Fantomas4xFitter manual

November 12, 2024

1 Installing Fantomas4xFitter

To download the Fantômas module for xFitter follow the steps below:

1. Download the `2.2.0_FutureFreeze` branch from the `Fantomas4xFitter` github page: `https://github.com/lucaskotz/Fantomas4xFitter.git`. You can download via `Download zip` or `git clone`.
2. Build the Fantomas4xFitter directory. Use the command `./make.sh install` while in the main Fantomas4xFitter directory.

The Fantômas module is implemented in a way that you do not need to manually change anything to have xFitter recognize the parameterization class.

2 Running the Fantômas examples

We include several examples that are separated into different directories, showcasing the features unique to the Fantômas module. These examples are located in `examples/Fantomas` folder. The examples are based off the settings and data used in the π^+ fit from arXiv:2311.08447. The output for each example is also provided for each fit within each example.
Each example is run similarly to any other xFitter fit. Below are the steps to run the provided example `add_CP/fit1`. These steps may be extended to the other example fits outlined in the subsequent subsections:

1. Enter the example fit directory. Using fit1 of the `add_CP` example:

   ```
   cd examples/Fantomas/add_CP/fit1
   ```

2. Link datafiles to fit directory: While in the `add_CP/fit1` directory:

   ```
   ln -sf ../../../../datafiles .
   ```

3. Link the xFitter executable to fit directory: While in `add_CP/fit1` directory:

   ```
   ln -sf ../../../../bin/xfitter .
   ```

4. Run the xFitter executable within the `add_CP/fit1` directory:

   ```
   ./xfitter
   ```

5. Optional: Create figures from the fit output. First, create a link, similar to the xFitter executable and then run the executable. While in the `add_CP/fit1` directory:

   ```
   ln -sf ../../../../bin/xfitter-draw .
   ./xfitter-draw output
   ```

The steps above rely on the use of soft-linking the xFitter executable to each fit directory. This is to prevent the use of other xFitter executables the user may have installed. You may replace the use of soft-linking with alias by skipping step 3 above and using the following line:

```
alias xfitter /path/to/Fantomas4xFitter/bin/xfitter
```

This allows the user to skip step 3 subsequent fits as the line above only needs to be run once. Note that if you use `alias` instead of `ln -sf`, then you would use the command `xfitter` instead of `./xfitter` during step 4. The same can be applied to step 5 for `xfitter-draw`.

2.1 add_CP

This example, located at `examples/Fantomas/add_CP`, contains fits demonstrating the process of adding an additional control point to the metamorphs. The order of the metamorphs, defined by the parameters in `steering_fantomas.txt`, is the only input that differs in each of the fits in the `add_CP` example. Below, I discuss each fit in greater detail:

1. `fit1`: The three metamorphs have $N_{m,eff} = 0$, with two fixed control points at $x_{\text{CP1/2,FIX}} = 10^{-3}, 0.8$ and no free control points.

2. `fit2`: A free control point is added to each of the three metamorphs at $x_{\text{CP1,FREE}} = 0.4$, making $N_{m,eff} = 1$ with a total of 3 control points.

3. `fit3`: An additional free control point is added to the sea and valence metamorphs at $x_{\text{CP2,FREE}} = 0.6$, making $N_{m,eff} = 2$ for the sea and valence. The gluon remains a metamorph of $N_{m,eff} = 1$ as it does not have an additional control point.

