

Theory @ CERN

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(slides partially from Aleksi Kurkela)

Theory division at CERN

- Collider physics, 19

Precision prediction in SM...

- Heavy ions, 5

Material properties of elementary particle matter, quark-gluon plasma, early universe, neutron stars...

- Beyond standard model physics, 12

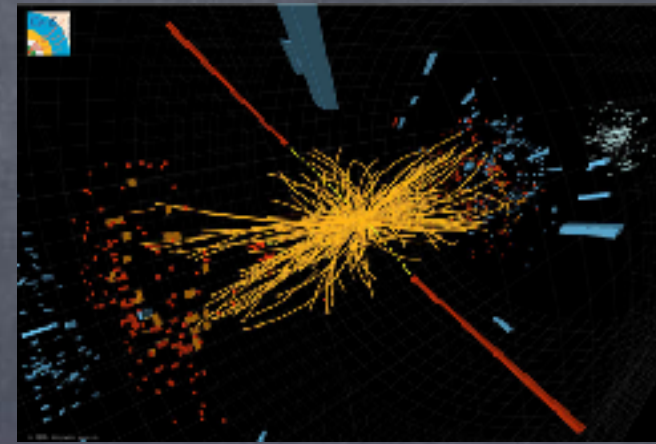
Dark matter, super symmetry, naturalness, hierarchy problem...

- Cosmology, 6

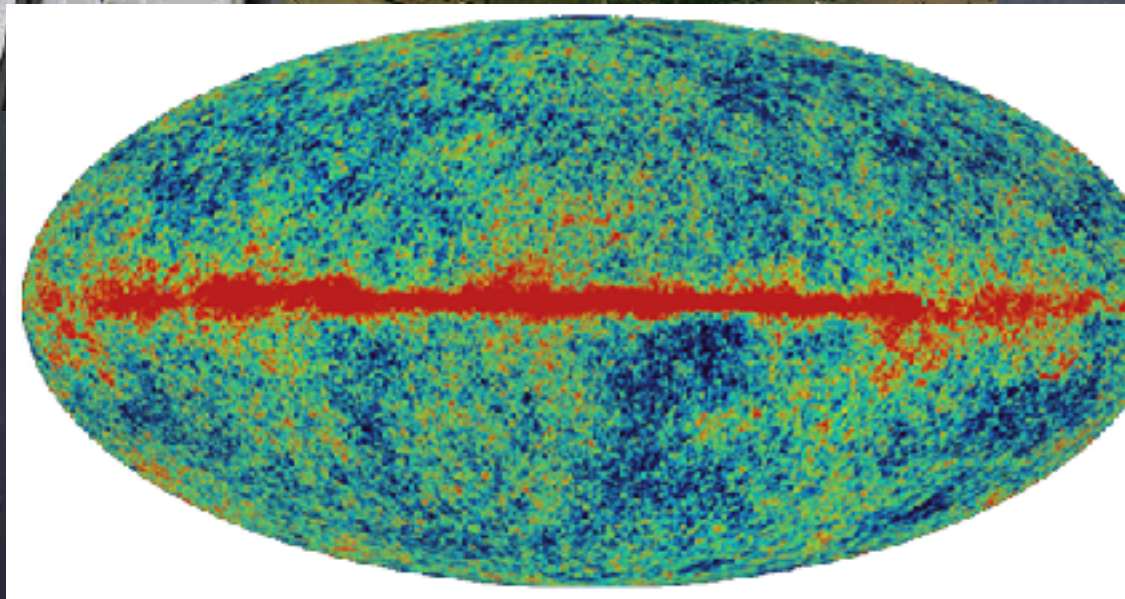
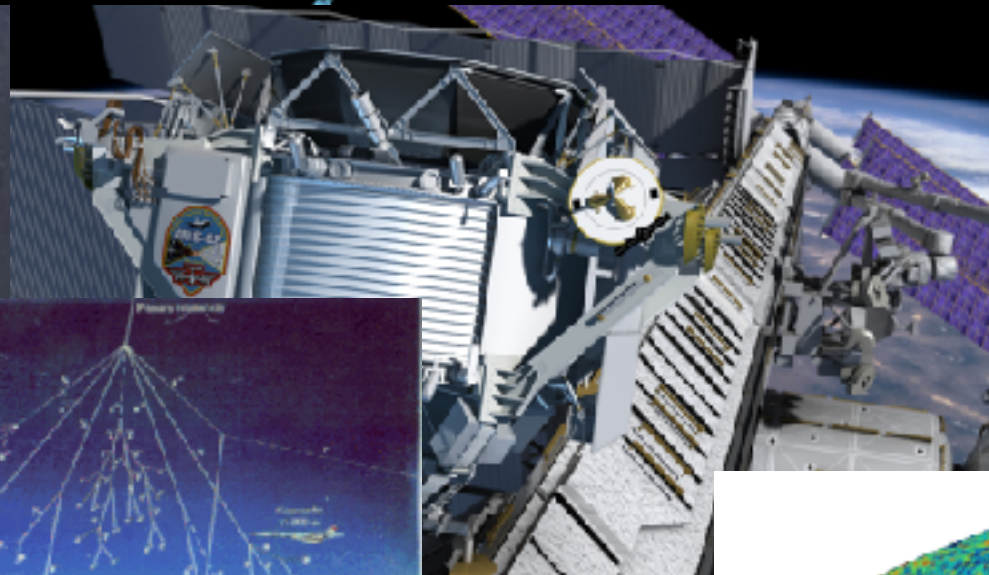
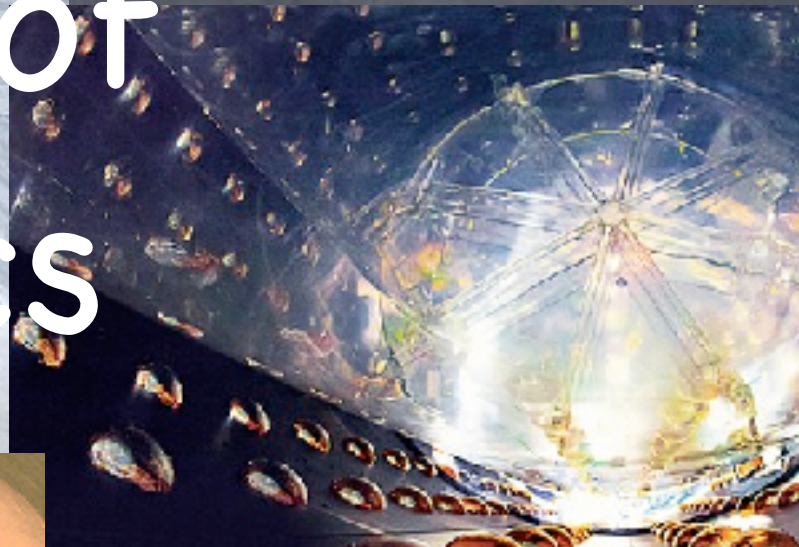
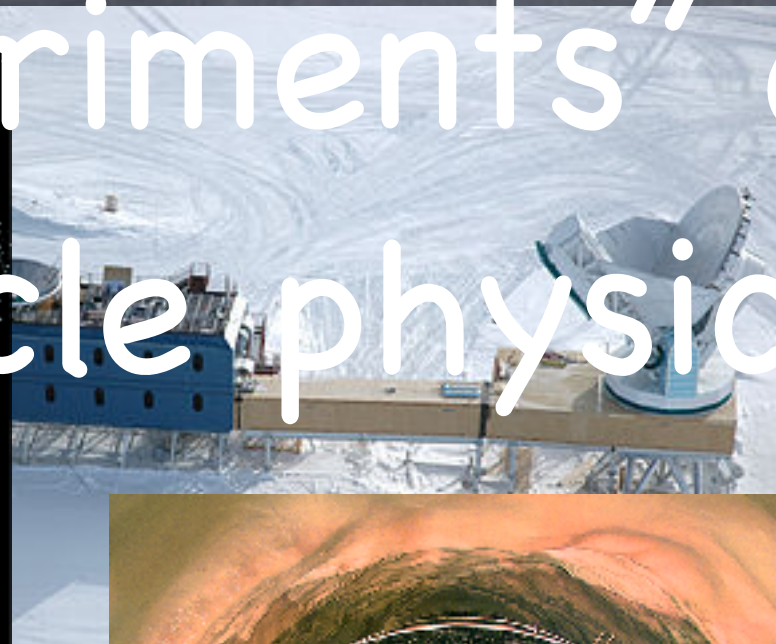
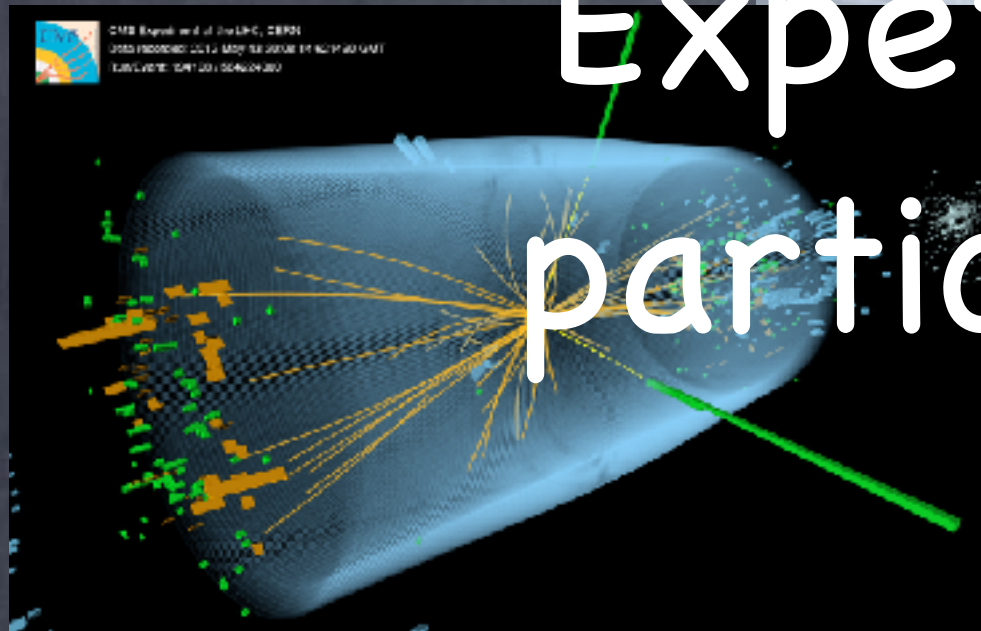
Big bang, large scale structure, inflation, baryogenesis...

- String theory, 12

Mathematical physics, condensed matter, AdS/CFT...

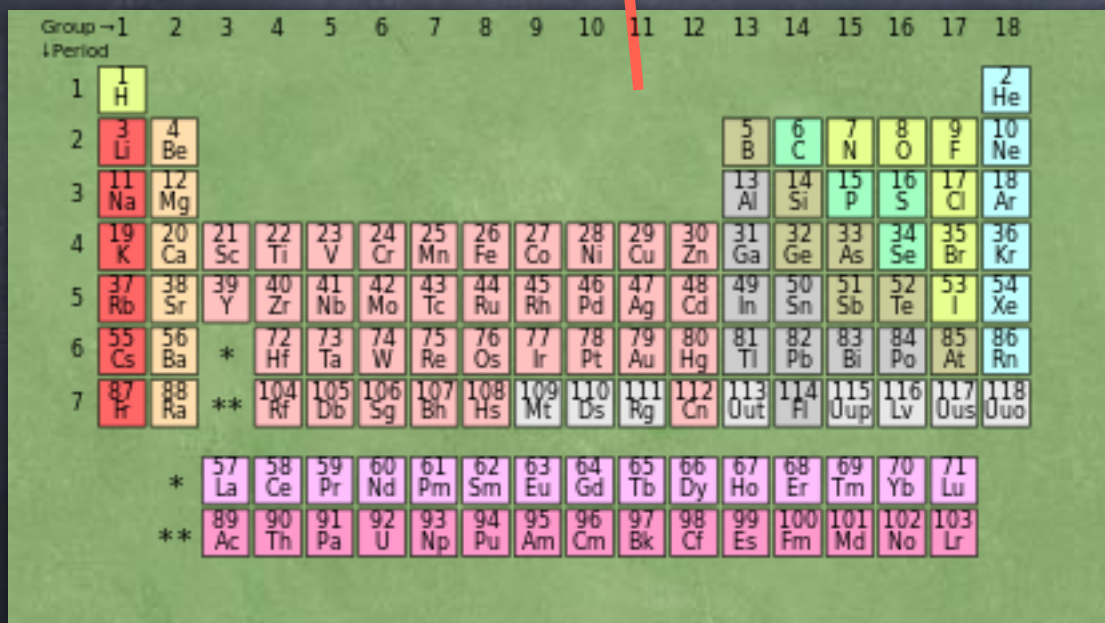


“Experiments” of particle physics



The diagram illustrates the SU(6) spin-flavor symmetry in the quark model. It consists of three main parts:

- Top Hexagon (Baryons):** Shows the decomposition of the 56 representation into 10 and 8 representations. The states are labeled by their spin (s) and isospin (q):
 - $s=0$: Σ^0 , Λ
 - $s=-1$: Σ^- , Σ^+
 - $s=-2$: Ξ^- , Ξ^0
- Bottom Hexagon (Mesons):** Shows the decomposition of the 35 representation into 8 and 16 representations. The states are labeled by their spin (s) and isospin (q):
 - $s=1$: K^0 , K^+
 - $s=0$: π^0 , η
 - $s=-1$: π^- , π^+
- Large Plot (All Hadrons):** A 3D-like plot showing the full SU(6) multiplets and their decomposition into SU(3) flavor multiplets. The states are labeled by their spin (s) and isospin (q):
 - $q=1$: Σ^+ , Σ^0 , Σ^- , Λ , Ξ^0 , Ξ^-
 - $q=0$: Σ^0 , Λ , Ξ^0 , Ξ^-
 - $q=-1$: Σ^- , Λ , Ξ^-



Standard model of particle physics

“Periodic table” of particle physics

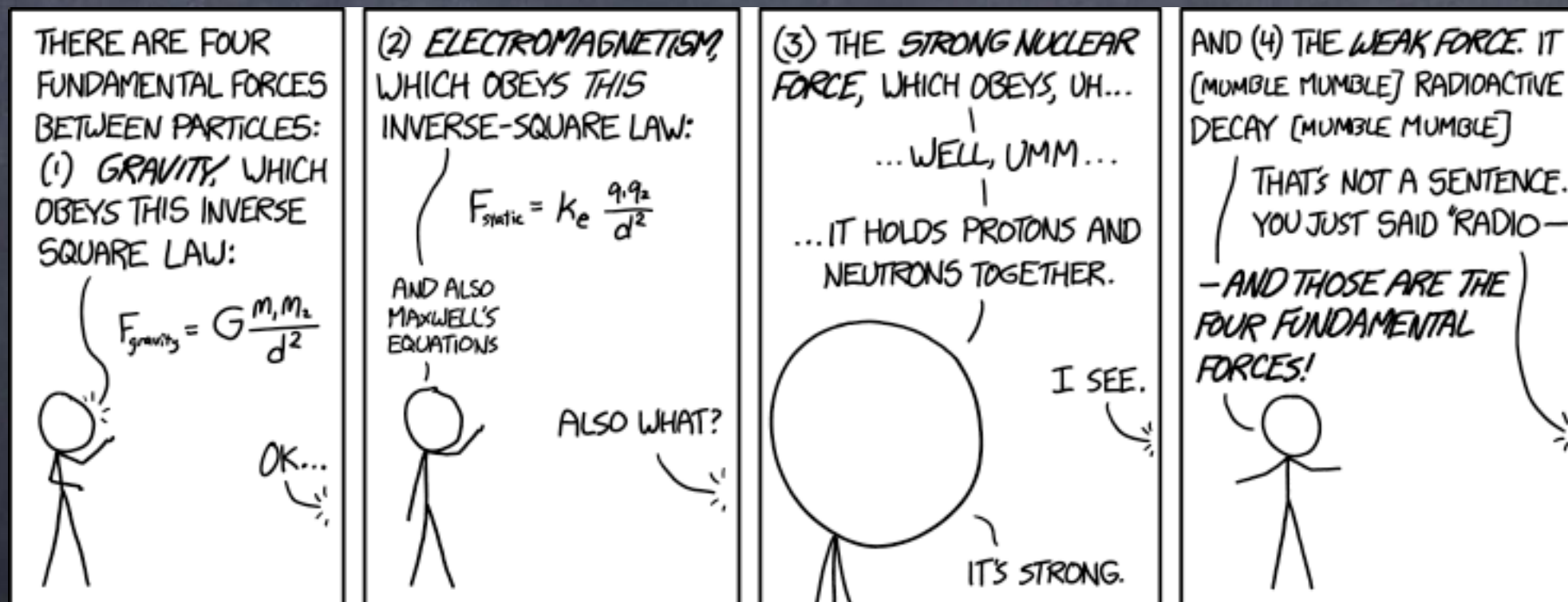
| THREE GENERATIONS OF MATTER | | | | CHARGE: | |
|-------------------------------|---------------------|----------|----------|---------------------------|--------------|
| MATTER CONSTITUENTS: FERMIONS | | | | | |
| | I | II | III | | |
| | 2.75 | 1300 | 178000 | $\leftarrow \frac{2}{3}$ | 91188 |
| QUARKS | UP | CHARM | TOP | 0 | Z^0 |
| | 6 | 110 | 4500 | $\leftarrow -\frac{1}{3}$ | 80430 |
| | DOWN | STRANGE | BOTTOM | ± 1 | W^+/W^- |
| LEPTONS | 0.511 | 105.7 | 1777 | $\leftarrow -1$ | $< 10^{-25}$ |
| | ELECTRON | MUON | TAU | 0 | PHOTON |
| | $< 3 \cdot 10^{-6}$ | < 0.19 | < 18.2 | $\leftarrow 0$ | theory: 0 |
| | NEUTRINO | NEUTRINO | NEUTRINO | 0 | GLUON |
| | | | | | |
| | | | | FORCE CARRIERS: BOSONS | |

ALL MASSES IN MEV;
ANIMAL MASSES
SCALE WITH
PARTICLE MASSES

The Standard Model
fundamental particle zoo

+ Higgs, 126GeV

Elementary forces



Interactions between particles through fields

- Electro-magnetism: electric- and magnetic fields
Photon
- Strong force: chromo-electric and magnetic
gluon
- weak force: "SU(2)" fields
W,Z bosons
- gravity: gravitational field (metric)
graviton?

Feynman Diagrams

Different lines for different types:

- fermion (matter particle)



- antifermion (antimatter particle)



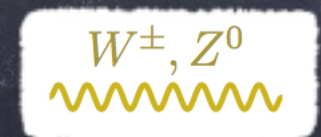
- photon



- gluon

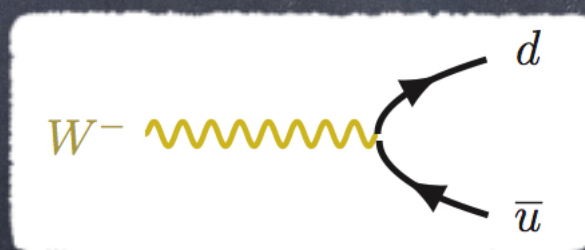
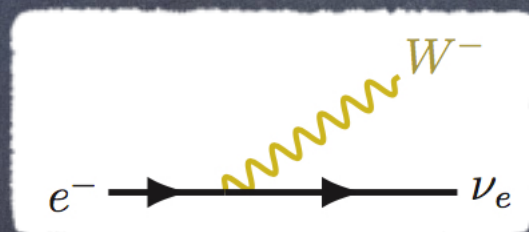
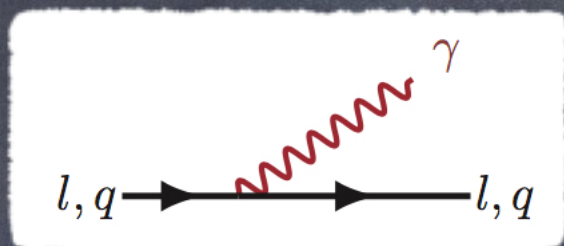


- weak boson

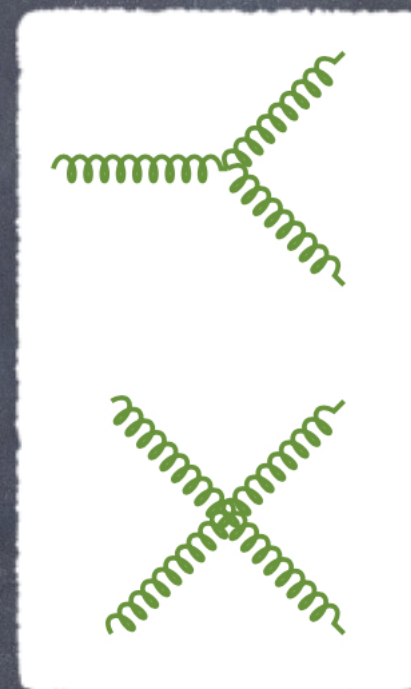


Feynman Diagrams

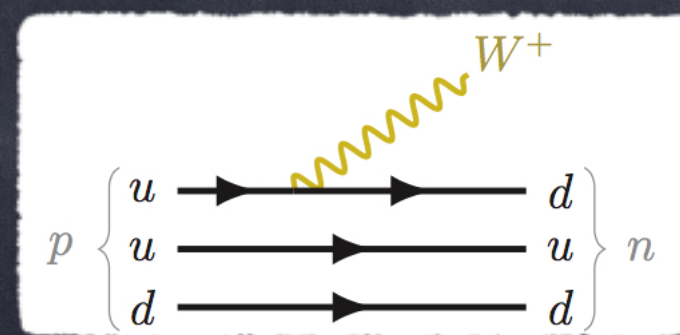
boson – fermion interactions



gluon self-interactions



proton \rightarrow neutron decay



Quantum mechanics

Uncertainty principle

$$\Delta x \Delta p > \hbar/2$$

Special relativity

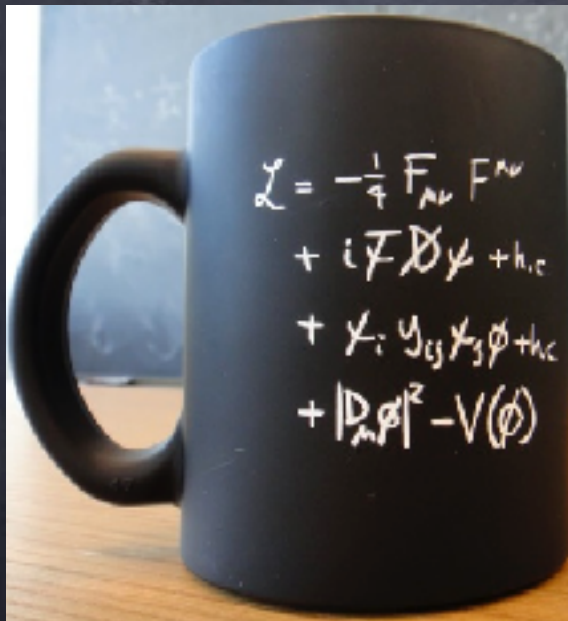
Constant speed of light,
frame independence

Gravity

General relativity

Quantum field theory

Particle-field duality



How do we do it?

Accelerators:

give lots of energy to particles

Colliders:

release energy to create new particles ($E=mc^2$)

Detectors:

identify and measure particles

Computers:

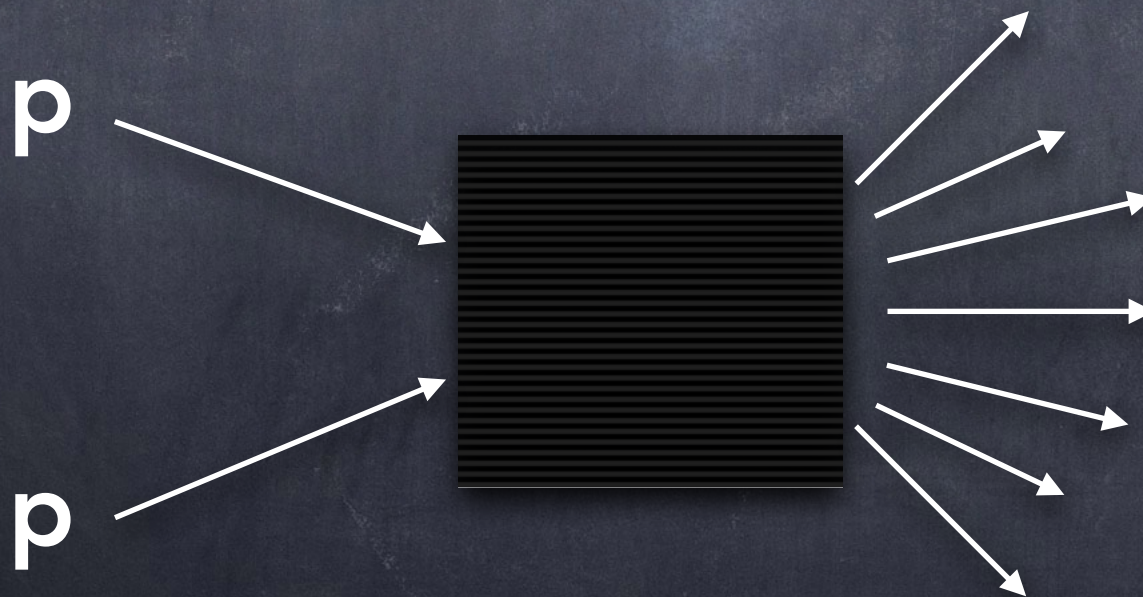
analyse and understand results

 (indirectly) discover new particles!

How do we do it?

Black Box Mechanism:

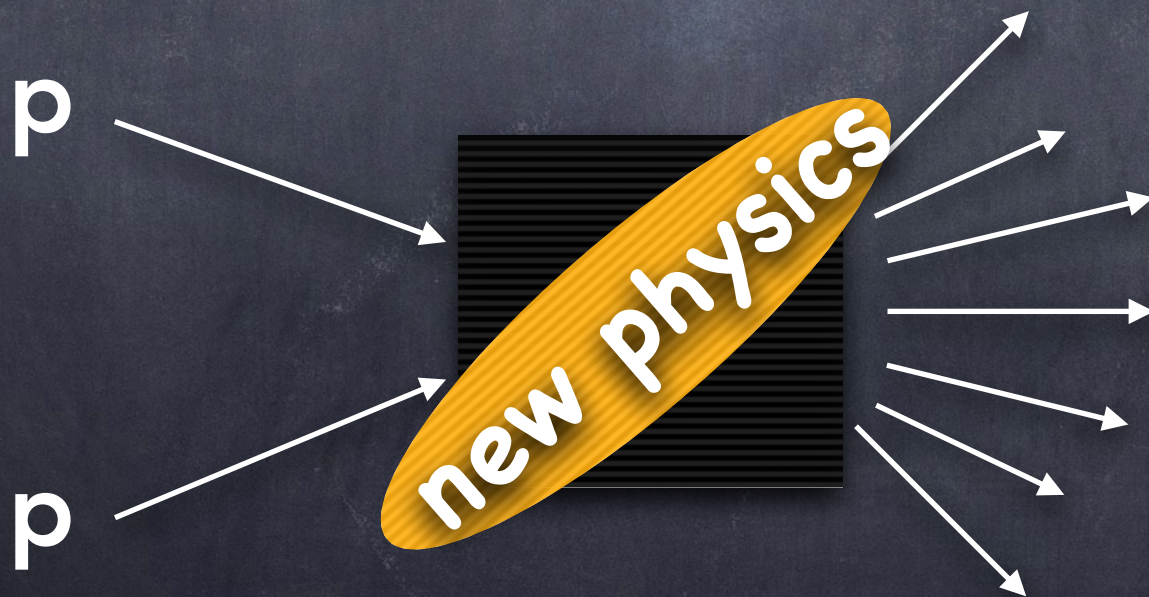
- we know what we put in
- we measure what comes out
- use statistics to deduce what happened in between



How do we do it?

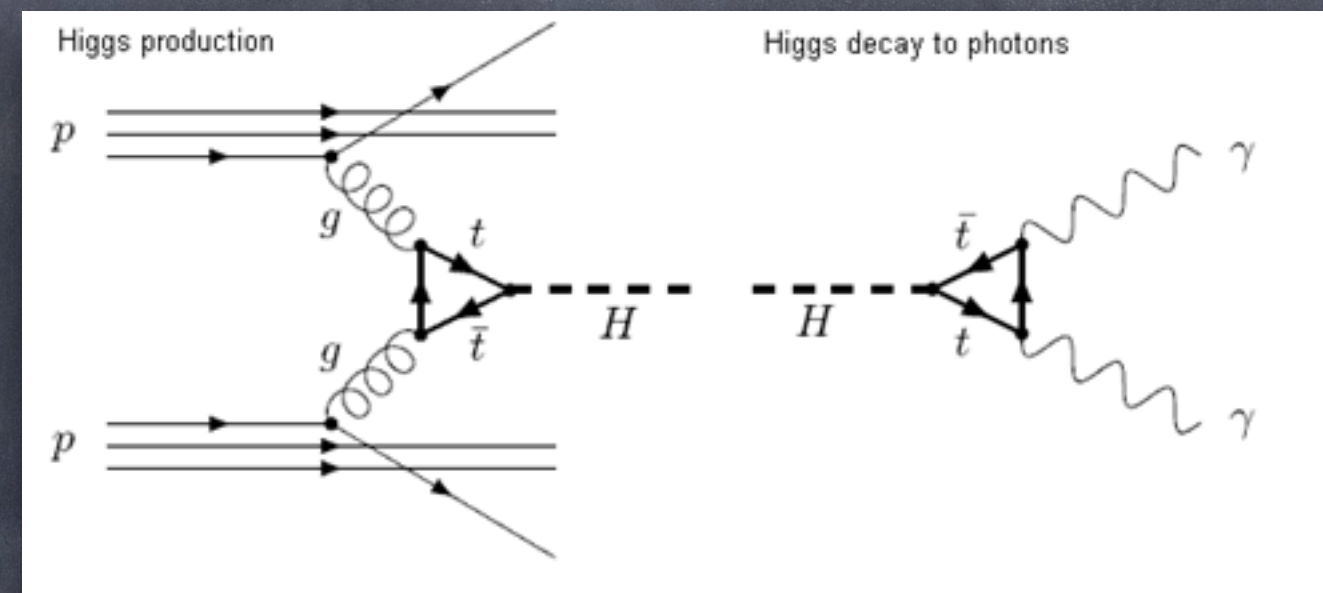
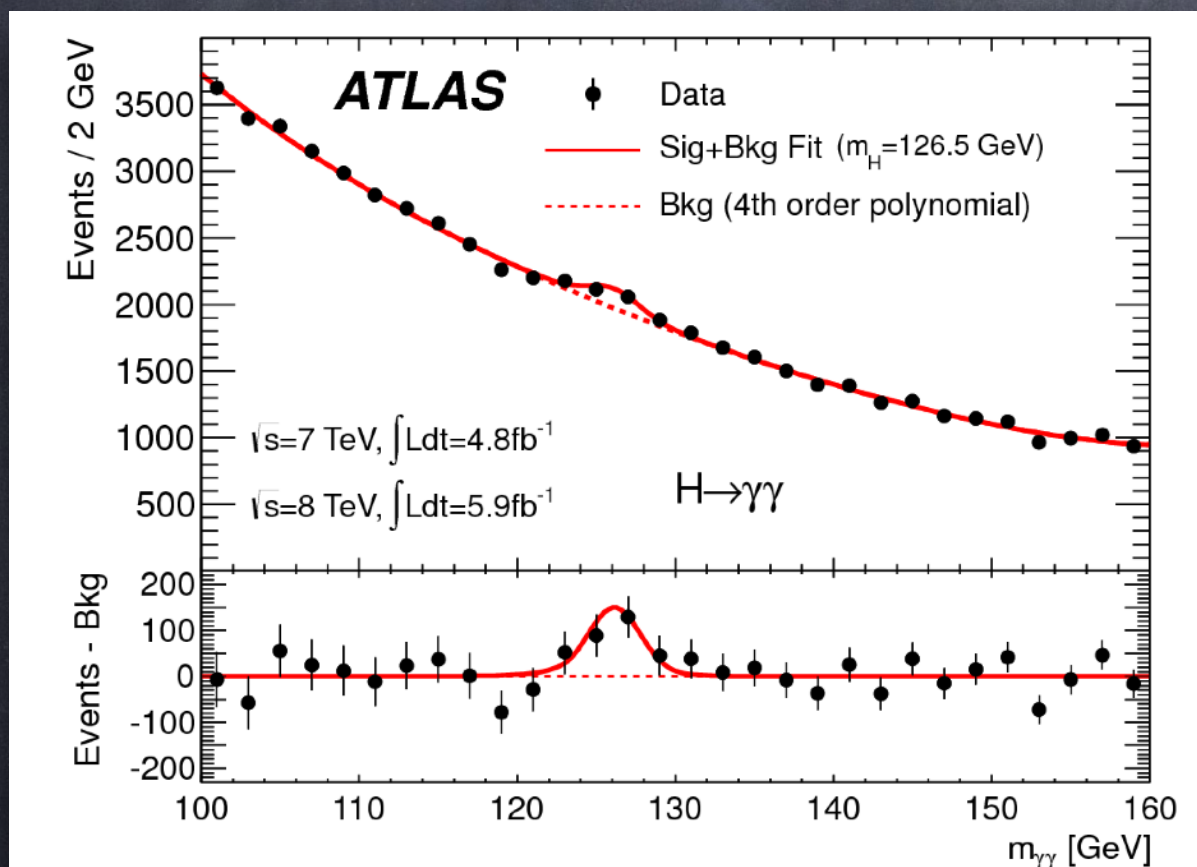
Black Box Mechanism:

- we know what we put in
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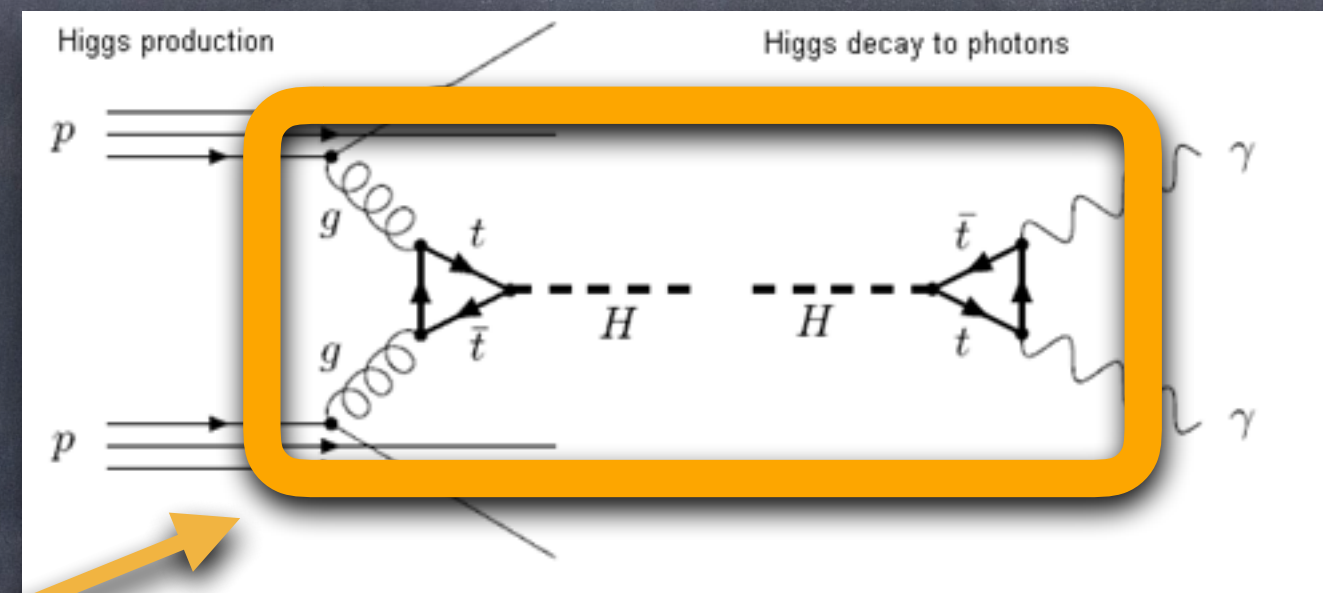
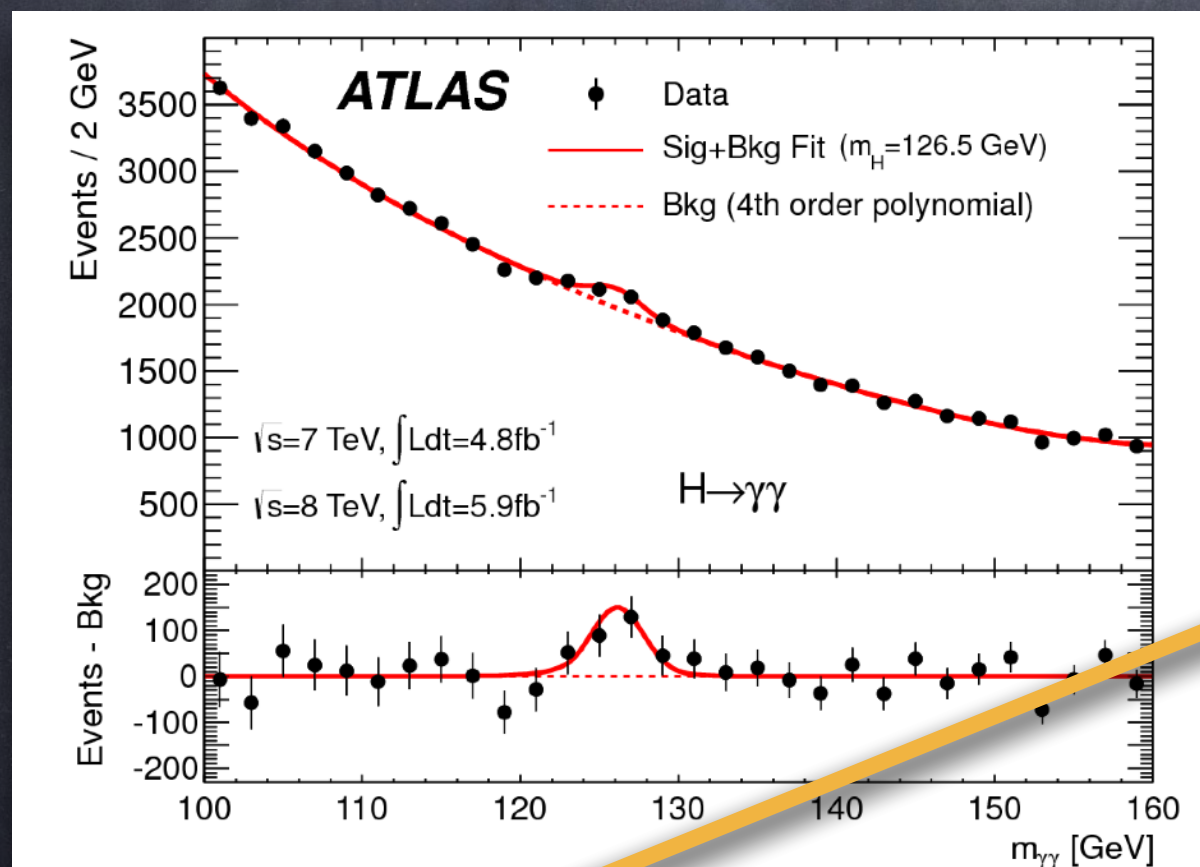
Statistics !

Higgs found!



Statistics !

Higgs found!

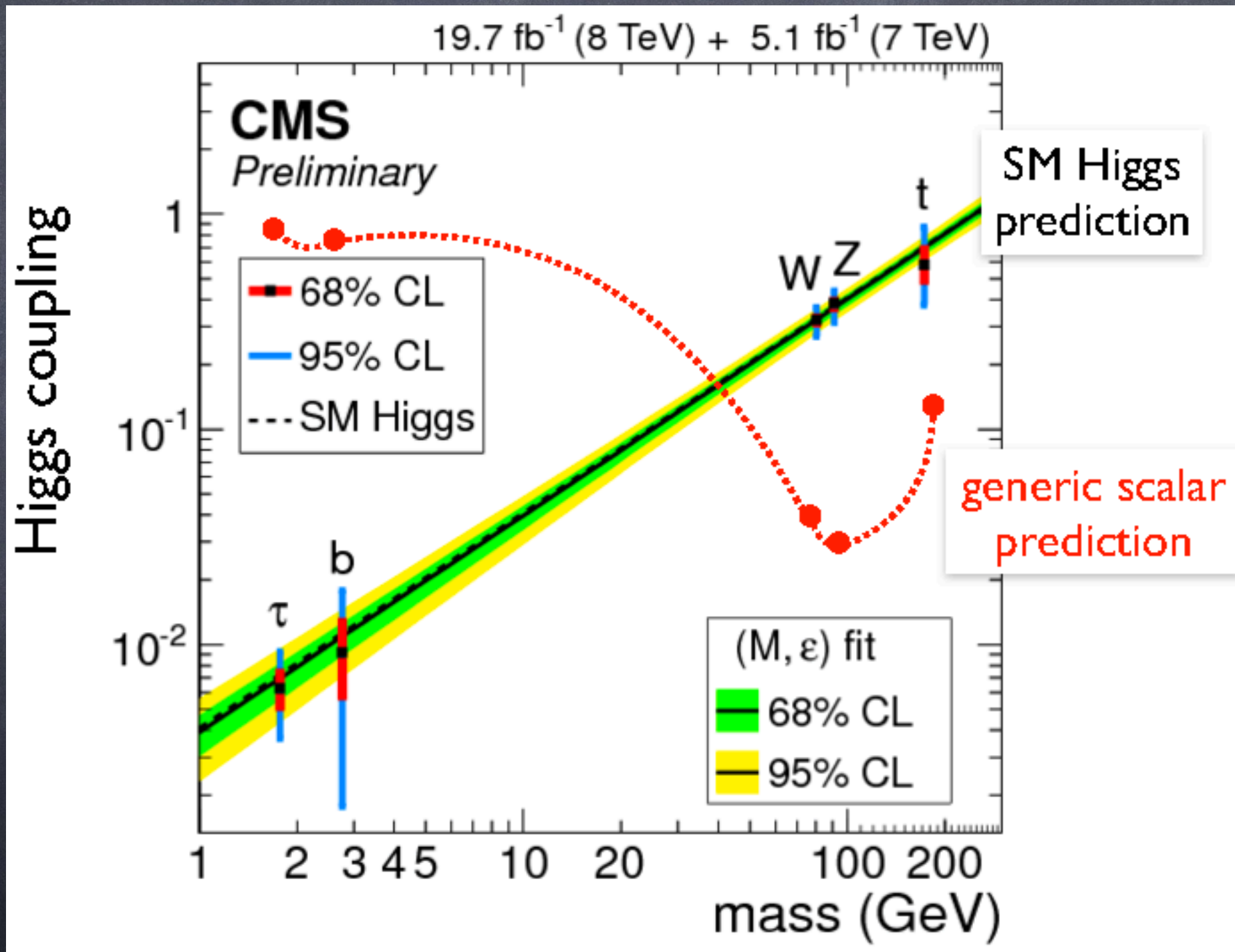


Black box:

Can be everything; we don't know (Higgs, photon, gluon,)

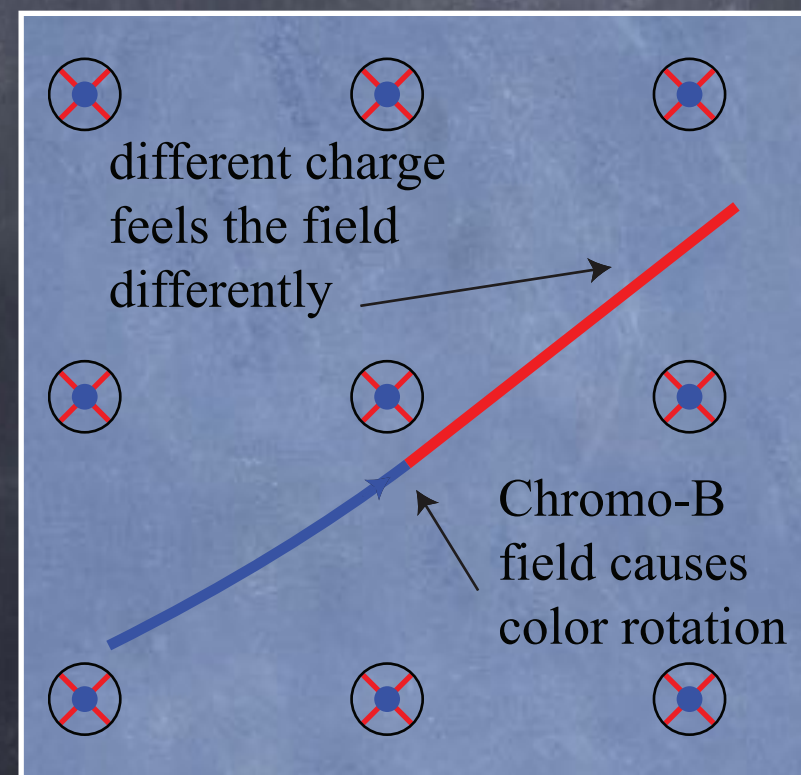
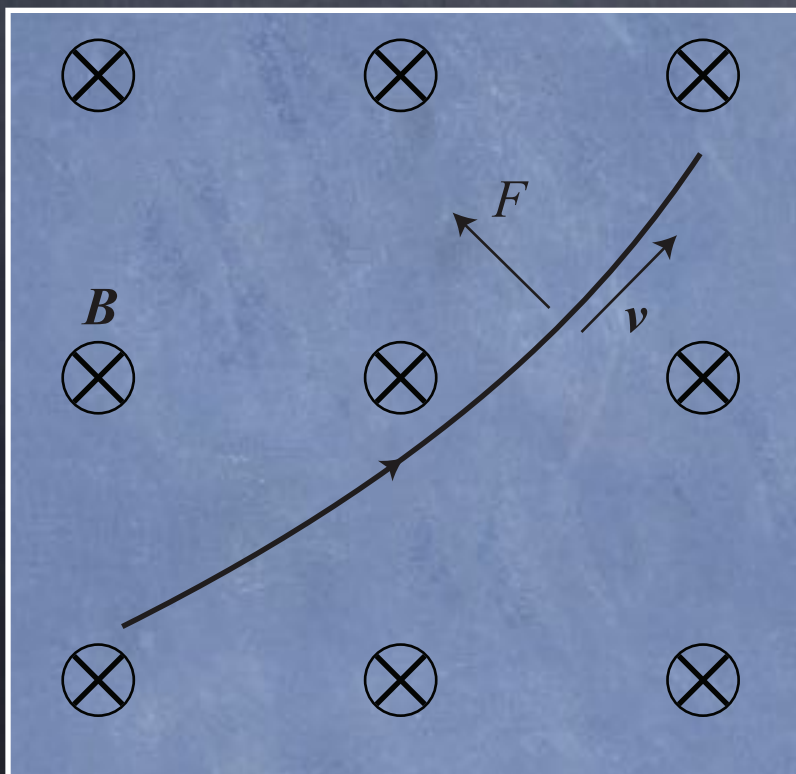
Use **statistics** and **probability** to peek into process

It walks like a Higgs



Strong force, QCD

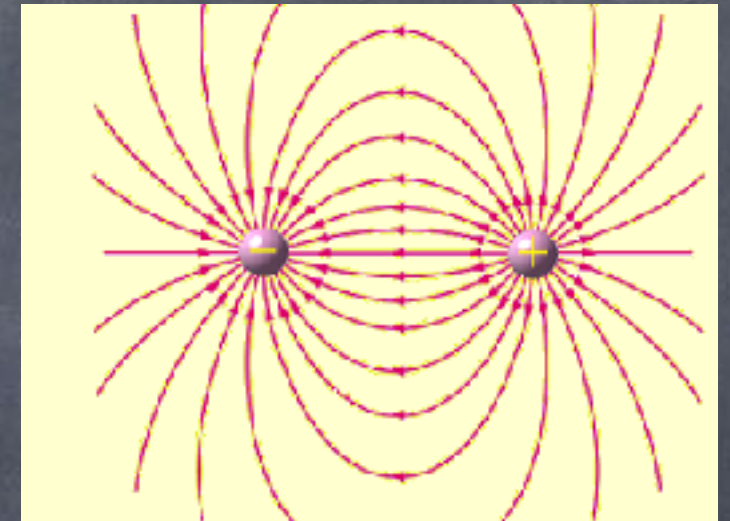
- 3 different colors of quarks [rgb]
- Gluons like photons, except couple to color instead of charge
- Chromomagnetic/electric fields not only change momentum but also color: rb , bg , ...
- Gluons colored \rightarrow self-interaction!



Gluons

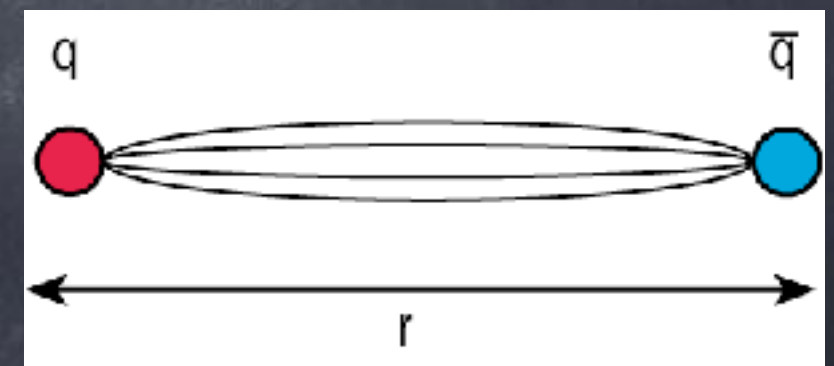
- The force between two electric charges

- $F = q_1 q_2 / r^2$



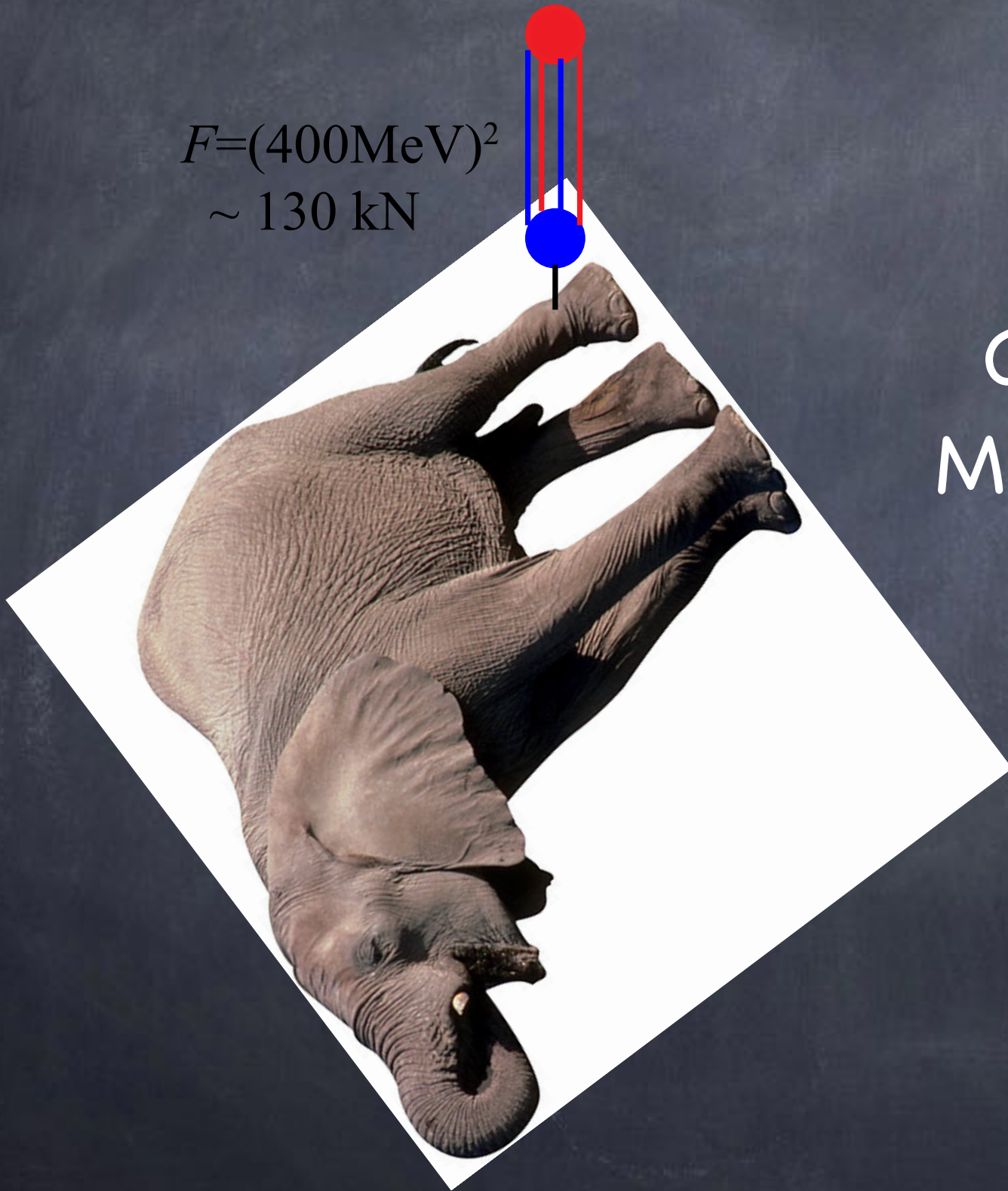
- Force between quarks

- $F = (400 \text{ MeV})^2$



Gluons

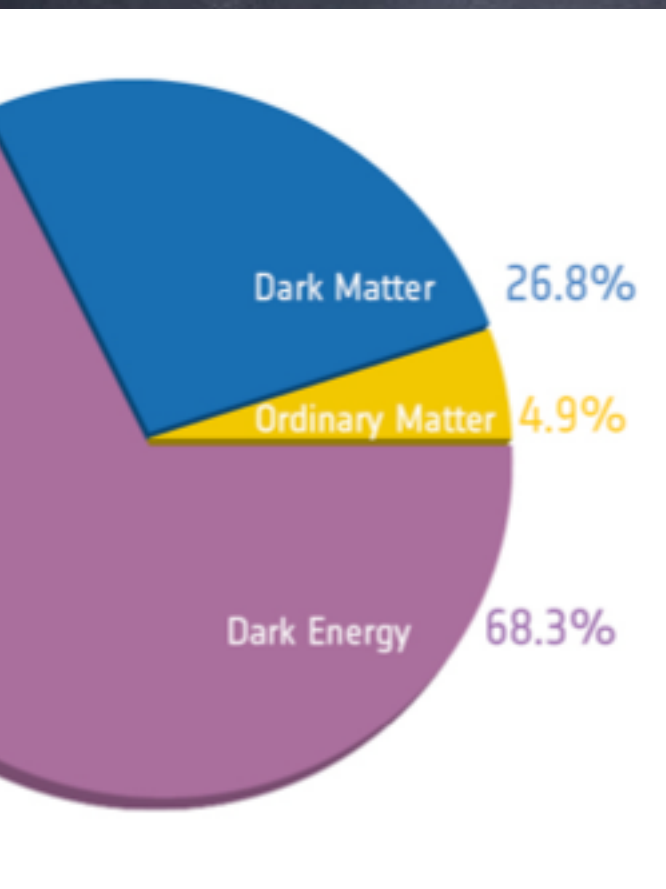
$$F=(400\text{MeV})^2$$
$$\sim 130 \text{ kN}$$



Color confinement
Millenium Prize 1M\$

Challenges of SM

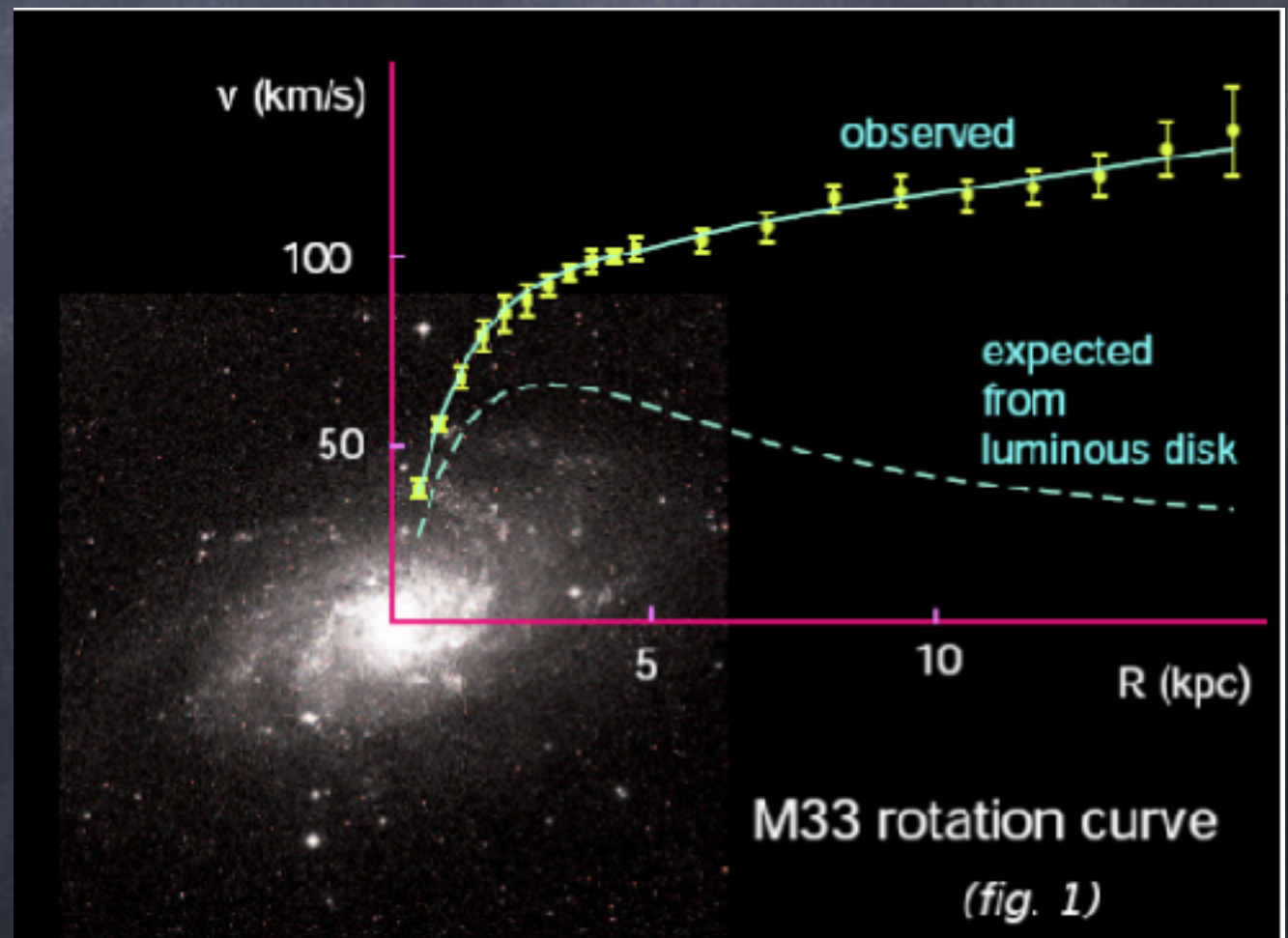
- Where does the structure of “periodic” table arise
- How to combine with gravity?
- Cosmo/astro:



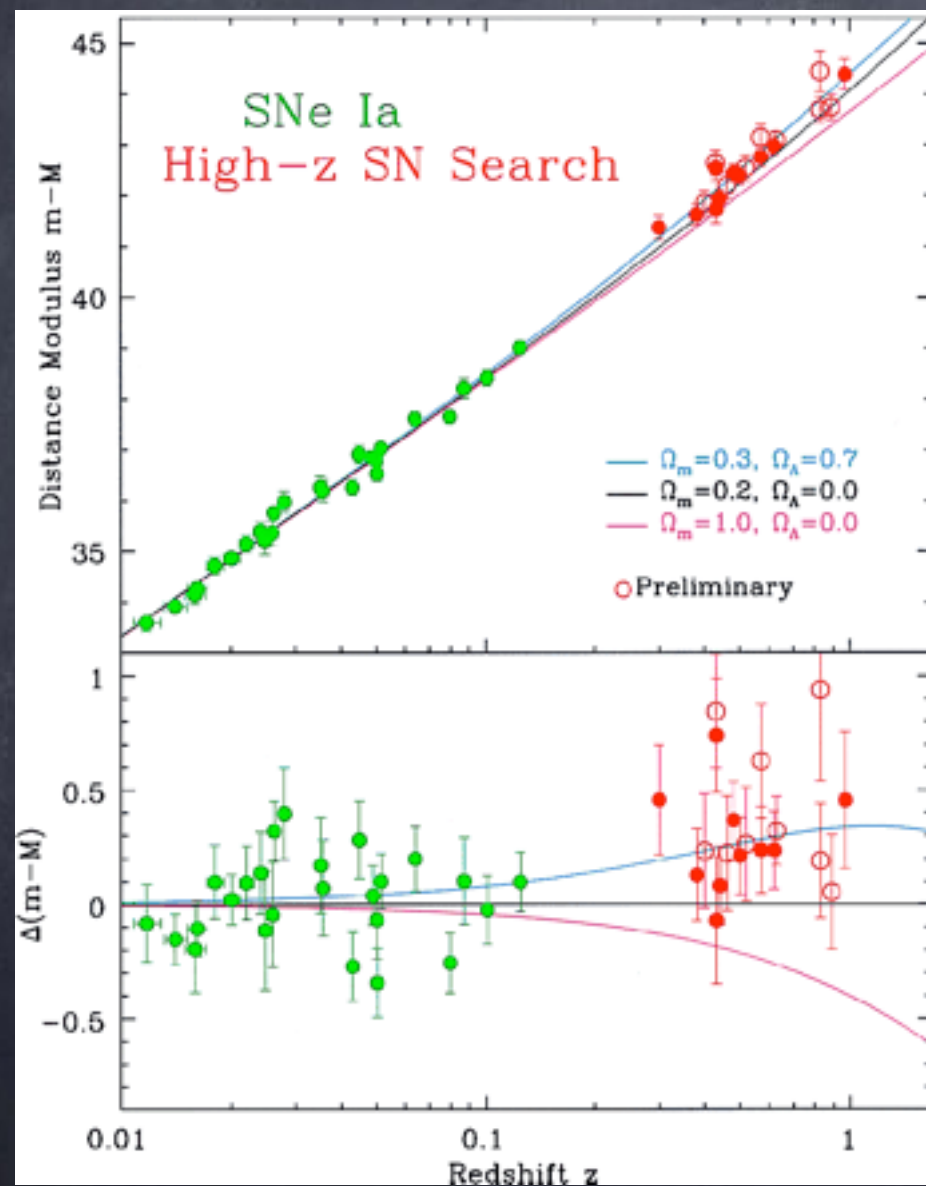
- Why more matter than anti-matter?
Baryogenesis
- Most of energy budget “dark”
 - Dark energy 68%, dark matter 27%,
SM particles only 5%!

Mystery: dark matter

- 80% of all matter
- Explanation requires new particle physics
- Weak or no interaction with photons, invisible



Mystery, dark energy



- ..or cosmological constant or vacuum energy...
- The expansion of universe accelerates

Thank you for your attention !

Questions ?