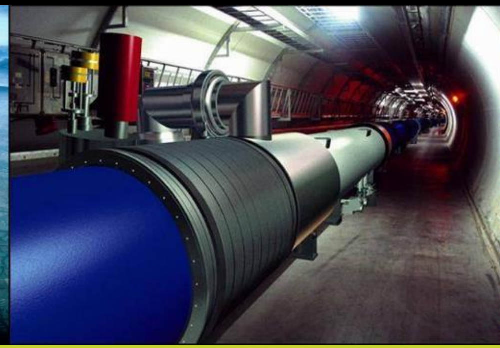
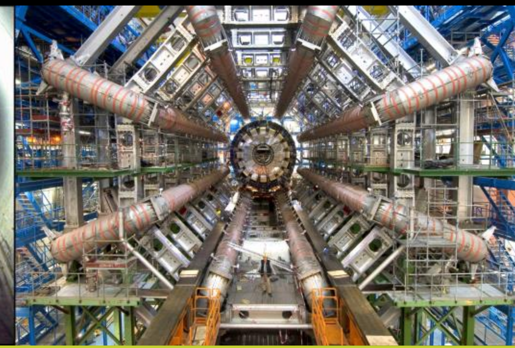
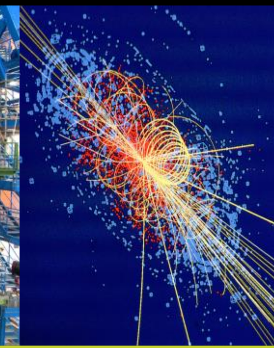
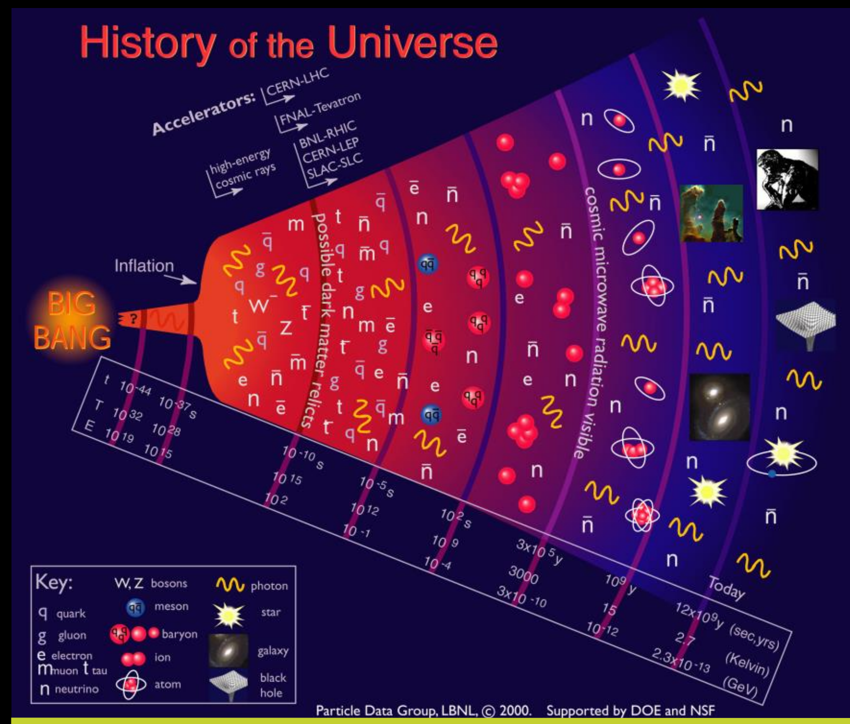





Uncovering the Universe with the LHC

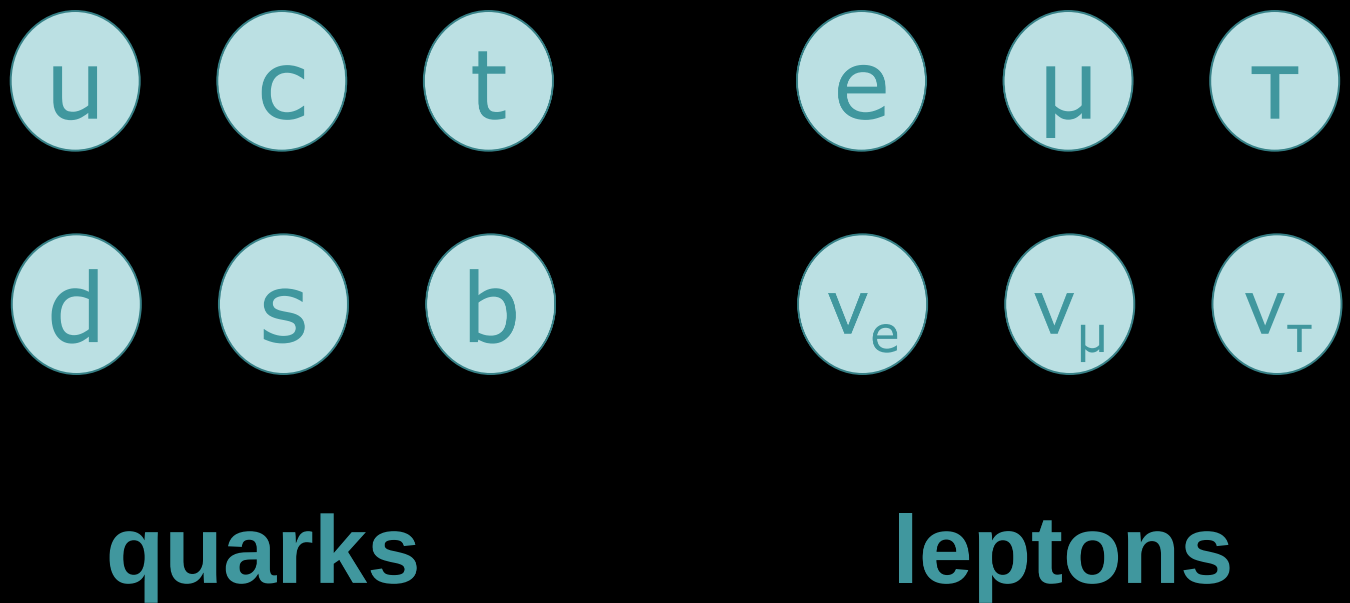
BIG BANG

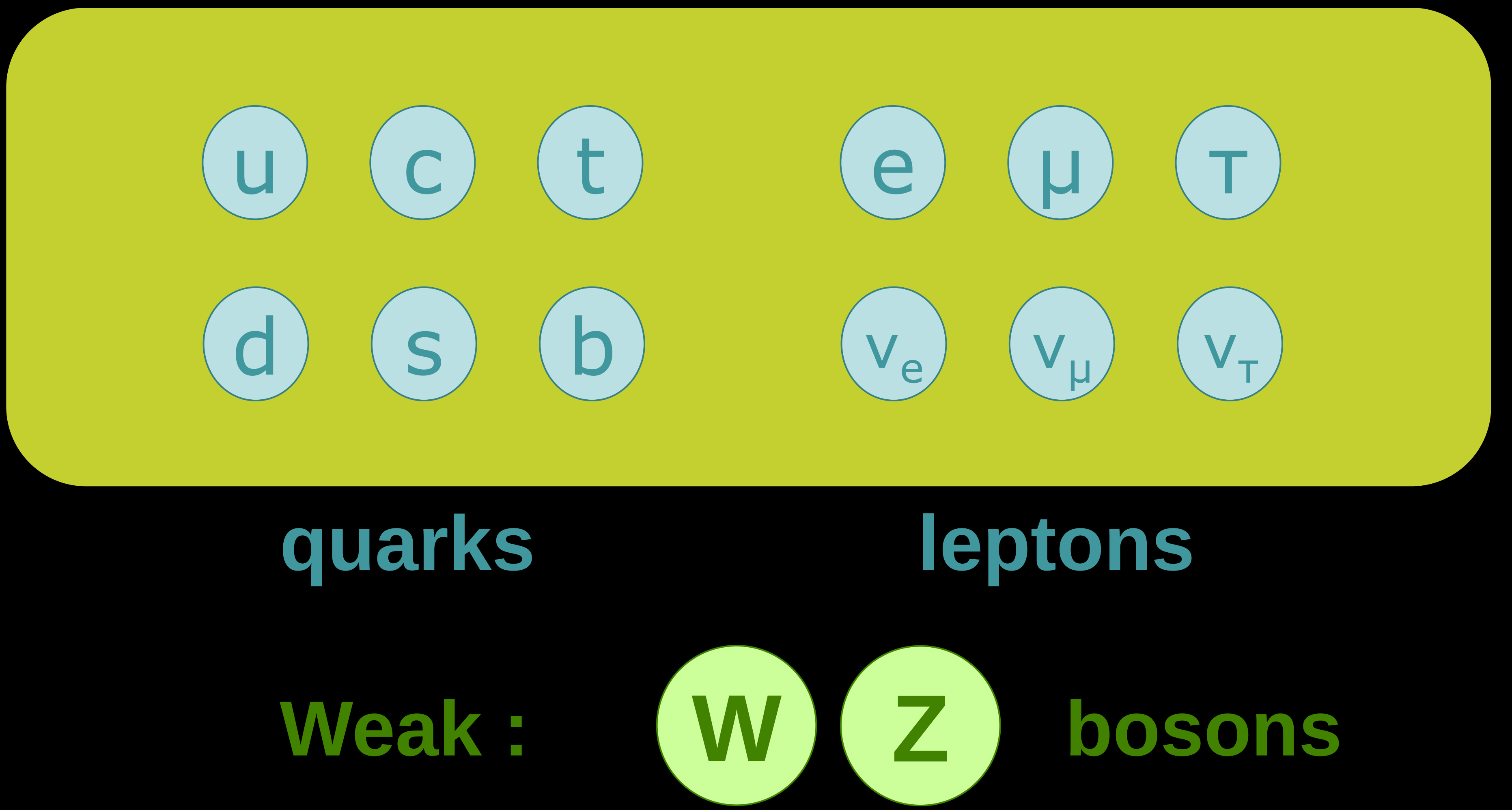


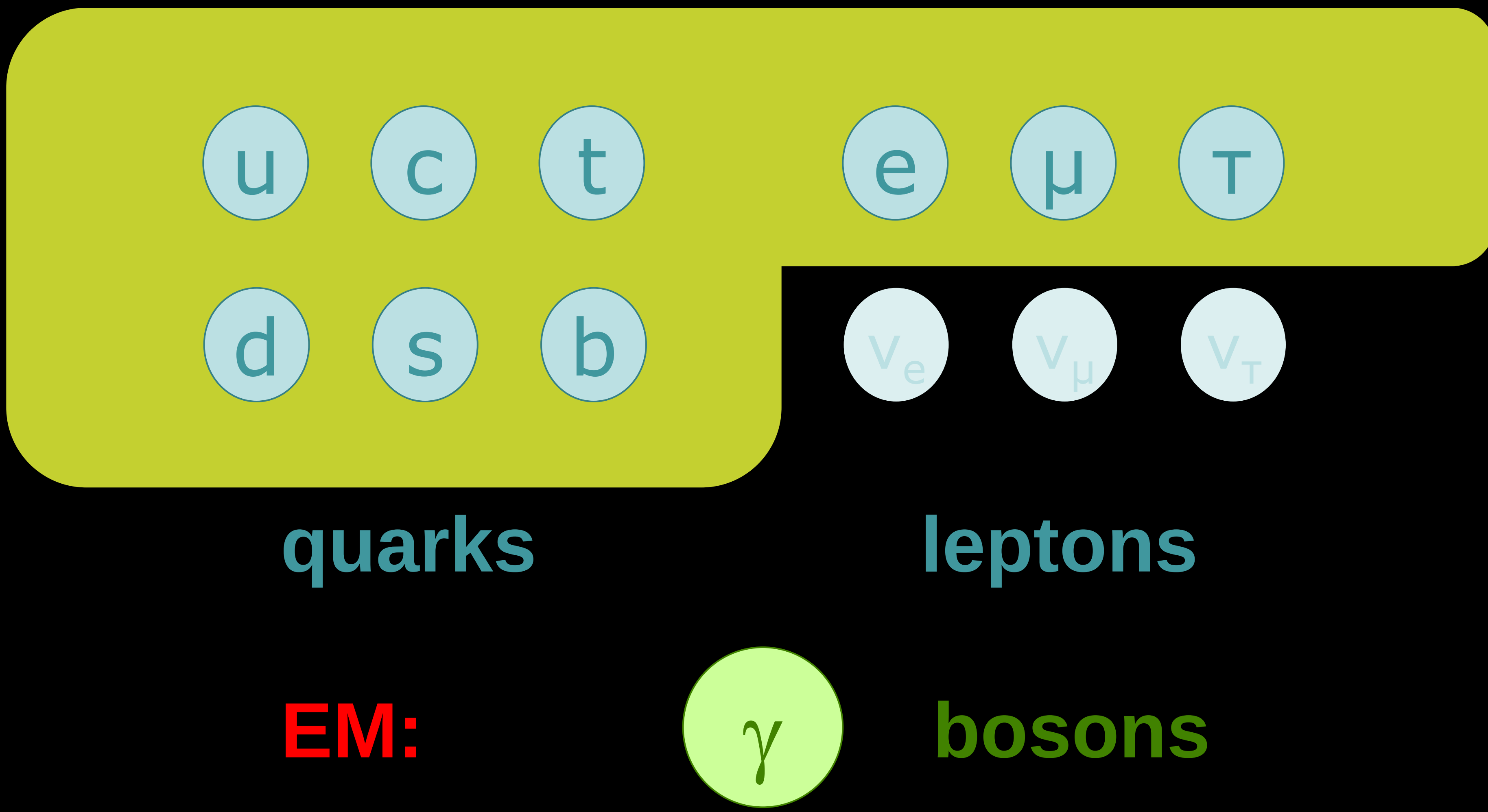
History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
Today
Key:
W, Z bosons
photon
quark
meson
star
gluon
baryon
electron
ion
galaxy
muon
tau
neutrino
atom
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

