Beyond the Standard Model

G.F. Giudice

Lecture 3

CERN Summer Student
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Why is supersymmetry interesting?

- supersymmetry relates particles with different spin ➔ must involve space-time transformations ➔ (super)gravity

- supersymmetry necessary ingredient for string theory?

- supersymmetry may be the answer to the naturalness problem

Why is supersymmetry interesting?

Higgs field affected by quantum fluctuations of the vacuum

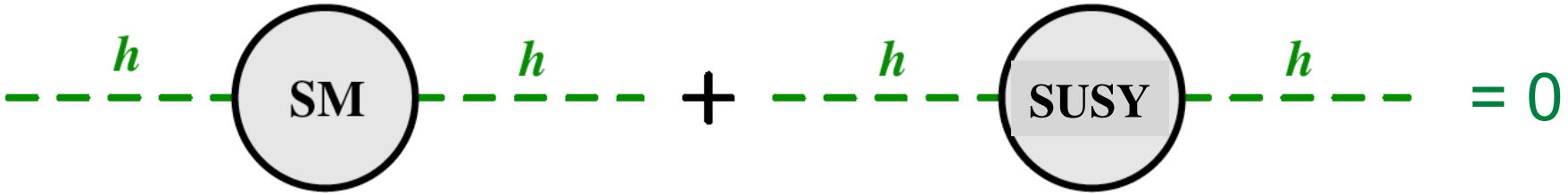
M_W , M_Z ➔ E_{max}

virtual particles increase the density of the Higgs field in the vacuum: M_W ↗

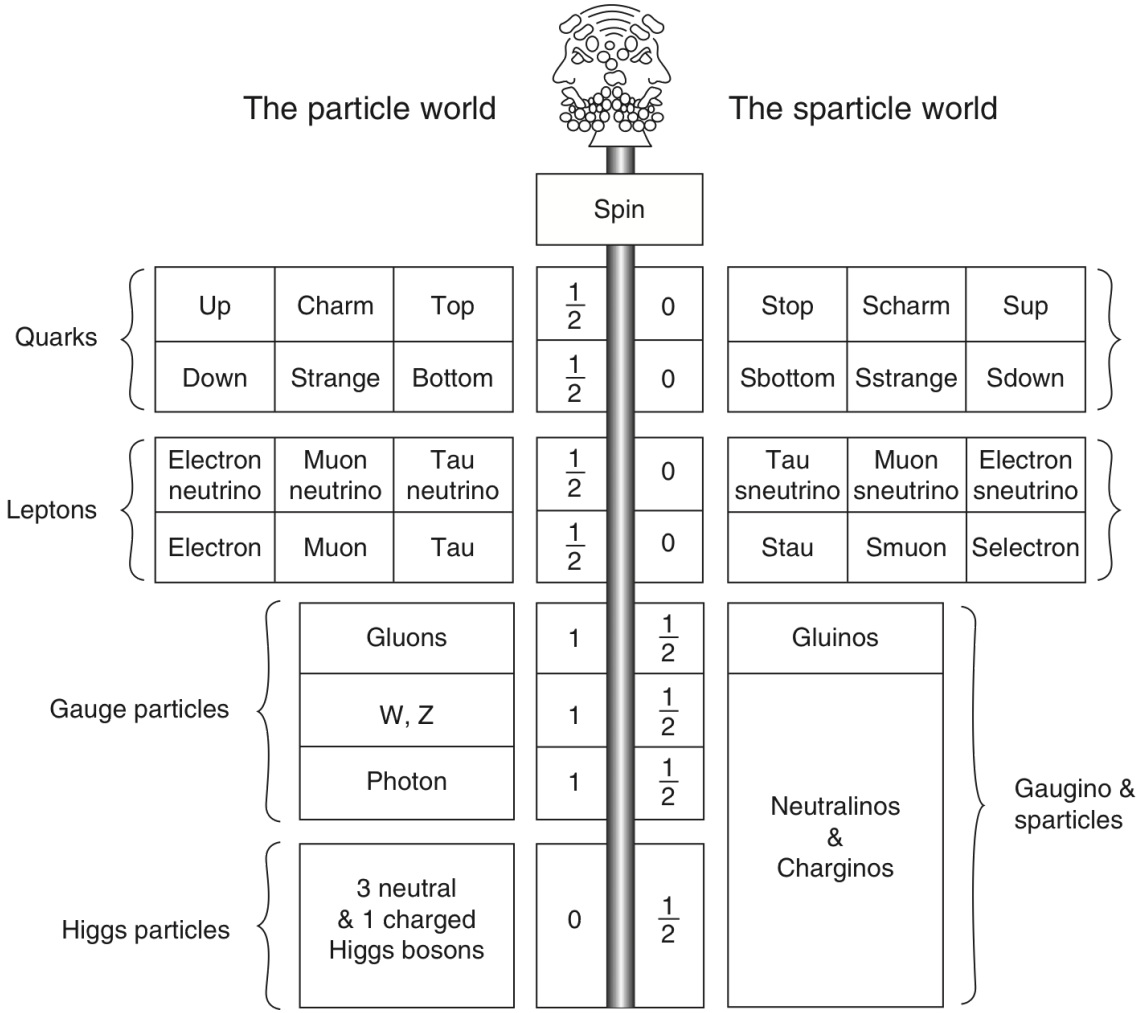
virtual sparticles decrease the density of the Higgs field in the vacuum: M_W ↘

total effect = 0

The magic of symmetry!



