

# Visita ai Laboratori dell'INFN

29-30 Gennaio 2016

## Laboratori Nazionali del Gran Sasso

Dipartimento di

*Fisica*



Universita' di TRIESTE

Gianrossano GIANNINI

Fisica Nucleare e Subnucleare

Dipartimento di Fisica

Universita' di Trieste

e INFN/Trieste

*Via Valerio 2, Trieste, 34127, Italy*

*(giannini@ts.infn.it)*





Legnaro(PD)

Trieste

Ancona

Gran Sasso

L'Aquila

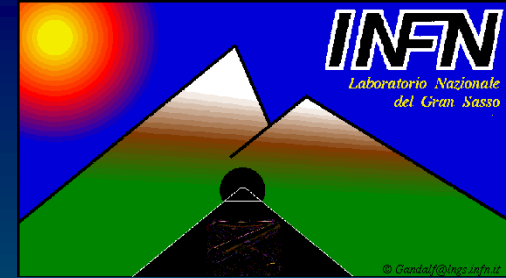
Roma



**Il Parco Nazionale del Gran Sasso e Monti della Laga, istituito nel giugno del 1995, e' una delle aree protette più estese e preziose d'Europa.**

**Il Parco, con un'area di circa 150.000 ettari, si estende in tre regioni (Abruzzo, Marche e Lazio) e cinque province (L'Aquila, Teramo, Ascoli Piceno, Pescara e Rieti). Comprende 44 comuni.**

# Laboratori Nazionali del Gran Sasso



**Location:** Gran Sasso Tunnel (Abruzzi, Italy)

**Depth:** 1400 m (3800 mwe)

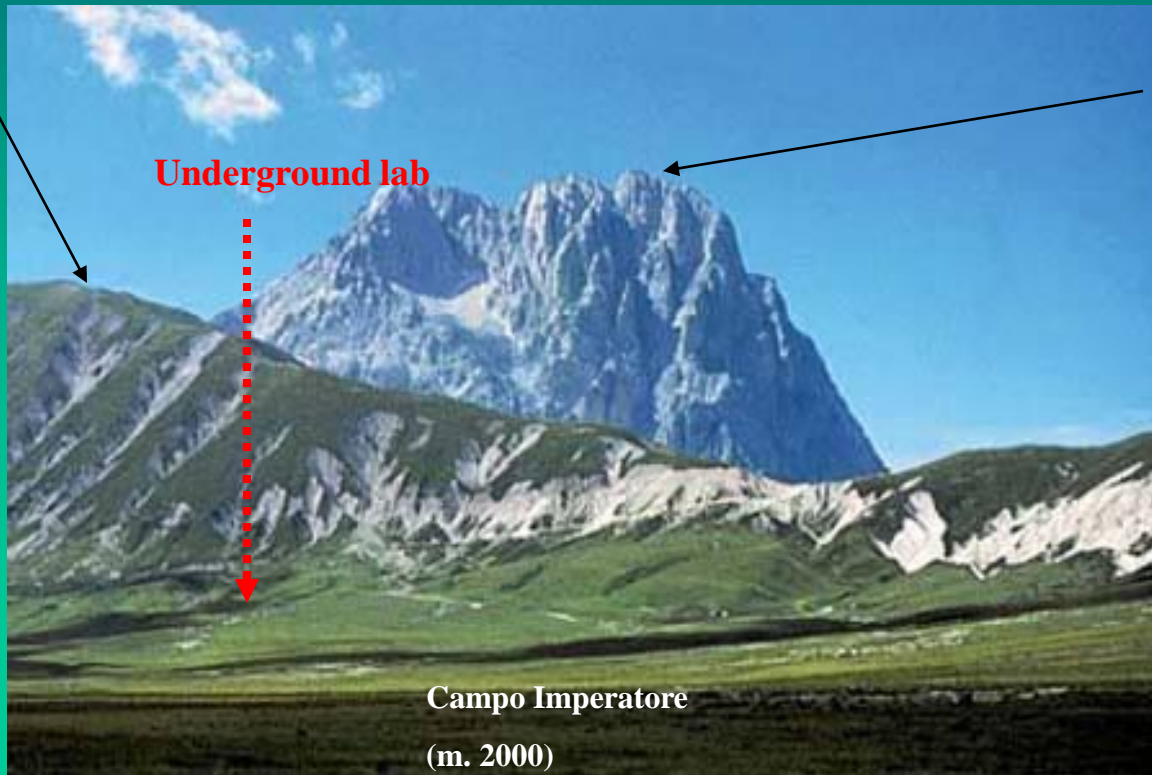
**Operating Institution:** Istituto Nazionale di Fisica Nucleare (INFN)

**LNGS permanent staff:** 60 (physicists, technicians, administration)

**Scientists involved in LNGS experiments:** 700 from 24 countries

Monte Aquila  
(m. 2600)

Corno Grande (m. 2910)



Underground lab

Campo Imperatore  
(m. 2000)

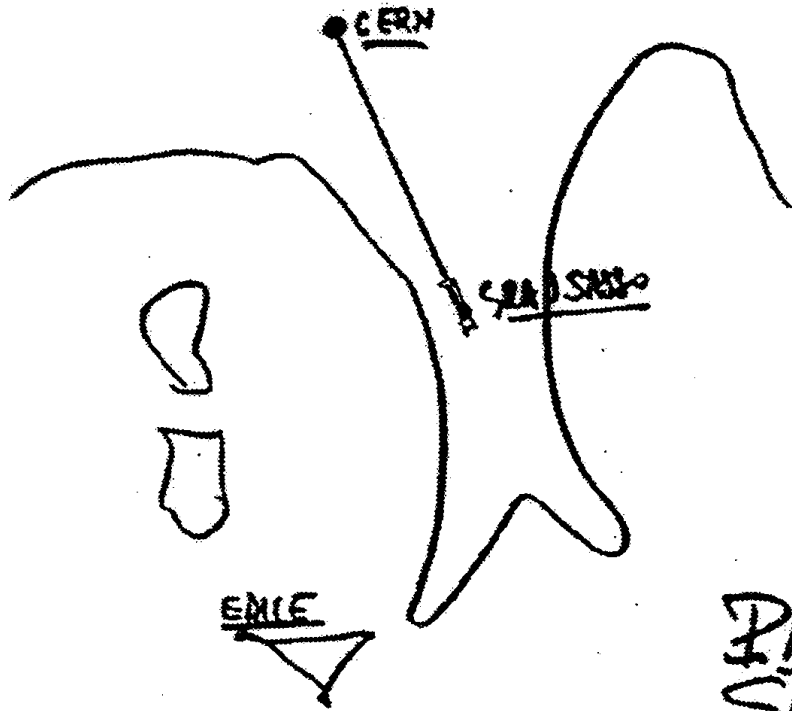
The area of Campo Imperatore  
above LNGS

Nel **1979**, durante la costruzione della autostrada A24 fra Roma e L'Aquila, A. Zichichi ha proposto l'idea di costruire un **laboratorio sotterraneo** sotto il **Gran Sasso**

- **1982**: il Parlamento approva la costruzione
- **1984**: nuovi finanziamenti
- **1989**: il primo esperimento, MACRO, inizia a prendere dati
  
- Fra i primi progetti ci sono:
  - **MACRO**: Ricerca di monopoli magnetici
  - **LVD**: rivelazione di supernovae e fisica dei neutrini
  - **Gallex**: rivelazione di neutrini solari

