Hadron Elecro and Photo Production Generators: An Update

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Outline

Hadron Background

- Wiser Generator Summary
- Hall D Generator

Electro-Production Implementation

Initial Results

Wiser Generator

- Electro and photo production cross-sections derived using Wiser fits are based on SLAC $\gamma \mathrm{N} \rightarrow \mathrm{X}$
  - SLAC bremsstrahlung beam at endpoint energies of 5, 7, 9, 11, 15 and 19 GeV
  - Data were taken for 1 to 8 GeV hadrons with $\mathrm{P_T}$ values from 0.5 GeV to 2.5 GeV
- The fits return the invariant cross section for monochromatic photon beam : $\mathrm{E}' \frac{\mathrm{d}^3\sigma}{\mathrm{d}\mathrm{p}'^3}$
- Where $(\mathrm{E}', \mathrm{p}')$ is the hadron momentum and E_γ is the incident photon energy
- Wiser fits are available for $\pi^{\pm}$,$K^{\pm}$,P^{+} and $\bar{P}^{-}$ (π^0 cross section is the average of $\pi^{\pm}$ cross sections)

$$E' \frac{d^3\sigma}{dp'^3} = \left(a_1 + \frac{a_2}{\sqrt{s}} \cdot \left(1 - x_R + \frac{a_3^2}{s} \right)^{a_4} \cdot e^{a_5 \cdot M_L} \cdot e^{a_6 \cdot P_T^2 / E} \right)$$

where P_T is the transverse momentum of the hadron and a_i are fit parameters.

Wiser Generator

Photo-Production:

$$\sigma_{\mathrm{i}} = \int \mathrm{d}\omega \mathrm{N}_{\gamma}(\omega) \frac{\mathrm{d}\sigma_{\mathrm{i}}^{\gamma}(\omega)}{\mathrm{d}\omega}$$

$$\mathrm{N}_{\gamma}(\omega) = \frac{\mathrm{d}}{\mathrm{X}_0} \frac{\left(\frac{4}{3} - \frac{4\omega}{3\mathrm{E}} + \frac{4\omega^2}{3\mathrm{E}^2}\right)}{\omega}$$

Electro-Production:

$$\sigma_{\mathrm{i}} = \int \mathrm{d}\omega \mathrm{N}_{\mathrm{EPA}}(\mathrm{E}_{\mathrm{beam}}, \omega) \frac{\mathrm{d}\sigma_{\mathrm{i}}^{\gamma}(\omega)}{\mathrm{d}\omega}$$

$$\mathrm{N}_{\mathrm{EPA}}(\mathrm{E}_{\mathrm{beam}}, \omega) \simeq \ln\left(\frac{\mathrm{E}_{\mathrm{beam}}}{\mathrm{m}_{\mathrm{e}}}\right) \frac{\alpha}{\pi} \frac{1 + (1 - \frac{\omega}{\mathrm{E}_{\mathrm{beam}}})^2}{\frac{\omega}{\mathrm{E}_{\mathrm{beam}}}}$$

Where ω is the photon energy and $\mathrm{E}_{\mathrm{beam}}$ is the electron beam energy

Issues with Wiser Generator

- The kinematics regions compatible with the wiser fit do not include all the phase-space of SoLID acceptance.
- The validity of the Wiser fit is checked using different data set obtained from SLAC and published in the reference [1] (Boyarski et. al.)

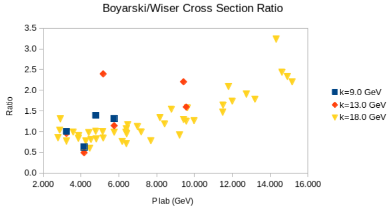

Figure: Cross section ratio for all transverse momentum

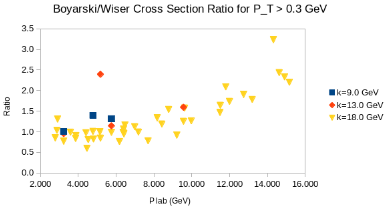

Figure: Cross section ratio for transverse momentum greater than 0.3 *GeV*

Hall D Photo-Production Generator

- Hall D generator uses various experimental data to generate photo-production cross sections for photon energies below $3\ \mathrm{GeV}$
- It uses modified version of PYTHIA to generate photo-production cross sections for photon energies above $3\ \mathrm{GeV}$
  - Hall D generator support from Eugene Chudekov and Mark Ito

