LHRS Analysis Update for d_2^n

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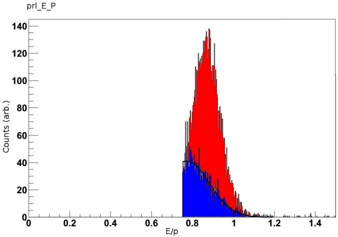
Outline

Contamination Studies

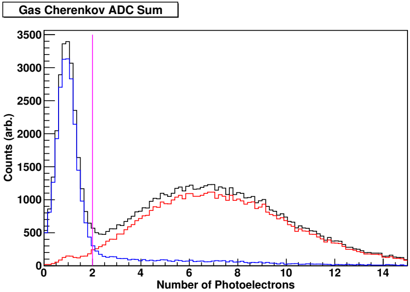
PID Detectors: Gas Čerenkov and Pion Rejector

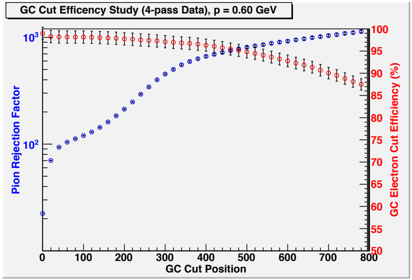
- When calculating cut efficiencies for the PID detectors, one needs to select a very clean e^- sample
- Due to our kinematics, these samples were difficult to achieve (a lot of π^-)
- Example: Calculating the efficiency of the gas Čerenkov:
  1. Make an e^- selection in a given detector (PR)
  2. Examine this distribution using GC cuts
  3. Correct the original sample by subtracting off the π^-
  4. Calculate the cut efficiencies



Gas Čerenkov

Efficiencies

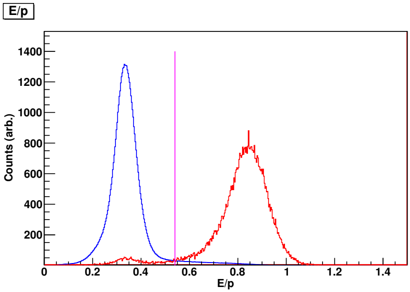


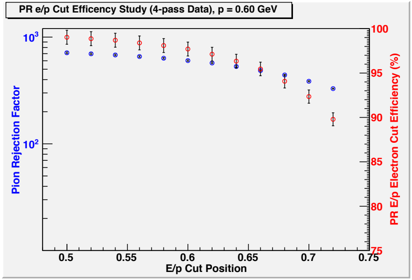


- Cut: GC $>$ 2 p.e. (400 ADC channels)
- $\varepsilon \sim$ 96%
- π-rejection factor $\sim$ 680
- Results are consistent across the whole kinematic range

Pion Rejector

Efficiencies





- Cut: E/p > 0.54
- $\varepsilon \sim 99\%$
- π-rejection factor ~ 600
- Combined with the GC: π-rejection $> 10^4$
- Results are consistent across the whole kinematic range

VDC (1)

Efficiencies: Description

- For our physics studies, we choose one-track events $\Rightarrow$ there's an efficiency tied to this cut
- The inefficiency of the VDC is attributed to no-track events and multi-track events
  - The inefficiency is dominated by the latter case, arising from many particles traversing the planes of the VDC, which results in a large number of possible trajectories that could be reconstructed by the software
- The efficiency of the one-track cut is given as:

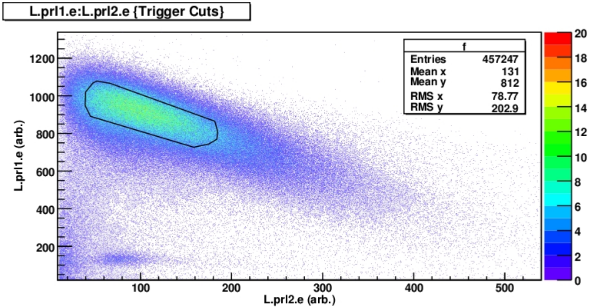
$$\varepsilon_1 = \frac{N_1}{\sum_{i=0}^{4} N_i}$$

Note: The VDC software reconstructs up to four tracks per event

VDC (2)

Efficiencies: Special Electron Cut in PR

- Since E/p relies on tracking (in p), we cannot use this cut when choosing electrons for the study
    - Use a graphical cut:



VDC (3)

Efficiencies: Results

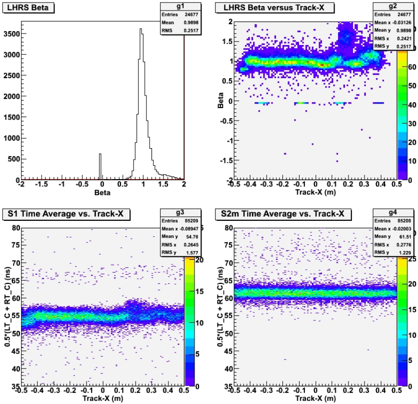
VDC Tracking Efficiency for Elastic Data		
# of Tracks	# of Events	ε (%)
0	16	0.003 ± 0.001
1	526460	98.981 ± 0.192
2	4946	0.929 ± 0.013
3	425	0.079 ± 0.004
4	33	0.006 ± 0.001

