FRAGMENTATION FUNCTIONS FOR THE EIC:

KAON FRAGMENTATION REVISITED

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Phys. Rev. D 95, 094019 (2017)

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PHYSICAL REVIEW D 75, 114010 (2007)

Global analysis of fragmentation functions for pions and kaons and their uncertainties

Daniel de Florian* and Rodolfo Sassot†
Departamento de Fisica, Universidad de Buenos Aires, Ciudad Universitaria, Pabellon 1 (1428) Buenos Aires, Argentina

Marco Stratmann‡
Radiation Laboratory, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

(Received 23 March 2007; published 22 June 2007)

We present new sets of pion and kaon fragmentation functions obtained in next-to-leading order combined analyses of single-inclusive hadron production in electron-positron annihilation, proton-proton collisions, and deep-inelastic lepton-proton scattering with either pions or kaons identified in the final state. At variance with all previous fits, the present analyses take into account data where hadrons of different electrical charge are identified, which allow one to discriminate quark from antiquark fragmentation functions without the need of nontrivial flavor symmetry assumptions. The resulting sets are in good agreement with all data analyzed, which cover a much wider kinematical range than in previous fits. A extensive use of the Lagrange multiplier technique is made in order to assess the uncertainties in t extraction of the fragmentation functions and the synergy from the complementary data sets in our gl analysis.

DOI: 10.1103/PhysRevD.75.114010

PACS numbers: 13.87.Fh, 12.38.Bx, 1

I. INTRODUCTION AND MOTIVATION

The hadronization process turns partons produced in hard-scattering reactions into the physical, colorless, nonperturbative hadronic bound states detected in experiments. Within the standard framework of leading-twist collinear QCD [1], processes with an observed hadron in the final state can be described in terms of perturbative hard-scattering cross sections and certain nonperturbative but universal functions: parton distributions, accounting for the partonic structure of the hadrons in the initial state just before the interaction, and fragmentation functions, encoding the details of the subsequent hadronization process [2].

These three ingredients are therefore the pillars of the perturbative QCD (pQCD) description of hard interactions; their precise knowledge has been crucial for its success in the past, and is imperative for the ongoing and future high energy research programs [3]. In the past few years, the improvement in each of these key areas has been remarkable. Higher order QCD calculations have been explored and validated for most processes up to next-to-leading order (NLO) accuracy, and are currently being extended even beyond that point for some observables [4].

The knowledge on parton distributions has become increasingly precise as a result of two decades of a wide variety of high precision measurements, and strenuous efforts to update and enlarge periodically the corresponding QCD analyses [5,6]. State-of-the-art sets of parton densities agree with each other well within the already fairly small estimated uncertainties, and provide a picture

of the proton structure fully consiste
most observables, and specifically fo
the present analysis, the differences
one or another modern set of parto
small compared with the uncert
ment or from unknown higher o
Also fragmentation function
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out attaining yet the precision
the information used to d
comes essentially from ele
charged hadrons. These d
tages of being very preci
surements from CERN
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addition to t
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PHYSICAL REVIEW D **91**, 014035 (2015)

Parton-to-pion fragmentation reloaded

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(Received 24 October 2014; published 29 January 2015)

We present a new, comprehensive global analysis of parton-to-pion fragmentation functions at leading-order accuracy in QCD. The obtained results are based on the latest experimental infor single-inclusive pion production in electron-positron annihilation, lepton-nucleon deep-inelastic and proton-proton collisions. An excellent description of all data sets is achieved, and th uncertainties in parton-to-pion fragmentation functions are estimated based on the Hess Extensive comparisons to the results from our previous global analysis are performed.

DOI: 10.1103/PhysRevD.91.014035

PACS numbers: 13.87.Fh, 1

I. INTRODUCTION AND MOTIVATION

The quantitative description of hard-scattering processes involving identified light hadrons in the final state requires a precise knowledge of how quarks and gluons hadronize. In the framework of perturbative QCD (pQCD), which we pursue in the following, this vital information is encoded in parton-to-hadron fragmentation functions (FFs) [1]. To match the increasing amount and precision of experimental results, the availability of reliable sets of FFs for a large variety of hadrons, in particular, for neutral and charged pions and kaons, as well as accurate estimates of their uncertainties is of the utmost relevance and the subject of this study.

Like parton distribution functions (PDFs), FFs are required in a pQCD calculation to consistently absorb classes of collinear parton-parton configurations distance physics, i.e., interactions happen- the actual hard-scattering process. tive quantities, and any

information about them ne preferably in a global QC obtained in a large variety are facilitated by assumi one to compute the rele matrix elements pertu predicts the scale evol way as for PDFs. Fr parton of flavor i four-momentum ta scale Q at which process. In wh $D_i^H(z, Q^2)$. All analysis of FF order (NLO) the kernels single-inclu annihilation [8], and inelastic A firs hadron

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(Received 22 February 2017; published 26 May 2017)

We revisit the global QCD analysis of parton-to-kaon fragmentation functions at next-to-le… accuracy using the latest experimental information on single-inclusive kaon production in elect… annihilation, lepton-nucleon deep-inelastic scattering, and proton-proton collisions. An exce… tion of all data sets is achieved, and the remaining uncertainties in parton-to-kaon fragment… are estimated and discussed based on the Hessian method. Extensive comparisons to the … previous global analysis are made.

DOI: 10.1103/PhysRevD.95.094019

I. INTRODUCTION AND MOTIVATION

Parton-to-hadron fragmentation functions (FFs) parametrize how quarks and gluons that are produced in hard … at high energies confine themselves into … and identified in experiment [1]. This … the reach of perturbative quantum … must therefore be inferred … hadron production …

Precise parton-to-kaon … key ingredient to prob… nucleon and are expec… further constraining th… butions at a future … charged kaon produ… scattering (SIDIS) … helicity dependent … $\Delta\bar{s}$ [5,6], largely … experimental co… weak deep-inel…

Kaon FFs update:

Several relevant new data sets since DSS07

Belle, BaBar, Compass, Hermes, Star, Alice

Pion FFs update DSS14

arXiv:1410.6027

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Belle, BaBar $e^+e^- \longrightarrow K^\pm + X$ Q ~10 GeV

DSS07 20% off at z~0.6 D_c

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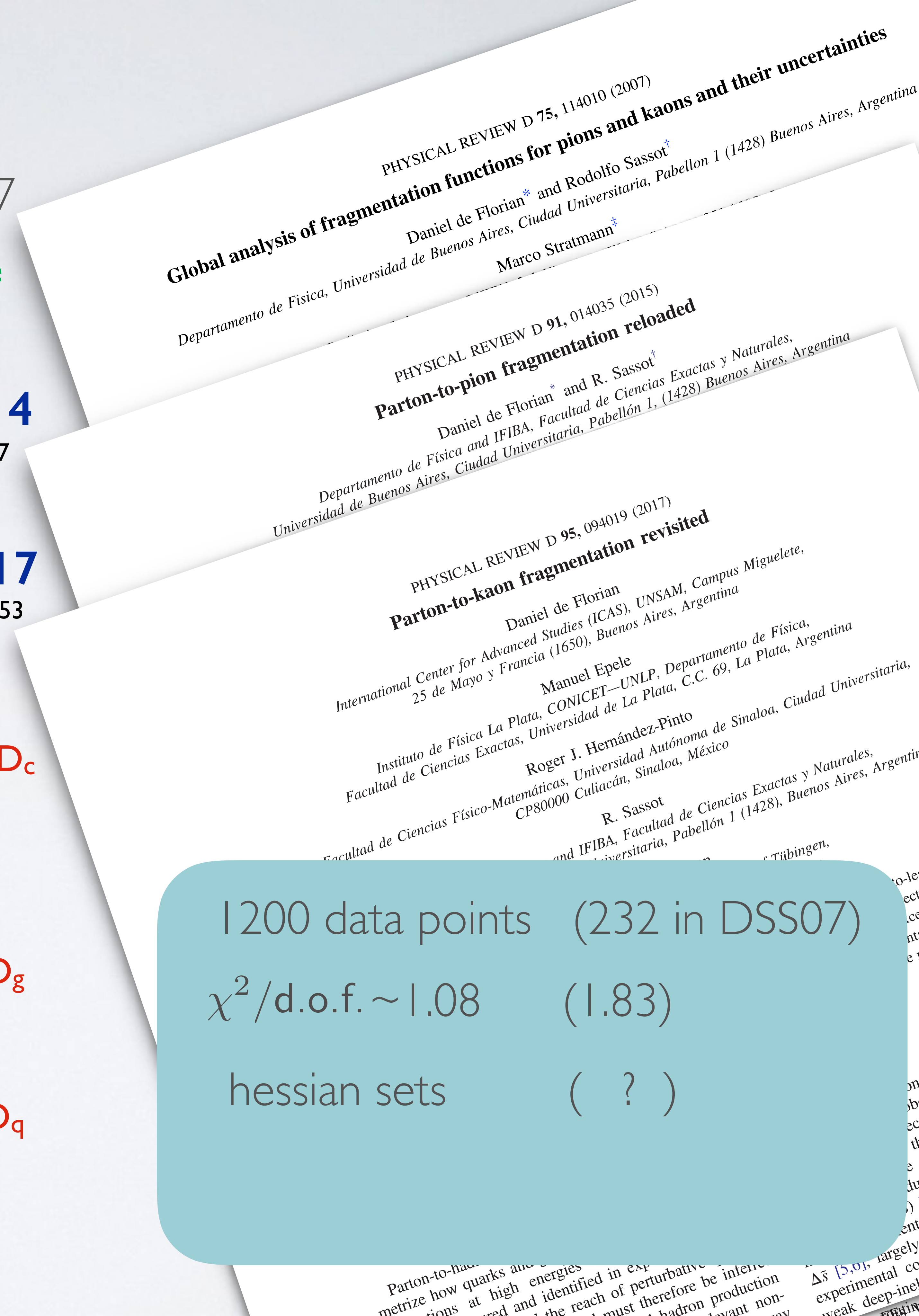
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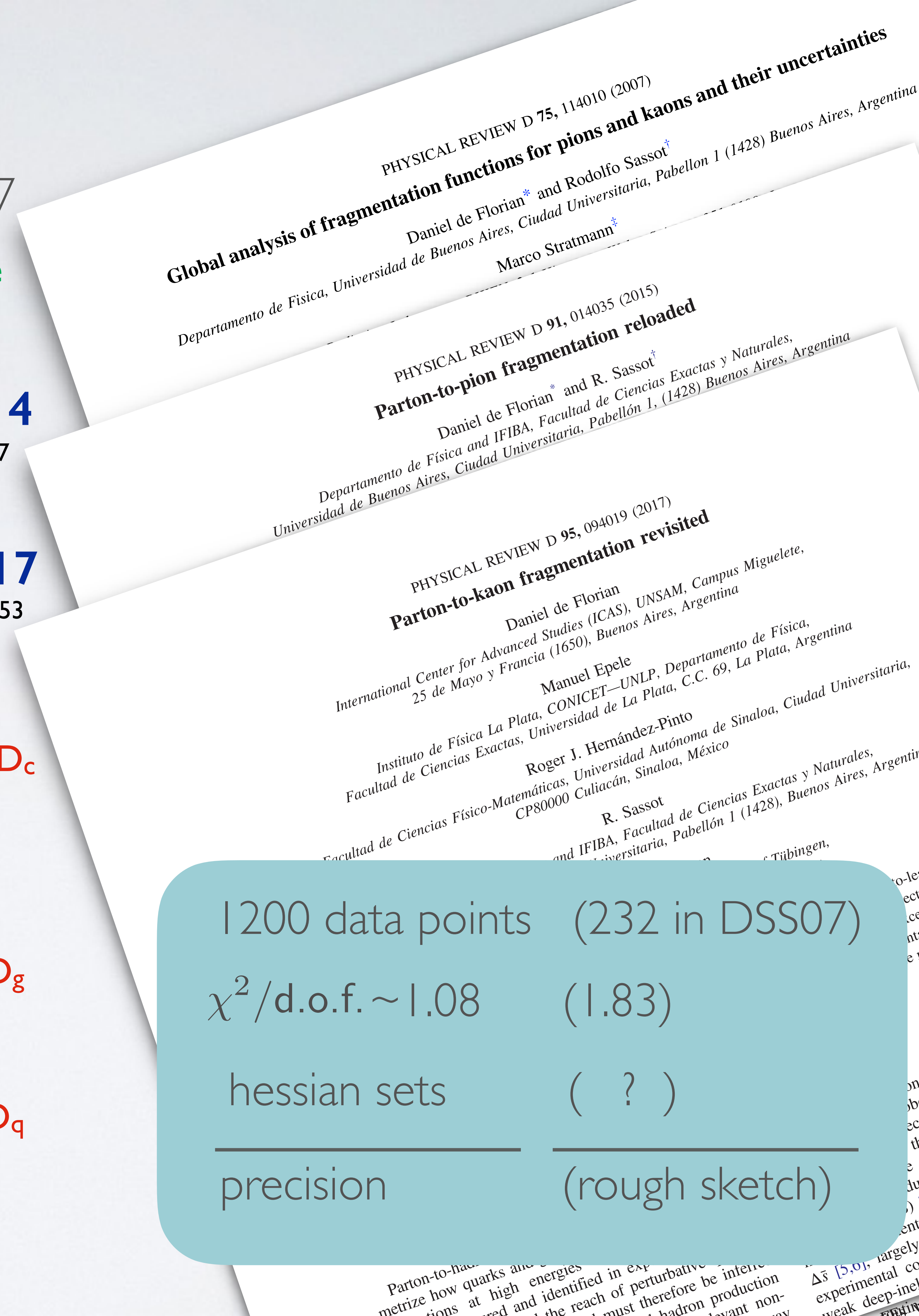

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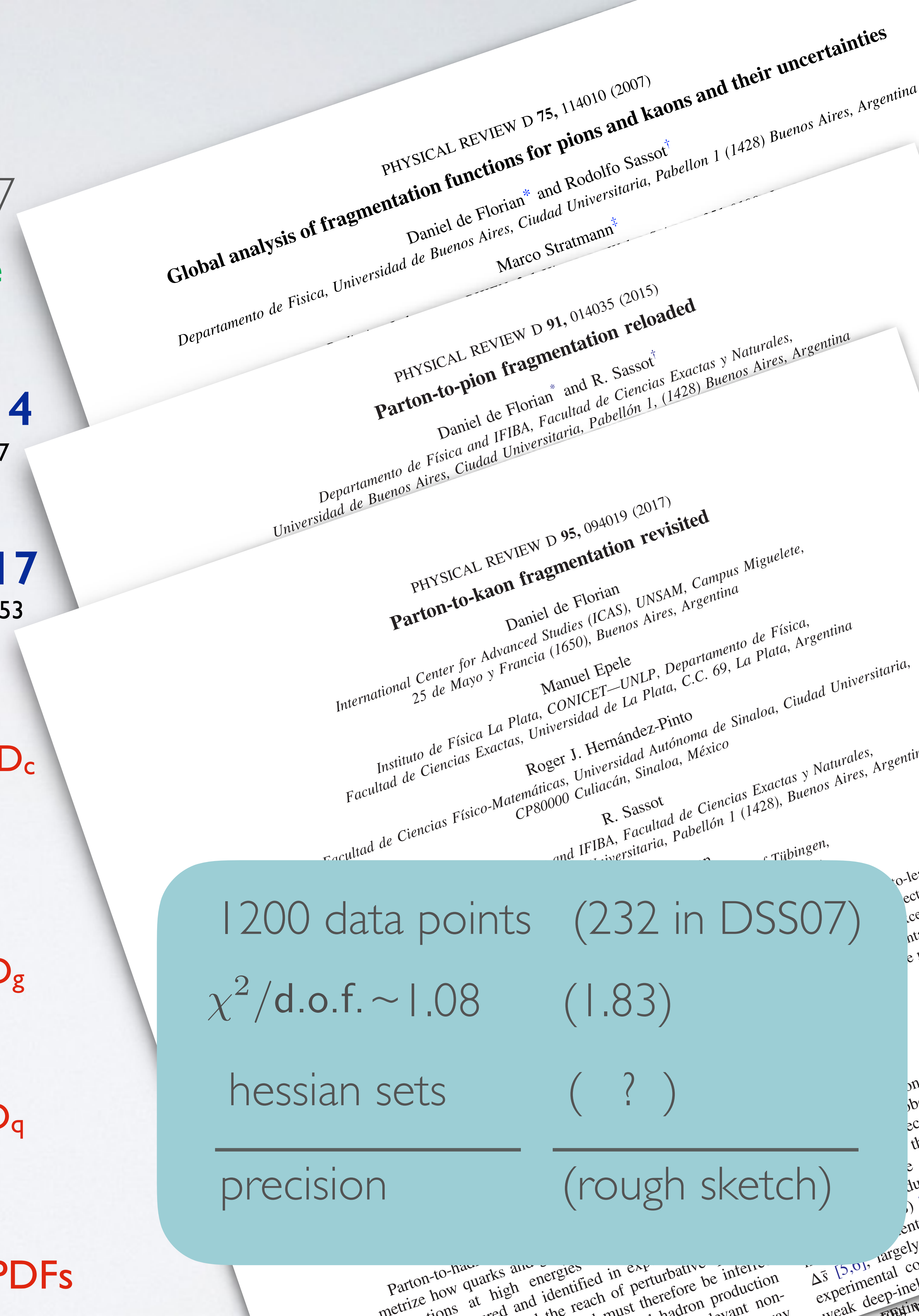
sensitivity to sea quarks PDFs



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68 and 90 % CL error estimates (improved hessian)

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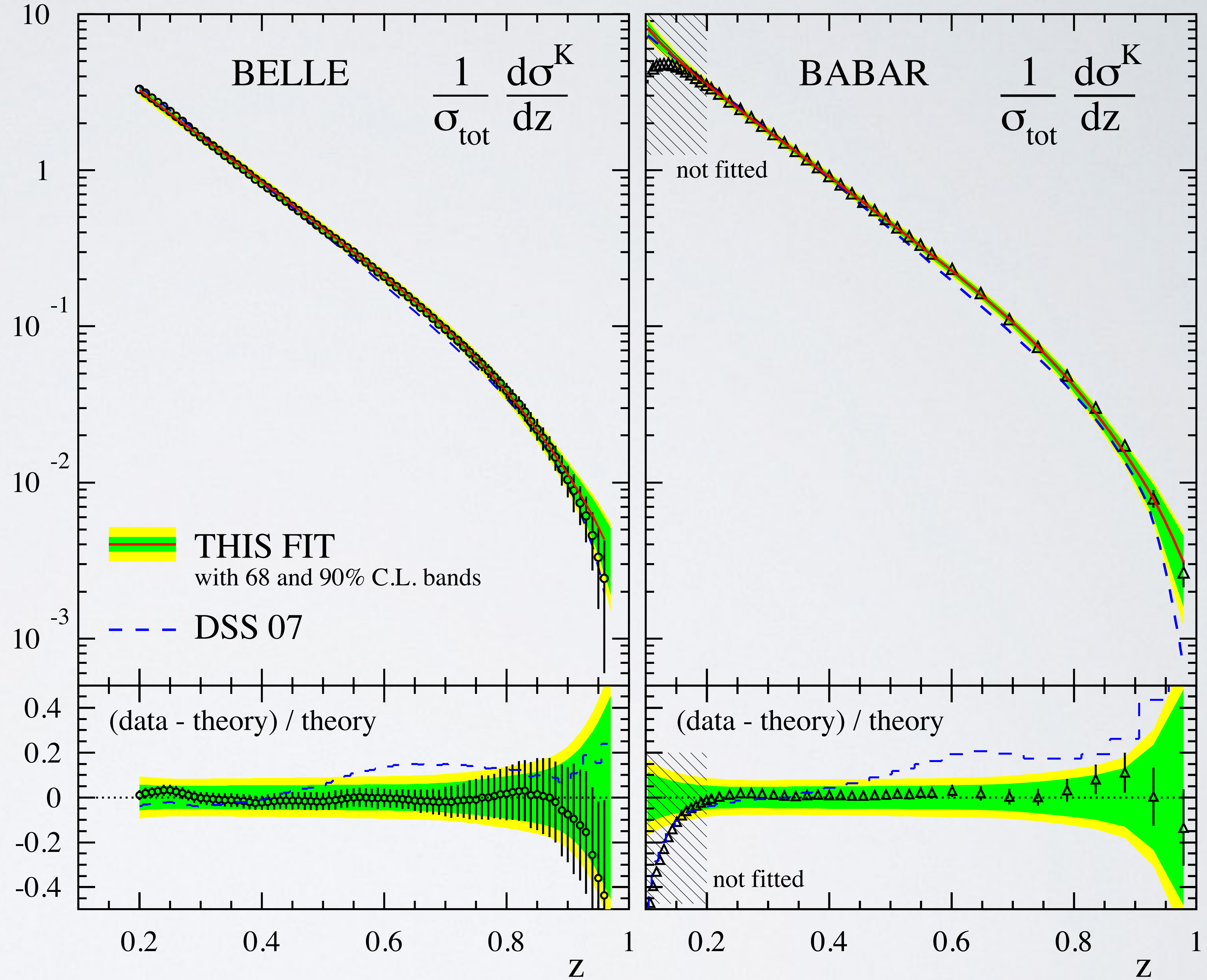

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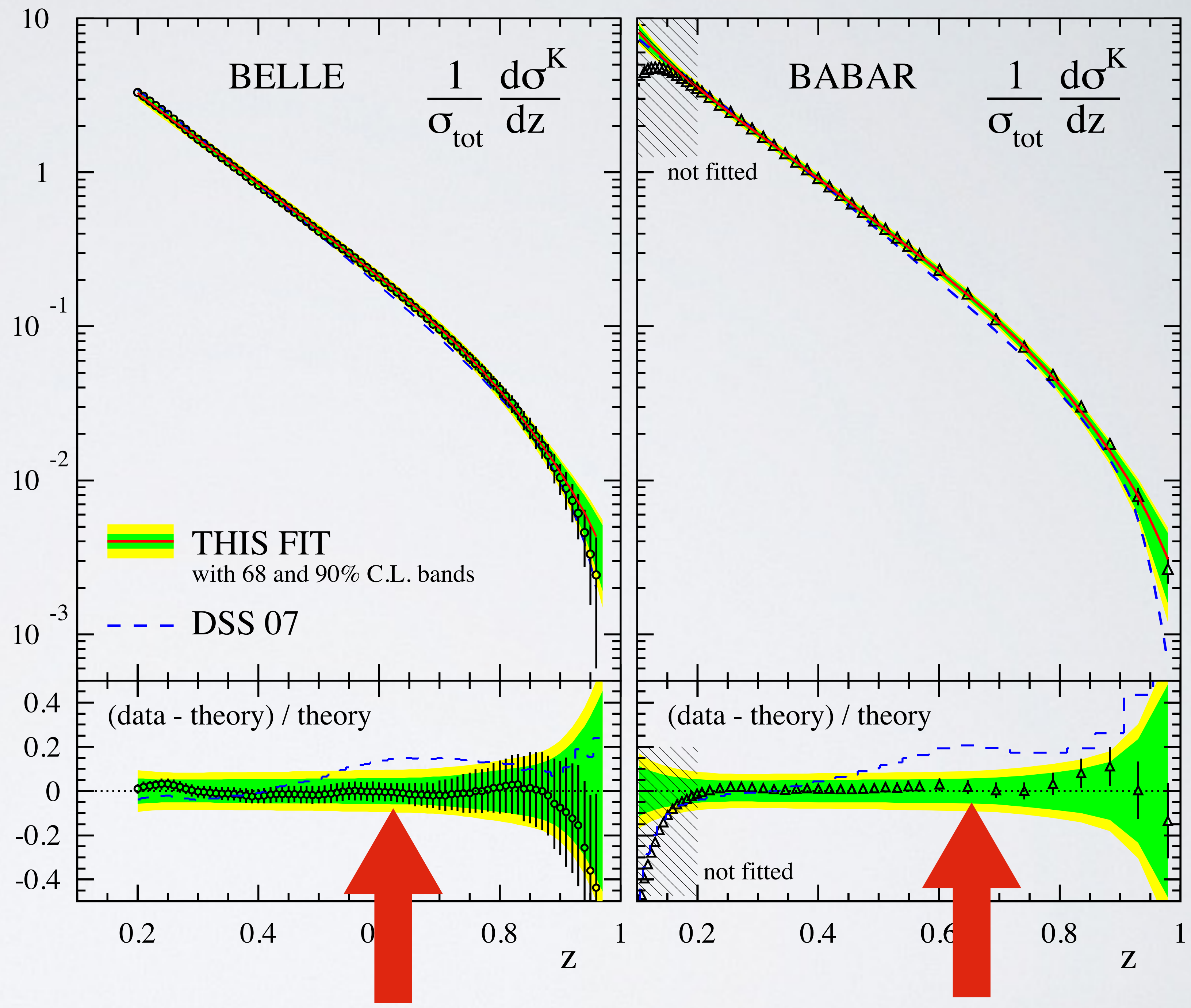

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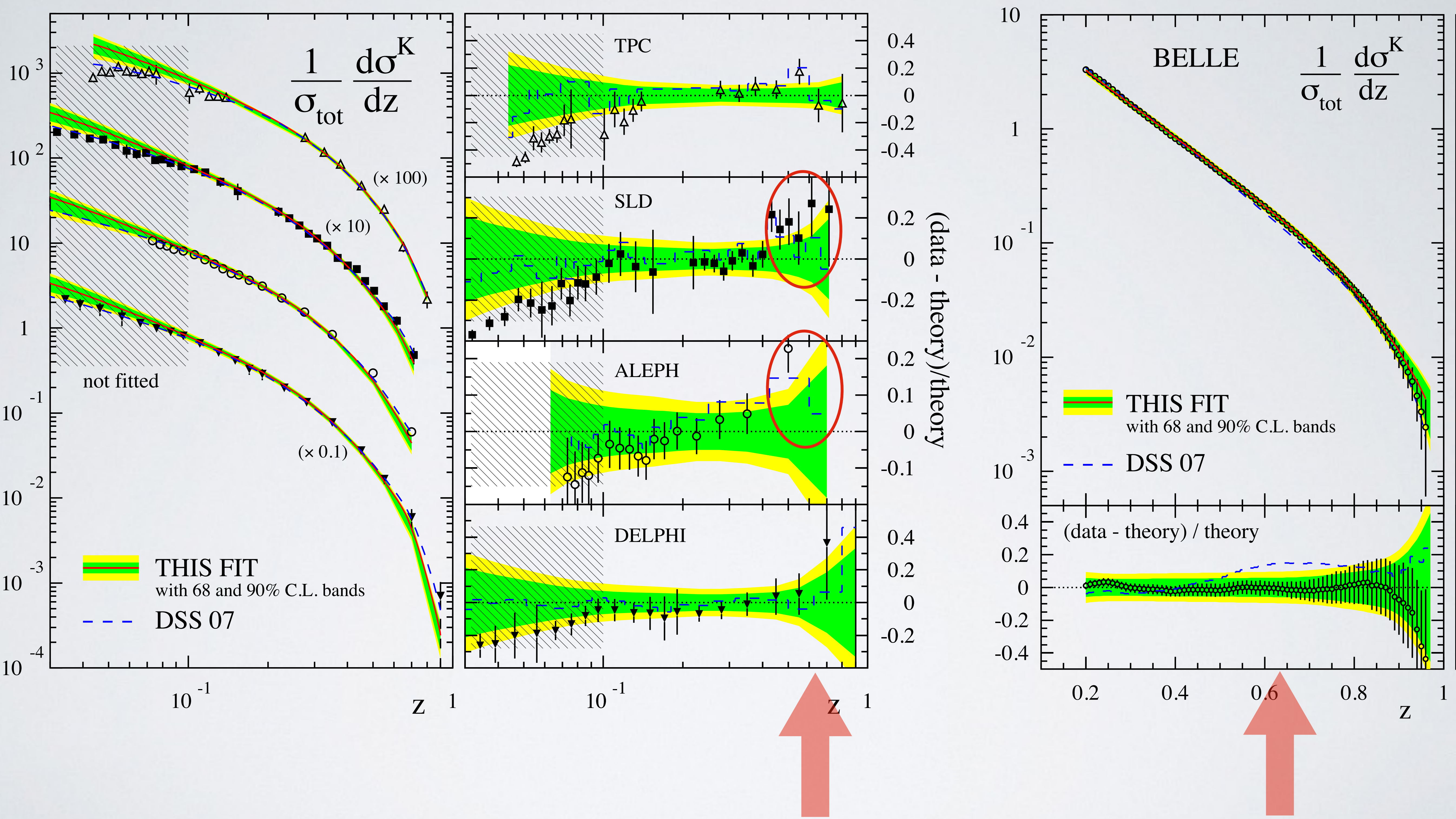

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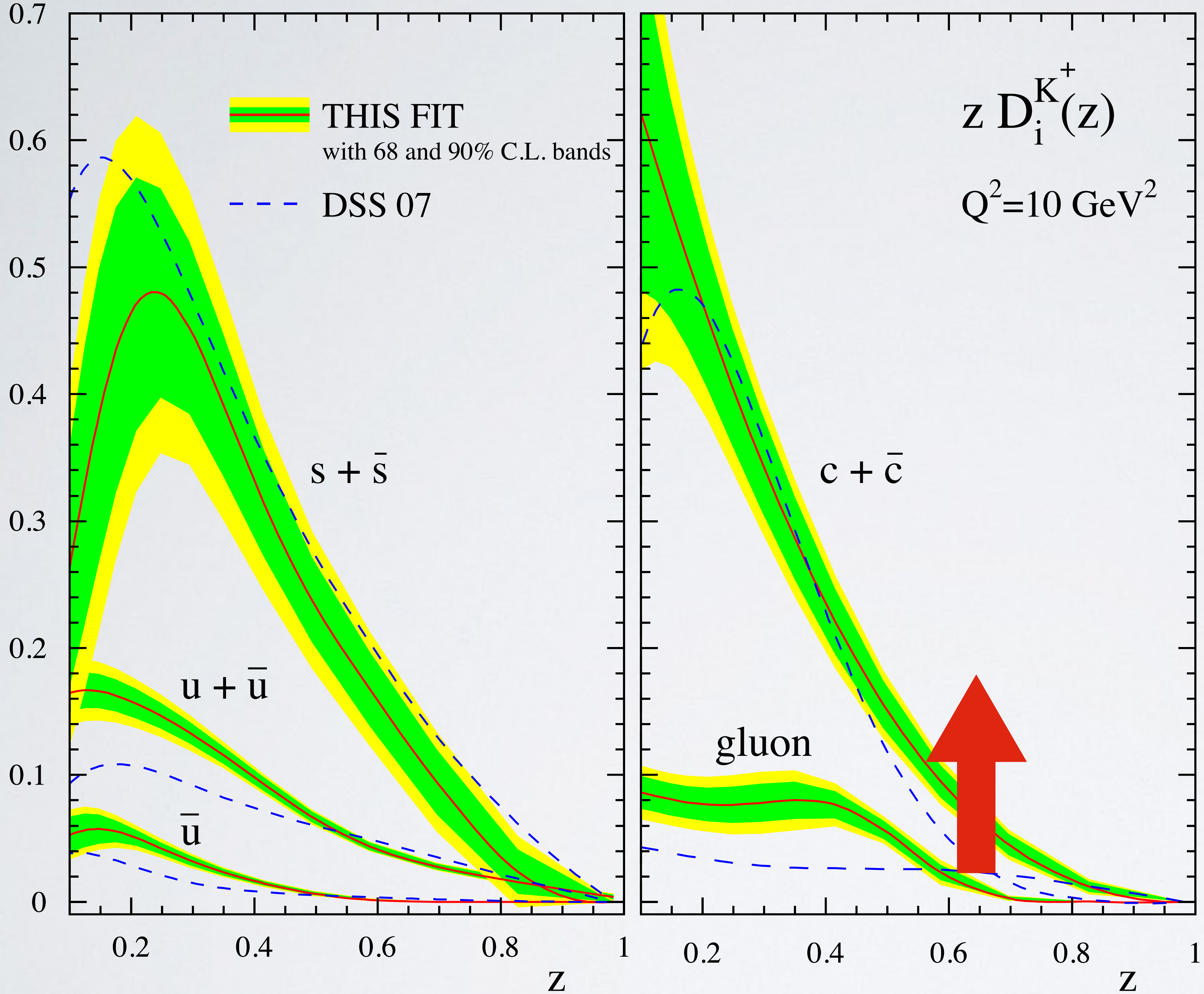
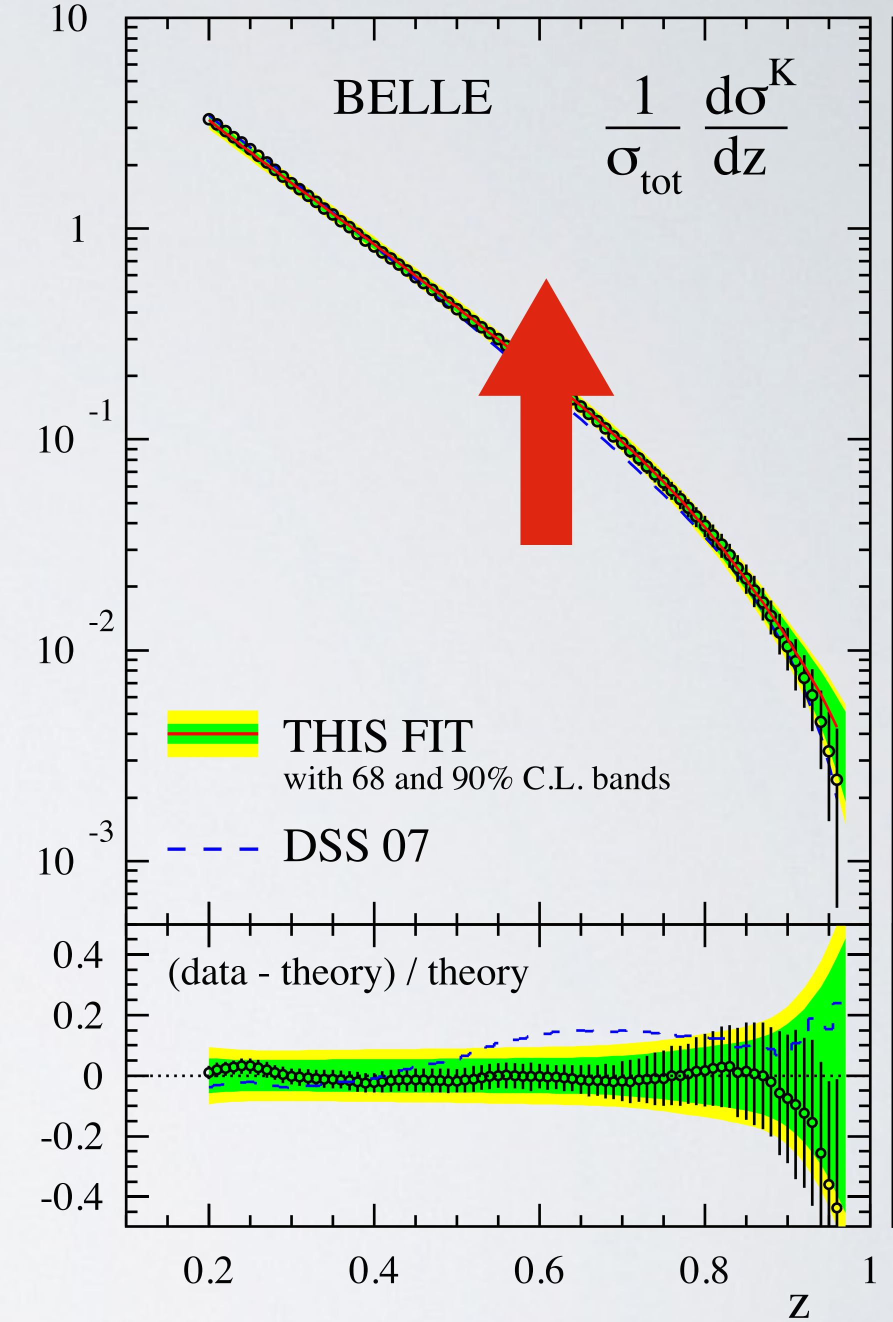
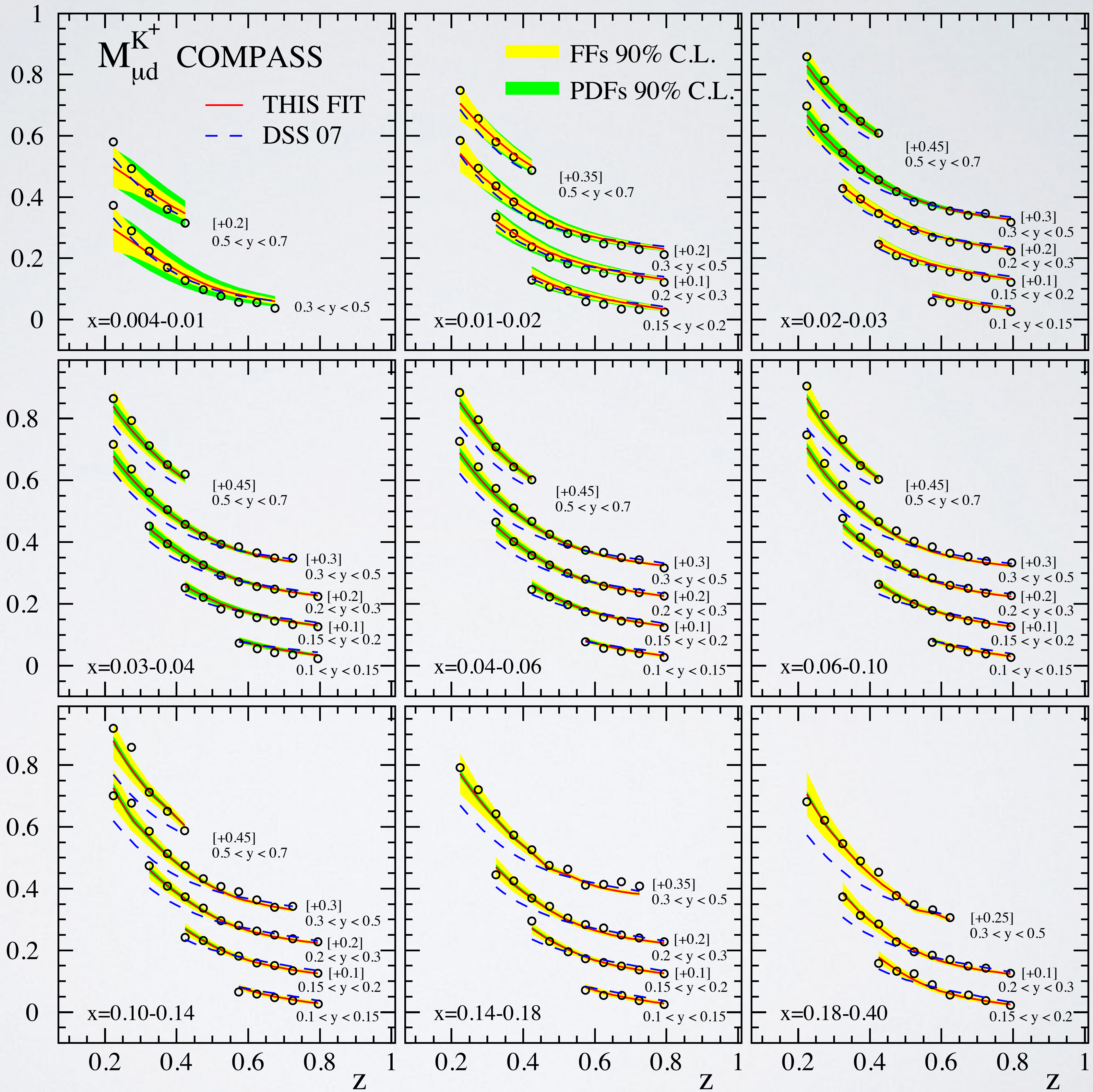




