JAM19: strange quark suppression from a simultaneous global fit of PDFs and FFs

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arXiv:1905.03788 [hep-ph]

Jefferson Lab Angular Momentum Collaboration

Jefferson Lab EXPLORING THE NATURE OF MATTER

JAM19

What is JAM19?

First **simultaneous** analysis of **unpolarized** PDFs and FFs

Why JAM19?

To study the **strange** quark distribution

Motivation

- Knowing the limits in x and Q^2 of collinear factorization
- Testing the universality of PDFs ,FFs…
- All the data must be studied using the **same** theoretical framework
- First step: (first) **simultaneous** analysis of **unpolarized** PDFs and

FFs $\longrightarrow$ **Strange** quark distribution

Motivation II

- The strange PDF is less known than the non-strange light flavors

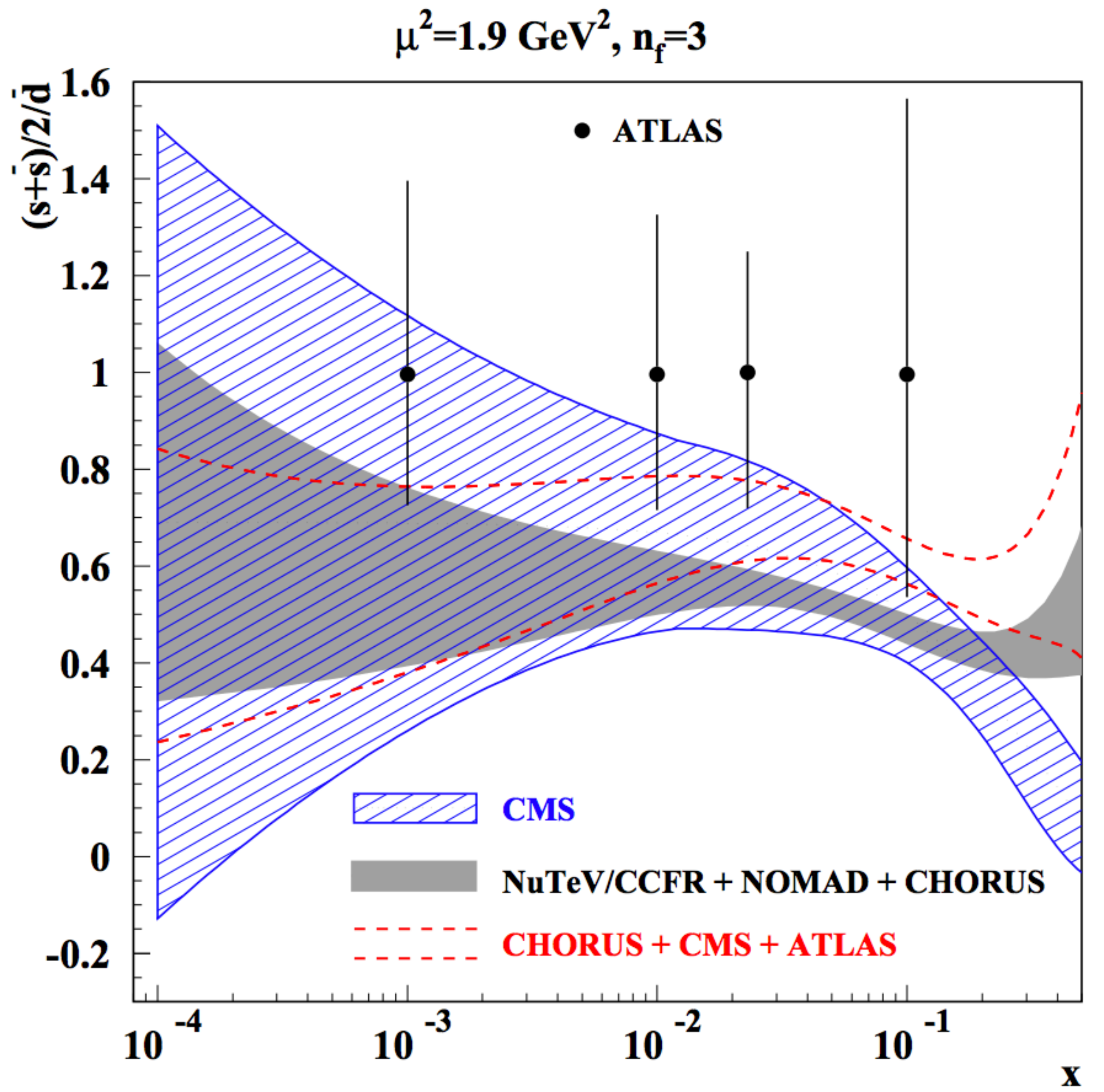
- Traditionally: neutrino-(heavy) nucleus DIS data used to extract the strange PDF.
    - Drawbacks: nuclear effects on PDFs.

- W and Z inclusive production in p-p collisions also sensitive to flavor separation
    - Drawbacks: tension between CMS and ATLAS results?

Motivation II

Alhekin et al. arXiv:1404.6469 [hep-ph]

$r_s =$



Why don't we use SIDIS?

Setup: data

$$W^2 > 10\,\mathrm{GeV}^2$$

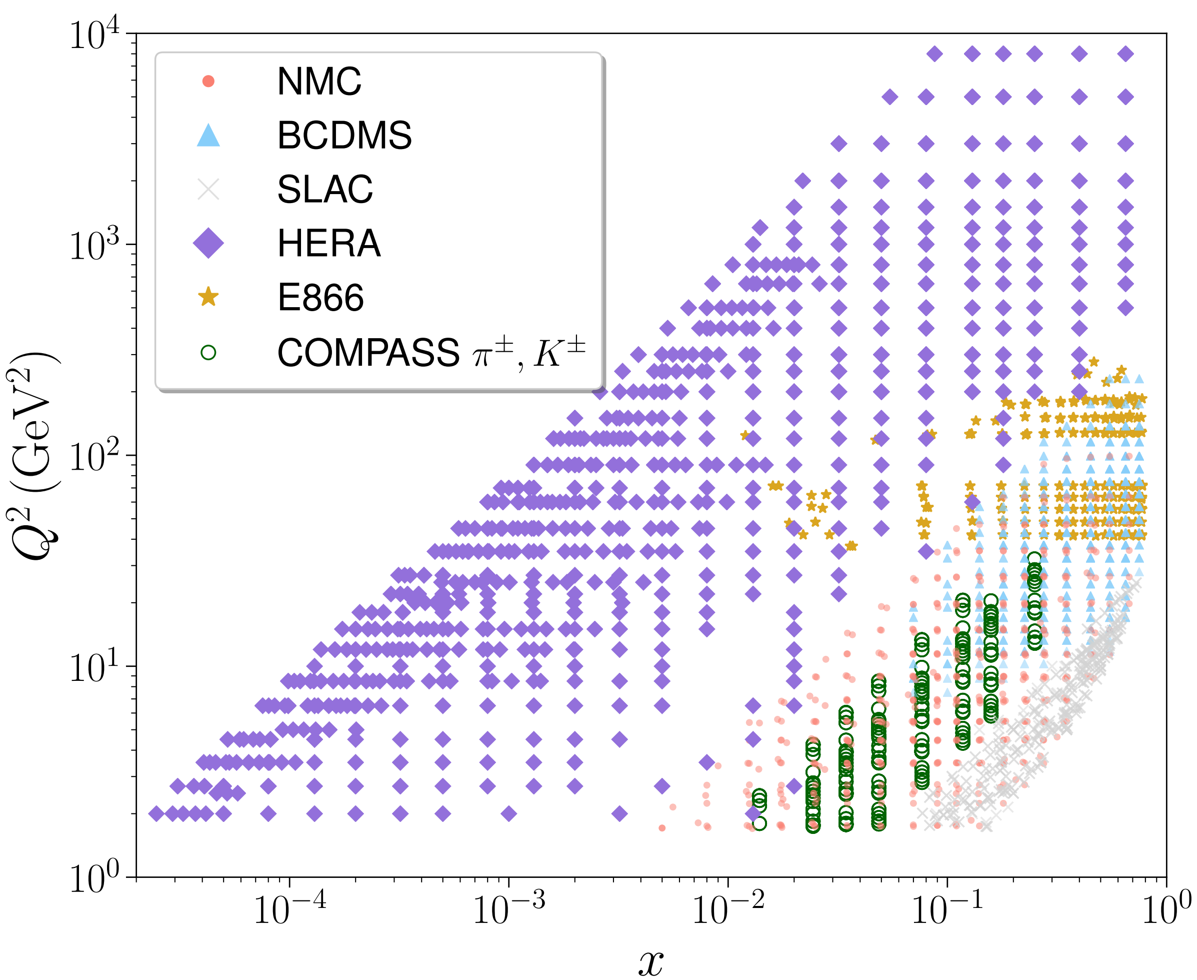
$$Q^2 > \mathrm{m}_c^2$$

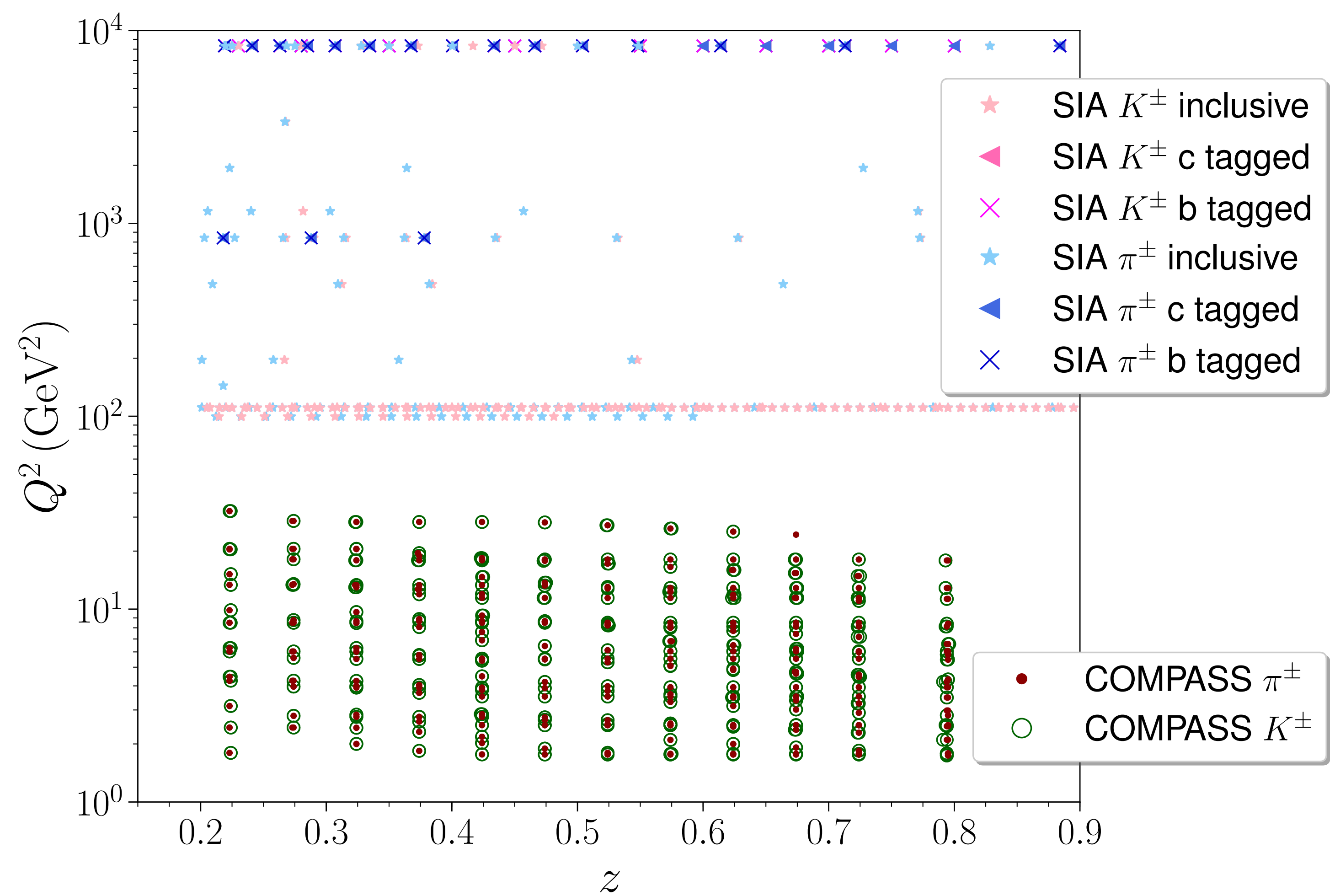
$$\mathrm{DIS} : l + (p, d) \to l' + X$$

$$\mathrm{DY} : l + (p, d) \to l\bar{l} + X$$

$$\mathrm{SIDIS} : l + d \to l' + h + X$$

$$\mathrm{SIA} : e^+ + e^- \to h + X$$





Setup: theory

- All observables computed at NLO in pQCD
- DGLAP truncated evolution at order α_s in Mellin space
- DIS/SIDIS/SIA cross sections computed at leading twist
- Nuclear smearing for deuterium DIS
- Heavy quark treatment : ZM-VFN
- Fitting methodology:
  - MC (multi-steps), k-means clustering, extended reduced χ^2

Why MC?

$$\chi^2 = \sum_{e}^{N_{exp}} \sum_{i}^{N_{data}} \frac{(D_i^e - T_i)^2}{(\sigma_i^e)^2}$$

- Typical PDF parametrization:

$$x\Delta f(x) = Nx^a(1-x)^b(1+c\sqrt{x}+dx)$$

- Perform single χ^2-fit: $\longrightarrow$ Multiple local minima!

Parameters difficult to constrain

Hessian method for uncertainties $\longrightarrow$ Introduces tolerance criteria

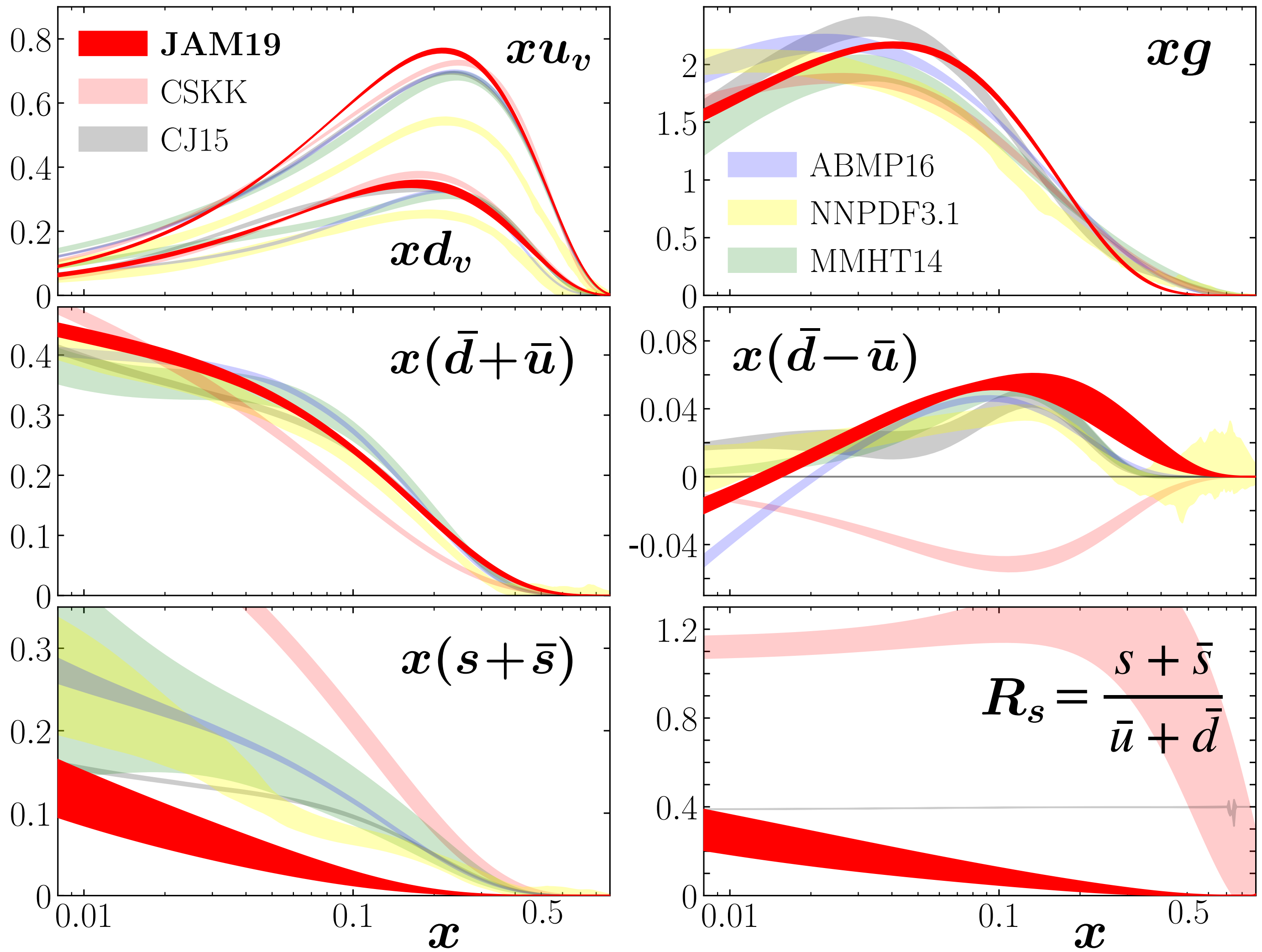
Unsuitable for simultaneous analysis of collinear distributions

- Monte Carlo methods:
  - Allows efficient exploration of the parameter space
  - Uncertainties directly obtained from MC replicas

PDF results

JAM19 PDFs

arXiv:1905.03788 [hep-ph]



$DIS(p, d)$

$DY(pp, pd)$

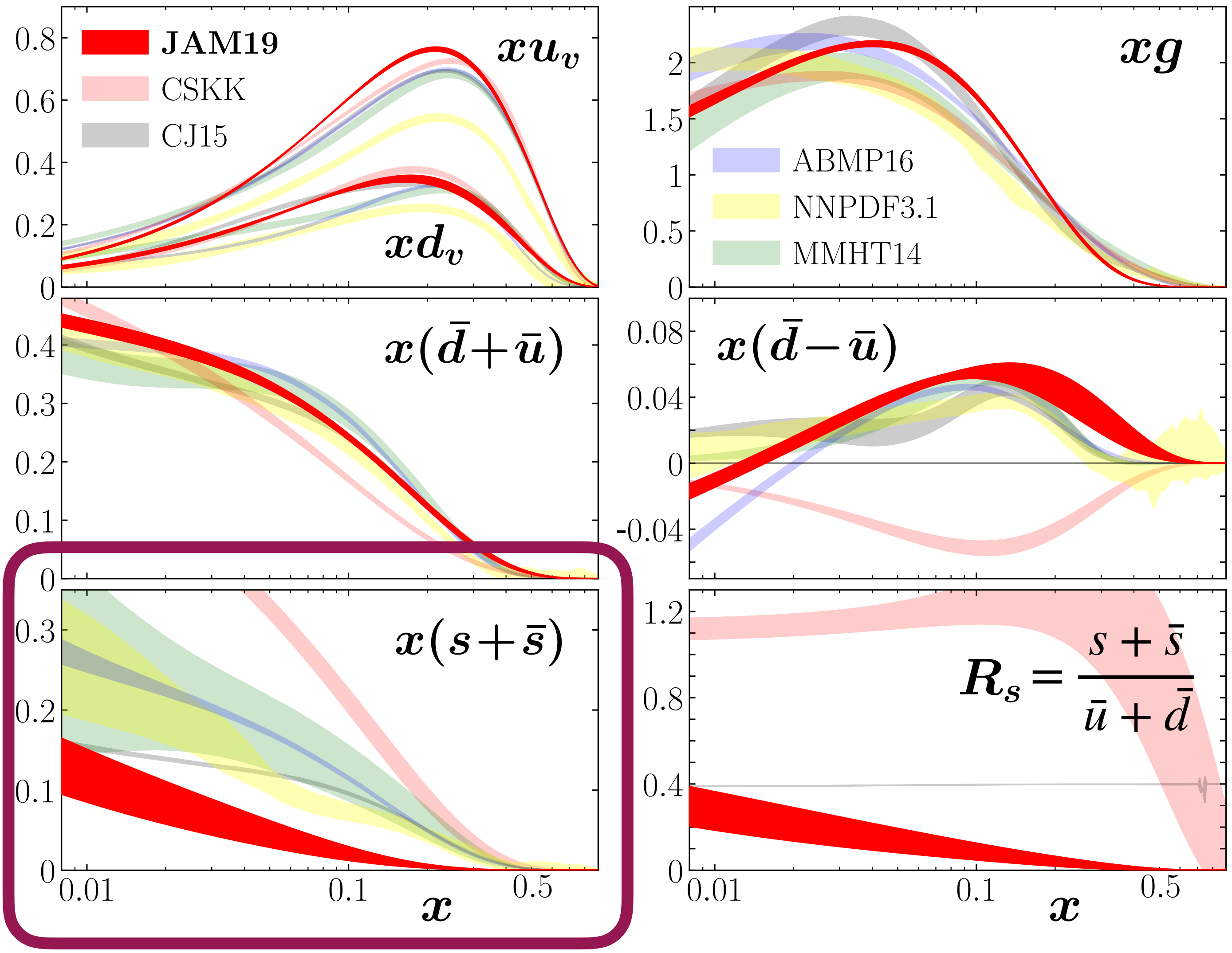
$SIA(\pi^{\pm}, K^{\pm})$

$SIDIS(\pi^{\pm}, K^{\pm})$

Q = m$_c$

JAM19 PDFs

arXiv:1905.03788 [hep-ph]



$\mathrm{DIS}(p, d)$
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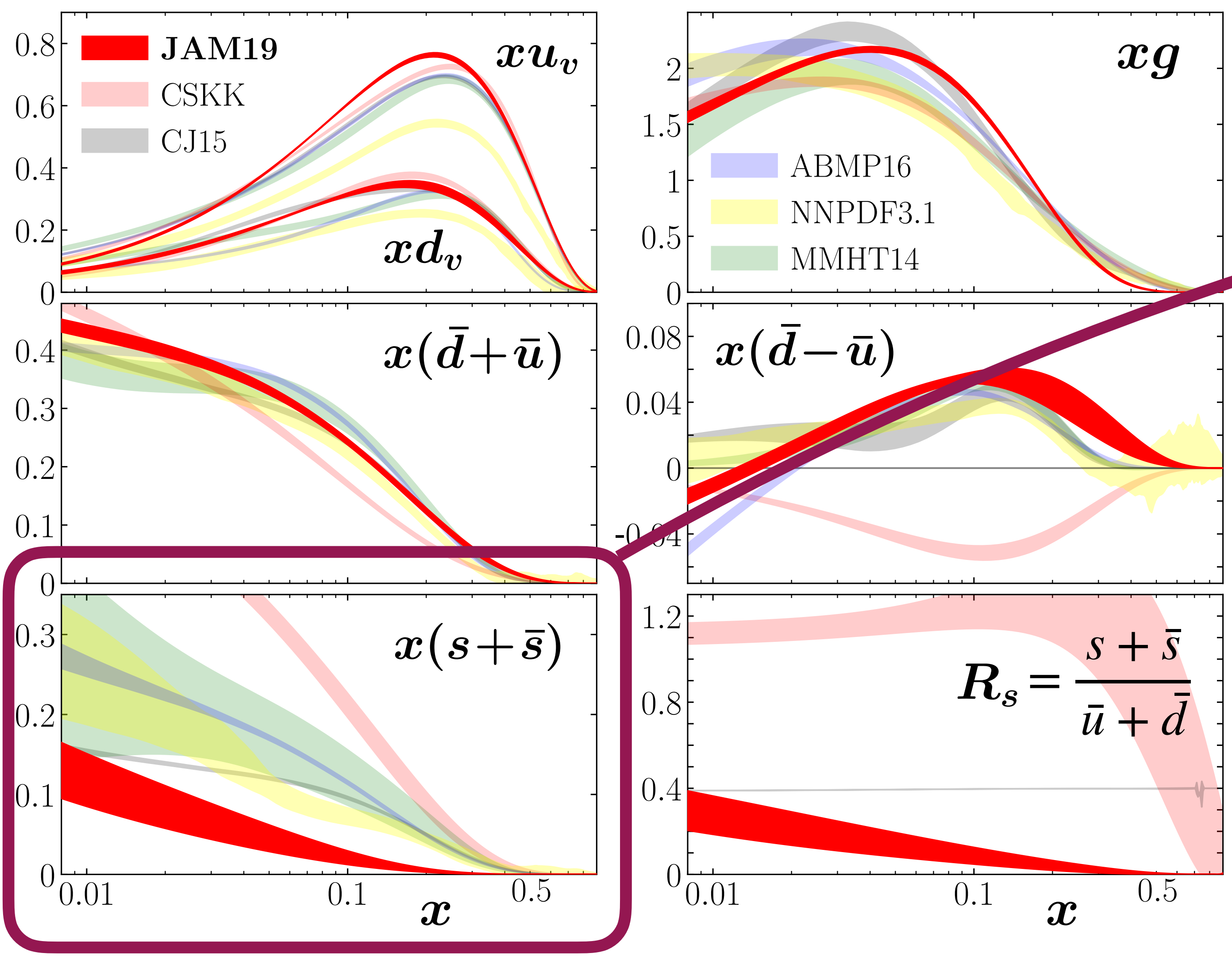

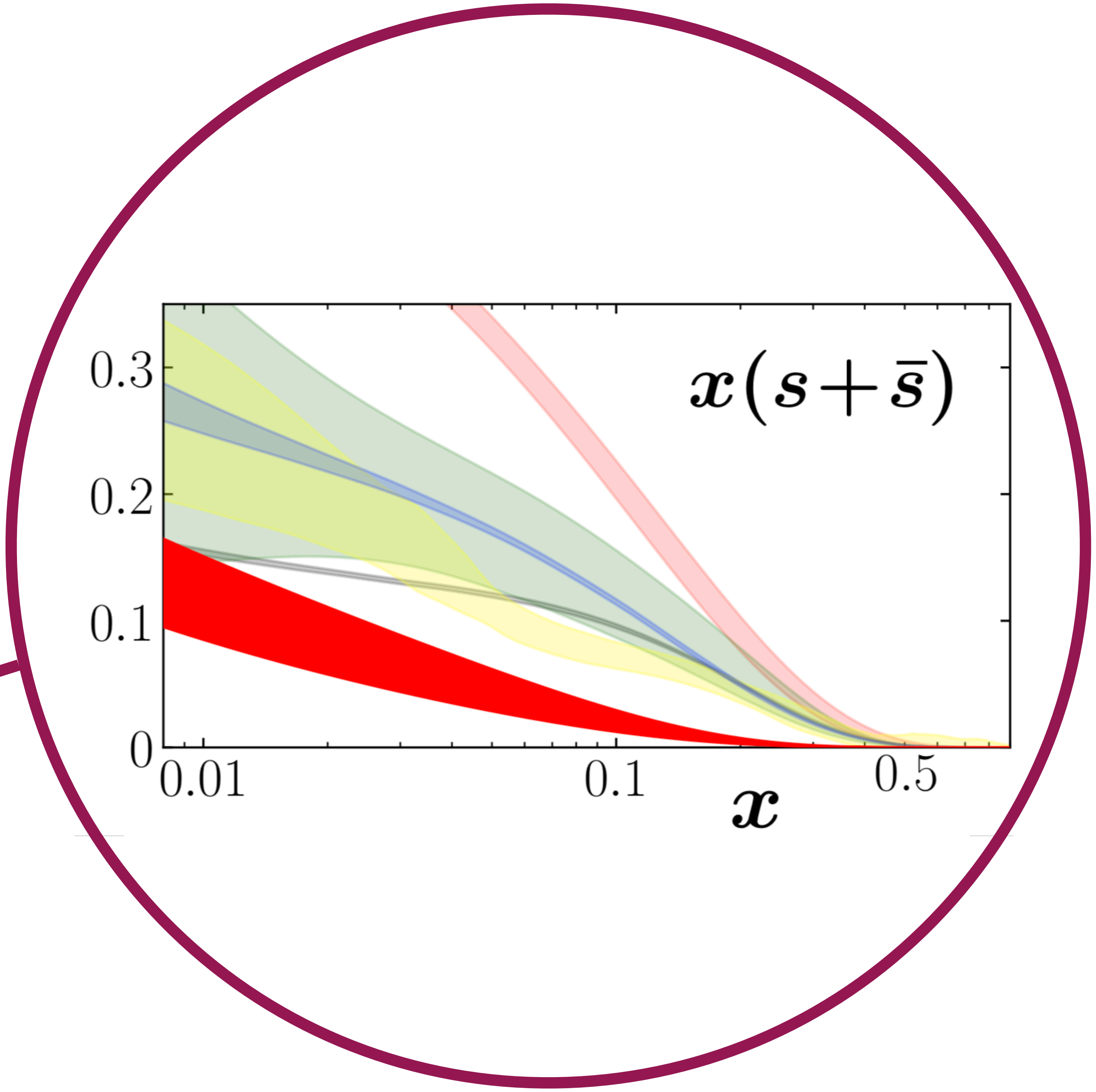

Strong strange suppression

$Q = m_c$

DIS(p, d)
DY(pp, pd)
SIA$(\pi^{\pm}, K^{\pm})$
SIDIS$(\pi^{\pm}, K^{\pm})$

JAM19 PDFs

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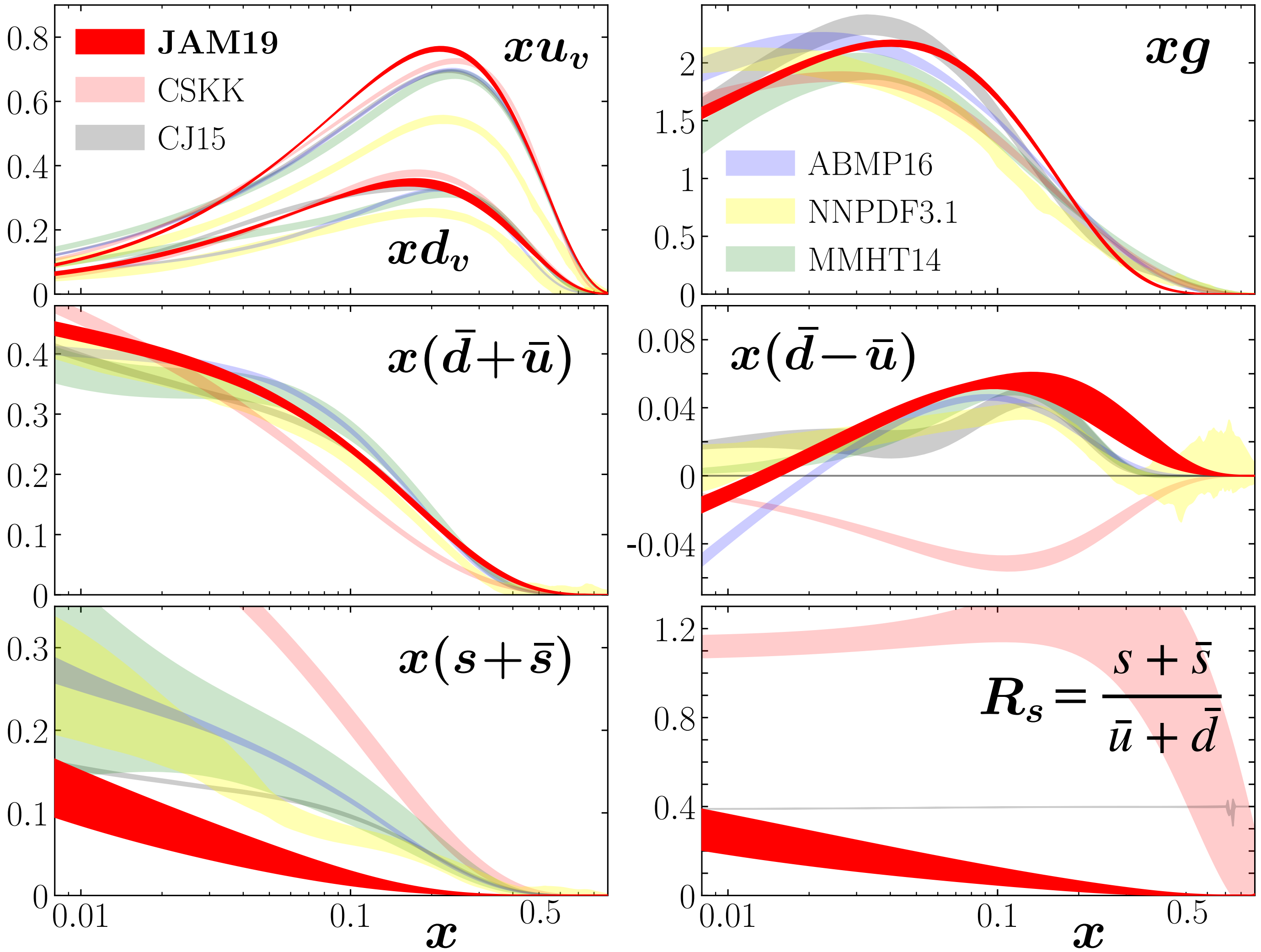

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JAM19 PDFs

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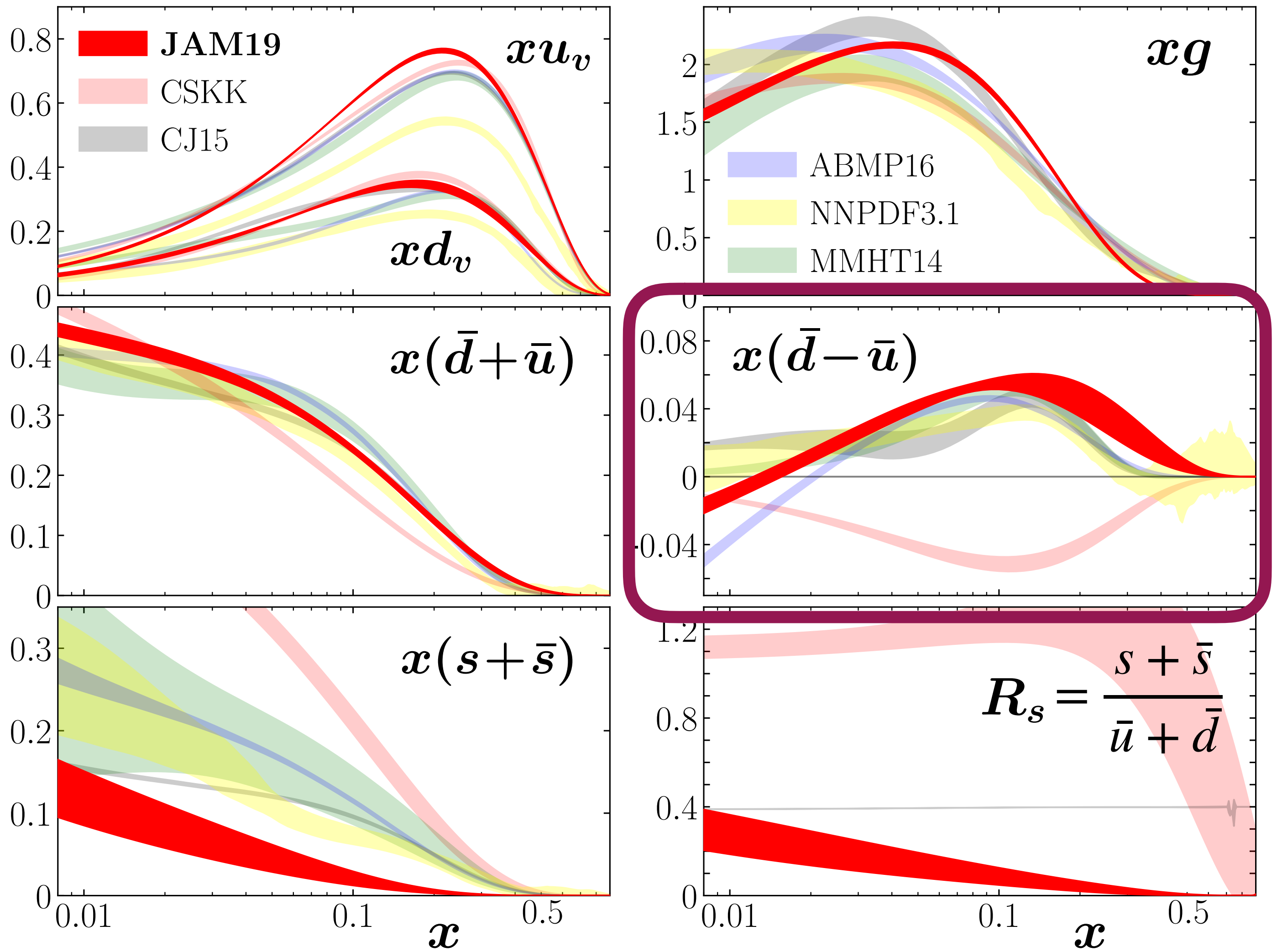

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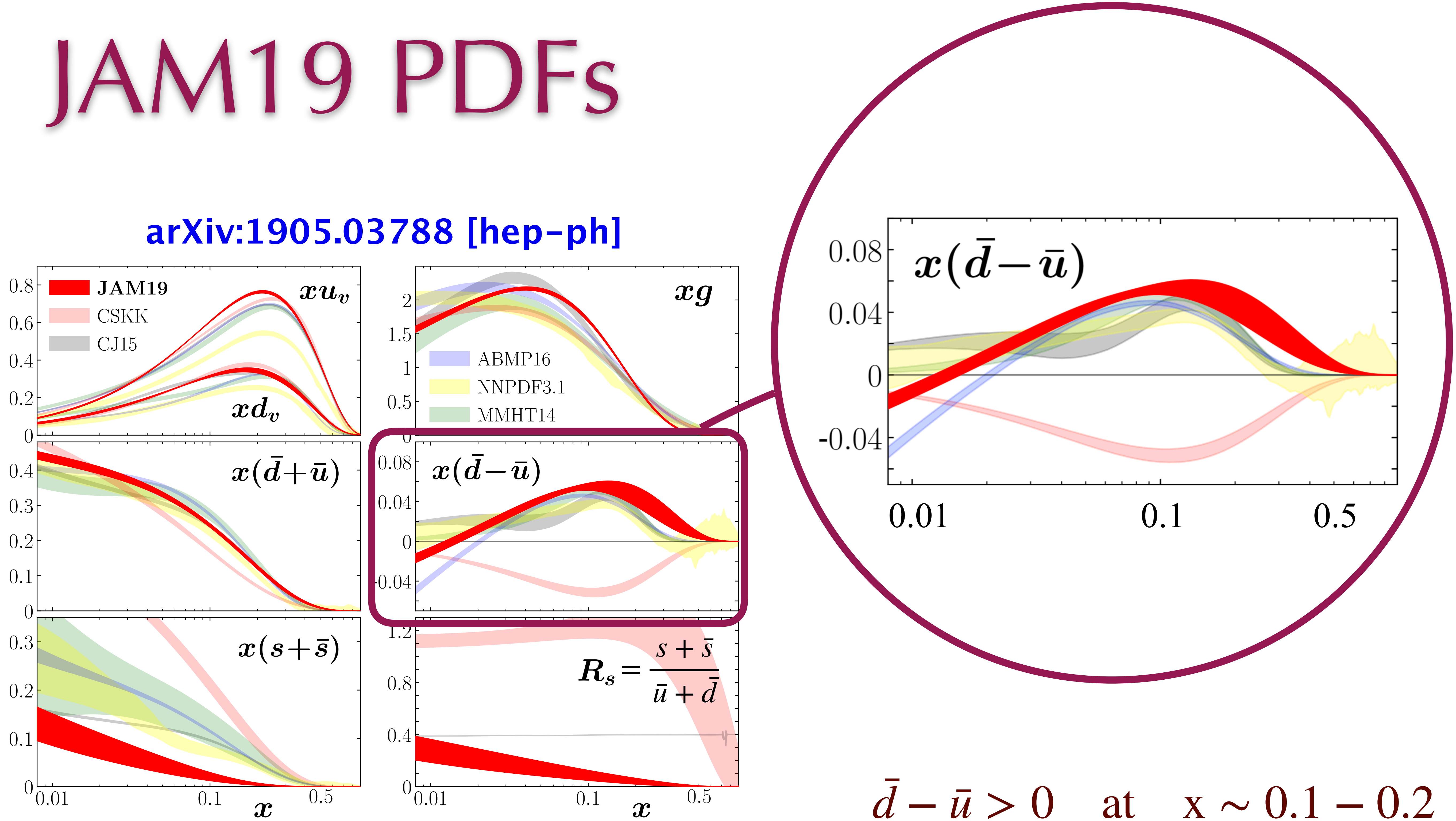


$\bar{d} - \bar{u} > 0$ at x ~ 0.1 – 0.2

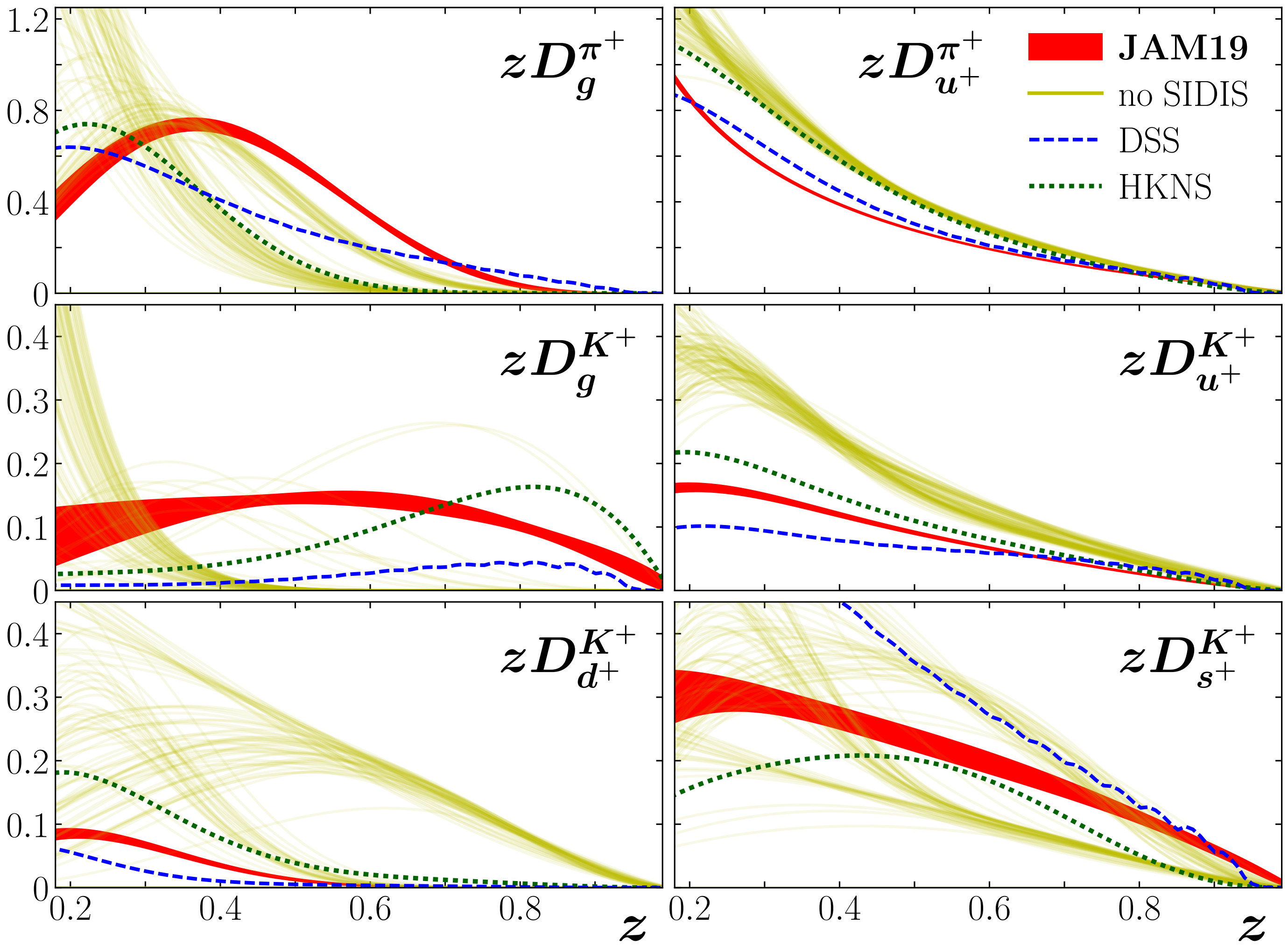
Q = m$_c$

DIS(p, d)
DY(pp, pd)
SIA($\pi^{\pm}, K^{\pm}$)
SIDIS($\pi^{\pm}, K^{\pm}$)

