Physics in Italy 1950 - 2000

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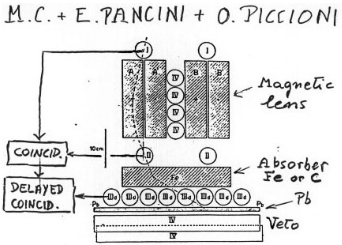
The Conversi, Pancini e Piccioni Experiment



Hourly counts of “mesotrons”
seen decaying into an electron

mesotroni	Fe	C
positivi	0.67 ± 0.07	0.36 ± 0.05
negativi	0.03 ± 0.03	0.27 ± 0.03

Negative Yukawa mesons
should be absorbed both in Fe and in C
and should note decay!

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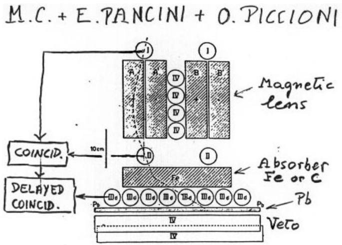

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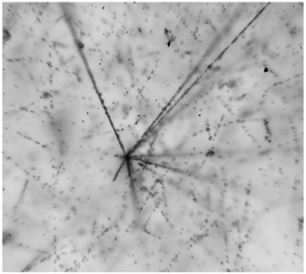
Negative Yukawa mesons should be absorbed both in Fe and in C and should note decay!

“modern particle physics started in the last days of World War II, when a group of young Italians, Conversi, Pancini, and Piccioni, who were hiding from the German occupying forces, initiated a remarkable experiment...”

(L. Alvarez, Nobel lecture 1968)

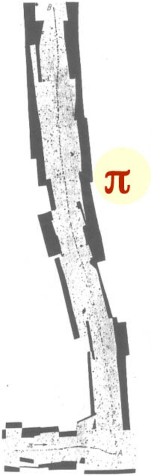
Nuclear Emulsions and Cosmic Rays

Giuseppe Occhialini perfected the nuclear emulsion technique, leading to the 1947 discovery of the true Yukawa meson, the pion — π.



The cosmic ray Laboratory at Testa Grigia, and a cosmic ray collision seen in nuclear emulsion.

The Amaldi group detected in emulsions the first observed antiproton.



Elementary particles in 1950 and 1960

1950:

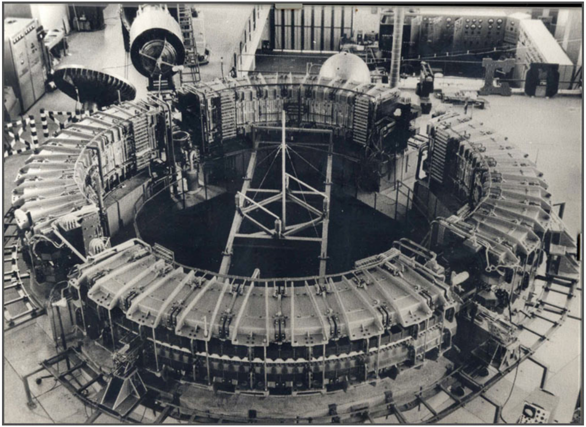
- Proton and Neutron — the Nucleons
- The pion — π, the Yukawa Meson.
- Electron and Positron.
- Neutrino — Observed only in 1957.
- Muon — the Conversi-Pancini-Piccioni particle
  "Who ordered that?" (Isadore Rabi)

In 1960 new particles appear:

- Strange Mesons — τ, θ (today K mesons)
- Strange Nucleons (Hyperons) — Λ, Σ, Ξ
- πP Resonance — E. Fermi (today Δ)

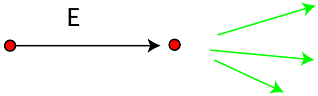
At the end of the fifties particle physics moves from cosmic rays to accelerators. Among these the CERN PS and the Frascati synchrotron.

