Particle Detectors 2/2

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The 'Standard Model'

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$$L_{GSW} = L_0 + L_H + \sum_l \left\{ \frac{g}{2} \overline{L}_l \gamma_\mu \vec{\tau} L_l \vec{A}^\mu + g' \left[\overline{R}_l \gamma_\mu R_l + \frac{1}{2} \overline{L}_l \gamma_\mu L_l \right] B^\mu \right\} +$$

$$+ \frac{g}{2} \sum_q \overline{L}_q \gamma_\mu \vec{\tau} L_q \vec{A}^\mu +$$

$$+ g' \left\{ \frac{1}{6} \sum_q \left[\overline{L}_q \gamma_\mu L_q + 4 \overline{R}_q \gamma_\mu R_q \right] + \frac{1}{3} \sum_{q'} \overline{R}_{q'} \gamma_\mu R_{q'} \right\} B^\mu$$

$$L_H = \frac{1}{2} (\partial_\mu H)^2 - m_H^2 H^2 - h\lambda H^3 - \frac{h}{4} H^4 +$$

$$+ \frac{g^2}{4} (W_\mu^+ W^\mu + \frac{1}{2\cos^2 \theta_W} Z_\mu Z^\mu)(\lambda^2 + 2\lambda H + H^2) +$$

$$+ \sum_{l,q,q'} (\frac{m_l}{\lambda} \bar{l}l + \frac{m_q}{\lambda} \bar{q}q + \frac{m_{q'}}{\lambda} \bar{q}'q')H$$

Over the last century
this "Standard Model" of
Fundamental Physics was discovered
by studying

Radioactivity
Cosmic Rays
Particle Collisions (Accelerators)

A large variety of Detectors and
experimental techniques have been
developed during this time.

Scales

$$E = m a^2$$
$$E = m b^2$$
$$E = m c^2 \quad \longleftarrow \quad \text{Energy} \Leftrightarrow \text{Mass}$$
$$\vdots$$

$$m(\text{electron}) = 9.1 \cdot 10^{-31} \text{ kg}$$
$$m_e c^2 = 8.19 \cdot 10^{-14} \text{ J}$$
$$= 510\ 999 \text{ Electron Volt } (eV)$$
$$= 0.511 \text{ MeV}$$

$$1 \text{ Electron Volt} = e_0 \cdot 1V = 1.603 \cdot 10^{-19} \text{ J}$$

$$E = e_0 \cdot 1V$$

0   1V
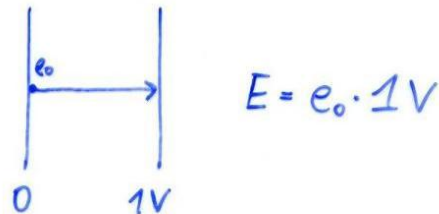
1 Electron Volt = Energy an Electron gains as
it traverses a Potential Difference of 1V

Build your own Accelerator
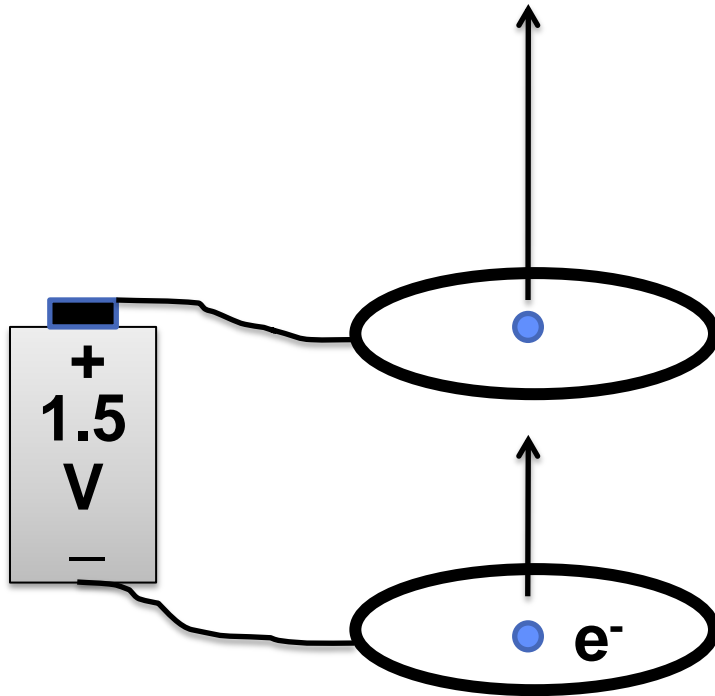
E_{kin}= 1.5eV =

2 615 596 km/h

+
1.5
V
−

e⁻

Scales

Visible Light: $\lambda = 500\,nm$, $h\nu \sim 2.5\,eV$

Excited States in Atoms: $1 - 100\,keV$ "X-Rays"

Nuclear Physics: $1 - 50\,MeV$

Particle Physics: $1 - 1000\,GeV$ (LHC 14 TeV)

Highest Measured Energy: $10^{20}\,eV$ (Cosmic Rays)

Basics

Lorentz Boost:

$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu \qquad \gamma = 2.2 \cdot 10^{-6} \, s$$

E.g. Produced by Cosmic Rays $(p, He, Li ...)$
colliding with air in the upper Atmosphere $\sim 10 \, km$

$$s = v \cdot \gamma \sim c \cdot \gamma = 660 \, m$$

But we see Muons here on Earth

$$E_\mu \sim 2 \, GeV, \; m_\mu c^2 = 105 \, MeV \; \to \gamma \sim 19$$

Relativity: $\bar{\gamma} = \gamma \cdot \gamma$

$$s = c \cdot \bar{\gamma} = 12.5 \, km \; \to \text{Earth}$$

Pions: $\pi^+, \pi^- \quad \gamma \sim 2.6 \cdot 10^{-8} s, \; m_\pi c^2 = 135 \, MeV$

$$2 \, GeV \to s = 115 \, m$$

Pions where discovered in Emulsions exposed
to Cosmic Rays on high Mountains.

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http://pdg.lbl.gov   ~ <u>180 Selected Particles</u>

$\gamma, W^{\pm}, Z^0, g, e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau, \pi^{\pm}, \pi^0, \eta, f_0(600), g(770),$

$\omega(782), \eta'(958), f_0(980), a_0(980), \phi(1020), h_1(1170), b_1(1235),$

$a_1(1260), f_2(1270), f_1(1285), \eta(1295), \pi(1300), a_2(1320),$

$f_0(1370), f_1(1420), \omega(1420), \eta(1440), a_0(1450), g(1450),$

$f_0(1500), f_2'(1525), \omega(1650), \omega_3(1670), \pi_2(1670), \phi(1680),$

$g_3(1690), g(1700), f_0(1710), \pi(1800), \phi_3(1850), f_2(2010),$

$a_4(2040), f_4(2050), f_2(2300), f_2(2340), K^{\pm}, K^0, K^0_S, K^0_L, K^*(892),$

$K_1(1270), K_1(1400), k^*(1410), K_0^*(1430), K_2^*(1430), K^*(1680),$

$K_2(1770), K_3^*(1780), K_2(1820), K_4^*(2045), D^{\pm}, D^0, D^*(2007)^0,$

$D^*(2010)^{\pm}, D_1(2420)^0, D_2^*(2460)^0, D_2^*(2460)^{\pm}, D_S^{\pm}, D_S^{*\pm},$

$D_{S1}(2536)^{\pm}, D_{SJ}(2573)^{\pm}, B^{\pm}, B^0, B^*, B^0_S, B^{\pm}_c, \eta_c(1S), J/\psi(1S),$

$\chi_{c0}(1P), \chi_{c1}(1P), \chi_{c2}(1P), \psi(2S), \psi(3770), \psi(4040), \psi(4160),$

$\psi(4415), \Upsilon(1S), \chi_{b0}(1P), \chi_{b1}(1P), \chi_{b2}(1P), \Upsilon(2S), \chi_{b0}(2P),$

$\chi_{b2}(2P), \Upsilon(3S), \Upsilon(4S), \Upsilon(10860), \Upsilon(11020), p, n, N(1440),$

$N(1520), N(1535), N(1650), N(1675), N(1680), N(1700), N(1710),$

$N(1720), N(2190), N(2220), N(2250), N(2600), \Delta(1232), \Delta(1600),$

$\Delta(1620), \Delta(1700), \Delta(1905), \Delta(1910), \Delta(1920), \Delta(1930), \Delta(1950),$

$\Delta(2420), \Lambda, \Lambda(1405), \Lambda(1520), \Lambda(1600), \Lambda(1670), \Lambda(1690),$

$\Lambda(1800), \Lambda(1810), \Lambda(1820), \Lambda(1830), \Lambda(1890), \Lambda(2100),$

$\Lambda(2110), \Lambda(2350), \Sigma^+, \Sigma^0, \Sigma^-, \Sigma(1385), \Sigma(1660), \Sigma(1670),$

$\Sigma(1750), \Sigma(1775), \Sigma(1915), \Sigma(1940), \Sigma(2030), \Sigma(2250), \Xi^0, \Xi^-,$

$\Xi(1530), \Xi(1690), \Xi(1820), \Xi(1950), \Xi(2030), \Omega^-, \Omega(2250)^-,$

$\Lambda_c^+, \Lambda_c^+, \Sigma_c(2455), \Sigma_c(2520), \Xi_c^+, \Xi_c^0, \Xi_c'^+, \Xi_c'^0, \Xi(2645)$

$\Xi_c(2780), \Xi_c(2815), \Omega_c^0, \Lambda_b^0, \Xi_b^0, \Xi_b^-, t\bar{t}$

There are Many more

All Particles with $c\gamma > 1\mu m$ @ GeV Level

Particle	Mass (meV)	Life time γ (s)	$c\gamma$
γ	0	∞	∞
$\pi^{\pm}(u\bar{d}, d\bar{u})$	140	$2.6 \cdot 10^{-8}$	7.8 m
$K^{\pm}(u\bar{s}, \bar{u}s)$	494	$1.2 \cdot 10^{-8}$	3.7 m
$K^0(d\bar{s}, \bar{d}s)$	497	$5.1 \cdot 10^{-8}$ $8.9 \cdot 10^{-11}$	15.5 m 2.7 cm
$D^{\pm}(c\bar{d}, \bar{c}d)$	1869	$1.0 \cdot 10^{-12}$	315 μm
$D^0(c\bar{u}, u\bar{c})$	1864	$4.1 \cdot 10^{-13}$	123 μm
$D_s^{\pm}(c\bar{s}, \bar{c}s)$	1969	$4.9 \cdot 10^{-13}$	147 μm
$B^{\pm}(u\bar{b}, \bar{b}u)$	5279	$1.7 \cdot 10^{-12}$	502 μm
$B^0(b\bar{d}, d\bar{b})$	5279	$1.5 \cdot 10^{-12}$	462 μm
$B_s^0(s\bar{b}, \bar{s}b)$	5370	$1.5 \cdot 10^{-12}$	438 μm
$B_c^{\pm}(c\bar{b}, \bar{c}b)$	~6400	~$5 \cdot 10^{-13}$	150 μm
p (uud)	938.3	$>10^{33}$ y	∞
n (udd)	939.6	885.7 s	$2.655 \cdot 10^8$ km
Λ^0 (uds)	1115.7	$2.6 \cdot 10^{-10}$	7.89 cm
Σ^+ (uus)	1189.4	$8.0 \cdot 10^{-11}$	2.404 cm
Σ^- (dds)	1197.4	$1.5 \cdot 10^{-10}$	4.434 cm
Ξ^0 (uss)	1315	$2.9 \cdot 10^{-10}$	8.71 cm
Ξ^- (dss)	1321	$1.6 \cdot 10^{-10}$	4.91 cm
Ω^- (sss)	1672	$8.2 \cdot 10^{-11}$	2.461 cm
Λ_c^+ (udc)	2285	~$2 \cdot 10^{-13}$	60 μm
Ξ_c^+ (usc)	2466	$4.4 \cdot 10^{-13}$	132 μm
Ξ_c^0 (dcs)	2472	~$1 \cdot 10^{-13}$	29 μm
Ω_c^0 (ssc)	2698	$6.0 \cdot 10^{-14}$	19 μm
Λ_b (udb)	5620	$1.2 \cdot 10^{-12}$	368 μm

"Secondary Vertices"

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From the 'hundreds' of Particles listed by the PDG there are only ~27 with a life time $c\tau > \sim 1 \mu m$ i.e. they can be seen as 'tracks' in a Detector.

~13 of the 27 have $c\tau < 500 \mu m$ i.e. only ~mm range at GeV Energies.
→ "short" tracks measured with Emulsions or Vertex Detectors.

From the ~14 remaining particles

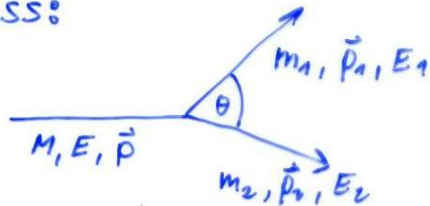$$e^{\pm}, \mu^{\pm}, \gamma, \pi^{\pm}, K^{\pm}, K^{o}, p^{\pm}, n$$

are <u>by far</u> the most frequent ones

A particle Detector must be able to <u>identify</u> and measure <u>Energy</u> and <u>Momenta</u> of these <u>8</u> particles.

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Basics

Invariant Mass:

LAB:

Relativity: $\tilde{a} = \begin{pmatrix} a_0 \\ \vec{a} \end{pmatrix}$ $\tilde{b} = \begin{pmatrix} b_0 \\ \vec{b} \end{pmatrix}$ $\tilde{a}\tilde{b} = a_0 b_0 - \vec{a}\vec{b}$

$$E = mc^2 \gamma \quad, \quad \vec{p} = m\vec{v}\gamma$$

$$\tilde{P} = \begin{pmatrix} \frac{E}{c} \\ \vec{p} \end{pmatrix} \quad, \quad \tilde{P}_1 = \begin{pmatrix} \frac{E_1}{c} \\ \vec{p}_1 \end{pmatrix} \quad, \quad \tilde{P}_2 = \begin{pmatrix} \frac{E_2}{c} \\ \vec{p}_2 \end{pmatrix}$$

$$\tilde{P} = \tilde{P}_1 + \tilde{P}_2 \qquad \text{Energy + Momentum Conservation}$$

$$\tilde{P}^2 = (\tilde{P}_1 + \tilde{P}_2)^2 \rightarrow \tilde{P}\tilde{P} = \tilde{P}_1\tilde{P}_1 + \tilde{P}_2\tilde{P}_2 + 2\tilde{P}_1\tilde{P}_2$$

$$M^2 c^2 = m_1^2 c^2 + m_2^2 c^2 + 2\left(\frac{E_1 E_2}{c^2} - p_1 p_2 \cos\theta\right)$$

- Measuring Momenta and Energies OR

- Measuring Momenta and identifying Particles

gives the Mass of the original Particle

Momentum Measurement

Magnetic Spectrometer: A charged particle describes a circle in a magnetic field:

$$\vec{B} \quad \otimes$$

$$p = q \cdot R \cdot B$$

$$p\left[\frac{GeV}{c}\right] = 0.3 \, R[m] \, B[T]$$
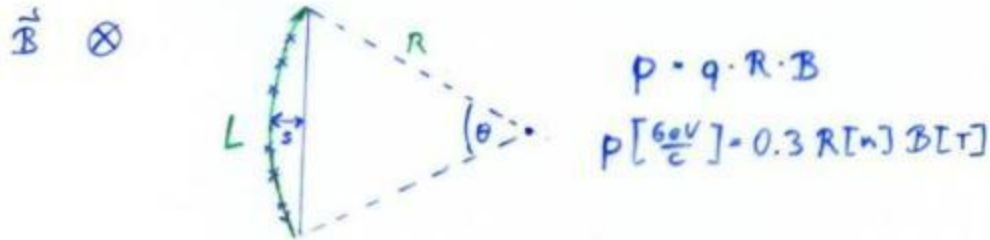
$$L = R \cdot \theta$$

$$S = R\left(1 - \cos\frac{\theta}{2}\right) \sim R\frac{\theta^2}{8} = \frac{L^2}{8R} \rightarrow R = \frac{L^2}{8S}$$

$$\Delta p = 0.3 \, B \, \Delta R = 0.3 \, B \, \frac{L^2}{8S^2} \, \Delta S$$

$$\Delta S = \frac{\sigma_x}{\sqrt{N}} \qquad \sigma_x \dots \text{point resolution}, \quad N \dots \text{Measured Points}$$

$$\boxed{\frac{\Delta p}{p} = \frac{\Delta S}{S} = \frac{\sigma_x[m]}{\sqrt{N}} \cdot \frac{3.3 \cdot 8 \, p\left[\frac{GeV}{c}\right]}{B[T] \cdot L^2[m]}}$$

E.g: $p = 10 \, \frac{GeV}{c}$, $B = 1T$, $L = 1m$, $\sigma = 200\mu m$, $N = 25$

$$\frac{\Delta p}{p} = 0.01 \rightarrow 1\%$$

Limit → Multiple Scattering

Multiple Scattering

Magnetic Deflection
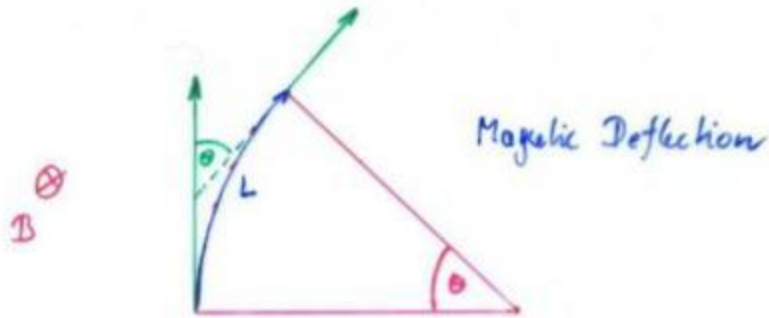
$$p\left[\frac{GeV}{c}\right] = 0.3 \ R[m] \ B[T]$$

$$\theta = \frac{L}{R} = \frac{L}{p} \cdot 0.3 \ B$$

$$\frac{\Delta p}{p} = \frac{\Delta \theta}{\theta} = \frac{\theta_0}{\theta} \sim \frac{0.05}{B[T] L[m]} \cdot \sqrt{\frac{L}{x_0}}$$

$\rightarrow$ Independent of p

$$\frac{\Delta p}{p}\bigg|_{tot} = \sqrt{\left(\frac{\Delta p}{p}\bigg|_{Sag}\right)^2 + \left(\frac{\Delta p}{p}\bigg|_{ms}\right)^2}$$

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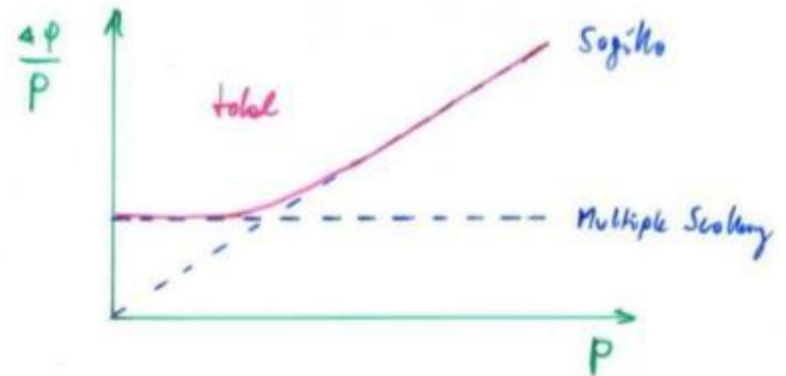
Multiple Scattering

ATLAS Muon Spectrometer:

N=3, sig=50um, P=1TeV,

L=5m, B=0.4T

$\Delta p/p \sim 8\%$ for the most energetic muons at LHC

π⁻

ρ

γ₁

Λ°

K⁺

γ₂

K°

π°

Ω⁻

π⁻

K⁻

W. Riegler/CERN

$e^{\pm}$ $m_e = 0.511$ MeV

$\mu^{\pm}$ $m_\mu = 105.7$ MeV $\sim 200\, m_e$

γ $m_\gamma = 0$, $Q = 0$

} EM

$\pi^{\mp}$ $m_\pi = 139.6$ MeV $\sim 270\, m_e$

$K^{\pm}$ $m_k = 493.7$ MeV $\sim 1000\, m_e$

$p^{\pm}$ $m_p = 938.3$ MeV $\sim 2000\, m_e$

} EM, Strong

$\sim 3.5\, m_\pi$

K^0 $m_{k^0} = 497.7$ MeV $Q = 0$

n $m_n = 939.6$ MeV $Q = 0$

} Strong

The Difference in

Mass, Charge, Interaction

is the key to the Identification

Tracking:

Momentum by bending in the B-field

Secondary vertices

Calorimeter:

Energy by absorption

Muons:

Only particles passing through calorimeters

TRACKING velocity measurement	CALORIMETERS electromagnetic hadronic		MUONS	

ELECTRONS — $e^{\pm}$

PHOTONS — γ

CHARGED HADRONS — $p^{\pm}, k^{\pm}, \pi^{\pm}$

NEUTRAL HADRONS (e.g. neutrons) — k^0, n

MUONS — $\mu^{\pm}$

100 – 200   50 – 100   200 – 400   200 – 400

Typical dimensions [cm]

$\vec{B} \oslash$ High   High   Tracking

Low
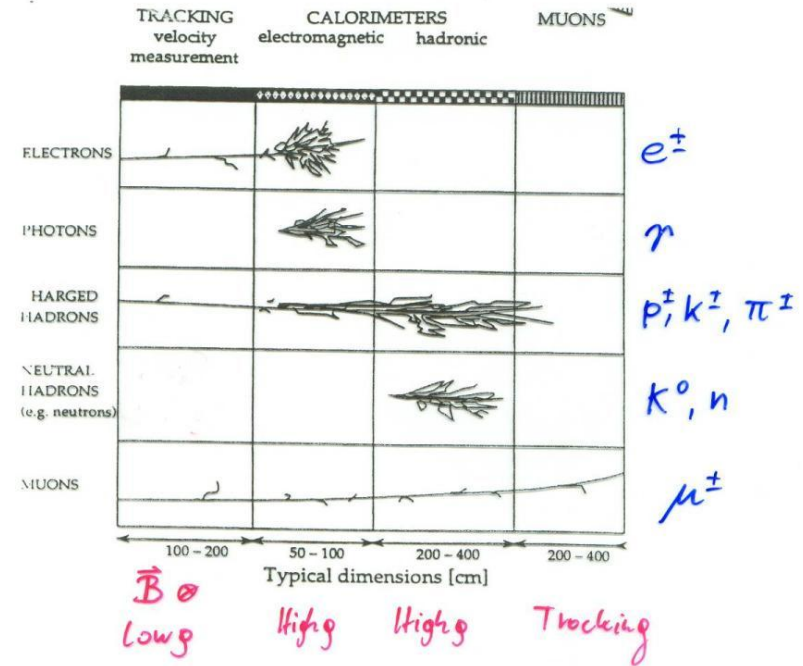
- Electrons ionize and show Bremsstrahlung due to the small mass

- Photons don't ionize but show Pair Production in high Z Material. From then on equal to $e^{\pm}$

- Charged Hadrons ionize and show Hadron Shower in dense material.