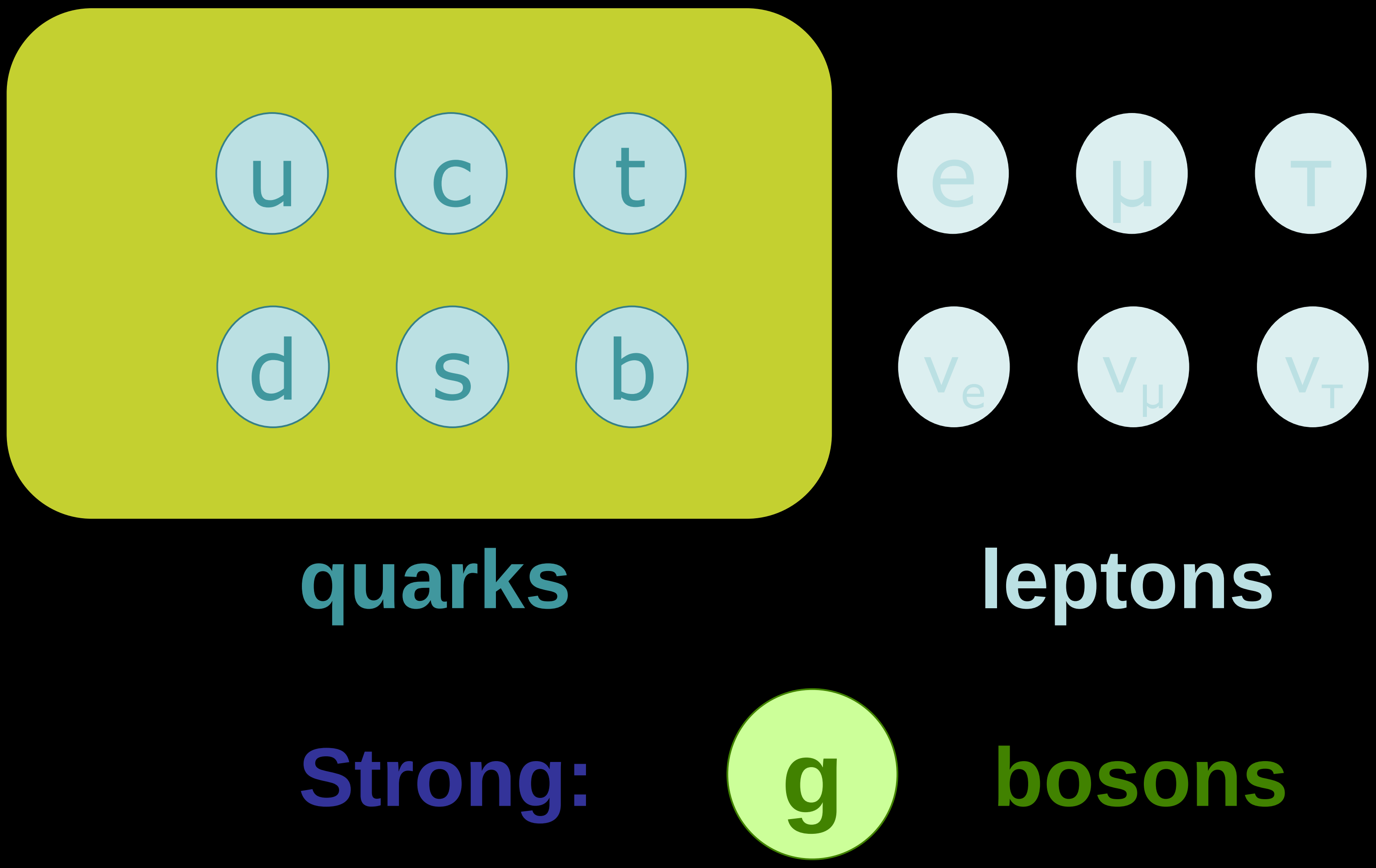
NOW

> > >


u c t
d s b
quarks
e μ τ
ν_e ν_μ ν_τ
leptons


u
c
t
e
μ
τ
d
s
b
ν_e
ν_μ
ν_τ
quarks
leptons
Weak :
W
Z
bosons

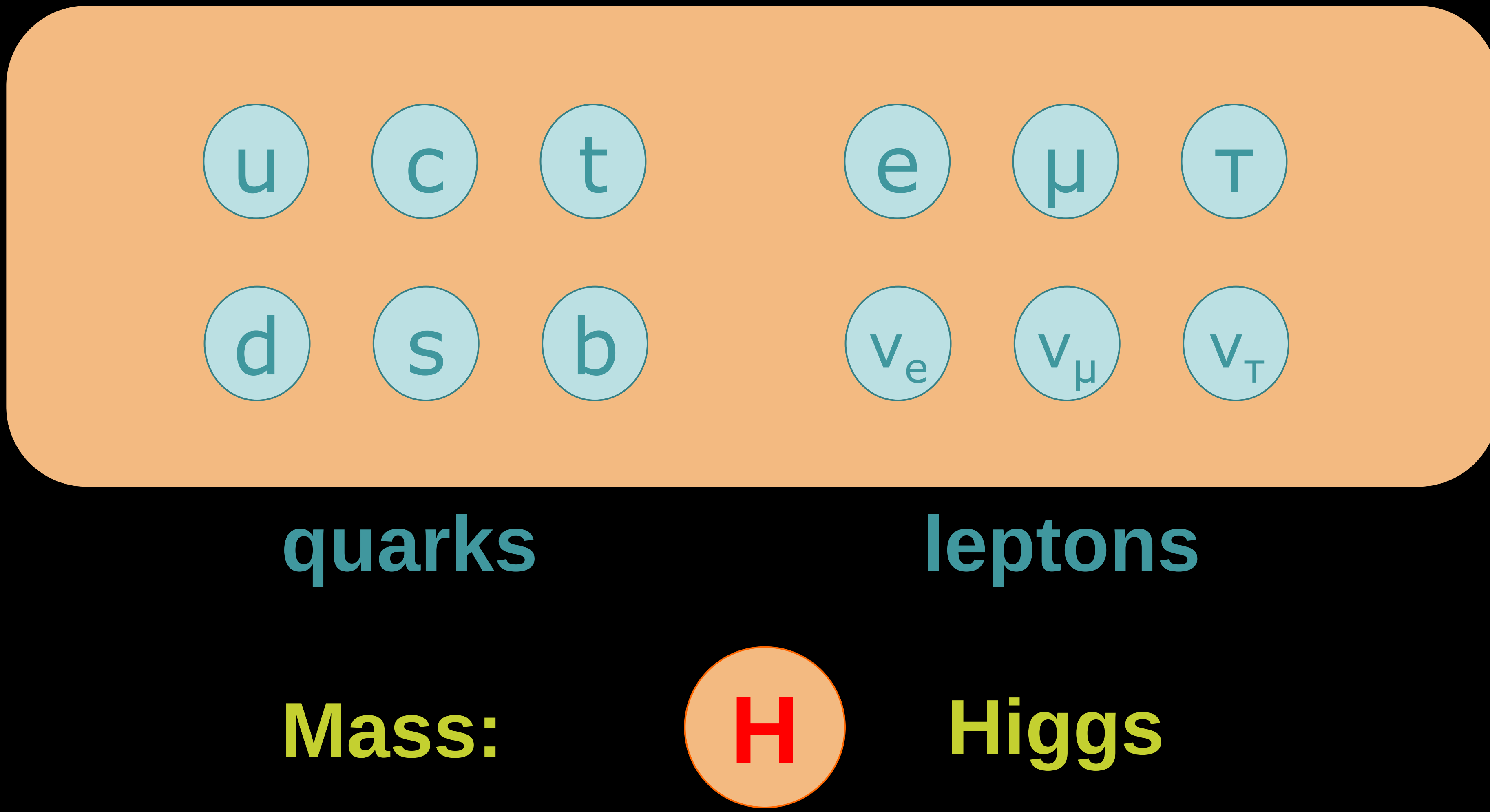

u
c
t
e
μ
τ
d
s
b
ν e
ν μ
ν τ
quarks
leptons
EM:
γ
bosons

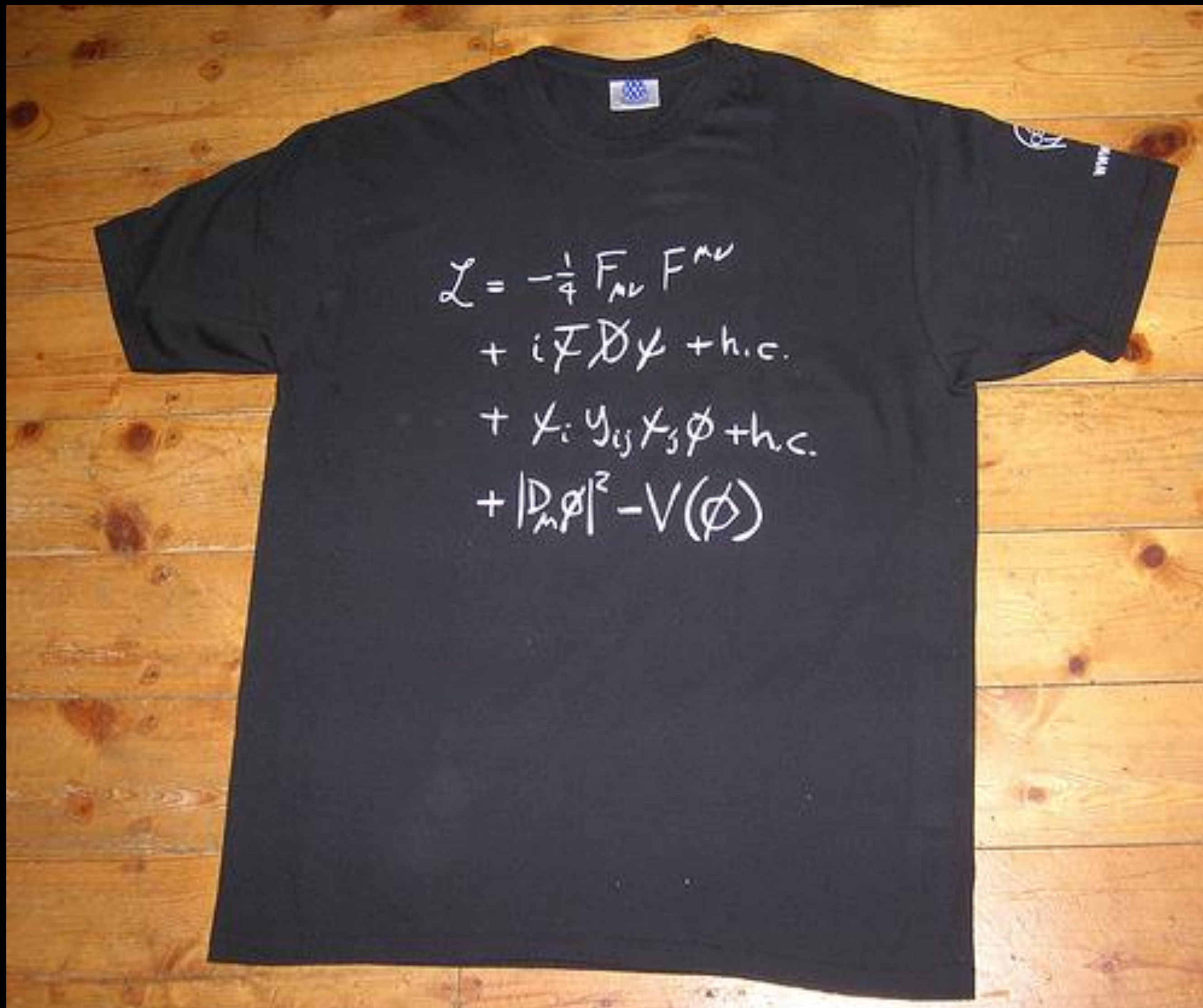

u
c
t
e
μ
τ
d
s
b
ν_e
ν_μ
ν_τ
quarks
leptons
Strong:
g
bosons

u	c	t	e	μ	τ
d	s	b	ν_e	ν_μ	ν_τ

quarks **leptons**

(and gravity) **?**

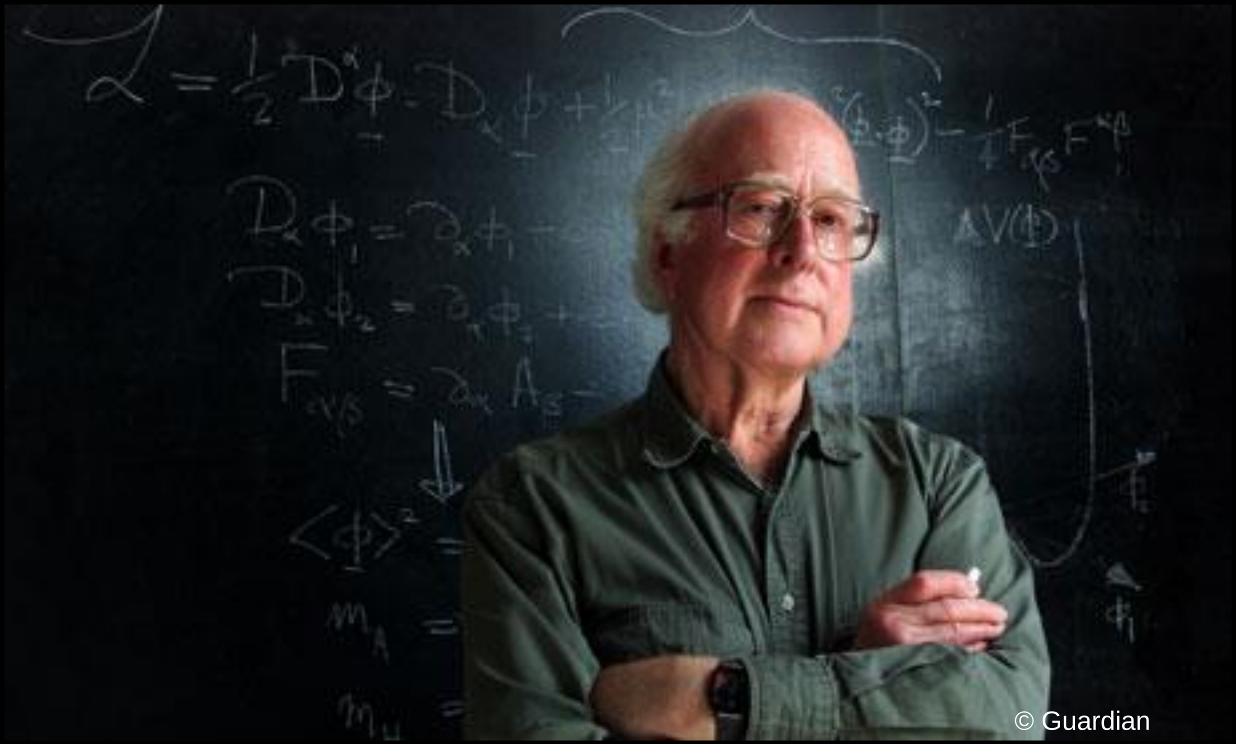

u
c
t
e
μ
τ
d
s
b
ν_e
ν_μ
ν_τ
quarks
leptons
Mass:
H
Higgs


$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$+ i \bar{\psi} \not{D} \psi + h.c.$