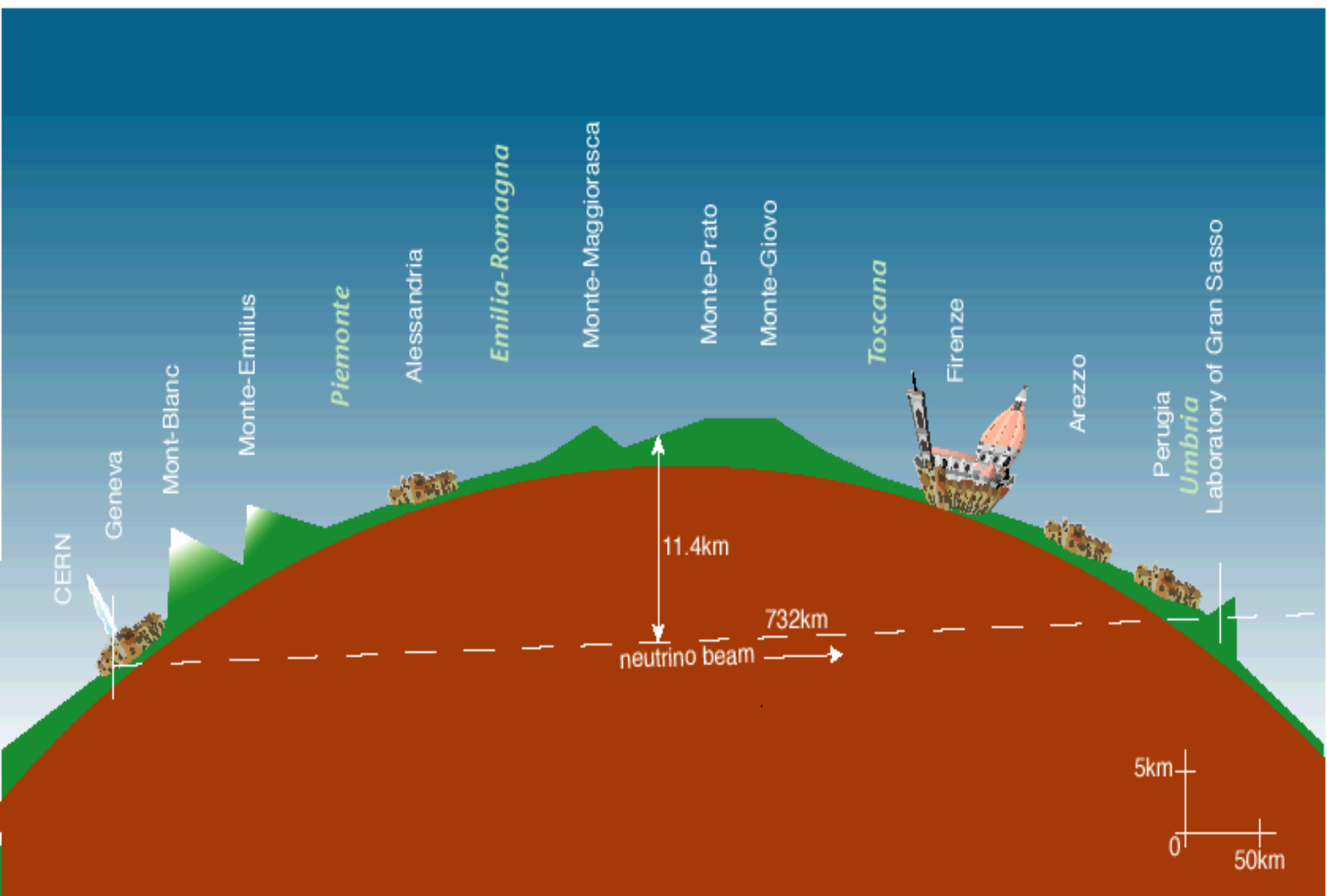


CONDIZIONE LAVORI PUBBLICI DEL SENATO



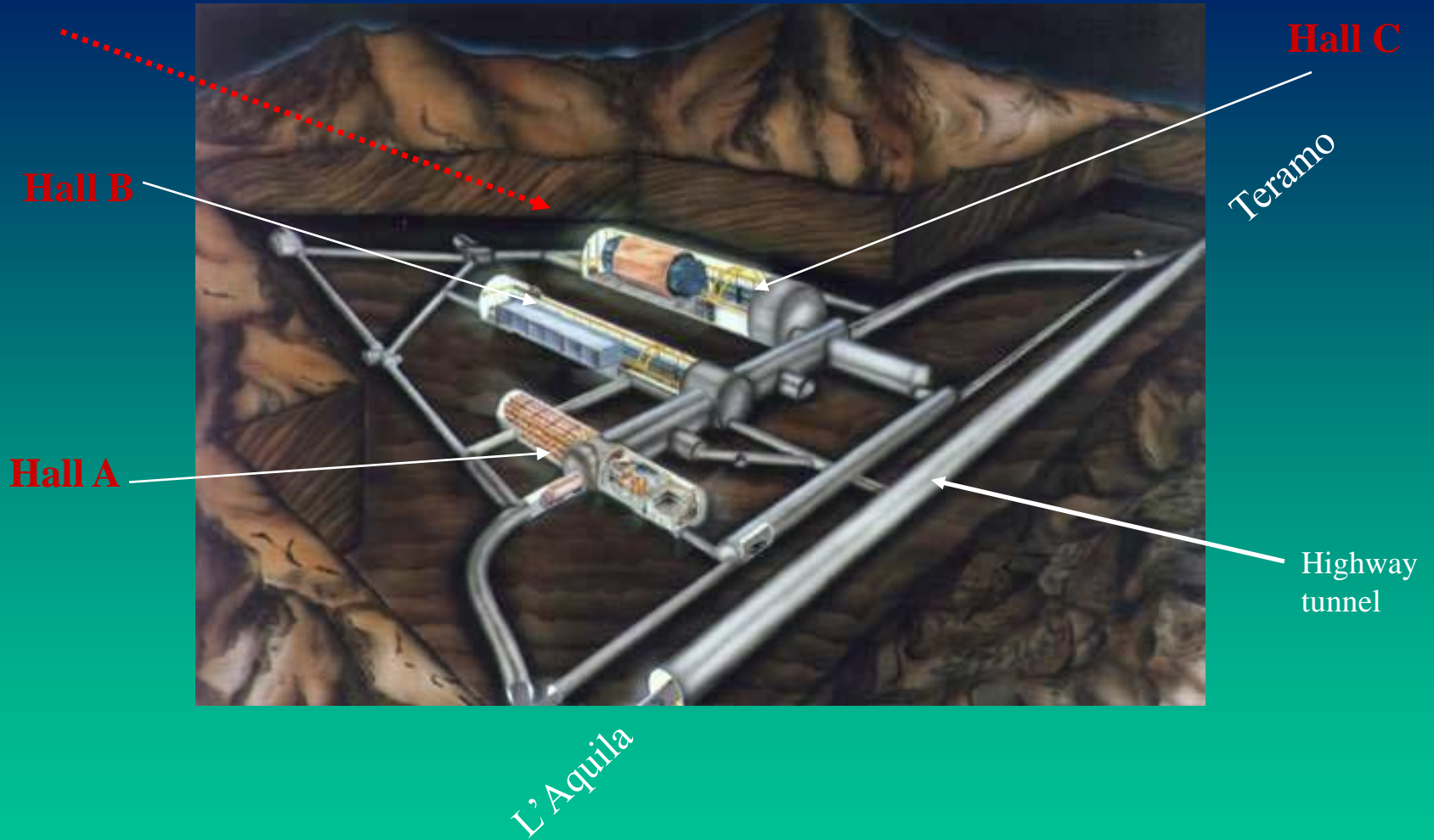
PROGETTO  
GRAN SASSO

Figure 1.1.1: Sketch by A. Zichichi, 1979



CERN  $\nu$  beam

## The LNGS Underground area



**Underground area :** 3 halls (100m x 20m x 15m) + service tunnels

**Total volume :** 180000 m<sup>3</sup>

**Surface:** > 6000 m<sup>2</sup>



# La sala B durante gli scavi e appena completata

~ 1985



E' il principale Laboratorio di Fisica delle Astroparticelle del mondo

**~130 Km da Roma, 1 ½ dall'aeroporto di Fiumicino**

## Scienza @ LNGS

### ■ Fisica dei neutrini

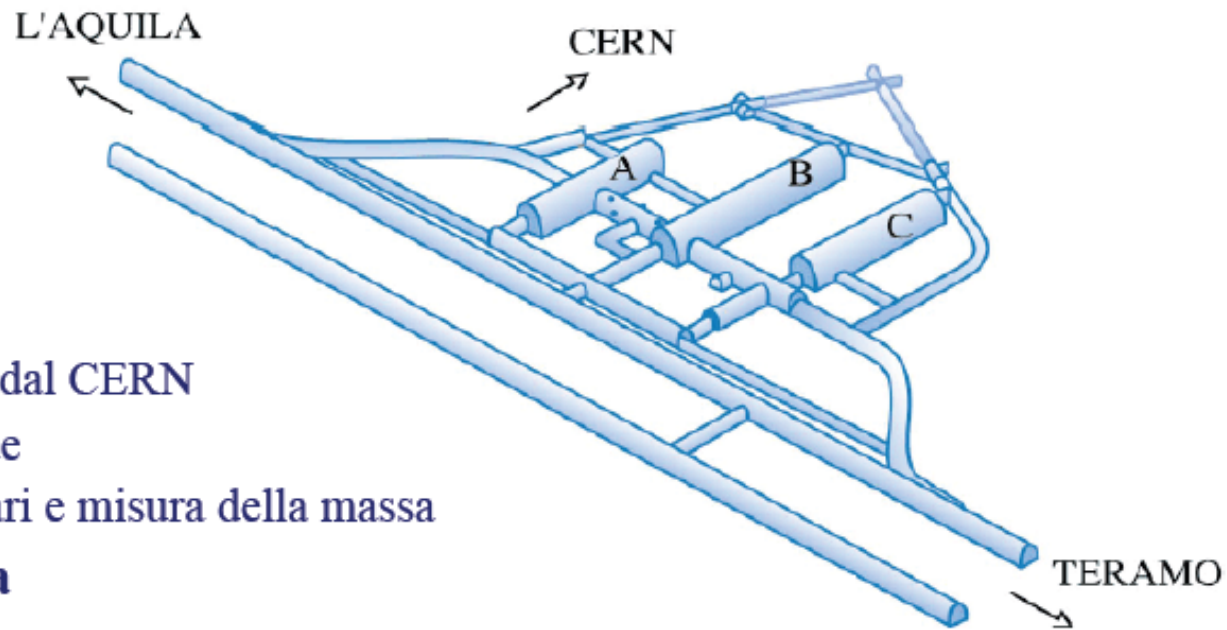
- Neutrini solari
- Esperimenti con neutrini dal CERN
- Rivelazione di supernovae
- Ricerca di decadimenti rari e misura della massa

