#### Physics in Italy 1950 - 2000

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Lares, 3 July 2009

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#### The Conversi, Pancini e Piccioni Experiment

# Hourly counts of "mesotrons" seen decaying into an electron

M.C. + E. PANCINI + O. PICCIONI



mesotroni	Fe	C
positivi	$0.67 \pm 0.07$	$0.36 \pm 0.05$
negativi	$0.03 \pm 0.03$	$0.27 \pm 0.03$

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

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"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)

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#### Nuclear Emulsions and Cosmic Rays



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



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.



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#### Elementary particles in 1950 and 1960

1950:

- Proton and Neutron the Nucleons
- The pion  $\pi$ , 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  $\tau, \theta$  (today K mesons)
- Strange Nucleons (Hyperons)  $\Lambda, \Sigma, \Xi$
- $\pi P$  Resonance E. Fermi (today  $\Delta$ )

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.

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Physics in Italy

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#### 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



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## The particle Zoo: Baryons

Baryon Summary Table

			-	_			_		_				
p	P <sub>11</sub>	****	$\Delta(1232)$	P <sub>33</sub>	****	Σ+	P <sub>11</sub>	****	$\Xi^0$	P <sub>11</sub>	****	$\Lambda_c^+$	****
п	P <sub>11</sub>	****	$\Delta(1600)$	P <sub>33</sub>	***	$\Sigma^0$	$P_{11}$	****	E-	P <sub>11</sub>	****	$\Lambda_{c}(2595)^{+}$	***
N(1440)	P <sub>11</sub>	****	$\Delta(1620)$	$S_{31}$	****	Σ-	$P_{11}$	****	$\Xi(1530)$	$P_{13}$	****	$\Lambda_{c}(2625)^{+}$	***
N(1520)	D <sub>13</sub>	****	$\Delta(1700)$	D33	****	Σ(1385)	$P_{13}$	****	$\Xi(1620)$		*	$\Lambda_{c}(2765)^{+}$	*
N(1535)	S <sub>11</sub>	****	<i>∆</i> (1750)	P <sub>31</sub>	*	Σ(1480)		*	$\Xi(1690)$		***	$\Lambda_{c}(2880)^{+}$	***
N(1650)	S <sub>11</sub>	****	<i>∆</i> (1900)	S <sub>31</sub>	**	$\Sigma(1560)$		**	$\Xi(1820)$	$D_{13}$	***	$\Lambda_{c}(2940)^{+}$	***
N(1675)	D <sub>15</sub>	****	$\Delta(1905)$	F <sub>35</sub>	****	$\Sigma(1580)$	$D_{13}$	*	$\Xi(1950)$		***	$\Sigma_c(2455)$	****
N(1680)	F <sub>15</sub>	****	<i>∆</i> (1910)	P <sub>31</sub>	****	$\Sigma(1620)$	$S_{11}$	**	Ξ(2030)		***	$\Sigma_{c}(2520)$	***
N(1700)	D <sub>13</sub>	***	$\Delta(1920)$	P33	***	$\Sigma(1660)$	P <sub>11</sub>	***	Ξ(2120)		*	$\Sigma_{c}(2800)$	***
N(1710)	P <sub>11</sub>	***	$\Delta(1930)$	D35	***	$\Sigma(1670)$	$D_{13}$	****	Ξ(2250)		**	Ξ±	***
N(1720)	P <sub>13</sub>	****	∆(1940)	D33	*	$\Sigma(1690)$		**	Ξ(2370)		**	=0	***
N(1900)	P13	**	$\Delta(1950)$	F37	****	$\Sigma(1750)$	$S_{11}$	***	Ξ(2500)		*	- c ='+	***
N(1990)	F <sub>17</sub>	**	$\Delta(2000)$	F35	**	Σ(1770)	$P_{11}$	*				- c =/0	***
N(2000)	F <sub>15</sub>	**	$\Delta(2150)$	S31	*	Σ(1775)	D15	****	$\Omega^{-}$		****	- c = (264E)	***
N(2080)	D <sub>13</sub>	**	$\Delta(2200)$	G37	*	Σ(1840)	P <sub>13</sub>	*	$\Omega(2250)^{-}$		***	$=_{c}(2045)$ = (2700)	***
N(2090)	S <sub>11</sub>	*	$\Delta(2300)$	Hag	**	Σ(1880)	P <sub>11</sub>	**	$\Omega(2380)^{-}$		**	$=_{c}(2790)$	***
N(2100)	P <sub>11</sub>	*	$\Delta(2350)$	D35	*	Σ(1915)	F15	****	$\Omega(2470)^{-}$		**	$=_{c}(2013)$	*
N(2190)	G17	****	$\Delta(2390)$	F37	*	Σ(1940)	D13	***				$=_{c}(2930)$	***
N(2200)	D15	**	$\Delta(2400)$	G30	**	Σ(2000)	S11	*				$=_{c}(2900)$	**
N(2220)	$H_{19}$	****	$\Delta(2420)$	H3 11	****	Σ(2030)	F <sub>17</sub>	****				$=_{c}(3033)$	***
N(2250)	G19	****	$\Delta(2750)$	12 12	**	Σ(2070)	F <sub>15</sub>	*				$=_{c}(3000)$	*
N(2600)	h 11	***	A(2950)	Kaar	**	Σ(2080)	P <sub>13</sub>	**				$=_{c}(3123)$	***
N(2700)	K1 13	**	L(2)50)	13,15		Σ(2100)	G17	*				12°	***
	2,25		Λ	Poi	****	Σ(2250)		***				32 <sub>c</sub> (2110) <sup>6</sup>	***
			A(1405)	S01	****	Σ(2455)		**				-+	.
			A(1520)	D02	****	Σ(2620)		**				=	- T
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The proliferation of hadronic particles: the relatives of the nucleon.

