

Visita ai Laboratori dell'INFN

24-25 Gennaio 2014

Laboratori Nazionali del Gran Sasso

Dipartimento di

Fisica



Universita' di TRIESTE

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Legnaro(PD)

Trieste

Ancona

Gran Sasso

L'Aquila

Roma



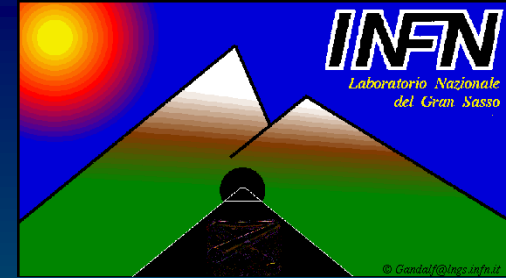
Il Parco Nazionale del Gran Sasso e Monti della Laga, istituito nel giugno del 1995, e' una delle aree protette più estese e preziose d'Europa.

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)

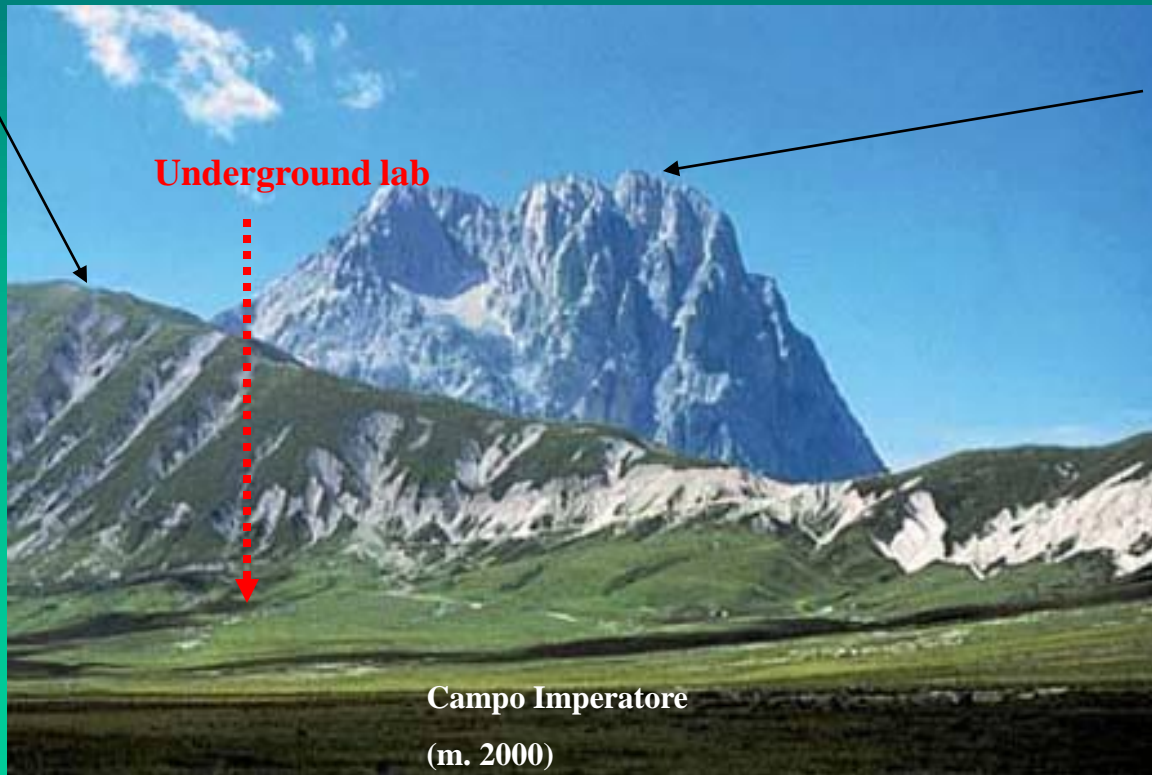
Operating Institution: Istituto Nazionale di Fisica Nucleare (INFN)

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

Scientists involved in LNGS experiments: 700 from 24 countries

Monte Aquila
(m. 2600)

Corno Grande (m. 2910)

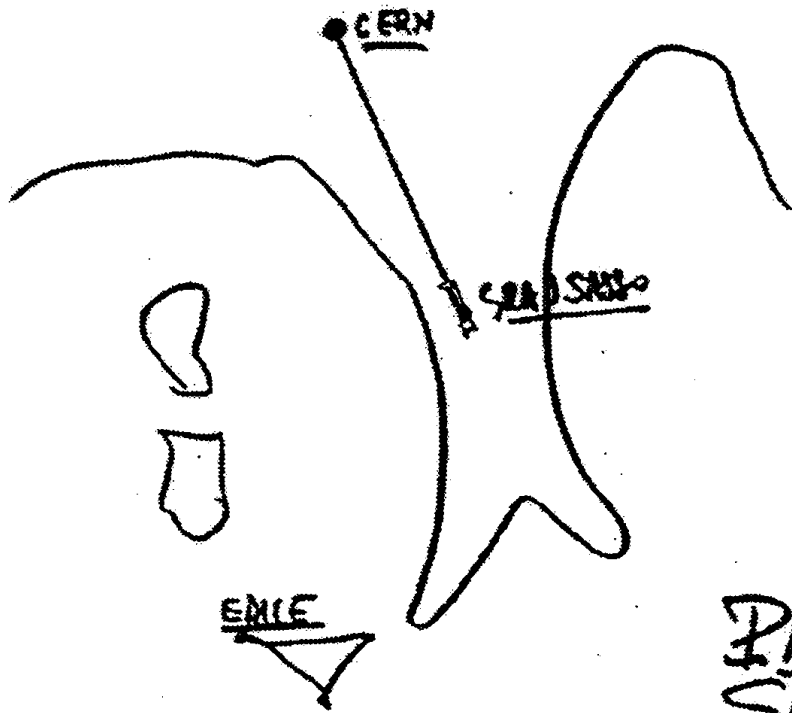


Underground lab

Campo Imperatore
(m. 2000)

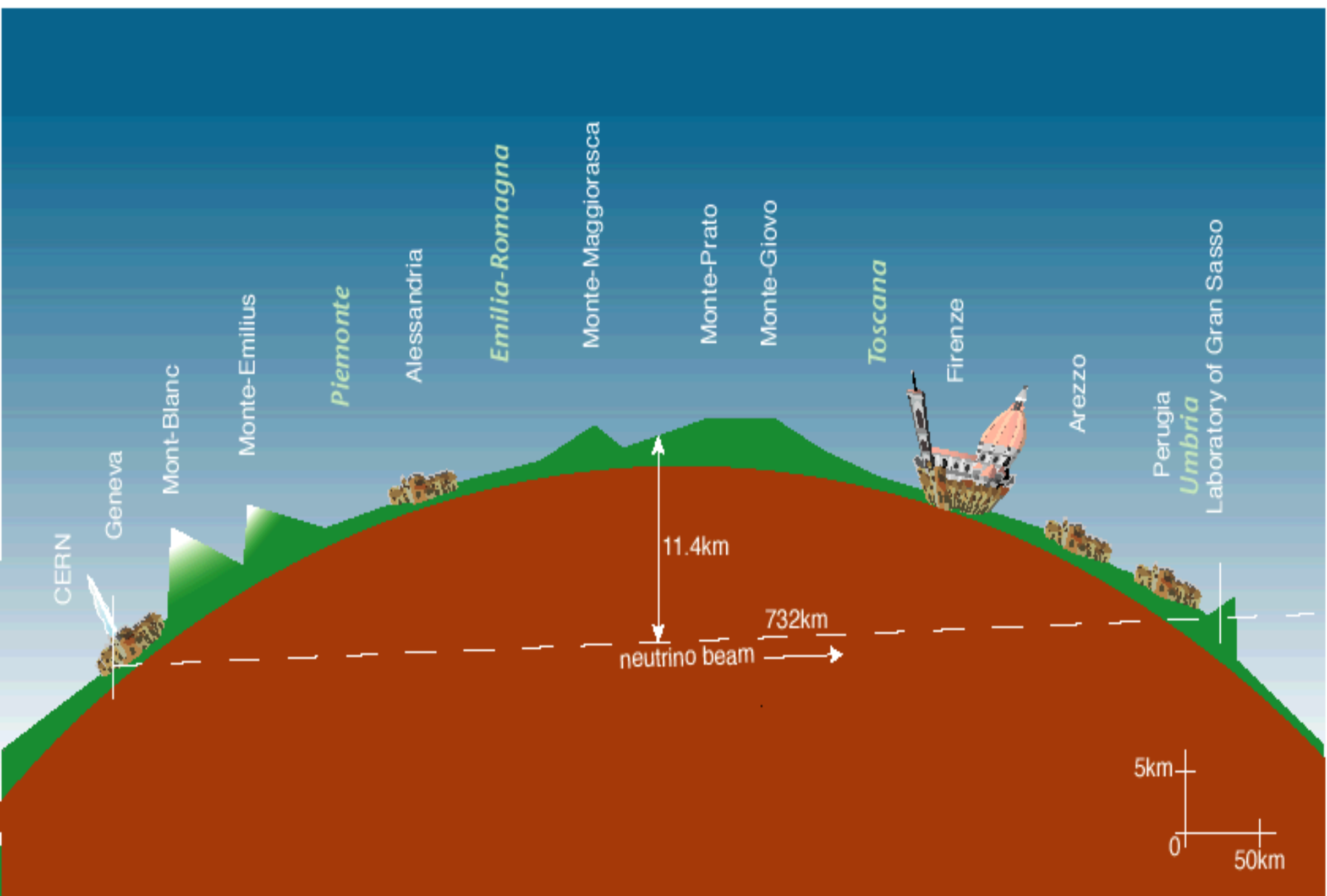
The area of Campo Imperatore
above LNGS

CONDIZIONE LAVORI PUBBLICI DEL SENATO



PROGETTO
GRAN SASSO

Figure 1.1.1: Sketch by A. Zichichi, 1979



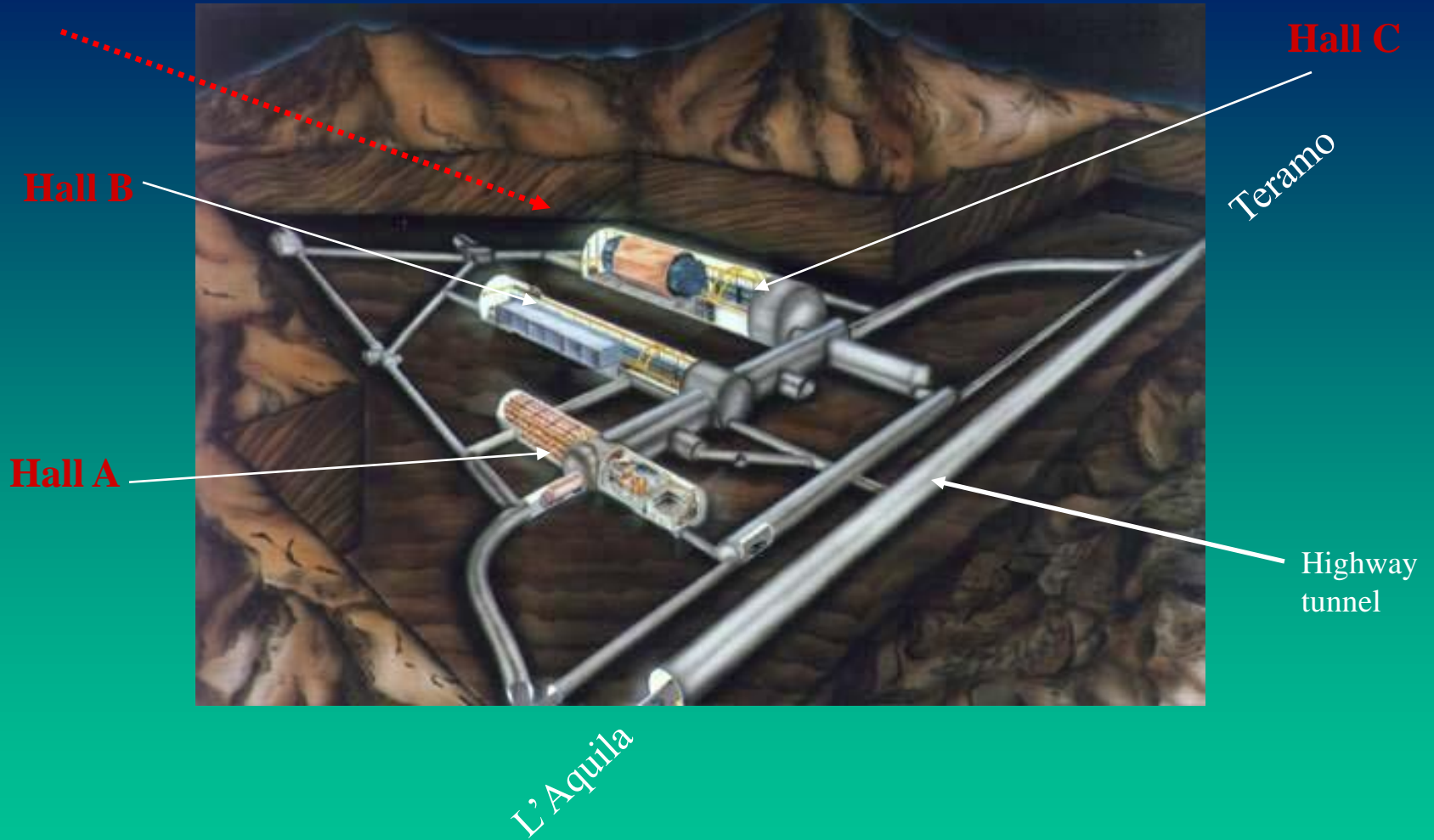
La sala B durante gli scavi e appena completata

