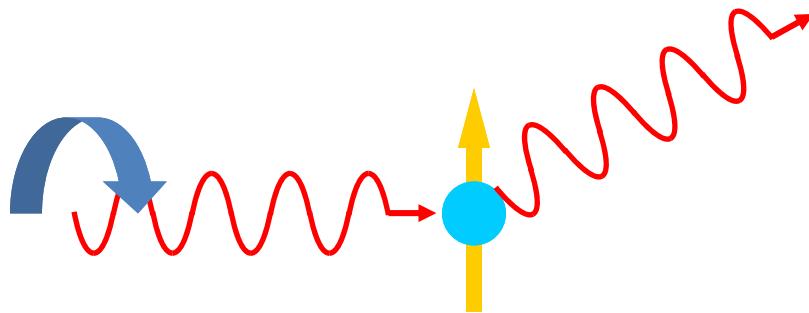


Measuring Spin-Polarizabilities of the Proton in Polarized Compton Scattering at MAMI-Mainz



Rory Miskimen
University of Massachusetts, Amherst
for the Mainz A2 Collaboration
Chiral Dynamics 2012

- Compton scattering and nucleon spin-polarizabilities
- First measurements of double-polarized Compton scattering asymmetries on the proton

Measuring nucleon spin-polarizabilities in polarized Compton scattering

- At $O(\omega^3)$ four nucleon structure terms involving nucleon spin-flip operators enter the Real Compton Scattering expansion.

$$H_{\text{eff}}^{(3),\text{spin}} = -\frac{1}{2} 4\pi \left(\gamma_{E1E1} \vec{\sigma} \cdot \vec{E} \times \dot{\vec{E}} + \gamma_{M1M1} \vec{\sigma} \cdot \vec{B} \times \dot{\vec{B}} - 2\gamma_{M1E2} E_{ij} \sigma_j H_j + 2\gamma_{E1M2} H_{ij} \sigma_j E_j \right)$$

Spin polarizabilities tell us about the response of the nucleon spin to the photon polarization.

The "stiffness" of the spin can be thought of as arising from the nucleon's spin interacting with the pion cloud.

Experiments

The GDH experiments at Mainz and ELSA used the Gell-Mann, Goldberger, and Thirring sum rule to evaluate the forward S.-P. γ_0

$$\gamma_0 = -\gamma_{E1E1} - \gamma_{E1M2} - \gamma_{M1M1} - \gamma_{M1E2}$$

$$\gamma_0 = \frac{1}{4\pi^2} \int_{m_\pi}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\omega^3} d\omega$$

$$\gamma_0 = (-1.01 \pm 0.08 \pm 0.10) \times 10^{-4} \text{ fm}^4$$

Backward spin polarizability from dispersive analysis of backward angle Compton scattering

$$\gamma_\pi = -\gamma_{E1E1} - \gamma_{E1M2} + \gamma_{M1M1} + \gamma_{M1E2}$$

$$\gamma_\pi = (-8.0 \pm 1.8) \times 10^{-4} \text{ fm}^4$$

The pion-pole contribution has been subtracted from γ_π

Proton spin-polarizability measurements and predictions in units of 10^{-4} fm^4

	O(p^3)	O(p^4)	O(p^4)	LC3	LC4	SSE	BGLMN	HDPV	KS	DPV	Δ Theory	Experiment
γ_{E1E1}	-5.7	-1.4	-1.8	-3.2	-2.8	-5.7	-3.4	-4.3	-5.0	-4.3	4.3	No data
γ_{M1M1}	-1.1	3.3	2.9	-1.4	-3.1	3.1	2.7	2.9	3.4	2.9	6.5	No data
γ_{E1M2}	1.1	0.2	.7	.7	.8	.98	0.3	-0.01	-1.8	0	2.9	No data
γ_{M1E2}	1.1	1.8	1.8	.7	.3	.98	1.9	2.1	1.1	2.1	1.8	No data
γ_0	4.6	-3.9	-3.6	3.1	4.8	.64	-1.5	-.7	2.3	-.7		-1.01 ± 0.08 ± 0.10
γ_π	4.6	6.3	5.8	1.8	-.8	8.8	7.7	9.3	11.3	9.3		$8.0 \pm 1.8^\dagger$