FF results

JAM19: FF

arXiv:1905.03788 [hep-ph]



Q = m$_c$

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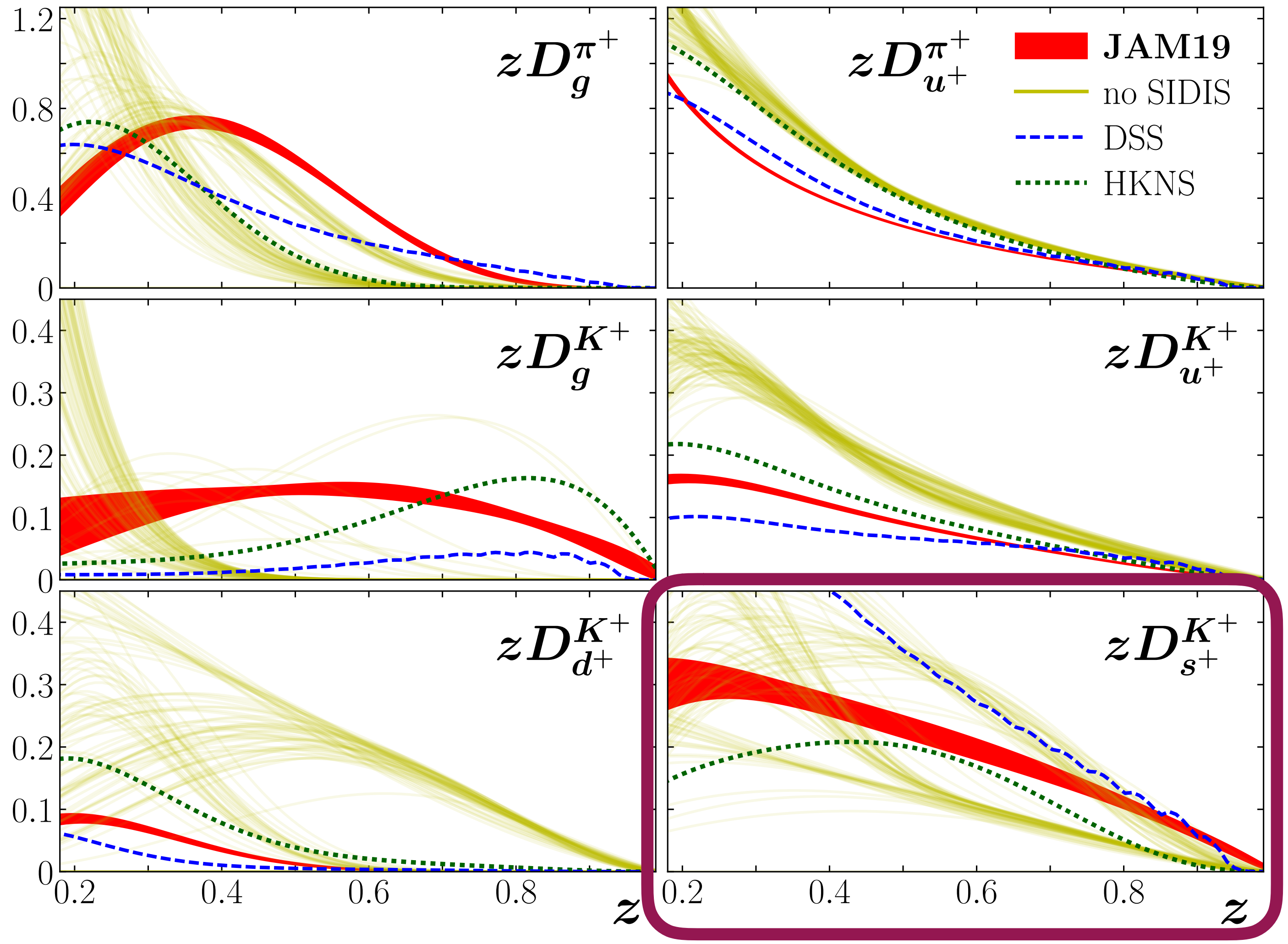

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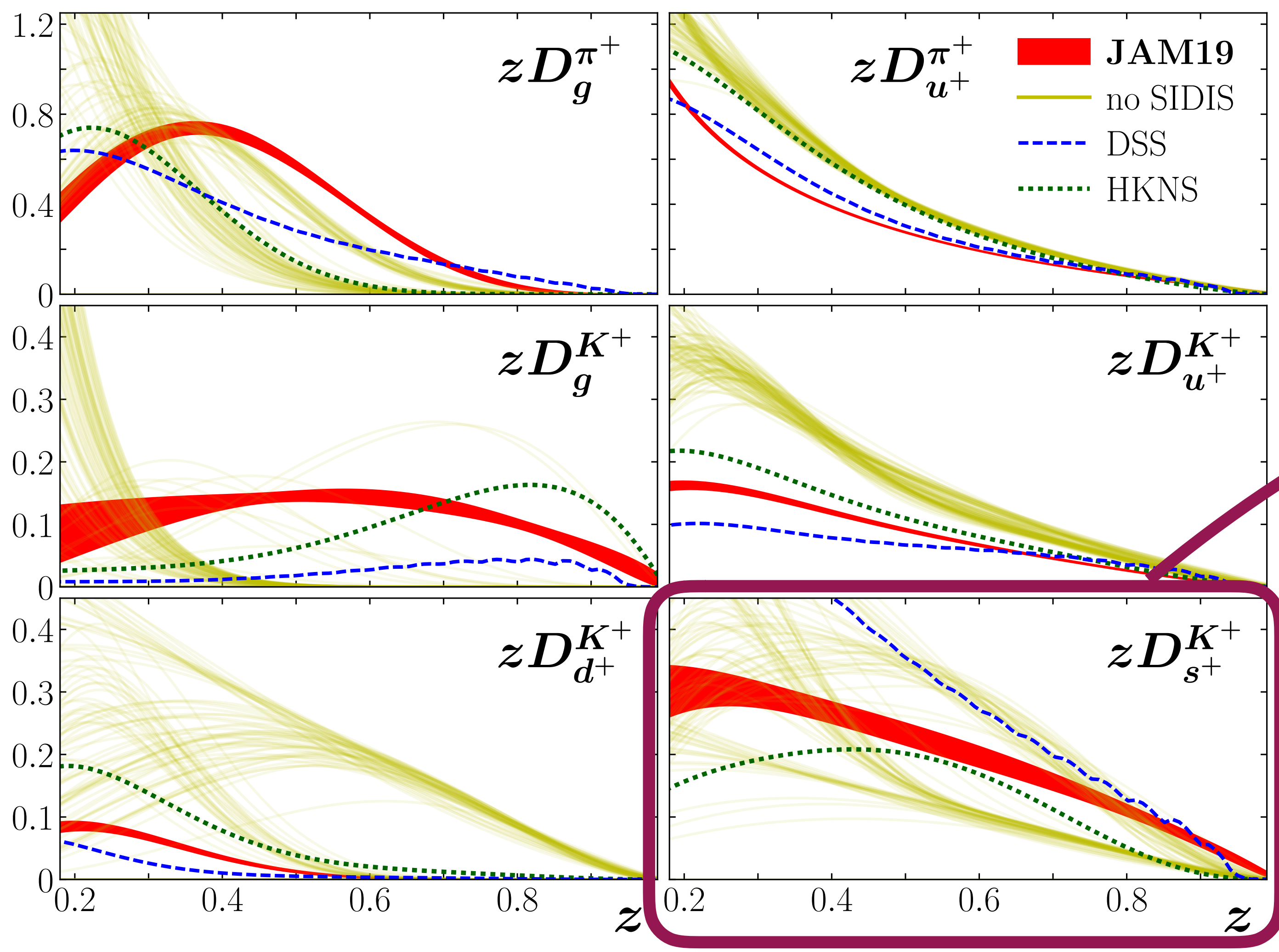

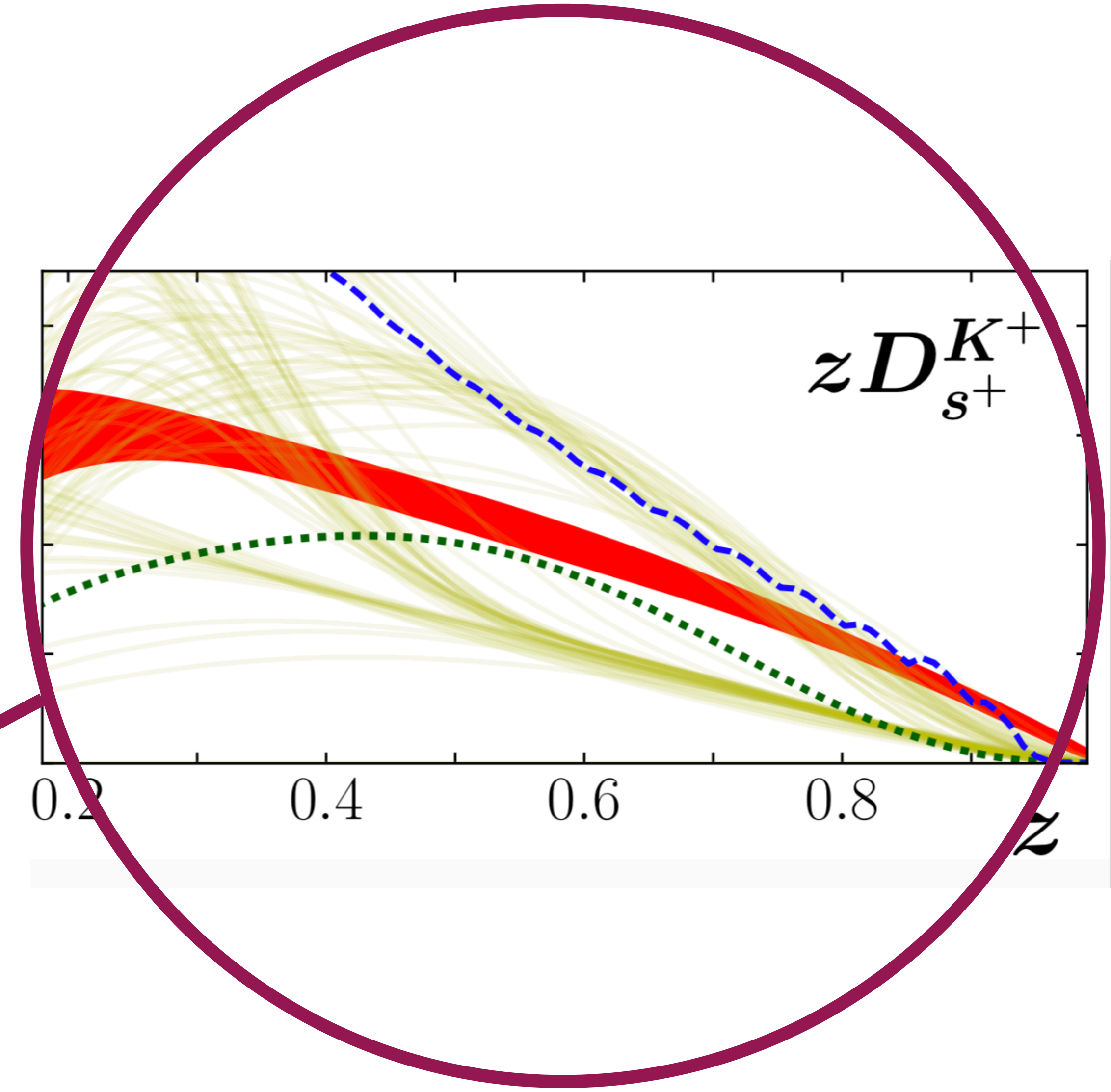

Large $\bar{s} \rightarrow K^+$

Q = m$_c$

JAM19: FF

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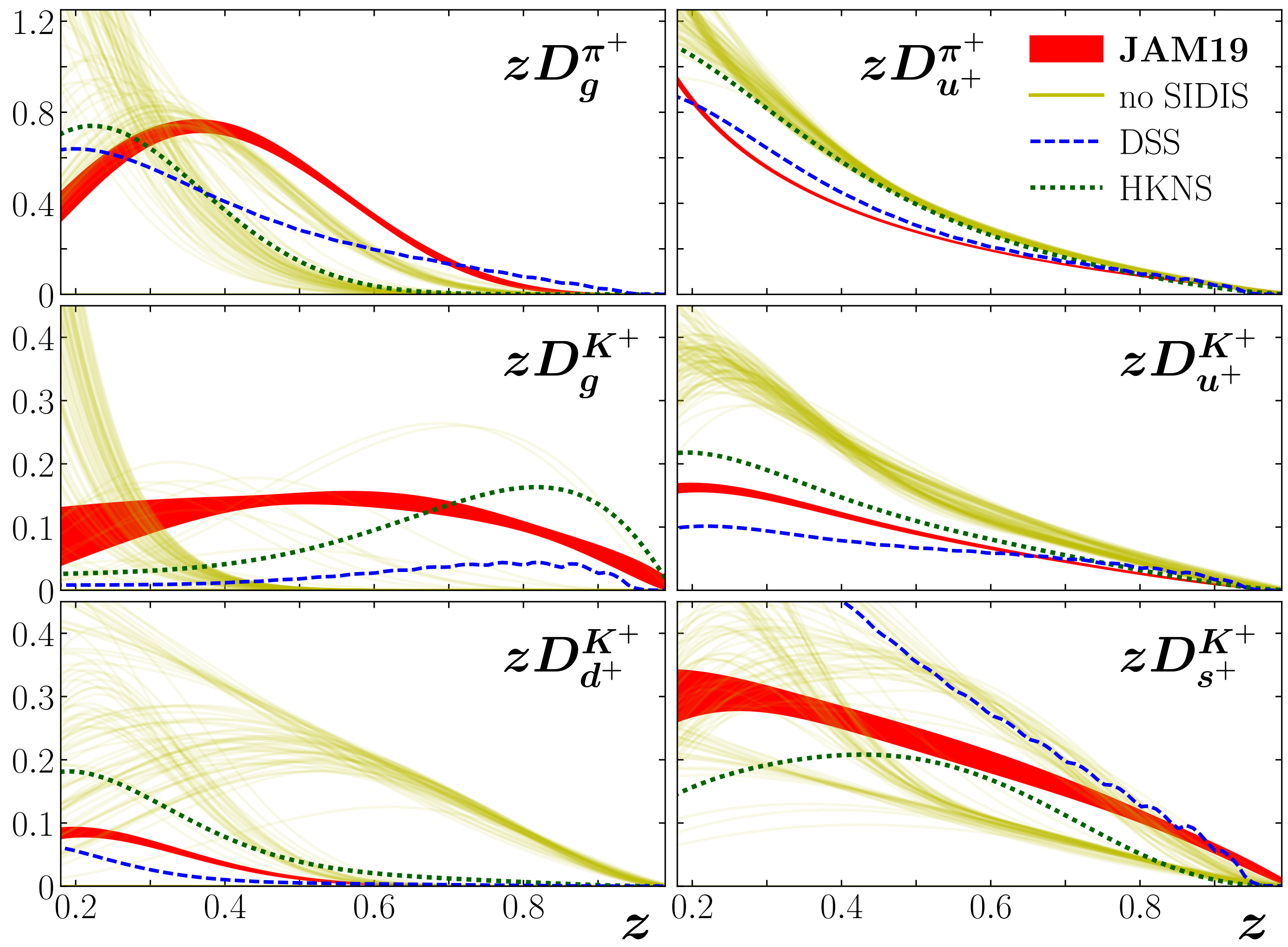

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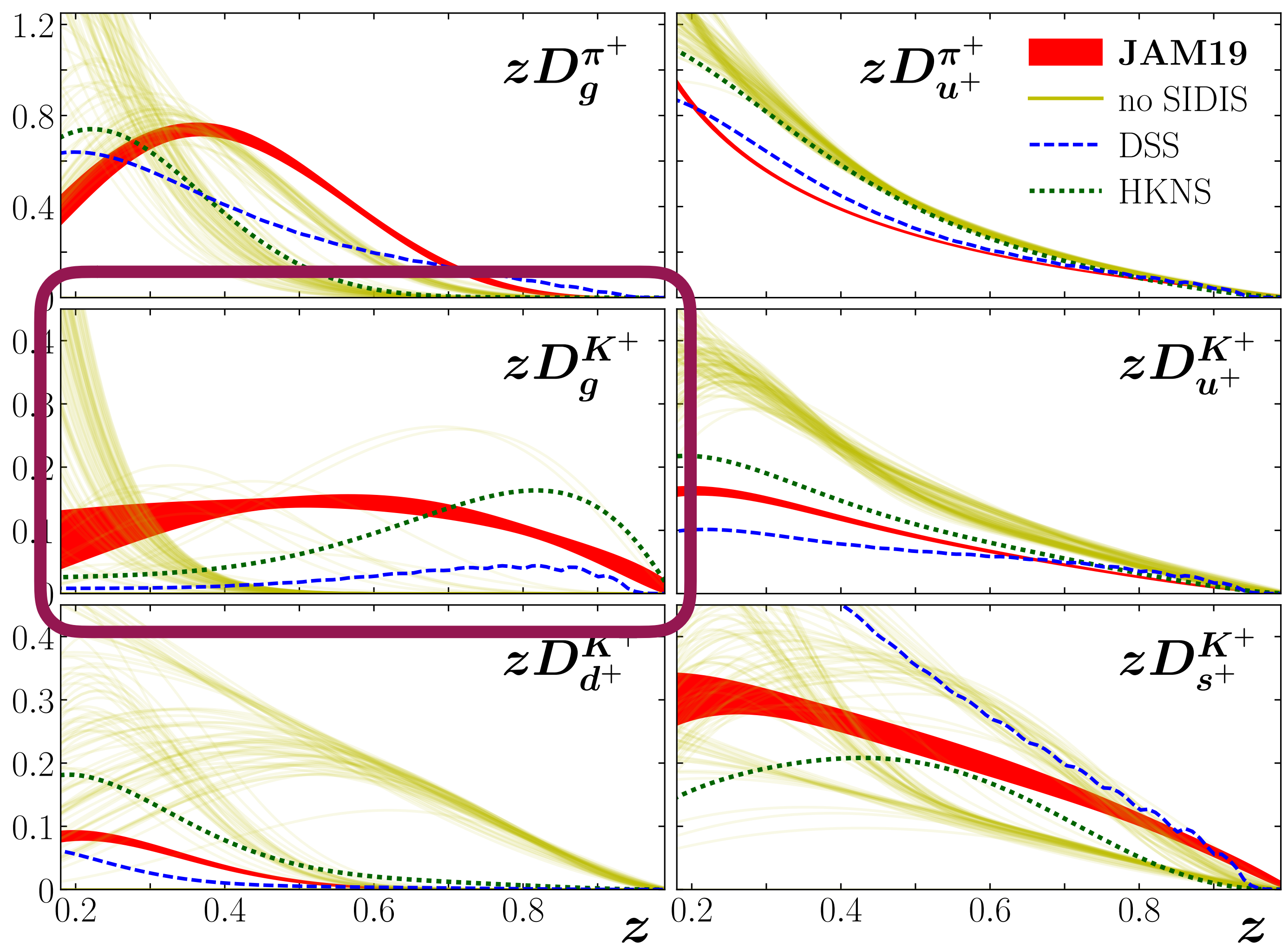

$Q = m_c$

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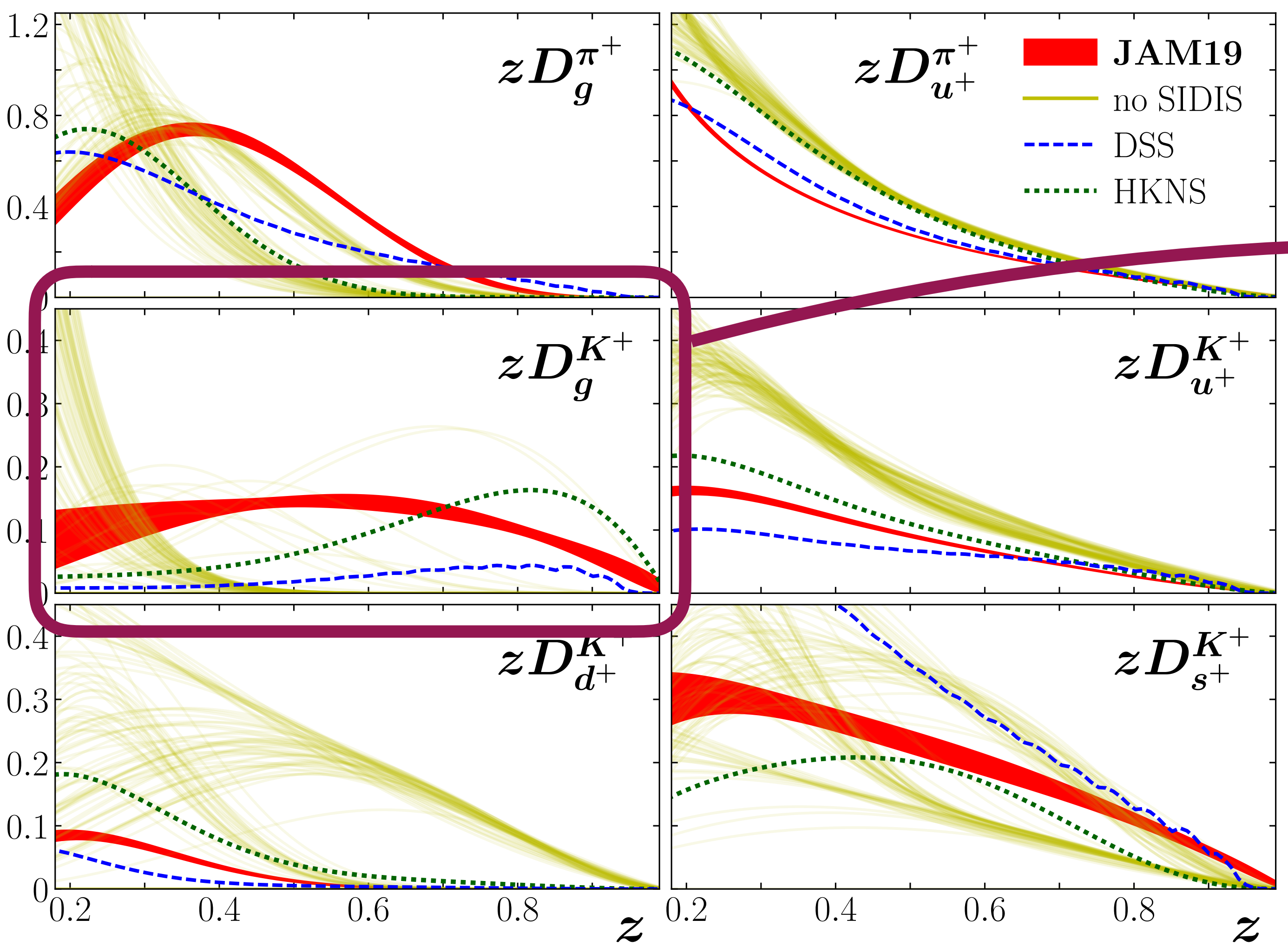

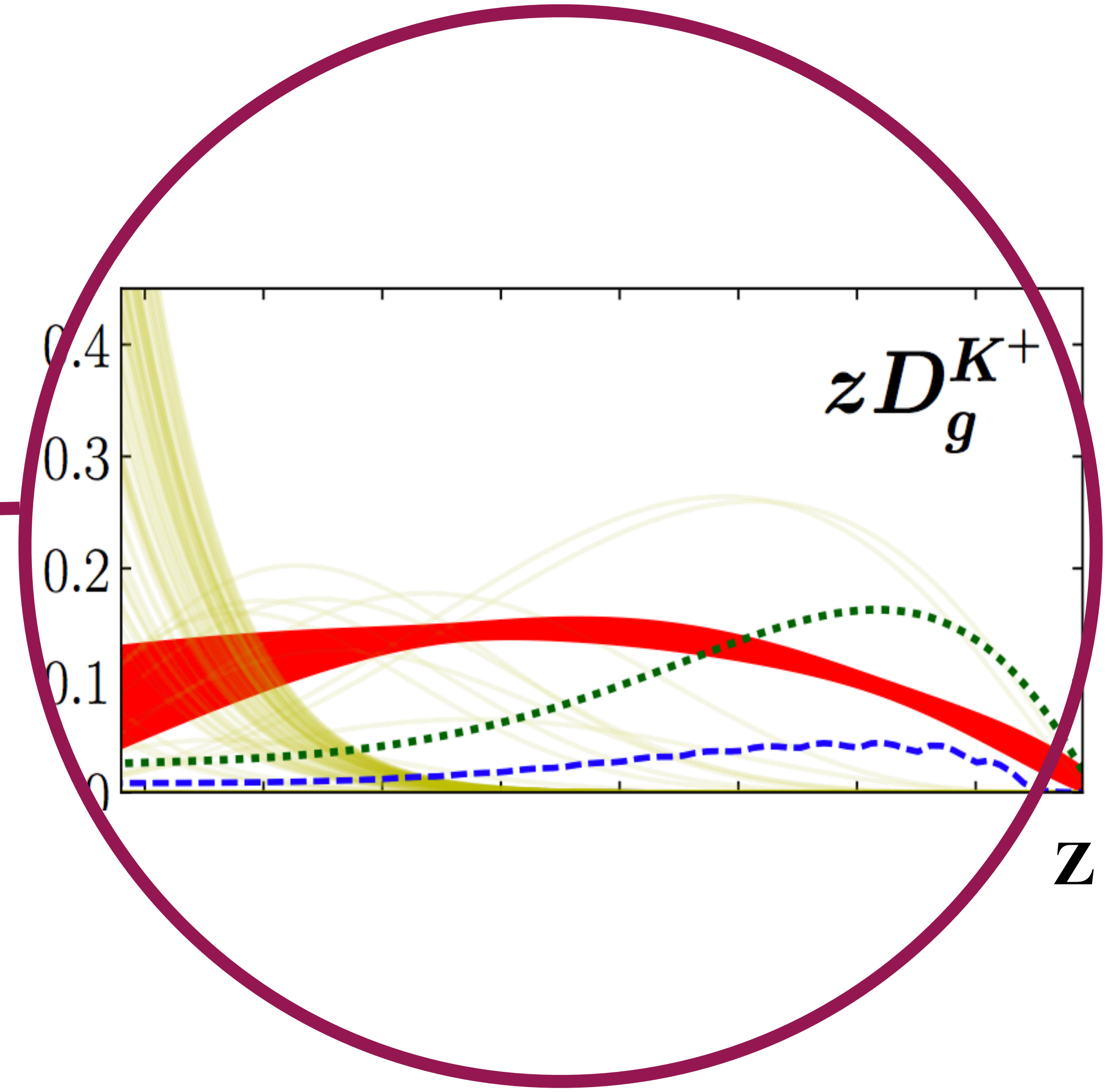

Q = m$_c$

Constraints on
$g \rightarrow K^+$

JAM19: FF

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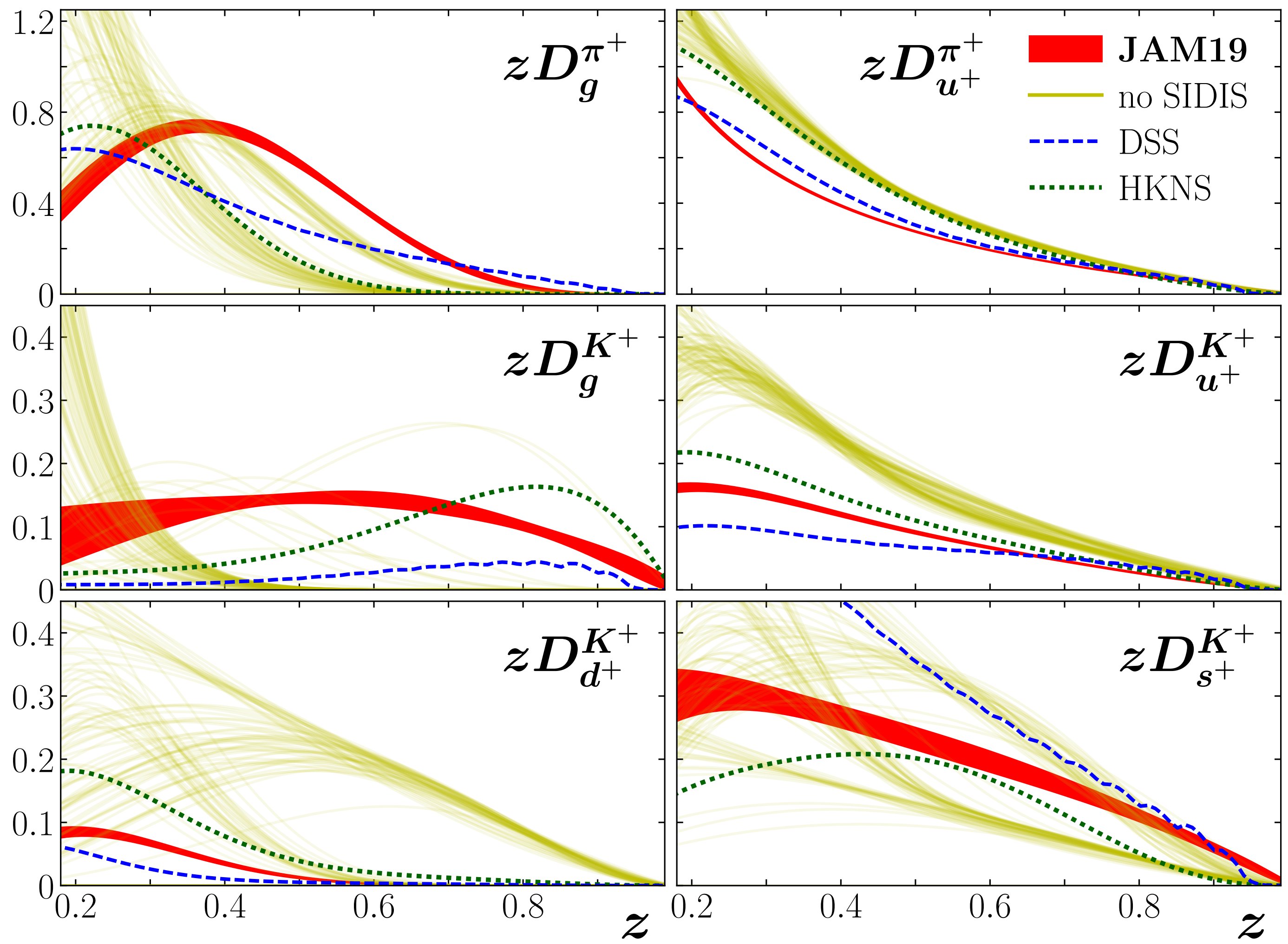

Q = m_c

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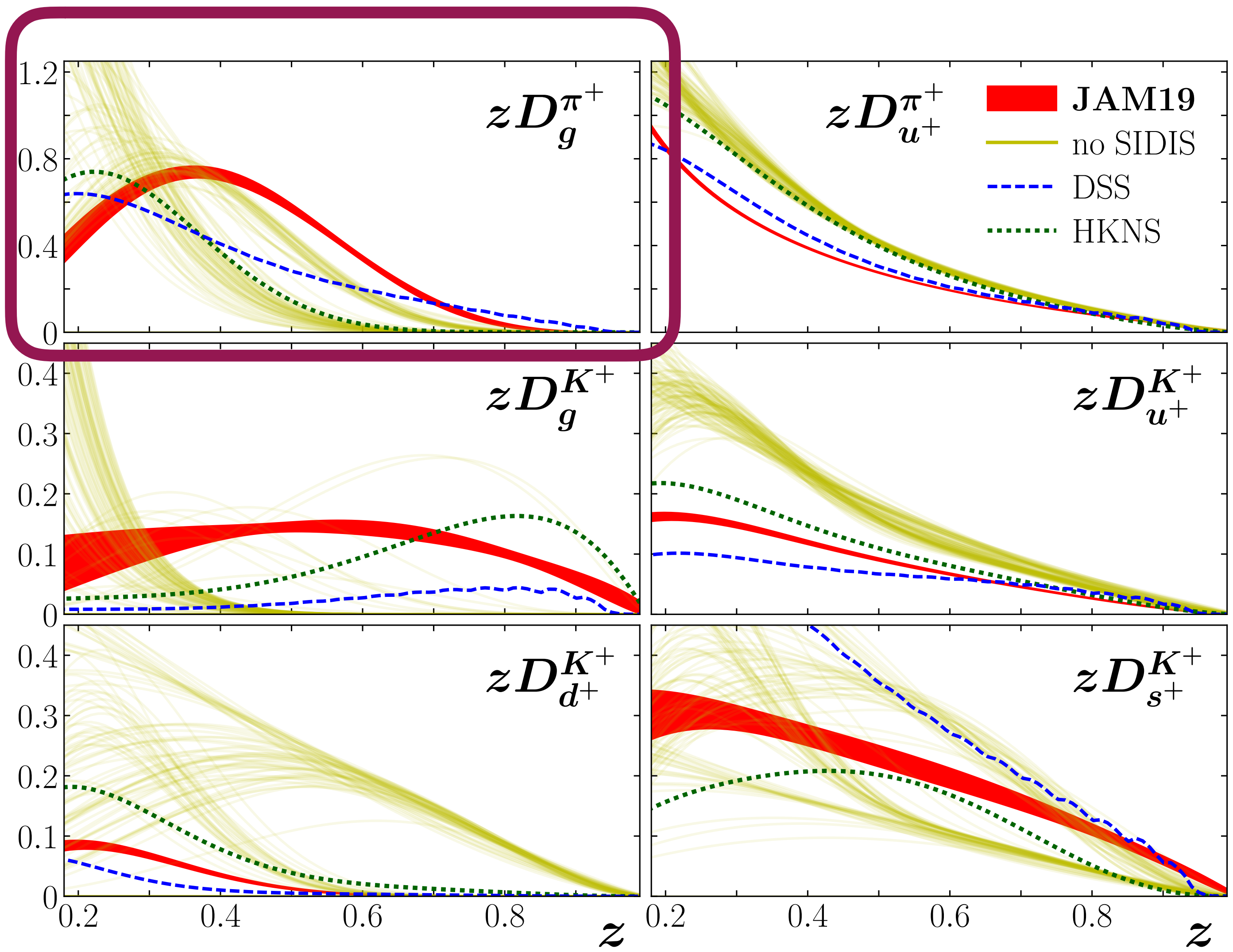

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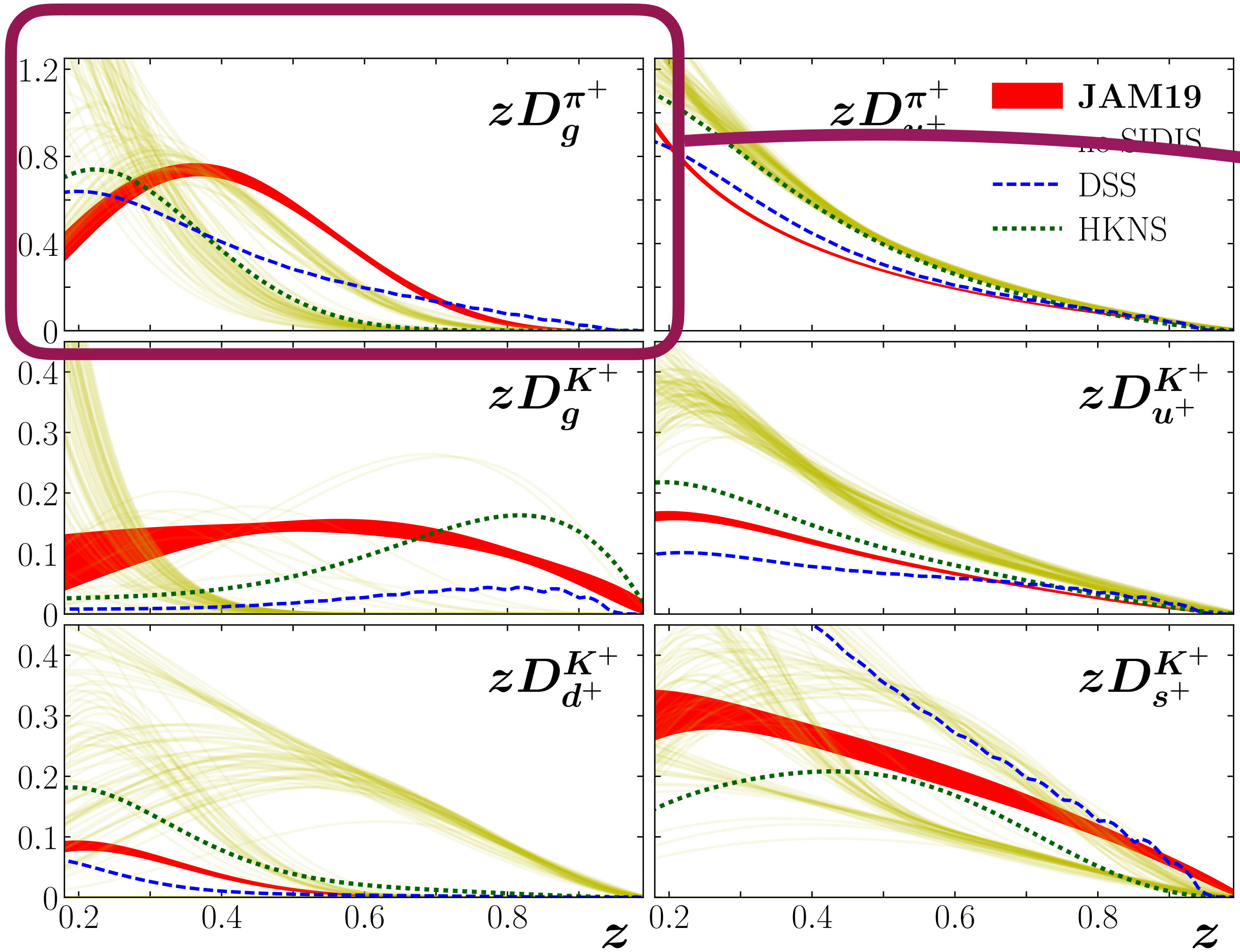
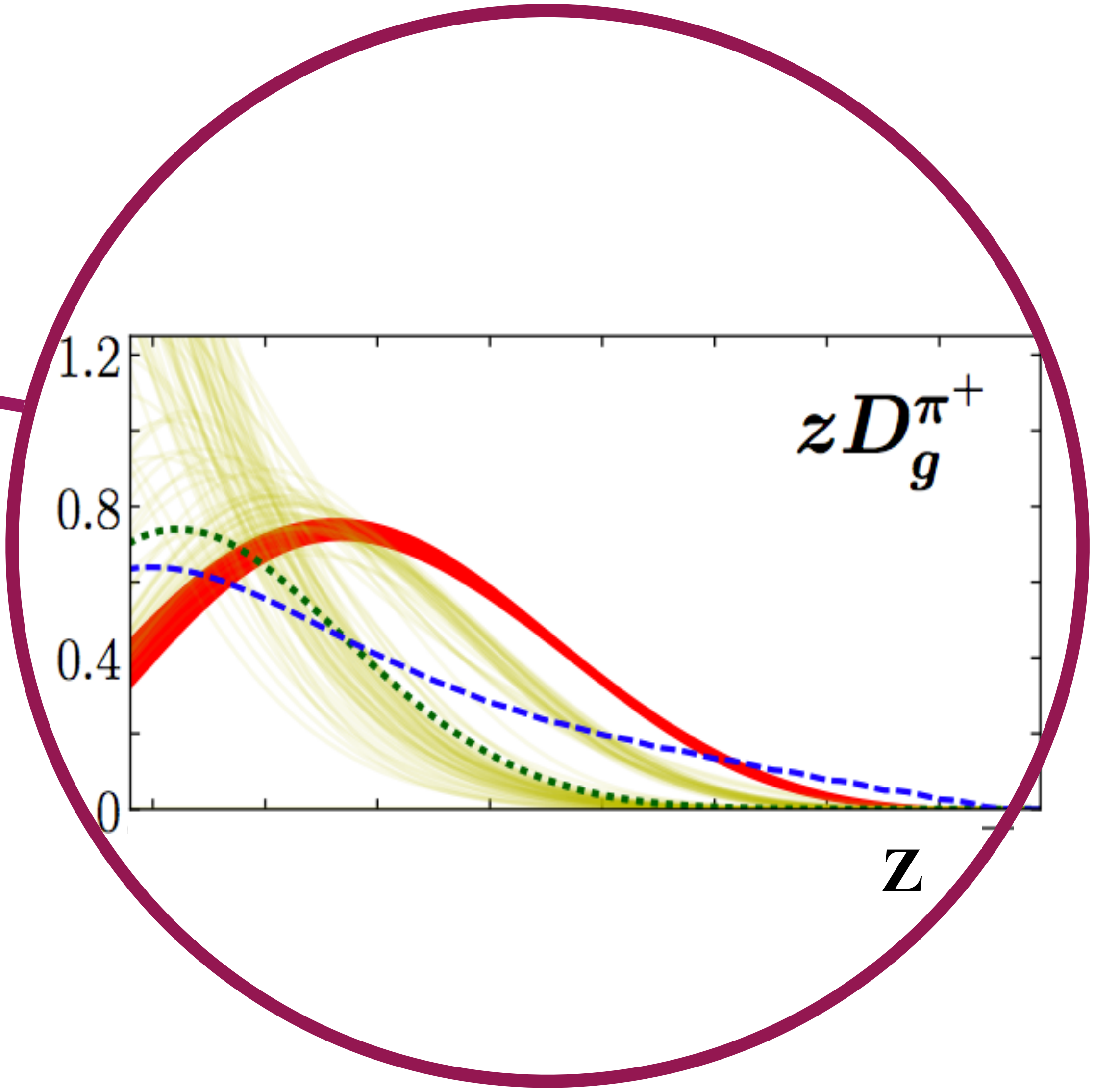


