Spin polarizabilities: new results and future plans

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A2 collaboration and
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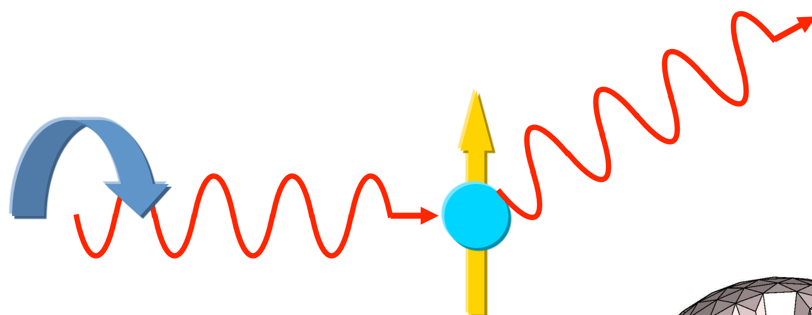
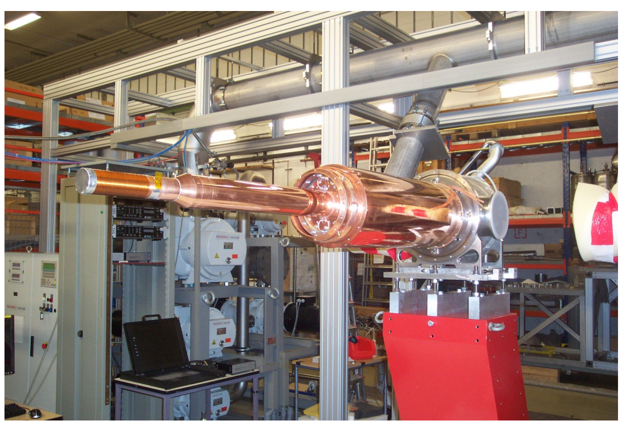
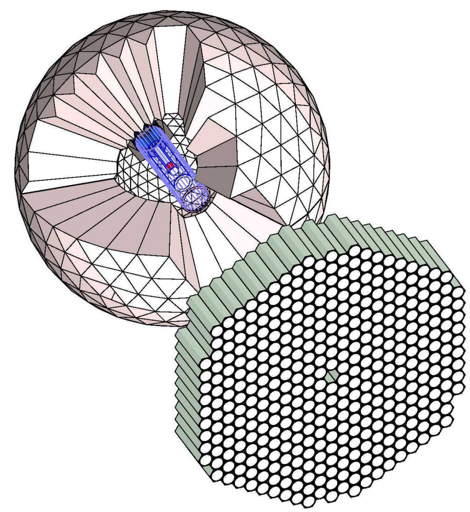




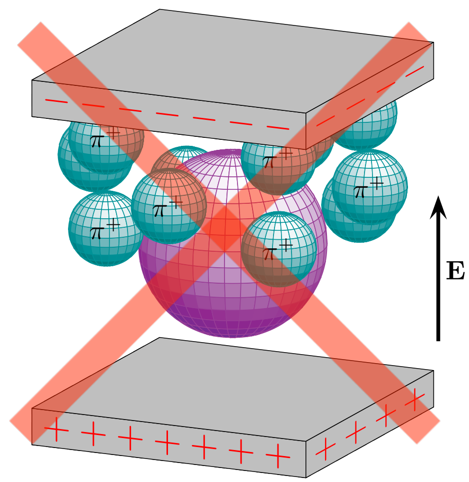


The physics of low-energy Compton scattering on the nucleon is governed by six structure constants:

- **the electric and magnetic polarizabilities,** α **and** β
- **four spin-polarizabilities,** γ_{E1E1}, γ_{M1M1}, γ_{E1M2}, **and** γ_{M1E2}

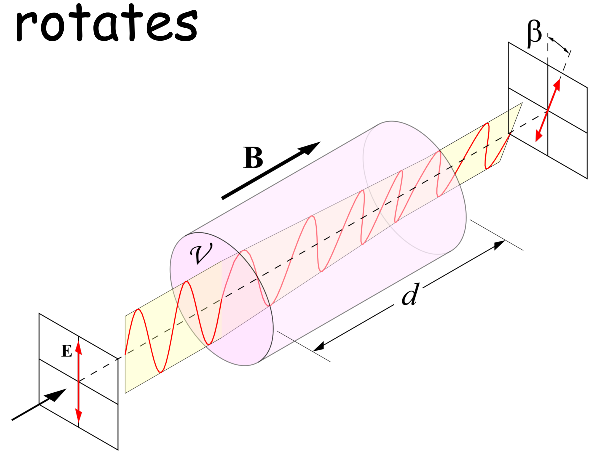
$$H_{eff}^{(3),spin} = -\frac{1}{2}4\pi\left(\gamma_{E1E1}\vec{\sigma}\cdot\vec{E}\times\dot{\vec{E}} + \gamma_{M1M1}\vec{\sigma}\cdot\vec{B}\times\dot{\vec{B}} - 2\gamma_{M1E2}E_{ij}\sigma_j H_j + 2\gamma_{E1M2}H_{ij}\sigma_j E_j\right)$$

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



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

- Nucleon spin precesses in rotating electric and magnetic fields
- Faraday effect is a *spin-polarizability-like* process: polarization plane of linearly polarized light transmitted through polarized, transparent medium rotates



- Laser-driven Faraday polarimeter proposed for JLab may have sensitivity to γ_{M1M1} for ^{3}He

