QCD & the Parton Model

Lecture 14 Physics 152/252

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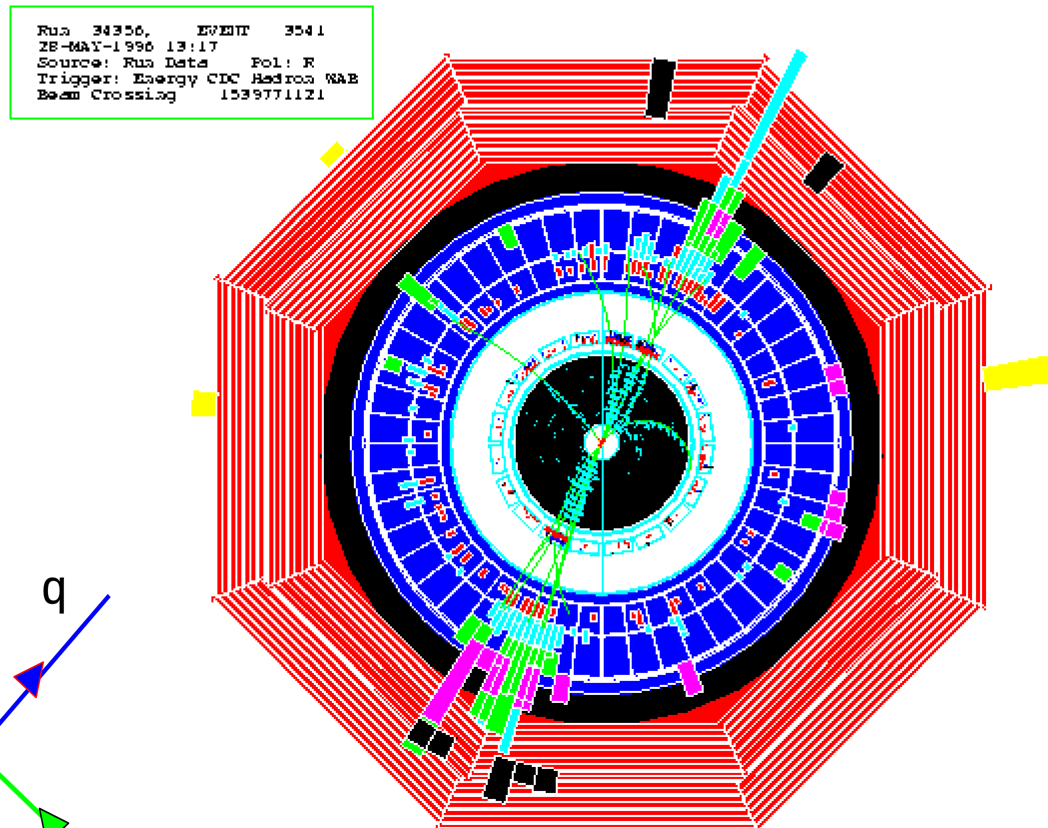
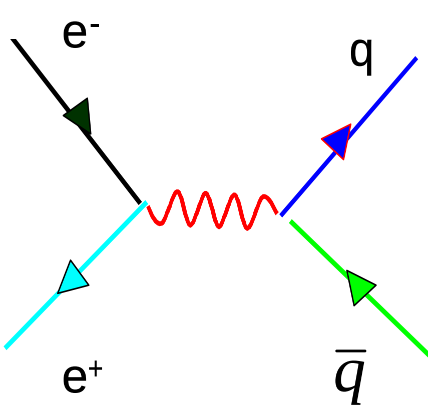
(thanks again to Colin Jessop)