- Neutral Hadrons don't ionize and show Hadron Shower in dense Material

- Myons ionize and don't shower

ATLAS

Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t

CERN AC - ATLAS V1997

Muon Detectors

Electromagnetic Calorimeters

Solenoid

Forward Calorimeters

End Cap Toroid

Barrel Toroid

Inner Detector

Hadronic Calorimeters

Shielding

ACORDE

EMCal

TOF

TRD

PMD V0

Absorber

Tracking Chambers

Dipole Magnet

Trigger Chamber

HMPID

L3 Magnet

PHOS

ITS

TPC

CMS

vacuum chamber

central detector
electromagnetic calorimeter

hadronic calorimeter

superconducting coil

return yoke

muon chambers

Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

Vertex Detector
Inner Tracking Chamber
Time Projection Chamber
Electromagnetic Calorimeter
Hadron Calorimeter
Muon Detectors
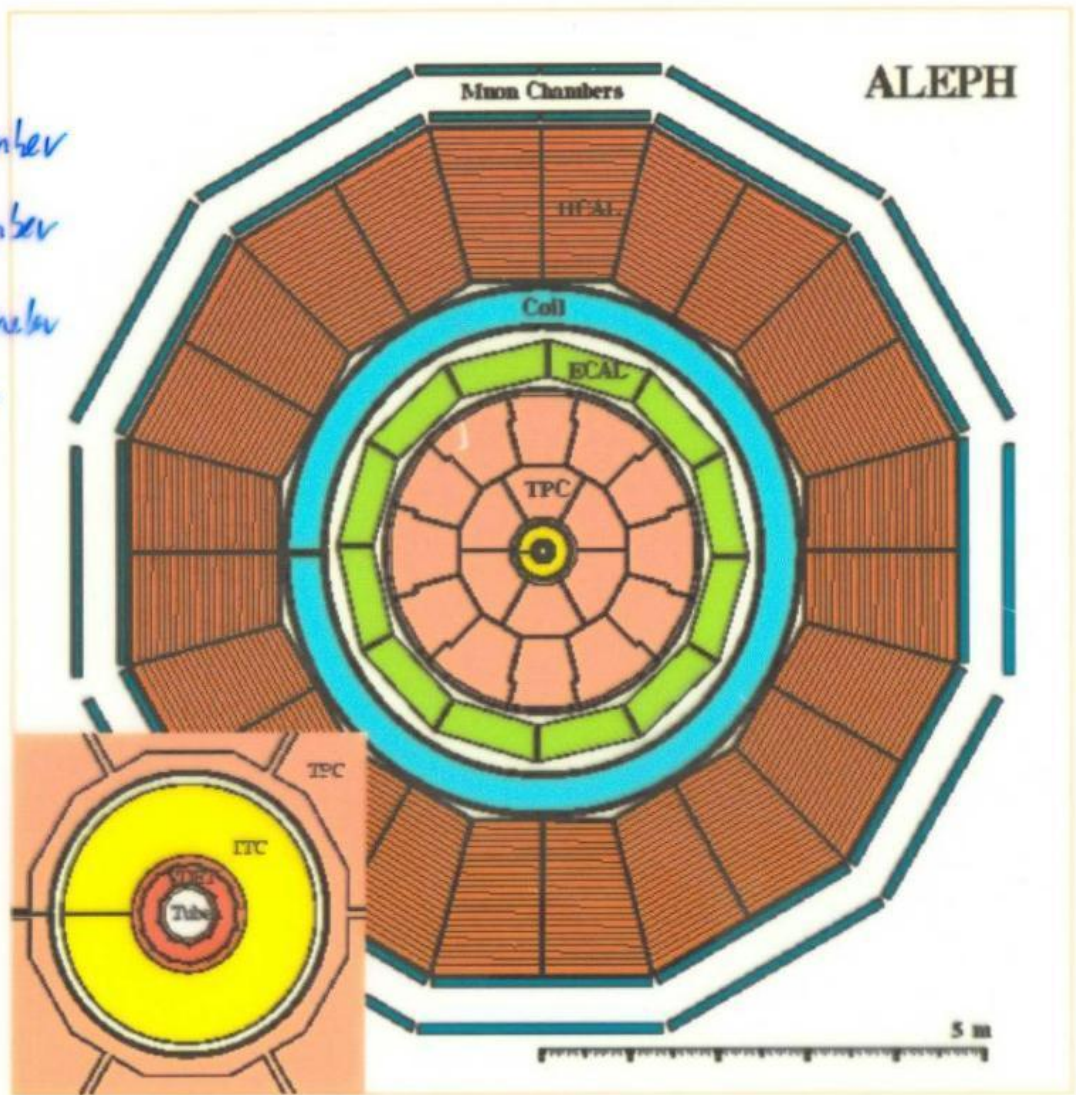
Fig. 1 - The ALEPH Detector
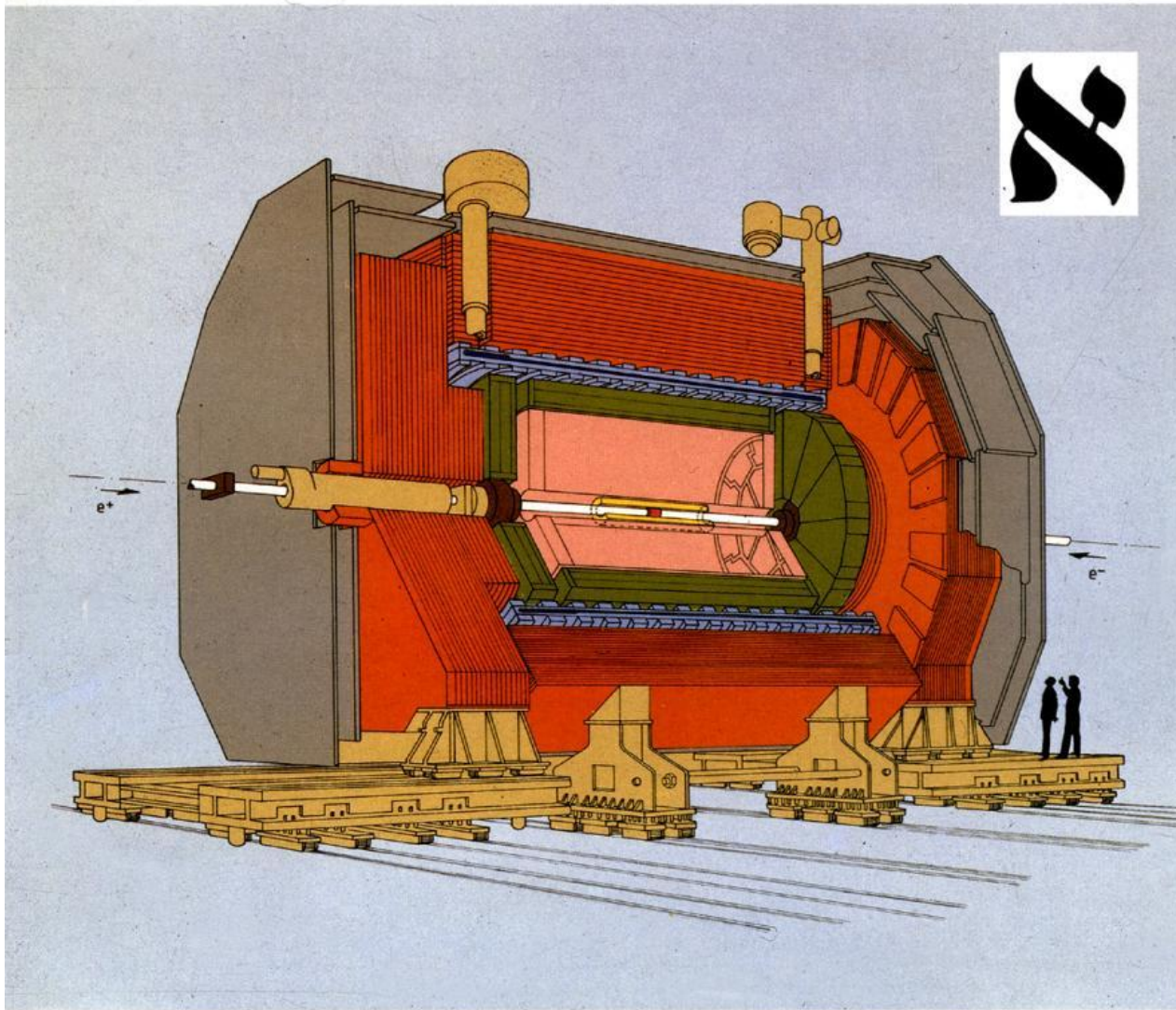
Vertex Detector

Inner Track Chamber

Time Projection Chamber

Electromagnetic Calorimeter

Superconducting Magnet Coil

Hadron Calorimeter

Muon Detection Chambers

Luminosity Monitors

W. Riegler/CERN

$\gamma, e^{\pm}, \pi^{\pm}, k^{\pm}$

$k^0, p, n, \mu^{\pm}$
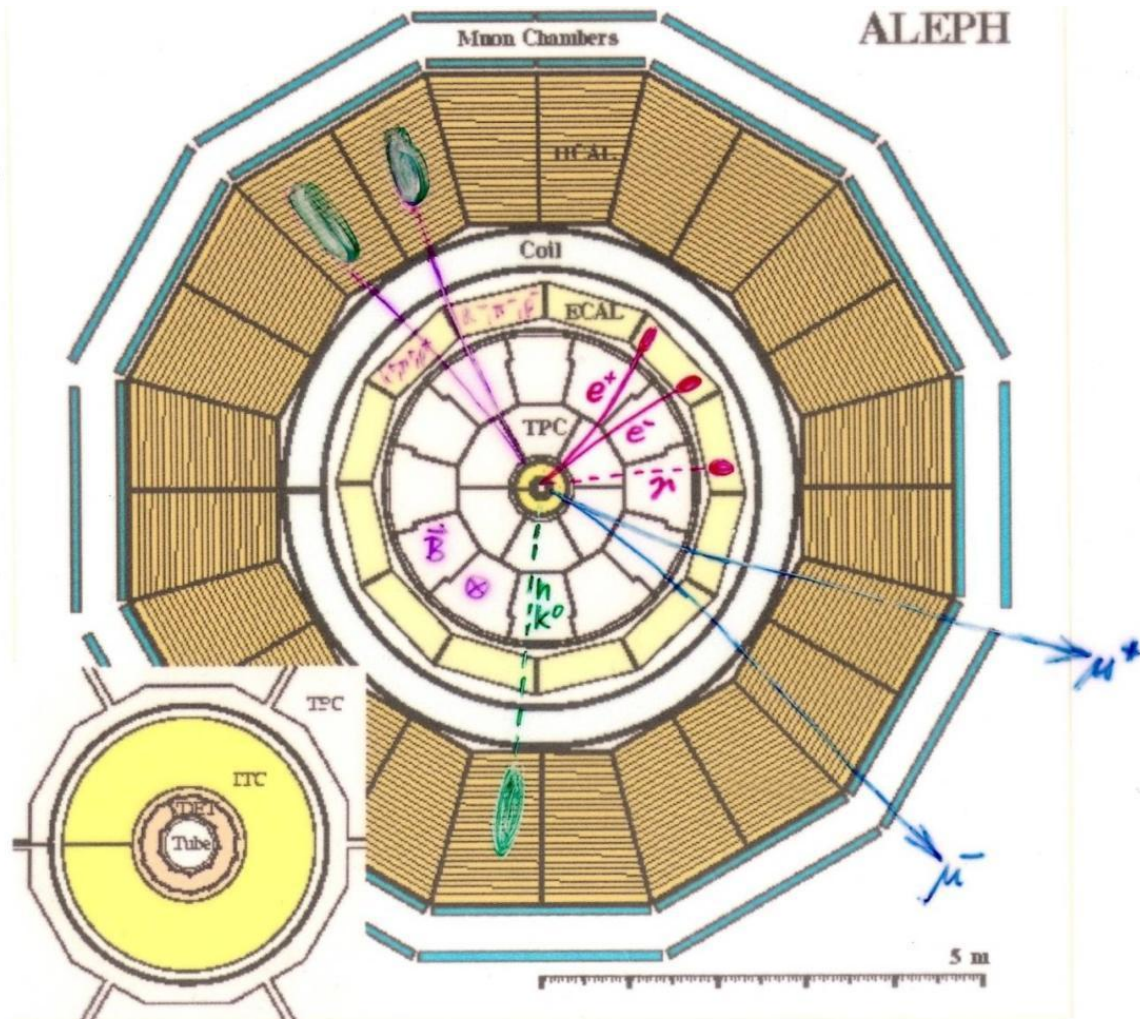
CMS
A Compact Solenoidal Detector for LHC

FORWARD CALORIMETER   MUON CHAMBERS   TRACKER   CRYSTAL ECAL   HCAL

SUPERCONDUCTING COIL

RETURN YOKE

Total weight   : 12,500t.
Overall diameter : 15.00m
Overall length   : 21.60m
Magnetic field   : 4 Tesla

0m   1m   2m   3m   4m   5m   6m   7m

Key:
— Muon
— Electron
— Charged Hadron (e.g. Pion)
- - - Neutral Hadron (e.g. Neutron)
- - - Photon

4T

2T

Silicon
Tracker

Electromagnetic
Calorimeter

Hadron
Calorimeter

Superconducting
Solenoid

Iron return yoke interspersed
with Muon chambers

Transverse slice
through CMS

D. Barney, CERN, February 2004

W. Riegler/CERN

Z → e⁺ e⁻

Two high momentum charged particles depositing energy in the Electro Magnetic Calorimeter

W. Riegler/CERN

Z → μ⁺ μ⁻
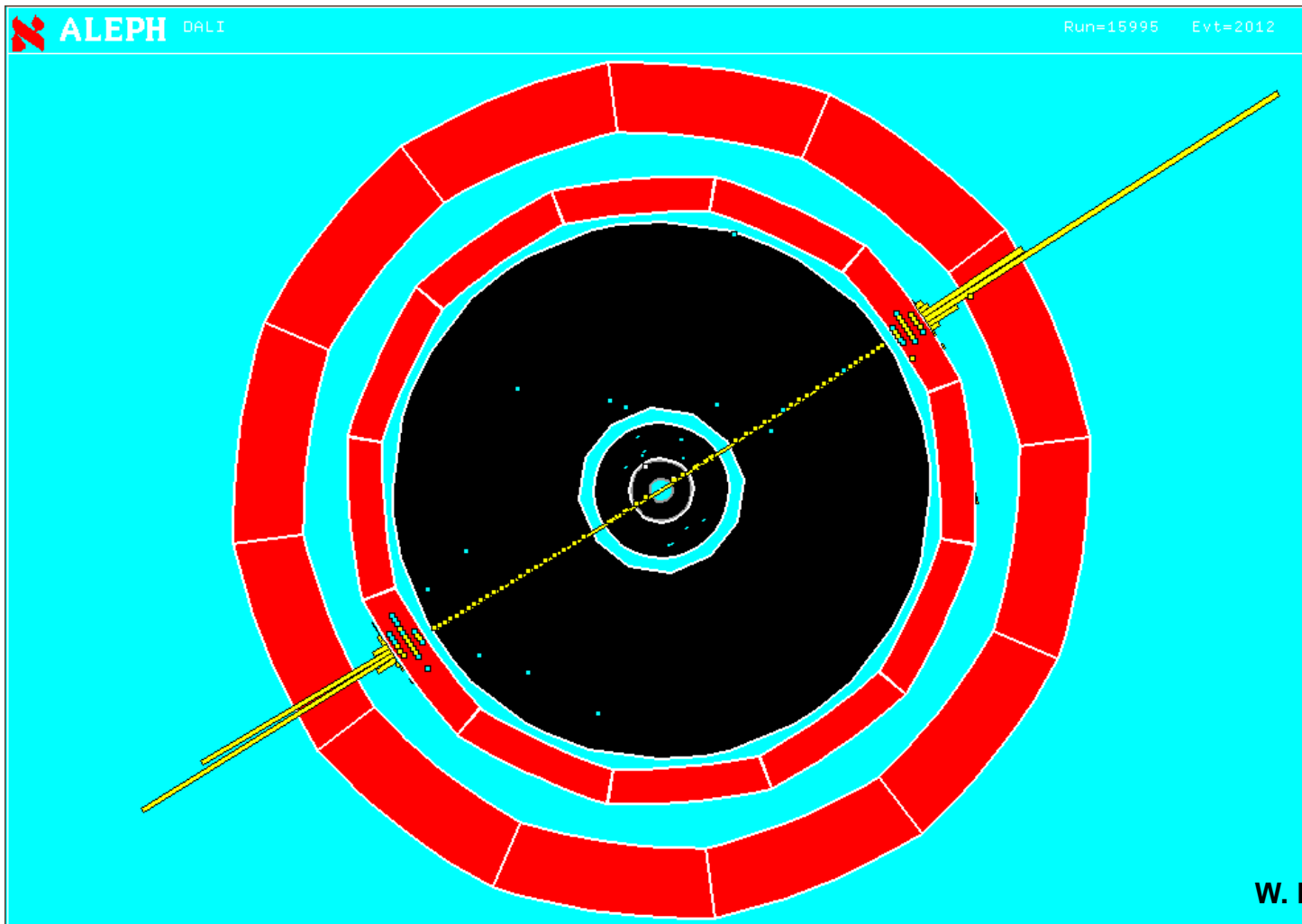
Two high momentum charged particles traversing all calorimeters and leaving a signal in the muon chambers.

W. Riegler/CERN
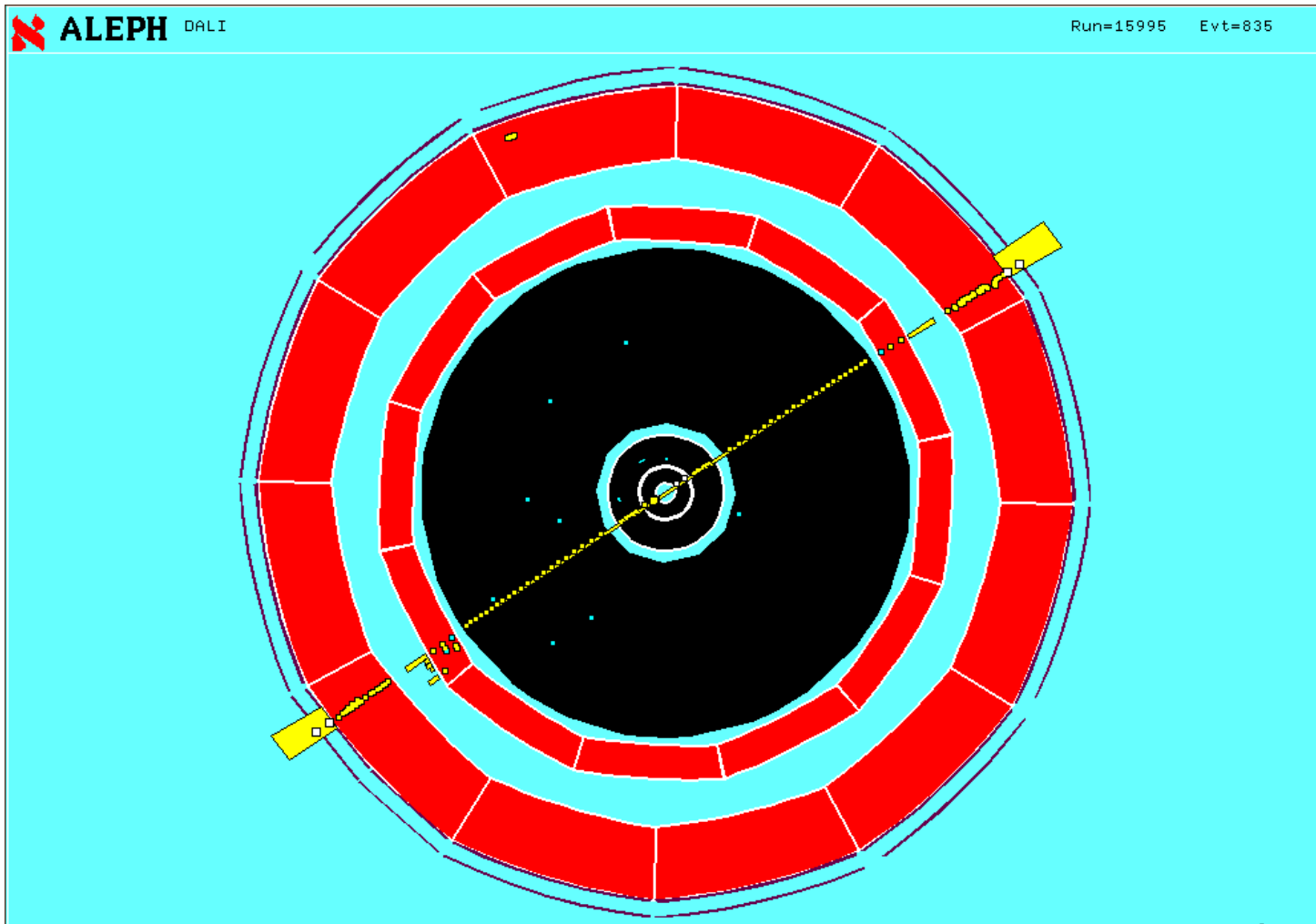
Interaction of Particles with Matter

Any device that is to detect a particle must interact with it in some way → almost …

In many experiments neutrinos are measured by missing transverse momentum.

E.g. e^+e^- collider. $P_{tot}=0$,

If the $\Sigma\, p_i$ of all collision products is ≠0 → neutrino escaped.

"Did you see it?"
"No nothing."
"Then it was a neutrino!"