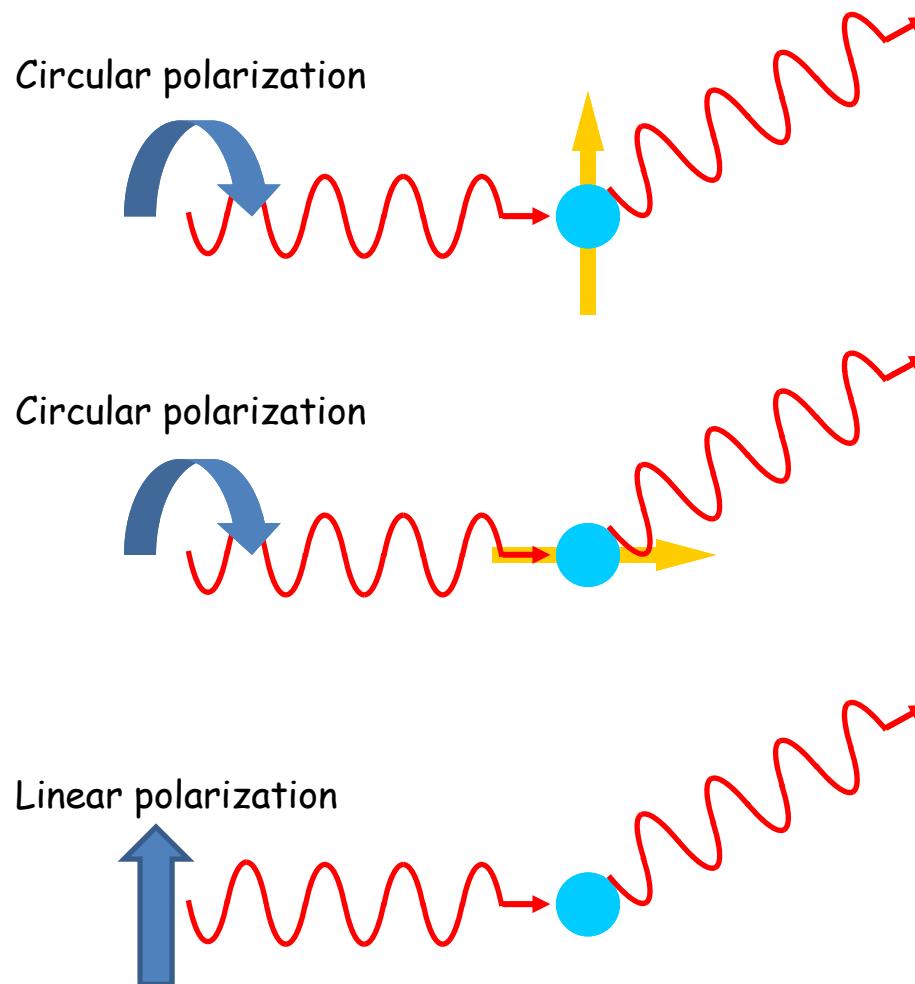
Calculations labeled O(p^n) are ChPT

LC3 and LC4 are O(p^3) and O(p^4) Lorentz invariant ChPT calculations

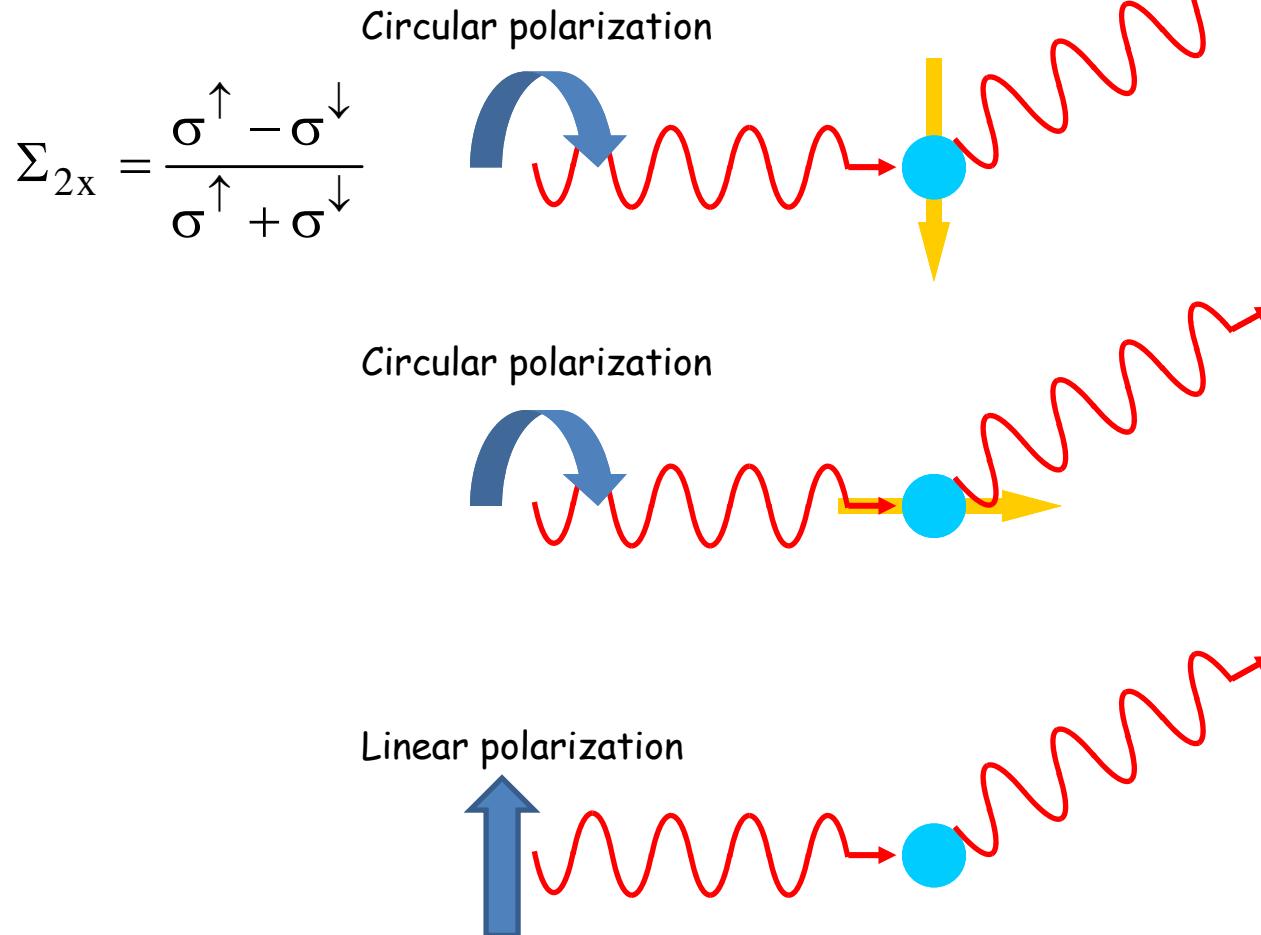
SSE is small scale expansion

Other calculations are dispersion theory

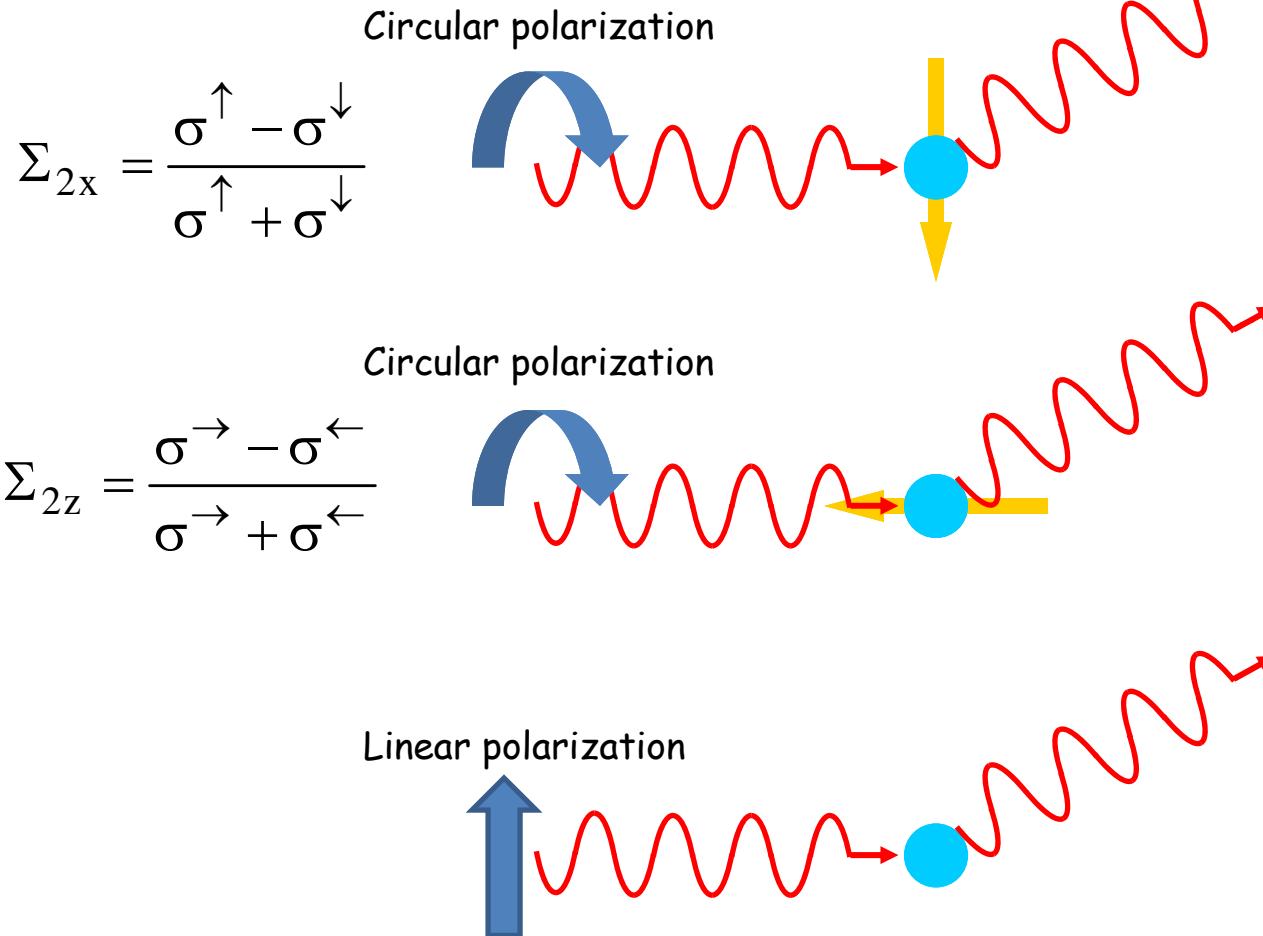
Polarization observables in real Compton scattering



Polarization observables in real Compton scattering



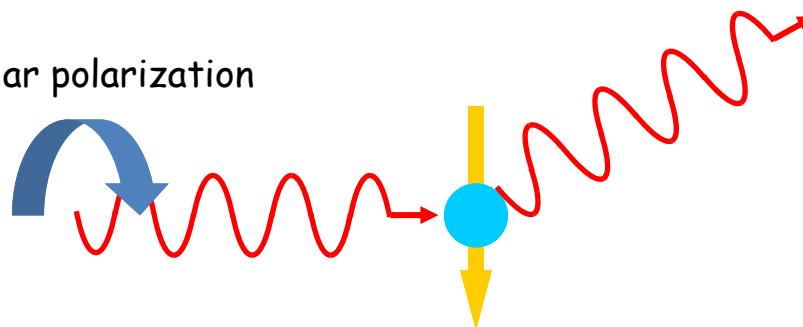
Polarization observables in real Compton scattering



Polarization observables in Compton scattering

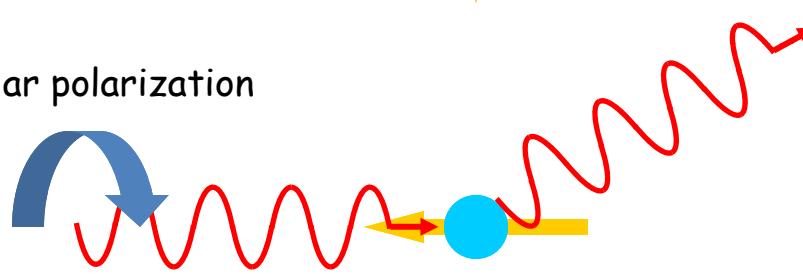
$$\Sigma_{2x} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Circular polarization



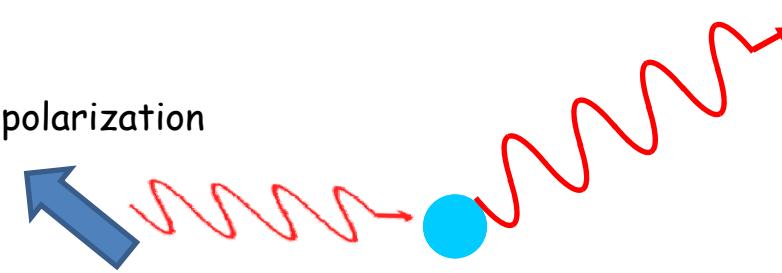
$$\Sigma_{2z} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

Circular polarization

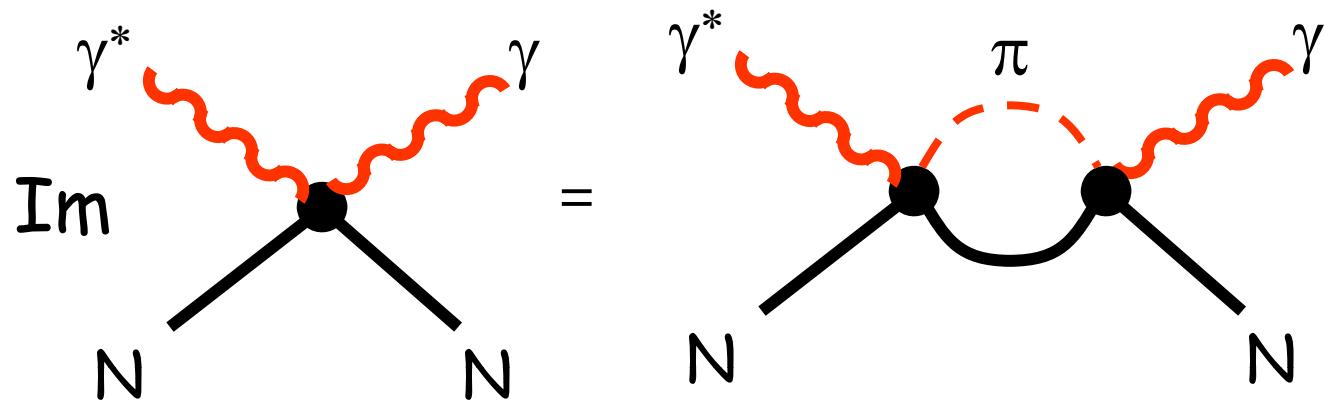


$$\Sigma_3 = \frac{\sigma^{\parallel} - \sigma^{\perp}}{\sigma^{\parallel} + \sigma^{\perp}}$$

Linear polarization



Dispersion Model for RCS and VCS[†]



Connects pion electroproduction amplitudes from MAID with VCS

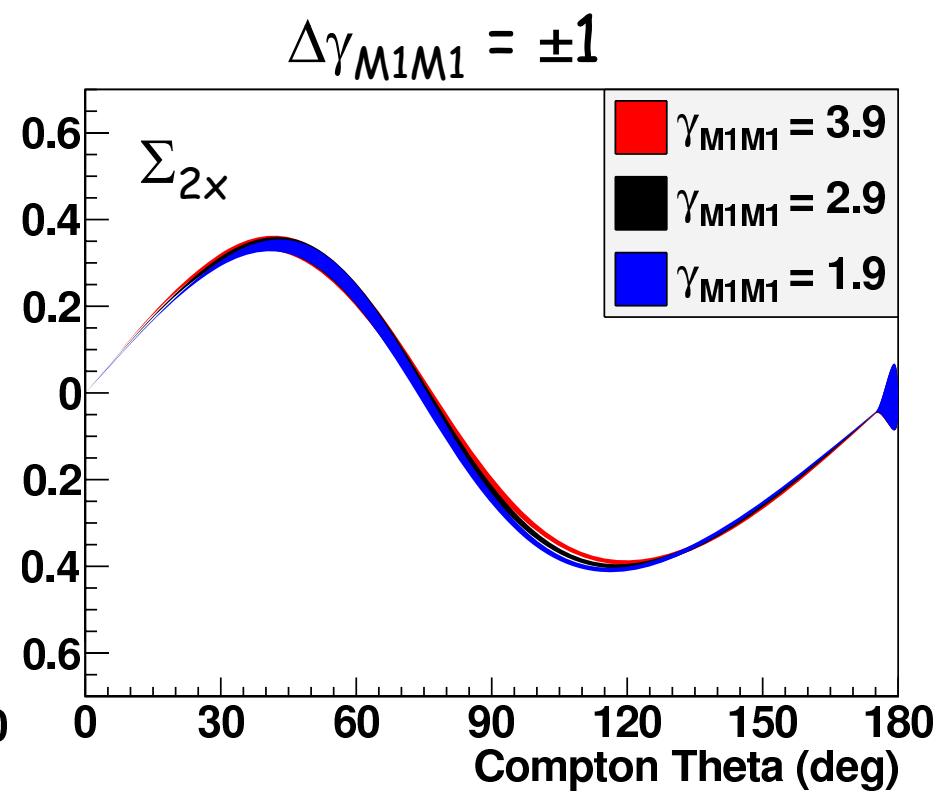
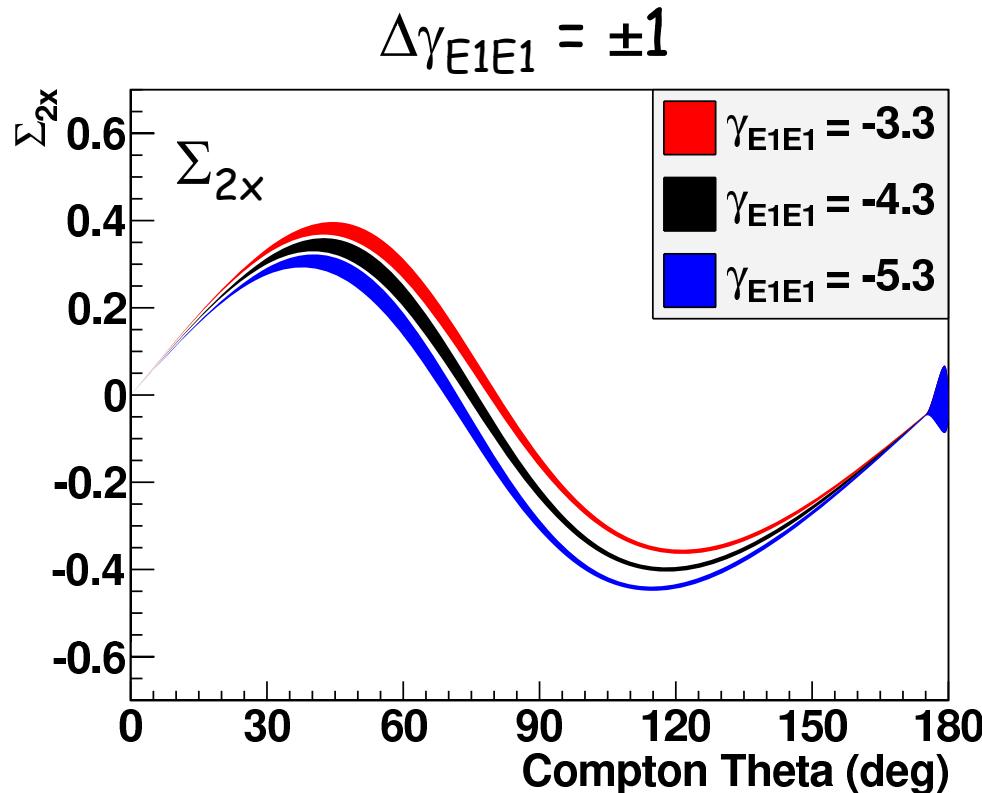
- Unconstrained asymptotic contributions to two of the 12 VCS amplitudes are fit to the data. Valid up to

$$\sqrt{s} \leq M_N + 2m_\pi \quad \longrightarrow \quad \text{Enhanced sensitivity to the polarizabilities}$$

