Beyond the Standard Model

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Lecture 5

CERN Summer Student
Programme 2014

Why is supersymmetry interesting?

Higgs field affected by quantum fluctuations of the vacuum

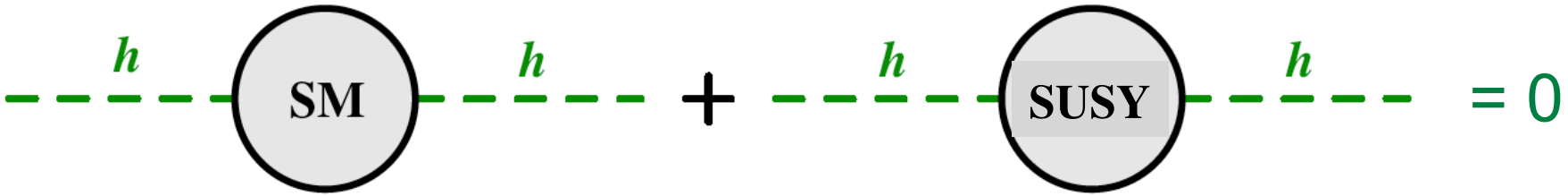
M_W , M_Z ➔ E_{max}

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

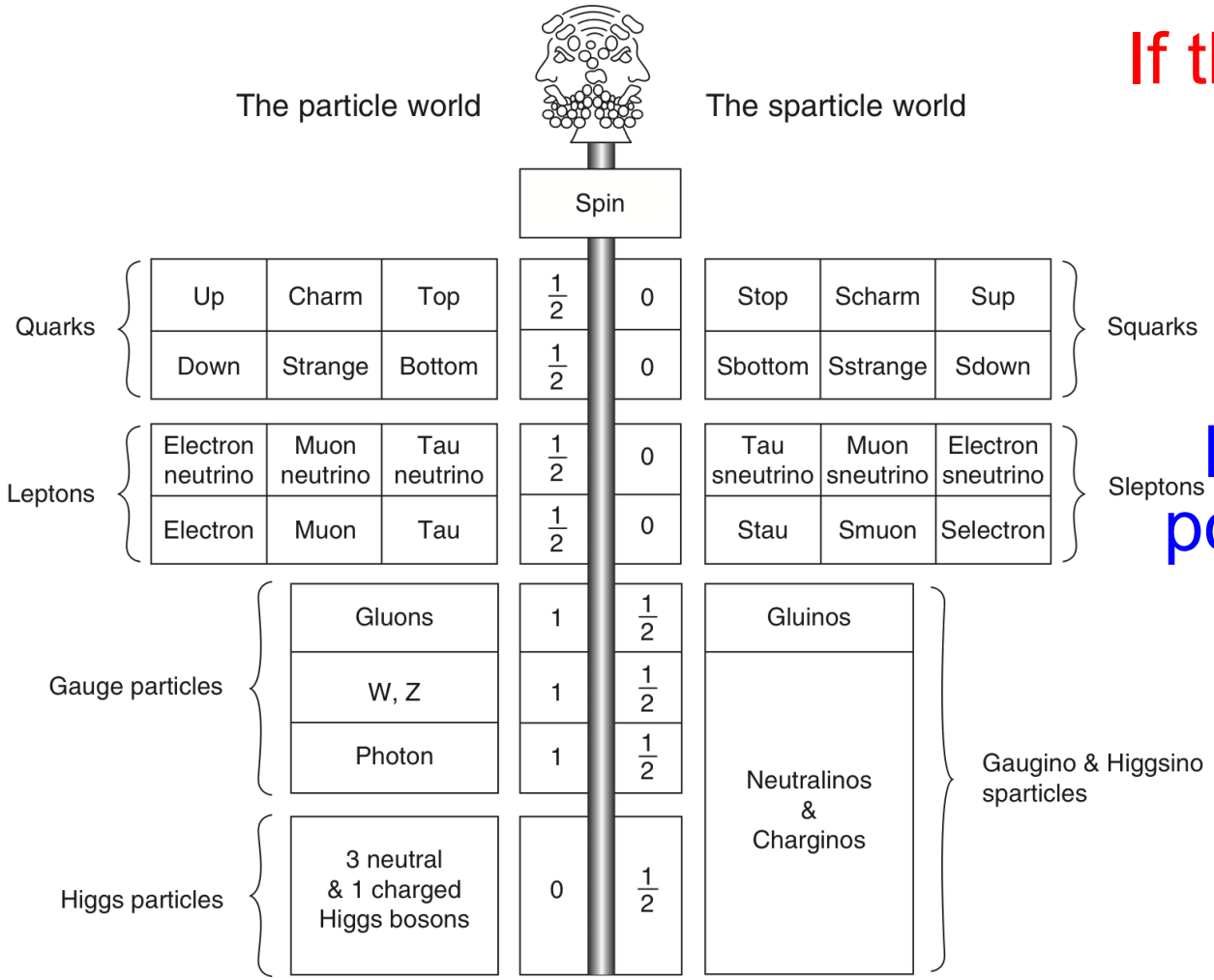
virtual sparticles decrease the density of the Higgs field in the vacuum: M_W ↘

total effect = 0

The magic of symmetry!



