Top Quark Production and Decay (Theory)

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I. Motivation

II. Top strong interactions

III. Top weak interactions

I. Motivation

Why study the top quark?

1. Is the top quark just an ordinary quark, or is it exotic in some way?

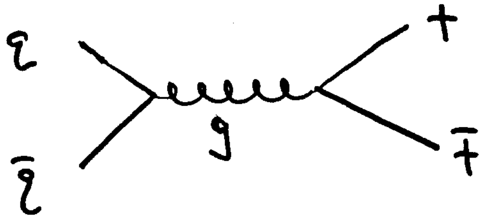
2. Top may be useful to discover new particles (e.g., $p\bar{p} \to t\bar{t}h$)

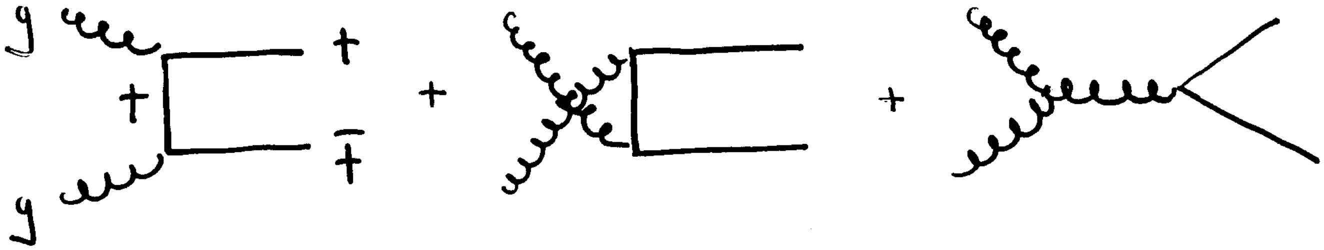
3. Top is a background to almost everything else (e.g. $h \to W^+W^-$)

<u>Strategy</u>: get to know the top quark by measuring everything about it

II. Top strong interactions

Top-quark production:

