

**Физика на елементарните
частици
или
От какво е направен светът?**

L. Litov
University of Sofia

April 2006, Sofia



Що е то?



Физика на елементарните частици



Опитва се да отговори на на два фундаментални въпроса

-Кои са елементарните съставлящи на материята?

-Кои са фундаменталните сили контролиращи тяхното поведение ?



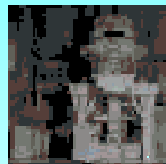
Мащаби



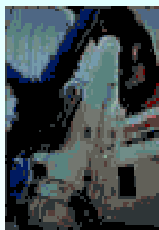
Instruments



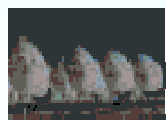
Accelerators
LHC, LEP



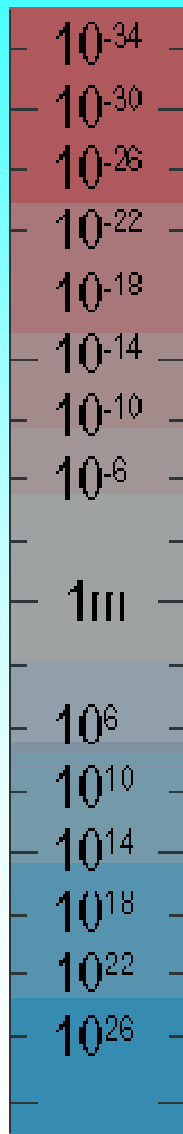
(Particle beams)
Electron
Microscope



Telescope

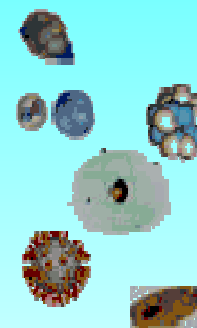


Radio
Telescope



Observables

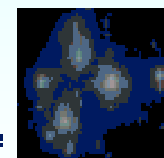
SUSY particle?
Higgs?
 Z/γ (range of nuclear force)
Proton Nuclei (range of weak force)
Atom
Virus
Cell

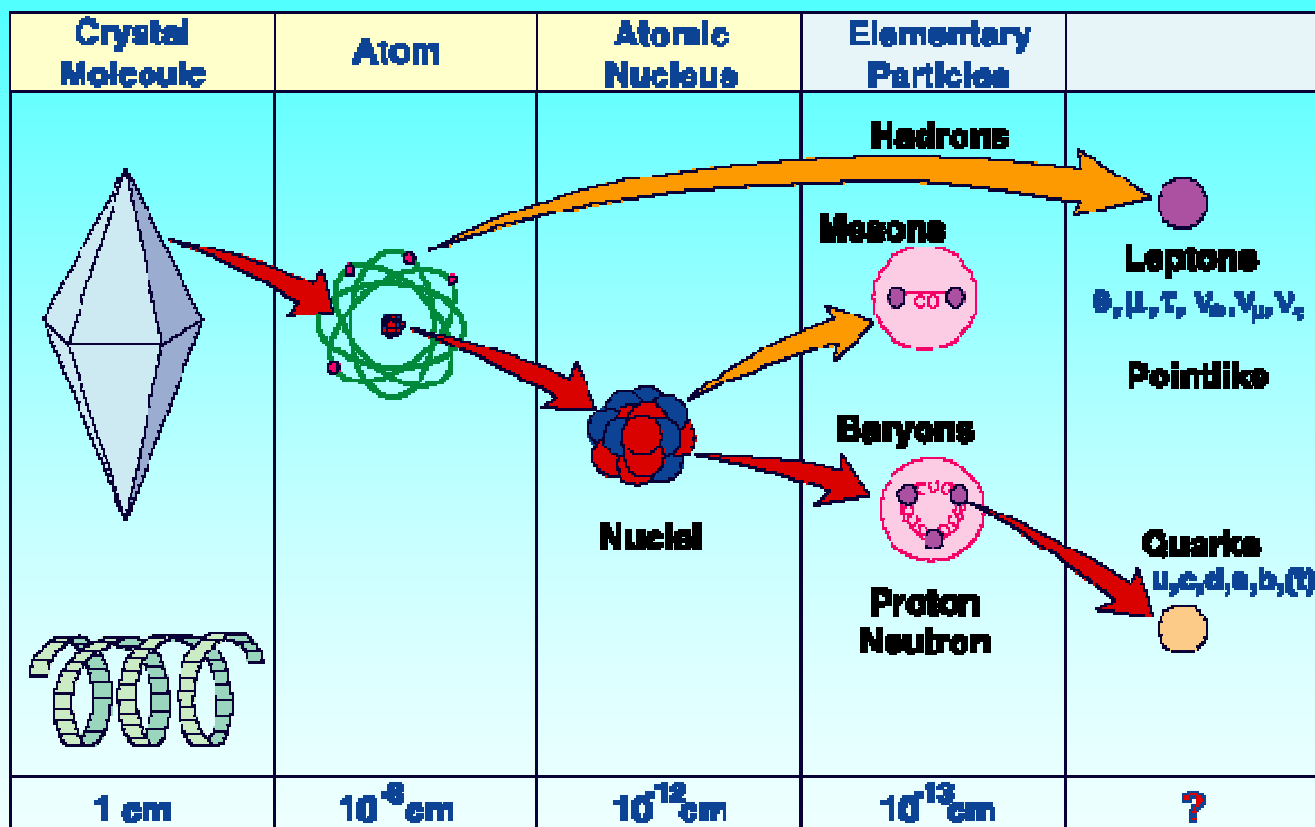


Earth radius
Earth to Sun



Galaxies
Radius of observable Universe



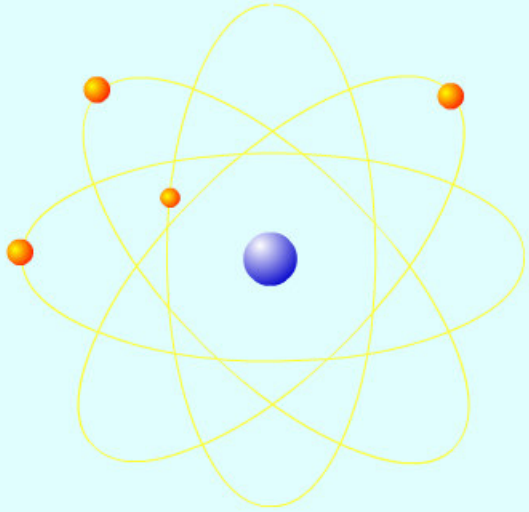


21101

Катедра Атомна физика








Structure of matter



Animation: *Elena Symeonidou*

Leptons

Tau		Electric Charge -1	Tau Neutrino		Electric Charge 0
Muon		-1	Muon Neutrino		0
Electron		-1	Electron Neutrino		0

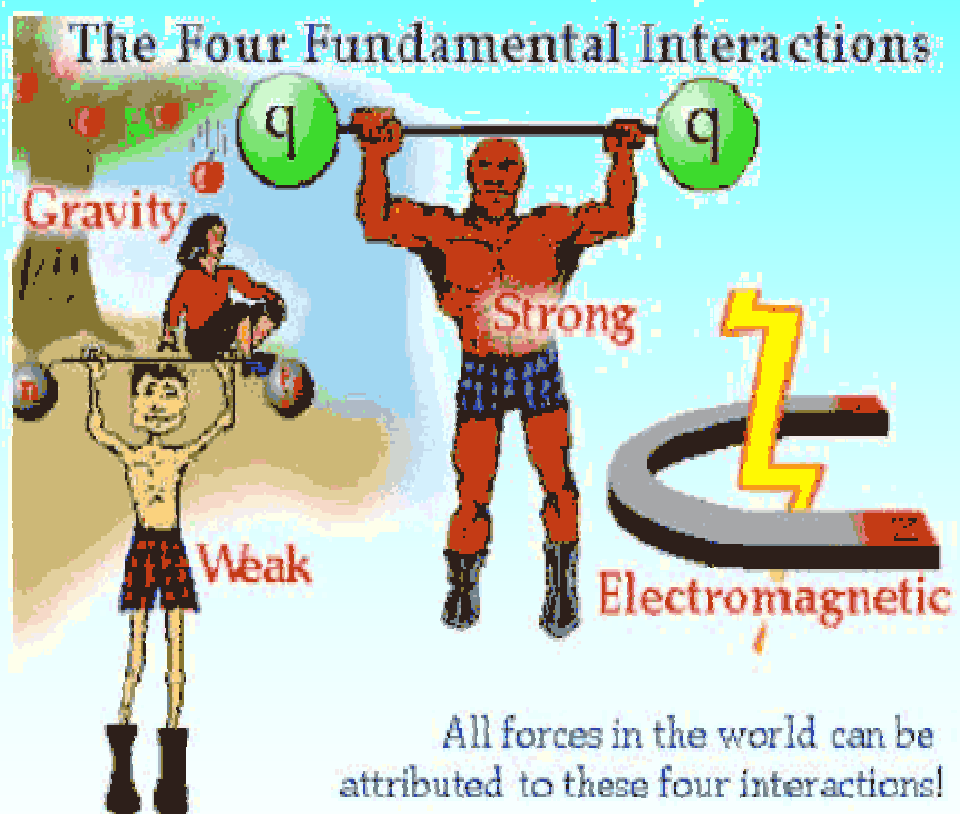
Quarks

Bottom		Electric Charge $-1/3$	Top		Electric Charge $2/3$
Strange		$-1/3$	Charm		$2/3$
Down		$-1/3$	Up		$2/3$

each quark: ●R, ●B, ●G 3 colors

The particle drawings are simple artistic representations

How are the composite objects held together ?
by forces

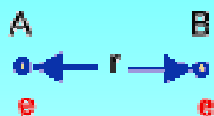


Gravity

Interaction between two **matter** particles e.g. electrons

Action at a distance

$$F \propto \frac{e^2}{r^2} \hat{r}$$



Newton

Force on A depends on where B is.
But how does A know where B is?

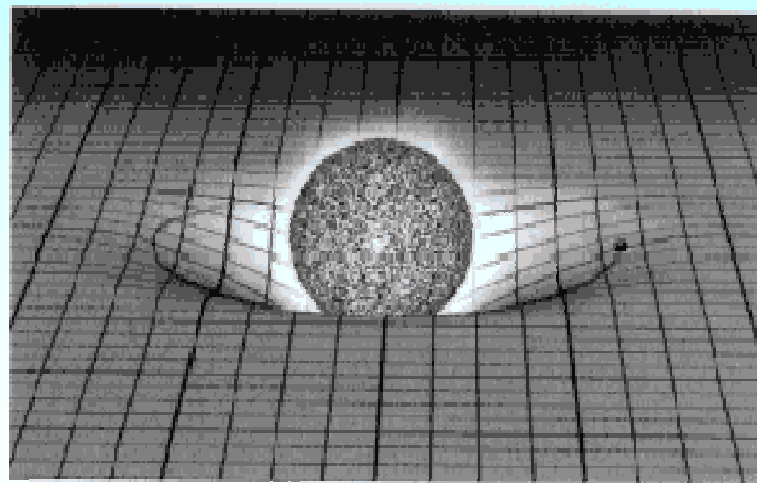
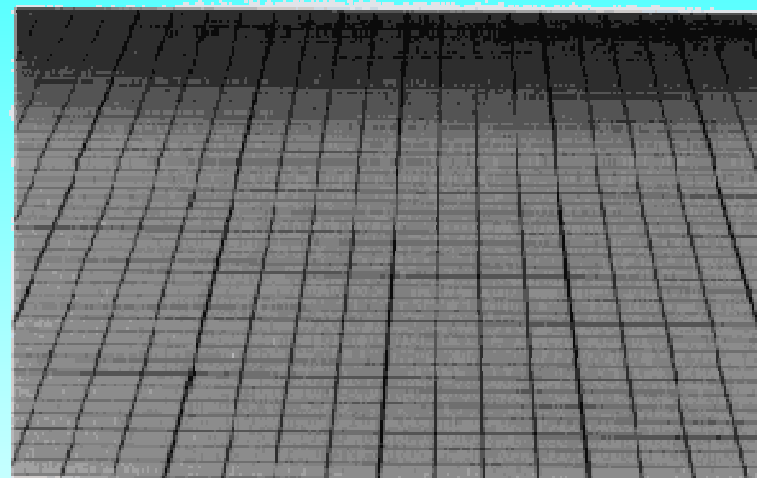
Interaction through Fields

Maxwell

B produces a field, characterized by a number (q/r^2) at every point in space.

Force on A is towards the direction in which the number changes fastest

A determines its response by 'sniffing' in its immediate neighbourhood





Как стават?



