Opportunities with constraining vacuum and nuclear FFs

P. Zurita

ePIC and EIC Physics Readiness Workshop (2nd edition)
Mar. 17-19, 2026

Outline

- Status of FFs: theory
- Status of FFs: pheno
- Opportunities with FFs at the EIC
- Idem with in-medium FFs (nFFs)

Status of FFs: theory

SIA

$$\frac{d\sigma^{e^+e^-\to h+X}}{dz} = \sum_{k=q,\bar{q},g} C_{e^+e^-\to V\to k} \otimes D_k^h$$

sensitive to $D_q^h + D_{\bar{q}}^h$

SIA

$$\frac{d\sigma^{e^+e^-\to h+X}}{dz} = \sum_{k=q,\bar{q},g} C_{e^+e^-\to V\to k} \otimes D_k^h$$

sensitive to $D_q^h + D_{\bar{q}}^h$

SIDIS

$$\frac{d\sigma^{ep\to h+X}}{dxdzdQ^2} = \sum_{i,j=q,\bar{q},g} C_{ei\to k} \otimes f_i \otimes D_k^h$$

sensitive to D_q^h, $D_{\bar{q}}^h$

SIA

$$\frac{d\sigma^{e^+e^-\to h+X}}{dz} = \sum_{k=q,\bar{q},g} C_{e^+e^-\to V\to k} \otimes D_k^h$$

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sensitive to D_q^h, $D_{\bar{q}}^h$

SIH

$$\frac{d^3\sigma^{pp\to h+X}}{d^3p} = \sum_{i,j,k=q,\bar{q},g} C_{ij\to k} \otimes f_i \otimes f_j \otimes D_k^h$$

sensitive to D_q^h, $D_{\bar{q}}^h$, D_g^h

SIA

Coefficients known up to NNLO for a long time

NNLO time-like evolution is much newer

P.J. Rijken and W.L. van Neerven.
NPB 487 (1997) 233, PLB 392 (1997) 207

A.A. Almasy, S. Moch, A. Vogt.
NPB 854 (2012) 133
D.P. Anderle, F. Ringer, M. Stratmann.
PRD 92 (2015) 11, 114017

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Coefficients known to NLO for a **long** time

G. Altarelli, R.K. Ellis, G. Martinelli, S.-Y. Pi.
NPB 160 (1979) 301

Coefficients known to NNLO **very** recently

S. Goyal, S.-O. Moch, V. Pathak, N. Rana, V. Ravindran. PRL 132 (2024) 25, 251902

L. Bonino, T. Gehrmann, G. Stagnitto.
PRL 132 (2024) 25, 251901

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PRL 132 (2024) 25, 251901

SIH

Coefficients known to NLO for a **long** time

F. Aversa, P. Chiappetta, M. Greco, J.P. Guillet.
NPB 327 (1989) 105

B. Jager, A. Schafer, M. Stratmann, W. Vogelsang. PRD 67 (2003) 054005

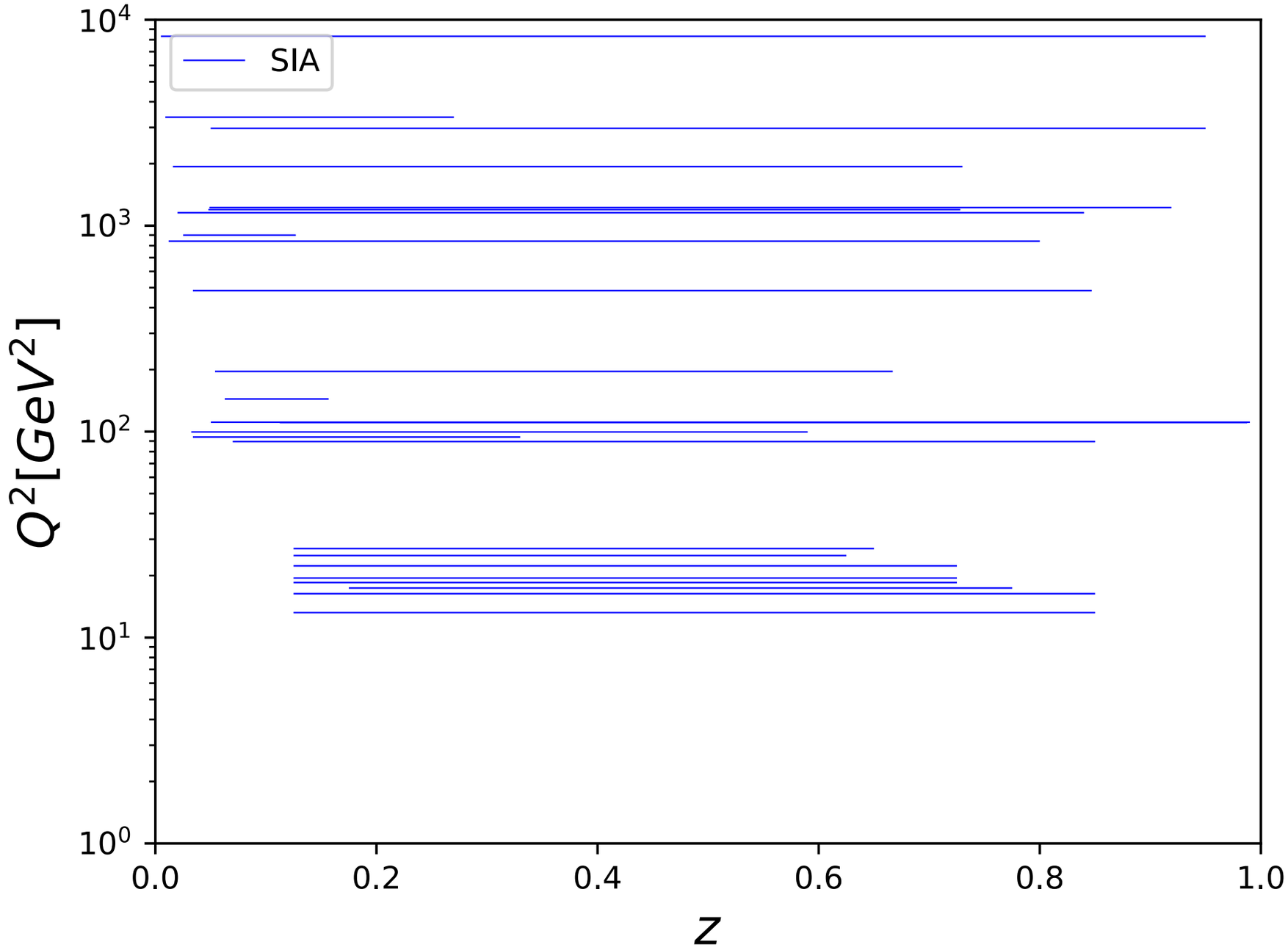
Coefficients known to NNLO **very** recently

M. Czakon, T. Generet, A. Mitov, R. Poncelet.
PRL 135 (2025) 17

Status of FFs: phenomenology

See talk by I. Borsa at SHARP CA meeting

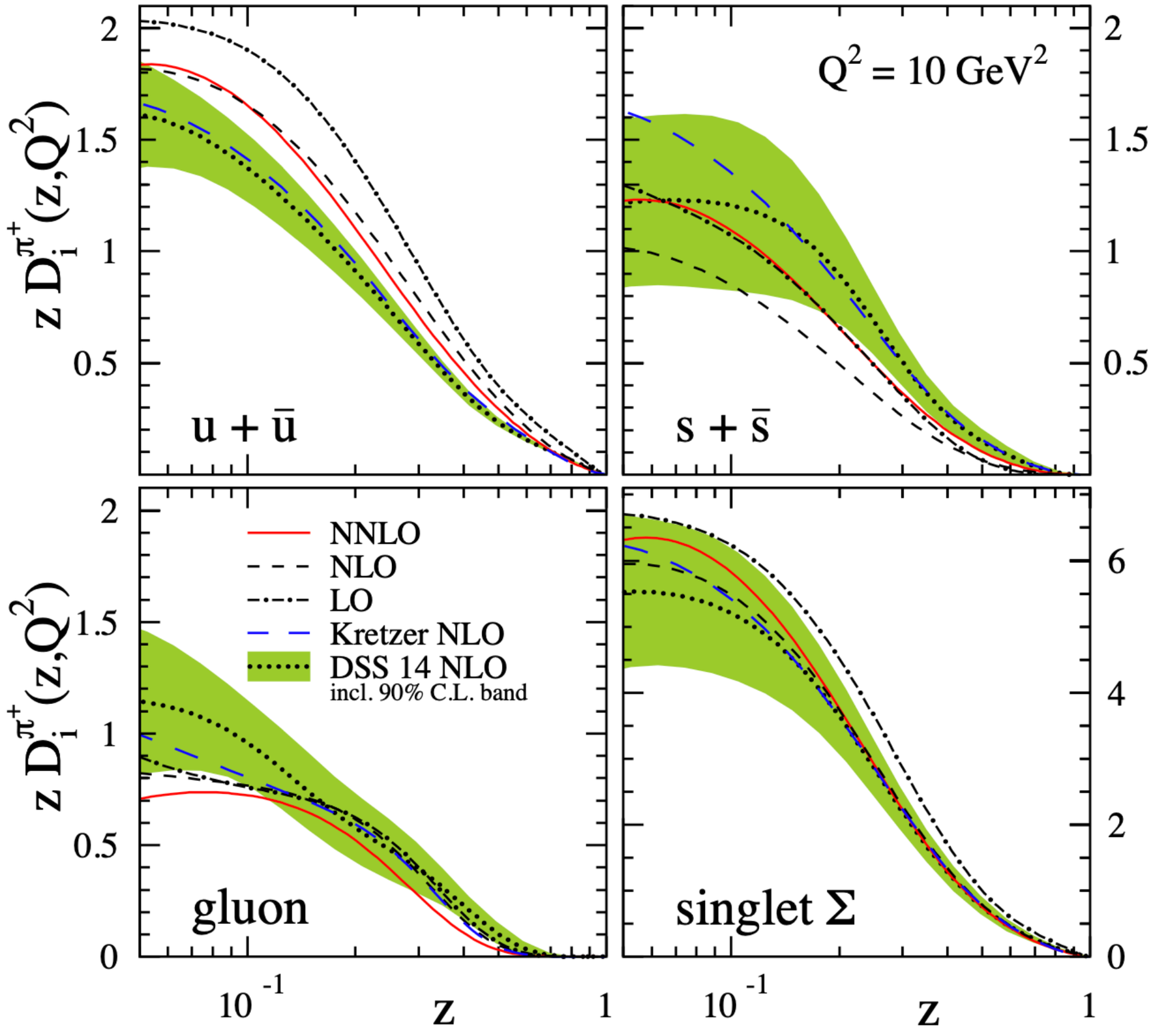
https://indico.cern.ch/event/1642976/



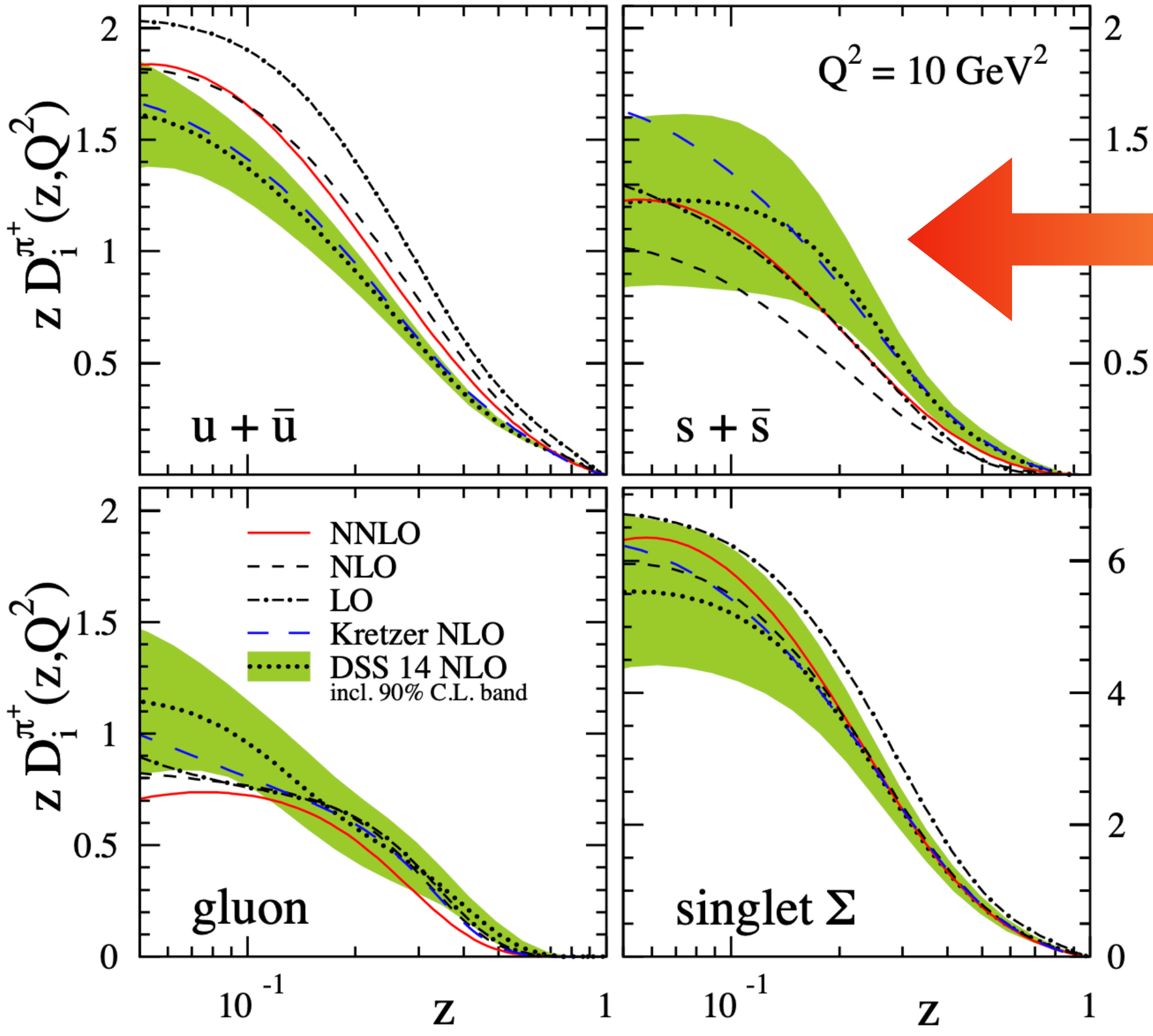
Warnings:

no separation in hadronic species

higher $\sqrt{s}$ only for charged hadrons (LEP)



