Preliminary Outcome of the FTF-Professor Fitting Exercise

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Geant4 Hadronic Group Meeting

July 25, 2018

Disclaimer

This is a VERY PRELIMINARY exercise.

Please do not take it for anything “larger” that it is.

The outcome should NOT be considered as a basis for any “major decision”.

General Information

- Motivation - experience from HAD validation activity
  - From time to time we see that what we consider as a model improvement gives good MC-data agreement in one area but then turns a degradation in some other areas
  - For at least 2 past releases we had to roll back FTF developments (better agreement with thin target data) because when included in a physics list(s) it was "giving bad showers"
- The idea of possibly applying fitting techniques, e.g. Professor, has been in the air for a while
- We had a discussion on this topic at the collaboration workshop 2017
  - Robert Hatcher pioneered such activity in Geant4, with respect to Bertini
- Recently expanded model configurability allows more flexibility and paves ways for applying fitting techniques, in a hope to be able to give developers a bit more numeric feedback than "works in one corner, jams in two others"

Professor Toolkit

- http://professor.hepforge.org
  - "Fundamentally, the idea of Professor is to reduce the exponentially expensive process of brute-force tuning to a scaling closer to a power law in the number of parameters, while allowing for massive parallelisation and systematically improving the scan results by use of a deterministic parameterisation of the generator's response to changes in the steering parameters." – from Professor's web site
  - A set of parameters $P_i=\{x_i , y_i , z_i ,...\}$ is a "point" in the multi-parameter space
  - Randomly sample multi-parameter space
    - For each P_i simulate data combinatorics: beam $\times$ energy $\times$ target …
    - Derived quantities are histograms
  - Each simulated (histogram) bin content is $f(P_i)$ - polynomial approximation
    - 3^{rd} order polynomial is a default
  - Fit experimental data with $f(P_i)$ to explore sensitivity and coupling of parameters

FTF-Professor Exercise (I)

- Only 3 FTF parameters + 1 switch (out of 18+4):
  - All these parameters are involved in modeling target nuclear destruction
  - The switch activates A-dependency of one of the parameters (as it was in 10.3.refXX)
  - 2 out of these 3 parameters seem to be “sensitive” (based on last year’s study)
  - (At least) 1 of them is believed to be the “blame” in the “thin target vs hadronic showers story”
- Only 9 datasets (references in backup materials)
  - Pion production by 5GeV/c proton on C or Pb from HARP
  - Proton production by 5GeV/c proton on C or Pb from ITEP771
  - Neutron production by 5GeV/c proton on C or Pb from ITEP771
  - Neutron production by 3GeV proton on C or Pb from IAEA/Ishibashi
  - Hadron production by 158GeV/c proton on C from NA49
    - Not much “sensitivity” of the MC results was expected
    - But it is more fair to ”balance” things up on the high energy end
    - Double diff. spectra are included only for secondary pions for the moment

FTF-Professor Exercise (II)

- Values of each of the 3 parameters was randomly selected within its validity range
  - The validity ranges are recommended by developers
- 25 groups of such randomly selected selected settings of parameters were used for each beam-momentum/energy-target simulation case
  - The switch is always the same, of course
- NOTE: In order to parameterize the MC output to a 3rd order polynomial in the 3-parameters space, Professor wants at least 20 groups of parameters (formula in backup materials); thus 25 is not a very large number but it is a valid one
- Geant4.10.4 is used in simulation as it is the first version that has official configuration interface to FTF
  - It will be the same with 10.4.p02 but I was already "set up" with 10.4…

Observations/Impressions (I)

- The fit converged (of sort ?)
  - Either because it was of a limited scope or perhaps because it was “meant” to converge ?
  - I personally would prefer it to be “meant to converge” !
- The ”best fit” values of the 3 parameters in the study are not very far from from their settings in 10.3.refXX and/or from “my expectations”
- So far these 3 parameters do not seem to be strongly correlated
  - However, the correlation matrix is not explicitly included in this report because the exact numbers may change if more parameters are included in the fit (in the future)
- Simulation reran with the “best fit” parameters, to benchmark outcome vs “default” results and vs exp.data

Observations/Impressions (II)

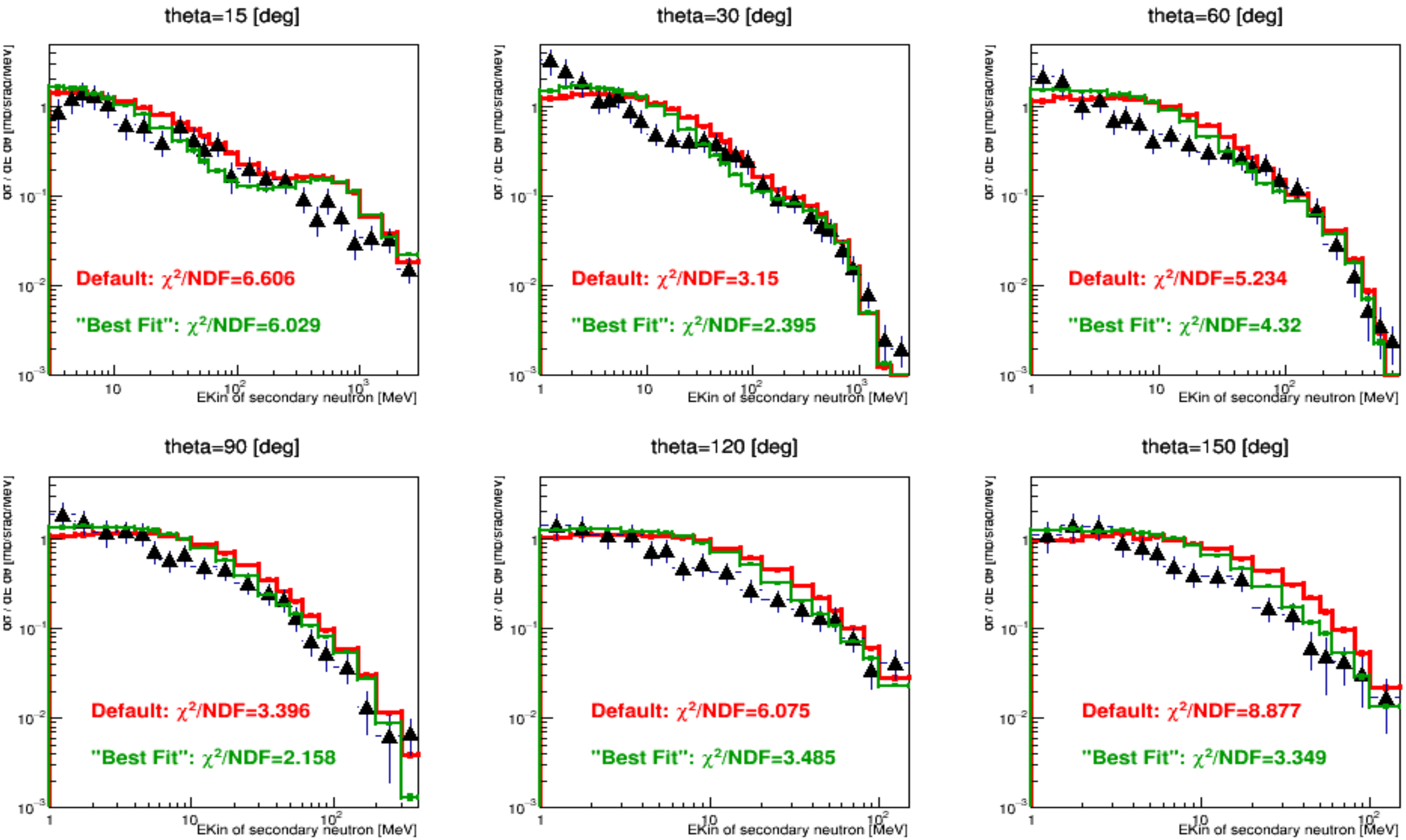
- Professor is not a "Magician"
- It will not always yield a 100% perfect MC-to-data agreement in every possible or impossible corner of the phase space
- In some areas the effects of Professor's "best fit" are quite mild
  - Regardless of whether the MC-to-data agreement is good or poor
- In some other areas Professor might "over do"
- But in a number of areas "best fit" will quite sharply move the MC towards the data…
- … so across the board there likely to be an improvement

Observations/Impressions (III)

- As anticipated, hadron production in proton+C at 158GeV/c is practically "immune" to the variations of the 3 parameters in study
  - The only exception is proton production
  - Plots in backup materials
- Production of protons, neutrons and even pions in proton-nucleus interactions at intermediate energies appears to be sensitive to the variations of these 3 parameters
  - The effect is larger for heavy targets
  - Selected plots included in the subsequent slides
  - Additional slides in backup
  - NOTE-1: green color in all the plots illustrate simulated results obtained with "best fit" parameters but it does not always mean that the "green" is better
  - NOTE-2: my apology if the font is some plots is tool small and/or for other possible imperfections

3GeV proton on C $\rightarrow$ neutron + X

Data: Ishibashi et al., J.Nucl.Sci.Tech. Vol.34 N.6, p.529-537 (1997)



Default FTF Parameters:

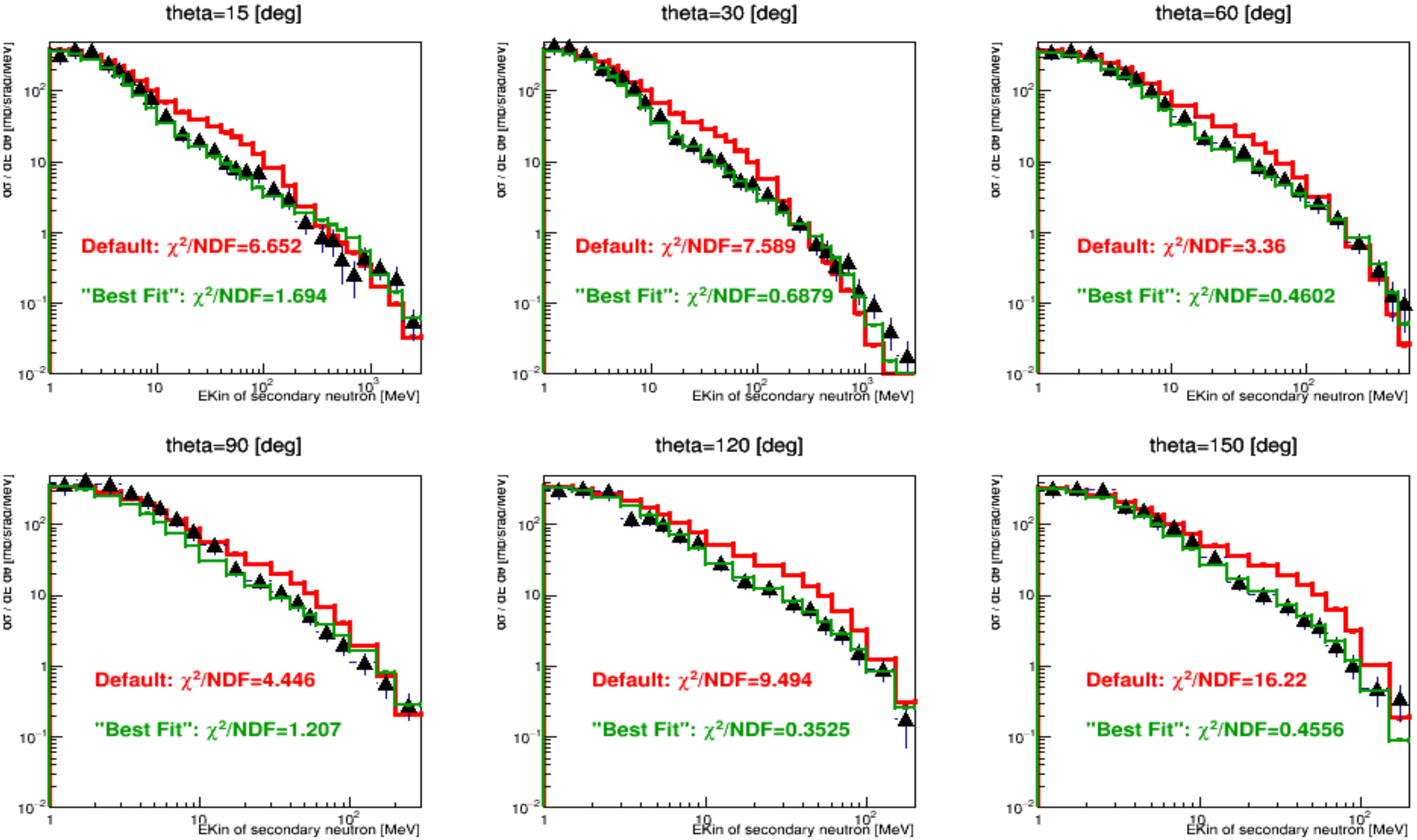
- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1
- Integral χ^2/NDF=5.36

"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996
- Integral χ^2/NDF=3.657

3GeV proton on Pb → neutron + X

Data: Ishibashi et al., J.Nucl.Sci.Tech. Vol.34 N.6, p.529-537 (1997)



Default FTF Parameters:

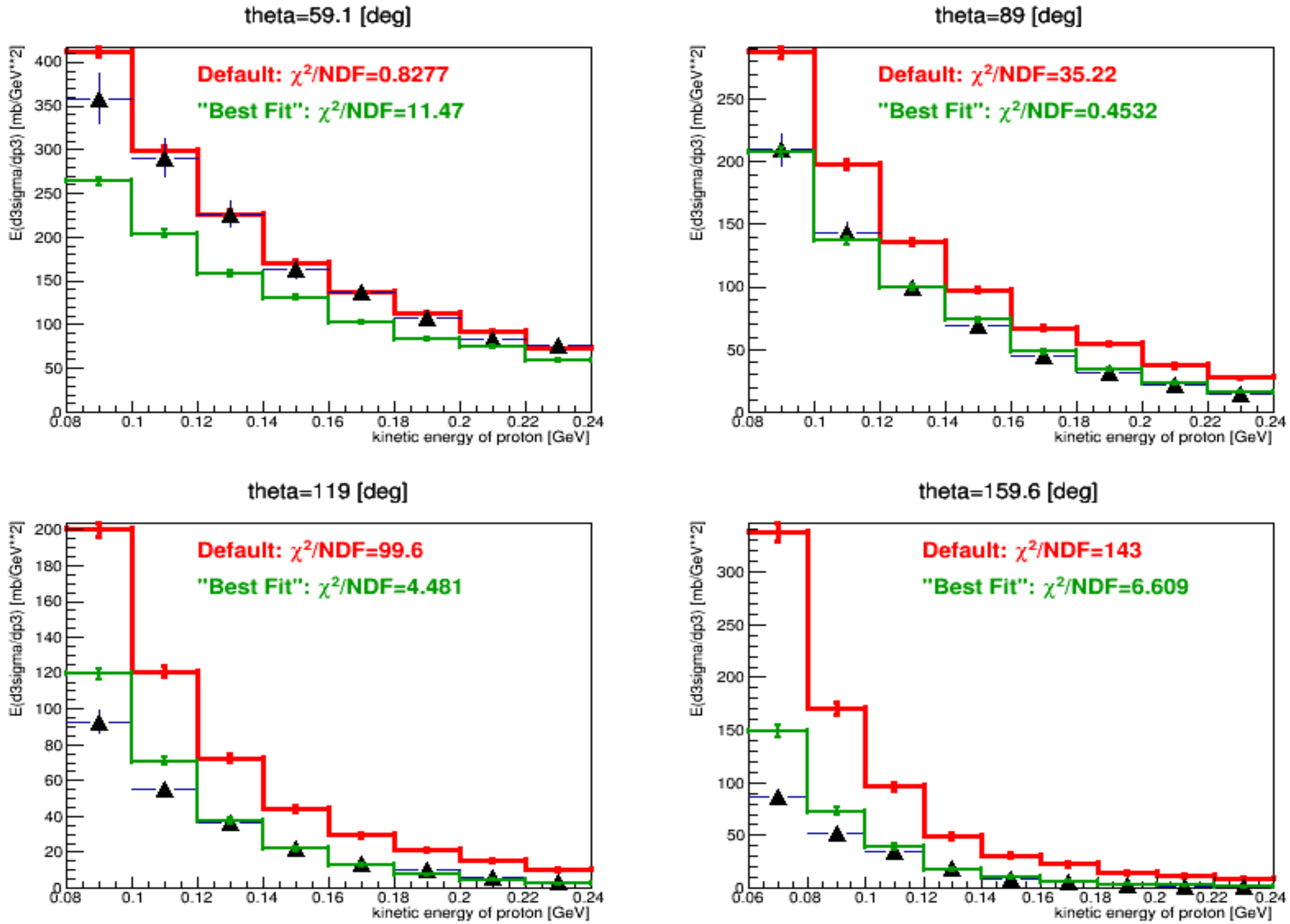
- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1
- Integral χ^2/NDF=7.678

"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996
- Integral χ^2/NDF=0.8544

5GeV/c proton on C $\rightarrow$ proton + X

Data: Yu.D.Bayukov et al, Preprint ITEP-148-1983; Sov.J.Nucl.Phys. 42 116, 1985



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Integral χ^2/NDF=71.89

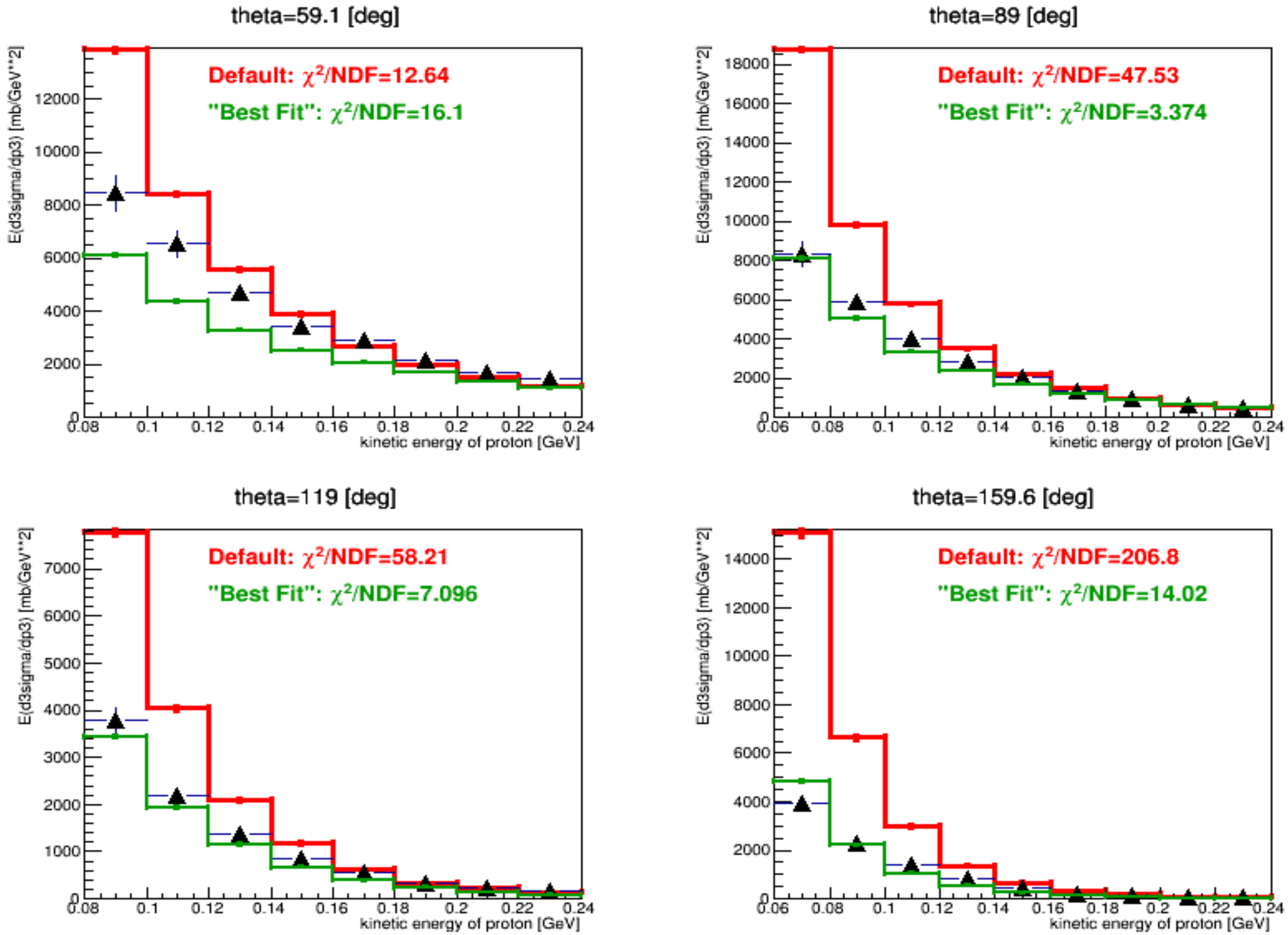
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

Integral χ^2/NDF=5.78

5GeV/c proton on Pb $\rightarrow$ proton + X

Data: Yu.D.Bayukov et al, Preprint ITEP-148-1983; Sov.J.Nucl.Phys. 42 116, 1985



Default FTF Parameters:

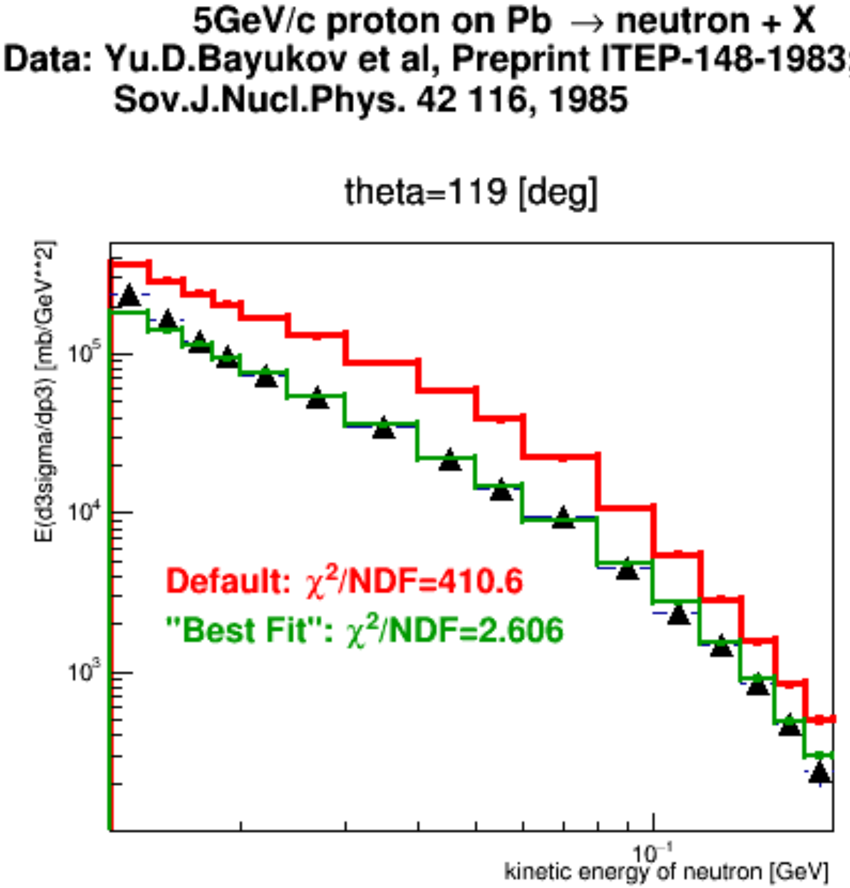
- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Integral χ^2/NDF=84

"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

Integral χ^2/NDF=10.06



At a close look it turns that the first 4 data points in the ITEP771 5GeV/c p + C → neutron + X spectrum are "incorrect" as they are roughly a factor of 5 off by comparison with distributions from reasonably similar beam-momentum-target interactions.

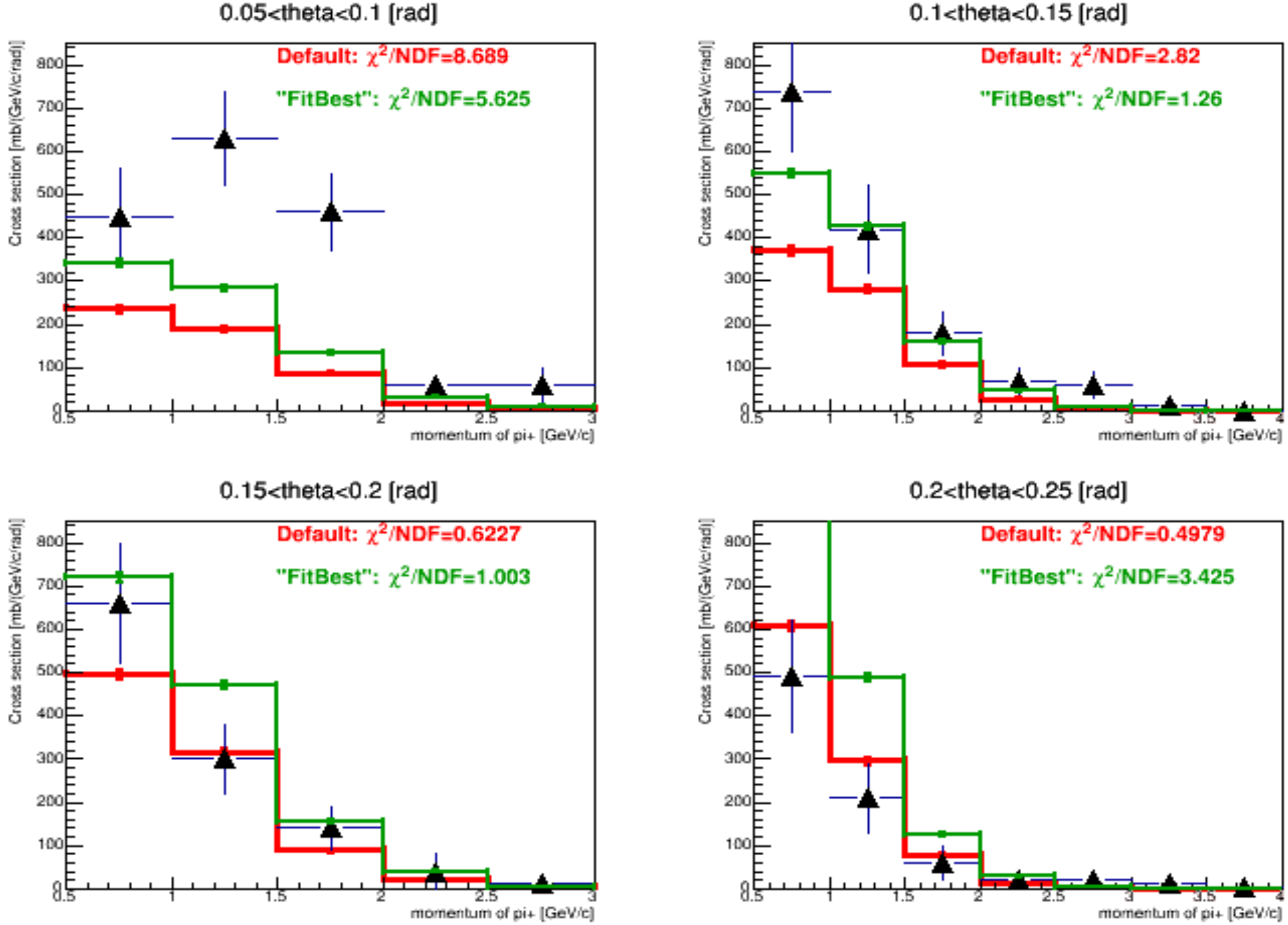
This dataset should be excluded from further study.

