Notes for the DIS deuteron code

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(Dated: May 31, 2011)

The code comes with a makefile. Run `make` in a shell in the dir where you unpacked everything to compile the code. The code is mainly written in c++ but also uses some fortran routines for structure function parametrizations, so both `g++` and `gfortran` should be present as well as the `libgfortran` library to link everything. After compiling you will have two executables: `dis` which runs the semi-inclusive code, and `inclusive` which runs the inclusive code. There is also a subdir `grids` which contains grids needed in the structure function parametrizations. This subdir can be anywhere, but in the same dir as the executables is easiest.

I. SEMI-INCLUSIVE CODE

A. Deeps-like output

The semi-inclusive code can be run in two different modes. The first calculates the $F_{2N}P(\vec{p}_r)$ variable that the Deeps experiment presented in their analysis. A typical commandline looks like this:

```
./dis 0 0 5.765 1.8 2.02 0.39 0 0 3 50. 6. -0.5 /home/wim/DeuteronDIS/
```

We now give an overview of all the extra parameters

- The first parameter controls the output mode of the code. 0 for Deeps-like output, 1 for differential cross section (see below), all other values are illegal. This corresponds with the `calc` variable in the code.
- DIS on a neutron with spectator proton (0) or DIS on a proton with spectator neutron (1).
- Incoming photon beam energy [GeV], taken 5.765 GeV here.
- Q^2 [GeV^2], taken 1.8 in this example.
- Invariant mass W of the produced X [GeV]. This is equal to $(p_D + q - p_r)^2$, taken 2.02 GeV here.
- Spectator proton momentum [GeV], taken 0.39 in this example.
- Structure function parametrization. Possible values are 0 (SLAC parametrization), 1 (Christy & Bosted parametrization), 2 (leading twist parametrization of Alekhin et al.). We used the SLAC parametrization in our calculations (0).
- Deuteron wave function parametrization. Possible values 0 (Paris), 1 (AV18), 2 (CDBonn), 3 (AV18b). We used the Paris wave function in our calculations (0).
- Parametrization of the off-shell rescattering amplitude. 0 and 1 are unused for now, 2 provides an off-shell amplitude with an "off-shell" slope parameter β_{off} (see article for details), 3 is the no off-shell approach (off-shell amplitude=0), 4 is full off-shell (off-shell amplitude is equal to on-shell one). This corresponds with the `offshellset` variable in the code.
- The next three parameters are the total cross section σ, slope parameter β and real to imaginary ratio ϵ which enter in the rescattering amplitude of the FSI. One exception is when you take the fitted off-shell description (`offsheelset=2`), then the last parameter is NOT ϵ but β_{off}. We always take $\epsilon = -0.5$, the other parameters can vary with Q^2 and W and have been fitted to the Deeps data (see below).
- The last parameter contains the dir where the `grids` subdir is located.

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If you run the code, it loops in $\cos(\theta_r)$ of the spectator nucleon and gives as output three values: $\cos(\theta_r)$, $F_{2N}P(\vec{p}_r)$[plane-wave], $F_{2N}P(\vec{p}_r)$[total]. With the abovementioned commandoline output should look like this:

```
-0.975 0.0051405 0.0044025
-0.875 0.00560821 0.00482728
-0.775 0.00607399 0.0052306
-0.675 0.00653777 0.00560213
-0.575 0.0069993 0.00593683
-0.475 0.00745822 0.0062444
-0.375 0.00791406 0.00656754
-0.275 0.00836625 0.00701061
-0.175 0.00881418 0.00780517
-0.075 0.00925716 0.00942106
0.025 0.00969448 0.0128009
0.125 0.0101254 0.0197046
0.225 0.0105491 0.0313713
0.325 0.0109649 0.0381944
0.425 0.0113719 0.0406888
0.525 0.0117692 0.0433651
0.625 0.0121561 0.0462745
0.725 0.0125315 0.0493692
0.825 0.0128947 0.0526033
0.925 0.0132447 0.0559301
```

B. Differential cross section output

The second mode in which the code can be run gives differential cross sections [nb/GeV^4] as outputs and has a commandline like this

```
./dis 1 0 5.765 1.8 0.5 0.39 0 0 3 50. 6. -0.5 /home/wim/DeuteronDIS/ 50
```

All the parameters are the same as before except:

- The first parameter has to be 1.
- The fifth parameter which was the invariant mass W before is now the Bjorken x value, taken here 0.5.
- An extra parameter is present which denotes the ϕ value of the spectator nucleon [degr], taken 50° here.

