Particle Detectors 2/2

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A particle detector is a device, that is collapsing wavefunctions of quantum mechanical states, which themselves are linear superpositions of irreducible representations of the inhomogeneous Lorentz Group.
A particle is an irreducible representation of the inhomogeneous Lorentz group.

ON UNITARY REPRESENTATIONS OF THE INHOMOGENEOUS LORENTZ GROUP

By E. WIGNER

(Received December 22, 1937)

of the invariance of the transition probability we have

\[ |(\varphi_i, \psi_i)|^2 = |(\varphi_{i'}, \psi_{i'})|^2 \]

and it can be shown that the aforementioned constants in the \( \varphi_i \) can be chosen in such a way that the \( \varphi_{i'} \) are obtained from the \( \varphi_i \) by a linear unitary operation, depending, of course, on \( l \) and \( l' \)

\[ \varphi_{i'} = D(l', l)\varphi_i. \]

By going over from a first system of reference \( l \) to a second \( l' = L_1l \) and then to a third \( l'' = L_2L_1l \) or directly to the third \( l'' = (L_2L_1)l \), one must obtain—apart from the above mentioned constant—the same set of wave functions. Hence from

\[ \varphi_{i''} = D(l'', l')D(l', l)\varphi_i \]
\[ \varphi_{i''} = D((l'', l'), l)\varphi_i \]

it follows

\[ D(l''', l')D(l', l) = \omega D(l'', l') \]

D. Classification of unitary representations from the point of view of infinitesimal operators

→ Scalars, spinors, vectors
→ \( m>0 \) and \( s=0, 1/2, 1, 3/2, 2 \)
The ‘Standard Model’

\[ L_{GSW} = L_0 + L_H + \sum_i \left( \frac{g}{2} \bar{L}_i \gamma_\mu \bar{\tau} L_i \bar{A}_\mu^i + g' \left[ \bar{R}_i \gamma_\mu R_i + \frac{1}{2} \bar{L}_i \gamma_\mu L_i \right] B^\mu \right) + \]

\[ + \frac{g}{2} \sum_q \bar{L}_q \gamma_\mu \bar{\tau} L_q \bar{A}_\mu^q + \]

\[ + g' \left\{ \frac{1}{6} \sum_q \left[ \bar{L}_q \gamma_\mu L_q + 4 \bar{R}_q \gamma_\mu R_q \right] + \frac{1}{3} \sum_q \bar{R}_q \gamma_\mu R_q \right\} B^\mu \]

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

\[ + \frac{g^2}{4} \left( W^+_{\mu} W^\mu + \frac{1}{2 \cos^2 \theta_W} Z_{\mu} Z^\mu \right) (\lambda^2 + 2 \lambda H + H^2) + \]

\[ + \sum_{l,q,q'} \left( \frac{m_l}{\lambda} \bar{l} l + \frac{m_q}{\lambda} \bar{q} q + \frac{m_{q'}}{\lambda} \bar{q'} q' \right) H \]
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**

\[ E = ma^2 \]
\[ E = ml^2 \]
\[ E = mc^2 \quad \text{Energy} \approx \text{Mass} \]

\[ m_e \approx 9.11 \times 10^{-31} \text{ kg} \]
\[ m_e c^2 \approx 8.19 \times 10^{-14} \text{ J} \]
\[ = 510.939 \text{ Electron Volt (eV)} \]
\[ = 0.511 \text{ MeV} \]

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

1 Electron Volt - Energy an Electron gains as it traverses a Potential Difference of 1V.
Build your own Accelerator

\[ E_{\text{kin}} = 1.5\text{eV} = 2\,615\,596\,\text{km/h} \]
Scales

Visible Light: $\lambda = 500 \text{ nm}, \ h\nu \approx 2.5 \text{ eV}$

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

Nuclear Physics: 1-50 MeV

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

Higher Measured Energy: $10^{20} \text{ eV} \ (\text{Cosmic Rays})$
**Basics**

**Lorentz Boosts:**

\[ \mu^- \rightarrow e^- + \bar{\nu}_e + \gamma \quad \gamma = 2.2 \cdot 10^{-6} \text{ s} \]

