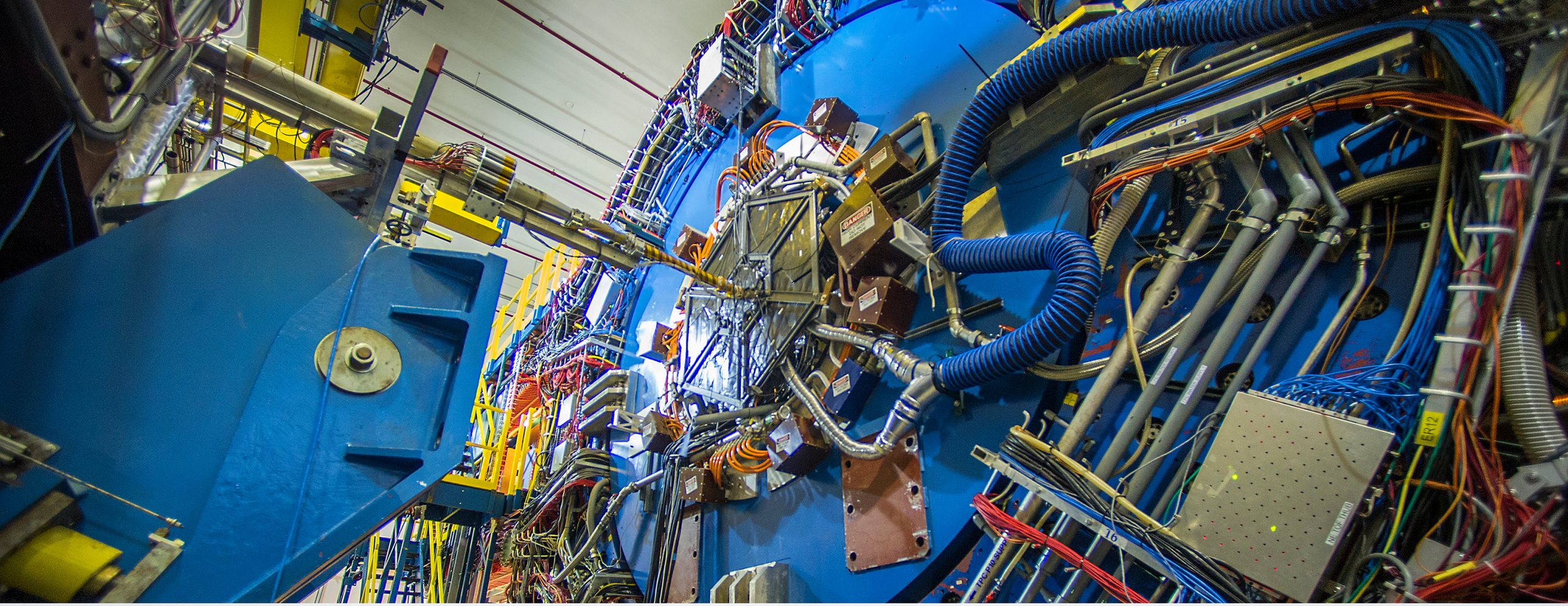
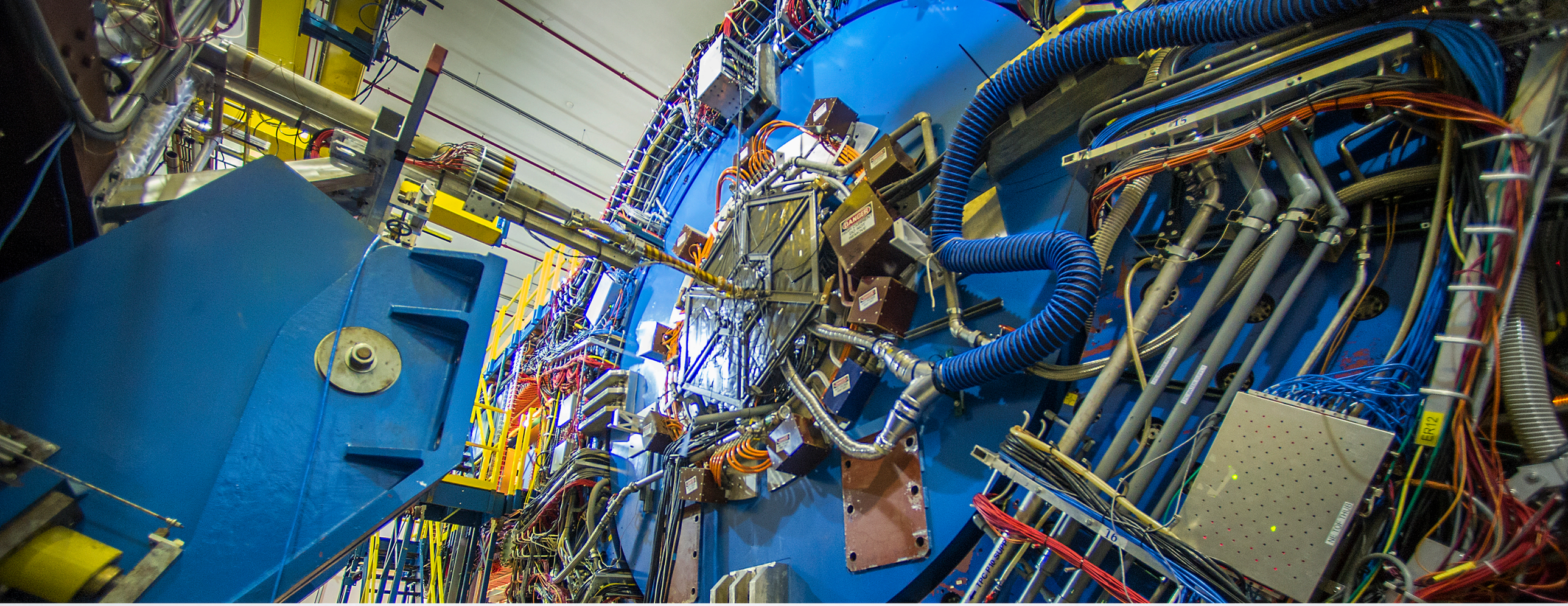


PROBING THE SEA QUARK CONTENT OF THE PROTON WITH IDENTIFIED FINAL STATE PARTICLES

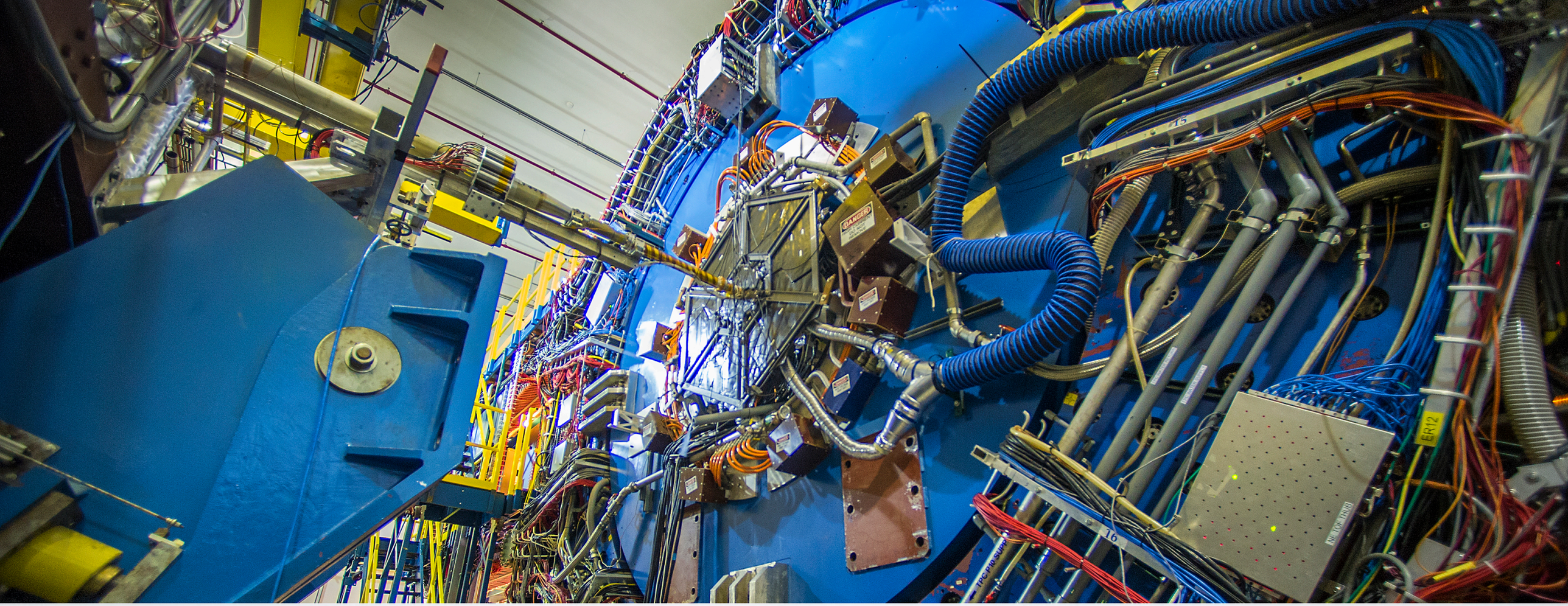
Ignacio Borsa
Universidad de Buenos Aires
RHIC&AGS Users' Annual Meeting 2018

Brookhaven National Laboratory



PDFs and FFs

In collaboration with R. Sassot and M. Stratmann



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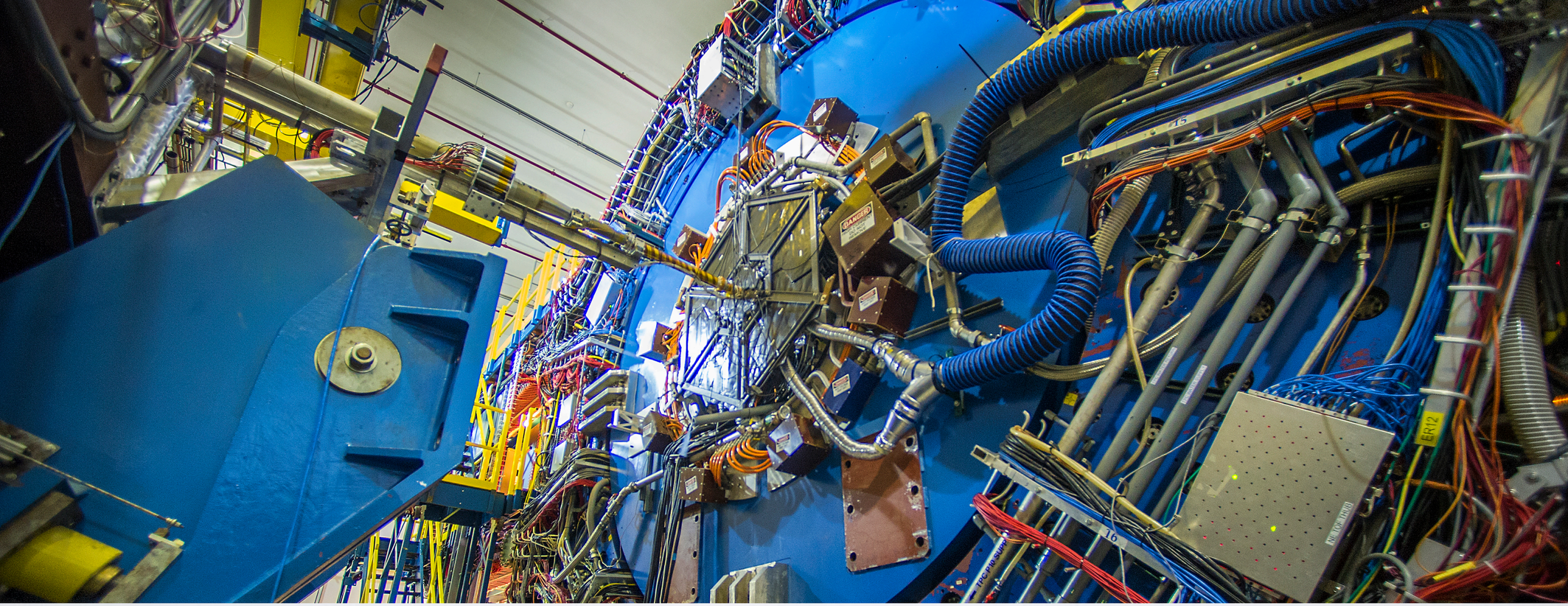
PDFs and FFs at RHIC In collaboration with E. Aschenauer and R. Sassot



PDFs and FFs	In collaboration with R. Sassot and M. Stratmann
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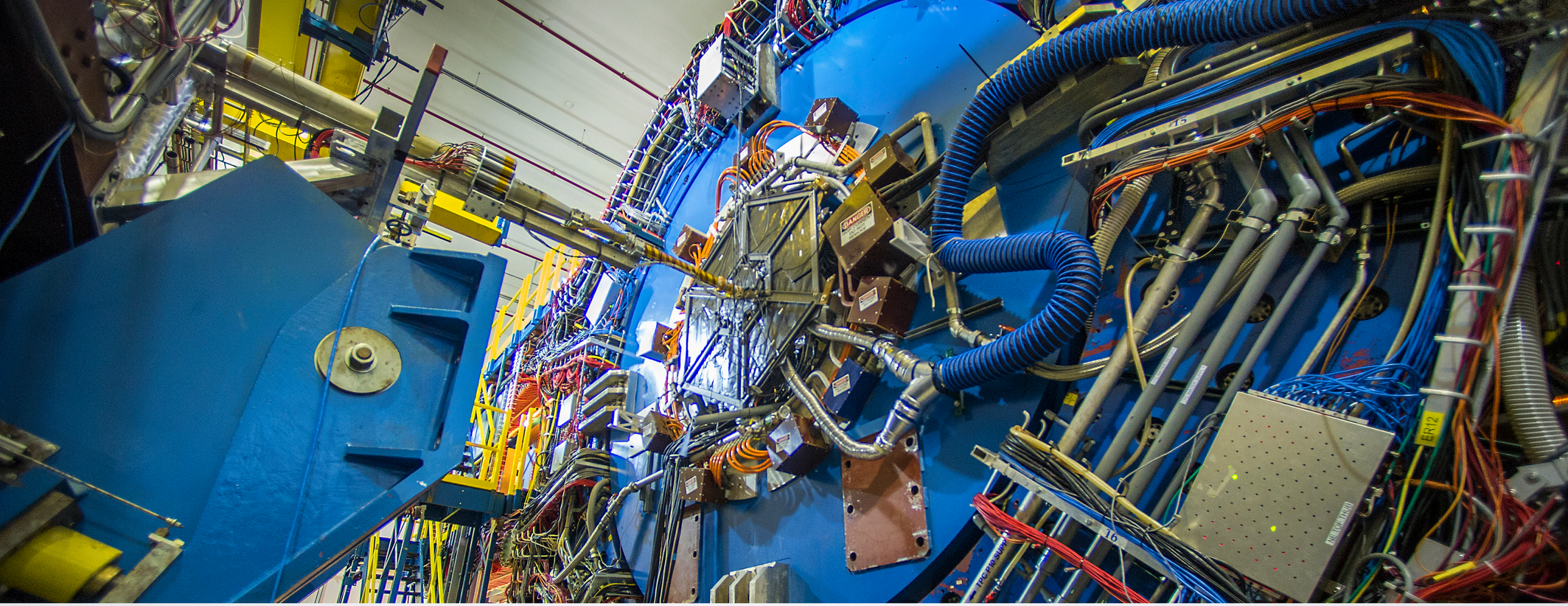
PDFs and FFs at EIC	In collaboration with E. Aschenauer, R. Sassot M. Stratmann and C. Van Hulse



PDFs and FFs

In collaboration with R. Sassot and M. Stratmann

FRAGMENTATION FUNCTIONS FOR HADRONIC PROCESSES

Fragmentation Functions releases and updates

- **NNFF1.0** (SIA)
  Eur.Phys.J.C77 (2017) no.8,516

- **DSS14 & DSS17** (SIA+SIDIS+pp)
  Phys.RevD.96.09020

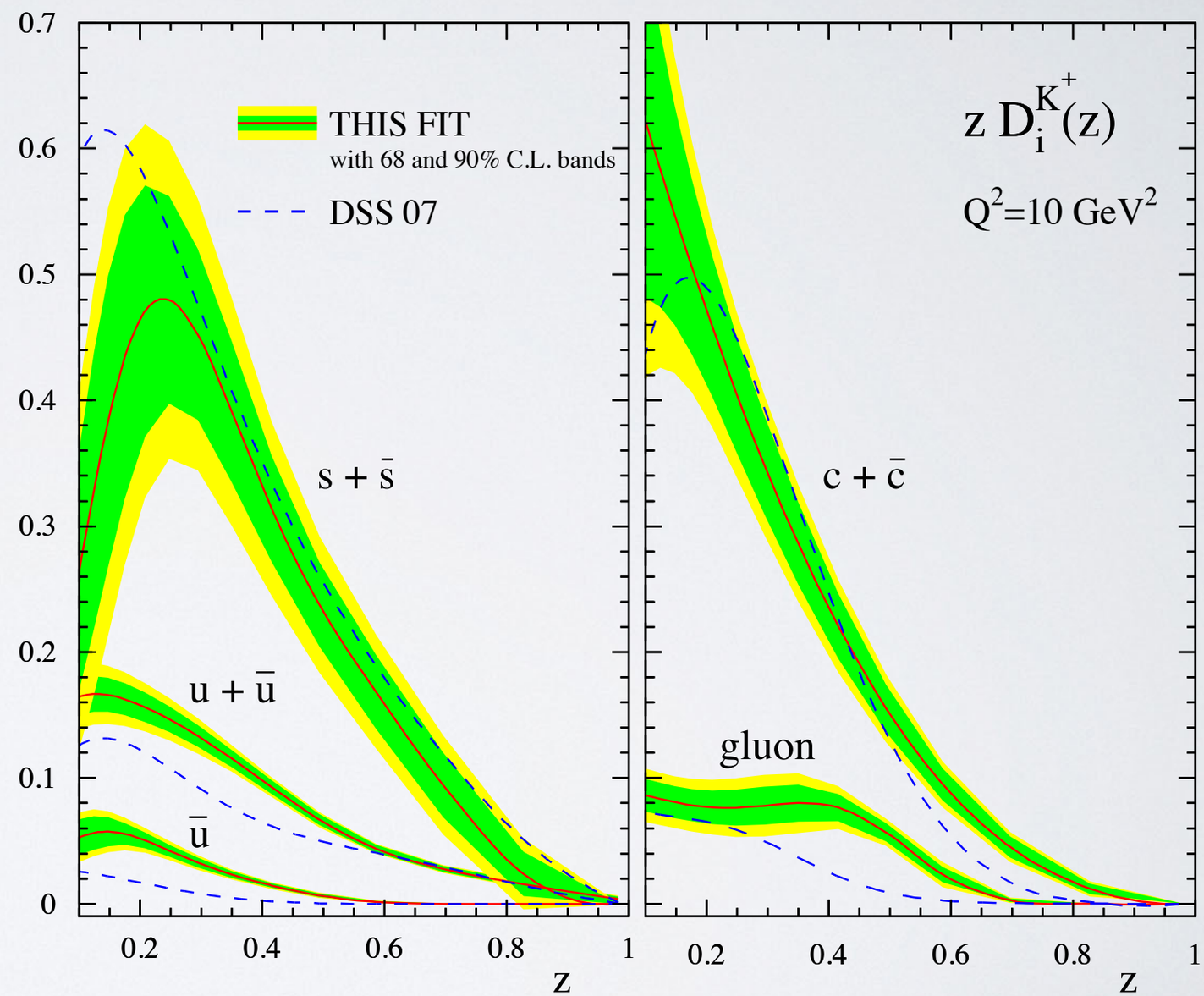
- **JAM17** (SIA+SIDIS)
  Phys.Rev.Lett.119 (2017)no.13,132001

FRAGMENTATION FUNCTIONS FOR HADRONIC PROCESSES

Fragmentation Functions updates in

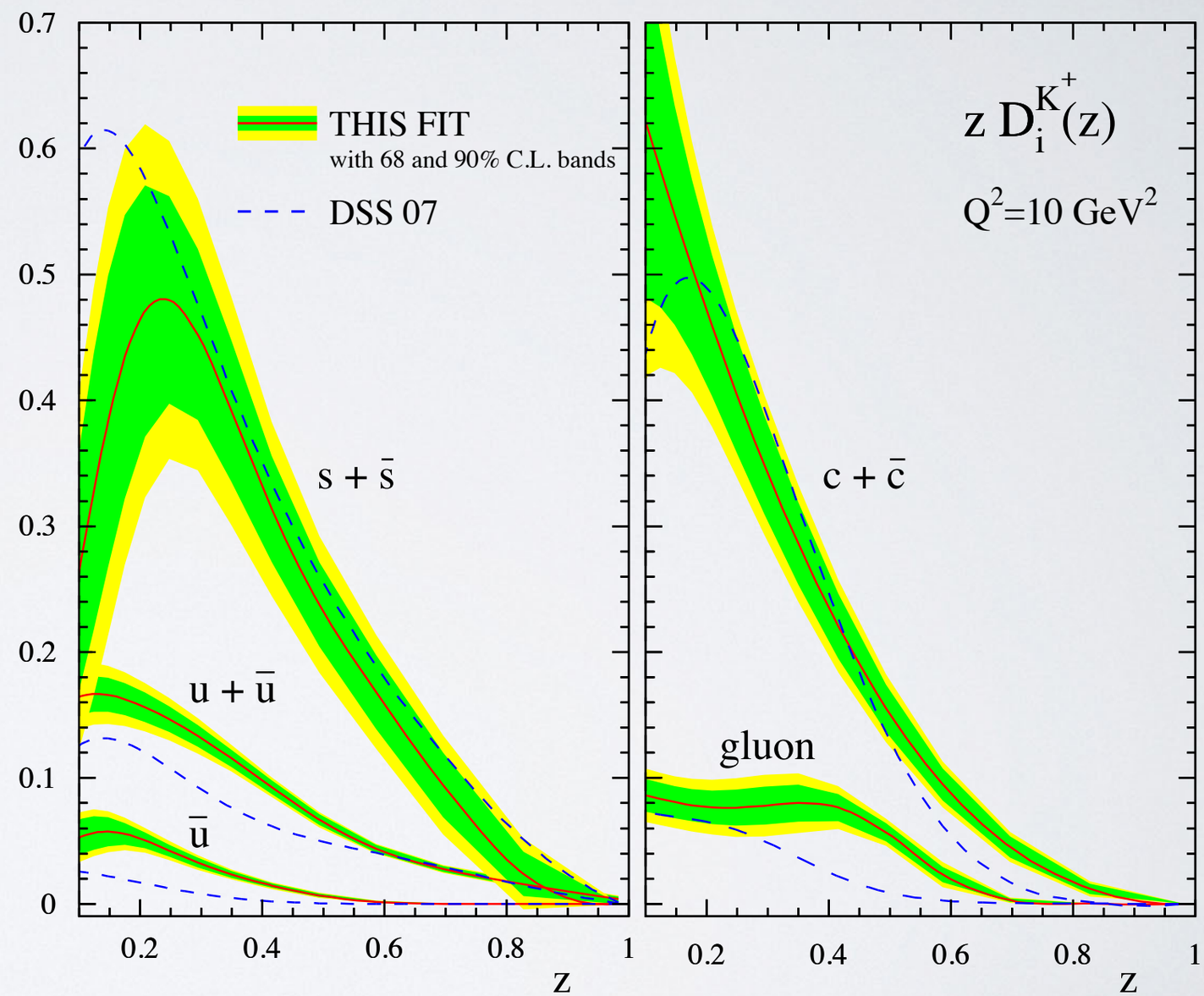
- **NNFF1.0** (SIA)
- **JAM17** (SIA+SIDIS)
- **DSS14 & DSS17** (SIA+SIDIS+pp)

+ STAR data for p+p
+ Compass SIDIS data



FRAGMENTATION FUNCTIONS FOR HADRONIC PROCESSES

- Significant increase in precision
- Strange quark's FFs inherit bigger uncertainties because of the lack of precision of PDFs



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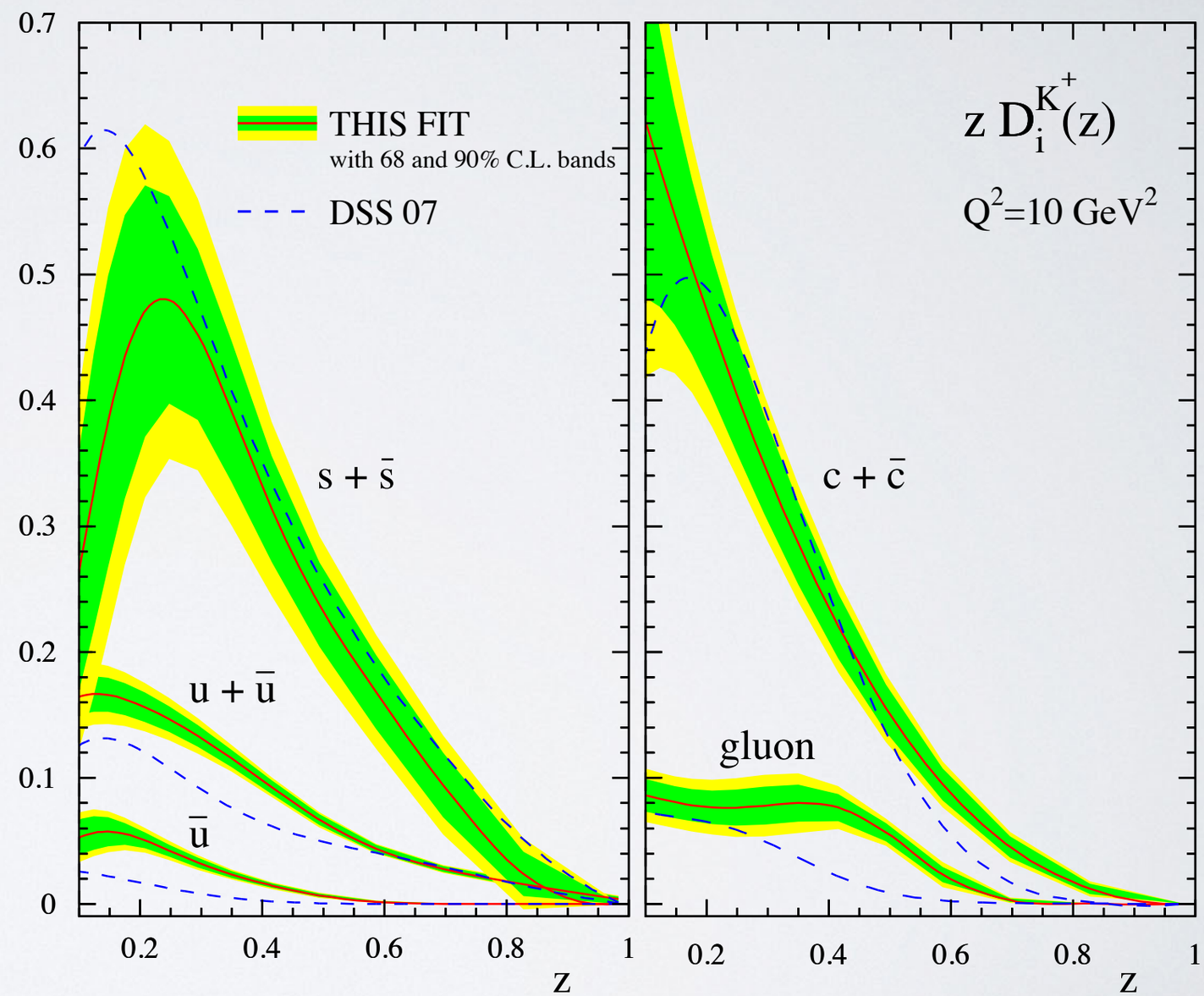
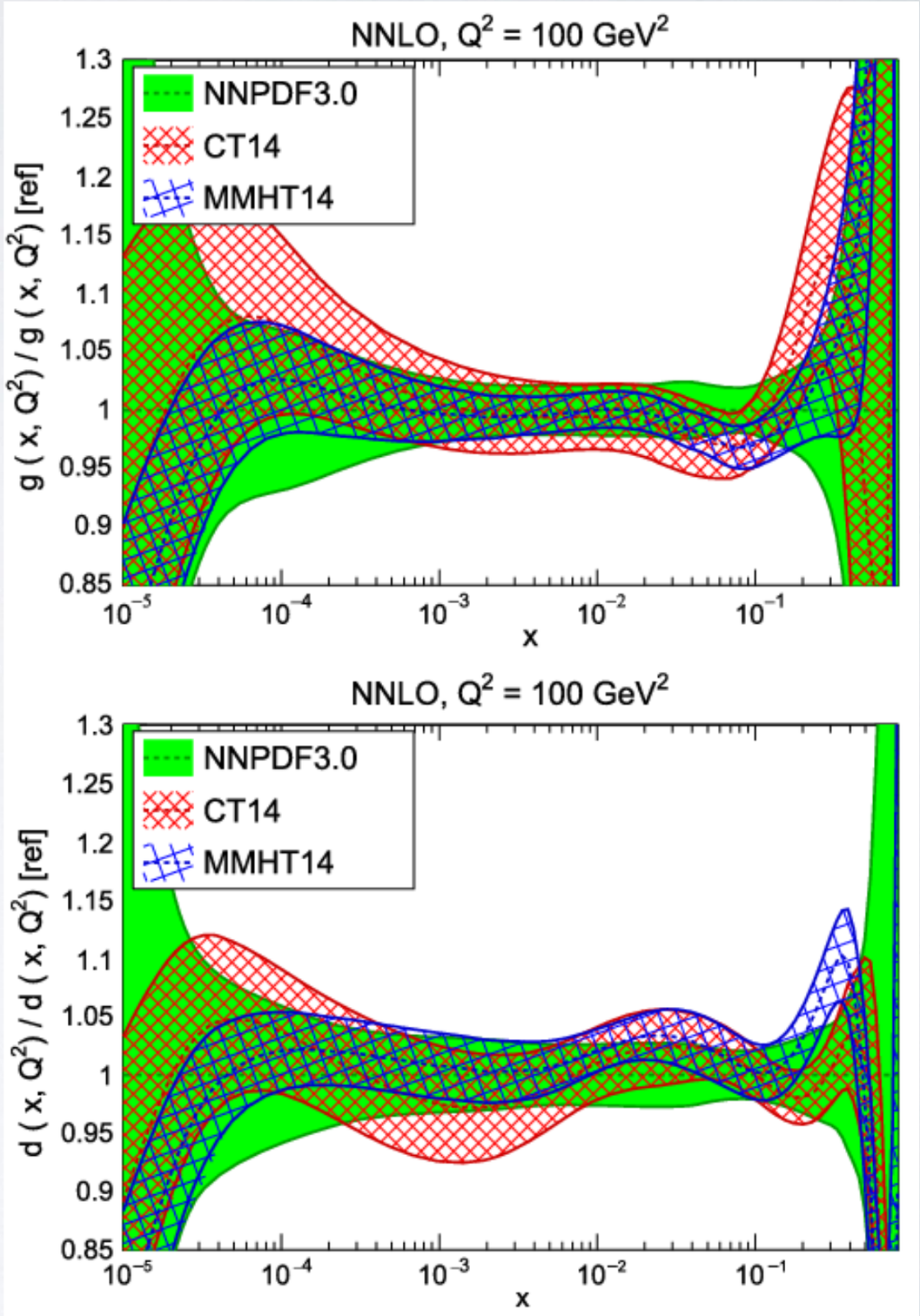


How good are the PDFs we are using?

