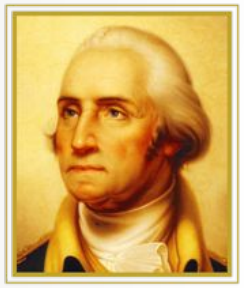
Determination of the Azimuthal Asymmetry of Deuteron Photodisintegration

in the Energy Region E_γ=1.1 – 2.3 GeV



THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON DC

Jefferson Lab

Nicholas Zachariou

CLAS collaboration Feb. 2012

Outline

- g13 experiment
- Analysis
- Systematic Studies
- Results
- Summary

The g13 Experiment

- LD_2 target 40 cm long
- Two photon polarization settings
  - Circular: g13a
  - Linear: g13b

g13b

- Two orientations of linear polarization (*Para* & *Perp*)
- Data obtained for 6 photon-energy bins 200 MeV wide between 1.1–2.3 GeV
- ~30 billion events collected

Analysis

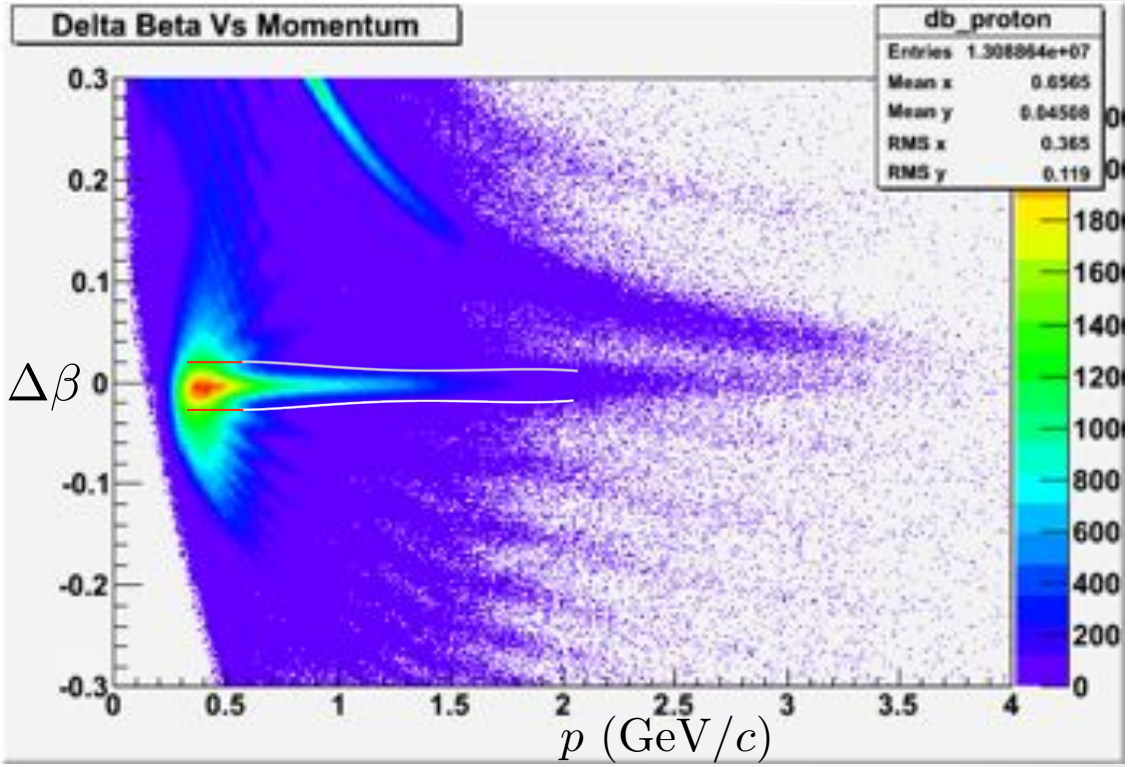
Event selection

- Particle ID

$$\Delta\beta = \beta_{meas} - \beta_{calc}$$

$$\beta_{calc} = \frac{p}{\sqrt{p^2 + m_0^2}}$$

$$\beta_{meas} = \frac{d_{TOF-ST}}{t_{TOF-ST}}$$



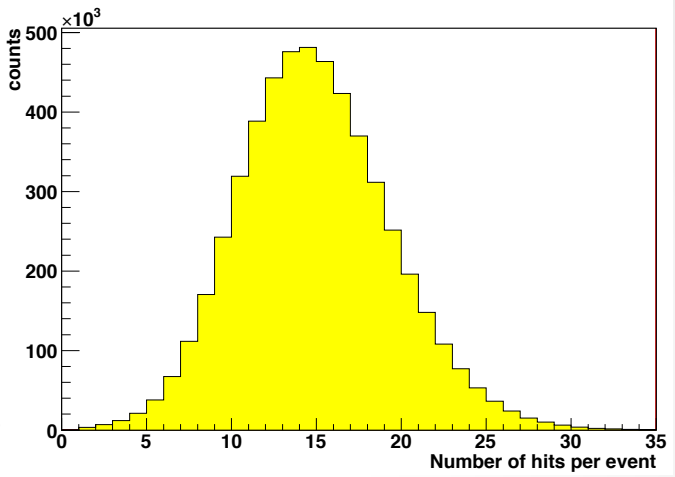
3σ cuts determined from fitting the different p bins with a Gaussian

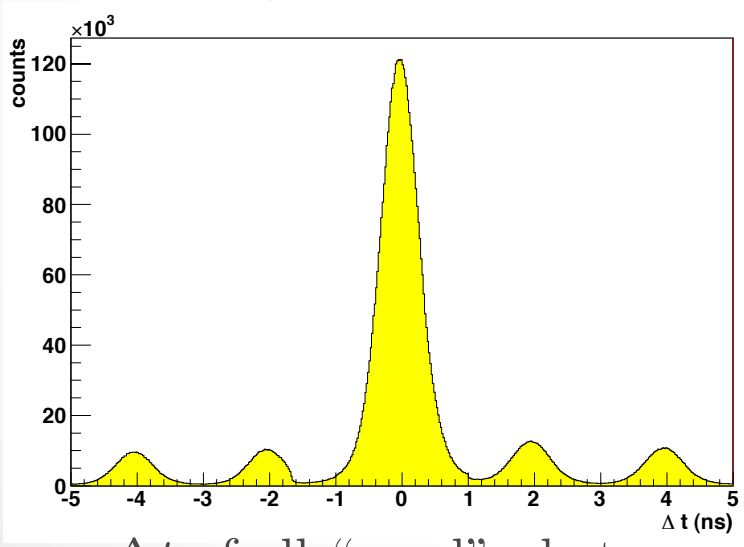
Analysis

Event selection

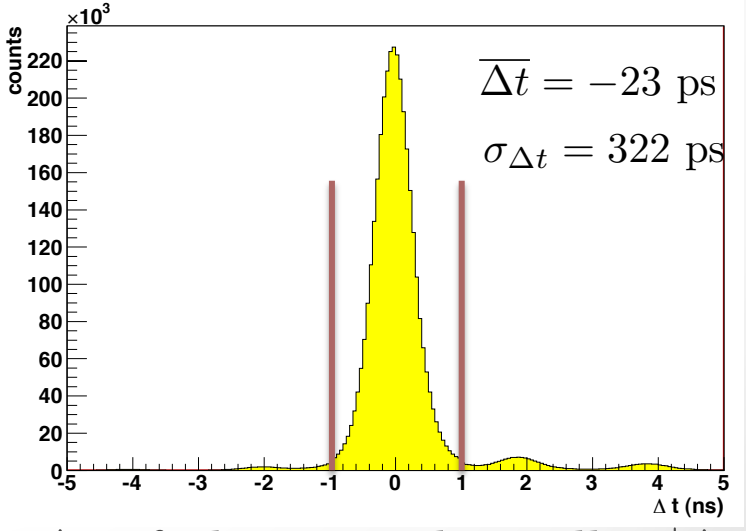
- Identifying the incident photon
  - ~13 photons per event
  - Coincidence time between photon and proton at vertex $\Delta t = t_p - t_\gamma$

$$t_p = t_{ST} - \frac{d}{c\beta_{calc}} \qquad t_\gamma = t_{TAG} + \frac{z_{vert} + 20.0}{c}$$





Δt of all "good" photons



Δt of photon with smallest $|\Delta t|$

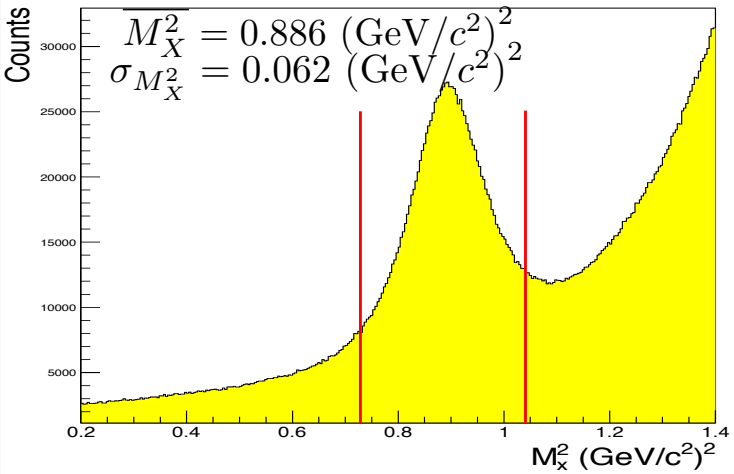
Analysis

Event selection

- Missing-mass cuts

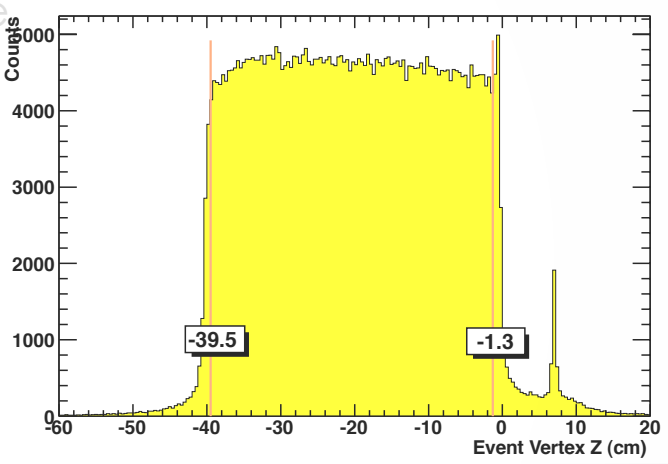
To select neutron peak

$$m_X^2 = m_d^2 + m_p^2 - 2E_p m_d + 2p_\gamma(m_d - E_p + p_p \cos\theta)$$



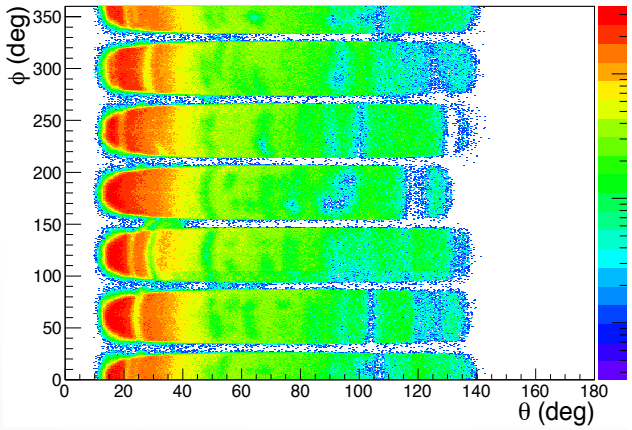
- Event-vertex cut

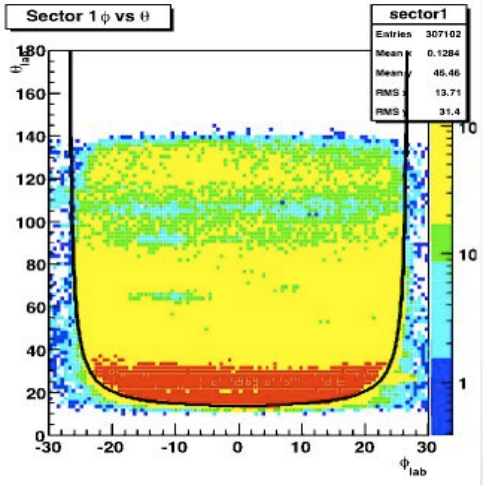
Determined as the point of closest approach between the particle's track and the beam line.



- Fiducial Cuts

Remove regions were the CLAS acceptance changes rapidly





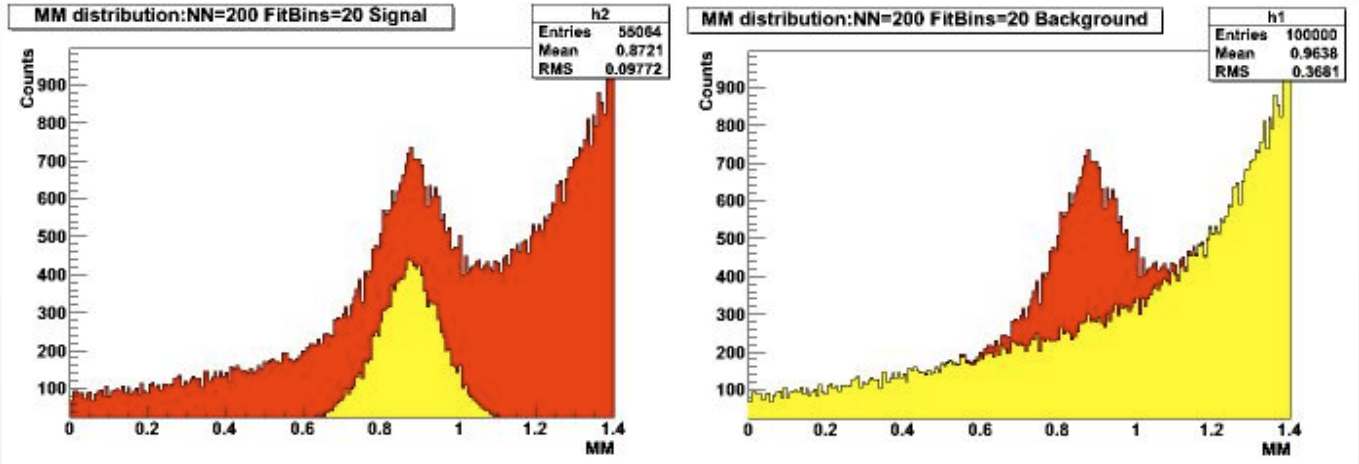
Analysis

Event selection

- Background subtraction
  - **Probabilistic event weighting***: Calculate probability of a given event being a signal event by fitting the missing-mass distribution of a given bin in θ and ϕ with a predetermined function

Signal: $$g(m_X^2) = Ae^{-\frac{1}{2}\left(\frac{m_X^2-\mu}{\sigma}\right)^2}$$

Background: $$b(m_X^2) = A_1 e^{A_2 m_X^2} + B_1 e^{B_2 m_X^2}$$

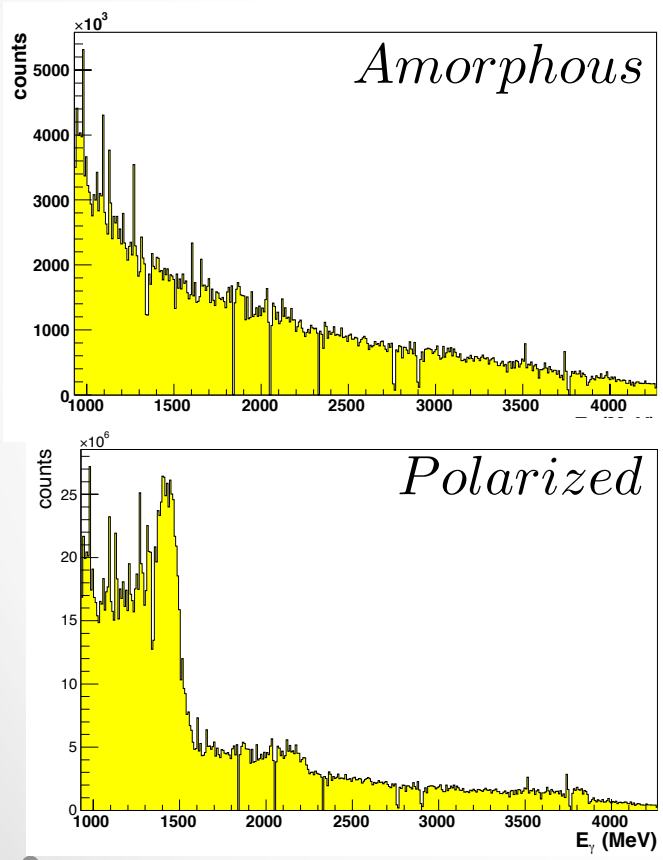


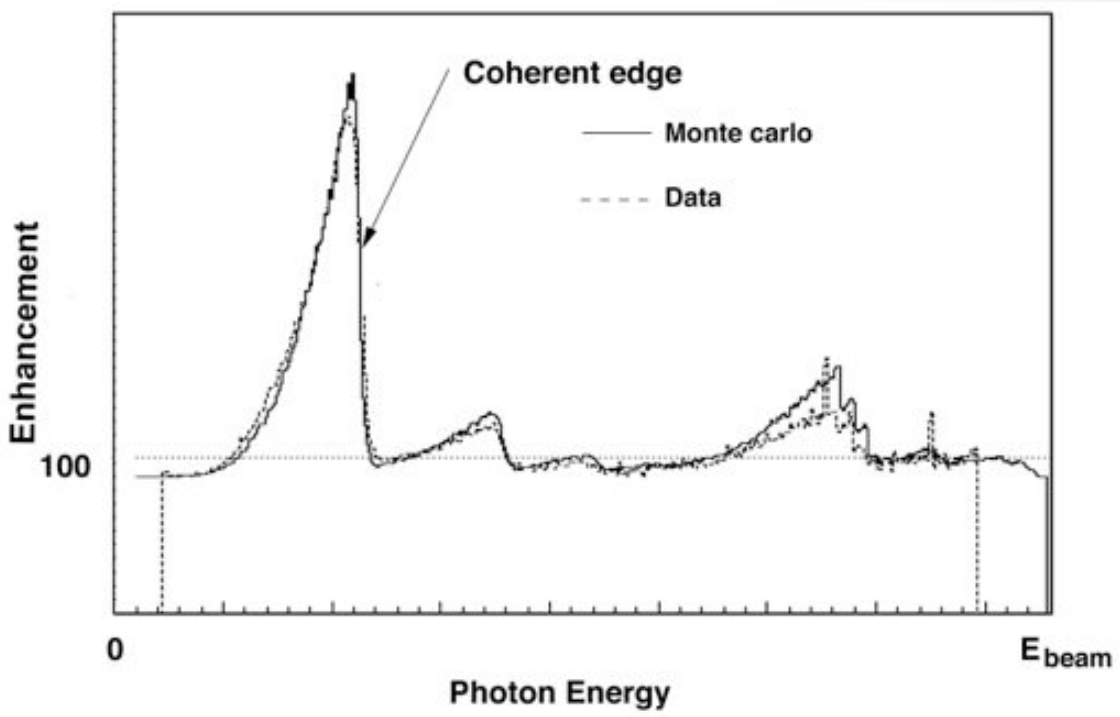
*Carnegie Mellon

Analysis

Photon Polarization

- Enhancements
  - Remove incoherent bremsstrahlung effects and tagger channel-to-channel fluctuations





