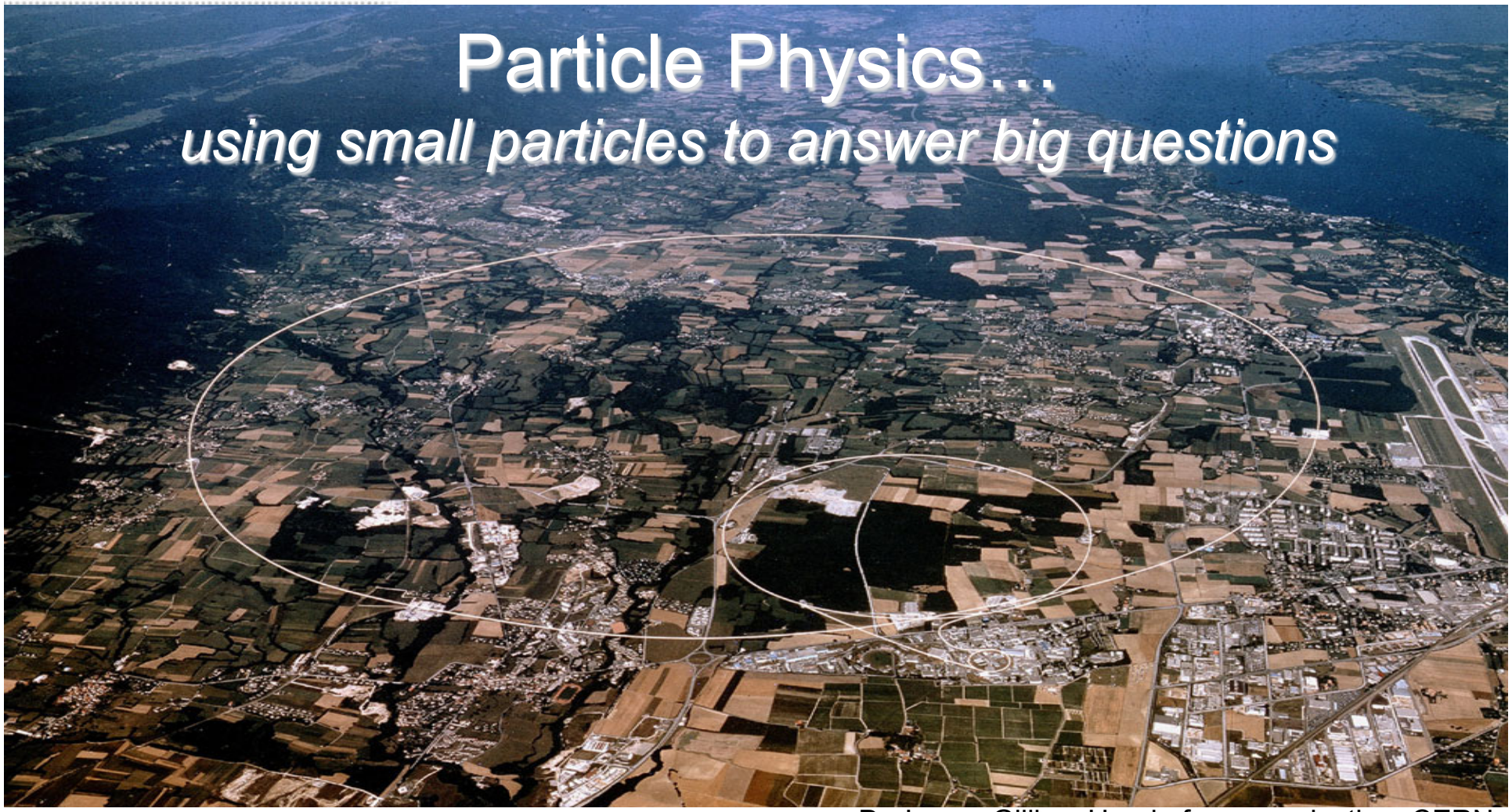
CERN

European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

Particle Physics…

using small particles to answer big questions



Dr James Gillies, Head of communication, CERN

Shortcuts

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LOT# 849

GuardianUnlimited think of escaping

The mother who never goes out without her daughters

A royal child's relationship with its parents is always going to be an intriguing one. Take Charles: a middle-aged man whose life purpose cannot commence until his mother pushes off, either off the throne or into the next dimension.

But it's Princesses Beatrice and Eugenie who provide the most fodder for thought on this account. These two young ladies, perfectly pleasant by all accounts, seem to have a relationship with their mother, the indefatigable Fergie, that is so close as to be downright stifling. The three are frequently photographed at parties and premieres together and this week Fergie and her ex-husband were photographed leaving a restaurant together. She did leave the girls at home but they were present in spirit, thanks to Fergie's Anya Hindmarch handbag, which was emblazoned with a picture of her daughters.

For New Year's Eve, Beatrice and Eugenie, 18 and 16 respectively, went to Thailand for the party where Pete Doherty sort-of-but-not-really married Kate Moss. Quite a good gig for two teenagers, you would think. Except that their mother went with them. Fergie has hooted in interviews about how she and Beatrice like to go "on the pull together" and Beatrice recently cooed that her ambition was to be "a mini-mummy [because] her behaviour is one I'd really like to follow". Ah-toe-sucking-choo!

In this day of family breakdowns and the end of the nuclear unit, isn't it heartening to see two teenagers so happily close to their mother? Others have been spotted partying with their mothers, too: Moss herself was photographed at Manumission in Ibiza with her mum. None the less, we all remember what it was like to be 18: the idea of going to a party with one's mother was pretty much up there with joining the after-school physics club in terms of social humiliation. So either they are doing this under

Inseparable . . . Fergie with Beatrice and Eugenie and, left, her bag with their picture on

In this day of family breakdowns, isn't it heartening to see two teenagers so close to their mother?

sufferance or, as has long been suspected, the royals don't have normal human reactions. This would explain how William and Harry continue to live day to day, seemingly unhampered by their father's once-professed wish to be a female sanitary product when most other people would have fled to Tanzania. But frankly, the thought of Fergie turning up in Manumission is enough to make you beg Beatrice and Eugenie to, please, take a stand now.

Hadley Freeman

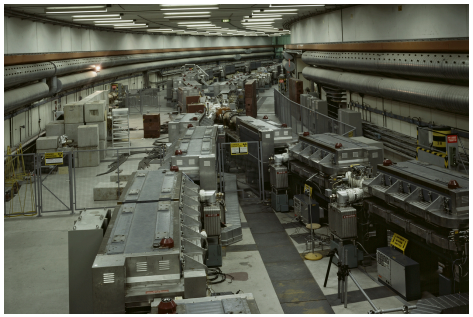
PHOTOGRAPH: EMPICS; COVER PHOTOGRAPH: GETTY

guardian.co.uk

"We all remember what it was like to be 18: the idea of going to a party with one's mother was pretty much up there with joining the after school physics club in terms of social humiliation.

Welcome to the after school physics club!

Small particles…



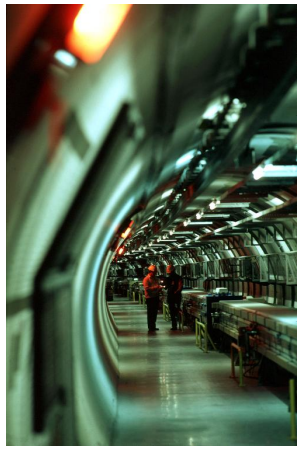
Proton: 10^{-27}kg, 10^{-15}m

π

Electron: 10^{-31}kg, pointlike

μ

ν



Big questions…

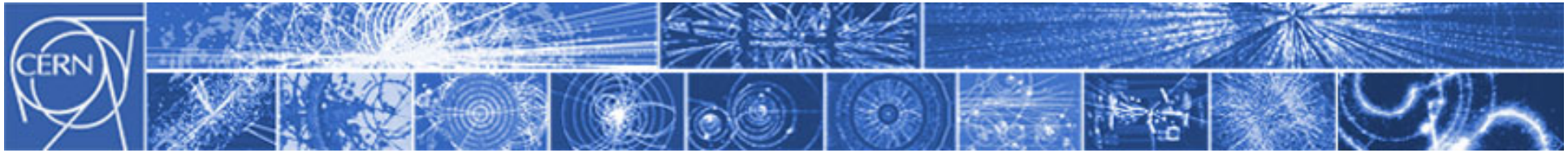
What happened to antimatter?

What gives rise to mass?

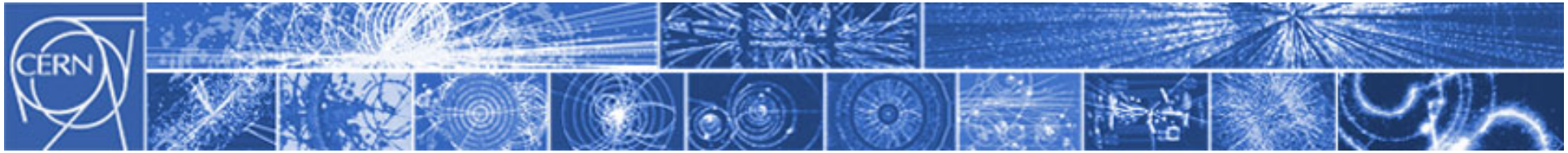
How did matter evolve right after the Big Bang?

What's 95% of the universe made of?

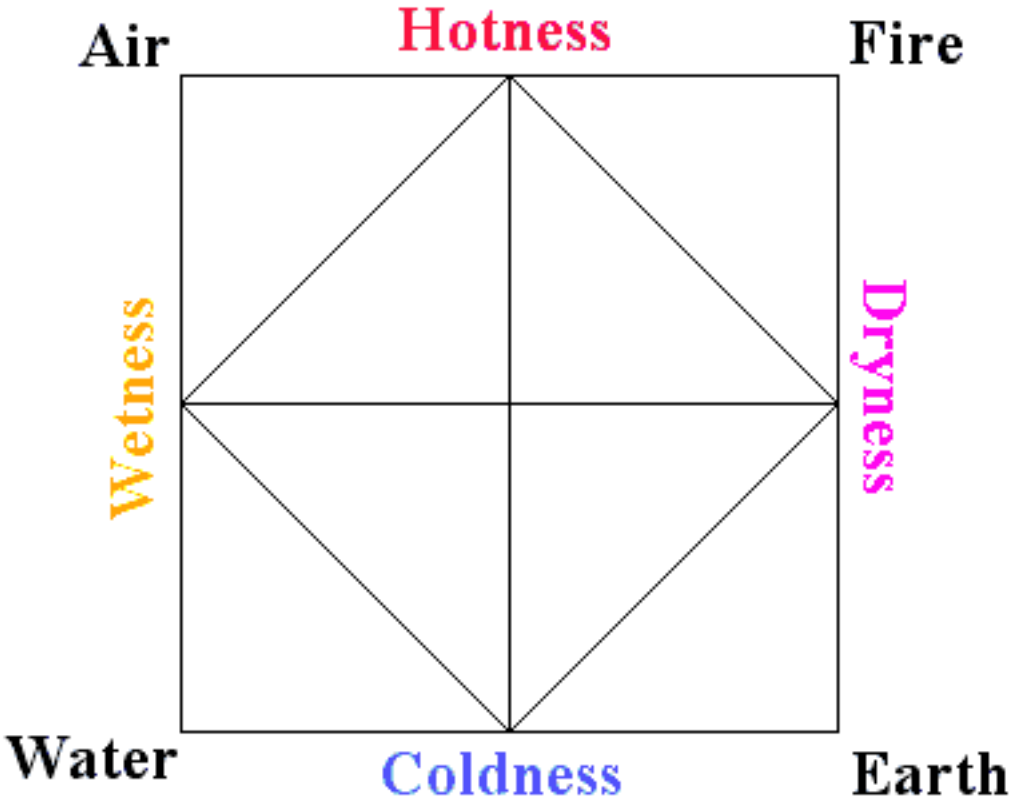
Are there extra dimensions?

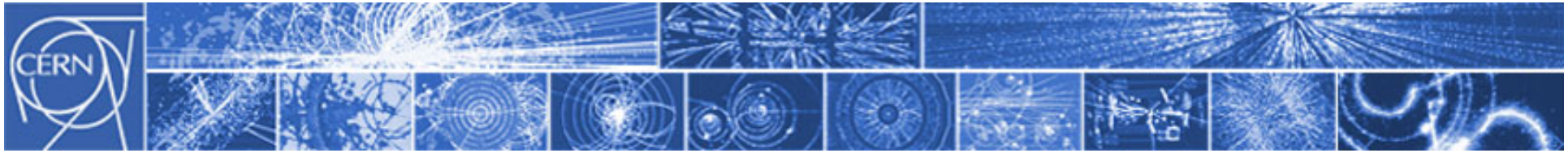


The (condensed) story of particles



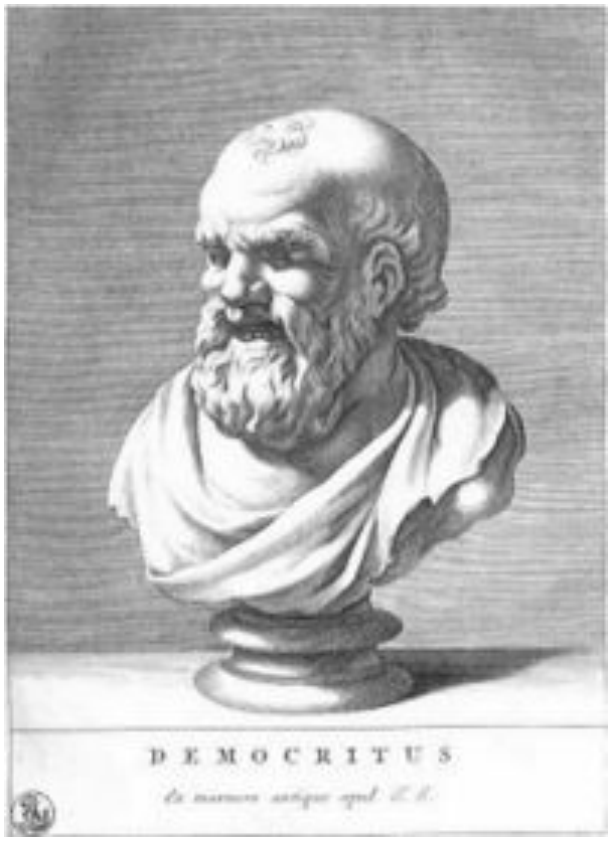
Particle physicists like to keep things simple



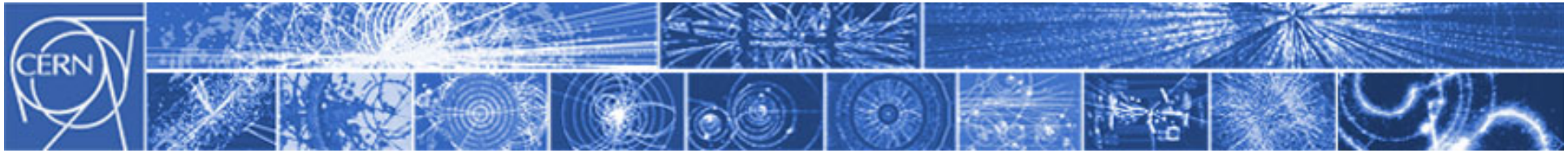


One problem: it’s wrong…

Particle physicists also like things to be right



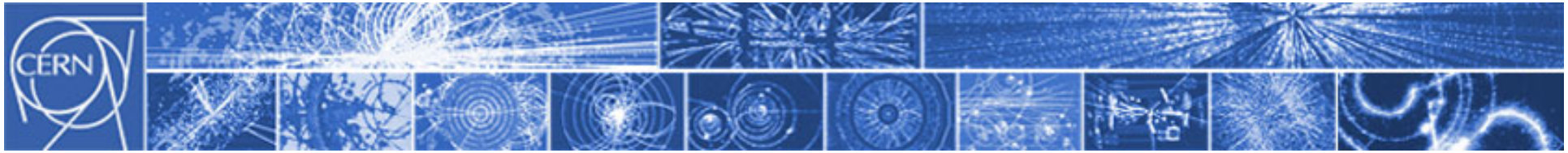
5th century BC: Leucippus, Democritus “all matter is composed of small indivisible particles: atoms”



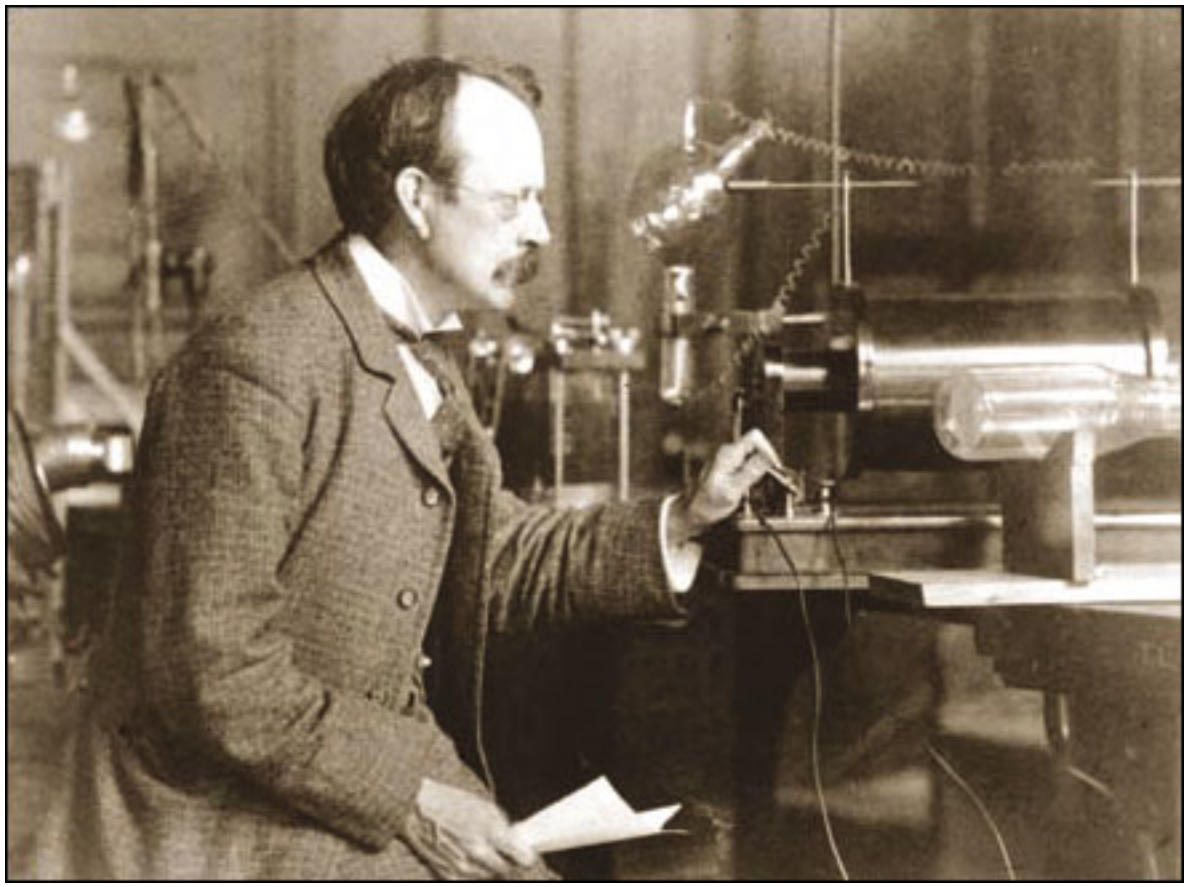
Fast forward to 19th century Russia

Reihen	Gruppe I. — $R^{I}O$	Gruppe II. — RO	Gruppe III. — $R^{III}O^{3}$	Gruppe IV. RH^{4} RO^{2}	Gruppe V. RH^{3} $R^{V}O^{5}$	Gruppe VI. RH^{2} RO^{3}	Gruppe VII. RH $R^{VII}O^{7}$	Gruppe VIII. — RO^{4}
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