~ 1985



CERN ν beam

The LNGS Underground area



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

Total volume : 180000 m³

Surface: > 6000 m²

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



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

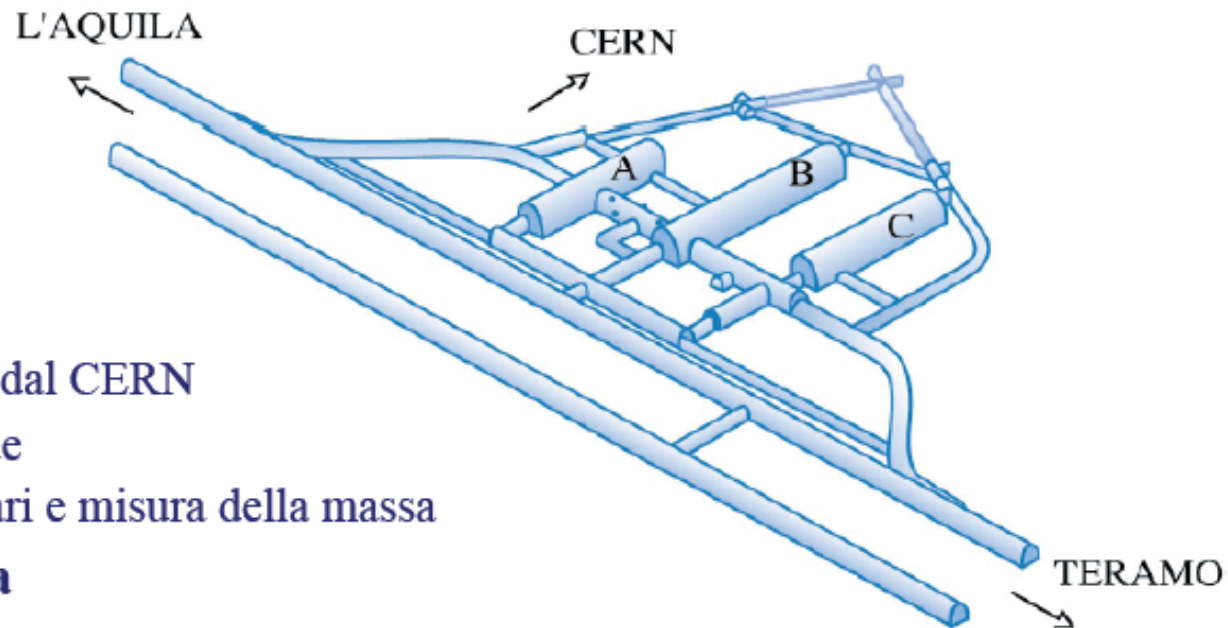
- Neutrini solari
- Esperimenti con neutrini dal CERN
- Rivelazione di supernovae
- Ricerca di decadimenti rari e misura della massa

■ Ricerca di materia oscura

■ Fisica nucleare dei processi rari

■ Geofisica

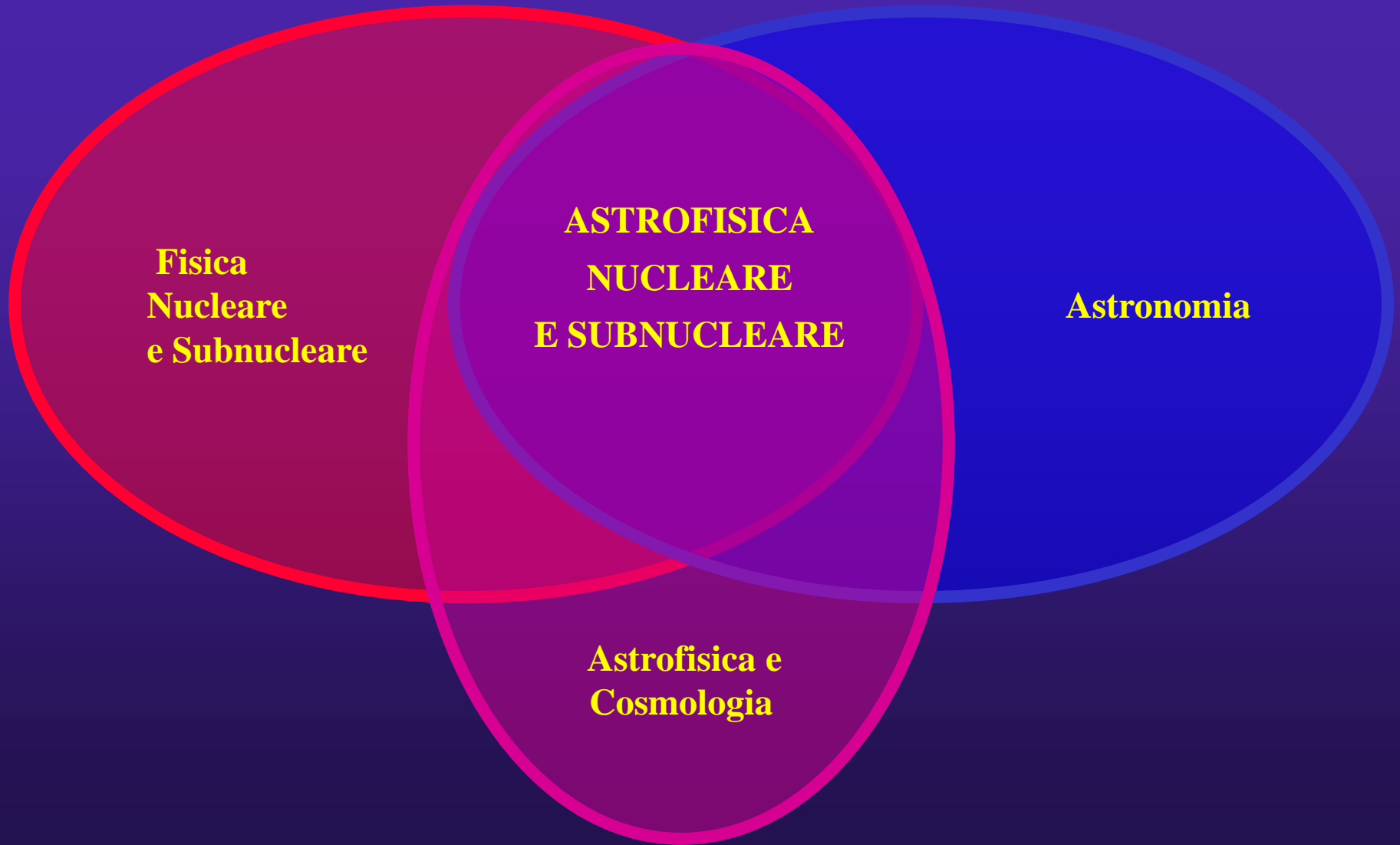
■ Biologia



Tunnel:	10.4 Km
Copertura:	~ 3200 m.w.e.
Riduzione flusso muoni:	~ 10⁶

Astrofisica Nucleare e Subnucleare

(Fisica Astroparticellare/Astrofisica Particellare)