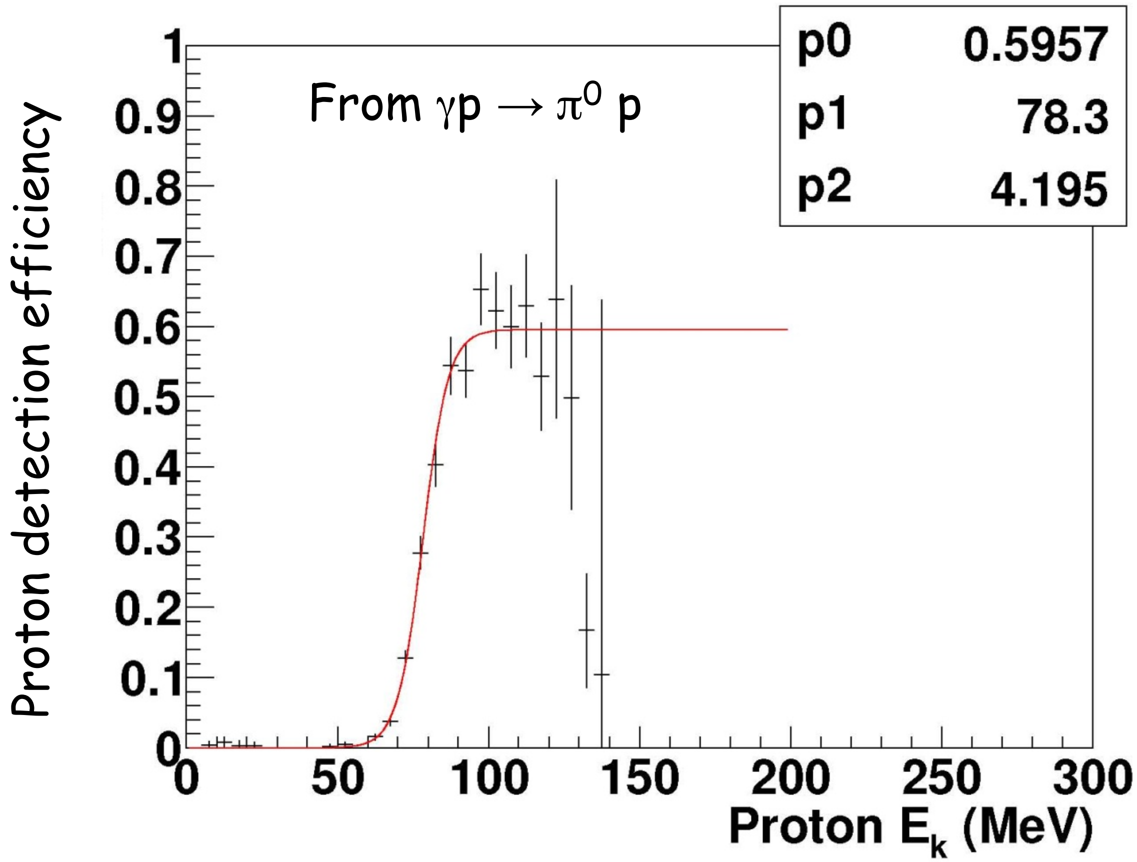
Outline

- Spin dependent Compton scattering in the $\Delta(1232)$ region: circularly polarized photons on transverse polarized target, Σ_{2x} asymmetry
- Preliminary new data
    i. Linearly polarized photons on unpolarized LH_2, Σ_3 asymmetry (nearly final)
    ii. Circularly polarized photons on longitudinally polarized target, Σ_{2z} asymmetry (very, very preliminary)
- Results for the spin polarizabilities
- Development of a polarized, scintillating target

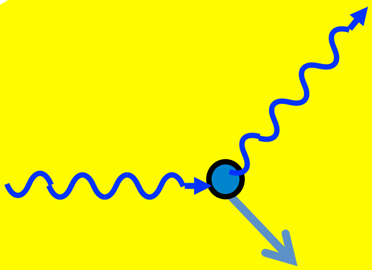
Spin-polarized Compton scattering experiments in the $\Delta(1232)$ region

Why the Δ region?

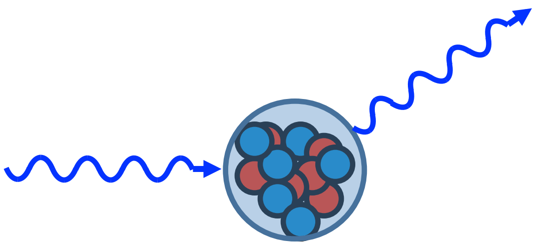
- To increase sensitivity to the spin polarizabilities
- Need sufficiently high energies for the recoil proton to escape the frozen spin target, E_i > 285 MeV



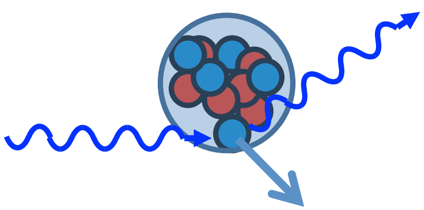
Signal and Background Reactions



Proton Compton



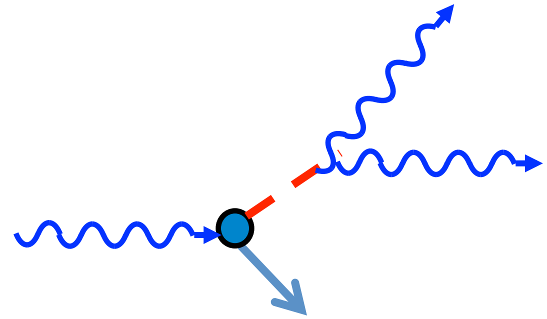
Coherent Compton



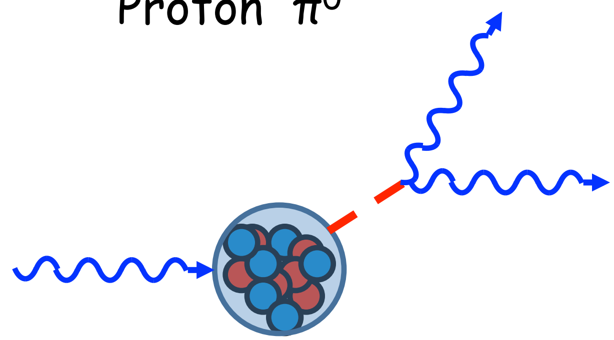
Incoherent Compton

i. Require only two tracks in the detector, one neutral and one charged, and

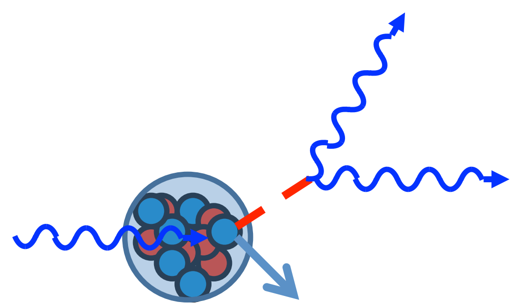
ii. require correct opening angle between Compton scattered photon and charged track, and co-planarity



