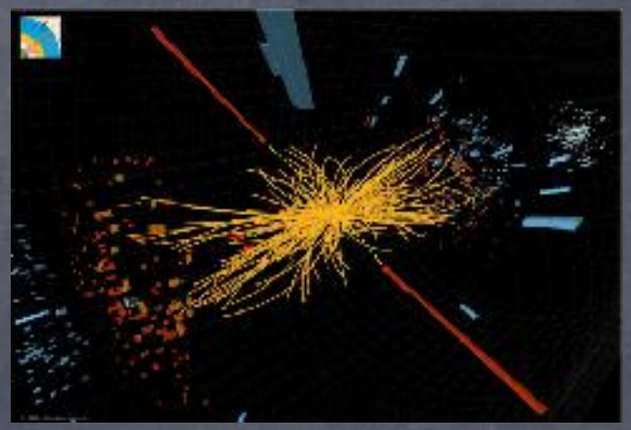
Who am I?

- Studies:
  Theoretical physics in Univ. Helsinki MSc
  2002-06, PhD 2008

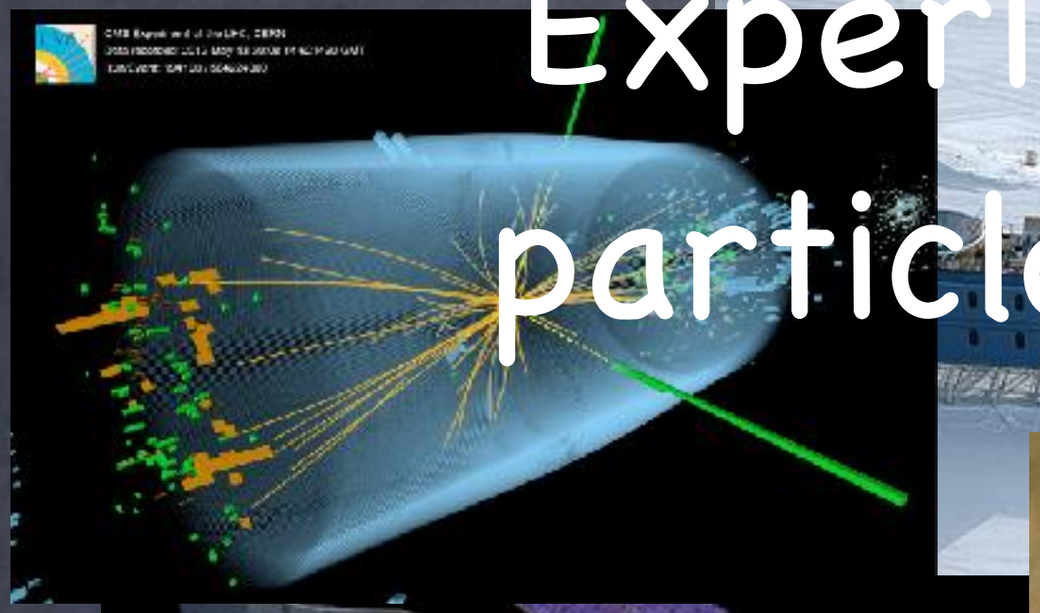
- Career:
  - ETH Zurich 2008-10,
  - McGill University, Montreal 2010-13
  - CERN, Geneve 2013-

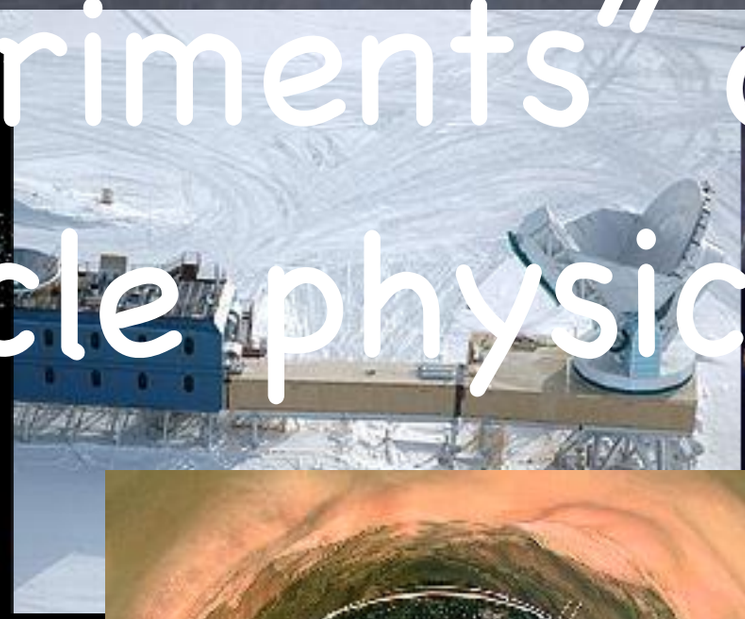
Theory division at CERN

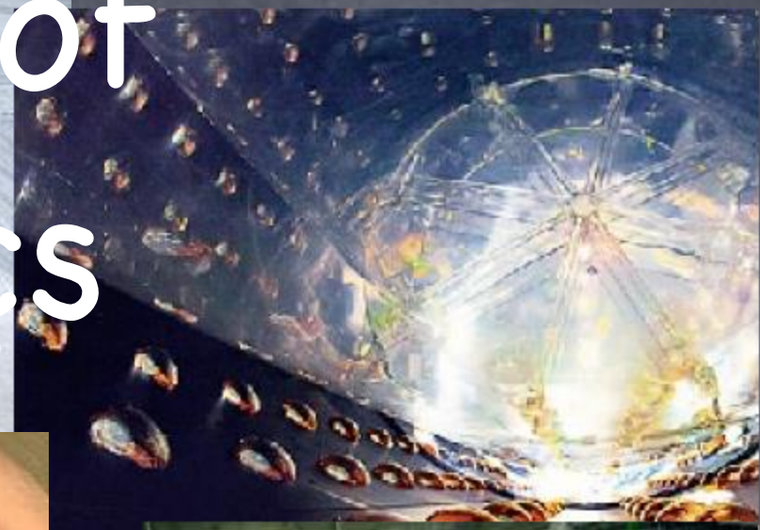


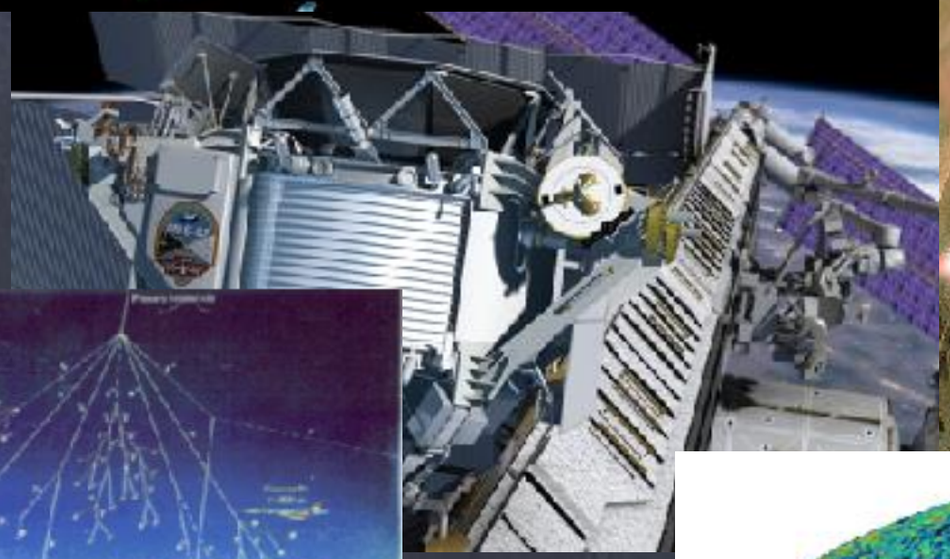
- Collider physics, 19
  Precision prediction in SM...
- Heavy ions, 5
  Material properties of elementary particle matter, quark-gluon plasma, early universe, neutron stars...
- Beyond standard model physics, 12
  Dark matter, super symmetry, naturalness, hierarchy problem...
- Cosmology, 6
  Big bang, large scale structure, inflation, baryogengesis...
- String theory, 12
  Mathematical physics, condensed matter, AdS/CFT...