Default FTF Parameters:
FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1

"Best Fit" FTF Parameters:
FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996

5GeV/c proton on Pb $\rightarrow \pi^+ + X$ (FW)

Data: HARP (various publications)



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default (FW): χ^2/NDF=2.907
Default (FW+LA): χ^2/NDF=12.02

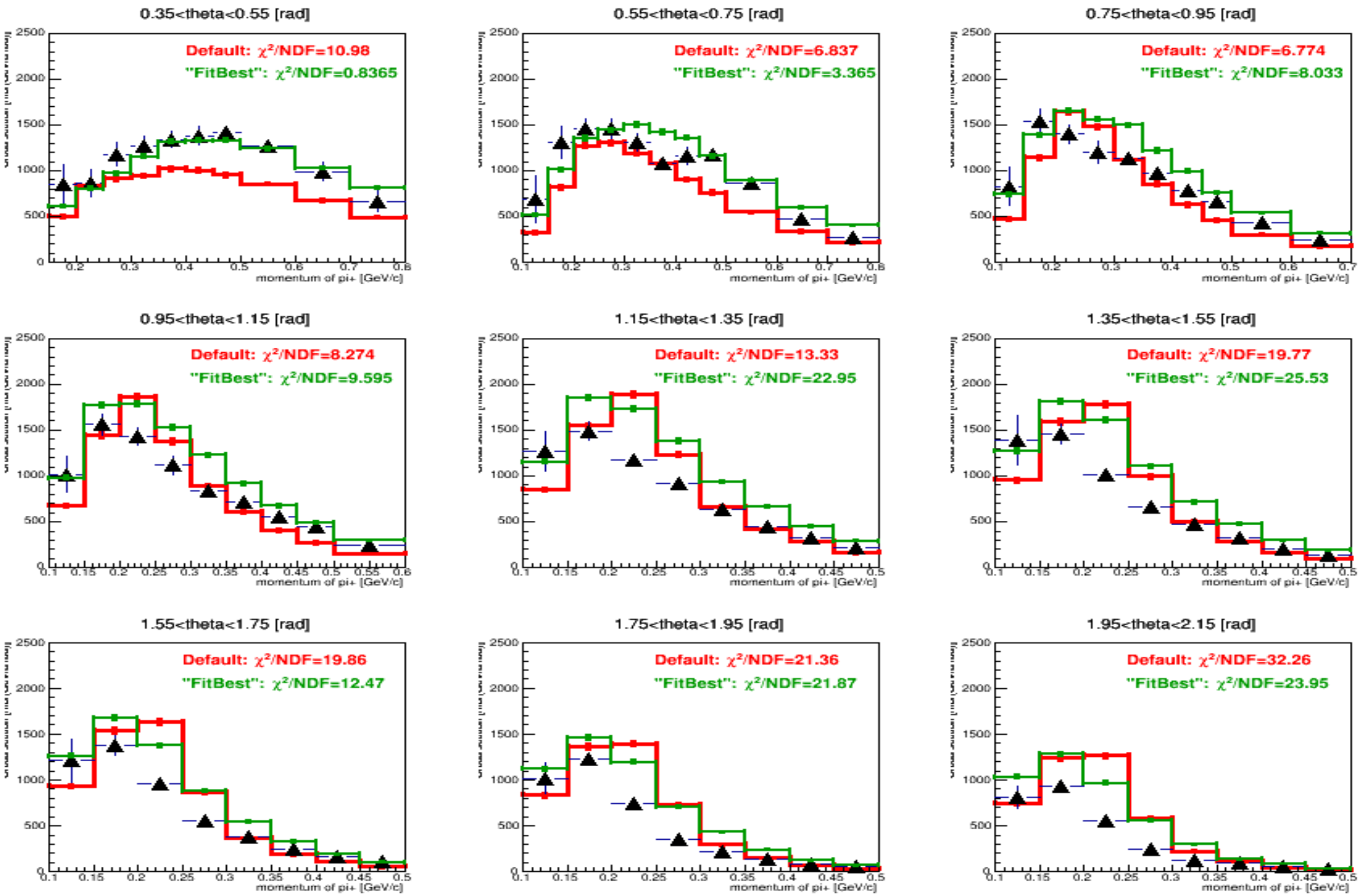
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"BestFit": (FW): χ^2/NDF=2.747
"Best Fit" (FW+LA): χ^2/NDF=10.89

5GeV/c proton on Pb $\rightarrow \pi^{+}$ + X (LA)

Data: HARP (various publications)



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default (LA): χ^2/NDF=14.7489
Default (FW+LA): χ^2/NDF=12.02

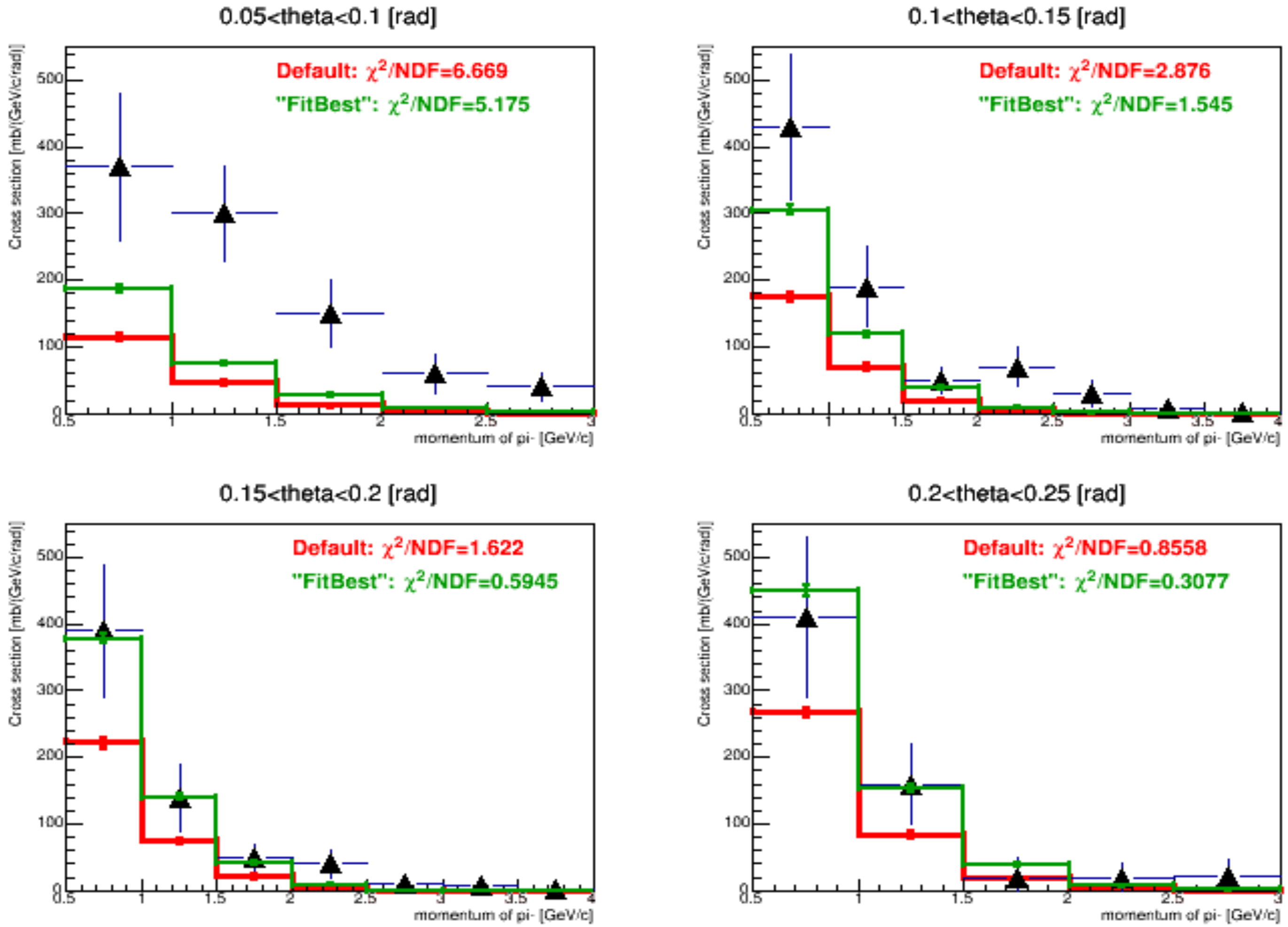
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": (LA): χ^2/NDF=13.33
"Best Fit" (FW+LA): χ^2/NDF=10.89

5GeV/c proton on Pb $\rightarrow \pi^- + X$ (FW)

Data: HARP (various publications)



Default FTF Parameters:

FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1

Default (FW): χ^2/NDF=2.88
Default (FW+LA): χ^2/NDF=41.5

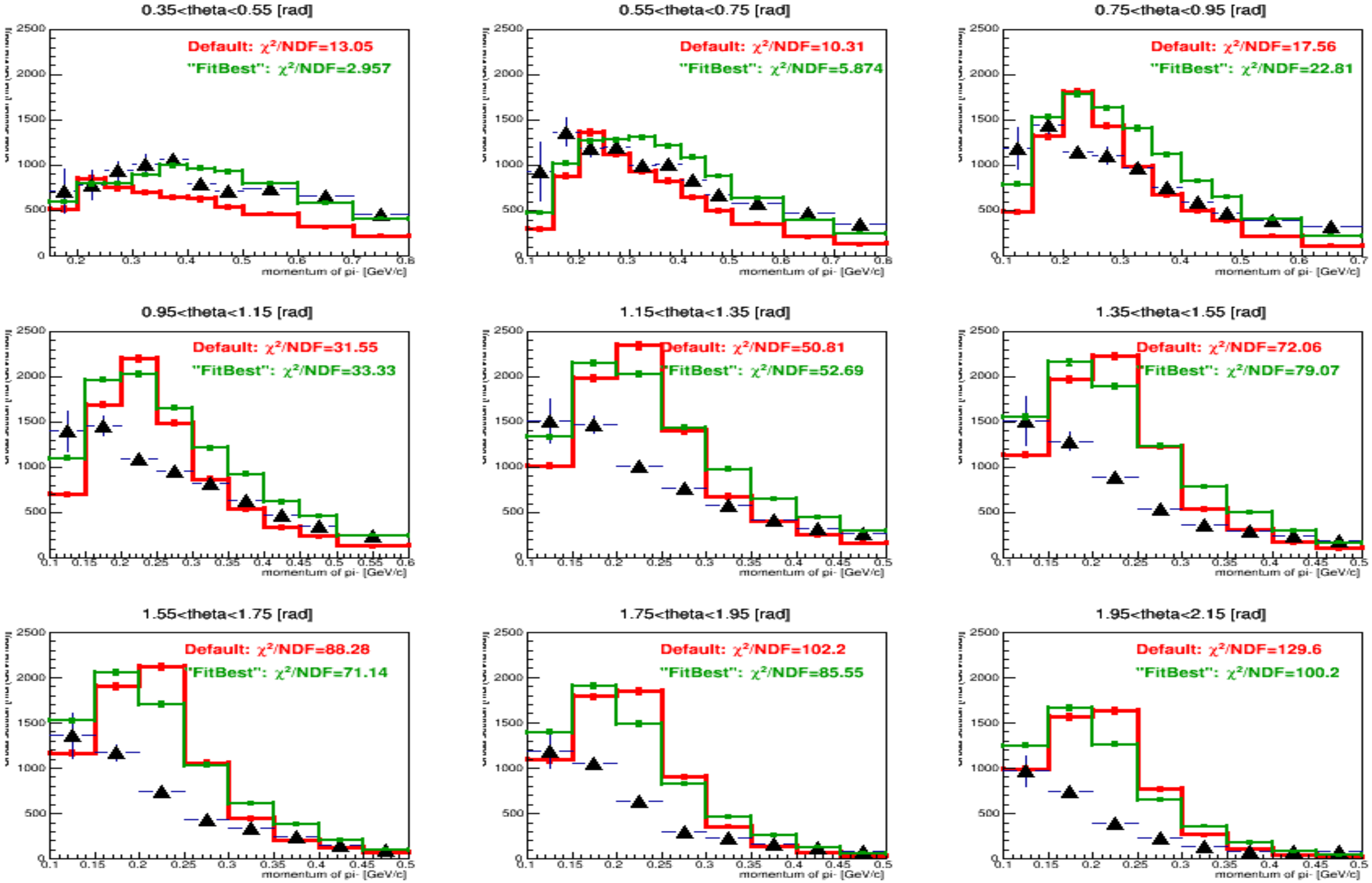
"Best Fit" FTF Parameters:

FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996

"BestFit": (FW): χ^2/NDF=1.766
"Best Fit" (FW+LA): χ^2/NDF=36.29

5GeV/c proton on Pb $\rightarrow \pi^- + X$ (LA)

Data: HARP (various publications)



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default (LA): $\chi^2/NDF=53.09$
Default (FW+LA): $\chi^2/NDF=41.5$

"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": (LA): $\chi^2/NDF=46.64$
"Best Fit" (FW+LA): $\chi^2/NDF=36.29$

Some Thoughts for the Future (Possibly…)

- Of course, this exercise is very preliminary and of limited scope
  - It can not serve as a basis for any "major decision"
- More extensive study (more parameters, more exp.datasets) is needed and is in progress
- Assuming that more detailed studies will deliver reasonable output, we might consider extending the scenario and include
  - QGS re-tuning
  - Full-scale Geant4 applications, in an attempt/hope to optimize physics list(s) composition and/or overlap region(s)
- Of course, such approach (if justified/accepted) will require certain coding work, CPU and manpower for analysis (nothing is "free")
- Basically, just wanted to lay some finding and ideas on the table
- Any decision is up to the HAD group, of course

Summary

- Having model configuration interface(s) in Geant4 paved way for applying fitting technique in the multi-parameters space, e.g. Professor
- At first try, Professor's fitting technique appears to be applicable to the Geant4 FTF model
- However, current exercise is of a very limited scope; more extensive fitting studies are needed to prove the initial optimism
- Even if more extensive study deliver "best fit" results that improve overall agreement between MC and data, it is entirely up to the developers to judge if such "best fit" values are physical or "pure luck"
  - This is true for any model, not just FTF
- However, if further Professor-based studies prove to be successful, we might consider extending the scenario and including
  - Other models, e.g. QGS
  - Attempts to optimize physics list(s) composition

BACKUP MATERIALS

Experimental Data
(all are for thin target)

- HARP:
  - M. Apollonio et al., Nucl. Phys. A821 118, 2009
  - M. Apollonio et al., Phys.Rev.C80 065207, 2009
  - M. Apollonio et al., Phys.Rev.C80 035208, 2009
  - M.G. Catanesi et al., Phys.Rev.C77 055207, 2008
- ITEP771:
  - Yu.D.Bayukov et al., Preprints ITEP-148-1983 and ITEP-172-1983; Sov.J.Nucl.Phys. 42 116, 1985
- “IAEA”:
  - K.Ishibashi et al., J.Nucl.Sci.Tech. Vol.34 N.6 1997
- NA49
  - https://spshadrons.web.cern.ch/spshadrons