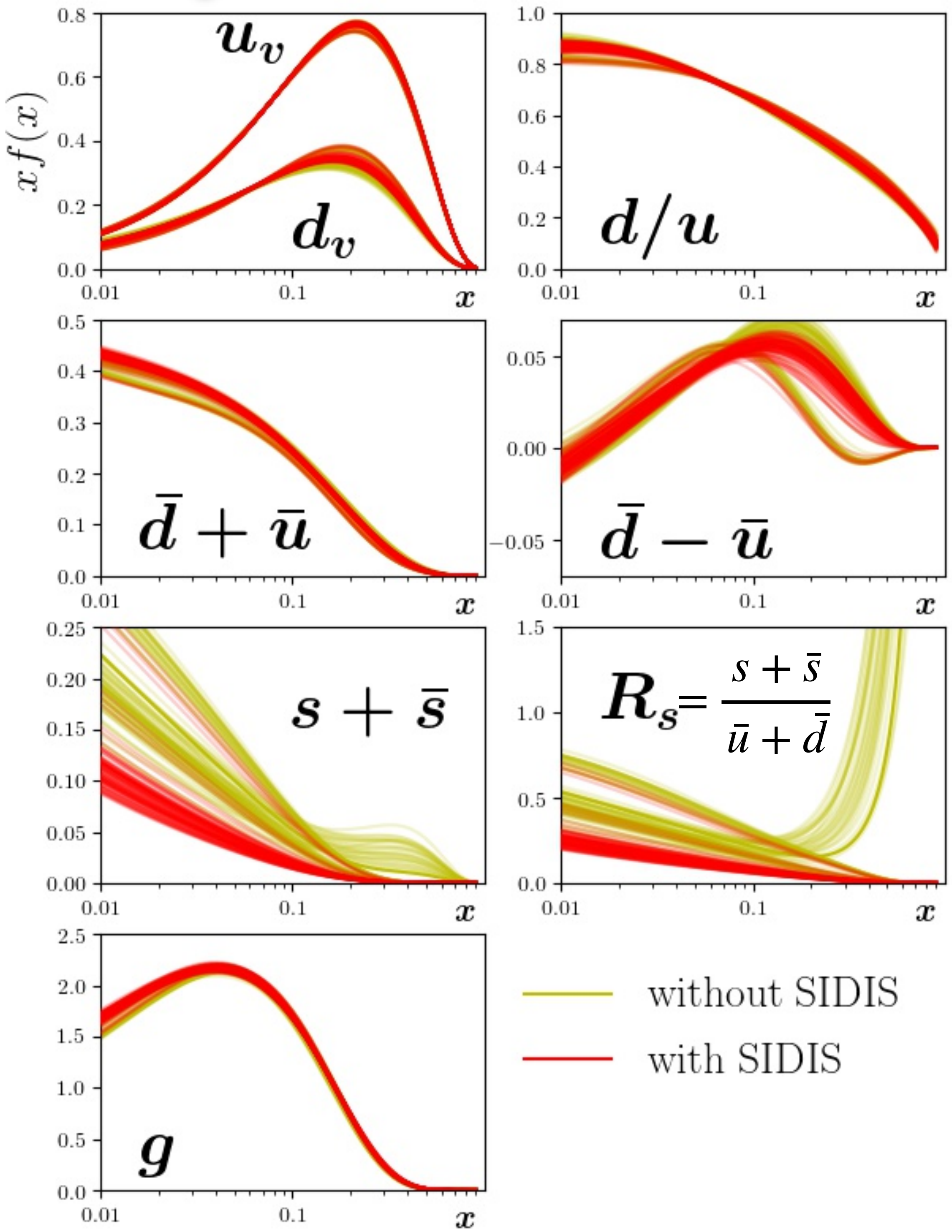


Constraints on
$g \rightarrow \pi^+$

Q = m$_c$

Impact of SIDIS data

Impact of SIDIS data on PDFs



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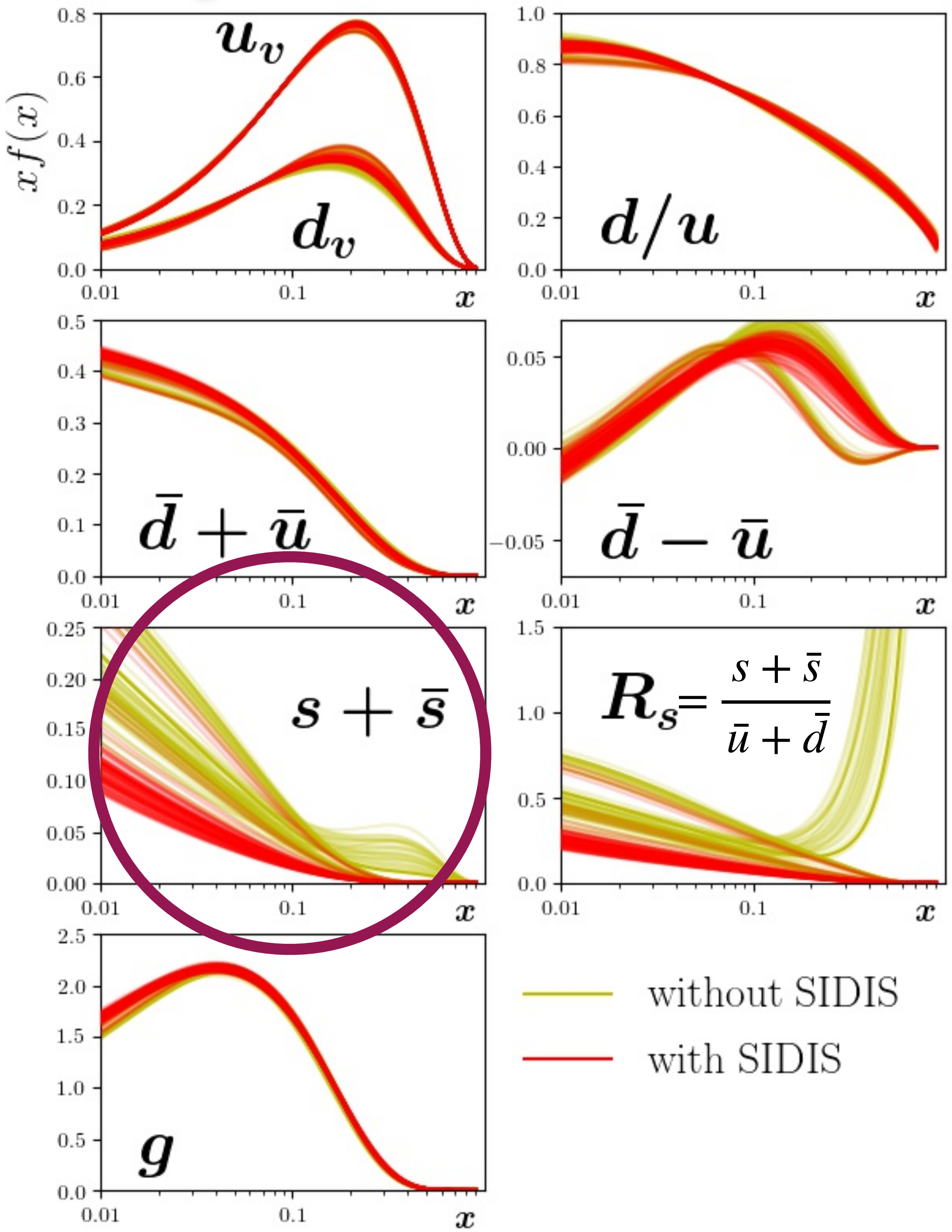

$Q = m_c$

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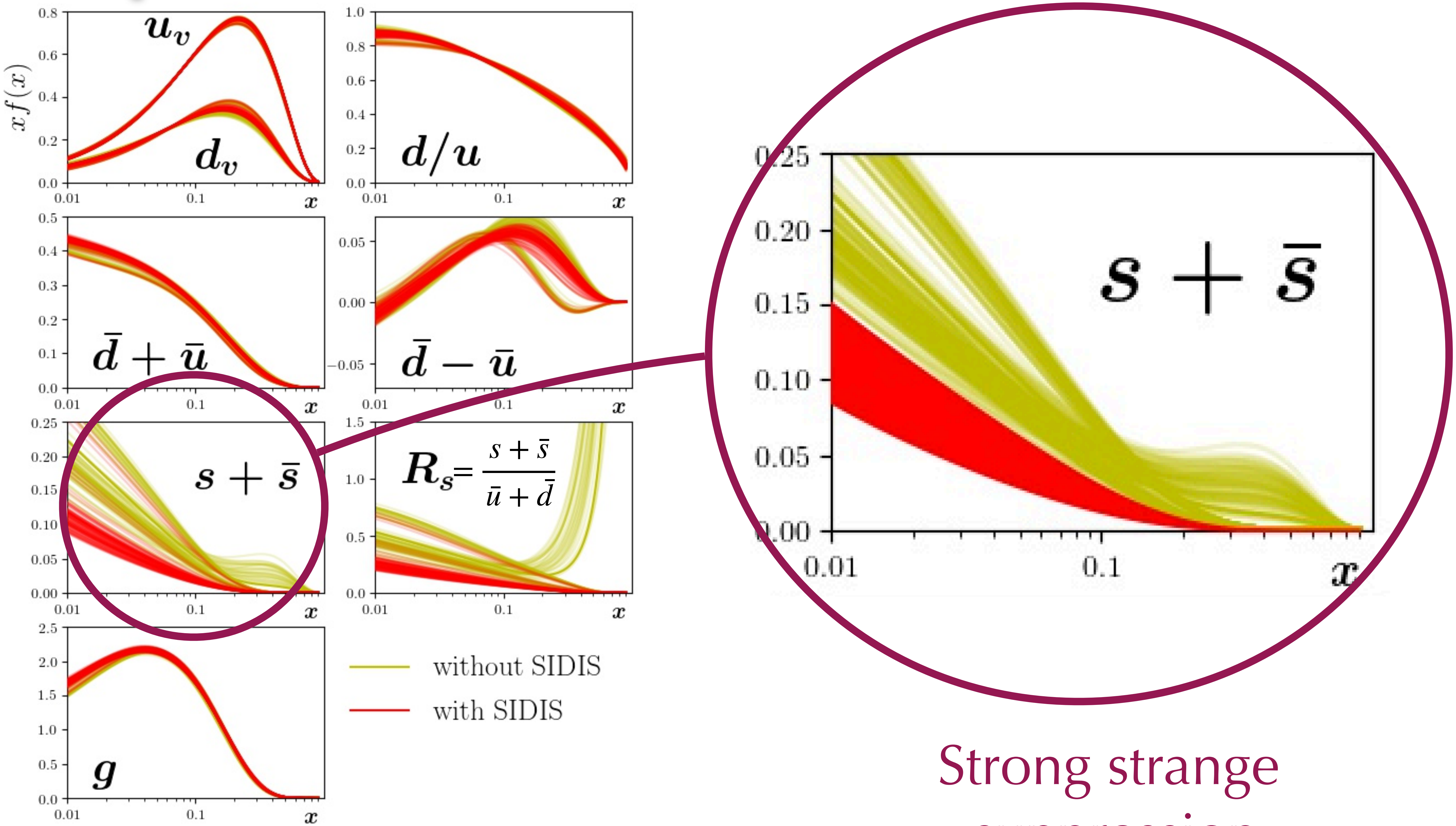

Q = m$_c$

Strong strange suppression

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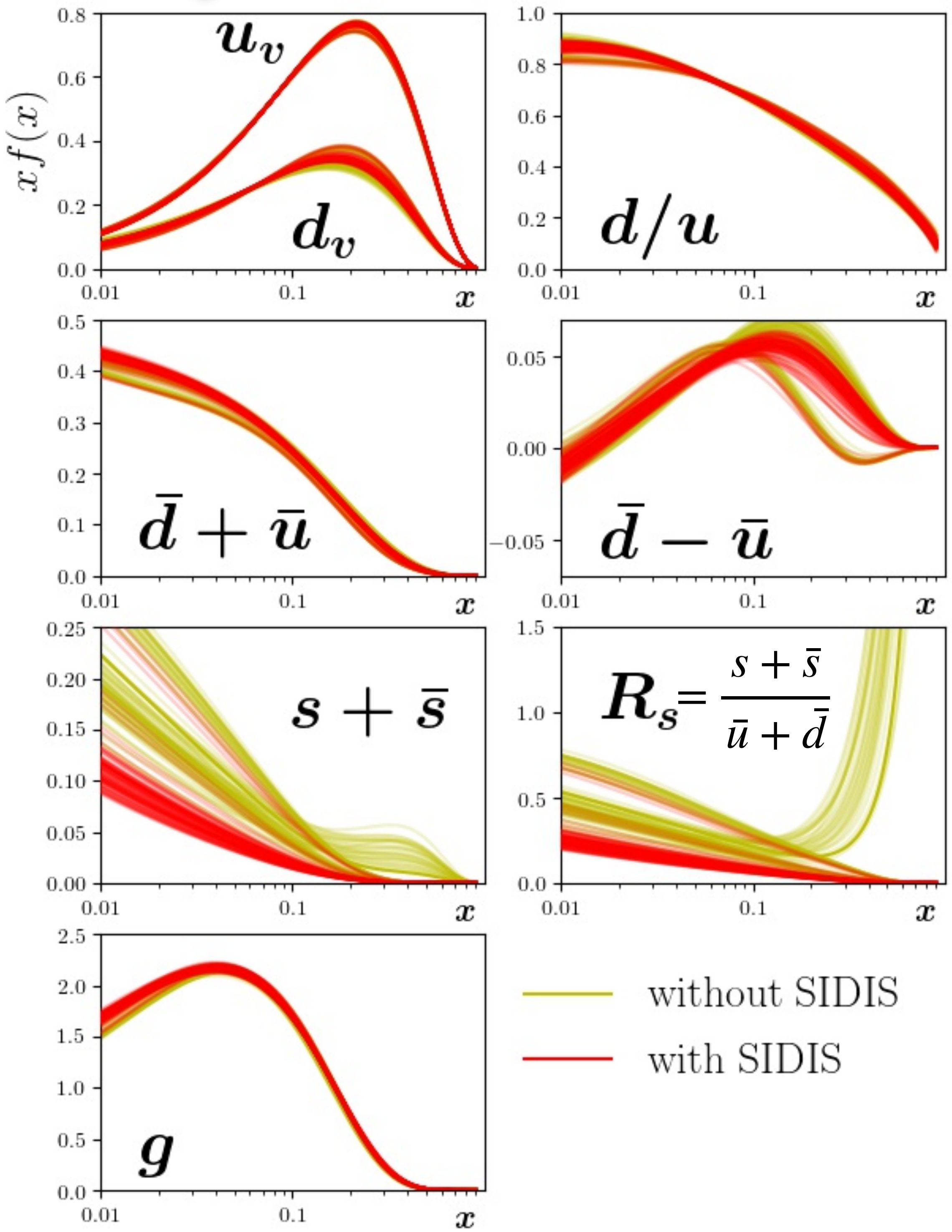

$$= \frac{s+\bar{s}}{\bar{u}+\bar{d}}$$

Q = m$_c$

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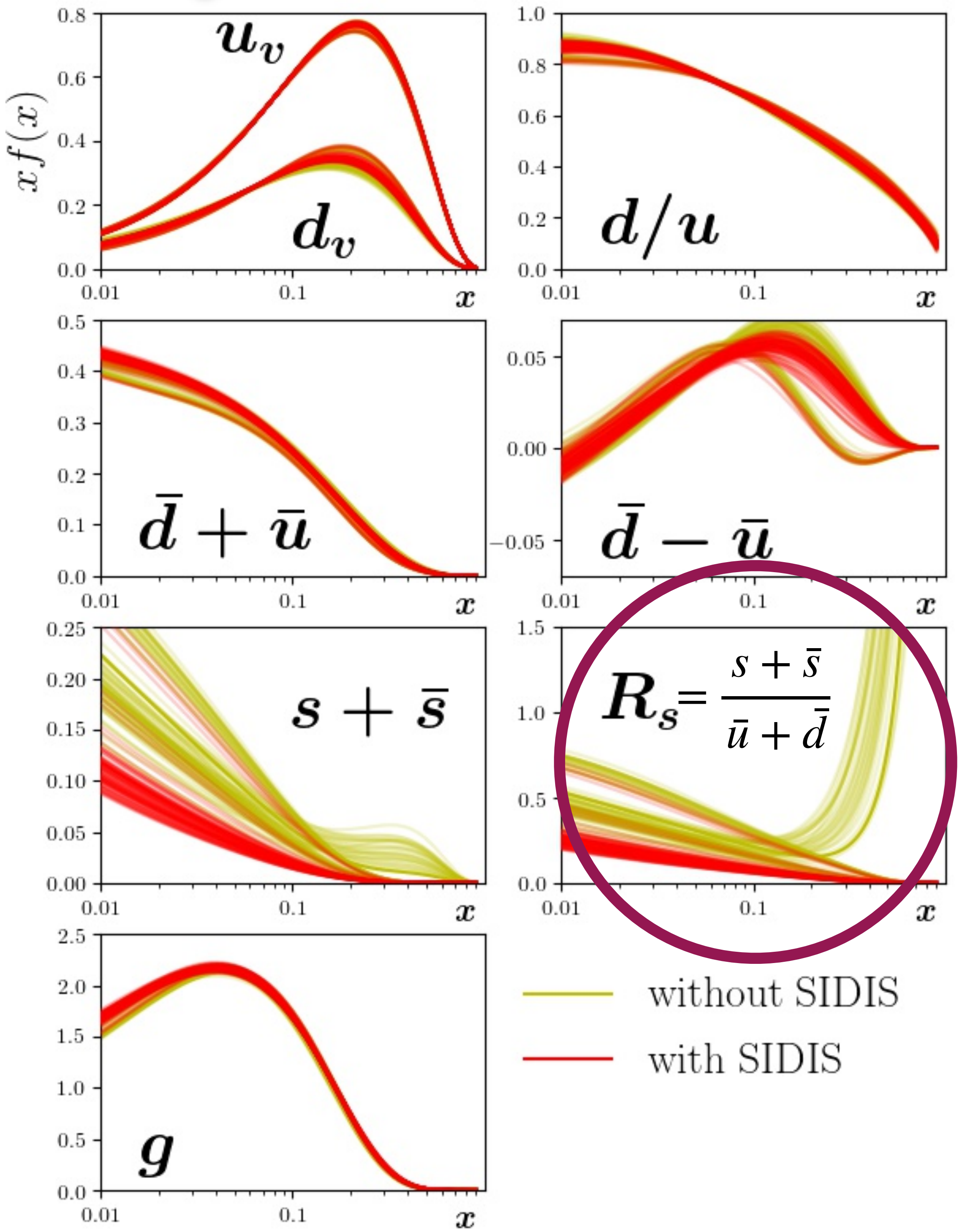

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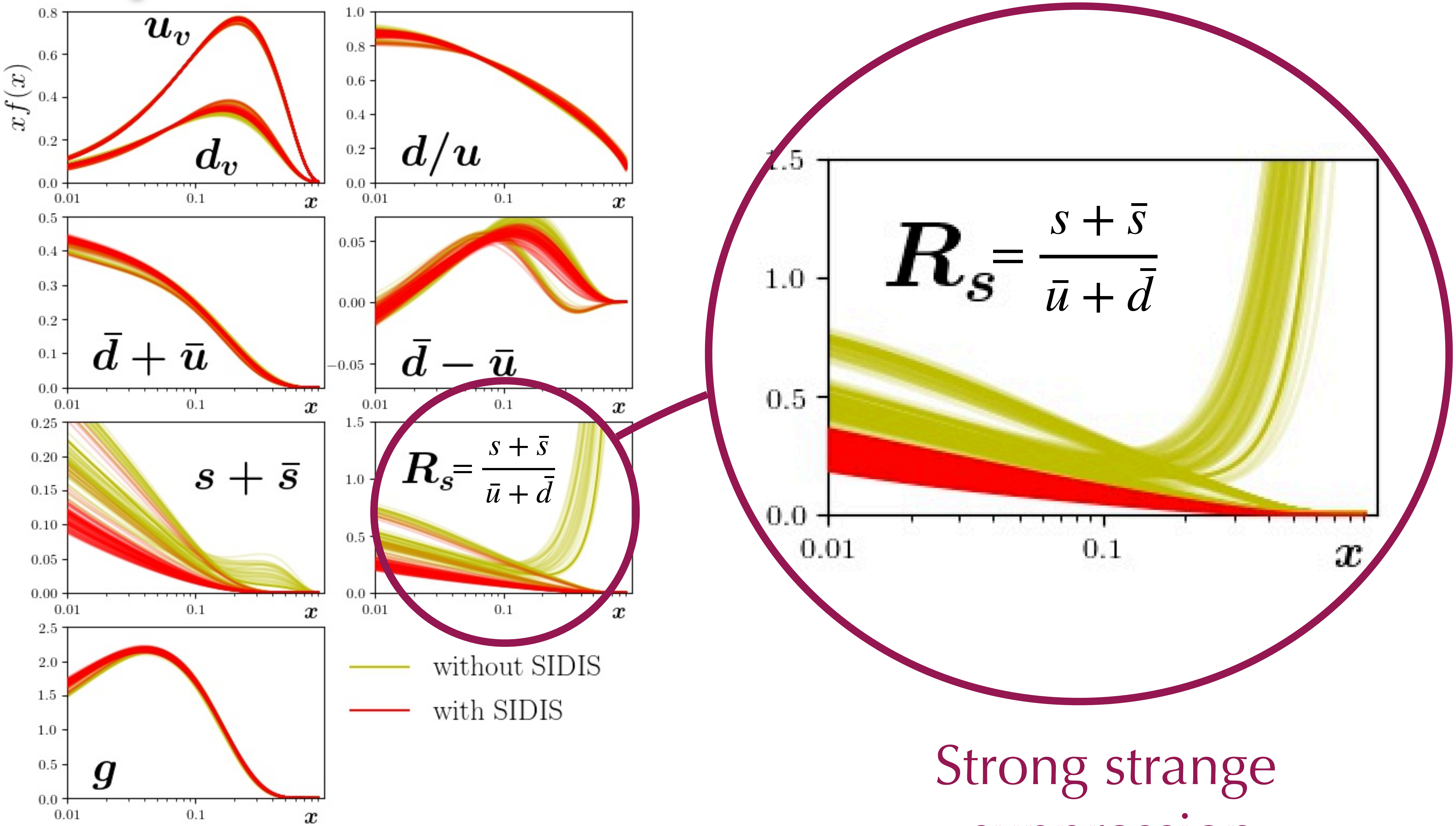

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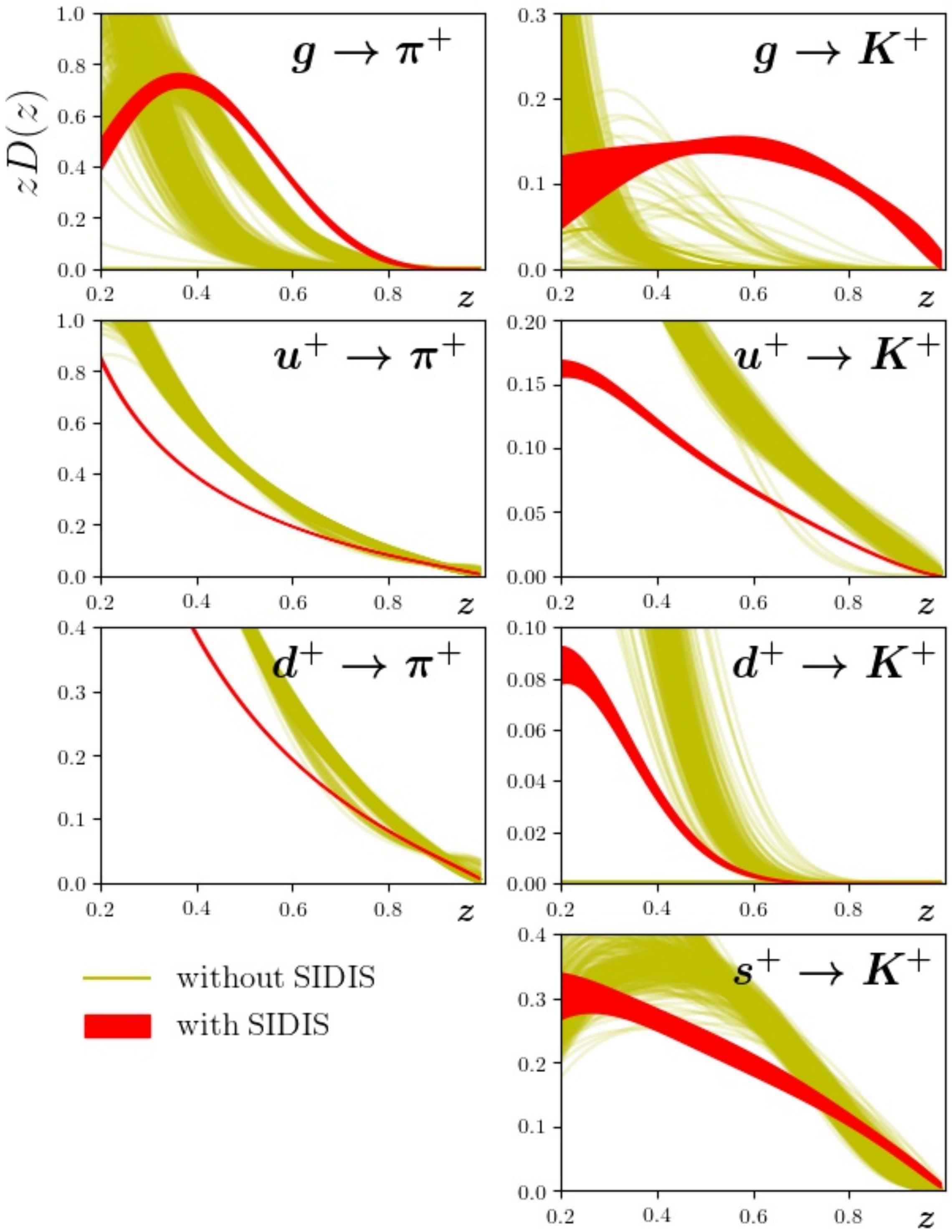

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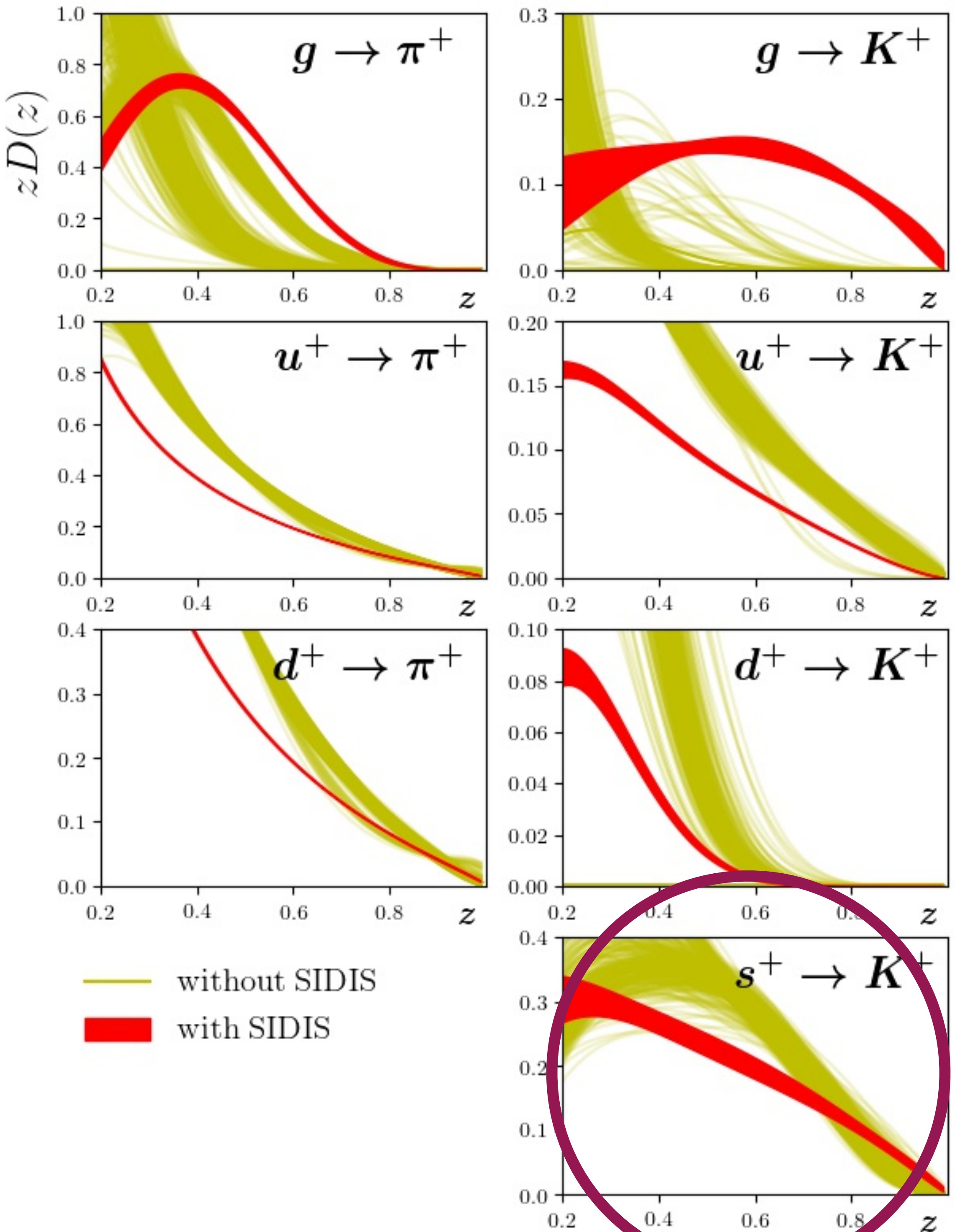

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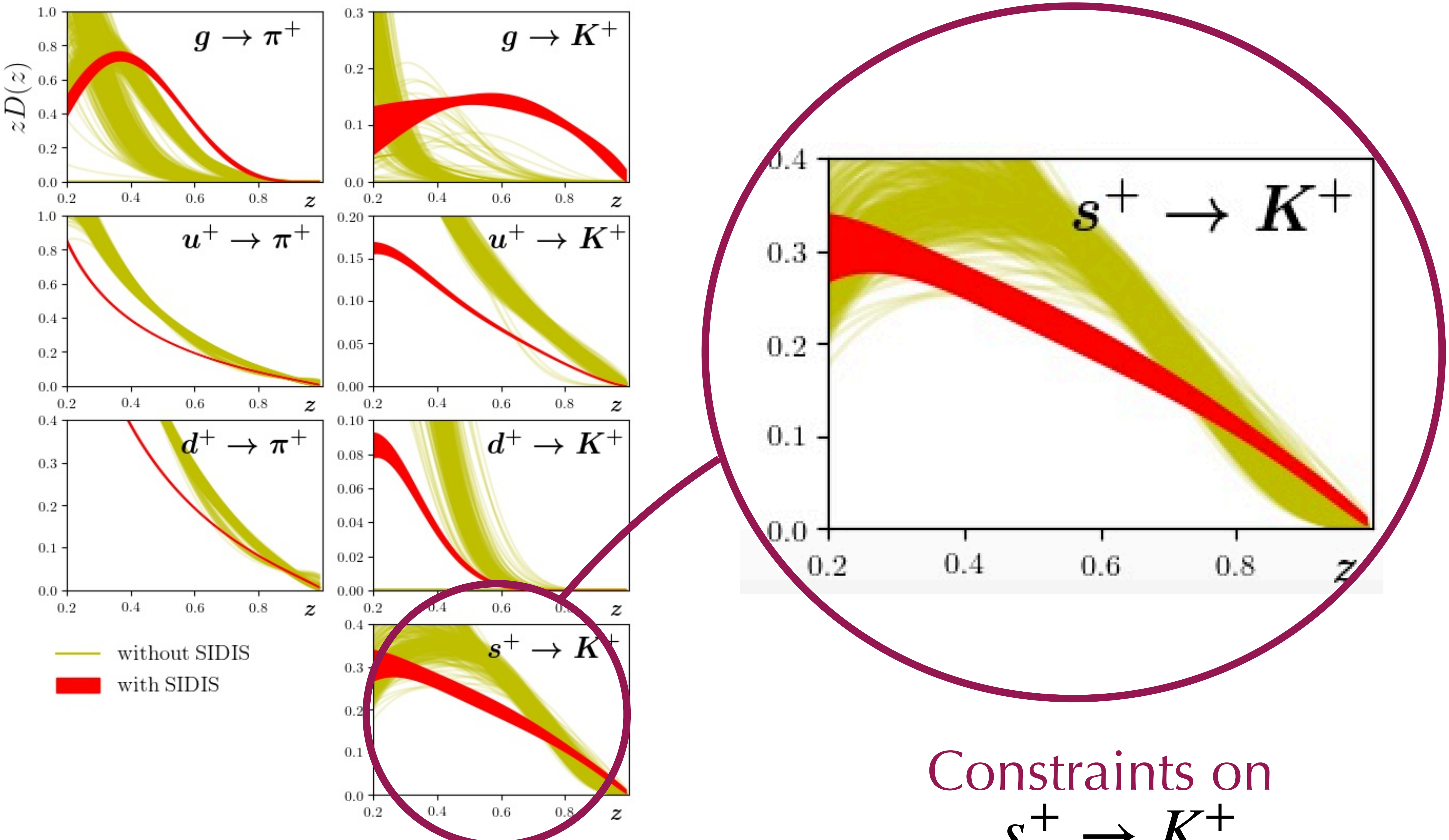
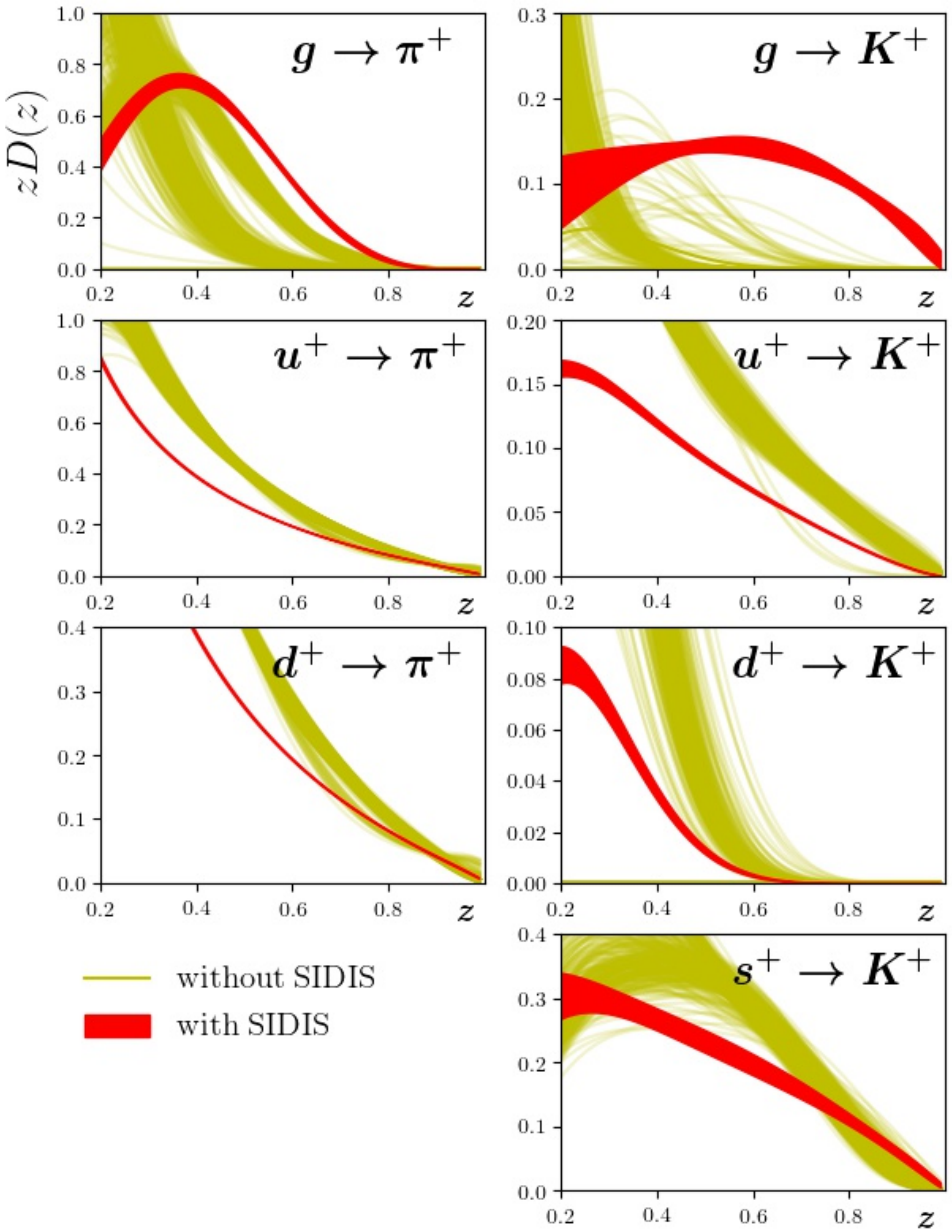


Q = m$_c$

Constraints on
$s^+ \to K^+$

Impact of SIDIS data on FF



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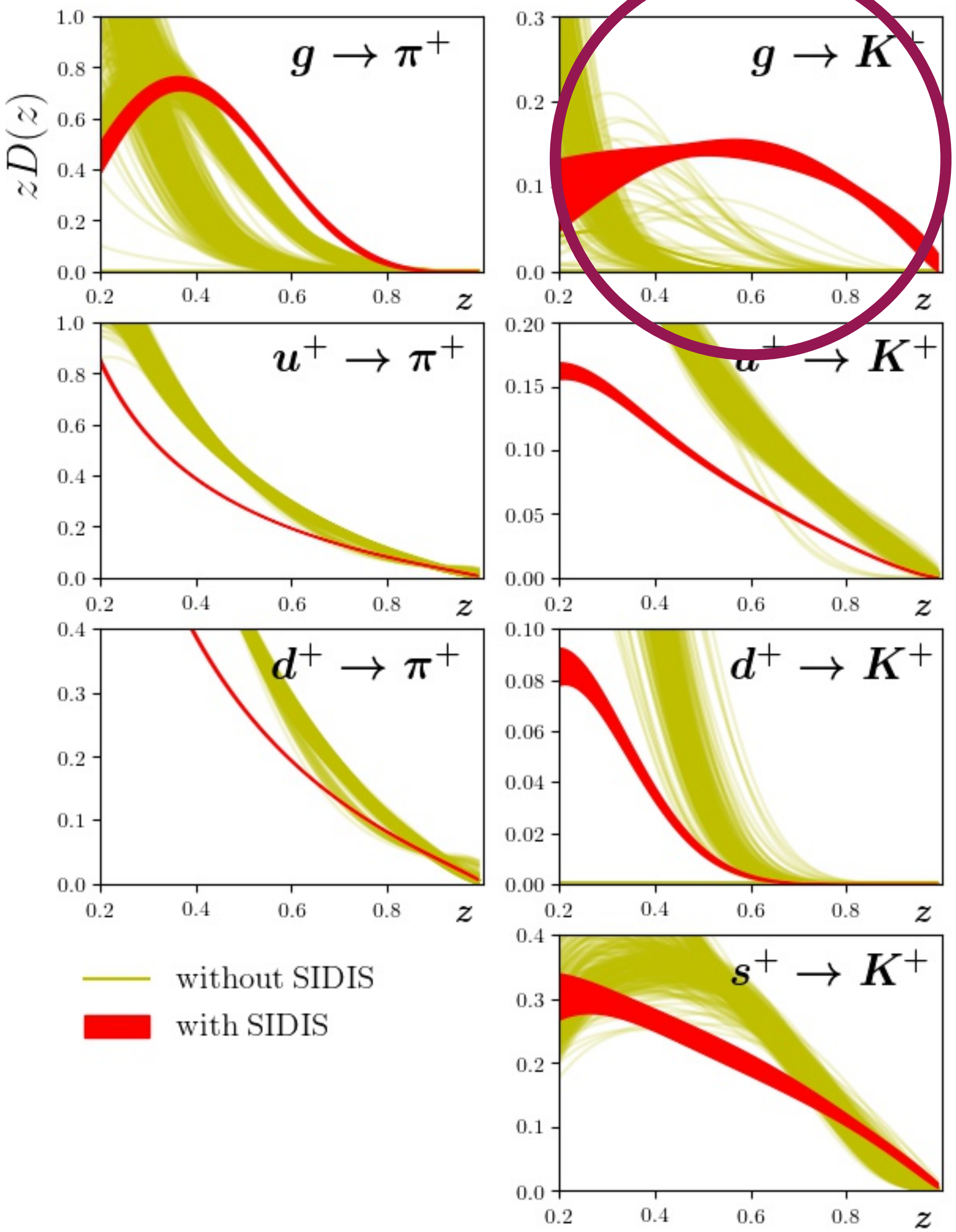