Analysis

Photon Polarization

- Analytic bremsstrahlung calculation

Degree of polarization depends on:

- Orientation of the crystal radiator
- Beam collimation
- Beam energy and divergence

5 fit parameters

θ Angle: beam/crystal plane

σ Gaussian smearing of θ

beam divergence

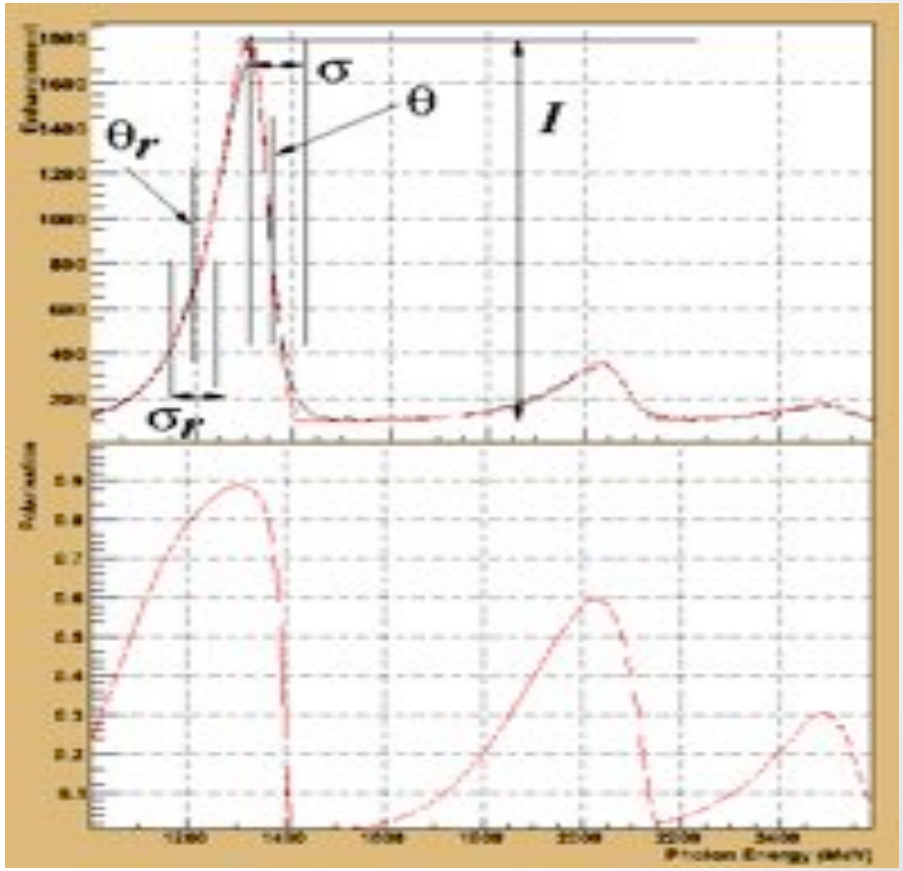
multiple scattering

θ_r Angle of collimation

σ_r Smearing factor

Amplitudes of peaks

$I_2^0, I_4^0, \ldots, I_6^0$

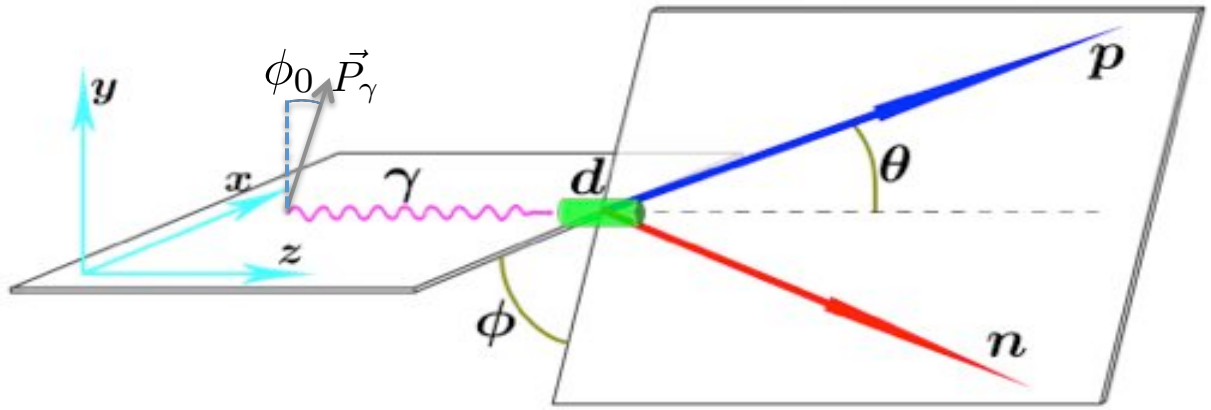


$P_\gamma \sim 80\%$

Asymmetry Determination

- Φ-bin method

$$N(\phi)_{||,\perp} \propto F_{||,\perp}(1 \pm P_{||,\perp}\Sigma\cos(2[\phi+\phi_0]))A(\phi)$$

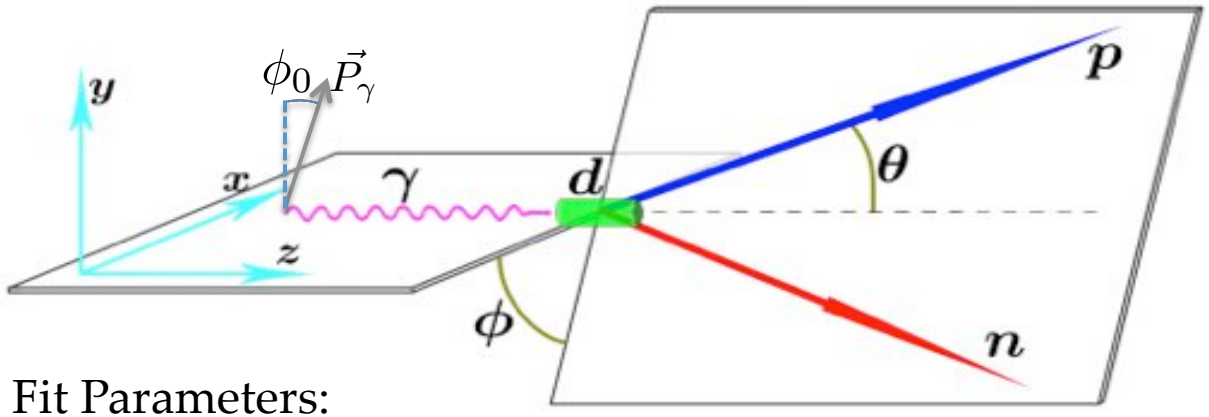


$$\text{if } F_{||} = F_\perp$$
$$\text{and } P_{||} = P_\perp = P$$
$$\text{then } \frac{N(\phi)_{||} - N(\phi)_\perp}{N(\phi)_{||} + N(\phi)_\perp} = P\Sigma\cos 2(\phi - \phi_0)$$

Asymmetry Determination

- Φ-bin method

$$N(\phi)_{||,\perp} \propto F_{||,\perp}(1 \pm P_{||,\perp}\Sigma\cos(2[\phi+\phi_0]))A(\phi)$$



4 Fit Parameters:

$$\frac{N(\phi)_{||}-N(\phi)_{\perp}}{N(\phi)_{||}+N(\phi)_{\perp}} = \frac{F_R - 1 + \frac{F_R P_R + 1}{P_R + 1} 2\bar{P}\Sigma\cos 2(\phi-\phi_0)}{F_R + 1 + \frac{F_R P_R - 1}{P_R + 1} 2\bar{P}\Sigma\cos 2(\phi-\phi_0)}$$

with: $F_R = \frac{F_{||}}{F_\perp}$, $P_R = \frac{P_{||}}{P_\perp}$

$$\bar{P} = \frac{P_{||}+P_\perp}{2},$$

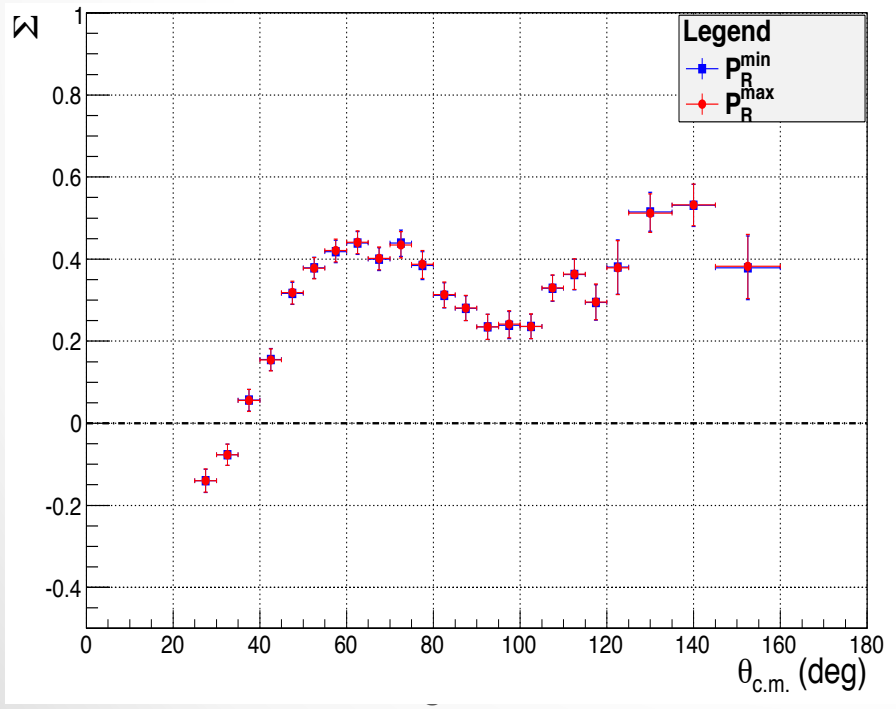
Systematic Studies

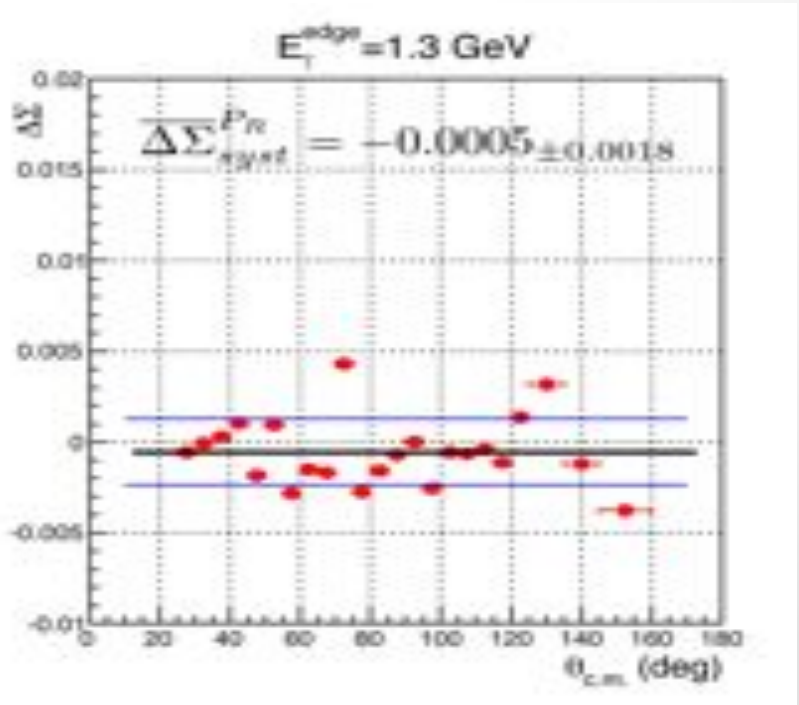
Source	Study	Value
Photon Polarization – P_γ	M. Dugger, Private Communication	$\sim 5\%$
Offset – ϕ_0	$\phi_0 = -0.047^\circ$ vs $\phi_0 = 0.297^\circ$ *	$< 0.2\%$
Flux ratio – F_R	F_R^{min} vs F_R^{max}	$< 0.5\%$
ϕ-bin Width	$\Delta\phi = 12.5^\circ$ vs $\Delta\phi = 25.0^\circ$	$\sim 7\%$
Particle ID cuts	3σ vs 2σ $\Delta\beta$ cuts	$\sim 7\%$
Missing-mass cuts	3σ cut vs 2σ cut	$\sim 5\%$
Fiducial Cuts	nominal vs $\sim 3^\circ$ tighter cuts	$\sim 3\%$
Background Subtraction	Probabilistic event weighting vs Bin scaling	$\sim 7\%$

Systematic Studies

Photon Polarization

- Estimated to be ~7%
- Propagates to asymmetry through P_R and $\bar{P}$
- Systematic due to P_R: ~0.1%
- Systematic due to $\bar{P}$:~5.0%

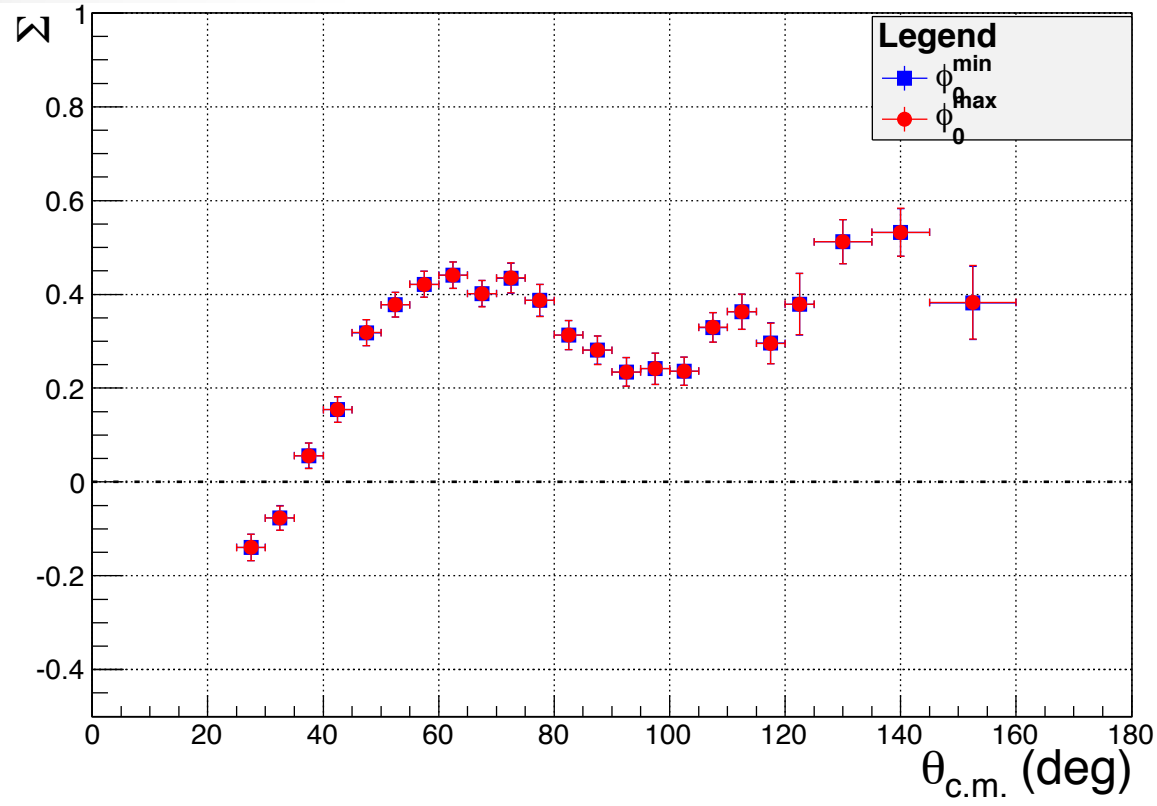


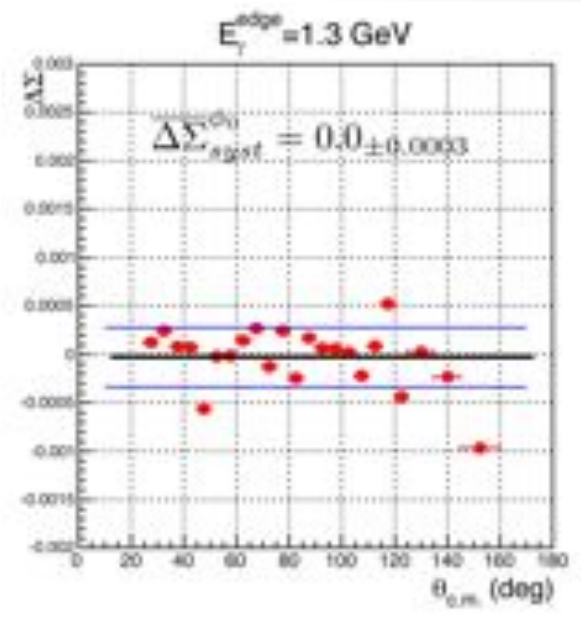


Systematic Studies

ϕ_0 offset

- Compared asymmetries obtained using upper and lower limits of ϕ_0 $(\phi_0^{min} = -0.047°,\ \phi_0^{max} = 0.297°)$