- $\varepsilon_1 \sim$ 99%, total inefficiency $\lesssim$ 1%
- Consistent across the whole kinematic range

Scintillator Analysis (1)

Identifying the Problem

- For the scintillators, what is typically done is that the self-timing peaks of the right TDCs of S2m are aligned, and from there the left side TDCs are aligned along with those S1
- After doing such, we still saw jitter in the S1 TDC times as a function of track-x:



Scintillator Analysis (2)

An Event-by-Event Approach: Points to Keep in Mind

- In order to correct the jitter we see in S1, we consider a few things:
  1. The raw S2m times are not aligned. The δ_j needed to align the TDC time for each paddle of index j should be (essentially) applied to the S1 paddles (as a starting point)
  2. For a given S2m paddle (of index j) that takes the trigger timing, there should be a correlated event for one of the S1 paddles (of index i)
  3. For a given S1 paddle, there should be a certain time difference Δt_{ij} for the j^{th} paddle in S2m that took the timing. Ideally, for a given i, these times would be virutally the same; however, they are not.

Scintillator Analysis (3)

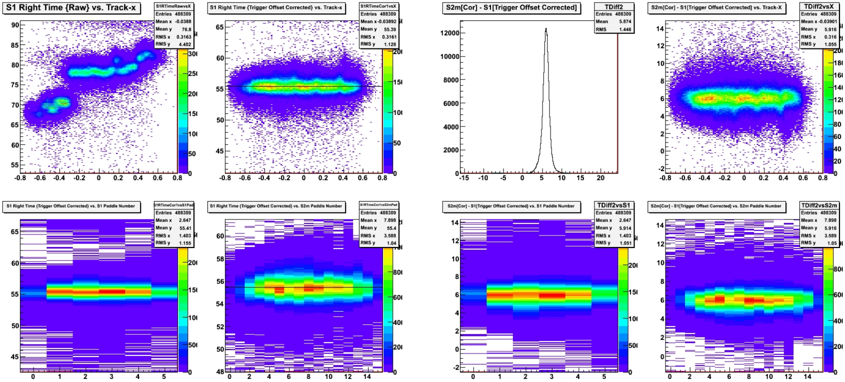
An Event-by-Event Approach: Procedure

- Given the points on the previous slide, we first align the S2m right raw times (yielding `L.s2.rt_c[j]`)
- From here we proceed as follows:
  1. Going event by event, we see which S2m paddle took the trigger time (i.e., the event has a time in the self-timing peak in S2m paddle j)
  2. For this event, we then scan through the S1 paddles to see which paddle it fired (call this paddle i)
  3. Form the time difference $t_{ij} = t_j^{s2m} - t_i^{s1}$. In total, there are 96 possible combinations, forming a matrix T_{ij}. We only consider 18 of the t_{ij} (based on the paddle mapping of S2m to S1); all other entries are set to zero.
  4. The new S1 time is formed as ($f = 0.05$ ns/ch.):

$$t_{i,cor} = f \times t_{i,raw} + t_{ij}$$

Scintillator Analysis (4)

An Event-by-Event Approach: Results



Trigger Efficiencies

Method

- For the main (T3) trigger efficiency, one usually considers the T4 trigger – as this variable gives the inefficiency of the T3 trigger:

$$\varepsilon_{T3} = \frac{N_{T3}}{N_{T3} + N_{T4}}$$

  - N_j = $ps_j \times \text{bit}_j$ for $j = T3, T4$
  - $ps_j =$ prescale for trigger j
  - $\text{bit}_j =$ bit pattern for trigger j (from the variable DL.bitj)
- There are a few points at which we can lose track of a T3 trigger:
  1. We generate a T3, and does not pass the prescale condition (depsite the fact that $ps = 1$ for production) at the Trigger Supervisor (TS)
  2. We generate a T3, it passes the prescale condition, but does not pass the L1A – a T4 beat it there

- Sample calculation for run 20676:

$$\begin{aligned} ps_3 &= ps_4 = 1 \\ N_{T3} &= 12275 \\ N_{T4} &= 4 \\ \varepsilon_{T3} &= \frac{12275}{12275+4} \times 100\% = 99.96\% \end{aligned}$$

- Such results are typical for all runs

Live Time Calculation (1)