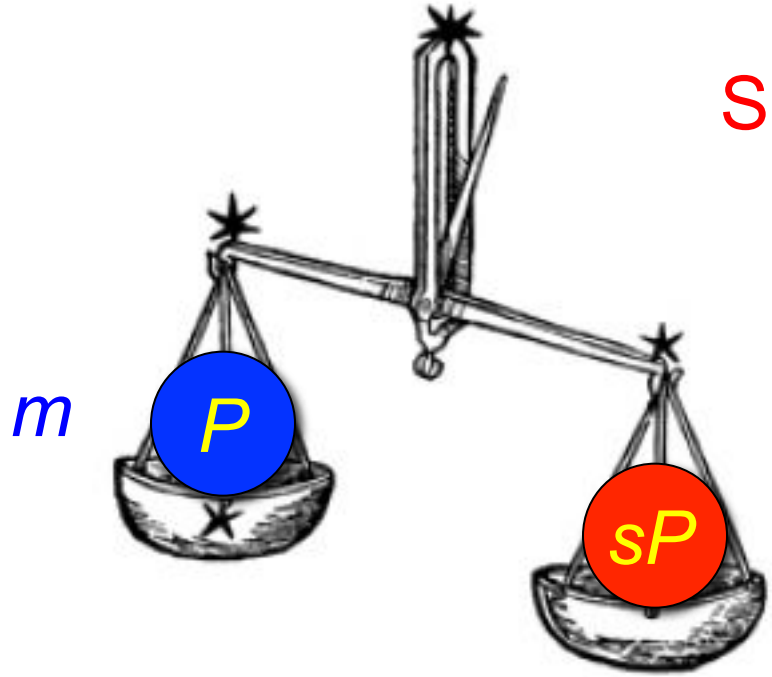
Supersymmetry gives the justification for an apparently miraculous coincidence



If the particle world took place in superspace…

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

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



Supersymmetry breaking

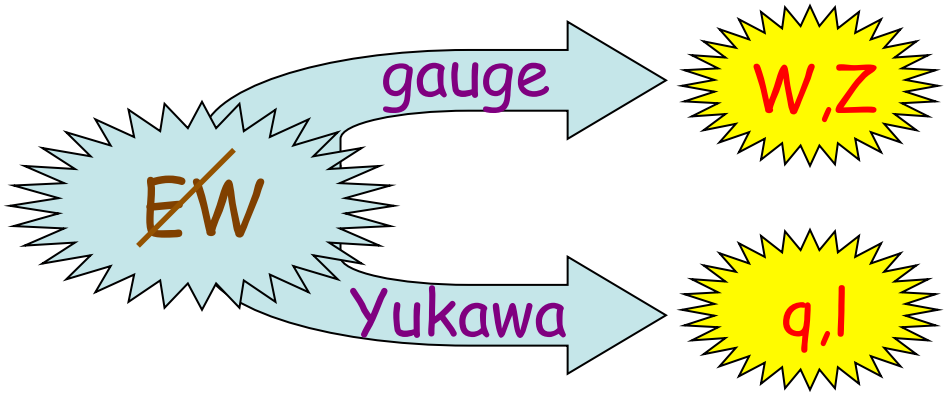
$\tilde{m} >> m$

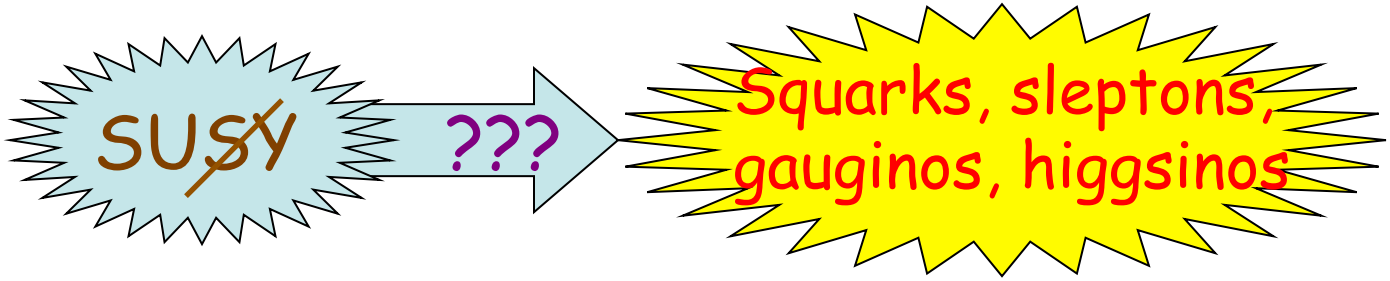
The dark side of the moon is hidden

We need the LHC!

