

EpIC: a Monte Carlo generator for exclusive processes

Kemal Tezgin

Brookhaven National Laboratory

kemaltezgin@gmail.com

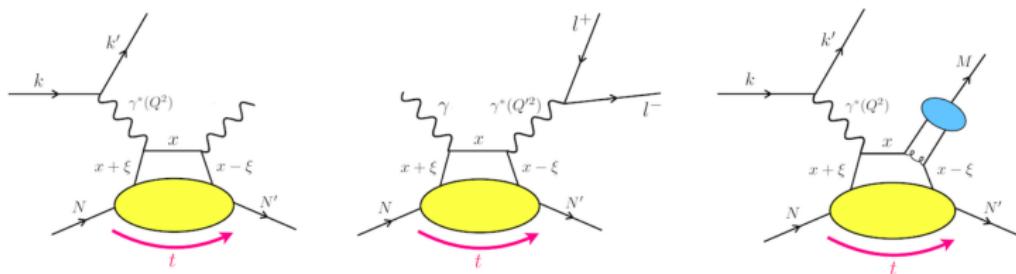
*In collaboration with: E.C. Aschenauer, V. Batozskaya, S. Fazio, K. Gates,
H. Moutarde, D. Sokhan, H. Spiesberger, P. Sznajder*

DIS 2022, 4 May 2022



EpIC

- EpIC: an event generator for exclusive reactions
- EpIC uses the PARTONS framework: takes advantage of
 - multiple GPD models that already exist
 - flexibility for adding new models
- Multiple channels: DVCS, TCS, DVMP (pseudoscalar mesons)



- Written in C++
- XML interface for automated tasks
- Open-source

EpIC: novel Monte Carlo generator for exclusive processes

E. C. Aschenauer^{a[1]}, V. Batzovskaya^{b[2]}, S. Fazio^{c[3]}, K. Gates^{d[4]},
 H. Moutarde^{e[5]}, D. Sokhan^{f[6]}, H. Spiesberger^{d[6]}, P. Sznajder^{b[2]},
 K. Tezgin^[1]

¹ Department of Physics, Brookhaven National Laboratory, Upton, New York 11973² National Centre for Nuclear Research (NCB), Pasteura 7, 02-093 Warsaw, Poland³ University of Calabria & INFN-Cosenza, Italy⁴ University of Glasgow, Glasgow G12 8QQ, United Kingdom⁵ IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France⁶ PRISMA+ Cluster of Excellence, Institut für Physik, Johannes Gutenberg-Universität, D-55099 Mainz, Germany

Received: date / Accepted: date

Abstract We present the EpIC Monte Carlo event generator for exclusive processes sensitive to generalised parton distributions. EpIC utilises the PARTONS framework, which provides a flexible software architecture and a variety of modelling options for the partonic description of the nucleon. The generator offers a comprehensive set of features, including multi-channel capabilities and radiative corrections. It may be used both in analyses of experimental data, as well as in impact studies, especially for future electron-ion colliders.

like separations. In case there is no momentum transfer to the nucleon, i.e. in the forward limit, certain GPDs become equivalent to PDFs. Additionally, the first Mellin moments of GPDs are related to elastic form factors. In this regard, GPDs may be viewed as a unified concept of elastic form factors studied via elastic scattering processes and one-dimensional parton distribution functions studied via (semi-) inclusive scattering processes. Another key aspect of GPDs is their relation to nucleon tomography. The Fourier transform of GPDs are related to the impact parameter space distri-

87 [hep-ph] 3 May 2022

E.C. Aschenauer et al., arXiv: 2205.01762 (2022)



Website: <https://pawelsznajder.github.io/epic>



B. Berthou et al., Eur.Phys.J. C78 (2018)

- PARtonic Tomography Of Nucleon Software (PARTONS) is a software framework dedicated to the phenomenology of GPDs
- Open source project under GPL licence
- Bridge between models of GPDs and experimental data
- Written in C++, XML interface for automated tasks
- PARTONS.V1: DVCS (2018), V2: TCS (2020)
- PARTONS.V3: DVMP (2022)
- Website: <http://partons.cea.fr>