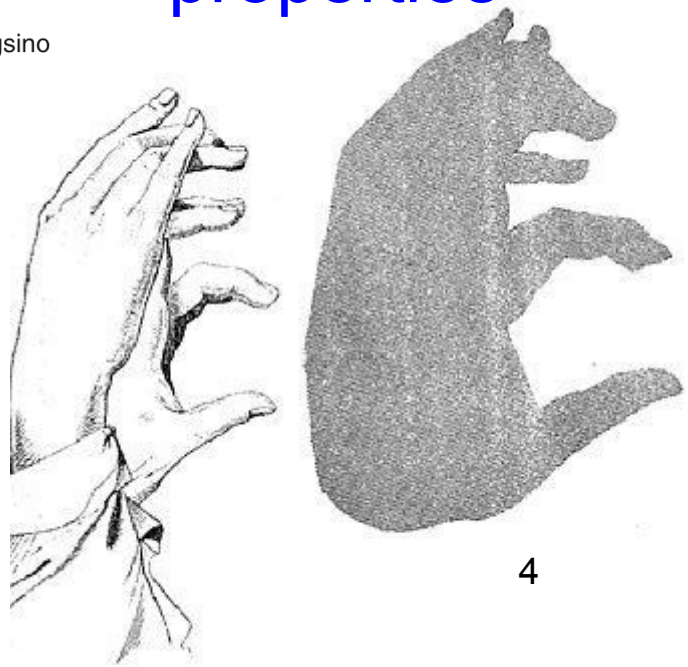
Supersymmetry gives the justification for an apparently miraculous coincidence



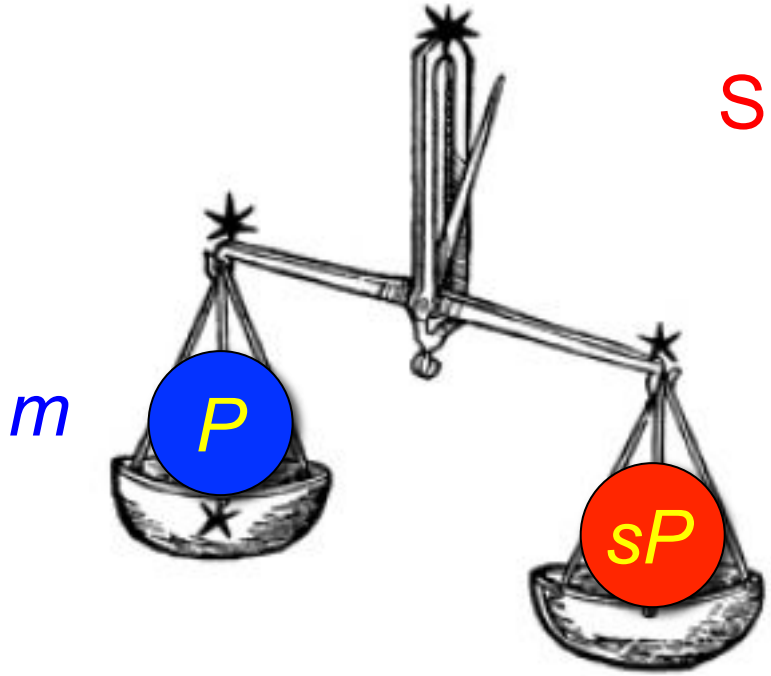
If the particle world took place in superspace…

… lots of new particles, but the power of symmetry relates all their properties

Staring at shadows can be deceitful…



Supersymmetry cannot be an exact symmetry of our world (spin-0 electrons do not exist)



Supersymmetry breaking

$\tilde{m} >> m$

The dark side of the moon is hidden

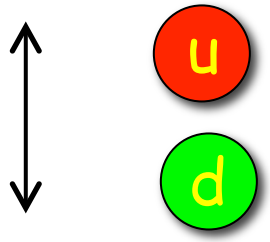
We need the LHC!

gauge symmetry ➔ $m = 0$

supersymmetry ➔ $\tilde{m} = 0$

With spontaneously broken symmetry, mass relations implied by exact symmetry can be modified