BUT - still no tangible connection between A and B

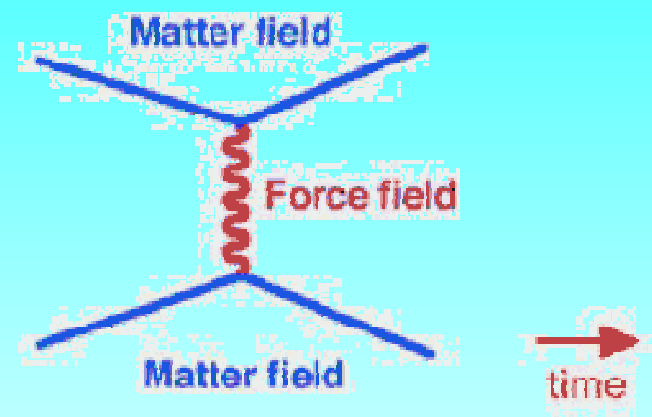
Forces are produced by exchange of force or 'messenger' particles

Feynman:

B continually emits carriers of the electromagnetic force - 'photons'

Electron A absorbs the photons and recoils - repulsive force between the electrons.

In Quantum Field Theory both signs of impulse are possible.





Преносители на взаимодействия



What characterizes a force ? Strength, range and source charge of the field.

Interaction	Exchanged quantum (source ch)	Range (m)	Relative Strength	Examples in nature
Strong	gluon <i>colour</i>	10^{-15}	1	proton (quarks)
Electromagnetic	photon <i>electric</i>		$<10^{-2}$	atoms
Weak	W, Z <i>hypercharge</i>	$<10^{-17}$	10^{-5}	radioactivity
Gravity	graviton ? <i>mass</i>		10^{-38}	solar system

Ratio of electrical to gravitational force between two protons is $\sim 10^{38}$!!

Can such different forces have the same origin ??

PROBLEM WITH MASS SCALES

Gauge Symmetry \longrightarrow $m_\gamma = 0$ Good
 $M_W = M_Z = 0$ Bad!



$$M_W = 80.43 \text{ GeV}$$

$$M_Z = 91.19 \text{ GeV}$$

Moreover $\mathcal{L}_{m_f} \equiv -m_f \bar{f} f = -m_f (\bar{f}_L f_R + \bar{f}_R f_L)$

Also Forbidden by Gauge Symmetry \longrightarrow $m_f = 0 \quad \forall f$

All Particles Massless



Спонтанно нарушение на симетрията



In the SM masses are generated through

Spontaneous Symmetry Breaking (**SSB**) – Higgs Mechanism

Introduce Scalar Higgs doublet \rightarrow The Lagrangian is invariant

However its vacuum state is degenerate – $\langle 0 | \Phi_0 | 0 \rangle = \frac{v}{\sqrt{2}}$

Choice of the vacuum state – leads to SSB

$SU(2)_L \times U(1)_Y \rightarrow U(1)_Q$

Couplings with gauge bosons and fermions – induce mass terms

Price – new particle **H-boson** – to be discovered

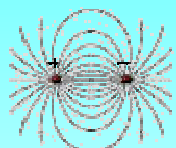


Обединение на взаимодействията



Universal Gravitation

Inertial vs. Gravitational mass
(I. Newton, 1687)



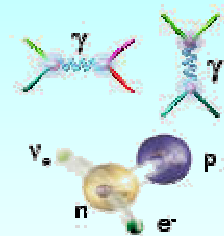
Electricity



Magnetism

Electromagnetism

Electromagnetic waves (photon)
(J.C. Maxwell, 1860)



Electromagnetism

Weak force

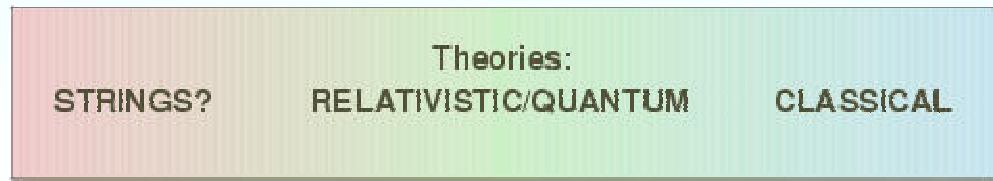
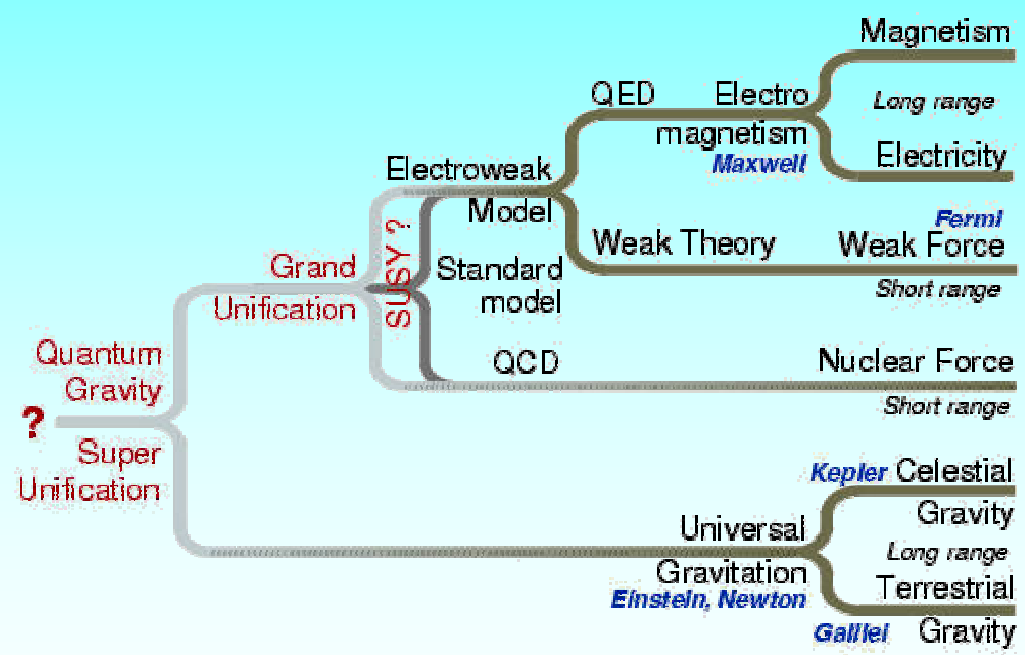
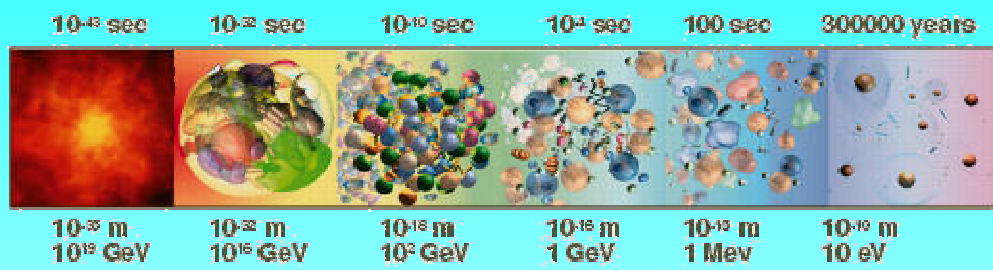
Electroweak

Intermediate bosons W, Z
(1970-83)





Обединение на взаимодействията





Суперсиметрия



How to unify ?

Gravity - space-time symmetry

Electroweak - internal symmetry

Strong - internal symmetry

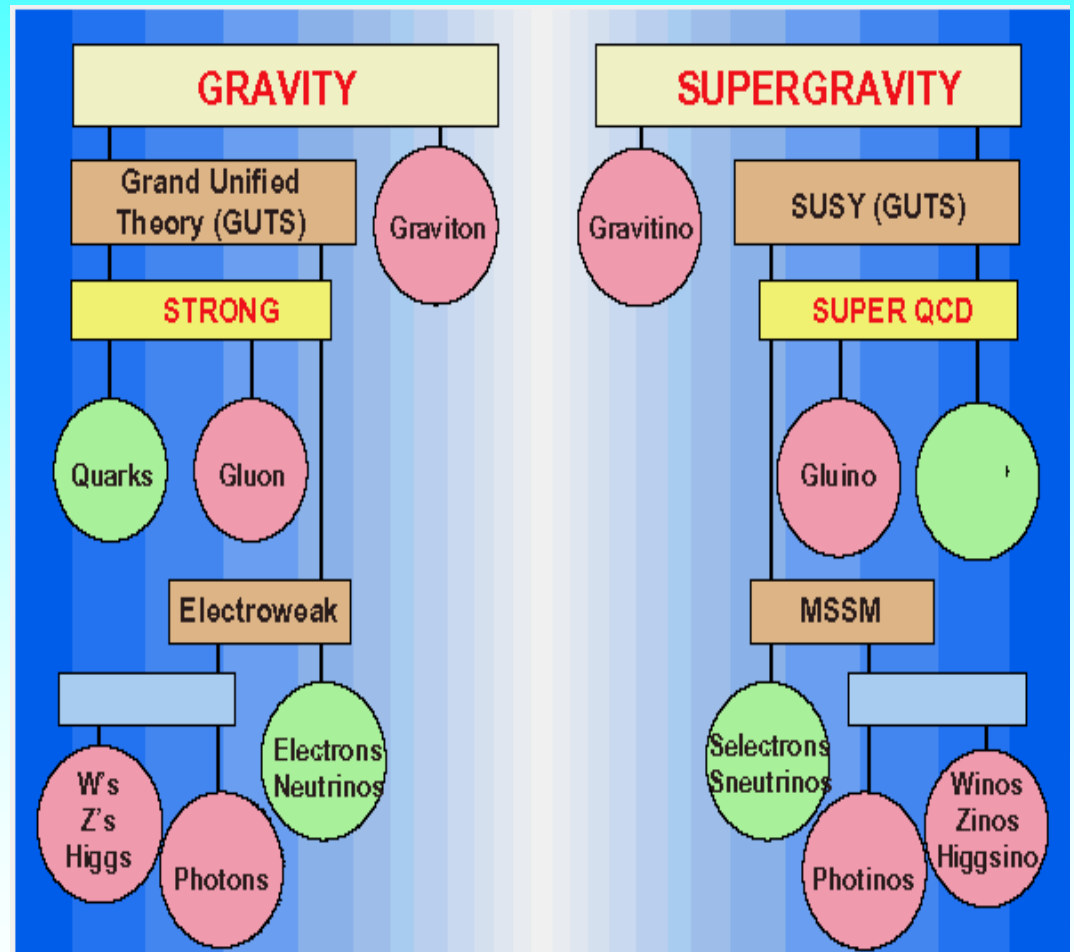
Supersymmetry – symmetry between bosons and fermions

Works well, but

Price to pay: many new particles!

To every fundamental particle – new boson

To every mediator – new fermion





Колко мерно е пространство-времето?



Two fundamental scales:

- Electroweak — $M_{EW} \sim 10^2\text{-}10^3 \text{ GeV}$
- Planck — $M_{Pl} \sim 10^{19} \text{ GeV}$

Observation:

- M_{EW} is established experimentally
 - EW interactions are tested down to distances $1/M_{EW} \sim 10^{-17} \text{ cm}$
- M_{Pl} is just a number
 - gravity tested only down to $\sim 1 \text{ mm}$, far away from $1/M_{Pl} \sim 10^{-35} \text{ m}$

Solution: cut the Gordian Knot!

- There is only one fundamental scale: M_{EW}
- M_{Pl} is just an effective constant
- Its high value is caused by additional spatial dimensions, compactified at radius $R \sim 1 \text{ mm}$

Extra dimension perspectives

Models with extra dimensions can

- **unify all interactions**
- **solve the hierarchy problem**
- **link String Theory to Standard Model**
- **make Quantum Gravity and String Theory accessible at LHC**

like Prometheus made the divine fire accessible for people

Perhaps it is only a dream...

But I wish you and me this dream to come true!