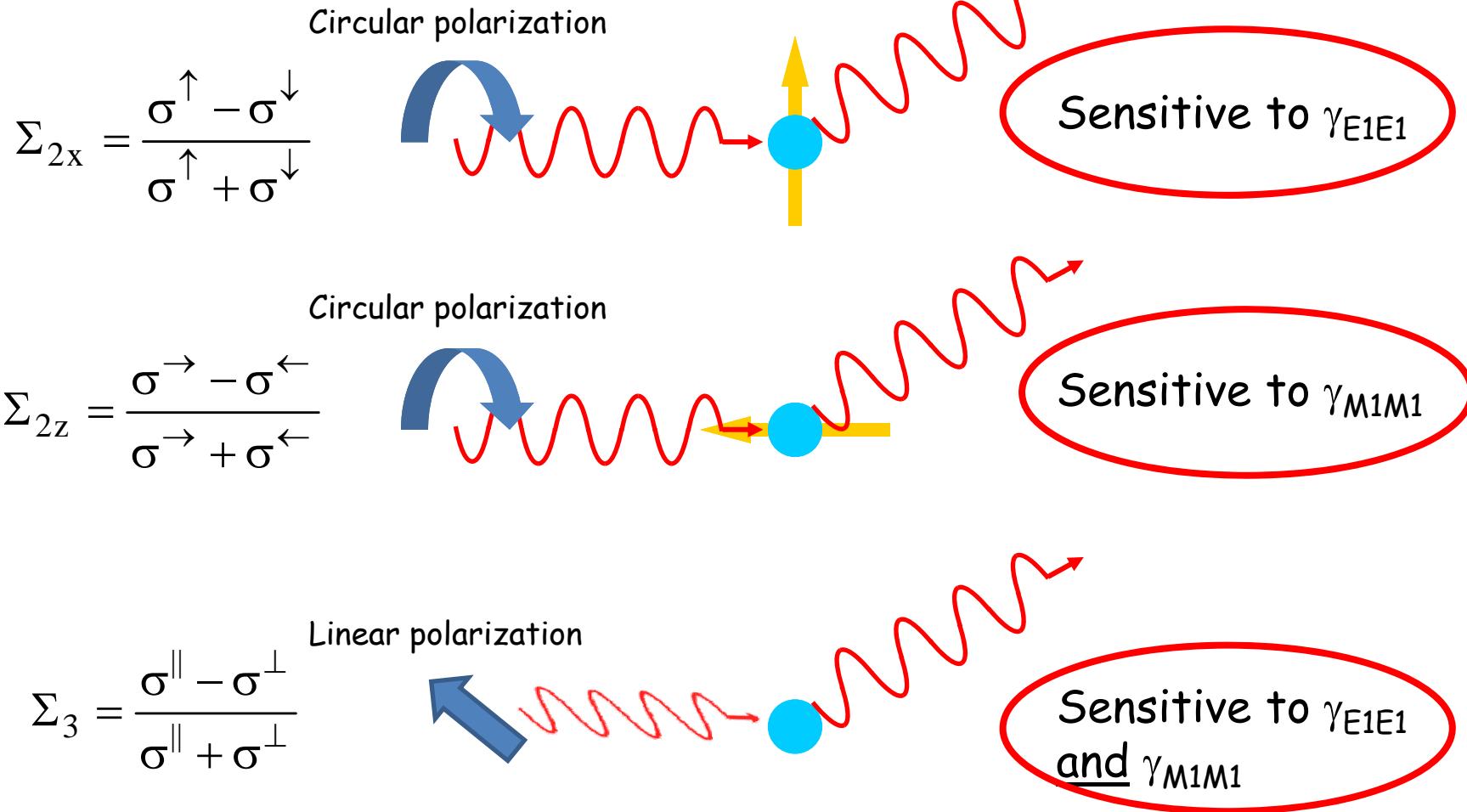
[†]B. Pasquini, et al., Eur. Phys. J. A11 (2001) 185, and D. Drechsel et al., Phys. Rep. 378 (2003) 99.

Sensitivity Study for Σ_{2x}

- Vary α , β , γ_0 and γ_π within experimental error bars, and
- vary γ_{E1E1} holding γ_{M1M1} fixed, or
- vary γ_{M1M1} holding γ_{E1E1} fixed
- $E_\gamma = 280$ MeV



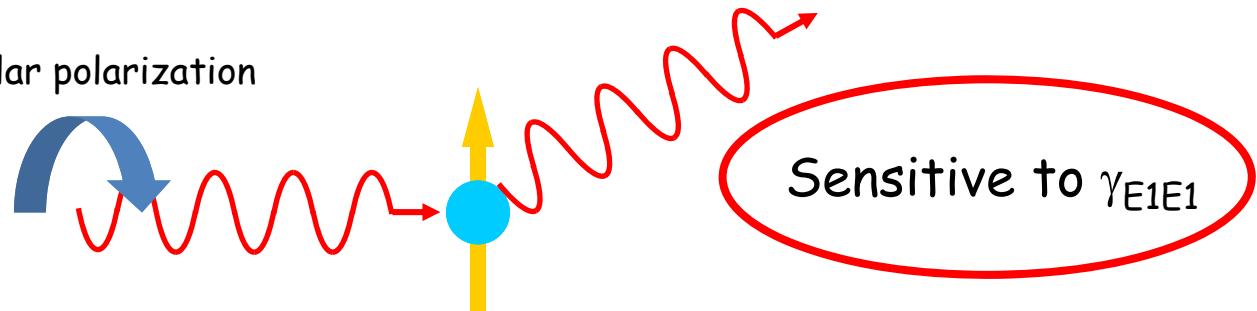
Polarization observables in real Compton scattering



Measurements of Σ_{2x} at MAMI-Mainz

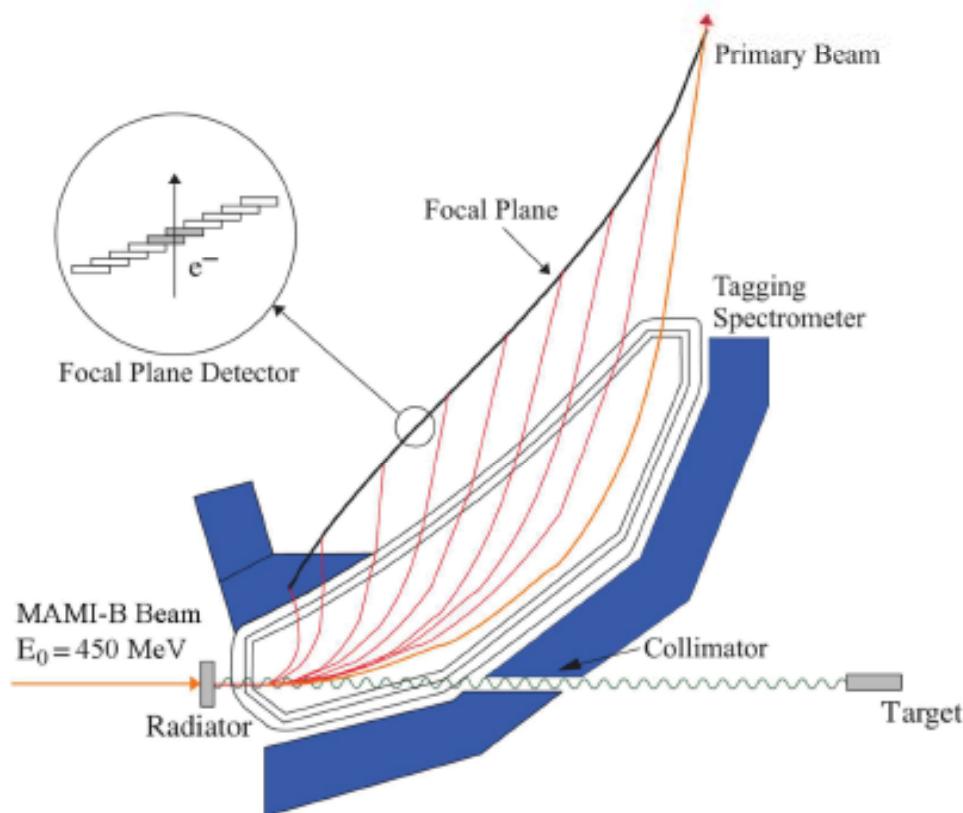
$$\Sigma_{2x} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Circular polarization



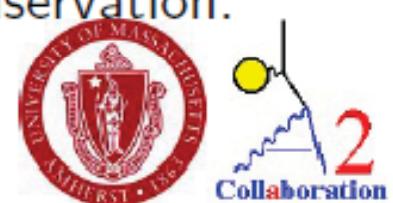
Phil Martel's Ph.D. thesis, UMass Amherst

Glasgow Photon Tagger



$E_\gamma \approx 280 \text{ MeV}$ (large sensitivity spin-polarizabilities)

- e^- beam with energy E_0 , strikes radiator producing Bremsstrahlung photon beam with energy distribution from 0 to E_0 .
- Residual e^- paths are bent in a spectrometer magnet.
- With proper magnetic field, array of 352 detectors determines the e^- energy, and 'tags' the photon energy by energy conservation.