W. Riegler/CERN

$W^+W^- \rightarrow e+ \mu+ \nu_e + \nu_\mu$

Single electron, single Muon, Missing Momentum

W. Riegler/CERN
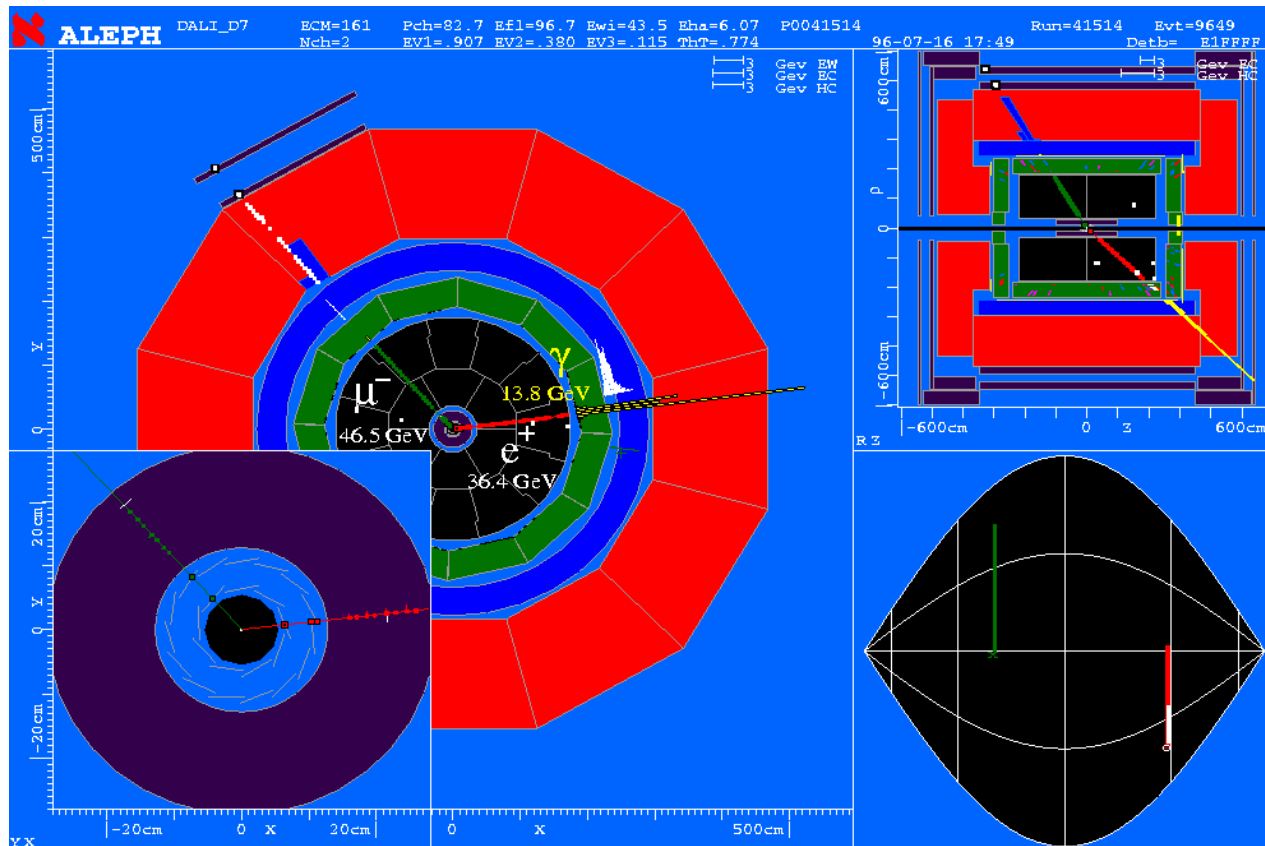
$Z \rightarrow q \bar{q}$

Two jets of particles

W. Riegler/CERN
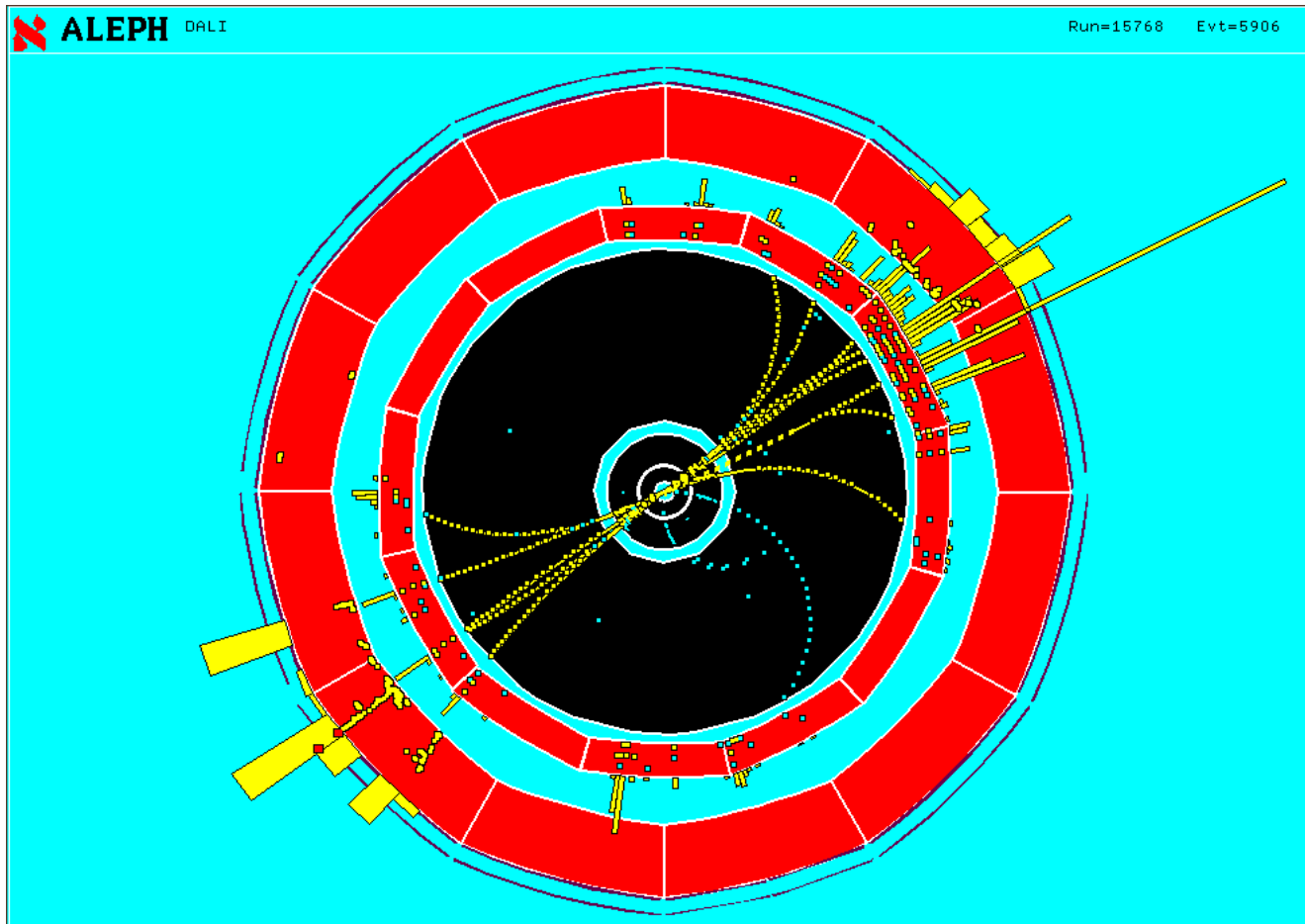
Z → q q̄ g

Three jets of particles

W. Riegler/CERN
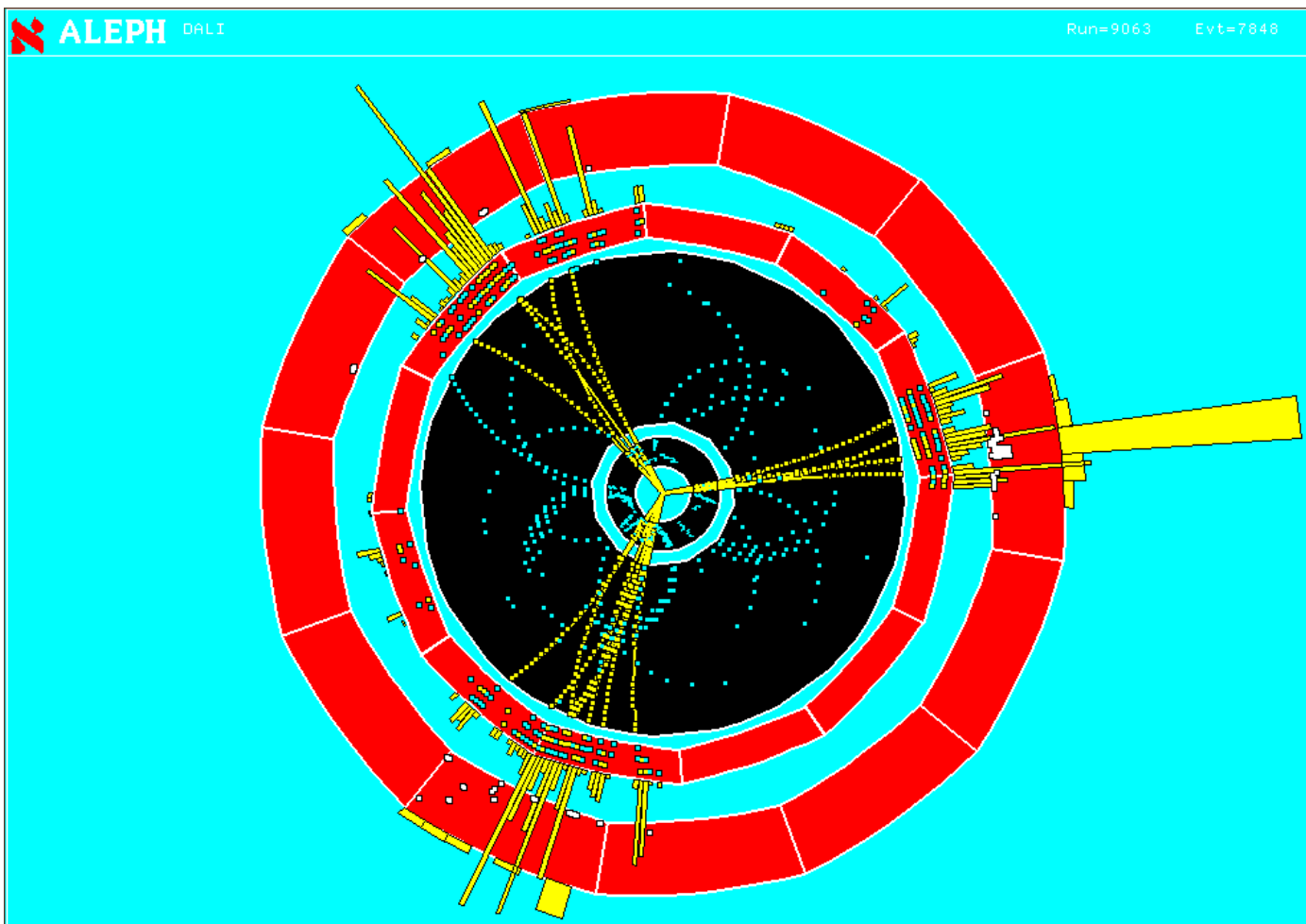
Two secondary vertices with characteristic decay particles giving invariant masses of known particles.

Bubble chamber like – a single event tells what is happening. Negligible background.
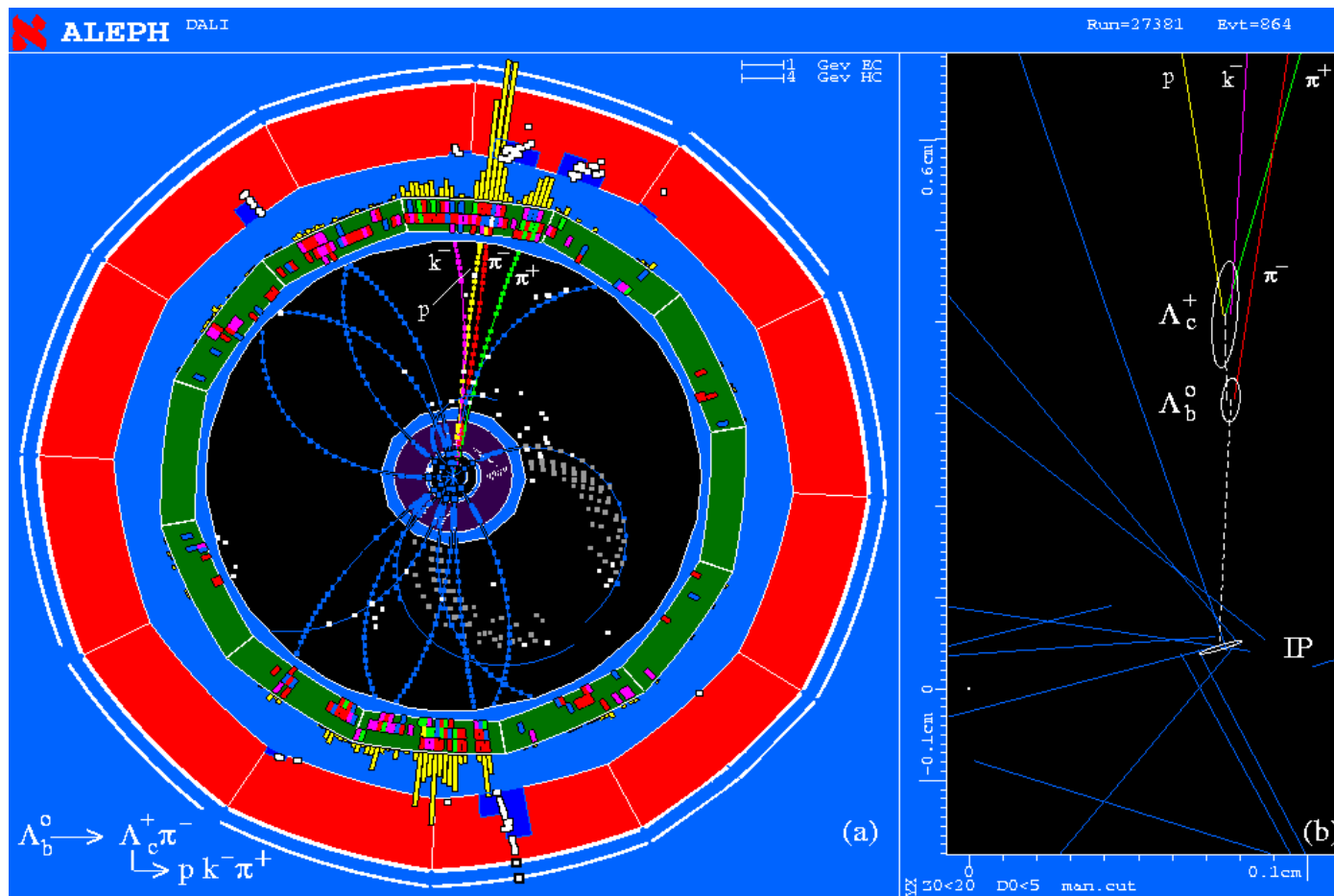
ALEPH Higgs Candidate
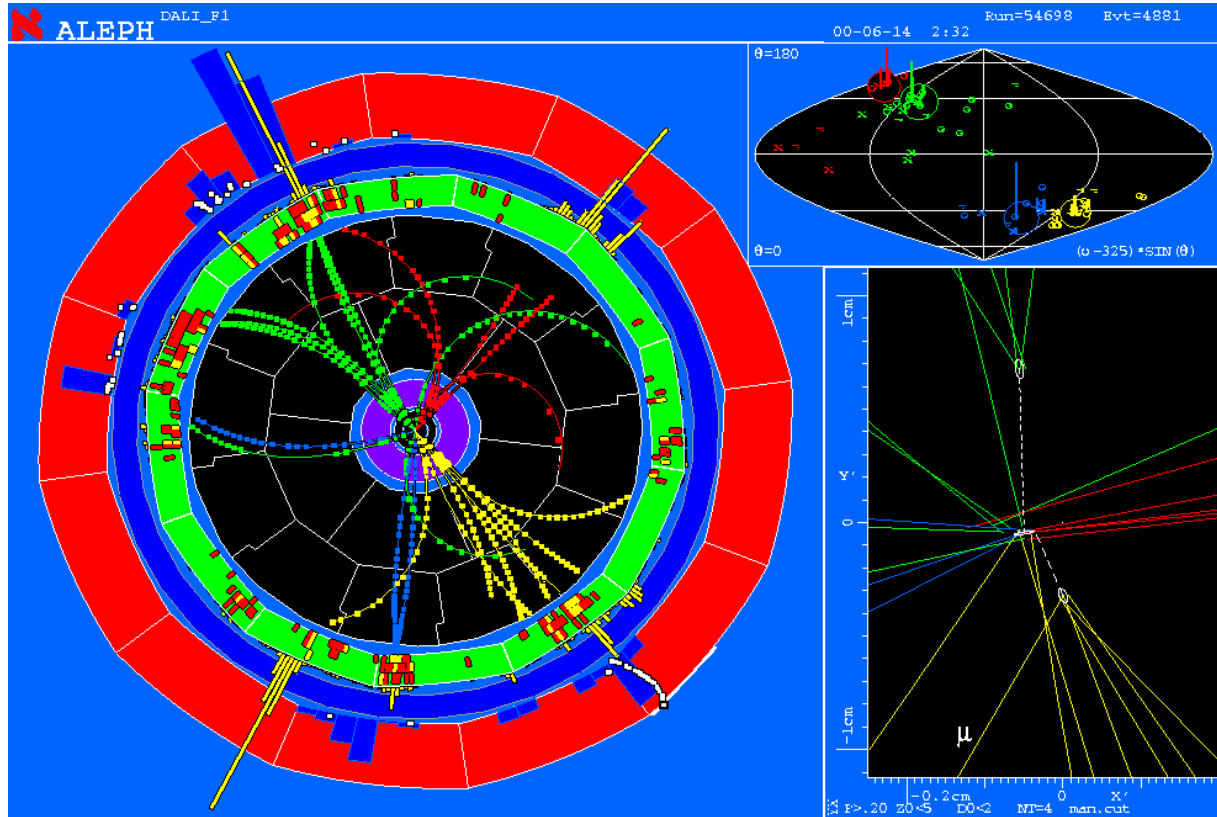
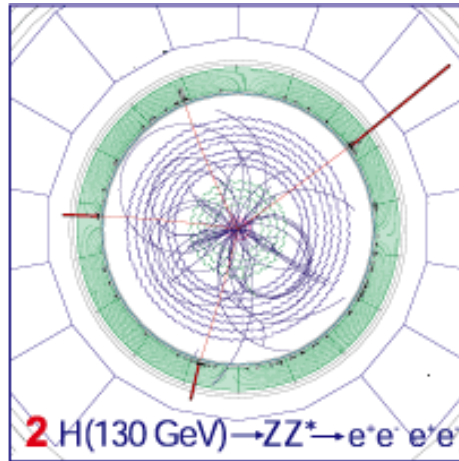**Undistinguishable background exists. Only statistical excess gives signature.**