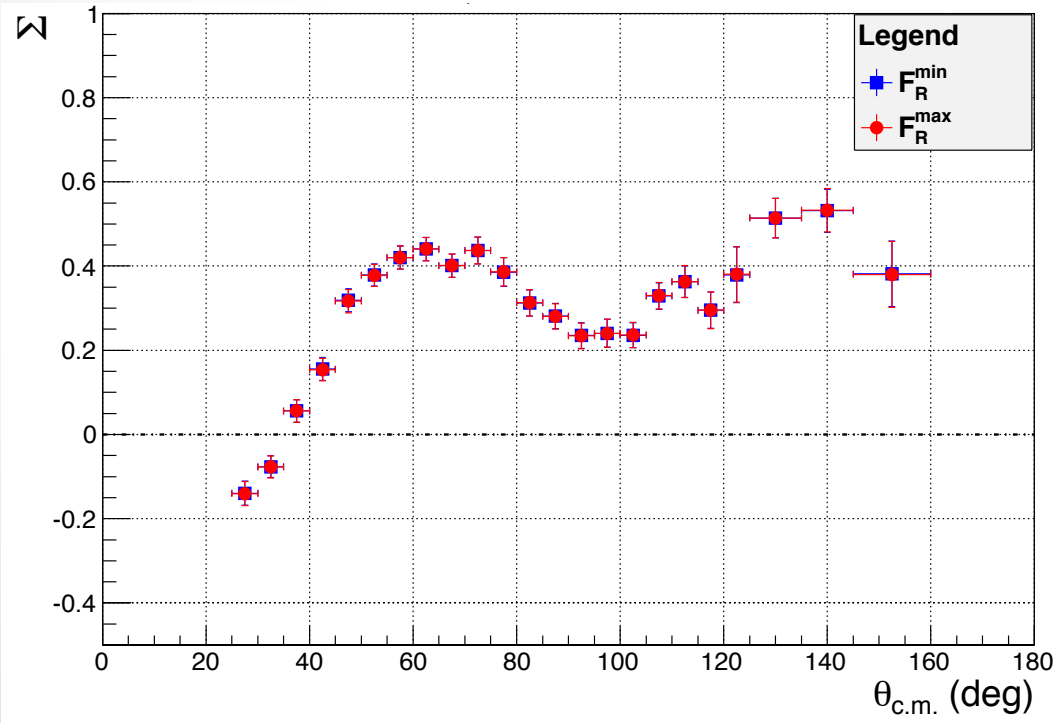
$$\overline{\Delta\Sigma}^{\phi_0} = 0.0_{\pm 0.0003} - 0.0004_{\pm 0.0011}$$

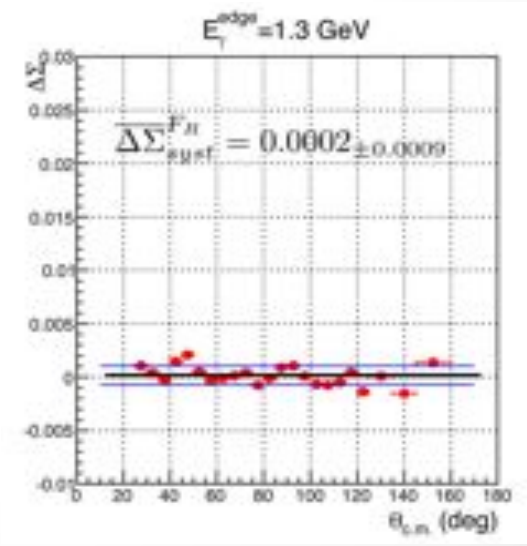
Systematic Studies

Flux ratio

- Compared asymmetries obtained using upper and lower limits of flux ratios

E_γ Bin (GeV)	F_R	ΔF_R
1.1 – 1.3	1.293	± 0.010
1.3 – 1.5	1.032	± 0.009
1.5 – 1.7	1.119	± 0.013
1.7 – 1.9	0.930	± 0.015
1.9 – 2.1	1.233	± 0.038
2.1 – 2.3	0.944	± 0.039



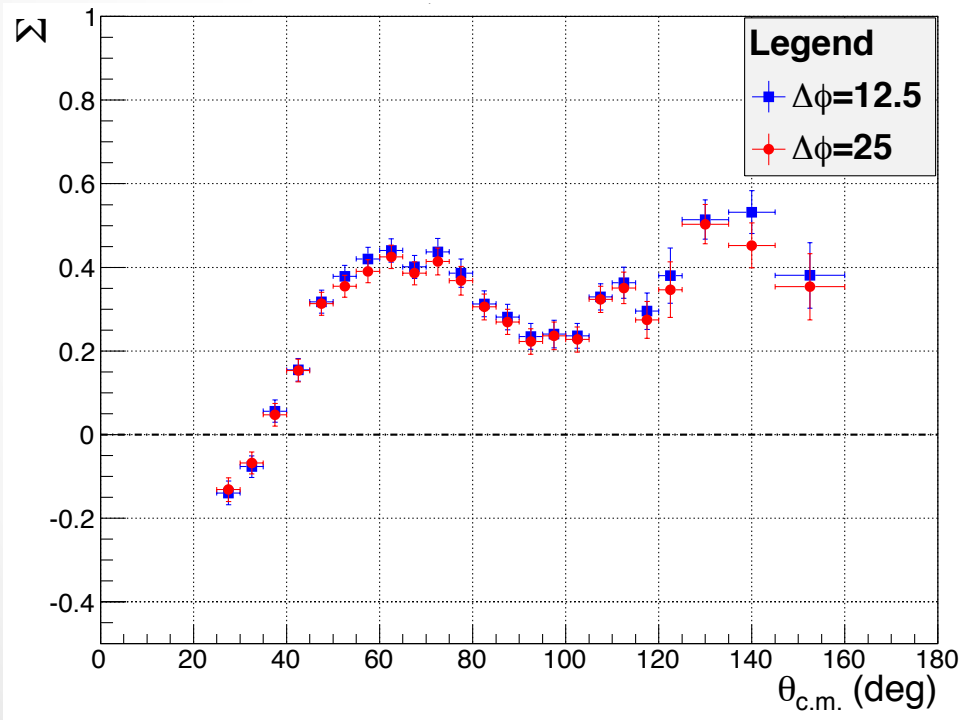


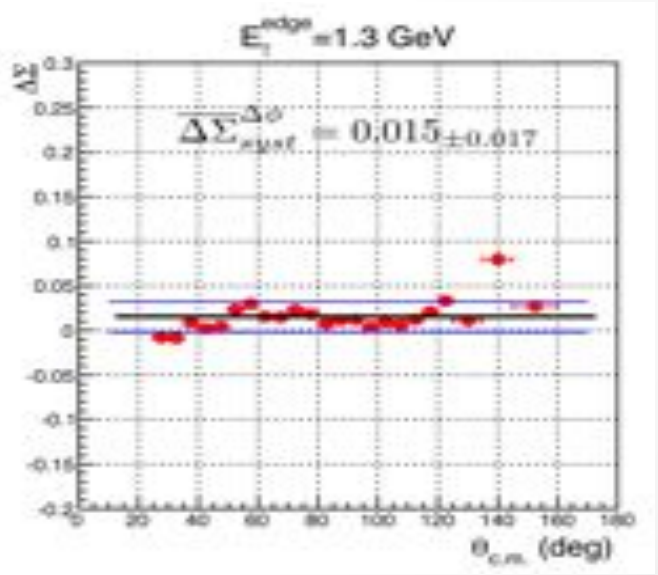
$$\overline{\Delta\Sigma}^{F_R} = 0.0002_{\pm 0.0009} - 0.004_{\pm 0.013}$$

Systematic Studies

ϕ-bin width

- Compared asymmetries obtained using 17 and 29 bins in ϕ $(\Delta\phi = 25.0^\circ,\ \Delta\phi = 12.5^\circ)$



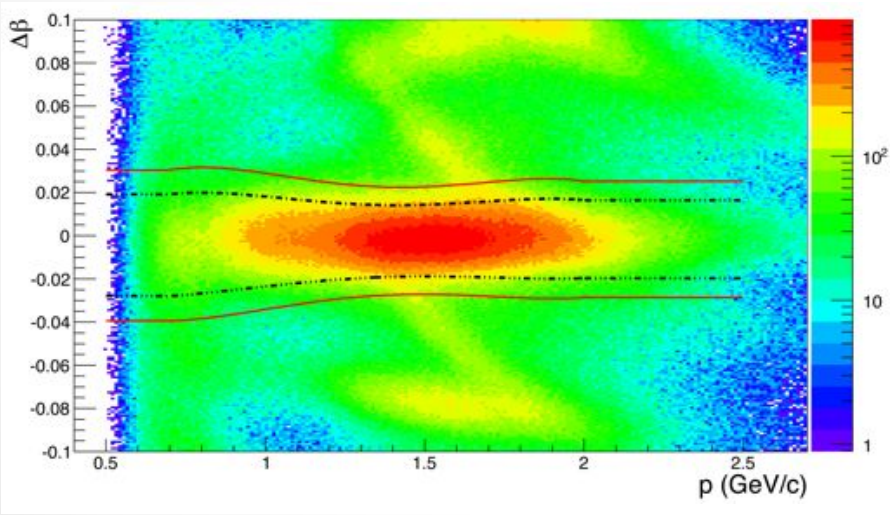


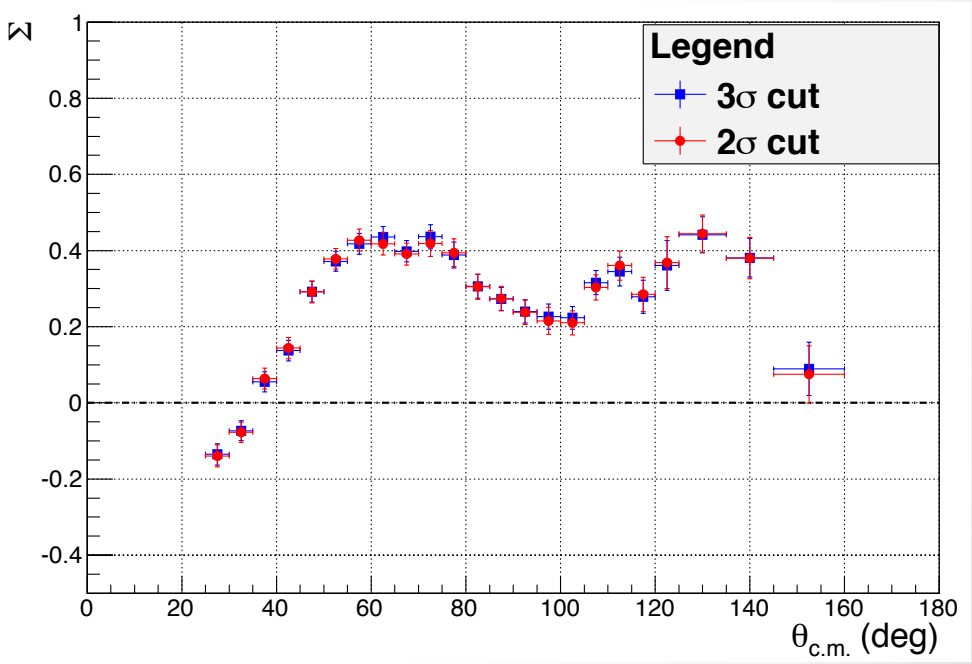
$$\overline{\Delta\Sigma}^{\Delta\phi} = 0.0065_{\pm 0.0072} - 0.009_{\pm 0.049}$$

Systematic Studies

Particle ID

- Compared asymmetries obtained using 2σ and 3σ $\Delta\beta$ cut



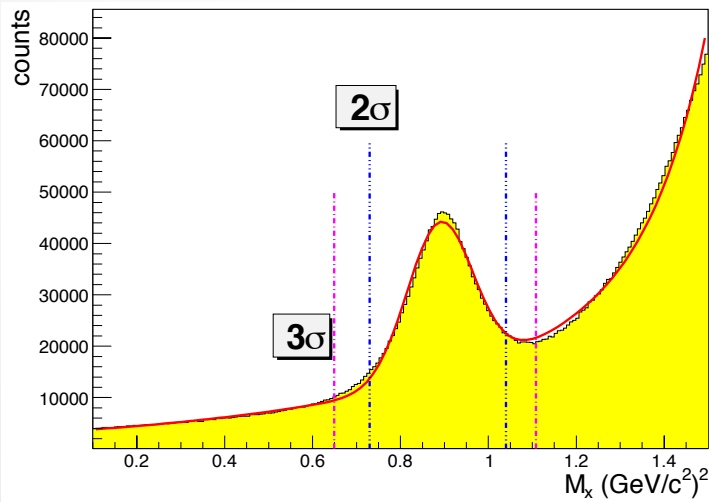


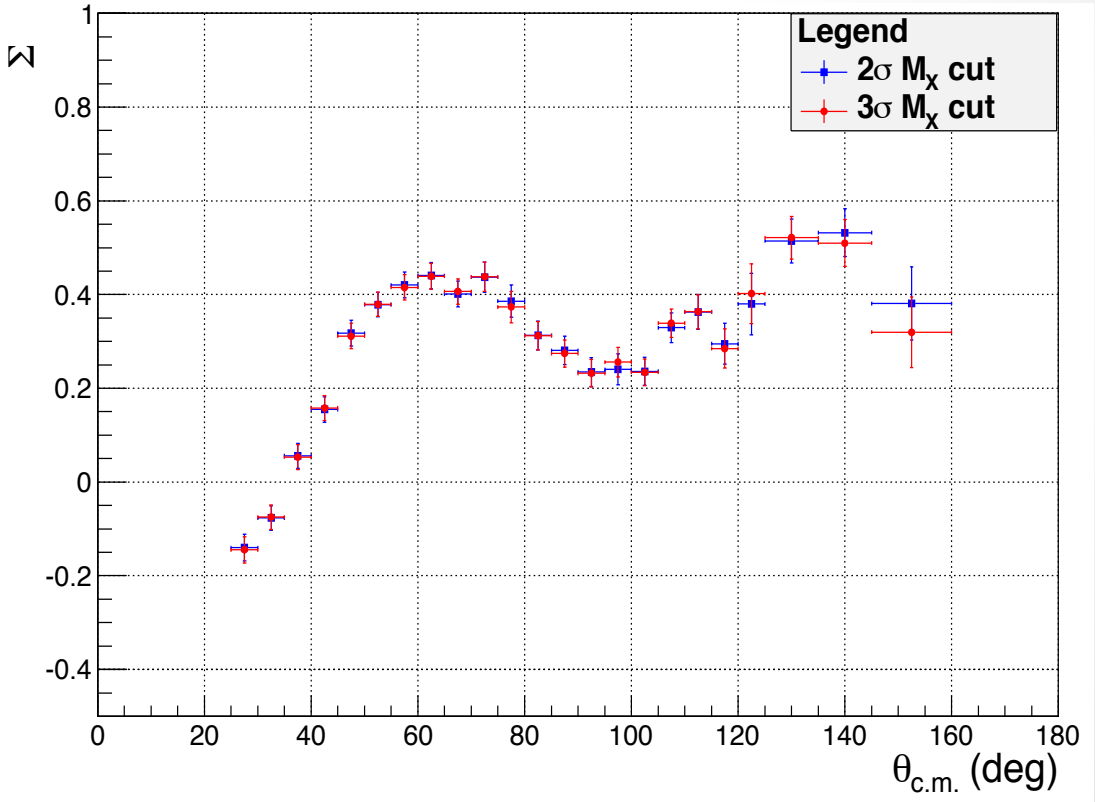
$$\overline{\Delta\Sigma}^{PID} = 0.0015_{\pm 0.0092} - 0.017_{\pm 0.040}$$

Systematic Studies

Missing-mass cut

- Compared asymmetries obtained using 2σ and 3σ missing-mass cut



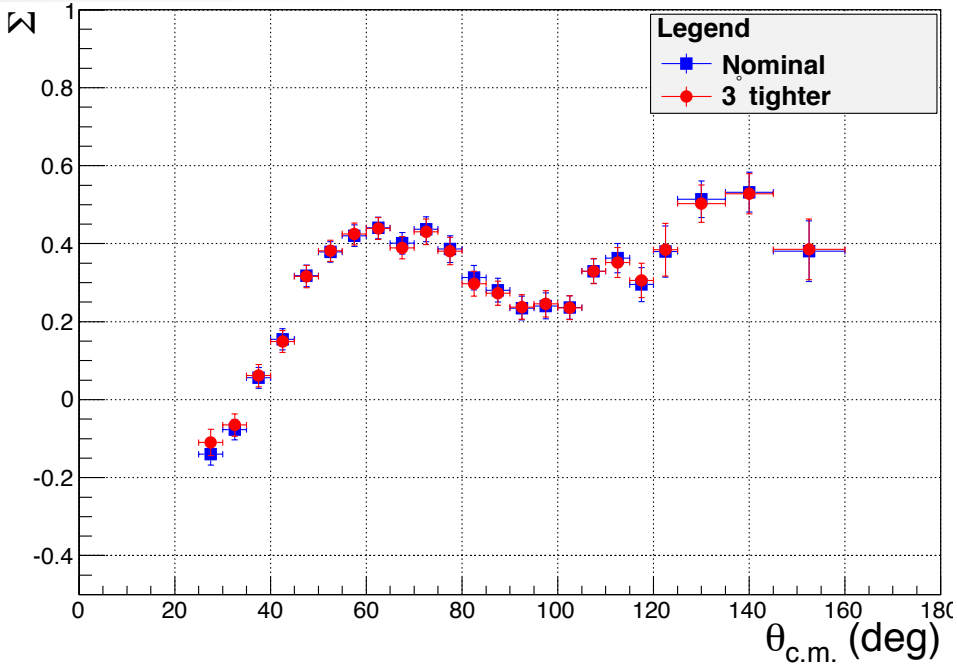


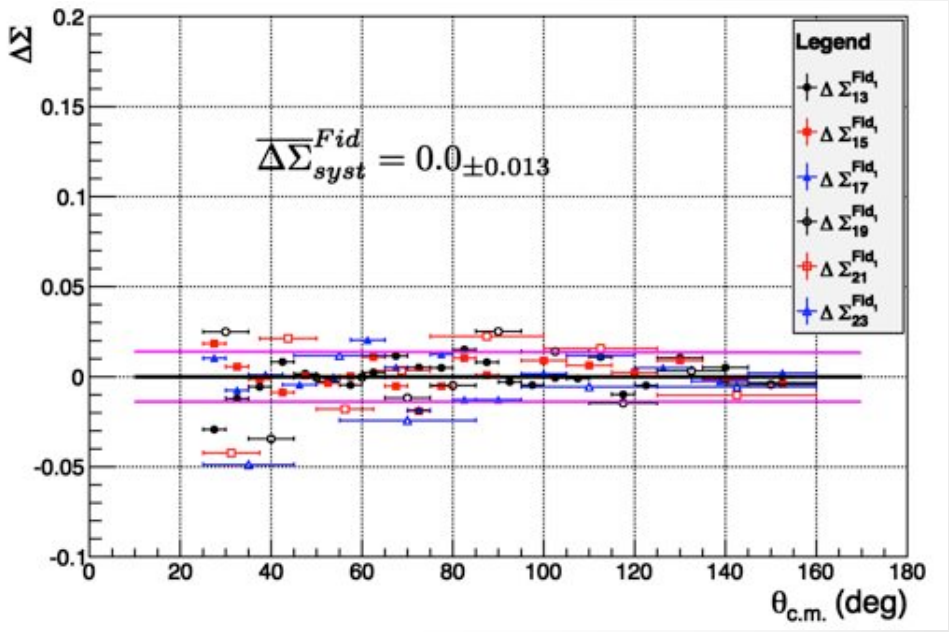
$$\overline{\Delta\Sigma}^{M_X^{cut}} = 0.003_{\pm 0.015} - 0.021_{\pm 0.089}$$