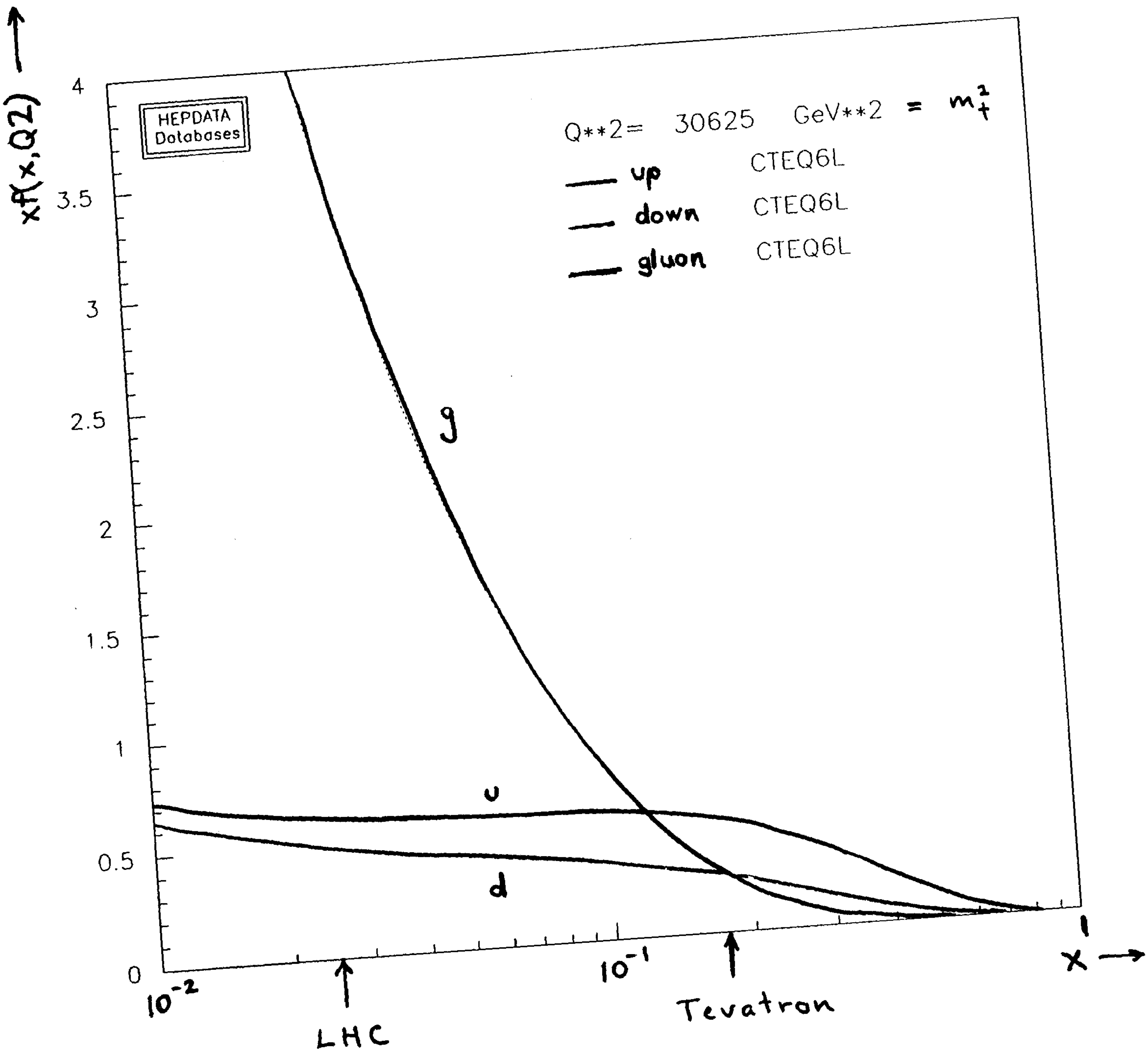




Predicted cross sections (NLO QCD) BCMN

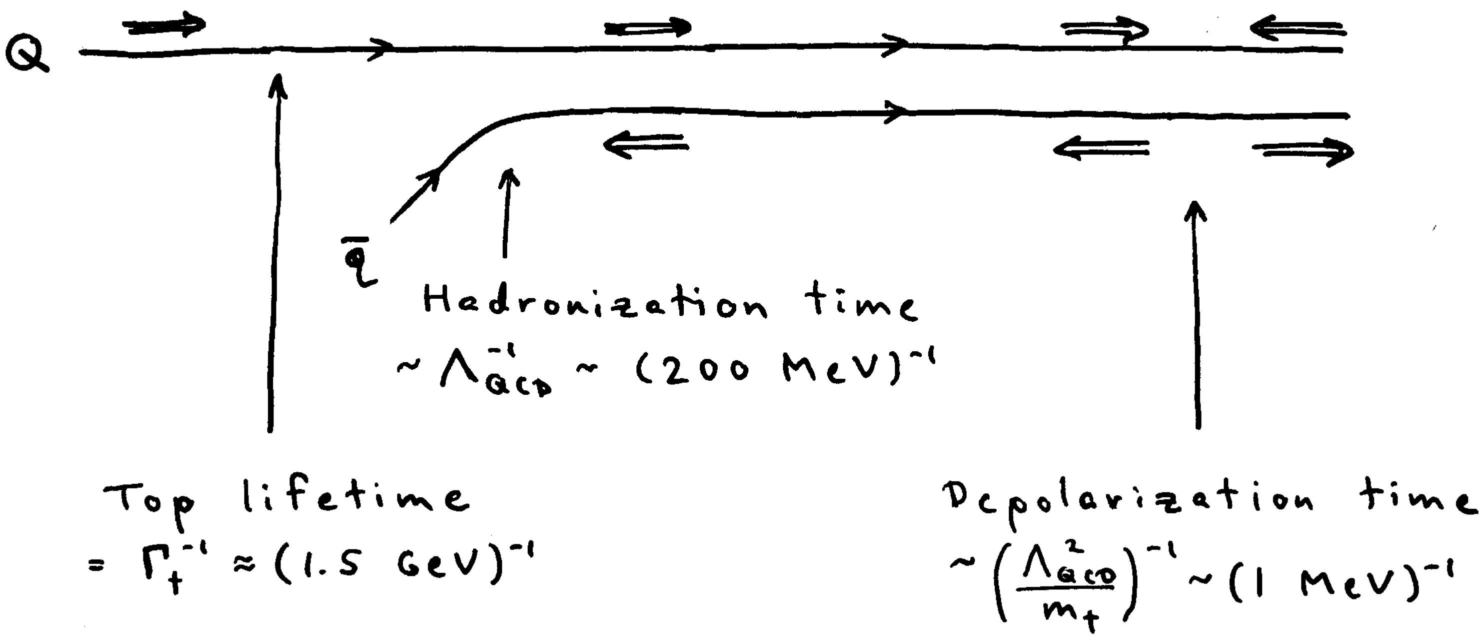
($m_t = 175$ GeV)

