EpIC: An Event Generator for Exclusive Reactions

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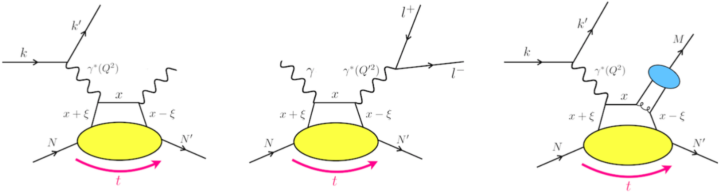
EpIC

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



- Written in C++
- Why EpIC? Epicurus, EIC, ...

PARTONS

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 (2021)
- Website: http://partons.cea.fr

mFOAM

- 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
- mFOAM can deal with integrable singularities
- works for dimensions ≤ 20

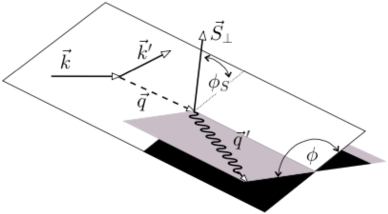
Leptoproduction of a real photon

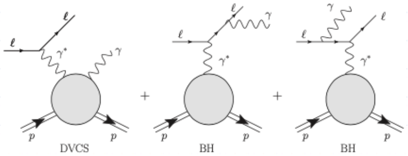
- Differential cross section for the leptoproduction of a real photon

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

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

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





EpIC

- 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
<!-- General configuration -->
<!-- Subprocess can be "ALL", "BH" or "DVCS" -->
<general_configuration>
   <param name="number_of_events" value="100000" />
   <param name="subprocess_type" value="DVCS" />
</general_configuration>

<!-- Kinematic limits -->
<!-- Limit on 'y' is optional, if not set 0 < y < 1 is assumed -->
<kinematic_range>
   <param name="range_xB" value="0.1|0.4" />
   <param name="range_t" value="-0.4|-0.3" />
   <param name="range_Q2" value="1.|100." />
   <param name="range_phi" value="0.02|6.263" />
   <param name="range_phiS" value="0.|2*pi" />
   <param name="range_y" value="0.0|1.0" />
</kinematic_range>

<!-- Experimental conditions -->
<experimental_conditions>
   <param name="lepton_energy" value="5.0" />
   <param name="lepton_type" value="e-" />
   <param name="lepton_helicity" value="1" />
   <param name="hadron_energy" value="50.0" />
   <param name="hadron_type" value="p" />
   <param name="hadron_polarisation" value="0.|0.|0." />
</experimental_conditions>

<!-- 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="DVCSConvolCoeffFunctionModule" name="DVCSCFFConstant">

                  <param name="qcd_order_type" value="LO" />

                  <param name="cff_value_H_Re" value="1." />
                  <param name="cff_value_H_Im" value="2." />
          </module>
   </module>
</computation_configuration>

<!-- Generator module configuration -->
<generator_configuration>
   <module type="EventGeneratorModule" name="EventGeneratorFOAM">
          <param name="nCells" value="10000" />
          <param name="nSamples" value="2000" />
          <param name="nBins" value="2000" />
          <!-- <param name="state_file_path" value="test.root" /> -->
   </module>
</generator_configuration>
```

EpIC – Output