Systematic Studies

Fiducial cuts

- Compared asymmetries obtained using nominal and ~3 degrees tighter fiducial cuts

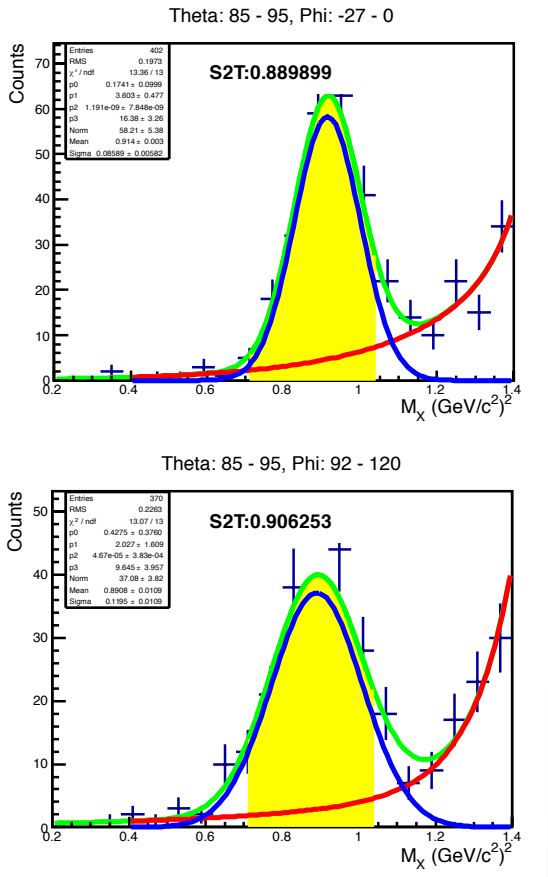


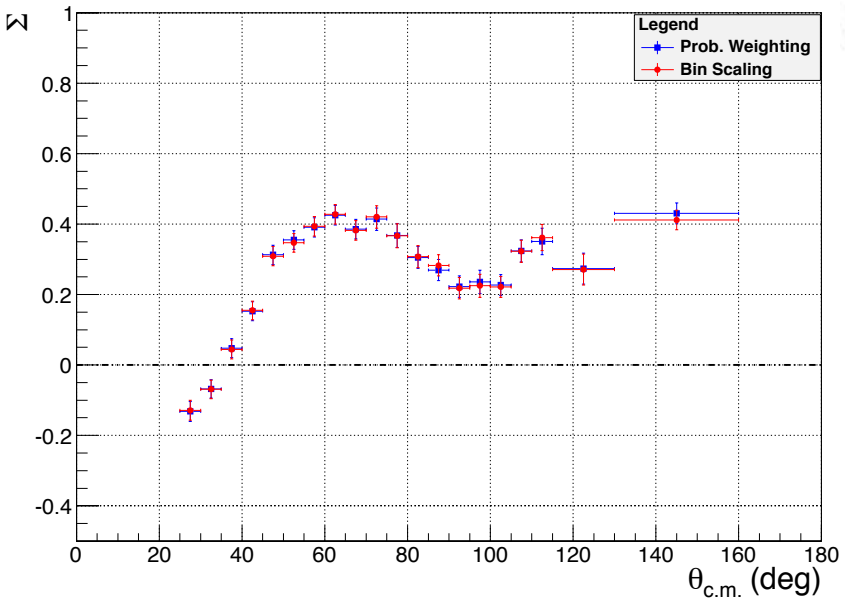


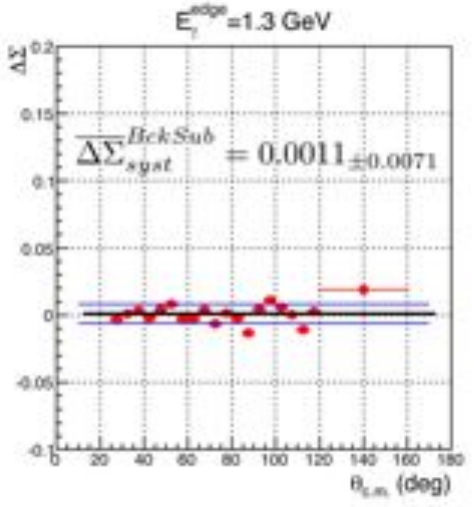
Systematic Studies

Background subtraction

- Compared asymmetries obtained using probabilistic event weighting and bin scaling





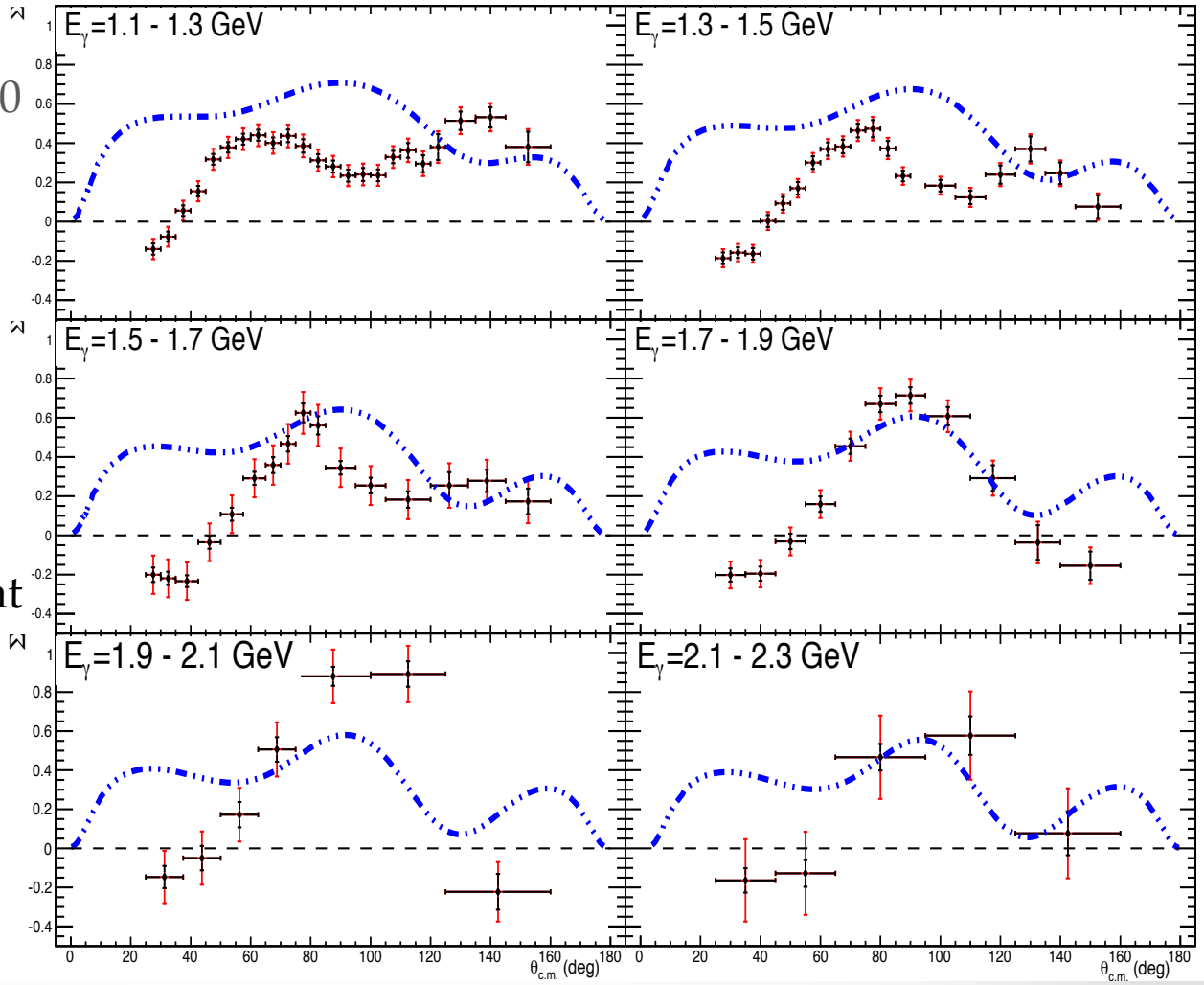


$$\overline{\Delta\Sigma}^{BckSub} = 0.0011_{\pm 0.0071} - 0.041_{\pm 0.023}$$

Results

Asymmetries compared to QGSM

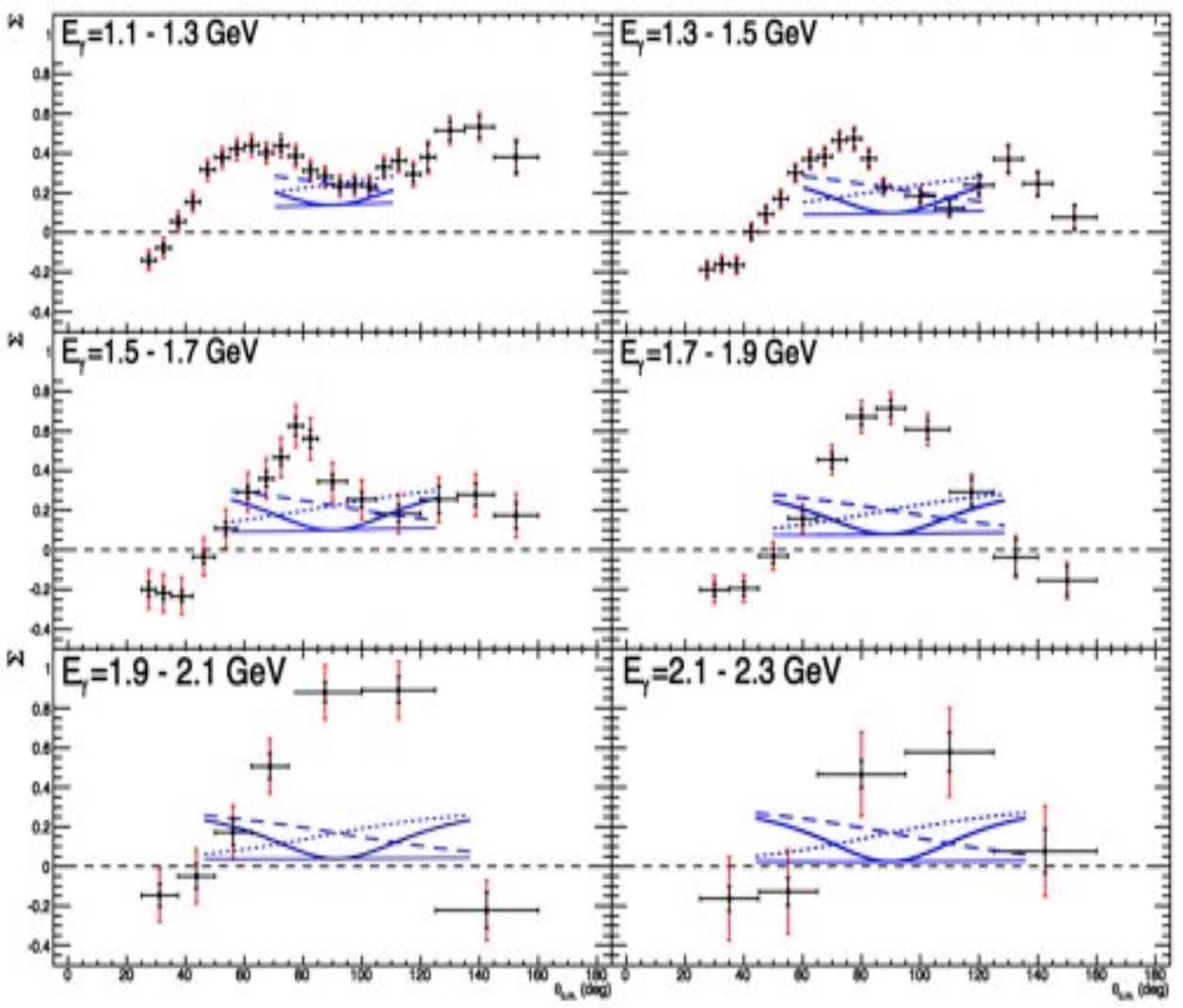
- Σ determined over 6 photon-energy bins (200 MeV wide)
- Σ shows a rich structure with minima at 90° at low photon energies and maxima at higher
- QGSM predicts maxima at higher energies but fails to give adequate predictions for lower



Results

Asymmetries compared to HRM

- Σ determined over 6 photon-energy bins (200 MeV wide)
- Σ shows a rich structure with minima at 90° at low photon energies and maxima at higher
- HRM predicts minima at lower energies but fails to give adequate predictions at higher

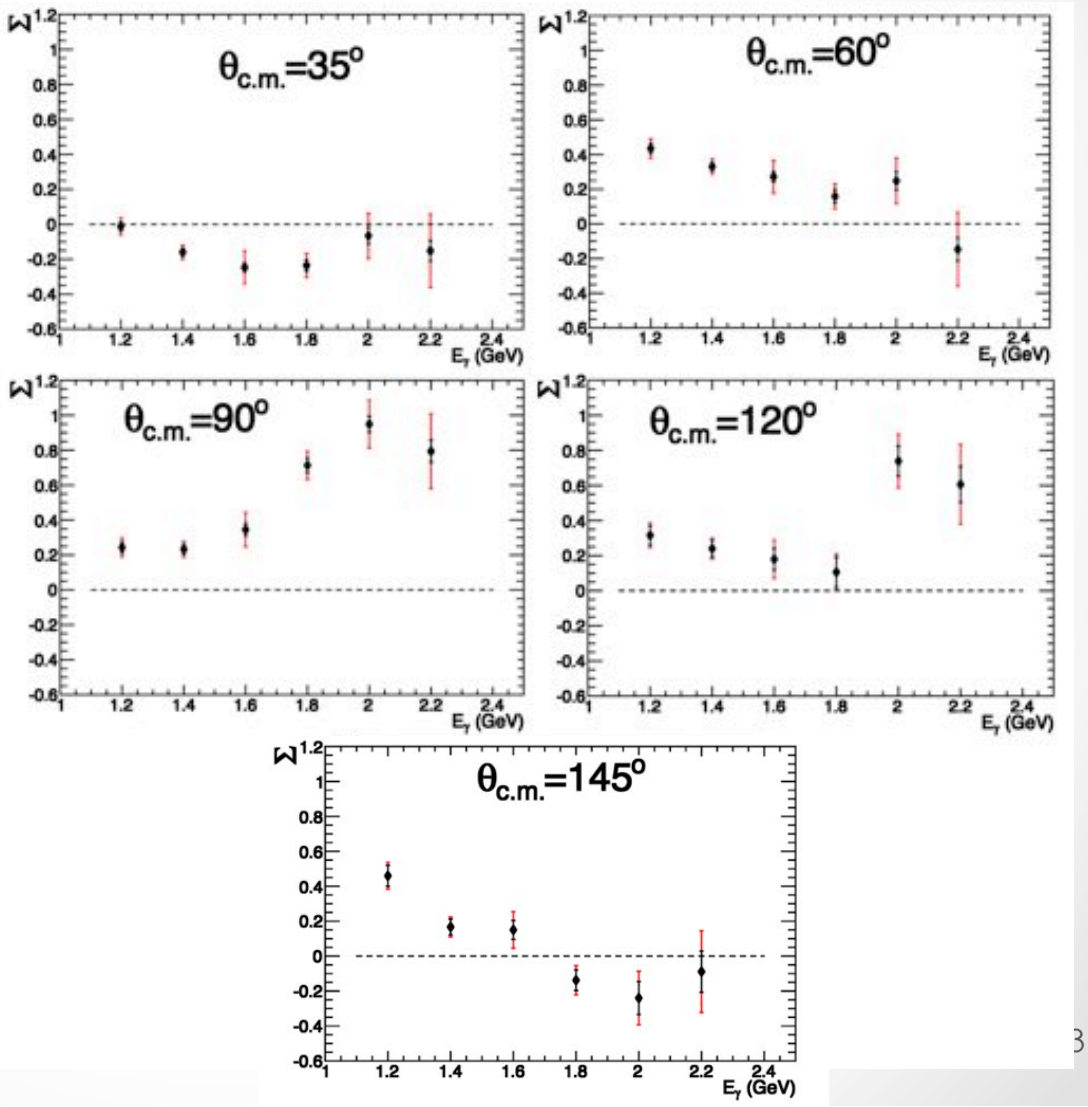


Results

asymmetry vs photon energy

- Σ determined for 5θbins (width varies between 5° and 30°)
- Extends available results to higher energies (and all angles)