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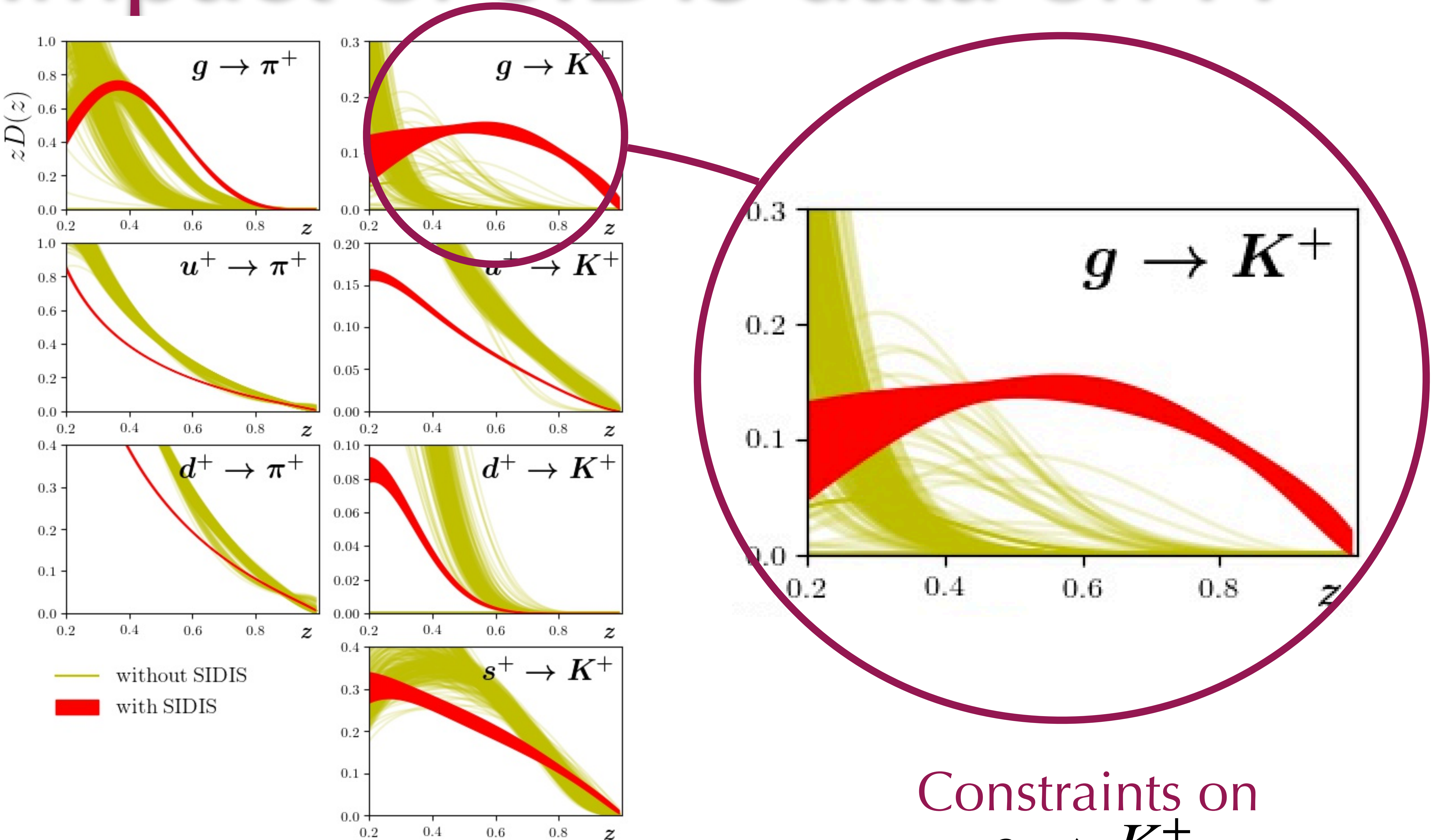
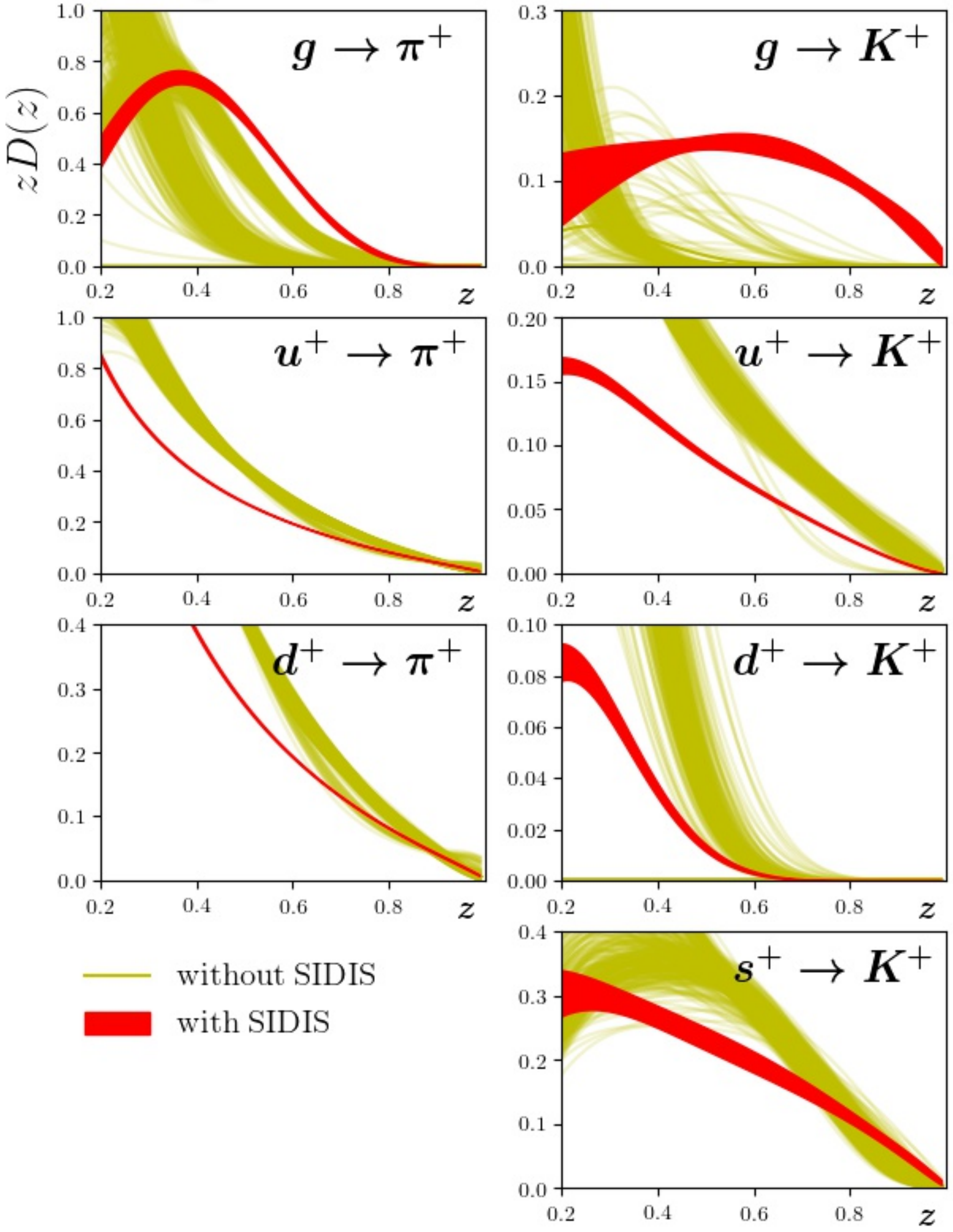
Impact of SIDIS data on FF



Q = m$_c$

Constraints on
$g \to K^+$

Impact of SIDIS data on FF



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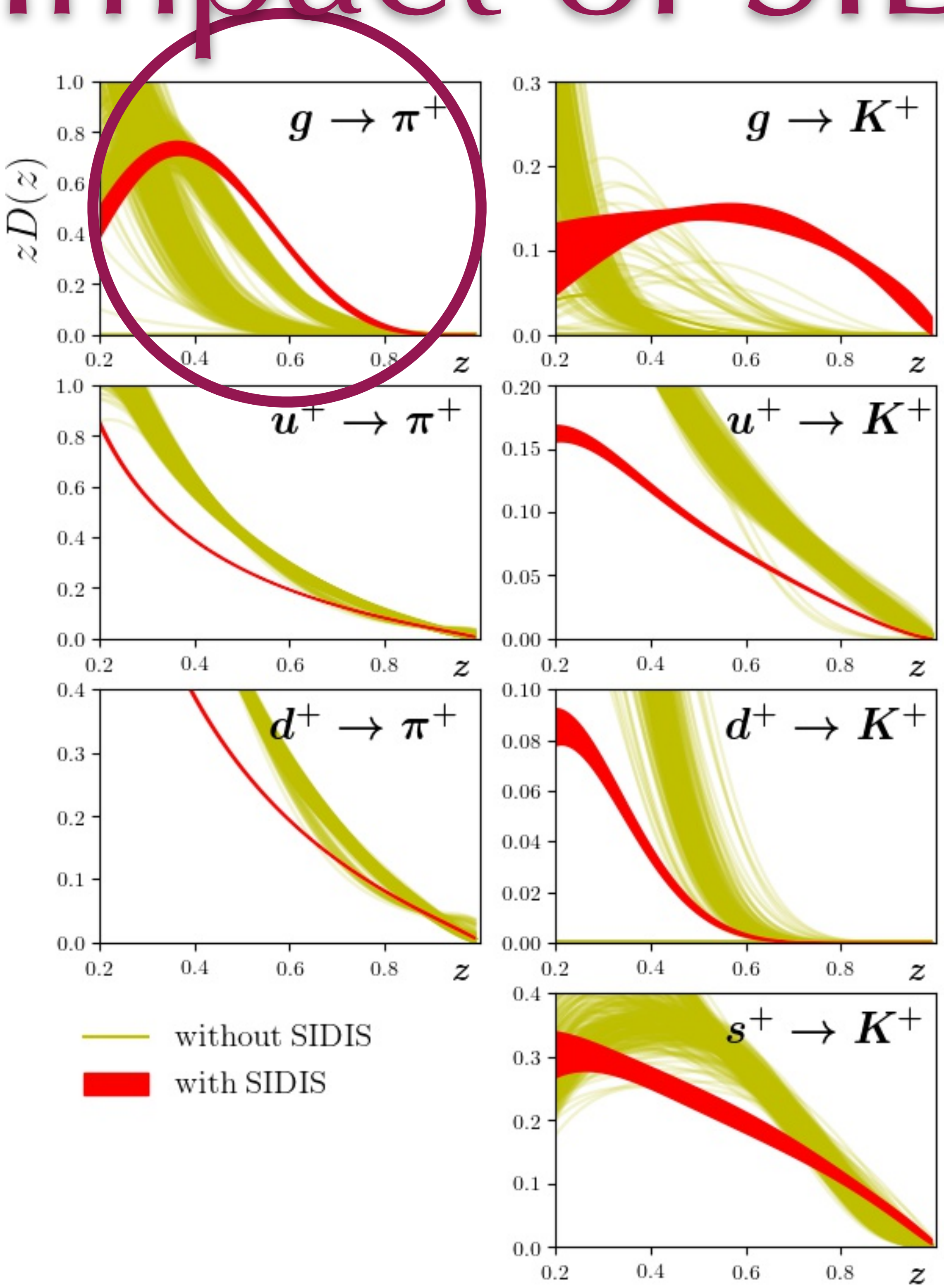

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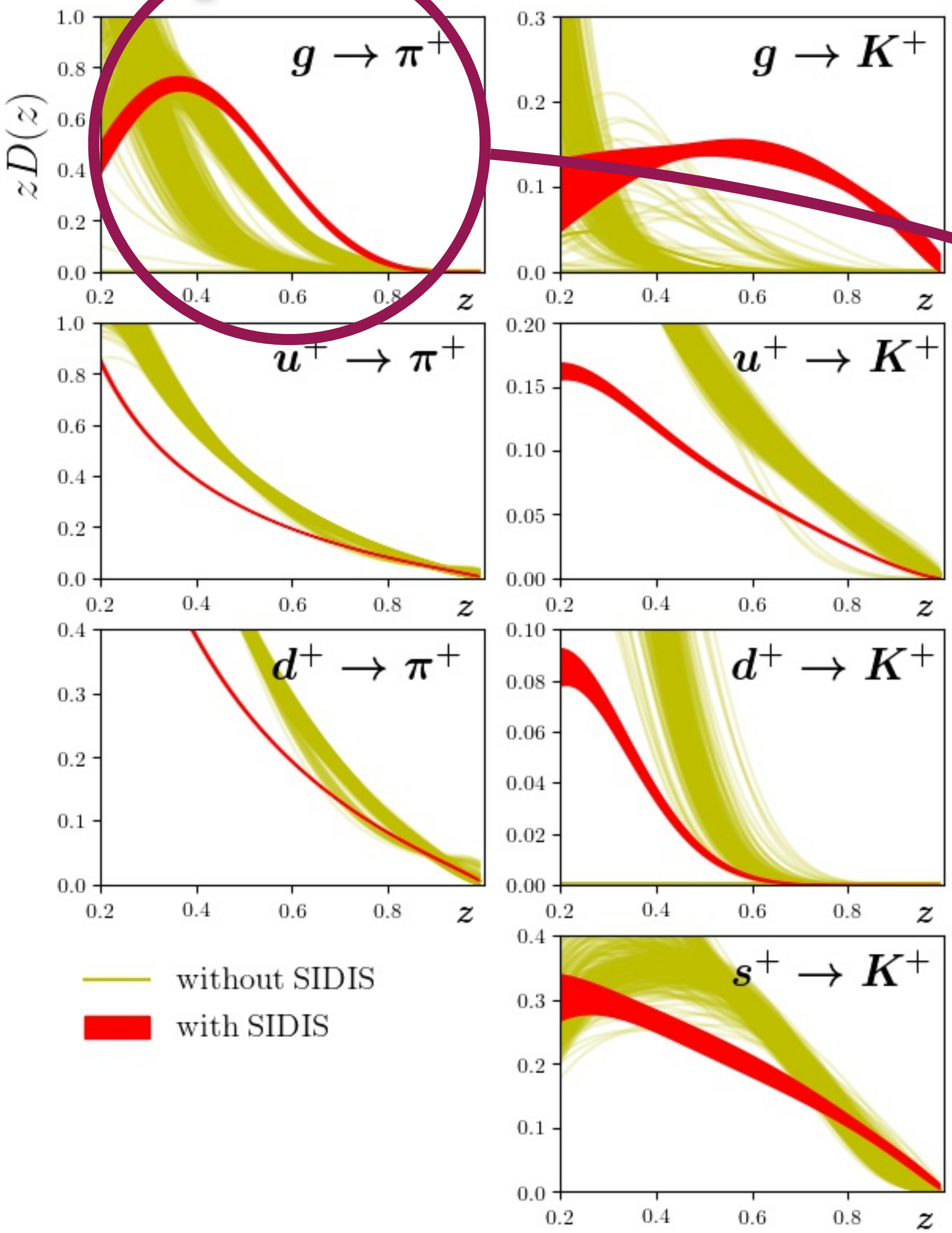
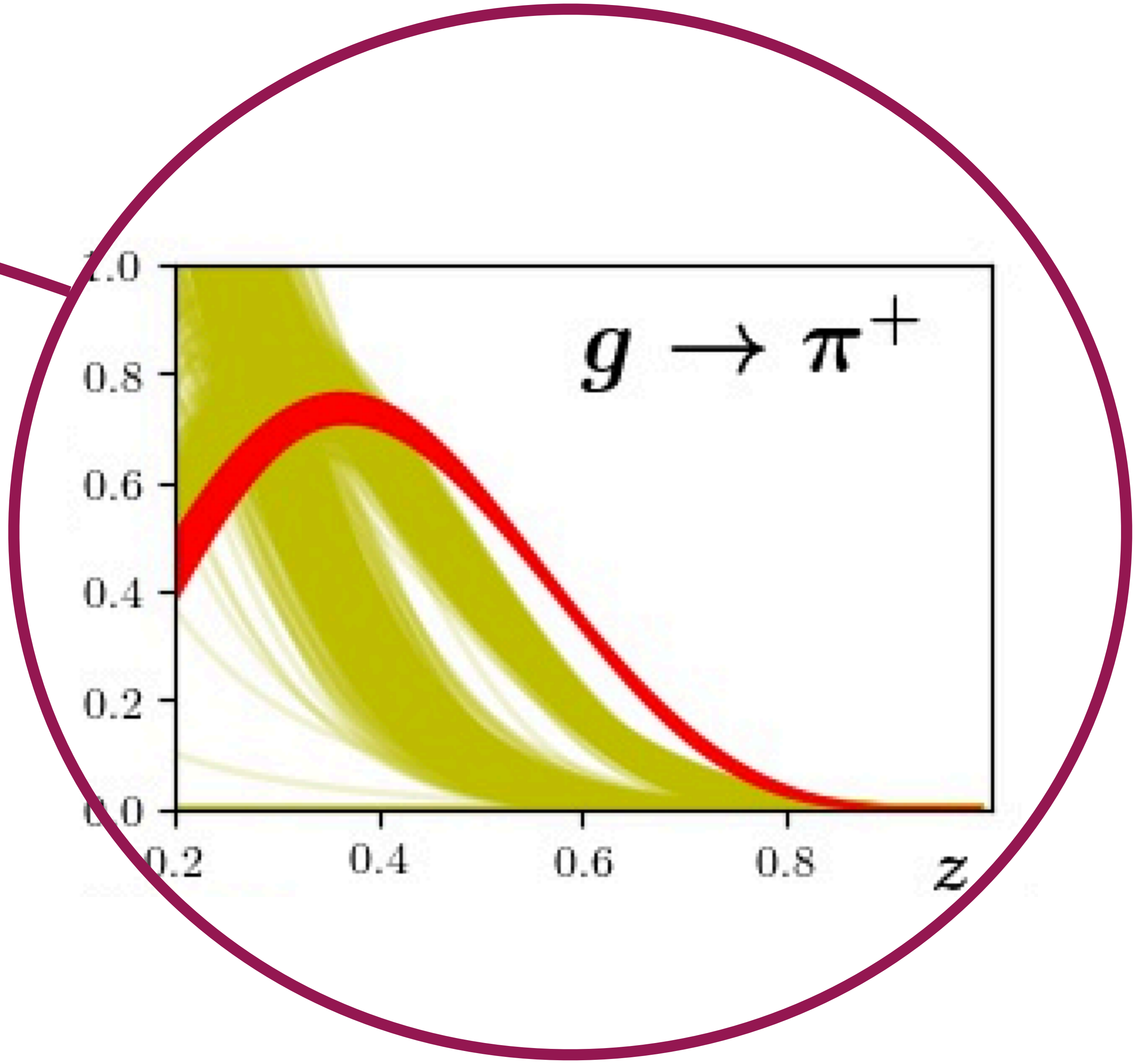


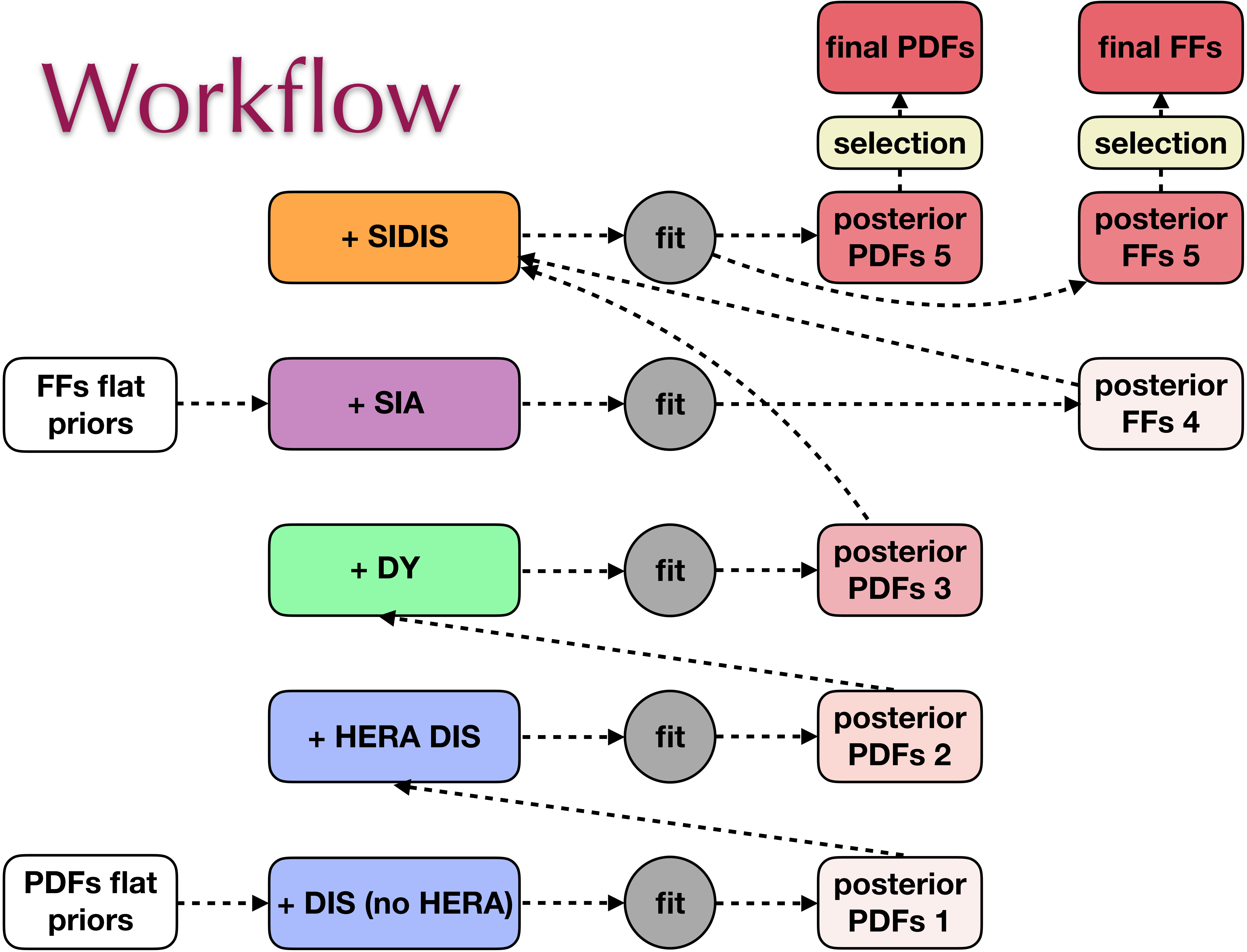


$\mathbf{Q = m_c}$

Constraints on
$g \to \pi^+$

JAM19 methodology

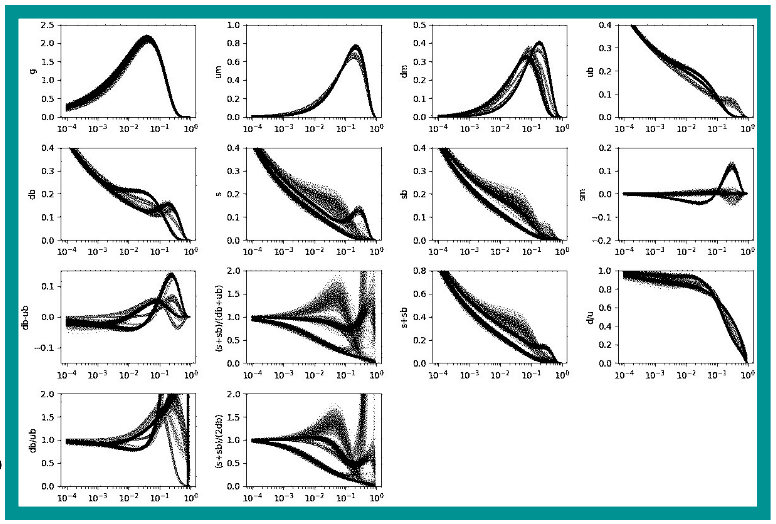
Workflow


final PDFs
final FFs
selection
selection
+ SIDIS
fit
posterior PDFs 5
posterior FFs 5
FFs flat priors
+ SIA
fit
posterior FFs 4
+ DY
fit
posterior PDFs 3
+ HERA DIS
fit
posterior PDFs 2
PDFs flat priors
+ DIS (no HERA)
fit
posterior PDFs 1

