

# LHRS Analysis Update for $d_2^n$

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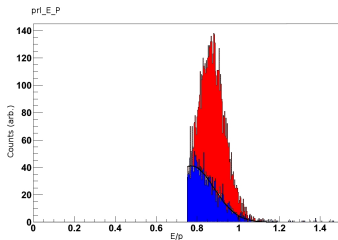
# Outline

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  - Pion Rejector
  - VDC
- 2 Scintillator Analysis**
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# Contamination Studies

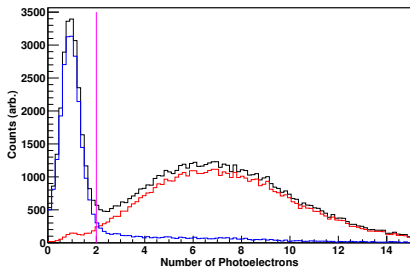
## PID Detectors: Gas Čerenkov and Pion Rejector

- 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  $\pi^-$ )
- 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  $\pi^-$
  - 4 Calculate the cut efficiencies

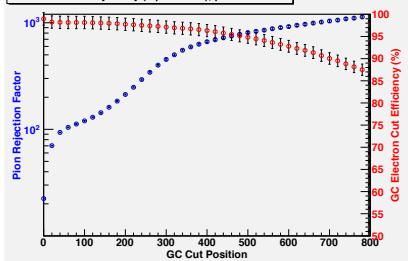


# Gas Čerenkov Efficiencies

Gas Cherenkov ADC Sum

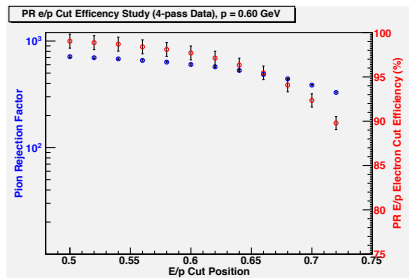
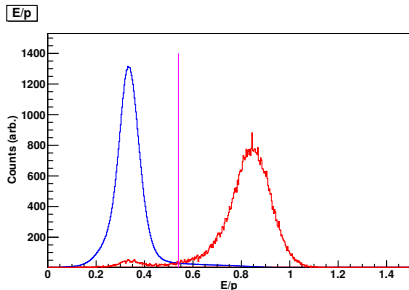


GC Cut Efficiency Study (4-pass Data),  $p = 0.60$  GeV



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

# Pion Rejector Efficiencies



- Cut:  $E/p > 0.54$
- $\varepsilon \sim 99\%$
- $\pi$ -rejection factor  $\sim 600$
- **Combined with the GC:**  $\pi$ -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 **efficiency** of the one-track cut is given as:

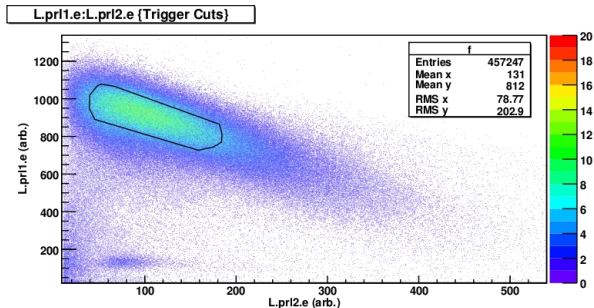
$$\varepsilon_1 = \frac{N_1}{\sum_{i=0}^4 N_i}$$

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	$\epsilon$ (%)
0	16	$0.003 \pm 0.001$
1	526460	$98.981 \pm 0.192$
2	4946	$0.929 \pm 0.013$
3	425	$0.079 \pm 0.004$
4	33	$0.006 \pm 0.001$