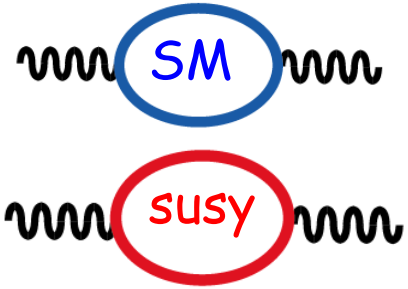
gauge symmetry ➔ $m = 0$
supersymmetry ➔ $\tilde{m} = 0$

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



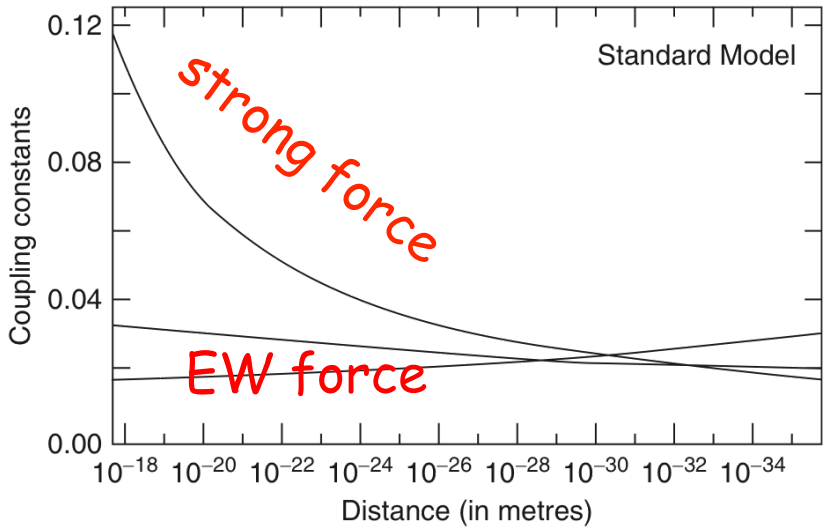


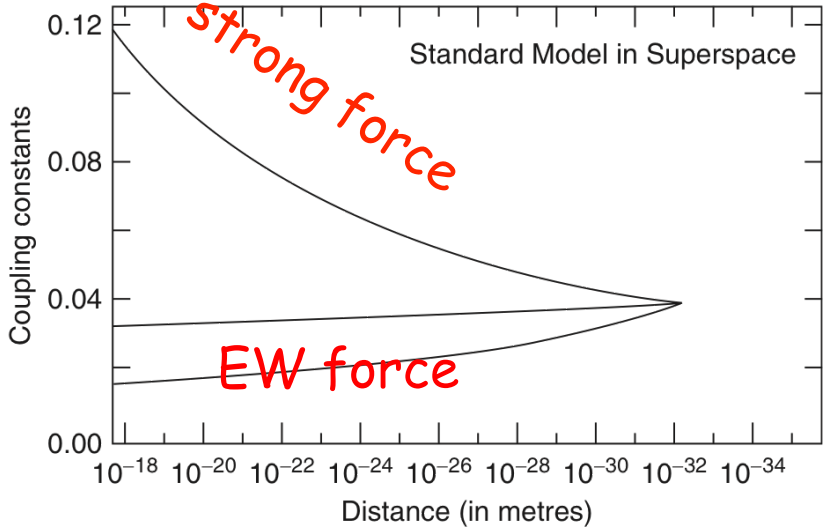
$$\frac{dg_i^{-2}}{d\ln Q} = \frac{b_i}{4\pi}$$