$+ \psi_i y_{ij} \psi_j \phi + h.c.$
$+ |D_\mu \phi|^2 - V(\phi)$

nice …

BUT

(0) is the Higgs ….
really the Higgs ?


© Guardian

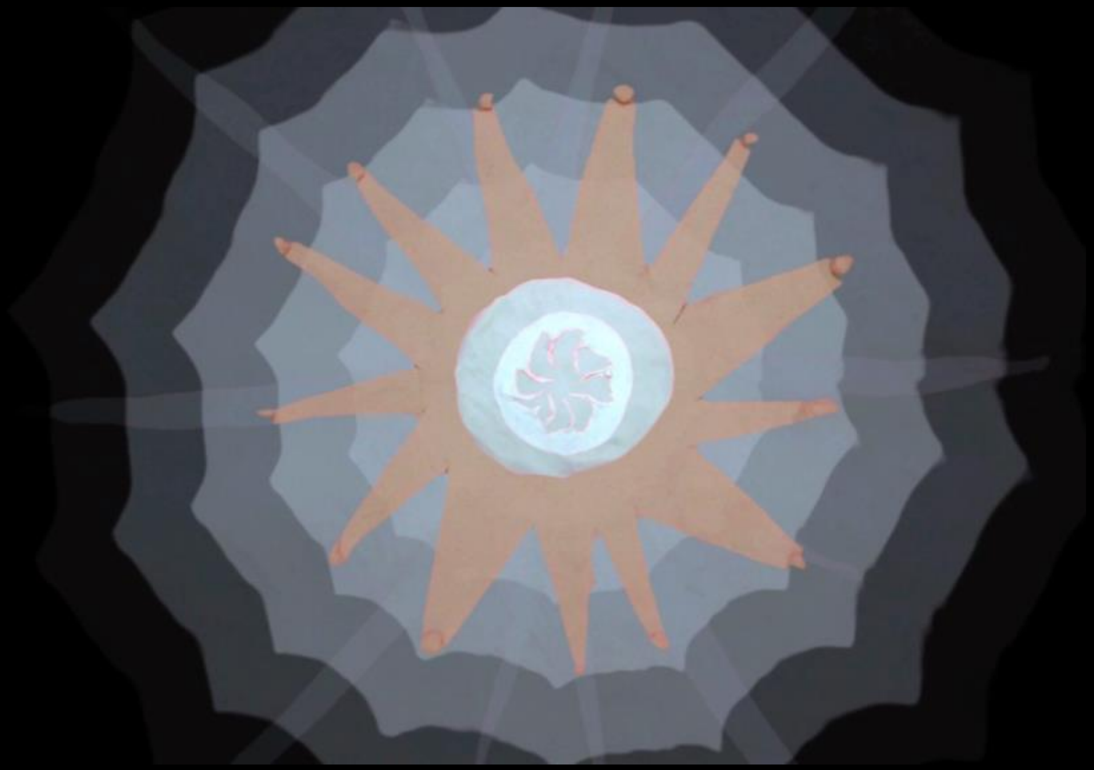
(1)

anti matter

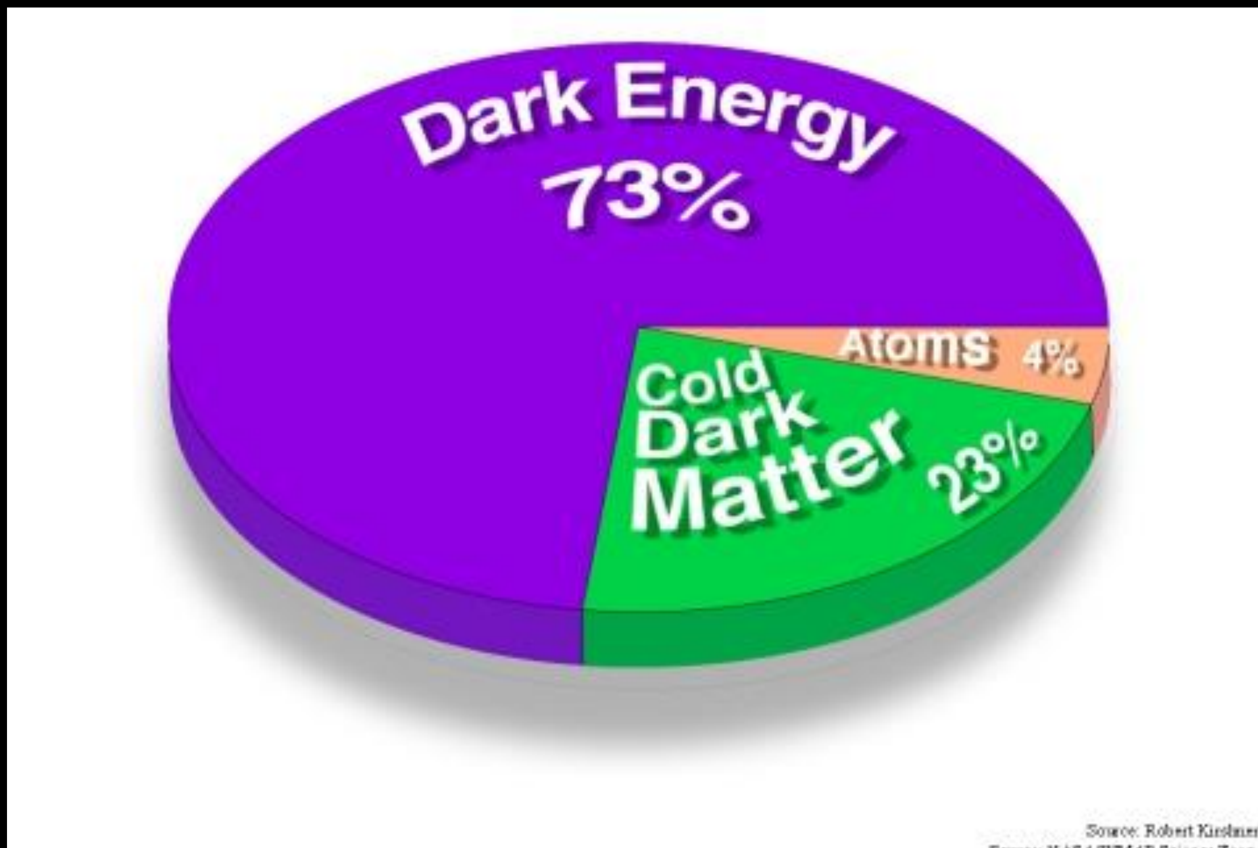
Big Bang:
equal amounts of matter
and antimatter created

Now:
we (matter) exist

Why?



(2)
and the other 96% ?



Many questions….

How many dimensions?

What is mass?

What about gravity?

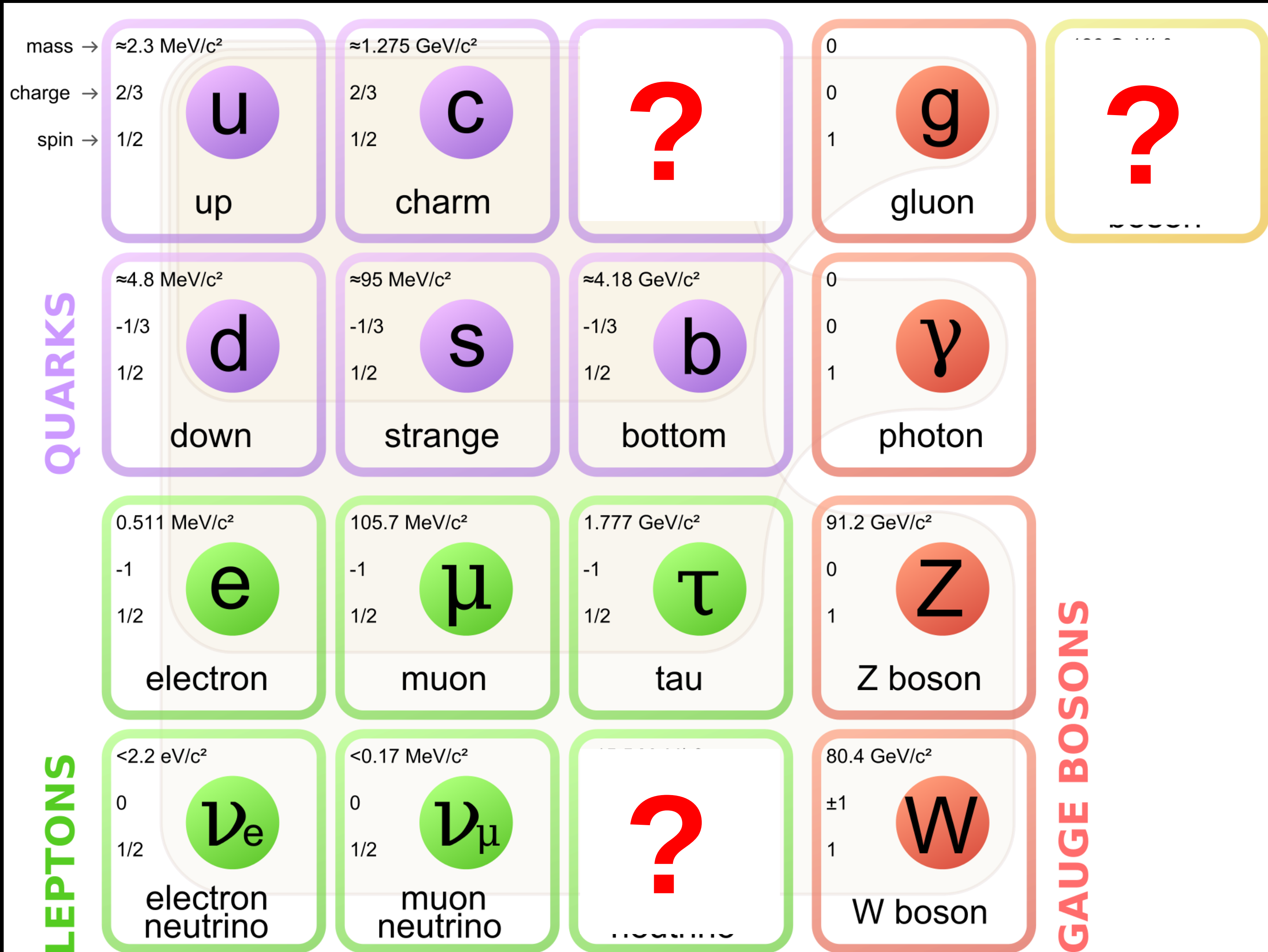
4 forces?

Where did all the antimatter go?

12 matter particles?

Mini black holes?

