Open KIAS Winter School on Collider Physics

Feb. 13-18, 2011

#### Lecture 1: Basics of QCD

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### Outline of the lectures

- Why QCD?
- Collider processes
- Basic properties of QCD
- Hard processes
- Fragmentation
- Hadronization and parton shower
- Parton distribution functions

#### Freedom and constaints

 Announced titles QCD, Hadronic interactions, Collider signatures of QCD, PDF and jets

Hadronic processes: tree-level only

#### Standard textbooks

- Collider Physics, V. D. Barger, R. J. N. Phillips, Addison and Wesley (1997)
- Applications of Perturbative QCD, R. D. Field, Addison and Wesley (1989)
- QCD and Collider Physics, R. K. Ellis, W. J. Stirling, B. R. Webber, Cambridge (1996)
- Foundations of Quantum Chromodynamics, (3<sup>rd</sup>. Ed.) T. Muta, World Scientific (2010)

#### Schematic hadronic processes



#### What we will do...

- Tree-level processes (no loops)
- Standard 2 → 2 processes (possibly 2 → 3 processes)
- Basic understanding of QCD
- We consider high-energy processes, so we neglect masses of light quarks.

## Why QCD?

- Omnipresent in collider processes
- Large effects
- Enormous background for new particle search
- It appears at all scales.
- The coupling constant varies rather wildly when the scale varies.
- Sometimes we have to sum all the contributions.

• Lagrangian  $\mathcal{L} = \overline{\psi} i \gamma^{\mu} D_{\mu} \psi - \frac{1}{4} G^{a}_{\mu\nu} G^{\mu\nu a}$  $D^{\mu} = \partial_{\mu} - ig A^{a}_{\mu} T^{a}$ 







$$bc[(p-q)_{\lambda}g_{\mu\nu} + (q-r)_{\mu}g_{\nu\lambda} + (r-p)_{\nu}g_{\lambda\mu}$$

$$p+q+r=0$$

$$[T^{a},T^{b}] = if^{abc}T^{c}$$

$$T^{a}T^{a} = C_{F} = \frac{4}{3} \quad \operatorname{tr} T^{a}T^{b} = \frac{1}{2}\delta^{ab}$$

$$f^{acd}f^{bcd} = 3\delta^{ab}$$



$$-ig^{2} \Big[ f^{abe} f^{cde} (g_{\lambda\nu}g_{\mu\rho} - g_{\lambda\rho}g_{\mu\nu}) \\ + f^{ace} f^{bde} (g_{\lambda\mu}g_{\nu\rho} - g_{\lambda\rho}g_{\mu\nu}) \\ + f^{ade} f^{bce} (g_{\lambda\mu}g_{\nu\rho} - g_{\lambda\nu}g_{\mu\rho}) \Big]$$

 $\mu, a$ 

#### Kinematics



All the scattering cross sections are functions of  $\ s,t$  and  $\ u$  .

$$s + t + u = 0$$

#### Phase space

Scattering cross section for n final-state particles

$$d\sigma = \frac{1}{2s} \sum |\mathcal{M}|^2 (2\pi)^4 \delta^4 \left( p_1 + p_2 - \sum_{i=1}^n p_i \right) \prod_{i=1}^n \frac{d^3 p_i}{(2\pi)^3 2E_i}$$



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Homework problem 2 Derive this.

# Lecture 2: $2 \rightarrow 2$ parton processes

- We consider scattering at the parton level.
- We average over initial spin and color.



$$\overline{|\mathcal{M}|^2} = g^4 \frac{4(s^2 + u^2)}{9t^2}$$

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha_s^2}{9}\frac{s^2 + u^2}{s^2t^2}$$



Homework Problem 3



$$\overline{|\mathcal{M}|^2} = \frac{4g^4}{9} \frac{t^2 + u^2}{s^2}$$



Homework problem 4





$$\boxed{|\mathcal{M}|^2 = \frac{g^4}{6}\frac{u^2 + t^2}{ut} - \frac{3g^4}{8}\frac{u^2 + t^2}{s^2}}$$

Homework problem 5

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 $qg \rightarrow qg$ 

$$\overline{|\mathcal{M}|^2} = g^4 \frac{s^2 + u^2}{t^2} - \frac{4g^4}{9} \frac{s^2 + u^2}{us}$$

Homework problem 6

 $gg \rightarrow gg$ 







Challenge problem