JAM 19: multi-step fitting

PDFs

$x\,f(x)$

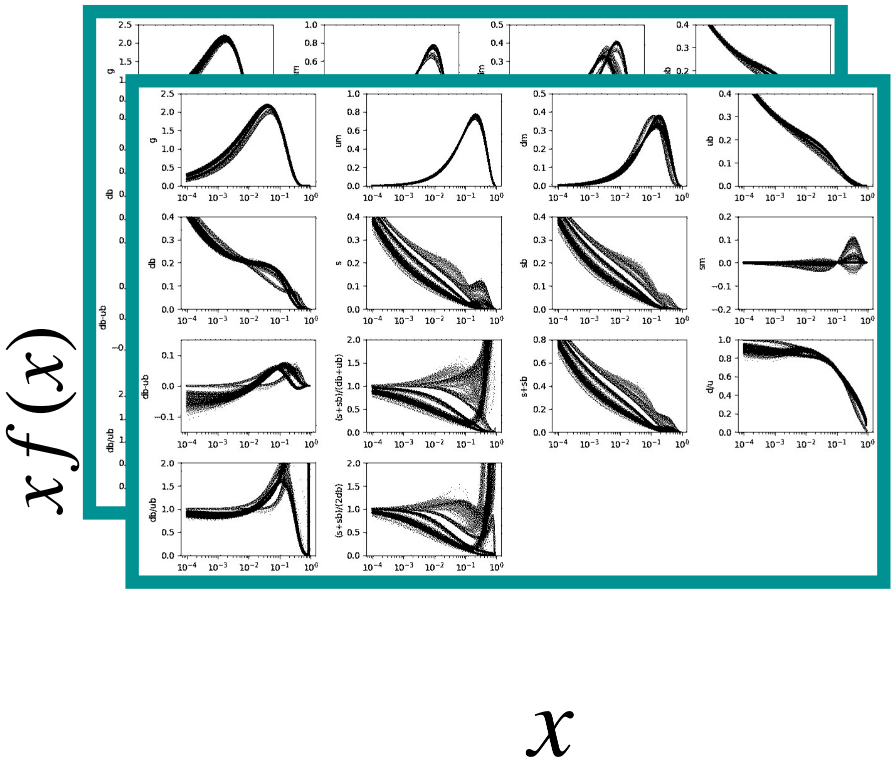


x

+ DIS data

JAM 19: multi-step fitting

PDFs

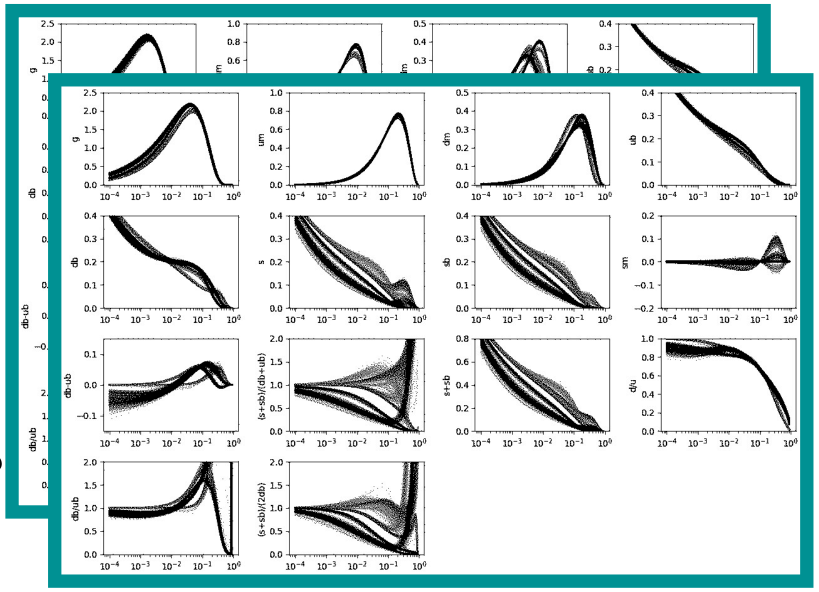


+ DIS data

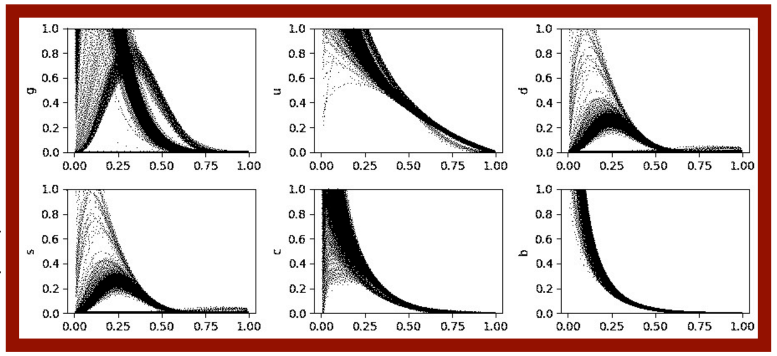
+ DIS + DY data

JAM 19: multi-step fitting

PDFs



PION FF



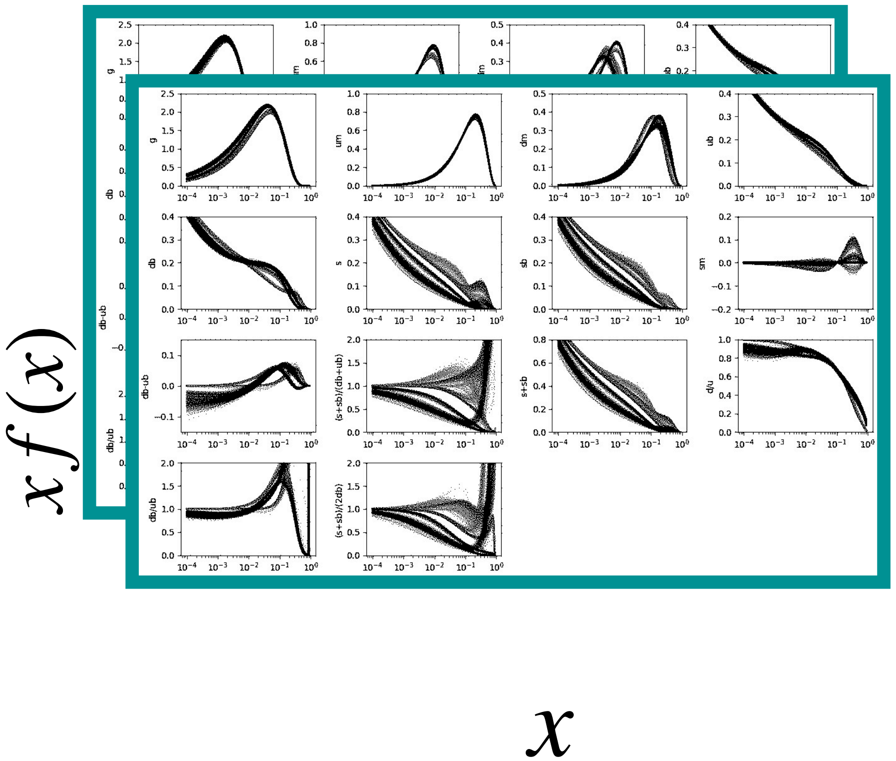
+ DIS data

+ DIS + DY data

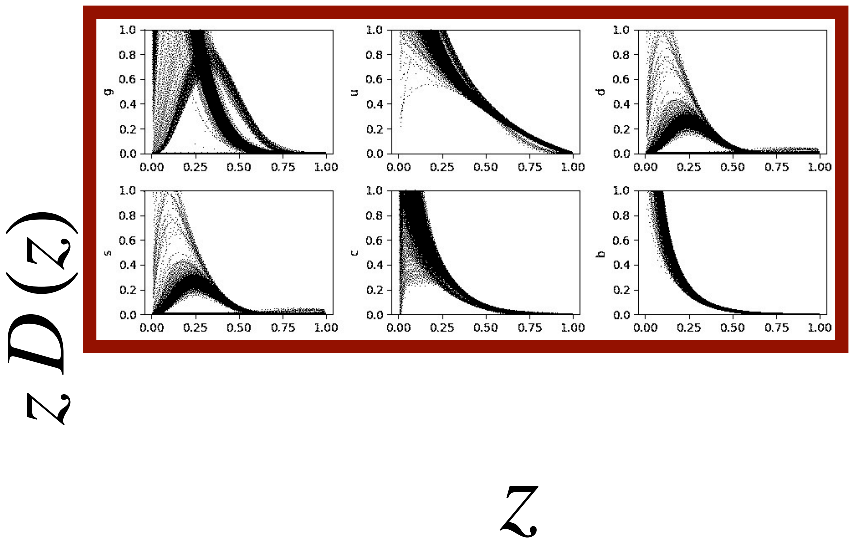
+ SIA pion data

JAM 19: multi-step fitting

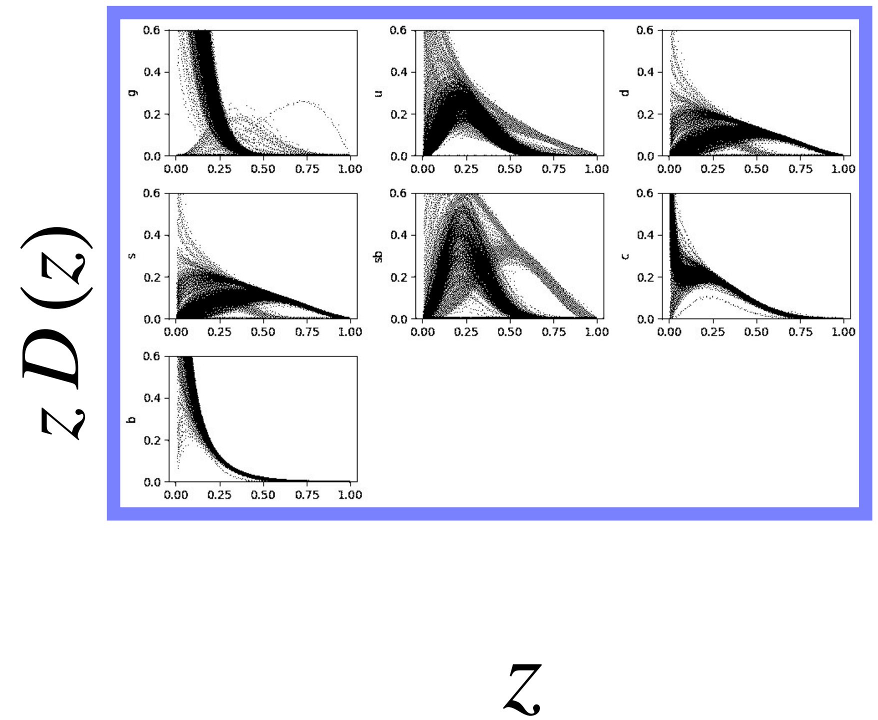
PDFs



PION FF



KAON FF



+ DIS data

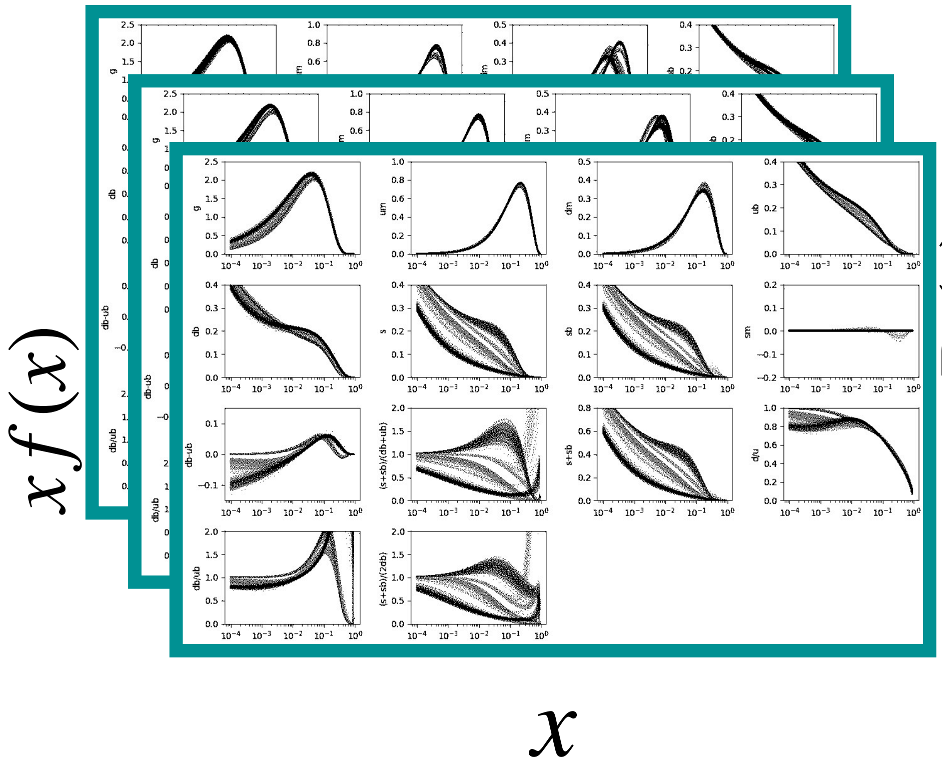
+ DIS + DY data

+ SIA pion data

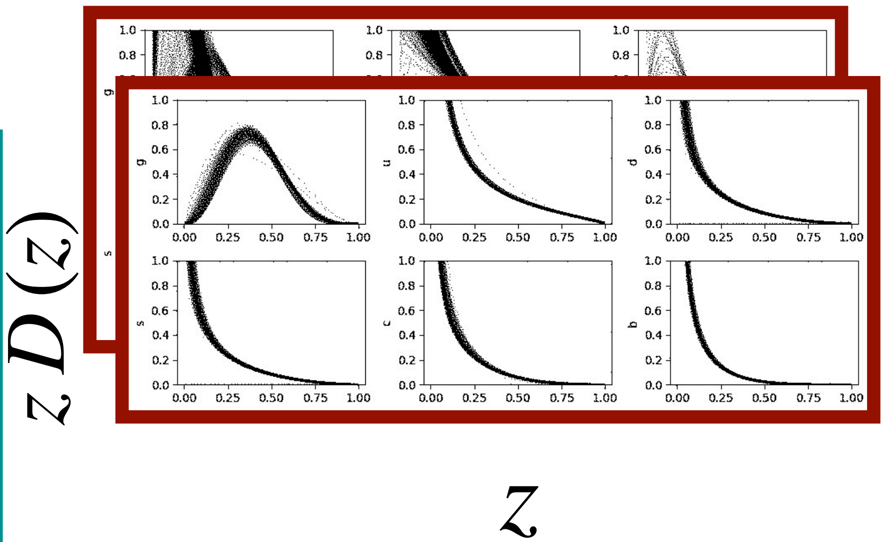
+ SIA kaon data

JAM 19: multi-step fitting

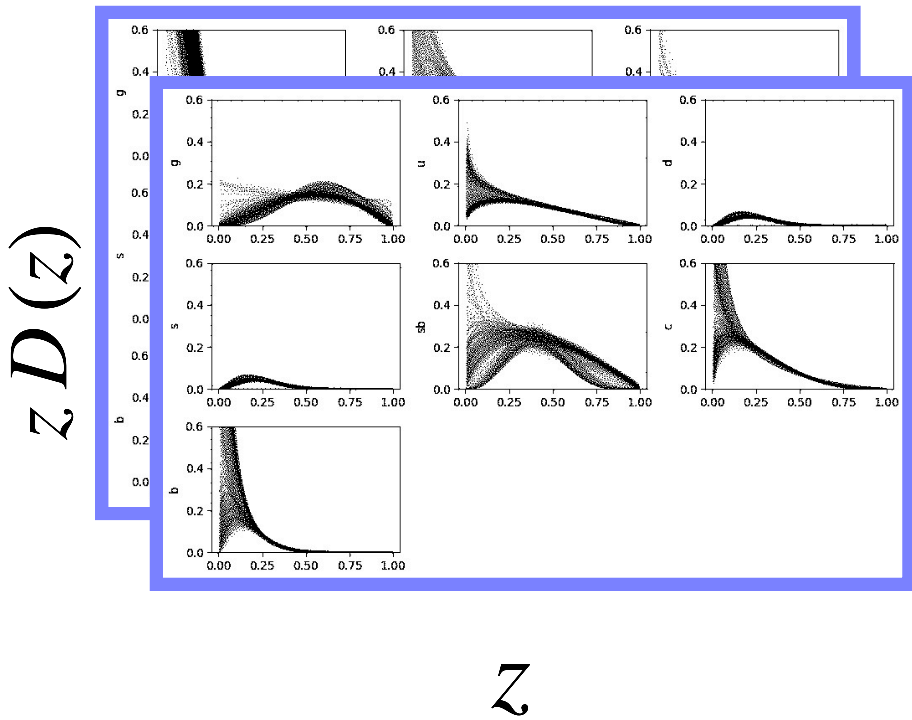
PDFs



PION FF



KAON FF



+ DIS data

+ DIS + DY data

+ SIDIS data

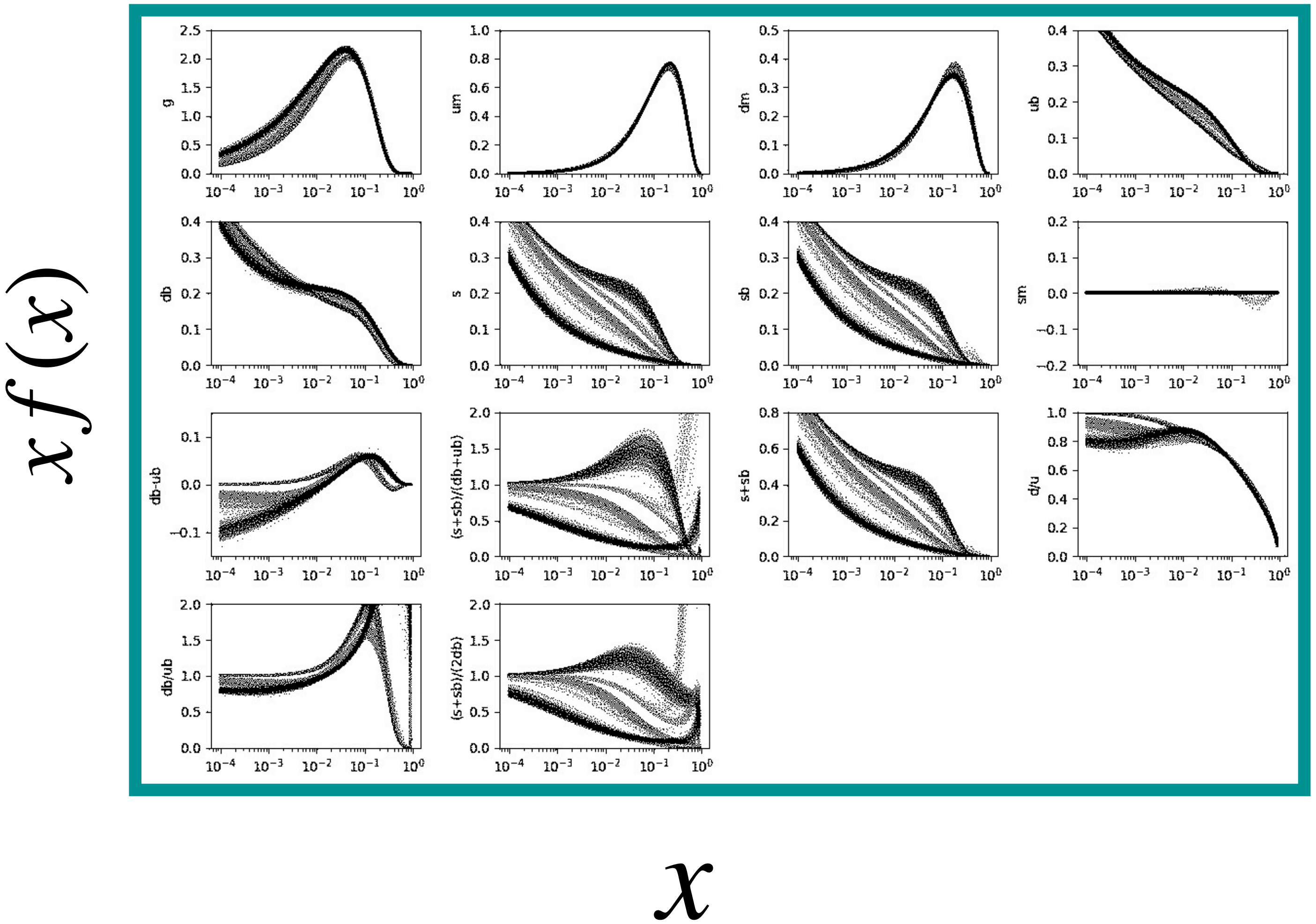
+ SIA pion data

+ SIDIS pion data

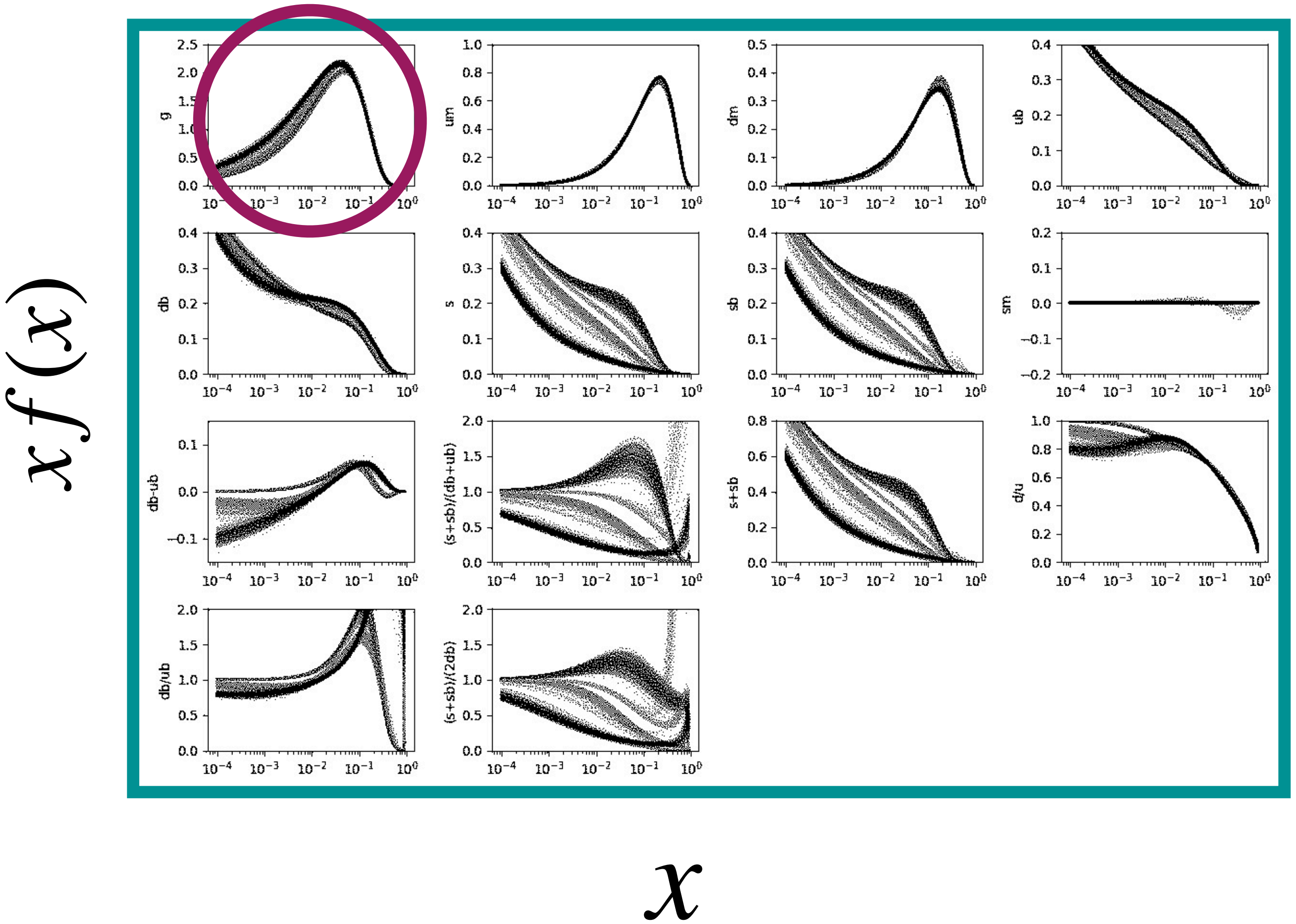
+ SIA kaon data

+ SIDIS kaon data

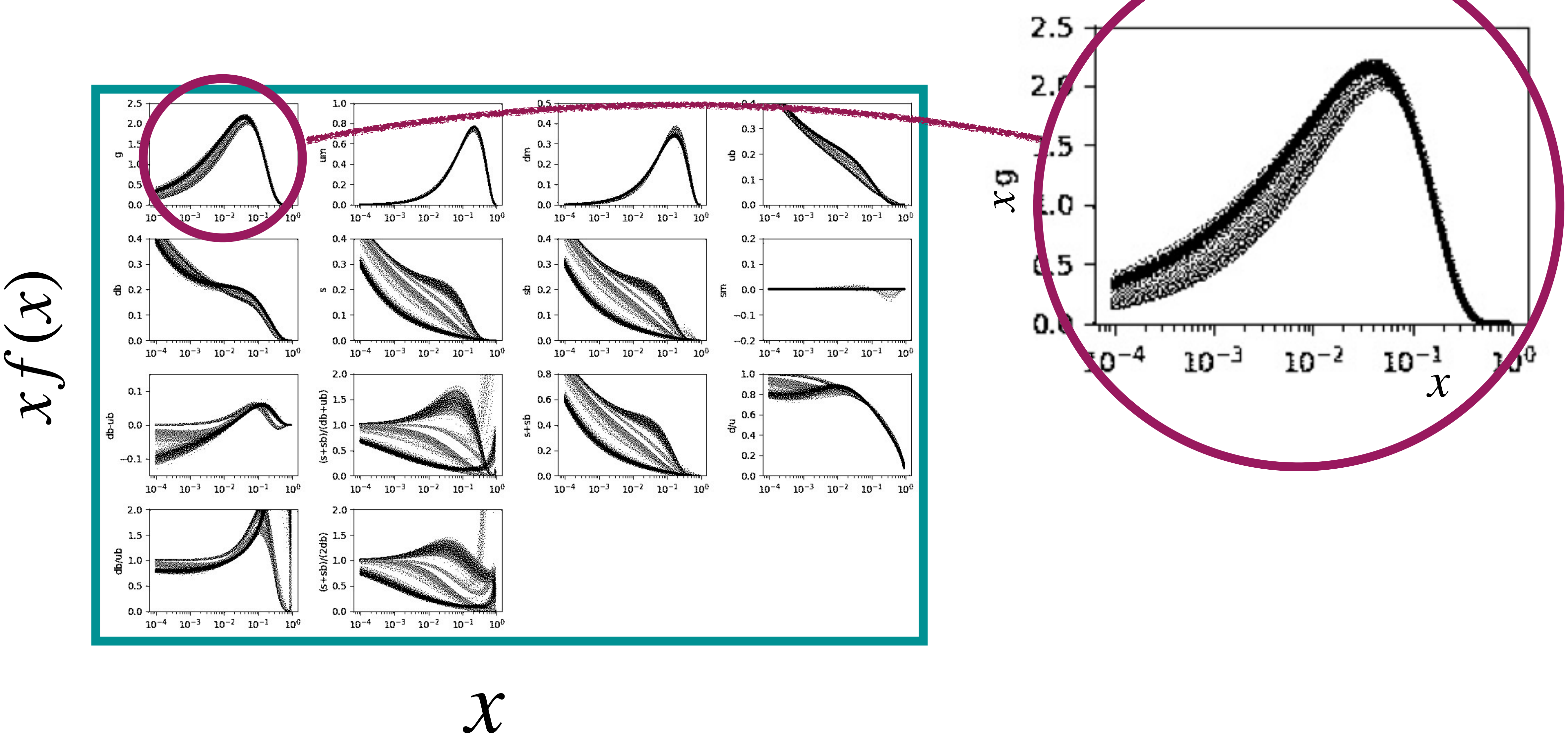
Discrminating multiple solutions



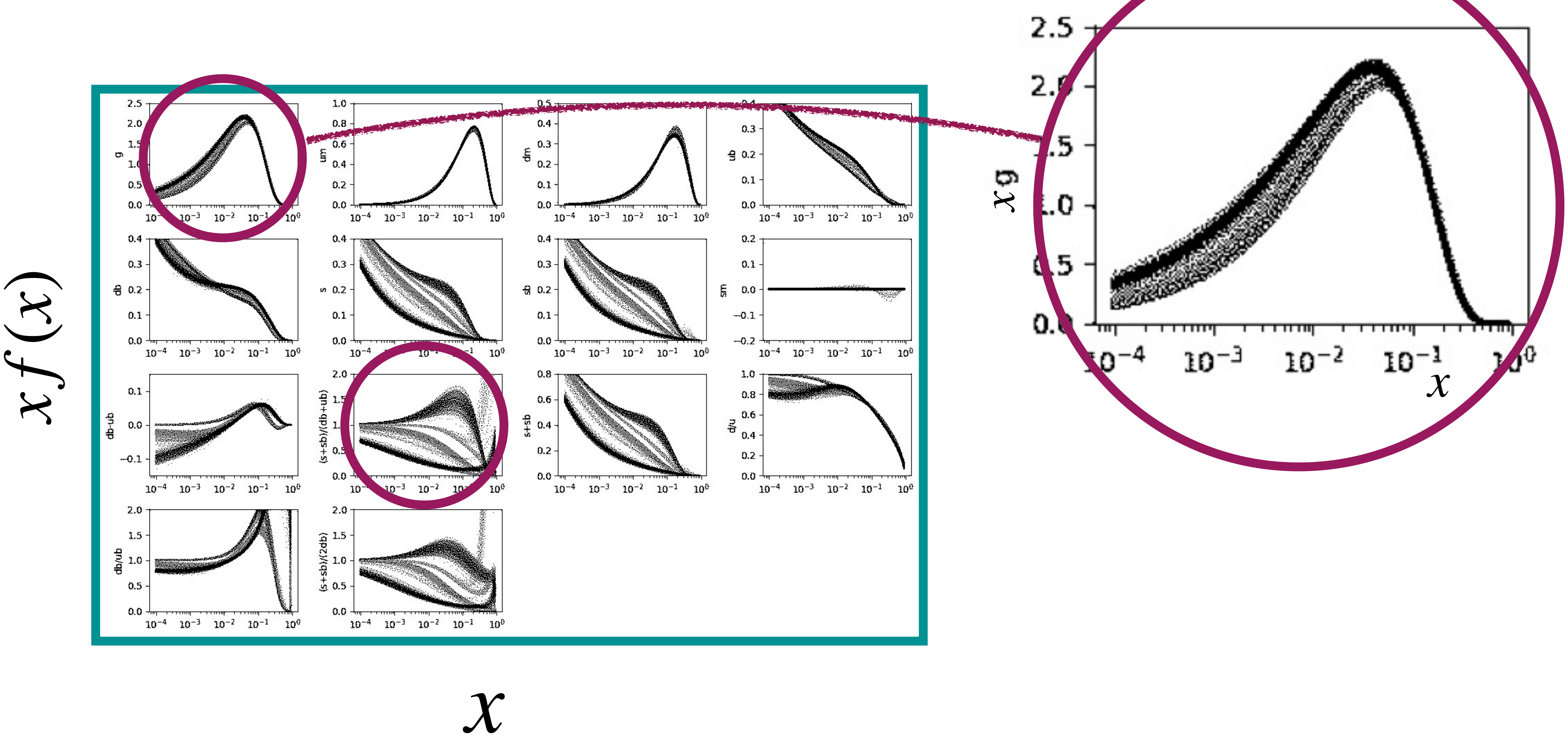
Discrminating multiple solutions



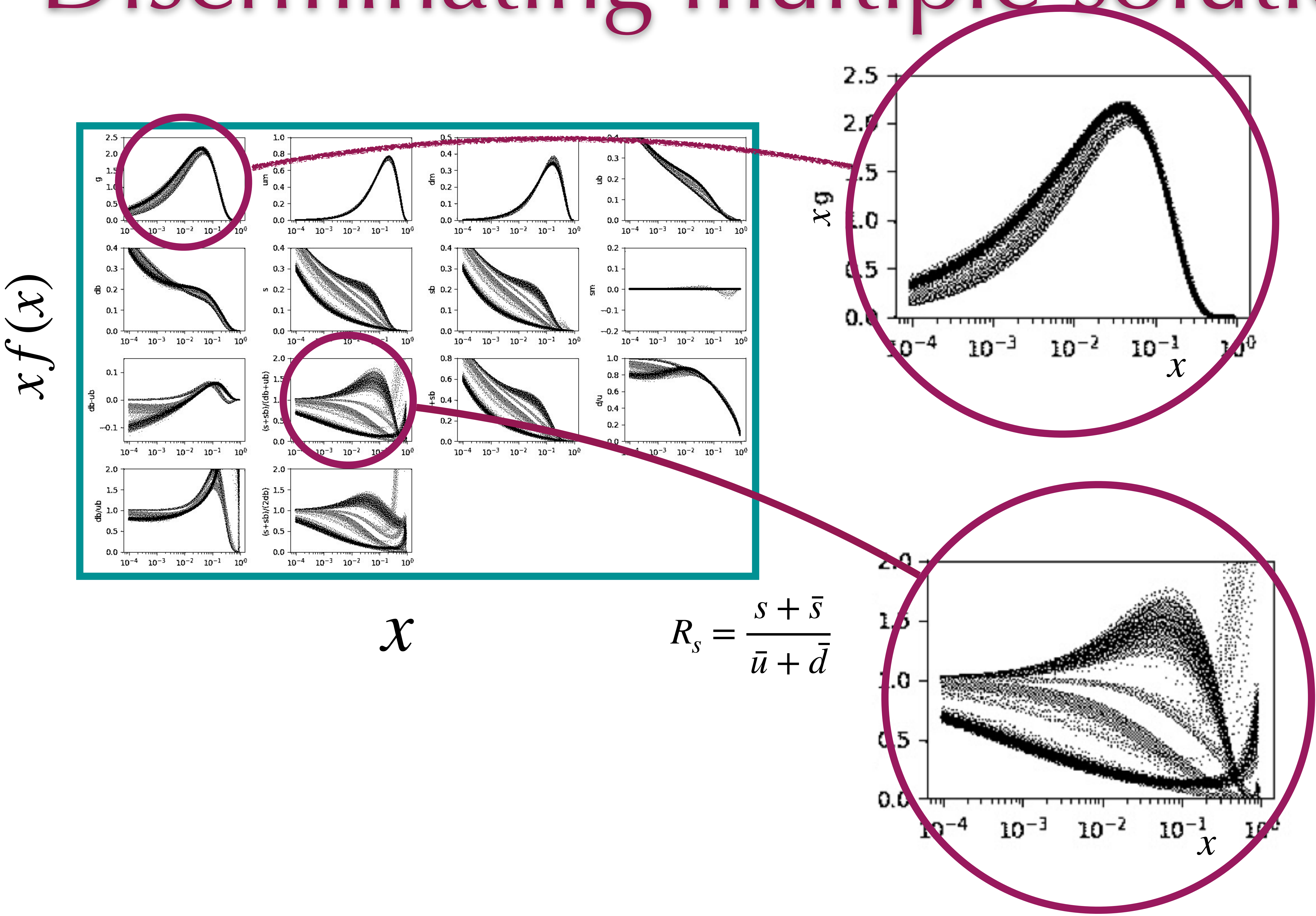
Discrminating multiple solutions



Discrminating multiple solutions



Discrminating multiple solutions

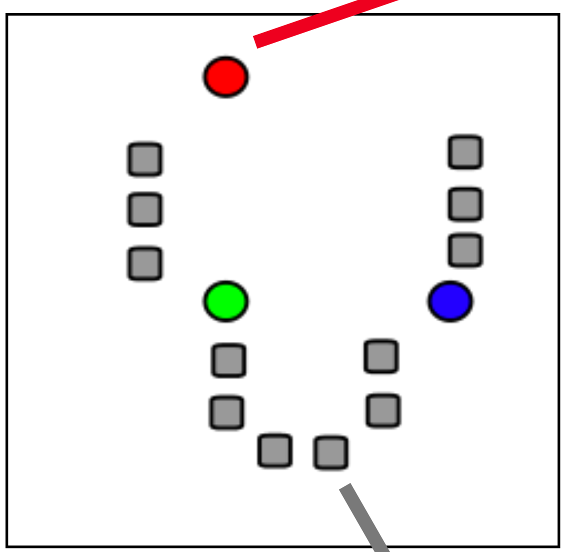


$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

k-means clustering

E.g. $f(x) = x^{\alpha}(1-x)^{\beta}$

(α^*, β^*) : centroid

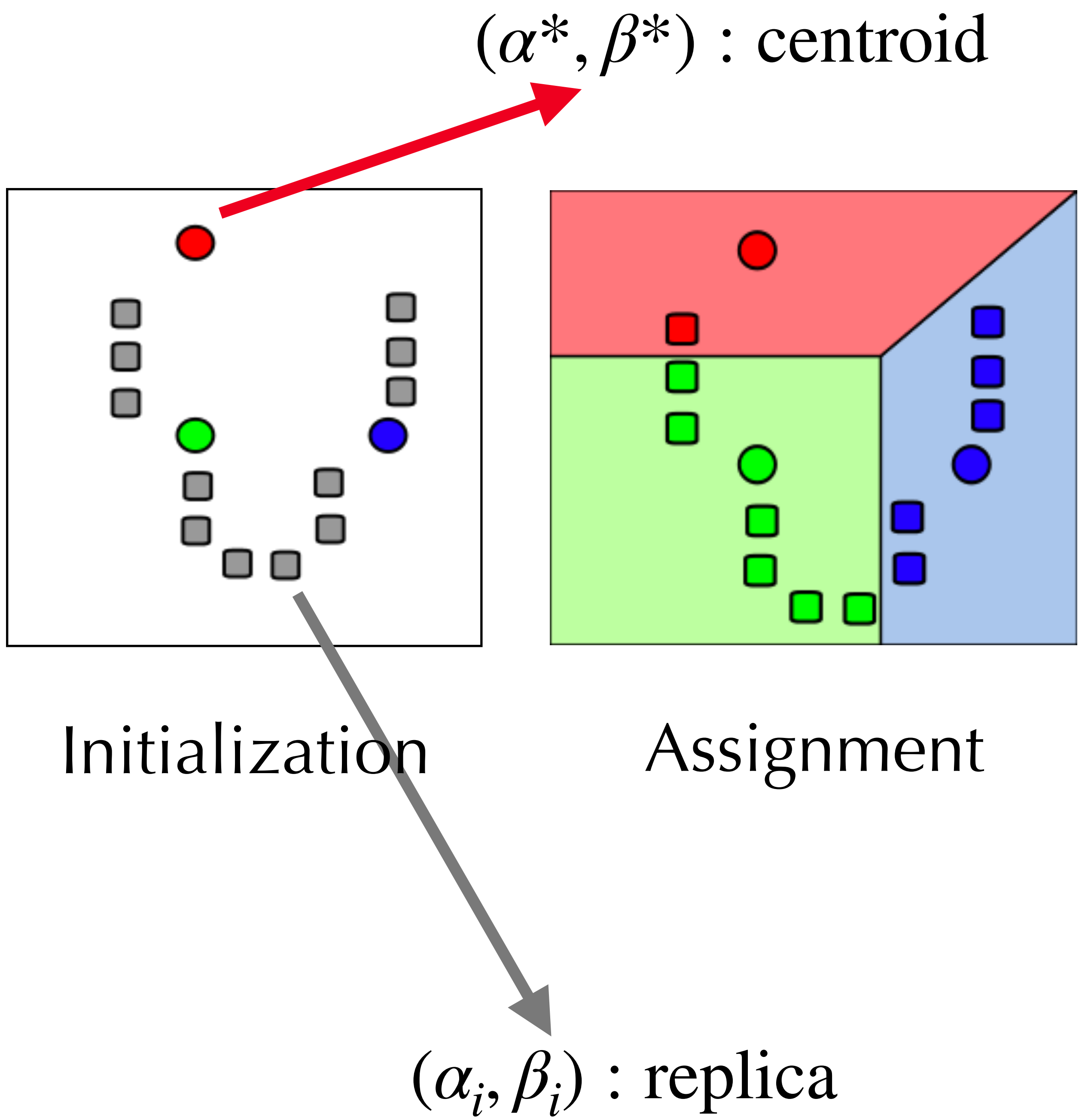


Initialization

(α_i, β_i) : replica

k-means clustering

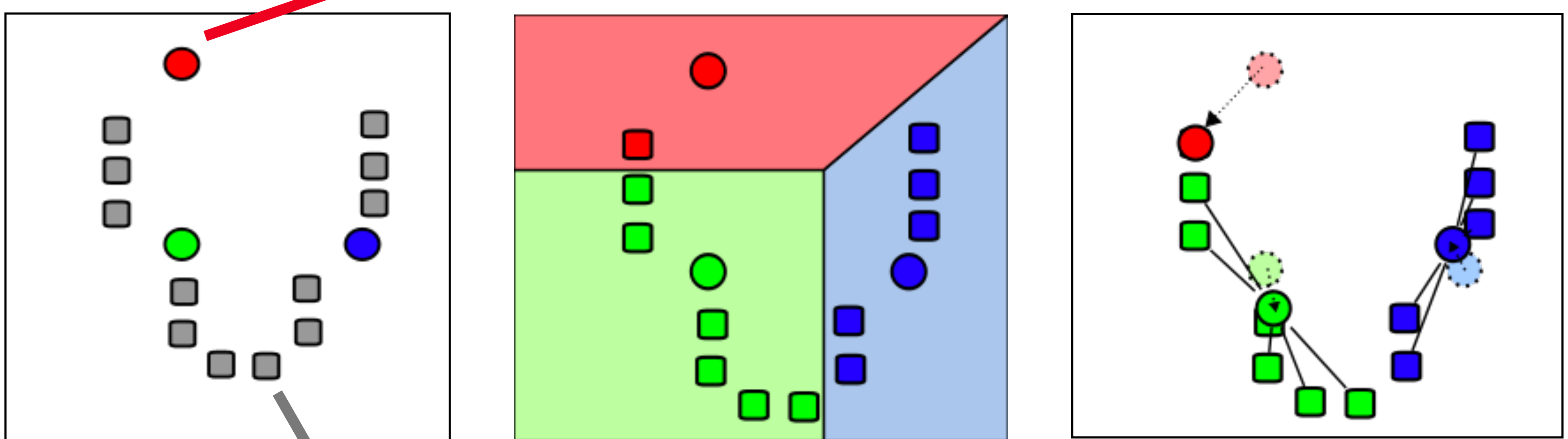
E.g. $f(x) = x^{\alpha}(1-x)^{\beta}$



k-means clustering

E.g. $f(x) = x^{\alpha}(1-x)^{\beta}$

(α^*, β^*) : centroid



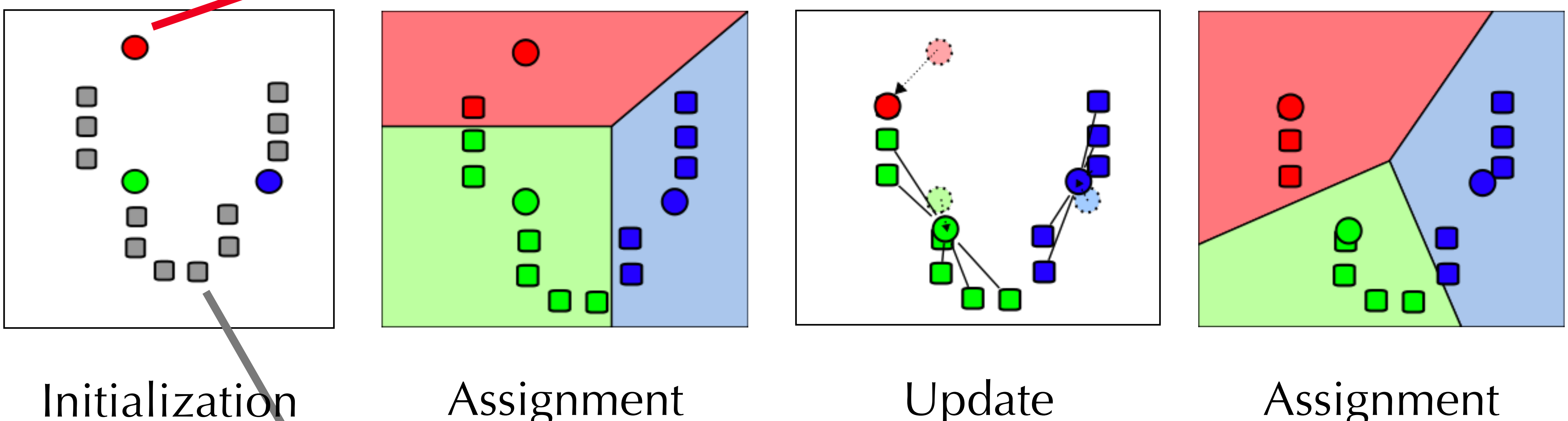
Initialization Assignment Update

(α_i, β_i) : replica

k-means clustering

E.g. $f(x) = x^{\alpha}(1-x)^{\beta}$