Two Jet Event





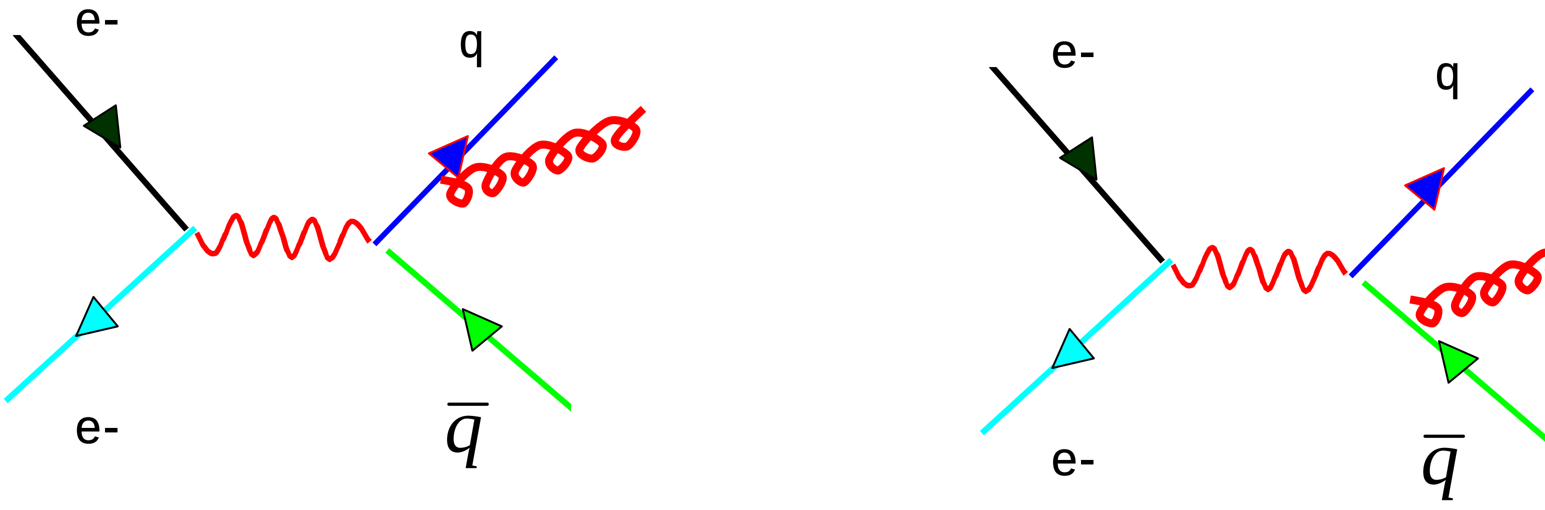
Distribution follows

$$\frac{d\sigma}{d(\cos\vartheta)_{cm}} \propto (1+\cos^2\vartheta)$$

Just like $e^+ e^- \to \mu^+ \mu^-$

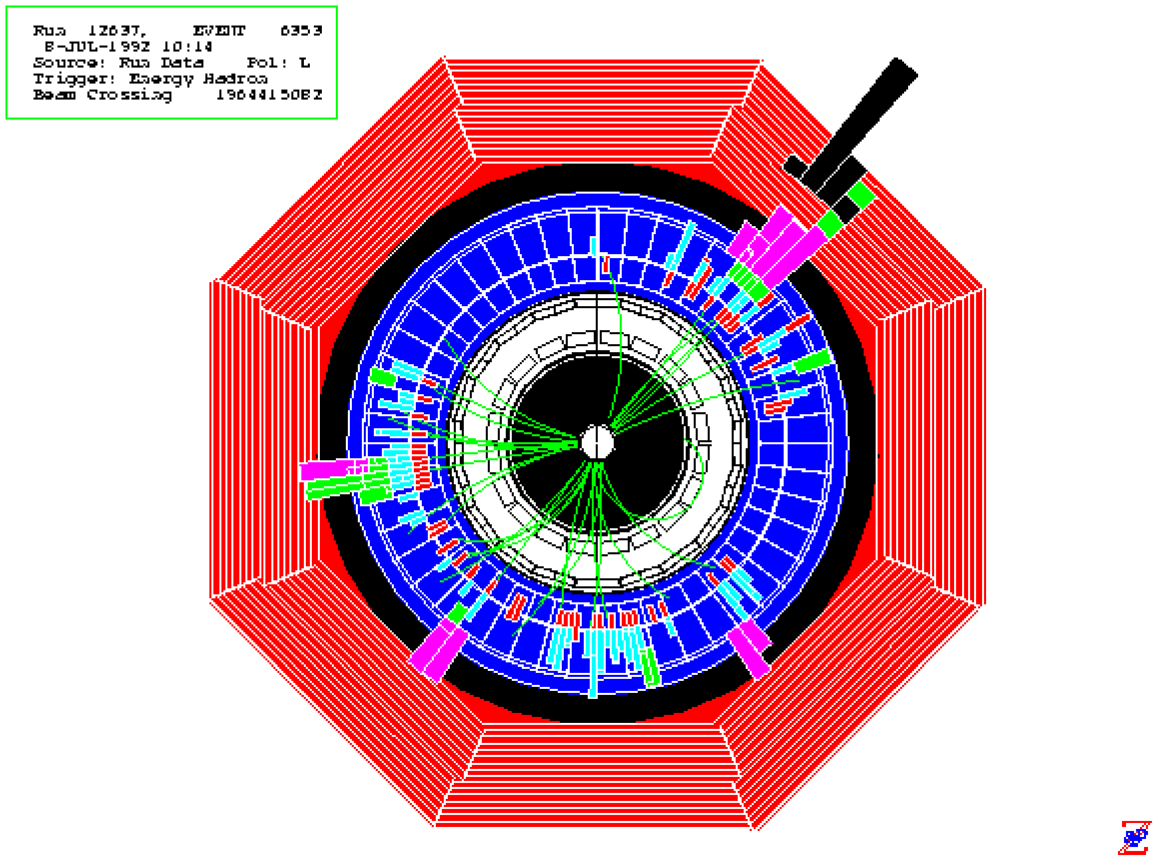
-> quarks have spin 1/2

Proof that Gluons Exist



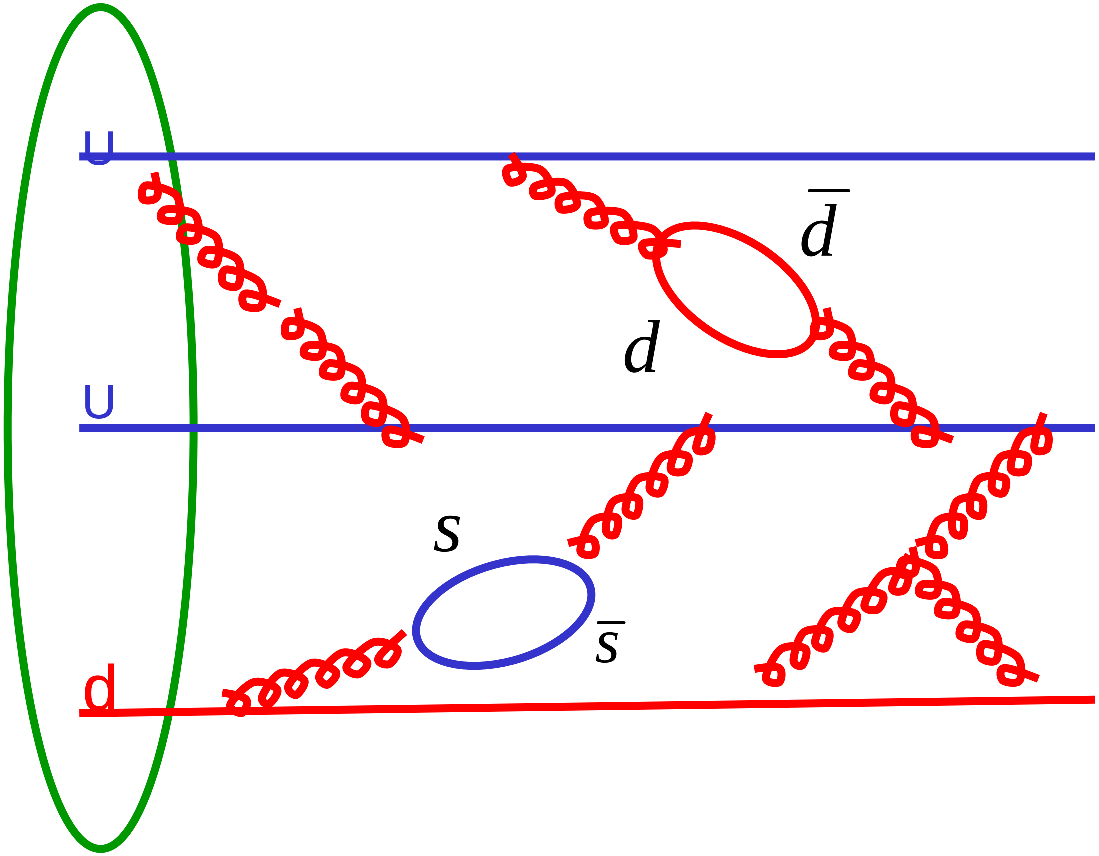
Gluons fragment into jets similarly to quarks so expect 3 jet events