PDF'S CURRENT STATUS

PDFs extractions are a couple of steps ahead of FFs extractions

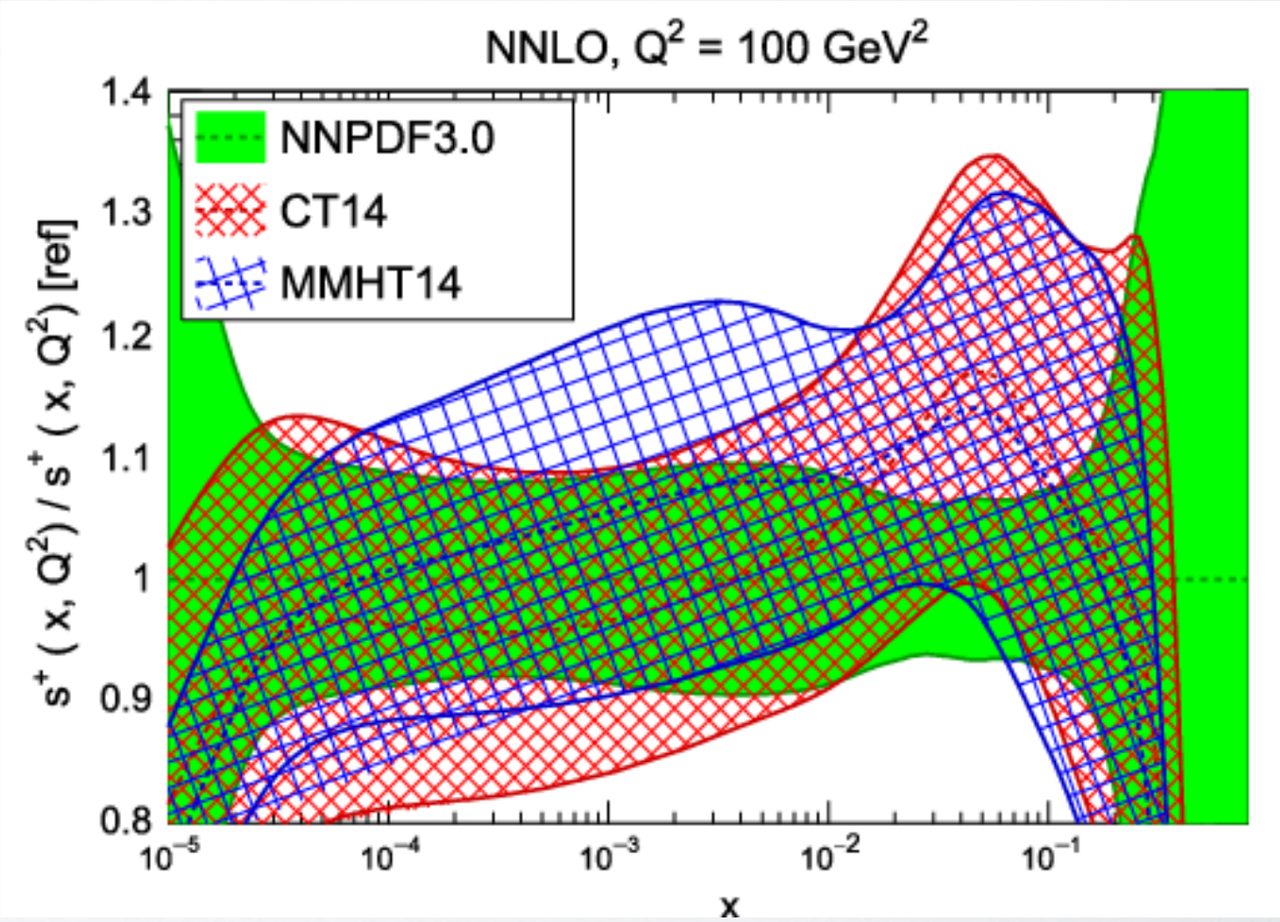
- Uncertainties reduction to a few percent points.
- Remarkable increase in the sophistication and precision of the extraction over the last years.
- NNLO extractions



PDF'S CURRENT STATUS

BUT…

- Strange content of the proton not so well constrained.
- Need for improvement in the precision and reliability of PDF determination



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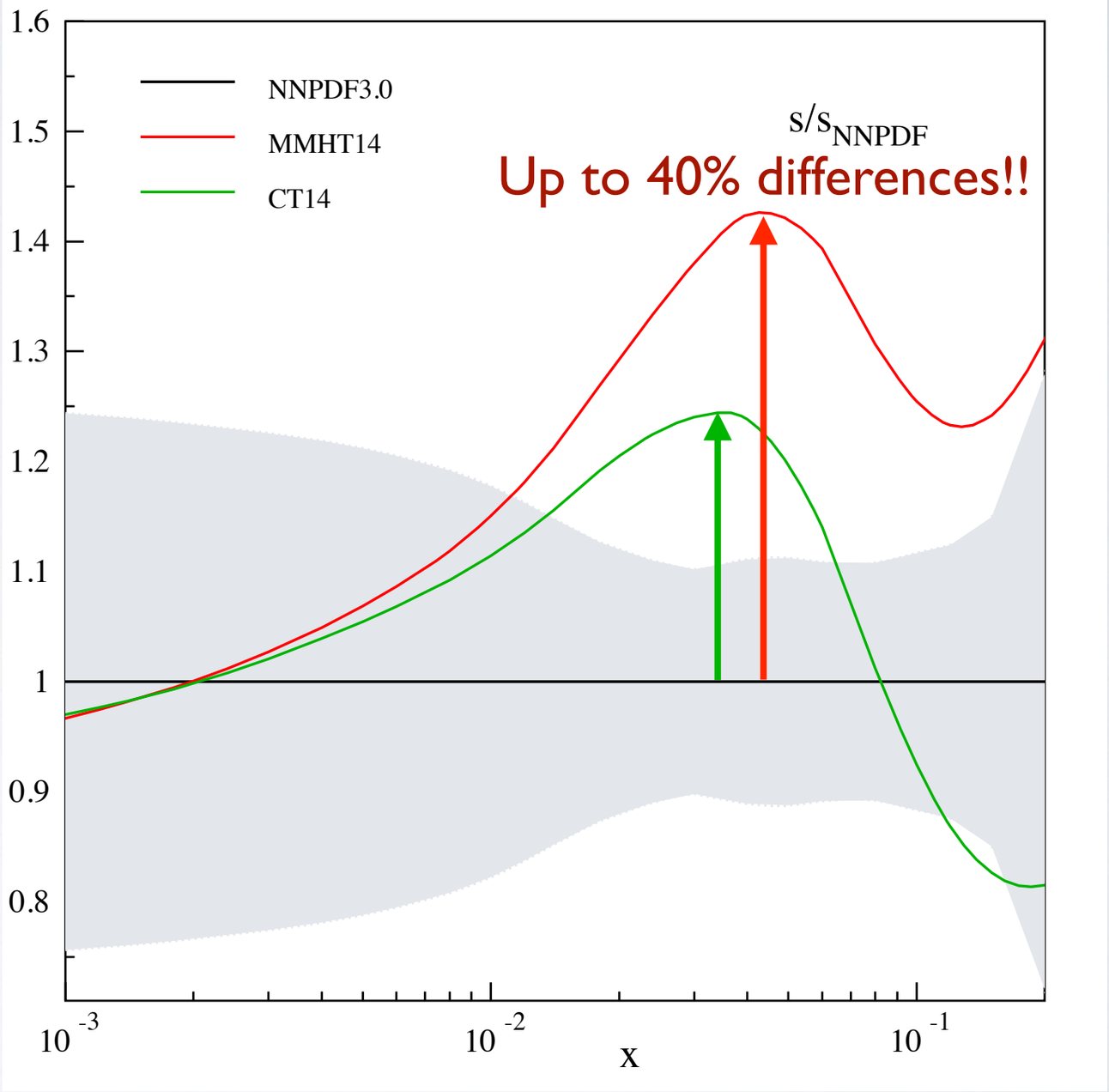
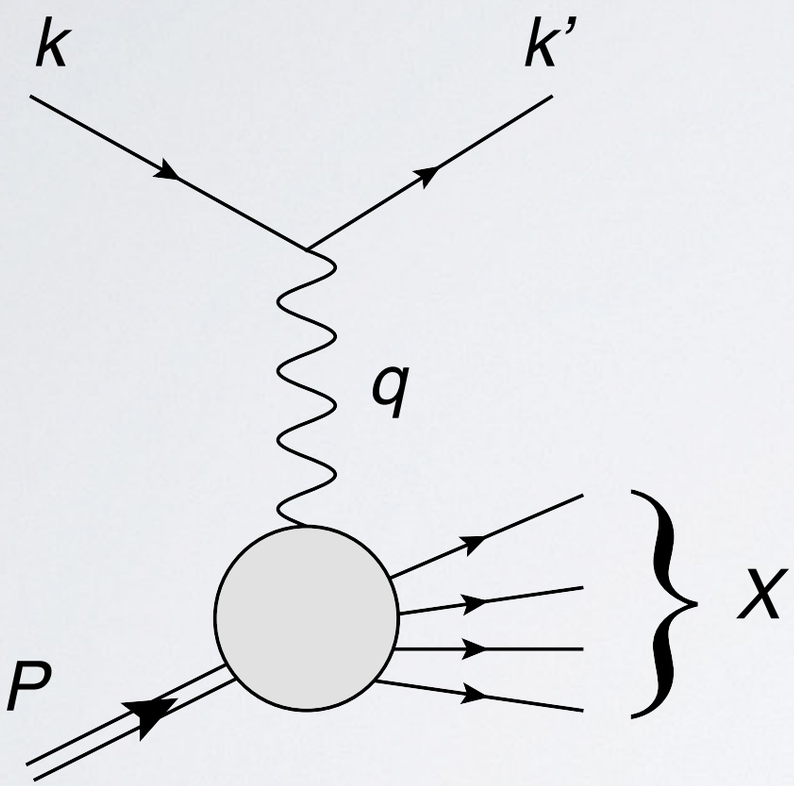


HOW WELL DETERMINED ARE THESE PARTON DISTRIBUTIONS?

The extraction has a strong dependence on the experiments that are used



Inclusive Processes (DIS)

$$[f_q^P(x) + f_{\bar{q}}^P(x)]$$

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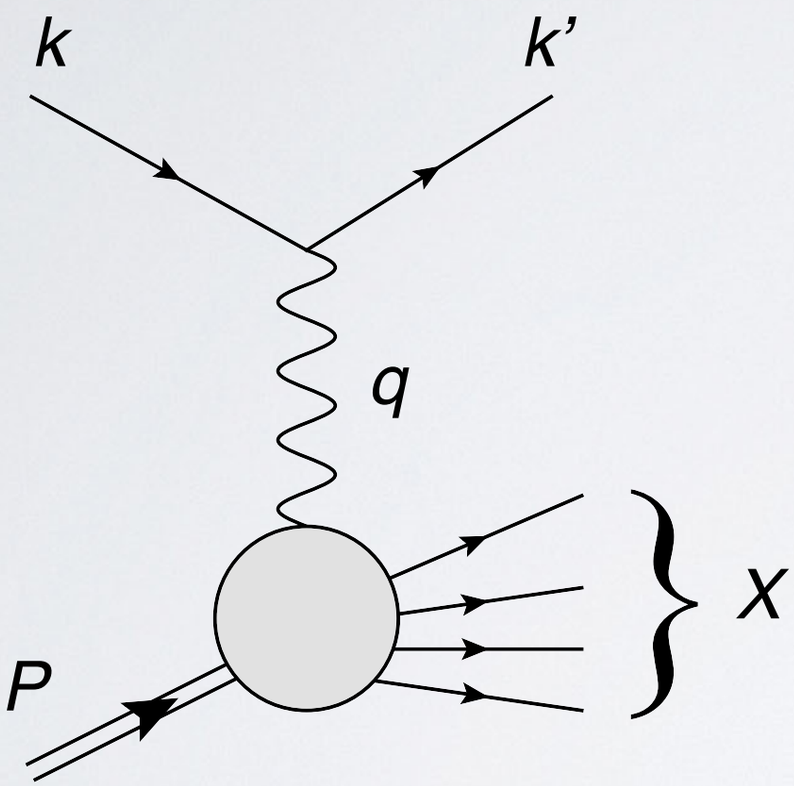

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Deuterium + Flavor symmetries

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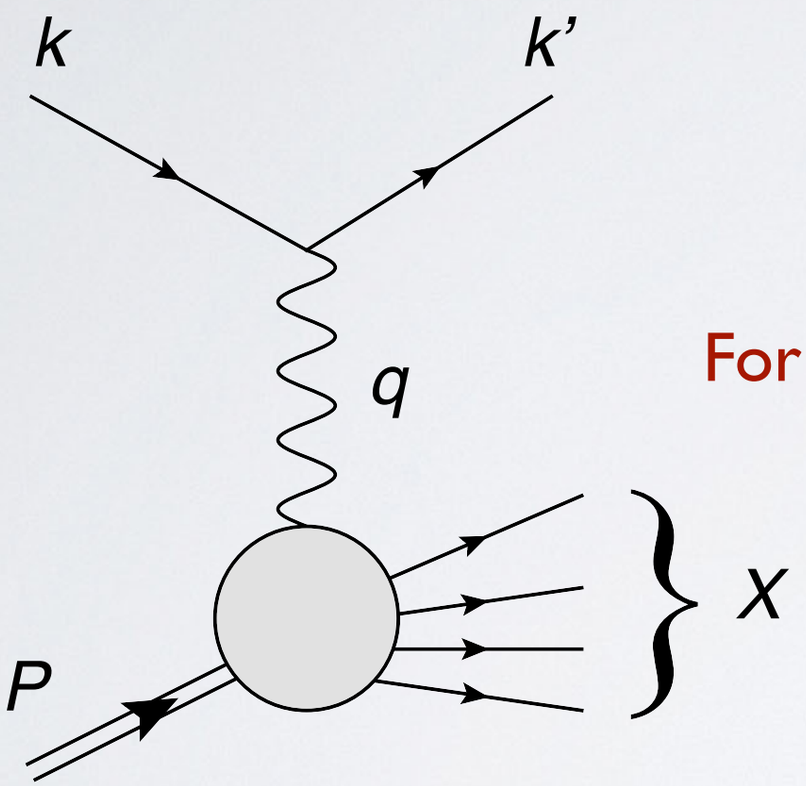
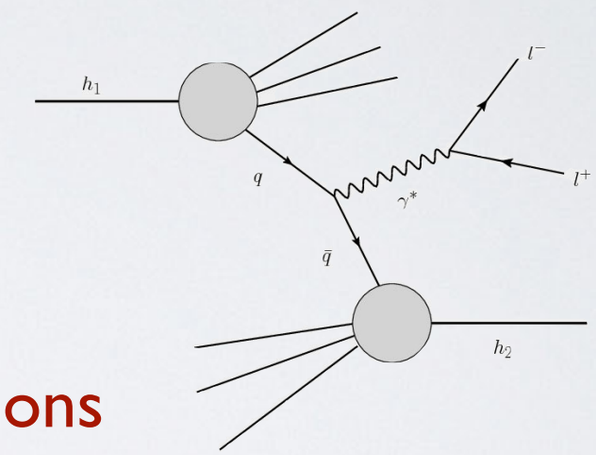
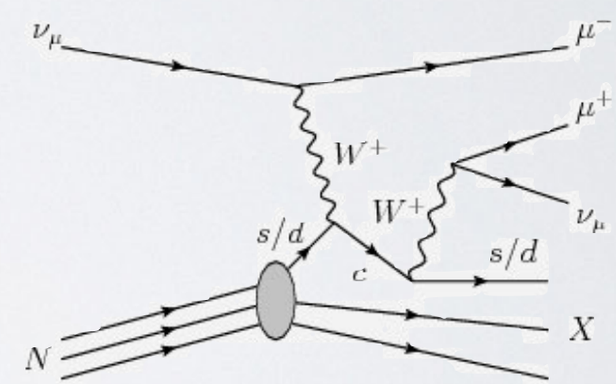


For strange distributions





Inclusive Processes (DIS)

$$[f_q^P(x) + f_{\bar{q}}^P(x)]$$

Deuterium + Flavor symmetries

- DIS with electroweak currents
- Leptonic decays of W bosons

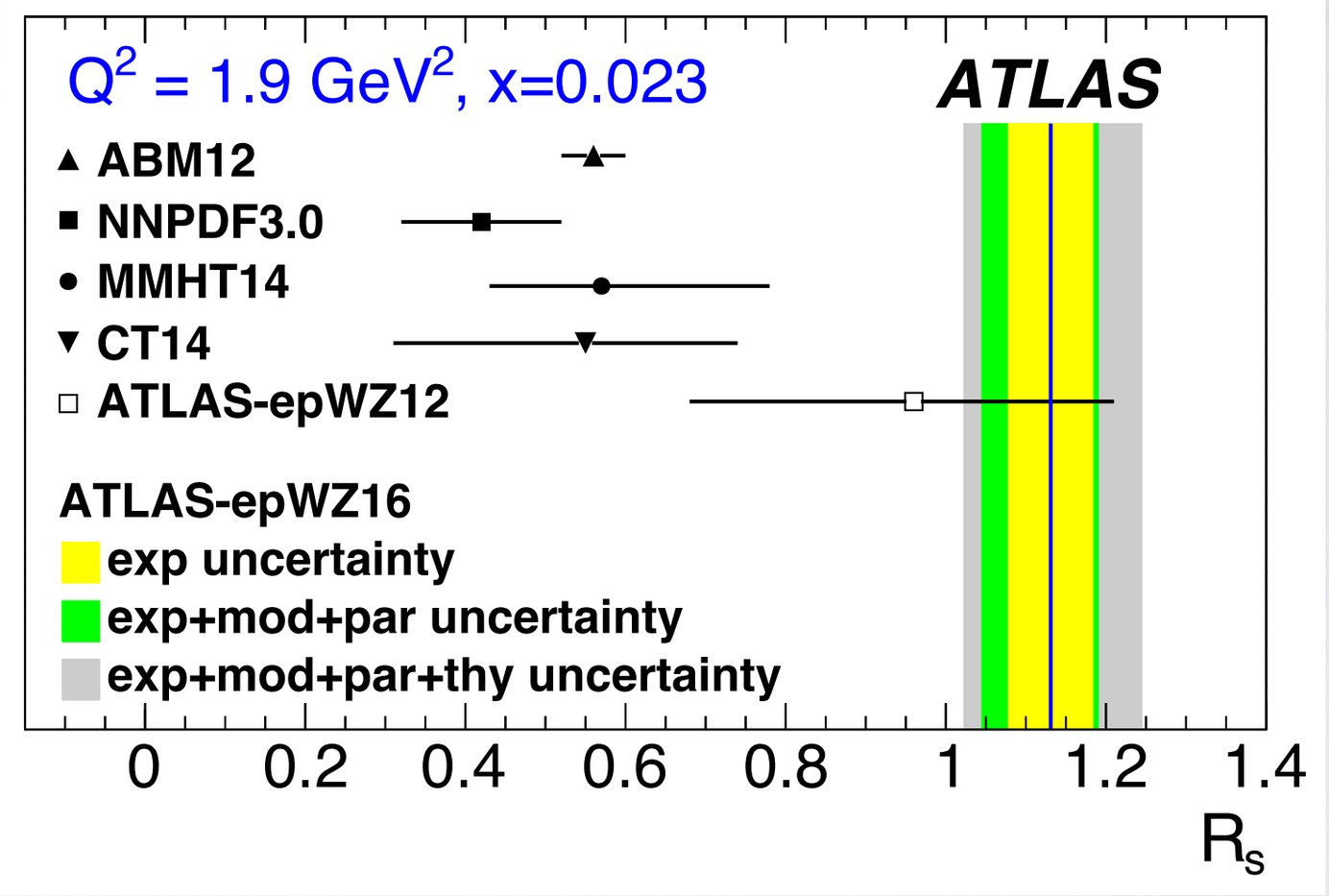
Indirect sensitivity to the sea content of the proton

HOW WELL DETERMINED ARE THESE PARTON DISTRIBUTIONS?

The strangeness puzzle

$$R_s(x,Q^2) = [s(x,Q^2) + \bar{s}(x,Q^2)] / [\bar{u}(x,Q^2) + \bar{d}(x,Q^2)]$$

Tension in strangeness driven by disagreement between collider data and neutrino DIS



	NNPDF3.1 Global	NNPDF3.1 Collider
ATLAS 2011 W/Z	2.14	1.55
ATLAS 2010 W/Z	0.96	0.92
NuTeV dimuon	0.82	26.5

Nathan Harland-DIS 2018

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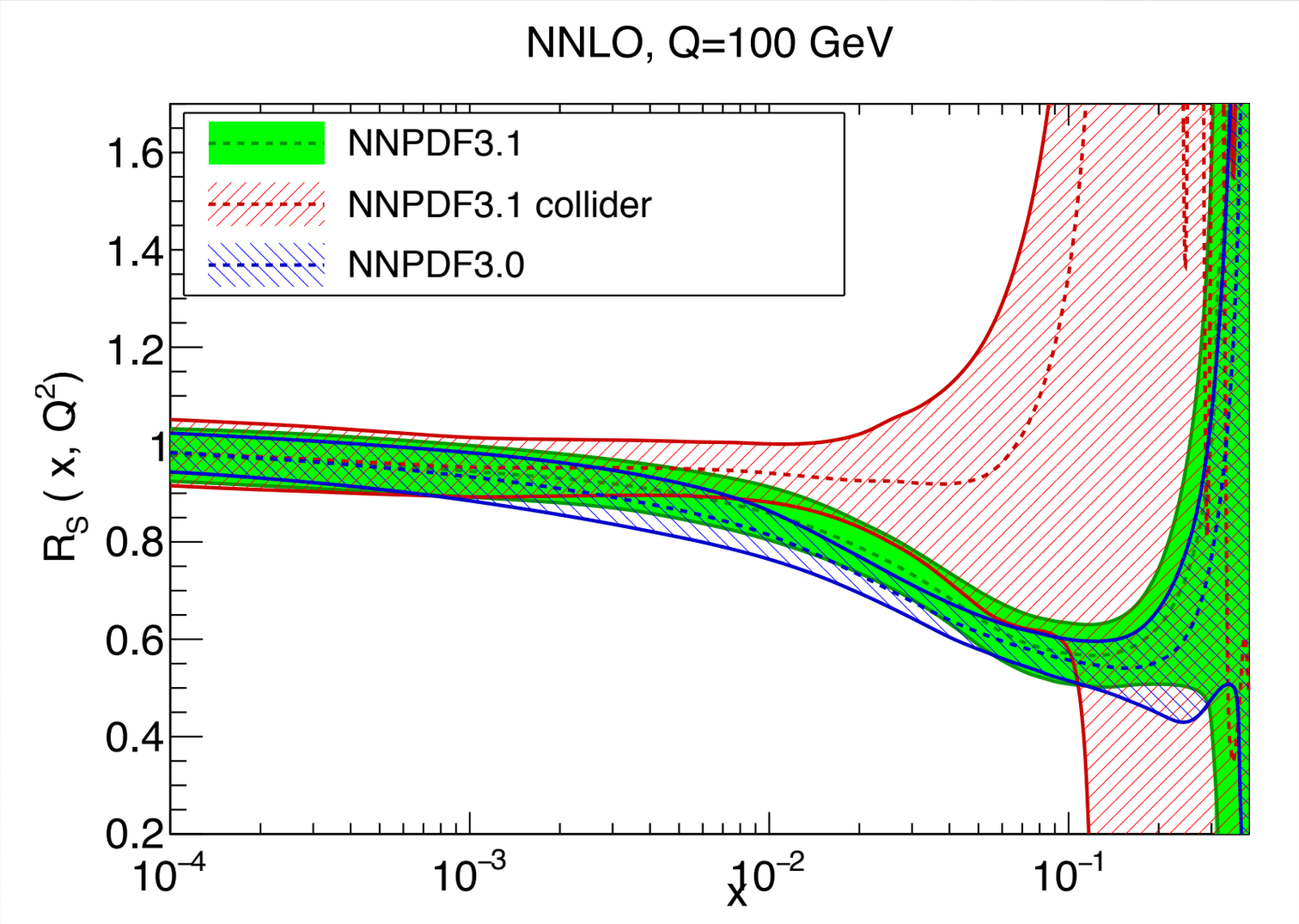

Nathan Harland-DIS 2018

HOW TO CONSTRAIN THE STRANGE QUARK DISTRIBUTION

HOW TO CONSTRAIN THE STRANGE QUARK DISTRIBUTION

Listen to this guy!

HOW TO CONSTRAIN THE STRANGE QUARK DISTRIBUTION

Improve parton distribution functions using data from flavor-sensitive experiments like SIDIS

PHYSICAL REVIEW D VOLUME 15, NUMBER 9 1 MAY 1977

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. The manner in which quarks cascade into hadrons is determined from particle distributions seen in lepton-hadron and lepton-lepton collisions supplemented by theoretical arguments. The quark elastic scattering cross section is parametrized in a purely phenomenological way and the choice $d\hat{\sigma}/d\hat{t} = 2.3\times10^6/(-\hat{s}\hat{t}^3)$ μb GeV^6 gives a reasonable fit to all the data for hadron + hadron → meson + anything for $p_\perp \gtrsim 2$ GeV/c. Many predictions do not depend sensitively on the exact form for $d\hat{\sigma}/d\hat{t}$ and therefore test our basic assumption. The data examined include single-particle production in pp collisions at various energies and angles. Particle ratios (π^+, π^-, K^+, K^-, and η) are predicted and discussed. In addition, the ratio of production of π^0's by beams of π^+ and protons on a proton target is explained. With this model we have found no serious inconsistency with data, but several predictions for charge ratios and beam ratios at other angles are presented that have yet to be tested experimentally.

I. INTRODUCTION

When hadrons collide at high energy most of the energy appears in many particles moving in the directions of the original momenta with only a small transverse momentum $\langle p_\perp \rangle \approx 0.35$ GeV. There are, however, a few hadrons of unusually high transverse momenta. When this was first discovered it was hoped that they arose from an intimate hard collision between the constituent partons of the colliding hadrons. Their study could therefore lead to a deeper understanding of the short-distance behavior of the fundamental strong forces. However, this plan has so far been frustrated by two features. First, the expectation from all field theories (and there is no other consistent relativistic formulation of quantum theory) suggests that the cross sections with all momenta scaled in the same proportion should fall off with $p_\perp$ nearly as $p_\perp^{-4}$ (with possible logarithmic modifications), whereas experimentally the behavior is closer to $p_\perp^{-8}$.

Because of this, many theorists have suggested that we are not yet observing the fundamental interaction between partons, but some other more complex mechanism—and only at much larger energies will the expected $p_\perp^{-4}$ appear (after the other mechanism, falling as $p_\perp^{-8}$, has fallen away). There is no consensus on what this other mechanism, which is operating in the present experimental region, might be; very many theories are available.

The second frustrating feature is that the observed large-$p_\perp$ particles need not be particles which are originally directly driven out, but may be the result of a disintegration or fragmentation of these originals. Interpretation of the data then needs considerable theoretical analysis requiring many assumptions of mechanism and decay functions. This makes it difficult, in any comparison to experiment, to judge from a fit whether the mechanism proposed by the theory is verified, or merely that the many possible unknown functions have been cleverly adjusted to fit.

We have no easy solution to these difficulties. In fact, after trying phenomenologically to test and distinguish some of the various models we have become unusually sensitive to these frustrations. We feel the only way out is a long hard job. One must take some one model and test it against everything experimentally available at the same time. Then if it succeeds, or can be adjusted to succeed so far, make as definite predictions as possible for experiments soon to come—indicating those which, if not fulfilled, will prove the model wrong. Only in that way can models be eliminated and progress made. In this paper we shall begin this work starting with one particular model.

The model we shall choose is not a popular one, so that we will not duplicate too much of the work of others who are similarly analyzing various models (e.g., constituent-interchange model, multiperipheral-type models, etc.). We shall assume that the high-$p_\perp$ particles arise from direct hard collisions between constituent quarks in the incoming particles, and in a fundamental quark$_a$ + quark$_b$ → quark$_a$ + quark$_b$ elastic collision the primary outgoing high-$p_\perp$ particles are quarks

HOW TO CONSTRAIN THE STRANGE QUARK DISTRIBUTION

Improve parton distribution functions using data from flavor-sensitive experiments like SIDIS

(in fact, of the same flavor as the quarks that came in), which fragment or cascade down into several hadrons.[1] This is illustrated in Fig. 1. We disregard the theoretical argument that this elastic cross section [which we write as $d\hat{\sigma}/d\hat{t}(\hat{s},\hat{t})$, where $\hat{s}$ and $\hat{t}$ are the s,t invariants for the quark collision] must vary as $\hat{s}^{-2}f(\hat{t}/\hat{s})$ and, instead, leave it as an unknown function to be determined empirically by the data. It will vary more like $\hat{s}^{-N}f(\hat{t}/\hat{s})$ with N about 4.

We shall need the distributions $G_{h\to q}(x)$ of quarks q in the initial hadrons; for protons and neutrons this is given to a large extent by deep-inelastic ep (or μp) scattering data. Also, we shall need to know what the chances, $D_q^h(z)$, are that a quark q going out at large momentum disintegrates into various kinds of hadrons, h, with a fraction z of

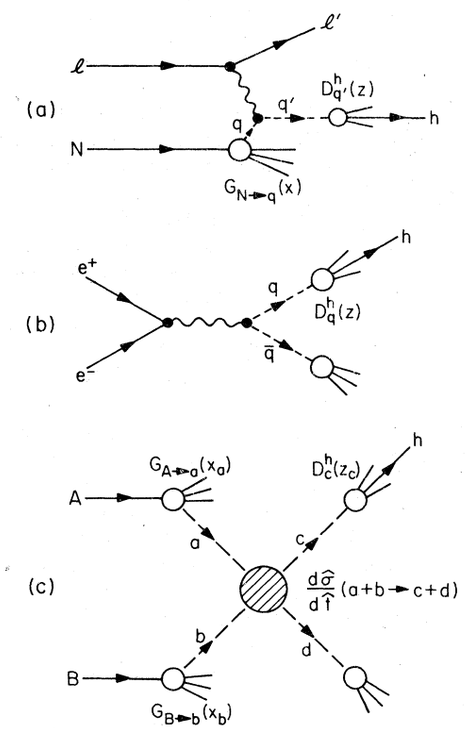

FIG. 1. (a) Quark-parton-model mechanism for single-hadron production in lepton-hadron processes. (b) Quark-parton-model mechanism for single-hadron production in e^+e^- annihilation. (c) Illustration of the common underlying structure of constituent or "hard-scattering" models for hadron-hadron collisions. The large-transverse-momentum reaction $A+B\to h+X$ is assumed to occur as a result of a single large-angle scattering of constituents $a+b\to c+d$, followed in general by the decay or fragmentation of c into the observed particle h. We further hypothesize that the dominant basic sub-

the original momentum of the quark. This is given, in principle, by the hadrons produced by the recoiling quarks in deep-inelastic neutrino proton scattering. Unfortunately, in both cases the data are incomplete and must be supplemented by theoretical arguments that require much discussion. This first paper deals primarily with these functions $G_{h\to q}(x)$ and $D_q^h(z)$ and with the behavior of outgoing particle and incoming beam ratios for large-$p_\perp$ single-particle production. We examine various forms for $d\hat{\sigma}/d\hat{t}$ and make predictions that are insensitive to its detailed form. Since the behavior of $G_{h\to q}(x)$ and $D_q^h(z)$ is inferred from lepton-hadron and lepton-lepton processes, much of this first paper can be viewed as an attempt to predict properties of hadron-hadron collisions from information gained studying lepton-initiated reactions. A subsequent paper will investigate experimental quantities that depend more strongly on the precise form of $d\hat{\sigma}/d\hat{t}$ (e.g., two-particle correlation data in large-$p_\perp$ hadron collisions). Then it will be necessary to include the effects of the transverse momentum spread of the quarks within the hadrons and of the hadrons that fragment from quarks. These effects have little influence on the results of the present paper and we have omitted them in our calculations reported here.

We are fully aware that all partons are not quarks, that half the momentum of the proton is something else (gluons?). And there is no good reason to exclude the possibility that some of the high-$p_\perp$ particles could result from gluon interactions. We are also aware that there is no good reason for the quark-quark cross section to vary as $\hat{s}^{-4}$. But we must start somewhere and we have chosen to start here. Let us see what experiments might exclude our specific choice, and indicate the presence of gluons, or some different model entirely.

Before we begin, however, we must say ahead of time in what region we expect our theory to hold. We must be careful, because we do not wish to be embarrassed later by appearing to think up an excuse as to why something does not fit. We expect to allow, generally, any data outside the low-$p_\perp$ main collision (for example, outside the low-$p_\perp$ "pionization" region) with enough momentum that our ubiquitous approximations of relativistic quarks and scaling hold. We take this to mean simply the condition $p_\perp \gtrsim 2$ GeV/c, although we can guess that down to 1.5 GeV/c it may still work fairly well. There is one situation where this may be insufficient. If we are calculating something of particularly low probability that is easy to find in

IDENTIFIED FINAL STATE PARTICLES OBSERVABLES

Improve parton distribution functions using data from flavor-sensitive experiments

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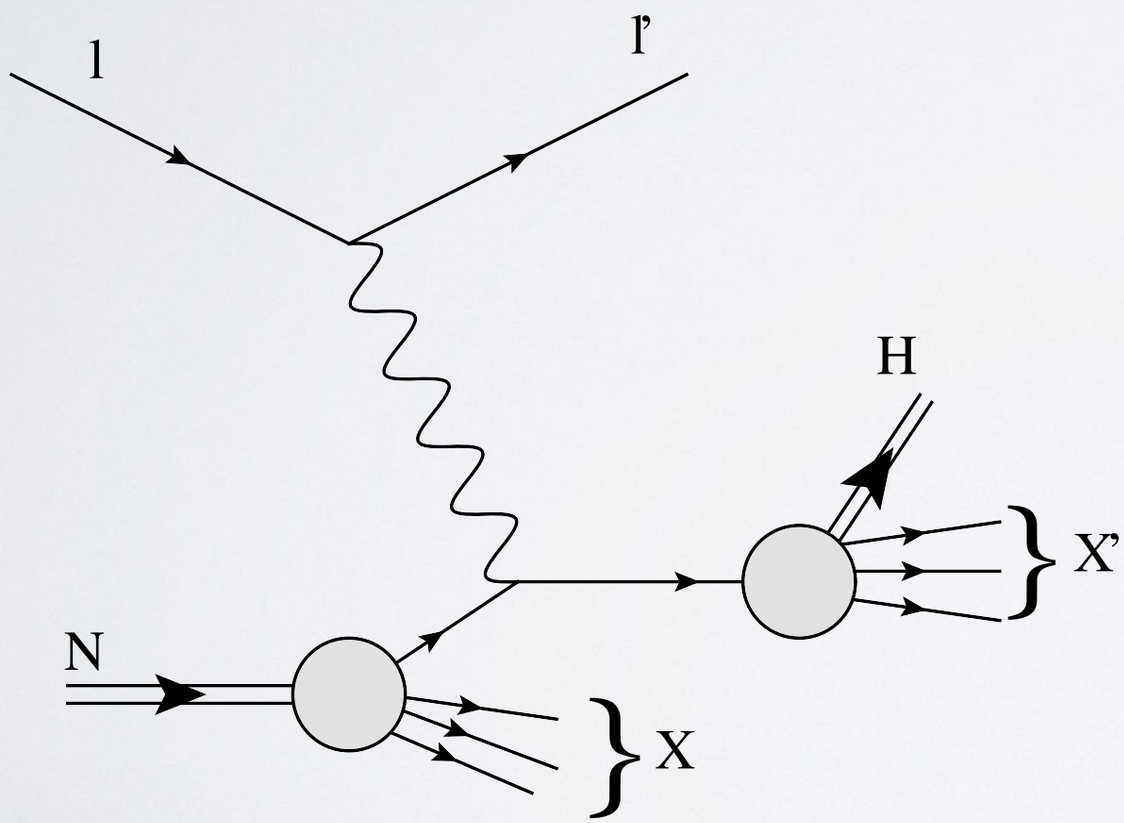
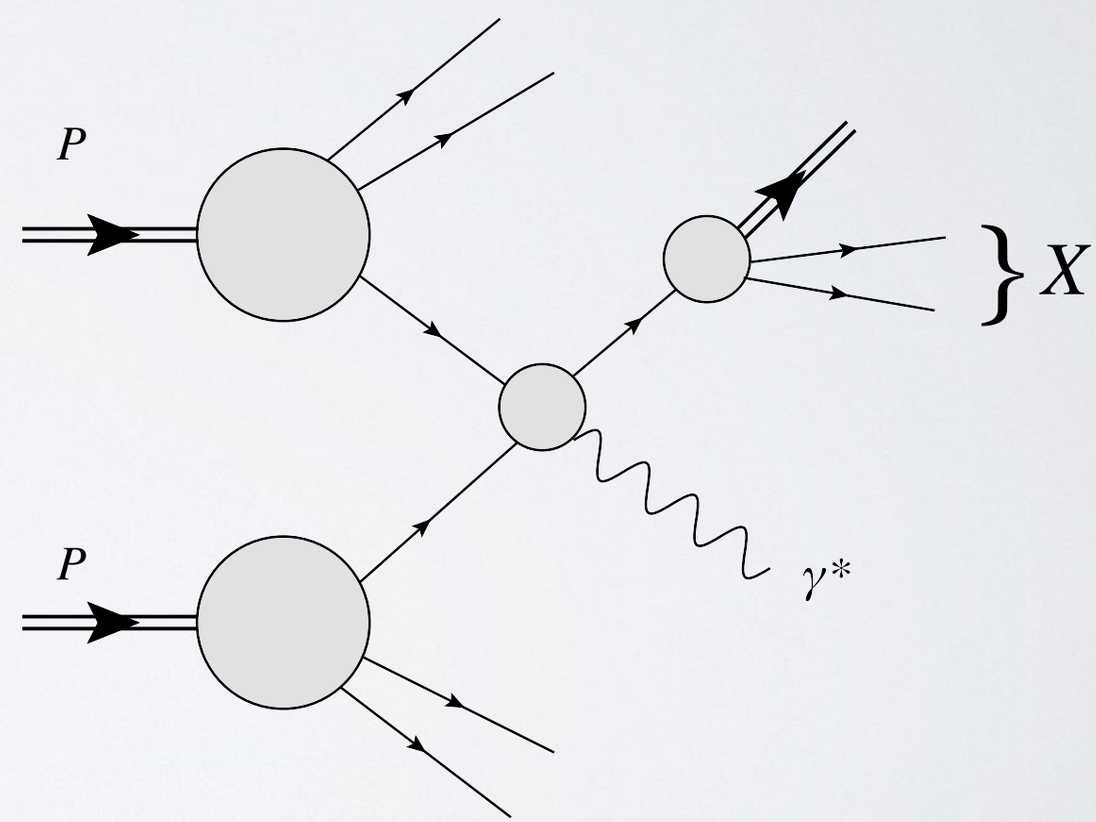