	σ_{NLO} (pb)	$q\bar{q} \to t\bar{t}$	$gg \to t\bar{t}$
Tevatron ($\sqrt{s} = 1.8$ TeV $p\bar{p}$)	4.87 ± 10%	90%	10%
Tevatron ($\sqrt{s} = 2.0$ TeV $p\bar{p}$)	6.70 ± 10%	85%	15%
LHC ($\sqrt{s} = 14$ TeV pp)	803 ± 15%	10%	90%



typical $x \sim \frac{2 m_t}{\sqrt{S}}$

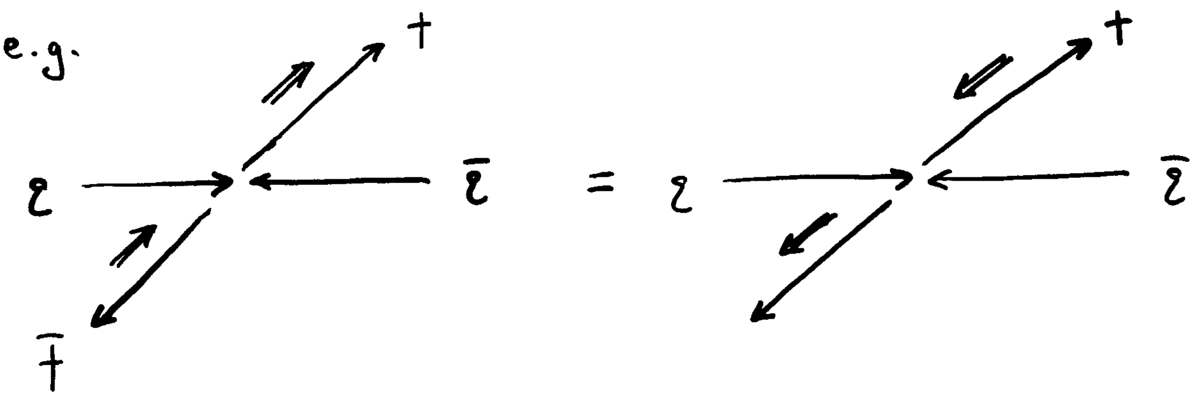
The top-quark spin is observable



Top decays well before there is time to depolarize its spin. BDKKZ

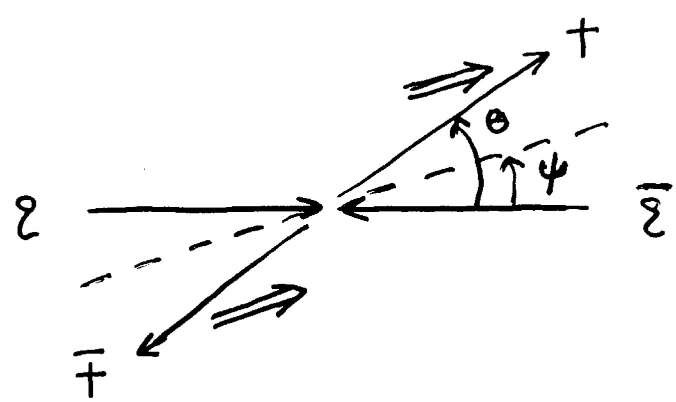
Unfortunately, QCD produces unpolarized top quarks (due to parity conservation):

e.g.