*E.g.* Produced by Cosmic Rays (*p*, *He*, *Li*, …) colliding with air in the upper atmosphere \(~10\text{ km}\)

\[ s = \alpha \cdot \gamma \approx c \cdot s = 660 \text{ m} \]

But we see Muons here on Earth

\[ E_{\mu} \approx 2\text{ GeV}, \quad m_{\mu}c^2 = 105\text{ MeV} \rightarrow \gamma \approx 19 \]

Relativity: \( \vec{s} = \vec{x} \cdot \vec{\gamma} \)

\[ s = c \cdot \vec{s} = 12.5 \text{ km} \rightarrow \text{Earth} \]

**Pions:** \( \pi^+, \pi^- \quad s \approx 2.6 \cdot 10^{-8} \text{ s}, \quad m_{\pi}c^2 \approx 135 \text{ MeV} \)

\[ 2\text{ GeV} \rightarrow s = 115 \text{ m} \]

Pions were discovered in Environments exposed to Cosmic Rays on high Mountains.
LHCb B decay
\textbf{Basics}

\textit{Invariant Mass:}

\textbf{LAB:}

\[ m_1, \vec{p}_1, E_1 \]

\[ m_2, \vec{p}_2, E_2 \]

\textbf{Relativity:}

\[ \hat{a} = \left( \frac{a_0}{c} \right), \quad \hat{b} = \left( \frac{b_0}{c} \right), \quad \hat{a} \cdot \hat{b} = a_0 b_0 - \hat{a} \cdot \hat{b} \]

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

\[ \hat{p} = \left( \frac{E}{c} \right), \quad \hat{p}_n = \left( \frac{E_n}{\hat{p}_n} \right), \quad \hat{p}_\perp = \left( \frac{E_\perp}{\hat{p}_\perp} \right) \]

\[ \hat{p} = \hat{p}_n + \hat{p}_\perp \quad \text{Energy+Momentum Conservation} \]

\[ \hat{p}^2 = (\hat{p}_n + \hat{p}_\perp)^2 \Rightarrow \hat{p} \cdot \hat{p} = \hat{p}_n \hat{p}_n + \hat{p}_\perp \hat{p}_\perp + 2 \hat{p}_n \hat{p}_\perp \]

\[ M^2 c^2 = m_1^2 c^2 + m_2^2 c^2 + 2 \left( \frac{E_1 E_2}{c^2} - \hat{p}_1 \hat{p}_2 \cos \theta \right) \]