2010 ATLAS W, Z candidates !

W. Riegler/CERN

2010 ATLAS W, Z candidates !

W. Riegler/CERN

Higgs Boson at CMS

1 H(100 GeV) → γγ

2 H(130 GeV) → ZZ* → e⁺e⁻ e⁺e⁻

3 H(150 GeV) → ZZ* → μ⁺μ⁻μ⁺μ⁻

4 H(800 GeV) → ZZ → e⁺e⁻ jet jet

$H \to \gamma\gamma$
$M_H = 130$ GeV

Higgs signal
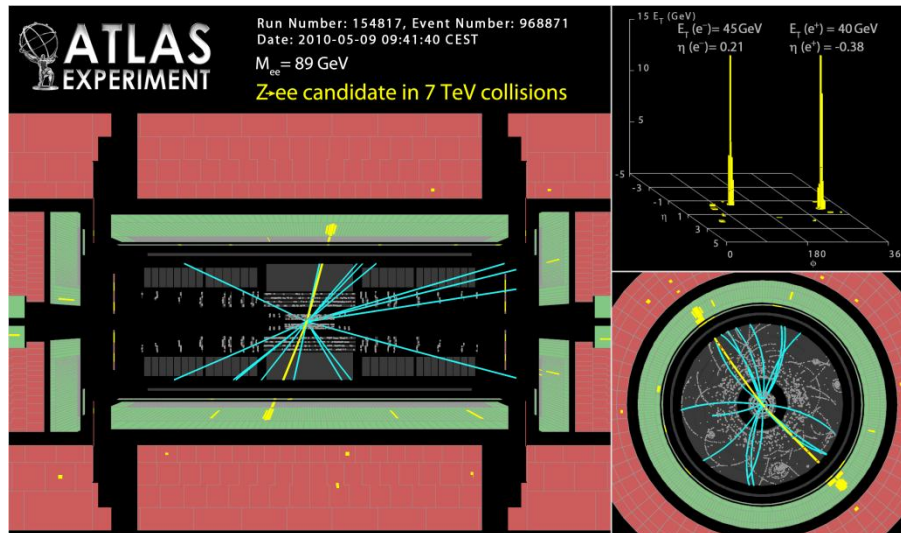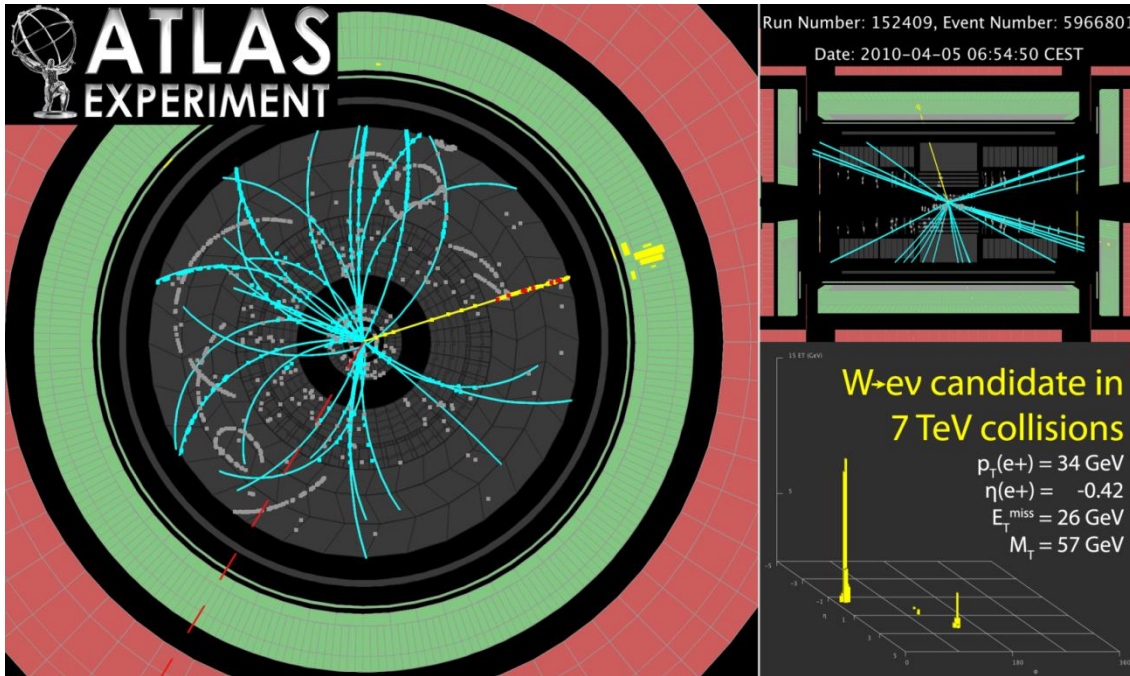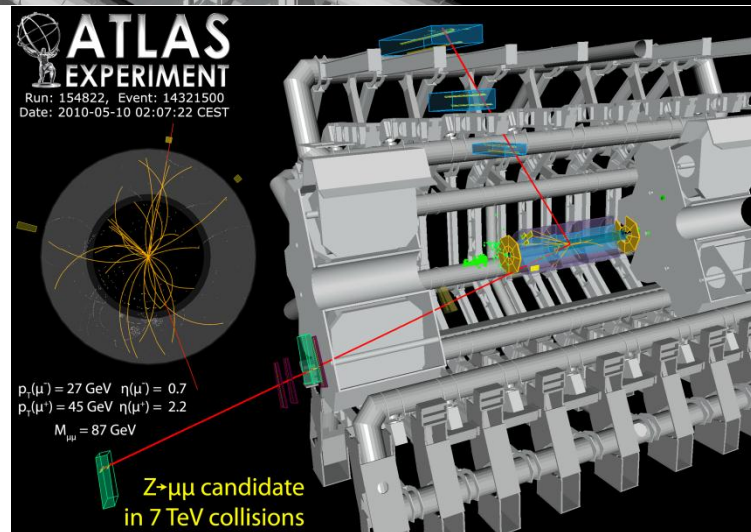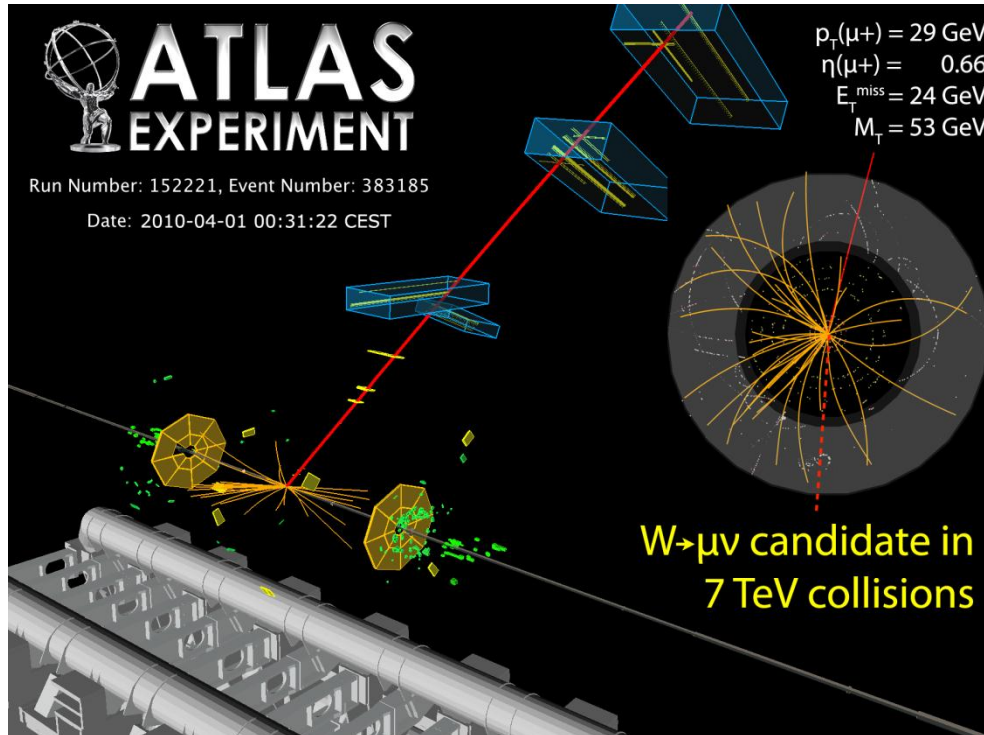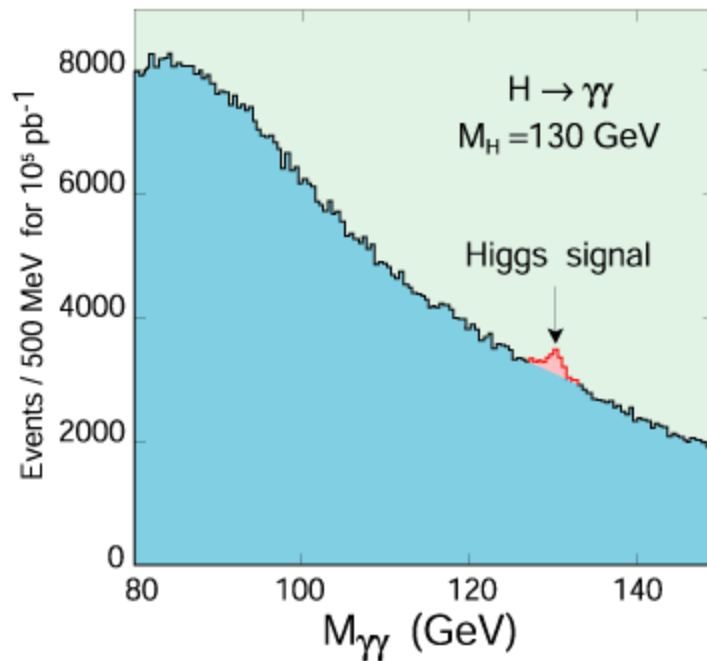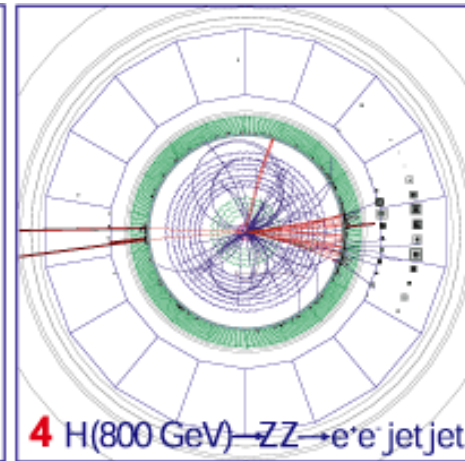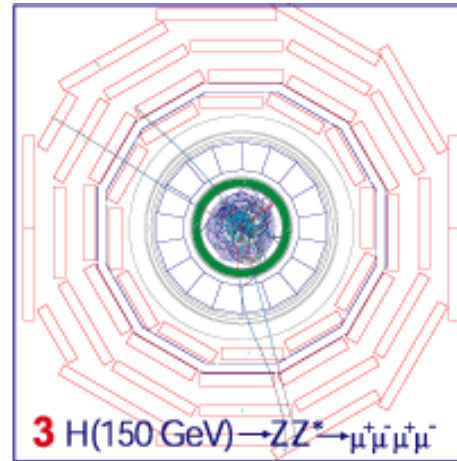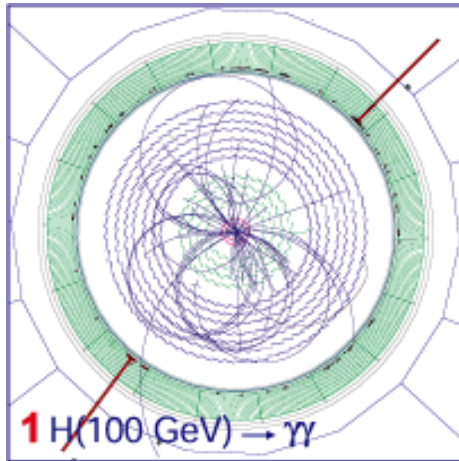
Particle seen as an excess of two photon events above the irreducible background.

W. Riegler/CERN
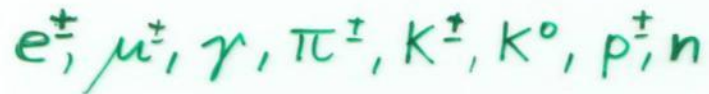
Principles:

Only a few of the numerous known particles have lifetimes that are long enough to leave tracks in a detector.

Most of the particles are measured though the decay products and their kinematic relations (invariant mass). Most particles are only seen as an excess over an irreducible background.

Some short lived particles (b,c –particles) reach lifetimes in the laboratory system that are sufficient to leave short tracks before decaying → identification by measurement of short tracks.

In addition to this, detectors are built to measure the

8 particles

$$e^{\pm}, \mu^{\pm}, \gamma, \pi^{\pm}, K^{\pm}, K^{o}, p^{\pm}, n$$

Their difference in mass, charge and interaction is the key to their identification.

Detector Technologies

Solid state detectors close to the collision point for excellent position resolution to find primary and secondary vertices → silicon pixel detectors.

Solid state detectors (silicon strip detectors) or gas detectors at larger distances for tracking and momentum measurement.
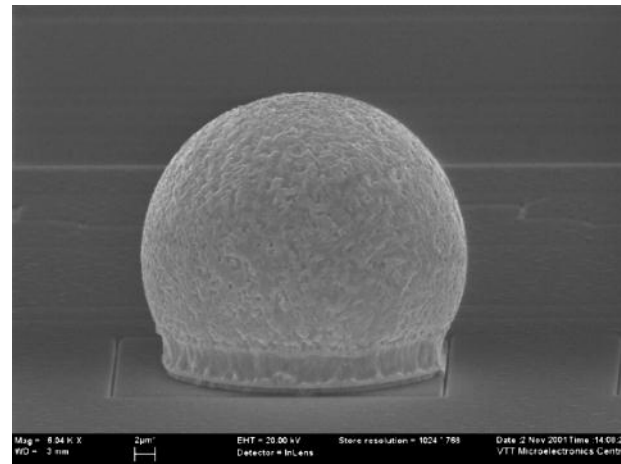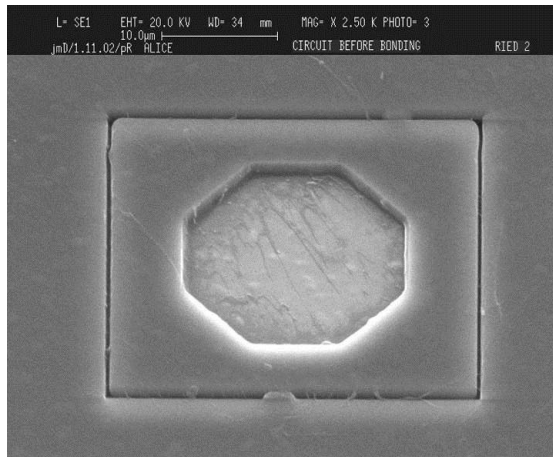
Massive calorimeters with alternating layers of passive absorber material and active detector material for measurement of particle energies.
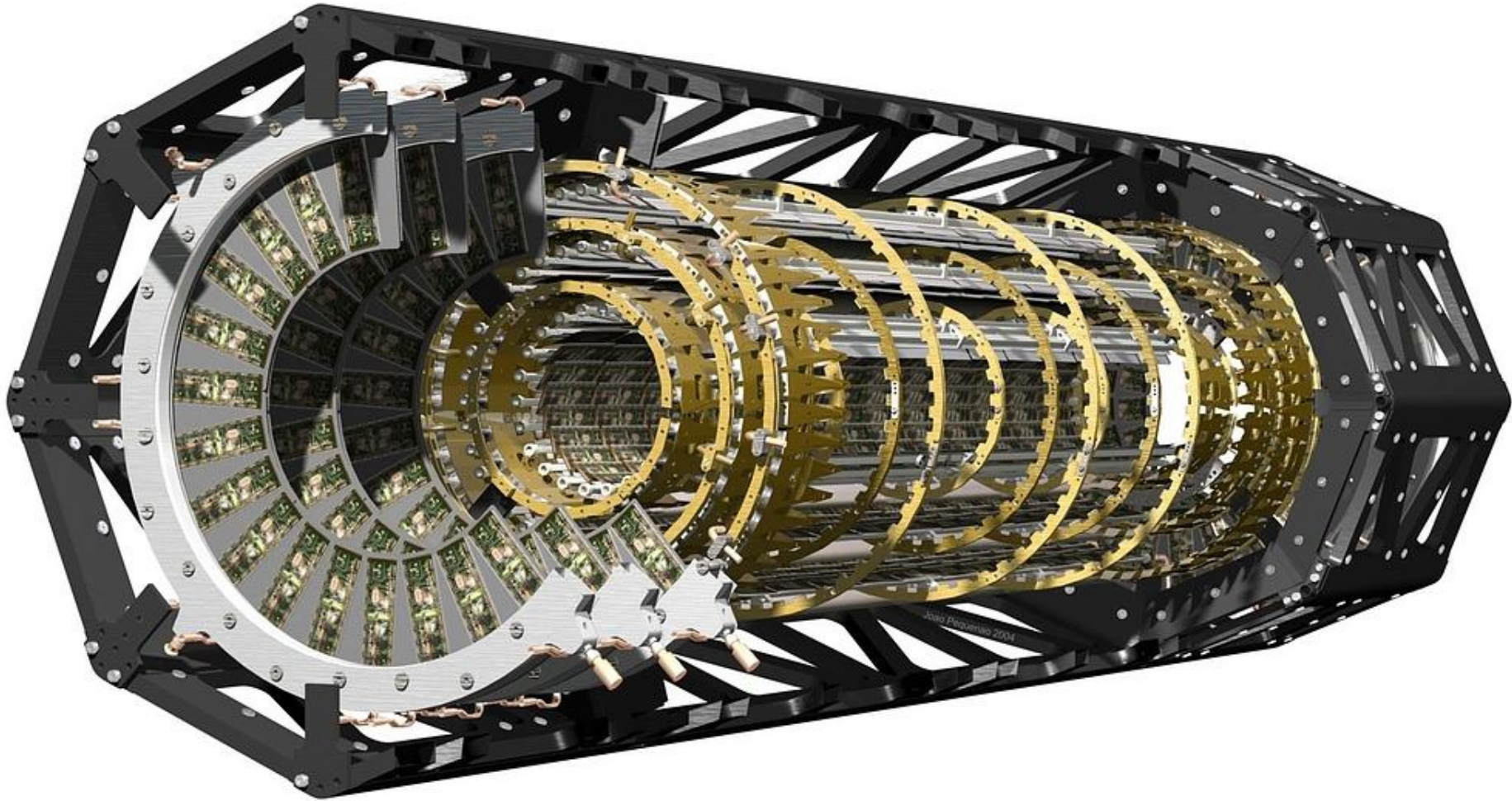
Silicon Pixel Detectors
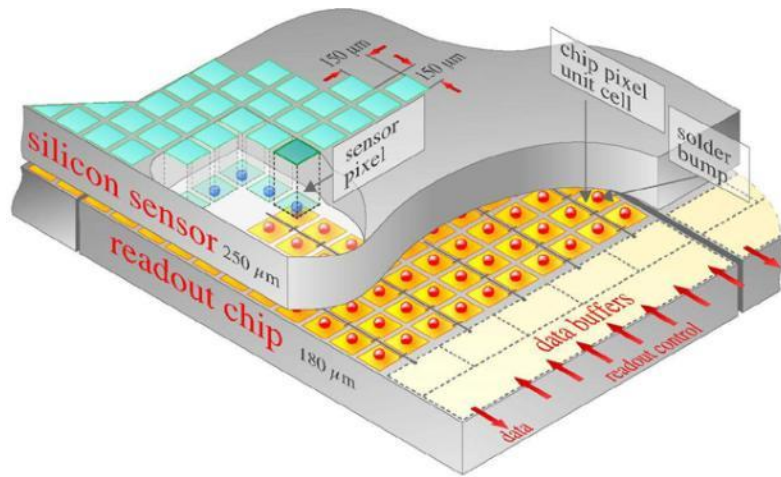
ATLAS: 1.4x10^8 pixels

40 000 000 'images' per second.

Solid State Detectors

ATLAS Silicon Pixel Detector

Silicon Strip Detectors

Every electrode is connected to an amplifier →
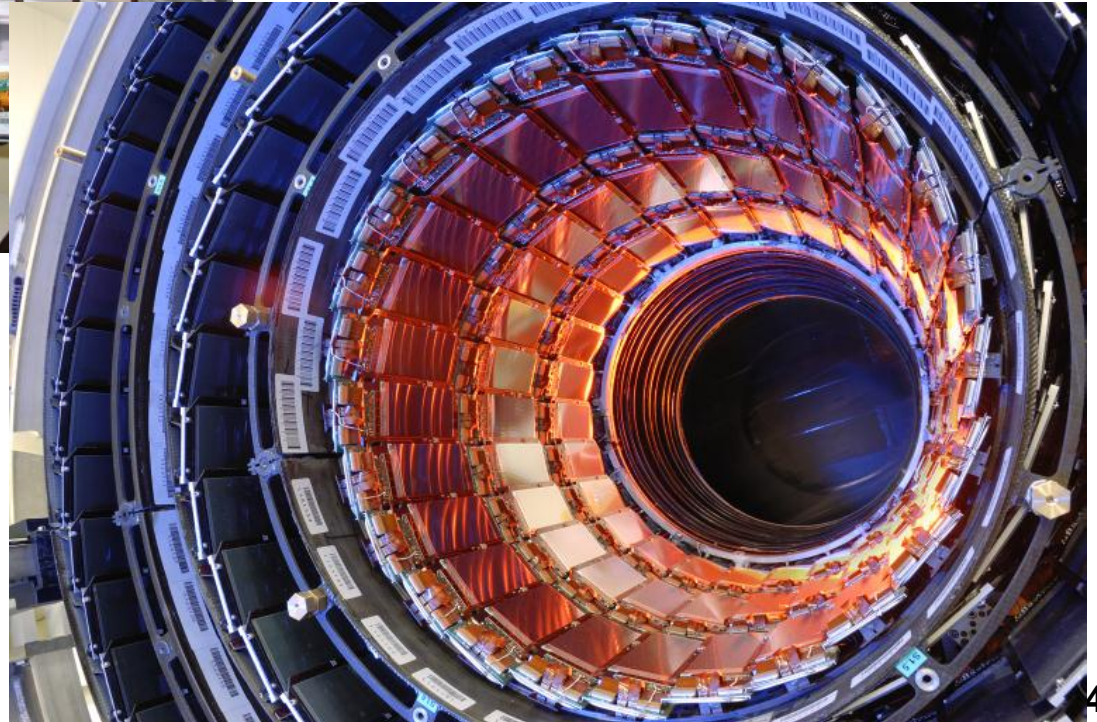**Highly integrated readout electronics.**

Two dimensional readout is possible.
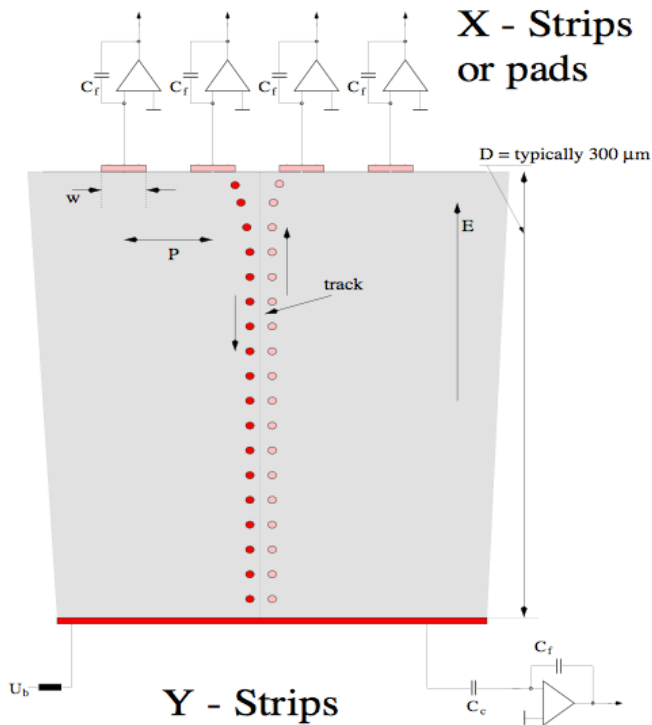
CMS Outer Barrel Module

Solid State Detectors

W. Riegler/CERN

Silicon Strip Detectors

W. Riegler/CERN
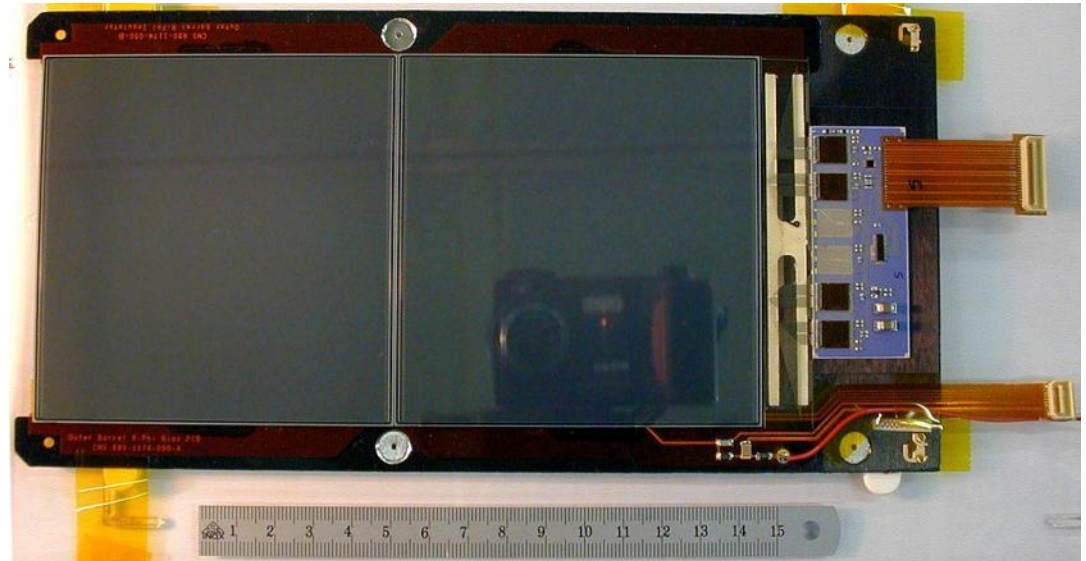
Time Projection Chamber (TPC):

Gas volume with parallel E and B Field.
B for momentum measurement. Positive effect:
**Diffusion is strongly reduced by E//B (up to a factor 5).**