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

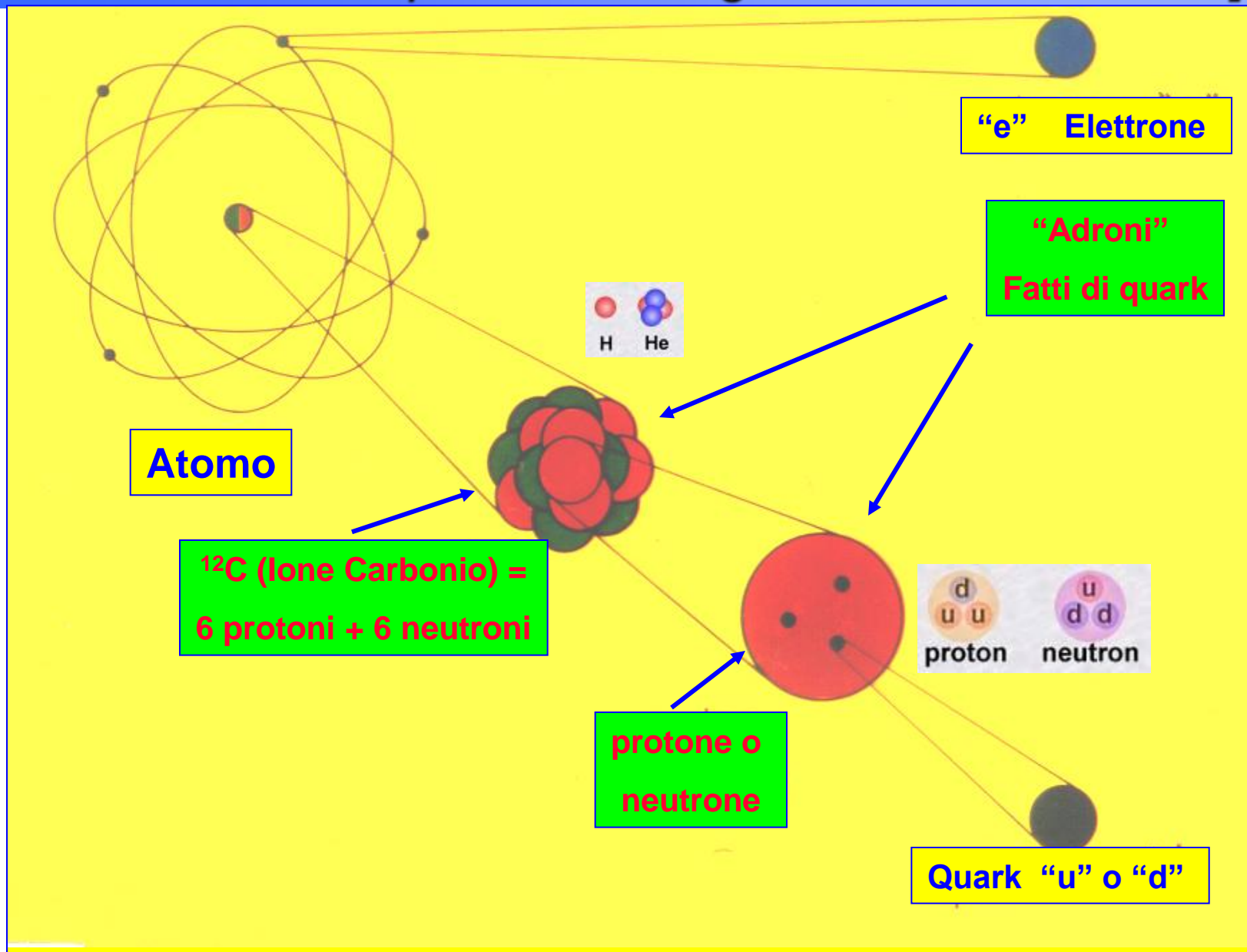
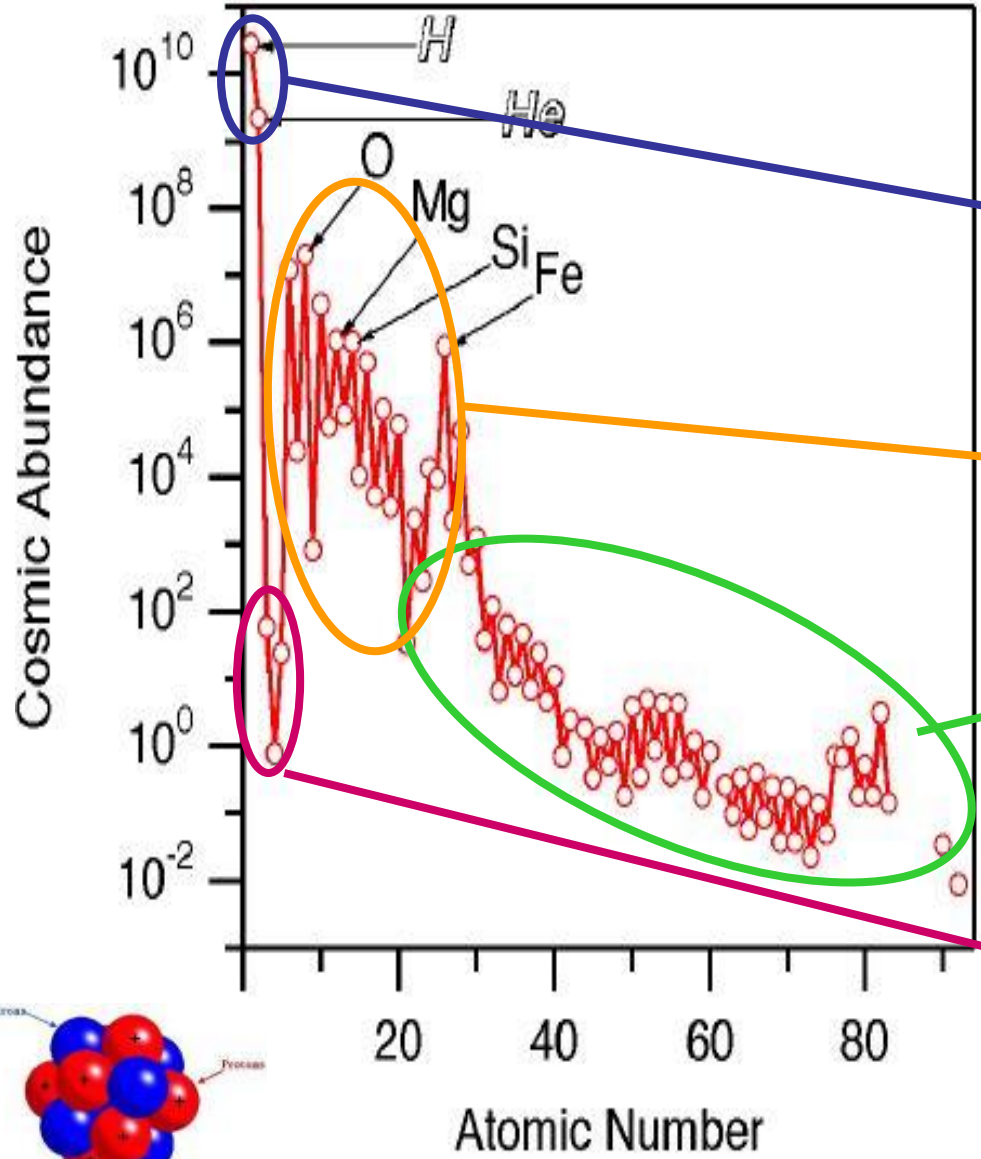


Tavola periodica degli elementi >

Periodic Table of the Elements

1	H	He																	18	Ar	19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
2	Li	Be																	10	Ne	11	Na	12	Mg	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																				
3	Na	Mg	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																																										
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																																						
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe																																						
6	Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu																																							
7	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Vd	No	Lr																																							

*Lanthanide Series
 †Actinide Series



- Origine
- Big Bang Nucleosintesi
- Stelle calde
- Esplosioni di Supernova
- Interazioni con raggi cosmici