$b_3=-7$, $b_2=-19/6$, $b_1=41/6$

$b_3=-3$, $b_2=1$, $b_1=11$

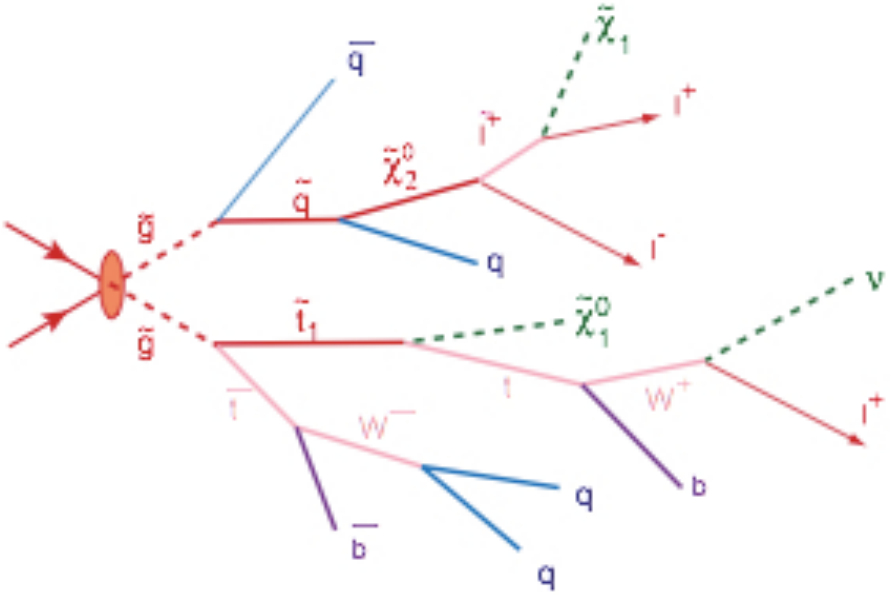




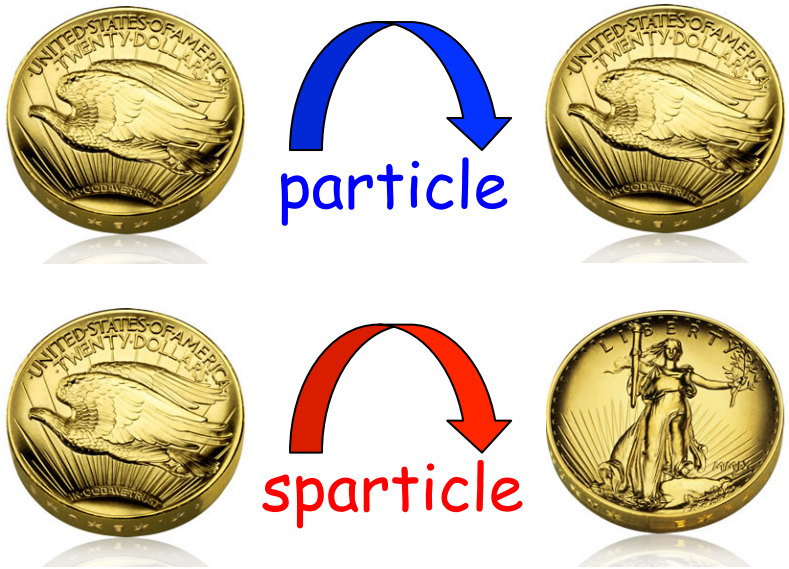
The screening (and antiscreening) depends on all species of existing particles

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

How will the LHC detect supersymmetry?