(α^*, β^*) : centroid

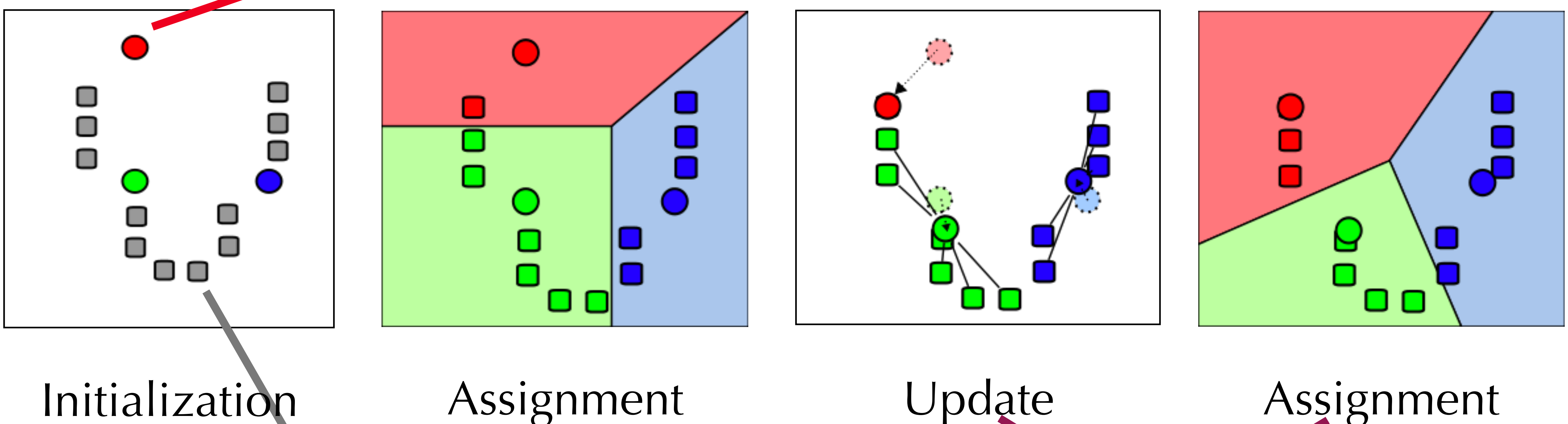


(α_i, β_i) : replica

k-means clustering

E.g. $f(x) = x^{\alpha}(1-x)^{\beta}$

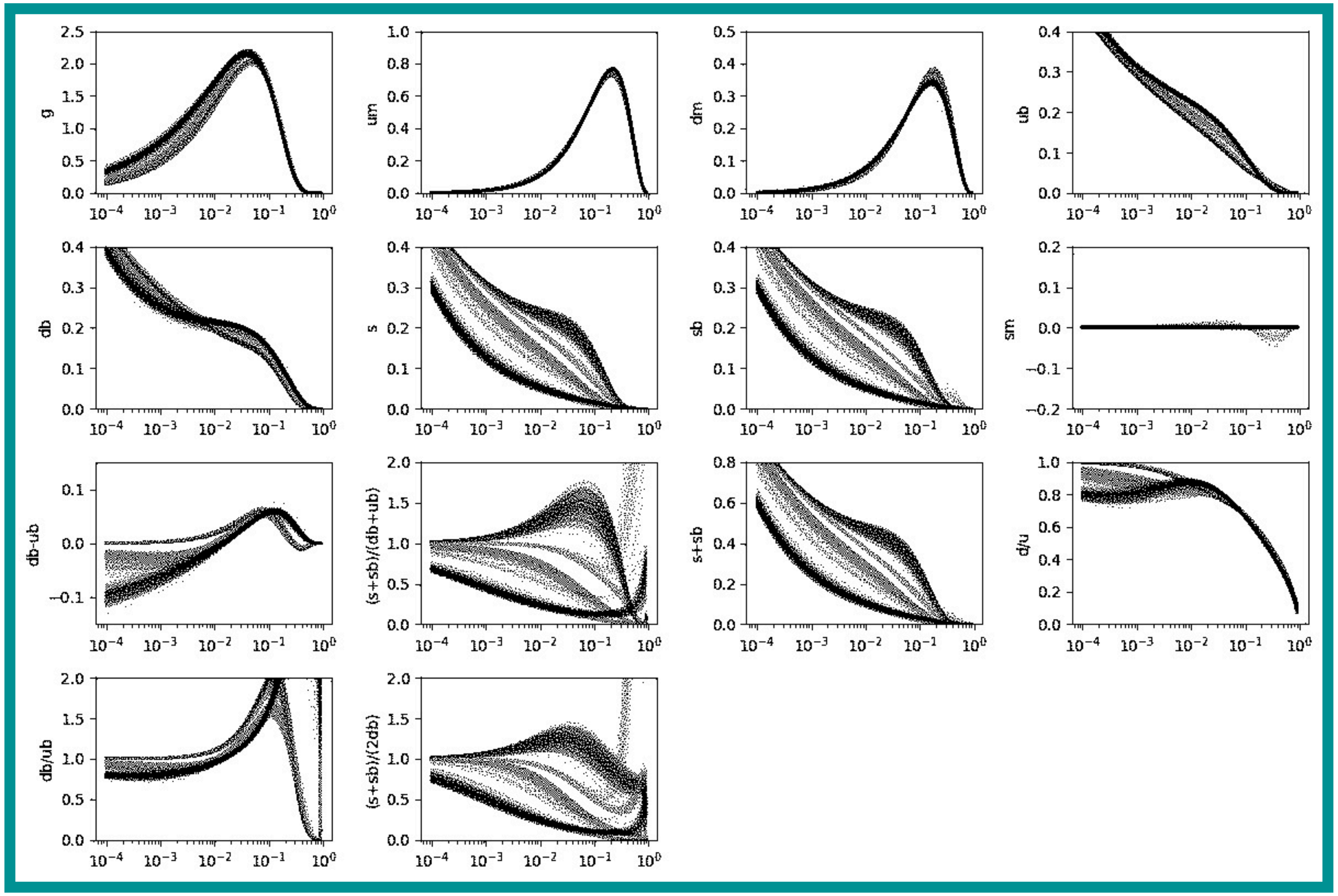
(α^*, β^*) : centroid



Repeat until convergence

(α_i, β_i) : replica

Discriminating multiple solutions

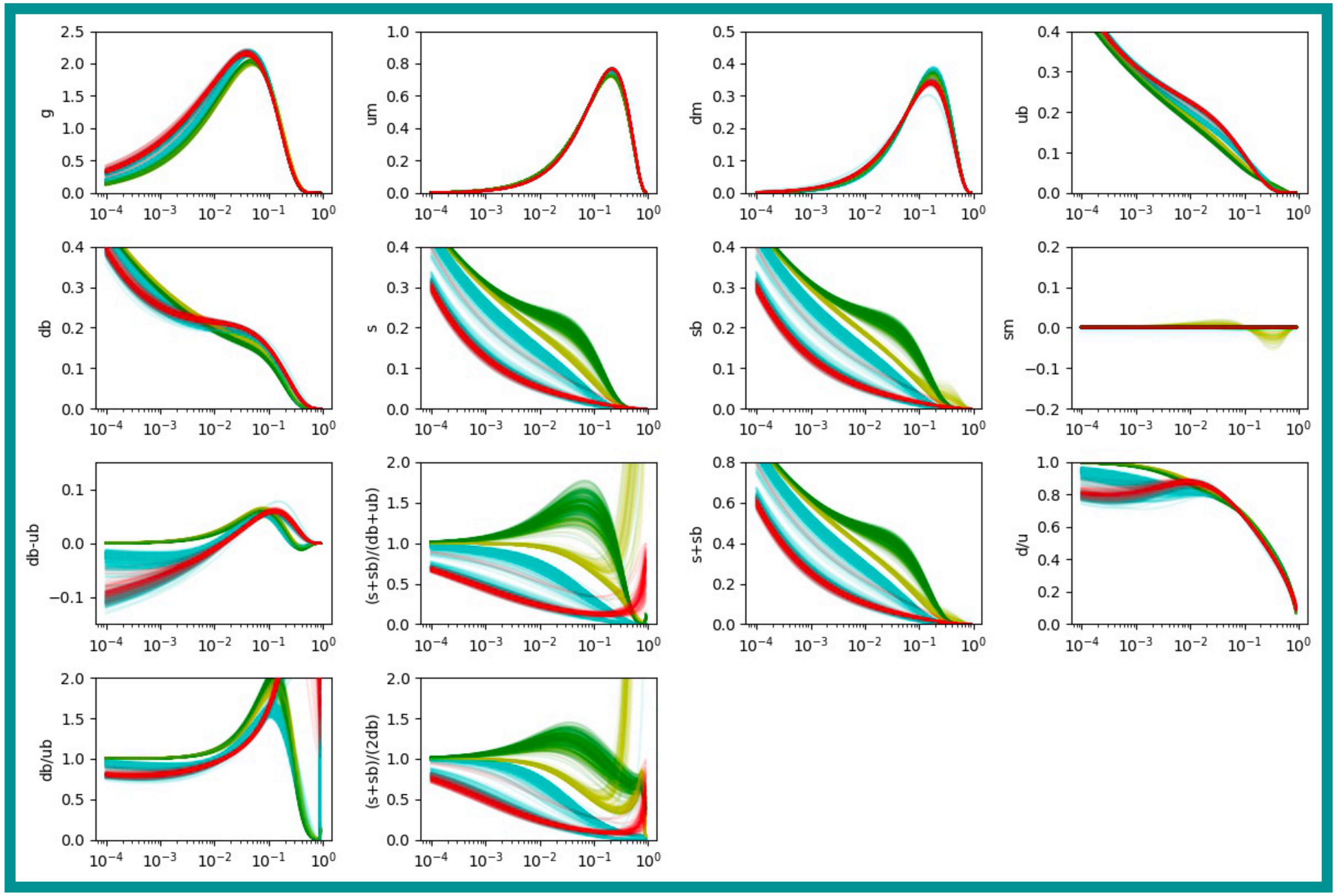


+ DIS data

+ DIS + DY data

+ SIDIS data

Discriminating multiple solutions



+ DIS data

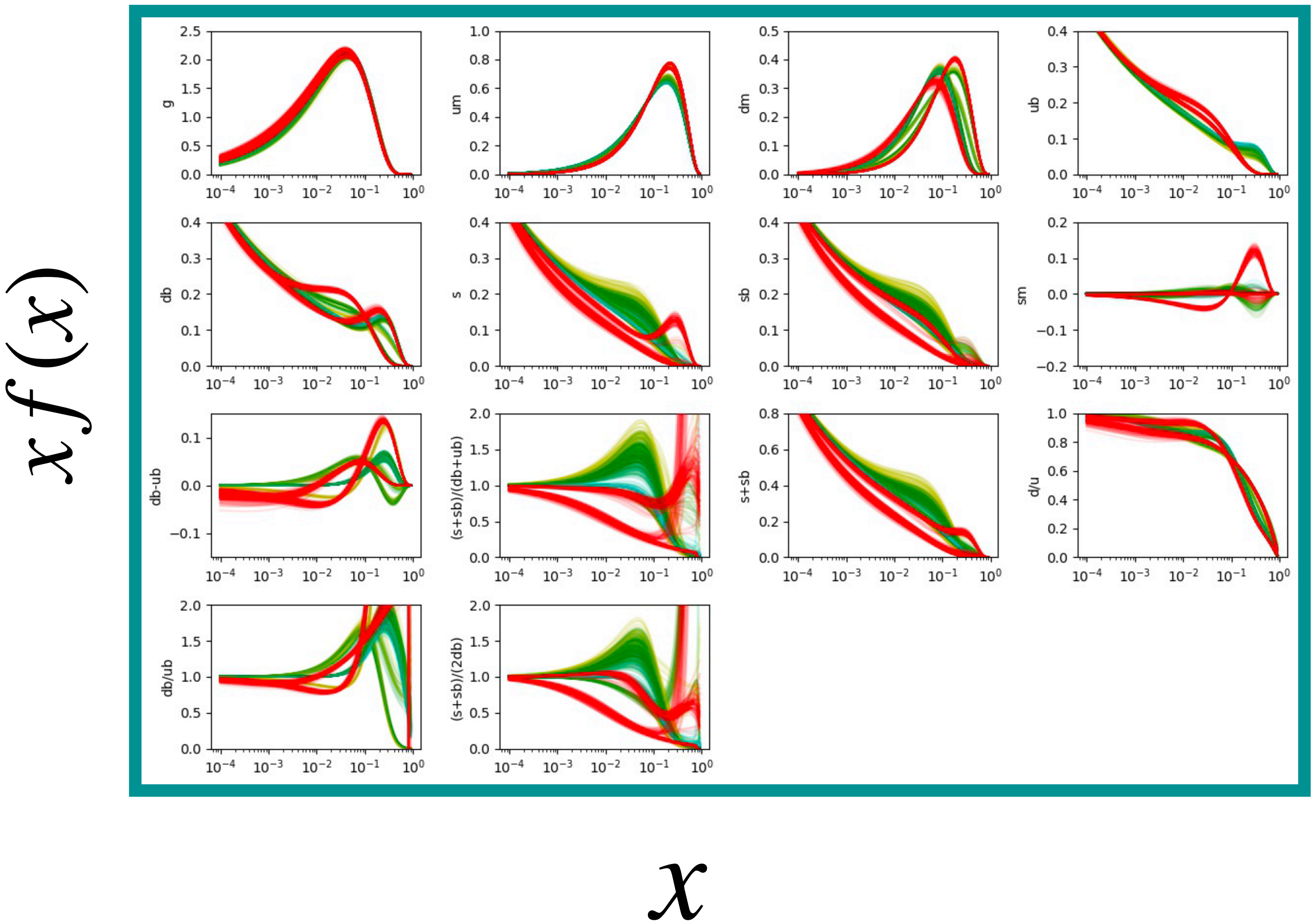
+ DIS + DY data

+ SIDIS data

Constraints on Rs

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs

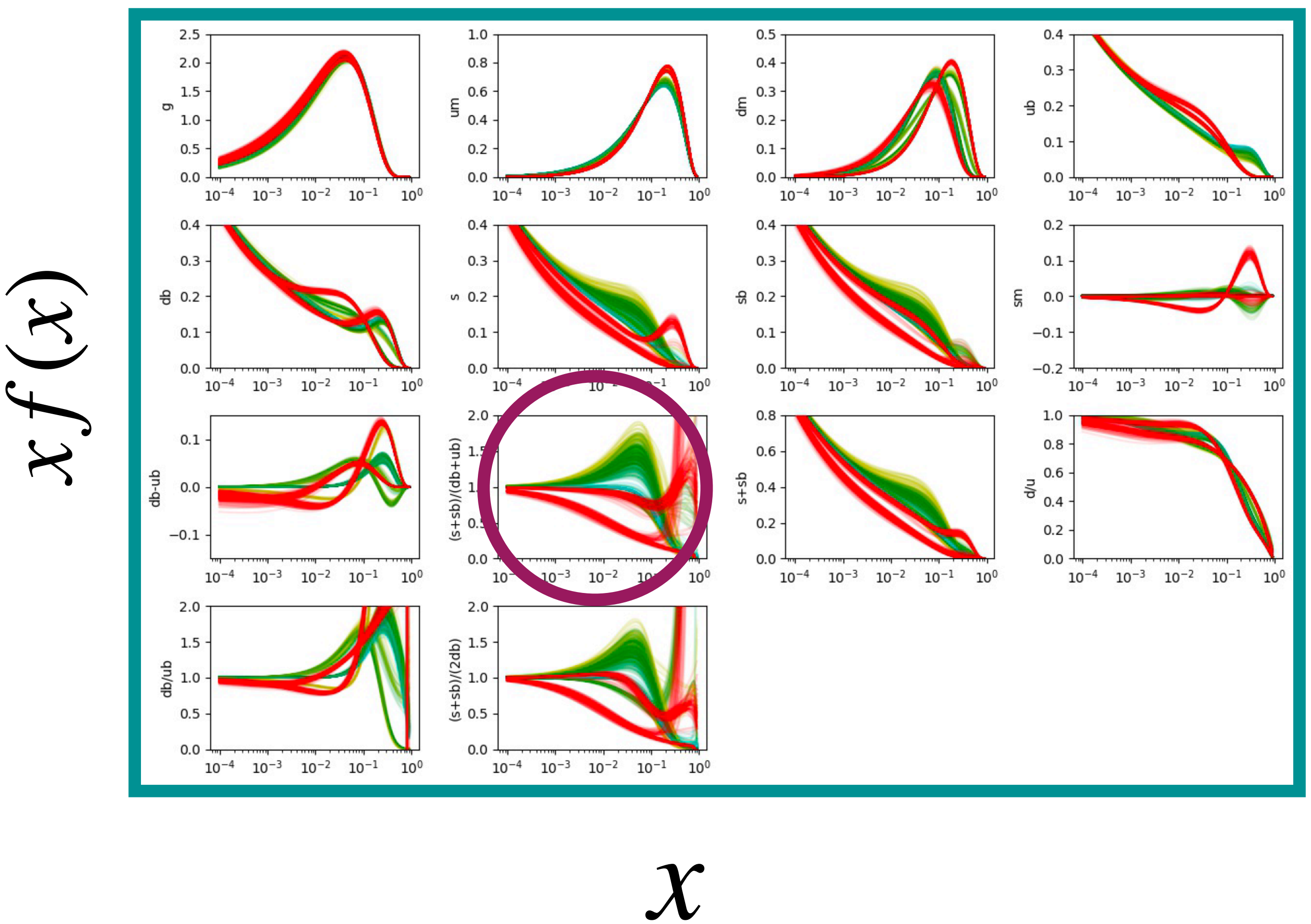


+ DIS data

Constraints on Rs

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs

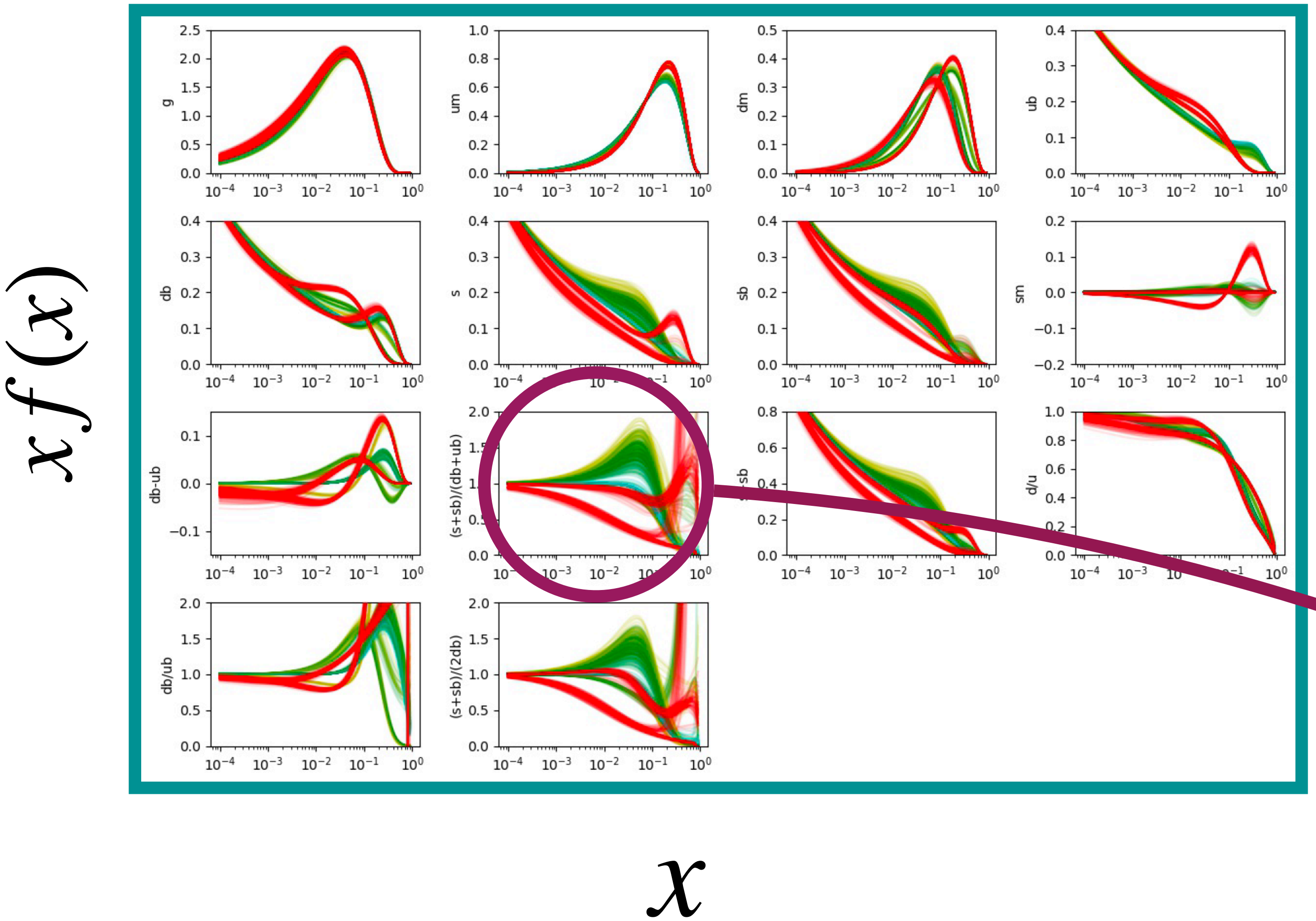


+ DIS data

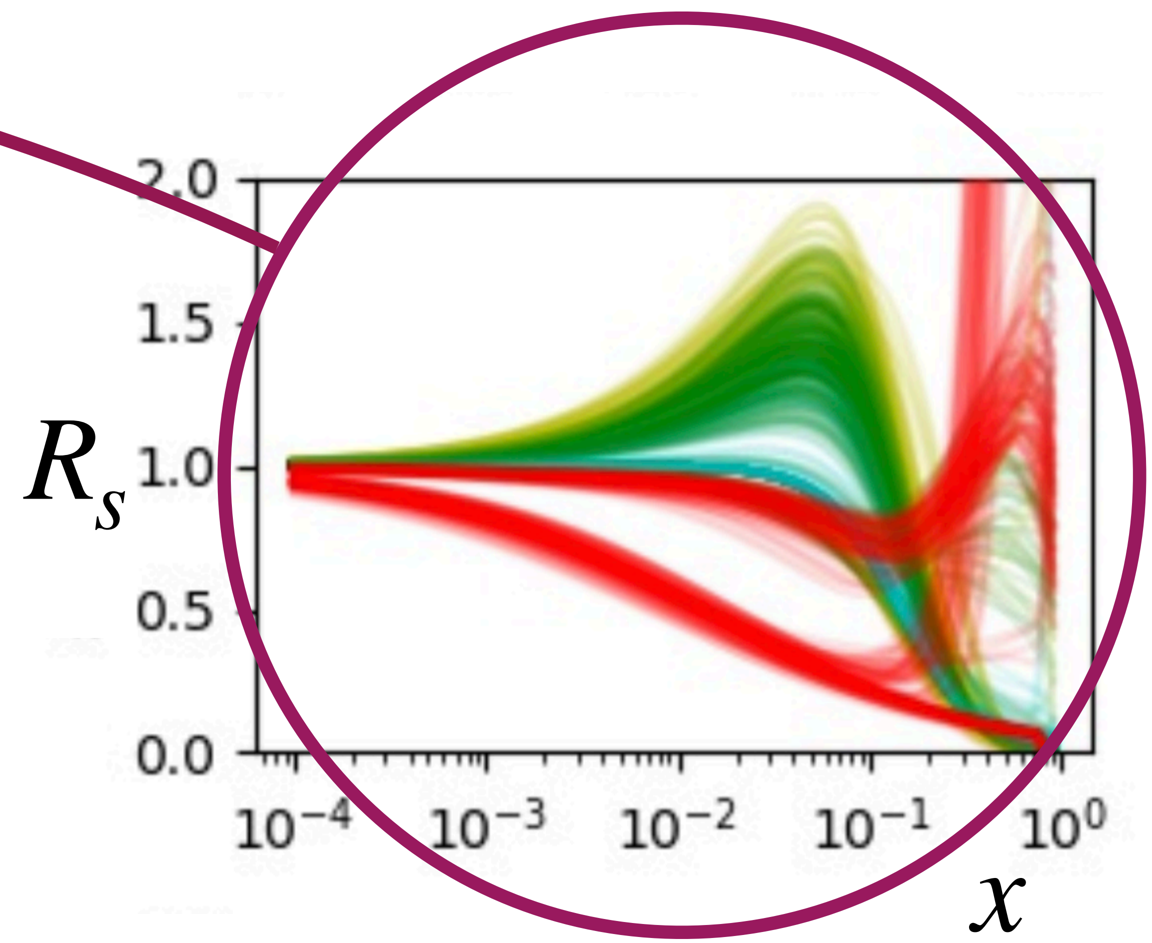
Constraints on Rs

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs



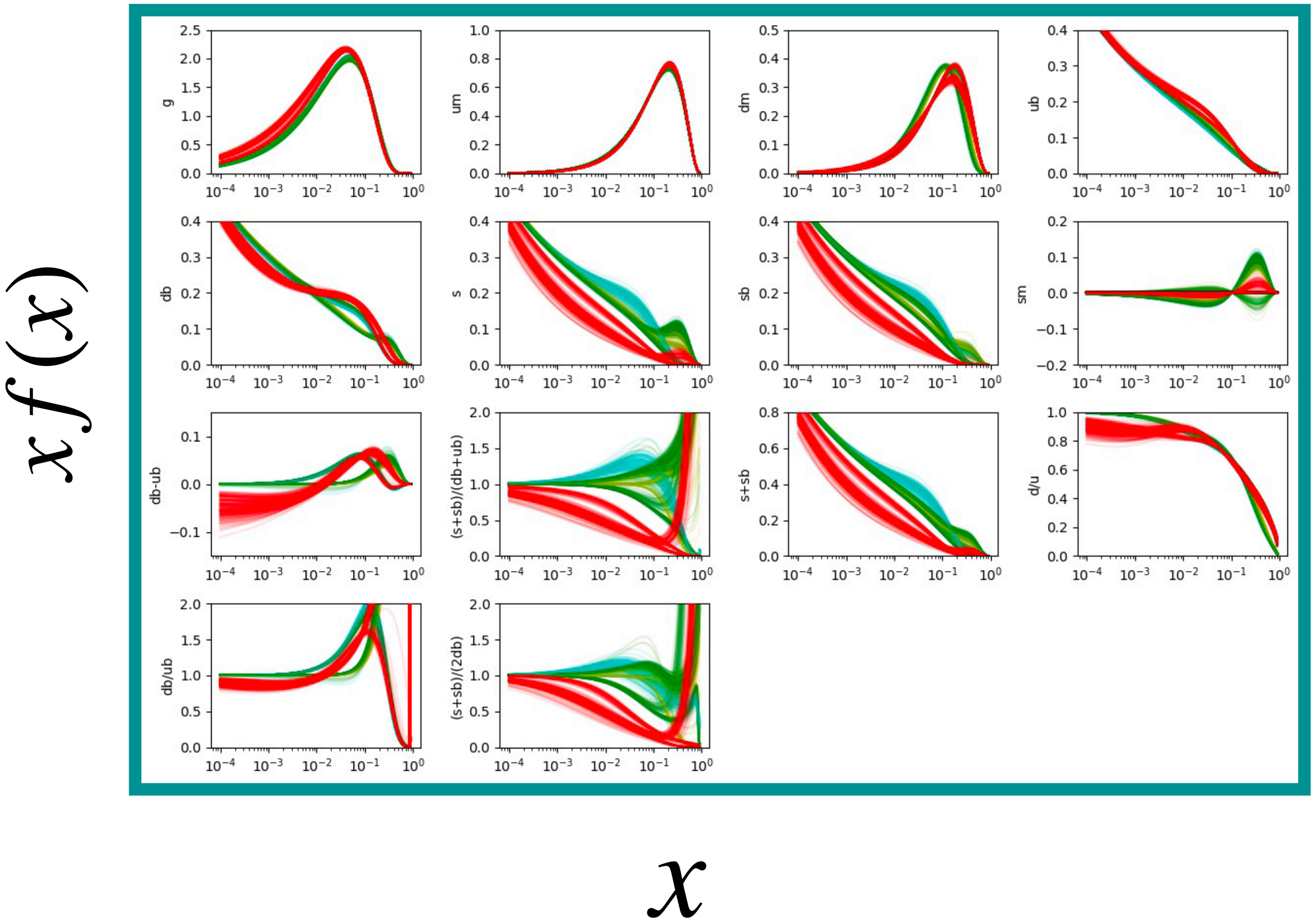
+ DIS data



Constraints on Rs

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs



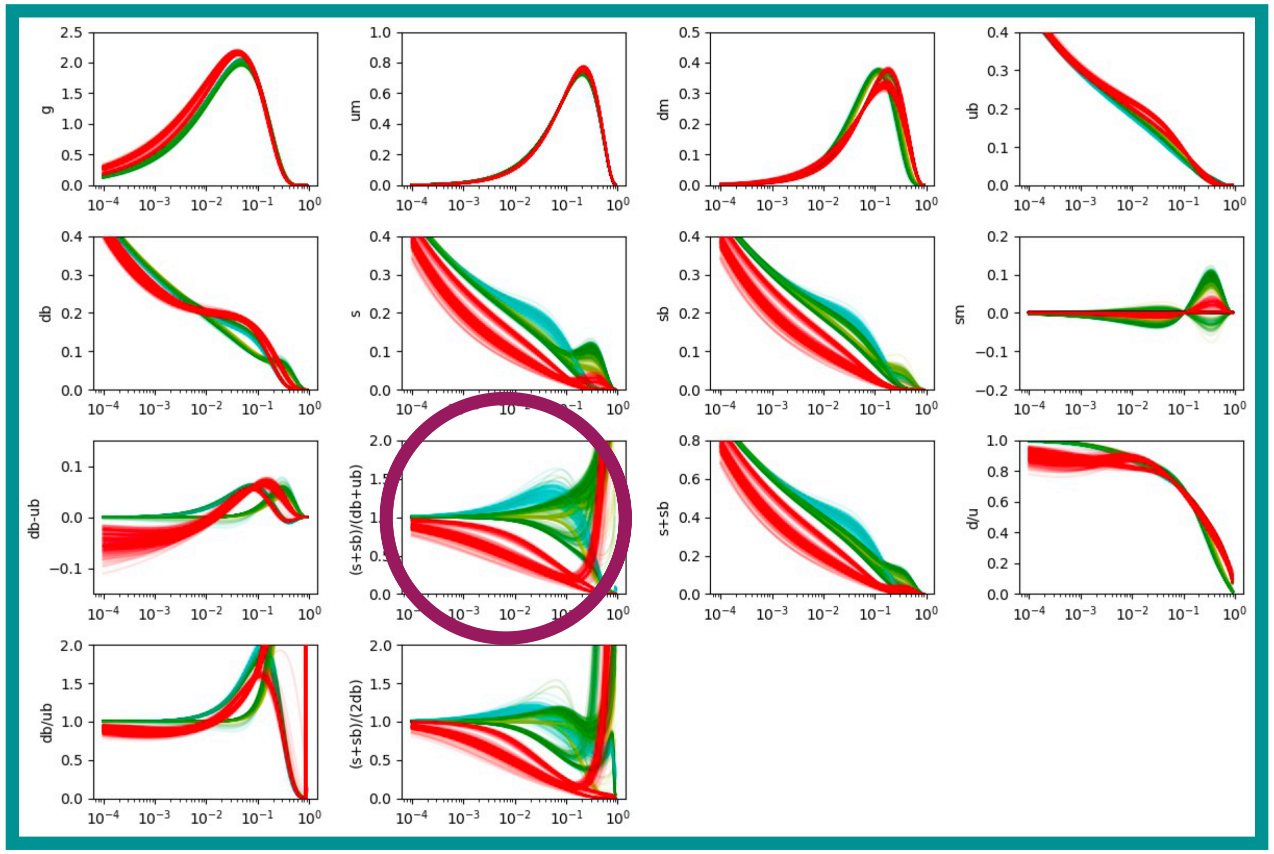
+ DIS data
+ DY data

Constraints on Rs

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs

$x\,f(x)$



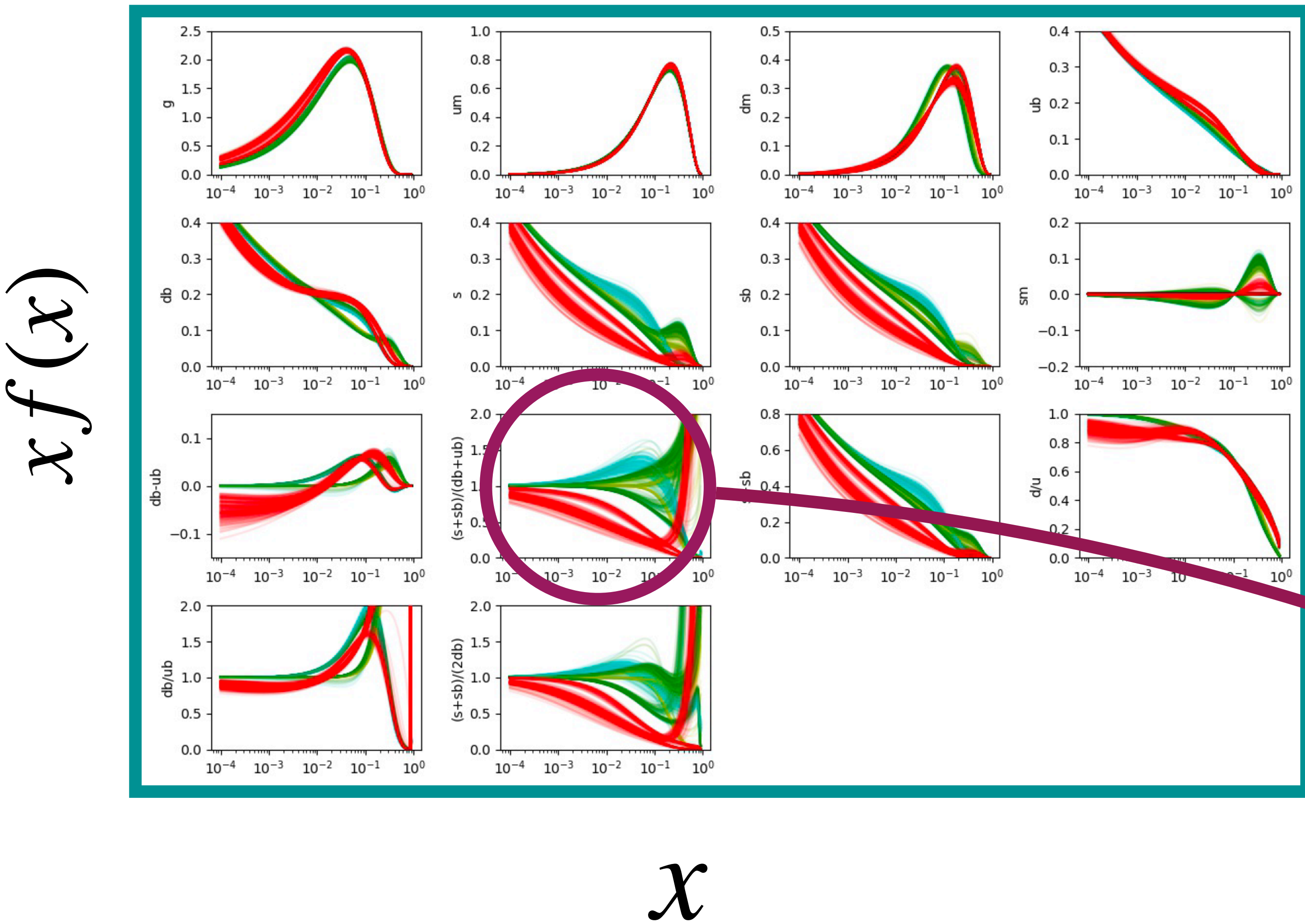
x

+ DIS data
+ DY data

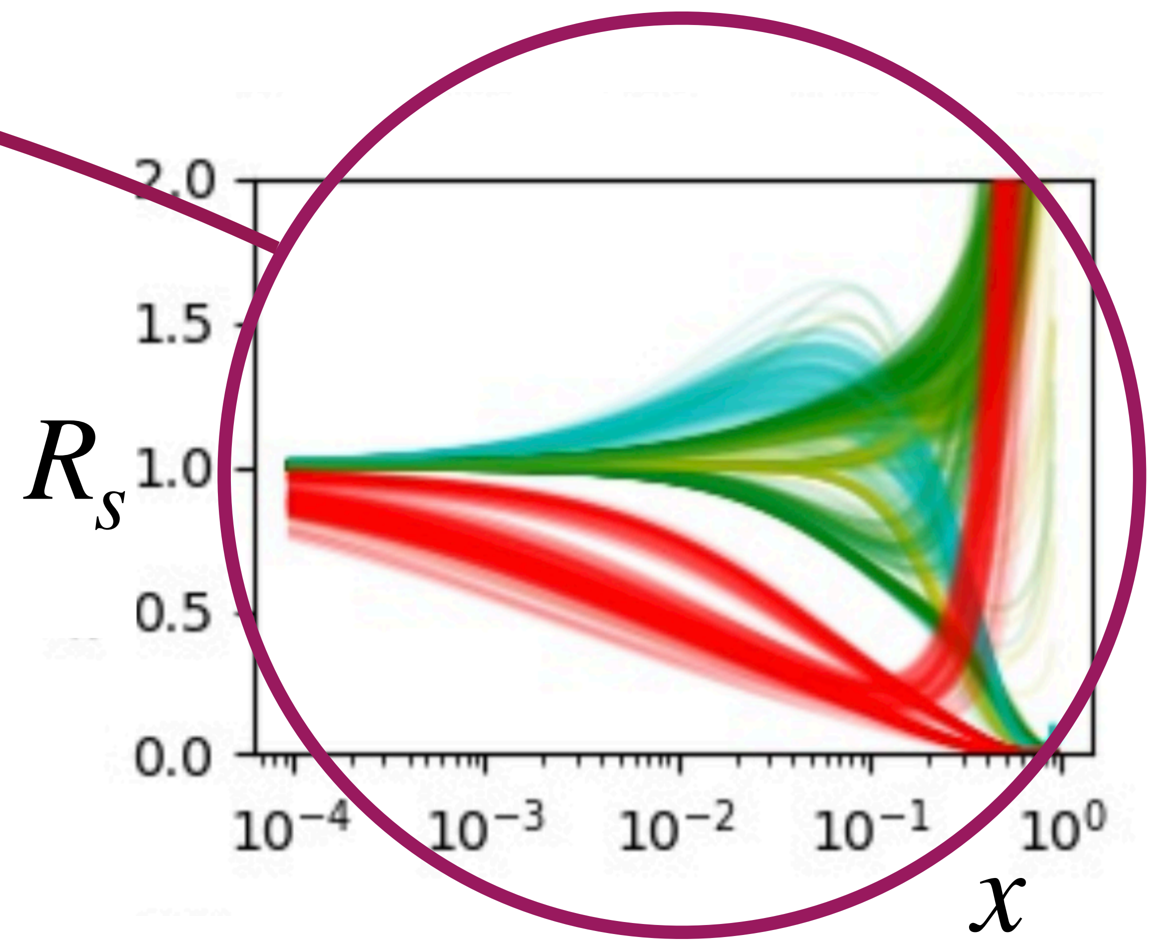
Constraints on Rs

$$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$$

PDFs



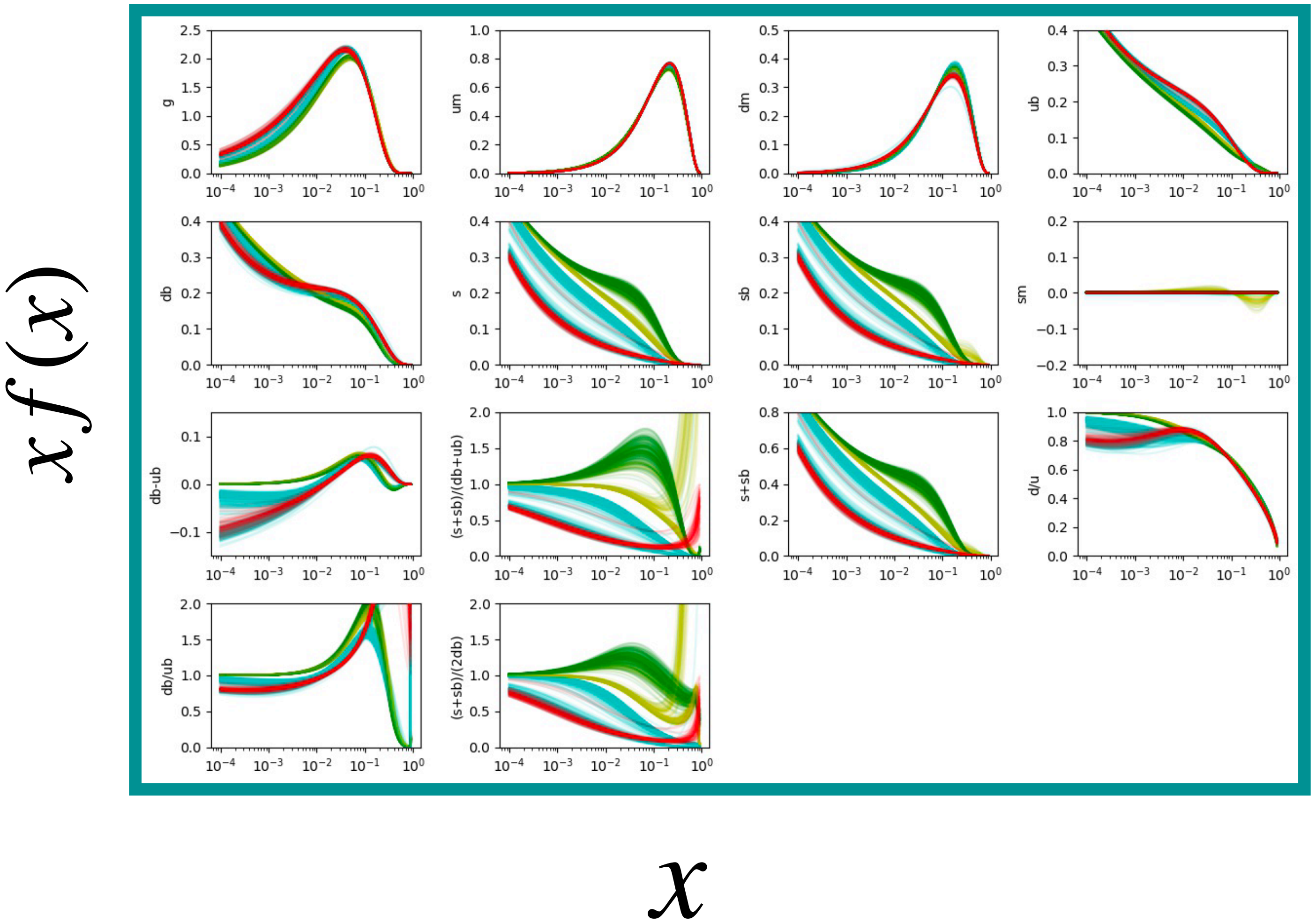
+ DIS data
+ DY data



Constraints on R_s

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs

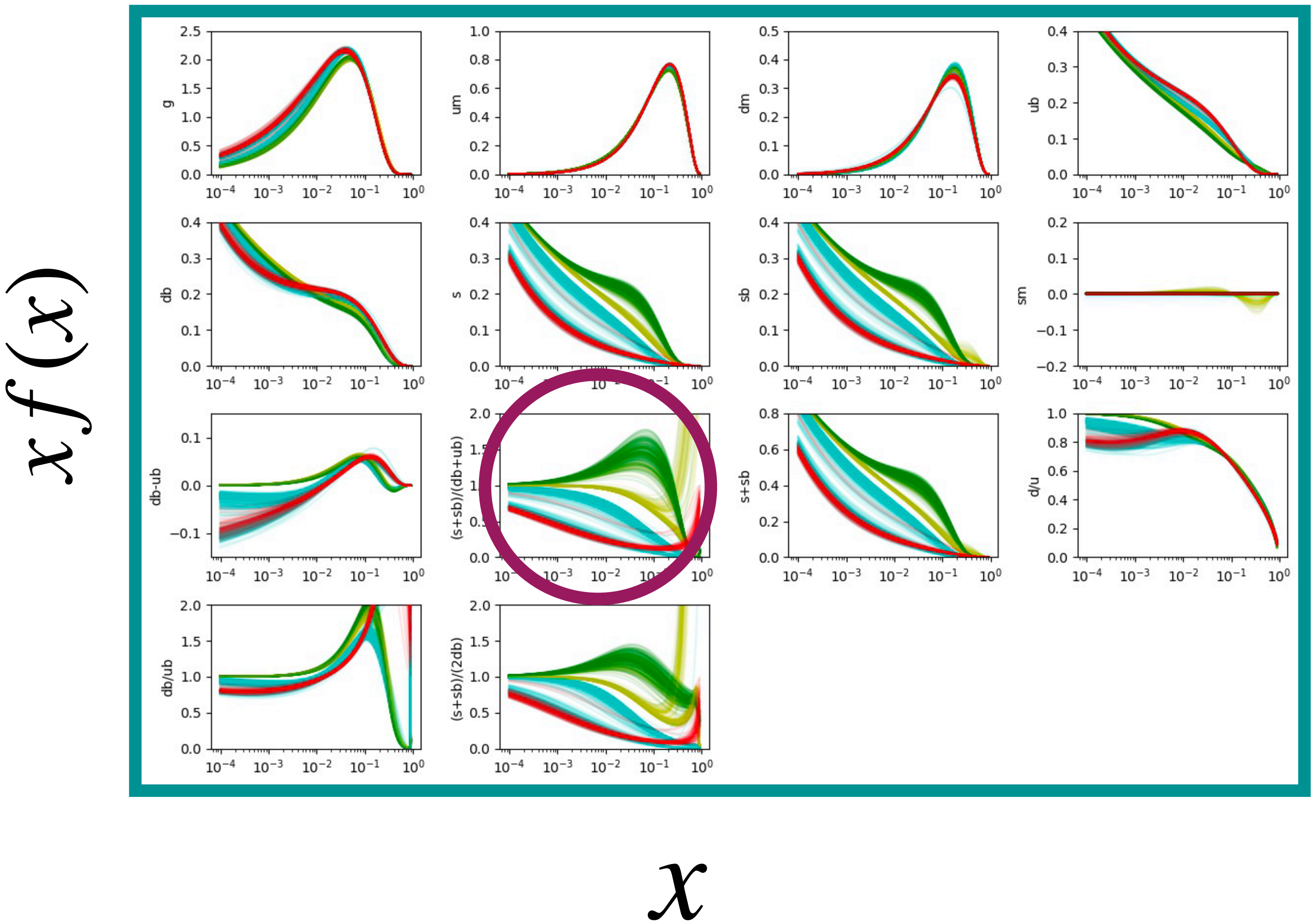


+ DIS data
+ DY data
+ SIA + SIDIS data

Constraints on R_s

$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs

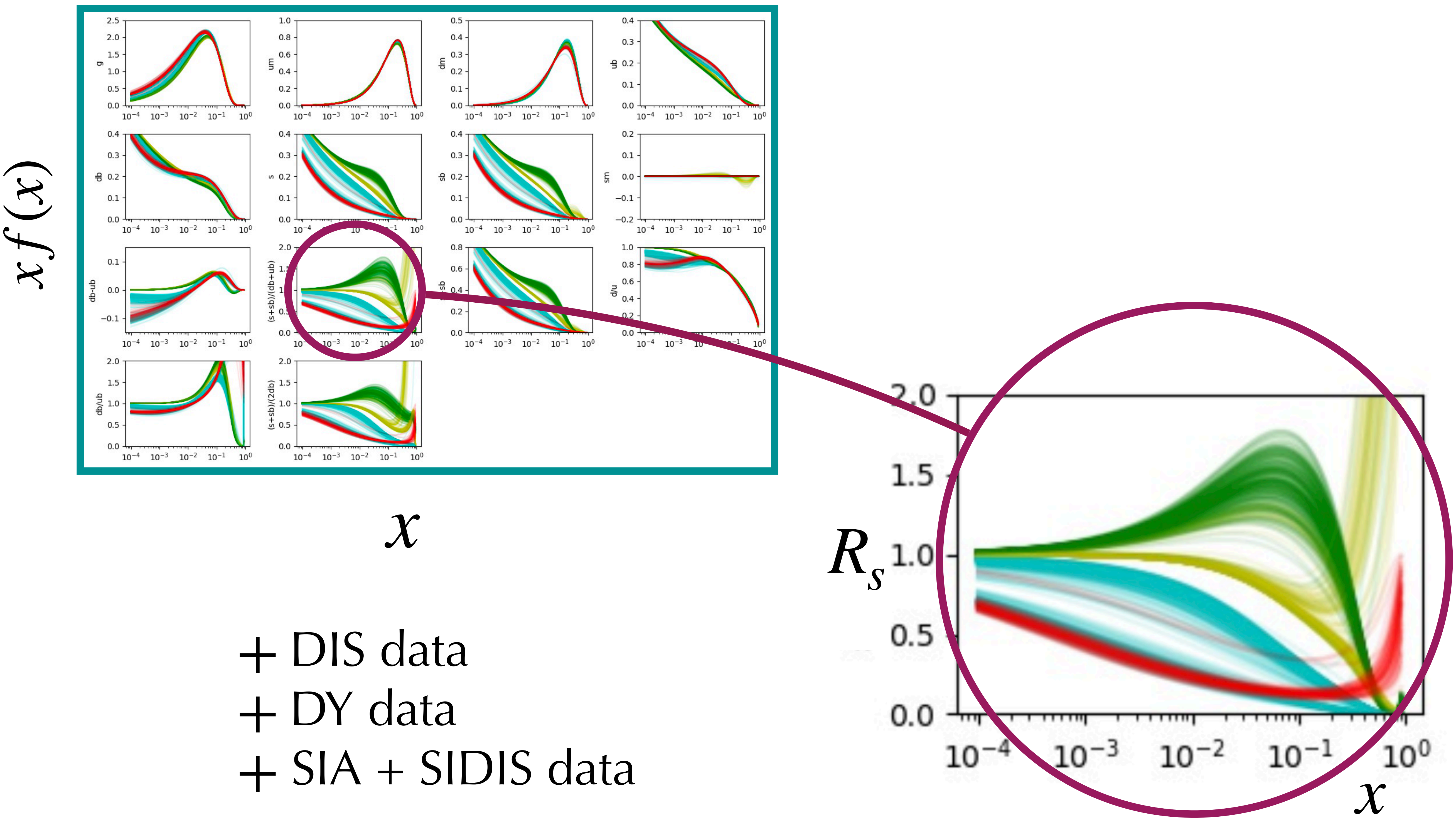


+ DIS data
+ DY data
+ SIA + SIDIS data

Constraints on R_s

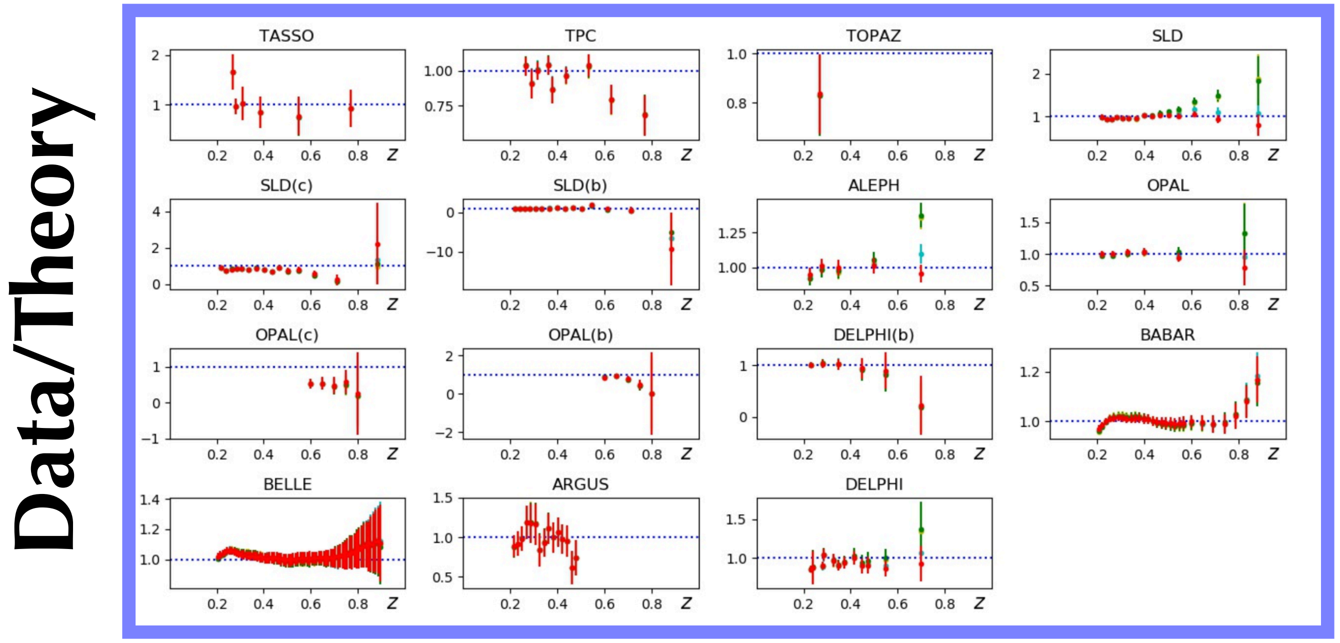
$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