Number of parameters vs polynomial order vs number of “points” in the parameter space

```
int numCoeffs(int dim, int order) {
  int ntok = 1;
  int r = min(order, dim);
  for (int i = 0; i < r; ++i) {
    ntok = ntok*(dim+order-i)/(i+1);
  }
return ntok;
}
```

3 dimensional parameter space:

Polynomial order	Minimum samples
0	1
1	4
2	10
3	20
4	35
5	56
6	84
7	120
8	165
9	220
10	286

20 dimensional parameter space:

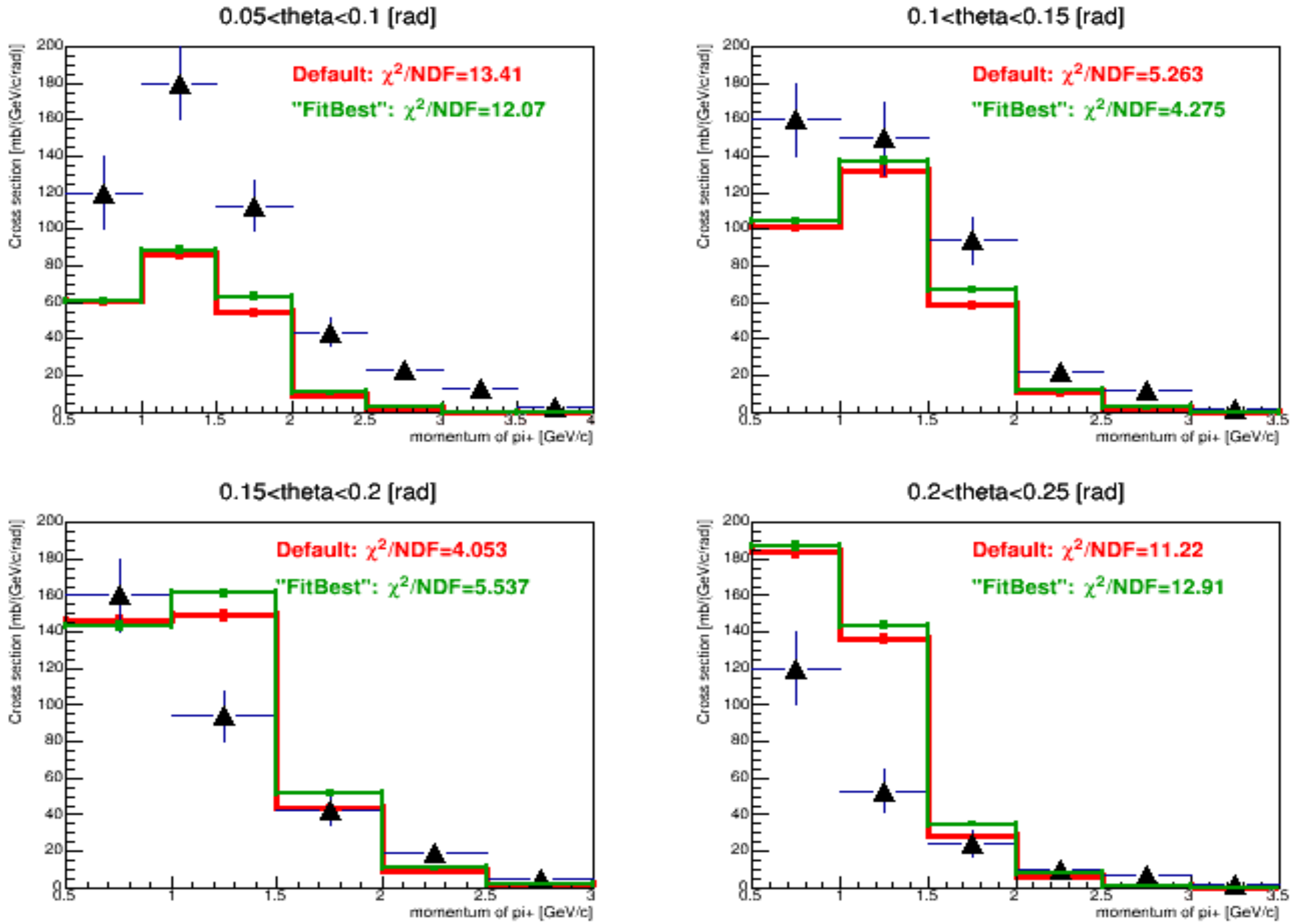
Polynomial order	Minimum samples
0	1
1	21
2	231
3	1771
4	10626
5	53130
6	230230
7	888030
8	3108105
9	10015005
10	30045015

50 dimensional parameter space:

Polynomial order	Minimum samples
0	1
1	51
2	1326
3	23426
4	316251
5	3478761
6	32468436
7	264385836

5GeV/c proton on C $\rightarrow \pi^{+}$ + X (FW)

Data: HARP (various publications)



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default (FW): χ^2/NDF=8.877
Default (FW+LA): χ^2/NDF=8.924

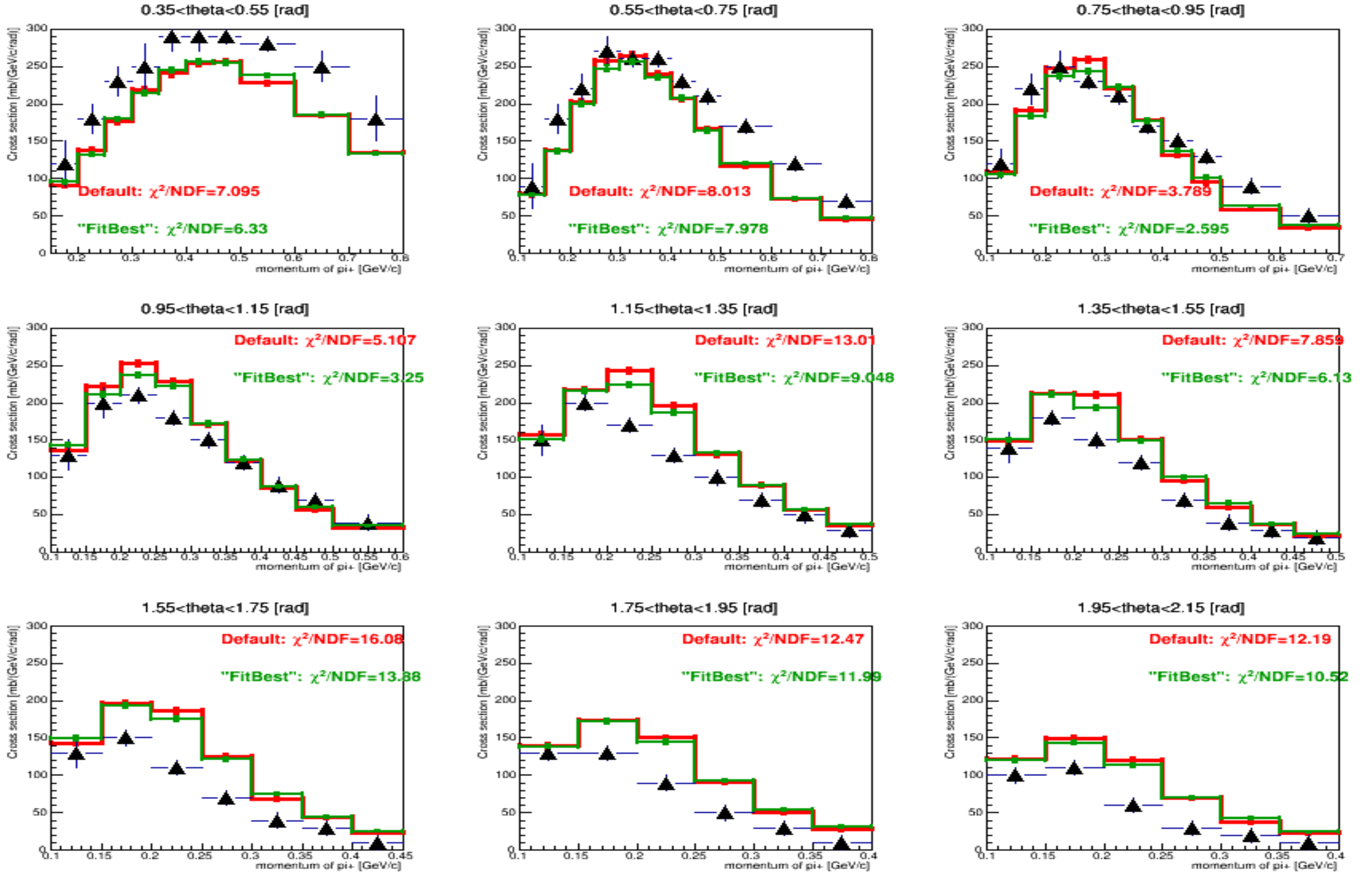
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"BestFit": (FW): χ^2/NDF=8.972
"Best Fit" (FW+LA): χ^2/NDF=7.831

5GeV/c proton on C $\rightarrow \pi^{+} + X$ (LA)

Data: HARP (various publications)



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default (LA): χ^2/NDF=8.939
Default (FW+LA): χ^2/NDF=8.924

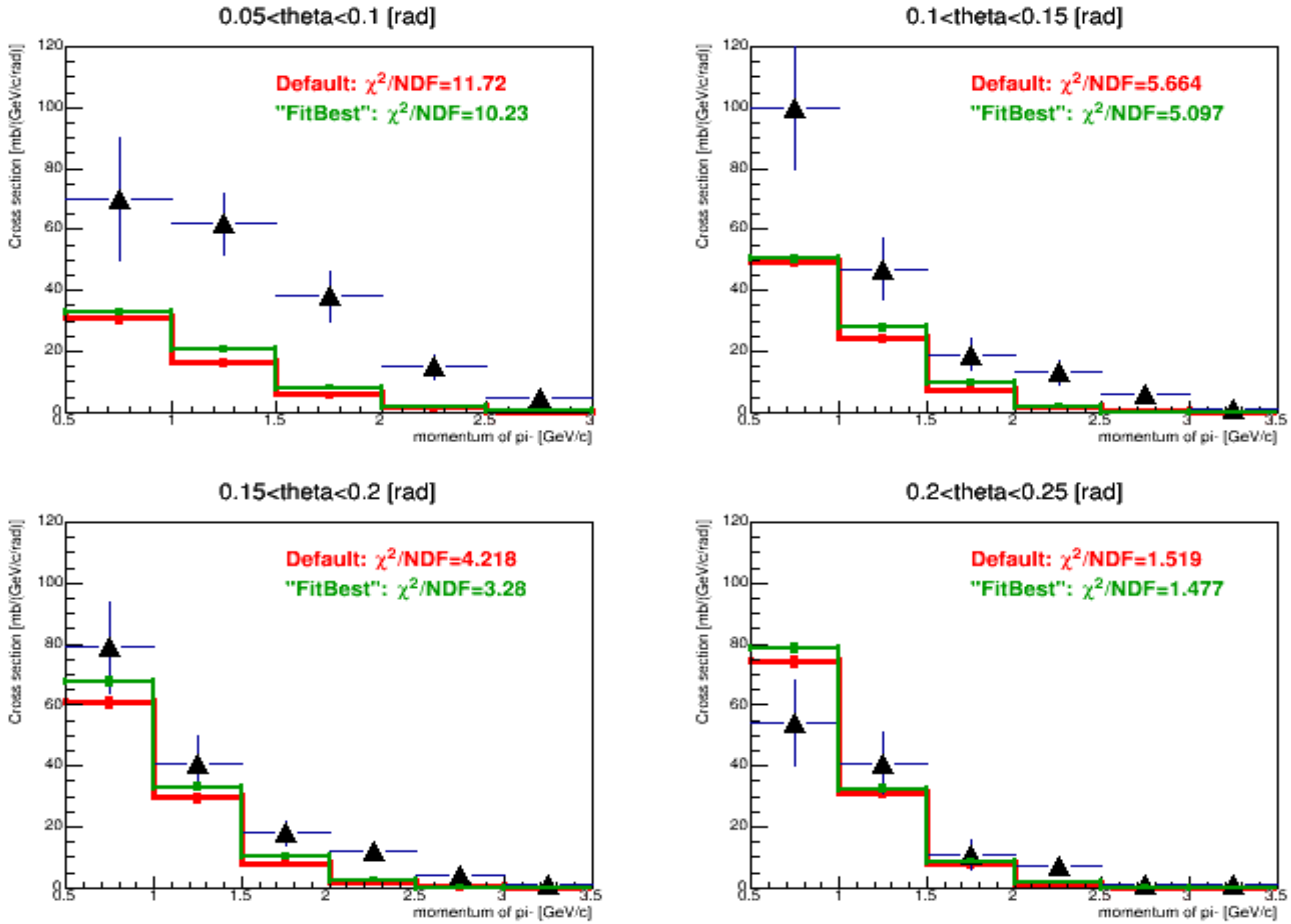
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": (LA): χ^2/NDF=7.465
"Best Fit" (FW+LA): χ^2/NDF=7.831

5GeV/c proton on C $\rightarrow \pi^- + X$ (FW)

Data: HARP (various publications)



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default (FW): χ^2/NDF=5.523
Default (FW+LA): χ^2/NDF=11.21

