Measurement of pion PDFs by xFitter

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xFitter project

- `xFitter` is an open source QCD analysis tool.
- Last release, `2.0.1` “Old Fashioned”: updates and bug fixes for `2.0.0` “Frozen Frog”.
- In development on https://gitlab.cern.ch/fitters/xfitter, aiming modular more general QCD fit platform.
- `xFitter` provides interface to many data samples, with complex correlation model, fast χ^2 computation, fast evolution using QCDNUM/APFEL, build-in computation of DIS cross sections and interfaces to APPLGRID and FastNLO, and other features such as different PDF parameterisations and regularisation methods.
- `xFitter` has interfaces to a number of external packages: APFEL, APFEL++, HELL, HATHOR.

Pion determination PDFs: motivation

- Many developments for proton PDFs, to simplify (N)NLO fits: APPLGRID, FastNLO.
- PDFs of the pion are theoretically more simple vs proton.
- New experiments are in planning to improve gluon density determination.
- Natural extension of xFitter fitting machinery, playground for new xFitter development.

arXiv:2002.02902

Data samples

Experiment	P_{lab} GeV	Reaction	N_{points}	Normalisation uncertainty
E615	252		140	15.%
NA10	194	$\pi^- \ _{74}W \to \mu^+\mu^- X$	67	6.4%
NA10	286		73	6.4%
WA70	280	$\pi^\pm p \to \gamma X$	99	32%

- DY and direct photon data from E615 (PRD 39 (1989) 92), NA10 (Z.Phys. C 28 (1985), revised) and WA70 (Z.Phys. C 37 (1988)) experiments.
- Systematic uncertainties are treated using nuisance parameters.

$$\chi^2 := \sum_i \frac{(d_i - t_i[1 - \sum_\alpha \gamma_{i\alpha} b_\alpha])^2}{\left(\delta_i^{\text{syst}}\right)^2 + \left(\sqrt{\frac{\tilde{t}_i}{d_i}}\delta_i^{\text{stat}}\right)^2} + \sum_\alpha b_\alpha^2$$

Fit settings for π^- fit

Evolution starting scale $Q_0^2 = 1.9\ \mathrm{GeV}^2$, just under the charm threshold. Assumes $\bar{u} = d$ as well flavour symmetric sea: $u = \bar{d} = s = \bar{s}$. The resulting fitted PDFs are

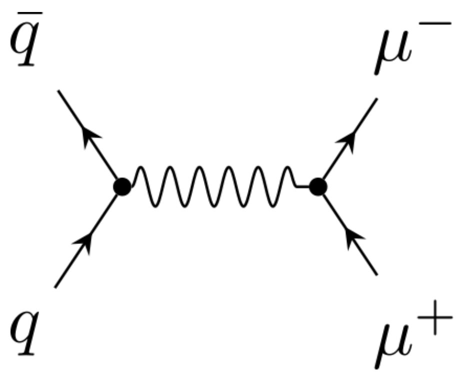
$$\begin{aligned} v &:= d_v - u_v = (d - \bar{d}) - (u - \bar{u}) = 2(d - u) = 2d_v, \\ S &:= 2u + 2\bar{d} + s + \bar{s} = 6u, \\ g &:= g, \end{aligned}$$

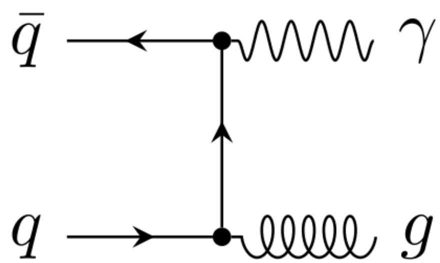
Standard parameterisation form

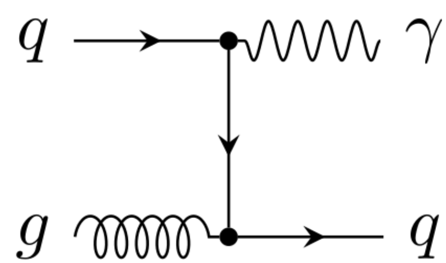
$$\begin{aligned} xv(x) &= A_v x^{B_v}(1-x)^{C_v}(1 + D_v x^{\alpha}), \\ xS(x) &= A_S x^{B_S}(1-x)^{C_S}/B(B_S + 1, C_S + 1), \\ xg(x) &= A_g(C_g + 1)(1-x)^{C_g}, \end{aligned}$$

with A_v and A_g determined by sum rules. $\alpha = 5/2$ with non-vanishing D_v improves the quality of the fit by $\Delta\chi^2 = 7$.