The Frascati Synchrotron — 1958

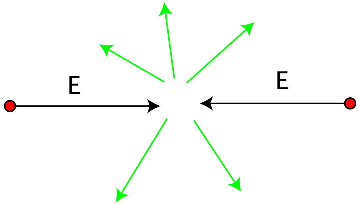


The 1100 MeV Synchrotron, and Giorgio Salvini, director of the Frascati Laboratories.

Particle Colliders, why



In the collision of a particle of energy E with one at rest with mass M the effective center of mass energy is only $\sqrt{2ME}$



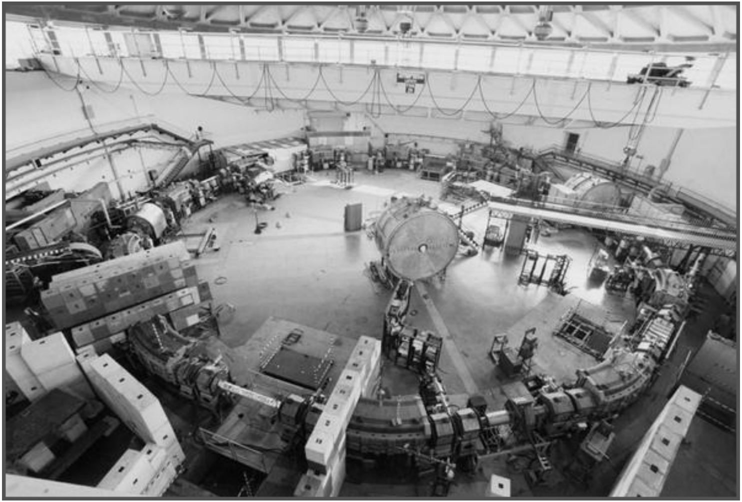
In the frontal collision of two particles with energy E, the center of mass energy is $2E$

Under the guidance of Bruno Toushek the Frascati Laboratories built AdA, the first machine to demonstrate beam-beam collisions. A larger electron-positron collider, Adone (big AdA), was completed in 1968.