Frozen spin target

- 2 cm butanol
- target polarized at 25 mK
- 0.6 T holding field
- $P \sim 90\%$
- > 1000 hours relaxation time

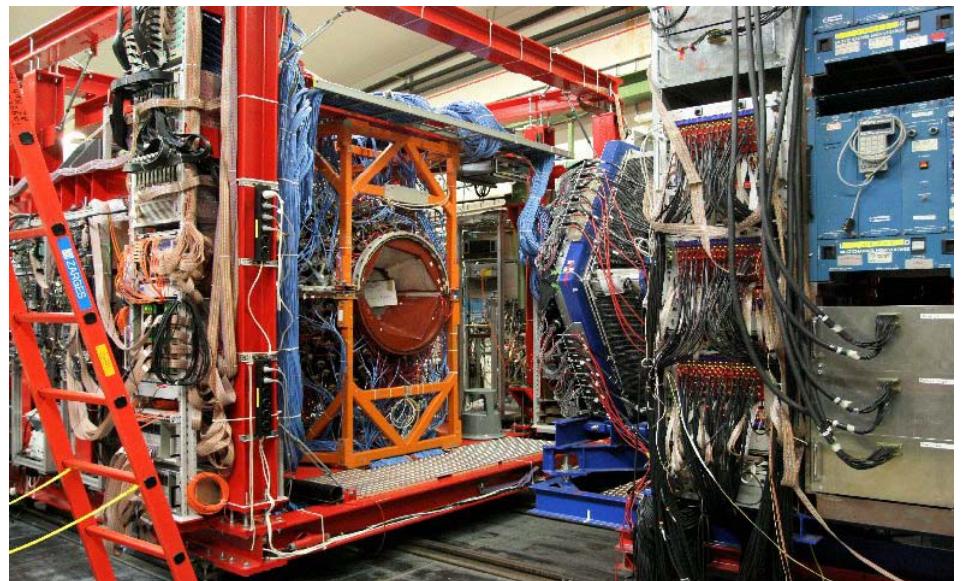
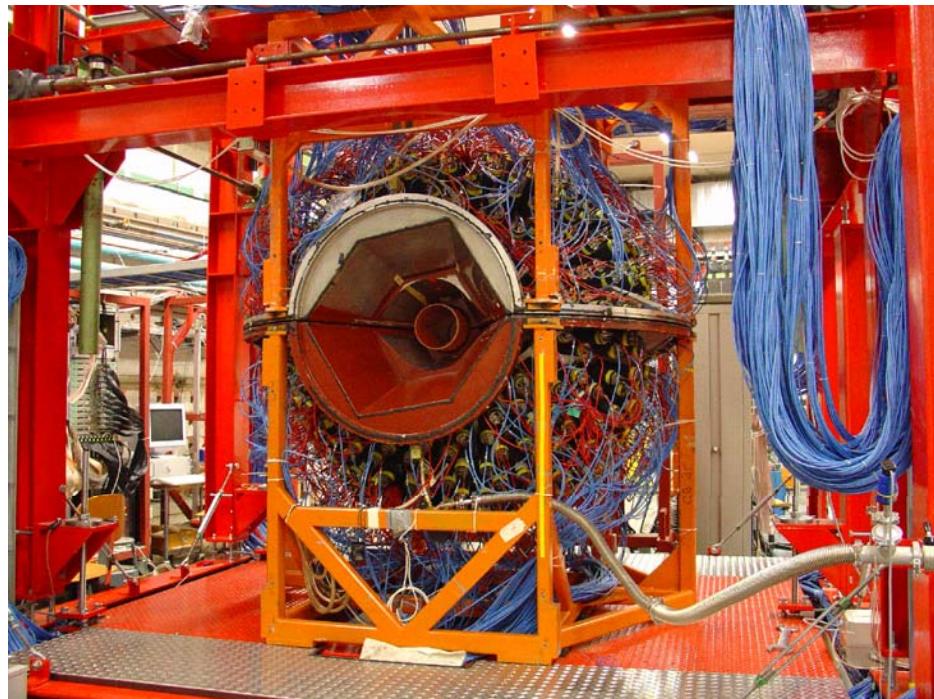
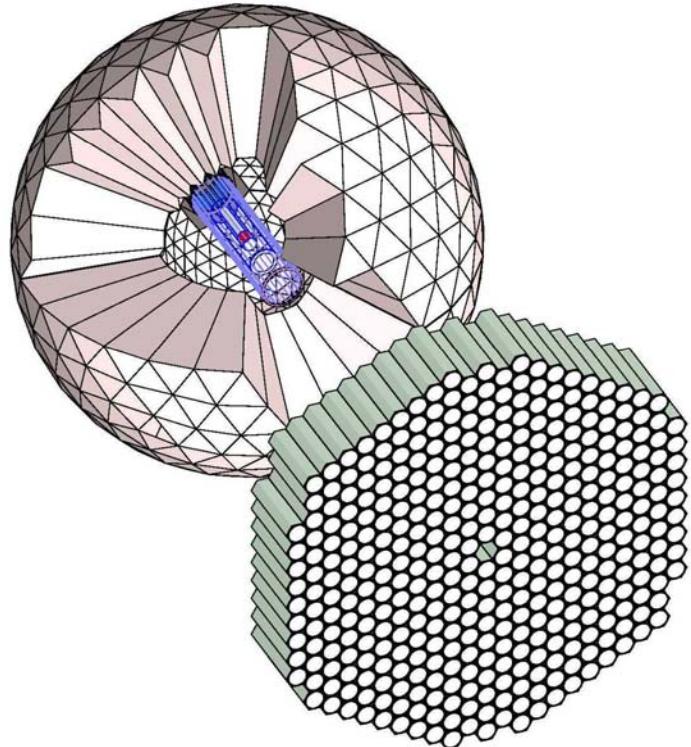


Crystal Ball and TAPS

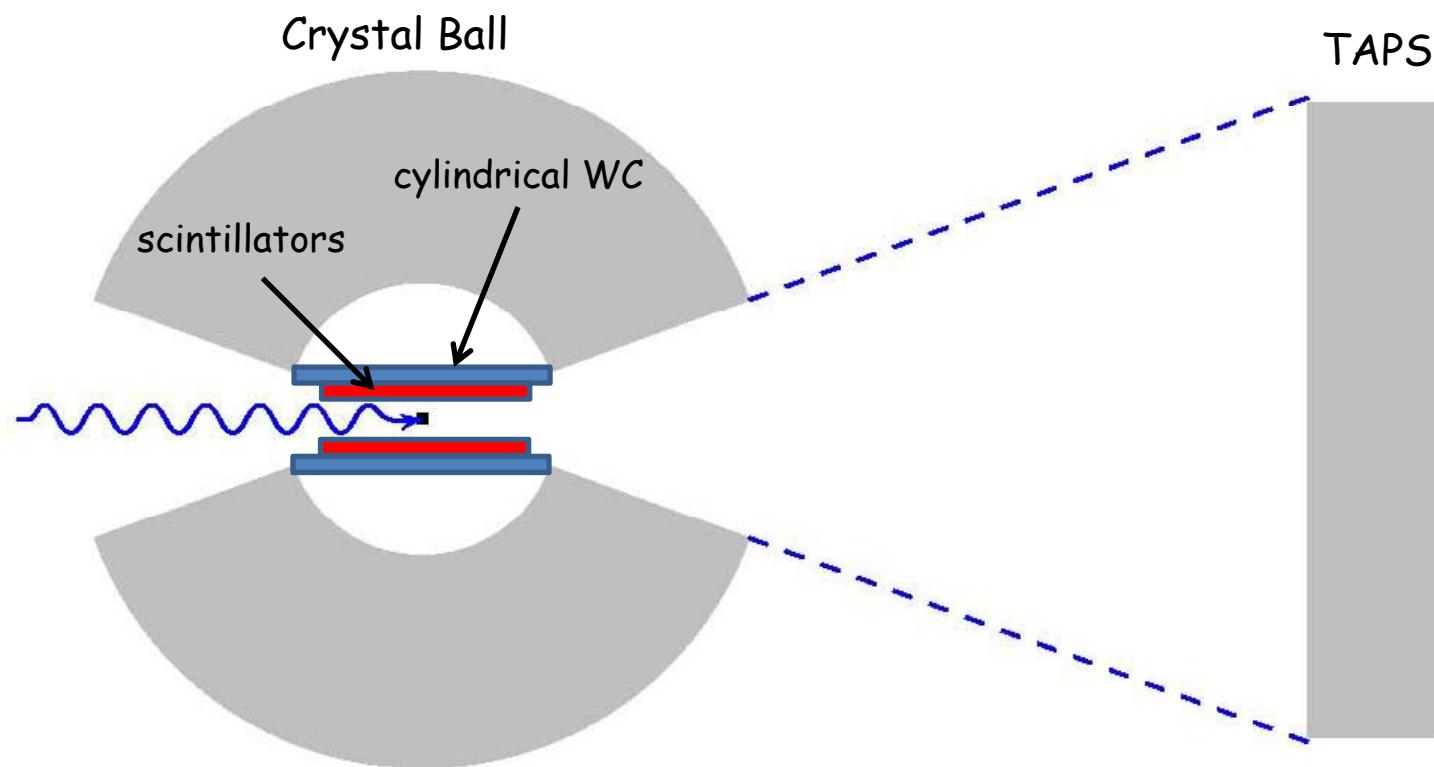
$\approx 4\pi$ photon detection, $4^\circ < \theta < 160^\circ$

CB: 672 NaI crystals, $\Delta E \sim 3\%$, $\Delta \theta \sim 2.5^\circ$

TAPS: 366 BaF₂ and 72 PbWO₄ crystals
 $\Delta E \sim 5\%$, $\Delta \theta \sim 0.7^\circ$

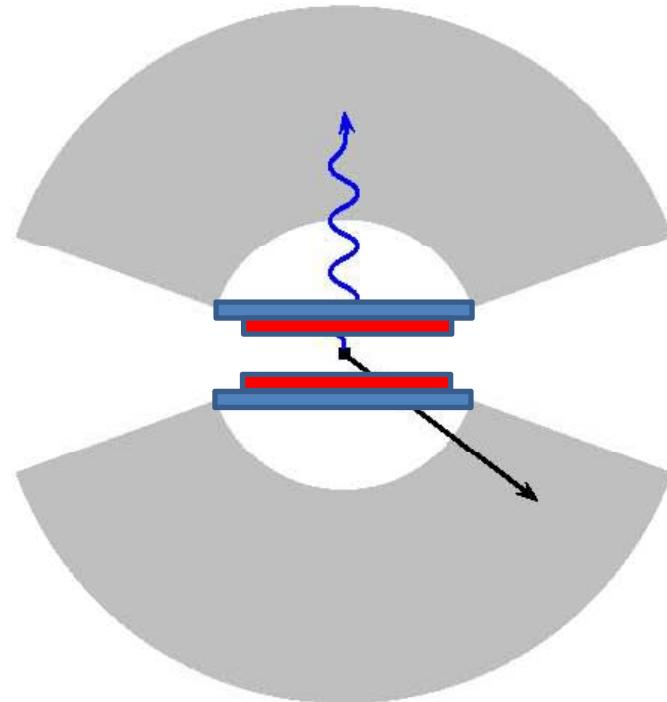


Event Selection



Event Selection

Crystal Ball



TAPS

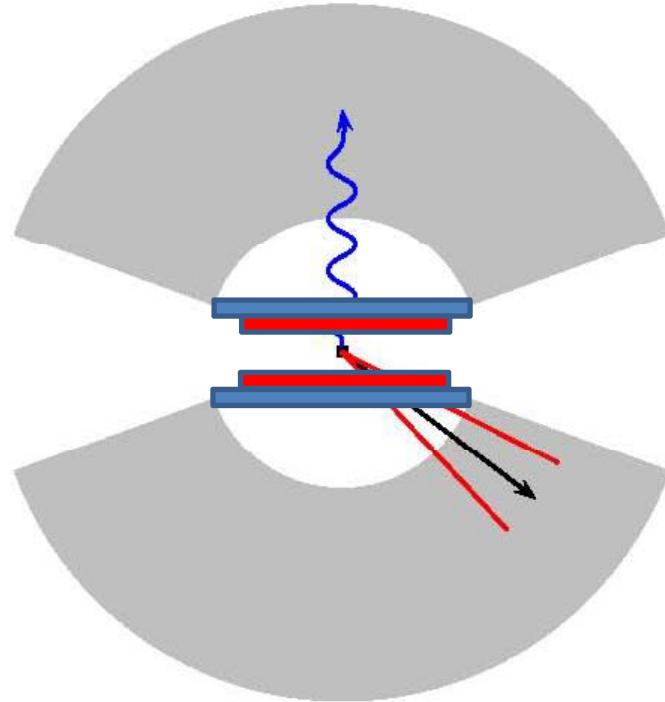


Require detection of ONLY one photon, and ONLY one charged particle, both in time with a tagger hit.