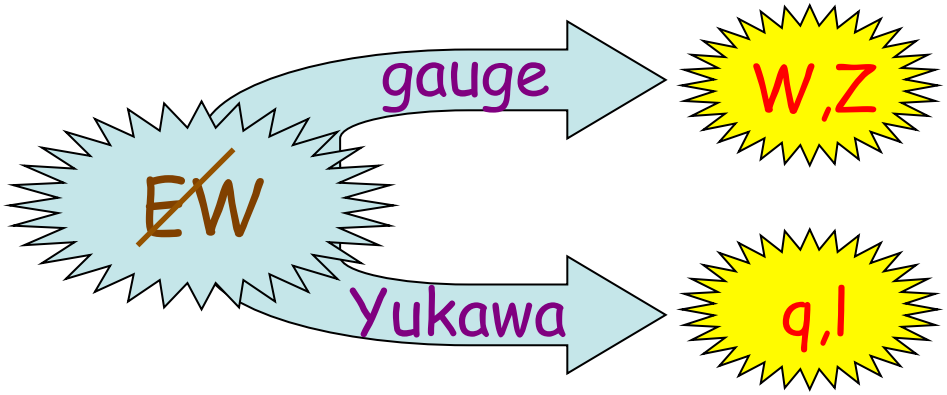
Equations invariant under exchange

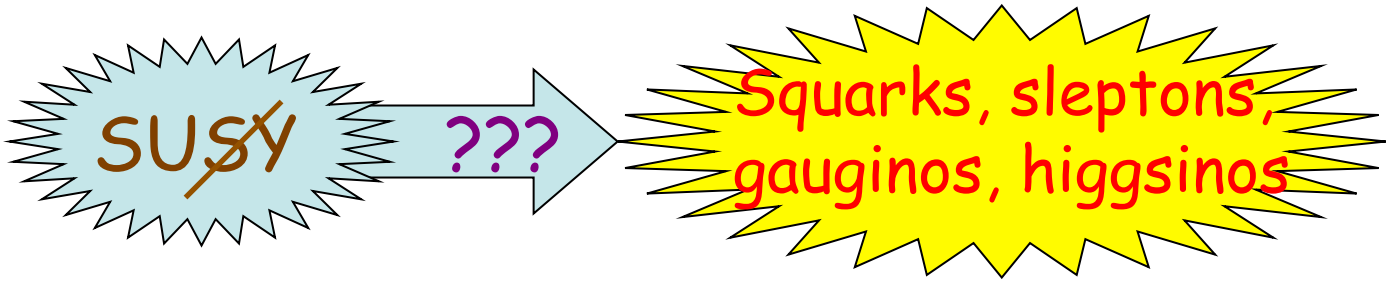


$\Rightarrow$ solutions with $M_u = M_d$

or solutions with $M_u > M_d$ possible,

as long as $M_d > M_u$ also exists

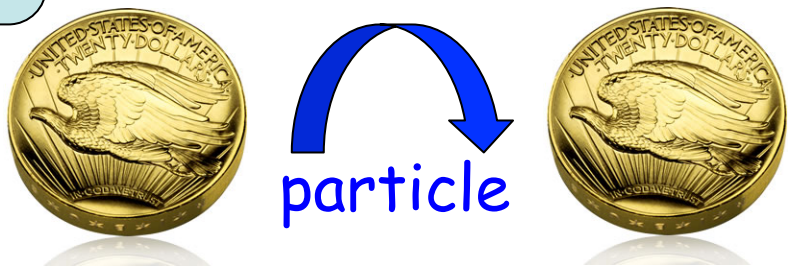

gauge
EW
W,Z
Yukawa
q,l

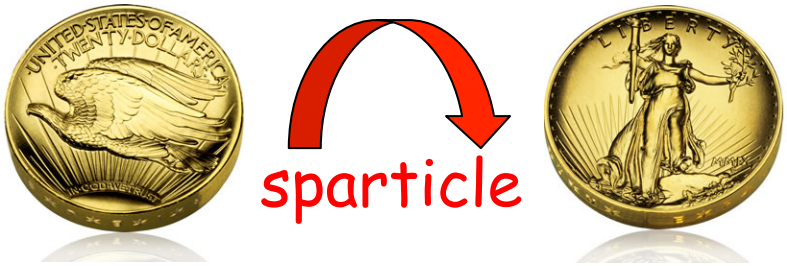

SUSY
???
Squarks, sleptons,
gauginos, higgsinos

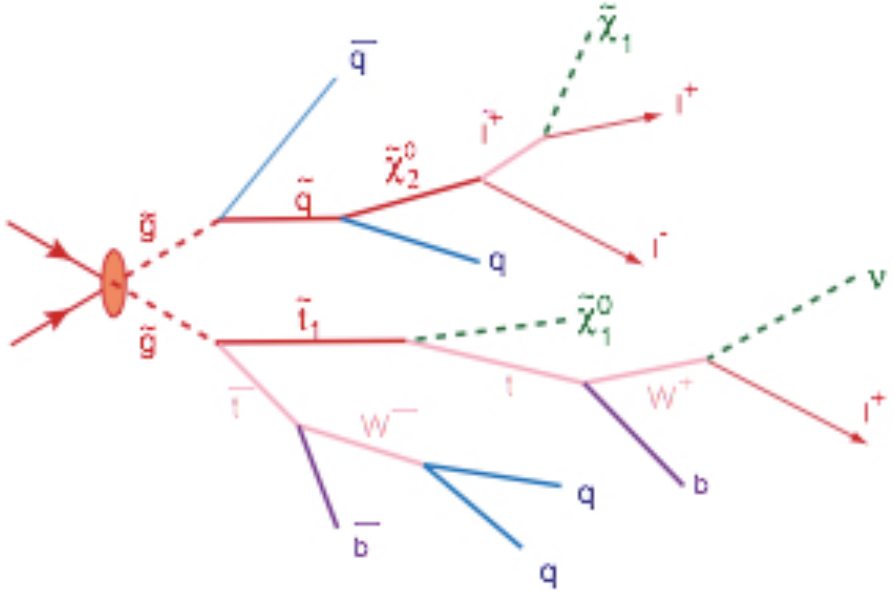
How will the LHC detect supersymmetry?

Supersymmetry will be discovered at the LHC, whether it exists or not!