Theory prediction

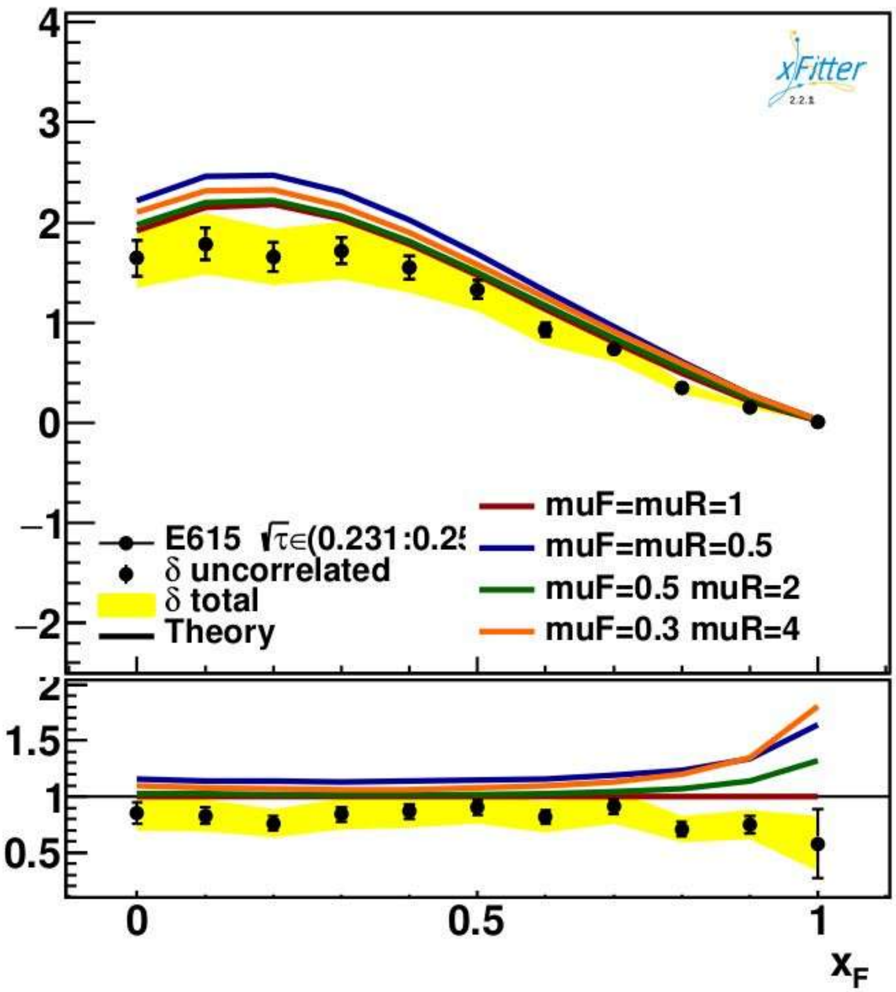






- NLO predictions using MCFM via APPLGRID.
- $\mu_R = \mu_F = m_{\ell\ell}$ for DY data, $\mu_R = \mu_F = p_T(\gamma)$ for prompt photon production.
- $_{74}W$ target modeled using nCTEQ15 PDF set.
- Photon fragmentation contribution not included, uncertainty assigned based on MCFM for pp with and without fragmentation.

Uncertainties used in the fit



Uncertainties included in the fit as nuisance parameters:

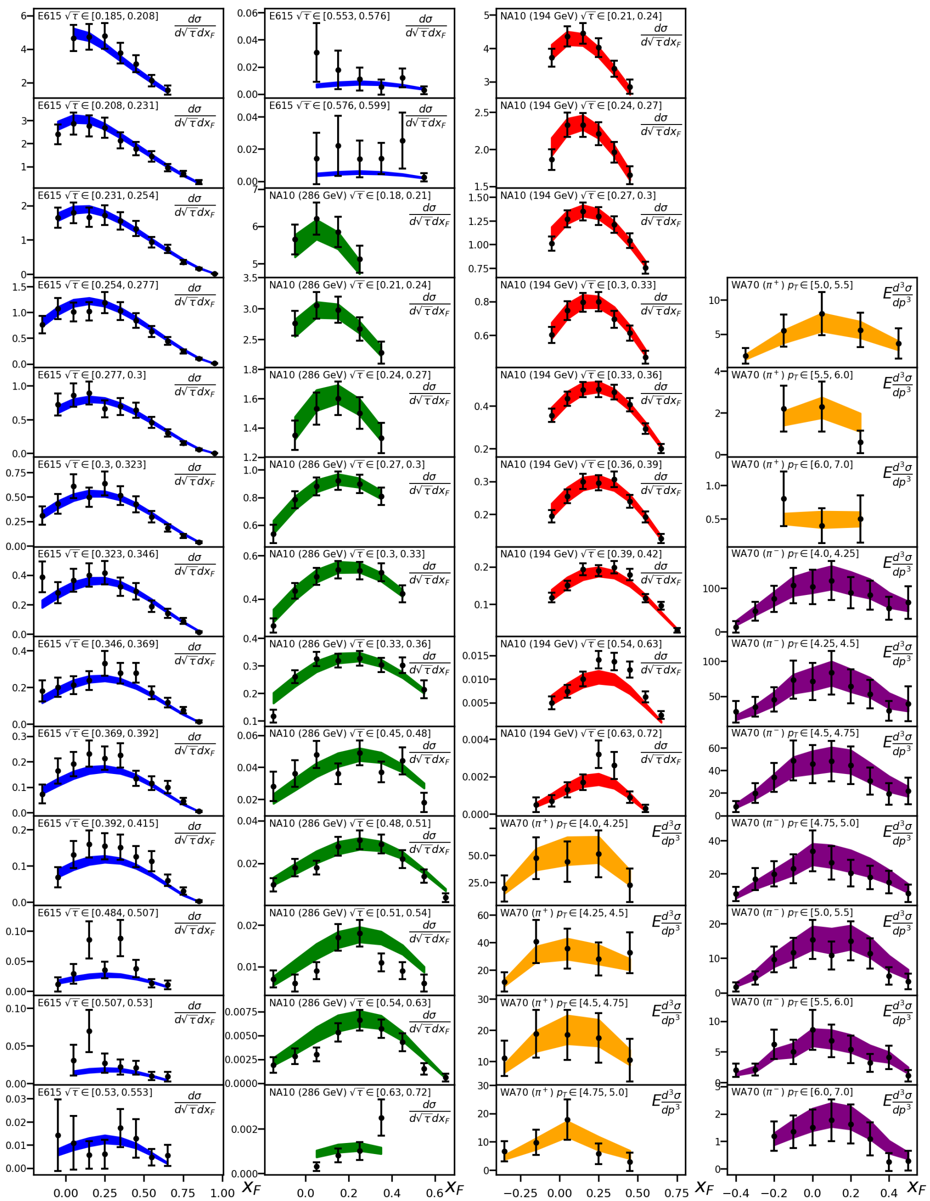
- Data set normalisation uncertainties.
- $\alpha_S = 0.118 \pm 0.001$ variation.
- PDF eigenvectors of nCTEQ15 nuclear PDF set.
- Fragmentation correction (as global normalisation)

Uncertainties treated by "offset" fits:

- μ_R and μ_F variation by factor 0.5 and 2.
- Starting scale variation $Q_0^2 = 1.9 \pm 0.4$ GeV^2.

→ sizable vs experimental errors scale uncertainties, for large x_F in particular.

Fit results: data description



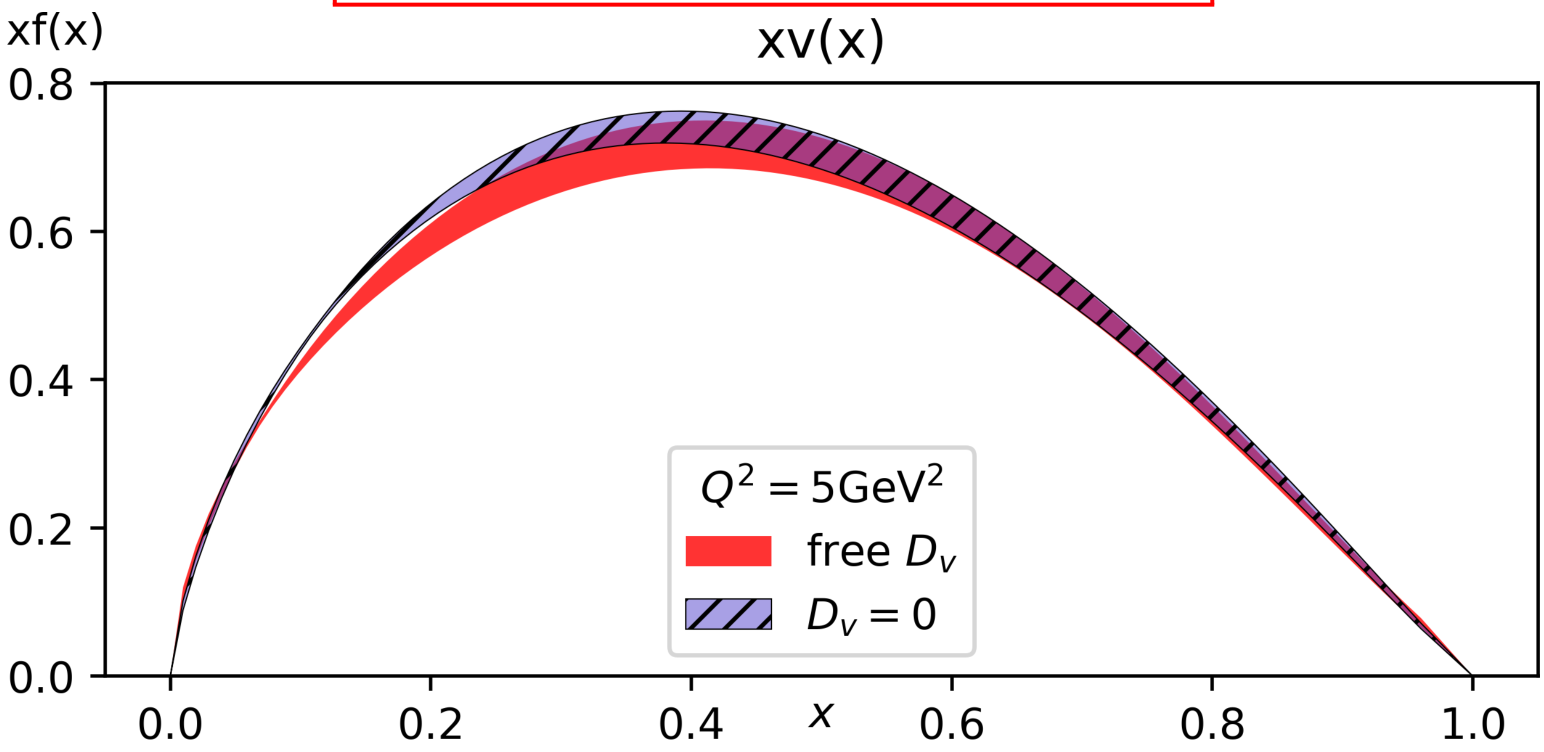
- $\chi^2/dof = 437/372$ (for the fit with free D_v), reasonable description of all data sets.
- Theory predictions include correlated shifts.

Fit results: data description

Experiment	Normalization uncertainty	Normalization factor	χ^2/N_{points}
E615	15 %	1.160 ± 0.020	$206/140$
NA10 (194GeV)	6.4%	0.997 ± 0.014	$107/67$
NA10 (286GeV)	6.4%	0.927 ± 0.013	$95/73$
WA70	32%	0.737 ± 0.012	$64/99$

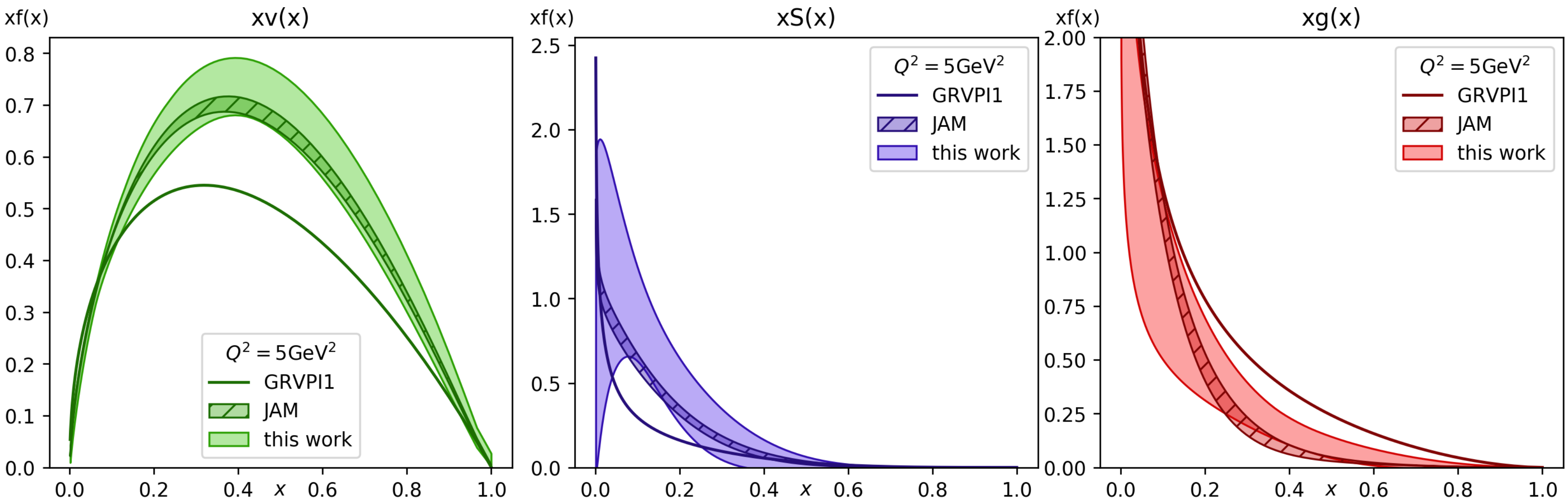
- Significant adjustment of E615 normalisation, but it is within experimental uncertainty.
- Large contribution to χ^2 from several data points, studies with removal of them and corresponding regions do not show significant variations of PDFs.

Valence high x behaviour



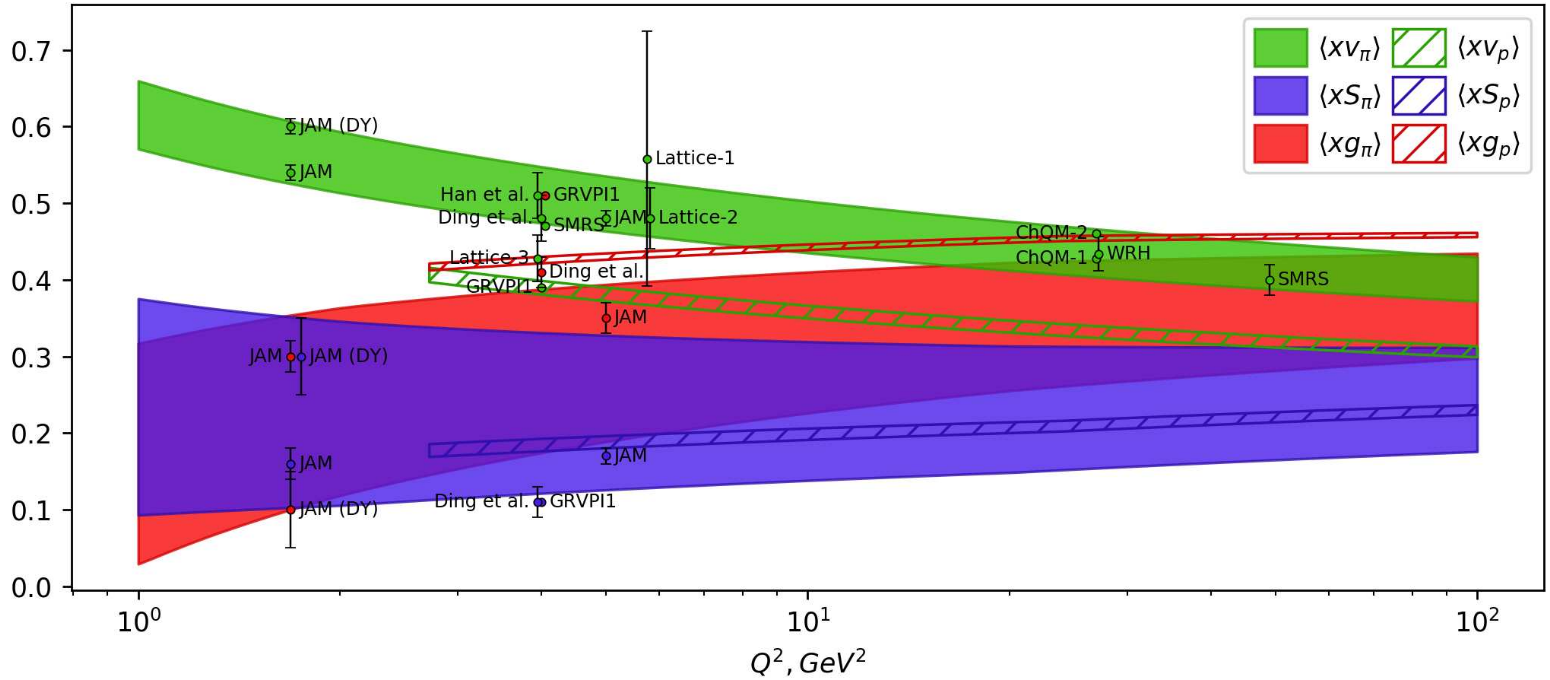
- Parameterisation scan found $\Delta\chi^2 = 7$ improvement for one extra parameter: $A_v x^{B_v}(1-x)^{C_v}(1 + D_v x^{5/2})$.
- Both "extended" and "minimal" parameterisations are consistent at high x. For minimal parameterisation $C_v = 0.95 \pm 0.03$ (no scale variation included): behaviour near $x = 1$ is linear in $(1 - x)$.