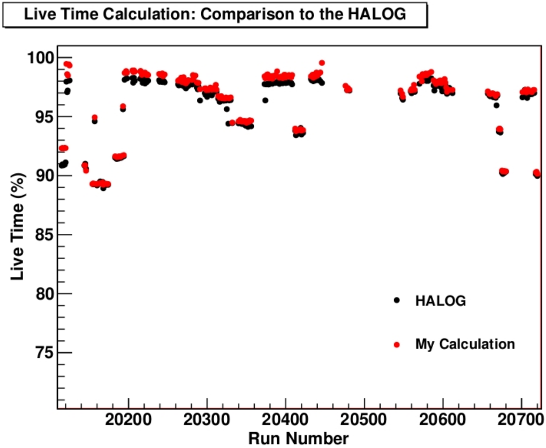
Method

$$
\begin{aligned}
t_{LT} &= \frac{evtypebits3}{t3c} \\
evtypebits3 &= \text{\# of (T3) triggers recorded for a given run} \\
t3c &= \text{\# of (T3) triggers generated for a given run}
\end{aligned}
$$

- Beam trips are removed in this study
  (see Data Quality section)

Live Time Calculation (2)

Results



- Percent difference compared to HALOG is $< 1\%$

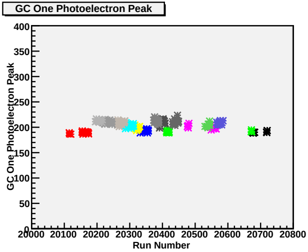
Data Quality (1)

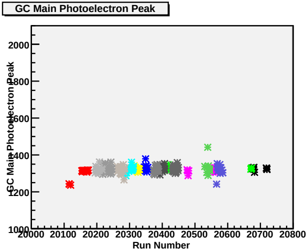
Overview

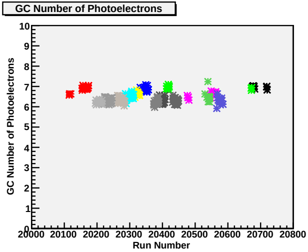
- After all the calibrations are implemented, we check each run to make sure that various quantities are behaving as expected (should be stable):
  1. Gas Čerenkov ADC 1 p.e. calibration
  2. Pion Rejector E/p calibration
  3. VDC t_0
- Find and remove beam trips

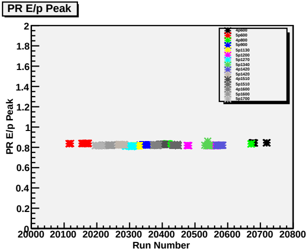
Data Quality (2)

Gas Čerenkov and Pion Rejector



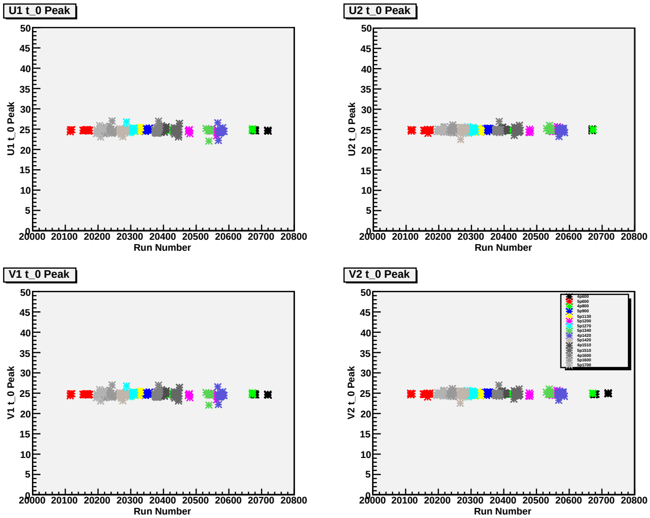






Data Quality (3)

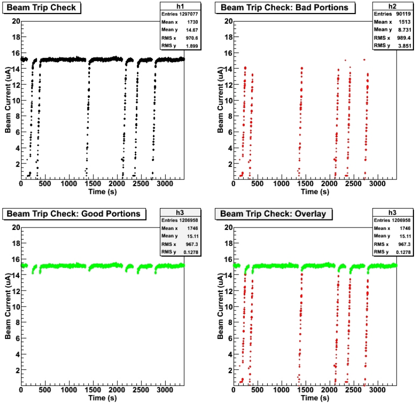
VDC t_0



Data Quality (2)

Beam Trips

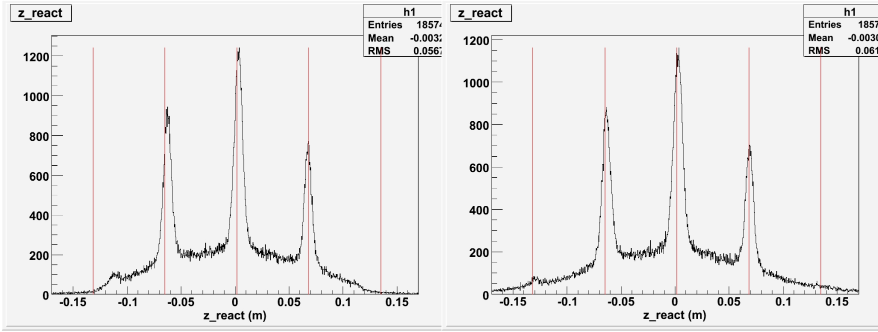
- During the course of a run, there are instances when the beam current drops
- Events correlated to these ‘trips’ are not desired in the final analysis
- Plot the beam current as a function of time and choose cuts (in time) to remove the trips
  - Manifested as a new ROOT variable for the analysis