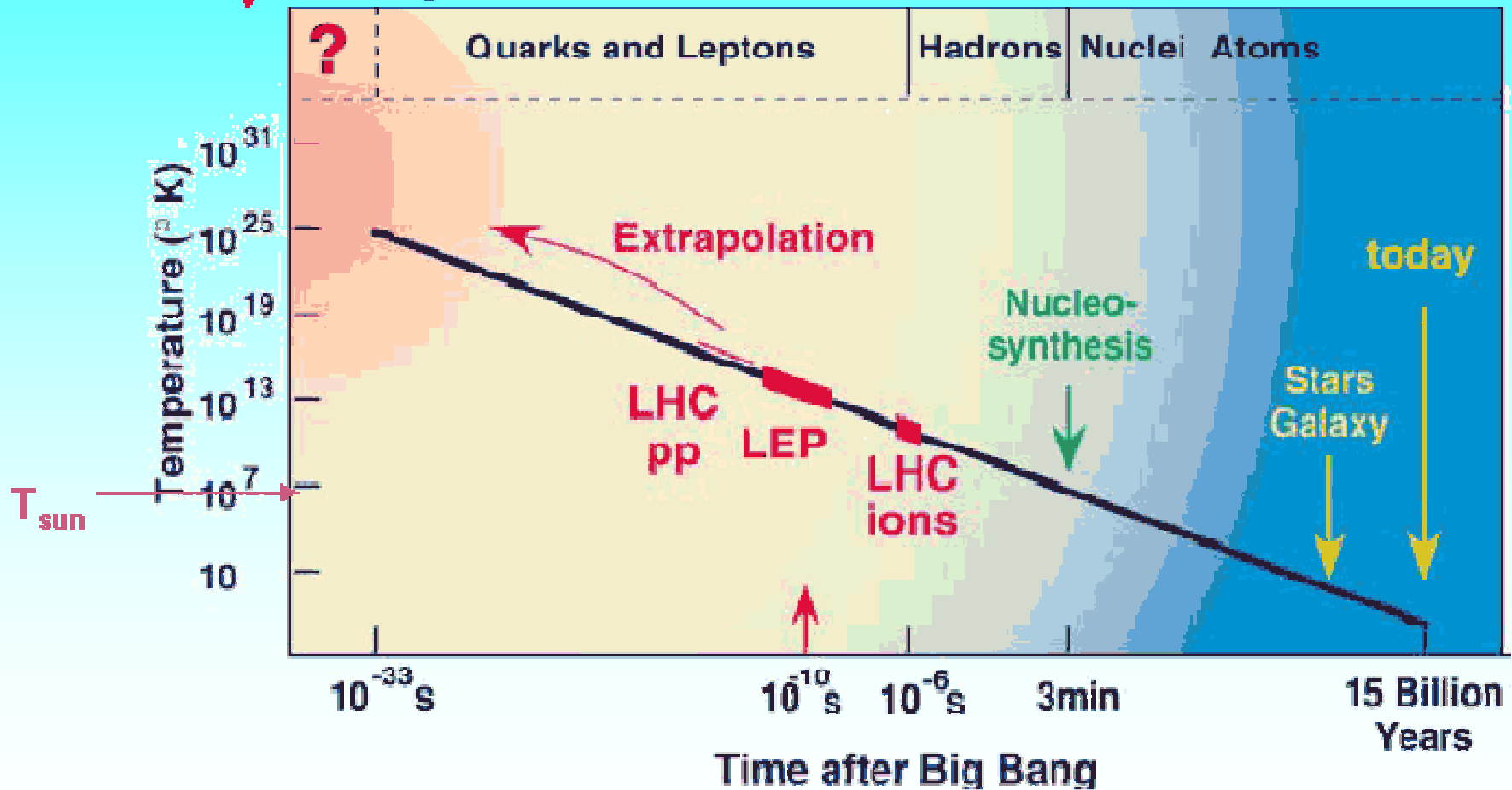


Назад към началото



Metaphysics **Quantum Gravity**

Electroweak Transition

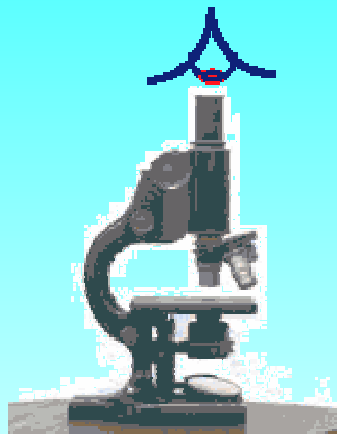




Как го правим?



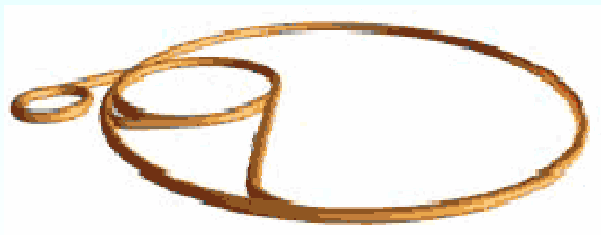
Как го правим?



Wavelength of probe radiation should be smaller than the object to be resolved

$$\lambda \ll \frac{h}{p} = \frac{hc}{E}$$

Object	Size	Energy of Radiation
Atom	10^{-10} m	0.00001 GeV (electrons)
Nucleus	10^{-14} m	0.01 GeV (alphas)
Nucleon	10^{-15} m	0.1 GeV (electrons)
Quarks	?	> 1 GeV (electrons?)



"electronic eyes"

Radioactive sources give energies in the range of MeV

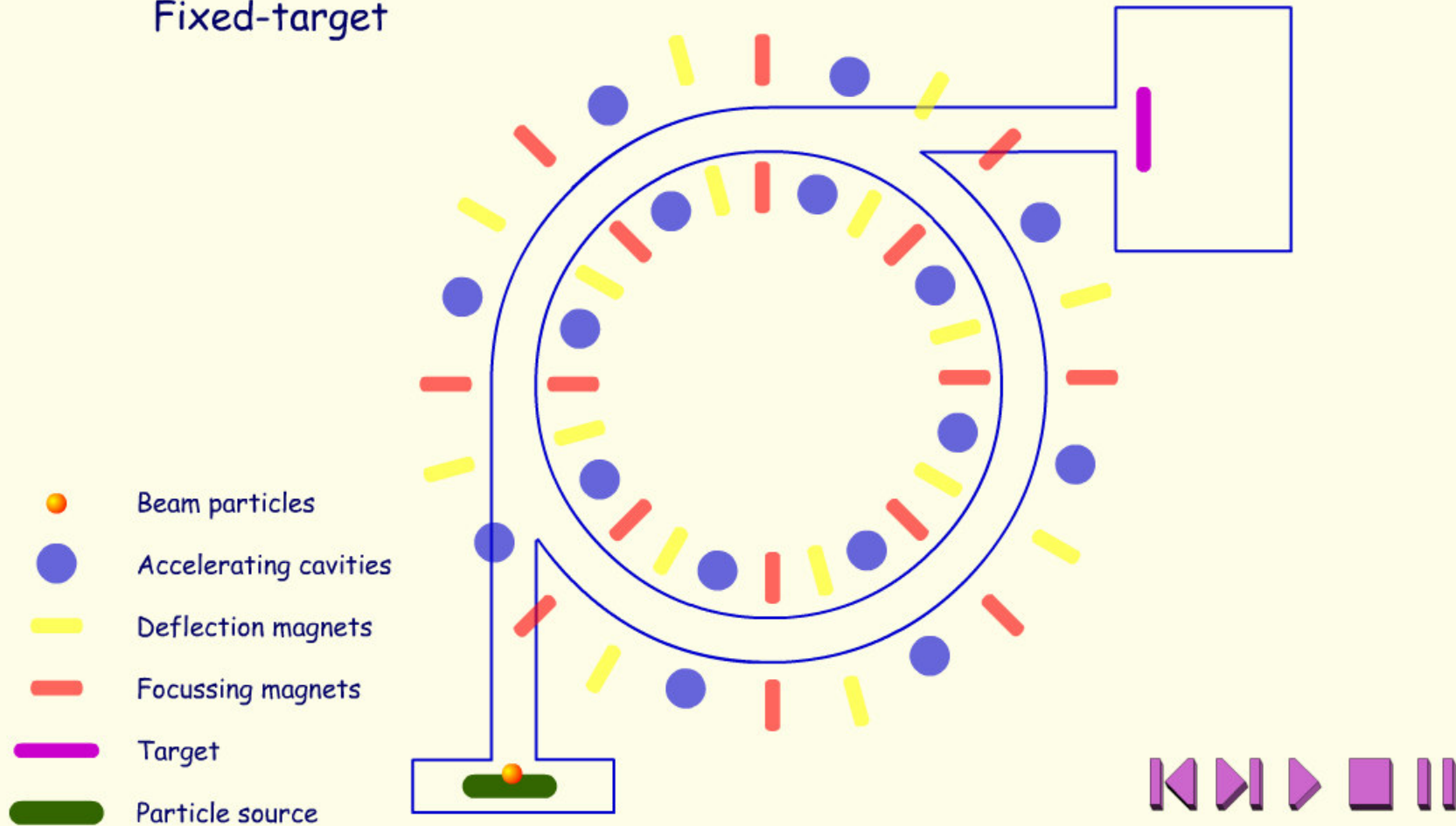
Need accelerators for higher energies.