Fortunately, t and $\bar{t}$ spins are <u>correlated</u>

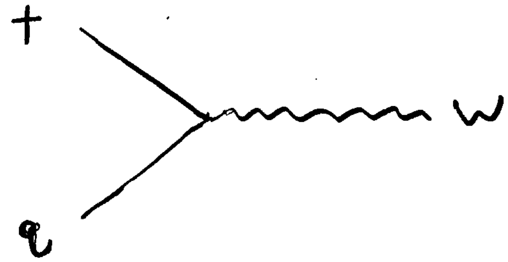
The correlation is 100% for $q\bar{q} \to t\bar{t}$ when a specific spin basis is chosen:



$$\tan\psi = \frac{\beta^2 \sin\theta \cos\theta}{1 - \beta^2 \sin^2\theta}$$

MP

III. Top weak interaction

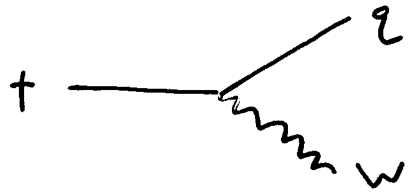


$$= -i\frac{g}{2\sqrt{2}}\,\gamma^{\mu}(1-\gamma_5)\,V_{tq}$$

↑ CKM matrix element

$q = d, s, b$

Top-quark decay:



$$\propto |V_{tq}|^2$$

CDF has measured

$$\frac{BR(t\to Wb)}{BR(t\to Wq)} = 0.99 \pm 0.29$$

$$\parallel$$

$$\frac{|V_{tb}|^2}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2}$$

This implies $|V_{tb}| \gg |V_{td}|, |V_{ts}|$

If you <u>assume</u> 3 generations, then CKM unitarity implies

$$|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 = 1$$

Thus

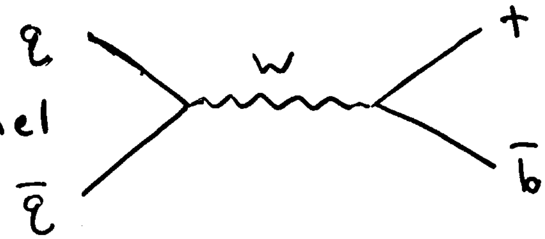
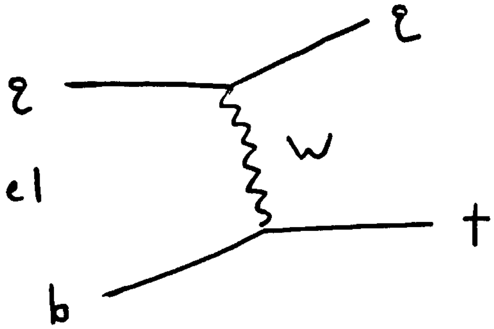
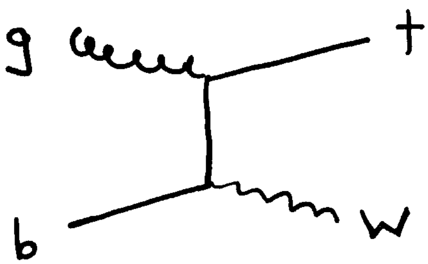
$$|V_{tb}| = 0.99 \pm 0.15 \qquad (3 \text{ gen})$$

Consistent with

$$V_{ij} = \begin{pmatrix} V_{ud} & V_{us} & 0.002 - 0.005 \\ V_{cd} & V_{cs} & 0.037 - 0.043 \\ V_{td} & V_{ts} & 0.9990 - 0.9993 \end{pmatrix} \begin{matrix} \leftarrow V_{ub} \\ \leftarrow V_{cb} \\ \leftarrow V_{tb} \end{matrix}$$

(3 gen) ↑ third column

Top-quark production via the weak interaction (Single top production) measures $|V_{tb}|$ directly: $\sigma \propto |V_{tb}|^2$

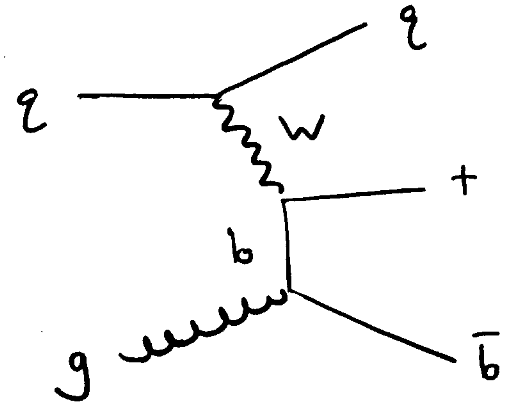
		Tevatron	LHC
-channel		0.90	10.6
hannel		2.1	250
Nt		0.1	75