charm growth at large z

SIDIS: charge and flavor separation



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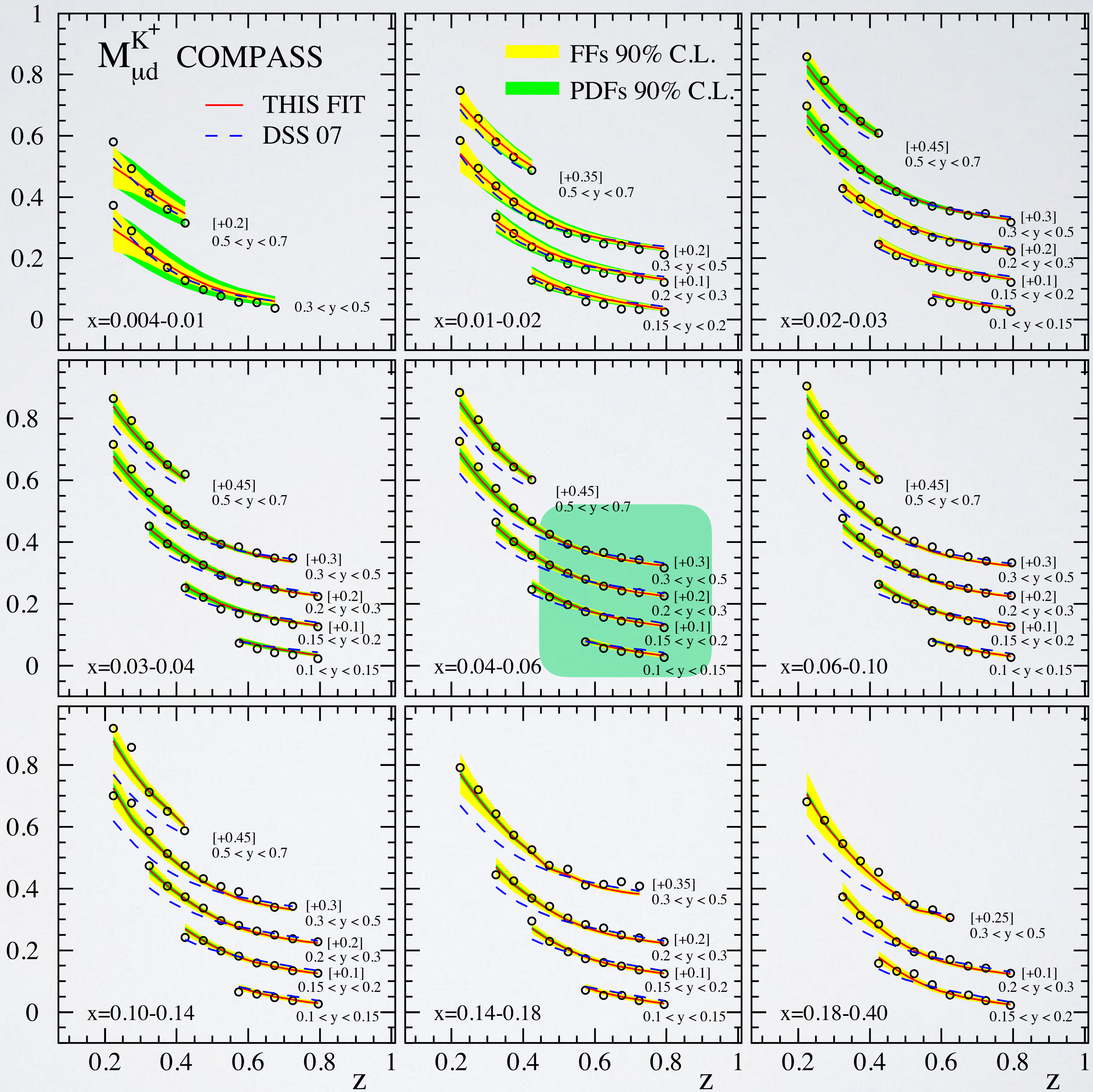

no difference at large z (no charm)

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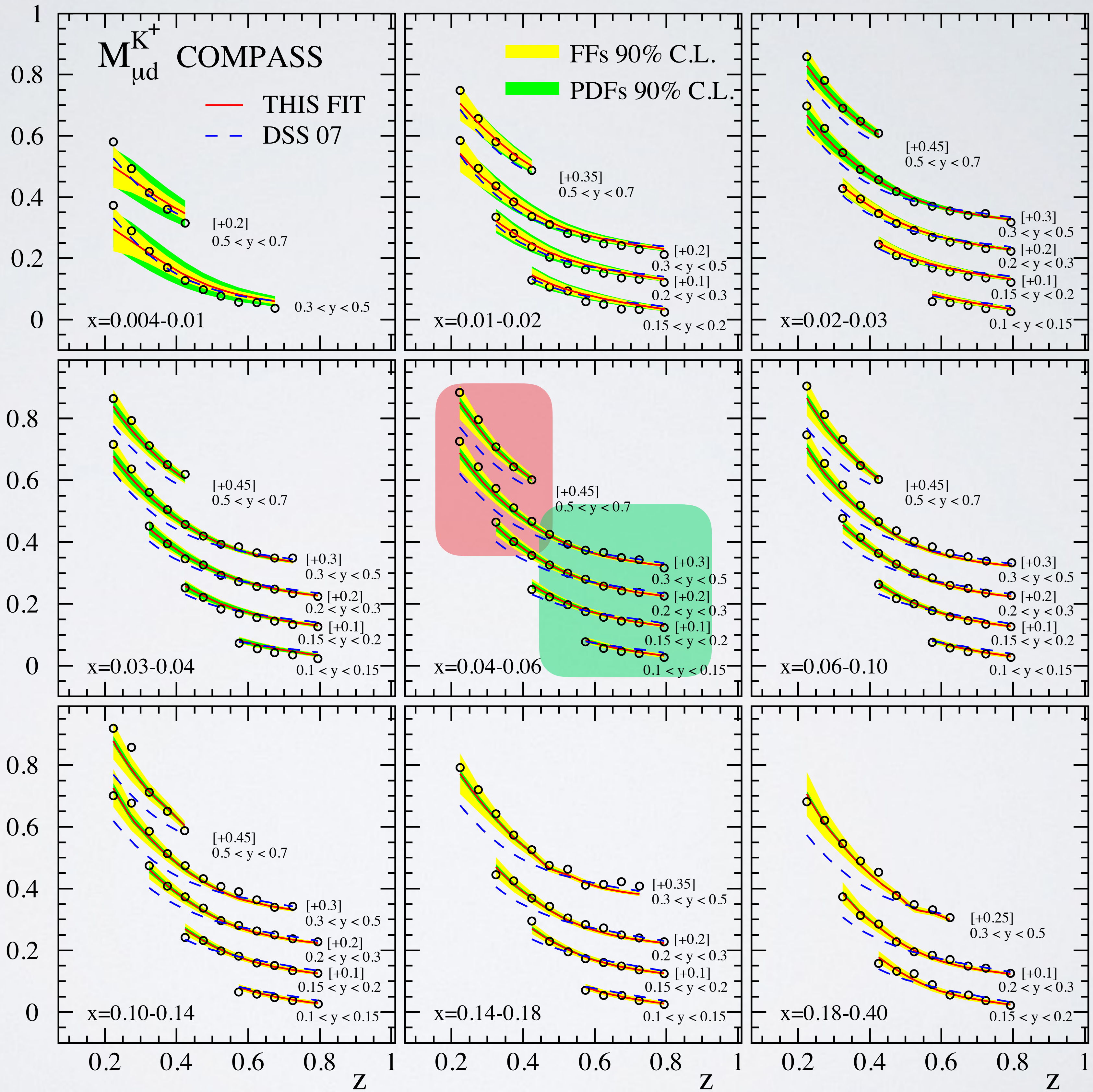

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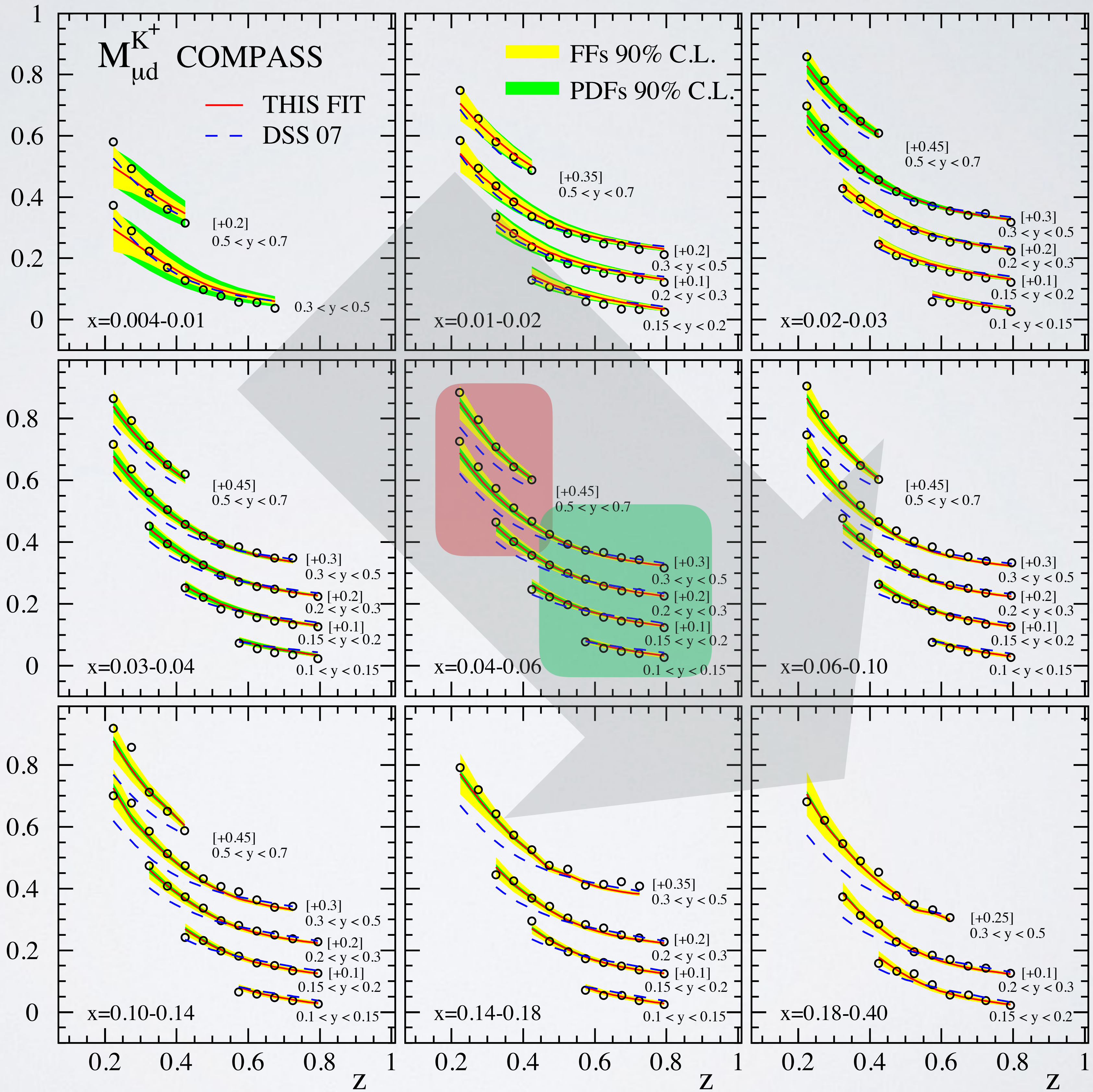

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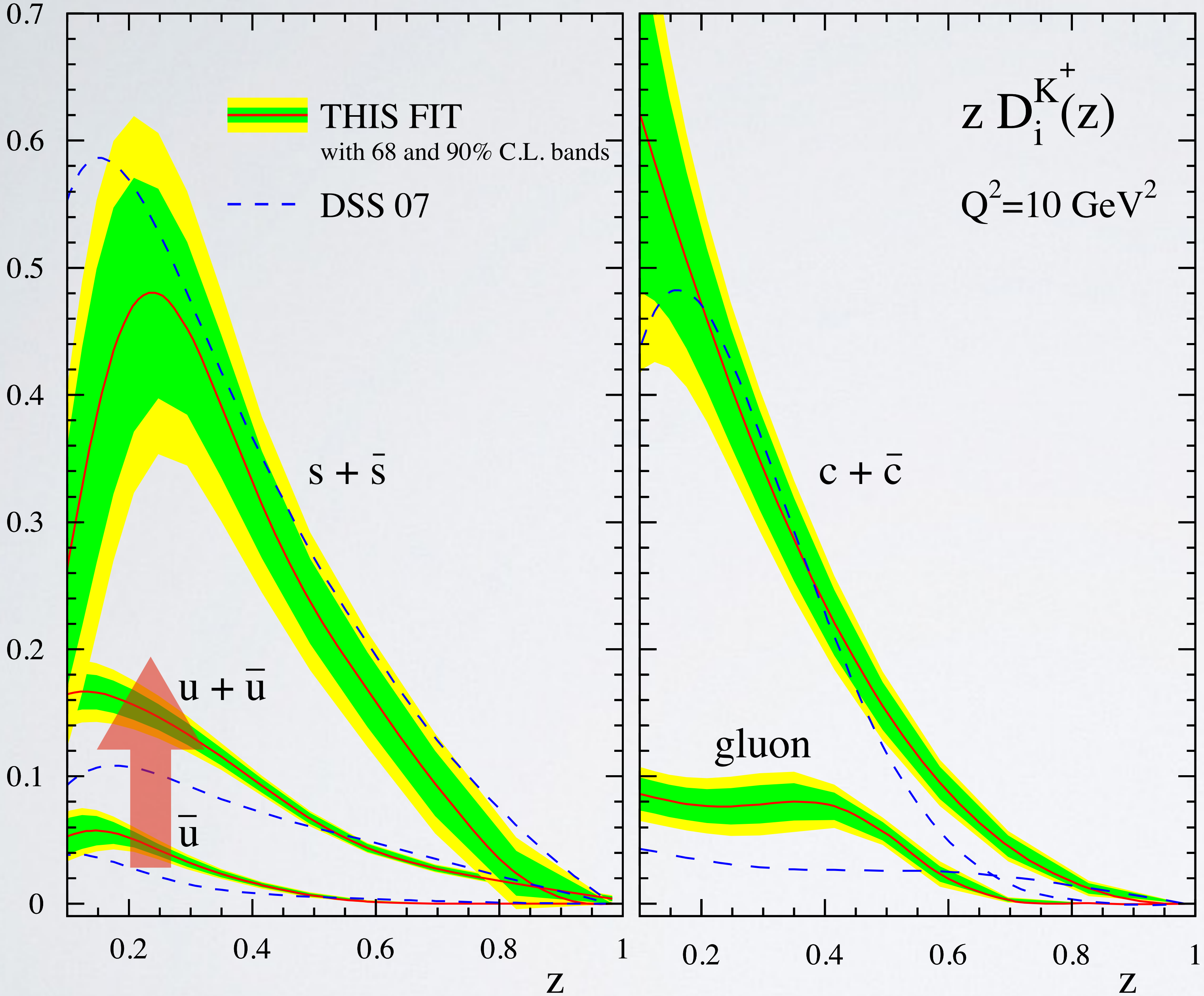

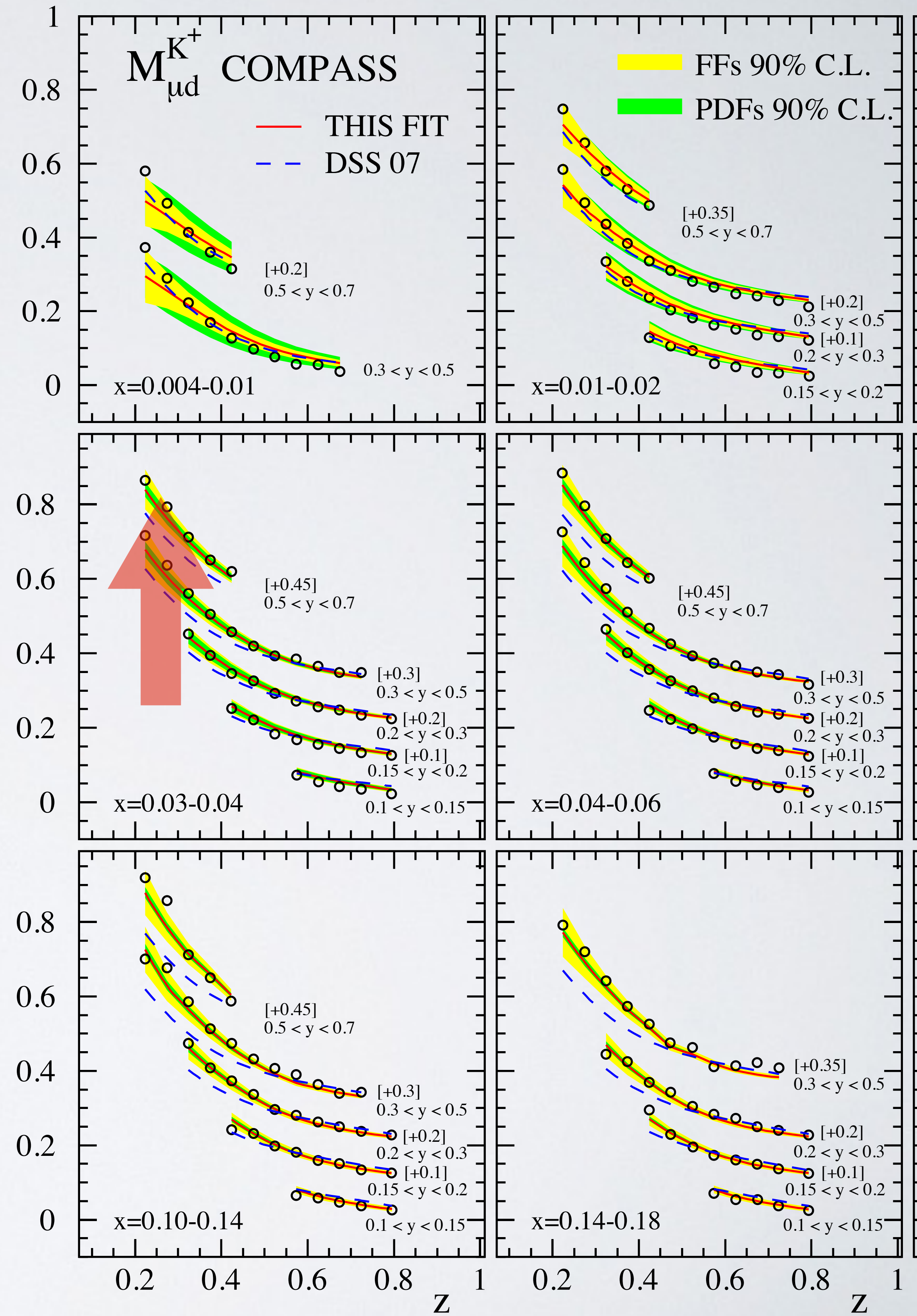

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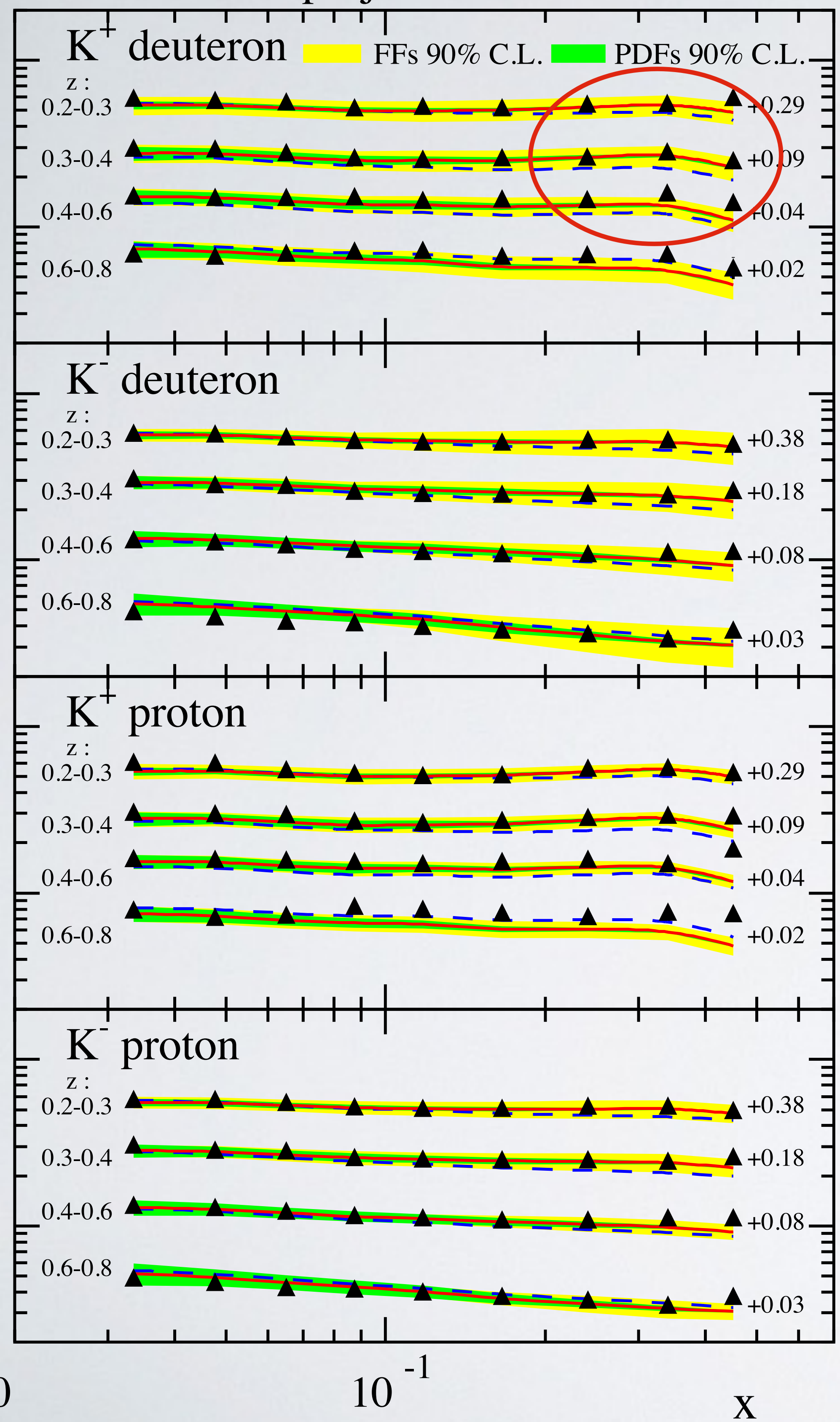
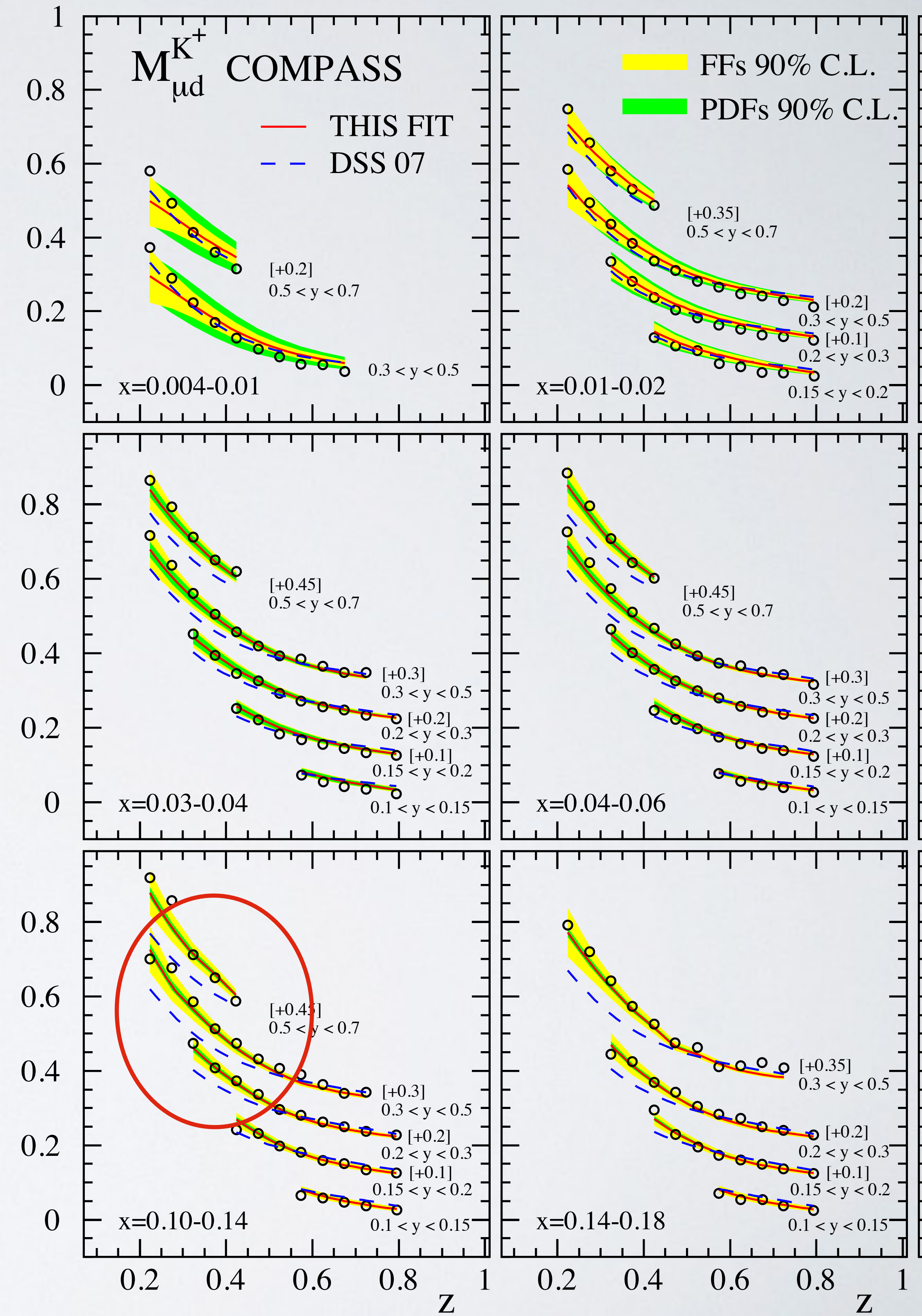
this is why SIDIS matter!

SIDIS: charge and flavor separation

HERMES z-x projection





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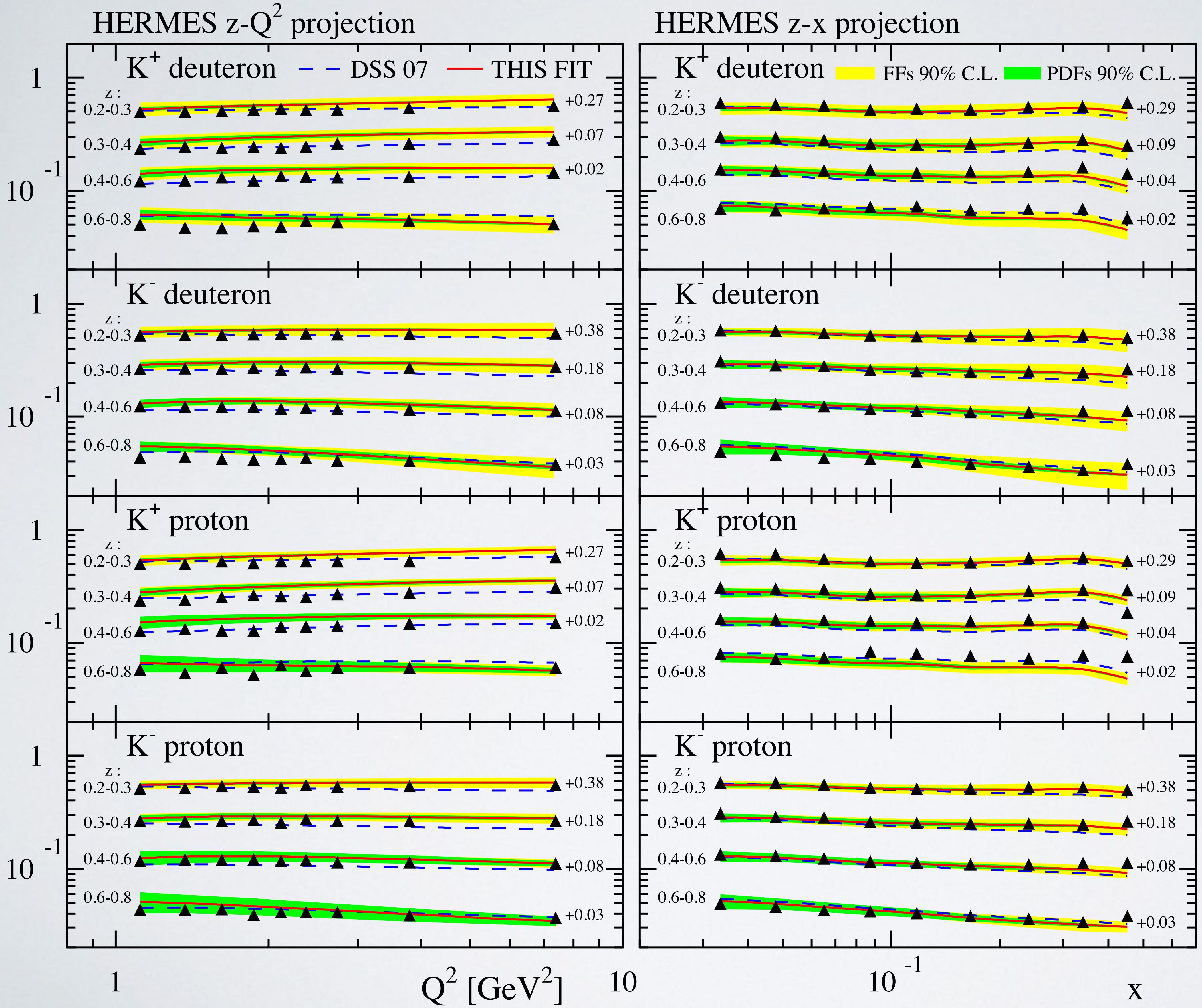

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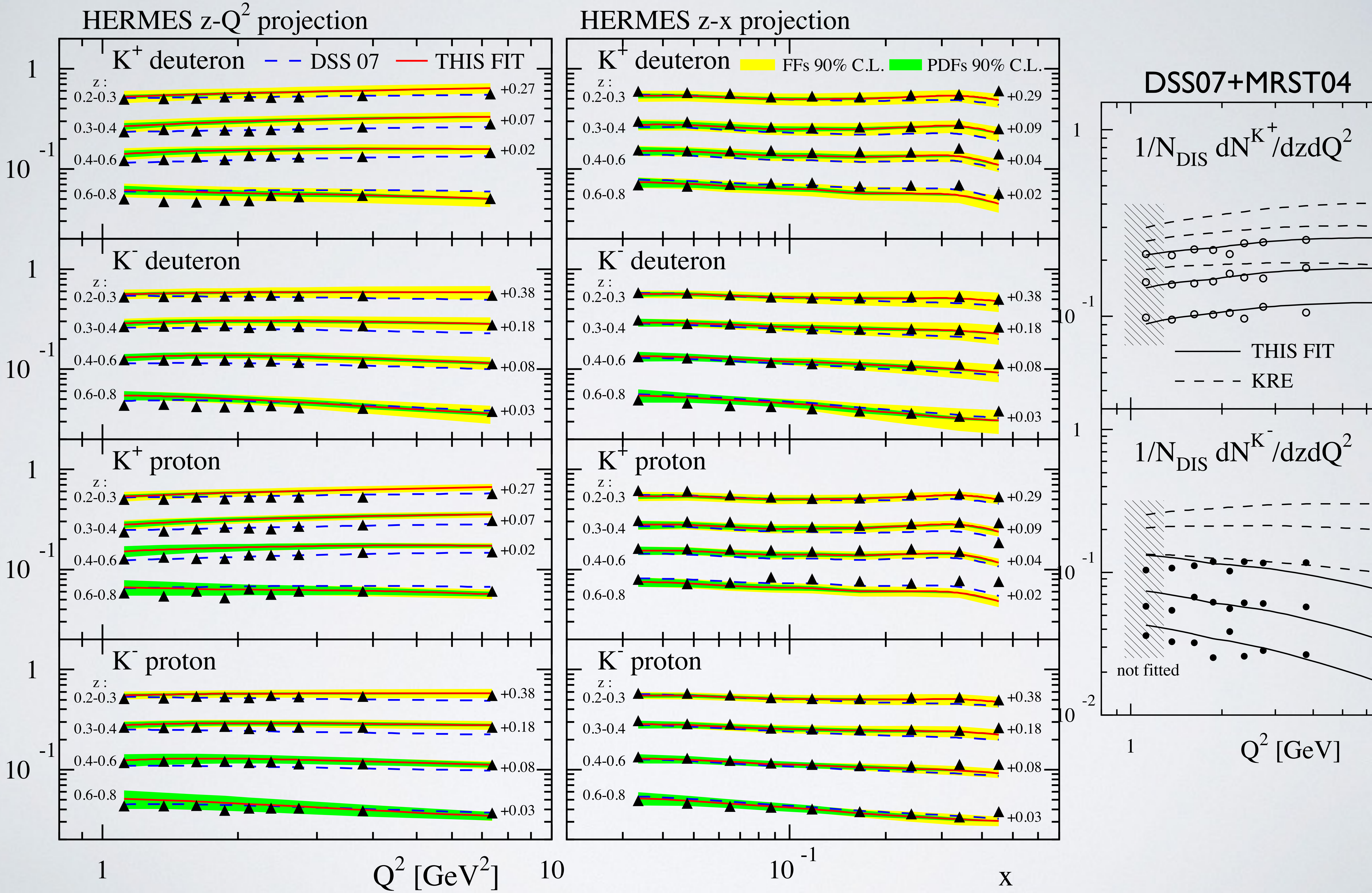