PDFs

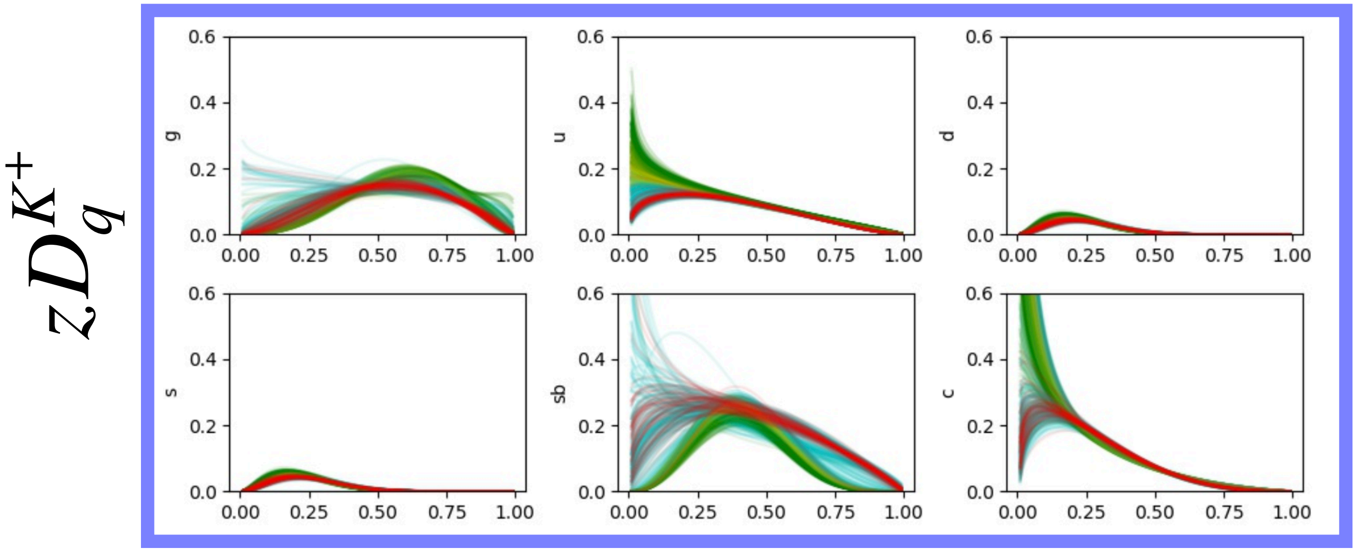


+ DIS data
+ DY data
+ SIA + SIDIS data

SIA K+/K- data



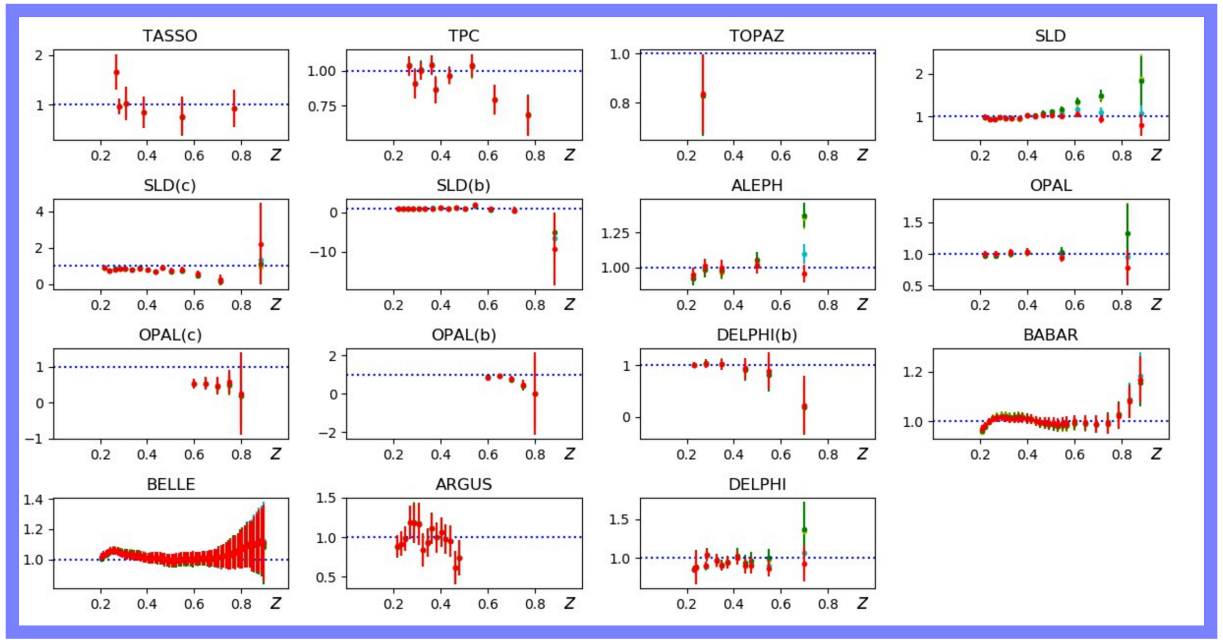
z



z

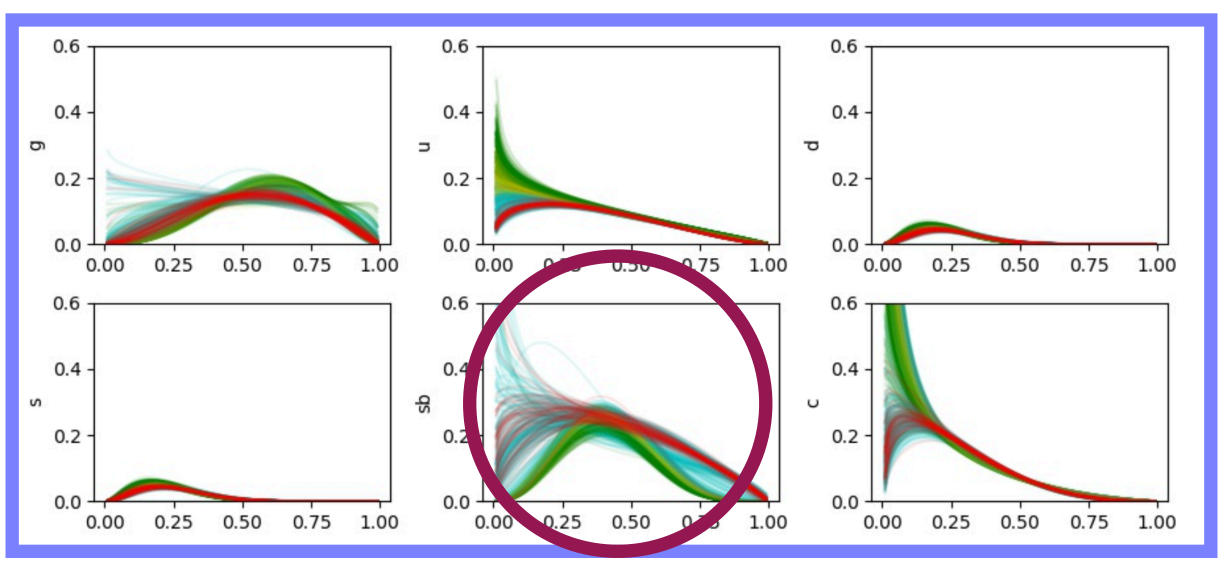
SIA K+/K- data

Data/Theory



z

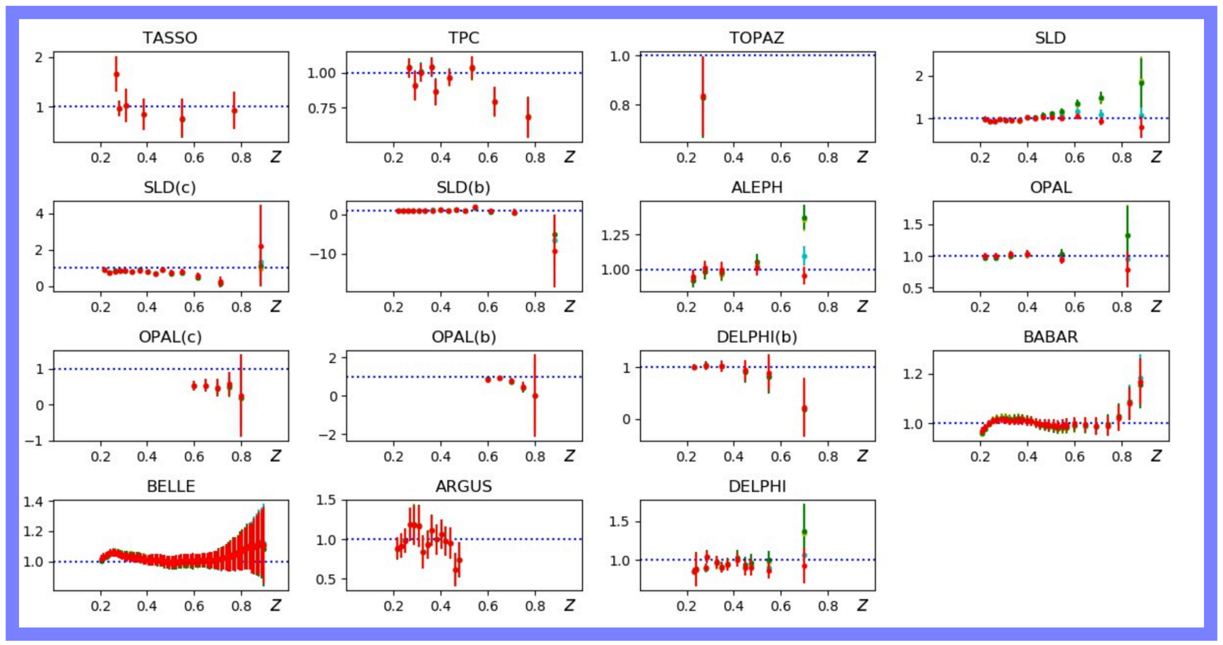
$zD_q^{K^+}$



z

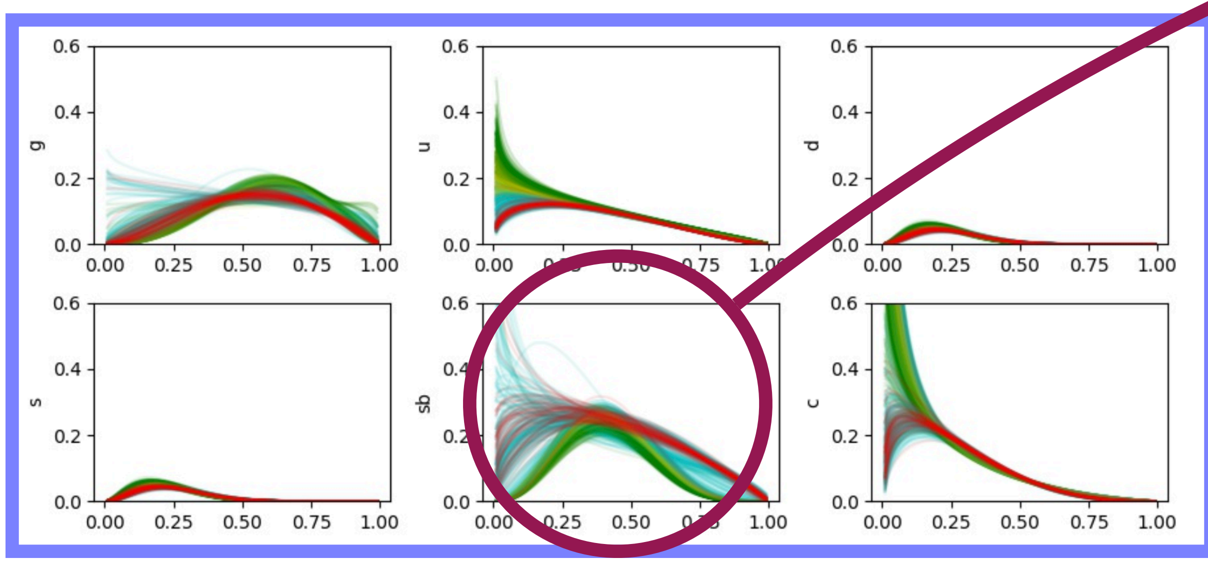
SIA K$^+$/K$^-$ data

Data/Theory

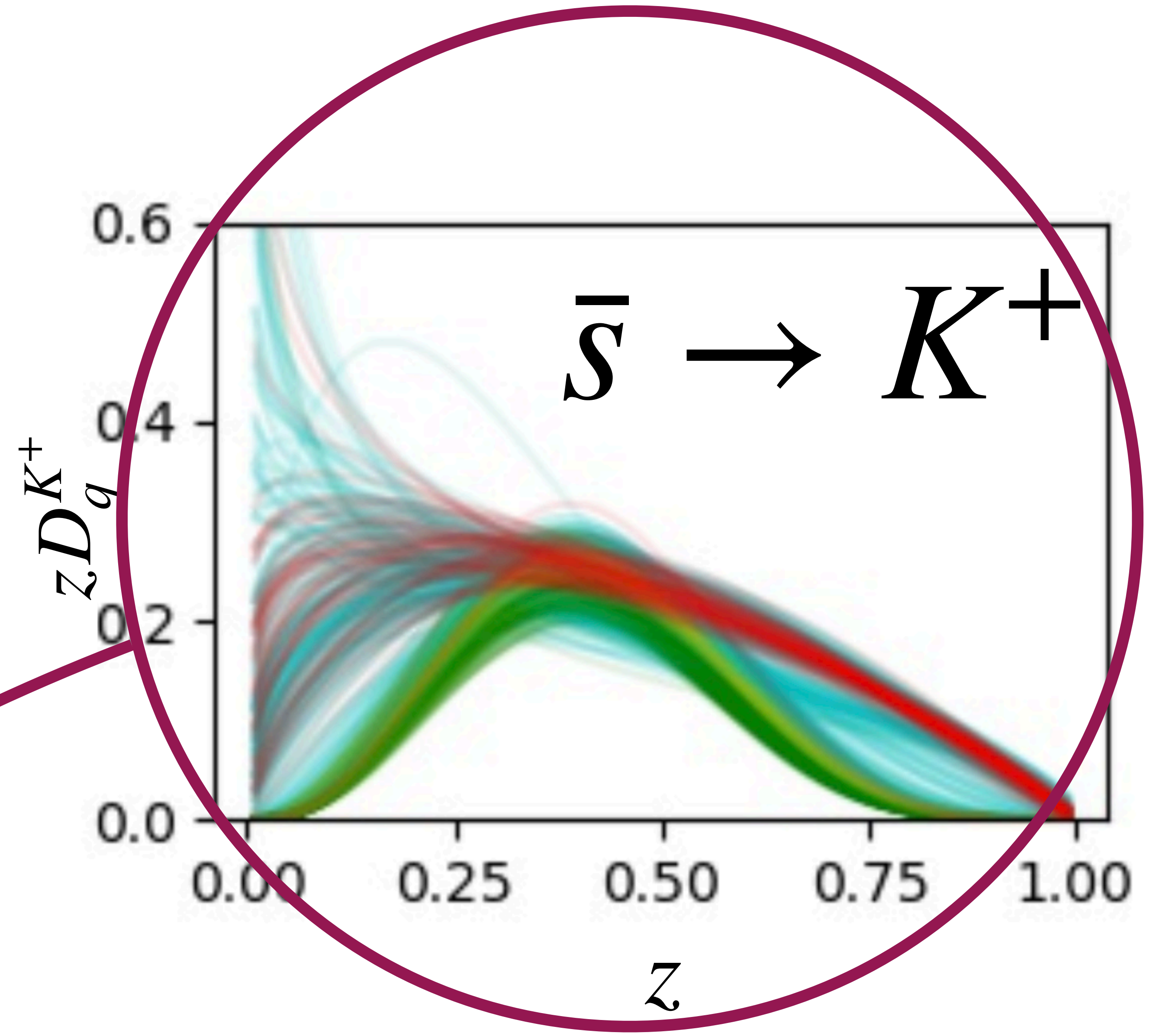


z

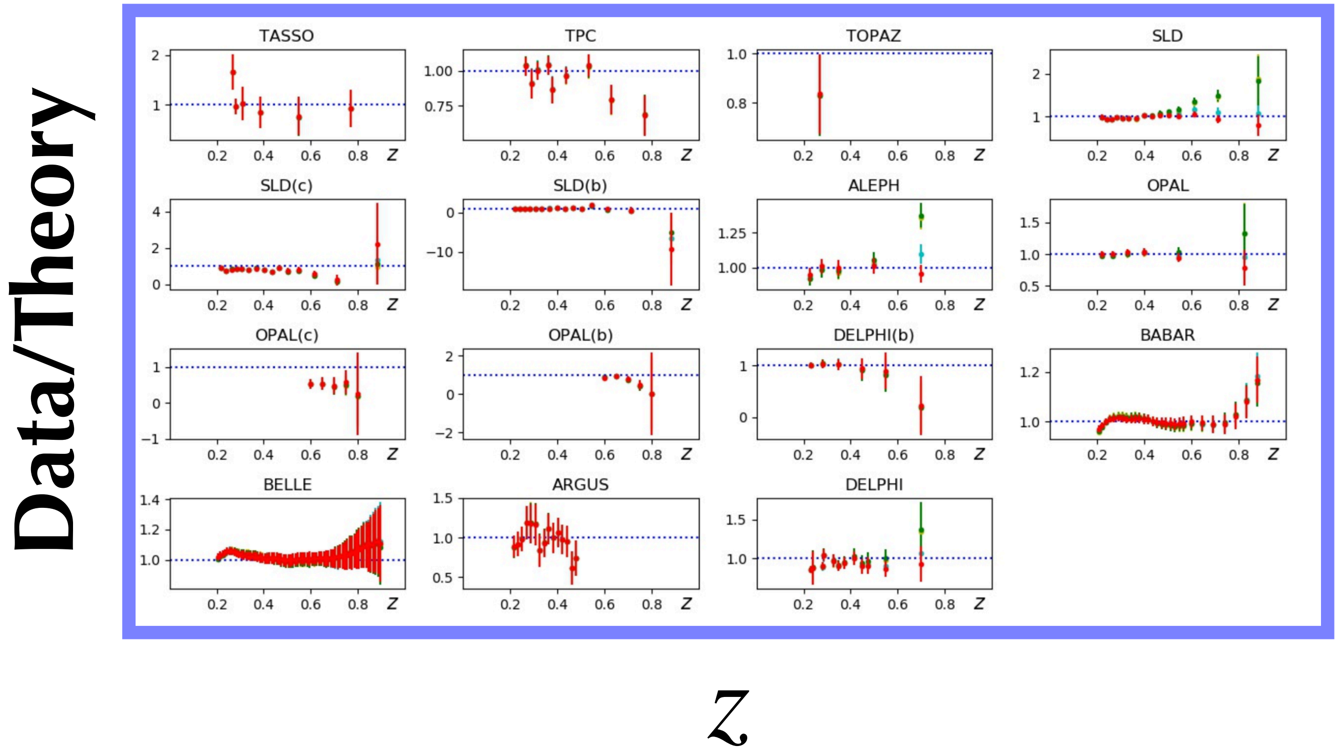
$zD_q^{K^+}$



z

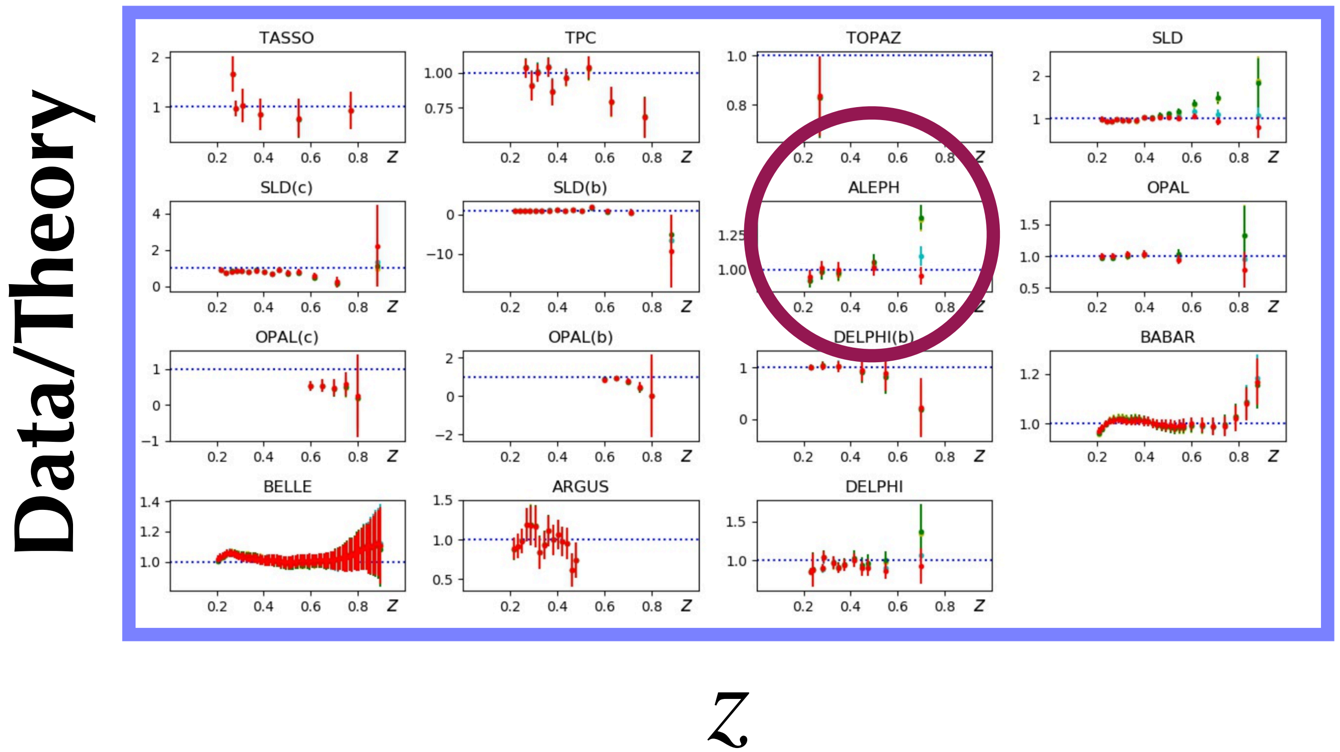


SIA K+/K- data



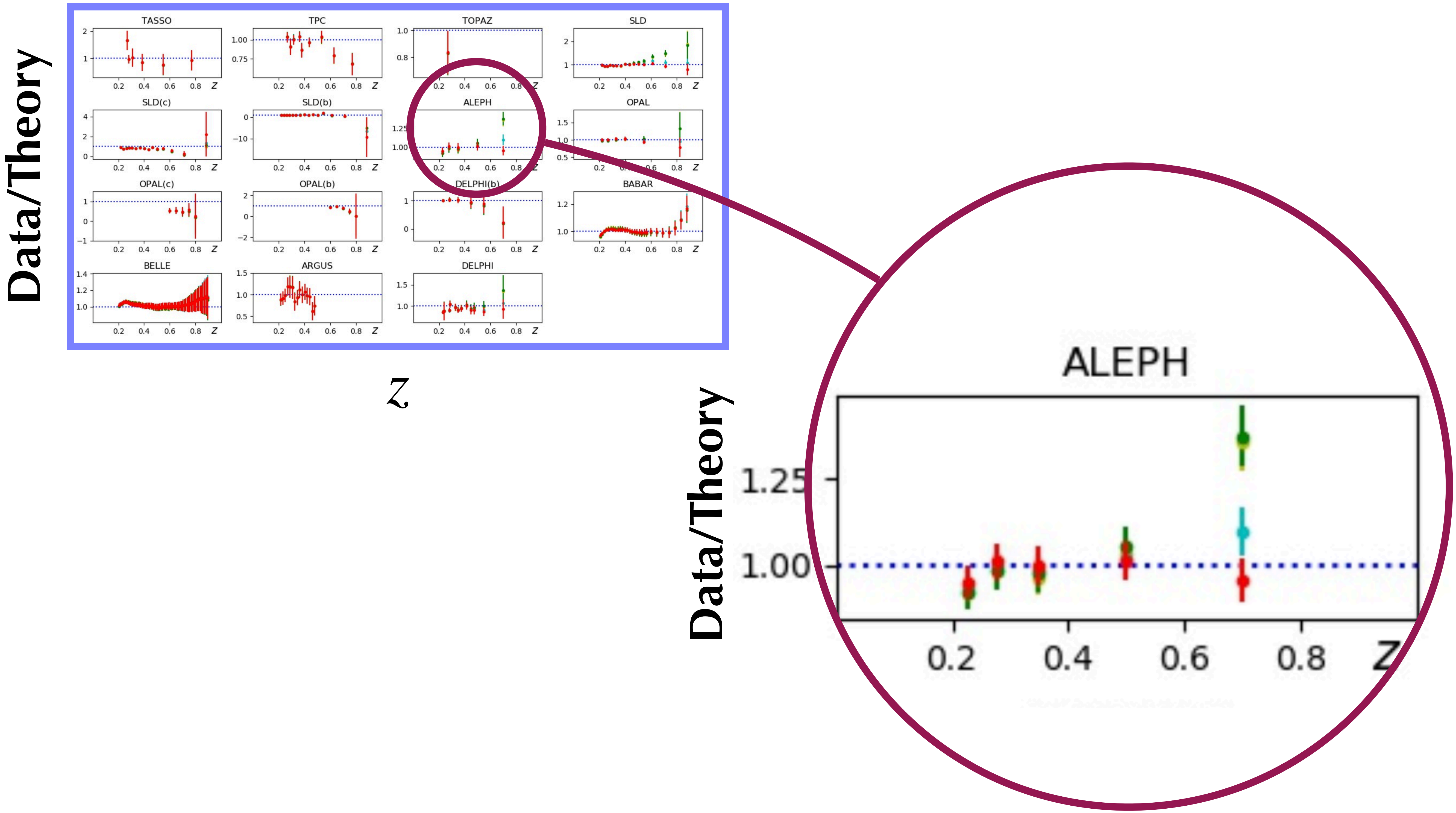
Data/Theory
TASSO
TPC
TOPAZ
SLD
SLD(c)
SLD(b)
ALEPH
OPAL
OPAL(c)
OPAL(b)
DELPHI(b)
BABAR
BELLE
ARGUS
DELPHI
z

SIA K+/K- data



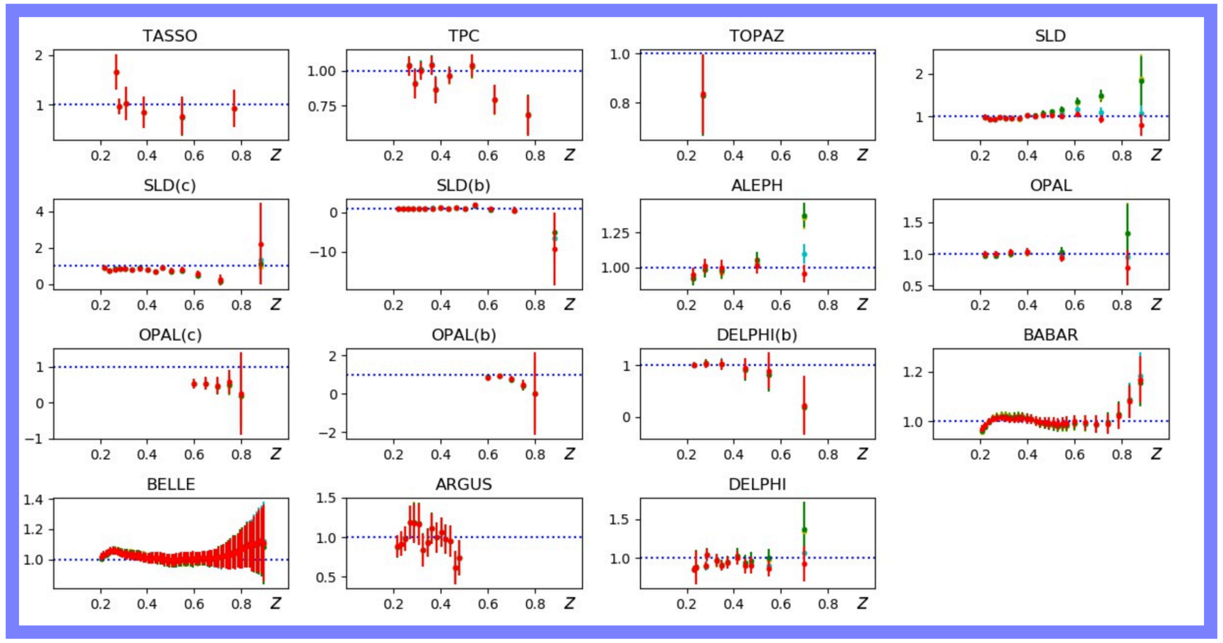
Data/Theory
TASSO
TPC
TOPAZ
SLD
SLD(c)
SLD(b)
ALEPH
OPAL
OPAL(c)
OPAL(b)
DELPHI(b)
BABAR
BELLE
ARGUS
DELPHI
z

SIA K+/K- data


Data/Theory
TASSO
TPC
TOPAZ
SLD
SLD(c)
SLD(b)
ALEPH
OPAL
OPAL(c)
OPAL(b)
DELPHI(b)
BABAR
BELLE
ARGUS
DELPHI
z
ALEPH
Data/Theory
1.25
1.00
0.2
0.4
0.6
0.8
z

SIA K+/K- data

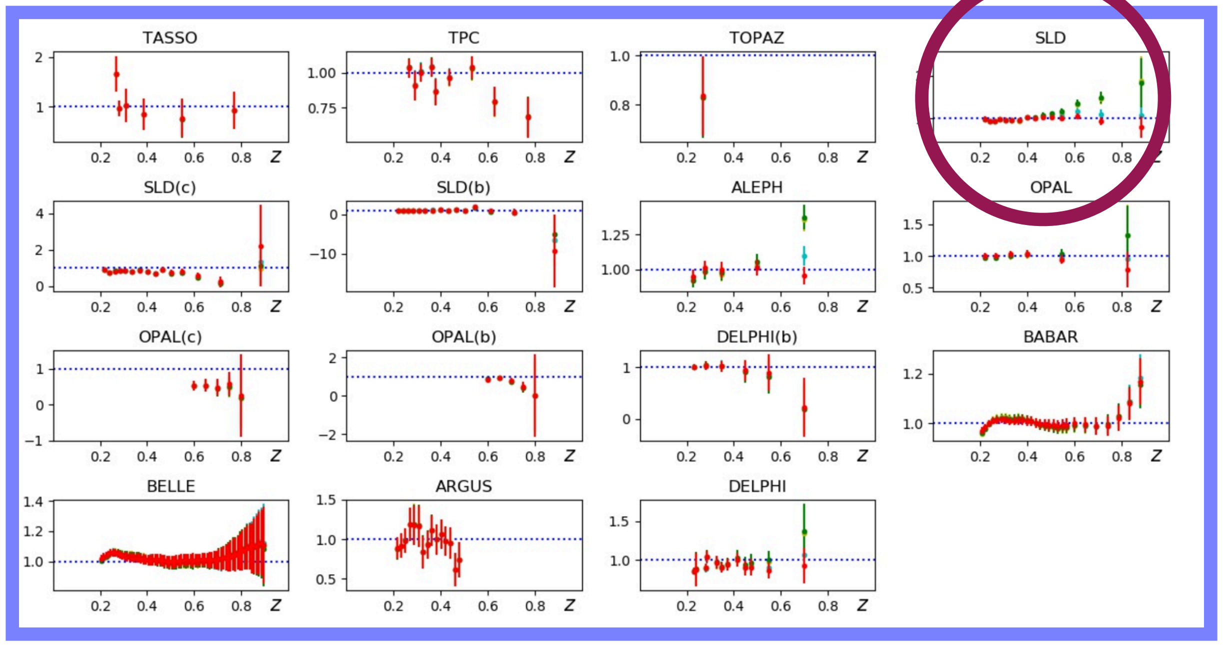
Data/Theory



z

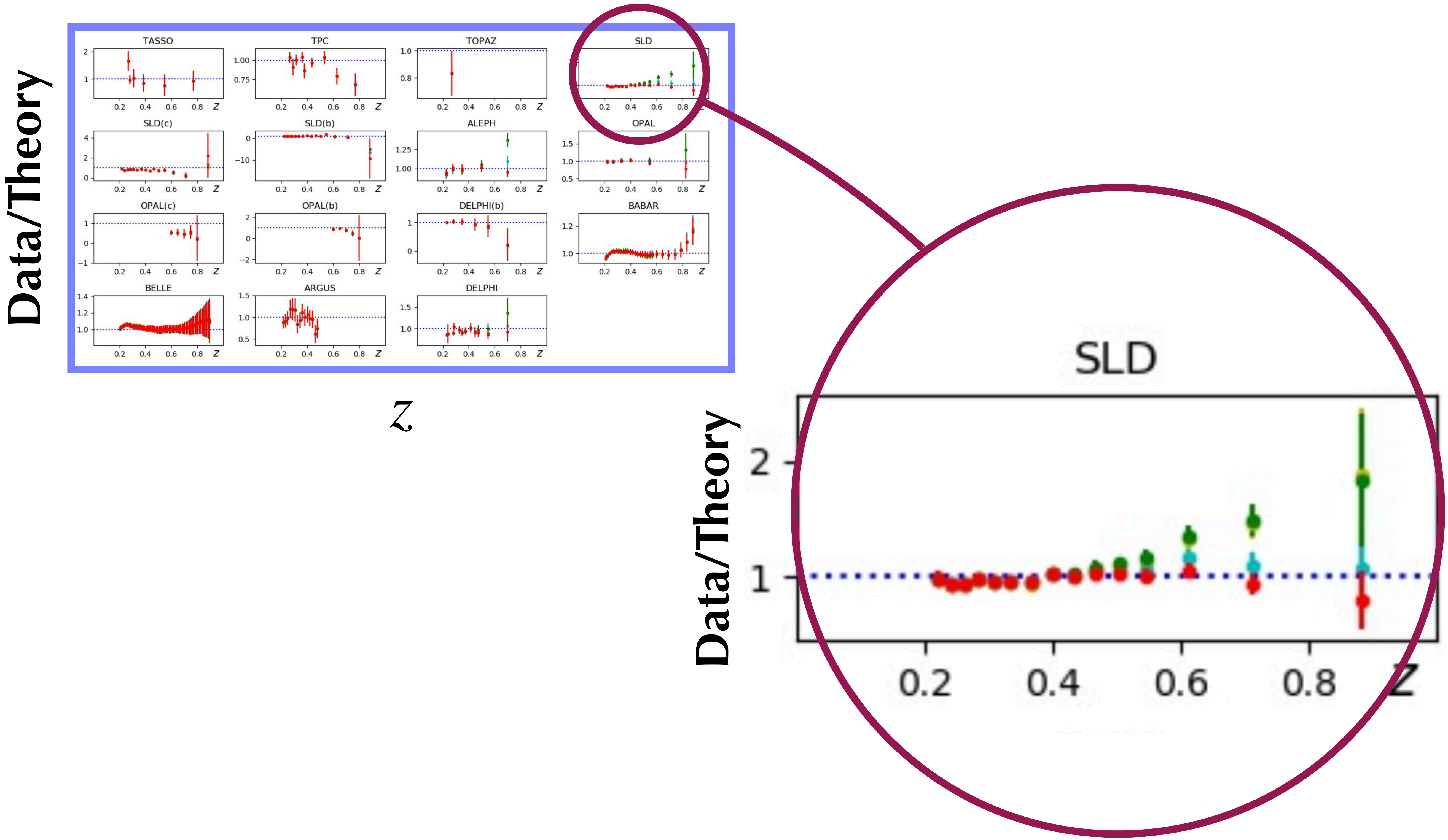
SIA K+/K- data

Data/Theory



z

SIA K+/K- data



Data/Theory
TASSO
TPC
TOPAZ
SLD
SLD(c)
SLD(b)
ALEPH
OPAL
OPAL(c)
OPAL(b)
DELPHI(b)
BABAR
BELLE
ARGUS
DELPHI
z
SLD
Data/Theory

SIDIS K-

Unfavored solutions

Large $s(x)$

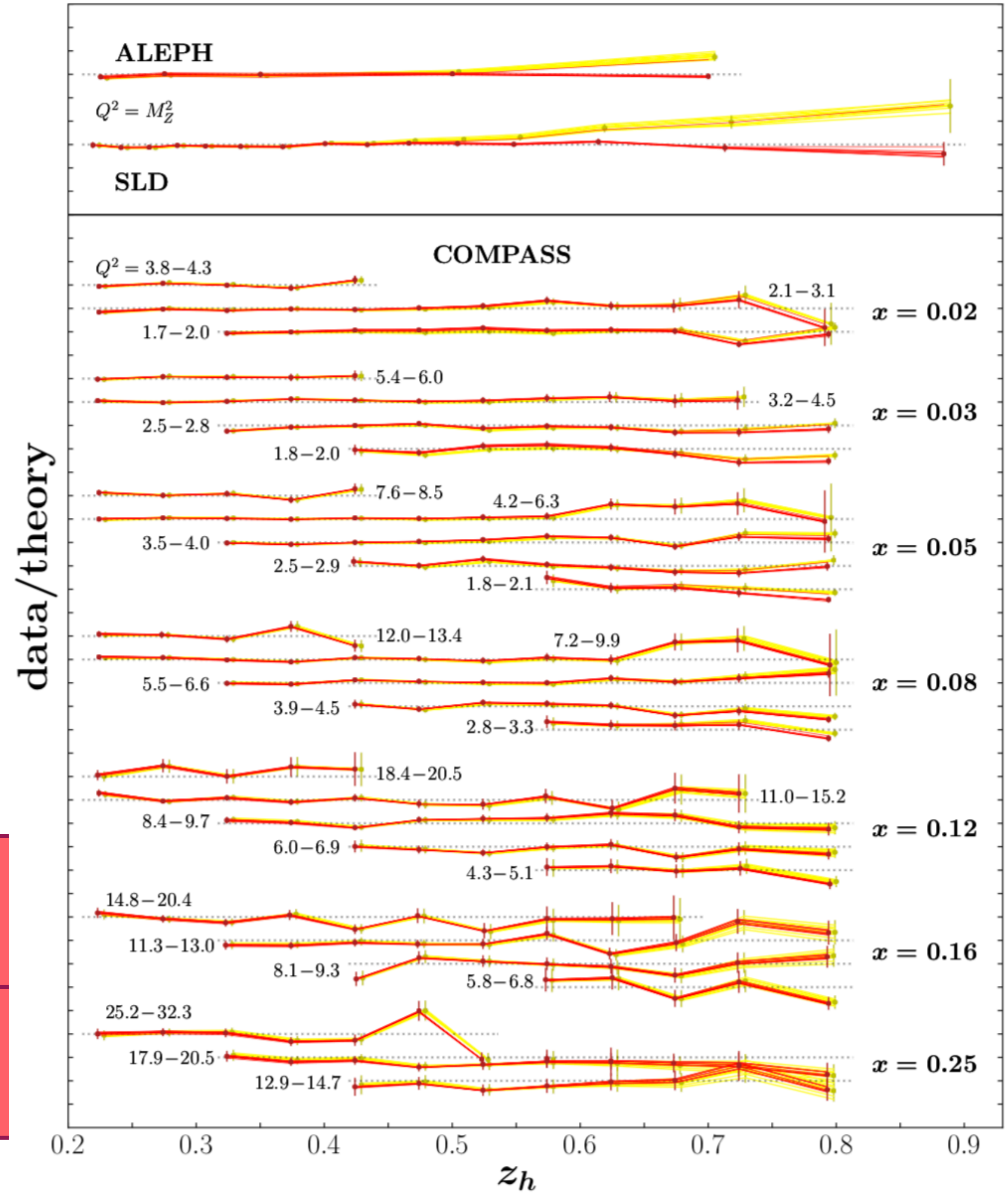
Small $D_{s^\pm}^{K^\pm}(z)$

Favored solutions

Large $D_{s^\pm}^{K^\pm}(z)$

Small $s(x)$

$\chi^2_{\mathrm{SLD}} = 4.10$	$\chi^2_{\mathrm{SLD}} = 1.38$
$\chi^2_{\mathrm{ALEPH}} = 4.62$	$\chi^2_{\mathrm{ALEPH}} = 0.34$



SIA

SIDIS

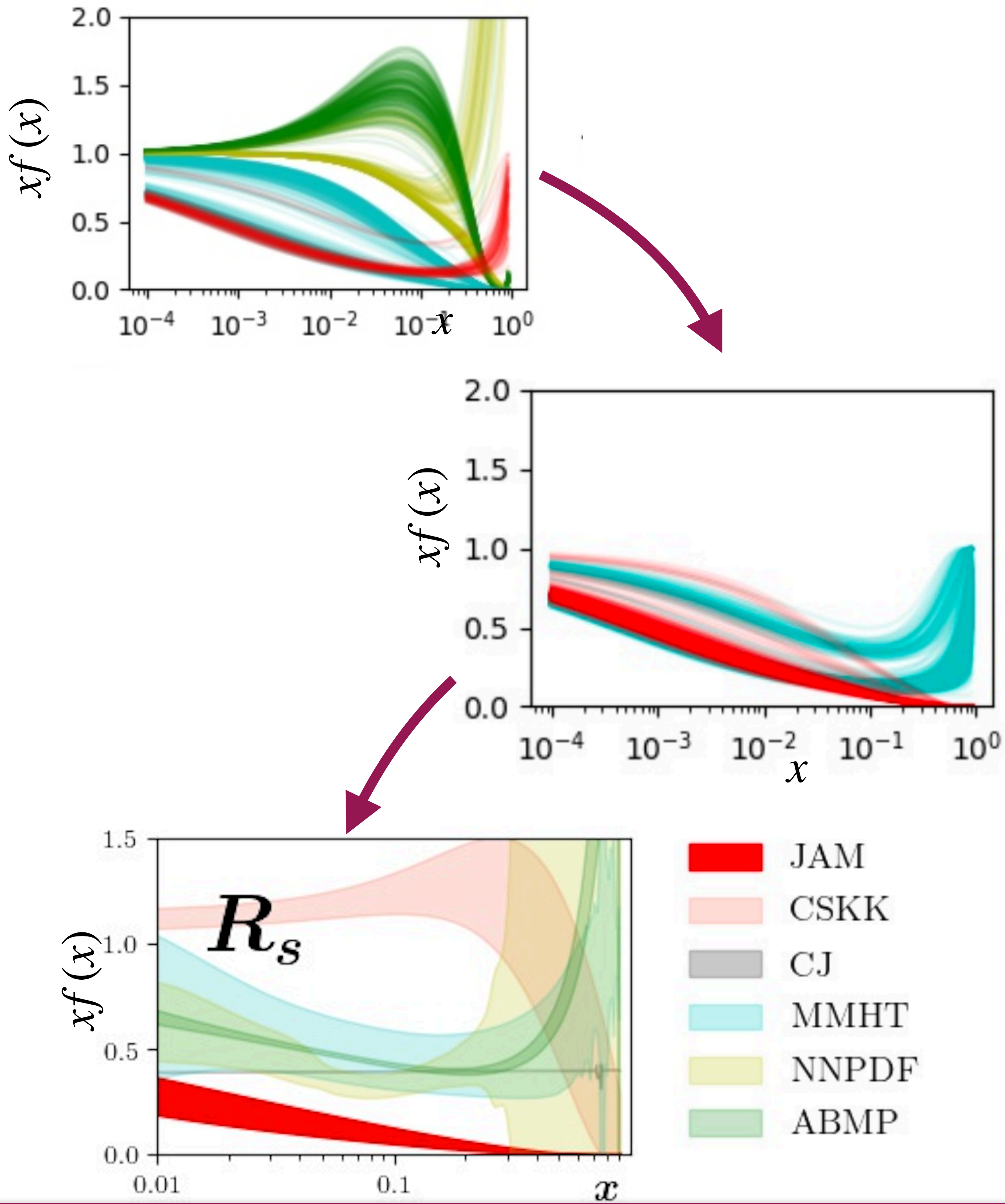
JAM19: Selection Criteria

- Apply k-means clustering

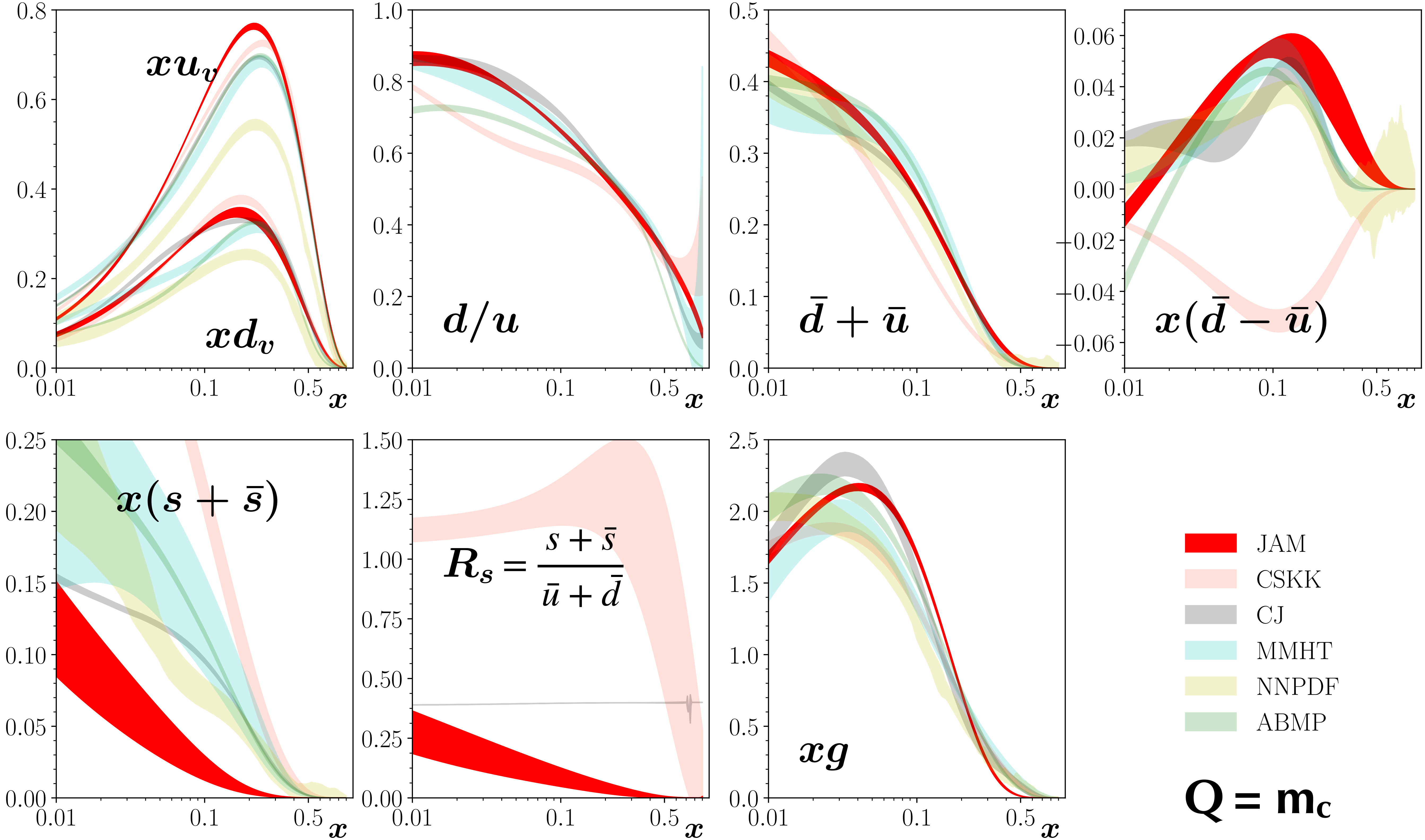
- Classify clusters by increasing order in 'extended' reduced χ^2

$$\frac{\chi^2}{N_{\rm tot}} + \sum_{exp} \frac{\chi^2_{\rm exp}}{N_{\rm exp}}$$

- Perform a new sampling with flat priors around the best cluster

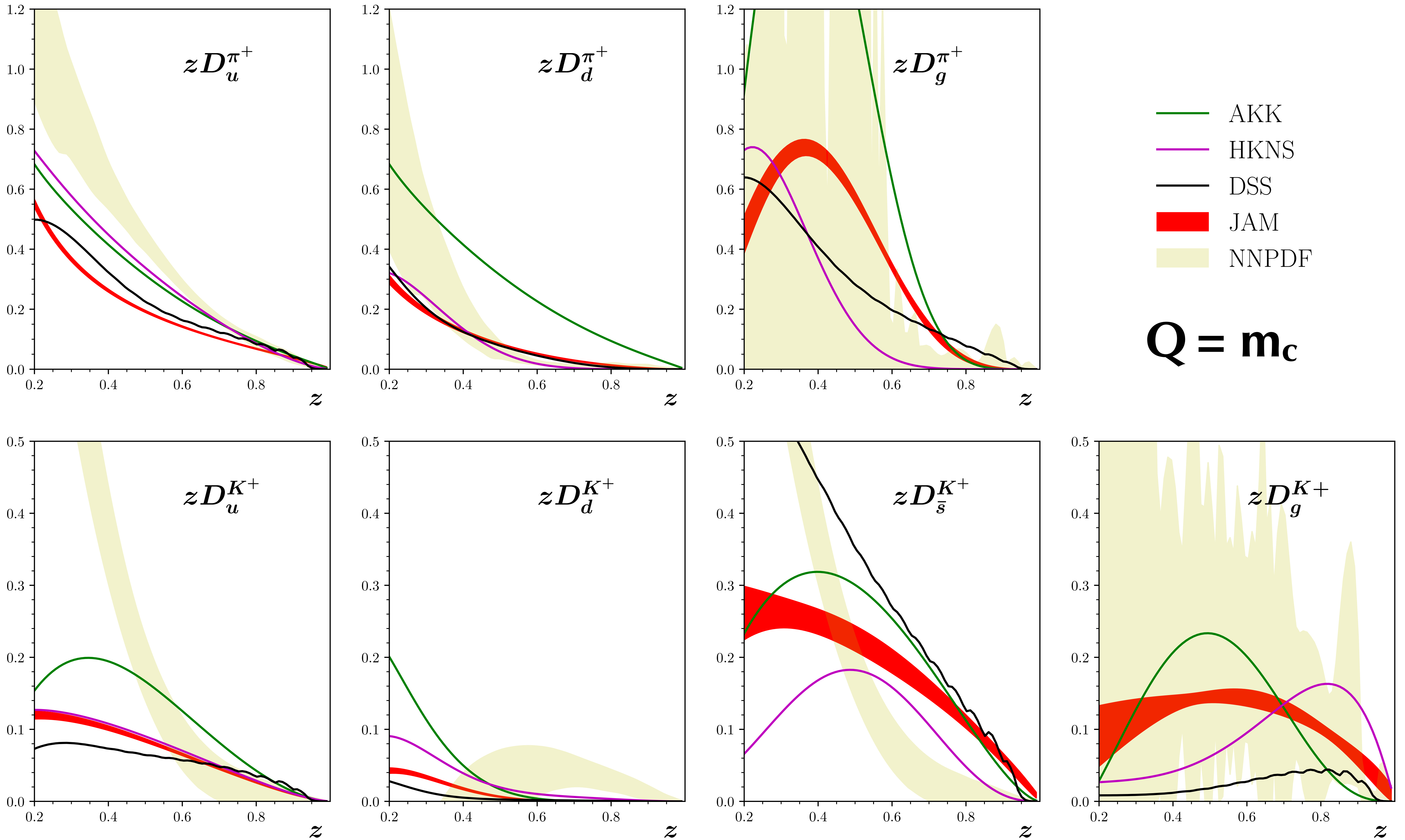


JAM19: PDFs



xu_v
xd_v
d/u
$\bar{d}+\bar{u}$
$x(\bar{d}-\bar{u})$
$x(s+\bar{s})$
$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$
xg
JAM
CSKK
CJ
MMHT
NNPDF
ABMP
$Q = m_c$

JAM19: FF



$zD_u^{\pi^+}$
$zD_d^{\pi^+}$
$zD_g^{\pi^+}$
$zD_u^{K^+}$
$zD_d^{K^+}$
$zD_{\bar{s}}^{K^+}$
$zD_g^{K^+}$
z
AKK
HKNS
DSS
JAM
NNPDF

Q = m$_c$

Summary

- MC statistical methods are important for a robust extraction of non-perturbative collinear distributions

  → Crucial for future Global TMDs, GPDs analysis

- First MC fit of PDFs and FFs using DIS, DY, SIDIS and SIA data

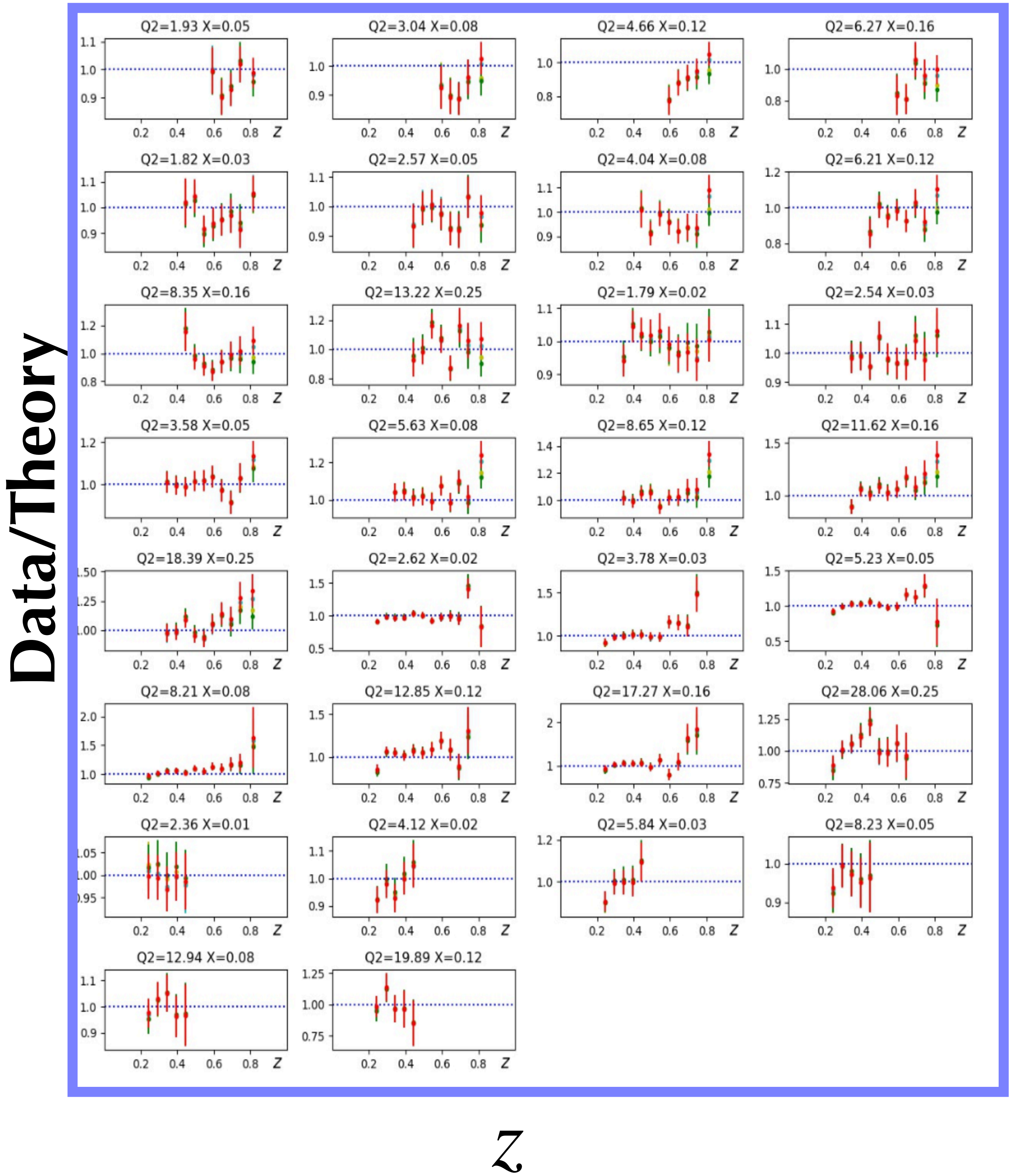
- JAM19 Methodology: MC (multi-steps), k-means clustering, ‘extended’ reduced χ^2