These are predicted cross sections (pb)

(NLO QCD) SSW

	Tevatron	LHC
Compare $\sigma(t\bar{t})$	6.7	800

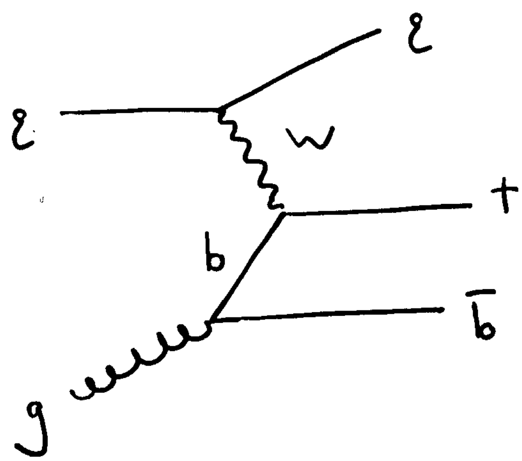
More on t-channel single top:



"W-gluon fusion"

This is correct LO subprocess if $\bar{b}$ is at high p_T.

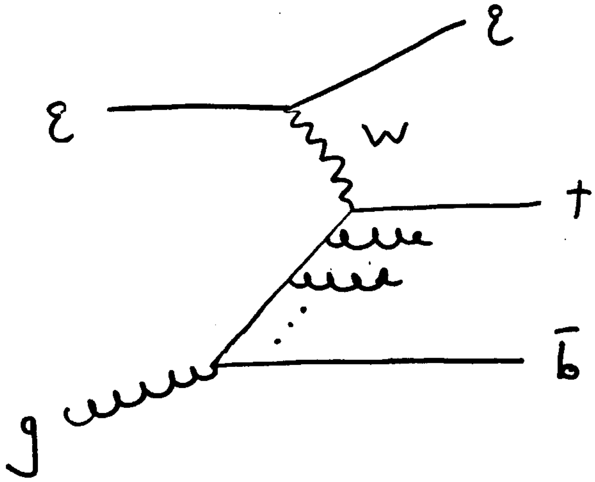
If we integrate over all p_T of the $\bar{b}$ we obtain a collinear enhancement:



$\sim \alpha_s \ln \frac{m_t^2}{m_b^2}$

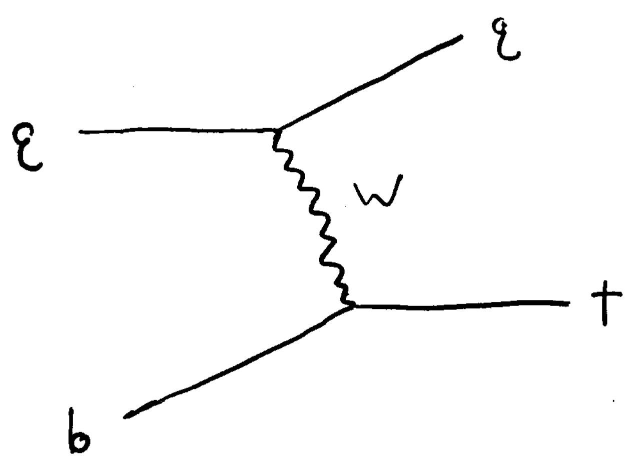
This is desirable but...

... it also makes perturbation theory less convergent:



$$\sim \alpha_s^n \ln^n \frac{m_t^2}{m_b^2}$$

Solution: Use DGLAP equations to sum enhanced terms to all orders into a b distribution function:



↳ Like any other PDF <u>except</u> it is perturbatively calculable. ACOT

Initial condition: $b(x, \mu^2 = m_b^2) = 0$ $(\overline{MS})$

Use DGLAP equations to calculate

$b(x, \mu^2)$ for $\mu^2 > m_b^2$.