What about the other 96% of the universe …..


mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
?
0
0
1
g
gluon
?
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
?
80.4 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS

European Laboratory for Particle Physics

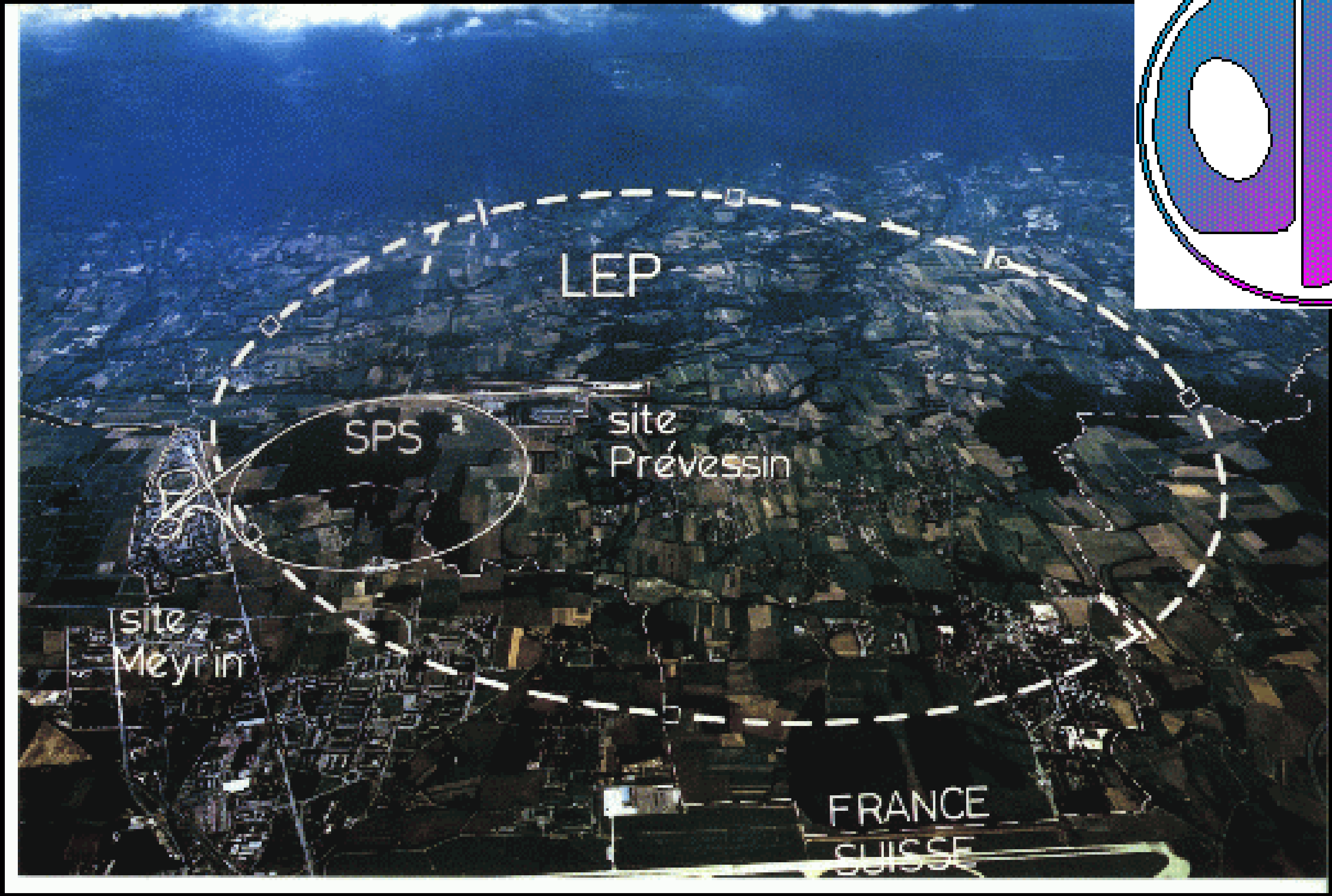
Founded in **1954**

20 member countries

More than **9,000** scientists

Over **100** nationalities

1991 - 2000

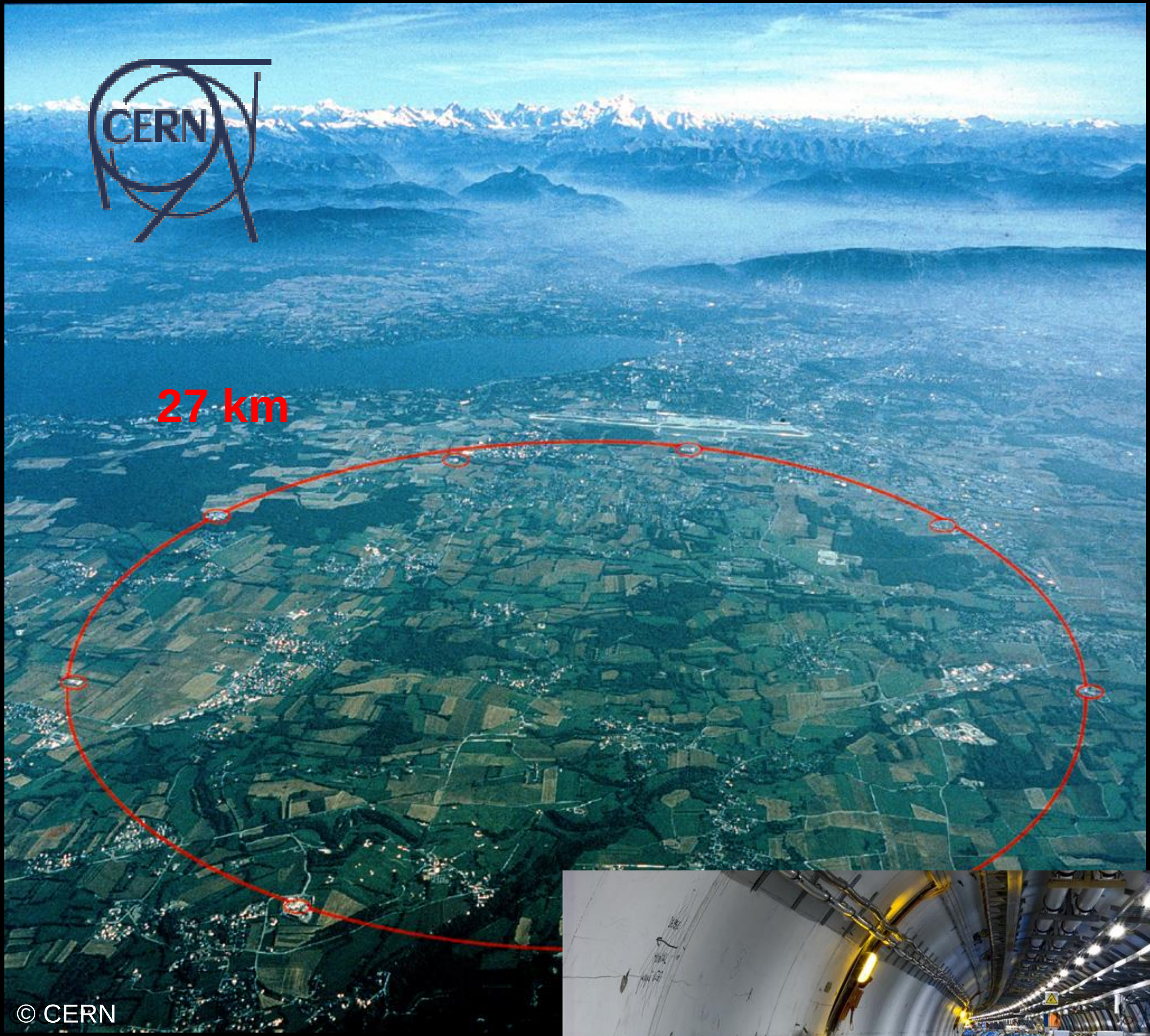


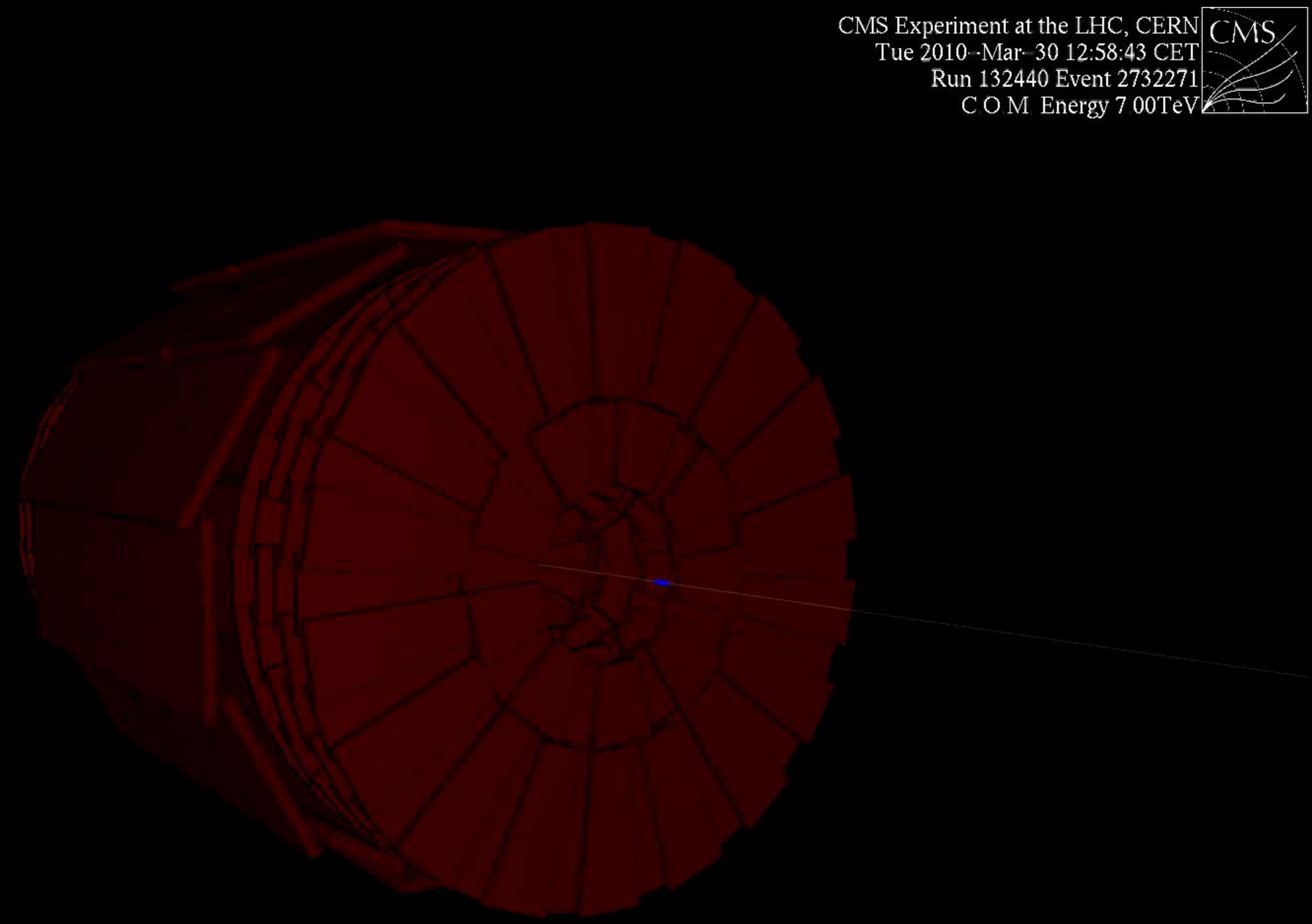
2000 -

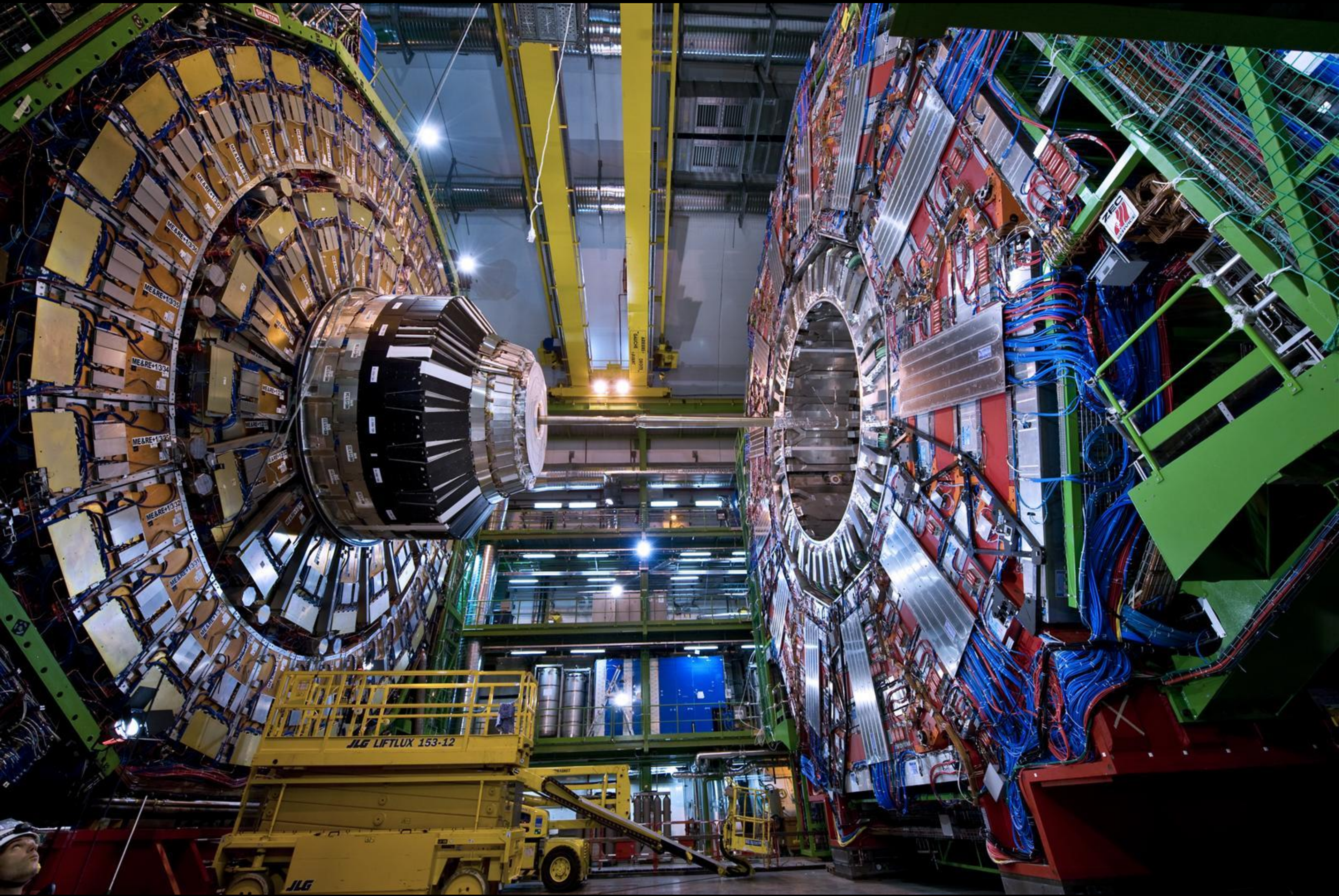
LHC:

2 beams of protons collide 40 million x a second at near light speed 100m underground

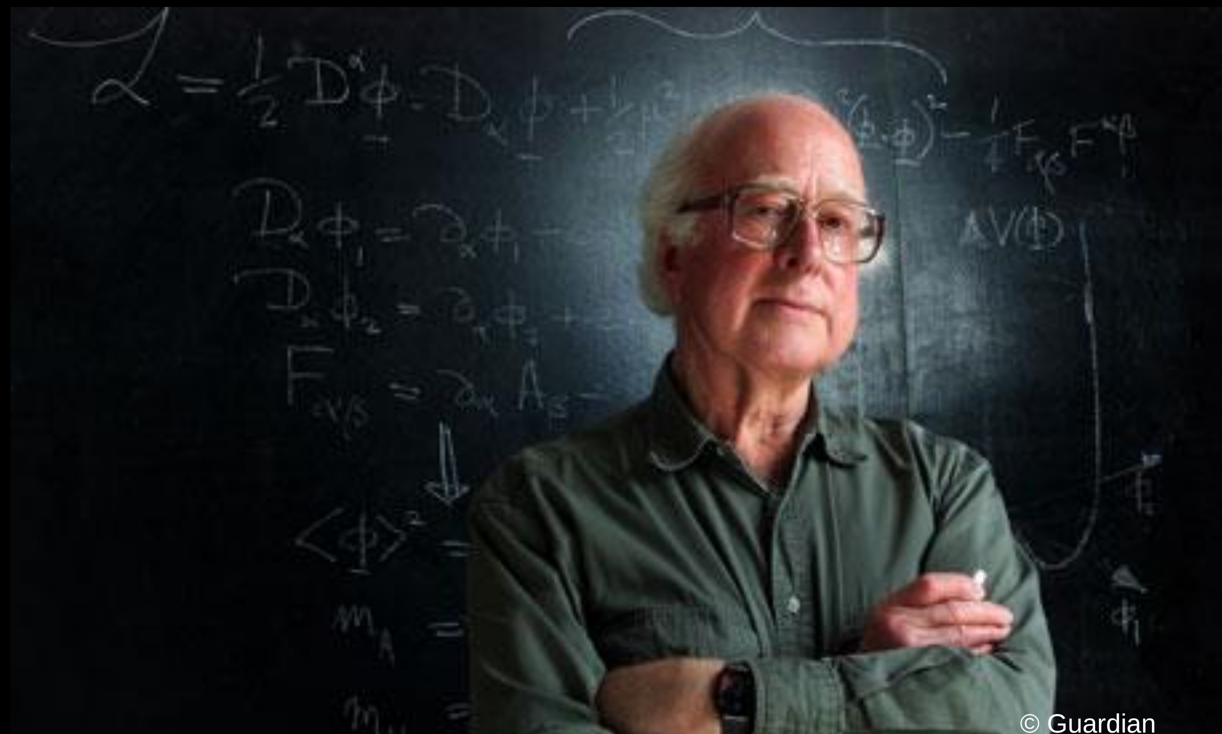
Recreating conditions when universe was a billionth of a second old ……



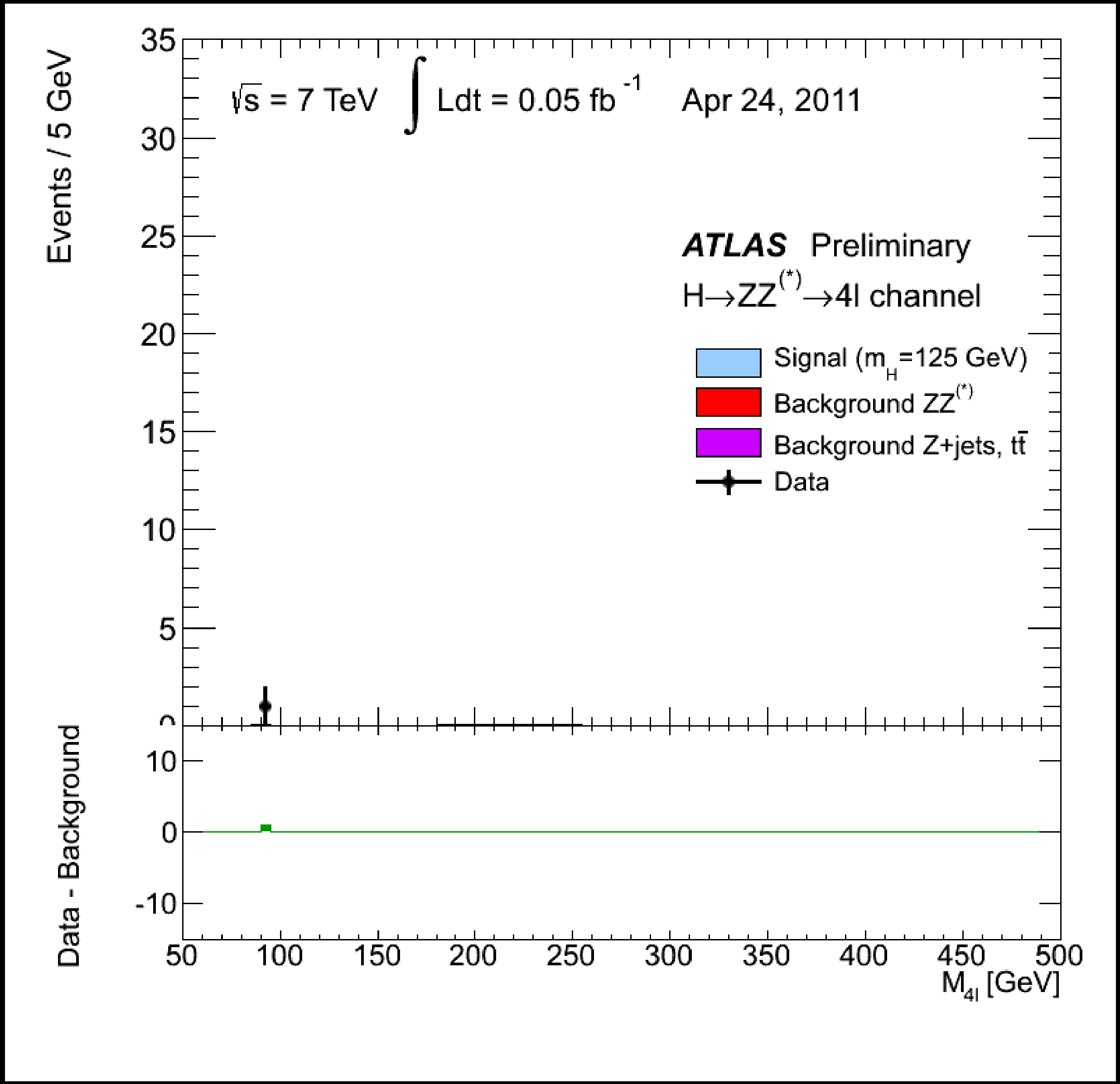

CMS Experiment at the LHC, CERN
Tue 2010-Mar-30 12:58:43 CET
Run 132440 Event 2732271
C.O.M. Energy 7.00TeV
CMS


JLG LIFTLUX 153-12
JLG

Higgs?

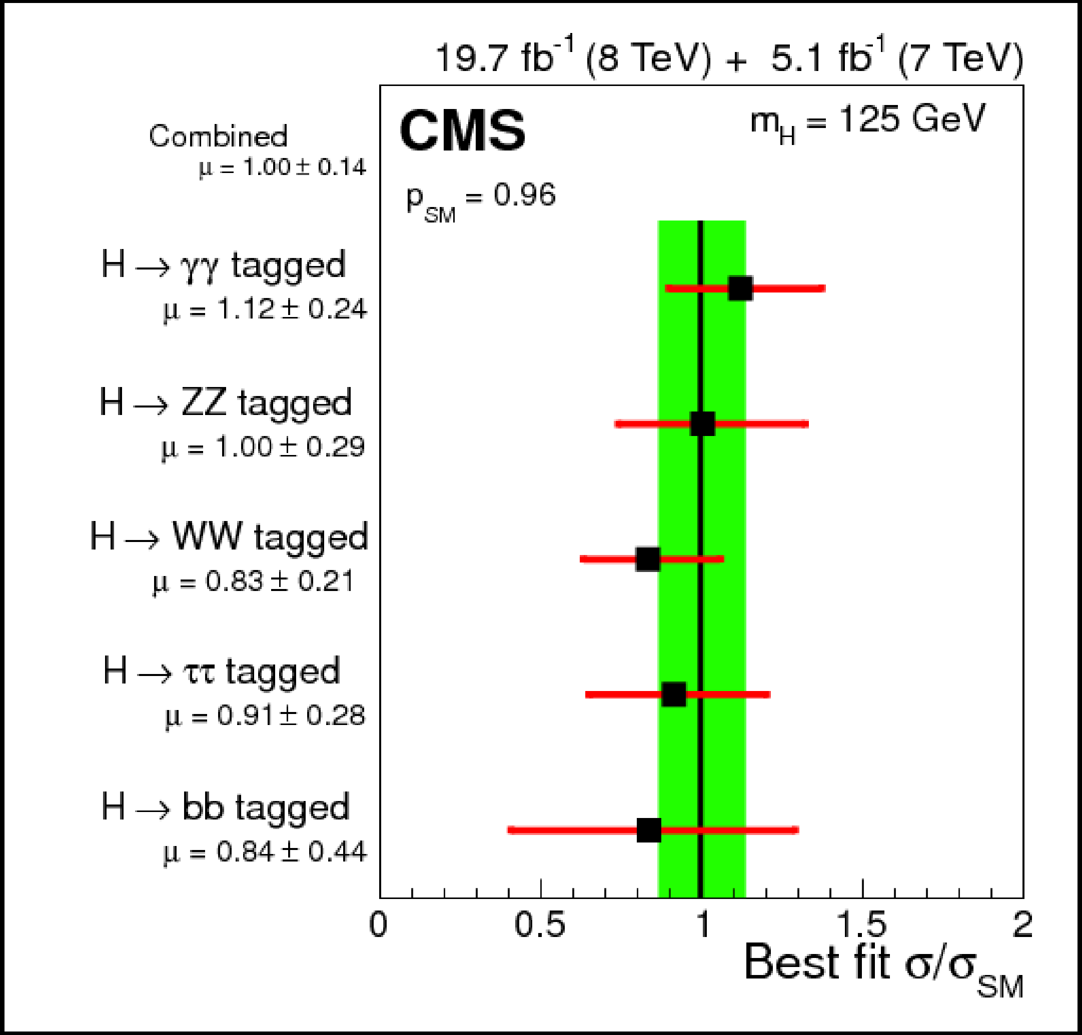



The Economist
JULY 7TH–13TH 2012
Economist.com
In praise of charter schools
Britain's banking scandal spreads
Volkswagen overtakes the rest
A power struggle at the Vatican
When Lonesome George met Nora
A giant leap for science
Finding the Higgs boson