- Measuring Momenta and Energies \textit{OR}

- Measuring Momenta and Identifying Particles

\textit{given the Mass of the original Particle}
There are many more
| Particle | Particle Lifetime | Mass (MeV) | $\tau$ (s) | Decay Length |
|---------|------------------|------------|------------|--------------|
| $\pi^0$ | $1.35 \times 10^{-6}$ | 135 | 9.4 x 10^{-8} | 7.8 mm |
| $K^0$ | $1.35 \times 10^{-6}$ | 484 | 1.2 x 10^{-8} | 3.7 mm |
| $K^0$ | $1.35 \times 10^{-6}$ | 487 | 5.7 x 10^{-8} | 15.5 mm |
| $D^0$ | $1.35 \times 10^{-6}$ | 1869 | 1.0 x 10^{-4} | 315 nm |
| $D^0$ | $1.35 \times 10^{-6}$ | 1864 | 4.1 x 10^{-3} | 123 nm |
| $D_s^0$ | $1.35 \times 10^{-6}$ | 1969 | 4.3 x 10^{-3} | 147 nm |
| $B^0$ | $1.35 \times 10^{-6}$ | 5279 | 1.7 x 10^{-2} | 502 nm |
| $B^0$ | $1.35 \times 10^{-6}$ | 5370 | 1.5 x 10^{-2} | 438 nm |
| $B^+$ | $1.35 \times 10^{-6}$ | ~6400 | ~5.1 x 10^{-3} | 150 nm |
| $\rho (uud)$ | $1.35 \times 10^{-6}$ | 938.3 | >10^{33} | 2.655 x 10^{8} km |
| $n (uda)$ | $1.35 \times 10^{-6}$ | 1339.6 | 885.75 | 2.655 x 10^{8} km |
| $\Lambda^0 (uds)$ | $1.35 \times 10^{-6}$ | 1115.7 | 2.6 x 10^{-40} | 7.89 cm |
| $\Sigma^+ (uss)$ | $1.35 \times 10^{-6}$ | 1183.4 | 8.0 x 10^{-49} | 2.404 cm |
| $\Sigma^- (dsd)$ | $1.35 \times 10^{-6}$ | 1197.4 | 1.5 x 10^{-40} | 4.434 cm |
| $\Xi^0 (uss)$ | $1.35 \times 10^{-6}$ | 1315 | 2.3 x 10^{-40} | 8.71 cm |
| $\Xi^- (dss)$ | $1.35 \times 10^{-6}$ | 1321 | 1.6 x 10^{-40} | 4.31 cm |
| $\Omega^- (sss)$ | $1.35 \times 10^{-6}$ | 1672 | 8.2 x 10^{-40} | 2.461 cm |
| $\Lambda_c^+ (udc)$ | $1.35 \times 10^{-6}$ | 2285 | ~2 x 10^{-43} | 60 pm |
| $\Xi_c^+ (usc)$ | $1.35 \times 10^{-6}$ | 2466 | ~2 x 10^{-43} | 132 pm |
| $\Xi_c^0 (dcs)$ | $1.35 \times 10^{-6}$ | 2472 | ~2 x 10^{-43} | 29 pm |
| $\Omega_c^0 (ssc)$ | $1.35 \times 10^{-6}$ | 2588 | ~6 x 10^{-49} | 19 pm |
| $\Lambda_b (ubd)$ | $1.35 \times 10^{-6}$ | 5620 | 1.2 x 10^{-42} | 368 pm |
From the 'hundreds' of Particles listed by the PDG there are only ~27 with a life time \( cs > 1 \mu m \) i.e. they can be seen as 'tracks' in a Detector.

~13 of the 27 have \( cs < 500 \mu m \) i.e. only \( < 500 \mu m \) range at GeV Energies.

→ "short" tracks measured with Emulsions or Vertex Detectors.

From the ~14 remaining particles

\[ e^+, \mu^+, \gamma, \pi^+, K^+, K^0, p^+, n \]

are by far the most frequent ones

A particle Detector must be able to identify and measure Energy and Momenta of these 8 particles.
\[ e^+ \quad m_e = 0.511 \text{ MeV} \]
\[ \mu^+ \quad m_\mu = 105.7 \text{ MeV} \sim 200 \text{ me} \]
\[ \gamma \quad m_\gamma = 0, \quad Q = 0 \]
\[ \pi^+ \quad m_\pi = 139.6 \text{ MeV} \sim 270 \text{ me} \]
\[ K^+ \quad m_K = 493.7 \text{ MeV} \sim 1000 \text{ me} \]
\[ p^+ \quad m_p = 938.3 \text{ MeV} \sim 2000 \text{ me} \]
\[ K^0 \quad m_{K^0} = 497.7 \text{ MeV} \quad Q = 0 \]
\[ n \quad m_n = 939.6 \text{ MeV} \quad Q = 0 \]

\( \{ \text{EM} \} \quad \{ \text{EM, Strong} \} \quad \{ \text{Strong} \} \)

The difference in mass, charge, interaction is the key to the identification.
Momentum Measurement

