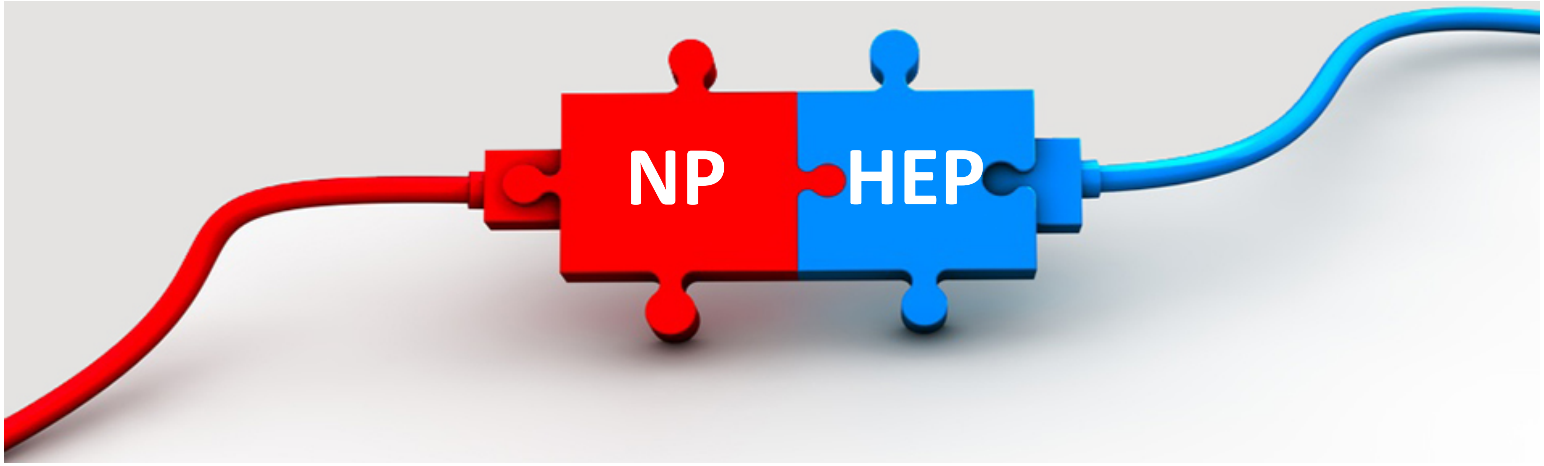
Phenomenological Study of Hadronization in Nuclear and High-Energy Physics Experiments



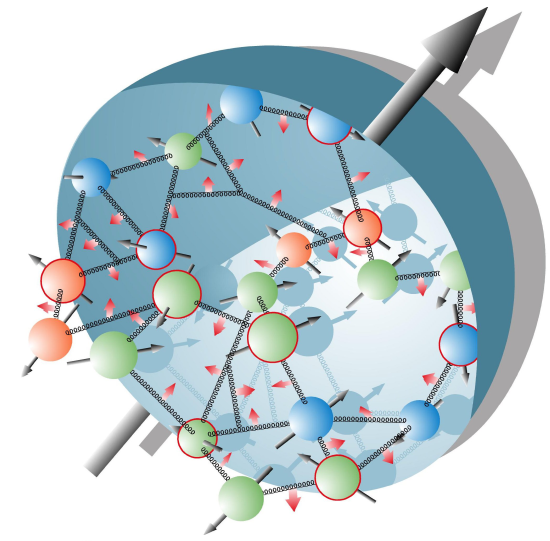
EIC User Group Meeting Trieste,
July 18 – 22 2017

Section

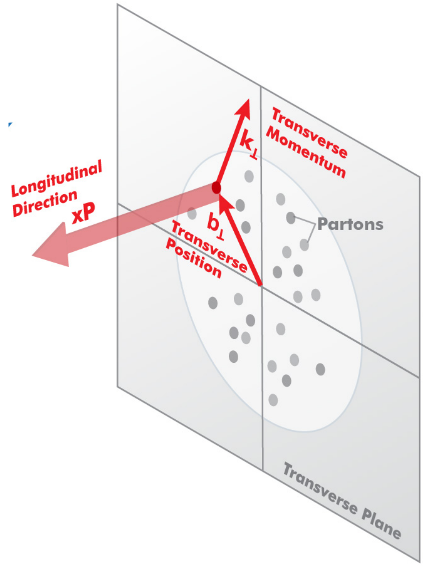
TMD measurements at the EIC

EIC: Ideal facility for studying QCD

Polarization
Understanding hadron structure cannot be done without understanding spin:
- polarized **electrons** and
- polarized **protons/light ions**



Transverse and longitudinal polarization of light ions (p, d, ^{3}He):
- 3D imaging in space and momentum
- spin-orbit correlations

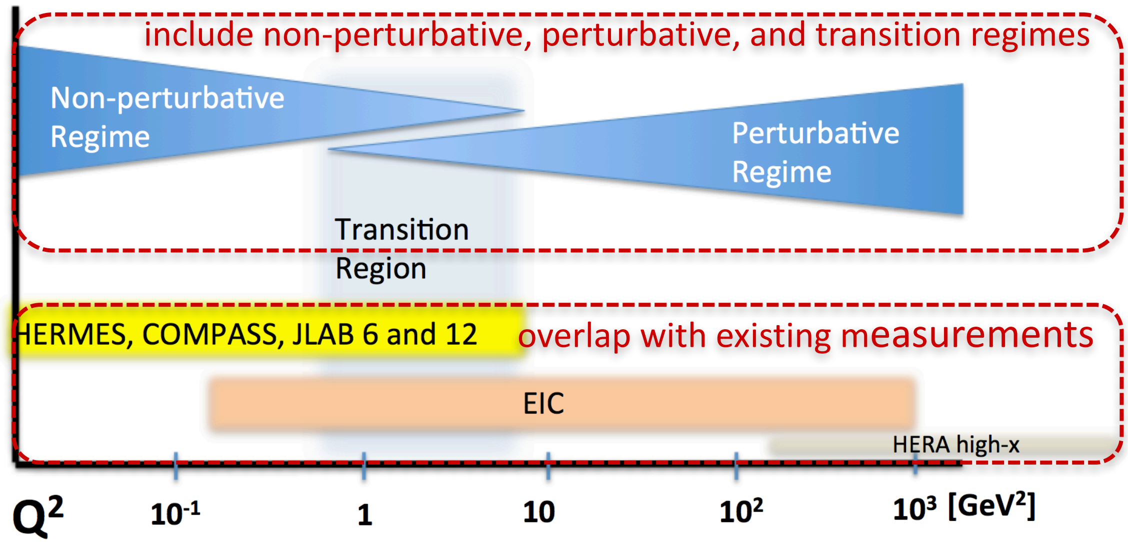


Broad range in A from hydrogen to uranium isotopes:
- 3D imaging in space and momentum
- hadronization in the nuclear medium
- EMC effect for gluons
- gluon saturation

EIC: Ideal facility for studying QCD

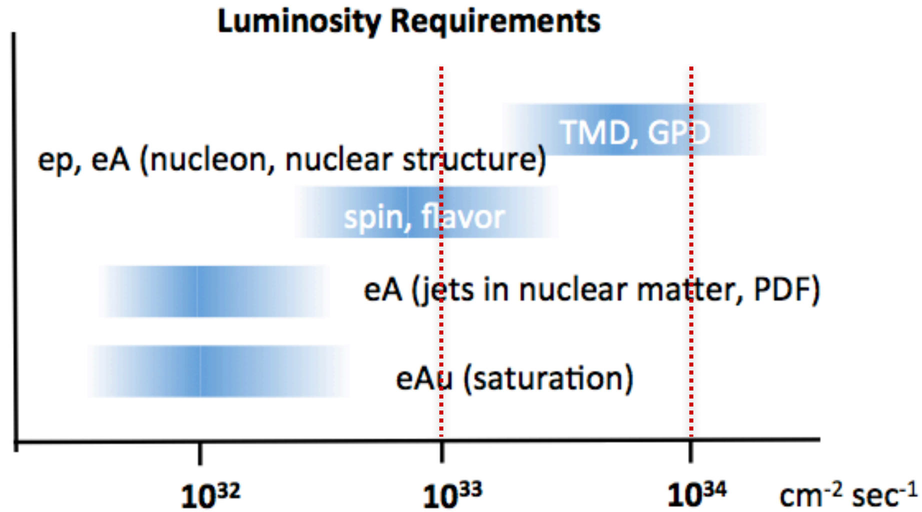
Various beam energy:

broad Q^2 range for
- studying evolution to Q^2 of ~1000 GeV^2
- disentangling non-perturbative and perturbative regimes
- overlap with existing experiments



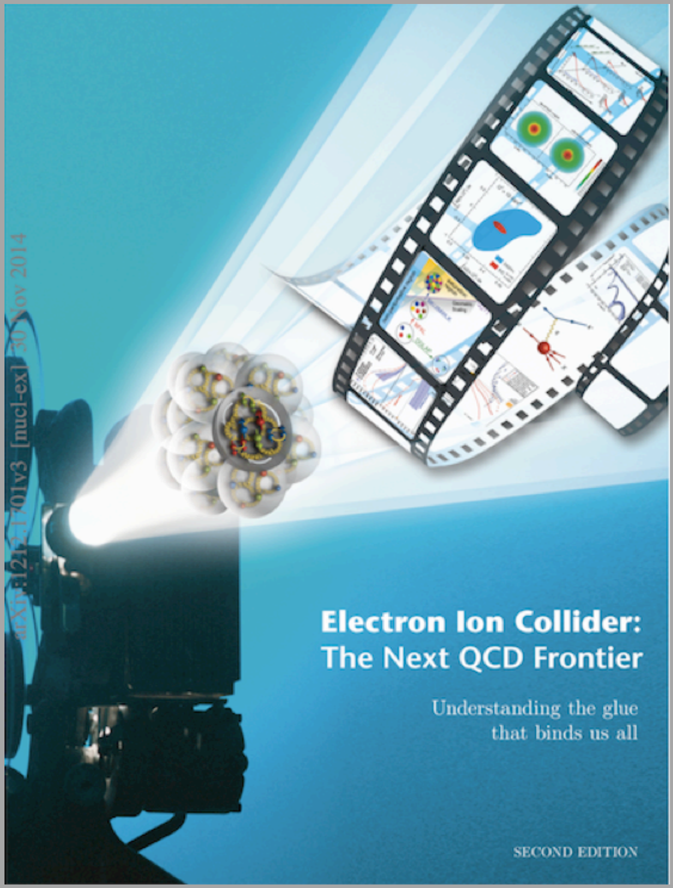
High luminosity:

high precision
- for various measurements
- in various configurations



TMD program in EIC White Paper

EIC: The Next QCD Frontier



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Ultimate measurement of TMDs for quarks

- **high luminosity**
  - high-precision measurement
  - multi-dimensional analysis (x, Q^2, ϕ_S, z, P_t, ϕ_h)
- **broad x coverage** $0.01 < x < 0.9$
- **broad Q^2 range** disentangling non-perturbative / perturbative regimes

First measurement of TMDs for sea quarks

First measurement of TMDs for gluons

Systematic study of QCD factorization

Ultimate measurement of TMDs

Selected analysis requirements

High-precision analysis tools:

- high-precision MCEG
- radiative correction library
- multi-dimensional analysis

pioneering work by H. Matevosyan: mPYTHIA

R_{SIDIS} from JLab 12GeV

Long-lived data repositories

- COMPASS, HERMES, JLab, RHIC
- document analysis publicly for analysis and theory development (RIVET)
- combined *global* analysis (e.g., HERA fit), possibly on event level