Optics Matrix

Before and After

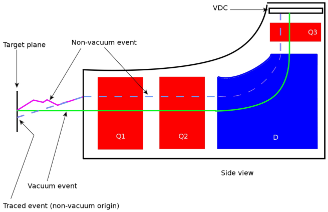
- Left: Original optics matrix; Right: Jin's optics matrix from Transversity



Single Arm Monte Carlo (1)

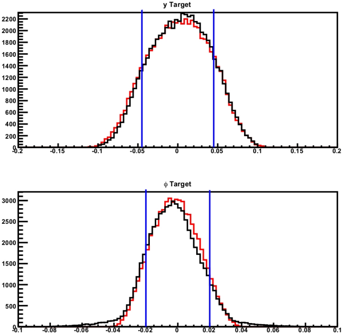
Sample Event

1. The event is generated at the target (t_{gen})
2. If the event reaches the focal plane, it is then traced back to the target (t_{ref})
   - This process assumes a vacuum between the Q1 magnet entrance and the target plane
3. Utilizing the transport matrix (J. LeRose), the event is constructed at the focal plane: $M t_{\text{ref}} = t_{fp}$
4. The reconstructed event at the target is then determined by: $M^{-1} t_{fp} = t_{\text{rec}}$



SAMC (2)

Comparison to Data



- Color code: simulation data
- Blue lines indicate cut positions

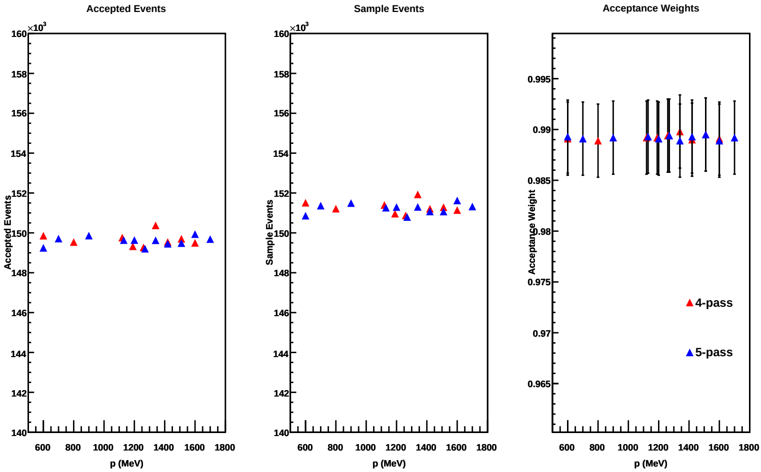
SAMC (3)

Acceptance Weight: Method

1. Generate events normally-distributed in y_{tg}, θ_{tg}, ϕ_{tg} and $\delta p/p$
2. Propagate them through the various apertures of the LHRS
3. If the event passes to the focal plane, it is accepted as a good event
4. The ratio of the number of events that pass to the focal plane to the generated distribution (each within cuts) gives the acceptance weight w

SAMC (4)

Acceptance Weight: Results



From σ_{raw} to σ_{exp} (1)

Descriptions and Definitions

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{N_{\text{cut}}}{(Q/e)\rho t_{LT}\varepsilon} \frac{1}{w\Delta E'\Delta\Omega\Delta Z}$$

N_{cut}	$=$	Number of e^- that pass all cuts
Q/e	$=$	Number of beam e^-
ρ	$=$	Target density [Amg]
t_{LT}	$=$	Live time
ε	$=$	Product of all detector (cut) efficiencies
w	$=$	Acceptance weight (from SAMC)
$\Delta E'$	$=$	Energy width [MeV] $(2 \cdot p_0 \cdot \delta p/p)$
$\Delta\Omega$	$=$	Solid angle [sr] $(\Delta\theta\Delta\phi)$
ΔZ	$=$	Target length seen by the spectrometer [cm]

From $\sigma_{\rm raw}$ to $\sigma_{\rm exp}$ (2)

Removing Background Signals

- In order to obtain the experimental cross section, we need to subtract off a few different contributions due to the presence of nitrogen in the target and pair-produced e^- according to:

$$\frac{d^2\sigma_{\rm exp}}{d\Omega dE'} = \frac{d^2\sigma_{\rm raw}}{d\Omega dE'} - \frac{d^2\sigma_{{\rm dil},-}}{d\Omega dE'} - \left(\frac{d^2\sigma_{e^+}}{d\Omega dE'} - \frac{d^2\sigma_{{\rm dil},+}}{d\Omega dE'}\right)$$

where:

$$\frac{d^2\sigma_{\rm dil}}{d\Omega dE'} = \frac{\rho_{\rm N}}{\rho_{\rm N} + \rho_{^3{\rm He}}}\frac{d^2\sigma_{\rm N}}{d\Omega dE'}$$

$$\frac{d^2\sigma_{e^+}}{d\Omega dE'} = \text{positron cross section}$$

$$\rho_i = \text{Filling densities of N or } {}^3\text{He (prod. cell)}$$

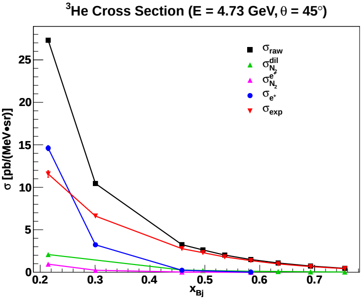
From σ_{raw} to σ_{exp} (3)

