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Quantum Chromodynamics

A Study of Some Hard Processes

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1st year Master: High Energy Physics

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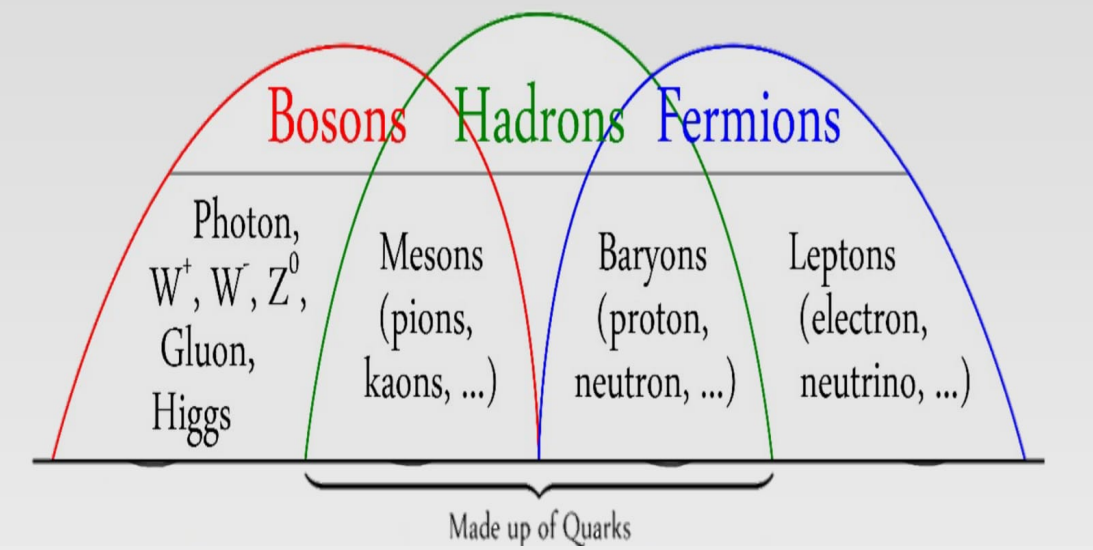
Preamble



- Quarks interact via the strong nuclear force, mediated by gluons, as described by QCD.
- Gluons carry color charge and can interact with each other, enabling the strong force to bind quarks within hadrons.
- Quarks can exist in 3 possible color states : Red , Blue, Green.
- The force acting between quarks is called color force which described by QCD.

Mathematical Foundation

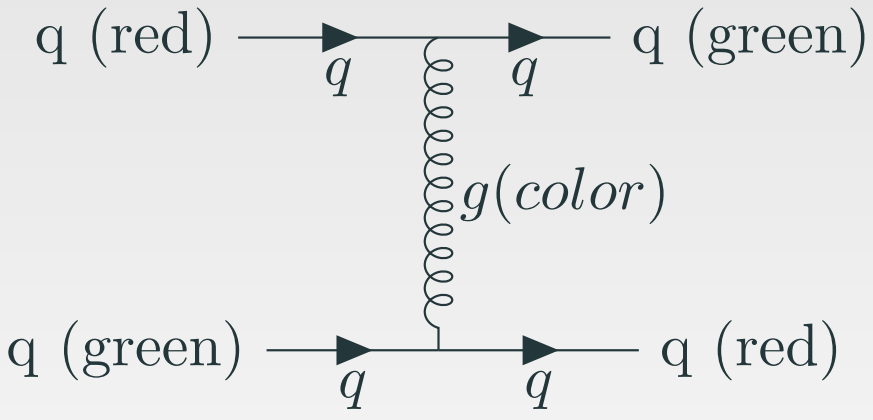
Lagrangian Density:

$$\mathcal{L}_{\text{QCD}} = -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \sum_{f \in \{u,d,s,c,b,t\}} \bar{\psi}_f \left(i \not{\partial} - g_s \not{A}^a \frac{\lambda^a}{2} - m_f \right) \psi_f$$

- $-\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu}$: The gluon field strength tensor term.
- $G^a_{\mu\nu}$: The gluon field strength tensor, defined as $G^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g_s f^{abc} A^b_\mu A^c_\nu$.
- A^a_μ: The gluon field.
- g_s: The strong coupling constant.