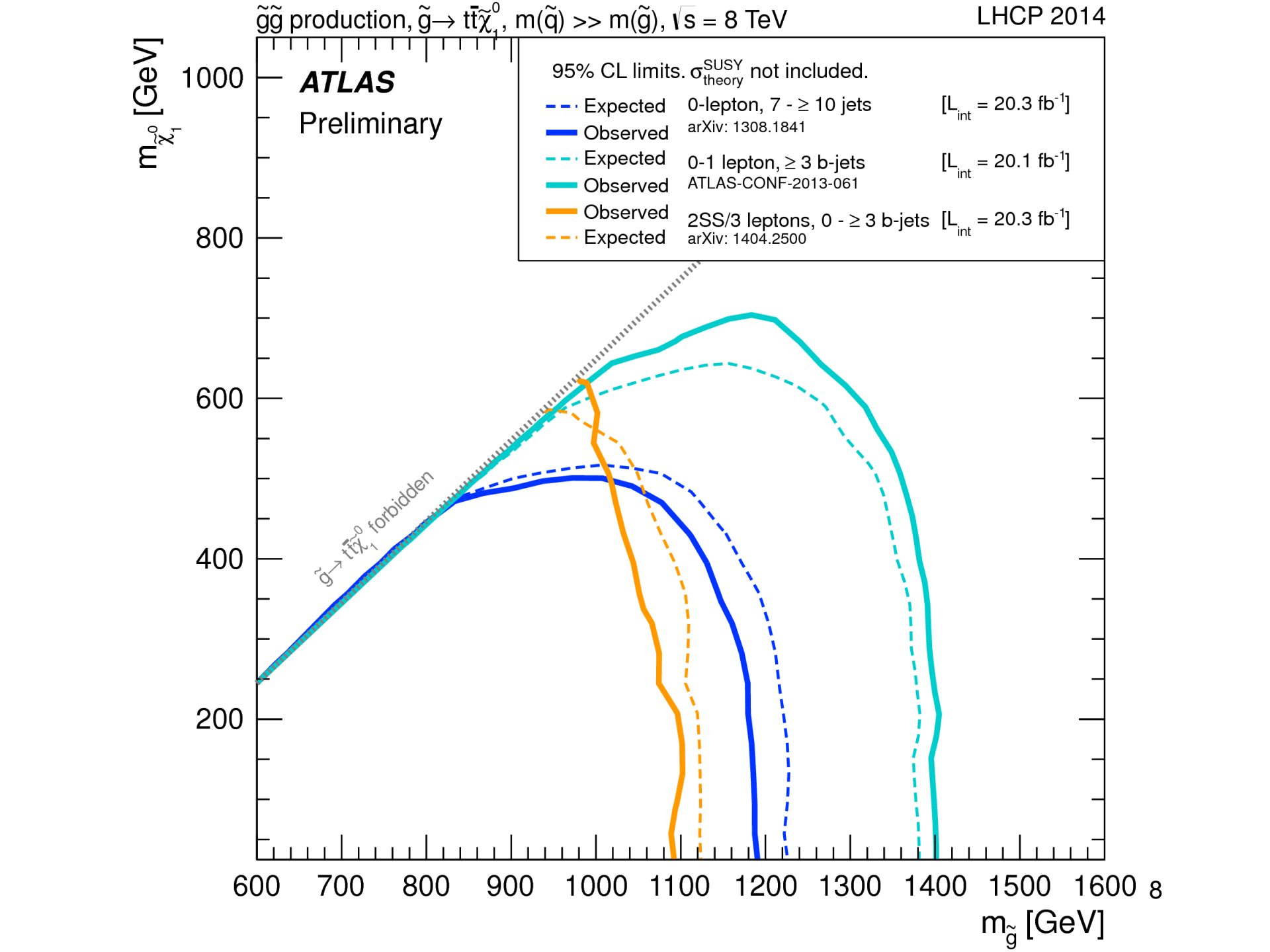


R-parity



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

➔ $\not{E}_T$


$\tilde{g}\tilde{g}$ production, $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$, $m(\tilde{q}) >> m(\tilde{g})$, $\sqrt{s}$ = 8 TeV
LHCP 2014
ATLAS
Preliminary
95% CL limits. σ^{SUSY}_{theory} not included.
Expected
Observed
0-lepton, 7 - ≥ 10 jets
arXiv: 1308.1841
[L_{int} = 20.3 fb^{-1}]
Expected
Observed
0-1 lepton, ≥ 3 b-jets
ATLAS-CONF-2013-061
[L_{int} = 20.1 fb^{-1}]