A plethora of elements. Mendeleev's periodic table of the elements indicated a simpler underlying structure…



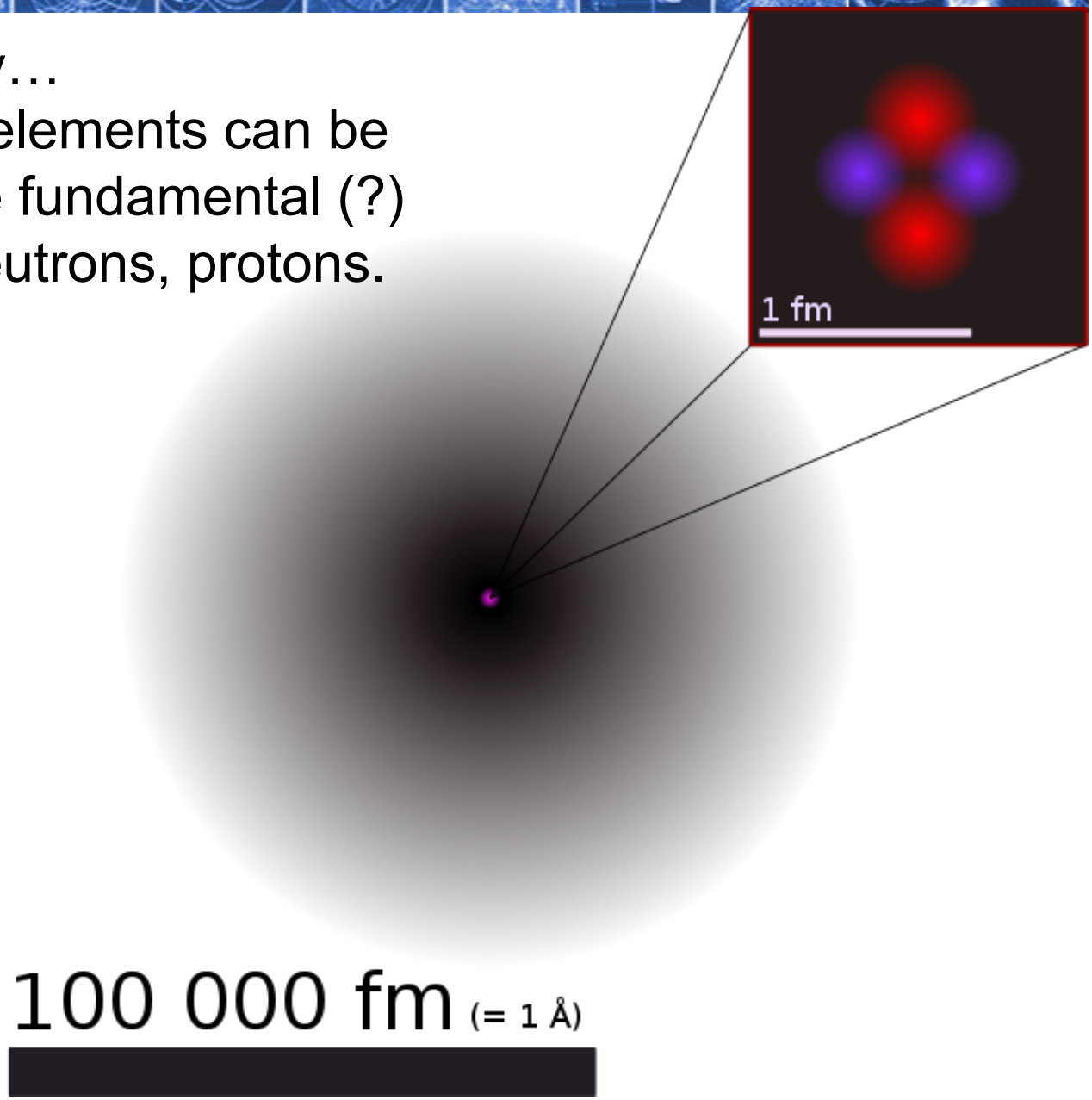
The atoms turn out not to be fundamental…



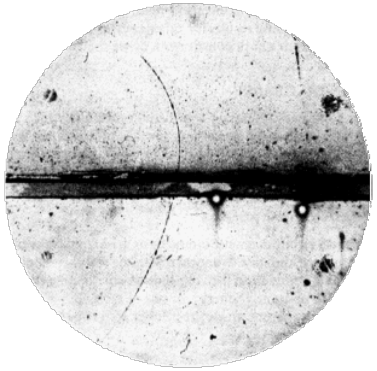
1897: Particle physics begins with the discovery of the electron

The return of simplicity…
all the diversity of the elements can be explained by just three fundamental (?) particles: electrons, neutrons, protons.

Electron: 1897
Proton: 1919
Neutron: 1932



Complexity's return…



Positron: 1932

Who ordered that?

Muon: 1937

1947: Pion

1947: Kaon

The PARTICLE ZOO

1956: Electron neutrino

1962: Muon neutrino…

Quarks and partons

Gell-Mann

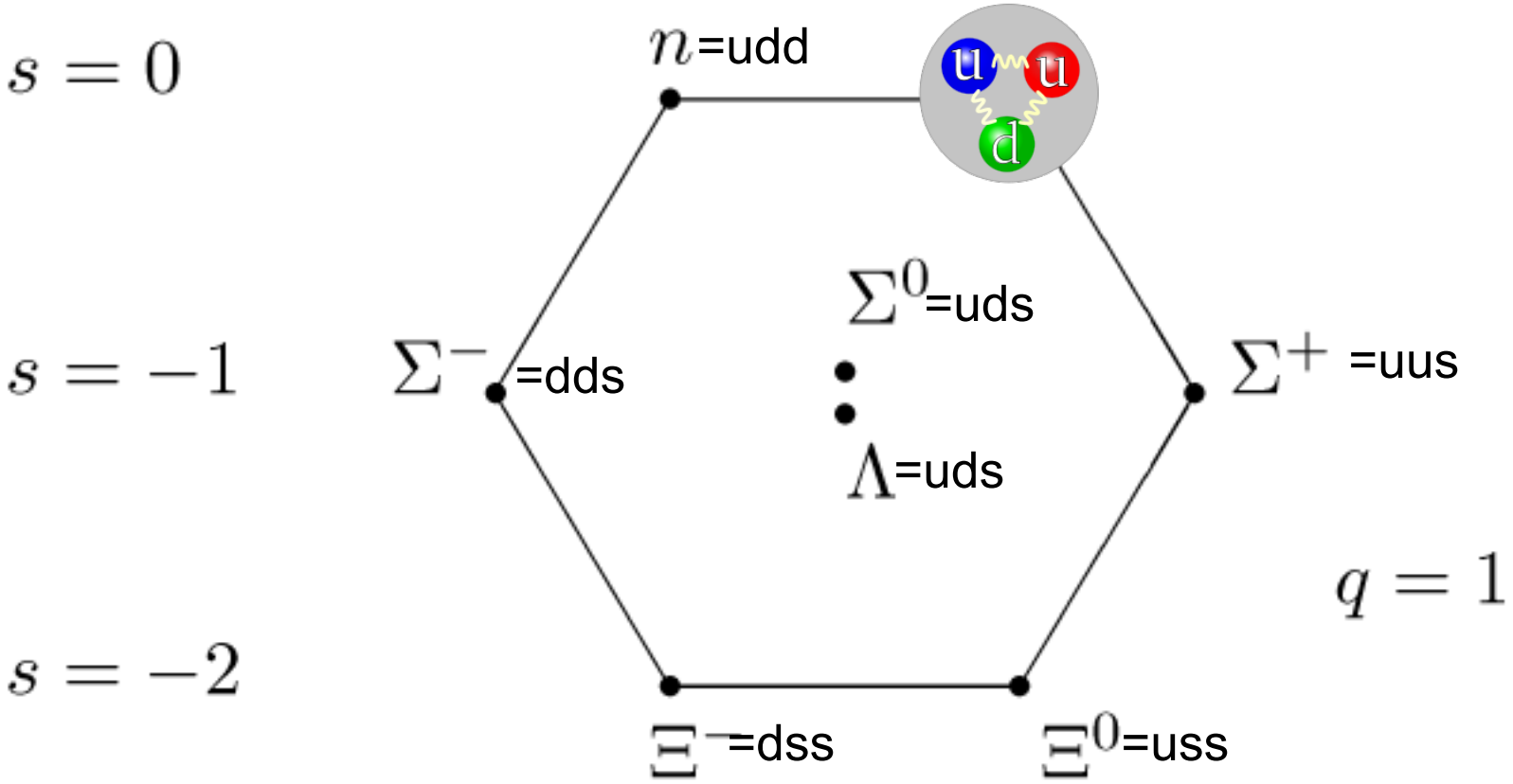
"Three quarks for muster Mark"

Emilio Segrè Visual Archives

Feynman

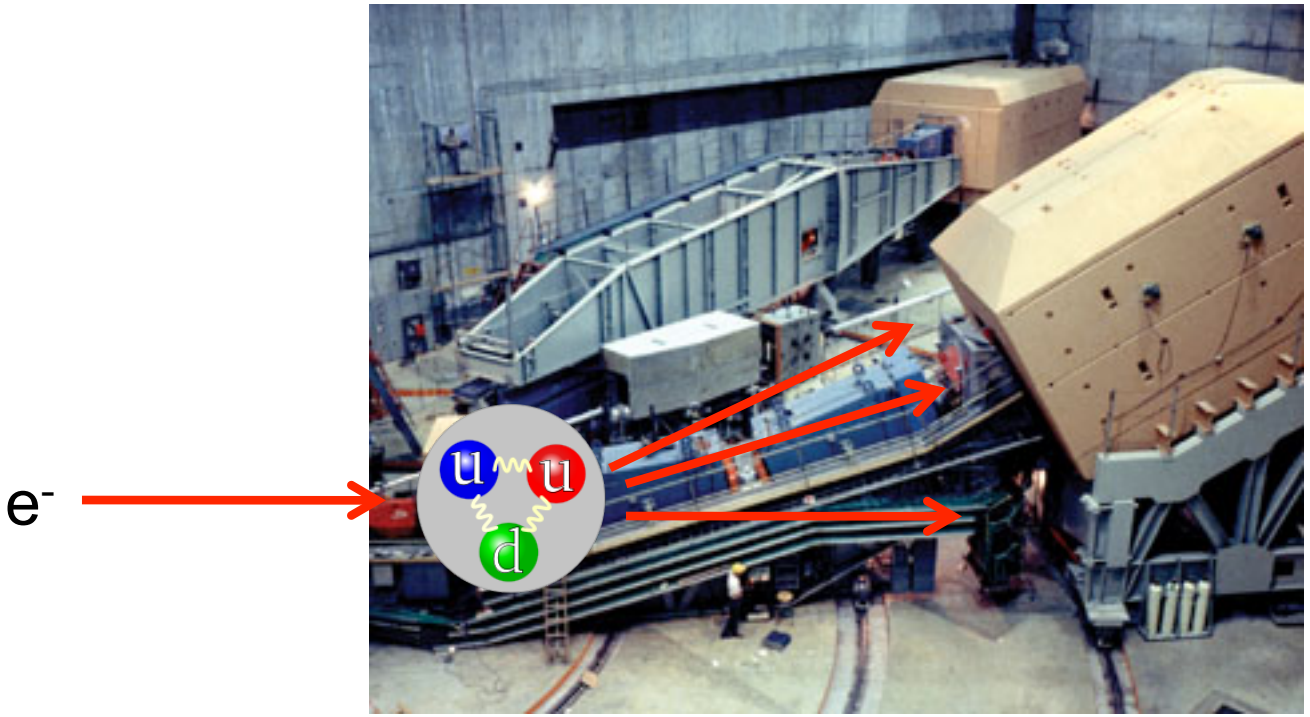
Rather more prosaic…

The eightfold way…



But are quarks real, or just book-keeping?

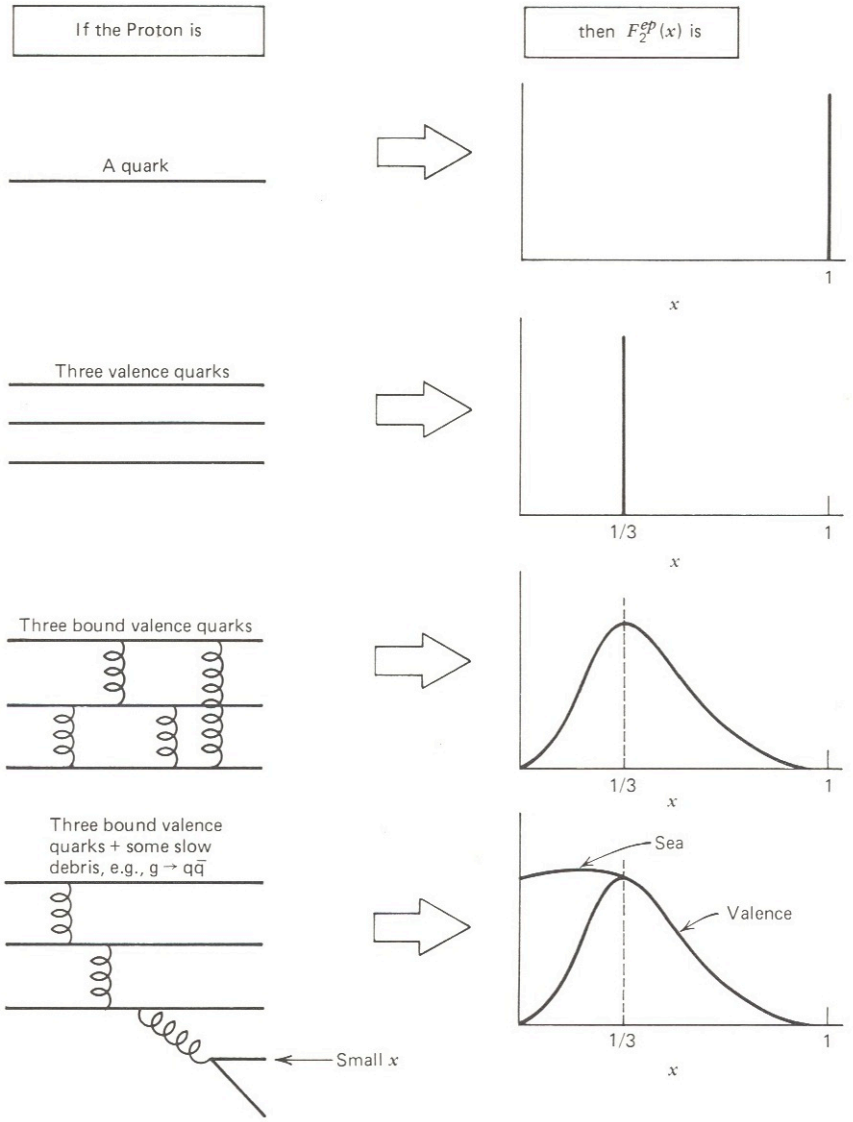
SLAC End station A, 1968…



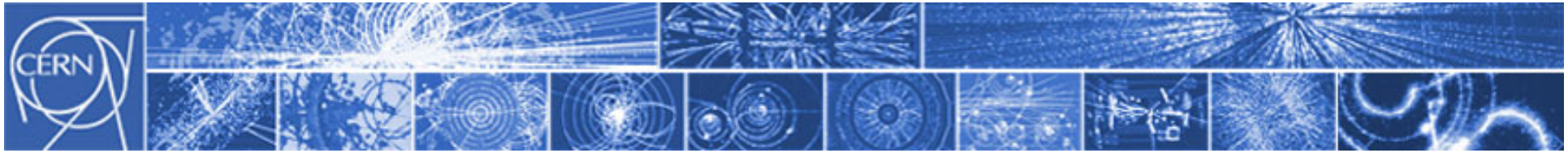
Nobel Prize 1990:
Jerome Fiedman
Henry Kendall
Richard Taylor

What can we learn from this kind of experiment?