10^{-43} sec

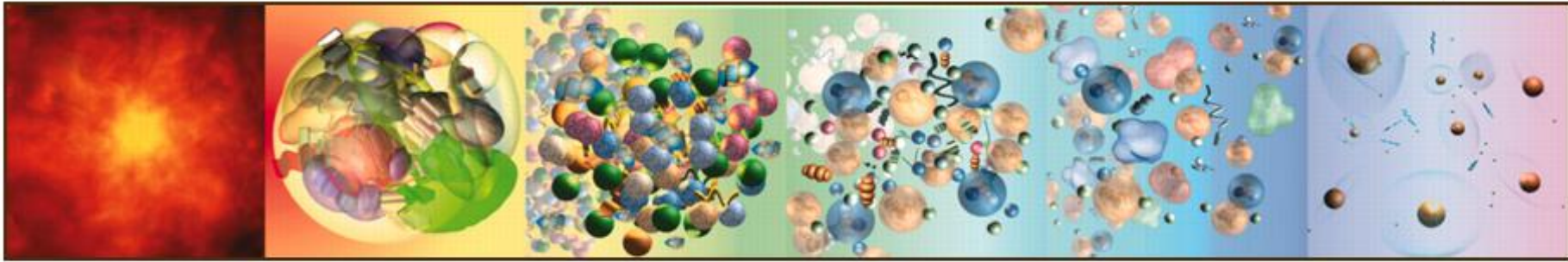
10^{-32} sec

10^{-10} sec

10^{-4} sec

100 sec

300000 years



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

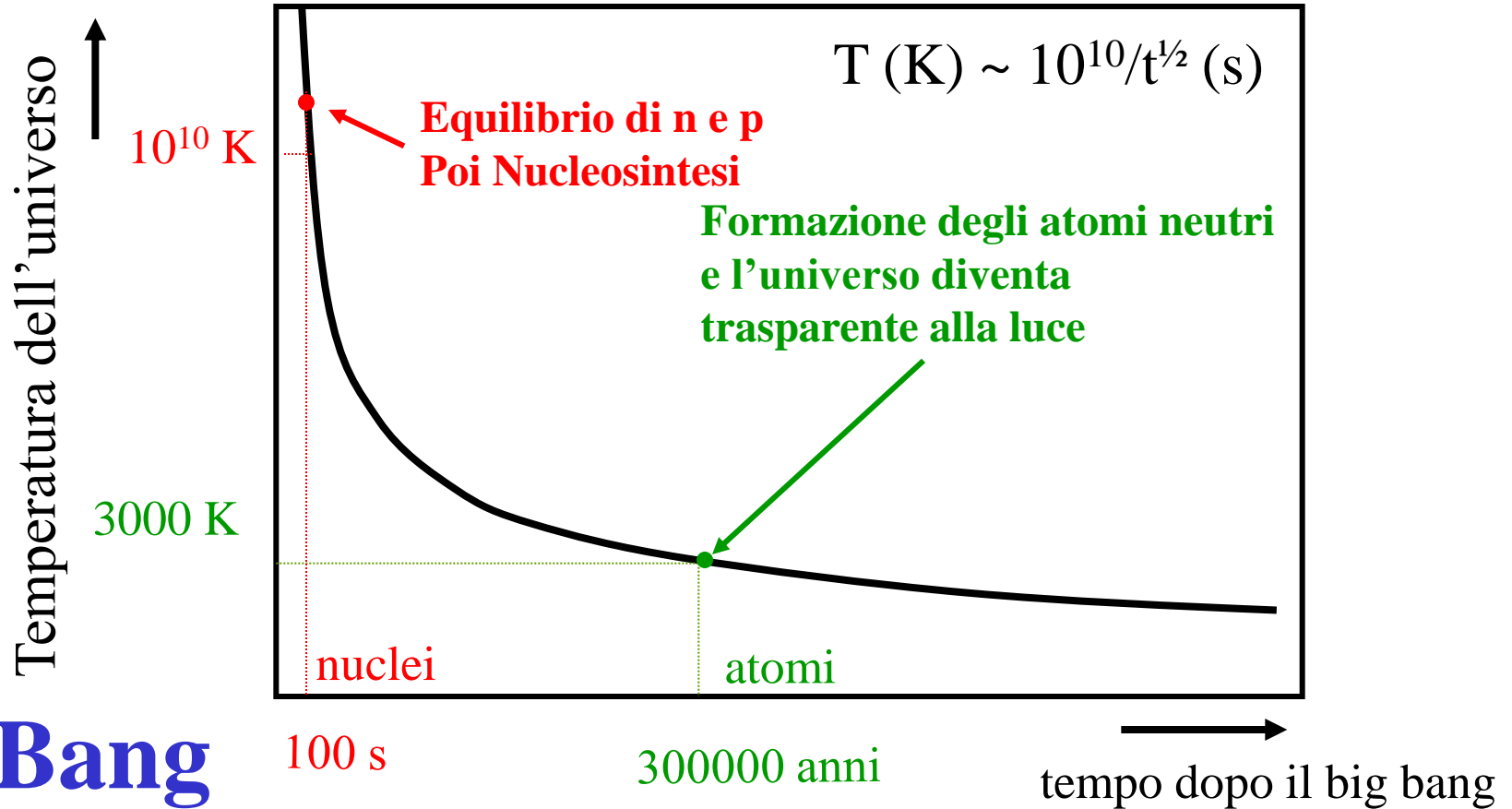
10^{-32} m
 10^{16} GeV

10^{-18} m
 10^2 GeV

10^{-16} m
1 GeV

10^{-15} m
1 MeV

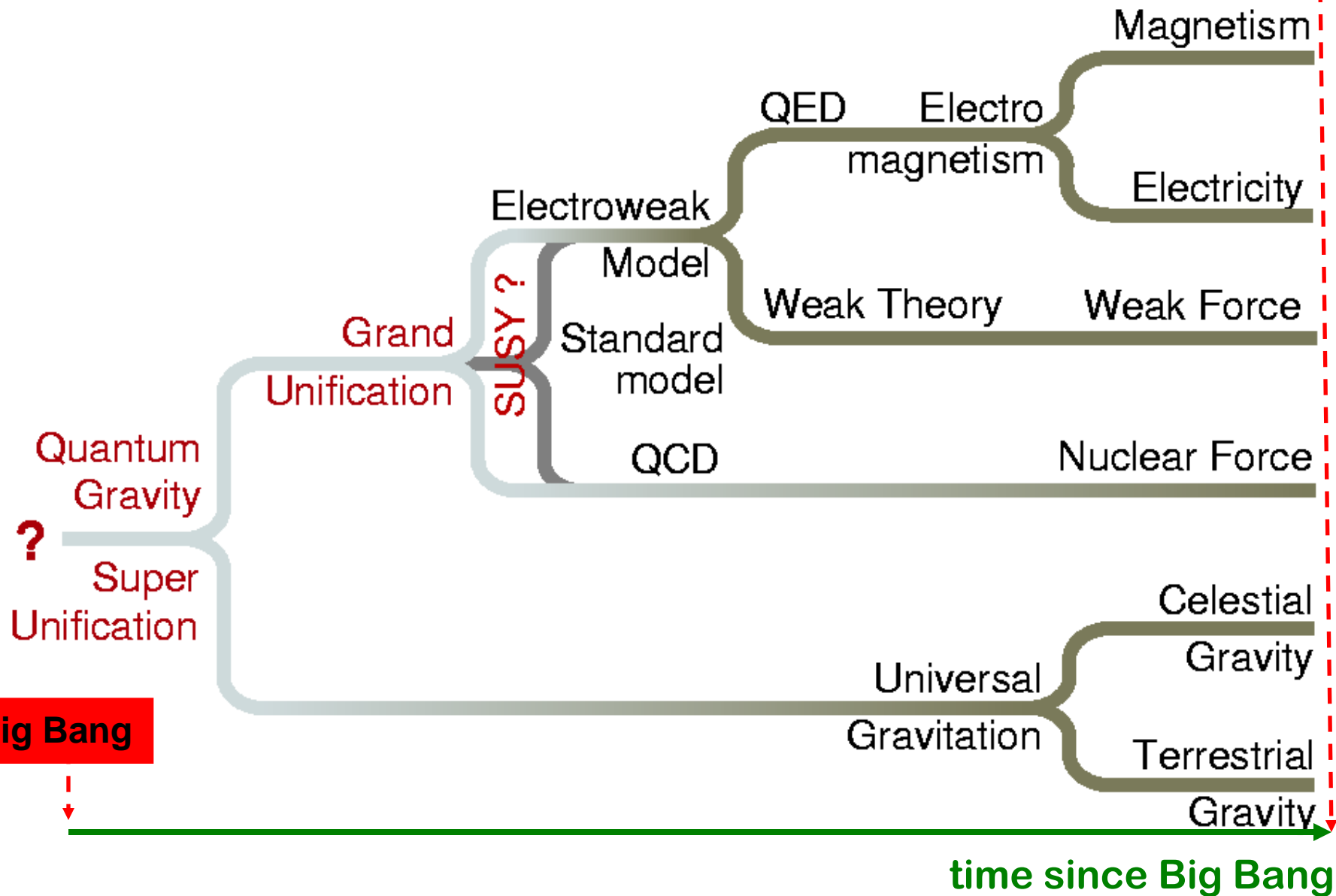
10^{-10} m
10 eV



Big Bang

Unificazione delle Forze

Today



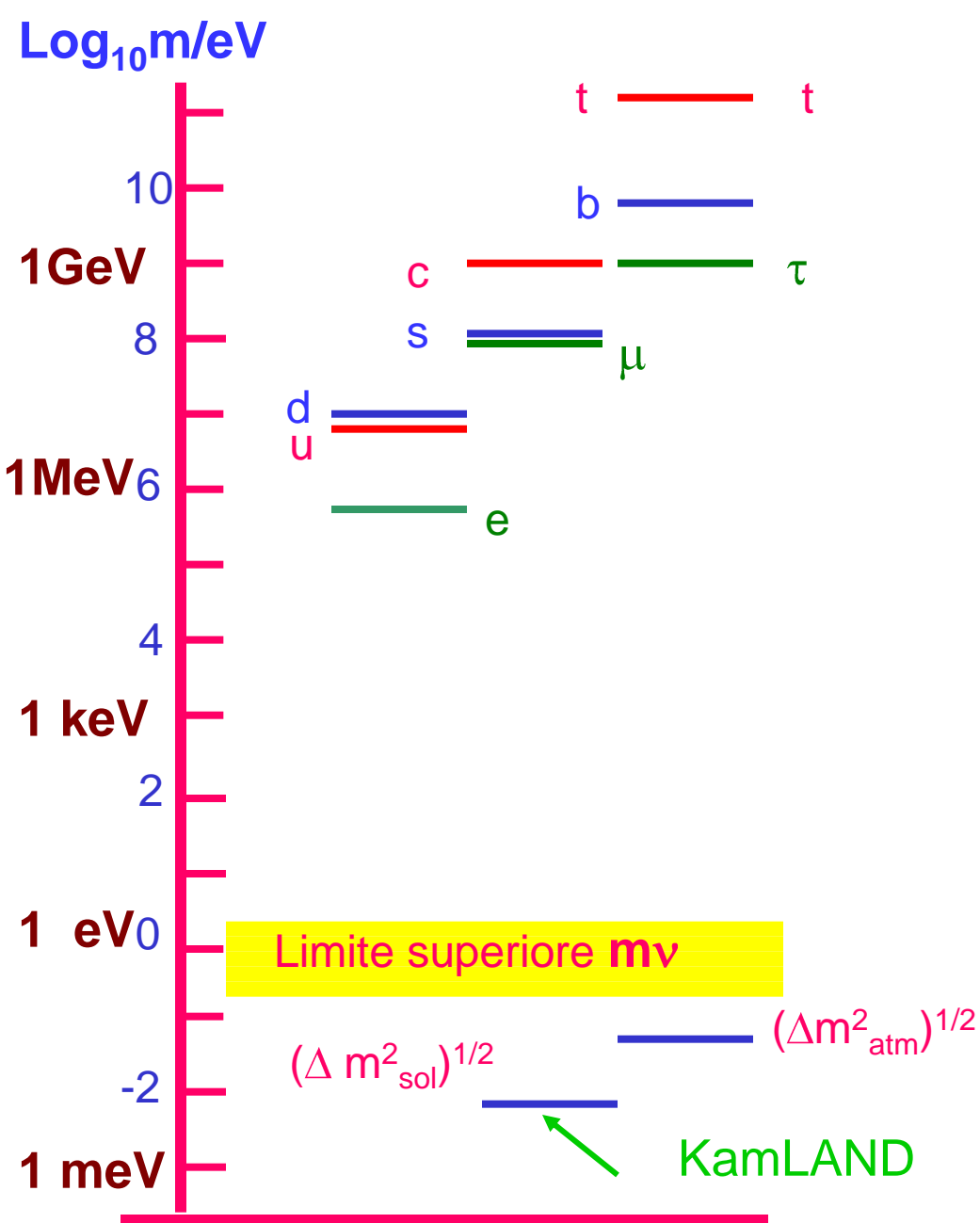
MODELLO STANDARD : Fermioni (Costituenti) e Bosoni (Mediatori)

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

ν : Massa=0 ?

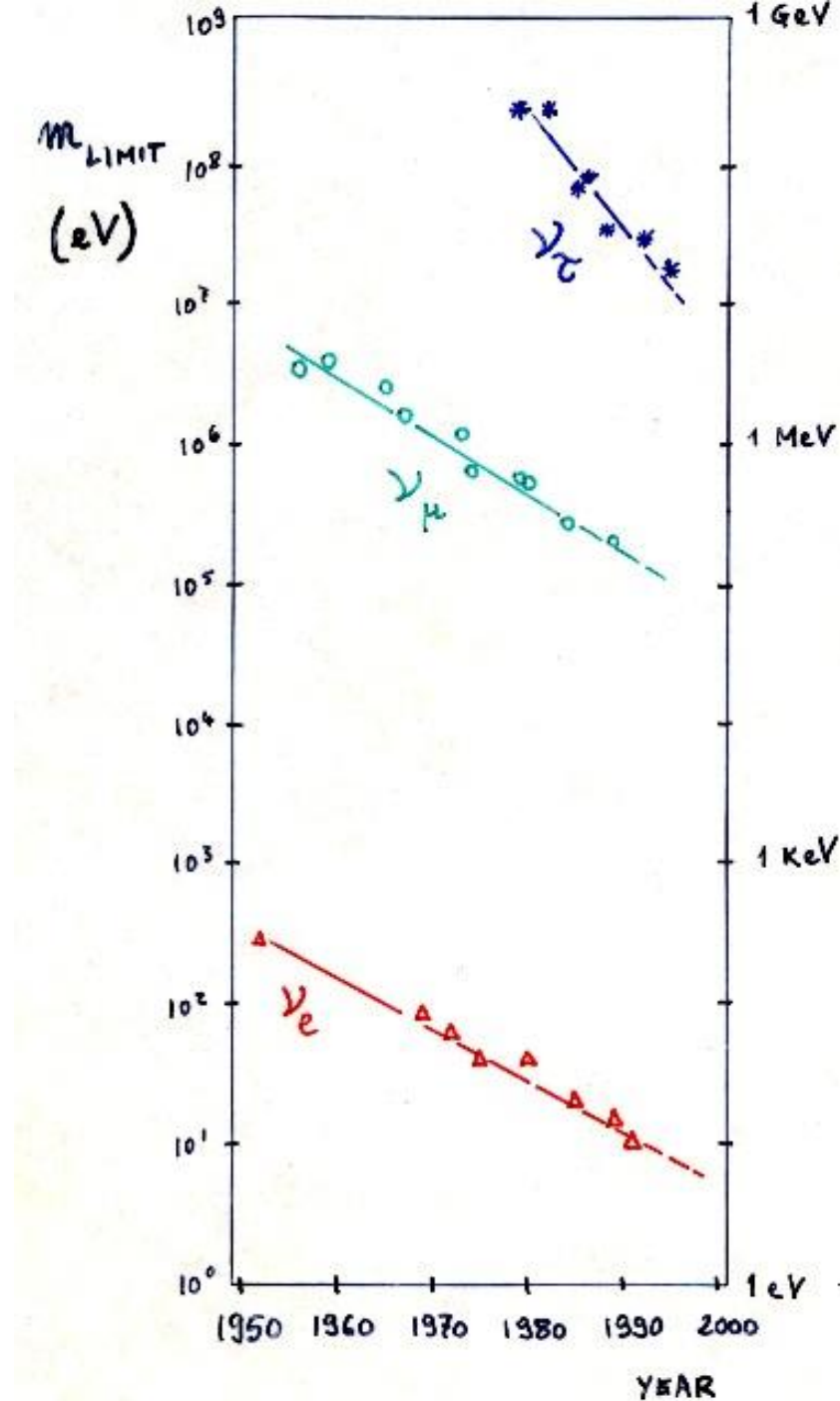
- no ν_R
- numero leptonico L conservato

ν : Massa >0 ?

- ν_R pesante
- numero leptonico L non conservato

Limiti Sperimentali per la Massa dei Neutrini

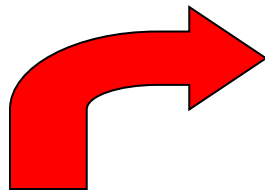
(50 anni di misure)



Oscillazioni dei Neutrini

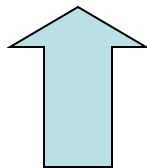
- Idea della massa dei neutrini suggerita per la prima volta da Bruno Pontecorvo

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



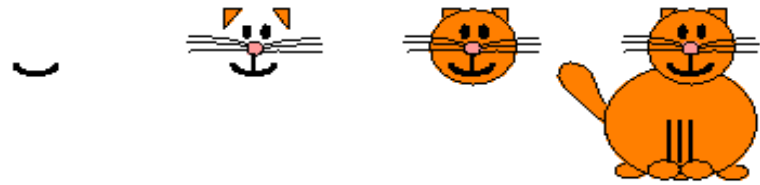
$|v_e\rangle$, $|v_\mu\rangle$, $|v_\tau\rangle$ = Autostati dell'Interazione Debole

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

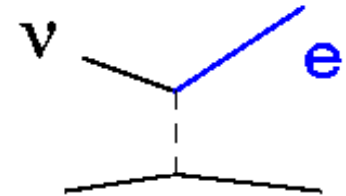


• I Neutrini si propagano (evolvono) come sovrapposizione di autostati di **massa**:
MESCOLAMENTO

Comparsa/Appearance

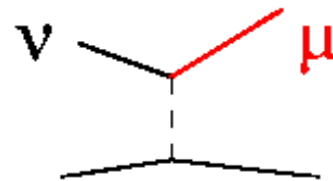


"Appearance Experiments"
see the new neutrino type
in the detector

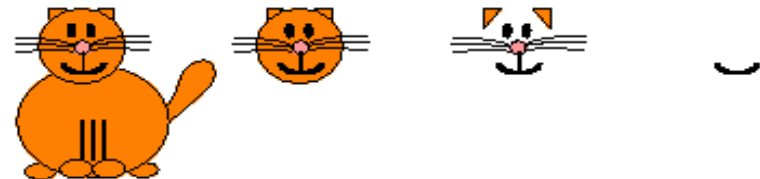


A *"Disappearance Experiment"* observes

fewer



than expected



Scomparsa/Desappearance

Esperimenti con Neutrini :