D.P. Anderle, F. Ringer, M. Stratmann. Phys.Rev.D 92 (2015) 11, 114017



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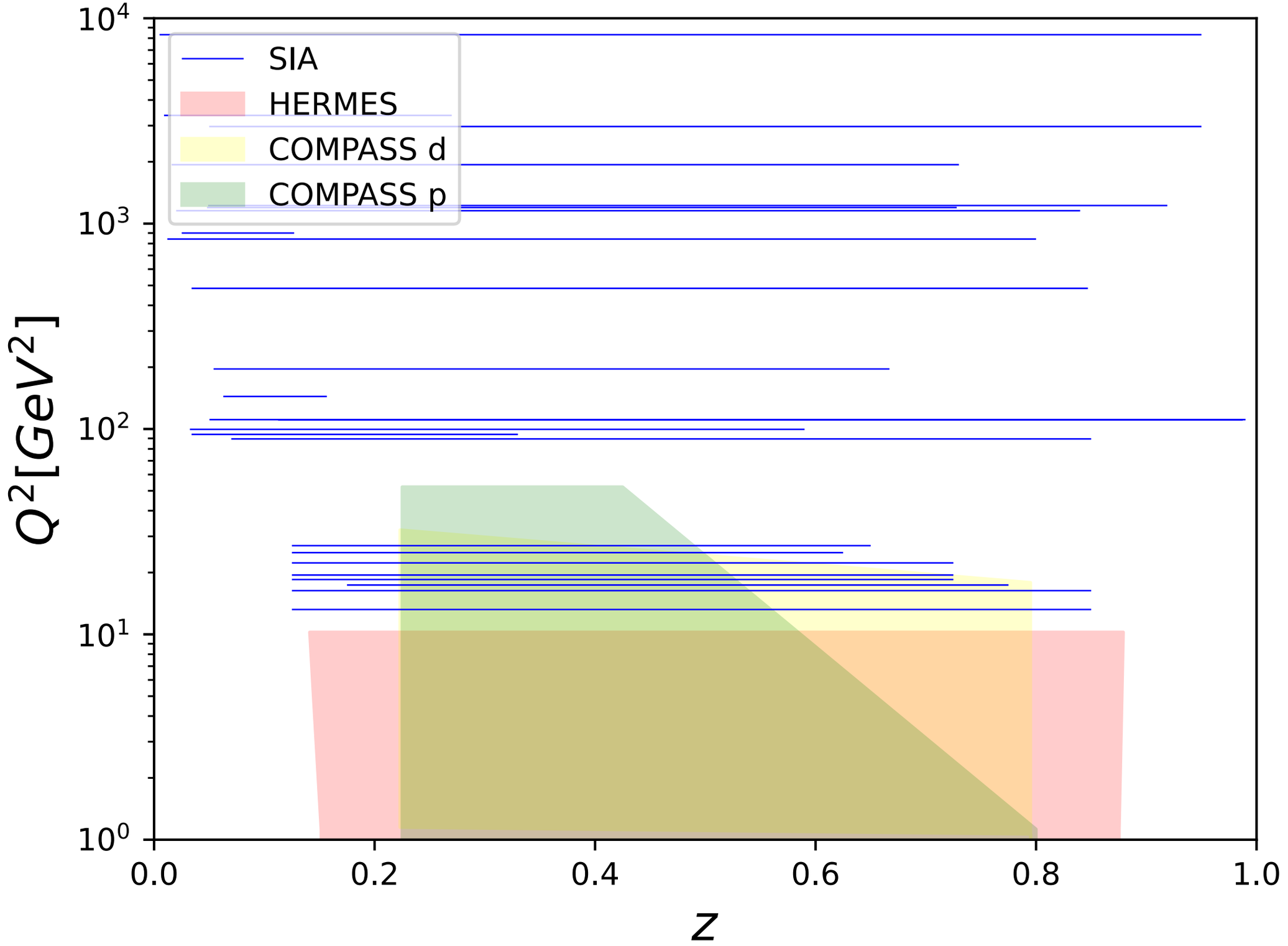
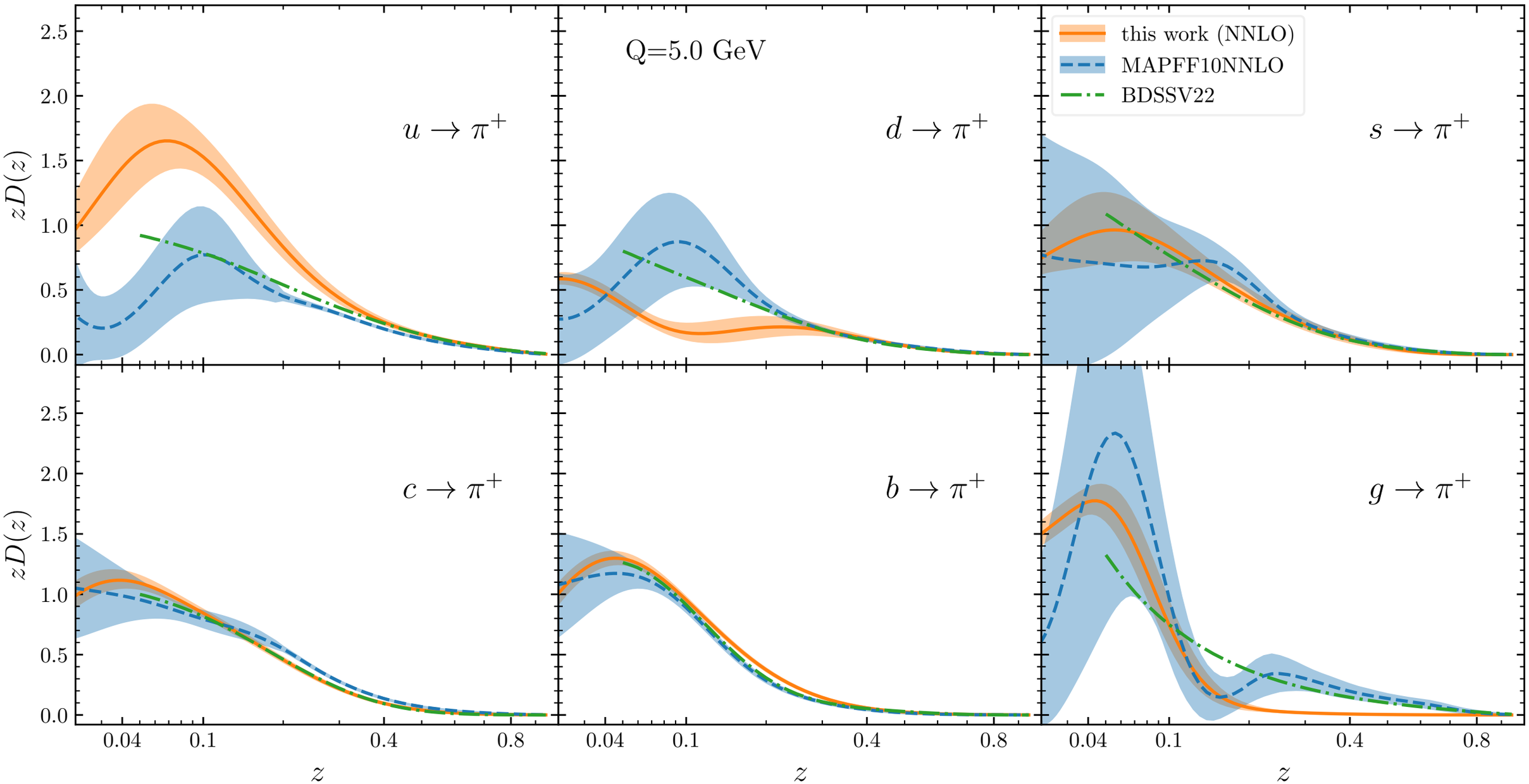


Warnings:

same as before

+ SIDIS limits from average values of z and Q^2



Approx. NNLO SIDIS by

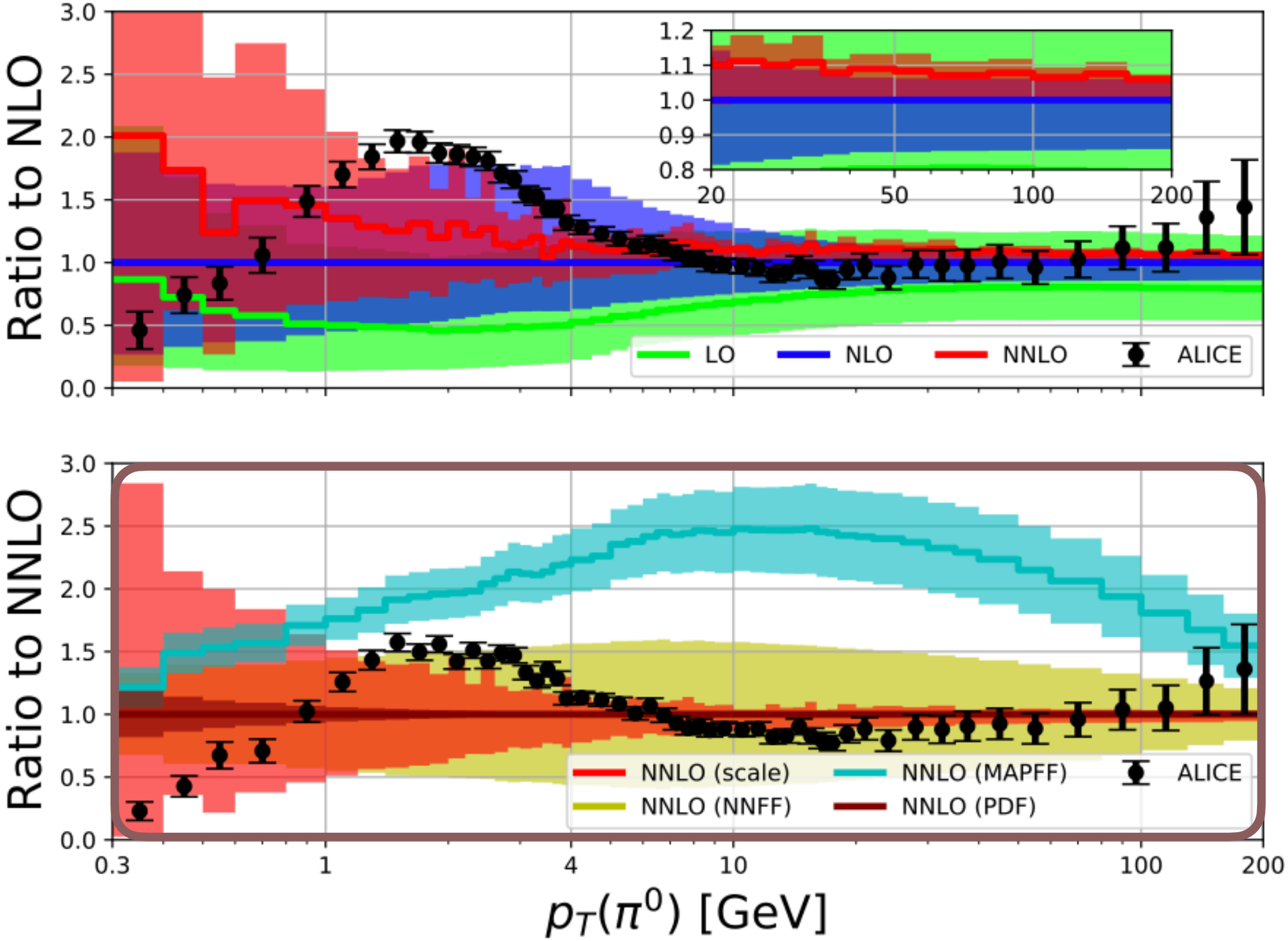
MAP Collaboration. Phys.Lett.B 834 (2022) 137456