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

\[ L = R \cdot \theta \]
\[ S = R (1 - \cos \theta) \sim R \frac{\theta^2}{2} = \frac{L^2}{4R} \rightarrow R = \frac{L^2}{8S} \]
\[ \Delta p = 0.3B \Delta R = 0.3B \frac{L^2}{8S^2} S \]
\[ \Delta S = \frac{e^2}{1N} \]

\[ \frac{\Delta p}{p} \cdot \frac{\Delta S}{S} = \frac{e^2}{1N} \frac{[m]}{\sqrt{N}} \cdot \frac{3.3 \cdot 8 \cdot p \frac{[600]}{e}}{B[T] \cdot L^2 \frac{[cm]}{m}} \]

E.g.: \( p = 10 \frac{[600]}{e}, B = 1T, L = 1m, \sigma = 200\mu m, N = 25 \)
\[ \frac{\Delta p}{p} = 0.01 \rightarrow 1\% \]

Limit \( \rightarrow \) Multiple Scattering
Multiple Scattering

\[
\frac{\Delta p}{p} = \frac{\Delta \theta}{\theta} = \frac{\theta_o}{\theta} \approx \frac{0.05}{\beta \delta \alpha} \sqrt{\frac{L}{x_0}}
\]

\[
\frac{\Delta \phi}{p} = \left( \frac{\Delta \phi}{p}_{\text{Sogila}} \right)^2 + \left( \frac{\Delta \phi}{p}_{\text{m}} \right)^2
\]

\[\Theta = \frac{L}{R} = \frac{L}{p} \cdot 0.3 B\]

\[p \left[ \frac{c \omega}{e} \right] \cdot 0.3 R \left( \frac{B}{\pi} \right)\]

\[\Rightarrow \text{Inverse of } p\]
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
Interaction with the atomic electrons. The incoming particle loses energy and the atoms are excited or ionized.

Interaction with the atomic nucleus. The particle is deflected (scattered) causing multiple scattering of the particle in the material. During this scattering a Bremsstrahlung photon can be emitted.

In case the particle’s velocity is larger than the velocity of light in the medium, the resulting EM shockwave manifests itself as Cherenkov Radiation. When the particle crosses the boundary between two media, there is a probability of the order of 1% to produced and X ray photon, called Transition radiation.
A charged particle of mass \( M \) and charge \( q = Z_1 e \) is deflected by a nucleus of Charge \( Ze \).

Because of the acceleration the particle radiated EM waves \( \rightarrow \) energy loss.

Coulomb-Scattering (Rutherford Scattering) describes the deflection of the particle.

Maxwell’s Equations describe the radiated energy for a given momentum transfer.

\[ dE/dx \]
Bremsstrahlung, QM

Proportional to $Z^2/A$ of the Material.

Proportional to $Z_1^4$ of the incoming particle.

Proportional to $\rho$ of the material.

Proportional $1/M^2$ of the incoming particle.

Proportional to the Energy of the Incoming particle $\rightarrow$

$$E(x) = \exp(-x/X_0) \rightarrow \text{‘Radiation Length’}$$

$$X_0 \propto M^2 A / (\rho Z_1^4 Z^2)$$

$X_0$: Distance where the Energy $E_0$ of the incoming particle decreases $E_0 \exp(-1) = 0.37E_0$. 

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For the muon, the second lightest particle after the electron, the critical energy is at 400GeV.

The EM Bremsstrahlung is therefore only relevant for electrons at energies of past and present detectors.

