The Elementary Particles in our Universe

Augusto Ceccucci / CERN

Contents

- The beginning of Particle Physics
- The three frontiers
- Standard Theory
- CERN: Accelerators & Experiments
- The Higgs Boson
- Neutrinos….

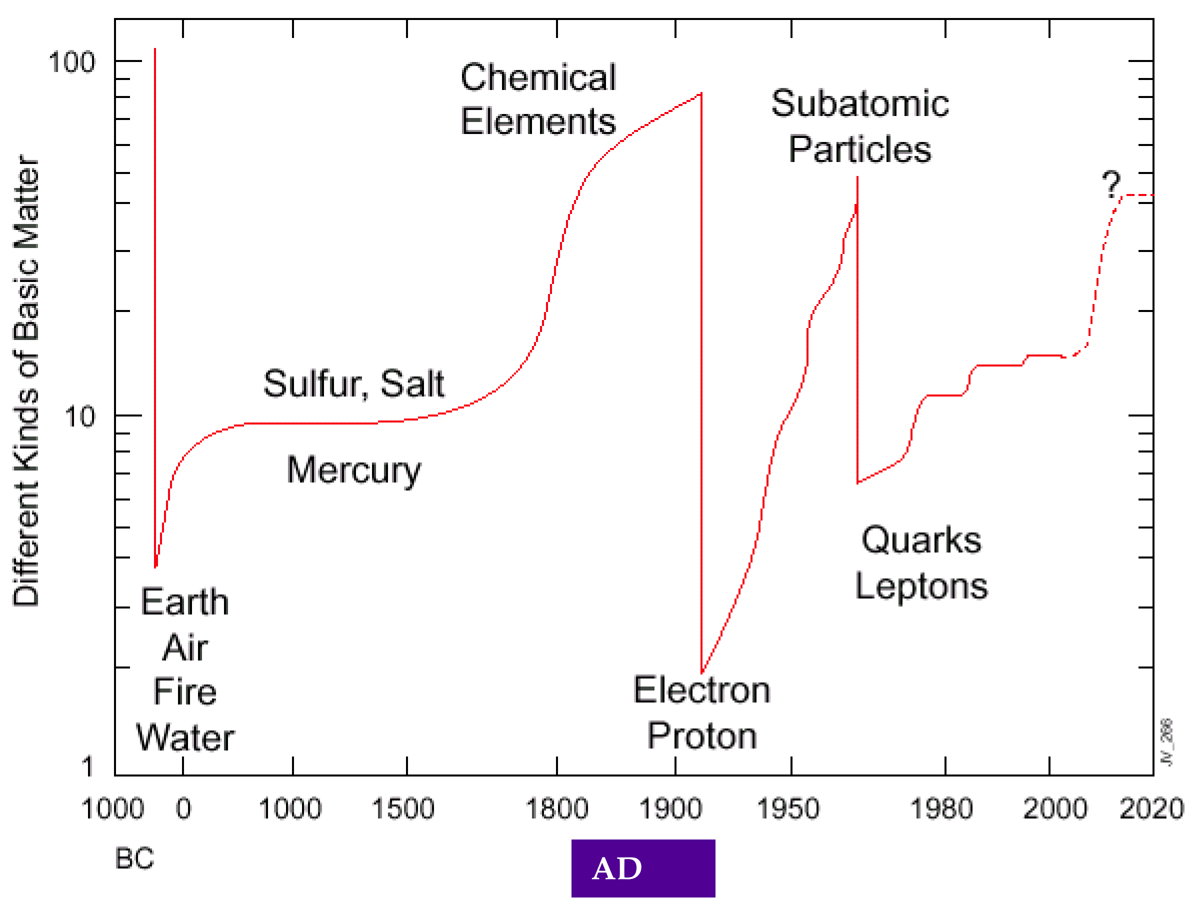
Particle Physicists

Wish to understand::

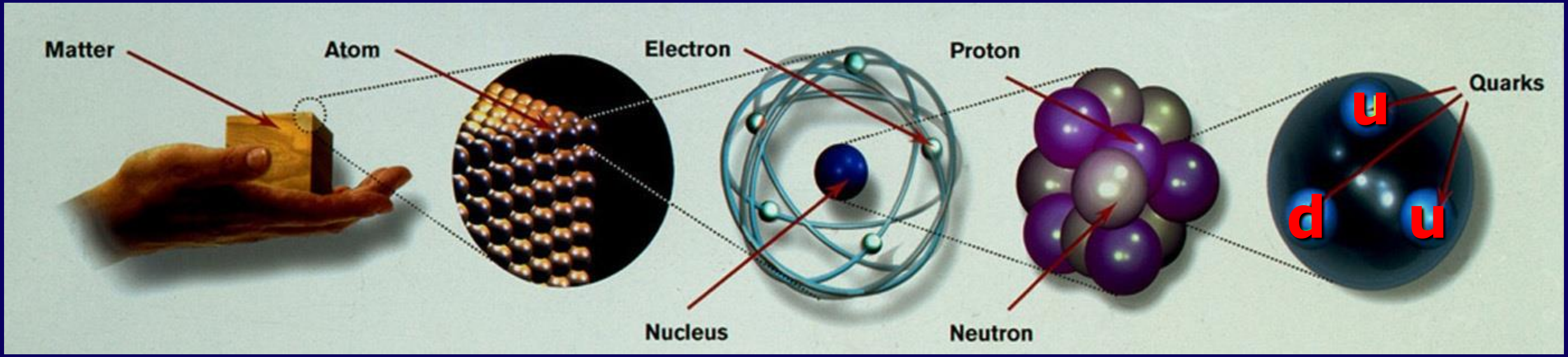
What are the fundamental constituents of matter?

What are the forces mediating the interactions between elementary particles??

The number of particles considered fundamental has evolved with time...



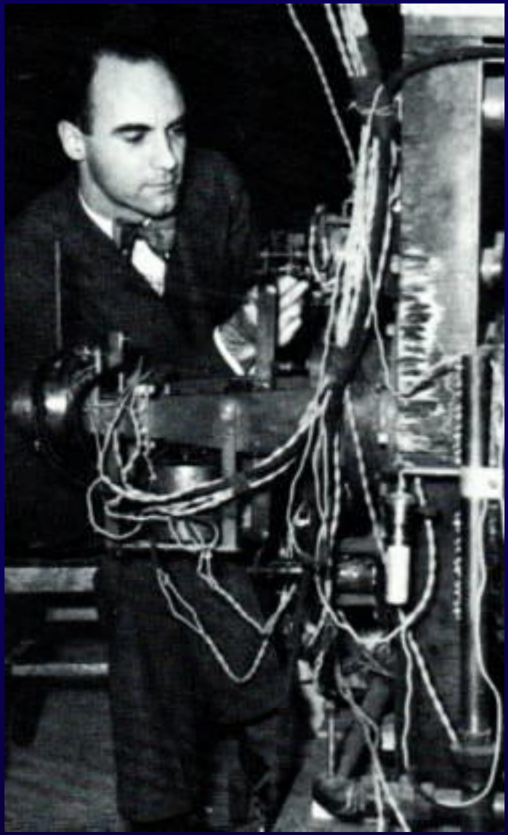
Matter Constituents



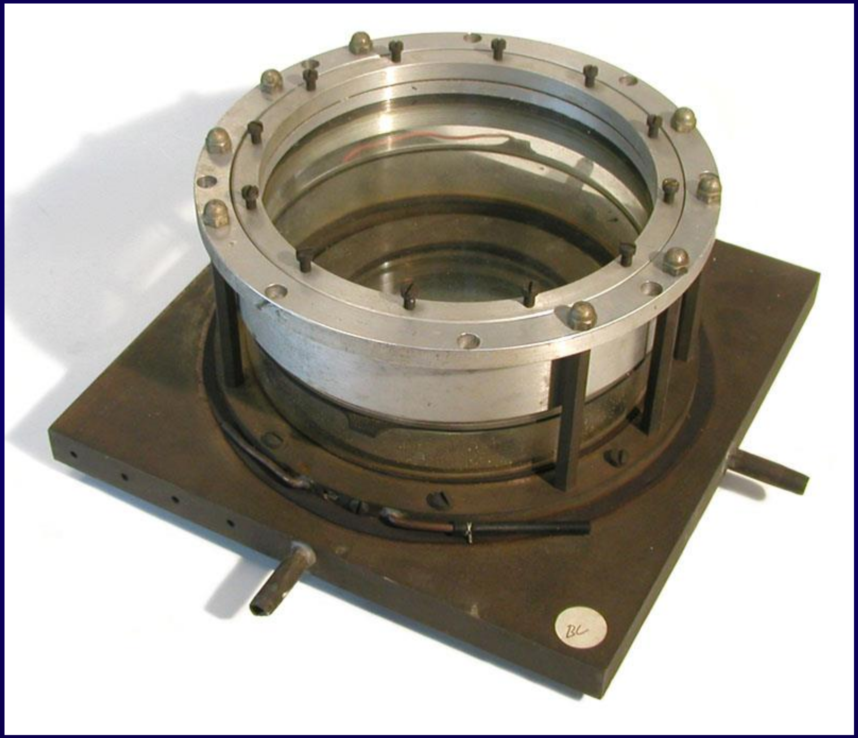
Bound state of 3 quarks = Baryon
Bond state of quark anti-quark = Meson

The Beginnings

Carl Anderson

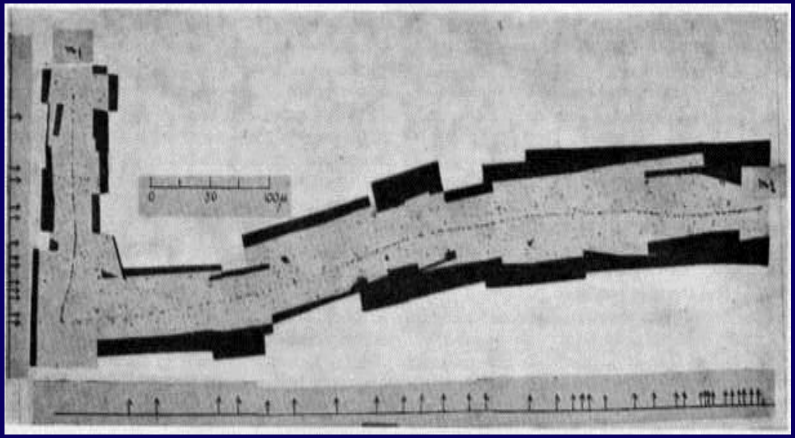


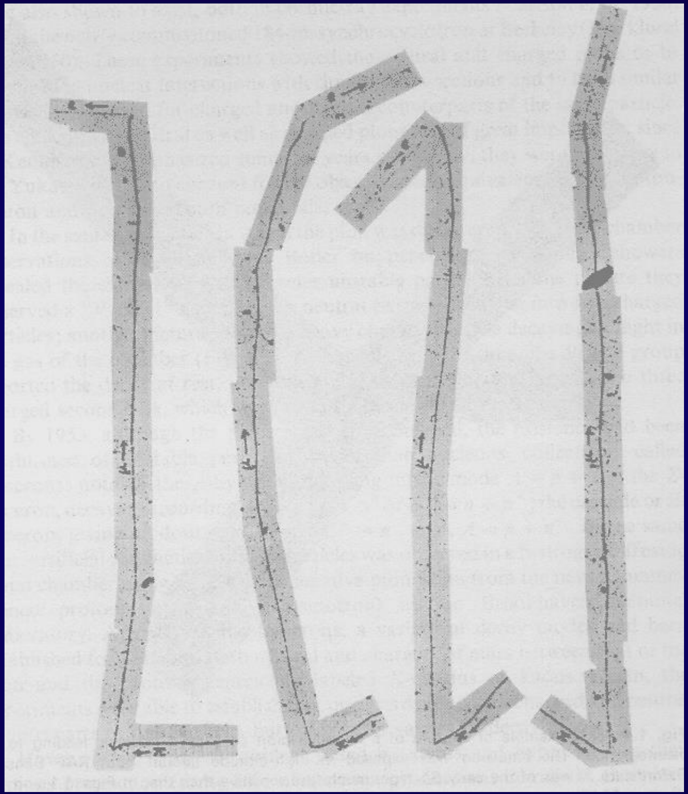
Cloud Chamber for the study of cosmic rays



Positron (1932)
Mesotrone (now Muon) 1936

Discovery of the pion





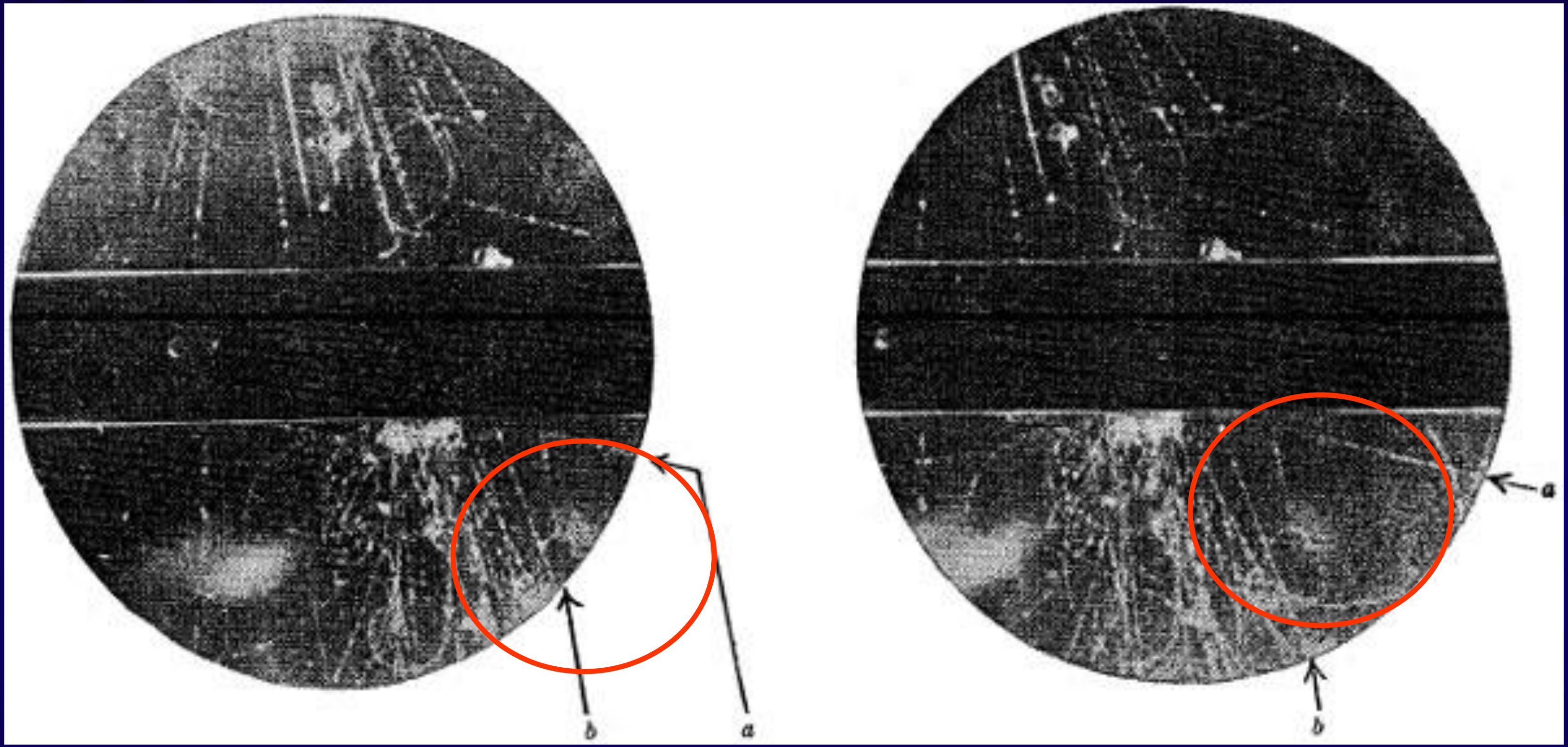
Pion decay in a nuclear emulsion

Lattes, Occhialini, Powell, 1947

1947: Discovery of the *K* mesons

Pb

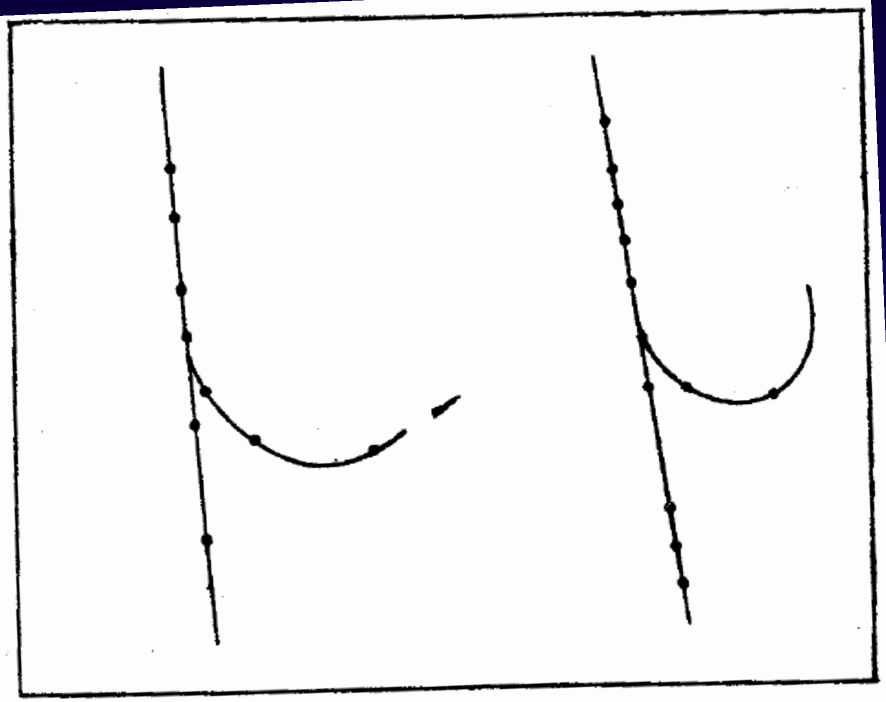
Gas



Rochester & Butler:

Cloud chamber exposed to **cosmic rays**

With Hindsight…



Dessin stéréoscopique de la collision.

