Spin Polarizability of a Proton via Measurement of Double Polarization Asymmetry $\sum_{2z}$

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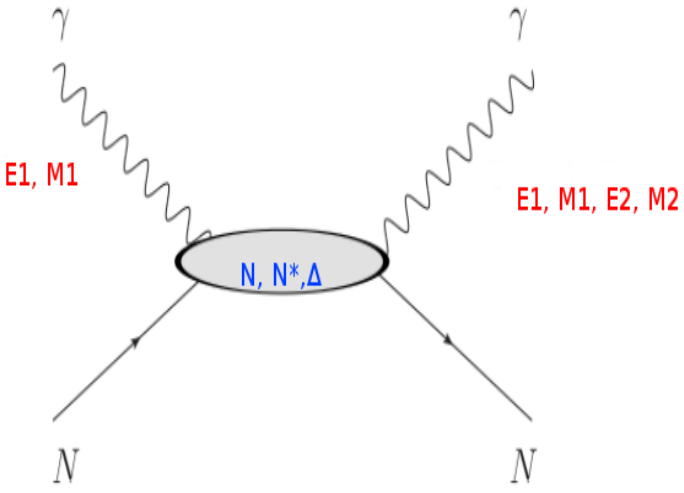
University of Regina

A2 Collaboration Meeting, March 20 - 22, 2017

Nuclear Compton Scattering and polarizabilities



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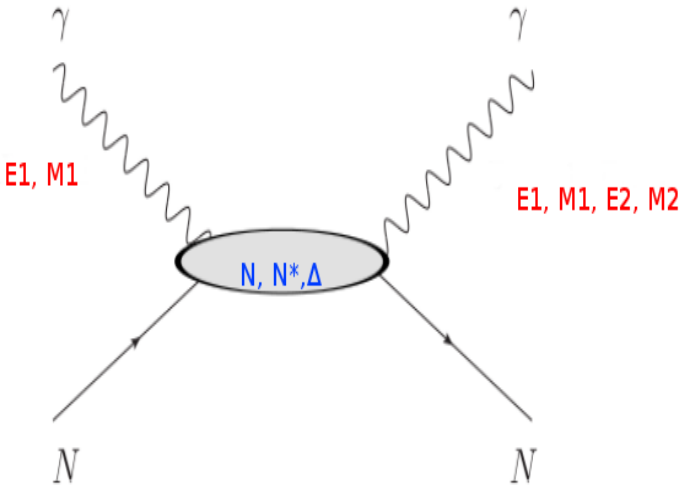

- Second Order → Scalar Polarizabilities

$$H_{eff}^{(2)} = -4\pi \left[\frac{1}{2} \alpha_{E1} \vec{E}^2 + \frac{1}{2} \beta_{M1} \vec{H}^2 \right] \tag{1}$$

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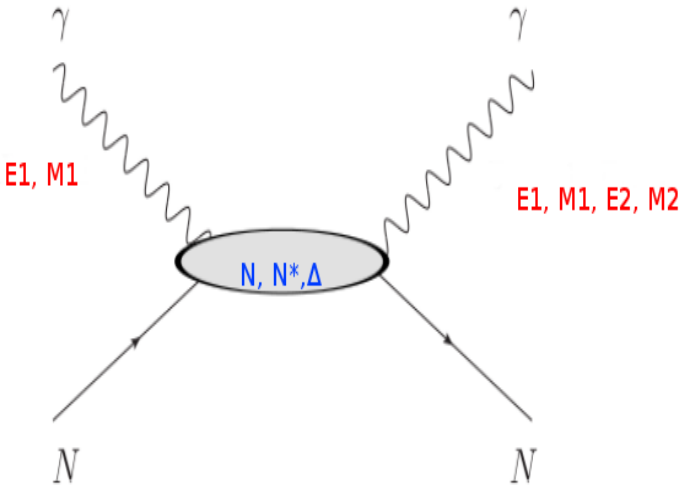

quantity	incident γ	scattered γ
α_{E1}	$E1$	$E1$
β_{M1}	$M1$	$M1$
γ_{E1E1}	$E1$	$E1$
γ_{M1M1}	$M1$	$M1$
γ_{M1E2}	$M1$	$E2$
γ_{E1M2}	$E1$	$M2$

- Second Order $\rightarrow$ Scalar Polarizabilities

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- Third Order $\rightarrow$ Spin Polarizabilities

$$H_{eff}^{(3)} = -4\pi \left[\frac{1}{2}\gamma_{E1E1}\vec{\sigma}.(\vec{E} \times \dot{\vec{E}}) + \frac{1}{2}\gamma_{M1M1}\vec{\sigma}.(\vec{H} \times \dot{\vec{H}}) - \gamma_{M1E2}E_{ij}\sigma_i H_j + \gamma_{E1M2}H_{ij}\sigma_i E_j \right] \quad (2)$$

where, $\dot{\vec{E}} = \partial_t \vec{E}$, $\dot{\vec{H}} = \partial_t \vec{H}$, $E_{ij} = \frac{1}{2}(\partial_i E_j + \partial_j E_i)$ and $H_{ij} = \frac{1}{2}(\partial_i H_j + \partial_j H_i)$

Previous Results on Spin Polarizabilities

- Forward spin polarizability (Ahrens et al., PRL**87**, 022003 (2001))

$$\begin{aligned}\gamma_0 &= -\gamma_{E1E1} - \gamma_{E1M2} - \gamma_{M1M1} - \gamma_{M1E2} \\ &= -\frac{1}{4\pi^2}\int_{\omega_{th}}^{\infty}\frac{\sigma_{3/2}(\omega)-\sigma_{1/2}(\omega)}{\omega^3}d\omega, \\ &= (-1.0 \pm 0.08 \pm 0.10)\times 10^{-4} fm^4\end{aligned} \tag{3}$$

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- Backward spin polarizability (Schumacher, Prog. Part. Nucl. Phys. **55**, 567 (2005))

$$\begin{aligned}\gamma_{\pi}^{disp.} &= -\gamma_{E1E1} - \gamma_{E1M2} + \gamma_{M1M1} + \gamma_{M1E2} \\ &= (8.0 \pm 1.8)\times 10^{-4} fm^4\end{aligned} \tag{4}$$

  - Note: $\gamma_{\pi}^{\pi^0-pole}$ contributes -46.7 $\times 10^{-4} fm^4$.

Best Way to extract Spin Polarizabilities.

- **Spin polarizabilities appear in the effective interaction Hamiltonian at third order in photon energy**
  - It is in the $\triangle$ (1232) resonance region ($E_\gamma = 250 - 350$ MeV) where their effect becomes significant.

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- **In this energy region, it is possible to accurately measure polarization asymmetries using a variety of polarized beam and target combinations**
  - The various asymmetries respond differently to the individual spin polarizabilities at different E_γ and θ.
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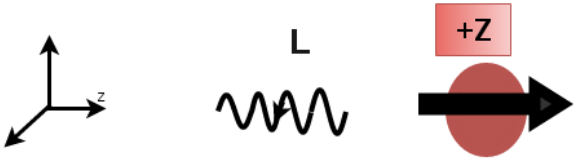
  - Measure three asymmetries at different E_γ, θ.
- **Our plan is to conduct a global analysis**:
  - include constraints from "known" γ_0, γ_π, α_{E1} and β_{M1}.
  - extract all four spin polarizabilities independently with small statistical, systematic and model-dependent errors.

Double Polarization Asymmetry $\sum_{2z}$



Left helicity state of the beam, target Polarized in +z direction (σ^{L}_{+z}).

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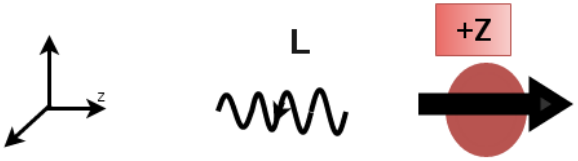

Left helicity state of the beam, target Polarized in +z direction (σ^{L}_{+z}).

Right helicity state of the beam, target Polarized in +z direction (σ^{R}_{+z}).

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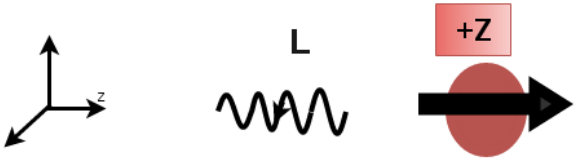

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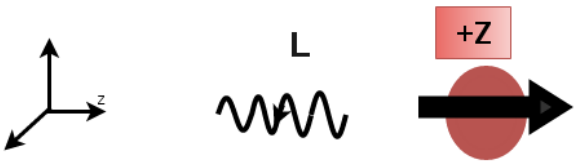

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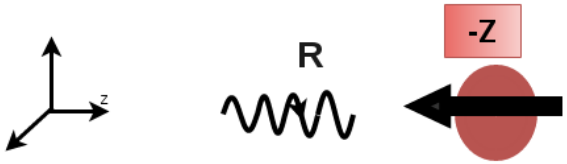


Right helicity state of the beam, target Polarized in -z direction (σ^{R}_{-z}).

$\sum_{2z}$ in terms of Cross section and Number of events

$$\sum_{2z} = \frac{1}{P_\gamma P_t}\left(\frac{\sigma^R_{+z} - \sigma^L_{+z}}{\sigma^R_{+z} + \sigma^L_{+z}}\right), \tag{5}$$

- The degree of target polarization is different for positively and negatively polarized target, so in terms of Number of events the Asymmetry formula is

$$\sum_{2z} = \frac{1}{P_\gamma}\left(\frac{(N^R_{+z} + N^L_{-z}) - (N^L_{+z} + N^R_{-z})}{P_{+z}(N^R_{+z} + N^L_{-z}) + P_{-z}(N^L_{+z} + N^R_{-z})}\right) \tag{6}$$

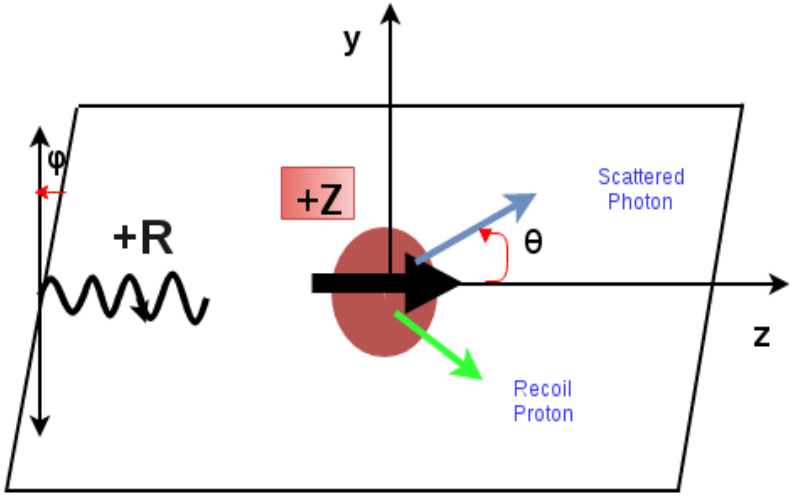
2014 and 2015 beamtime summary

	April 2014	May 2014	June 2015	June 2015
Target Material	Carbon	FS Butanol	FS Butanol	Carbon
Radiator	Moeller	Moeller	Moeller	Moeller
Time (hours)	140	190 + 90	140 + 160	55
Electron Energy (MeV)	450	450	450	450
Beam Current (nA)	7.5	7.5	20	20
Collimator (mm)	2.5	2.5	2.5	2.5
Energy Sum (MeV)	> 40	> 40	> 90	>90
Tagger Channels used	270	270	180	180
Target Polarization	-	62%, 59%	63%, 60%	-
E_γ Polarization	72%	72 %	72 %	72%

- **Positively polarized**, Negatively polarized.
- **Note: Problem with PID ADC (2014), MWPC CH1 High Voltage off(2015), no multiplicity and no TAPS trigger.**

Compton Scattering: Event Selection

- Require ONLY one **neutral** and one **charged track**.
- Require a cut on Coplanarity Angle,
  $\Delta\phi = |\phi_\gamma - \phi_{recoil}| = 180^\circ \pm 15^\circ$