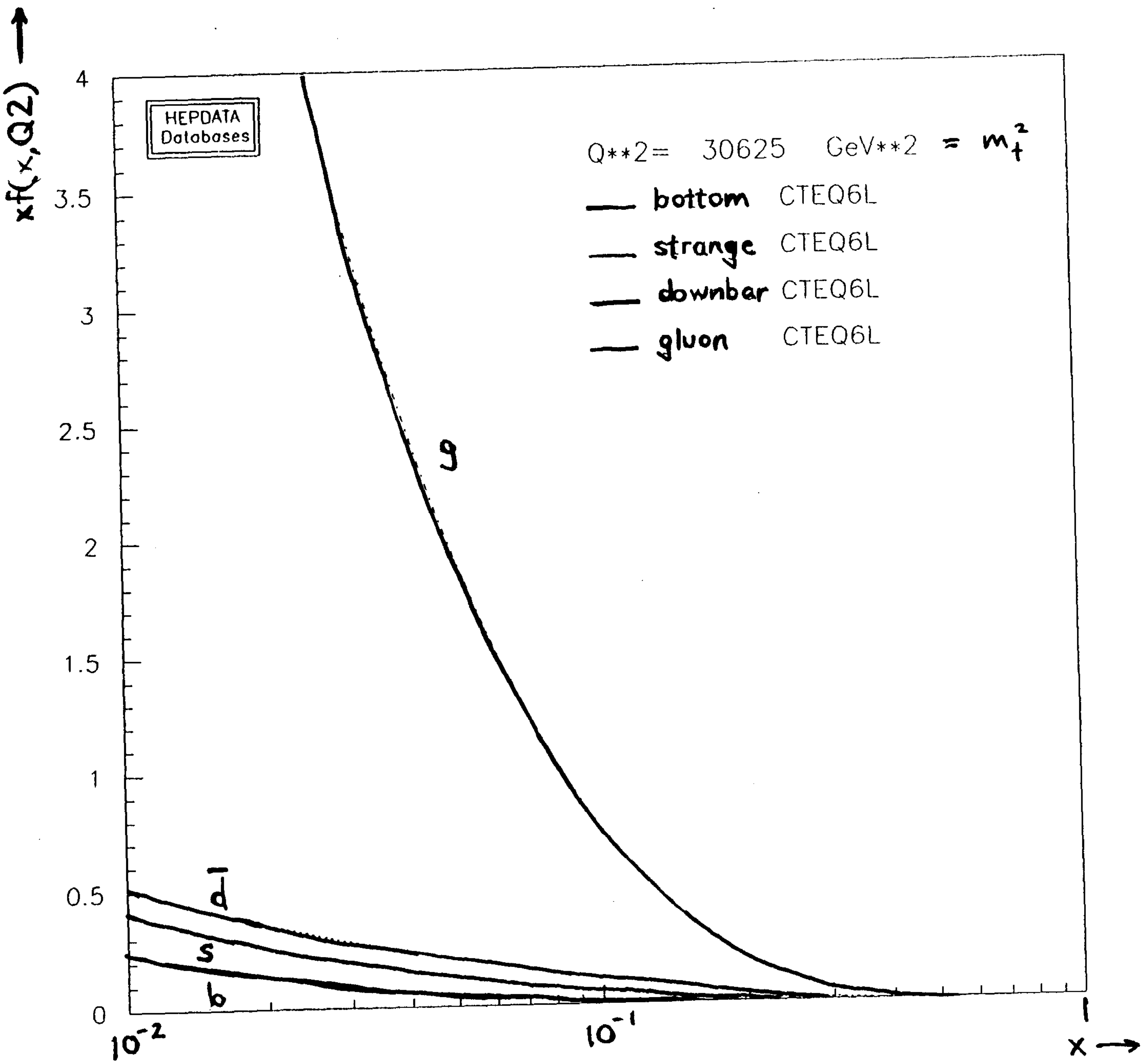
Power counting: Crude solution to

DGLAP equations is

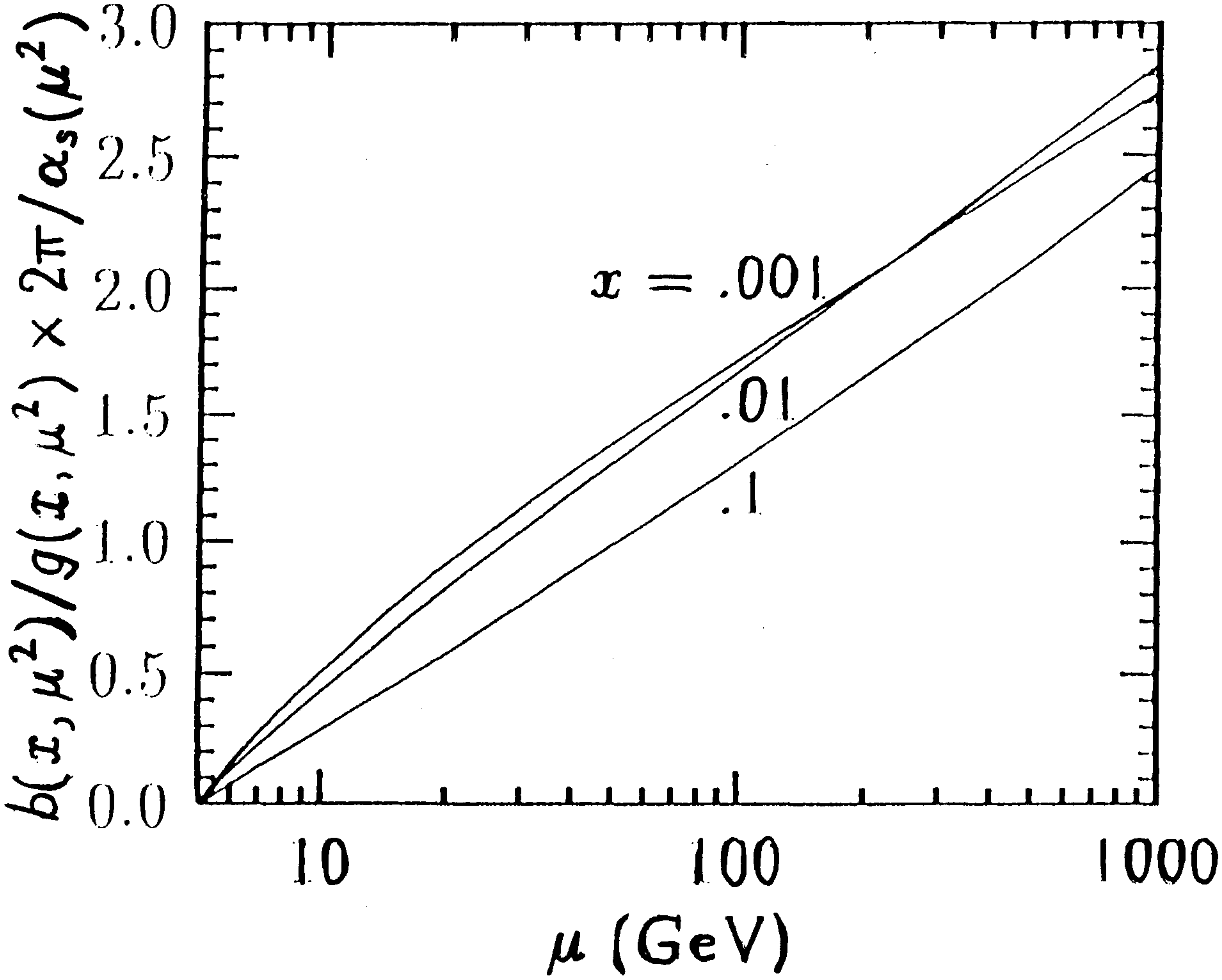
$$b(x, \mu^2) = \frac{\alpha_s(\mu^2)}{2\pi} \ln \frac{\mu^2}{m_b^2} \, g(x, \mu^2)$$

so b distribution function is intrinsically

$\mathcal{O}\left(\alpha_s \ln \frac{\mu^2}{m_b^2}\right)$



HEPDATA Databases
Q**2= 30625 GeV**2 = m_t^2
bottom CTEQ6L
strange CTEQ6L
downbar CTEQ6L
gluon CTEQ6L
g
$\bar{d}$
s
b
xf(x,Q2)
4
3.5
3
2.5
2
1.5
1
0.5
0
10^{-2}
10^{-1}
1
x