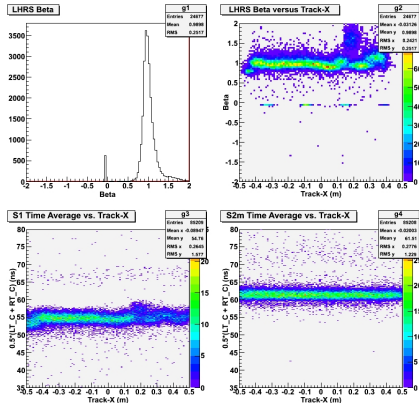
- $\epsilon_1 \sim 99\%$ , total inefficiency  $\lesssim 1\%$
- Consistent across the whole kinematic range



# Scintillator Analysis (1)

## Alignment of S2m TDCs

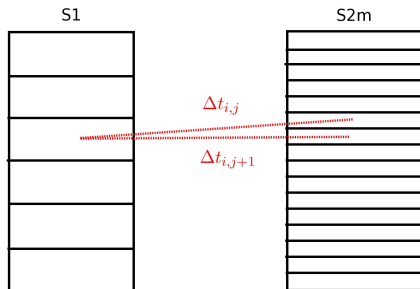
- For the scintillators, what is typically done is that the self-timing peaks of the **right** TDCs of S2m are aligned, and from there the left side TDCs are aligned along with those S1
- After doing such, we still saw jitter in the S1 TDC times as a function of track-x:



# Scintillator Analysis (2)

## Identifying the Problem

- S1 paddles: index  $i$ ,  
S2m paddles: index  $j$
- $\Delta t_{i,j} \neq \Delta t_{i,j+1}$  despite  
the alignment of S1,  
S2m times



# Scintillator Analysis (3)

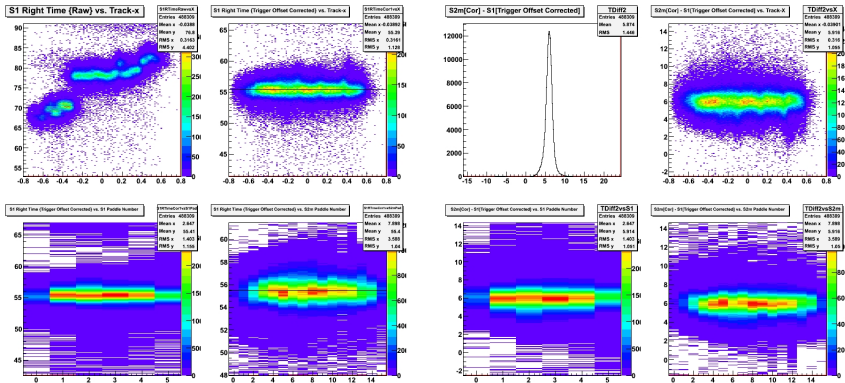
## An Event-by-Event Approach: Procedure

- 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 (despite 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

# Trigger Efficiencies

## Results

- Sample calculation for run 20676:

$$ps_3 = ps_4 = 1$$

$$N_{T3} = 12275$$

$$N_{T4} = 4$$

$$\varepsilon_{T3} = \frac{12275}{12275 + 4} \times 100\% = 99.96\%$$

- Such results are typical for all runs

# Live Time Calculation (1)

## Method

$$t_{LT} = \frac{evtypebits3}{t3c}$$

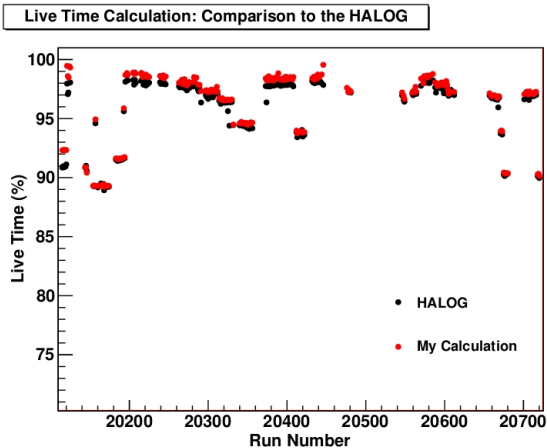
$evtypebits3$  = # of (T3) triggers recorded for a given run