I. Borsa, R. Sassot, D. de Florian, M. Stratmann, W. Vogelsang. Phys.Rev.Lett. 129 (2022) 1, 012002

“This work”= full NNLO SIDIS by

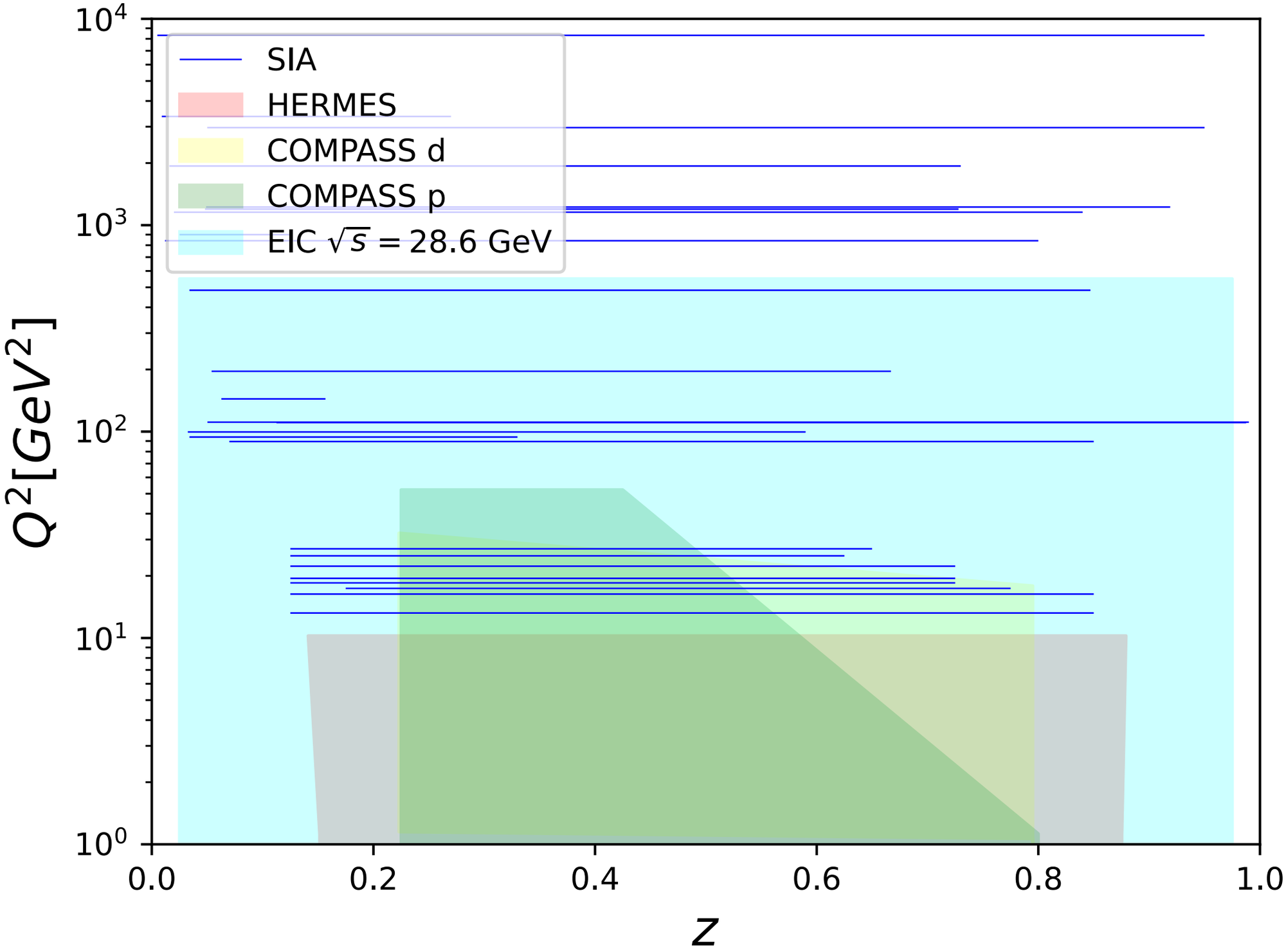
J. Gao, X. Shen, H. Xing, Y. Zhao, B. Zhou. Phys.Rev.Lett. 135 (2025) 4, 041902

With SIH NNLO (predictions)

