

QCD for Collider Physics

Part 4

M. Diehl

Deutsches Elektronen-Synchrotron DESY

DESY Summer Student Programme 2022, Hamburg

HELMHOLTZ



Parton density fits

Parton densities involve QCD at low momentum scales \leftrightarrow large coupling

- ▶ can compute $\partial f(x, \mu)/\partial\mu$ in perturbation theory, but not $f(x, \mu)$
- ▶ ongoing effort to compute with non-perturbative methods
e.g. in lattice QCD
- ▶ in practice: determined from experimental data

Principle of PDF determinations:

- ▶ data for observables with factorisation formulae
most important: DIS ($ep \rightarrow e + X$), Drell-Yan ($pp \rightarrow \ell^+\ell^- + X$,
 $pp \rightarrow \ell\nu + X$), jets in ep and pp , $t\bar{t}$ production in pp , ...
- ▶ parameterise PDFs at “starting” scale μ_0
use DGLAP eqs. to evolve to scales μ needed in fact. formulae
- ▶ determine PDF parameters by fit to data

Uncertainties on extracted PDFs

“PDF errors”

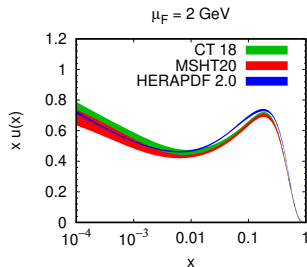
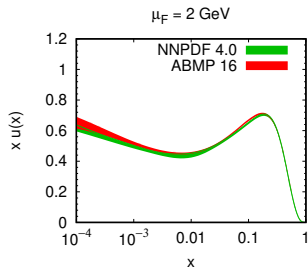
- ▶ errors (stat. and syst.) of fitted data propagated to PDF parameters

“systematic theory uncertainties”

- ▶ selection of data sets and kinematics
- ▶ perturbative order of evolution and hard-scattering cross sections
- ▶ values of α_s and m_c, m_b and possibly other constants if taken as external parameters rather than fitted
- ▶ fine details of perturbative calculations
e.g. treatment of heavy quarks, resummation
- ▶ power corrections (try to avoid by using data with $Q > Q_{\min}$)

recent work: include uncertainties from higher orders in PDF errors
(using scale variation) Harland-Lang, Thorne 2018; Khalek et al. 2019

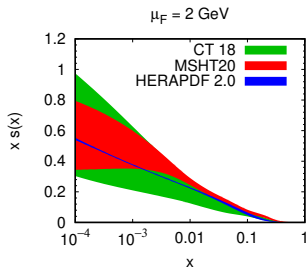
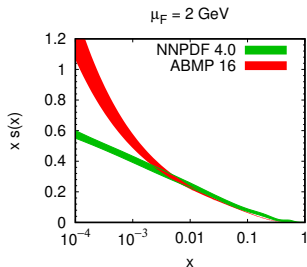
Illustration of PDF sets and their errors



all PDFs at NNLO, error bands for 68% CL

- ▶ spread between different parameterisation often larger than error bands of single parameterisation
- ▶ error bands propagate uncertainties of fitted data into PDFs but do **not** reflect “systematic theory uncertainties” of extraction

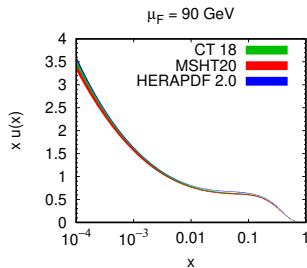
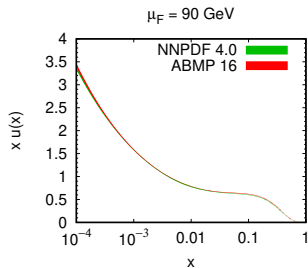
Illustration of PDF sets and their errors



all PDFs at NNLO, error bands for 68% CL

- ▶ strangeness distribution remains poorly known
sometimes assume $s(x) \propto \bar{u}(x) + \bar{d}(x)$ or $s(x) \propto \bar{d}(x)$ at $\mu = \mu_0$
 \rightsquigarrow small errors in fit

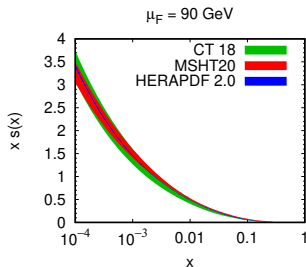
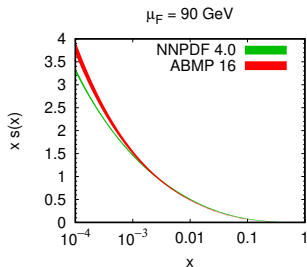
Illustration of PDF sets and their errors



all PDFs at NNLO, error bands for 68% CL

- ▶ evolution to higher scales $\rightsquigarrow q\bar{q}$ pairs at low x

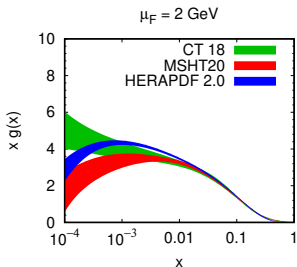
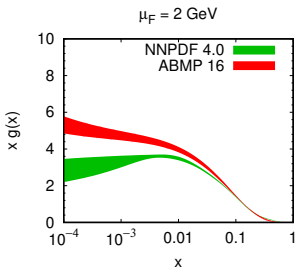
Illustration of PDF sets and their errors



all PDFs at NNLO, error bands for 68% CL

- ▶ evolution to higher scales \rightsquigarrow $q\bar{q}$ pairs at low x
- ▶ all $q(x)$ and $\bar{q}(x)$ become similar at high scales and low x
- ▶ relative uncertainties shrink

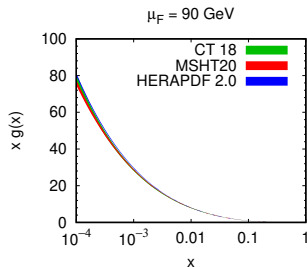
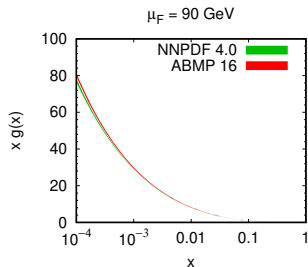
Illustration of PDF sets and their errors



all PDFs at NNLO, error bands for 68% CL

- ▶ $g(x) \gg q(x)$ for x below 0.1
- ▶ at low scale and low x gluon known very poorly

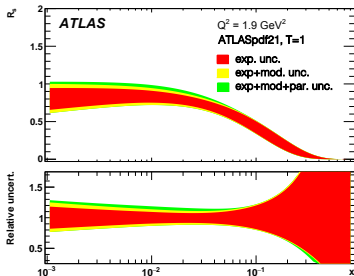
Illustration of PDF sets and their errors



all PDFs at NNLO, error bands for 68% CL

- ▶ $g(x) \gg q(x)$ for x below 0.1
- ▶ evolution for $g(x)$ even stronger than for $q(x)$

Strange quarks: recent results



ratio of strange to
non-strange sea quarks:

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

ATLAS, arXiv:2112.11266

