EIC Software Meeting 2019
Trieste, May 2019

F Hautmann

EICUG-MCnet DESY Workshop Overview and MCEG for the EIC

- Highlights from the Workshop on
  "MCEG for future ep/eA facilities", DESY, February 2019
  (see summary by convenors)

- What can MCEGs contribute to EIC physics program
  (personal perspective)

https://indico.desy.de/indico/event/22030/

EICUG-MCnet MCEG Workshop

Summary of workshop

Feb. 20 – 22

DESY

Elke-Caroline Aschenauer (BNL), Andrea Bressan (Trieste), Markus Diefenthaler (JLAB), Hannes Jung (DESY), and Simon Plätzer (Vienna)

EICUG-MCnet Workshop Scientific Program

Wednesday, February 20, 2019

14:00 - 15:45 General-Purpose MCEG: Precision for ep processes
- 14:00 **Intro** *5'*
  Speaker: Dr. Hannes Jung (DESY)
  Material: Slides
- 14:05 **Simulation of ep and eA processes in general-purpose M**
  Speaker: Dr. Ilkka Helenius (University of Jyväskylä)
  Material: Slides
- 14:35 **Status of higher-order QCD predictions for DIS** *30'*
  Speaker: Dr. Stefan Hoeche (SLAC)
  Material: Slides
- 15:05 **Status of MG5 aMC@NLO for ep colliders** *10'*
  Speaker: Dr. Buarque Franzosi Diogo (Chalmers University of T
  Material: Slides
- 15:15 **Discussion** *30'*

15:40 - 16:00 Coffee

16:00 - 18:00 General-Purpose MCEG: Combining QED+QCD effects
- 16:00 **QED corrections for electron scattering** *30'*
  Speaker: Prof. Hubert Spiesberger (Johannes Gutenberg- Unive
  Material: Slides
- 16:30 **Semi-analytic vs. Monte-Carlo Approaches for QED Corr**
  Speaker: Prof. Andrei Afanasev (George Washington University
  Material: Slides
- 17:00 **Discussion and next steps** *1h0'*

Thursday, February 21, 2019

09:00 - 10:30 TMDs and MCEGs: Part I
- 09:00 **TMDs from Parton Branching** *30'*
  Speaker: Dr. Francesco Hautmann
  Material: Slides
- 09:30 **nTMD using PB method** *30'*
  Speaker: Prof. Krzysztof Kutak (Institute of Nuclear Physics Polish Academy of Sciences)
  Material: Slides
- 10:00 **Updates for KaTie** *30'*
  Speaker: Dr. Andreas van Hameren (Institute of Nuclear Physics Polish Academy of Sciences)
  Material: Slides

10:30 - 11:00 Coffee

11:00 - 12:00 TMDs and MCEGs: Part II
- 11:00 **TMD and parton shower: CASCADE-3** *30'*
  Speaker: Dr. Hannes Jung (DESY)
  Material: Slides
- 11:30 **Revisited version of a recursive model for the fragmentation of polarized quarks** *30'*
  Speaker: Albi Kerbizi (University of Trieste)
  Material: Slides

12:00 - 14:00 Lunch

14:00 - 15:30 TMDs and MCEGs: Part III
- 14:00 **Discussion: TMDs and MCEG** *1h30'*

15:30 - 16:00 Coffee

16:00 - 18:30 GPDs and MCEGs
- 16:00 **Towards event generation for GPD physics with PARTONS** *30'*
  Speaker: Dr. Herve Moutarde (IRFU, CEA)
  Material: Slides
- 16:30 **DVCS and exclusive pi0 event generator for JLab fixed-target experiments** *30'*
  Speaker: Dr. Carlos Munoz Camacho (IPN-Orsay)
  Material: Slides
- 17:00 **Discussion: GPDs and MCEGs** *1h0'*

Friday, February 22, 2019

09:00 - 10:30 Requirements
- 09:00 **Physics at an EIC: Consequences for MC Generators** *30'*
  Speaker: Dr. Elke-Caroline Aschenauer (BNL)
  Material: Slides
- 09:30 **Jets in eA Collisions: Challenges and Opportunities for MCEGs** *30'*
  Speaker: Dr. Kolja Kauder (BNL)
  Material: Slides
- 10:00 **Discussion** *30'*

10:30 - 11:00 Coffee

11:00 - 12:00 Wrapping up

EICUG-MCnet Workshop Scientific Program

- I. <u>*Specific Topics*</u>: QED radiative corrections in DIS Monte Carlo
  Deeply virtual Compton scattering and Monte Carlo

- II. <u>*General Purpose Monte Carlo*</u>: Perturbative DIS calculations
  Parton shower generators
  Pythia, Herwig, Sherpa

  (based on “1D” collinear QCD evolution picture + “intrinsic kT” modeling at fixed scale)

- III. <u>*Toward TMD Monte Carlo*</u>: Parton branching
  KaTie
  Cascade

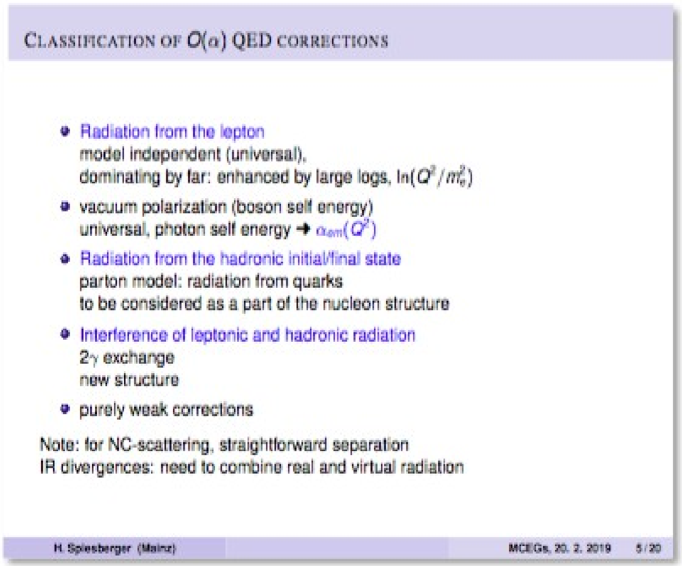
  EIC aims at hadron 3D imaging via GPD, TMD density and fragmentation functions, including “3D” picture of QCD evolution

  need MC with TMD evolution

QED radiative corrections in DIS

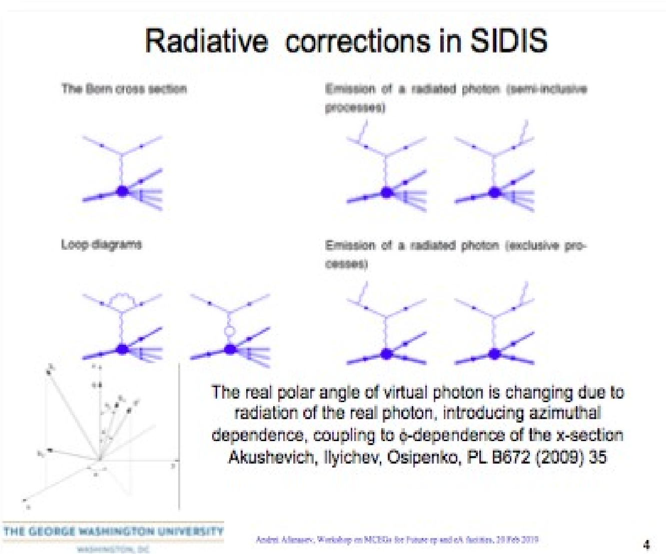
[from the summary by workshop convenors]

Merging QED and QCD effects



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.



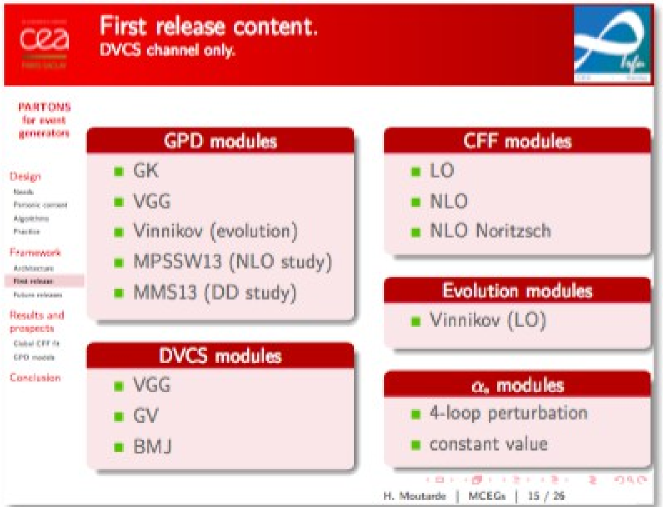
Andrei Afanasev (GWU): Semi-analytic vs. Monte-Carlo Approaches for QED Corrections to SIDIS

- 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

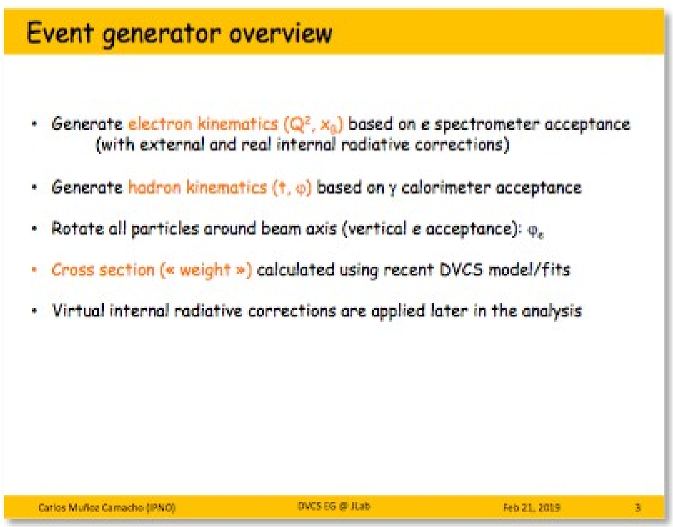
DVCS and Monte Carlo

GPDs and MCEGs



Hervé Moutarde (IRFU, CEA): Towards event generation for GPD physics with PARTONS

- GPD framework should become available to a wide community of users. Forthcoming v2 with TCS as a demonstration of multi-channel capacity.
- Extreme modularity should benefit to event generation.
- Extension beyond GPD physics through a Virtual Access structure within STRONG2020 program.



Carlos Muñoz Camacho (Orsay): DVCS and exclusive π^0 event generator for JLab fixed-target experiments

- MCEG for DVCS and exclusive π^0 production available (used for JLAB analysis for the last ~15 years).
- DVCS cross section implemented based on CCF lookup table.
- No explicit background generated – only pure DVCS/π0 events.
- C++ based code. Parameters set via C++ script or via MySQL database (as a function of configuration number).
- Portable to collider configuration, but not done.

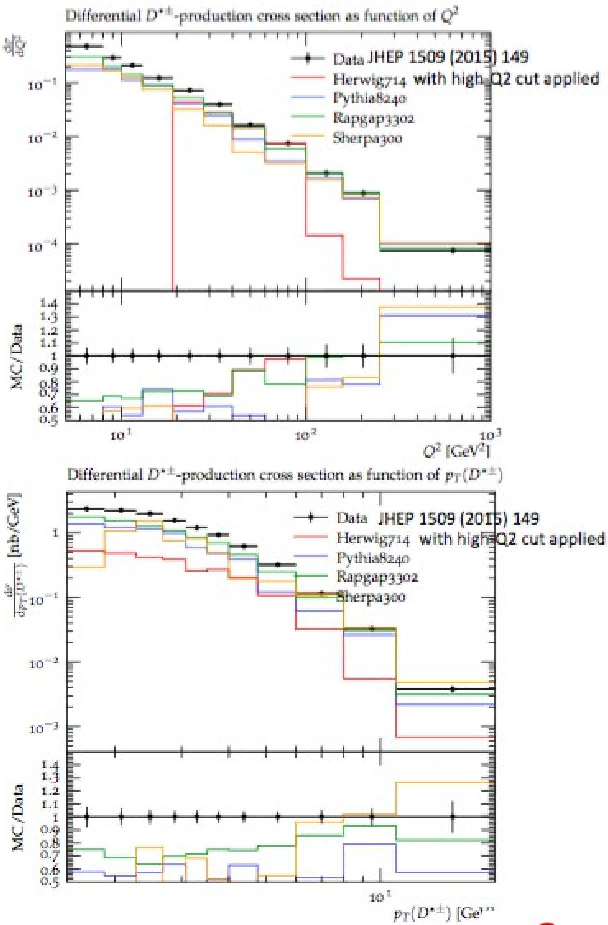
- **GPD physics**
  - No modern MCEG available.
  - There is a path from PARTONS to a GPD MCEG, similar there is a project to extend MCEG for exclusive processes from JLAB12 to EIC.

[from the summary by workshop convenors]

General purpose MCEG (1)

Status of ep and eA in general-purpose MCEG   Ilkka Helenius (Jyväskylä)

Comparisons to combined H1 and ZEUS analysis (A. Verbytskyi)



MCEGs for future ep and eA facilities

General-purpose MCEG and ep collisions

- **Sherpa**
  - 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
- **Herwig**
  - Two shower options with spin correlations and NLO matching
  - Good description for single-particle properties in DIS
  - Also QED radiation for angular-ordered shower
- **Pythia**
  - 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
- **Detailed comparisons between modern MCEG and HERA data**
  - **Feb 18—20** Workshop on Rivet for ep, rivet-ep-l@lists.bnl.gov mailing list
  - HERA data not (yet) included in MCEG tunes