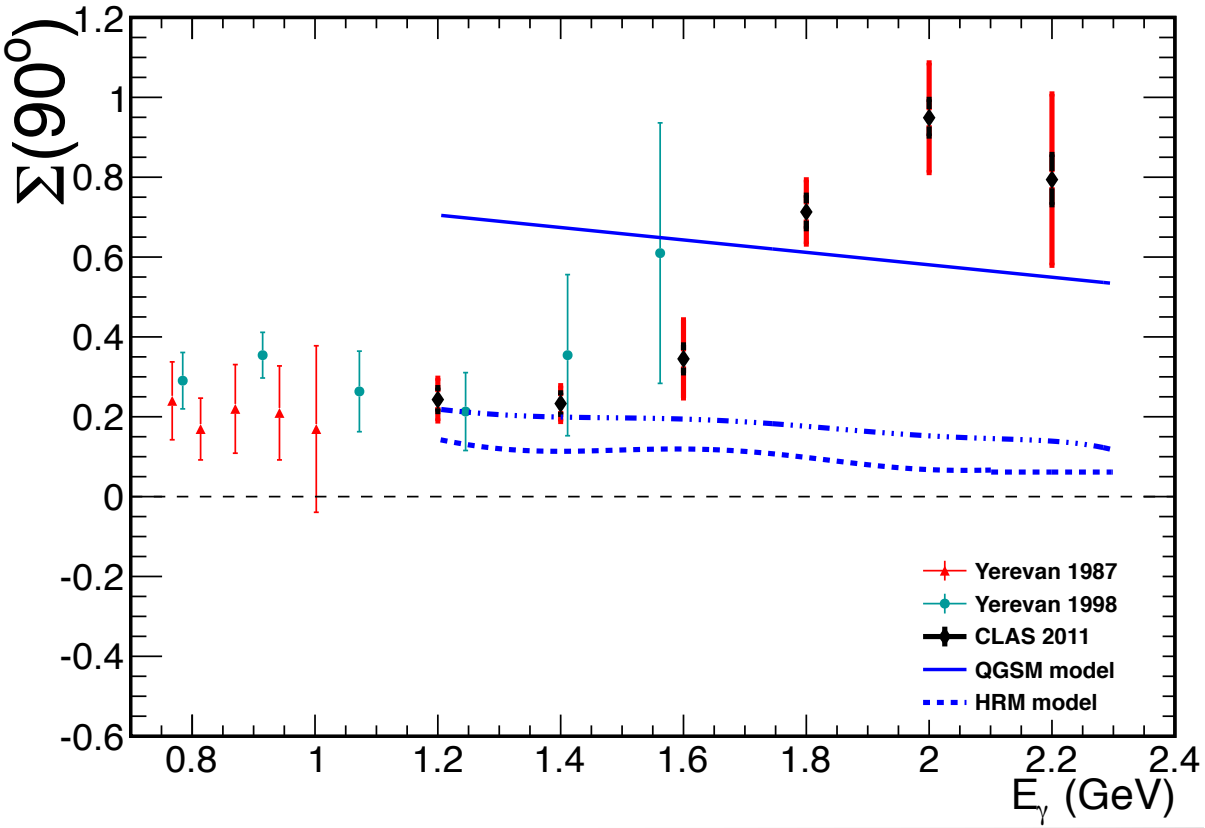
- Σchanges sign for backward angles
- Σ(90°) contradicts predictions of pQCD (Σ(90°) →1)
- Results hint a transition between $E_\gamma = 1.6 - 1.8$ GeV (change in production mechanism?)



Results

asymmetry vs photon energy

- Results agree with previous experiments
- $\Sigma(90^o)$ contradicts predictions of pQCD ($\Sigma(90^o) \rightarrow -1$)
- Results hint a transition between $E_\gamma = 1.6 - 1.8$ GeV (change in production mechanism?)



Summary

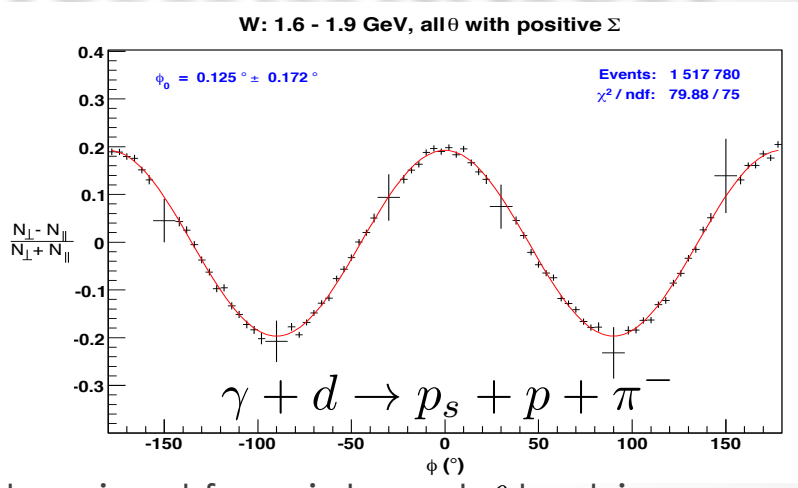
- Presented the analysis steps followed for the determination of the azimuthal asymmetry
- Statistical uncertainties range between 0.02 and 0.10 with systematic uncertainties between ~0.04 and ~0.20
- The available theoretical description of the dynamics of this reaction does not explain the data
- Analysis note in progress.

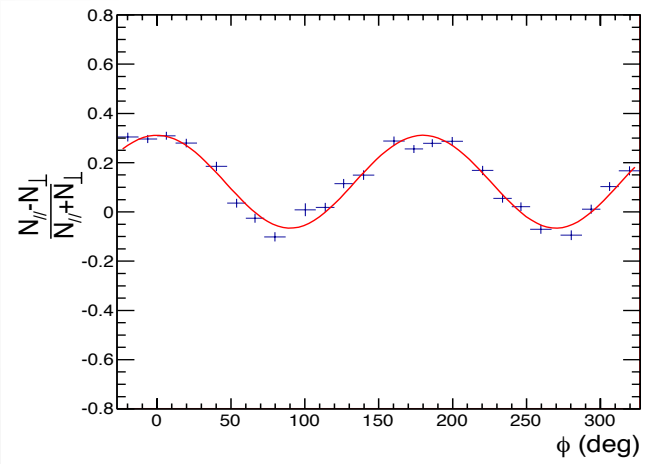
Asymmetry Determination

- Φ-bin method
  - Optimization of fit parameters

ϕ_0 determined from*

$$\phi_0 = 0.125^\circ \pm 0.172^\circ$$





F_R determined from integrated θ-bin

E_γ Bin (GeV)	F_R	ΔF_R
1.1 – 1.3	1.293	±0.010
1.3 – 1.5	1.032	±0.009
1.5 – 1.7	1.119	±0.013
1.7 – 1.9	0.930	±0.015
1.9 – 2.1	1.233	±0.038
2.1 – 2.3	0.944	±0.039

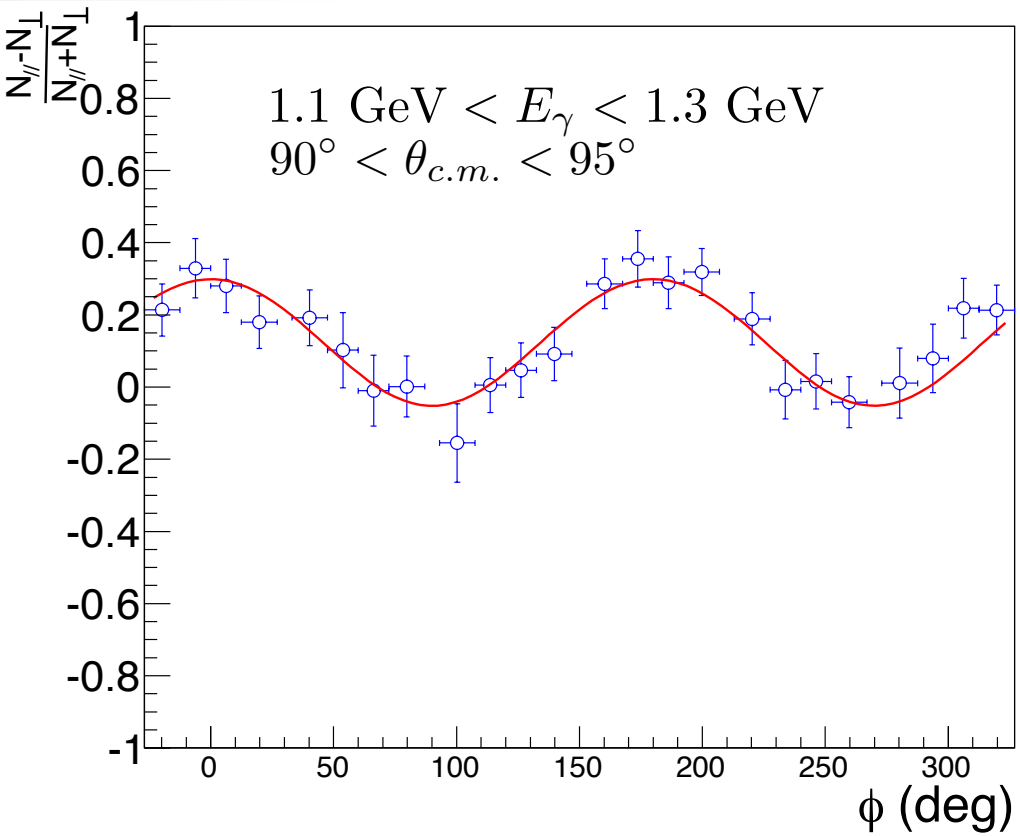
P_R determined from the polarization tables

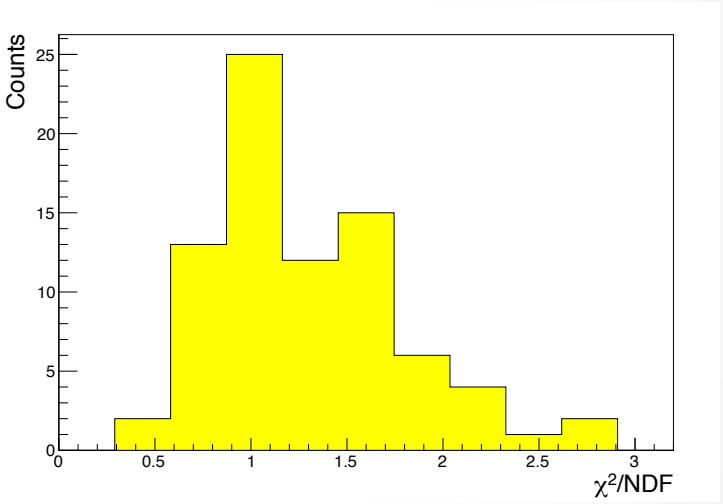
Only one free parameter $\overline{P}\Sigma$

* Performed by Daria Sokhan

Asymmetry Determination

- Φ-bin method



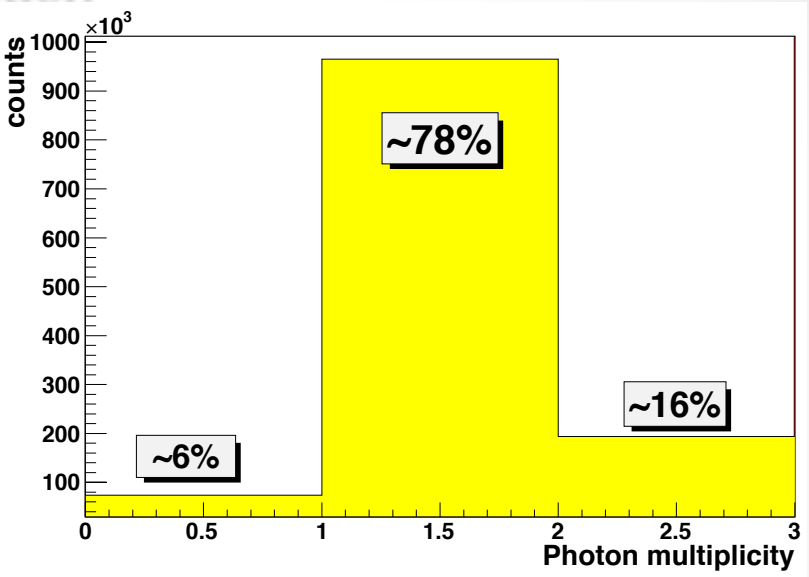


* Performed by Daria Sokhan

Analysis

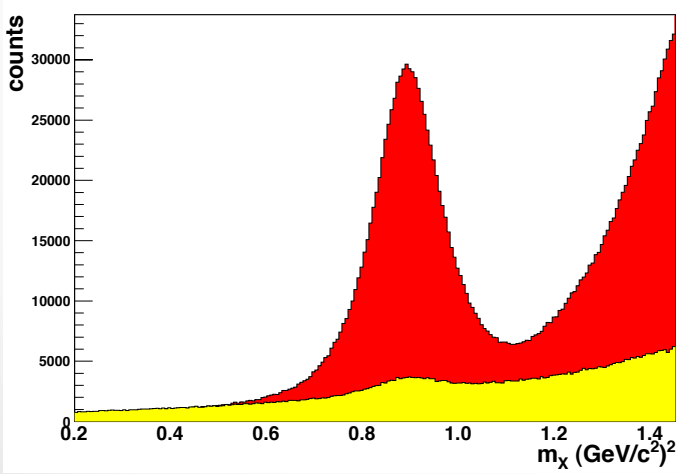
Event selection

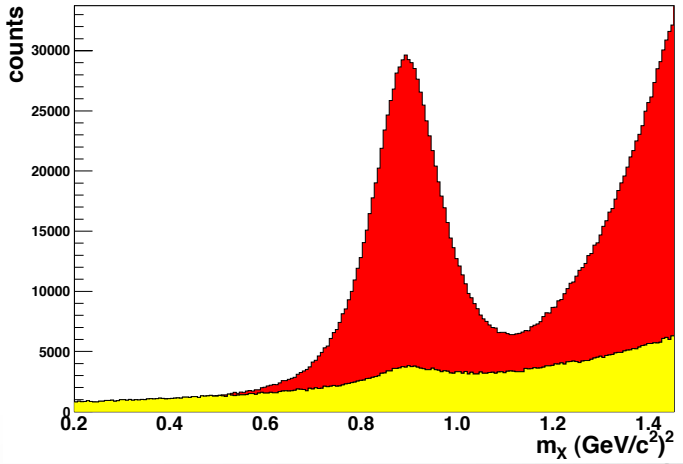
- Identifying the incident photon
  - Events with more than 1 photon with coincidence time <1 ns are excluded from further analysis



Events with 1 photon with $|\Delta t| < 1.0$ ns

Events with 2 photons with $|\Delta t| < 1.0$ ns





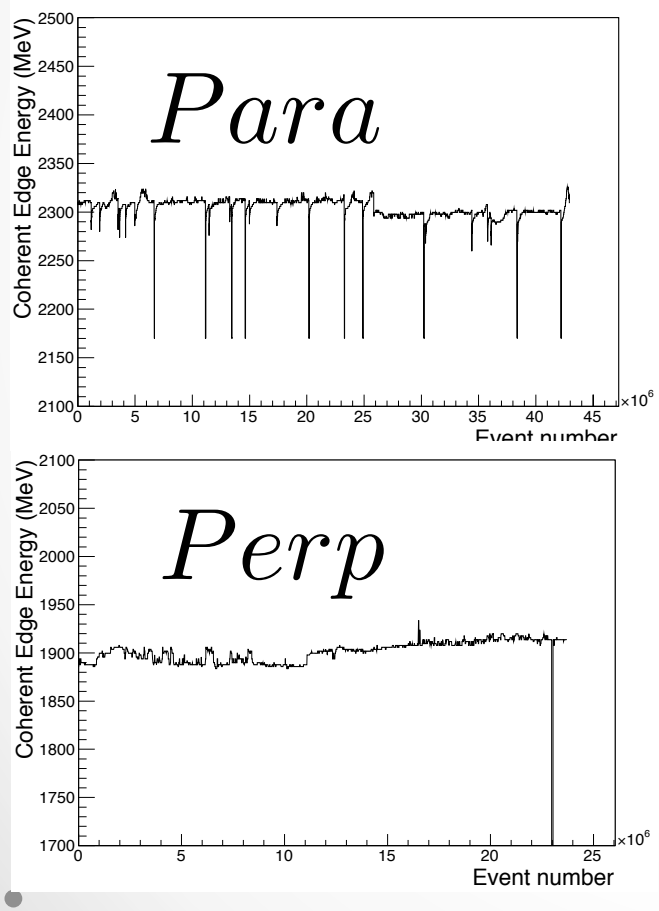
- Calculated using smallest c.t.γ

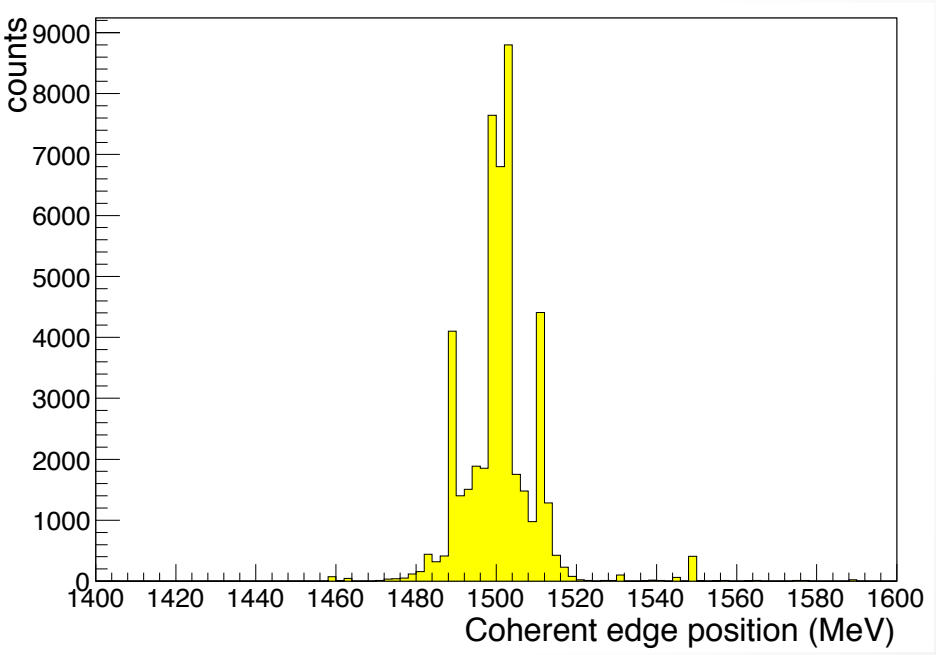
Calculated using 2^{nd} smallest c.t.γ

Analysis

Photon Polarization

- Coherent-edge position drift
  - Photon polarization had to be determined for each coherent edge position