$t3c$  = # of (T3) triggers generated for a given run

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

# Live Time Calculation (2)

## Results



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



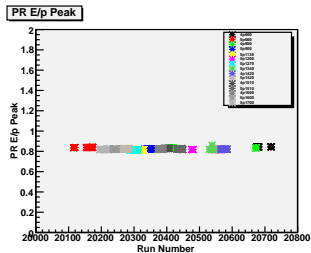
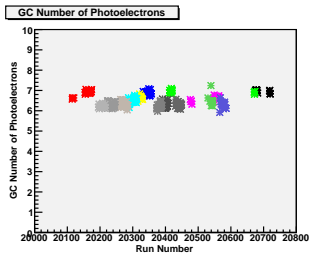
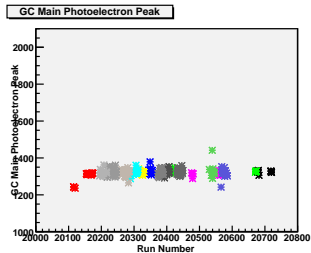
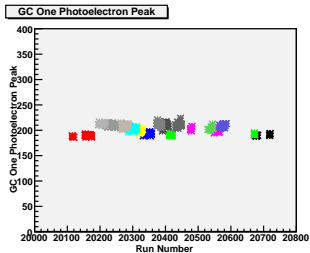
# Data Quality (1)

## 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

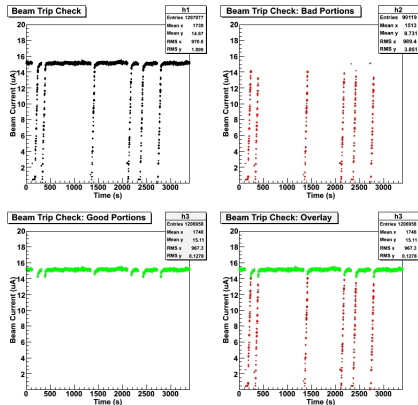




# Data Quality (2)

## Beam Trips

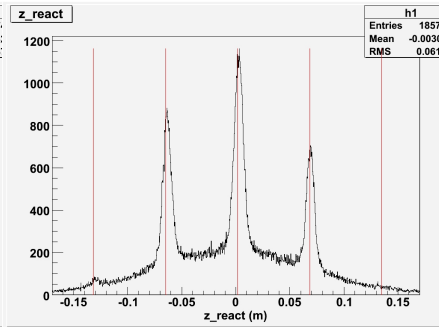
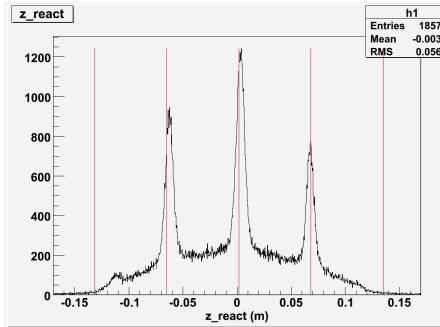
- During the course of a run, there are instances when the beam current drops
- Events correlated to these ‘trips’ are not desired in the final analysis
- Plot the beam current as a function of time and choose cuts (in time) to remove the trips
  - Manifested as a new ROOT variable for the analysis



# Optics Matrix

## Before and After

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



# Single Arm Monte Carlo (1)

## Sample Event

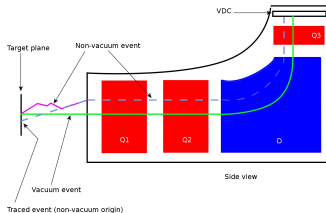
- 1 The event is generated at the target ( $t_{gen}$ )
- 2 If the event reaches the focal plane, it is then traced back to the target ( $t_{ref}$ )
  - This process **assumes** a vacuum between the Q1 magnet entrance and the target plane

