Nuclear and Hadron Physics

Kandisky “Circles in a circle” (1923)

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Nuclear and Hadron Physics

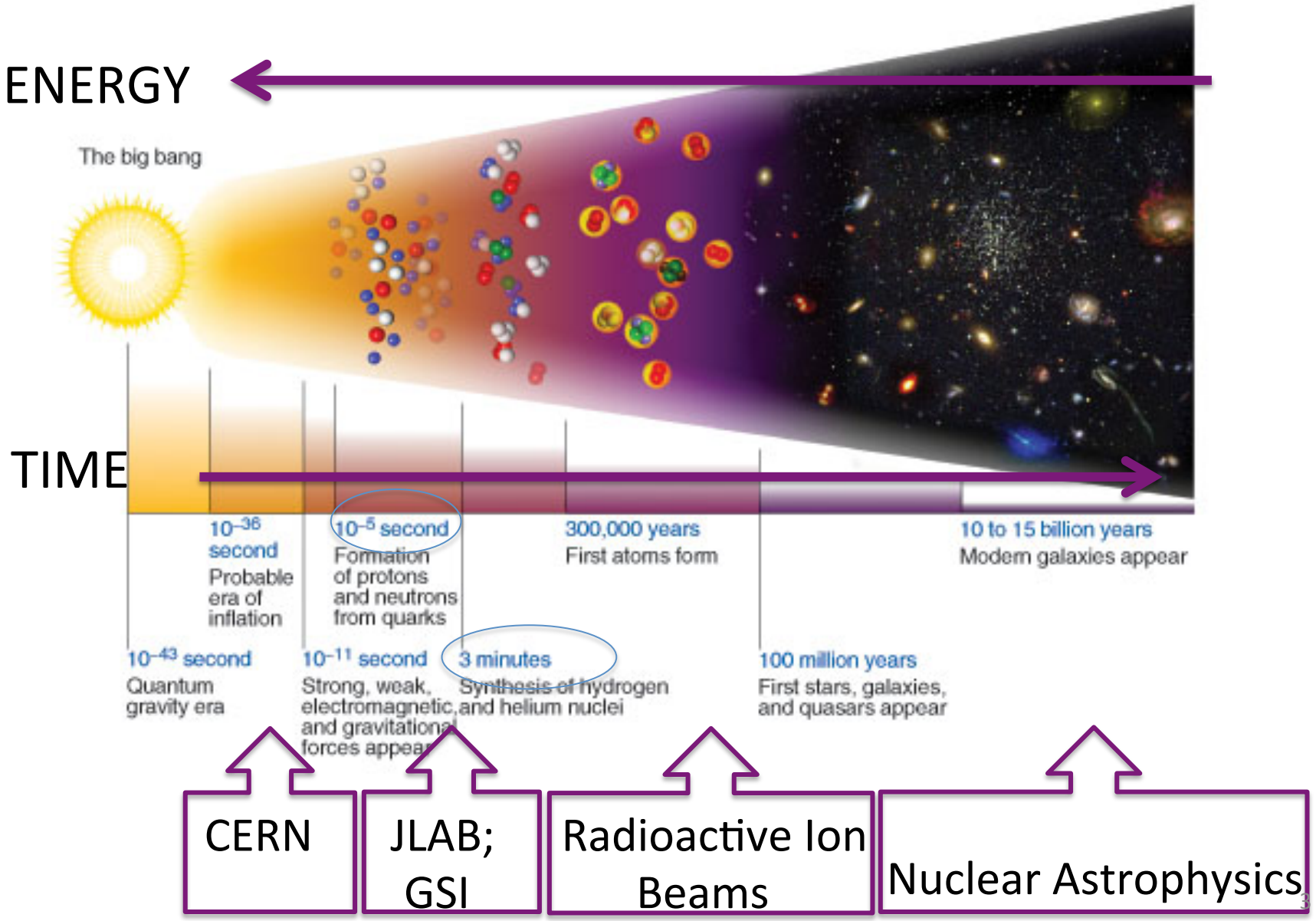
Investigates the “core” of visible, ordinary matter (hadrons, nuclei) and the mechanism of its mass formation.