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

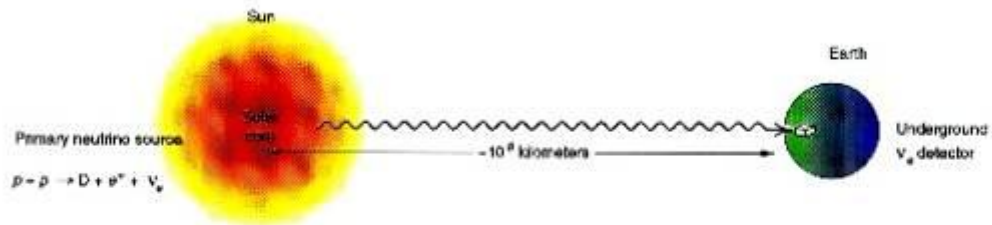
Sorgenti naturali:

Sole, Supernovae, Raggi cosmici

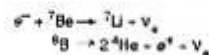
Sorgenti Artificiali:

Acceleratori, Reattori Nucleari

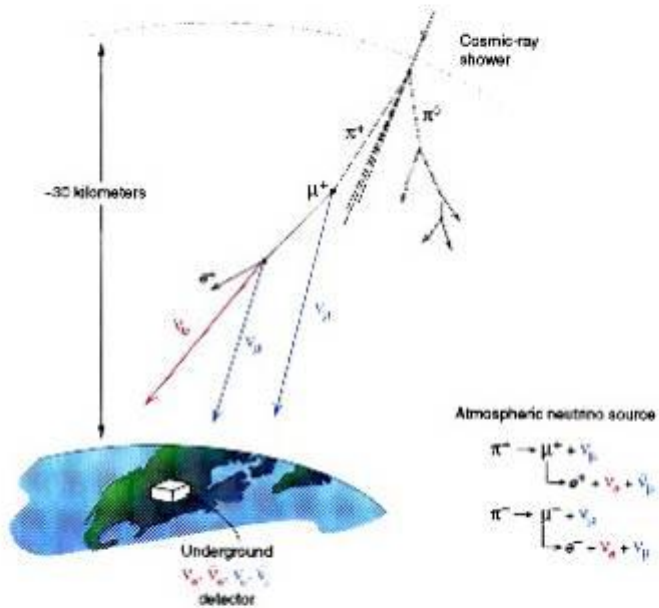
SOLAR ν : (ν_e)



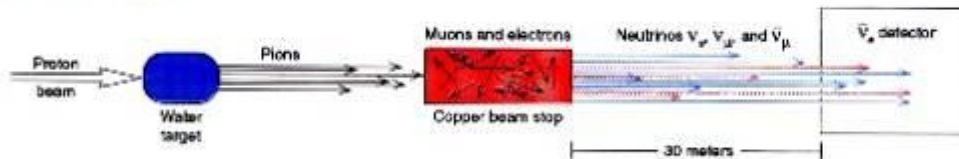
Other sources of neutrinos:



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



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

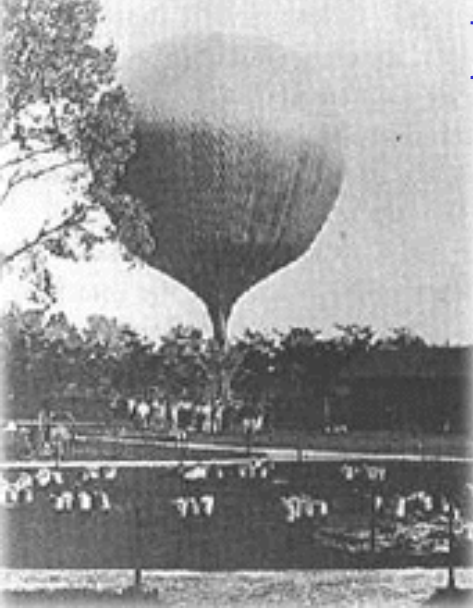


REACTOR ν :
 ($\bar{\nu}_e$)



Raggi Cosmici

Colhoster 1914
@ 9km



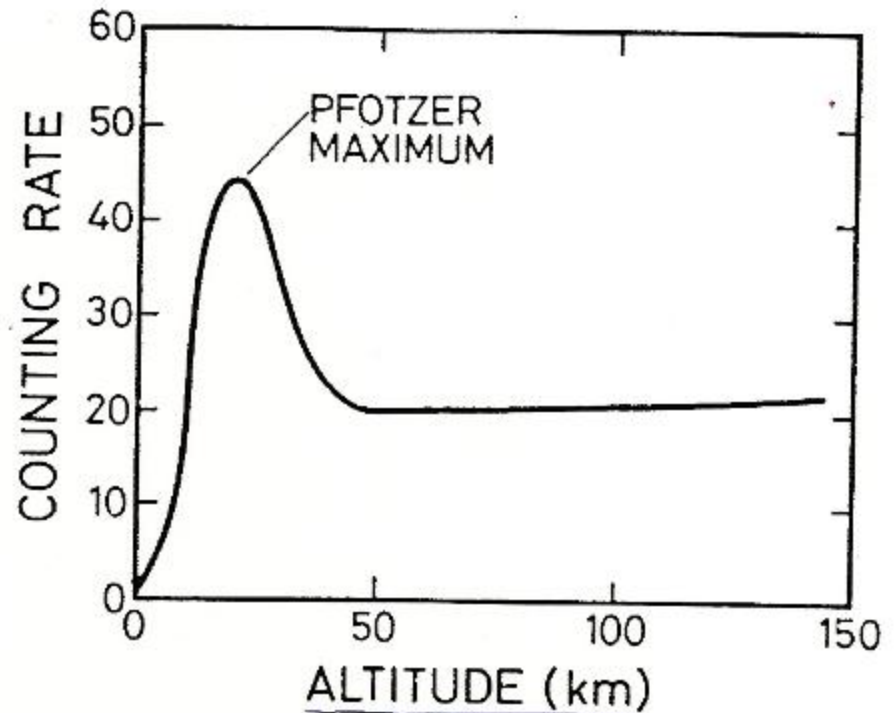
Altitude
(km)

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

Ascese su Pallone:
Hess 1912 @ 5km



Composizione dei Raggi Cosmici

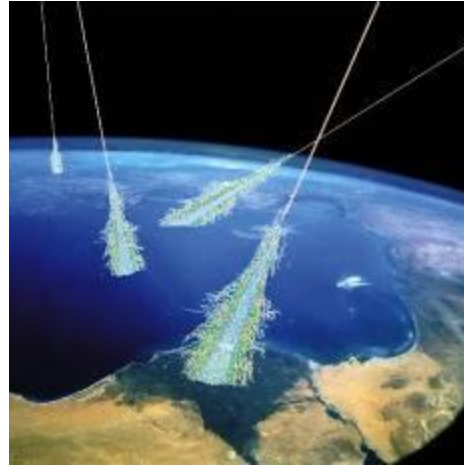
PRIMARI:

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

$e \sim 2 \%$

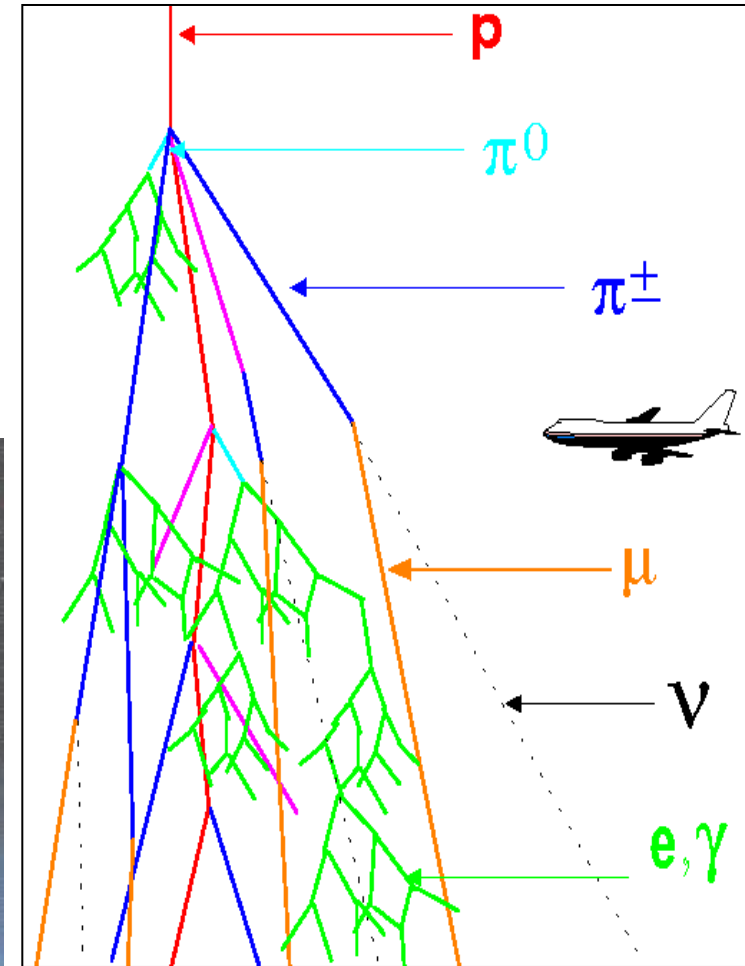
$\gamma \sim 0.1 \%$, $\nu \sim 0.1 \%$?