Ускорители



Circular accelerator with
Fixed-target



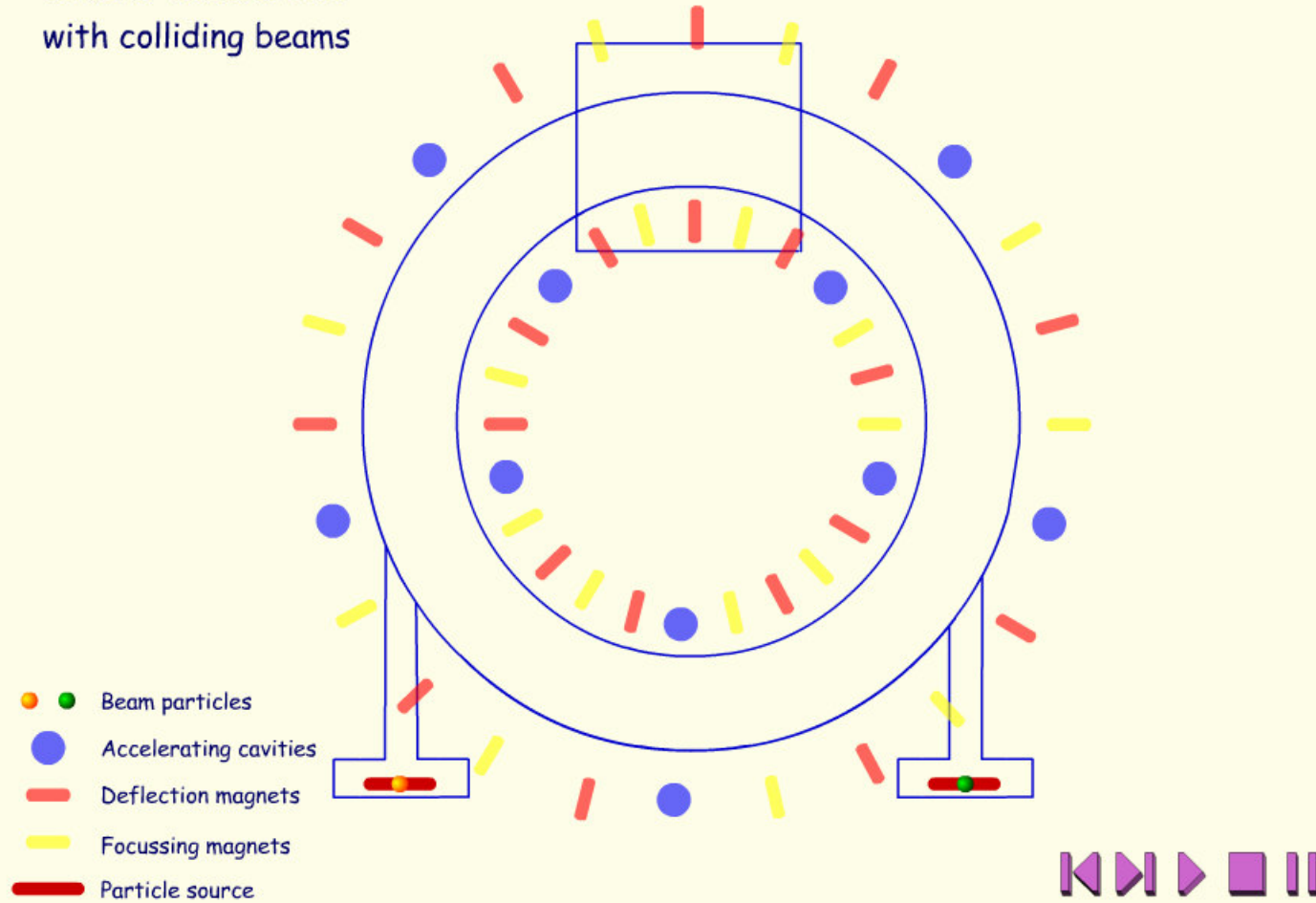
Animation: Elena Symeonidou



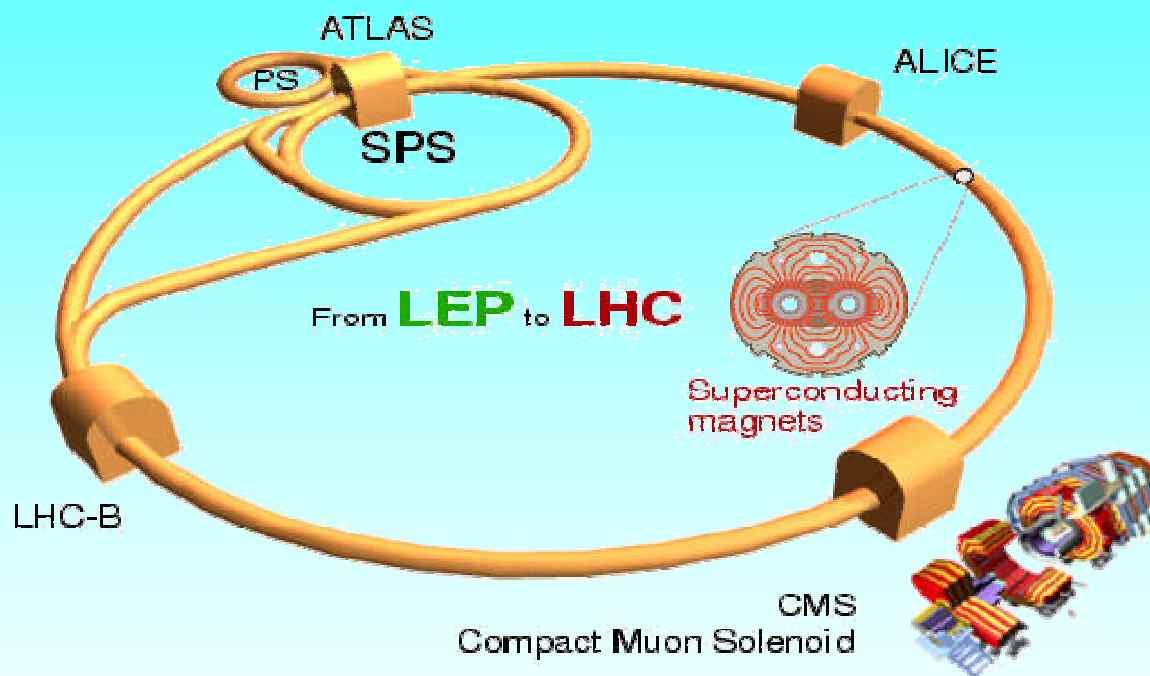
Ускорители



Circular accelerator
with colliding beams



The Large Hadron Collider (LHC)