- 3 Utilizing the **transport matrix** (J. LeRose), the event is constructed at the focal plane:

$$Mt_{ref} = t_{fp}$$

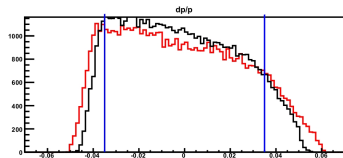
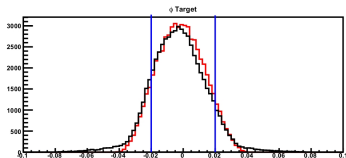
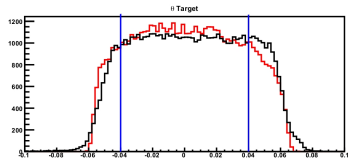
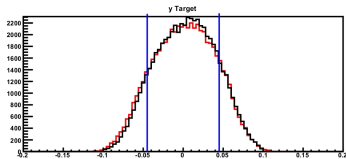
- 4 The **reconstructed event at the target** is then determined by:

$$M^{-1}t_{fp} = t_{rec}$$



# SAMC (2)

## Comparison to Data



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

# SAMC (3)

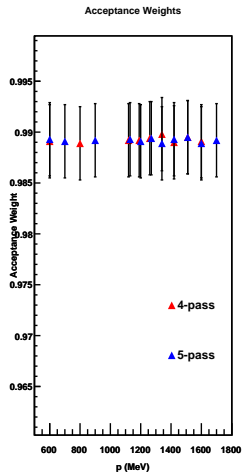
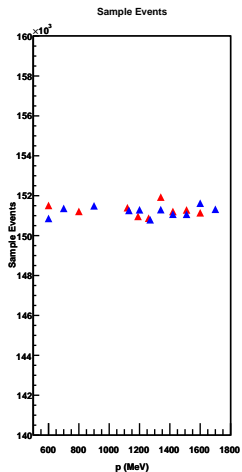
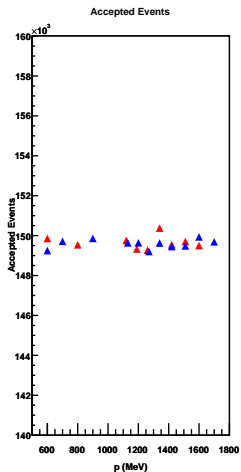
## Acceptance Weight: Method

- 1 Generate events normally-distributed in  $y_{tg}$ ,  $\theta_{tg}$ ,  $\phi_{tg}$  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 $\sigma_{\text{raw}}$ to $\sigma_{\text{exp}}$ (1)

## Descriptions and Definitions

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

$N_{\text{cut}}$  = Number of  $e^-$  that pass all cuts

$Q/e$  = Number of beam  $e^-$

$\rho$  = Target density [Amg]

$t_{LT}$  = Live time

$\varepsilon$  = 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] ( $\Delta\theta\Delta\phi$ )

$\Delta Z$  = Target length seen by the spectrometer [cm]

## From $\sigma_{\text{raw}}$ to $\sigma_{\text{exp}}$ (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:

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

where:

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

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

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

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

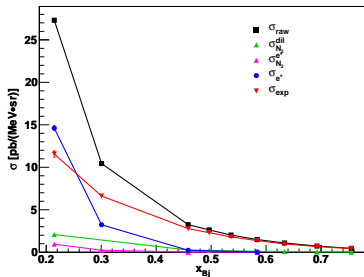
## Electron Cuts

- **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)`
- $\beta$ : `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

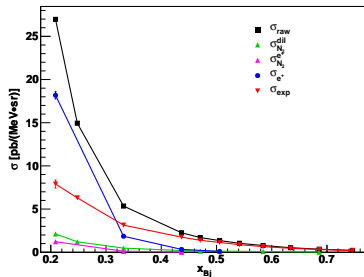
# From $\sigma_{\text{raw}}$ to $\sigma_{\text{exp}}$ (3)

## Cross Sections at $E_s = 4.73$ GeV and 5.89 GeV

$^3\text{He}$  Cross Section ( $E = 4.73$  GeV,  $\theta = 45^\circ$ )