Observed
Expected
2SS/3 leptons, 0 - ≥ 3 b-jets
arXiv: 1404.2500
[L_{int} = 20.3 fb^{-1}]
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ forbidden
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{g}}$ [GeV]
200
400
600
800
1000
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
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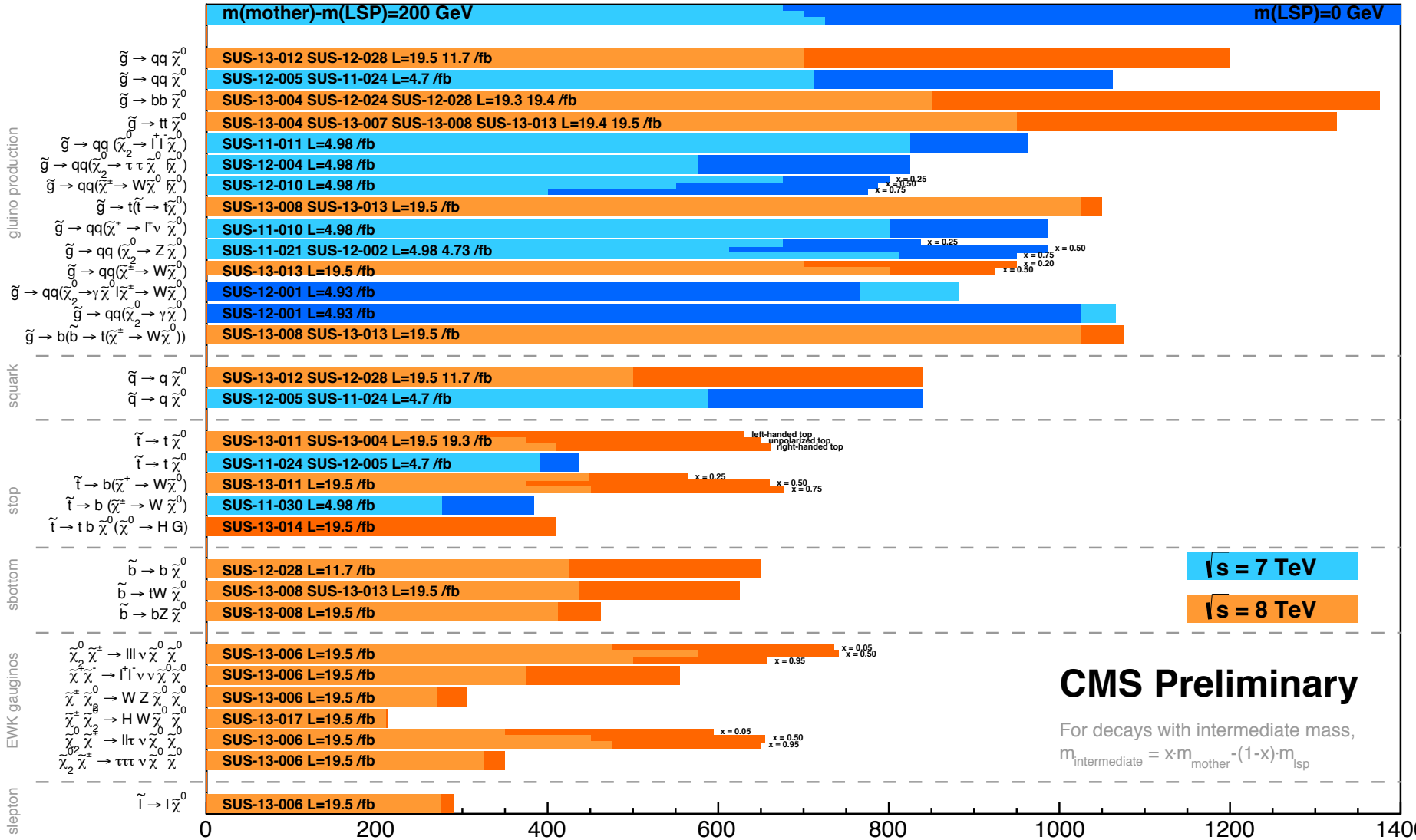
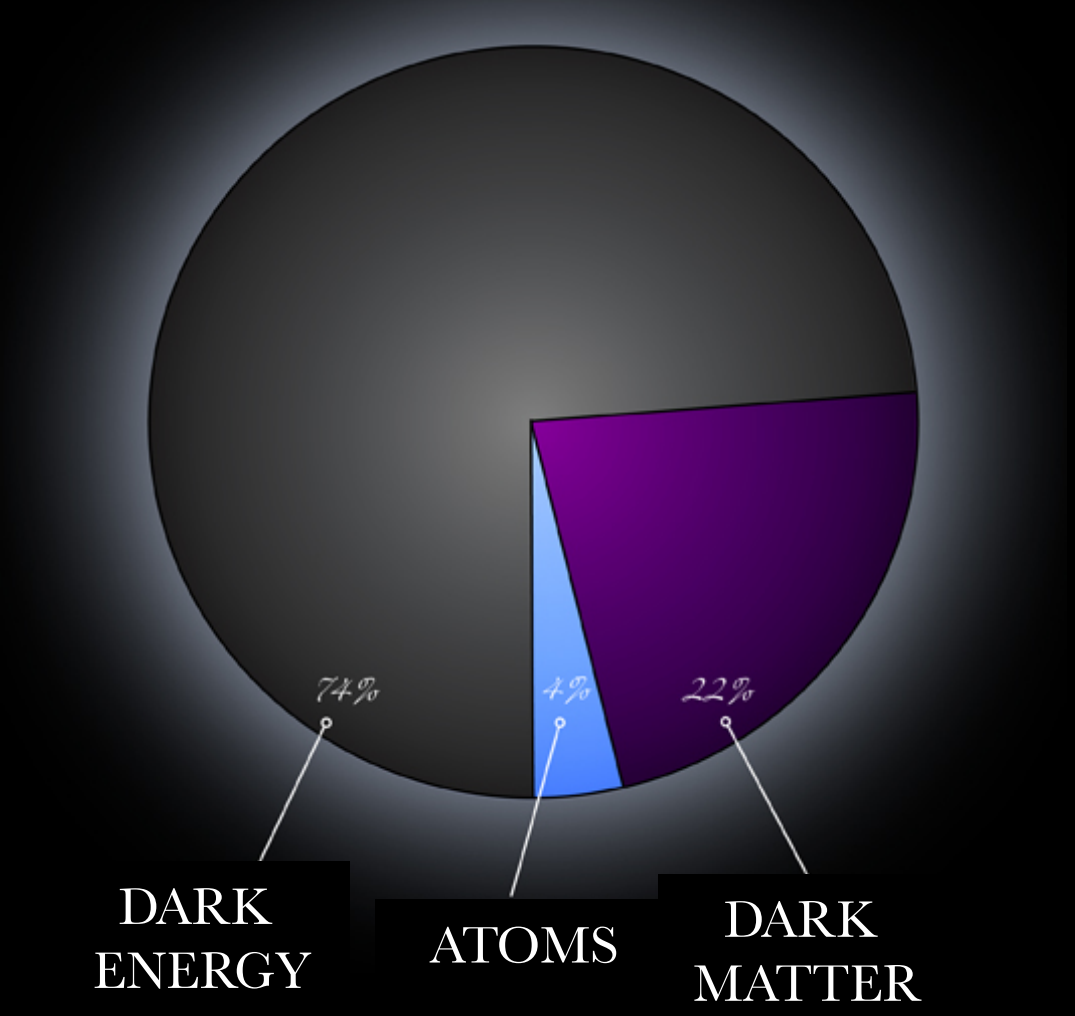
Summary of CMS SUSY Results* in SMS framework SUSY 2013