AdA: the first electron-positron collider – 1960

Bruno Toushek, inventor of the $e^+ - e^-$ colliders, with Edoardo Amaldi

Adone – 1968



The particle Zoo: Baryons

Baryon Summary Table

p	P_{11}	****	$\Delta(1232)$	P_{33}	****	Σ^+	P_{11}	****	Ξ^0	P_{11}	****	Λ_c^+	****
n	P_{11}	****	$\Delta(1600)$	P_{33}	***	Σ^0	P_{11}	****	Ξ^-	P_{11}	****	$\Lambda_c(2595)^+$	***
$N(1440)$	P_{11}	****	$\Delta(1620)$	S_{31}	****	Σ^-	P_{11}	****	$\Xi(1530)$	P_{13}	****	$\Lambda_c(2625)^+$	***
$N(1520)$	D_{13}	****	$\Delta(1700)$	D_{33}	****	$\Sigma(1385)$	P_{13}	****	$\Xi(1620)$		*	$\Lambda_c(2765)^+$	*
$N(1535)$	S_{11}	****	$\Delta(1750)$	P_{31}	*	$\Sigma(1480)$		*	$\Xi(1690)$		***	$\Lambda_c(2880)^+$	***
$N(1650)$	S_{11}	****	$\Delta(1900)$	S_{31}	**	$\Sigma(1560)$		**	$\Xi(1820)$	D_{13}	***	$\Lambda_c(2940)^+$	***
$N(1675)$	D_{15}	****	$\Delta(1905)$	F_{35}	****	$\Sigma(1580)$	D_{13}	*	$\Xi(1950)$		***	$\Sigma_c(2455)$	****
$N(1680)$	F_{15}	****	$\Delta(1910)$	P_{31}	****	$\Sigma(1620)$	S_{11}	**	$\Xi(2030)$		***	$\Sigma_c(2520)$	***
$N(1700)$	D_{13}	***	$\Delta(1920)$	P_{33}	***	$\Sigma(1660)$	P_{11}	***	$\Xi(2120)$		*	$\Sigma_c(2800)$	***
$N(1710)$	P_{11}	***	$\Delta(1930)$	D_{35}	***	$\Sigma(1670)$	D_{13}	****	$\Xi(2250)$		**	Ξ_c^+	***
$N(1720)$	P_{13}	****	$\Delta(1940)$	D_{33}	*	$\Sigma(1690)$		**	$\Xi(2370)$		**	Ξ_c^0	***
$N(1900)$	P_{13}	**	$\Delta(1950)$	F_{37}	****	$\Sigma(1750)$	S_{11}	***	$\Xi(2500)$		*	$\Xi_c'^+$	***
$N(1990)$	F_{17}	**	$\Delta(2000)$	F_{35}	**	$\Sigma(1770)$	P_{11}	*				$\Xi_c'^0$	***
$N(2000)$	F_{15}	**	$\Delta(2150)$	S_{31}	*	$\Sigma(1775)$	D_{15}	****	Ω^-		****	$\Xi_c(2645)$	***
$N(2080)$	D_{13}	**	$\Delta(2200)$	G_{37}	*	$\Sigma(1840)$	P_{13}	*	$\Omega(2250)^-$		***	$\Xi_c(2790)$	***
$N(2090)$	S_{11}	*	$\Delta(2300)$	H_{39}	**	$\Sigma(1880)$	P_{11}	**	$\Omega(2380)^-$		**	$\Xi_c(2815)$	***
$N(2100)$	P_{11}	*	$\Delta(2350)$	D_{35}	*	$\Sigma(1915)$	F_{15}	****	$\Omega(2470)^-$		**	$\Xi_c(2930)$	*
$N(2190)$	G_{17}	****	$\Delta(2390)$	F_{37}	*	$\Sigma(1940)$	D_{13}	***				$\Xi_c(2980)$	***
$N(2200)$	D_{15}	**	$\Delta(2400)$	G_{39}	**	$\Sigma(2000)$	S_{11}	*				$\Xi_c(3055)$	**
$N(2220)$	H_{19}	****	$\Delta(2420)$	$H_{3,11}$	****	$\Sigma(2030)$	F_{17}	****				$\Xi_c(3080)$	***
$N(2250)$	G_{19}	****	$\Delta(2750)$	$I_{3,13}$	**	$\Sigma(2070)$	F_{15}	*				$\Xi_c(3123)$	*
$N(2600)$	$I_{1,11}$	***	$\Delta(2950)$	$K_{3,15}$	**	$\Sigma(2080)$	P_{13}	**				Ω_c^0	***
$N(2700)$	$K_{1,13}$	**				$\Sigma(2100)$	G_{17}	*				$\Omega_c(2770)^0$	***
			Λ	P_{01}	****	$\Sigma(2250)$		***					
			$\Lambda(1405)$	S_{01}	****	$\Sigma(2455)$		**				Ξ_{cc}^+	*
			$\Lambda(1520)$	D_{03}	****	$\Sigma(2620)$		**					

The proliferation of hadronic particles: the relatives of the nucleon.

