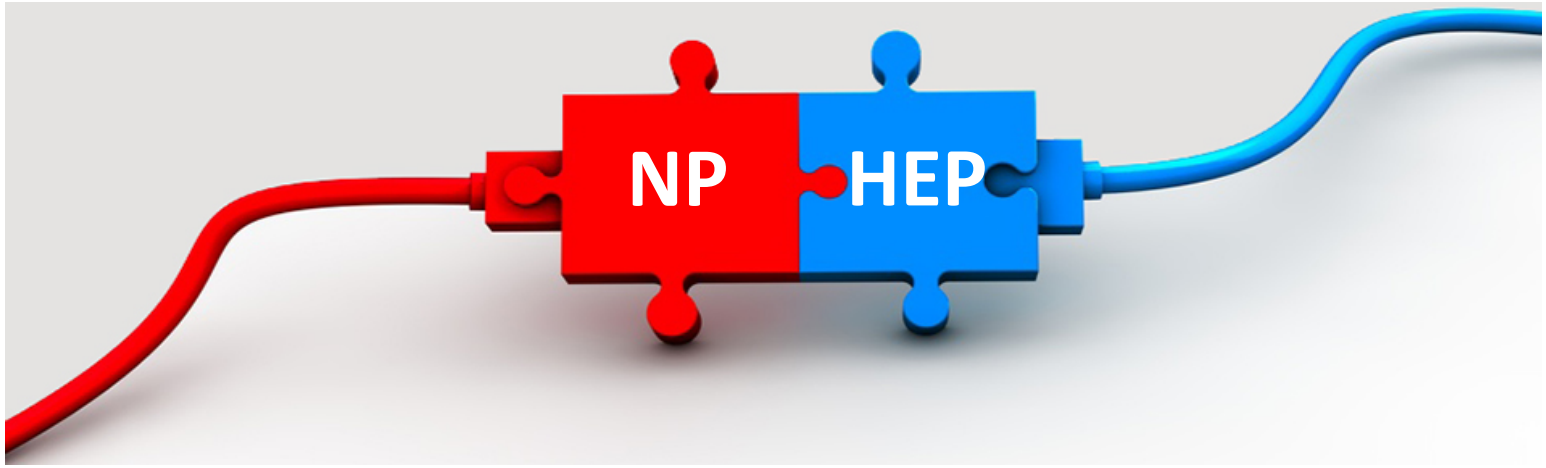
Mapping the hadronization description in the Pythia MCEG to the correlation functions of TMD factorization

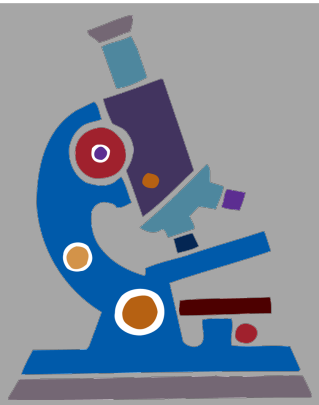


LDRD project at Jefferson Lab

LDRD:
LABORATORY DIRECTED
RESEARCH & **DEVELOPMENT**

Study of hadronization

Correlation functions of TMD factorization ⟷ Pythia Monte Carlo Event Generator



Urgent requirement: MCEG for TMDs.

Unique approach: Connection between hadronization phenomena in **NP** and **HEP**.

By doing so: Improve theoretical framework for TMDs.