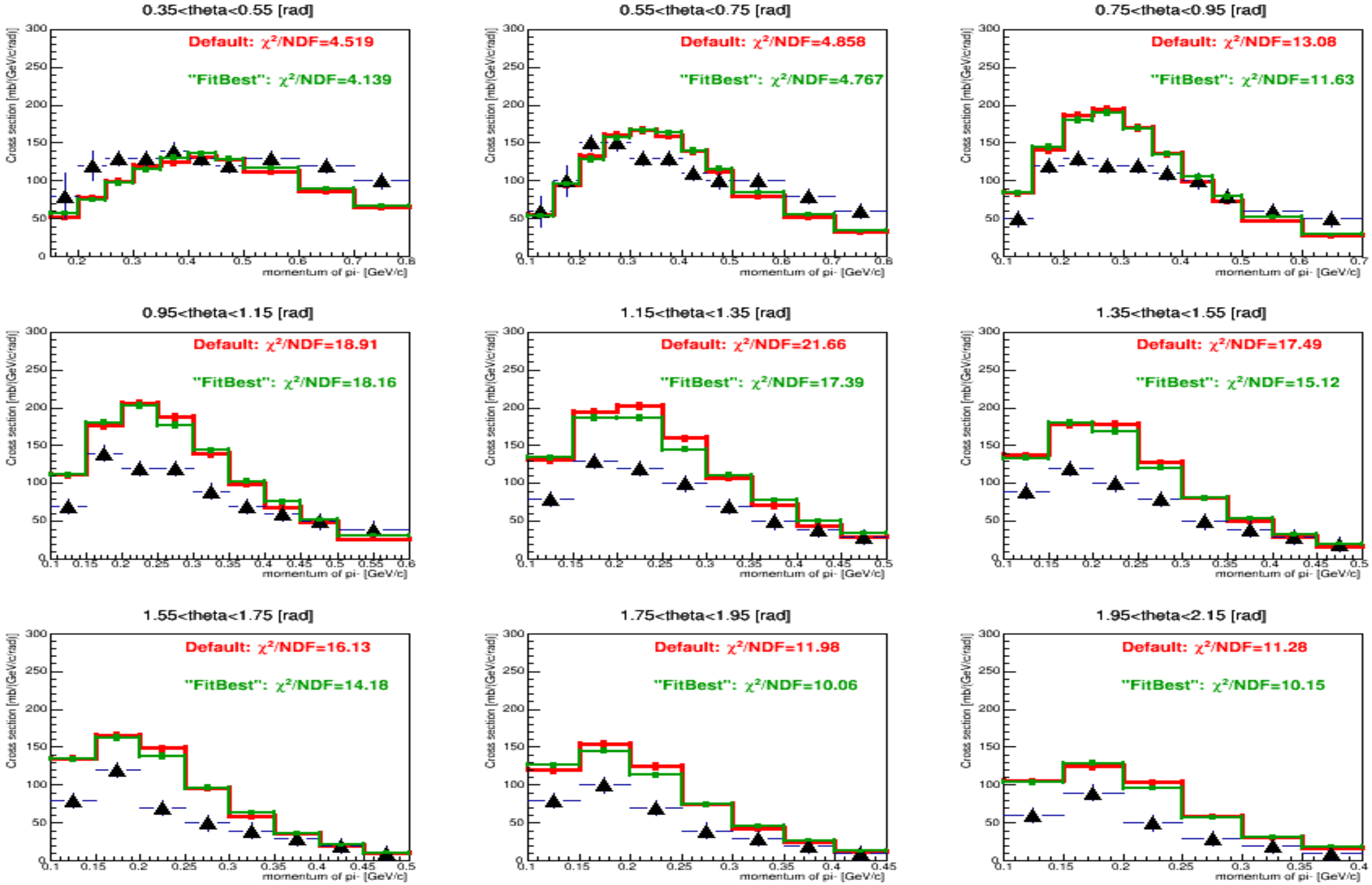
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"BestFit": (FW): χ^2/NDF=4.794
"Best Fit" (FW+LA): χ^2/NDF=9.886

5GeV/c proton on C → π^- + X (LA)

Data: HARP (various publications)



Default FTF Parameters:

FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1

Default (LA): χ^2/NDF=12.9
Default (FW+LA): χ^2/NDF=11.21

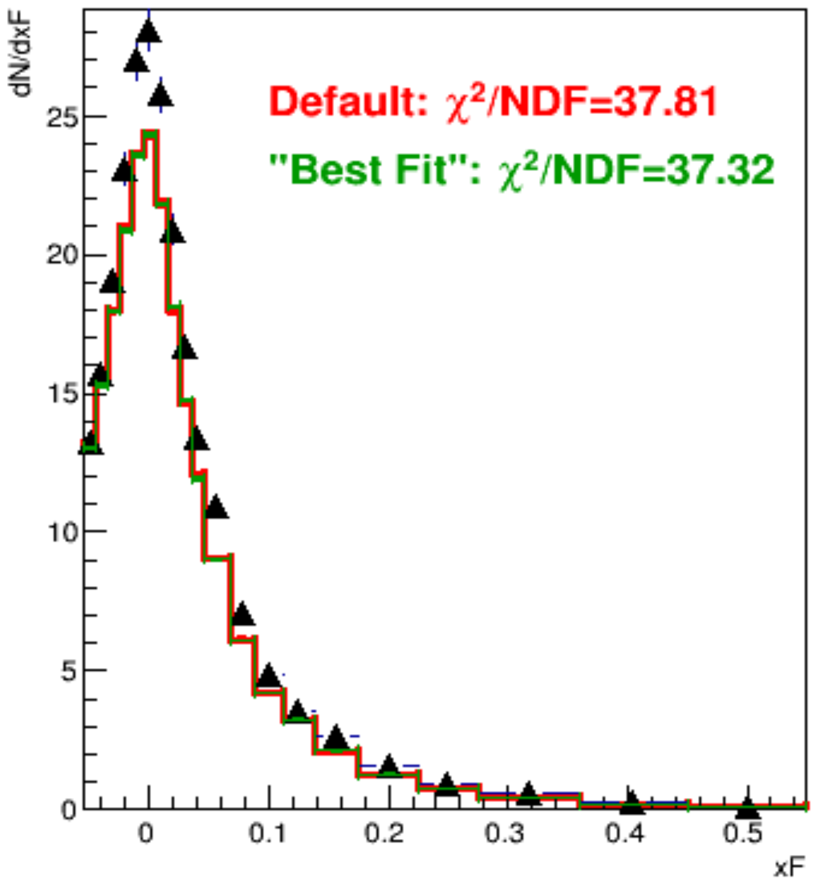
"Best Fit" FTF Parameters:

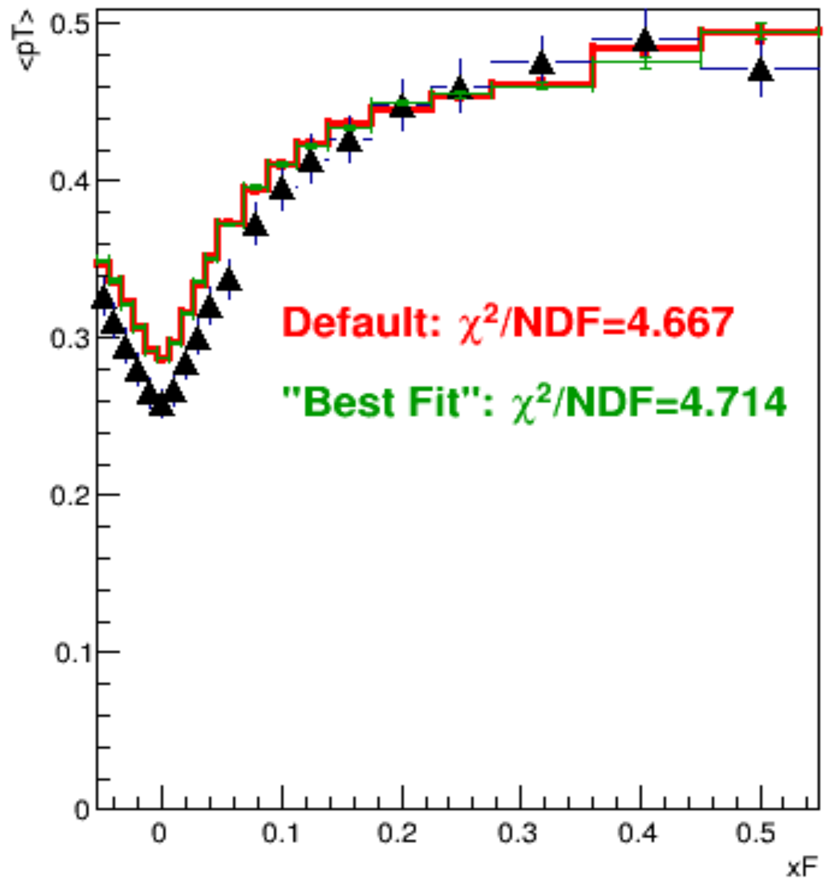
FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": (LA): χ^2/NDF=11.41
"Best Fit" (FW+LA): χ^2/NDF=9.886

158GeV/c proton on C $\rightarrow \pi^+ + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/





Default FTF Parameters:

FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1

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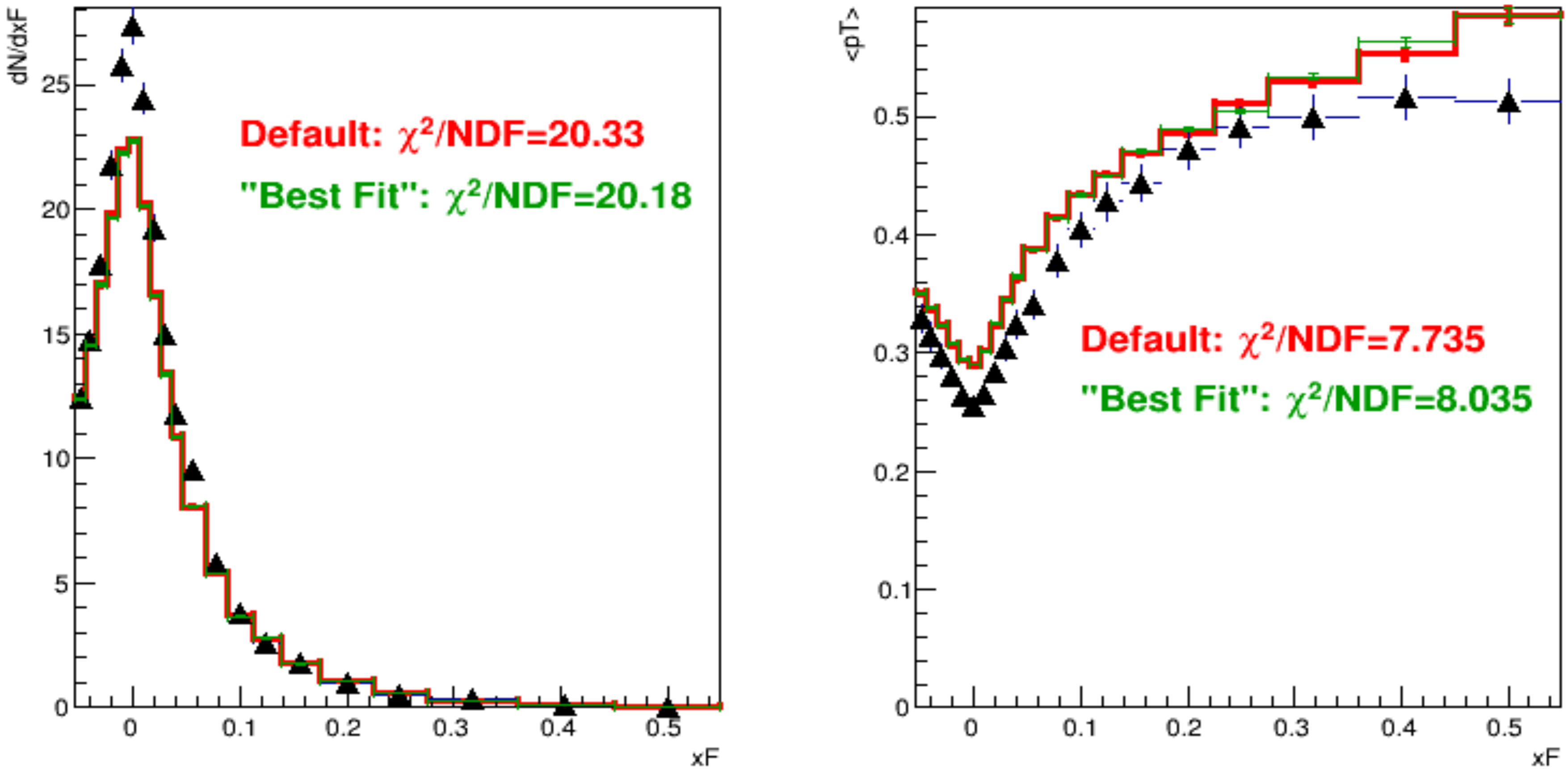
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996

158GeV/c proton on C $\rightarrow \pi^- + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



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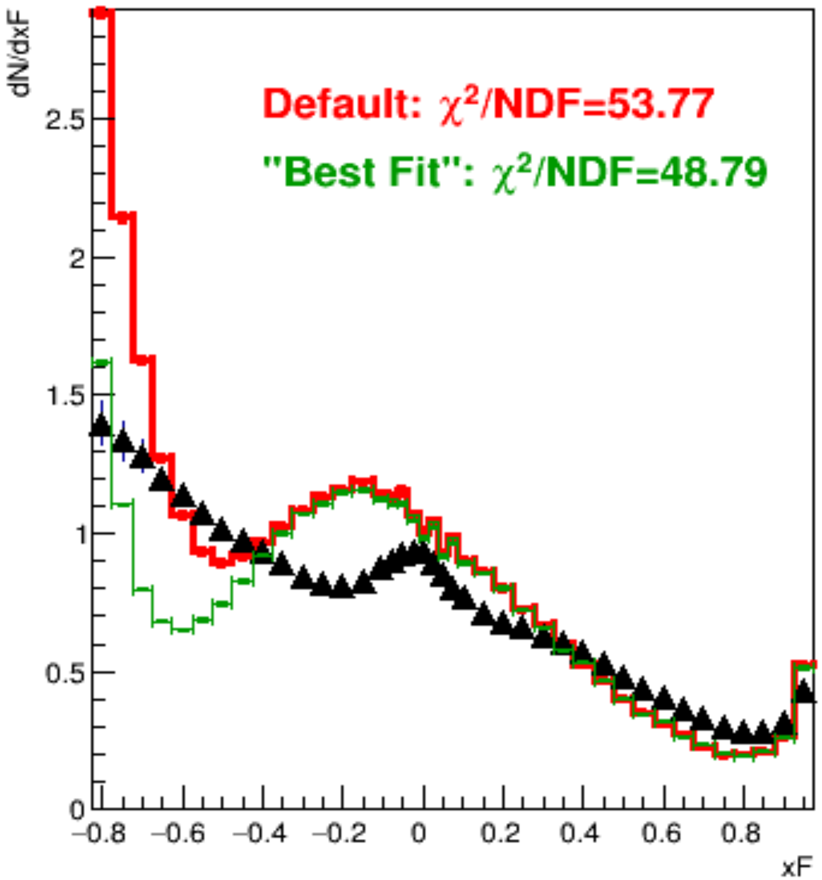
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