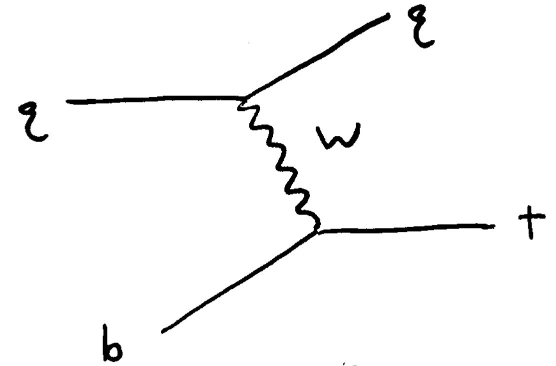


The ratio of the b distribution function to the gluon distribution function, times $2\pi/\alpha_s(\mu^2)$, versus the factorization scale μ, for various fixed values of x. The curves are approximately linear when μ is plotted on a logarithmic scale, indicating that $b(x,\mu^2) \propto [\alpha_s(\mu^2)/2\pi]\ln(\mu^2/m_b^2)g(x,\mu^2)$, as suggested by the approximation of Eq. (1).

SSW

Power counting:

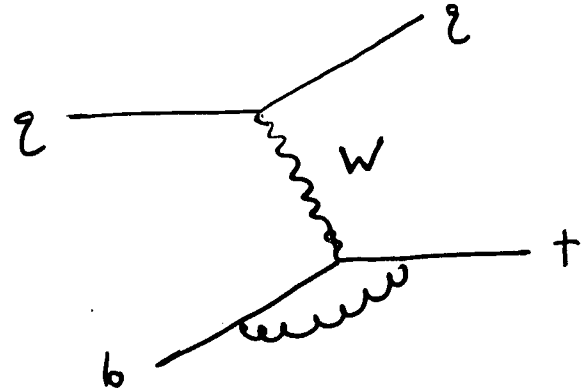
LO:



$\sim \alpha_s \ln \frac{m_t^2}{m_b^2}$

$\uparrow\!\!\!\lrcorner$ $\alpha_s \ln \frac{m_t^2}{m_b^2}$

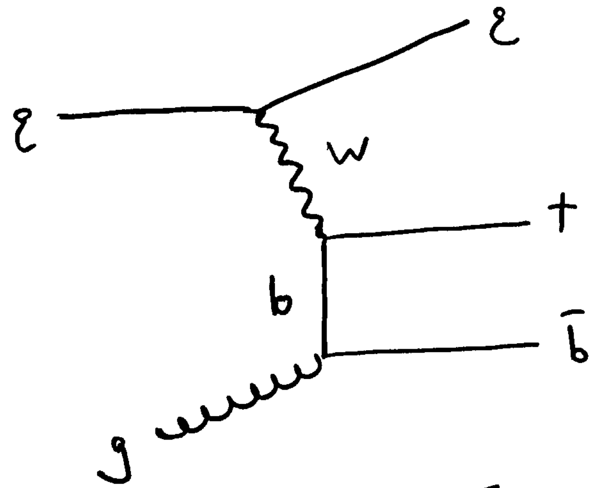
NLO:



$\sim \alpha_s$ correction

$$\alpha_s(m_t^2) \sim \frac{1}{\ln \frac{m_t^2}{\Lambda_{QCD}^2}}$$

NLO:



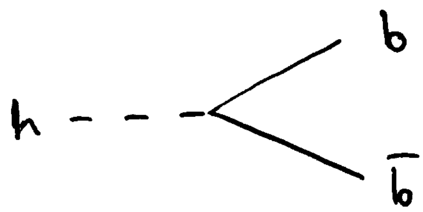
minus collinear enhancement

$$\sim \alpha_s \cancel{\ln \frac{m_t^2}{m_b^2}} + \alpha_s$$

$\uparrow$ $\frac{1}{\ln \frac{m_t^2}{m_b^2}}$ relative to LO

SSW

Excercise: The Higgs boson couples to bottom quarks:



Draw the LO Feynman diagrams for these three processes:

1. $p\bar{p} \to h + X$
2. $p\bar{p} \to hb + X$
3. $p\bar{p} \to hb\bar{b} + X$

where the b quarks are at high p_T.

Estimate the size of processes 2. and 3. relative to 1. (power counting)

CEMW

Selected references

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