Interazioni e Particelle

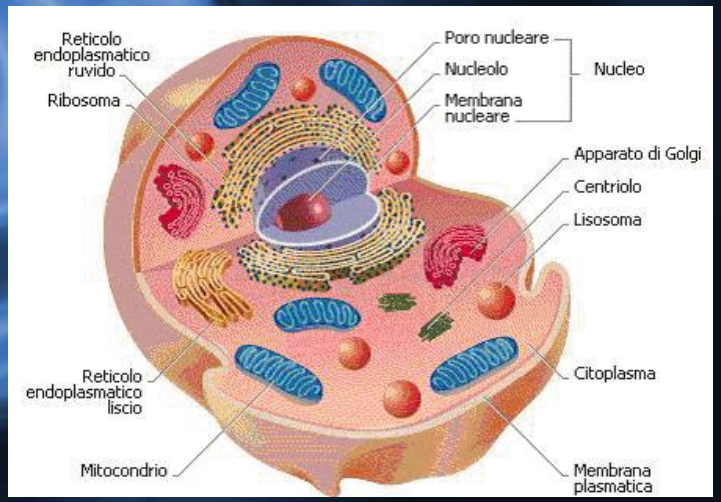
Oreste Nicrosini

Progetto Lauree Scientifiche – Fisica

Pavia, 11 maggio 2012

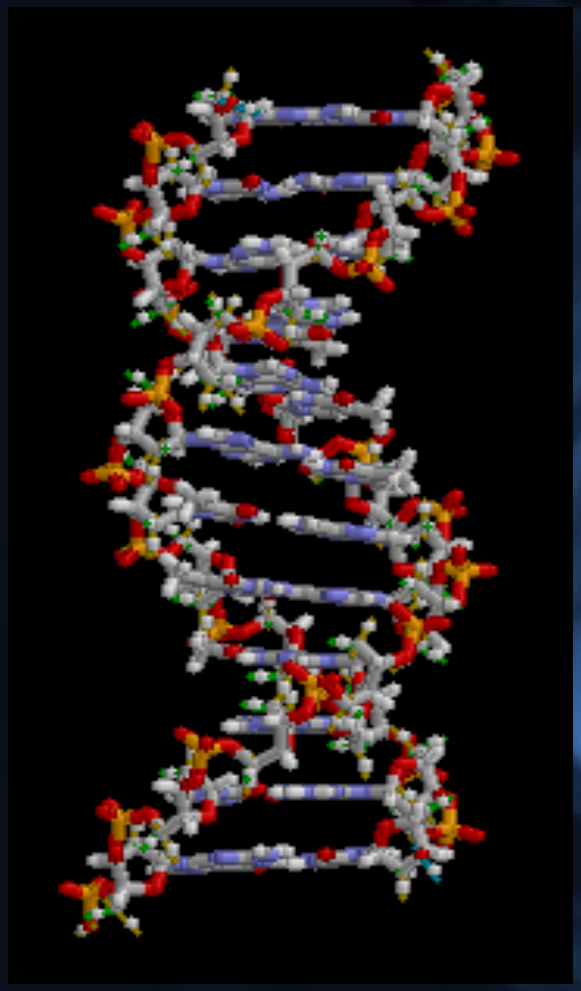
Di cosa siamo fatti?

1m

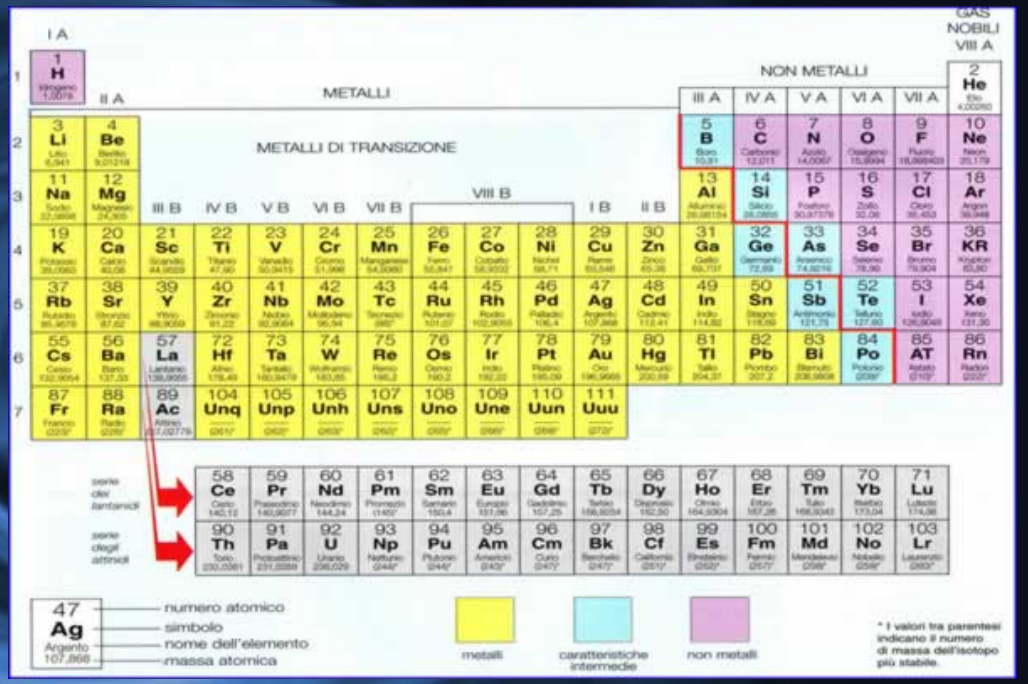


1-10μ = 1-10×10^{-6}m

Di cosa siamo fatti?



$2\text{-}3\times10^{-9}\text{m}=2\text{-}3\text{nm}$

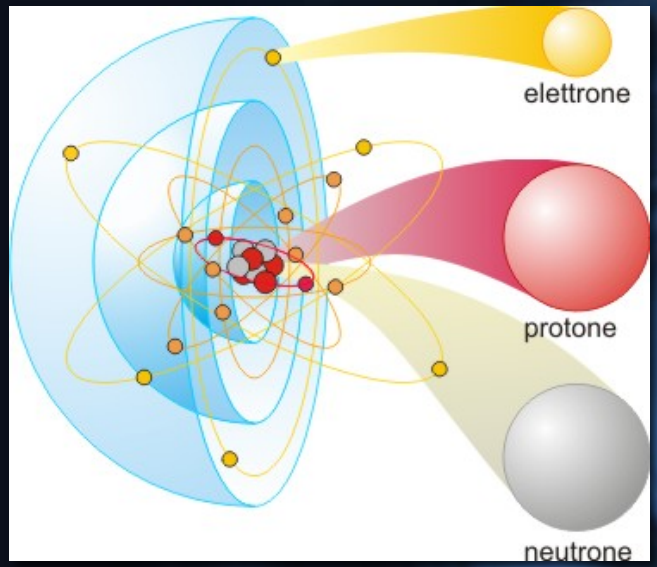


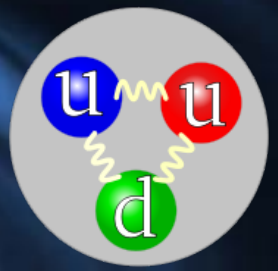
Di cosa siamo fatti?

1/2 MeV

Meccanica quantistica

1 GeV





10^{-15}m=1fm

1-10Å=1-10×10^{-10}m

elettrone: J.J. Thompson (1897)
nucleo: E. Rutherford (1911)
neutrone: J. Chadwick (1932)

"Radiografia" del protone: SLAC (1969)
M. Gell-Mann, K. Nishijima
Y. Ne' eman, G. Zweig
R. Feynman, J. Bjorken
J.I. Friedman, H.W. Kendall, R.E. Taylor

Il quadro concettuale

Teoria della Relatività (ristretta)

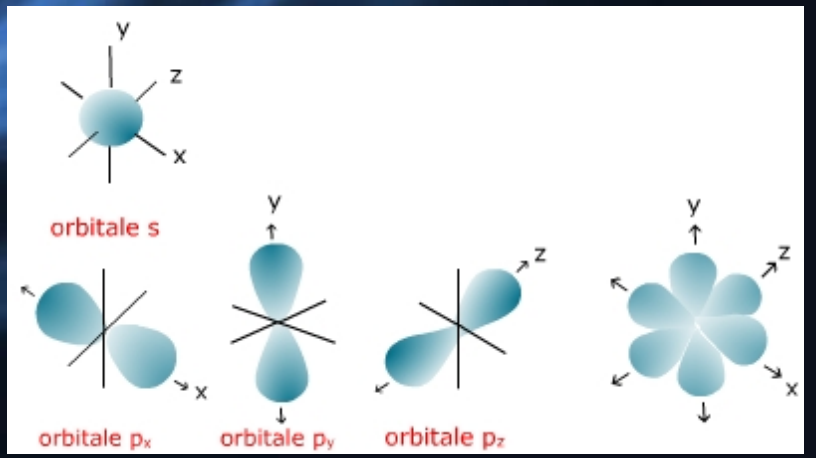
- Le eq. di Maxwell contengono *c* (velocità della luce nel vuoto)
- Sono covarianti per trasformazioni di Lorentz (TL)
- La meccanica è covariante per trasformazioni di Galileo (TG)
- TL → TG per velocità piccole rispetto a *c*
- Einstein: "corregge" meccanica in modo che sia covariante per TL

Conseguenze:

- *c* = velocità <u>limite</u>
- Relatività della simultaneità
- Dilatazione dei tempi
- Contrazione delle lunghezze
- $E=mc^2$

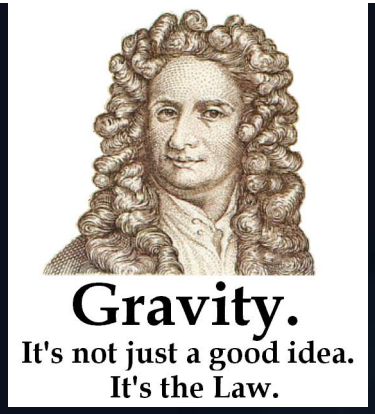
Meccanica quantistica

- Spettro di corpo nero, effetto fotoelettrico, effetto Compton, spettri atomici…: non è possibile spiegare esperimenti con fisica classica (meccanica ed elettromagnetismo)
- Ipotesi di De Broglie: $\lambda=h/p$
- Heisenberg: $\Delta x\, \Delta p \approx h$
- Equazione di Scrödinger: permette di determinare l'onda associata alle particelle



Cosa lega i mattoni fondamentali?
Le forze fondamentali

- Forza di gravità
- Forza elettromagnetica
- Forza nucleare forte
- Forza nucleare debole



I. Newton (1643-1727)

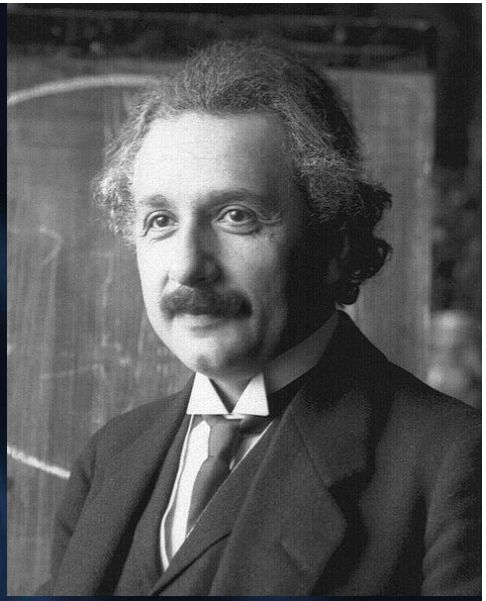
La forza di gravità

$$F = G\frac{m_1 m_2}{r^2}$$

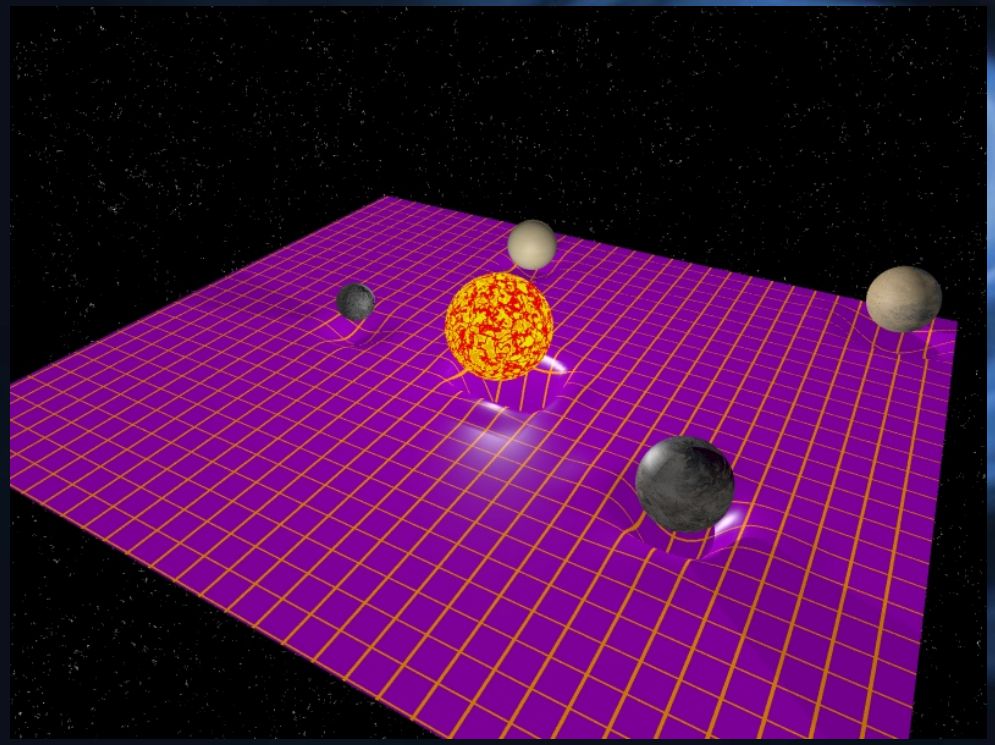
- Studiata da I. Newton
- Attrattiva, riguarda masse
- A lungo raggio d'azione
- Meccanica terrestre (peso) e celeste (orbite)

La forza di gravità

- Oggi descritta da Relatività Generale (A. Einstein)
- Gravità=deformazione spazio-tempo*



A. Einstein (1879-1955)



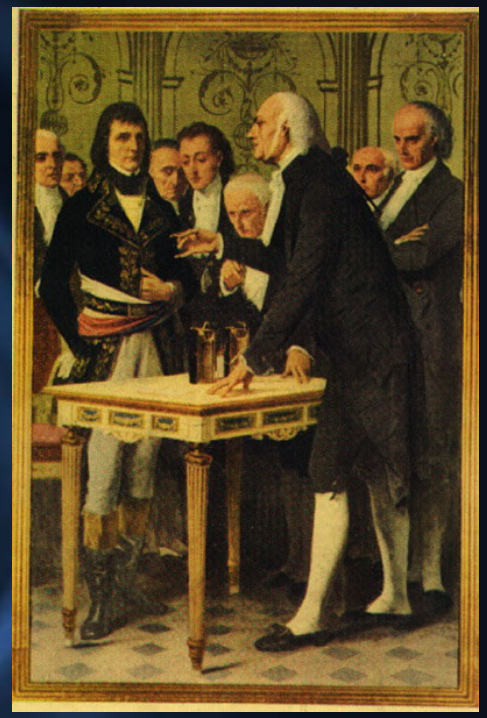
$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Relatività Generale (1916)