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

1. $p^+ + \pi^0$
2. $n + \pi^+$
3. $p^+ + \pi^+ + \pi^-(non - res.)$
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 γ momentum less than $3\ \mathrm{GeV}$ it uses combination of different models including SAID
- For γ momentum greater than $3\ \mathrm{GeV}$ it uses PYTHIA

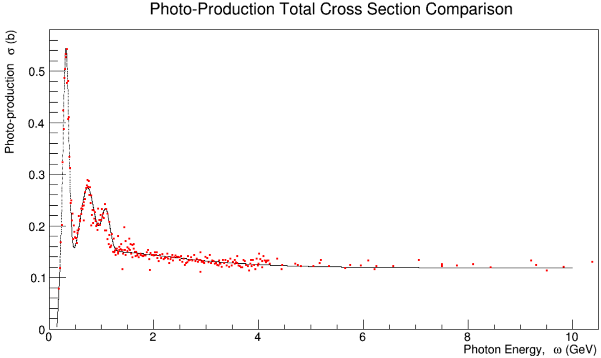

Figure: Black line : Hall D genertor, Red points : PDG

From Photo-Production to Electro-Production

- Hadron Production can takes place either from real bremsstrahlung photon radiated in the target or from virtual photon interaction approximated by Equivalent Photon Radiator (EPA) approximation
  - Bremsstrahlung contribution is implemented following PDG-2012 [2] and [3]
  - EPA contribution is implemented according to the reference [4]
- Next few slide will summarize the electro-production implementation

Electro-Production with Equivalent Photon Approximation

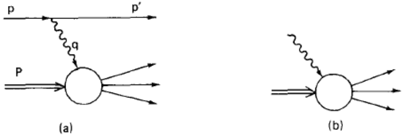

Figure: Electro-Production (a) and Photo-Absorption (b) equivalency [4]

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

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

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

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

$$N_{EPA}(\omega) = \frac{\alpha}{\pi}\left[\left(1 - \frac{\omega}{E} + \frac{\omega^2}{E^2}\right) ln\frac{q^2_{max}}{q^2_{min}} - \left(1 - \frac{\omega}{2E}\right)^2 ln\frac{(\omega^2+q^2_{max})}{(\omega^2+q^2_{min})} - \frac{m_e^2\omega^2}{E^2 q^2_{min}}\left(1 - \frac{q^2_{min}}{q^2_{max}}\right)\right]$$

Electro-Production with Radiated Real Photons

The Bremsstrahlung cross section for electron of energy E traveling inside a material [2]

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

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 ρ is target density and t is target thickness

Electro-Production with Hall-D Generator

- Photon energy is sampled using electro-production cross section weighted distribution
  - Where the total cross section is the sum of real (Bremsstrahlung) and virtual (EPA) contributions
- $11\ \mathrm{GeV}$ electron beam $(50\ \mu\mathrm{A})$ is incident into a $40\ \mathrm{cm}$ hydrogen target

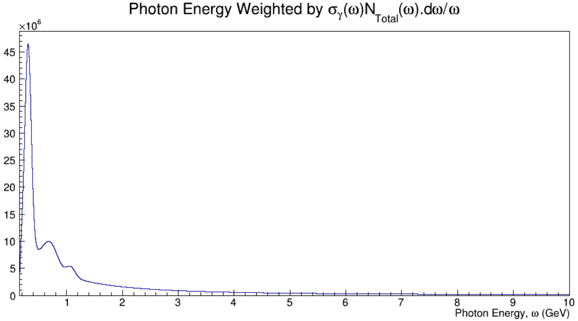

Figure: Hall D generator now samples the photon energy using electro-production cross section weighted distribution