**Drift Fields 100-400V/cm. Drift times 10-100 μs.**
Distance up to 2.5m !

gas volume

B

drift

E

y

x

z

charged track

Wire Chamber to detect the tracks

ALEPH DALI

Run=15768   Evt=5906

O.Ullaland CERN 2005
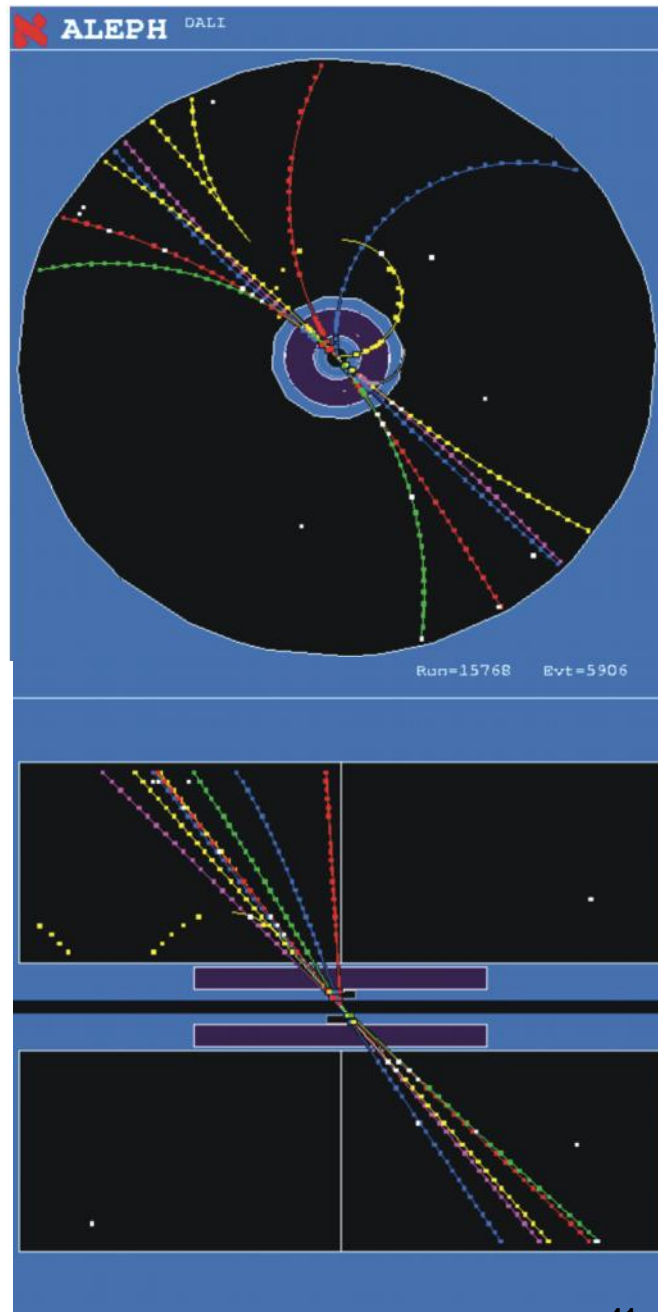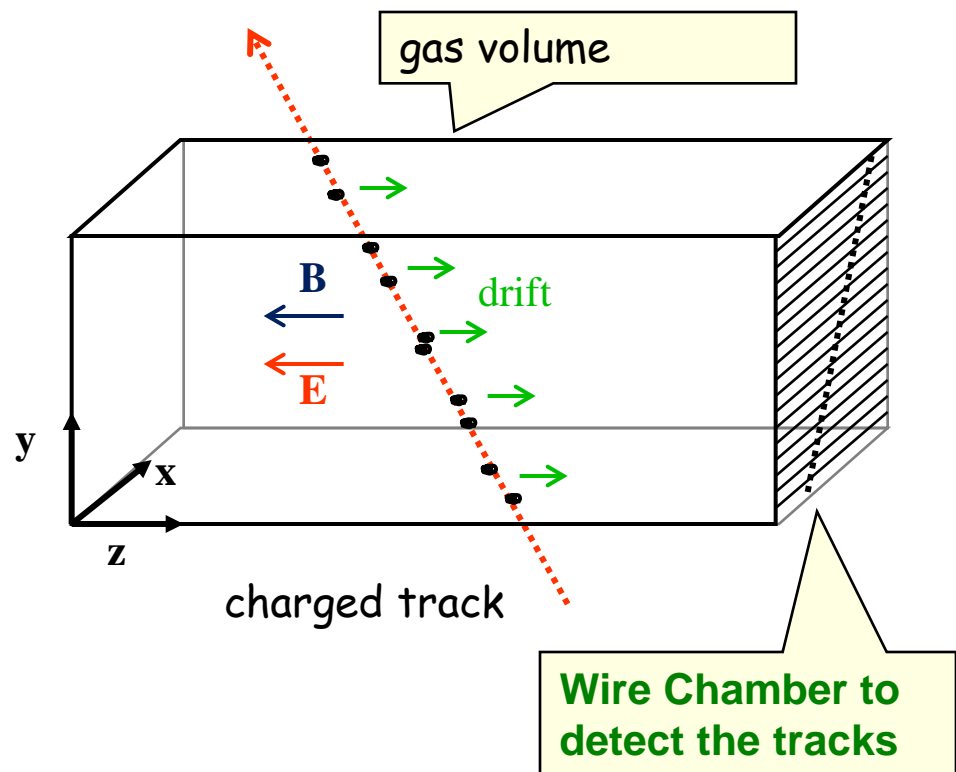
ALICE TPC: Construction Parameters

- **Largest TPC:**
  - **Length 5m**
  - **Diameter 5m**
  - **Volume 88m^3**
  - **Detector area 32m^2**
  - **Channels ~570 000**

- **High Voltage:**
  - **Cathode -100kV**

- **Material X_0**
  - **Cylinder from composite materials from airplane industry (X_0= ~3%)**
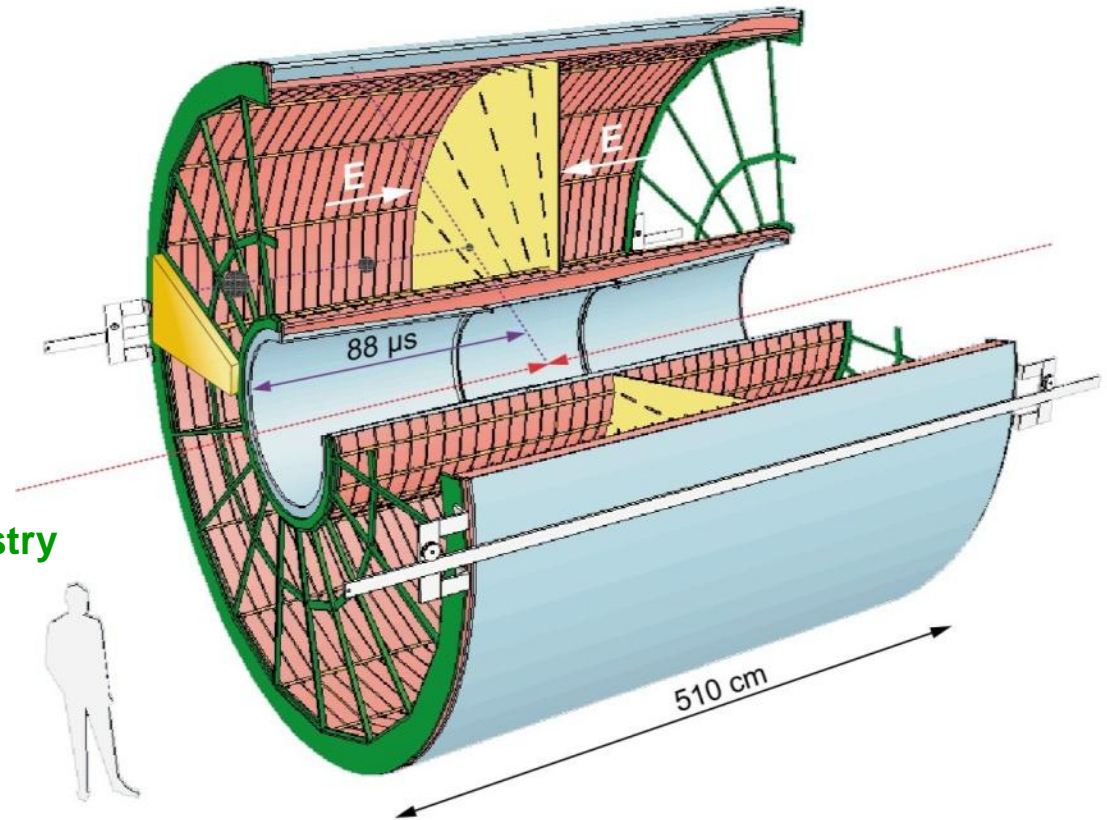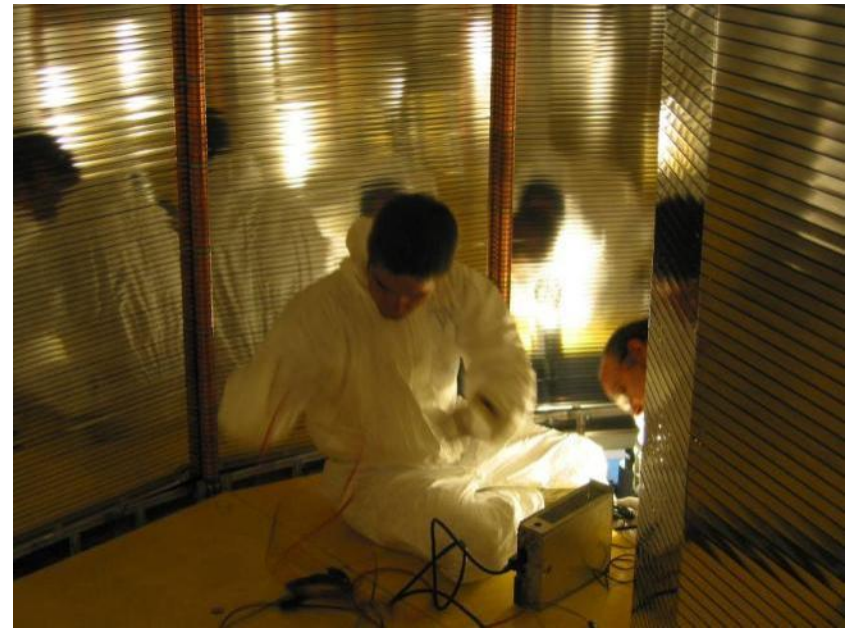
ALICE TPC: Pictures of the Construction

Precision in z: 250μm
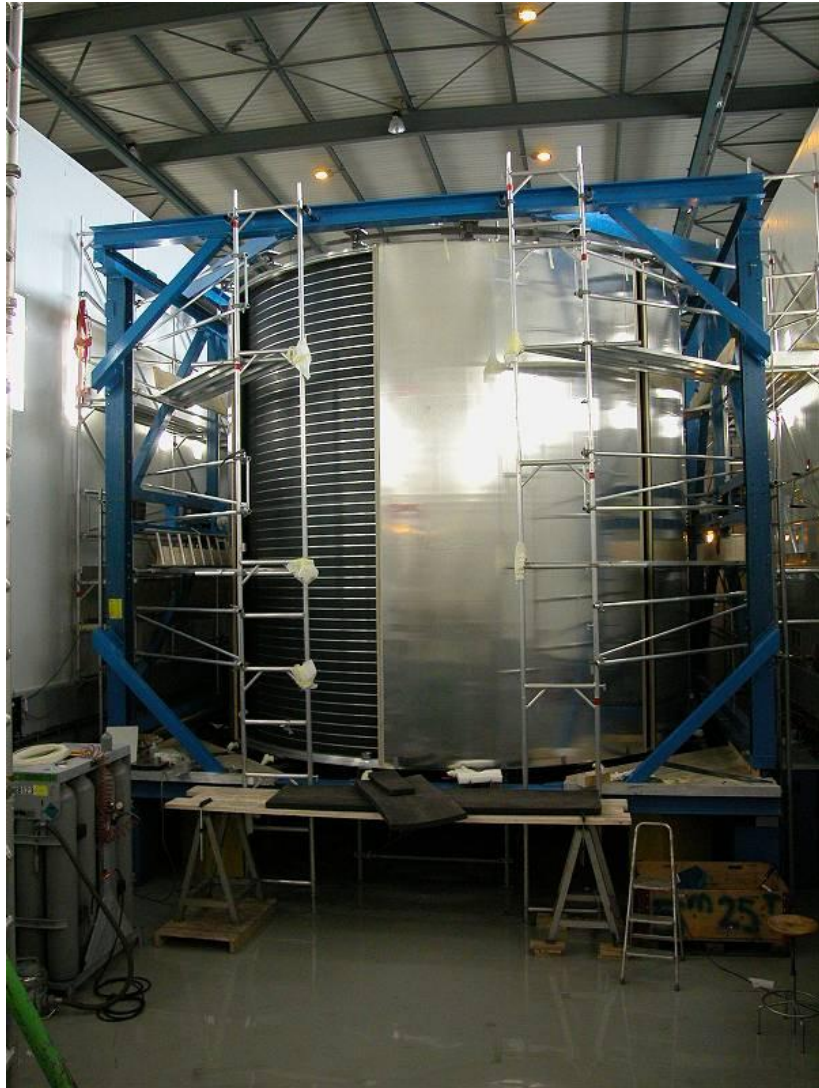
End plates 250μm

Wire chamber: 40μm

ALICE TPC Construction

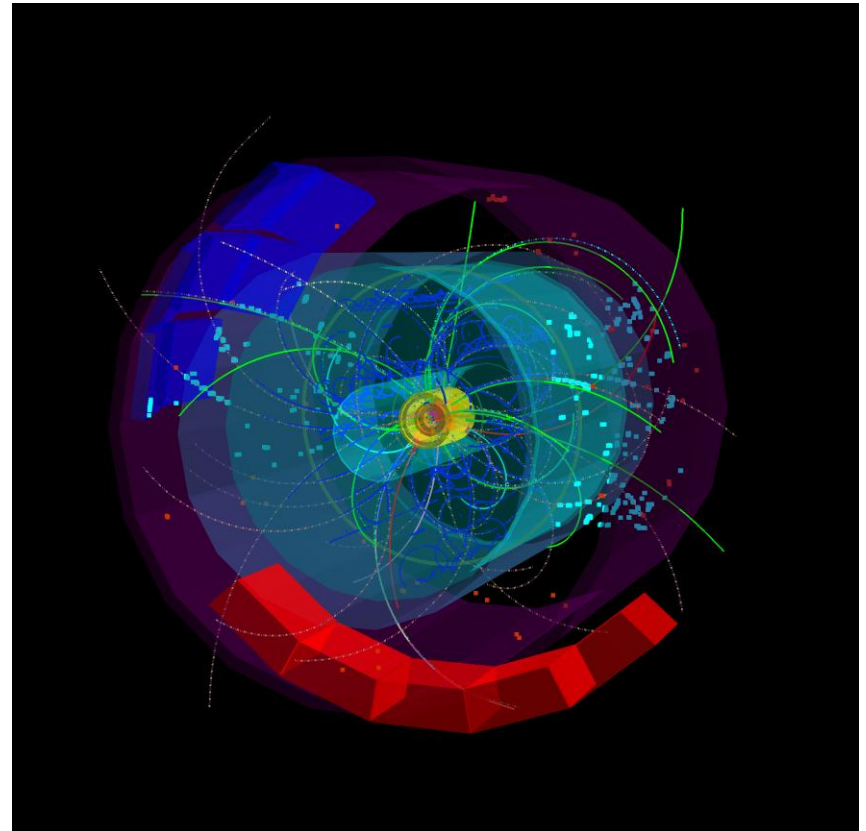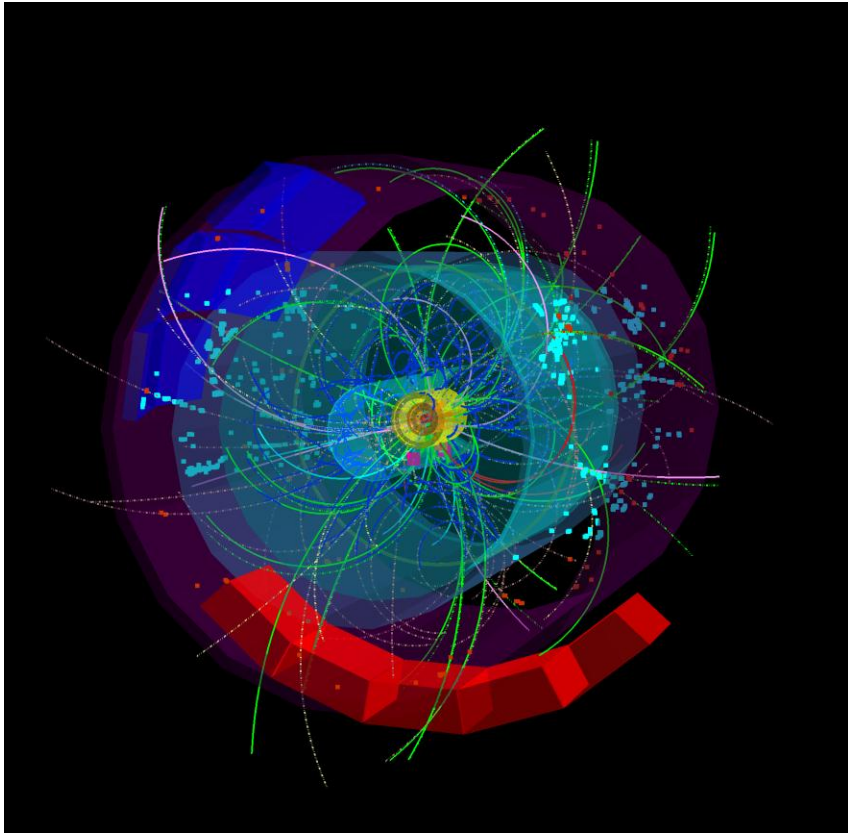**My personal contribution:**
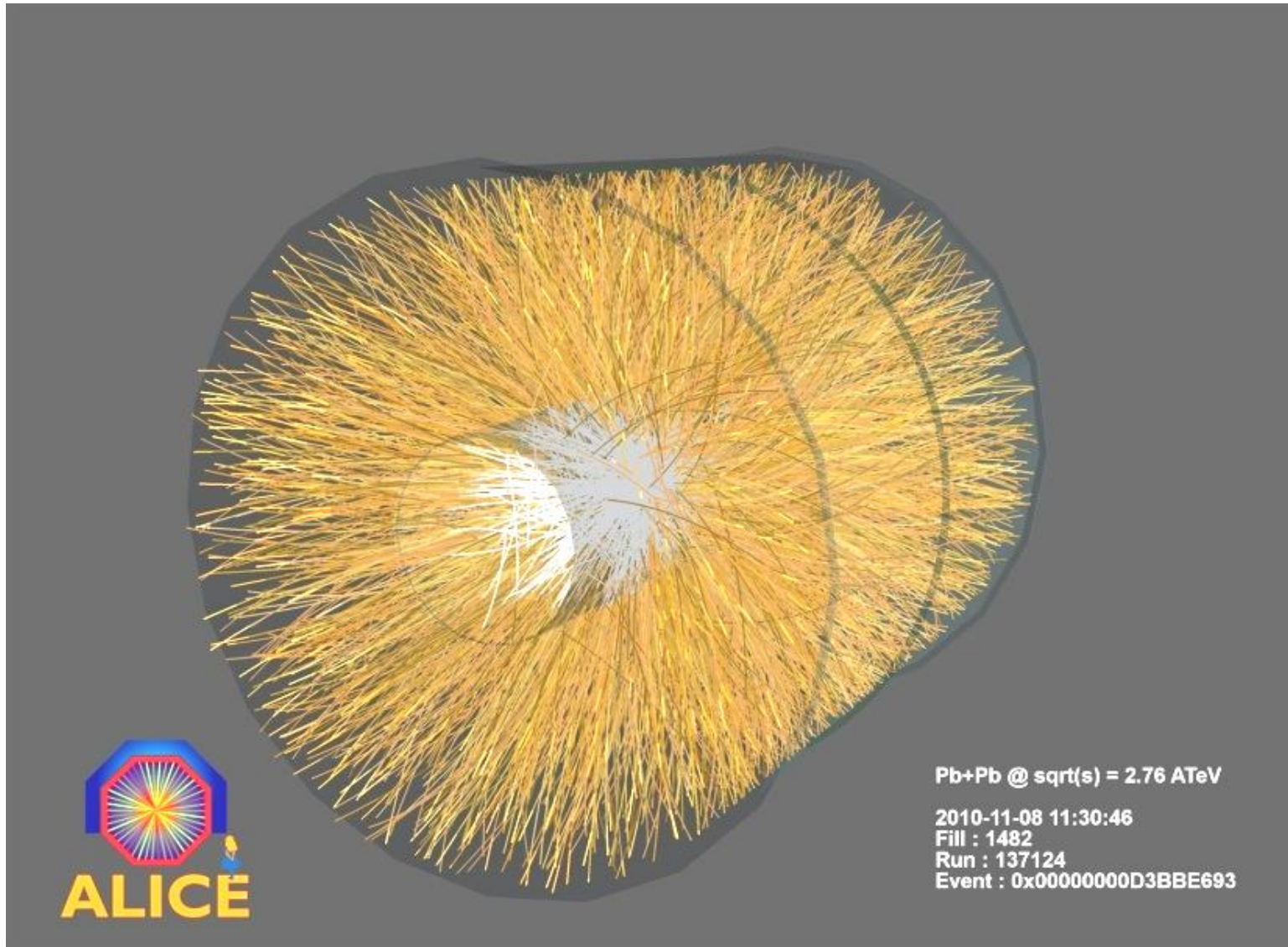
A visit inside the TPC.

TPC installed in the ALICE Experiment
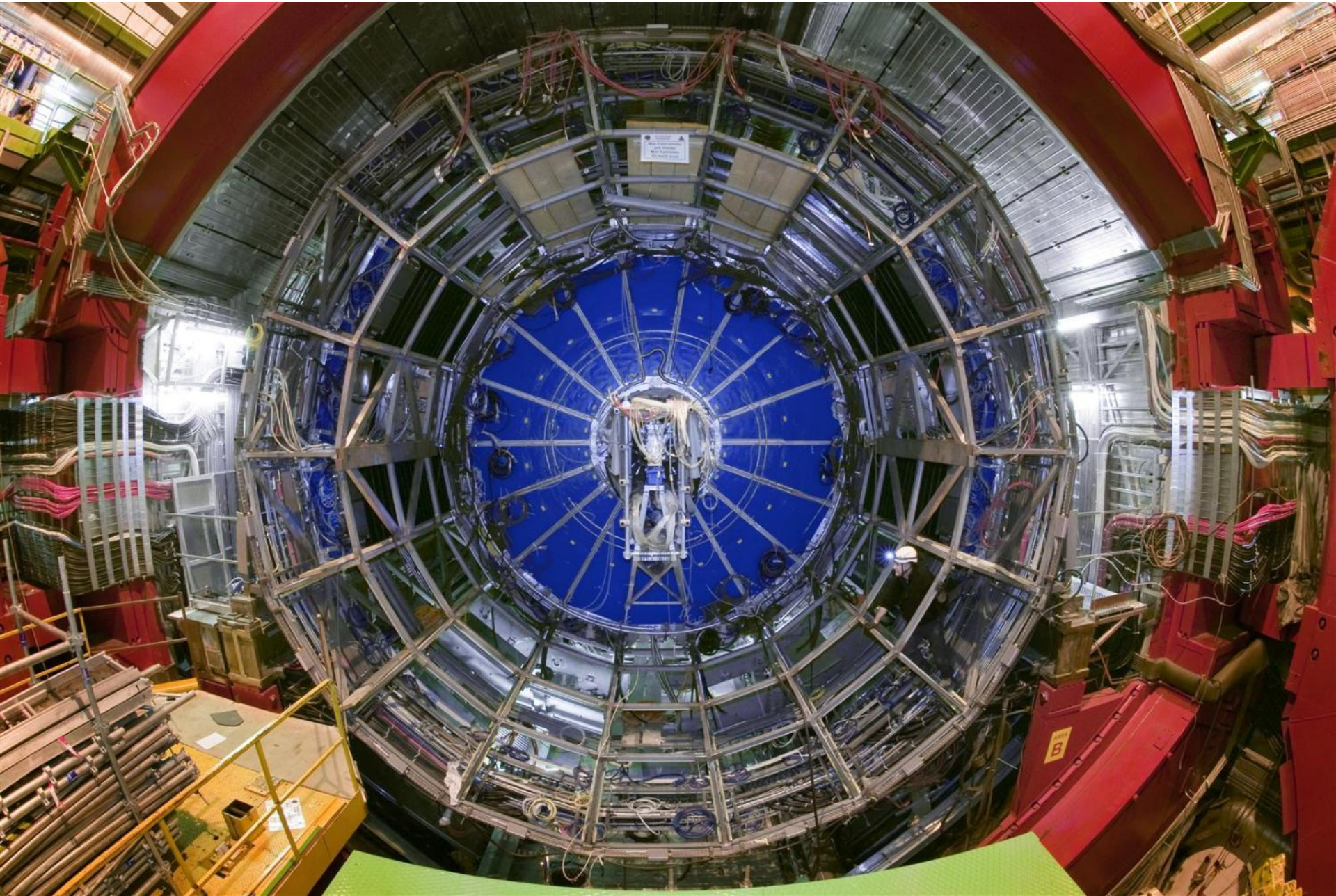
First 7 TeV p-p Collisions in the ALICE TPC in March 2010 !

