Describing (SI)DIS in Monte Carlo Event Generators

Hadronization and

The role of Monte Carlo Event Generators

MCEGs for future ep and eA facilities (EIC)

Outlook: NP research model and MCEGs

Markus Diefenthaler

Color confinement and hadronization

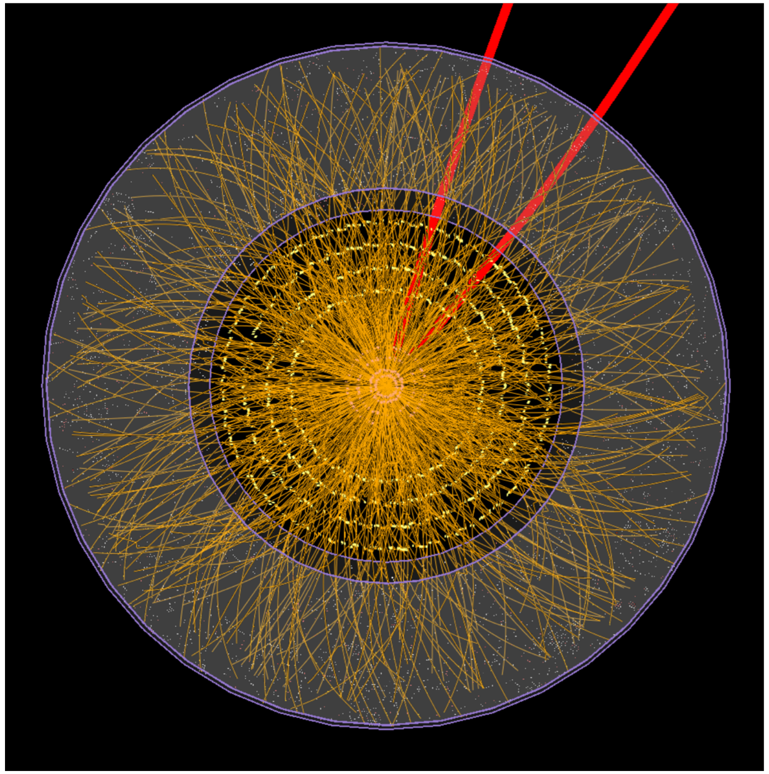
Confinement Essential feature of QCD

- We study quark–gluon dynamics in bound states of QCD.
- No states for isolated quarks and gluons have been observed.
- **Craig Roberts** "In the Universe, all readily accessible matter is defined by light quarks. Confinement is therefore a complex, dynamical phenomenon unrelated to static potentials in quantum mechanical models."
- Mathematical proof of confinement included among the seven Millennium Prize Problems in mathematics.

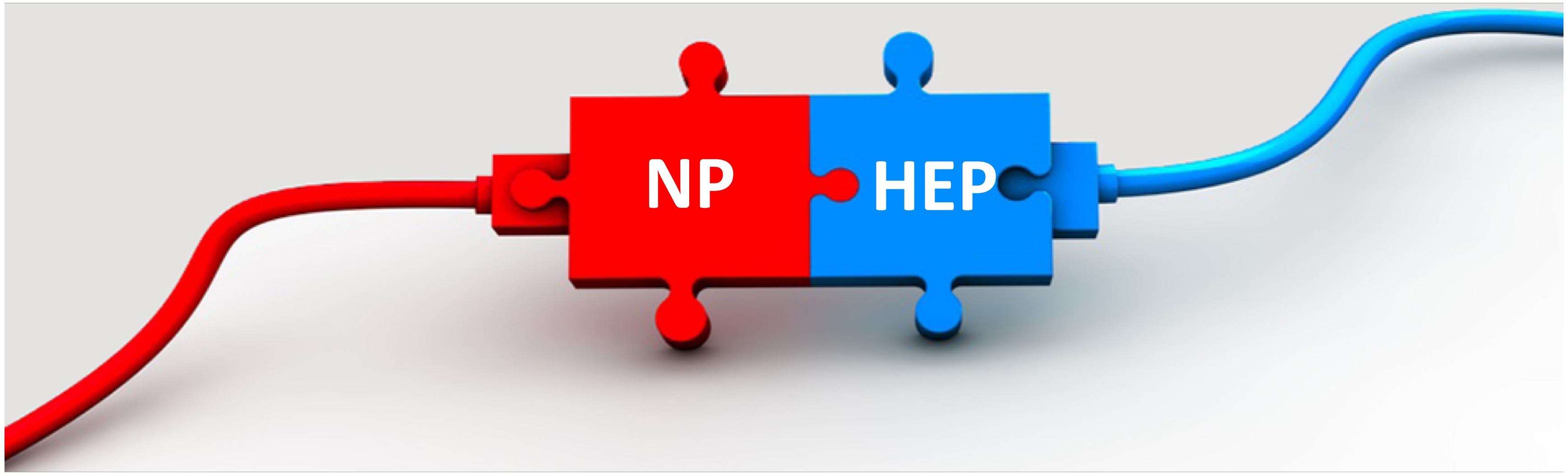
Hadronization Study confinement

- Process by which a struck quark or gluon develops into a jet or a hadron.
- Phenomenon of the strong interaction that is not yet fully understood.

"Quarks are born free, but everywhere they are in chains."
Frank Wilczek



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

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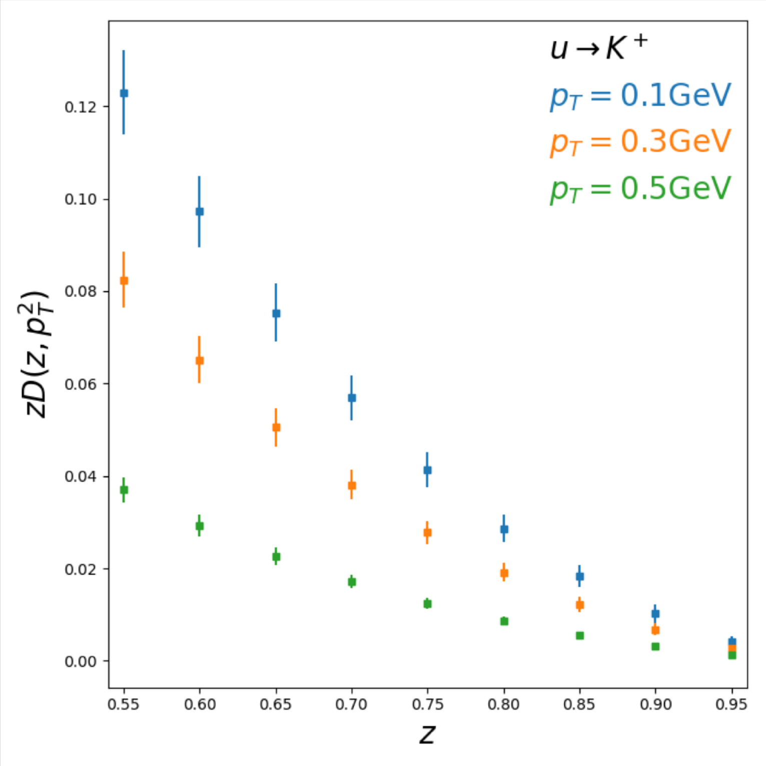
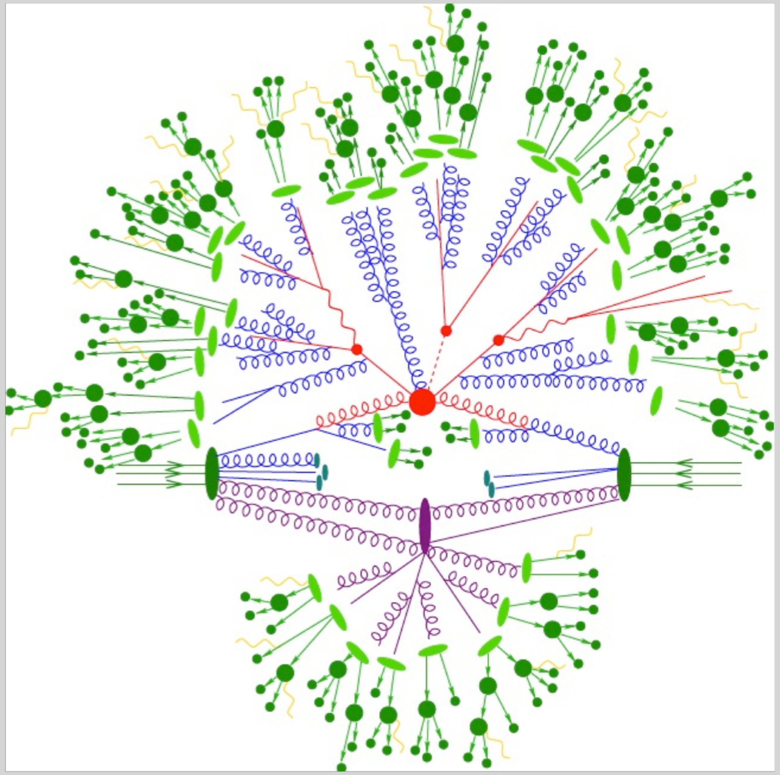
Studying hadronization in two complementary approaches

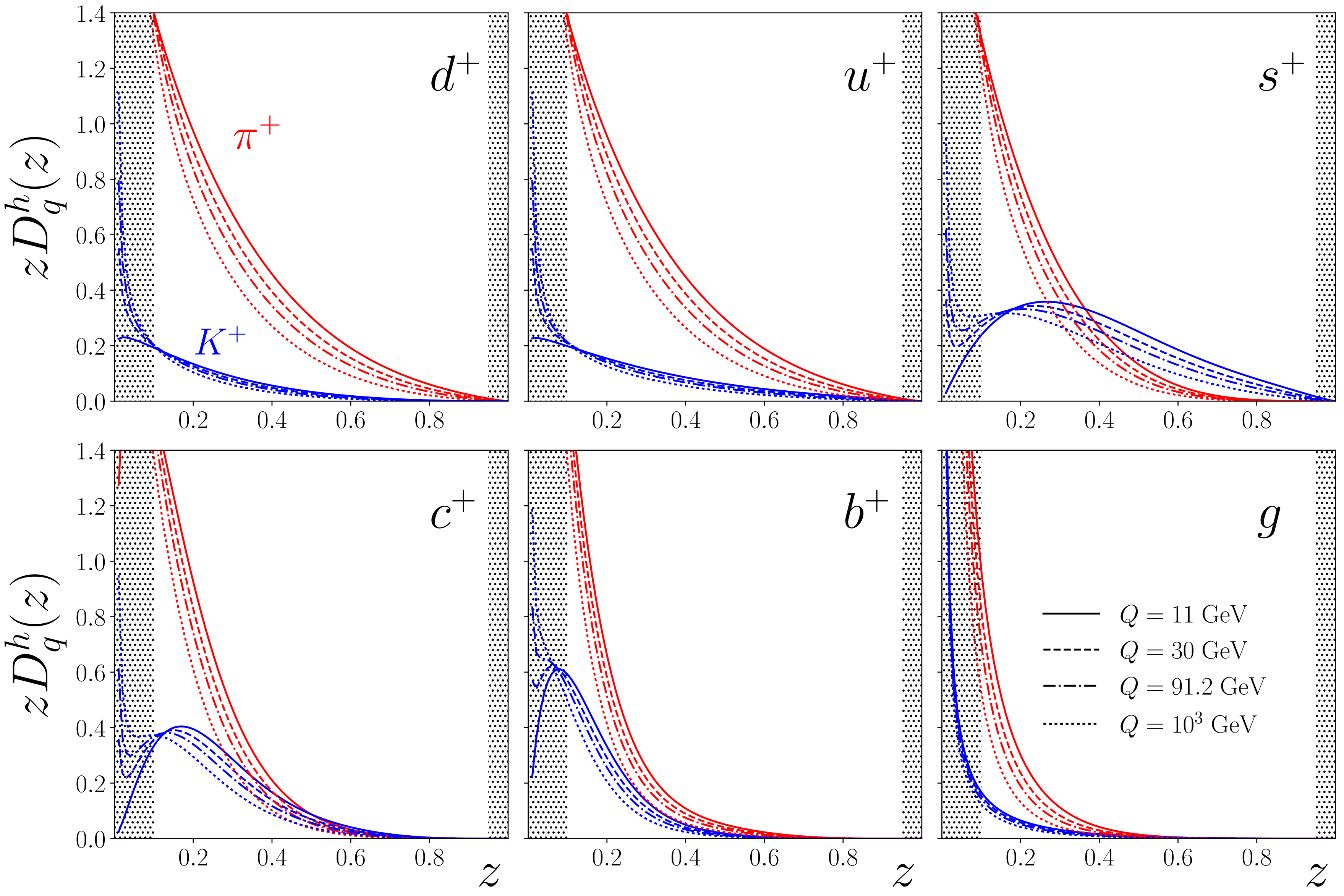
Purely phenomenological description with empirical fragmentation functions using factorization theorems in pQCD



Hadronization models folded with many parameters to describe experimental observations as applied in Monte Carlo Event Generators.



Fit π and K FFs from Pythia8 pseudodata using pQCD @ NLO



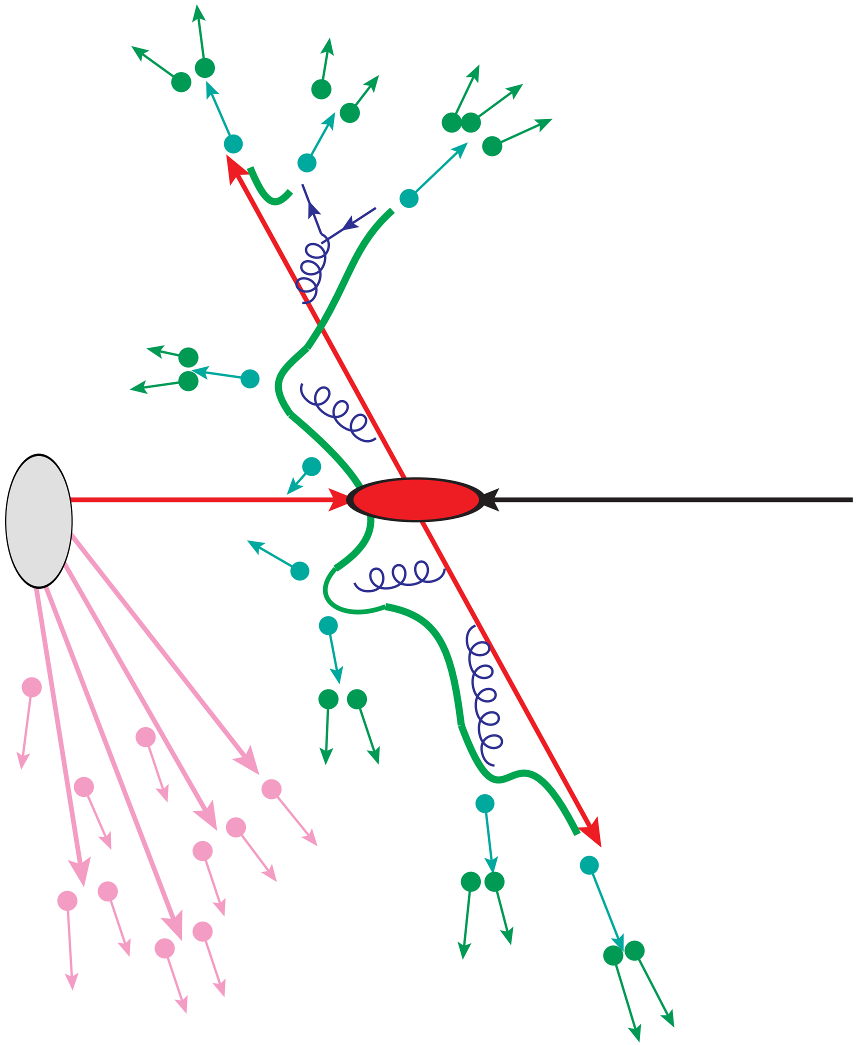
Monte Carlo Event Generator

MCEG

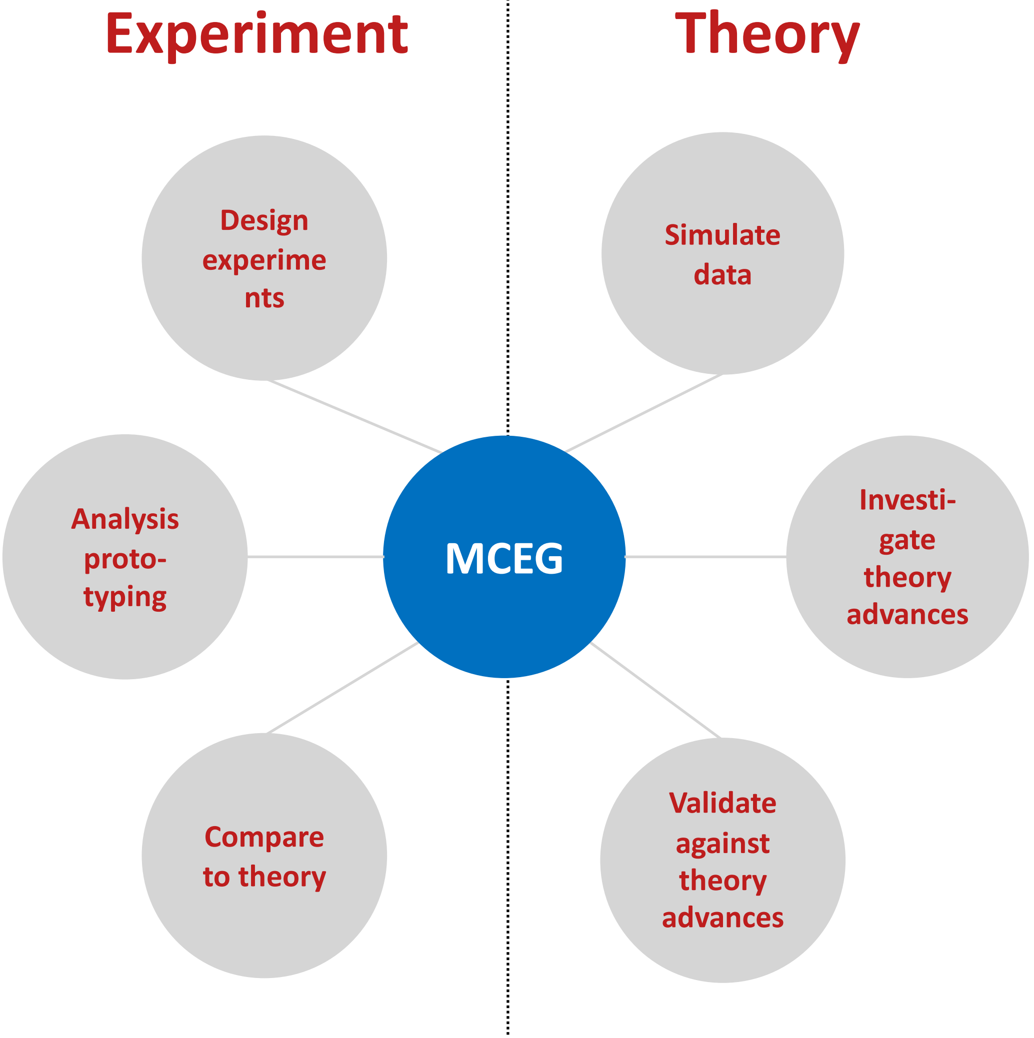
- faithful representation of QCD dynamics
- based on QCD factorization and evolution equations

MCEG algorithm

1. Generate kinematics according to fixed-order matrix elements and a PDF.
2. QCD Evolution via parton shower model (resummation of soft gluons and parton-parton scatterings).
3. Hadronize all outgoing partons including the remnants according to a model.
4. Decay unstable hadrons.



MCEG in Experiment and Theory



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

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MCEGs and PDFs

- **Central role of PDFs in MCEGs**:
  - simulation of hard processes
  - parton showers
  - multiple parton interactions

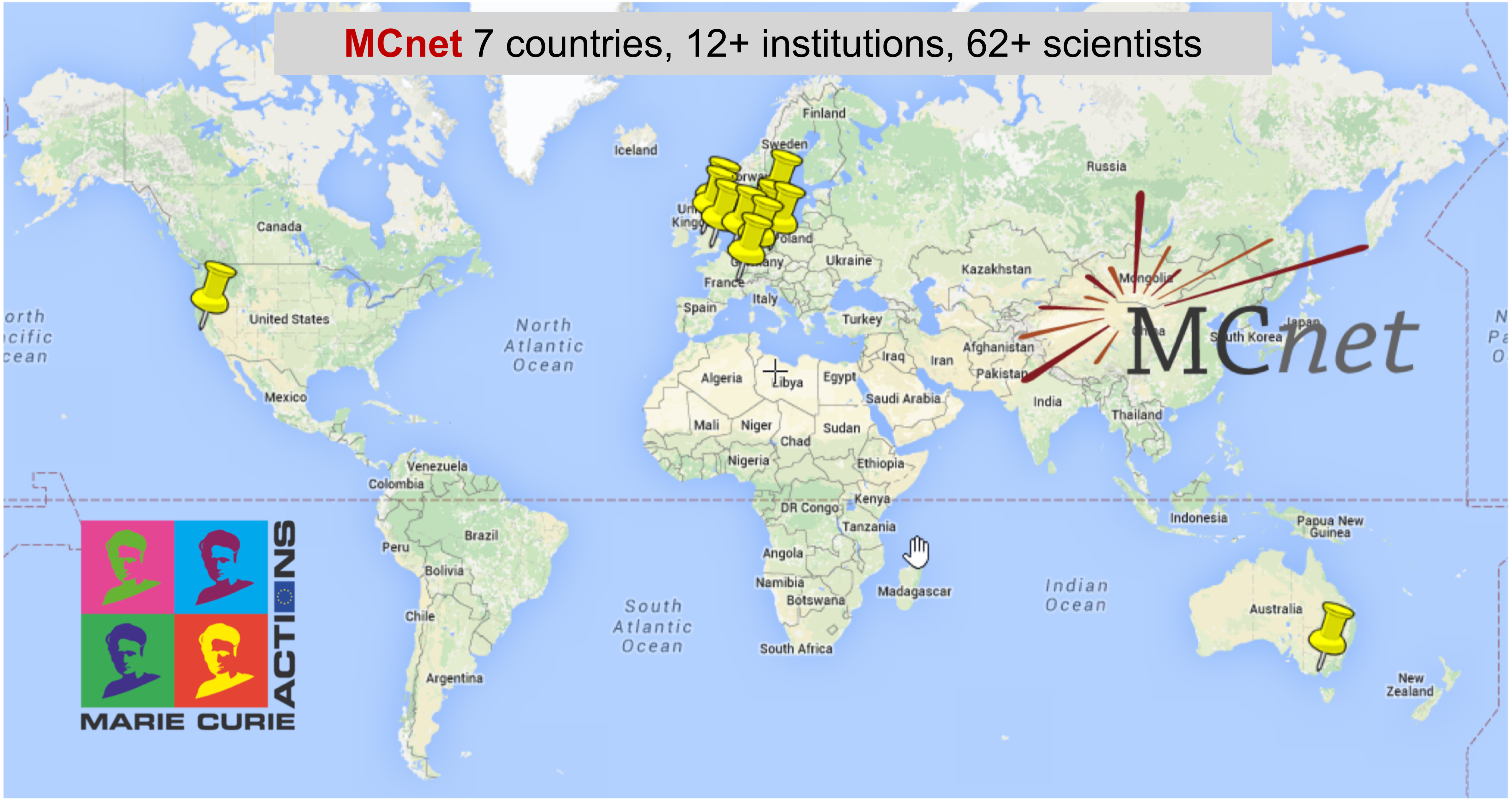
- Choice of PDF set influences both cross section and event shapes

- HEP precision tests of QCD:
  - comparisons with NLO matrix elements convoluted with NLO PDFs

- Older LO MCEGs require LO PDFs

- Also required for future MCEGs: nuclear PDFs, TMDs, nuclear TMDs

MCEG Developers



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Workshops: MCEGs for future ep and eA facilities

MCEG2018 19–23 March 2018

- Started as satellite workshop during POETIC-8

P O E T I C 8
8th International Conference on Physics Opportunities at an ElecTron-Ion-Collider
19-23 March 2018, University of Regensburg

- Collaboration EICUG-MCnet

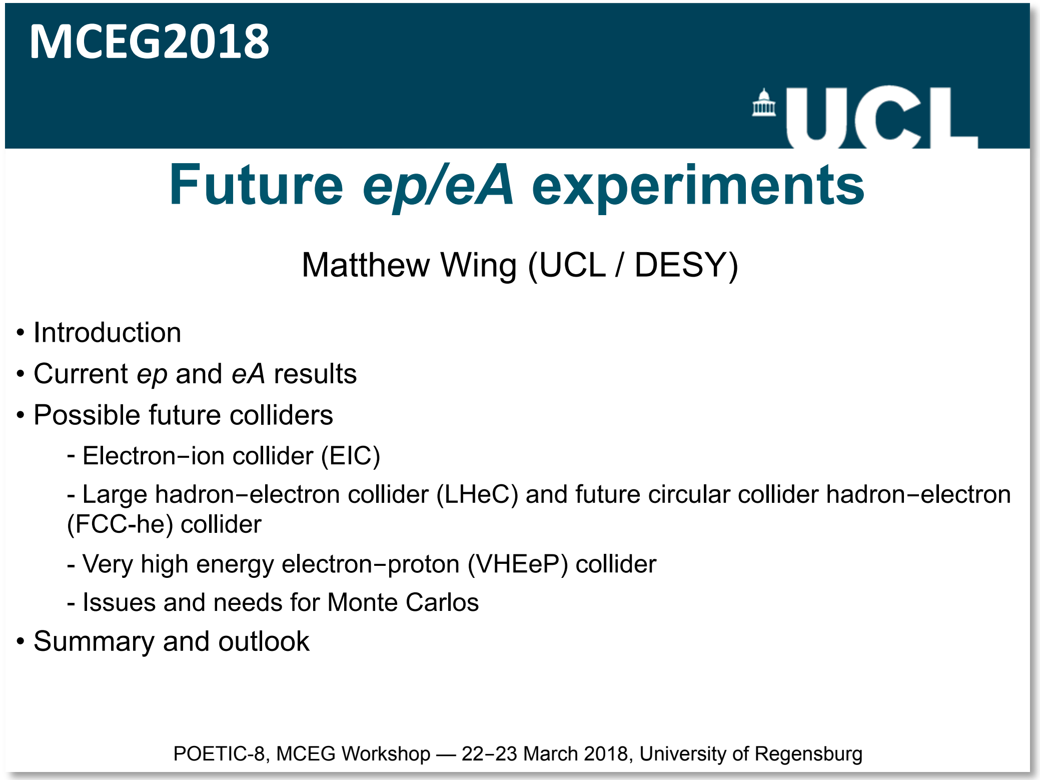
Goal of workshop series

- Requirements for MCEGs for ep and eA
- R&D for MCEGs for ep and eA

MCEG2019 20–22 February 2019

- Status of ep and eA in general-purpose MCEG
- Status of NLO simulations for ep
- TMDs and GPDs and MCEGs
- Merging QED and QCD effects

MCEG2018 – Keynote presentations



- MCEG not about tuning but about physics
- multi-leg NLO matching with parton showers
- ready to work on ep/eA

MCEG approaches

Copied from L. Lönnblad's keynote

Matching and merging

- A fixed-order matrix element (ME) generator gives the first few orders in α_s exactly.
- The parton shower gives approximate (N)LL terms to all orders in α_s through the Sudakov form factors.