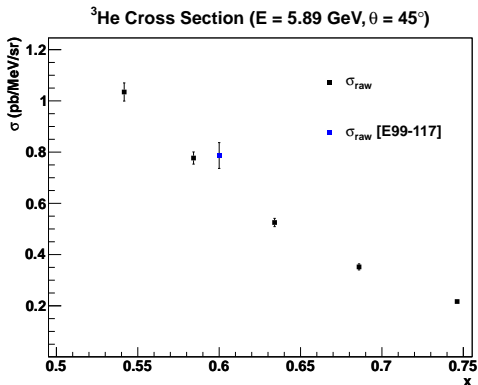


$^3\text{He}$  Cross Section ( $E = 5.89$  GeV,  $\theta = 45^\circ$ )



# 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 Electron 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)
  - $\beta$ :  $> 0$
  - $\delta p/p$ : 3.0, 3.3, 3.7%
  - $\theta_{tg}$ : 36, 38, 42 mrad
  - $\phi_{tg}$ : 16, 18, 22 mrad
  - $y_{tg}$ : 4.0, 4.3 cm

# Systematic Errors of Electron Cuts

## Results: PID Cuts

$E_s = 4730$ MeV			
p (MeV)	GC (%)	E/p (%)	$\beta$ (%)
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 (%)	$\beta$ (%)
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 Electron Cuts

## Results: Target Cuts

E <sub>s</sub> = 4730 MeV				
p (MeV)	$\delta p/p$ (%)	$\theta_{tg}$ (%)	$\phi_{tg}$ (%)	$y_{tg}$ (%)
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 <sub>s</sub> = 5890 MeV				
p (MeV)	$\delta p/p$ (%)	$\theta_{tg}$ (%)	$\phi_{tg}$ (%)	$y_{tg}$ (%)
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

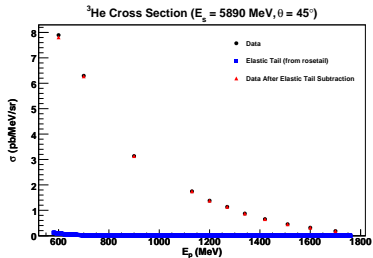
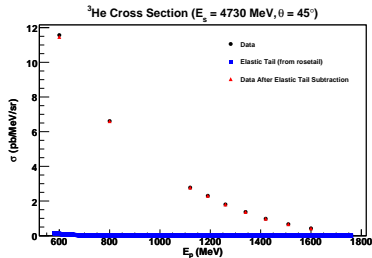
# Radiative Corrections (1)

## 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 typically 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

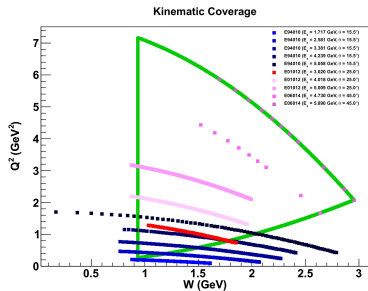
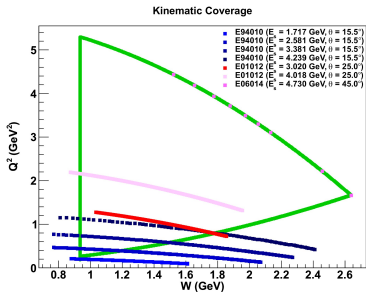
# Radiative Corrections (2)

