# Supersymmetry and the ATLAS Experiment

Francesca Ungaro
Albert Ludwigs Universität, Freiburg

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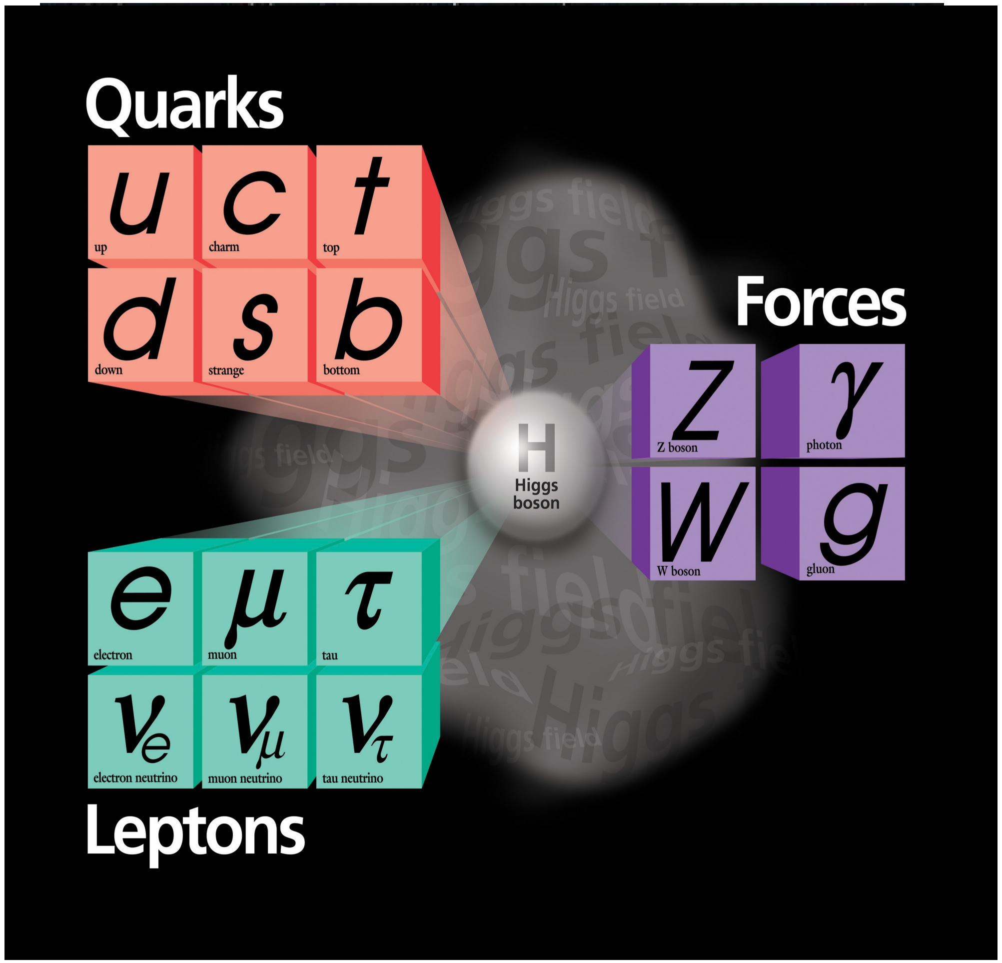
# The Standard Model

- The most precise and complete theory for elementary particles ever built

- **Matter** composed of **fermions**, spin-½ particles

- **Interactions** (strong, electromagnetic,weak) mediated by gauge **bosons**, spin-1 particles

- **Mass** obtained via interaction with the **Higgs** field



# Questions you can ask yourself...

- The Standard Model is **THE** theory of fundamental interactions?
- Does it provide a complete description of all the experimental evidences?
- Is mathematically completely consistent?
- Are there viable extensions of it?
- What can the ATLAS experiment do in this sense?

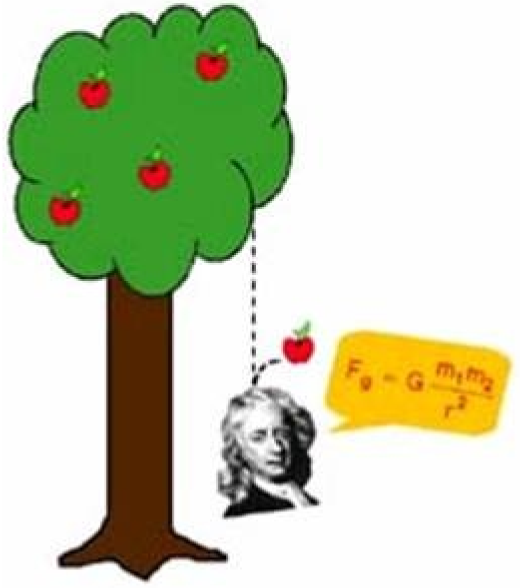
**Q: The Standard Model of particle phisics is THE theory of fundamental interactions?**

# The Standard Model is THE theory of fundamental interactions?

The answer is **NO**.

- It does not include the oldest known interaction: **gravity**

- At usual energy scales, **too weak to have any effect**



$$\frac{F_e}{F_g} = \frac{\frac{Ke^2}{r^2}}{\frac{Gm_e^2}{r^2}} = \frac{Ke^2}{Gm_e^2} \sim 10^{42}$$

$K = 9\ 10^{9}\ N\ m^{2}\ C^{-2}$
$G = 6.7\ 10^{-11}\ m^{3}\ kg^{-1}\ s^{-2}$
$e = 1.6\ 10^{-19}\ C$
$m_e = 9.1\ 10^{-31}\ kg$

- It becomes relevant at an energy scale E ~ $10^{18}$ GeV

- The Standard Model is an **effective theory** of a **more complete theory** of fundamental interactions

**Q: Does it provide a complete description of all the experimental evidences?**

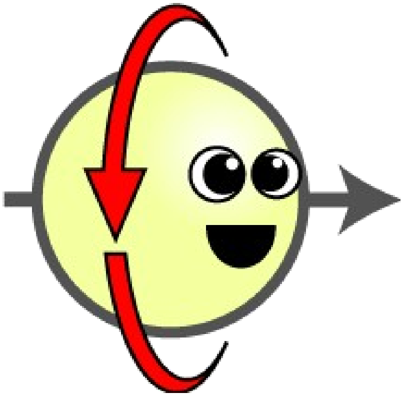
# Does it provide a complete description of all the experimental evidences?

- On a **microscopic** point of view **<u>YES</u>**, with an **incredible precision**

$$\vec{\mu} = g_l \mu_B \vec{S}$$

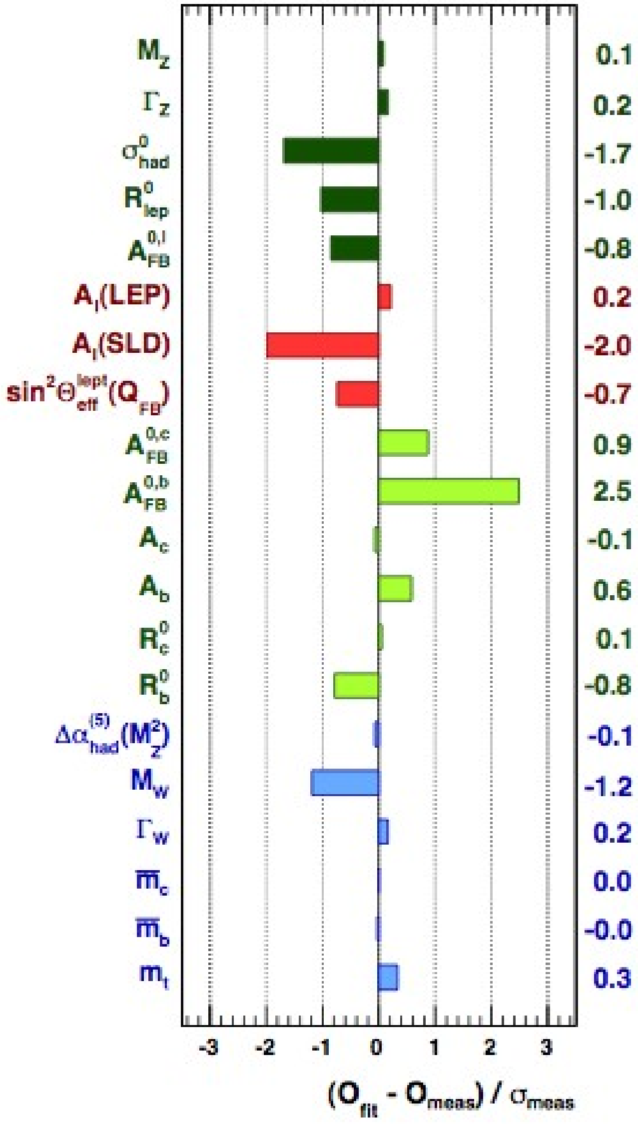
$$\mu_B = \frac{e\hbar}{2me}$$

$$a = \frac{|\vec{\mu}|}{\mu_B} - 1$$



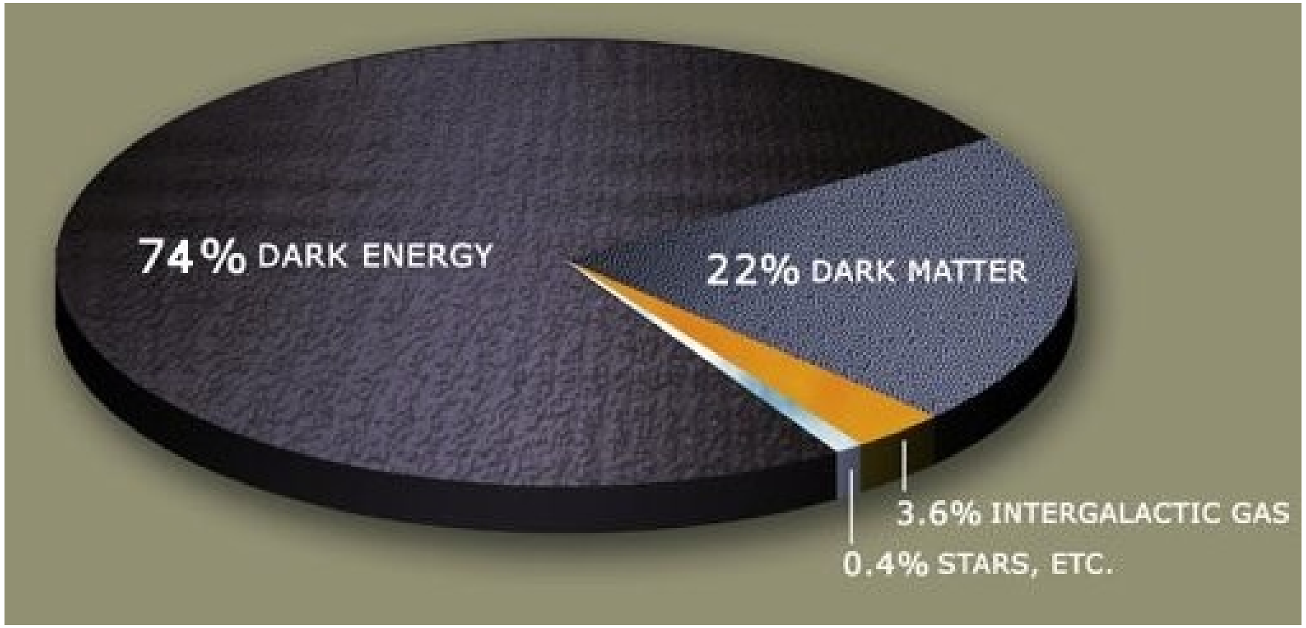
$a^{theo} = 1.16591793(68)\ 10^{-3}$

$a^{exp} = 1.16592080(63)\ 10^{-3}$



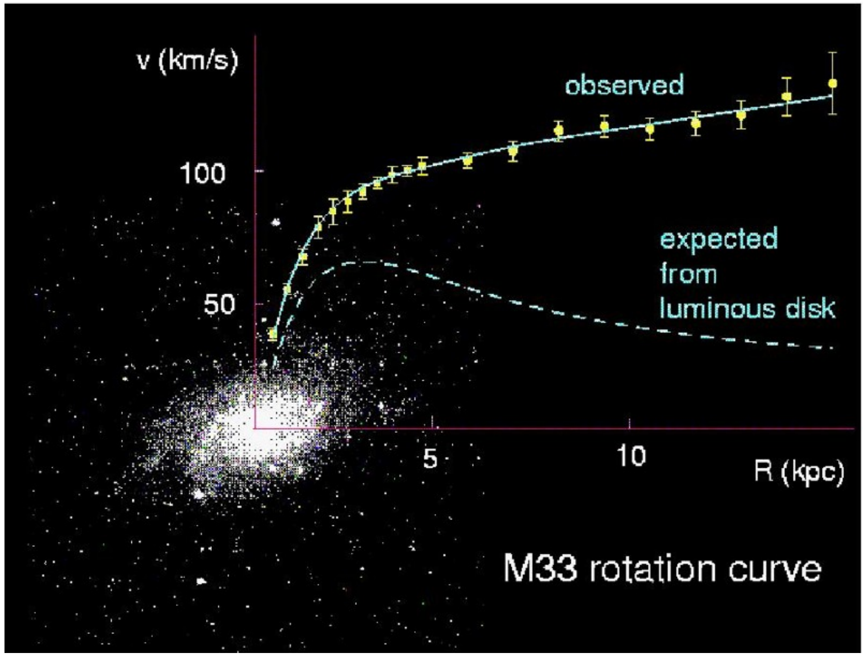
# Does it provide a complete description of all the experimental evidences?

- On a **macroscopic** point of view, **is a disaster!**
  - We have no idea what compose the **95% of our universe:** we know is not made of particles and interactions described by the Standard Model



# How do we know dark matter really exists?

- Indirect observations, based on **gravitational lensing** and measurement of **galaxy rotation velocity**



- Example: rotation velocity of M33 galaxy. **particle with mass m** in the orbit of a sphere of mass M

$$m\frac{v^2}{r} = \frac{GmM(r)}{r^2}$$

with $M(r) = 4/3r^3$ for $r < R$ and $M(r) = \hat{M}$ for $r > R$. Therefore

$$v \sim r \text{ if } r < R$$

$$v \sim \sqrt{\frac{1}{r}} \text{ if } r > R$$

- Something is obscure here....

# Dark Matter

A part of what is missing is **very likely** composed of a **stable particle**, produced in the early universe: **the dark matter**

The **“missing particle”** must be:

- **Neutral** (otherwise we should have seen it!)
- **Weakly interacting** (otherwise we should have seen it!)
- **Massive** (produce detectable gravitational effects)

**WIMP: Weakly Interacting Massive Particle**

The **“right”** density of dark metter is obtained for WIMP masses in the range **100 GeV - 1 TeV**

**Q: Is mathematically completely consistent?**

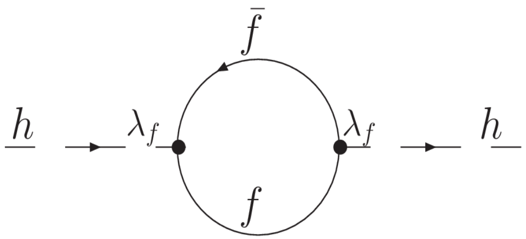
# Is mathematically completely consistent?

- **Technically yes**, but.....
- There is a problem with the **Higgs boson** and its mass

In quantum field theory, the mass of a particle is given by the sum of its “**bare mass”** plus **“radiative corrections”**.

- The radiative corrections take into account the possibility of **emitting and absorbing** other particles. This “slow down” the particle, modifies its mass

m = ............................ +



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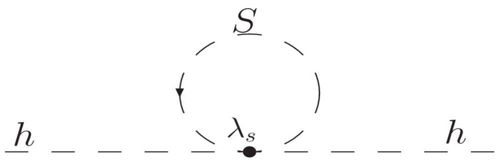

$$m = m_{bare} + \Delta m_{fermion} + \Delta m_{boson}$$

The **Higgs Boson is extremely sensitive** to the energy scale entering in the loops

# Fine tuning in the Standard Model

Dominating corrections from top quark, heaviest fermion

$$m_H = m_H(\text{bare}) + \frac{|\lambda_f|^2 \Lambda_{UV}^2}{8\pi^2}$$

- We **know** $m_H$=125 GeV
- with $\lambda_f$ ~ 1 and Λ ~$10^{18}$ GeV correction ~$10^{34}$

**bare mass and corrections have to cancel** with a precision of ~$10^{30}$ decimal digits

- A bit strange, isn't it?

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# (More than) Midway Summary

# Midway Summary

- **The Standard Model is THE theory of fundamental interactions?**
  - **No.** THE theory of fundamental interactions must **include gravity.**
- **Does it provide a complete description of all the experimental evidences?**
  - **On the particles point of view YES.** No experimental results falsifying the Standard Model exist.
  - On a more general prospective, we know at least of **one new type of particle (dark matter),** with a mass **around 1 TeV**.
- **Is mathematically completely consistent?**
  - **Yes.** Higgs mass is sensitive to the radiative corrections in a disturbing way.

**Q: Are there viable extensions of it?**

# Extensions of the Standard Model

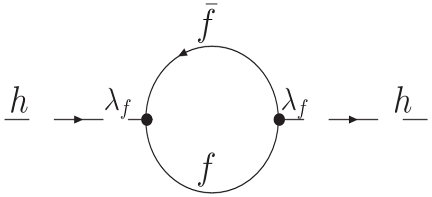
- **Different models** extend the Standard Modello standard
- The **Supersymmetric** extension is the most ….
- Supersimmetry:
  - Allow to include **gravity**.
  - Solve the **fine tuning** problem.
  - Provides a **candidate for dark matter**

But:

- Not **experimentally confirmed** (yet?)

# What is Supersymmetry?

Loop corrections to the Higgs boson mass



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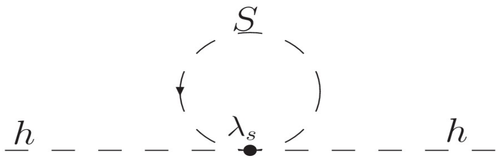

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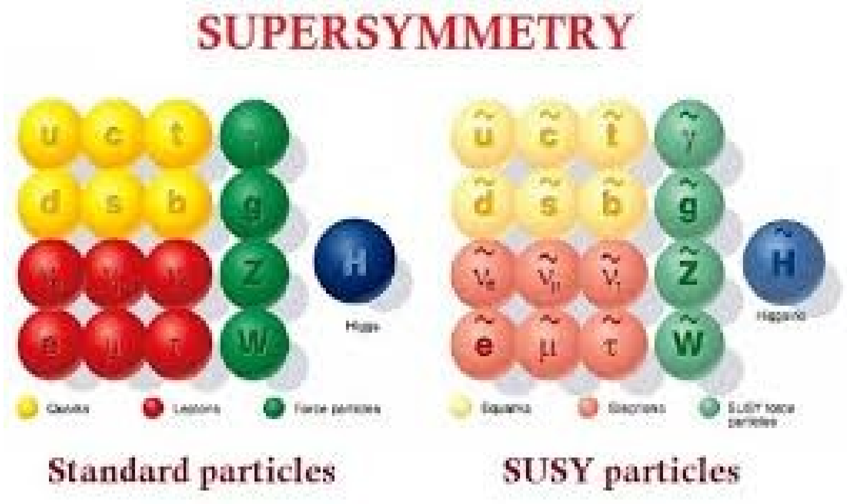
- If for each **fermion** of the Standard Model there is a **new boson** and for each **boson** a **new fermion** with the **same mass**, the radiative corrections cancel exactly

- This is the basis of **Supersymmetry (SUSY)**, the new particles are called **superpartners**



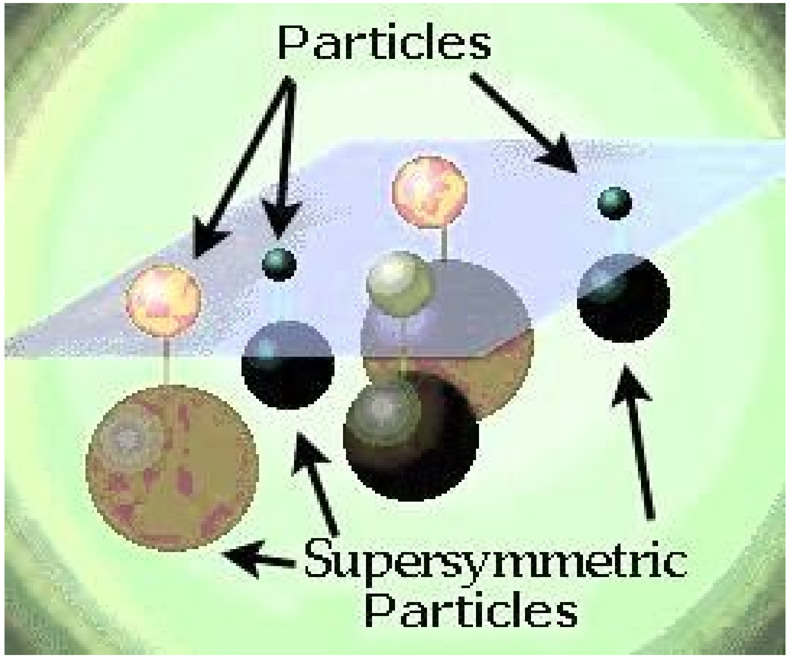
- Superpartners of the fermions are called **s-**fermions (e.g. top → stop)

- Superpartners of the bosons are bos**ino**s (e.g. gluon → gluino)

- Higgsinos, wino, zino and photino mix and form **charginos** and **neutralinos**

# Supersymmetry

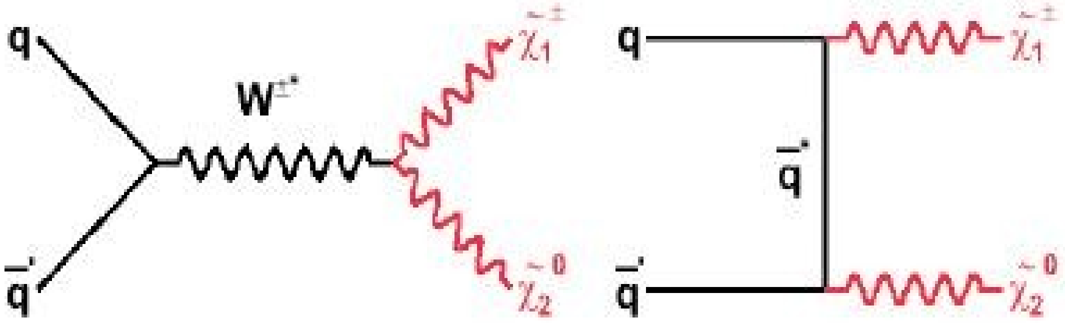
- First problem: superpartners **never observed**
  - **SUSY must be broken.** Superpartners must be heavier than Standard Model particles
  - What about fine tuning? Acceptable if **$M_{SUSY}$ < TeV** (that means, can be observed at the LHC)



- This is the right order of magnitude for the **WIMPs**!
- Do we have a dark matter candidate among the new particles?

# Supersymmetry

- Second problem: **many new interactions possible**, leading to fast **proton decay**
  - To avoid this introduce **R-parity**, a quantity conserved in any interaction.
  - R-parity 1 for Standard Model particles, -1 for superpartners
- Consequence 1: **superparticles are produced in pairs**
- Consequence 2: The **lightes superparticle** is stable. If is neutral and weakly interacting is a good **dark matter candidate**



# Supersymmetry

- Extension of the Standar Model introducing the minimum number of superparticles is the **Minimal Supersymmetric Standard Model (MSSM).**
- Even this formulation introduces **many new parameters** (third problem). Is the theory predictive?
- Yes and no:
  - No: We do **not know** the values of the **parameters**
  - Yes: **Not all the values** for the parameters are **compatible with the experimental constraints**. Ones fixed, the processes can be evaluated with the **same precision as in the Standard Model.**
- There is only one way to know the details of SUSY (if it exist): **find it**!

**Q: What can the ATLAS experiment do in this sense?**

**A: Ask Simone, he knows everything about it :)**