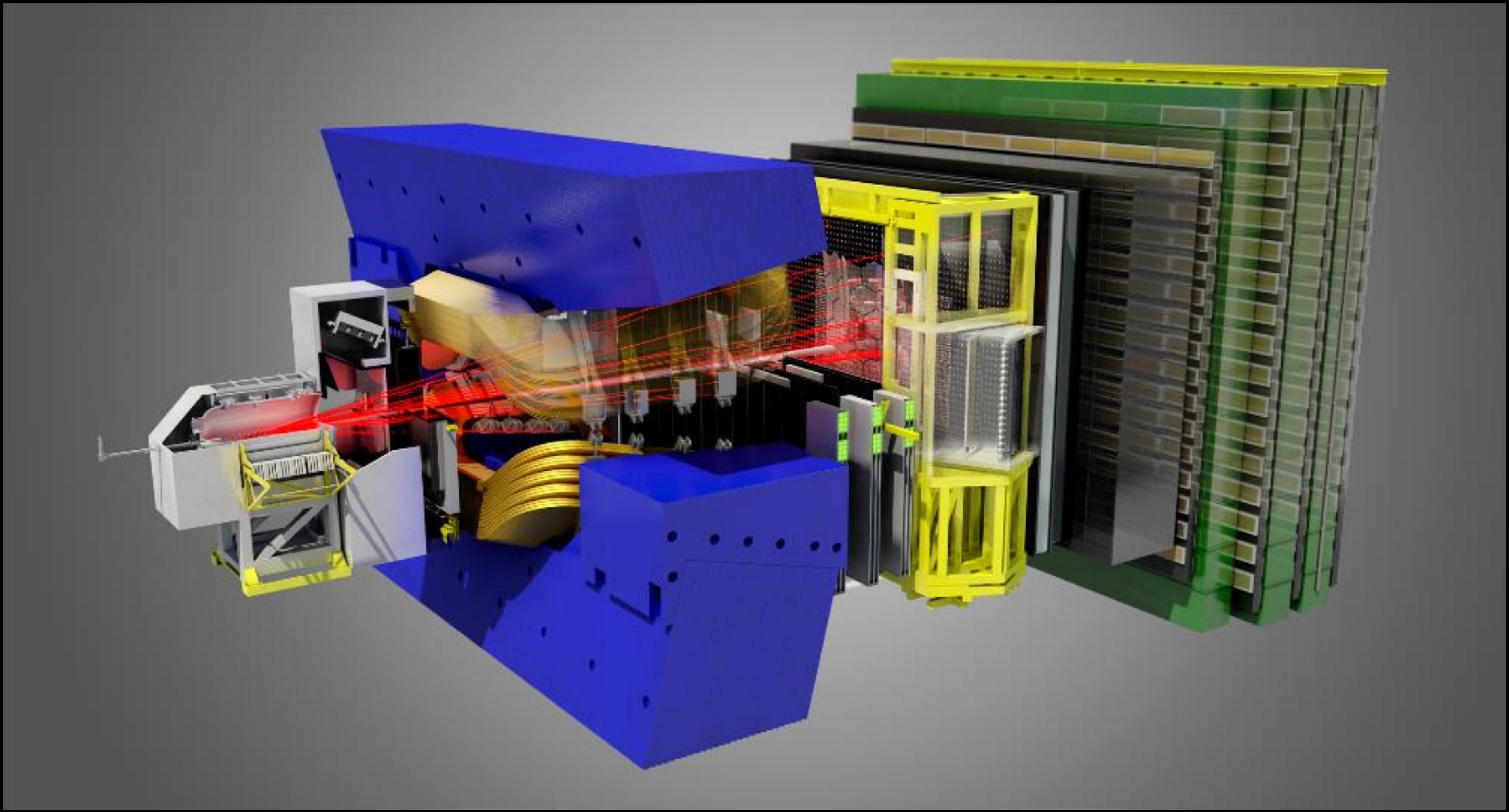
√s = 7 TeV ∫Ldt = 0.05 fb-1 Apr 24, 2011
ATLAS Preliminary
H→ZZ(*)→4l channel
Signal (mH=125 GeV)
Background ZZ(*)
Background Z+jets, tt̄
Data
Events / 5 GeV
Data - Background
M4l [GeV]

A Higgs?
The Higgs?



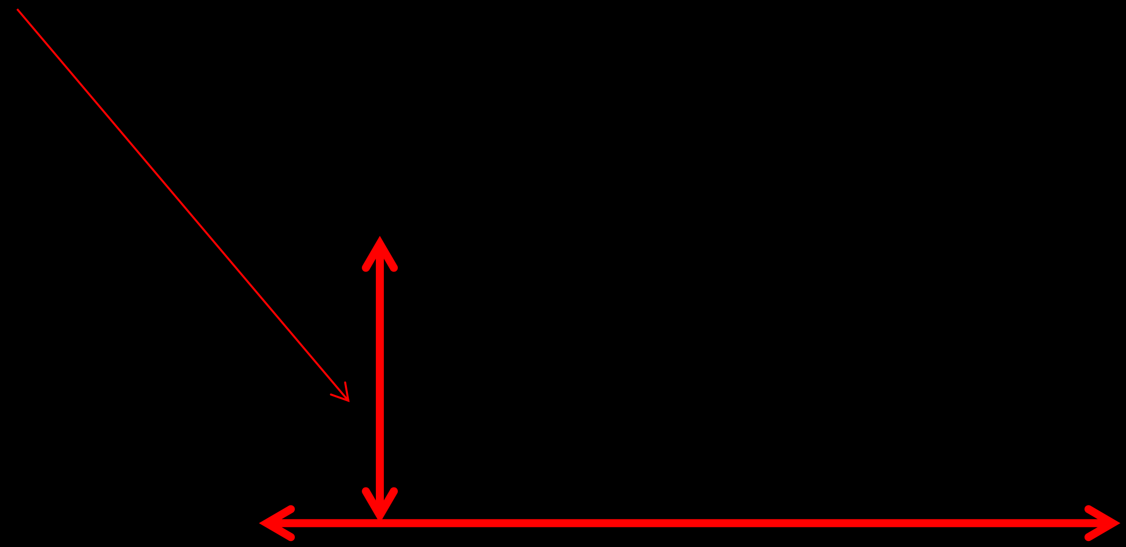
~1,000 papers / year.