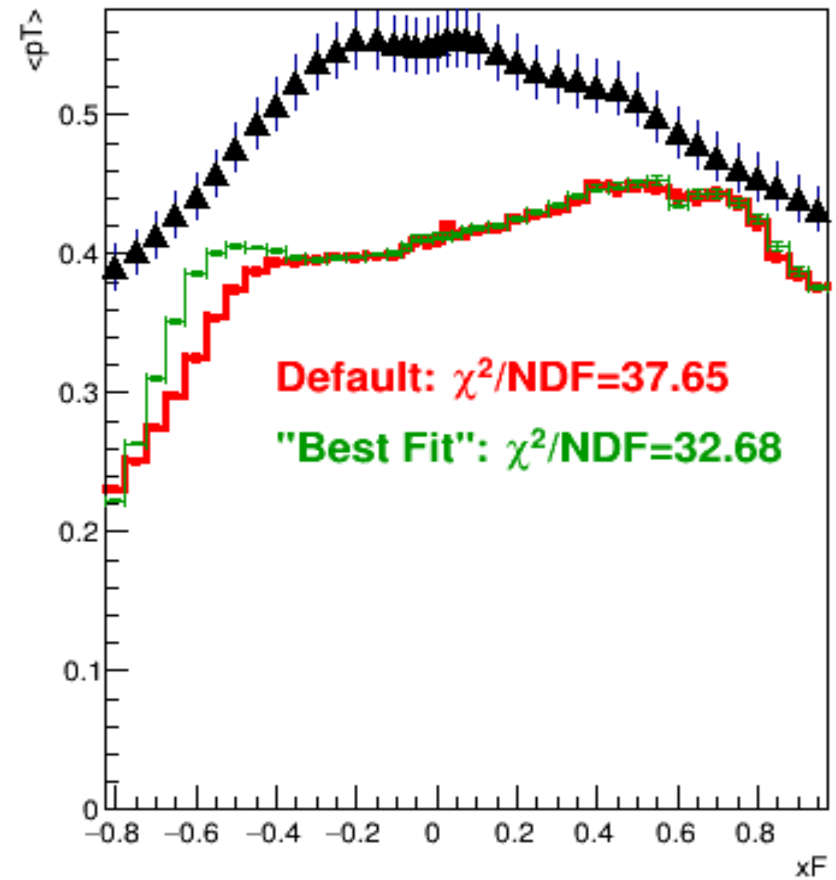
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

158GeV/c proton on C → proton + X

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/





Default FTF Parameters:

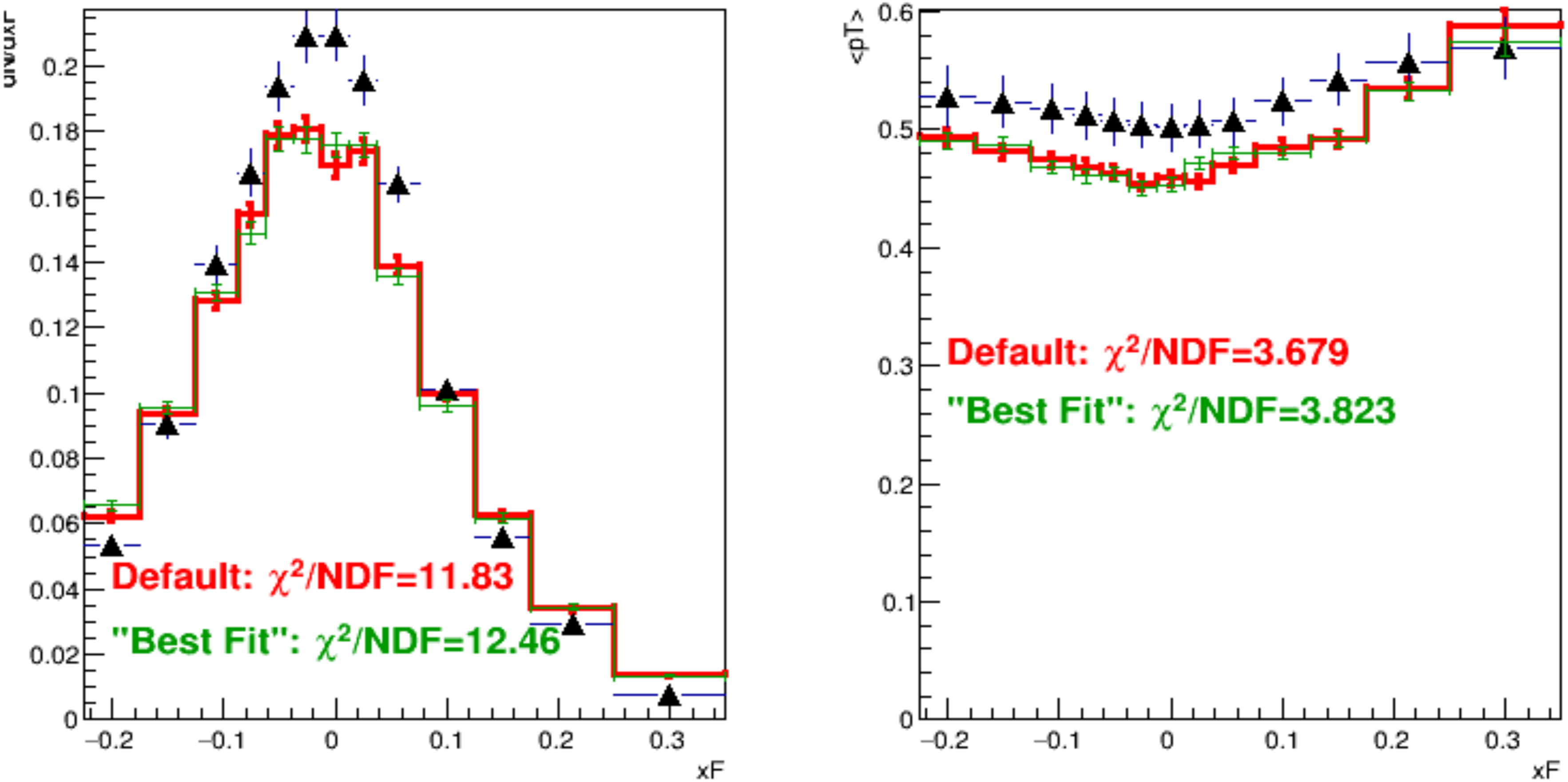
- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

158GeV/c proton on C $\rightarrow$ antiproton + X

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

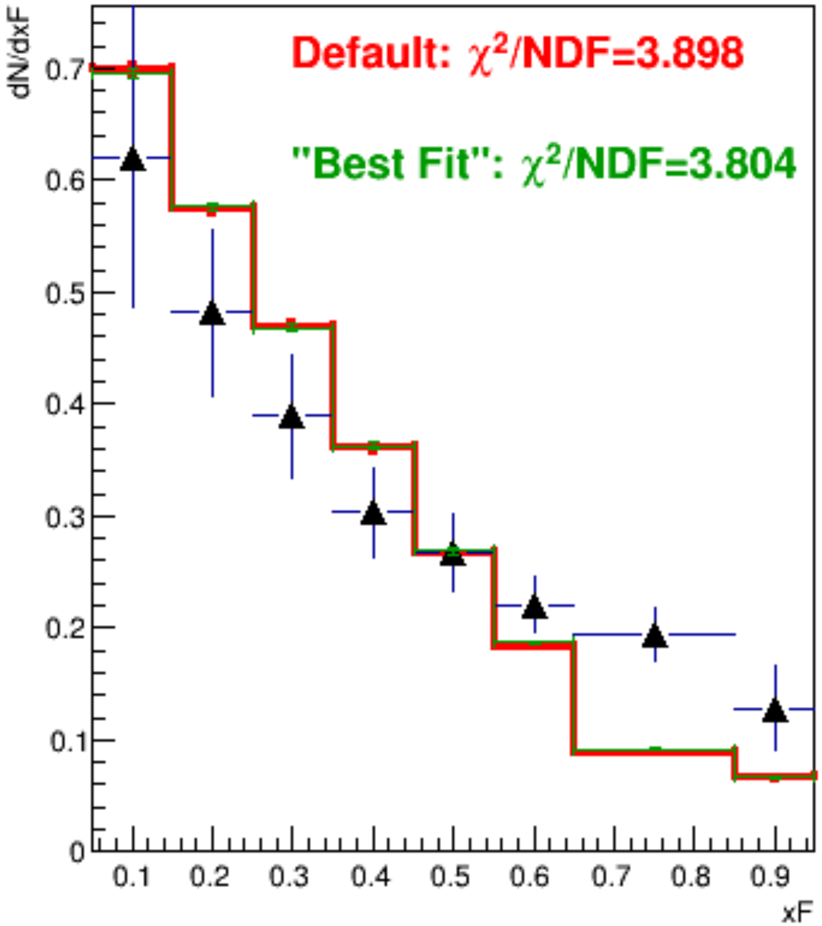
FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1

"Best Fit" FTF Parameters:

FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996

158GeV/c proton on C $\rightarrow$ neutron + X

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

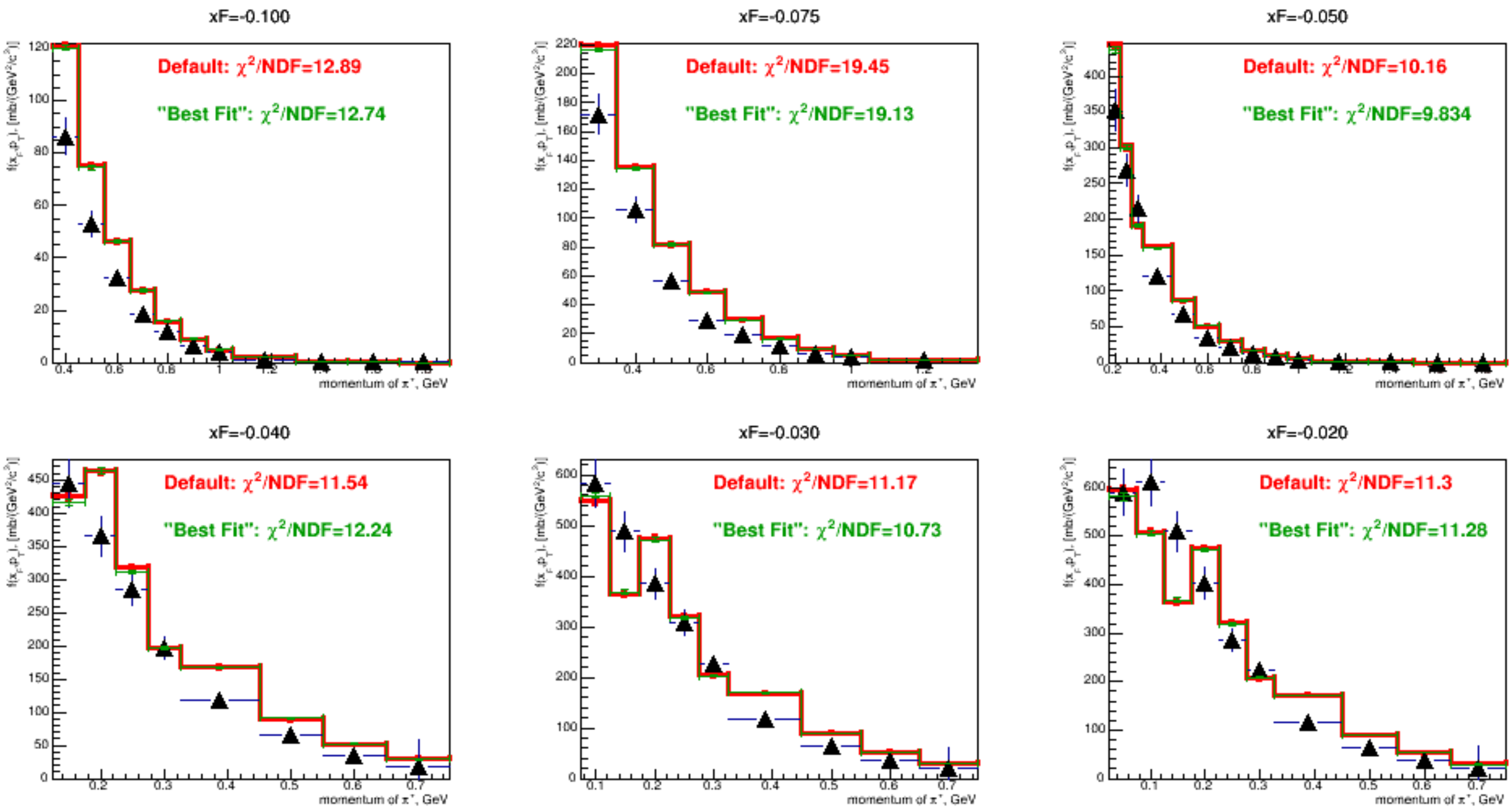
FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1

"Best Fit" FTF Parameters:

FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996

158GeV/c proton on C $\rightarrow \pi^+ + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default: Integral (all xF-bins) χ^2/NDF=6.85

