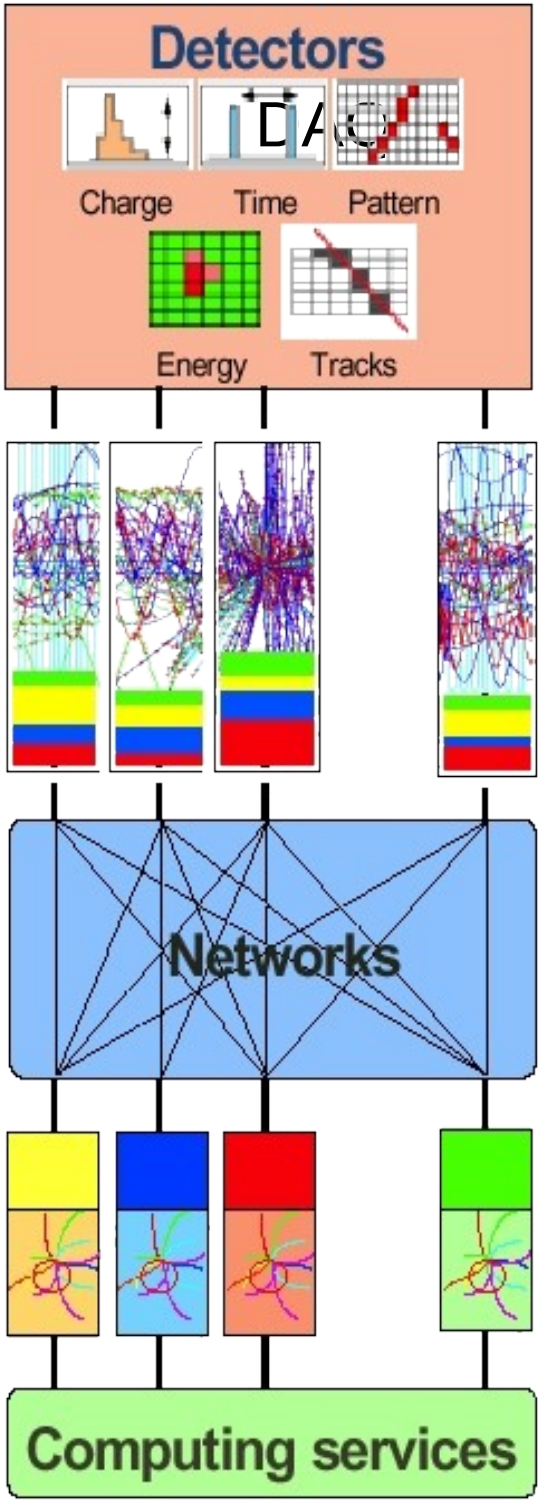
40 MHz
COLLISION RATE

100 kHz
LEVEL-1 TRIGGER

1 Terabit/s
(50000 DATA CHANNELS)

500 Gigabit/s

Gigabit/s SERVICE LAN



16 Million channels
3 Gigacell buffers

1 Megabyte EVENT DATA

200 Gigabyte BUFFERS
500 Readout memories

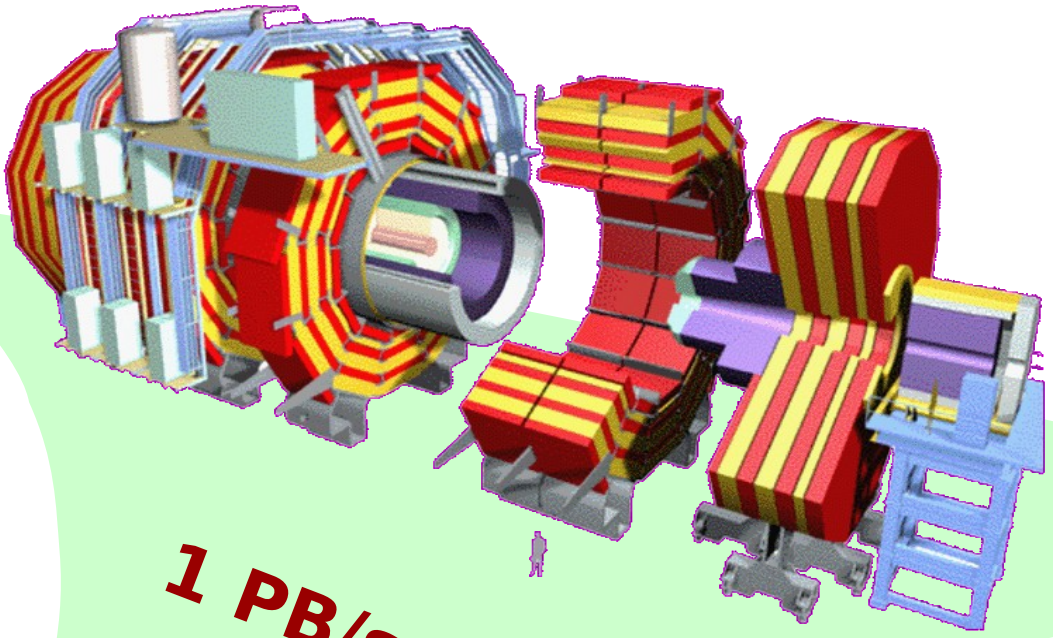
EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and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