Theory:

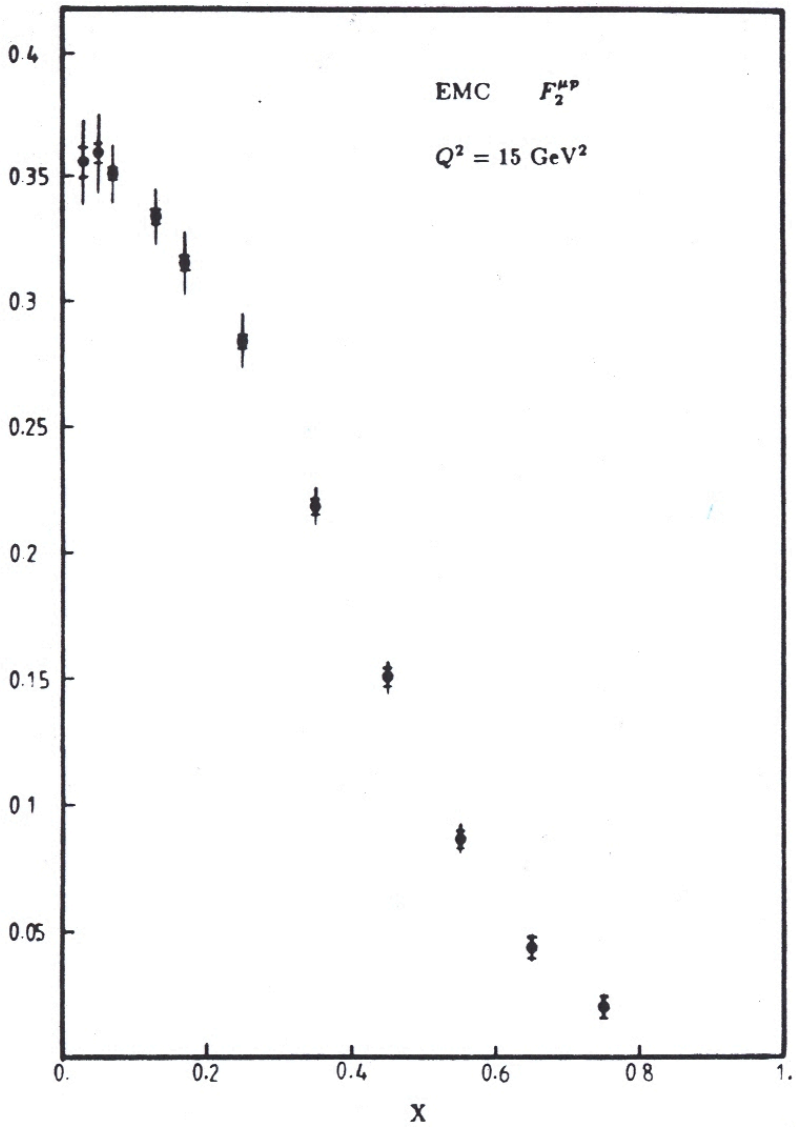


Halzen & Martin
Quarks and Leptons
Wiley 1984

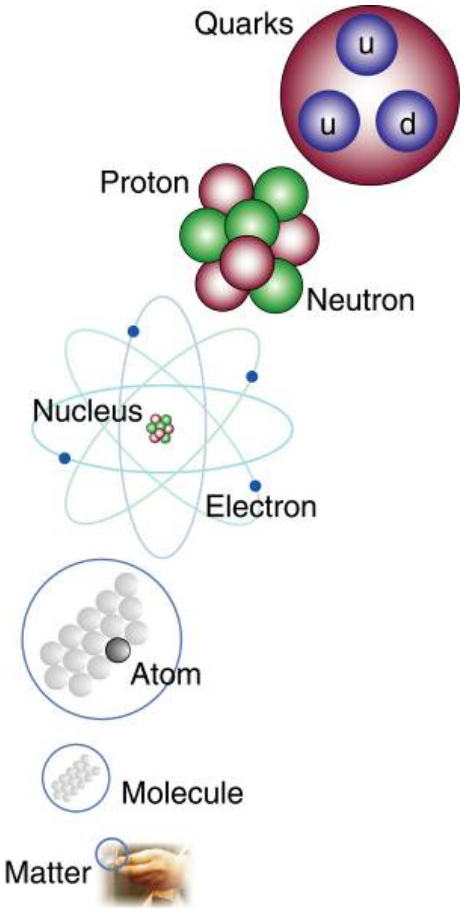


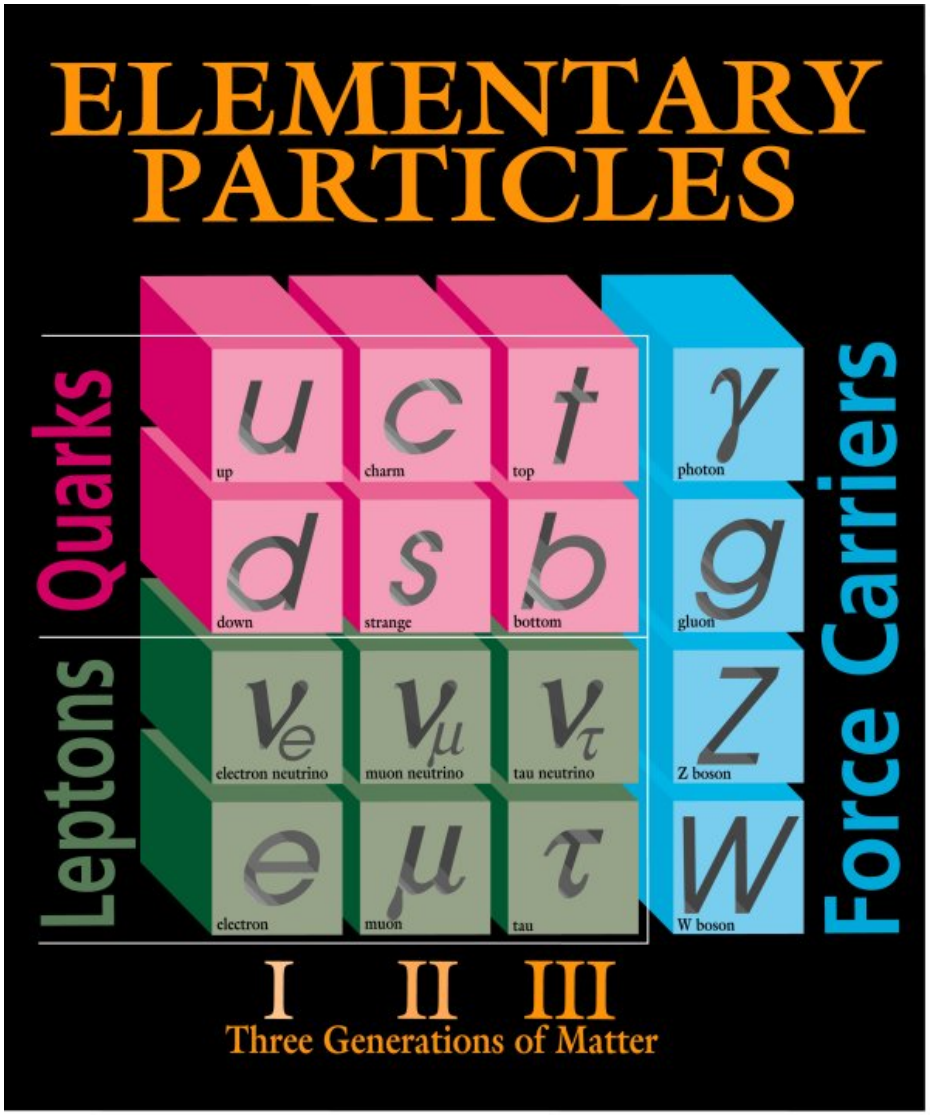
What can we learn from this kind of experiment?

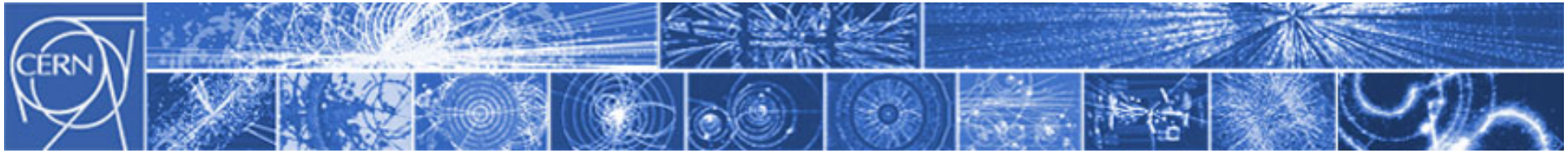
Experiment:



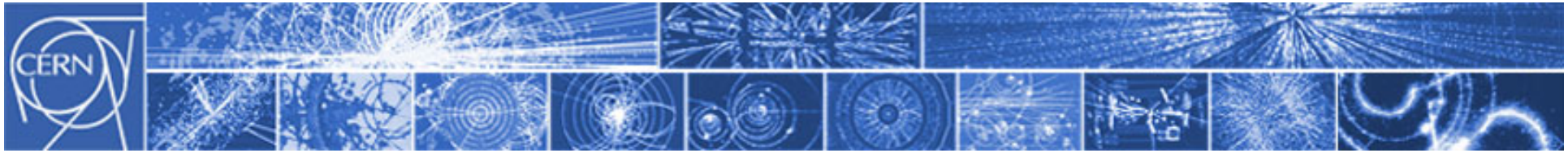
The Standard Model



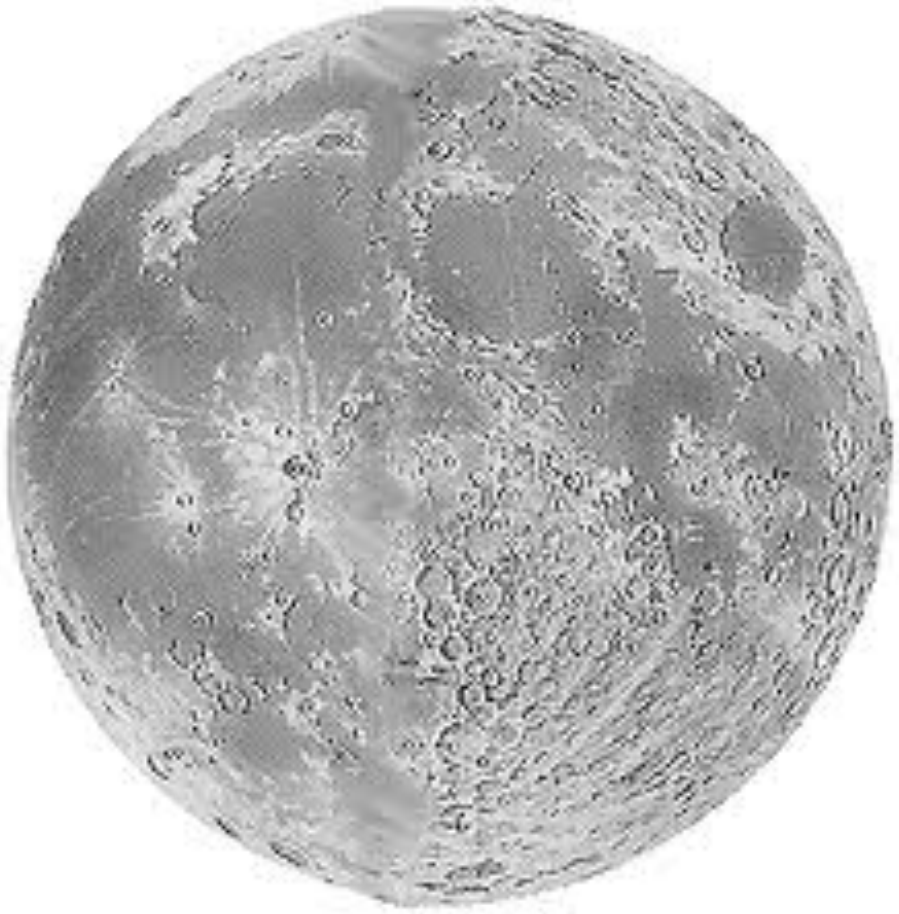


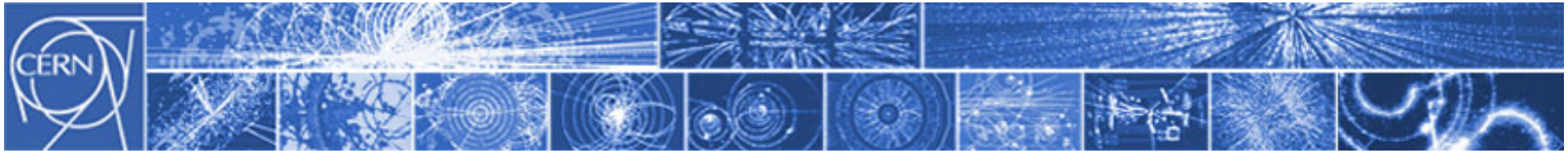


The (condensed) story of forces

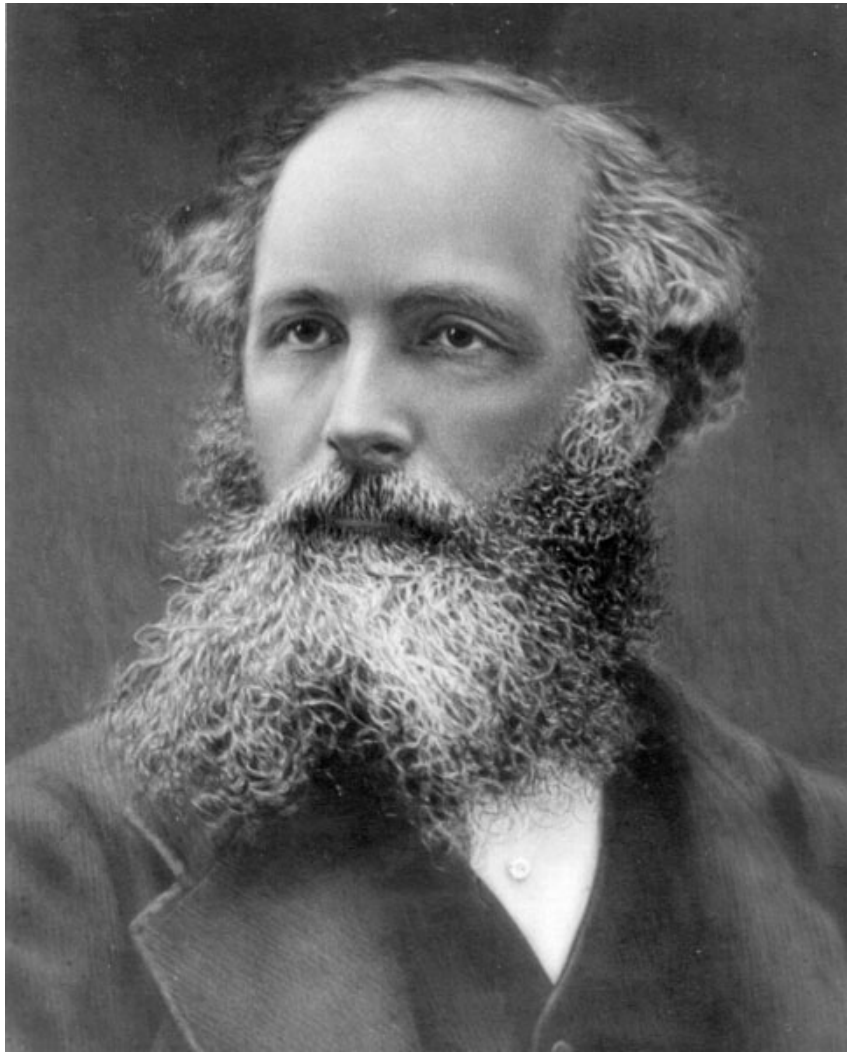


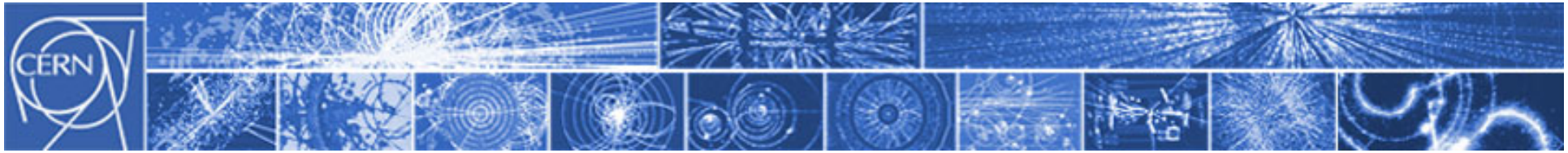
Gravity: 1687





Electromagnetism: 1861

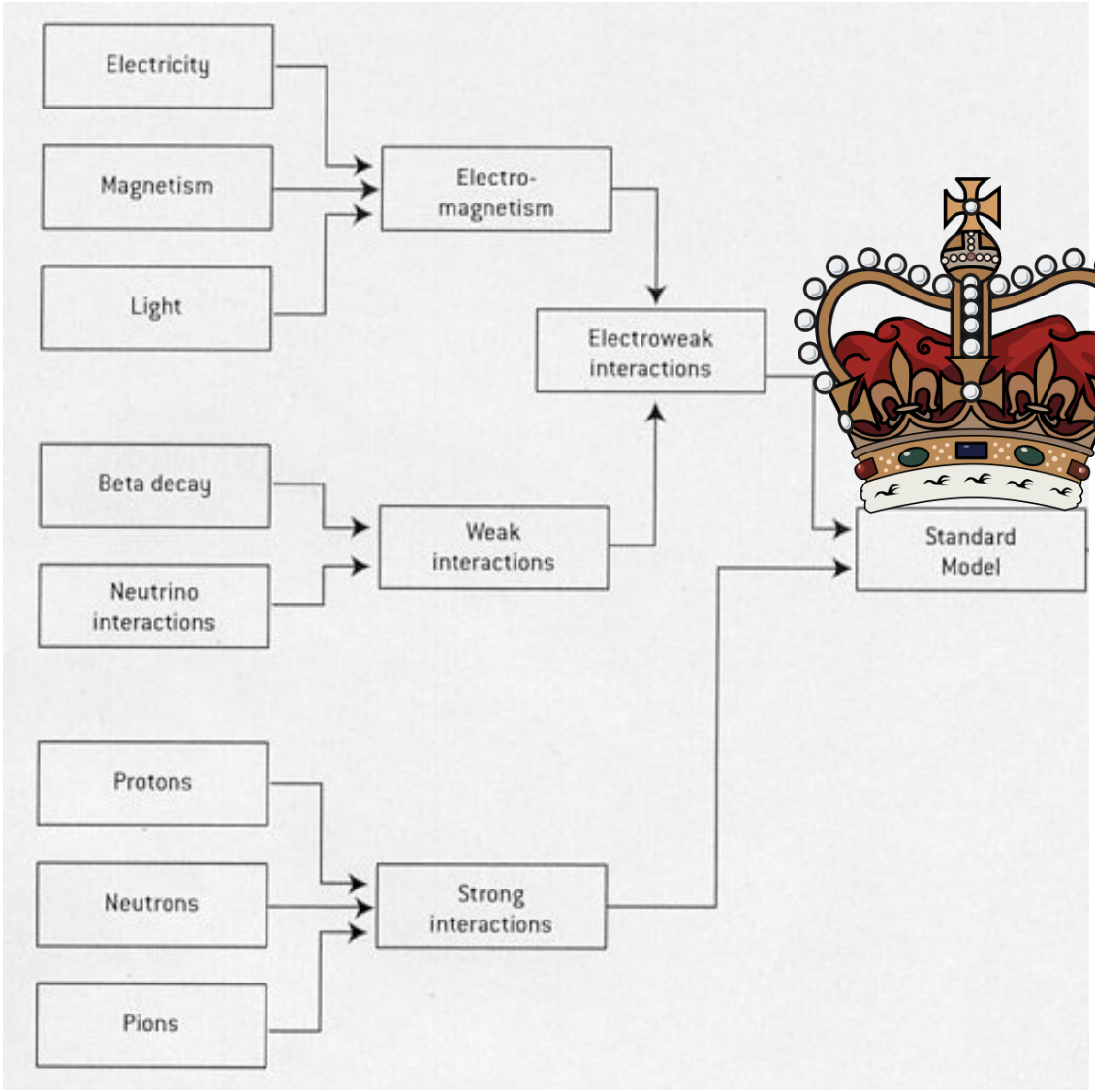




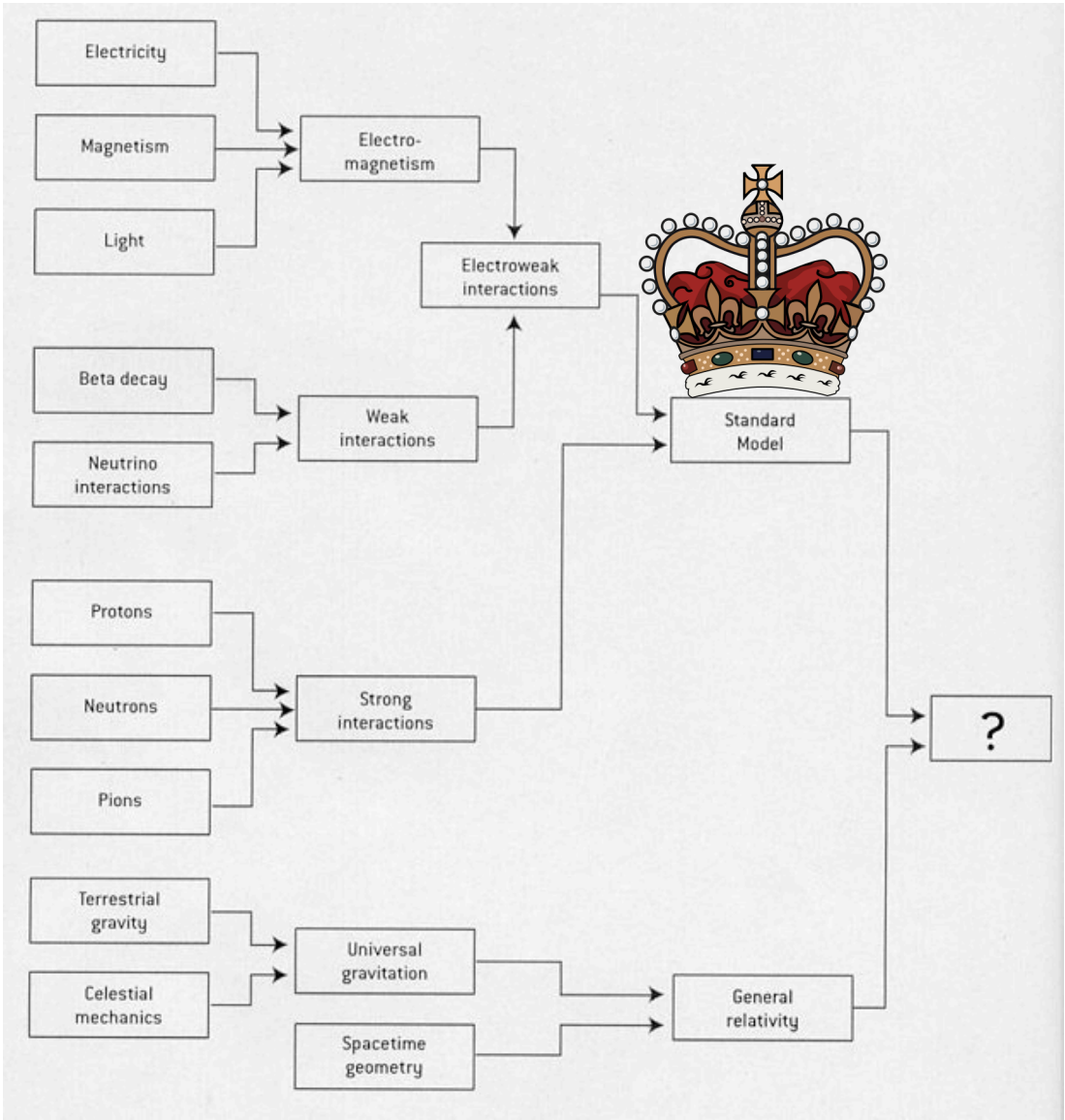
Electroweak: 1960s

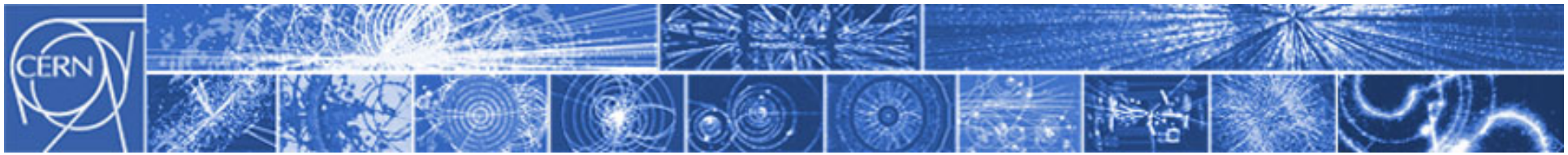
Sheldon Glashow, Abdus Salam, and Steven Weinberg sharing the Nobel Prize, 1979

Standard Model

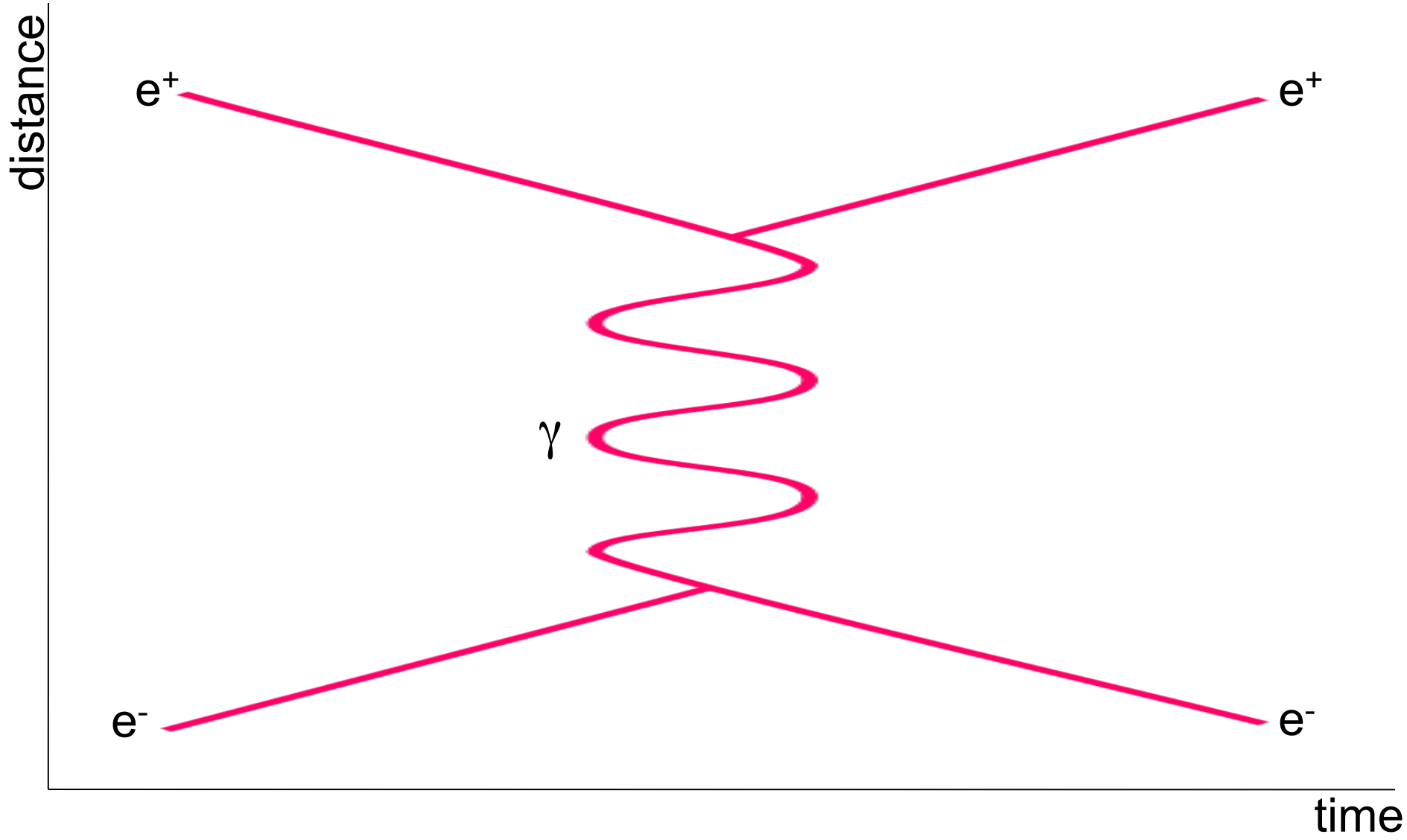


So where's gravity?

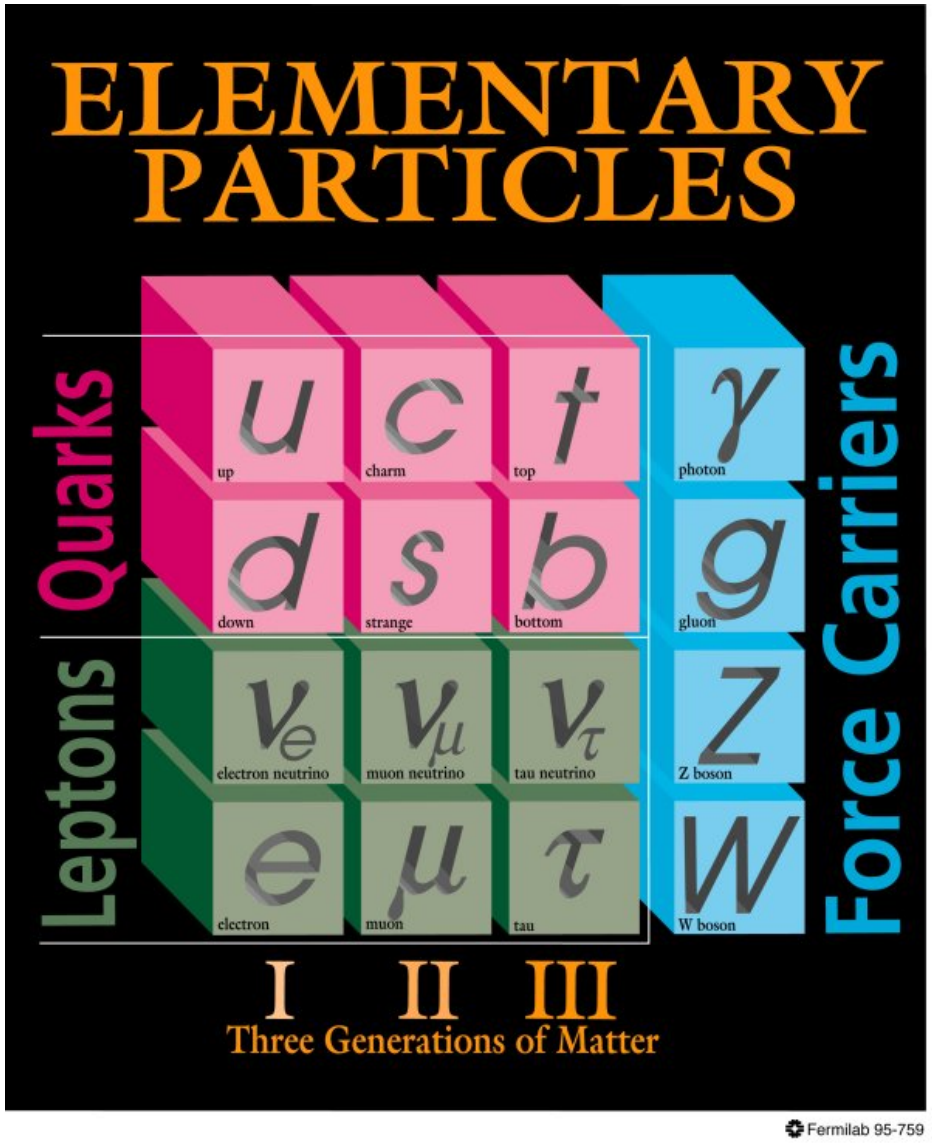




What's happening?