The particle Zoo: Mesons

Meson Summary Table

LIGHT UNFLAVORED ($S = C = B = 0$)	$I^G(J^{PC})$		$I^G(J^{PC})$
• $\pi^\pm$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$
• $f_0(600)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$
• $\rho(770)$	$1^+(1^{--})$	$a_2(1700)$	$1^-(2^{++})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$\eta(1760)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$
• $a_0(980)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$
• $\phi(1020)$	$0^-(1^{--})$	$X(1835)$	$?^?(?^{-+})$
• $h_1(1170)$	$0^-(1^{+-})$	• $\phi_3(1850)$	$0^-(3^{--})$
• $b_1(1235)$	$1^+(1^{+-})$	$\eta_2(1870)$	$0^+(2^{-+})$
• $a_1(1260)$	$1^-(1^{++})$	• $\pi_2(1880)$	$1^-(2^{-+})$
• $f_2(1270)$	$0^+(2^{++})$	$\rho(1900)$	$1^+(1^{--})$
• $f_1(1285)$	$0^+(1^{++})$	$f_2(1910)$	$0^+(2^{++})$
• $\eta(1295)$	$0^+(0^{-+})$	• $f_2(1950)$	$0^+(2^{++})$
• $\pi(1300)$	$1^-(0^{-+})$	$\rho_3(1990)$	$1^+(3^{--})$
• $a_2(1320)$	$1^-(2^{++})$	• $f_2(2010)$	$0^+(2^{++})$
• $f_0(1370)$	$0^+(0^{++})$	$f_0(2020)$	$0^+(0^{++})$
$h_1(1380)$	$?^-(1^{+-})$	• $a_4(2040)$	$1^-(4^{++})$
• $\pi_1(1400)$	$1^-(1^{-+})$	• $f_4(2050)$	$0^+(4^{++})$
• $\eta(1405)$	$0^+(0^{-+})$	$\pi_2(2100)$	$1^-(2^{-+})$
• $f_1(1420)$	$0^+(1^{++})$	$f_0(2100)$	$0^+(0^{++})$
• $\omega(1420)$	$0^-(1^{--})$	$f_2(2150)$	$0^+(2^{++})$
$f_2(1430)$	$0^+(2^{++})$	$\rho(2150)$	$1^+(1^{--})$

STRANGE ($S = \pm1$, $C = B = 0$)	$I(J^P)$
• $K^\pm$	$1/2(0^-)$
• K^0	$1/2(0^-)$
• K^0_S	$1/2(0^-)$
• K^0_L	$1/2(0^-)$
$K^*_0(800)$	$1/2(0^+)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K^*_0(1430)$	$1/2(0^+)$
• $K^*_2(1430)$	$1/2(2^+)$
$K(1460)$	$1/2(0^-)$
$K_2(1580)$	$1/2(2^-)$
$K(1630)$	$1/2(?^?)$
$K_1(1650)$	$1/2(1^+)$
• $K^*(1680)$	$1/2(1^-)$
• $K_2(1770)$	$1/2(2^-)$
• $K^*_3(1780)$	$1/2(3^-)$
• $K_2(1820)$	$1/2(2^-)$
$K(1830)$	$1/2(0^-)$
$K^*_0(1950)$	$1/2(0^+)$
$K^*_2(1980)$	$1/2(2^+)$
• $K^*_4(2045)$	$1/2(4^+)$
$K_2(2250)$	$1/2(2^-)$
$K_3(2320)$	$1/2(3^+)$

CHARMED, STRANGE ($C = S = \pm1$)	$I(J^P)$
• $D_s^\pm$	$0(0^-)$
• $D_s^{*\pm}$	$0(?^?)$
• $D^*_{s0}(2317)^\pm$	$0(0^+)$
• $D_{s1}(2460)^\pm$	$0(1^+)$
• $D_{s1}(2536)^\pm$	$0(1^+)$
• $D_{s2}(2573)^\pm$	$0(?^?)$
$D_{s1}(2700)^\pm$	$0(1^-)$
BOTTOM ($B = \pm1$)	
• $B^\pm$	$1/2(0^-)$
• B^0	$1/2(0^-)$
• $B^\pm/B^0$ ADMIXTURE	
• $B^\pm/B^0/B^0_s/b$-baryon ADMIXTURE	
V_{cb} and V_{ub} CKM Matrix Elements	
• B^*	$1/2(1^-)$
$B^*_J(5732)$	$?(?^?)$
• $B_1(5721)^0$	$1/2(1^+)$
• $B^*_2(5747)^0$	$1/2(2^+)$
BOTTOM, STRANGE ($B = \pm1$, $S = \mp1$)	
• B^0_s	$0(0^-)$
• B^*_s	$0(1^-)$