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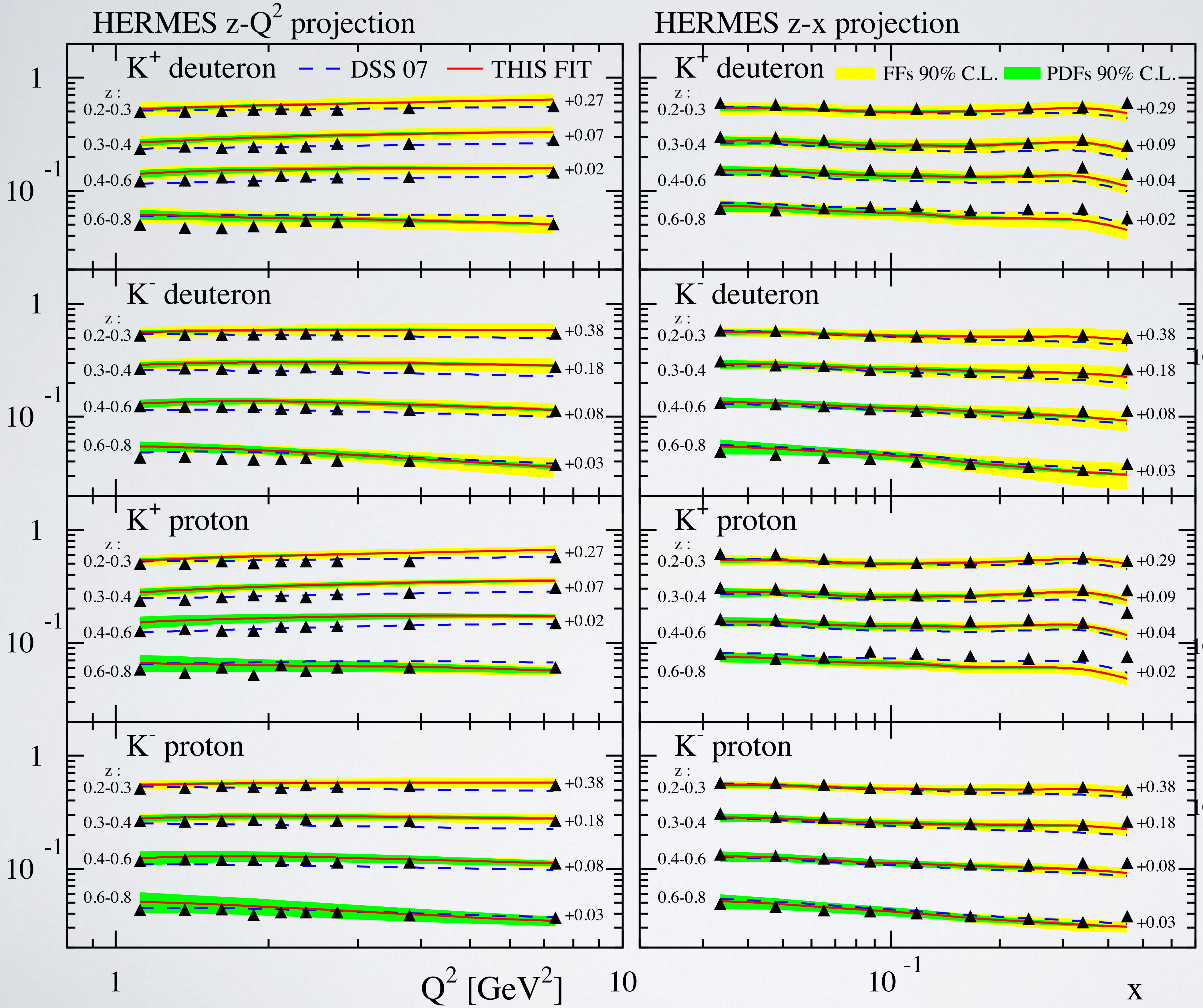

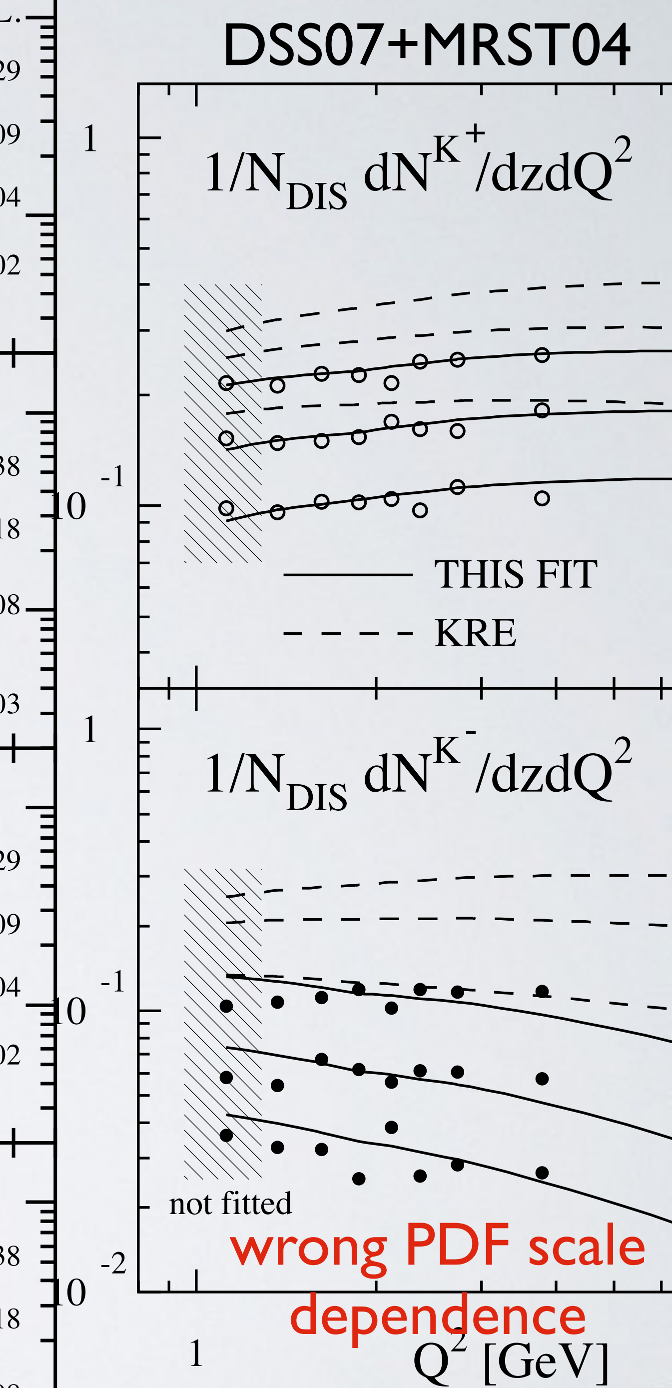

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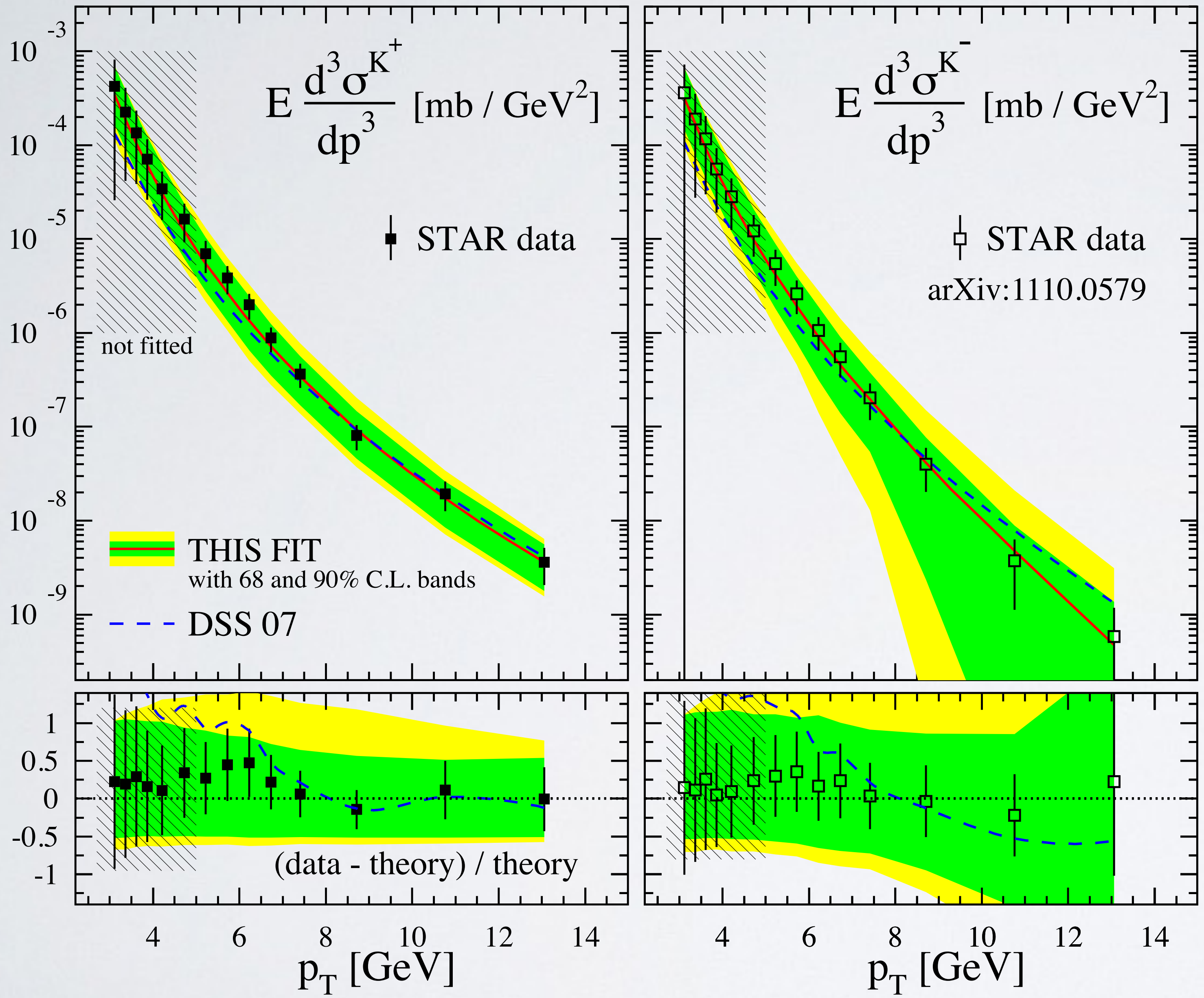

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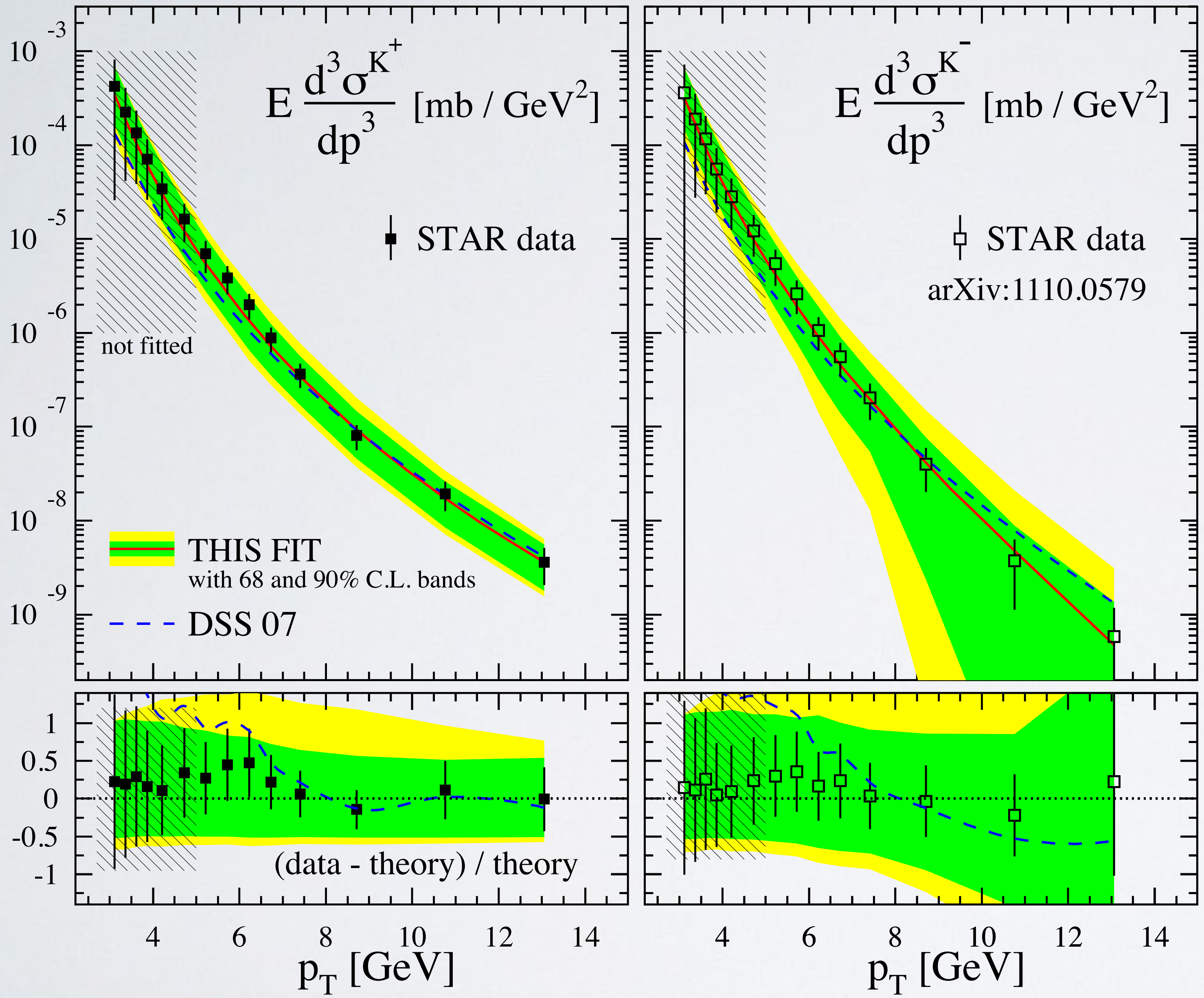

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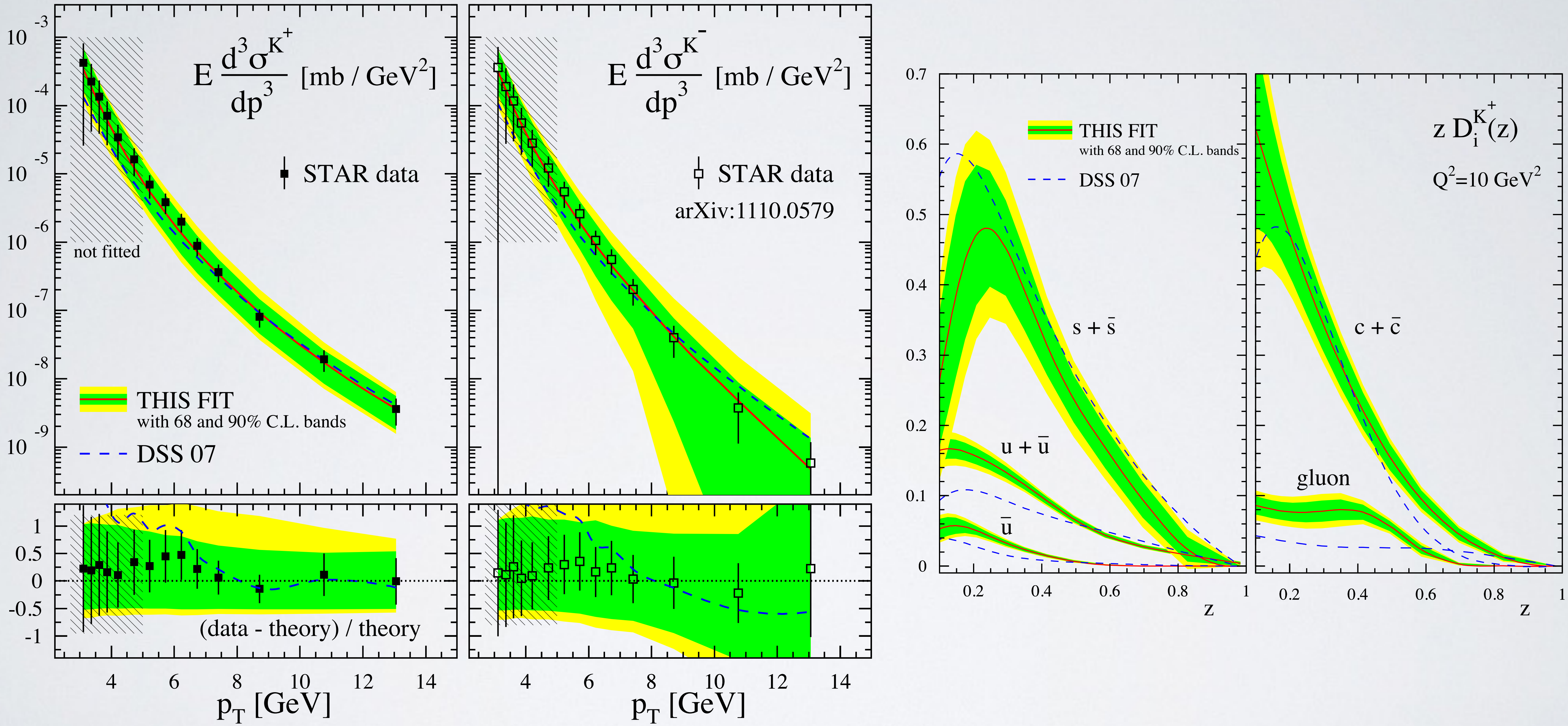

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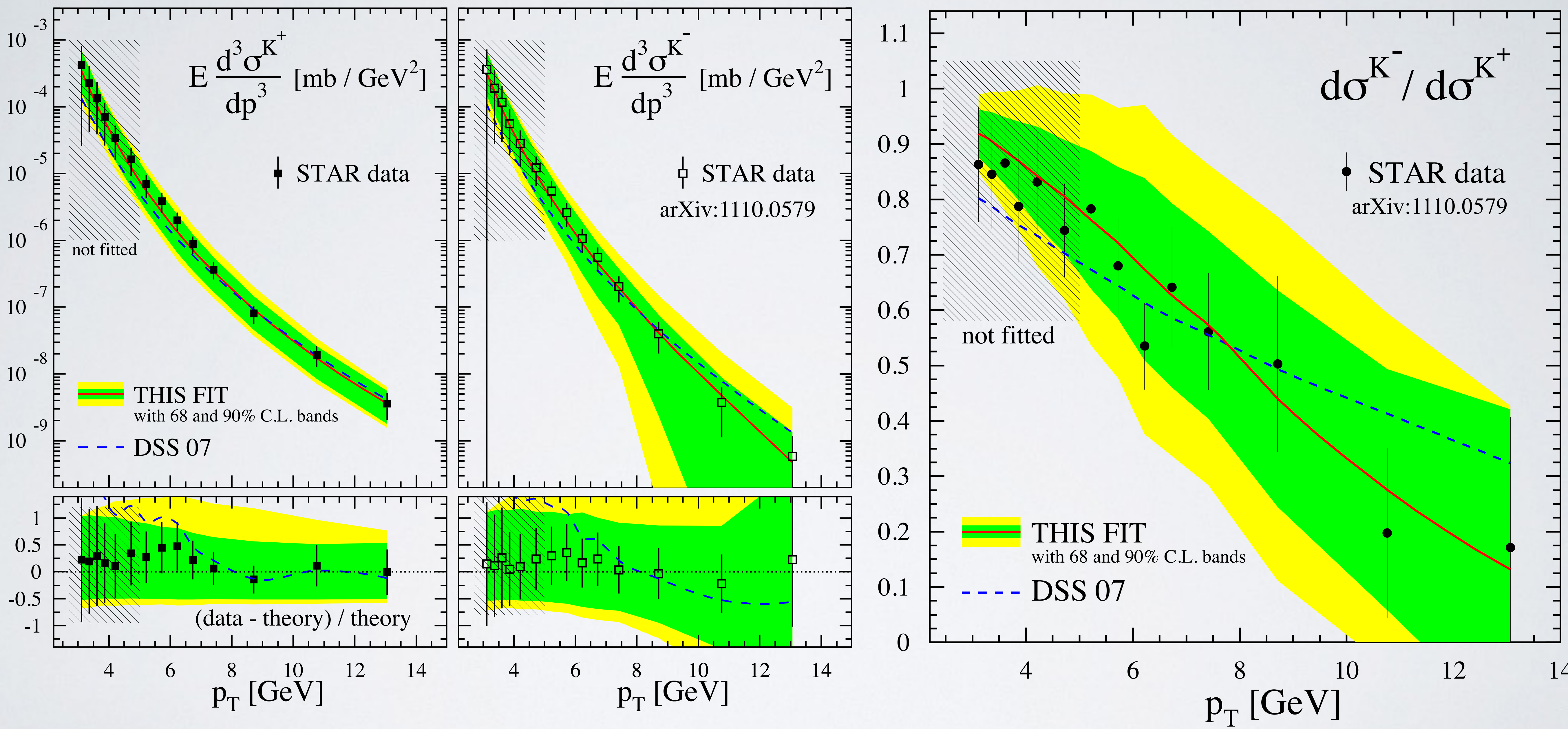

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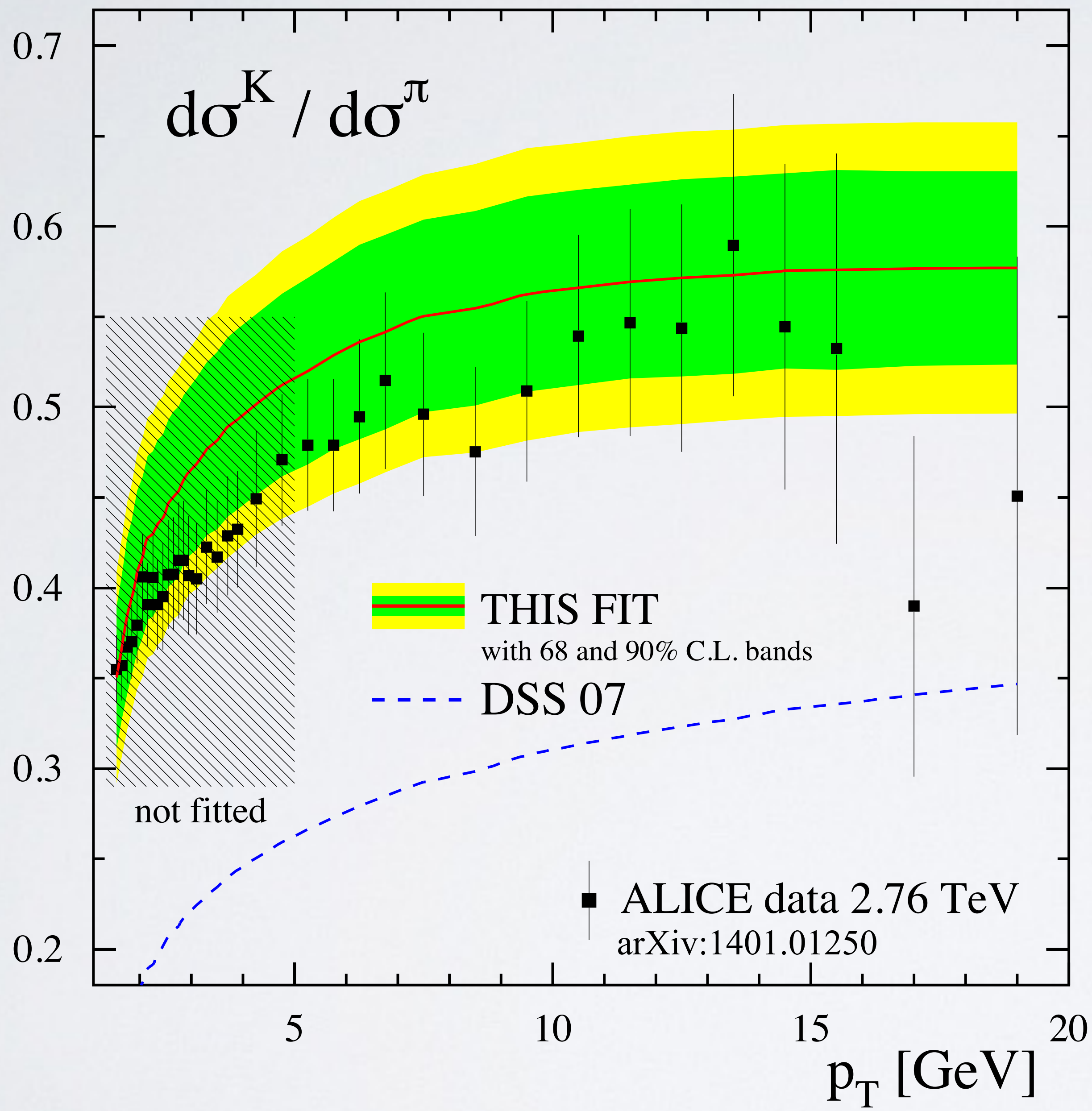
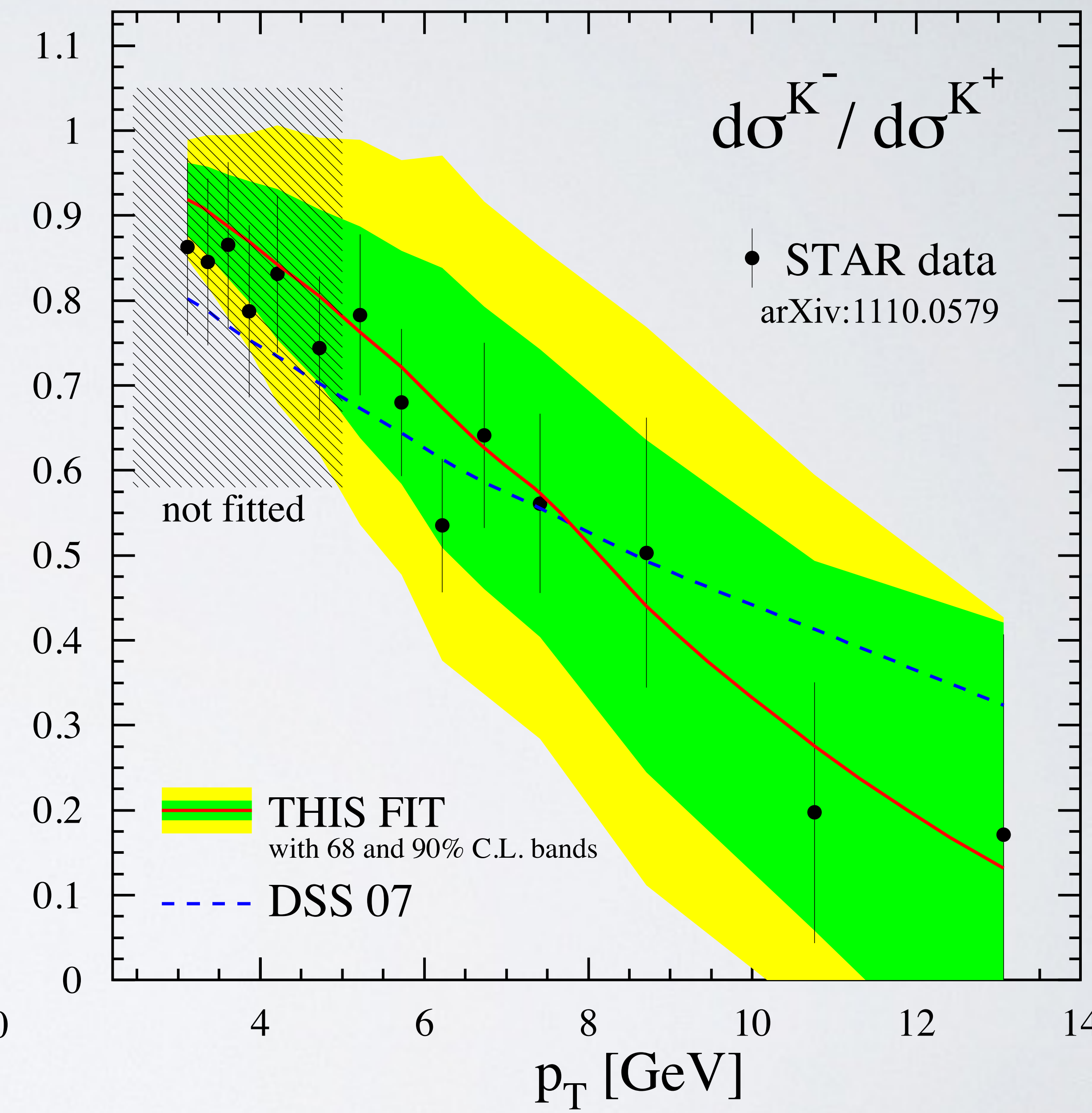
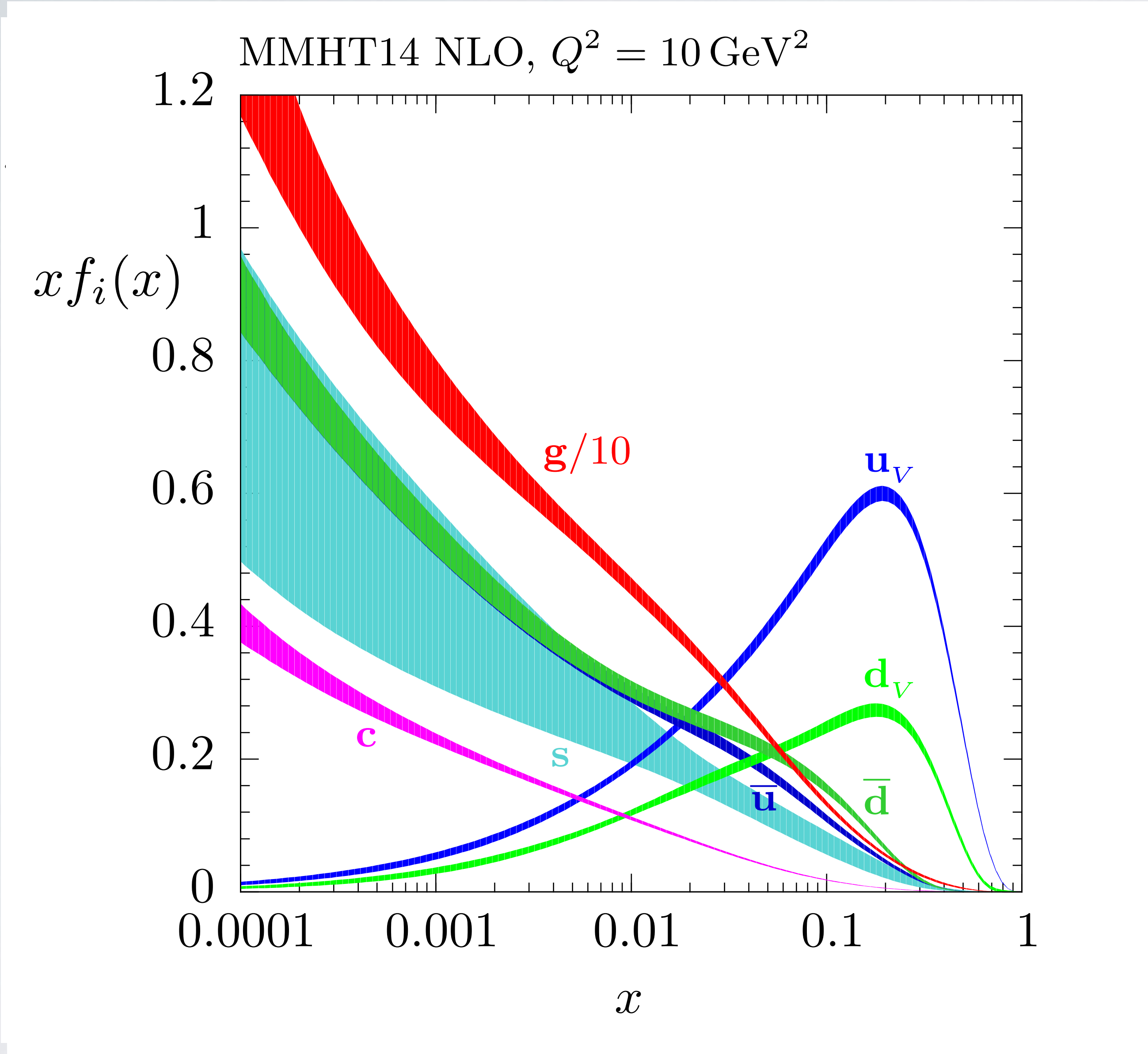




are PDFs that good?