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

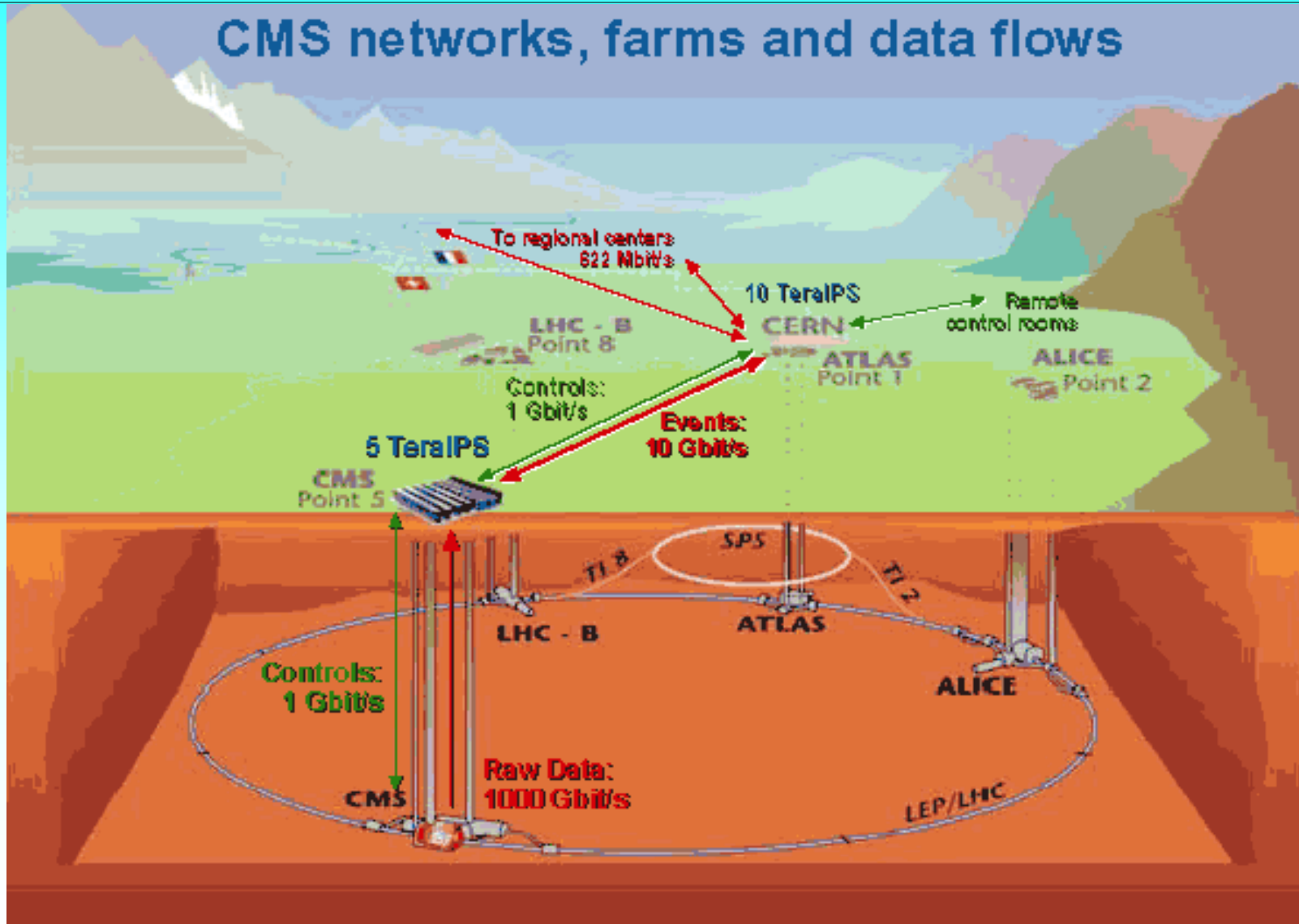




LHC

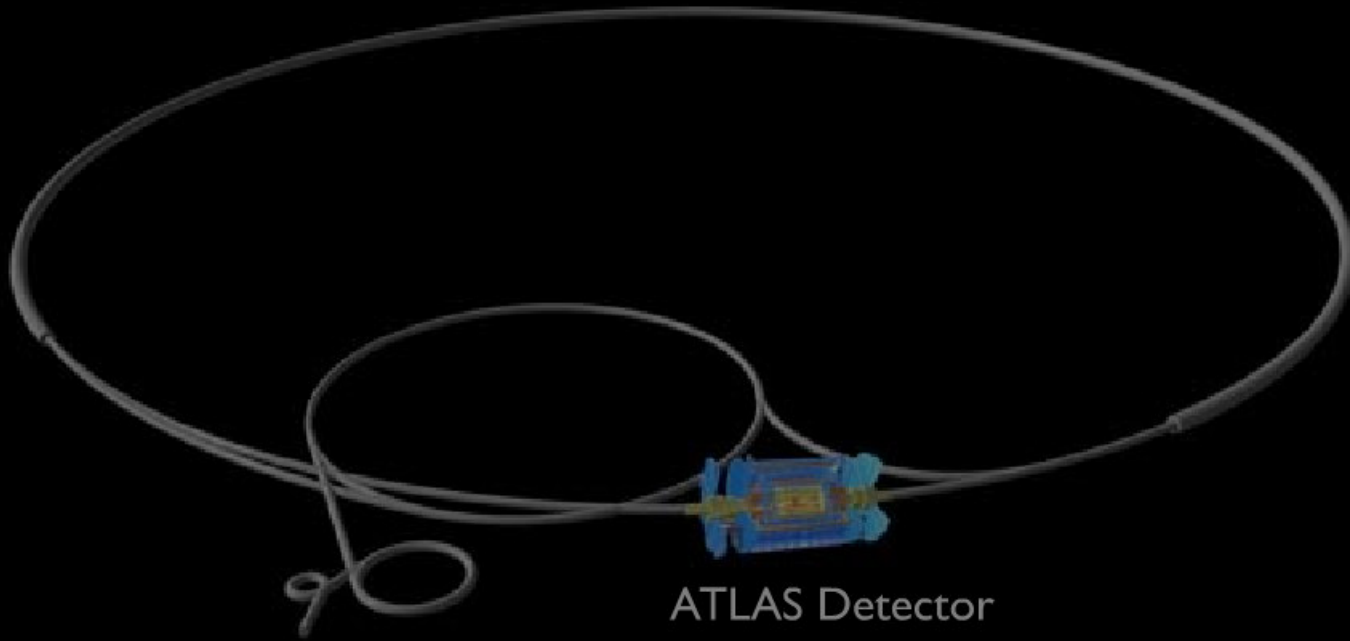


CMS networks, farms and data flows



PLAY ▶

Large Hadron Collider



ATLAS Detector



LHC: Контролна зала



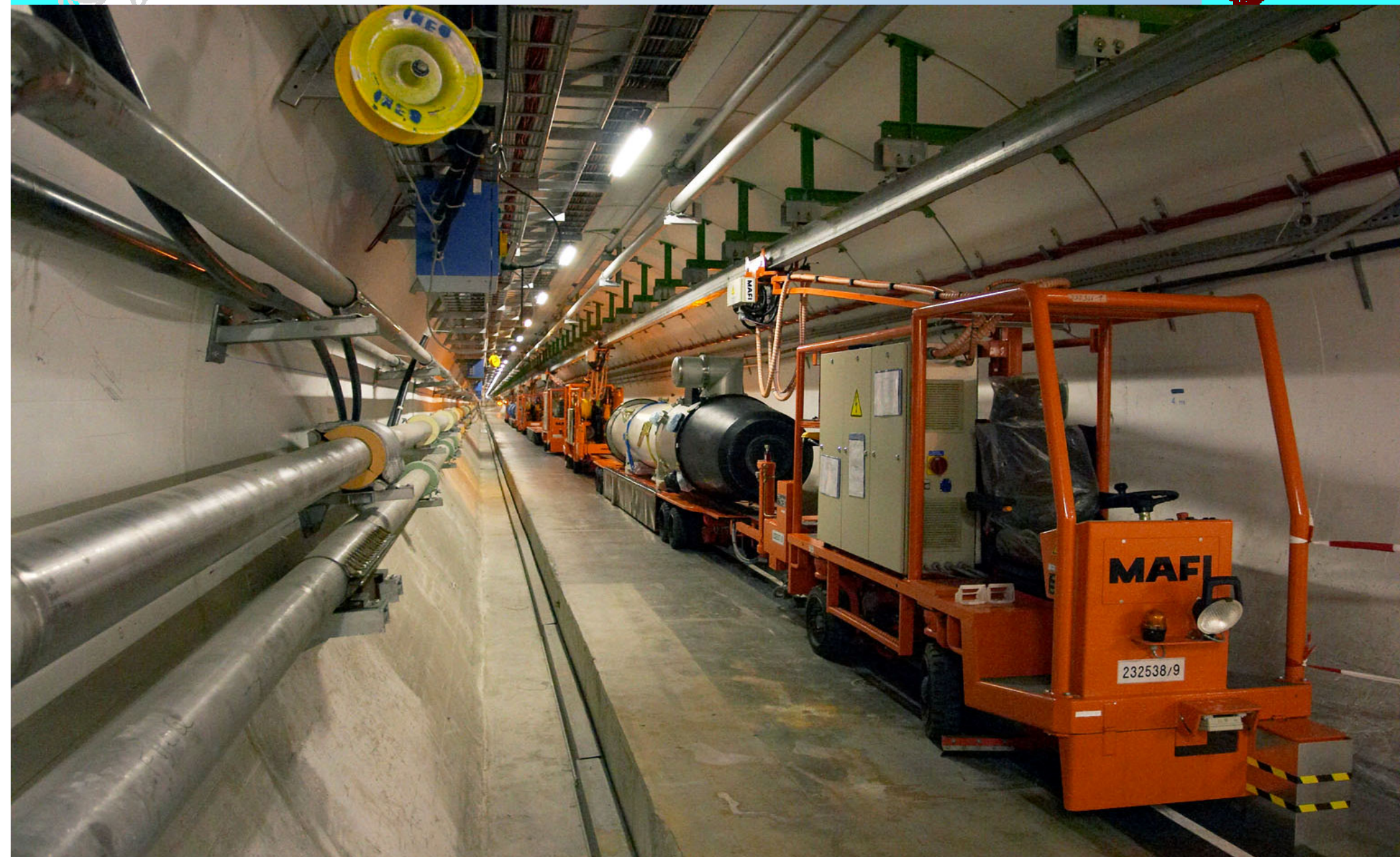
L. Litov

Particle Physics

Sofia, April 2006



LHC: в тунела

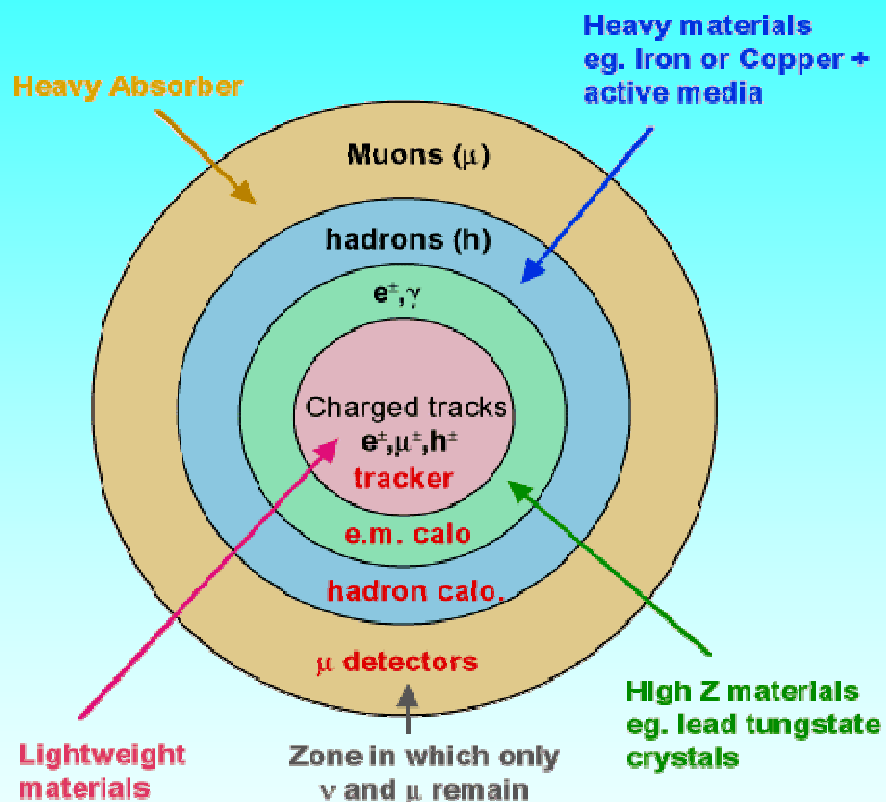




L. Litov

Particle Physics

Sofia, April 2006

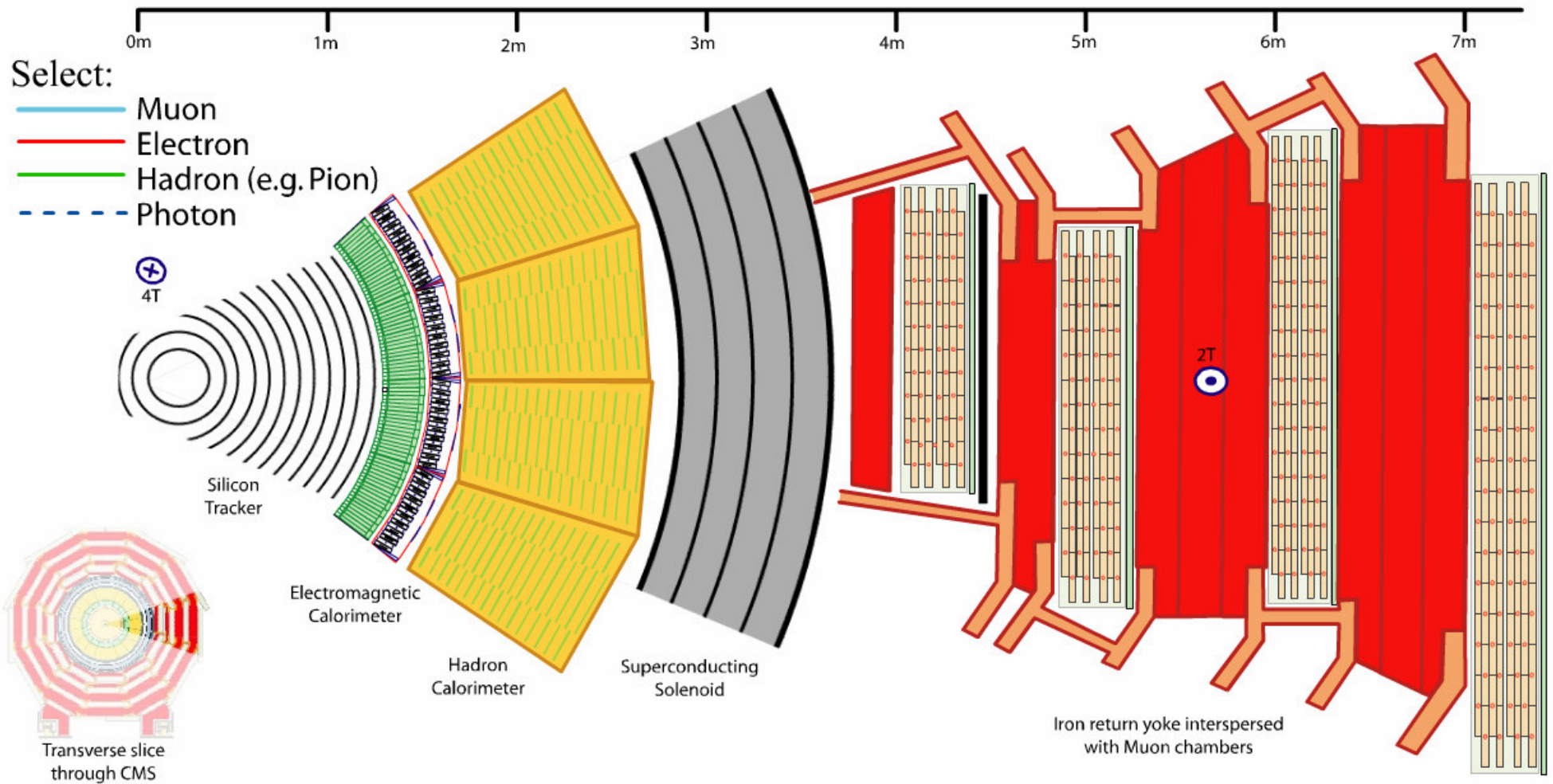


Each layer identifies and measures (or remeasures) the energy of particles unmeasured by the previous layer

No single detector can determine identity and measure energies/momenta of all particles



Как и какво измерваме



D. Barney, CERN, 2002



NA48 experiment





62 GeV Gold + Gold

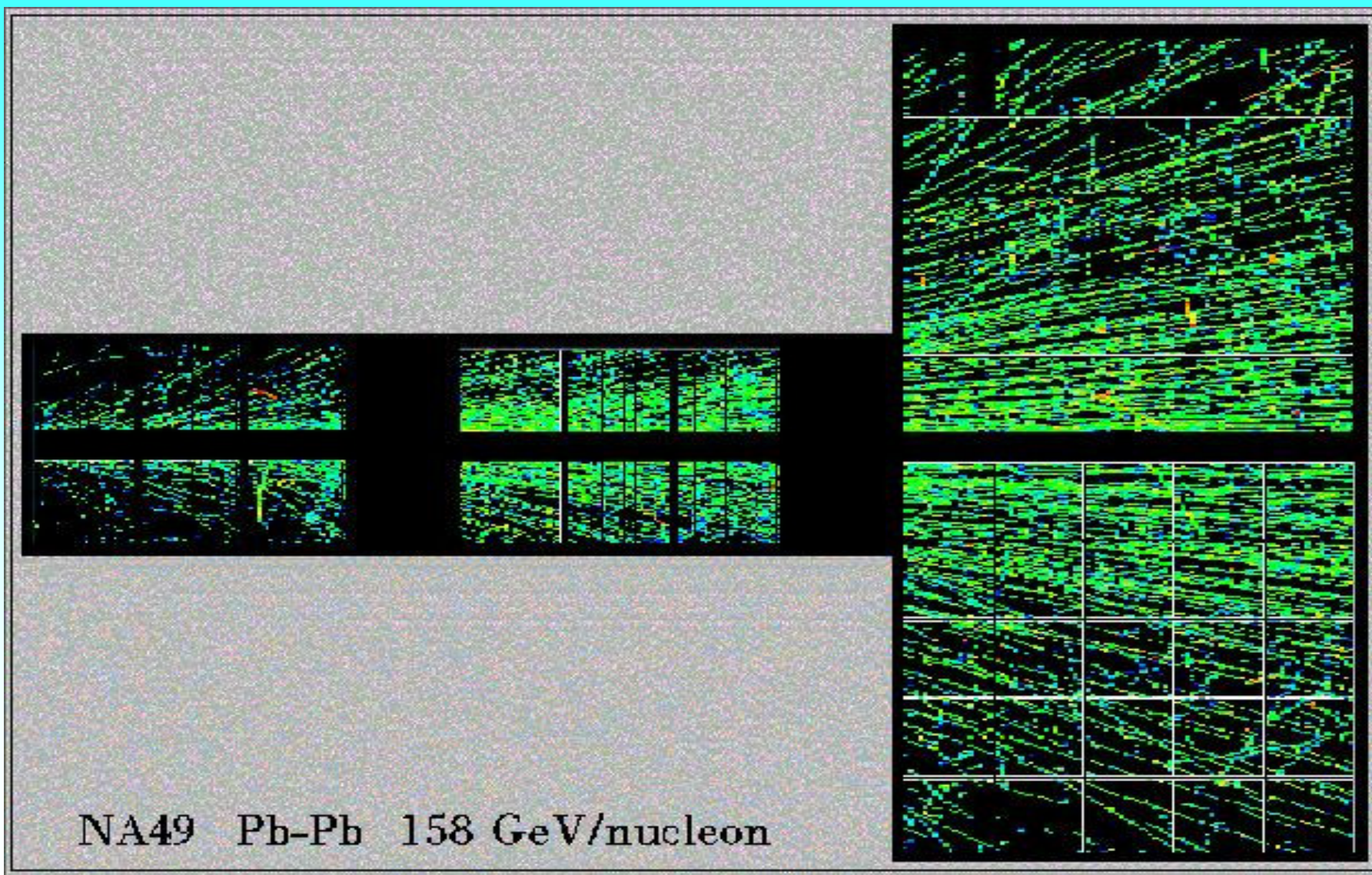
10/10/2000

10/10/2000

RHIC at BNL



NA49 PbPb event





CMS Detector



31 Nations, 150 Institutions, 1870 Scientists

TRIGGER & DATA ACQUISITION

Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER

Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Switzerland, UK, USA

CRYSTAL ECAL

Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Switzerland, UK, USA

PRESHOWER

Armenia, Belarus, CERN, Greece, India, Russia, Taiwan (PC), Uzbekistan

RETURN YOKE

Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET

All countries in CMS contribute to Magnet financing in particular:
Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan
China

FORWARD CALORIMETER

Hungary, Iran, Russia, Turkey, USA

HCAL

Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HC: India

MUON CHAMBERS

Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Korea, Pakistan, Russia, USA