## Elastic Tail Study



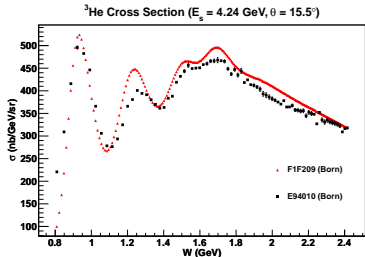
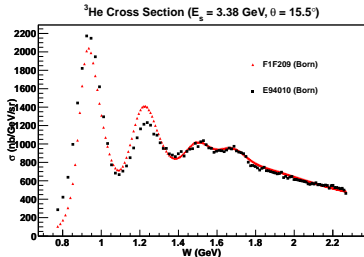
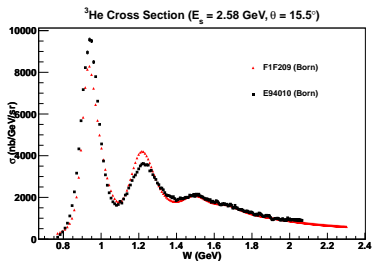
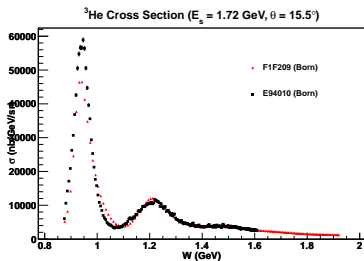
# Radiative Corrections (3)

## Phase Space Coverage



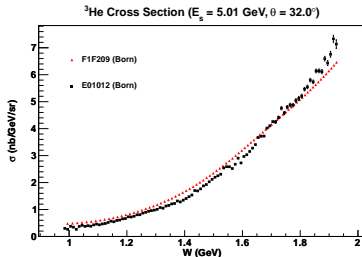
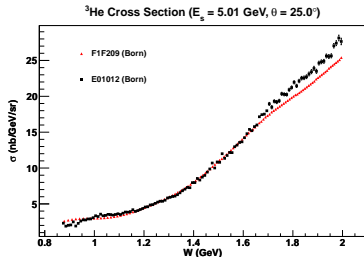
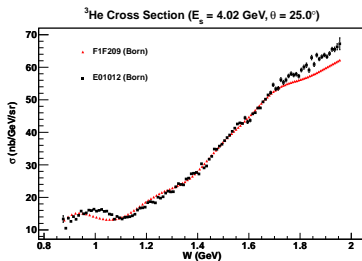
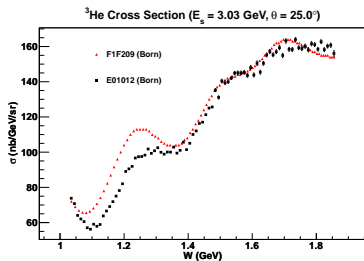
# Radiative Corrections (4)

## F1F209 Model: Comparison to E94010 Data



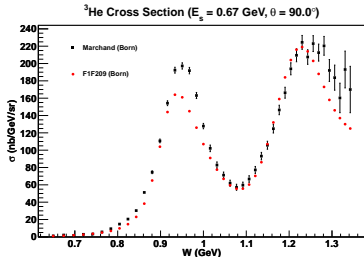
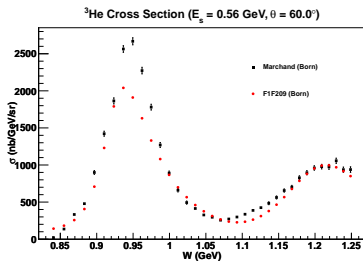
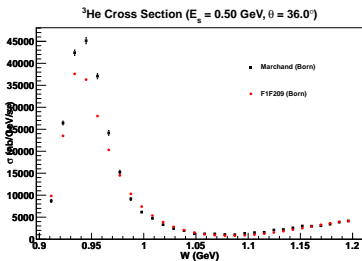
# Radiative Corrections (5)

## F1F209 Model: Comparison to E01012 Data



# Radiative Corrections (6)

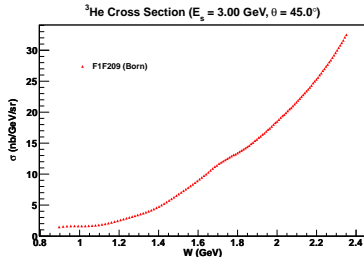
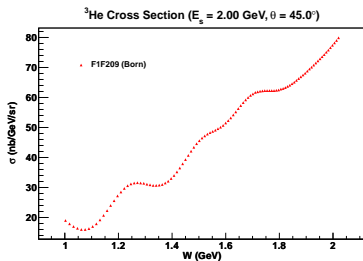
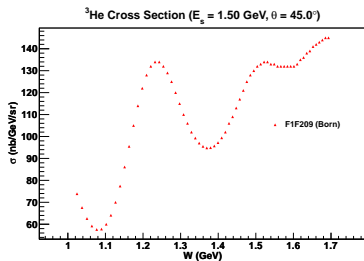
## F1F209 Model: Comparison to Marchand Data