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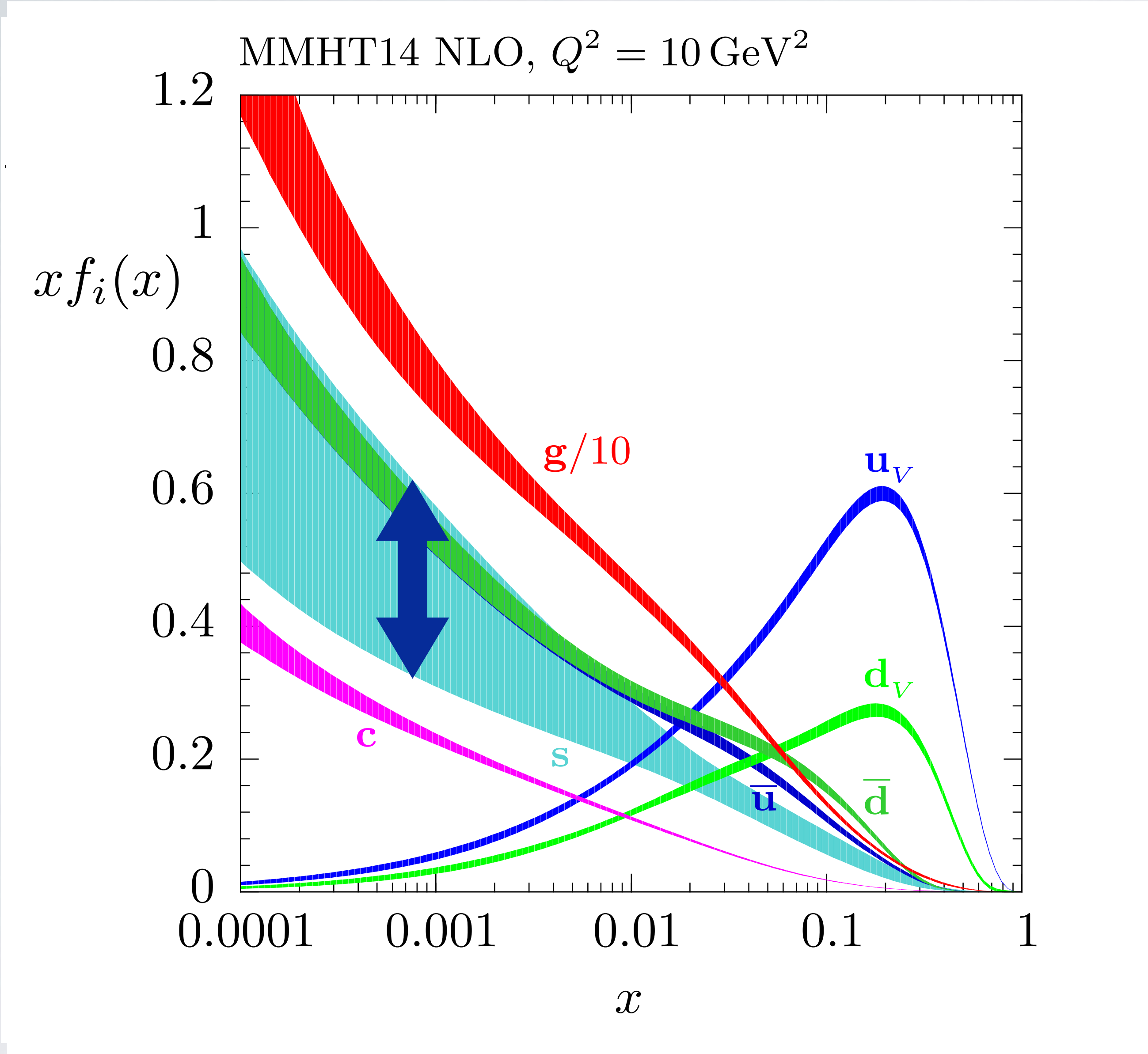

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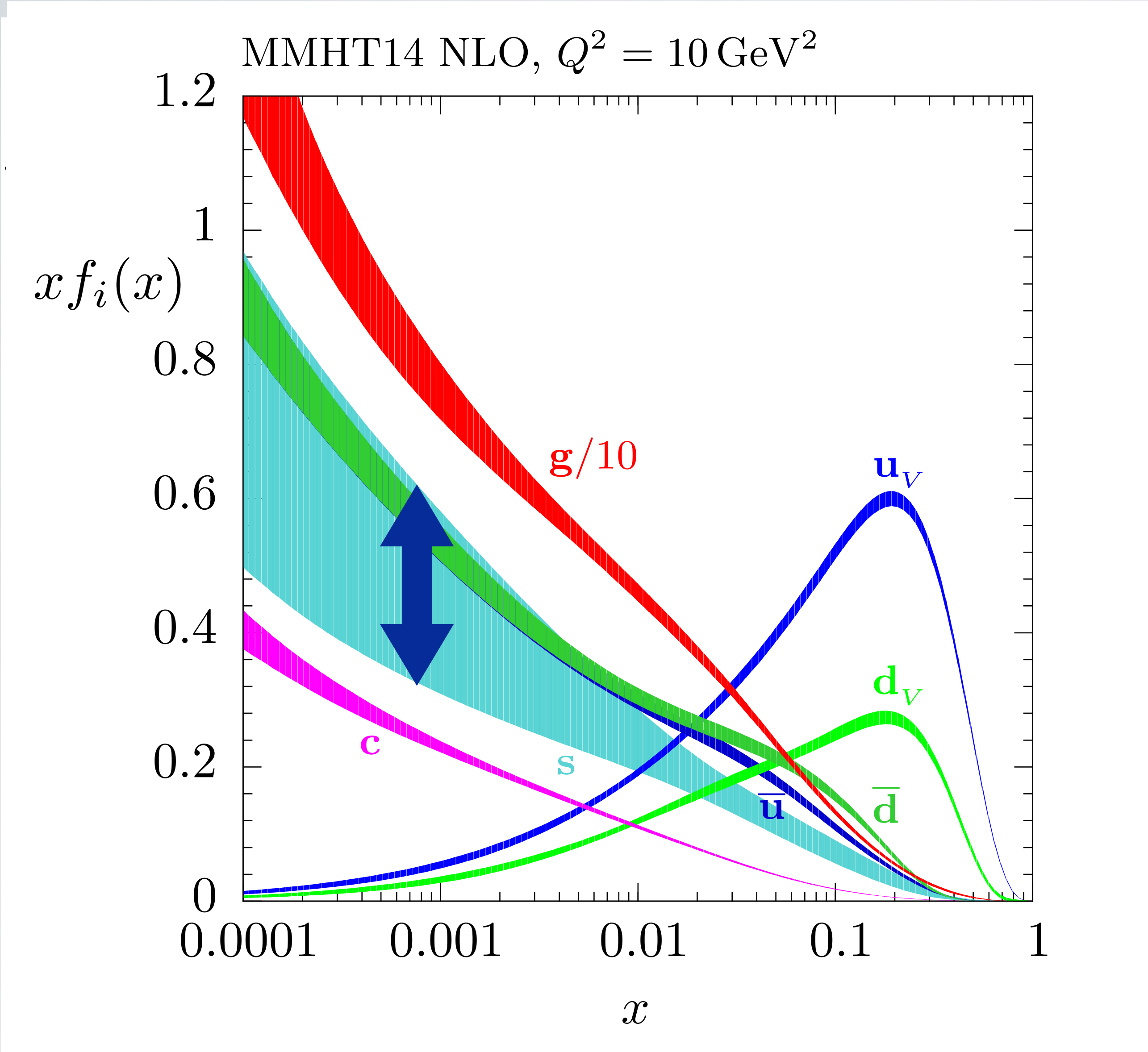

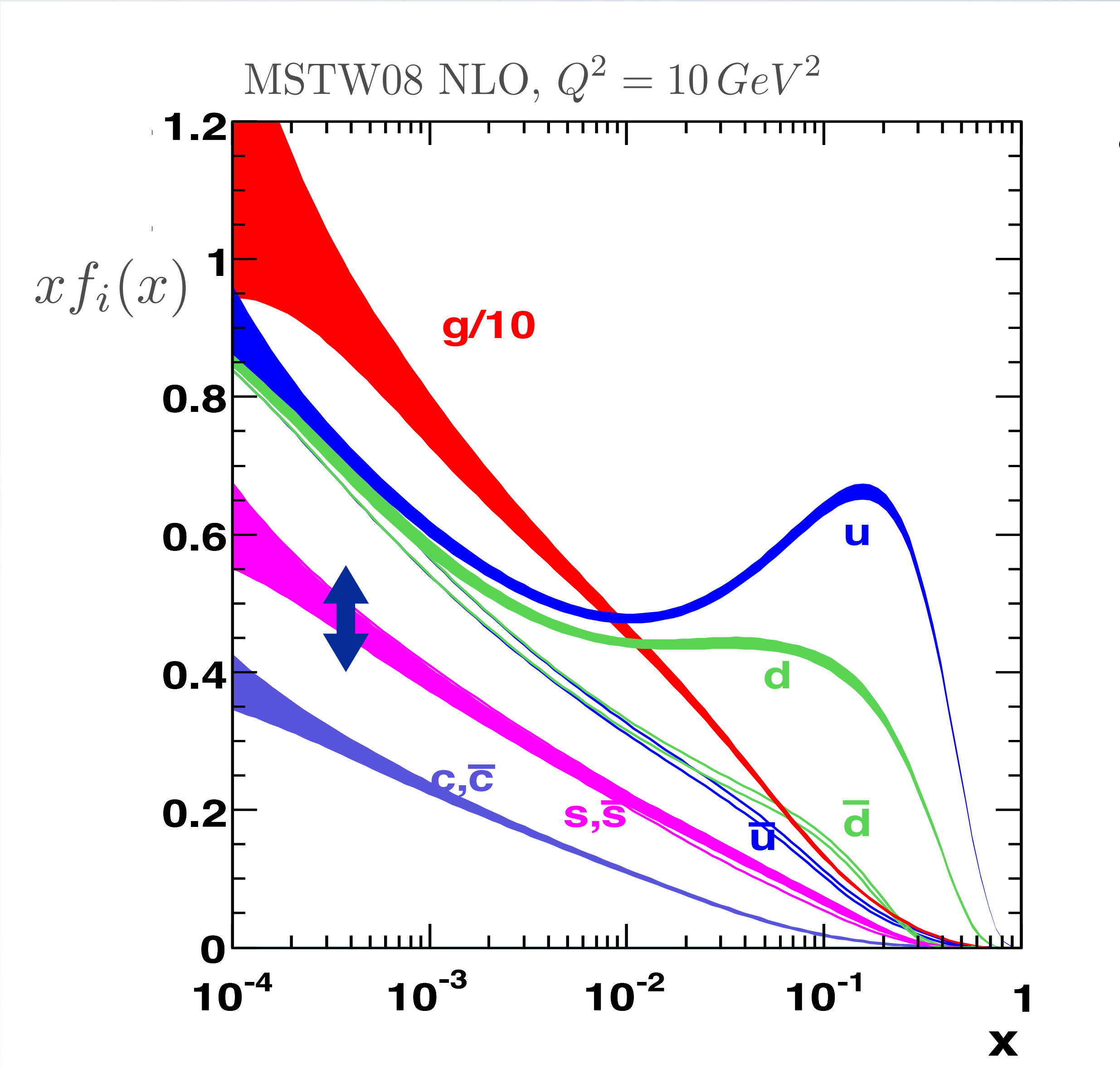

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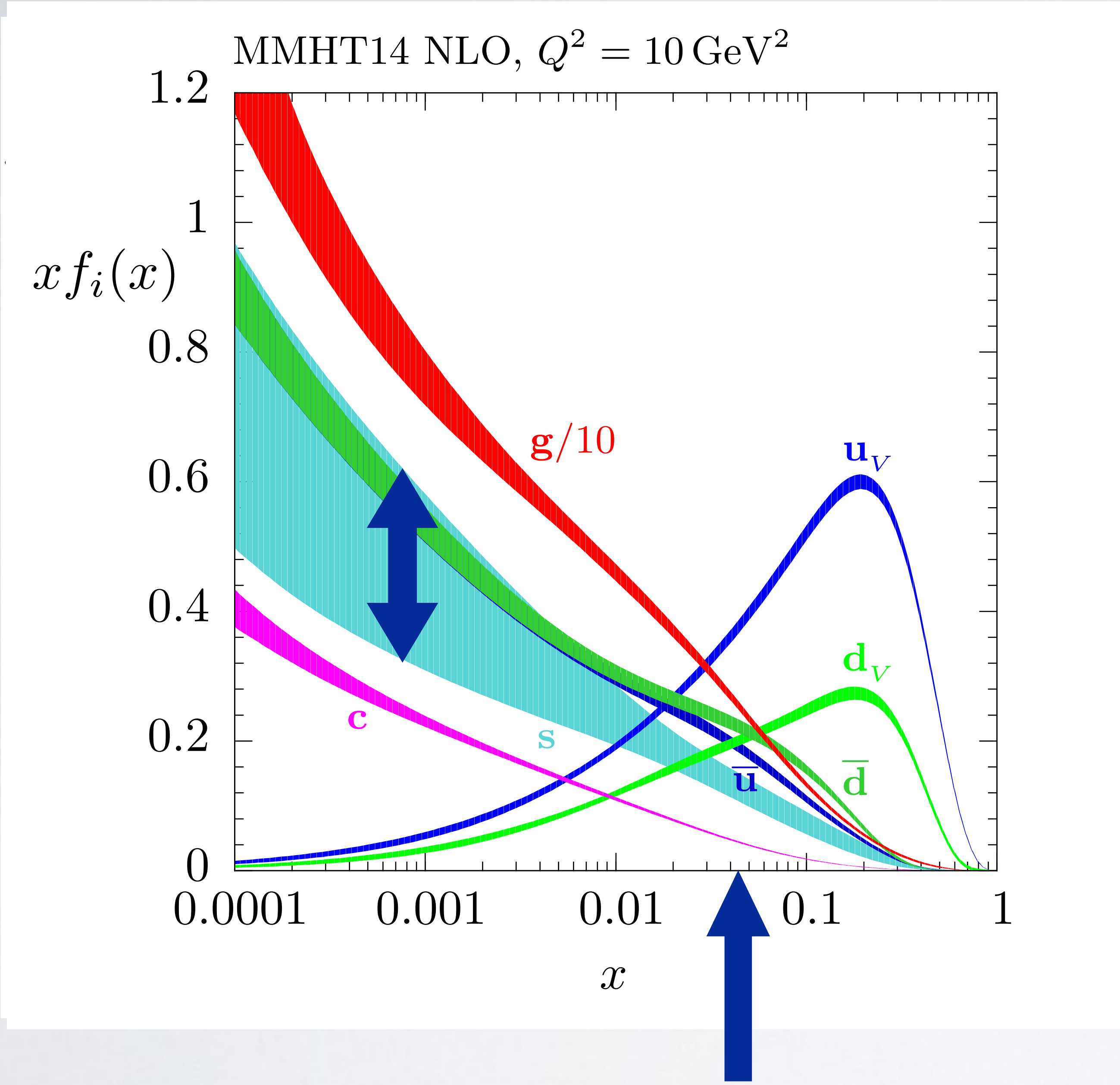

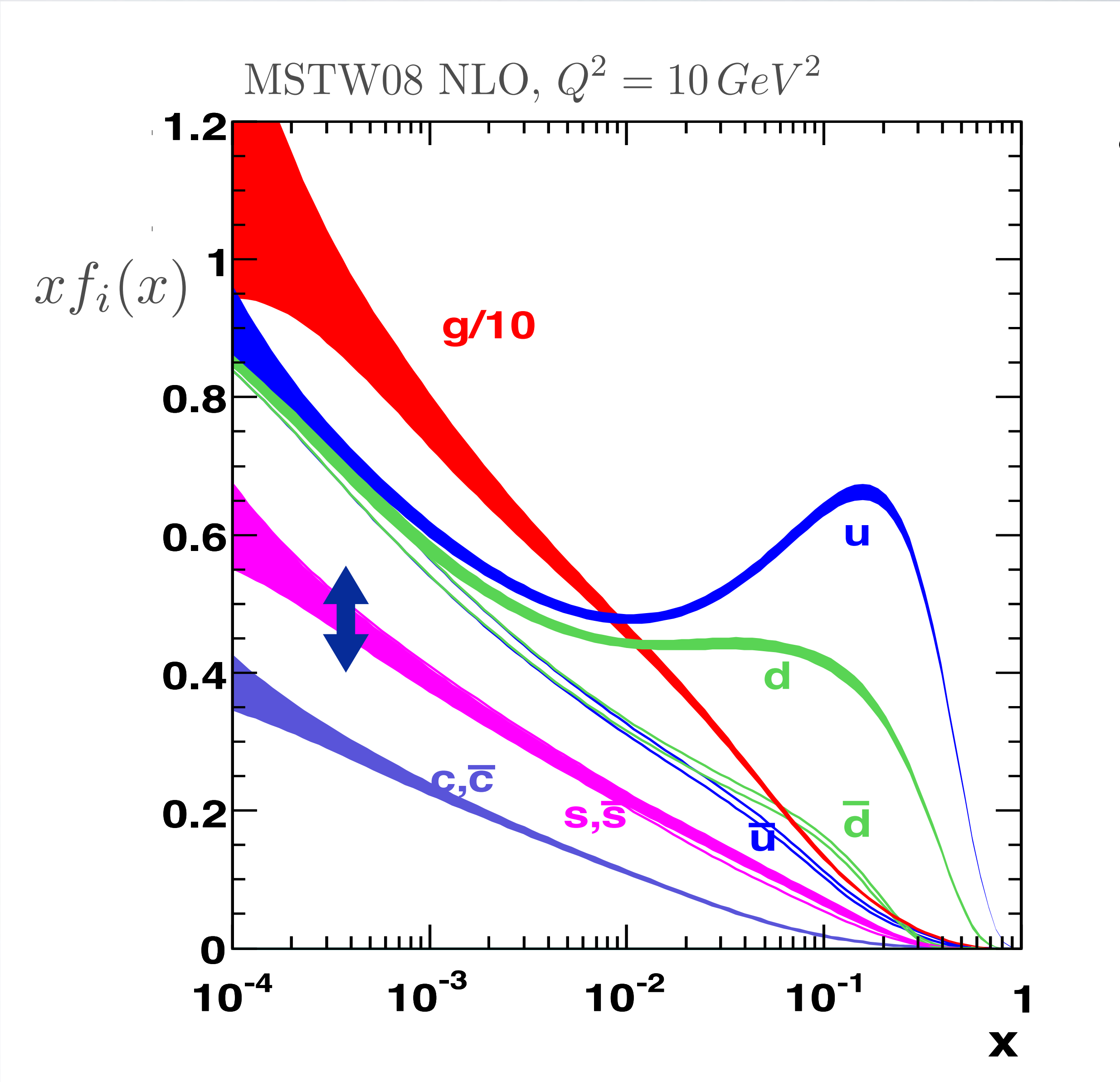

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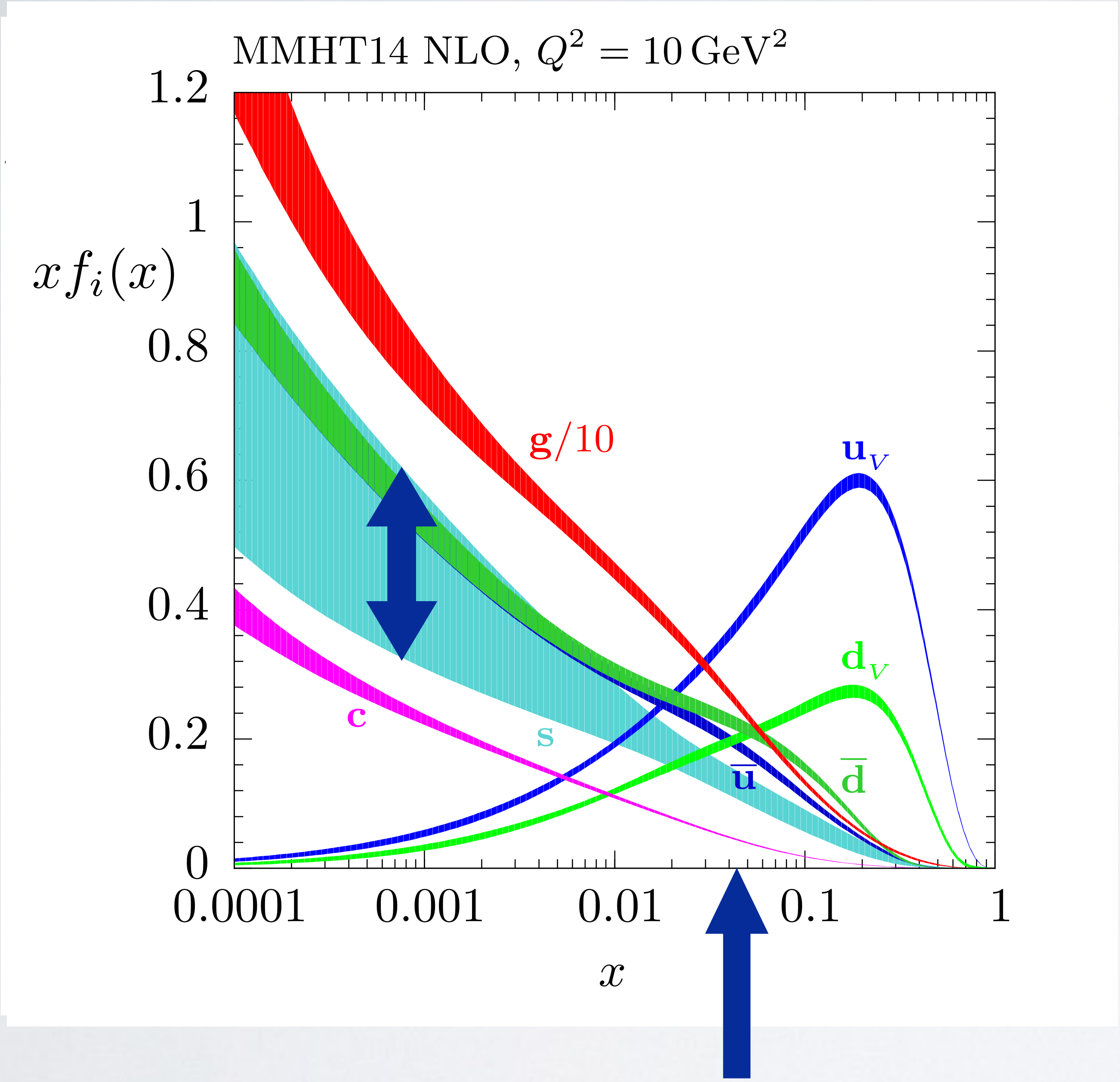

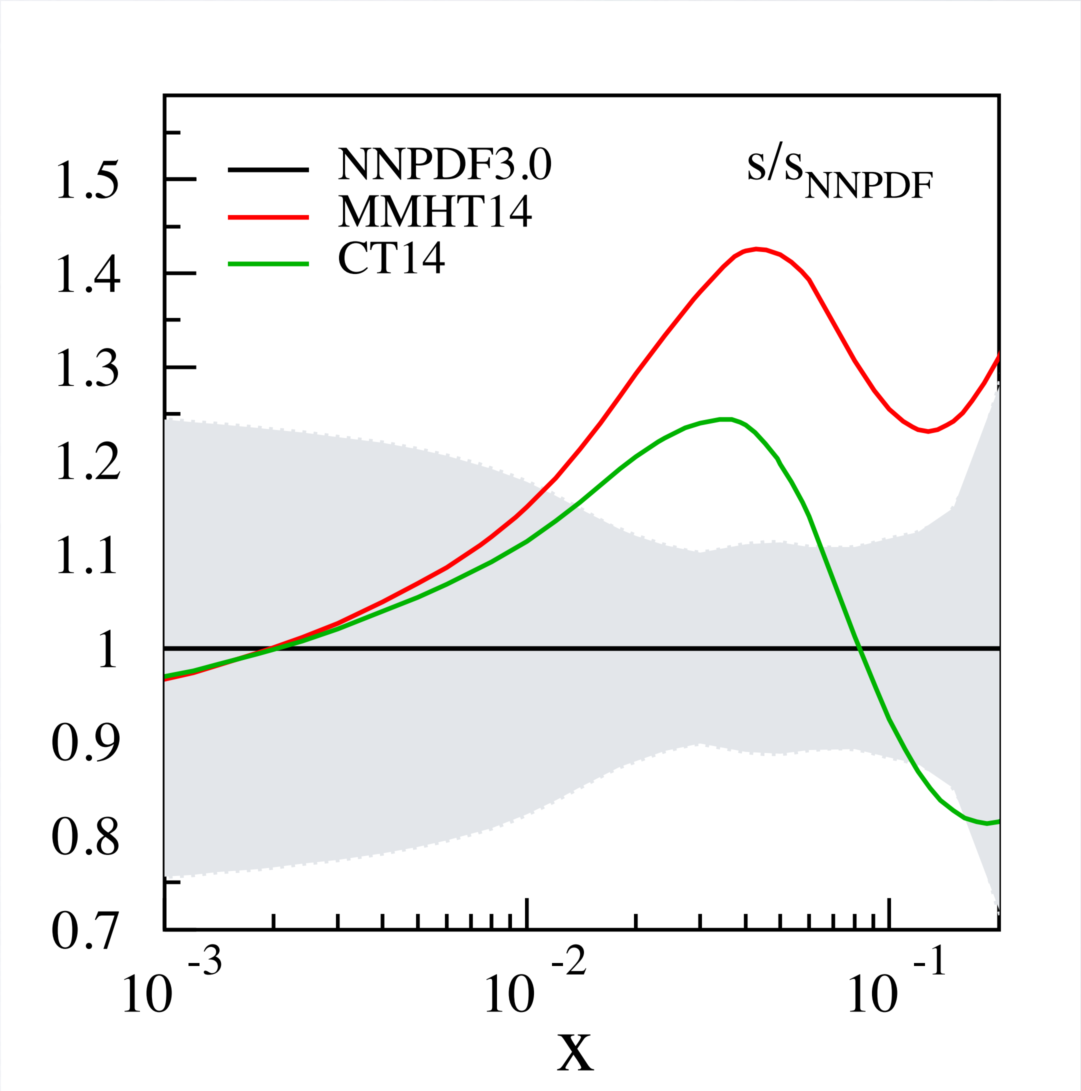

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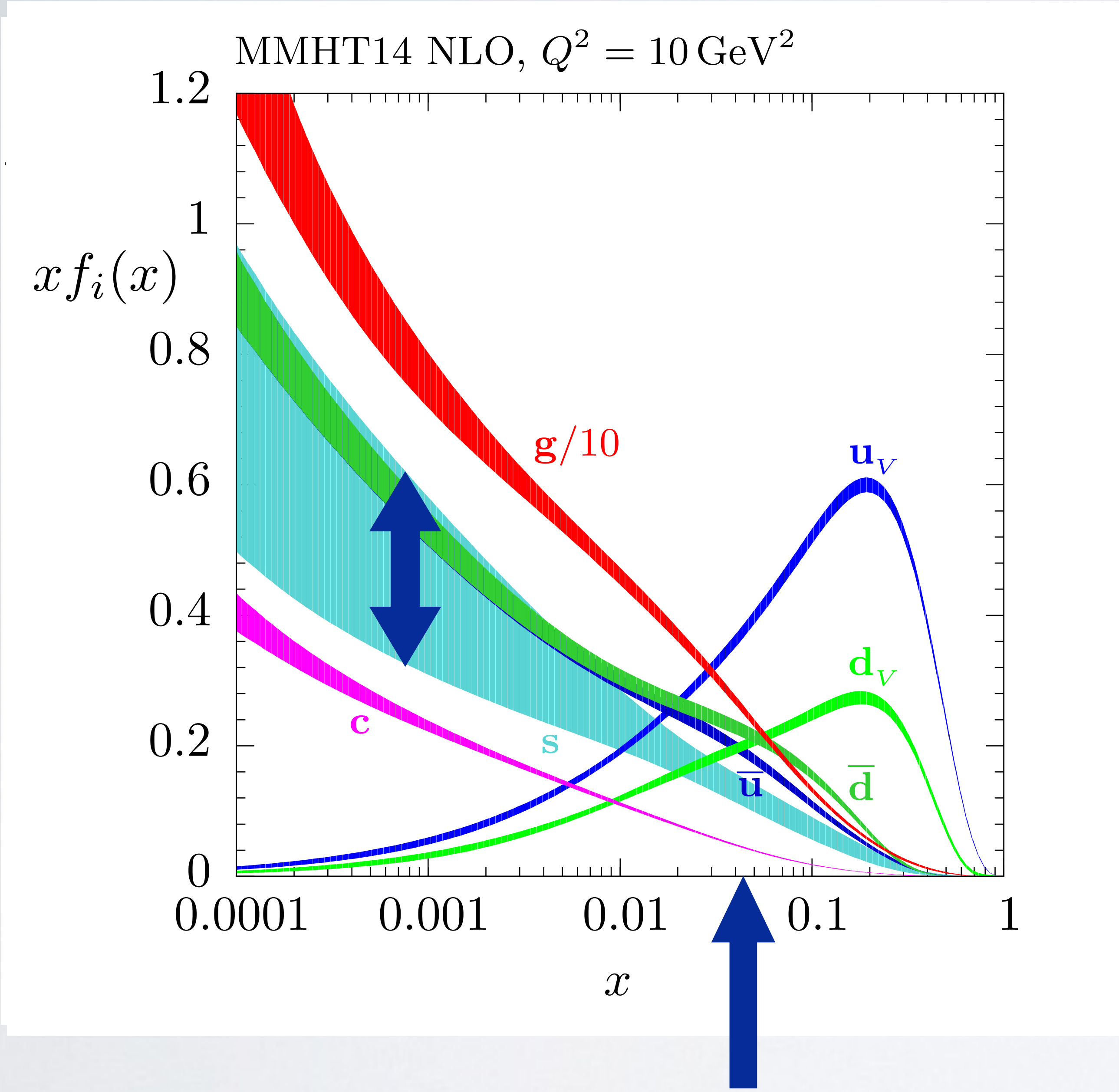
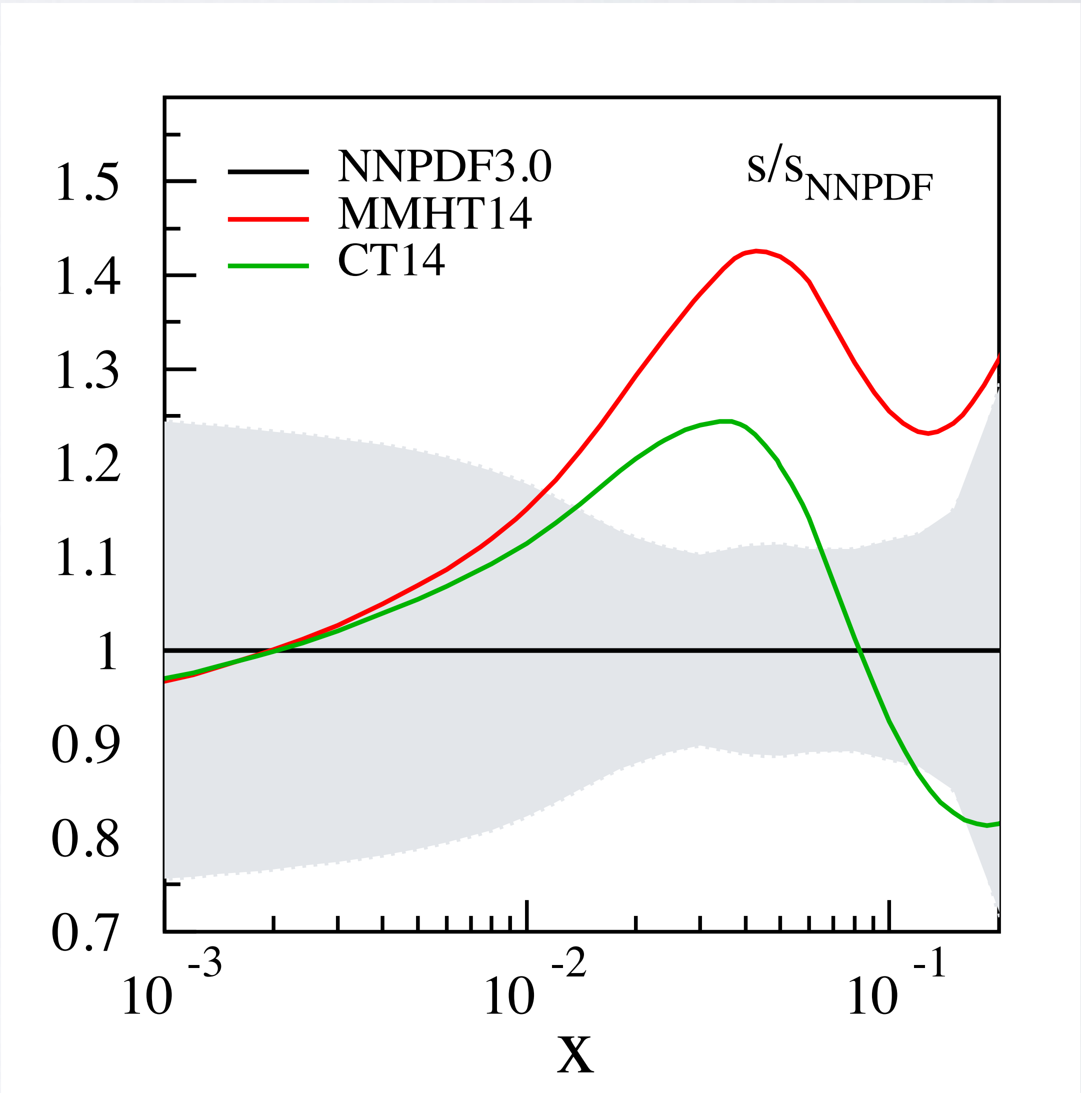




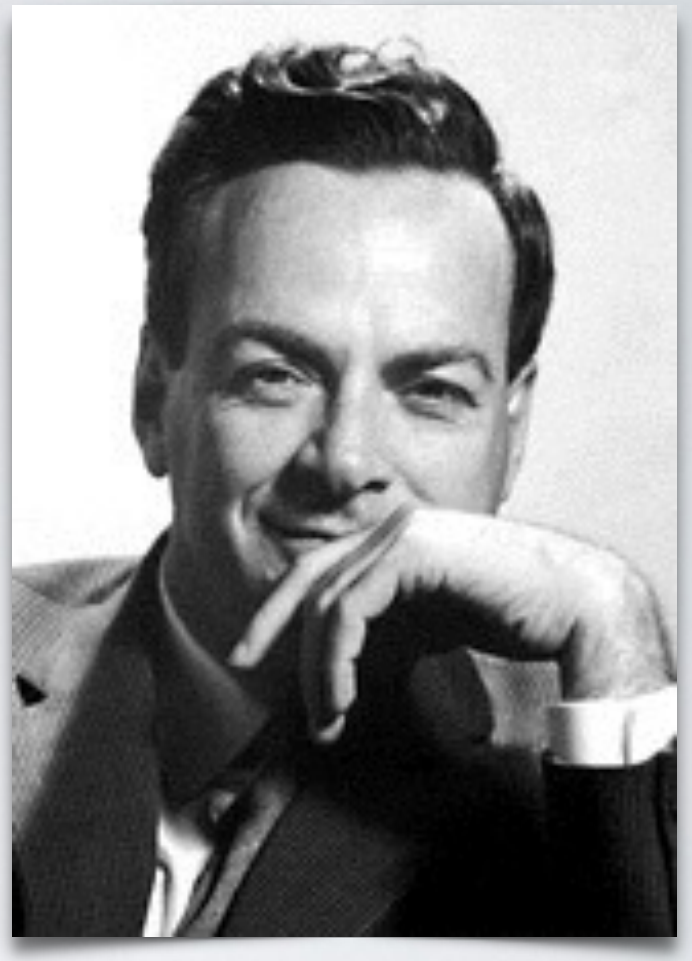
$$\chi^2_{\mathrm{MMHT14}} = 1271.7$$

$$\chi^2_{\mathrm{CT14}} = 1185.3$$

$$\chi^2_{\mathrm{NNPDF3.0}} = 1017.2$$

combined PDFs and FFs extraction

combined PDFs and FFs extraction



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Quark elastic scattering as a source of high-transverse-momentum mesons*

R. D. Field and R. P. Feynman
California Institute of Technology, Pasadena, California 91125

(Received 20 October 1976)

We investigate the consequences of the assumption that the high-transverse-momentum particles seen in hadron-hadron collisions are produced by a single, hard, large-angle elastic scattering of quarks, one from the target and one from the beam. The fast outgoing quarks are assumed to fragment into a cascade jet of hadrons. The distributions of quarks in the incoming hadrons are determined from lepton-hadron inelastic scattering data, together with certain theoretical constraints such as sum rules, etc.

combined PDFs and FFs extraction

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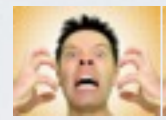
number parameter/unknowns  

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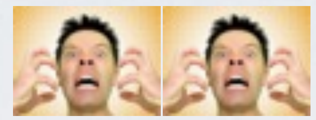
number parameter/unknowns 

topography 

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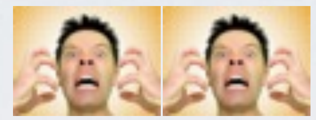
number parameter/unknowns 

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reweighting:

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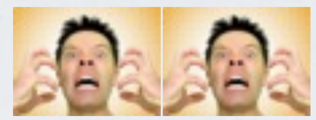
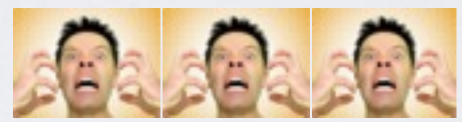
number parameter/unknowns 

topography 

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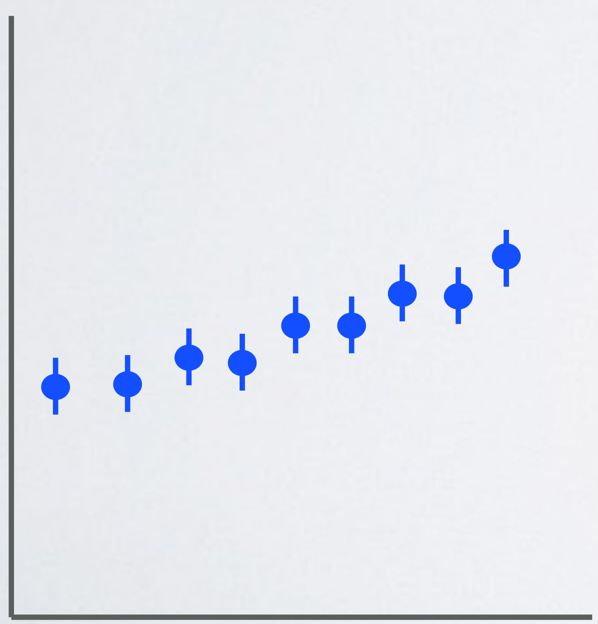

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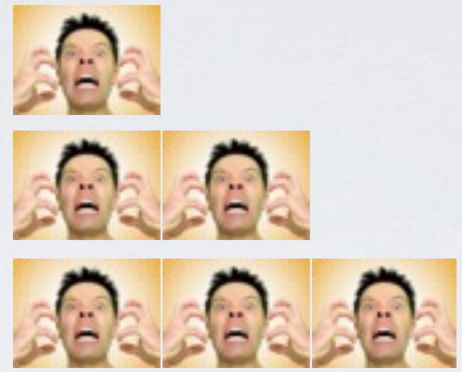

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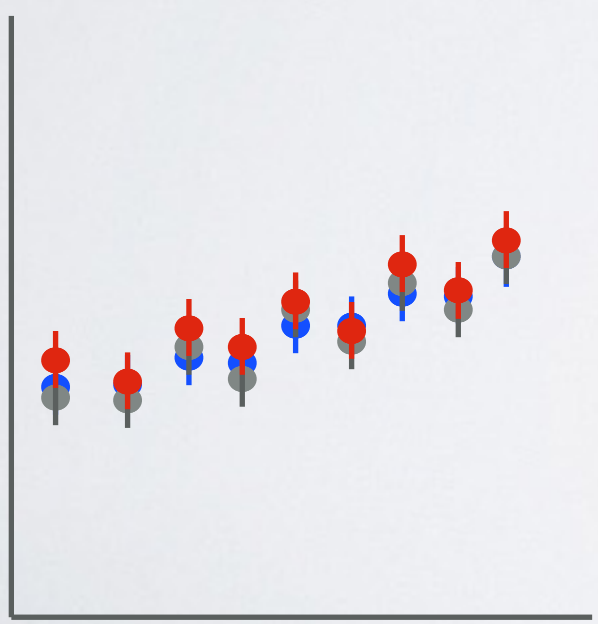


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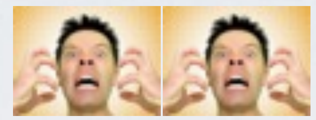
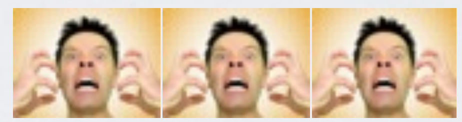
number parameter/unknowns 

topography 

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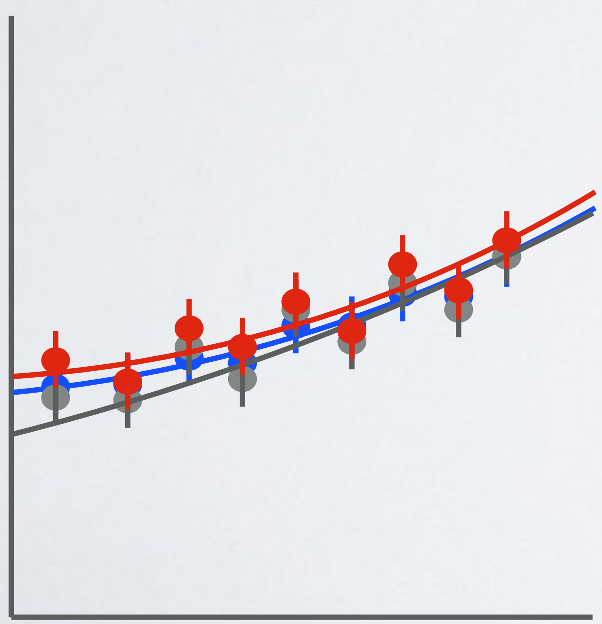

