Building An Event Generator For EIC

Tobias Toll

What’s on the market?
XDVMP - A first attempt
Open Questions
To do

INT 10-3 Workshop on Perturbative and Non-Perturbative Aspects of QCD at Collider Energies 29/9 2010
# The Market ep/pp

<table>
<thead>
<tr>
<th>Generator</th>
<th>Underlying Principle</th>
<th>pp</th>
<th>ep</th>
<th>Diffraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pythia 8</td>
<td>DGLAP</td>
<td>x</td>
<td>x</td>
<td>Some</td>
</tr>
<tr>
<td>Pythia 6</td>
<td>DGLAP</td>
<td>x</td>
<td>x</td>
<td>Some</td>
</tr>
<tr>
<td>HERWIG++</td>
<td>Ang. Ord. DGLAP</td>
<td>x</td>
<td>x</td>
<td>Some</td>
</tr>
<tr>
<td>SHERPA</td>
<td>DGLAP CKKW</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>LEPTO</td>
<td>DGLAP</td>
<td>x</td>
<td></td>
<td>x (Soft)</td>
</tr>
<tr>
<td>RAPGAP</td>
<td>DGLAP</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Ariadne</td>
<td>Large colour dipoles</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>CASCADE</td>
<td>CCFM</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# The Market AA

<table>
<thead>
<tr>
<th>Generator</th>
<th>Underlying Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOS (NEXUS)</td>
<td>Multiple Scattering in Parton Ladders</td>
</tr>
<tr>
<td>VENUS</td>
<td>String formation/fragmentation</td>
</tr>
<tr>
<td>HIJING</td>
<td>Mini-Jet Structures</td>
</tr>
<tr>
<td>UrQMD</td>
<td>Dense Hadronic Matter Properties</td>
</tr>
<tr>
<td>RQMD</td>
<td>Dense Hadronic Matter Properties</td>
</tr>
<tr>
<td>(VNI)</td>
<td>Hadronic Decomposition + DGLAP</td>
</tr>
<tr>
<td>MARTINI</td>
<td>DGLAP in a Thermal Medium</td>
</tr>
<tr>
<td>JEWEL</td>
<td>Jet Quenching</td>
</tr>
<tr>
<td>Q-Pythia, Q-HERWIG</td>
<td>Jet Quenching</td>
</tr>
</tbody>
</table>

...
What we want

- A multi purpose generator
  - High and low Q2
  - High and low x
  - Exclusive final states
  - Diffraction
  - ...

Will probably need to be a collection of many programs collected in a package.
What we want

Plan:
To have a workshop on a multi purpose event generator for an EIC
eXclusive Diffractive Vector Meson Production

http://rhig.physics.yale.edu/~ullrich/xdvmp/
eXclusive Diffractive Vector Meson Production

Work in progress!!!

http://rhig.physics.yale.edu/~ullrich/xdvmp/
The Dipole Model

Elastic photon-proton scattering

\[ A_{\gamma^p}(x, Q, \Delta) = \sum_f \int d^2r \int_0^1 \frac{dz}{4\pi} \Psi_{h\bar{h}}^*(r, z, Q) A_{q\bar{q}}(x, r, \Delta) \Psi_{h\bar{h}}(r, z, Q) \]

Vector Meson Production

Known from QED

Needs to be modeled

\[ A_{T,L}^{\gamma^* p \to V p}(x, Q, \Delta) = \]

\[ i \int dr \int_0^1 \frac{dz}{4\pi} \int d^2b (\Psi^*_V \Psi)_{T,L} (2\pi r) J_0([1 - z] r \Delta) (2\pi b) J_0(b \Delta) \frac{d\sigma_{q\bar{q}}}{d^2b} \]
The Dipole Models

\[ \frac{d\sigma_{q\bar{q}}}{d^2b} \]

Two models for the dipole cross-section implemented in XDVMP:

\textbf{b-Sat}

\textbf{b-CGC}
The b-Sat Model

\[
\frac{d\sigma_{q\bar{q}}}{d^2b} = 2 \left[ 1 - \exp \left( -\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) T(b) \right) \right]
\]
The b-Sat Model

\begin{align*}
\frac{\partial xg(x, \mu^2)}{\partial \ln \mu^2} &= \frac{\alpha_s(\mu^2)}{2\pi} \int_x^1 dz P_{gg}(z) \frac{x}{z} g \left( \frac{x}{z}, \mu^2 \right) \\
\frac{d\sigma_{q\bar{q}}}{d^2b} &= 2 \left[ 1 - \exp \left( -\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2) x g(x, \mu^2) T(b) \right) \right] \\
\mu^2 &= \frac{4}{r^2} + \mu_0^2
\end{align*}
The b-Sat Model

\[ T_G(b) = \frac{1}{2\pi B_G} e^{-\frac{b^2}{2B_G}} \]

\[ \frac{d\sigma_{q\bar{q}}}{d^2b} = 2 \left[ 1 - \exp\left( -\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2)x g(x, \mu^2) T(b) \right) \right] \]
The b-CGC Model

\[ Y = \ln(1/x), \gamma_s = 0.63, \kappa = 9.9 \]

\[
\frac{d\sigma_{q\bar{q}}}{d^2b} = 2 \times \begin{cases} 
N_0 \left( \frac{rQ_s}{2} \right)^{2(\gamma_s + \frac{1}{\kappa \lambda Y} \ln \frac{2}{rQ_s})} & rQ_s \leq 2 \\
1 - e^{-A \ln^2(BrQ_s)} & rQ_s > 2
\end{cases}
\]

\[ Q_s \equiv Q_s(x, b) = \left( \frac{x_0}{x} \right)^{\lambda/2} \left[ \exp \left( -\frac{b^2}{2B_{CGC}} \right) \right]^{\frac{1}{2\gamma_s}} \]
First comparison with data

Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695

Black Curve: XDVMP b-CGC

Red Curve: Black Curve × 1.5

Something is missing!!

Plots produced by Ramiro Debbe
Real Amplitude Corrections

So far the amplitude has been assumed to be purely imaginary.

To take the Real part of the amplitude into account it can be multiplied by a factor \((1 + \beta^2)\)

\(\beta\) is the ratio Real/Imaginary parts of the Amplitude:

\[
\beta = \tan \left( \frac{\pi \lambda}{2} \right)
\]

\[
\lambda \equiv \frac{\partial \ln \left( \mathcal{A}_{T,L}^{\gamma^* p \rightarrow E_p} \right)}{\partial \ln (1/x)}
\]

This goes bad for large \(x \sim 10^{-2}\)
Real Amplitude Corrections

$$\beta = \tan\left(\frac{\pi \lambda}{2}\right)$$

$$\lambda \equiv \frac{\partial \ln \left( A_{T,L}^{\gamma p \rightarrow Ep} \right)}{\partial \ln (1/x)}$$
Skewedness Corrections

The two gluons carry different momentum fractions

This is the Skewed effect

In leading $\ln(1/x)$ this effect disappears

It can be accounted for by a factor $R_g$

\[
R_g(\lambda) = \frac{2^{2\lambda+3}}{\sqrt{\pi}} \frac{\Gamma(\lambda + 5/2)}{\Gamma(\lambda + 4)}
\]

\[
\lambda \equiv \left\{ \begin{array}{c}
\frac{\partial[xg(x,\mu^2)]}{\partial \ln(1/x)} \\
\frac{\partial \ln(A_{\gamma^* p \rightarrow E p}^{T,L})}{\partial \ln(1/x)}
\end{array} \right\}
\]

Again, this goes bad for large $x \sim 10^{-2}$!

Implemented with exponential damping to control this.
Exclusive electroproduction of J/Ψ mesons at HERA Nuc. Phys. B695

$0.15 \text{ GeV}^2 < Q^2 < 0.8 \text{ GeV}^2$

$5 \text{ GeV}^2 < Q^2 < 10 \text{ GeV}^2$

$10 \text{ GeV}^2 < Q^2 < 100 \text{ GeV}^2$

Plots produced by M. Savastio
Exclusive electroproduction of J/Psi mesons at HERA Nuc. Phys. B695

With all corrections!!

Plots produced by M. Savastio

Thursday, September 30, 2010
Going from ep to eA

ep:

\[
\text{Re}(S) = 1 - \mathcal{N}^{(p)}(x, r, b) = 1 - \frac{1}{2} \frac{d\sigma_{qq}^{(p)}(x, r, b)}{d^2b}
\]

eA:

\[
1 - \mathcal{N}^{(A)} = \prod_{i=1}^{A} \left( 1 - \mathcal{N}^{(p)}(x, r, |b - b_i|) \right)
\]

Should follow the Wood-Saxon distribution
Generating a Nucleus

Generate radii according to the Wood-Saxon distribution

Generate angles

\[ \cos(\theta) \text{ uniform in } [-1:1] \]
\[ \phi \text{ uniform in } [0:2\pi] \]

Check if the new nucleon is within a core-distance from any previous nucleon
If not -> keep it
else -> regenerate angles

If this fails 1000 times discard nucleus and restart
Technical Problems!

MC has the same cross-section formula all the time. Our’s fluctuate event by event!!! This makes the code unreliable in present form...
**Technical Problems!**

MC has the same cross-section formula all the time.
Our’s fluctuate event by event!!!
This makes the code unreliable in present form...

<table>
<thead>
<tr>
<th>nucleus #</th>
<th>rho cross-section</th>
<th>j/psi cross section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9020.225804638240</td>
<td>1224.251854397390</td>
</tr>
<tr>
<td>2</td>
<td>9121.111637252360</td>
<td>1158.990897781200</td>
</tr>
<tr>
<td>3</td>
<td>9196.210773654010</td>
<td>1127.206952442990</td>
</tr>
<tr>
<td>4</td>
<td>8871.020004394170</td>
<td>1156.314391203930</td>
</tr>
<tr>
<td>5</td>
<td>9207.502618556510</td>
<td>1157.482694319310</td>
</tr>
<tr>
<td>6</td>
<td>8924.520804975000</td>
<td>1235.28828006791</td>
</tr>
<tr>
<td>7</td>
<td>9236.943000895560</td>
<td>1185.627428172140</td>
</tr>
<tr>
<td>8</td>
<td>8980.411710585330</td>
<td>1176.667559345780</td>
</tr>
<tr>
<td>9</td>
<td>9302.28426421595</td>
<td>1207.730165816750</td>
</tr>
<tr>
<td>10</td>
<td>9019.48693863964</td>
<td>1125.247843117940</td>
</tr>
</tbody>
</table>

Mean                | 9087.97175578068 | 1175.48080666653   |
RMS                  | 137.788595       | 35.9400177         |
Technical Problems!

MC has the same cross-section formula all the time. Our’s fluctuate event by event!!! This makes the code unreliable in present form...

At the moment:
Use same nucleus for all events
Does not affect total cross-section much but has effect on shapes in distributions.

Other Solutions?
Weighted events (with unweighting procedure)??
Technical Problems!

\[
\frac{d\sigma^{(A)}_{q\bar{q}}(r, x, b)}{d^2b} = 2 \left[ 1 - \prod_{i=1}^{A} \left( 1 - \frac{1}{2} \frac{d\sigma^{(p)}_{q\bar{q}}(r, x, |b - b_i|)}{d^2b} \right) \right]
\]

Extremely slow!!!!!

bSat:

\[
\frac{d\sigma^{A}_{q\bar{q}}}{d^2b} = 2 \left[ 1 - \exp \left( -\frac{\pi^2}{2N_c} r^2 \alpha_s(\mu^2)xg(x, \mu^2) \sum_{i=1}^{A} T_p(b - b_i) \right) \right]
\]

Product becomes a sum over a function only dependent on \( b \).

Not possible for bCGC!!
Technical Problems!

To speed things up for bSat a look-up table is created for the b-dependence at the beginning of the run:
Results
Results

$10^{-4} < Q^2 < 10^{-3}$

150k events
Results

$10^{-4} < Q^2 < 10^{-3}$

180k events

t–slope $\approx 5$

Thursday, September 30, 2010
To Do

DVCS has been implemented
(no BH yet)
Open Questions (at the moment)

How to average over the nuclei correctly?

How to distinguish between incoherent and coherent part?
Break-up of the nucleus?

Generalize \( eA \rightarrow e'A'V \) to \( eA \rightarrow e'A'X \)
What has been done

- Real part of Amplitude corrections (done)
- Skewedness Corrections (done)
- Nucleus Generation and Implementation (ongoing)
- DVCS amplitude (ongoing/todo)
Back Up
Results

$10^{-4} < Q^2 < 10^{-3}$

150k events
Results

\[ p^2(J/\psi) \text{ [GeV}^2] \]

\[ -t \text{ [GeV}^2] \]