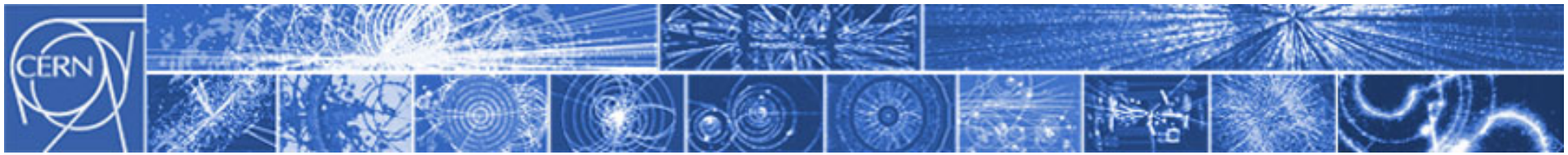
The forces



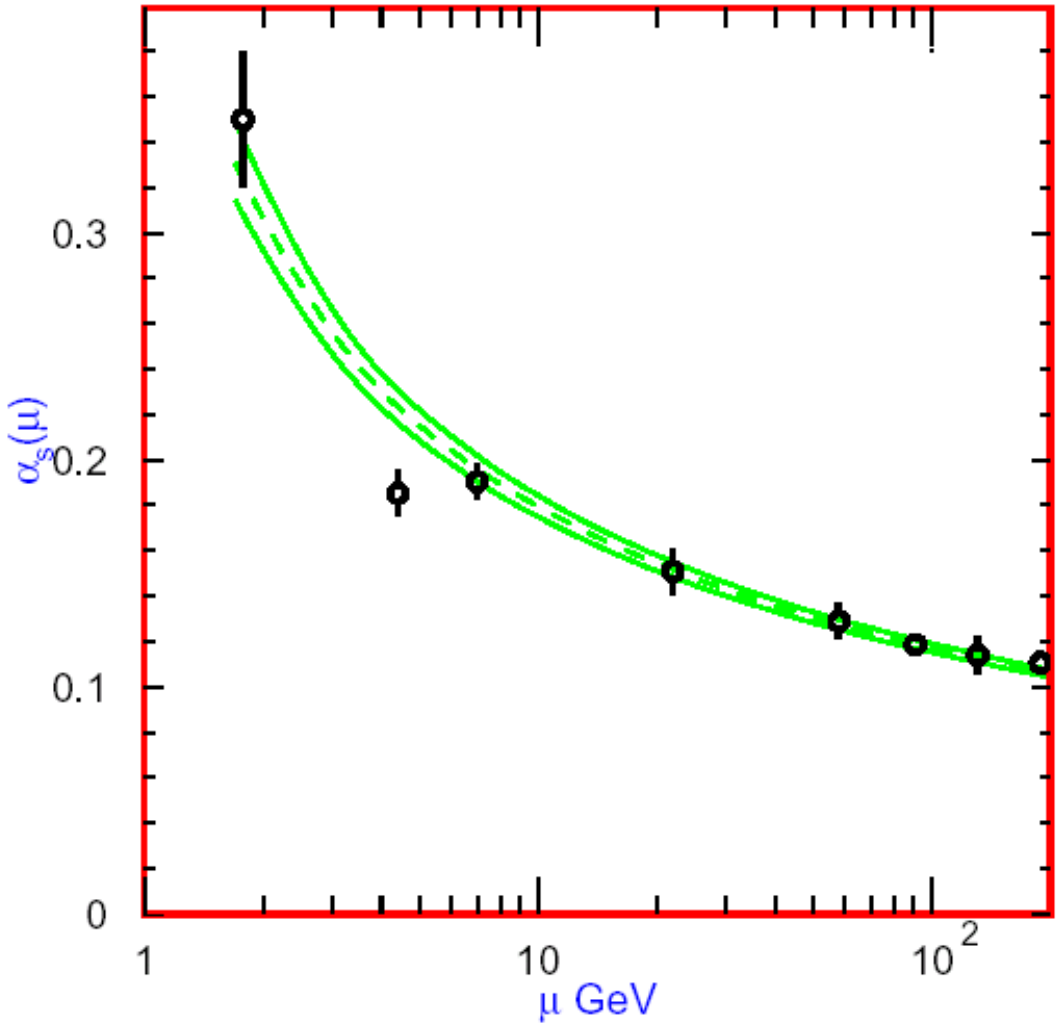
Electromagnetic

Strong

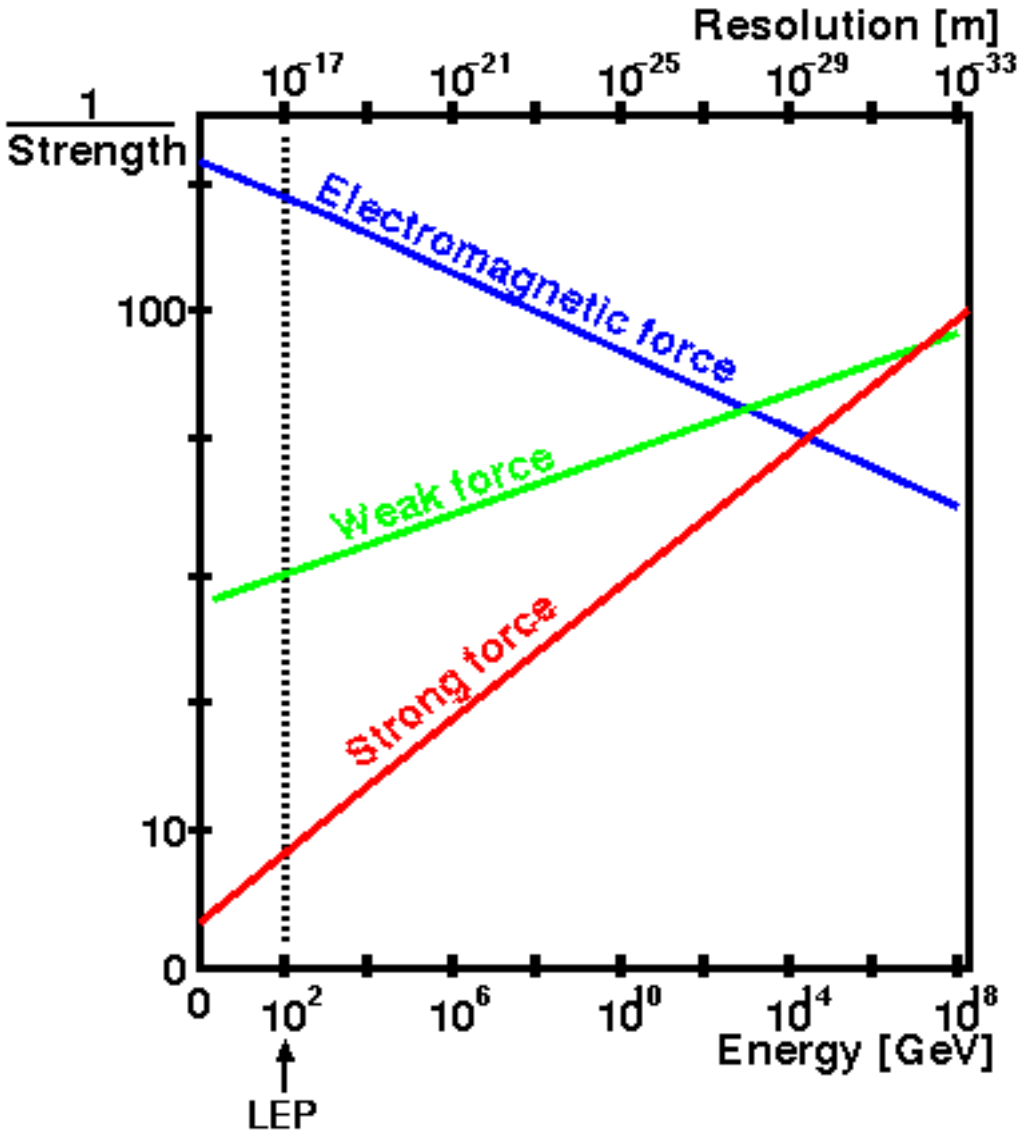
Weak

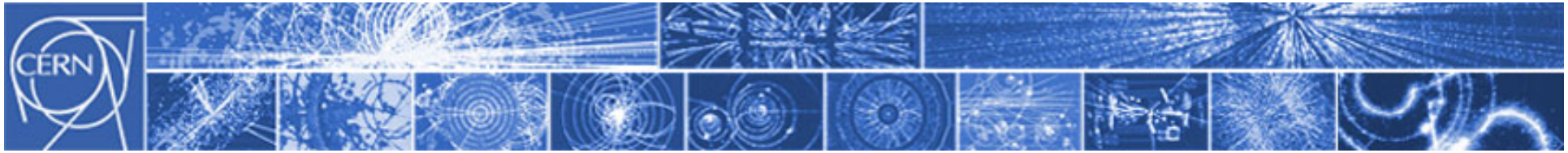


Running coupling constants

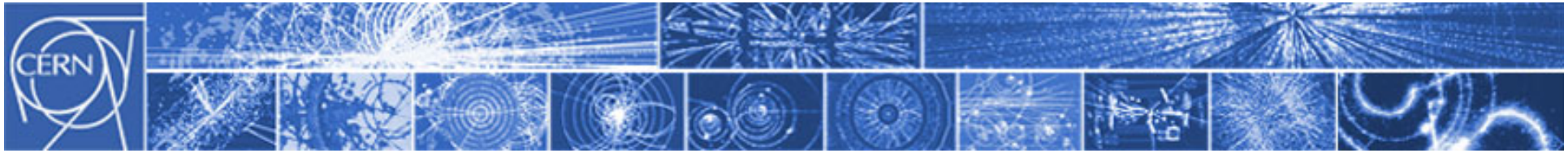


Running coupling constants





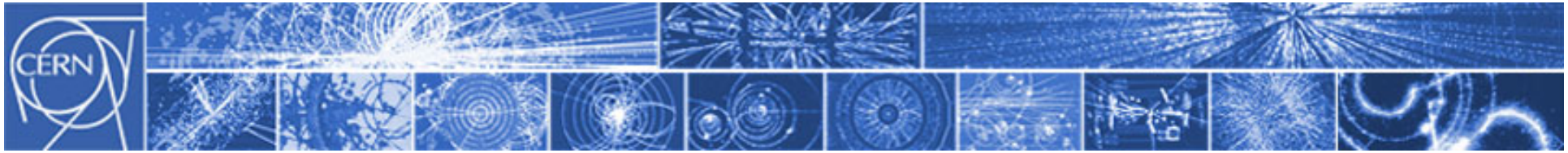
What’s missing from the Standard Model?



Long range and short range…

Question? Why are some forces long range and others short range? Specifically, why does electromagnetism have infinite range, whereas the weak interaction is short range?

Answer (1964-5, Brout, Englert, Higgs, Guralnik, Hagen, Kibble…): Because the carrier of the weak force is heavy. The symmetry that unifies electromagnetism and weak interactions is broken.

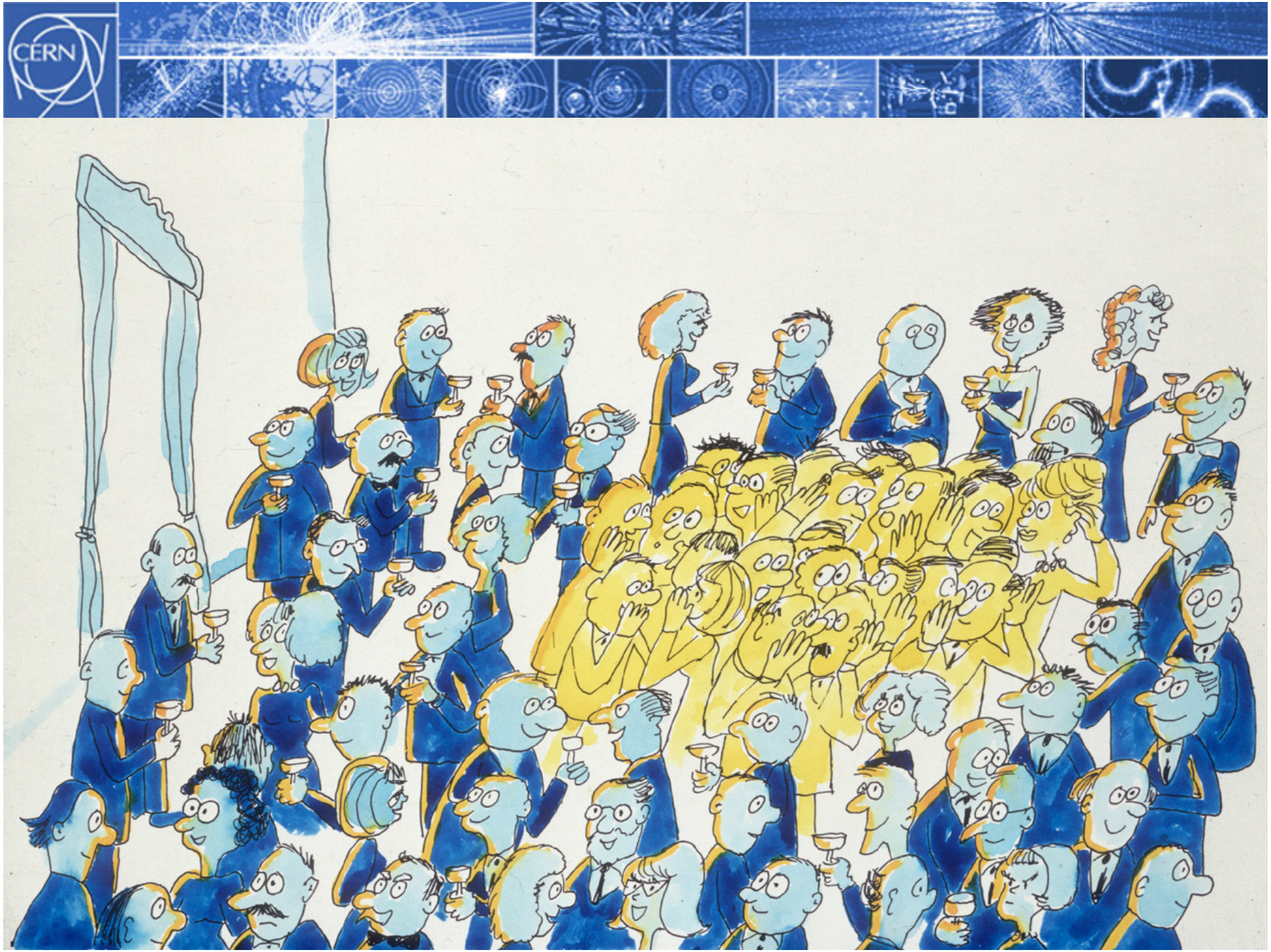


One little snag…

The theory all these people were working in predicted infinities..

Their mechanism languished for a decade, until Gerardus ‘t Hooft and Martinus Veltman renormalised it in the 1970s (Nobel Prize 1999).

By an accident of fate, the mechanism and associated particle became known as Higgs.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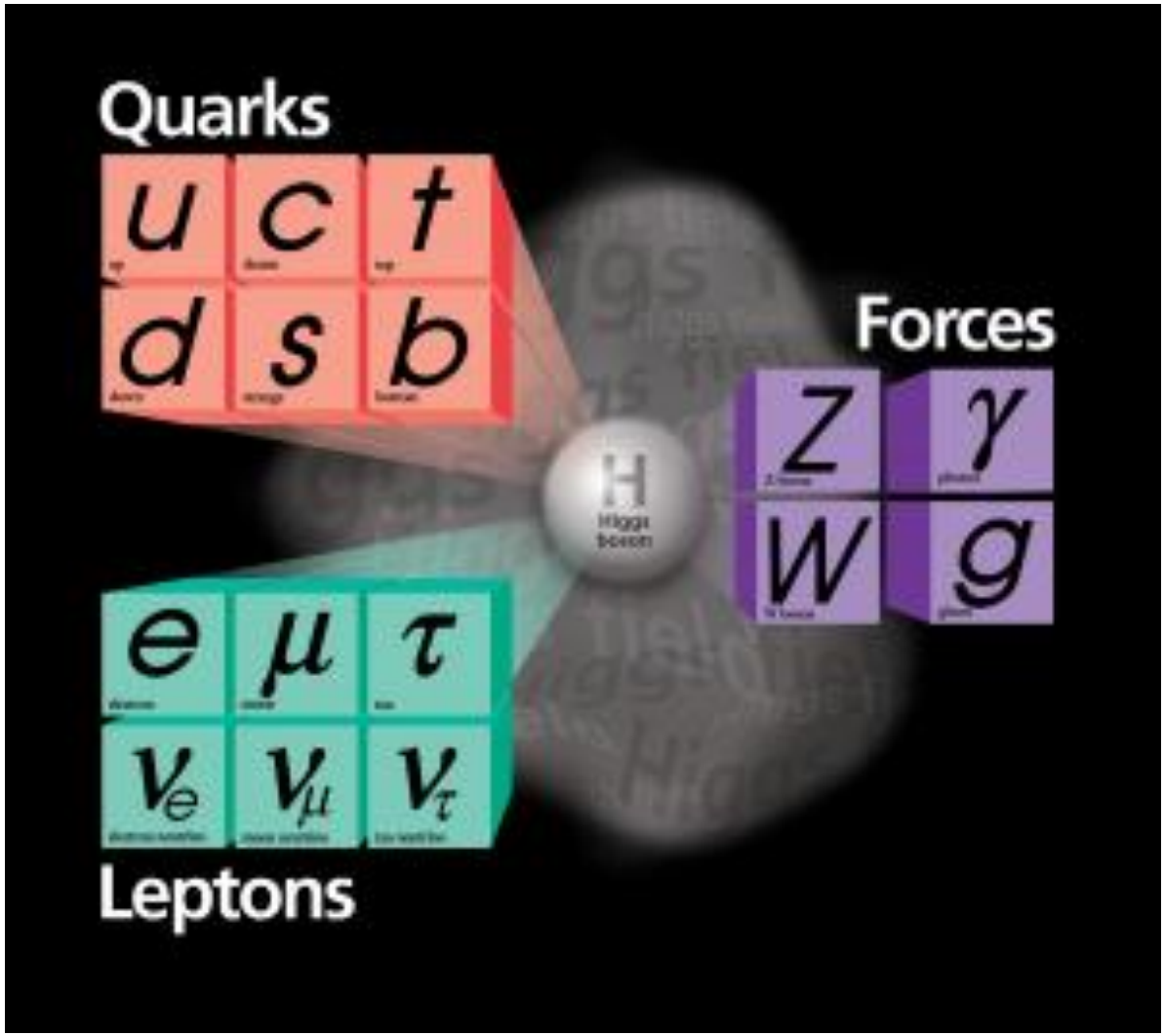
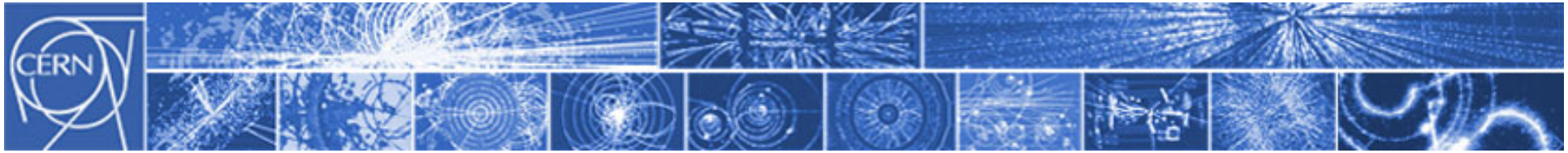
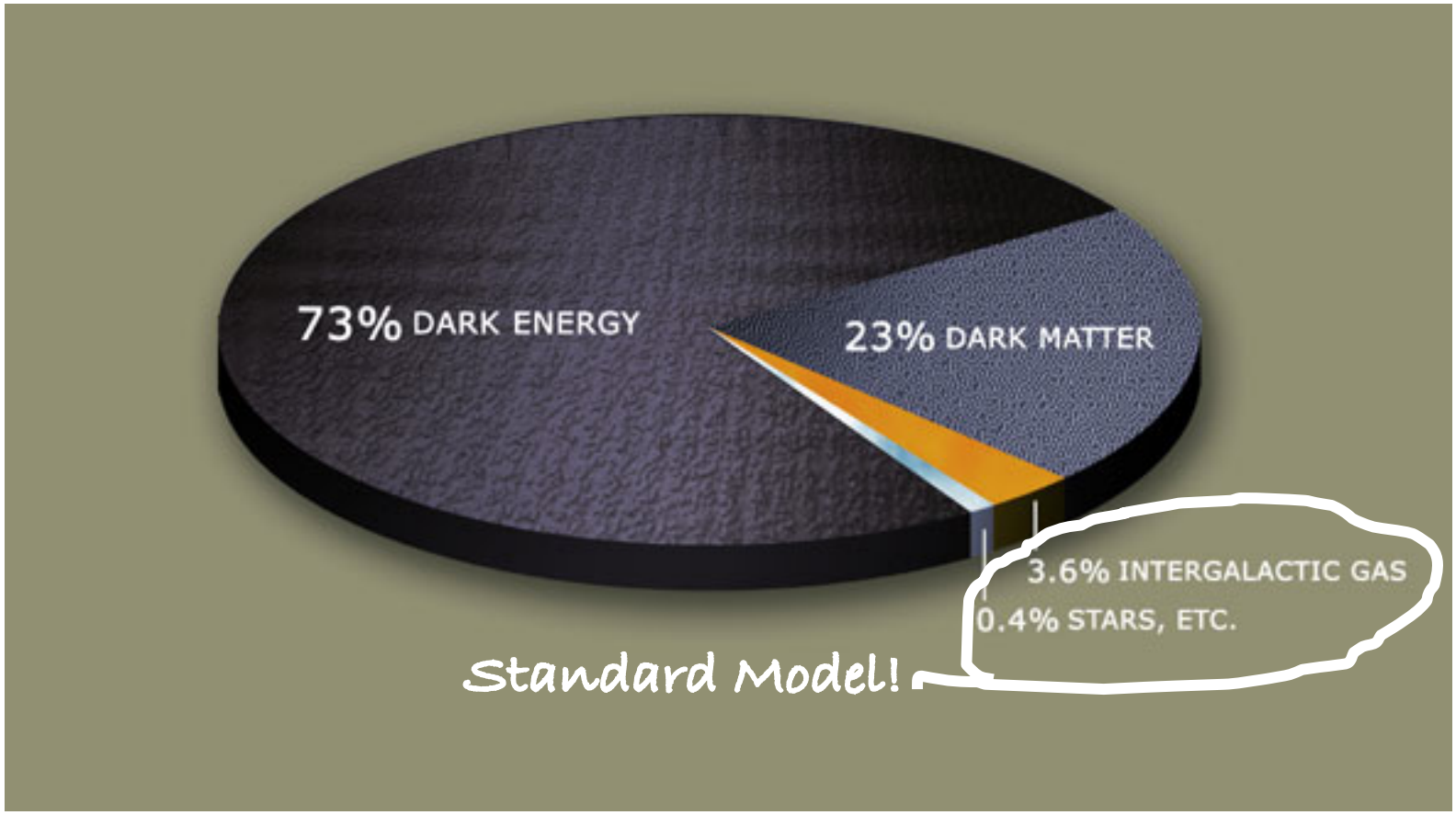
The Standard Model today



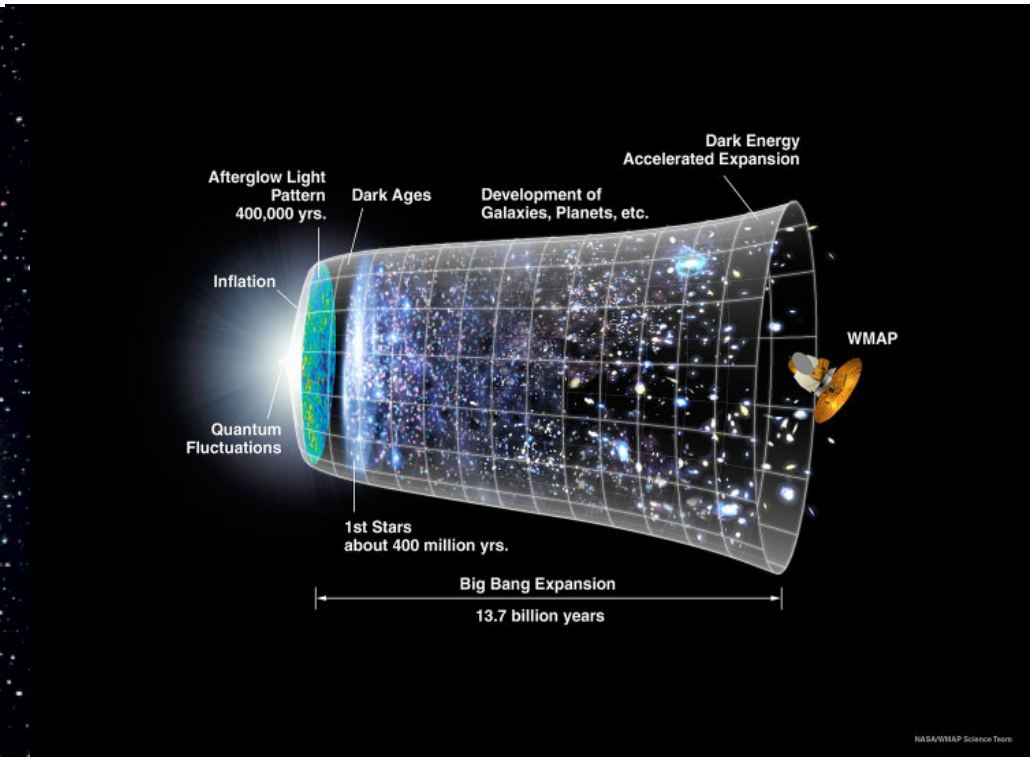


Is that it?