Hall D Electro-Production : π^0

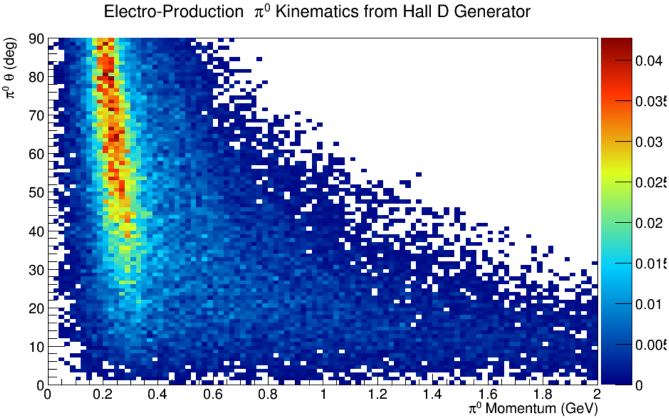

Figure: π^0 Only for $\theta < 90^0$ and $P < 2$ GeV. Total cross-section is ~ 30 μb for this limited kinematic phase-space

Geant4 Electro-Production : π^0

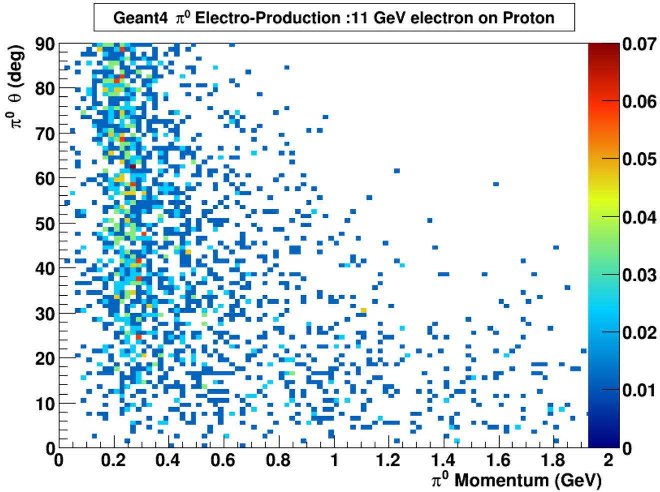

Figure: π^0 Only for $\theta < 90^0$ and $P < 2$ GeV. Total cross-section is $\sim 24\ \mu\mathrm{b}$ for this limited kinematic phase-space

Wiser Electro-Production : π^0

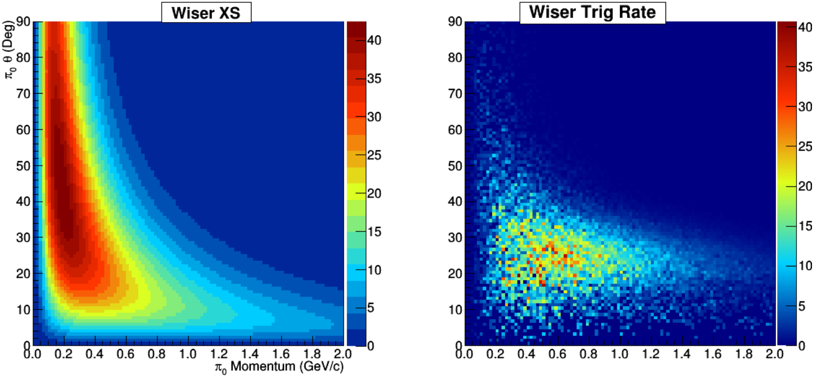

Figure: Using Std. Wiser Generator, the total cross section is $\sim 80\mu\mathrm{b}$

Next-Steps

At present the Hall D based MC generator is a standalone program that generate final state hadrons for 11 *GeV* electron beam incident on 40 *cm* liquid hydrogen target. Following is list of short term goals with this generator.