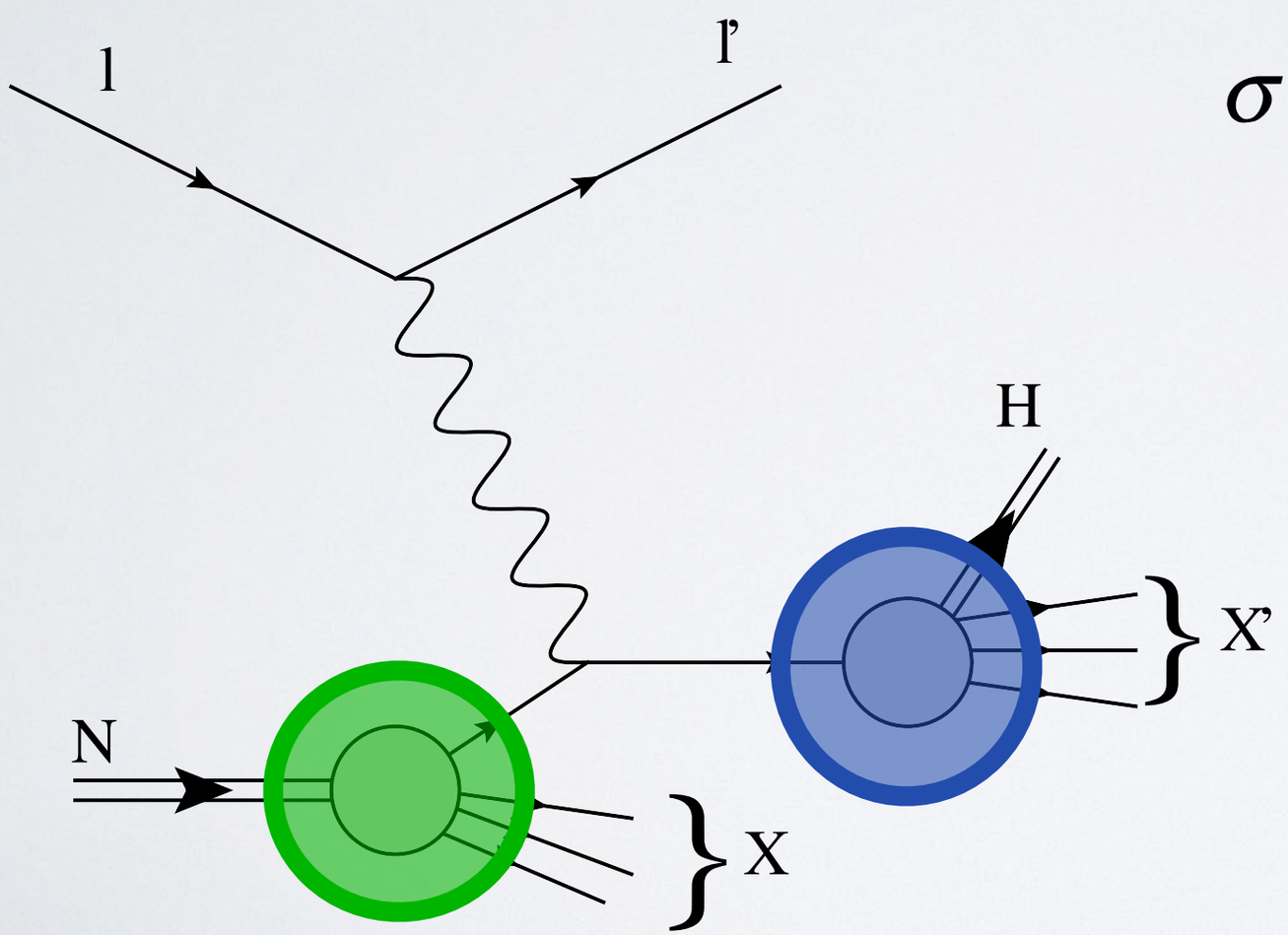
SIDIS data from Hermes & Compass



Hadron production in p+p collisions

IDENTIFIED FINAL STATE PARTICLES OBSERVABLES

Improve parton distribution functions using data from flavor-sensitive experiments



$$\sigma = \frac{1}{2}\sum_{q,\bar{q}} e_q^2 f_q^P(x,Q^2) \otimes D_q^H(z,Q^2)$$

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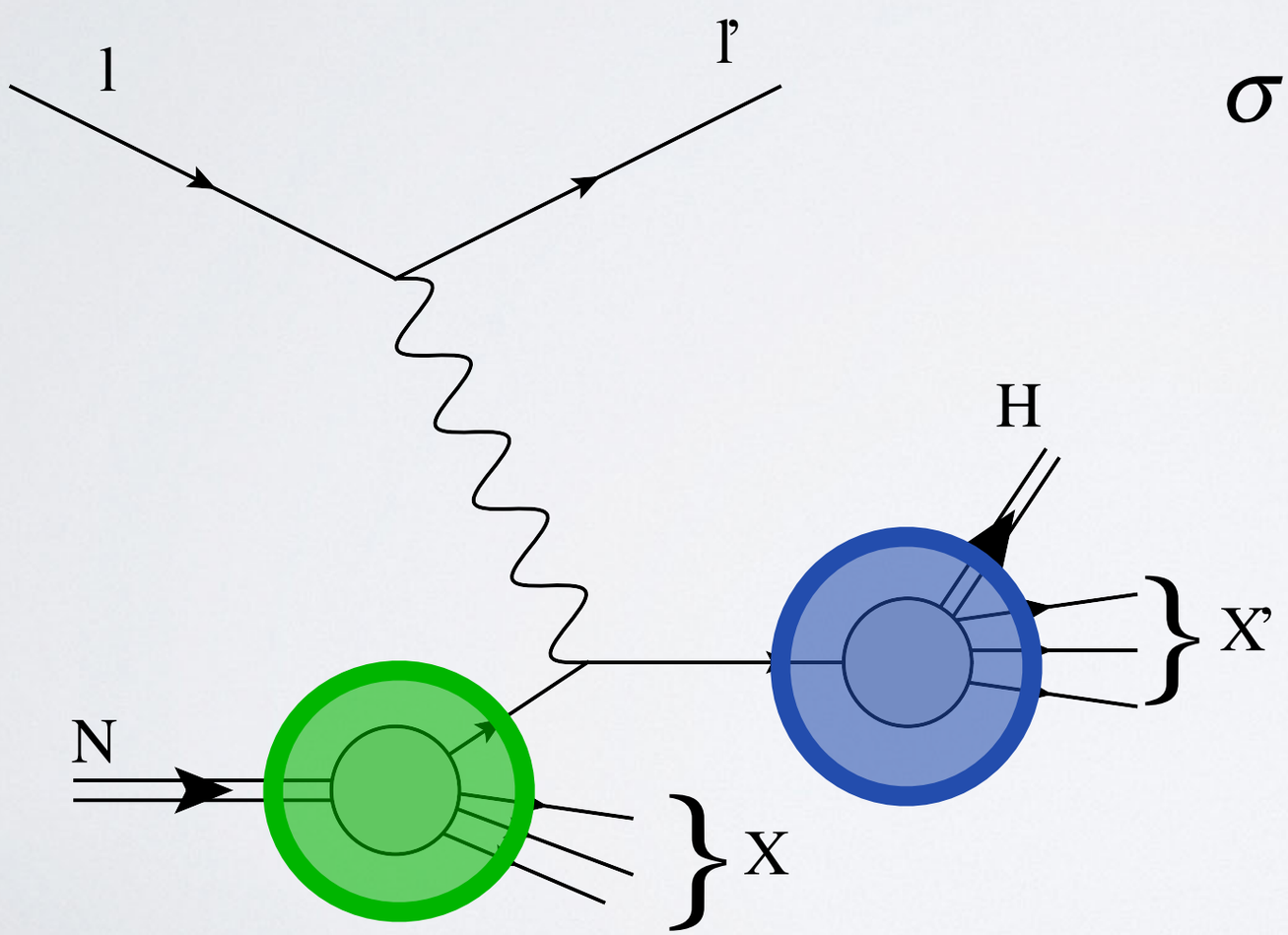

$$\sigma = \frac{1}{2}\sum_{q,\bar{q}} e_q^2 f_q^P(x,Q^2) \otimes D_q^H(z,Q^2)$$

For example

$$|K^+\rangle = |u\bar{s}\rangle \quad |K^-\rangle = |\bar{u}s\rangle$$

Charged kaon production in SIDIS or p+p can improve the strange PDFs & FFs!

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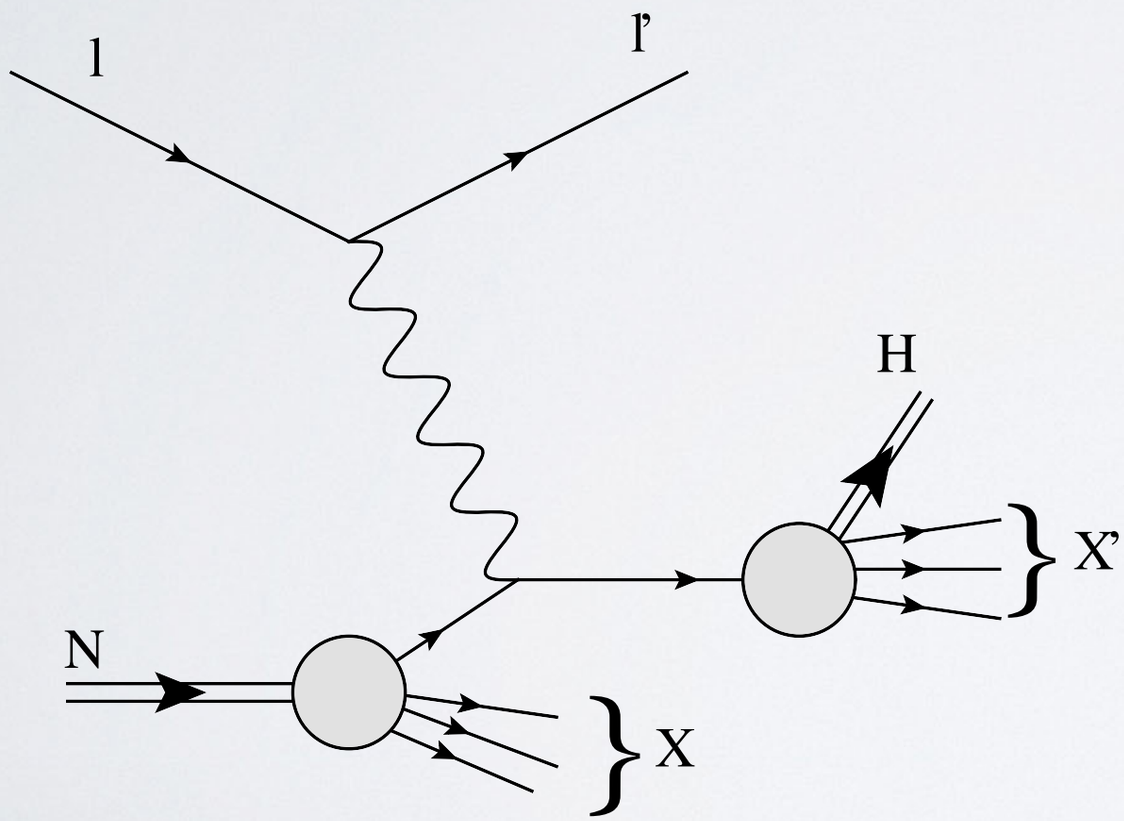
Improve parton distribution functions using data from flavor-sensitive experiments

PhysRevD.96.094020



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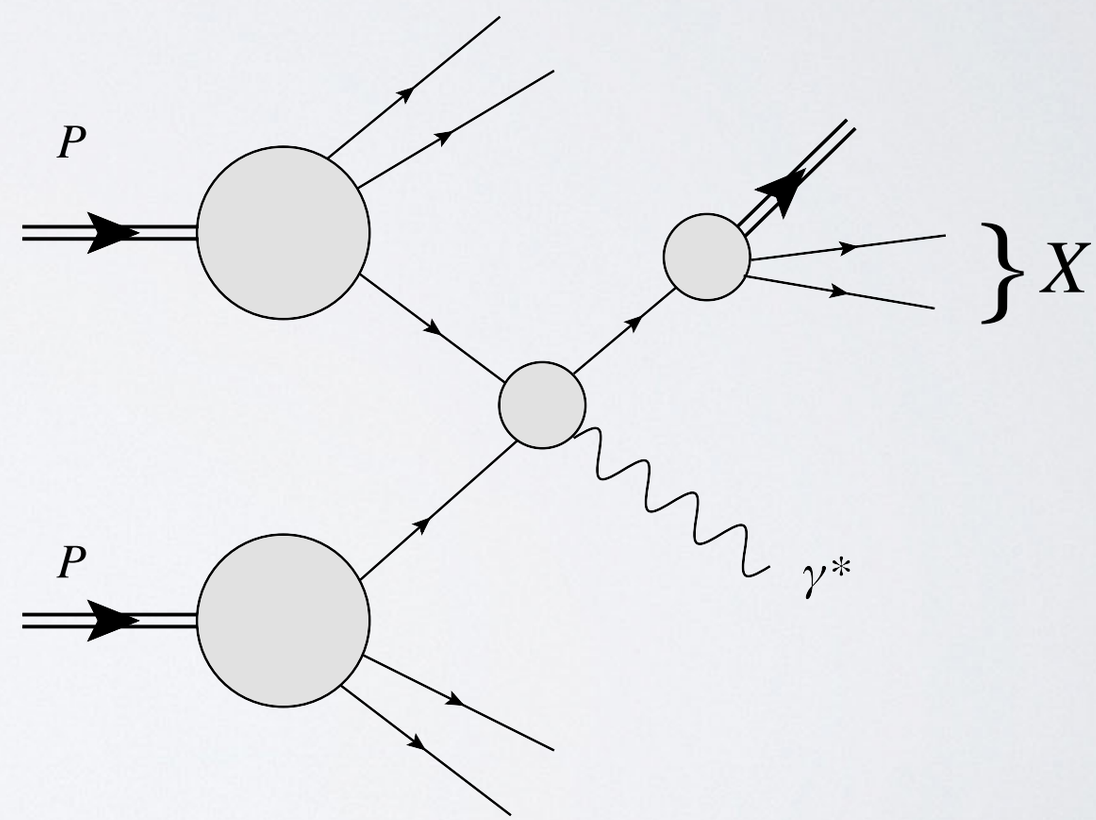

Hadron production in p+p collisions

IDENTIFIED FINAL STATE PARTICLES OBSERVABLES

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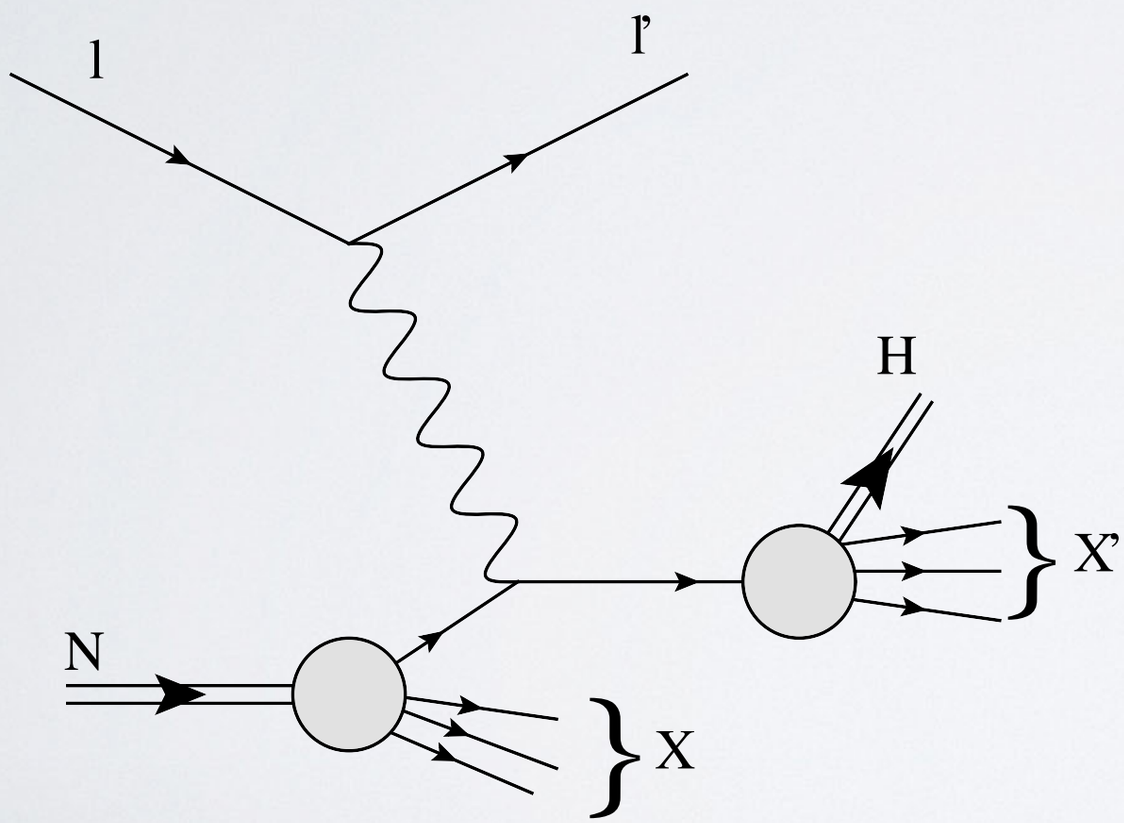

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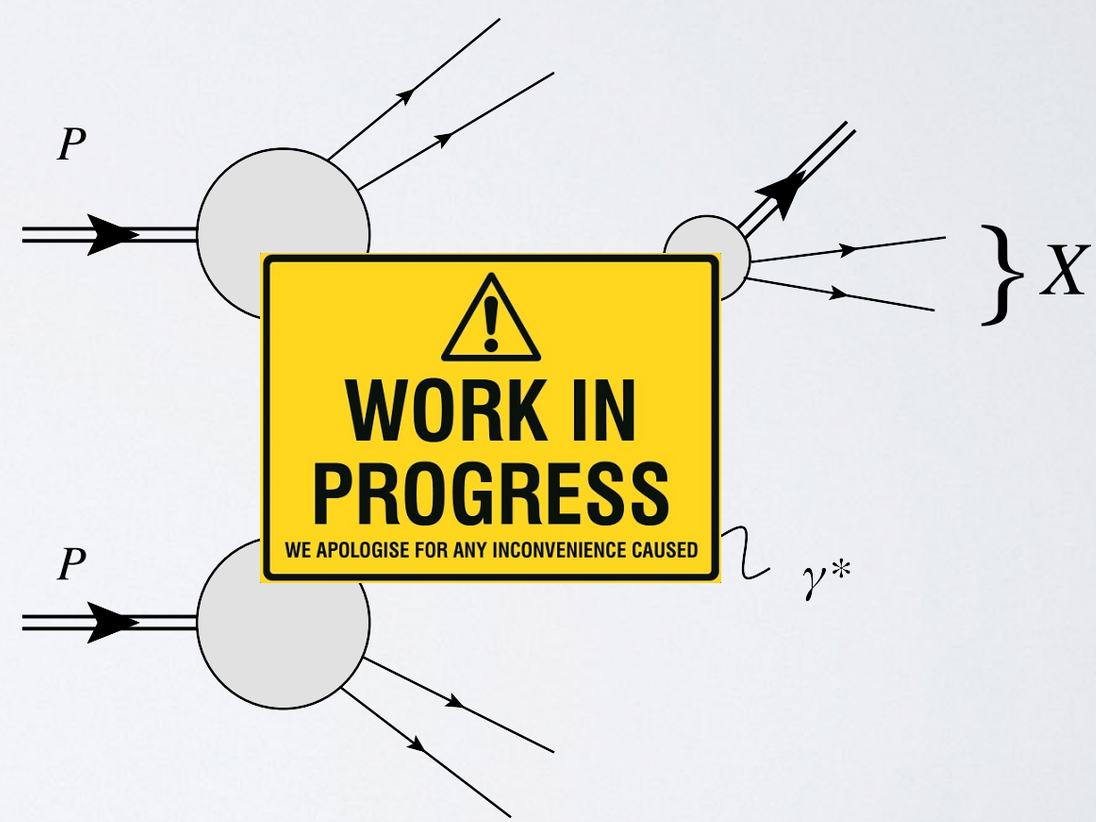

Hadron production in p+p collisions

IDENTIFIED FINAL STATE PARTICLES OBSERVABLES

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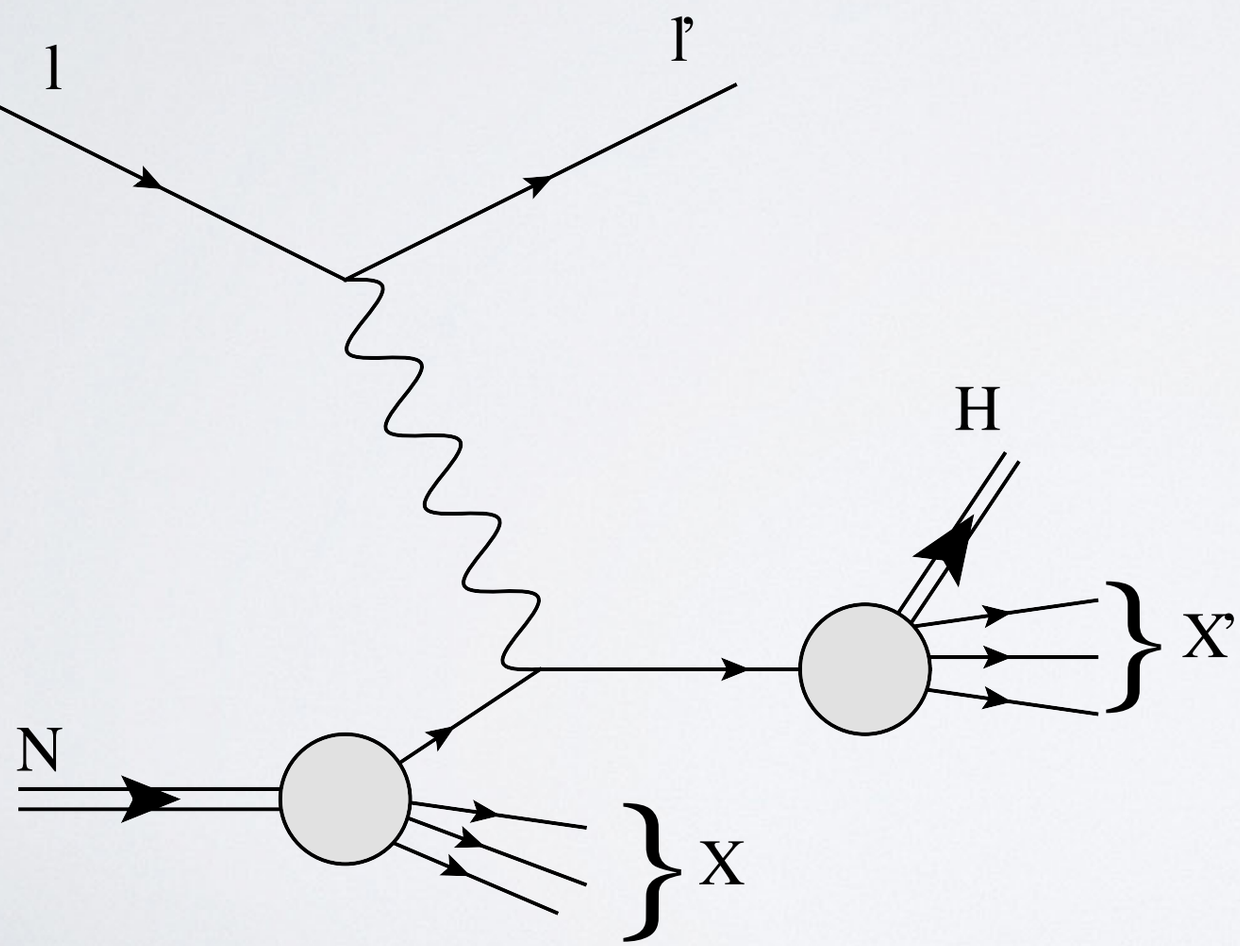

Slightly Cumbersome

- Big number of parameters to fit
-
-

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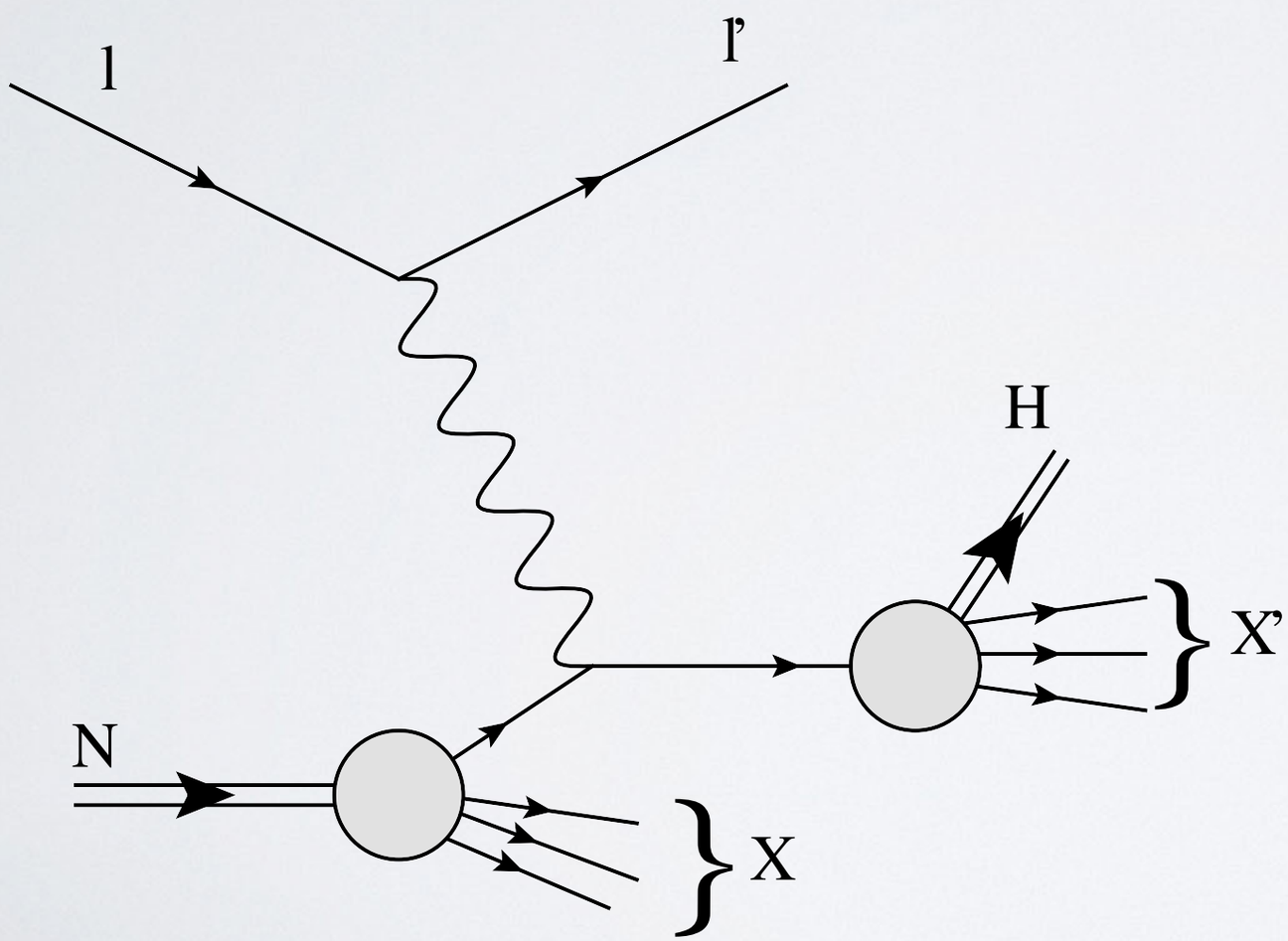

Slightly Cumbersome

- Big number of parameters to fit
- Factorial-like growth of the number of iterations needed
-

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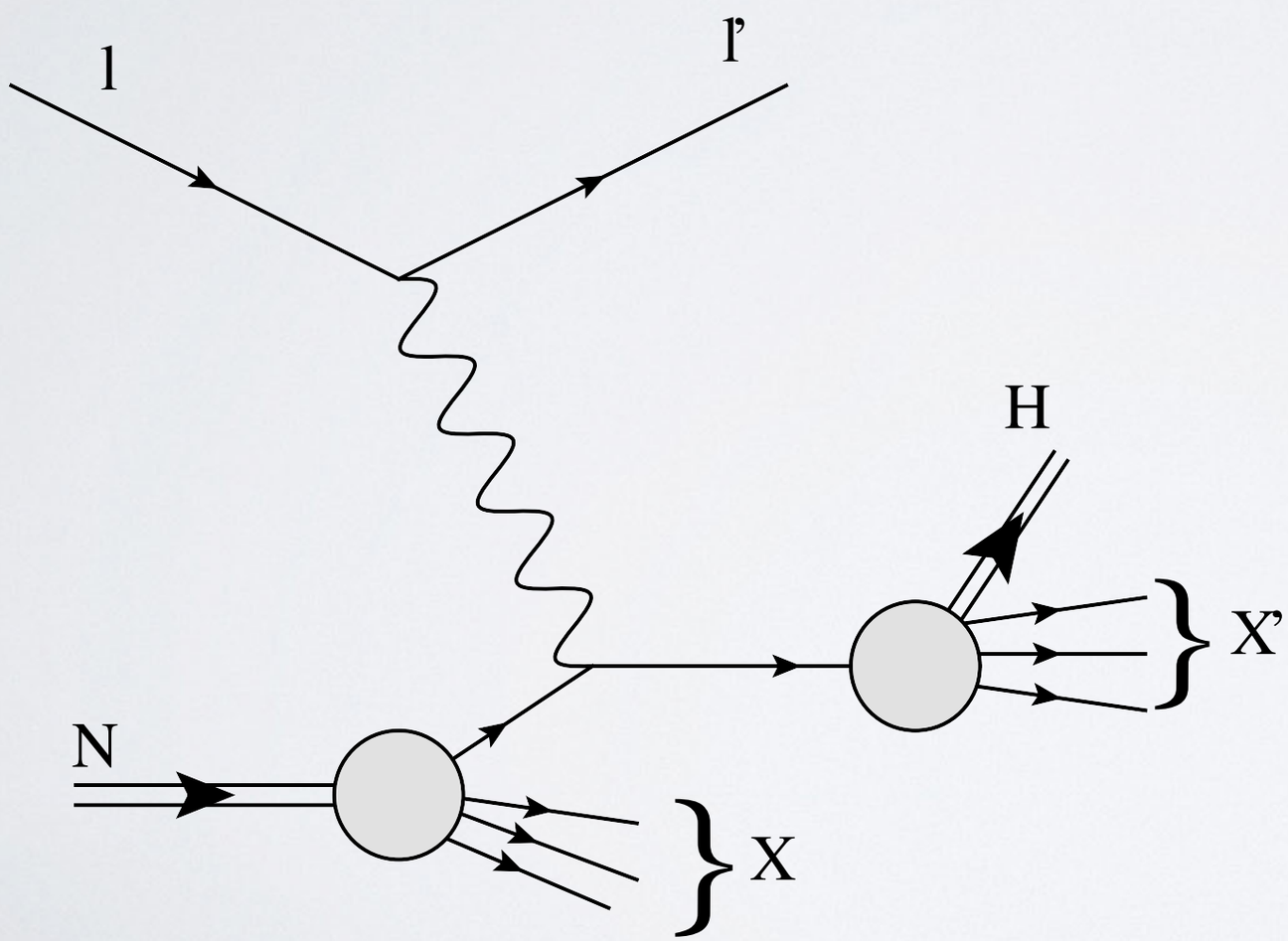

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- Different Phase Space/Topography

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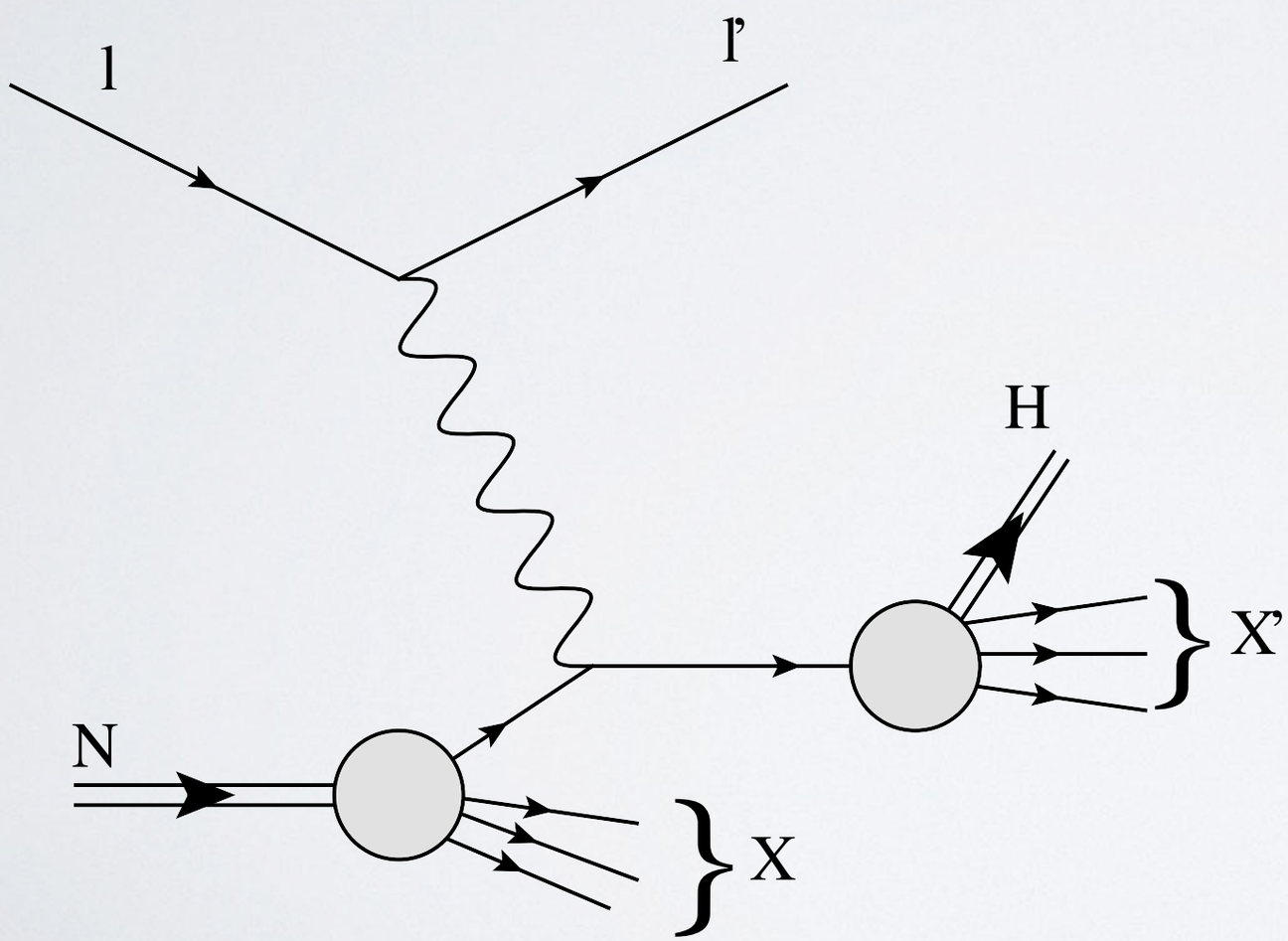