Not really..


73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.
Standard Model!

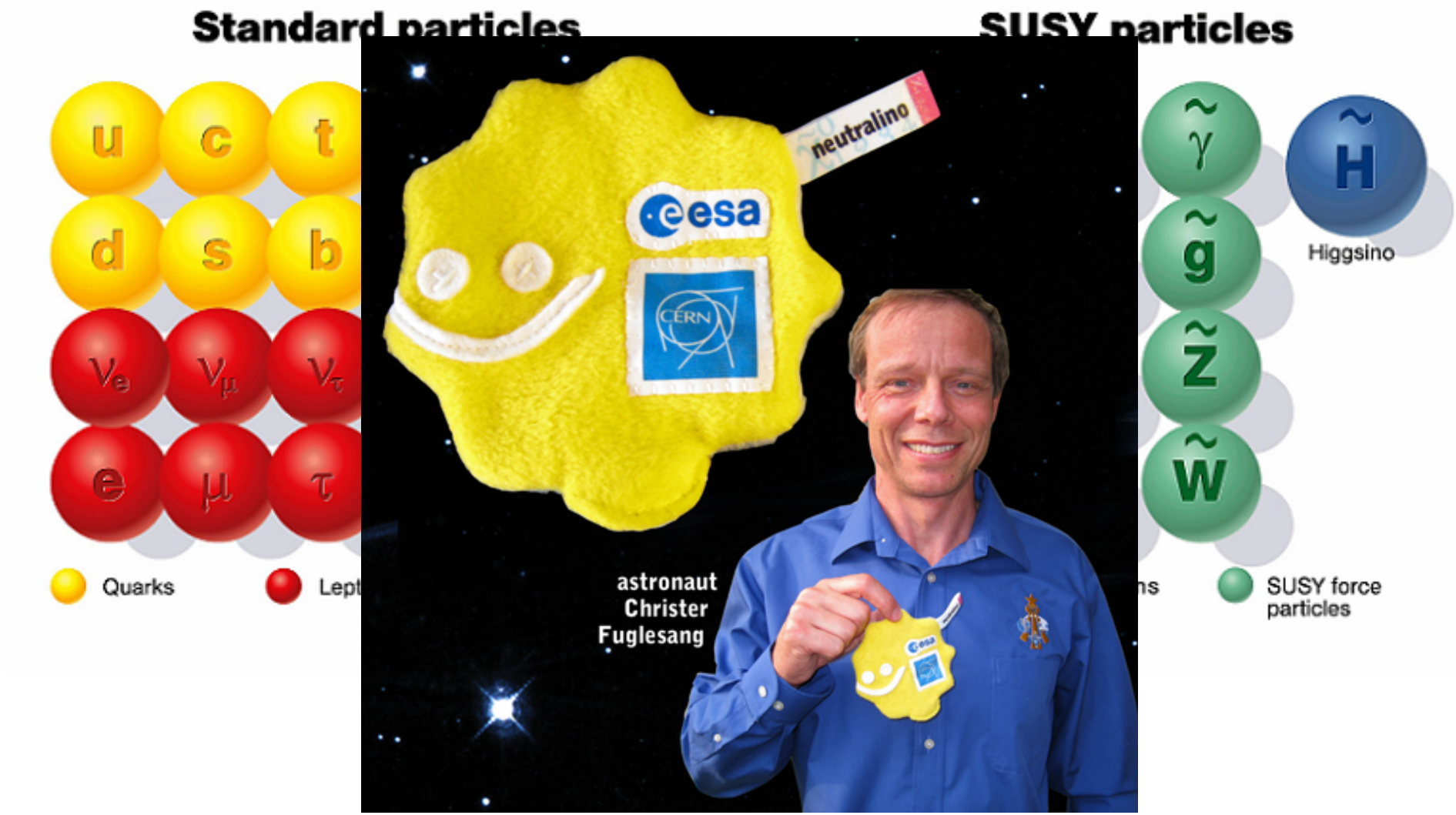
The Dark Side of the Universe

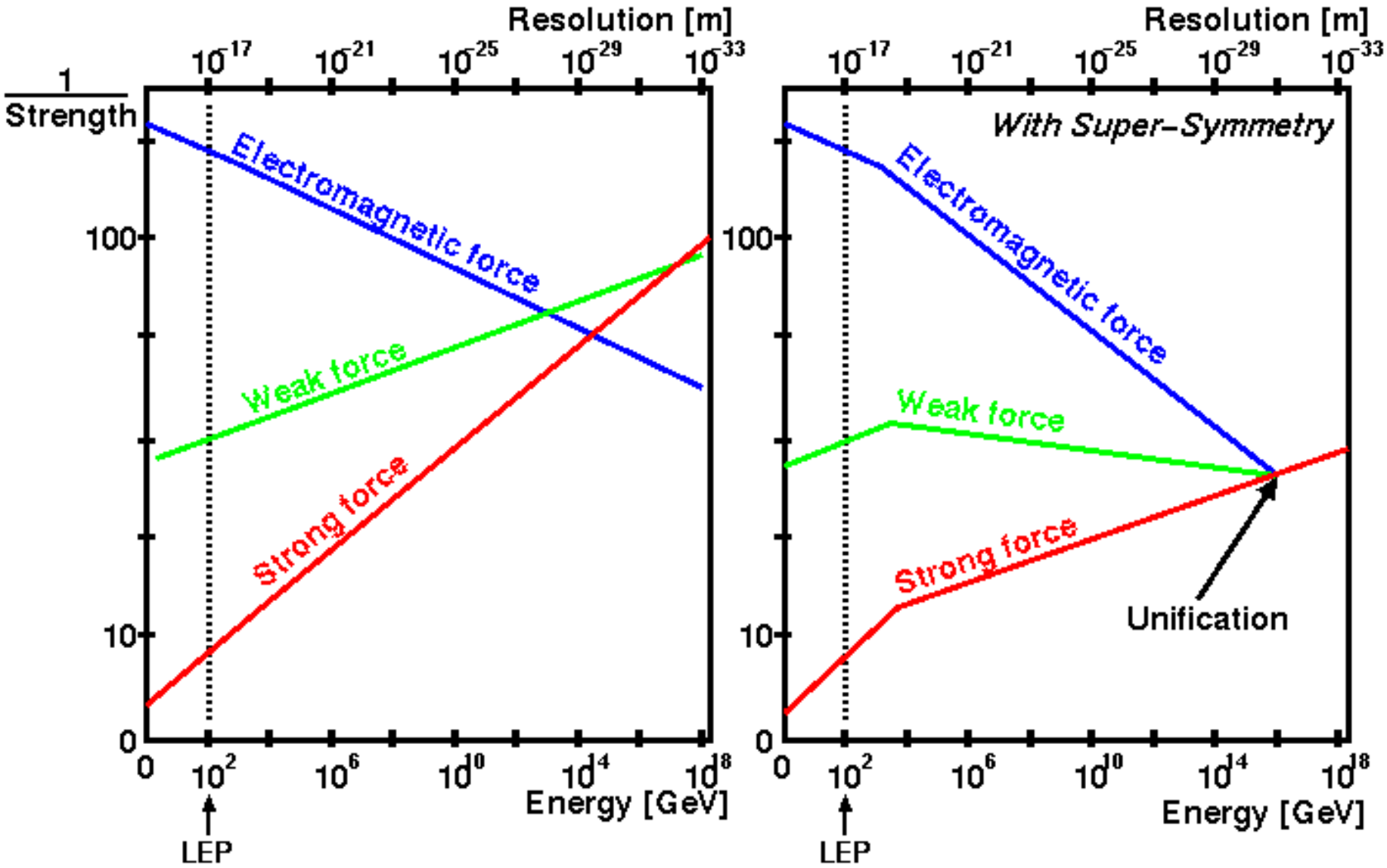


Dark Matter…

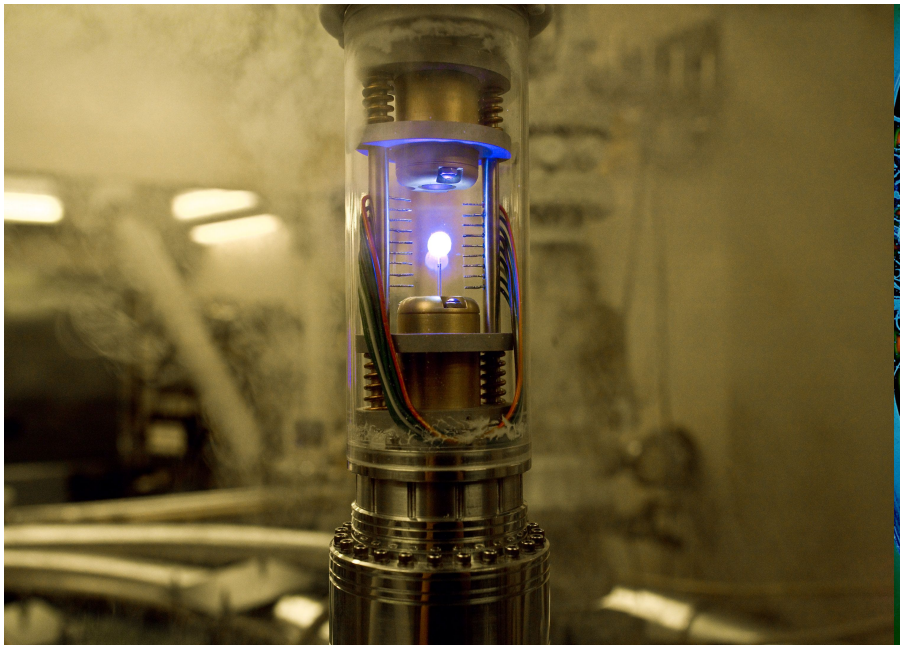
Dark Energy…

Bring on SUSY…

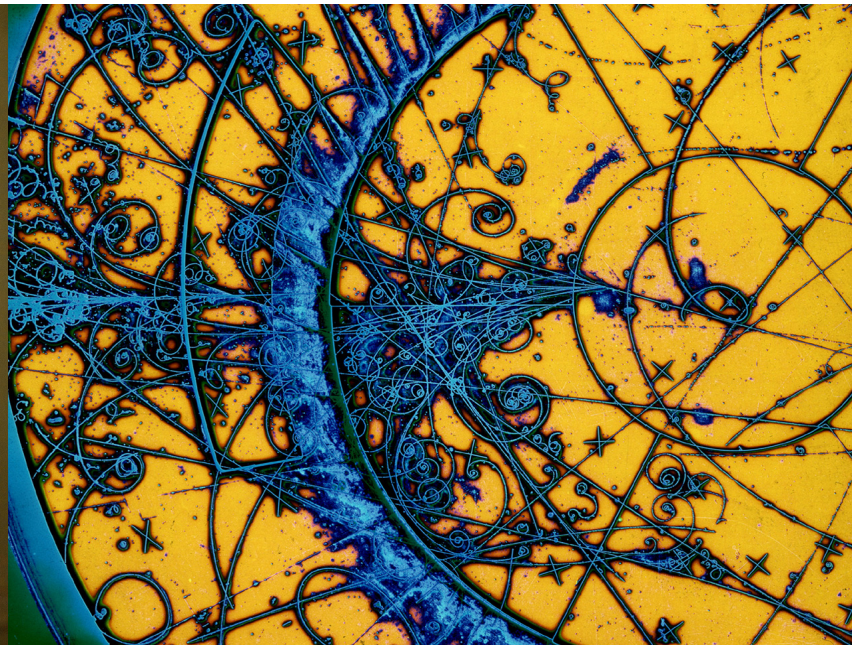



Resolution [m]
10^{-17}
10^{-21}
10^{-25}
10^{-29}
10^{-33}
1
Strength
100
10
0
Electromagnetic force
Weak force
Strong force
0
10^{2}
10^{6}
10^{10}
10^{14}
10^{18}
Energy [GeV]
LEP
Resolution [m]
With Super-Symmetry
Electromagnetic force
Weak force
Strong force
Unification
Energy [GeV]
LEP