Critical Energy: If $dE/dx$ (Ionization) = $dE/dx$ (Bremsstrahlung)

Myon in Copper: $p \approx 400$GeV
Electron in Copper: $p \approx 20$MeV
For $E_{\gamma} \gg m_e c^2 = 0.5 \text{MeV}$: $\lambda = 9/7 X_0$

Average distance a high energy photon has to travel before it converts into an $e^+ e^-$ pair is equal to $9/7$ of the distance that a high energy electron has to travel before reducing its energy from $E_0$ to $E_0 \times \exp(-1)$ by photon radiation.

\[
\frac{d\sigma}{dE} (E, E') = 4\pi \frac{Z^2 v_e^2}{E} \cdot G(E, E')
\]

\[
G(E, E') = \frac{1}{2} \left( (\frac{E + m_e c^2}{E})^2 - 1 \right) \left( (1 - \frac{E + m_e c^2}{E}) \ln \frac{E - 2m_e c^2}{E} \right)
\]

\[
\sigma = \int_0^E \frac{d\sigma}{dE} \, dE' = 4\pi \frac{Z^2 v_e^2}{3} \ln 183 Z^{-2/3}
\]

\[
P(x) = \frac{1}{2} e^{-\frac{x}{\lambda}} \quad \lambda = \frac{A}{9 \text{Na}^0} = \frac{3}{7} X_0
\]

\[
\text{Probability that photon converts to } e^+ e^- \text{ after a distance } x.
\]
Bremsstrahlung + Pair Production → EM Shower

Electromagnetic Shower → EN Colorimeter
**Tracking:**
Momentum by bending in the B-field
Secondary vertices

**Calorimeter:**
Energy by absorption

**Muons:**
Only particles passing through calorimeters

- Electrons ionize and show Bremsstrahlung due to the small mass
- Photons don't ionize but show Pair Production in high Z Material. From the on equal to $e^2$
- Charged Hadrons ionize and show Hadron Shower in Dense Material
- Neutral Hadrons don't ionize and show Hadron Shower in Dense Material
- Muons ionize and don't shower
Detector characteristics
- Width: 44m
- Diameter: 22m
- Weight: 7000t

Detector characteristics
- Width: 22m
- Diameter: 15m
- Weight: 14500t
Verlex Detector
Inner Tracking Chamber
Time Projection Chamber
Electromagnetic Calorimeter
Hadron Calorimeter
Muon Detectors
Fig. 1 - The ALEPH Detector
Z → e⁺ e⁻

Two high momentum charged particles depositing energy in the Electro Magnetic Calorimeter
Two high momentum charged particles traversing all calorimeters and leaving a signal in the muon chambers.
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. \( P_{\text{tot}}=0 \),

If the \( \Sigma p_i \) of all collision products is \( \neq 0 \) → neutrino escaped.
$W^+ W^- \rightarrow e^+ + \mu^- + \nu_e + \bar{\nu}_\mu$

Single electron, single Muon, Missing Momentum
Two jets of particles
$Z \rightarrow q \bar{q} g$

Three jets of particles
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.
Undistinguishable background exists. Only statistical excess gives signature.
2010 ATLAS W, Z candidates
2010 ATLAS W, Z candidates
Discovery of omega minus in the Brookhaven National Laboratory 80 inch hydrogen bubble chamber in 1964. Discovery claimed by a single event – ‘background free’
Particles are typically seen as an excess of events above an irreducible (i.e. indistinguishable) background.
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

\[ e^+, \mu^+, \gamma, \pi^+, K^+, K^0, p^+, n \]

Their difference in mass, charge and interaction is the key to their identification.
Solid state detectors close to the collision point for excellent position resolution to find vertices 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: $1.4 \times 10^8$ pixels

40 000 000 ‘images’ per second.
ATLAS Silicon Pixel Detector
Silicon Strip Detectors

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

Two dimensional readout is possible.
Silicon Strip Detectors
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!
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 ($X_0 = \sim 3\%$)
ALICE TPC: Pictures of the Construction

Precision in z: $250\mu m$

End plates $250\mu m$

Wire chamber: $40\mu m$
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 !
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
The Geiger Counter reloaded: Drift Tube

Primary electrons are drifting to the wire.