Proof that Gluons Exist



3 jet events observed at rate consistent with expectations

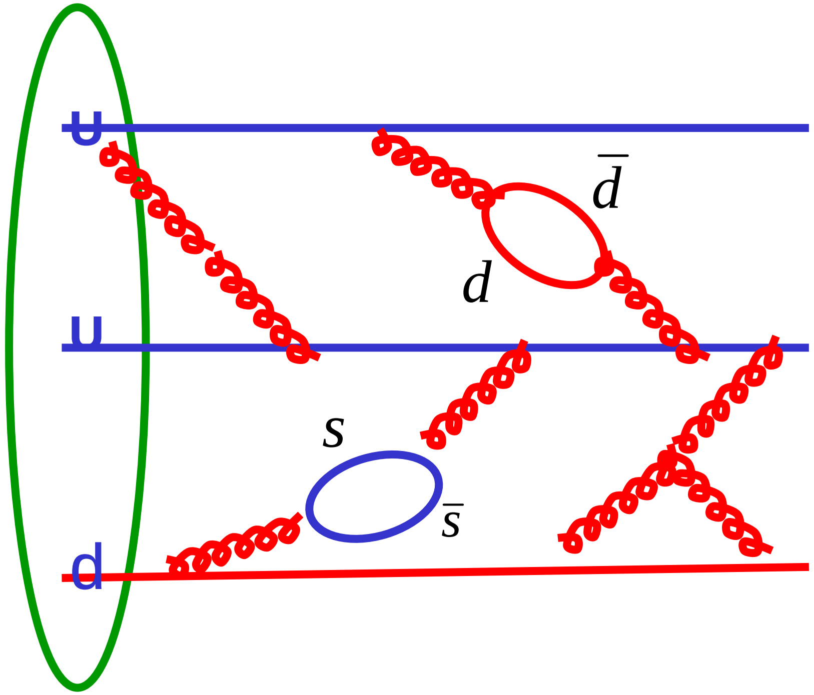
Structure of the Proton



Proton is composed of u,d valence quarks which carry quantum numbers and

"*sea*" *of* $u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}, t, \bar{t}$ *with no net quantum number*

Parton density Function



Quarks and gluons are collectively known as partons and the composition of the proton is described by a parton density functions q(x)

q(x) is the probability for the quark flavor q or gluon g to carry a fraction x of the total momentum of the Proton $0 < x < 1$

Constraints on Parton Density Functions

The charm,beauty and truth compositions are negligible so proton is composed of uds quarks and anti quarks and glue . The observed quantum number constraints

No net strangeness

$$\int (s(x) - \bar{s}(x))\, dx = 0$$

Isospin $I_3 = 1/2$

$$\int [\frac{1}{2}(u(x) - \bar{u}(x)) - \frac{1}{2}(d(x) - \bar{d}(x))]\, dx = \frac{1}{2}$$

Charge =1

$$\int \frac{2}{3}(u(x) - \bar{u}(x)) - \frac{1}{3}(d(x) - \bar{d}(x)) - \frac{1}{3}(s(x) - \bar{s}(x))\, dx = 1$$

Leads to

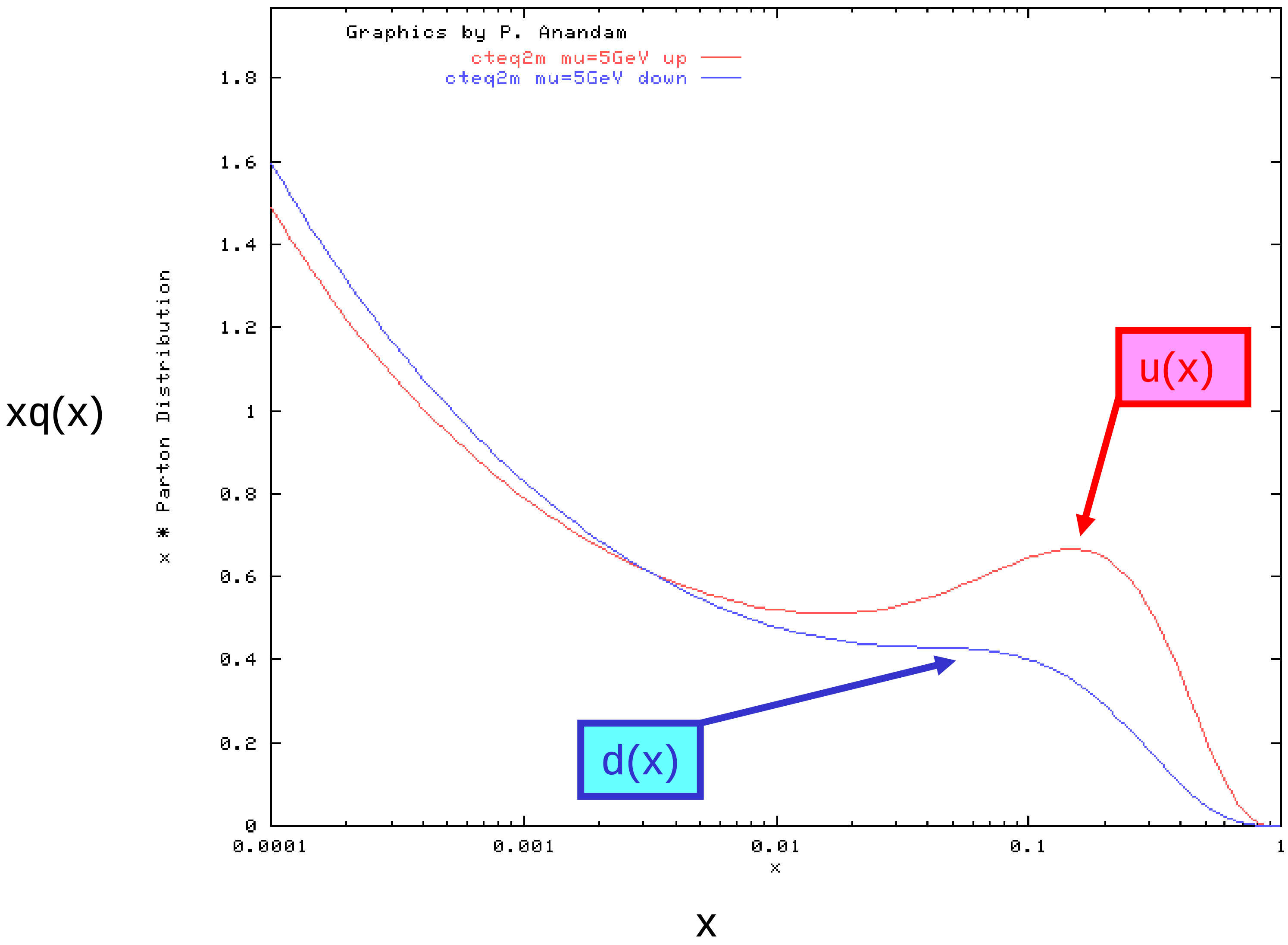
$$\int (u(x) - \bar{u}(x))\, dx = 2 \qquad \int (d(x) - \bar{d}(x))\, dx = 1$$

Two u quarks and 1 d quark as expected. These are called sum rules and there is one for every quantum number.