Color Charge

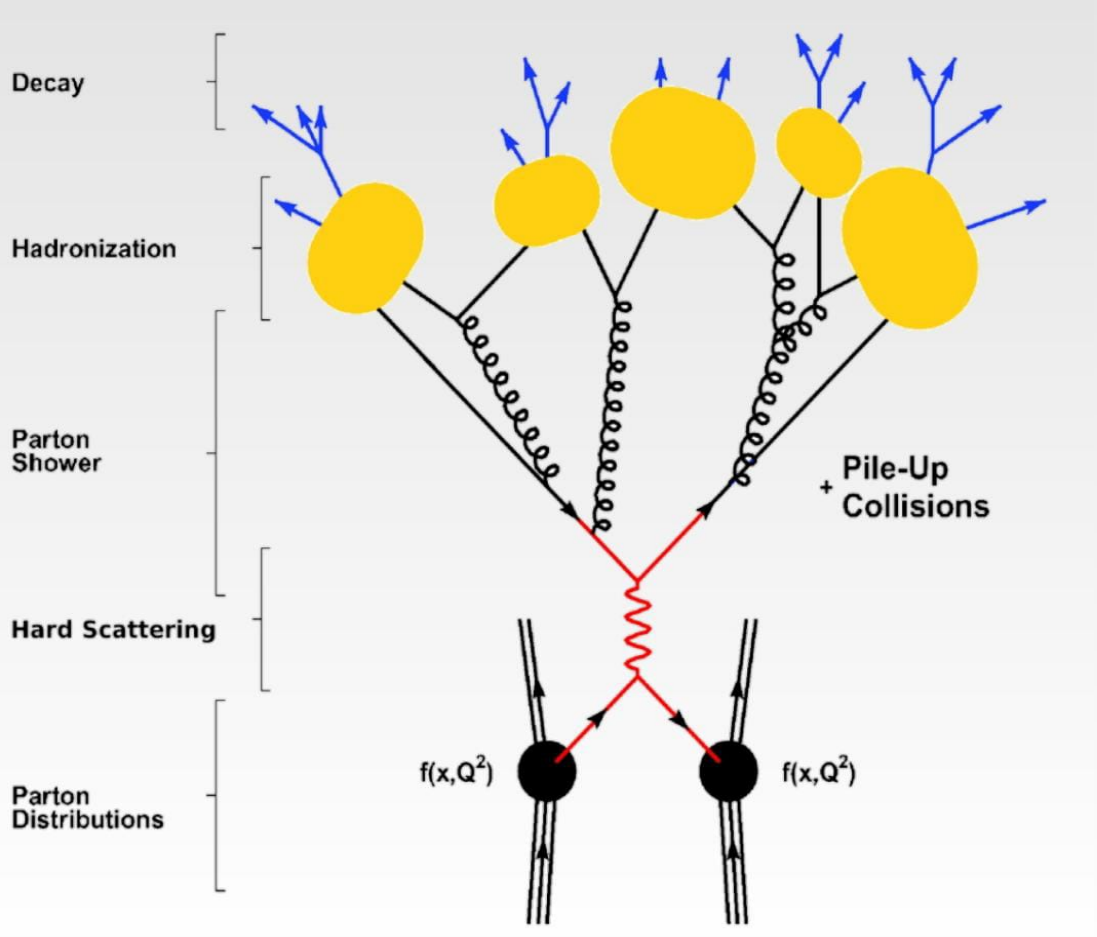
quark-quark interaction:



- Gluons carry a combination of color and anticolor.
- the gluon generates a color change for the quarks.
- The colors (red, green, blue, and anti-blue) associated with the quarks indicate the conservation of color charge.

Parton Scattering

From Parton Scattering to Final States in Proton Collisions:

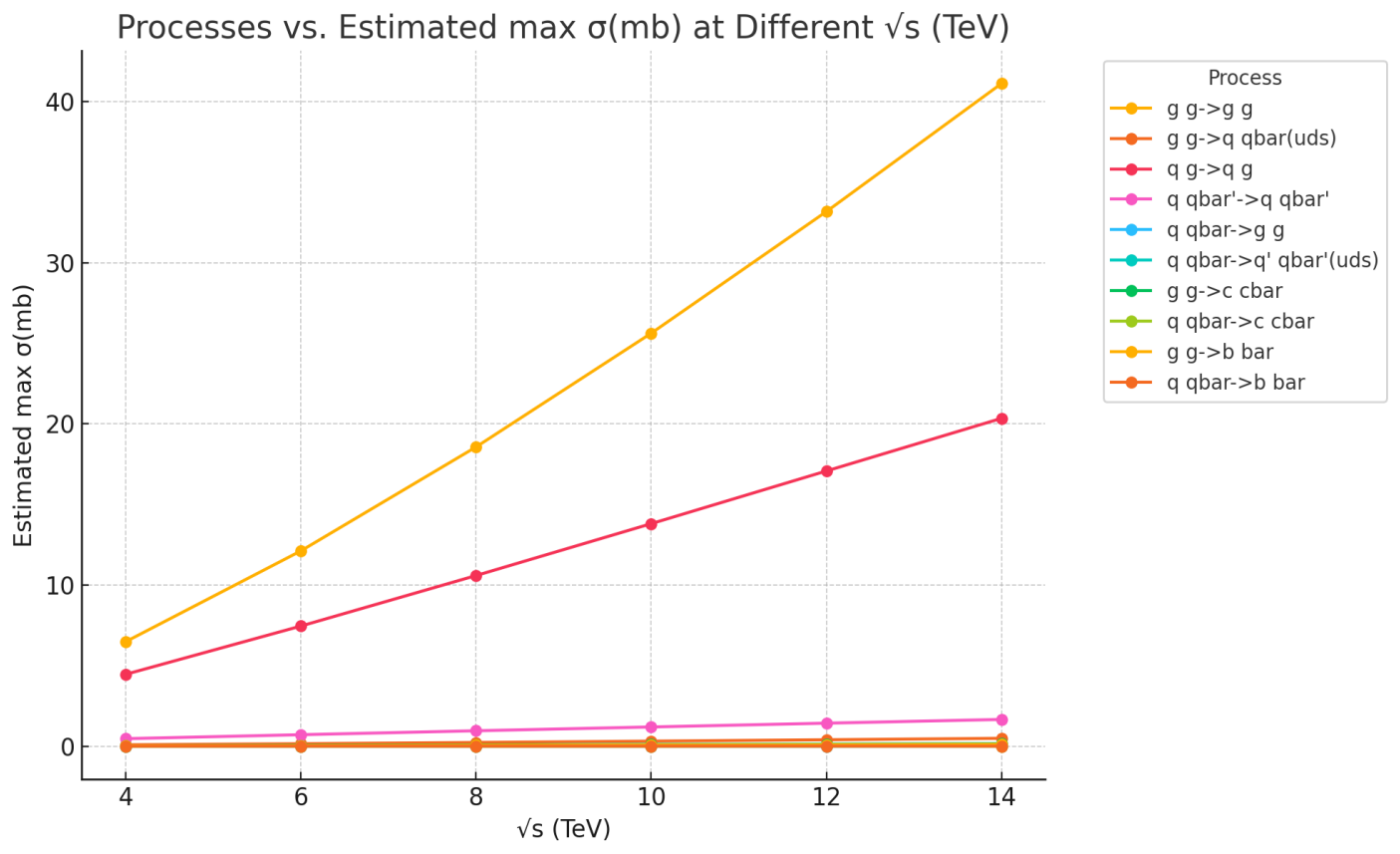


Monte Carlo Simulation

Pythia:

- is a program for the generation of high-energy physics events, for the description of collisions at high energies between e^+, e^-, p and $\bar{p}$ in various combinations. It contains theory and models for hard and soft interactions, parton distributions, initial- and final-state parton showers, multiparton interactions, fragmentation and decay.
- It is categorized as general-purpose Monte Carlo event generator.

Evaluating Proton-Proton collision using Pythia:



With final state Partons $P_T > 10\ GeV$

Analyzing the results

- $gg \to gg$ consistently has the highest cross-section, and the strongest energy dependence.The process is due to gluon self coupling.
- $qg \to qg$ shows a relative increase as the collision energy increases. QCD Compton process" which contribute significantly to the production of gluons at higher energies.
- $q\bar{q}' \to q\bar{q}'$ shows a minor increase of the cross section, though it is important for producing high-energy jets of particles.
- Higher energy collisions enable more frequent parton interactions and particle production, aligning with theoretical predictions from QCD.

Synthesis and recapitulation

- QCD is a gauge theory, based on $SU(3)$ symmetry, considered to be the language of the strong force, and that Pauli exclusion principle gives rise to the notion of color as the quarks are fermions.
- The Lagrangian density's importance manifests in the prediction of what lies exactly in the relativistic nature of Quarks which are the subject of this project.
- The center of mass energy energy in the evolution of the subpresses resulting from the p-p collision , which leads eventually to deduct that gluon self interaction is important in the formation of hadrons

Thank you for your attention