Data processing



1 PB/sec

Filtering in real time:
Selection of intwresting events and data compresion

1 PB per year

LCG

Level 0

Trigger system

0.1-1.5 GB/sec

CERN computing center

Level 1

~40Gb/sec

USA

France

CERN

Italy

…

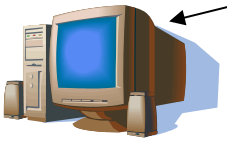
1-2.5 Gb/sec

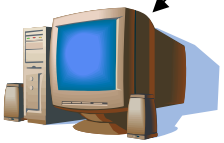
Level 2

University

Laboratory

University

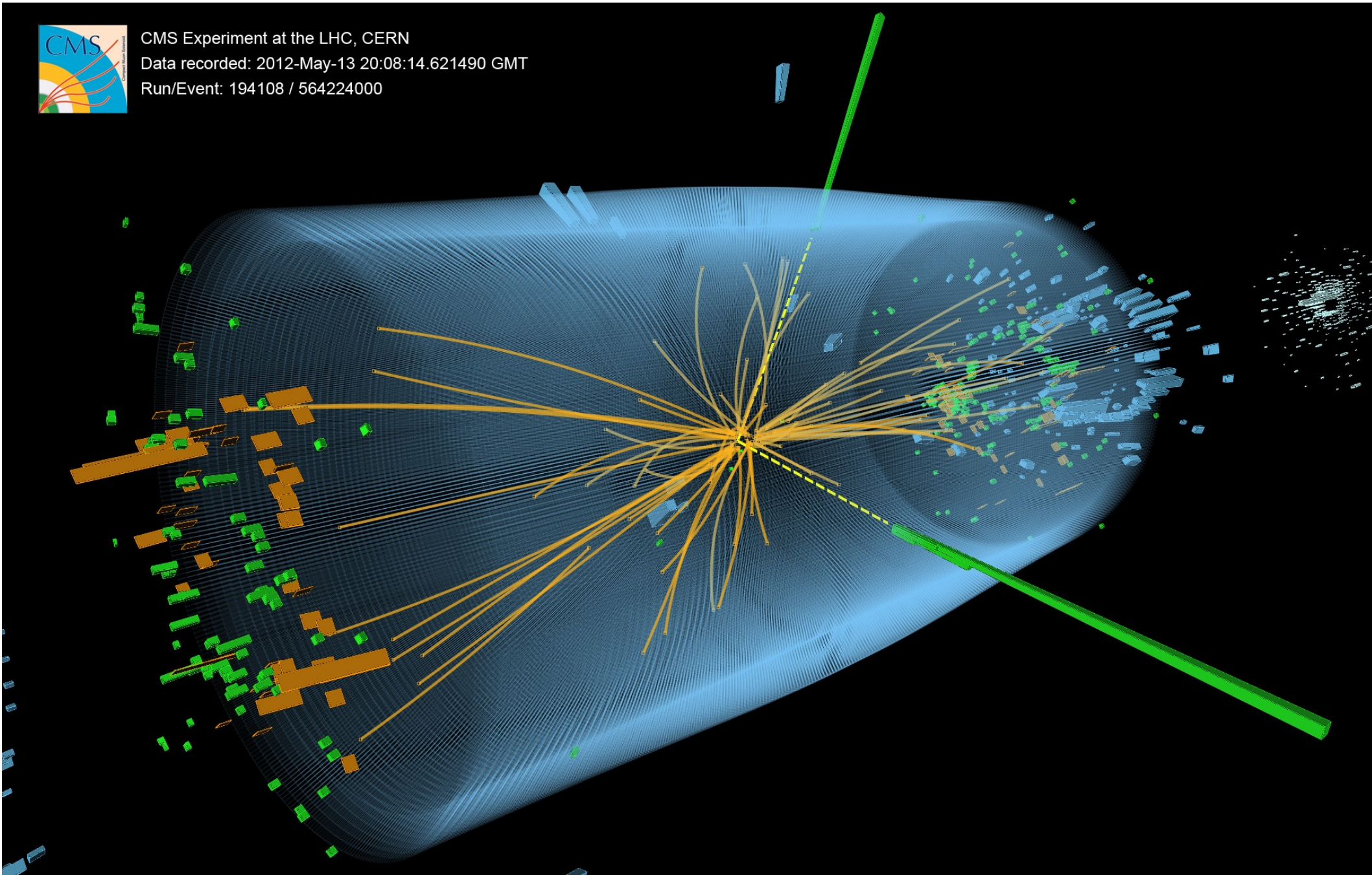


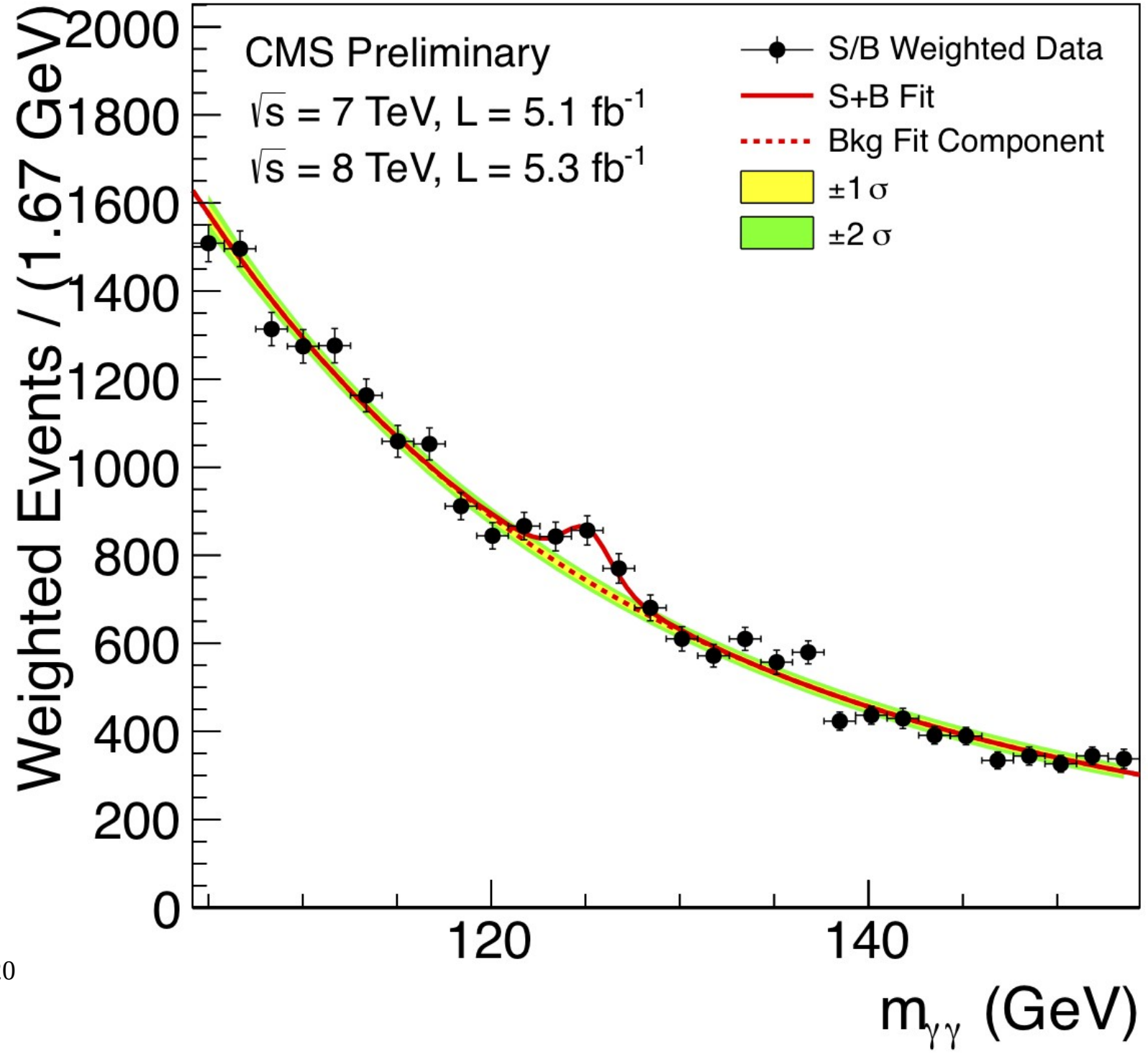


Level 3

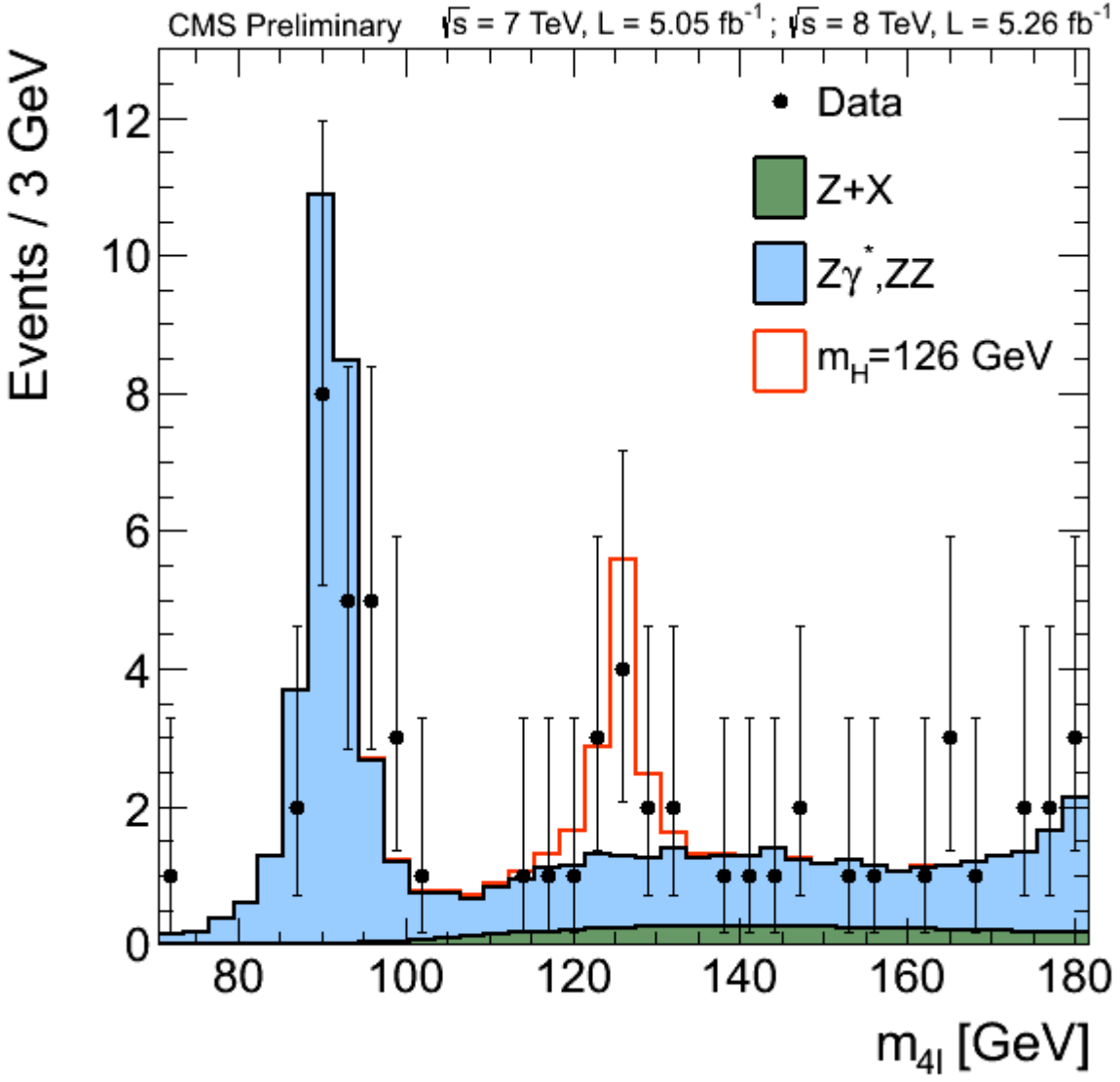
1-10 Gb/sec

Хиггс бозон