Gives the basis of the Cosmic creation and distribution of elements in the Universe.

Shows that we are a cosmic nuclear accident.

Would the effective nuclear force be slightly weaker, we would not exist. The deuteron, the first step in formation of all elements, would not have been formed. $E_B = (2.22461 \pm 7 \times 10^{-5})$ MeV; $V_{nuclear} = 40$ MeV

Experimental facilities are time travel machines



Odd far-away world

100 000 000 000 000 m = 10^{14}m

Typical inter-galactic distances

0.000 000 000 000 001 m = 10^{-15}m

Distance scale of the quarks inside the proton

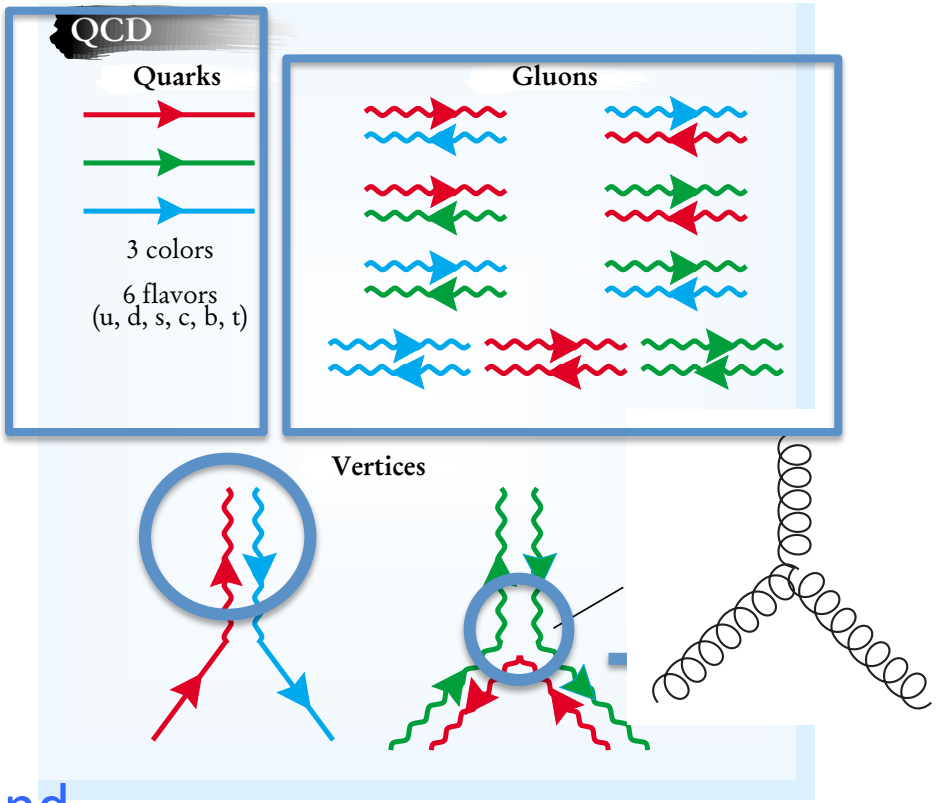
Hadrons mass and identity emerge from a very crowded and dynamic vacuum.

There is plenty of room in the **inner** space of matter to be explored.

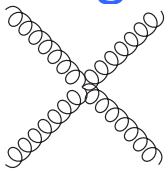
QCD portrait: the elegance of simplicity

Besides 2 **electric** charges and 6 flavors, in **QCD** there are also 3 **color** charges.

In contrast to photons to QED, in QCD gluons carry unbalanced color charge, and self-interact.

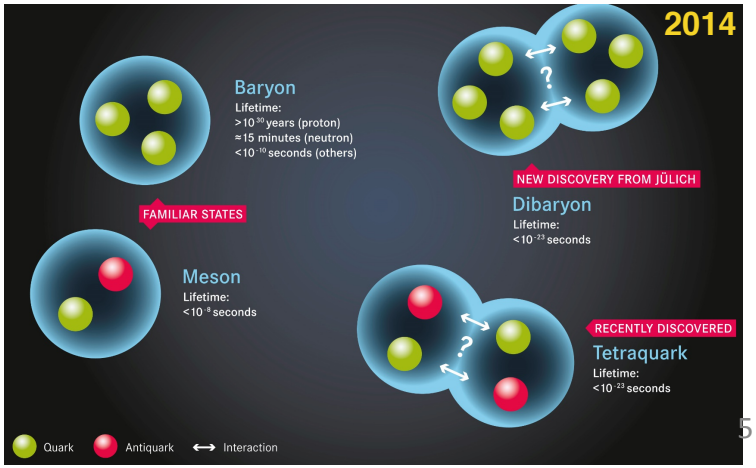


Star wars laser sword fights demand color gluon lasers.



Hadrons only exist in color charge singlet states.

No isolated q or g was ever seen.



Eqs. of QCD are not analitycally solved in the low energy limit of confinement.

Answer to the problem**?**

Use Simulations!

They solve complex systems. This is called LQCD.

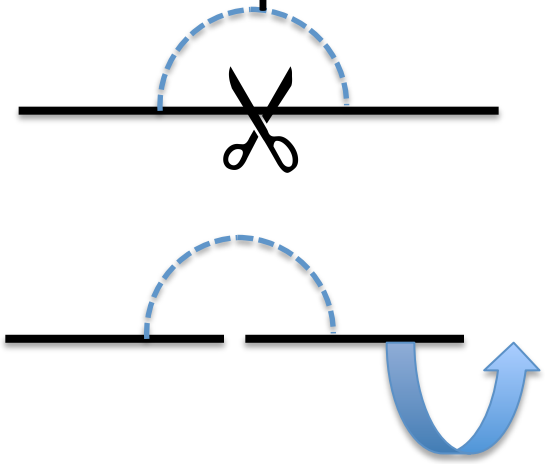
"They are not the end of desire (…) it is not entirely satisfying to have our computers acting as oracles", Frank Wilczek

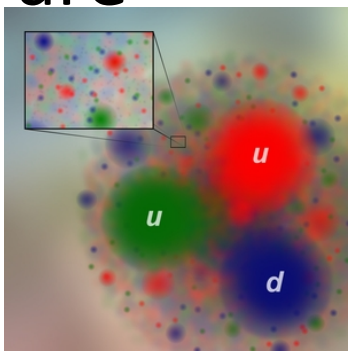
Number crushing is important, but make also models.

They create insight.

Combine models with LQCD *data*.

Quark self-interaction with gluons and virtual quark –antiquark pairs and gluons is responsible for the mass of constituent quarks which are effective particles. Huge effect!





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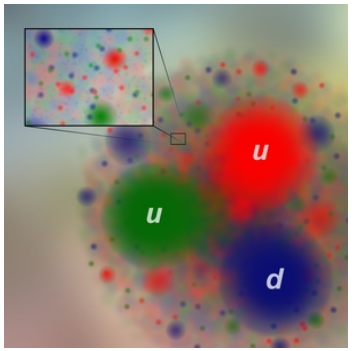
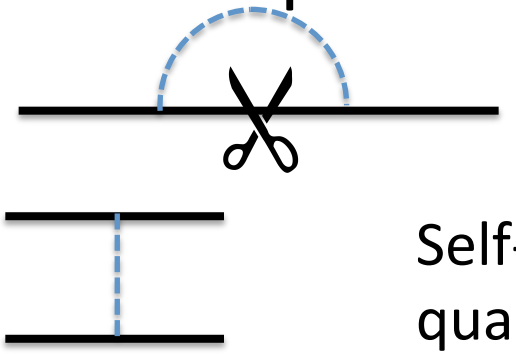
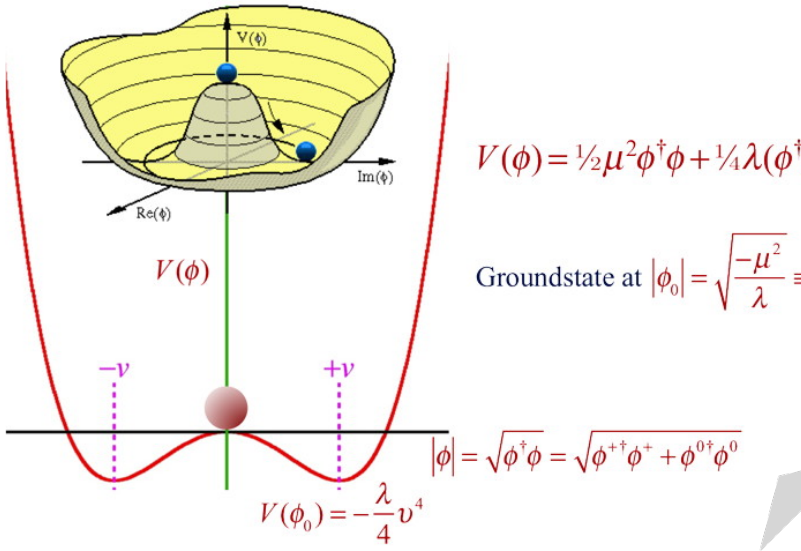




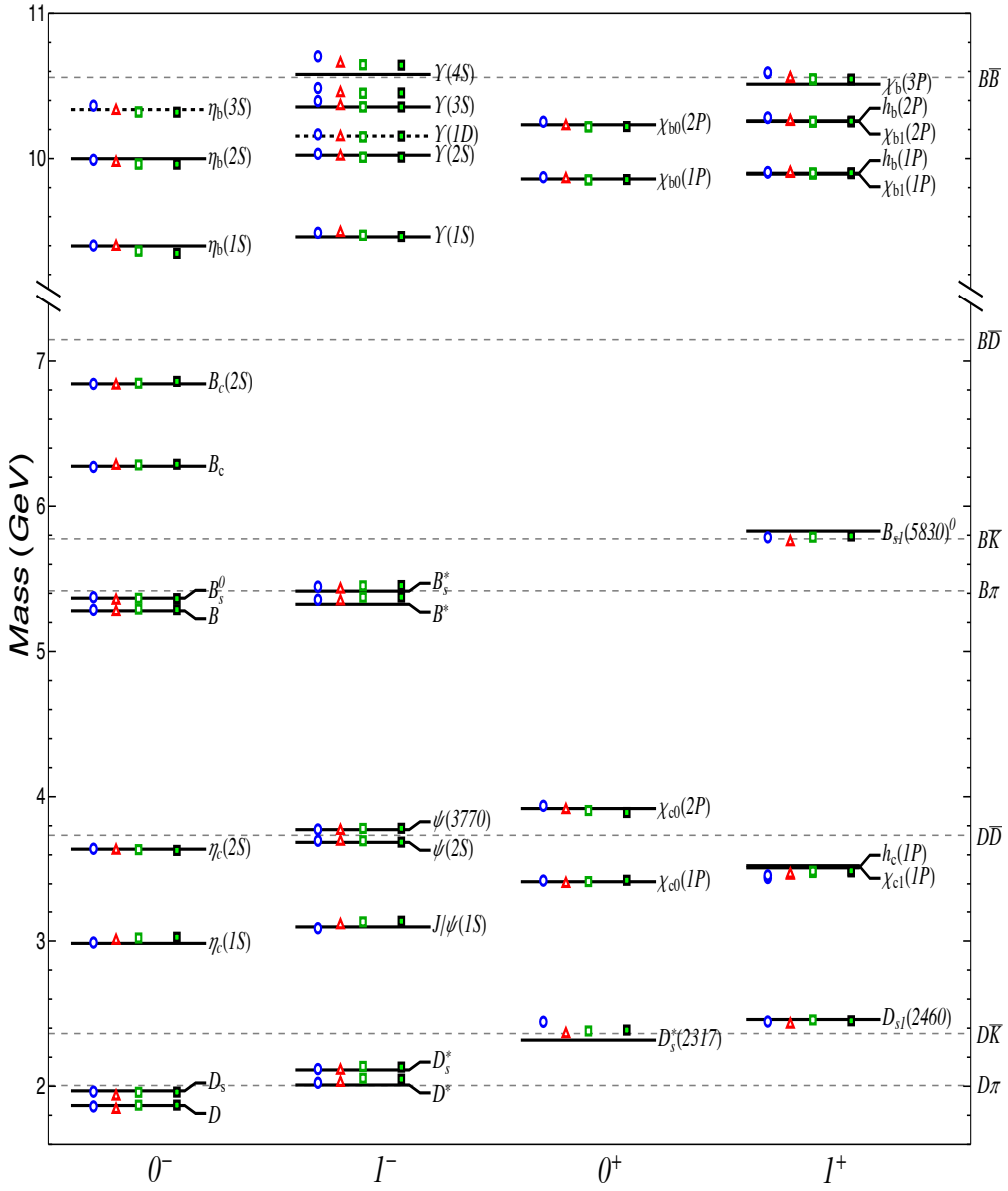
Self-interaction is consistent with quark-anti-quark interaction

Two body equation for bound state is consistent with one body equation for self-energy, in the chiral limit.

This is necessary for spontaneous chiral symmetry dynamical breaking.



Recent results



Next developments

Extend to light mesons (unified model)

Make quark masses are dynamic: self-interaction consistent with quark-anti-quark interaction

Much to do: Shopping list

- ❑ Extension of current model to the light-quark sector
- ❑ Calculation of tensor mesons (spin ≥ 2)
- ❑ Effect on meson spectrum of running quark-gluon coupling
- ❑ Calculation of self-consistent dynamical quark masses
- ❑ Calculation of meson decay properties
- ❑ Systematic study of the confining interaction (Lorentz scalar vs. vector, etc.)
- ❑ Calculation of consistent photon-quark current
- ❑ Calculation of (generalized) parton distribution functions
- ❑ Starting a new project to derive the nucleon-nucleon interaction from quark-gluon dynamics

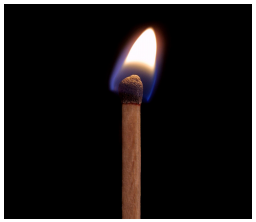
Quantum Chromo Dynamics QCD is the theory of the strong interaction, quarks and gluons.

What we do: Cold QCD

"Art exists for us not to be crushed by reality"

Friedrich Wilhelm Nietzsche

Hot QCD



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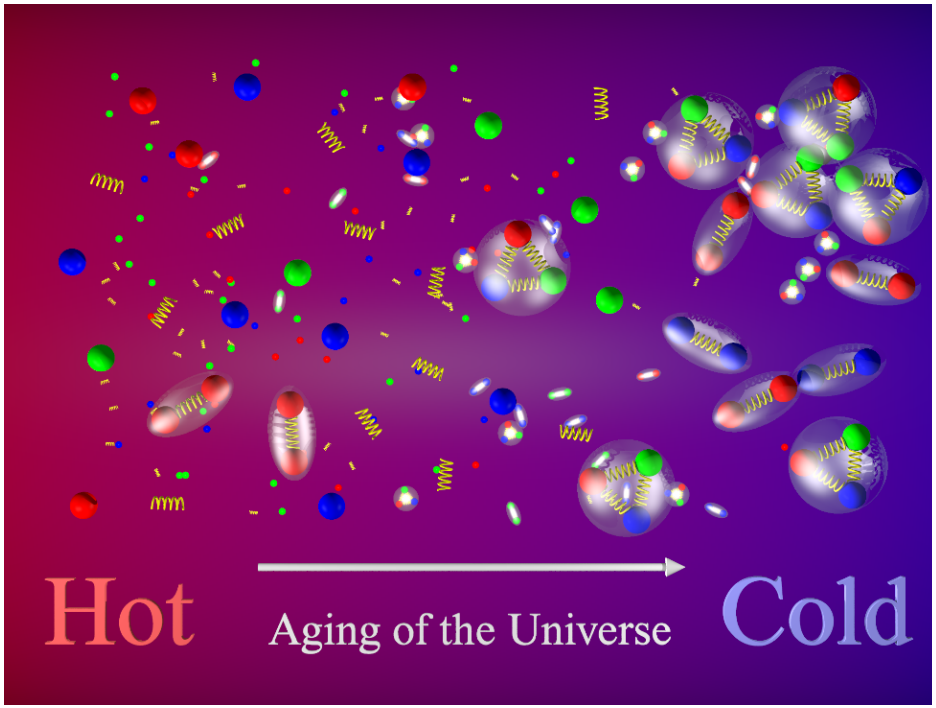
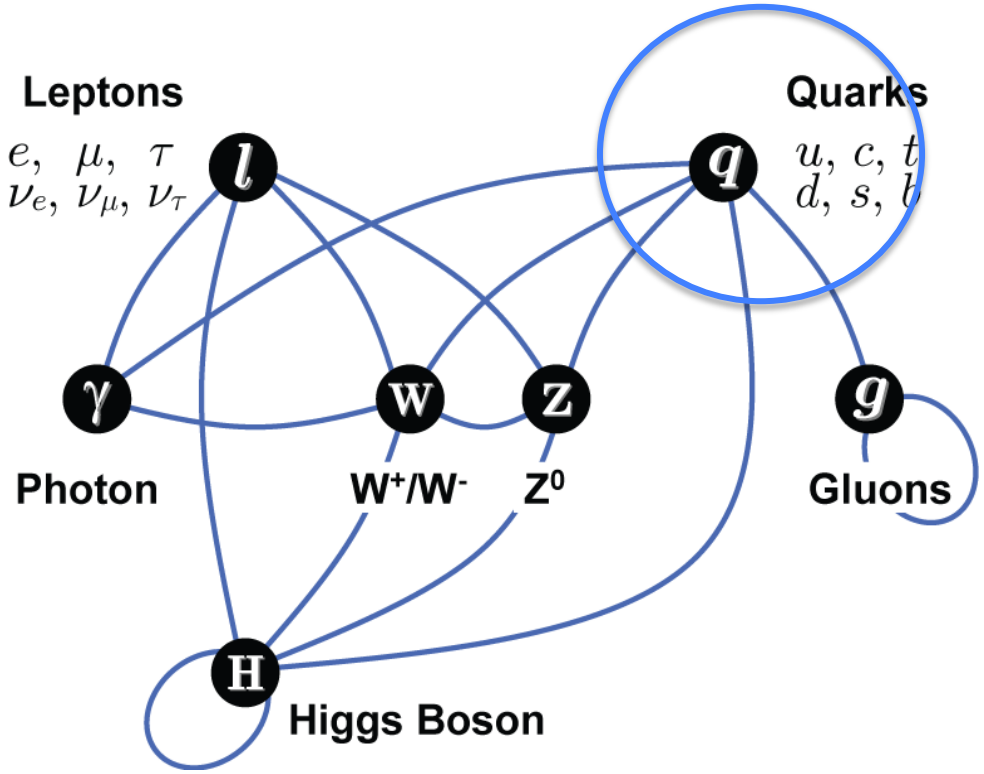


3 colors x 3 flavors x 2 spin projections x 2 gluon polarizations x 2 (quark/anti-quark) =

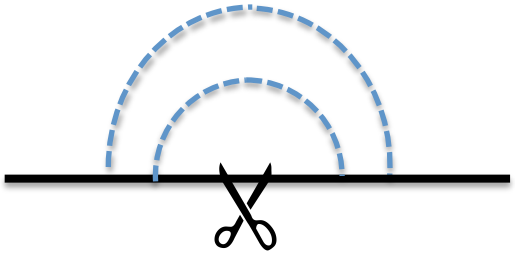
52 dof's

Quarks interact via all forces.