*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

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

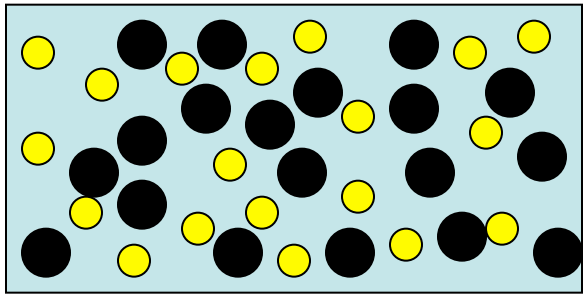


We still have to discover 96% of the universe!

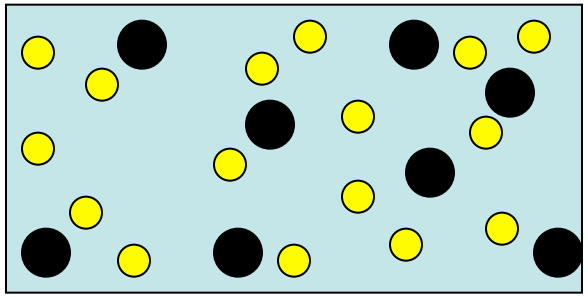
Maybe supersymmetric particles are all around us at this very moment…

Link dark matter ⟷ weak scale

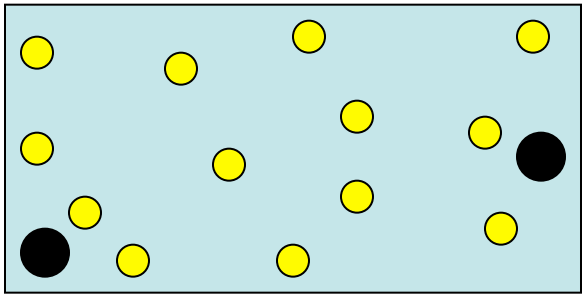
If a stable massive particle is in thermal equilibrium in the early universe, its density today can be computed



T >> M



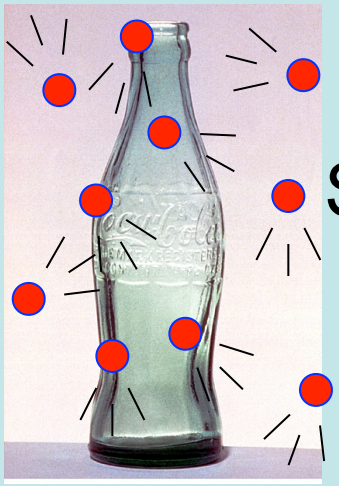
T ≈ M



T << M

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

Peculiar coincidence with the weak scale:
is dark matter made of supersymmetric particles?
Because of R-parity, LSP can behave as DM



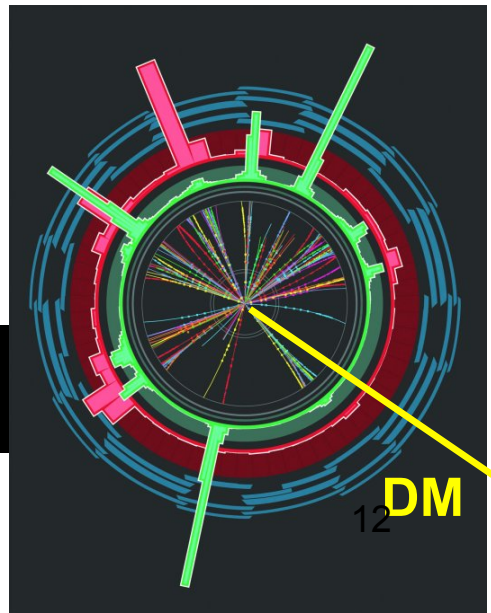
Several LSP per liter of space (moving at one million km/h)