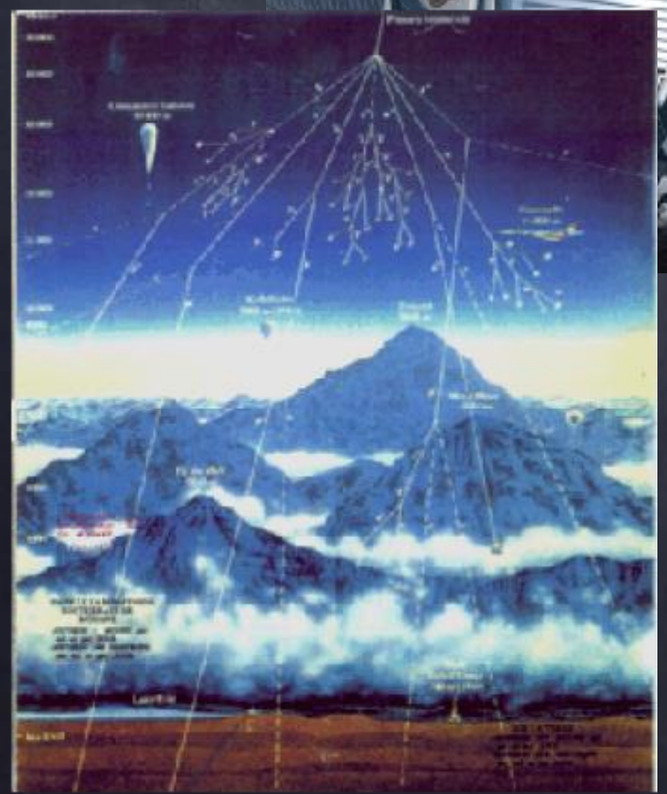
"Experiments" of particle physics

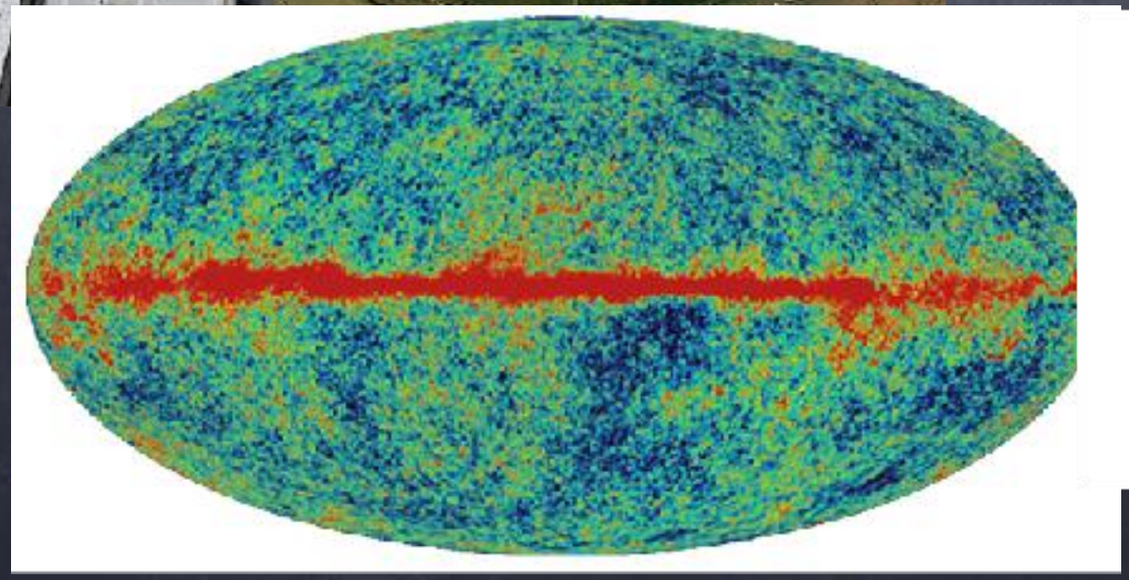




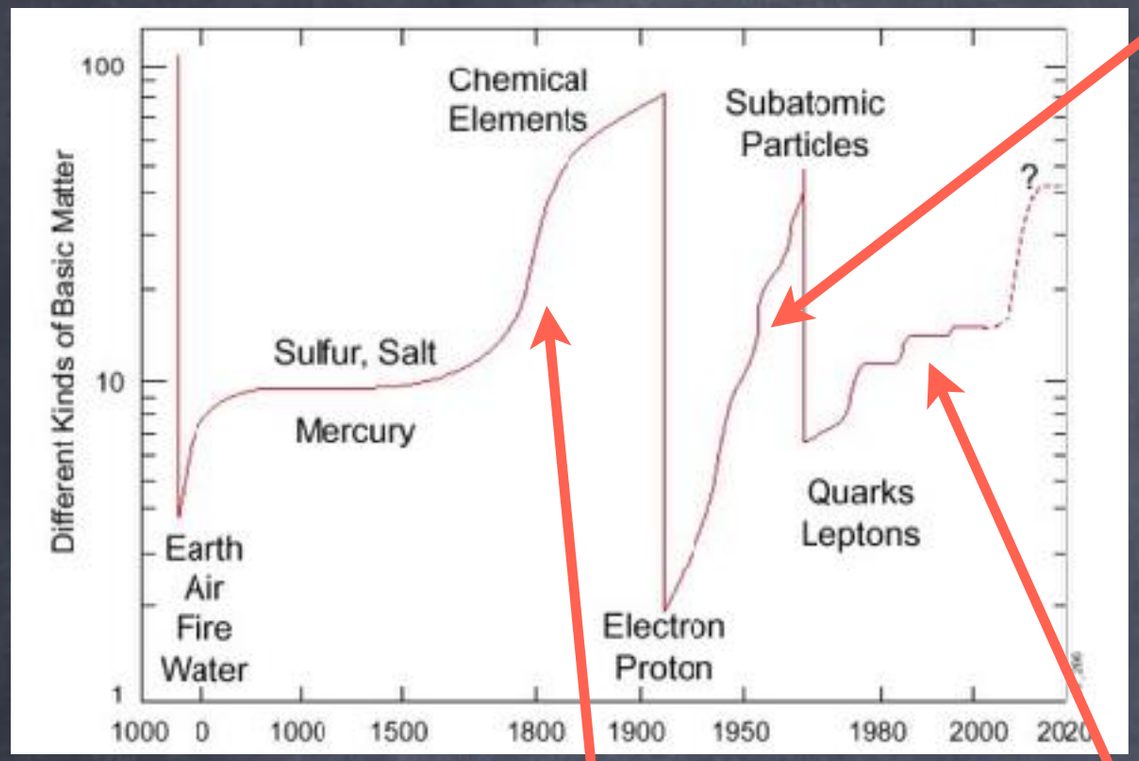