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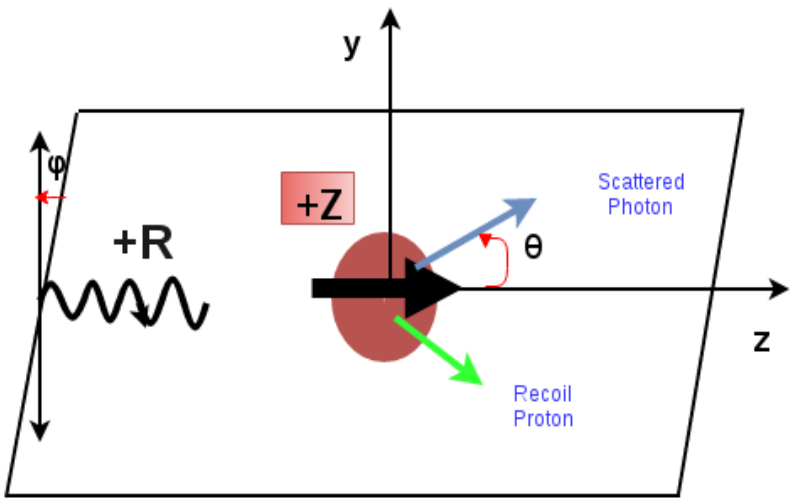
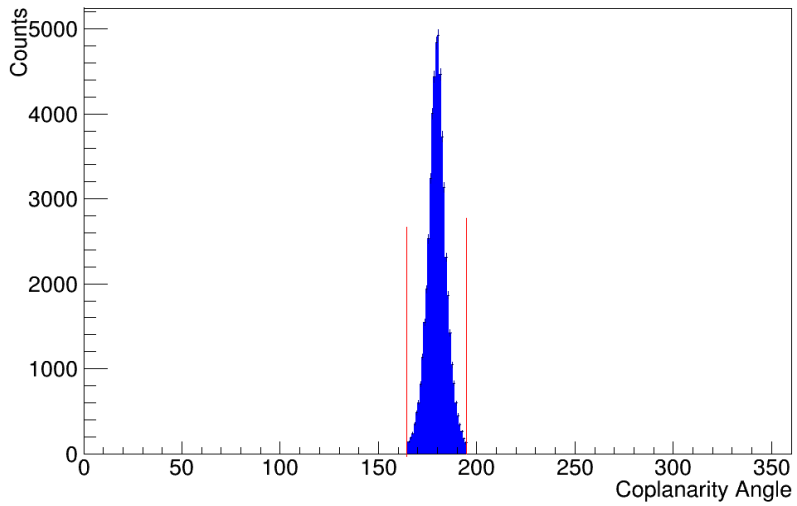
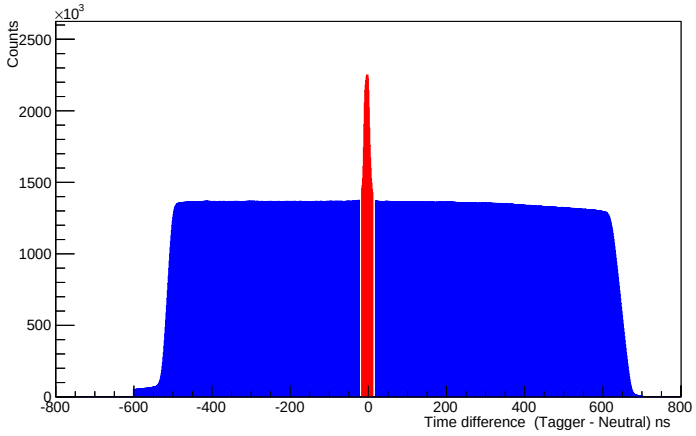




Event Selection: Accidentals - Prompt versus Random



Tagger - Neutral Time without Random Cut

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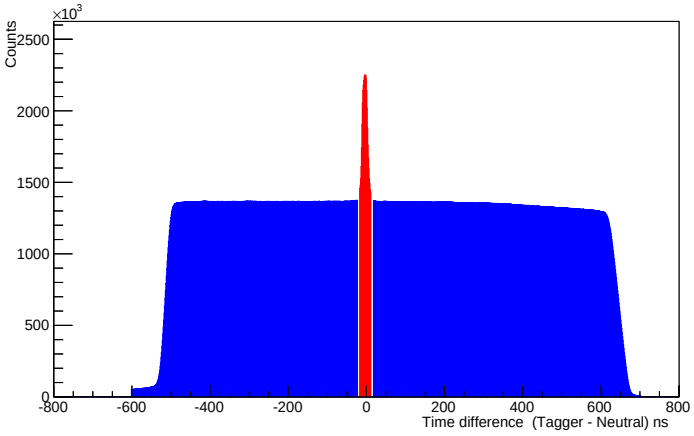

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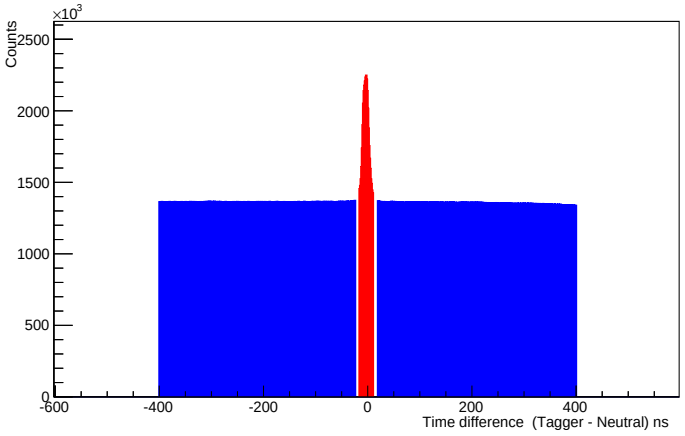

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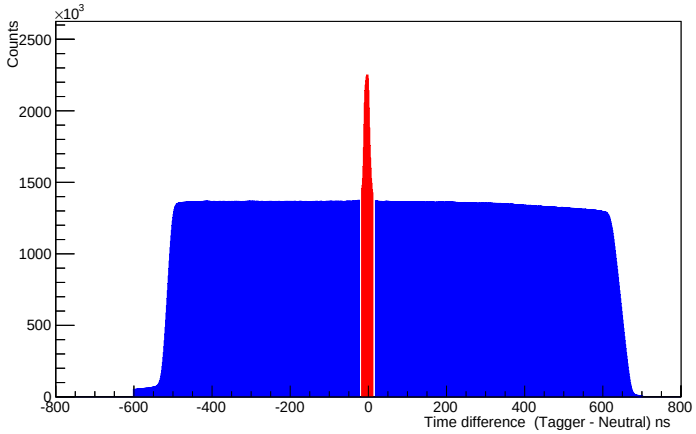

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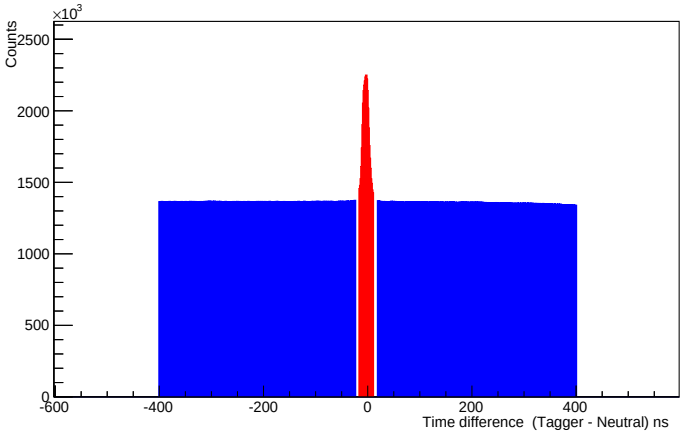

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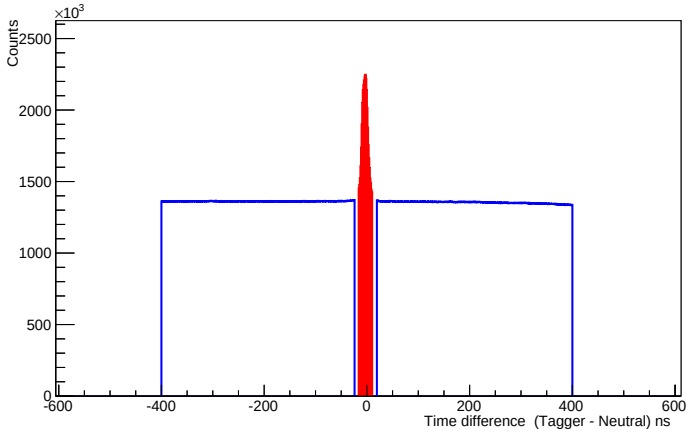

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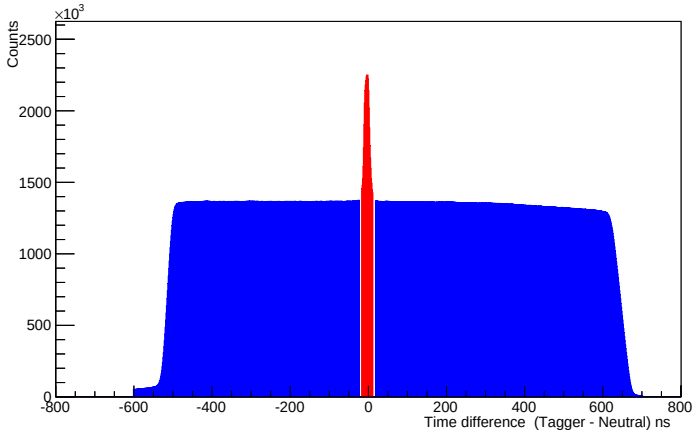

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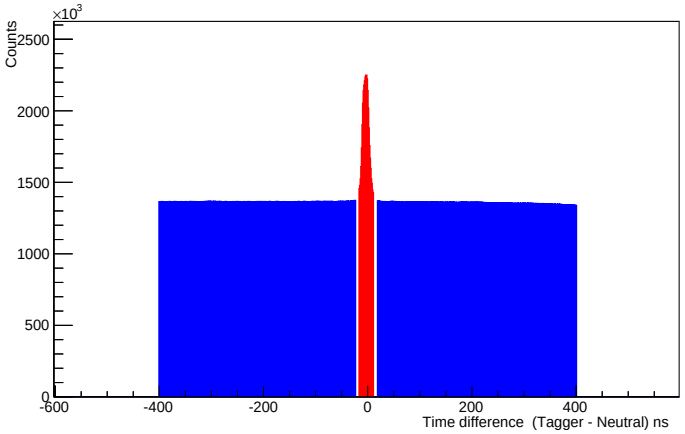

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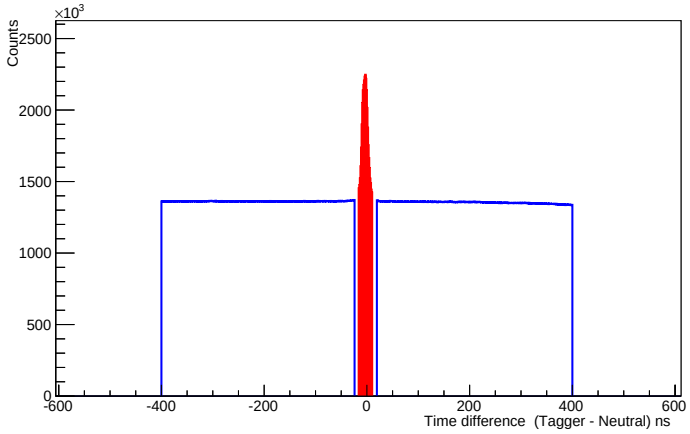

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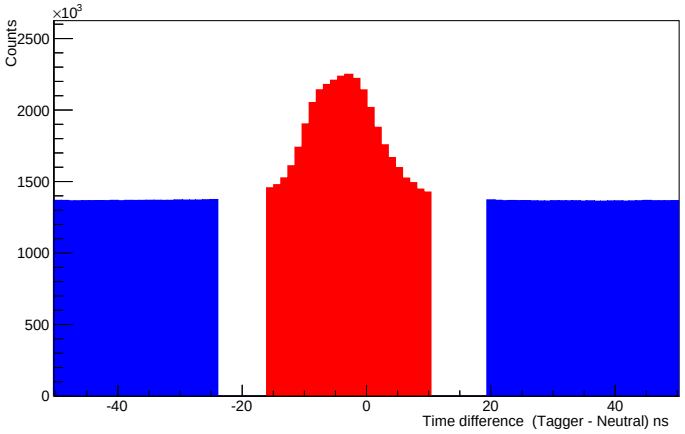
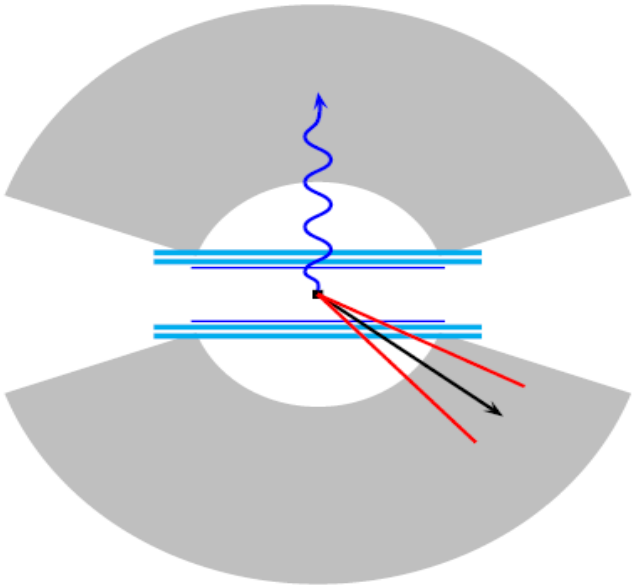


Zoomed in on the Prompt

Event Selection contd .....