11/16/2011

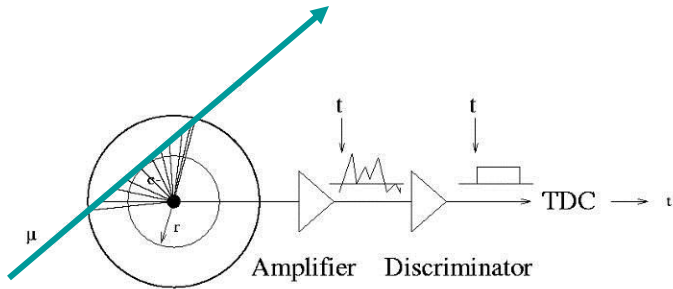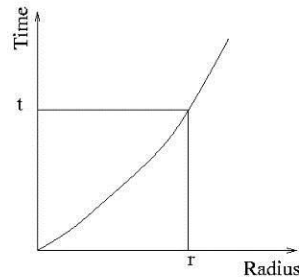# First Pb Pb Collisions in the ALICE TPC in Nov 2010 !

Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

ALICE

The Geiger Counter reloaded: Drift Tube

Primary electrons are drifting to the wire.

ATLAS MDT R(tube) =15mm

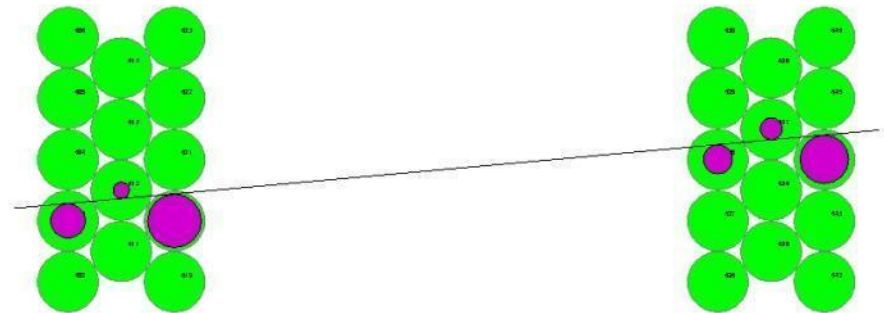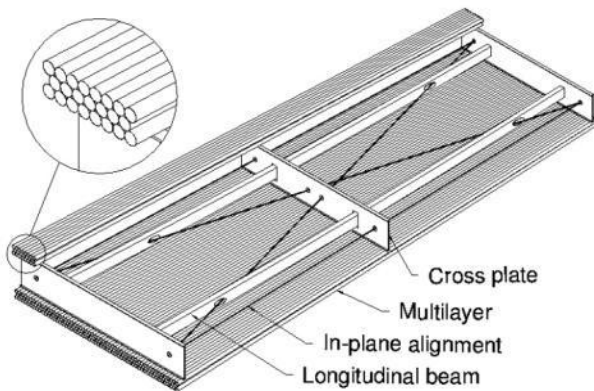**Calibrated Radius-Time correlation**

Electron avalanche at the wire.

The measured drift time is converted to a radius by a (calibrated) radius-time correlation.

Many of these circles define the particle track.

ATLAS Muon Chambers

- Cross plate
- Multilayer
- In-plane alignment
- Longitudinal beam

ATLAS MDTs, 80μm per tube

The Geiger counter reloaded: Drift Tube

Atlas Muon Spectrometer, 44m long, from r=5 to11m.

1200 Chambers
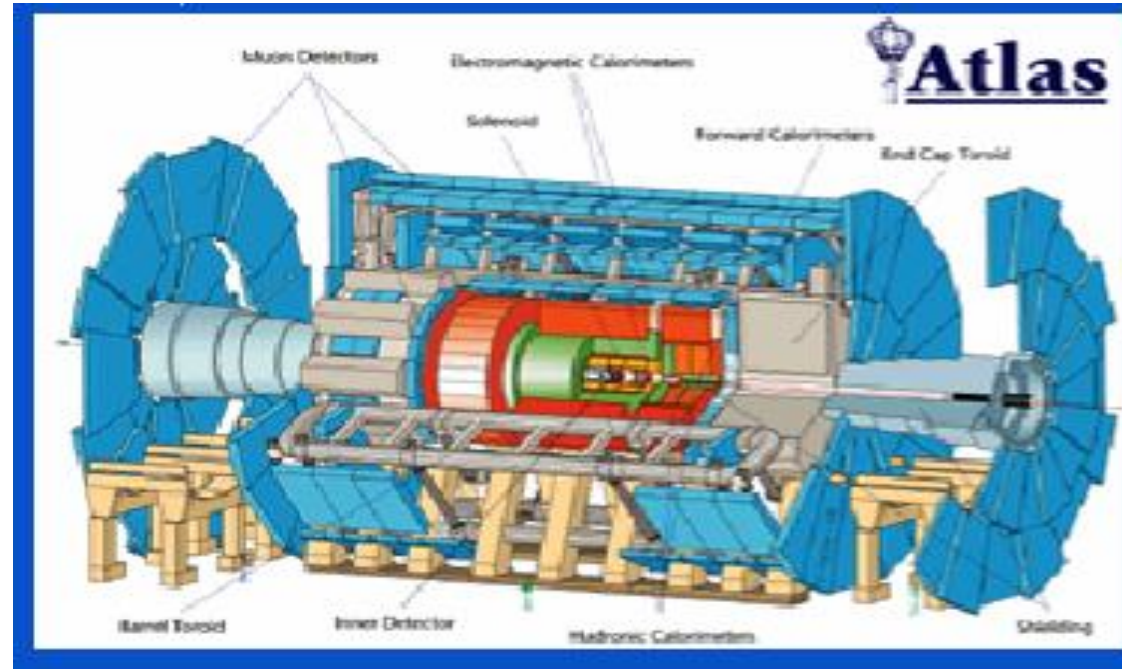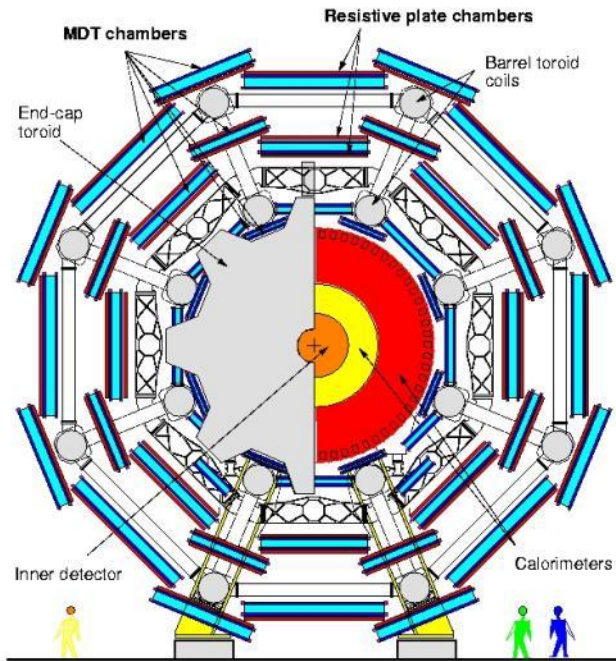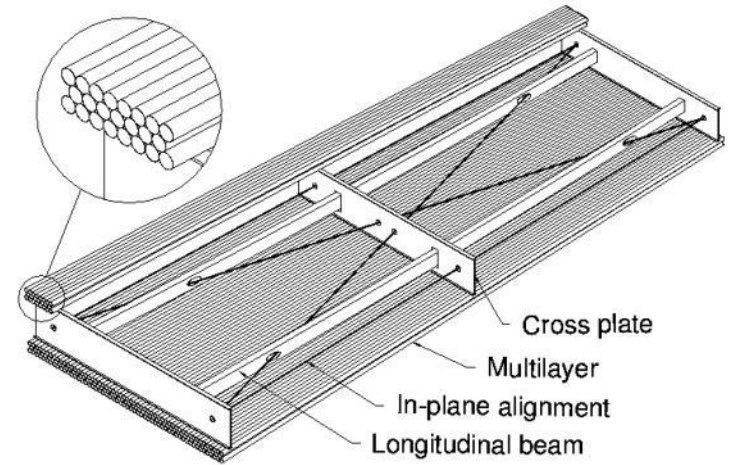
6 layers of 3cm tubes per chamber.

Length of the chambers 1-6m !

Position resolution: 80μm/tube, <50μm/chamber (3 bar)

Maximum drift time $\approx$700ns

Gas Ar/CO_2 93/7

Cross plate
Multilayer
In-plane alignment
Longitudinal beam

MDT chambers
Resistive plate chambers
Barrel toroid coils
End-cap toroid
Inner detector
Calorimeters

Detector Systems

CERN Neutrino Gran Sasso

(CNGS)

CNGS

If neutrinos have mass:

$$\nu_e$$

$$\nu_\mu \longleftrightarrow \nu_\tau$$
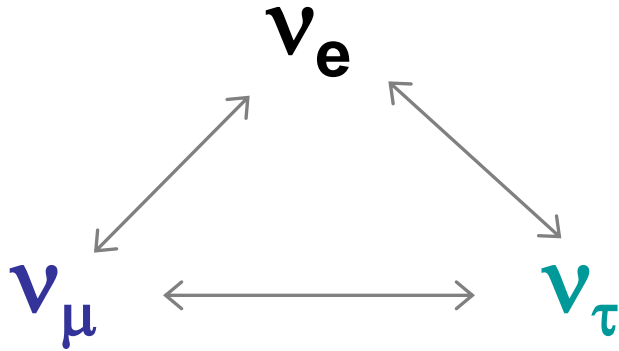
Muon neutrinos produced at CERN.
See if tau neutrinos arrive in Italy.

CERN

$\nu_\mu \longrightarrow \nu_\tau \longrightarrow \nu_\mu \longrightarrow \nu_\tau$
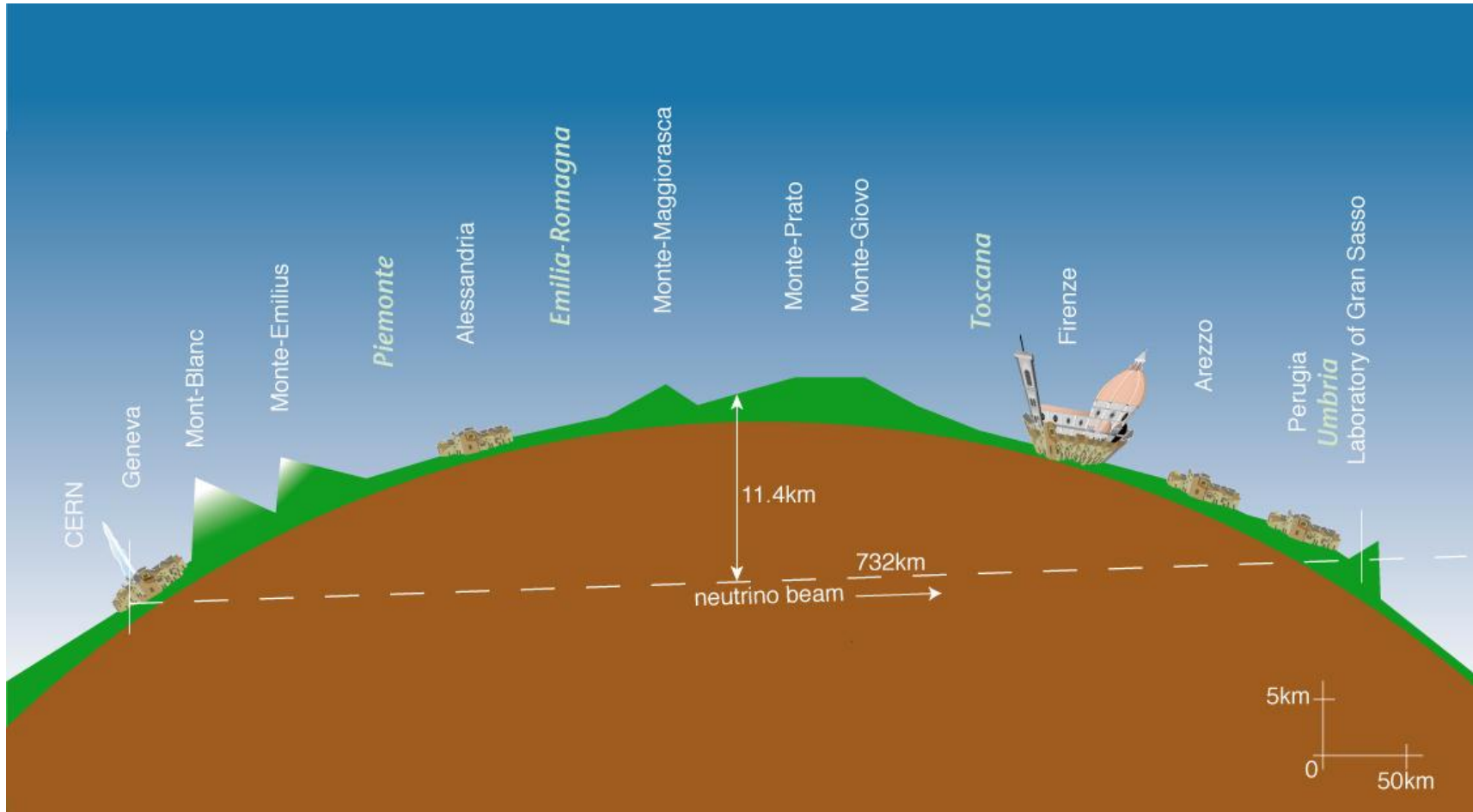
neutrino trajectory
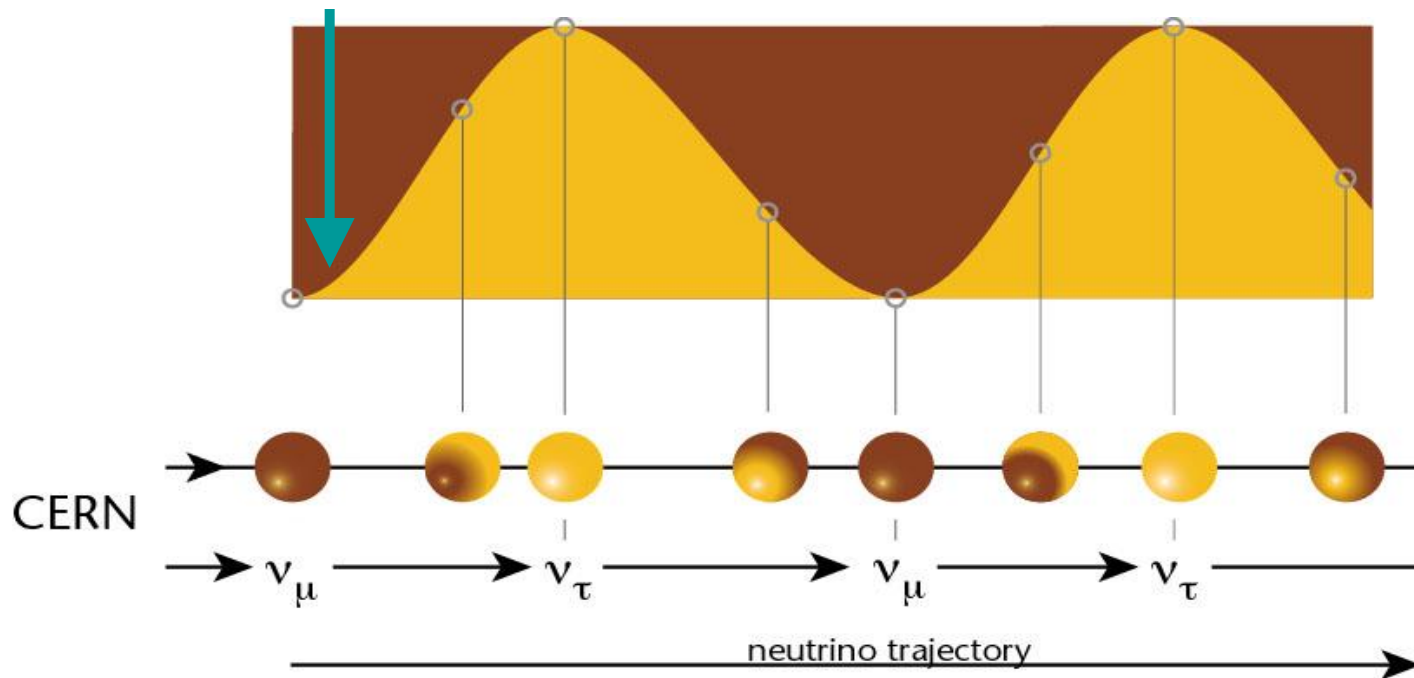
CNGS Project

CNGS (CERN Neutrino Gran Sasso)

– A long base-line neutrino beam facility (732km)

– send ν_μ beam produced at CERN

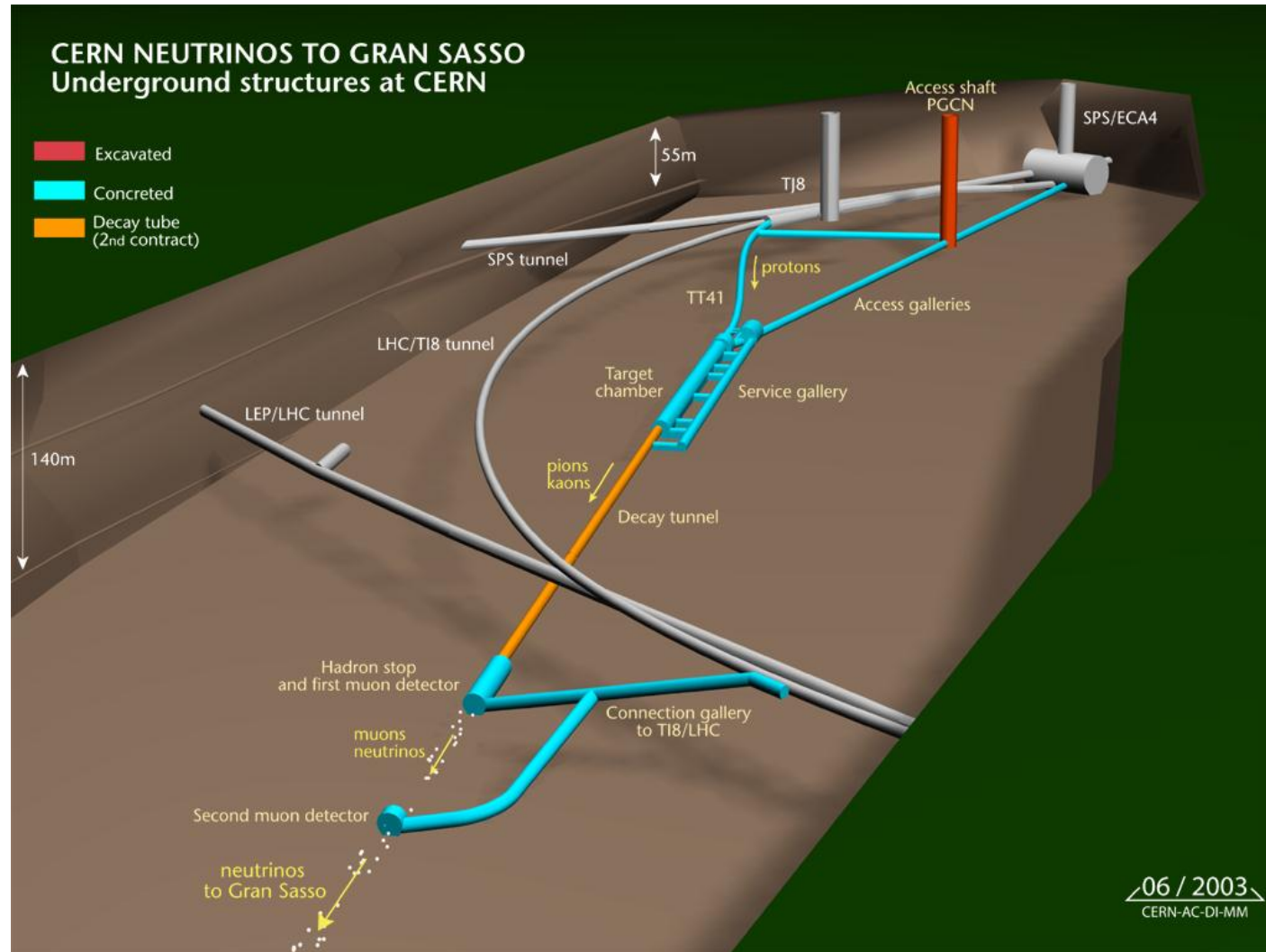– detect ν_τ appearance in OPERA experiment at Gran Sasso

