Answers to Homework II

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1 Question 3

1.1 Q1

I downloaded the data from `http://hepdata.cedar.ac.uk/pdf/pdf3.html`. I used group CTEQ45 and set cteq5m. I used $Q^2 = 100\mathrm{GeV}^2$. I chose particle type all to get PDFs for $u, \bar{u}, d, \bar{d}, s, c, b, g$. The site did not have information on $\bar{s}, \bar{c}, \bar{b}$ so I assume they have the same PDFs as their antiparticles. Virtual particles are created in particle-antiparticle pairs. The PDFs, $f(x, Q^2)$, were given as $g(x, Q^2) = xf(x, Q^2)$. Integrating these functions gives the mean energy fraction for that particle type.

$$\frac{E_i}{E_{proton}} = \int_0^1 xf_i(x, Q^2)\mathrm{d}x = \int_0^1 g_i(x, Q^2)\mathrm{d}x \tag{1}$$

This has been calculated numerically and the result is seen in Table 1.
Integrating $f_i(x, Q^2)$ gives the number of particle i present in the proton. But this diverges in the low energy limit. What can be calculated instead is the asymetry in number between particle and antiparticle.

$$n_i = \int_0^1 x(g_i(x, Q^2) - g_{\bar{i}}(x, Q^2))\mathrm{d}x \tag{2}$$

This is 0 by assumption for s, c, b but not for u, d. This has been calculated numerically and the result is seen in Table 1. The total charge and energy has been calculated using this and the result is seen in Table 1. My code for the numerical calculations is available at `https://github.com/kpws/StandardModel`.

1.2 Q2

I varied the value of Q^2 and the results are seen in Table 2, 3, 1, 4. The results are the same but the precision of the numerical integral goes down as the PDFs become more peaked at lower energy for the high Q^2-values.

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Table 1: Results for $Q^2 = 100\text{GeV}^2$

Parton	t asymmetry	Charge contribution	Energy contribution
u	1.9993	1.3329	0.2601
d	1.0059	-0.3353	0.1308
$\bar{u}$	-	-	0.0323
$\bar{d}$	-	-	0.0392
$s, \bar{s}$	-	-	0.0249
$c, \bar{c}$	-	-	0.0147
$b, \bar{b}$	-	-	0.0049
g	-	-	0.4615
Total	3.0052	0.9976	1.0129

Table 2: Results for $Q^2 = 0.001\text{GeV}^2$

Parton	t asymmetry	Charge contribution	Energy contribution
u	1.9999	1.3332	0.3791
d	1.0004	-0.3335	0.1769
$\bar{u}$	-	-	0.0229
$\bar{d}$	-	-	0.0337
$s, \bar{s}$	-	-	0.0113
$c, \bar{c}$	-	-	0.0000
$b, \bar{b}$	-	-	0.0000
g	-	-	0.3654
Total	3.0003	0.9998	1.0006

1.3 Q3

The antiproton is the antiparticle to the proton. The PDFs are the same but for the antiparticles of the partons. So the u PDF is that of $\bar{u}$ and so on.
The u and d-quarks have similar masses and the electromagnetic interaction is weak compared to the strong interaction which is isospin invariant. $u, \bar{u}$ and $d, \bar{d}$ can then be interchanged assuming isospin invariance and the neutron PDFs are obtained.

2 Question 4

The integral in the handwritten notes has been calculated numerically for different invariant masses and proton-proton center of mass energy. The result is seen in Figure 1. My code for this is available at `https://github.com/kpws/StandardModel`.

3 Question 5

They have been looking for extra Z bosons by colliding protons with 8 TeV center of mass energy. They have measured what I plotted in 1. They took more processes into account. They could exclude two models from having extra Z bosons of masses below about 2.4 TeV at confidence level 95 %.

Table 3: Results for $Q^2 = 1\text{GeV}^2$

Parton	t asymmetry	Charge contribution	Energy contribution
u	1.9999	1.3332	0.3791
d	1.0004	-0.3335	0.1769
$\bar{u}$	-	-	0.0229
$\bar{d}$	-	-	0.0337
$s, \bar{s}$	-	-	0.0113
$c, \bar{c}$	-	-	0.0000
$b, \bar{b}$	-	-	0.0000
g	-	-	0.3654
Total	3.0003	0.9998	1.0006

Table 4: Results for $Q^2 = 10000\text{GeV}^2$

Parton	t asymmetry	Charge contribution	Energy contribution
u	1.9991	1.3327	0.2210
d	0.9997	-0.3332	0.1151
$\bar{u}$	-	-	0.0356
$\bar{d}$	-	-	0.0412
$s, \bar{s}$	-	-	0.0295
$c, \bar{c}$	-	-	0.0213
$b, \bar{b}$	-	-	0.0132
g	-	-	0.4763
Total	2.9988	0.9995	1.0173

If I were to search for an extra Z boson, then I would calculate the differential cross-section as above but with an extra contribution in M. This would give an extra peak that could be searched for in the experimental data. I would calculate how high this peak would be for different masses and then try to exclude it from existing over all measureable masses. I would try to exclude the standard model if it is impossible to exclude the boson at one of the measureable masses.

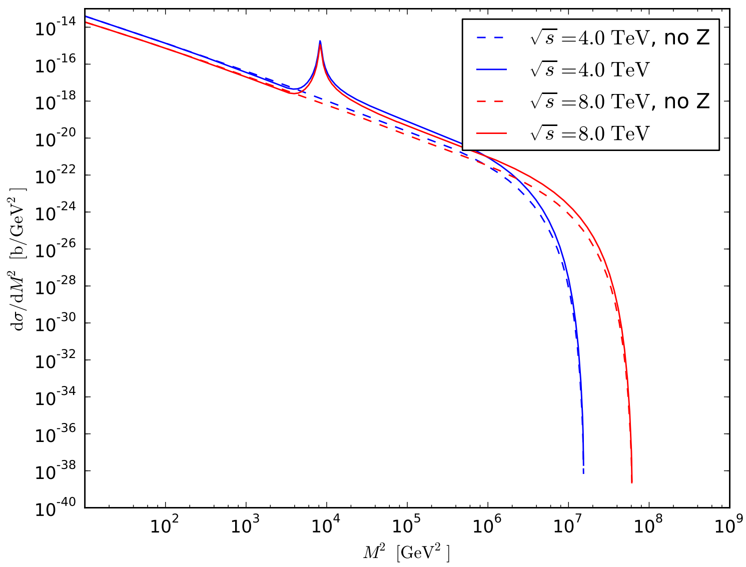

Figure 1: Differential cross-section calculated by numerical integration.