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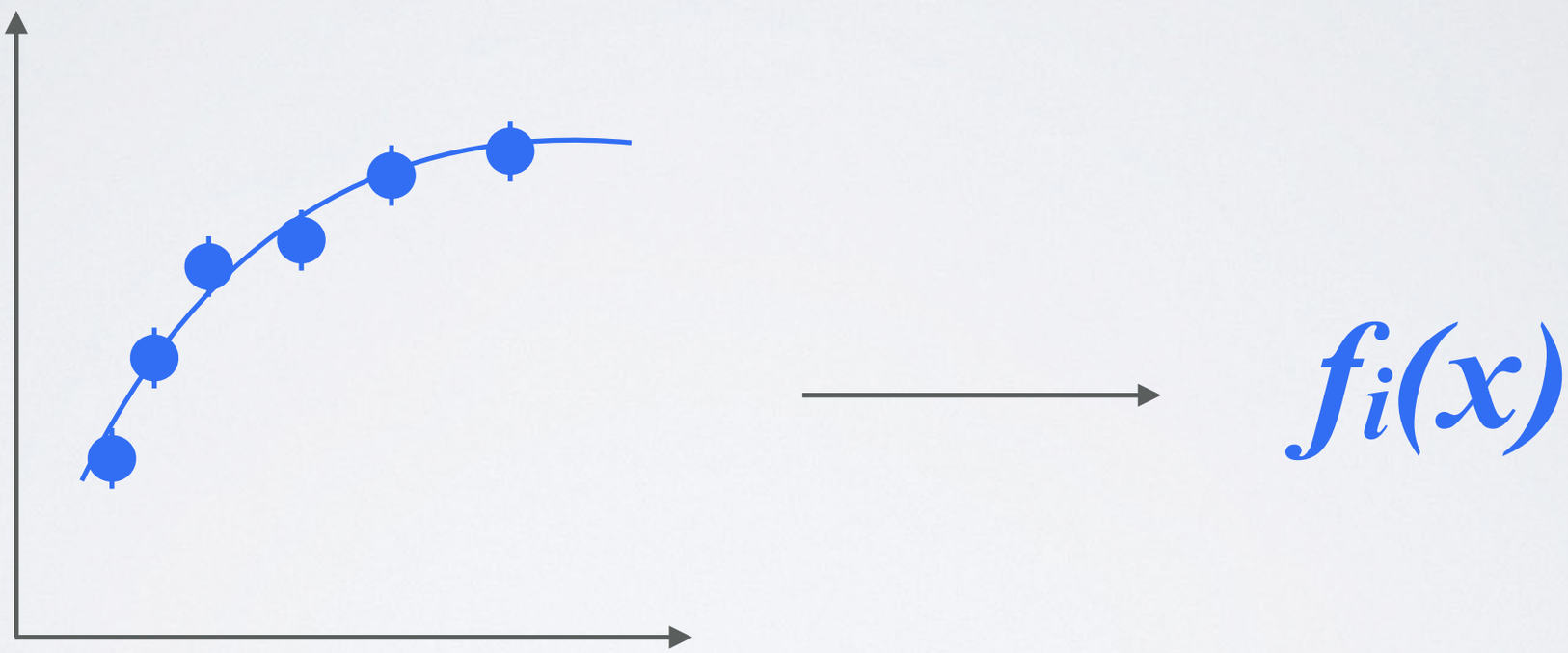
REWEIGHTING

Inclusion data of semi-inclusive observables through Bayesian inference



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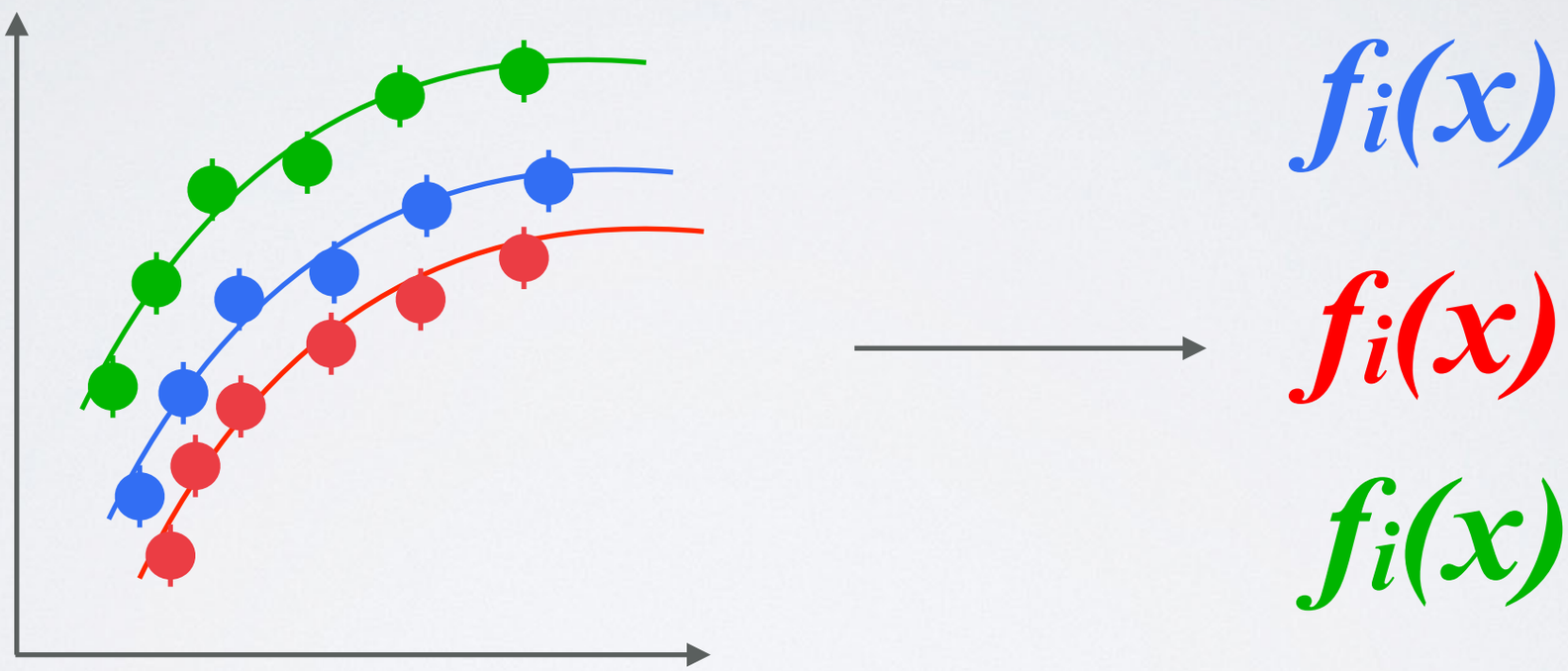
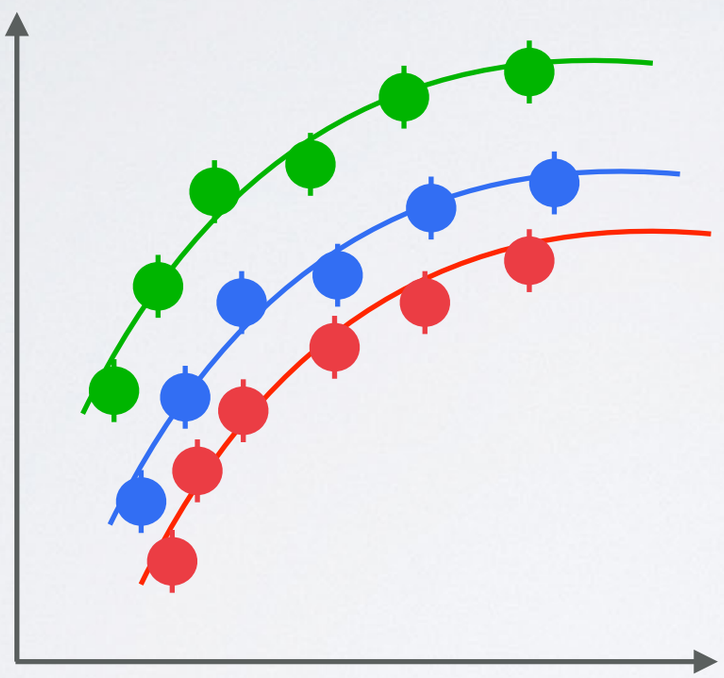


$$\langle O \rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N} O[f(k)]$$

REWEIGHTING

Inclusion data of semi-inclusive observables through Bayesian inference



New data

$f_i(x)$ $w(k)$

$f_i(x)$ $w(k)$

$f_i(x)$ $w(k)$

$$\langle O \rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N} O[f(k)]$$

REWEIGHTING

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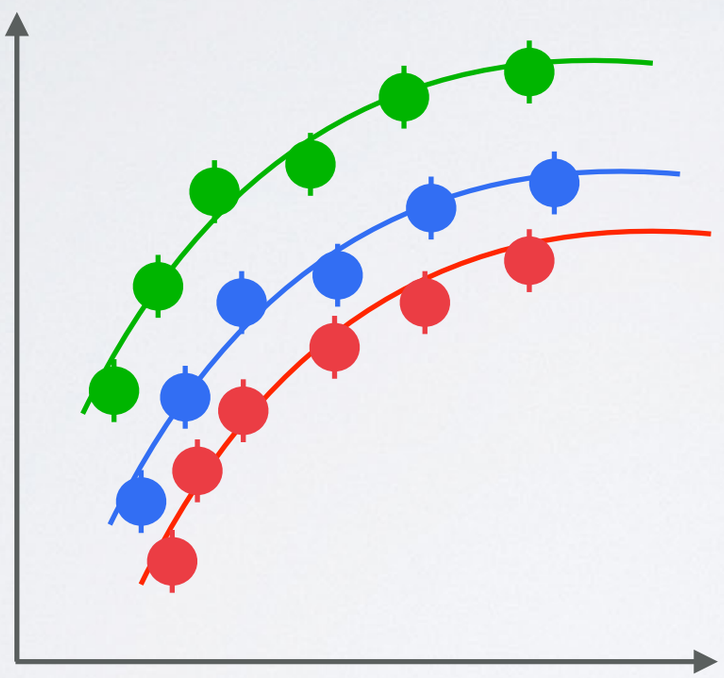


$f_i(x)$ $w(k)$

$f_i(x)$ $w(k)$

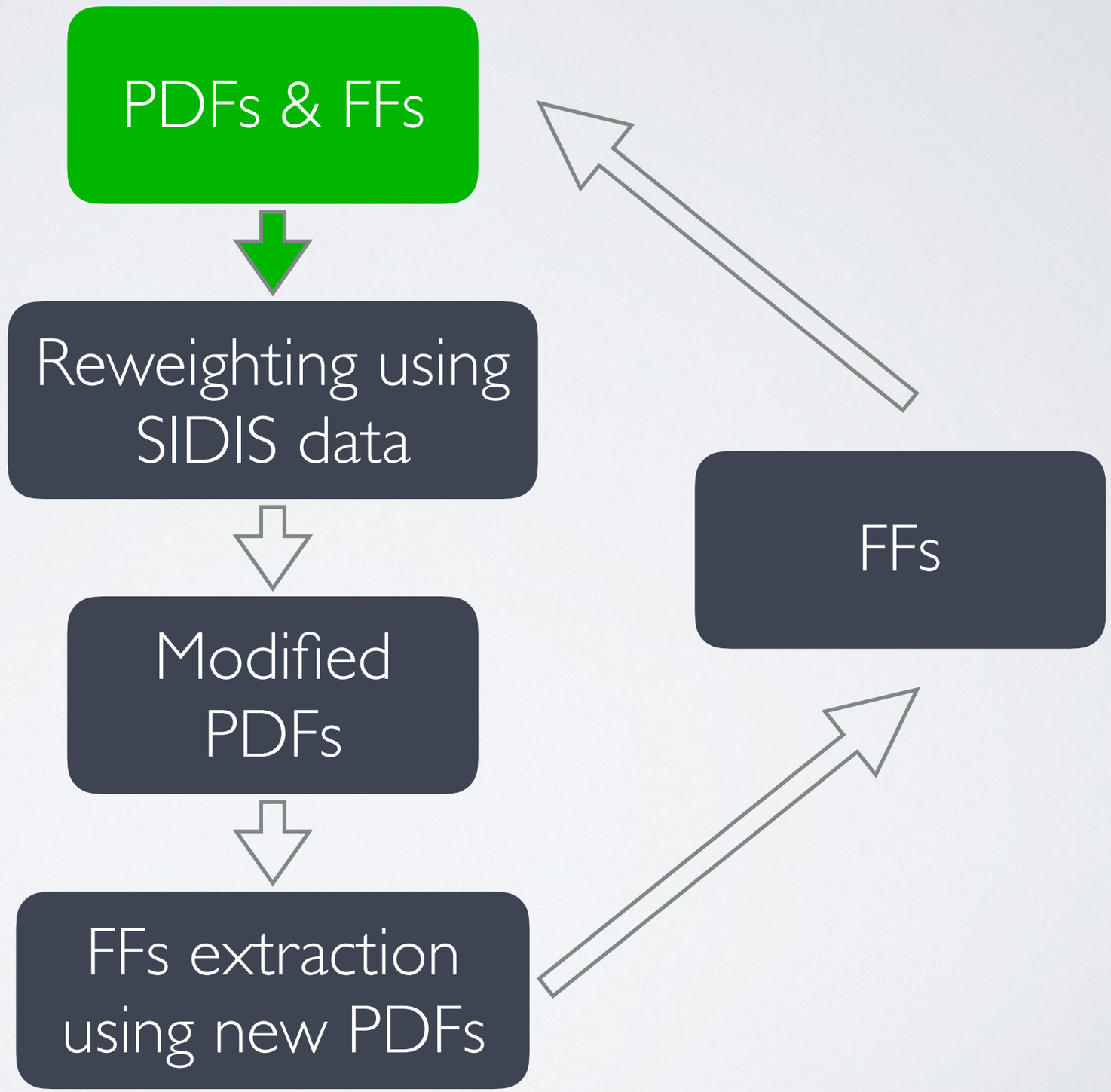
$f_i(x)$ $w(k)$

$$\langle O \rangle = \sum_{k=1}^{N} w(k) \times O[f(k)]$$

We can include new data without performing a new global fit

ITERATIVE PDF & FF EXTRACTION

Is the result independent form the original sets?



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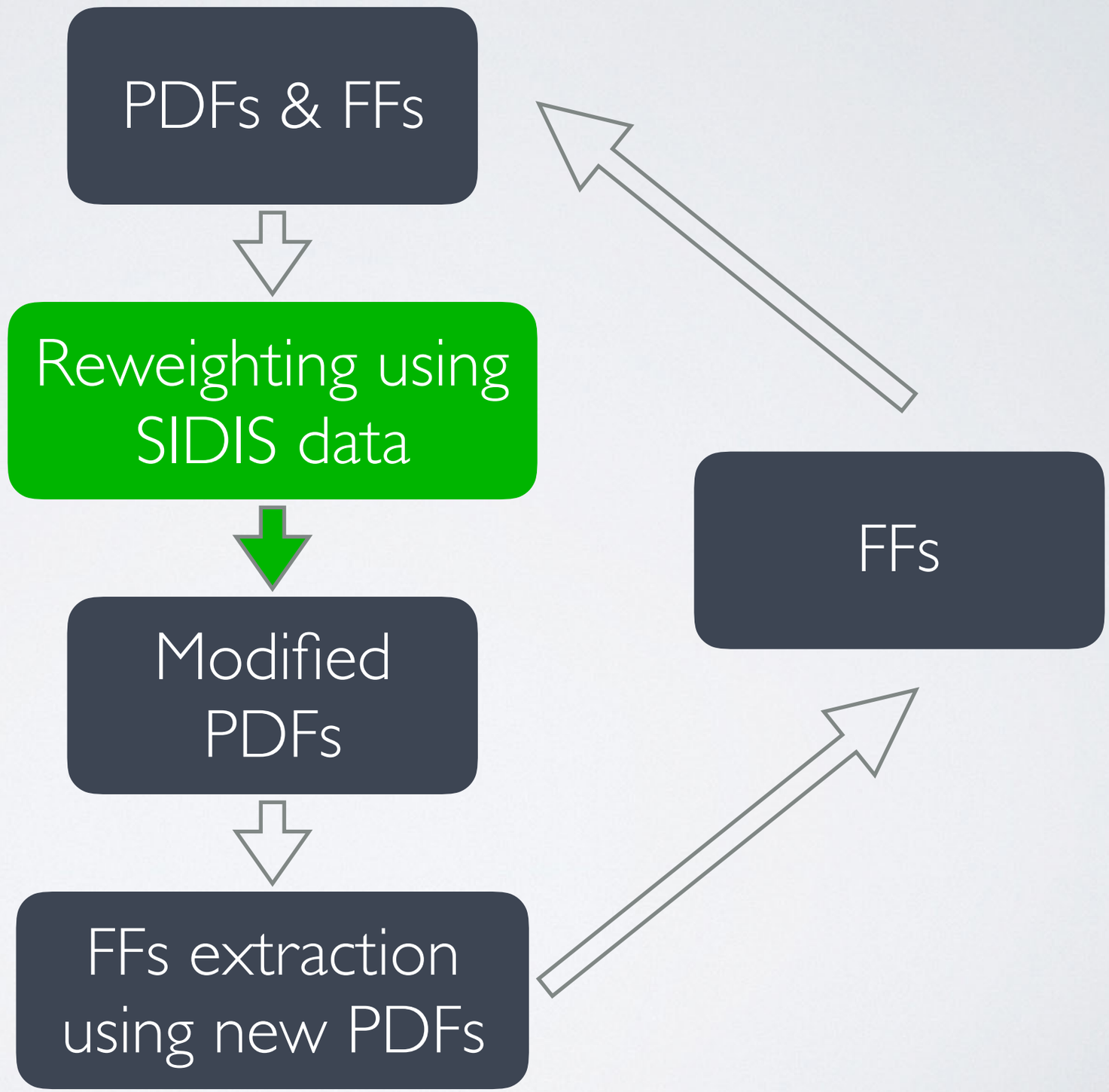
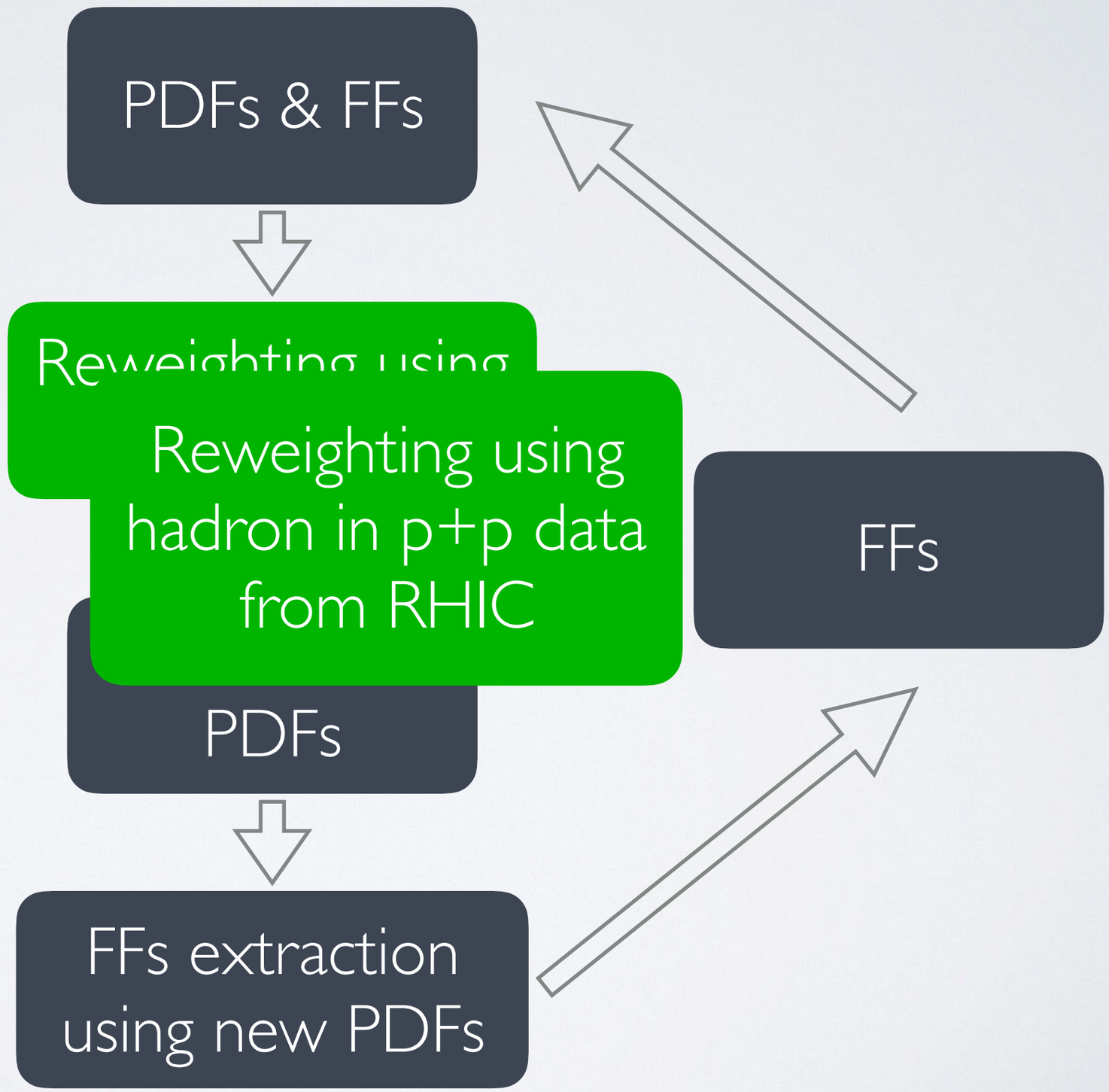


ITERATIVE PDF & FF EXTRACTION

Is the result independent form the original sets?

Is the result independent form the replicas used?



ITERATIVE PDF & FF EXTRACTION

Is the result independent form the original sets?

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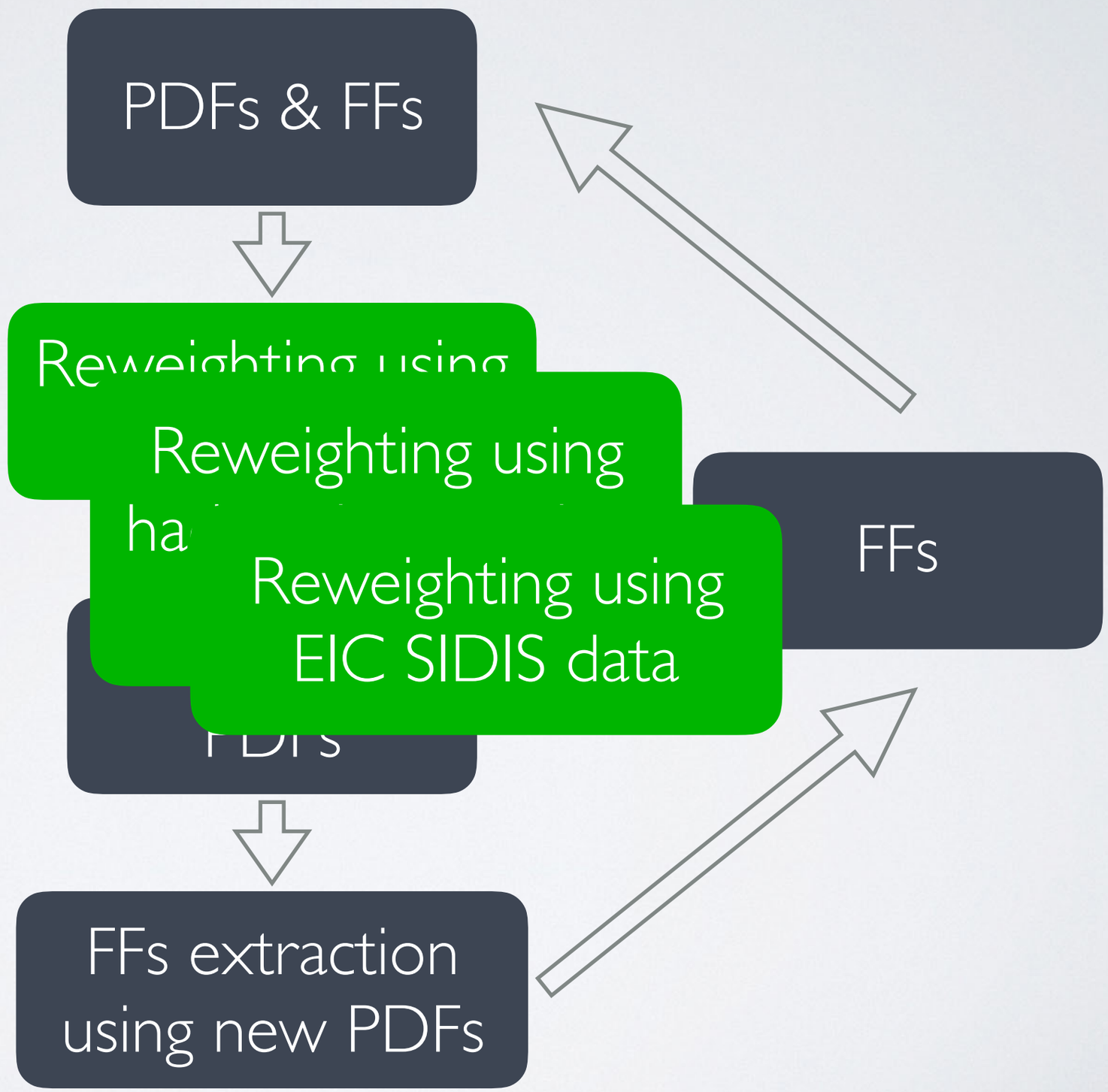

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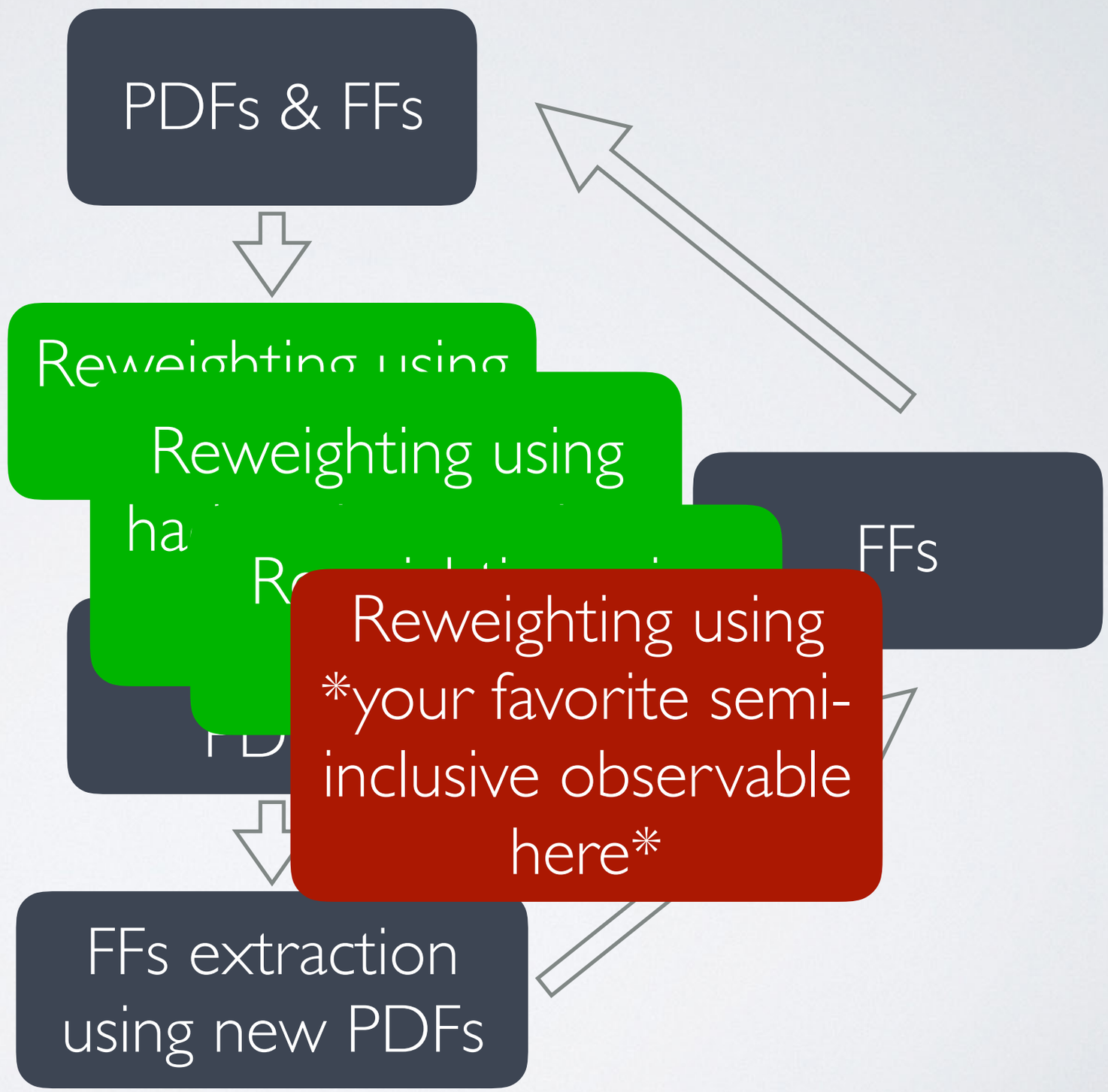
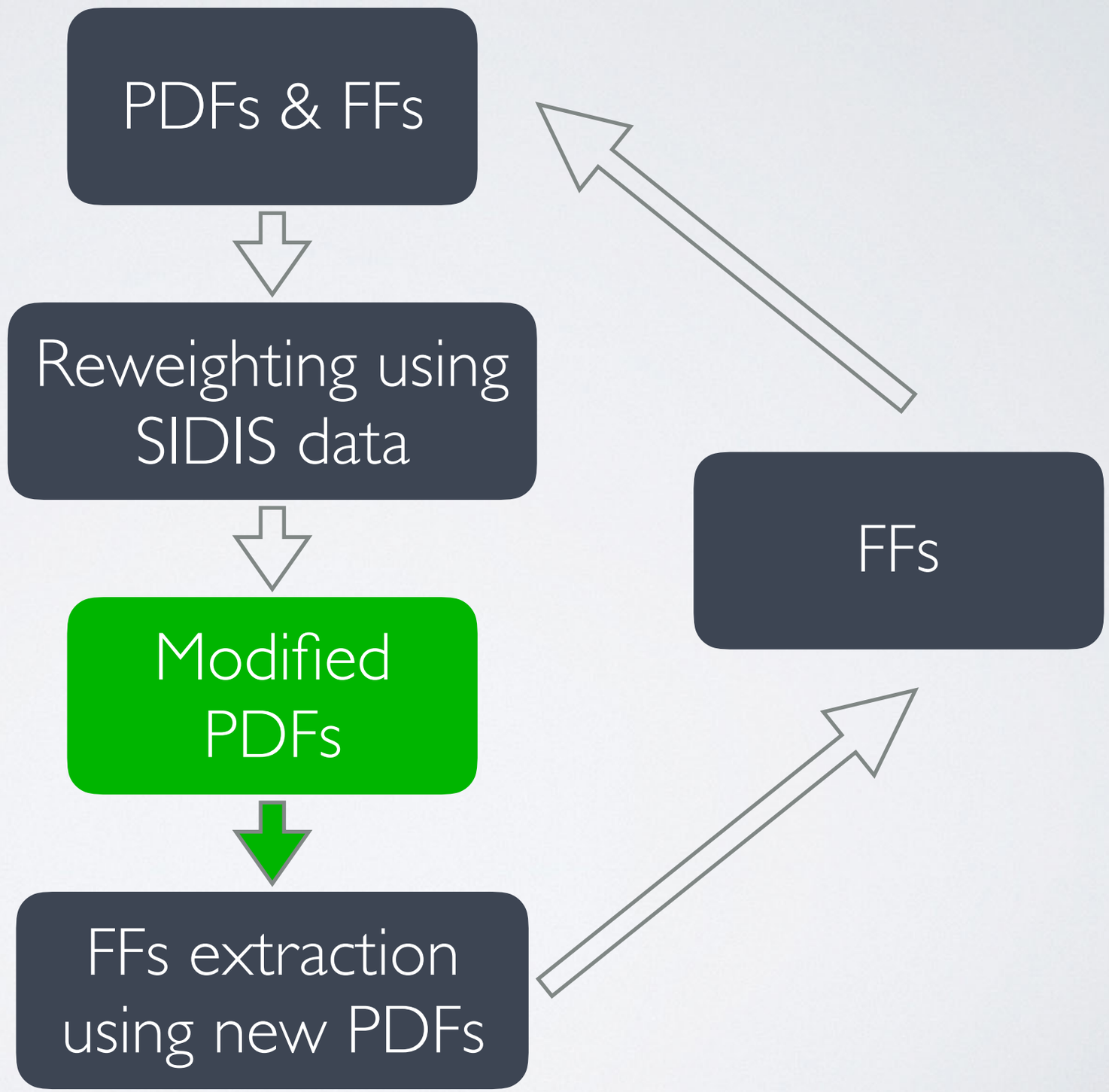


ITERATIVE PDF & FF EXTRACTION

Is the result independent form the original sets?

Is the result independent form the replicas used?

Is the modified set of PDFs an improvement?



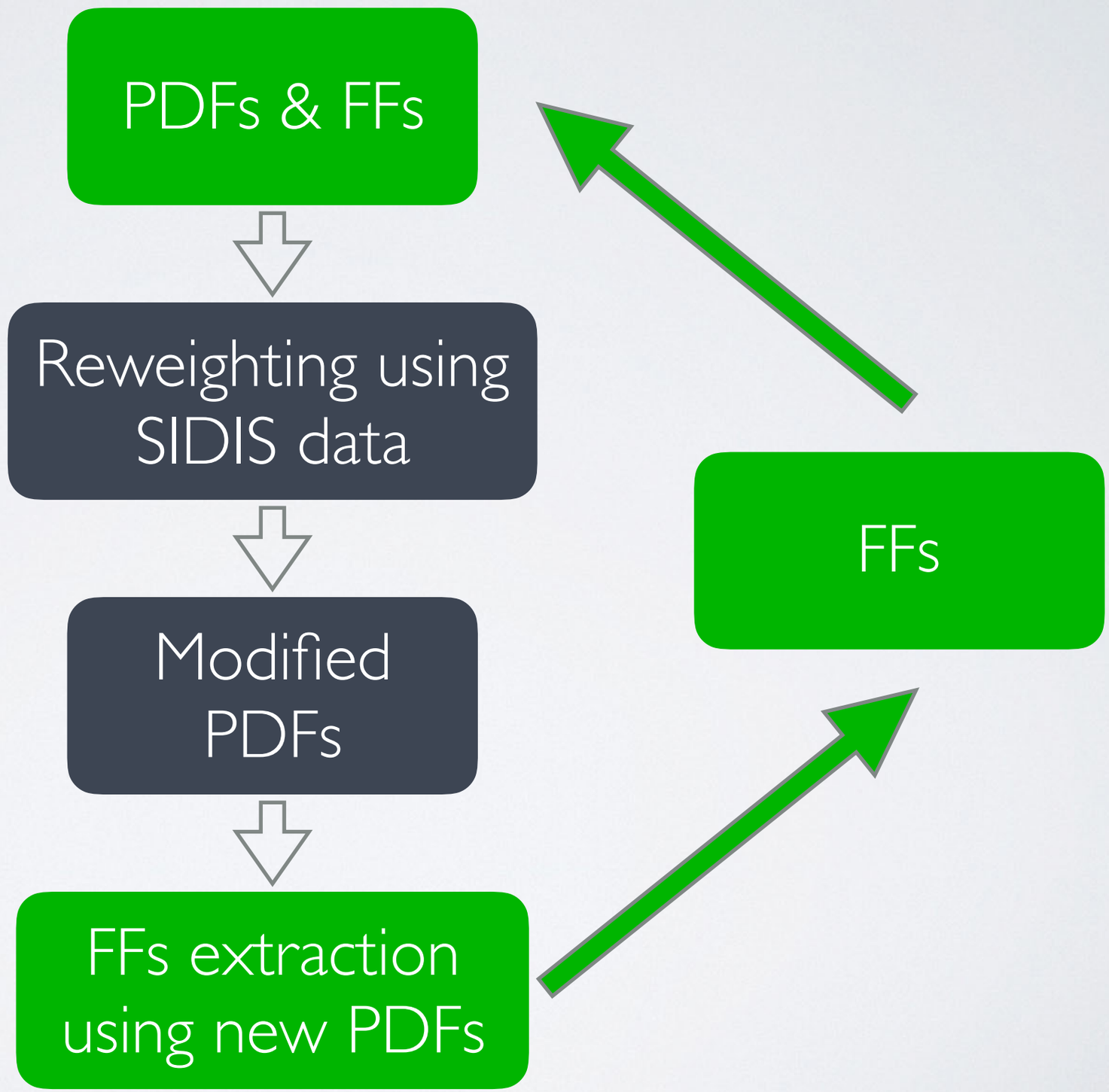
ITERATIVE PDF & FF EXTRACTION

Is the result independent form the original sets?