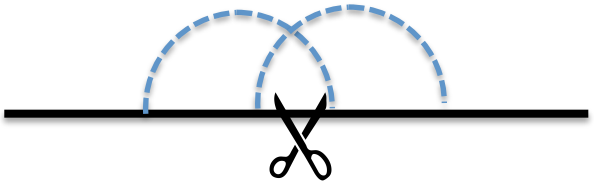


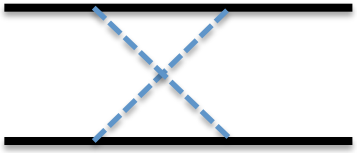
This gives us tools to probe the structures due to confinement by observing the emissivity of matter originated by reactions with electroweak or hadronic probes.

Higher order diagrams are also important



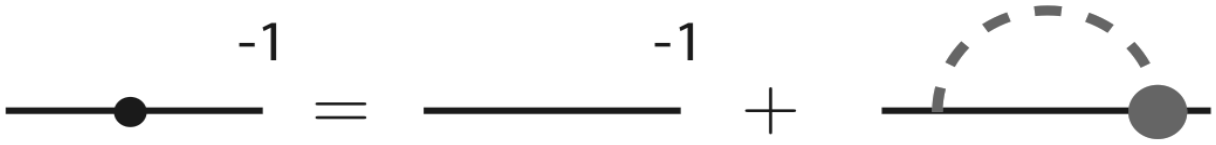
Ladder diagrams

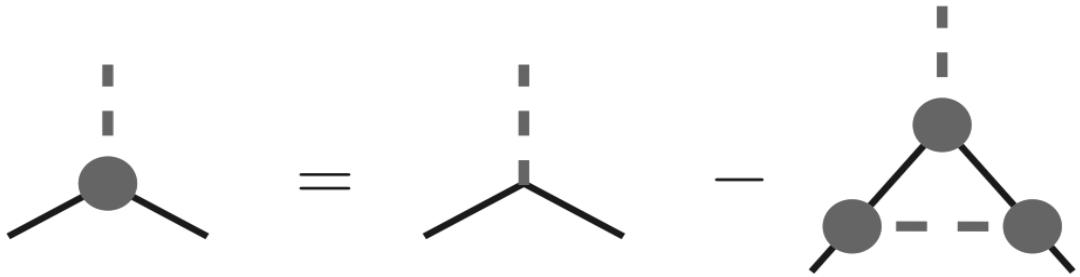


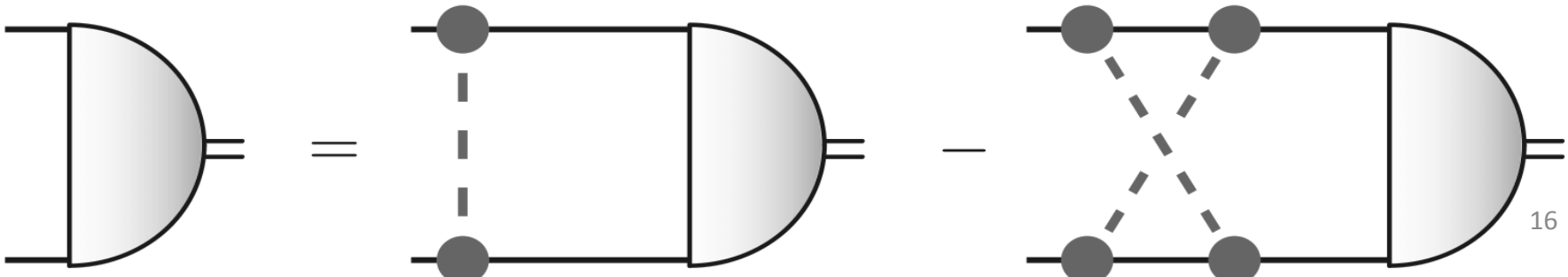


Crossed ladder diagrams