Antimatter

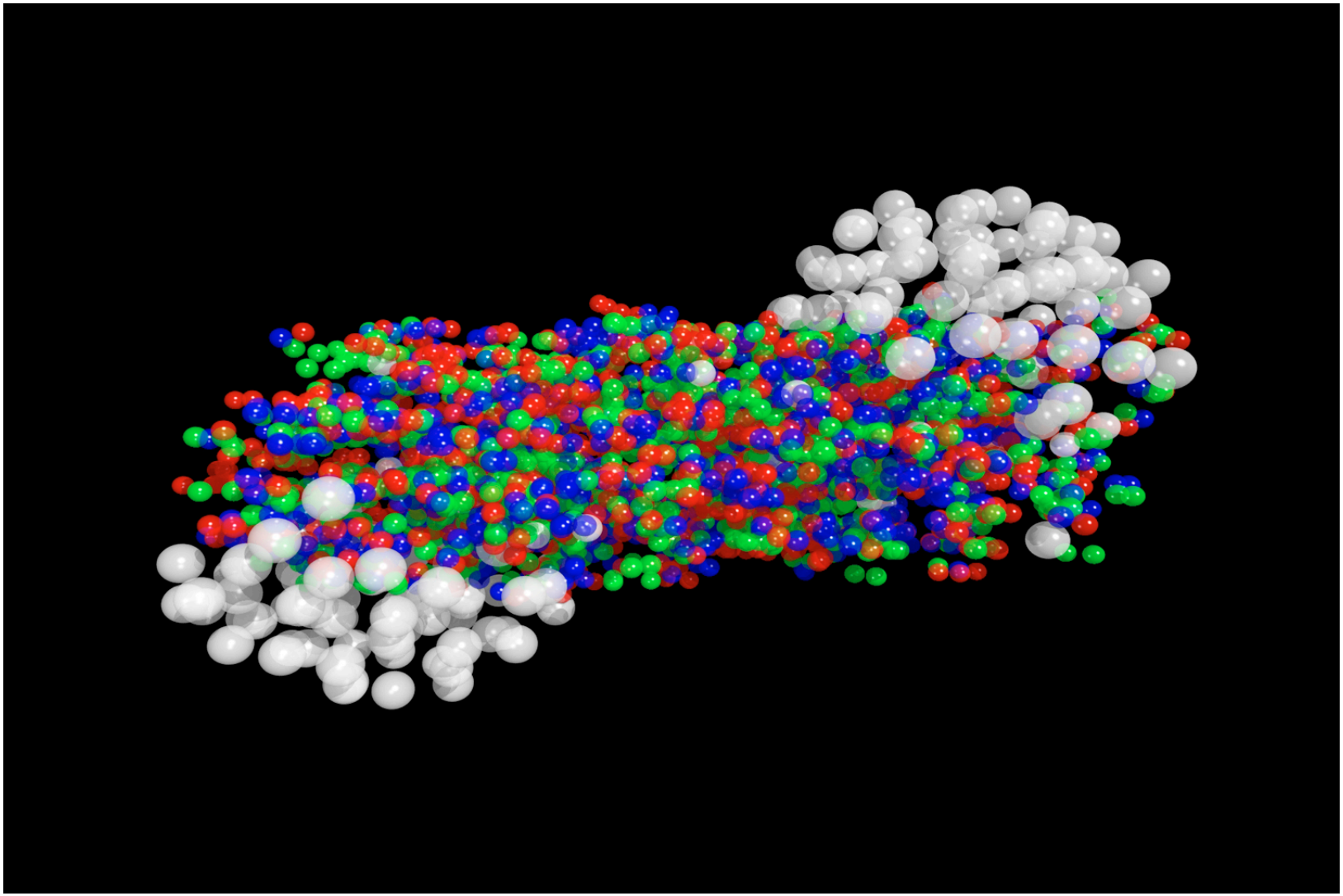


Hollywood

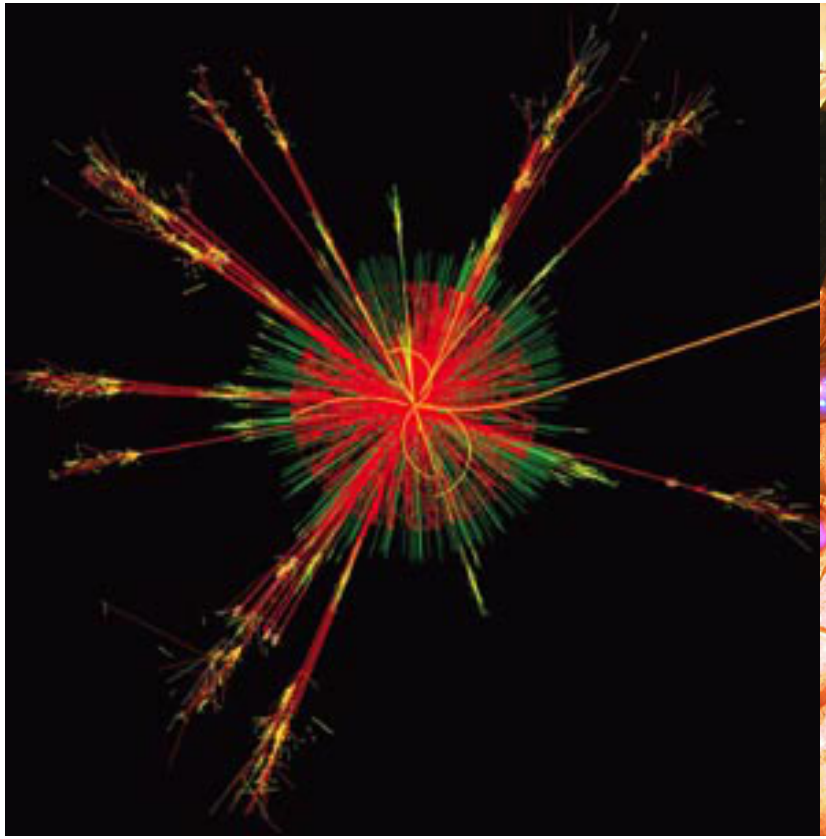


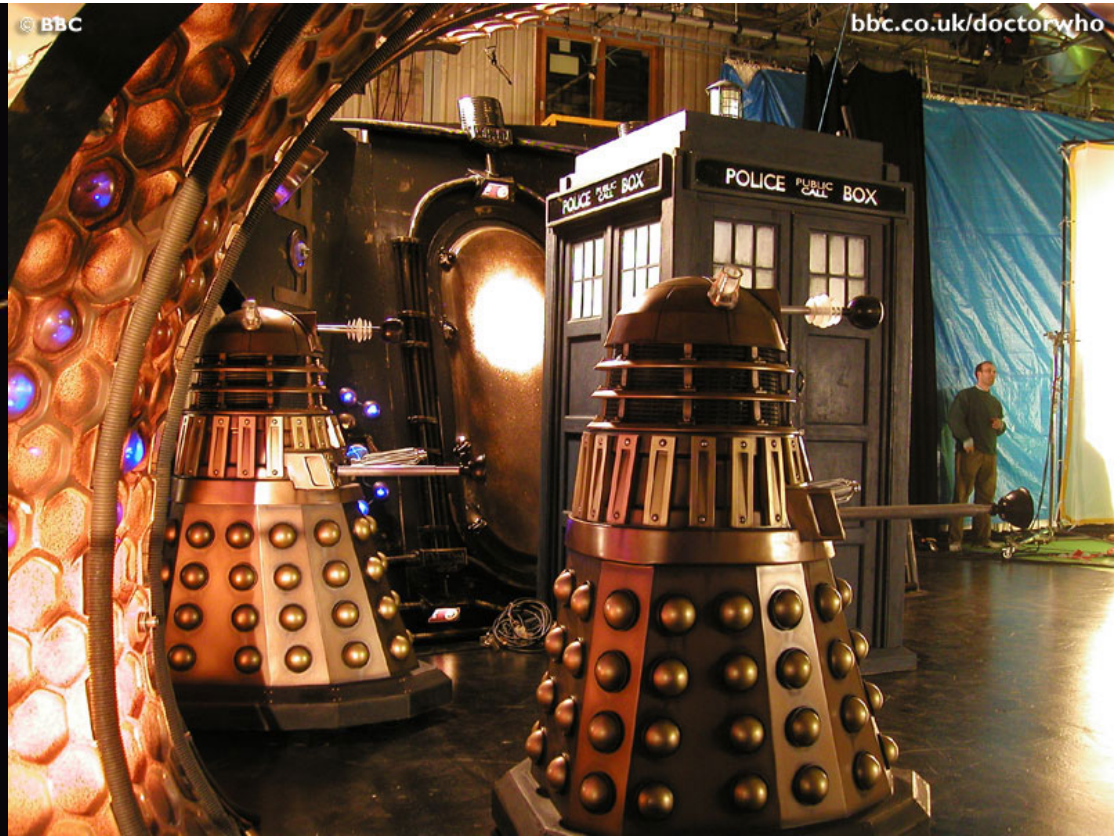
CERN

Primordial soup

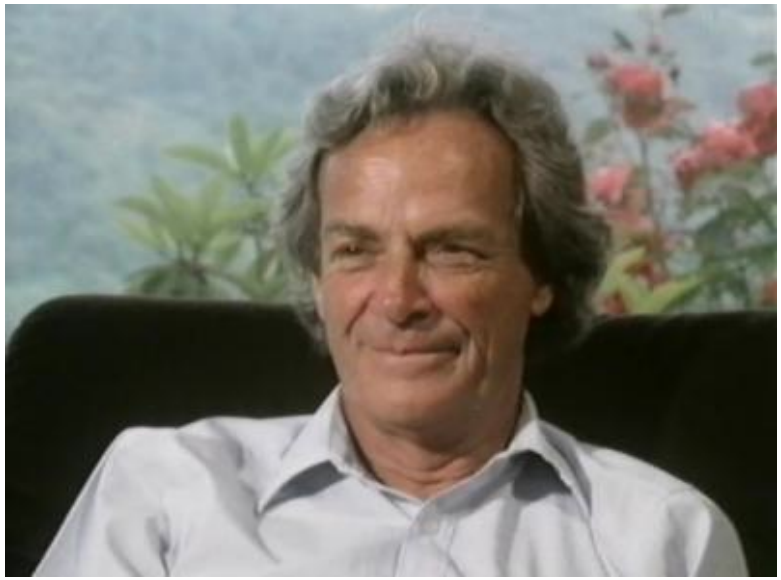


Where science and science fiction meet

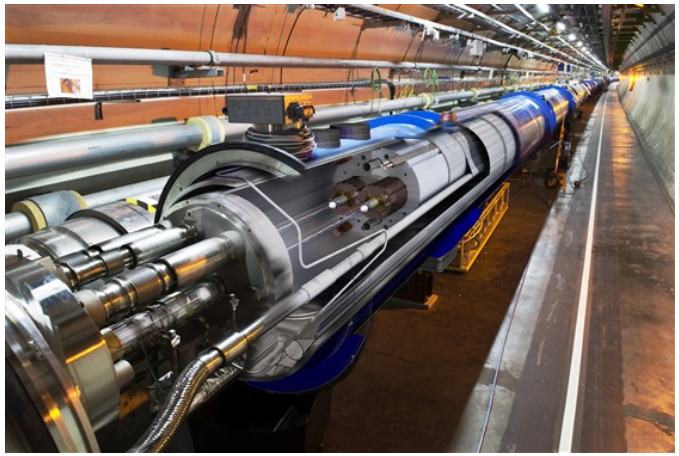


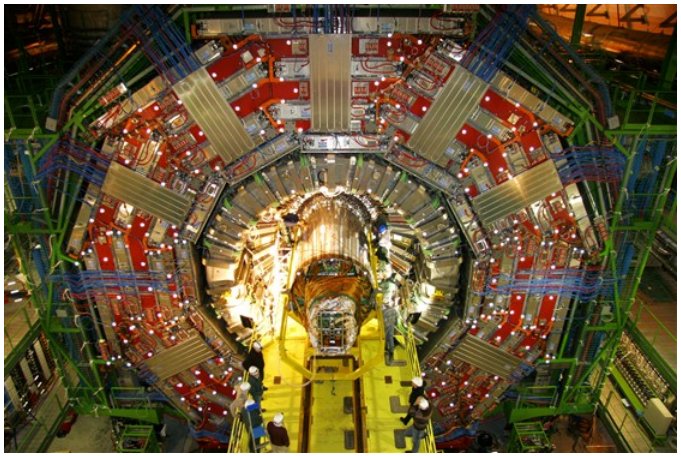


Does all this make you feel small?



How do we measure these things?

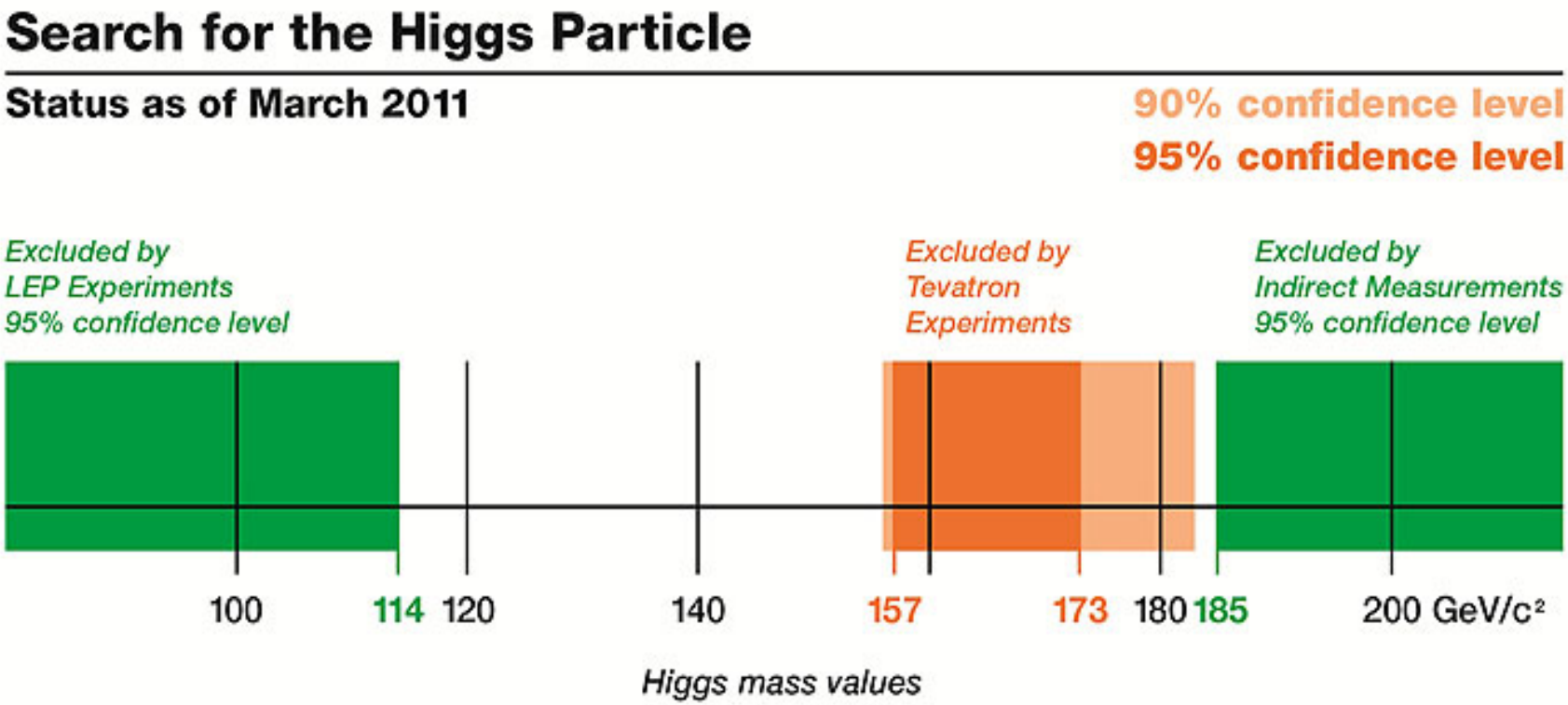




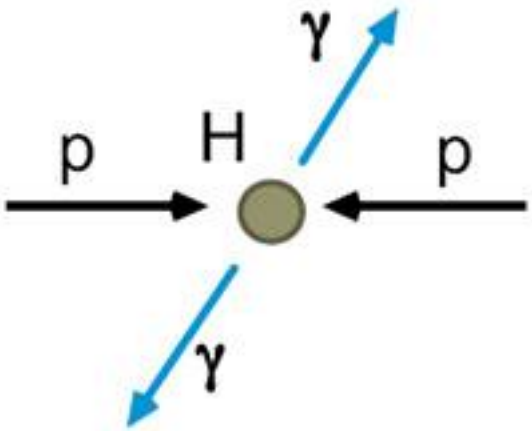
LHC + detectors + Grid = fantastic discovery machine.

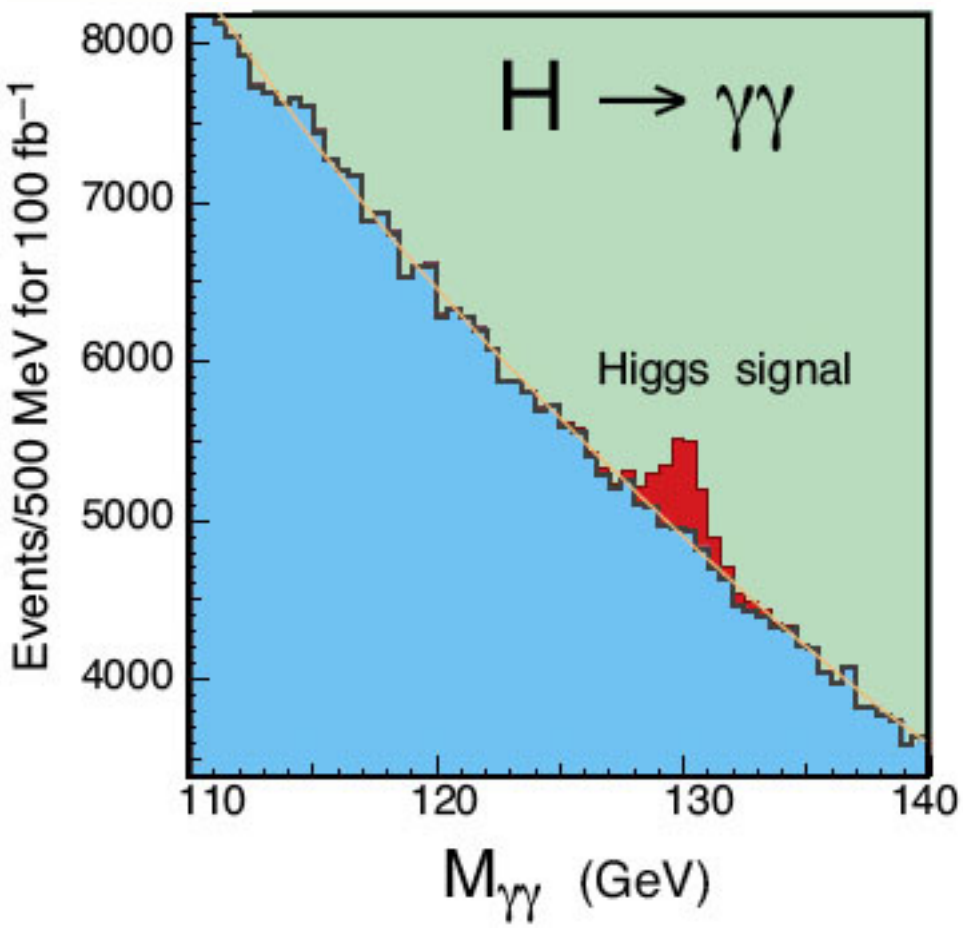
What's LHC got to do with it?