Proton π^0



Coherent π^0

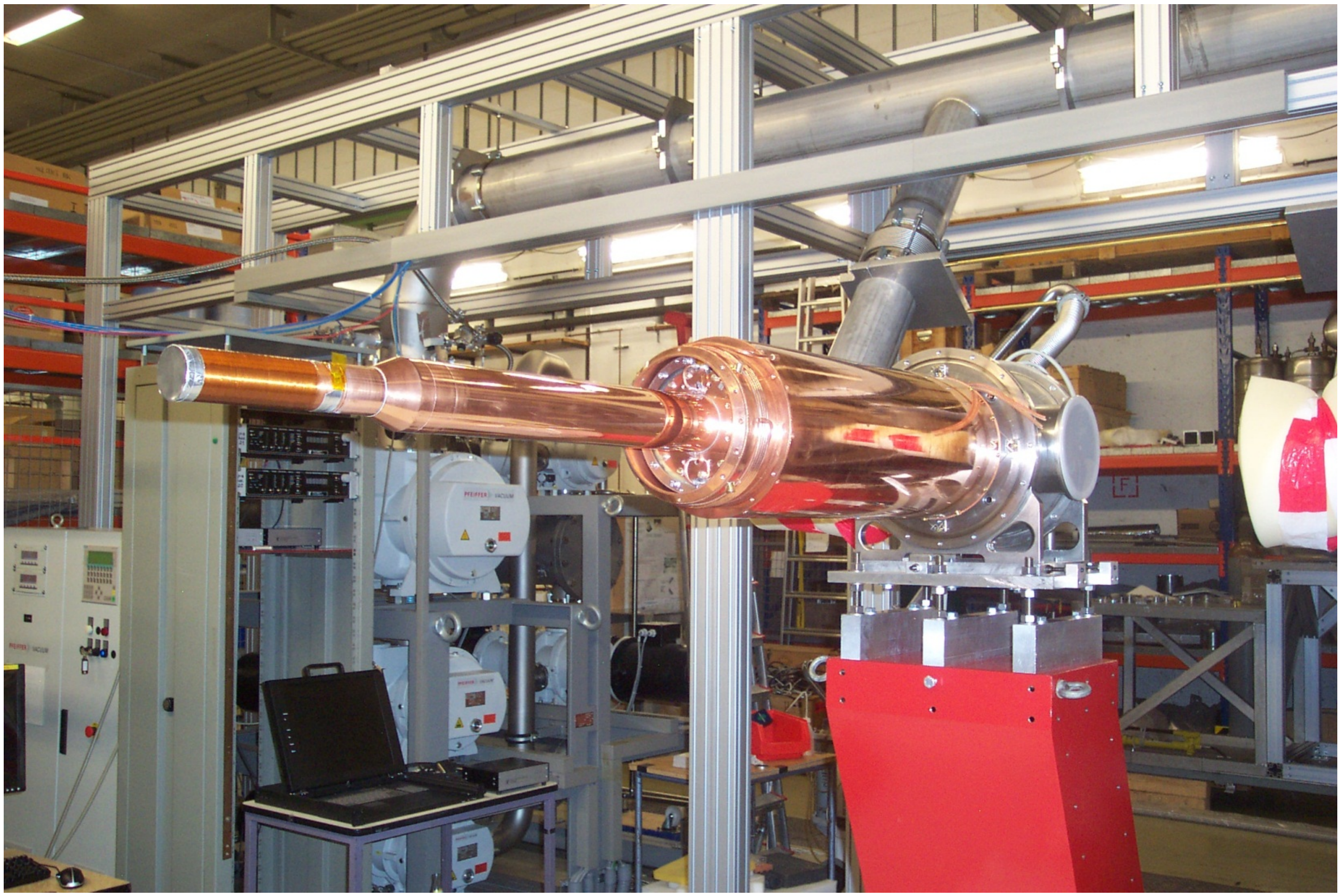


Incoherent π^0

Frozen spin target

- 2 cm butanol
- target polarized at 25 mK
- 0.6 T holding field

- P ~ 90%
- > 1000 hours relaxation time

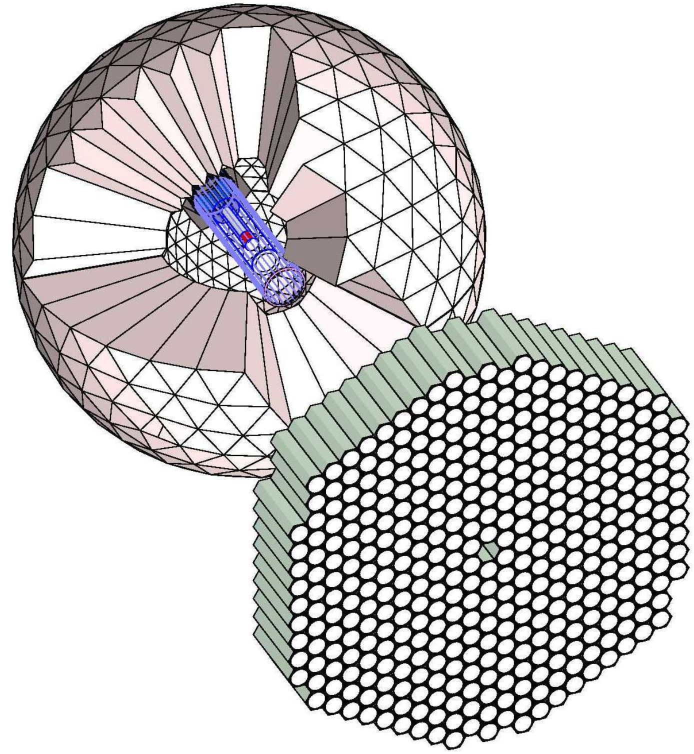


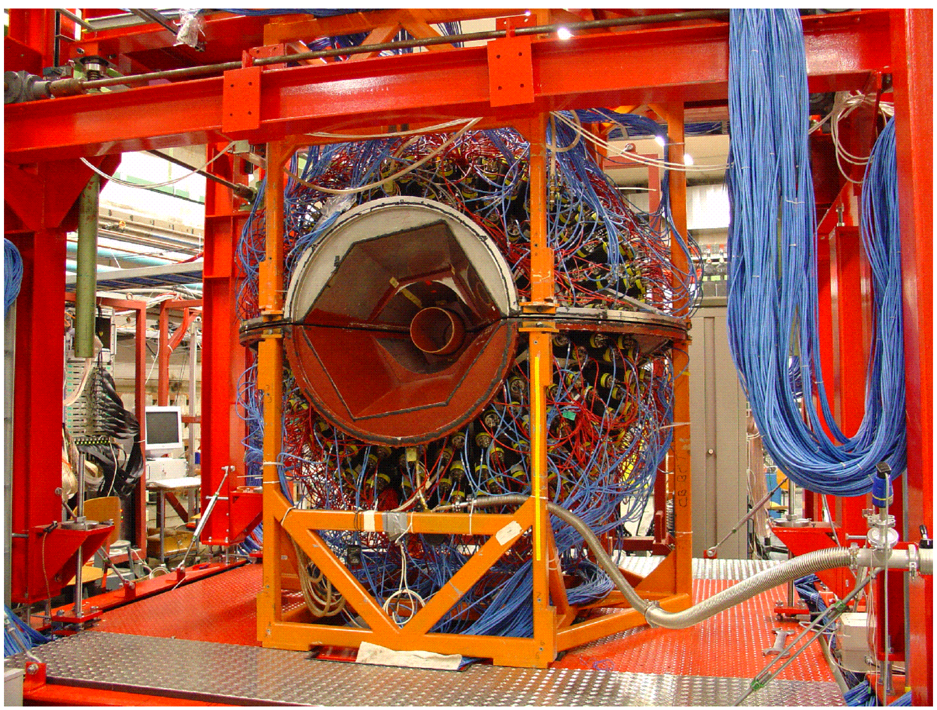
Crystal Ball and TAPS

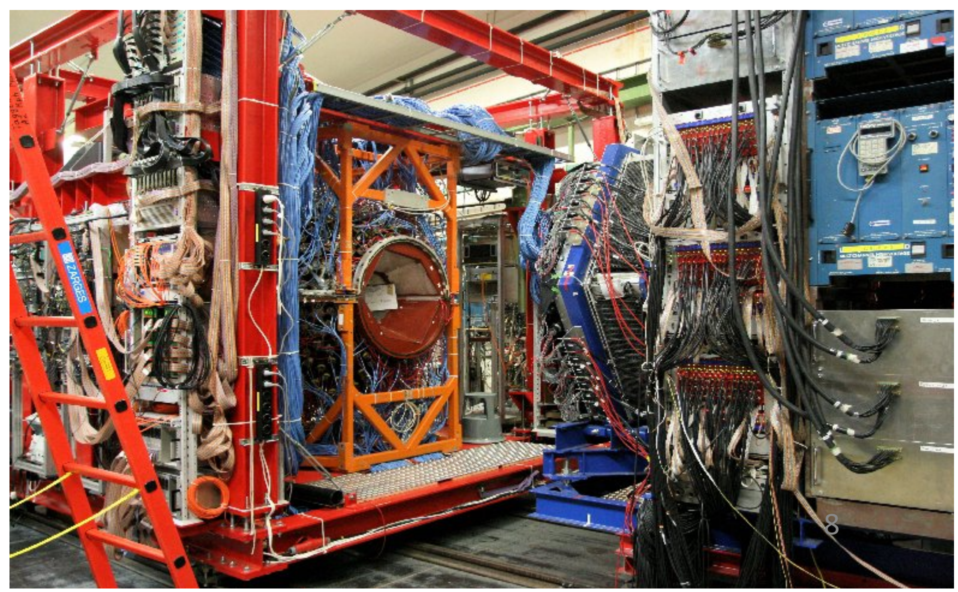
≈ 4π photon detection, $4° < \theta < 160°$