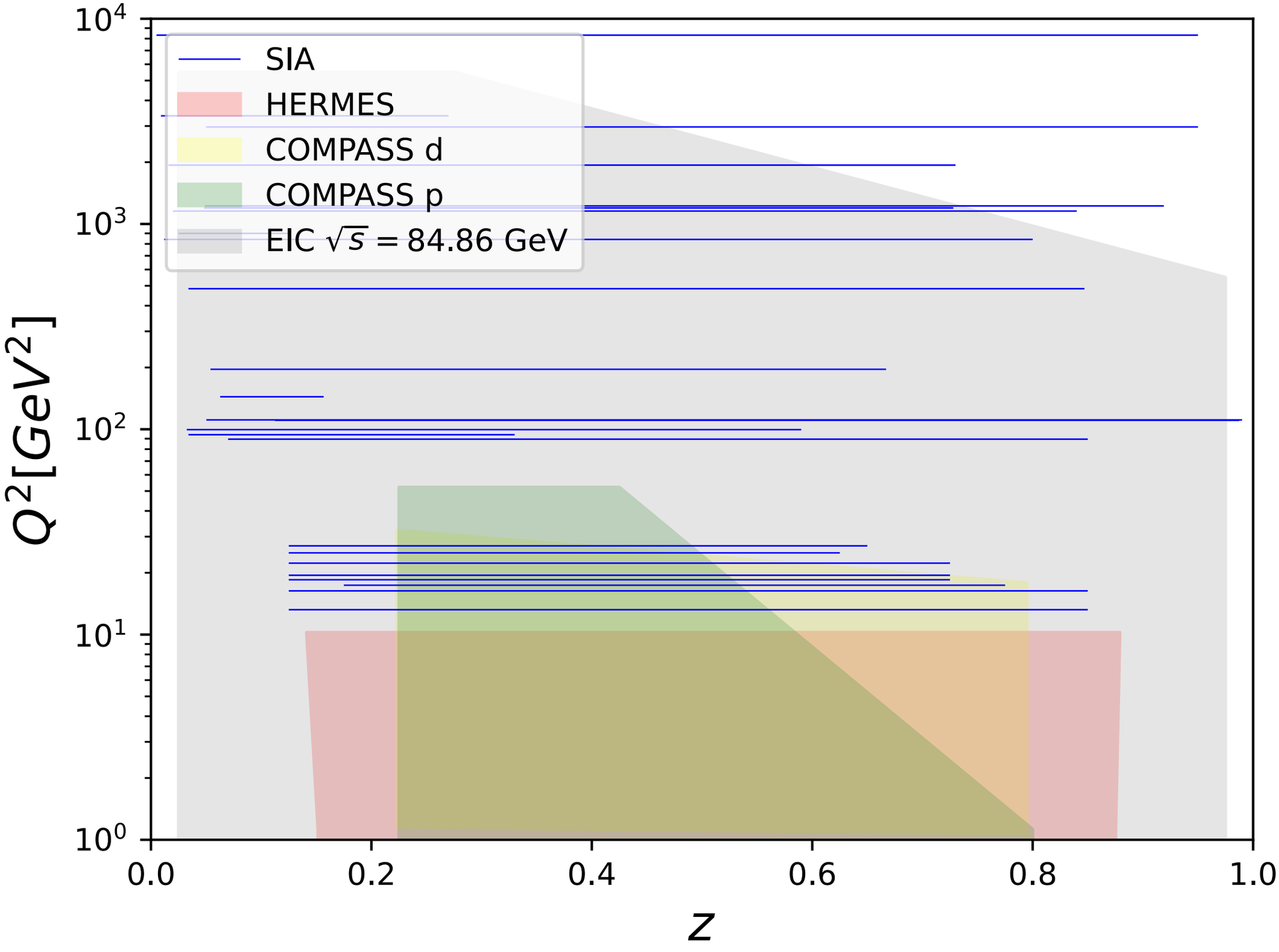


M. Czakon, T. Generet, A. Mitov, R. Poncelet. Phys.Rev.Lett. 135 (2025) 17

Opportunities with FFs at the EIC

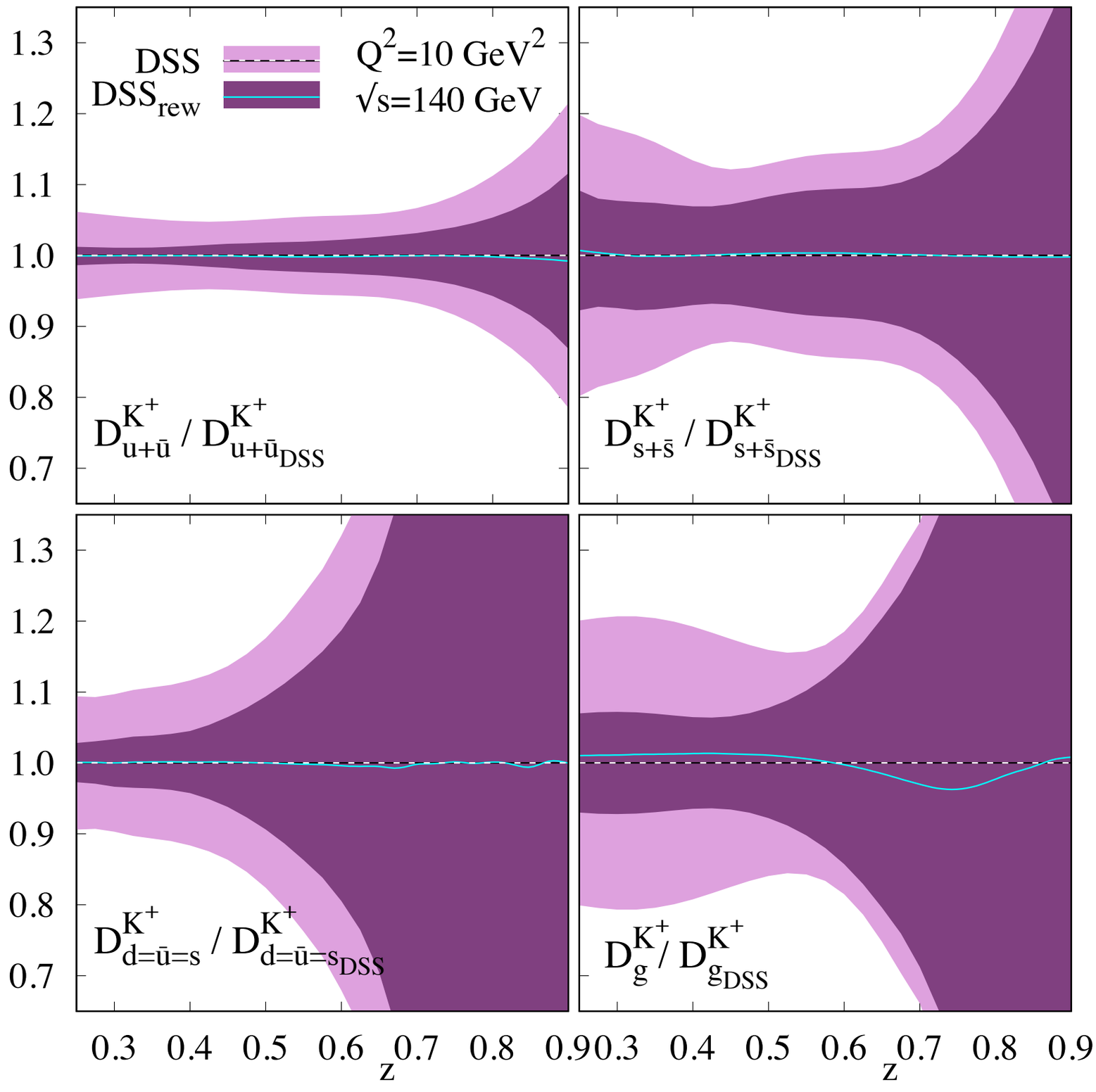


Warnings: same as before



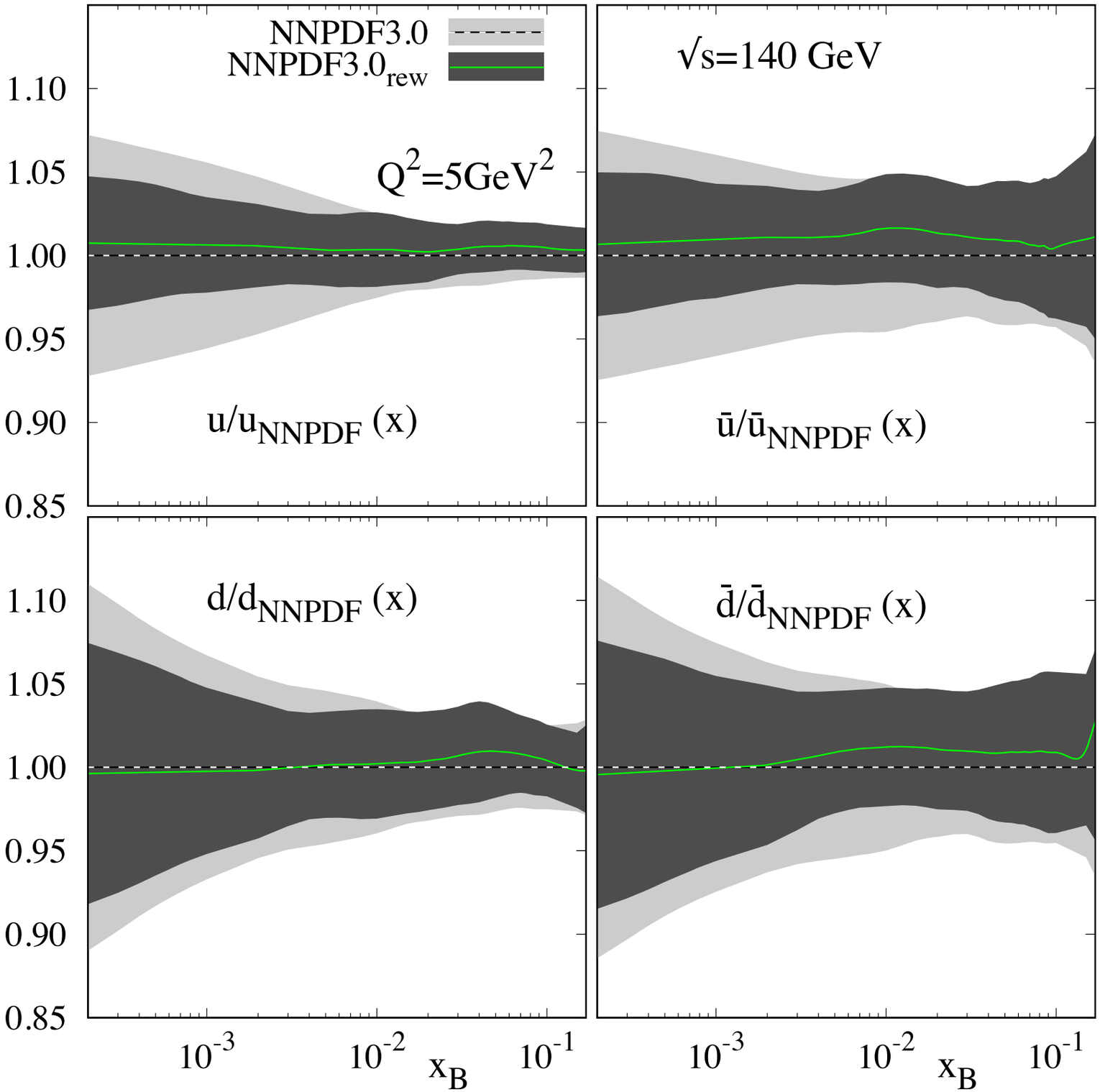
Warnings: same as before

Improve knowledge of FFs



E.-C. Aschenauer, I. Borsa, R. Sassot, C. Van Hulse. Phys.Rev.D 99 (2019) 9, 094004

Improve knowledge of **PDFs**



E.-C. Aschenauer, I. Borsa, R. Sassot, C. Van Hulse. Phys.Rev.D 99 (2019) 9, 094004

Let's go nuclear:

all the same, in a

nuclear environment

Status of in-medium theory

SIA

Status of in-medium theory

Status of in-medium theory

~~SI~~

SIDIS

$$\frac{d\sigma^{eA\to h+X}}{dxdzdQ^2} = \sum_{i,j=q,\bar{q},g} C_{ei\to k} \otimes f_{i/A} \otimes D^h_{k/A}$$

sensitive to $D^h_{q/A}$, $D^h_{\bar{q}/A}$

Status of in-medium theory

~~SI~~

SIDIS

$$\frac{d\sigma^{eA\to h+X}}{dxdzdQ^2} = \sum_{i,j=q,\bar{q},g} C_{ei\to k} \otimes f_{i/A} \otimes D^h_{k/A}$$

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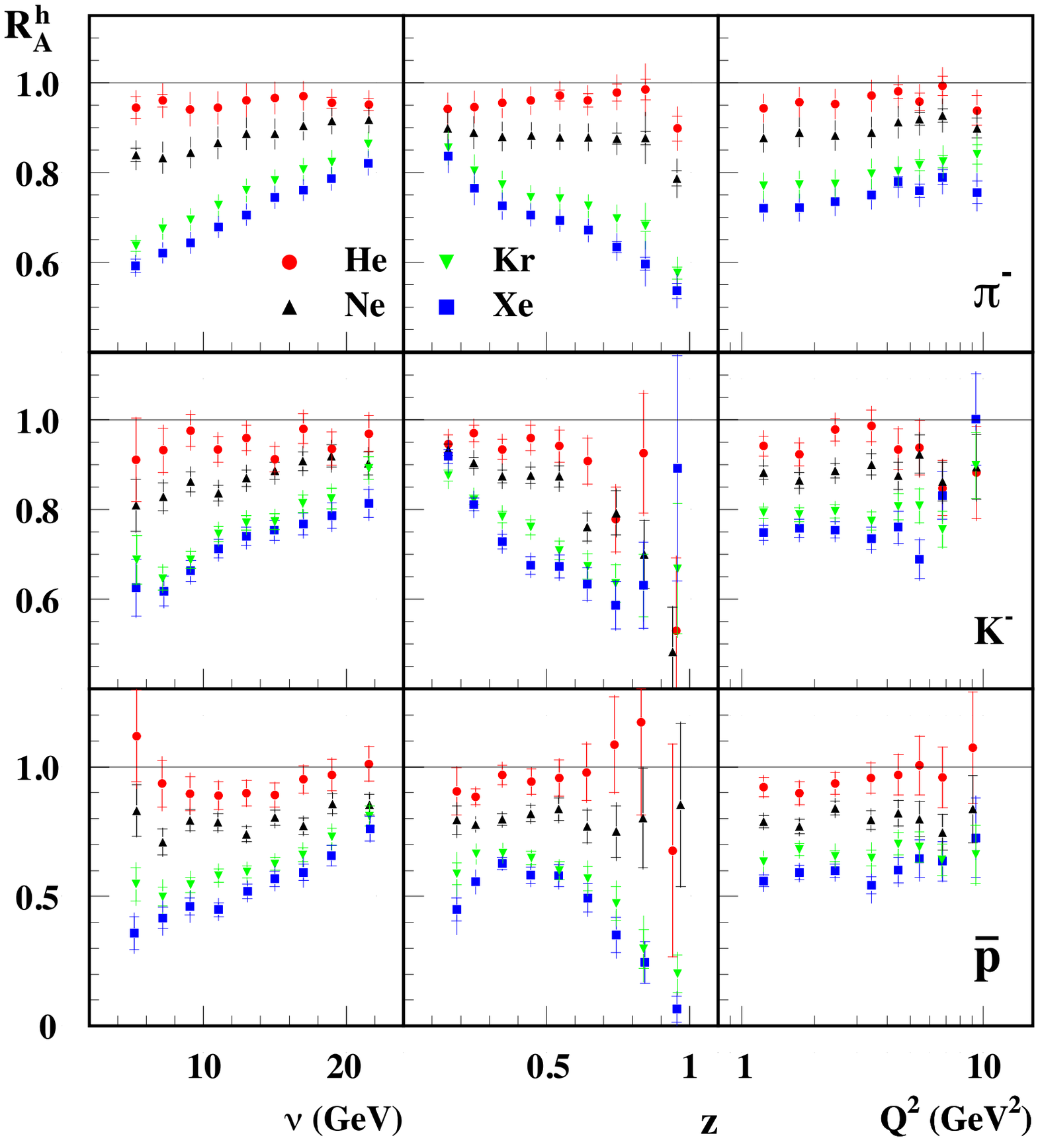
$$\frac{d^3\sigma^{pA\to h+X}}{d^3p} = \sum_{i,j,k=q,\bar{q},g} C_{ij\to k} \otimes f_{i/p} \otimes f_{j/A} \otimes D^h_{k/A}$$

sensitive to $D^h_{q/A}$, $D^h_{\bar{q}/A}$, $D^h_{g/A}$

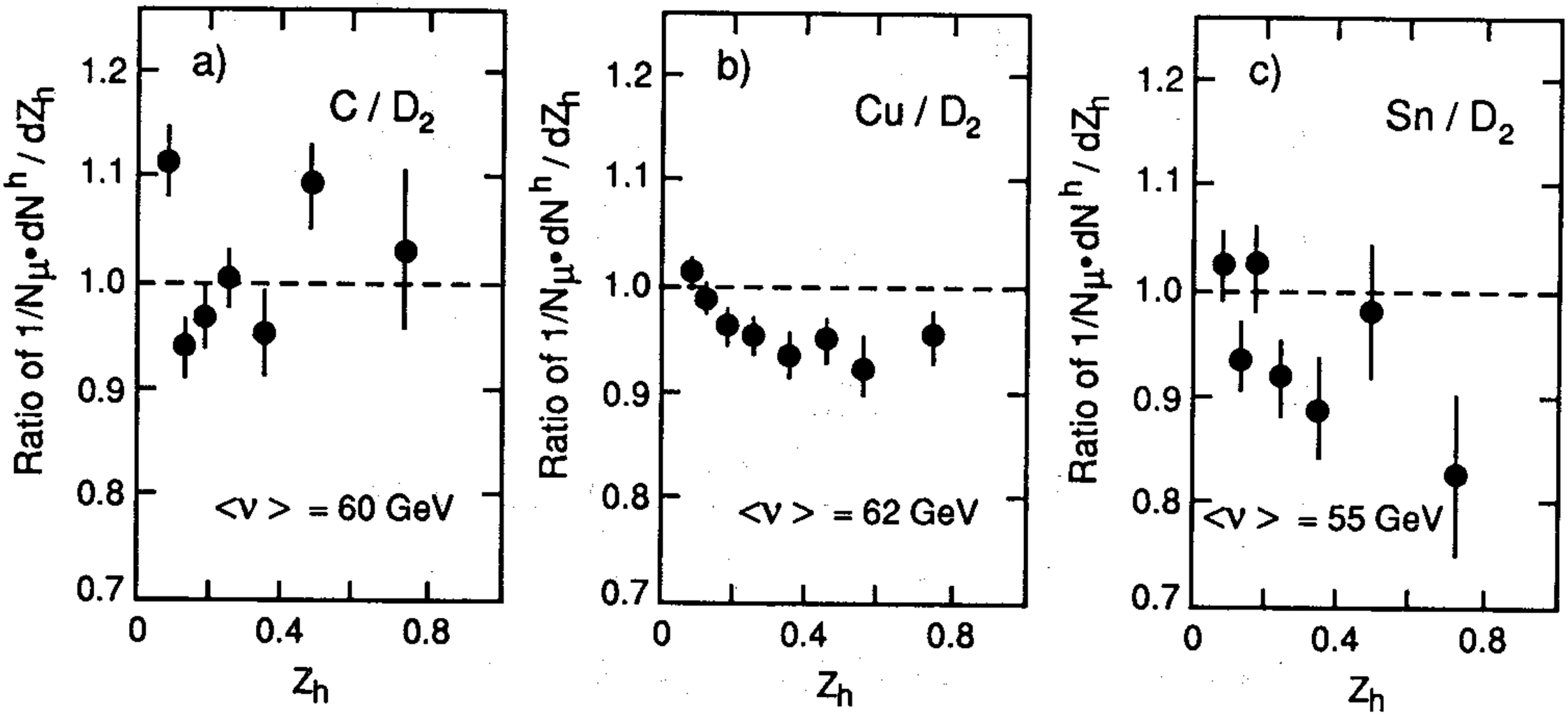
Status of SIDIS off nuclei: phenomenology

HERMES Collaboration. Nucl.Phys.B 780 (2007) 1

$$R_A^h(\nu, z, Q^2, p_t^2) = \frac{\left(\frac{N^h(\nu, z, Q^2, p_t^2)}{N^e(\nu, Q^2)}\right)_A}{\left(\frac{N^h(\nu, z, Q^2, p_t^2)}{N^e(\nu, Q^2)}\right)_D}$$



EMC: not fully differential like HERMES



European Muon Collaboration. Z.Phys.C 52 (1991)