General-purpose MCEG and eA collisions

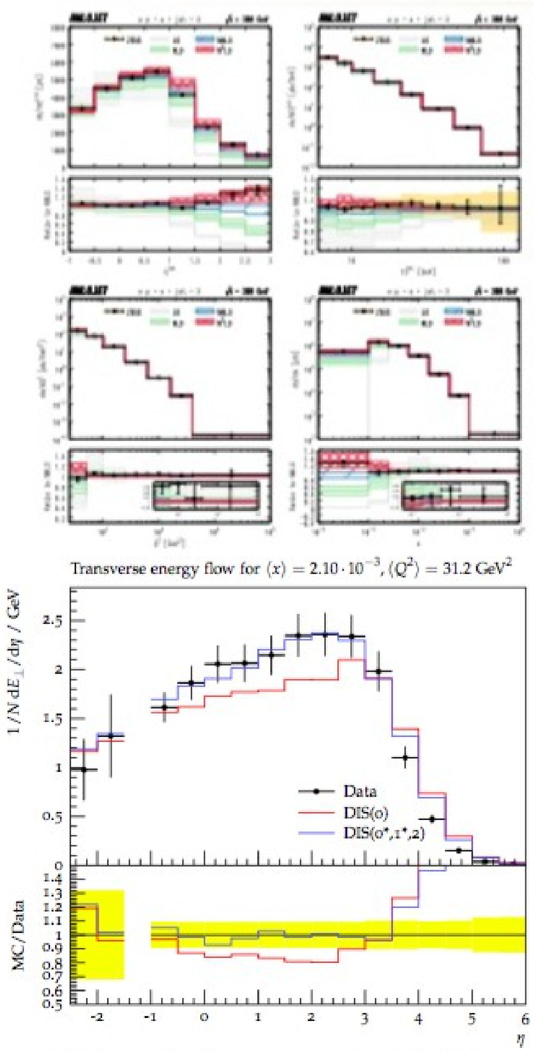
- No strong modifications for DIS (nuclear PDFs, what else?)
- For photoproduction need to include interactions between resolved photon and other nucleons
- Complementary to ultra-peripheral collisions at the LHC and RHIC

- **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. y
  - 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).

General purpose MCEG (2)

Status of NLO simulations for ep

Stefan Hoeche (SLAC)



arXiv:1803.09973

Fixed-order QCD

- QCD calculations available up to N³LO 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

MCEGs for future ep and eA facilities 7 Workshop Summary

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

Toward TMD Monte Carlo

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.

NCN

nTMD using PB method

Krzysztof Kutak

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

21st February 2019, DESY, Hamburg

INFN

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.

MCEGs for future ep and eA facilities 8 Workshop Summary

- TMD physics:
  - currently only unpolarized → CASCADE
  - need radiative corrections
  - no polarization
  - need more verification of MC models with TMD theory / phenomenology

E. Aschenauer, summary talk at DESY MCEG Workshop

3D Imaging and Monte Carlo: TMDs from Parton Branching (PB)

MOTIVATION

- Evolution equation connected in a controllable way with DGLAP evolution of collinear parton distributions
- Applicable over broad kinematic range from low to high transverse momenta, for inclusive as well as non-inclusive observables
- Implementable in Monte Carlo event generators

TMDs from Parton Branching (PB)

$$\widetilde{\mathcal{A}}_a(x,\mathbf{k},\mu^2) \;=\; S_a(\mu^2)\,\widetilde{\mathcal{A}}_a(x,\mathbf{k},\mu_0^2) + \sum_b \int \frac{d^2\mathbf{q}'}{\pi\mathbf{q}'^2}\,\frac{S_a(\mu^2)}{S_a(\mathbf{q}'^2)}\,\Theta(\mu^2-\mathbf{q}'^2)\,\Theta(\mathbf{q}'^2-\mu_0^2)$$

$$\times \int_x^{z_M} dz\, P_{ab}^{(R)}(\alpha_s(\mathbf{q}'^2),z)\,\widetilde{\mathcal{A}}_b(x/z,\mathbf{k}+(1-z)\mathbf{q}',\mathbf{q}'^2)$$

Solve iteratively : $\widetilde{\mathcal{A}}_a^{(0)}(x,\mathbf{k},\mu^2) = S_a(\mu^2)\,\widetilde{\mathcal{A}}_a(x,\mathbf{k},\mu_0^2)$,

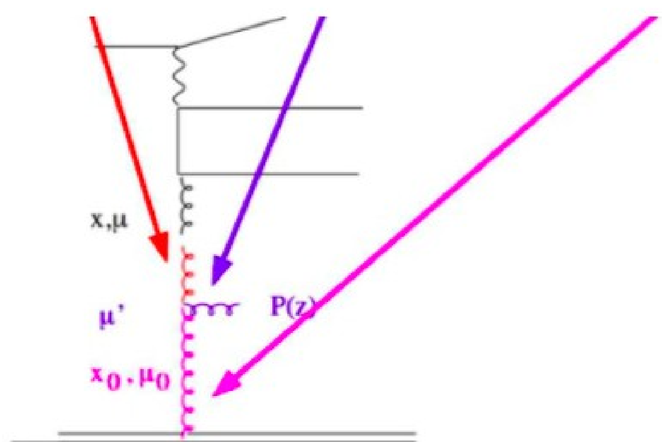
$$\widetilde{\mathcal{A}}_a^{(1)}(x,\mathbf{k},\mu^2) = \sum_b \int \frac{d^2\mathbf{q}'}{\pi\mathbf{q}'^2}\,\Theta(\mu^2-\mathbf{q}'^2)\,\Theta(\mathbf{q}'^2-\mu_0^2)$$

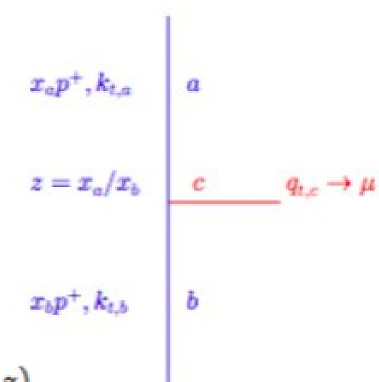
$$\times\; \frac{S_a(\mu^2)}{S_a(\mathbf{q}'^2)} \int_x^{z_M} dz\, P_{ab}^{(R)}(\alpha_s(\mathbf{q}'^2),z)\,\widetilde{\mathcal{A}}_b(x/z,\mathbf{k}+(1-z)\mathbf{q}',\mu_0^2)\, S_b(\mathbf{q}'^2)$$

↖ NB: angular ordering

Jung, Lelek, Radescu, Zlebcik & H, JHEP 01 (2018) 070

- A new evolution equation!

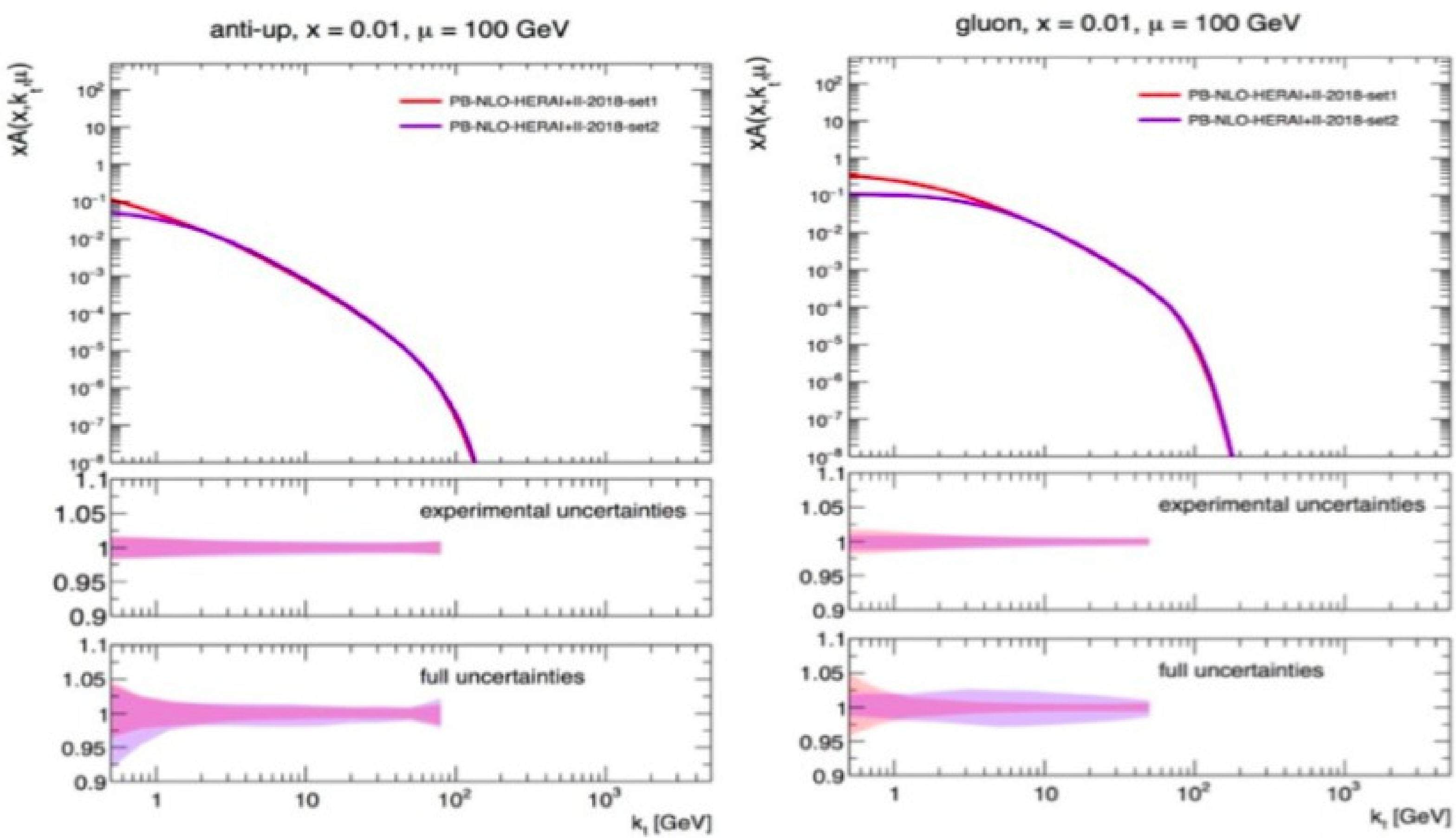




$\mu = |\mathbf{q}_c|/(1-z)$

TMDs from Parton Branching (PB)

TMD distributions from fits to precision HERA data
using the open source QCD platform
xFitter [S. Alekhin et al., E. Phys. J. C 75 (2014) 304]



A Bermudez et al, arXiv:1804.11152

Phys. Rev. D 99 (2019) 074008

- NLO determination of TMDs with uncertainties

Where to find TMDs? TMDlib and TMDplotter

- TMDlib proposed in 2014 as part of the REF Workshop and developed since
- A library of parameterizations and fits of TMDs (LHAPDF-style)

  http://tmdlib.hepforge.org
  http://tmdplotter.desy.de

- Also contains collinear (integrated) pdfs

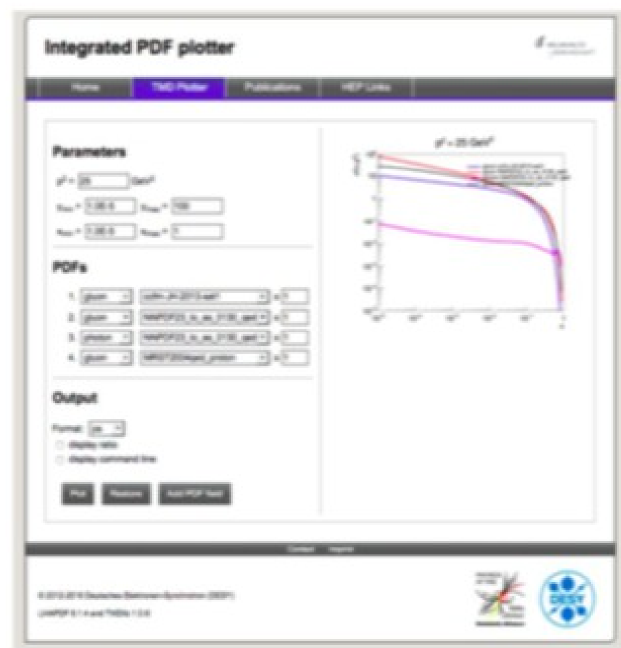
Eur. Phys. J. C (2014) 74:3220
DOI 10.1140/epjc/s10052-014-3220-9
THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

TMDlib and TMDplotter: library and plotting tools for transverse-momentum-dependent parton distributions

F. Hautmann[1,2], H. Jung[3,4], M. Krämer[3], P. J. Mulders[5,6], E. R. Nocera[7], T. C. Rogers[8,9], A. Signori[5,6,a]

[1] Rutherford Appleton Laboratory, Oxford, UK
[2] Department of Theoretical Physics, University of Oxford, Oxford, UK
[3] DESY, Hamburg, Germany
[4] University of Antwerp, Antwerp, Belgium
[5] Department of Physics and Astronomy, VU University Amsterdam, Amsterdam, The Netherlands
[6] Nikhef, Amsterdam, The Netherlands
[7] Università degli Studi di Genova, INFN, Genoa, Italy
[8] C.N. Yang Institute for Theoretical Physics, Stony Brook University, Stony Brook, USA
[9] Department of Physics, Southern Methodist University, Dallas, TX 75275, USA



How to compare the PB approach to TMDs with analytic results from CSS evolution?

- $d_a(\alpha_s)$ and $k_a(\alpha_s)$ perturbative coefficients

$$\text{one} - \text{loop} \ :$$

$$d_q^{(0)} = \frac{3}{2} C_F \quad , \quad k_q^{(0)} = 2 \ C_F$$

$$\text{two} - \text{loop} \ :$$

$$d_q^{(1)} = C_F^2 \left(\frac{3}{8} - \frac{\pi^2}{2} + 6 \ \zeta(3) \right) + C_F C_A \left(\frac{17}{24} + \frac{11\pi^2}{18} - 3 \ \zeta(3) \right) - C_F T_R N_f \left(\frac{1}{6} + \frac{2\pi^2}{9} \right) \ ,$$

$$k_q^{(1)} = 2 \ C_F \ \Gamma \ , \quad \text{where} \ \Gamma = C_A \left(\frac{67}{18} - \frac{\pi^2}{6} \right) - T_R N_f \frac{10}{9}$$

- The k and d coefficients of the PB formalism match, order by order, the A and B coefficients of the CSS formalism:

$$\text{LL} \ : \ k_q^{(0)} = 2 \ C_F = 2 \ A_q^{(1)}$$

$$\text{NLL} \ : \ k_q^{(1)} = 2 \ C_F \ \Gamma = 4 \ A_q^{(2)} \ ; \ d_q^{(0)} = \frac{3}{2} C_F = -B_q^{(1)}$$

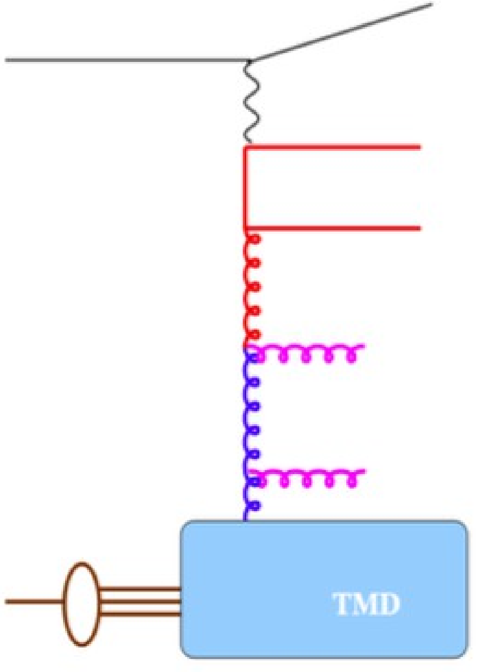
$$\text{NNLL} \ : \ \text{analysis in progress}$$

Discussion session at DESY MCEG Workshop; Lelek et al, in progress

3D Imaging and Monte Carlo: the CASCADE event generator

TMDs and parton shower

- basic elements are:
  - Matrix Elements:
    - ➔ on shell/off shell
  - PDFs
    - ➔ PB - TMDs
  - Parton Shower
    - ➔ backward evolution
      - ➔ from hard scattering towards hadrons
    - ➔ reverse of PB evolution
    - ➔ following PB -TMDs for initial state !

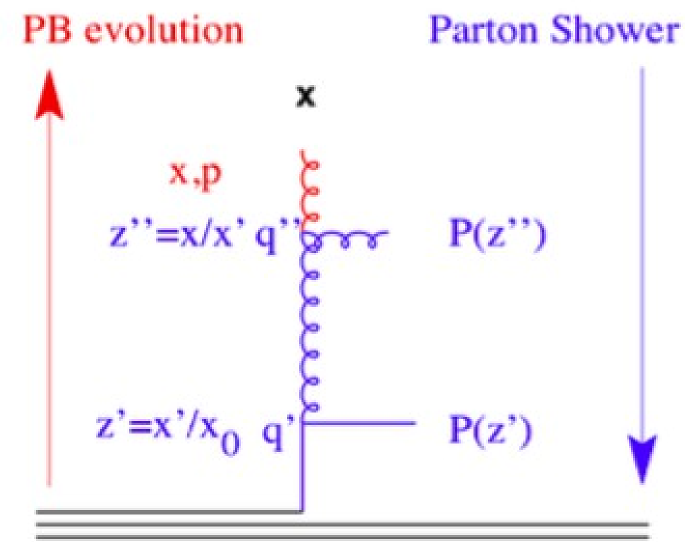


H. Jung, TMD and Parton Shower CASCADE3 , MCEG for future ep facilities, Hamburg, Feb 2019

3D Imaging and Monte Carlo: the CASCADE event generator

- **Parton Branching evolution**
  - start from hadron side and evolve from small to large scale μ^2

$$\Delta_s = \exp\left(- \int^{z_M} dz \int_{\mu_0^2}^{\mu^2} \frac{\alpha_s}{2\pi} \frac{d\mu'^2}{\mu'^2} P(z) \right)$$



- **Parton Shower**
  - backward evolution from hard scale μ^2 to hadron scale $\mu^2{}_0$ (for efficiency reasons)

$$\Delta_s = \exp\left(- \int^{z_M} dz \int_{\mu_0^2}^{\mu^2} \frac{\alpha_s}{2\pi} \frac{d\mu'^2}{\mu'^2} P(z) \frac{\frac{x}{z}\mathcal{A}\left(\frac{x}{z}, k'_\perp, \mu'\right)}{x\mathcal{A}(x, k_\perp, \mu')} \right)$$

➔ in backward evolution, parton density (TMD) imposed further constraint !

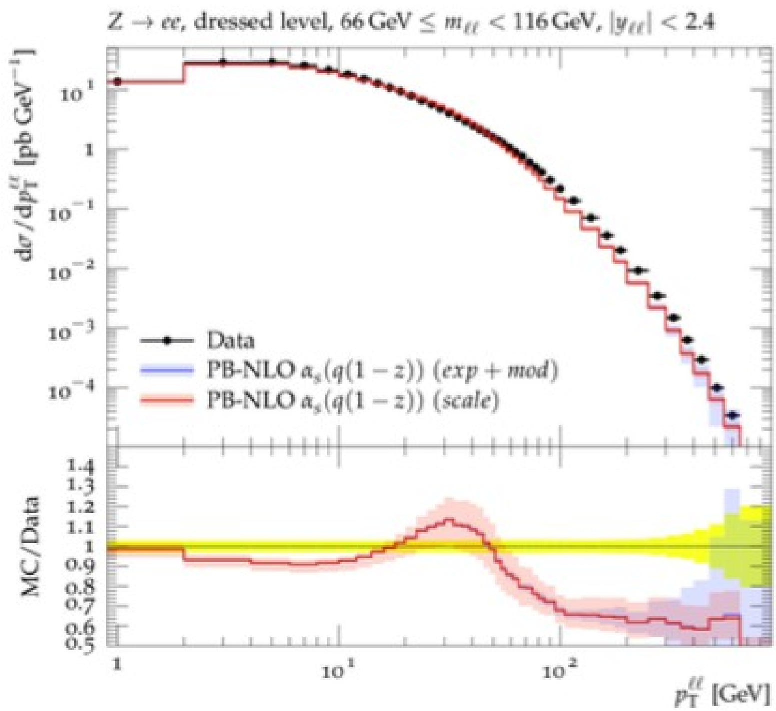
H. Jung, TMD and Parton Shower CASCADE3 , MCEG for future ep facilities, Hamburg, Feb 2019 21

3D Imaging and Monte Carlo: the CASCADE event generator

Matching to hard process: MC@NLO method

Frixione, S. and Webber, B. JHEP, 0206, 029, arXiv hep-ph/0204244
Alwall, J., et al JHEP, 1407, 079 arXiv 1405.0301

- MC@NLO subtracts soft & collinear parts from NLO (added by TMD and shower)
- MC@NLO without shower unphysical
  - DY-process as example
  - low q_T region affected by subtraction of soft & collinear parts
    - to be filled by TMD (+ PS)
  - DY production very well described by TMD with MC@NLO
    - TMD fills low q_T part



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

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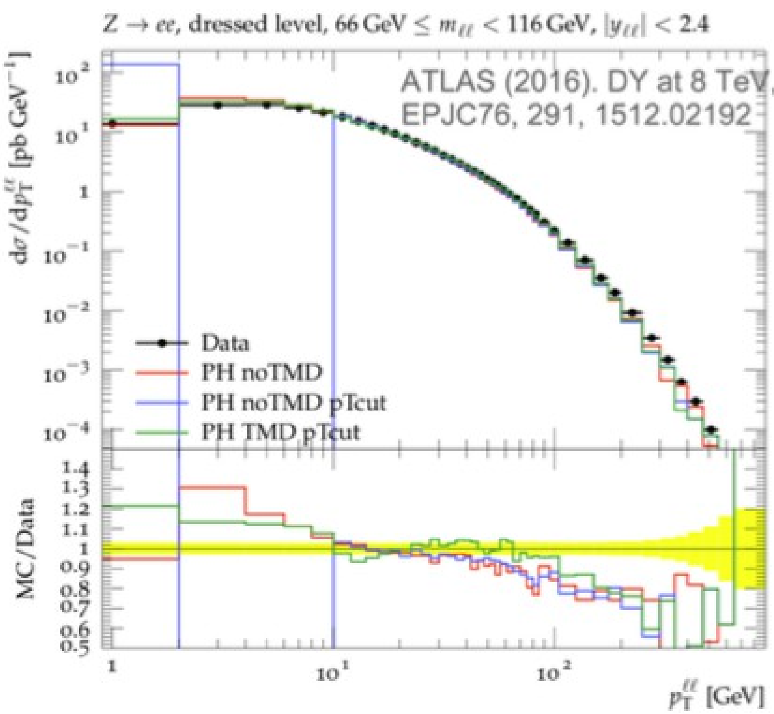
3D Imaging and Monte Carlo: the CASCADE event generator

Matching to hard process: POWHEG method

Frixione, S., Nason, P., and Ridolfi, G. (2007). JHEP, 09, 126 arXiv 0707.3088
Frixione, S., Nason, P., and Oleari, C. JHEP, 0711(), 070 arXiv 0709.2092

- POWHEG exponentiates real emission (soft part): Sudakov for 1st emission
  - DY-process as example
  - q_T cut applied (`ptsqmin`) to allow for contribution from TMD (and PS)
    - low q_T region filled by TMD + PS
    - large q_T by real emission
  - DY production described reasonably well with TMD + POWHEG with q_T cut
    - TMD fills low q_T part



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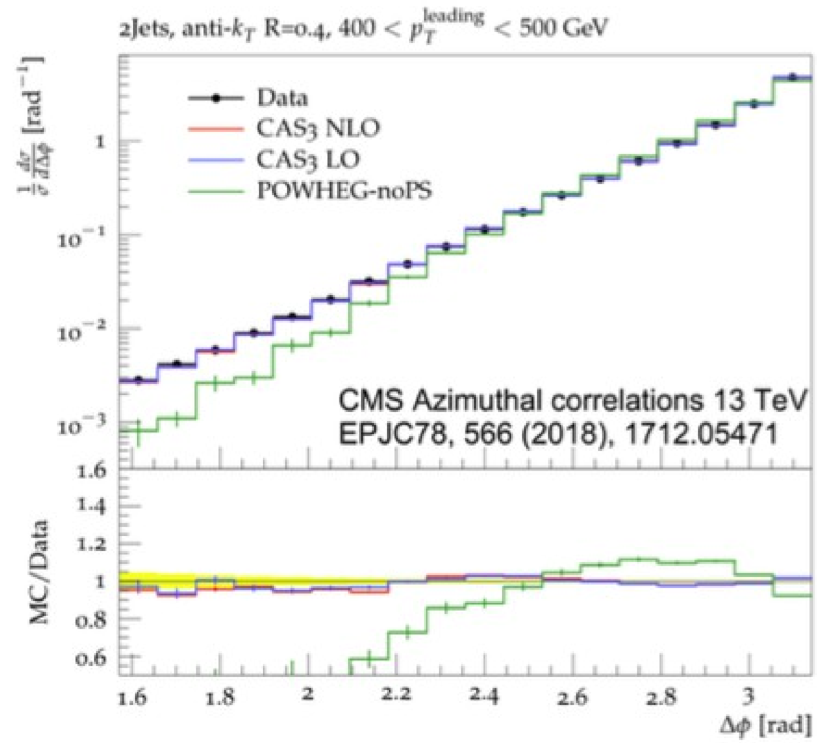
3D Imaging and Monte Carlo: the CASCADE event generator

Matching to hard process: POWHEG + TMD + PS

- POWHEG dijets NLO
  - k_t included from TMD
  - initial state parton shower included
    - LO splitting fct and LO α_s
    - NLO splitting fct and NLO α_s
- Effect of NLO shower on observables
- TMD + PS gives very good description of measurement
  - Due to constraint from TMD, little difference of LO and NLO splitting fcts are observed !



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

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How to export this from pp to DIS?

TMD shower and DIS

- keep DIS parton shower as in pp
  - important for systematic treatment
  - understanding of transverse momentum effects – comparison to DY
  - determination and constraining TMD from DY
    - Application to DIS:

      ➔ need NLO calculation ala MC@NLO, POWHEG
- Needed for DIS:
  - full k_T dependent (off-shell) matrix elements:
    - LO → KaTie (A. van Hameren)
      - can be used with TMD shower in CASCADE3: to be released in next days
    - NLO and higher order matching
  - TMD fits including off-shell matrix elements
  - small x improved TMDs → CCFM

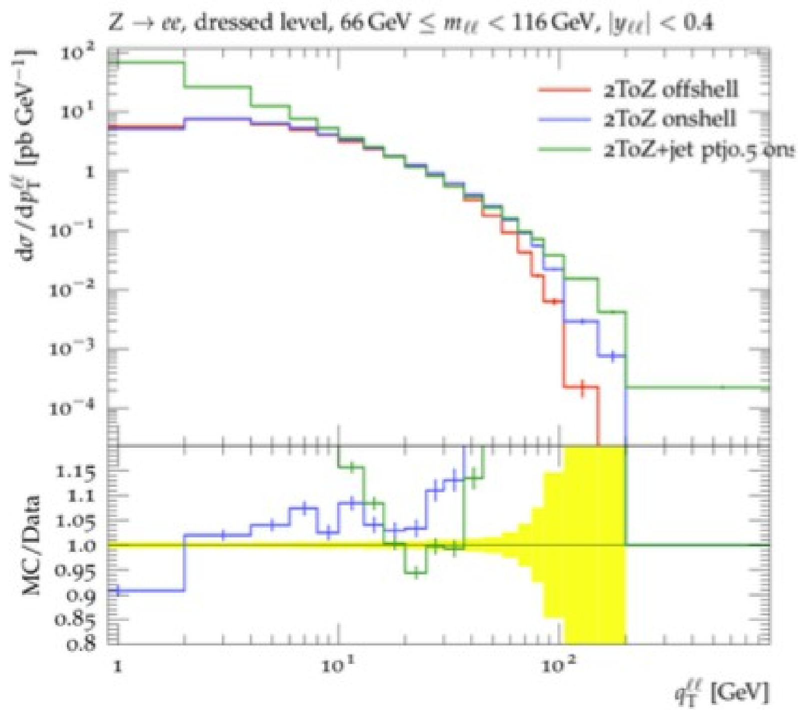
H. Jung, TMD and Parton Shower CASCADE3 , MCEG for future ep facilities, Hamburg, Feb 2019

3D Imaging and Monte Carlo: the CASCADE event generator

Matching to hard process: off-shell ME with KaTie

van Hameren, A. CPC, 224, 371, 2018, arXiv 1611.00680

- KaTie (see talk by A. Kusina on Z+jet)
  - off-shell kinematics with TMDs used to calculate hard process
    - no kinematic corrections needed
    - parton shower below scale μ
  - off-shell agrees with on-shell with TMD added (and keeping mass fixed) at small q_T
    - → important check for application with collinear NLO calculation
  - off-shell agrees with $2 \rightarrow 2$ on-shell at medium q_T
    - → important check for merging different parton multiplicities



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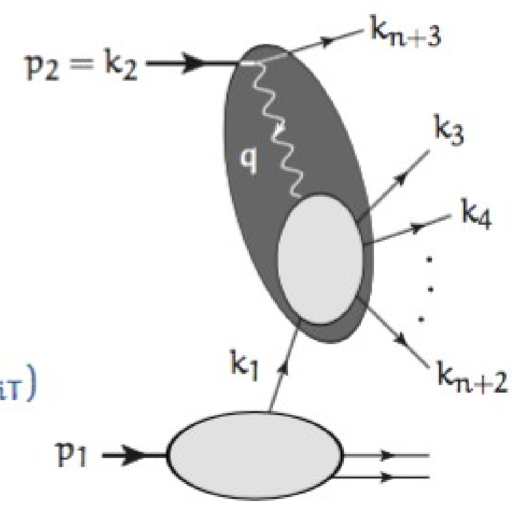
KaTie

[A. Van Hameren, talks at DESY MCEG Workshop, February 2019 and DIS2019 Workshop, April 2019]

What does KaTie do?

Let $Y = \{y = y_1 y_2 \to y_3 y_4 \cdots y_n\}$ be a list of partonic processes contributing to a eh-scattering process with a multi-jet final state, with differential cross section

$$d\sigma_Y(p_1, p_2; k_3, \dots, k_{3+n}) = \sum_{y \in Y} \int d^4k_1\, \mathcal{P}_{y_1}(k_1) \qquad d\hat{\sigma}_y(k_1, k_2; k_3, \dots, k_{3+n})$$



Collinear factorization:

$$\mathcal{P}_{y_i}(k_i) = \int \frac{dx_i}{x_i} f_{y_i}(x_i, \mu)\, \delta^4(k_i - x_i p_i)$$

k_T-dependent factorization factorization:

$$\mathcal{P}_{y_i}(k_i) = \int \frac{d^2\mathbf{k}_{iT}}{\pi} \int \frac{dx_i}{x_i} \mathcal{F}_{y_i}(x_i, |\mathbf{k}_{iT}|, \mu)\, \delta^4(k_i - x_i p_i - k_{iT})$$

Differential partonic cross section:

$$d\hat{\sigma}_y(k_1, k_2; k_3, \dots, k_{3+n}) = d\Phi_Y(k_1, k_2; k_3, \dots, k_{3+n})\, \Theta_Y(k_3, \dots, k_{3+n}) \times \text{flux}(k_1, k_2) \times \mathcal{S}_y\, |\mathcal{M}_y(k_1, \dots, k_{3+n})|^2$$

KaTie creates tree-level event files corresponding to $d\sigma_Y$, if supplied with f_y and/or $\mathcal{F}_y$.

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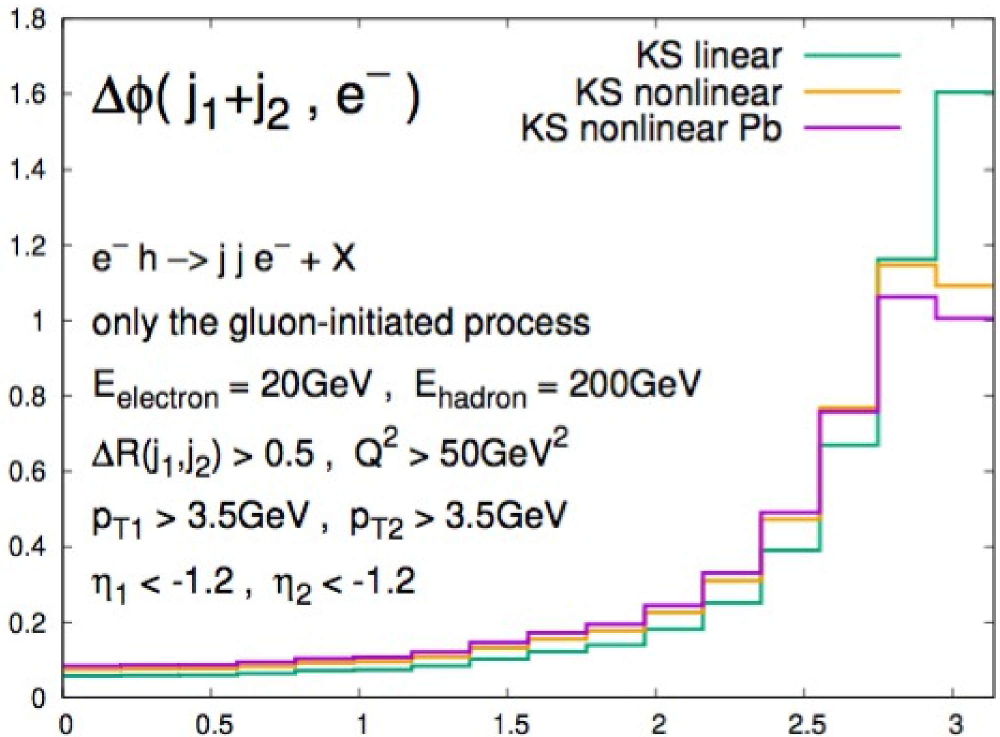
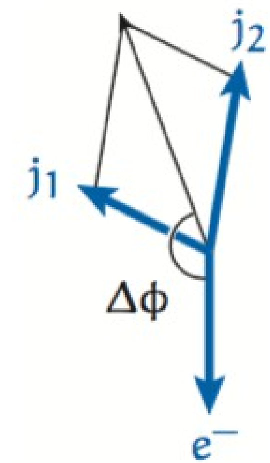
KaTie

[A. Van Hameren, talks at DESY MCEG Workshop, February 2019 and DIS2019 Workshop, April 2019]

Azimuthal angle at EIC energies

Need observable sensitive to final state momentum inbalance, eg. the angle between the electron and the jet pair.





Angle between final-state lepton and jets studied previously by H1 (2012), and in the context of azimuthal assymetries Jacobsson PhD-thesis 1994.

The shapes of the distribution are clearly different, for TMDs with different rates of saturation included.

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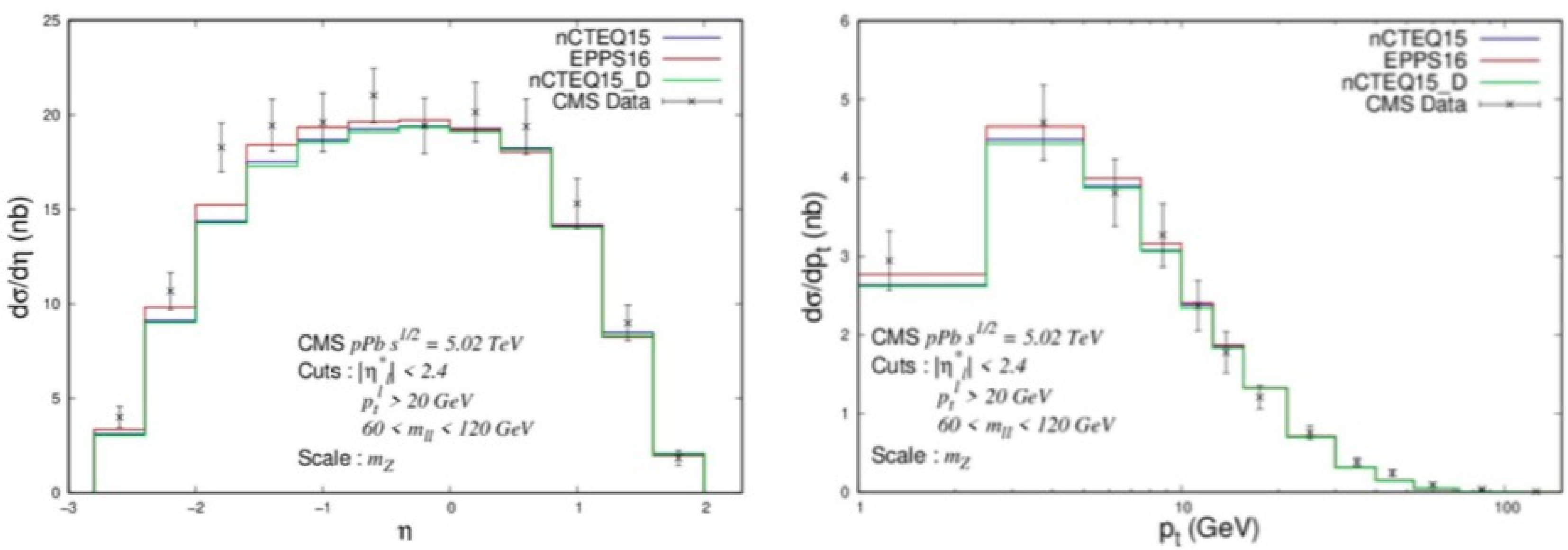
Application of KaTie + PB-TMD to Drell-Yan on nuclei

[K. Kutak, talk at DESY MCEG Workshop, February 2019; arXiv:1905.07331]

Drell-Yan using TMD

$$p + Pb \to Z^* \to \mu^+ + \mu^-$$

preliminary results



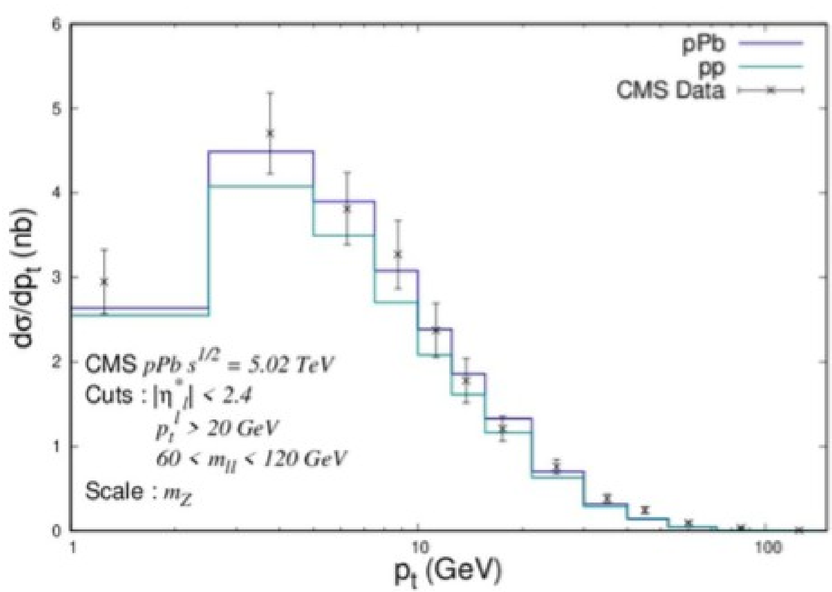
Calculated using KaTie i.e. TMD by Monte Carlo by A. van Hameren

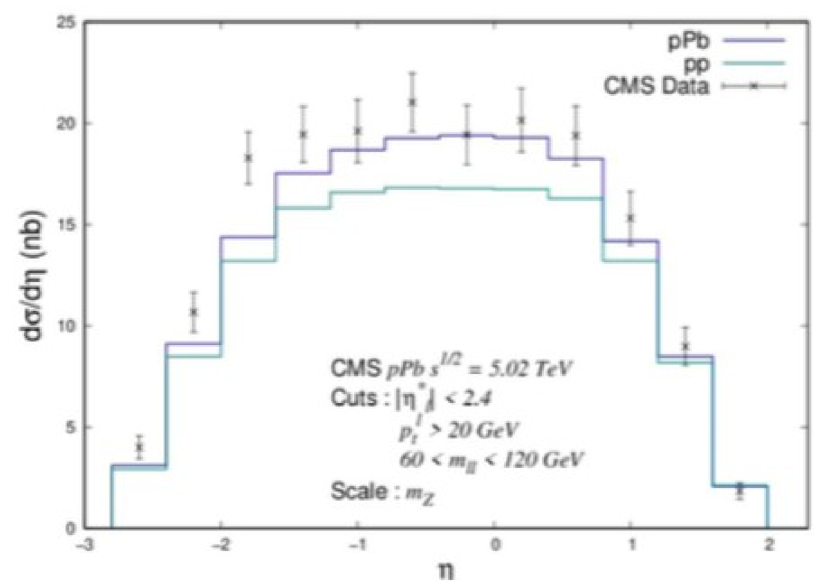
Application of KaTie + PB-TMD to Drell-Yan on nuclei

[K. Kutak, talk at DESY MCEG Workshop, February 2019; arXiv:1905.07331]

p-Pb vs. p-p

preliminary results





nTMD = nCTEQ 15 + PB method
TMD = HERAP pdf + PB

Concluding remarks

- TMDlib, xFitter software tools available to EICUG community
- DIS framework being developed by all general purpose parton-shower MCEG (Pythia, Herwig, Sherpa)
- TMD Monte Carlo tools: Cascade, KaTie (unpolarized TMD) – to be developed for polarized TMDs; nuclear TMDs; QED corrections
- NLO + TMD framework needed (a la MC-at-NLO, Powheg, . . . : Pythia/Herwig framework not sufficient)
- EICUG – MCnet co-operation much needed for EIC physics