- Use final state pion distributions from Hall D based MC generator as an input to Remoll-SoLID (SoLID Geant4 simulation package) to obtain hadron background
  - This step requires few technical implementation to Remoll-SoLID to read above input
- Compare new hadron background rates with Wiser background rates
- Repeat a trigger rate estimation study for updated hadron background

Wiser Generator to Get Total Photo-Production Cross Sections

- Wiser fits for electron production cross-sections are based on SLAC $\gamma N \rightarrow X$
- The fits return the invariant cross section for monochromatic photon beam : $E' \frac{d^3\sigma}{dp'^3}$
- Where (E', p') is the hadron momentum and E_γ is the incident photon energy
- The total Photo-Production cross section for a monochromatic photon beam for i^{th} type interaction,

$$\sigma_i(E_\gamma) = \int_{phase-space} E' \frac{d^3\sigma}{dp'^3} dp'^3$$

- Where subscript i is,

1. $i = 0, 1 : \pi^\pm$
2. $i = 2, 3 : K^\pm$
3. $i = 4, 5 : P^+$ and $\bar{P}^-$

π^0 cross section is the average of $\pi^\pm$ cross sections

Photo-Production with Radiated Real Photons

The Bremsstrahlung cross section for electron of energy E traveling inside a material [2]

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

The electro-production cross section due to Bremsstrahlung photons,

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

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

Where X_0 is the radiation length and $d = \rho \cdot t$ where ρ is target density and t is target thickness

EPA Photon Spectrum

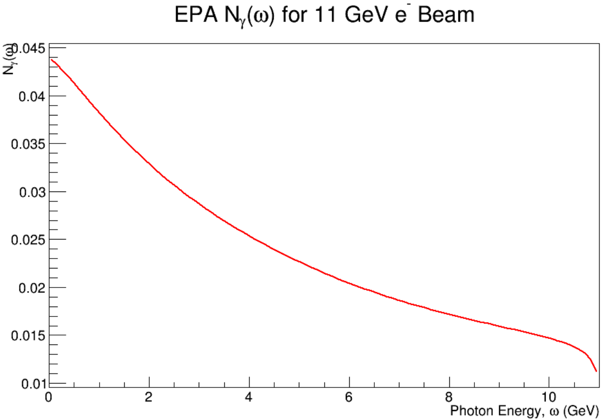

Figure: Photon Spectrum $N_{EPA}(\omega)$

Bremsstrahlung Photon Spectrum

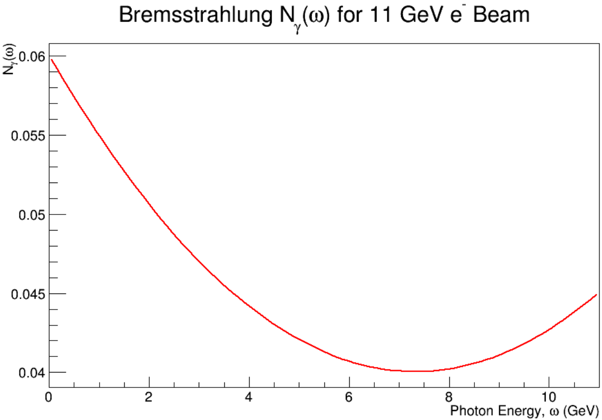

Figure: Photon Spectrum $N_{BREMS}(\omega)$

Complete Photon Spectrum

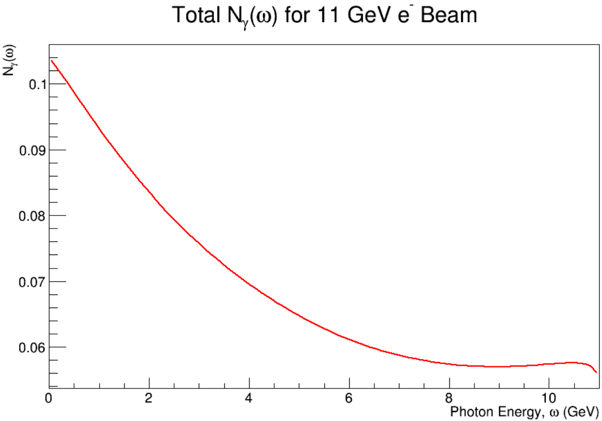

Figure: Photon Spectrum $N_{EPA}(\omega) + N_{BREMS}(\omega)$ for electron incident on a proton target

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