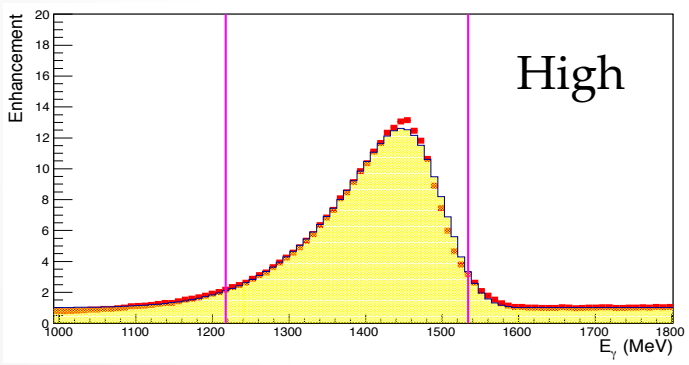


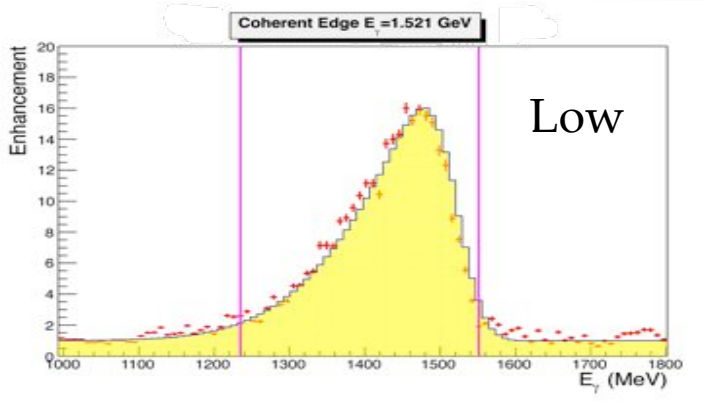


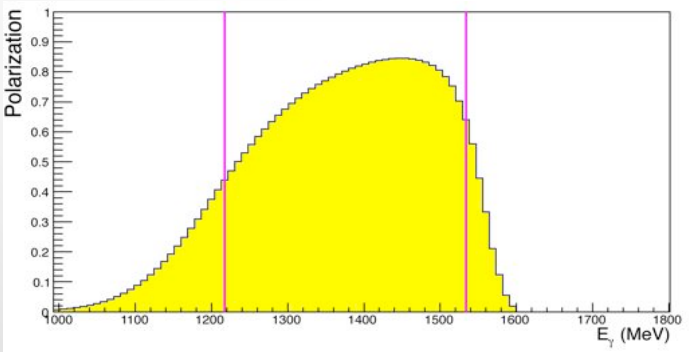
Analysis

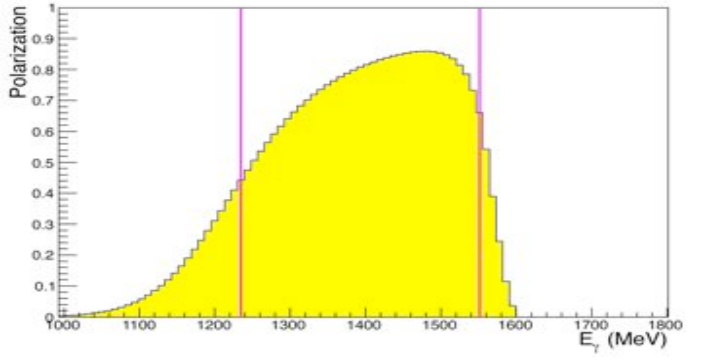
Photon Polarization

- Procedure: Pass 0
  - Initial fitting
  - Fix two parameters that describe the beam collimation
  - Fit all other bins





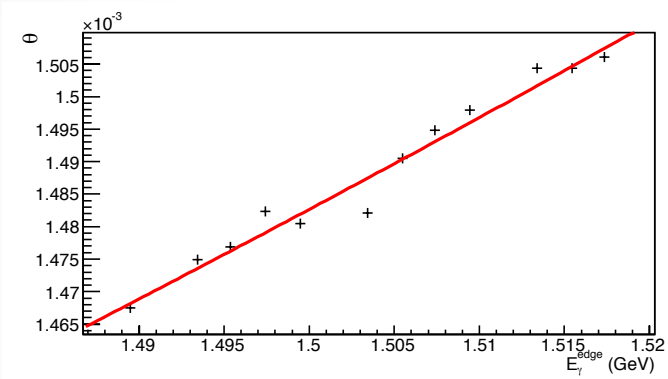


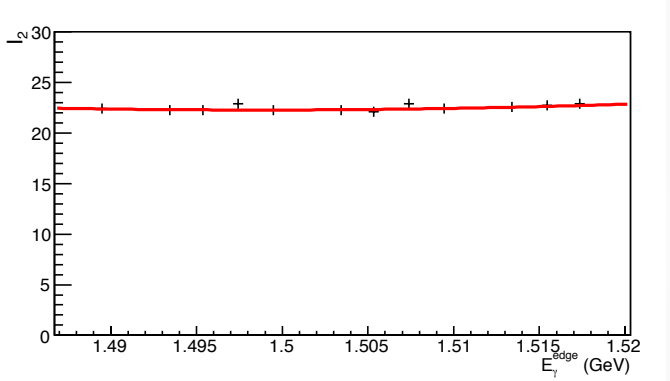


Analysis

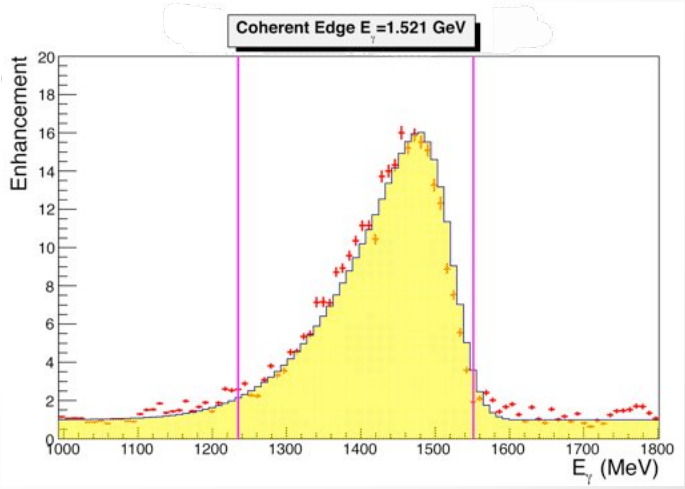
Photon Polarization

- Procedure: Pass 0
  - Determine behavior of fit parameters with coherent-edge position





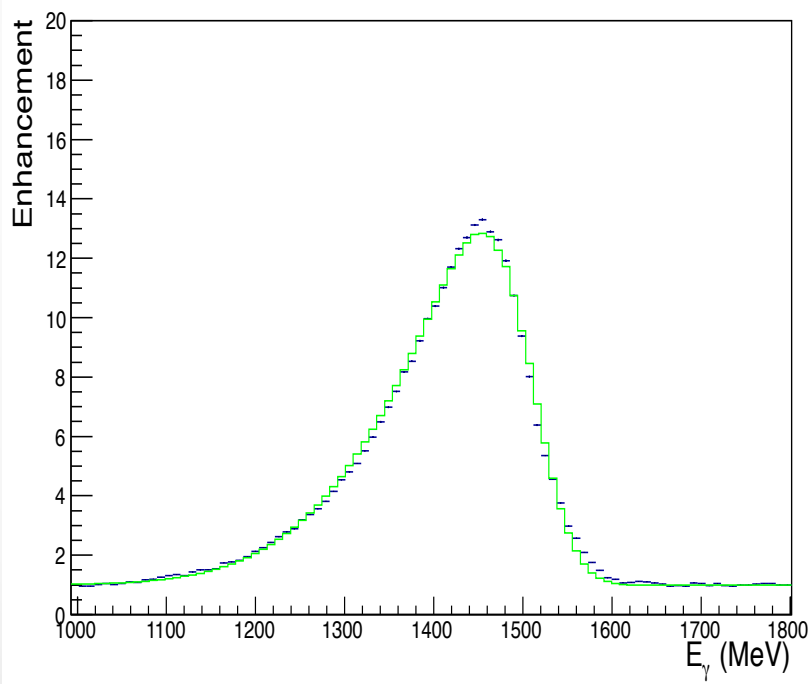
- Procedure: Pass 1
  - Pass 0 results were used in Pass 1 to rescal the enhancements.
  - Crucial for bins with low statistics

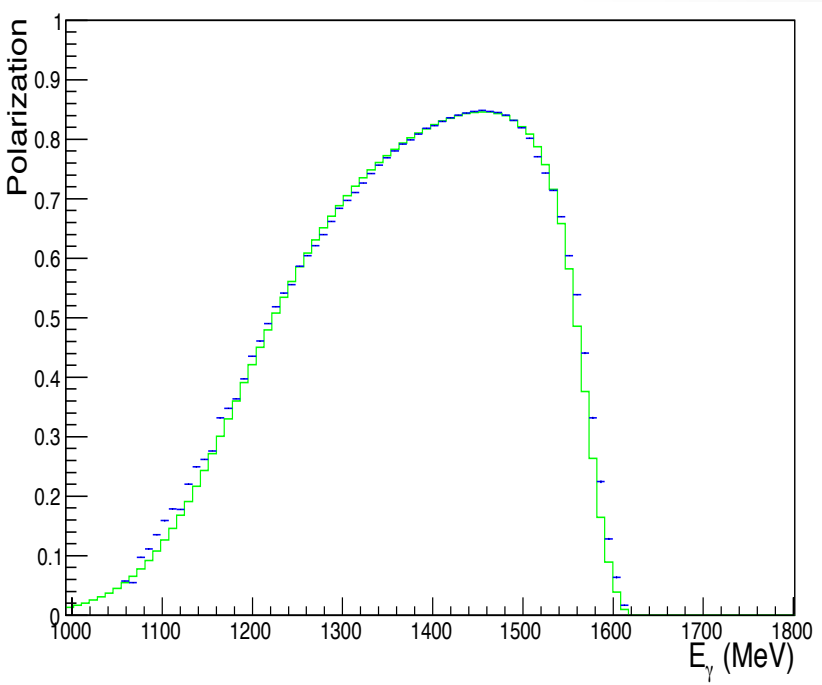


Analysis

Photon Polarization

- Procedure: Pass 1
  - Compare between the enhancement from the data and enhancement from fitting
  - Correct photon polarization to account for differences between the fit and



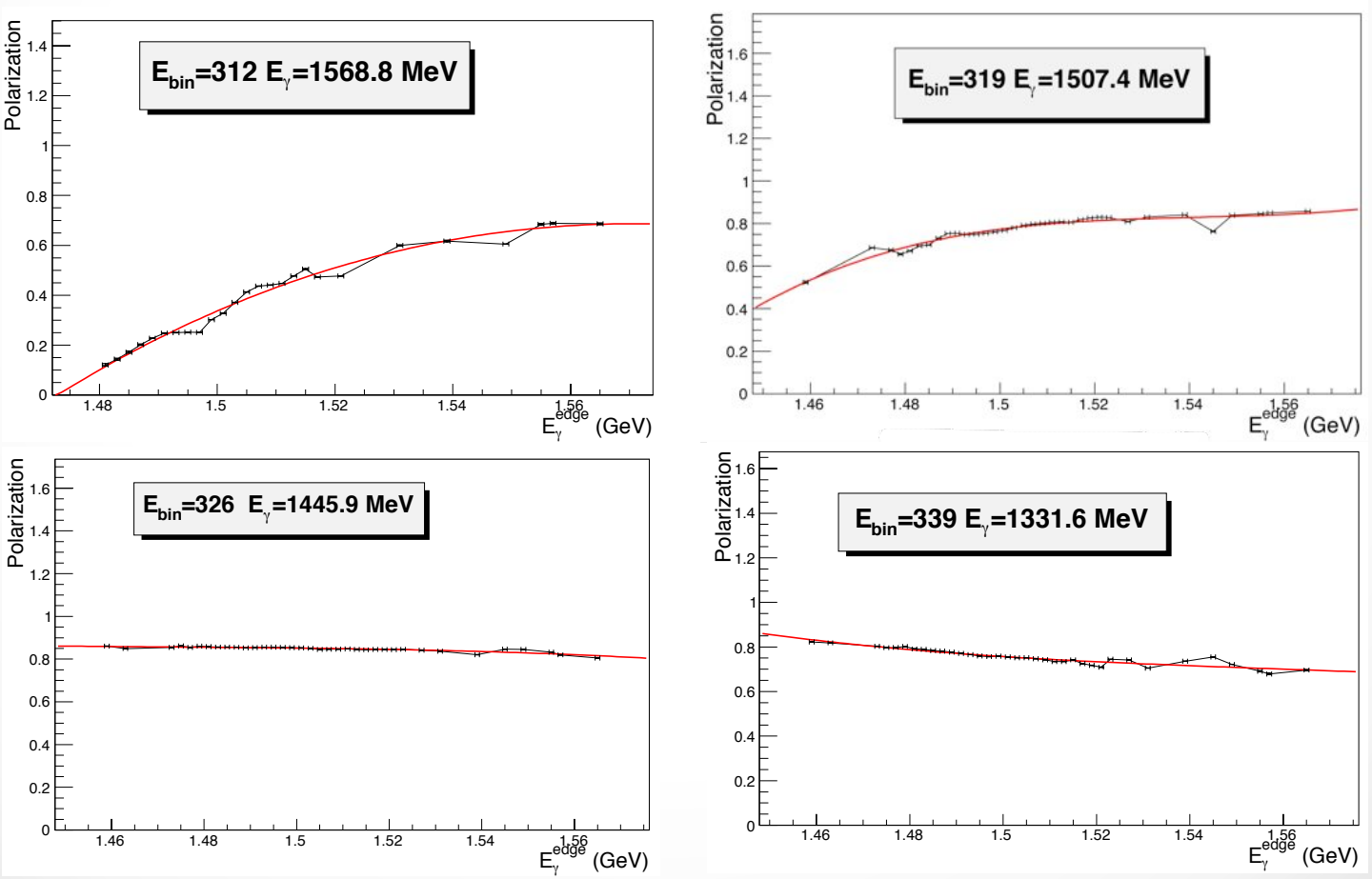


$$\frac{\Delta P_g}{P_g} = \frac{1}{\xi - 1}\frac{\Delta \xi}{\xi}.$$

Analysis

Photon Polarization

- Procedure: Pass 1
  - Account for statistical fluctuation in corrections
  - Only systematic differences are taken into account



Analysis

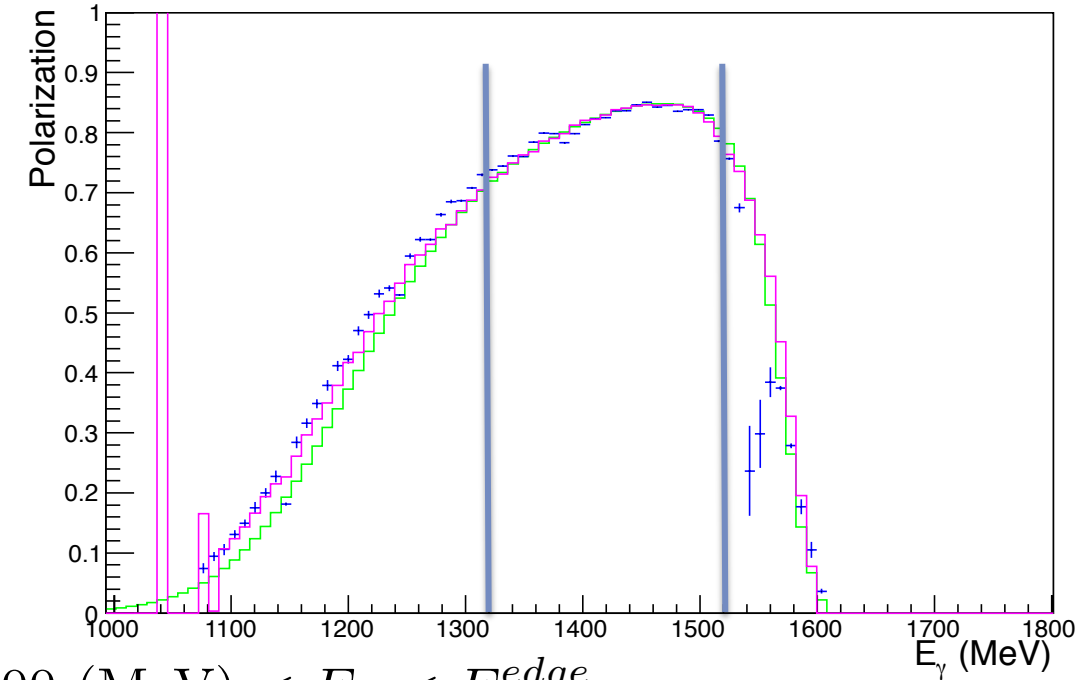
Photon Polarization

- Procedure: Pass 1
  - Determine the degree of photon polarization

Polarization from fit

Corrected polarization that accounts for differences between enhancement and fit

Polarization removing statistical fluctuations



  - Events with $E_\gamma^{edge} - 200\ (\mathrm{MeV}) < E_\gamma < E_\gamma^{edge}$ and $P_\gamma > 0.5$ used for further analysis in an attempt to reduce the uncertainty on the photon polarization