*Orologi in campo gravitazionale rallentano

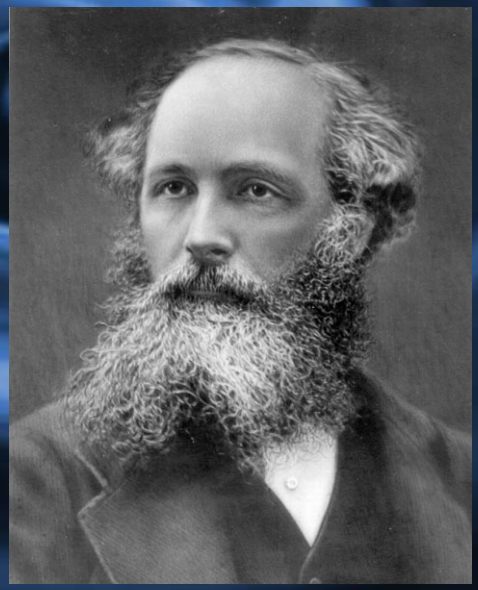
La forza elettromagnetica

- Molti padri (Coulomb, Faraday, Volta, Ampere, Biot, Savart, Herz… Maxwell)
- Riguarda cariche elettriche



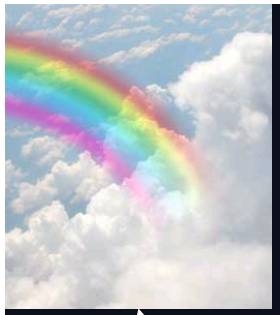
A. Volta (1745-1827)

- A lungo raggio d'azione
- È responsabile della gran parte dei fenomeni della vita di tutti i giorni
- $F_e/F_G \approx 10^{36}$ (protoni)

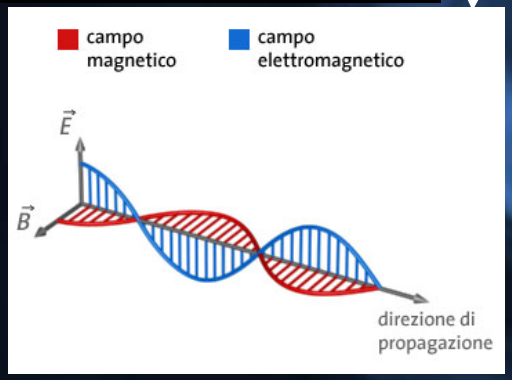


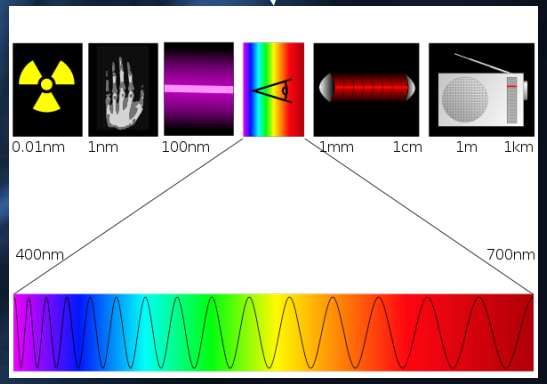
J.C. Maxwell (1831-1879)

La forza elettromagnetica



$$\begin{cases} \nabla \cdot \mathbf{E} = \dfrac{\rho}{\epsilon_0} \\ \nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t} \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \epsilon_0 \mu_0 \dfrac{\partial \mathbf{E}}{\partial t} \end{cases}$$

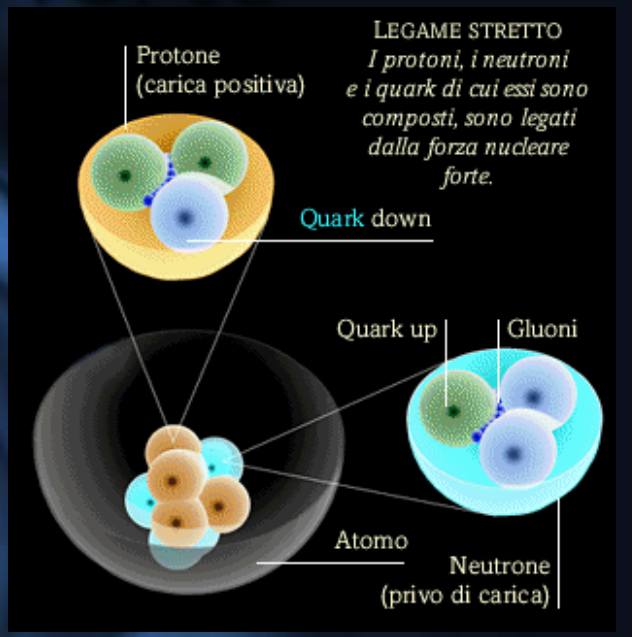


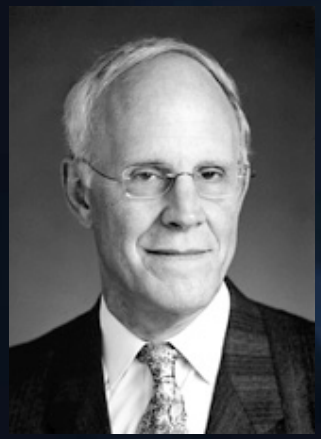


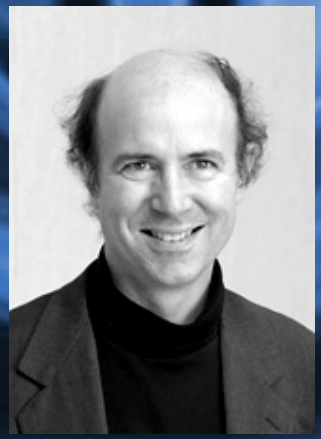
- Descritta da elettrodinamica quantistica (QED, fotoni)
- Esistono le antiparticelle (positrone)

La forza nucleare forte

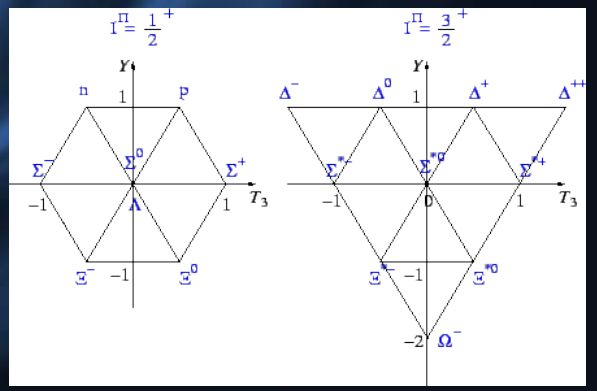
- Lega protoni e neutroni a formare i nuclei (residuale)
- Lega i quark a formare protone e neutrone (più in generale barioni e mesoni, detti adroni)
- Corto raggio d'azione ($\leq 10^{-15}$m=fm)
- Descritta da Cromodinamica Quantistica (QCD)
- quark e gluoni "confinati" all'interno degli adroni, dove sono liberi





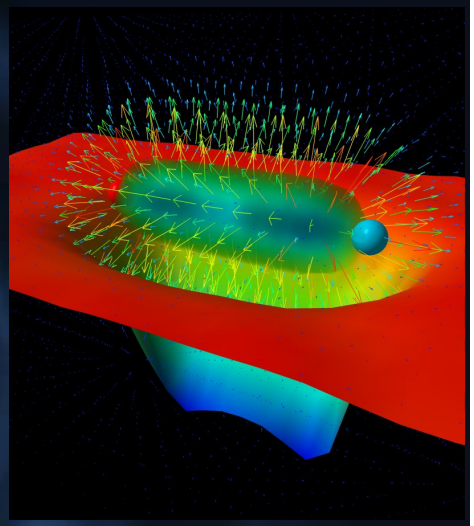


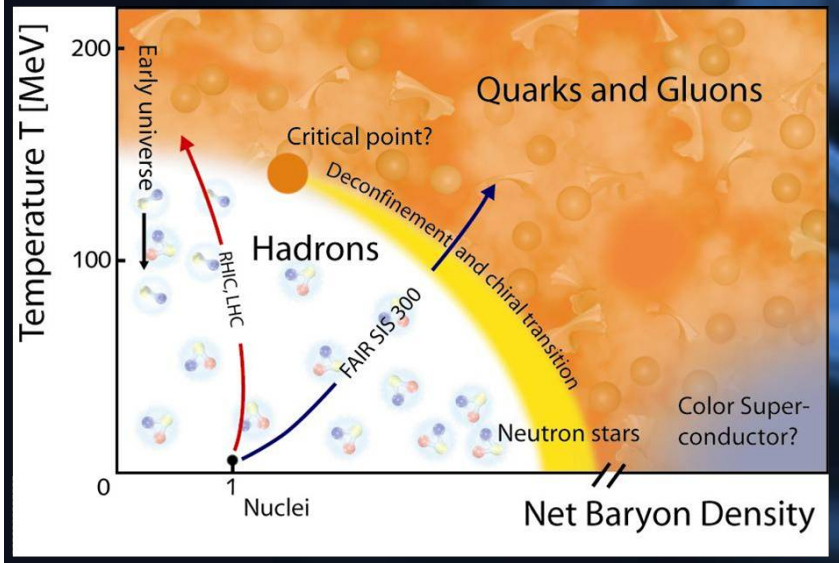
D.J. Gross, H.D. Politzer, F. Wilczek

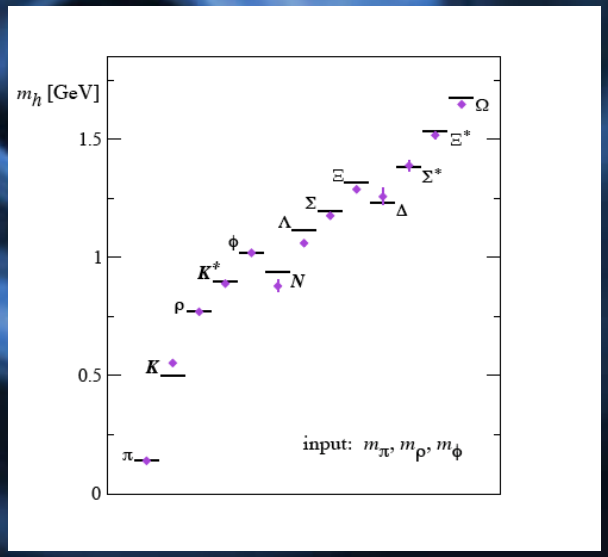


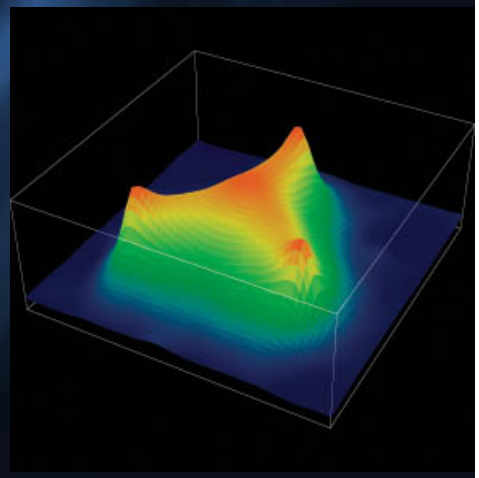
La forza nucleare forte

- Quantum Chromo Dynamics calcolabile “a mano” solo in particolari situazioni; in generale necessarie simulazioni numeriche
- Confinamento e “frammentazione”



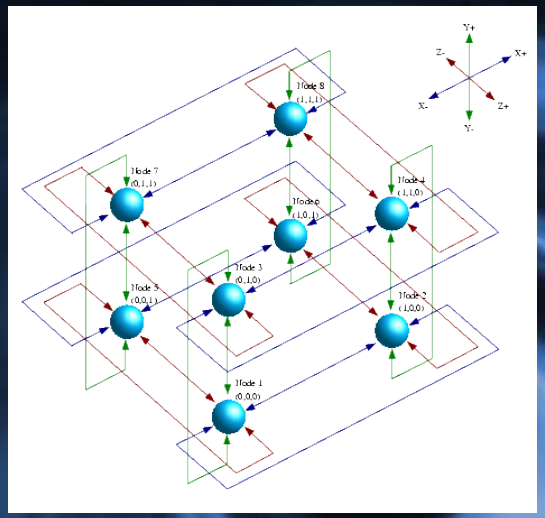




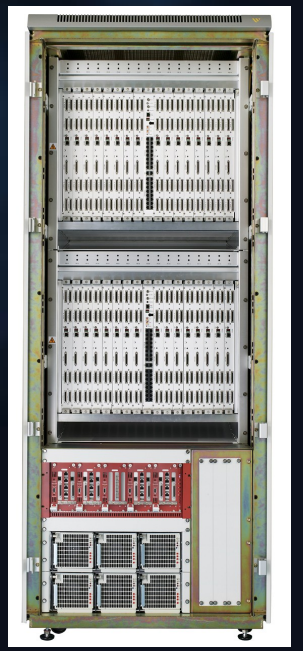


Supercomputing

ovvero il progetto APE



N. Cabibbo



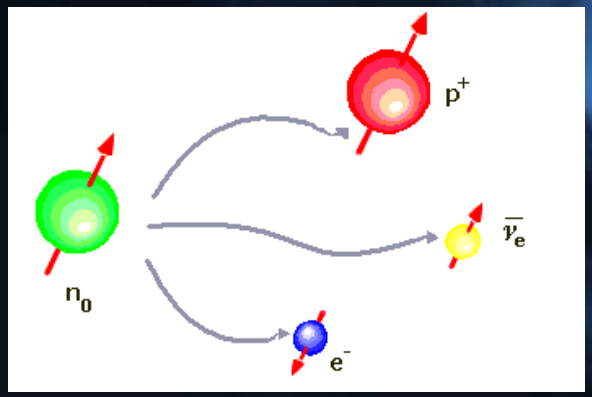
EXADRON

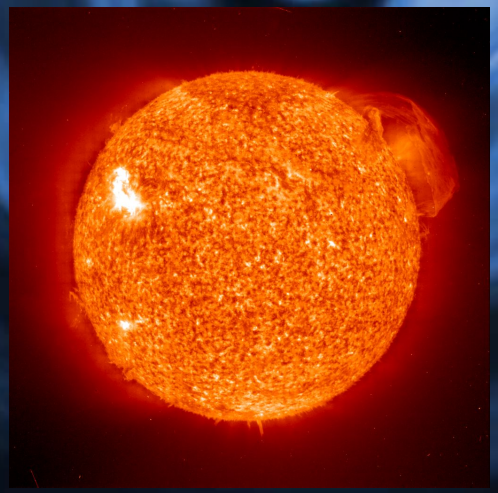
Progetto INFN, in collaborazione con
DESY Zeuthen e Université Paris-Sud 11

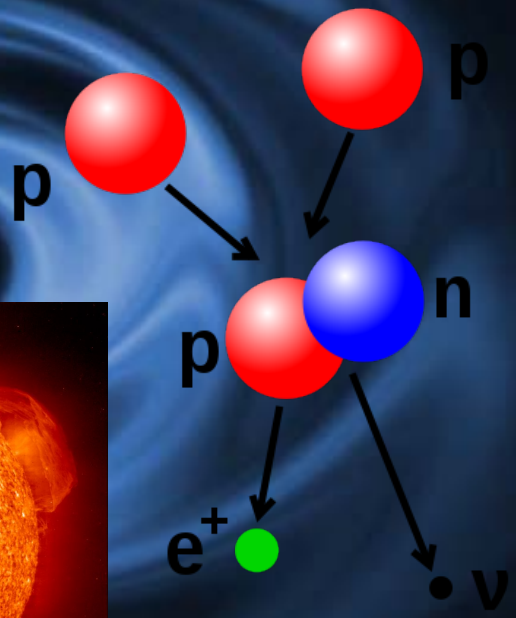
"Italiano uno dei supercomputer più potenti al mondo"
Newton, 24 gennaio 2005