Is the result independent form the replicas used?

Is the modified set of PDFs an improvement?

Convergence?



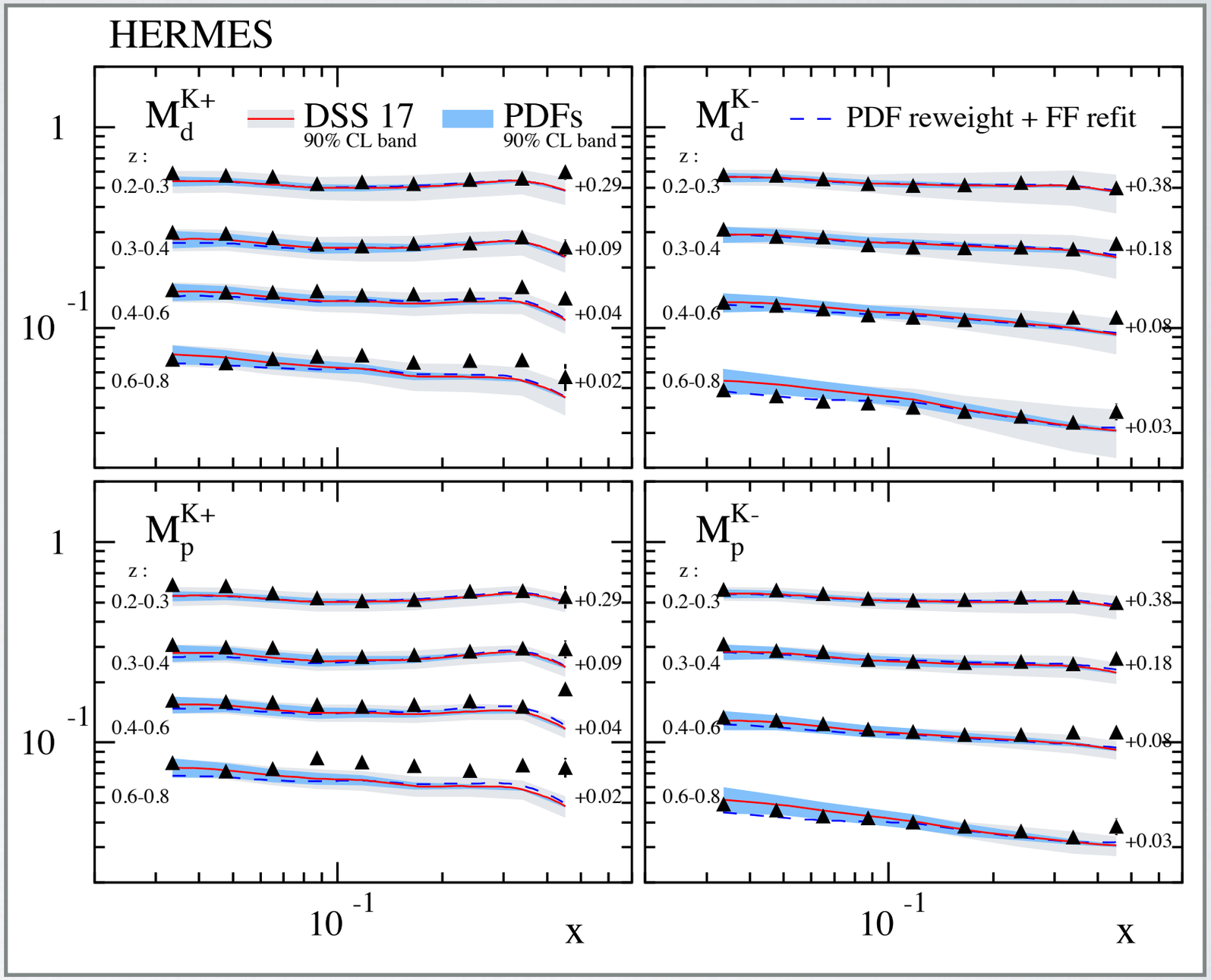
REWEIGHTING IN ACTION: SIDIS

PhysRevD.96.094020. In collaboration with R. Sassot & M. Stratmann

HERMES SIDIS DATA

$$M^{K^\pm}_{p(d)} = \frac{d\sigma^{K^\pm}_{p(d)} / dx\, dy\, dz}{d\sigma_{p(d)} / dx\, dy}$$

Hermes Multiplicity data in bins of *x* *and z*



NEW COMPASS SIDIS DATA

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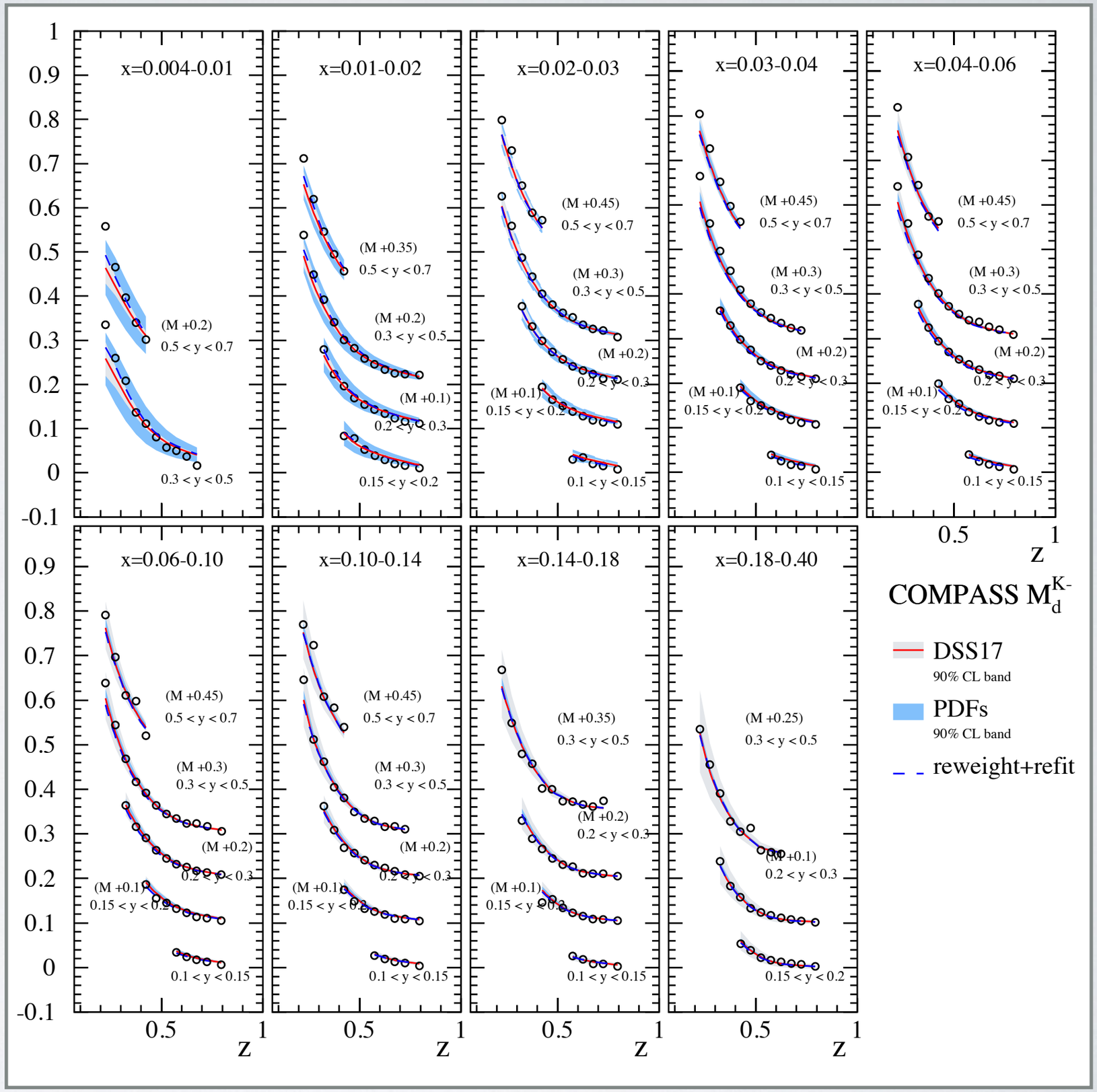
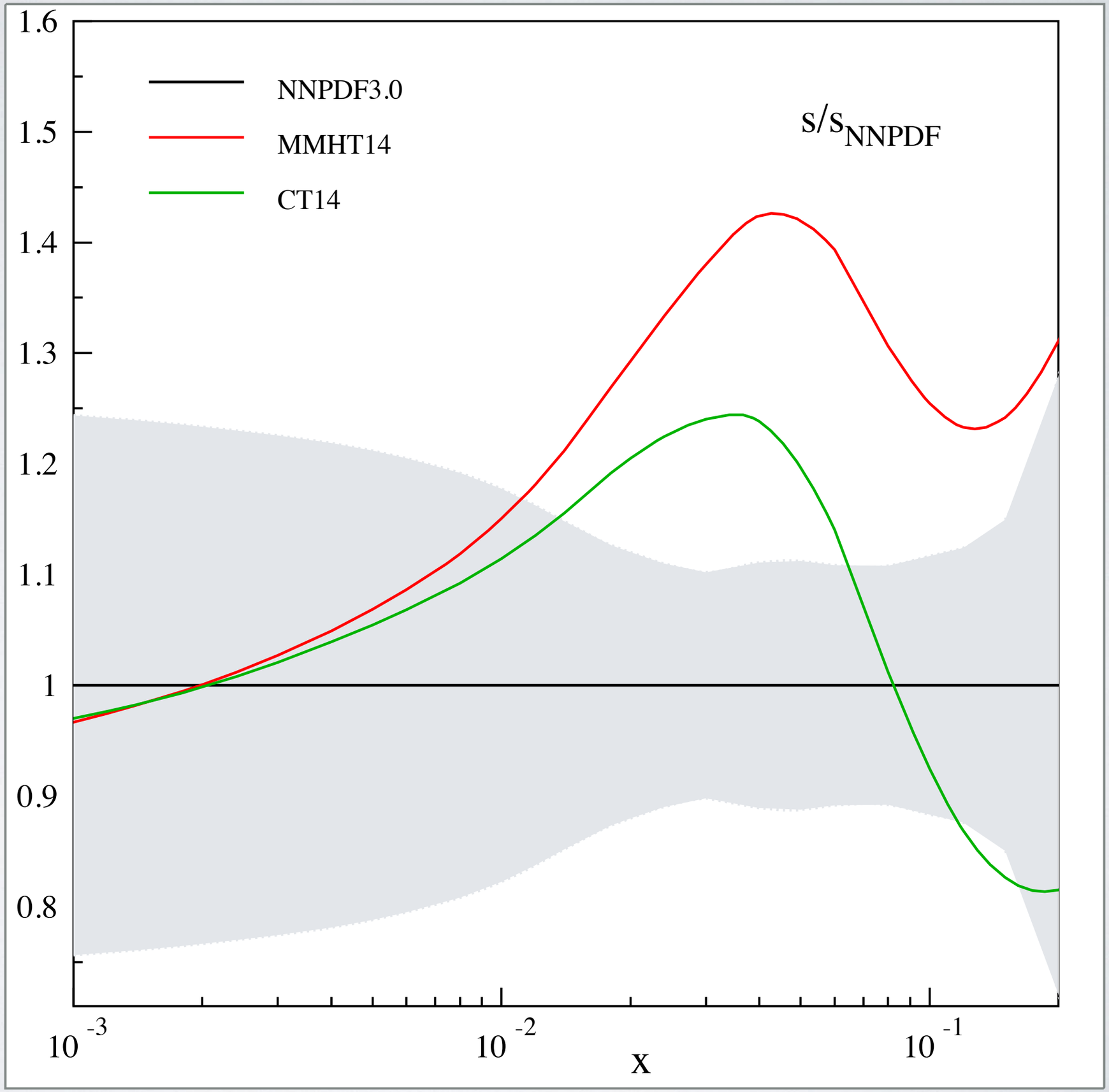
Compass Multiplicity data in bins of *x*, *z* and *y*



REWEIGHTING IN ACTION: STRANGE QUARK DISTRIBUTION

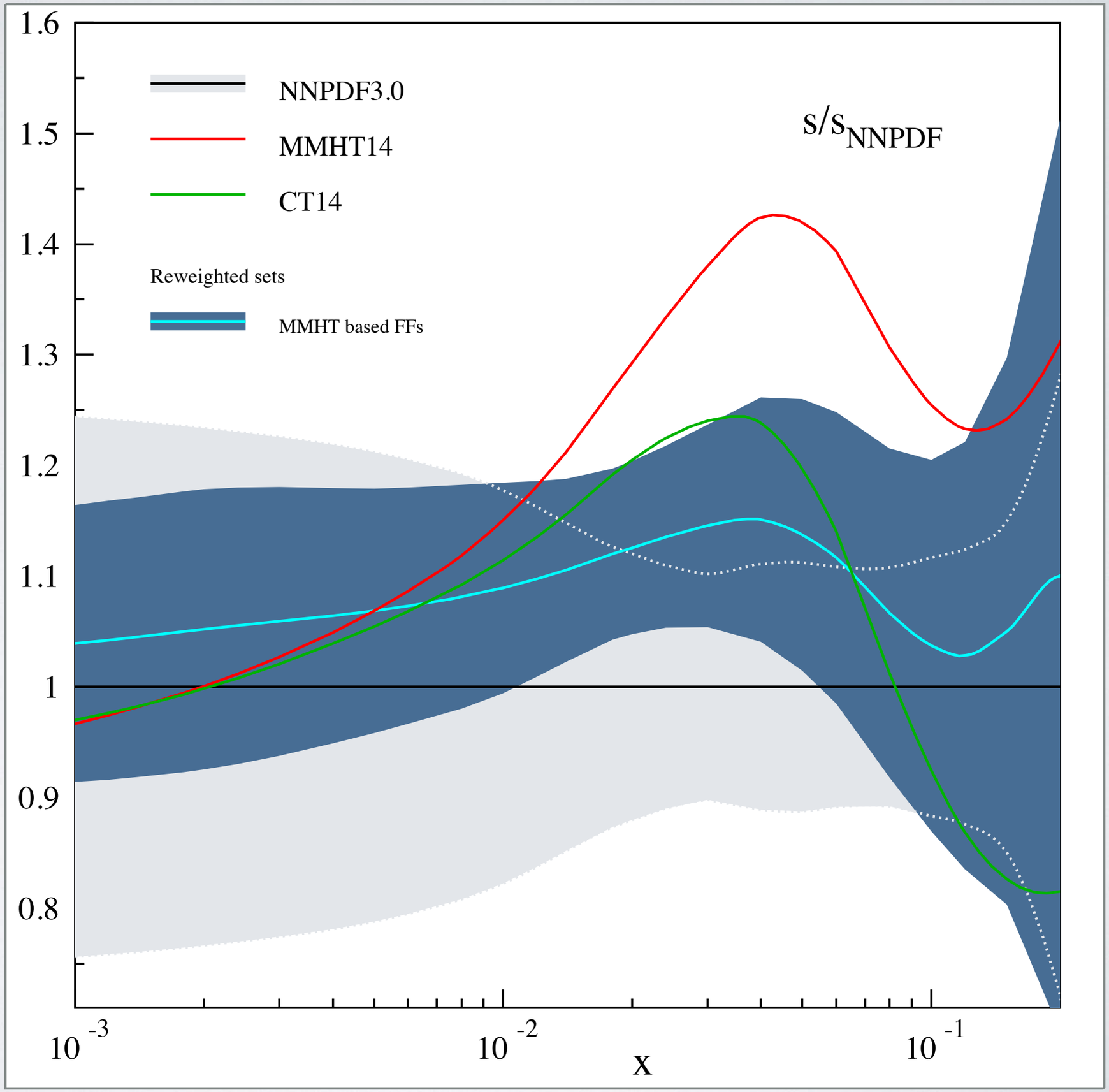
$$\chi^2_{FFs} = 1271$$



REWEIGHTING IN ACTION: STRANGE QUARK DISTRIBUTION

$$\chi^2_{FFs} = 1271$$

$$\chi^2_{FFs} = 1041$$

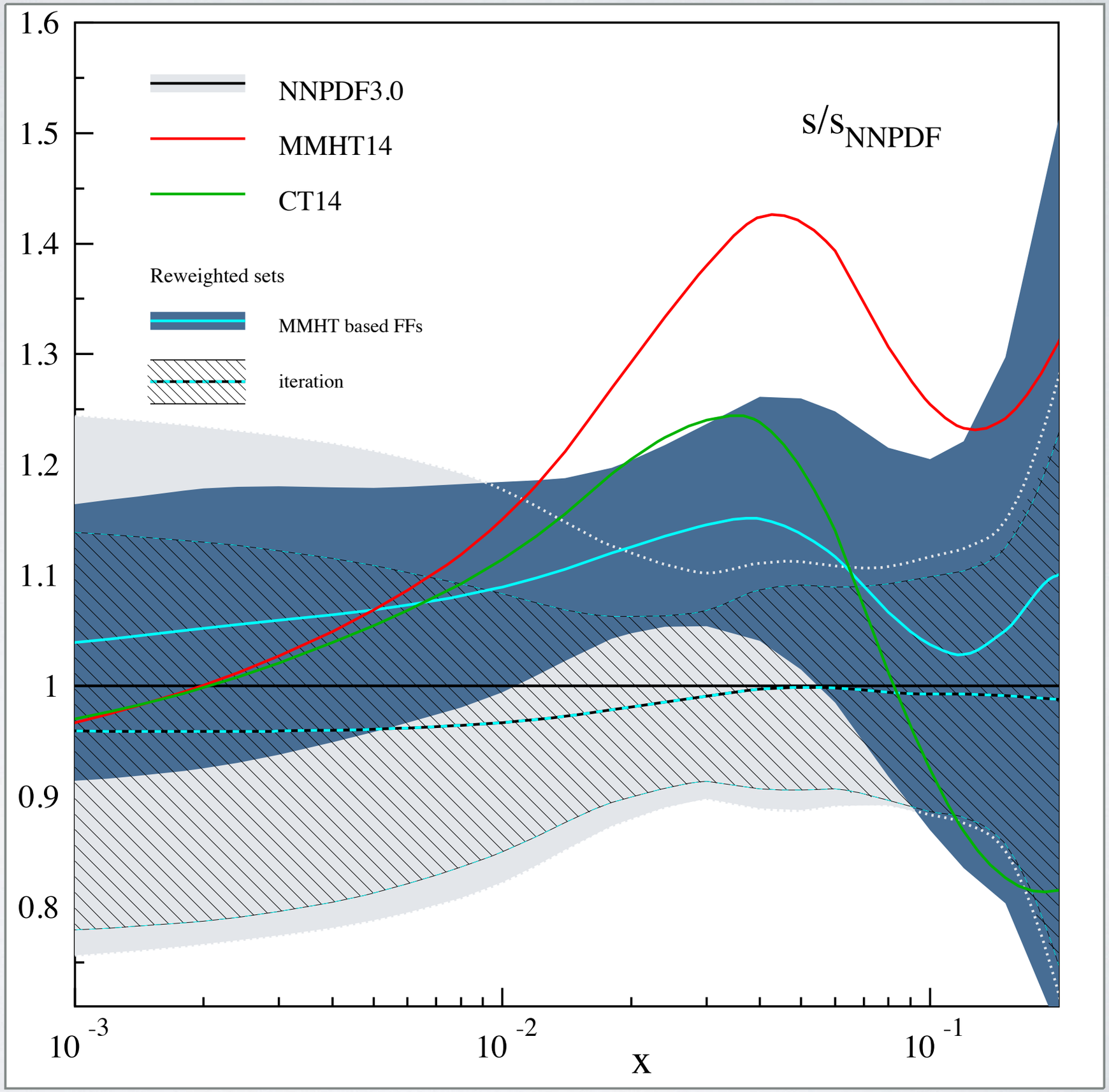


REWEIGHTING IN ACTION: STRANGE QUARK DISTRIBUTION

$$\chi^2_{FFs} = 1271$$

$$\chi^2_{FFs} = 1041$$

$$\chi^2_{FFs} = 1002$$



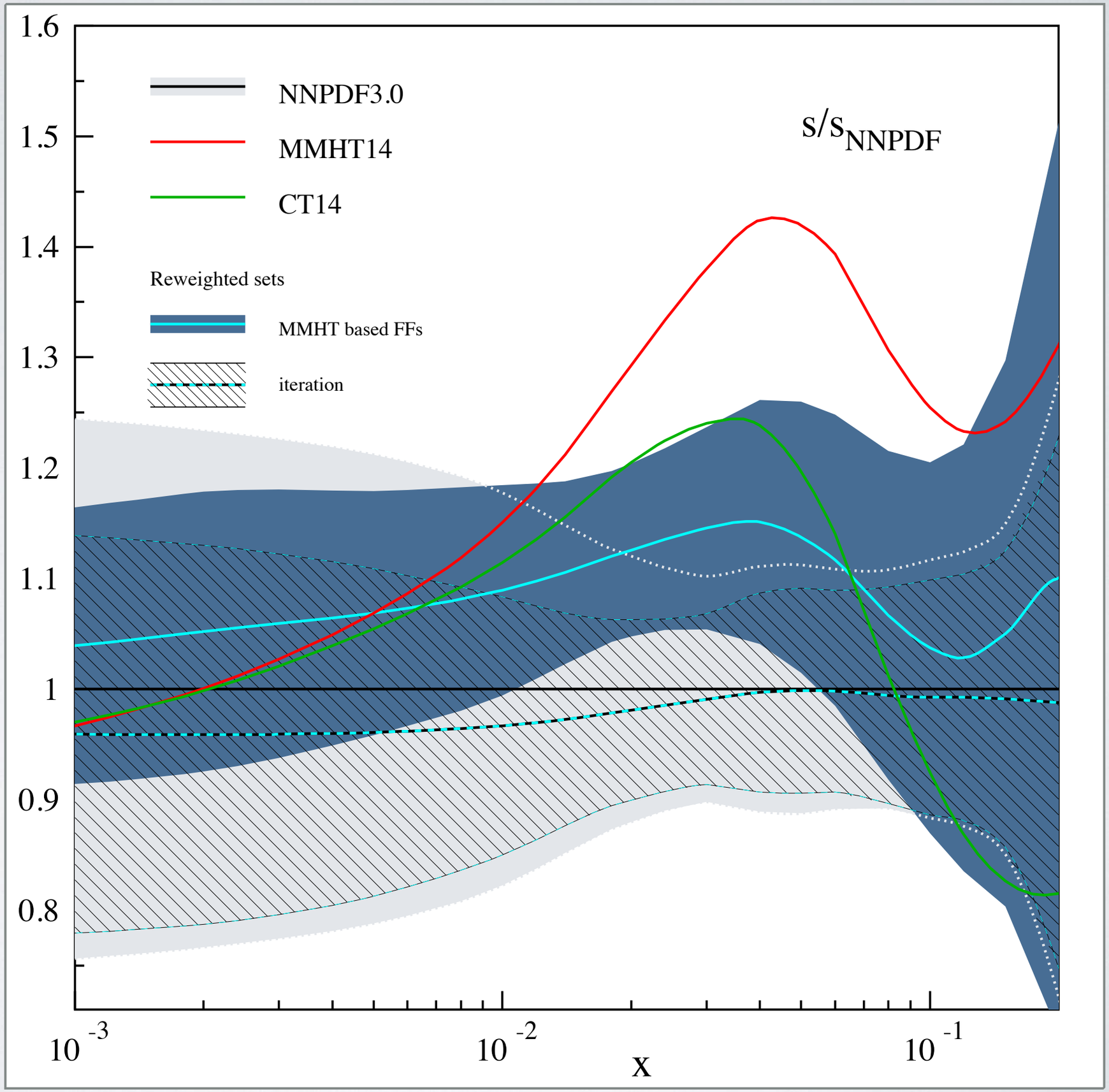
REWEIGHTING IN ACTION: STRANGE QUARK DISTRIBUTION