$c\bar{c}$	$I^G(J^{PC})$
• $\eta_c(1S)$	$0^+(0^{-+})$
• $J/\psi(1S)$	$0^-(1^{--})$
• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $\chi_{c1}(1P)$	$0^+(1^{++})$
• $h_c(1P)$	$?^?(1^{+-})$
• $\chi_{c2}(1P)$	$0^+(2^{++})$
• $\eta_c(2S)$	$0^+(0^{-+})$
• $\psi(2S)$	$0^-(1^{--})$
• $\psi(3770)$	$0^-(1^{--})$
• $X(3872)$	$0^?(?^{?+})$
$\chi_{c2}(2P)$	$0^+(2^{++})$
$X(3940)$	$?^?(?^{??})$
$X(3945)$	$?^?(?^{??})$
• $\psi(4040)$	$0^-(1^{--})$
• $\psi(4160)$	$0^-(1^{--})$
• $X(4260)$	$?^?(1^{--})$
$X(4360)$	$?^?(1^{--})$
• $\psi(4415)$	$0^-(1^{--})$

$b\bar{b}$	
$\eta_b(1S)$	$0^+(0^{-+})$
• $\Upsilon(1S)$	$0^-(1^{--})$
• $\chi_{b0}(1P)$	$0^+(0^{++})$
• $\chi_{b1}(1P)$	$0^+(1^{++})$
• $\chi_{b2}(1P)$	$0^+(2^{++})$
• $\Upsilon(2S)$	$0^-(1^{--})$

The proliferation of hadronic particles: the relatives of the π meson.

Quarks

Quarks spin = 1/2		
Flavor	**Approx. Mass GeV/c^2**	**Electric charge**
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

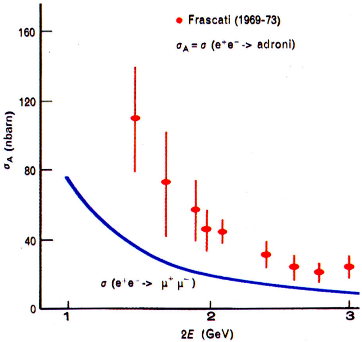
Baryons are bound states of three quarks,
For instance the proton: $P = uud$

Mesons are bound states of a quark-antiquark
pair, for instance the pion: $\pi^+ = u\bar{d}$

Heavier baryons or mesons are excited states of three quarks or of a quark-antiquark pair

The "zoo" is simplified!
Do quarks really exist?

Adone: Colored Quarks exist!



R is the ratio between hadron and muon-pair production in $e^+ - e^-$ collisions

$$R = \frac{e^+e^- \to \pi^+\pi^- + \dots}{e^+e^- \to \mu^+\mu^-}$$

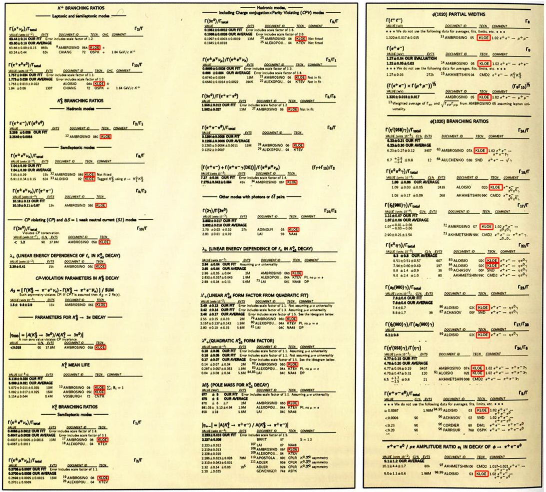
To produce hadrons in $e^+ - e^-$ collisions means producing quark–antiquark pairs, and we obtain

$$R = \sum_{\text{quarks}} (Q)^2 = \begin{cases} \frac{2}{3} & \text{(For each “color”)} \\ 2 & \text{(For three “colors”)} \end{cases}$$

Adone established the existence of the “color” quantum number: each quark exists in three copies, and the color symmetry is the foundation of Quantum Chromo Dynamics, the theory of quark interactions.