- Opening Angle, $cos(\Omega_{OA}) = \frac{\vec{p}_{miss} \cdot \vec{p}_{recoil}}{|\vec{p}_{miss}| \times |\vec{p}_{recoil}|} = 10^{\circ}$



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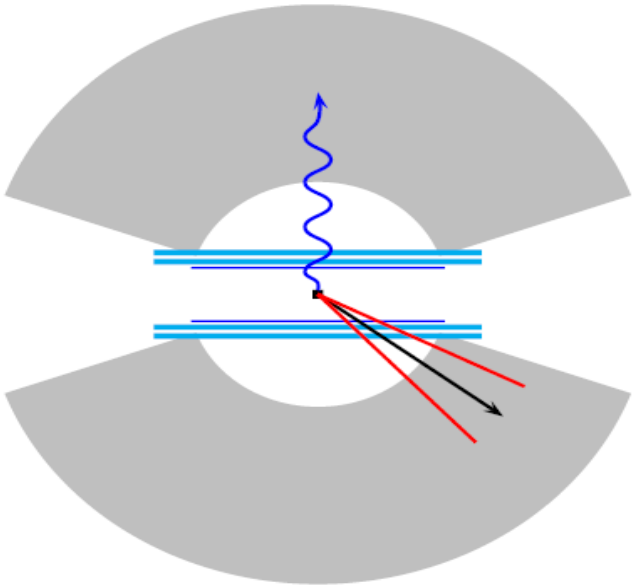

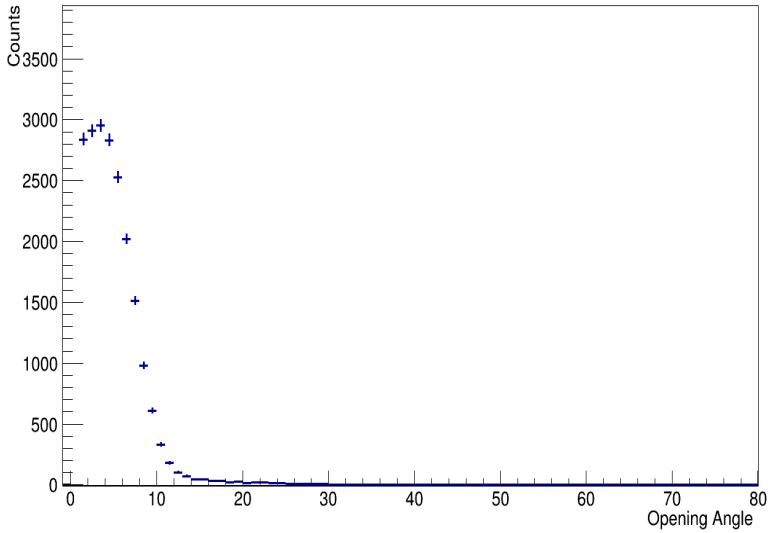

Dominant Background

Butanol Target (C_4H_9OH)

- Compton Scattering off H
- **Coherent scattering off C (or O)**
- **Incoherent scattering off C (or O)**
- Pion photoproduction off H
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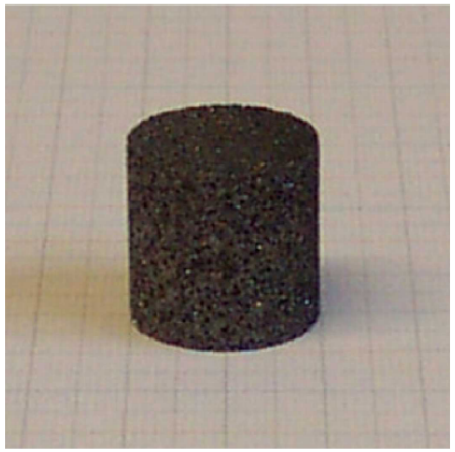
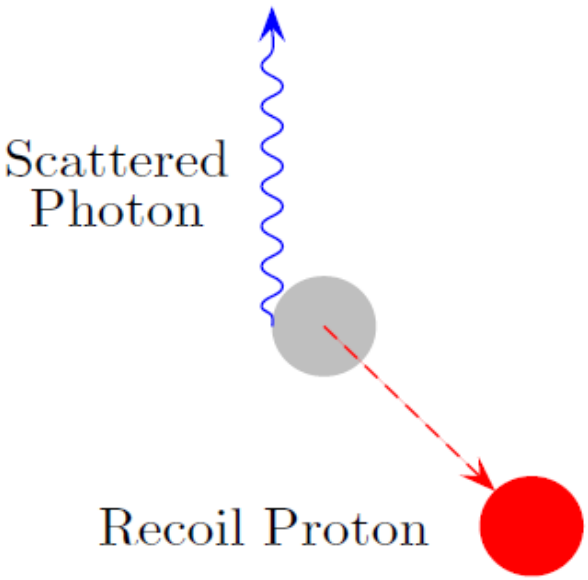


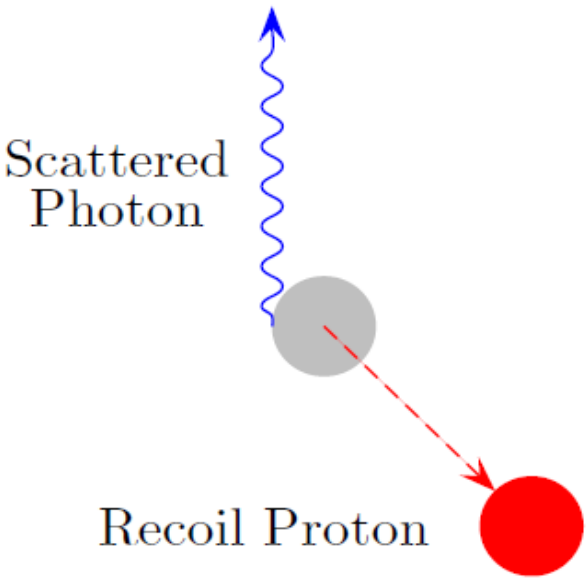
- Density of carbon target is chosen to match the number of non-hydrogen nucleons in the Butanol target so we can directly subtract data taken on a carbon.

π^0 Background



Compton Scattering .

π^0 Background



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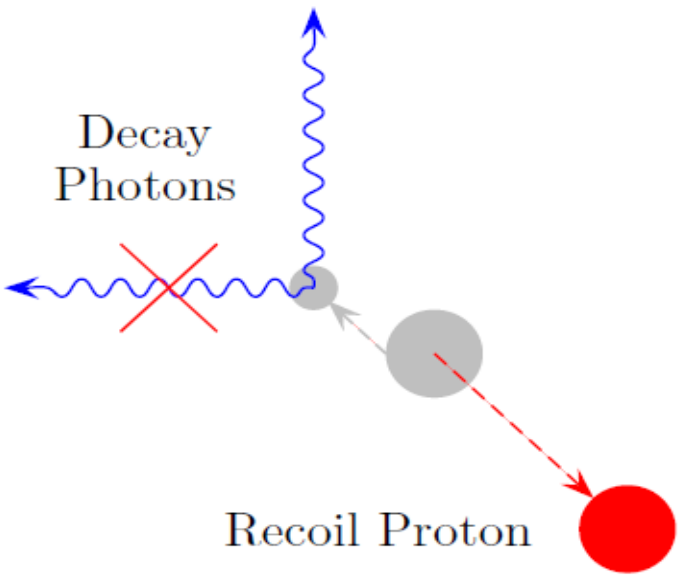
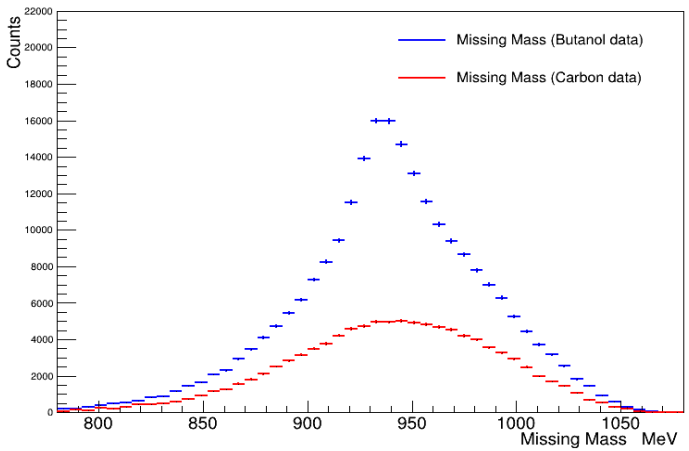


π^0 Photoproduction .

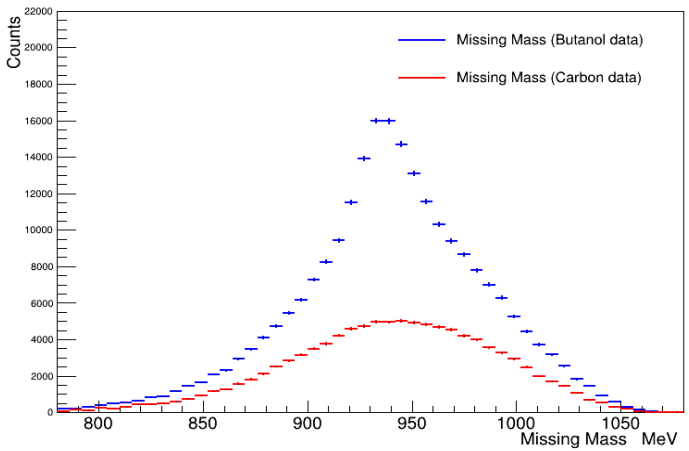
- Provides an excellent reaction for systematic checks and constraints. Due to the large cross-section (and clean reaction signal), π^0 production is an ideal reaction to perform systematic checks.

π^0 Background as a systematic check



Carbon is scaled by a base scaling factor.

π^0 Background as a systematic check



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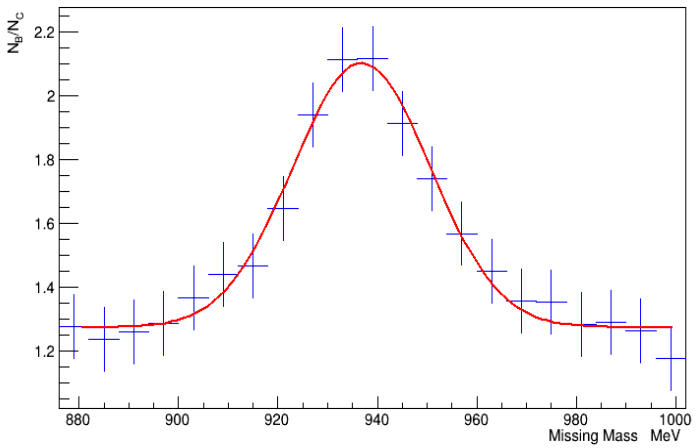
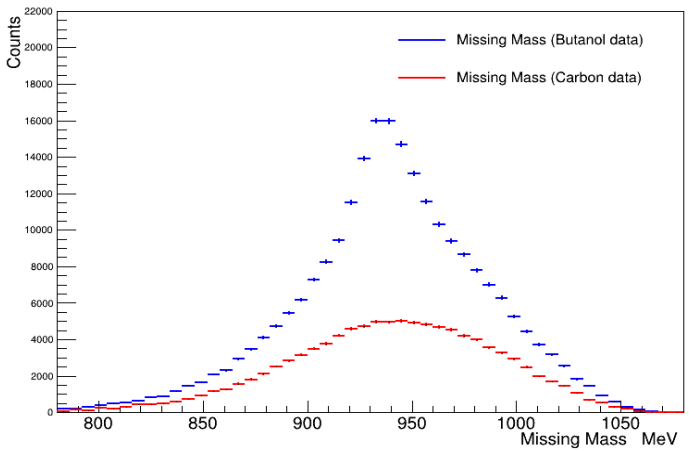


Ratio of Yield of butanol to carbon target (only base scaling factor).