Dyson-Schwinger-Bethe- Salpeter Equations



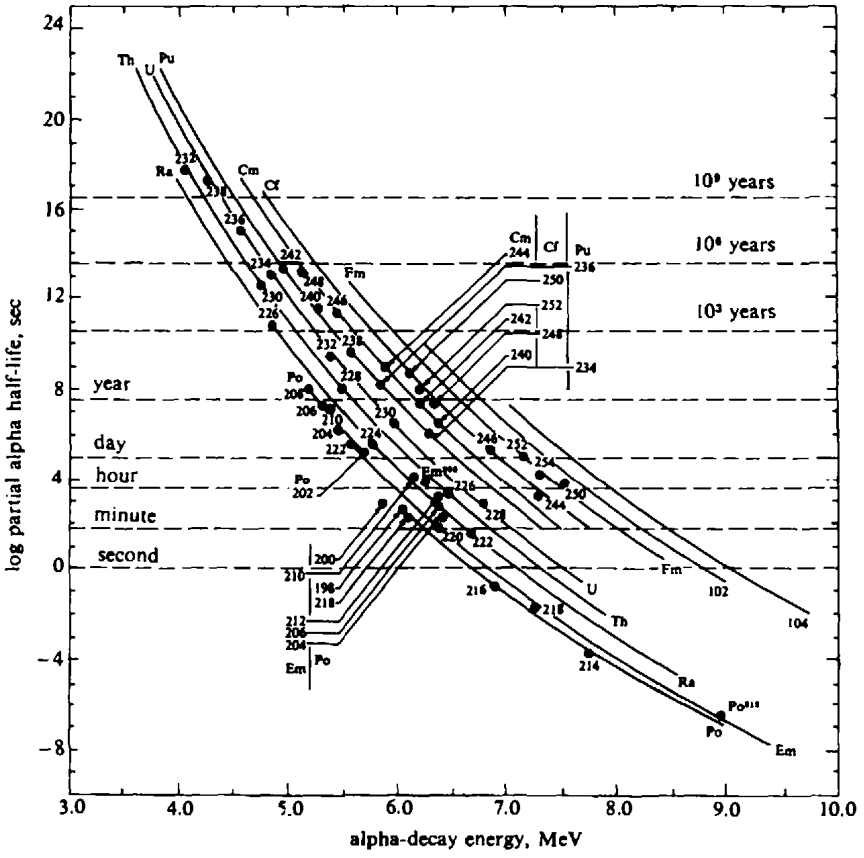


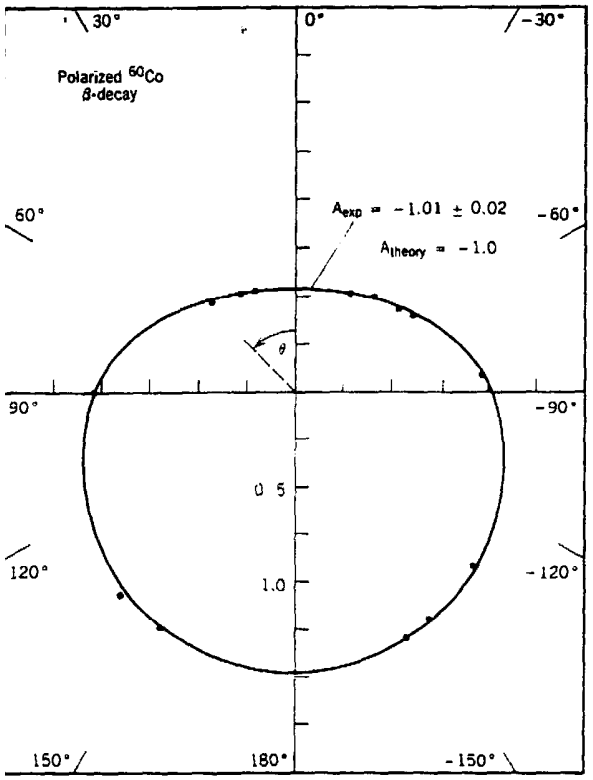


Quantum Mechanics :

One of the first success was the explanation of the half-lifes of nuclear alfa decay.

Parity Violation experiment by C. S. Wu.





Improved results of C. S. Wu and co-workers on the parity violation decay. The data points (plotted on a polar diagram) give the observed an angle θ with respect to the direction of polarization (spin direction)