Momentum sum rule:

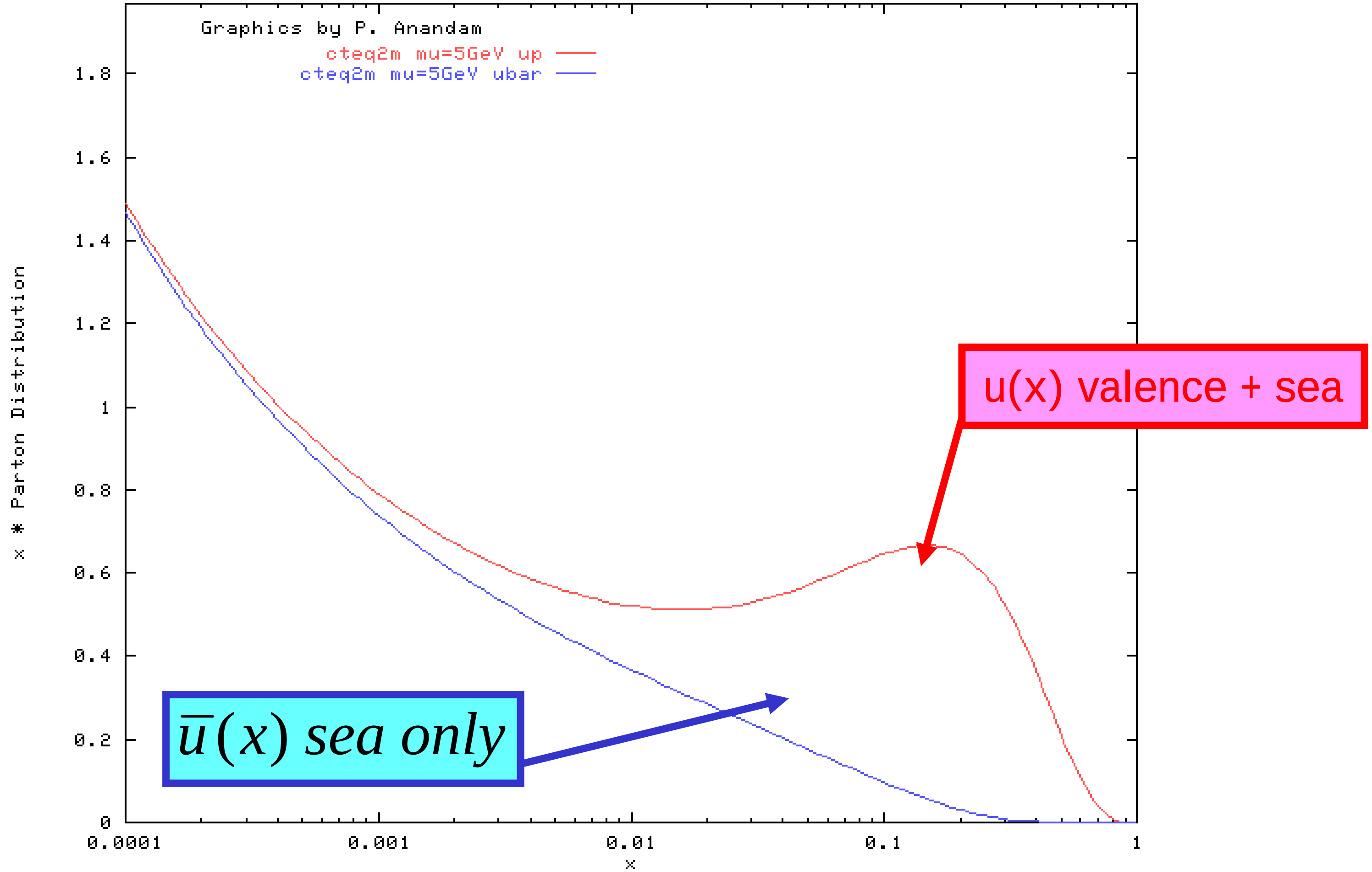
$$\int x[u(x) + \bar{u}(x) + d(x) + \bar{d}(x) + s(x) + \bar{s}(x) + ... + g(x)]\, dx = 1$$

u(x) and d(x) parton distributions for proton



u(x) and $\bar{u}$(x) parton distributions for proton

xq(x)



x

Gluon distribution

Quark distributions can be measured by e or μ scattering
--- but not the gluon distribution as gluons are not electrically charged.
A nonzero gluon distribution can be inferred from the momentum sum rule:

$$\int x(u(x)+\bar{u}(x)+d(x)+\bar{d}(x)+s(x)+\bar{s}(x)+g(x))\,dx=1.0$$

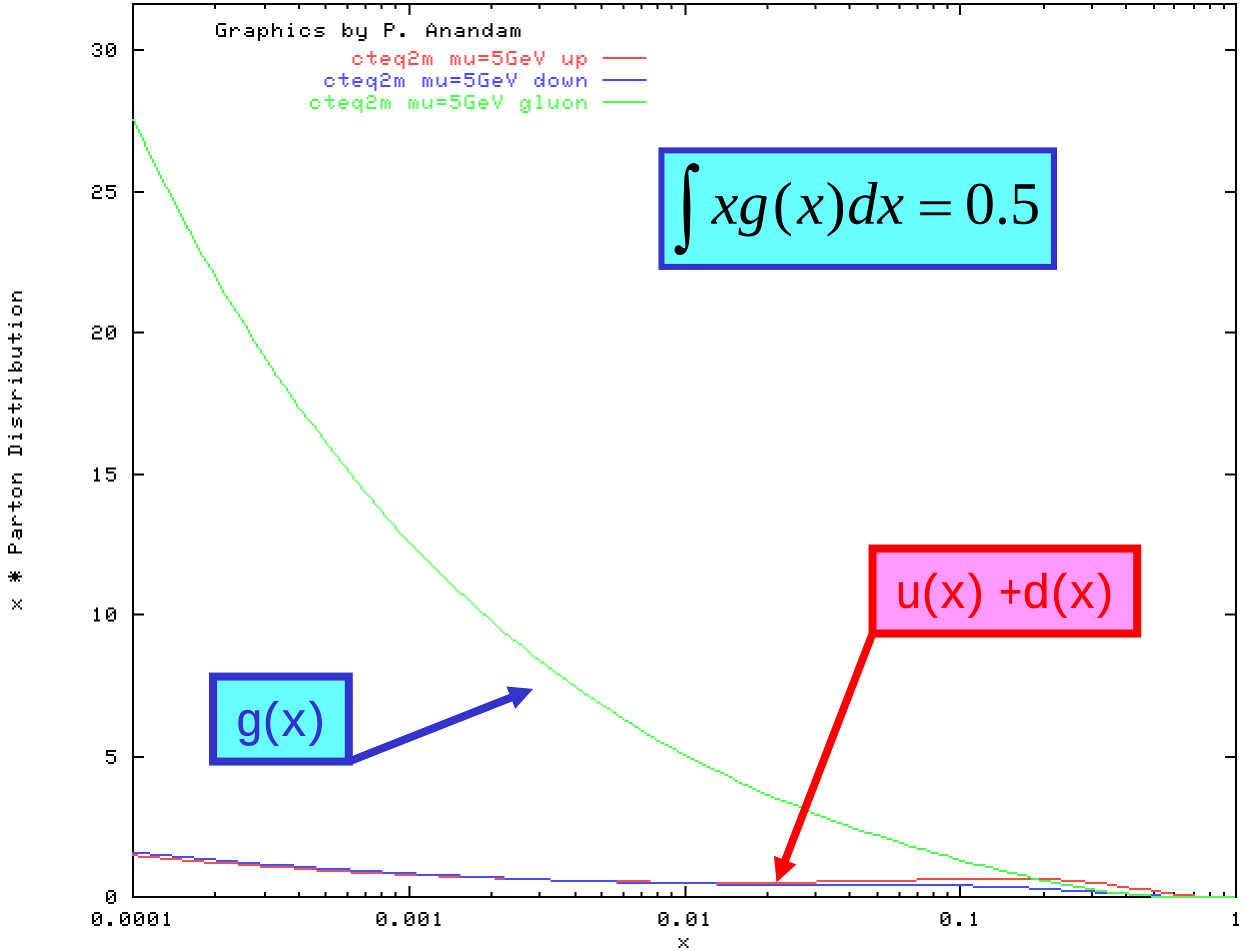
so:

$$\int xg(x)dx=\int 1.0-(u(x)+\bar{u}(x)+d(x)+\bar{d}(x)+s(x)+\bar{s}(x))\,dx$$

More generally, Q^2 evolution of q(x,Q^2), and hence F_i(x,Q^2), involves g(x,Q^2), so gluon distribution can be extracted that way. Nevertheless, it is not as well known as the quark distributions.