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

TAPS: 366 BaF_2 and 72 $PbWO_4$ crystals
$\Delta E \sim 5\%$, $\Delta\theta \sim 0.7°$

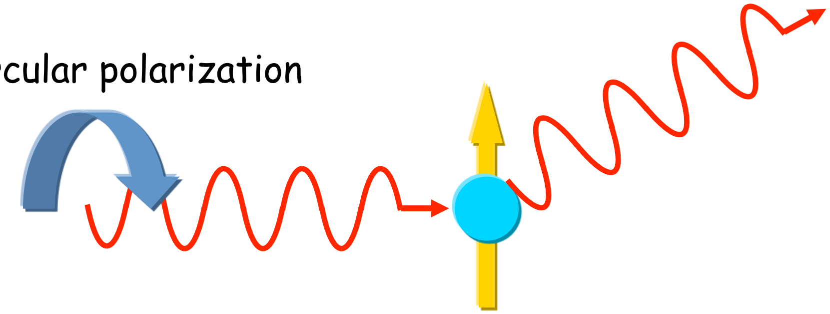






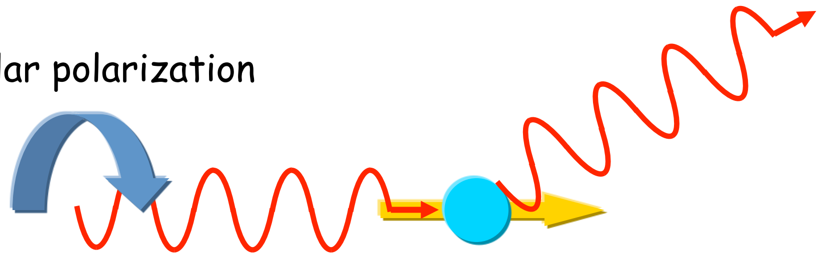
Polarization observables for Compton scattering in the Δ region

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



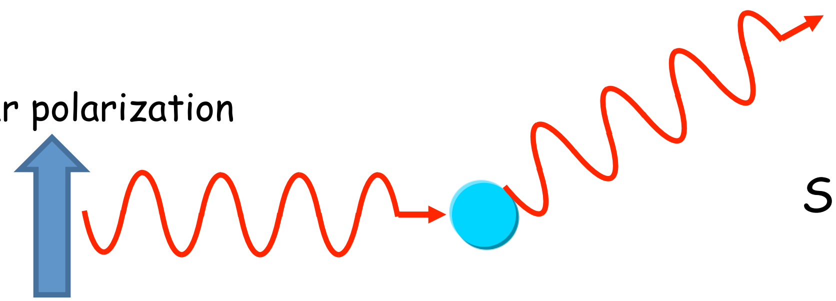
Sensitive to γ_{E1E1}

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



Sensitive to γ_{M1M1} and γ_{π}

$$\Sigma_{3} = \frac{\sigma^{\parallel} - \sigma^{\perp}}{\sigma^{\parallel} + \sigma^{\perp}}$$



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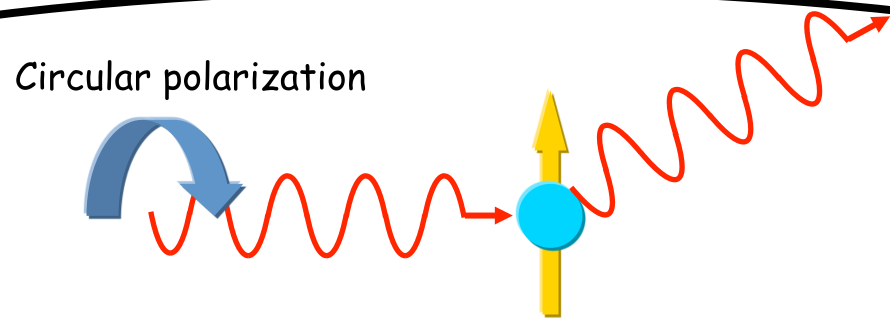

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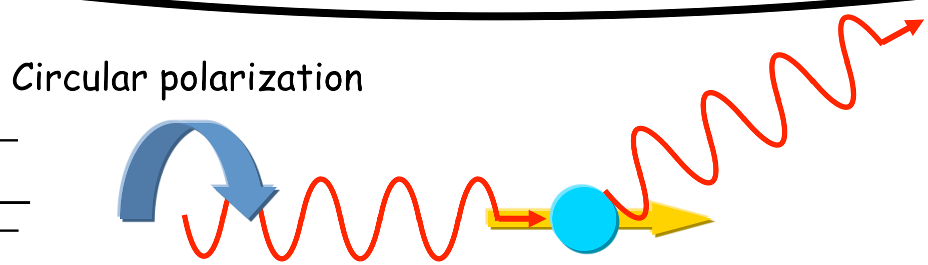

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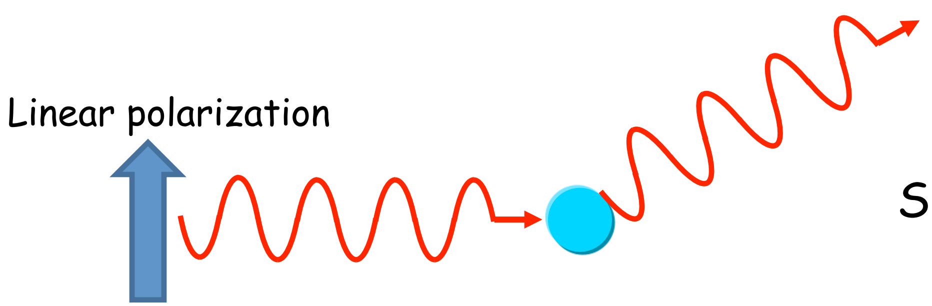
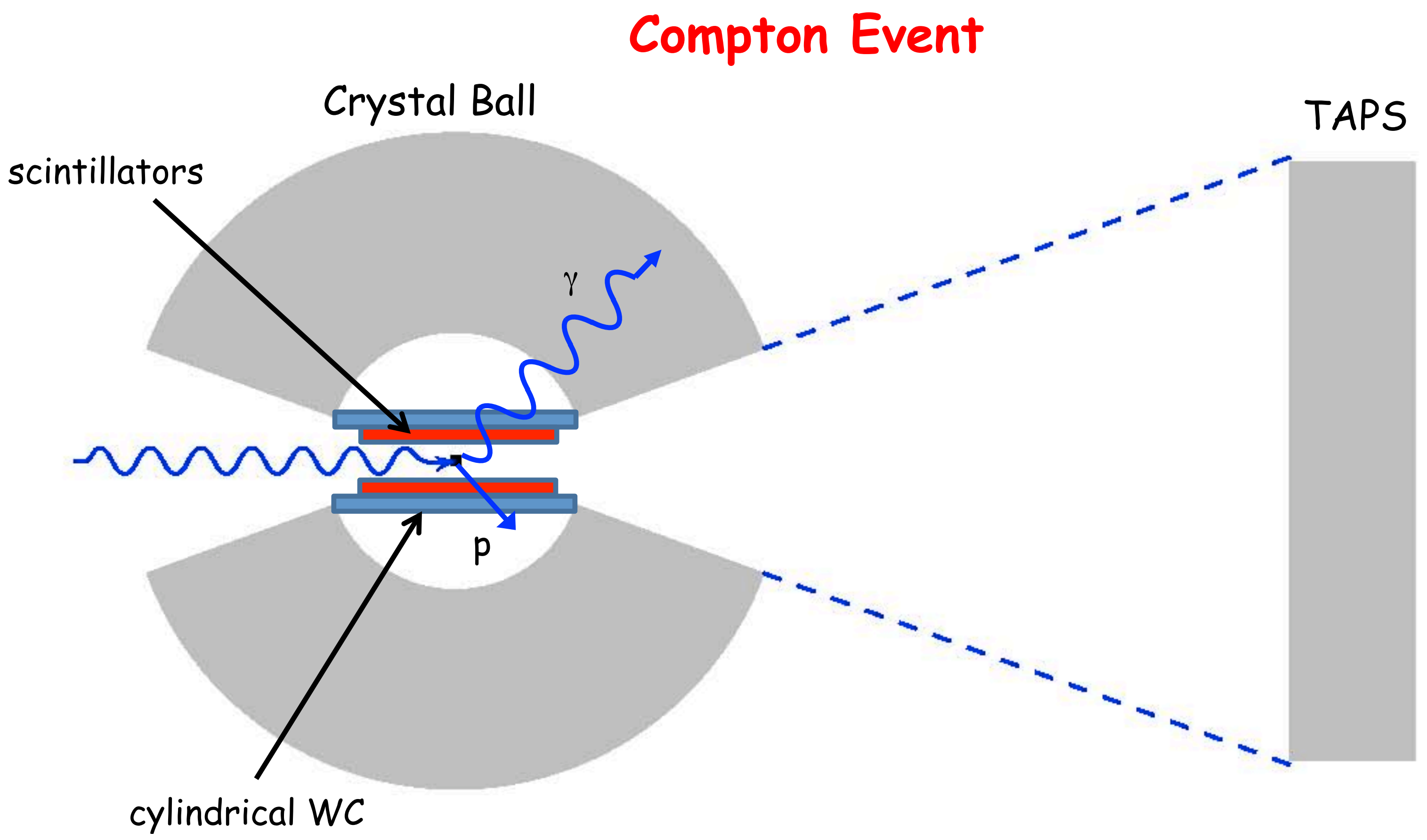