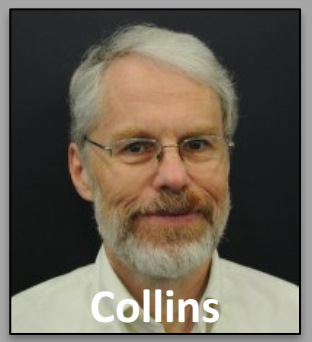
LDRD personnel

JLab

Pythia

Other

Experimentalists



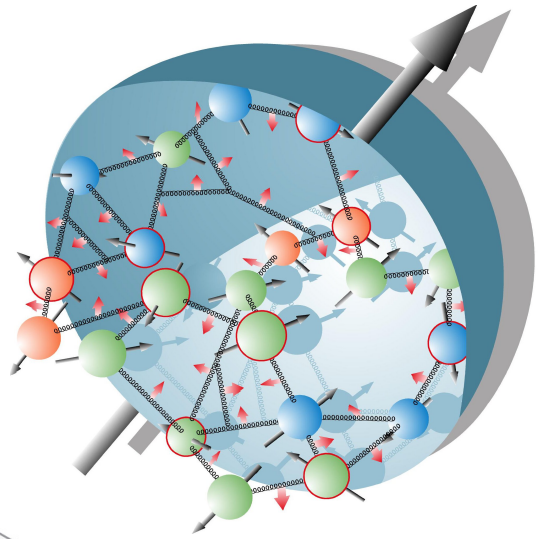
Theorists

Section

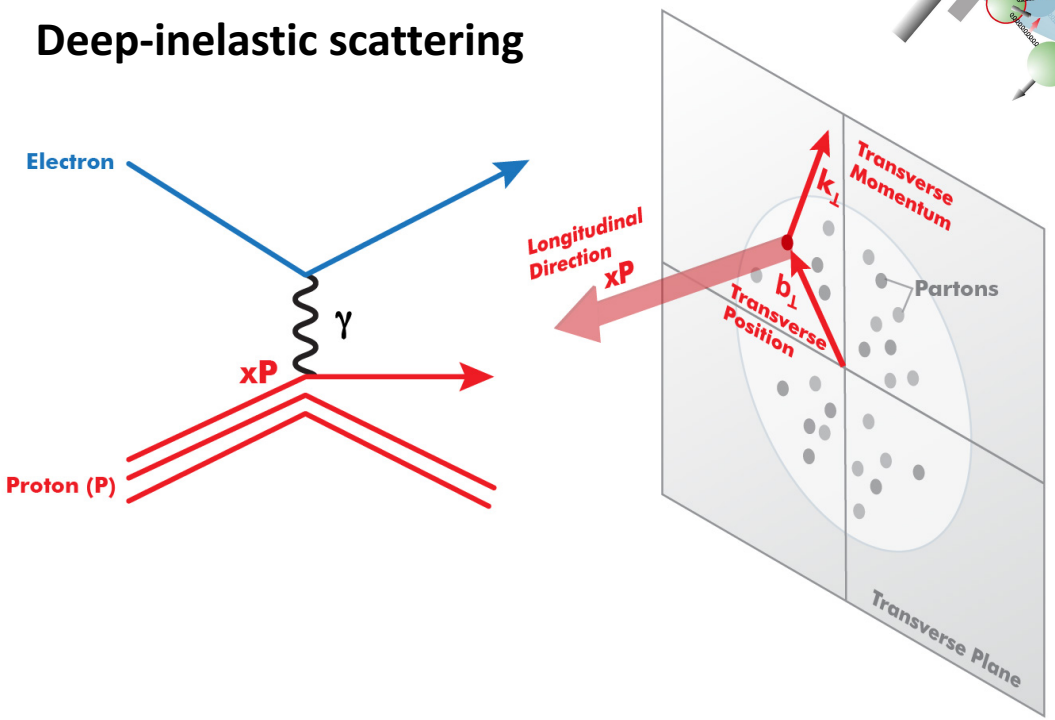
QCD factorization and TMDs

Hadron structure and TMDs

Transverse momentum densities
- novel ways to study confinement
- TMD factorization: **TMD PDF** + **TMD FF**
- spin-orbit correlations



Deep-inelastic scattering

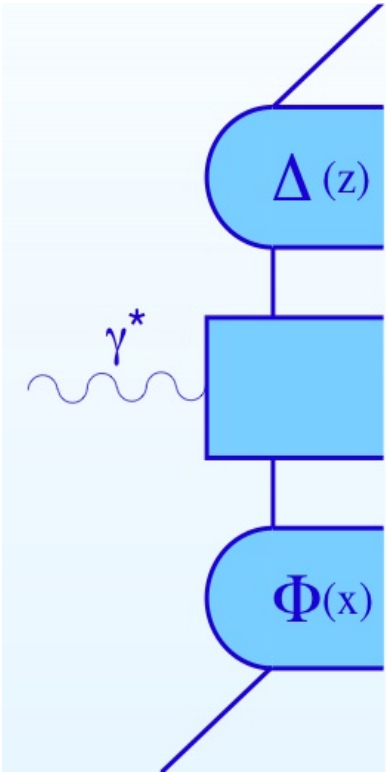


TMDs and QCD factorization

QCD
- non-abelian gauge theory
- self-consistent theory of a fundamental interaction

QCD factorization theorem
- defines quarks and gluons and their dynamics
- allows to study QCD in experiments

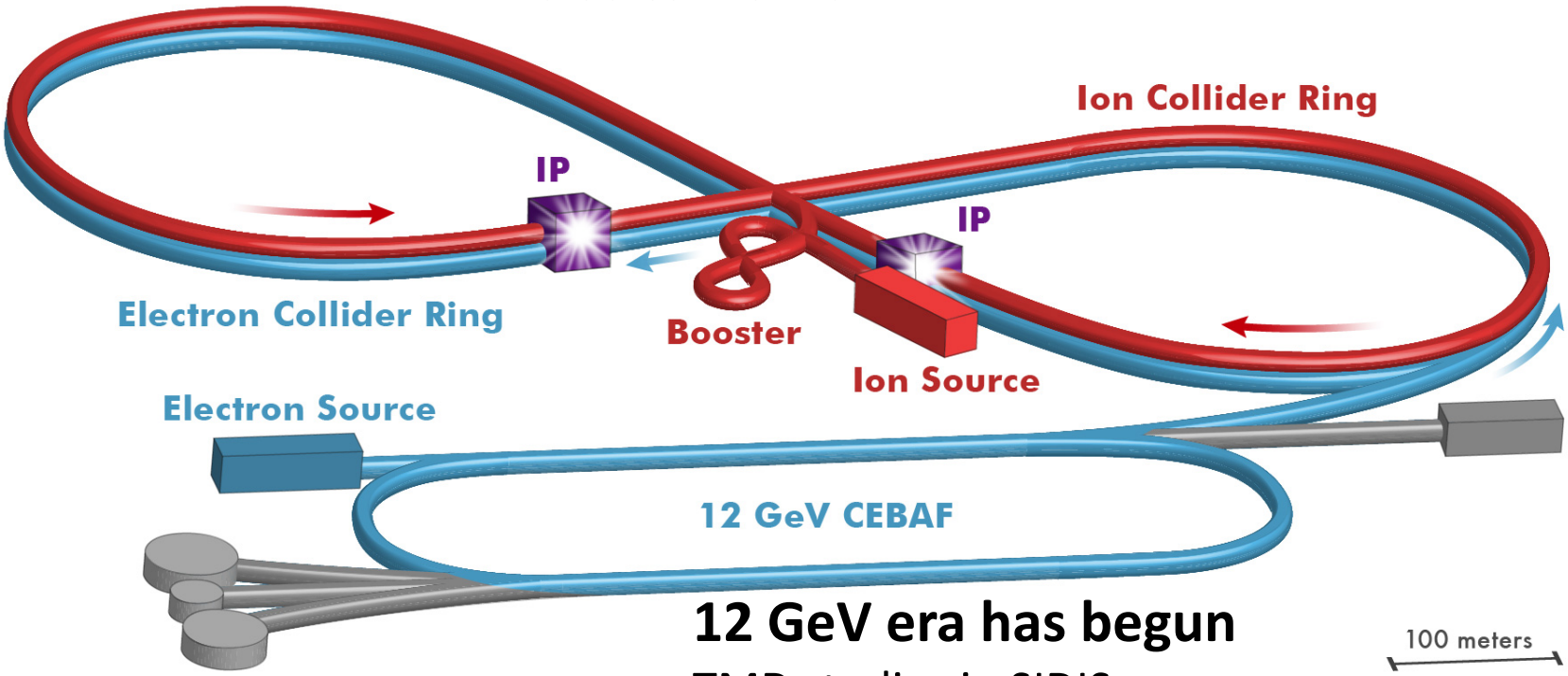
Broadening our understanding of QCD
- studying the QCD theorem for TMDs
- studying he related transition regions
- studying TMD evolution



Upcoming TMD measurements

Electron-Ion Collider on horizon

TMD studies in SIDIS



12 GeV era has begun

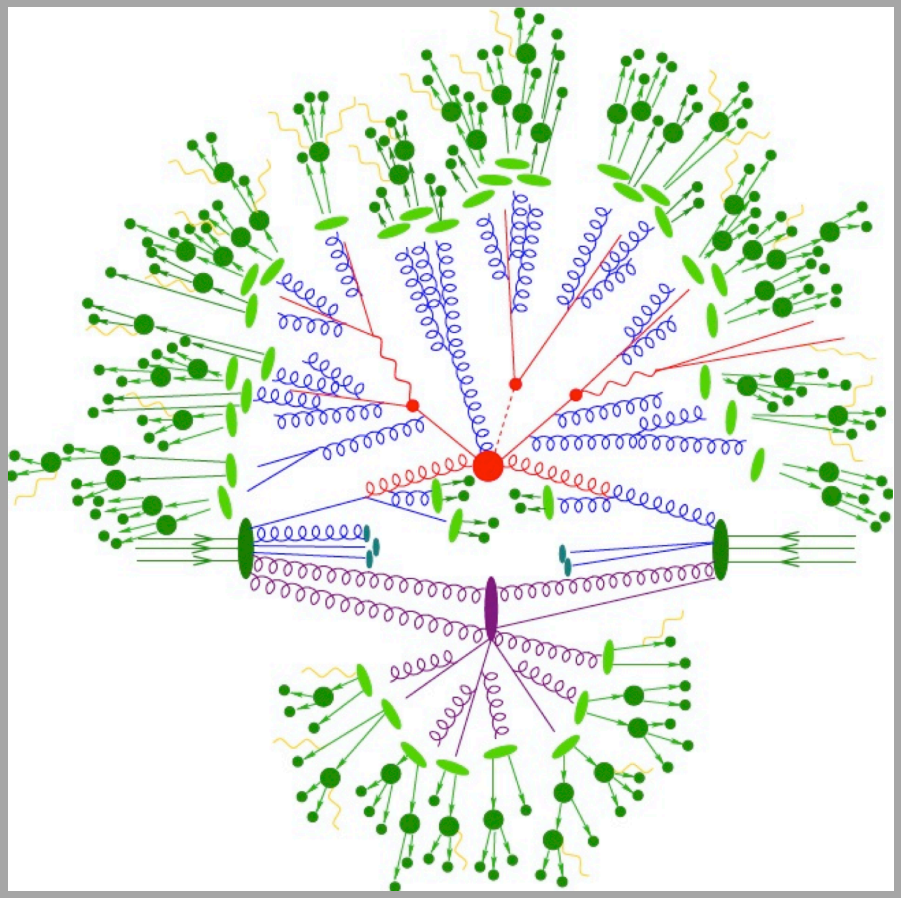
TMD studies in SIDIS

Urgent requirement: Monte Carlo Event Generator for TMDs for analysis prototyping and optimizing the Electron-Ion Collider for TMD measurements

Section

Monte Carlo Event Generators and Pythia

Monte Carlo Event Generator (MCEG)



Map: hard scattering, evolution through radiation, secondary scatterings, dynamical fragmentation with string model, initial-state p_T-dependence

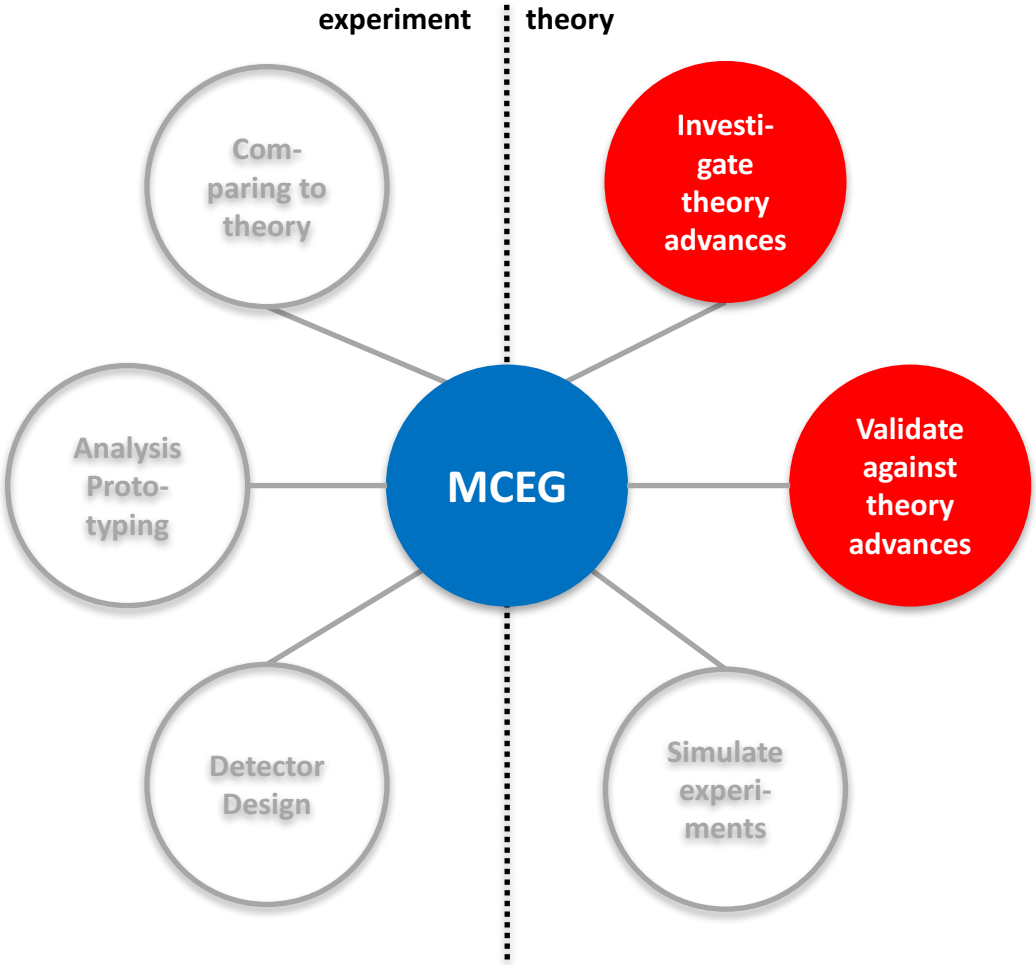
MCEG:

- faithful representation of QCD dynamics
- based on QCD factorization and evolution equations

Algorithm of general-purpose MCEG:

- generate kinematics according to fixed-order matrix elements and a PDF
- parton shower model for resummation of soft gluons and parton-parton scatterings
- hadronize all outgoing partons including the remnants according to a model
- decay unstable hadrons

MCEG in HEP and NP

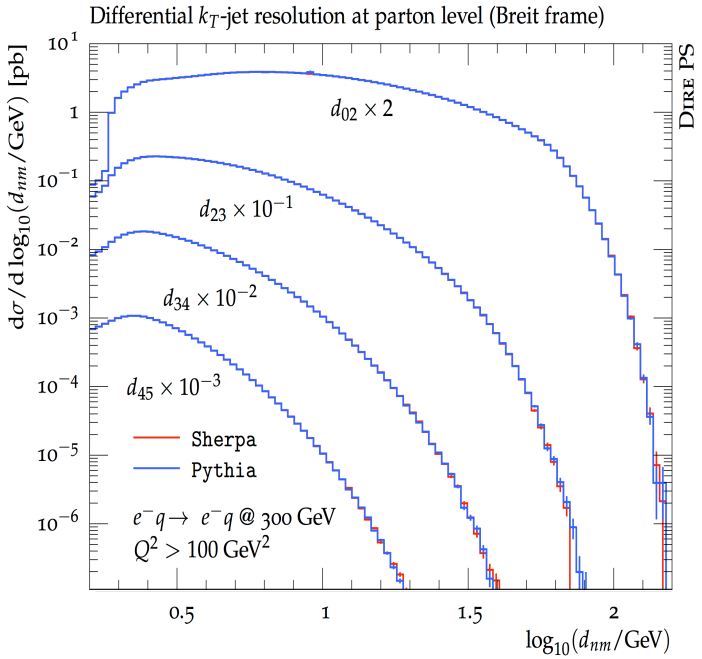


General-purpose MCEG: HERWIG, Pythia, SHERPA

DIRE parton shower

Parton shower:
numerical, fully differential solution of evolution equation by iterating parton decay

DIRE:
- **Fundamental goal**: compare directly to analytical approaches, e.g., the one by Collins-Soper-Sterman
- **Unique verification**: implemented in both Pythia and Sherpa



Section

High-energy and nuclear physics

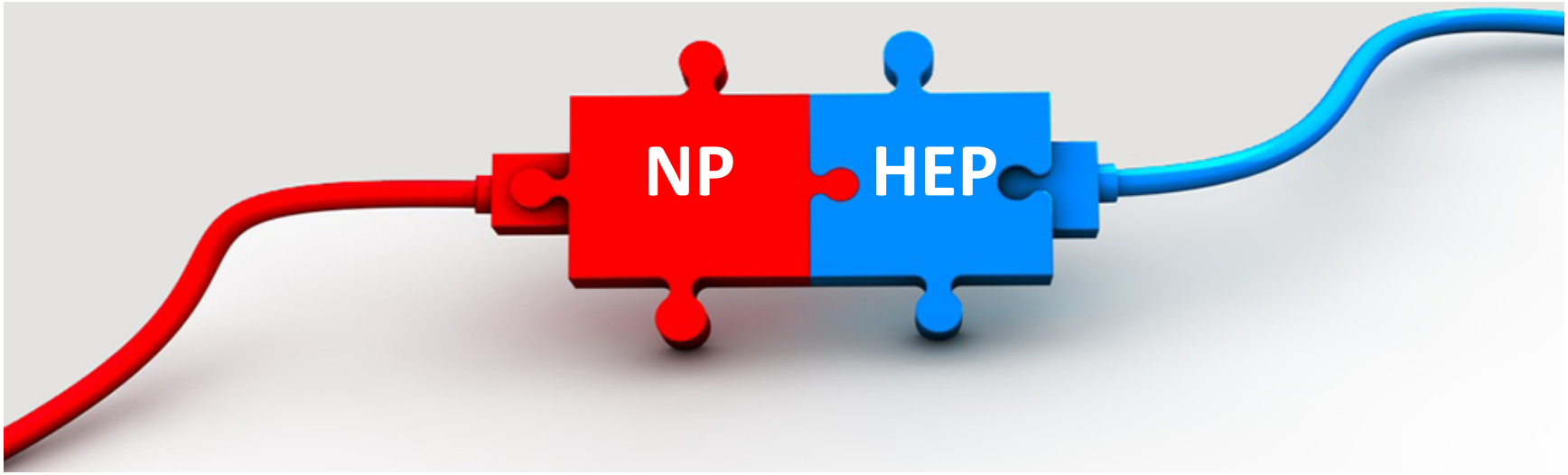
Measurements in NP and HEP

Nuclear physics (NP)

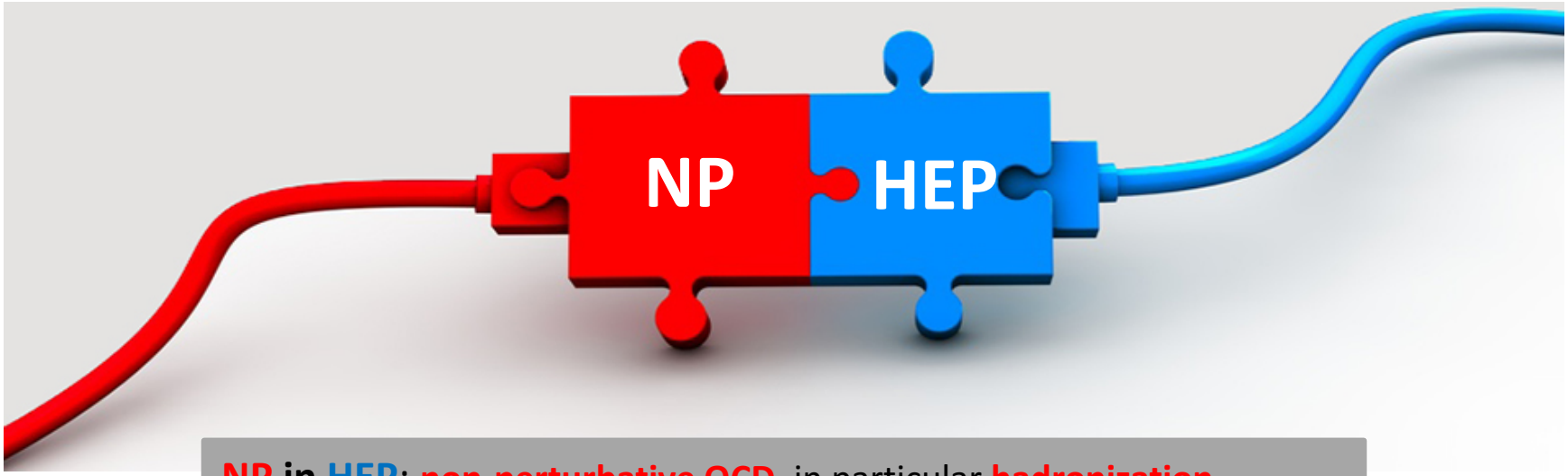
- investigation of nucleon and nuclear structure and associated dynamics
- observables of non-perturbative QCD
- non-perturbative quark-gluon dynamics parameterized in PDFs and FFs

High energy physics (HEP)

- investigation of the elemental constituents of matter and energy and their interactions
- observables of perturbative QCD
- perturbative QCD calculations up to $N^{N}LO$
- assuming the knowledge of the hadron structure / PDFs at low energies



Connection between NP and HEP



NP in HEP: **non-perturbative QCD**, in particular **hadronization**

- **background suppression**, relevant for any analysis and also for the *new physics* searches
- **reducing systematic uncertainties**, e.g., of non-perturbative QCD models
- **high-precision measurements,** e.g., improving the knowledge on the coupling constants by studying the p_T spectra

HEP in NP:

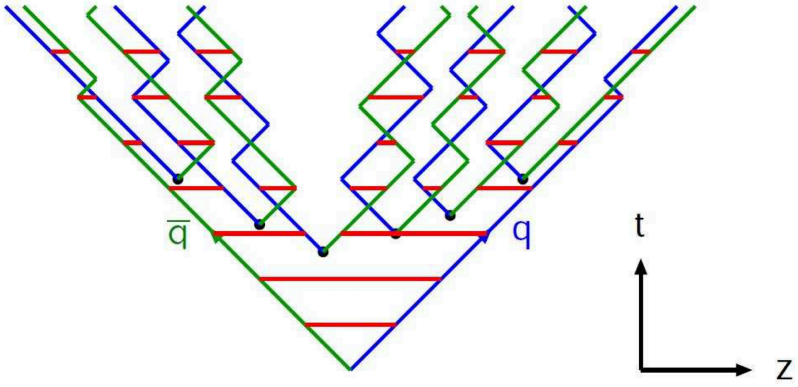
- combine MCEG approaches with first principle QCD calculations to proceed with QCD studies of non-perturbative structure

Section

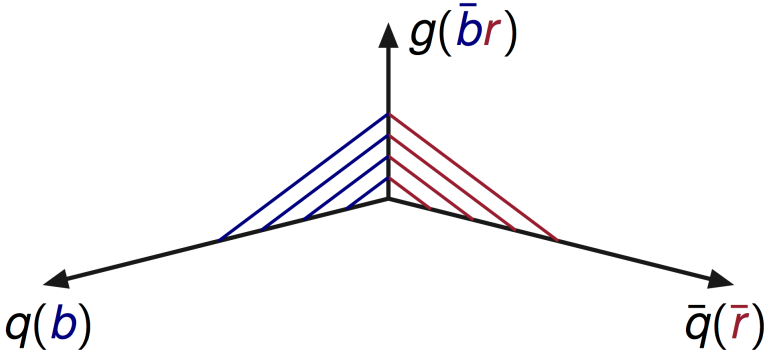
Early state of the LDRD project

LUND string hadronization

String breakup



String drawing



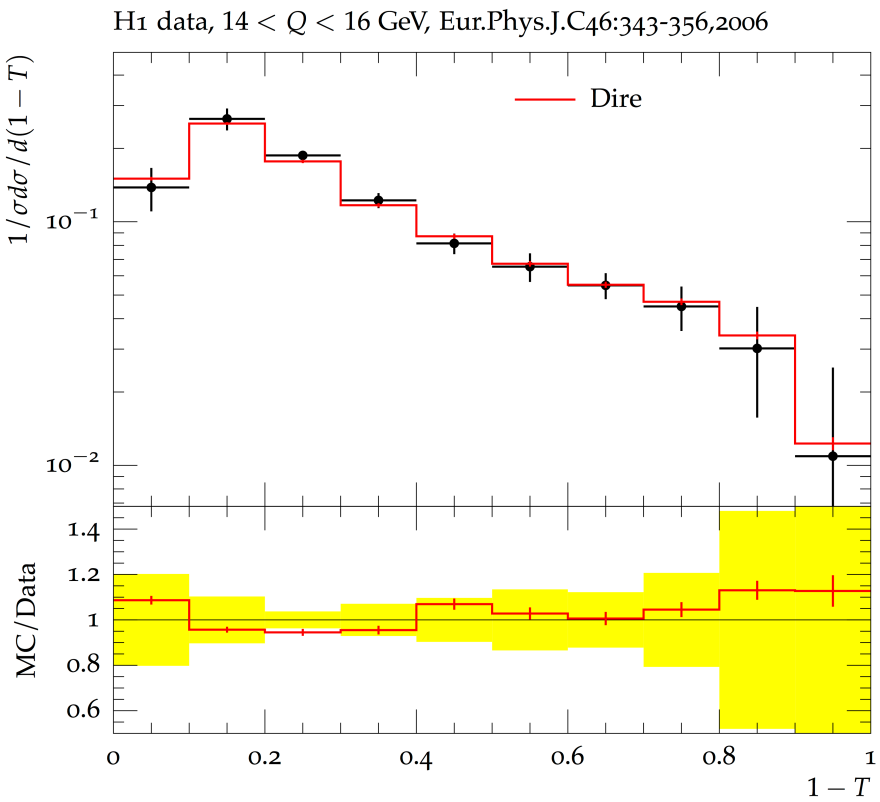
PYTHIA8/DIRE at low energies

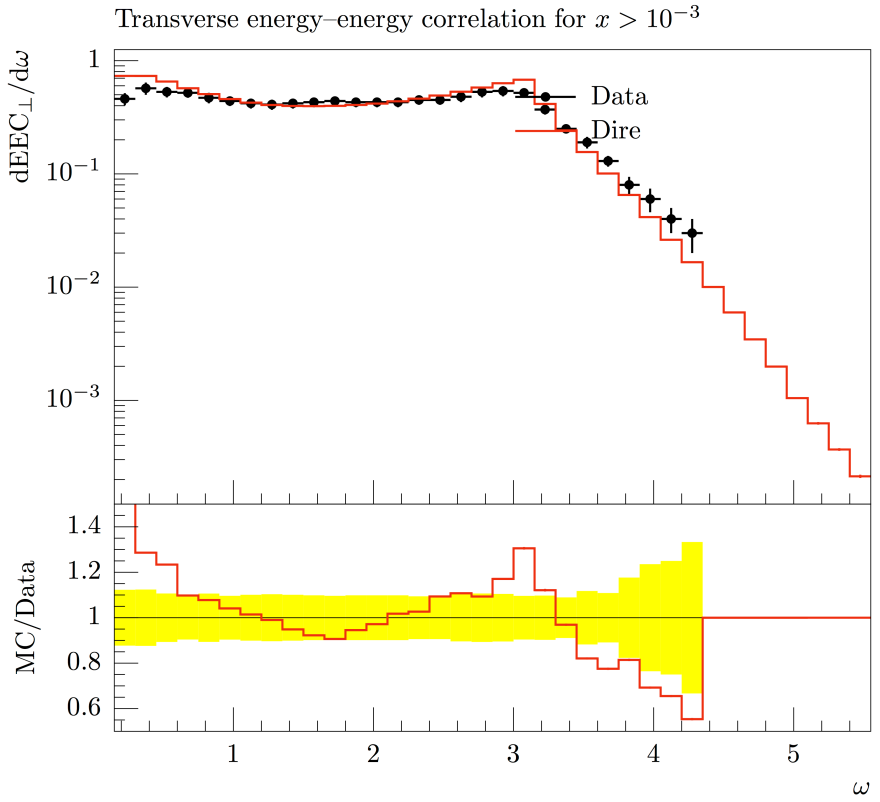
, e.g., at W = 10 GeV:

- average number of primary hadrons is < 6
- two hadrons will be produced by the final, somewhat ad-hoc, decay of the string into two hadrons
- for sea-quarks one hadron comes from a somewhat ad-hoc remnant treatment

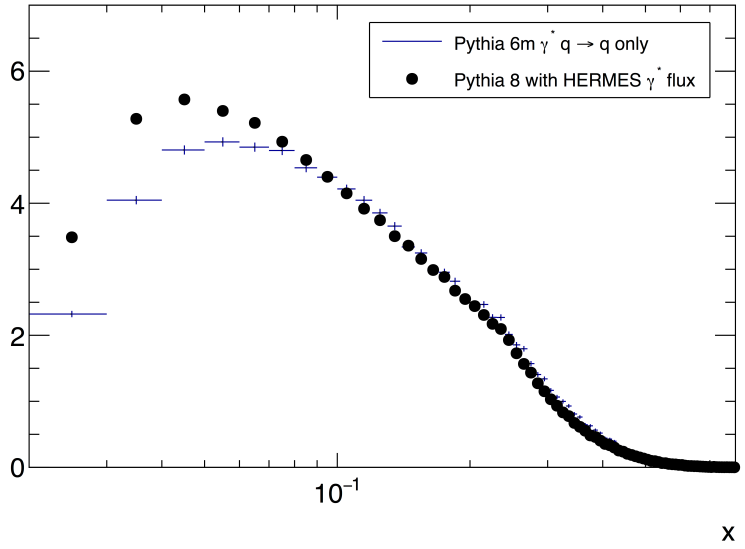
Tuning and **possible modifications** required.

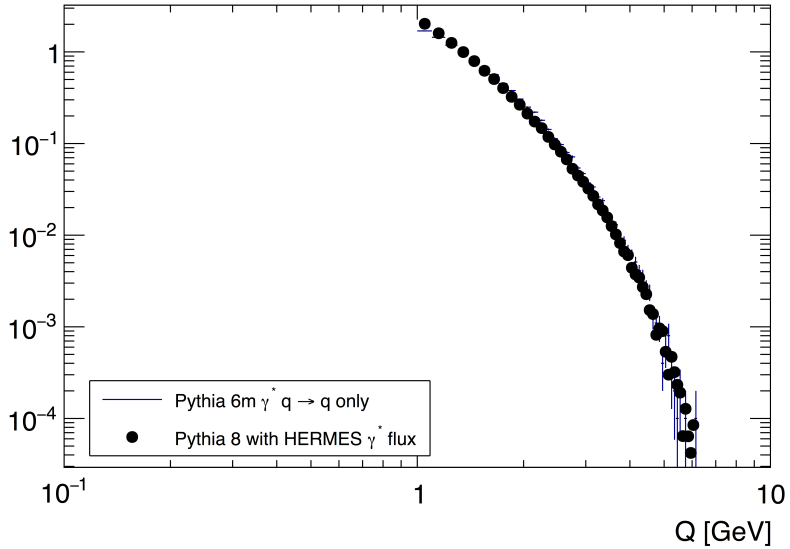
Pythia8+DIRE and DIS

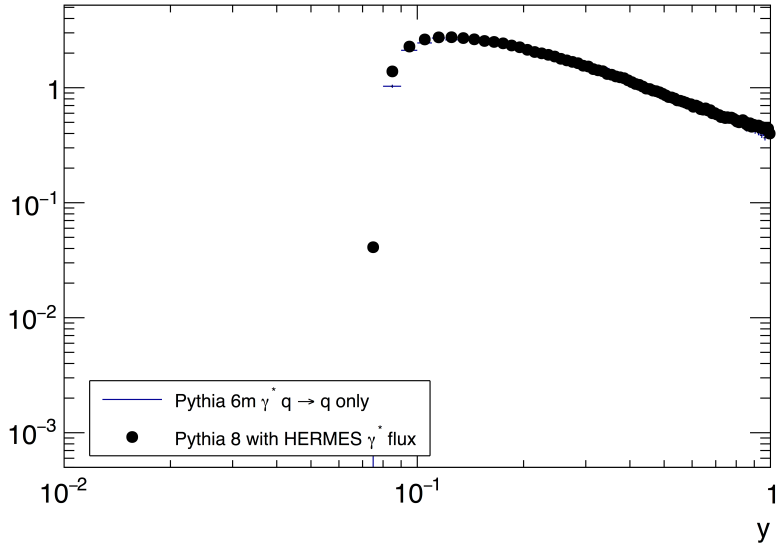


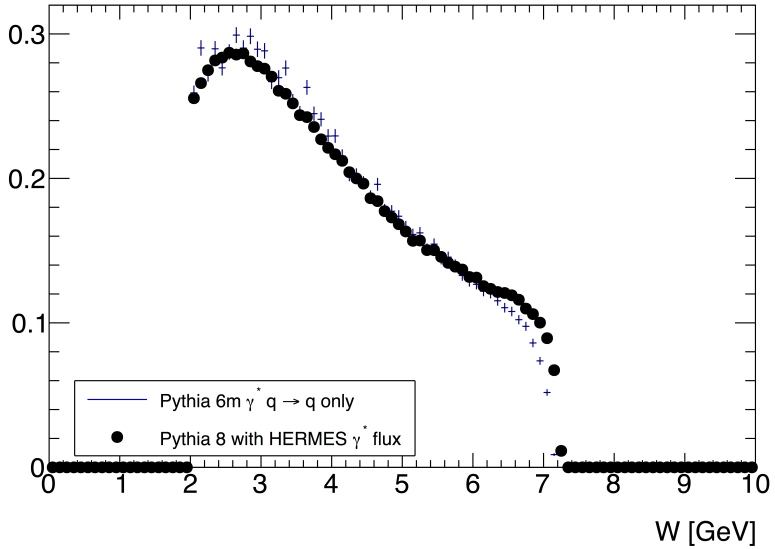


Pythia8+DIRE at low energies









Summary

LDRD:
LABORATORY DIRECTED
RESEARCH & **DEVELOPMENT**

Study of hadronization, started in FY17

Correlation functions of TMD factorization ⟷ Pythia Monte Carlo Event Generator

Current Status:

- identify mismatches between factorization theorem and Pythia
- establish Pythia8+DIRE as SIDIS generator
- FF analysis from Pythia