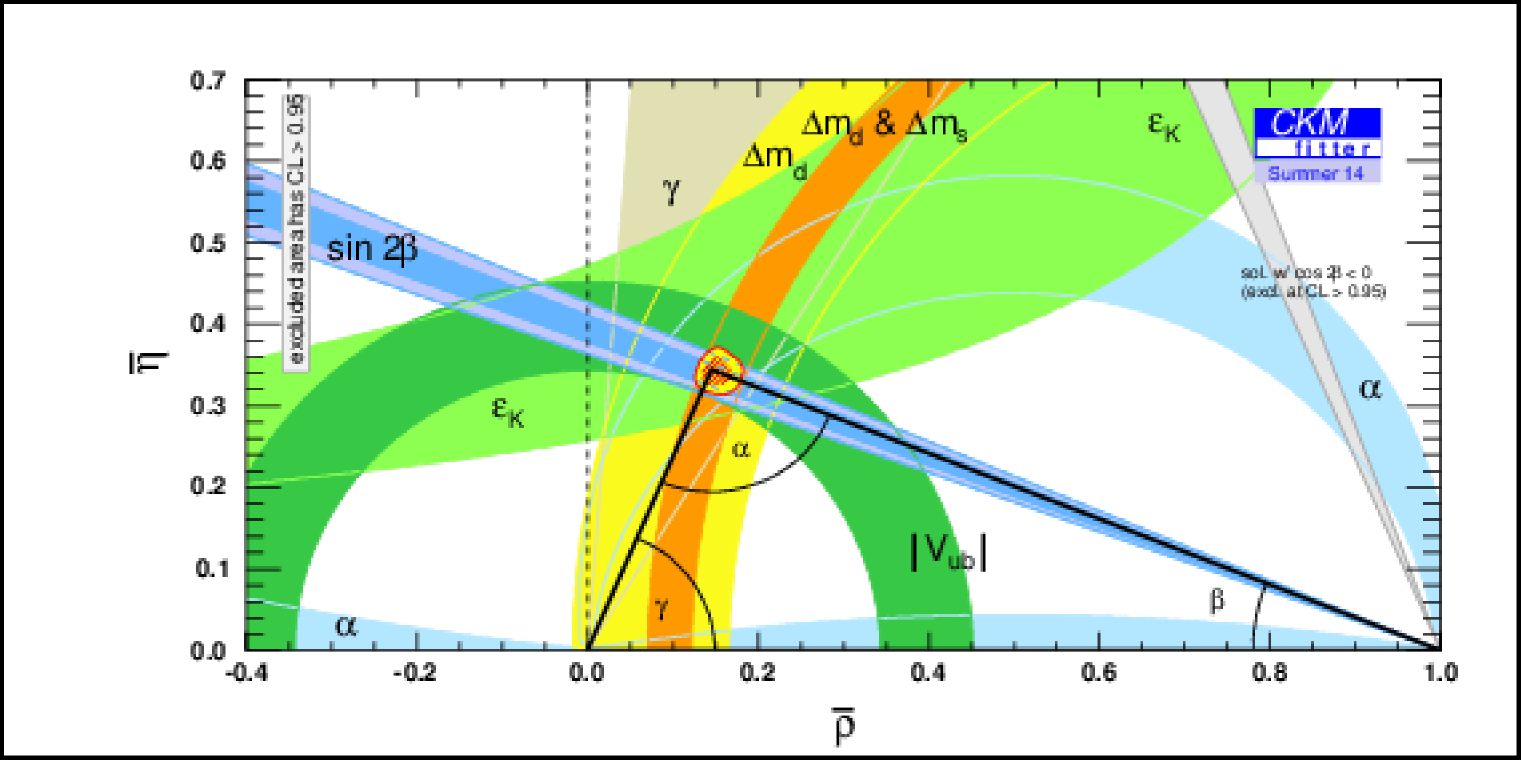
Antimatter - CERN: LHCb



1 number

Measure of matter / antimatter difference

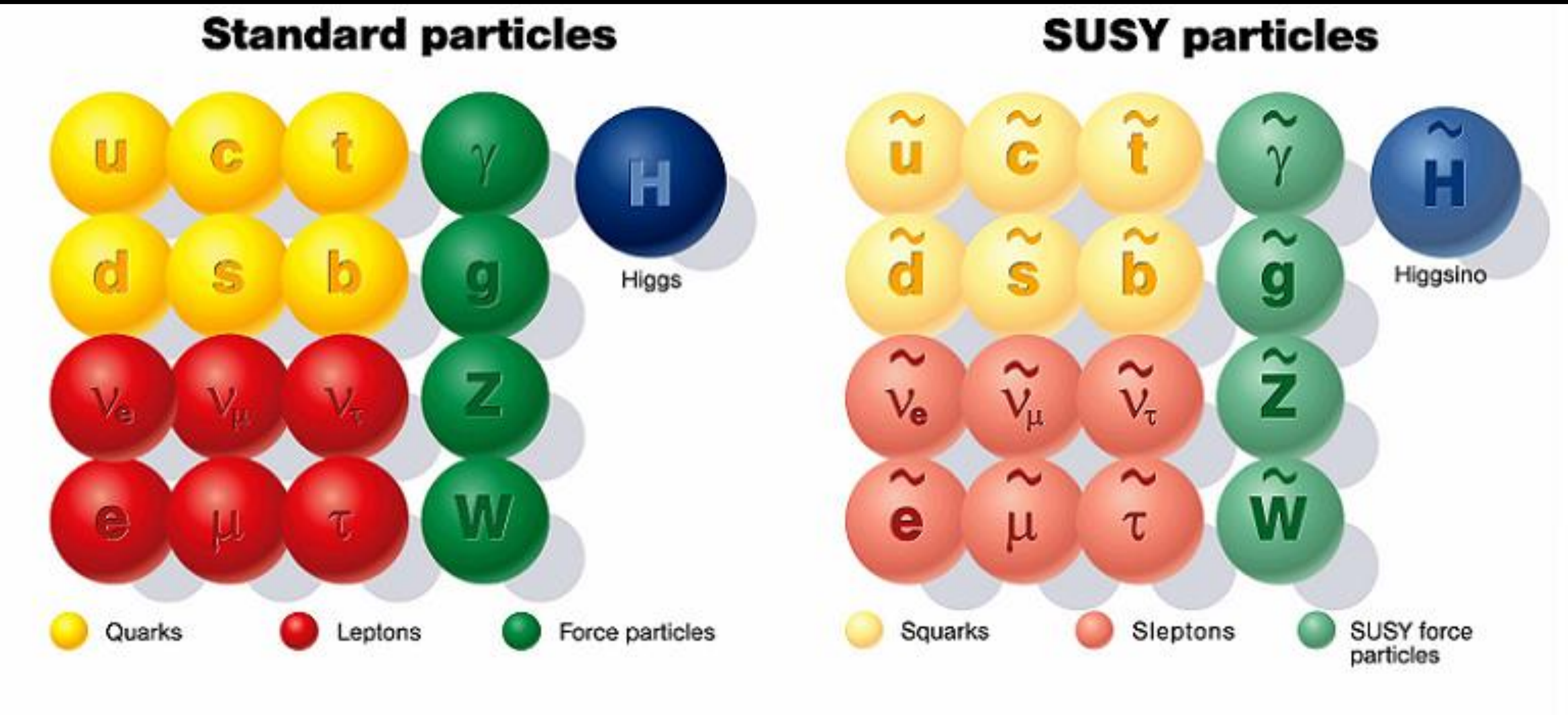


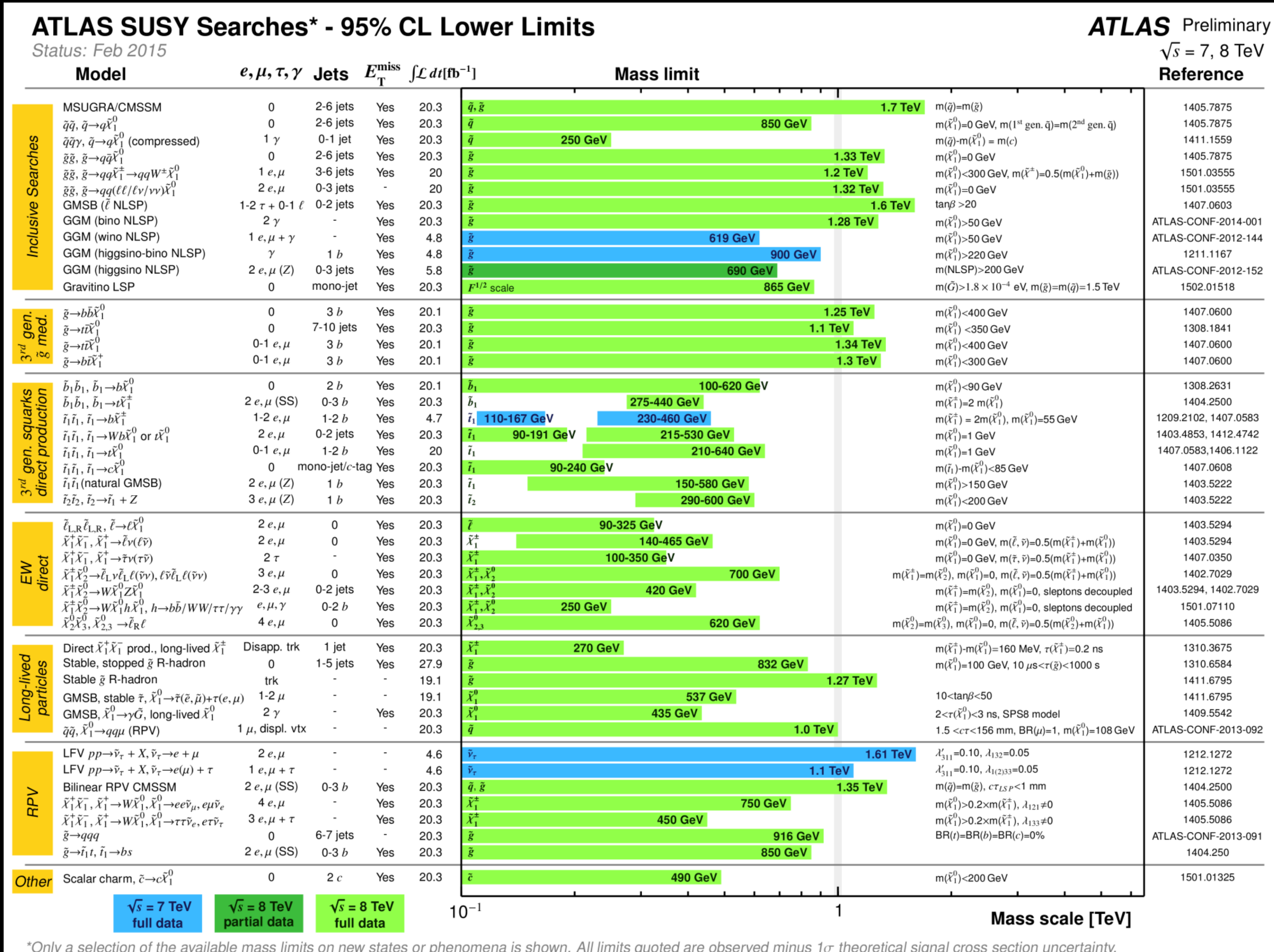

excluded areas has CL > 0.95
sin 2β
Δm_d & Δm_s
Δm_d
γ
ε_K
ε_K
CKM
fitter
Summer 14
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
α
α
α
γ
β
$|V_{ub}|$
$\bar{\eta}$
$\bar{\rho}$
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

?

And **beyond**
the Standard Model?

… supersymmetry….
..dark matter?


Standard particles
SUSY particles
u
c
t
γ
H
d
s
b
g
Higgs
ν_e
ν_μ
ν_τ
Z
e
μ
τ
W
Quarks
Leptons
Force particles
$\tilde{u}$
$\tilde{c}$
$\tilde{t}$
$\tilde{\gamma}$
$\tilde{H}$
$\tilde{d}$
$\tilde{s}$
$\tilde{b}$
$\tilde{g}$
Higgsino
$\tilde{\nu}_e$
$\tilde{\nu}_\mu$
$\tilde{\nu}_\tau$
$\tilde{Z}$
$\tilde{e}$
$\tilde{\mu}$
$\tilde{\tau}$
$\tilde{W}$
Squarks
Sleptons
SUSY force particles


ATLAS SUSY Searches* - 95% CL Lower Limits
Status: Feb 2015
ATLAS Preliminary
$\sqrt{s}$ = 7, 8 TeV
Model | e, μ, τ, γ | Jets | E_T^{miss} | $\int \mathcal{L}\, dt[fb^{-1}]$ | Mass limit | Reference
Inclusive Searches
MSUGRA/CMSSM | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q}, \tilde{g}$ 1.7 TeV | $m(\tilde{q})=m(\tilde{g})$ | 1405.7875
$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q}$ 850 GeV | $m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$) | 1405.7875
$\tilde{q}\tilde{q}\gamma, \tilde{q}\to q\tilde{\chi}_1^0$ (compressed) | 1 γ | 0-1 jet | Yes | 20.3 | $\tilde{q}$ 250 GeV | $m(\tilde{q})-m(\tilde{\chi}_1^0) = m(c)$ | 1411.1559
$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{g}$ 1.33 TeV | $m(\tilde{\chi}_1^0)$=0 GeV | 1405.7875
$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$ | 1 e,μ | 3-6 jets | Yes | 20 | $\tilde{g}$ 1.2 TeV | $m(\tilde{\chi}_1^0)$<300 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$ | 1501.03555
$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$ | 2 e,μ | 0-3 jets | - | 20 | $\tilde{g}$ 1.32 TeV | $m(\tilde{\chi}_1^0)$=0 GeV | 1501.03555
GMSB ($\tilde{\ell}$ NLSP) | 1-2 τ + 0-1 ℓ | 0-2 jets | Yes | 20.3 | $\tilde{g}$ 1.6 TeV | $\tan\beta$ >20 | 1407.0603
GGM (bino NLSP) | 2 γ | - | Yes | 20.3 | $\tilde{g}$ 1.28 TeV | $m(\tilde{\chi}_1^0)$>50 GeV | ATLAS-CONF-2014-001
GGM (wino NLSP) | 1 $e,\mu + \gamma$ | - | Yes | 4.8 | $\tilde{g}$ 619 GeV | $m(\tilde{\chi}_1^0)$>50 GeV | ATLAS-CONF-2012-144
GGM (higgsino-bino NLSP) | γ | 1 b | Yes | 4.8 | $\tilde{g}$ 900 GeV | $m(\tilde{\chi}_1^0)$>220 GeV | 1211.1167
GGM (higgsino NLSP) | 2 e,μ (Z) | 0-3 jets | Yes | 5.8 | $\tilde{g}$ 690 GeV | m(NLSP)>200 GeV | ATLAS-CONF-2012-152
Gravitino LSP | 0 | mono-jet | Yes | 20.3 | $F^{1/2}$ scale 865 GeV | $m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV | 1502.01518
3rd gen. $\tilde{g}$ med.
$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$ | 0 | 3 b | Yes | 20.1 | $\tilde{g}$ 1.25 TeV | $m(\tilde{\chi}_1^0)$<400 GeV | 1407.0600
$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$ | 0 | 7-10 jets | Yes | 20.3 | $\tilde{g}$ 1.1 TeV | $m(\tilde{\chi}_1^0)$ <350 GeV | 1308.1841
$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$ | 0-1 e,μ | 3 b | Yes | 20.1 | $\tilde{g}$ 1.34 TeV | $m(\tilde{\chi}_1^0)$<400 GeV | 1407.0600
$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$ | 0-1 e,μ | 3 b | Yes | 20.1 | $\tilde{g}$ 1.3 TeV | $m(\tilde{\chi}_1^0)$<300 GeV | 1407.0600
3rd gen. squarks direct production
$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$ | 0 | 2 b | Yes | 20.1 | $\tilde{b}_1$ 100-620 GeV | $m(\tilde{\chi}_1^0)$<90 GeV | 1308.2631
$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^{\pm}$ | 2 e,μ (SS) | 0-3 b | Yes | 20.3 | $\tilde{b}_1$ 275-440 GeV | $m(\tilde{\chi}_1^{\pm})=2\, m(\tilde{\chi}_1^0)$ | 1404.2500
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^{\pm}$ | 1-2 e,μ | 1-2 b | Yes | 4.7 | $\tilde{t}_1$ 110-167 GeV, 230-460 GeV | $m(\tilde{\chi}_1^{\pm}) = 2m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV | 1209.2102, 1407.0583
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$ | 2 e,μ | 0-2 jets | Yes | 20.3 | $\tilde{t}_1$ 90-191 GeV, 215-530 GeV | $m(\tilde{\chi}_1^0)$=1 GeV | 1403.4853, 1412.4742
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}_1^0$ | 0-1 e,μ | 1-2 b | Yes | 20 | $\tilde{t}_1$ 210-640 GeV | $m(\tilde{\chi}_1^0)$=1 GeV | 1407.0583,1406.1122
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$ | 0 | mono-jet/c-tag | Yes | 20.3 | $\tilde{t}_1$ 90-240 GeV | $m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$<85 GeV | 1407.0608
$\tilde{t}_1\tilde{t}_1$ (natural GMSB) | 2 e,μ (Z) | 1 b | Yes | 20.3 | $\tilde{t}_1$ 150-580 GeV | $m(\tilde{\chi}_1^0)$>150 GeV | 1403.5222
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$ | 3 e,μ (Z) | 1 b | Yes | 20.3 | $\tilde{t}_2$ 290-600 GeV | $m(\tilde{\chi}_1^0)$<200 GeV | 1403.5222
EW direct
$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$ | 2 e,μ | 0 | Yes | 20.3 | $\tilde{\ell}$ 90-325 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | 1403.5294
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$ | 2 e,μ | 0 | Yes | 20.3 | $\tilde{\chi}_1^{\pm}$ 140-465 GeV | $m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$ | 1403.5294
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$ | 2 τ | - | Yes | 20.3 | $\tilde{\chi}_1^{\pm}$ 100-350 GeV | $m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$ | 1407.0350
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$ | 3 e,μ | 0 | Yes | 20.3 | $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 700 GeV | $m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$ | 1402.7029
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$ | 2-3 e,μ | 0-2 jets | Yes | 20.3 | $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 420 GeV | $m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled | 1403.5294, 1402.7029
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$ | e,μ,γ | 0-2 b | Yes | 20.3 | $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 250 GeV | $m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled | 1501.07110
$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$ | 4 e,μ | 0 | Yes | 20.3 | $\tilde{\chi}_{2,3}^0$ 620 GeV | $m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$ | 1405.5086
Long-lived particles
Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$ | Disapp. trk | 1 jet | Yes | 20.3 | $\tilde{\chi}_1^{\pm}$ 270 GeV | $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns | 1310.3675
Stable, stopped $\tilde{g}$ R-hadron | 0 | 1-5 jets | Yes | 27.9 | $\tilde{g}$ 832 GeV | $m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s | 1310.6584
Stable $\tilde{g}$ R-hadron | trk | - | - | 19.1 | $\tilde{g}$ 1.27 TeV | | 1411.6795
GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$ | 1-2 μ | - | - | 19.1 | $\tilde{\chi}_1^0$ 537 GeV | 10<$\tan\beta$<50 | 1411.6795
GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$ | 2 γ | - | Yes | 20.3 | $\tilde{\chi}_1^0$ 435 GeV | 2<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model | 1409.5542
$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV) | 1 μ, displ. vtx | - | - | 20.3 | $\tilde{q}$ 1.0 TeV | 1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV | ATLAS-CONF-2013-092
RPV
LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$ | 2 e,μ | - | - | 4.6 | $\tilde{\nu}_\tau$ 1.61 TeV | λ'_{311}=0.10, λ_{132}=0.05 | 1212.1272
LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$ | 1 $e,\mu+\tau$ | - | - | 4.6 | $\tilde{\nu}_\tau$ 1.1 TeV | λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05 | 1212.1272
Bilinear RPV CMSSM | 2 e,μ (SS) | 0-3 b | Yes | 20.3 | $\tilde{q}, \tilde{g}$ 1.35 TeV | $m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm | 1404.2500
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$ | 4 e,μ | - | Yes | 20.3 | $\tilde{\chi}_1^{\pm}$ 750 GeV | $m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^{\pm})$, $\lambda_{121}\neq0$ | 1405.5086
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$ | 3 $e,\mu+\tau$ | - | Yes | 20.3 | $\tilde{\chi}_1^{\pm}$ 450 GeV | $m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^{\pm})$, $\lambda_{133}\neq0$ | 1405.5086
$\tilde{g}\to qqq$ | 0 | 6-7 jets | - | 20.3 | $\tilde{g}$ 916 GeV | BR(t)=BR(b)=BR(c)=0% | ATLAS-CONF-2013-091
$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$ | 2 e,μ (SS) | 0-3 b | Yes | 20.3 | $\tilde{g}$ 850 GeV | | 1404.250
Other
Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$ | 0 | 2 c | Yes | 20.3 | $\tilde{c}$ 490 GeV | $m(\tilde{\chi}_1^0)$<200 GeV | 1501.01325
$\sqrt{s}$ = 7 TeV full data
$\sqrt{s}$ = 8 TeV partial data
$\sqrt{s}$ = 8 TeV full data
10^{-1}
1
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