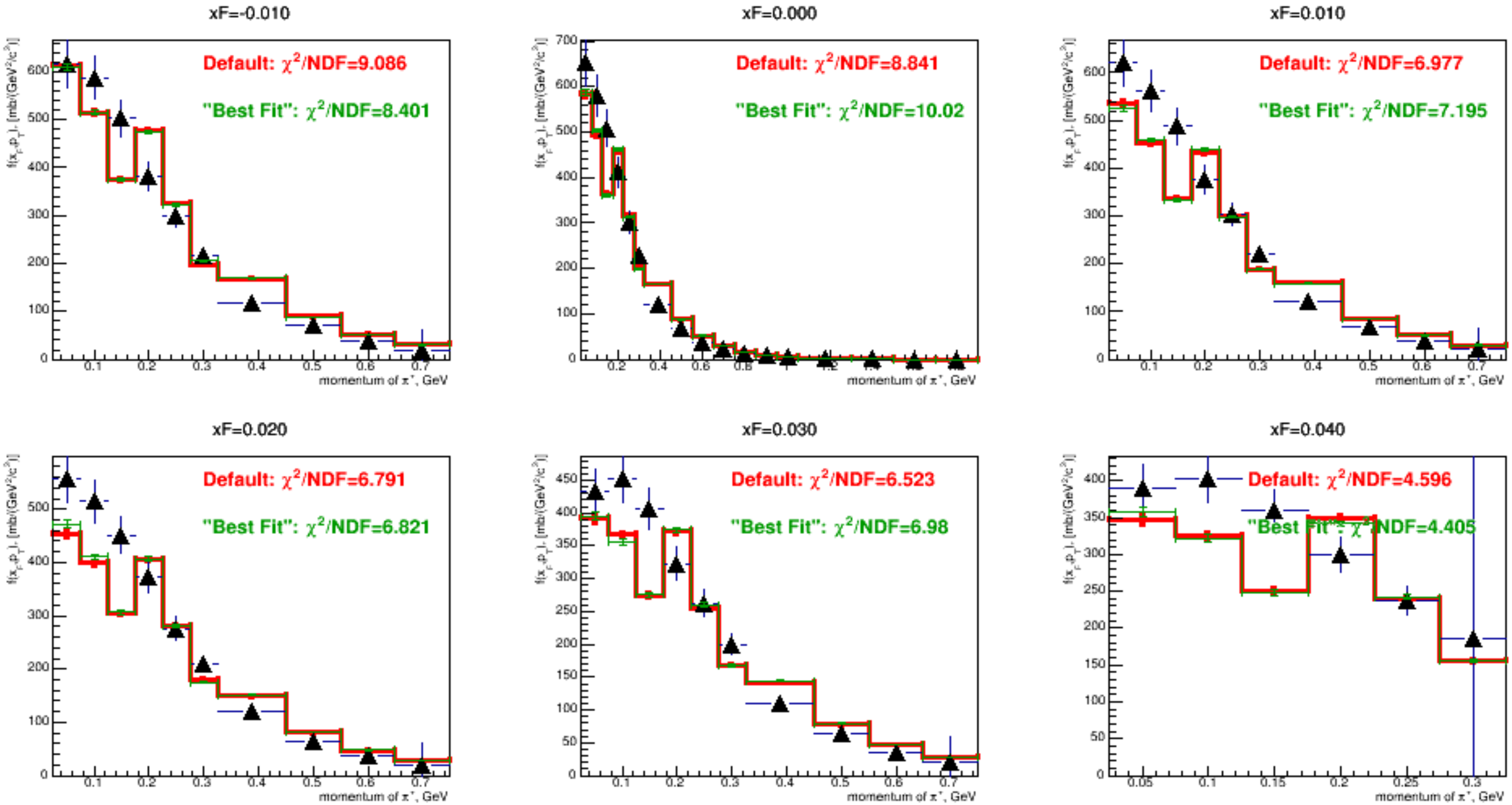
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": Integral (all xF-bins) χ^2/NDF=6.851

158GeV/c proton on C $\rightarrow \pi^+ + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

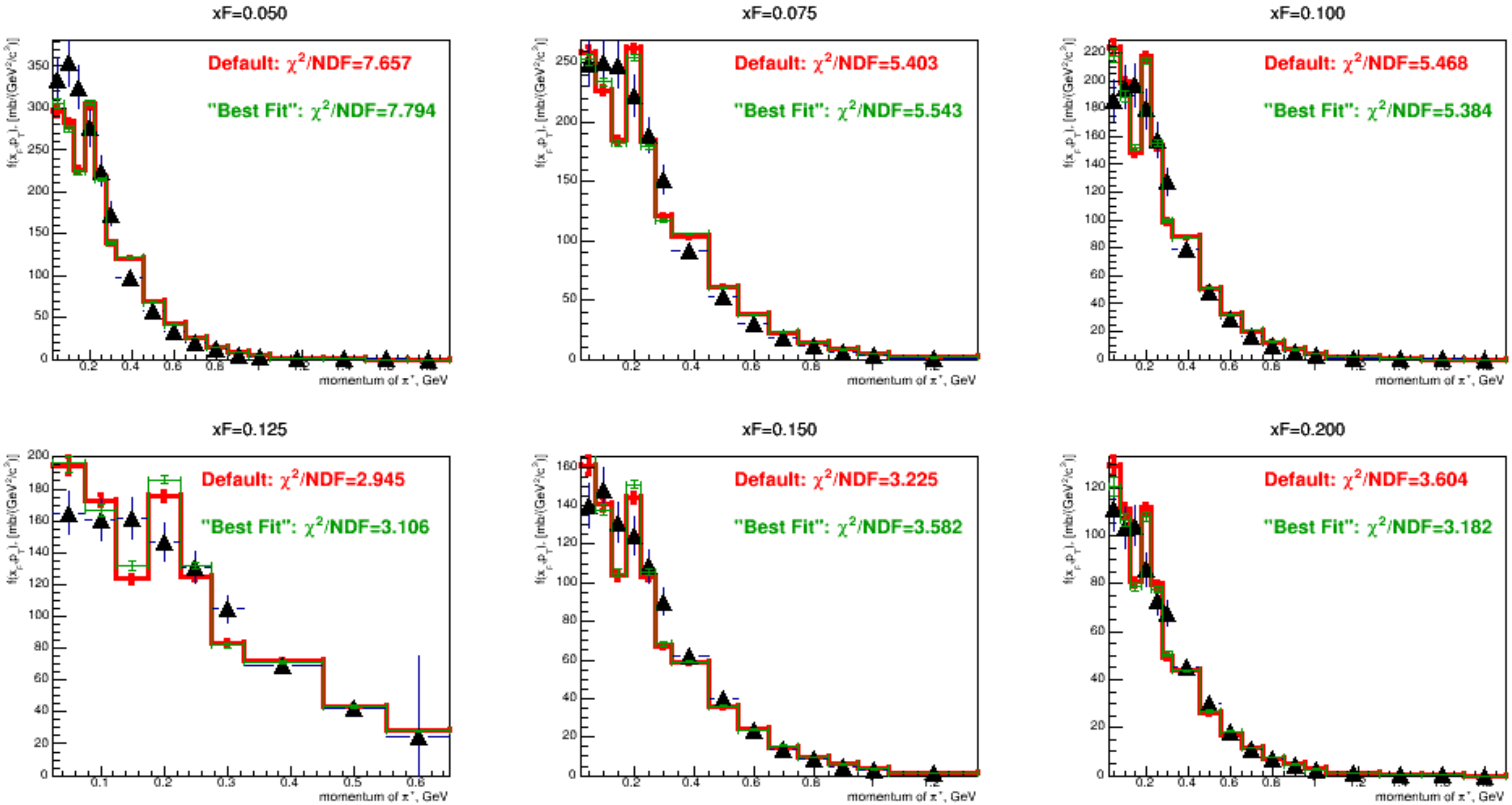
FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1
Default: Integral (all xF-bins) χ^2/NDF=6.85

"Best Fit" FTF Parameters:

FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996
"Best Fit": Integral (all xF-bins) χ^2/NDF=6.851

158GeV/c proton on C → π^+ + X

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default: Integral (all xF-bins) χ^2/NDF=6.85

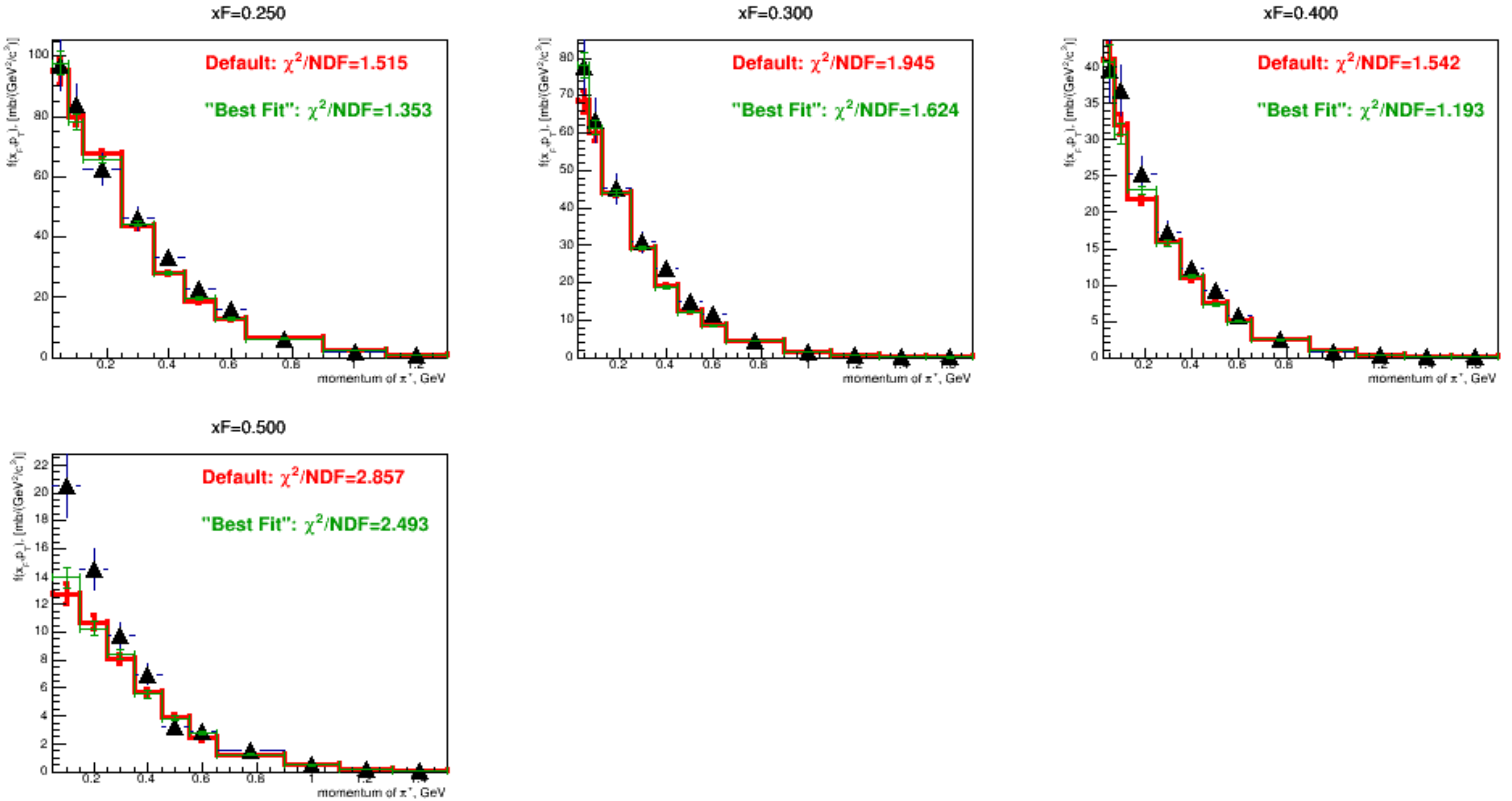
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": Integral (all xF-bins) χ^2/NDF=6.851

158GeV/c proton on C $\rightarrow \pi^+ + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default: Integral (all xF-bins) χ^2/NDF=6.85

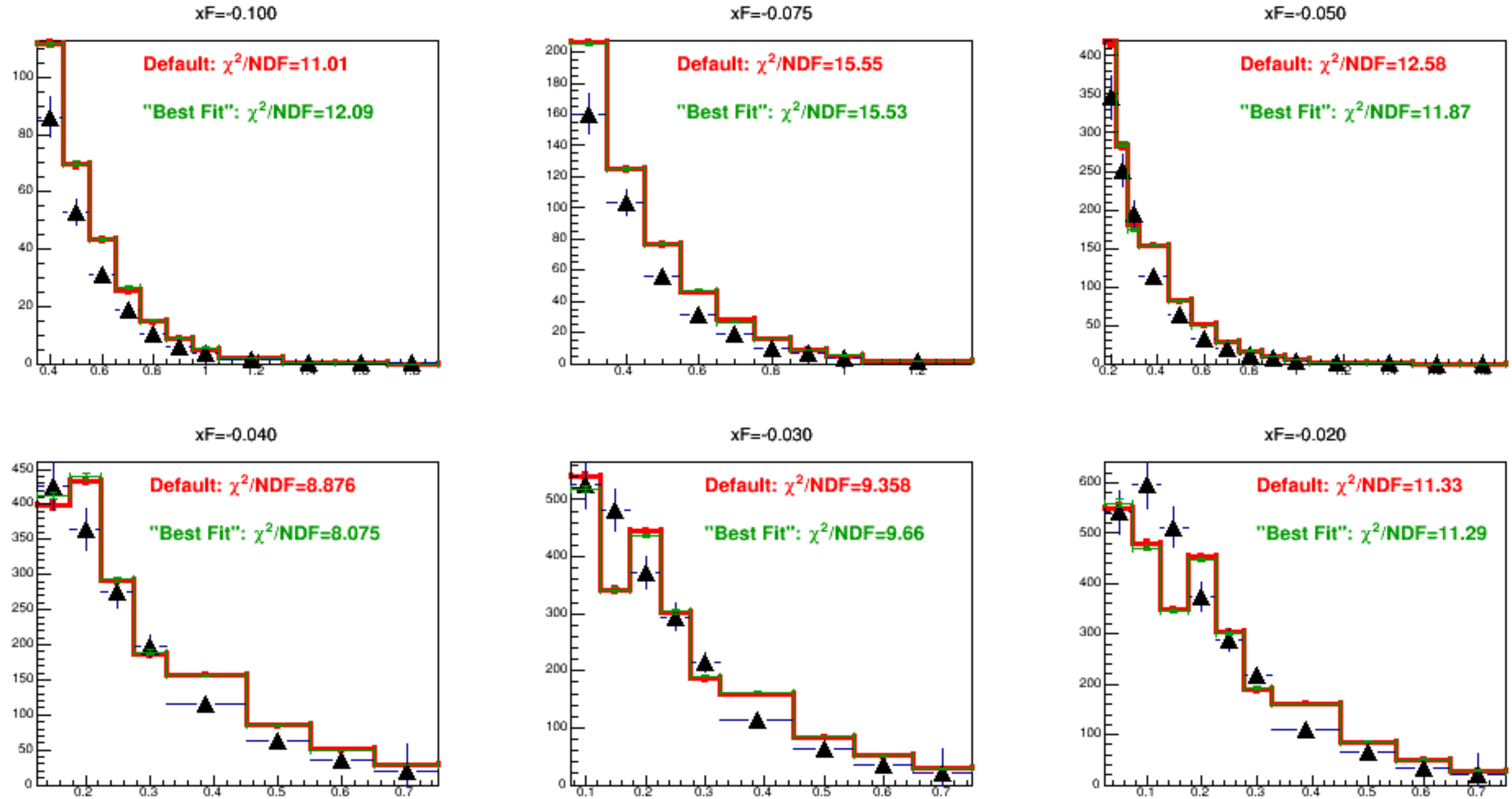
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": Integral (all xF-bins) χ^2/NDF=6.851