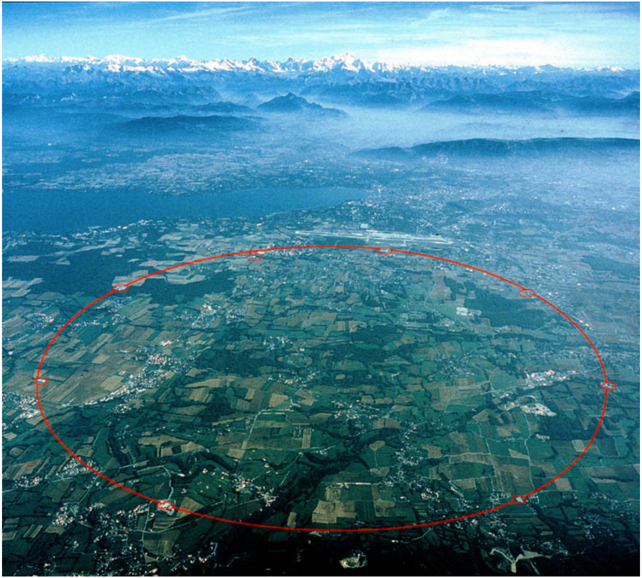
DAFNE: towards the new millennium.

KLOE in the Particle Data Group book

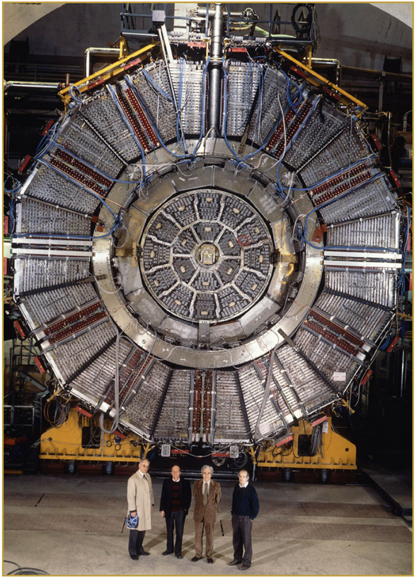


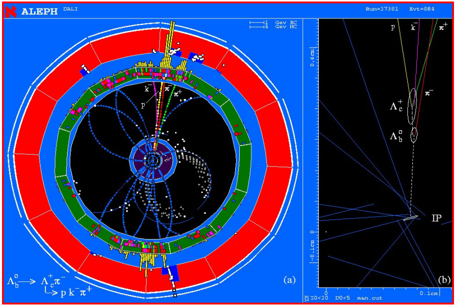
With the KLOE detector, DAFNE has practically rewritten the physics of K e Φ mesons, leading also to a precise test of the quark-mixing hypothesis.

CERN: the LEP and LHC tunnel



The LEP experiments

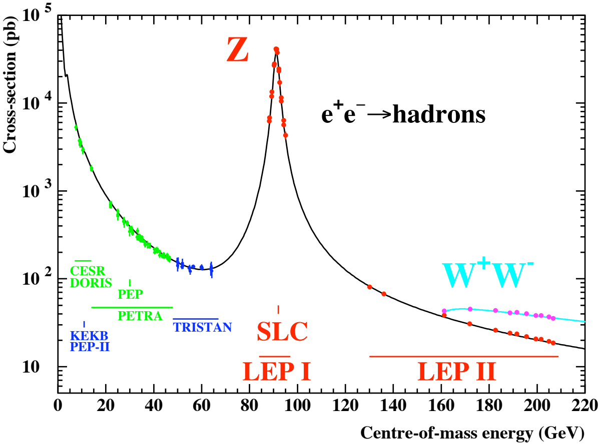




INFN had a leading role
in the four LEP detectors:
DELPHI, OPAL, L3 e ALEPH.