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

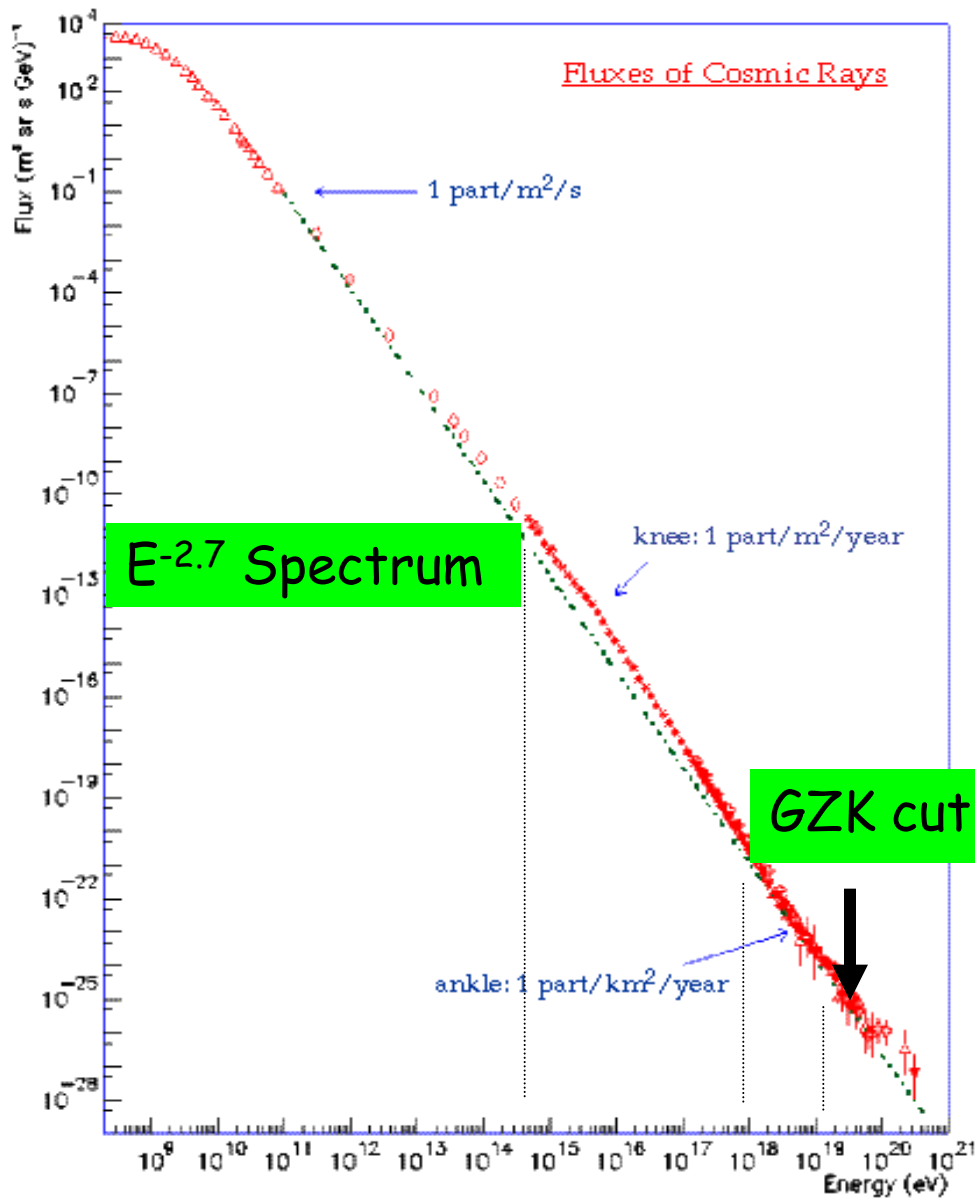
$\mu \sim 30 \%$

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

$\nu \sim 68 \%$

The primary spectrum

Possible Origins



$E < 10^{15}$ eV
Galactic

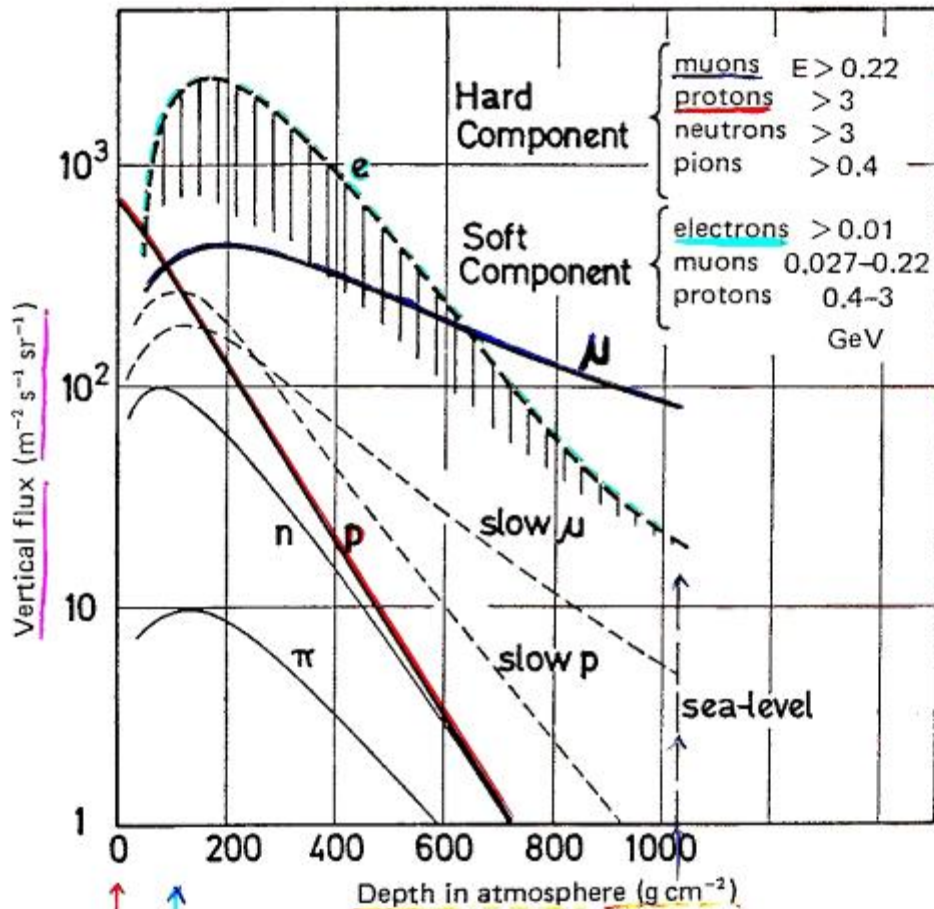
$10^{15} < E < 10^{18}$ eV
Extra-galactic ?

$10^{18} < E < 5 \cdot 10^{19}$ eV
Unknown

$5 \cdot 10^{19} < E < 3 \cdot 10^{20}$ eV
Unexpected

UHECR

EECR



3000 $\text{m}^{-2} \text{s}^{-1} \text{sr}^{-1}$

100 $\text{m}^{-2} \text{s}^{-1} \text{sr}^{-1}$

Spazio

Pfozter maximum
@ ~ 20 km

Livello del mare

NOTE: $\tau_0(\mu) = 2.2 \mu\text{s}$

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

$E = \gamma m_0 c^2$

$\tau = \gamma \tau_0 \Rightarrow \gamma > 20$

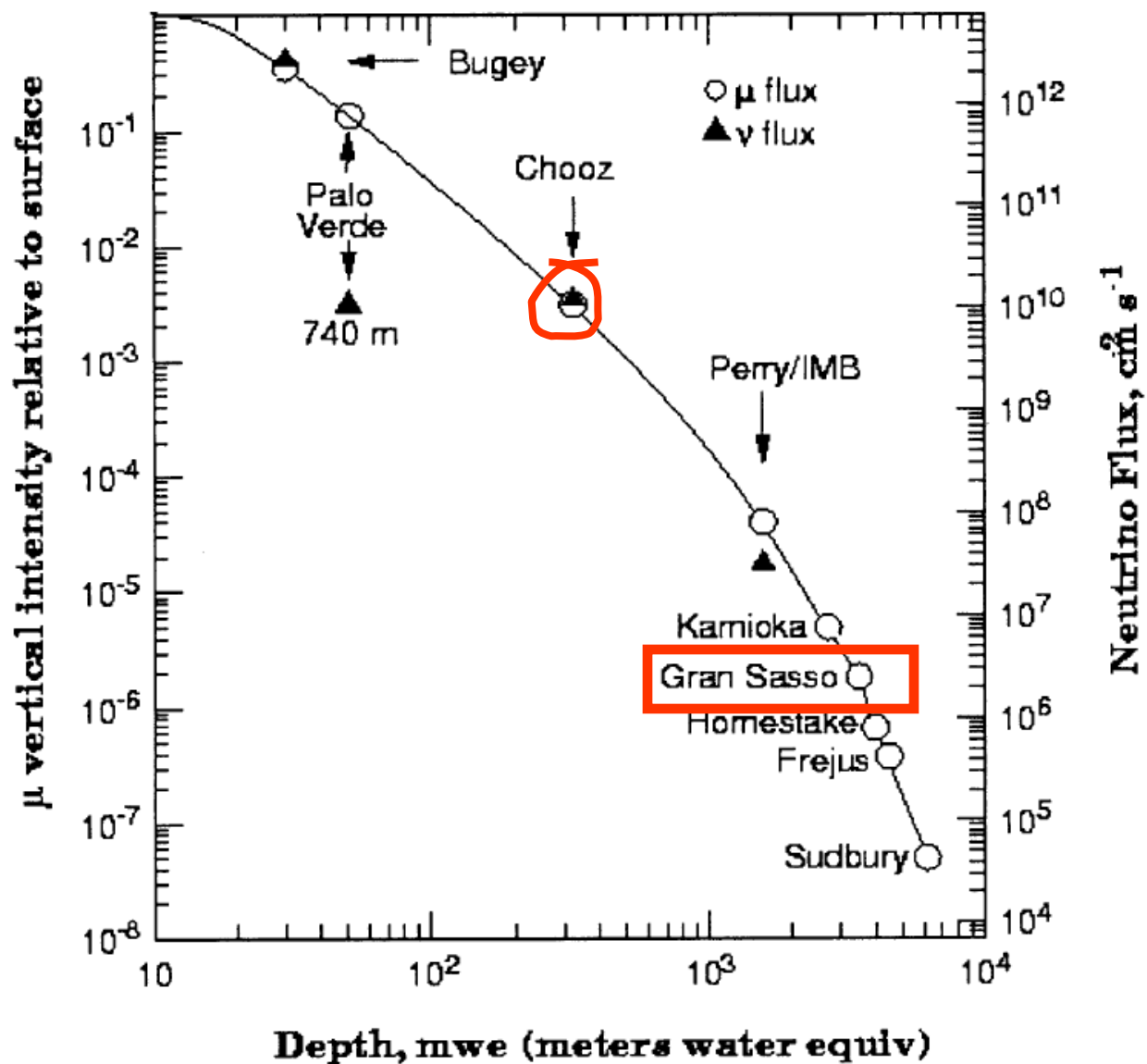
$m \cdot \mu = 105 \text{ MeV}/c^2$

RELATIVISTIC

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

Flusso di μ

μ Depth-Intensity and ν Flux
for various sites



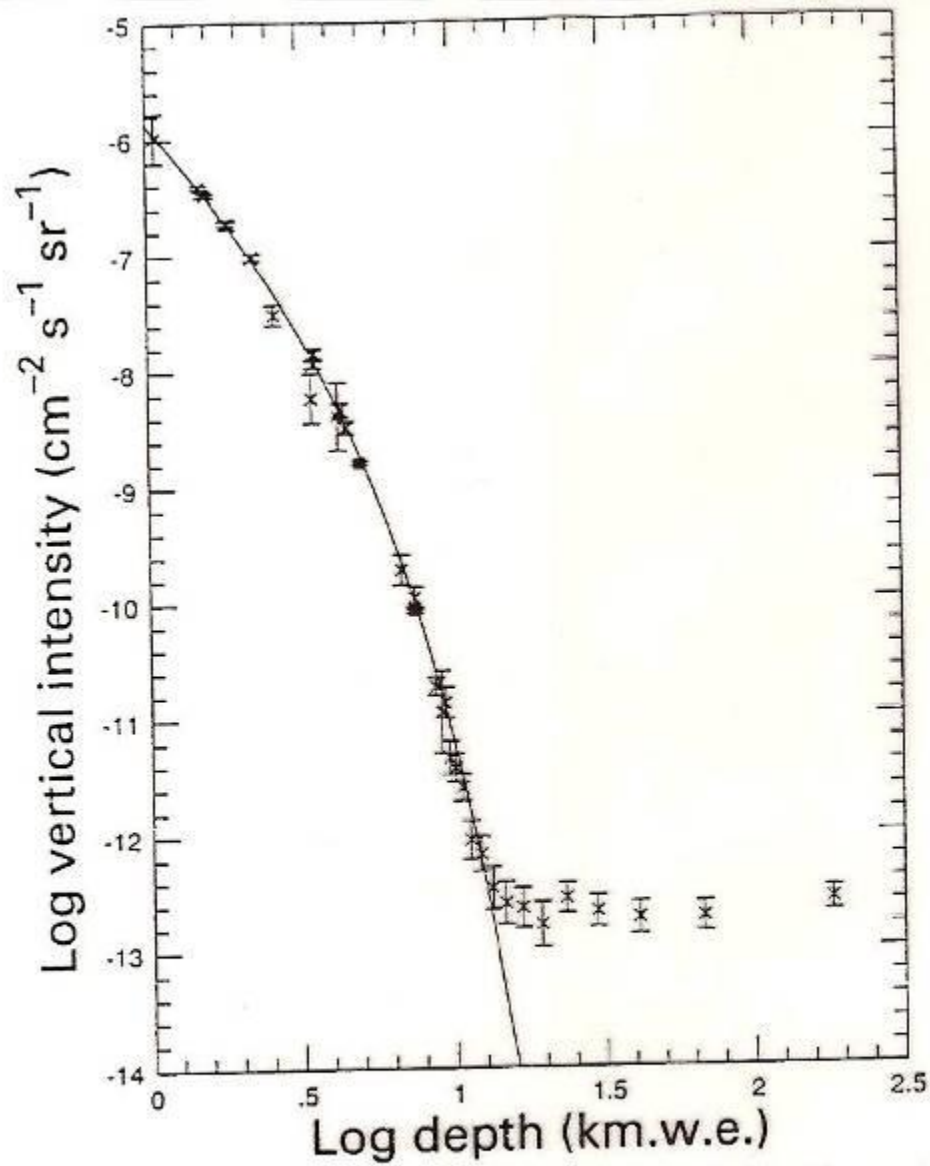
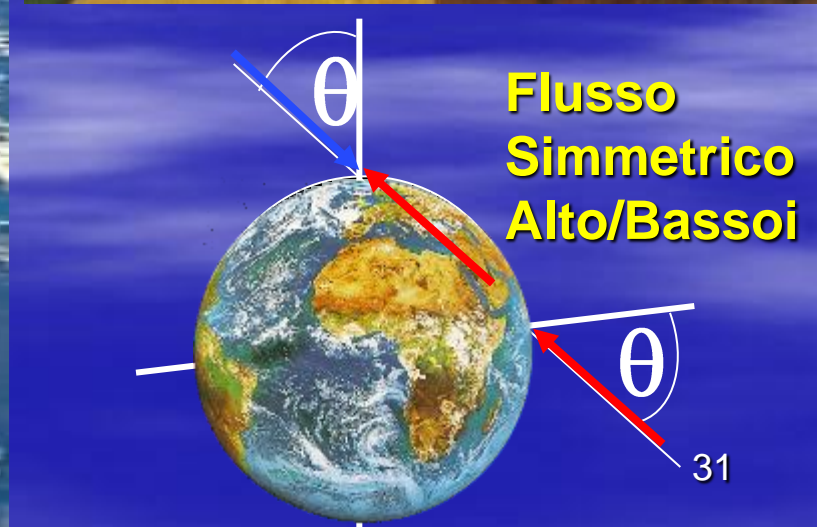
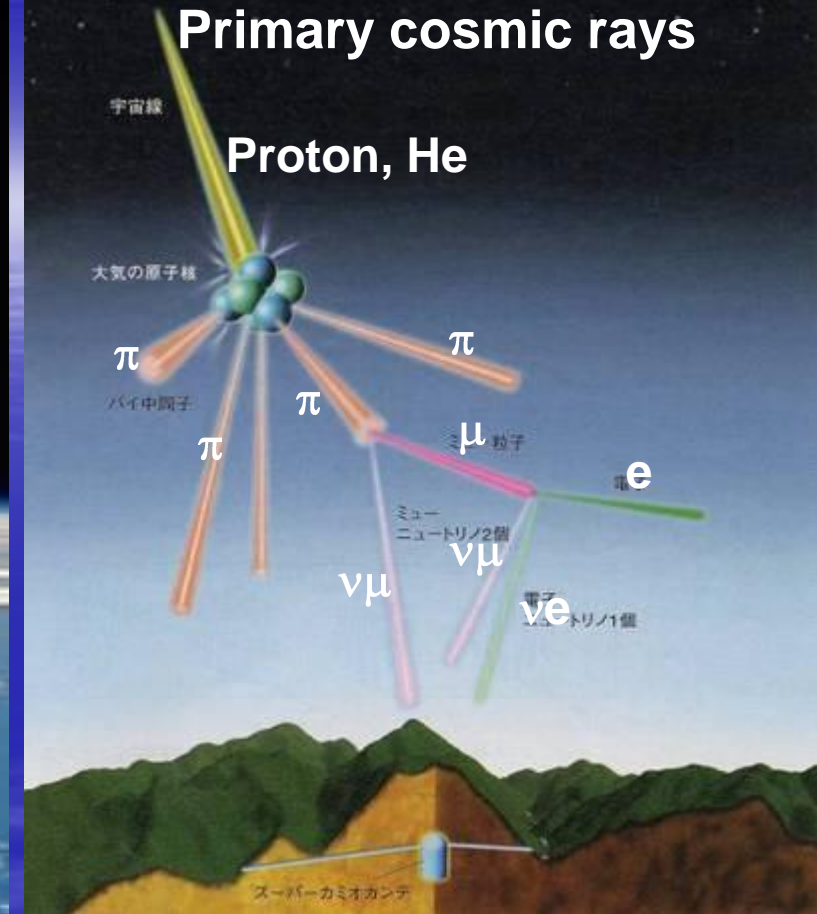