- EpIC uses mini FOAM (mFOAM, a compact version of FOAM) to generate events randomly
- mini FOAM is a general-purpose Monte Carlo event simulator

[Jadach and Sawicki, Comput.Phys.Commun. 177 (2007)]

- fully integrated with ROOT
- works for dimensions ≤ 20

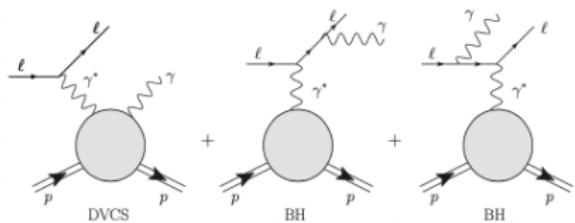
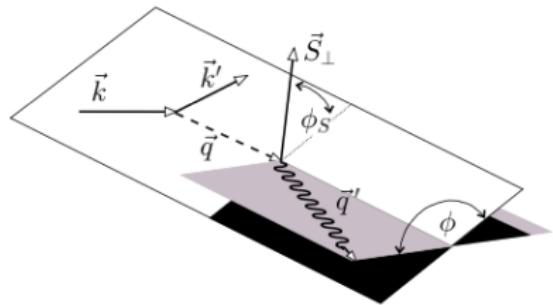
Leptoproduction of a real photon

- Differential cross section for the leptoproduction of a real photon

[Belitsky, Mueller, and Kirchner Nucl.Phys.B 629 (2002)]

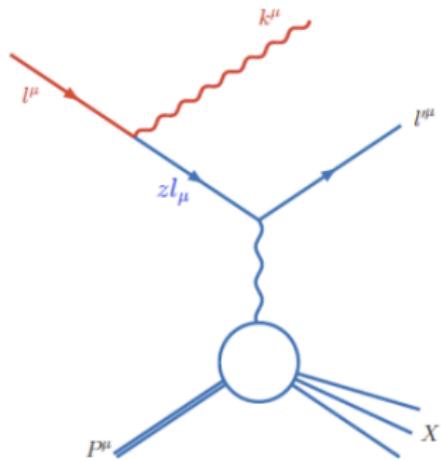
$$\frac{d^5\sigma}{dx_B dQ^2 d|t| d\phi d\phi_S} = \frac{\alpha^3 x_B y}{16\pi^2 Q^2 \sqrt{1+\epsilon^2}} |\mathcal{T}|^2$$

where $|\mathcal{T}|^2 = |\mathcal{T}_{\text{DVCS}}|^2 + |\mathcal{T}_{\text{BH}}|^2 + \mathcal{I}$



Radiative corrections – collinear approximation

- Collinear approximation: Neglect the transverse component of the 4-momenta of the emitted photon



Radiative corrections – collinear approximation

- Initial and final state electromagnetic radiative corrections

[Kripfganz, Möhring, Spiesberger, Z.Phys.C 49 (1991)]

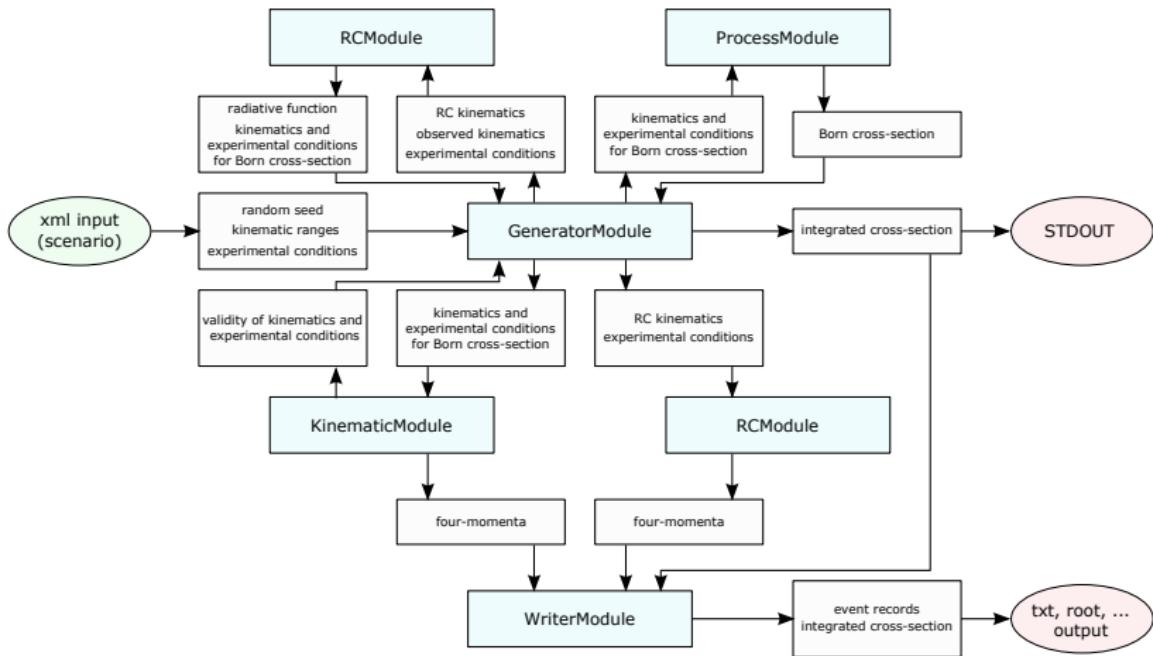
$$\frac{d^2\sigma}{dx dQ^2} = \int_0^1 dz_1 z_1 D_{e/e}(z_1) \int_0^1 \frac{dz_3}{z_3^2} \bar{D}_{e/e}(z_3) \frac{y}{\hat{y}} \frac{d\hat{\sigma}_{\text{Born}}}{d\hat{x} d\hat{Q}^2}$$

$$D_{e/e}(z) = \bar{D}_{e/e}(z) = \left[\delta(1-z) \left[1 + \frac{\alpha}{2\pi} L \left(2 \ln \epsilon + \frac{3}{2} \right) \right] + \theta(1-\epsilon-z) \frac{\alpha}{2\pi} L \frac{1+z^2}{1-z} \right]$$

- For DVCS:

$$\frac{d^5\sigma}{dx dQ^2 dt d\phi d\phi_S} = \int_0^1 dz_1 z_1 D_{e/e}(z_1) \int_0^1 \frac{dz_3}{z_3^2} \bar{D}_{e/e}(z_3) \frac{y}{\hat{y}} \frac{d^5\hat{\sigma}_{\text{Born}}}{d\hat{x} d\hat{Q}^2 dt d\phi d\phi_S}$$

EpIC – architecture





- Input file: model, model parameters, number of events, kinematic limits, beam and target type, beam helicity, target polarization, beam and target energy, mFOAM parameters
- Output file: 4-vectors of all particles

EpIC – input

```
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>

<!-- Scenario starts here --&gt;
<!-- For your convenience and for bookkeeping provide creation date and unique description --&gt;
&lt;scenario date="2017-07-18" description="Select specific GPD types"&gt;

    &lt;!-- Indicate service and its methods to be used --&gt;
    &lt;task service="DVCSGeneratorService" method="generate"&gt;

        &lt;!-- General configuration --&gt;
        &lt;!-- Subprocess can be "ALL", "BH" or "DVCS" --&gt;
        &lt;general_configuration&gt;
            &lt;param name="number_of_events" value="1000000" /&gt;
            &lt;param name="subprocess_type" value="DVCS" /&gt;
        &lt;/general_configuration&gt;

        &lt;!-- Kinematic limits --&gt;
        &lt;!-- Limit on 'y' is optional, if not set 0 &lt; y &lt; 1 is assumed --&gt;
        &lt;kinematic_range&gt;
            &lt;param name="range_xB" value="0.0001|0.6" /&gt;
            &lt;param name="range_t" value="-1.0|-0.0" /&gt;
            &lt;param name="range_Q2" value="1.0|100.0" /&gt;
            &lt;param name="range_phi" value="0.0|2*pi" /&gt;
            &lt;param name="range_phiS" value="0.0|2*pi" /&gt;
            &lt;param name="range_y" value="0.01|0.95" /&gt;
        &lt;/kinematic_range&gt;

        &lt;!-- Experimental conditions --&gt;
        &lt;experimental_conditions&gt;
            &lt;param name="lepton_energy" value="10.0" /&gt;
            &lt;param name="lepton_type" value="e-" /&gt;
            &lt;param name="lepton_helicity" value="1" /&gt;
            &lt;param name="hadron_energy" value="100.0" /&gt;
            &lt;param name="hadron_type" value="p" /&gt;
            &lt;param name="hadron_polarisation" value="0.|0.|0." /&gt;
        &lt;/experimental_conditions&gt;
    &lt;/task&gt;
&lt;/scenario&gt;</pre>
```

EplC – input

```
<!-- Computation scenario -->
<computation_configuration>

<module type="DVCSProcessModule" name="DVCSProcessBMJ12">
    <module type="DVCSScalesModule" name="DVCSScalesQ2Multiplier">
        <param name="lambda" value="1." />
    </module>
    <module type="DVCSXiConverterModule" name="DVCSXiConverterXBToXi">
    </module>
    <module type="DVCSConvolutionFunctionModule" name="DVCSConvolutionTables">
        <param name="qcd_order_type" value="LO" />
        <param name="cff_set_file" value="/gpfs/mnt/gpfs02/eic/sznajder/software/epic/data/DVCSConvolutionTables/tables_GK.root" />
    </module>
</module>
</computation_configuration>

<!-- Generator module configuration -->
<generator_configuration>
    <module type="EventGeneratorModule" name="EventGeneratorFOAM">
        <param name="nCells" value="8000" />
        <param name="nSamples" value="1600" />
        <param name="nBins" value="1600" />
        <!-- param name="state_file_path" value="/gpfs/mnt/gpfs02/eic/tezgin/initialization.txt" /-->
    </module>
</generator_configuration>

<!-- Kinematic module configuration -->
<kinematic_configuration>
    <module type="DVCSKinematicModule" name="DVCSKinematicDefault">
    </module>
</kinematic_configuration>

<!-- Radiative correction module configuration -->
<rc_configuration>
    <module type="DVCSRModule" name="DVCSRNull">
        <!--param name="epsilon" value="1.E-6" /-->
    </module>
</rc_configuration>

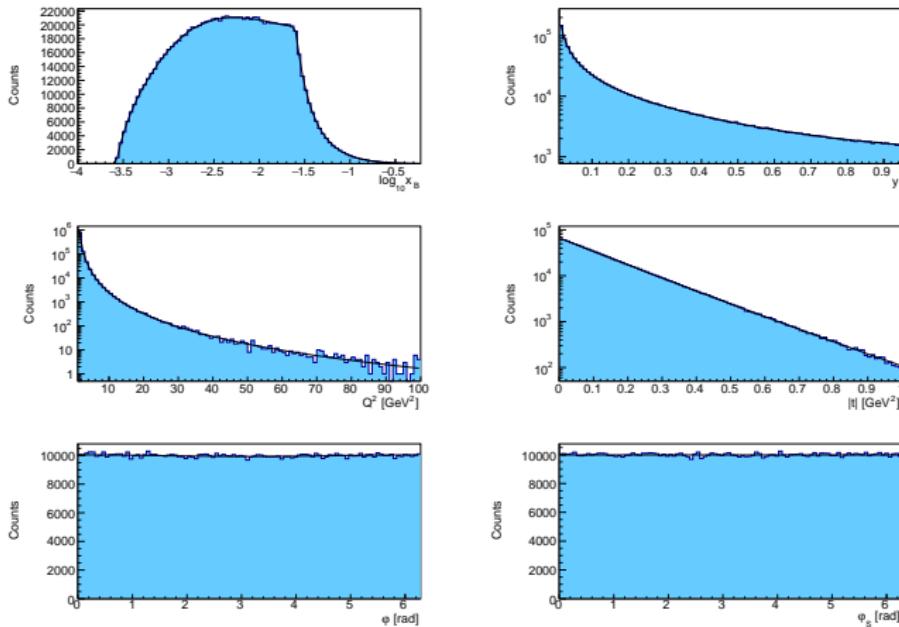
<!-- Writer module configuration-->
<writer_configuration>
    <module type="WriterModule" name="WriterHepMC3">
        <param name="output_file_path" value="events.txt" />
        <param name="HepMC3_writer_type" value="ascii" />
    </module>
</writer_configuration>
```

EpIC – output

```
P 1 0 11 0.000000000000000e+00 0.000000000000000e+00 -9.999999869440064e+00 1.000000000000000e+01 5.1099888971089147e-04 4  
P 2 1 11 -1.6312711640584632e+00 -1.0719364504885067e+00 -8.3614755990274716e+00 8.5862895256760741e+00 5.1090927818740880e-04 1  
P 3 1 22 1.6312711640584632e+00 1.0719364504885067e+00 -1.6385243878612528e+00 1.4137104743909799e+00 -2.1204429322167280e+00 13  
P 4 0 2212 0.000000000000000e+00 0.000000000000000e+00 9.9995598131265865e+01 1.000000000000001e+02 9.3827201300135255e-01 4  
V -2 0 [3,4]  
P 5 -2 22 1.1283554718872257e+00 7.8035908453753633e-01 -1.2167636309168302e+00 1.8337557376446791e+00 8.0478135311501022e-06 1  
P 6 -2 2212 5.0291569217122734e-01 2.9157736595096451e-01 9.9573837374175241e+01 9.9579954736597685e+01 9.3827201299941387e-01 1
```

EpIC – DVCS

Unpolarized target, $E_e = 10 \text{ GeV}$, $E_p = 100 \text{ GeV}$ (DVCSProcessBMJ12 & GK GPDs)



$$0.0001 \leq x_B \leq 0.6, 0.01 \leq y \leq 0.95, 1 \leq Q^2 \leq 100 \text{ GeV}^2, 0 \leq |t| \leq 1 \text{ GeV}^2$$

Consistency check

Compare generated events with the theory values

$$\text{Events}_{\text{bin}} = \text{Total number of events} \times \frac{\int_{\text{bin}} \frac{d\sigma}{dx_B} dx_B}{\sigma_{\text{total}}}$$

$$\int_{\text{bin}} \frac{d\sigma}{dx_B} dx_B = \int_{\text{bin}} dx_B \int dQ^2 \int d|t| \int d\phi \int d\phi_S \frac{d^5\sigma}{dx_B dQ^2 d|t| d\phi d\phi_S}$$

EpIC – performance

- Generation of 1M events
- DVCSCFFCMIL0U3DTables for the parameterisation of CFFs obtained from the GK GPD model and LO coefficients functions
- DVCSProcessBMJ12 for the evaluation of DVCS cross-section
- FOAM parameters: nCells = 3000, nSamples = 600, nBins = 600
- Initialisation time \approx 40 min
- Generation time per event \approx 0.0052 sec at BNL farms

Outlook

- EpIC is a new MC event generator for exclusive reactions
- EpIC has a flexible architecture that utilises a modular programming paradigm
- Generation of events are consistent with the values from the theory side
- Initial and final state of radiative corrections based on the collinear approximation are implemented
- TCS and DVMP (pseudoscalar mesons) are also available
- EpIC is generic: it can generate events from all existing modules in PARTONS