Leprince-Ringuet e L'Héritiere, Camera di Wilson, 1943

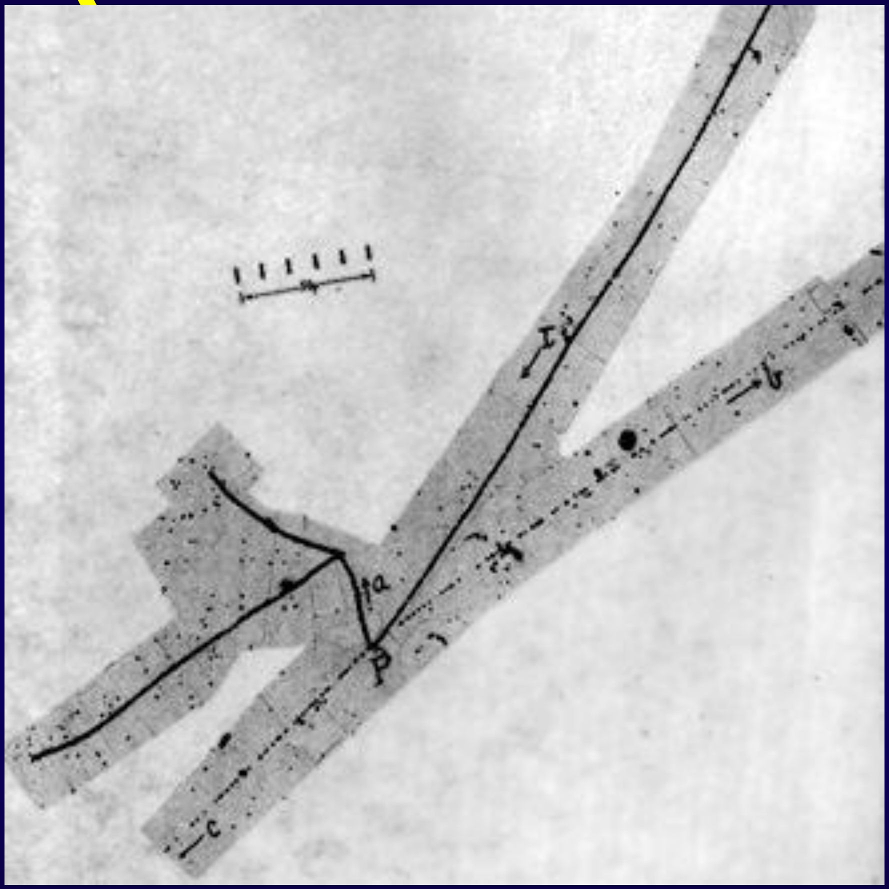
Diffusion of positively charged particles on atomic electrons.

Assuming elastic diffusion:

990 m_e ~ 500 MeV …with hindsight …

Perhaps Kaons were discovered even before pions!

Discovery of τ^+ (now $K^+ \rightarrow \pi^+\pi^+\pi^-$)

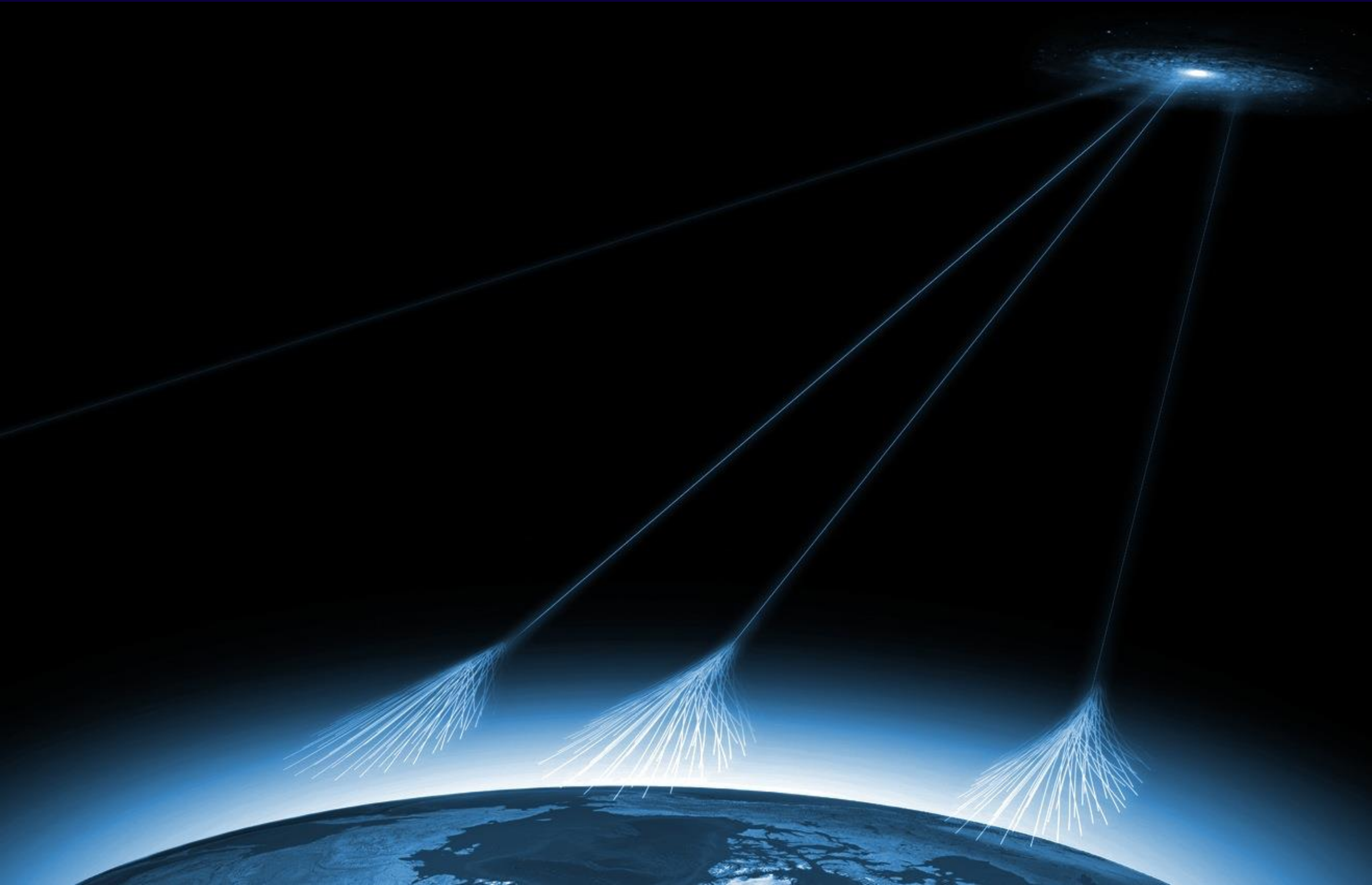


Old Name	New Name
τ	$K_{\pi 3}$: $K^+ \rightarrow \pi^+\pi^+\pi^-$
V_1^0	$\Lambda^0 \rightarrow p\pi^-$
V_2^0 (θ^0)	$K^0_S \rightarrow \pi^+\pi^-$
κ	$K_{\mu 2}$: $K^+ \rightarrow \mu^+\nu$
	$K_{\mu 3}$: $K^+ \rightarrow \mu^+\pi^0\nu$
χ (θ^+)	$K_{\pi 2}$: $K^+ \rightarrow \pi^+\pi^0$
V^+, Λ^+	$\Sigma^+ \rightarrow p\pi^0$, $n\pi^+$

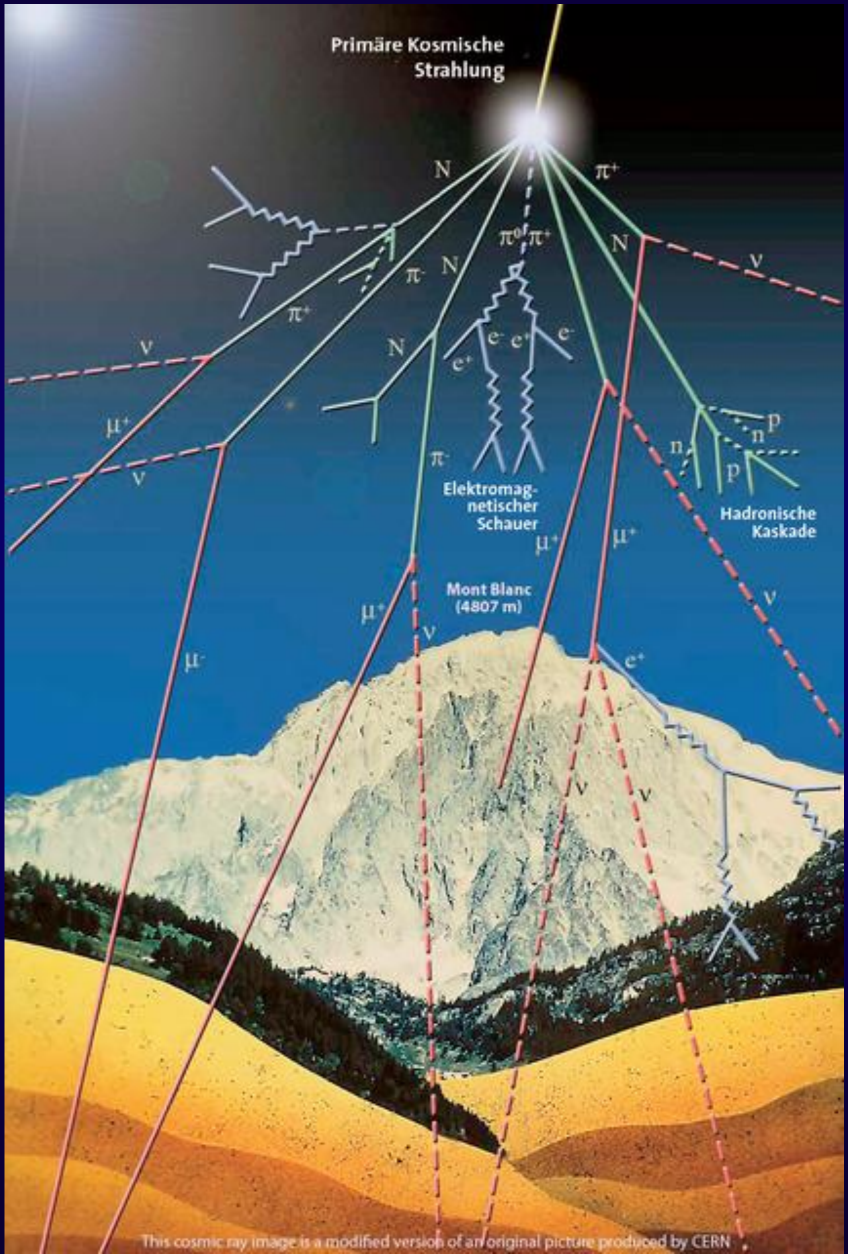
"Stripped" emulsion technique, Bristol group, 1949

…and then things moved fast thanks to accelerators…

Cosmic Rays



How can we measure cosmic rays?



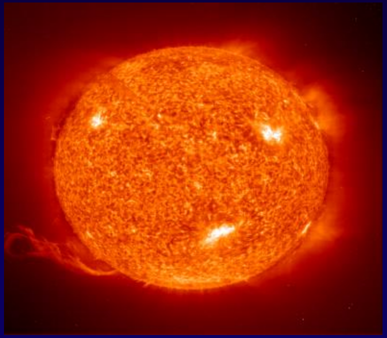
Each second....

- ....for each square meter
- ~200 Particles

- Where are they coming from ?
- What are they?
- Which information are they carrying?

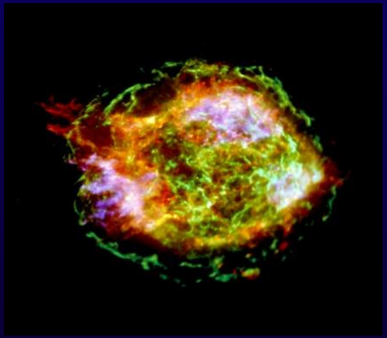
Where are they from?

- From the Sun



- From Galaxies

- From Supernovae



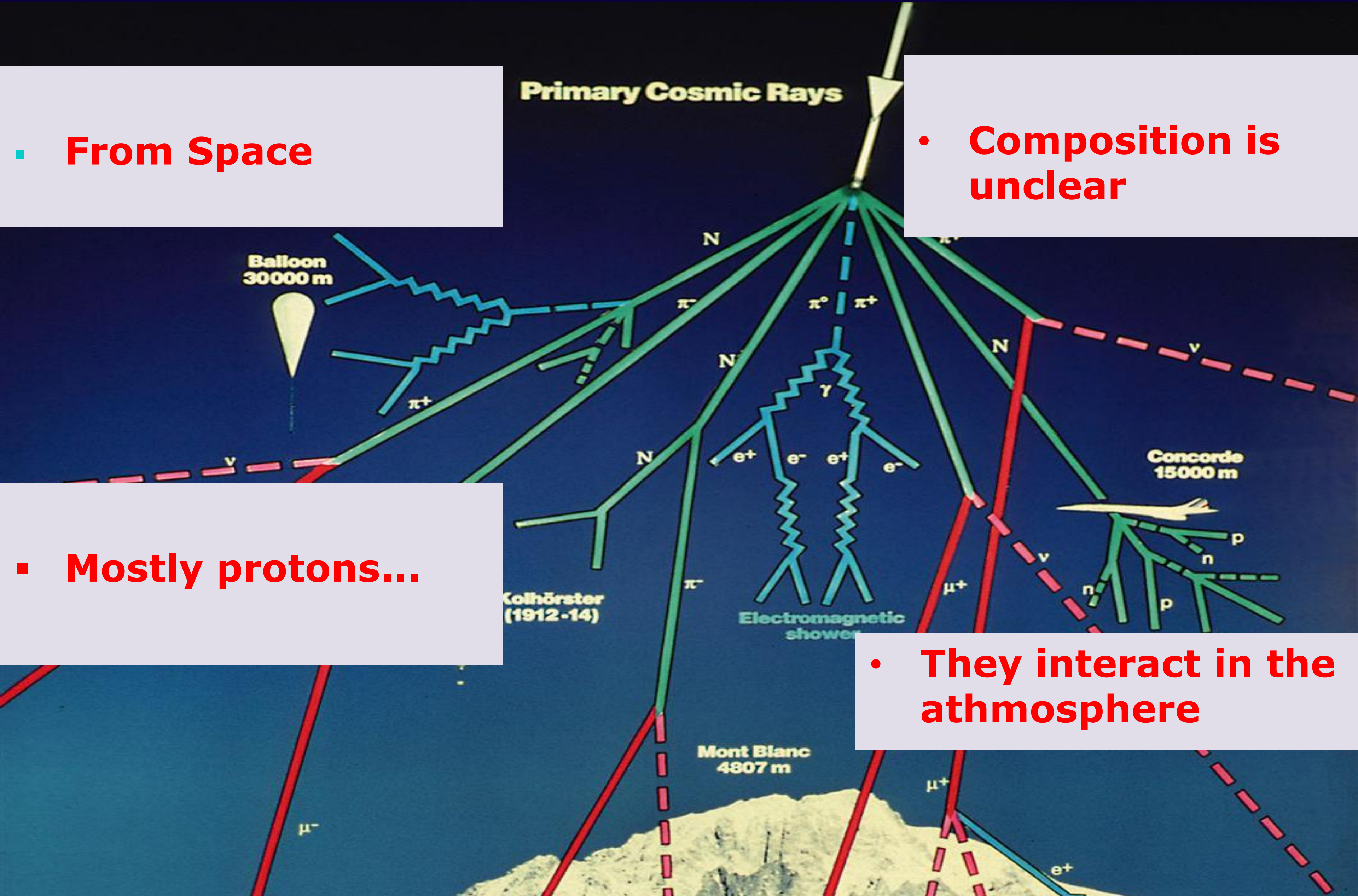
Primary Cosmic Rays...

- From Space

- Composition is unclear

- Mostly protons...

- They interact in the athmosphere

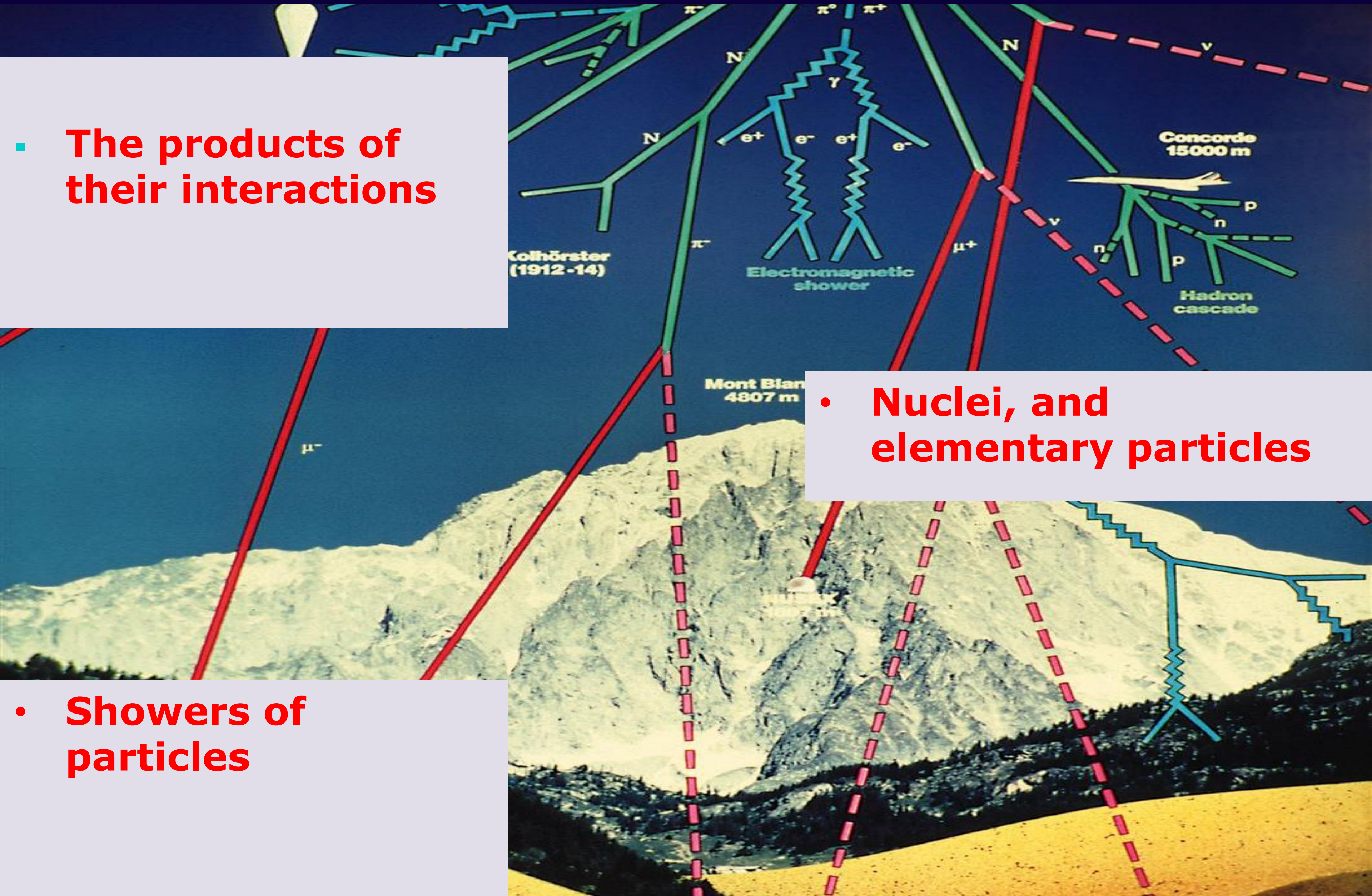


What do we observe?