Event Selection

Crystal Ball



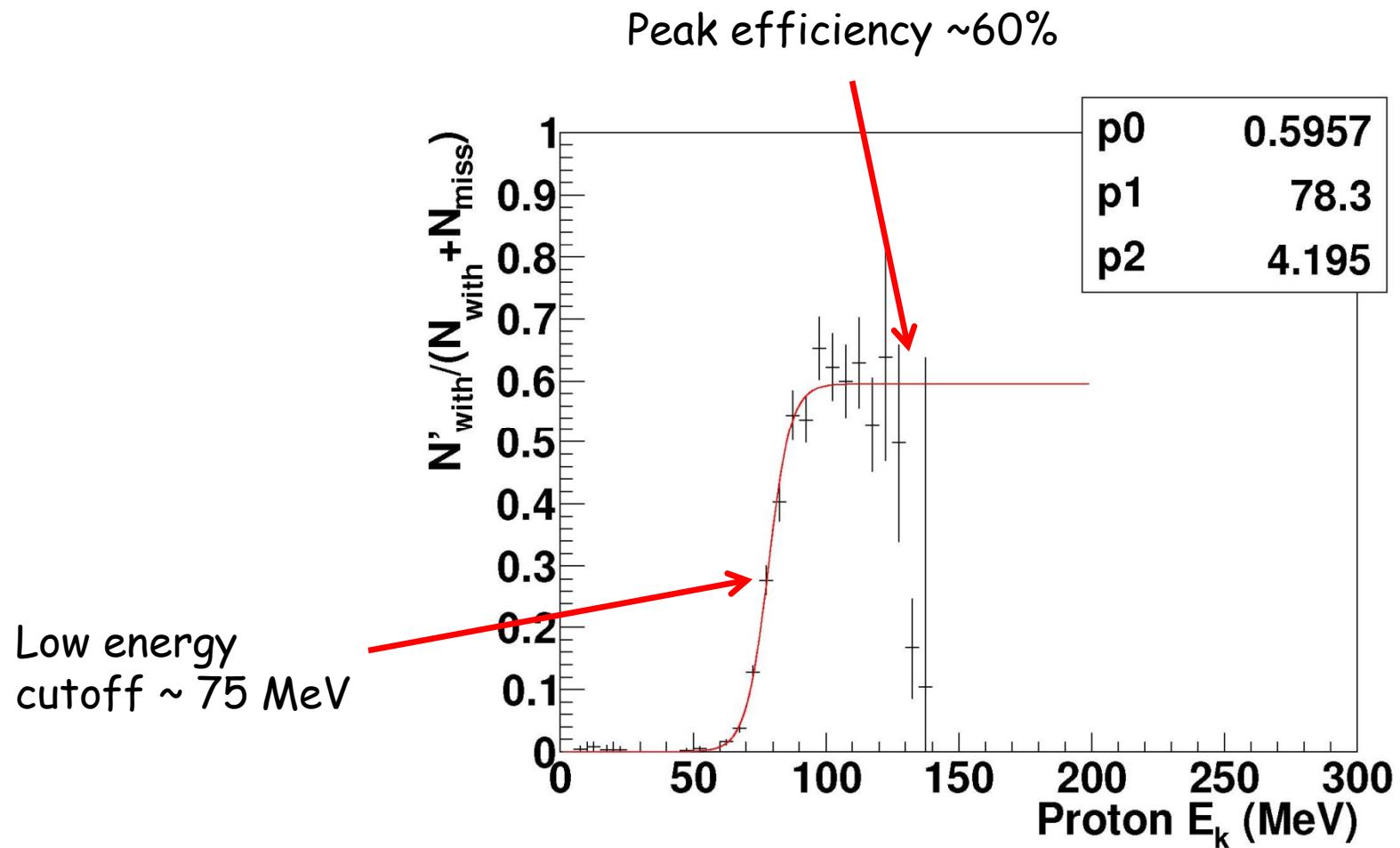
TAPS



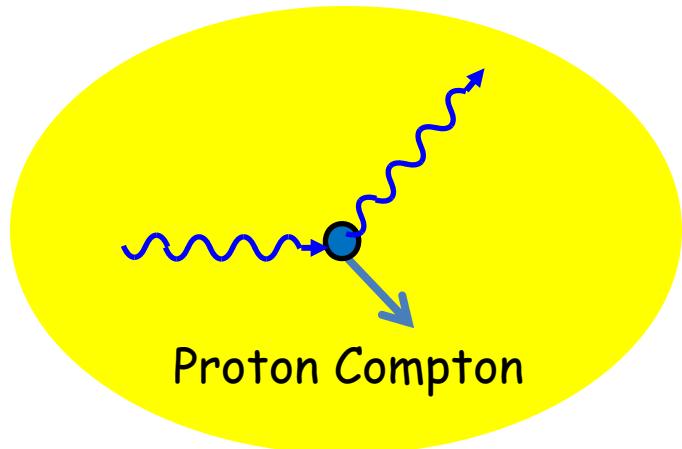
Make an ‘opening angle’ cut, requiring that the proton is detected within a cone of its expected angle.



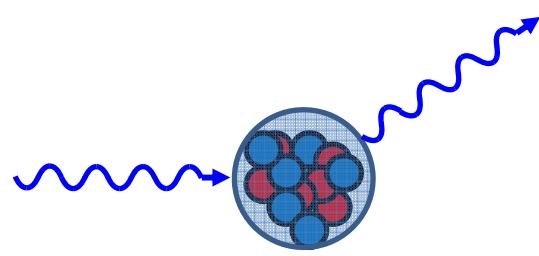
Proton detection efficiency measured in the $\gamma p \rightarrow \pi^0 p$ reaction



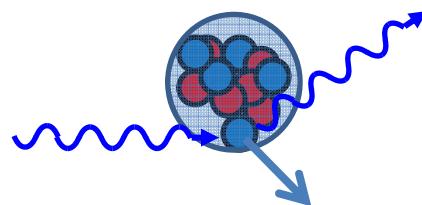
Signal and Background Reactions



Proton Compton

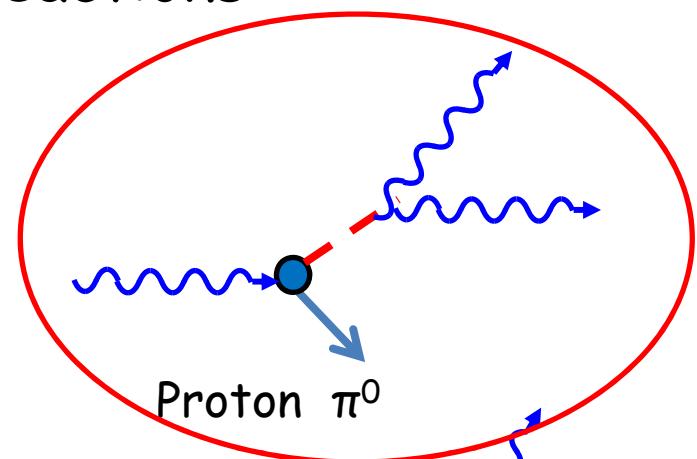


Coherent Compton

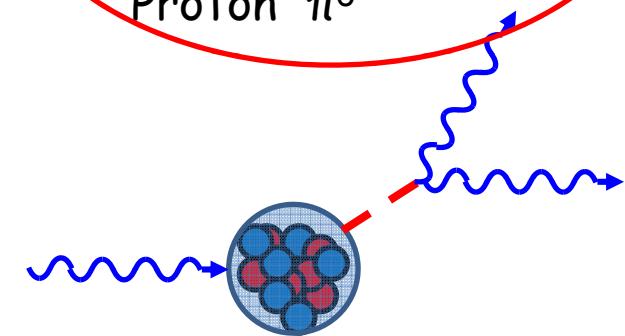


Incoherent Compton

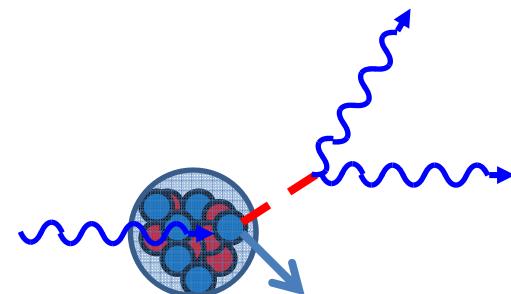
- i. Require only two tracks in the detector, one neutral and one charged, and
- ii. require correct opening angle between Compton scattered photon and charged track, and co-planarity