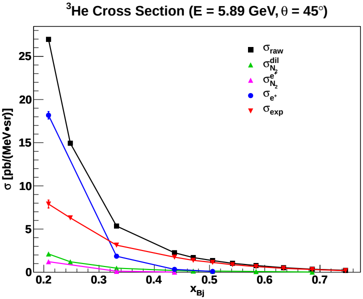
Electron Cuts

- One track: `L.tr.n==1`
- Triggers:
  `(DL.edtpl==0)&&((DL.evtypebits&(1<<3))==(1<<3))`
- VDC: `L.vdc.u1.nclust==1` (same for U2, V1 and V2)
- GC: `L.cer.asum_c>400` (2 p.e.) and TDC cuts
- PR: `(prl_E_P>0.54)&&(L.prl1.e>200)`
- β: `L.tr.beta>-0.15`
- No beam trip: `skim_beam_trip==0`
- Target:
  - $|\delta p/p| < 3.5\%$
  - $|\theta_{tg}| < 40$ mrad
  - $|\phi_{tg}| < 20$ mrad
  - $|y_{tg}| < 4.5$ cm

From $\sigma_{\rm raw}$ to $\sigma_{\rm exp}$ (3)

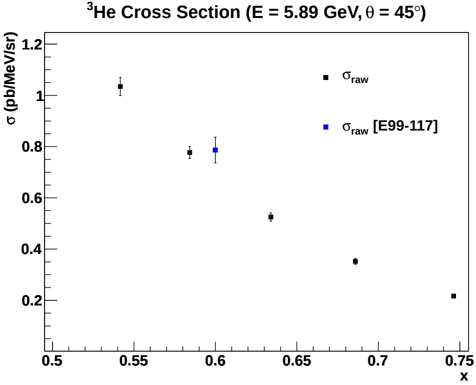
Cross Sections at E_s = 4.73 GeV and 5.89 GeV





Comparison to World Data

Raw Cross Section



- E99-117 data is scaled down by the ratio of our Mott cross section to theirs
- Only statistical errors are shown for our data

Systematic Errors of Electon Cuts

Description and Method

- To determine the systematic errors on the various electron cuts, we vary each cut individually within a reasonable range and see how the resulting cross section compares to the result using the ‘final cut’
- Test cuts:
  - GC: 380, 420 (ADC channels)
  - PR: 0.50, 0.52, 0.56, 0.58 (E/p)
  - β: $>$ 0
  - $\delta p/p$: 3.0, 3.3, 3.7%
  - θ_{tg}: 36, 38, 42 mrad
  - ϕ_{tg}: 16, 18, 22 mrad
  - y_{tg}: 4.0, 4.3 cm

Systematic Errors of Electon Cuts

Results: PID Cuts

E_s = 4730 MeV			
p (MeV)	GC (%)	E/p (%)	β (%)
600	0.10	0.10	0.20
800	0.20	0.10	0.20
1120	0.15	0.10	0.22
1190	0.08	0.10	0.18
1260	0.08	0.10	0.15
1420	0.22	0.10	0.18
1510	0.15	0.10	0.20
1600	0.15	0.10	0.38

E_s = 5890 MeV			
p (MeV)	GC (%)	E/p (%)	β (%)
600	0.12	0.10	0.20
700	0.02	0.10	0.12
900	0.12	0.10	0.18
1130	0.22	0.12	0.25
1200	0.20	0.10	0.18
1270	0.10	0.11	0.18
1340	0.10	0.12	0.20
1420	0.12	0.12	0.25
1510	0.02	0.22	0.42
1600	0.08	0.10	0.22
1700	0.22	0.12	0.80

Systematic Errors of Electon Cuts

Results: Target Cuts

E_s = 4730 MeV				
p (MeV)	$\delta p/p$ (%)	θ_{tg} (%)	ϕ_{tg} (%)	y_{tg} (%)
600	0.8	1.0	2.2	1.0
800	0.8	1.0	2.0	1.0
1120	0.6	1.0	2.0	1.0
1190	0.6	0.8	2.0	0.8
1260	1.0	1.0	2.0	1.0
1340	1.0	1.0	2.0	1.0
1420	1.0	0.8	2.2	1.0
1510	1.0	1.0	2.2	0.8
1600	1.0	1.0	2.2	1.0