- EMC: not fully differential like HERMES

- HERMES

HERMES Collaboration. Nucl.Phys.B 780 (2007) 1

- EMC: not fully differential like HERMES

- HERMES

HERMES Collaboration. Nucl.Phys.B 780 (2007) 1

- CLAS

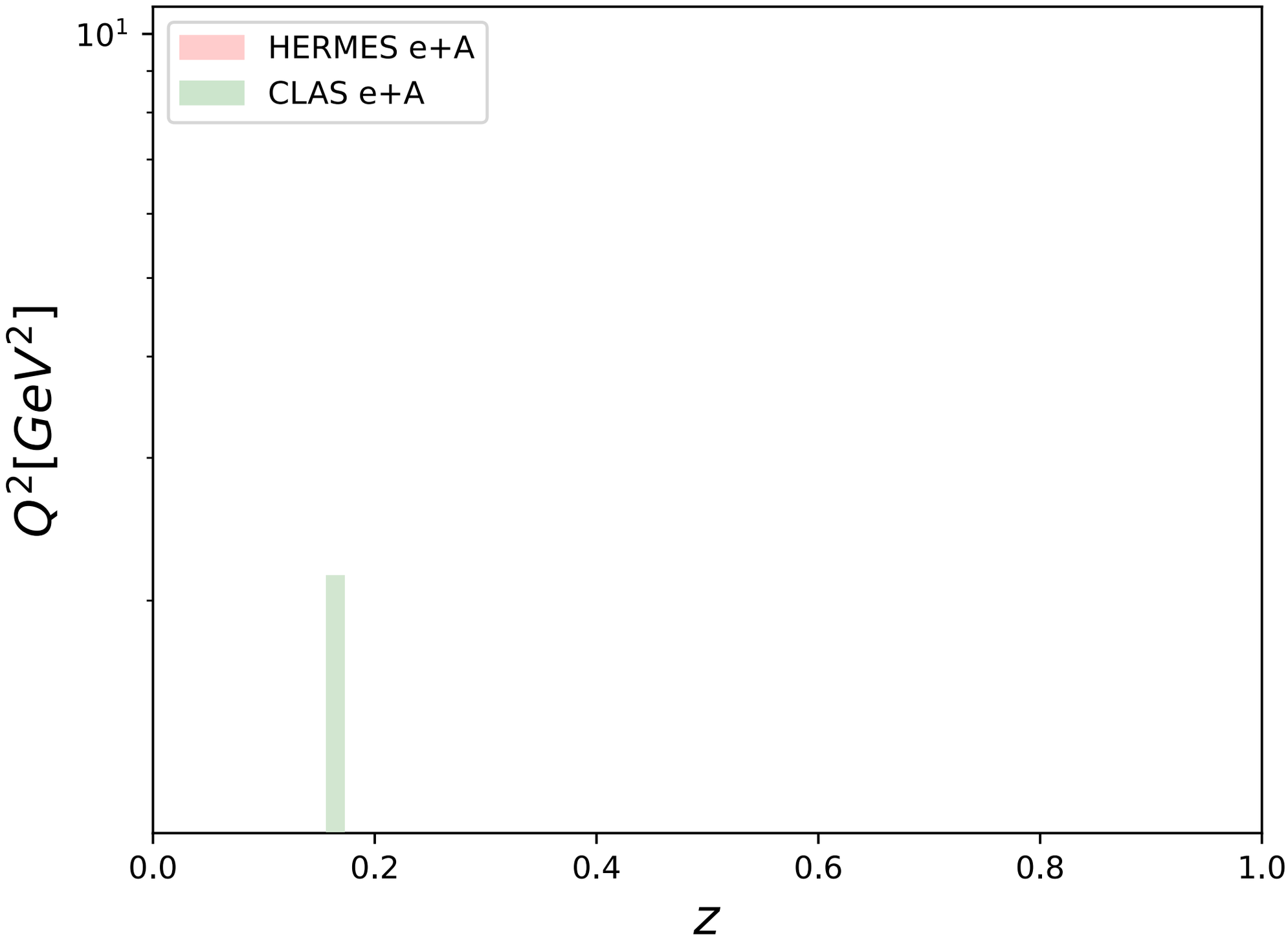
CLAS Collaboration. Phys.Rev.C 105 (2022) 1, 015201

- EMC: not fully differential like HERMES

- HERMES — **HERMES Collaboration. Nucl.Phys.B 780 (2007) 1**

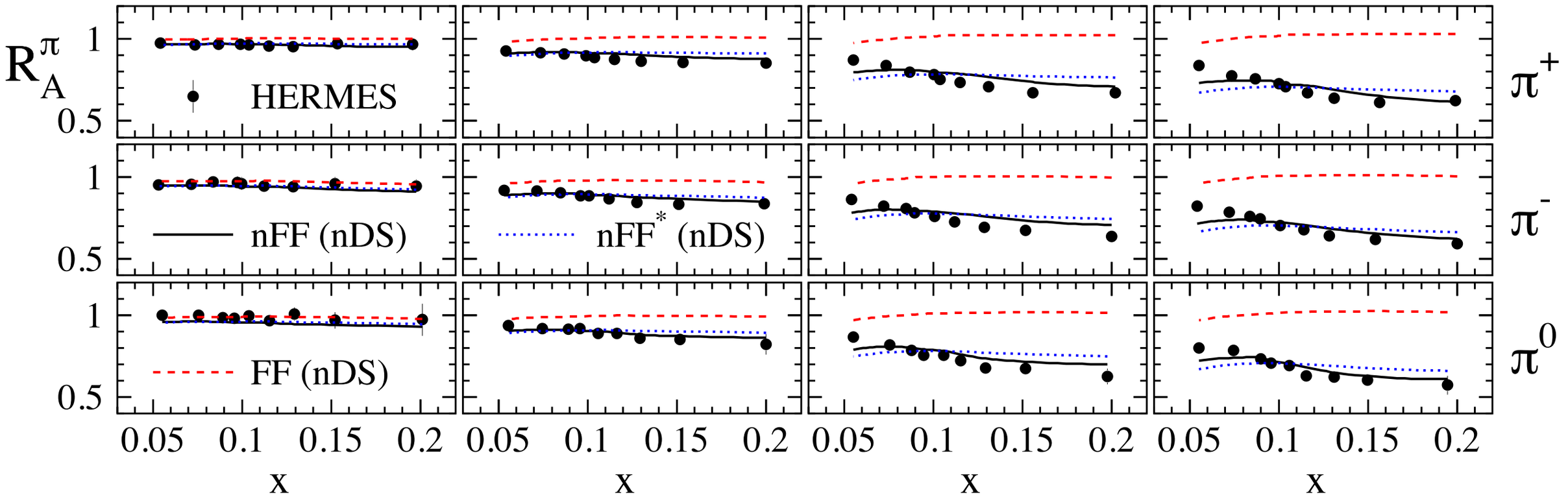
- CLAS — **CLAS Collaboration. Phys.Rev.C 105 (2022) 1, 015201**

- RHIC (d+Au) & LHC (p+Pb)



Warnings: SIDIS limits from average values of z and Q^2

nPDFs are not enough to describe the data



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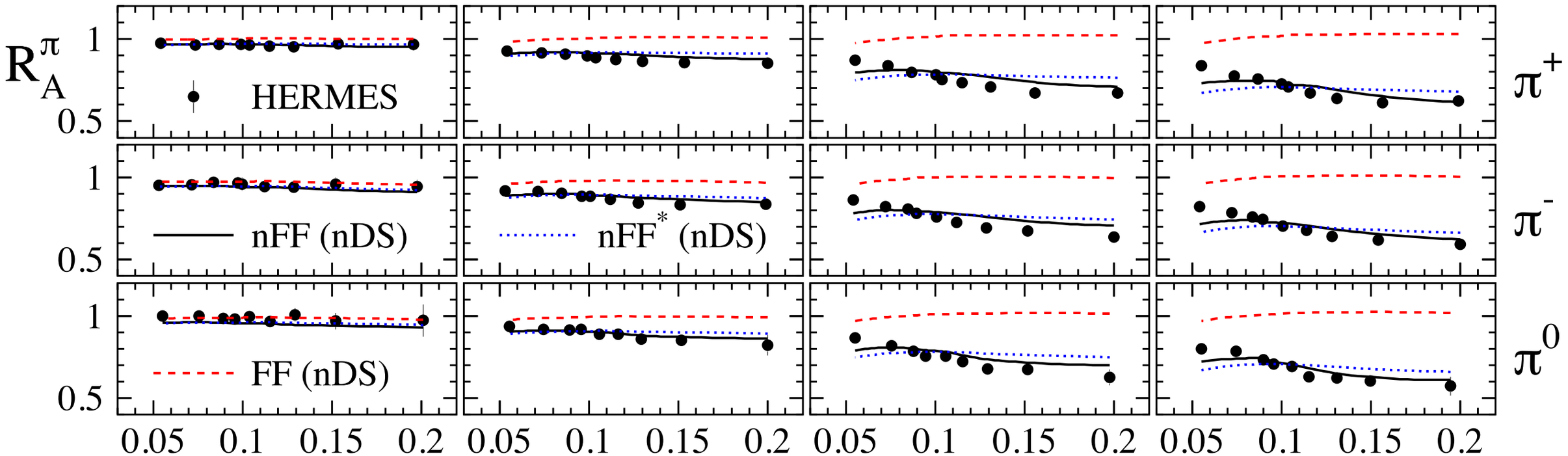
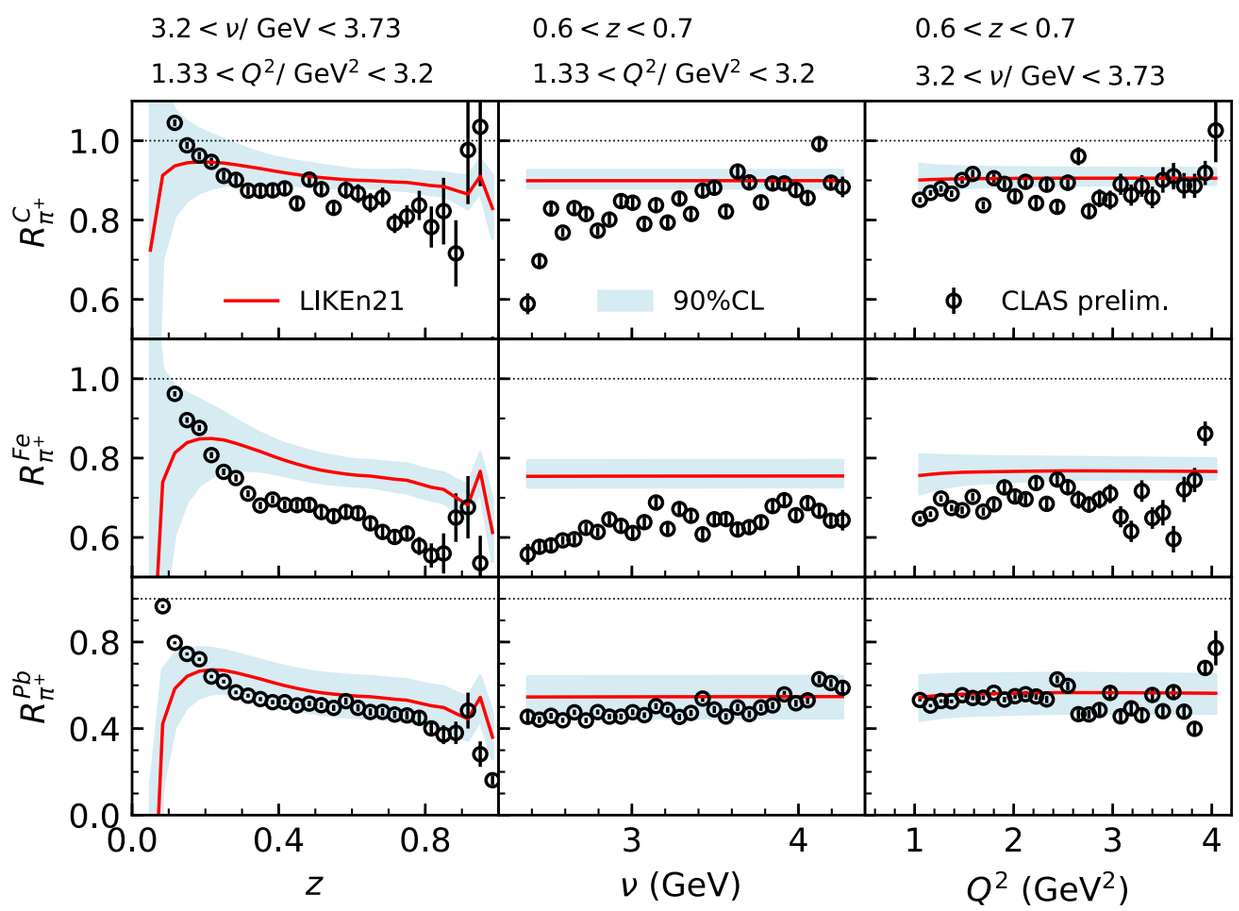
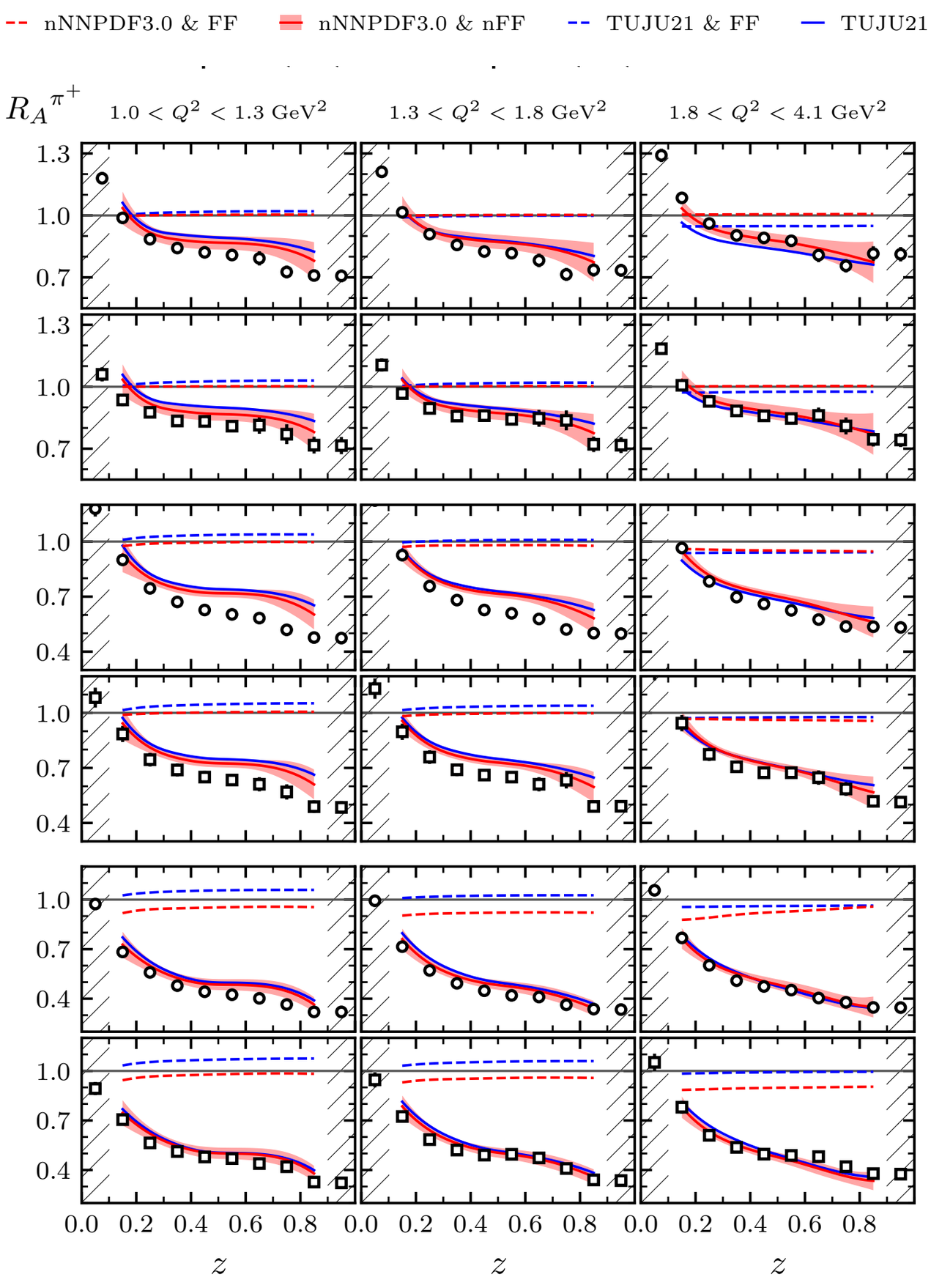