- Strange PDF strongly suppressed

Thanks

Backup

SIDIS K- data


Data/Theory
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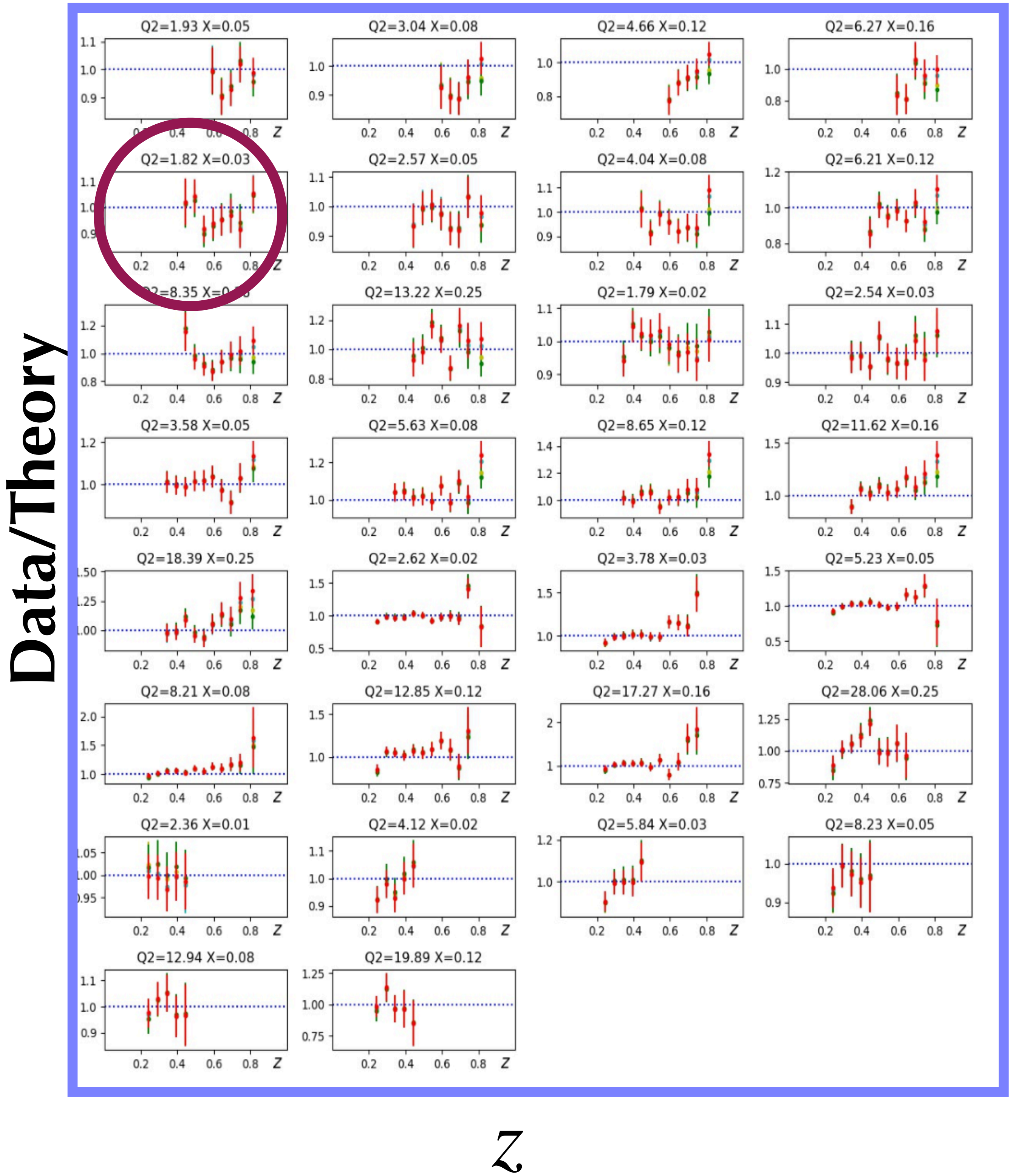
Q2=3.04 X=0.08
Q2=4.66 X=0.12
Q2=6.27 X=0.16
Q2=1.82 X=0.03
Q2=2.57 X=0.05
Q2=4.04 X=0.08
Q2=6.21 X=0.12
Q2=8.35 X=0.16
Q2=13.22 X=0.25
Q2=1.79 X=0.02
Q2=2.54 X=0.03
Q2=3.58 X=0.05
Q2=5.63 X=0.08
Q2=8.65 X=0.12
Q2=11.62 X=0.16
Q2=18.39 X=0.25
Q2=2.62 X=0.02
Q2=3.78 X=0.03
Q2=5.23 X=0.05
Q2=8.21 X=0.08
Q2=12.85 X=0.12
Q2=17.27 X=0.16
Q2=28.06 X=0.25
Q2=2.36 X=0.01
Q2=4.12 X=0.02
Q2=5.84 X=0.03
Q2=8.23 X=0.05
Q2=12.94 X=0.08
Q2=19.89 X=0.12
z

SIDIS K- data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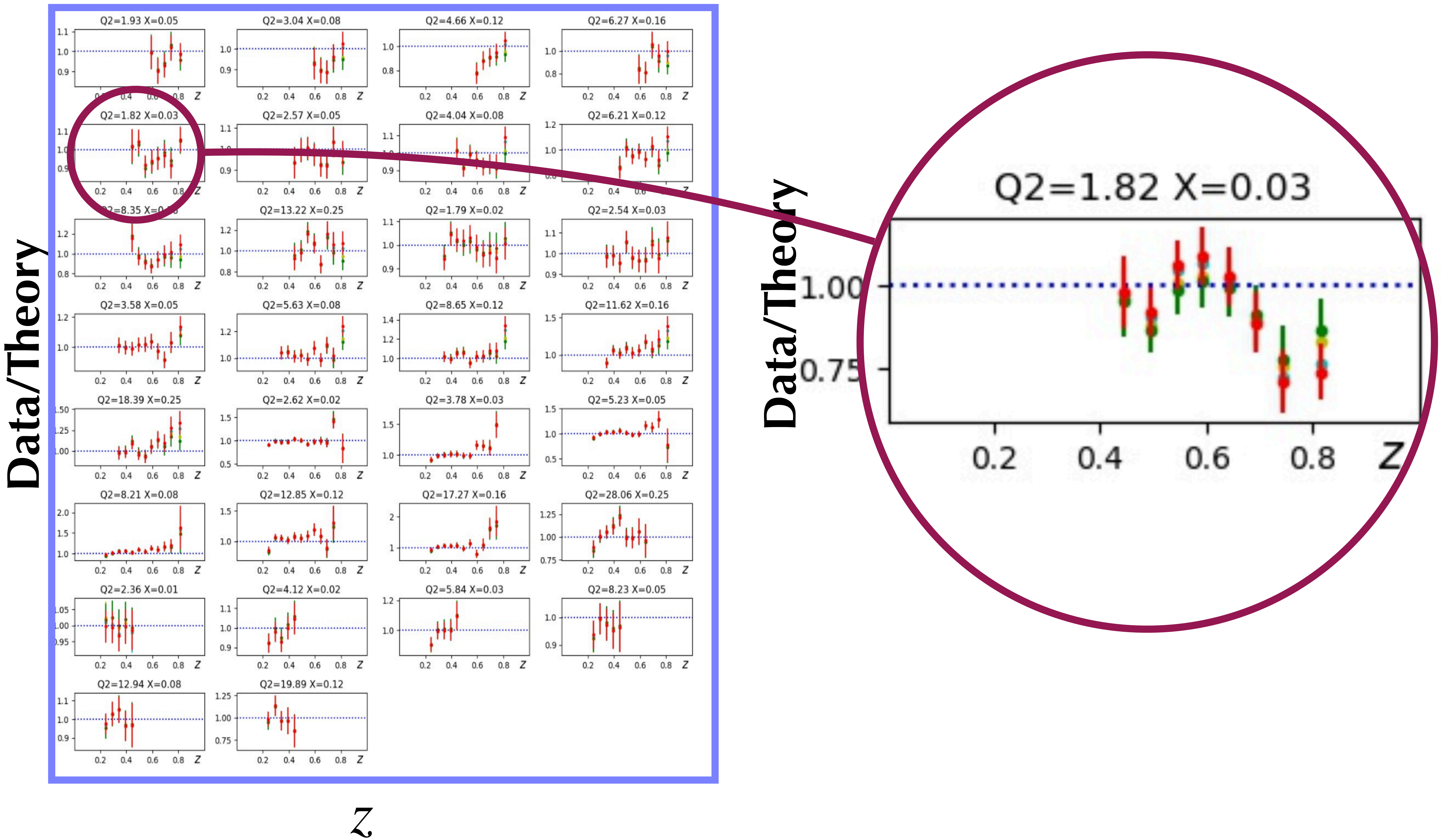
Q2=17.27 X=0.16
Q2=28.06 X=0.25
Q2=2.36 X=0.01
Q2=4.12 X=0.02
Q2=5.84 X=0.03
Q2=8.23 X=0.05
Q2=12.94 X=0.08
Q2=19.89 X=0.12
z

SIDIS K- data



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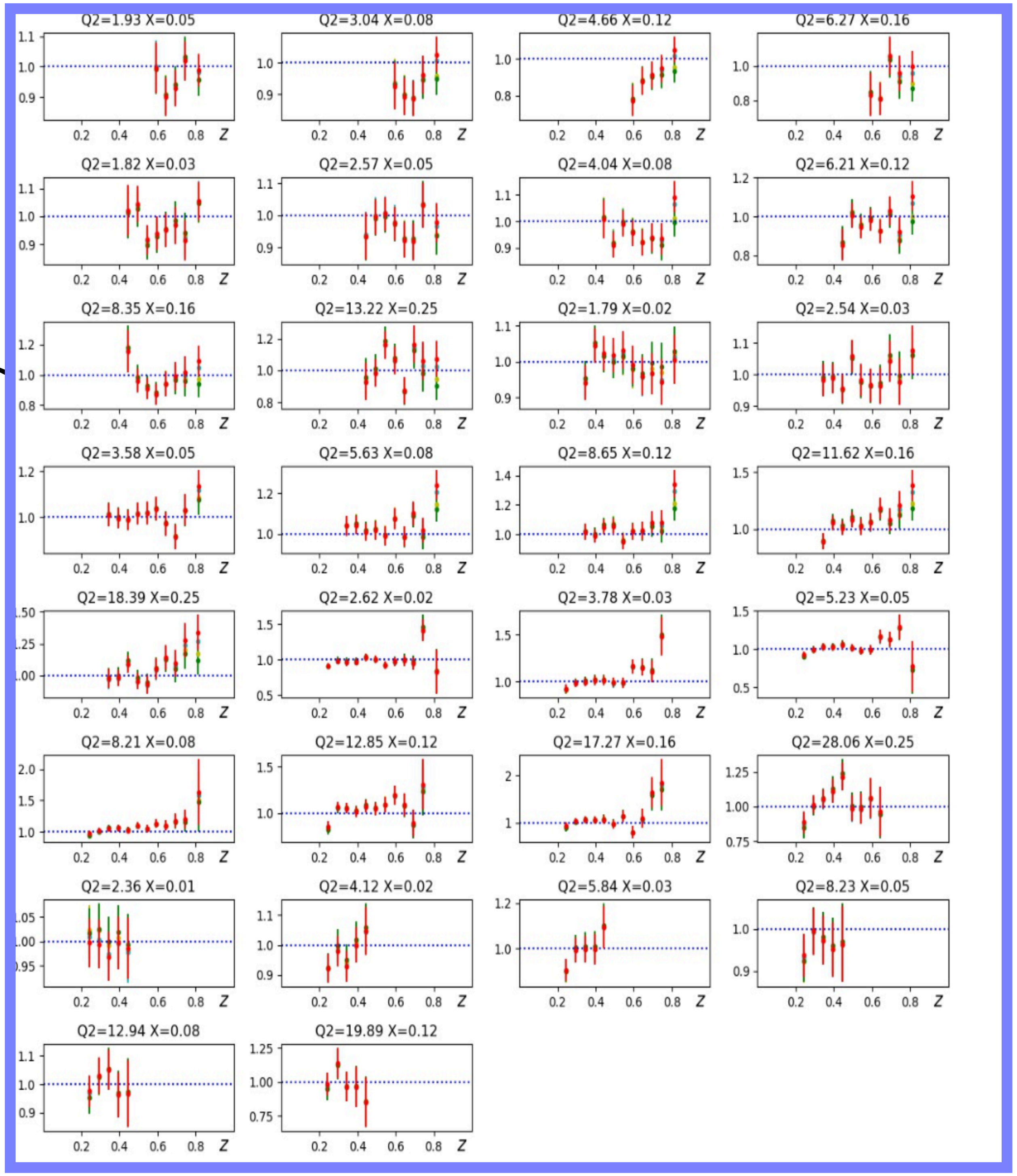
Q2=28.06 X=0.25
Q2=2.36 X=0.01
Q2=4.12 X=0.02
Q2=5.84 X=0.03
Q2=8.23 X=0.05
Q2=12.94 X=0.08
Q2=19.89 X=0.12
z
Data/Theory
Q2=1.82 X=0.03
1.00
0.75
0.2
0.4
0.6
0.8
z

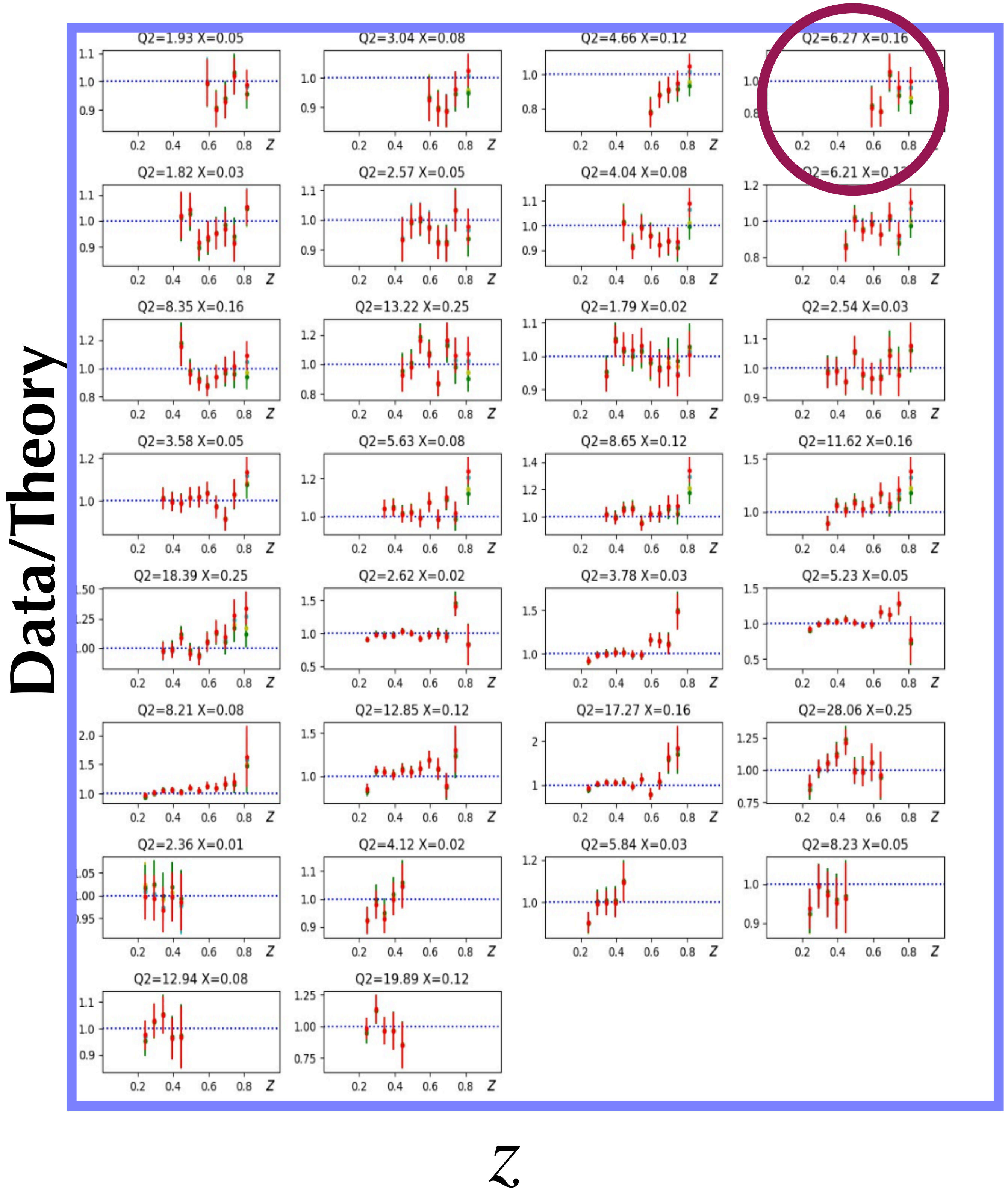
SIDIS K+ data

Data/Theory



z

SIDIS K+ data



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Q2=1.82 X=0.03
Q2=2.57 X=0.05
Q2=4.04 X=0.08
Q2=8.35 X=0.16
Q2=13.22 X=0.25
Q2=1.79 X=0.02
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Q2=5.63 X=0.08
Q2=8.65 X=0.12
Q2=11.62 X=0.16
Q2=18.39 X=0.25
Q2=2.62 X=0.02
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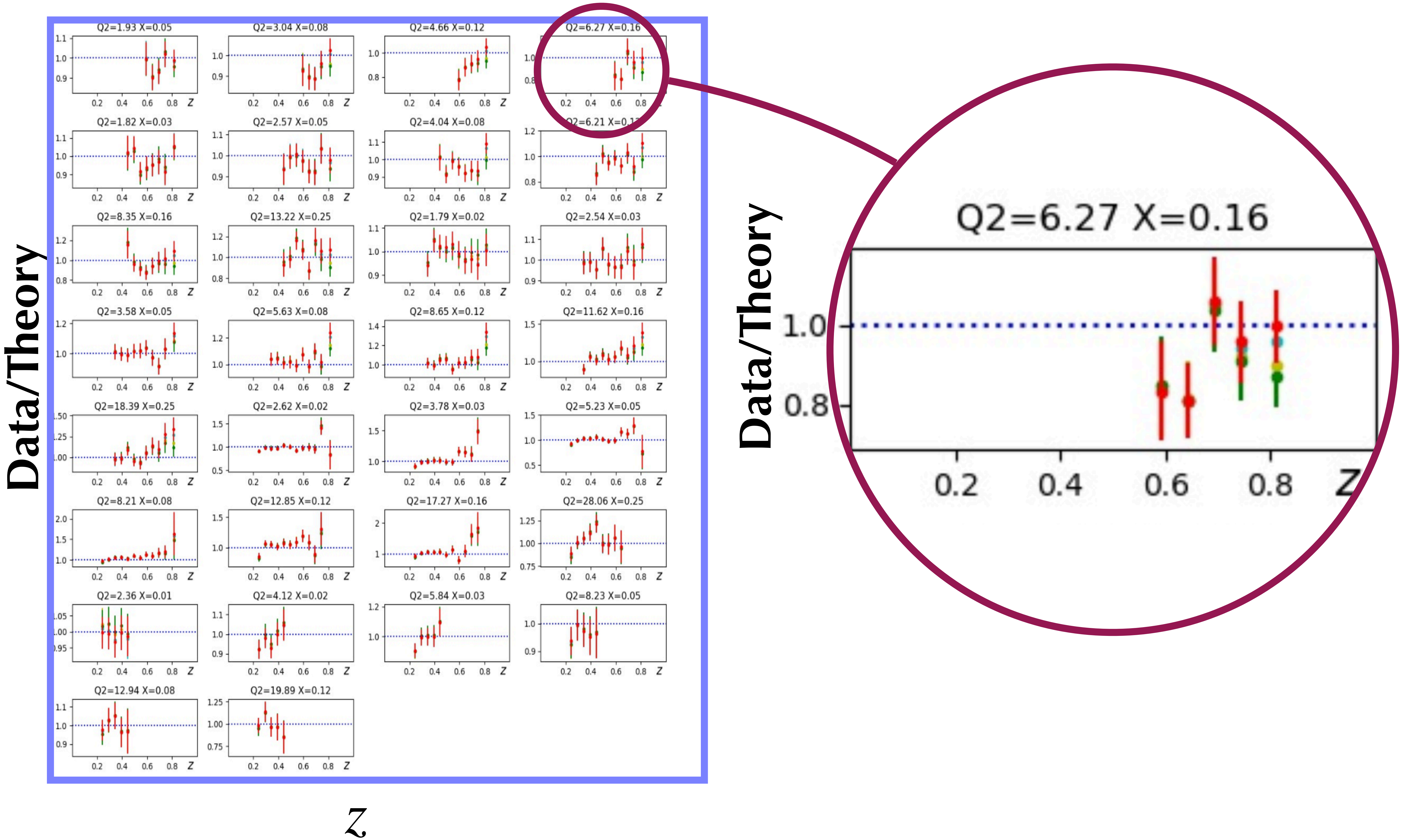
Q2=8.21 X=0.08
Q2=12.85 X=0.12
Q2=17.27 X=0.16
Q2=28.06 X=0.25
Q2=2.36 X=0.01
Q2=4.12 X=0.02
Q2=5.84 X=0.03
Q2=8.23 X=0.05
Q2=12.94 X=0.08
Q2=19.89 X=0.12
z

SIDIS K^+ data



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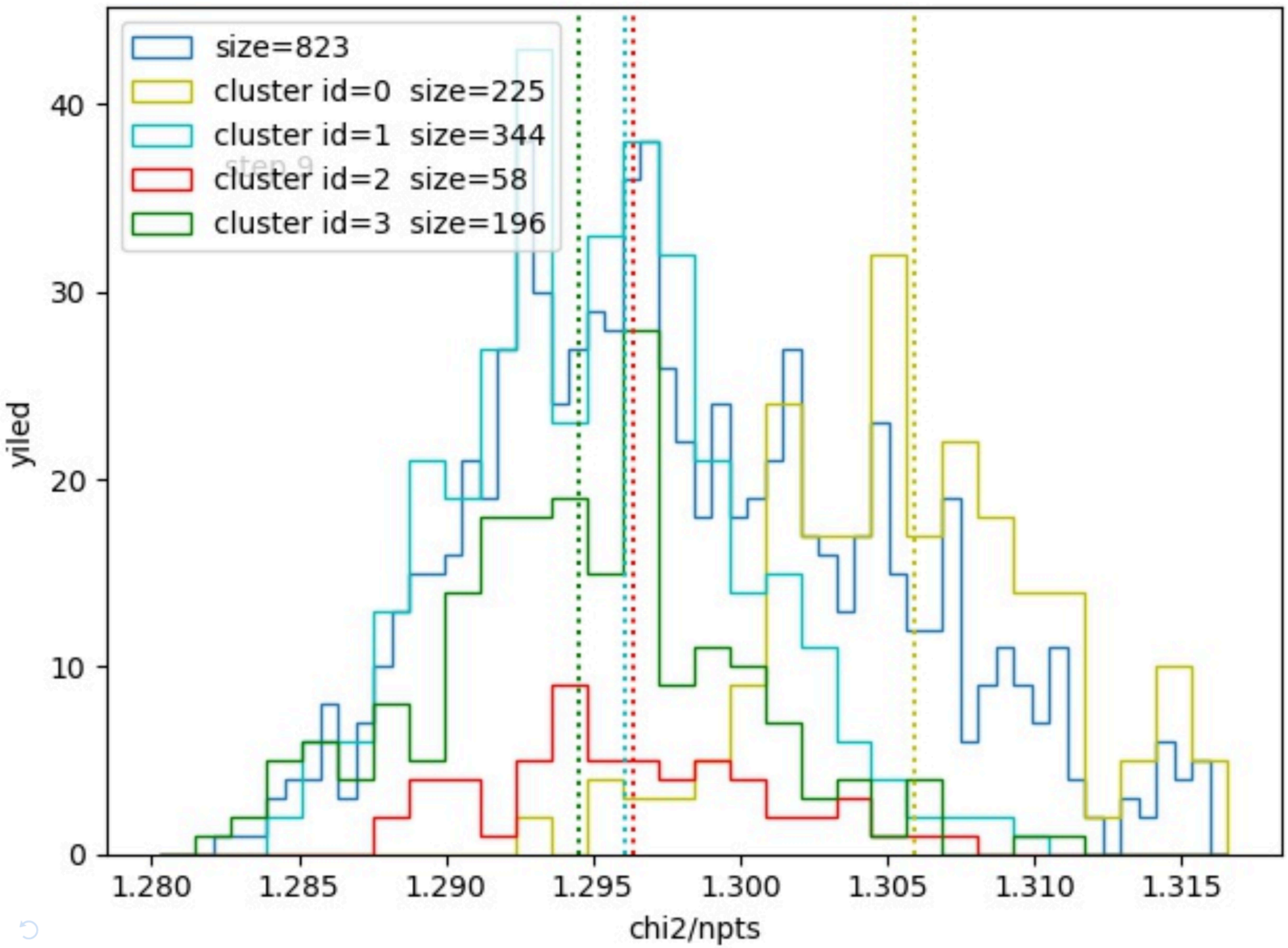
Q2=1.82 X=0.03
Q2=2.57 X=0.05
Q2=4.04 X=0.08
Q2=8.35 X=0.16
Q2=13.22 X=0.25
Q2=1.79 X=0.02
Q2=2.54 X=0.03
Q2=3.58 X=0.05
Q2=5.63 X=0.08
Q2=8.65 X=0.12
Q2=11.62 X=0.16
Q2=18.39 X=0.25
Q2=2.62 X=0.02
Q2=3.78 X=0.03
Q2=5.23 X=0.05
Q2=8.21 X=0.08
Q2=12.85 X=0.12
Q2=17.27 X=0.16
Q2=28.06 X=0.25
Q2=2.36 X=0.01
Q2=4.12 X=0.02
Q2=5.84 X=0.03
Q2=8.23 X=0.05
Q2=12.94 X=0.08
Q2=19.89 X=0.12
Data/Theory
z
Q2=6.27 X=0.16
Data/Theory

Chi2



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cluster id=0 size=225
cluster id=1 size=344
cluster id=2 size=58
cluster id=3 size=196
yiled
chi2/npts
40
30
20
10
0
1.280
1.285
1.290
1.295
1.300
1.305
1.310
1.315

Chi2

Reaction	N_{dat}	χ^2	χ^2/N_{dat}
SIDIS	992	1243.12	1.25
SIA	444	562.80	1.27
DIS	2680	3437.96	1.28
DY	250	416.29	1.67

Reaction	N_{dat}	χ^2	χ^2/N_{dat}
SIDIS $(\pi^{\pm})$	498	585.48	1.18
SIDIS$(K^{\pm})$	494	657.64	1.33
SIA$(\pi^{\pm})$	231	247.27	1.07
SIA $(K^{\pm})$	213	315.53	1.48

Experiment	target	hadron	N_{dat}	χ^2/N_{dat}
COMPASS	d	π^+	249	1.26
COMPASS	d	π^-	249	1.09
COMPASS	d	K^+	247	1.24
COMPASS	d	K^-	247	1.43

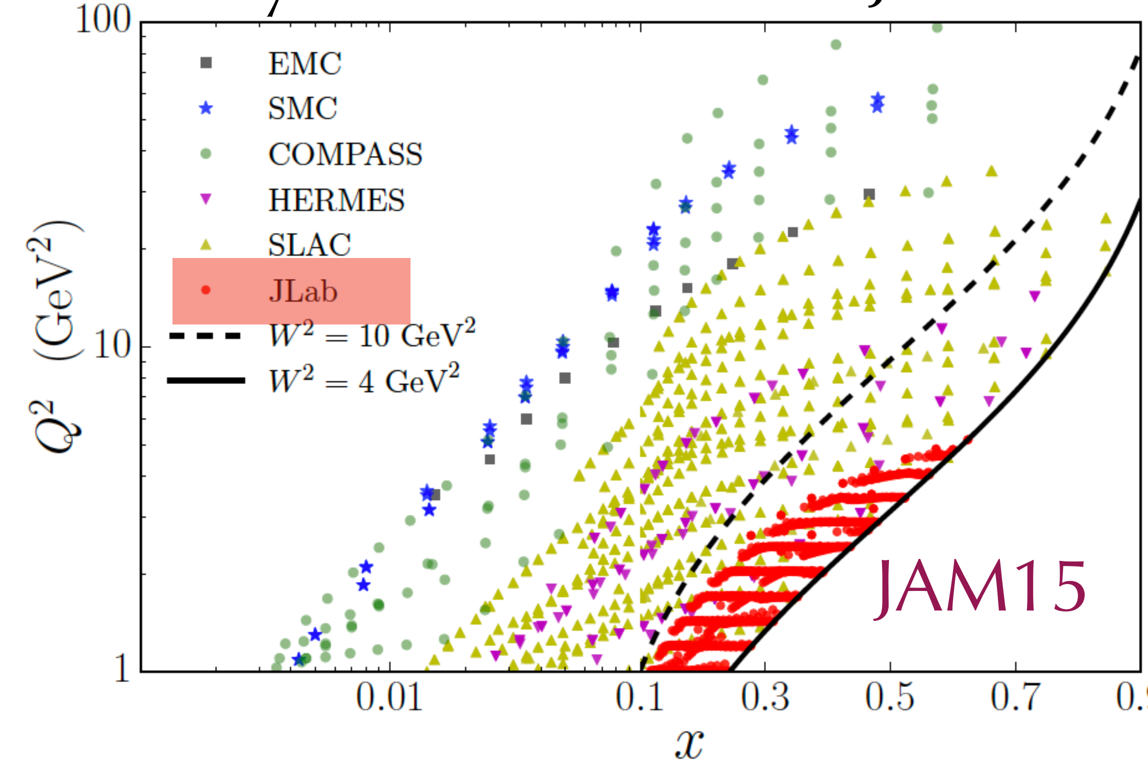
Evolution of JAM

JAM15

Iterative MC fitting technique

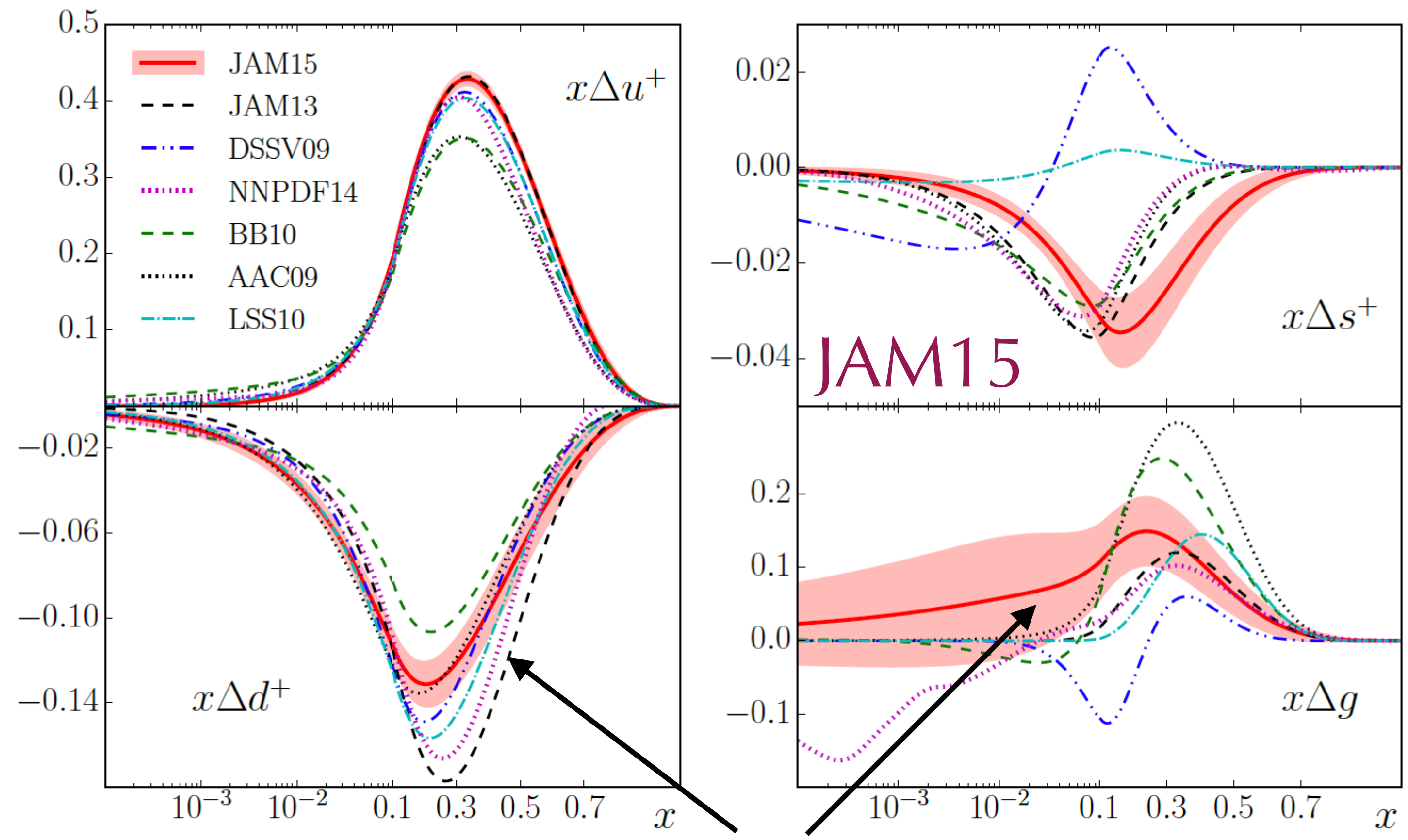
		JAM15	JAM16	JAM17	JAM18
Process	DIS	☑	☒	☑	☑
	SIA	☒	☑	☑	☑
	SIDIS	☒	☒	☑	☑
	DY	☒	☒	☒	☑
Function	f	☒	☒	☒	☑
	Δf	☑	☒	☑	☑
	D_f^h	☒	☑	☑	☑

IMC analysis + all available JLab data



Uses CJ12 NLO unpolarized PDFs

- Δu^+ **and** Δd^+ **consistent with previous analysis**
- Δs^+ **slightly harder**



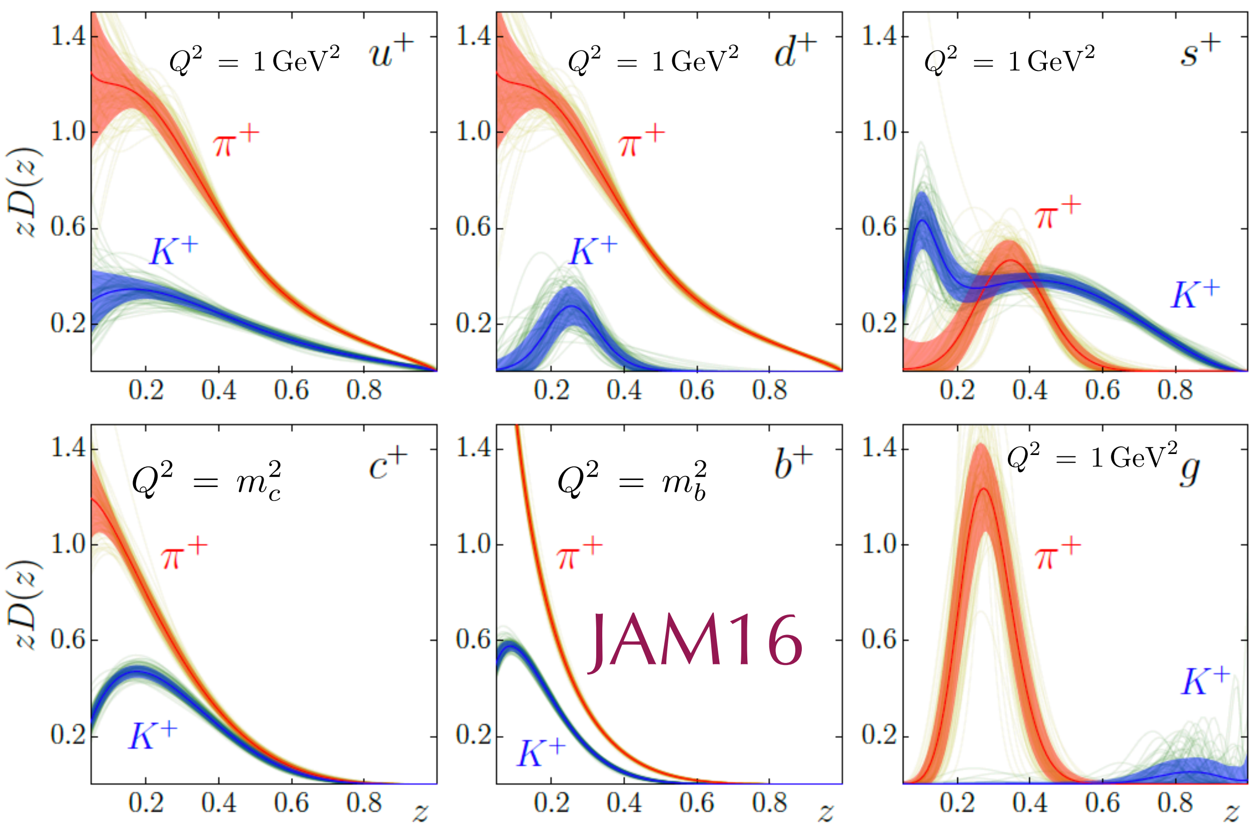
Impact of JLab data

Sato, Melnitchouk, Kuhn, Ethier, Accardi
Phys. Rev. D 93, 074005 (2016)

JAM16

JAM17

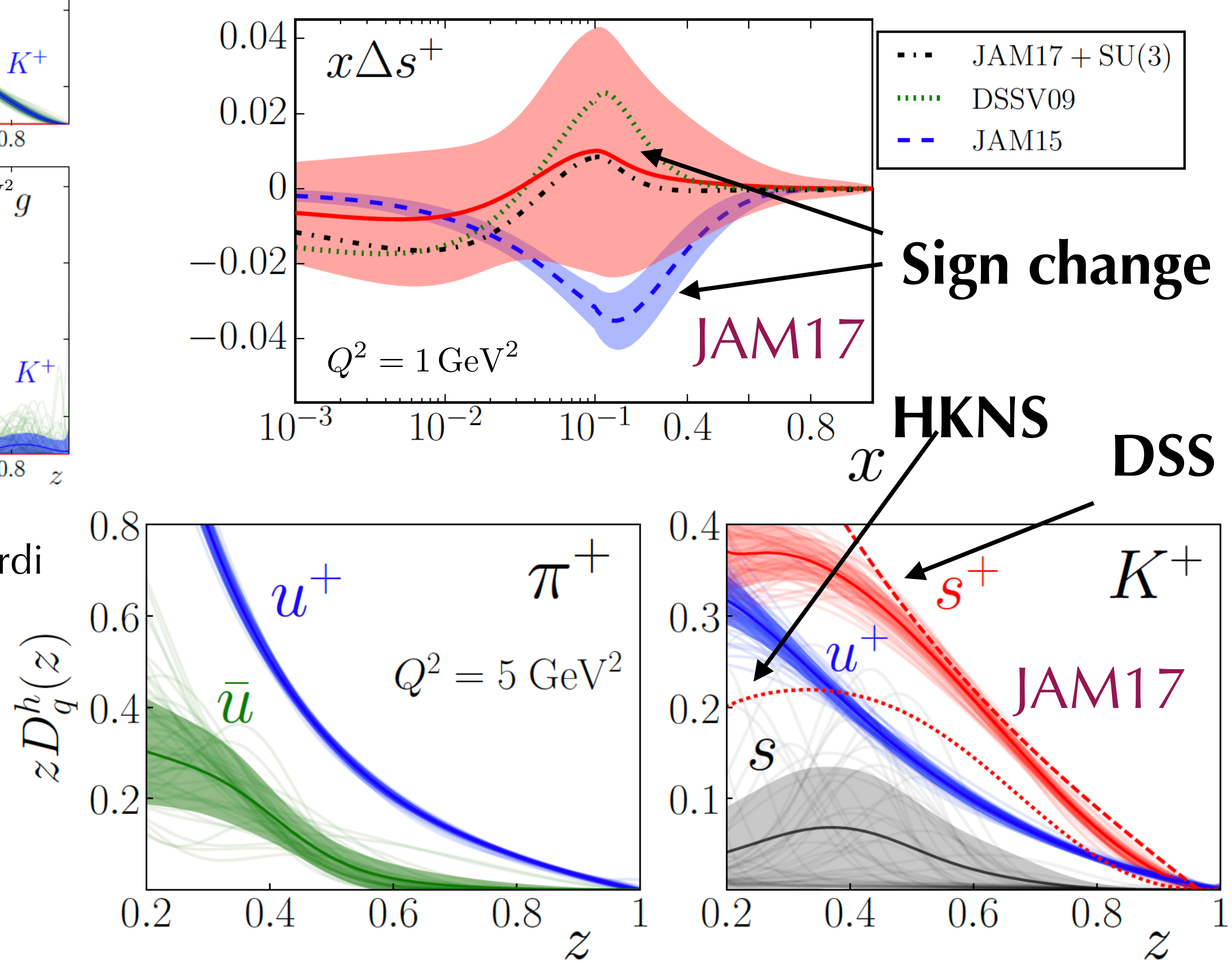
- First IMC analysis of FFs
- Only SIA included



Sato, Ethier, Melnitchouk, Hirai, Kumano and Accardi

Phys. Rev. D 94, 114004 (2016)

- First (simultaneous) MC analysis of polarized PDFs and FFs
- Polarized SIDIS, polarized DIS and SIA included



JAM17 FFs better agreement with other analysis

 Ethier, Sato, Melnitchouk: Phys. Rev. Lett. 119, 132001 (2017