- The products of their interactions

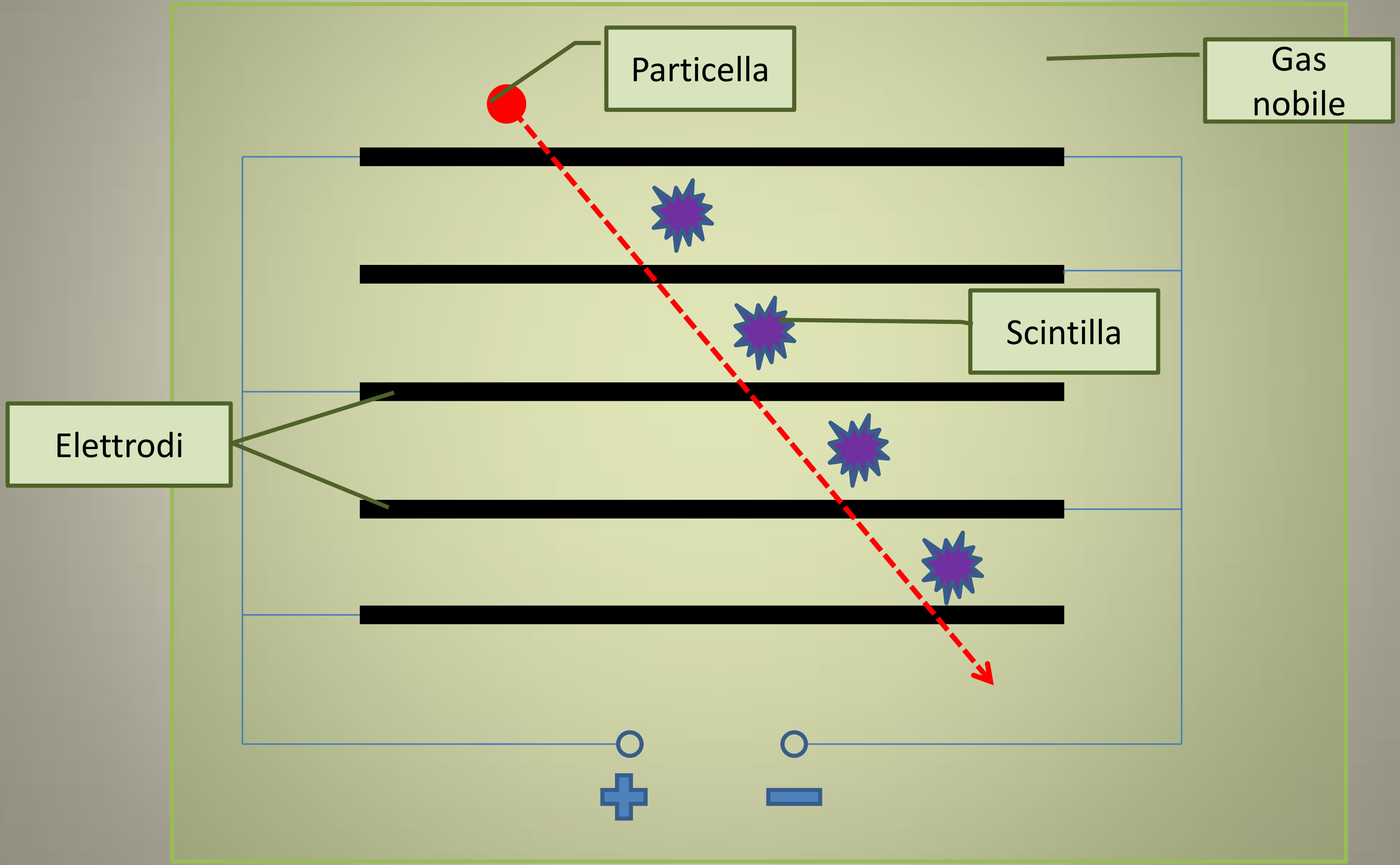
- Nuclei, and elementary particles

- Showers of particles



Spark Chamber in action

Principle of a Spark Chamber

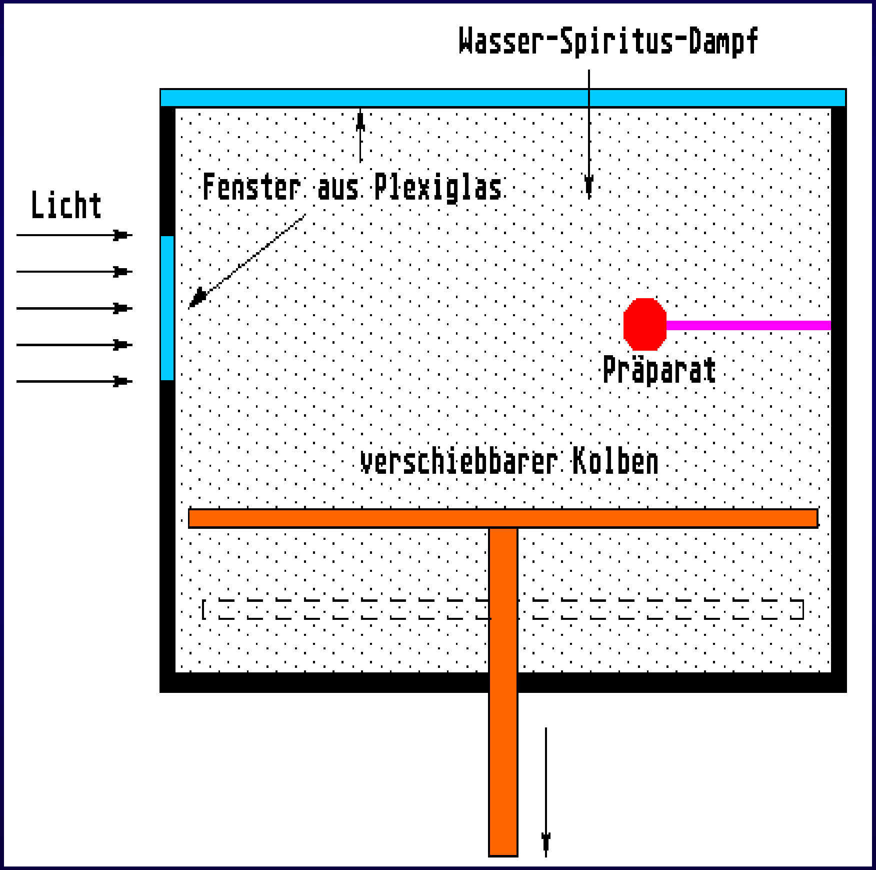


Other detectors….

-
- Cloud Chamber Geiger-Müller Elettrometer

Cloud Chamber in action

How does a cloud chamber work?



Auger Observatory (Mendoza)

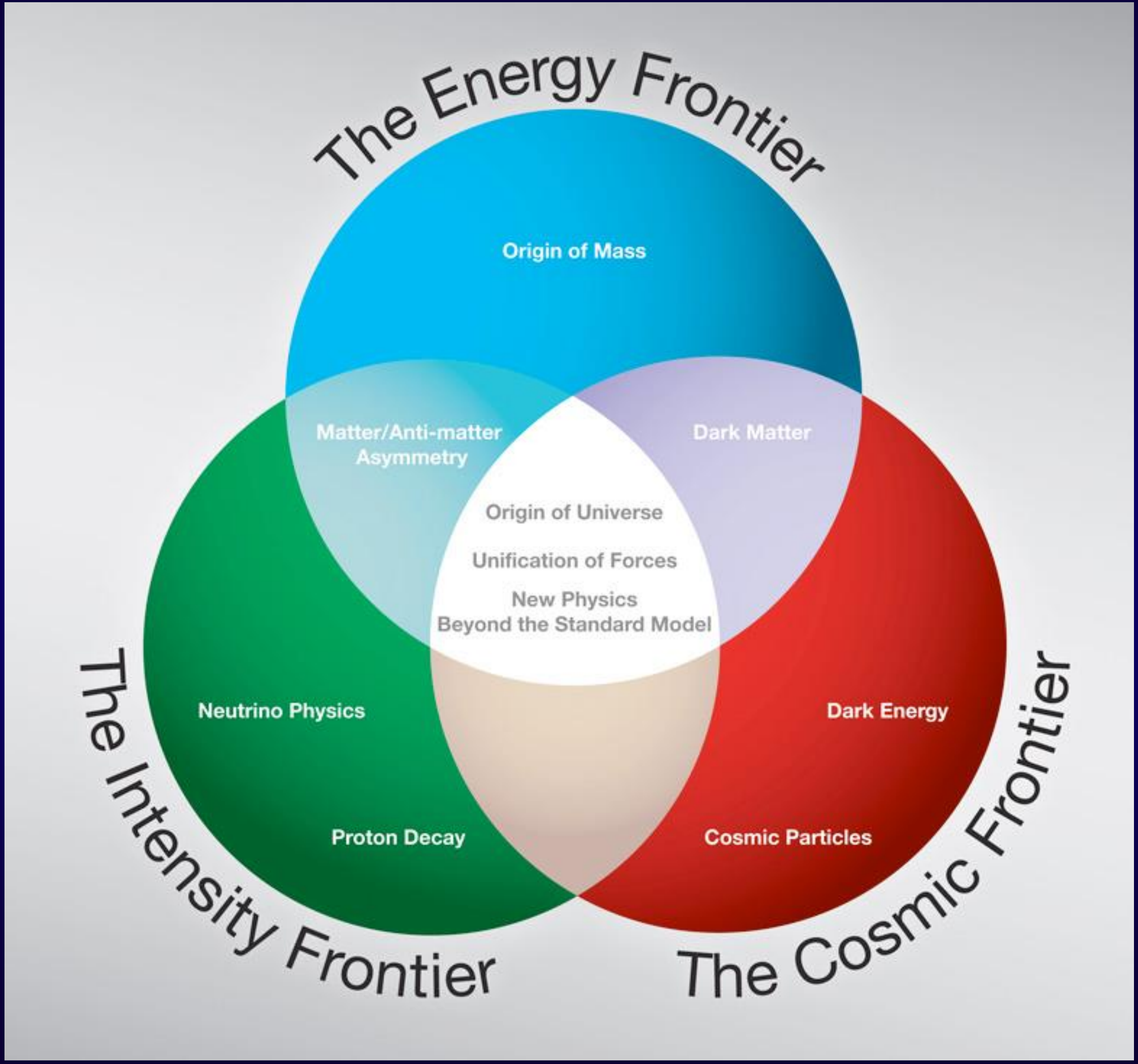
- Over hundreds of square Km
- Measuring energies up to 10^{20} eV

