Yield normalization

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1 Formula for normalizing yields

Equation 4.14 from Gleb's analysis note, in the absence of Empty-Target-Background-Subtraction terms and with some re-grouping and some new definition of terms and symbols can be written as

$$\frac{\Delta^7 \sigma^{ep \to e' p' \pi^+ \pi^-}}{\Delta W \Delta Q^2 \Delta^5 \tau} = \frac{1}{L} \frac{1}{F \cdot F_{cherenkov} \cdot R} \frac{\Delta^7 N_R^{ep \to e' p' \pi^+ \pi^-}}{\Delta W \Delta Q^2 \Delta^5 \tau} \tag{1}$$

where

- $\Delta^7 N_R^{ep \to e' p' \pi^+ \pi^-}$ = Reconstructed events in a 7D cell specified by binning in $Q^2, W, M1, M2, \theta, \phi, \alpha$
- F=Acceptance*Efficiency factor in a 7D cell obtained from Simulation
- $F_{cherenkov}$ = Efficiency factor in a 7D cell for the Cherenkov detector
- R=Radiative correction factor in a 7D cell
- $L = \frac{Q_{tot} l_t D_t N_A}{q_e M_H}$

Equation 4.15, also from Gleb's analysis note, which is used to extract the Cross Section for the Hadronic Interaction, is directly reproduced here

$$\frac{\Delta^5 \sigma^{\gamma^* p \to p' \pi^+ \pi^-}}{\Delta^5 \tau} = \frac{1}{\Gamma_v} \frac{\Delta^7 \sigma^{ep \to e' p' \pi^+ \pi^-}}{\Delta W \Delta Q^2 \Delta^5 \tau} \tag{2}$$

where

- $\Gamma_v = \frac{\alpha}{4\pi} \frac{1}{E^2 M_p^2} \frac{W(W^2 - M_p^2)}{(1-\epsilon) Q^2}$ (Gleb 4.17)

- $\epsilon = \frac{1}{1+\frac{2(Q^2+\omega^2)}{4EE'-Q^2}}$ (Gleb 4.18 re-formulated)

Therefore, from Eq. 2

$$\sum_{\Delta^5\tau} \frac{\Delta^5\sigma^{\gamma^* p\to p'\pi^+\pi^-}}{\Delta^5\tau}\Delta^5\tau = \sum_{\Delta^5\tau} \frac{1}{\Gamma_v}\frac{\Delta^7\sigma^{ep\to e'p'\pi^+\pi^-}}{\Delta W\Delta Q^2\Delta^5\tau}\Delta^5\tau \tag{3}$$

Substituting a part of RHS of Eq. 3 from Eq. 1

$$\sum_{\Delta^5\tau} \frac{\Delta^5\sigma^{\gamma^* p\to p'\pi^+\pi^-}}{\Delta^5\tau}\Delta^5\tau = \sum_{\Delta^5\tau} \frac{1}{\Gamma_v}\underbrace{\frac{1}{L}\frac{1}{F\cdot F_{cherenkov}\cdot R}\frac{\Delta^7 N_R^{ep\to e'p'\pi^+\pi^-}}{\Delta W\Delta Q^2\Delta^5\tau}}_{\frac{\Delta^7\sigma^{ep\to e'p'\pi^+\pi^-}}{\Delta W\Delta Q^2\Delta^5\tau}}\Delta^5\tau \tag{4}$$

Carrying on mathematically,

$$\sum_{\Delta^5\tau} \frac{\Delta^5\sigma^{\gamma^* p\to p'\pi^+\pi^-}}{\Delta^5\tau}\Delta^5\tau = \frac{1}{\Gamma_v}\frac{1}{L}\frac{1}{\Delta W\Delta Q^2}\sum_{\Delta^5\tau}\frac{1}{F\cdot F_{cherenkov}\cdot R}\frac{\Delta^7 N_R^{ep\to e'p'\pi^+\pi^-}}{\Delta^5\tau}\Delta^5\tau \tag{5}$$

Therefore, finally we obtain the following formula for the Integrated Hadronic Cross Section in a Q2-W bin ($[Q^2+\Delta Q^2, W+\Delta W]$)

$$\sigma^{\gamma^* p\to p'\pi^+\pi^-} = \frac{1}{\Gamma_v}\frac{1}{L}\frac{1}{\Delta W\Delta Q^2}N^{ep\to e'p'\pi^+\pi^-} \tag{6}$$

where

- $$N^{ep\to e'p'\pi^+\pi^-} = \sum_{\Delta^5\tau}\frac{1}{F\cdot F_{cherenkov}\cdot R}\frac{\Delta^7 N_R^{ep\to e'p'\pi^+\pi^-}}{\Delta^5\tau}\Delta^5\tau$$

- Γ_v is evaluated at the center of the bin.

Therefore, to calculate the Integrated Cross Section in a $Q^2 - W$ bin, one can simply count all the Events in that bin and divide it by the $Q^2 - W$ bin width multiplied by the Luminosity and the Virtual Photon Flux.

2 Technical implementation of the formula

- My data is organized in 7D histograms (:= h7) (ROOT's THnSparse Objects), where the 7 dimensions are:$Q^2, W, M1, M2, \theta, \phi, \alpha$.
- The histogram is binned as per the binning requirements of the finally needed Observables.

Therefore, in order to implement Eq. 6, I take the following steps:

1. Set the appropriate range in Q2,W dimensions for h7
2. Project h7 onto $M1, M2, \theta, \phi, \alpha$(:= h5)
   - In Simulation: h5-ST,h5-SR $\rightarrow$ h5-SA
     (ST=Sim. Thrown, SR=Sim. Reconstructed, SA=Sim. Acceptance)
   - In Experiment: h5-ER,h5-SA $\rightarrow$ h5-EC $\rightarrow$ h5-EH $\rightarrow$ h5-EF(=h5-EC+h5-EH)
     (ER=Exp. Reconstructed,EC=Exp. Acceptance Corrected,EH=Exp. Holes,EF=Exp. Acceptance and Hole Corrected)
3. $N^{ep\rightarrow e'p'\pi^+\pi^-}$=Get total entries(=total number of Events) in h5-EC (and h5-EF to keep track of Holes)
4. Divide $N^{ep\rightarrow e'p'\pi^+\pi^-}$ by $\Gamma_v L \Delta W \Delta Q^2$

3 Term by term analysis of the results obtained using the formula

My Cross Section, currently, is lower by a factor of ≈4 as compared to data from Ripani at $Q^2 bin = [1.1, 1.5] GeV^2$. Generally the matter could be that

1. N_R is less by a factor of 4
2. L is larger by a factor of 4
3. $\Gamma_v \cdot \Delta W \cdot \Delta Q^2$ is larger by a factor of 4

4. $F \cdot F_{cherenkov} \cdot R$ is overestimated and that leads to underestimated N by a factor of 4

Following is a term by term analysis and on their refinement, possible effect on the Cross Section:

3.1 N_R: Possible effect: Not determined

- Run over 576 Golden Runs for E1F as identified by Wes Gohn (11790 files).
- Investigating
  - Possible errors relating to techincalities of going from data in 11790 files $\rightarrow$ h7 $\rightarrow$ h5 $\rightarrow$ N

3.2 L: Possible effect: Marginally increase Cross Section

- Estimated a Luminosity of $\approx 20fb^{-1}$from Golden Runs for E1F.
- I expect the Luminosity to marginally decrease after
  - File-by-file Luminosity analysis is done. This has to be done because not only are 208 files missing at the beginning of a Run, but also 70 files from in between a Run; Due to the tecnicalities of how Q_{FC} is stored in the files, calculation of Q for a Run has to be done on a file-by-file basis to get the most accurate measure of Luminosity.

3.3 $\Gamma_v \cdot \Delta W \cdot \Delta Q^2$: Possible effect: Not determined

- Is my formula for ϵ equivalent to Gleb's?
- $\Gamma_v \cdot \Delta W \cdot \Delta Q^2$ with Γ_v evaluated at the center of the bin is within +/-2%-3% of result of integration.

3.4 $F \cdot F_{cherenkov} \cdot R$: Possible effect: increase in Cross Section, upto $> 10\%$

- Currently $F_{cherenkov} = R = 1$ i.e. these correction factors have not been determined; when determined, I expect them to increase $\Delta^7 N$ in each 7D cell and therefore increase the total yield.
- F
  - Missing Mass cuts currently do not have the same efficiency in Experiment and Simulation. Efficiency of the cut in Experiment is generally lower and this leads to a (theoreticaly estimated) underestimation of the Acceptance Corrected yield by upto a factor of 10% level at the highest W bin.

4 Comparison with Evan's $p\omega$ Cross Section

The following is relevant only if at $W \approx 1.8 GeV$, Cross Section from $p\pi^+\pi^-$ can be compared with $p\omega$. If so then:

- Are Evan and I in agreement and together, in systematic disagreement with the true Cross Section?