π^0 Background as a systematic check



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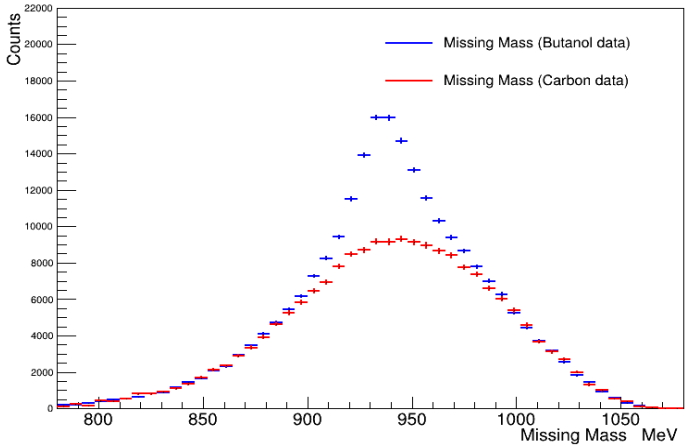
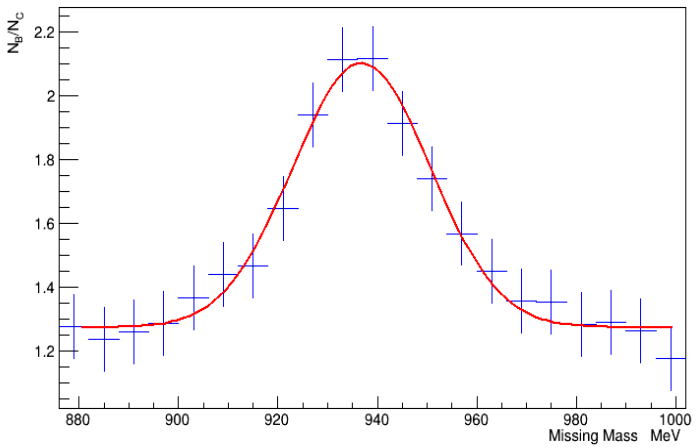
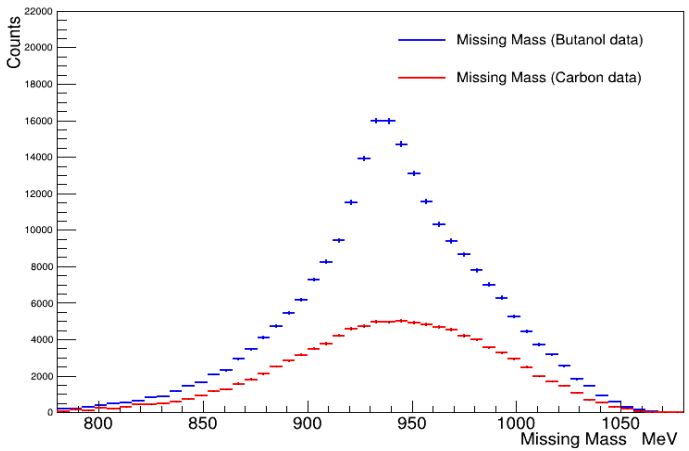


Carbon is scaled by a corrected scaling factor

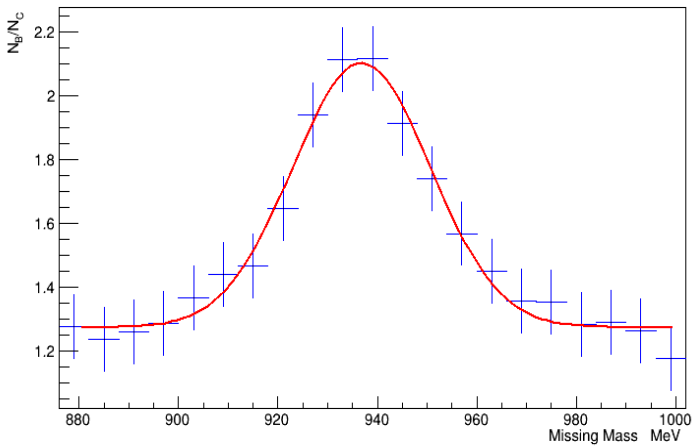


Ratio of Yield of butanol to carbon target (only base scaling factor).

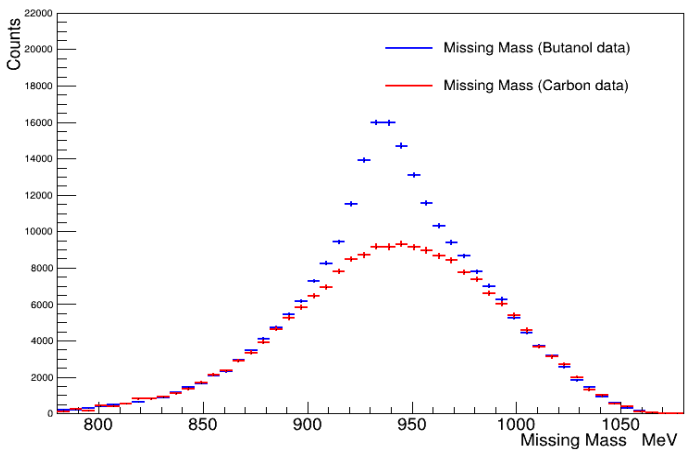
π^0 Background as a systematic check



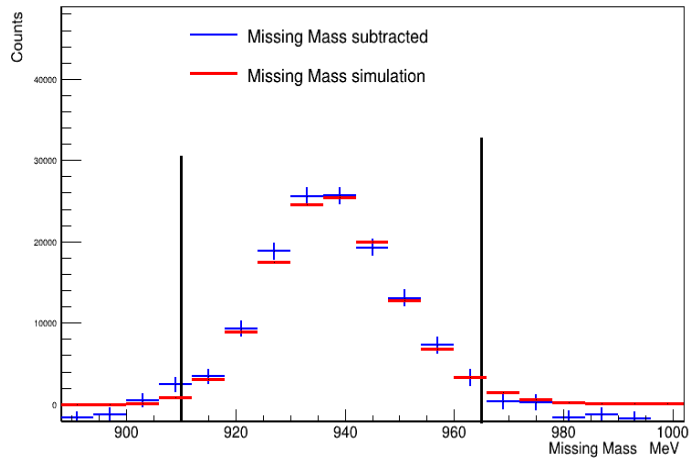
Carbon is scaled by a base scaling factor.



Ratio of Yield of butanol to carbon target (only base

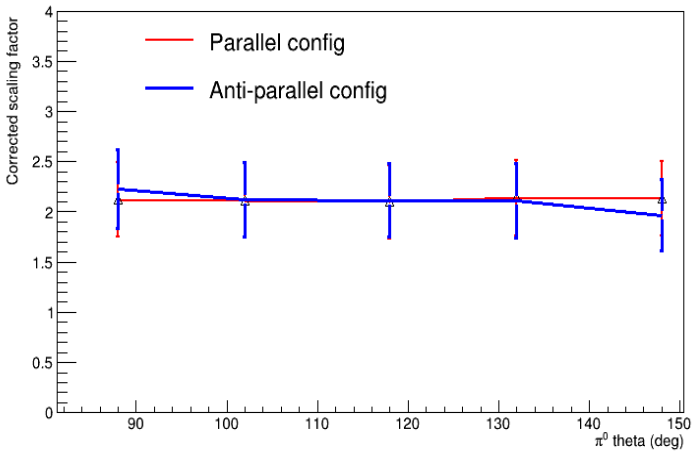


Carbon is scaled by a corrected scaling factor



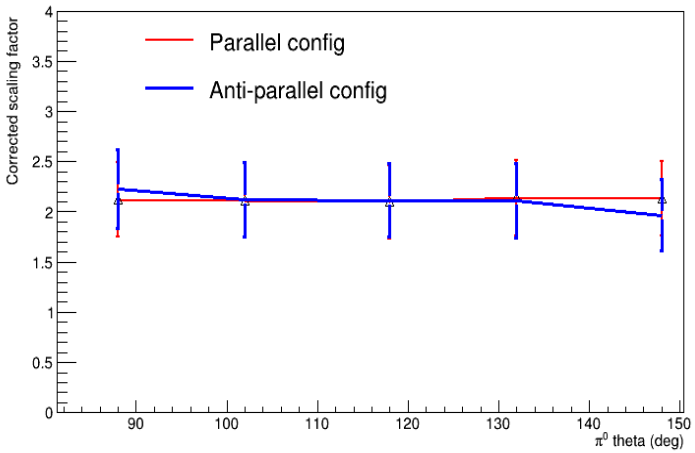
Subtracted Missing Mass compared with simulation.

Corrected scaling factor and π^0 $\sum_{2z}$ Asymmetry

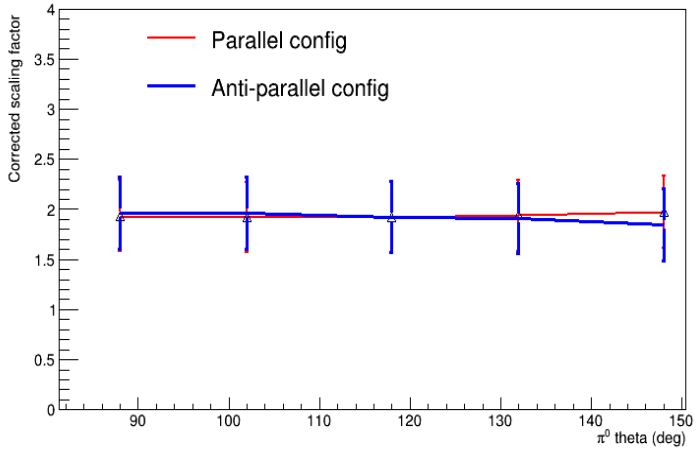


Corrected carbon scaling factor 265 - 285 MeV

Corrected scaling factor and π^0 $\sum_{2z}$ Asymmetry

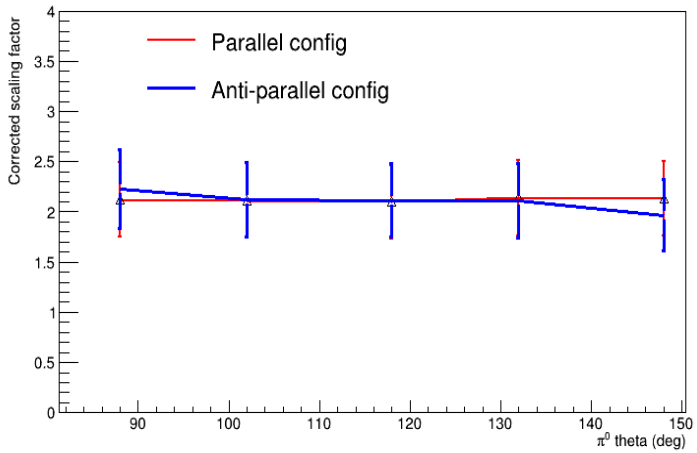


Corrected carbon scaling factor 265 - 285 MeV

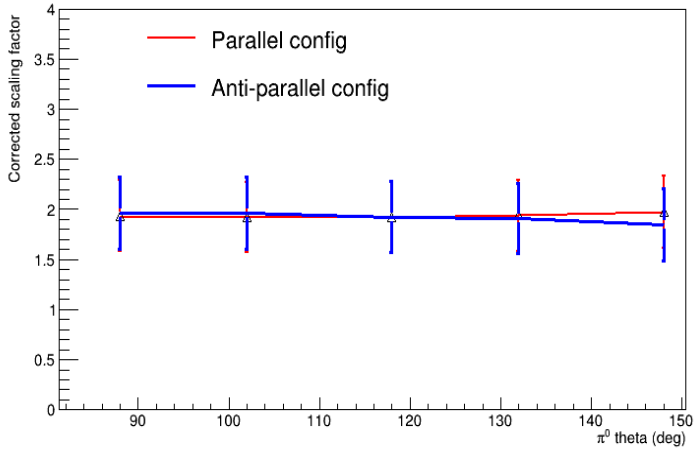


Corrected carbon scaling factor 285 - 305 MeV.

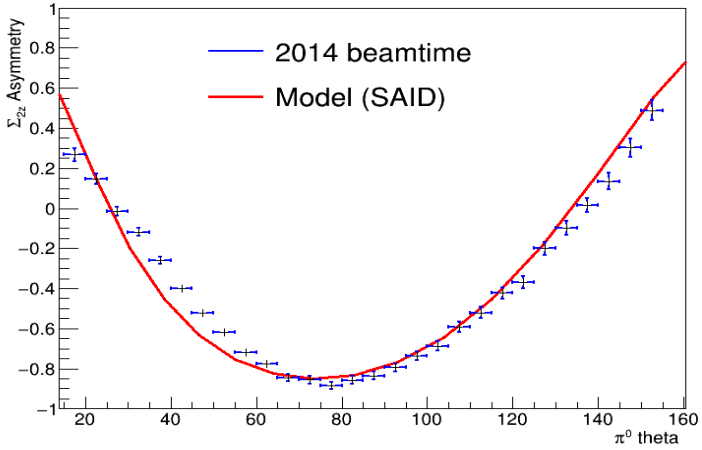
Corrected scaling factor and π^0 $\sum_{2z}$ Asymmetry



Corrected carbon scaling factor 265 - 285 MeV

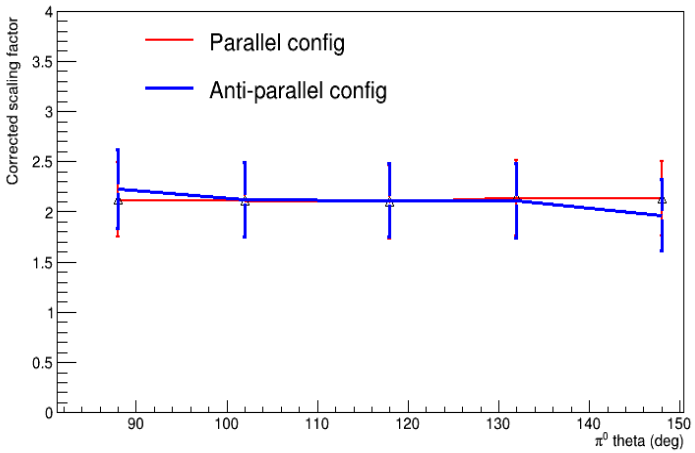


Corrected carbon scaling factor 285 - 305 MeV.