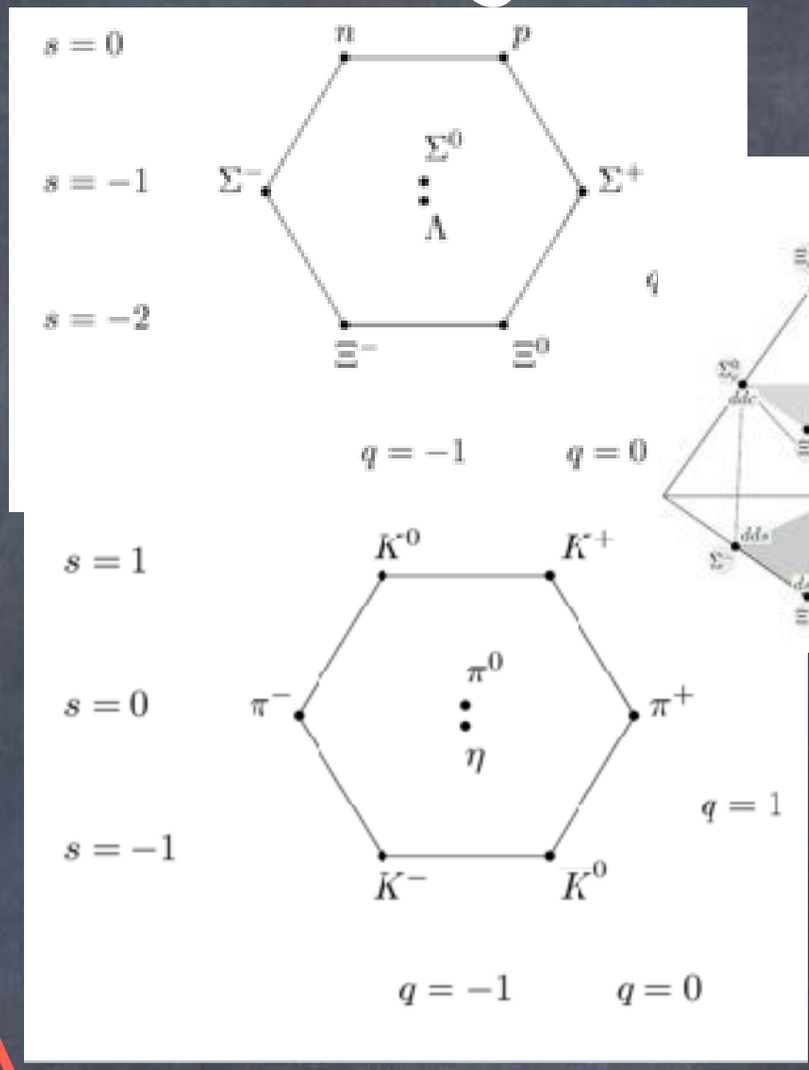


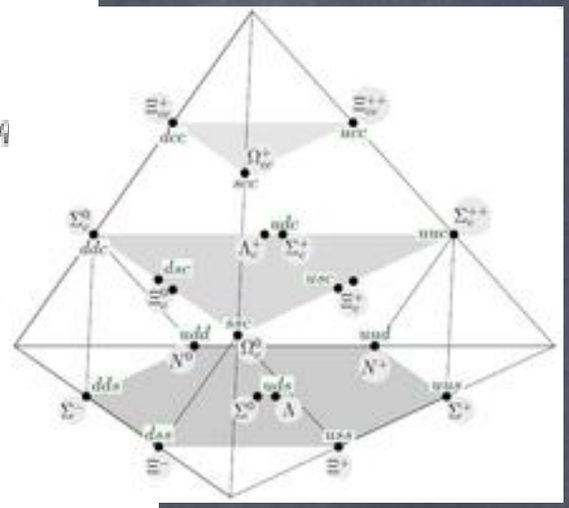


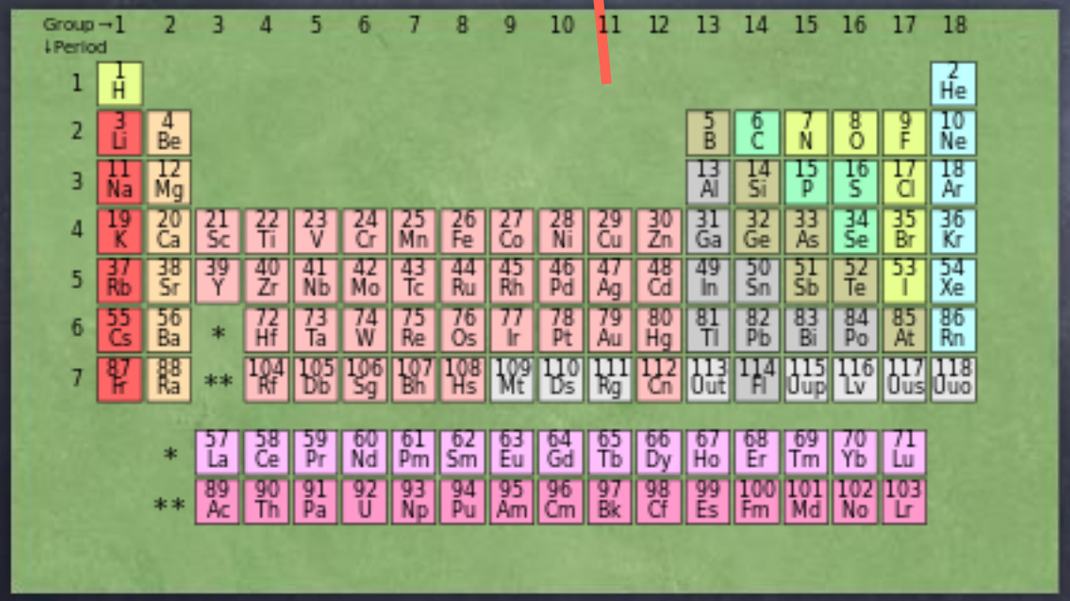


"The eightfold way"



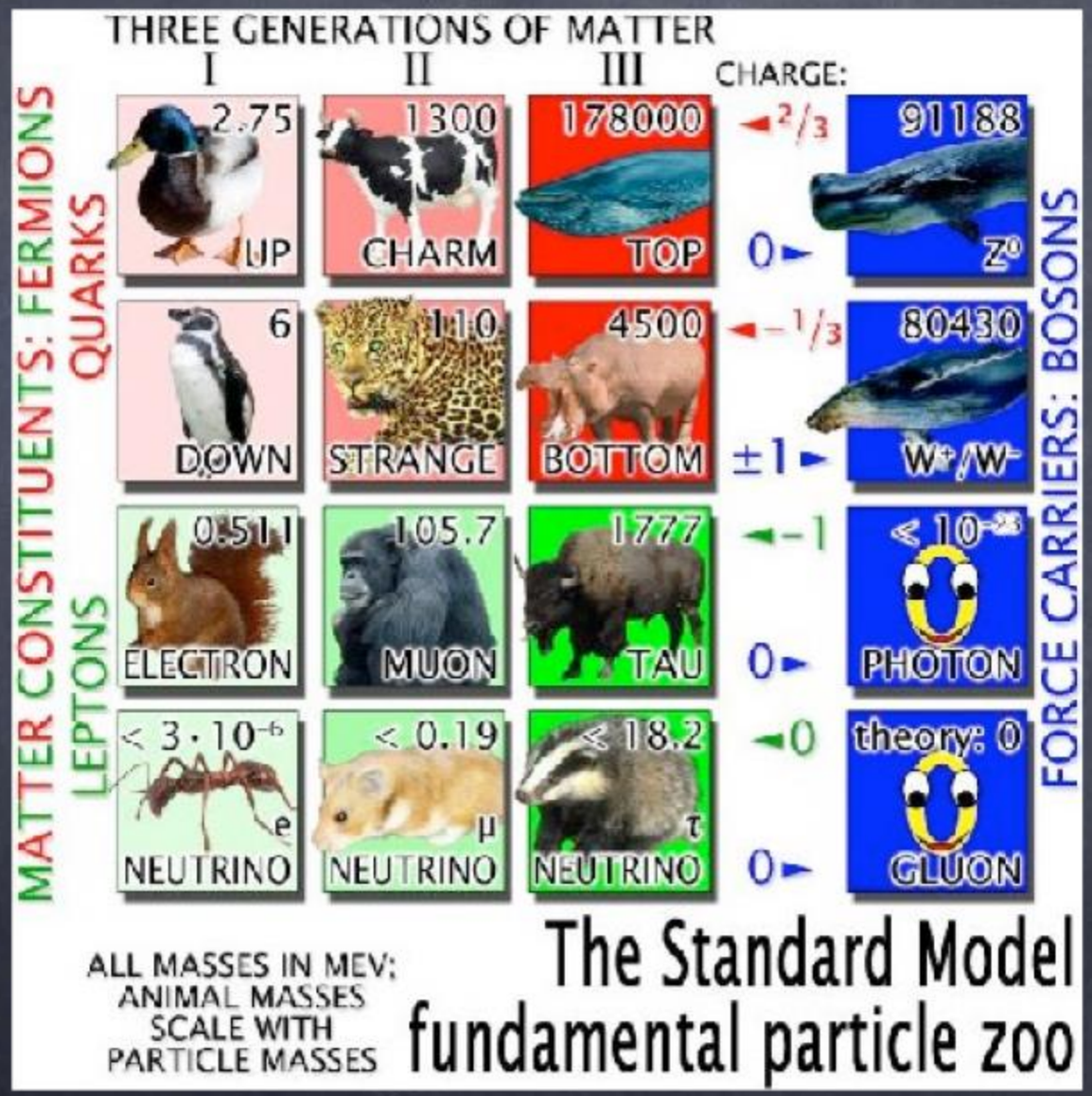






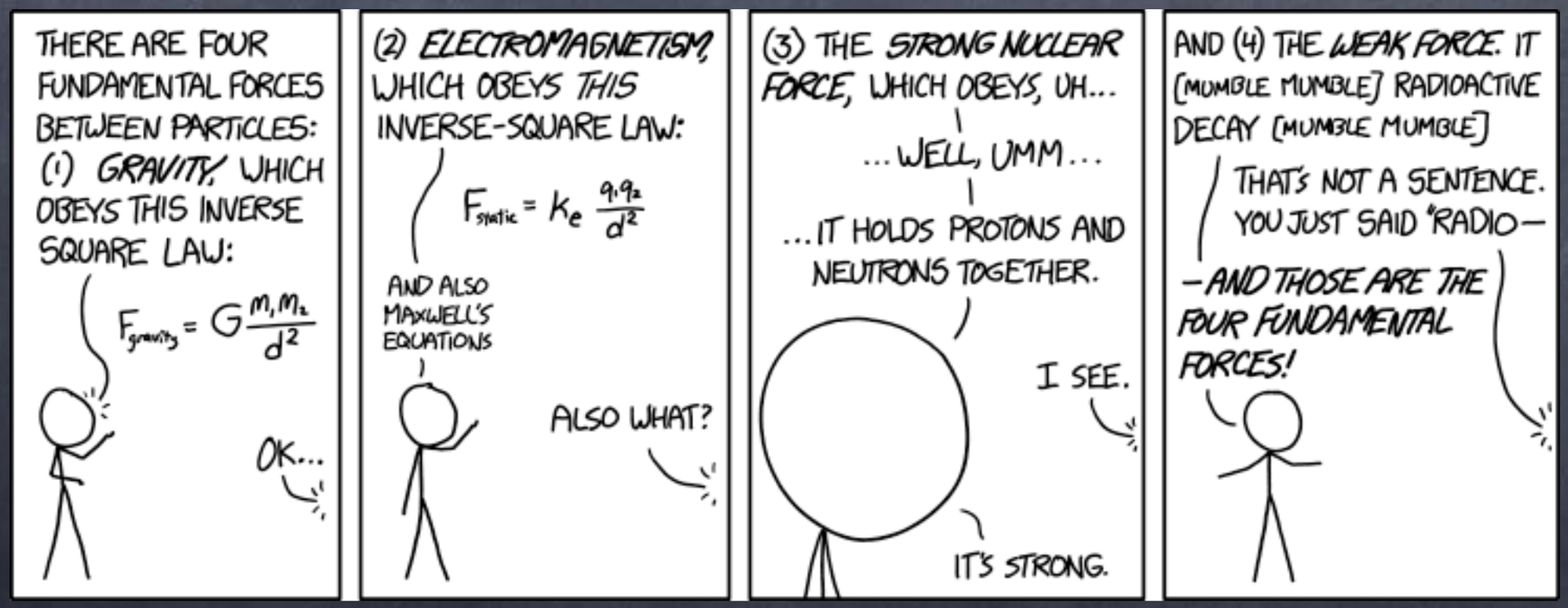
Standard model of particle physics

"Periodic table" of particle physics



+ Higgs, 126GeV

Elementary forces



Quantum mechanics

Uncertainty principle

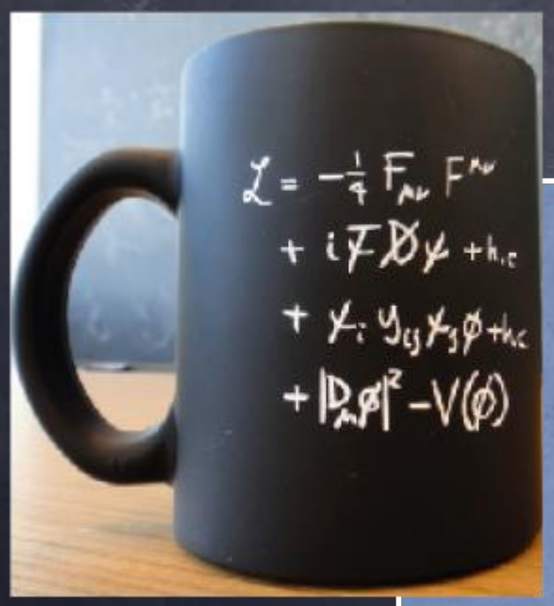
$\Delta x \, \Delta p > \hbar$

Special relativity

Constant speed of light,
frame indepence

Gravity

General relativity



Quantum field theory

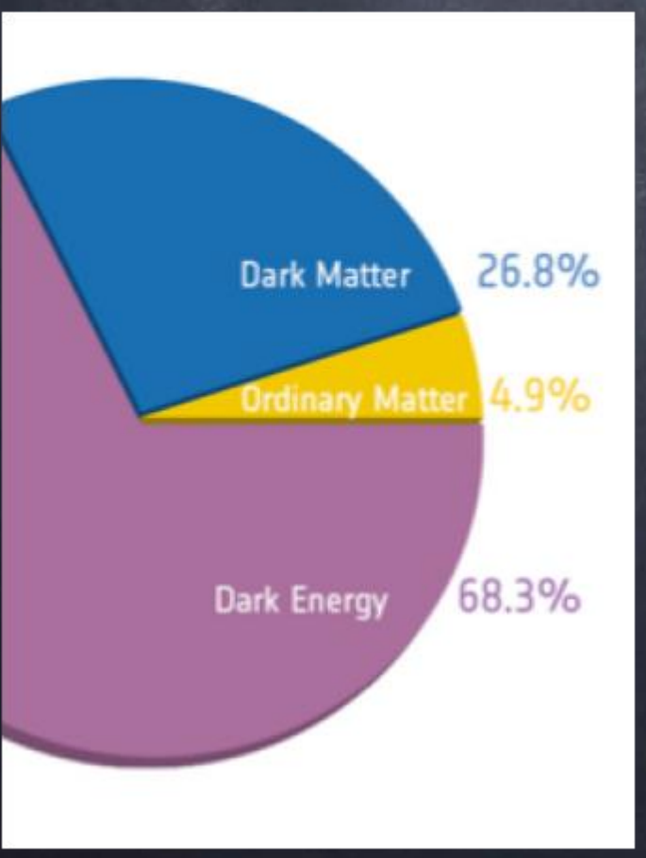
Particle-field duality

Interactions between particles through fields

- Eletro-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?

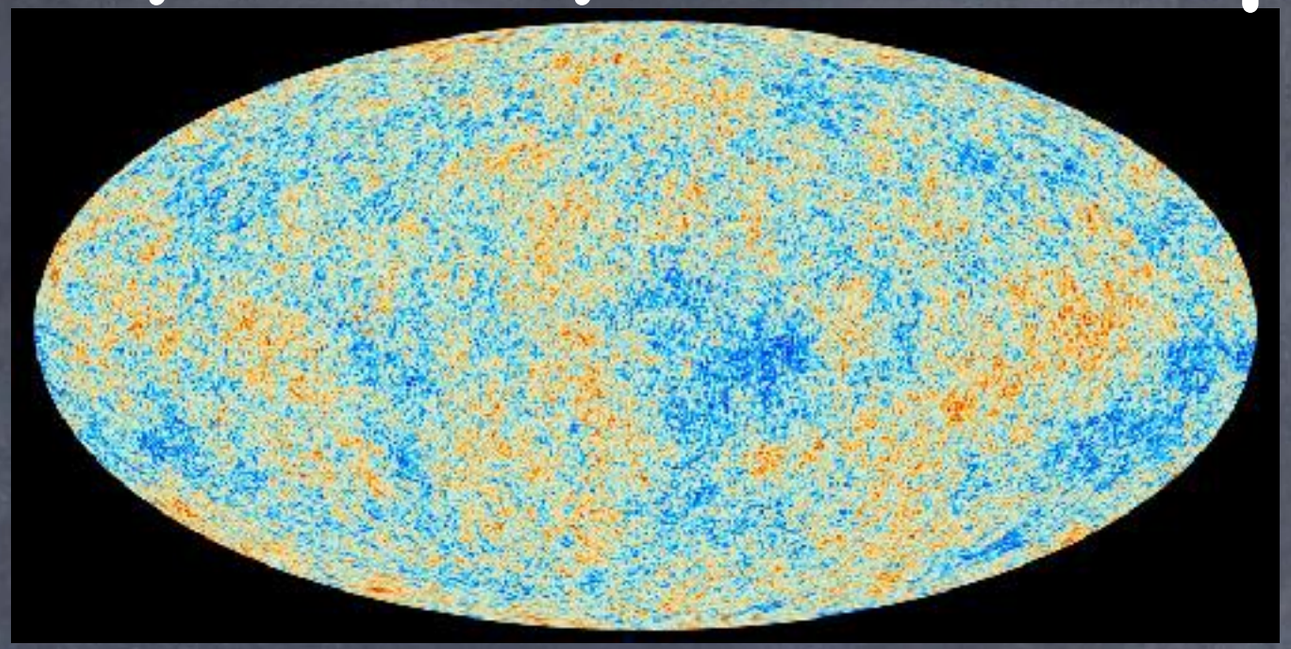
Challenges of SM

- 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%!

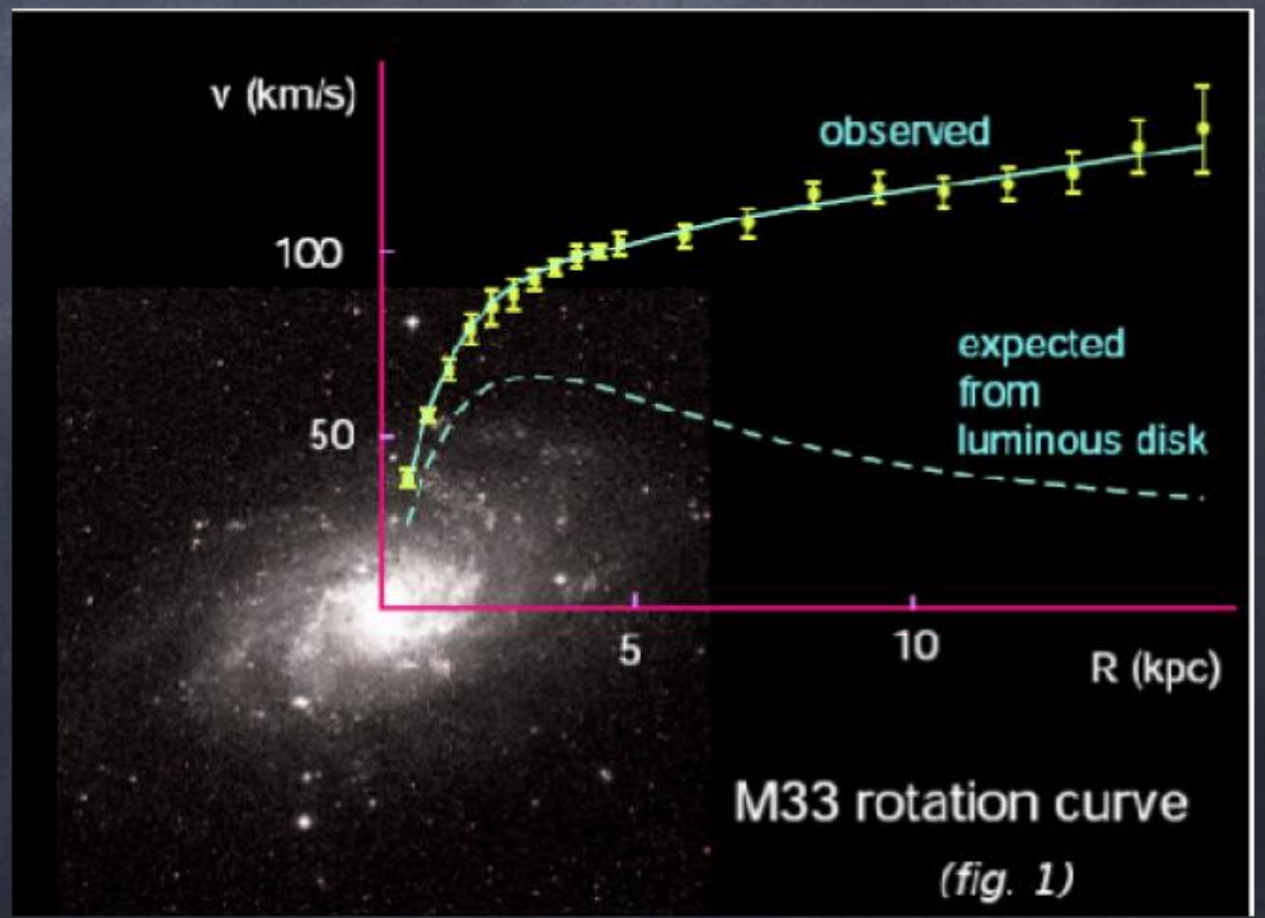
Mystery: isotropy



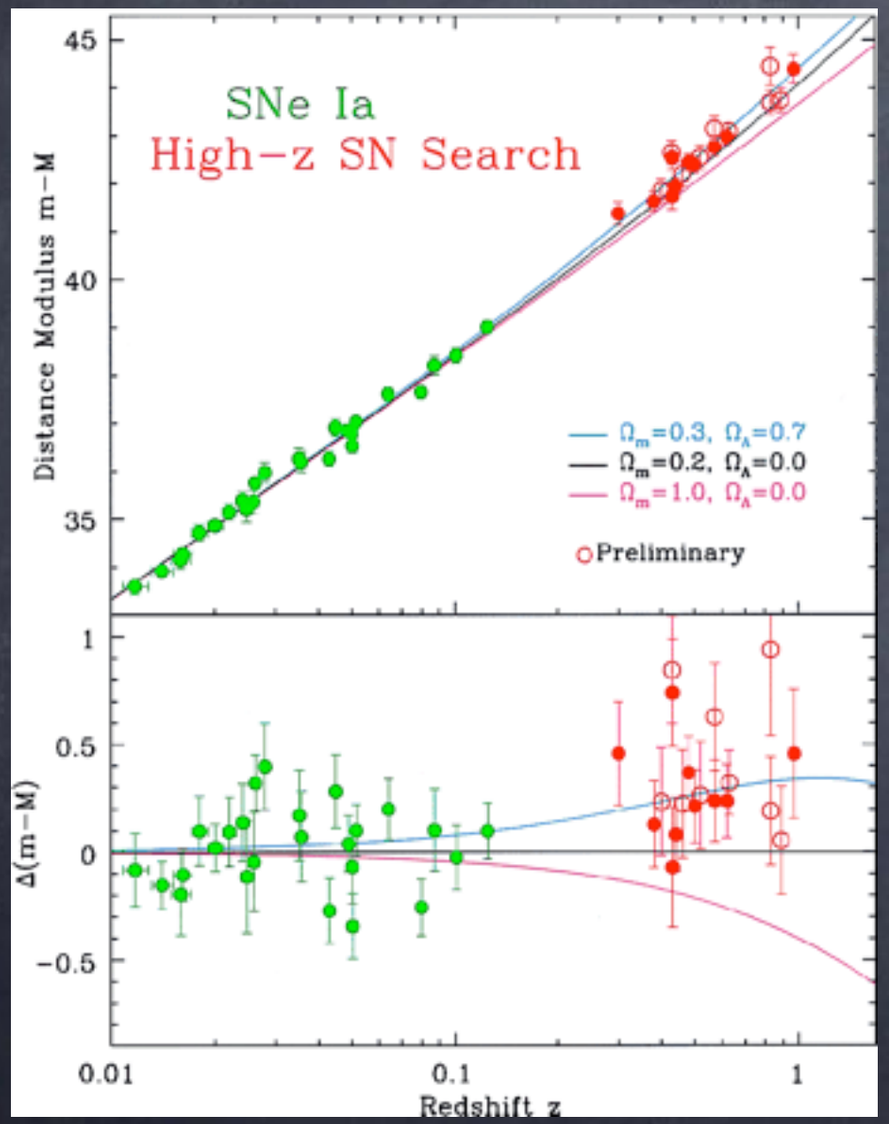
- Temperature of cosmic microwave background very isotropic (2.7±0.00001K)
- Different directions causally disconnected
- Possible solution: inflation

Mystery: dark matter

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



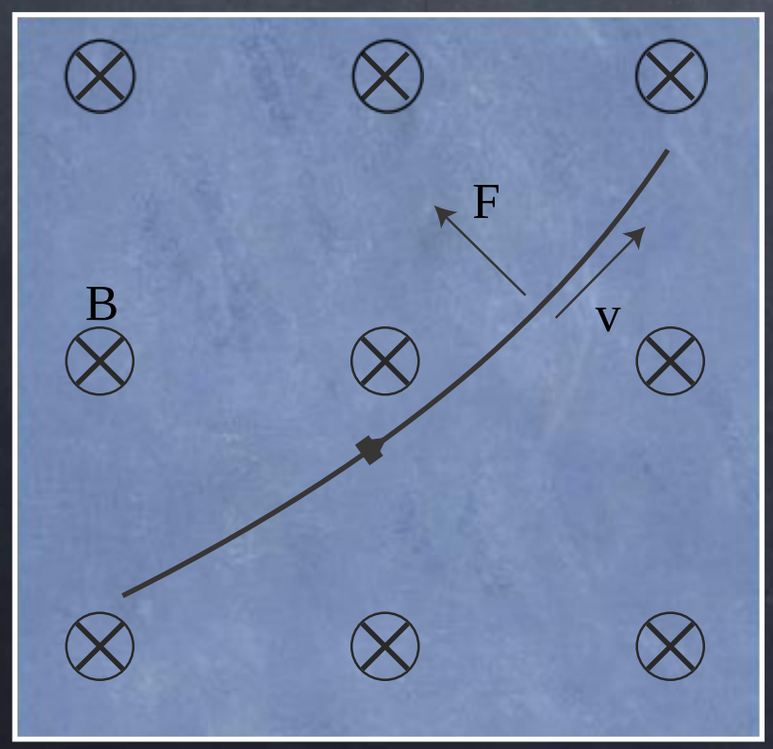
Mystery, dark energy

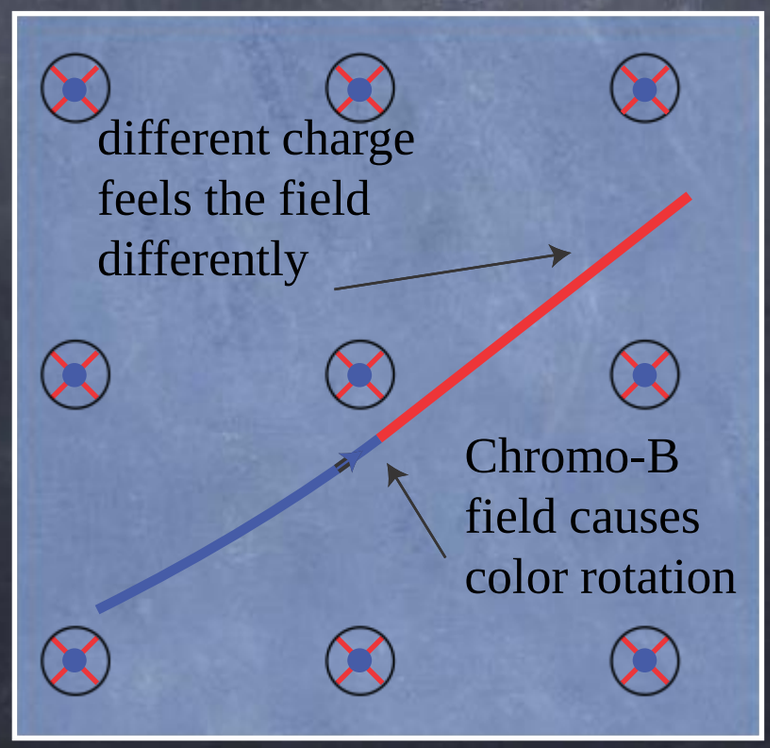


- ..or cosmological constant or vacuum energy...
- The expansion of universe accelerates

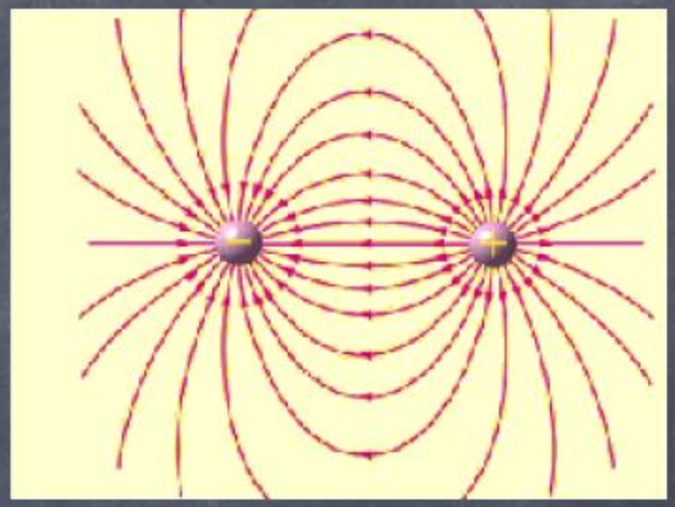
Strong force, QCD

- 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 -> self-interaction!



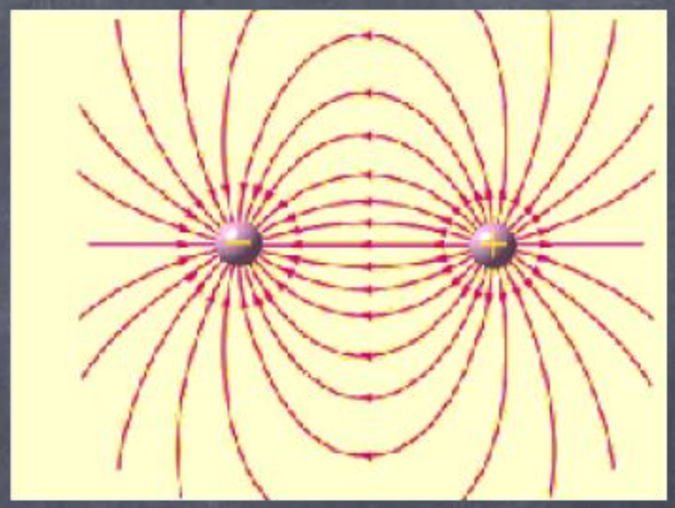


Gluons



Gluons

- The force between two electric charges
  - F = q1 q2 / r^2



Gluons

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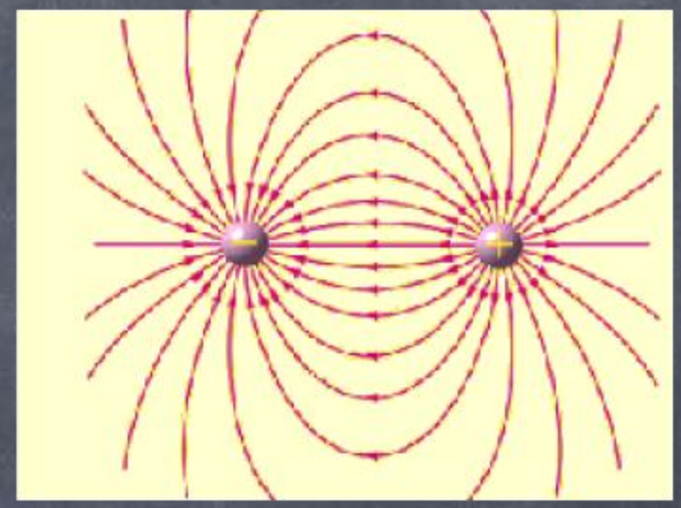
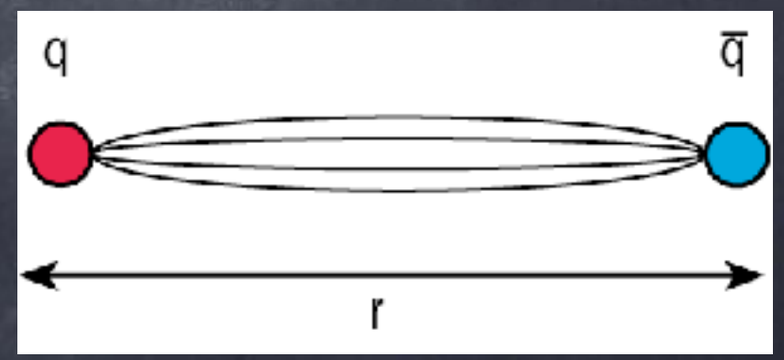
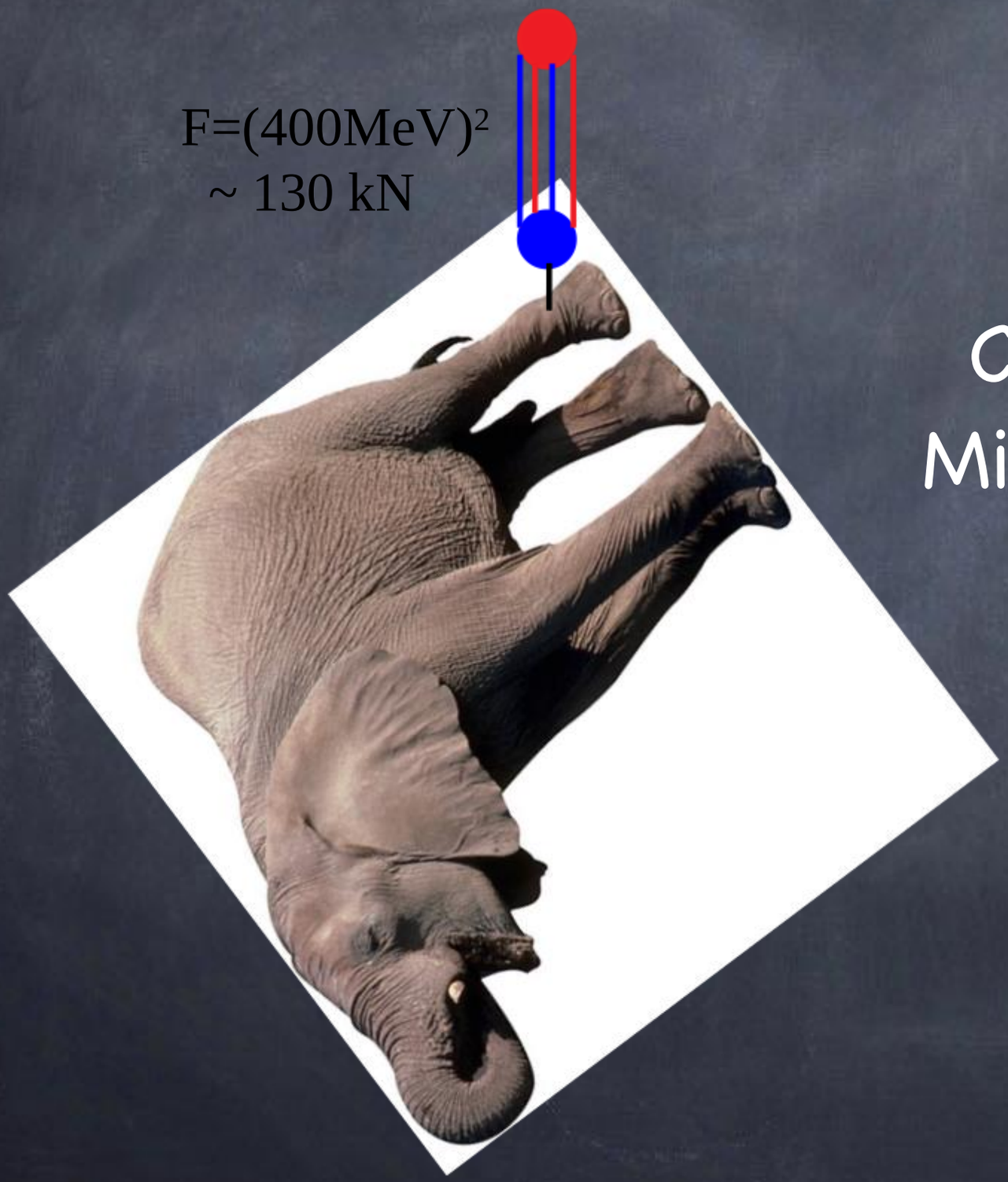


- Force between quarks
  - F = (400 MeV)^2



Gluons

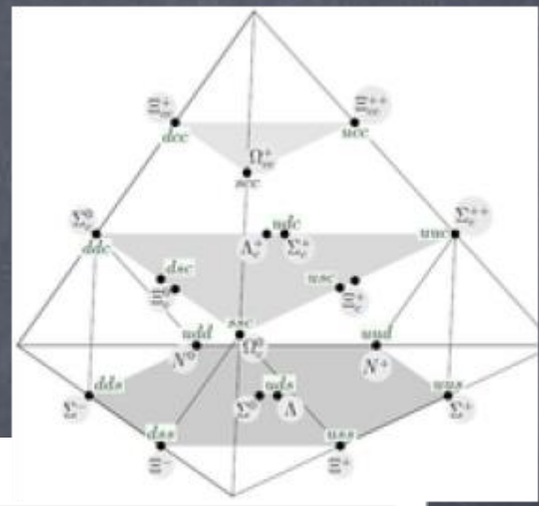
$F=(400MeV)^2$
~ 130 kN

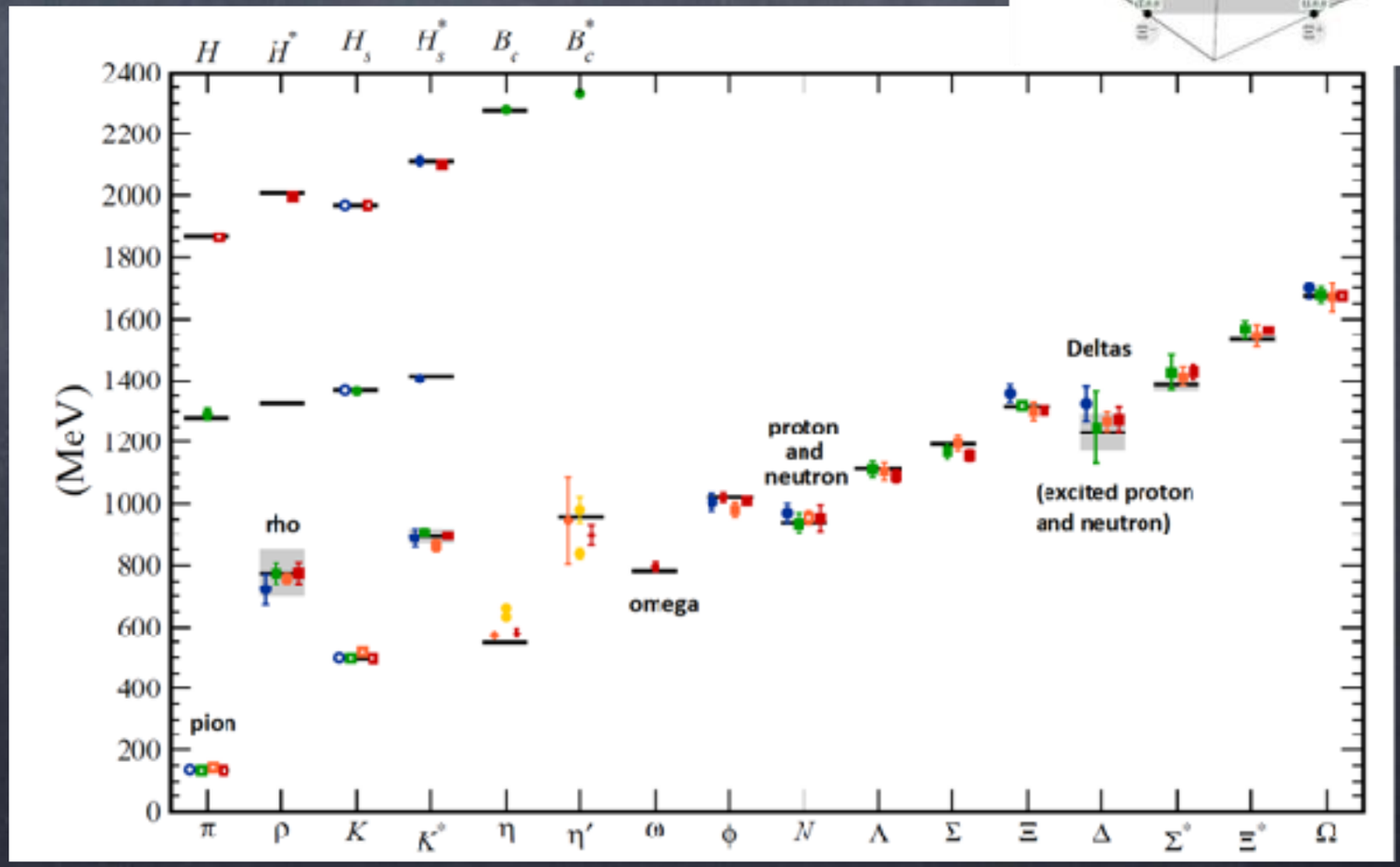


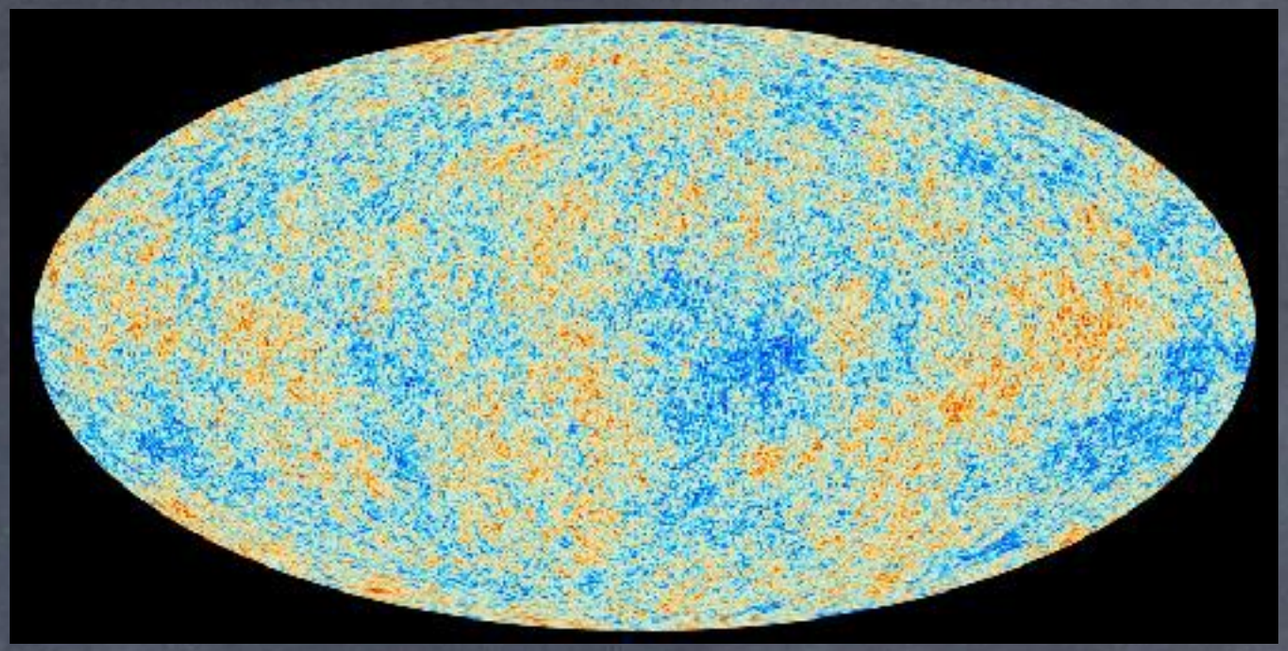
Color confinement
Millenium Prize 1M$

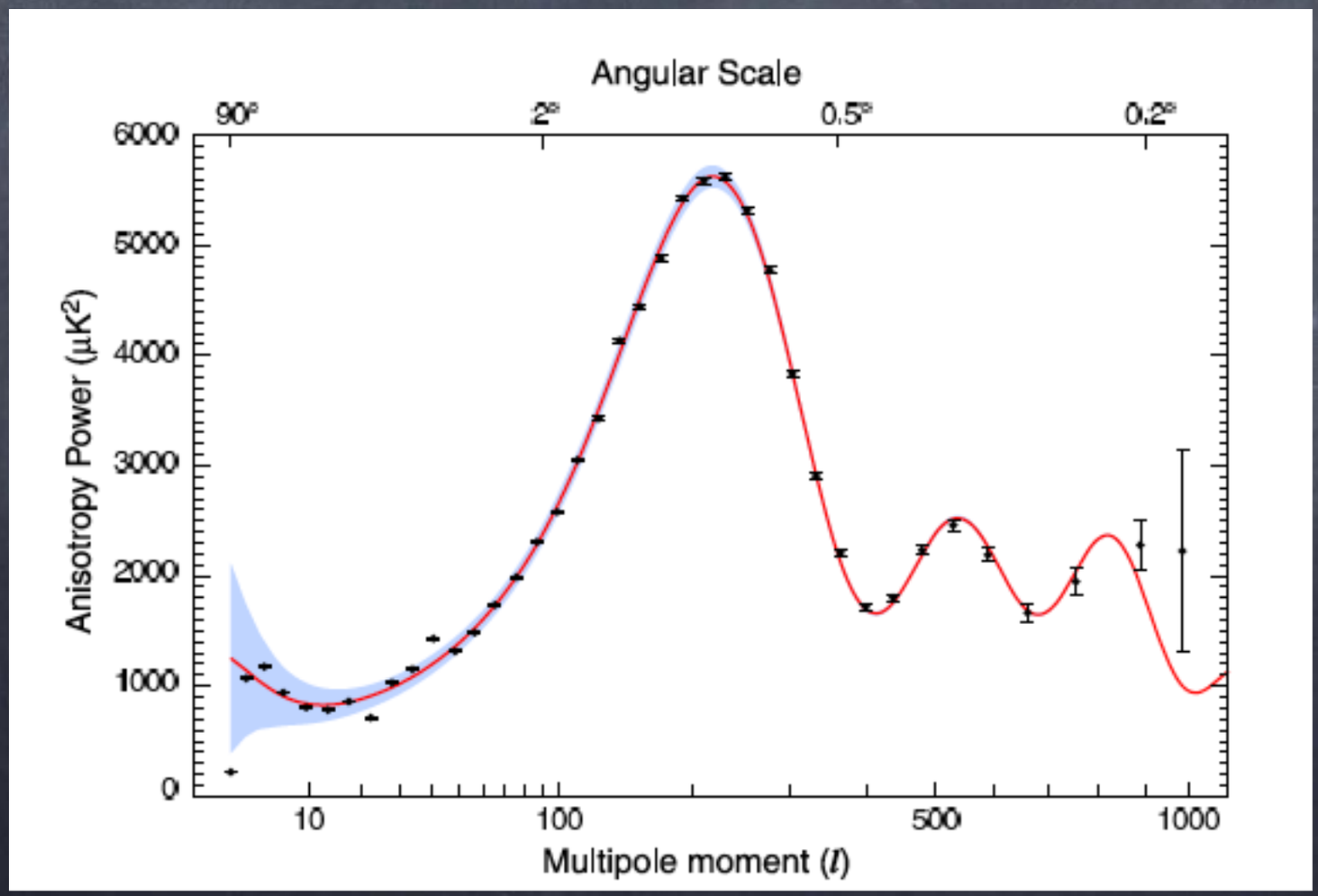
Standardimallin gluonit

- Because of confinement, quarks and gluons confined to color neutral lumps. Hardons!








Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
Anisotropy Power (μK²)
10
100
500
1000
Multipole moment (l)