Comparison to other determinations.



- Agreement with determination of JAM (arXiv:1804.01965).
- Valence distribution is reasonably well constrained, difference of JAM/xFitter vs GRVM1.
- Gluon and sea distributions are poorly constrained.

PDF momentum fractions



- Compute momentum fractions carried by the gluon, sea- and valence quarks (solid bands). Compare to other estimations.
- Compare with the proton fractions, using NNPDF3.1 NLO set (dashed bands).
- Larger valence fraction and smaller gluon while the sea is comparable.

Summary and outline

- xFitter determination of pion PDFs at NLO using MCFM/APPLGRID for predictions.
- Good description of the data, data are self-consistent.
- Large uncertainties for the gluon distribution.
- Valence quarks are reasonably well constrained, NLO fits prefer PDFs with large momentum fraction carried by the valence quarks.
- Theoretical uncertainties estimated in the fit using scale variations; they are sizable at high x_F in particular. Fits using NNLO and/or threshold resummation corrections would be interesting.

The fit setup, data, predictions (APPLGRIDs) and PDFs are public: data, fit, `xFitterPI_NLO_EIG`, `xFitterPI_NLO_VAR`.

Momentum fraction estimates comparison

	$\langle xv \rangle$	$\langle xS \rangle$	$\langle xg \rangle$	Q^2 (GeV^2)
JAM (arXiv:1804.01965)	0.54 ± 0.01	0.16 ± 0.02	0.30 ± 0.02	1.69
JAM (DY)	0.60 ± 0.01	0.30 ± 0.05	0.10 ± 0.05	1.69
this work	0.55 ± 0.06	0.26 ± 0.15	0.19 ± 0.16	1.69
Lattice-3 (arXiv:1507.04936)	0.428 ± 0.030			4
SMRS (PRD45, 2349 (1992))	0.47			4
Han et al. (arXiv:1809.01549)	0.51 ± 0.03			4
GRVPI1 (ZPC53, 651 (1992))	0.39	0.11	0.51	4
Ding et al. (arXiv:1905.05208)	0.48 ± 0.03	0.11 ± 0.02	0.41 ± 0.02	4
this work	0.50 ± 0.05	0.25 ± 0.13	0.25 ± 0.13	4
JAM	0.48 ± 0.01	0.17 ± 0.01	0.35 ± 0.02	5
this work	0.49 ± 0.05	0.25 ± 0.12	0.26 ± 0.13	5
Lattice-1 (arXiv:hep-lat/9703014)	0.558 ± 0.166			5.76
Lattice-2 (arXiv:hep-lat/0303015)	0.48 ± 0.04			5.76
this work	0.48 ± 0.05	0.25 ± 0.12	0.27 ± 0.13	5.76
WRH (arXiv:nucl-ex/0509012)	0.434 ± 0.022			27
ChQM-1 (arXiv:1205.4156)	0.428			27
ChQM-2 (arXiv:1710.09529)	0.46			27
this work	0.42 ± 0.04	0.25 ± 0.10	0.32 ± 0.10	27
SMRS	0.49 ± 0.02			49
this work	0.41 ± 0.04	0.25 ± 0.09	0.34 ± 0.09	49