### ■ Ricerca di materia oscura

### ■ Fisica nucleare dei processi rari

### ■ Geofisica

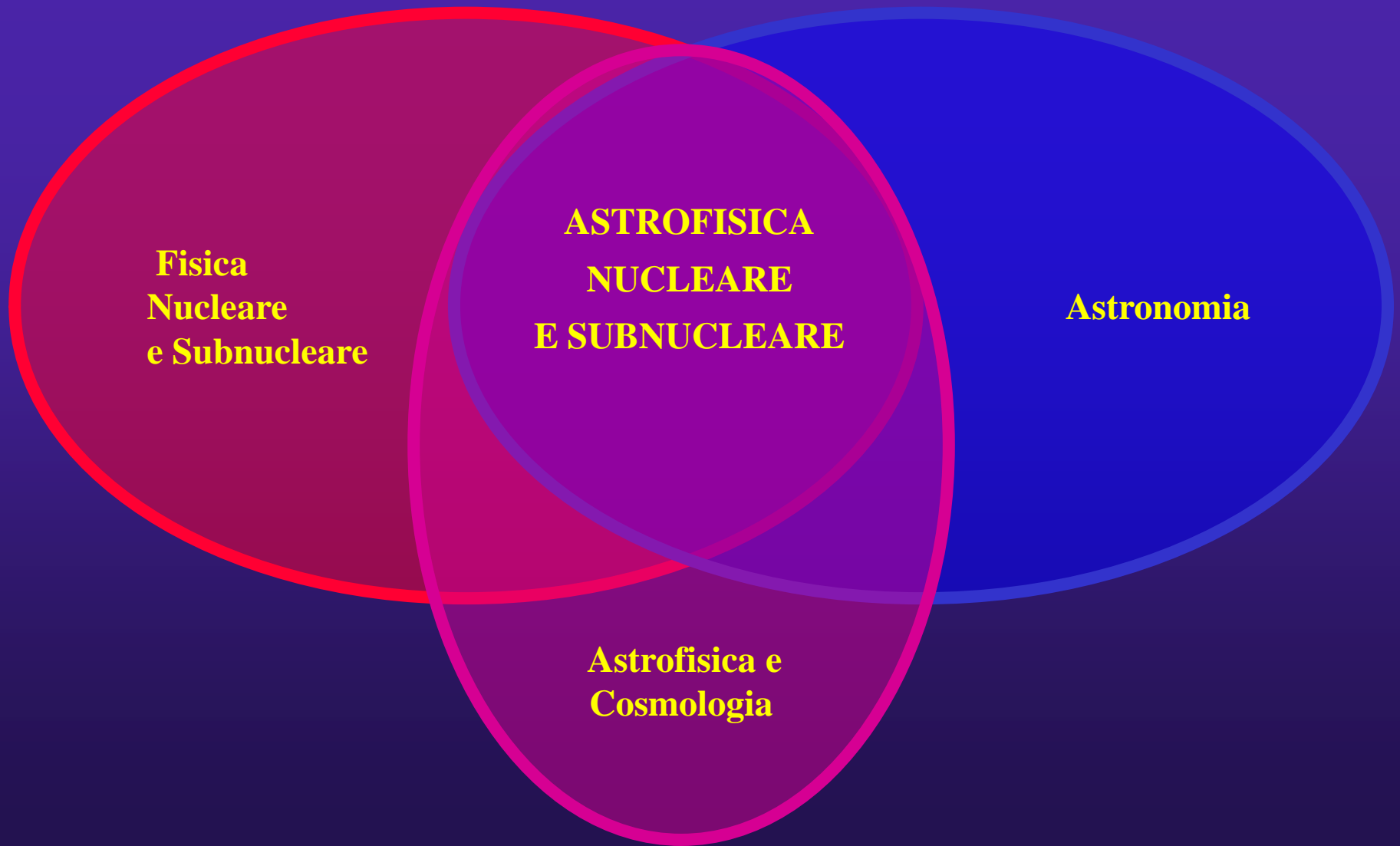
### ■ Biologia



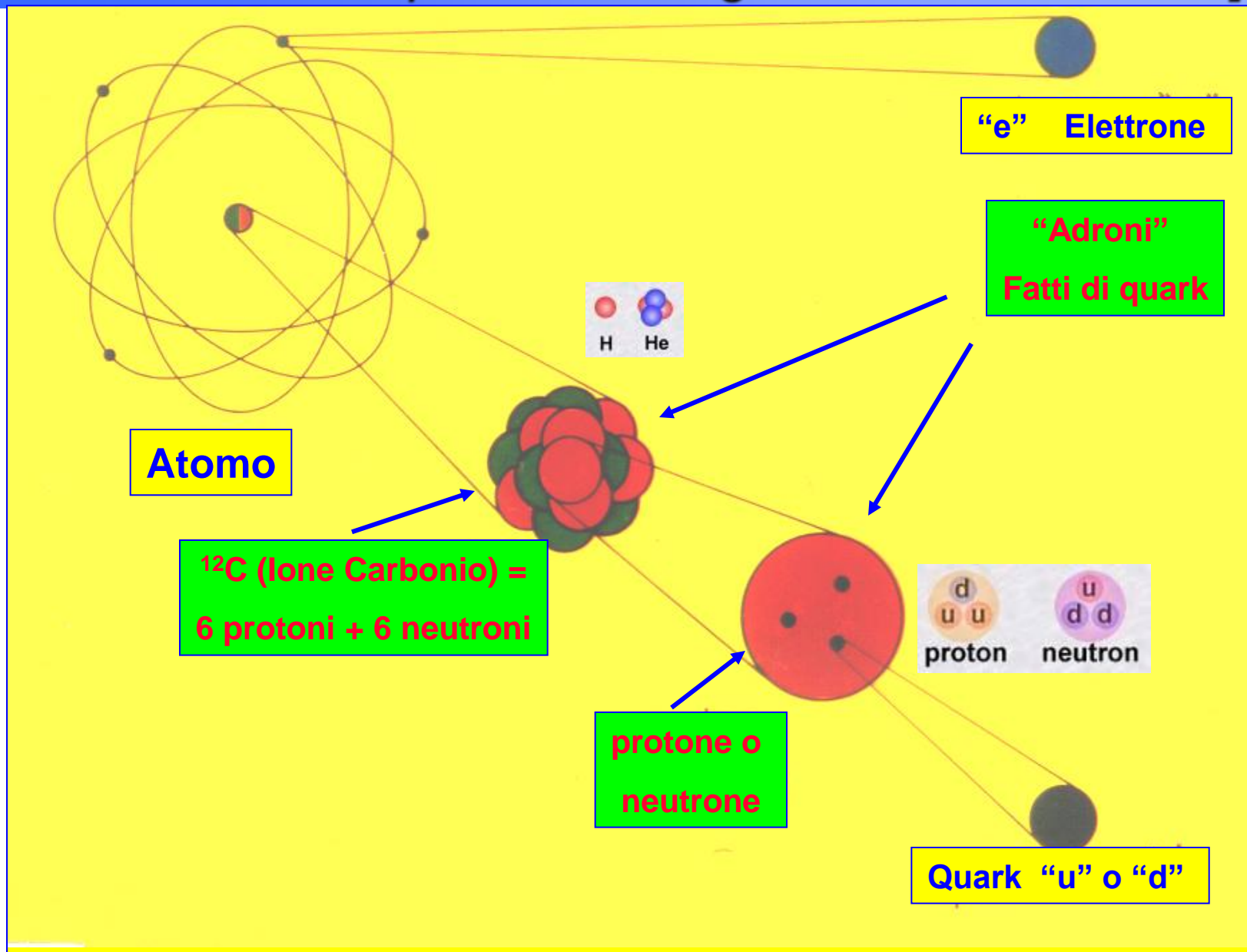
<b>Tunnel:</b>	<b>10.4 Km</b>
<b>Copertura:</b>	<b>~ 3200 m.w.e.</b>
<b>Riduzione flusso muoni:</b>	<b>~ 10<sup>6</sup></b>

# Astrofisica Nucleare e Subnucleare

( Fisica Astroparticellare/Astrofisica Particellare )



*Atomo → Nucleo → Nucleoni: protoni e neutroni,  
ADRONI = Fatti di quark: con legame nucleare forte]*