R-parity

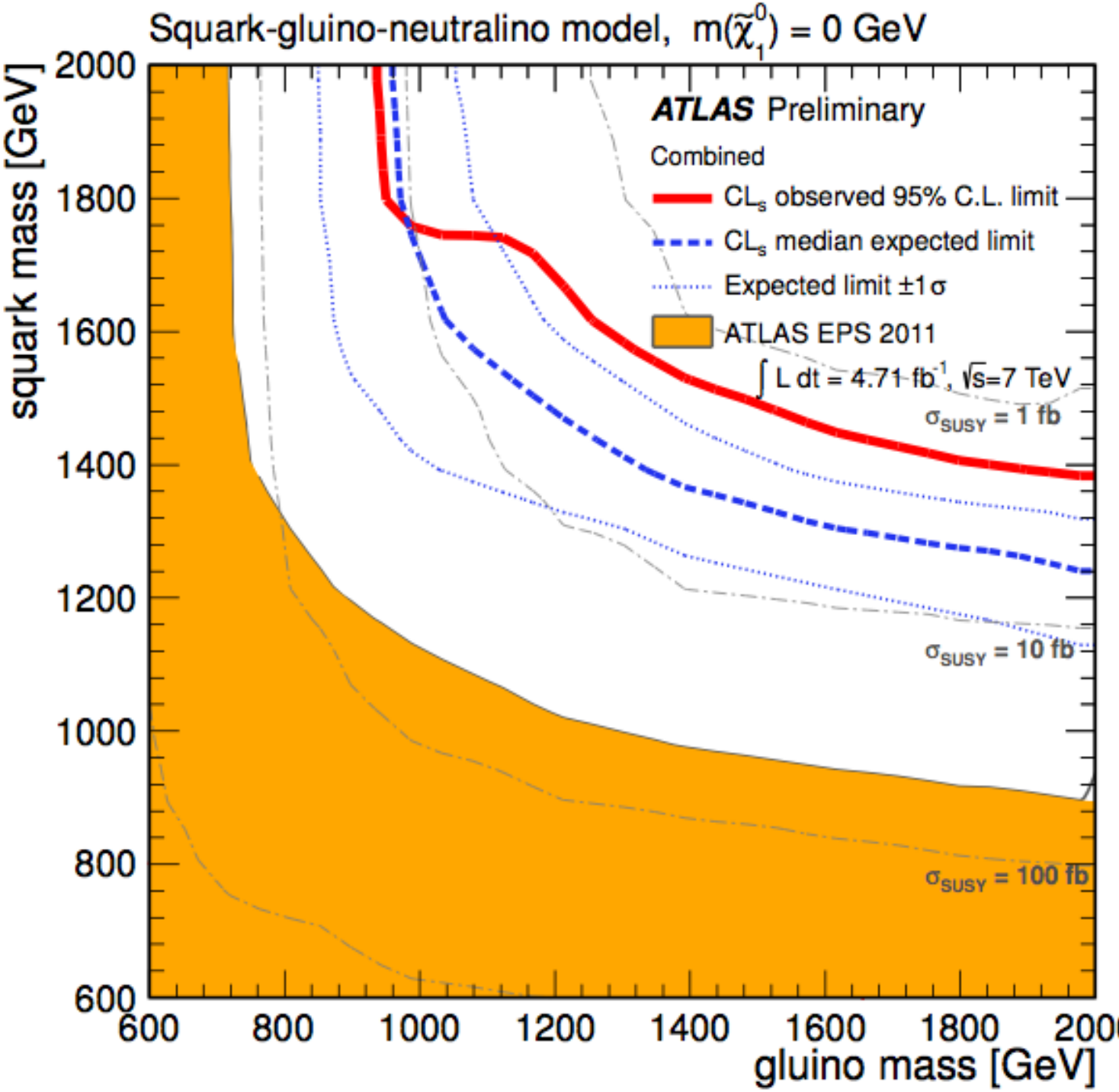


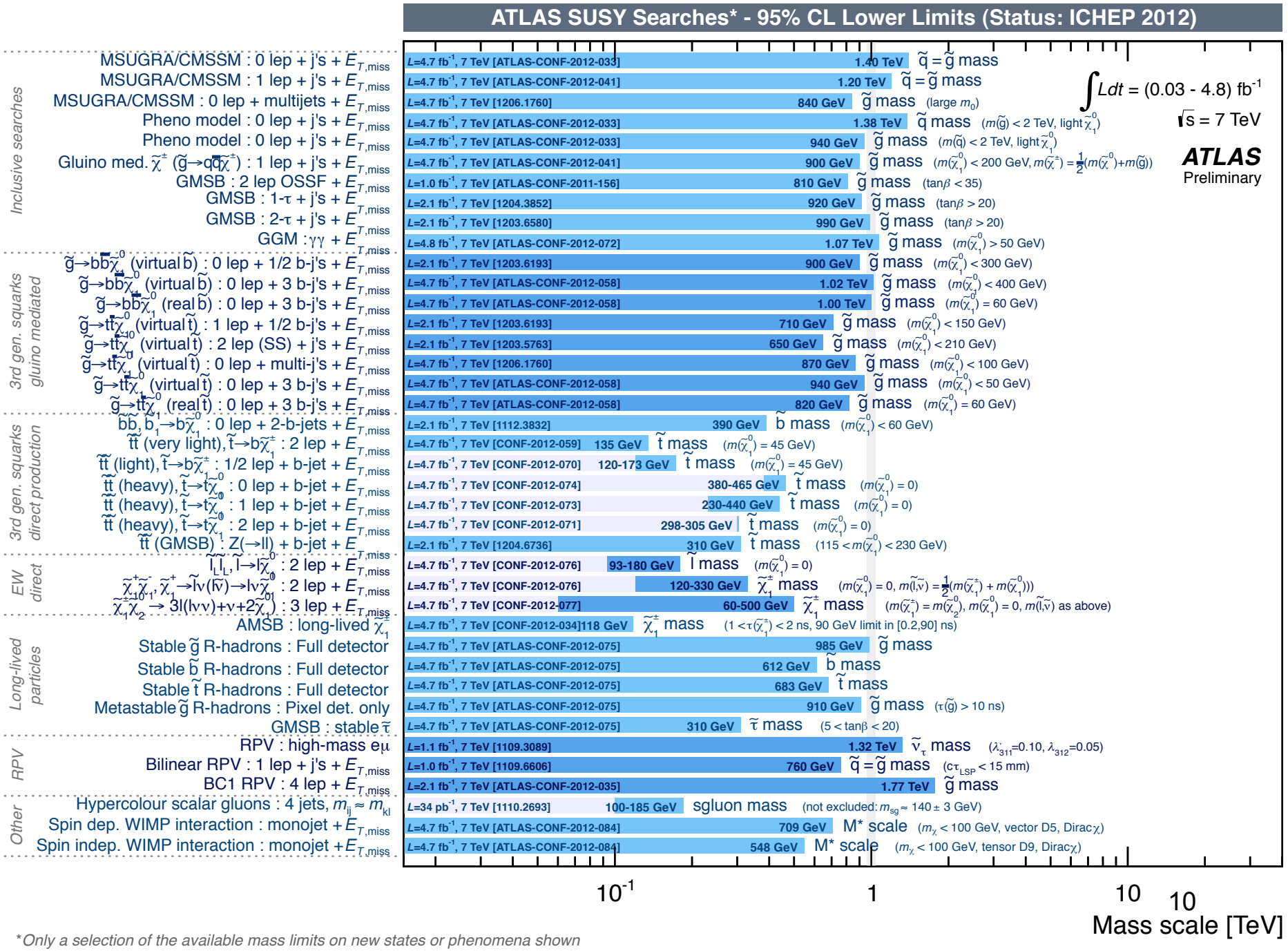




LSP: neutralino ($\tilde{\gamma}$, $\tilde{Z}$, $\tilde{H}$)

➔ $\not{E}_T$


Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0)$ = 0 GeV
ATLAS Preliminary
Combined
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit ±1σ
ATLAS EPS 2011