Proton π^0



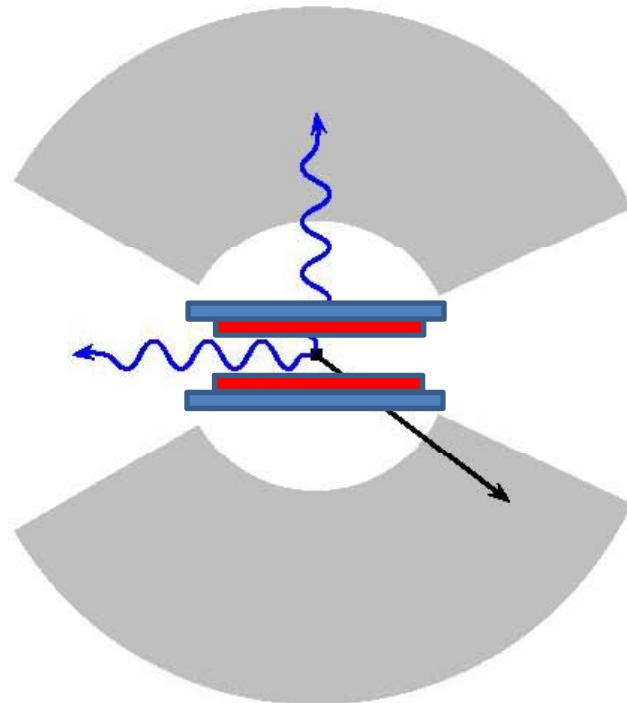
Coherent π^0



Incoherent π^0

Pion Background

Crystal Ball



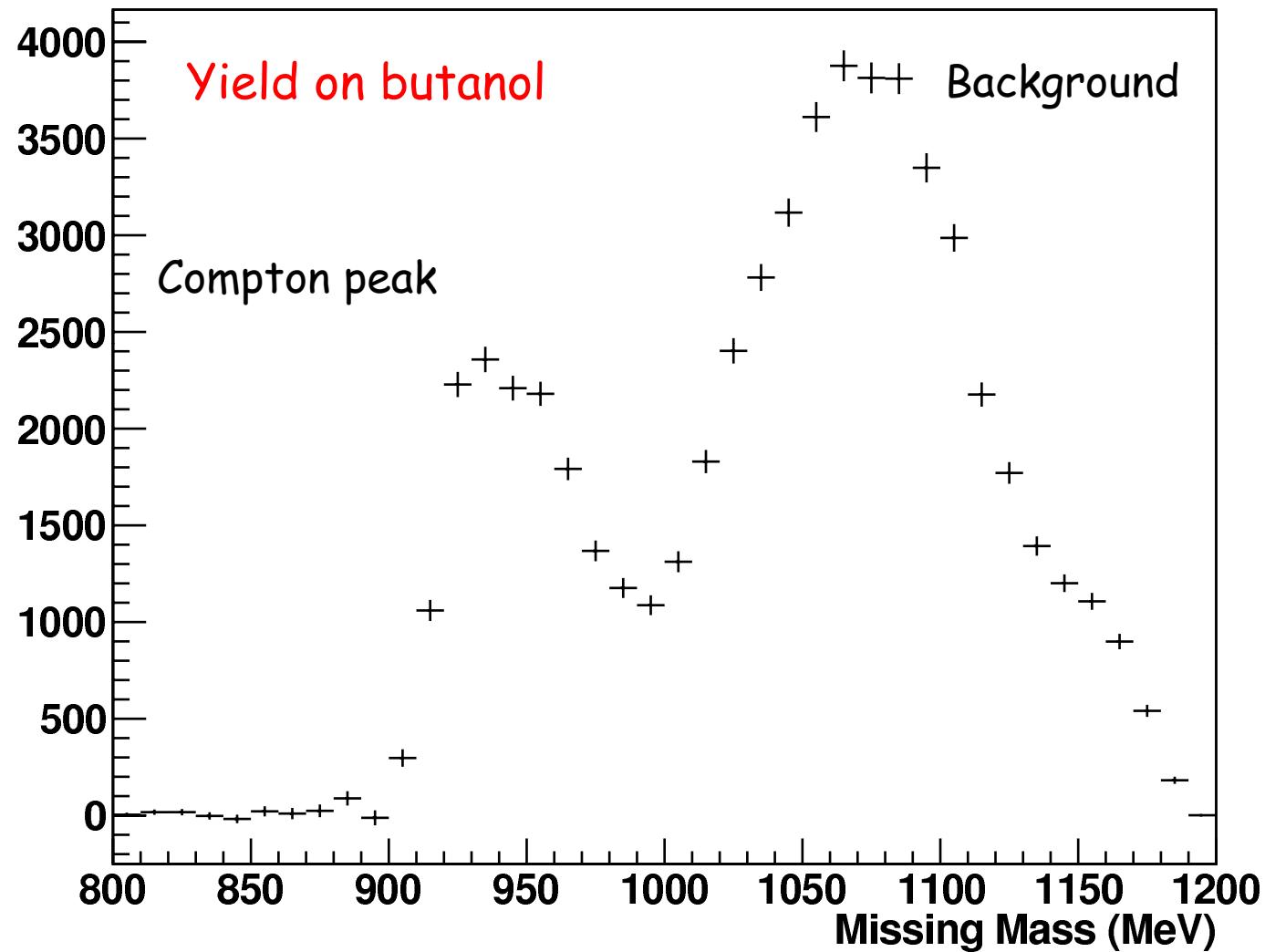
TAPS



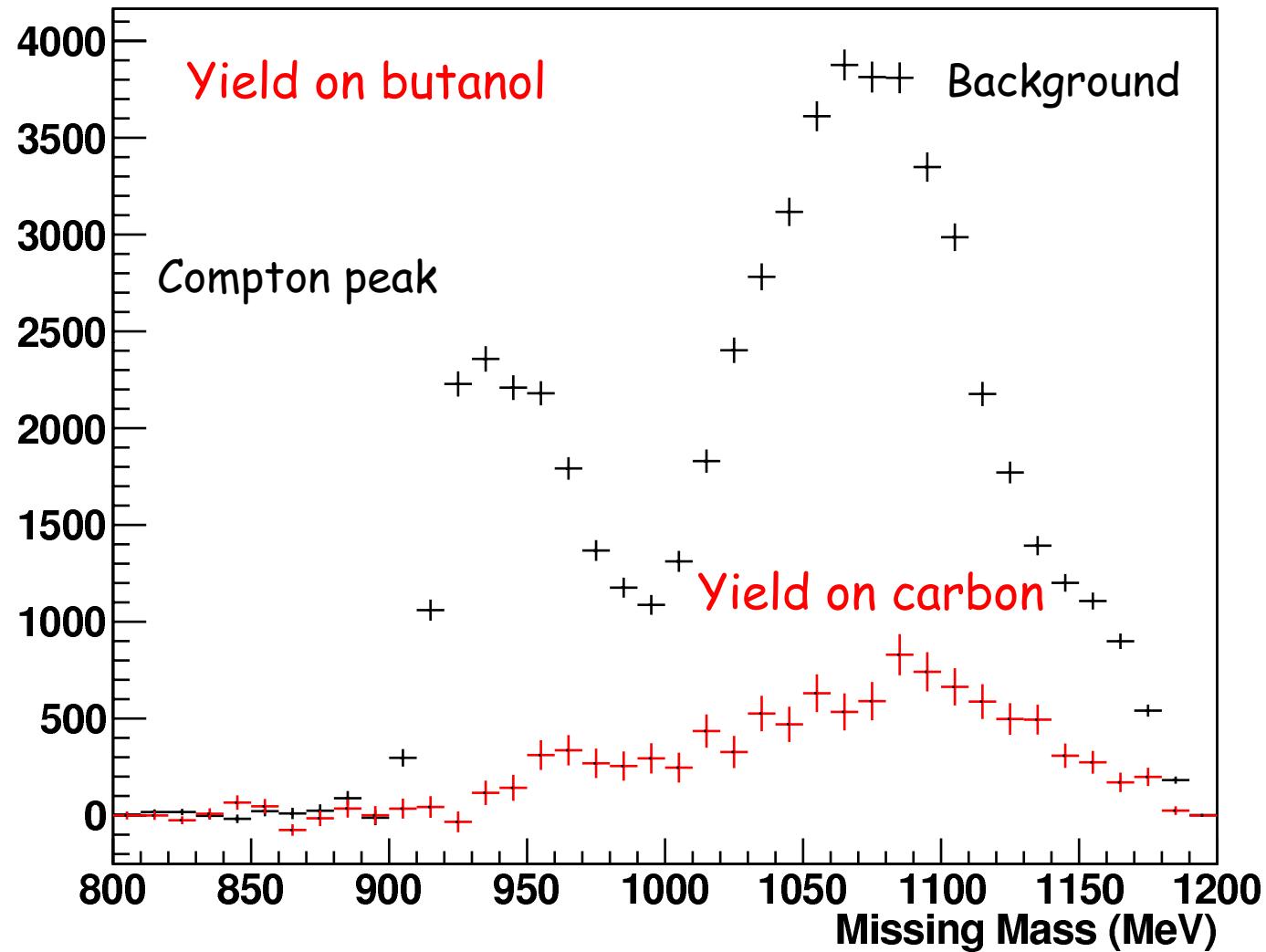
Especially now, there are obvious places where a π^0 decay photon can escape.