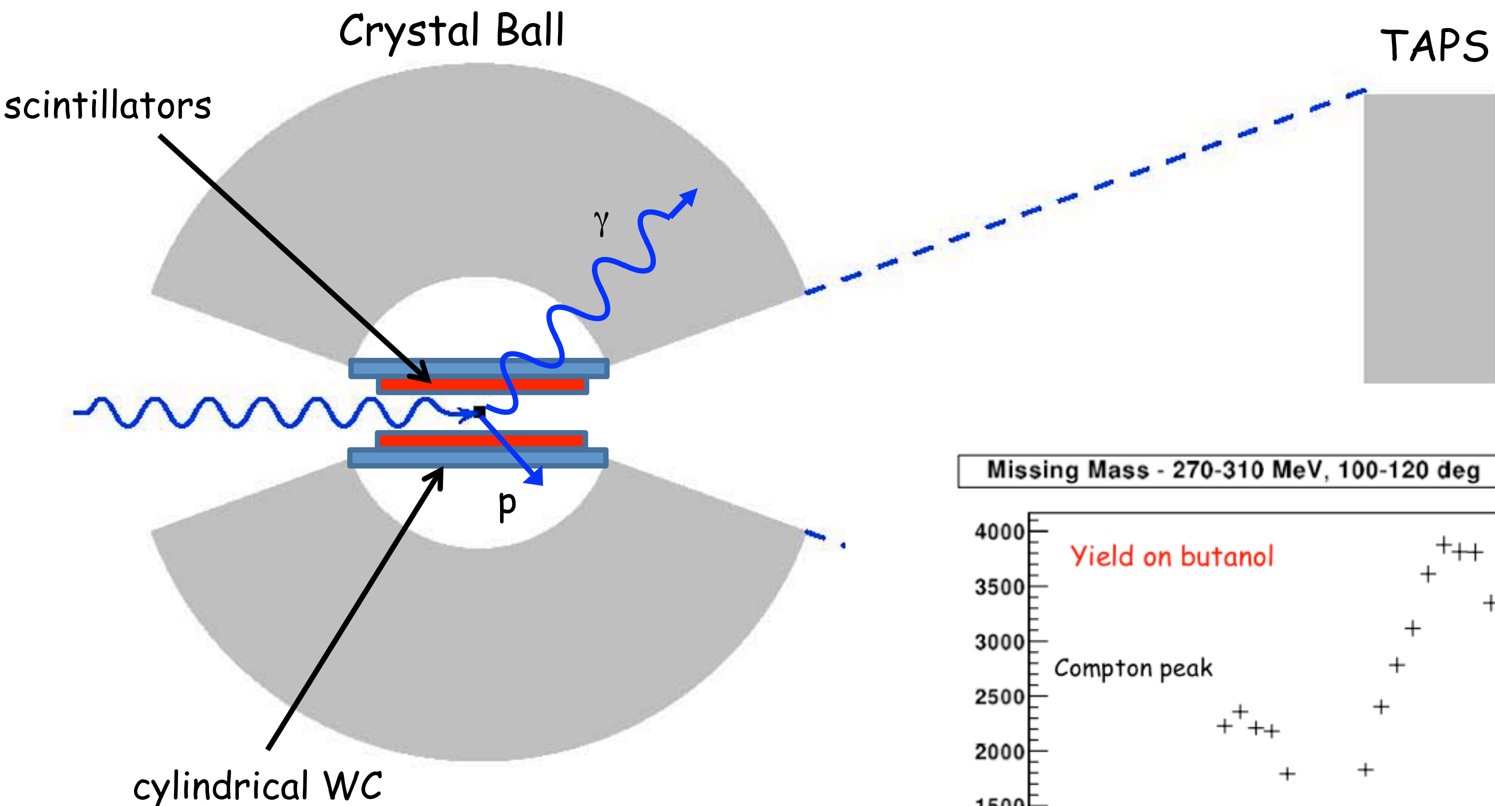
Sensitive to γ_{M1M1}

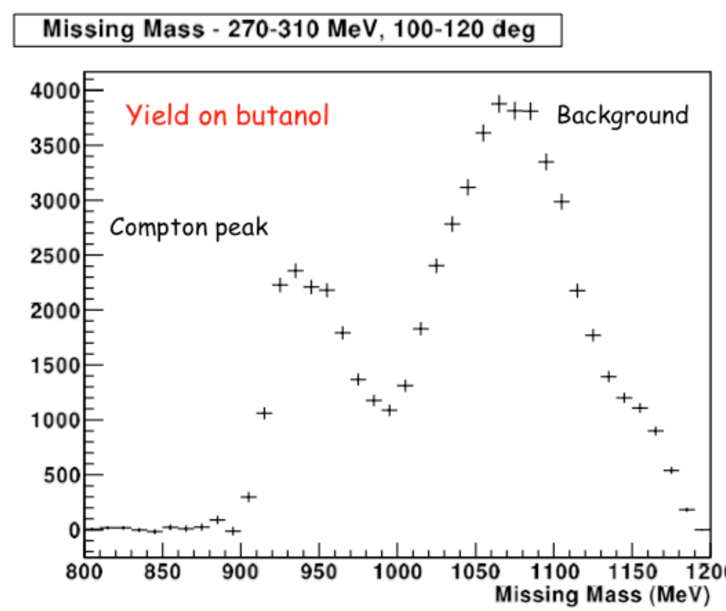
Event Selection



Event Selection

Compton Event