$10^{-43}$  sec

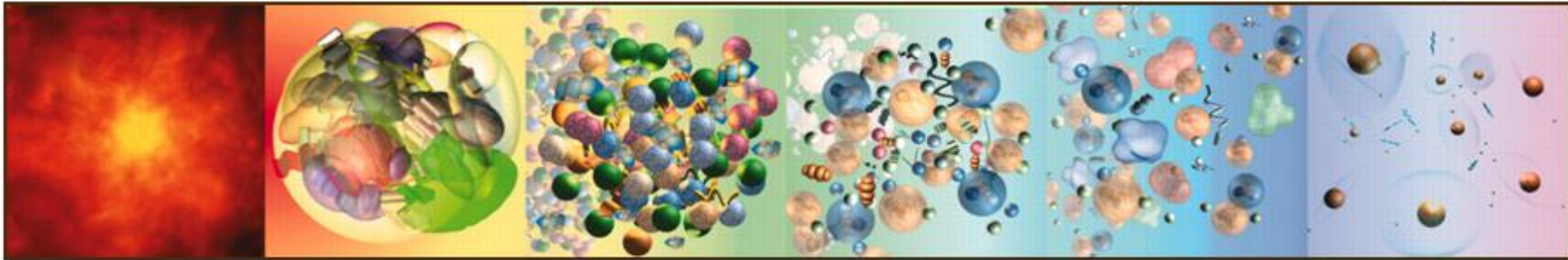
$10^{-32}$  sec

$10^{-10}$  sec

$10^{-4}$  sec

100 sec

300000 years



$10^{-35}$  m  
 $10^{19}$  GeV

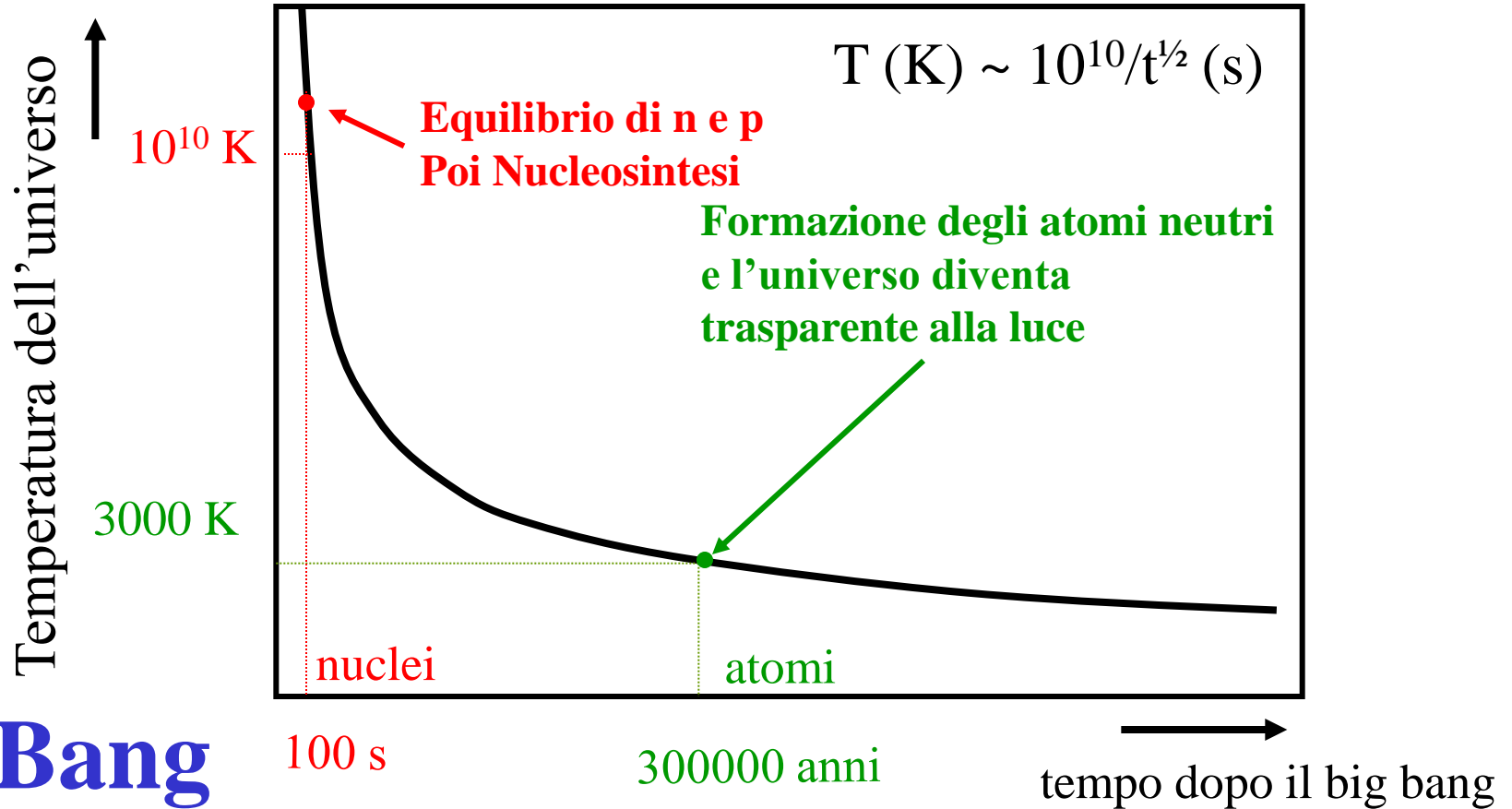
$10^{-32}$  m  
 $10^{16}$  GeV

$10^{-18}$  m  
 $10^2$  GeV

$10^{-16}$  m  
1 GeV

$10^{-15}$  m  
1 MeV

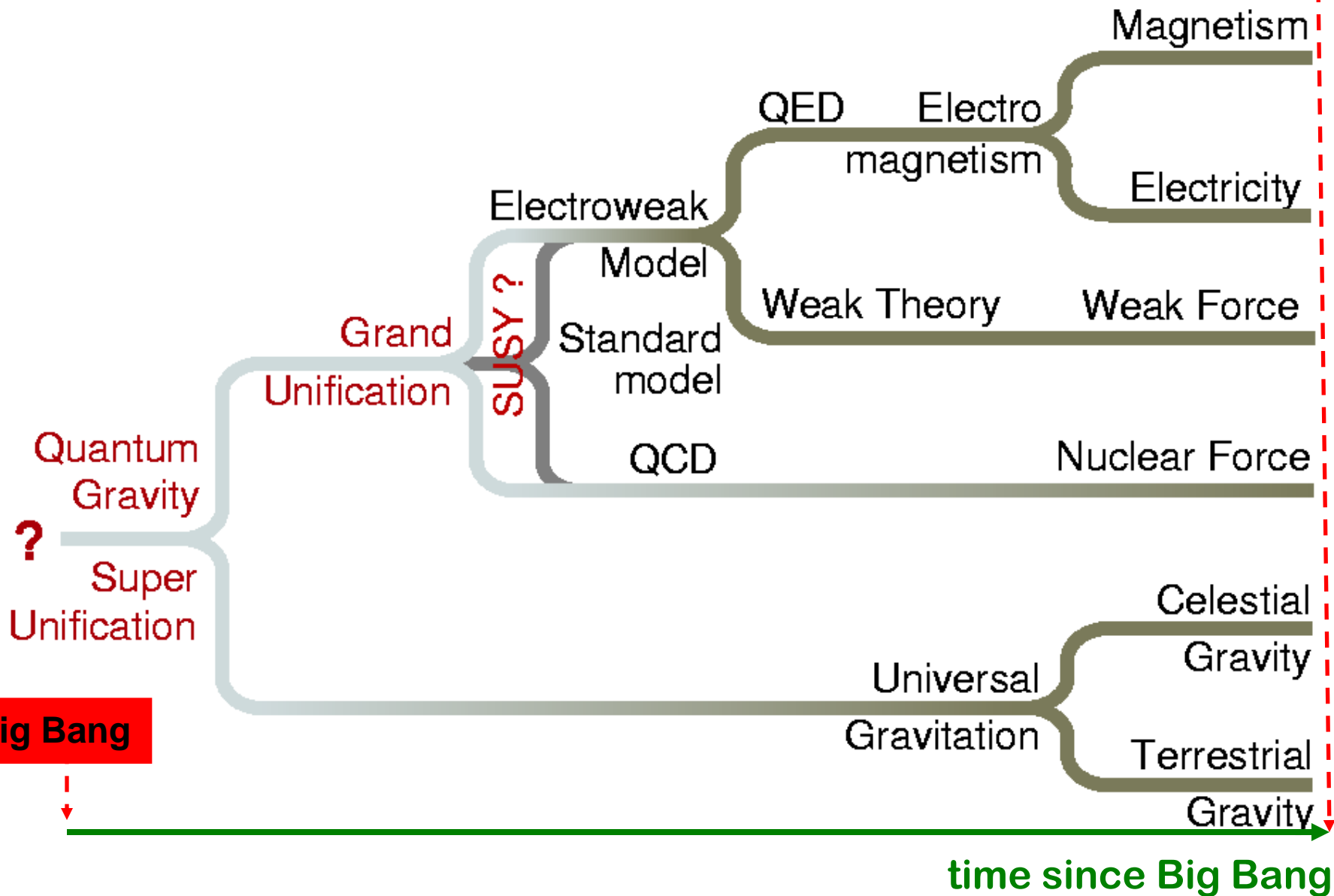
$10^{-10}$  m  
10 eV



# Big Bang

# Unificazione delle Forze

Today



# MODELLO STANDARD : Fermioni (Costituenti) e Bosoni (Mediatori)

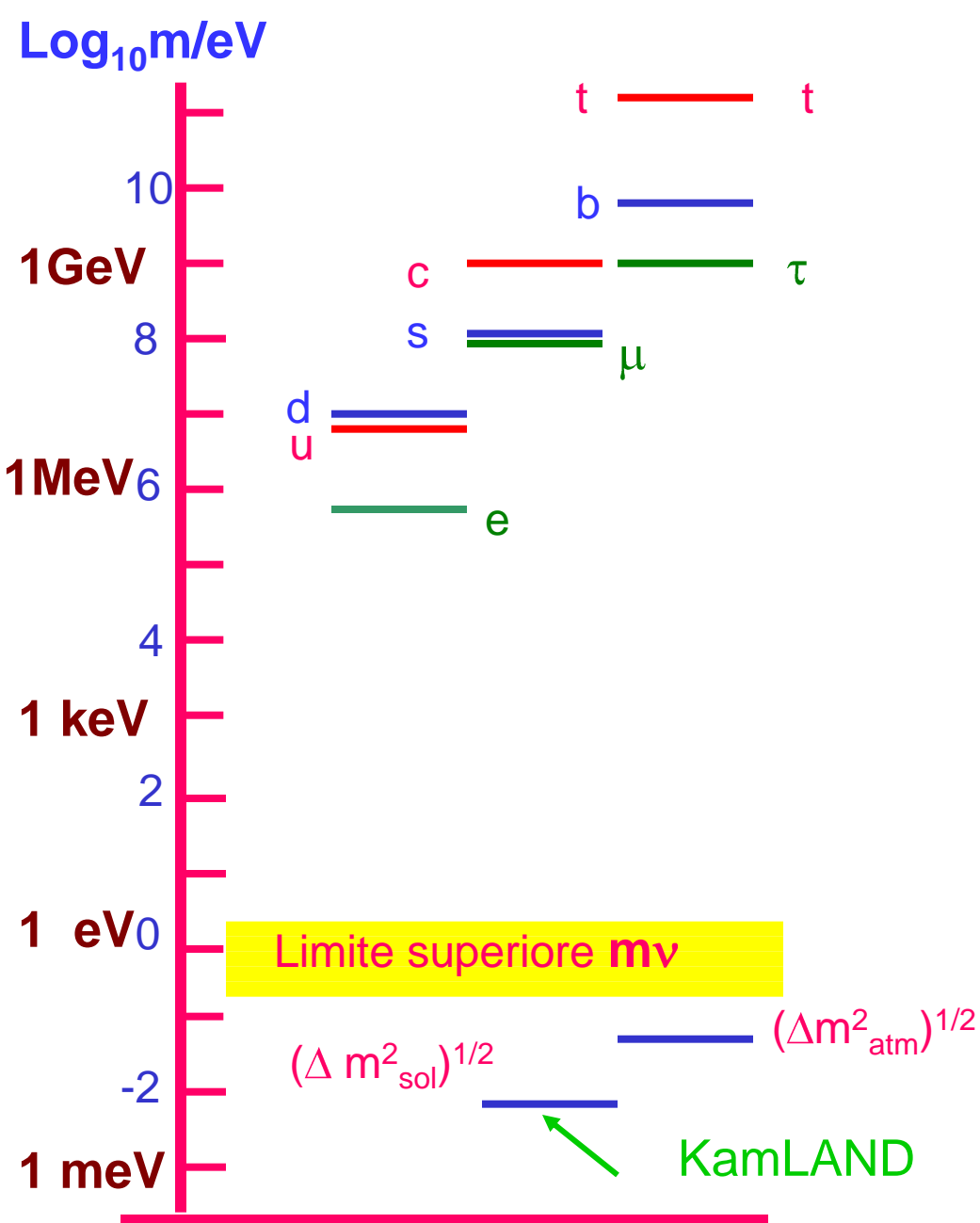
		Famiglie di Fermioni			Bosoni (mediatori delle interazioni)																	
		I	II	III																		
$\left( \begin{matrix} u_i \\ d'_i \end{matrix} \right)_L$	<b>Q u a r k</b>	<table border="1"> <tr><td>up</td><td>+2/3</td></tr> <tr><td><b>u</b></td><td><math>\frac{3}{4}</math></td></tr> </table>	up	+2/3	<b>u</b>	$\frac{3}{4}$	<table border="1"> <tr><td>charm</td><td>+2/3</td></tr> <tr><td><b>c</b></td><td><math>\frac{3}{1500}</math></td></tr> </table>	charm	+2/3	<b>c</b>	$\frac{3}{1500}$	<table border="1"> <tr><td>top</td><td>+2/3</td></tr> <tr><td><b>t</b></td><td><math>\frac{3}{170000}</math></td></tr> </table>	top	+2/3	<b>t</b>	$\frac{3}{170000}$	<table border="1"> <tr><td>Fotone</td><td>0</td></tr> <tr><td><b><math>\gamma</math></b></td><td>0</td></tr> </table>	Fotone	0	<b><math>\gamma</math></b>	0	<b>Interazione elettromagnetica</b>
		up	+2/3																			
<b>u</b>	$\frac{3}{4}$																					
charm	+2/3																					
<b>c</b>	$\frac{3}{1500}$																					
top	+2/3																					
<b>t</b>	$\frac{3}{170000}$																					
Fotone	0																					
<b><math>\gamma</math></b>	0																					
<table border="1"> <tr><td>down</td><td>-1/3</td></tr> <tr><td><b>d</b></td><td><math>\frac{3}{80}</math></td></tr> </table>	down	-1/3	<b>d</b>	$\frac{3}{80}$	<table border="1"> <tr><td>strange</td><td>-1/3</td></tr> <tr><td><b>s</b></td><td><math>\frac{3}{160}</math></td></tr> </table>	strange	-1/3	<b>s</b>	$\frac{3}{160}$	<table border="1"> <tr><td>bottom</td><td>-1/3</td></tr> <tr><td><b>b</b></td><td><math>\frac{3}{4700}</math></td></tr> </table>	bottom	-1/3	<b>b</b>	$\frac{3}{4700}$	<table border="1"> <tr><td>Gluone</td><td>0</td></tr> <tr><td><b>g</b></td><td><math>\frac{8}{0}</math></td></tr> </table>	Gluone	0	<b>g</b>	$\frac{8}{0}$	<b>Interazione forte</b>		
down	-1/3																					
<b>d</b>	$\frac{3}{80}$																					
strange	-1/3																					
<b>s</b>	$\frac{3}{160}$																					
bottom	-1/3																					
<b>b</b>	$\frac{3}{4700}$																					
Gluone	0																					
<b>g</b>	$\frac{8}{0}$																					
$\left( \begin{matrix} \nu_i \\ l_i \end{matrix} \right)_L$	<b>L e p t o n i</b>	<table border="1"> <tr><td>Neutrino elett.</td><td>0</td></tr> <tr><td><b><math>\nu_e</math></b></td><td><math>&lt;0.000007</math></td></tr> </table>	Neutrino elett.	0	<b><math>\nu_e</math></b>	$<0.000007$	<table border="1"> <tr><td>Neutrino muon.</td><td>0</td></tr> <tr><td><b><math>\nu_\mu</math></b></td><td><math>&lt;0.27</math></td></tr> </table>	Neutrino muon.	0	<b><math>\nu_\mu</math></b>	$<0.27$	<table border="1"> <tr><td>Neutrino taun.</td><td>0</td></tr> <tr><td><b><math>\nu_\tau</math></b></td><td><math>&lt;31</math></td></tr> </table>	Neutrino taun.	0	<b><math>\nu_\tau</math></b>	$<31$	<table border="1"> <tr><td>Z zero</td><td>0</td></tr> <tr><td><b><math>Z^0</math></b></td><td>91187</td></tr> </table>	Z zero	0	<b><math>Z^0</math></b>	91187	<b>Interazione debole</b>
		Neutrino elett.	0																			
<b><math>\nu_e</math></b>	$<0.000007$																					
Neutrino muon.	0																					
<b><math>\nu_\mu</math></b>	$<0.27$																					
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Z zero	0																					
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<table border="1"> <tr><td>Elettrone</td><td>-1</td></tr> <tr><td><b>e</b></td><td>0.511</td></tr> </table>	Elettrone	-1	<b>e</b>	0.511	<table border="1"> <tr><td>Muone</td><td>-1</td></tr> <tr><td><b><math>\mu</math></b></td><td>105.66</td></tr> </table>	Muone	-1	<b><math>\mu</math></b>	105.66	<table border="1"> <tr><td>Tauone</td><td>-1</td></tr> <tr><td><b><math>\tau</math></b></td><td>1777.1</td></tr> </table>	Tauone	-1	<b><math>\tau</math></b>	1777.1	<table border="1"> <tr><td>W positivo</td><td><math>\pm 1</math></td></tr> <tr><td><b><math>W^+</math></b></td><td>80220</td></tr> </table>	W positivo	$\pm 1$	<b><math>W^+</math></b>	80220			
Elettrone	-1																					
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Tauone	-1																					
<b><math>\tau</math></b>	1777.1																					
W positivo	$\pm 1$																					
<b><math>W^+</math></b>	80220																					