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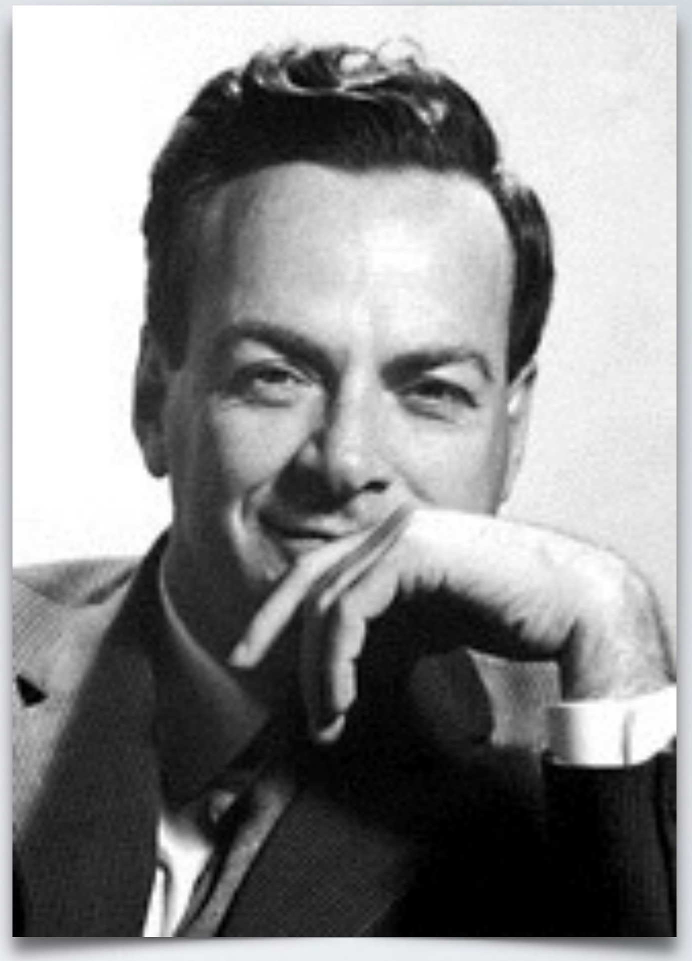

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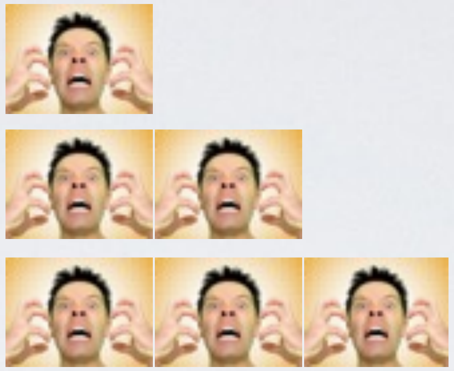

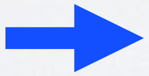

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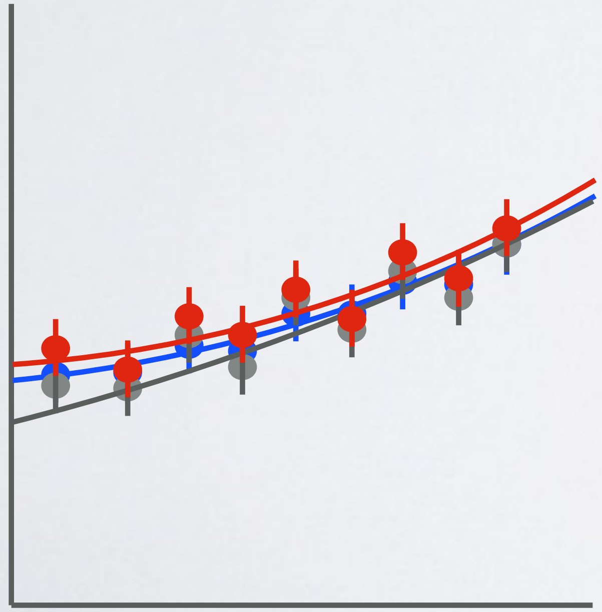


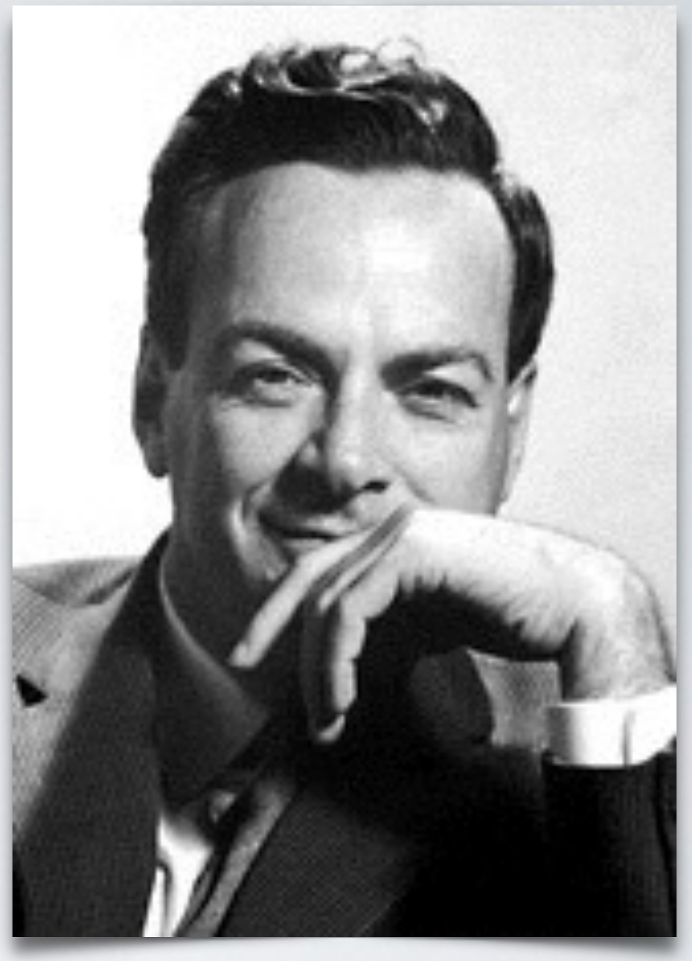
$$f_i(x)$$
$$f_i(x)$$
$$f_i(x)$$

combined PDFs and FFs extraction

number/type data

number parameter/unknowns

topography



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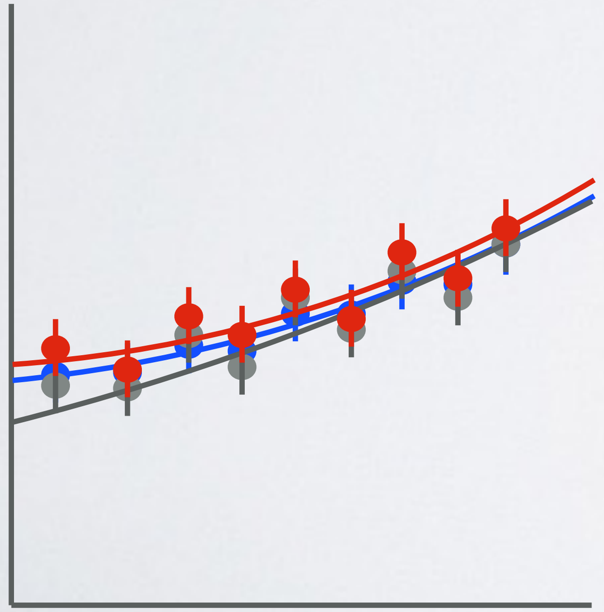


$$f_i(x)$$
$$f_i(x)$$
$$f_i(x)$$

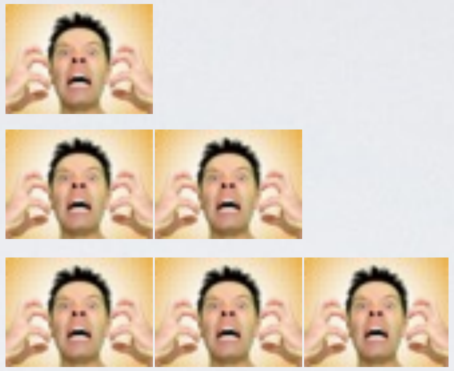
$$f_i^{best}(x) = \frac{1}{N_{rep}} \sum f_i(x)$$

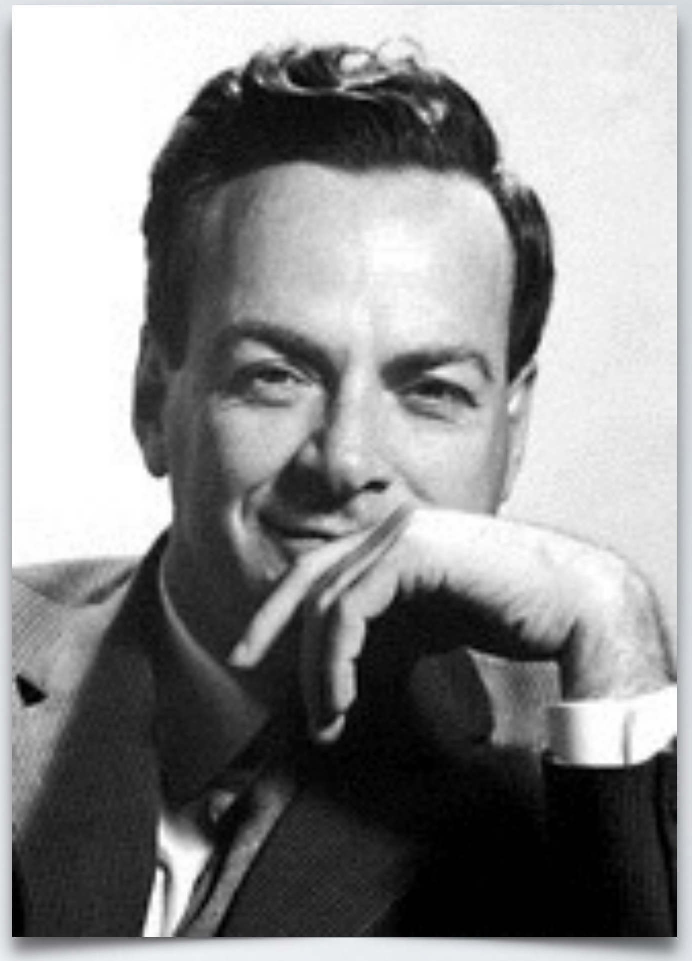
combined PDFs and FFs extraction

number/type data

number parameter/unknowns

topography





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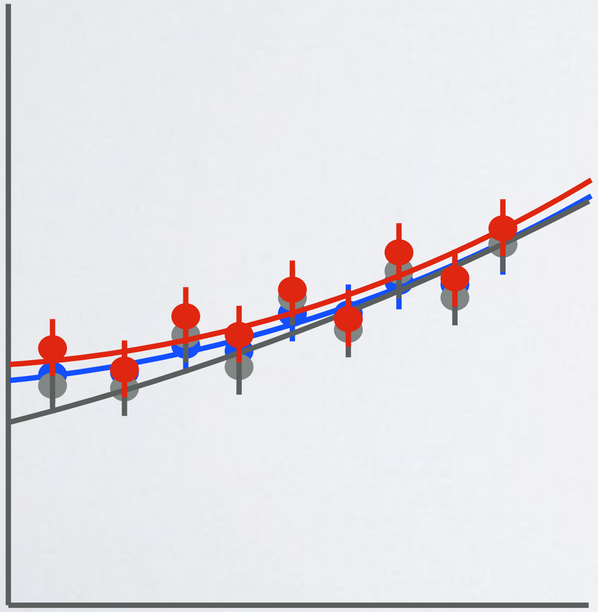

$$f_i(x) \quad w(\chi^2)$$
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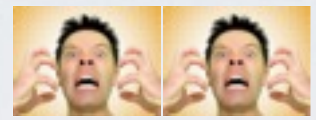
$$f_i^{best}(x) = \frac{1}{N_{rep}} \sum f_i(x)$$

combined PDFs and FFs extraction

number/type data

number parameter/unknowns



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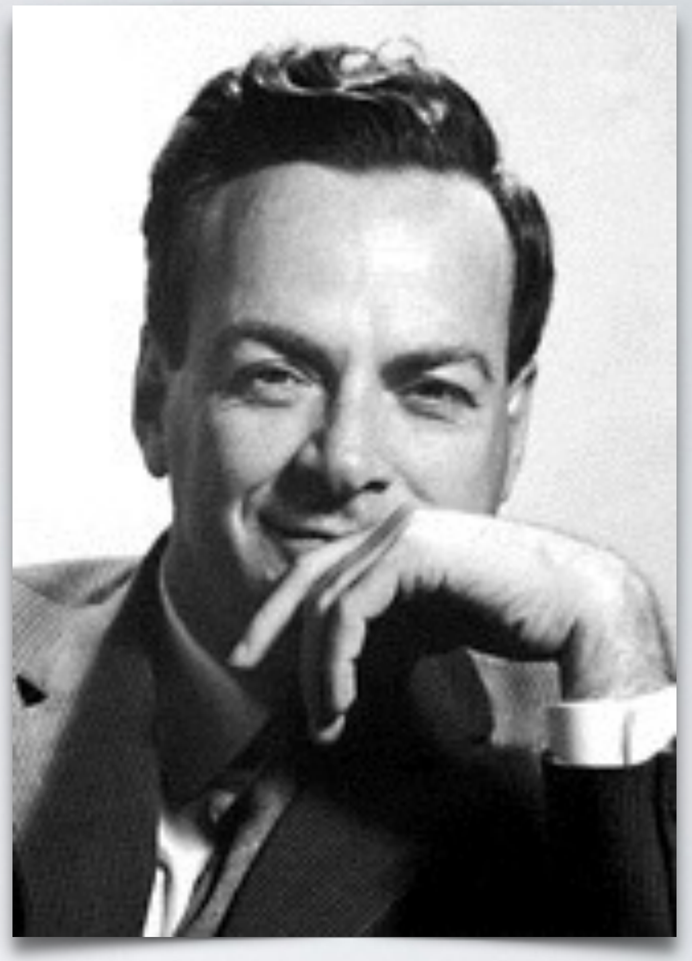

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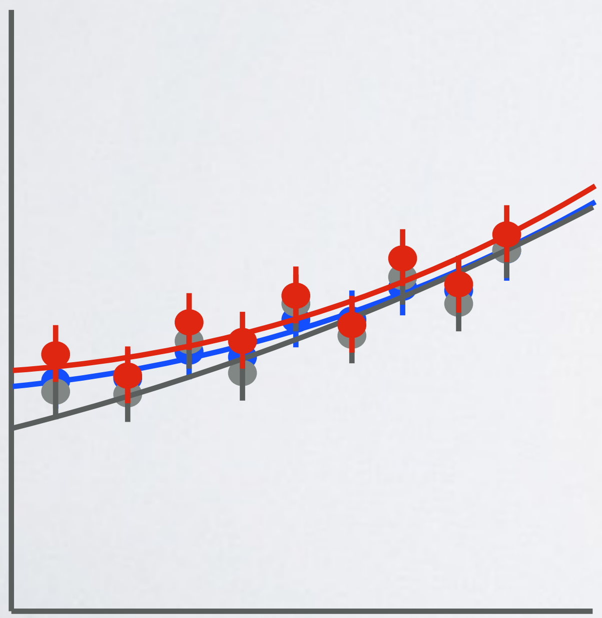

$f_i(x) \quad w(\chi^2)$

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$f_i(x) \quad w(\chi^2)$

$$f_i^{best}(x) = \frac{1}{N_{rep}} \sum f_i(x)$$

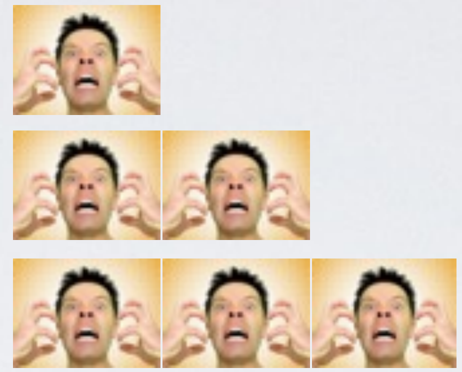
$$f_i^{reweight}(x) = \frac{1}{N_{rep}} \sum w f_i(x)$$

combined PDFs and FFs extraction

number/type data

number parameter/unknowns

topography



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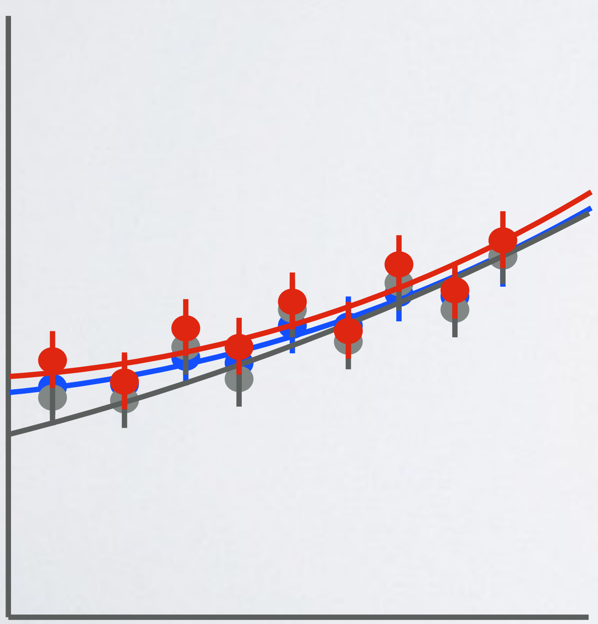


$$\color{red}{f_i(x) \quad w(\chi^2)}$$

$$\color{blue}{f_i(x) \quad w(\chi^2)}$$

$$f_i(x) \quad w(\chi^2)$$

$$f_i^{best}(x) = \frac{1}{N_{rep}} \sum f_i(x)$$

$$f_i^{reweight}(x) = \frac{1}{N_{rep}} \sum w f_i(x)$$

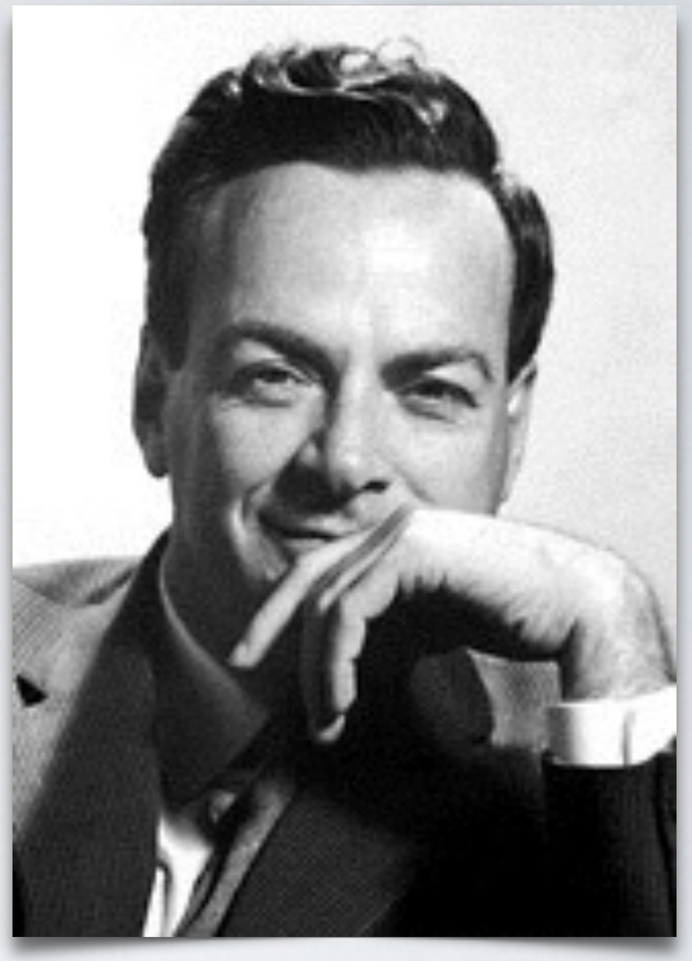
$$\chi^2(\mathrm{FFs})$$

combined PDFs and FFs extraction

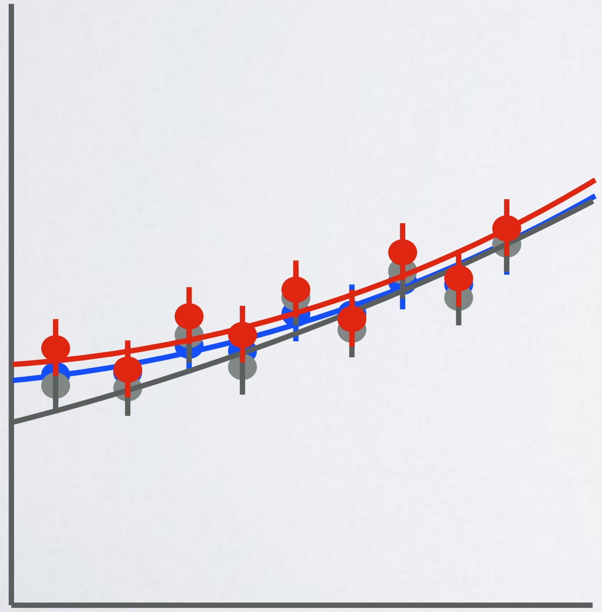
number/type data 

number parameter/unknowns 

topography 



reweighting:



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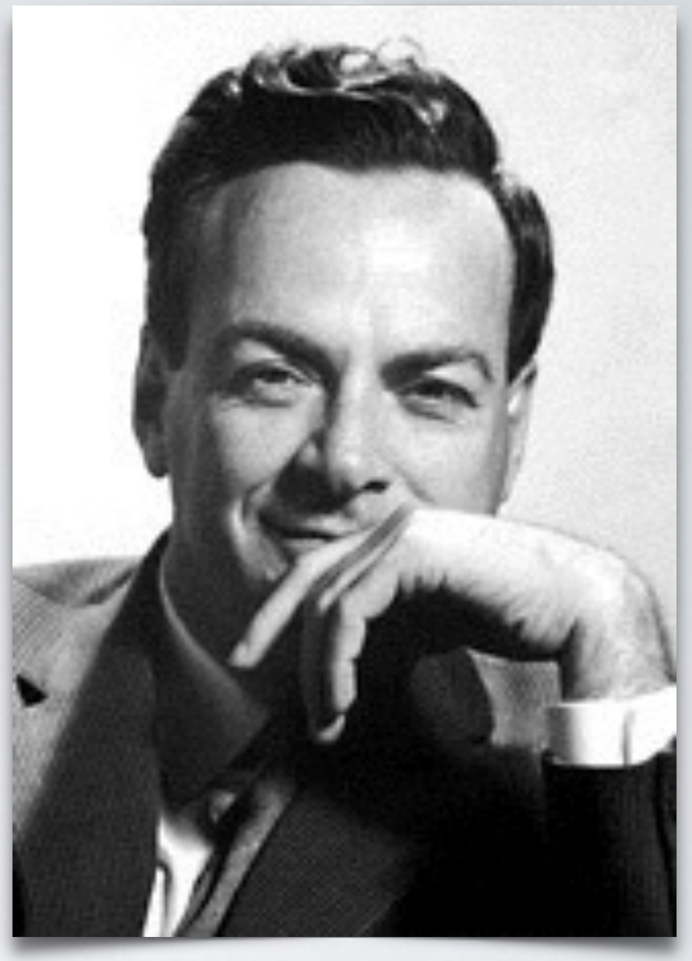
$$\chi^2(\mathrm{FFs}(\mathrm{PDFs}))$$

combined PDFs and FFs extraction



number/type data 

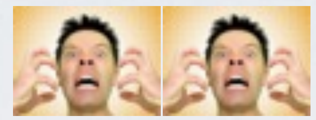
number parameter/unknowns 

topography 

iterative FFs & PDFs determination:

combined PDFs and FFs extraction

number/type data 

number parameter/unknowns 

topography 

iterative FFs & PDFs determination:

PDFs FFs

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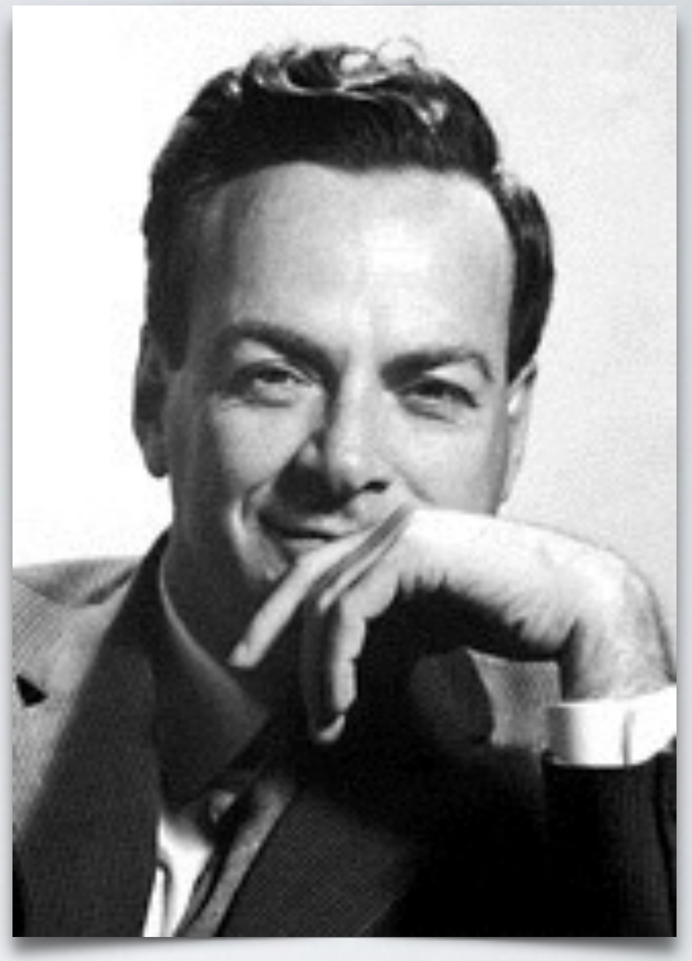


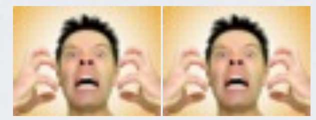
iterative FFs & PDFs determination:

PDFs FFs

PDFs reweigh with SIDIS

combined PDFs and FFs extraction

number/type data 

number parameter/unknowns 

topography 

iterative FFs & PDFs determination:

PDFs FFs

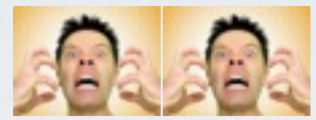
↓ ↓

PDFs reweigh with SIDIS

PDFs

combined PDFs and FFs extraction

number/type data 

number parameter/unknowns 

topography 

iterative FFs & PDFs determination:

PDFs FFs

PDFs reweigh with SIDIS

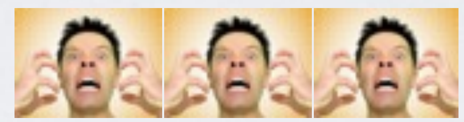
PDFs

FFs fit with new PDFs

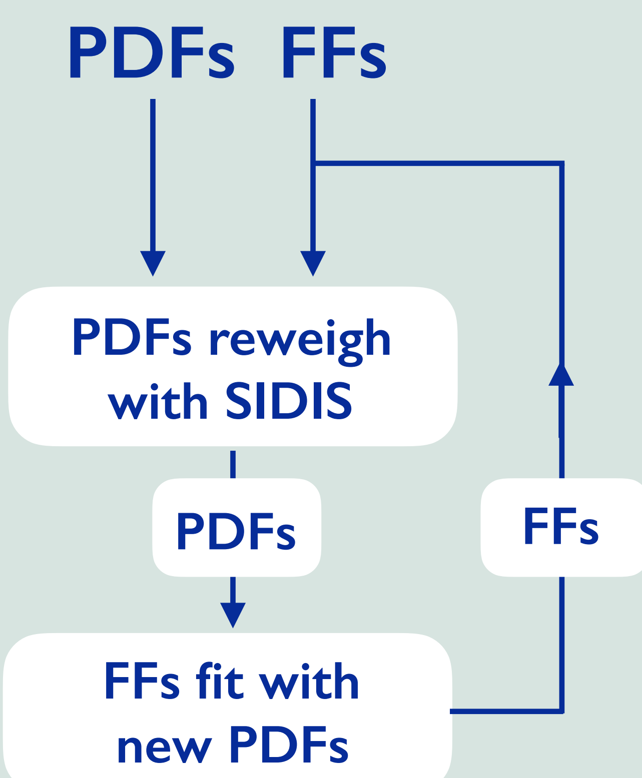
combined PDFs and FFs extraction

number/type data 

number parameter/unknowns 

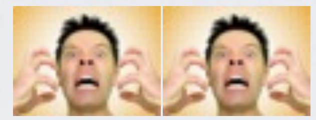
topography 

iterative FFs & PDFs determination:



combined PDFs and FFs extraction

number/type data 

number parameter/unknowns 

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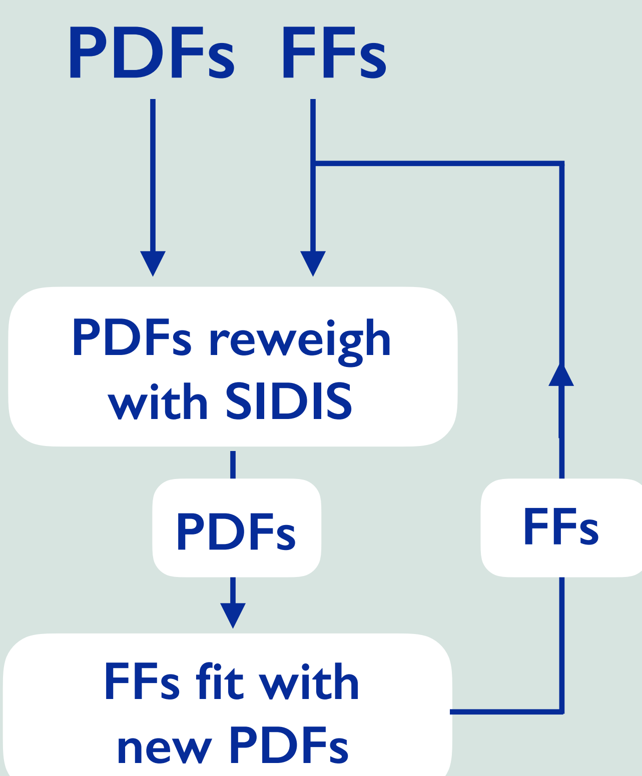


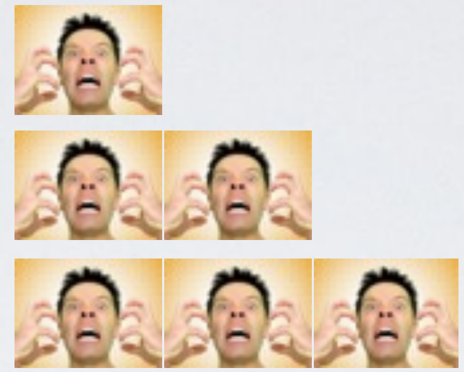
convergence?

combined PDFs and FFs extraction

number/type data

number parameter/unknowns

topography



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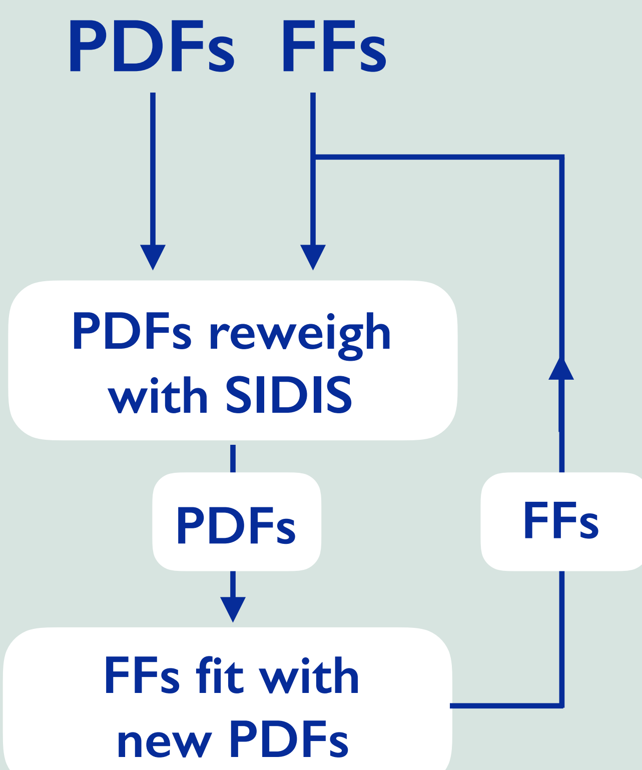
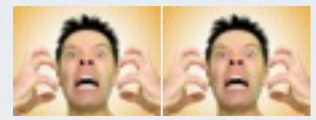


convergence?

and very fast!

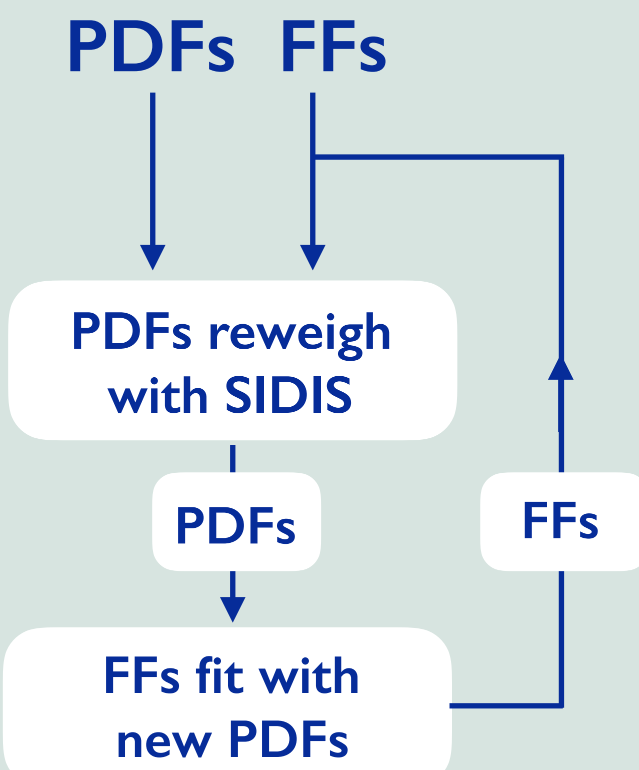
combined PDFs and FFs extraction

number/type data 

number parameter/unknowns 

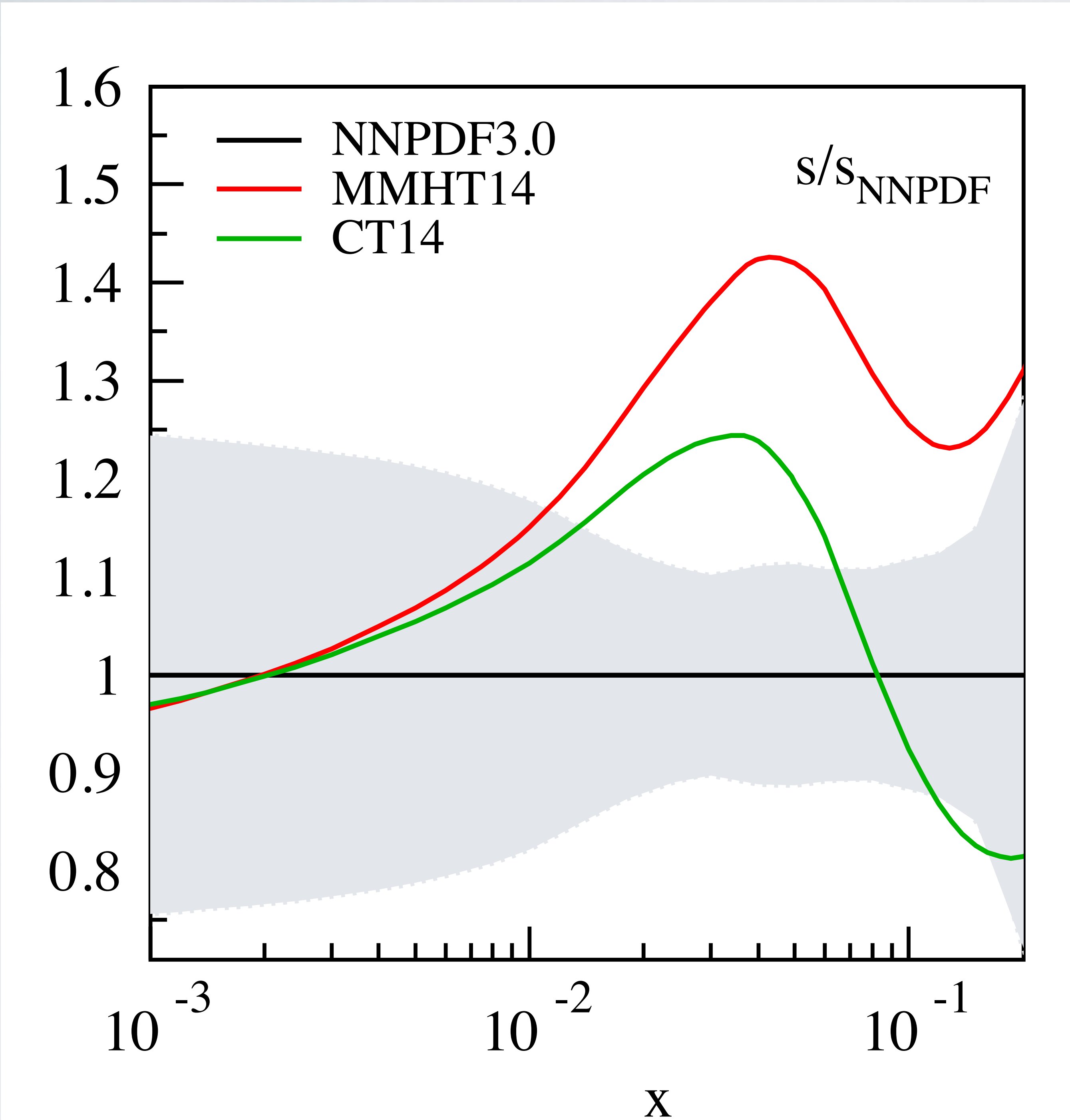
topography 

iterative FFs & PDFs determination:



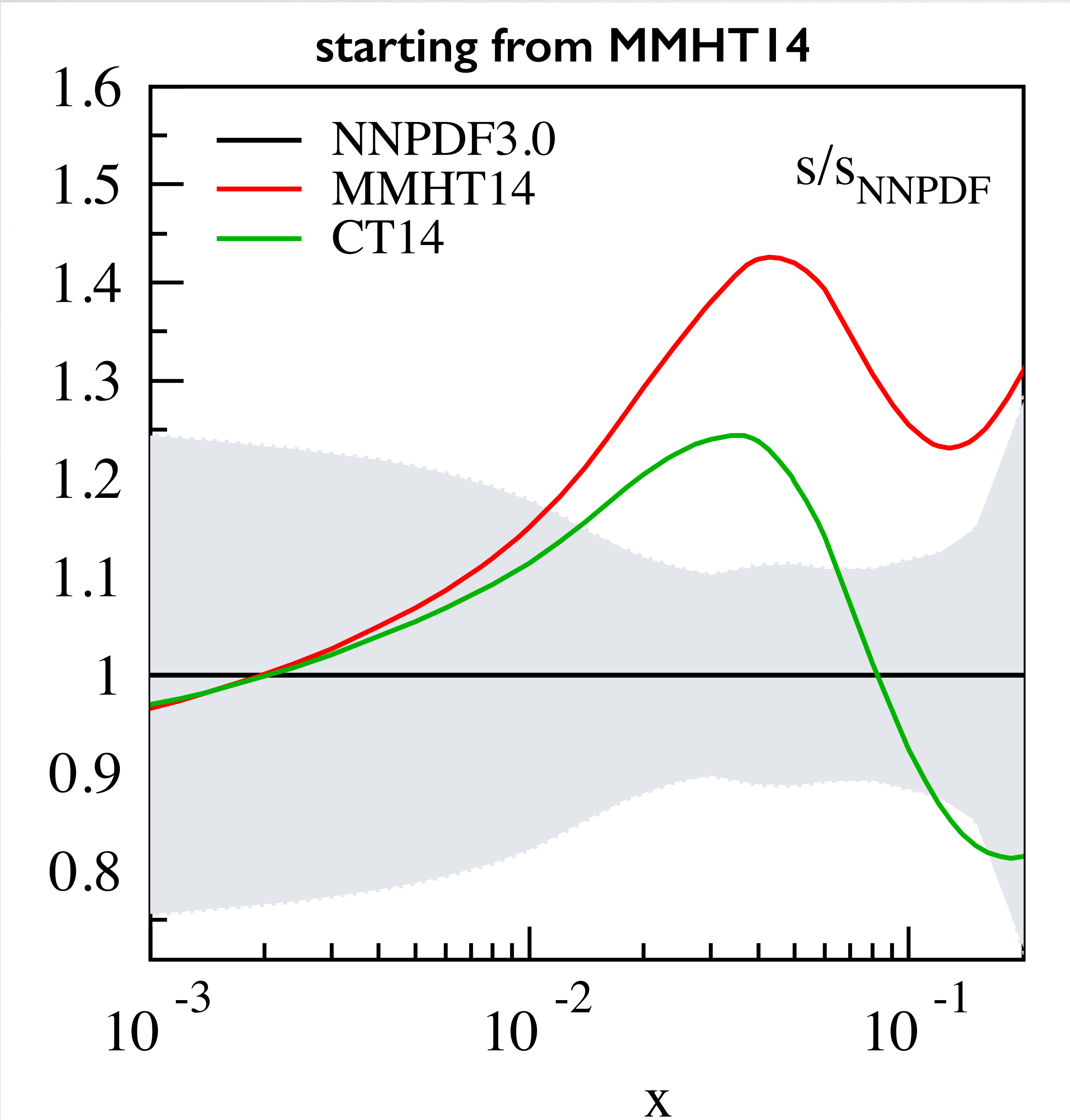
convergence?
and very fast!
robust!

combined PDFs and FFs extraction



$\chi^2_{FF} = 1271.7$

combined PDFs and FFs extraction



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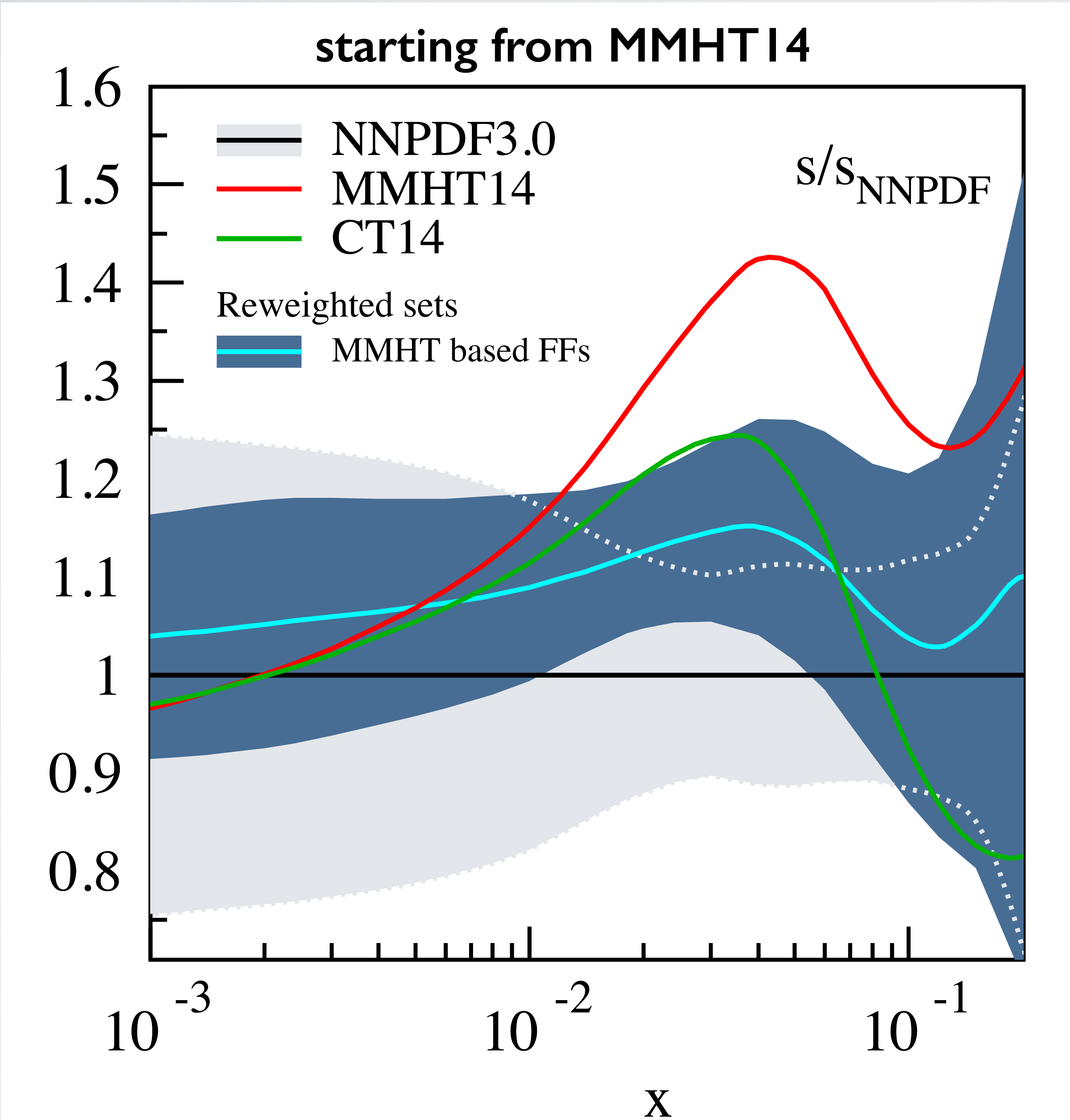
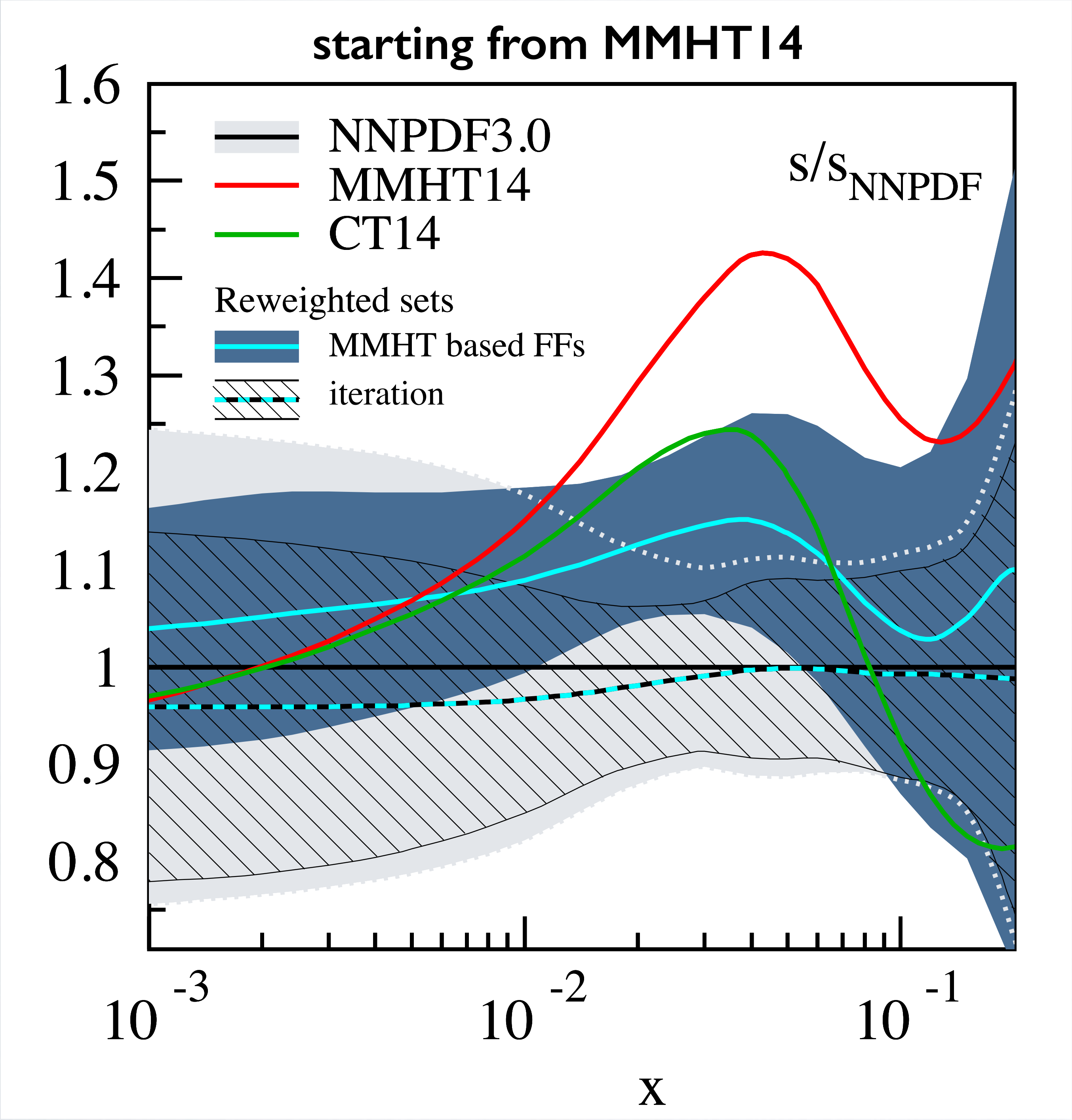


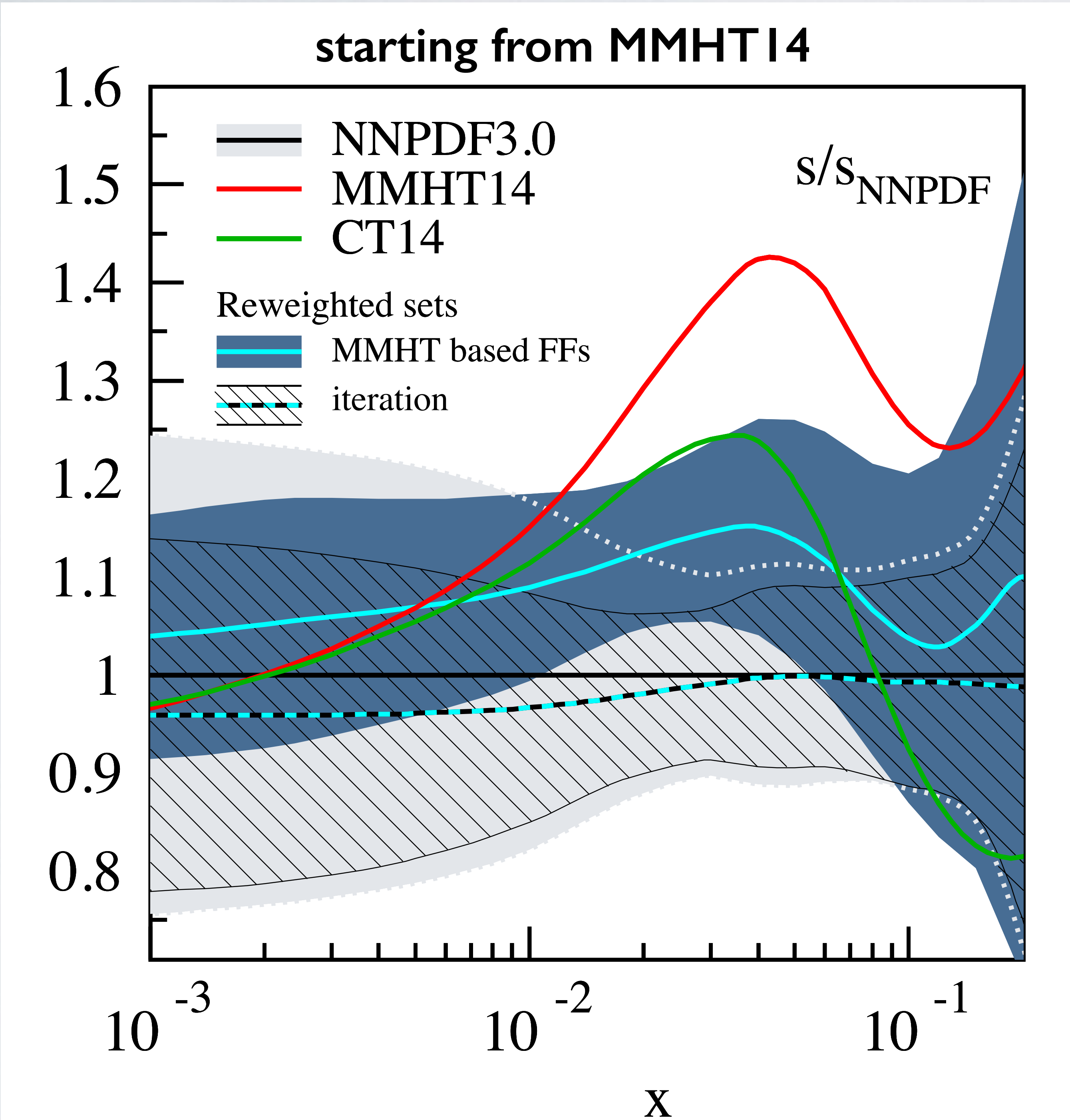
$\chi^2_{FF} = 1271.7$ $\boxed{1041.3}$

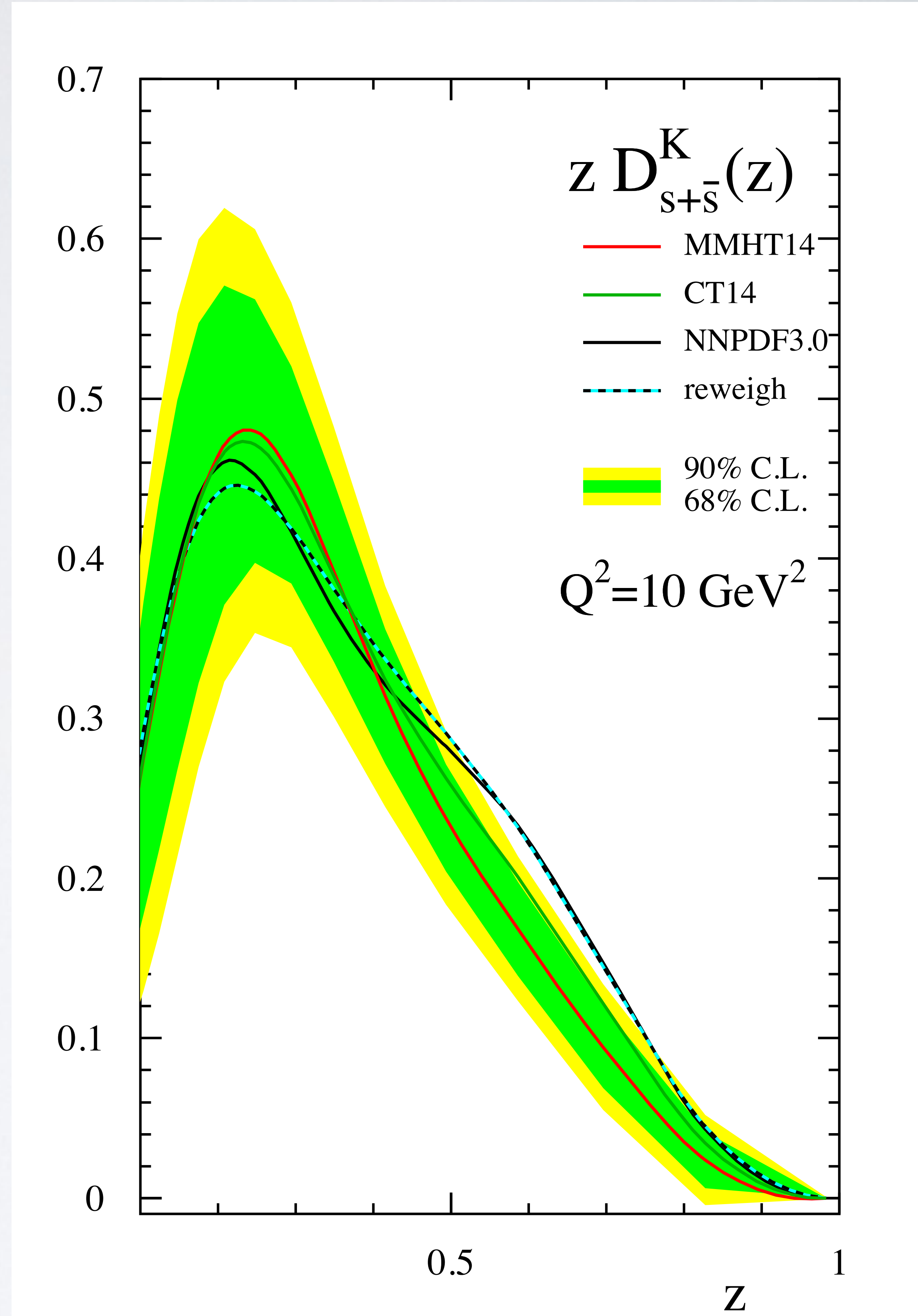
combined PDFs and FFs extraction



$\chi^2_{FF} =$ 1271.7 1041.3 1002.3

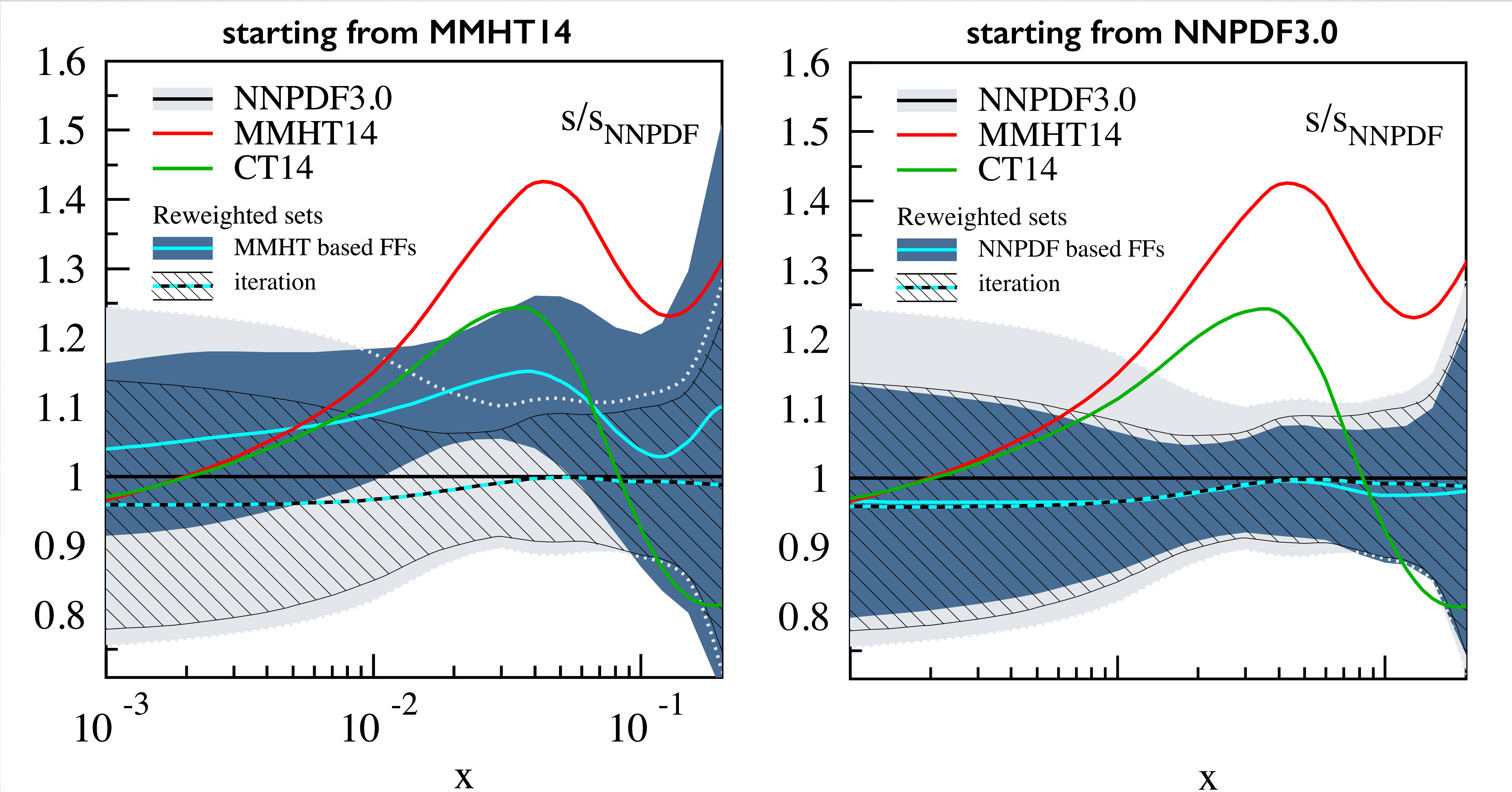
combined PDFs and FFs extraction





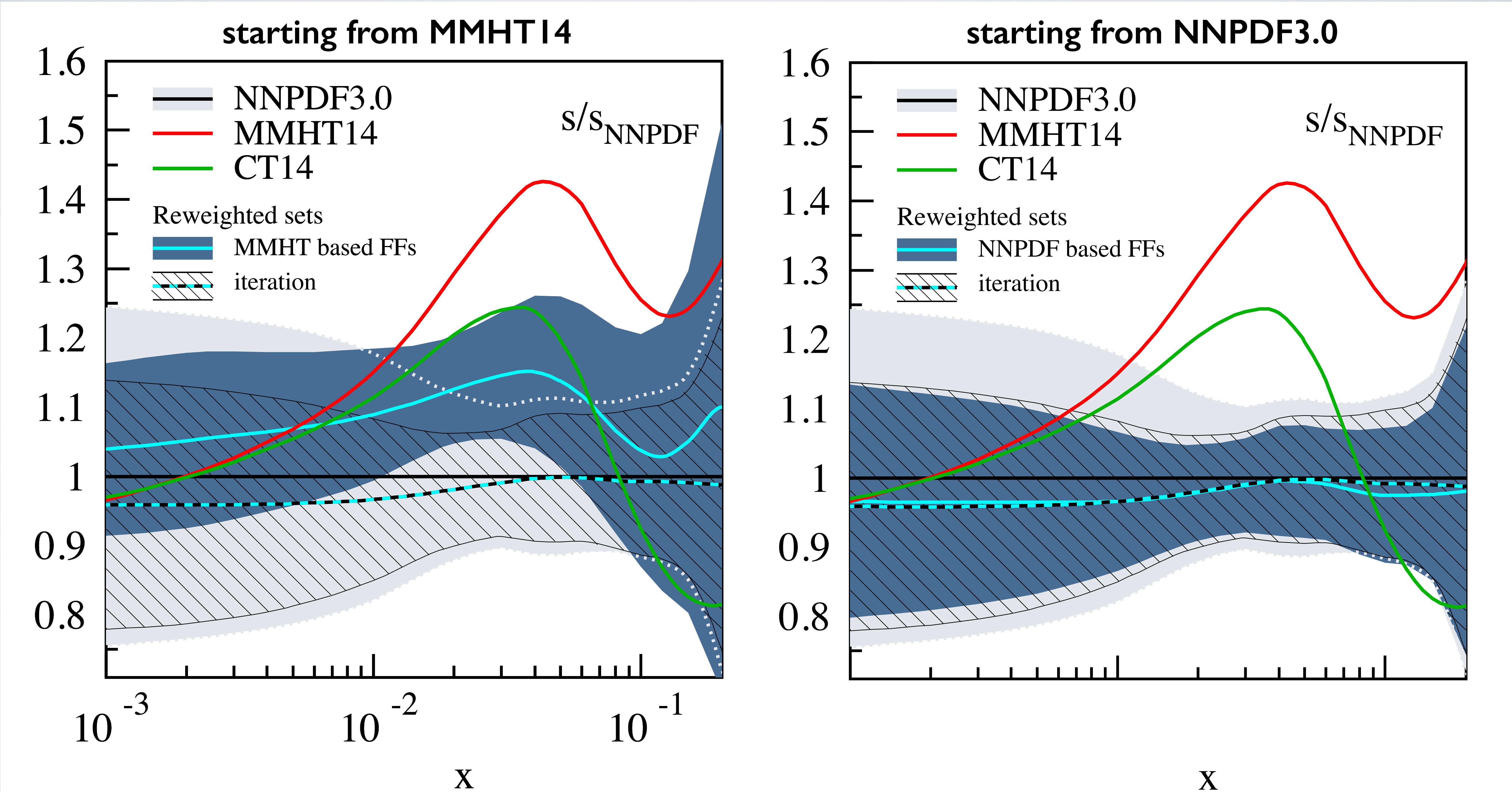
$\chi^2_{FF} = 1271.7$ 1041.3 1002.3

combined PDFs and FFs extraction



$\chi^2_{FF} =$ 1271.7 | 1041.3 | 1002.3 | 1017.2 | 1005.3 | 1000.6

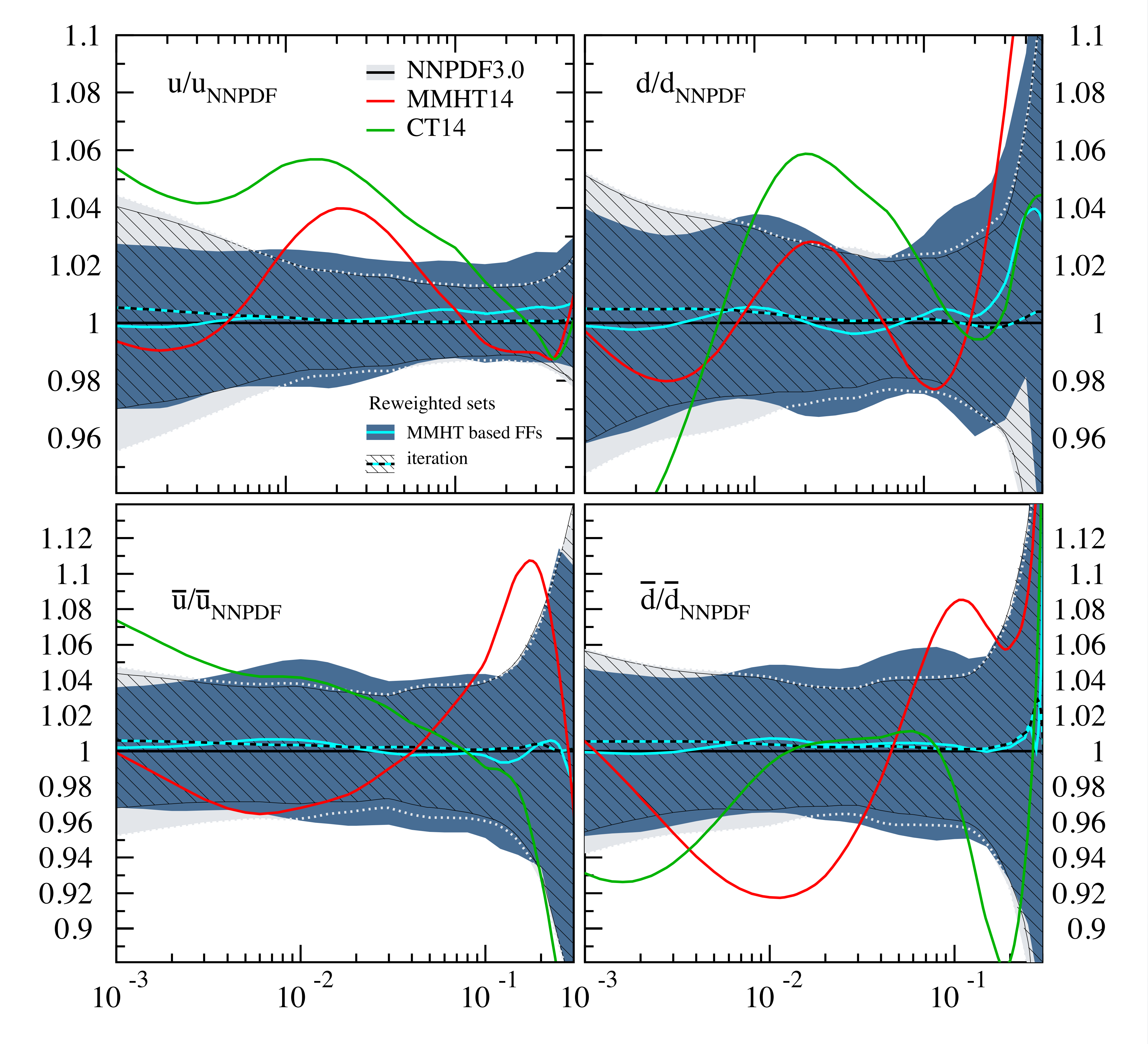
combined PDFs and FFs extraction



$\chi^2_{FF} =$ 1271.7 | 1041.3 | 1002.3 | 1017.2 | 1005.3 | 1000.6

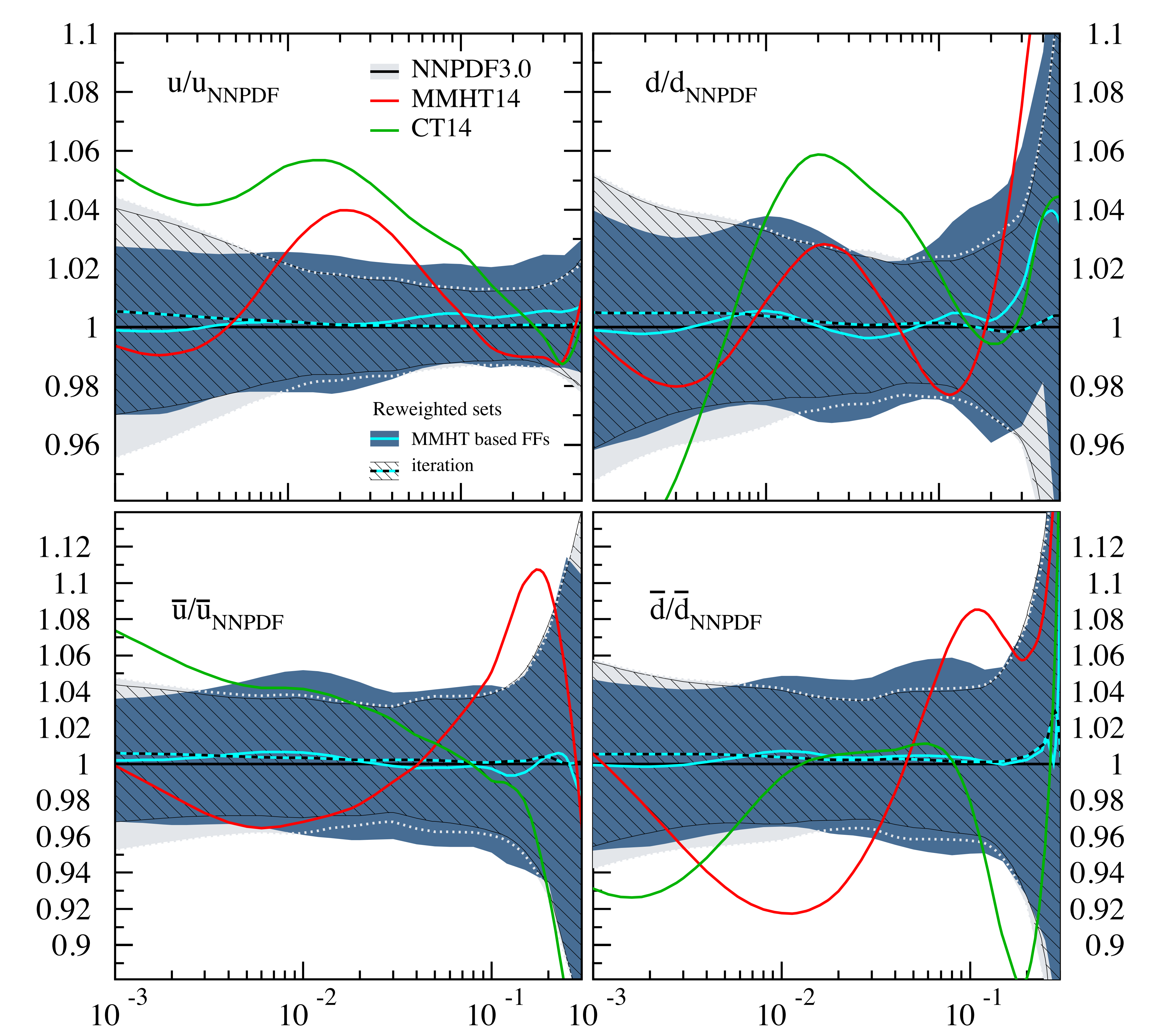
similar results with CT14 replicas

combined PDFs and FFs extraction



combined PDFs and FFs extraction

craving for pions

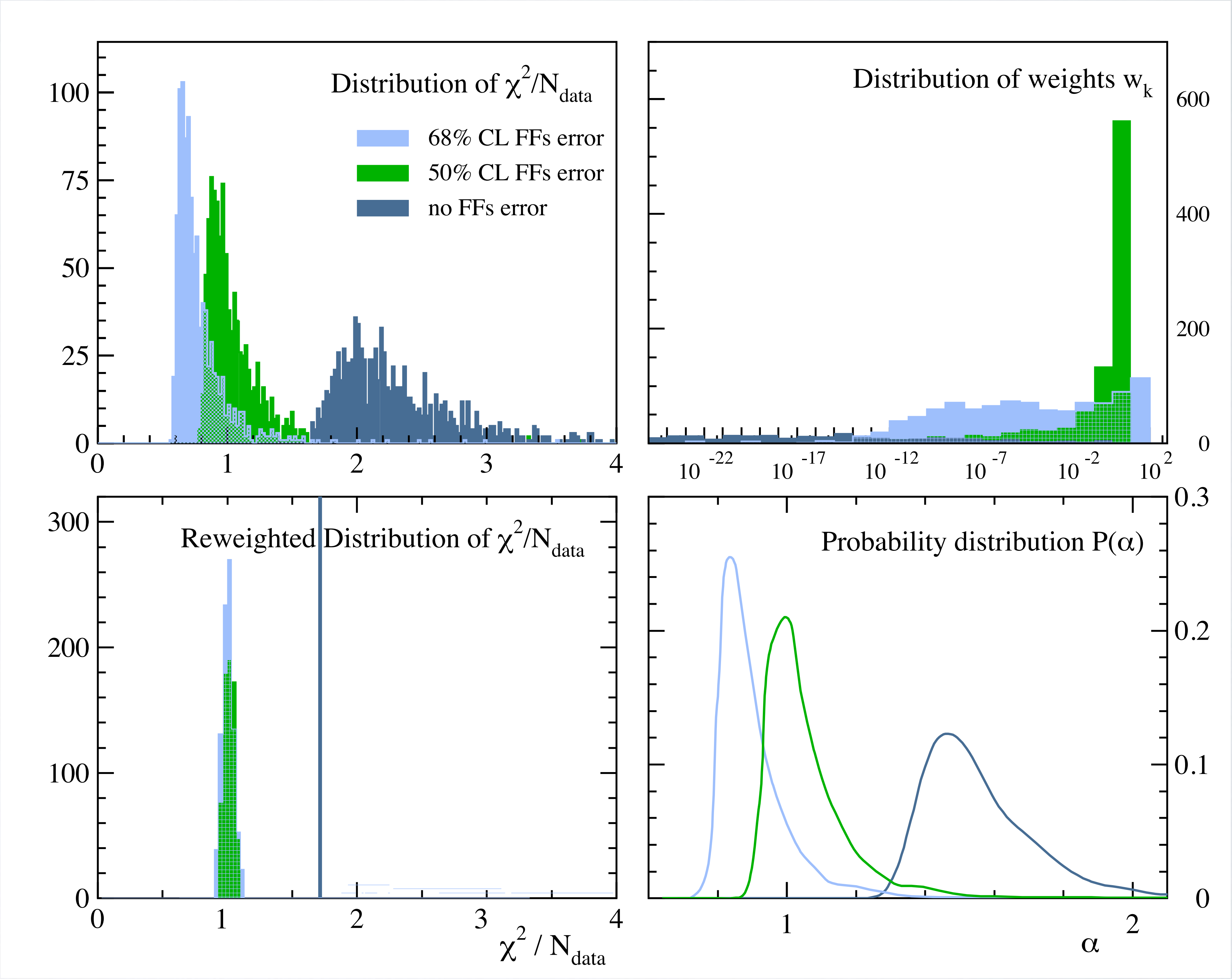


reweighting esoterica:

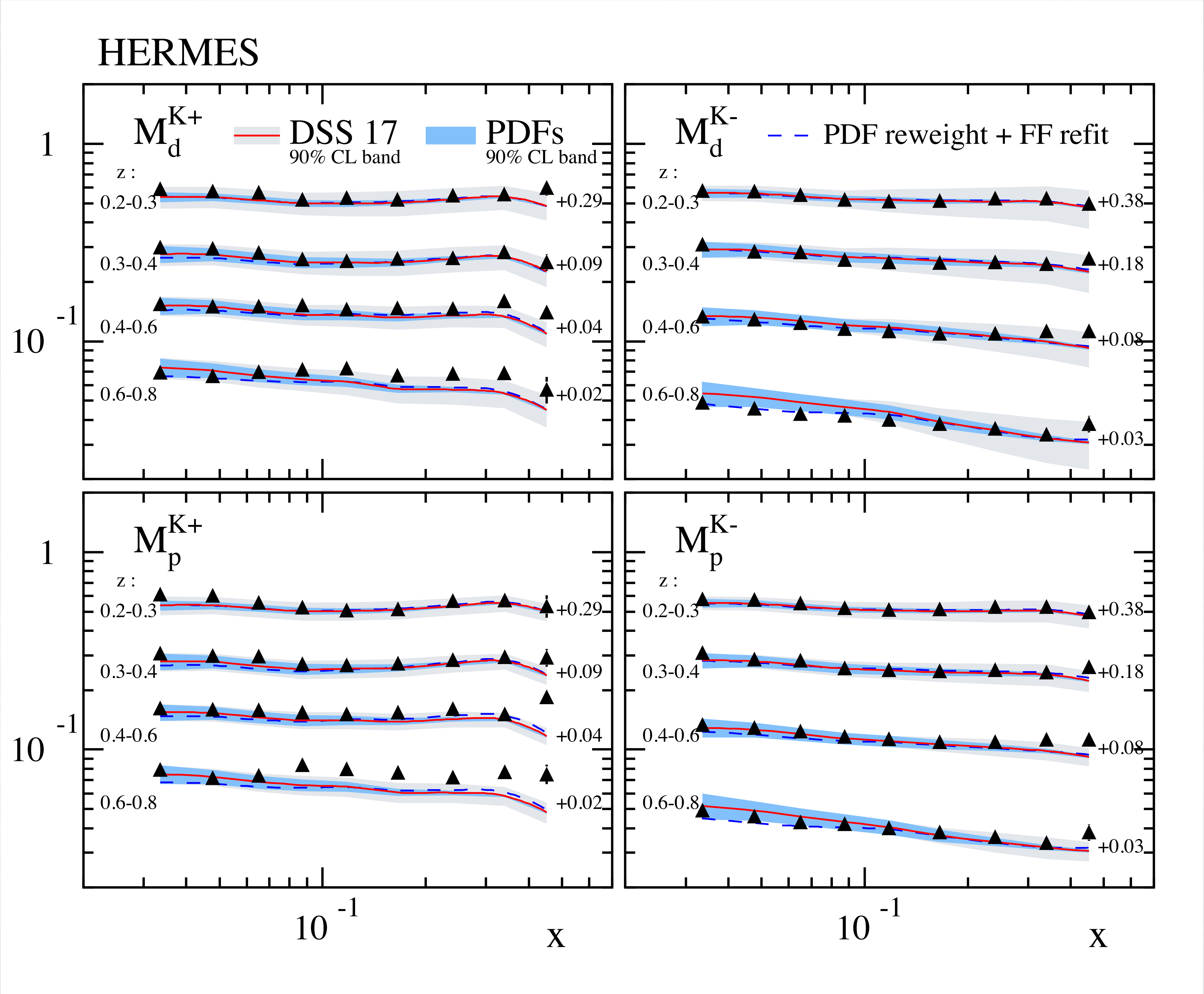
consistency checks:

double counting

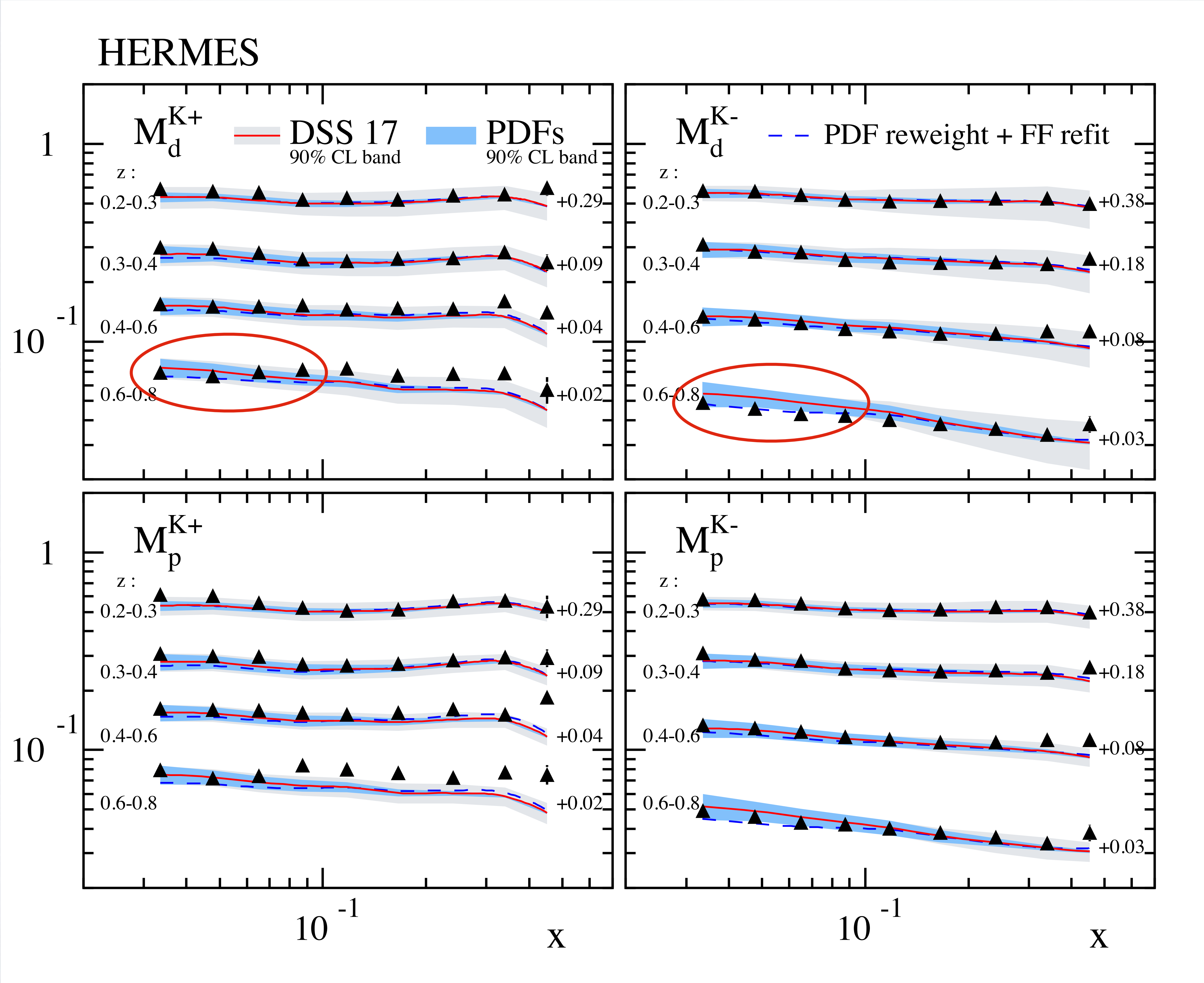
surviving replicas

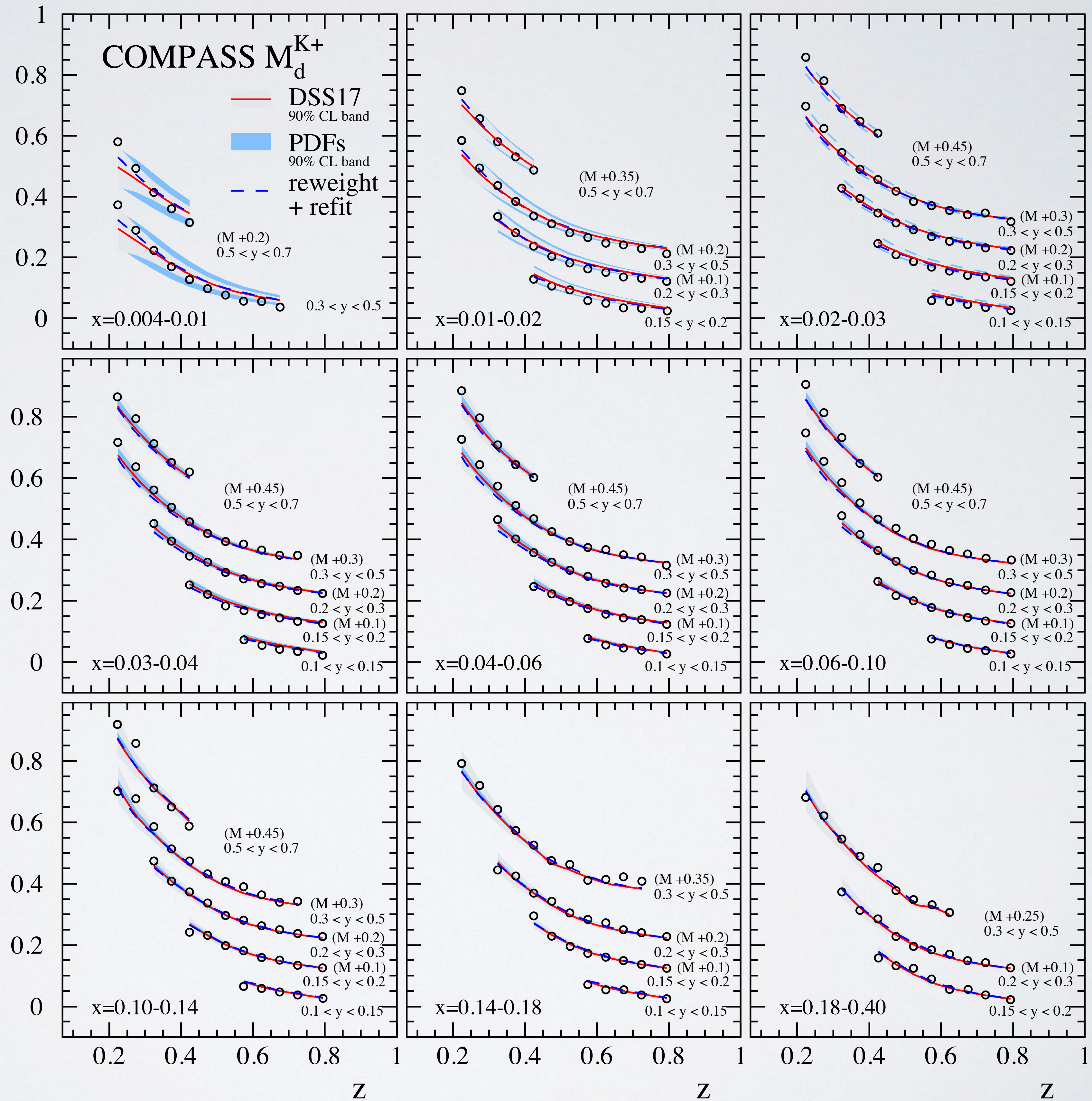


SIDIS revisited:

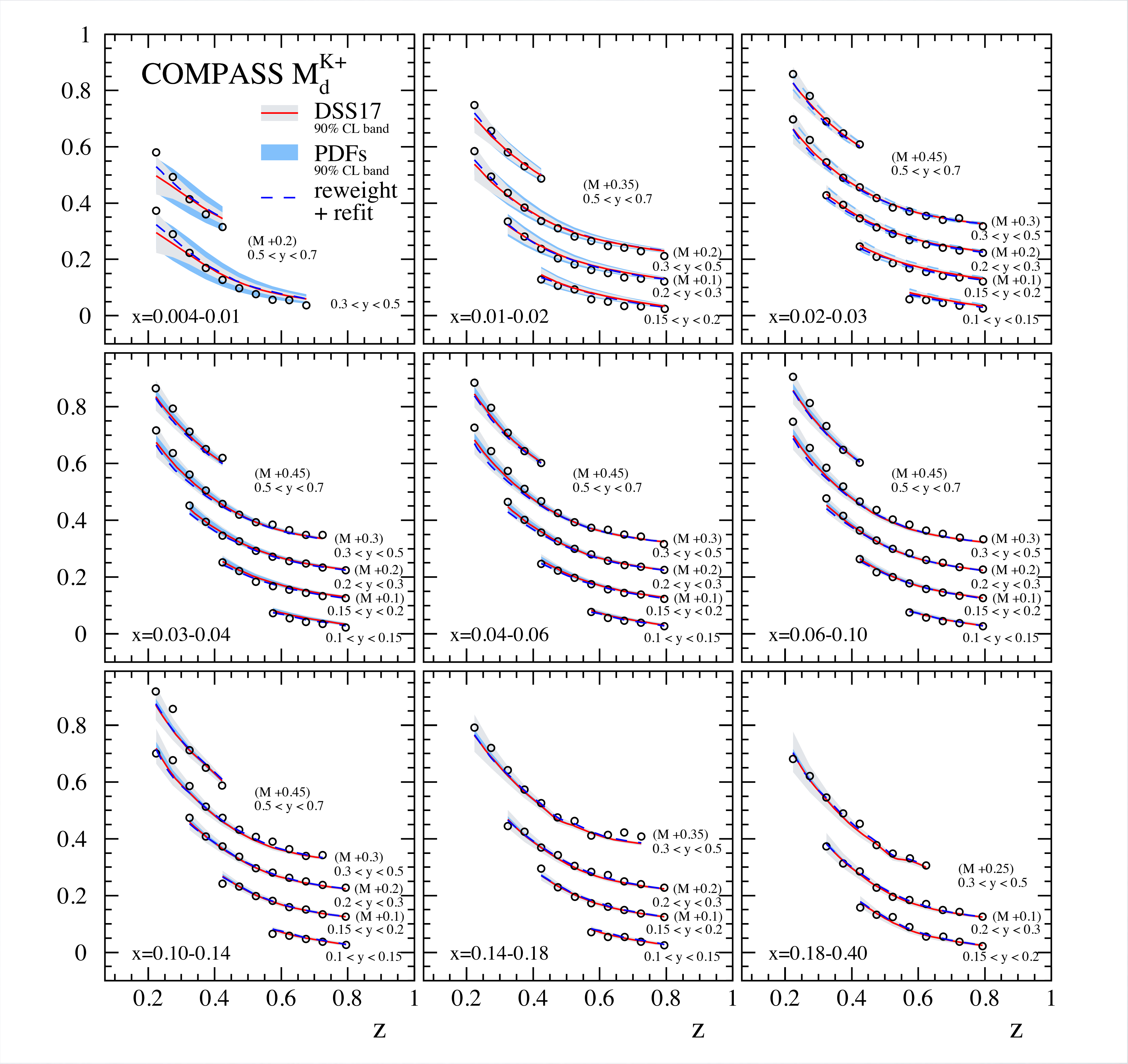


SIDIS revisited:

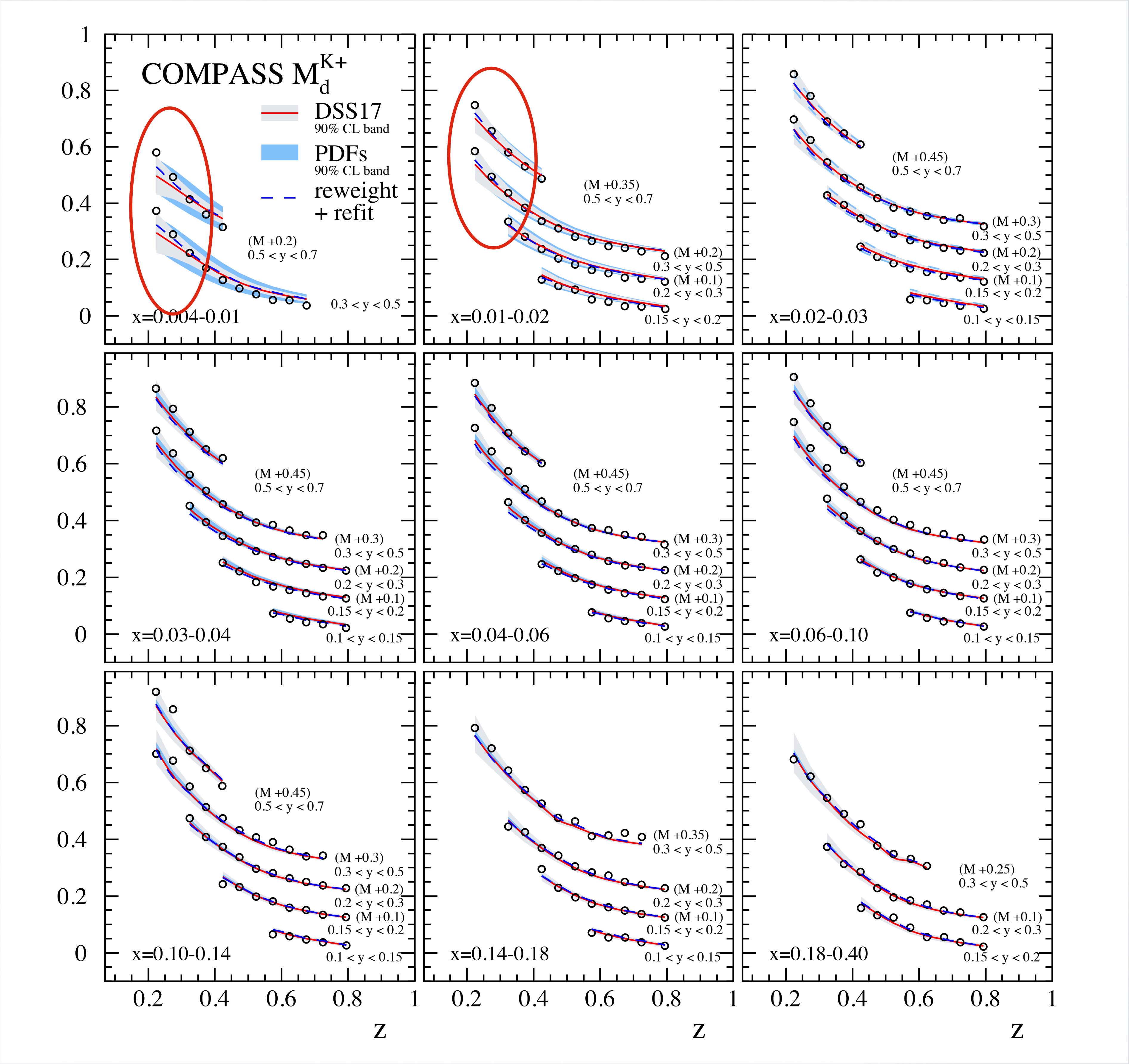



COMPASS M_d^{K+}
DSS17
90% CL band
PDFs
90% CL band
reweight
+ refit
(M +0.2)
0.5 < y < 0.7
0.3 < y < 0.5
x=0.004-0.01
(M +0.35)
0.5 < y < 0.7
(M +0.2)
0.3 < y < 0.5
(M +0.1)
0.2 < y < 0.3
0.15 < y < 0.2
x=0.01-0.02
(M +0.45)
0.5 < y < 0.7
(M +0.3)
0.3 < y < 0.5
(M +0.2)
0.2 < y < 0.3
(M +0.1)
0.15 < y < 0.2
0.1 < y < 0.15
x=0.02-0.03
x=0.03-0.04
x=0.04-0.06
x=0.06-0.10
x=0.10-0.14
(M +0.35)
0.3 < y < 0.5
x=0.14-0.18
(M +0.25)
0.3 < y < 0.5
(M +0.1)
0.2 < y < 0.3
0.15 < y < 0.2
x=0.18-0.40
z

SIDIS revisited:



SIDIS revisited:

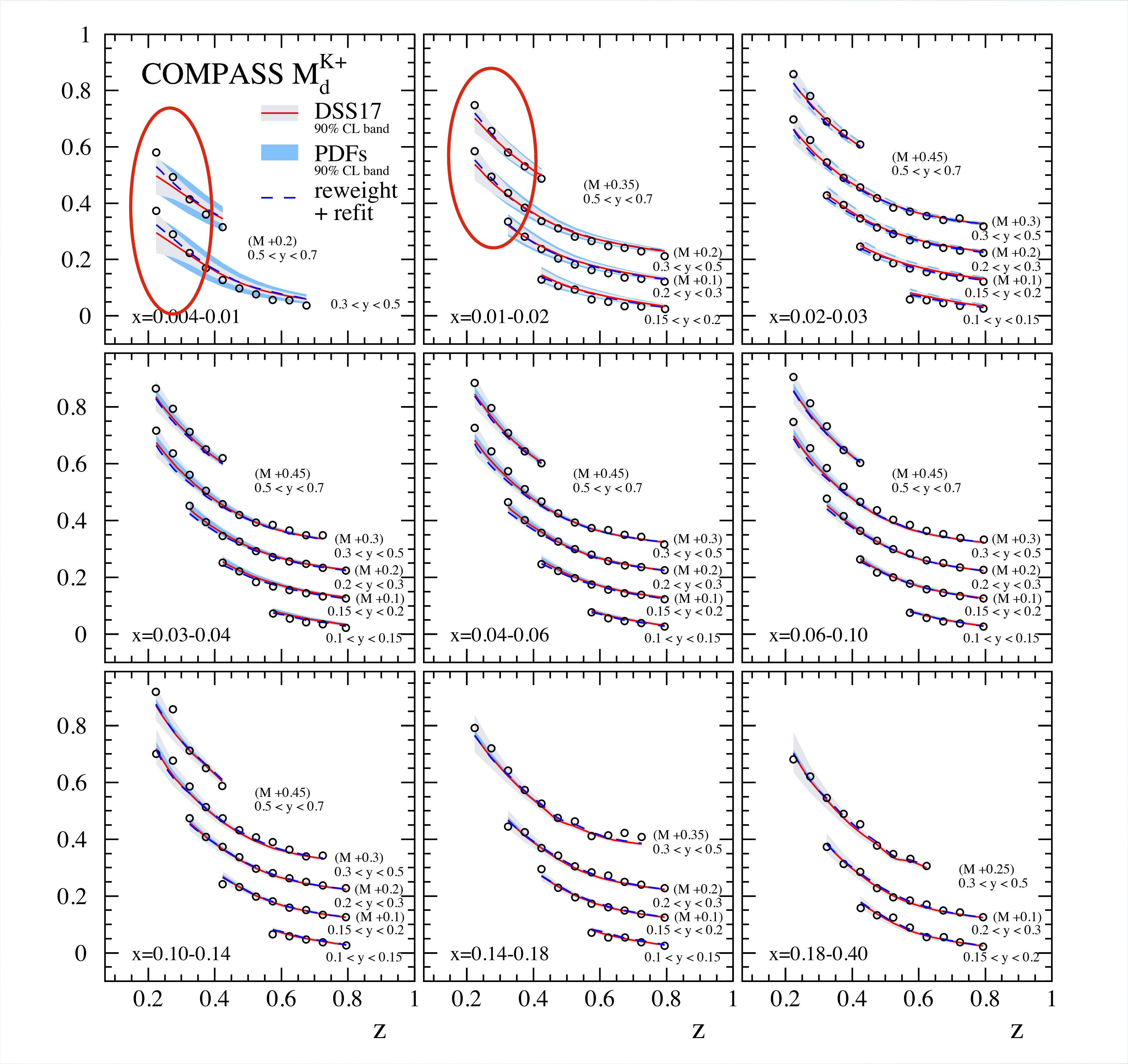


SIDIS revisited:

555.9

467.6

434.5



SIDIS at EIC:

in collaboration with E. Aschenauer, I. Borsa, M. Stratmann, C. Van Hulse

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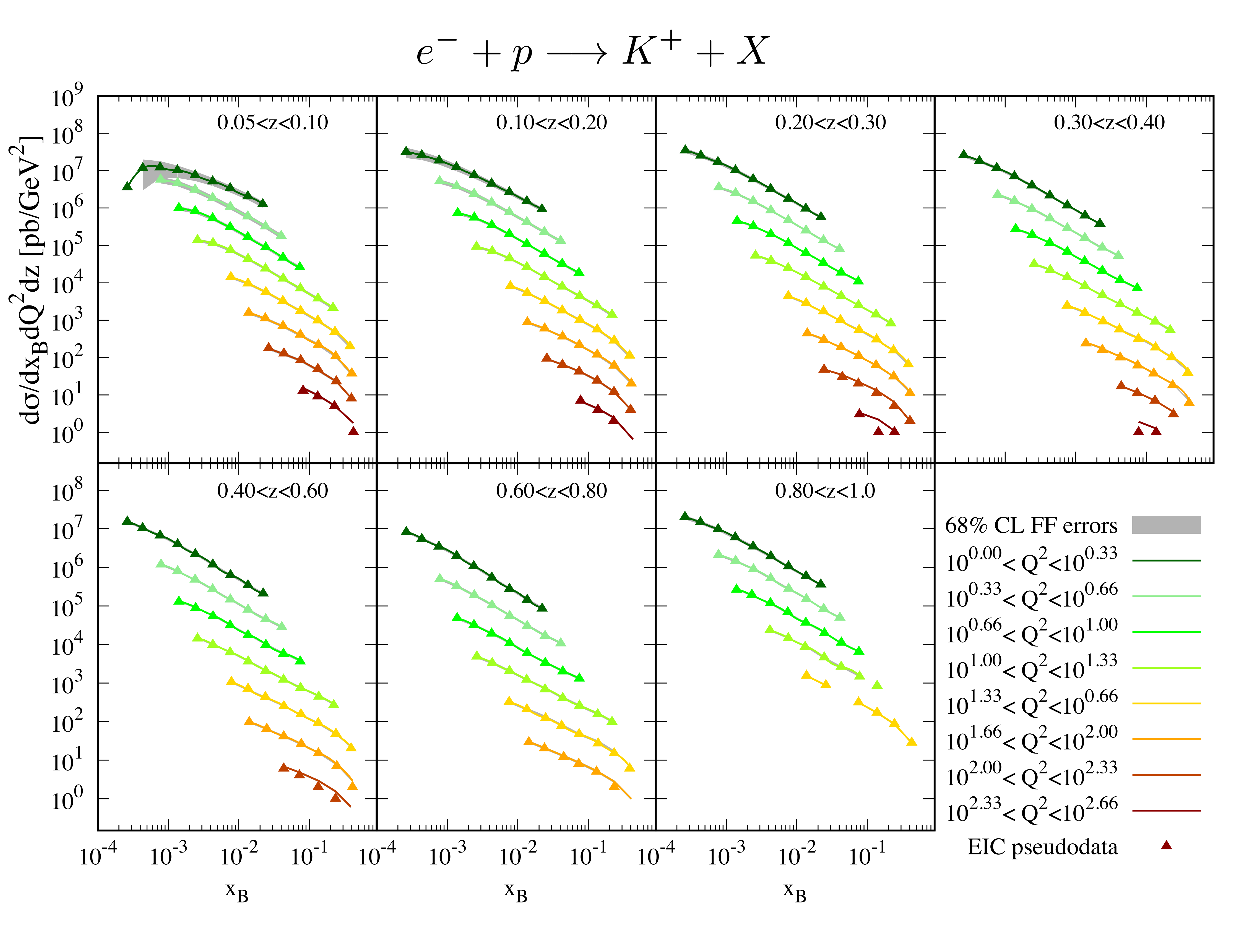
E_e=15 GeV
E_p=100 GeV

10 fb^{-1}



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E_e=15 GeV
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10 fb^{-1}

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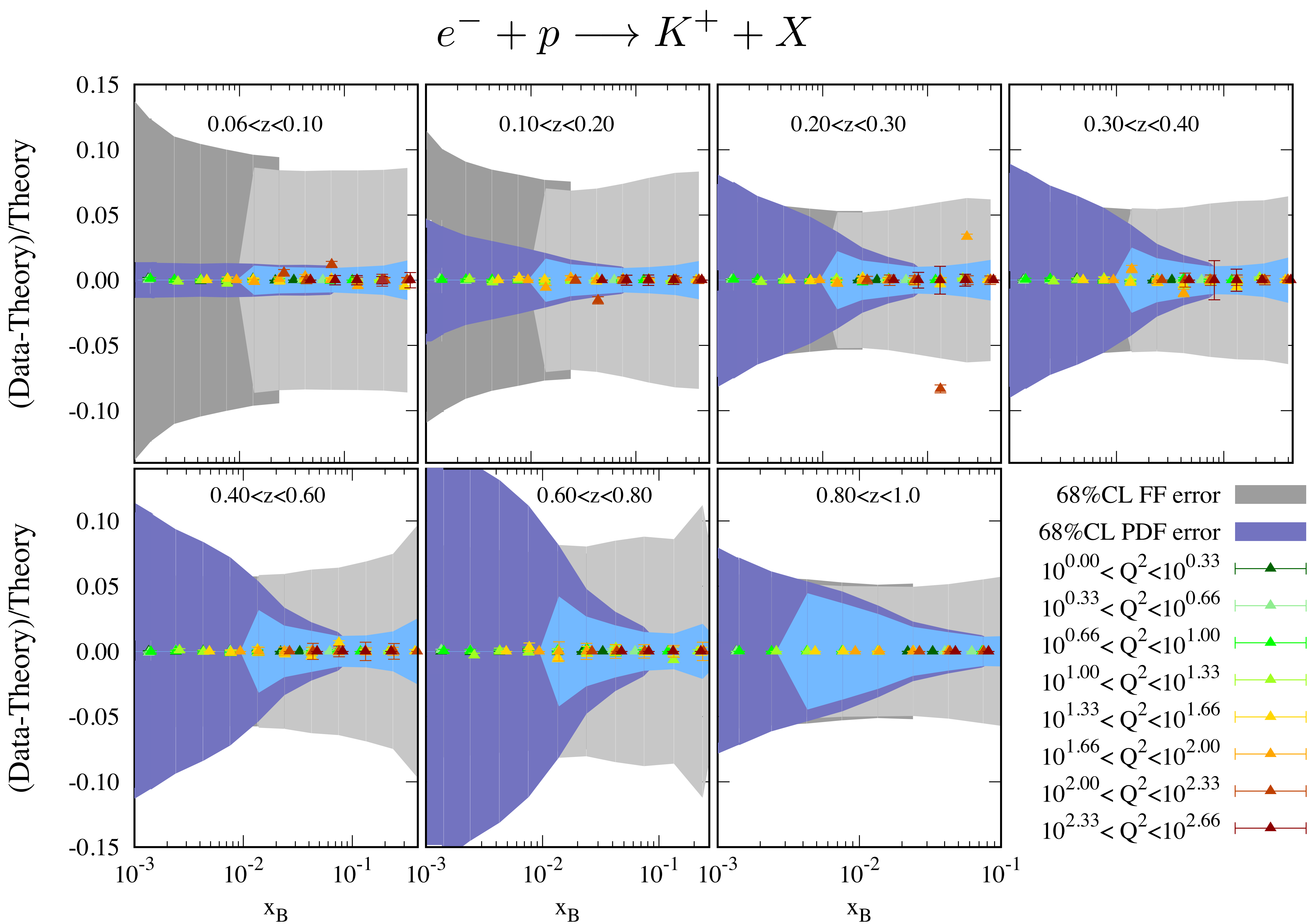
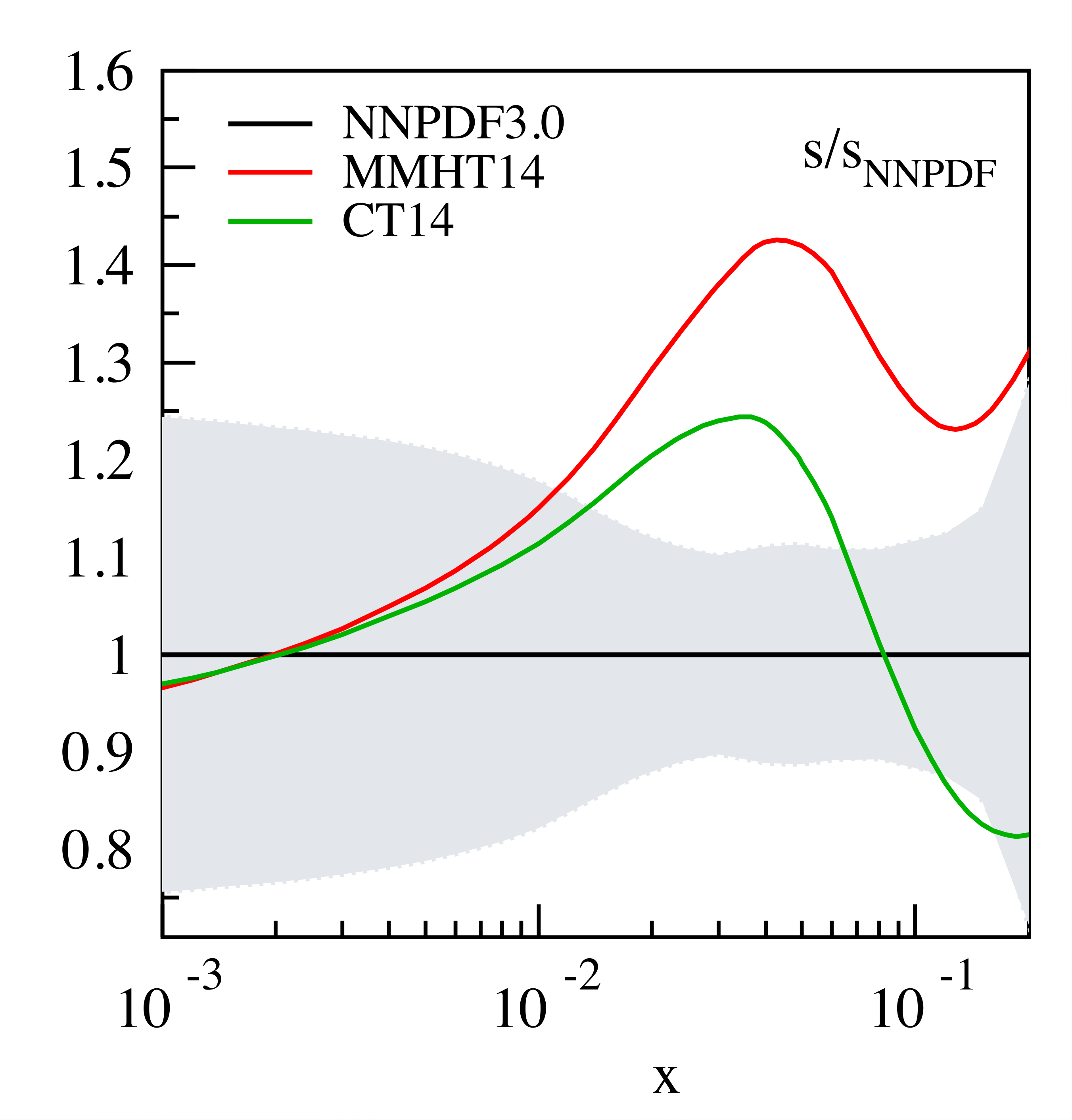
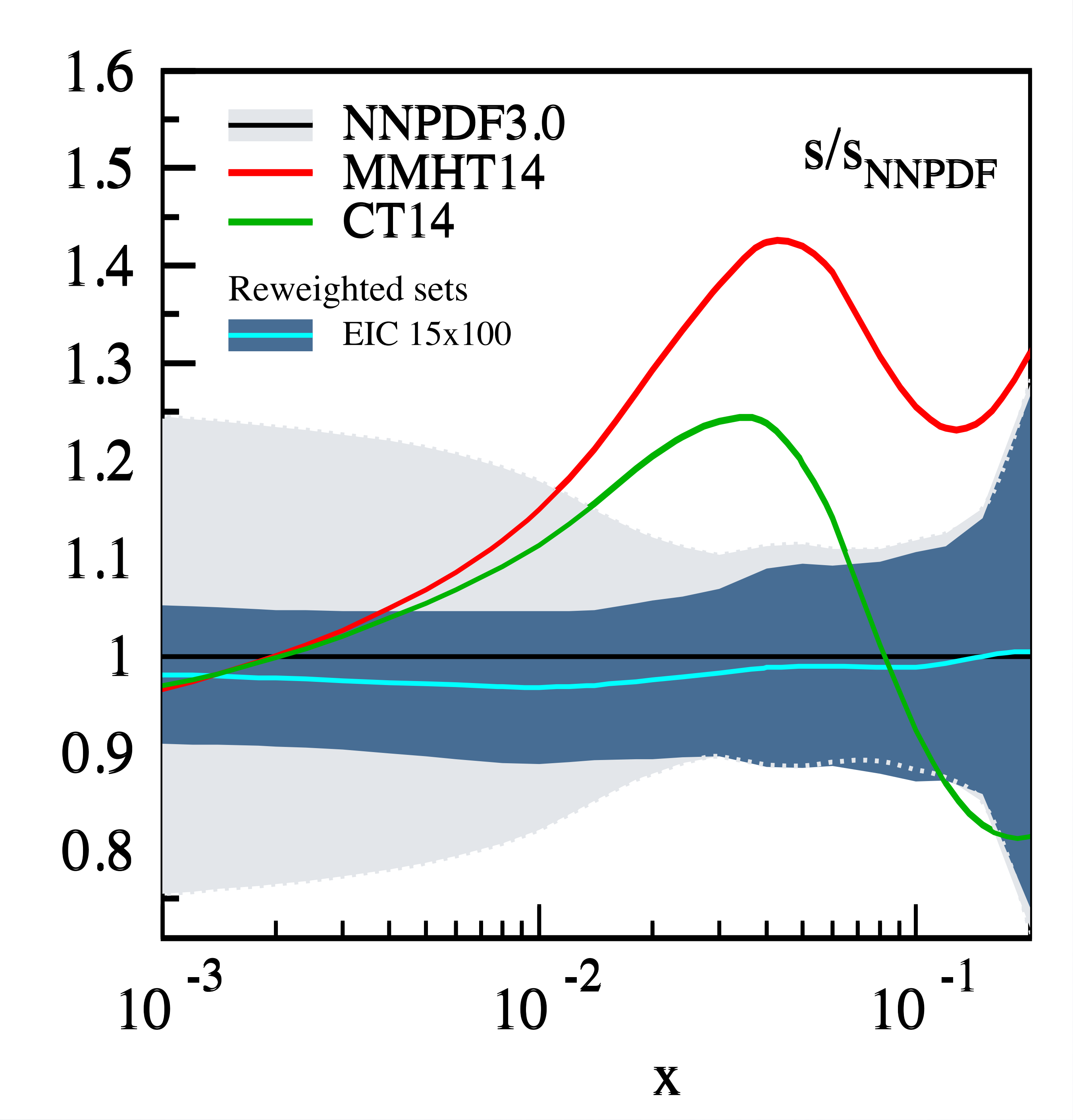