Detectors of the Auger Observatory

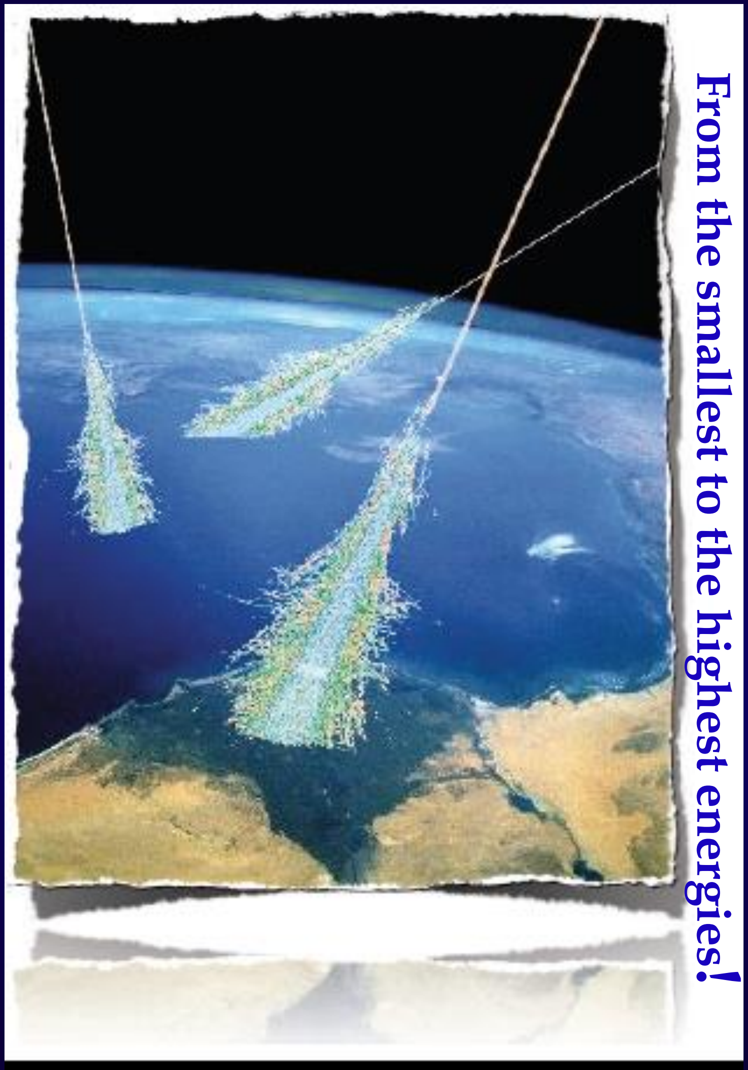
Surface: 3000 km²

- 1600 Detectors

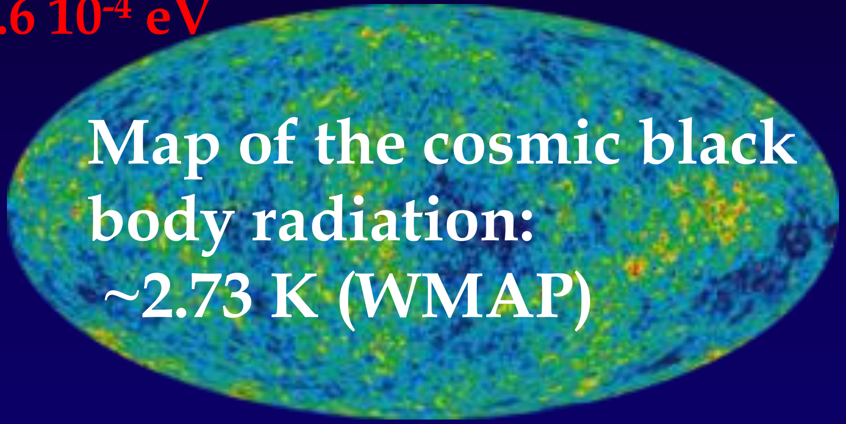
The Three Frontiers

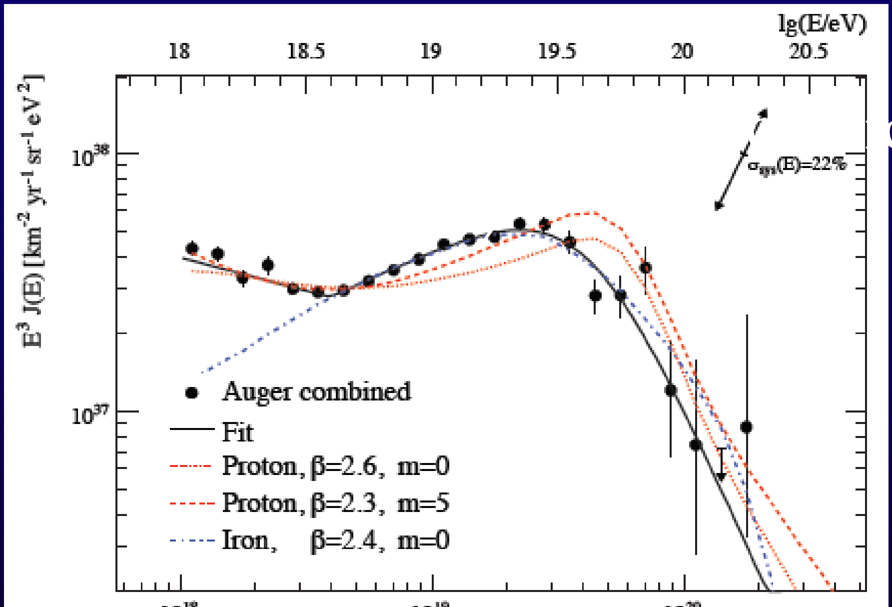


Cosmic Frontier



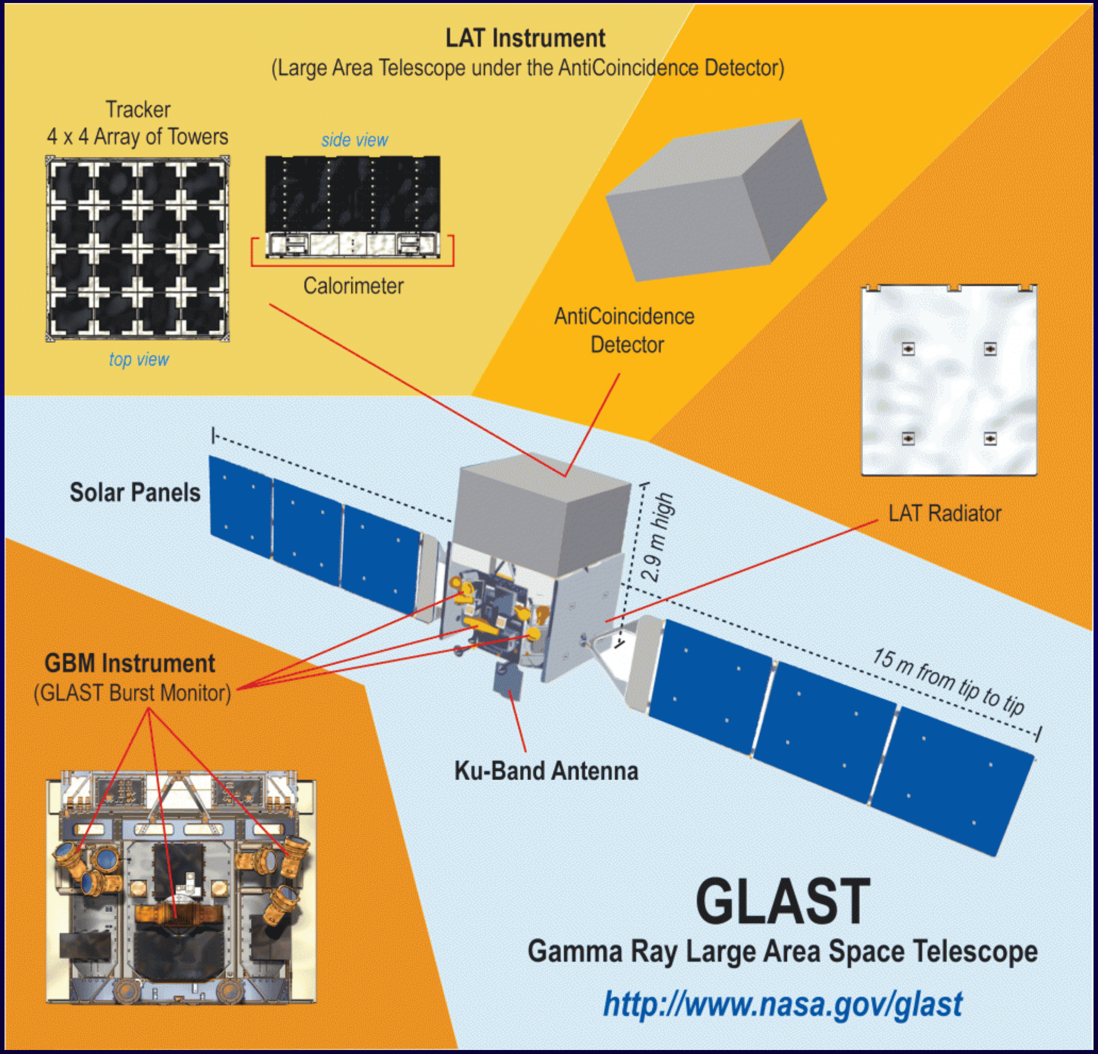
~2.6 10^{-4} eV



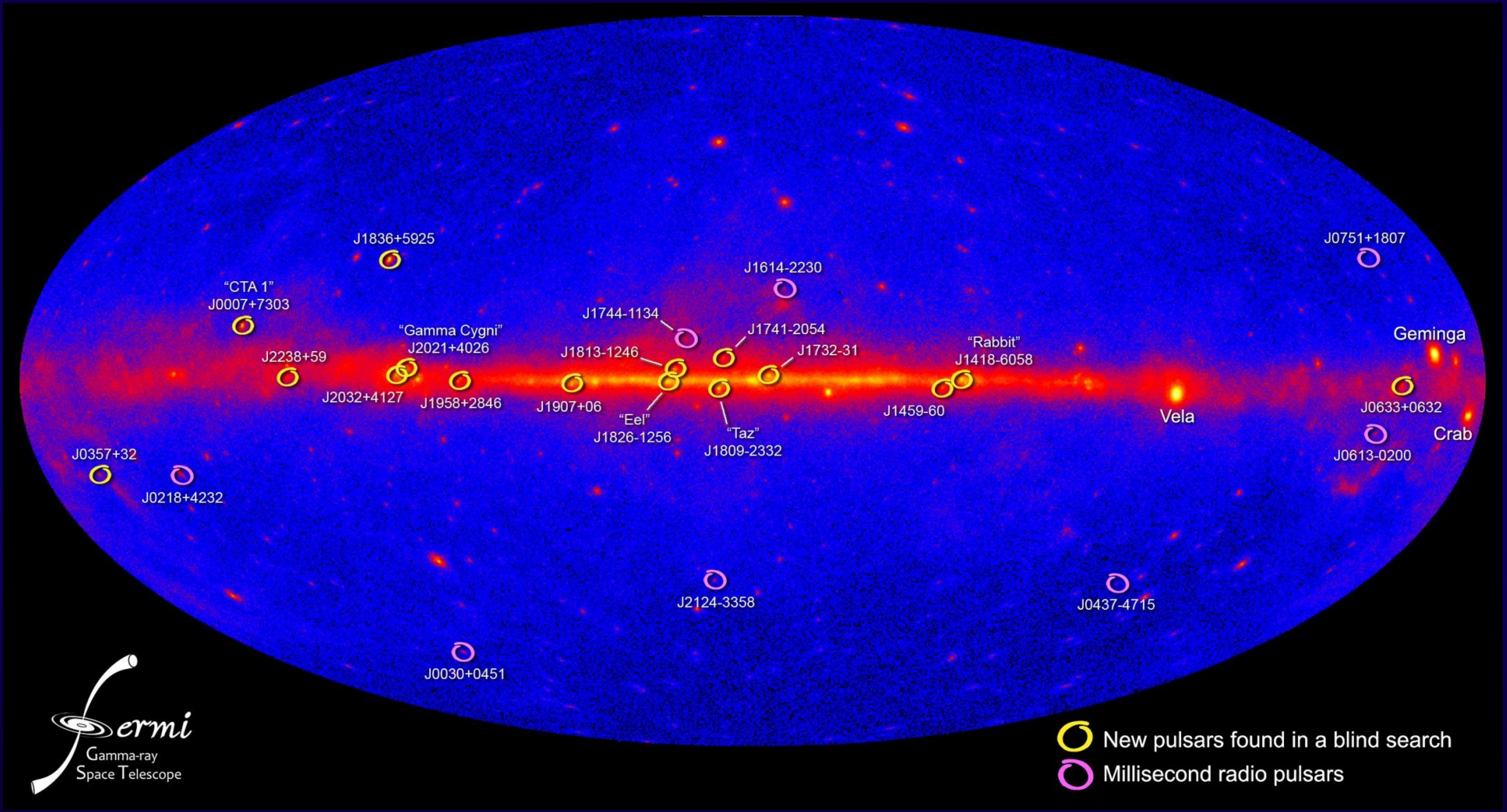


~10^{20} eV

Fermi Telescope



Fermi satellite: map of γ rays



The “Standard Theory”

$1\ eV \sim 1.6\ 10^{-19}\ J$

		Fermioni (Materia)			Bosoni	Interazioni
$Q = +2/3\,|q_e|$	Quark	~3 MeV u up	1.3 GeV c Charm	173 GeV t top	elettromagnetiche γ photon	
$Q = -1/3\,|q_e|$	Quark	~5 MeV d down	~100 MeV s strange	4.2 GeV b bottom	forti g gluon	
$Q = 0$	Leptoni	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	deboli cariche W W boson	
$Q = -\,|q_e|$	Leptoni	511 keV e electron	105 MeV μ muon	1.8 GeV τ tau	deboli neutre Z Z boson	
	Generations	I	II	III		