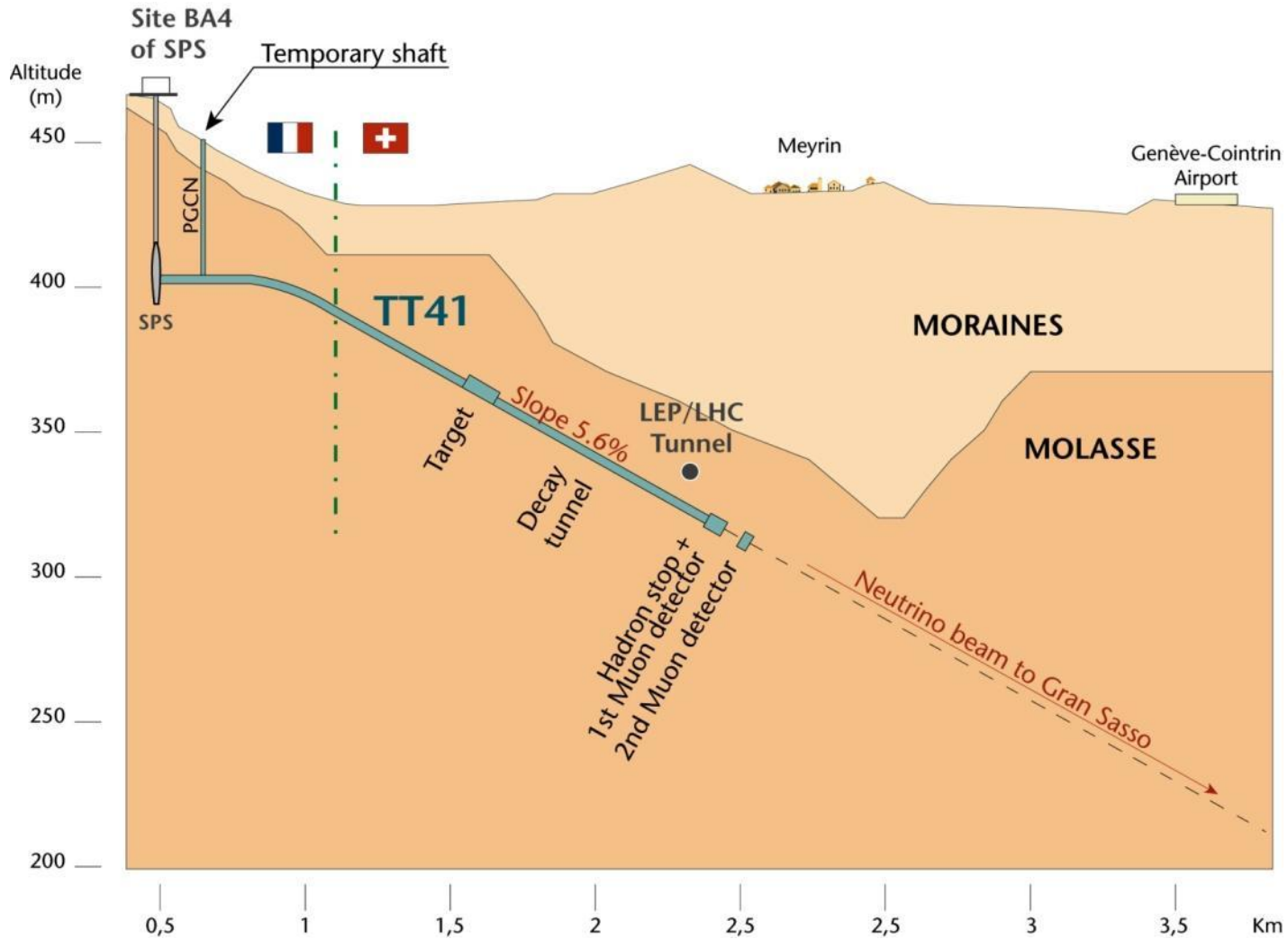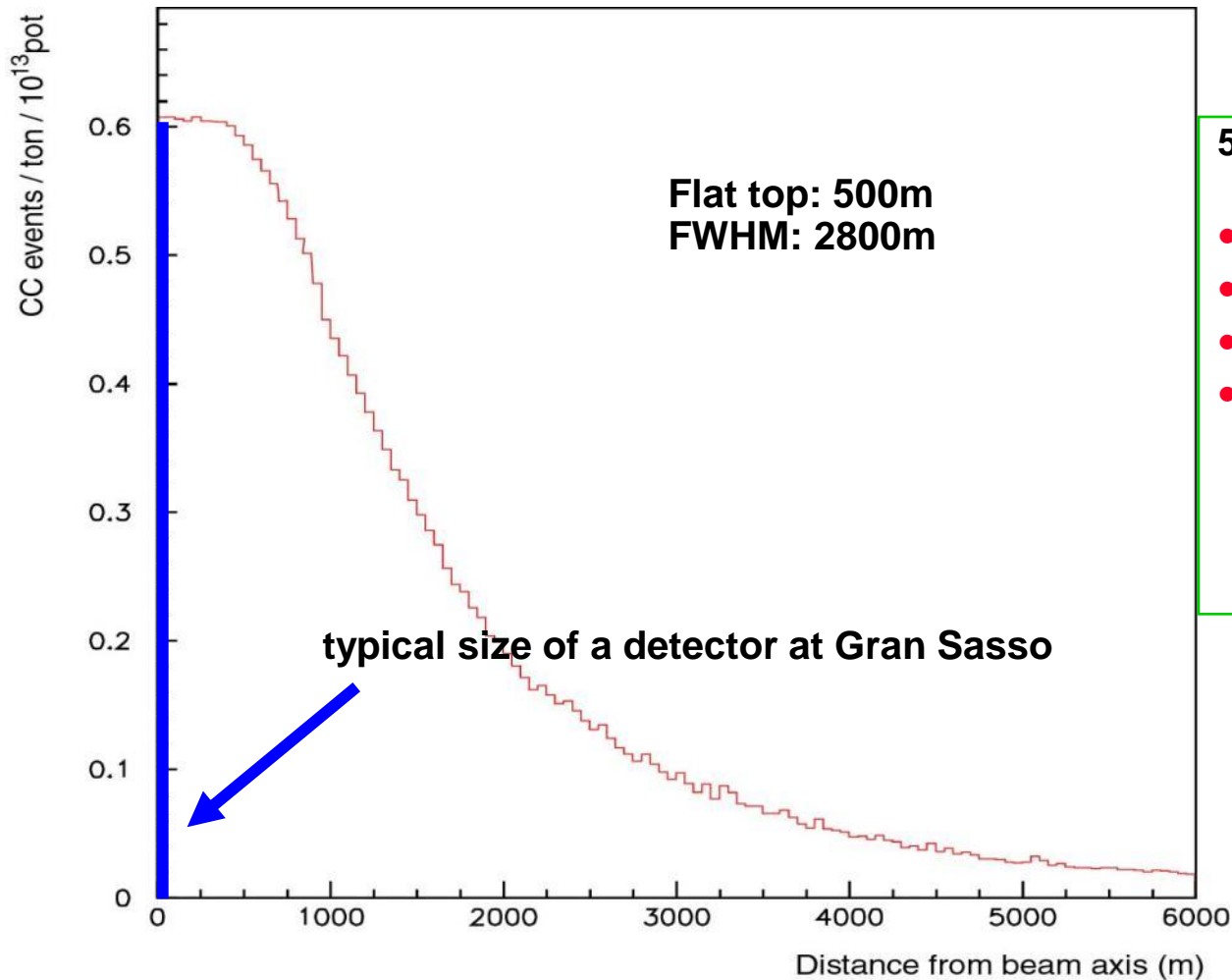➡ **direct proof of ν_μ - ν_τ oscillation (appearance experiment)**

CNGS

CNGS

CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN

CNGS

Radial Distribution of the ν_μ-Beam at GS

Flat top: 500m
FWHM: 2800m

typical size of a detector at Gran Sasso

5 years CNGS operation, 1800 tons target:

- **30000 neutrino interactions**
- **~150 ν_τ interactions**
- **~15 ν_τ identified**
- **< 1 event of background**

Neutrinos at CNGS: Some Numbers

For 1 year of CNGS operation, we expect:

|	
protons on target	**2×10^{19}**
pions / kaons at entrance to decay tunnel	**3×10^{19}**
ν_μ **in direction of Gran Sasso**	**10^{19}**
ν_μ **in 100 m^2 at Gran Sasso**	**3×10^{14}**
ν_μ **events per day in OPERA**	**≈ 2500**
ν_τ **events (from oscillation)**	**≈ 2**

Opera Experiment at Gran Sasso

Basic unit: brick

56 Pb sheets + 56 photographic films (emulsion sheets)

Lead plates: massive target
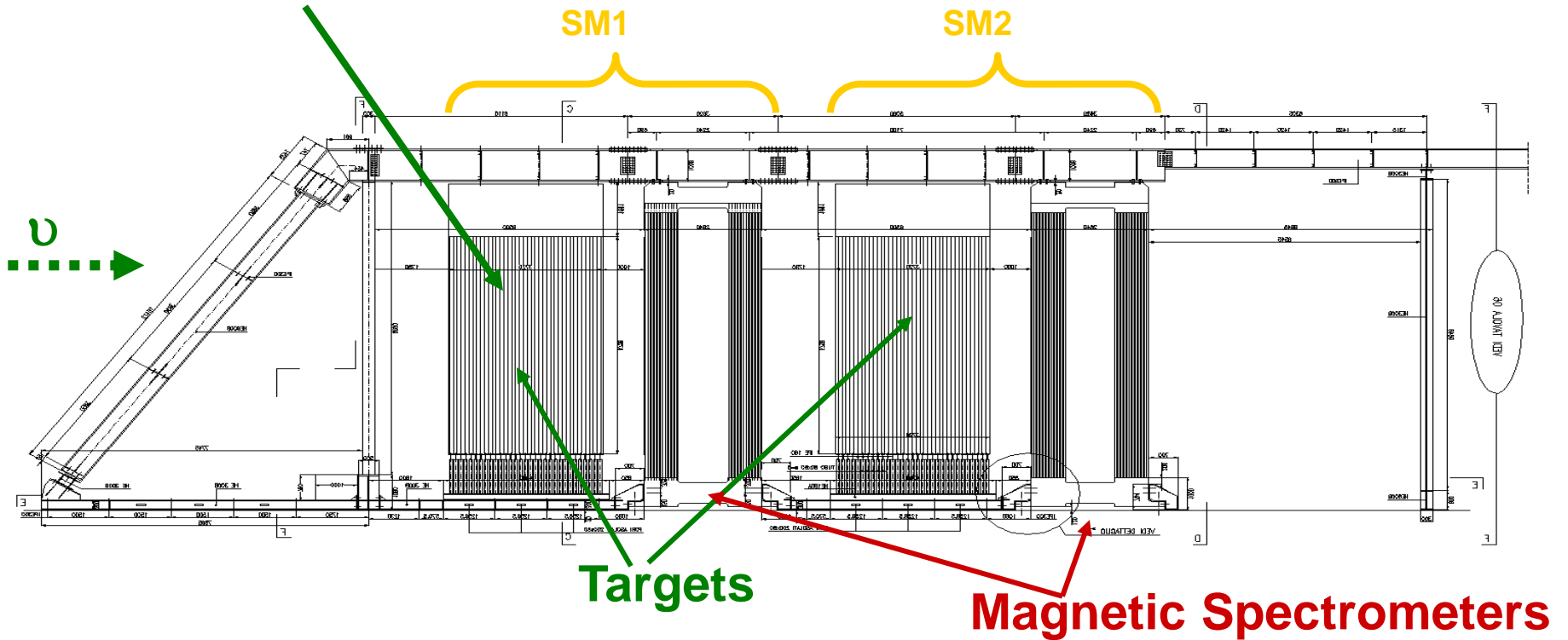**Emulsions: micrometric precision**

Brick

1 mm

Pb

τ

ν

Couche de gélatine photographique 40 μm

brick

8.3kg
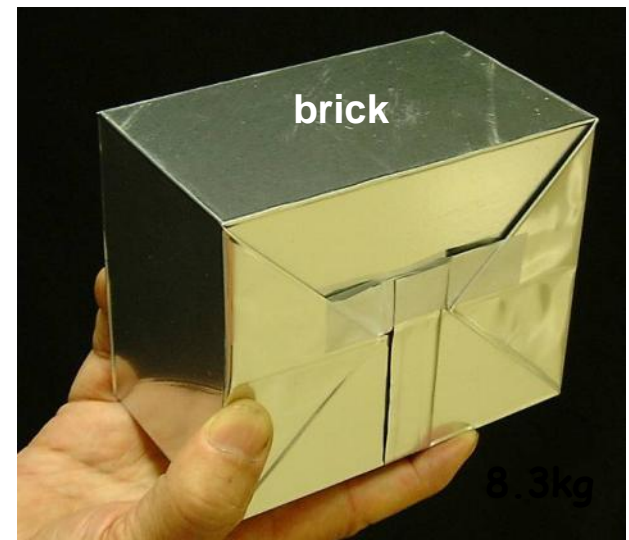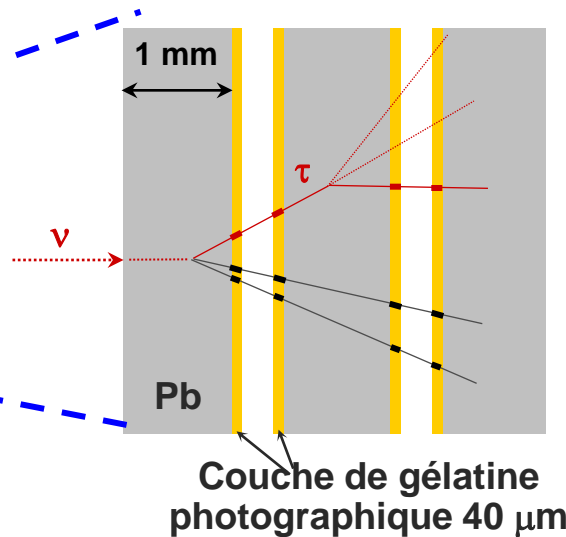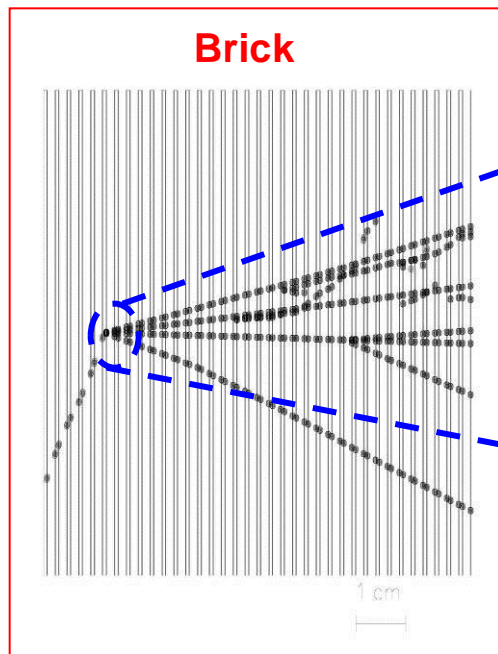
10.2 x 12.7 x 7.5 cm^3

Opera Experiment at Gran Sasso

31 target planes / supermodule   **In total: 206336 bricks, 1766 ton**

SM1   SM2

ν

Targets

Magnetic Spectrometers

First observation of CNGS beam neutrinos : August 18th, 2006

Opera Experiment at Gran Sasso

Second Super-module

Details of the first spectrometer

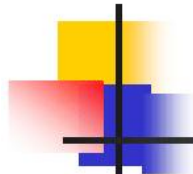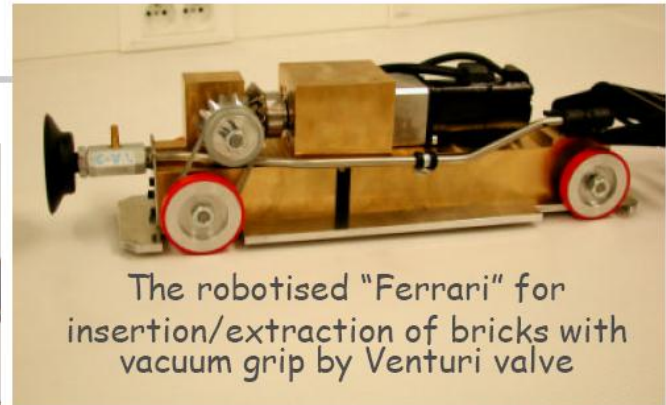**Scintillator planes 5900 m²**

8064 7m long drift tubes
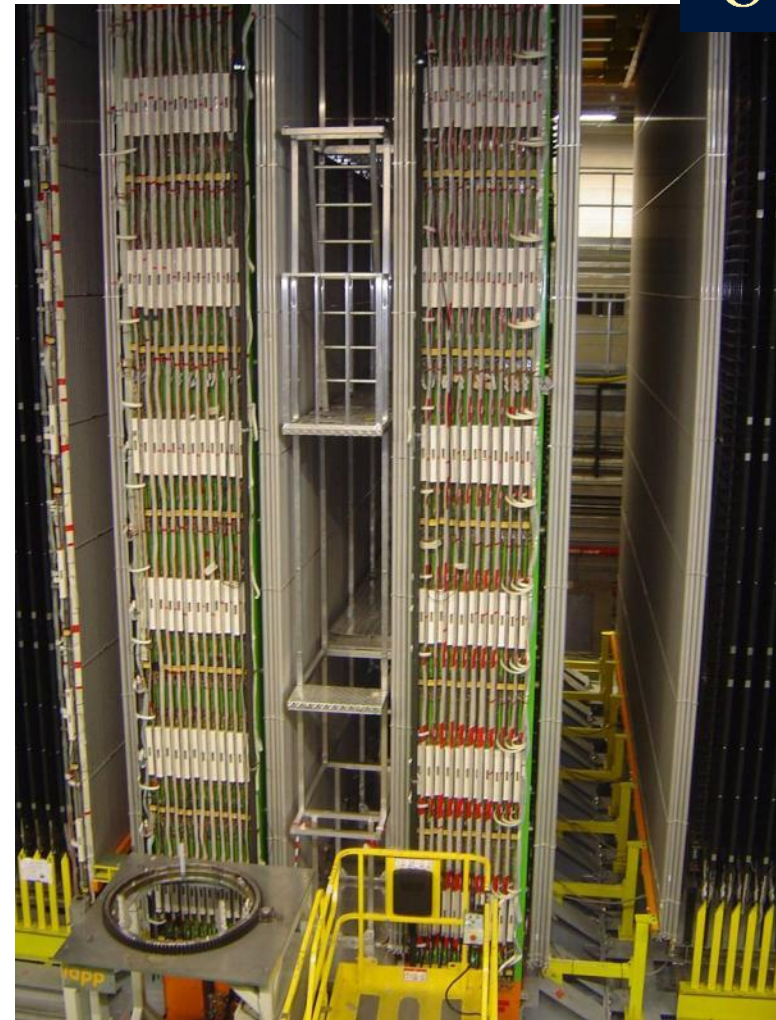
3050 m² Resistive Plate Counters

2000 tons of iron for the two magnets

Opera Experiment at Gran Sasso

The Brick Manipulator System (BMS) prototype:
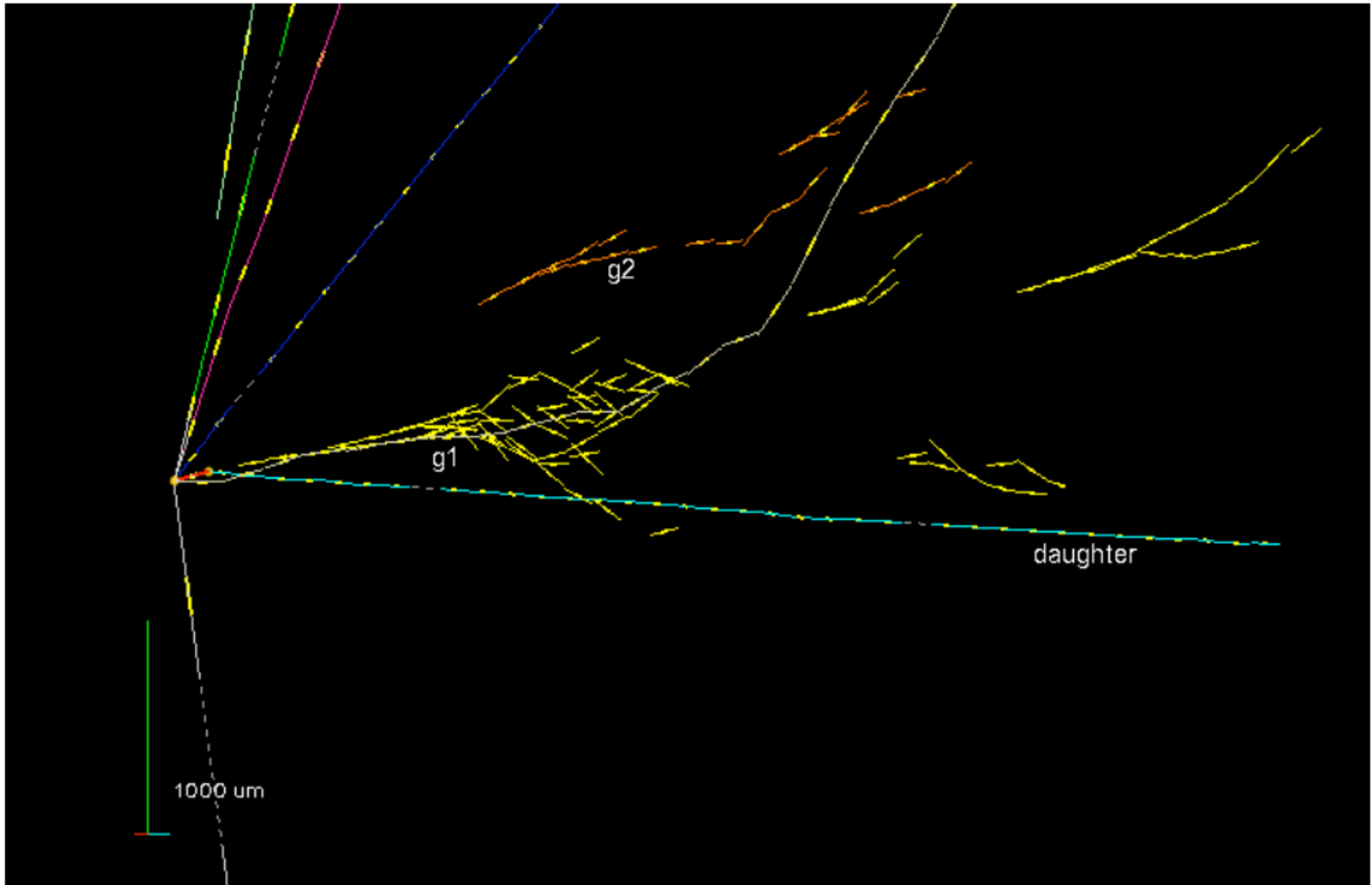a lot of fun for children and adults !