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

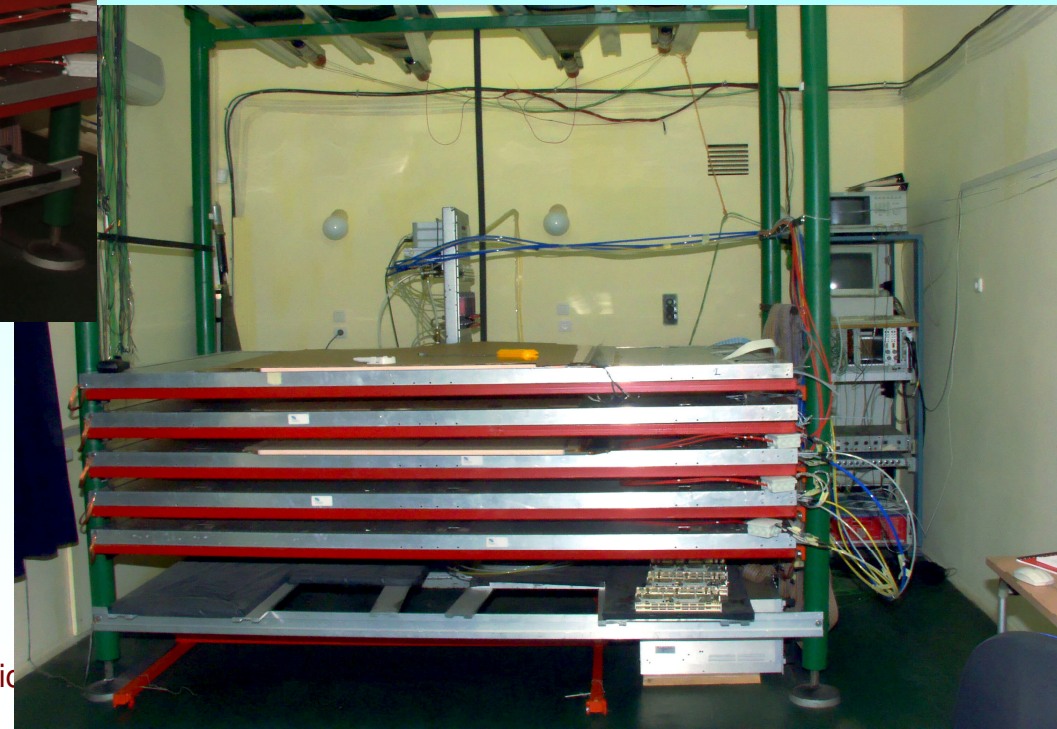
L. Litov

Particle Physics

* Only through industrial contracts
Sofia, April 2006



София: мюонен телескоп



L. Litov

Particle Physics



Реконструиране на мюонни следи



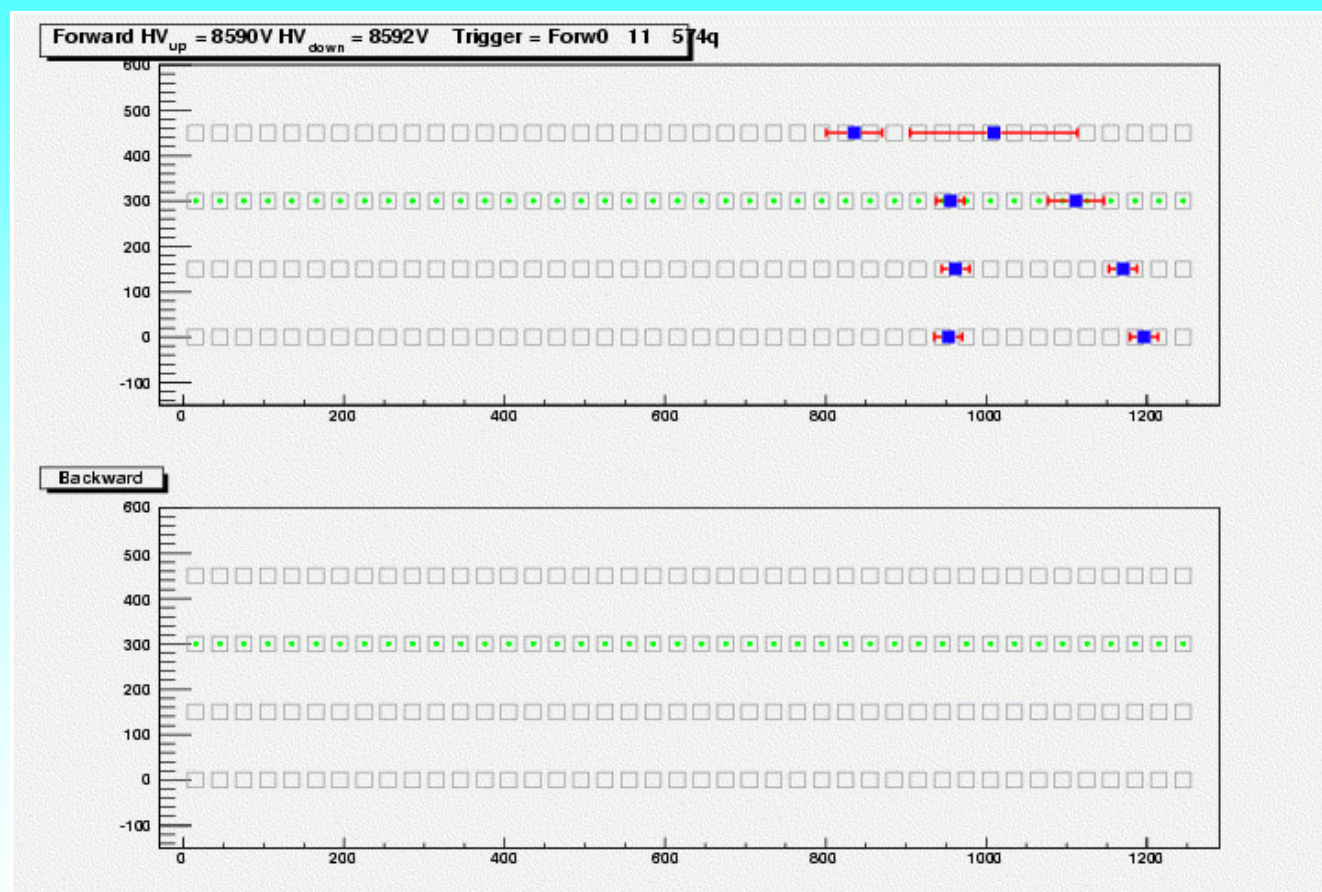
Брой камери = 4

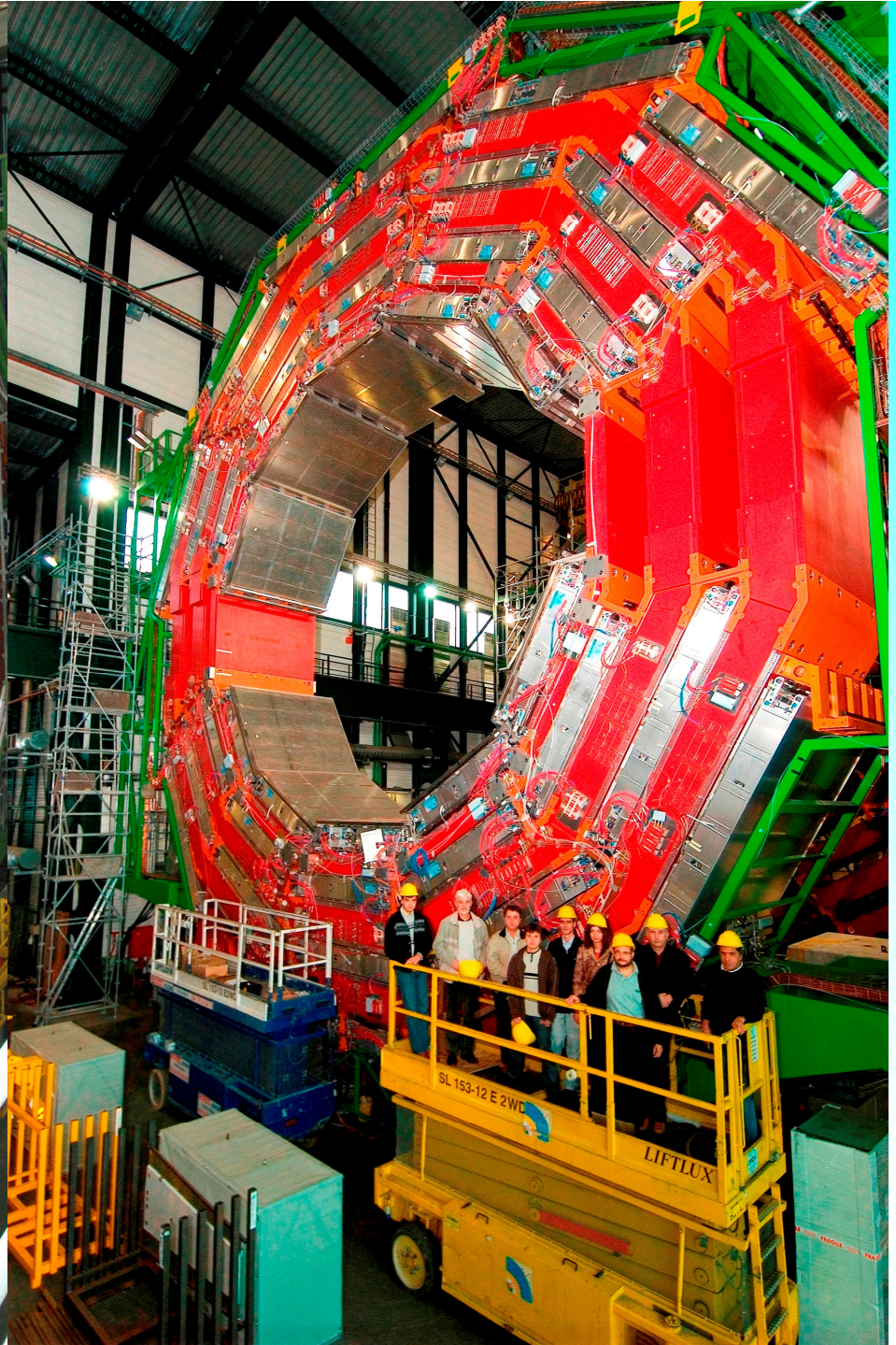
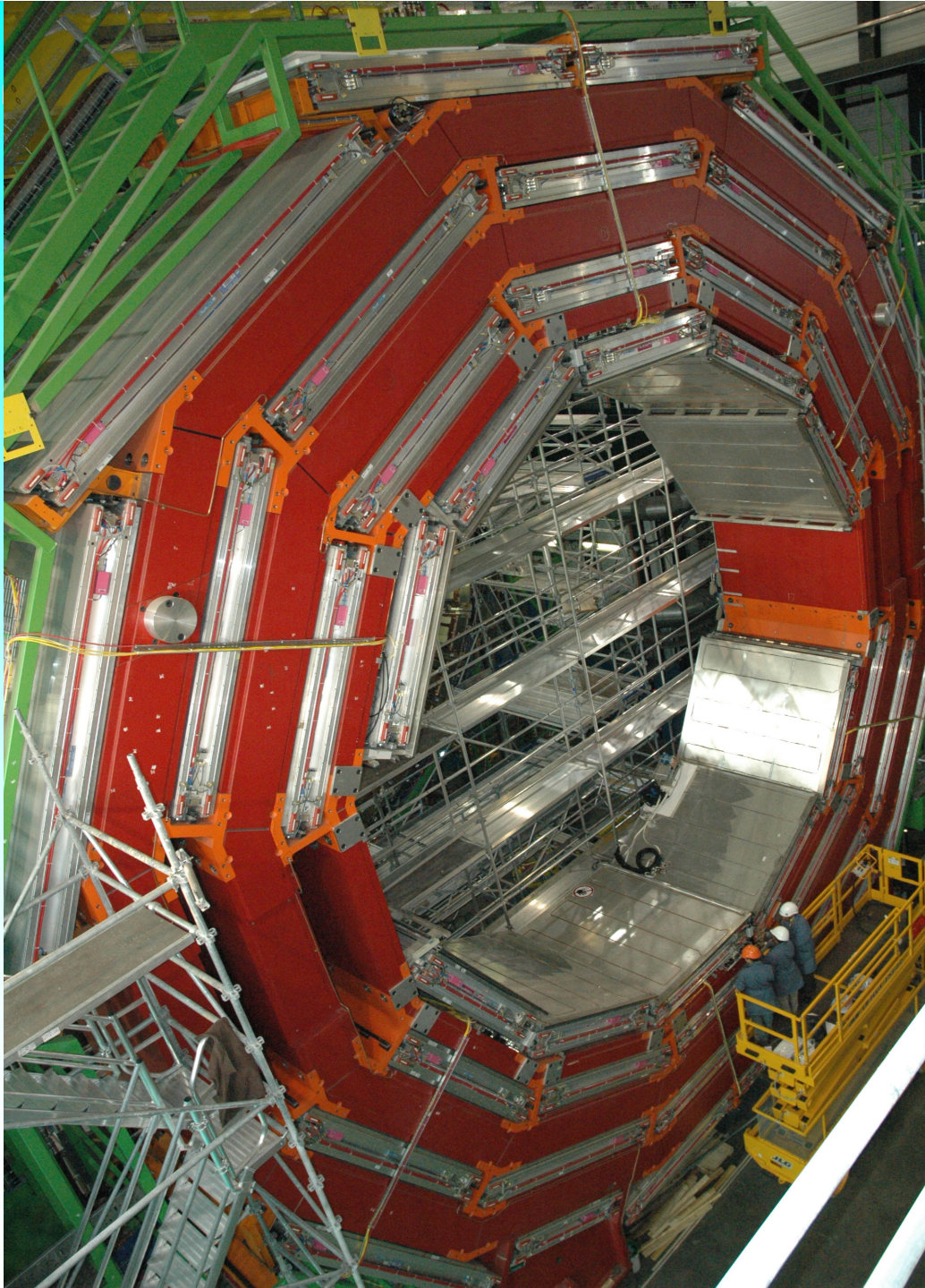
Избор на тестова станция

