MCEG for TMD physics: the quest to characterize perturbative and non perturbative QCD phenomena

(On behalf of Jefferson Lab TMD LDRD)

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25th International Workshop on Deep Inelastic Scattering, Apr 6 2017
Motivations

- **Main objectives:**
  - Urgent requirement: MCEG for TMD physics
  - Language dictionary between in NP and HEP
  - Improve the theoretical framework for TMDs
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  - Is a numerical implementation of QCD evolution and nonperturbative physics
  - Needed for high-precision nonperturbative physics
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  - Use Pythia8+DIRE as a starting point
  - Use QCD factorization theorems as a guidance
LDRD personnel

- Jake Ethier
- Eric Moffat
- Andrea Signori

**Theorists**
- Diefenthaler
- Melnitchouk
- Rogers
- Sato
- Joosten
- Lönnblad
- Prestel
- Collins
- Sjöstrand

**Experimentalists**

- JLab
- Pythia
- Other

3D Nucleon Tomography, March 16th 2017
Progress

- Validation of Pythia8+DIRE against HERA data
  - Implementation of DIS in pythia8 via DIRE parton shower
  - Dedicated comparisons between HERMES tune in pythia6 with against Pythia8
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- **Dedicated study of FFs in pythia (this talk)**
  - FFs in pythia
  - Validation of DGLAP formalism against parton shower+Lund string model
  - Pythia8+DIRE vs world $e^+e^-$ data
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- **Extensions of the CSS formalism**
  - Inclusion of string effects in QCD factorization
Validation of Pythia8+DIRE against HERA data


Transverse energy-energy correlation for $x > 10^{-3}$
Factorization in SIDIS

\[ \frac{d\sigma}{d\phi} = H \otimes f \otimes D \]

Hadrons can also be produced in the mid rapidity region → see discussion by J. Collins arXiv:1610.09994

String type effects are potentially important

QCD event
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- String type effects are potentially important
3 Jets events: $Q\bar{Q}$ and gluon jets. Jets are projected into a plane

- $\psi$: angle of a given particle relative to the quark jet with the highest energy
- $\psi_A$: angle between highest energetic jet and gluon jet
- $\psi_C$: angle between quark jets

Only events with $\psi_A = \psi_C$ are kept

Particle flow asymmetry is observed → evidence of string effects
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Study of FFs in pythia8+DIRE
Technical details

- Simulate $e^+e^-$ at $Q = 30, 91.2, 1000$ GeV flavor by flavor.
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- Fit $\pi$ and $K$ FFs using pQCD @ NLO

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\frac{1}{\sigma_{TOT}} \frac{d\sigma_q^{h\pm}}{dz}(z, Q^2) = \frac{2}{\sigma_{TOT}} \left[ C_q \otimes D_q^+(z, Q^2) + C_g \otimes D_g(z, Q^2) \right]
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- ZMVS with input $Q_0 = 11$GeV
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- Parametrization: $D_{q^+}(z) = N z^\alpha (1 - z)^\beta (1 + c_1 z + c_2 z^2 + ...)$
Pythia8 vs. collinear factorization (preliminary)

\[
\frac{1}{\sigma_{TOT}} \frac{d\sigma}{dz}
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\[Q = 11\text{GeV}\]

\[Q = 30\text{GeV}\]

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\( u^+ \)
\( s^+ \)
\( c^+ \)
\( b^+ \)

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Pythia8 + DIRE FFs (preliminary)
Pythia8+DIRE FFs (preliminary)
Pythia8+DIRE $\pi$ FFs and other global analyses
Pythia8+DIRE $K$ FFs and other global analyses
Pythia8+DIRE vs global $e^+e^- \rightarrow \pi + X$
Pythia8+DIRE vs global $e^+e^- \rightarrow K + X$
Summary of FF studies

- So far...
  - DGLAP formalism seems to work in Pythia8+DIRE from $Q > 30\text{GeV}$
  - Difficulties in describing Pythia8’s sample at $Q = 11\text{GeV}$
  - Extracted FFs are comparable with existing global QCD analyses
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- Further questions
  - Test the role of quark and hadron masses
  - Extract FFs from Pythia8’s SIDIS at low energies
  - Does collinear factorization work in the combined SIDIS+$e^+e^-$?
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■ 3D tomography
  ■ Extended the analysis to TMD FFs
  ■ Extract the nonperturbative components of CSS from Pythia8
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Ongoing studies of SIDIS and MCEG-theory mismatches