$\int L\,dt$ = 4.71 fb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 1 fb
σ_{SUSY} = 10 fb
σ_{SUSY} = 100 fb
squark mass [GeV]
gluino mass [GeV]
600
800
1000
1200
1400
1600
1800
2000



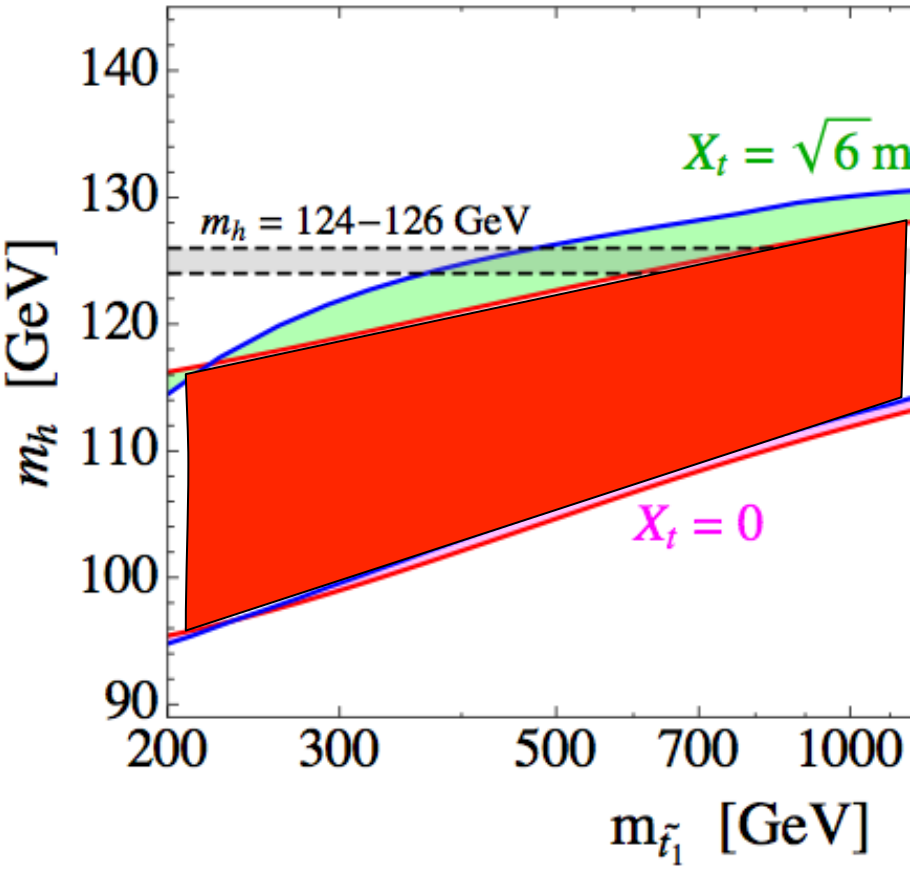
*Only a selection of the available mass limits on new states or phenomena shown

What about the Higgs boson in supersymmetry?