$1keV = 10^3\ eV$

$1MeV = 10^6\ eV$

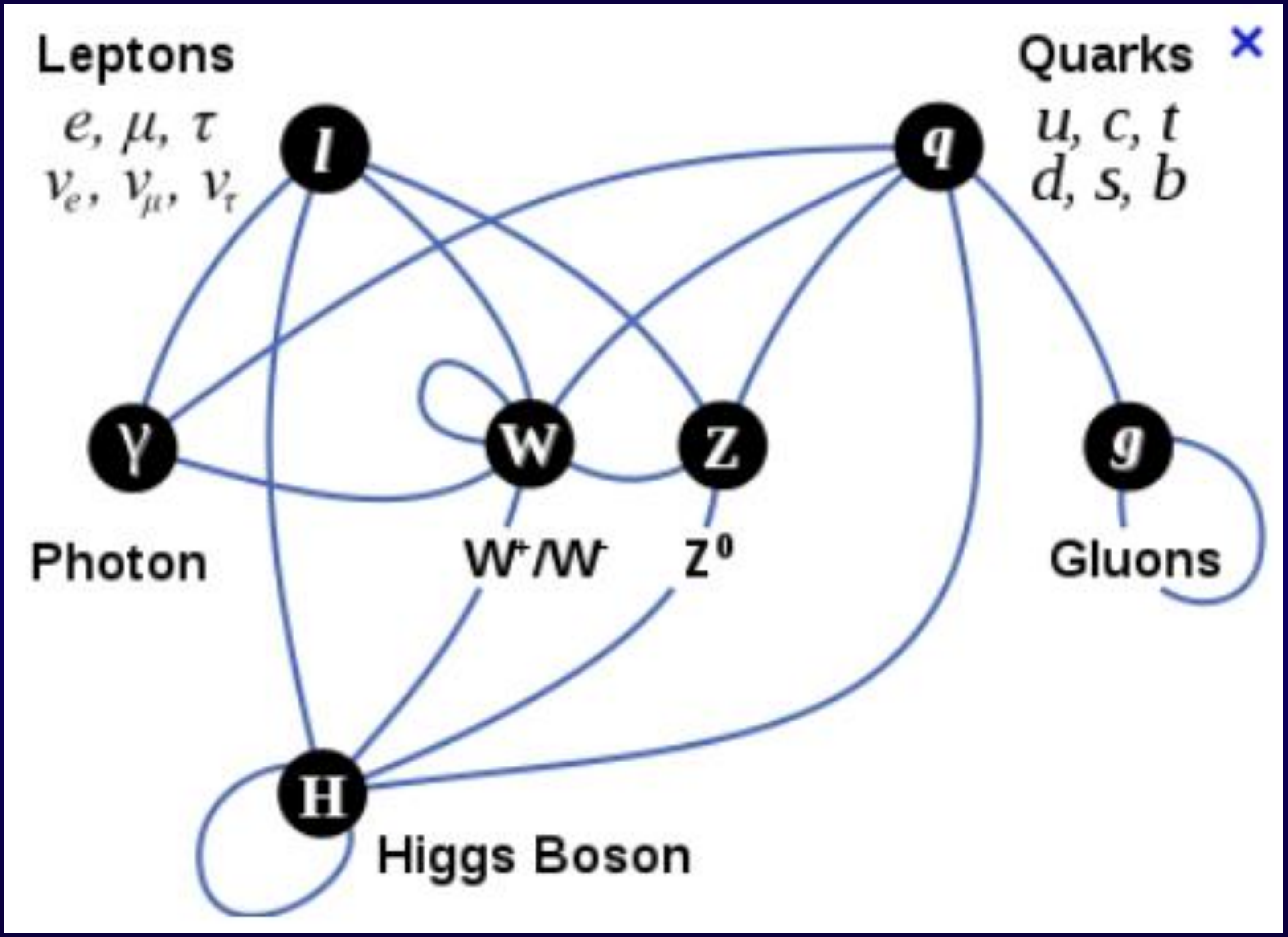
$1GeV = 10^9\ eV$

$m_p \sim 938\ MeV$

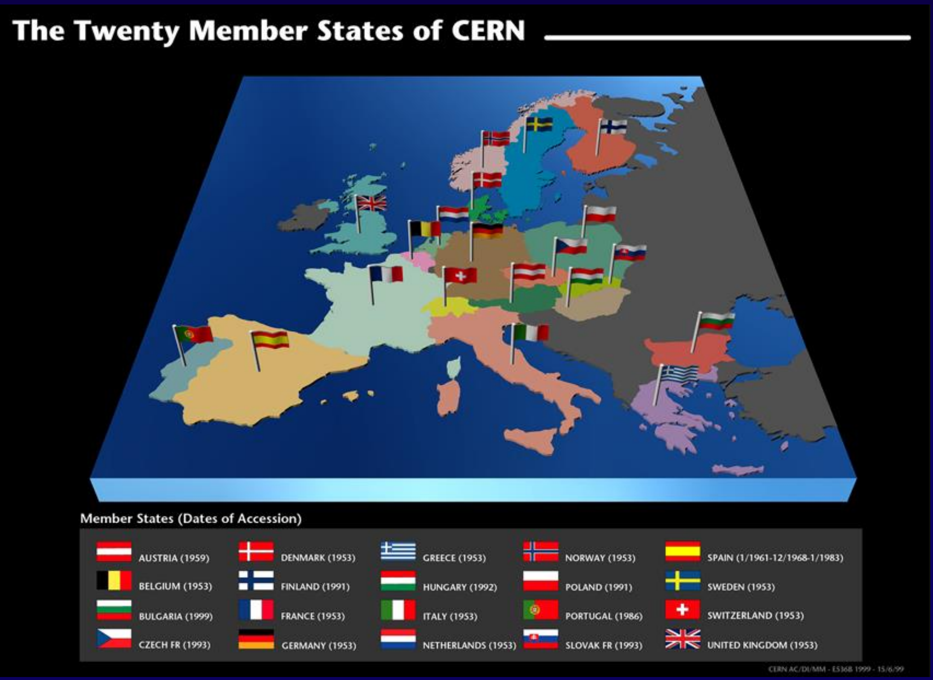
Higgs boson

To each particle corrisponds an antiparticle

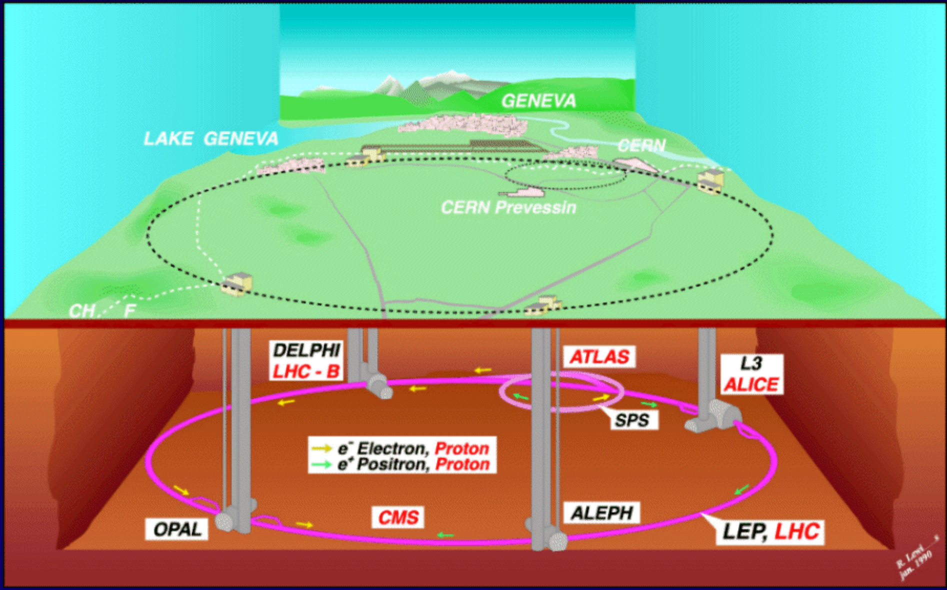
Elementary Particles



CERN: European Organization for Nuclear Research



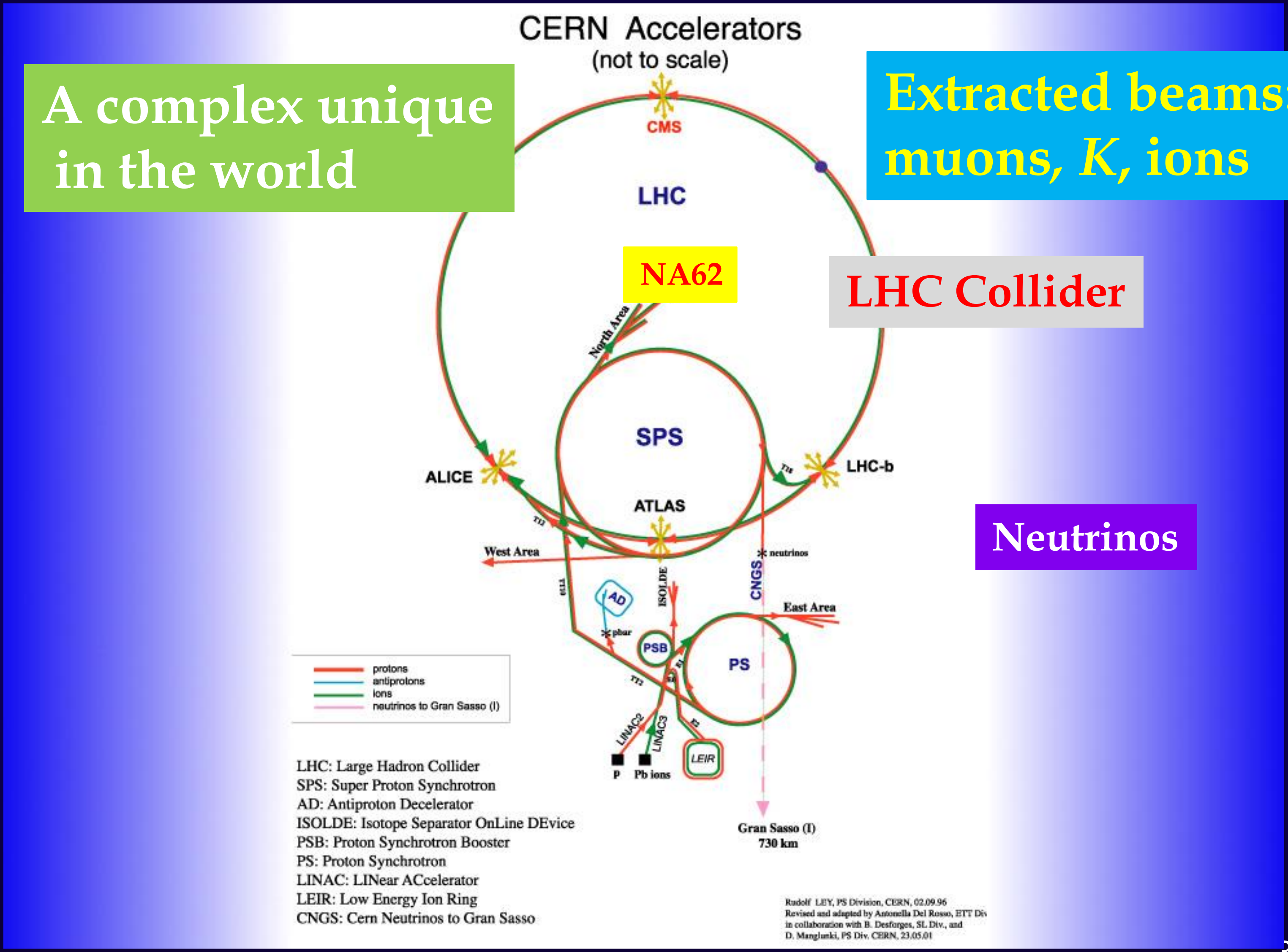
21 Member States



Near Geneva across Switzerland and France

CERN Mission Statement: Research, Technology, Collaboration, Education

CERN Accelerators



A complex unique in the world

Extracted beams: muons, *K*, ions

NA62

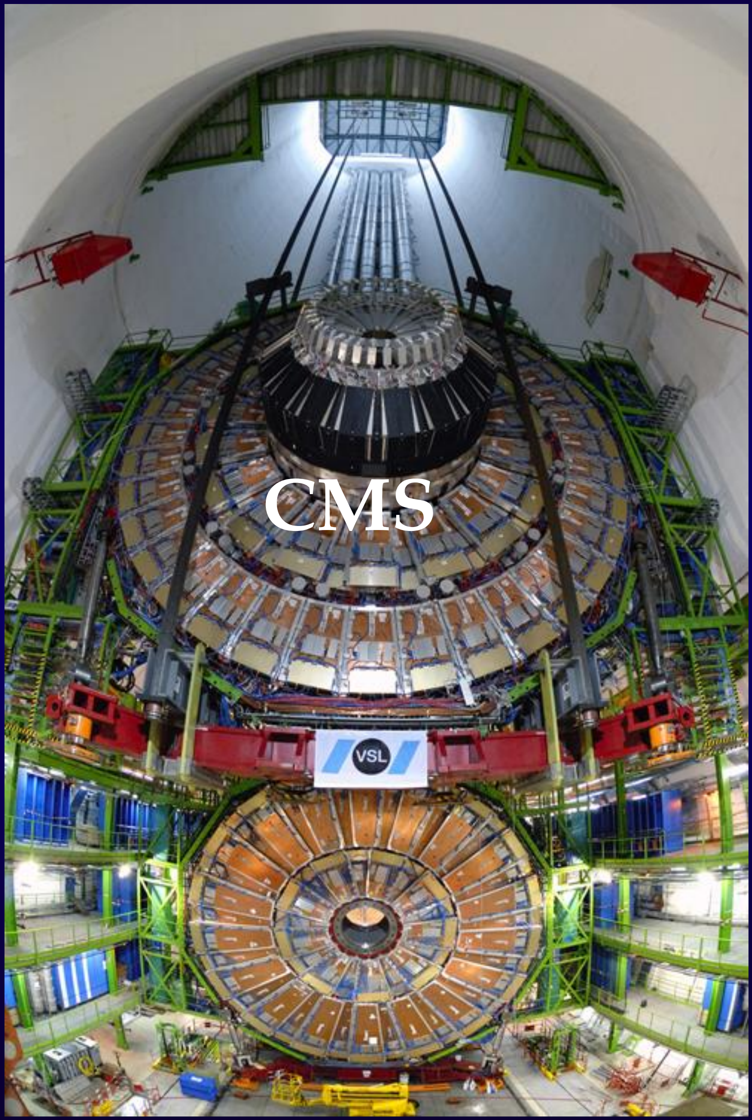
LHC Collider

Neutrinos

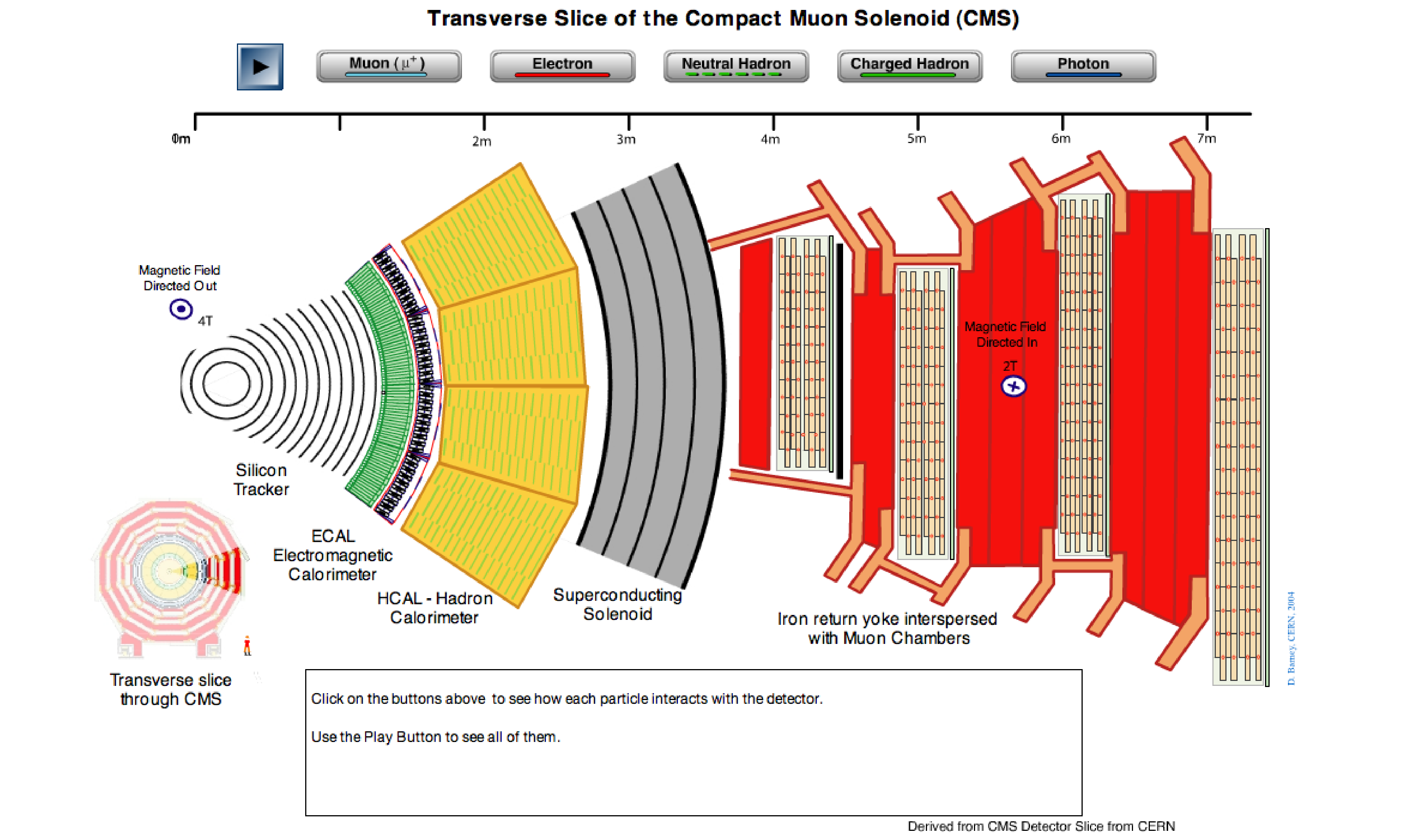
Example of LHC experiment:CMS

A modern experiments includes different detectors to measure different particles

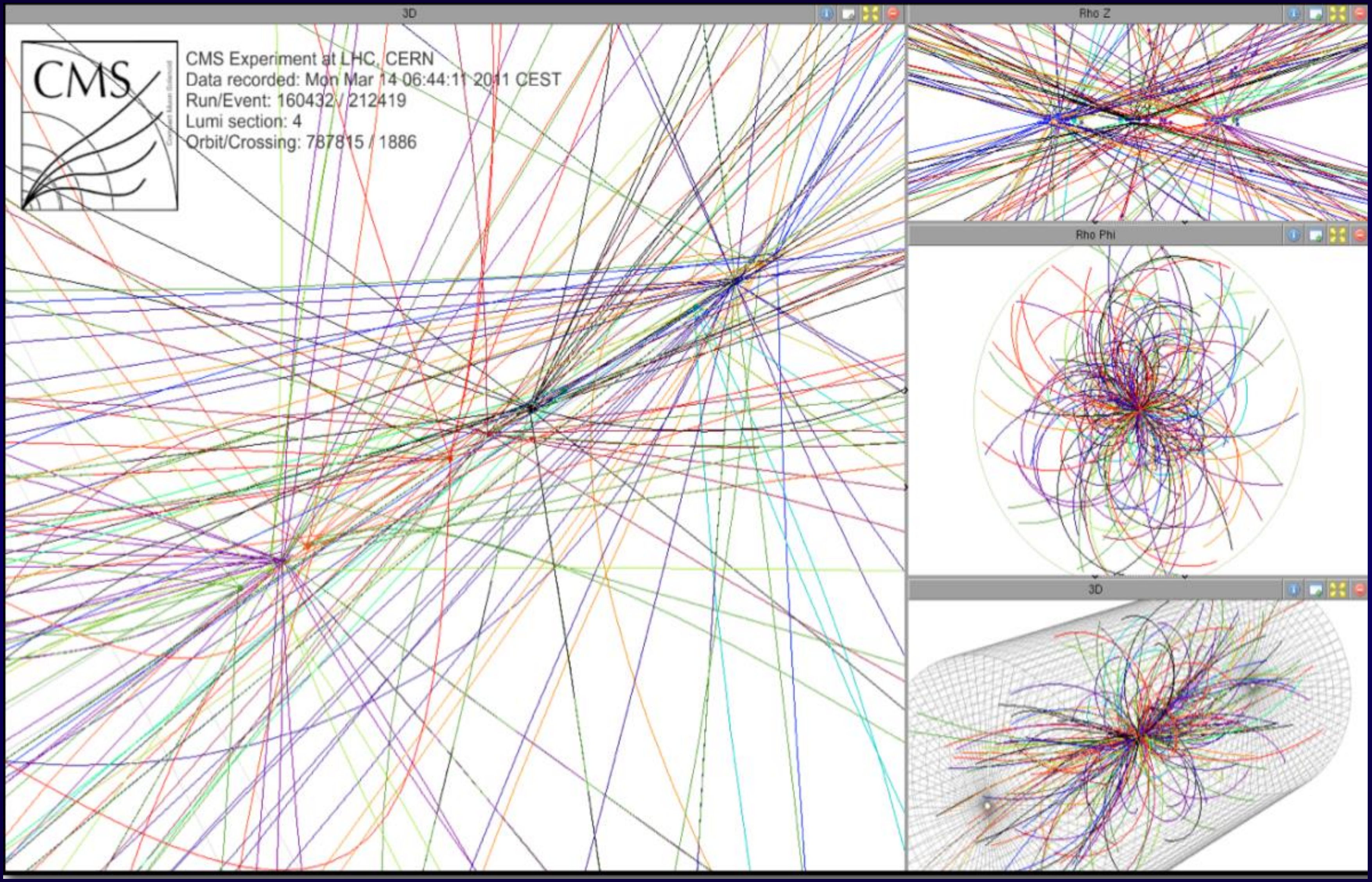
We exploit the fact that different particles interact in a particular way with matter



Compact Muon Solenoid (CMS)

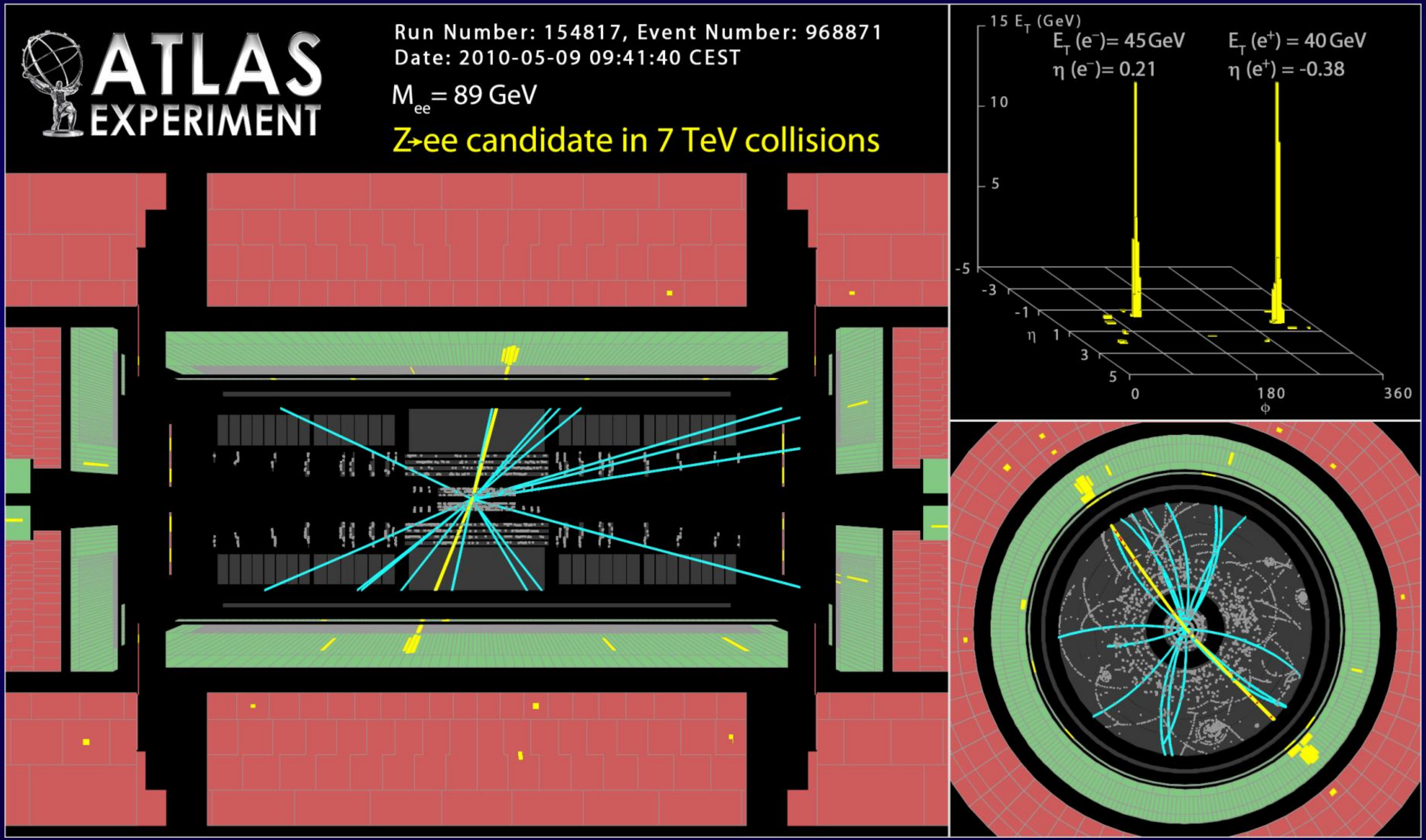


Proton Proton Interactions in CMS



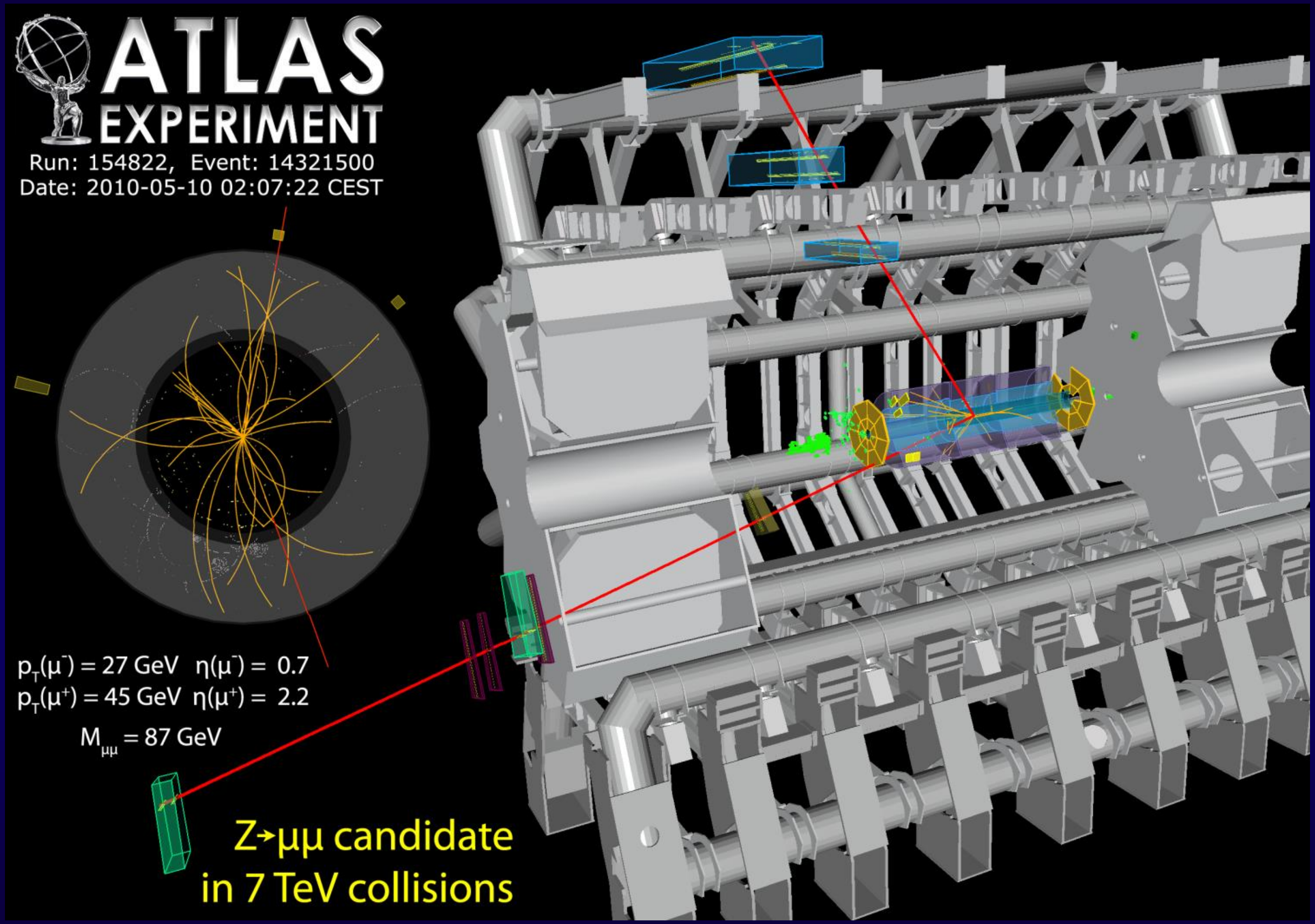
How many p-p interaction can you find?

ATLAS Experiment: $Z \rightarrow e^+e^-$



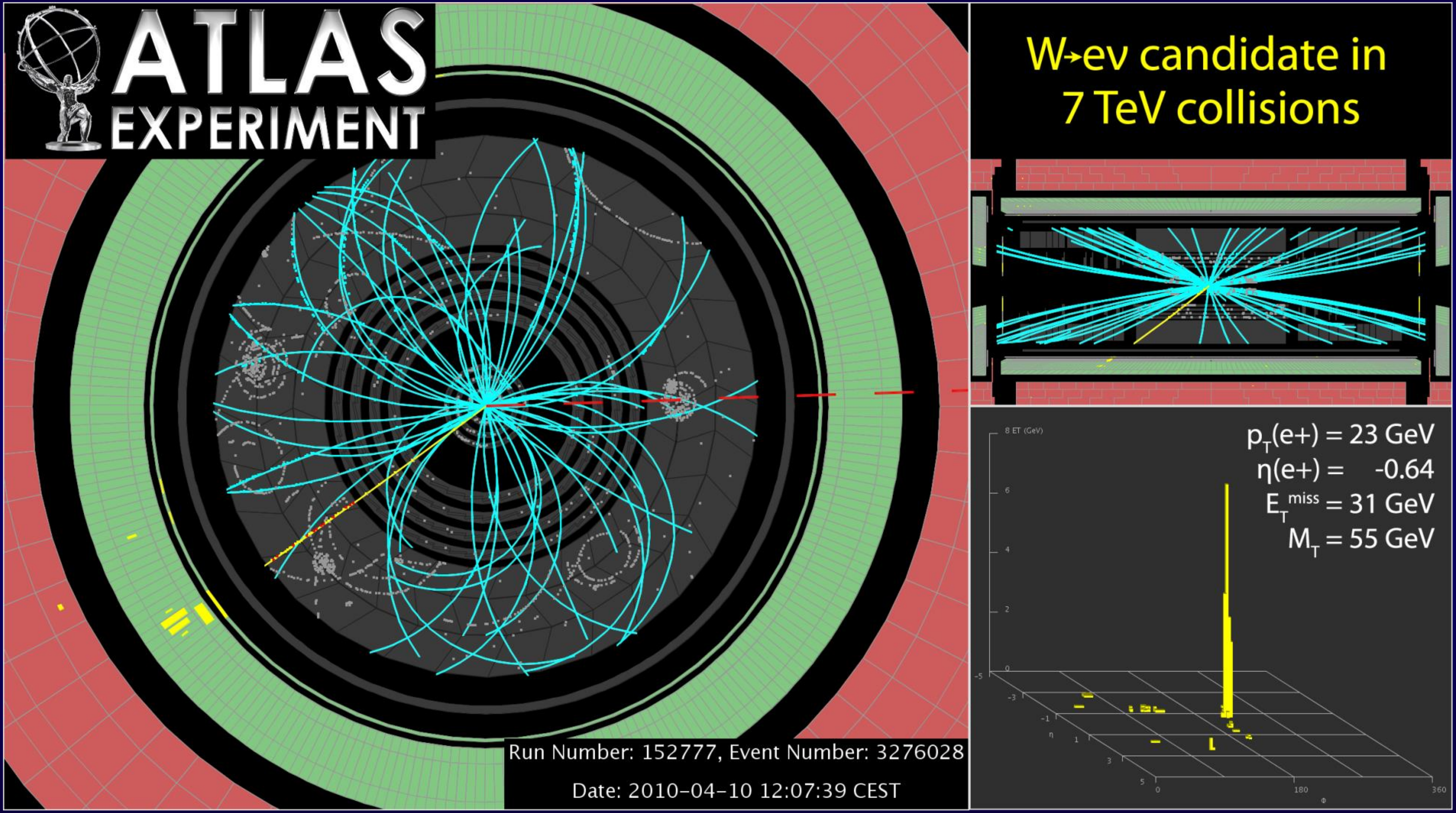
Can you identify the electron pair?

$Z \rightarrow \mu^+\mu^-$



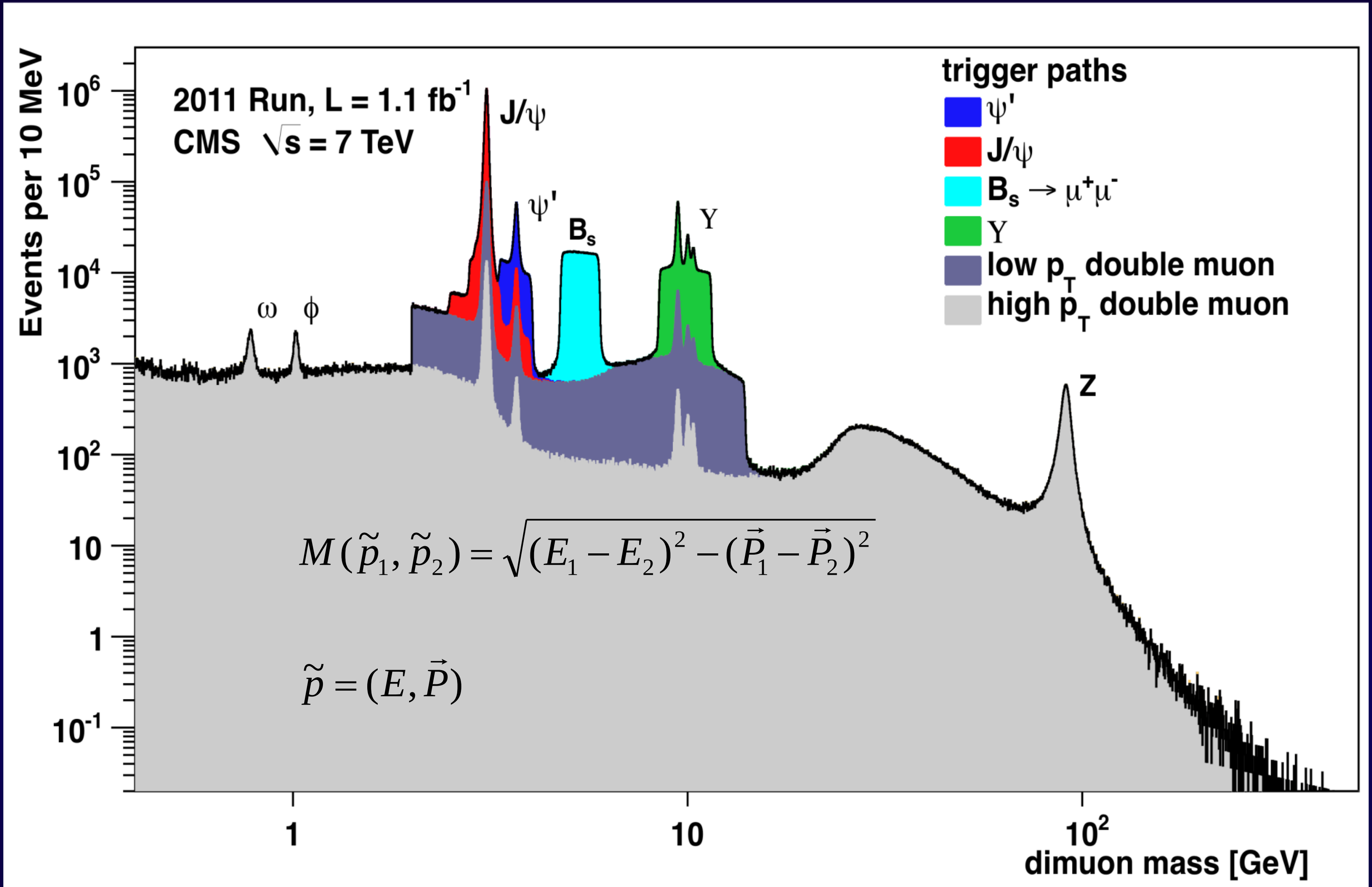
Muons (μ) are like electrons..but ~200 times heavier…
Can you explain why they escape from the inner detectors?

$W^+ \rightarrow e^+ \; \nu$



Can you see the neutrino (ν)???

CMS: Events selected with $\mu^+ \mu^-$ pairs



$$M(\tilde{p}_1, \tilde{p}_2) = \sqrt{(E_1 - E_2)^2 - (\vec{P}_1 - \vec{P}_2)^2}$$

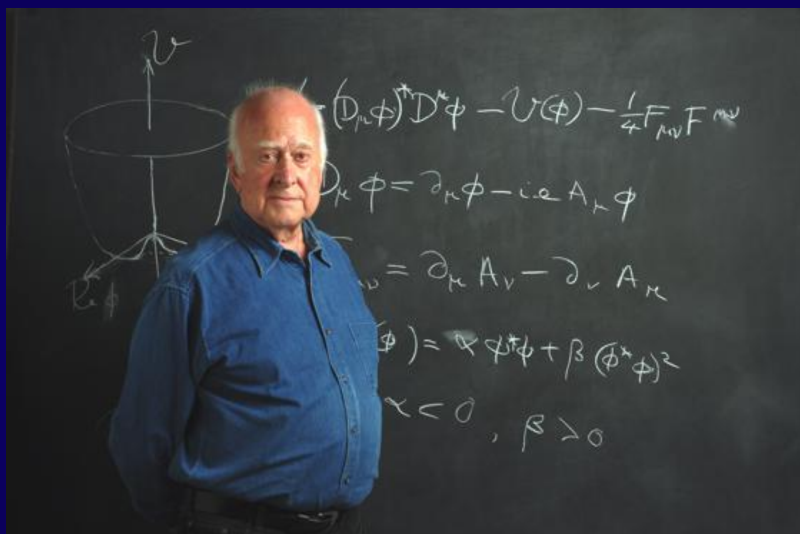
$$\tilde{p} = (E, \vec{P})$$

How many "resonances" do you see ?

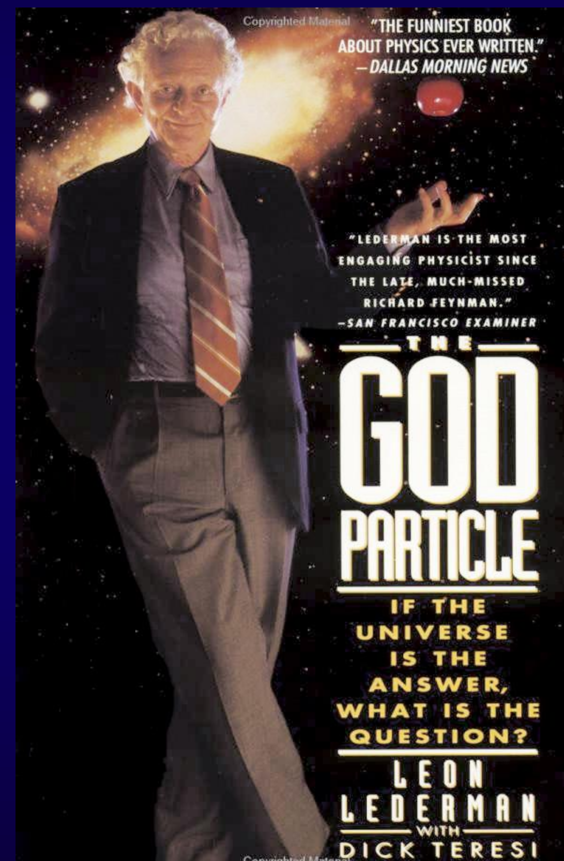
Particle Mass

- Equivalence between mass and energy:
  - $E = mc^2$
- **Only ~1%** of the proton mass is due to the mass of the constituents (the quarks)
- **The remaining 99%** is due to dynamic effects
- Within the Standard Theory, elementary particles and fields have no mass
- To produce mass one needs to break necessario the electroweak symmetry **(Higgs mechanism)**

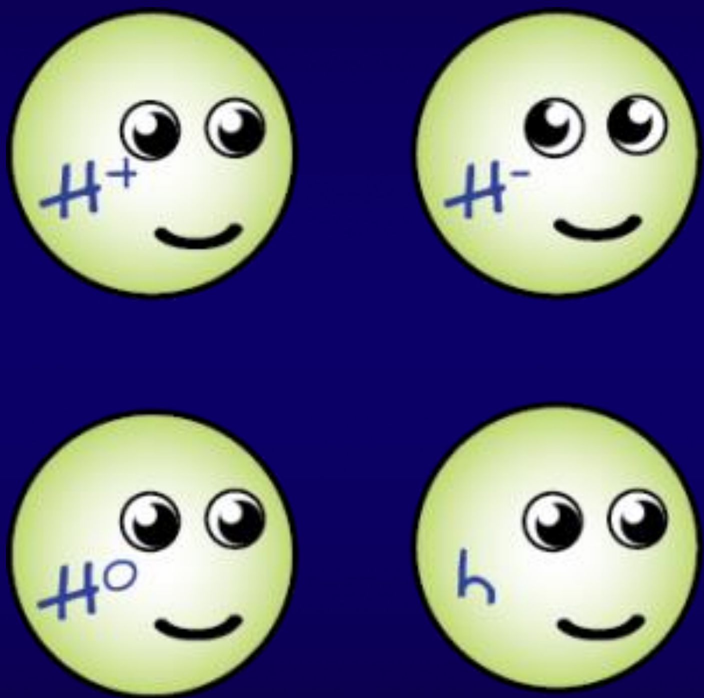
Higgs Boson

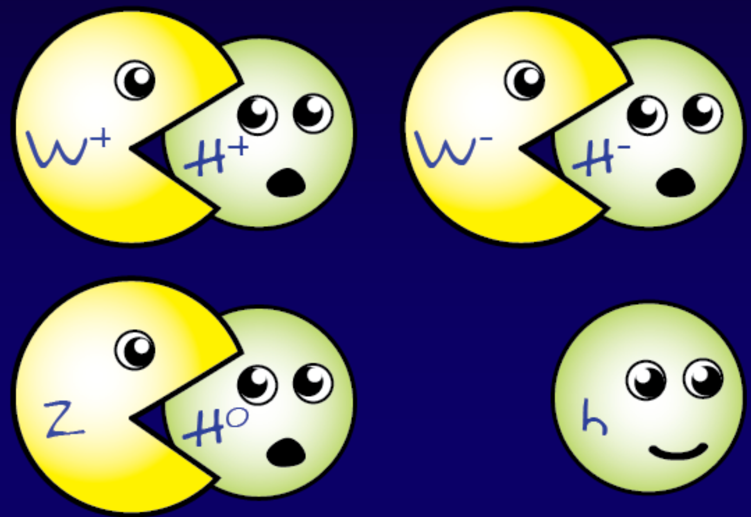


Peter Higgs



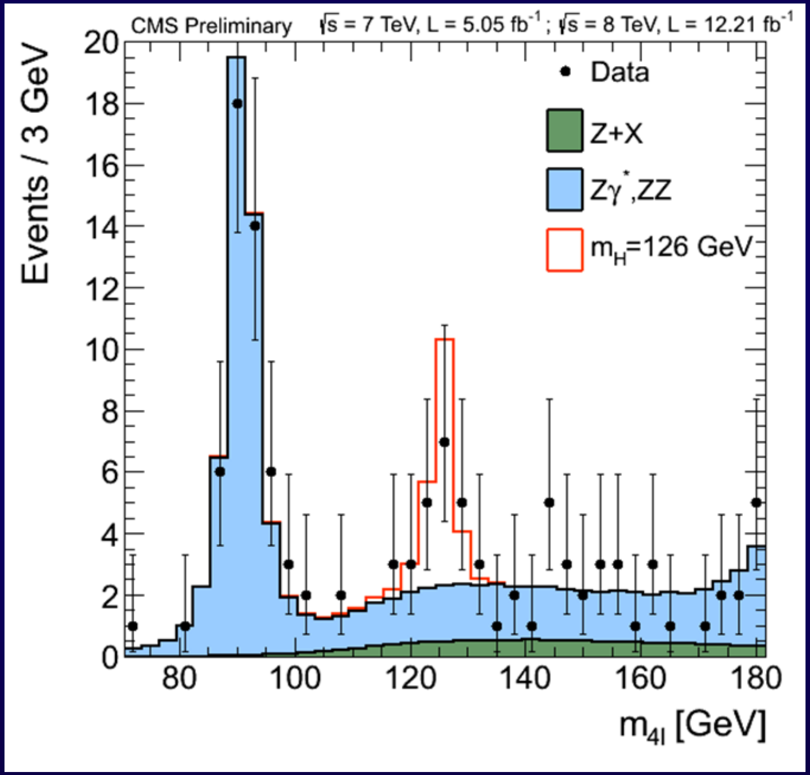
…From the "Quantum Diaries" Blog



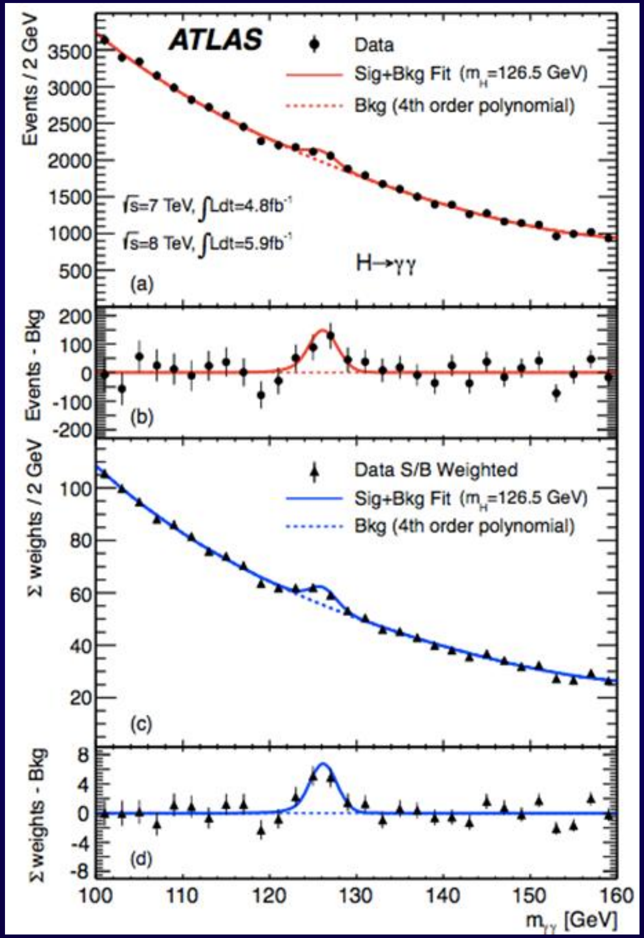


- …. Three Higgs give mass to the vector bosons and disappear… only one remains

Discovery of Higgs-like boson: CERN July 4, 2012

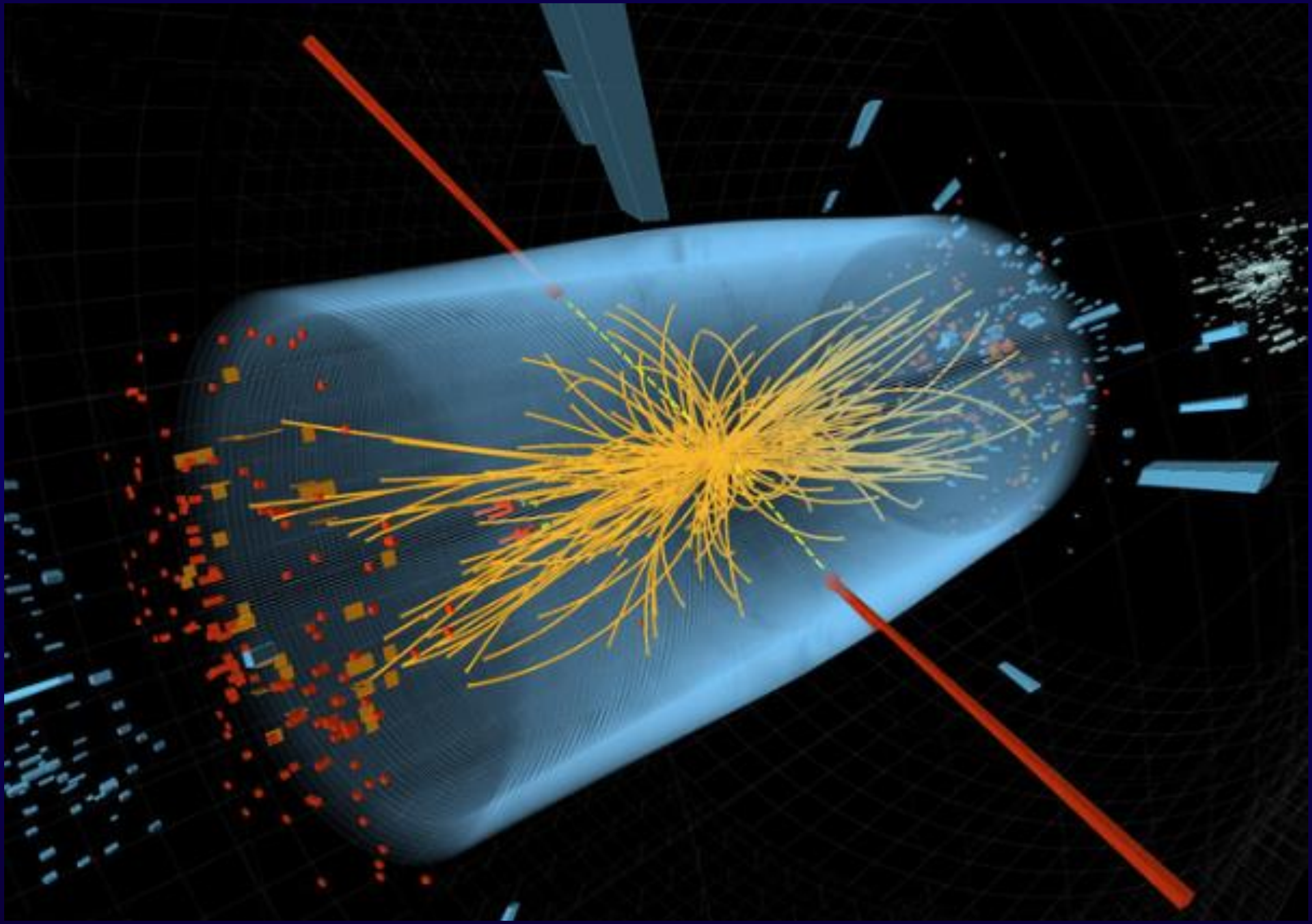


CMS

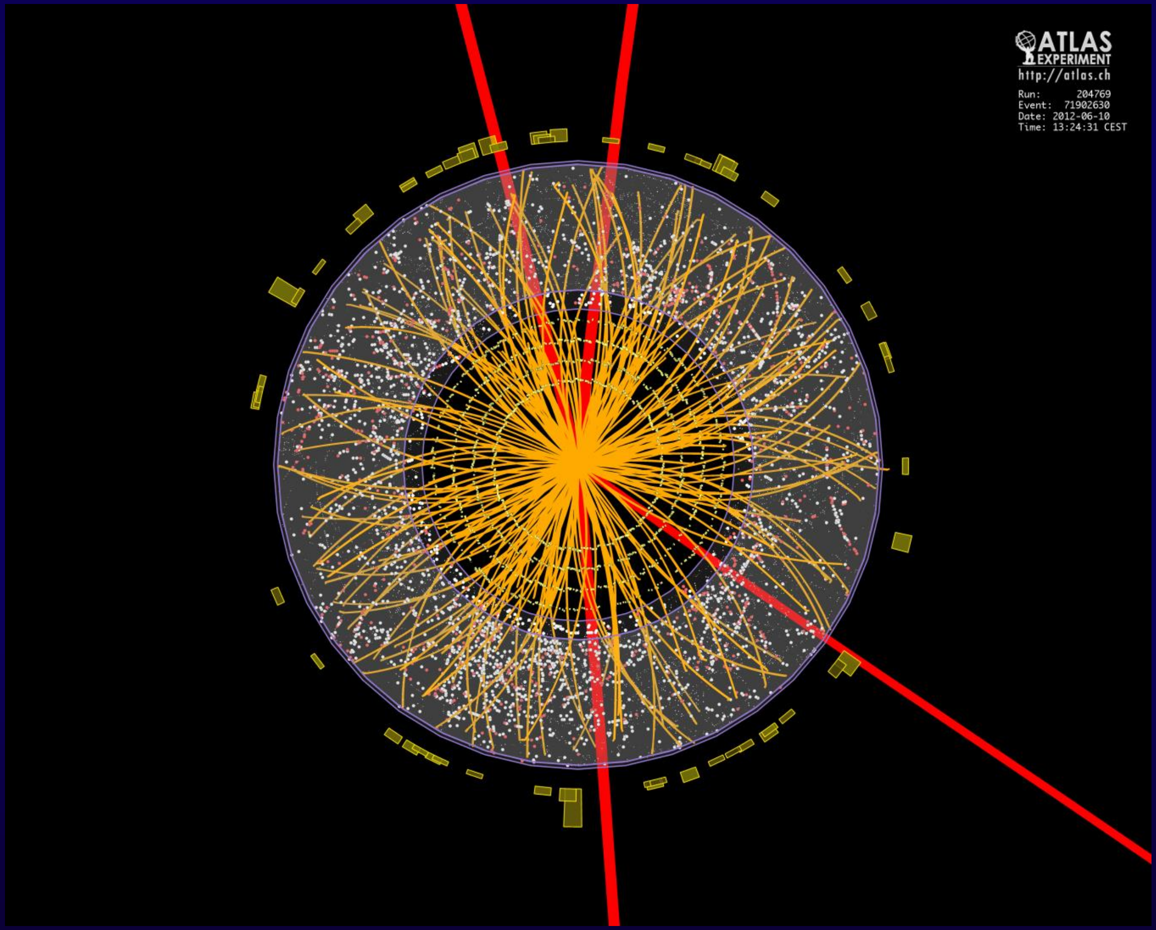


ATLAS

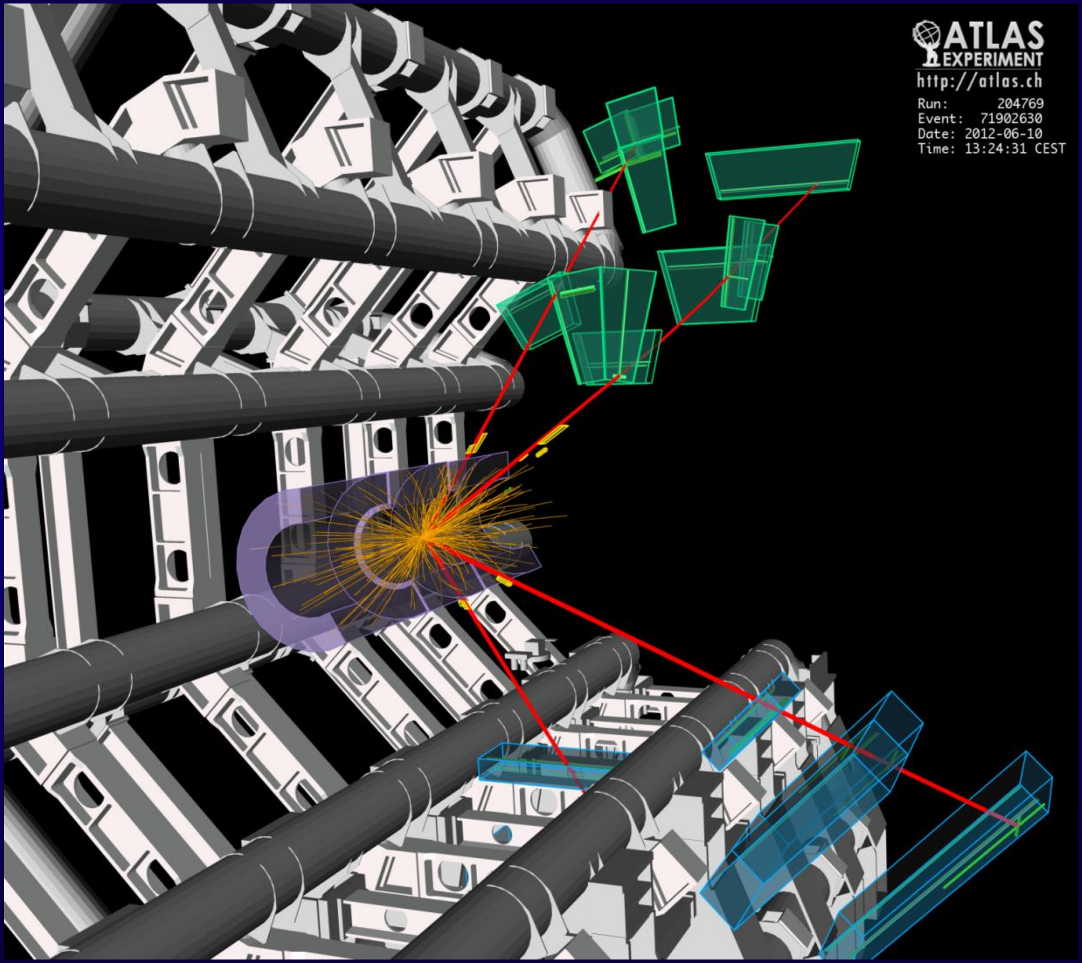
CMS: $H \to \gamma\gamma$



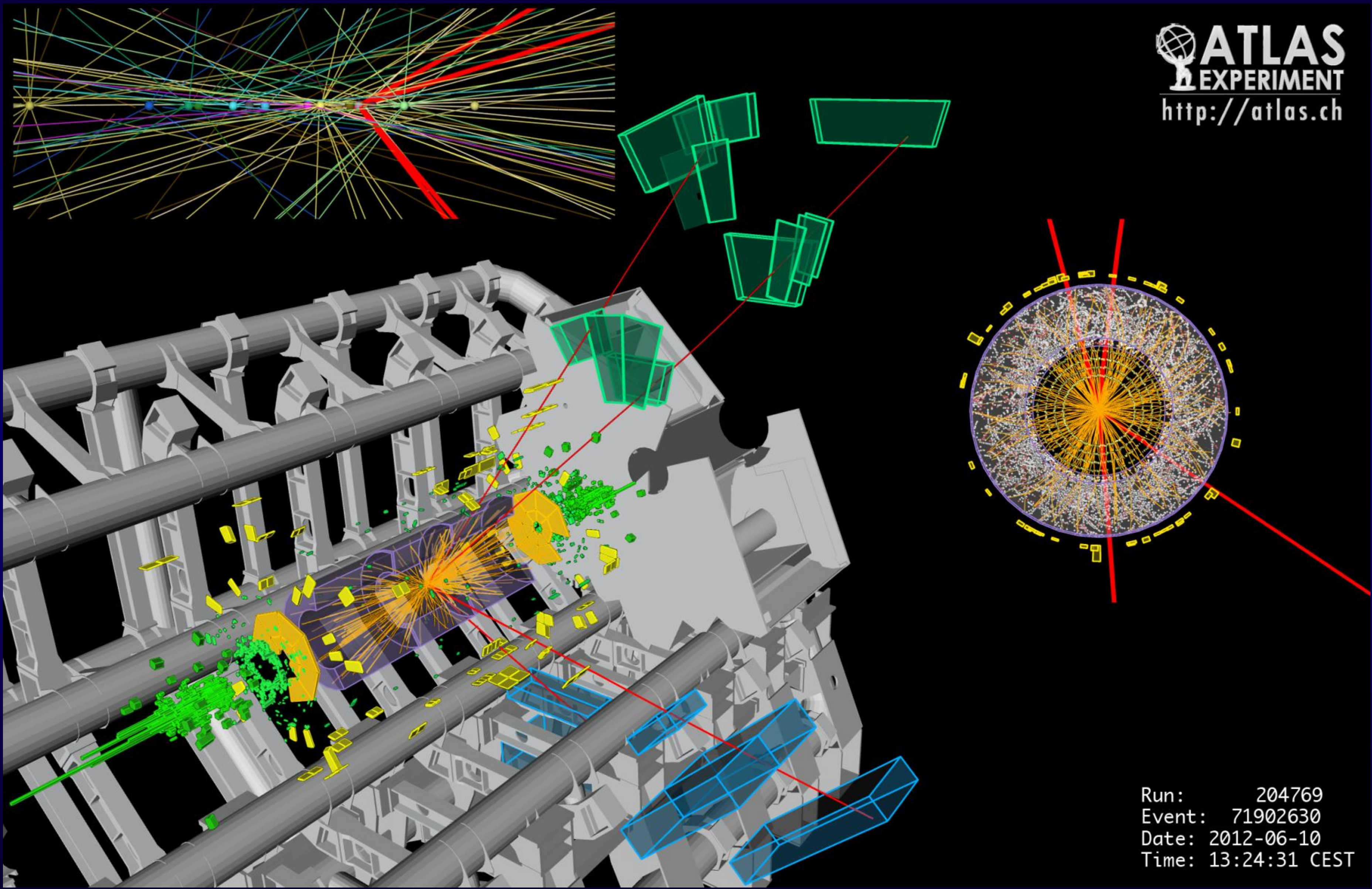
$H \rightarrow Z Z^* \rightarrow \mu^+ \mu^- \mu^+ \mu^-$



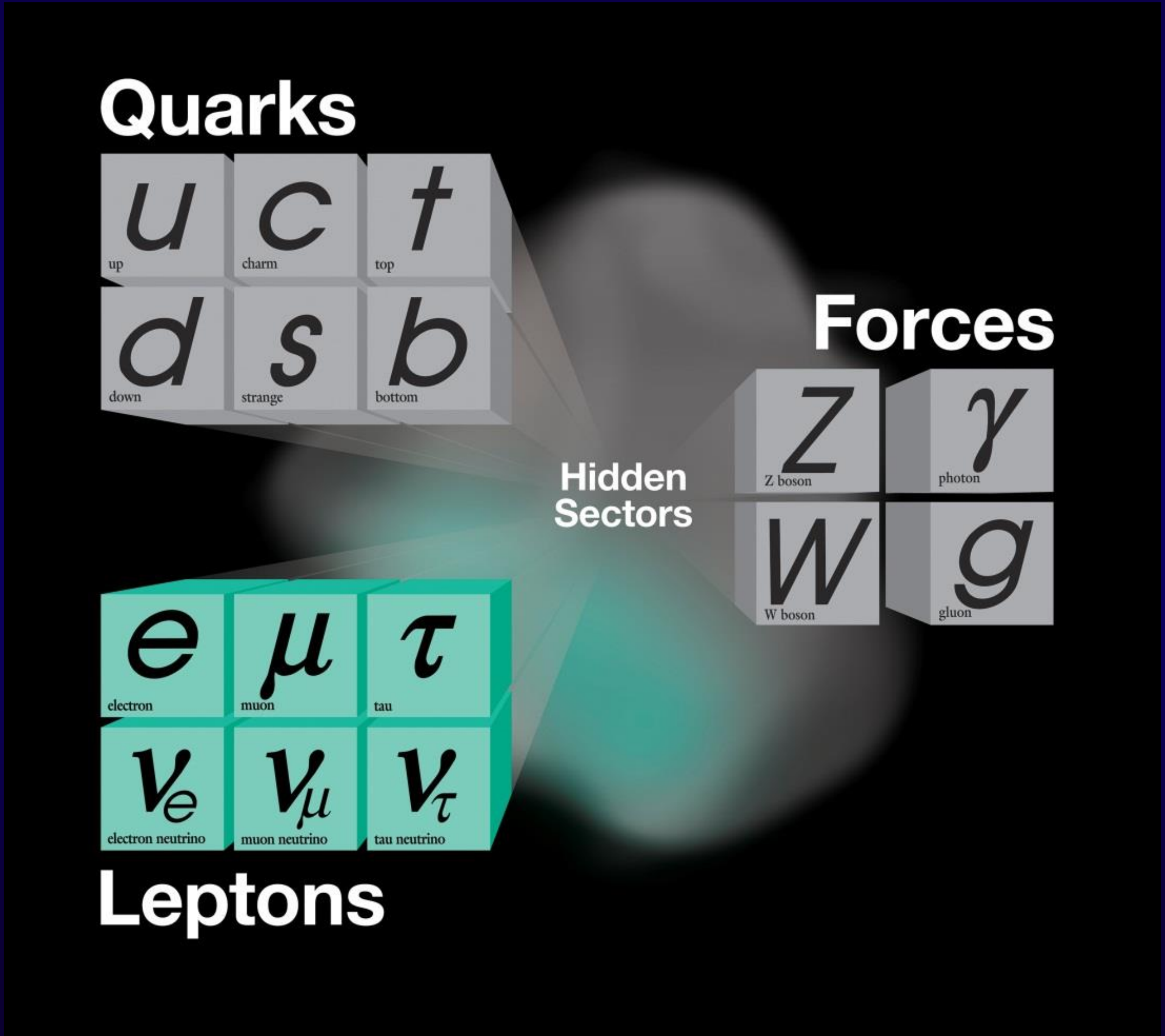
$H \rightarrow Z Z^* \rightarrow \mu^+ \mu^- \mu^+ \mu^-$