Nicola Cabibbo

#### The particle Zoo: Mesons

Meson Summary Table

	LIGHT UN	FLAVORED		STRAM	IGE	CHARMED, S	TRANGE	0	7
	(S = C =	= B = 0)		$(S = \pm 1, C)$	= B = 0)	(C = S =	±1)		$P(J^{PC})$
	$I^{G}(J^{PC})$		$I^{G}(J^{PC})$		$I(J^{P})$		$I(J^p)$	<ul> <li>η<sub>c</sub>(1S)</li> </ul>	0+(0-+)
• $\pi^{\pm}$	$1^{-}(0^{-})$	<ul> <li>π<sub>2</sub>(1670)</li> </ul>	1-(2-+)	• K <sup>±</sup>	1/2(0)	• D_{s}^{\pm}	0(0_)	<ul> <li>J/ψ(1S)</li> </ul>	0-(1)
• $\pi^0$	$1^{-}(0^{-+})$	<ul> <li></li></ul>	0-(1)	• K <sup>0</sup>	1/2(0-)	• D <sup>*±</sup>	0(? <sup>?</sup> )	• $\chi_{c0}(1P)$	$0^{+}(0^{++})$
• 1	0+(0-+)	<ul> <li>         ρ<sub>3</sub>(1690)     </li> </ul>	1+(3)	• K <sup>0</sup> <sub>S</sub>	$1/2(0^{-})$	<ul> <li>D<sup>*</sup><sub>s0</sub>(2317)<sup>±</sup></li> </ul>	0(0+)	• $\chi_{c1}(1P)$	$0^+(1^{++})$
• f <sub>0</sub> (600)	$0^{+}(0^{++})$	<ul> <li>ρ(1700)</li> </ul>	$1^+(1^{})$	• K <sup>0</sup> <sub>L</sub>	$1/2(0^{-})$	<ul> <li>D<sub>s1</sub>(2460)<sup>±</sup></li> </ul>	$0(1^+)$	<ul> <li><i>h<sub>c</sub></i>(1<i>P</i>)</li> </ul>	? (1 + -)
<ul> <li>ρ(770)</li> </ul>	$1^{+}(1^{-})$	$a_2(1700)$	$1^{-}(2^{++})$	K <sup>*</sup> <sub>0</sub> (800)	$1/2(0^+)$	<ul> <li>D<sub>s1</sub>(2536)<sup>±</sup></li> </ul>	$0(1^+)$	• $\chi_{c2}(1P)$	$0^+(2^{++})$
<ul> <li>ω(782)</li> </ul>	0-(1)	<ul> <li>f<sub>0</sub>(1710)</li> </ul>	$0^{+}(0^{++})$	<ul> <li>K*(892)</li> </ul>	$1/2(1^{-})$	<ul> <li>D<sub>s2</sub>(2573)<sup>±</sup></li> </ul>	0(??)	<ul> <li>η<sub>c</sub>(25)</li> </ul>	0+(0-+)
<ul> <li>η'(958)</li> </ul>	0+(0-+)	$\eta(1760)$	$0^{+}(0^{-+})$	• K <sub>1</sub> (1270)	$1/2(1^+)$	$D_{s1}(2700)^{\pm}$	0(1-)	• \u03cb(25)	0-(1)
<ul> <li>f<sub>0</sub>(980)</li> </ul>	$0^{+}(0^{++})$	<ul> <li>π(1800)</li> </ul>	$1^{-}(0^{-+})$	<ul> <li>K<sub>1</sub>(1400)</li> </ul>	$1/2(1^+)$			<ul> <li>ψ(3770)</li> </ul>	$0^{-}(1^{-})$
<ul> <li>a<sub>0</sub>(980)</li> </ul>	$1^{-}(0^{++})$	f <sub>2</sub> (1810)	$0^+(2^{++})$	• K*(1410)	$1/2(1^{-})$	BOTTO	M	• X(3872)	0'(?'+)
<ul> <li>         \$\phi(1020)\$</li> </ul>	0-(1)	X(1835)	?!(? - +)	<ul> <li>K<sup>*</sup><sub>0</sub>(1430)</li> </ul>	$1/2(0^+)$	(D = 1	1)	$\chi_{c2}(2P)$	$0^+(2^+)$
<ul> <li>h<sub>1</sub>(1170)</li> </ul>	$0^{-}(1^{+})$	<ul> <li>\$\phi_3\$(1850)</li> </ul>	0-(3)	<ul> <li>K<sup>*</sup><sub>2</sub>(1430)</li> </ul>	$1/2(2^+)$	• B <sup>±</sup>	$1/2(0^{-})$	X(3940)	?'(?'')