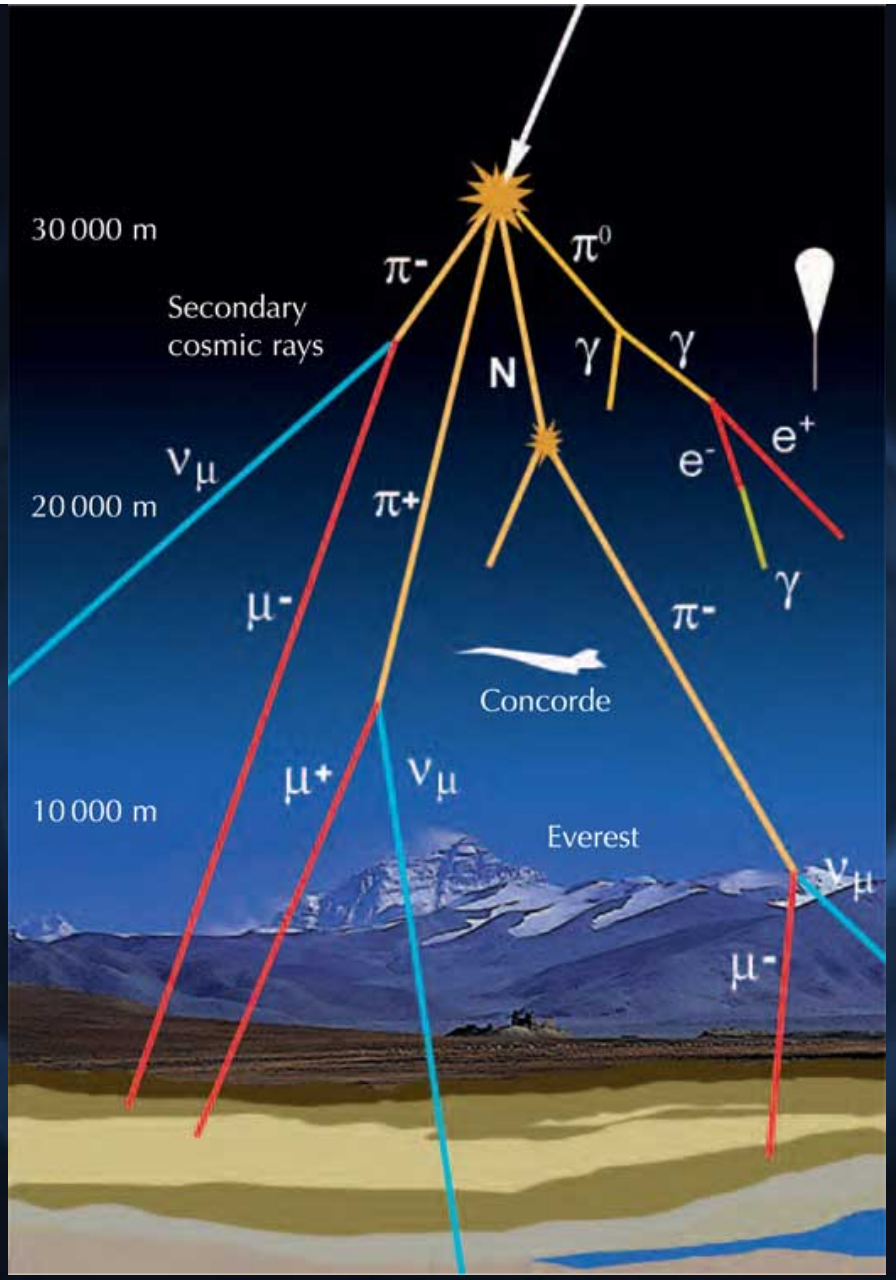
La forza nucleare debole

- Responsabile della “trasformazione” di particelle
- Corto raggio di azione ($\leq 10^{-15}$m=fm)
- Neutrini
- Combustione del sole (e delle stelle) per fusione nucleare
- Composizione cosmici



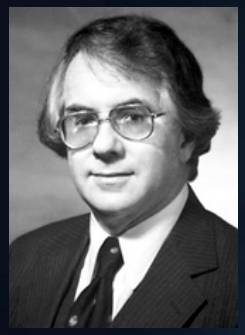
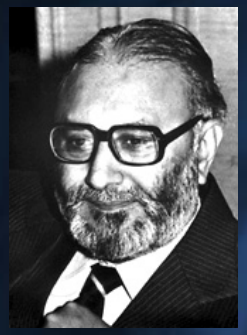
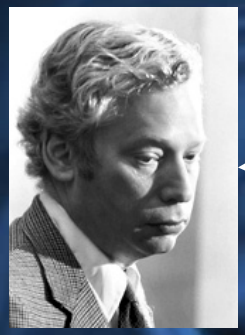





30 000 m
Secondary
cosmic rays
π-
π0
N
γ
γ
e+
e-
γ
νμ
20 000 m
π+
μ-
π-
Concorde
μ+
νμ
10 000 m
Everest
νμ
μ-

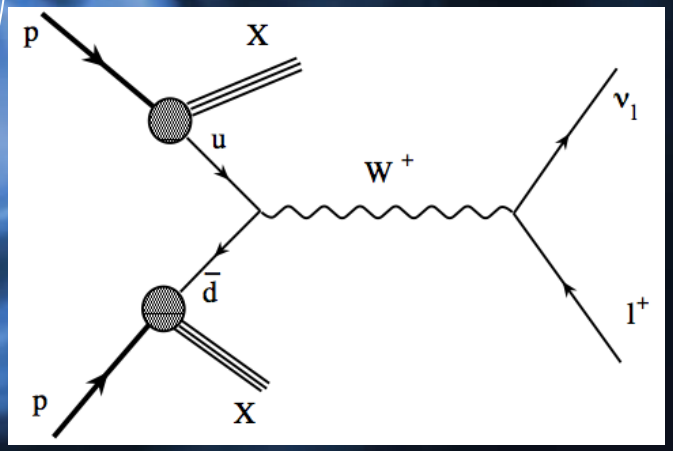
La forza nucleare debole

- Oggi unificata a elettrodinamica nella "Teoria dell'Unificazione Elettrodebole"

S.L. Glashow, A. Salam, S. Weinberg

Bosoni W e *Z* (≈100 GeV)

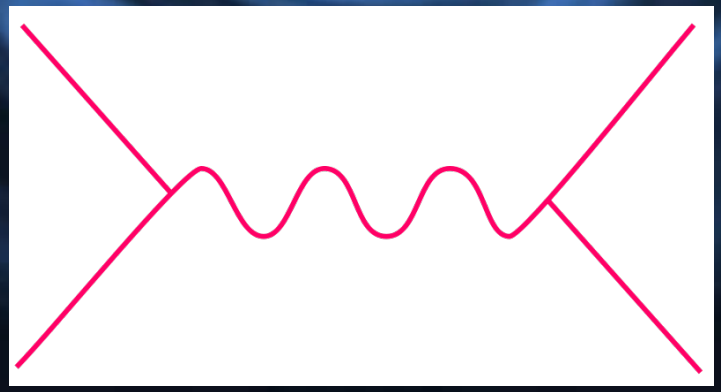


C. Rubbia, S. van der Meer

CERN, UA1&UA2, 1984

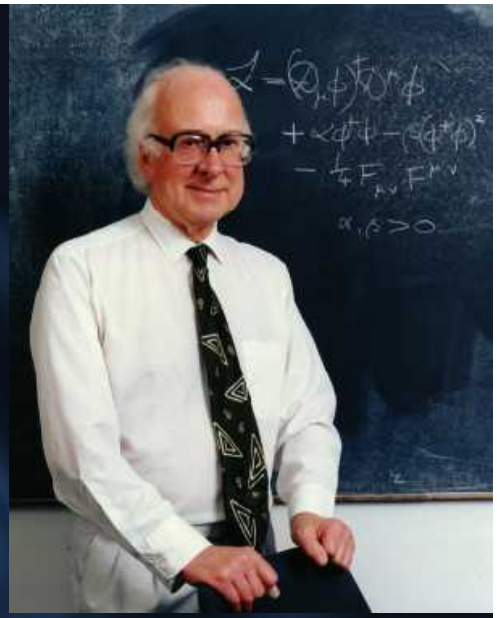
Campi di forza

- Descrizione fisico/matematica odierna: le forze sono dovute a *campi* che si propagano, generati da proprietà della materia dette *cariche*
- Campo gravitazionale (massa), elettromagnetico/ elettrodebole (carica elettrica/debole), forte (carica forte, colore)
- Campi *messaggeri* delle interazioni

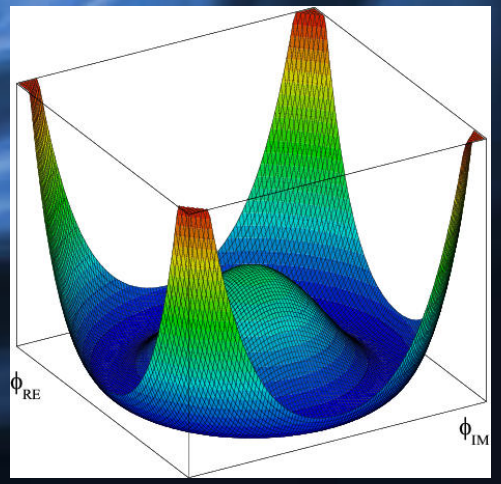


Il bosone di Higgs

- Necessario per generare le masse delle particelle elementari
- Vuoto carico: massa dovuta a "viscosità" (rottura spontanea della simmetria)



P. Higgs



Il Modello Standard (MS)

$$E = mc^2$$

Relatività

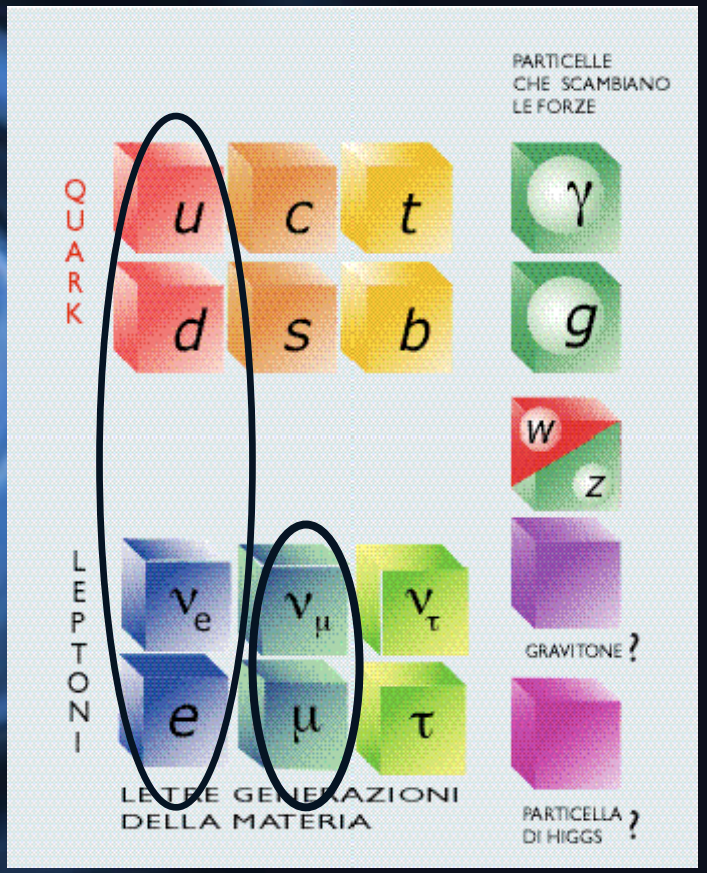
$$i\hbar\frac{\partial\psi(\boldsymbol{x},t)}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi(\boldsymbol{x},t) + V(\boldsymbol{x})\psi(\boldsymbol{x},t)$$

Meccanica quantistica

- Teoria quantistica relativistica di campo
- Descrive in modo unificato forze elettromagnetica, debole e forte (campi di Yang-Mills non abeliani)

La nostra "tavola periodica"

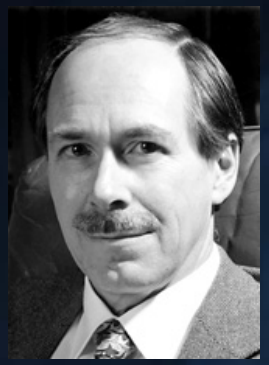
- Particelle "materia" e particelle "forza" (+ relative antiparticelle)
- Tre famiglie (?), il nostro mondo fatto della prima (e un po' di seconda)