The Higgs potential is computable
(in terms of susy masses)

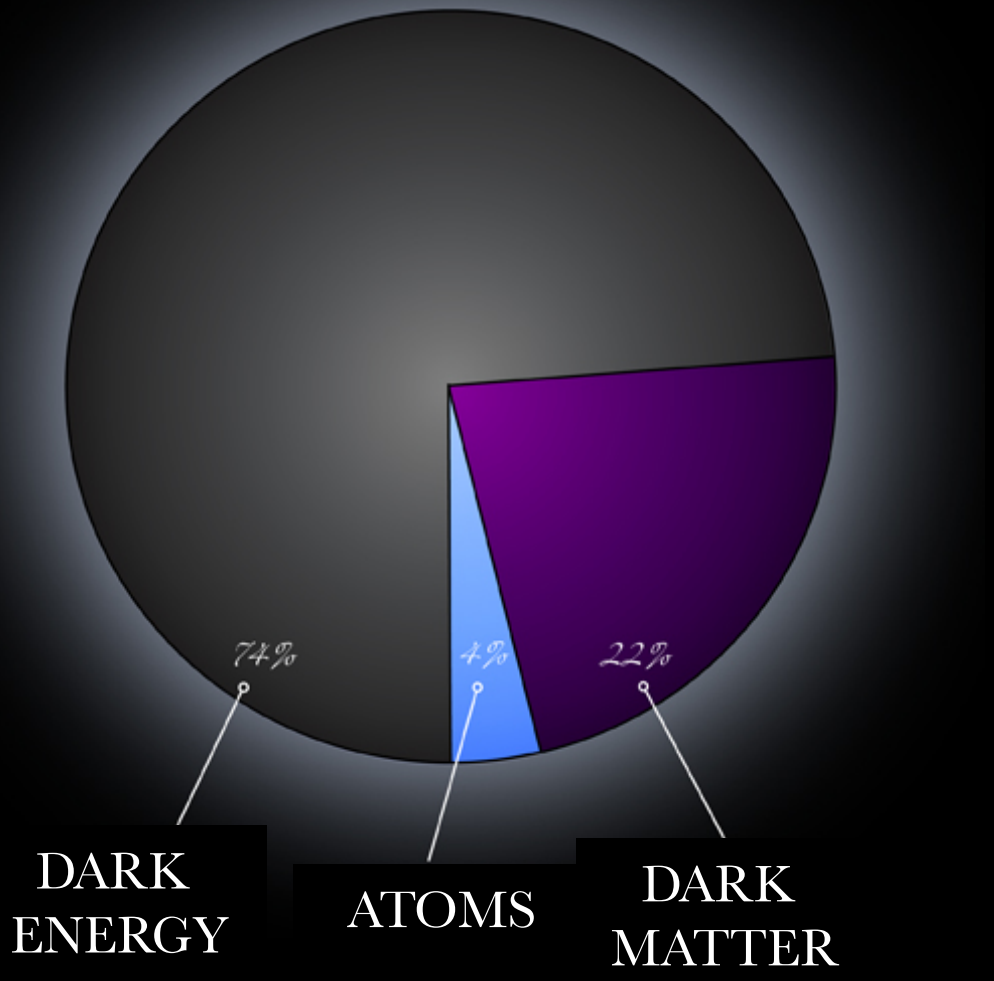
$$V = \frac{\lambda}{4}\left(|h|^2 - v^2\right)^2$$

$$V = m_1^2|H_1^0|^2 + m_2^2|H_2^0|^2 - m_3^2\left(H_1^0 H_2^0 + \text{h.c.}\right) + \frac{g_2^2 + g_Y^2}{8}\left(|H_1^0|^2 - |H_2^0|^2\right)^2$$



Susy Higgs
couplings deviate
from SM prediction

In spite of our successes, we are still in the dark...

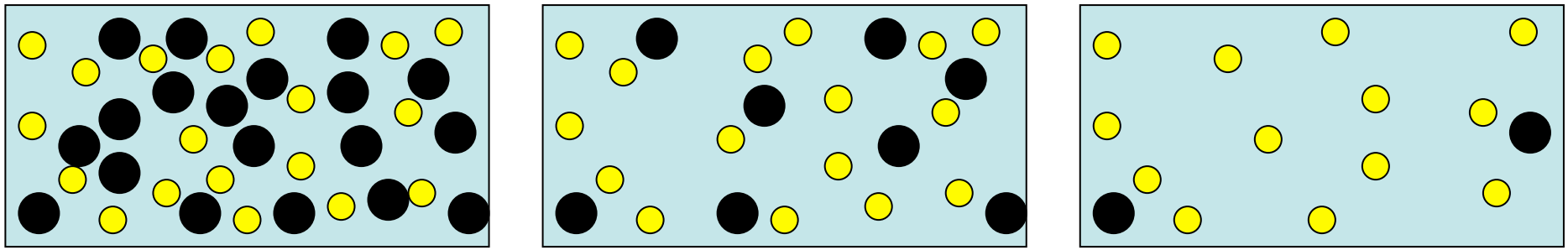


We still have to discover 96% of the universe!