```
P 1 0 11 0.0000000000000000e+00 0.0000000000000000e+00 -4.9999999738880110e+00 5.0000000000000000e+00 5.1099891404459905e-04 4
P 2 1 11 -1.0130887206630721e+00 0.0000000000000000e+00 -4.9296992502022476e+00 5.0327213030875502e+00 5.1104980719664781e-04 1
P 3 1 22 1.0130887206630721e+00 0.0000000000000000e+00 -7.0300723684439959e-02 -3.2721303088068421e-02 -1.0149976669970797e+00 3
P 4 0 2212 0.0000000000000000e+00 0.0000000000000000e+00 4.9991195681135906e+01 5.0000000000000000e+01 9.3827201299989860e-01 4
V -2 0 [3,4]
P 5 -2 22 9.8252520311285418e-01 2.8186124565789972e-01 1.6247277194816292e+01 1.6279398569411377e+01 -4.1295309247228556e-07 1
P 6 -2 2212 3.0563517549938912e-02 -2.8186124565807469e-01 3.3673617762641229e+01 3.3687880127506610e+01 9.3827201299989860e-01 1
E 1 3 8
U GEV MM
A 0 GenCrossSection 1.00000000e+00 0.00000000e+00 -1 -1
P 1 7 11 0.0000000000000000e+00 0.0000000000000000e+00 -4.9865280777327472e+00 4.9865281039152816e+00 5.1099891056835523e-04 1
P 2 1 11 -1.0142326697445965e+00 0.0000000000000000e+00 -4.9274840245525411e+00 5.0307819453517473e+00 5.1095924508611325e-04 1
P 3 1 22 1.0142326697445965e+00 0.0000000000000000e+00 -5.9044053183008316e-02 -4.4253841436692948e-02 -1.0149855694105339e+00 3
P 4 0 2212 0.0000000000000000e+00 0.0000000000000000e+00 4.9991195681135906e+01 5.0000000000000000e+01 9.3827201299989860e-01 4
V -2 0 [3,4]
P 5 -2 22 2.4668315255909973e-01 -1.8186786706303593e-01 8.8105790901078684e+00 8.8159079170481647e+00 -2.0647654623614278e-07 1
P 6 -2 2212 7.6754951718528541e-01 1.8186786706339469e-01 4.1121572537844045e+01 4.1139838241514155e+01 9.3827201300014096e-01 1
P 7 0 11 0.0000000000000000e+00 0.0000000000000000e+00 -4.9999999738880110e+00 5.0000000000000000e+00 5.1099891404459905e-04 4
P 8 7 22 0.0000000000000000e+00 0.0000000000000000e+00 -1.3471896084718549e-02 1.3471896084718549e-02 0.0000000000000000e+00 1
```

Leptoproduction of a real photon

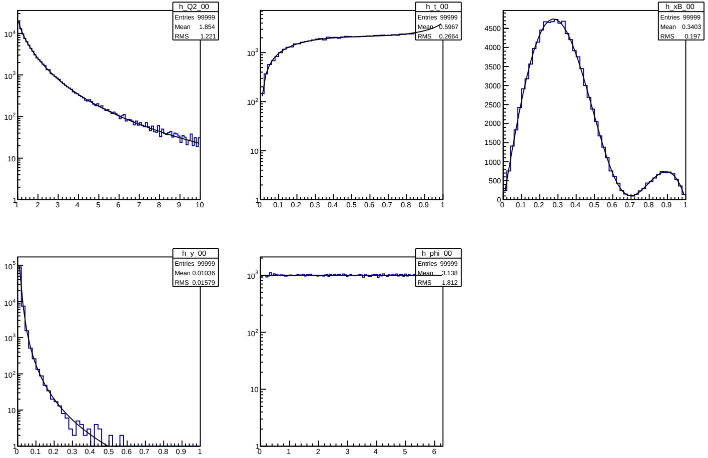
- Compare generated events with theory expectation curves

$$\int_{\mathrm{bin}} \frac{d\sigma}{dx_B}\, dx_B = \int_{\mathrm{bin}} dx_B \int dQ^2 \int d|t| \int d\phi \int d\varphi \frac{d^5\sigma}{dx_B dQ^2 d|t| d\phi d\varphi}$$

$$\text{Events} = \text{Total number of events} \times \frac{\int_{\mathrm{bin}} \frac{d\sigma}{dx_B}\, dx_B}{d\sigma}$$

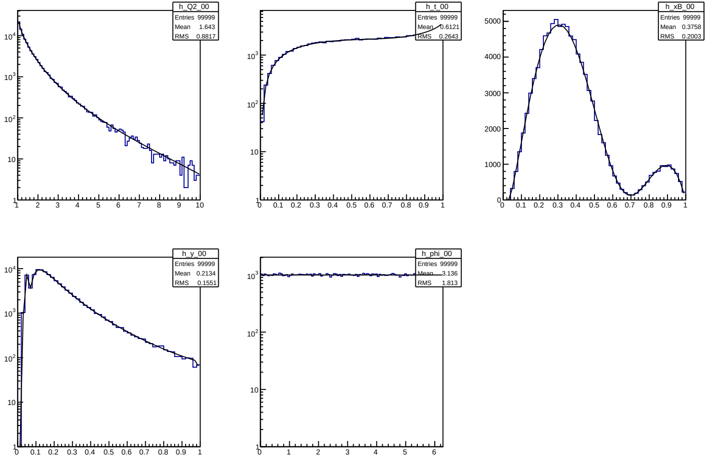
EpIC – DVCS

Unpolarized target, $E_e = 5\,\text{GeV}$, $E_p = 41\,\text{GeV}$ (DVCSProcessGV08)

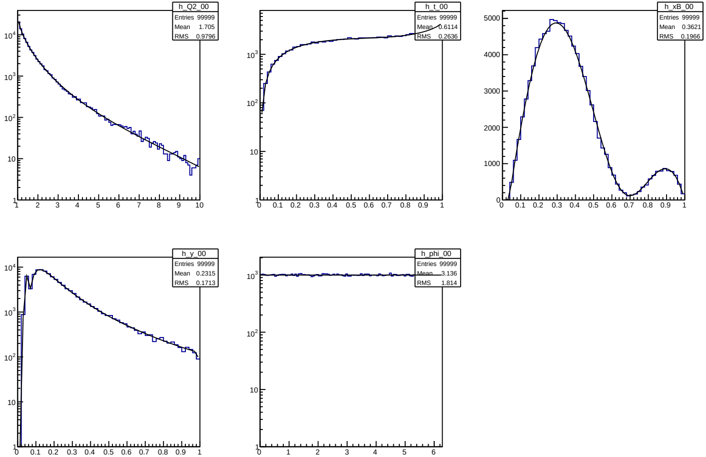


EpIC – DVCS

Longitudinally polarized target, $E_e = 10\,\mathrm{GeV}$, $E_p = 1\,\mathrm{GeV}$



Transversely polarized target, $E_e = 10\,\mathrm{GeV}$, $E_p = 1\,\mathrm{GeV}$



EpIC – Bethe-Heitler

- Bethe-Heitler amplitude includes singularities

$$|\mathcal{T}_{\mathrm{BH}}|^2 = \frac{1}{x_B y^2 (1+\epsilon^2) t \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\mathrm{BH}} + \sum_{n=1}^{2} c_n^{\mathrm{BH}} cos(n\phi) + s_1^{\mathrm{BH}} sin(\phi) \right\}$$

with

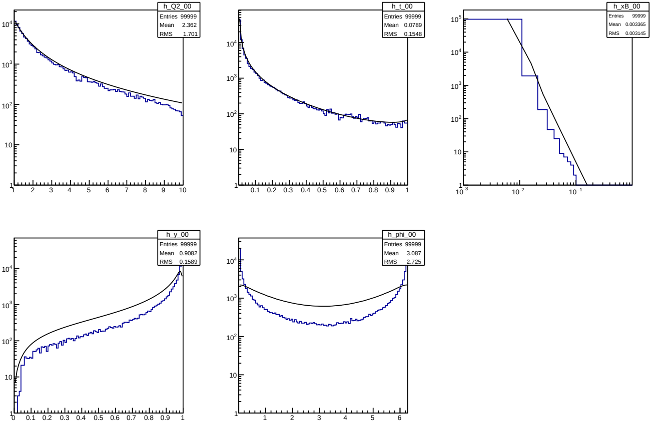
$$\mathcal{P}_1(\phi) = 1 + \frac{2k\cdot\Delta}{Q^2} \qquad \mathcal{P}_2(\phi) = \frac{t - 2k\cdot\Delta}{Q^2}\,, \quad \text{where}$$

$$k\cdot\Delta = -\frac{Q^2}{2y(1+\epsilon^2)}\left\{1 + 2Kcos\phi - \frac{t}{Q^2}(1 - x_B(2-y) + \frac{y\epsilon^2}{2}) + \frac{y\epsilon^2}{2}\right\}$$

$$K^2 = -\frac{t}{Q^2}(1-x_B)(1-y-\frac{y^2\epsilon^2}{4})(1-\frac{t_{\min}}{t^2})\left\{\sqrt{1+\epsilon^2} + \frac{4x_B(1-x_B)+\epsilon^2}{4(1-x_B)}\frac{t-t_{\min}}{Q^2}\right\}$$

EpIC – Bethe-Heitler

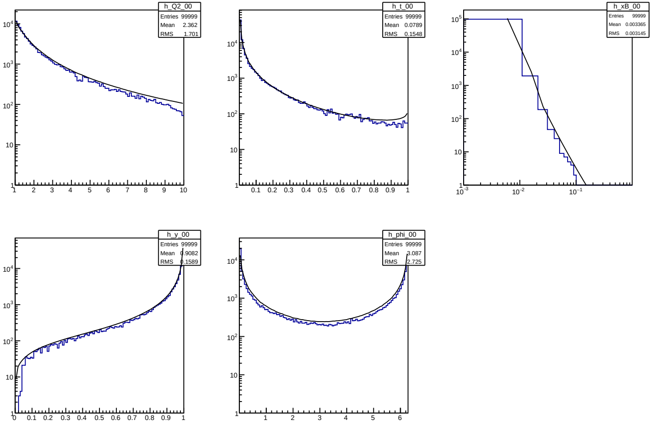
Unpolarized target, $E_e = 5$ GeV, $E_p = 41$ GeV ($\epsilon = 0.01$)



Cuts: $0.001 < x_B < 0.999$, $0.001\,\mathrm{GeV}^2 < |t| < 1\,\mathrm{GeV}^2$, $1\,\mathrm{GeV}^2 < Q^2 < 10\,\mathrm{GeV}^2$

EpIC – Bethe-Heitler

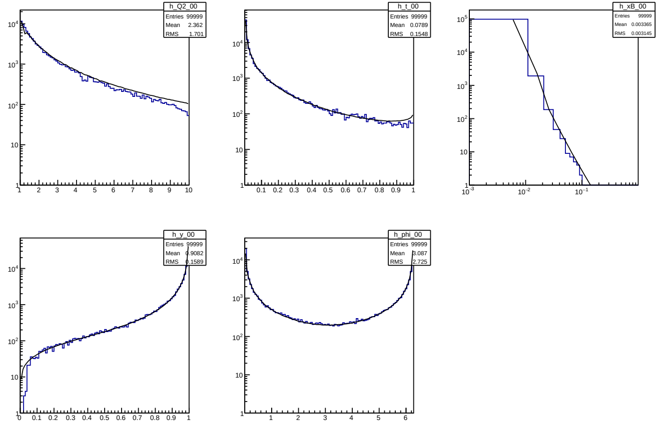
Unpolarized target, $\mathrm{E_e} = 5\,\mathrm{GeV}$, $\mathrm{E_p} = 41\,\mathrm{GeV}$ ($\epsilon = 0.00001$)



Cuts: $0.001 < x_B < 0.999$, $0.001\,\mathrm{GeV}^2 < |t| < 1\,\mathrm{GeV}^2$, $1\,\mathrm{GeV}^2 < Q^2 < 10\,\mathrm{GeV}^2$

EpIC – Bethe-Heitler

Unpolarized target, $E_e = 5$ GeV, $E_p = 41$ GeV ($\epsilon = 0.000001$)



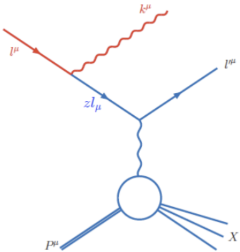
Cuts: $0.001 < x_B < 0.999$, $0.001\,\mathrm{GeV}^2 < |t| < 1\,\mathrm{GeV}^2$, $1\,\mathrm{GeV}^2 < Q^2 < 10\,\mathrm{GeV}^2$

Radiative Corrections

$$d\sigma_{ISR} = \int \frac{dz}{z} R_{ISR}(z) d\sigma_{Born}(l^{\mu} \to z l^{\mu})$$

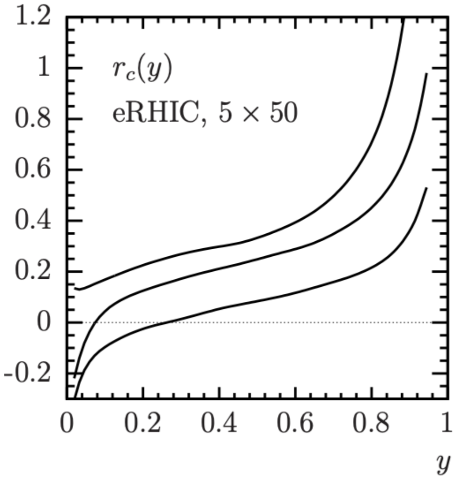
$$R_{ISR}(z) = \left[\delta(1-z)[1 + \frac{\alpha}{2\pi} L(2 ln\, \epsilon + \frac{3}{2})] + \theta(1-\epsilon-z)\frac{\alpha}{2\pi} L \frac{1+z^2}{1-z}\right]$$

where $L = ln\frac{Q^2}{m_e^2}$

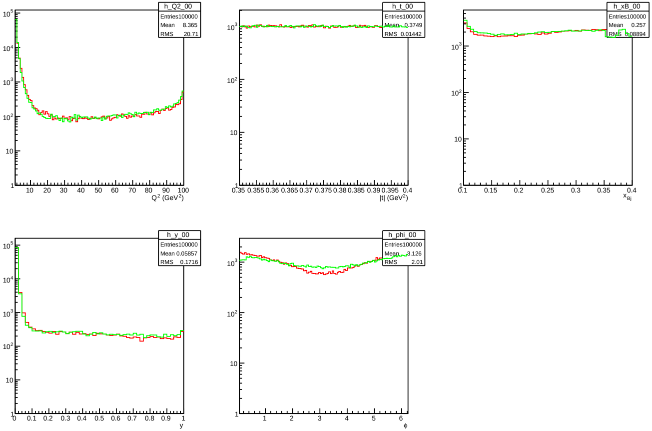


Radiative Corrections

$$r_c(y) = \frac{d\sigma/dy|_\alpha}{d\sigma/dy|_{Born}} - 1$$ [The EIC Science case report, arXiv:1108.1713]



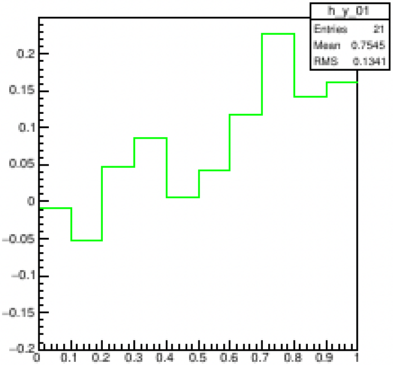
Unpolarized target, $E_e = 5$ GeV, $E_p = 50$ GeV $(\epsilon = 10^{-7})$



Cuts: $0.1 < x_B < 0.4$, $0.35\,\mathrm{GeV}^2 < |t| < 0.4\,\mathrm{GeV}^2$, $1\,\mathrm{GeV}^2 < Q^2 < 100\,\mathrm{GeV}^2$

EpIC – Radiative Corrections

Unpolarized target, $E_e = 5\,\text{GeV}$, $E_p = 50\,\text{GeV}$ ($\epsilon = 10^{-7}$)



Cuts: $0.1 < x_B < 0.4$, $0.35\,\text{GeV}^2 < |t| < 0.4\,\text{GeV}^2$, $1\,\text{GeV}^2 < Q^2 < 100\,\text{GeV}^2$

Outlook

- Generation of pure DVCS events give consistent results
- Bethe-Heitler process involves singularities. However, EpIC can deal with singularities and produce consistent results
- Initial and final state of radiative corrections are implemented
- TCS and DVMP are currently being tested