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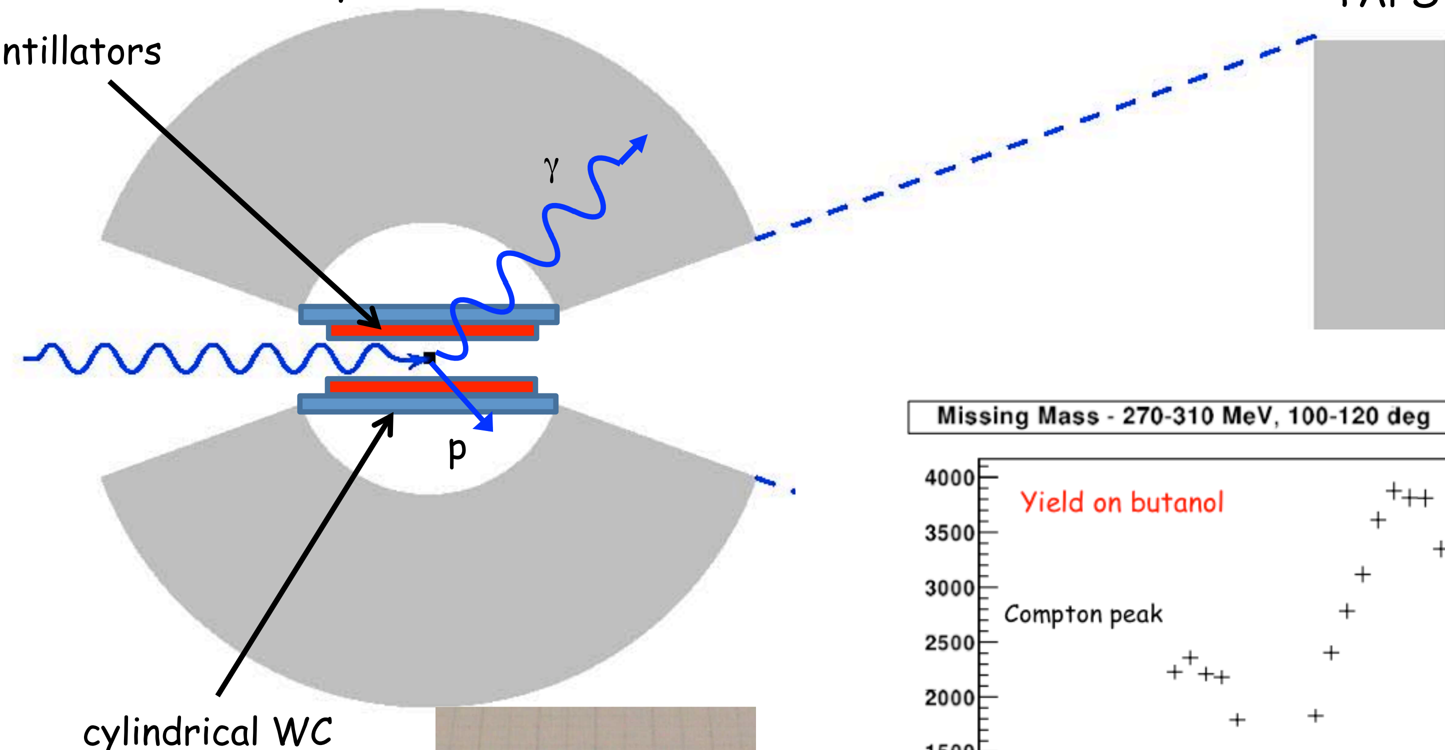
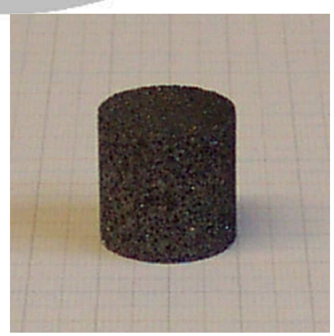
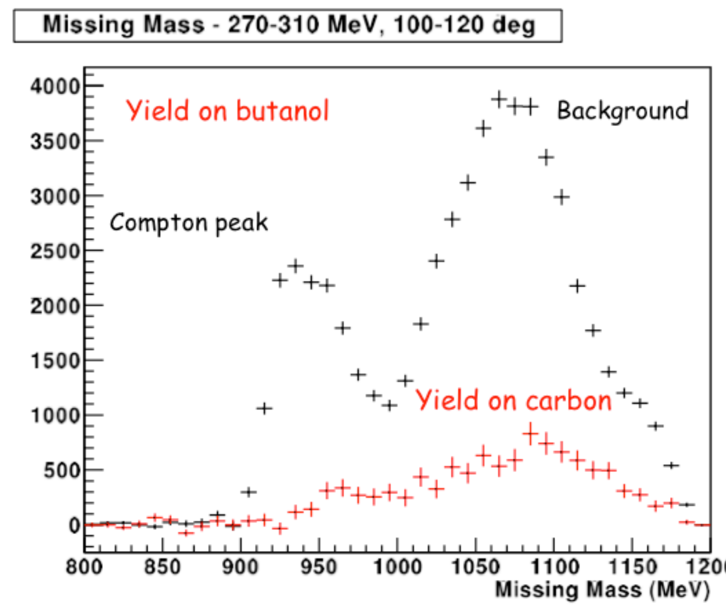