E_s = 5890 MeV				
p (MeV)	$\delta p/p$ (%)	θ_{tg} (%)	ϕ_{tg} (%)	y_{tg} (%)
600	0.8	0.8	2.0	1.2
700	0.8	0.8	2.0	1.2
900	0.8	0.8	1.5	1.2
1130	0.8	0.8	2.2	1.2
1200	0.8	1.2	2.2	1.5
1270	0.8	0.8	2.2	1.2
1340	0.8	1.5	2.2	1.2
1420	0.8	0.4	2.2	1.2
1510	0.8	1.2	1.5	1.0
1600	0.8	1.2	2.0	1.0
1700	0.8	1.2	2.0	1.0

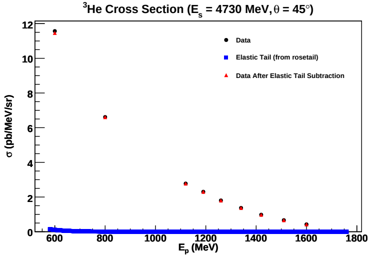
Radiative Corrections (1)

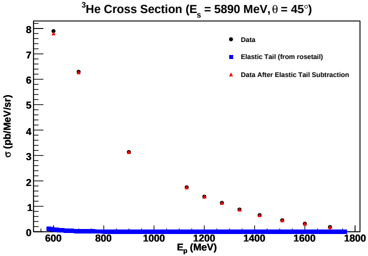
Description

- To compute the radiative corrections, one typically uses real data at the same scattering angle that fills out the integration region required in the calculation
  - Due to a lack of data, we use a model (F1F209)
- Before the calculations are carried out, the elastic tail is subtracted off first
  - Affects the whole range in W
  - We did not do this, since it was found that the elastic tail was $\lesssim 1\%$ of the experimental cross section (see next slide)
- Calculations are carried out using the fortran code RADCOR

Radiative Corrections (2)

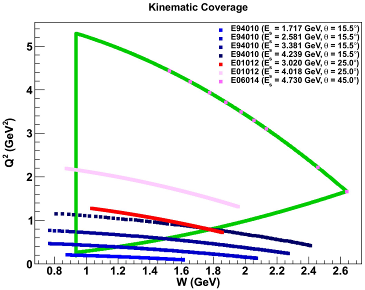
Elastic Tail Study

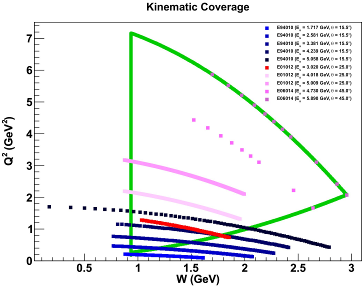




Radiative Corrections (3)

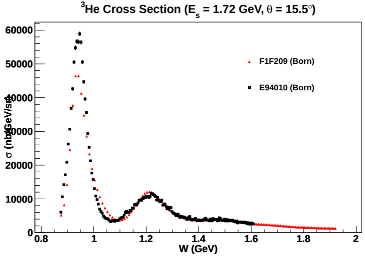
Phase Space Coverage

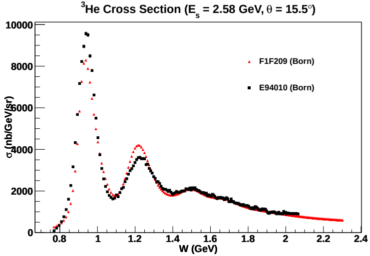


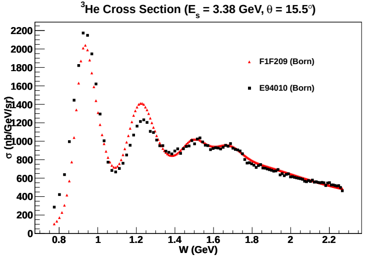


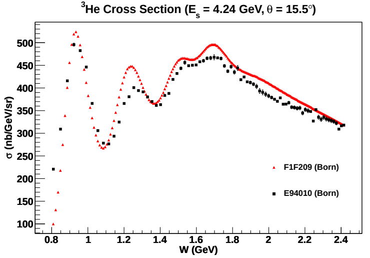
Radiative Corrections (4)