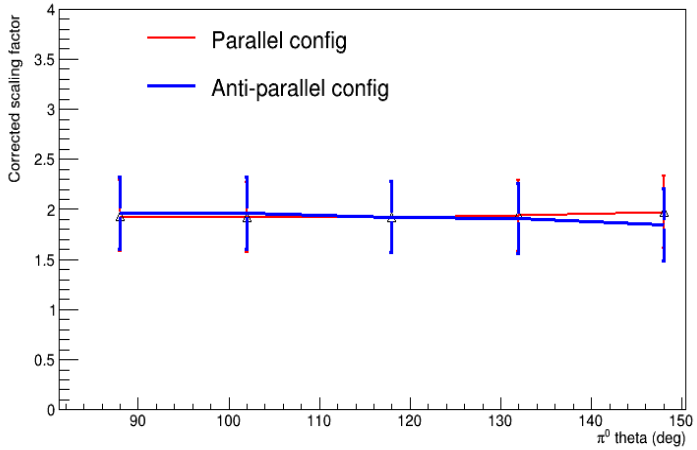


Tagged photon energy 265 - 285 MeV.

Corrected scaling factor and π^0 $\sum_{2z}$ Asymmetry



Corrected carbon scaling factor 265 - 285 MeV



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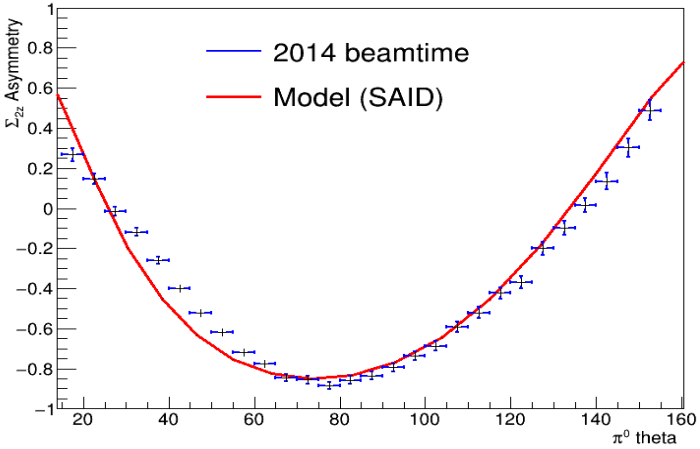
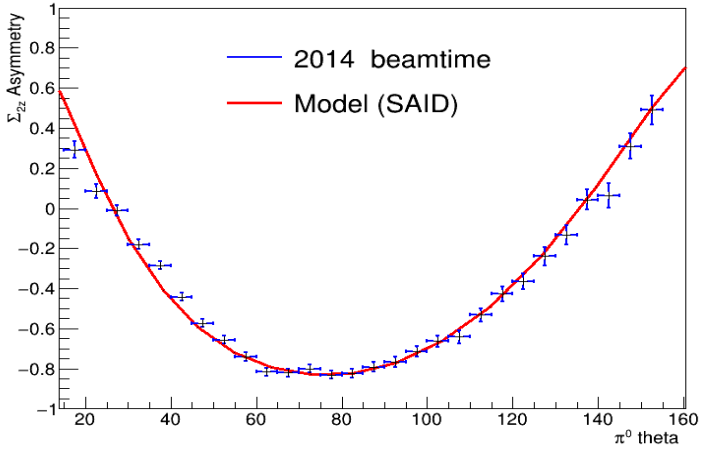


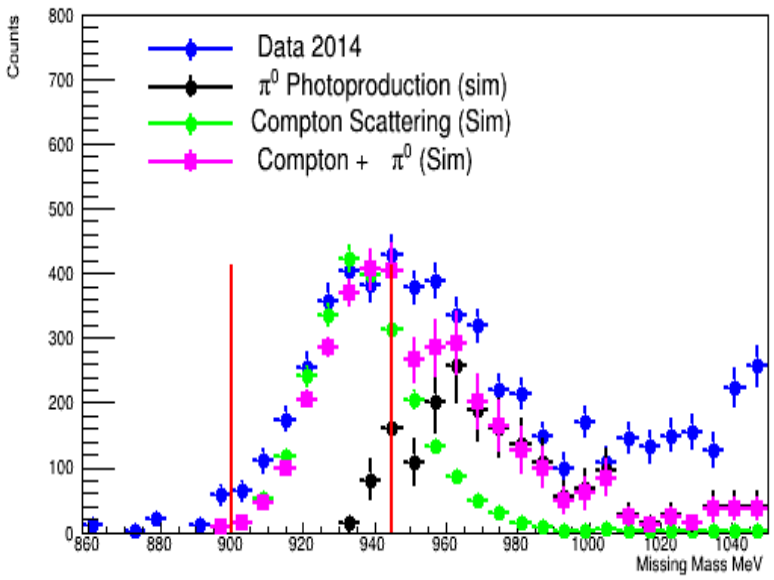
Tagged photon energy 265 - 285 MeV.



Tagged photon energy 285 - 305 MeV.

Compton Missing Mass

$$m_{miss} = m_p = \sqrt{\left(E_{\gamma i} + m_p - E_{\gamma f}\right)^2 - \left(\vec{P}_{\gamma i} - \vec{P}_{\gamma f}\right)^2} \quad (7)$$



Missing Mass at E_γ = (285 - 305) MeV

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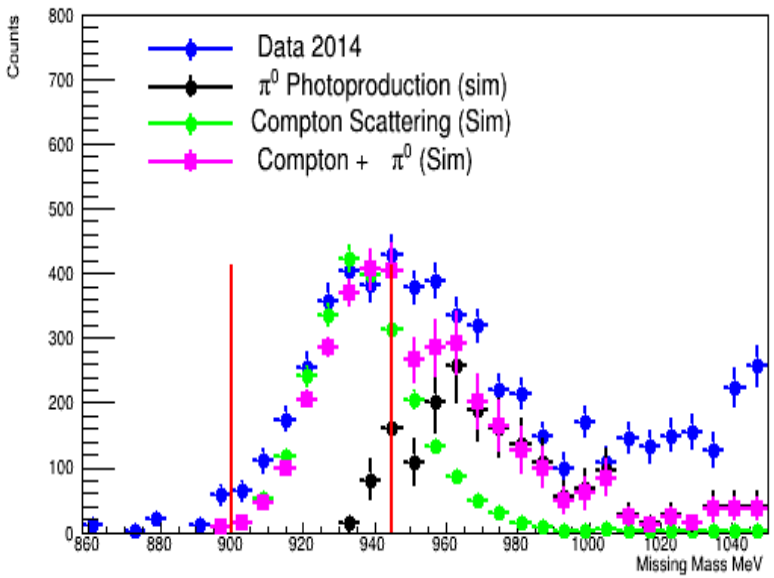
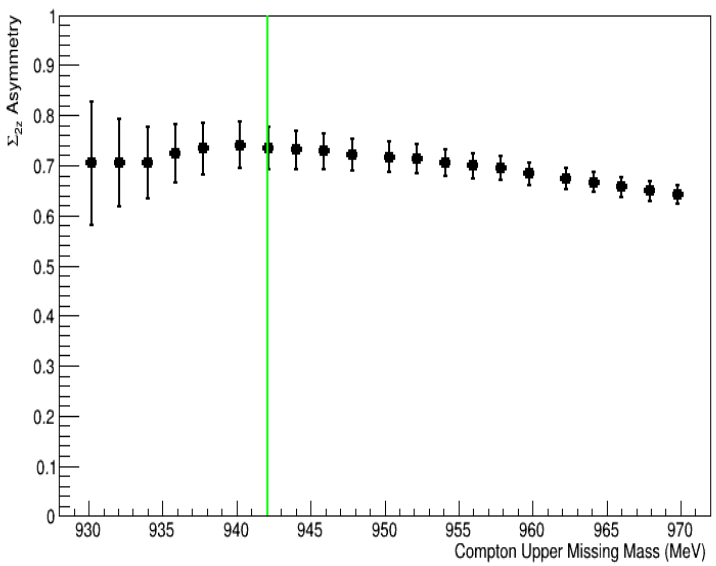


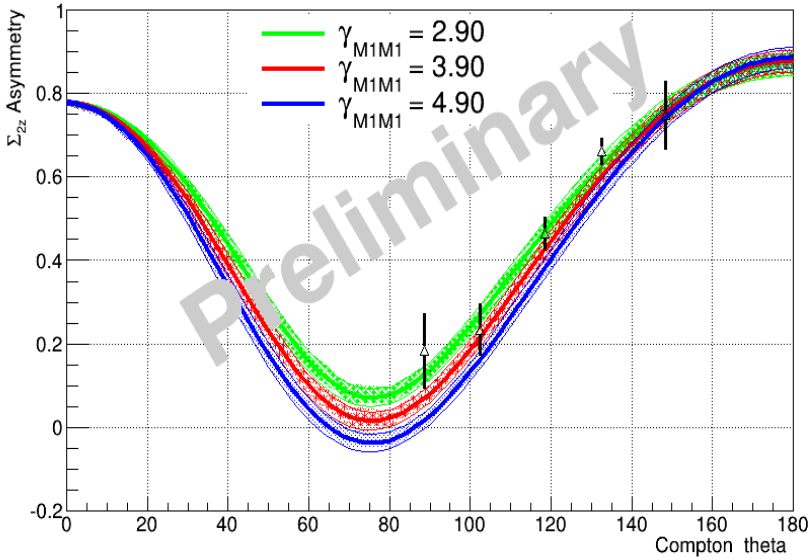
Missing Mass at E_γ = (285 - 305) MeV



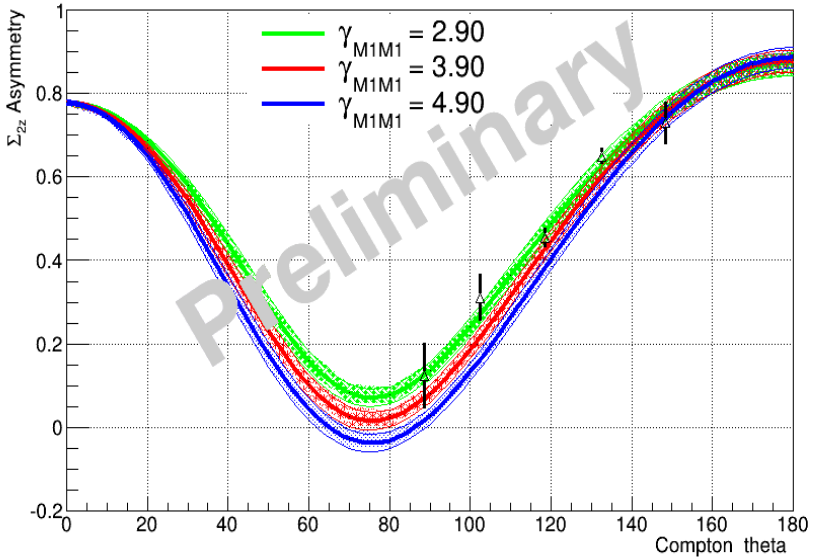
Compton $\sum_{2z}$ Asymmetry versus upper missing mass at $\theta_\gamma = 125 - 140^\circ$.

Compton $\sum_{2z}$ Asymmetry at E_γ = (265 - 285) MeV

- Curves are from DR calculation of Pasquini et al., making use of constraints on γ_0, γ_π, $\alpha_{E1} + \beta_{M1}$ and $\alpha_{E1} - \beta_{M1}$ to vary by their experimental errors.