SIDIS at EIC:



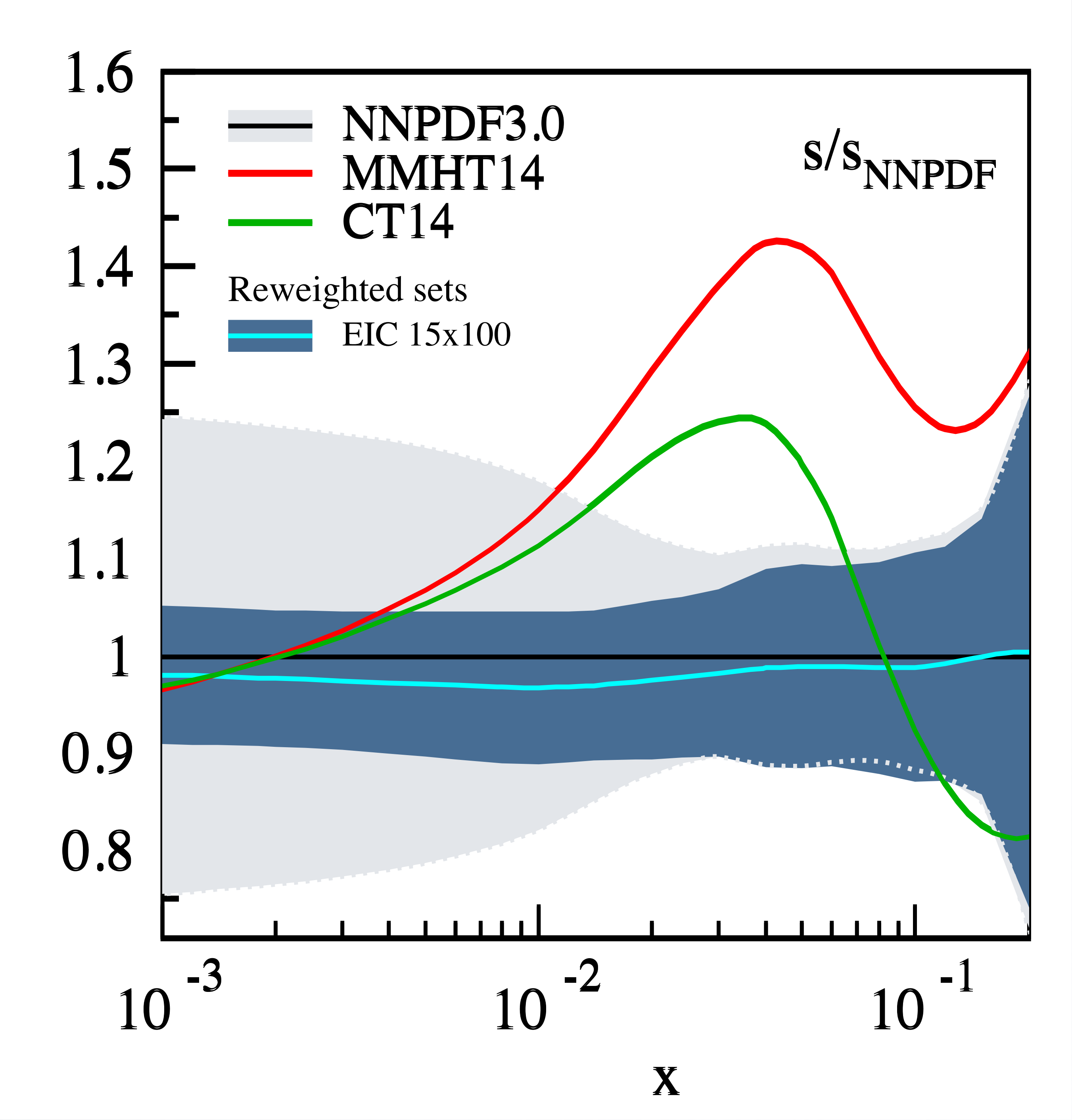
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
NNPDF3.0
MMHT14
CT14
s/s_NNPDF
10 -3
10 -2
10 -1
x

SIDIS at EIC:



NNPDF3.0
MMHT14
CT14
Reweighted sets
EIC 15x100
s/s_{NNPDF}
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
10^{-3}
10^{-2}
10^{-1}
x

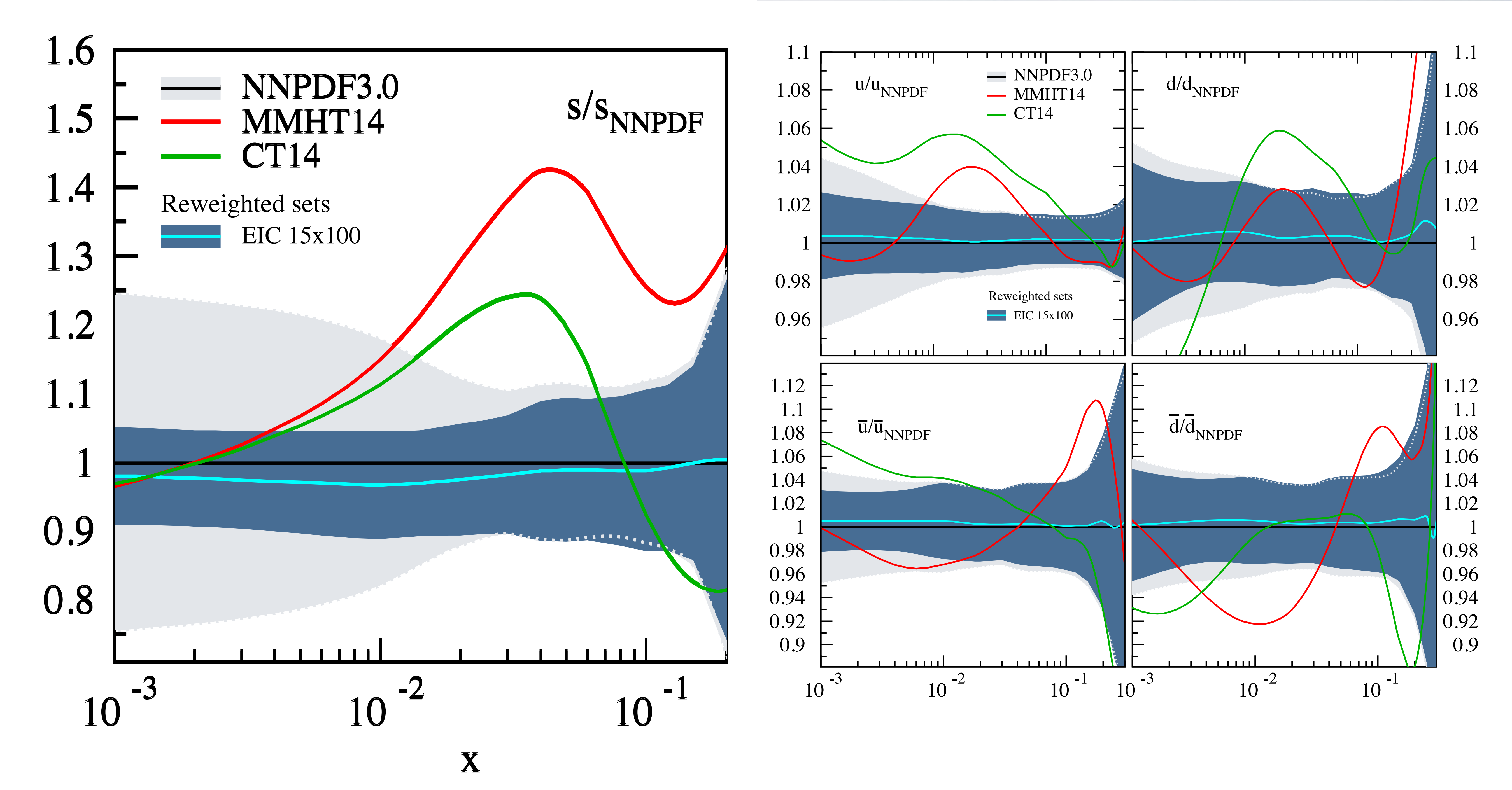
SIDIS at EIC:



precision tool for:

strangeness in the proton

SIDIS at EIC:



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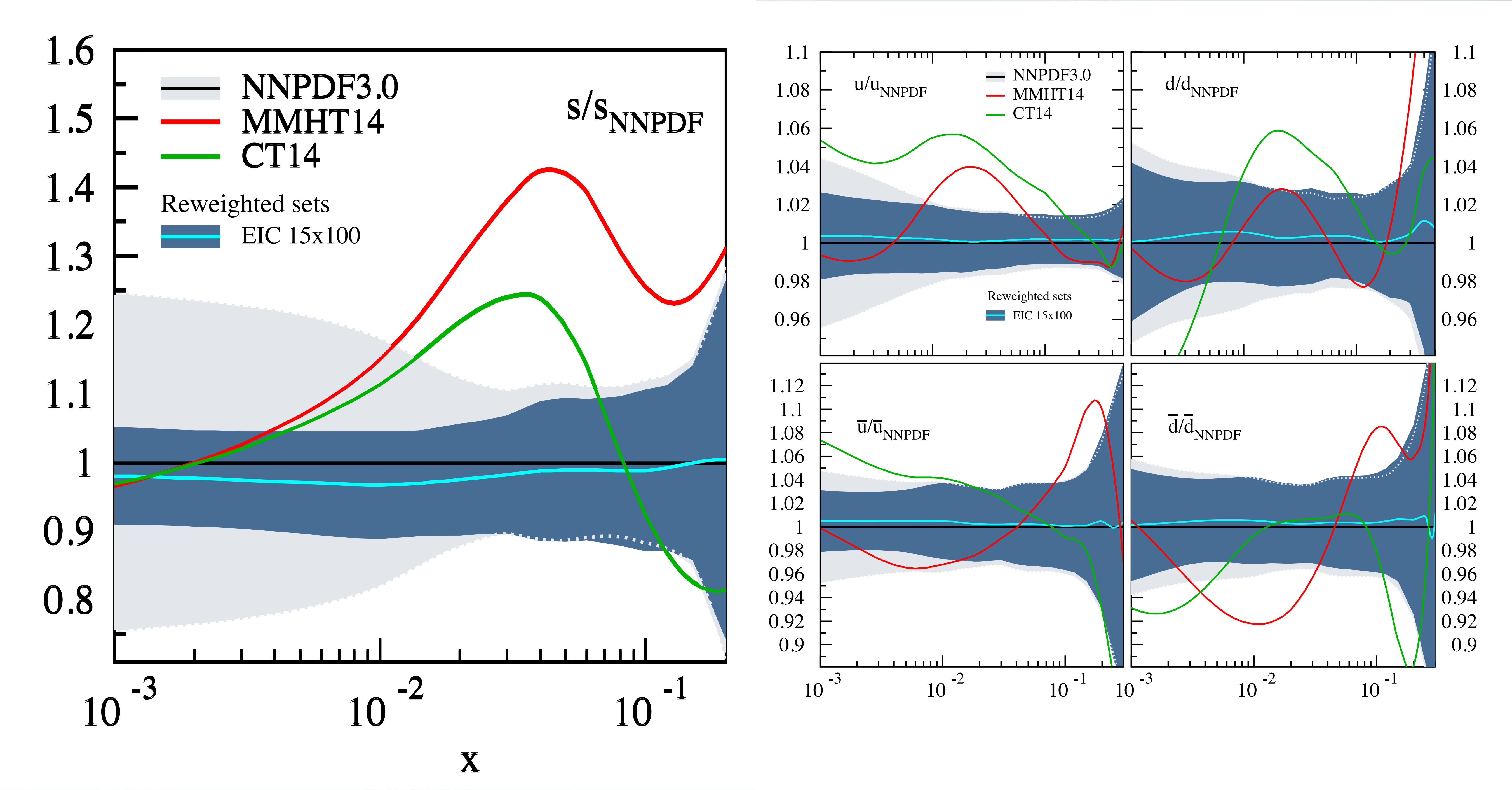
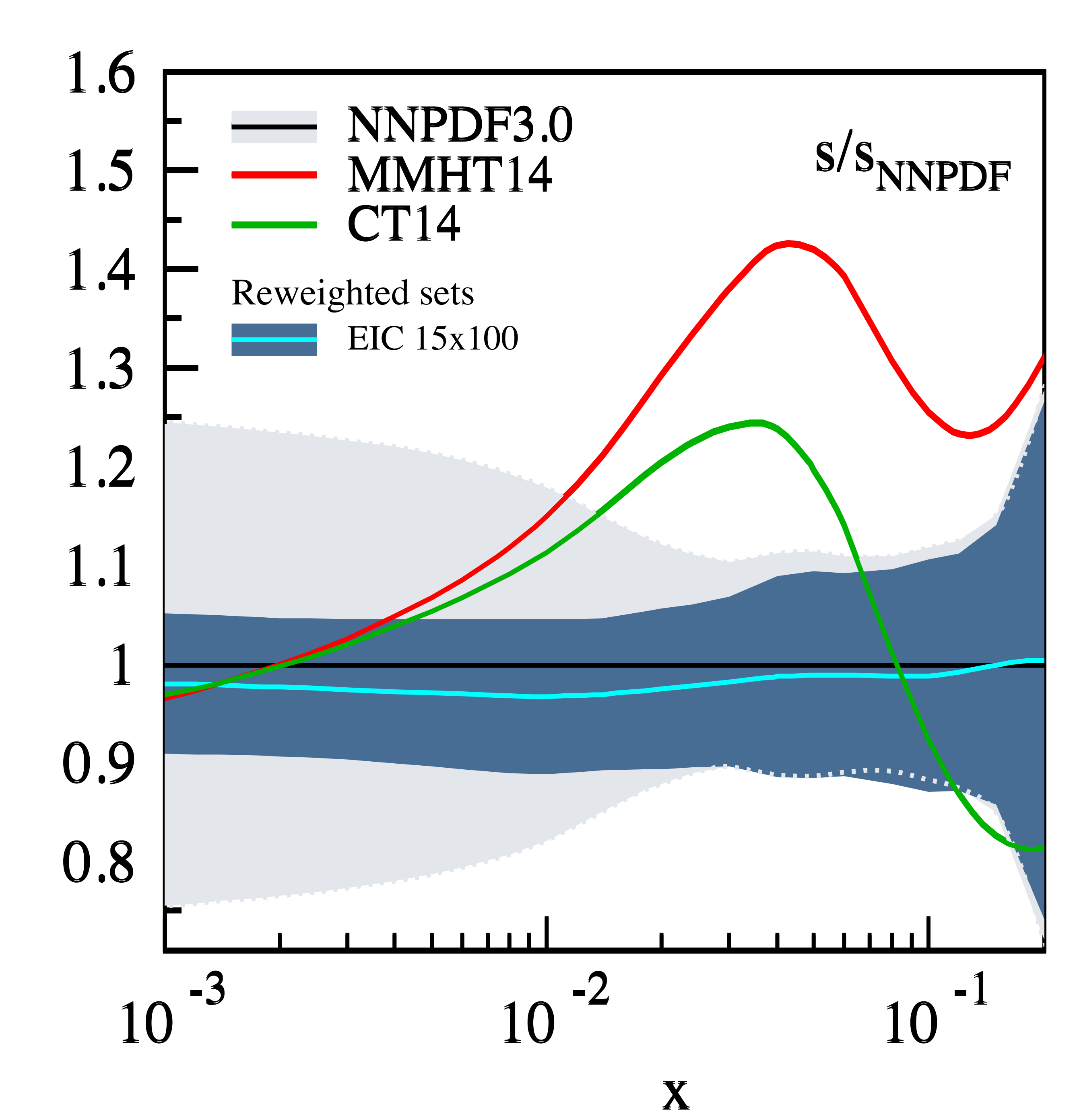
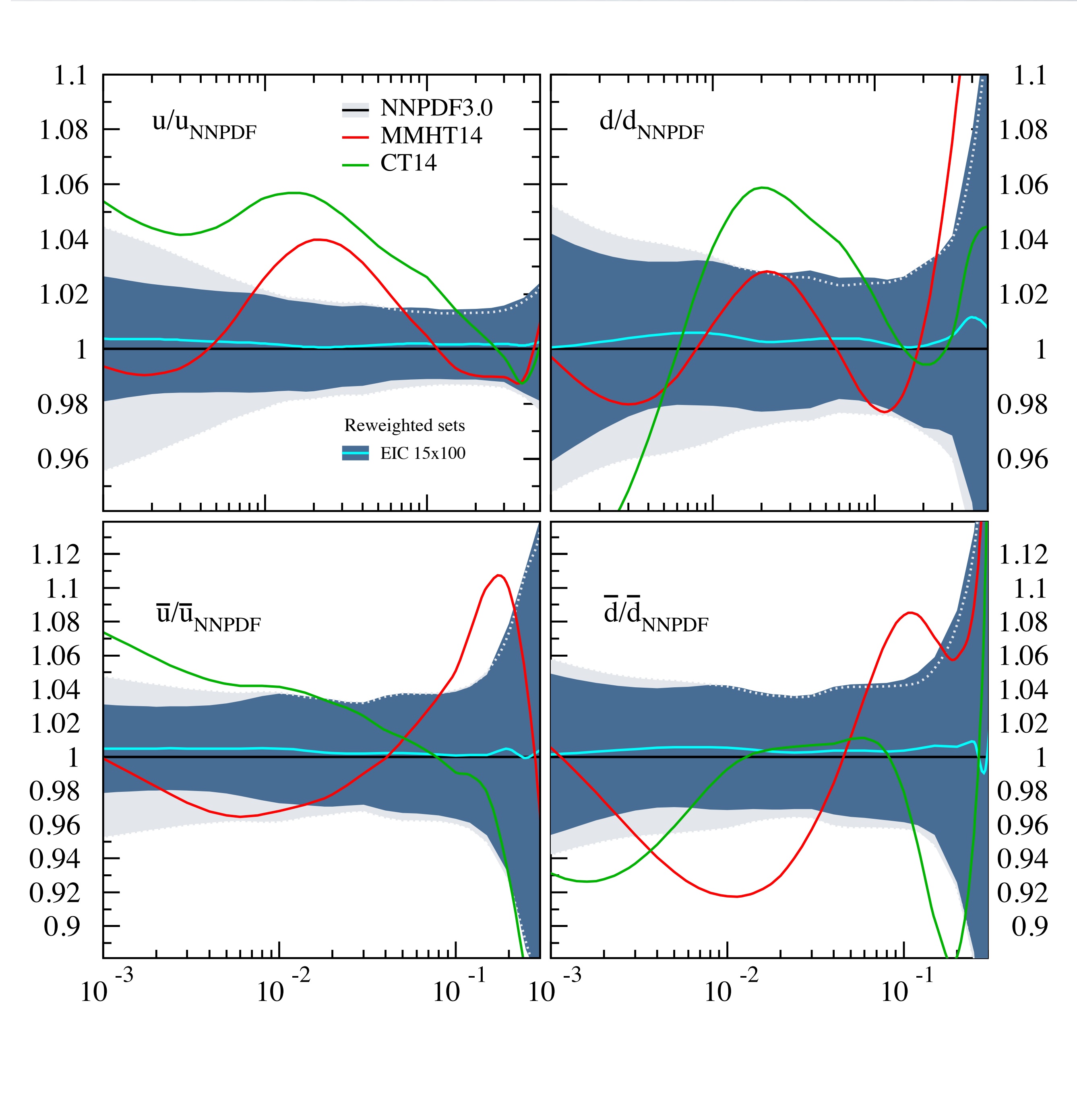


precision tool for:

- **strangeness in the proton**
- **isospin breaking**
- **charge symmetry breaking**

SIDIS at EIC:



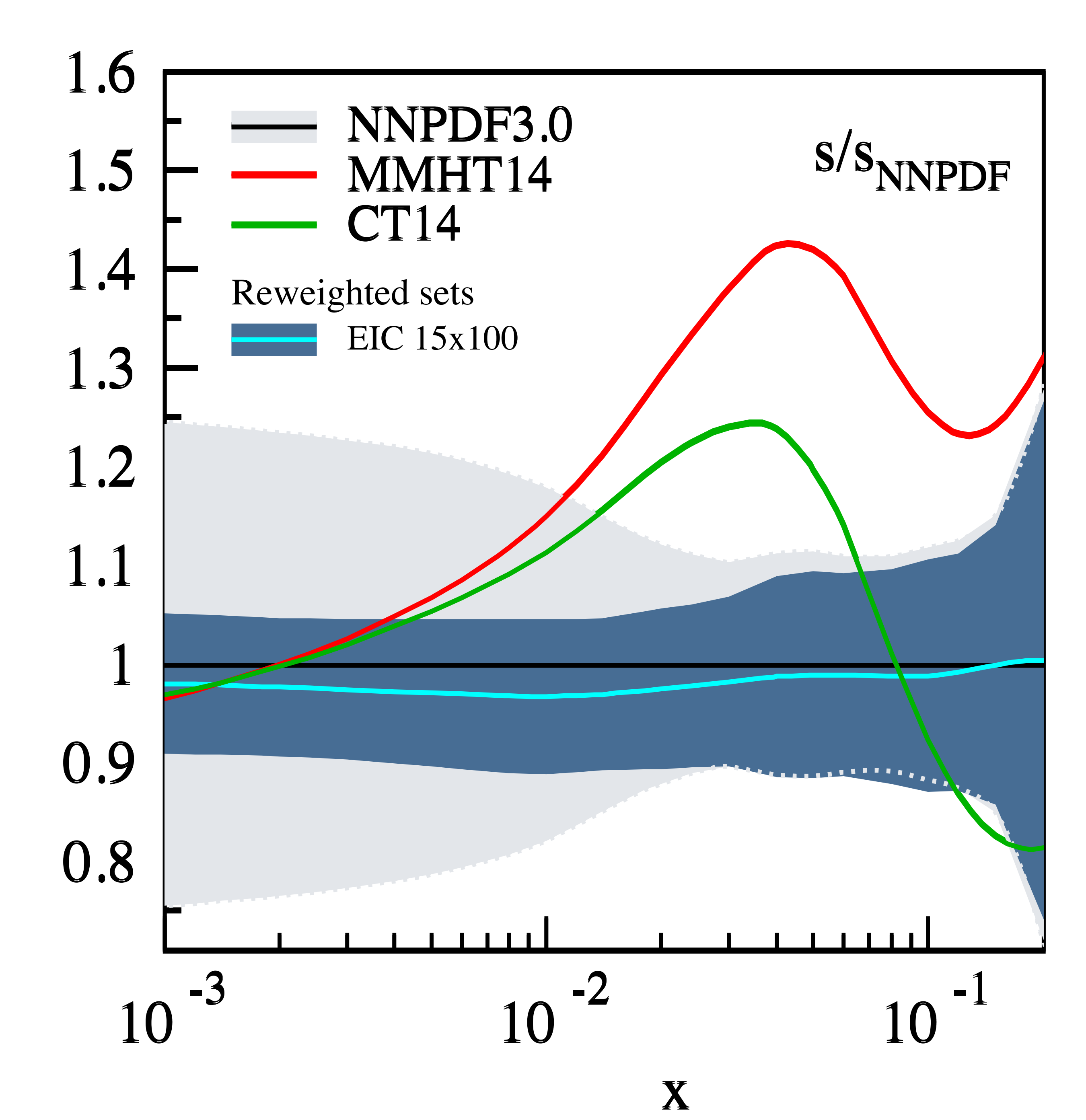


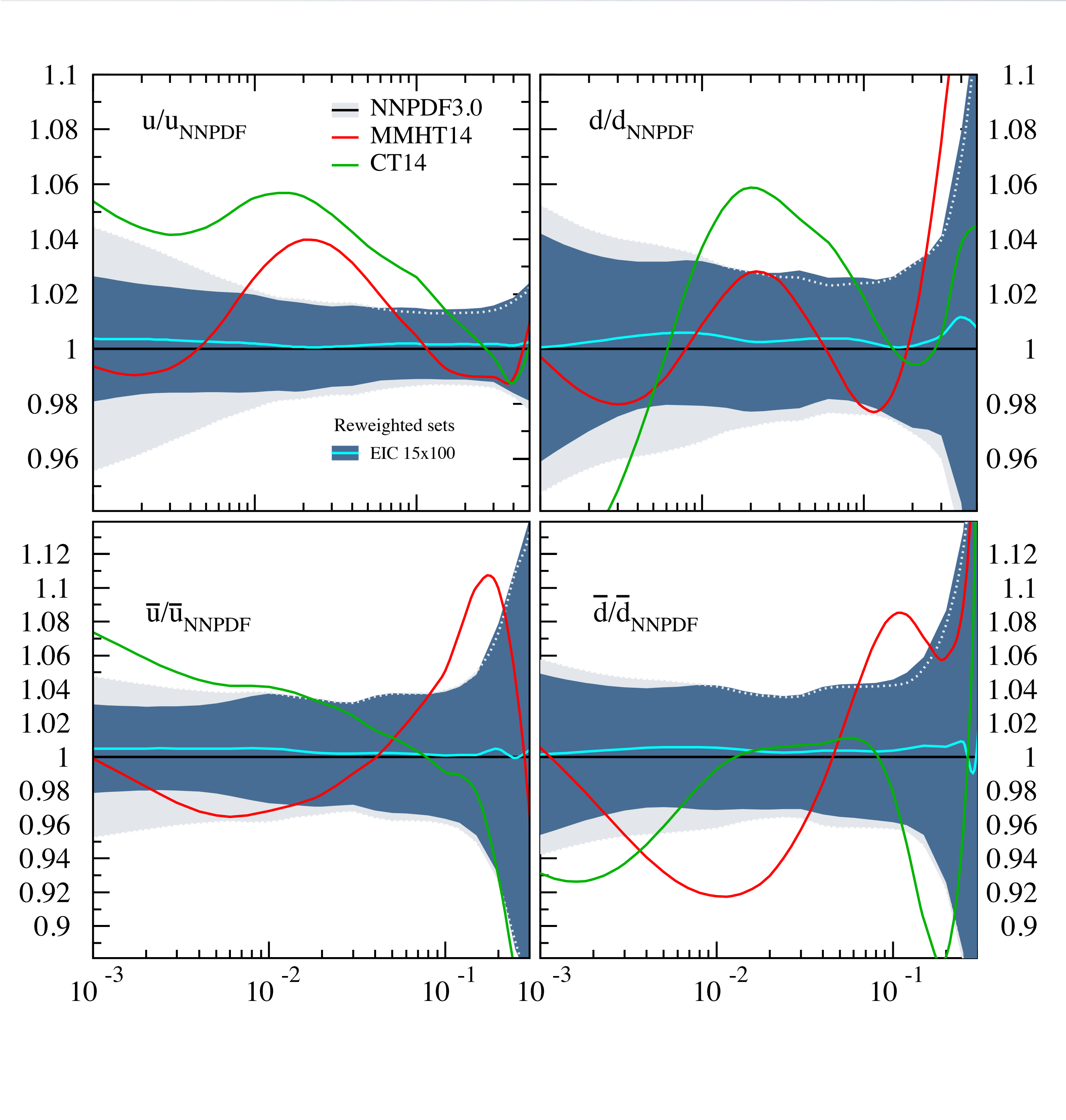
precision tool for:

strangeness in the proton
isospin breaking
charge symmetry breaking

flavor without d or A targets

SIDIS at EIC:



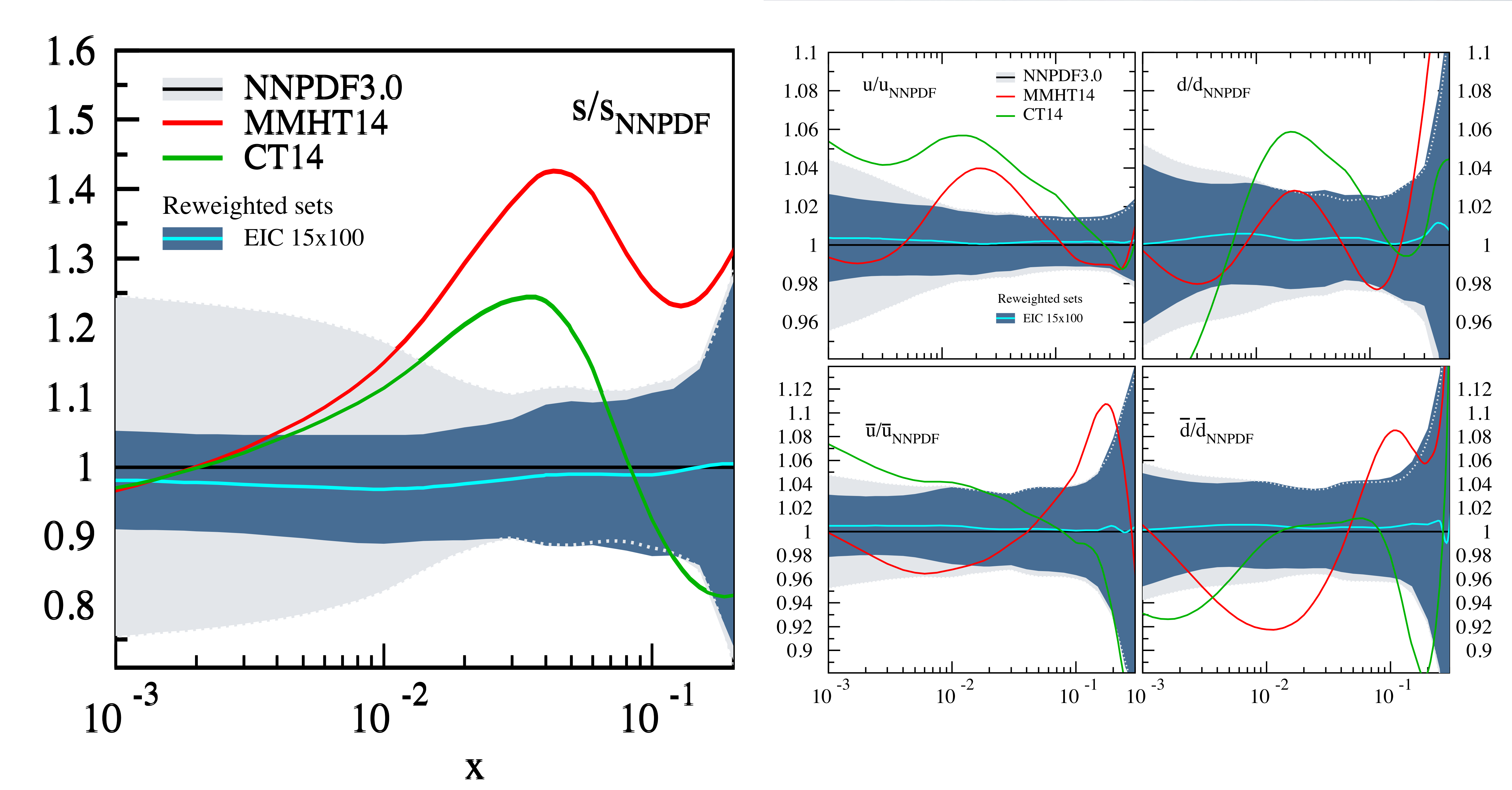


precision tool for:

- strangeness in the proton
- isospin breaking
- charge symmetry breaking

flavor without d or A targets
nuclear effects

SIDIS at EIC:



precision tool for:

- **strangeness in the proton**
- **isospin breaking**
- **charge symmetry breaking**

flavor without d or A targets

nuclear effects for PDFs and FFs

Summary:

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updated DSS set of FFs for kaons: new data (x5), uncertainties, input PDFs

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EIC SIDIS data expected to have a significant **impact** for PDFs & FFs:

strangeness in the proton

isospin/charge symmetry breaking

nuclear effects in initial and final states

experiment	data type	norm. $\mathcal{N}_i$	# data in fit	χ^2
TPC [39]	incl.	1.003	12	13.4
SLD [35]	incl.	1.014	18	17.2
	uds tag	1.014	10	31.5
	c tag	1.014	10	21.3
	b tag	1.014	10	11.9
ALEPH [32]	incl.	1.026	13	29.7
DELPHI [33]	incl.	1.000	12	6.9
	uds tag	1.000	12	13.1
	b tag	1.000	12	11.0
OPAL [36]	u tag	0.778	5	9.6
	d tag	0.778	5	7.7
	s tag	0.778	5	23.4
	c tag	0.778	5	42.5
	b tag	0.778	5	16.9
BABAR [19]	incl.	1.077	45	30.6
BELLE [20]	incl.	0.996	78	15.6
HERMES [21]	K^+ (p) Q^2	0.843	36	61.9
	K^- (p) Q^2	0.843	36	29.6
	K^+ (p) x	1.135	36	75.8
	K^- (p) x	1.135	36	42.1
	K^+ (d) Q^2	0.845	36	44.7
	K^- (d) Q^2	0.845	36	41.9
	K^+ (d) x	1.095	36	48.9
	K^- (d) x	1.095	36	44.4
COMPASS [24]	K^+ (d)	0.996	309	285.8
	K^- (d)	0.996	309	265.1
STAR [26]	K^+,K^-/K^+	1.088	16	7.6
ALICE [25] 2.76 TeV	K/π	0.985	15	21.6
TOTAL:			1194	1271.7