27 August 2011 Last updated at 06:41 GMT

7,886 Share

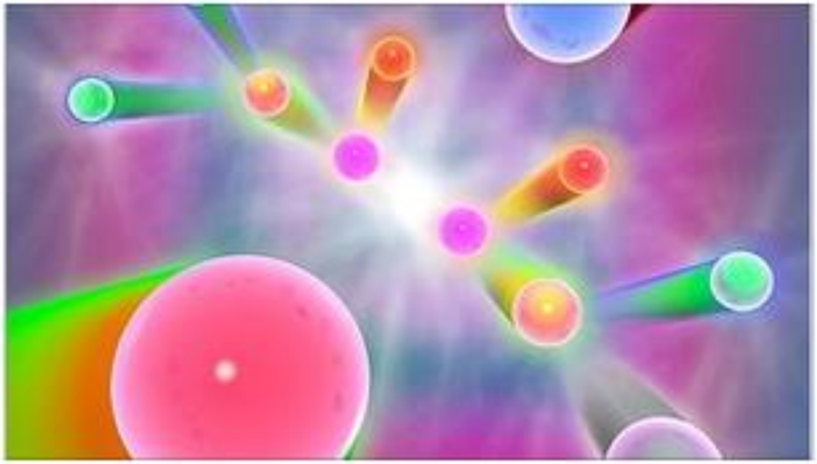
LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

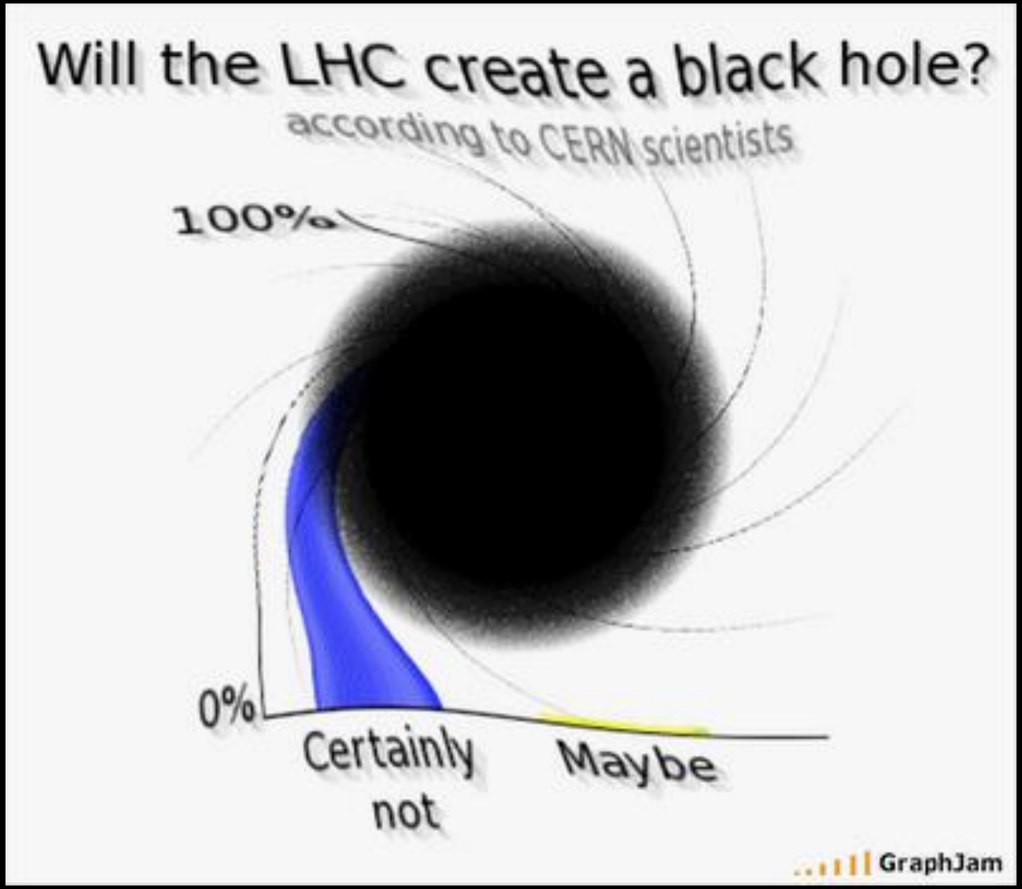
Theorists working in the field have told BBC News that they may have to come up with a completely new idea.



Supersymmetry predicts the existence of mysterious super particles.

And **beyond**

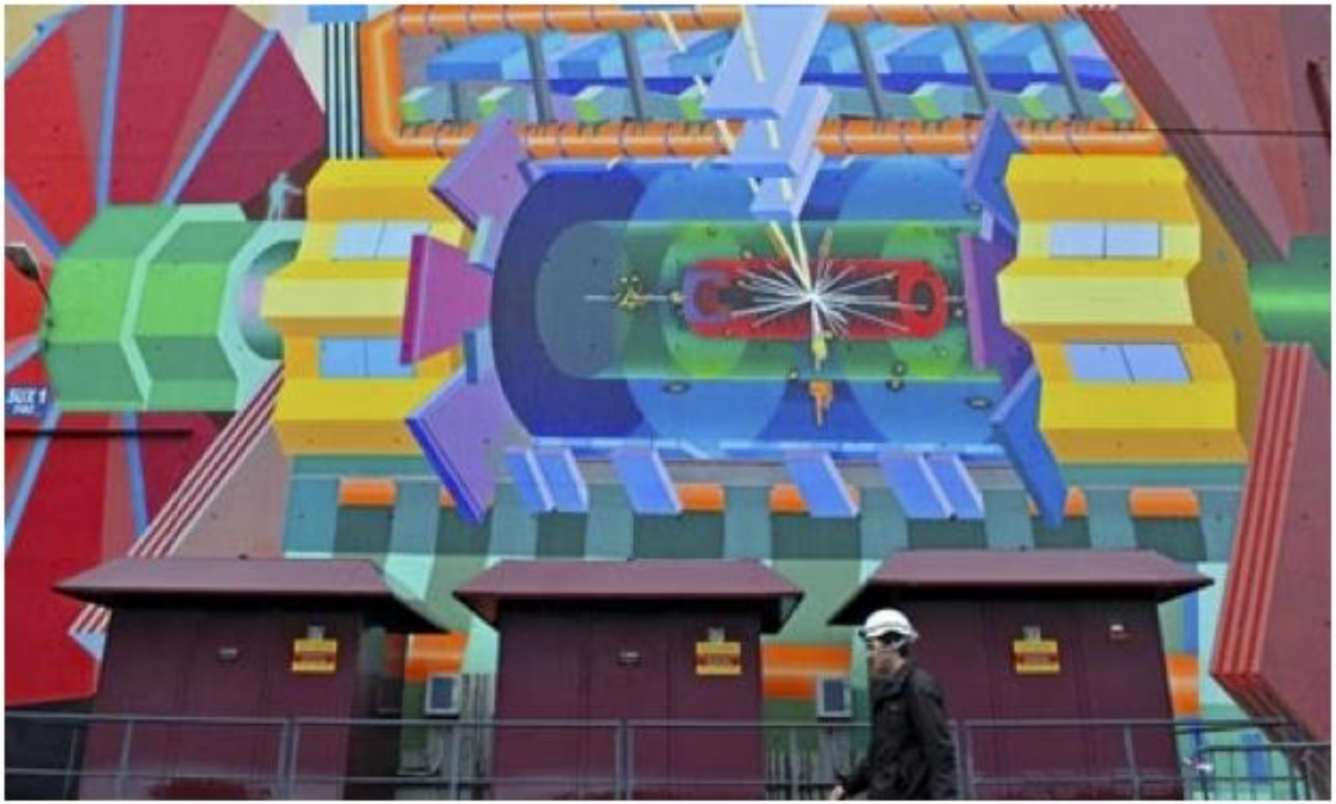
SUSY?



… still looking….

One year on from the Higgs boson find, has physics hit the buffers?

Despite the success of the Large Hadron Collider, evidence for the follow-up theory - supersymmetry - has proved elusive



A Cern worker walks past a painted representation of the Atlas detector of the LHC on 13 December 2011 in Geneva, Switzerland. Photograph: Harold Cunningham/Getty Images

?

Now
what?

2015

Upgrade
Maintenance
Run 2: Energy increase
Run 2: Dataset increase

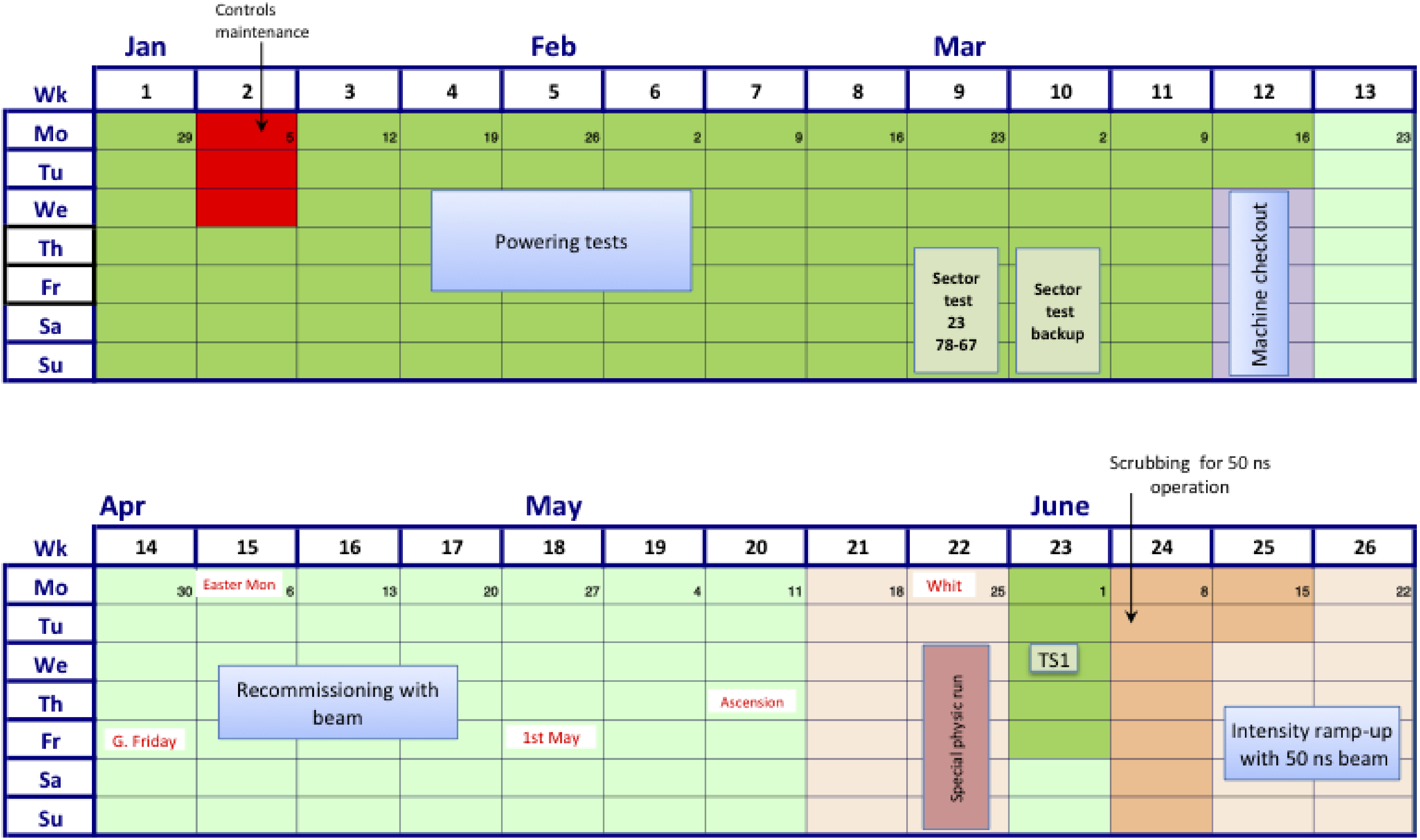
ML

January 28, 2015

V1.1

LHC Schedule 2015

Approved by the Research Board, December 2014



What will we find?

?

………. wait and see ……….

Reflections:

- Pick something you are interested in! Then you can’t go wrong.

Reflections:

- Don’t obsess (needlessly).
- Learn to be (self-) critical, so you can rely on your judgement.

Reflections:

- Don't obsess (needlessly).
- Be realistic.
- Try new things, new avenues, when you have a chance. That way, you learn.

Reflections:

- Don’t obsess (needlessly).
- Be realistic.
- Be creative.
- Careers only look logical in retrospect…

Reflections:

- Don't obsess (needlessly).
- Be realistic.
- Be creative.
- Be brave.

Good luck!!