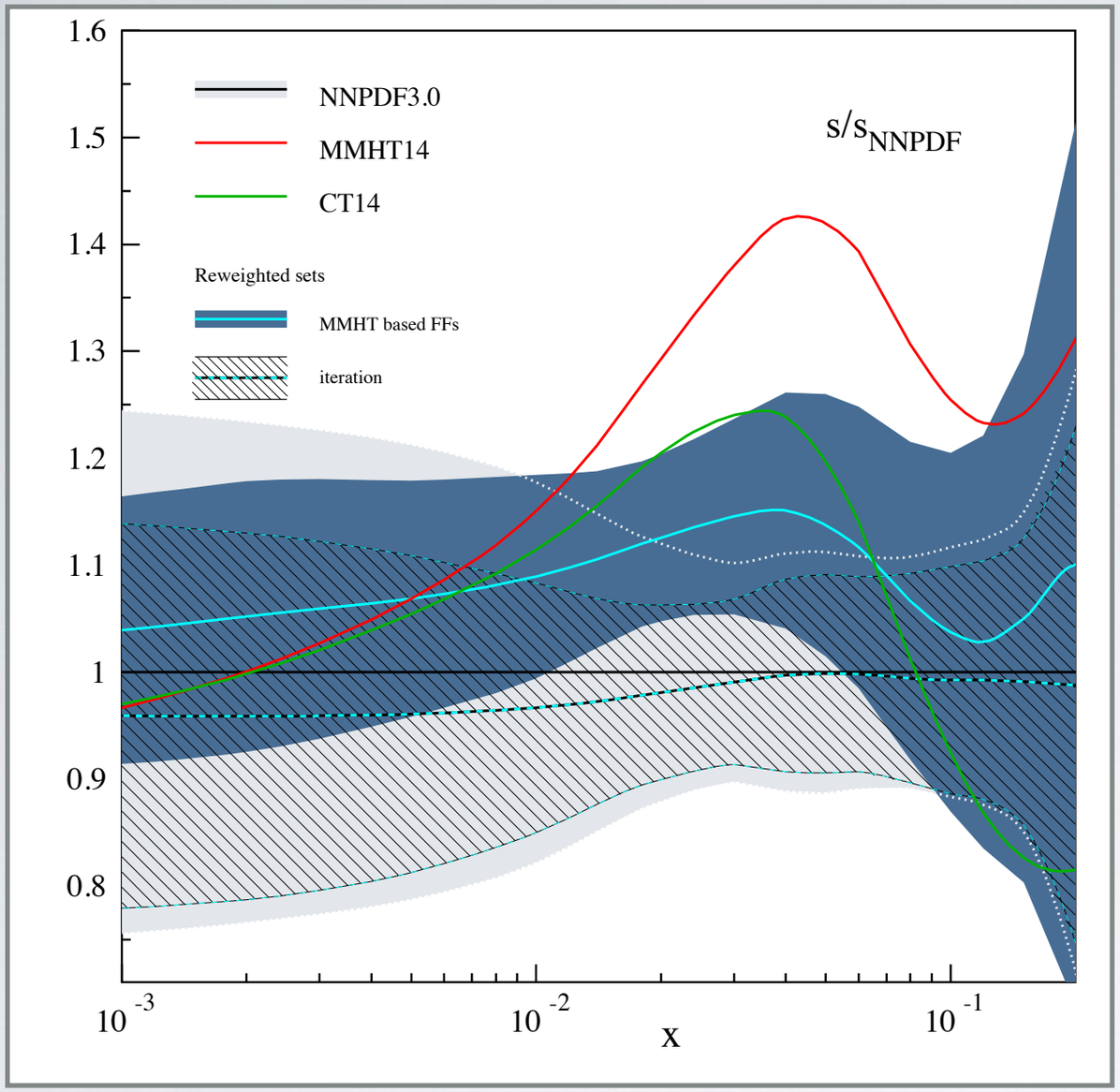
$$\chi^2_{FFs} = 1271$$

$$\chi^2_{FFs} = 1041$$

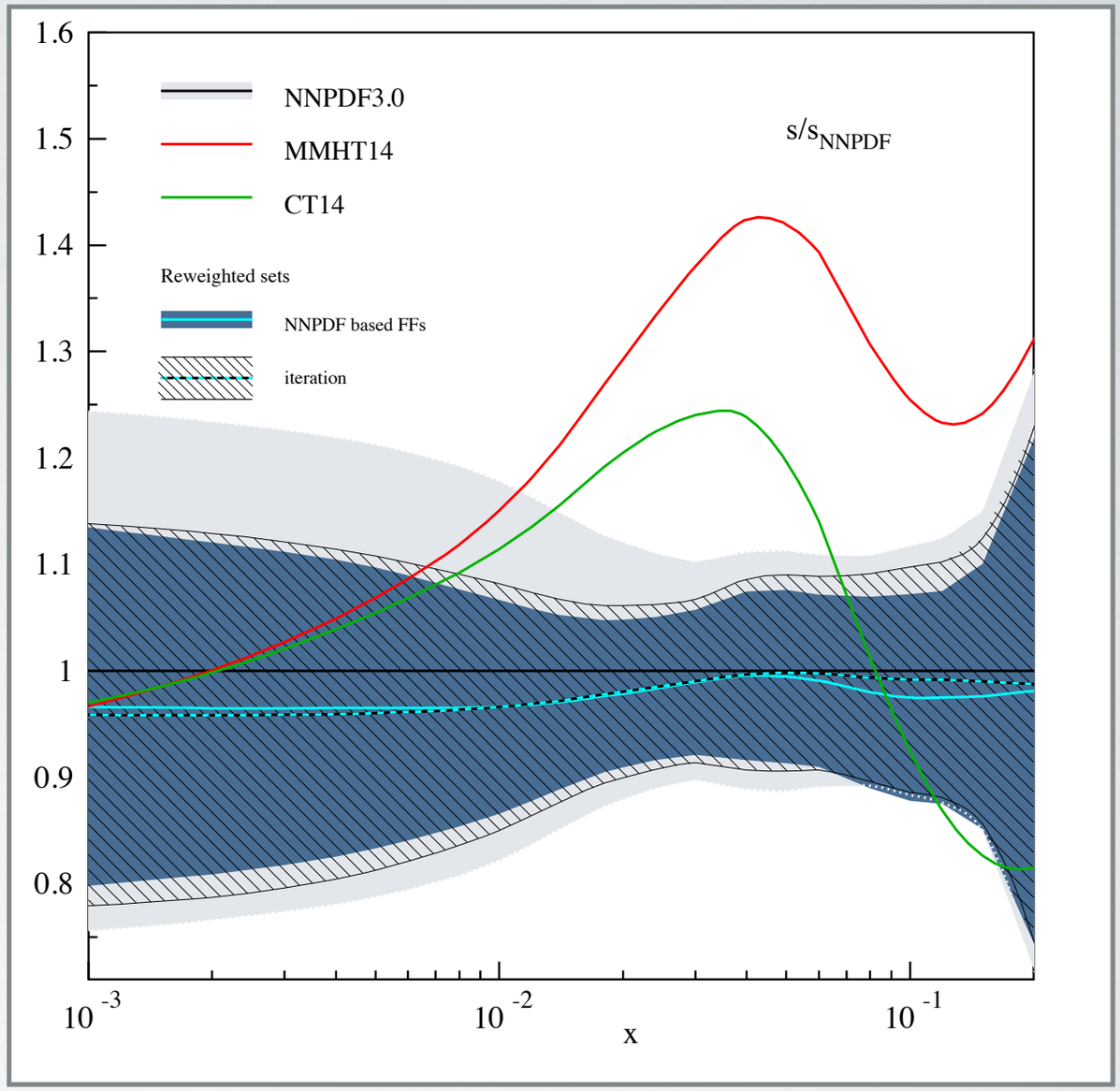
$$\chi^2_{FFs} = 1002$$

- Fast convergence
- Uncertainties reduction of order 10%



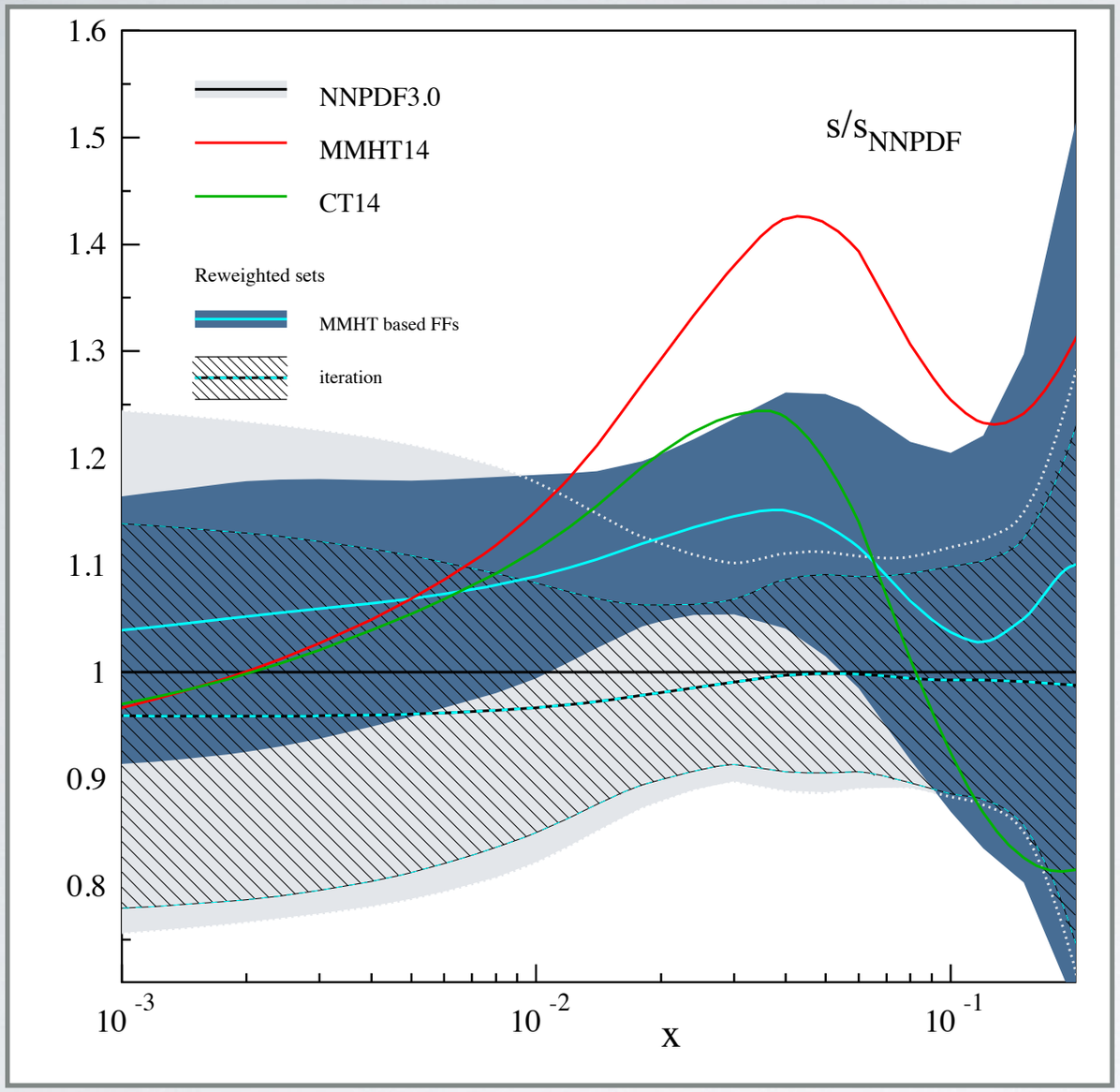


Starting from DSS based MMHT14

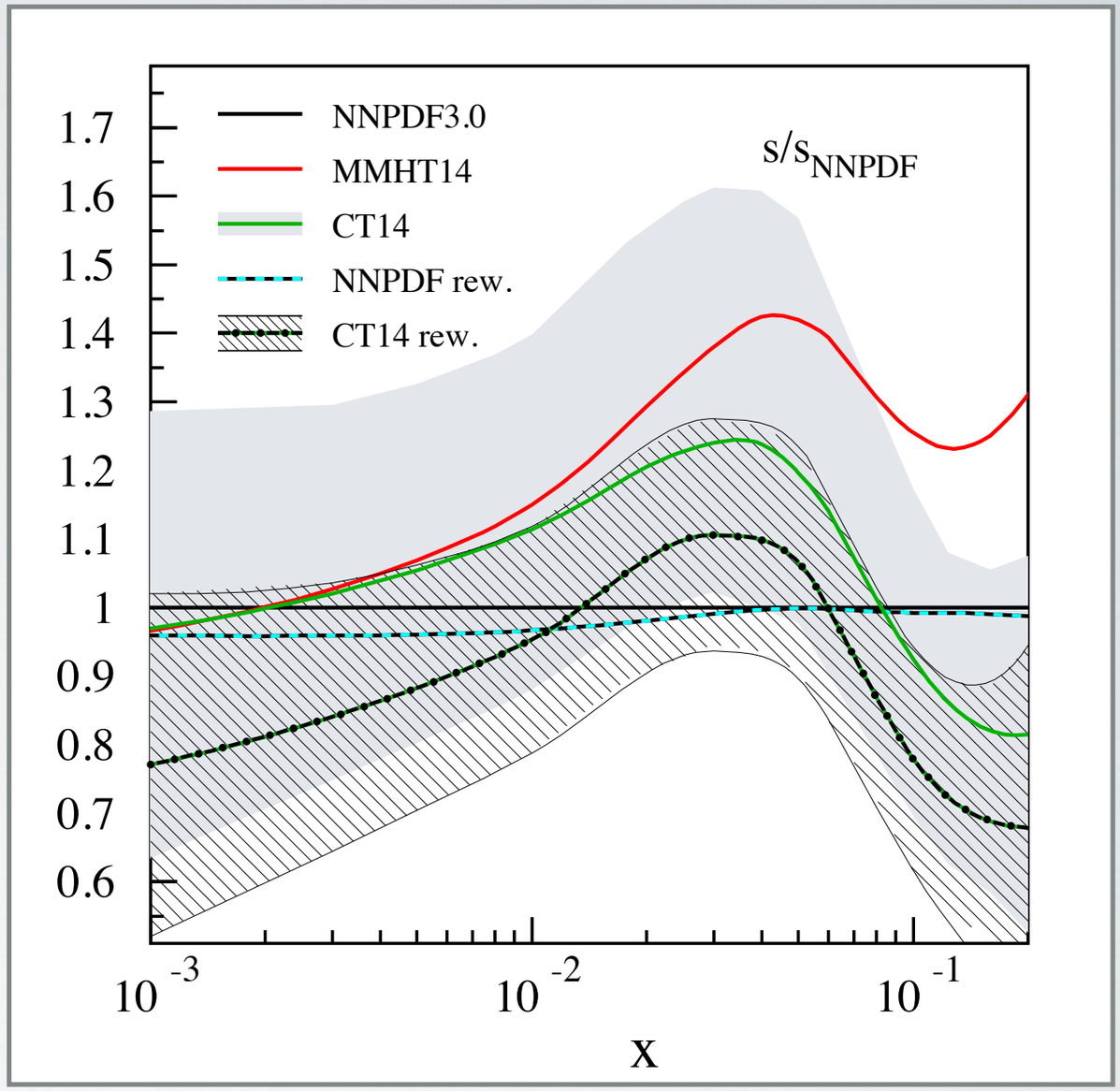


Starting from DSS based NNPDF3.0

Independency from the starting set of PDFs



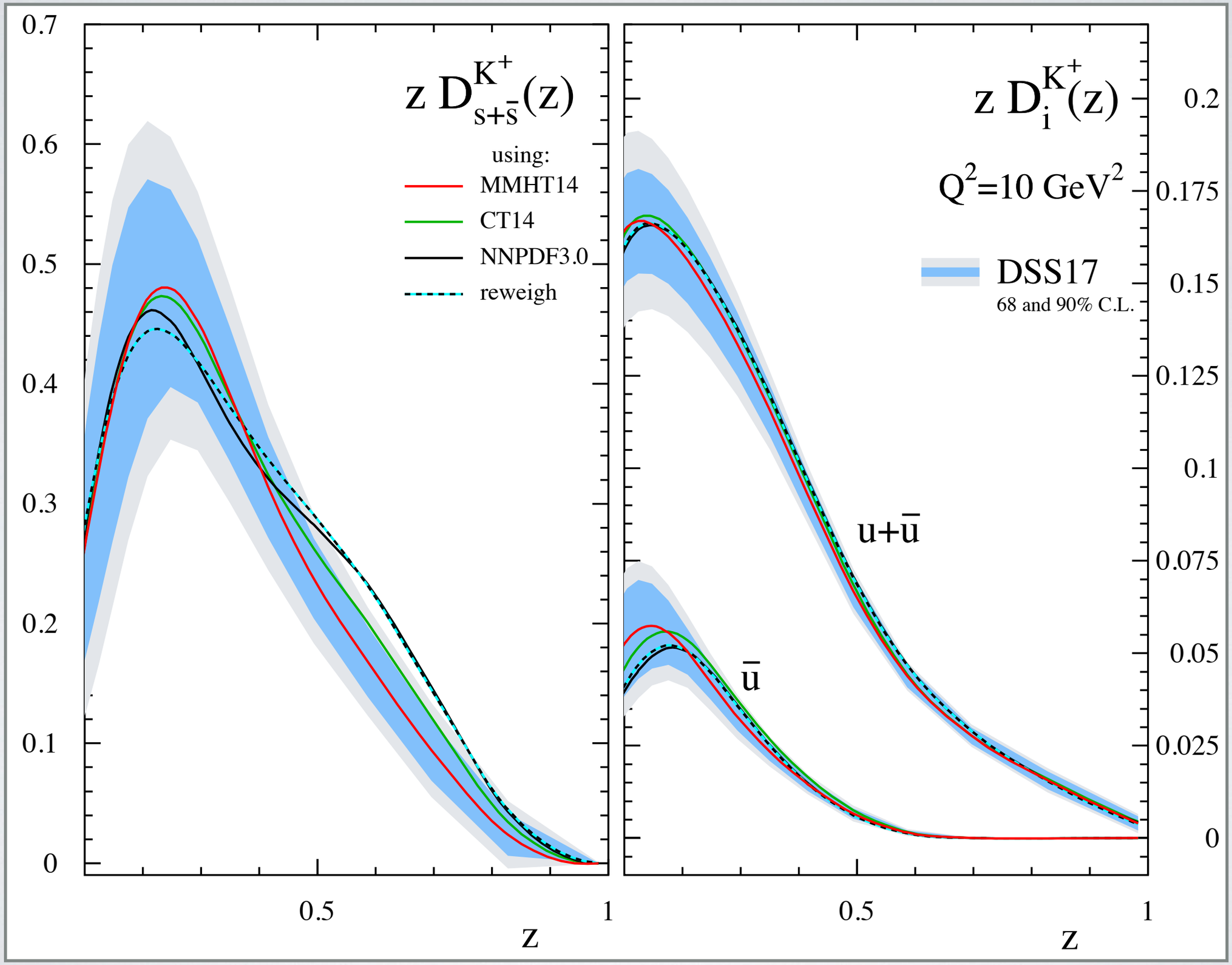
Using NNPDF3.0 Replicas



Using CT14 Replicas

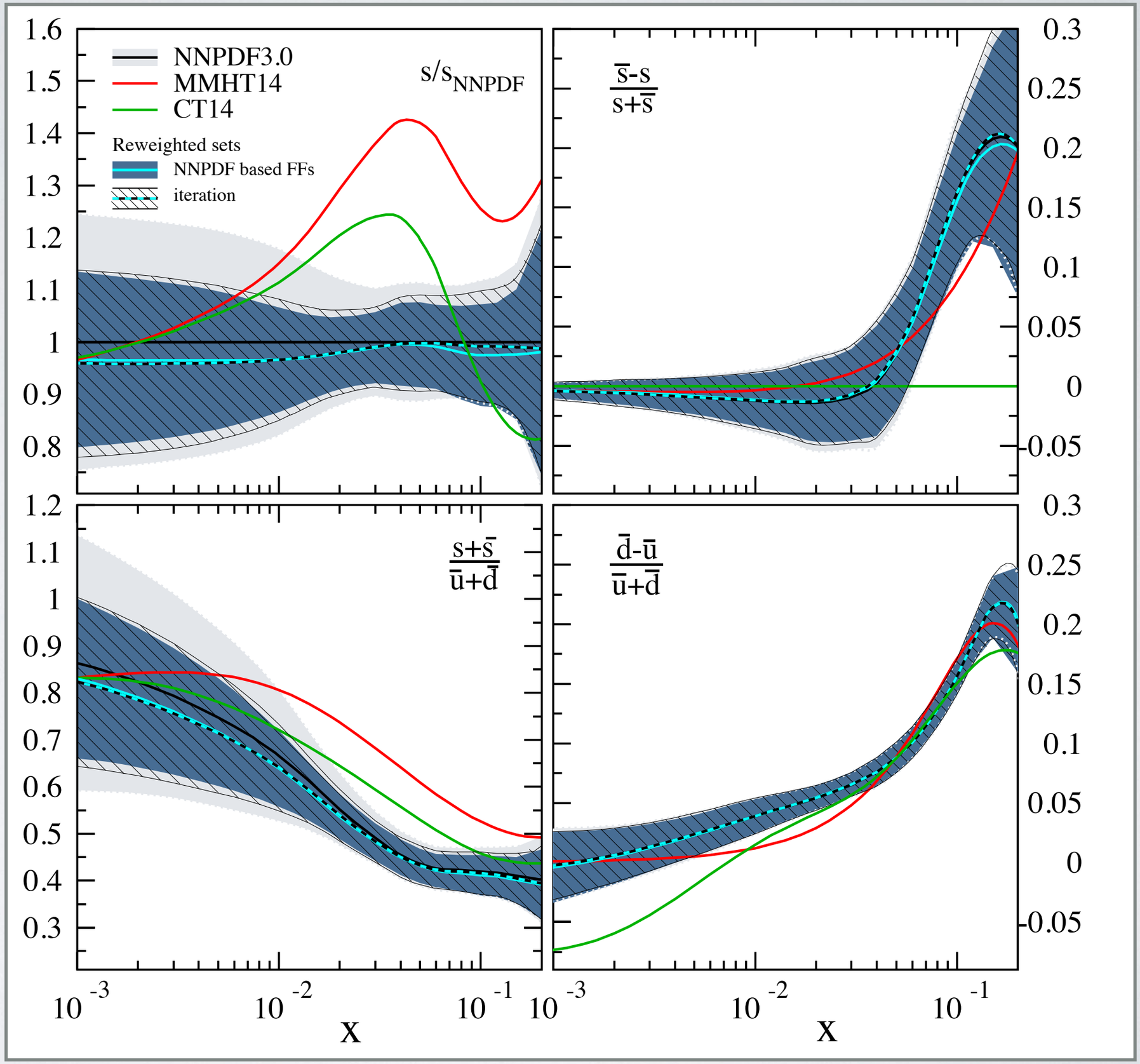
Independency from the set of replicas used

REWEIGHTING IN ACTION: REWEIGHTED FFS



REWEIGHTING IN ACTION: ASYMMETRIES

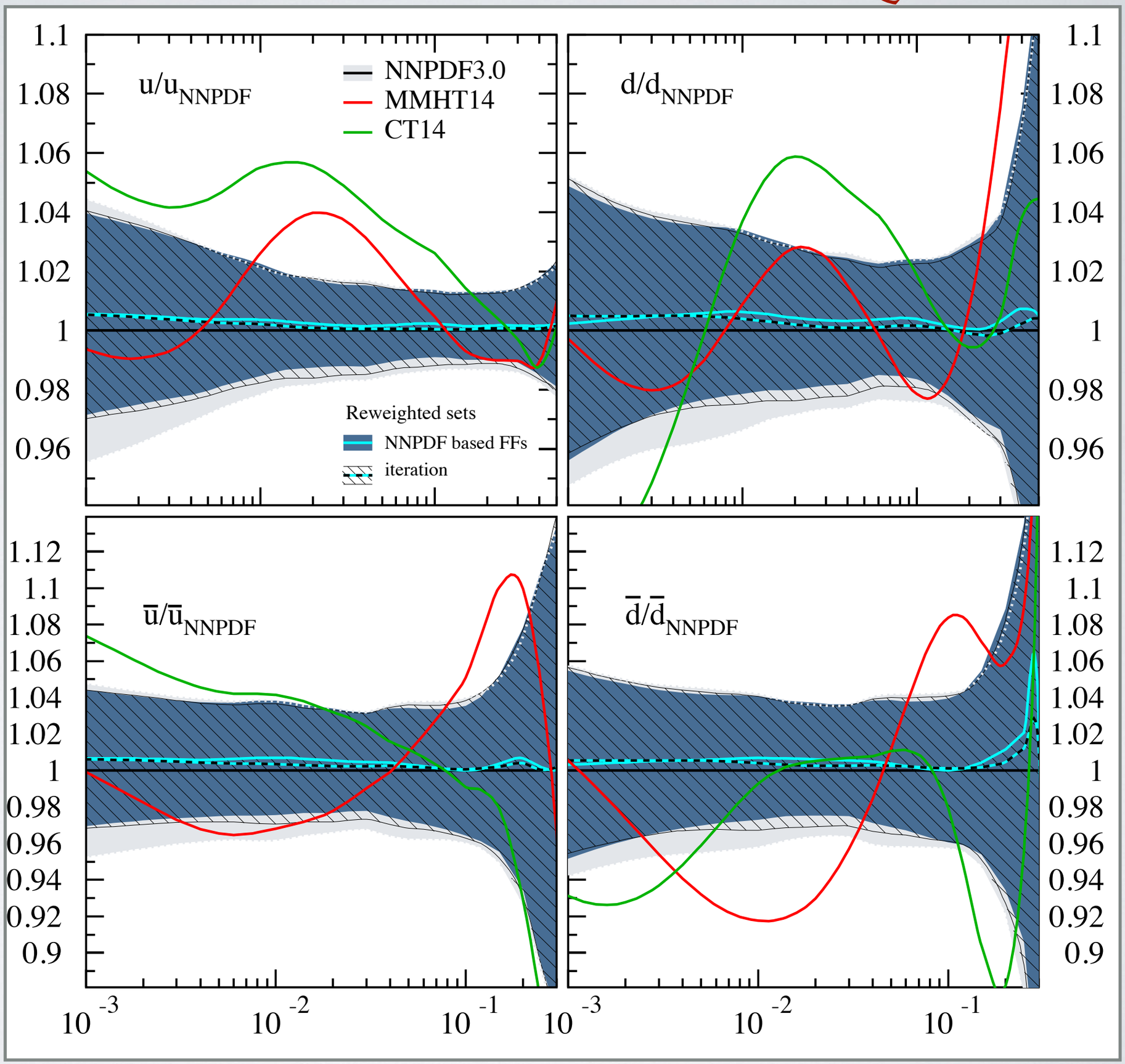
- Favors a suppressed strange fraction of the sea
- Little impact on the other asymmetries



REWEIGHTING IN ACTION: LIGHT QUARKS

Little impact on the other light distributions

- Kaons are not the best tool to grasp them



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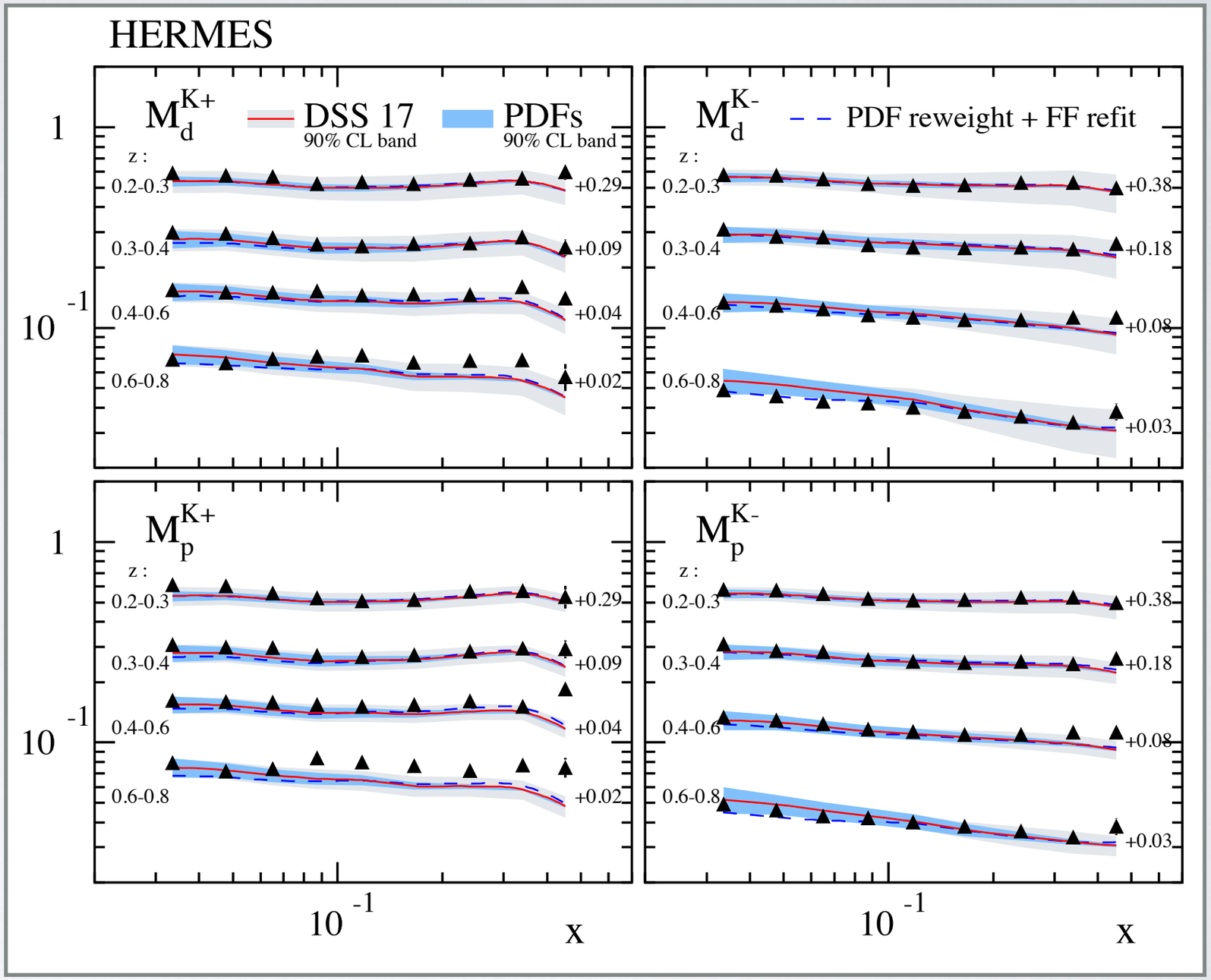

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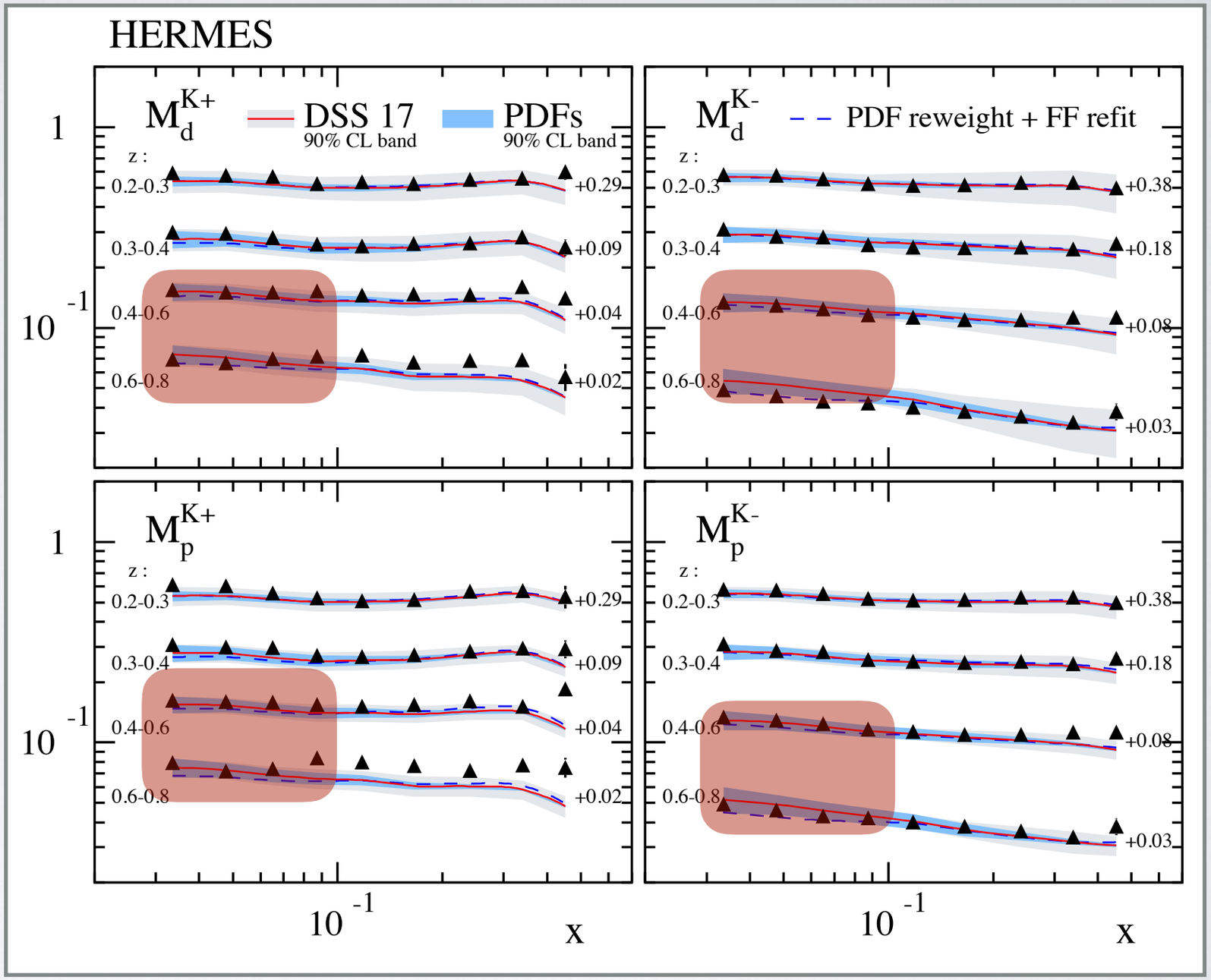

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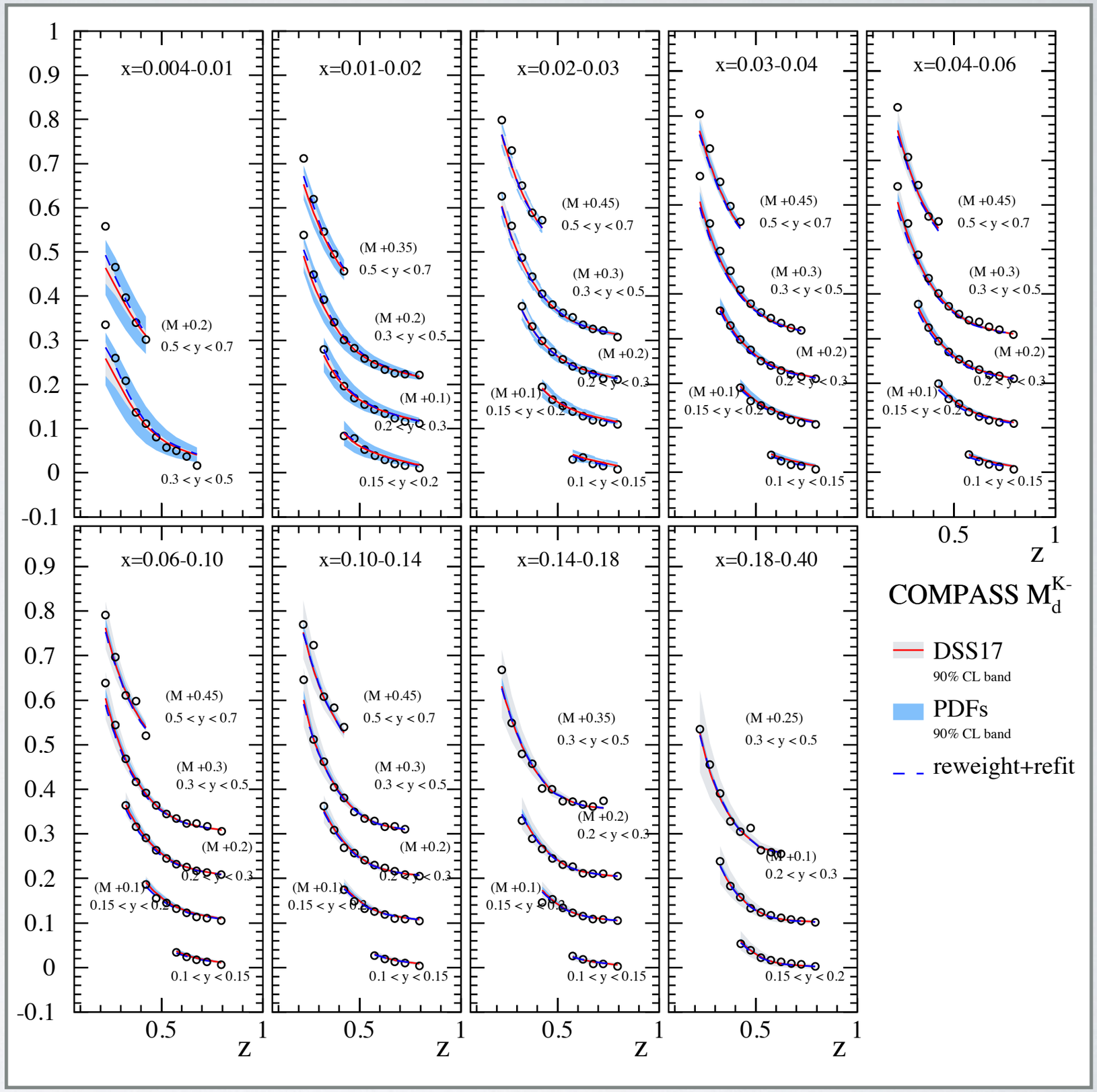

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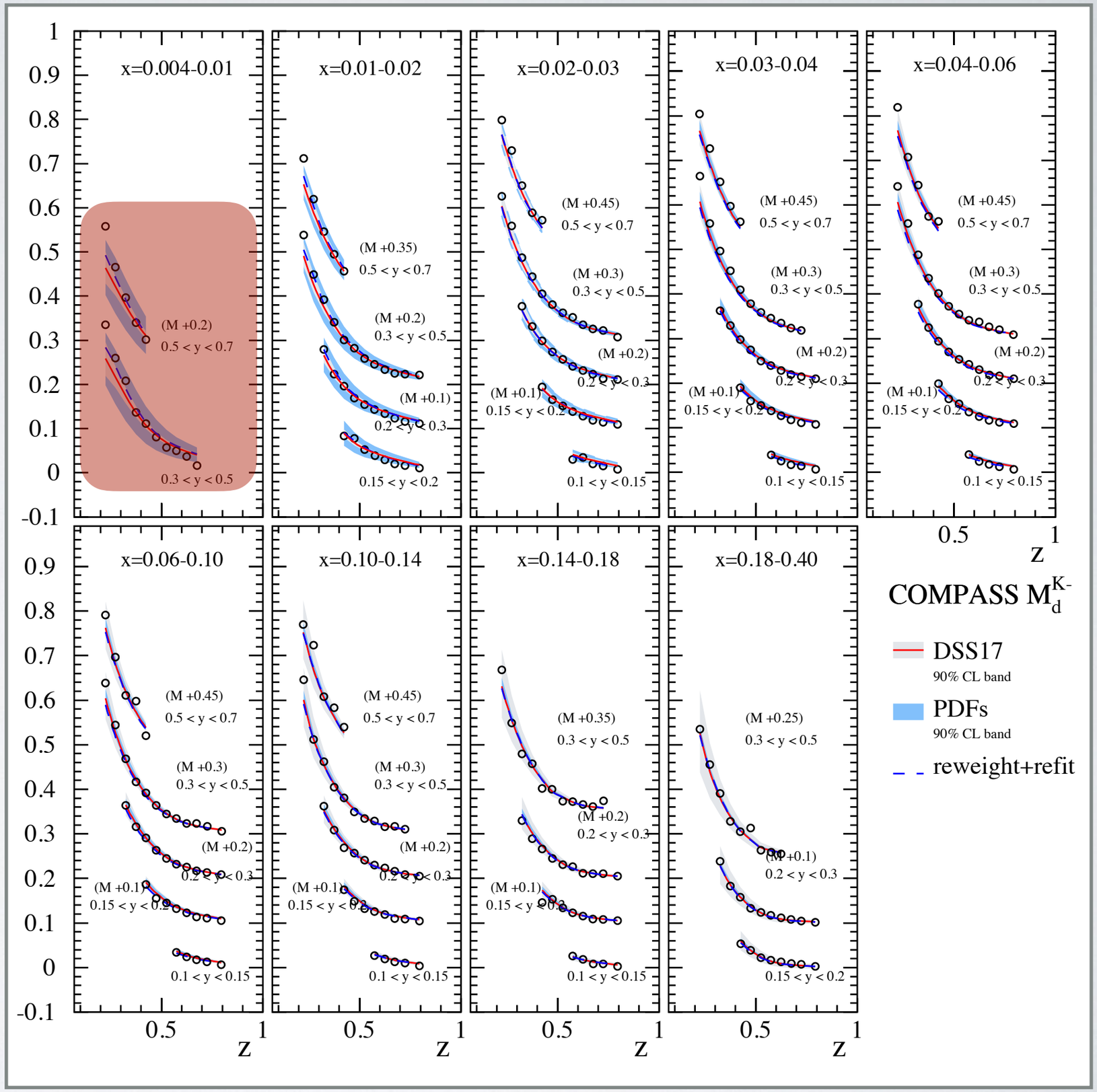

Can we repeat the same analysis for another semi-inclusive observable?

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In collaboration with R. Sassot & E. Aschenauer

Charged Kaon production at STAR

$$\sqrt{s} = 200\ GeV$$

$$-0.5 \leq \eta \leq 0.5$$

Can we repeat the same analysis for another semi-inclusive observable?