Maybe supersymmetric particles are all around us at this very moment…

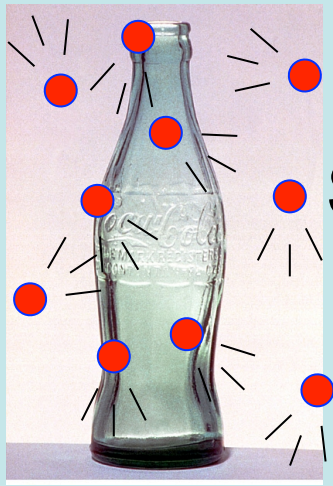
Link dark matter ←→ weak scale

If a stable massive particle is in thermal equilibrium in the early universe, its density today can be computed



$$\sigma = \frac{k}{128\,\pi\,M^2} \quad \Rightarrow \quad \Omega_{DM} = 0.22 \left(\frac{M}{\sqrt{k}\ \mathrm{TeV}} \right)^2$$

Peculiar coincidence with the weak scale:
is dark matter made of supersymmetric particles?



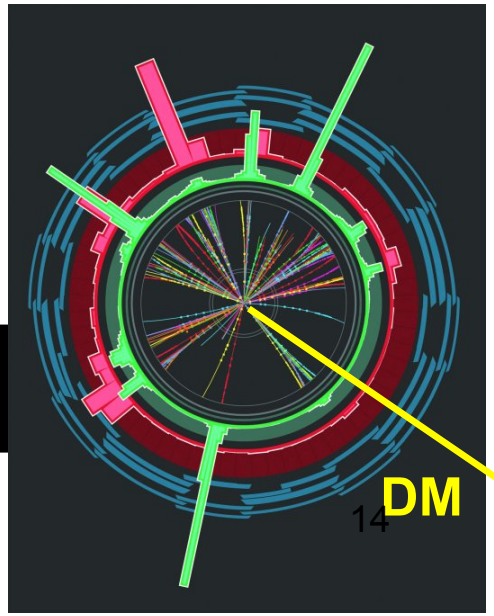
Several LSP per liter of space
(moving at one million km/h)

Half a kg of them in the space occupied by the earth

matter: 6×10^{24} kg
dark matter: 0.6 kg

Power generated by DM on one kg of matter: 10^{-19} watts ➔ 1% of the moon for one light bulb