H→ Z Z* →$\mu^+ \mu^- \mu^+ \mu^-$

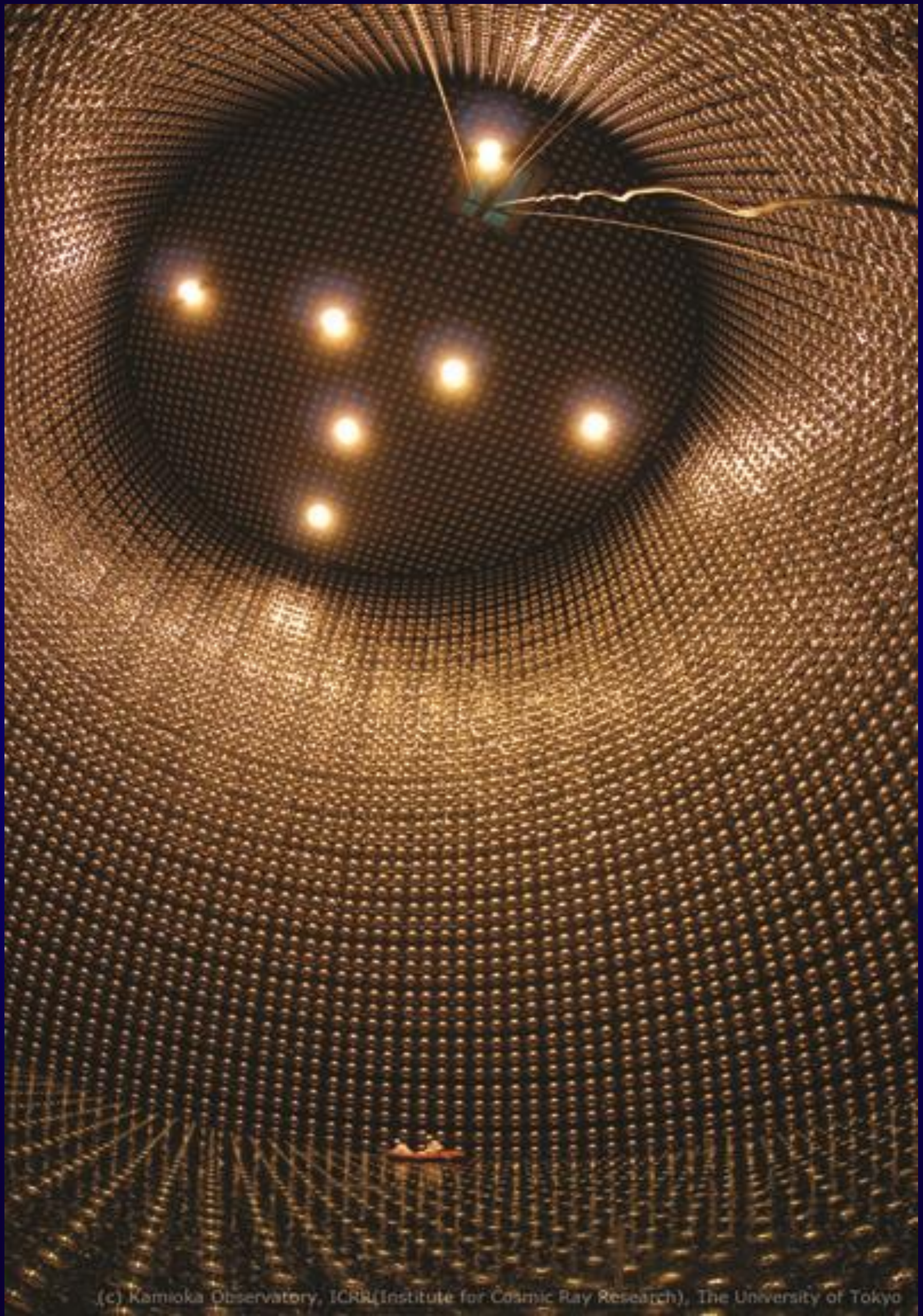


Frontiera dell'Intensita`: Neutrini



Superkamiokande Neutrino Detector (Japan)

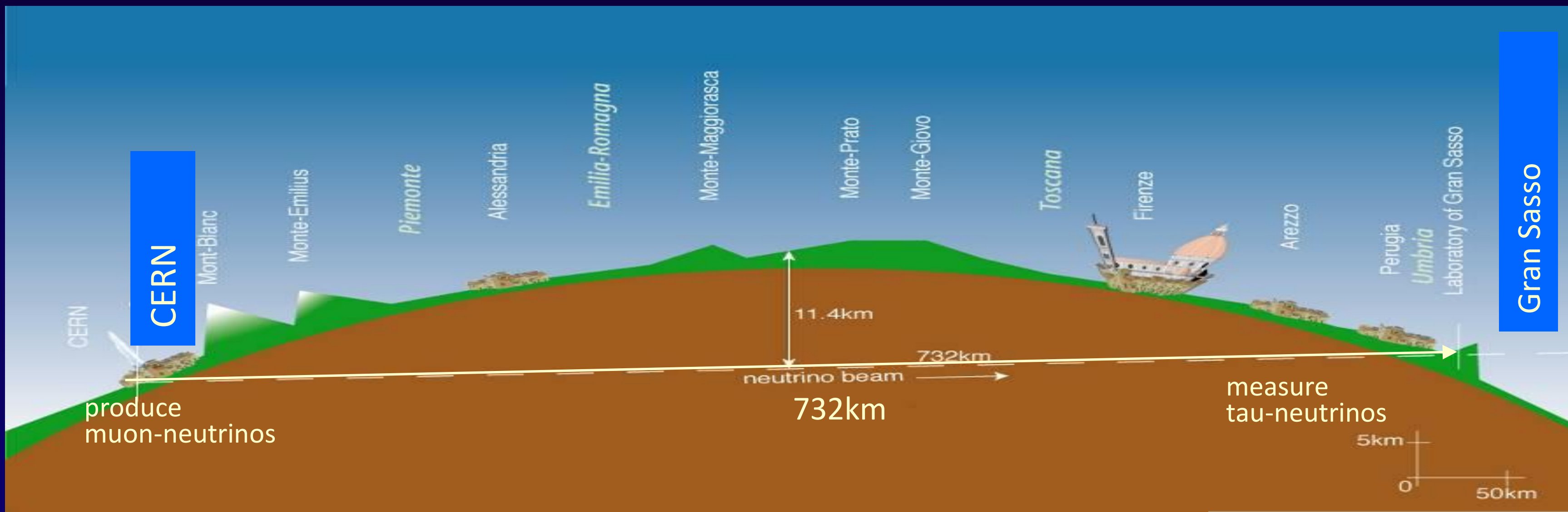
Where neutrino oscillations Where discovered



Do you know what the active detector medium is?

CERN Neutrinos to Gran Sasso:

Long Baseline neutrino beam



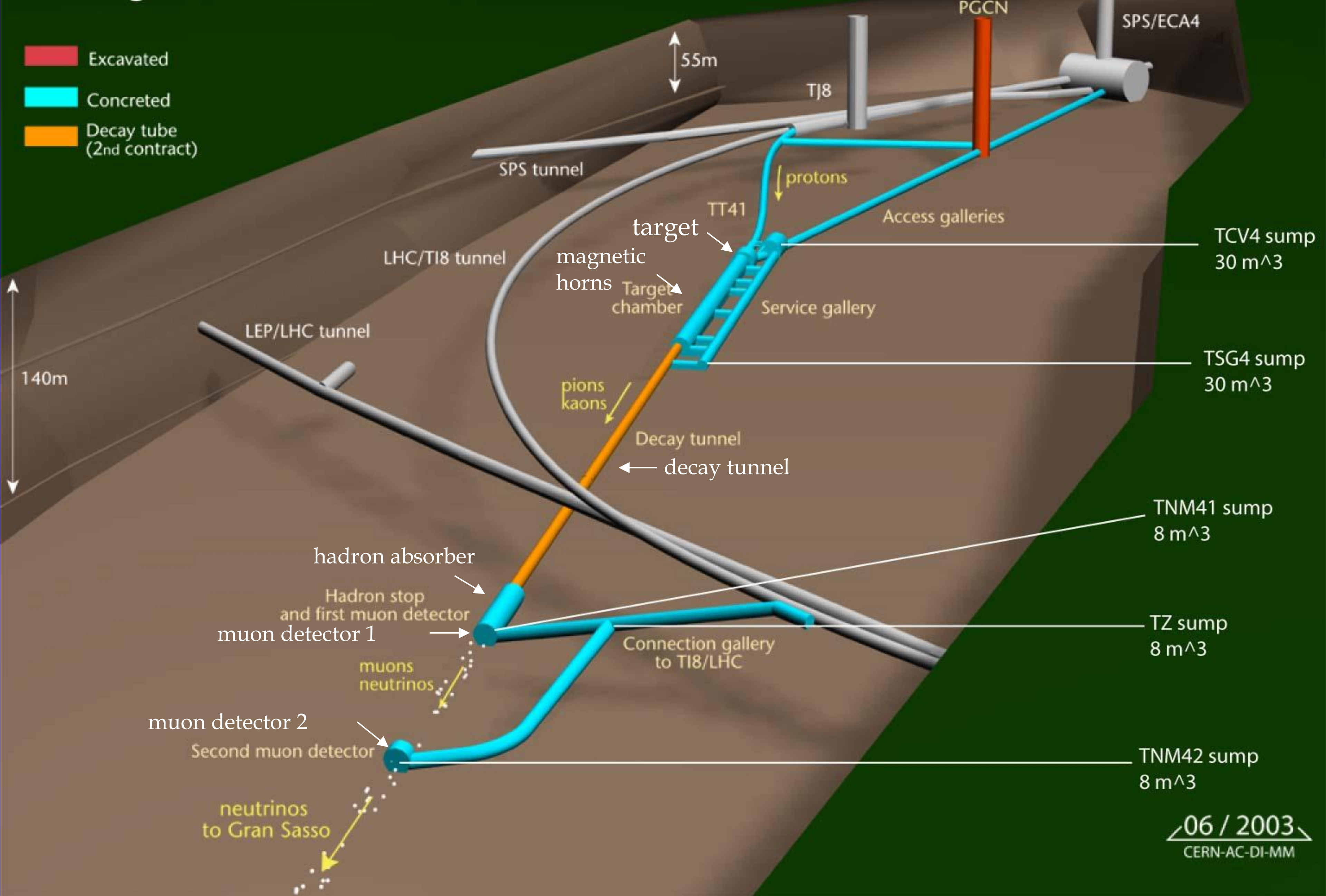
~$4 \cdot 10^{19}$ p/year

~$2 \cdot 10^{19}$ ν_μ/year

~2 ν_τ/year (~$1 \cdot 10^{17}$ ν_μ/year)

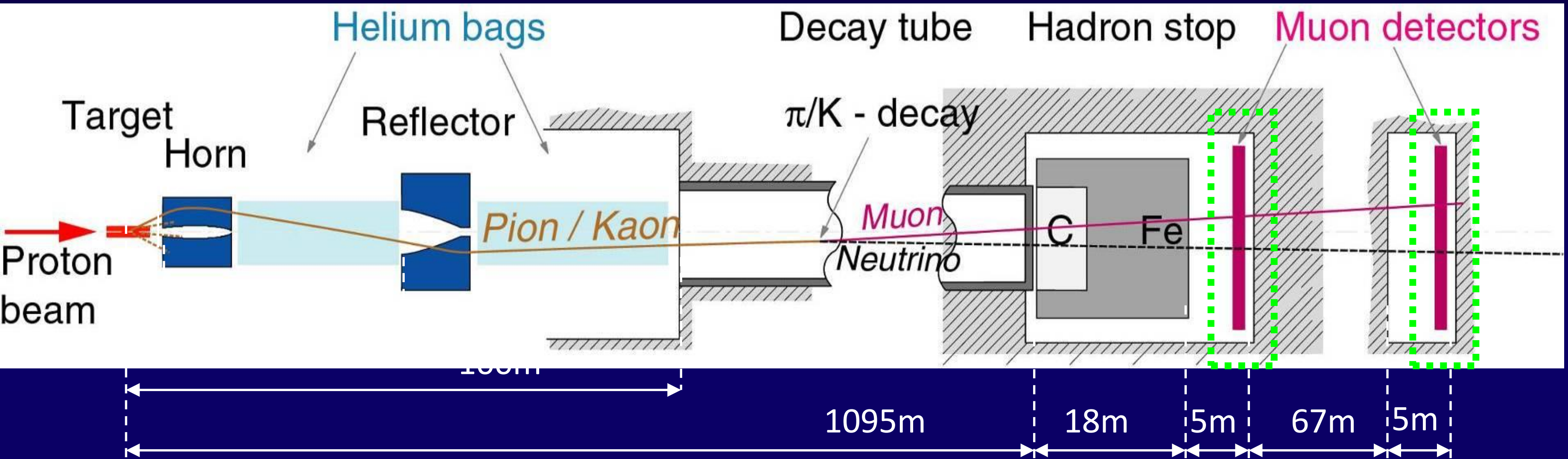
Expect ~10 ν_τ events in OPERA

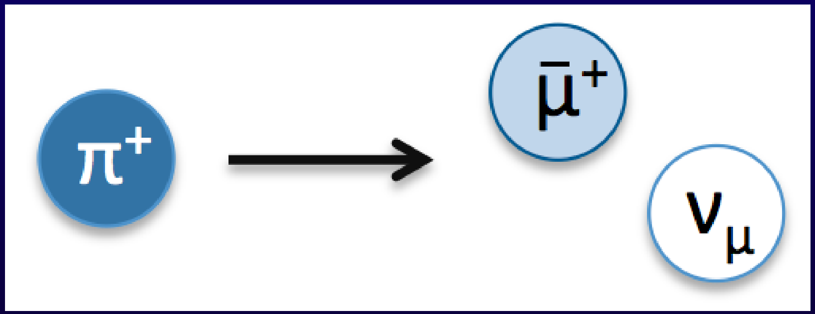
CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN



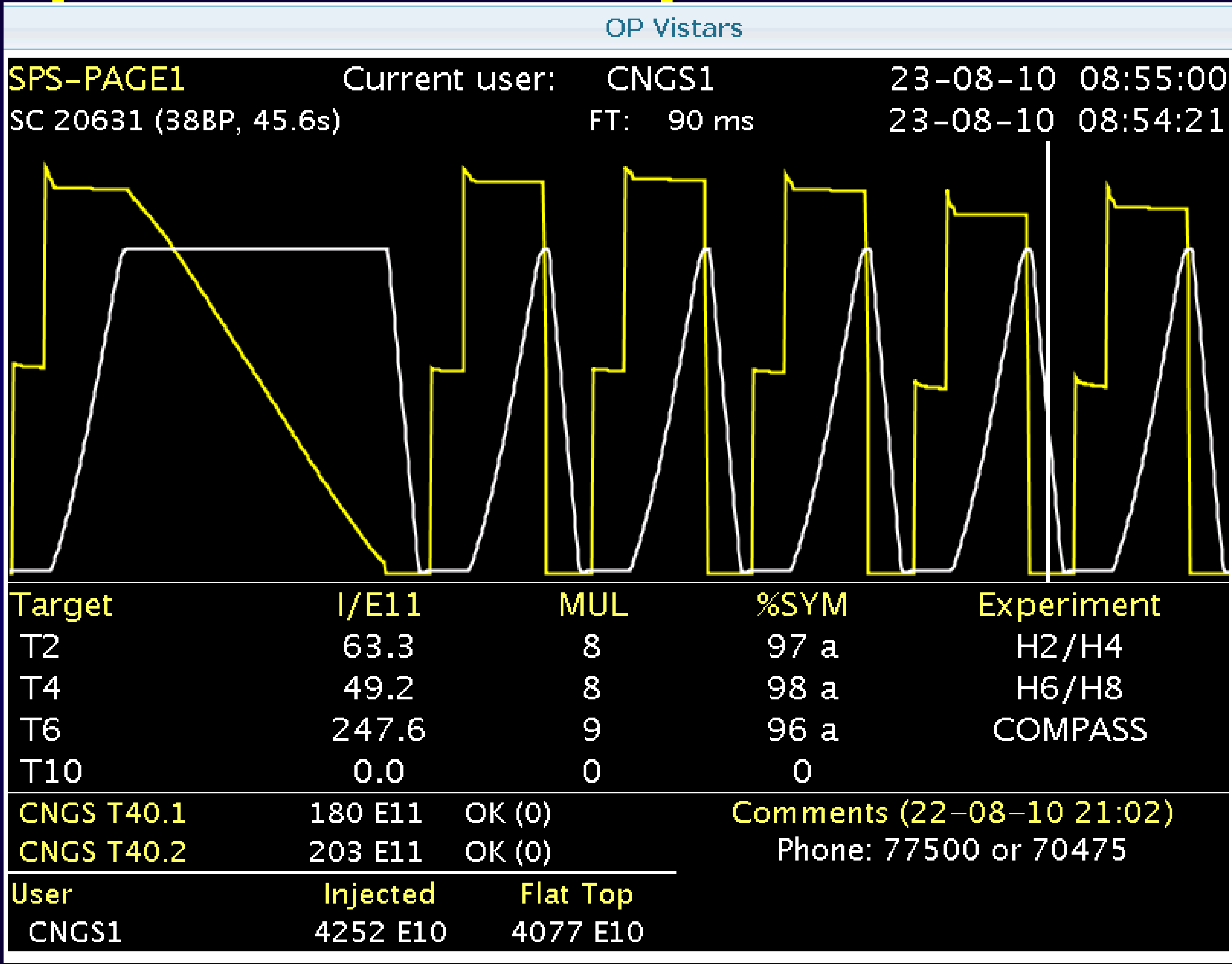
Primary Beamline

CNGS: secondary beam





Operazione SPS per CNGS



Dark MAtter? Dark Energy?

- **Dark Matter** is invisible matter, it does not emit light. Its evidence comes from the study of the motion of galaxies and groups of galaxies
- **Dark Energy** is the term introduced to justify the acceleration of the Universe expansion (is it equivalent to Einstein's cosmological constant)

Summary

- This is a simple introduction meant to entice your interest
- During the semester we will explore many more aspects relating the infinitely small to the infinitely large
- Next Tuesday, to start with, we will have a special guest: distinguished theorist Chris Quigg telling us about the Higgs Boson, Symmetries and much more!