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

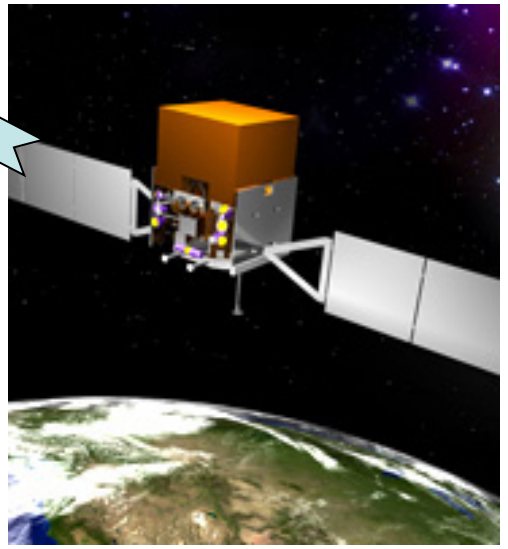


Complementarity of information

Direct detection

DM

LHC



Indirect detection

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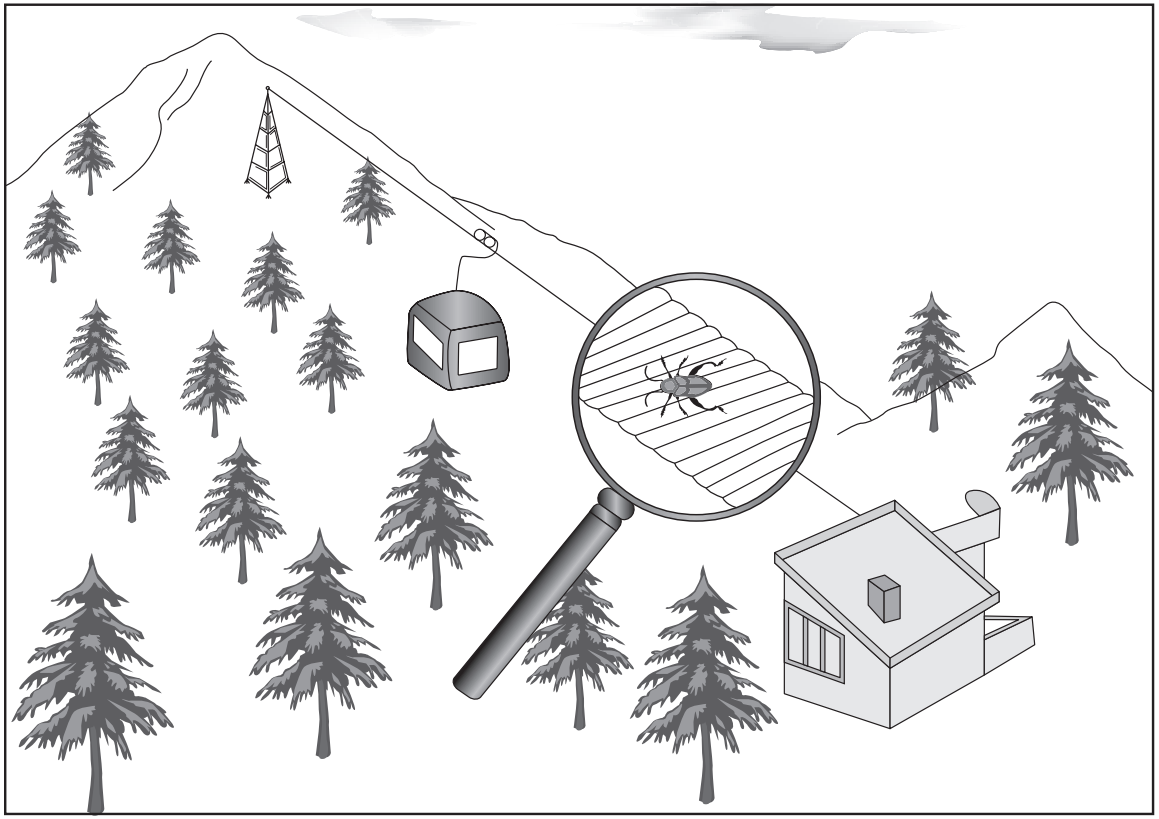
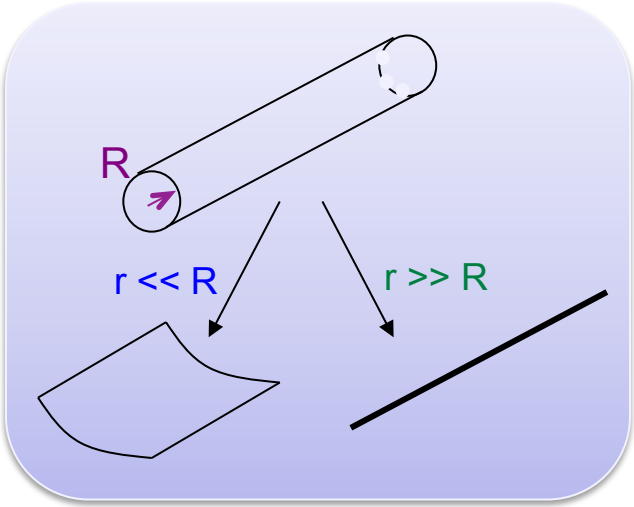
EXTRA DIMENSIONS?





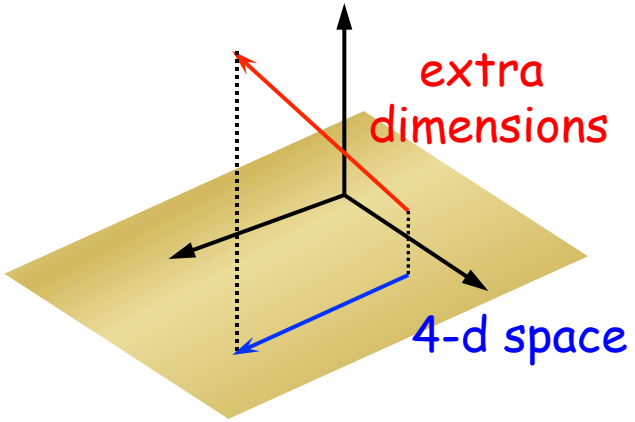
Extra dim is periodic or "compactified" $x_5 + 2\pi R = x_5$

All fields can be expanded in Fourier modes

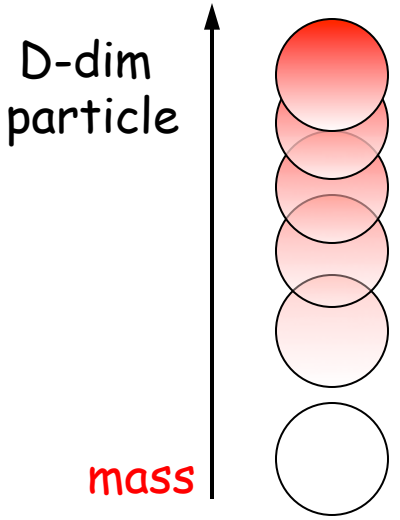
$$\varphi(\hat{x}) = \sum_{n=-\infty}^{+\infty} \frac{\varphi^{(n)}(x)}{\sqrt{2\pi R}} \exp\left(i \frac{n x_5}{R} \right)$$

5-dim field ⇔ set of 4-dim fields: $\varphi^{(n)}(x)$ Kaluza-Klein modes

Each $\varphi^{(n)}$ has a fixed momentum $p_5 = n/R$ along 5th dim



$$E^2 = \vec{p}^{\,2} + \underbrace{p^2_{extra} + m^2}_{\text{KK mass}}$$



From KK mass spectrum we can measure the geometry of extra dimensions

If you have any questions:

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If you want to know more: