Hadron Generator Summary

Rakitha S. Beminiwattha
Syracuse University

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1 Wiser Generator

Wiser electro-production generator is based on photo-production cross-sections derived using fits to data from SLAC γN $\rightarrow$ X [1]. Fits are based on data taken for 1 to 8 GeV hadrons with $\mathrm{P_T}$ values from 0.5 GeV to 2.5 GeV using SLAC bremsstrahlung beam at endpoint energies of 5, 7, 9, 11, 15 and 19 GeV. The fits return the invariant cross section for monochromatic photon beam,

$$E' \frac{d^3\sigma}{dp'^3}(\omega) \tag{1}$$

where $(\mathrm{E}', \mathrm{p}')$ is the hadron momentum and ω 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). The final form of the fit for the invariant cross section for monochromatic photon beam was

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

where P_T is the transverse momentum of the hadron and a_i are fit parameters. The above fit is only applicable for $\pi^{\pm}$,$K^{\pm}$, and $\bar{P}^{-}$ only. There is a separate fit for P^{+} photo-production and see Wiser thesis for more details on the fit and fit parameters. An executive summary of the Wiser generator which is based on above fit is given in the reference [2]

The kinematics regions compatible with the wiser fit do not include all the phase-space of SoLID acceptance. No data available for the hadrons with momentum less than 1 GeV and at smaller transverse momentum. The validity of the Wiser fit is checked using different data set obtained from SLAC and published in the reference [3] (Boyarski et. al.). The Boyarski data set is based on end point photon energies of 18 GeV, 13 and 9 GeV. The measurements were made using the SLAC 20 GeV spectrometer. The photo-production cross section ratio of Boyarski data to Wiser fit are shown in Figures 1 and 2.

There are the significant differences that are relevant to SoLID as well as MOLLER. For low transverse momentum (P_T), Boyarski data is low probably because Wiser is wrong. The low P_T points are out of Wiser fit range and the assumption about the Wiser uses an exponential fit to P_T, which fails at low P_T where there is no Wiser data. Boyarski data is high at large hadron momentum (P_{lab}), above 10 GeV and it is probably correct. Notice that Wiser used a 8 GeV spectrometer and higher energy range is only extrapolated.

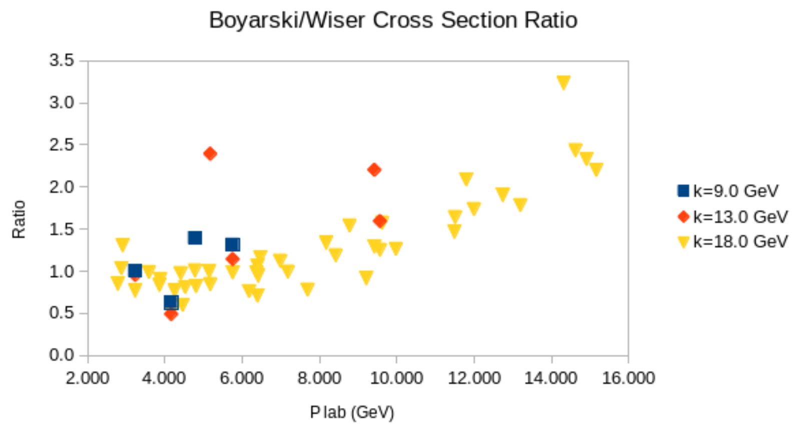

Figure 1: Cross section ratio for all transverse momentum

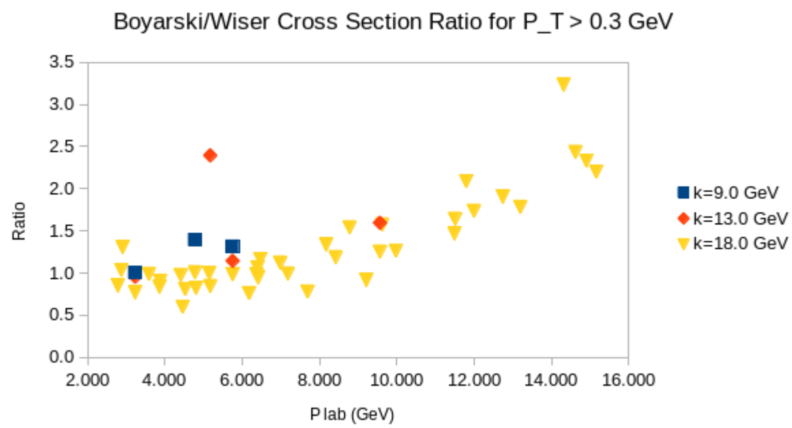

Figure 2: Cross section ratio for transverse momentum greater than 0.3 GeV

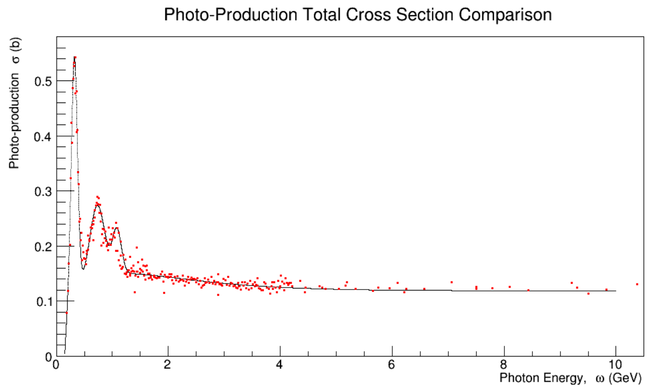

Figure 3: Black line : cross section from Hall D generator, Red points : from PDG.

2 Hall D Generator

Hall D MC generator was studies as a potential candidate for SoLID experiment. Hall D photo-production generator uses various experimental data to generate photo-production proton cross sections for photon energies below 3 GeV [4, 5]. Following $\gamma + p^{+}$ reactions are considered for photon energies below 3 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. $n + \pi^{+} + \pi^{+} + \pi^{-}$

It uses modified version of PYTHIA to generate photo-production proton cross sections for photon energies above 3 GeV [4, 5]. A simple comparison of total photo-production cross sections extracted from the Hall D generator agrees well with the PDG data [6] as shown in the Figure 3

The hall D generator is only a photo-production Monte-Carlo (MC) event generator. SoLID experiment requires electro-production MC generator. Next section summarizes the electro-production implementation for Hall D MC generator.

3 Electro-Production with Hall D Generator

Hadron Production in electron nucleon interactions can originate either from real bremsstrahlung photon radiated in the target or from virtual photon interaction with the nucleons. The virtual contribution is approximated by Equivalent Photon Radiator (EPA) approximation [7]. The Bremsstrahlung contribution is implemented following PDG-2012 [6, 8] and EPA contribution is implemented according to the reference [7]

3.1 Hadron Production with Bremsstrahlung Photons

The Bremsstrahlung cross section (photon energy ω) for electron of energy E traveling inside a material [6] was given by

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

and the hadron production cross section due to Bremsstrahlung photons,

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

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

3.2 Hadron Production Approximated with EPA Photons

The electro-production cross section for electron energy E is obtained using the Equivalent Photon Approximation (EPA) as shown in Figure 4. The hadron production cross section with EPA photons was,

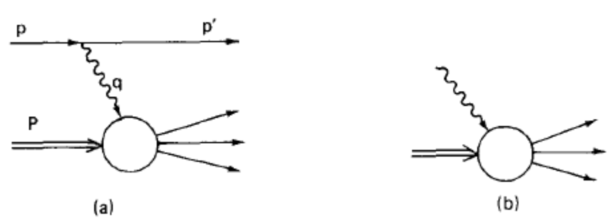

Figure 4: Electro-Production (a) and Photo-Absorption (b) equivalency [7]

$$d\sigma = \sigma_\gamma(\omega) \cdot dn(\omega) \tag{5}$$
$$dn(\omega) = \int_{q^2_{min}}^{q^2_{max}} dn(\omega, q^2) \qquad = N_{EPA}(\omega)\frac{d\omega}{\omega}$$

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

$$N_{EPA}(\omega) = \frac{\alpha}{\pi}\left[\left(1-\frac{\omega}{E}+\frac{\omega^2}{E^2}\right) ln\frac{q_{max}^2}{q_{min}^2} - \left(1-\frac{\omega}{2E}\right)^2 ln\frac{(\omega^2+q_{max}^2)}{(\omega^2+q_{min}^2)} - \frac{m_e^2\omega^2}{E^2 q_{min}^2}\left(1-\frac{q_{min}^2}{q_{max}^2}\right)\right] \quad (6)$$

The total hadron production cross section in electro-production can be approximated to be the sum of real photon contribution and EPA approximated virtual contribution (eq. 4 and 5). With this implementaion, the electro-production MC generator will now sample its photon energy based on the total hadron production cross section weighted photon distribution. This sampling photon distribution is obtained for 11 GeV electron beam (50 μA) incident on a 40 cm hydrogen target (Figure 5).

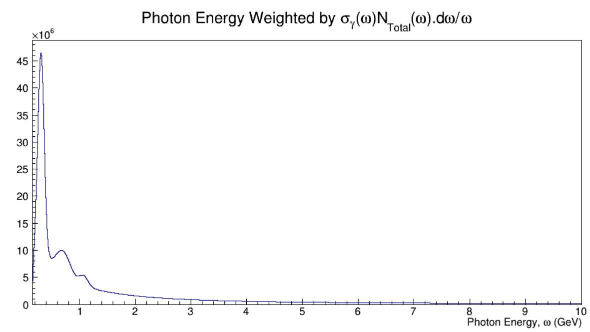

Figure 5: Hall D based MC generator now samples the photon energy using electro-production cross section weighted photon distribution

4 Initial Results and Comparisons

As an initial test π^0 electron production is compared with Geant4 simulation. In this test Hall D based MC generator is ran for 11 GeV electron beam incident on 40 cm liquid hydrogen target. The final state π^0 momentum and scattering angle distribution is plotted in Figure 6. Geant4 simulation (version 4.9.6.p01 and using physics list QGSP_BERT) was done using 11 GeV electron beam incident on 40 cm liquid hydrogen target. The π^0 momentum and scattering angle distribution is plotted in Figure 7. The results from Hall D based MC generator for π^0 production and Geant4 simulation agree to within 20%. Also note that Geant4 simulation has very limited statistics (only about 3×10^3 π^0 after 5×10^7 electrons)

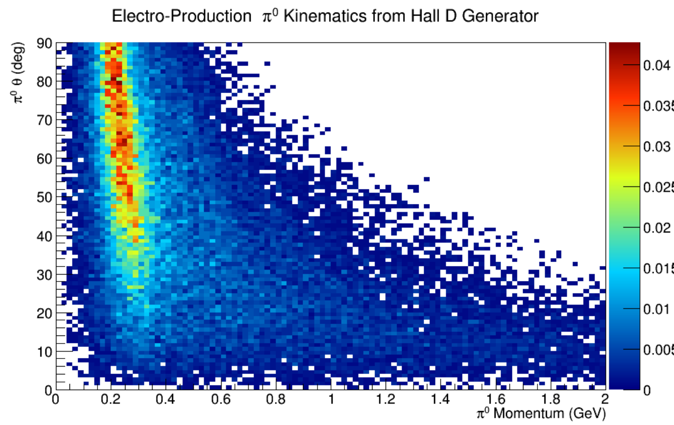

Figure 6: Using Hall D based MC generator, π^0 Only for $\theta < 90^0$ and $P < 2\ GeV$. Total cross-section is $\sim 30\ \mu$b for this limited kinematic phase-space.

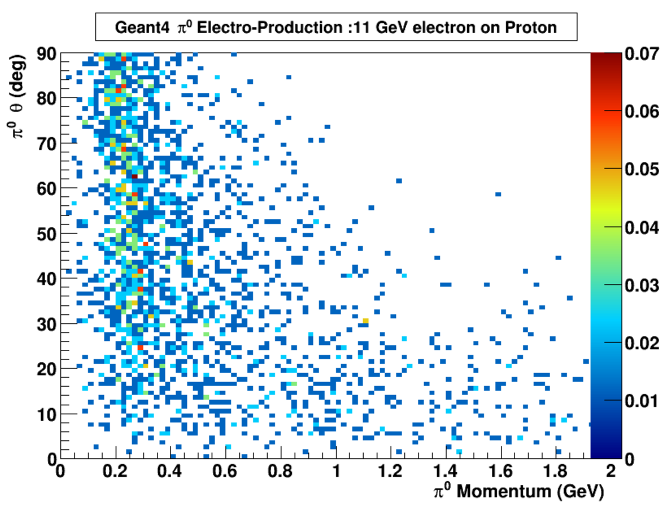

Figure 7: Using Geant4, π^0 Only for $\theta < 90^0$ and $P < 2\ GeV$. Total cross-section is $\sim 24\ \mu$b for this limited kinematic phase-space.

5 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

References

[1] David E. Wiser. *Inclusive Photoproduction of Protons, Kaons, and Pions at SLAC Energies*. PhD thesis, Wisconsin U., Madison, 1977.

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