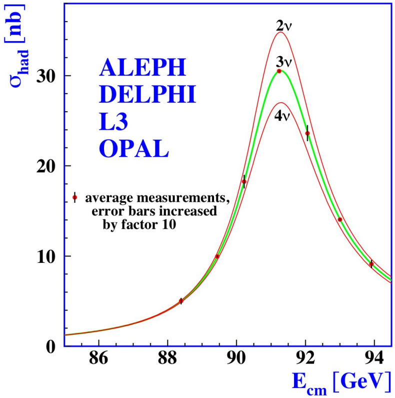
ALEPH and an ALEPH event

Hadron production in e$^+$-e$^-$ collisions



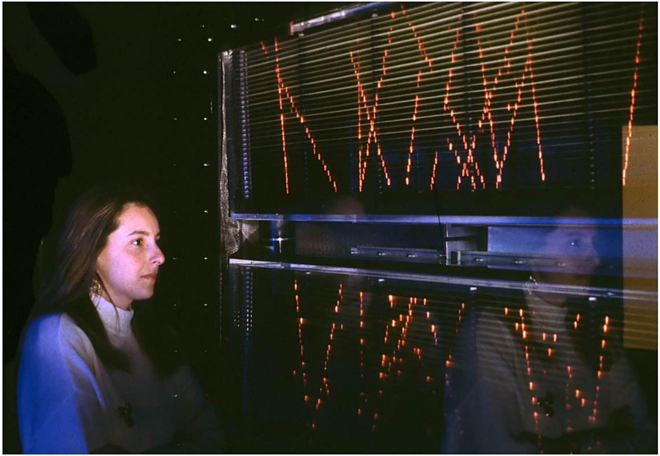
This figure omits lower energy data from Adone, SPEAR, etc.

How many neutrinos?



The study of the Z resonance confirms that the invisible channels correspond to three neutrino-antineutrino pairs — ν_e, ν_μ, ν_τ

Particle detectors: Spark Chambers ($\sim$ 1960).



Invented by Marcello Conversi, spark chambers dominated particle physics in the sixties.

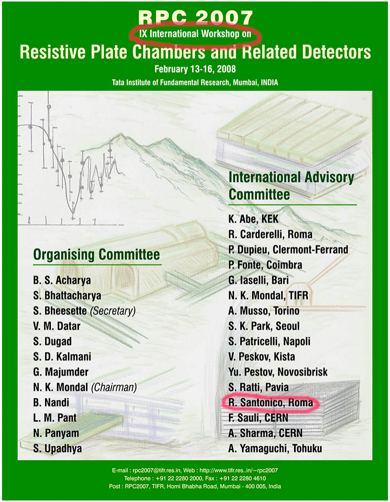
Particle detectors: the Iarocci tubes ($\sim$ 1980).

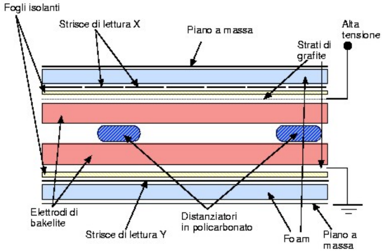
Experiments using Iarocci Tubes

ALEPH	E802	RD94
BaBar	γγ2	SLD
CHARM	MACRO	UA1
CLEO	Mount Blanc Detector	WA80
DELPHI	OPAL	ZEUS
DM2	PHENIX	
D0		

Invented by Enzo Iarocci, they are a modern fast version of the Geiger-Müller counters, and have been widely used in the eighties: at LEP, at Frascati, Stanford, DESY (Hamburg), Fermilab (Chicago), Gran Sasso.

Detectors: “Resistive Plate Chambers” – (RPC)

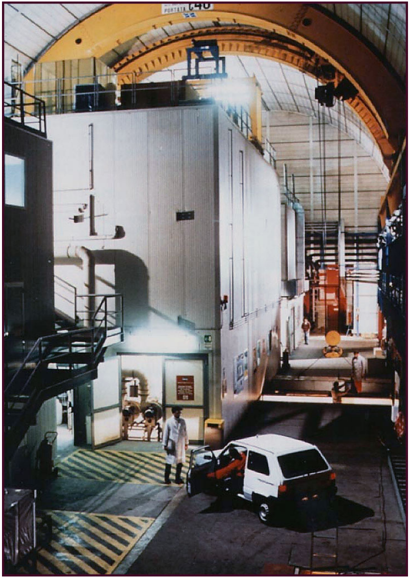


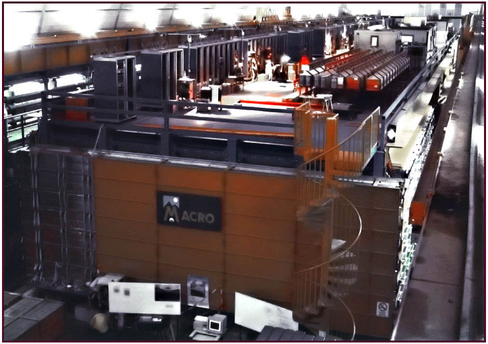


Invented by Rolando Santonico, widely used in contemporary experiments.

In the photo the structure of the RPC used in the ATLAS experiment at LHC.

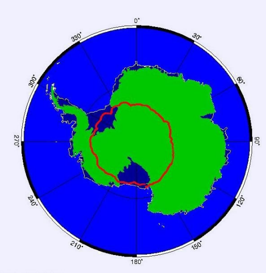
Neutrino Oscillations at Gran Sasso.

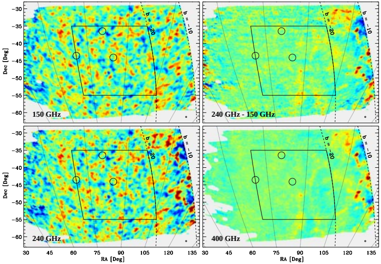


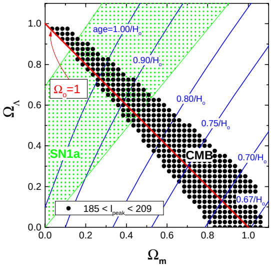


Gallex and Macro in the underground Gran Sasso Laboratories gave essential contributions to the discovery of neutrino oscillations

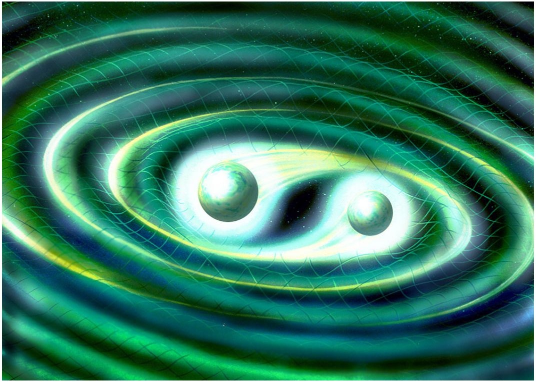
Boomerang: Universe is flat!



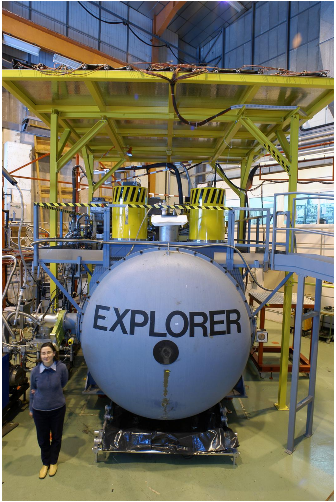


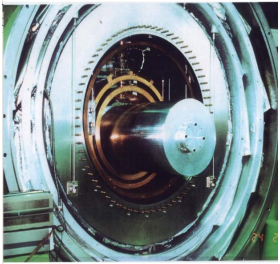


Gravitational waves: Amaldi's last enterprise.



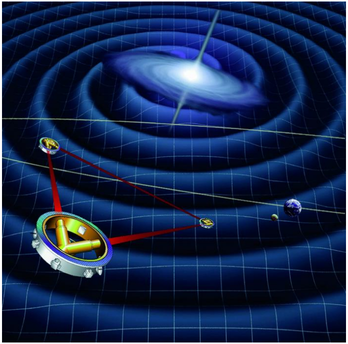
Gravitational waves: Amaldi's last enterprise.





Two cryogenic bar antennas of the Amaldi group:
Explorer (CERN) and Nautilus (Frascati).

Gravitational waves present and future.



The future of gravitational waves is with large interferometers
Today on the Earth surface (Virgo near Pisa),
Tomorrow in space (The LISA satellites).