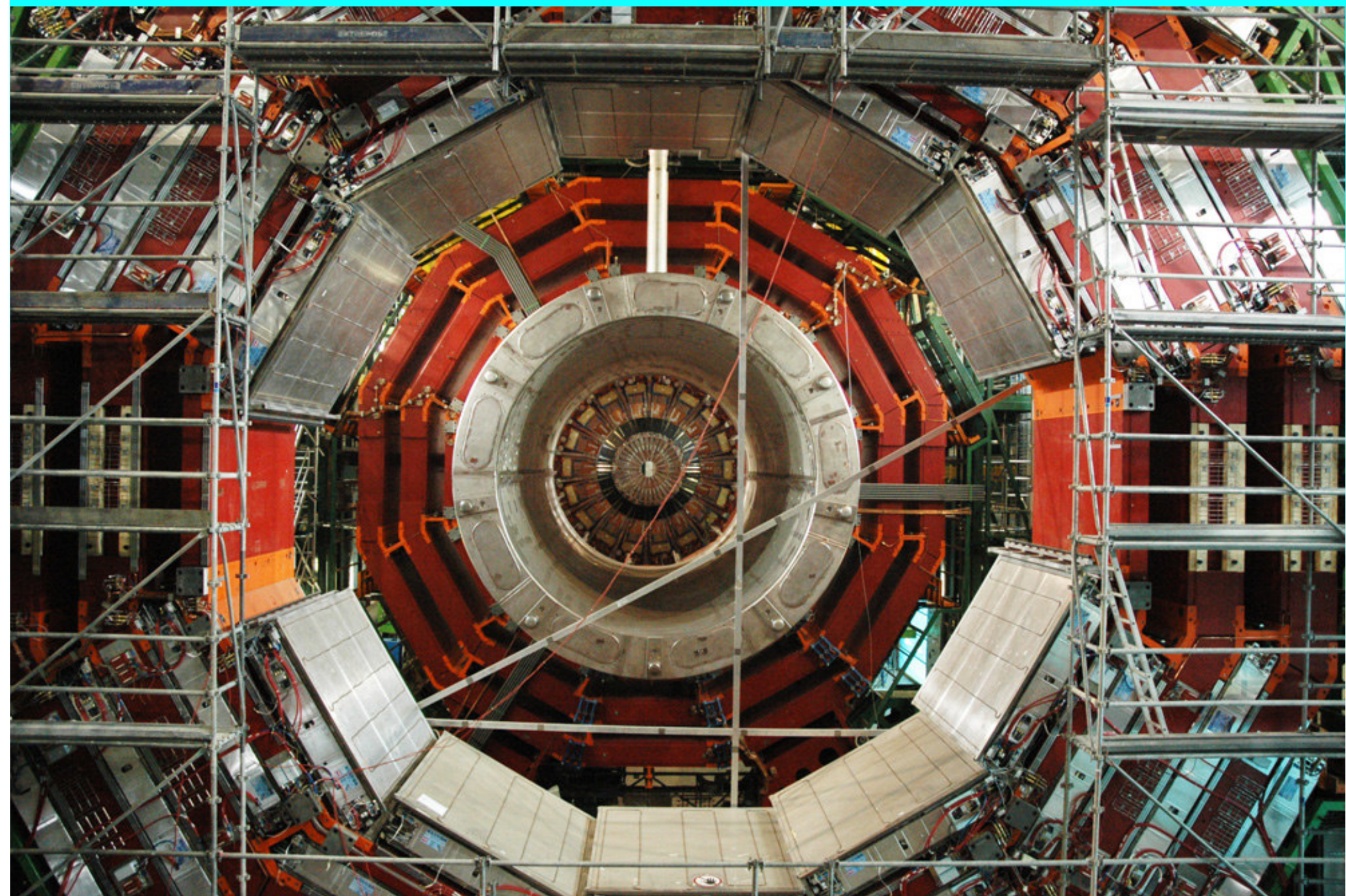
3 съвместими клъстера в рефените станции, точно по един във всяка, с големина ≤ 7

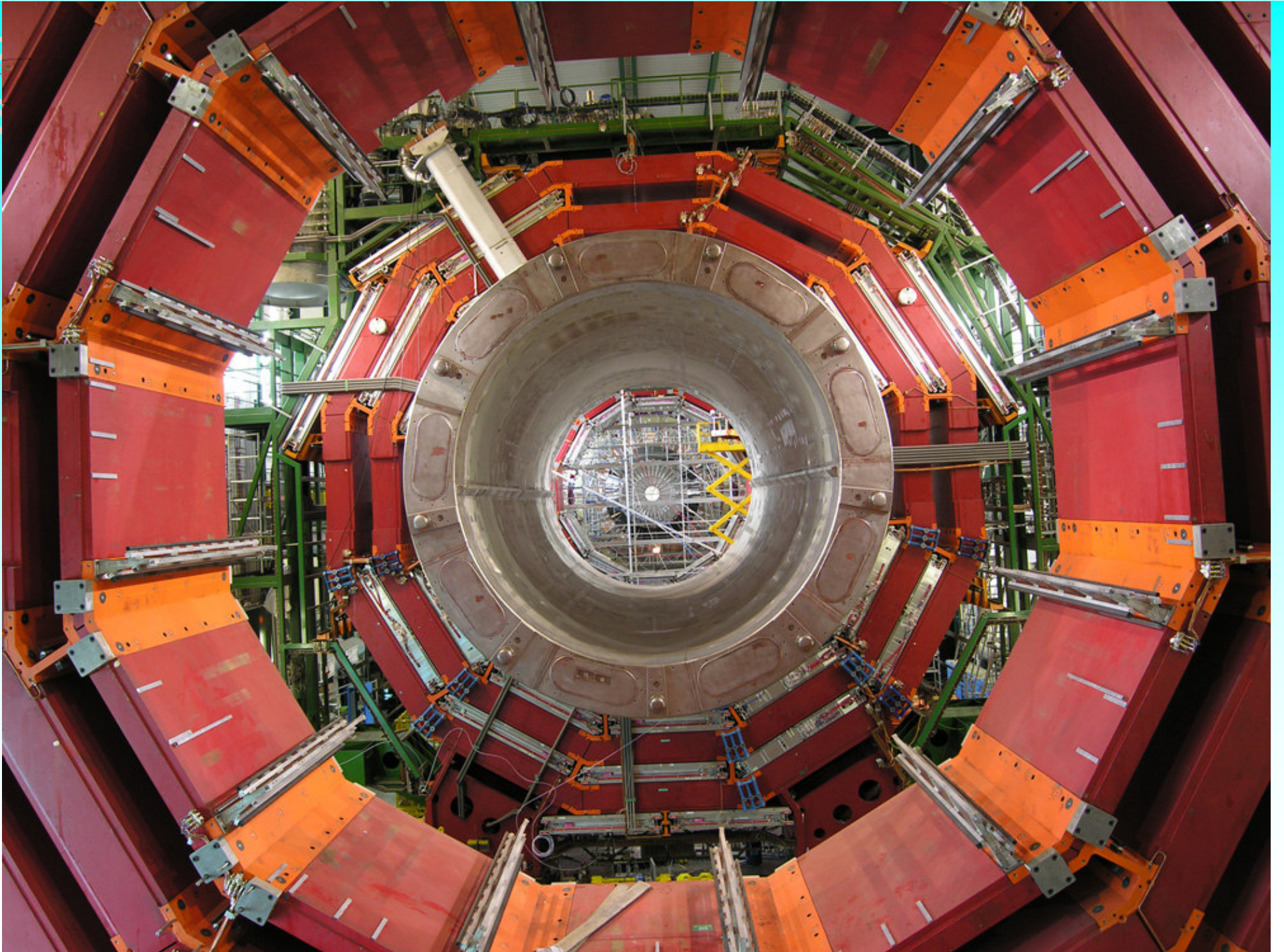
Реконструиране на мюонната следа

Камерата се счита за ефективна, ако в нея има клъстер съвместим със следата



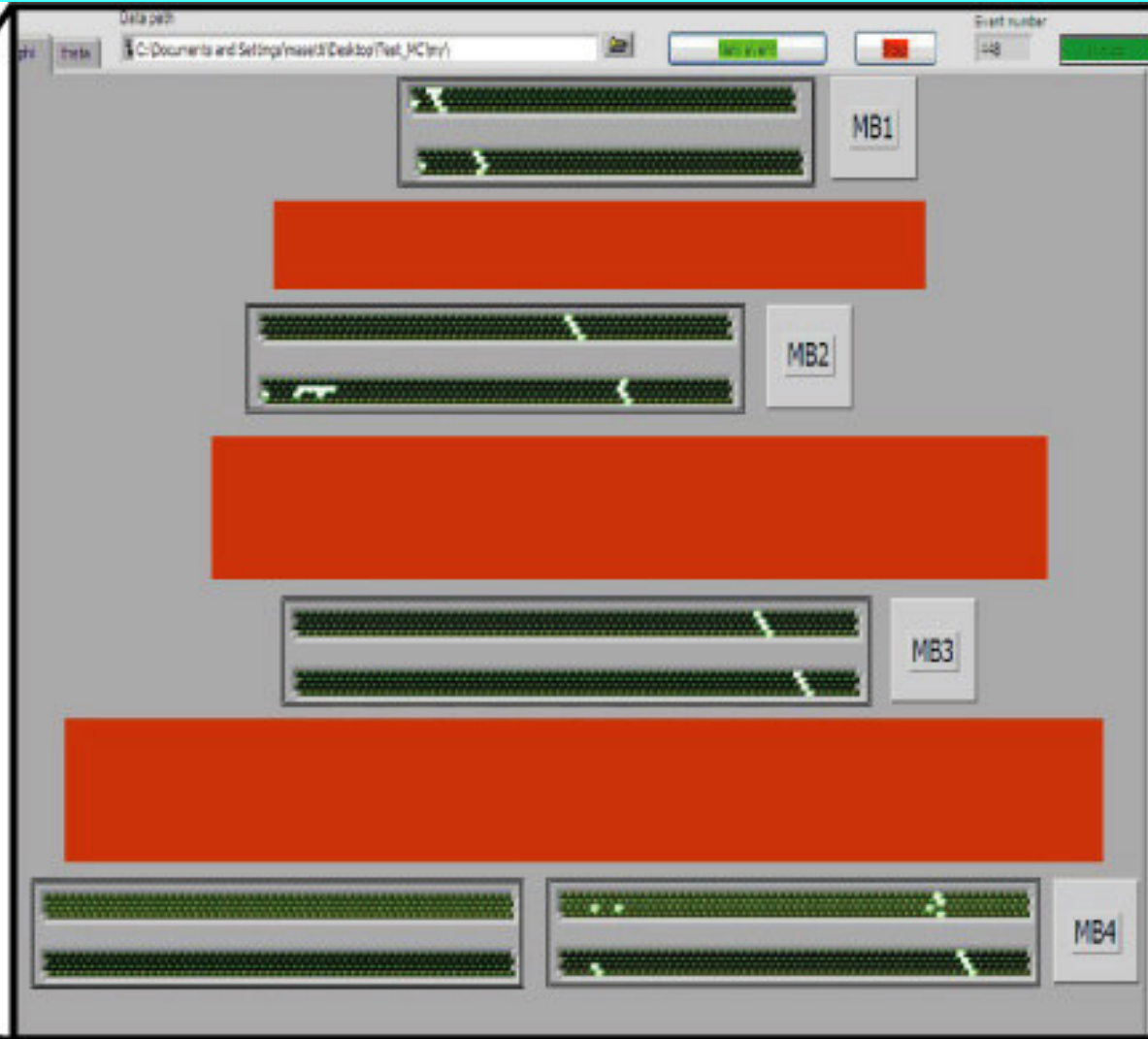
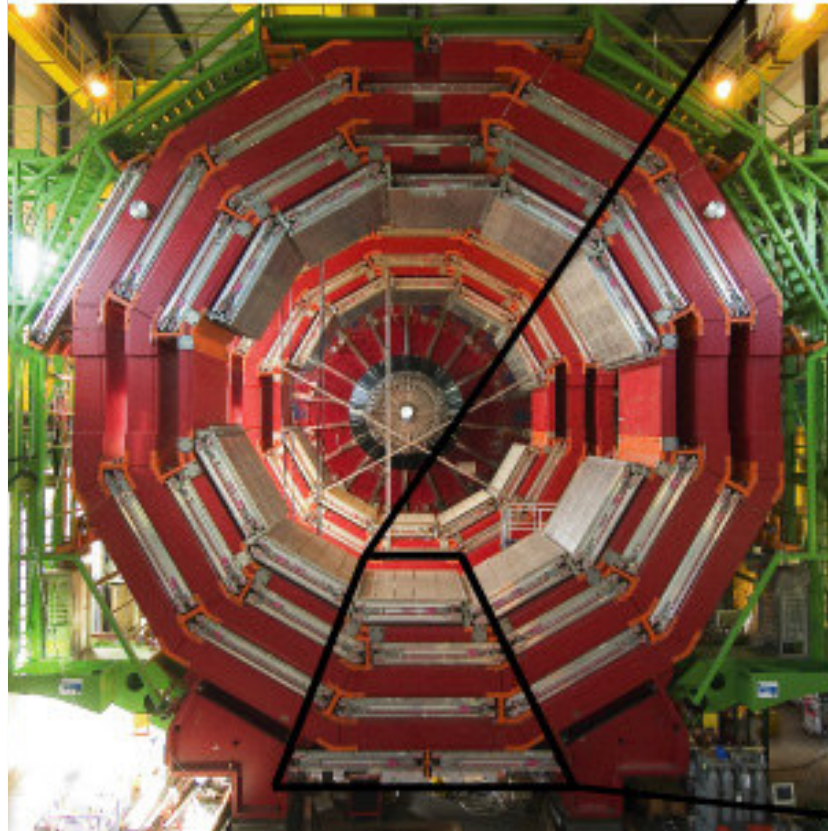