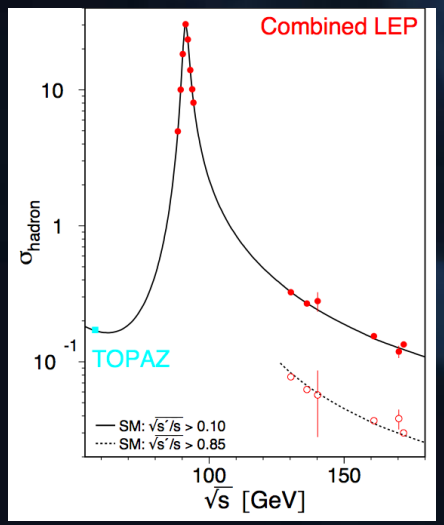
Dimensione particelle < 10^{-19}m

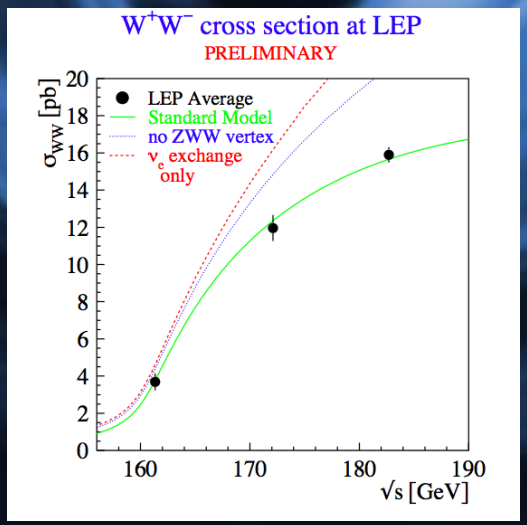
Test di precisione del MS

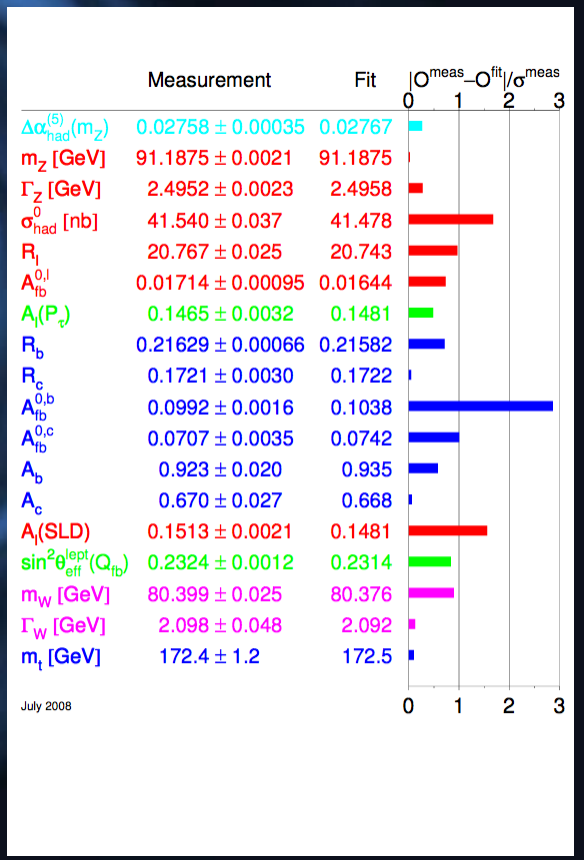
CERN, LEP, 1989-2000



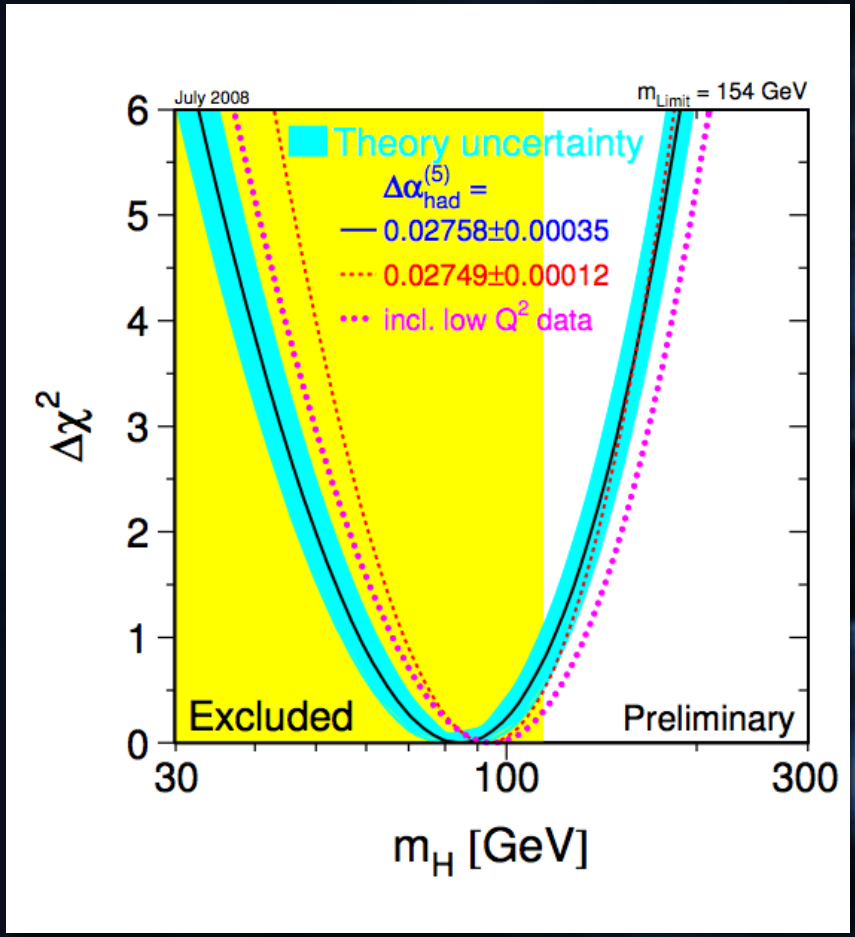
G. 't Hooft, M. Veltman

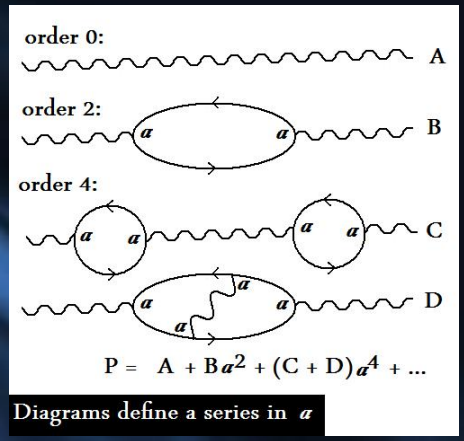


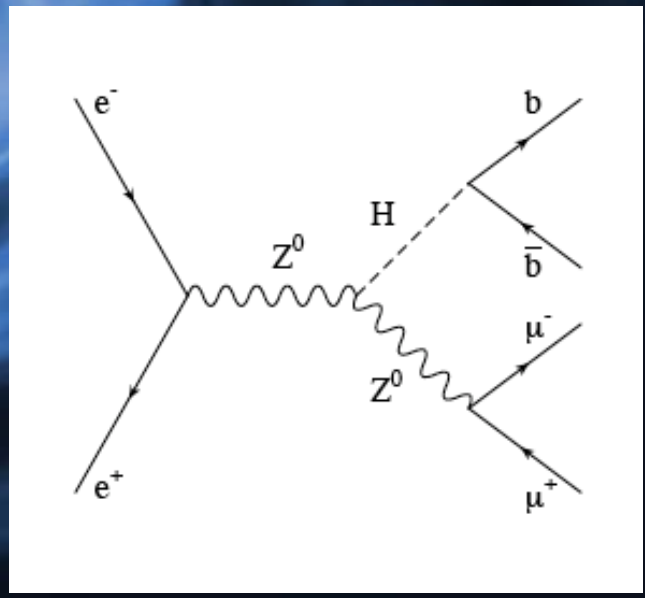




E Il bosone di Higgs?





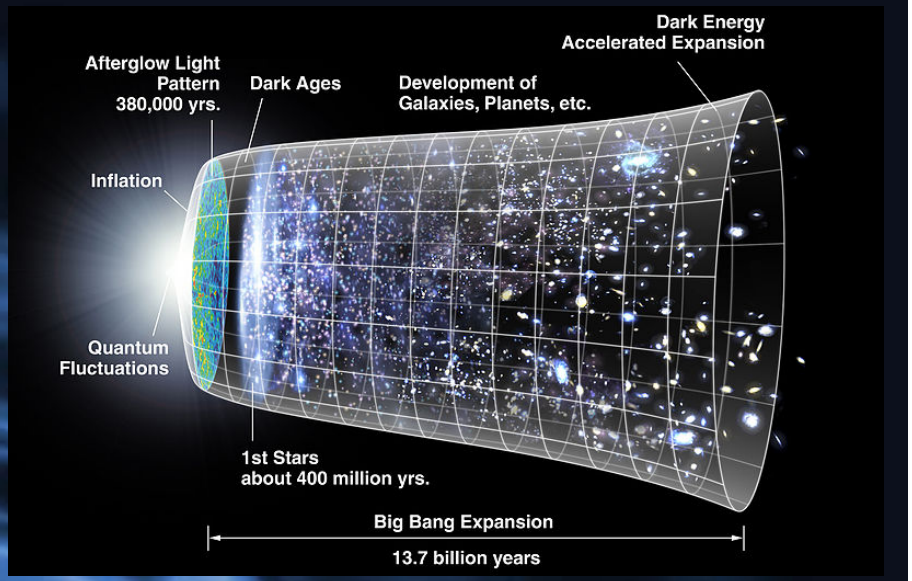


LEP Electroweak working group

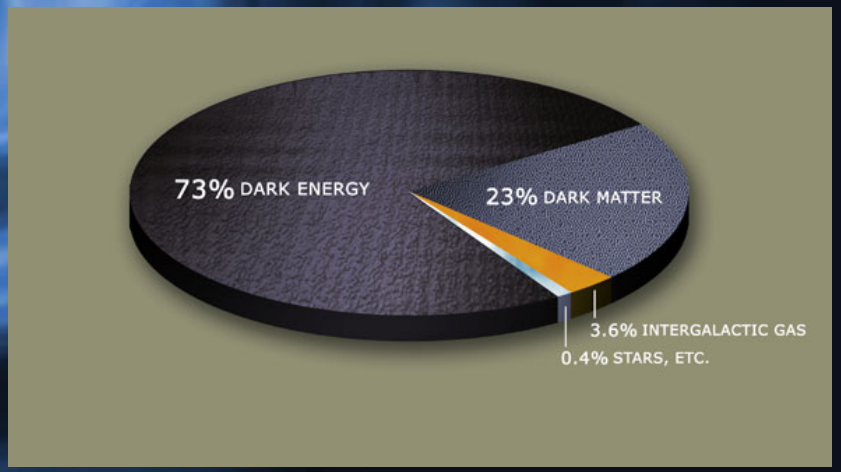
Limiti del Modello Standard e "nuova fisica"

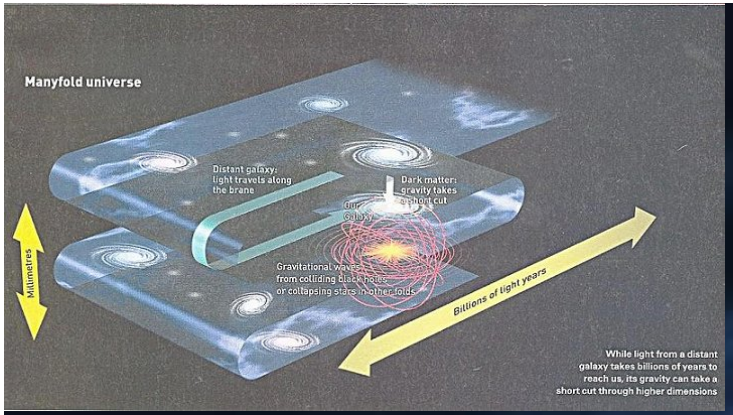
- Non include gravità
- Naturalezza/gerarchia (presenza di scalari elementari)
- Grande unificazione?
- Masse e oscillazioni di neutrini

- Non include gravità
- Naturalezza/gerarchia (presenza di scalari elementari)
- Grande unificazione?
- Masse e oscillazioni di neutrini

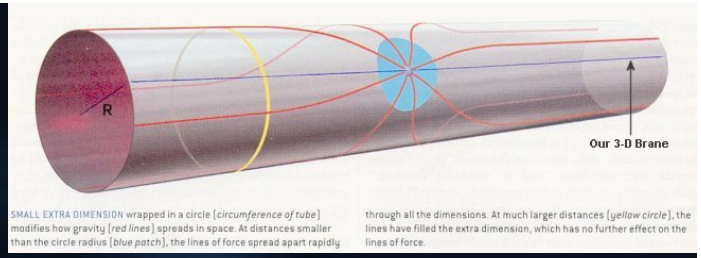


- Materia oscura(!)
- Energia oscura(!!)



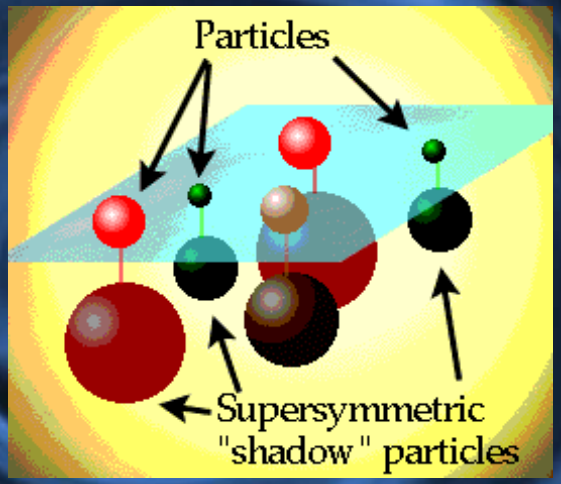


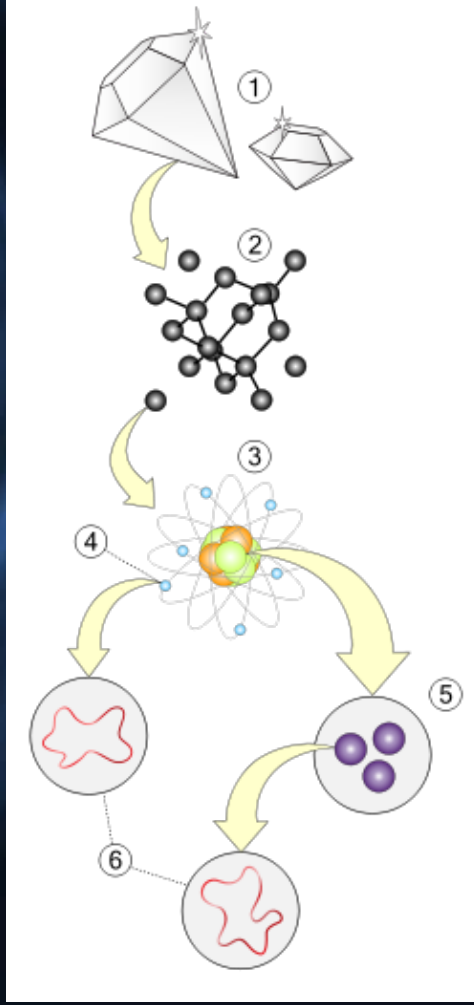
Sviluppi
(speculazioni)

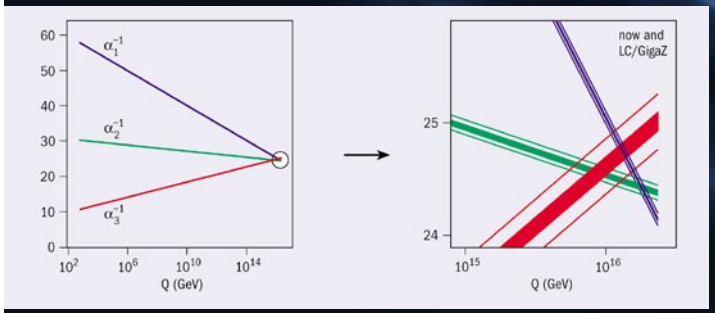


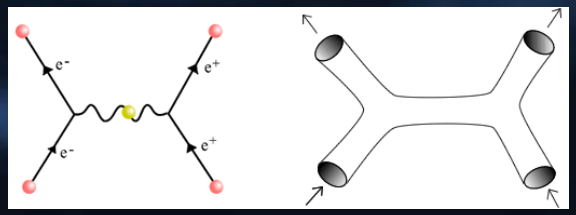
- Scalari compositi
- ***Supersimmetria***

- Teorie Grandunificate
- Dimensioni extra
- Teoria di stringa







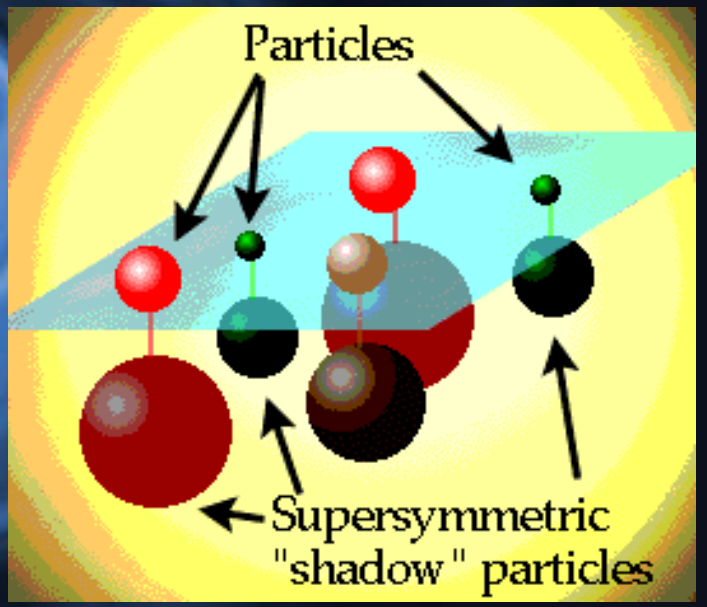


Scalari compositi: una nuova forza fondamentale

- Nuove particelle (tecniquark) e nuova forza forte
- Higgs=particella composta da tecniquark
- Massa plausibile: 1-10TeV
- Sfavorito da dati di precisione (LEP)

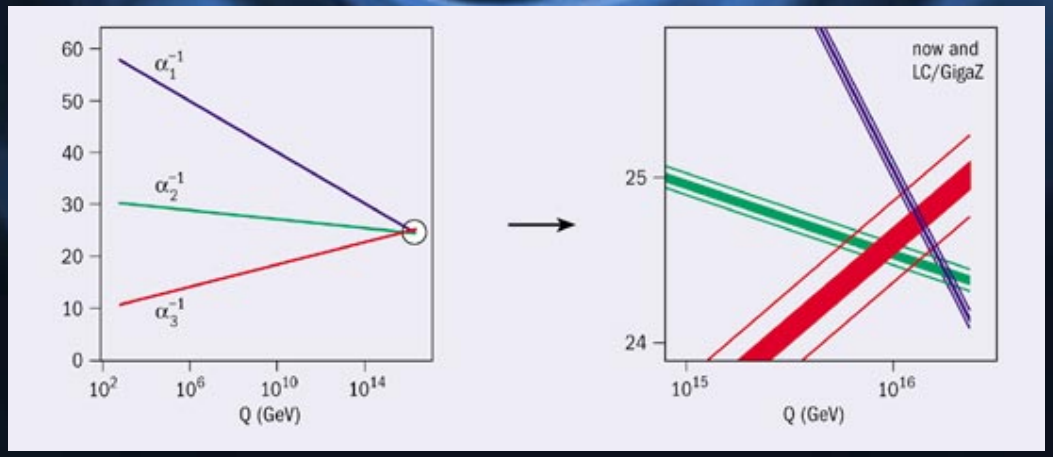
Supersimmetria: una simmetria che lega materia e forza