Figure 6.3: Relation between muon intensity and depth underground. The data are taken from a summary by Crouch (1987) with the addition of recent data from the Frejus experiment (Berger et al., 1989 – filled squares).

Sorgente Raggi Cosmici: ν Atmosferici

atmosfera



Gli esperimenti “storici”

- Macro
 - Ricerca dei monopoli magnetici

- LVD
 - Ricerca di supernovae

- Gallex
 - Studio di neutrini solari

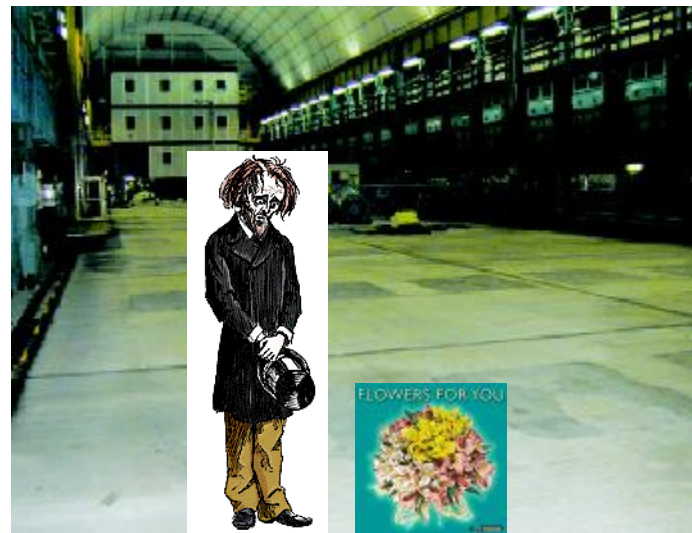


The MACRO experiment

1984 : Proposal

1989 : First Supermodule ON

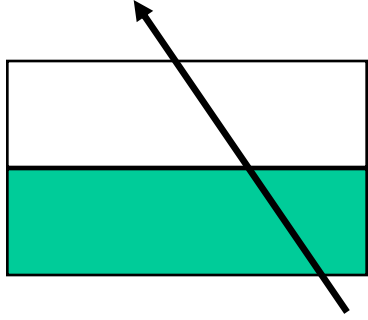
1987 : Construction starts



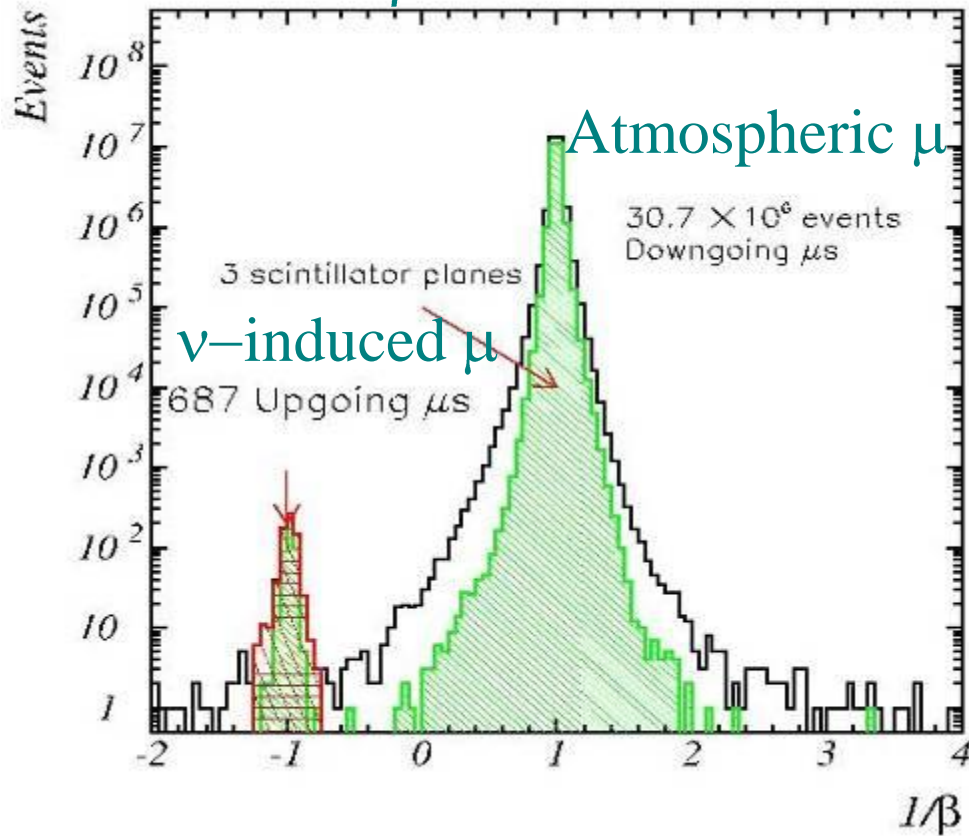
4/1994 : Full detector ON

12/2000 : Rest In Peace

MACRO Upward throughgoing muons



$1/\beta$ distribution:



LVD Large Volume Detector

Collab.:
Italy, Brazil, Russia, USA, Japan

Running since 1992

1000 billions ν in 20s from the SN core

Measurement of neutrinos spectra and time evolution provides important information on ν physics and on SN evolution.

Neutrino signal detectable from SN in our Galaxy or Magellanic Clouds

2 - 5 SN/century expected in our Galaxy.

Plan for multidecennial observations

1000 tons liquid scintillator + layers of streamer tubes

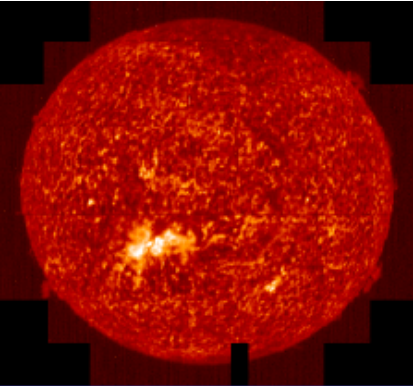
300 ν from a SN in the center of Galaxy (8.5 kpc)



SN1987A



Early warning of neutrino burst important for astronomical observations with different messengers (photons, gravitational waves)
SNEWS = Supernova Early Warning System
LVD, SNO, SuperK
in future: Kamland, BOREXINO



GNO

Collab.:
Italy, France, Germany

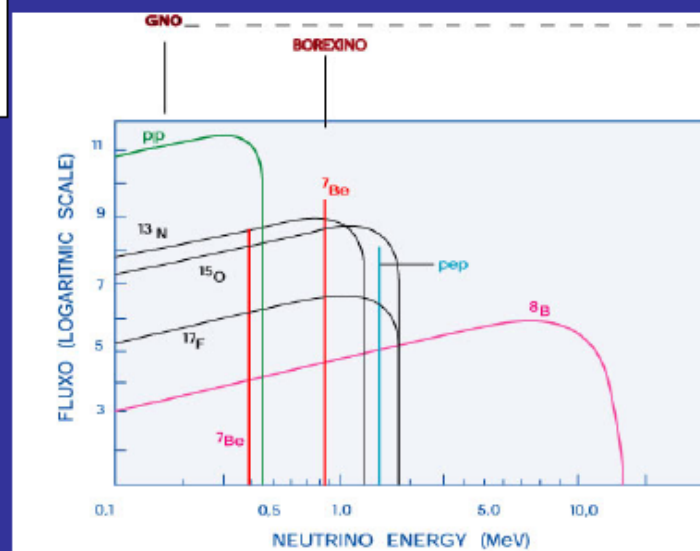
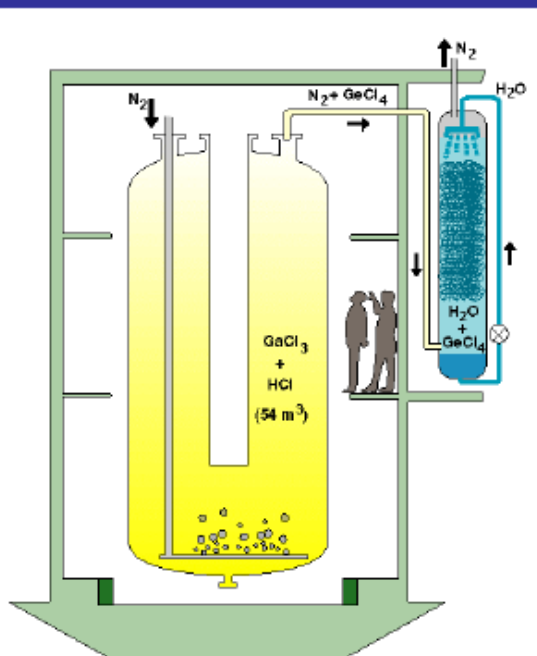
Goals: measurement of the interaction rate with an accuracy of 4-5% and monitoring the neutrino flux over a complete solar cycle.