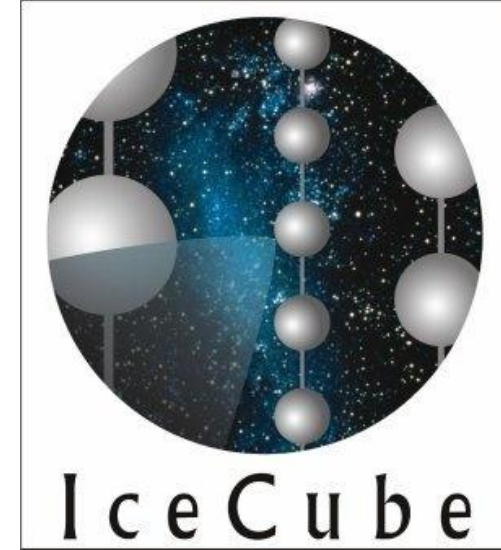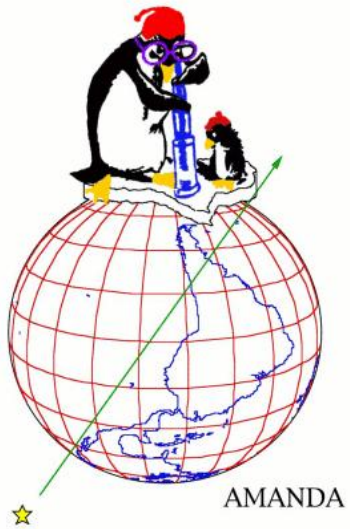The robotised "Ferrari" for insertion/extraction of bricks with vacuum grip by Venturi valve
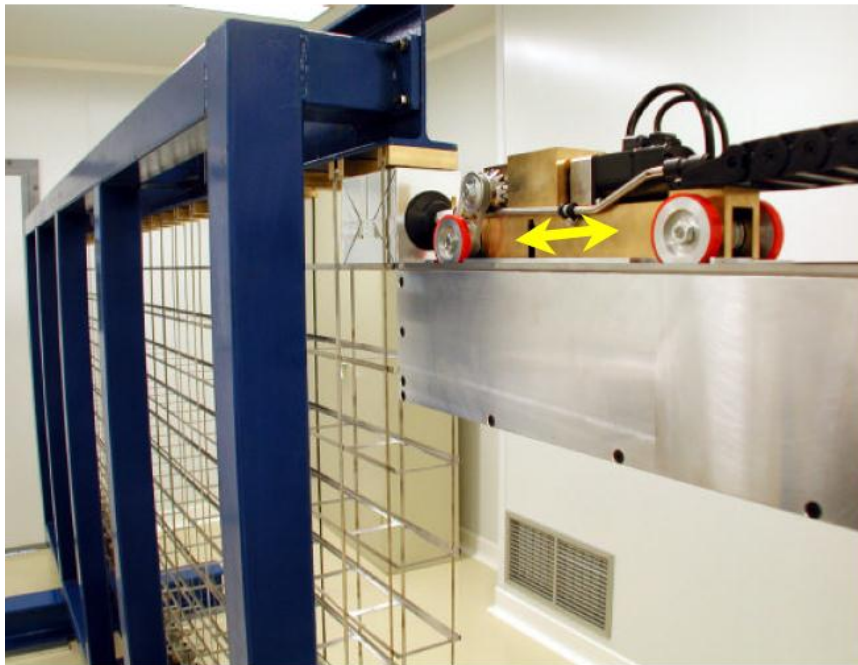
Tests with the prototype wall

"Carousel" brick dispensing and storage system

First Tau Candidate seen a few weeks ago !

AMANDA

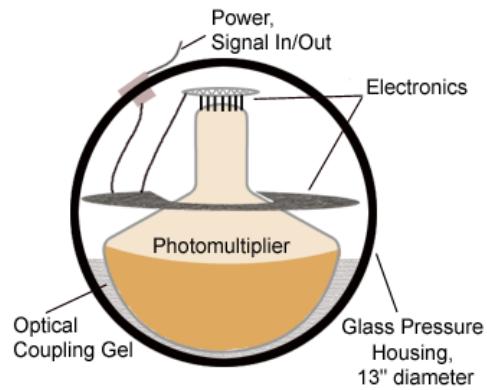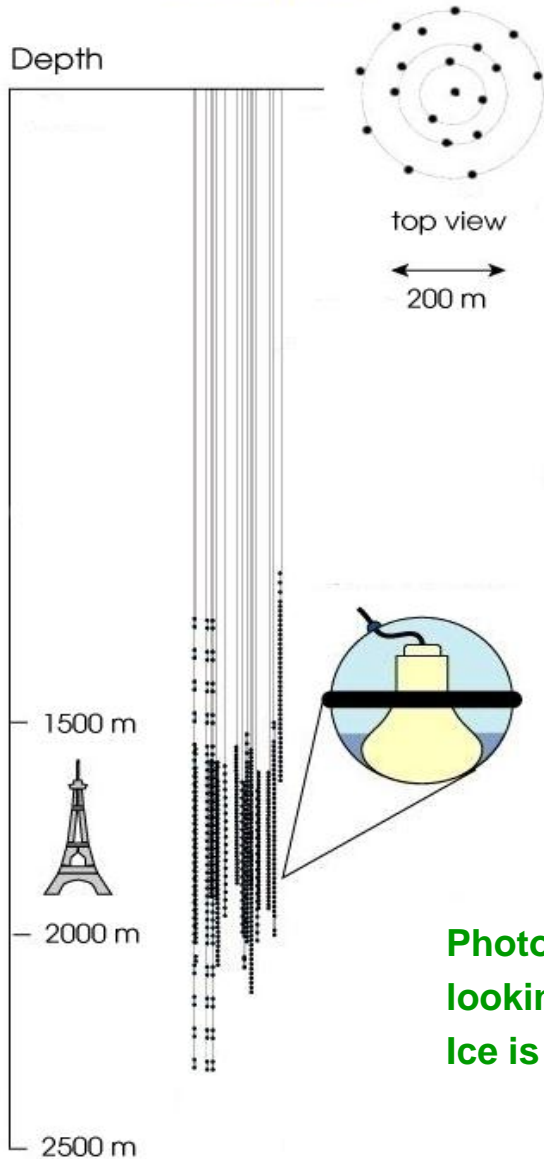**Antarctic Muon And Neutrino Detector Array**

AMANDA

South Pole

AMANDA

AMANDA-II

Depth

top view

200 m

1500 m

2000 m

2500 m

Power,
Signal In/Out

Electronics

Photomultiplier

Optical
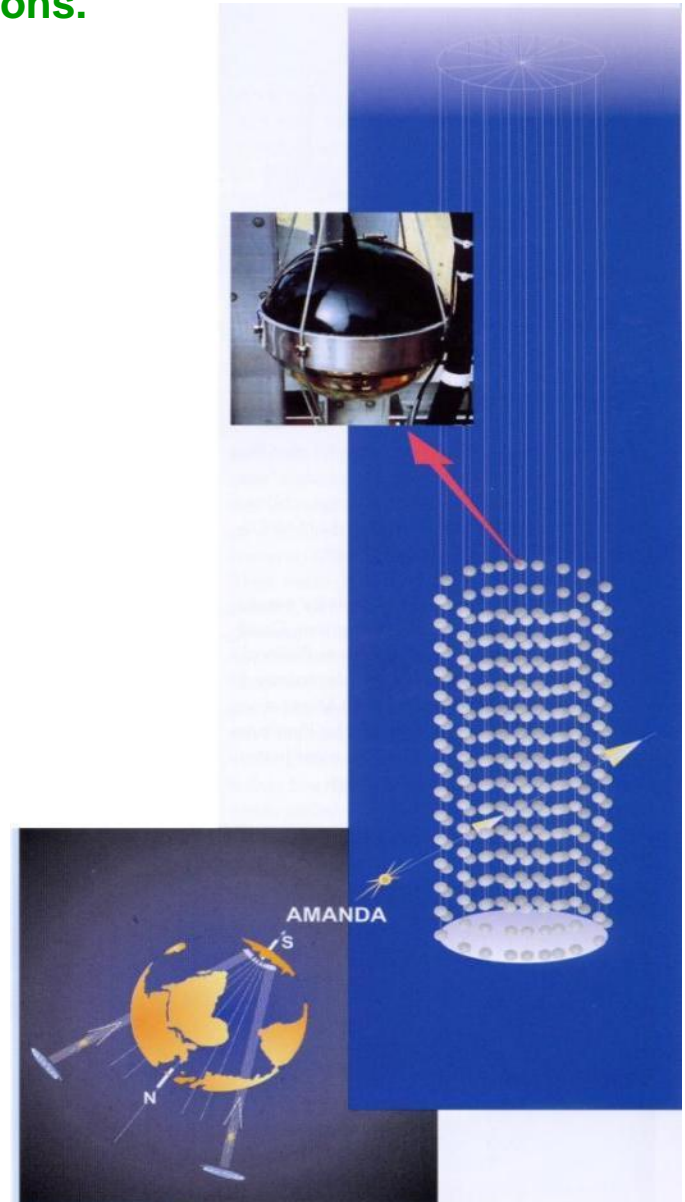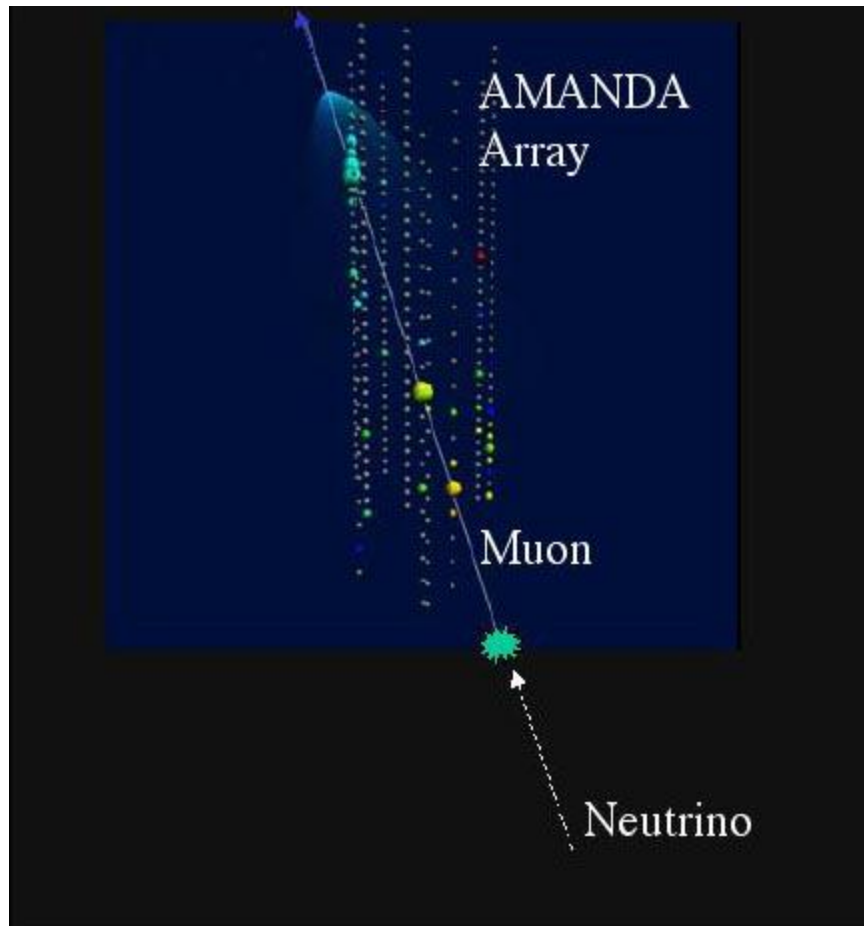Coupling Gel

Glass Pressure
Housing,
13" diameter

**Photomultipliers in the Ice,
looking downwards.
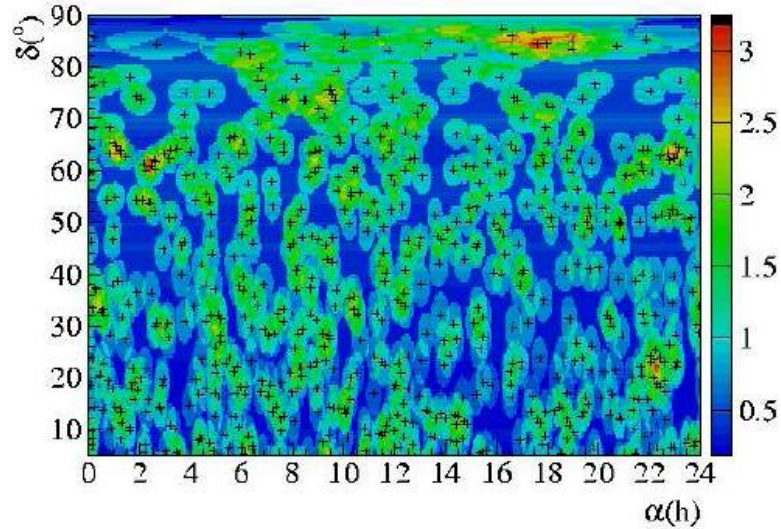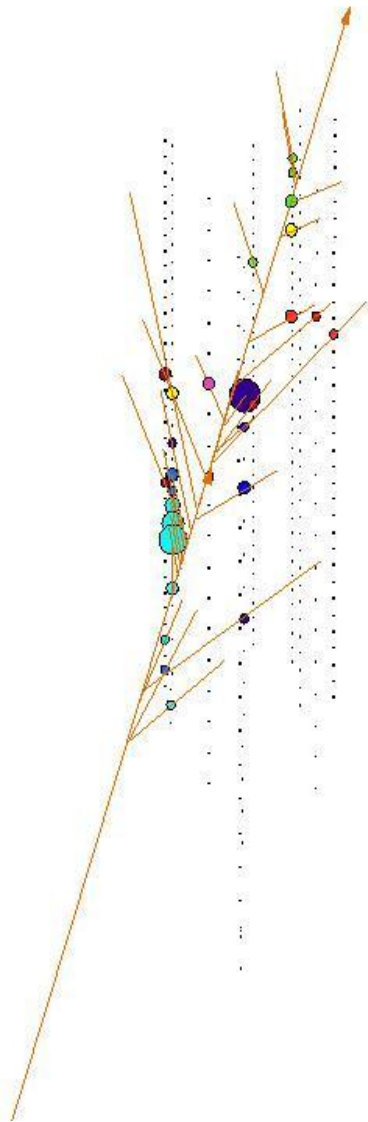Ice is the detecting medium.**

AMANDA

Look for upwards going Muons from Neutrino Interactions.
Cherekov Light propagating through the ice.

$\rightarrow$ **Find neutrino point sources in the universe !**
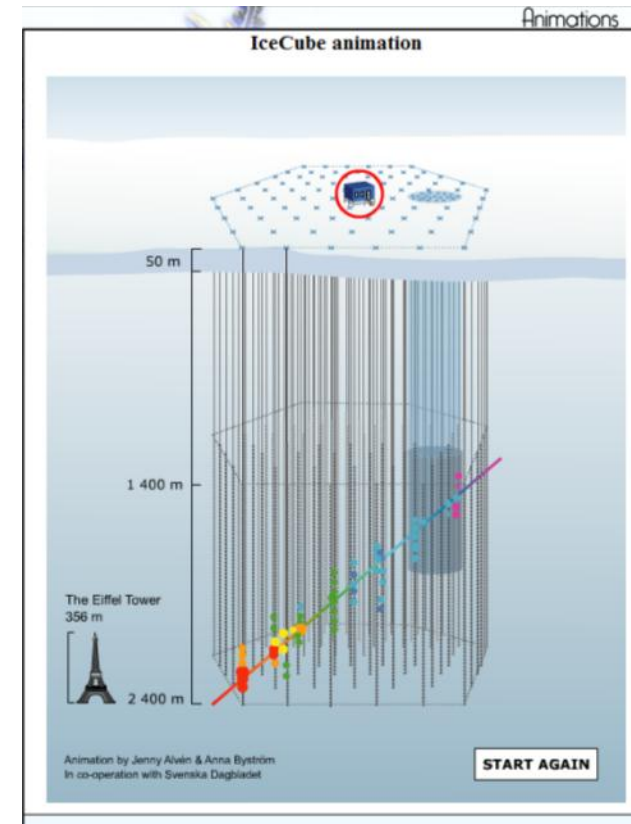
AMANDA

Event Display

Up to now: No significant point sources but just neutrinos from cosmic ray interactions in the atmosphere were found .
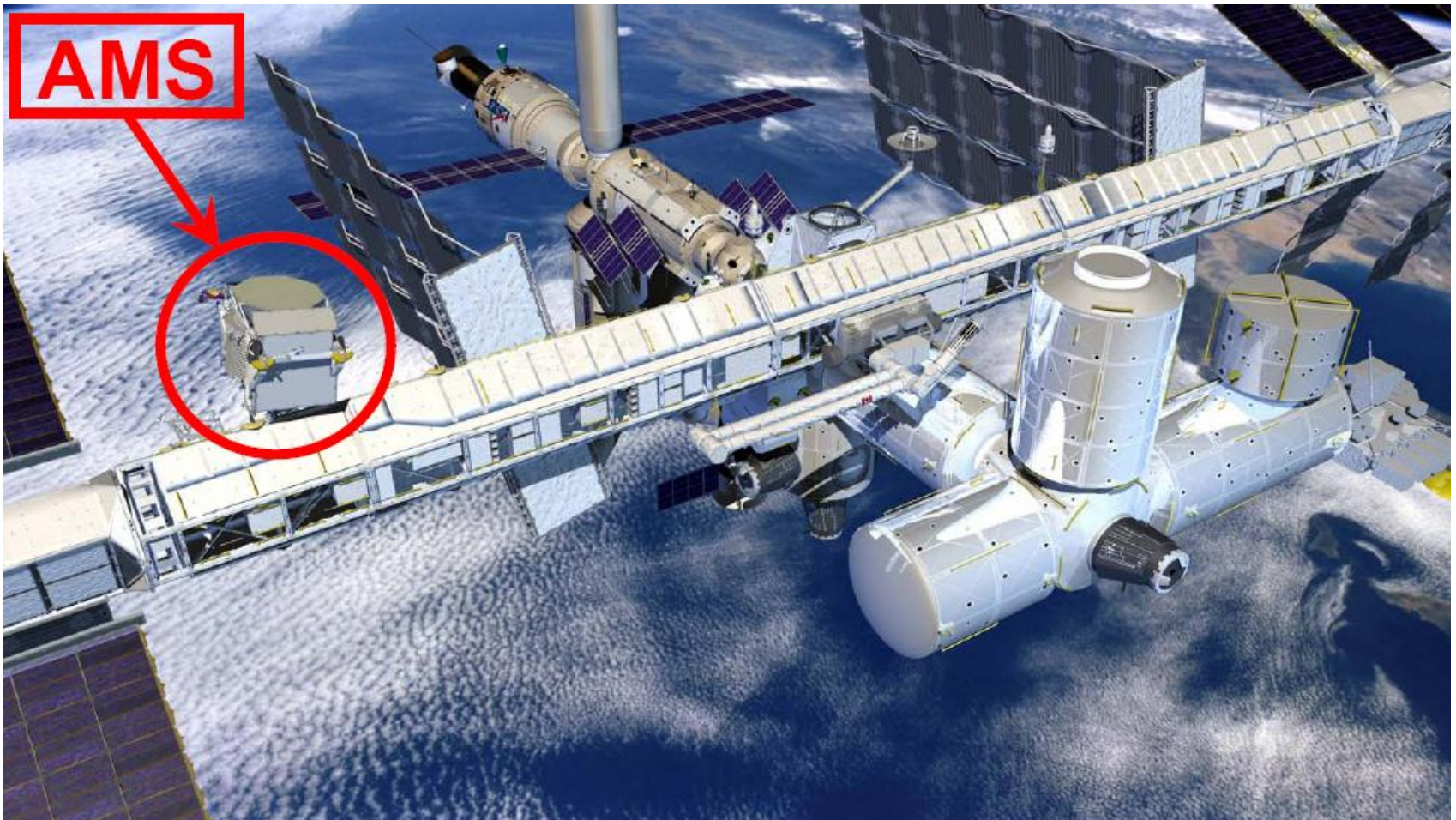
→ Ice Cube for more statistics !
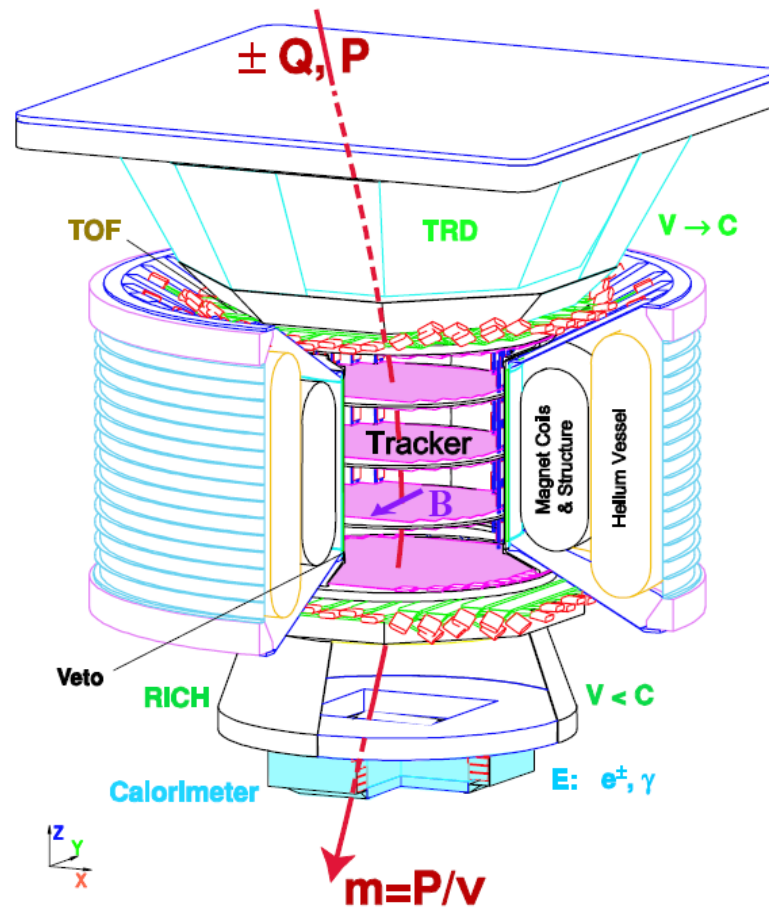
AMS

Alpha **M**agnetic **S**pectrometer

Try to find Antimatter in the primary cosmic rays.
Study cosmic ray composition etc. etc.

AMS

Will be installed on the space station.

AMS

AMS

Zenith Radiator

TRD:
Transition Radiation Detector

USS:
Unique Support Structure

Tracker Radiator

TOF (s1,s2) Time of Flight

Star Tracker

Tracker Radiator

GPS

Grapple Fixture

TRD Gas Box

Wake Radiator & Electronics

TOF (s3,s4) Time of Flight

Ram Radiator

RICH:
Ring Image Cherenkov Counter

Lower USS

ECAL:
Electromagnetic Calorimeter

USS Keel

PAS:
Payload Attach System