LHC could artificially produce DM

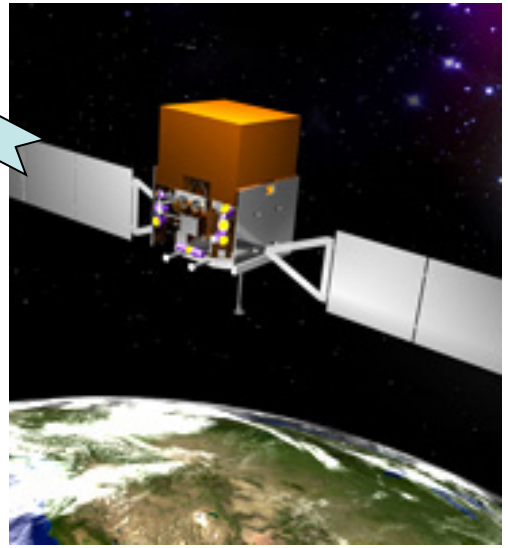


Complementarity of information

Direct detection

LHC

DM

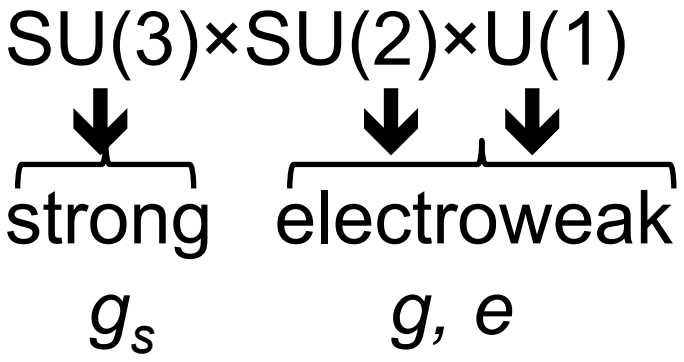


Indirect detection

15

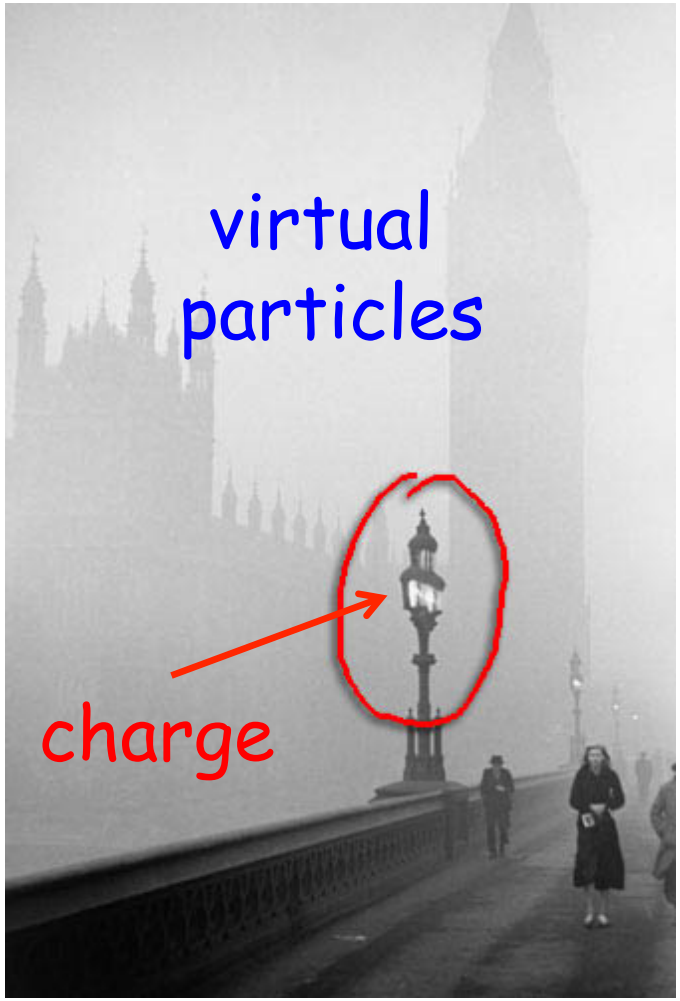
Supersymmetry and unification

SM based on a symmetry principle:



Grand unification: single force ➔ single coupling

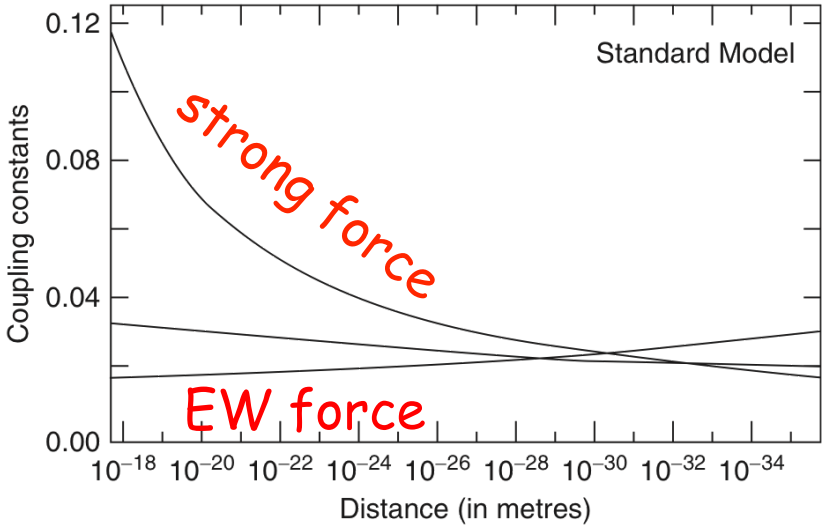
Classical physics: force depends on distance
Quantum physics: charge depends on distance

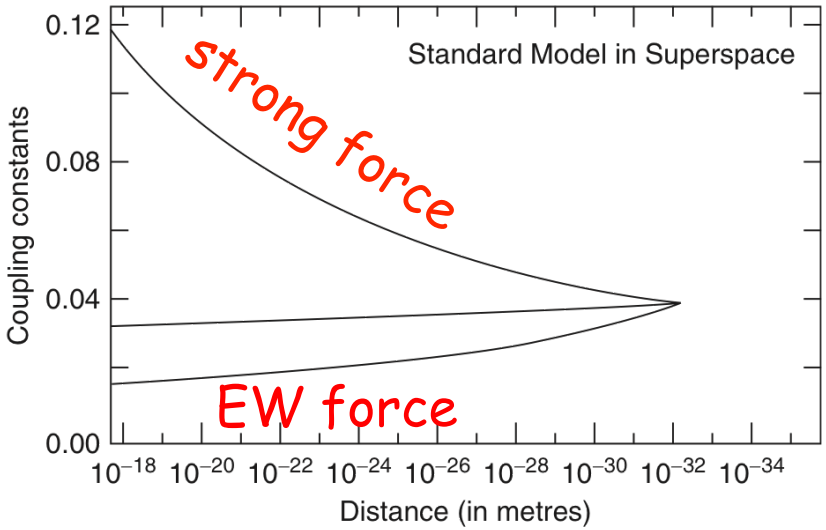


A strange phenomenon
QED: virtual particles screen the charge ➔ charge gets weaker as we move away

Even stranger
QCD: virtual particles antiscreen the charge ➔ charge gets stronger as we move away

The screening (and antiscreening) depends on all species of existing particles





If supersymmetry is discovered, it could hint towards unification of forces at 10^{16} GeV

CONCLUSIONS

It is fascinating to speculate about the properties of matter and the physical laws at less than 10^{-19} m.

It is exciting to live in the age in which this unknown and strange space is explored by experiments.

If you have any questions:

G.F. Giudice
CERN-TH, room 4-2.056
phone: 022 767 3203
e-mail: gian.giudice@cern.ch

If you want to know more: