Hadron Elecro-Production with HallD Generator

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Outline

Overview

Hall D Generator

Electro-Production Implementation

Initial Results
From Last Meeting: Photo-Production Models Compared

- Total Photo-production cross sections from hall D
- Total Photo-production cross sections from PDG [1]
- Wiser Photo-production cross section summed for all the processes [2]
Hall D Photo-Production Generator

- Hall D generator uses various experimental data to generate photo-production cross sections for photon energies below 3 GeV
- It uses modified version of PYTHIA to generate photo-production cross sections for photon energies above 3 GeV
  - I have not looked at PYTHIA generator in details yet.

Following $\gamma + p^+$ reactions are considered for photon energies below 3 GeV

1. $p^+ + \pi^0$
2. $n + \pi^+$
3. $p^+ + \pi^+ + \pi^-(\text{non-res.})$
4. $p^+ + \rho^0$
5. $\Delta^{++} + \pi^-$
6. $p^+ + \pi^0 + \pi^0$
7. $n + \pi^+ + \pi^0$
8. $p^+ + \eta^0$
9. $p^+ + \pi^+ + \pi^- + \pi^0$
10. $n + \pi^+ + \pi^+ + \pi^-$
Compare Hall D vs. PDG

- Compared total cross sections from Hall D event generator and PDG photo-production cross sections on proton
- For $\gamma$ momentum less than 3 GeV it uses combination of different models including SAID
- For $\gamma$ momentum greater than 3 GeV it uses PYTHIA

**Figure:** Black line: Hall D generator, Red points: PDG
From Photo-Production to Electro-Production

- Electro-Production can take place either from real bremsstrahlung photon radiated in the target or from virtual photon interaction approximated by Equivalent Photon Radiator (EPA) approximation.
- Wiser generator estimates these two components to compute the electro-production cross-section.
  - Bremsstrahlung contribution approximated according to MO and TSAI [3].
  - Virtual contribution approximated using the reference [4].
- I have implemented electro-production part to the hall D event generator.
  - Bremsstrahlung contribution is implemented using equations available at PDG-2012 [5] and [6].
  - EPA contribution is implemented according to the reference [7].
- Next few slides will summarize the electro-production implementation.
Electro-Production Implementation

Electro-Production with Equivalent Photon Approximation

Figure: Electro-Production (a) and Photo-Absorption (b) equivalency [7]

The electro-production cross section for electron energy $E$ using Equivalent Photon Approximation (EPA),

$$d\sigma = \sigma_\gamma(\omega) \cdot dn(\omega)$$

$$dn(\omega) = \int_{q_{\min}^2}^{q_{\max}^2} dn(\omega, q^2) = N_{EPA}(\omega) \frac{d\omega}{\omega}$$

where $\sigma_\gamma(\omega)$ is photo-production cross section at photon energy $\omega$ and,

$$N_{EPA}(\omega) = \frac{\alpha}{\pi} \left[ \left( 1 - \frac{\omega}{E} + \frac{\omega^2}{E^2} \right) \ln \frac{q_{\max}^2}{q_{\min}^2} - \left( 1 - \frac{\omega}{2E} \right)^2 \ln \frac{\omega^2 + q_{\max}^2}{\omega^2 + q_{\min}^2} - \frac{m_e^2 \omega^2}{E^2 q_{\min}^2} \left( 1 - \frac{q_{\min}^2}{q_{\max}^2} \right) \right]$$
Electro-Production with Radiated Real Photons

The Bremsstrahlung cross section for electron of energy $E$ traveling inside a material [5]

$$ \frac{d\sigma}{d\omega} = \frac{A}{X_0 N_A \omega} \left( \frac{4}{3} - \frac{4\omega}{3E} + \frac{4\omega^2}{3E^2} \right) $$

The electro-production cross section due to Bremsstrahlung photons,

$$ d\sigma = \sigma_\gamma(\omega) \cdot N_{BREMS}(\omega) \frac{d\omega}{\omega} $$

$$ N_{BREMS}(\omega) = \frac{d}{X_0} \left( \frac{4}{3} - \frac{4\omega}{3E} + \frac{4\omega^2}{3E^2} \right) $$

Where $X_0$ is the radiation length and $d = \rho \cdot t$ where $\rho$ is target density and $t$ is target thickness.
EPA Photon Spectrum