F1F209 Model: Comparison to E94010 Data



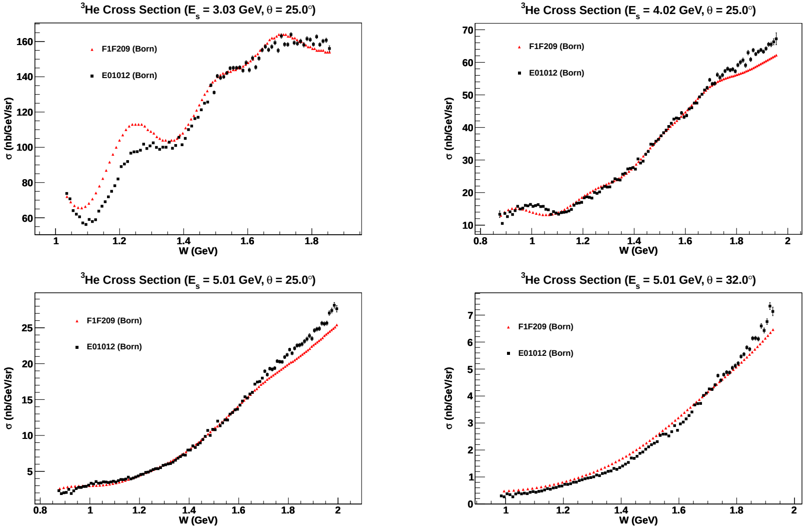






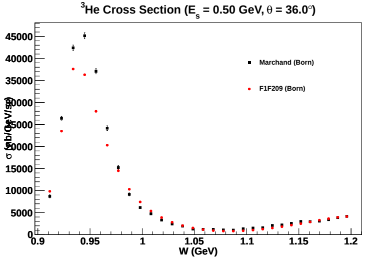
Radiative Corrections (5)

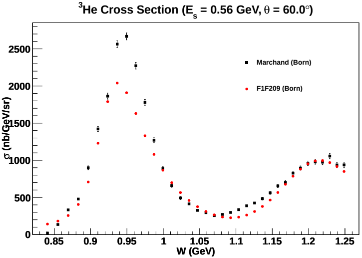
F1F209 Model: Comparison to E01012 Data

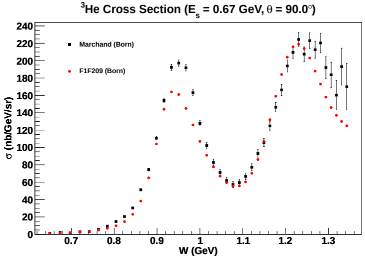


Radiative Corrections (6)

F1F209 Model: Comparison to Marchand Data



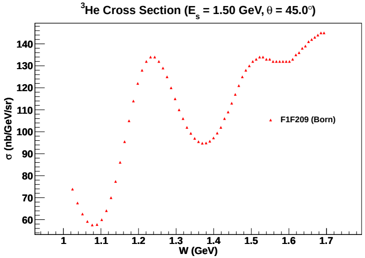


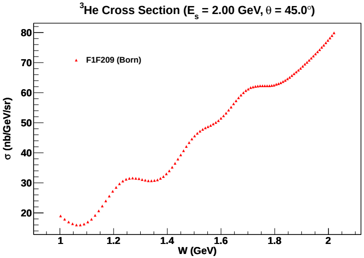


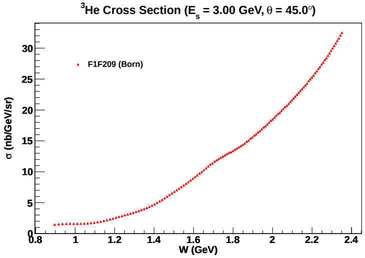
- This scaled version of F1F209 fits reasonably well to world data at various E_s, θ

Radiative Corrections (7)

F1F209 Model: Input Cross Sections







- To fill out our phase space, we use these spectra in addition to our data

Radiative Corrections (8)

Systematic Errors: Description

- We test three different components to the radiative correction results:
  1. Radiation lengths
     - Vary the thicknesses t_b, t_a by up to $\pm$10%
  2. Model dependence
     - Vary the cross section by up to $\pm$ 20% at random bin-by-bin in E_p
  3. Number of input spectra used in RADCOR

Radiative Corrections (9)

Systematic Errors: Results

E_s = 4730 MeV			
E_p (MeV)	$t_{b,a}$ (%)	σ_m (%)	N_σ (%)
600	1.5	2.0	2.5
800	1.5	2.0	2.0
1120	1.5	2.0	2.0
1190	1.5	2.0	3.0
1260	1.5	2.0	4.0
1340	1.5	2.0	6.0
1420	1.5	2.0	8.0
1510	1.5	2.0	11.0
1600	1.5	2.0	15.0

E_s = 5890 MeV			
E_p (MeV)	$t_{b,a}$ (%)	σ_m (%)	N_σ (%)
600	1.5	1.5	3.0
700	1.5	1.5	2.0
900	1.5	1.5	1.0
1130	1.5	1.5	2.0
1200	1.5	1.5	2.5
1270	1.5	1.5	3.0
1340	1.5	1.5	4.0
1420	1.5	1.5	6.0
1510	1.5	1.5	6.0
1600	1.5	1.5	6.0
1700	1.5	1.5	8.5

- $t_{b,a}$ = Varying the radiation lengths t_b and t_a by $\pm$ 10%
- σ_m = Varying the F1F209 model bin-by-bin in E_p by as much as $\pm$ 20%
- N_σ = Increasing the number of input spectra to RADCOR

Error Roundup (1)