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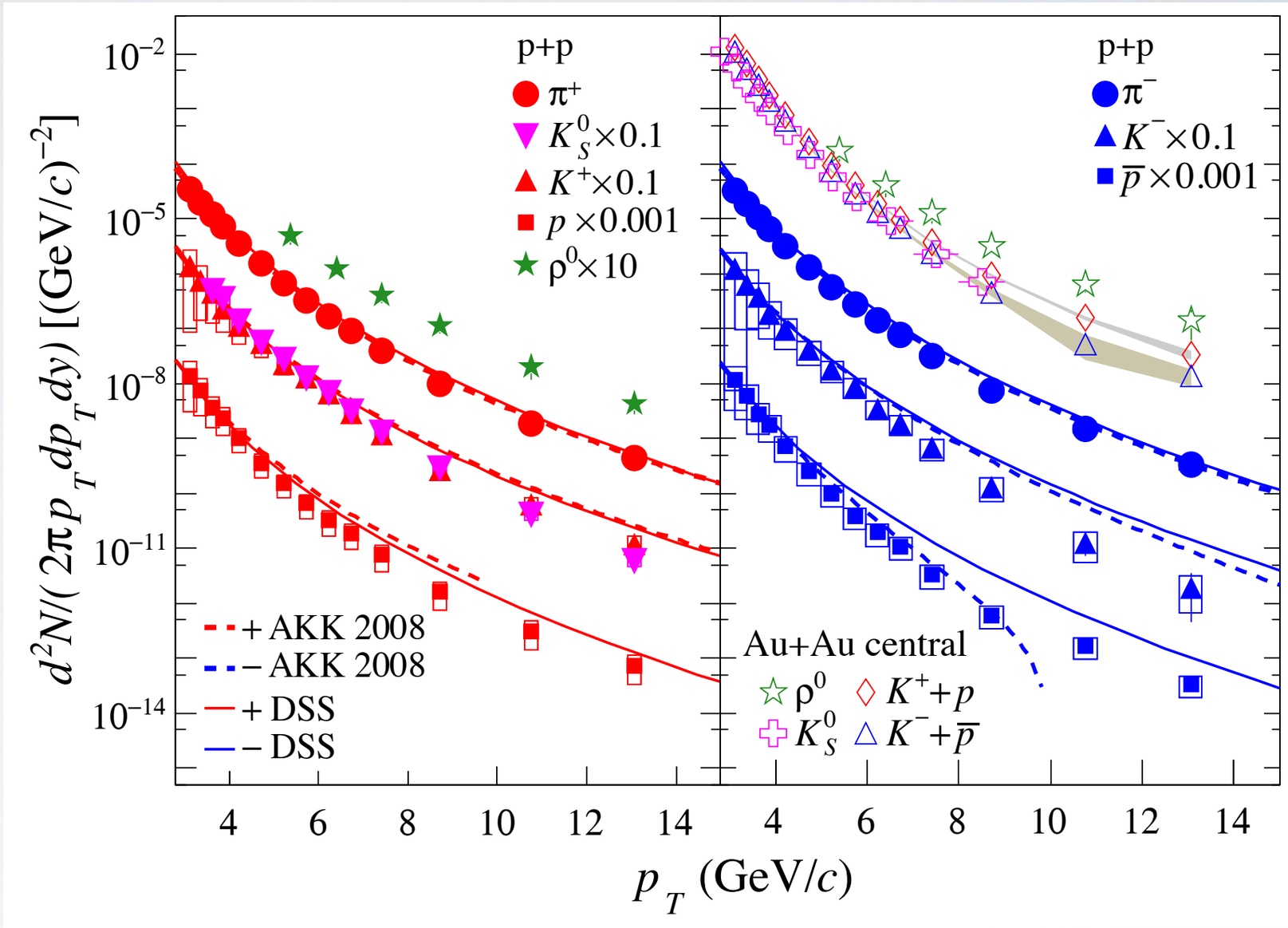
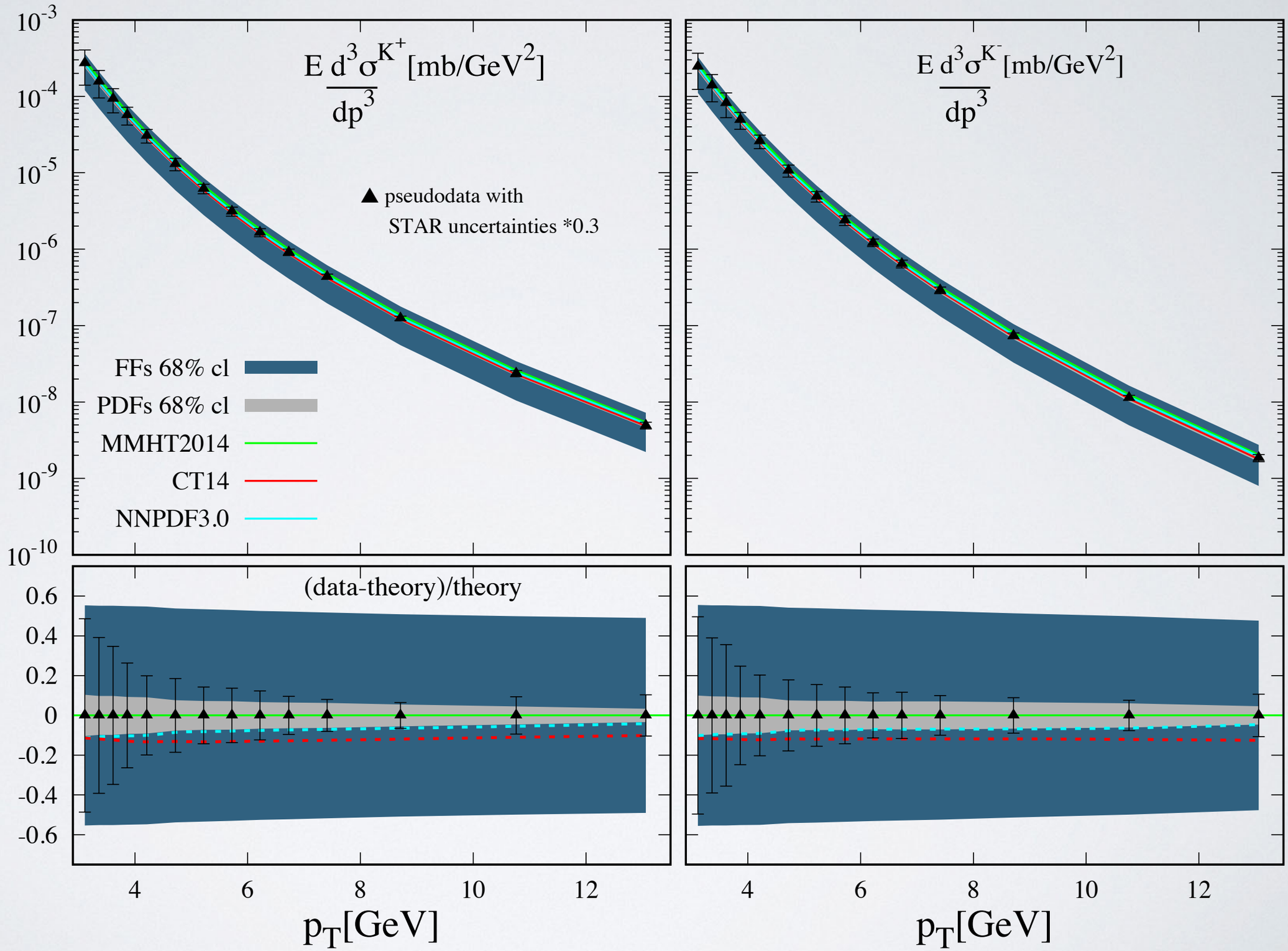


Phys.Rev.Lett. 108 (2012) 072302

Can we repeat the same analysis for another semi-inclusive observable?

$\sqrt{s} = 200\ GeV$

$-0.8 \leq \eta \leq 0.8$



Big uncertainty associated to the FFS

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$\sqrt{s} = 200\ GeV$

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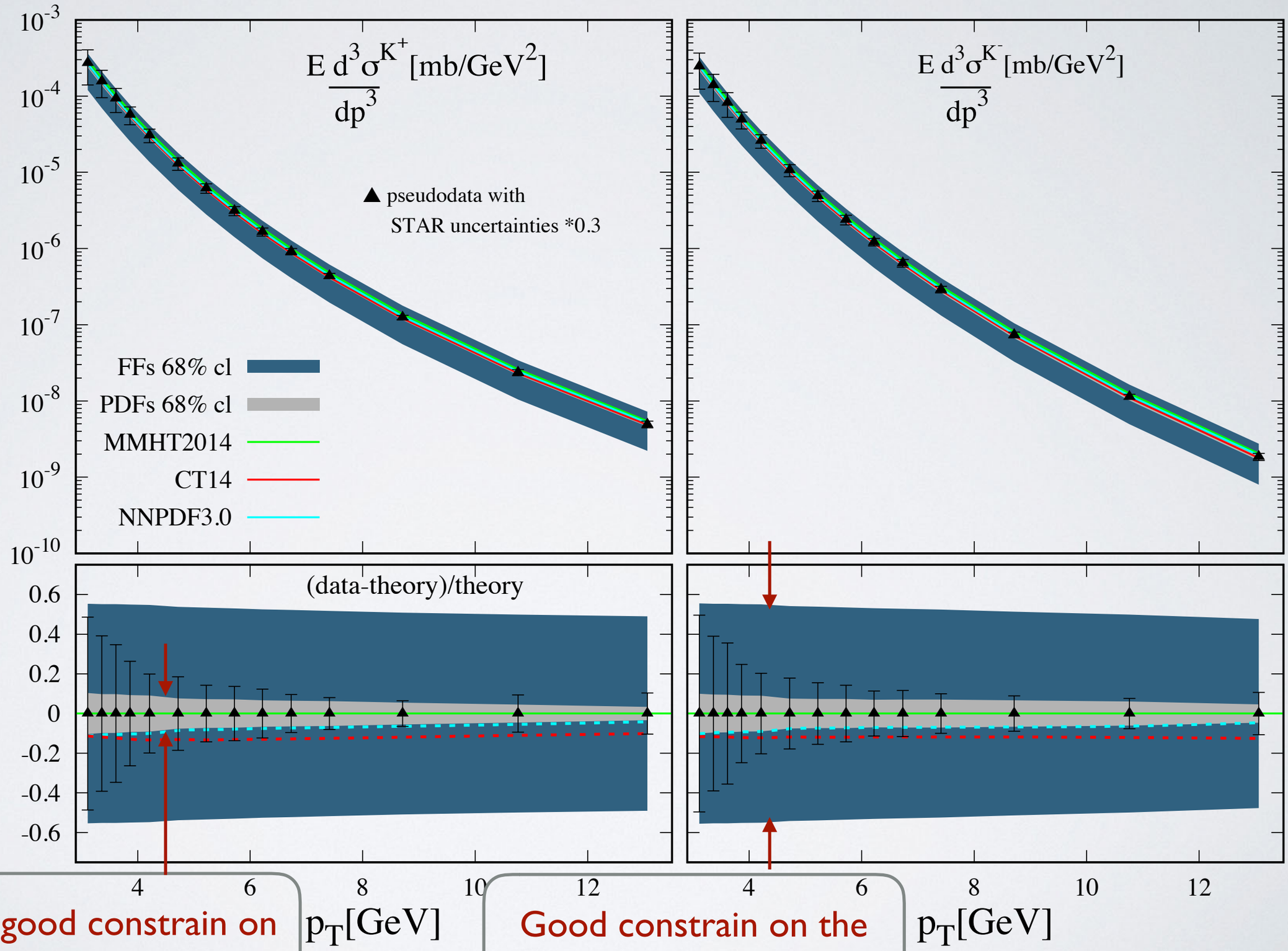


Big uncertainty associated to the FFS

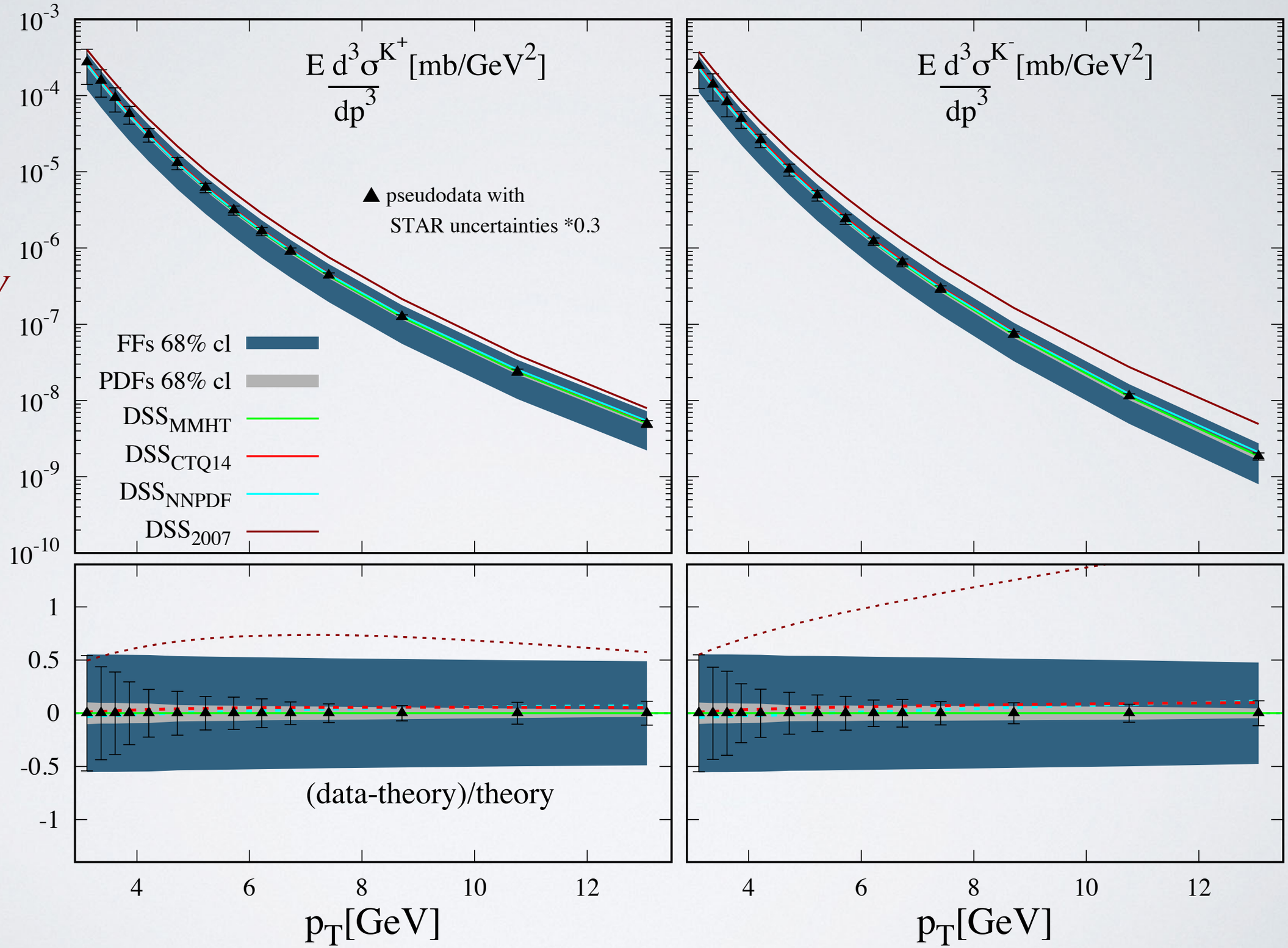
Not a good constrain on the PDFs

Good constrain on the FFs

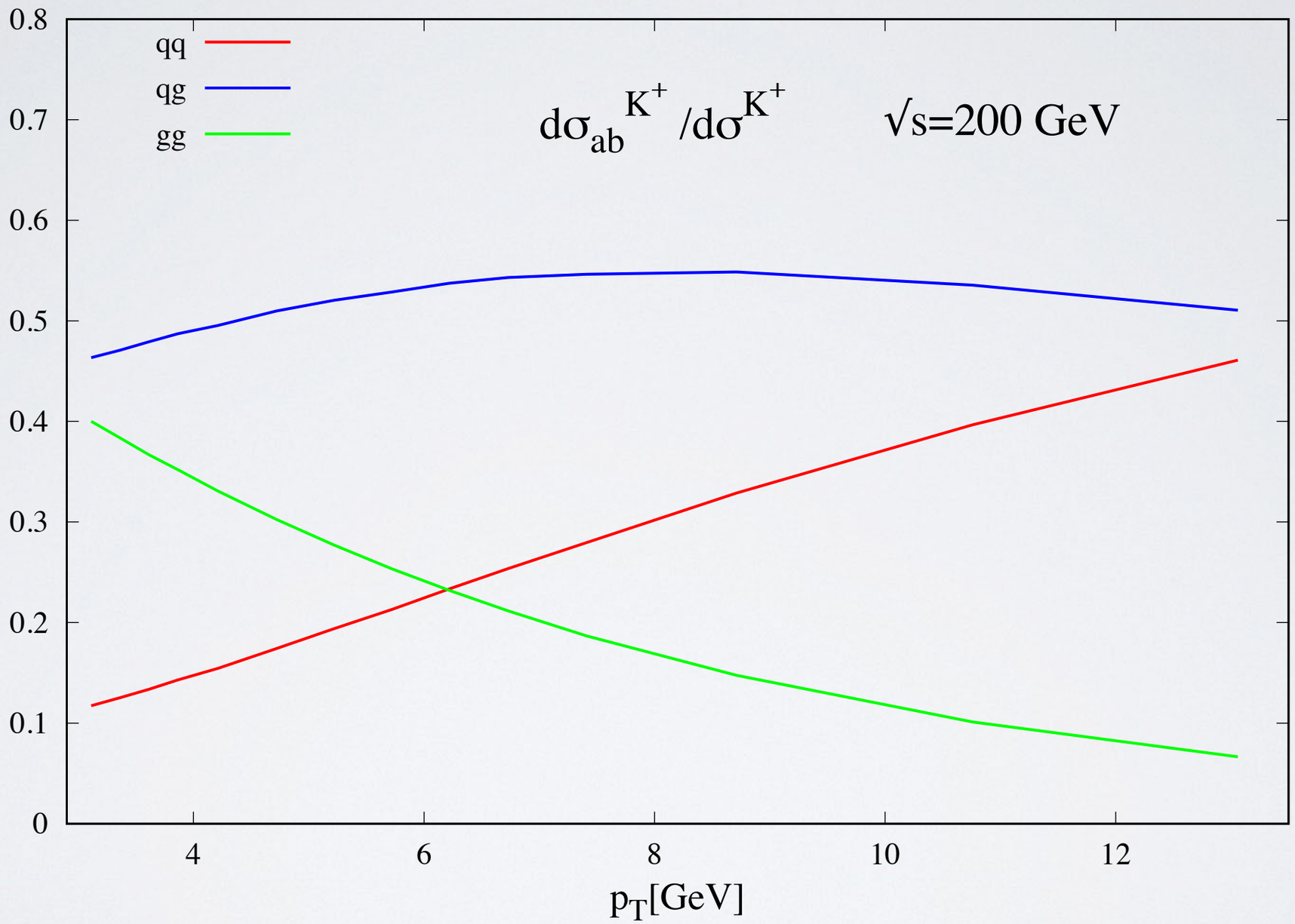
Can we repeat the same analysis for another semi-inclusive observable?

$\sqrt{s} = 200\ GeV$

$-0.8 \leq \eta \leq 0.8$



What distributions are we ***actually*** looking at?



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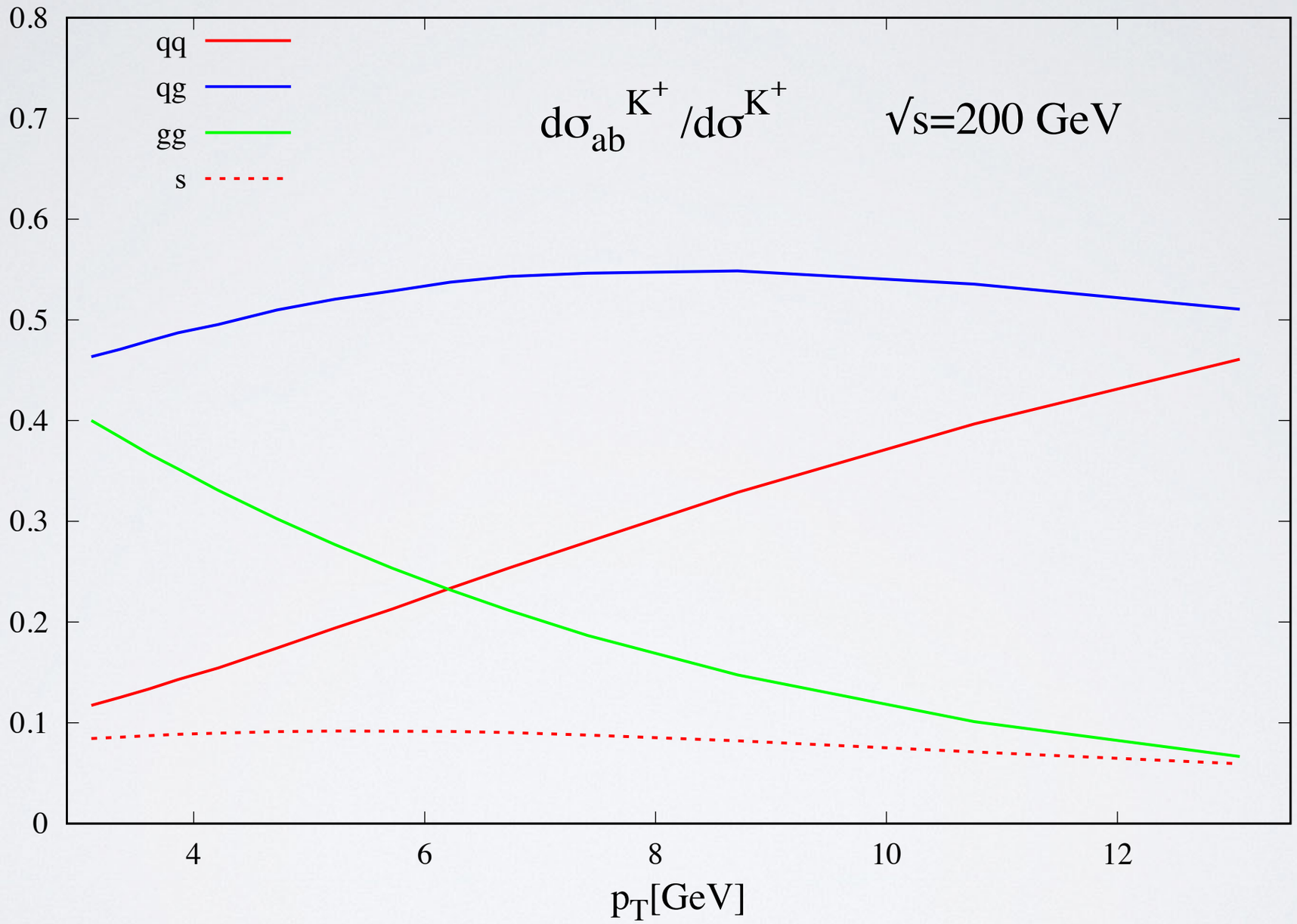

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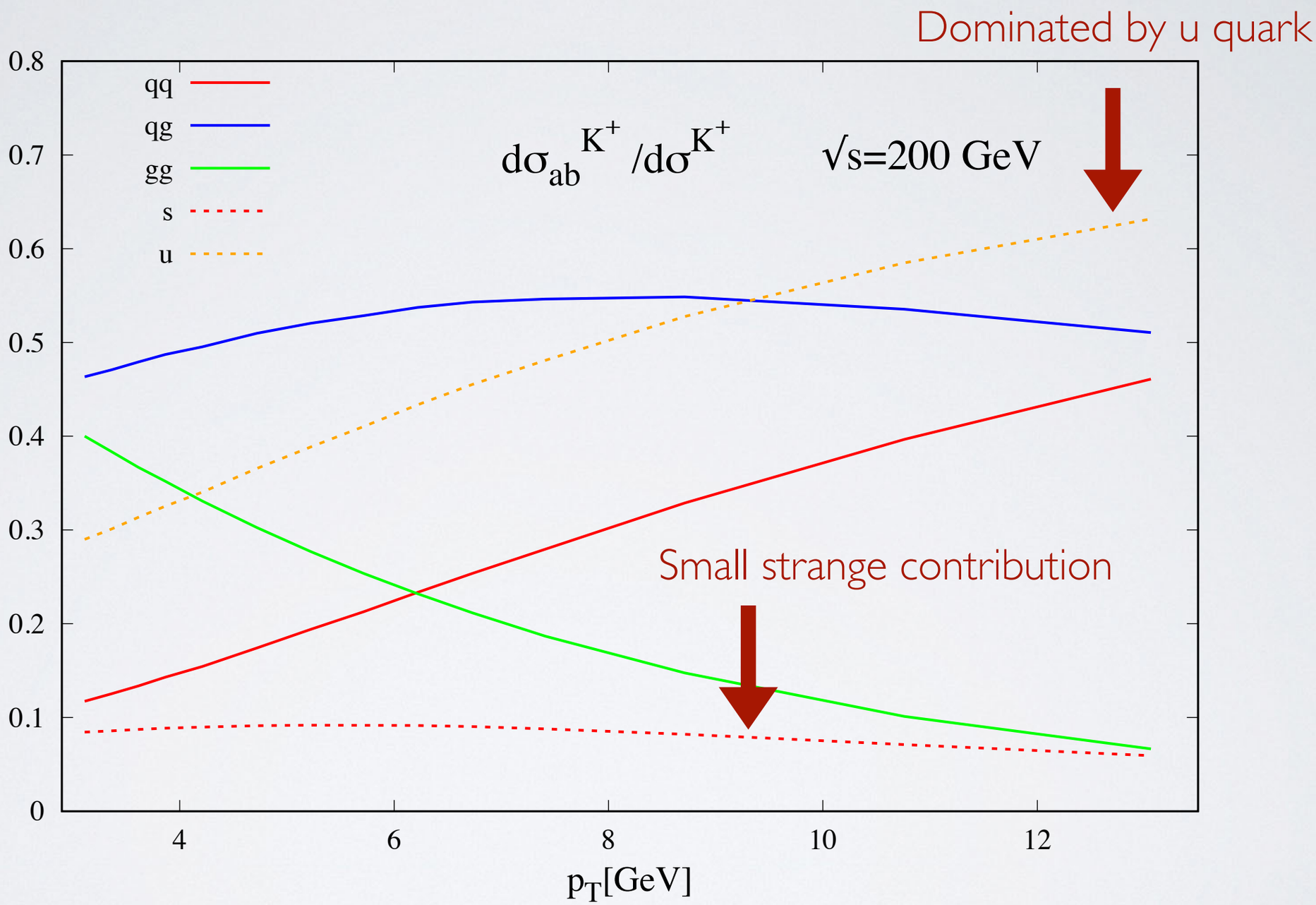
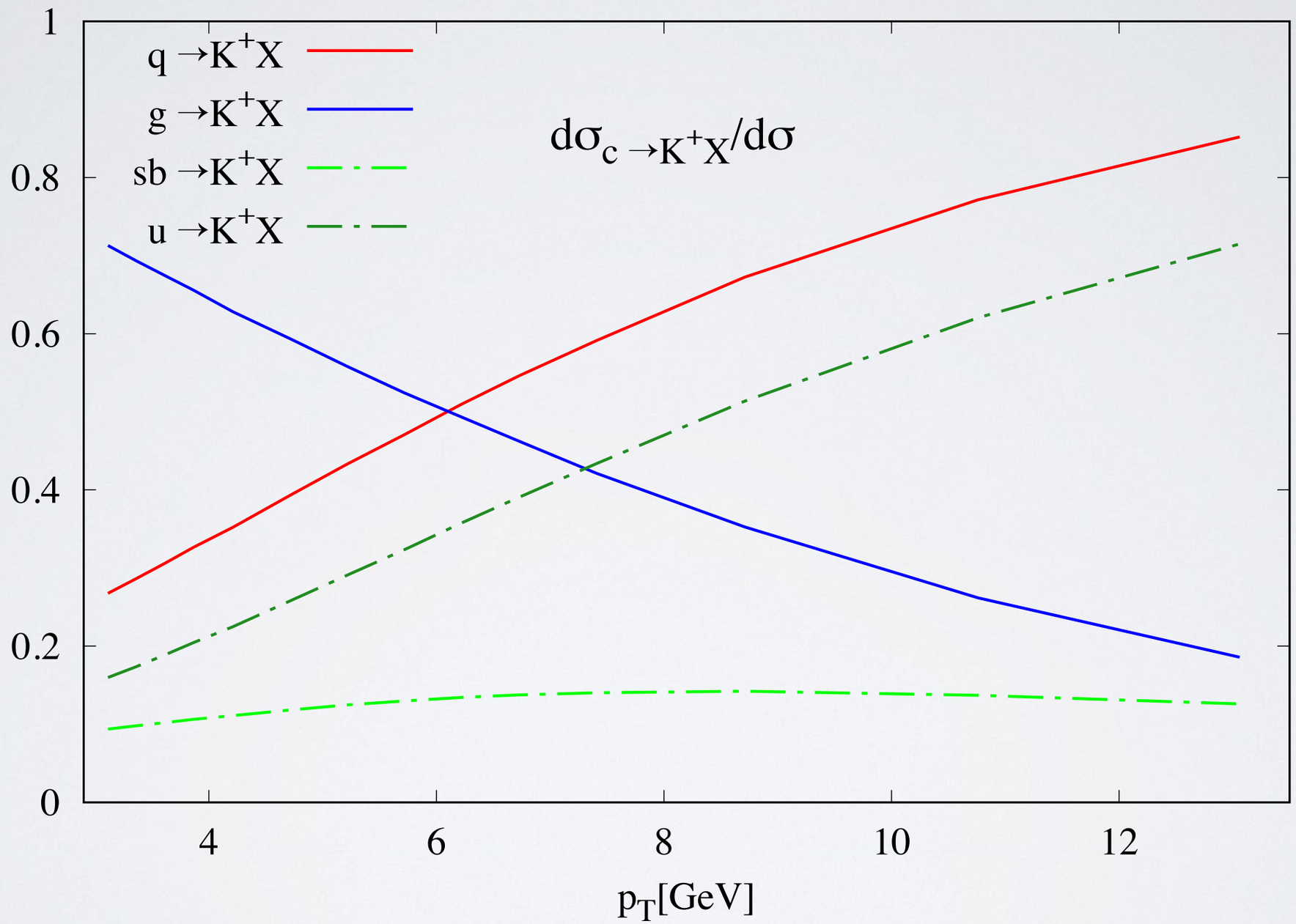


Small uncertainties associated to the PDFs

What distributions are we ***actually*** looking at?



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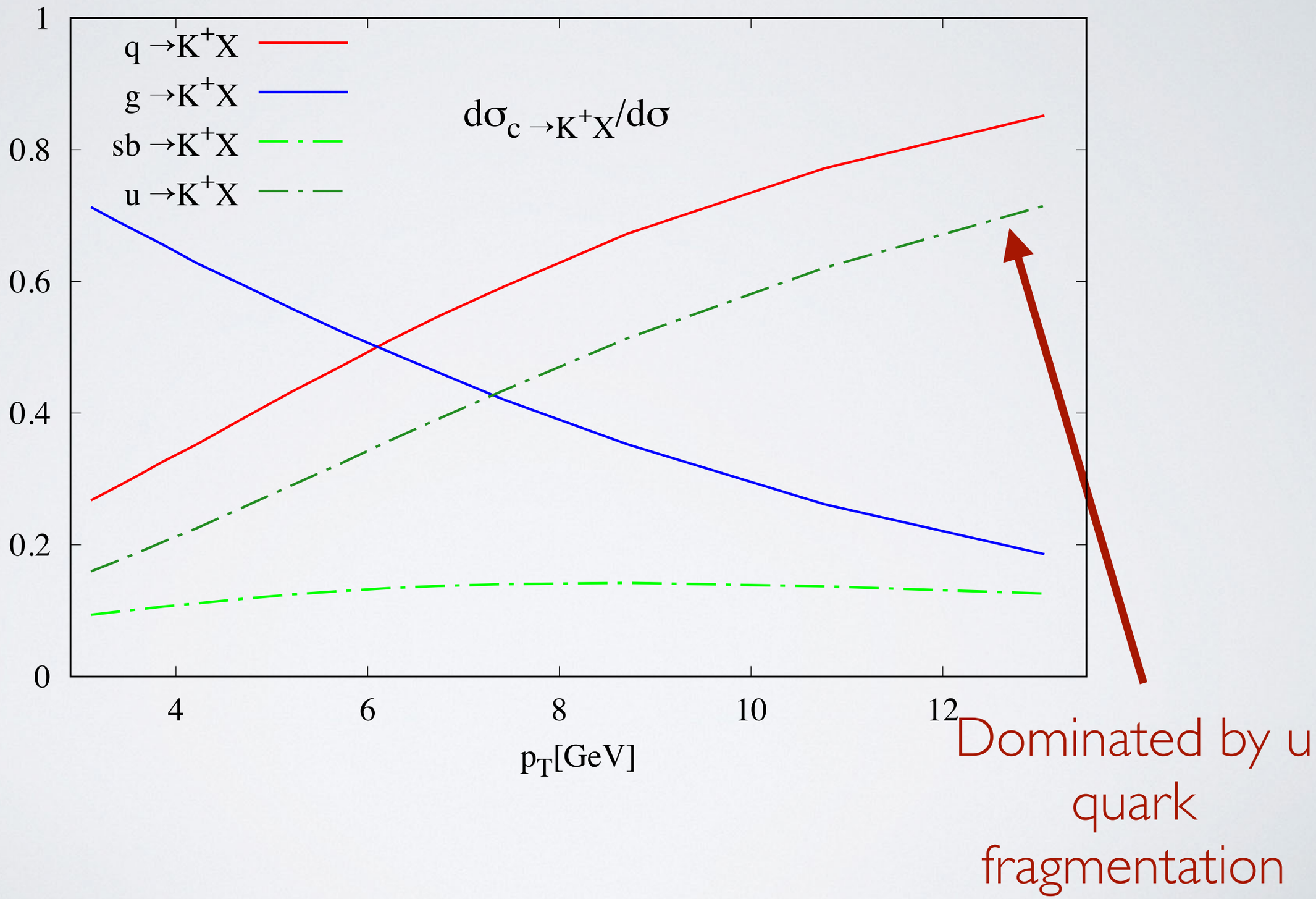

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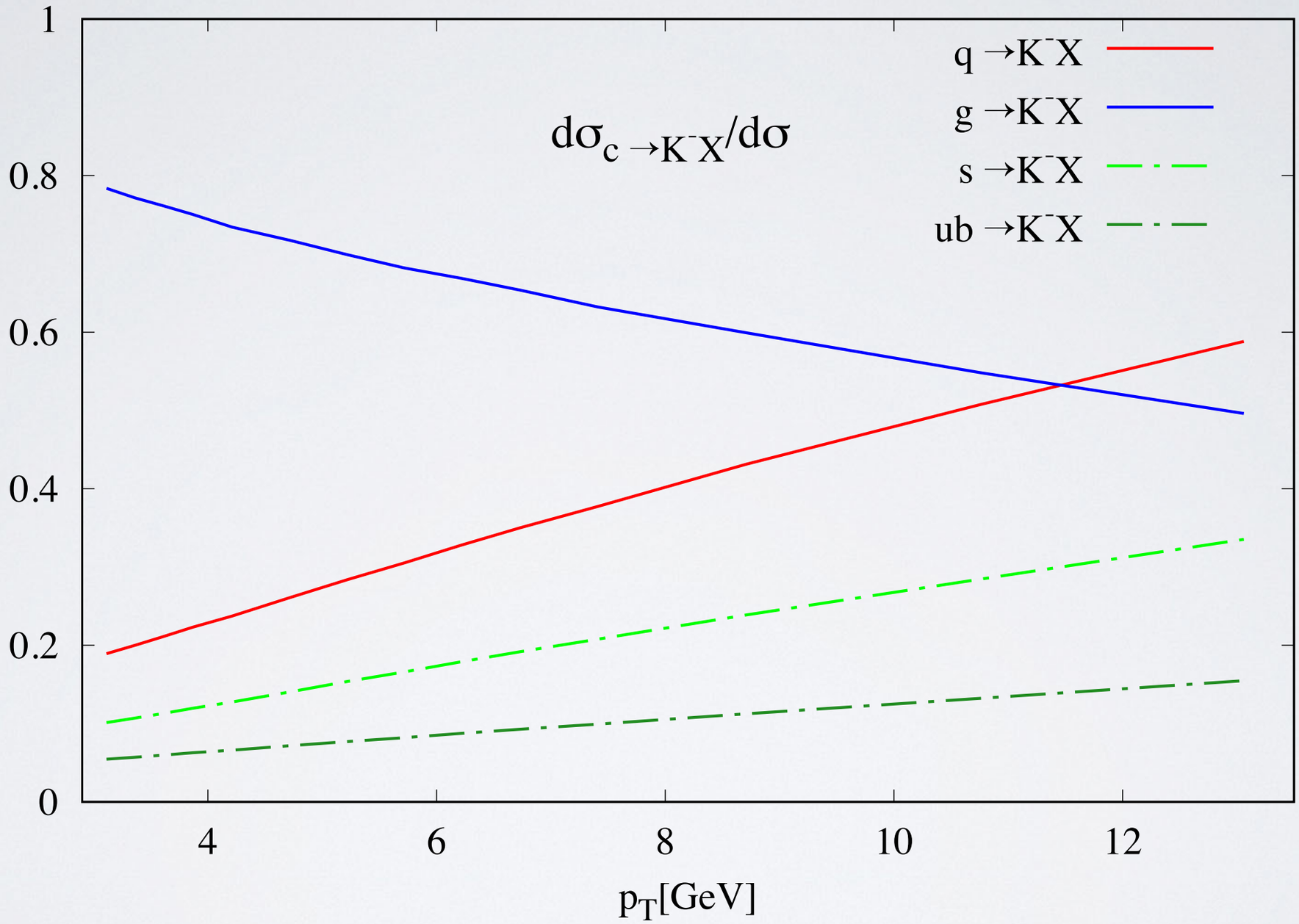