- Materia e forza manifestazioni diverse di un'unica "supermateria"
- Ogni particella avrebbe partner "supersimmetrico"
- Masse plausibili: 1-10TeV
- Esistono "neutralini" candidati ottimali per materia oscura (WIMP)



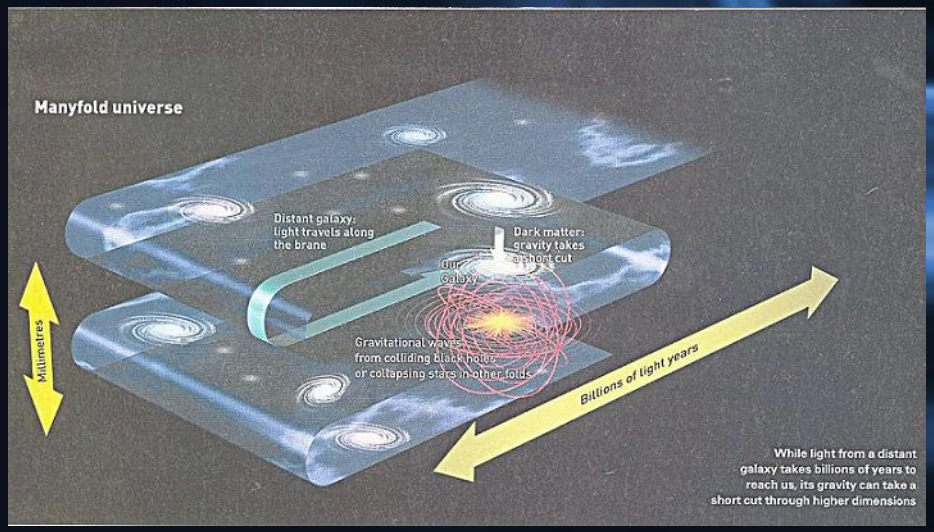
Teorie Grandunificate

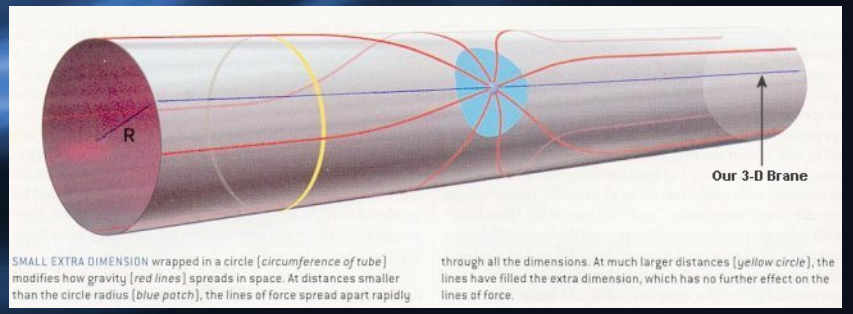
- Grandunificazione attesa a energie $\approx 10^{15}$-10^{16} GeV
- Offre scenario naturale per masse (piccole) dei neutrini e loro oscillazioni (gruppo SO(10))
- Decadimento del protone



Dimensioni extra: il mondo è più complesso di quanto appaia

- Perché gravità così debole?
- Dimensioni extra compatte
- Mondo membrana

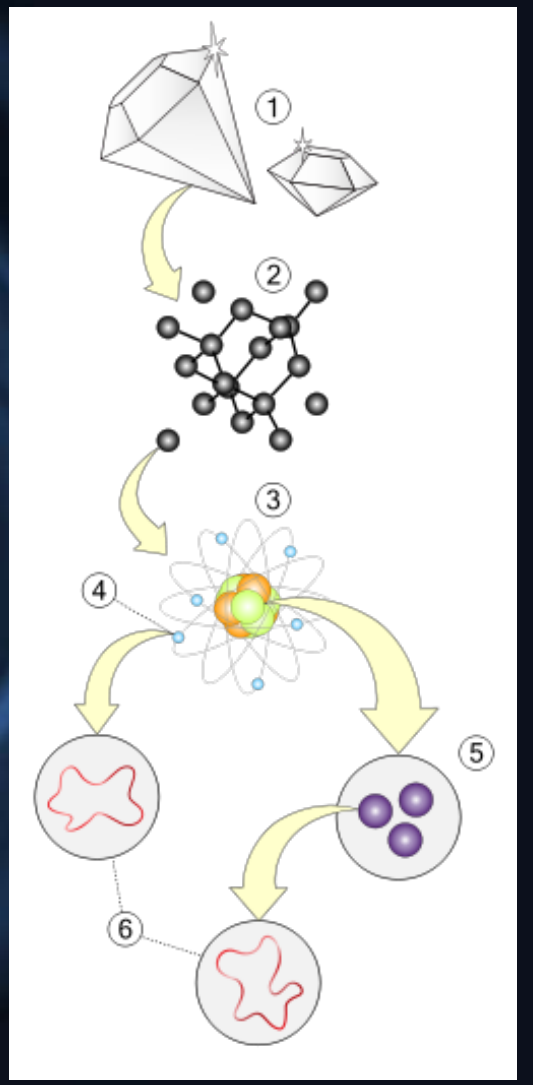


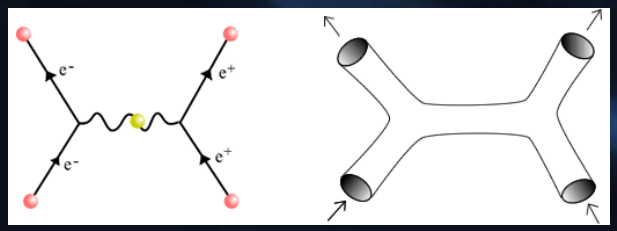


SMALL EXTRA DIMENSION wrapped in a circle (*circumference of tube*) modifies how gravity (*red lines*) spreads in space. At distances smaller than the circle radius (*blue patch*), the lines of force spread apart rapidly through all the dimensions. At much larger distances (*yellow circle*), the lines have filled the extra dimension, which has no further effect on the lines of force.

Teoria di stringa: gli elementi sono estesi

- Particelle elementari come vibrazioni di stringa; masse ⇔ "suoni armonici"
- Gravità inclusa in modo naturale, e quindi quantizzata (gravitone)
- Previste 11 dimensioni spazio-temporali (7 compatte?)
- Lunghezza naturale della stringa: lunghezza di Planck 1.6×10^{-35}m(!)
- Energia necessaria a rivelare sottostruttura così minuscola: energia di Planck 10^{19}GeV(!)





Domande inevase
per i prossimi acceleratori (LHC)

- Origine della massa (il bosone di Higgs)
- Esiste la supersimmetria?

  …O una nuova forza fondamentale? E la grandunificazione? Viviamo su una membrana 4-dim? Tracce di stringhe?…
- La materia oscura può essere prodotta in laboratorio? (neutralini)
- Quali sono le proprietà del plasma di quark e gluoni?

Domande inevase
per i prossimi acceleratori (LHC)

- Ma forse: c'è qualcosa di

completamente inatteso?

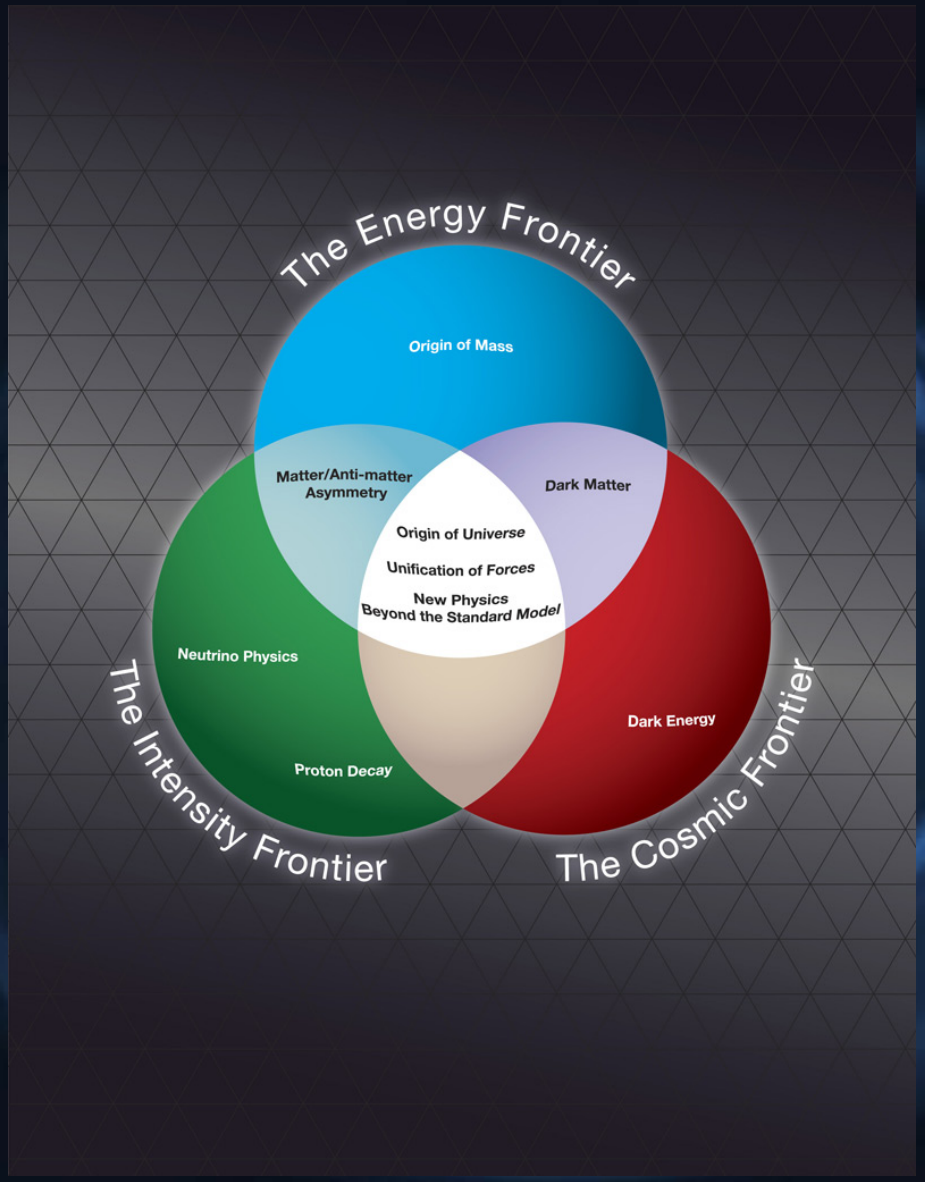
Galileo Galilei (1564-1642)

“Il gran libro della natura è scritto in caratteri matematici”

“Sensate esperienze”

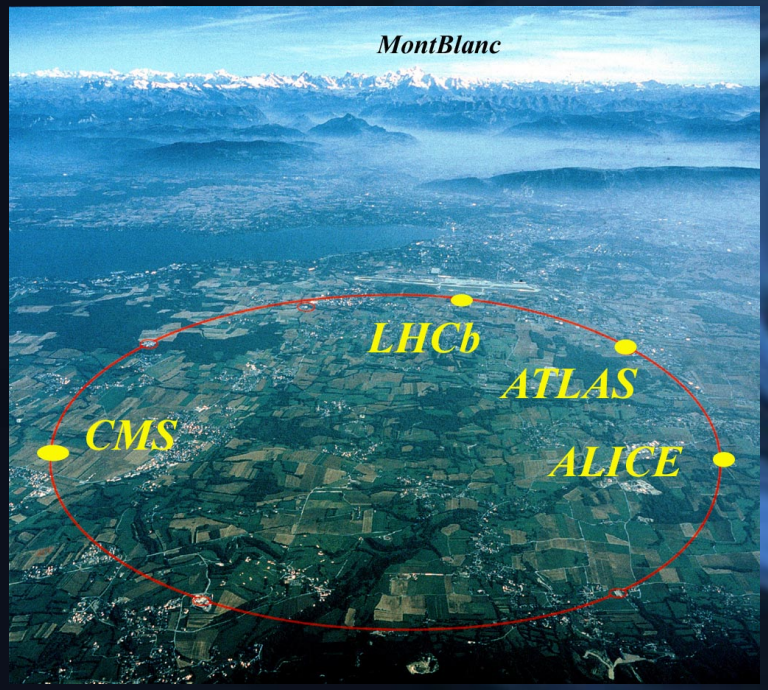
↕

“Certe dimostrazioni”


The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Dark Energy
Proton Decay
The Intensity Frontier
The Cosmic Frontier

Il CERN

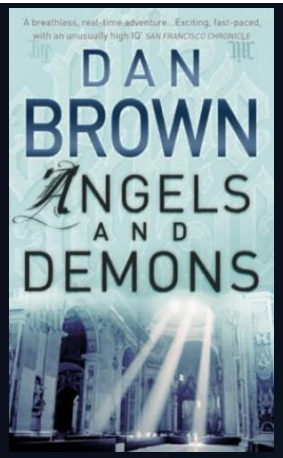
Centro Europeo Ricerca Nucleare



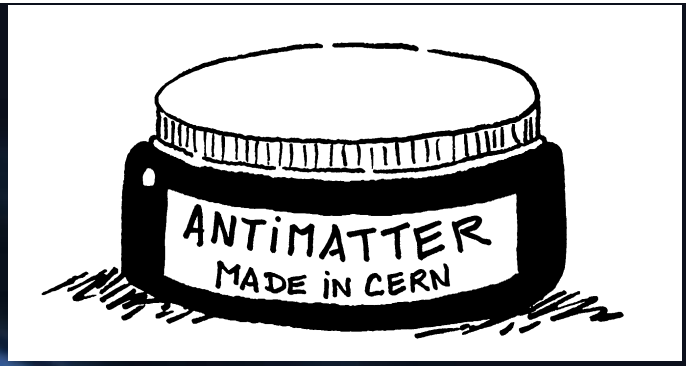
- Uno dei maggiori centri mondiali di ricerca scientifica
- Ricerca sui costituenti fondamentali della materia e sulle loro interazioni
- 20 stati membri, aperto a scienziati di tutto il mondo
- Correnti deboli neutre; W e Z; antimateria; oscillazioni di neutrini
- Numerosi premi Nobel

Member States Contributions to the CERN budget - 2009

	%	MCHF (rounded figures)
Austria	2.24%	24.661
Belgium	2.77%	30.446
Bulgaria	0.22%	2.406
Czech Republic	1.15%	12.690
Denmark	1.76%	19.390
Finland	1.55%	16.992
France	15.34%	168.725
Germany	19.88%	218.583
Greece	1.96%	20.473
Hungary	0.78%	8.572
Italy	11.51%	126.544
Netherlands	4.79%	52.715
Norway	2.53%	27.821
Poland	2.85%	31.376
Portugal	1.14%	12.485
Slovak Republic	0.54%	5.914
Spain	8.52%	93.726
Sweden	2.76%	30.376
Switzerland	3.01%	33.086
United Kingdom	14.70%	161.587
	100.00%	1'098.490