Systematic Errors: Cuts and Radiative Corrections

E_s = 4730 MeV		
E_p (MeV)	Cuts (%)	RC (%)
600	2.75	3.54
800	2.59	3.20
1120	2.54	3.20
1190	2.39	3.91
1260	2.65	4.72
1340	2.66	6.50
1420	2.75	8.38
1510	2.75	11.28
1600	2.83	15.21

E_s = 5890 MeV		
E_p (MeV)	Cuts (%)	RC (%)
600	2.60	3.67
700	2.60	2.92
900	2.24	2.35
1130	2.77	2.92
1200	3.04	3.28
1270	2.76	3.67
1340	3.04	4.53
1420	2.68	6.36
1510	2.36	6.36
1600	2.67	6.36
1700	2.79	8.76

Error Roundup (2)

Computing the Total Systematic Error

$$\delta\sigma_{\rm born}^2 = \delta\sigma_{\rm exp}^2 + \left(\frac{\sigma_{\rm born} - \sigma_{\rm exp}}{\sigma_{\rm born}}\right)^2 \delta\sigma_{\rm RC}^2$$

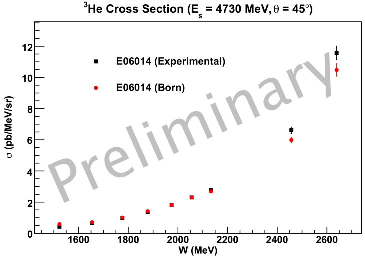
E_s = 4730 MeV		
E_p (MeV)	Stat. (%)	Syst. (%)
600	3.28	2.77
800	2.79	2.62
1120	1.79	2.54
1190	1.54	2.39
1260	1.51	2.65
1340	2.04	2.66
1420	1.98	2.76
1510	1.83	2.83
1600	2.89	5.11

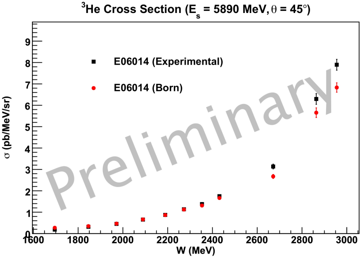
Table: The statistical and systematic errors on the born cross section. The statistical error is the same as that for the experimental cross section, and is shown for comparison. The systematic error is calculated according to the equation above.

E_s = 5890 MeV		
E_p (MeV)	Stat. (%)	Syst. (%)
600	5.80	2.67
700	1.92	2.62
900	3.28	2.28
1130	2.26	2.78
1200	2.21	3.05
1270	1.95	2.76
1340	1.85	3.04
1420	1.93	2.68
1510	2.26	2.36
1600	2.43	2.73
1700	3.51	3.97

Born Cross Sections (1)

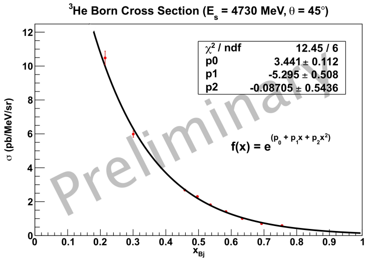
Results at E_s = 4.73 GeV and 5.89 GeV

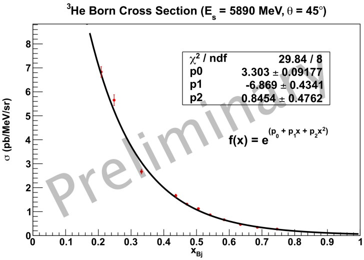




Born Cross Sections (2)

Fits for E_s = 4.73 GeV and 5.89 GeV





Analysis Outlook

Systematic Error Budget

Type	Proposal (%)	Experiment (%)
PID Efficiency	≈ 1	1
Background Rejection Efficiency	≈ 1	1
Beam Charge	< 1	≈ 0.3
Beam Position	< 1	—
Acceptance Cut	2–3	2.7
Target Density	2–3	2.2
Nitrogen Dilution	2–3	—
Dead time	< 1	< 1
Finite Acceptance Correction	< 1	—
Radiative Corrections	≤ 10	$\approx$ 5–6†

† Varies bin-by-bin in E_p, value shown is an average

Type	Complete?
Detector Calibrations	✓
PID Cut Efficiencies	✓
Trigger Efficiencies	✓
Live Time Calculation	✓
Scintillators/β Check	✓
Optics	✓
Acceptance	✓
$\sigma_{\rm raw}$, $\sigma_{\rm exp}$, $\sigma_{\rm Born}$	✓
Radiative Corrections	✓
$\sigma_{\rm N}$, σ_{e^+} Fit Systematic Error	
$\sigma_{\rm Born}$ Fit Systematic Error	
Finite Acceptance Correction (E_p, ϕ, θ)	

Summary

- Most major studies and calculations are complete and major issues have been solved
- We are within the limits of our error budget for all quantities
- Born cross sections have been calculated and fit to a reasonable function
  - For the extraction of g_1 and g_2

What's Next?

- Systematic errors of Born cross section fits and background subtraction needs to be looked at
- Finite acceptance correction for the cross sections