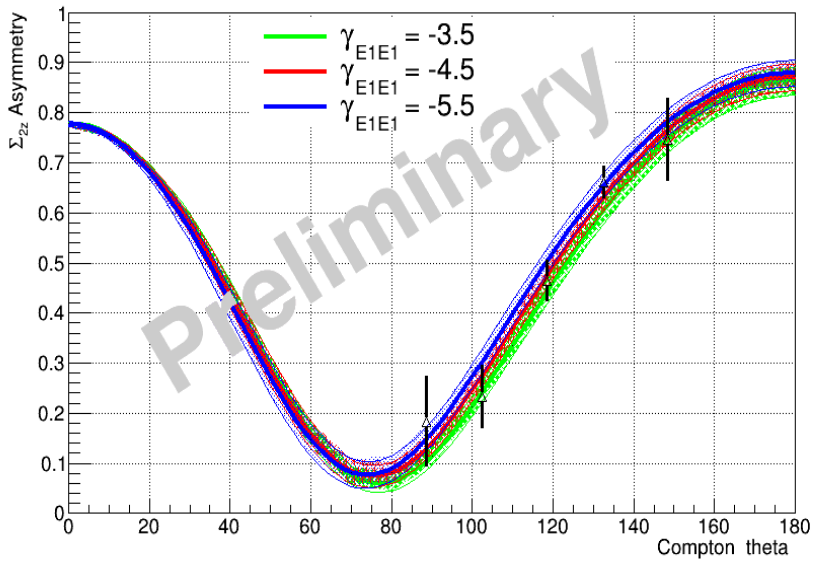


Fix $\gamma_{E1E1} = -3.7$, vary γ_{M1M1} (2014 beamtime)

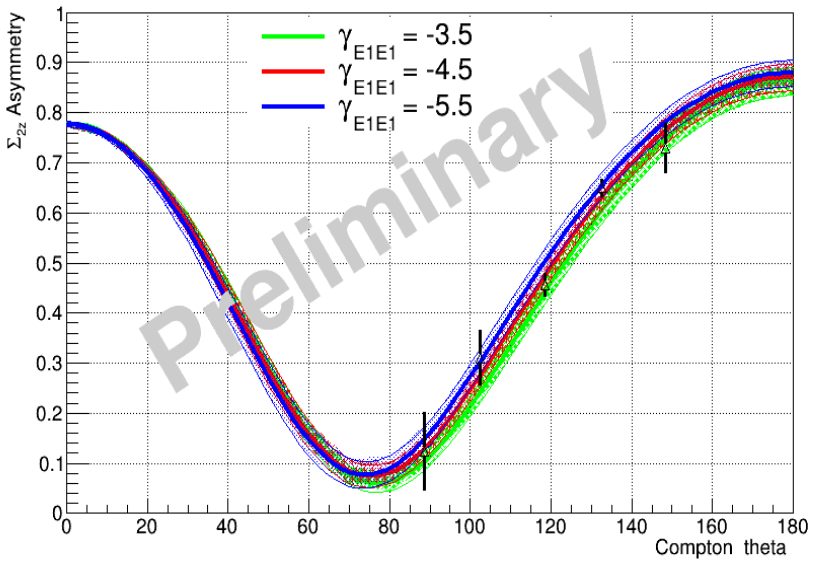


Fix $\gamma_{E1E1} = -3.7$, vary γ_{M1M1} (2015 beamtime)

Compton $\sum_{2z}$ Asymmetry at E_γ = (265 - 285) MeV



Fix $\gamma_{M1M1} = 2.9$, vary γ_{E1E1} (2014 beamtime)



Fix $\gamma_{M1M1} = 2.9$, vary γ_{E1E1} (2015 beamtime)

Final $\sum_{2z}$ Asymmetry at E_γ = (265 - 285) MeV

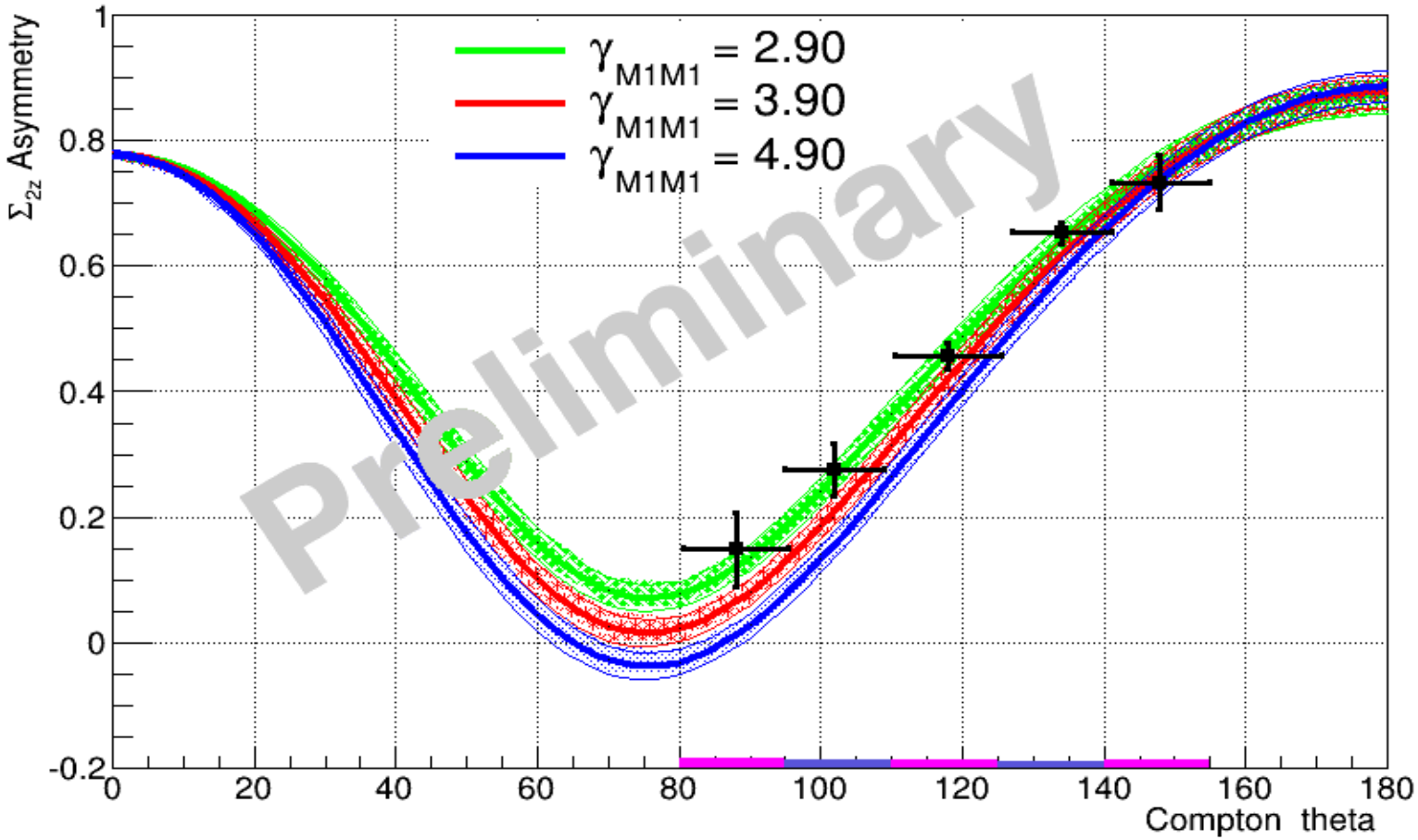


Figure: Fix $\gamma_{E1E1} = -3.7$, vary γ_{M1M1} (2014 and 2015 combined)

Final $\sum_{2z}$ Asymmetry at E_γ = (265 - 285) MeV

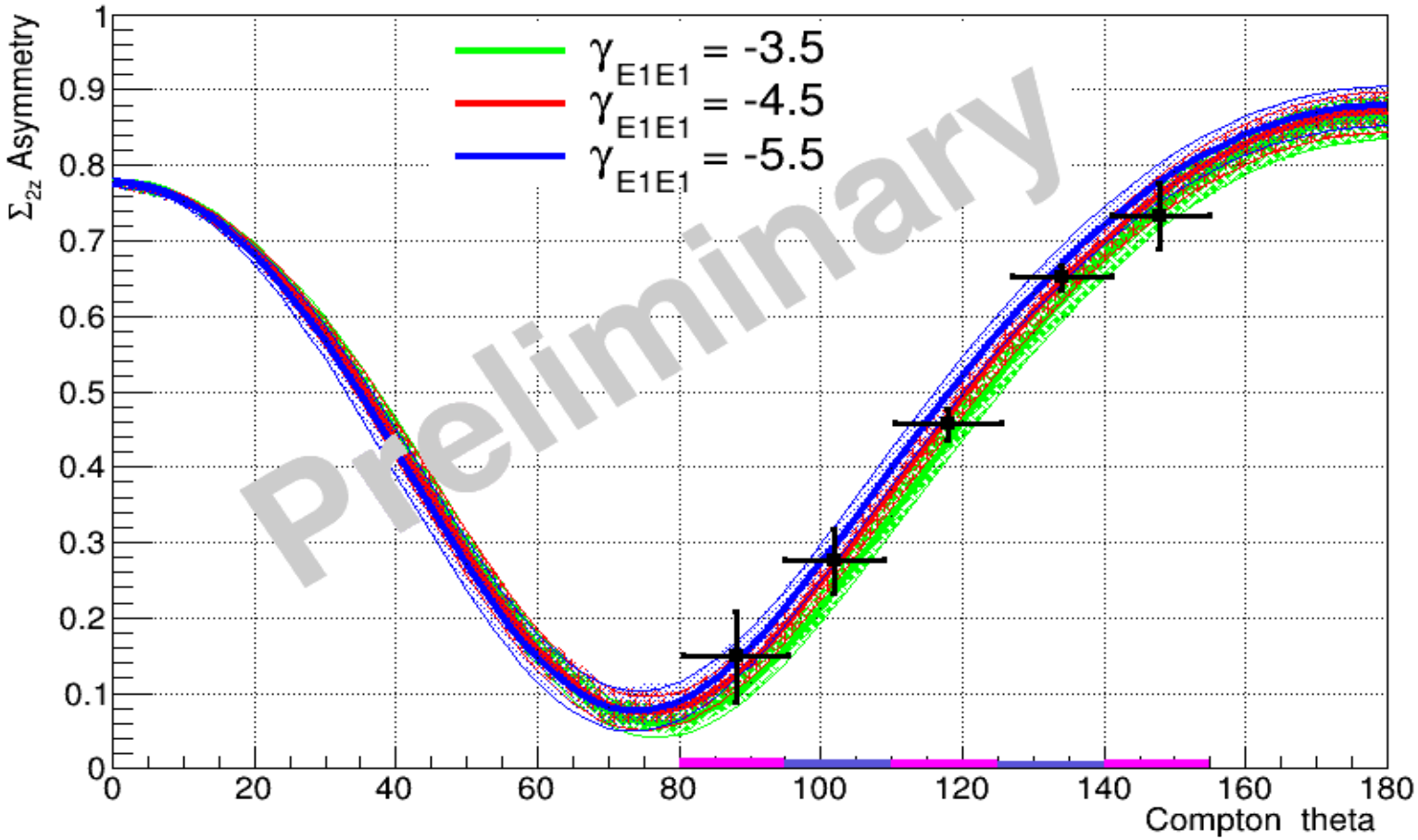
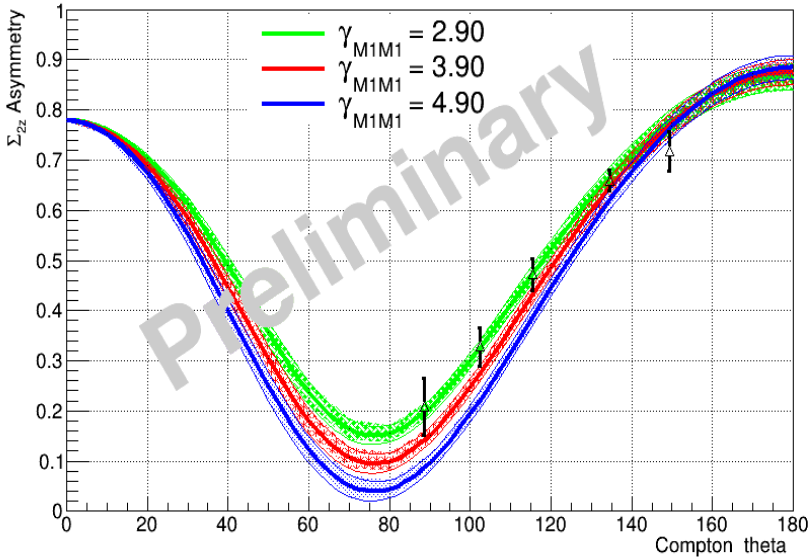


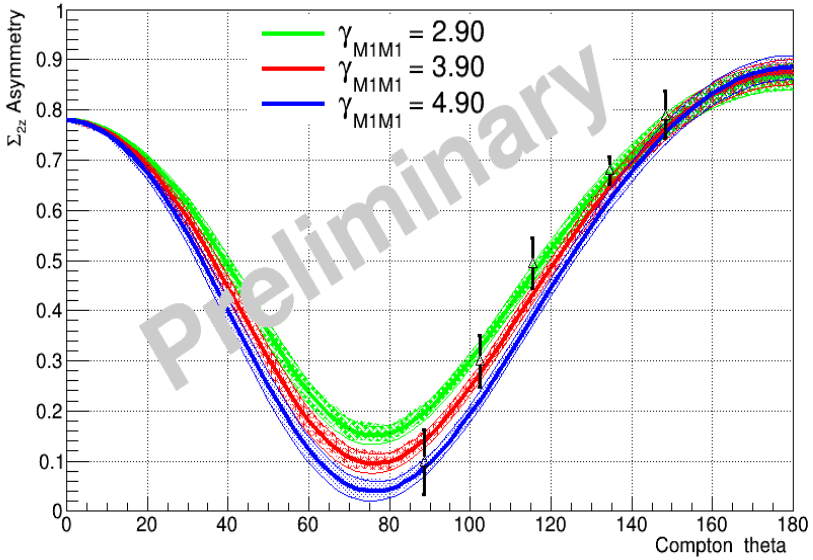
Figure: Fix $\gamma_{M1M1} = 2.9$, vary γ_{E1E1} (2014 and 2015 combined)

Compton $\sum_{2z}$ Asymmetry at E_γ = (285 - 305) MeV

- Curves are from DR calculation of Pasquini et al., making use of constraints on γ_0, γ_π, $\alpha_{E1} + \beta_{M1}$ and $\alpha_{E1} - \beta_{M1}$ to vary by their experimental errors.