Figure: Photon Spectrum $N_{EPA}(\omega)$
Bremsstrahlung Photon Spectrum

Bremsstrahlung $N_{\gamma}(\omega)$ for 11 GeV $e^{-}$ Beam

Figure: Photon Spectrum $N_{\text{BREMS}}(\omega)$
Complete Photon Spectrum

Figure: Photon Spectrum $N_{EPA}(\omega) + N_{BREMS}(\omega)$ for electron incident on a proton target
Electro-Production with Hall-D Generator

- Photon energy is sampled using electro-production cross section weighted distribution
- 11 GeV electron beam (50 μA) is incident into a 40 cm hydrogen target

Figure: Hall D generator now samples the photon energy using electro-production cross section weighted distribution
Electro-Production: $\pi^0$

**Figure:** $\pi^0$ Only for $\theta < 90^0$ and $P < 2$ GeV. Total cross-section is $\sim 30 \, \mu b$ for this limited kinematic phase-space.
Pion Background from Different Methods

Figure: Using EPC code (see Michael Paolone’s May 2015 collaboration meeting talk). Total cross section is $\sim 14 \, \mu b$
Pion Background from Different Methods

Figure: Using Std. Wiser Generator (see Michael Paolone’s May 2015 collaboration meeting talk). Total cross section is $\sim 80\mu b$
Summary

- Hall D generator is now configured with electro-production from proton target.
- Needs to tweak $\frac{q_{\text{max}}^2}{q_{\text{min}}^2}$ better: Paul working on this.
- Initial result match with the EPC code.
- Cross section to a factor of 2 but not sure EPC results have real photon contribution.
- Next immediate step: folding SoLID acceptance into these distribution and do a rate estimation.
- Next long term step: implement a proper Geant4 generator based on the hall D generator.
Electro-Production: $\pi^0$
Electro-Production: $\pi^-$
Electro-Production: $\pi^+$

[Graphs showing Electro-Production $\pi^+$ Kinematics from Hall D Generator]
Electro-Production : $\pi^0$

Electro-Production $\pi^0$ Momentum from Hall D Generator

Electro-Production $\pi^0$ $\theta$ from Hall D Generator
Initial Results

Electro-Production: $\pi^-$

Electro-Production $\pi^-$ Momentum from Hall D Generator

Electro-Production $\pi^-$ $\theta$ from Hall D Generator
Electro-Production : $\pi^+$

**Electro-Production $\pi^+$ Momentum from Hall D Generator**

**Electro-Production $\pi^+$ $\theta$ from Hall D Generator**
Compare Hall D vs. PDG

Compared total cross sections from Hall D low energy event generator and PDG photo-production cross sections on proton for $\gamma$ momentum less than 3 GeV
Wiser Photo-Production Cross Section

- Wiser cross section, $\sigma_i(E_\gamma)$ is computed for all the processes: $\pi^\pm$, $K^\pm$, $P^+$ and $\bar{P}^-$
- The cross section for $\pi^0$ is the average of $\pi^\pm$ cross sections
- Then all the cross sections are summed to compute the total wiser cross section
- See slide 27 for steps
Wiser Photo-Production Cross Section

![Gamma-p Cross Section Comparison](image)

- **Wiser**
- **PDG**
- **Hall D**

Cross Section (mb)

Gamma Lab Momentum (GeV)
Wiser Photo-Production Cross Section

**Figure:** Wiser cross section only for 10 deg. to 90 deg.
Wiser Code Steps

- The main FORTRAN routine returns the differential cross section per monochromatic photon beam: \( E' \frac{d^3\sigma}{dp'd\Omega} / E_\gamma \)
- Where \((E', p')\) is the hadron momentum and \(E_\gamma\) is the incident photon energy
- The total cross section for a monochromatic photon beam for \(i^{th}\) type interaction,

\[
\sigma_i(E_\gamma) = \int_{\text{phase-space}} \frac{d\sigma_i(E_\gamma)}{dp'd\Omega} dp'd\Omega
\]

- Where \( \frac{d\sigma_i(E_\gamma)}{dp'd\Omega} = \frac{p'^2}{E'} \cdot \left( E' \frac{d^3\sigma}{dp'^3} / E_\gamma \right) \cdot E_\gamma \)
- And subscript \(i\) is,
  1. \(i = 0, 1: \pi^\pm\)
  2. \(i = 2, 3: K^\pm\)
  3. \(i = 4, 5: P^+\) and \(\bar{P}^-\)

\(\pi^0\) cross section is the average of \(\pi^\pm\) cross sections
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