<ul> <li>b<sub>1</sub>(1235)</li> </ul>	$1^+(1^{+-})$	$\eta_2(1870)$	$0^+(2^{-+})$	K(1460)	$1/2(0^{-})$	• B <sup>0</sup>	$1/2(0^{-})$	X(3945)	?'(?'')
<ul> <li>a<sub>1</sub>(1260)</li> </ul>	$1^{-}(1^{++})$	<ul> <li>π<sub>2</sub>(1880)</li> </ul>	1-(2-+)	K2(1580)	$1/2(2^{-})$	• B <sup>±</sup> /B <sup>0</sup> ADM	IXTURE	<ul> <li>ψ(4040)</li> </ul>	0-(1)
<ul> <li>f<sub>2</sub>(1270)</li> </ul>	$0^+(2^{++})$	$\rho(1900)$	$1^+(1^{})$	K(1630)	$1/2(?^{?})$	• B <sup>±</sup> /B <sup>0</sup> /B <sup>0</sup> <sub>s</sub> /	b-baryon	• \u03c6 (4160)	$0^{-}(1^{-})$
<ul> <li>f<sub>1</sub>(1285)</li> </ul>	$0^{+}(1^{++})$	f <sub>2</sub> (1910)	$0^{+}(2^{++})$	K1(1650)	$1/2(1^+)$	ADMIXTURE	CKM Ma-	• X(4260)	$?_{2}^{!}(1^{})$
<ul> <li>η(1295)</li> </ul>	0+(0 - +)	<ul> <li>f<sub>2</sub>(1950)</li> </ul>	$0^+(2^{++})$	<ul> <li>K*(1680)</li> </ul>	$1/2(1^{-})$	trix Elements	cram mu	X(4360)	?!(1)
<ul> <li>π(1300)</li> </ul>	$1^{-}(0^{-+})$	$\rho_3(1990)$	1+(3)	• K <sub>2</sub> (1770)	$1/2(2^{-})$	• B*	$1/2(1^{-})$	<ul> <li>ψ(4415)</li> </ul>	0-(1)
<ul> <li>a<sub>2</sub>(1320)</li> </ul>	$1^{-}(2^{++})$	<ul> <li>f<sub>2</sub>(2010)</li> </ul>	$0^{+}(2^{++})$	<ul> <li>K<sup>*</sup><sub>3</sub>(1780)</li> </ul>	$1/2(3^{-})$	B <sup>*</sup> <sub>J</sub> (5732)	?(??)		T
<ul> <li>f<sub>0</sub>(1370)</li> </ul>	$0^+(0^{++})$	f <sub>0</sub> (2020)	$0^+(0^{++})$	<ul> <li>K<sub>2</sub>(1820)</li> </ul>	$1/2(2^{-})$	<ul> <li>B<sub>1</sub>(5721)<sup>0</sup></li> </ul>	$1/2(1^+)$	6	D
$h_1(1380)$	?-(1+-)	<ul> <li>a<sub>4</sub>(2040)</li> </ul>	$1^{-}(4^{++})$	K(1830)	$1/2(0^{-})$	<ul> <li>B<sup>*</sup><sub>2</sub>(5747)<sup>0</sup></li> </ul>	$1/2(2^+)$	$\eta_b(15)$	0+(0-+)
• $\pi_1(1400)$	$1^{-}(1^{-+})$	<ul> <li>f<sub>4</sub>(2050)</li> </ul>	$0^+(4^{++})$	K*(1950)	$1/2(0^{+})$	DOTTOLLO	ED LUCE	• 7(15)	0 (1)
<ul> <li>η(1405)</li> </ul>	0+(0-+)	$\pi_2(2100)$	$1^{-}(2^{-+})$	K*(1980)	$1/2(2^+)$	BUITOM, S	I RANGE	• χ <sub>b0</sub> (1P)	$0^+(0^{++})$
• f <sub>1</sub> (1420)	$0^{+}(1^{++})$	f <sub>0</sub> (2100)	0+(0++)	• K*(2045)	$1/2(4^+)$	(D = ±1, 3	- ++)	• $\chi_{b1}(1P)$	$0^{+}(1^{++})$
<ul> <li>ω(1420)</li> </ul>	0-(1)	f <sub>2</sub> (2150)	0+(2++)	Ka(2250)	1/2(2-)	• B <sup>0</sup> <sub>s</sub>	0(0-)	• $\chi_{b2}(1P)$	$0^{+}(2^{++})$
fs(1430)	$0^+(2^{++})$	o(2150)	$1^{+}(1^{-})$		-/-(- )	• B*	$0(1^{-})$	• T(25)	$0^{-}(1^{-})$