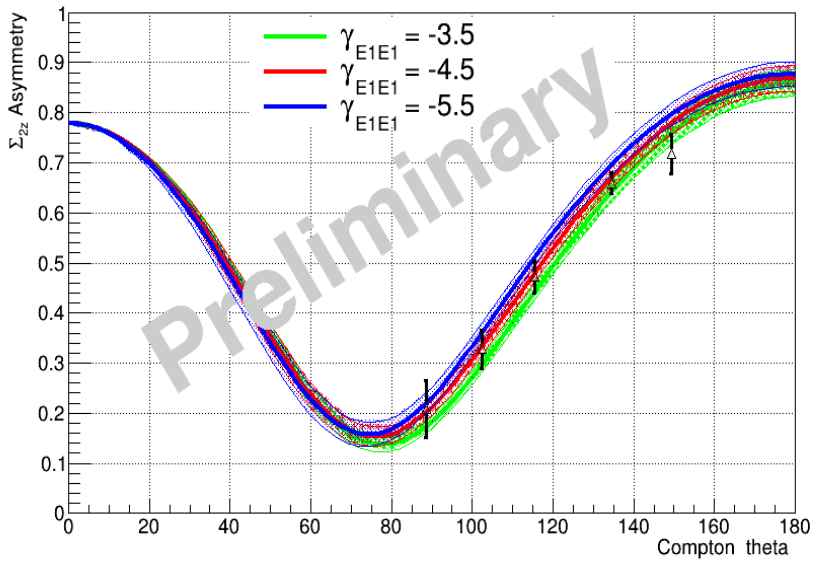


Fix $\gamma_{E1E1} = -3.7$, vary γ_{M1M1} (2014 beamtime)



Fix $\gamma_{E1E1} = -3.7$, vary γ_{M1M1} (2015 beamtime)

Compton $\sum_{2z}$ Asymmetry at E_γ = (285 - 305) MeV



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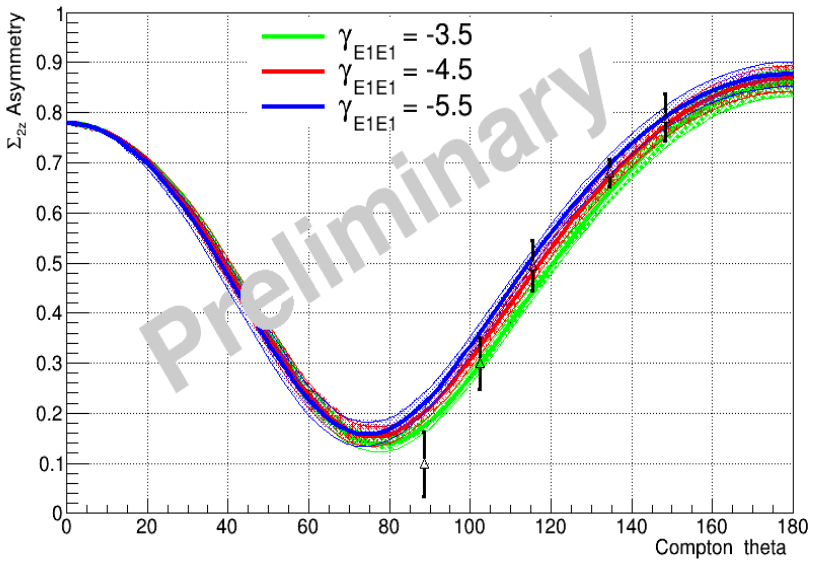


Fix $\gamma_{M1M1} = 2.9$, vary γ_{E1E1} (2015 beamtime)

Final $\sum_{2z}$ Asymmetry at E_γ = (285 - 305) MeV

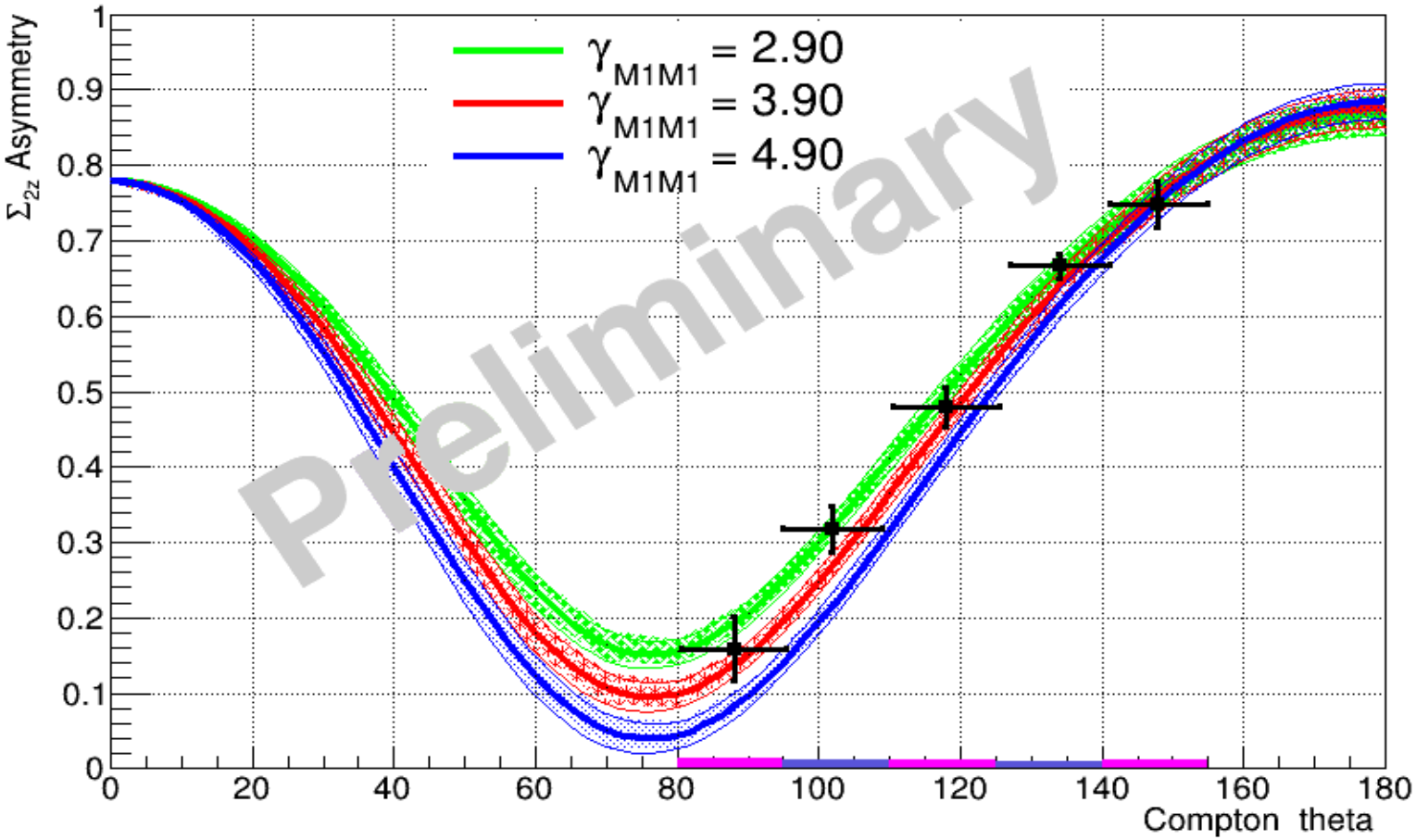


Figure: Fix $\gamma_{E1E1} = -3.7$, vary γ_{M1M1} (2014 and 2015 combined)

Final $\sum_{2z}$ Asymmetry at E_γ = (285 - 305) MeV

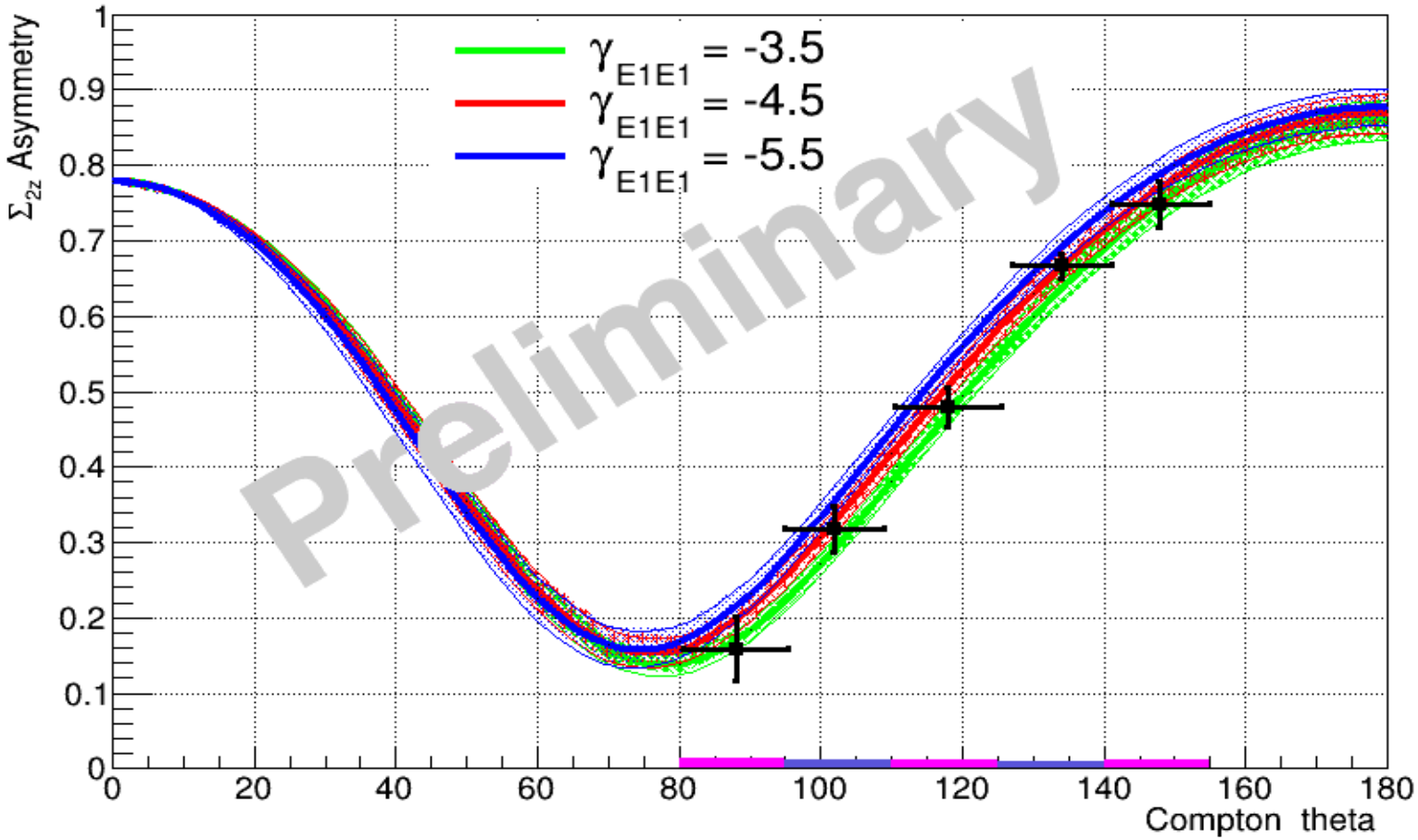


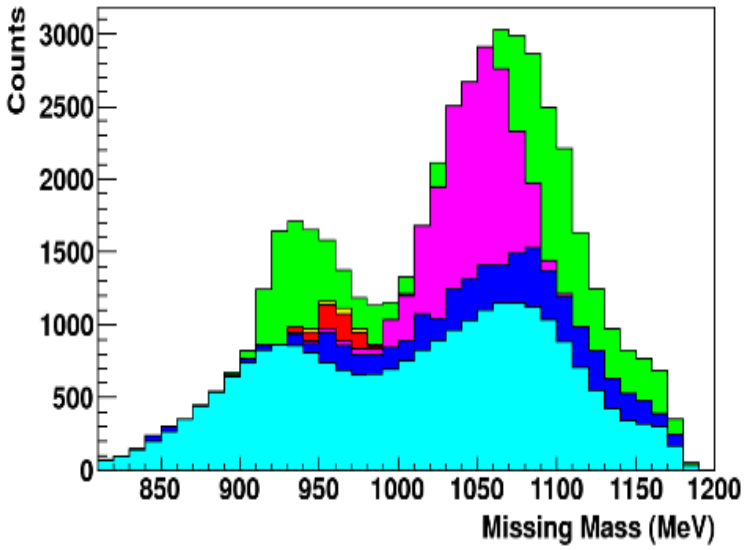
Figure: Fix $\gamma_{M1M1} = 2.9$, vary γ_{E1E1} (2014 and 2015 combined)