Understanding of hadronization

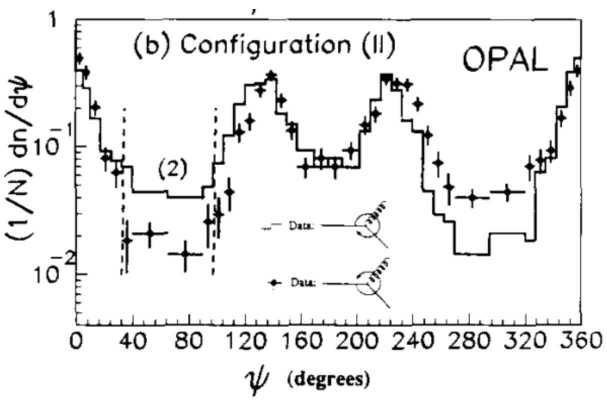
Section

Study of Hadronization in NP and HEP

Describing the hadronization process

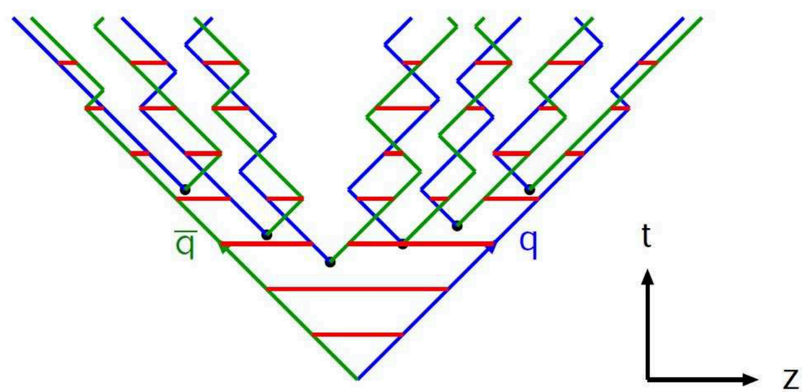
LUND String Model for hadronization (1977 –   )

- simple but powerful phenomenological model
- no (promising) new hadronization models in last 40 years
- **ToDo**
  - review
  - connect with modern QCD, including TMD and spin effects

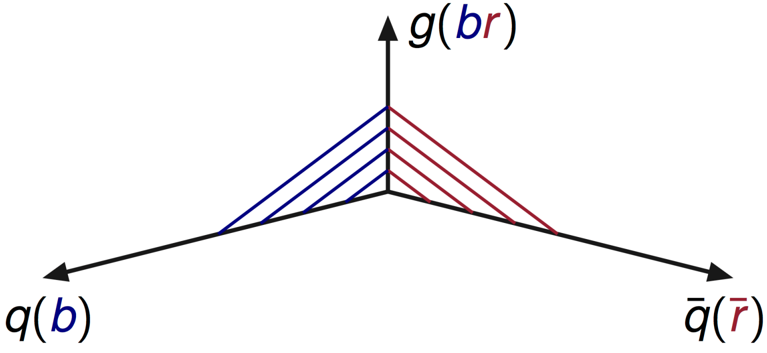


evidence of string effects
particle flow asymmetry at OPAL

String breakup



String drawing



LDRD project at Jefferson Lab

NP – QCD factorization theorem

- interpret collision experiments using QCD factorization theorem
- development driven by **John Collins** (2009 J. J. Sakurai Prize)
- Novel way to study confinement: QCD factorization theorem for TMDs

HEP – Monte Carlo Event Generator

- describe collision processes by a combination of theory and phenomenological models
- **Pythia**, development led by LUND group (**Leif Lönnblad**), recognized by 2012 J. J. Sakurai Prize (for T. Sjöstrand)

Correlation functions of TMD factorization ⟷ Pythia MCEG

LDRD goal

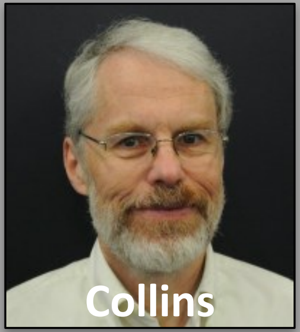
LDRD personnel (FY17)

JLab

Pythia

Other

Experimentalists



Theorists

Section

Monte Carlo Event Generator

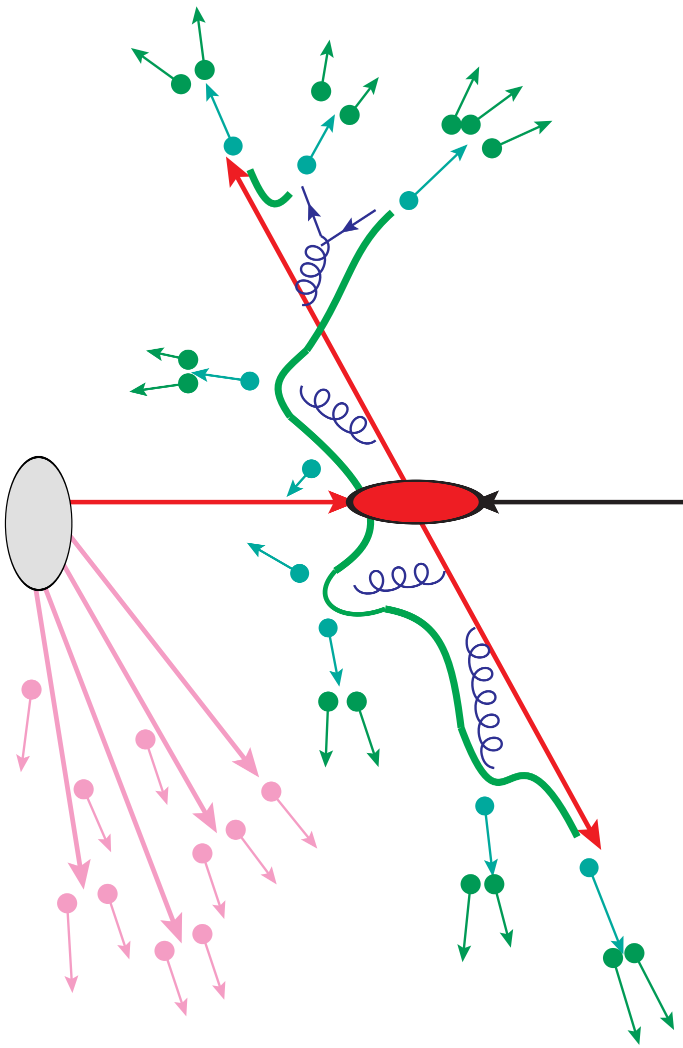
Monte Carlo Event Generator (MCEG)

MCEG:

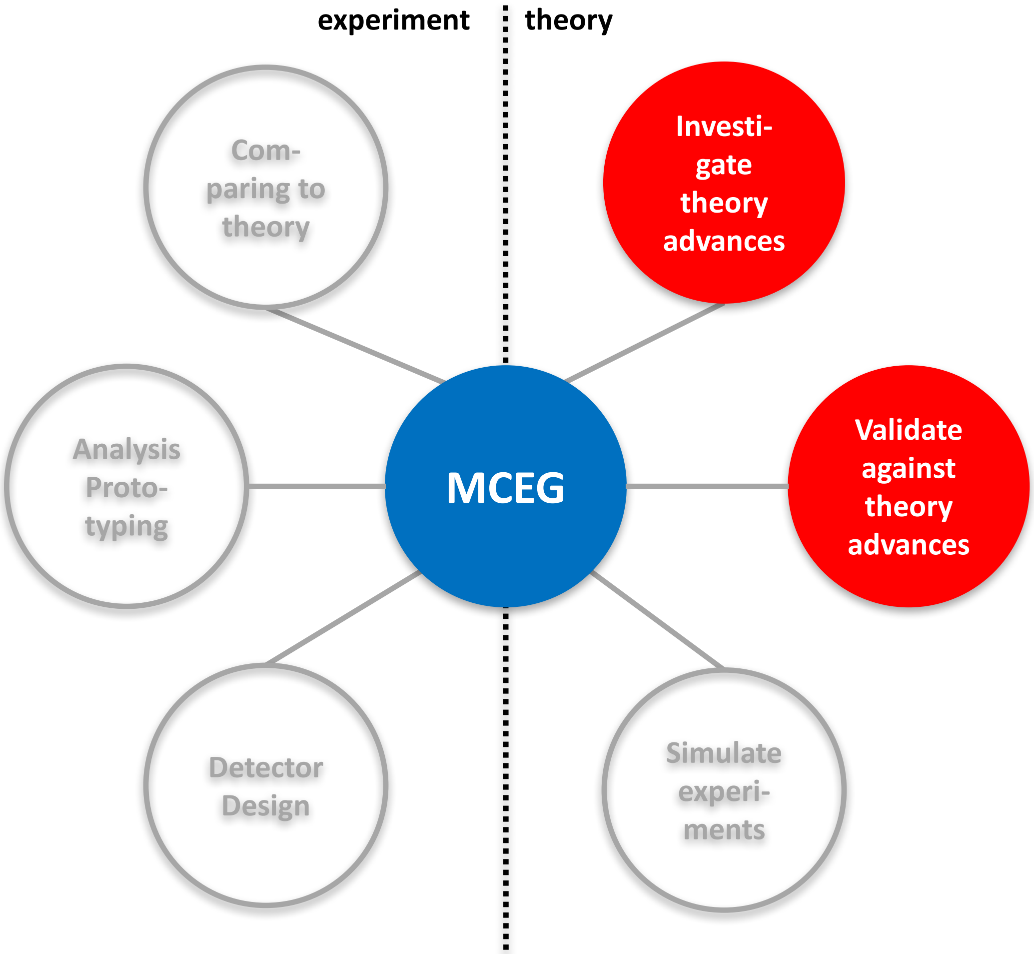
- faithful representation of QCD dynamics
- based on QCD factorization and evolution equations

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



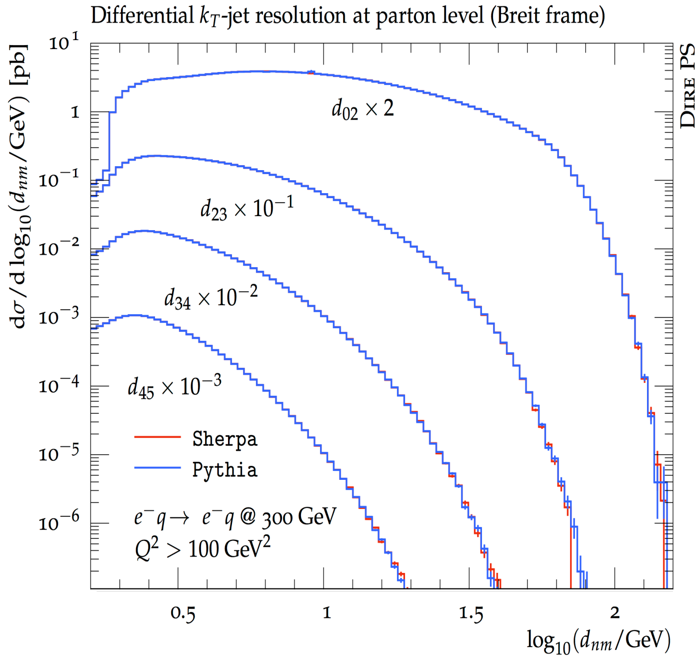
Lesson from HEP: high-precision QCD measurements require high-precision MCEGs

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

NP and HP

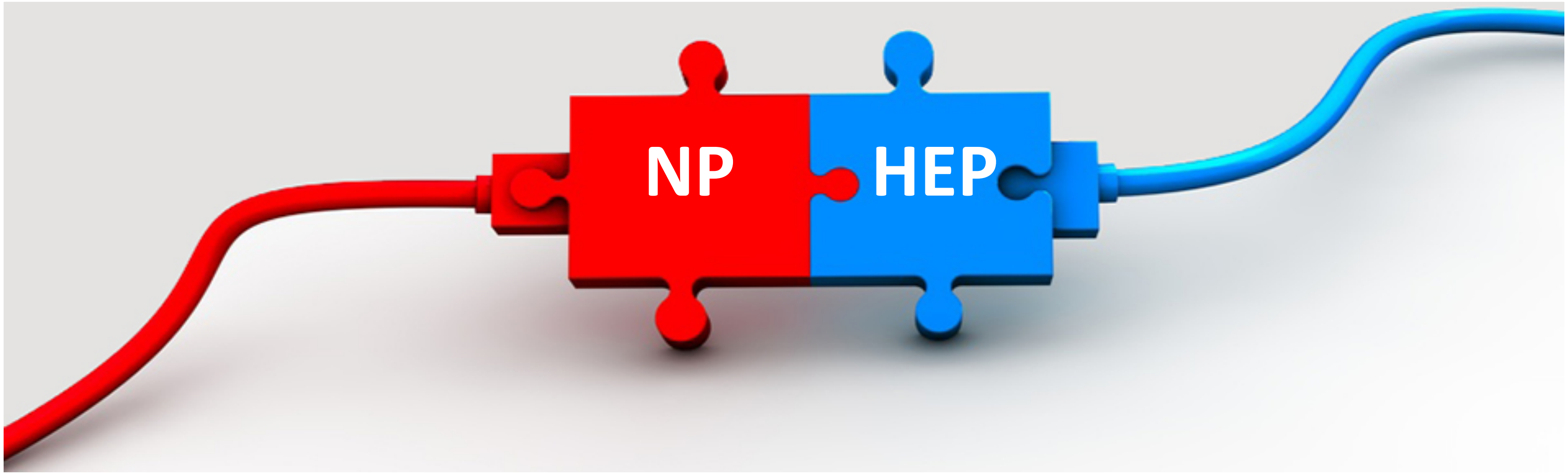
Measurements in NP and HEP

Nuclear physics (NP)

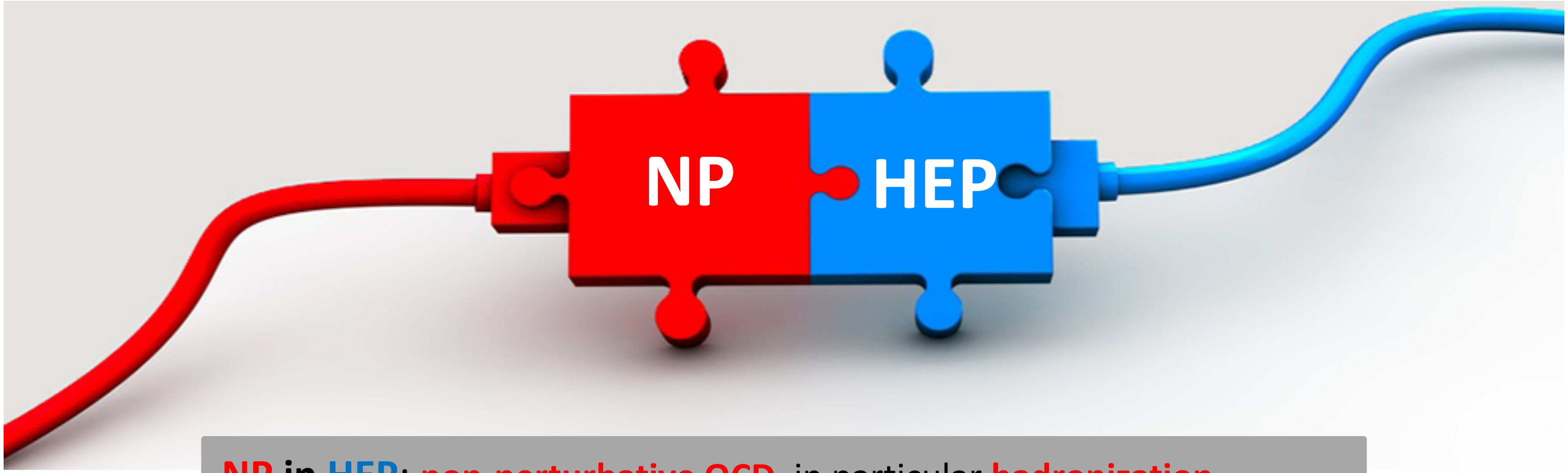
- investigation of nucleon and nuclear structure and associated dynamics
- observables of non-perturbative QCD
- non-perturbative quark-gluon dynamics parameterized in PDFs and FFs

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 our project

Work plan

FY17

FY18

FY19

Publication: DIS in Pythia8

Publication: LUND validation

+ TMD observables

Publication: Hadronization in NP and HEP

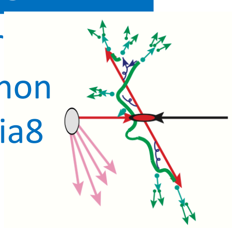
- comparison Pythia8-TMD factorization
- language dictionary
- Pythia8 with spin-independent TMDs

Spin-dependent hadronization

- Incorporate model of trans-verse spin effects (see **Xavier Artru's** talk) into Pythia8
- Anna Martin and Albi Kerbizi will join project in FY18

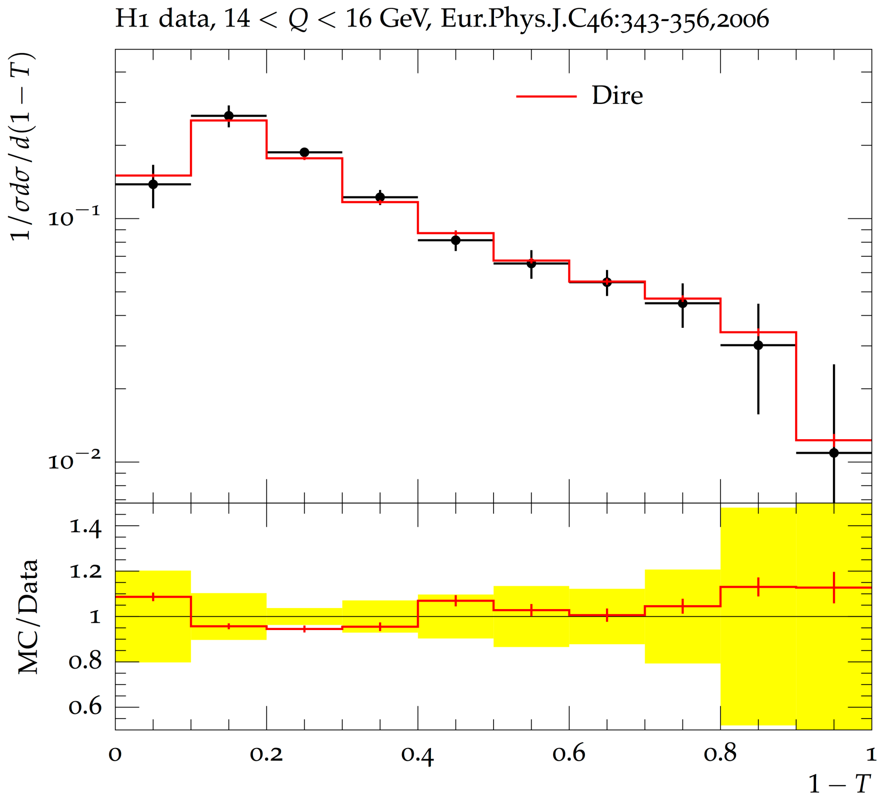
Hadronization plugin

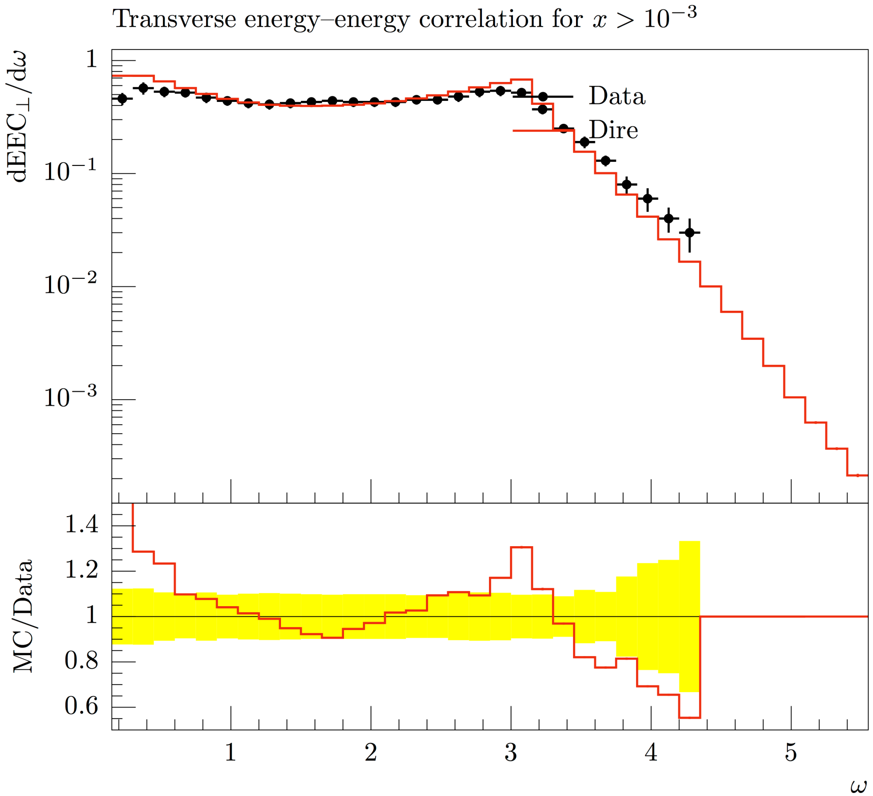
- user model for one phenomenon
- rest from Pythia8



Pythia8: Simulating HERA collider results

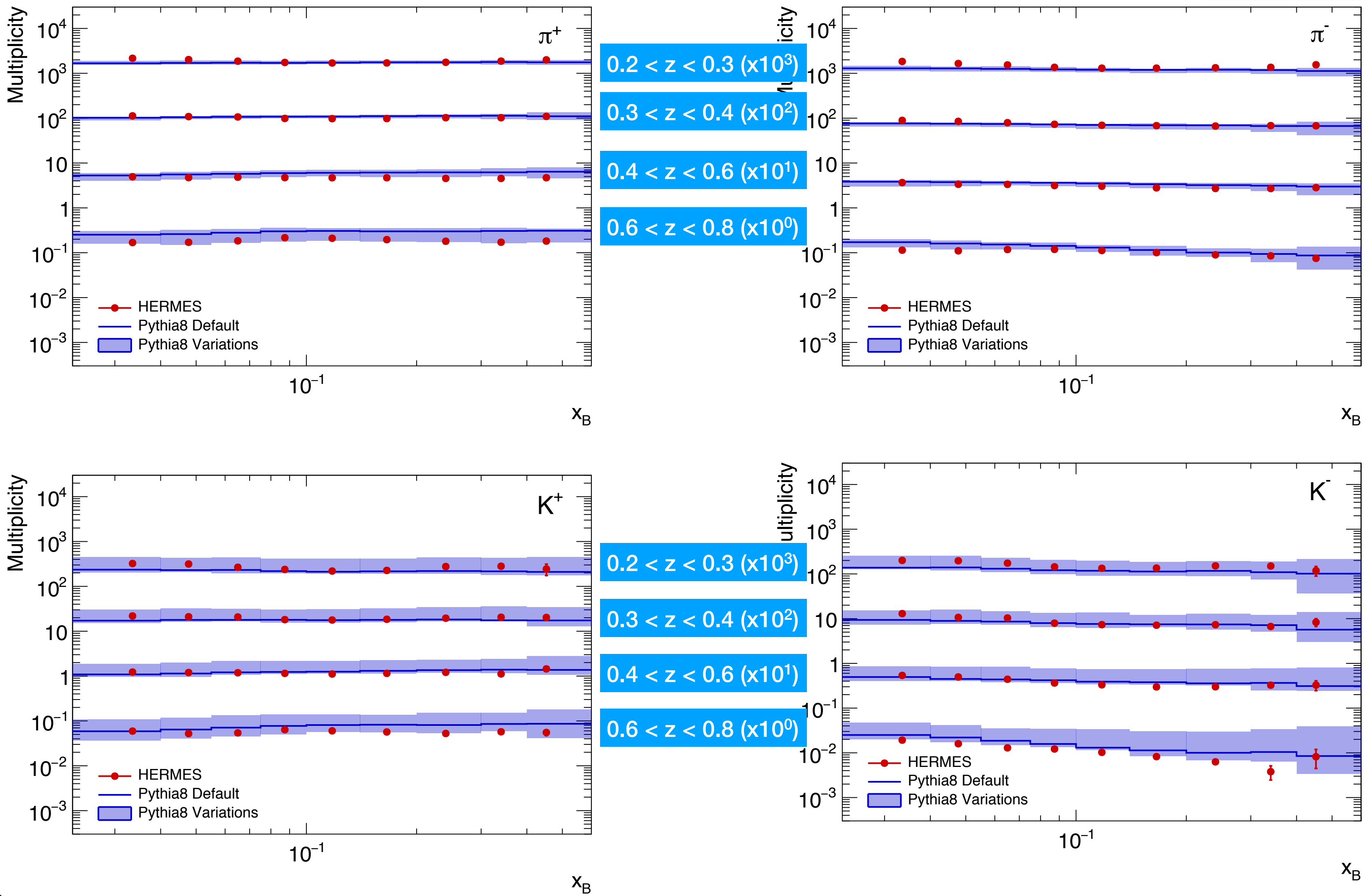
preliminary





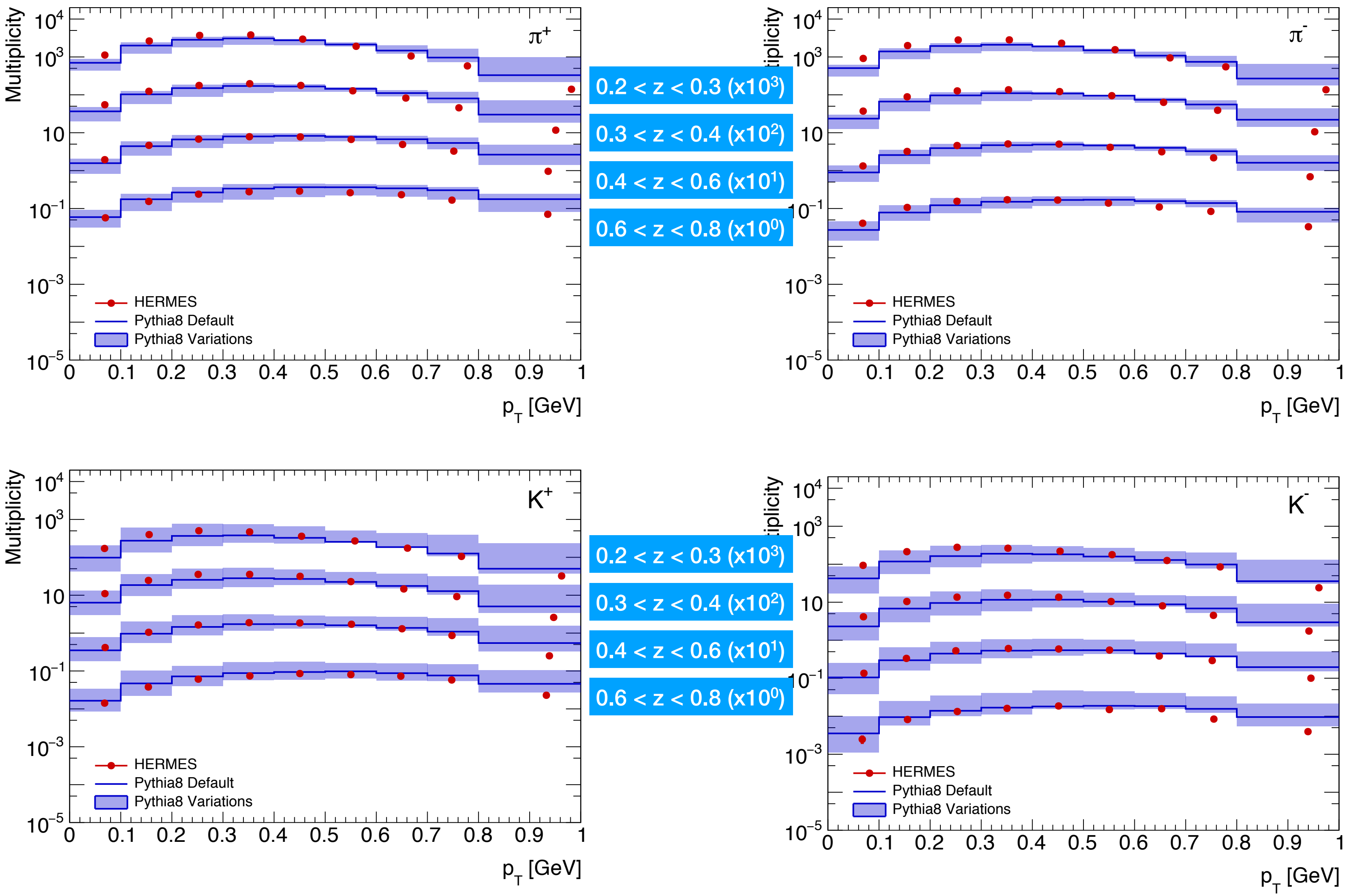
Pythia8: Simulating HERA fixed-target results

preliminary



Pythia8: Simulating HERA fixed-target results

preliminary

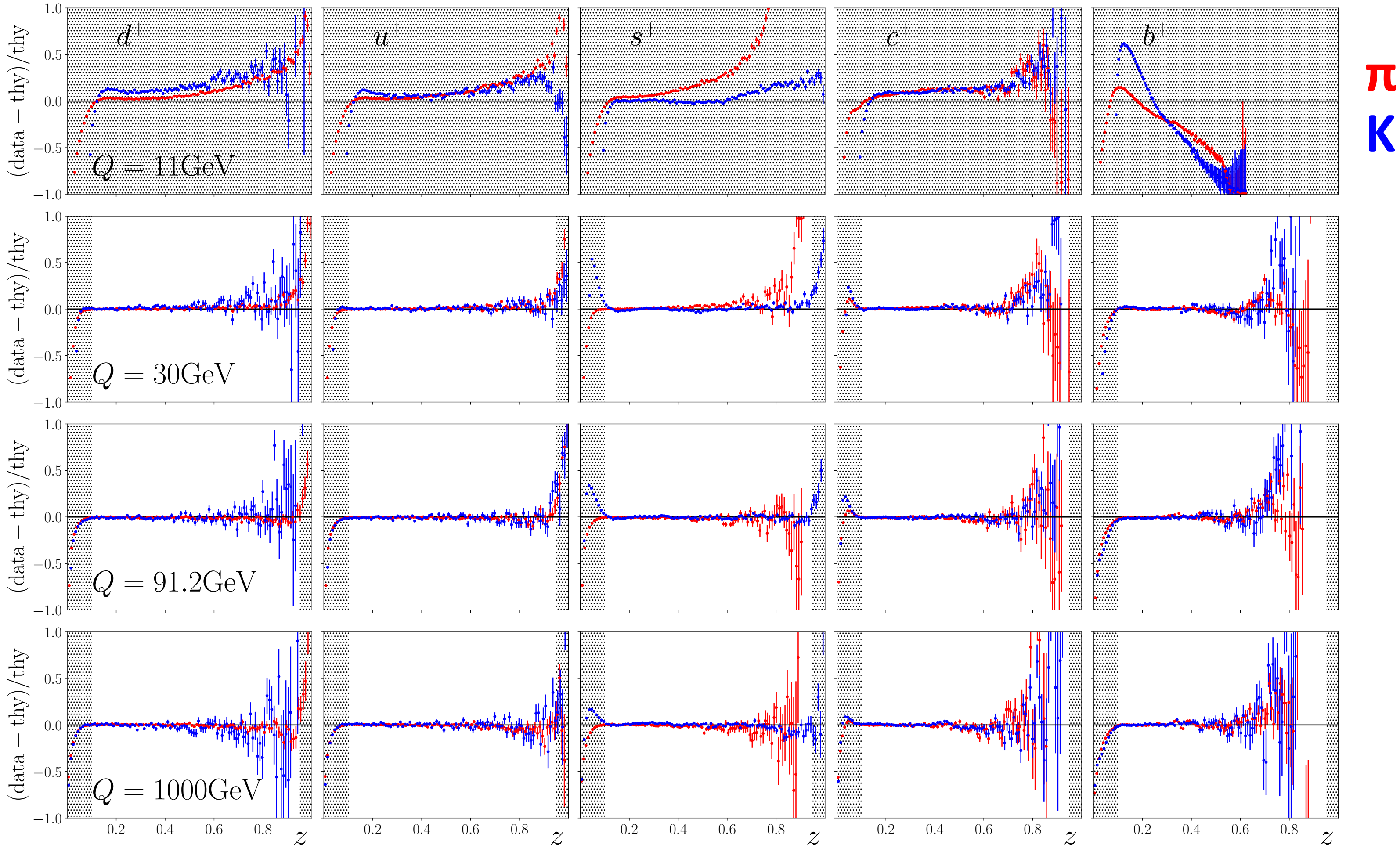


Validation of LUND string model

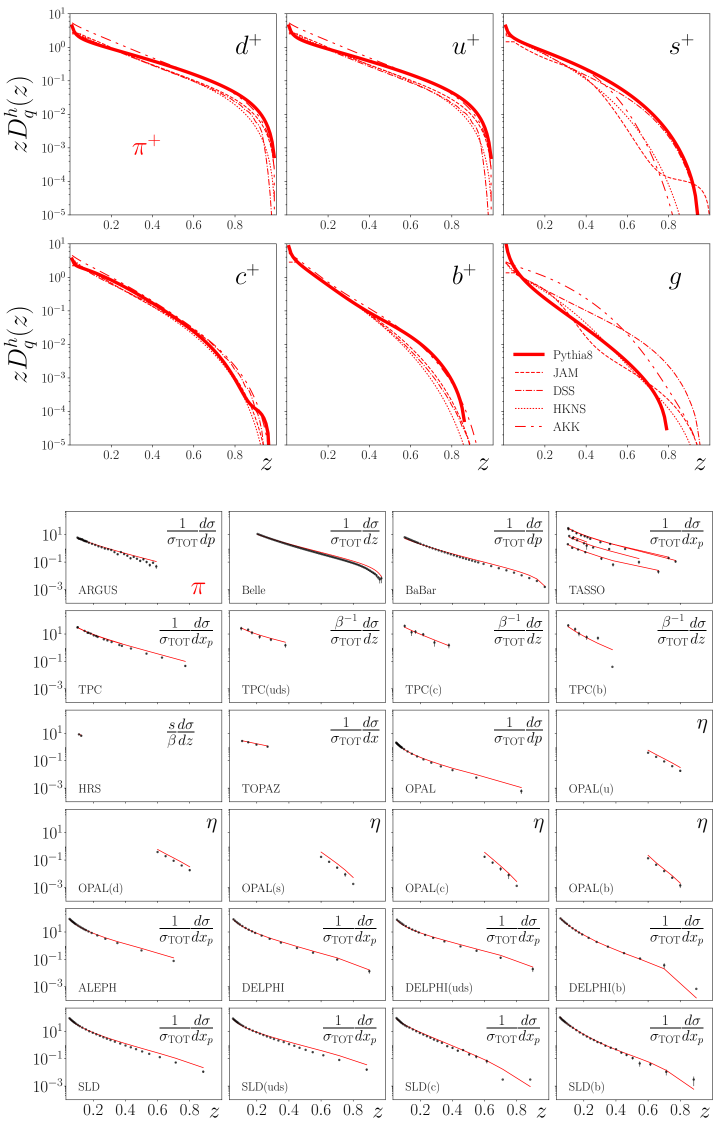
Data Pythia8 simulation of e^+e^-

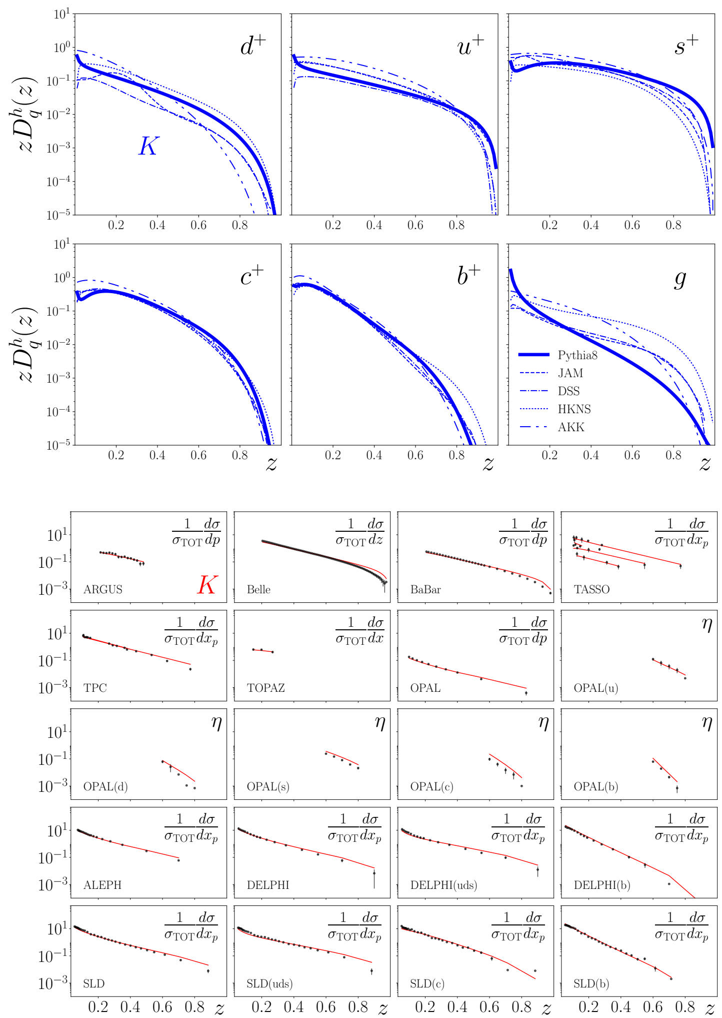
Theory collinear factorization

preliminary



FF analysis from Pythia8 (preliminary)





Study of Hadronization in NP and HEP

LDRD:
started in FY17
at **JLab**

Connection between **NP** and **HEP**

Correlation functions of TMD factorization ⟷ Pythia MCEG LUND string model

Urgent requirement

- MCEG for TMDs
- Understanding of hadronization process

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

By doing so:

- **NP** Improve theoretical framework for TMDs.
- **HEP** Improve hadronization models.