nFFs introduced

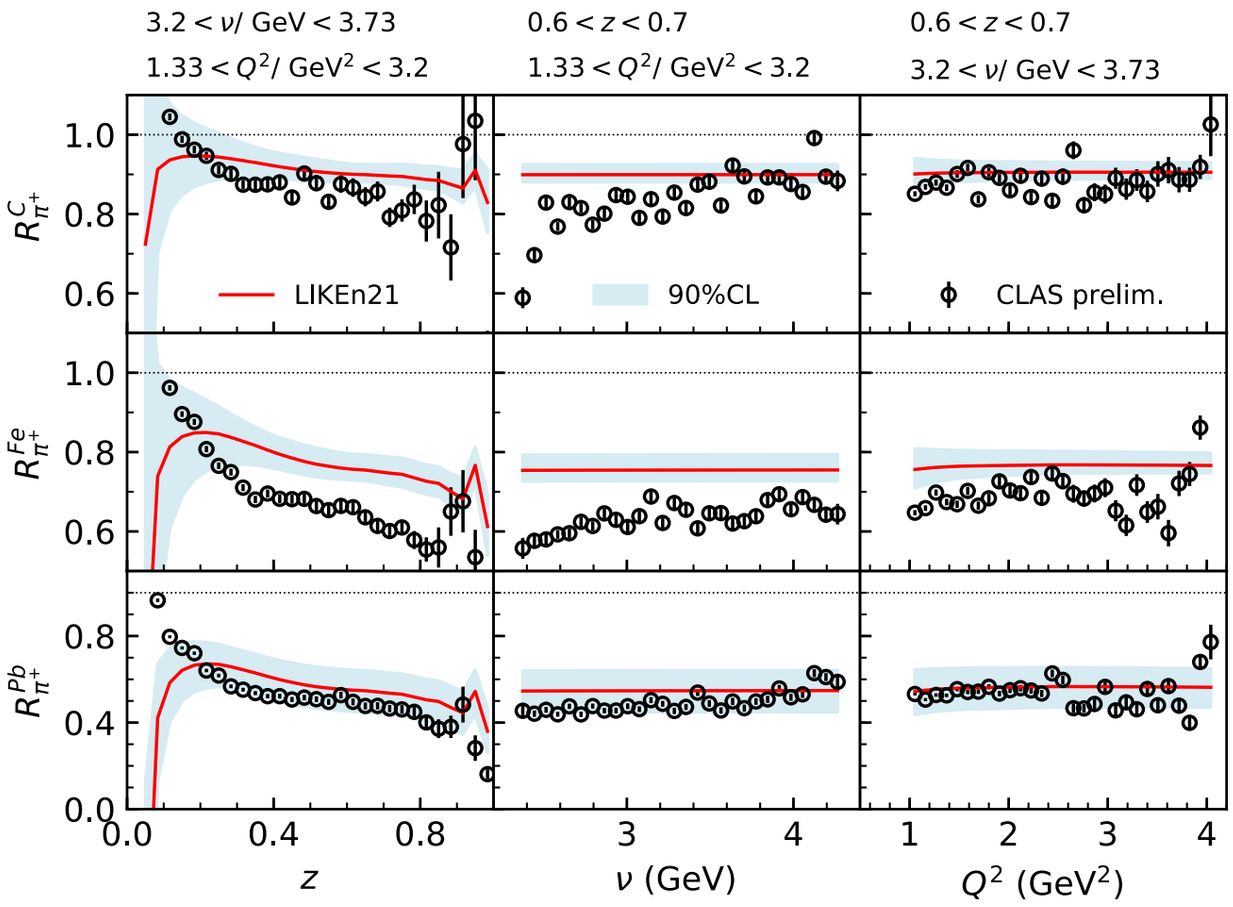
- SIDIS@HERMES and SIH@RHIC. **R. Sassot, M. Stratmann, PZ. Phys.Rev.D 81 (2010) 054001**
- SIDIS@HERMES. **PZ. arXiv:2101.01088**
- SIDIS@HERMES/CLAS and SIH@RHIC/LHC. **M. Doradau, R.T. Martinez, R. Sassot, M. Stratmann. Phys.Rev.D 111 (2025) 3, 034045**