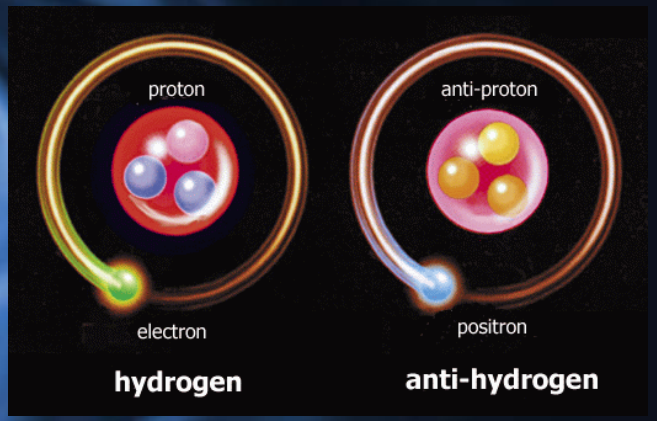
Antimateria

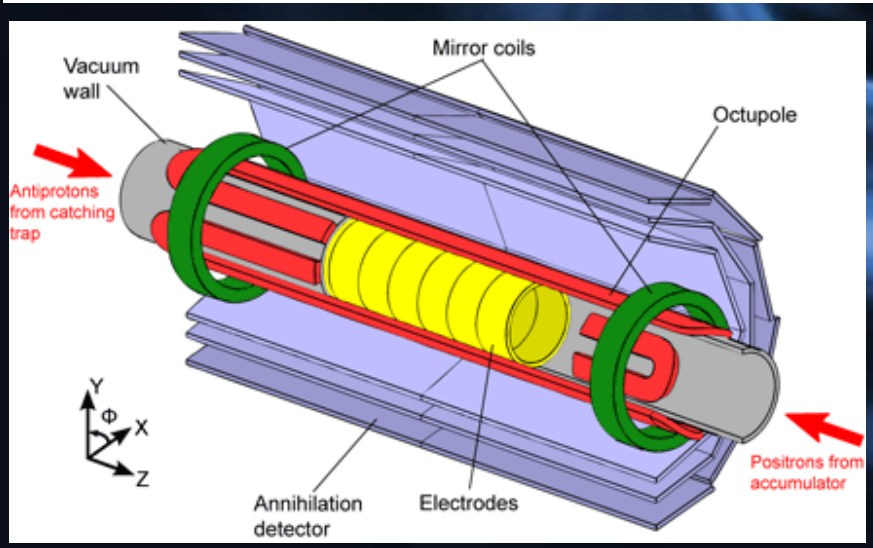


PRESSE
Organisation Européenne pour la Recherche Nucléaire
European Organization for Nuclear Research
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics
Europäisches Laboratorium für Teilchenphysik
Laboratorio europeo per la fisica delle particelle

First atoms of antimatter produced at CERN

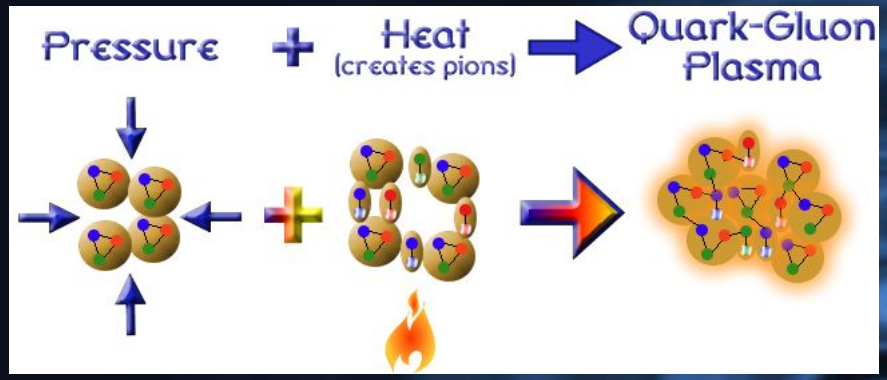
In September 1995, Prof. Walter Oelert and an international team from Jülich IKP-KFA, Erlangen-Nuernberg University, GSI Darmstadt and Genoa University succeeded for the first time in synthesising atoms of antimatter from their constituent antiparticles. Nine of these atoms were produced in collisions between antiprotons and xenon atoms over a period of three weeks. Each one remained in existence for about forty billionths of a second, travelled at nearly the speed of light over a path of ten metres and then annihilated with ordinary matter. The annihilation produced the signal which showed that the anti-atoms had been created.

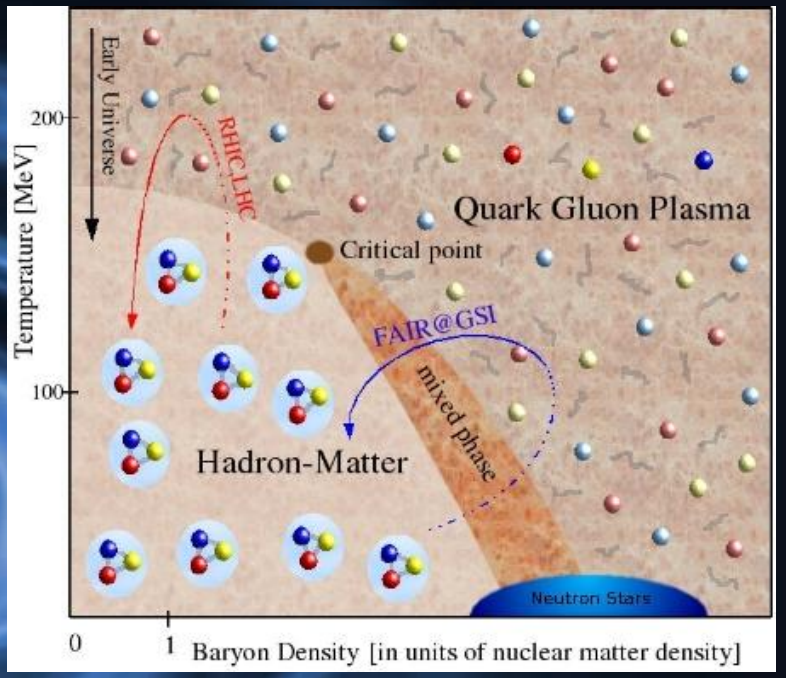




- Esperimento ALPHA (CERN), 2011
- ≈300 atomi di anti-idrogeno
- Oltre 16 minuti
- Studio delle proprietà dell'antimateria

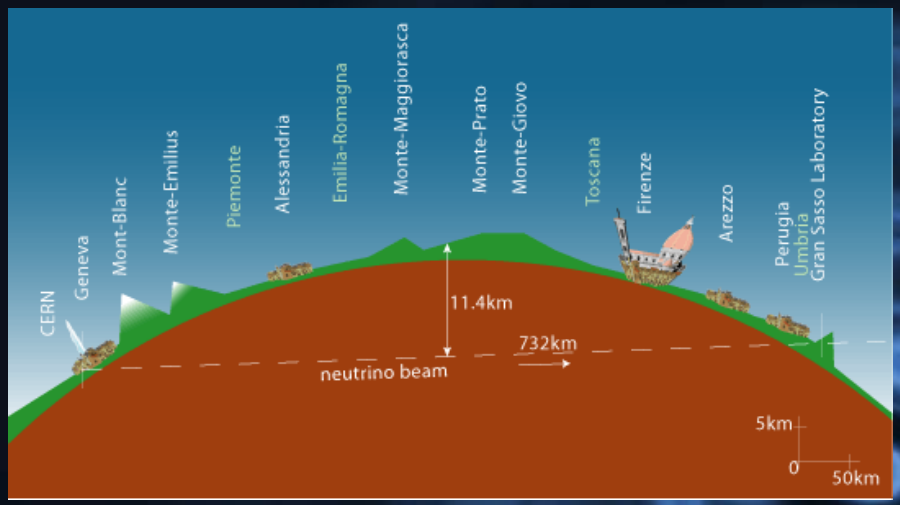
Quark-gluon plasma





- Nuovo stato della materia
- 10 μs dopo il Big Bang
- Fascio ad alta energia di ioni piombo (33 TeV) su targhetta
- Temperatura 100000 volte il centro del sole (dove $T \approx 16 \times 10^6$ K)
- Densità ≈ 20 volte quella della materia nucleare

Neutrini superluminali?



- Tre tipi di neutrini: ν_e, ν_μ e ν_τ
- I neutrini "oscillano" (fenomeno quanto-meccanico), cioè si trasformano l'uno nell'altro (masse)
- Al Gran Sasso OPERA ha osservato l'oscillazione $\nu_\mu \rightarrow \nu_\tau$
- Sottoprodotto: misura indiretta della velocità

OPERA experiment reports anomaly in flight time of neutrinos from CERN to Gran Sasso

PR19.11
23.09.2011

Geneva, 23 September 2011. The OPERA[1] experiment, which observes a neutrino beam from CERN[2] 730 km away at Italy's INFN Gran Sasso Laboratory, will present new results in a seminar at CERN this afternoon at 16:00 CEST. The seminar will be webcast at http://webcast.cern.ch. Journalists wishing to ask questions may do so via twitter using the hash tag #nuquestions, or via the usual CERN press office channels.

The OPERA result is based on the observation of over 15000 neutrino events measured at Gran Sasso, and appears to indicate that the neutrinos travel at a velocity 20 parts per million above the speed of light, nature's cosmic speed limit. Given the potential far-reaching consequences of such a result, independent measurements are needed before the effect can either be refuted or firmly established. This is why the OPERA collaboration has decided to open the result to broader scrutiny. The collaboration's result is available on the preprint server arxiv.org: http://arxiv.org/abs/1109.4897.

UPDATE 23 February 2012

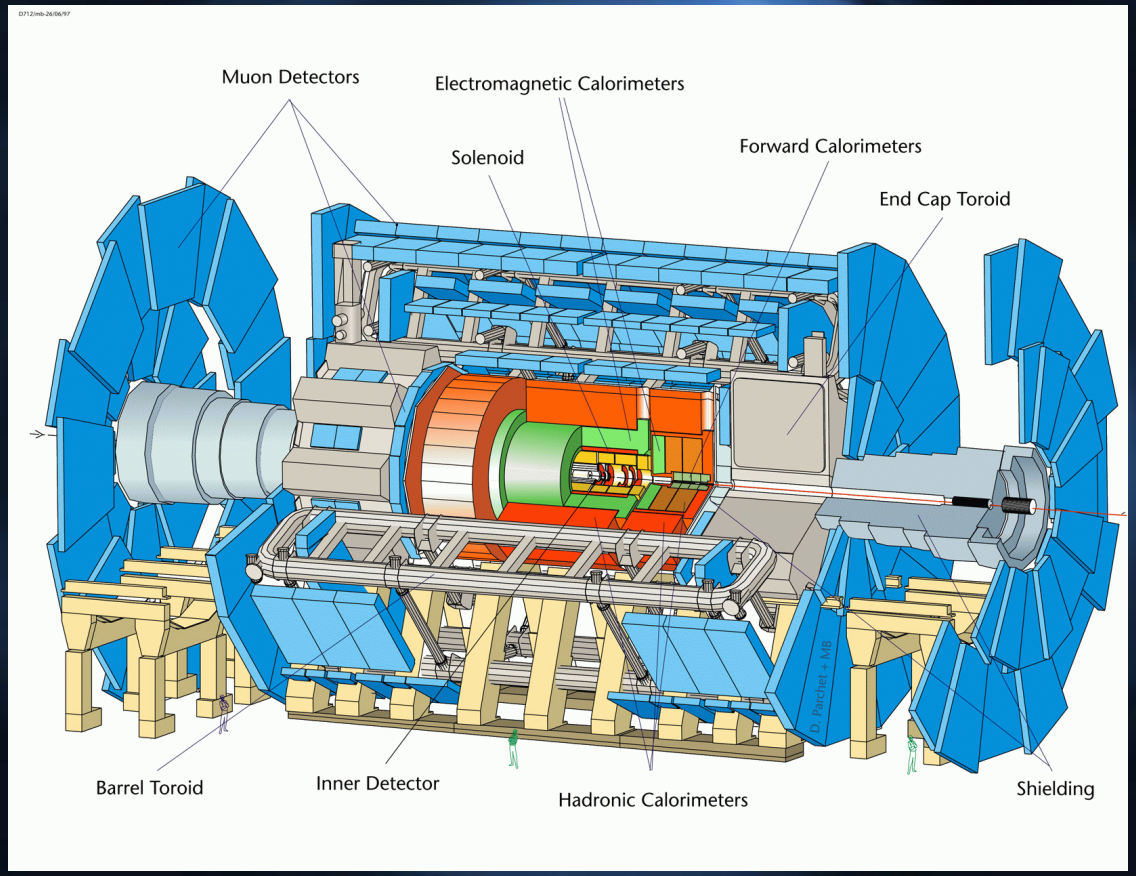
The OPERA collaboration has informed its funding agencies and host laboratories that it has identified two possible effects that could have an influence on its neutrino timing measurement. These both require further tests with a short pulsed beam. If confirmed, one would increase the size of the measured effect, the other would diminish it. The first possible effect concerns an oscillator used to provide the time stamps for GPS synchronizations. It could have led to an overestimate of the neutrino's time of flight. The second concerns the optical fibre connector that brings the external GPS signal to the OPERA master clock, which may not have been functioning correctly when the measurements were taken. If this is the case, it could have led to an underestimate of the time of flight of the neutrinos. The potential extent of these two effects is being studied by the OPERA collaboration. New measurements with short pulsed beams are scheduled for May.

L'acceleratore LHC

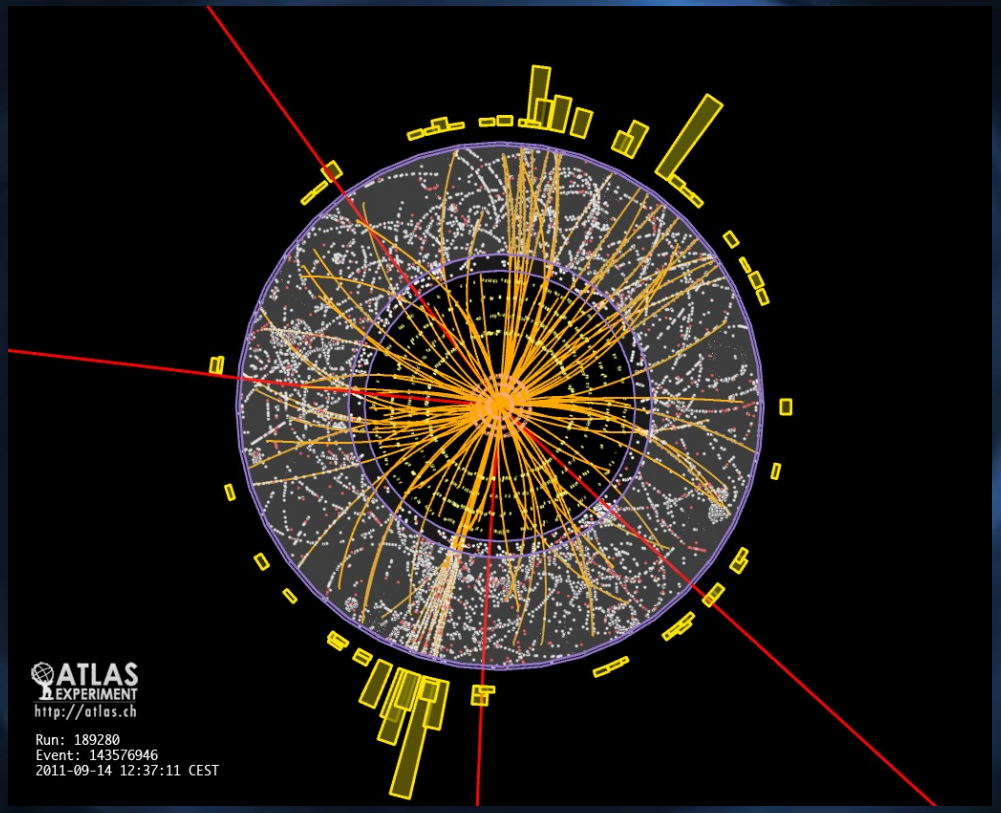
(Large Hadron Collider)
Impresa senza precedenti!

