PDFs from an EIC perspective

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Why PDFs?

- **High-energy** *(large to small x)*
  - Beyond the Standard Model searches
  - Precision (Higgs) physics
  - NuTeV weak mixing angle
  - Gluonic “matter” at small x

- **Hadron structure** *(large to medium x)*
  - Effects of confinement on valence quarks
  - $q - \bar{q}$ asymmetries; isospin asymmetry
  - Strangeness, intrinsic charm

- **Nuclear Physics**
  - Bound nucleons, EMC effect, SRC
  - $p + A$ and $A + A$ collisions at RHIC / LHC
  - Color propagation in nuclear matter
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A PDF landscape

Pert. order

N3LO

“Do we need N³LO parton distributions?”
→ Forte et al., PLB 731 (2014)

Plenty of opportunities @ NLO

QED corrections

NNLO

Resummation(s)

NLO

On the way to “1% precision” for the LHC

Theory input (roughly x)

Quark-hadron duality

HERAPDF

CT

NNPDF

MMHT

JR

ABMP

CTEQ-JLab

LT

NUCL

TMC/HT

RESUM

NNPDF

Do we need N³LO parton distributions?”

"Do we need N³LO parton distributions?”

"Do we need N³LO parton distributions?”
A nPDF landscape

Atomic number

→ K. Kovarik

Much room for progress!

nCTEQ
DSSZ
EPS
HKN
Kulagin-Petti

nCTEQ
DSSZ
EPS
HKN
Kulagin-Petti

MMHT
ABMP / JR
CTEQ-JLab

LT
NUCL
TMC/HT
RESUM

x > 1, SRC, exotica

accardi@jlab.org  Large x at the EIC, 16 Nov 2016
Needs the betrothal of HEP and NUCL

- A global approach across subfields

**Diagram:***

- **Nuclear data**
- **HEP data**
- **New physics**
- **Hadron structure**
- **In-medium q & g**
- **Nuclear, hadron theory**

**Flow arrows:**
- PDFs
- pQCD
- Global QCD fits

**Equations:**
- $\theta$

**Additional text:**

Needs the betrothal of HEP and NUCL

- A global approach across subfields
Enters the EIC

- The EIC is the machine to bind them all

- Global QCD fits

- Hadronic Physics

- HEP & BSM

- pQCD

- Nuclear Physics

- Global QCD fits
Enters the EIC

- Interpolates fixed target and HERA
- Large $Q^2$ leverage
  - More evolution at large $x$
  - Better separation of LT and HT
- High luminosity → large $x$ capabilities

- EIC can “do it all”:
  - “Easy” spectator tagging in DIS
  - Strong PID capabilities: $F_2^c$, $F_2^{cc}$, Fragmentation Functions, ...
  - High luminosity → CC, PVDIS → d/u, strange quarks, dbar/ubar, ...
  - Unpolarized & polarized scattering (also light ions)
  - Nuclear targets → K. Kovarik
Example 1: Tevatron as NUCL facility (!)

*Reconstructed* $W \rightarrow$ constrain $d$-quark at largest $x$ on proton targets

$A_W(y) \xrightarrow{x \rightarrow 1} \frac{1 - d/u(x_1)}{1 + d/u(x_1)}$

- Compare to abundant deuteron *DIS data:*
  - constrain deuteron corrections
  - precise $u, d$ flavor separation
Example 1: Tevatron as NUCL facility (!)

Accardi, Brady, Melnitchouk, Owens, Sato, PRD93 (2016) 114017

- Two results in 1:
  - confinement at large x
  - off-shell corrections in deuteron PDFs
Example 2: large x PDFs at the EIC

Include **EIC projected data** in global fit:

- \( L = 100/\text{fb} \) @ 10x100 GeV\(^2\) energy
- \( F_2(\text{proton}), F_2(\text{deuteron}), F_2(\text{tagged neutron}) \) at \( 0.1 < x < 0.9 \)
Example 2: large $x$ PDFs at the EIC

Accardi, Ent, Keppel, Park, Yoshida – in progress

Results:
- The $d$ quark precision will become comparable to current $u$ !
- The $u$ quark uncertainty becomes less than 1%
- 20% improvement in $g(x)$ through evolution

Can impact BSM searches, e.g., heavy $W'$ boson production at LHC

- 3.4 $\sigma$ excess in $WZ$ diboson channel at $\sim 2$ TeV
- extended gauge model $W' \to WZ$ with $M < 1.5$ TeV excluded at 95% c.l.

$$\mathcal{L}_{W'} \to d(x_1) \bar{u}(x_2) \text{ at large } y_{W'}, \text{ or } M_{W'}$$

$$x_{1,2} \approx \frac{M_{W'}}{\sqrt{s}} e^{\pm y_{W'}}$$
Example 3: strange, strange quarks

- $\gamma + A \rightarrow \text{dimuons}$ vs. $p + p \rightarrow W + c$ at LHC

Alekhin et al., arXiv:1404.6469

Final state propagation of $c$ quark / D meson

- Not quite under theoretical or phenomenological control, yet (cf. heavy quark “puzzle” in A+A at RHIC, LHC)
Example 3: strange, strange quarks

- Use PVDIS projected data at EIC
  → Y. Zhao [Mon]

\[ A_L = \frac{G_F Q^2}{2 \sqrt{2} \pi \alpha} \left[ g_5^{e} \frac{g_5^{\gamma Z}}{F_1^{\gamma}} + g_1^{e} \frac{Y_+ - g_1^{\gamma Z}}{F_1^{\gamma}} \right] \]

- Can constrain strange at ~20% level, and
  - Help resolve LHC vs. ν+A tension (also with RHIC W&Z, PVDIS@JLab12)
  - Study charm propagation in nuclear matter

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Some final thoughts
EIC to bind them all

- EIC has excellent potential, for example, for
  - \textbf{u, d, g flavor determination at large }x\textbf{ } \leftrightarrow \textbf{hadronic structure, BSM}
  - \textbf{Strangeness} in complementary \(x\) range to LHC, similar to RHIC
  - \textbf{Revolutionizing nuclear physics studies using hard probes}
What else can we dream of doing at the EIC?

- **Isospin violations**
  - Play free n from BONUS/EIC vs. free p from D0, RHIC W-asym.

- **Intrinsics charm**
  - Positive signal only from (contested) EMC data
  - Take new and better data with EIC!

- **Large leverage in A – from light to heavy**
  - Combined PDF / nPDF fits \(\rightarrow K. Kovarik (?)\)
  - Structure of light nuclei, by contrast with heavy & p, d

- **Polarized and unpolarized data at large Q2 from same machine**
  - Another combined fit \(\leftarrow\rightarrow\) helicity separation

- **SIDIS & DIS (at large Q2) from same machine** \(\rightarrow N. Sato\)
  - Will reduce many uncertainties
  - Yet another combined fit \(\leftarrow\rightarrow\) flavor separation

- ...

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Large \(x\) at the EIC, 16 Nov 2016