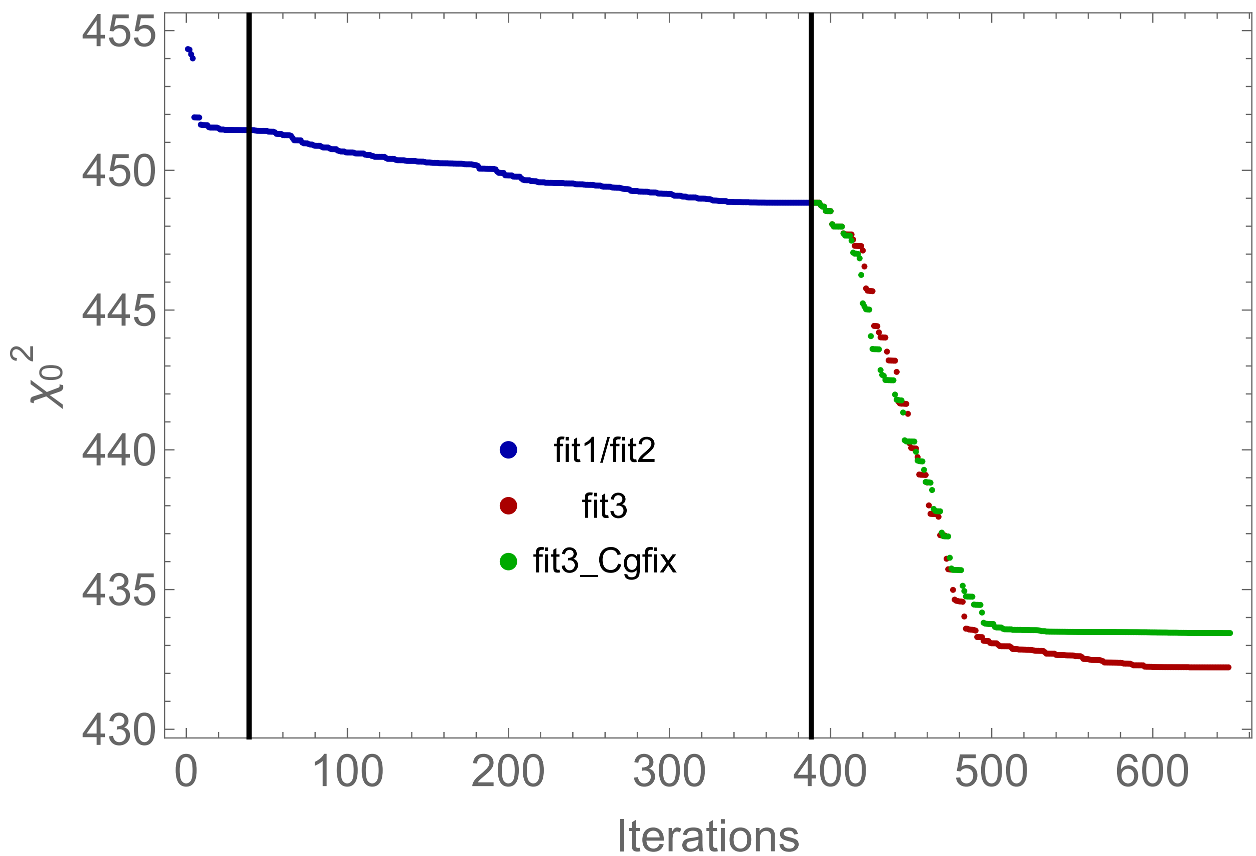

Figure 1: The evolution of χ_0^2 is presented for all four fits within in the example `add_CP`. The vertical black lines differentiate the χ_0^2 values from the various fits. The first one separates `fit1`(Blue) from `fit2`(Blue) and the second line separates fit2 from `fit3`(Red) and `fit3_Cgfix`(Green).

4. `fit3_Cgfix`: Like `fit3`, this fit uses $N_{m,\text{eff}} = 2$ for the sea and valence and $N_{m,\text{eff}} = 1$ for the gluon. The key difference is that in `fit3_Cgfix`, C_g is fixed at $C_g = 2.133$, a value obtained from `fit2`. The χ^2 curve for C_g is notably flat, complicating convergence in `fit3` due to the high number of free parameters (12) in xFitter. By fixing C_g in `fit3_Cgfix`, convergence is successfully achieved.

In addition to demonstrating the procedure for adding control points to metamorph parameterizations, this example illustrates the evolution of the best fit over successive iterations. We print out the χ^2 quoted by `xFitter` when an improvement in χ^2 is detected, which we call χ_0^2. The list of χ_0^2 values was taken from each fit within this example to portray how χ_0^2 evolves over iterations as seen in Fig. 1.

2.2 alpha_x

This example contains two fits to demonstrate the effect α_x inside the modulator function has on the overall fit. The two fits included define the sea and valence metamorphs as a

$N_{m,eff} = 2$ with $x_{\mathrm{CP1/2,FREE}} = 0.2, 0.4$ and $x_{\mathrm{CP1,FIX}} = 10^{-3}, 0.8$. The gluon metamorph is defined with $N_{m,eff} = 0$ with $x_{\mathrm{CP1,FIX}} = 10^{-3}, 0.8$.
The differences between the fits are outlined below:

1. `fit1`: $\alpha_x = 0.3$ by setting `xPower` within the Fantômas steering card for each flavor.
2. `fit2`: $\alpha_x = 1.$ by setting `xPower` within the Fantômas steering card for each flavor.

3 Input files

Each of the examples contains the necessary input files to run xFitter:

- `steering_fantomas.txt`: Contains the initial parameters used to create the metamorphs.
- `parameters.yaml`: Existing xFitter input file. Requires the user to define flavor ID and parameters passed into metamorphs. The flavor ID used in this file must match the ones defined within `steering_fantomas.txt`.
- `steering.txt`: Standard xFitter steering card file.
- `constants.yaml`: Contains the physical constraints used in the analysis.

4 Output files

Along with the new input files, there are four new output files introduced in the xFitter output file.