→ Carica elettrica  
 → Numero di colori di carica  
 → Massa in MeV

$l_{iR}, d_{iR}, u_{iR}$

$SU(3)_C \times SU(2)_L \times U(1)_Y$





## Massa dei fermioni: Quark e Leptoni

$\nu$  : Massa=0 ?

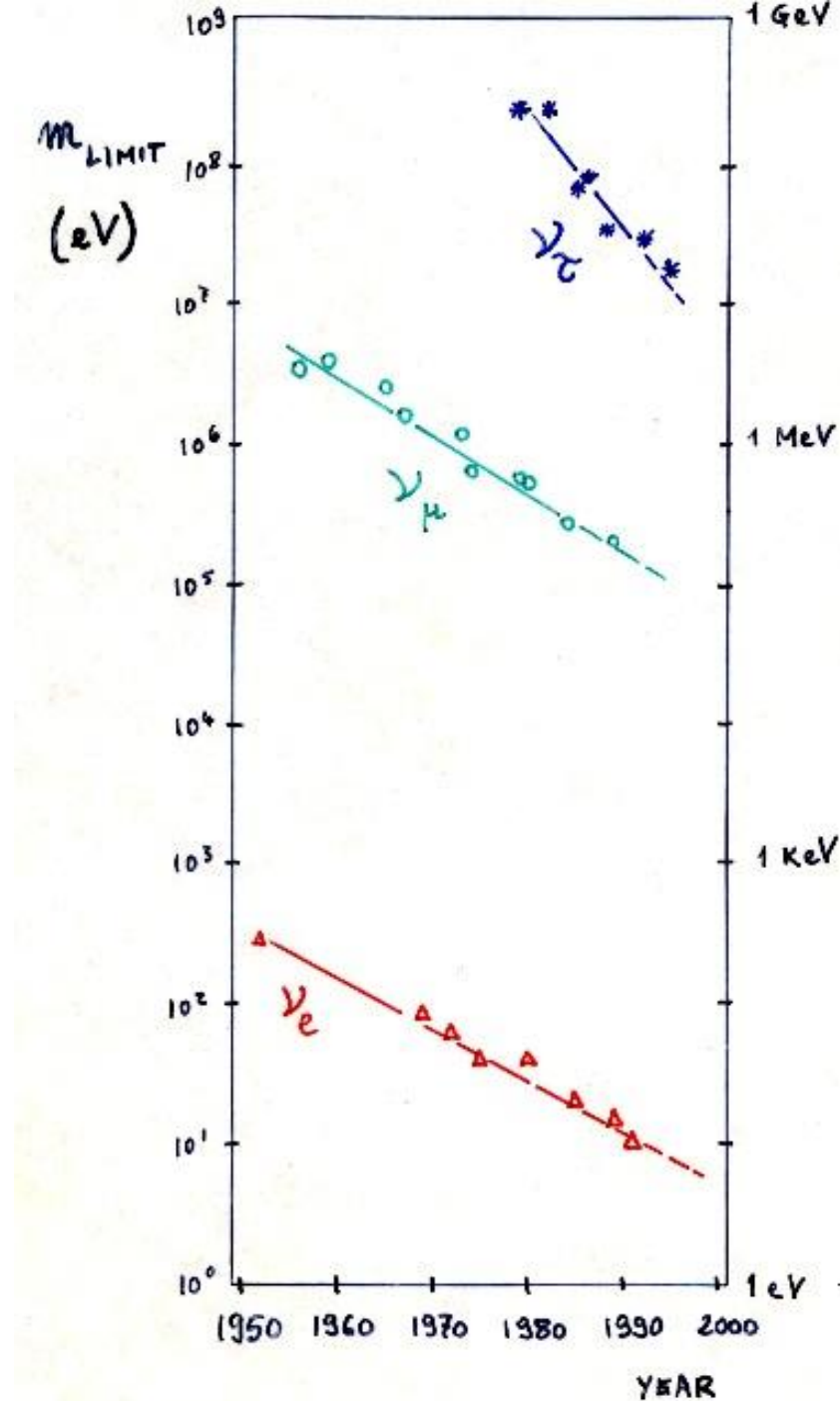
- no  $\nu_R$
- numero leptonico L conservato

$\nu$ : Massa >0 ?

- $\nu_R$  pesante
- numero leptonico L non conservato

# Limiti Sperimentali per la Massa dei Neutrini

(50 anni di misure)



# Oscillazioni dei Neutrini

- Idea della massa dei neutrini suggerita per la prima volta da Bruno Pontecorvo

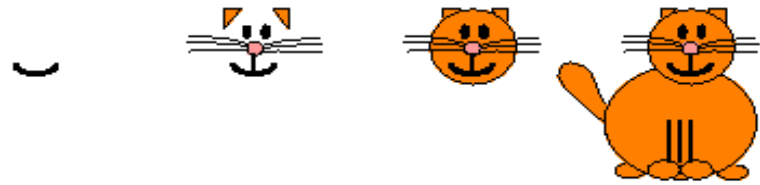
**I Neutrini Interagiscono  
(Produzione o Rivelazione) come  
Autostati dell'Interazione Debole**

$|v_e\rangle$  ,  $|v_\mu\rangle$  ,  $|v_\tau\rangle$  = Autostati dell'Interazione Debole

$|v_1\rangle$  ,  $|v_2\rangle$  ,  $|v_3\rangle$  = Autostati di Massa (H  $\rightarrow$  Evoluzione t)

• I Neutrini si propagano (evolvono) come sovrapposizione di autostati di **massa**:  
**MESCOLAMENTO**

# Comparsa/Appearance

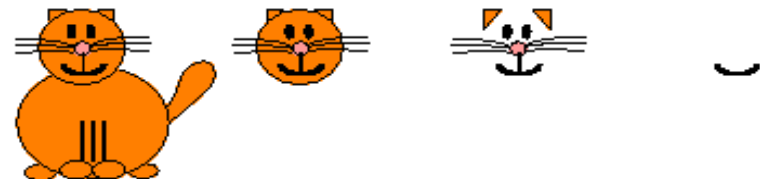


*"Appearance Experiments"*  
see the new neutrino type  
in the detector



A *"Disappearance Experiment"* observes

fewer  $\nu$    $\mu$  than expected



# Scomparsa/Desappearance

# Esperimenti con Neutrini :

- 1) Sorgenti (Molto) Potenti
- 2) Apparatati (Molto) Sensibili  
e (Molto) Massivi

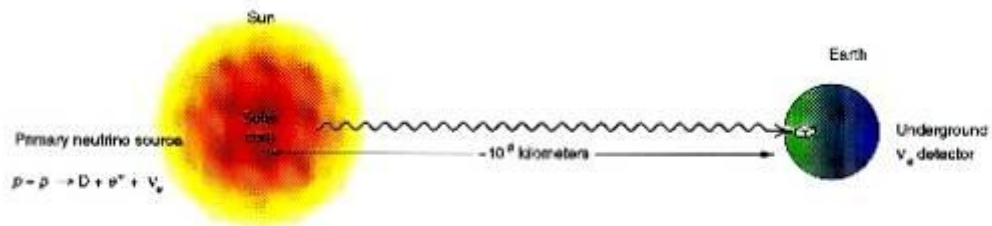
## Sorgenti naturali:

**Sole, Supernovae, Raggi cosmici**

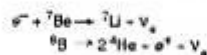
## Sorgenti Artificiali:

**Acceleratori, Reattori Nucleari**

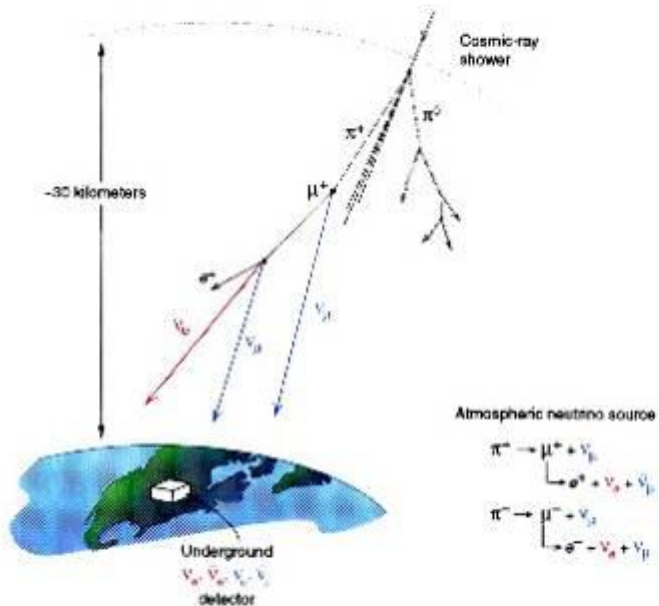
SOLAR  $\nu$ : ( $\nu_e$ )



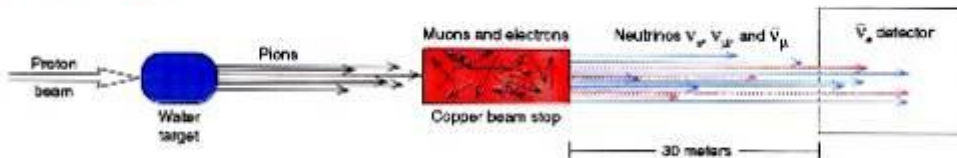
Other sources of neutrinos:



ATMOSPHERIC  $\nu$ :  
 ( $\nu_\mu \bar{\nu}_\mu \nu_e \bar{\nu}_e$ )



ACCELERATOR  $\nu$ :  
 ( $\nu_\mu \bar{\nu}_\mu \nu_e$ )



REACTOR  $\nu$ :  
 ( $\bar{\nu}_e$ )



# Raggi Cosmici

Colhoster 1914  
@ 9km



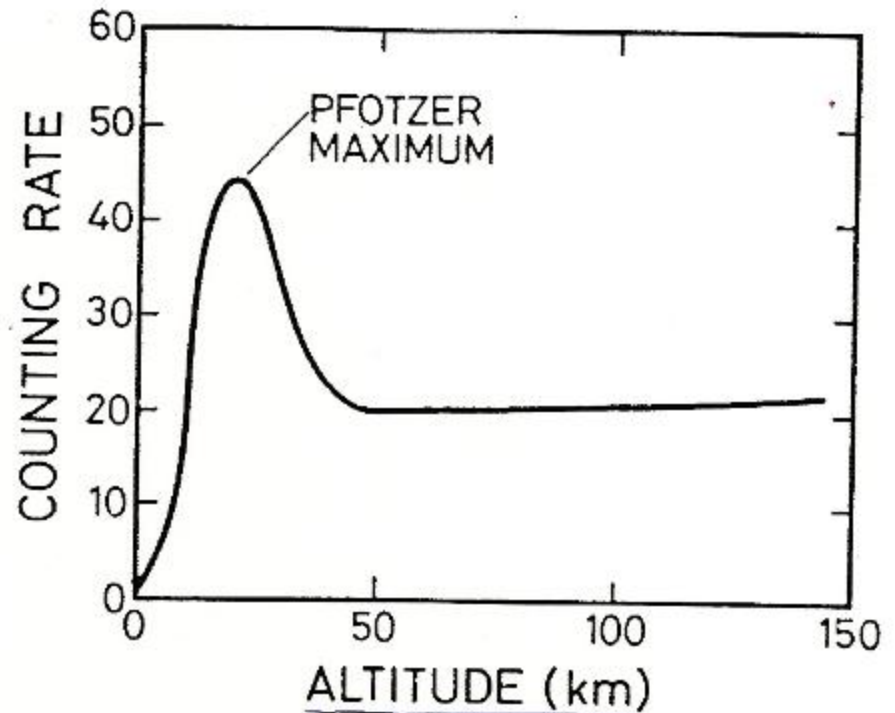
Altitude  
(km)

Difference between observed  
ionisation and that at sea-level  
(ions  $\text{cm}^{-3}$ )  $\text{s}^{-1}$

1	-1.5
2	+1.2
3	+4.2
4	+8.8
5	+16.9
6	+28.7
7	+44.2
8	+61.3
9	+80.4

Millikan scettico sui "...Raggi ... Cosmici"  $\gamma_s$ "

Ascese su Pallone:  
Hess 1912 @ 5km



# Composizione dei Raggi Cosmici

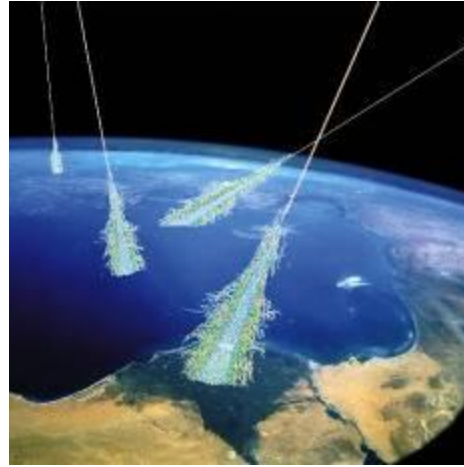
## PRIMARI:

$p \sim 87 \%$ ,  $\alpha \sim 10 \%$ ,  $N \sim 1 \%$

$e \sim 2 \%$

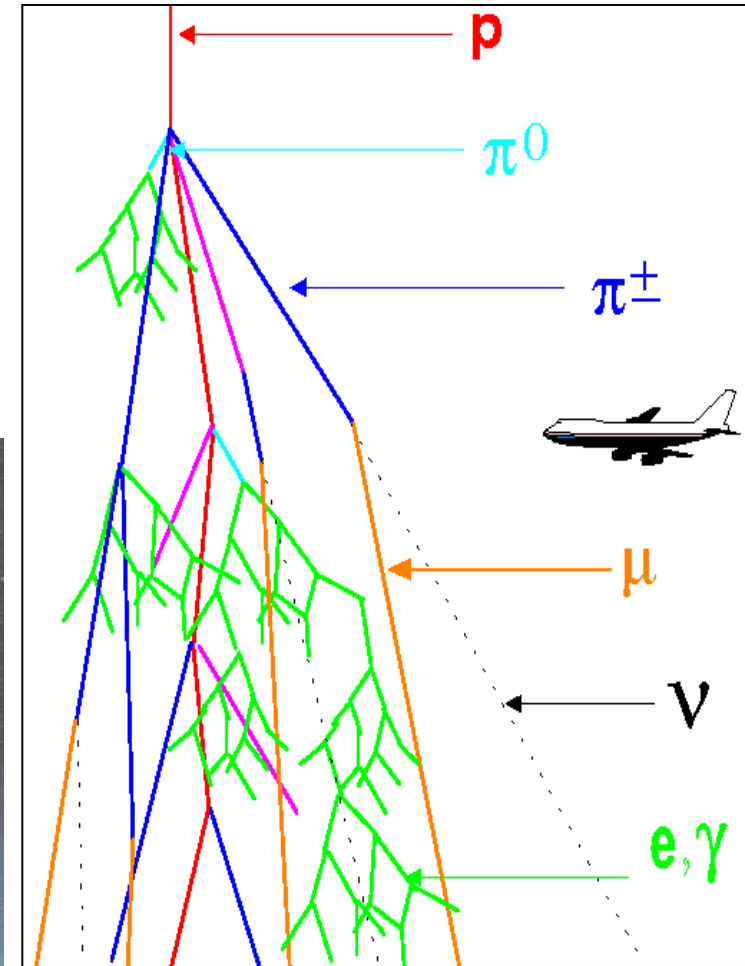
$\gamma \sim 0.1 \%$ ,  $\nu \sim 0.1 \%$  ?

Alta atmosfera :  $\sim 1000/m^2/s$



I Raggi Cosmici Primari producono sciami di secondari in atmosfera

A livello del mare :  $\sim 100/m^2/s$



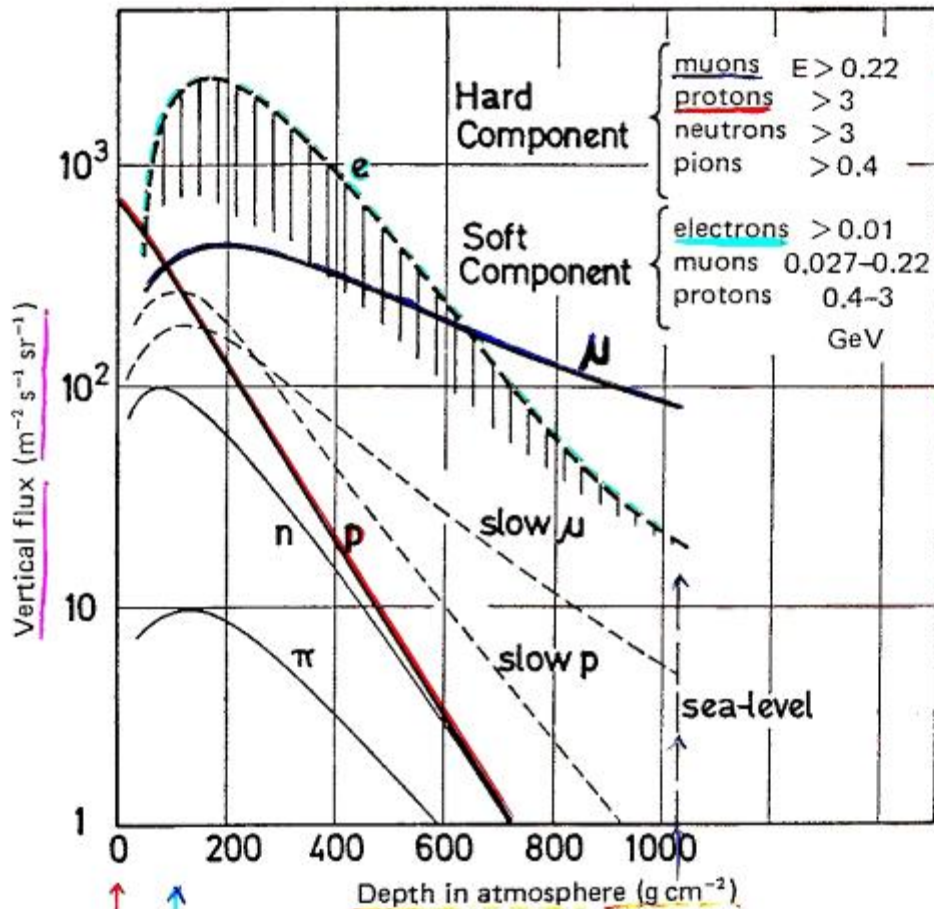
**SECONDARI al livello del mare**

$\mu \sim 30 \%$

$p, n, \dots \sim 2 \%$

$\nu \sim 68 \%$





Spazio

Pfozter maximum  
@ ~ 20 km

Livello del mare

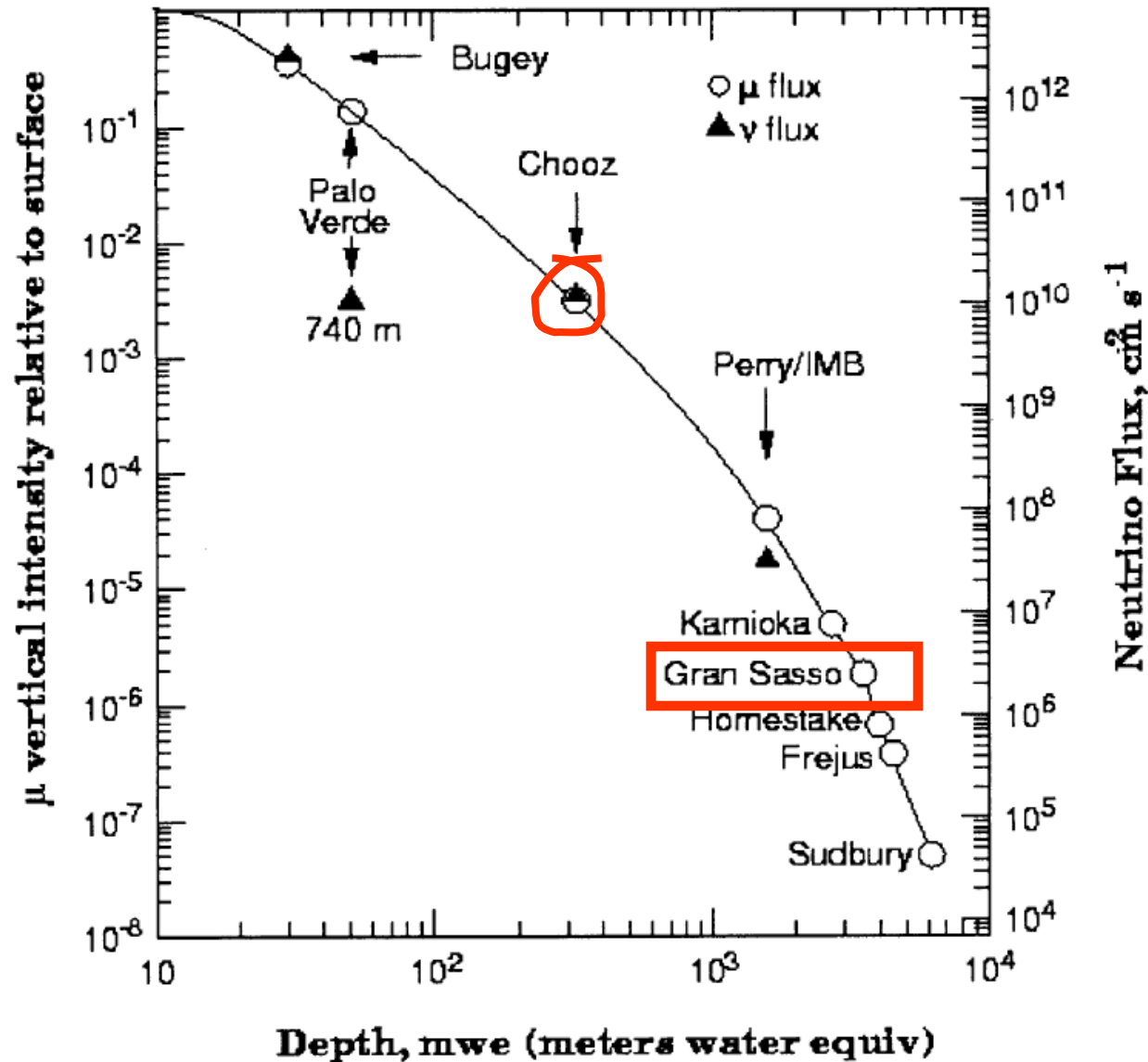
NOTE:  $\tau_0(\mu) = 2.2 \mu\text{s}$   
 $c\tau_0(\mu) = 2.2 \cdot 10^{-6} \cdot 3 \cdot 10^8 \text{ms}^{-1} = 660 \text{m}$

# Flusso verticale di Raggi Cosmici vs. profondita' nell'atmosfera

$E = \gamma m_0 c^2$   
 $\tau = \gamma \tau_0 \Rightarrow \gamma > 20$  RELATIVISTIC  
 $w_\mu = 10^5 \text{ MeV}/c^2$

# Flusso di $\mu$

$\mu$  Depth-Intensity and  $\nu$  Flux  
for various sites



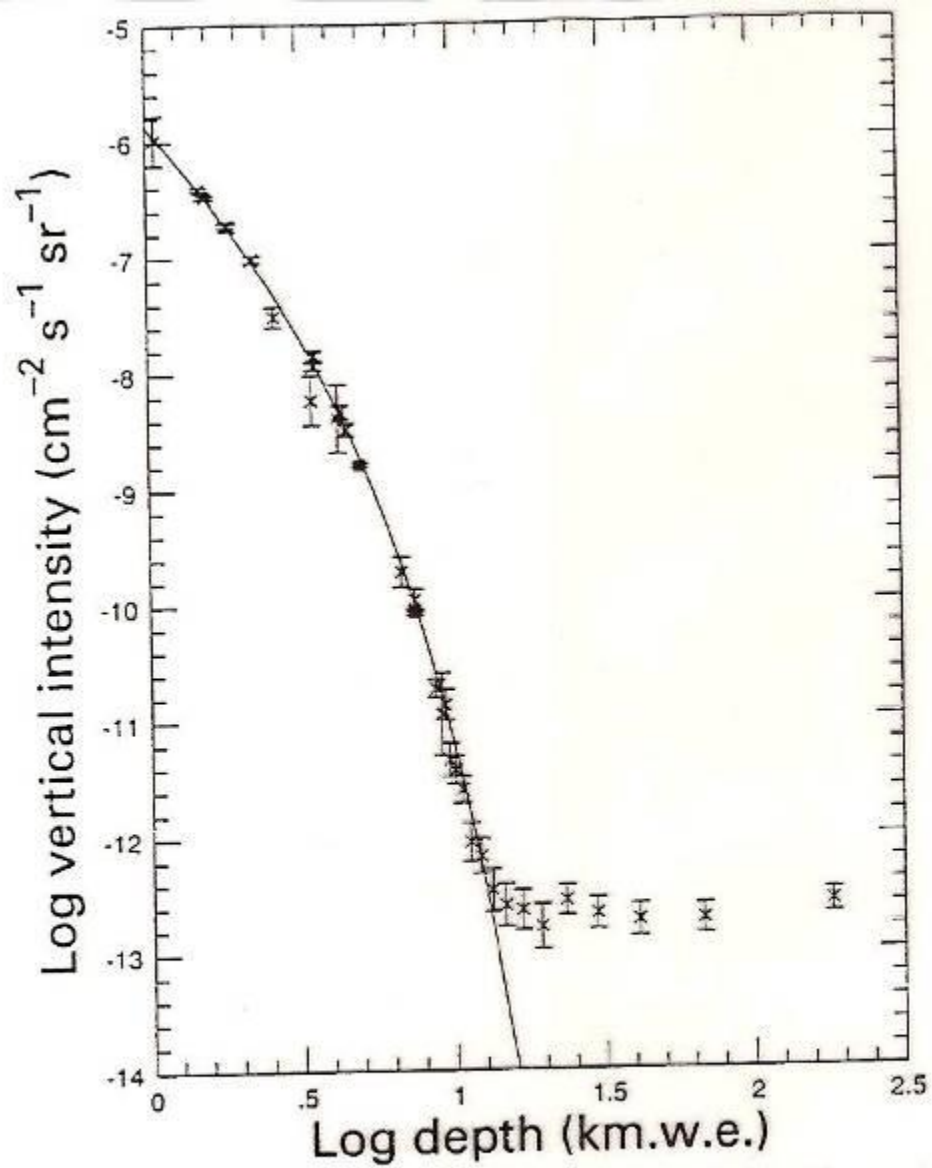
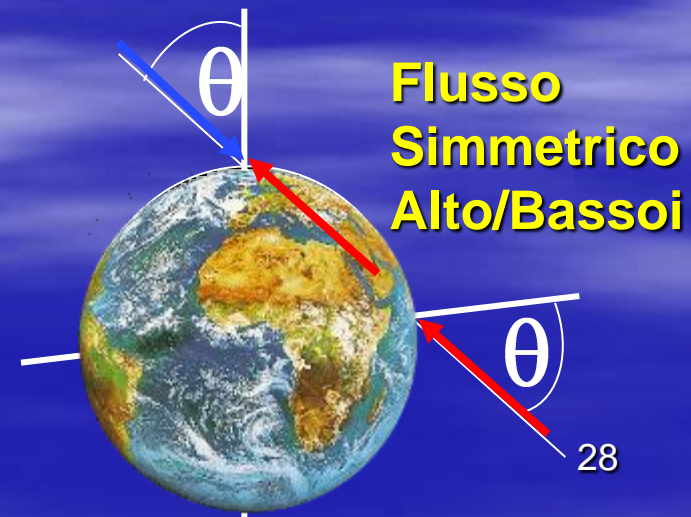
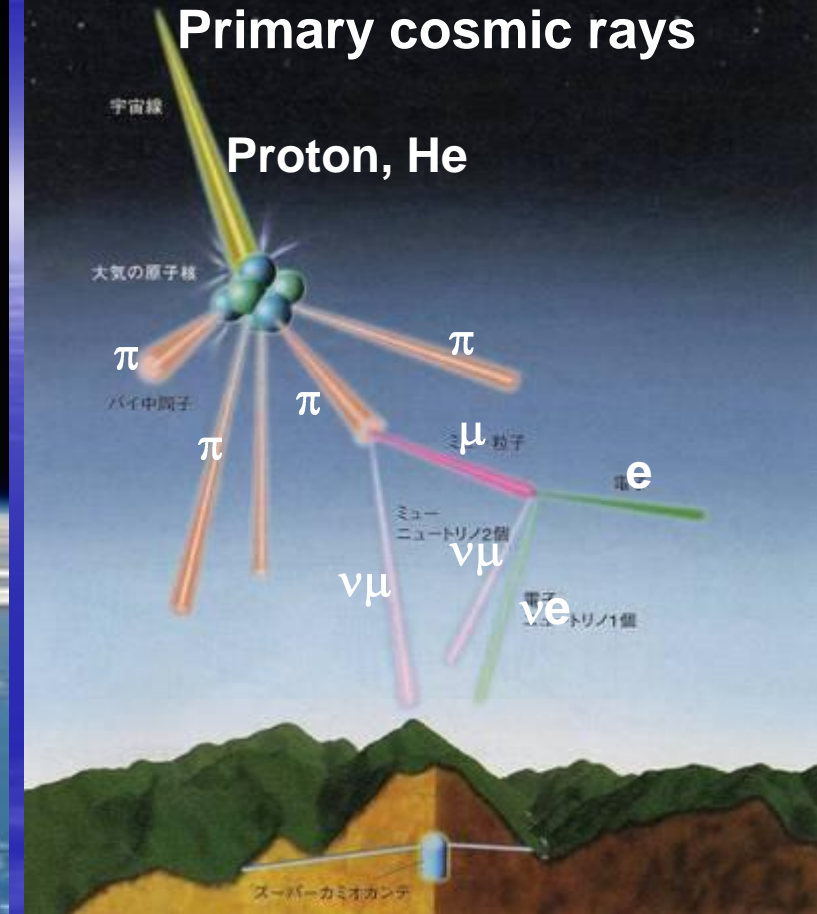


Figure 6.3: Relation between muon intensity and depth underground. The data are taken from a summary by Crouch (1987) with the addition of recent data from the Frejus experiment (Berger et al., 1989 – filled squares).

# Sorgente Raggi Cosmici: $\nu$ Atmosferici

atmosfera

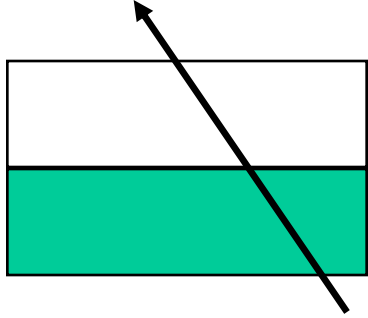


# Gli esperimenti “storici”

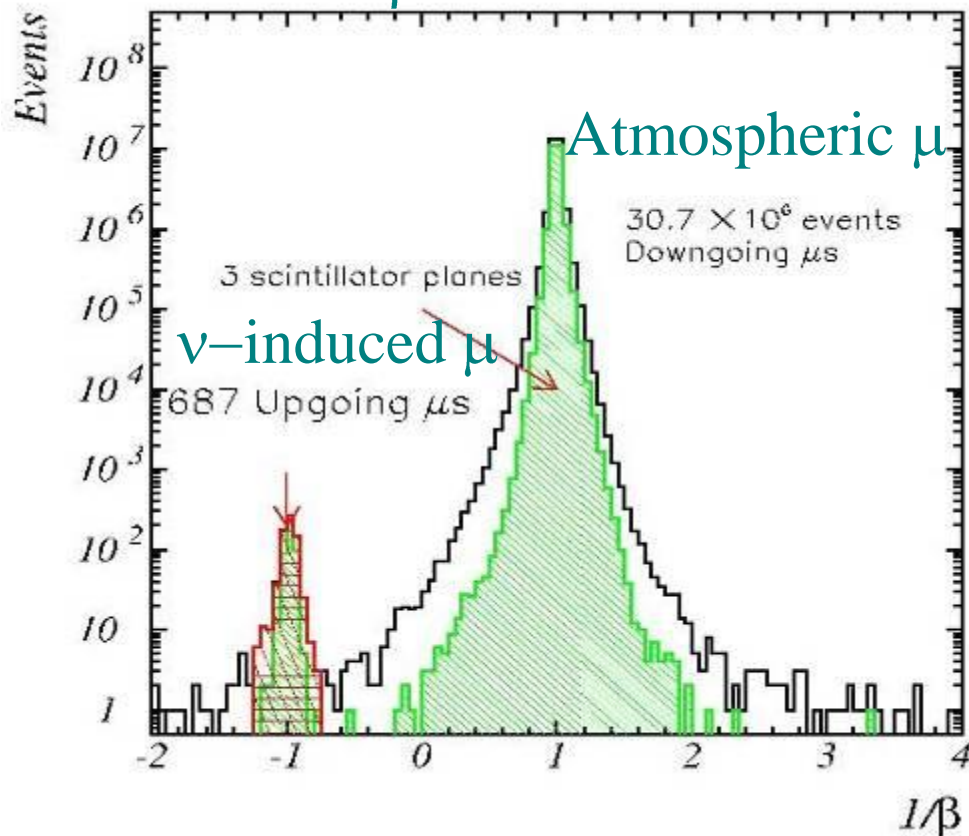
- Macro
  - Ricerca dei monopoli magnetici
  
- LVD
  - Ricerca di supernovae
  
- Gallex
  - Studio di neutrini solari

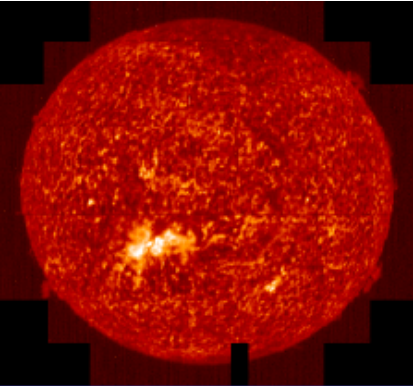


# MACRO Upward throughgoing muons



$1/\beta$  distribution:





# GNO

Collab.:  
Italy, France, Germany

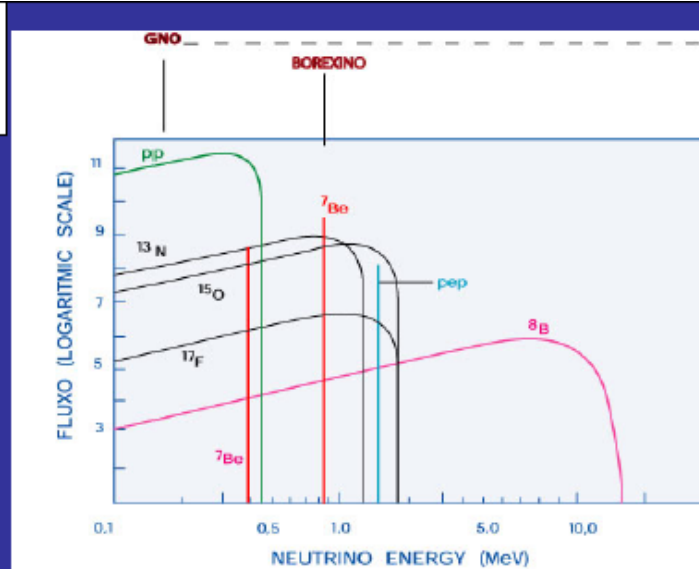
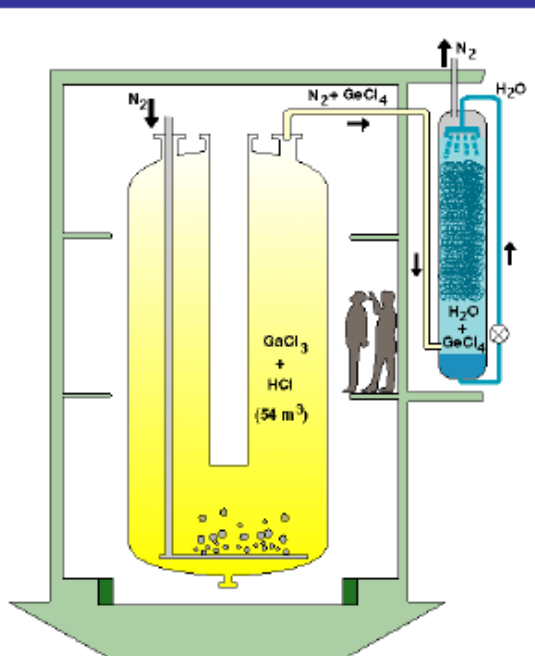
Goals: measurement of the interaction rate with an accuracy of 4-5% and monitoring the neutrino flux over a complete solar cycle.

101 tons Gallium Chloride solution

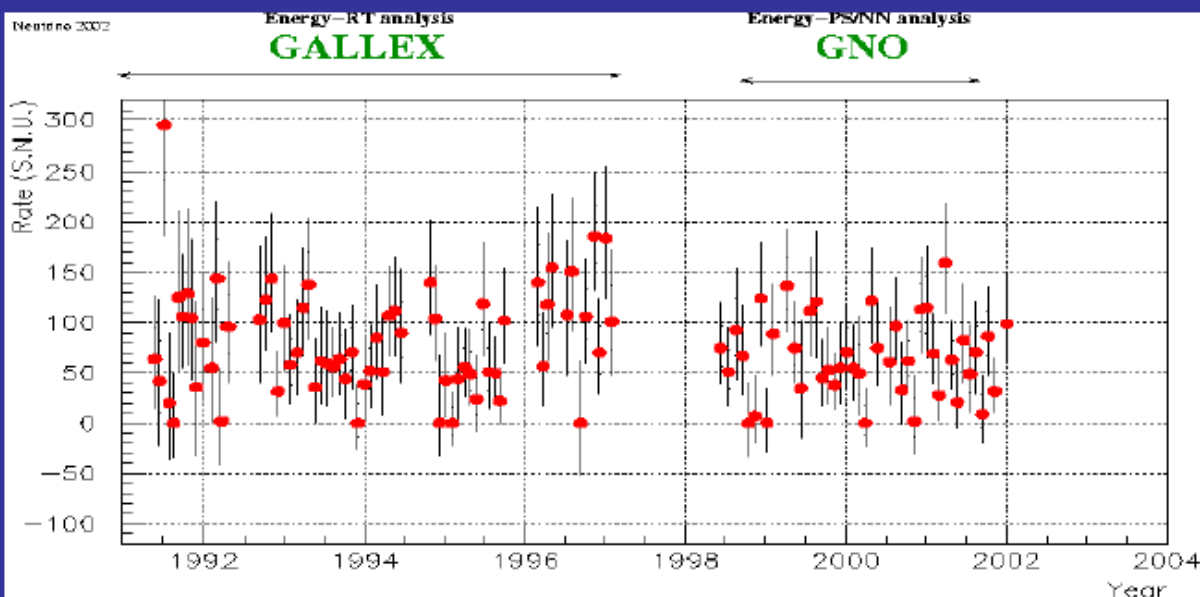
$^{71}\text{Ge}(\nu_e, e)^{71}\text{Ge}$

Energy threshold > 233 keV

Sensitive mainly to pp -neutrinos



SSM → 115 -135 SNU



<b>GALLEX</b>	<b>65 SR</b>	<b>77.5 ± 6.2 (stat) ± 4.5 (sys) SNU</b>
<b>GNO</b>	<b>43 SR</b>	<b>65.2 ± 6.4 (stat) ± 3.0 (sys) SNU</b>
<b>GNO+GALLEX</b>	<b>108 SR</b>	<b>70.8 ± 4.5 (stat) ± 3.8 (sys) SNU</b>