Gluons carry 50% of proton momentum

xq(x)

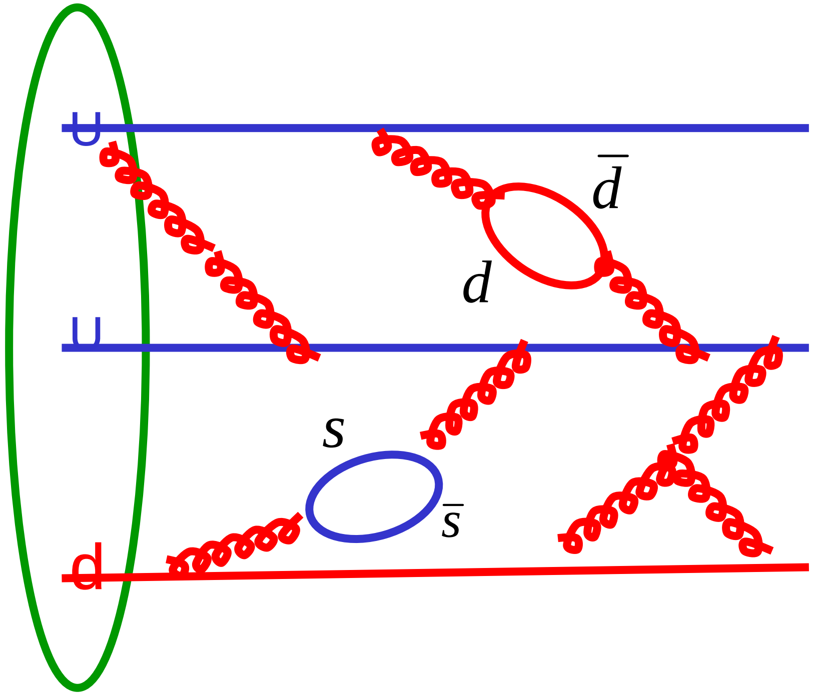


$$\int xg(x)dx = 0.5$$

x

Parton density Functions are function of Δp

$$\Delta p \Delta x \geq \frac{h}{2\pi}$$

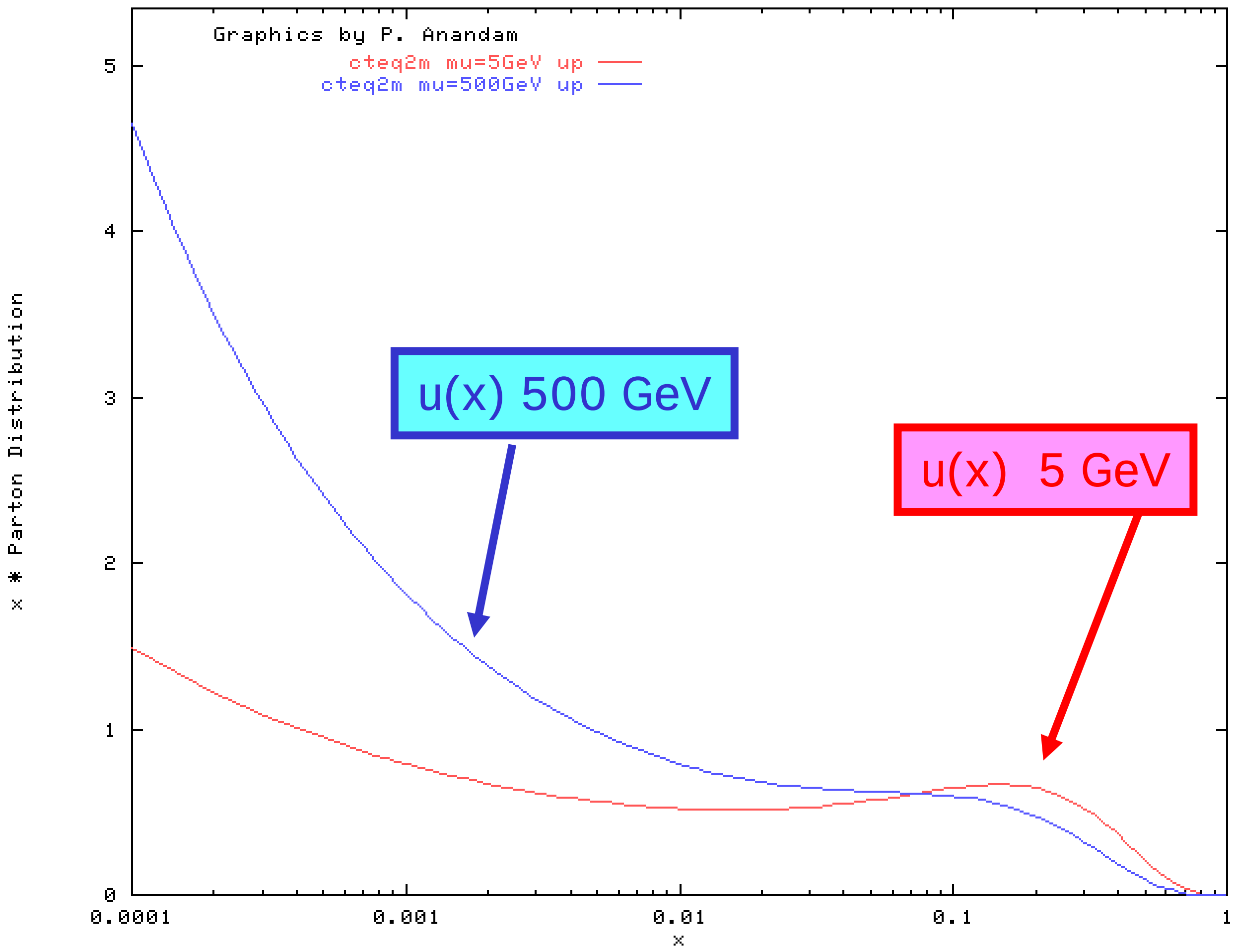


Q(x, Δp) is calculable if you know q(x) at one Δp $Q_0(x, \Delta p_0)$ - called Altarelli Parisi evolution equations