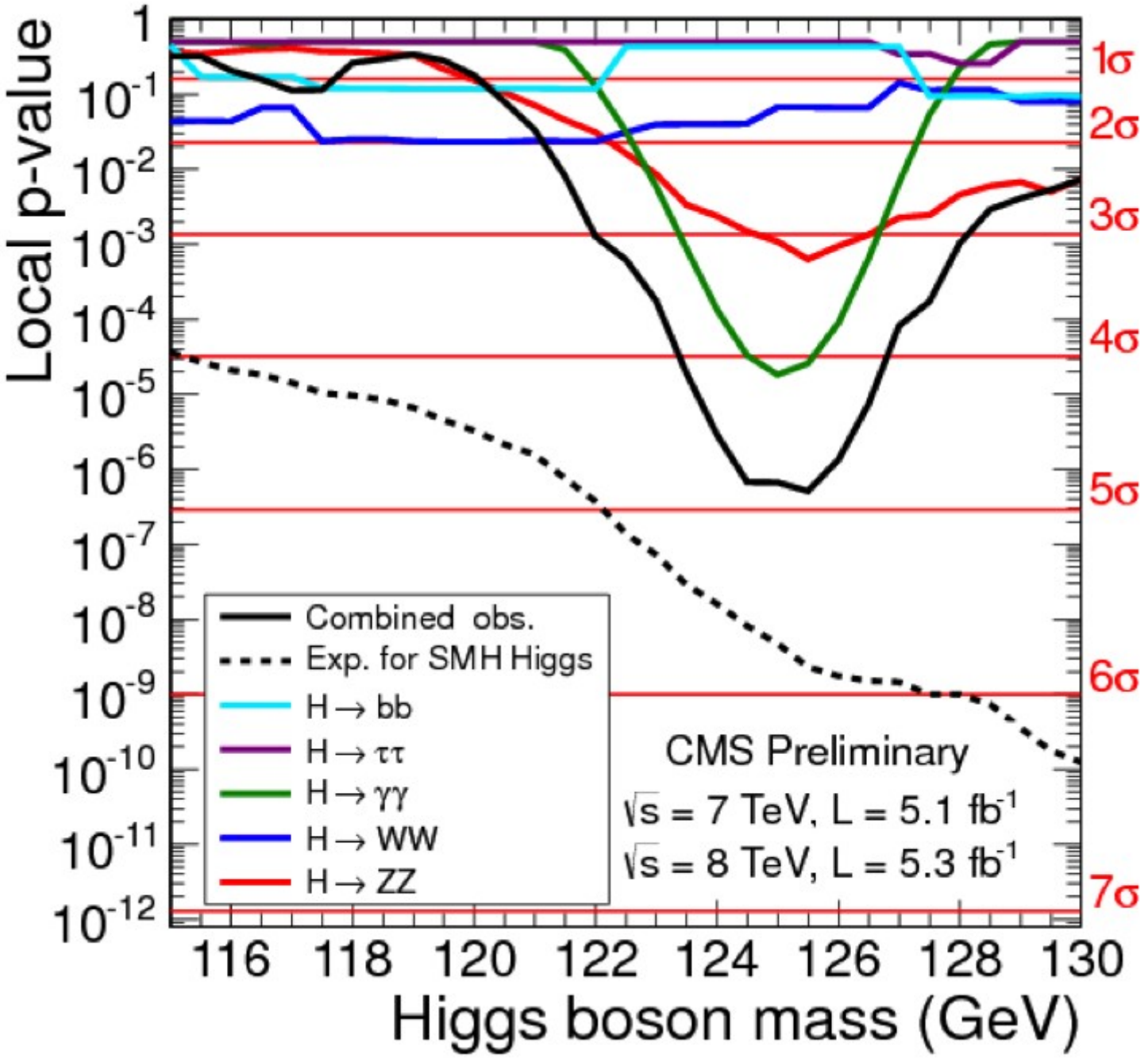

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000


CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
120
140
mγγ (GeV)