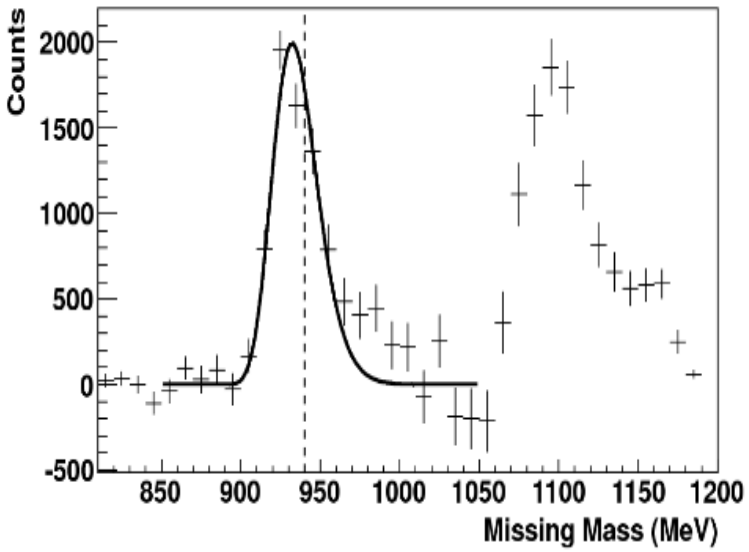
Proton Spin Polarizabilities Status and Future Work

- Finalize proton spin polarizabilities from 2014 and 2015 beamtime.
- Finalize the systematic errors.
- Finalize $\sum_{2z}$ Asymmetry at E_γ = (310 - 330) MeV from 2014 and 2015 beamtime.

Thank You

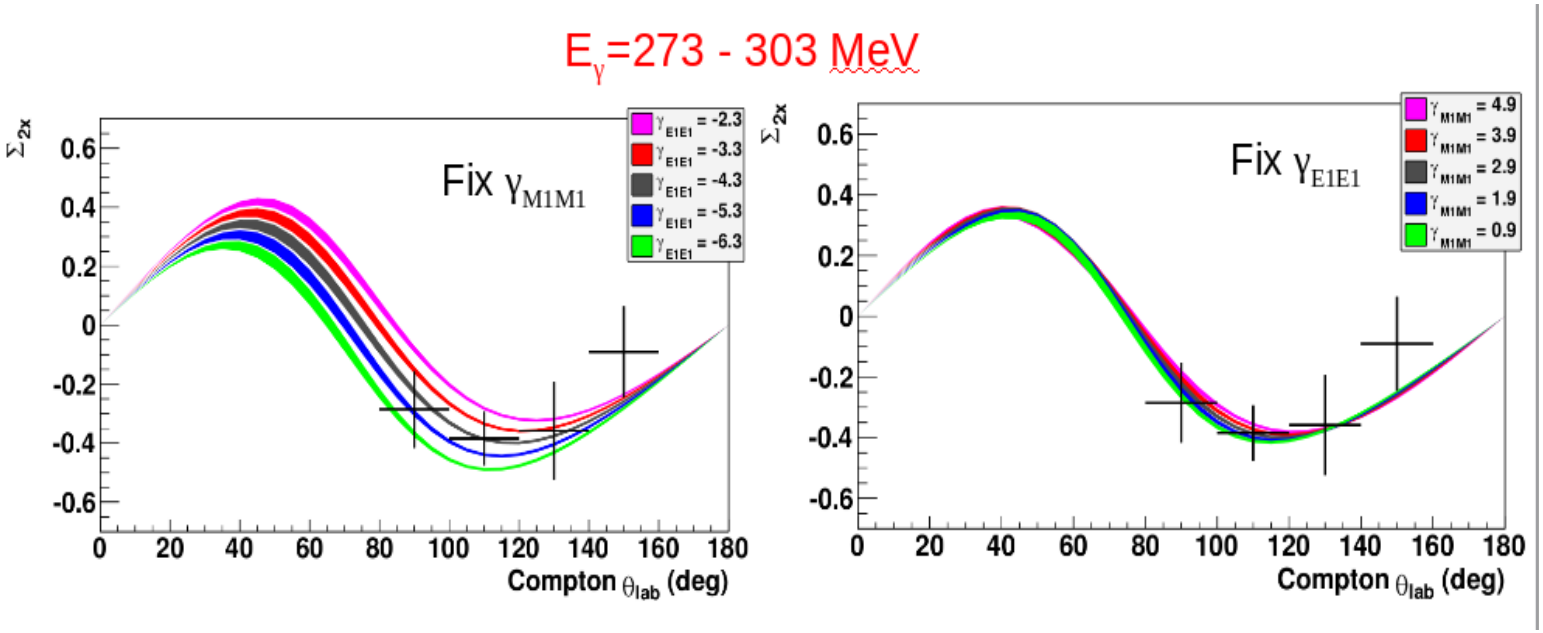
$\sum_{2x}$ Martel, et al.





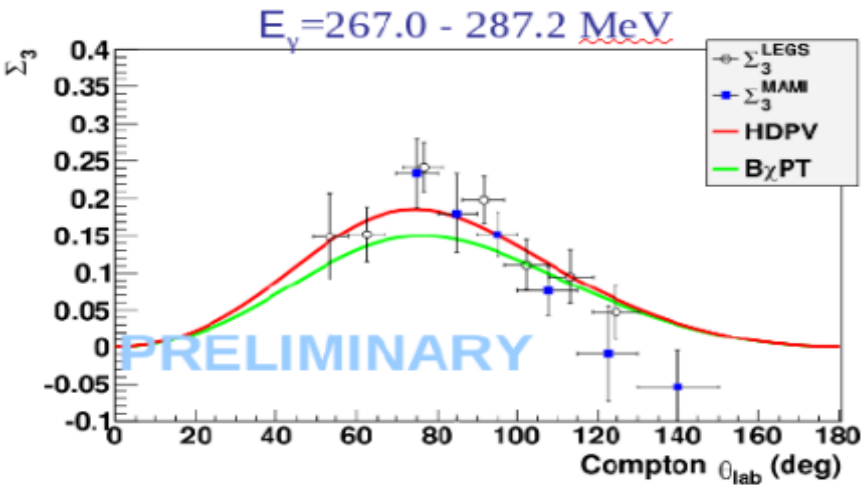
- MM distribution for $E_\gamma = 273 - 303$ MeV, $\theta_{\gamma'} = 100 - 120$ degree.
- Background contributions to MM: accidental coincidences , carbon/cryostat contributions (blue), reconstructed π_0. background where one decay γ escapes setup in: TAPS downstream hole and CB upstream hole.
- Right: Fully-subtracted MM spectrum with simulated Compton peak and conservative MM <940 MeV cut is applied to exclude neutral pion production.

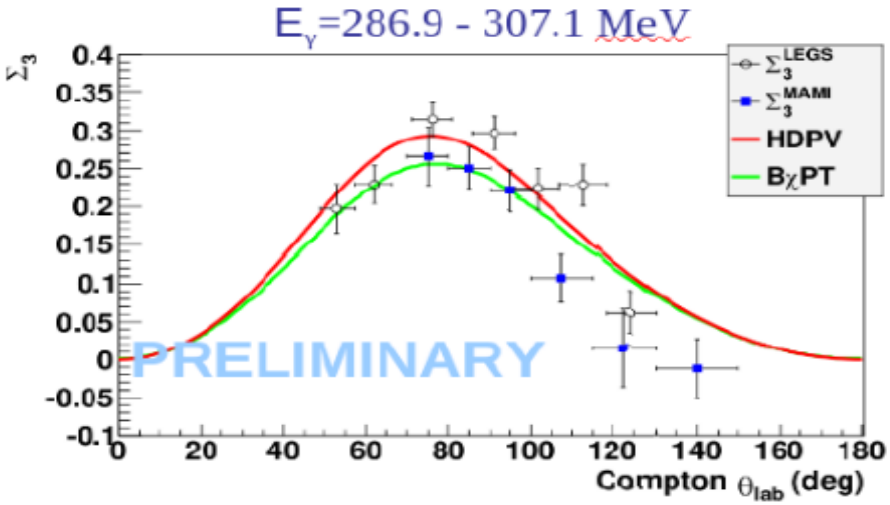
$\sum_{2x}$ Martel, et al.

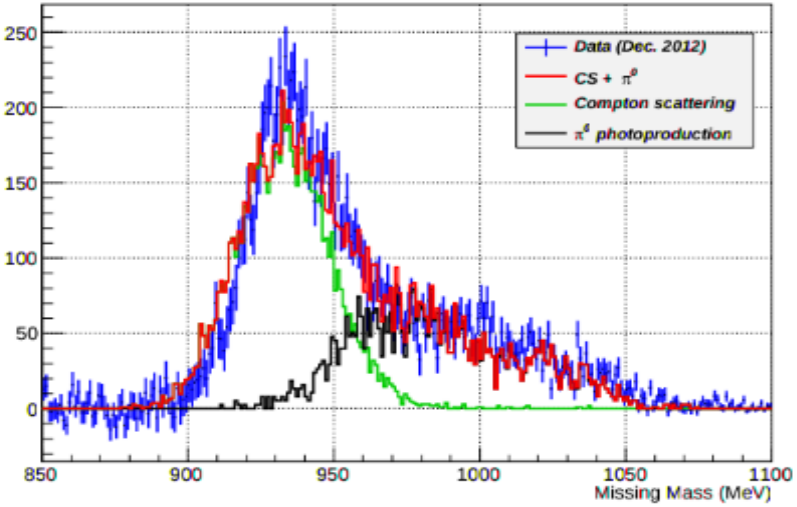


- New results. Physical Review Letters 114, 112501 (2015), arXiv:1408.1576 [nucl-ex]
- Measurement of a $\sum_{2x}$ asymmetry on the nucleon. Curves are from DR calculation of Pasquini et al., making use of constraints on γ_0, γ_π,$\alpha_{E1} + \beta_{M1}$, $\alpha_{E1} - \beta_{M1}$ (allowed to vary within experimental errors).
- Checks were done with $B\chi PT$ calculation of Lensky and Pascalutsa.

$\sum_3$ Collicot, et al.







- **New MAMI and Older LEGS measurements along with two theoretical curves using their preferred polarizabilities**
- **Simulation of neutral pion photoproduction in Liquid hydrogen target matches background of the distribution quite well**

Frame Preliminary Combined Spin Polarizabilities

	HDPV	BχPT	Σ_{2x} and Σ_3^{LEGS}	Σ_{2x} and Σ_3^{MAMI}
γ_{E1E1}	-4.3	-3.3	-3.5±1.2	-5.0±1.5
γ_{M1M1}	2.9	3.0	3.16±0.85	3.13±0.88
γ_{E1M2}	-0.0	0.2	-0.7±1.2	1.7±1.7
γ_{M1E2}	2.2	1.1	1.99±0.29	1.26±0.43
γ_0	-0.8	-1.0	-1.03±0.18	-1.00±0.18
γ_π	9.4	7.2	9.3±1.6	7.8±1.8
$\alpha+\beta$			14.0±0.4	13.8±0.4
$\alpha-\beta$			7.4±0.9	6.6±1.7
χ^2/df			1.05	1.25

- Dispersion relation fits to $\sum_{2x}$ along with either $\sum_3^{MAMI}$ or $\sum_3^{LEGS}$
- (Note: Pion pole contribution has been subtracted)