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 MDT R(tube) =15mm**

**Calibrated Radius-Time correlation**

**ATLAS Muon Chambers**

**ATLAS MDTs, 80µm per tube**
The Geiger counter reloaded: Drift Tube

Atlas Muon Spectrometer, 44m long, from r=5 to 11m.
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 ≈700ns
Gas Ar/CO₂ 93/7
Detector Systems
CERN Neutrino Gran Sasso

(CNGS)
If neutrinos have mass:

- $\nu_e$
- $\nu_\mu$
- $\nu_\tau$

Muon neutrinos produced at CERN. See if tau neutrinos arrive in Italy.
CNGS Project

CNGS (CERN Neutrino Gran Sasso)
- A long base-line neutrino beam facility (732km)
- send $\nu_\mu$ beam produced at CERN
- detect $\nu_\tau$ appearance in OPERA experiment at Gran Sasso

$\Rightarrow$ direct proof of $\nu_\mu - \nu_\tau$ oscillation (appearance experiment)
CNGS
CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN

- Excavated
- Concreted
- Decay tube (2nd contract)

SPS tunnel
TT41
Target chamber
Service gallery
Access galleries
Access shaft PGCN
SPS/ECA4

LEP/LHC tunnel
LHC/T18 tunnel
Decay tunnel
Protons
Pions/kaons
Muons/neutrinos
Second muon detector
Neutrinos to Gran Sasso

06 / 2003
CERN/AC-DI/MM

W. Riegler/CERN
Radial Distribution of the $\nu_\mu$-Beam at GS

Flat top: 500m
FWHM: 2800m

5 years CNGS operation, 1800 tons target:
- 30000 neutrino interactions
- $\sim$150 $\nu_\tau$ interactions
- $\sim$15 $\nu_\tau$ identified
- $<$ 1 event of background

typical size of a detector at Gran Sasso
Neutrinos at CNGS: Some Numbers

For 1 year of CNGS operation, we expect:

- protons on target \(2 \times 10^{19}\)
- pions / kaons at entrance to decay tunnel \(3 \times 10^{19}\)
- \(\nu_\mu\) in direction of Gran Sasso \(10^{19}\)
- \(\nu_\mu\) in 100 m\(^2\) at Gran Sasso \(3 \times 10^{14}\)
- \(\nu_\mu\) events per day in OPERA \(\approx 2500\)
- \(\nu_\tau\) events (from oscillation) \(\approx 2\)
Opera Experiment at Gran Sasso

Basic unit: brick

56 Pb sheets + 56 photographic films (emulsion sheets)

Lead plates: massive target
Emulsions: micrometric precision

Brick

Couche de gélatine photographique 40 μm

8.3 kg

10.2 x 12.7 x 7.5 cm³
Opera Experiment at Gran Sasso

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

First observation of CNGS beam neutrinos: August 18th, 2006
Opera Experiment at Gran Sasso

Second Super-module

Scintillator planes 5900 m²
8064 7m long drift tubes

Details of the first spectrometer

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!

Tests with the prototype wall

The robotised “Ferrari” for insertion/extraction of bricks with vacuum grip by Venturi valve

“Carousel” brick dispensing and storage system
First Tau Candidate seen a few weeks ago!
AMANDA

Antarctic Muon And Neutrino Detector Array
AMANDA

South Pole
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.

→ Find neutrino point sources in the universe!
AMANDA

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 Magnetic Spectrometer**

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

Is installed on the international space station.
AMS

$\pm Q, P$

TOF

TRD

$V \rightarrow C$

Tracker

Magnet Cells & Structure

Helium Vessel

Veto

RICH

Calorimeter

$E: e^+, \gamma$

$m=P/v$

W. Riegler/CERN
AMS

USS:
Unique Support Structure

TRD:
Transition Radiation Detector

TOF (s1,s2) Time of Flight

TOF (s3,s4) Time of Flight

RICH:
Ring Image Cherenkov Counter

ECAL:
Electromagnetic Calorimeter

USS Keel

PAS:
Payload Attach System

Zenith Radiator

Tracker Radiator

Grapple Fixture

GPS