Basic idea

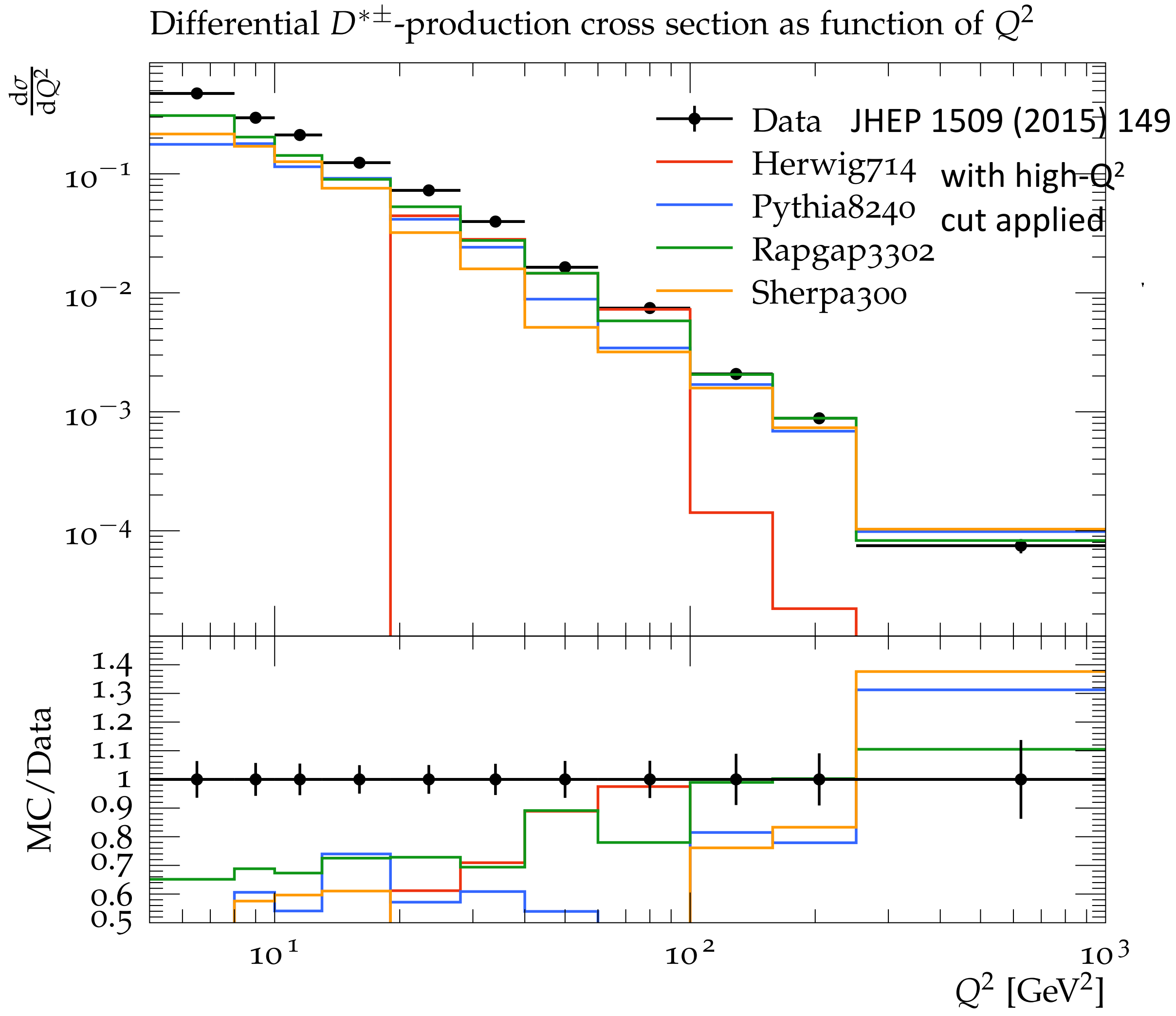
- Take a parton shower and correct the first few terms in the resummation with (N)LO ME.
- Take events generated with (N)LO ME with subtracted parton shower terms. Add parton shower.
- Take events samples generated with (N)LO ME, reweight and combine with parton showers.

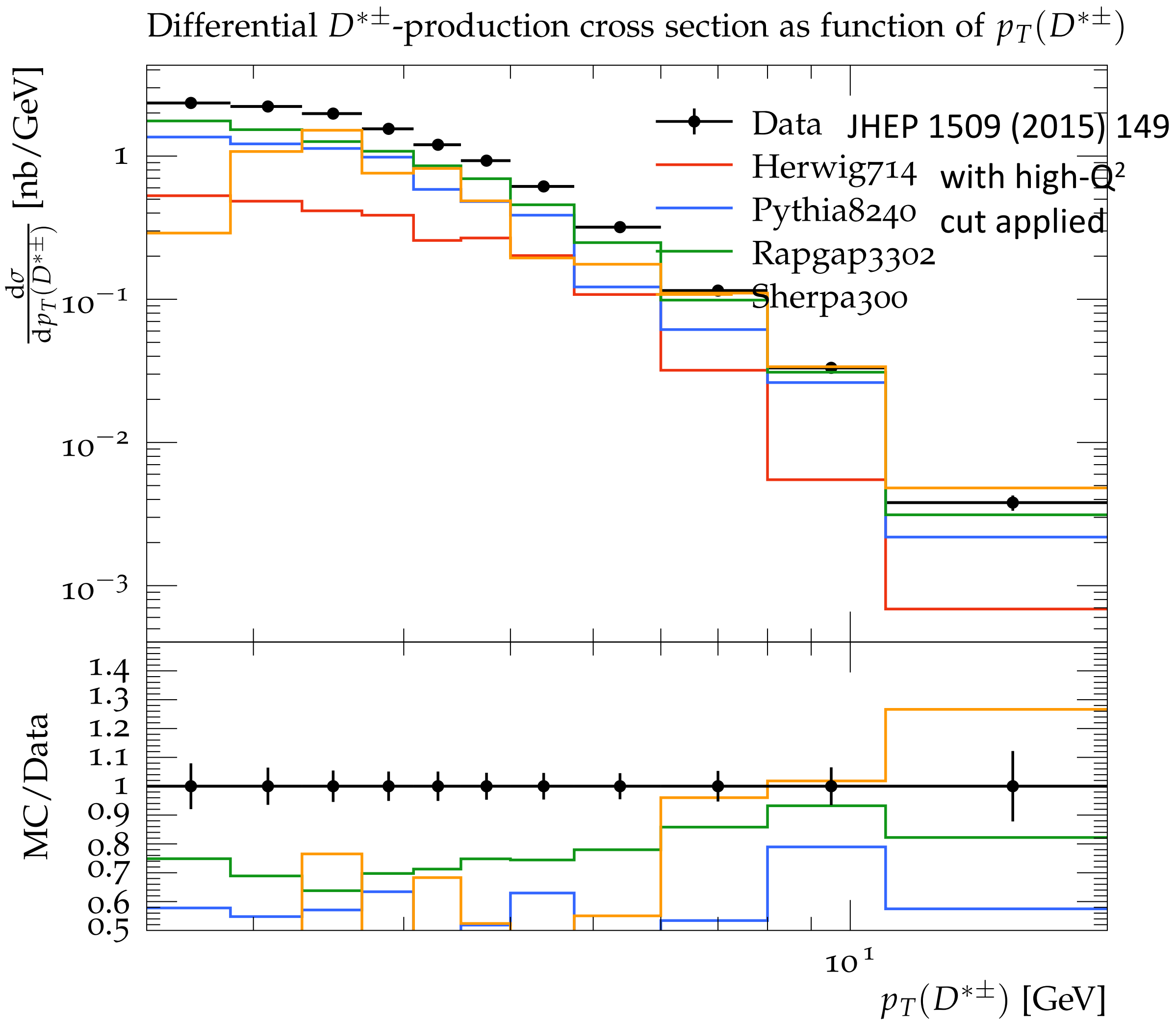
Tree-level merging

- Combines samples of tree-level (LO) ME-generated events for different jet multiplicities. Reweights with proper Sudakov form factors (or approximations thereof).
- Needs a merging scales to separate ME and shower region and avoid double counting. Only observables involving jets above that scale will be correct to LO.

Comparisons to combined H1 and ZEUS analysis

A. Verbytskyi (MPI Munich)





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Pythia (1978 – now)

General-purpose MCEG

- extensively used for e^+e^-, ep and pp physics, e.g. at LEP, HERA, Tevatron, and LHC
- as a building block used in heavy-ion and cosmic-ray physics
- recent pA effort in Pythia8 with Angantyr model

Pythia 6 product of over thirty years of progress

Pythia 8 successor to Pythia 6, standalone generator, but several optional hooks for links to other programs are provided

MCEG2018 and **MCEG2019**

ep in Pythia 8

POETIC-8 Satellite Workshop on Monte Carlo Event Generators

Ilkka Helenius

March 23rd, 2018

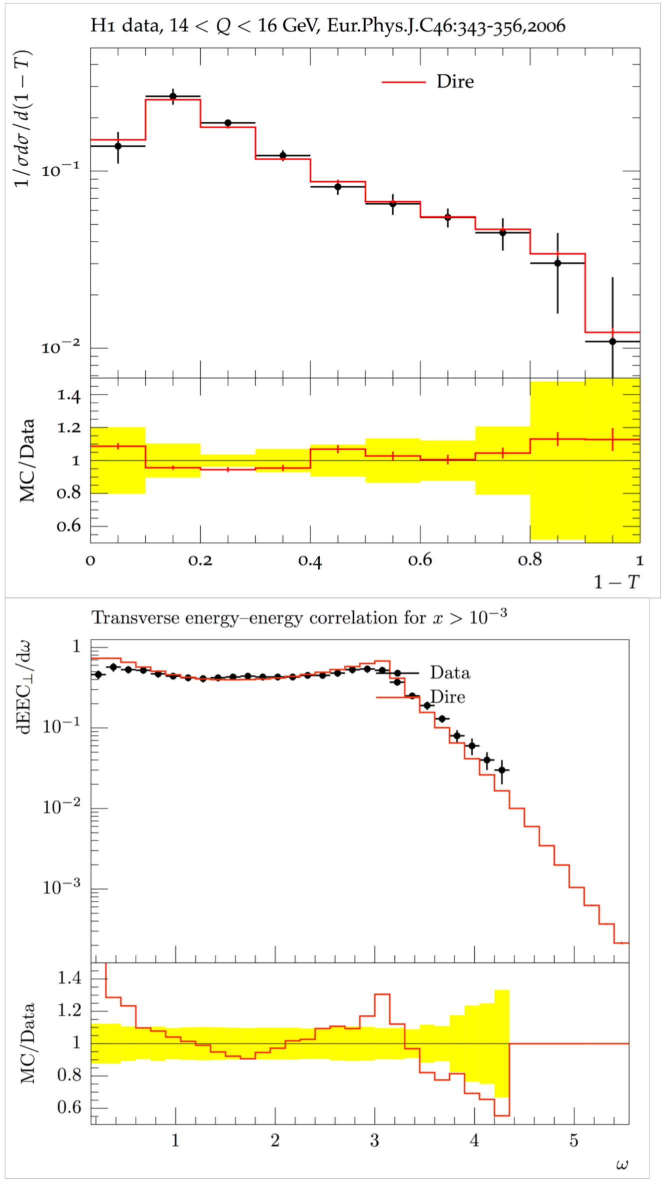
Tübingen University
Insititute for Theoretical Physics

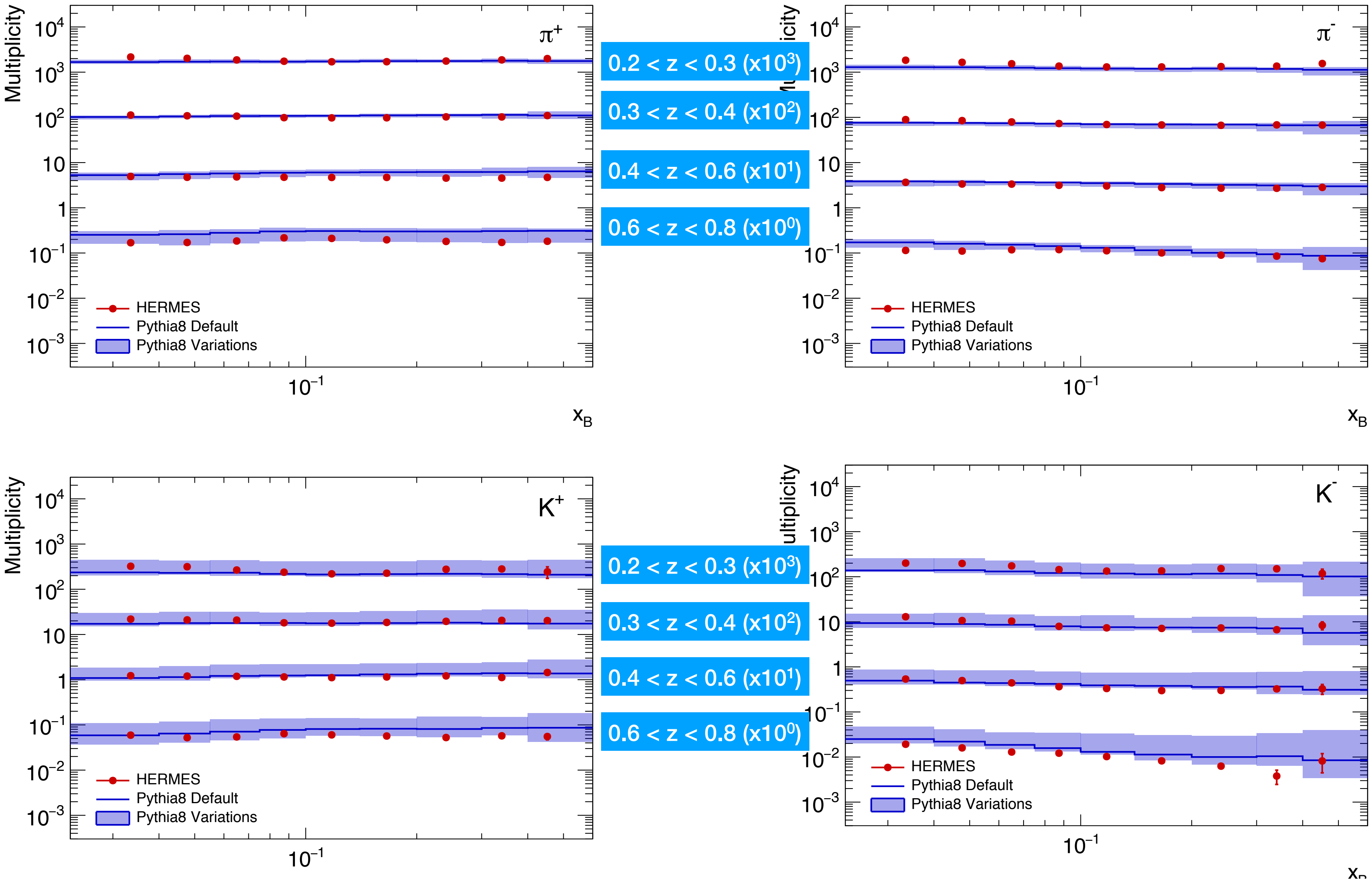
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

- possible to generate DIS events with the new dipole shower implementation
- higher-order corrections via Dire plugin, soon part of Pythia core
- photoproduction for hard and soft QCD processes, also hard diffraction

DIS in Pythia8

JLAB LDRD





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Getting started with Pythia8

JLAB LDRD

Container for Pythia8+DIRE by Nadine Fischer (Pythia)

jupyter README 8 minutes ago Logout

File Edit View Language Plain Text

```
Welcome to the Jupyter notebooks for Pythia 8 and DIRE!


You have the choice to run the following notebooks:

pythiaPI.ipynb
  Gives a basic idea of the Pythia 8 event generator, by using the Python
  interface of Pythia 8. You can adjust a set of parameters and choose
  from different different histograms to be plotted.

pythiaRivetPI.ipynb
  Shows how to use the Pythia 8 event generator, together with Rivet,
  by using the Python interface of Pythia 8.

pythiaRivet.ipynb
  Shows how to use Pythia 8, together with Rivet, by using an already
  compiled executable called pythiaHepMC. You can adjust a set of parameters
  and a settings file is created.

pythiaRivetUS.ipynb
  As pythiaRivet.ipynb, but uses a prepared settings file, to be provided
  by the user.

direRivet.ipynb
  Shows how to use Pythia 8 with the DIRE parton shower, together with
  Rivet, by using the default DIRE executable. You can adjust a set of
  parameters and a settings file is created.

direRivetUS.ipynb
  As direRivet.ipynb, but uses a prepared settings file, to be provided
  by the user.

direEvent.ipynb
  Pythia 8 with the DIRE parton shower, graphical output of one event
  with the default DIRE exectuable.
  The process can be choosen as well as a few basic parameters.

tuning.ipynb
  Tuning with Professor, Rivet, and Pythia 8 / DIRE.
```

Jupyter notebook interface

Pythia 8 standalone

This notebook gives a basic idea of the Pythia 8 event generator, by using the Python interface of Pythia 8. You can adjust a set of parameters and choose from different different histograms to be plotted.

First, lets import all neccessary modules.

In [1]:
```
import os, sys, pythia8
from plotting import MULTHIST
import py8settings as py8s
```

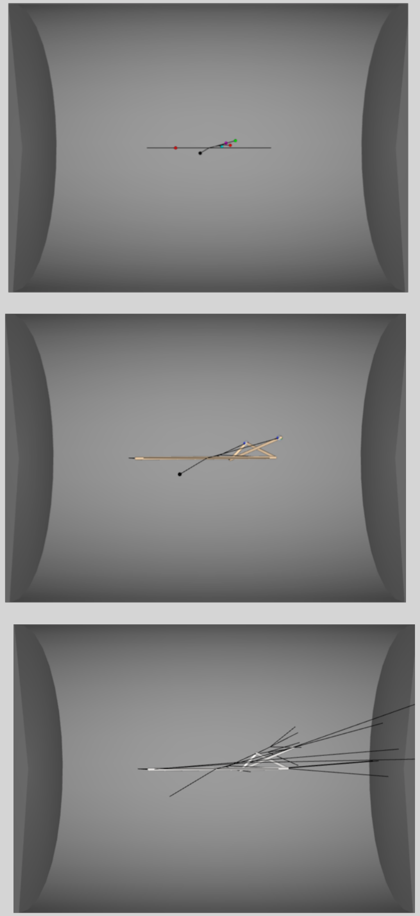
Now we create a Pythia 8 object and apply the settings to define the incoming beams. More settings can be adjusted later.

In [2]:
```
# Setup pythia, apply beam settings.
pythia = pythia8.Pythia()
py8s.beam_settings(pythia)
```

You can now set the parameters for the incoming beams:

beam A id [Beams:idA]	e-
beam B id [Beams:idB]	p
beam frame type [Beams:frameType]	2: back-to-back beams with different energies, set Beams:eA and Beams:eB
CMS energy for Beams:frameType = 1 [Beams:eCM]	65.7
beam A energy for Beams:frameType = 2 [Beams:eA]	10.8
beam B energy for Beams:frameType = 2 [Beams:eB]	100

Visualization of ep collision



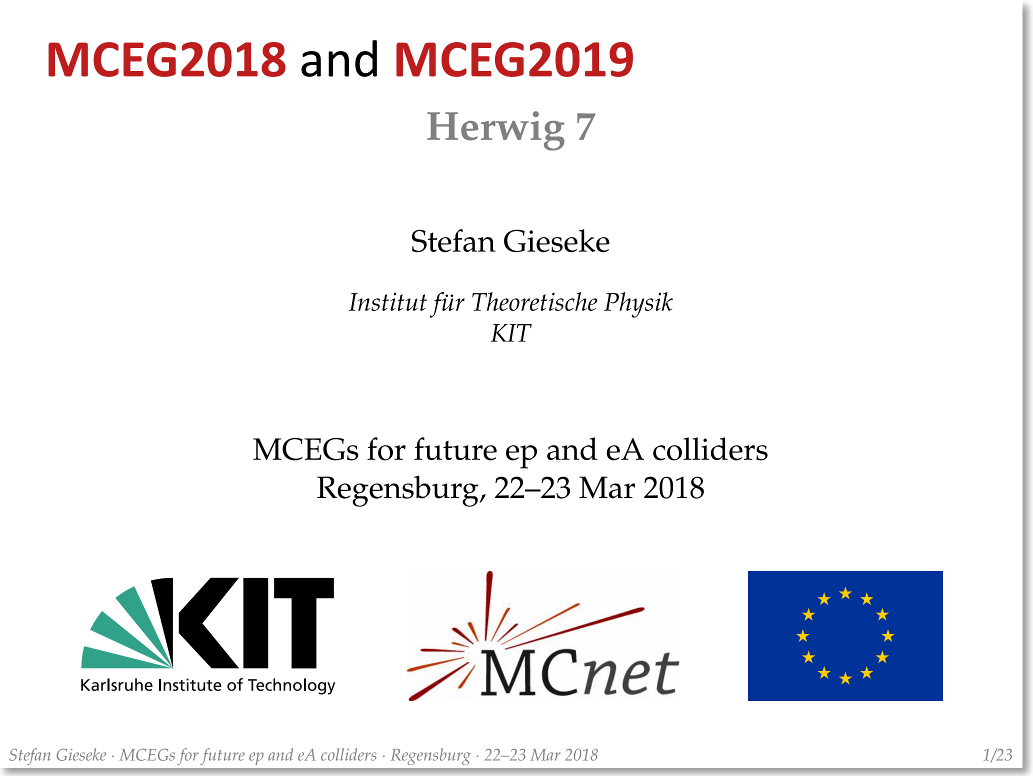
Hadron Emission Reactions With Interfering Gluon (1986 – now)

General-purpose MCEG

- developed throughout the era of LEP
- introduced cluster hadronization model

Distinctive features

- automatic generation of hard processes and decays with full spin correlations for many BSM models
- completely generic matching and merging
- hard and soft multiple partonic interactions to model the underlying event and soft inclusive interactions
- sophisticated hadronic decay models, e.g., for bottom hadrons and τ leptons.



- two shower options with spin correlations and NLO matching
- good description for single-particle properties in DIS
- also QED radiation for angular-ordered shower

Simulation of High Energy Reactions of PArticles (2004 – now)

General-purpose MCEG
- e^+e^-, ep and pp physics , e.g. at LEP, HERA, Tevatron, and LHC
- also eγ and $\gamma\gamma$ physics

Modular MCEG (C++ from the beginning)
- full simulation is split into well defined event phases, based on QCD factorization theorems
- each module encapsulates a different aspect of event generation for high-energy particle reactions

Versatile MCEG
- automated generation of tree-level matrix elements
- two fully-fledged matrix element generators with highly advanced phase-space integration methods

MCEG2018 and **MCEG2019**

- DIS with ME corrections and PS merging
- good description of jet data at low Q^2 with $\gtrsim 3$ partons in the final state
- automated NLO matching with Powheg method, applicable for jets at high-Q^2

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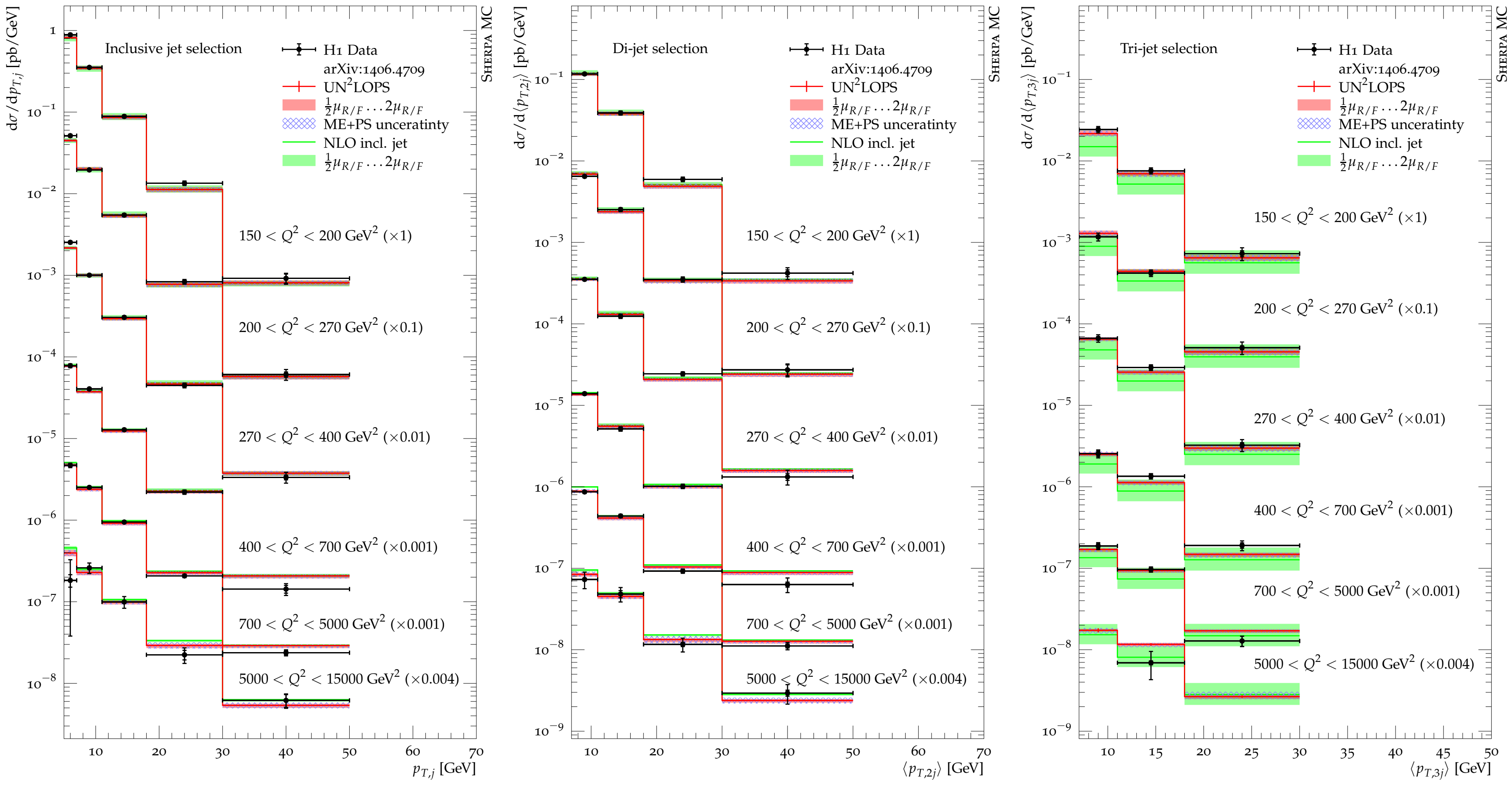
Sherpa NNLO particle-level simulation vs. H1 high-Q^2 data

Slide prepared by S. Hoeche (SLAC)

[Höche,Kuttimalai,Li] arXiv:1809.04192



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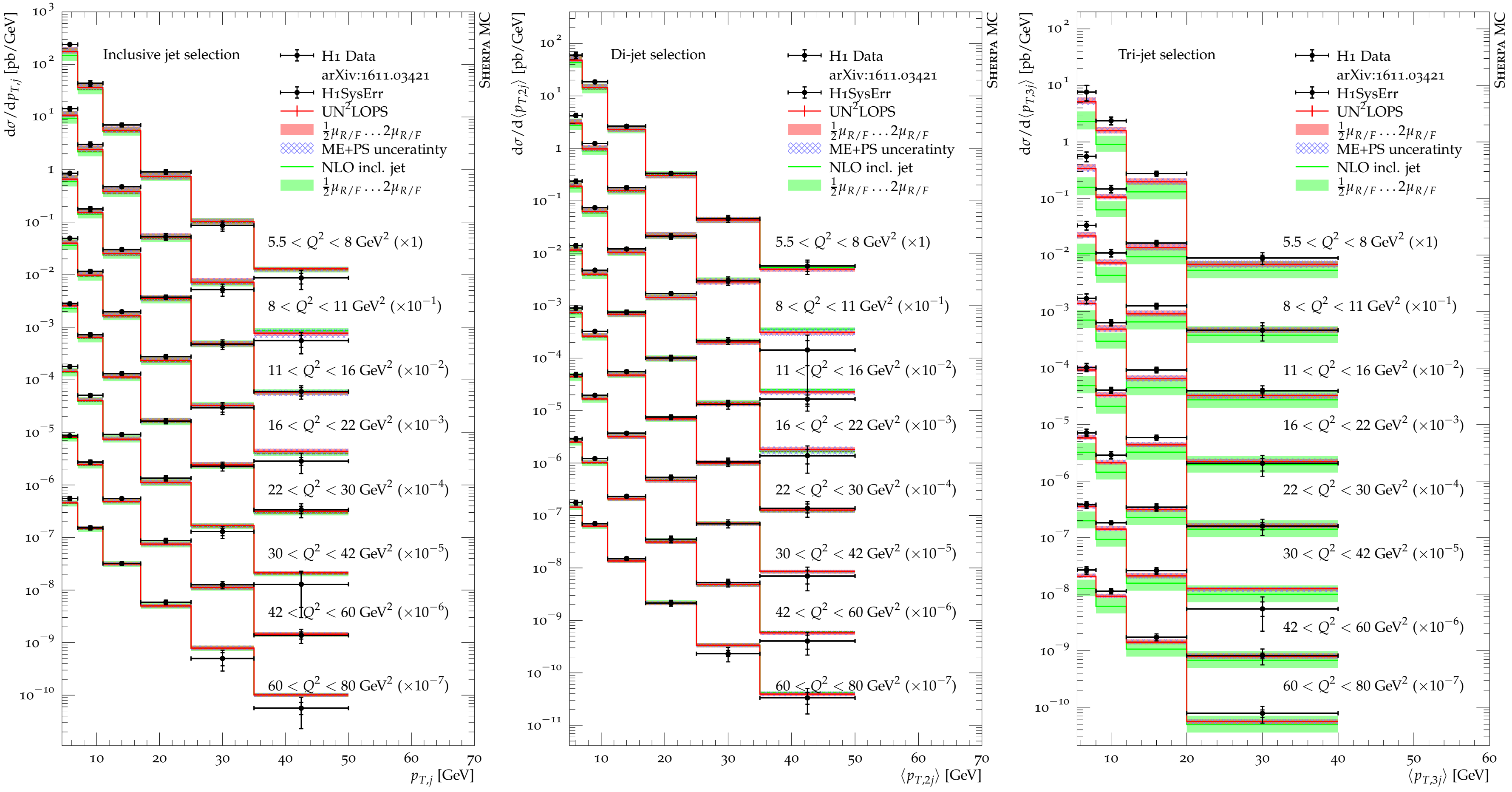
Sherpa NNLO particle-level simulation vs. H1 low-Q^2 data

Slide prepared by S. Hoeche (SLAC)

[Höche,Kuttimalai,Li] arXiv:1809.04192



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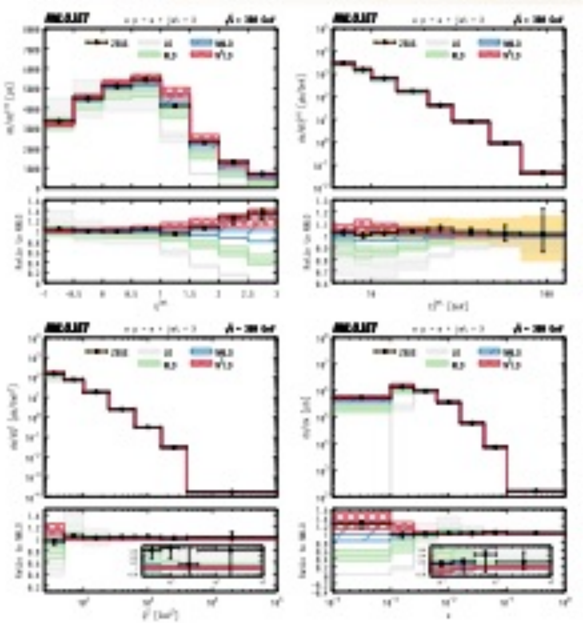
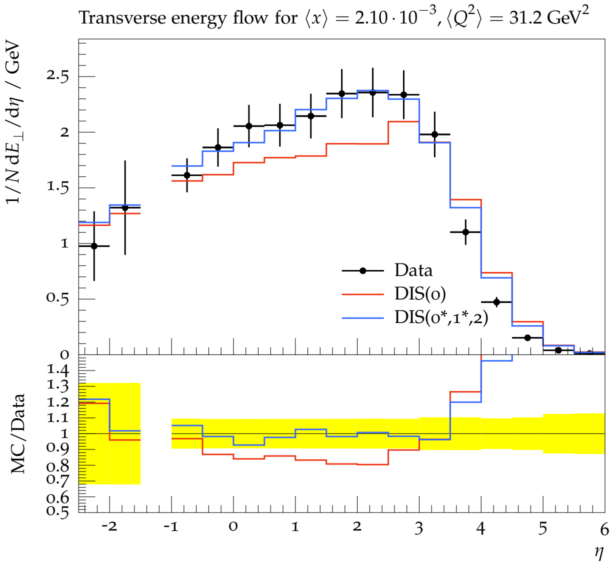


arXiv:1803.09973



Fixed-order QCD

- QCD calculations available up to N^{3}LO for inclusive DIS
- Peculiarities of DIS require careful selection of scales
- Excellent description of experimental data from HERA

MC event simulation

- DIS simulations available in all three event generation frameworks
- NLO matching & merging standard, NNLO matching available
- Peculiarities of DIS require careful selection of clustering history
- Very good description of wide range of experimental data

MCEG–HERA comparisons and MCEG validation for ep

Rivet example

SIDIS analysis at HERMES

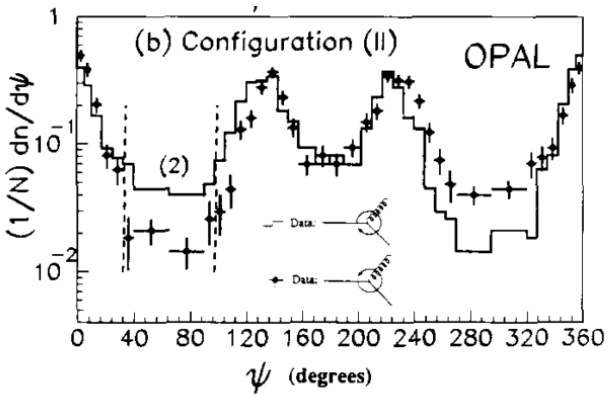
```
// Extract the particles other than the lepton
const FinalState& fs = apply<FinalState>(event, "FS");
Particles particles;
particles.reserve(fs.particles().size());
const GenParticle* dislepGP = dl.out().genParticle();
foreach (const Particle& p, fs.particles()) {
  const GenParticle* loopGP = p.genParticle();
  if (loopGP == dislepGP)
    continue;
  particles.push_back(p);
}

// Apply HERMES cuts.
bool validx = (x > 0.023 && x < 0.6);
if (q2 < 1. || w2 < 10. || y < 0.1 || y > 0.85 || !validx)
  vetoEvent;

// good inclusive event, let's do bookkeeping before we look at the hadrons
dis_tot += weight;
dis_x->fill(x, weight);
dis_Q2->fill(q2, weight);

for (size_t ip1 = 0; ip1 < particles.size(); ++ip1) {
  const Particle& p = particles[ip1];

  // get the particle index, check if it is a particle of interest
  const int part_idx = get_index(p.genParticle()->pdg_id());
  if (part_idx < 0) {
    continue;
  }

  // we have a particle of interest, let's calculate the kinematics
  // z
  const double z = (p.momentum() * pProton) / (pProton * q);
  // pt
  const double pth = sqrt(p.momentum().pT2());

  // get our z index, if negative, we have a particle outside of [.2, .8]
  const int z_idx = calc_zslice(z);
  if (z_idx < 0) {
    continue;
  }

  // store the events and make cuts where necessary
  //
  // pt cut for variables not binned in pt
  if (pth > 0 && pth < 1.2) {
    mult_z[part_idx]->fill(z, weight);
    mult_zx[part_idx][z_idx]->fill(x, weight);
    mult_zQ2[part_idx][z_idx]->fill(q2, weight);
  }
  mult_zpt[part_idx][z_idx]->fill(pth, weight);
}
```

- **MCEG R&D** requires *easy* access to *data*
- data := analysis description + data points
- **HEP** existing workflow for MCEG R&D using tools such as Rivet and Professor
- **Detailed comparisons between modern MCEG and HERA data**
  - workshop on Rivet for ep (Feb 18—20 2019)
  - mailing list rivet-ep-l@lists.bnl.gov
  - HERA data not (yet) included in MCEG tunes

Understanding the hadronization process

LUND String Model for hadronization (1977 – *now*)

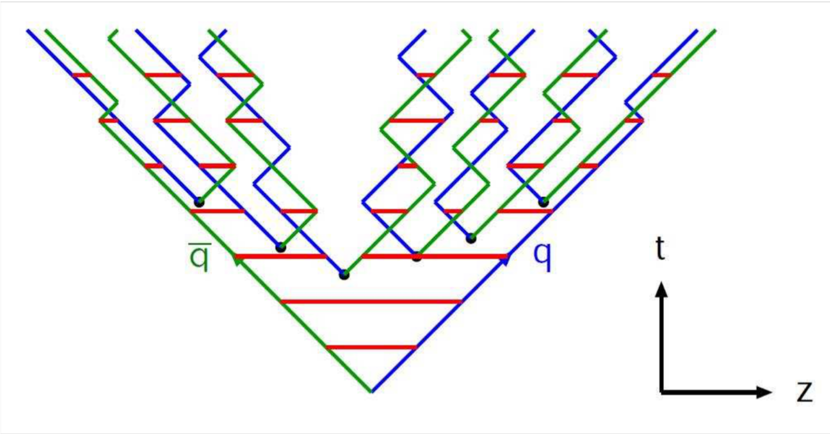
- simple but powerful phenomenological model
- no (promising) new hadronization models in last 40 years
- **LDRD project at Jefferson Lab**
  - review
  - connect with modern QCD, including TMD and spin effects



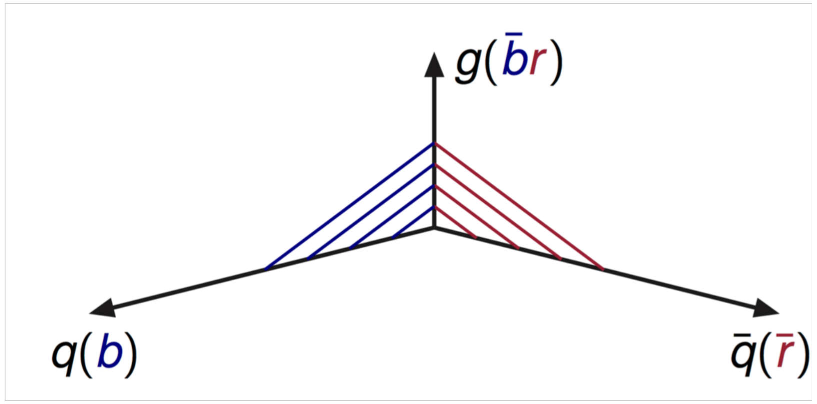
evidence of string effects

particle flow asymmetry at OPAL

String breakup



String drawing



TMDs and MCEGs

Vibrant community

MCEG Workshop
DESY, February 2019

F Hautmann
TMDs from Parton Branching

First all flavor. all Q^2, all x and all k_t TMD at NLO determined.

- Introduction
- The Parton Branching (PB) method
- New results and applications

F Hautmann: MCEG Workshop, DESY - February 2019 1

TMD and parton shower: CASCADE-3

Hannes Jung (DESY)

with contributions from
A. van Hameren, K. Kutak, A. Kusina,
A. Bermudez Martinez, P. Connor F. Hautmann, O. Lelek, R. Zlebcik

- From inclusive to exclusive distributions
  - Parton Branching method for TMDs

First TMD parton shower using higher order splitting function.

H. Jung, TMD and Parton Shower CASCADE3 , MCEG for future ep facilities, Hamburg, Feb 2019 1

NCN

nTMD using PB method

Krzysztof Kutak

Instytut Fizyki Jądrowej
im. Henryka Niewodniczańskiego
Polskiej Akademii Nauk

First all Q^2, all x, all k_t TMD at NLO for nuclei. Comparison with DY data (pp, pPb, CMS)

Updates for KaTie

Andreas van Hameren
Institute of Nuclear Physics
Polish Academy of Sciences
Kraków

presented at the
MCEGs for future ep and eA facilities
21-02-2019, DESY, Hamburg

First ever off-shell hard process calculation for ep including all flavors.

Lively discussion: Factorization Theorem and MCEG approaches

To what extent are TMDs a result of a coherent branching evolution as, e.g., implemented in Herwig

Next: Comparison to TMD theory

Extract TMD from the different MCs and compare to analytic results.

UNIVERSITÀ
DEGLI STUDI DI TRIESTE

INFN
Istituto Nazionale di Fisica Nucleare

21st February 2019,
DESY,
Hamburg

Revisited version of a recursive model for the fragmentation of polarized quarks

Albi Kerbizi
University of Trieste, Trieste INFN Section

Lund string + 3P0; good description of Collins and di-hadron asymmetries; Boer-Mulders, jet handedness can be simulated.

CASCADE

CASCADE

Eur. Phys. J. C (2010) 70: 1237–1249
DOI 10.1140/epjc/s10052-010-1507-z

THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

The CCFM Monte Carlo generator CASCADE Version 2.2.03

H. Jung[1,2,a], **S. Baranov**[3], **M. Deak**[4], **A. Grebenyuk**[1], **F. Hautmann**[5], **M. Hentschinski**[1], **A. Knutsson**[1], **M. Krämer**[1], **K. Kutak**[2], **A. Lipatov**[6], **N. Zotov**[6]

[1]DESY, Hamburg, Germany
[2]University of Antwerp, Antwerp, Belgium
[3]Lebedev Physics Institute, Moscow, Russia
[4]Instituto de Física Teórica UAM/CSIC, University of Madrid, Madrid, Spain
[5]University of Oxford, Oxford, UK
[6]SINP, Moscow State University, Moscow, Russia

Abstract CASCADE is a full hadron level Monte Carlo event generator for ep, γp and $p\bar{p}$ and pp processes, which uses the CCFM evolution equation for the initial state cascade in a backward evolution approach supplemented with off-shell matrix elements for the hard scattering. A detailed program description is given, with emphasis on parameters the user wants to change and common block variables which completely specify the generated events.

TMDs from parton branching and parton showers in MC event generators

MCEG2018

Hannes Jung (DESY)
in collaboration with
A. Bermudez-Martinez, F. Hautmann, A. Lelek, V. Radescu, R. Zlebcik
M. Bury, A. van Hameren, K. Kutak, S. Sapeta, M. Serino

- Why TMDs are needed
  - TMDs for hadron-hadron collisions
- New developments
  - parton branching algorithm to solve evolution equations
    - benchmark tests
    - advantages for integrated PDFs
  - determination of TMD densities at NLO with xFitter
- Application to DY production
- Application to TMD parton showers

H. Jung, MDs from parton branching and parton showers in MC event generators, POETIC2018 MC satellite WS, Regensburg, March 22, 2018 1

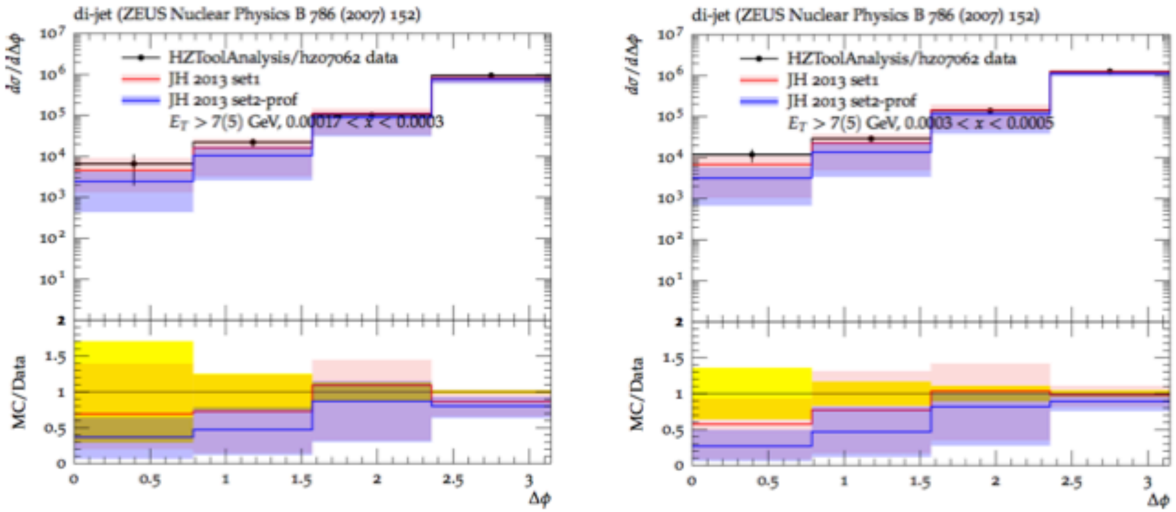
CCFM evolulution
- BFKL variant including large x
- √s >> M

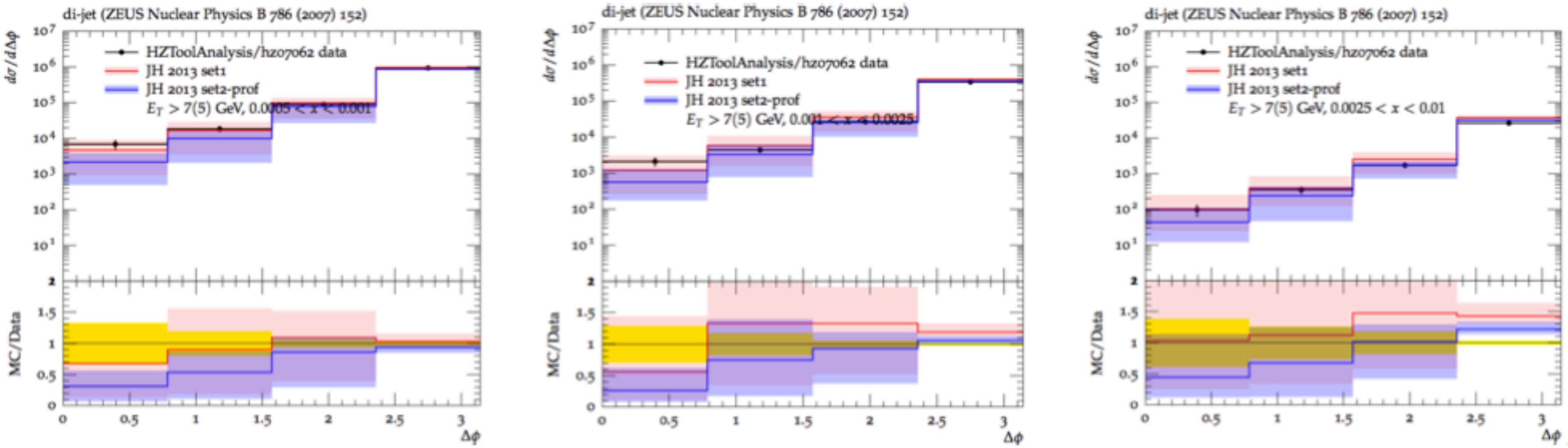
Parton Branching
- evolution equation, connected in a controllable way with DGLAP evolution of collinear PDF
- applicable over broad kinematic range from low to high k_T,

DIS dijet azimuthal distribution from CASCADE

Slide prepared by F. Hautmann (University of Oxford)

- CASCADE with TMD pdfs from precision F2 and F2-charm data
- ZEUS 2007 jet measurements

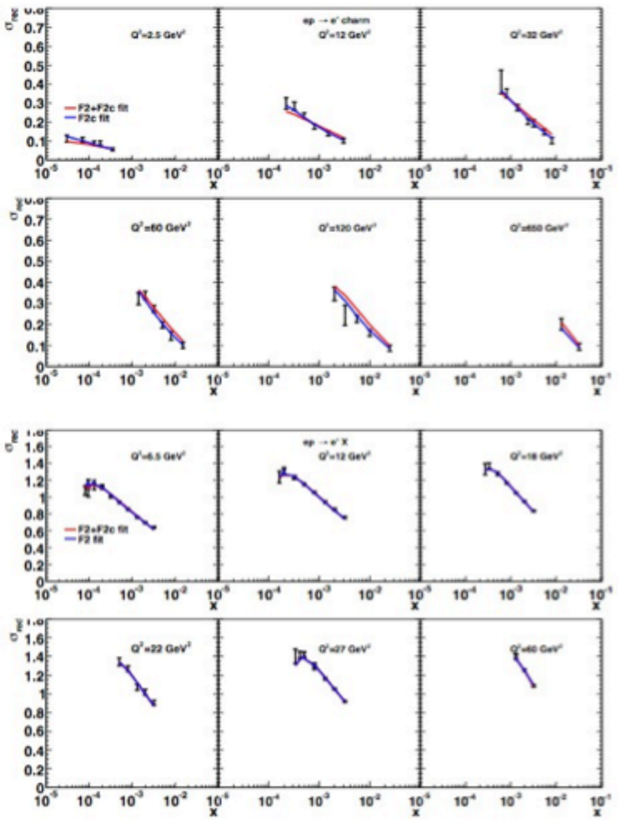




Jefferson Lab

Gluon TMDs from precision DIS data using CCFM evolution

Slide prepared by F. Hautmann (University of Oxford)



[Hautmann and Jung,
Nucl. Phys. B 883 (2014) 1]

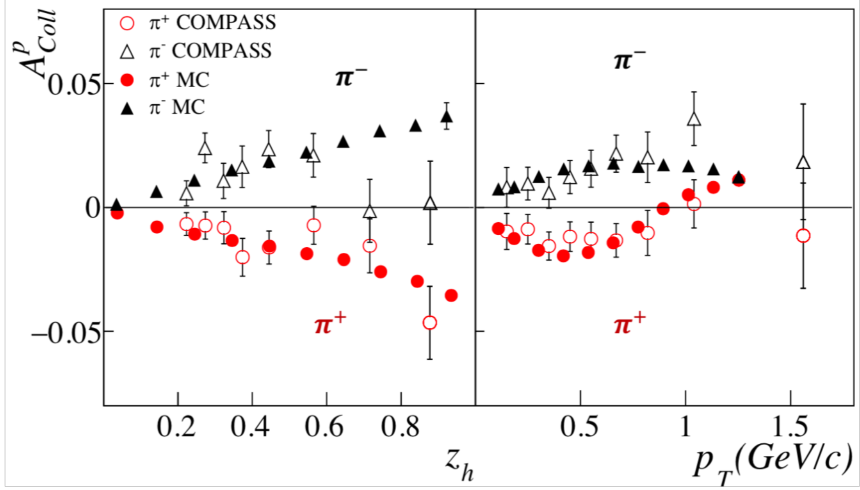
- Good description of inclusive DIS data with TMD gluon
- Sea quark yet to be included at TMD level
- Uses uPDFevolv evolution code arXiv:1407.5935 [hep-ph]
- Fit performed with xFitter arXiv:1410.4412 [hep-ph]

	$\chi^2/ndf\,(F_2^{(\mathrm{charm})})$	$\chi^2/ndf\,(F_2)$	$\chi^2/ndf\,\left(F_2 \text{ and } F_2^{(\mathrm{charm})}\right)$
3-parameter	0.63	1.18	1.43
5-parameter	0.65	1.16	1.41

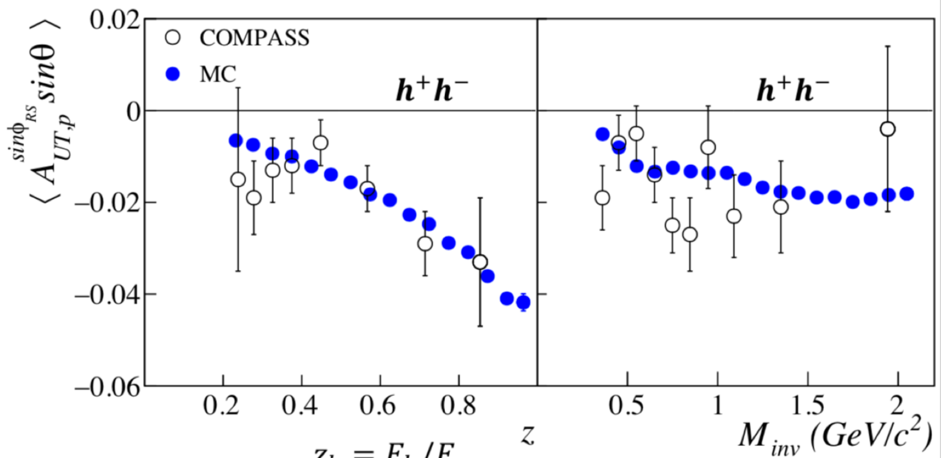
Recursive model for the fragmentation of polarized quarks

Albi Kerbizi (Trieste)

COMPASS Collins SSA



COMPASS di-hadron asymmetry



$z_h = E_h/E_{q_A}$

$z = z_{h^+} + z_{h^-}$

- The string + $^3P_0$ model for pseudo-scalar meson emission has been implemented in a stand alone MC code
- The comparison with experimental data on Collins and di-hadron asymmetries is very promising
- Other effects like Boer-Mulders or jet-handedness can be simulated

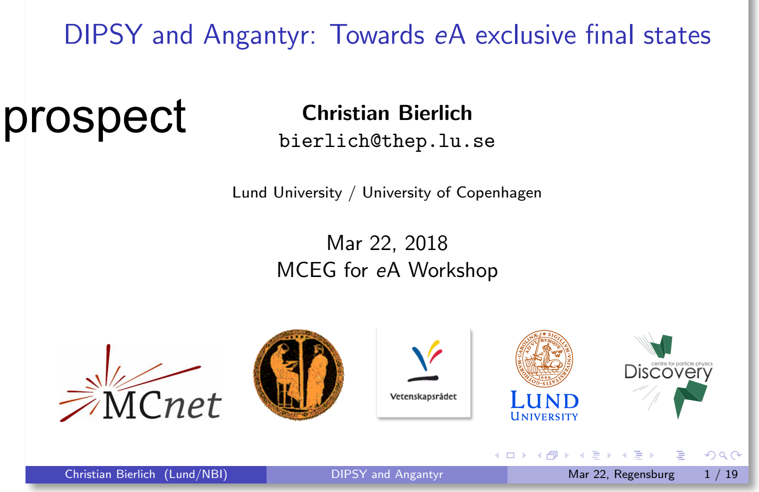
- The same results can be obtained with different choices for the $\breve{g}$ function acting on the spin-independent correlations between quark transverse momenta
- The choice $\breve{g} = 1/\sqrt{N_a(\varepsilon_h^2)}$ guarantees again LR symmetry and allows to simplify
  - the formalism and the analytical calculations
  - **the improvement of the simulations (i.e. adding vector mesons) → ongoing**
  - **the interface with external event generators and in particular with PYTHIA → ongoing**

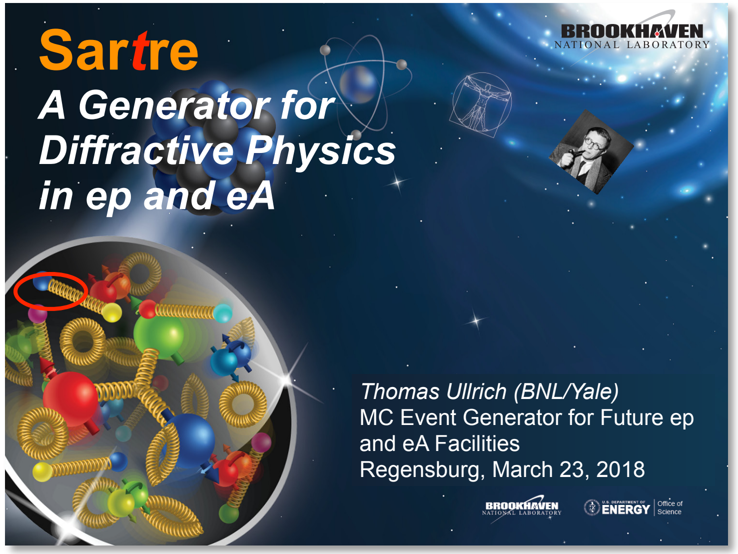
2019)

MCEG2018 – eA

γ*A pA, AA

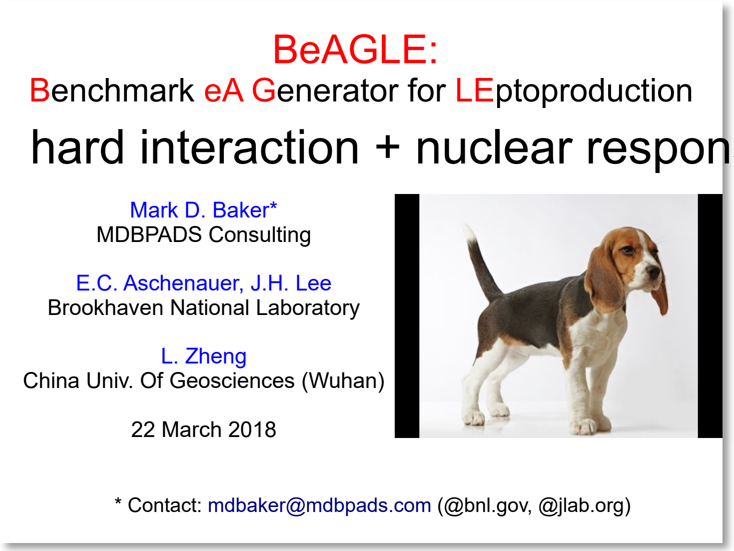
eA: interesting prospect



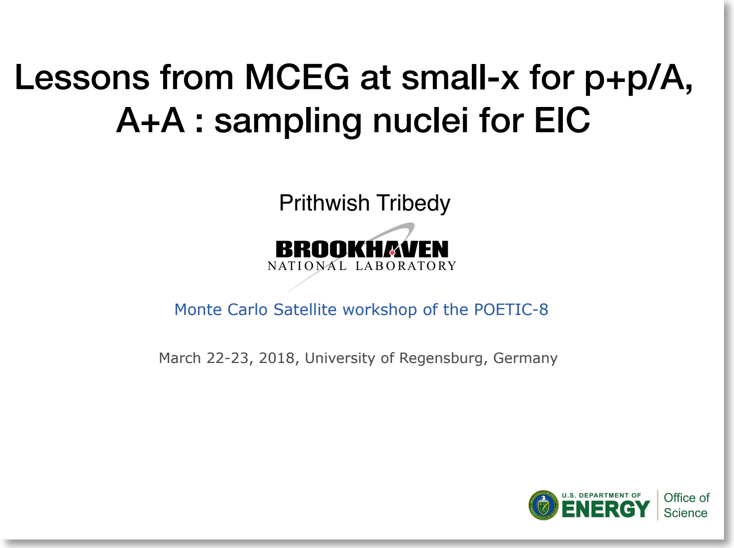


collaborate with BeAGLE

hard interaction + nuclear response



CGC + Pythia6



MCEG2018 Benchmark eA Generator for LEptoproduction

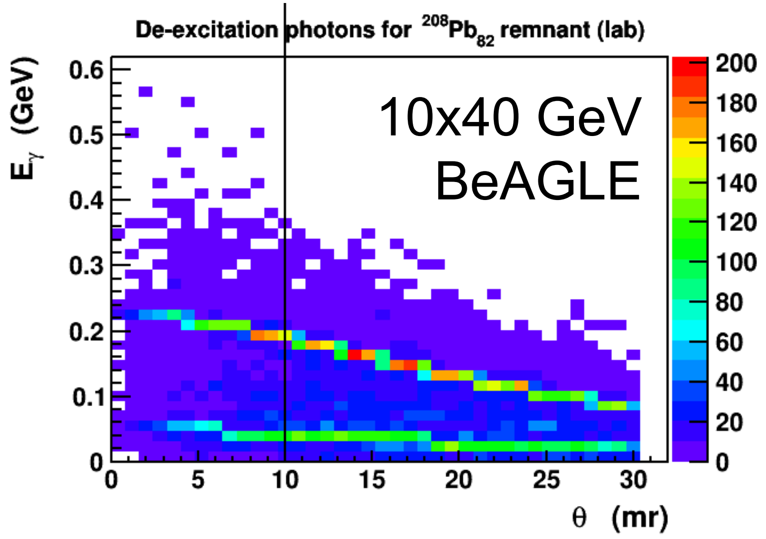
Slide prepared by M. Baker

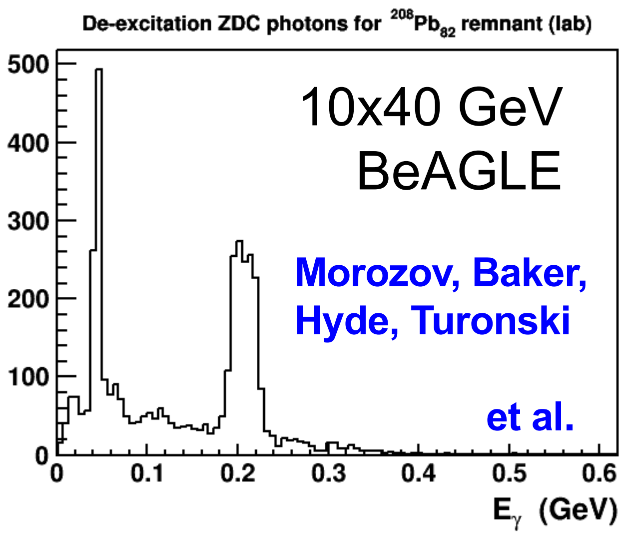
- E.Aschenauer, M.D.Baker, J.H.Lee, L.Zheng (+PyQM+DPMJET+Fluka+…)
- Contact: mdbaker @mdbpads.com,@jlab.org, @bnl.gov
- Merger of
  - Pythia6: hard interaction (adding RAPGAP option)
  - Glauber + multinucleon shadowing
  - PyQM: Optional radiative jet quenching
  - DPMJET3-F (DPMJET3+Fluka) – nuclear response
- Tuned to ZEUS forward nucleons, FNAL E665 (FixTarg) slow neutrons, + HERMES
  - Working on E665 e-by-e charged hadrons (SC)

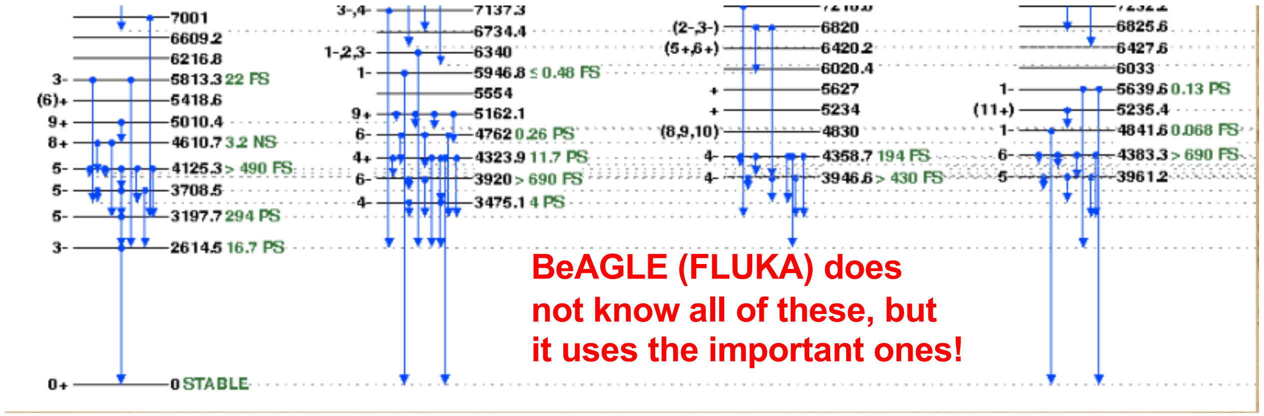
Simulation challenge in eA: Nuclear detail

Slide prepared by M. Baker

One example: de-excitation photons from $^{208}Pb_{82}$ following
$e+Pb \rightarrow e'+Pb^{*}+J/\psi \rightarrow e'+Pb+\gamma+\gamma+\gamma+J/\psi$ in (collider) lab frame







BeAGLE (FLUKA) does
not know all of these, but
it uses the important ones!

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Simulation challenge in eA: Nuclear PDF issues

Slide prepared by M. Baker

- Pythia 6 issue: NLO vs. LO for $R^{(A)}(x,Q^2)$.
  - Using LO w/ running α_s (e.g. CTEQ6L1) for ep to match Pythia 6 processes.
  - But many latest $R^{(A)}(x,Q^2)$ reported only at NLO.
  - Is it kosher to multiply $R^{(A\text{-}NLO)}(x,Q^2) \bullet q^{(LO)}(x,Q^2)$?
- "Fermi"-smearing can be substantial due to short-range correlations.
  - $R(x_B,Q^2)$ isn't really diagonal in x. Especially at high x (e.g. x>1!), $q^{(A)}(x)$ is a convolution of $q^{(N)}(x')$ values with $x' \neq x$.

Merging QED and QCD effects

Classification of $O(\alpha)$ QED corrections

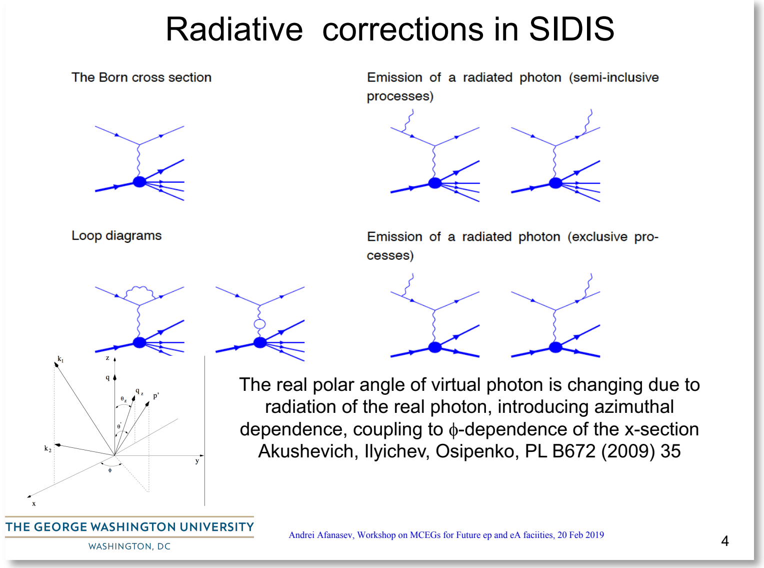
- Radiation from the lepton
  model independent (universal),
  dominating by far: enhanced by large logs, $\ln(Q^2/m_e^2)$
- vacuum polarization (boson self energy)
  universal, photon self energy ➜ $\alpha_{em}(Q^2)$
- Radiation from the hadronic initial/final state
  parton model: radiation from quarks
  to be considered as a part of the nucleon structure
- Interference of leptonic and hadronic radiation
  2γ exchange
  new structure
- purely weak corrections

Note: for NC-scattering, straightforward separation
IR divergences: need to combine real and virtual radiation

H. Spiesberger (Mainz) MCEGs, 20. 2. 2019 5 / 20

Hubert Spiesberger (Mainz): QED corrections for electron scattering

- High-precision measurements need careful treatment of radiative corrections.
- Closely related to experimental conditions need full Monte Carlo treatment (Unfolding) including simulation of hadronic final states.
- The basics are known and available …
- … but improvements are needed.



Andrei Afanasev (GWU): Semi-analytic vs. Monte-Carlo Approaches for QED Corrections to SIDIS

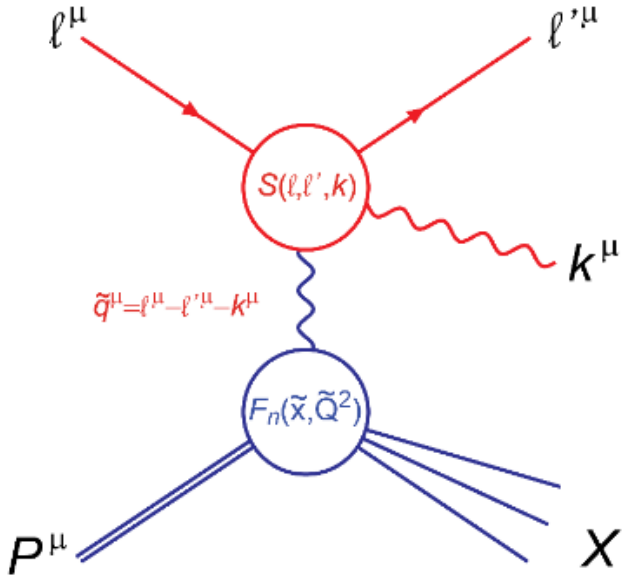
- Consistent approach to address RC for SSA in polarized SIDIS

- SSA due to two-photon exchange need to be included in analysis of SSA from strong interaction, of same size at JLAB experiments
- More detailed calculation of the two-photon exchange at quark level required: elastic scattering, inclusive, semi-inclusive, and exclusive DIS

EIC Software Consortium: Radiative Effects and MCEG

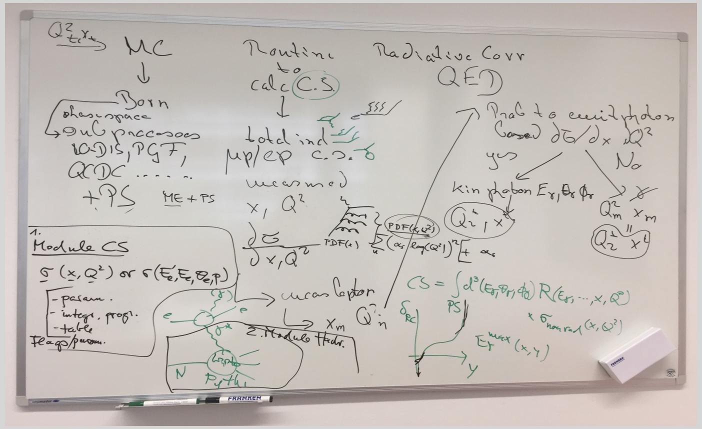
Radiative effects

- change kinematics on an event by event basis:
  - smearing of kinematic distributions
- change of virtual-photon direction:
  - false asymmetries in the azimuthal distribution of hadrons
- correction:
  - unfolding procedure, requires MCEG including radiative corrections / effects



ESC Radiative effects library

- Elke-Caroline Aschenauer, Andrea Bressan
- essential for high-precision measurements at the EIC
- collaboration with Hubert Spiesberger:
  - start back from HERACLES part of Djangoh
  - work on interface to PYTHIA6/8



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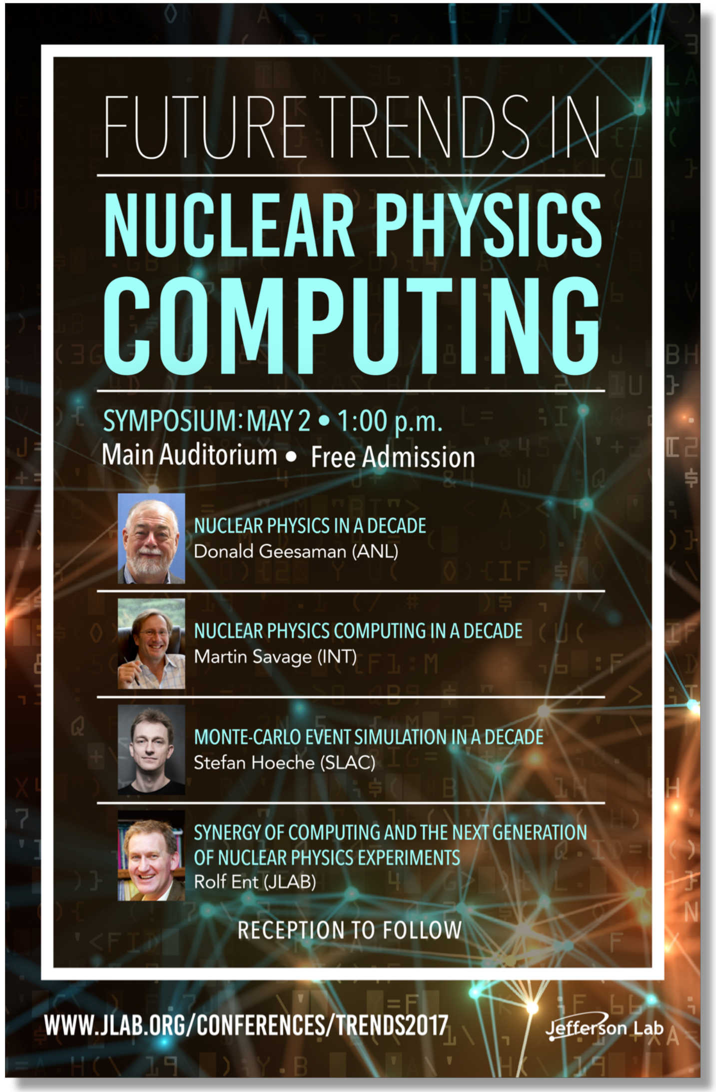
MCEG2019: Next steps

Discussion based on EIC science review by Elke-Caroline Aschenauer (BNL)

- **General-purpose MCEG**s, HERWIG, PYTHIA, and SHERPA, will be significantly improved w.r.t. MCEGs at HERA time:
  - MCEG-data comparisons in Rivet will be critical to tune the MCEGs to DIS data and theory predictions.
  - The existing general-purpose MCEG should soon be able to simulate NC and CC unpolarized observables also for eA. A precise treatment of the nucleus and its breakup is needed.
  - First parton showers and hadronization models for ep with spin effects, but far more work needed for polarized ep / eA simulations.
  - Need to clarify the details about merging QED+QCD effects (in particular for eA).
- **TMD physics**
  - Vibrant community working on various computational tools for TMDs.
  - CASCADE: MCEG for unpolarized TMDs at high energy.
  - Need more verification of MCEG models with TMD theory / phenomenology.

Future Trends in Nuclear Physics Computing



Donald Geesaman (ANL, former NSAC Chair) *"It will be **joint progress of theory and experiment** that moves us forward, not in one side alone"*

Martin Savage (INT) *"The next decade will be looked back upon as a **truly astonishing period in NP** and in our understanding of fundamental aspects of nature. This will be **made possible by advances in scientific computing** and in how the NP community organizes and collaborates, and how DOE and NSF supports this, to take full advantage of these advances."*

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Towards the next generation research model in NP

NP research model not changed for over 30 years
Science & Industry remarkable advances in computing & microelectronics

goal evolve & develop **NP research model** based on these advances

rethink **how measurements are compared to theory**

- examine capabilities of event level analysis taking the multi-dimensional challenges of NP fully into account

What are our requirements? What do theoreticians wish from experiments?
What do experimentalists wish from theoreticians? What technical and sociological challenges do we face?
Role of MCEG Theory – experiment comparison on event level

Markus Diefenthaler

mdiefent@jlab.org

Summary

MCEGs

- interplay theory – experiment
- interplay HEP – NP
- study hadronization

MCEGs for ep and eA

- Collaboration EICUG - MCnet
- **MCEGs for ep** We are on a very good path, but still quite some work ahead.
- **MCEGs for eA** Less clear situation about theory and MCEG.

Vibrant community for TMDs and MCEGs.