158GeV/c proton on C $\rightarrow \pi^- + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

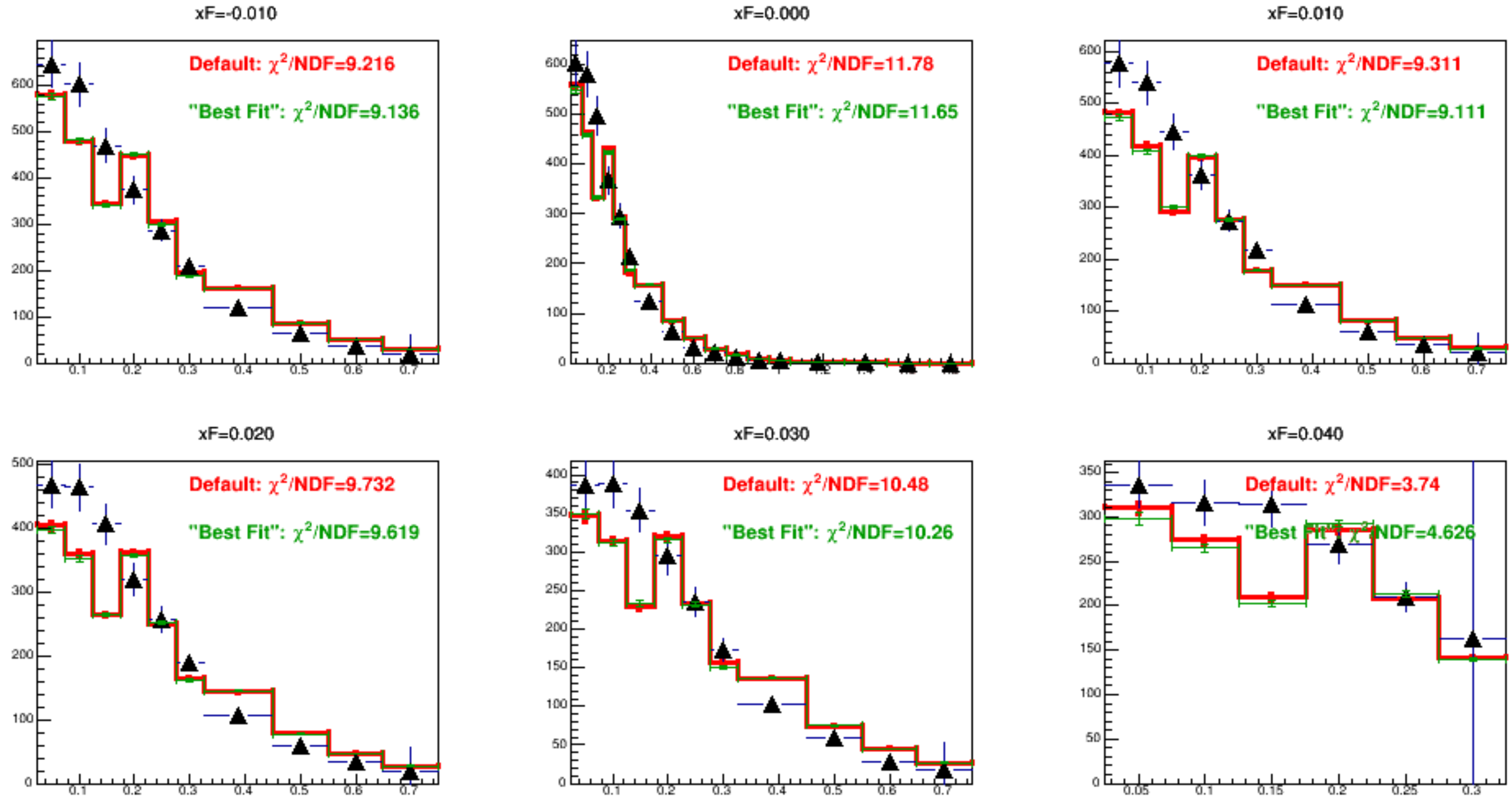
FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1
Default: Integral (all xF-bins) χ^2/NDF=11.27

"Best Fit" FTF Parameters:

FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996
"Best Fit": Integral (all xF-bins) χ^2/NDF=11.23

158GeV/c proton on C $\rightarrow \pi^- + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default: Integral (all xF-bins) χ^2/NDF=11.27

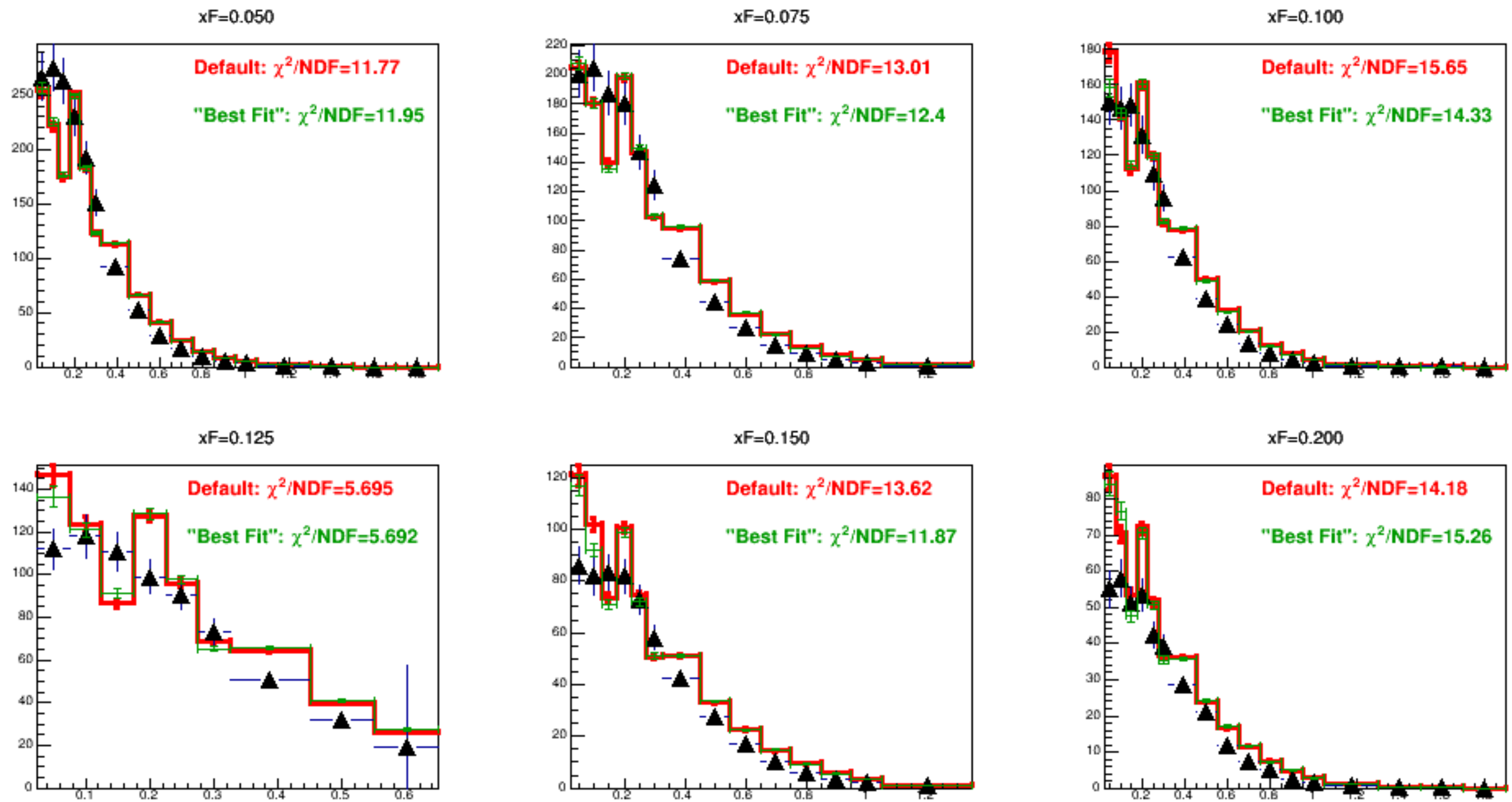
"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": Integral (all xF-bins) χ^2/NDF=11.23

158GeV/c proton on C $\rightarrow \pi^{-} + X$

Data: NA49 https://spshadrons.web.cern.ch/spshadrons/



Default FTF Parameters:

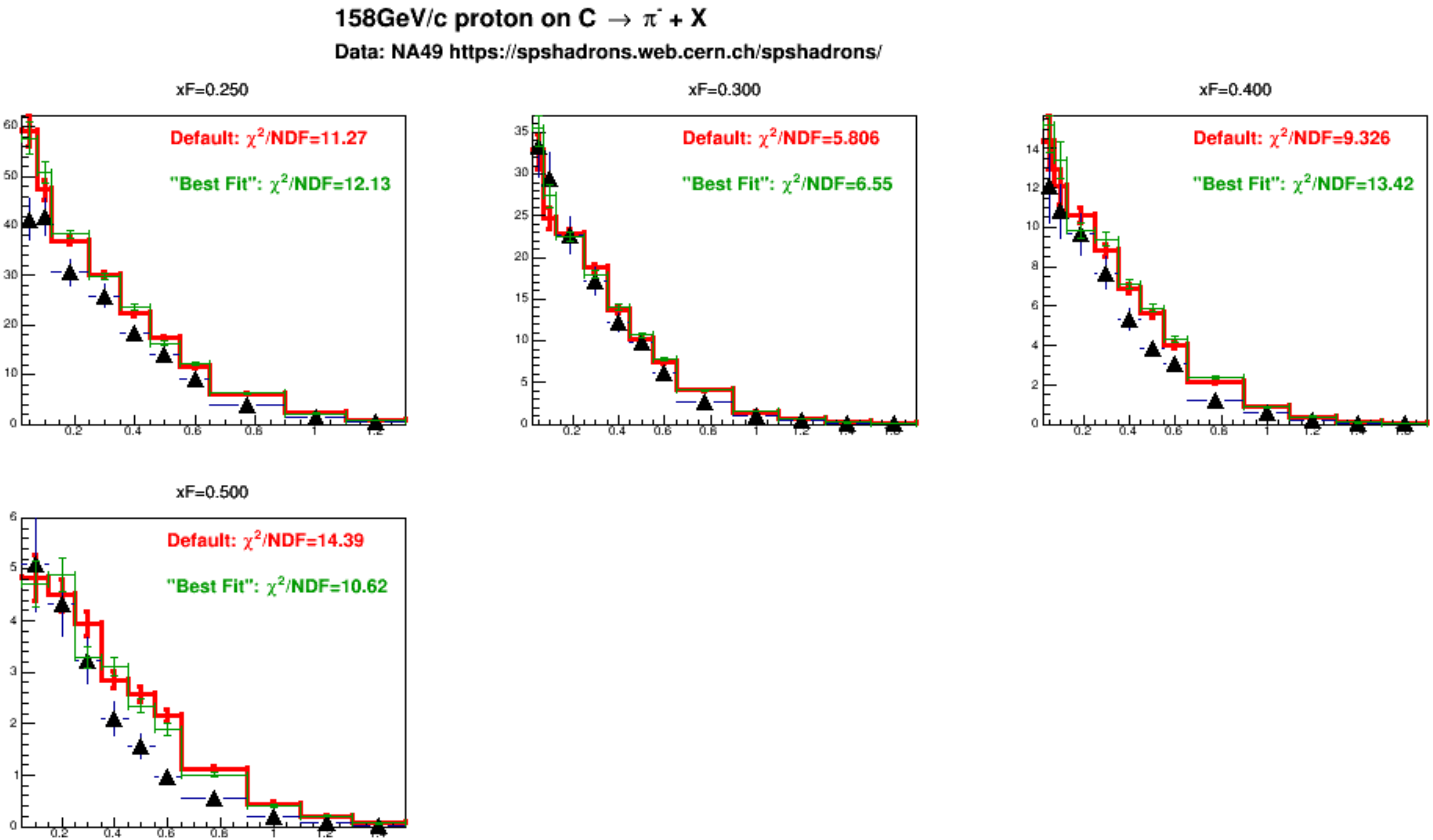
- FTF_NUCDESTR_P1_TGT = 1.
- FTF_NUCDESTR_P1_ADEP_TGT = false
- FTF_NUCDESTR_P2_TGT = 4.
- FTF_NUCDESTR_P2_TGT = 2.1

Default: Integral (all xF-bins) χ^2/NDF=11.27

"Best Fit" FTF Parameters:

- FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
- FTF_NUCDESTR_P1_ADEP_TGT = true
- FTF_NUCDESTR_P2_TGT = 2.919
- FTF_NUCDESTR_P2_TGT = 2.996

"Best Fit": Integral (all xF-bins) χ^2/NDF=11.23



Default FTF Parameters:

FTF_NUCDESTR_P1_TGT = 1.
FTF_NUCDESTR_P1_ADEP_TGT = false
FTF_NUCDESTR_P2_TGT = 4.
FTF_NUCDESTR_P2_TGT = 2.1
Default: Integral (all xF-bins) χ^2/NDF=11.27

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FTF_NUCDESTR_P1_TGT = 0.0026 * A(target)
FTF_NUCDESTR_P1_ADEP_TGT = true
FTF_NUCDESTR_P2_TGT = 2.919
FTF_NUCDESTR_P2_TGT = 2.996
"Best Fit": Integral (all xF-bins) χ^2/NDF=11.23