CMS Muon system





DAQ



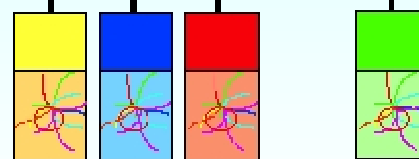
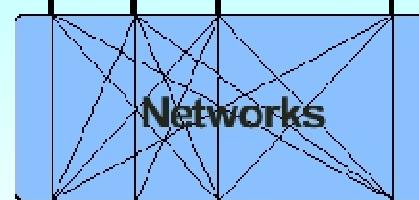
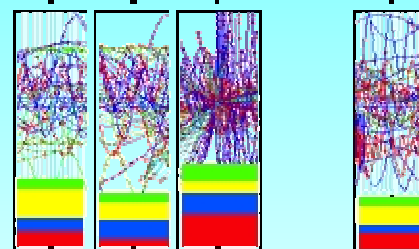
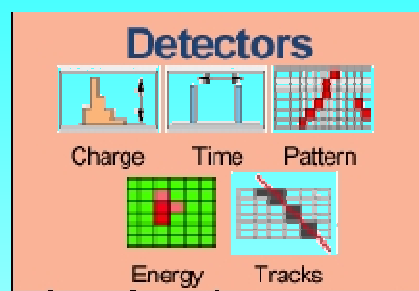
40 MHz
COLLISION RATE

100 kHz
LEVEL-1 TRIGGER

1 Terabit/s
(50000 DATA CHANNELS)

500 Gigabit/s

Gigabit/s SERVICE LAN



16 Million channels
3 Gigacell buffers

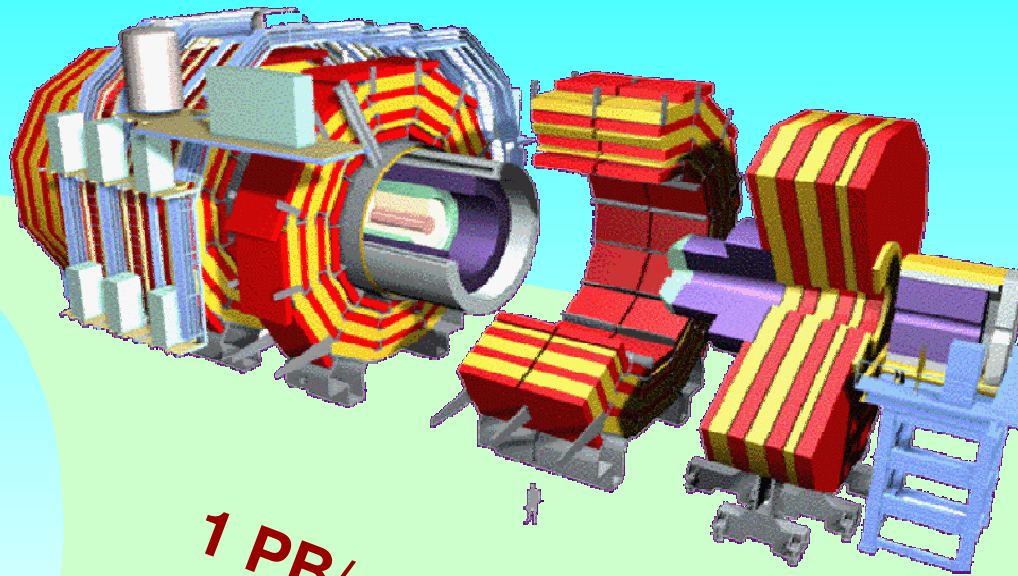
1 Megabyte EVENT DATA

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 RUPMs

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



1 PB/sec

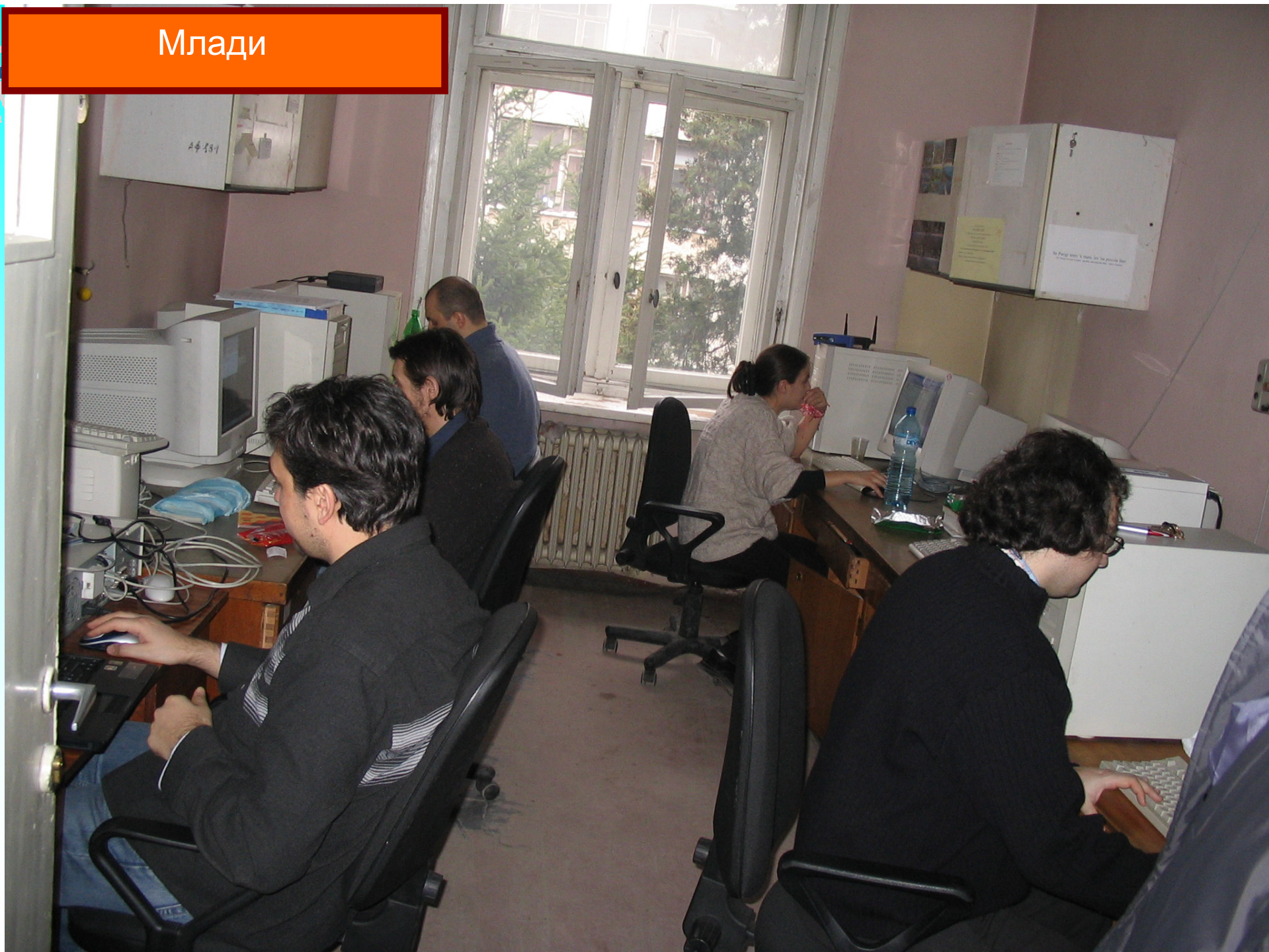
Филтриране в реално време:
Подбор на интересните събития
и компресия на данните

1 PB за година

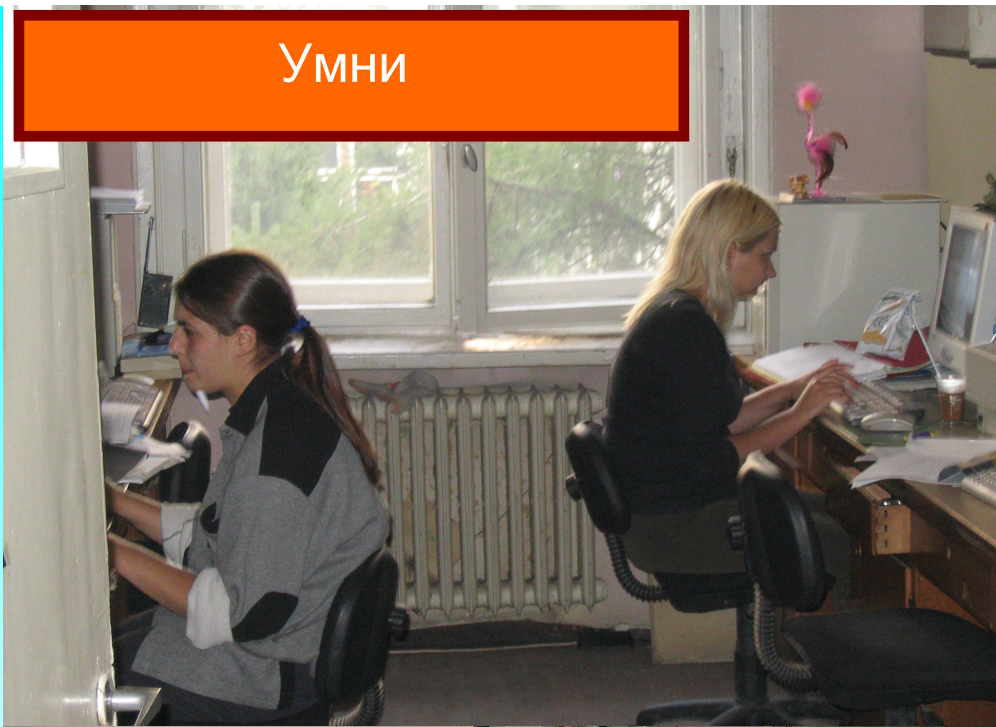


Кой го прави?

Млади



УМНИ



Красиви





Понякога е трудно



L. Litov

Particle Physics



Може и така



L. Litov

Particle Physics



Физиката на ел. Частици е най-:

- Фундаменталния раздел на физиката
- Сложна от теоретична гл. точка
- Развита експериментално
- скъпа
- възбуждаща

Тя дава:

- Ново знание и разбиране на света
- Нови технологии
- Голямо удоволствие

Изисква