1. `output/fantomas_functional_parameters.txt`: Contains the full metamorph functional form of each PDF flavor central fit along with the momentum fraction.
2. `output/steering_fantomas_out.txt`: Contains the updated metamorph parameters after xFitter finds the best fit for each PDF.
3. `output/fantomas_error_log.txt`: This file will contain all error messages that arise within the Fantômas module. The errors include:
   (a) **Condition number**: A message will appear quoting the condition number of the matrix containing the positions of the control point. It is encouraged to keep this number as low as possible by spreading the control points from each other. Note: the magnitude of the condition number will increase with more control points.
   (b) **Non-integrable metamorphs**: There will be a warning that appears if it is detected that the metamorph is non-integrable based off the conditions:

$$
\begin{aligned}
Sc(1) &< -n_{\mathrm{Mellin}} + \epsilon \\
Sc(2) &< -n_{\mathrm{Mellin}} + \epsilon
\end{aligned} \tag{1}
$$

where $Sc(1/2)$ are the low-/high-x power in the carrier function, n_{Mellin} is the n-th Mellin moment use in the xFitter calculation, and $\epsilon = 0.07$ to avoid instabilities in the integration method at x^{-1} and $(1-x)^{-1}$.

4. `output/fantomas_chi2.log`: This file contains all the χ^2 values from xFitter fitting process when there is an improvement in χ^2.

4.1 Best fit parameters

4.1.1 add_CP

The χ_0^2 is quoted for each fit within this example in Fig. 1.

	χ_0^2	d.o.f.	χ_0^2/d.o.f.
fit1	451.44	401	1.126
fit2	448.84	398	1.128
fit3	432.22	396	1.091
fit3_Cgfix	433.44	397	1.092

Table 1: χ_0^2, degrees of freedom, and χ_0^2/d.o.f. values for all four fits within `add_CP` example.

The minuit δ parameters from `output/minuit.out.txt` are quoted for each fit within the `add_CP` example in Tab. 7 and 8. The metamorph parameters from `output/steering_fantomas_out.txt` are quoted in Tab. 10 and 9.

	A_s	δB_g	δB_s	δB_v
fit1	10 ± 8.0	$0. \pm 0.2$	$0. \pm 0.3$	-0.02 ± 0.03
fit2	1.0 ± 0.8	-0.2 ± 0.4	-0.6 ± 0.3	-0.01 ± 0.04
fit3	1.1 ± 0.9	$0. \pm 1.$	0.1 ± 0.7	-0.3 ± 0.5
fit3_Cgfix	0.9 ± 0.4	-0.1 ± 0.3	$0. \pm 0.2$	-0.30 ± 0.09

	δC_g	δC_s	δC_v
fit1	$0. \pm 2.$	$0. \pm 2.$	0.02 ± 0.02
fit2	$-1 \pm 2.$	$0. \pm 2$	-0.05 ± 0.07
fit3	7.86 ± 0.05	$-4. \pm 1.$	-0.3 ± 0.8
fit3_Cgfix	$0.$	-4.3 ± 0.7	-0.3 ± 0.2

Table 2: Table containing the minuit carrier parameters and their errors located in `output/minuit.out.txt` for the example `add_CP`.

	δD_g	δD_s	δD_v	δE_g	δE_s	δE_v
fit1	0	0	0	0	0	0
fit2	0	0	0	$2. \pm 4.$	3.75 ± 0.05	0.06 ± 0.08
fit3	0	0	0	$-3. \pm 1.$	$0. \pm 1.$	-0.2 ± 0.9
fit3_Cgfix	0	0	0	$-2. \pm 2.$	0.07 ± 0.09	-0.2 ± 0.2

	δF_g	δF_s	δF_v	δG_g	δG_s	δG_v
fit1	n/a	n/a	n/a	n/a	n/a	n/a
fit2	0	0	0	n/a	n/a	n/a
fit3	0	$1. \pm 1.$	0.1 ± 0.5	n/a	0	0
fit3_Cgfix	0	0.46 ± 0.04	0.1 ± 0.2	n/a	0	0

Table 3: Table containing the minuit modulator parameters and their errors located in `output/minuit.out.txt` for the example `add_CP`.

	gluon – metamorph 0			sea – metamorph 1			valence – metamorph 2		
	$Sc(0)$	$Sc(1)$	$Sc(2)$	$Sc(0)$	$Sc(1)$	$Sc(2)$	$Sc(0)$	$Sc(1)$	$Sc(2)$
fit1	0.421	-0.374	2.826	9.796	0.733	8.187	2.542	0.743	0.952
fit2	0.123	-0559	2.133	1.025	0.182	8.039	2.361	0.730	.907
fit3	1.200	-0.192	9.999	1.093	0.246	3.754	1.219	0.398	0.562
fit3_Cgfix	0.096	-0.629	2.133	0.892	0.133	3.734	1.297	0.428	0.602