Great to probe $D_s^K(z)$ & $D_g^K(z)$

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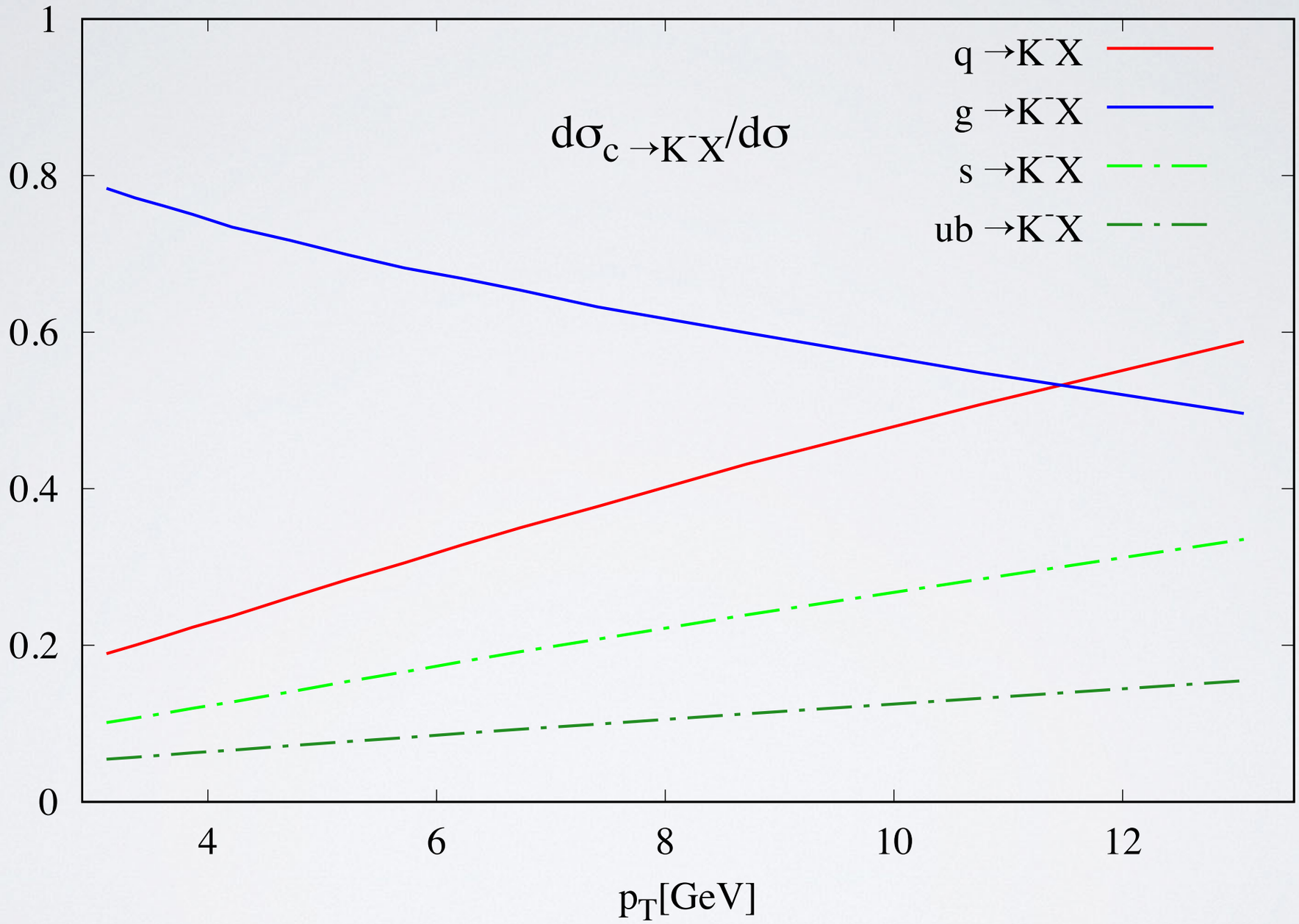
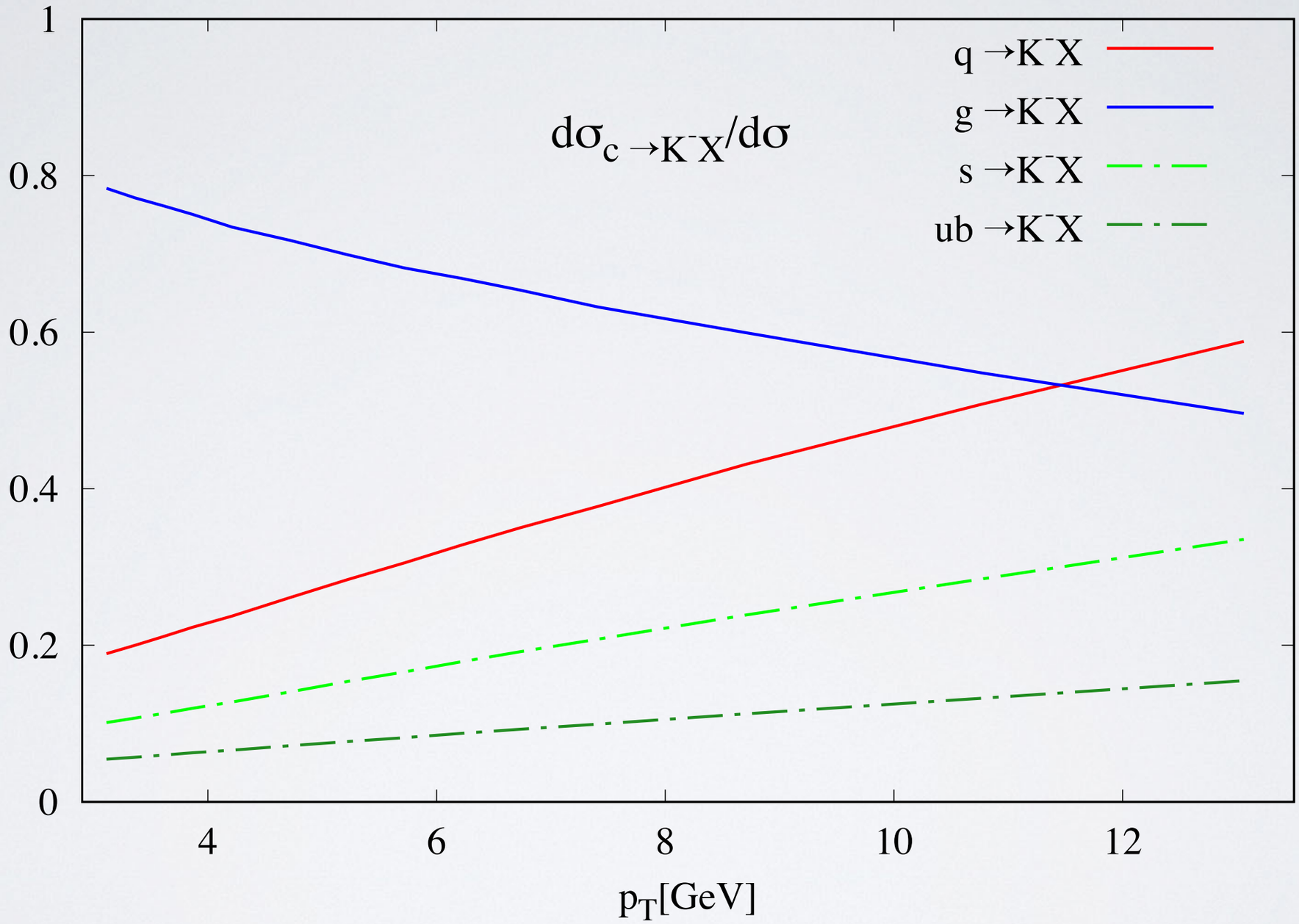


Great to probe $D_s^K(z)$ & $D_g^K(z)$

Modified PDFs through SIDIS reweighing

What distributions are we ***actually*** looking at?

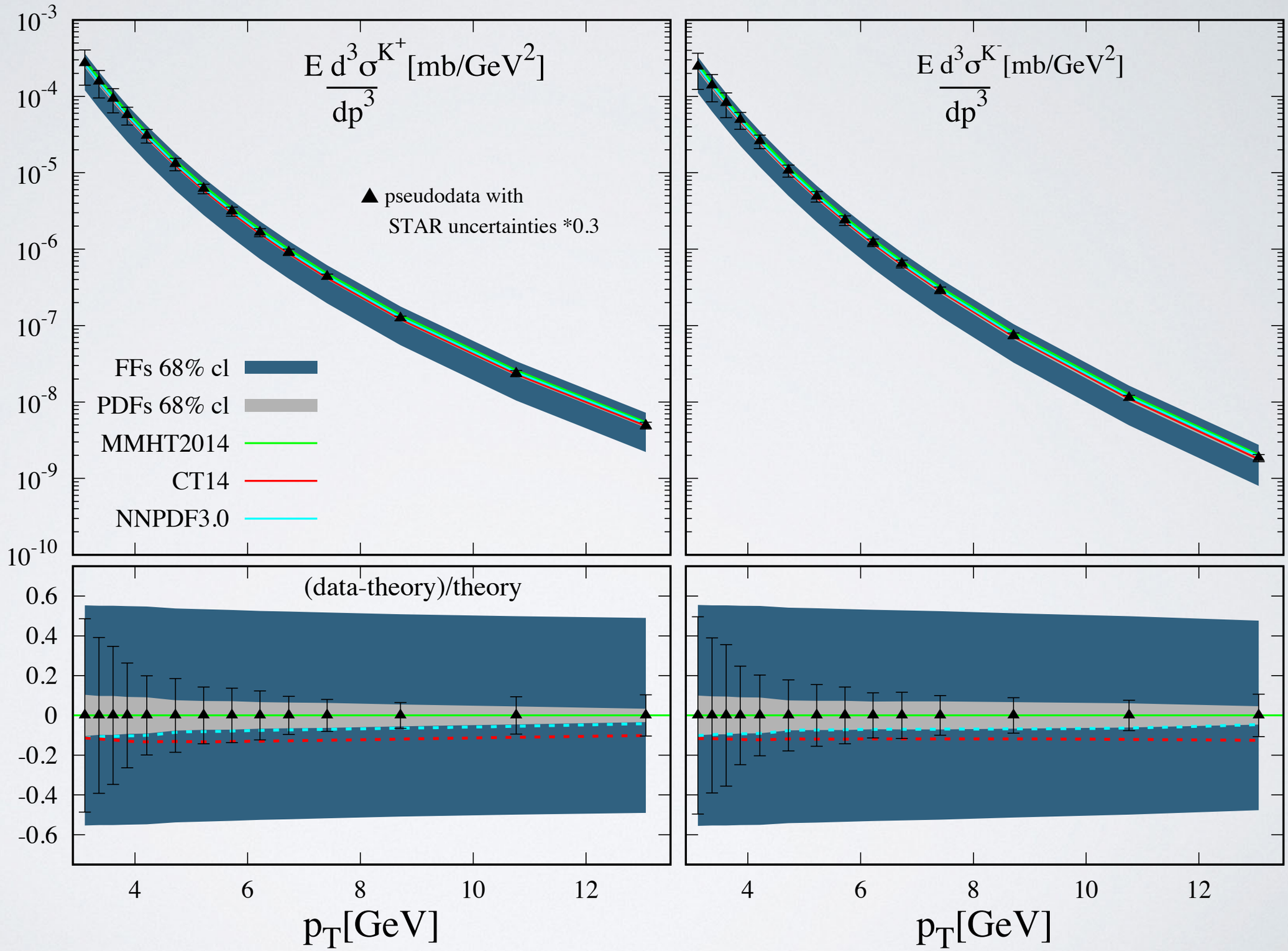


Easy to extend to nuclear distributions to probe nuclear effects on pDFs & FFs

Future STAR data

$\sqrt{s} = 200\ GeV$

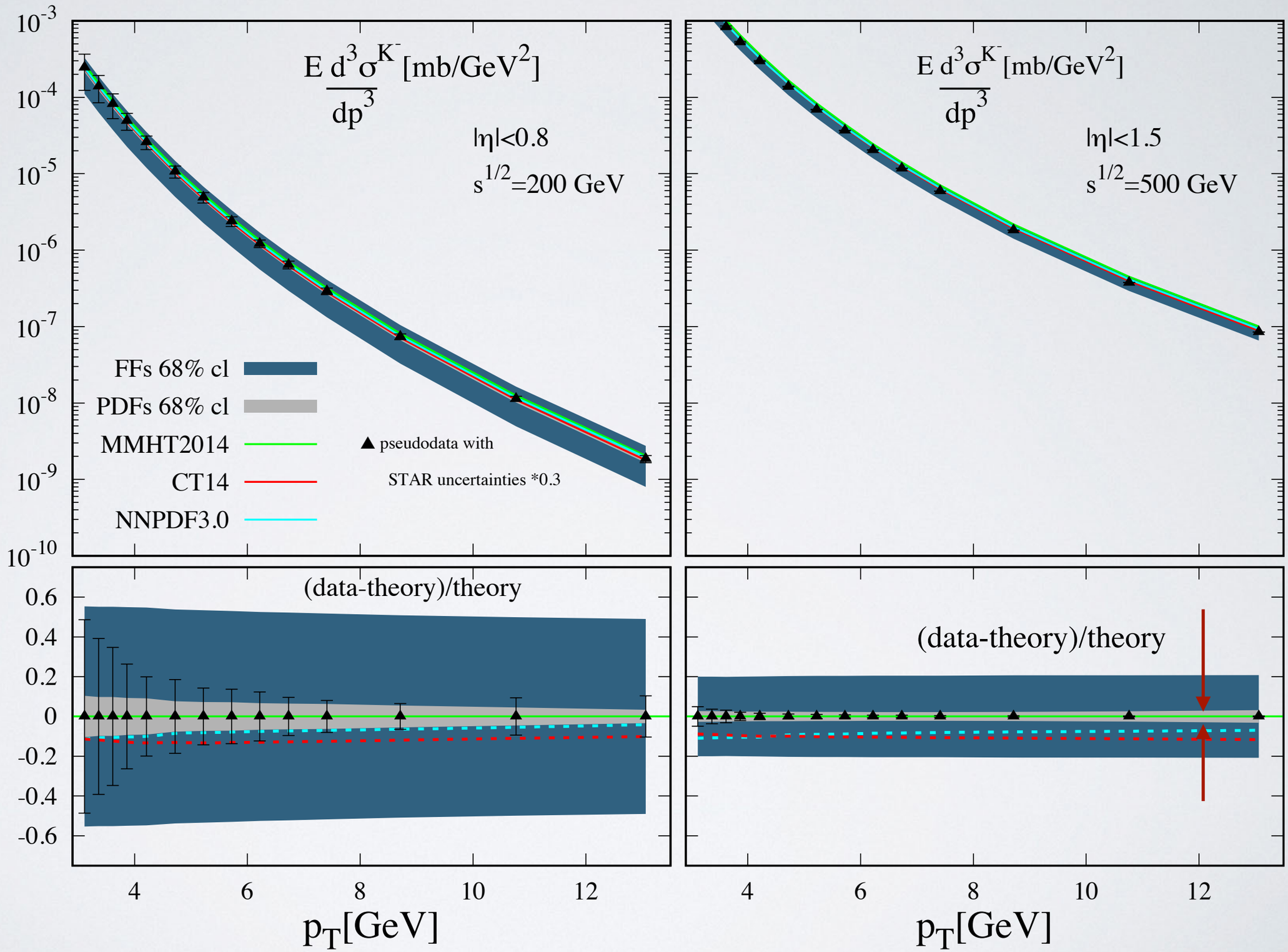
$-0.8 \leq \eta \leq 0.8$



Future STAR data

$\sqrt{s} = 500\ GeV$

$-1.5 \leq \eta \leq 1.5$



SIDIS AT EIC

In collaboration with E. Aschenauer, R. Sassot & C. Van Hulse

SIDIS AT EIC

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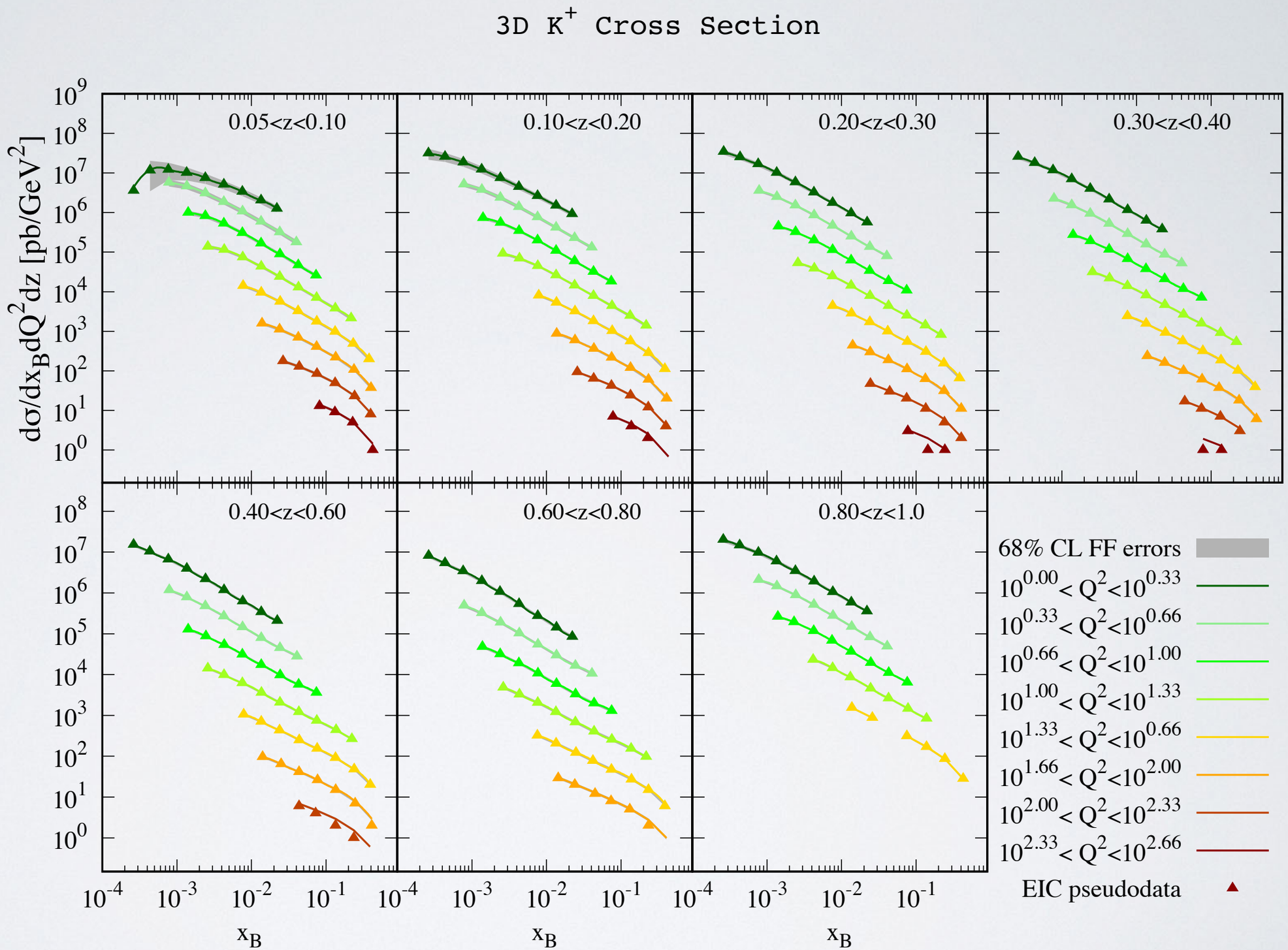
SIDIS pseudodata
Ee= 15 GeV
Ep=100 GeV



SIDIS AT EIC

In collaboration with E. Aschenauer, R. Sassot & C. Van Hulse

SIDIS pseudodata
Ee= 15 GeV
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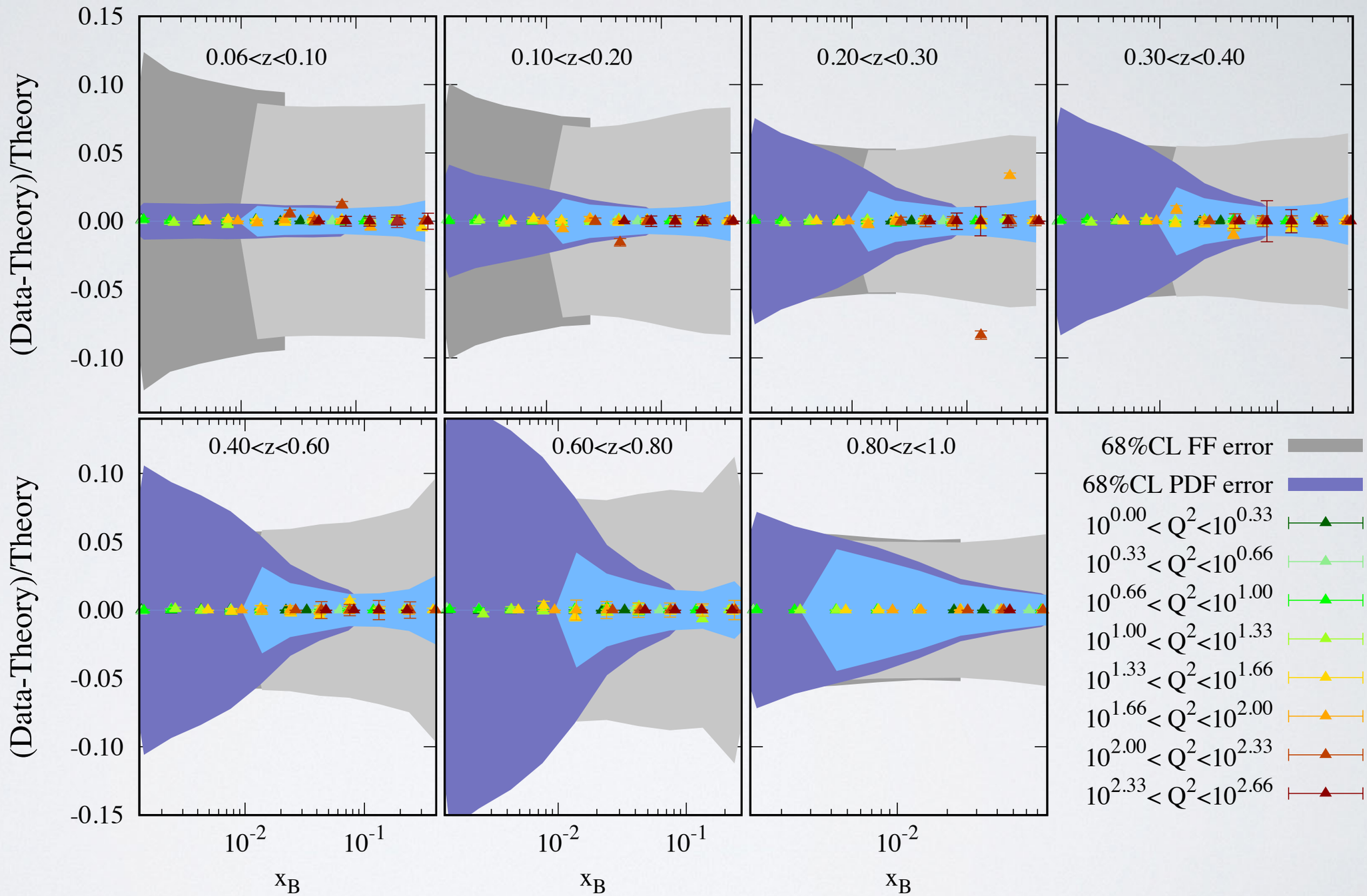
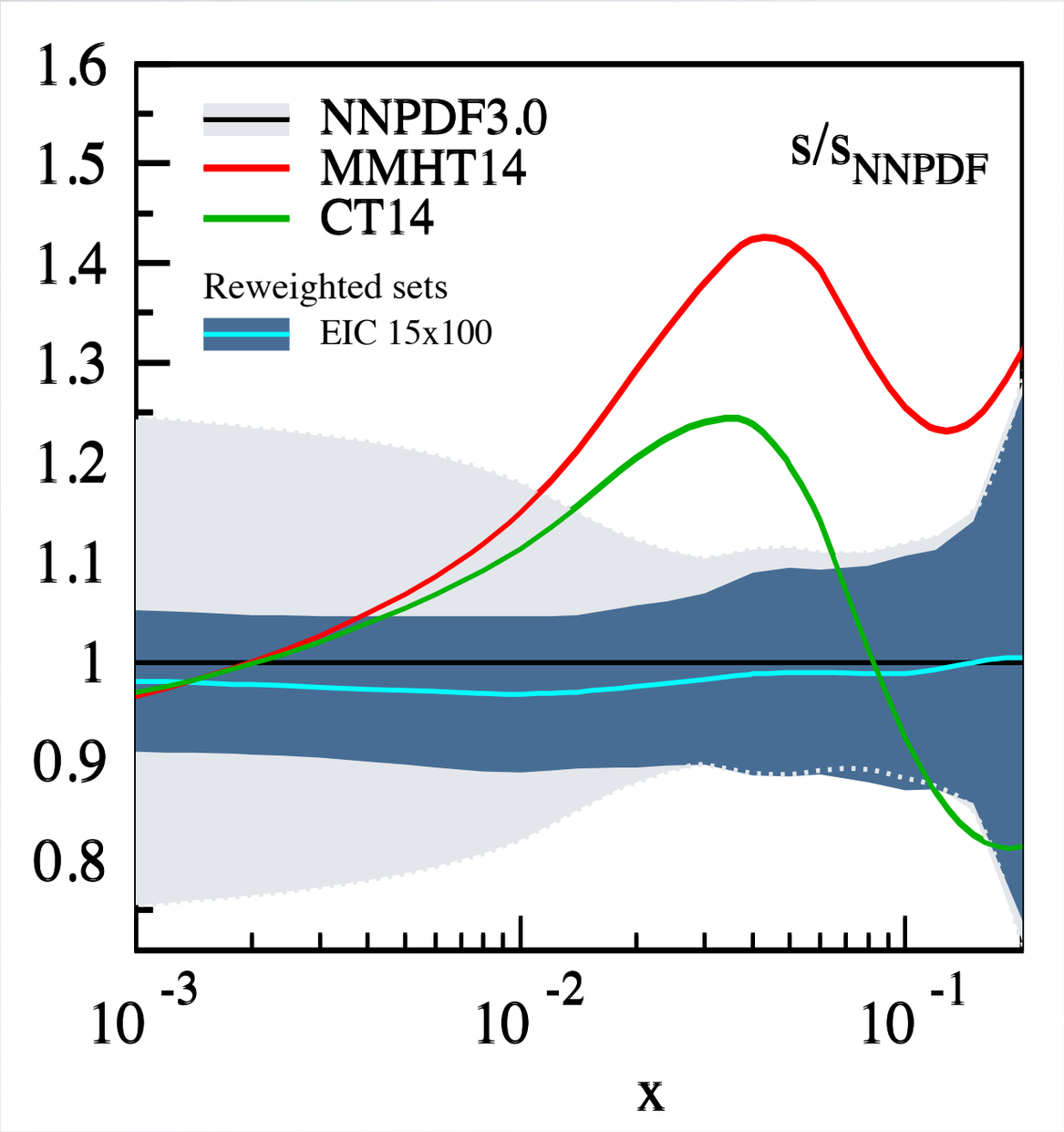
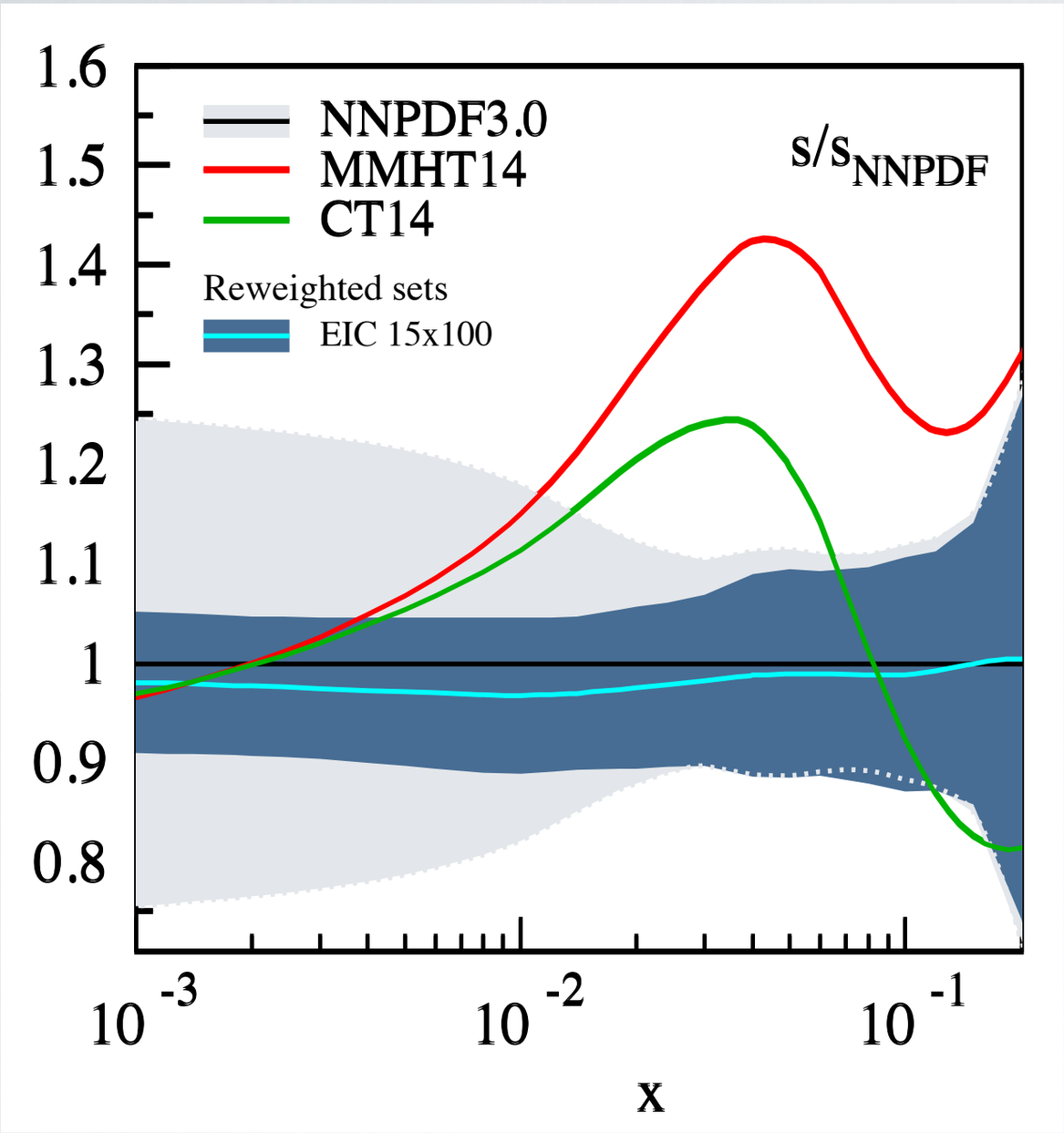
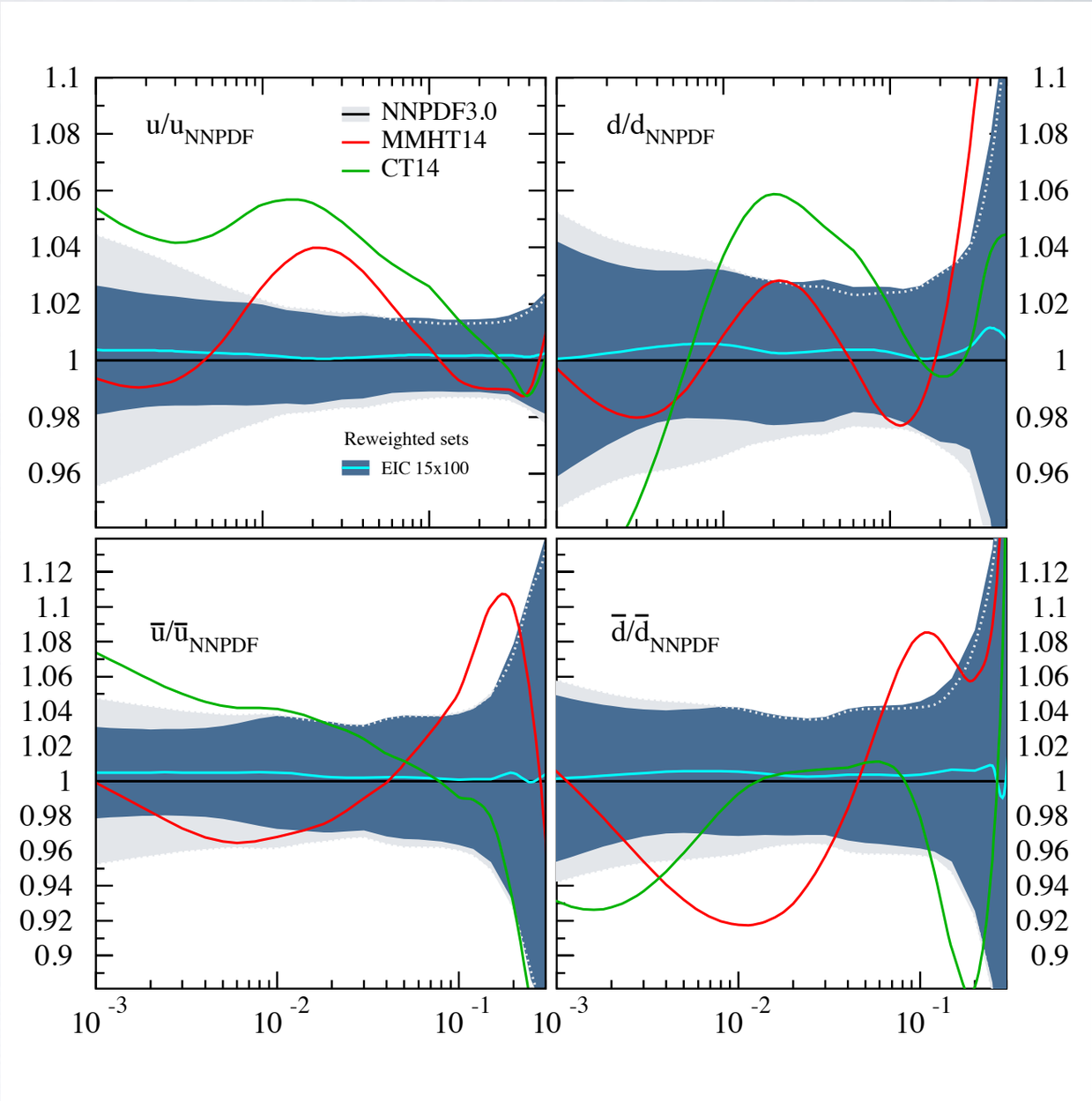


SIDIS AT EIC


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





Great tool to probe:

- the strange content of the proton
- Isospin and charge asymmetry
- Nuclear effects on PDFs and FFs

SUMMARY

- **The combined extraction of PDFs & FFs** :
    - strong constrains on the strange sea of the proton
    - The method proved to be robust
- **RHIC data for charged kaon production** expected to provide an important constrain on the strange FFs:

New insights on the

- Proton's strange content
- Charge (& isospin) symmetry breaking
- Nuclear effects on PDFs & FFs

THANK YOU!