- This **scaled** version of F1F209 fits reasonably well to world data at various  $E_s$ ,  $\theta$

# 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

$E_S = 4730 \text{ MeV}$			
$E_p \text{ (MeV)}$	$t_{b,a} \text{ (%)}$	$\sigma_m \text{ (%)}$	$N_\sigma \text{ (%)}$
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

$E_S = 5890 \text{ MeV}$			
$E_p \text{ (MeV)}$	$t_{b,a} \text{ (%)}$	$\sigma_m \text{ (%)}$	$N_\sigma \text{ (%)}$
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  $\pm 10\%$
- $\sigma_m$  = Varying the F1F209 model bin-by-bin in  $E_p$  by as much as  $\pm 20\%$
- $N_\sigma$  = Increasing the number of input spectra to RADCOR

# Error Roundup (1)

## Systematic Errors: Cuts and Radiative Corrections

$E_s = 4730 \text{ MeV}$		
$E_p \text{ (MeV)}$	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

$E_s = 5890 \text{ MeV}$		
$E_p \text{ (MeV)}$	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

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

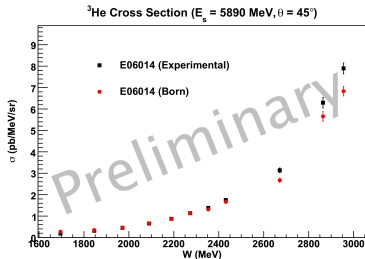
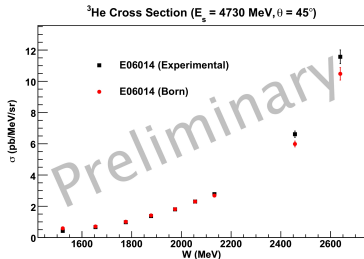
E <sub>s</sub> = 4730 MeV		
E <sub>p</sub> (MeV)	Stat. (%)	Syst. (%)
600	3.28	2.77
800	2.79	2.62
1120	1.79	2.54
1190	1.54	2.39
1260	1.51	2.65
1340	2.04	2.66
1420	1.98	2.76
1510	1.83	2.83
1600	2.89	5.11

E <sub>s</sub> = 5890 MeV		
E <sub>p</sub> (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

**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.

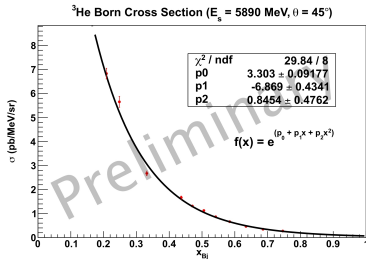
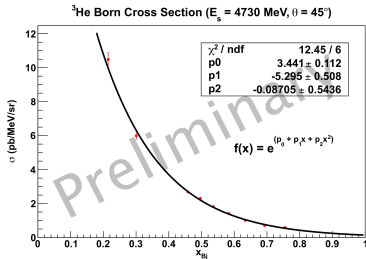
# Born Cross Sections (1)

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 (1)

## Systematic Error Budget

Type	Proposal (%)	Experiment (%)
PID Efficiency	$\approx 1$	1
Background Rejection Efficiency	$\approx 1$	1
Beam Charge	$< 1$	$\approx 0.3$
Acceptance Cut	2–3	2.7
Target Density	2–3	2.2
Dead time	$< 1$	$< 1$
Finite Acceptance Correction	$< 1$	—
Radiative Corrections	$\leq 10$	$\approx 5\text{--}6^\dagger$

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

# Analysis Outlook (2)

## Analysis Checklist

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



# 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

# Backup

## Acceptance Cuts