As Δp increases see more of sea contribution

At high Δp see more of sea

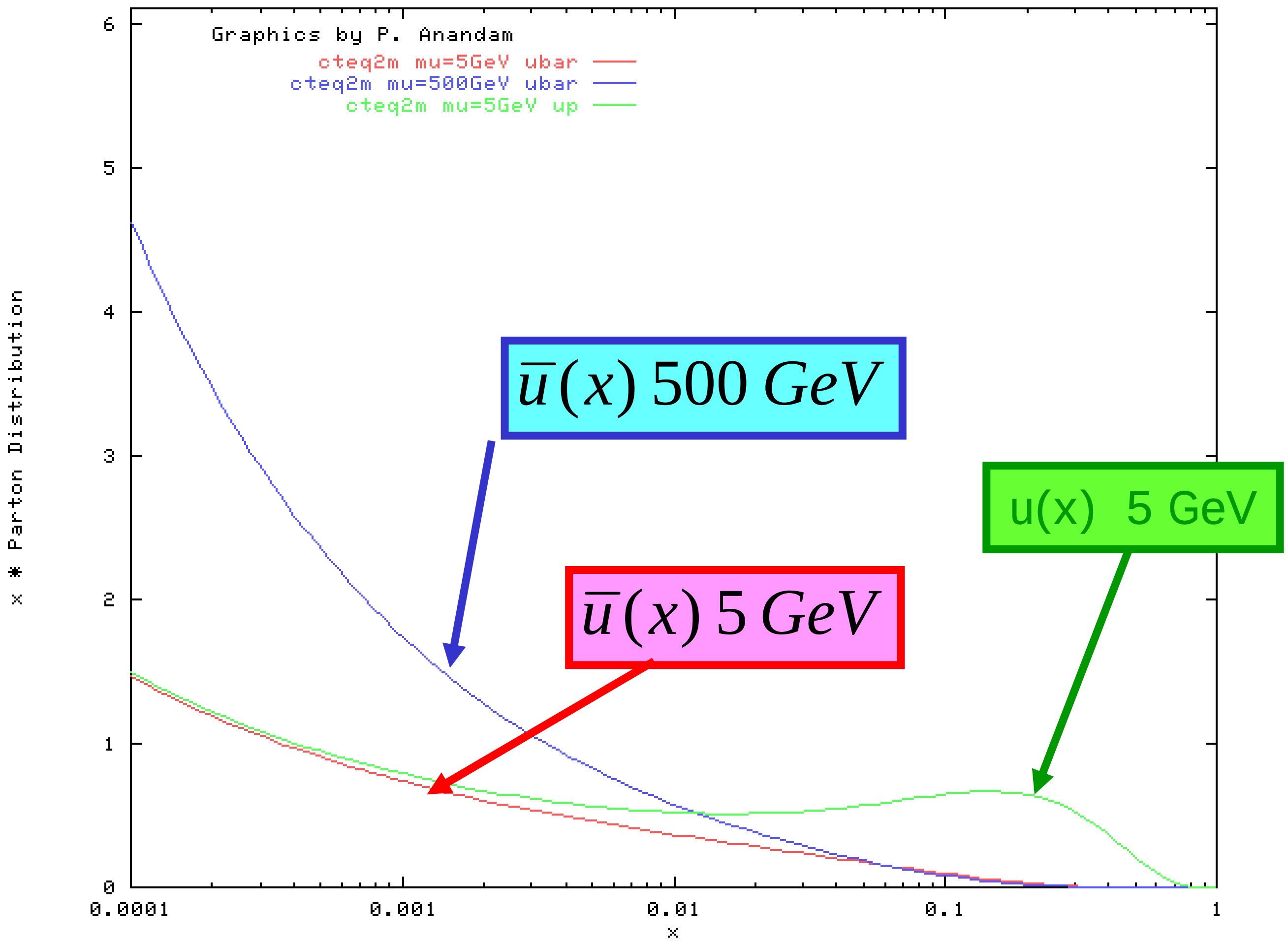
xq(x)



x

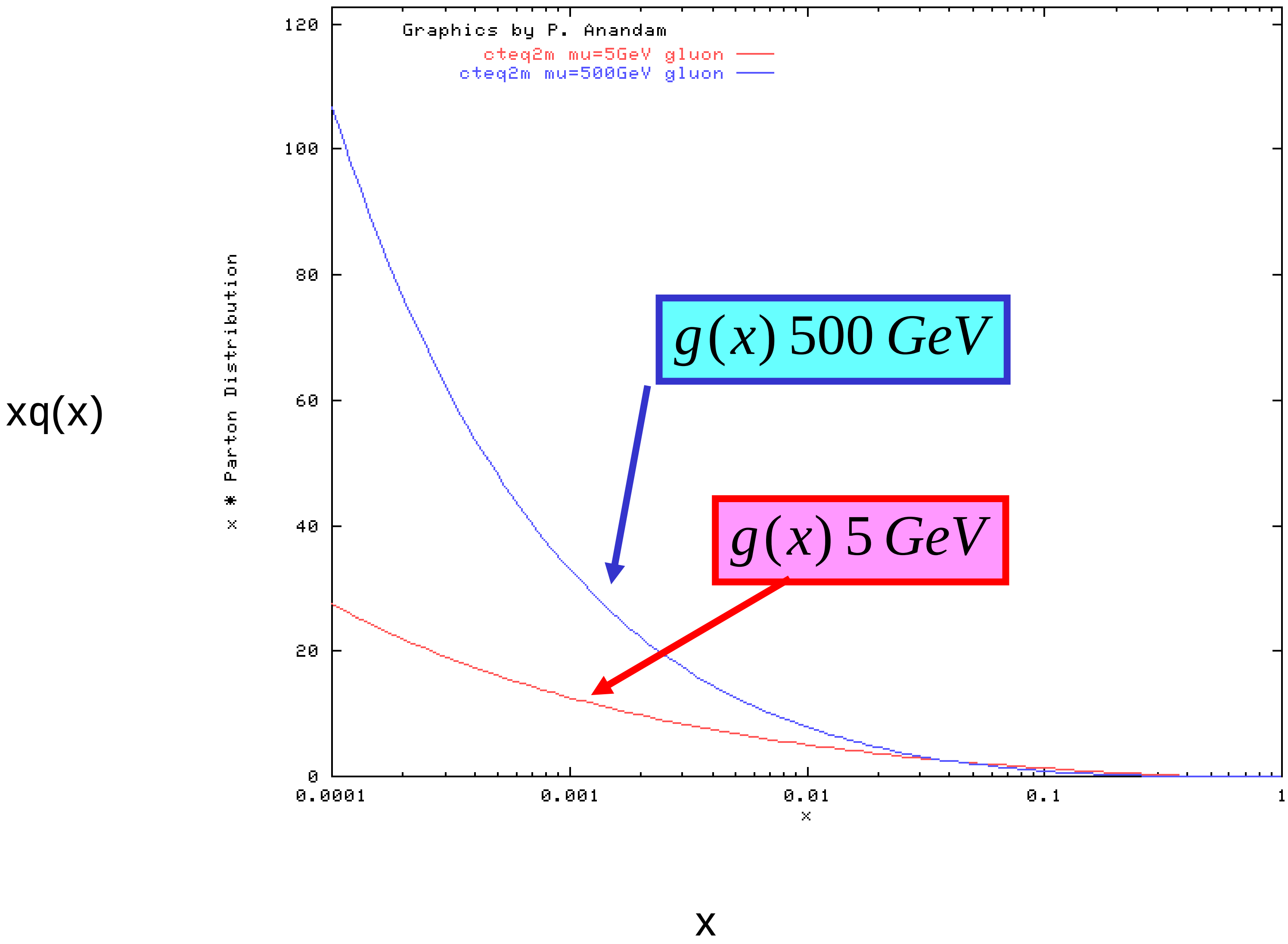
At high Δp see less valence quarks more sea antiquarks

xq(x)



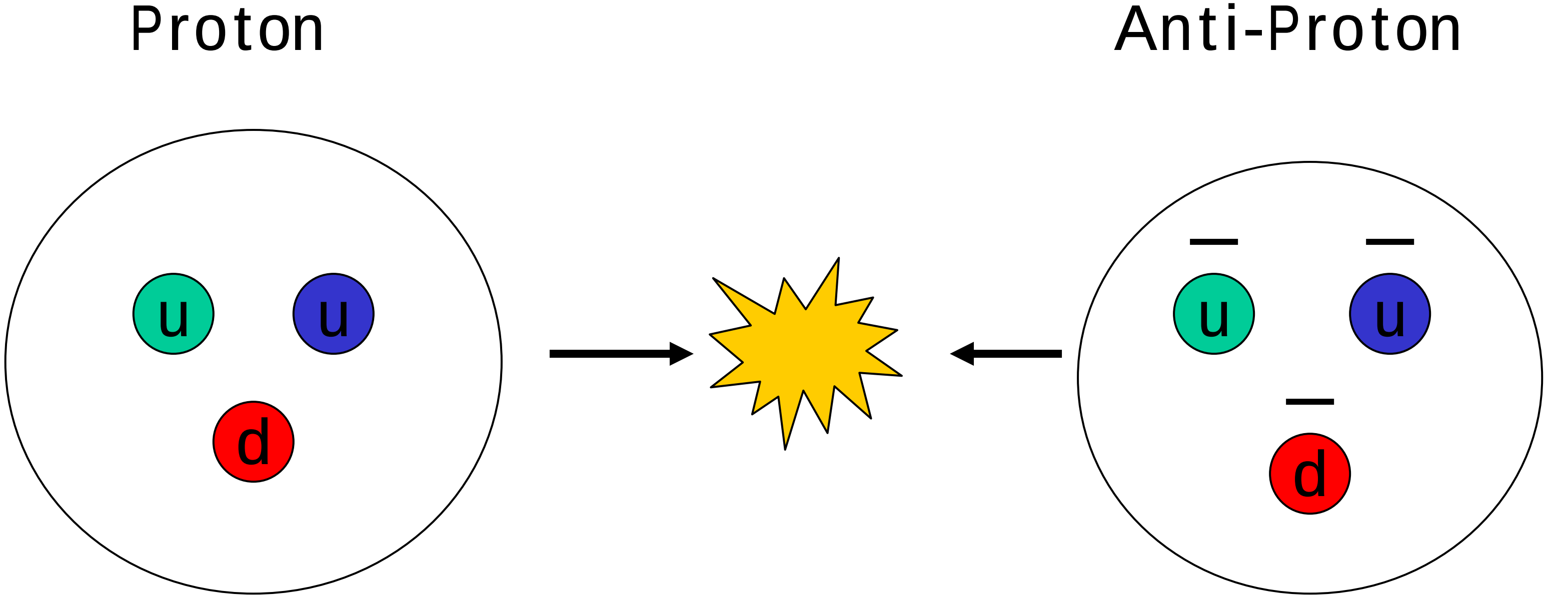
x

More low x gluons less high x valence quarks at high Δp

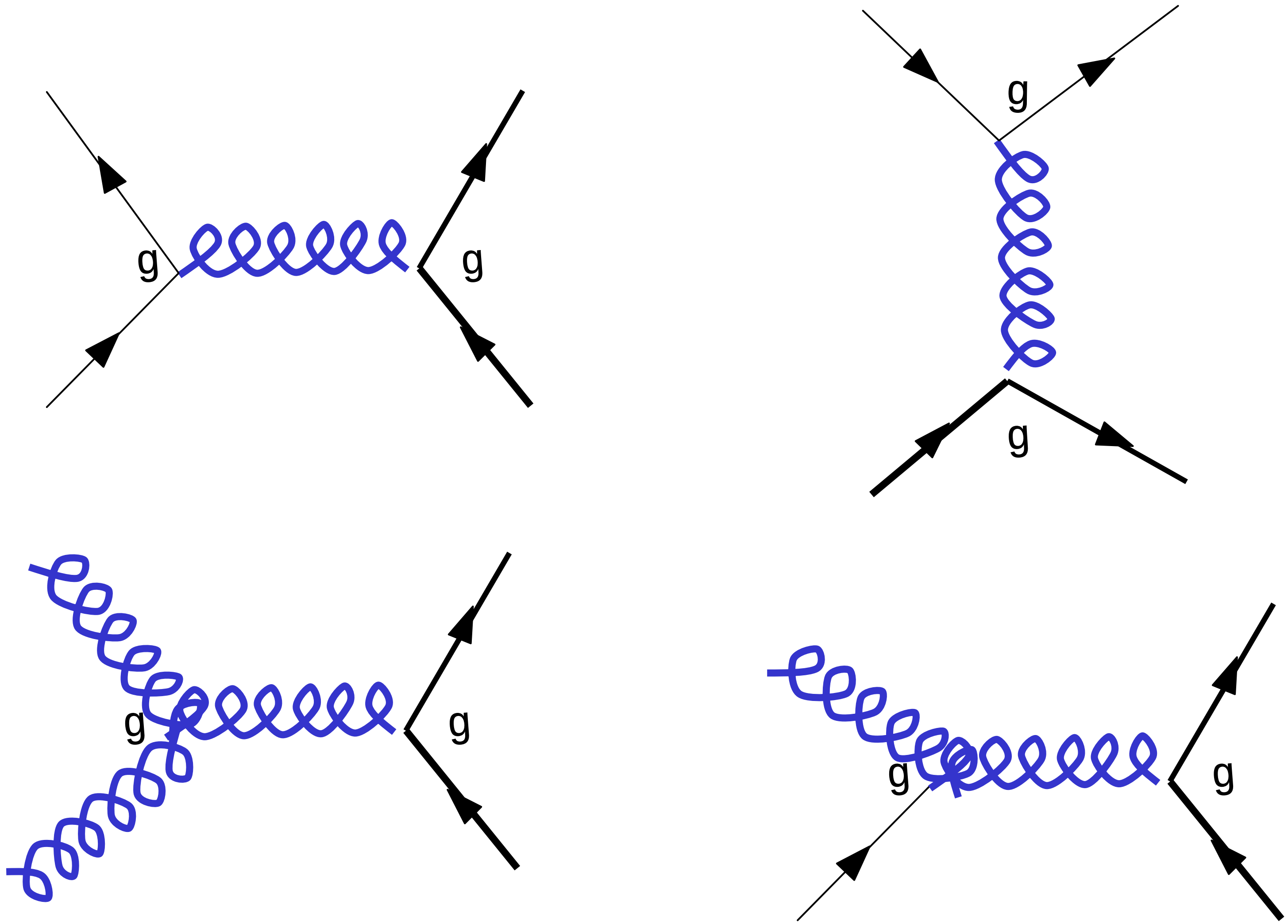


Matter-Antimatter Collisions

It is possible to accelerate protons and antiprotons to much greater energies than electrons and positrons. This effectively makes a quark-antiquark collider

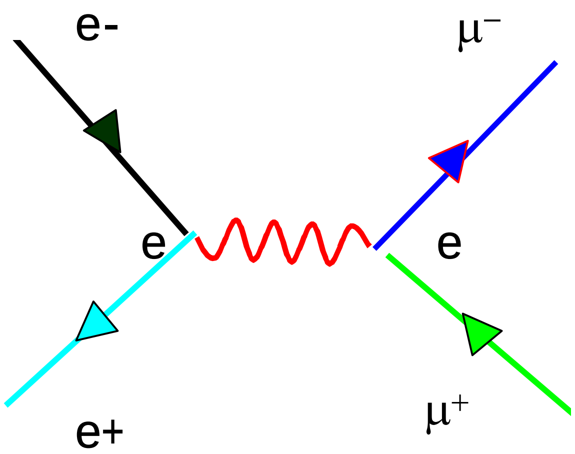


Many Different Processes at lowest order contribute to $q\bar{q}$ production

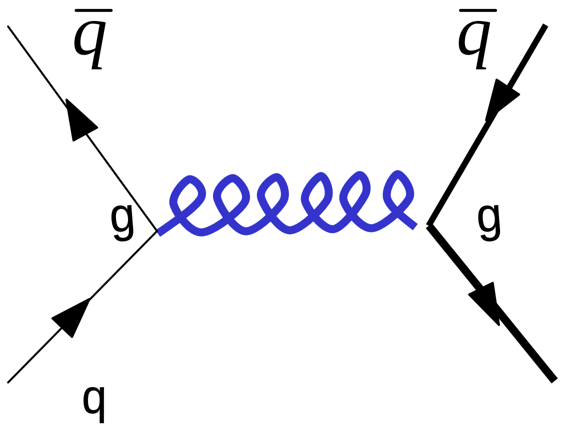


Can Calculate Simple Processes in same way as QED

QED

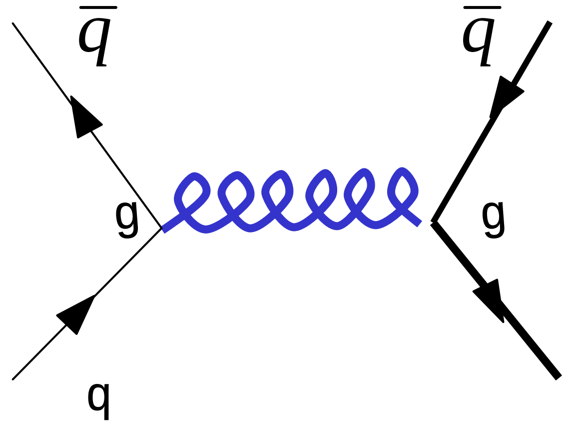


QCD



1. e <-> g
2. Average over initial colour and sum over final colour
3. Integrate over Parton distribution functions

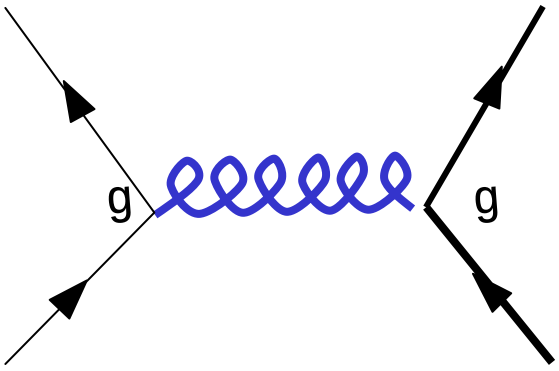
Can Calculate Simple Processes in same way as QED

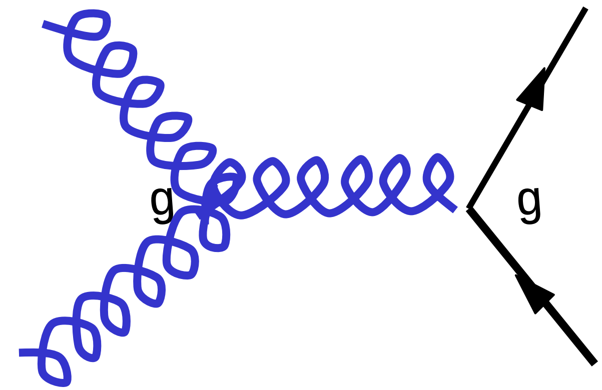


$$\frac{d\sigma}{d(\cos\vartheta)_{cm}} = \sum_{color} \sum_{flavor} \iint dxdy\ q(x)\bar{q}(y) \frac{g^4}{32\pi xys}(1+\cos^2\vartheta)$$

This is just one example: In general, "partonic cross section" (including partonic flux factor) goes to the right of the appropriate parton distributions.

Many Different Processes at lowest order contribute to q $\bar{q}$ production





At 2 TeV qq production dominated by qq initial state but at 14 TeV gg dominates because of evolution of q(x) g(x) so at the LHC (14 TeV) will collide protons and protons whereas at the Tevatron it is protons and antiprotons

Tevatron 2 GeV

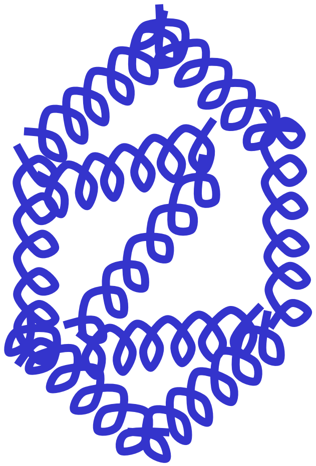
Quark -antiquark collider

LHC 14 TeV

Gluon collider

Glueballs

It is possible that a particle made entirely of gluons could exist



Search for presence in e+e- collisions and absence in photon - photon collisions since photon does not couple to gluons but does to quarks

Several Candidates but no clear evidence yet