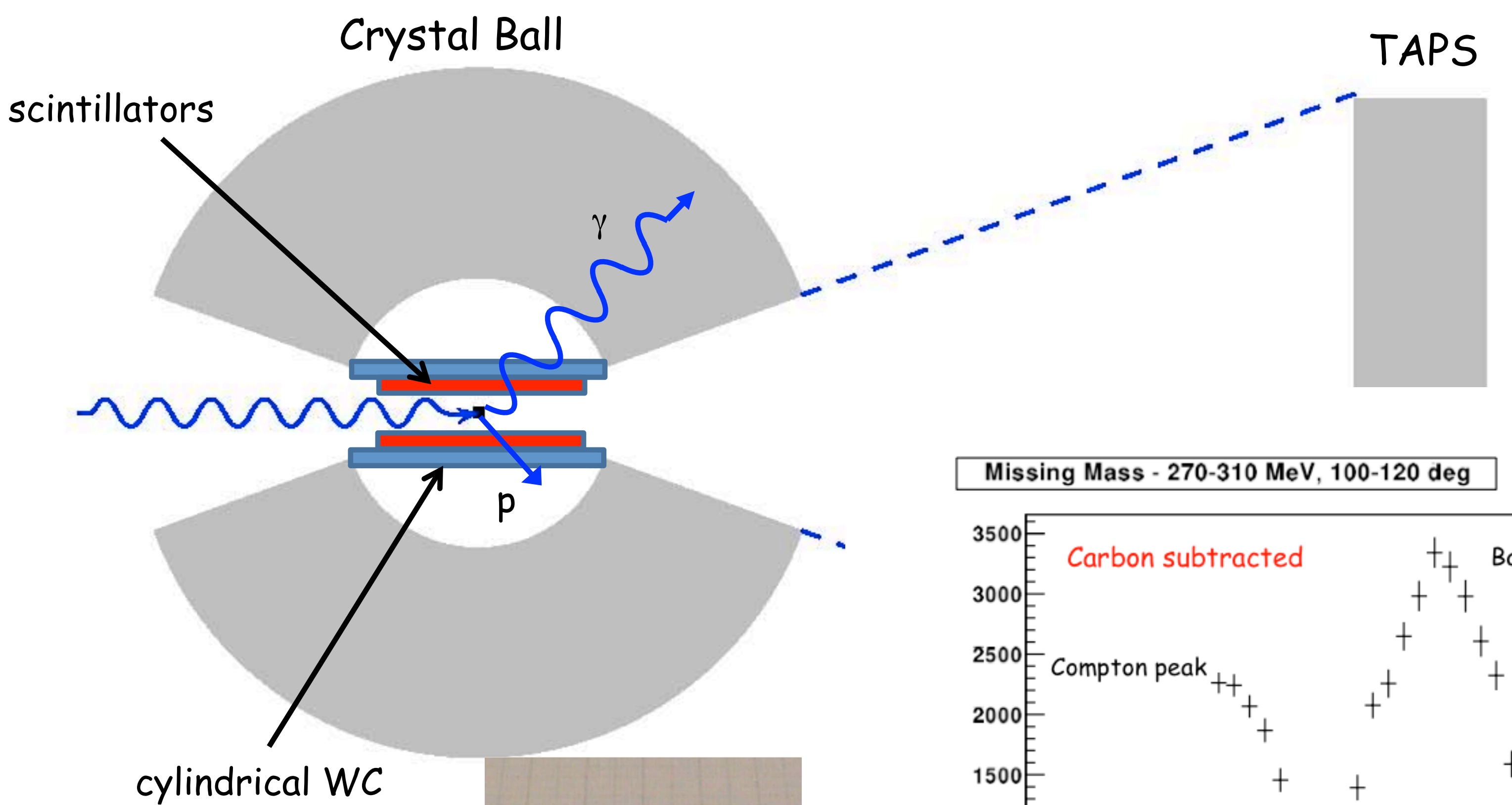
Carbon foam target has same density as CNO in butanol





Event Selection

Compton Event



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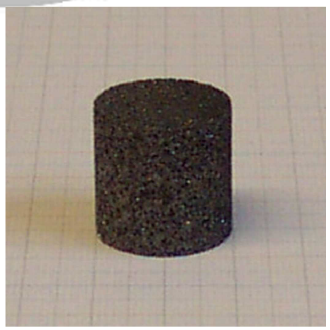
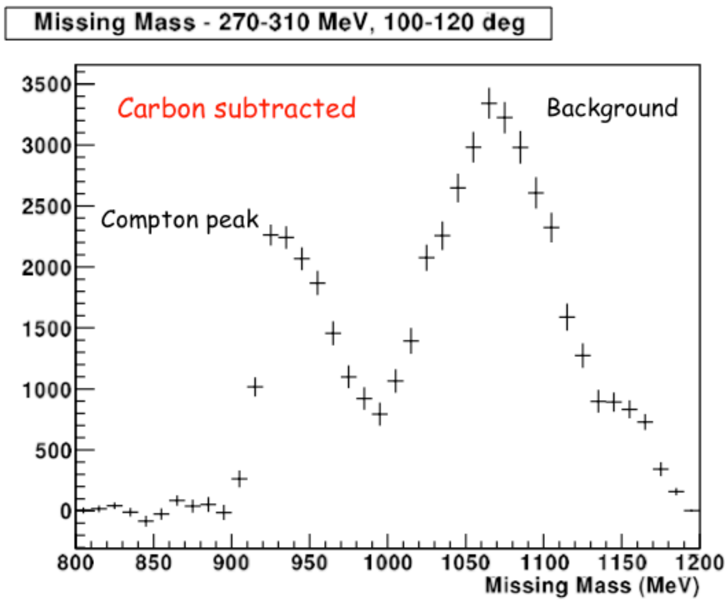
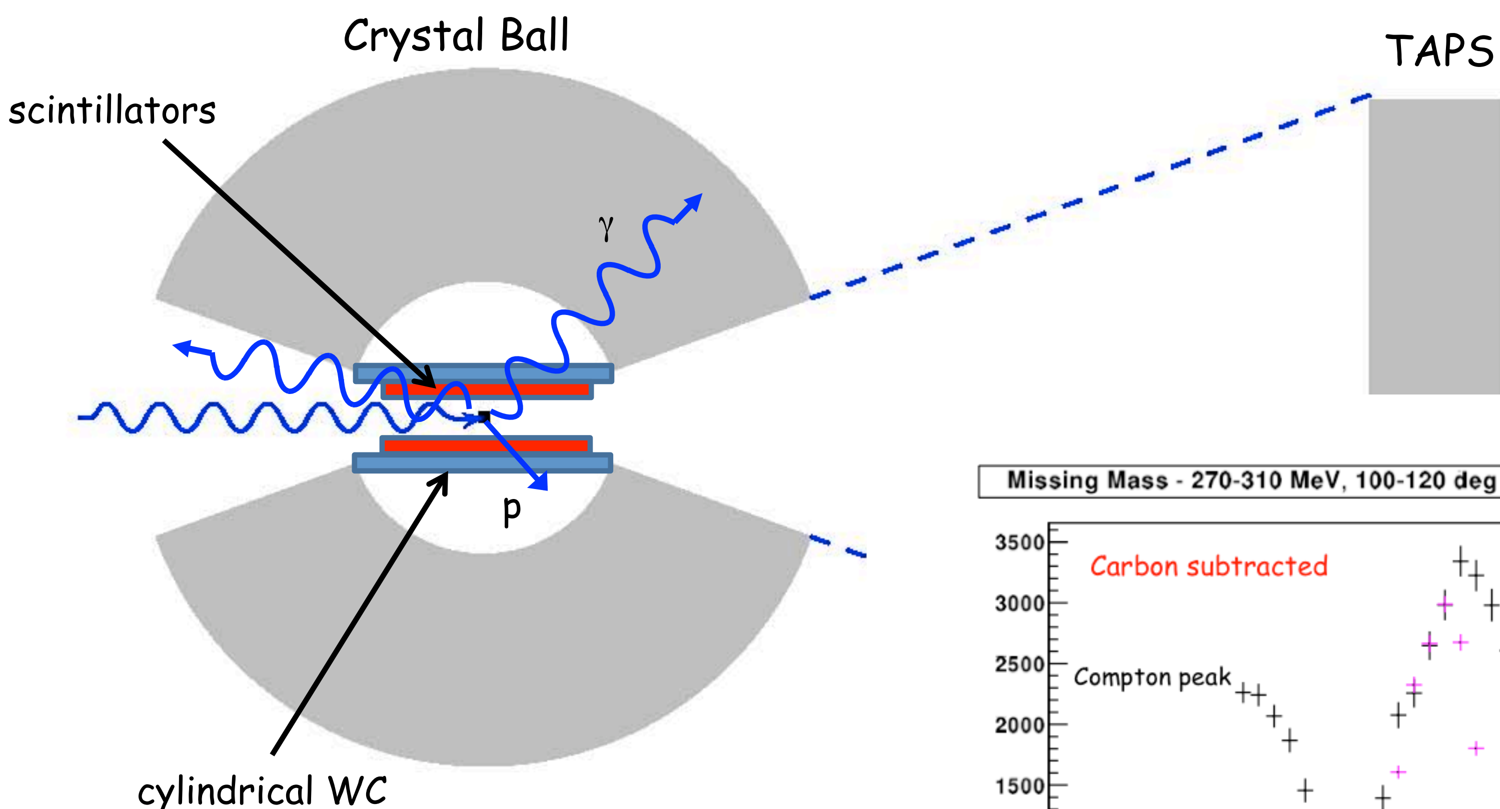