Analysis

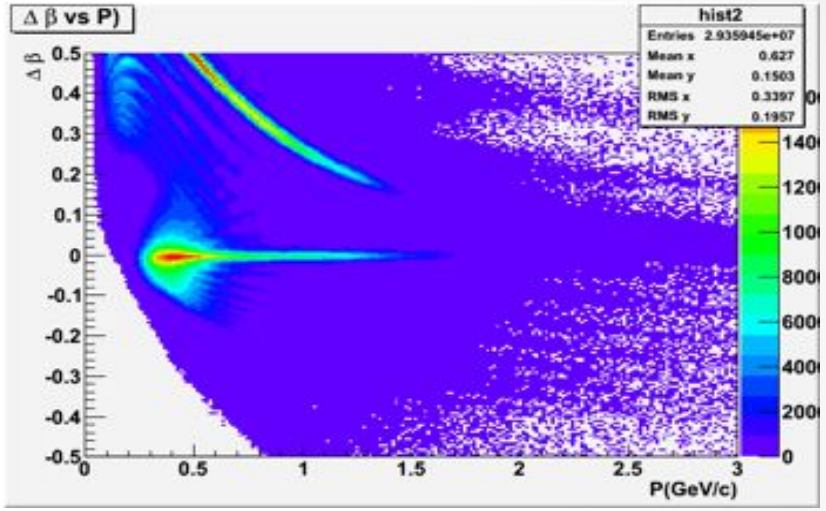
Event selection

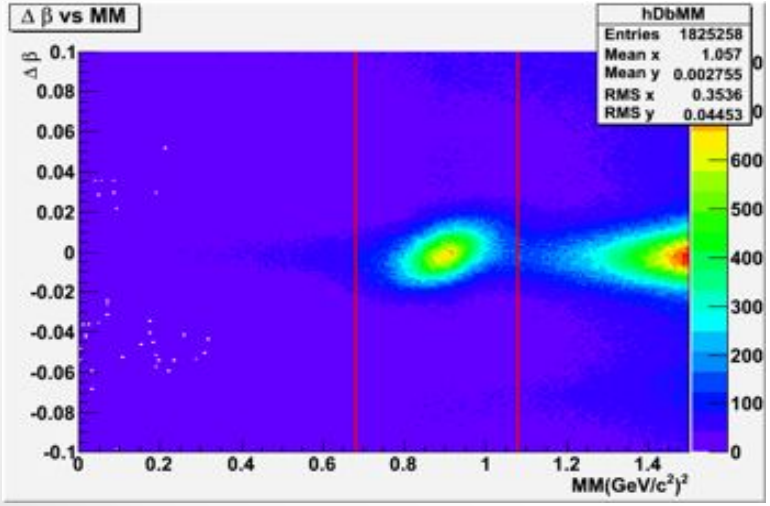
- Particle ID

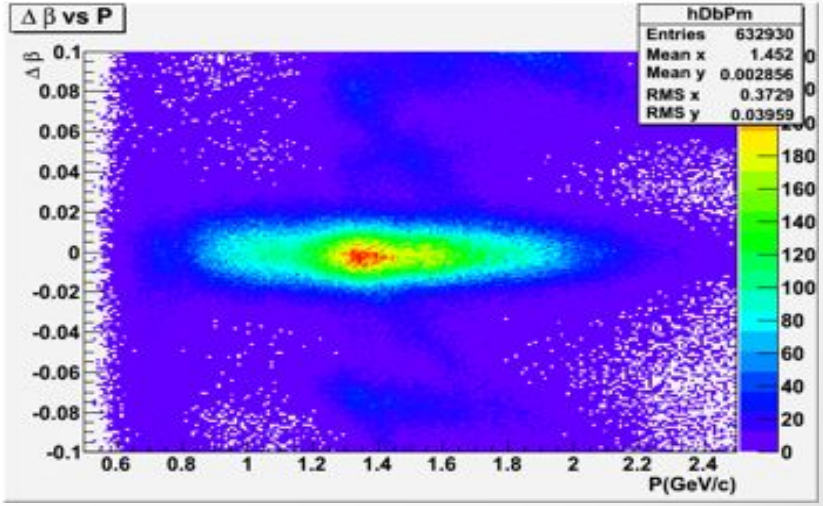
$$\Delta\beta = \beta_{meas} - \beta_{calc}$$

$$\beta_{calc} = \frac{P_{EVNT}}{\sqrt{P_{EVNT}^2 + m_{PDG}^2}}$$

$$\beta_{meas} = \beta_{EVNT}$$



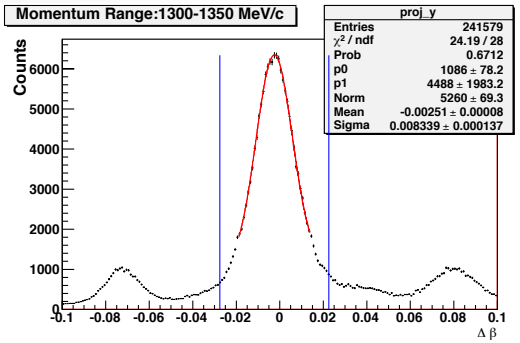


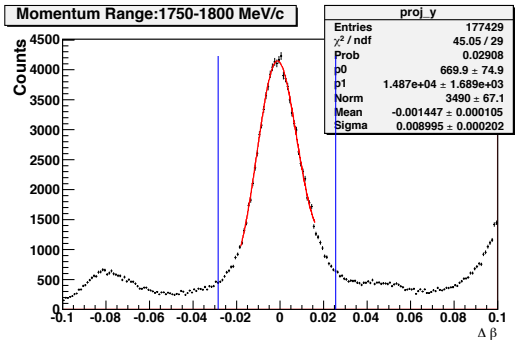


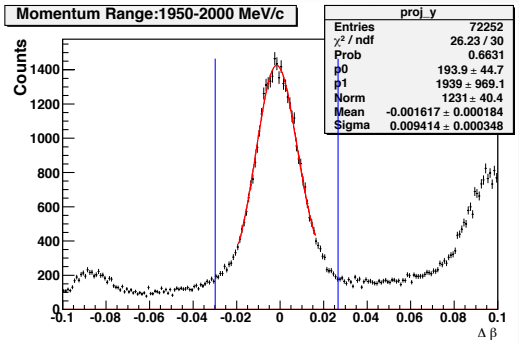
Analysis

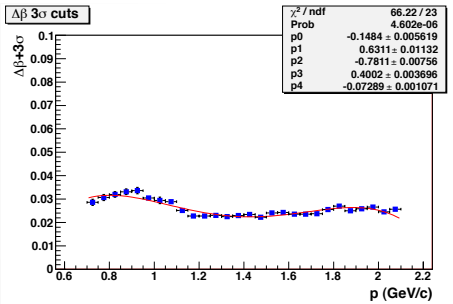
Event selection

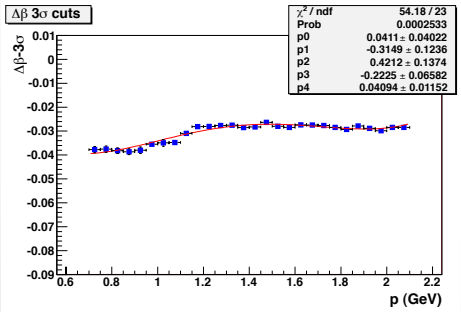
- Particle ID

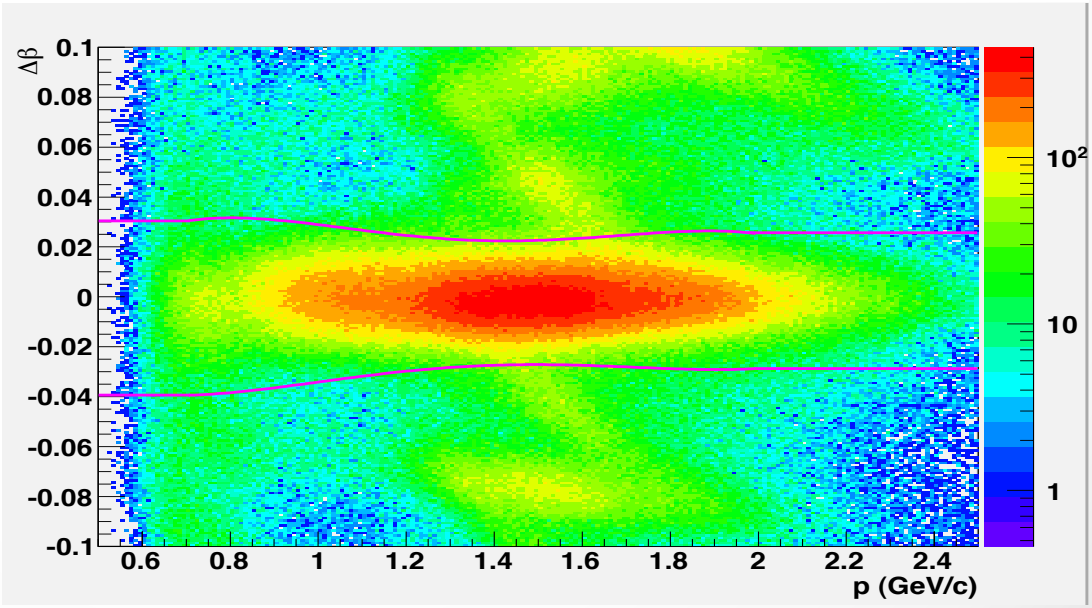








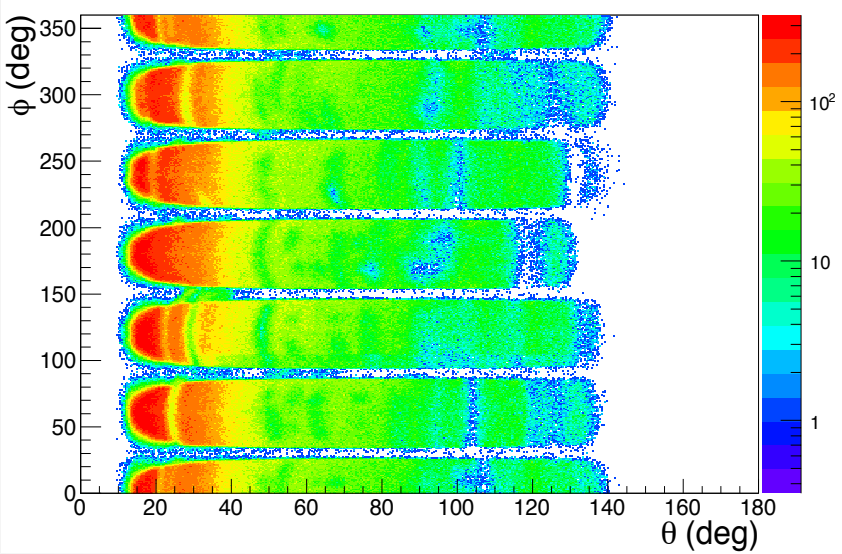


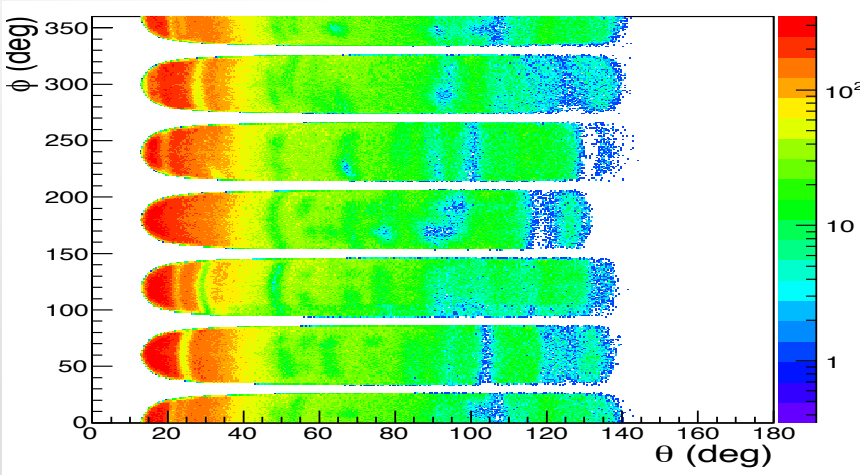


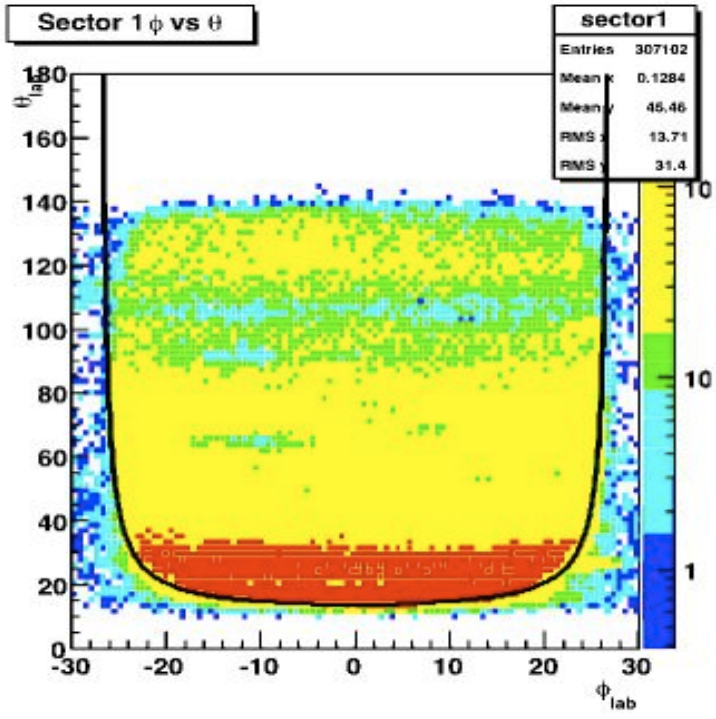
Analysis

Event selection

- Fiducial cuts Remove regions were the CLAS acceptance changes rapidly







$$\theta = -\frac{1}{c_0(|\phi - c_1| - c_2)} + c3$$

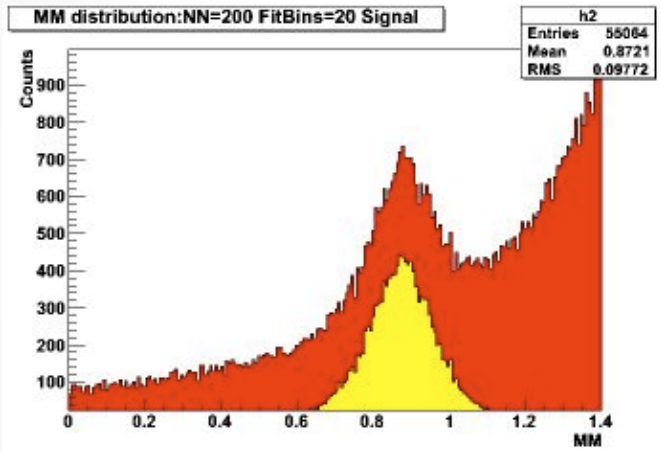
Analysis

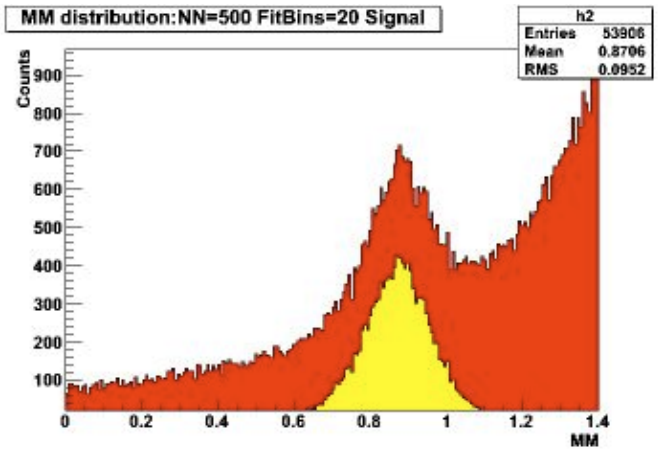
Event selection

- Background subtraction: Probabilistic Event Weighting

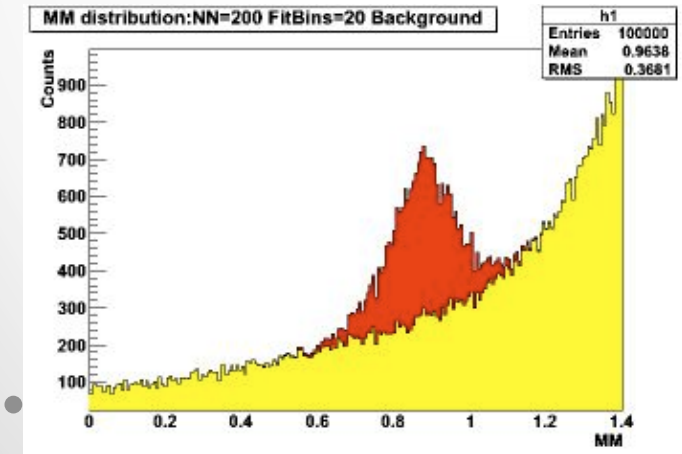
DBW: 200 Events

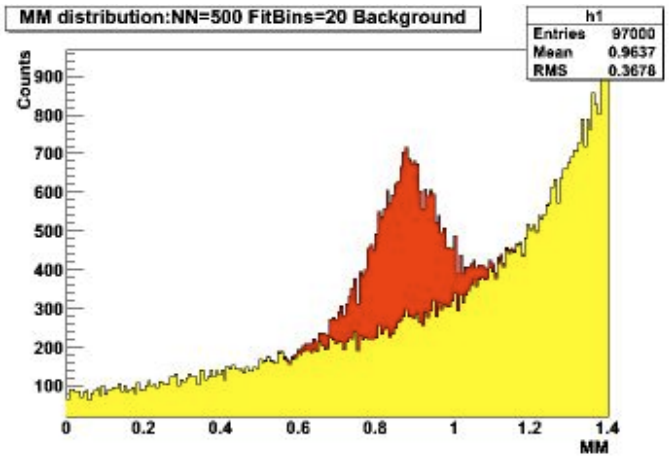
DBW: 500 Events





Signal





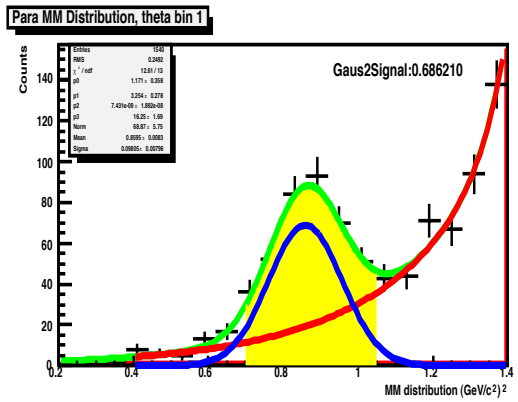
Bkgnd

Analysis

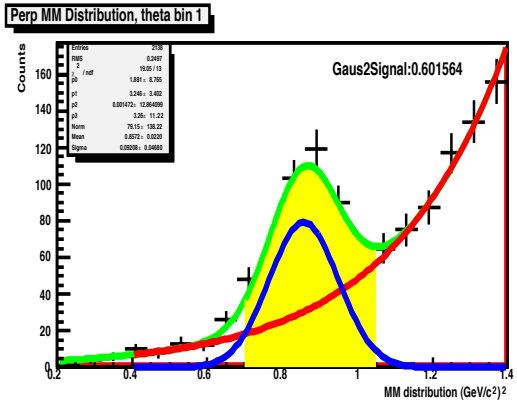
Event selection

- Background subtraction: Signal-to-total ratio

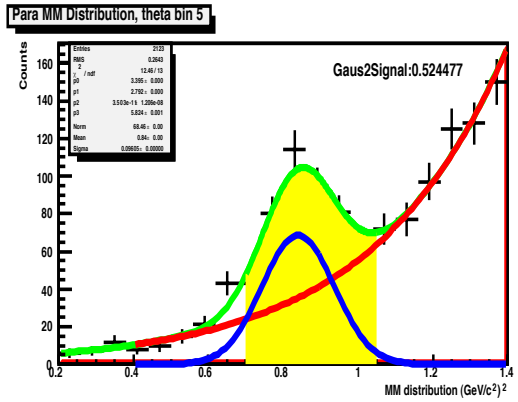
  Calculate signal-to-total ratio for each bin in theta and phi, then use this to weight all events in the bin

