Parton Distribution Functions from JLab to LHC

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JAM Collaboration

• Understand the 3-dimensional structure of the nucleons through global QCD analysis of parton distribution functions (PDFs), fragmentation functions (FFs) and transverse momentum dependent (TMD) distributions.

• Use collinear factorization in perturbative QCD to perform simultaneous determinations of PDFs, FFs, TMDs.

• Utilize Monte Carlo methods and modern Bayesian analysis techniques
Spin-Averaged PDF Analysis

Two major goals of this analysis:

1. Examine high-$x$ phenomena ($\frac{x^2 M^2}{Q^2}$) using deep inelastic scattering data
   a) Target Mass Corrections
   b) Higher Twist Corrections
   c) Nuclear Smearing and Off-shell Corrections

2. Include new $W$-boson production data from the LHC and analyze impact on spin-averaged PDFs.
   Potentially provides important information on valence and light sea quarks.

$x$: Parton momentum fraction
$Q^2$: Momentum transfer
Data

- **Deep Inelastic Scattering**: BCDMS, NMC, SLAC, HERA, Jefferson Lab (3,863 points)
- **Drell-Yan**: Fermi Lab E866 (250 points)
- **W/Z Boson Production**: Tevatron CDF/D0, LHC ATLAS/CMS (239 points)

New LHC Data

Low $W^2$ cut allows inclusion of high-$x$ data, particularly from Jefferson Lab

High-x Data
JAM Methodology

- Parameterize PDFs at input scale $Q_0^2 = m_c^2$
- Evolve PDFs using DGLAP and compute observables
- Determine parameters through Bayesian posterior sampling with likelihood function $e^{-\chi^2/2}$

**Mult-Step Strategy:**

<table>
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<tr>
<th>Step</th>
<th>Data</th>
<th>$W_\text{cut}^2$ (GeV$^2$)</th>
<th>TMC</th>
<th>$a_3, a_4$</th>
<th>HT</th>
<th>Offshell</th>
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</table>

$\tilde{\sigma} = \sigma + R\alpha$

- $\tilde{\sigma}$: Pseudo-Data
- $\sigma$: Original Data
- $R$: Random Gaussian number $-1 < R < 1$
- $\alpha$: Quadrature sum of uncertainties

$$PDF = a_0 x^{a_1} (1 - x)^{a_2} (1 + a_3 \sqrt{x} + a_4 x)$$
LHC Observables

Overall: $\chi^2/#$ points = 1.11

LHC: $\chi^2/#$ points = 1.35

Top left: $p\bar{p}$ data from Tevatron
Everything else: $pp$ data from LHC
Parton Distribution Functions

- Suppressed $d_v$, enhanced $s^+$
- Large $\bar{d} - \bar{u}$ at low $x$ due to LHC data
- $d/u$ well constrained, except at very high $x$
Impact of LHC Data

- Constrains $u, d$ quarks at $x < 0.2$
- Constrains and enhances $\bar{d} - \bar{u}$ at $x < 0.2$
- Constrains $d/u$ at $x < 0.3$
Off-shell Corrections

- Consistent with zero, due to tension between Jefferson Lab and SLAC data
- Different than CJ15 and KP results
- Result is consistent regardless of
  - parameterization choice
  - choice of target mass correction (GP, AOT)
  - choice of deuteron wave function (Paris, AV18, CD-Bonn, WJC-1, WJC-2)
Conclusions

• New LHC data provides new constraints at $x < 0.2$ on the valence quarks, sea asymmetry, and $d/u$ ratio.

• Sea asymmetry at low $x$ is found to be larger than previous extractions.

• $d_\nu$ at low $x$ is found to be smaller, while $s^+$ is found to be larger.

• Offshell corrections are found to be consistent with zero due to tension in datasets. Result is consistent regardless of parameterization or model choice.
Collaboration

This project was done in collaboration with:

Jacob Ethier  Wally Melnitchouk  Andreas Metz  Nobuo Sato

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Extra: Higher Twist