101 tons Gallium Chloride solution

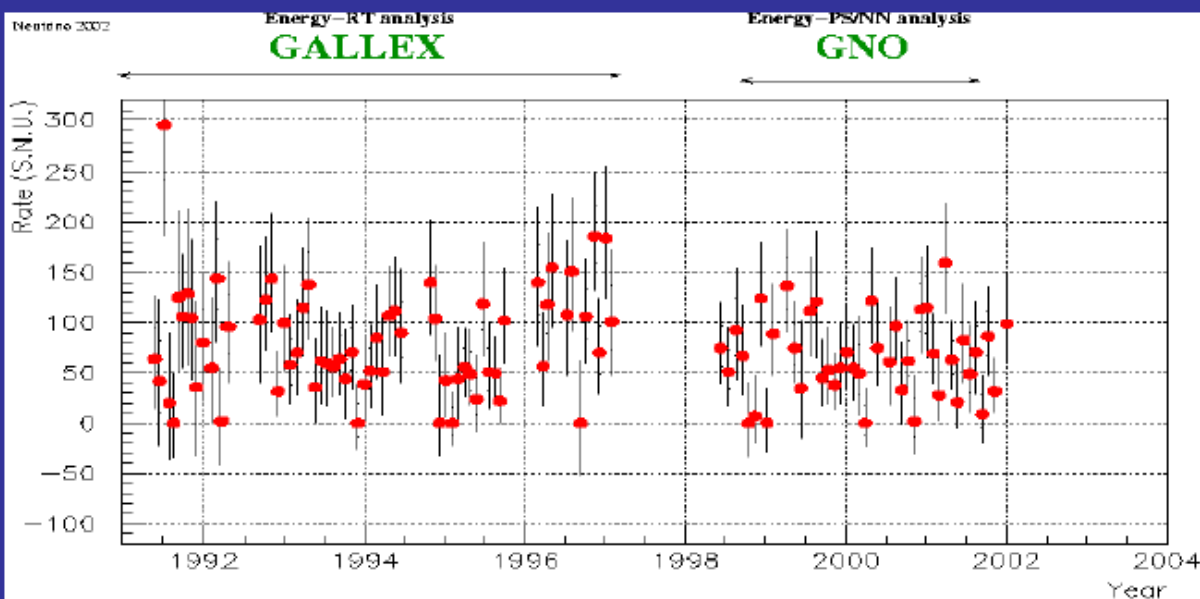
$^{71}\text{Ge}(\nu_e, e)^{71}\text{Ge}$

Energy threshold > 233 keV

Sensitive mainly to pp -neutrinos



SSM → 115 -135 SNU

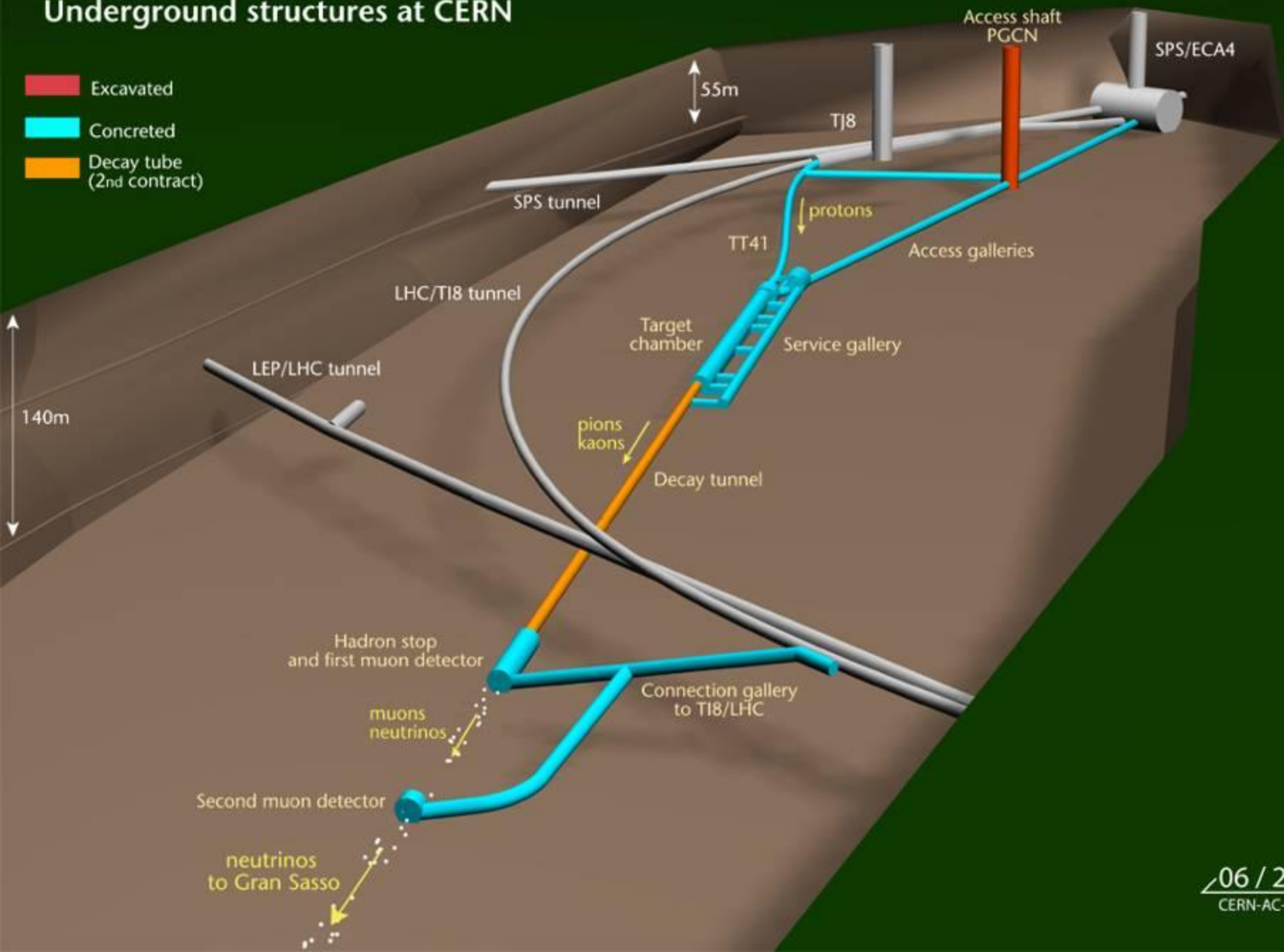


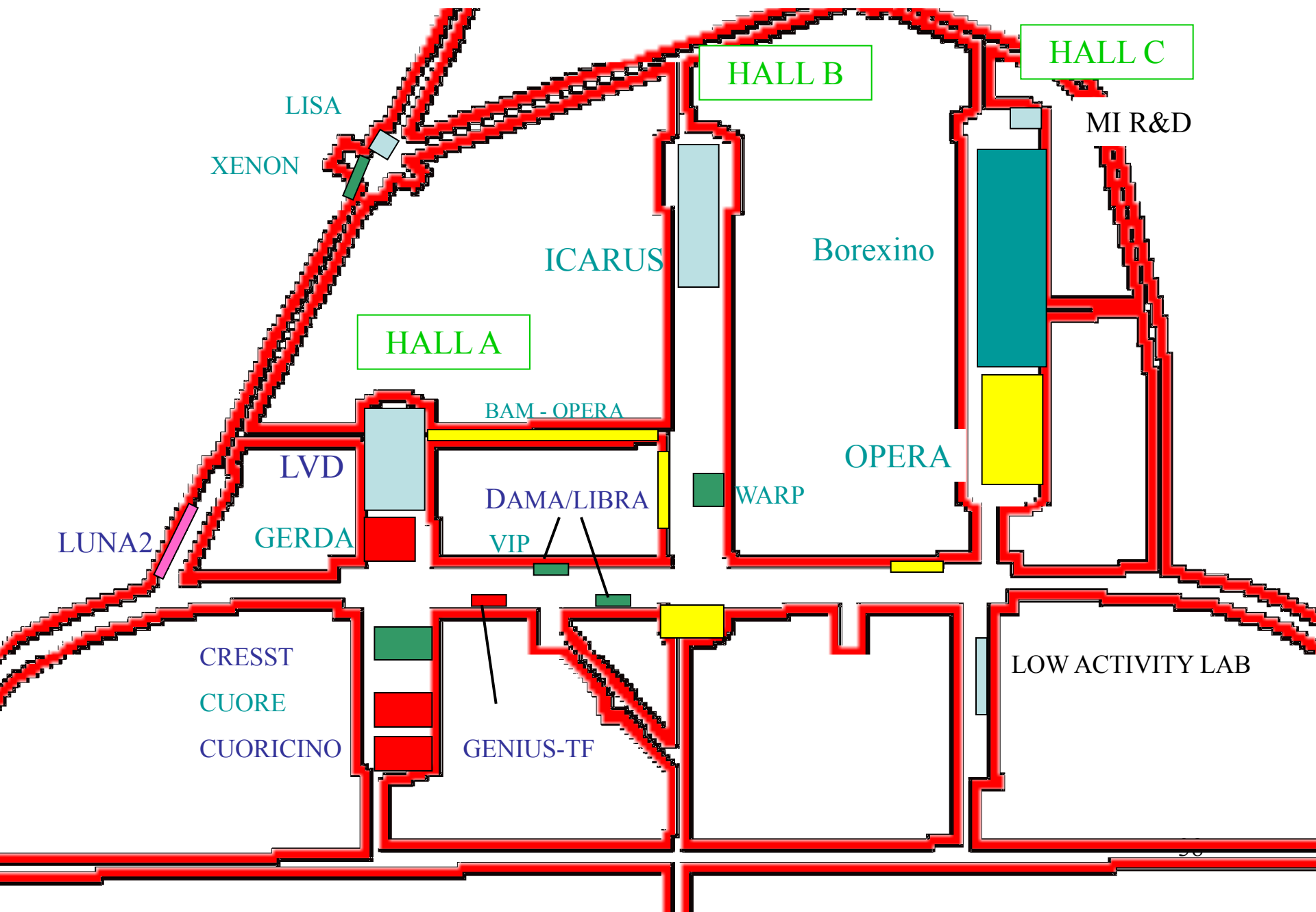
GALLEX	65 SR	77.5 ± 6.2 (stat) ± 4.5 (sys) SNU
GNO	43 SR	65.2 ± 6.4 (stat) ± 3.0 (sys) SNU
GNO+GALLEX	108 SR	70.8 ± 4.5 (stat) ± 3.8 (sys) SNU

CERN NEUTRINOS TO GRAN SASSO

Underground structures at CERN

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





- **Neutrino**
 - **Borexino** (solari, geo, SN)
 - Scintillatore Liquido
 - **LVD** (SN)
 - Scintillatore Liquido

- **Doppio Beta Decay**
 - **Cuoricino, Cuore:** cristalli TeO_2
 - **Gerda:** cristalli di Ge
 - **Cobra:** cristalli CdZnTe

- **Materia oscura**
 - **Libra (Dama):** NaI
 - **Cresst:** cristalli CaWO_2
 - **Xenon:** xenon liquido
 - **Warp:** argon liquido

- **Neutrini CNGS**
 - **Opera:** spettrometro + emulsioni
 - **Icarus:** TPC ad Argon Liquido

- **Astrofisica Nucleare**
 - **Luna2**

- **Onde gravitazionali**
 - **Lisa R&D**

- **Geologia, biologia, misure di bassa radioattvita'**

- **Futuro:**
 - **ModuLAR:** un grande esperimento con i neutrini dal CERN basato su Argon Liquido
 - Non ancora approvato



External facilities

- Administration**
- Public relationships support**
- Secretariats (visa, work permissions)**
- Outreach**
- Environmental issues**
- Prevention, safety, security**
- General safety, electrical plants**
- Civil works**
- Chemistry**
- Cryogenics**
- Mechanical shop**
- Electronics**
- Computing and networks**
- Offices**
- Assembly halls**
- Lab & storage spaces**
- Library**
- Conference rooms**
- Canteen**