#### The proliferation of hadronic particles: the relatives of the $\pi$ meson.

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11/27

#### Quarks

Quarks spin = 1/2							
Flavor	Approx. Mass GeV/c <sup>2</sup>	Electric charge					
U up	0.003	2/3					
<b>d</b> down	0.006	-1/3					
<b>C</b> charm	1.3	2/3					
<b>S</b> strange	0.1	-1/3					
t top	175	2/3					
<b>b</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 quarkantiquark

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!



Nicola

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

$$\mathsf{R} = rac{oldsymbol{e}^+ oldsymbol{e}^- o \pi^+ \pi^- + \dots}{oldsymbol{e}^+ oldsymbol{e}^- o \mu^+ \mu^-}$$

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.

Physics in Italy

#### DAFNE: towards the new millennium.



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

Nicola Cabibbo

Physics in Italy

#### CERN: the LEP and LHC tunnel



Nicola Cabibbo

#### Physics in Italy

Lares, 3 July 2009 16 / 27

#### The LEP experiments





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

ALEPH and an ALEPH event

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

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#### How many neutrinos?



The study of the Z resonance confirms that the invisible channels correspond to three neutrino-antineutrino pairs —  $\nu_e, \nu_\mu, \nu_\tau$ 

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



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

Nicola Cabibbo

	Experiments using Iarocci Tubes	
ALEPH BaBar CHARM CLEO DELPHI DM2 D0	E802 YY2 MACRO Mount Blanc Detector OPAL PHENIX	RD94 SLD UA1 WA80 ZEUS

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.

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#### 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.

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#### Neutrino Oscillations at Gran Sasso.





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

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## Boomerang: Universe is flat!









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#### Gravitational waves: Amaldi's last enterprise.



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#### Gravitational waves: Amaldi's last enterprise.





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

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#### 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).