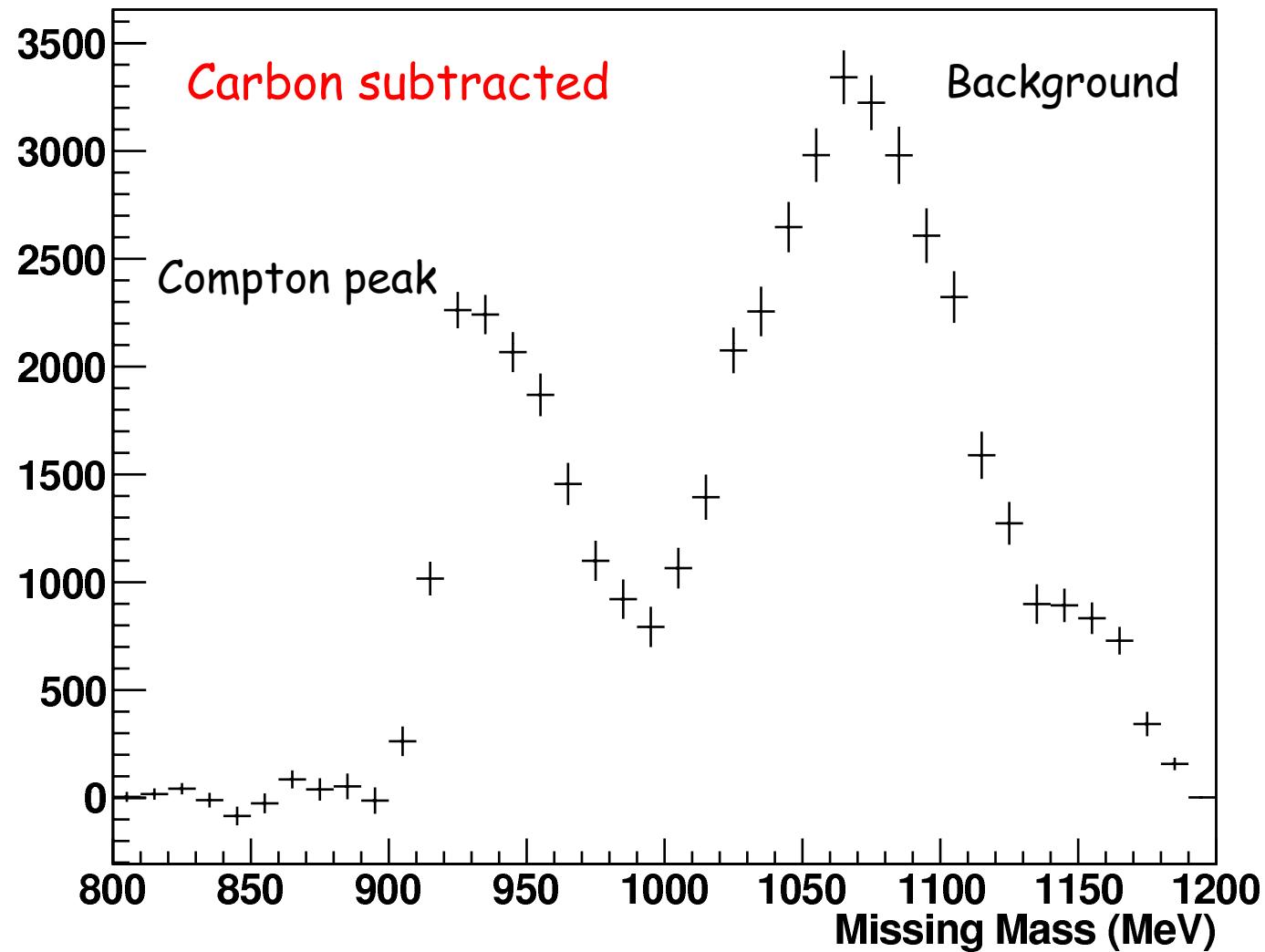
Missing Mass - 270-310 MeV, 100-120 deg



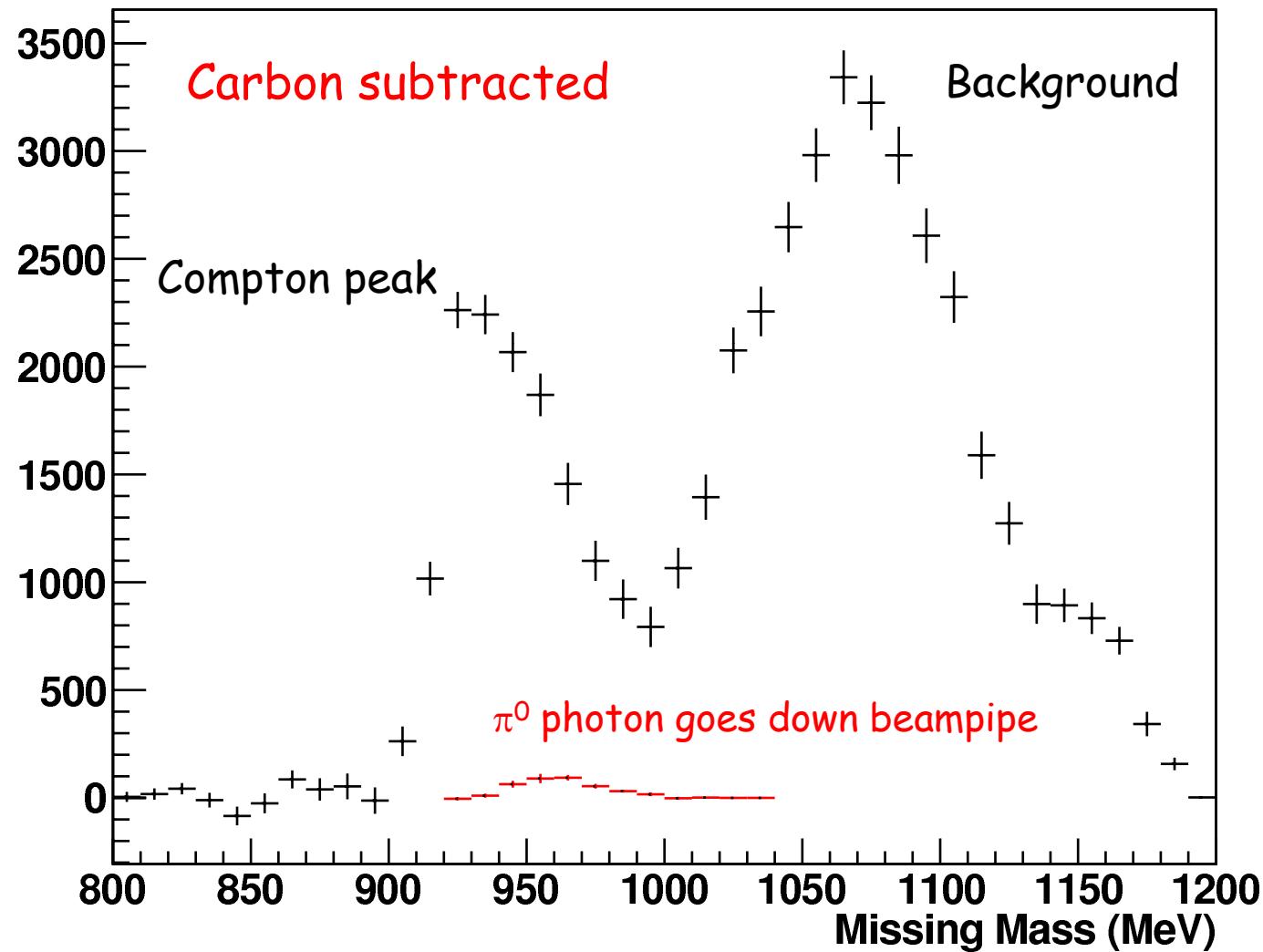
Missing Mass - 270-310 MeV, 100-120 deg



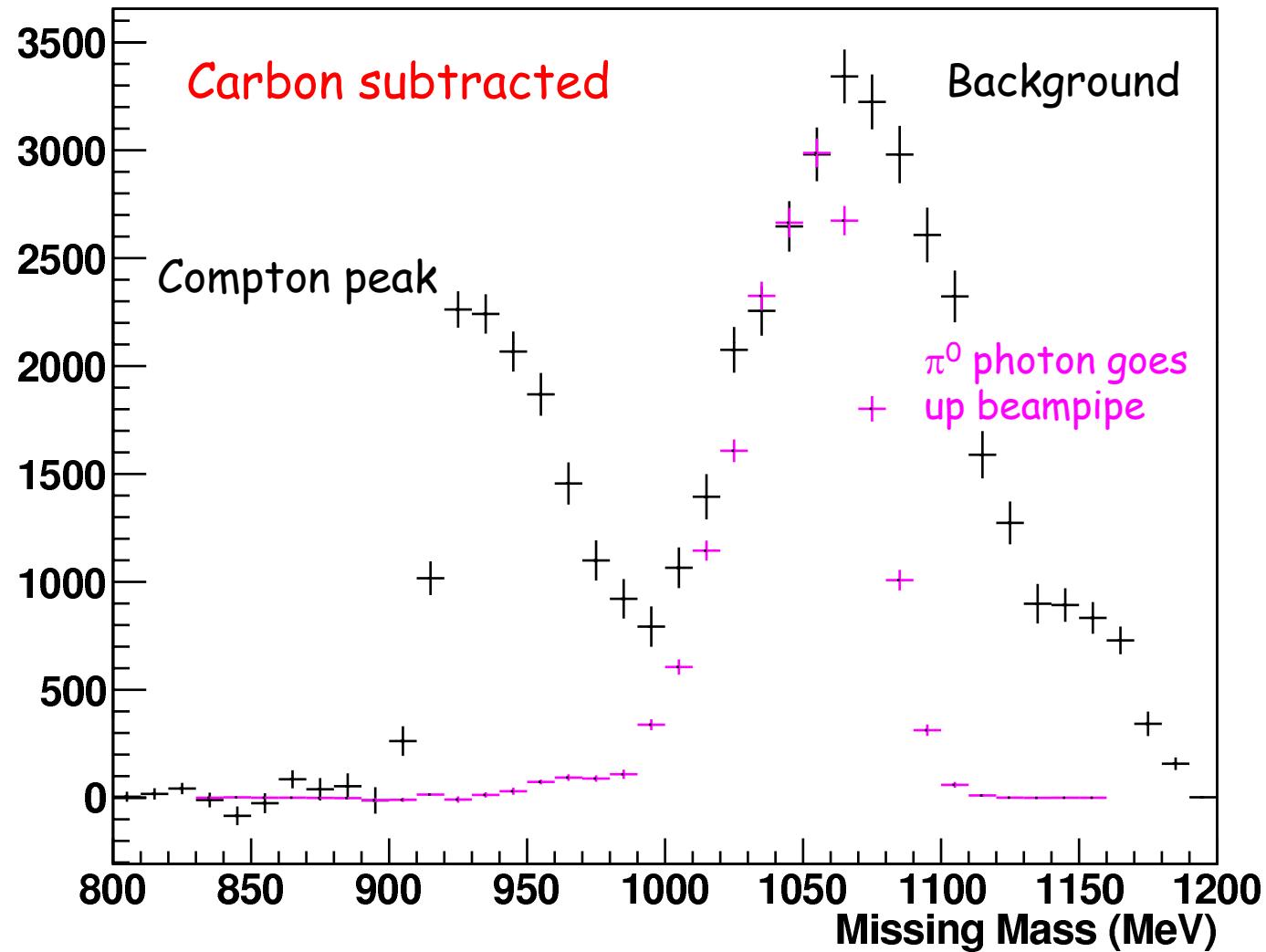
Missing Mass - 270-310 MeV, 100-120 deg



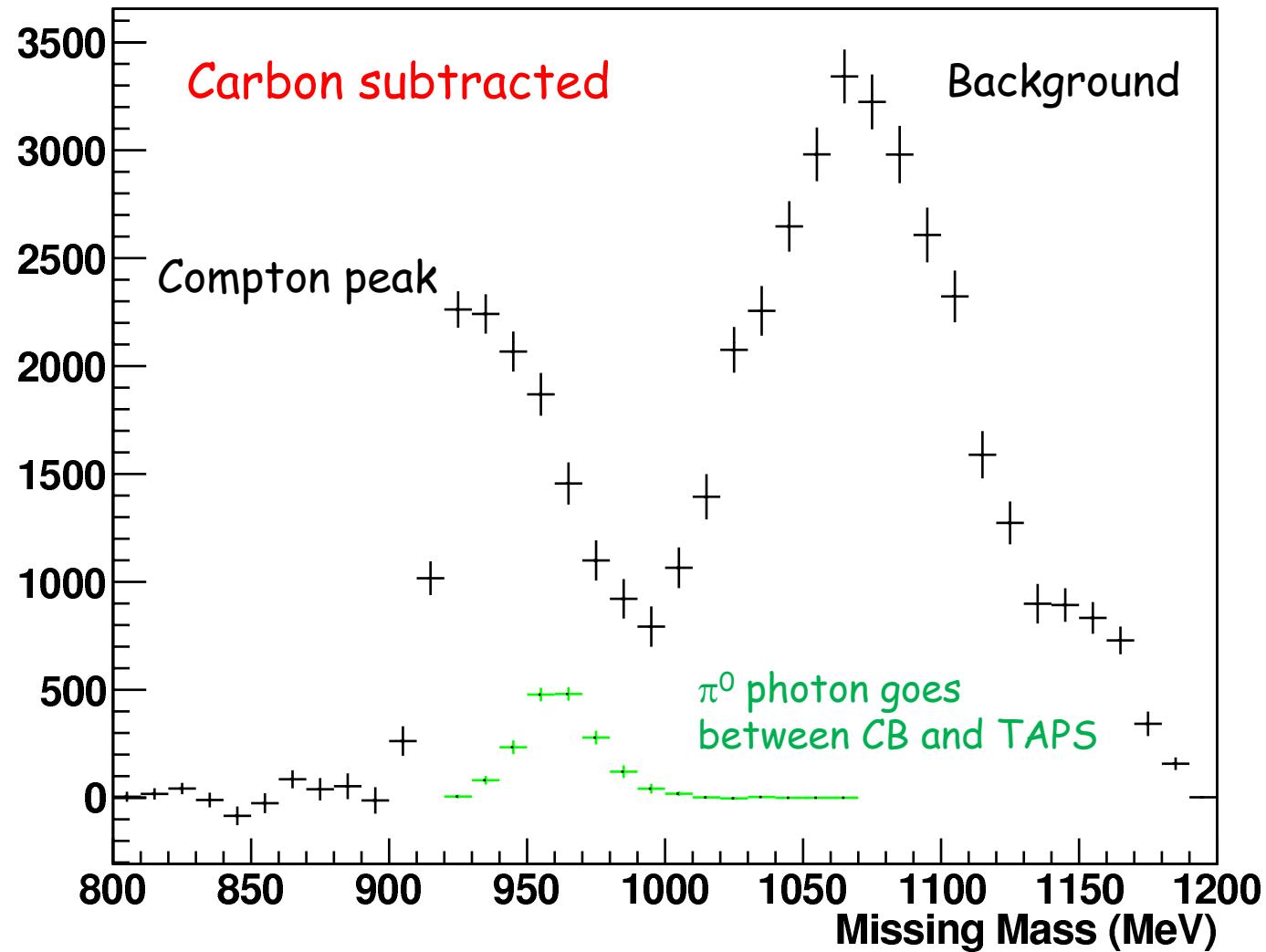
Missing Mass - 270-310 MeV, 100-120 deg



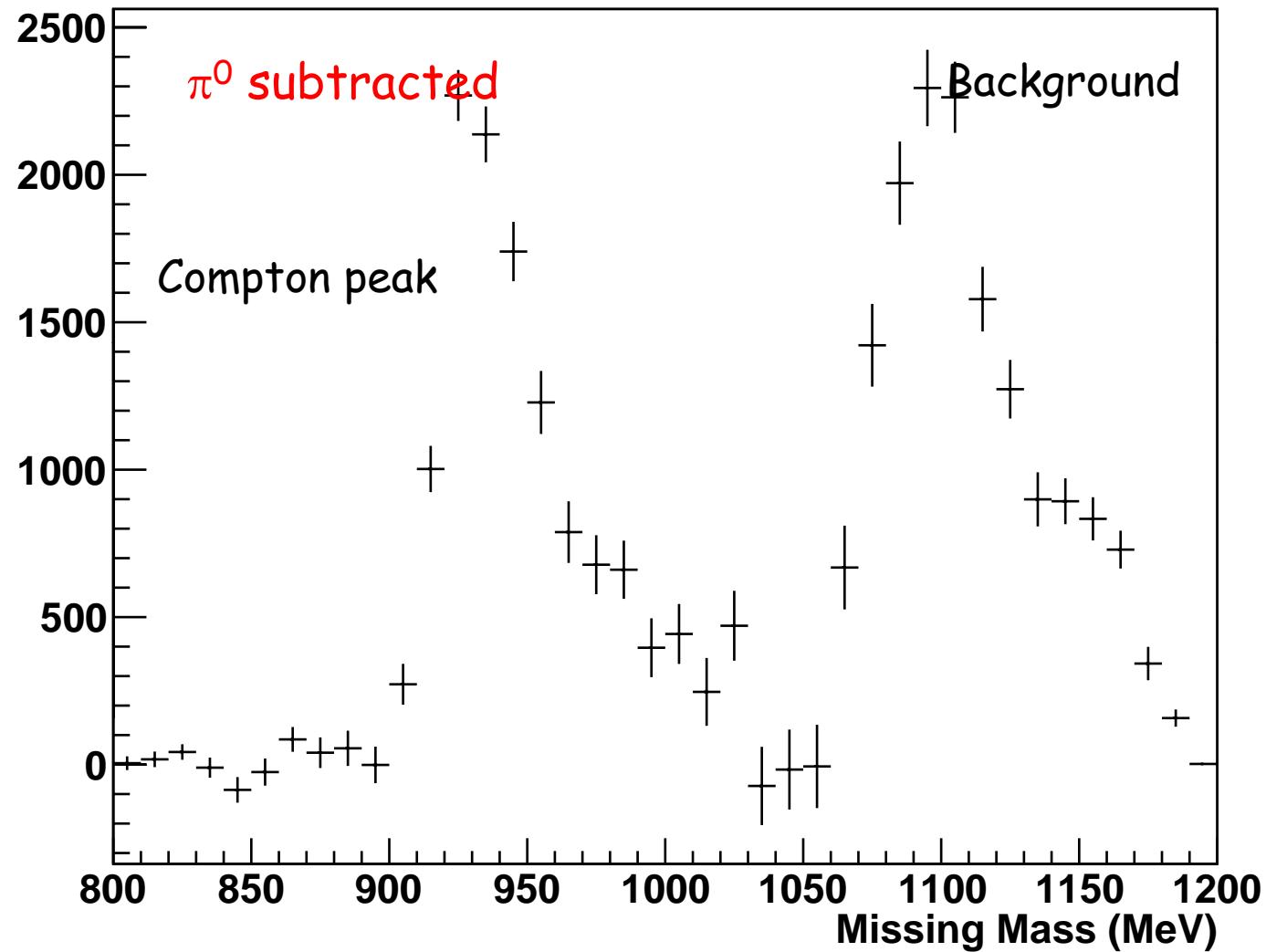
Missing Mass - 270-310 MeV, 100-120 deg



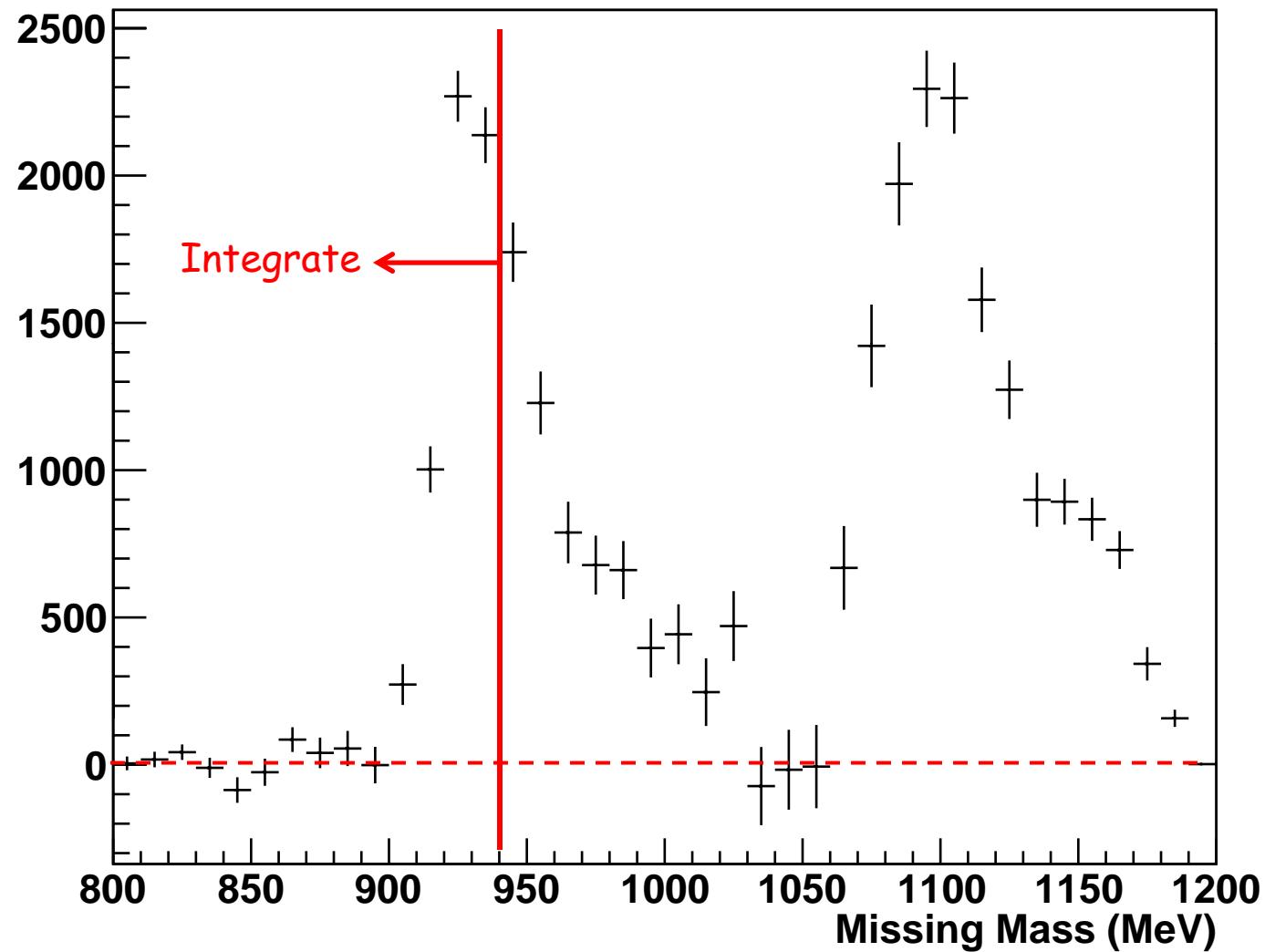
Missing Mass - 270-310 MeV, 100-120 deg



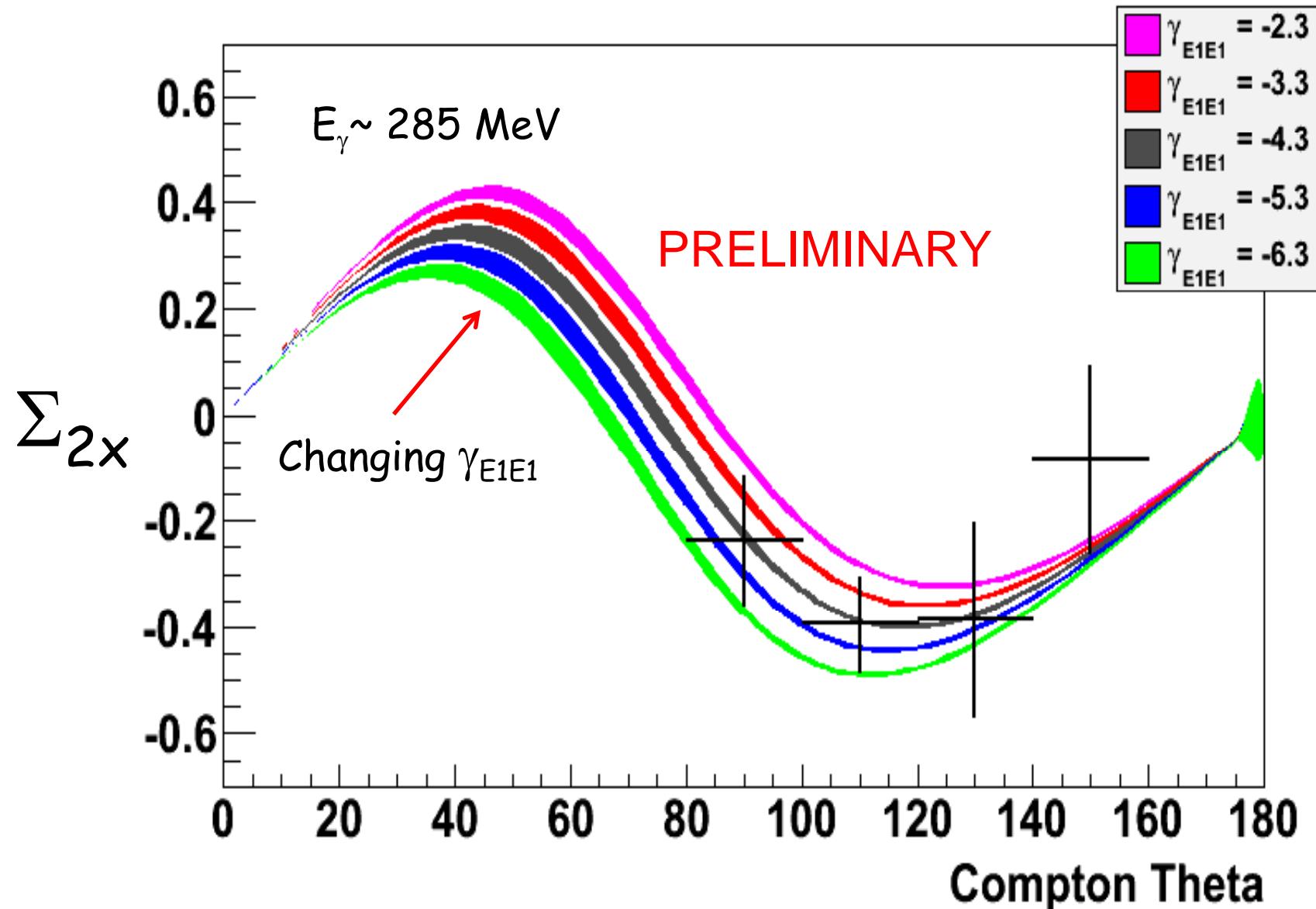
Missing Mass - 270-310 MeV, 100-120 deg



Missing Mass - 270-310 MeV, 100-120 deg



Asymmetry with transverse polarized target and circularly polarized photons



Summary

- First measurement of a double-polarized Compton scattering asymmetry on the nucleon, Σ_{2x}
- Data have sensitivity to the γ_{E1E1} spin-polarizability

Outlook

- Data taking on Σ_3 later this year at MAMI (for γ_{E1E1} and γ_{M1M1})
- Data taking on Σ_{2z} in 2013 (for γ_{M1M1})
- A global analysis of all polarized Compton scattering data on the proton using dispersion analysis treatment is in progress
- *Development of an active polarized target has been approved for MAMI.* Polarizable scintillators have been developed at UMass.