PZ, arXiv:2101.01088





PZ, arXiv:2101.01088



M. Doradau, R.T. Martinez, R. Sassot, M. Stratmann. Phys.Rev.D 111 (2025) 3, 034045

Opportunities with SIDIS off nuclei at the EIC

Could in principle be used to improve nPDFs

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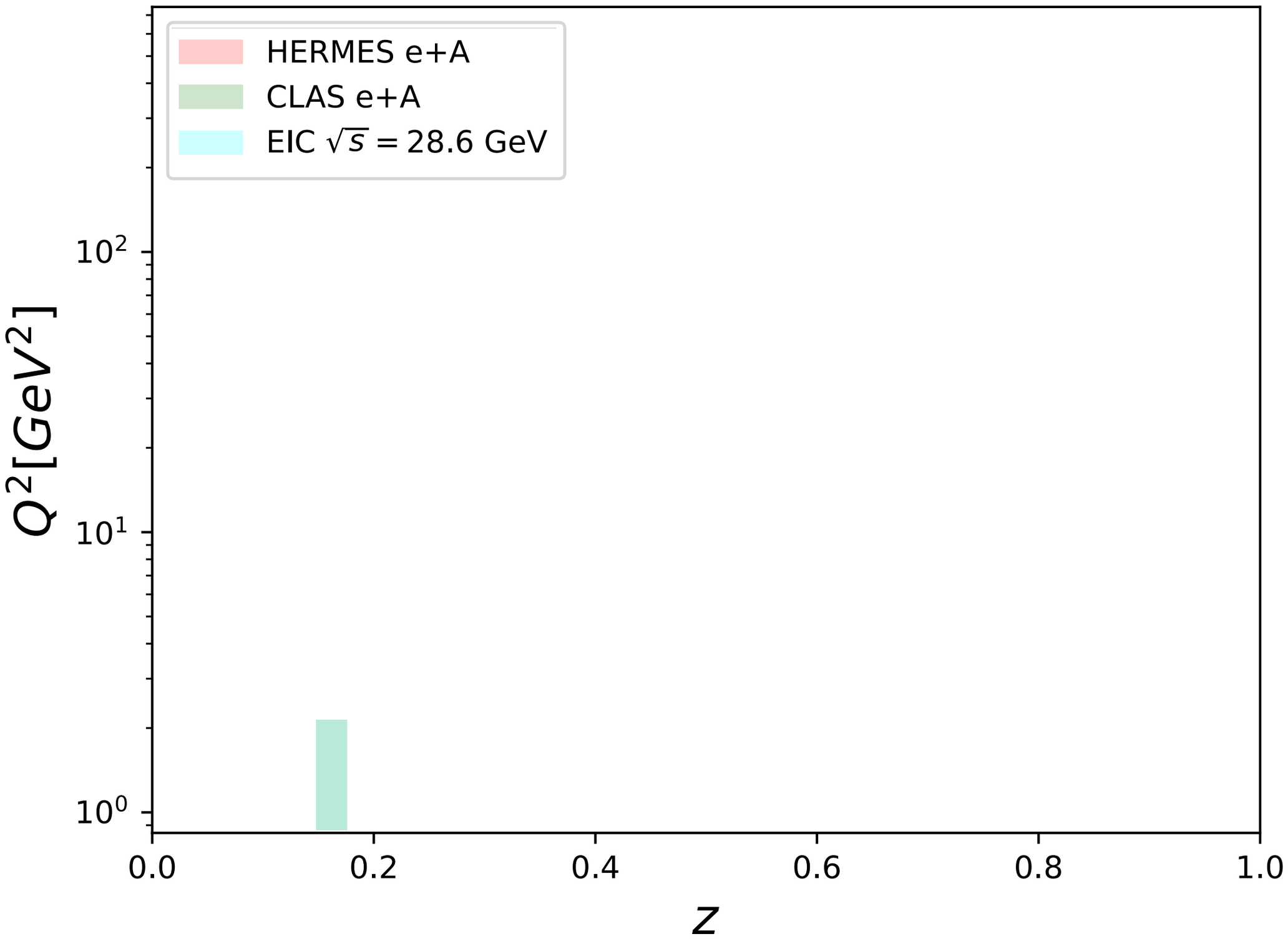
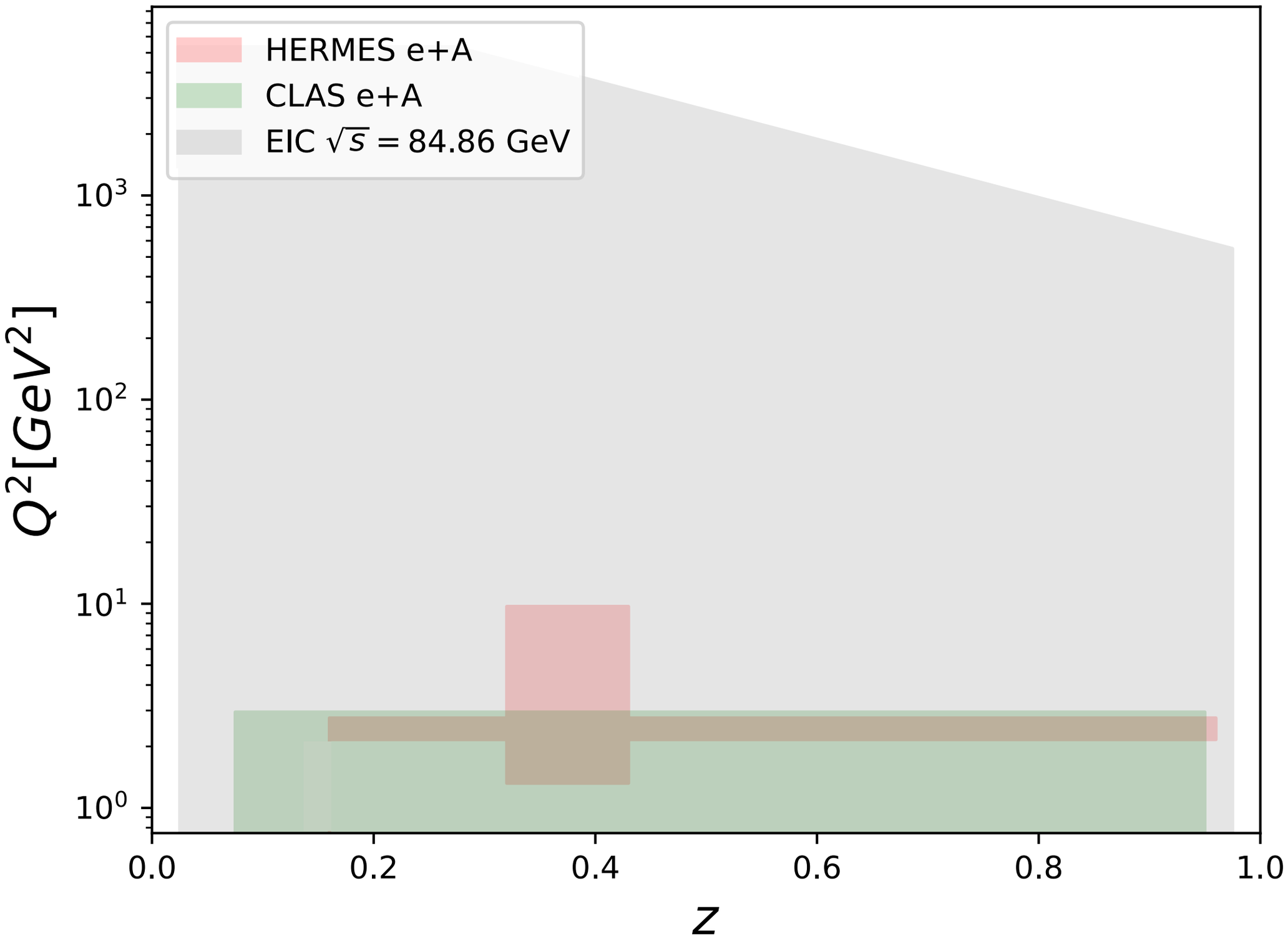
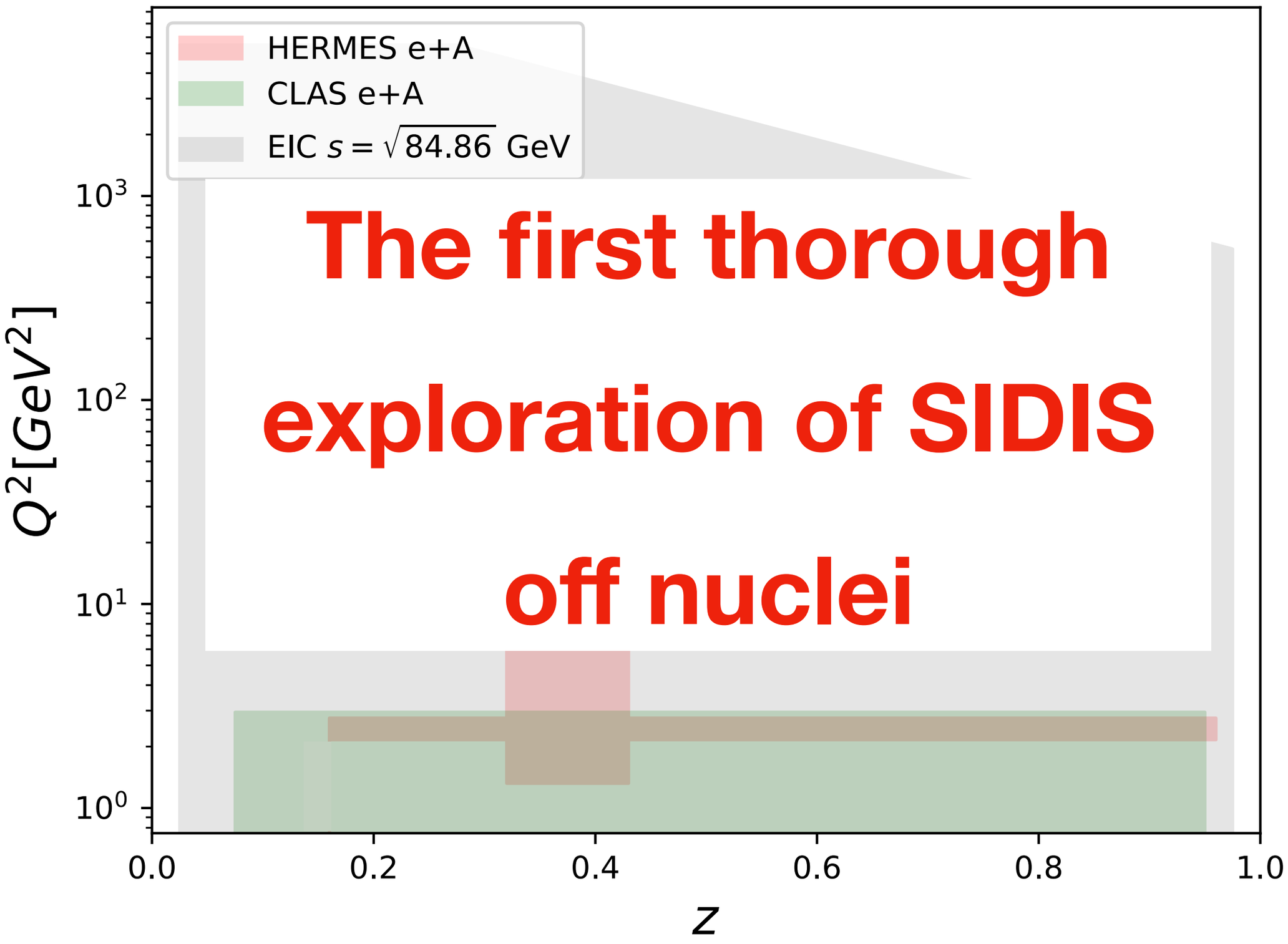
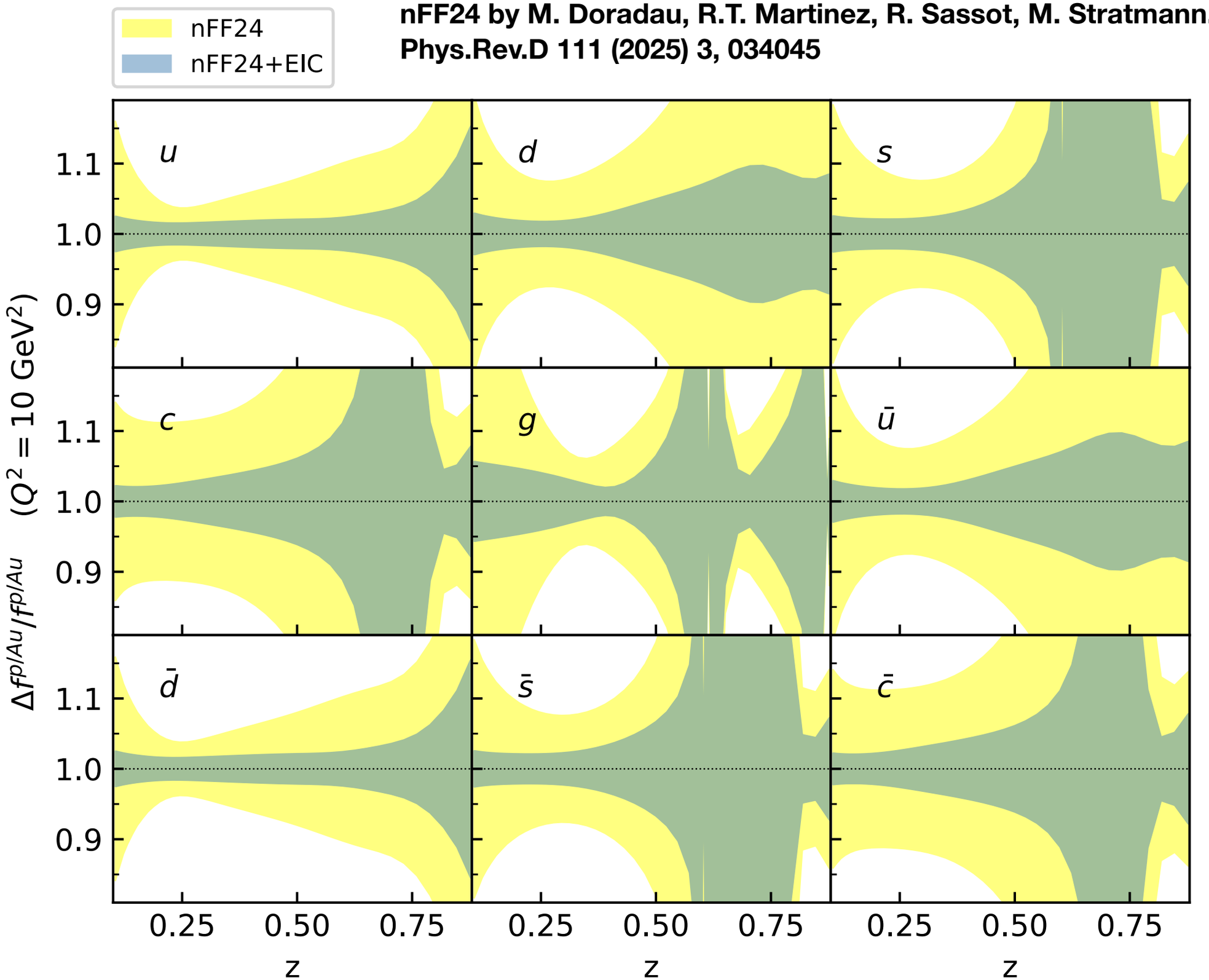



HERMES e+A
CLAS e+A
EIC $\sqrt{s} = 84.86$ GeV
$Q^2[GeV^2]$
10^3
10^2
10^1
10^0
0.0
0.2
0.4
0.6
0.8
1.0
z



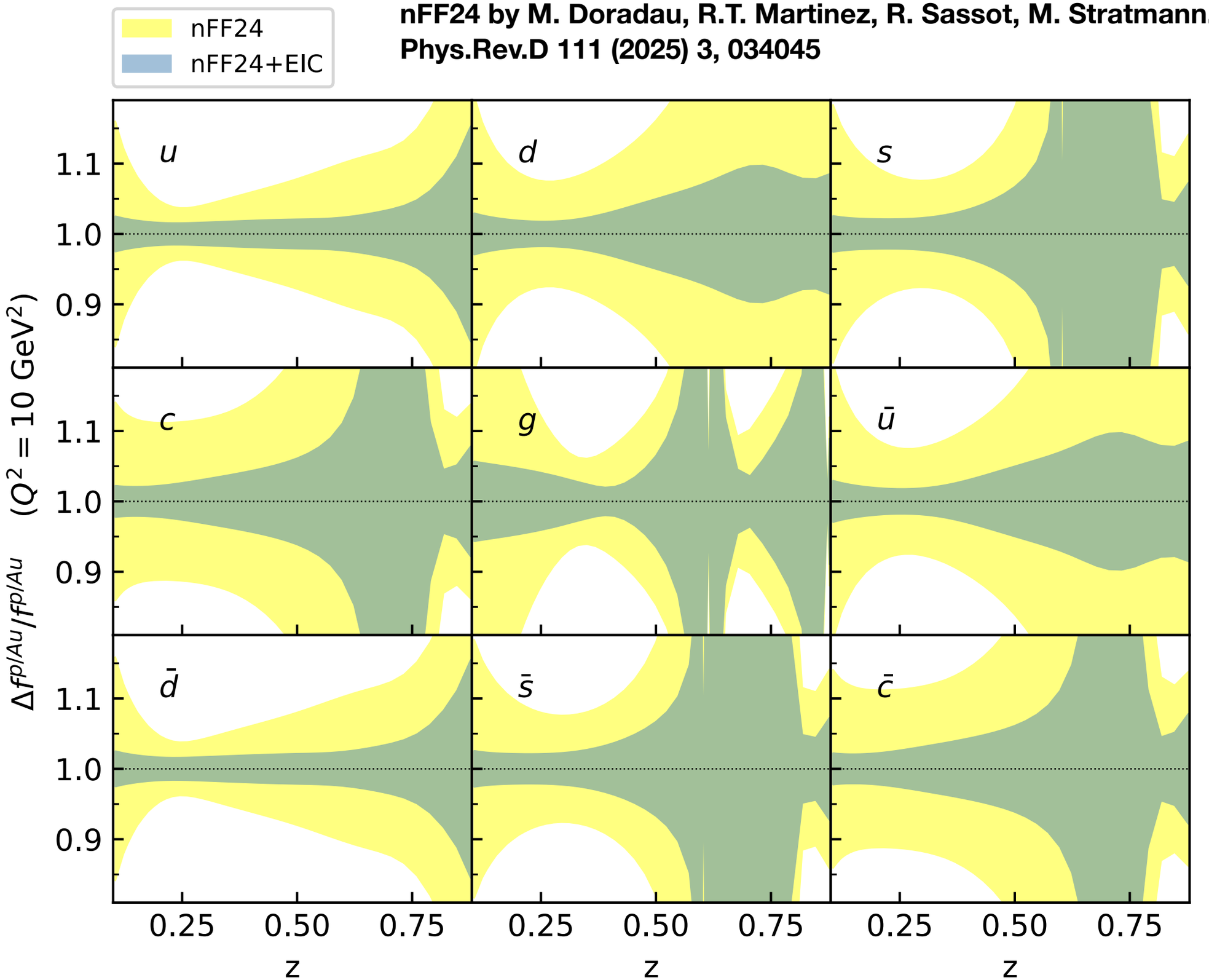
The first thorough exploration of SIDIS off nuclei

nFF24 by M. Doradau, R.T. Martinez, R. Sassot, M. Stratmann.
Phys.Rev.D 111 (2025) 3, 034045