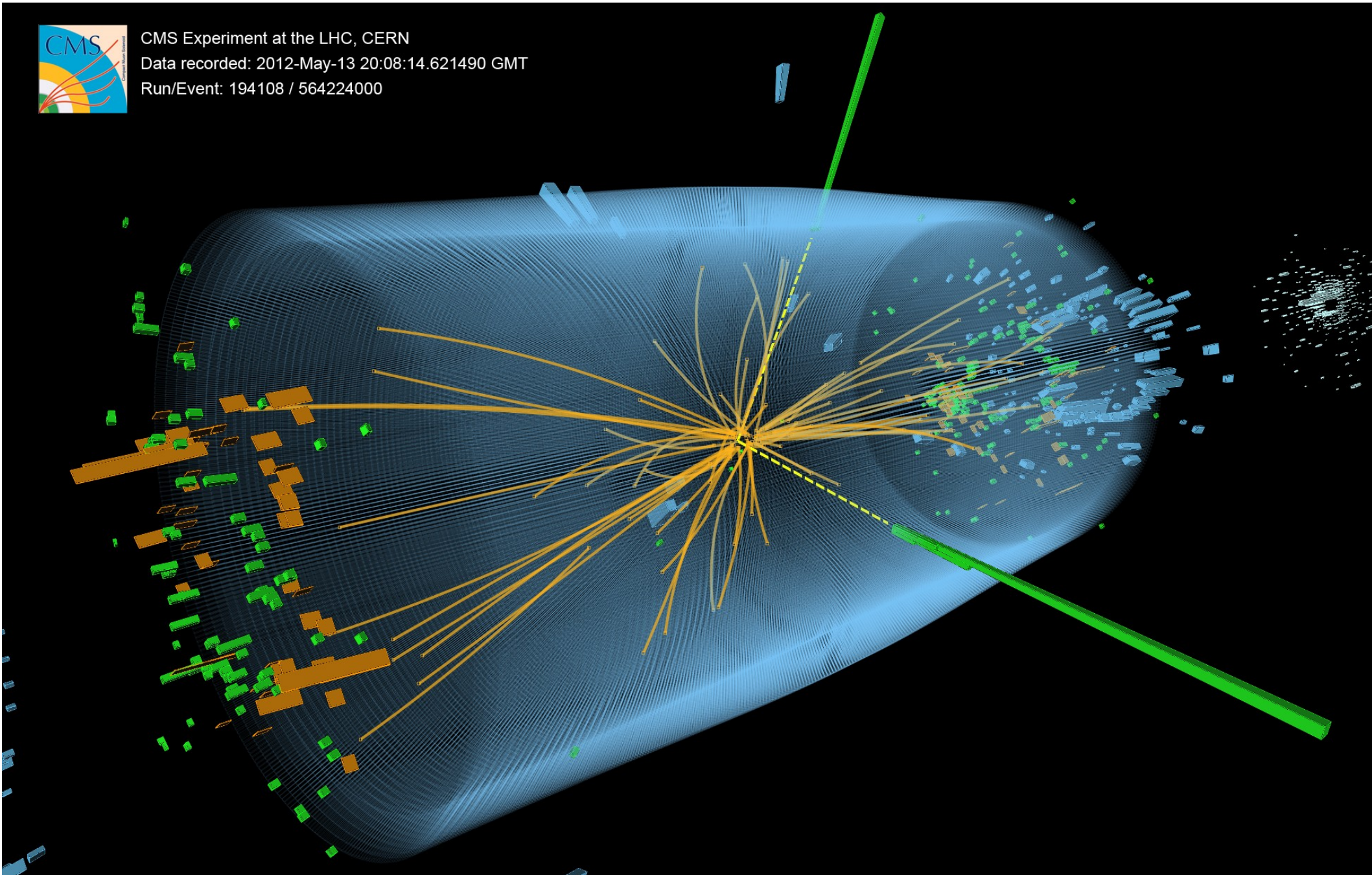
Хиггс бозон


CMS Preliminary
√s = 7 TeV, L = 5.05 fb-1 ; √s = 8 TeV, L = 5.26 fb-1
Data
Z+X
Zγ*,ZZ
mH=126 GeV
Events / 3 GeV
0
2
4
6
8
10
12
80
100
120
140
160
180
m4l [GeV]

Хиггс бозон


Local p-value
1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
10-10
10-11
10-12
1σ
2σ
3σ
4σ
5σ
6σ
7σ
Combined obs.
Exp. for SMH Higgs
H → bb
H → ττ
H → γγ
H → WW
H → ZZ
CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
116
118
120
122
124
126
128
130
Higgs boson mass (GeV)

Хиггс бозон


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

Back up

Backup slides