Table 4: The modulator parameters quoted by `output/steering_fantomas_out.txt` for all three metamorph cards rounded to the nearest thousandth place for the example `add_CP`.

	gluon – metamorph 0				sea – metamorph 1			
	$Sm0$	$Sm1$	$Sm2$	$Sm3$	$Sm0$	$Sm1$	$Sm2$	$Sm3$
fit1	FIX	FIX	n/a	n/a	FIX	FIX	n/a	n/a
fit2	FIX	1.730	FIX	n/a	FIX	1.730	**2.527**	FIX
fit3	FIX	-1.618	FIX	n/a	FIX	4.146	3.140	FIX
fit3_Cgfix	FIX	-0.499	FIX	n/a	FIX	3.816	2.989	FIX

	valence – metamorph 2			
	$Sm0$	$Sm1$	$Sm2$	$Sm3$
fit1	FIX	FIX	n/a	n/a
fit2	FIX	1.730	**0.0374**	FIX
fit3	FIX	-0.193	0.142	FIX
fit3_Cgfix	FIX	-0.145	0.135	FIX

Table 5: The carrier parameters quoted by `output/steering_fantomas_out.txt` for all three metamorph cards rounded to the nearest thousandth place for the example `add_CP`. The numbers in bold are the values from the `CALC` option, which calculates the value at a given point but does not use that point as a control point within the metamorph.

4.1.2 alpha_x

The χ_0^2 is quoted for each fit within this example in Fig. 6.

	χ_0^2	d.o.f.	χ_0^2/d.o.f.
fit1	441.46	397	1.112
fit2	443.40	397	1.117

Table 6: χ_0^2, degrees of freedom, and χ_0^2/d.o.f. values for all four fits within `alpha_x` example.

The minuit δ parameters from `output/minuit.out.txt` are quoted for each fit within the `alpha_x` example in Tab. 7 and 8. The metamorph parameters from `output/steering_fantomas_out.txt` are quoted in Tab. 10 and 9.

	A_s	δB_g	δB_s	δB_v	δC_g	δC_s	δC_v
fit1	11±1.0	0.01±0.2	0.2±0.2	0.09±0.07	7.14±0.03	0.±1.	0.96±0.05
fit2	0.25±0.02	0.	-1.03±0.04	-0.02±0.01	-20±30	-1.9±0.2	-0.07±0.03

Table 7: Table containing the minuit carrier parameters and their errors located in `output/minuit.out.txt` for the example `alpha_x`.

	δD_g	δD_s	δD_v	δE_g	δE_s	δE_v	δF_g	δF_s	δF_v
fit1	0	0	0	0	0.5 ± 0.5	-0.8 ± 0.2	n/a	-0.1 ± 0.4	-0.91 ± 0.08
fit2	0	0	0	0	4.3 ± 0.4	0.10 ± 0.02	n/a	$5. \pm 1.$	0.10 ± 0.01

	δG_g	δG_s	δG_v
fit1	n/a	0	0
fit2	n/a	0	0

Table 8: Table containing the minuit modulator parameters and their errors located in `output/minuit.out.txt` for the example `alpha_x`.

	gluon – metamorph 0			sea – metamorph 1			valence – metamorph 2		
	$Sc(0)$	$Sc(1)$	$Sc(2)$	$Sc(0)$	$Sc(1)$	$Sc(2)$	$Sc(0)$	$Sc(1)$	$Sc(2)$
fit1	0.567	-0.313	9.995	11.234	0.971	4.599	2.051	0.333	0.904
fit2	0.123	-0559	2.133	1.025	0.182	8.039	2.361	0.730	.907

Table 9: The modulator parameters quoted by `output/steering_fantomas_out.txt` for all three metamorph cards rounded to the nearest thousandth place for the example `alpha_x`.

	gluon – metamorph 0				sea – metamorph 1				valence – metamorph 2			
	$Sm0$	$Sm1$	$Sm2$	$Sm3$	$Sm0$	$Sm1$	$Sm2$	$Sm3$	$Sm0$	$Sm1$	$Sm2$	$Sm3$
fit1	FIX	FIX	n/a	n/a	FIX	0.481	-0.132	FIX	FIX	-0.739	-0.348	FIX
fit2	FIX	FIX	n/a	n/a	FIX	4.296	5.385	FIX	FIX	0.188	0.668	FIX

Table 10: The carrier parameters quoted by `output/steering_fantomas_out.txt` for all three metamorph cards rounded to the nearest thousandth place for the example `alpha_x`. The numbers in bold are the values from the `CALC` option, which calculates the value at a given point but does not use that point as a control point within the metamorph.