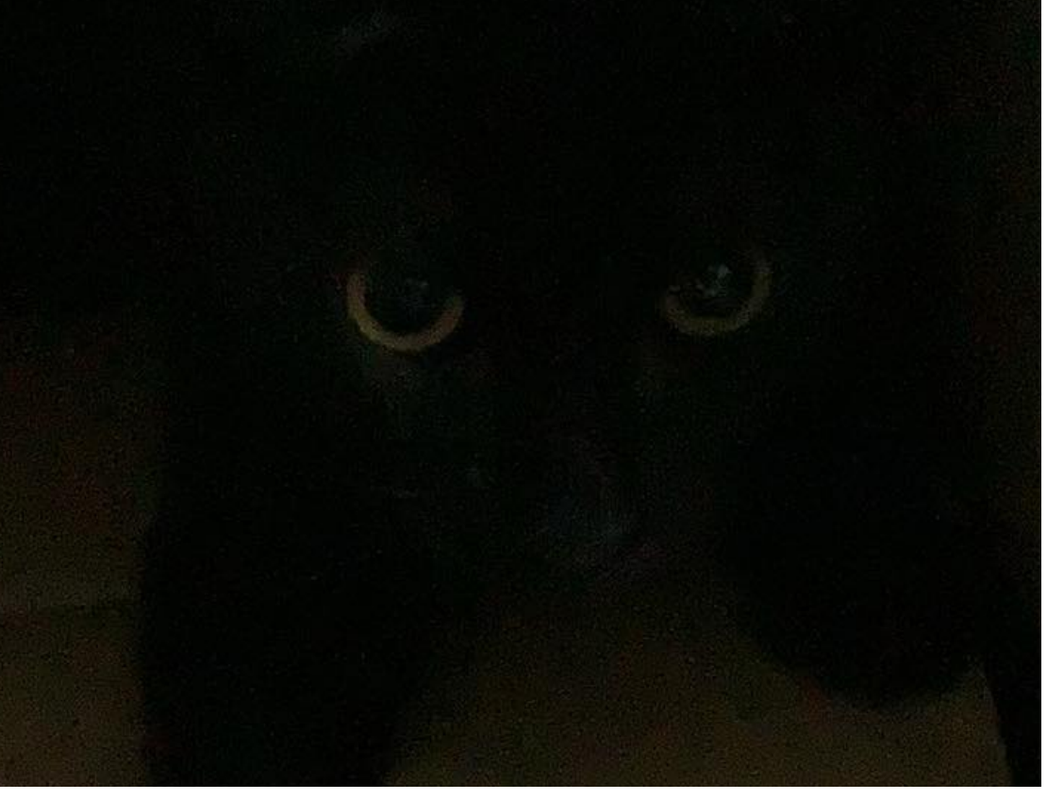
updates coming soon!

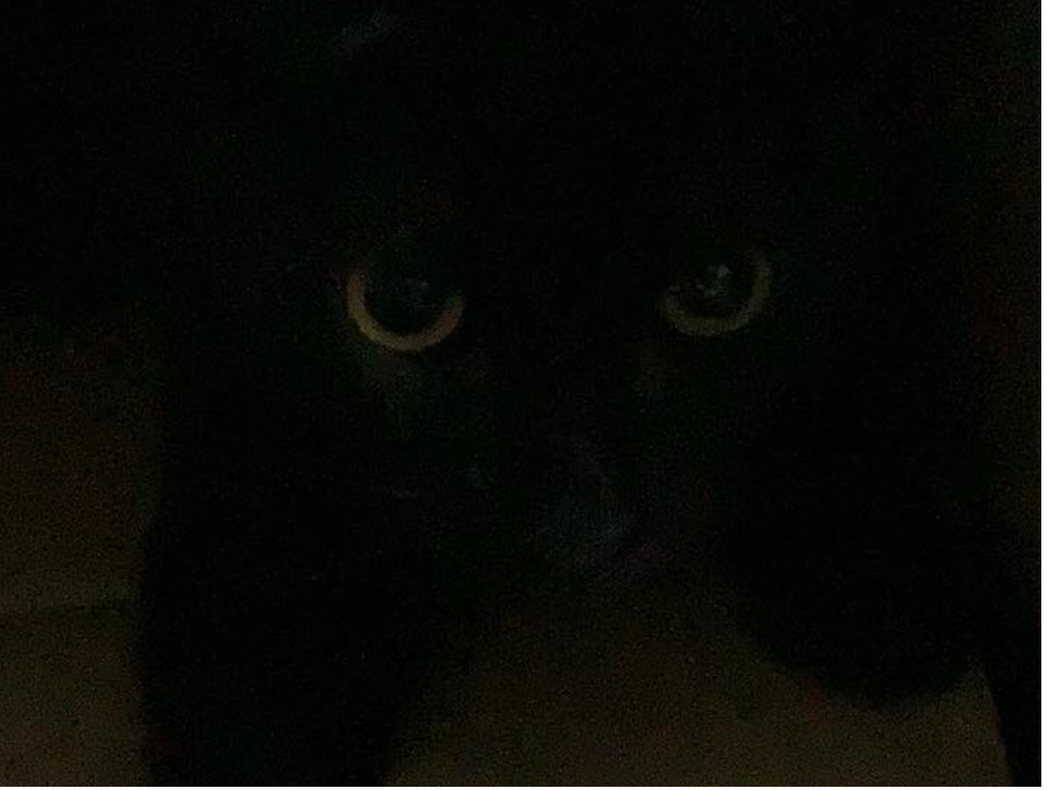
nFF24 by M. Doradau, R.T. Martinez, R. Sassot, M. Stratmann.
Phys.Rev.D 111 (2025) 3, 034045

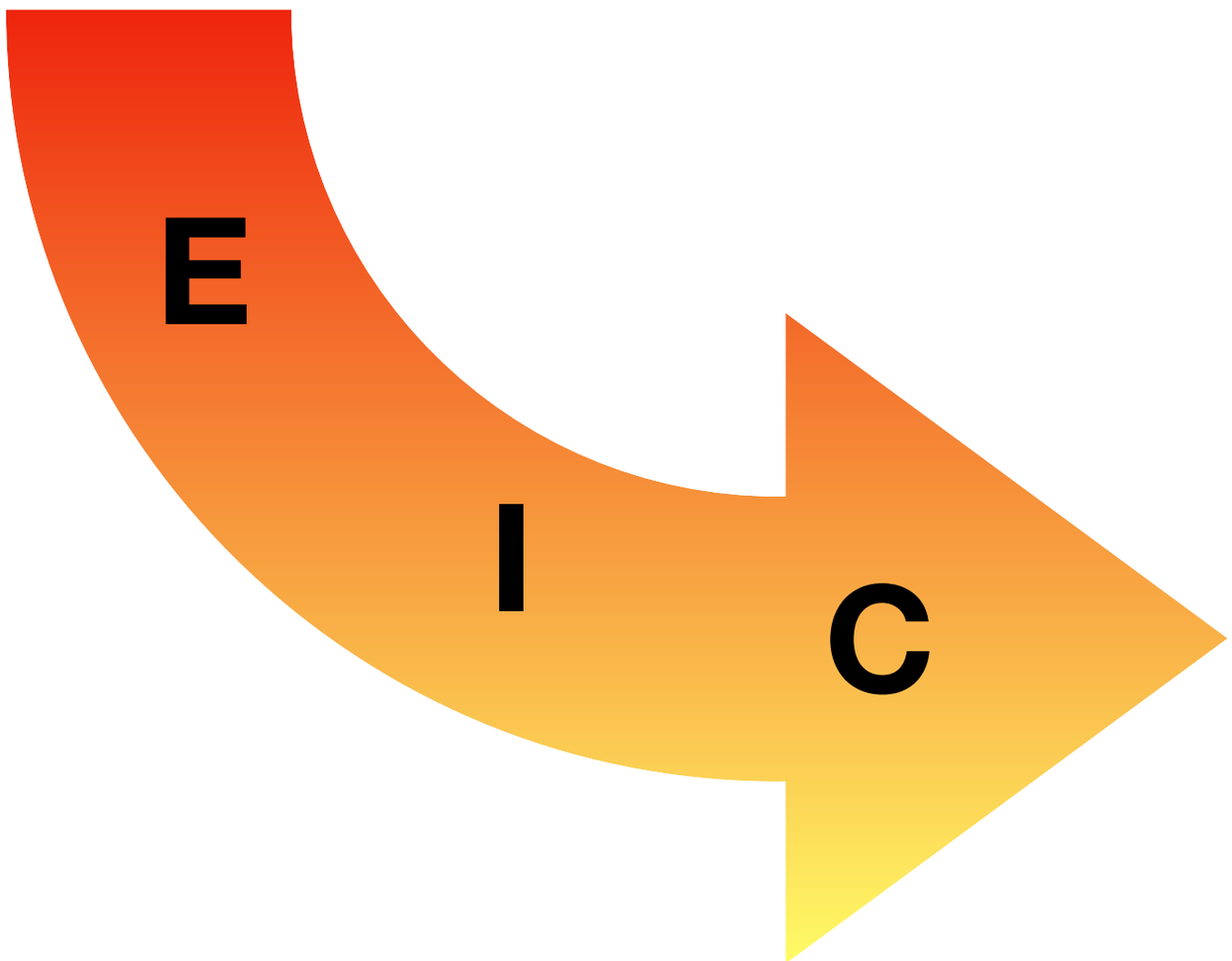


See my talk at the ePIC meeting January 2025 for more details on nPDFs/nFFs:

https://agenda.infn.it/event/43344/



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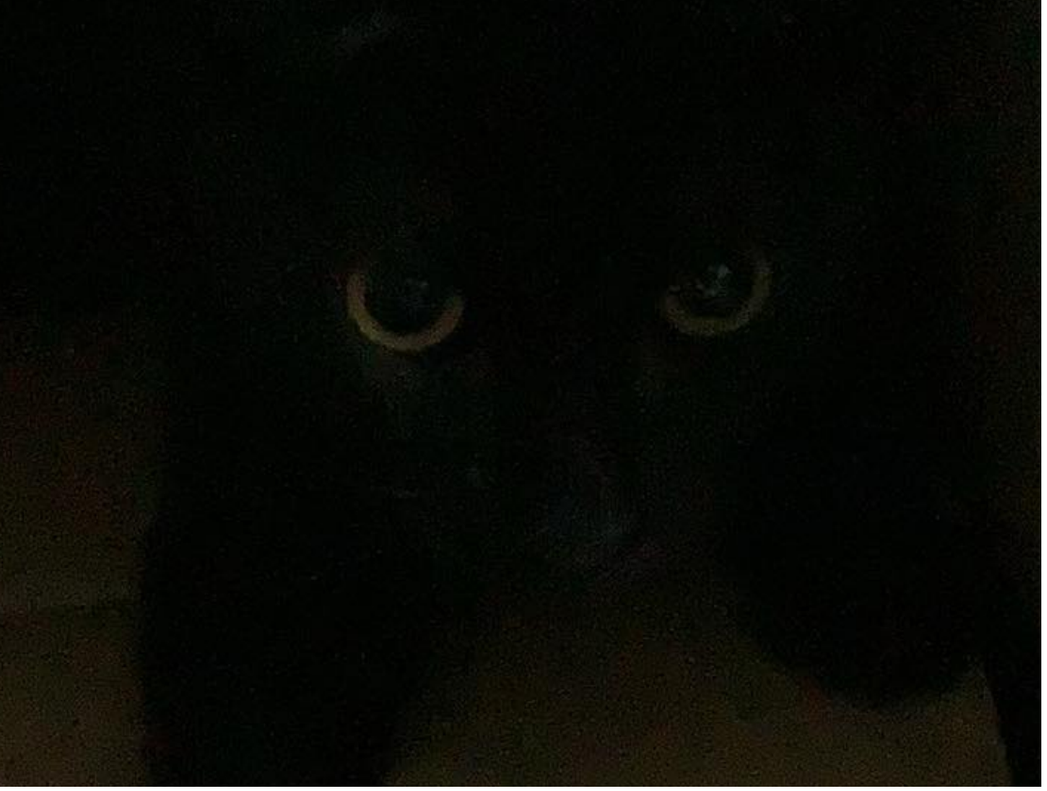
C



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