- 10^9 eventi al secondo
- Energia 7x Tevatron at FNAL: 14 TeV
- 3000 km di cavi (ATLAS)
- 1 TB/s dati registrati
- Temperatura 1.9 K^o (il sistema criogenico più grande del mondo)
- Circa 5000 fisici coinvolti
- 6 esperimenti: ATLAS, CMS, ALICE, LHCb, TOTEM, LHCf

L’esperimento ATLAS



Eventi tipici in ATLAS



ATLAS Experiment © 2012 CERN

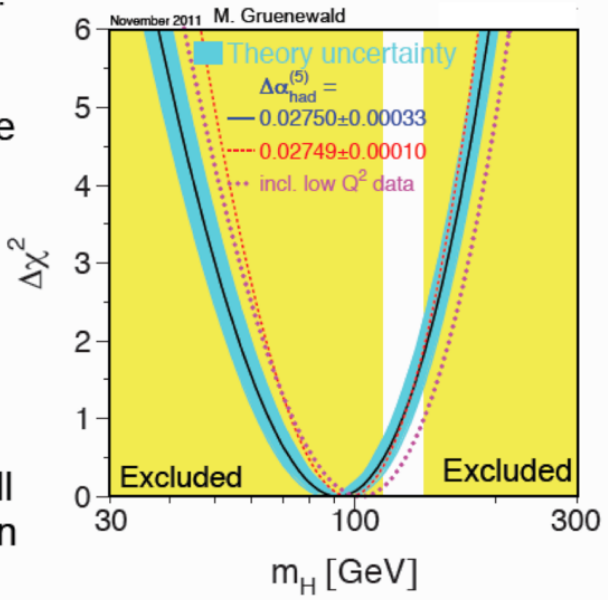
La ricerca del bosone di Higgs

Little room left for the SM Higgs !
$114 < m_H < 141$ GeV @ 95% CL

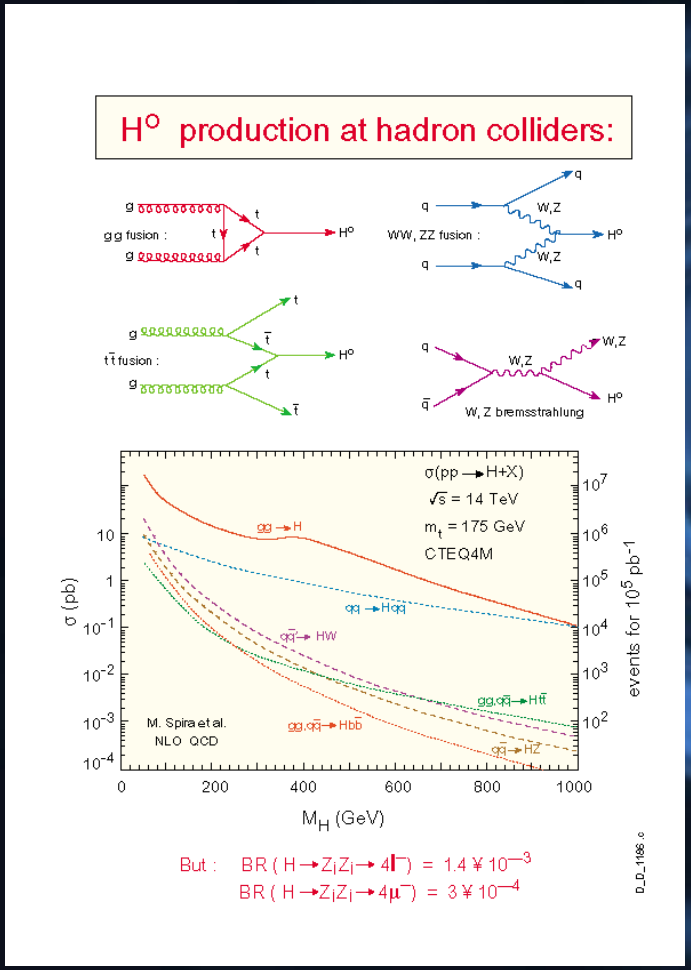
LHC experiments will analyze the x3 data already collected before 2012 Winter Conferences

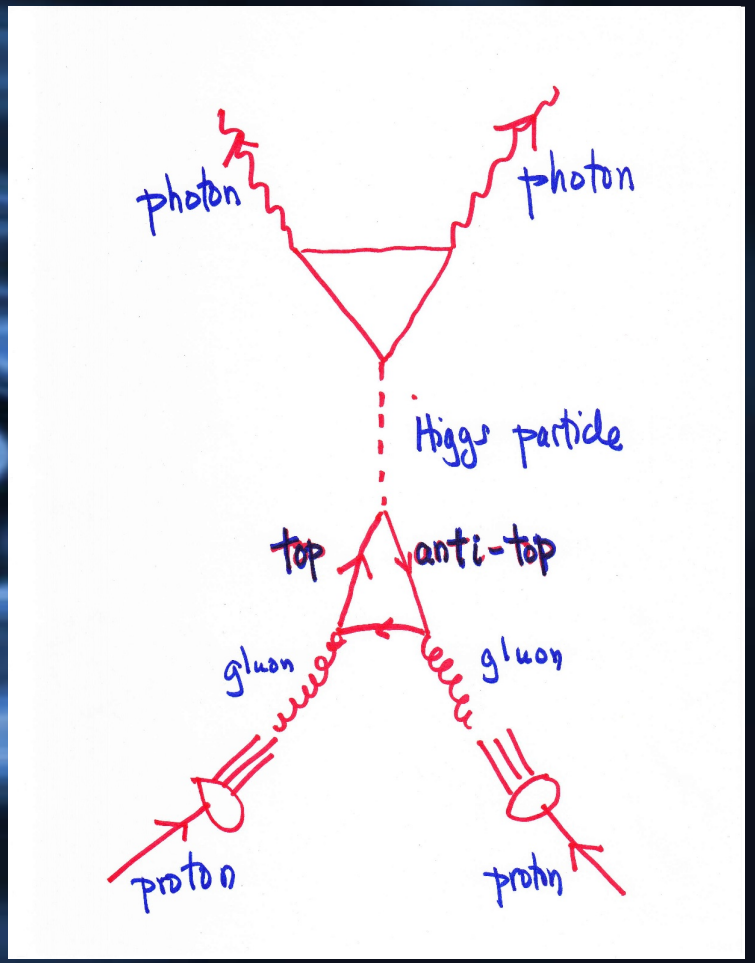
Tevatron will provide the final results on 10 fb^{-1} by the 2012 Summer Conferences

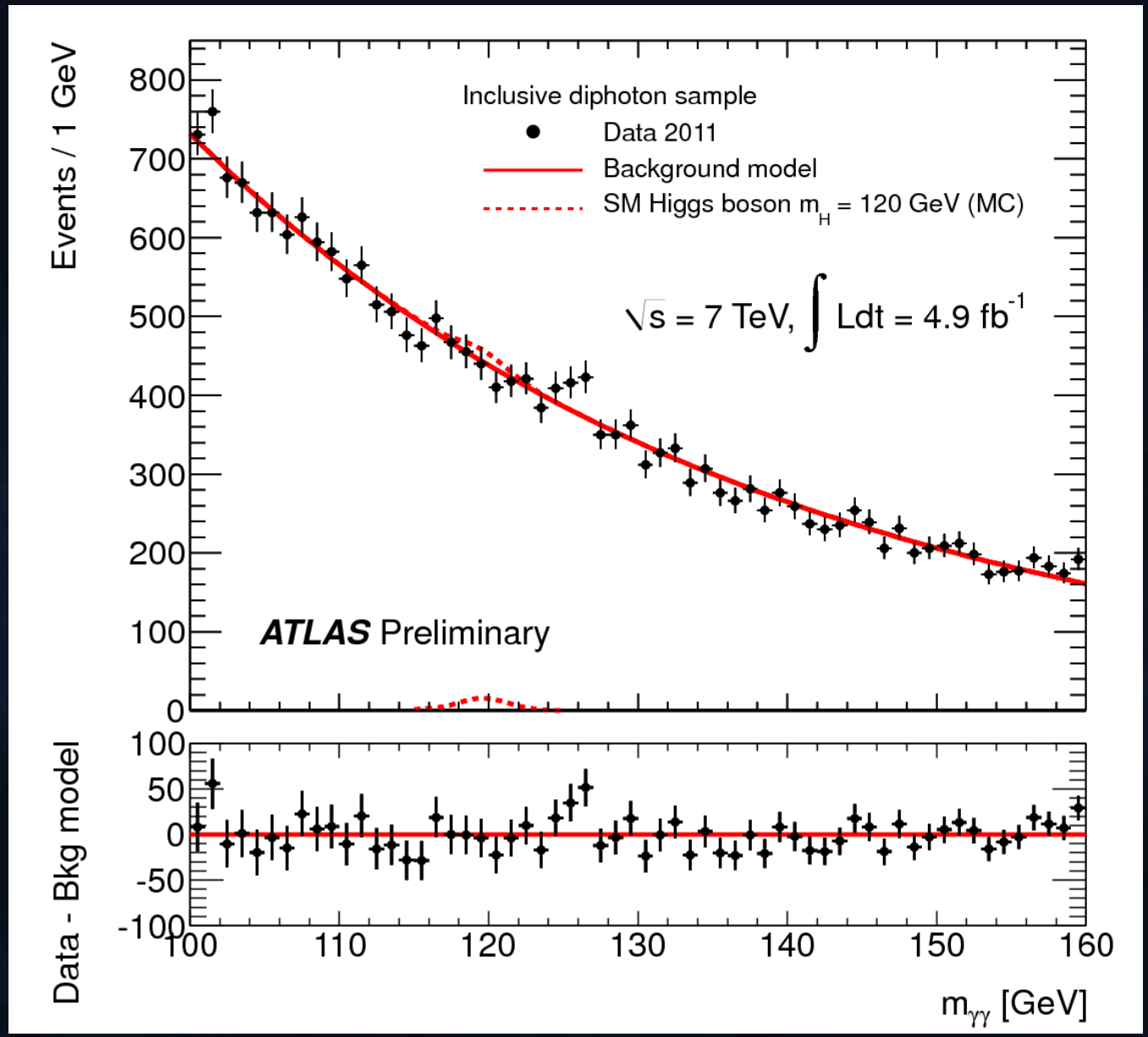
On the same time scale there will be a combination LHC + Tevatron



La ricerca del bosone di Higgs






Inclusive diphoton sample
Data 2011
Background model
SM Higgs boson m_H = 120 GeV (MC)
√s = 7 TeV, ∫ Ldt = 4.9 fb^-1
ATLAS Preliminary
Events / 1 GeV
Data - Bkg model
m_γγ [GeV]

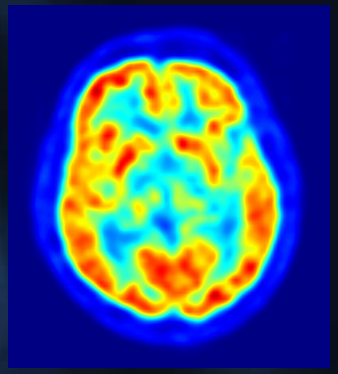
Applicazioni

- M.: bello il suo laboratorio; ma… a cosa serve tutto questo?
- F.: non lo so; ma sono certo che il suo successore tra cinquant'anni su tutto questo imporrà delle tasse…

Biomedicale

Positron Emission Tomography (PET)

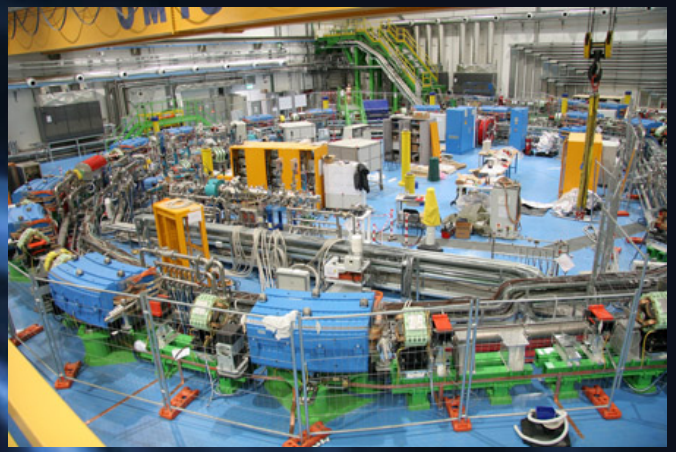
- Produzione di radionuclidi a breve emivita (ciclotrone)
- Somministrazione (p.e. iniezione) zuccheri “drogati”
- Rilevazione di γγ da annichilazione e^+e^-
- Ricostruzione immagine

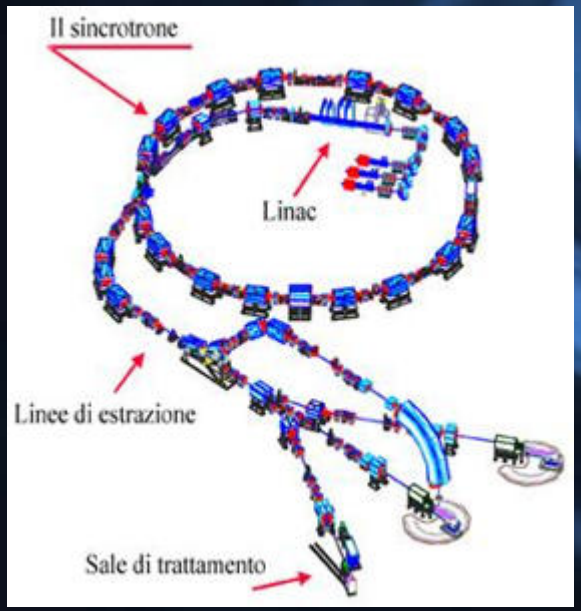


Betatronoterapia (radioterapia)

- Elettroni accelerati in betatrone
- Produzione di raggi X o γ penetranti
- Cura di tumori profondi

CNAO: Centro Nazionale Adroterapia Oncologica



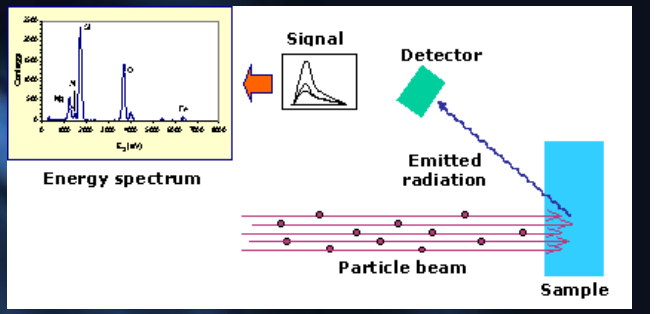


- Primo Centro in Italia, Pavia (quarto al mondo dopo USA, D, J)
- Fondazione CNAO, U. Amaldi
- Cura di tumori localizzati mediante fasci di protoni e ioni carbonio
- Pazienti volontari da 10.2011

Beni culturali

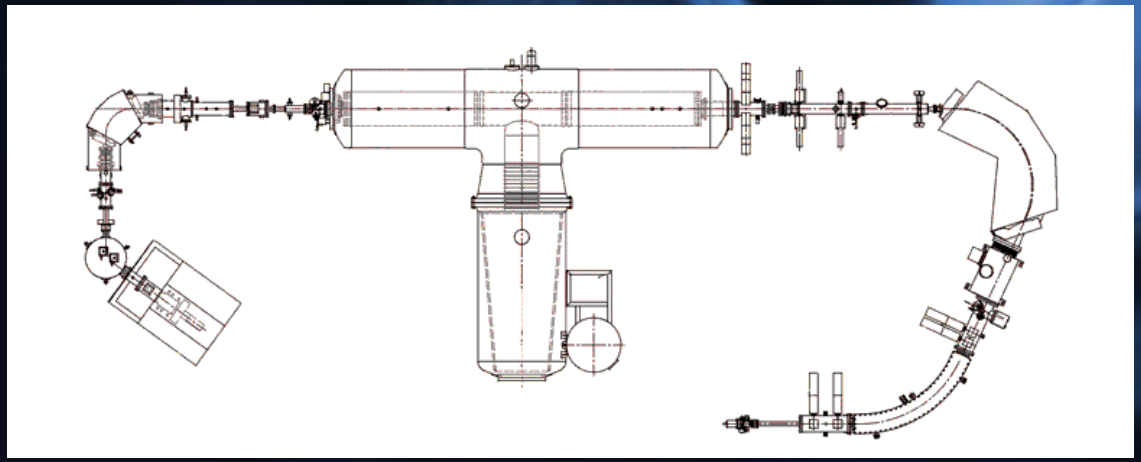
Ion Beam Analysis (IBA)

- Per I beni culturali (analisi non invasive)
- Per l'ambiente (ng/m^3)

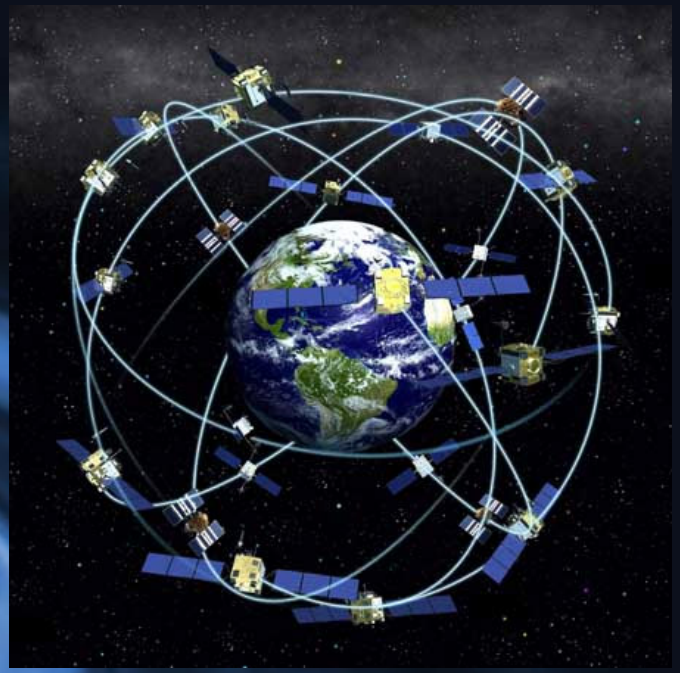


Accelerator Mass Spectrometry (AMS)

- Analisi al radiocarbonio



Gps



Ciascun satellite trasmette continuamente:

- Informazioni orbitali (sua posizione, effemeridi)
- Tempo (a bordo) al quale informazioni sono trasmesse (x_i, y_i, z_i, t_i)
- Il ricevitore risolve (per almeno 4 satelliti):

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = \left([t_r + b - t_i]c\right)^2, \; i = 1, 2, \ldots, n$$

- 1 μs ←→ 300 m (!)