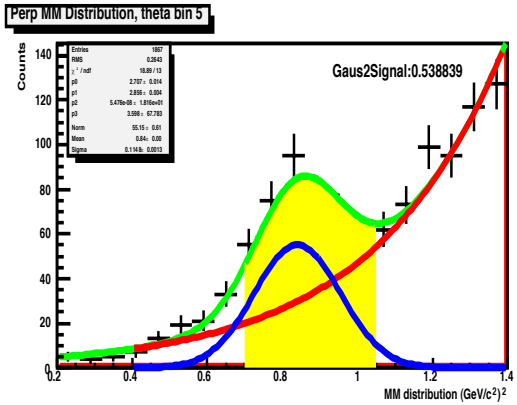


$Para \quad \theta = 55^o$



$Perp \quad \theta = 55^o$

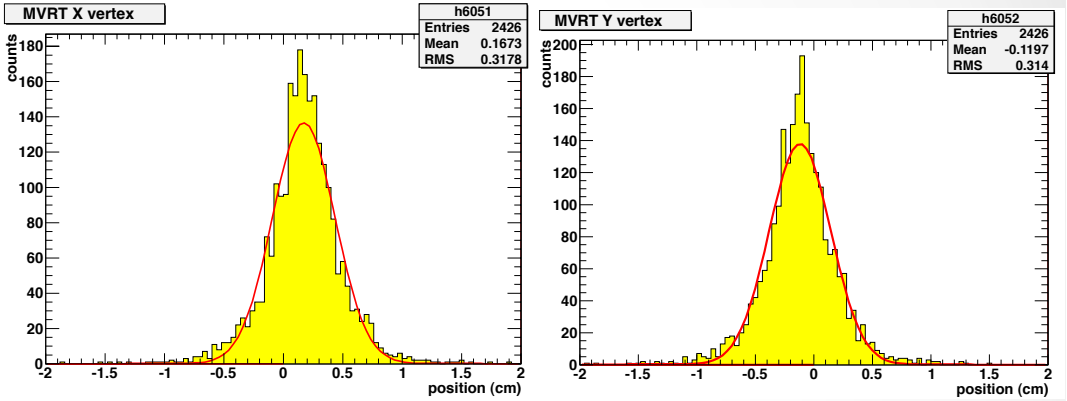




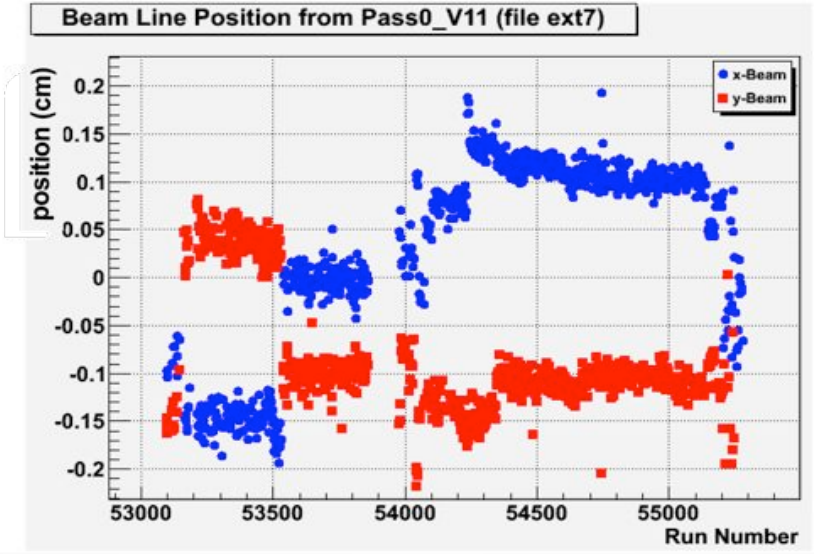
Analysis

Beam-Line position

X and Y vertex positions in multiple-track events is determined via the MVRT routine that minimizes the distance to each track, weighted by the appropriate error from the covariance matrix of each track



Mean position determined by Gaussian fits



Analysis

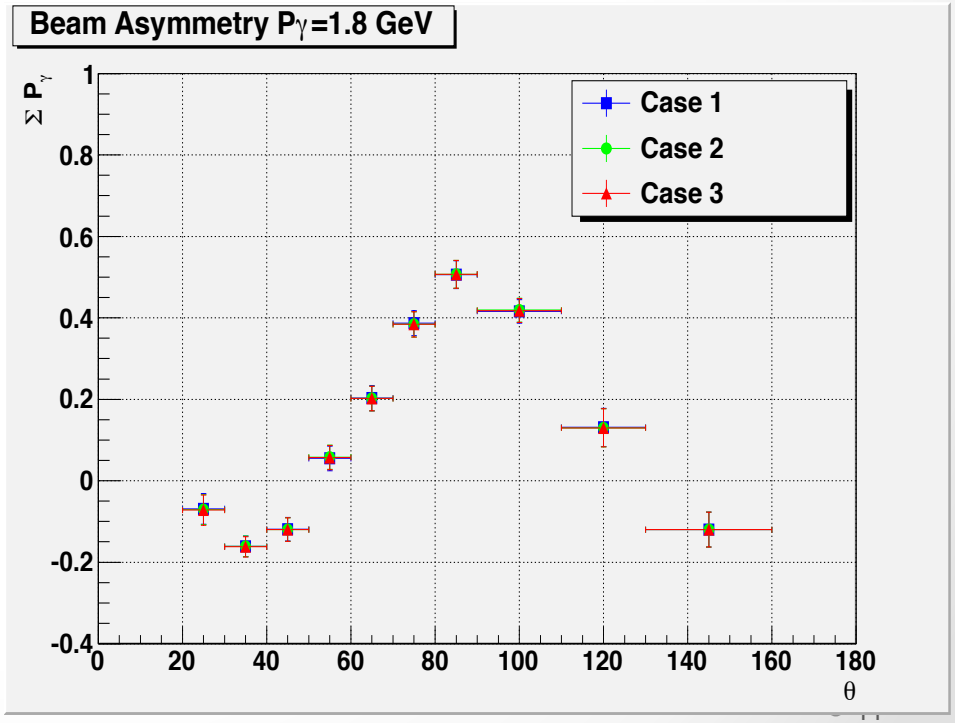
Flux Ratio sensitivity

- Determined asymmetry using 3 different values of flux ratio

  Case 1: Flux ratio was treated as a parameter

  Case 2: Flux ratio value fixed to the weighted average: 0.909

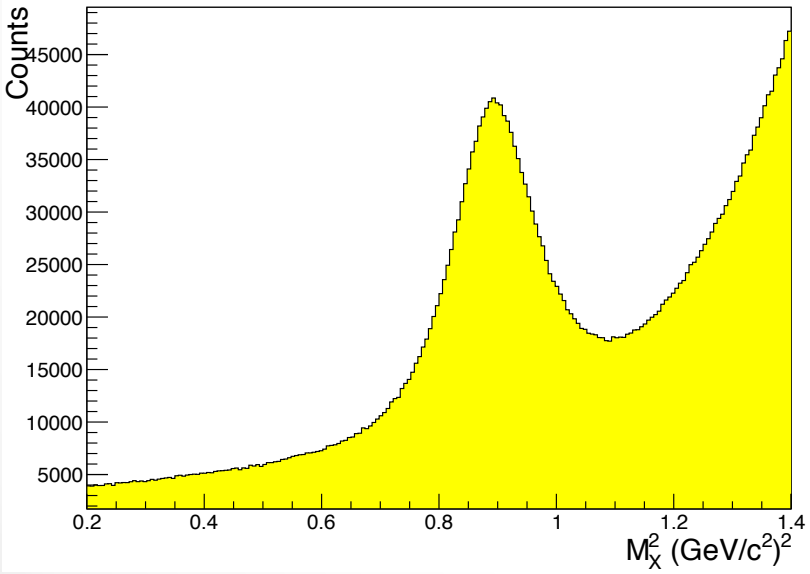
  Case 3: Flux ratio value fixed to the value extracted using integrated theta bin: 0.912



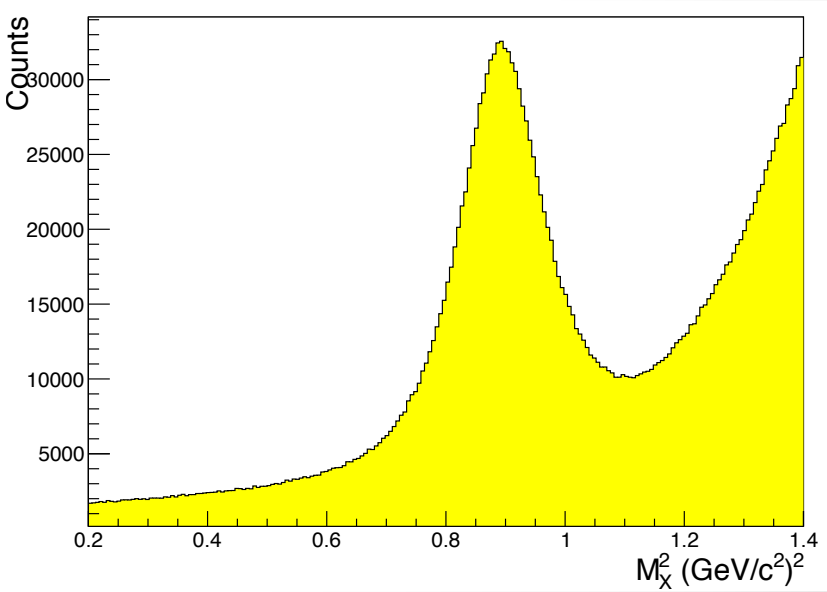
Analysis

Missing Mass Distribution

Before Analysis Cuts



After Analysis Cuts



Analysis

Event selection

- Background subtraction
  - Performed using probabilistic event weighting: Probability of a given event being a signal event using a dynamic bin width (number of events)

$$d_{i,j} = \left(\frac{\cos\theta_i - \cos\theta_j}{2}\right)^2 + \left(\frac{\phi_i - \phi_j}{2\pi}\right)^2$$

Signal: Gaussian

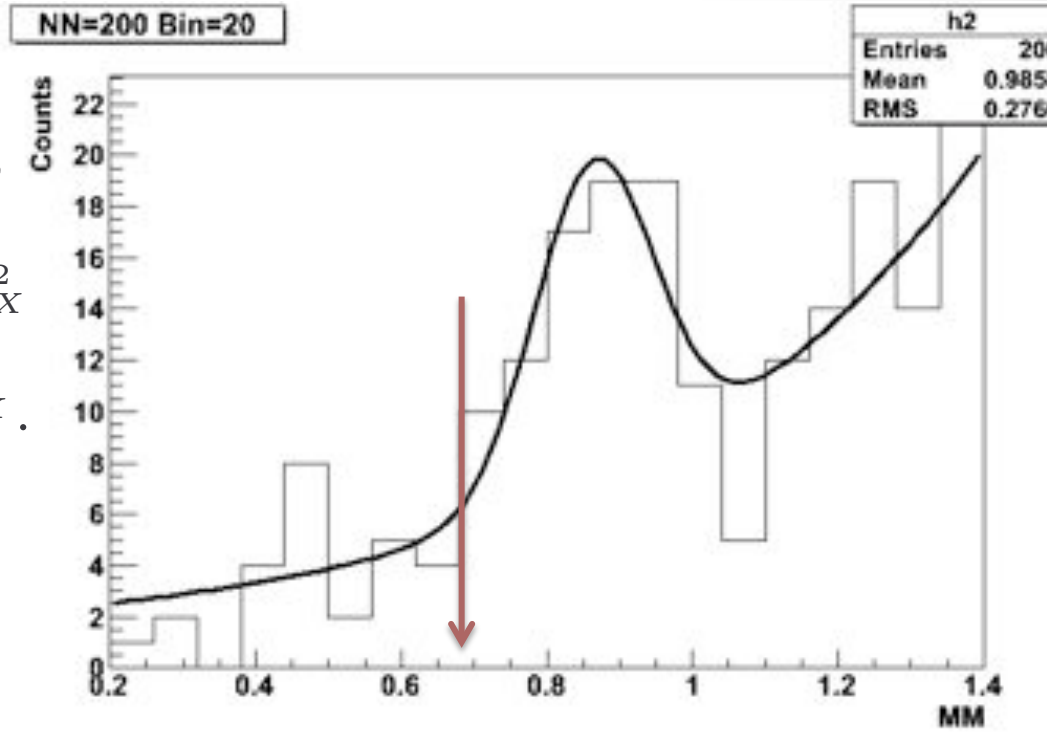
$$g(m_X^2, A, \mu, \sigma) = Ae^{-\frac{1}{2}\left(\frac{m_X^2-\mu}{\sigma}\right)^2},$$

Background: two exponentials

$$b(m_X^2, A_1, A_2, B_1, B_2) = A_1 e^{A_2 m_X^2} + B_1 e^{B_2 m_X^2}.$$

Probability

$$P(s) = \frac{g(m_{Xi}^2)}{g(m_{Xi}^2) + b(m_{Xi}^2)}$$



Systematics

Photon Energy Bin (GeV)	Source of Systematic	$\lvert\overline{\Delta\Sigma}\rvert$	$\sigma_{\overline{\Delta\Sigma}}$	Overall
$1.1-1.3$	Photon Polarization	5%	–	Depending on Σ
	ϕ_0 offset	0.0	0.0003	
	Flux Ratio	0.0002	0.0009	
	ϕ-bin width	0.015	0.017	
	Particle ID cuts	0.0015	0.0092	0.015 ± 0.027
	Missing-mass cuts	0.003	0.015	
	Fiducial cuts	0.0	0.0095	
	Background Subtraction	0.0011	0.0071	
$1.3-1.5$	Photon Polarization	5%	–	Depending on Σ
	ϕ_0 offset	0.0	0.0003	
	Flux Ratio	0.0006	0.0013	
	ϕ-bin width	0.0065	0.0072	
	Particle ID cuts	0.004	0.012	0.008 ± 0.025
	Missing-mass cuts	0.003	0.015	
	Fiducial cuts	0.0017	0.0089	
	Background Subtraction	0.0	0.012	
$1.5-1.7$	Photon Polarization	5%	–	Depending on Σ
	ϕ_0 offset	0.0002	0.0004	
	Flux Ratio	0.0010	0.0011	
	ϕ-bin width	0.025	0.046	
	Particle ID cuts	0.0	0.022	0.028 ± 0.062
	Missing-mass cuts	0.011	0.032	
	Fiducial cuts	0.0	0.011	
	Background Subtraction	0.004	0.011	

Photon Energy Bin (GeV)	Source of Systematic	$\lvert\overline{\Delta\Sigma}\rvert$	$\sigma_{\overline{\Delta\Sigma}}$	Overall
$1.7-1.9$	Photon Polarization	5%	–	Depending on Σ
	ϕ_0 offset	0.0	0.0003	
	Flux Ratio	0.0013	0.0019	
	ϕ-bin width	0.015	0.019	
	Particle ID cuts	0.007	0.023	0.017 ± 0.041
	Missing-mass cuts	0.005	0.019	
	Fiducial cuts	0.0	0.015	
	Background Subtraction	0.0	0.015	
$1.9-2.1$	Photon Polarization	5%	–	Depending on Σ
	ϕ_0 offset	0.0003	0.0007	
	Flux Ratio	0.0017	0.0054	
	ϕ-bin width	0.012	0.044	
	Particle ID cuts	0.027	0.025	0.048 ± 0.072
	Missing-mass cuts	0.020	0.022	
	Fiducial cuts	0.018	0.027	
	Background Subtraction	0.027	0.038	
$2.1-2.3$	Photon Polarization	5%	–	Depending on Σ
	ϕ_0 offset	0.0004	0.0011	
	Flux Ratio	0.004	0.013	
	ϕ-bin width	0.009	0.049	
	Particle ID cuts	0.017	0.040	0.080 ± 0.12
	Missing-mass cuts	0.021	0.089	
	Fiducial cuts	0.062	0.047	
	Background Subtraction	0.041	0.023	