The code loops over θ_r this time and output should look like this

```
 0 1.3033 5.64787
10 1.34374 5.79686
20 1.35923 5.77704
30 1.34058 5.56111
40 1.27002 5.09742
50 1.16061 4.47121
60 1.29457 4.78634
70 0.955048 3.38557
80 0.859496 1.91691
90 0.554618 0.64423
100 0.387314 0.338937
110 0.4461 0.370758
120 0.00903617 0.00762684
130 0 0
140 0 0
150 0 0
160 0 0
170 0 0
180 0 0
```

With θ_r[degr] in the first column, plane-wave differential cross section in the second and the full differential cross section in the third.

C. Fits

For every Q^2, W value in the Deeps experiment, we fitted one or more parameters in the rescattering amplitude. Either σ or σ, β were taken as free parameters. In the `offshellset=2` case, $\beta_{\rm off}$ was taken as an extra free parameter. ϵ was always fixed at 0.5, if β was fixed, the value 8 GeV^{-2} was adopted. The values of the fit are included in the files `fitoffshell.14.dat` (`offshellset=2`), `nooffshell.14.dat` (`offshellset=3`), `fulloffshell.14.dat` (`offshellset=4`). Columns in the files are as follows:

- Q^2 value. 0 for 1.8 GeV^2, 1 for 1.8 GeV^2
- W value. [1.25, 1.5, 1.73, 2.02, 2.4]
- σ [mb] value for fit with fixed $\beta = 8$GeV^{-2} and $\epsilon = -0.5$. [Extra column in the `fitoffshell.14.dat` for the $\beta_{\rm off}$ parameter].
- χ^2 value of this first fit.
- σ [mb] and β [GeV^{-2}] value for fit with only fixed $\epsilon = -0.5$.[Extra column in the `fitoffshell.14.dat` for the $\beta_{\rm off}$ parameter].
- χ^2 value of this second fit.

II. INCLUSIVE CODE

The inclusive code is based on the semi-inclusive one and can also be run in two modes. The FSI part of the code has not been included for now, because it is still in development.

A. Cross section mode

The output in this mode is the differential cross section for the inclusive process [nb/GeV]. A typical commandline looks like

```
./inclusive 0 12. 5. 0.29 2 0 /home/wim/DeuteronDIS/
```

Parameter breakdown:

- The first parameter controls the output mode of the code. 0 for cross section output, 1 for F_2 mode (see below), all other values are illegal. This corresponds with the `calc` variable in the code.
- Incoming photon beam energy [GeV], taken 12 GeV here.
- Q^2 [GeV^2], taken 5 in this example.
- Bjorken x, taken 0.29 here.
- Structure function parametrization. Possible values are 0 (SLAC parametrization), 1 (Christy & Bosted parametrization), 2 (leading twist parametrization of Alekhin et al.). We usually take the Alekhin parametrization here.
- Deuteron wave function parametrization. Possible values 0 (Paris), 1 (AV18), 2 (CDBonn), 3 (AV18b). We used the Paris wave function in our calculations (0).
- The last parameter contains the dir where the `grids` subdir is located.

Output for this commandline looks like this

```
12 5 0.29 0.000584512 3.07638 3.07696
```

Values are incoming beam energy, Q^2, x, quasi-elastic plane-wave contribution [nb/GeV], DIS plane-wave contribution [nb/GeV], sum.

B. F_2 mode

The output in this mode is the ratio of $F_{2D}/F_{2N} + F_{2P}$, with F_{2D} the inclusive structure function of the deuteron. A typical commandline looks like

```
./inclusive 1 12. 5. 0.29 2 0 /home/wim/DeuteronDIS/
```

Completely the same as in the previous case, except the first parameter is 1. Output looks like

```
12 5 0.29 0.00157639 0.993707 0.995283
```

Values are incoming beam energy, Q^2, x, quasi-elastic plane-wave ratio (normalized in the same way as F_{2D}) [nb/GeV], DIS plane-wave ratio [nb/GeV], sum.