Correzioni relativistiche:

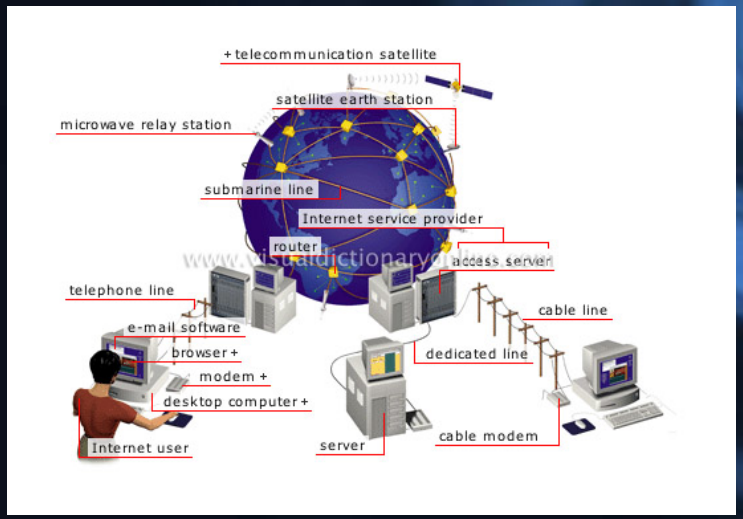
- + 45.900 ns/day GR
- -- 7.200 ns/day SR

anticipo complessivo: ≈ 40 μs/day

9.192.631.770

Internet e Il www

Tim Berners-Lee (2009)



- ARPANET, progetto del Ministero Difesa USA
- Definizione di TCP/IP
- HTTP nel 1989 da T. Berners-Lee
- Concepito e sviluppato per consentire scambio informazioni tra scienziati di tutto il mondo
- ***Rivoluzione*** tecnologica e sociologica
- Uno dei motori dello sviluppo economico

Grazie per l’attenzione!

Il sistema Università/Ricerca

Pos.	Paese	Lista del FMI[1]	Pos.	Lista della Banca Mondiale[2]	Pos.	Lista della CIA[3]	Pos.
—	**Mondo**	**57.843.376**	—	**58.141.498**	—	**58.090.000**	—
—	**Gruppo del G7**	**30.816.184**	—	**n/a**	—	**n/a**	—
—	**Unione europea**	**16.414.697**	—	**16.375.423**[4]	—	**16.210.000**	—
—	**Zona Euro**	**12.483.643**	—	**12.443.594**	—	**n/a**	—
1	Stati Uniti d'America	14.119.050	1	14.119.000	1	14.120.000	1
2	Giappone	5.068.894	2	5.068.996	2	5.069.000	2
3	Cina[5]	4.984.731	3	4.985.461	3	4.985.000	3
4	Germania	3.338.675	4	3.330.032	4	3.339.000	4
5	Francia	2.656.378	5	2.649.390	5	2.656.000	5
6	Regno Unito	2.178.856	6	2.174.530	6	2.179.000	6
7	Italia	2.118.264	7	2.112.780	7	2.118.000	7
8	Brasile	1.574.039	8	1.573.409	8	1.574.000	8
9	Spagna	1.467.889	9	1.460.250	9	1.468.000	9
10	Canada	1.336.066	10	1.336.068	10	1.336.000	10
11	India	1.236.943	11	1.310.171	11	1.237.000	11
12	Russia	1.231.892	12	1.231.893	12	1.232.000	12
13	Australia	994.246	13	924.843	13	994.200	13
14	Messico	874.810	14	874.810	14	874.800	14
15	Corea del Sud	832.512	15	832.512	15	832.500	15
16	Paesi Bassi	796.651	16	792.128	16	796.700	16
17	Turchia	614.466	17	614.603	17	614.500	17
18	Indonesia	539.377	18	540.274	18	539.400	18
19	Svizzera	491.923	19	491.924	19	491.900	19
20	Belgio	472.103	20	471.161	20	472.100	20

PIL in milioni di dollari statunitensi

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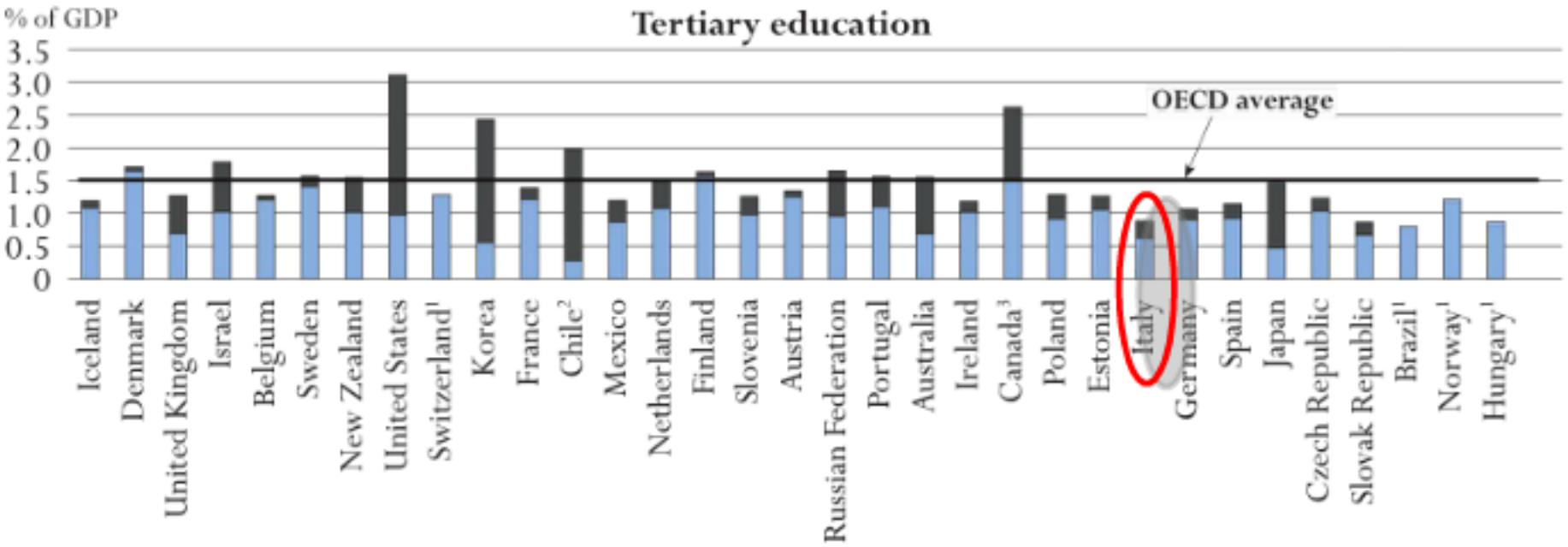
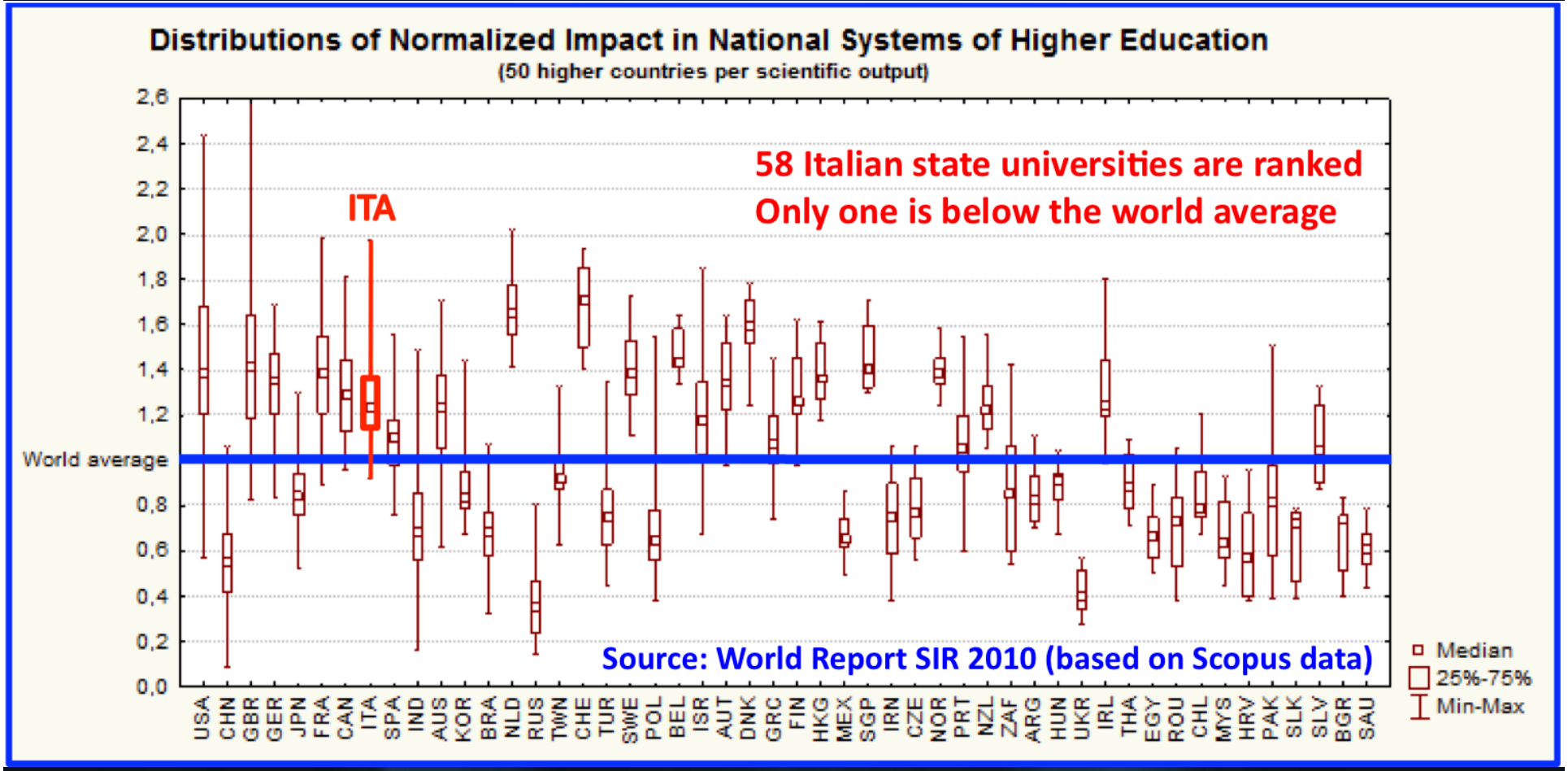
	Country	Documents	Citable documents	Citations	Self-Citations	Citations per Document	H index
1	United States	5.285.514	4.934.052	94.410.591	43.892.266	19,11	1.190
2	United Kingdom	1.522.264	1.382.080	22.915.219	5.557.332	16,48	721
3	Germany	1.390.547	1.314.218	19.093.931	5.082.481	14,90	636
4	Japan	1.455.721	1.420.486	15.457.102	4.697.914	11,08	549
5	France	1.014.578	957.274	13.233.405	3.113.786	14,26	580
6	Canada	785.711	743.758	11.346.285	2.260.578	16,57	559
7	Italy	758.912	716.532	9.187.350	2.174.374	13,63	496
8	Netherlands	432.768	407.255	7.255.319	1.257.538	18,90	489
9	Australia	516.104	481.001	6.550.854	1.426.173	15,09	432
10	China	1.837.943	1.819.917	6.549.901	3.472.378	5,27	300
11	Spain	579.773	543.612	6.066.477	1.576.052	12,34	395
12	Switzerland	308.172	290.576	5.587.746	796.867	20,53	487
13	Sweden	303.427	290.572	5.055.951	858.022	18,01	431
14	Belgium	235.389	223.011	3.362.100	521.601	16,14	380
15	South Korea	425.842	417.558	3.040.178	704.237	9,20	272
16	India	528.024	501.960	2.917.886	1.003.734	6,76	240
17	Denmark	161.858	153.544	2.801.908	424.539	19,25	358
18	Israel	185.472	176.841	2.697.589	409.525	15,64	354
19	Russian Federation	479.095	474.317	2.288.869	693.521	4,87	274
20	Finland	152.957	148.239	2.277.054	392.301	16,64	318

Classifica per # citazioni – tutte le discipline

Expenditure for university education as %GDP'07





Scimago institution Ranking (SIR)

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	Country	Documents	Citable documents	Citations	Self-Citations	Citations per Document	H index
1	United States	51.100	50.793	802.463	347.513	15,85	232
2	Germany	28.961	28.609	422.825	160.843	14,69	170
3	Italy	19.418	19.243	259.769	80.929	13,47	138
4	United Kingdom	15.549	15.457	243.834	66.723	16,33	147
5	France	16.416	16.294	238.397	64.109	14,98	137
6	Japan	20.145	20.033	223.533	80.751	11,04	122
7	Russian Federation	19.727	19.583	221.865	68.950	11,38	138
8	Switzerland	11.494	11.411	207.049	46.325	17,57	154
9	Spain	8.397	8.335	120.825	29.727	15,58	112
10	Canada	7.083	7.041	99.016	18.914	14,65	100
11	China	9.457	9.404	86.272	34.872	11,19	83
12	Poland	5.496	5.453	78.914	19.032	14,93	102
13	India	6.822	6.776	77.827	20.727	12,47	83
14	Netherlands	4.358	4.332	62.071	10.577	14,57	91
15	South Korea	5.063	5.031	61.799	12.822	13,33	80
16	Sweden	3.819	3.789	55.788	10.563	14,74	81
17	Belgium	3.929	3.892	51.631	10.605	13,84	76
18	Israel	2.887	2.872	49.258	7.364	16,89	77
19	Brazil	4.978	4.946	48.476	15.814	10,16	68
20	Finland	2.283	2.275	38.160	5.966	17,41	70

Classifica per #citazioni – Fisica e Astronomia – NHEP(!)