$E = mc^2$

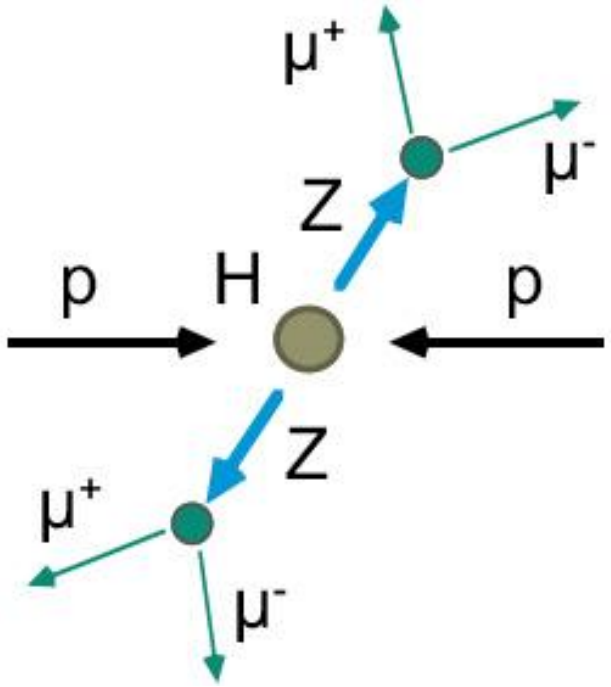


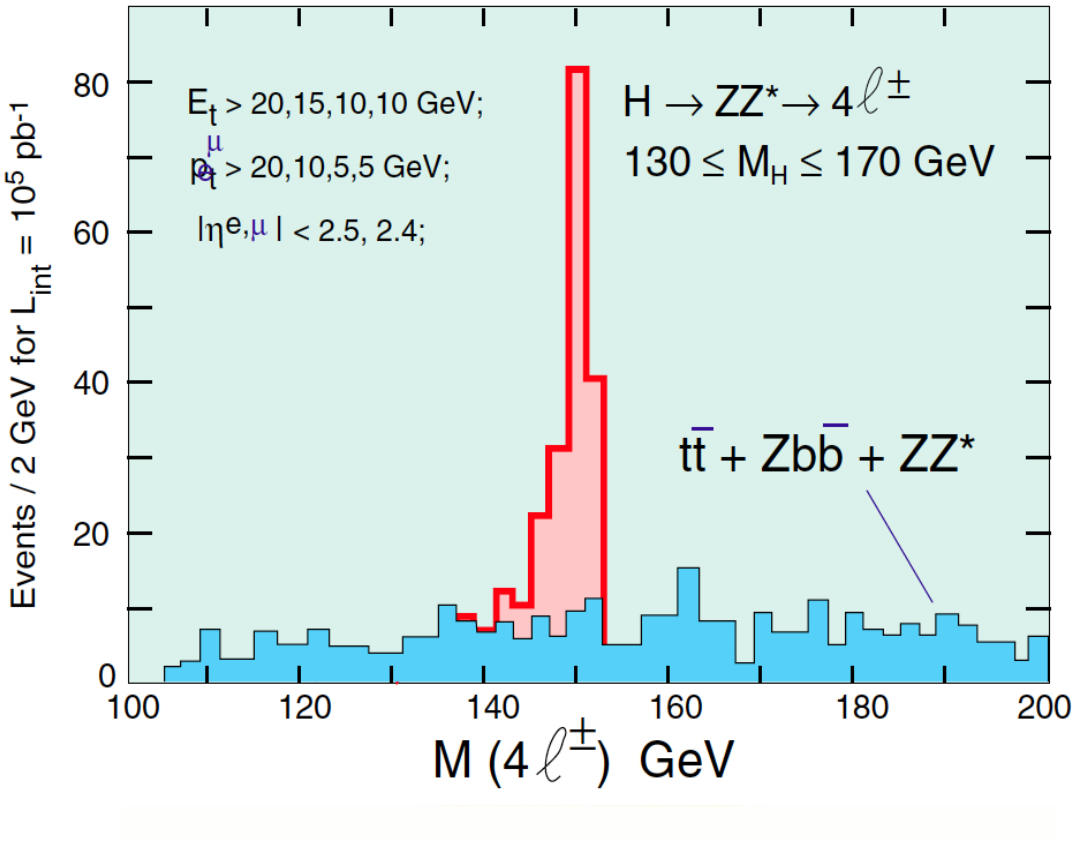
Bump hunting…



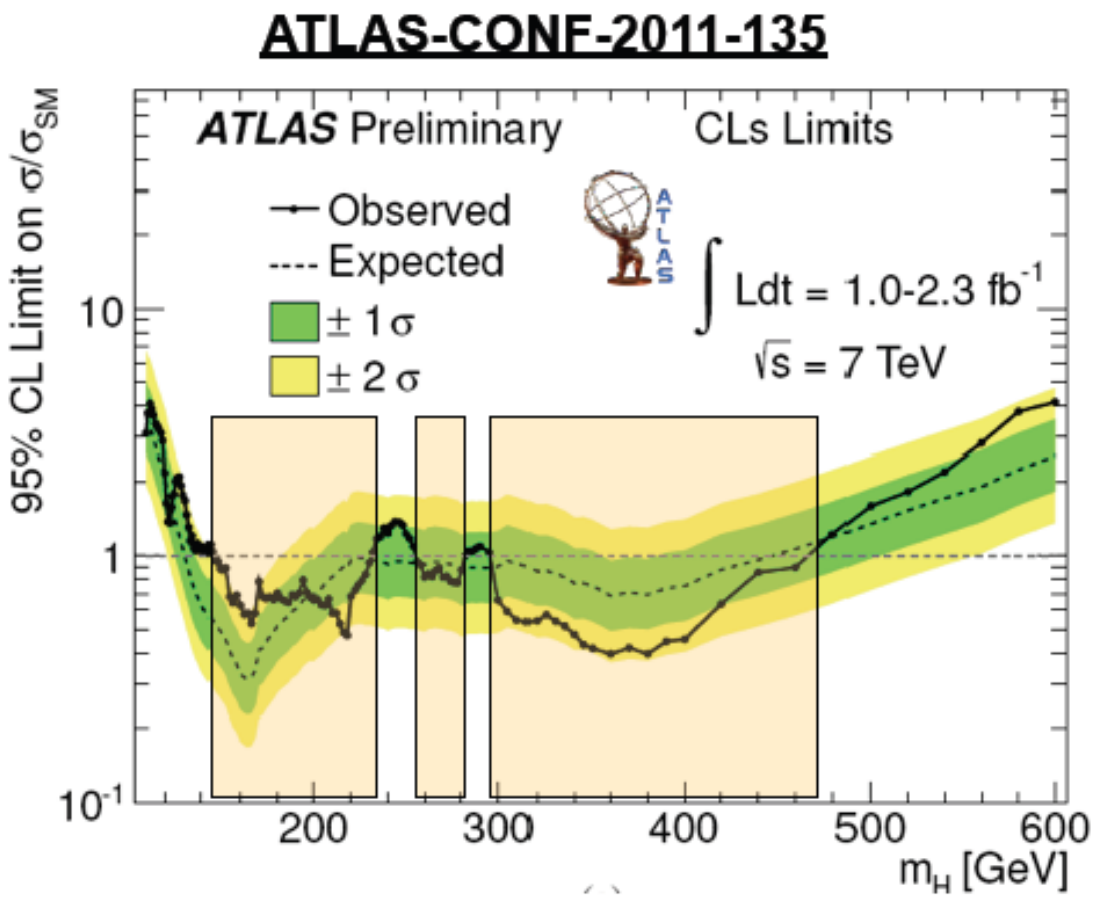


Bump hunting…



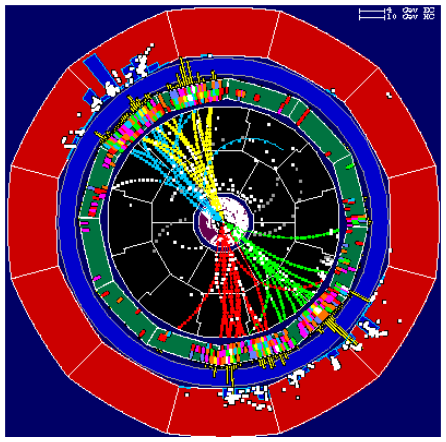


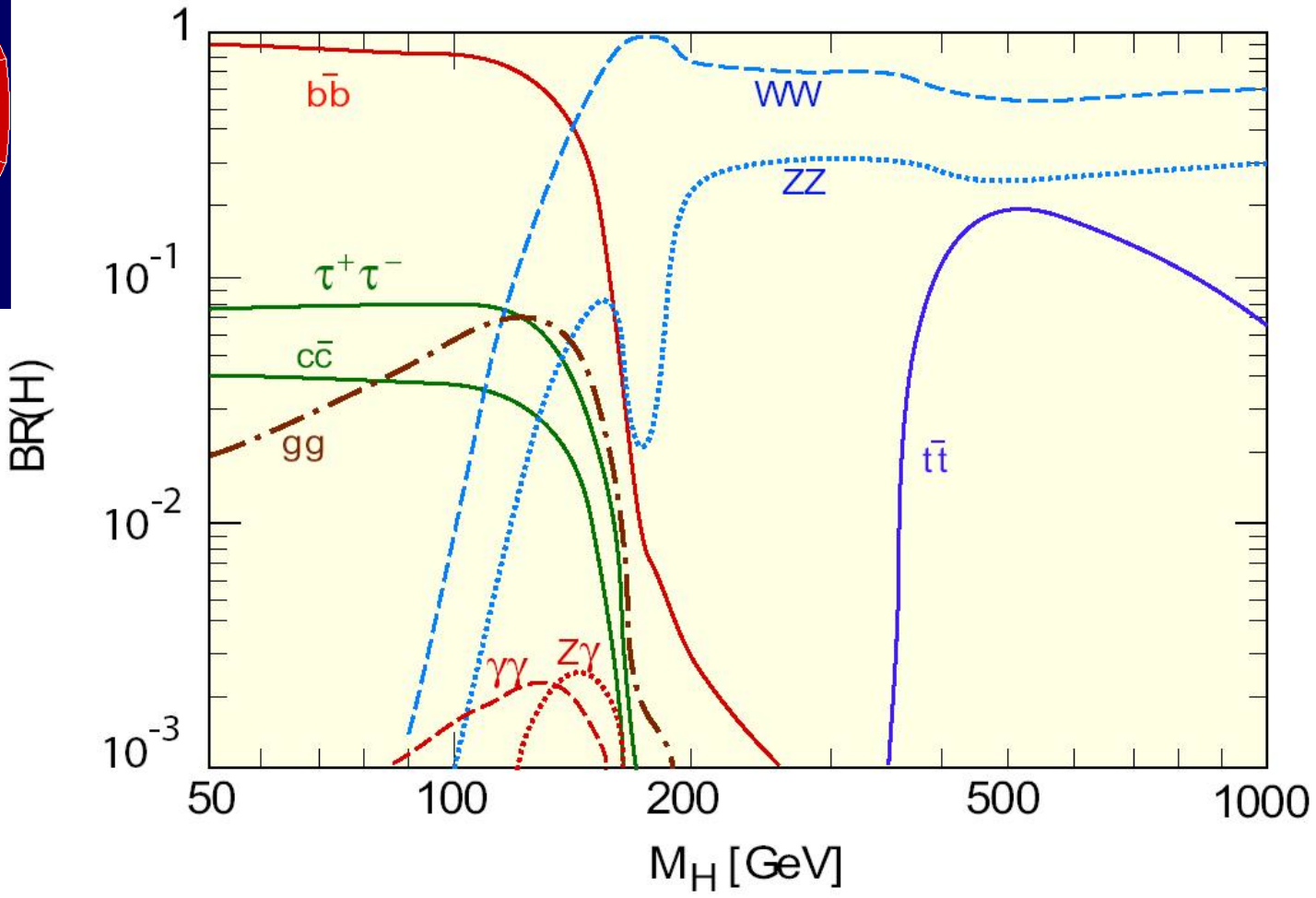
Latest results from the LHC

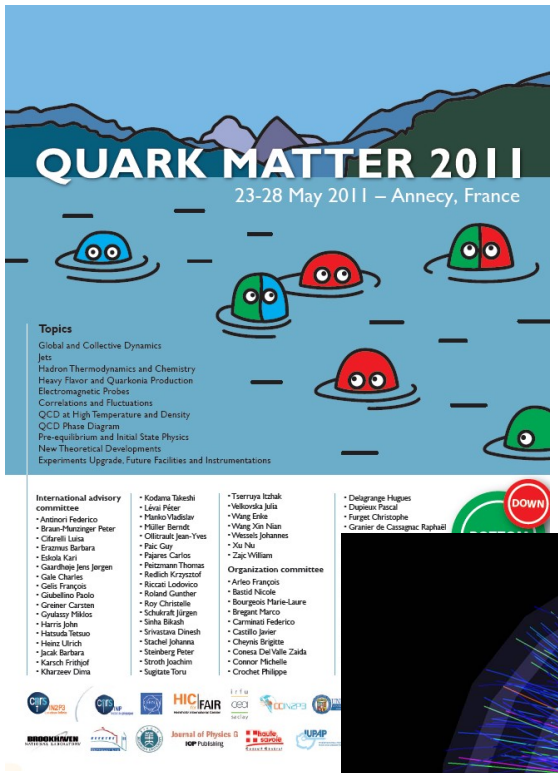


Higgs is 115 GeV – 145 GeV – or nowhere

Light Higgs

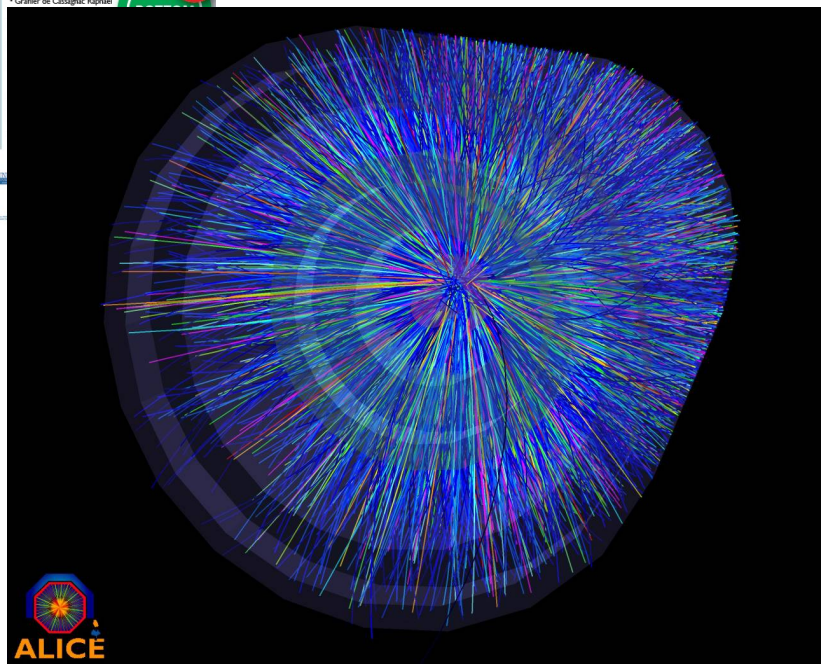



1
10^{-1}
10^{-2}
10^{-3}
BR(H)
$b\bar{b}$
WW
ZZ
$\tau^+\tau^-$
$c\bar{c}$
gg
$t\bar{t}$
$\gamma\gamma$
$Z\gamma$
50
100
200
500
1000
M_H [GeV]

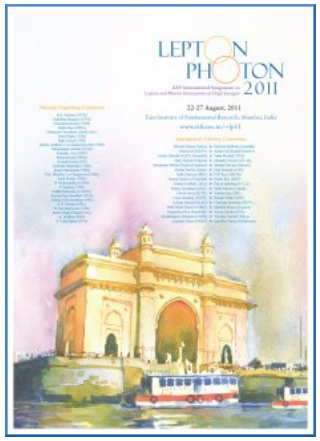


ALICE

The early universe was a liquid… denser than neutron stars.

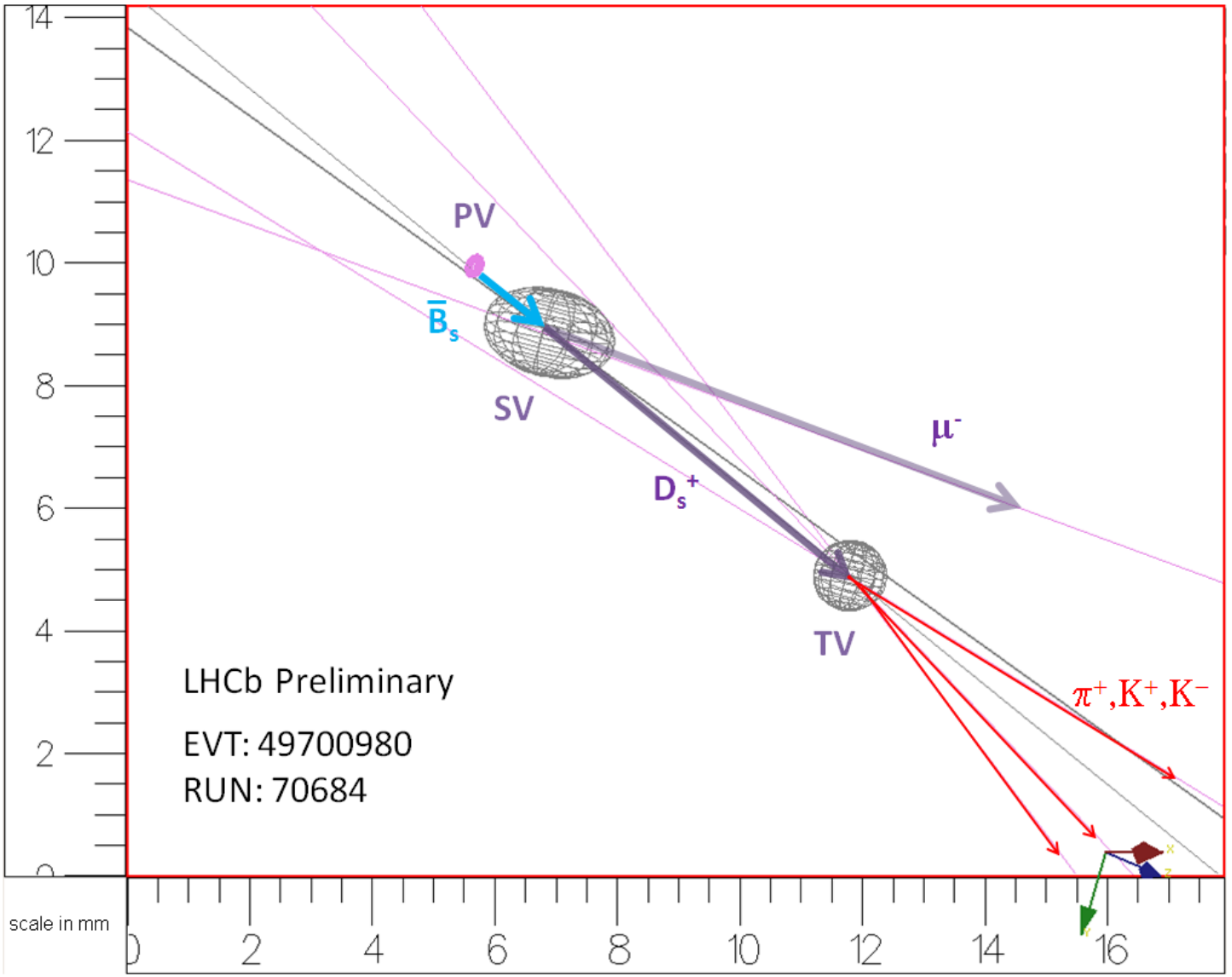


The entire human population squashed to the size of a sugar cube…

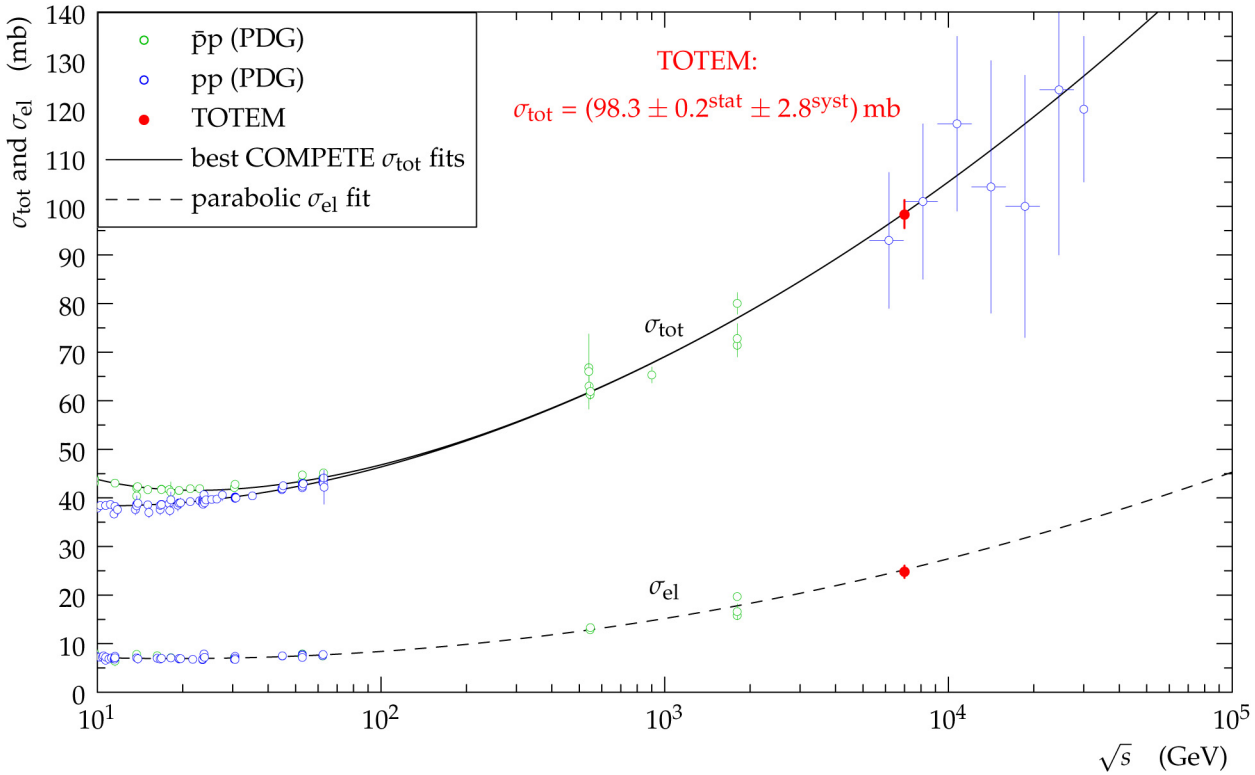


LHCb

$Bs \rightarrow J/\psi\ \varphi$



TOTEM


p̄p (PDG)
pp (PDG)
TOTEM
best COMPETE σ_{tot} fits
parabolic σ_{el} fit
TOTEM:
$\sigma_{tot} = (98.3 \pm 0.2^{stat} \pm 2.8^{syst})$ mb
σ_{tot}
σ_{el}
σ_{tot} and σ_{el} (mb)
$\sqrt{s}$ (GeV)


Next time….
The Large Hadron Collider:
The world’s most complex machine