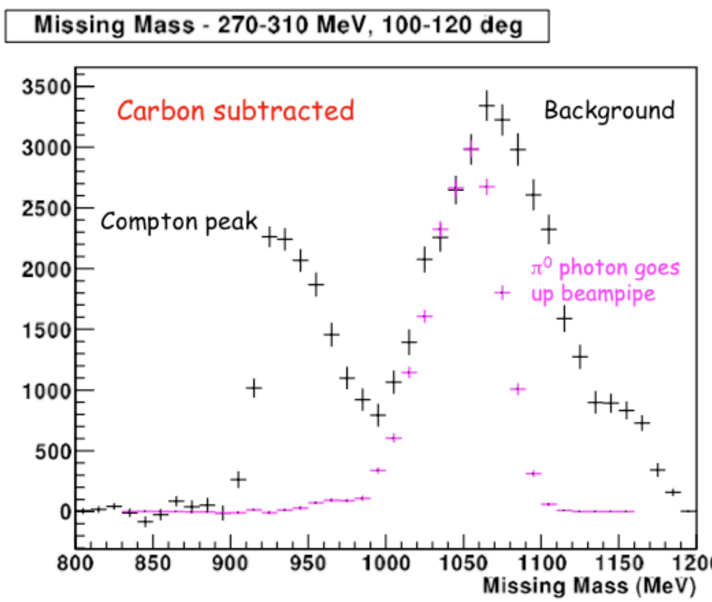


Event Selection

π^0 Event

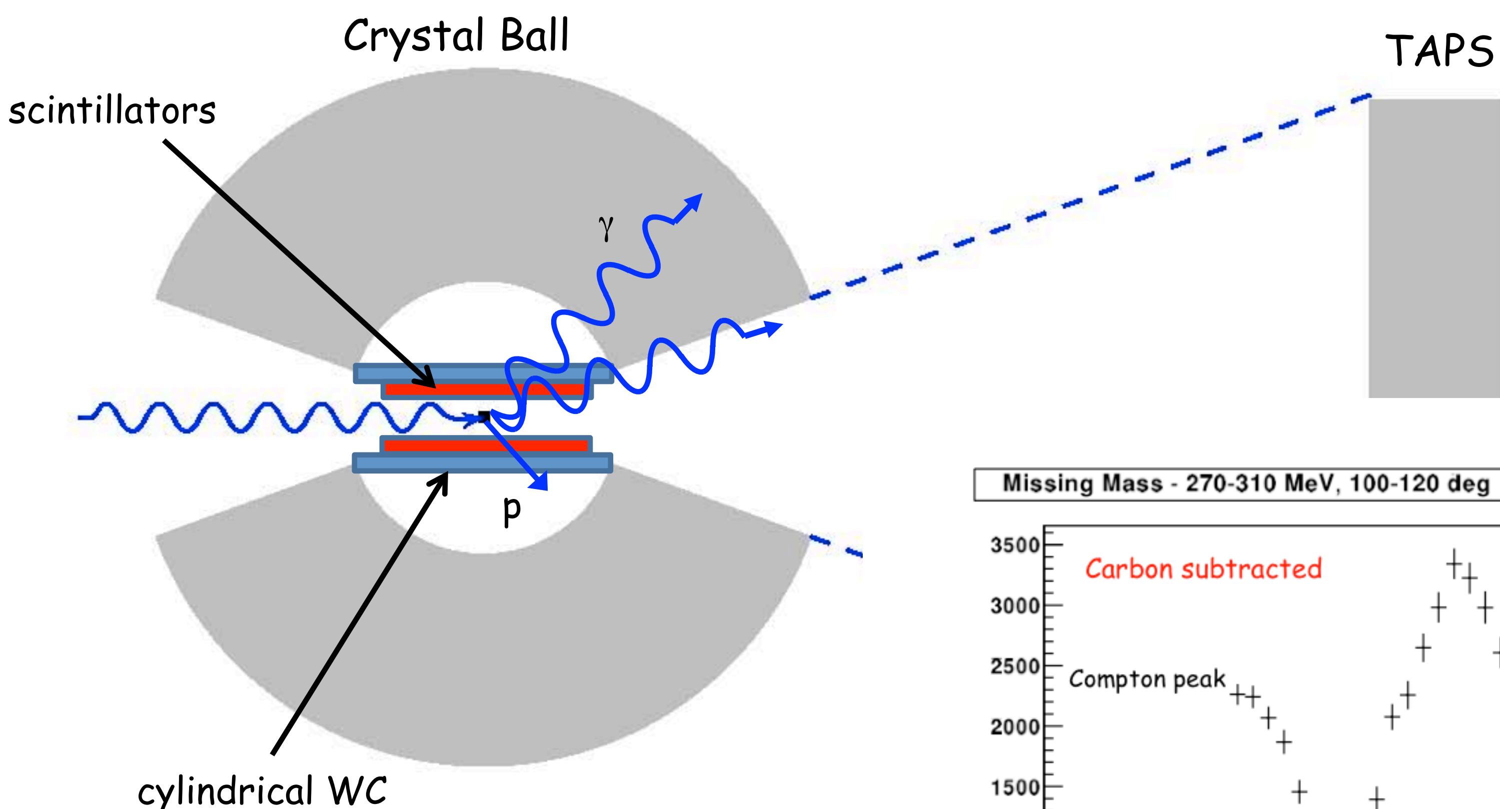


$$\frac{\sigma(\gamma p \to \gamma p)}{\sigma(\gamma p \to \pi^0 p)} \approx \frac{1}{100}$$



Event Selection

π^0 Event



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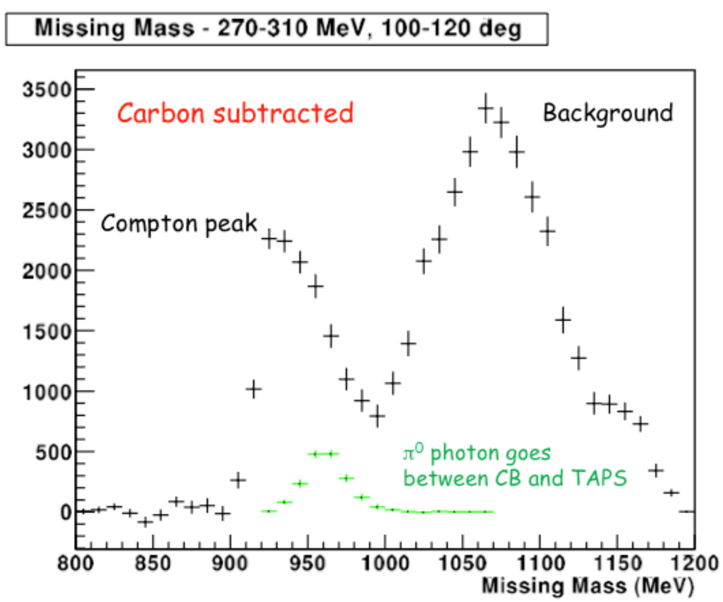
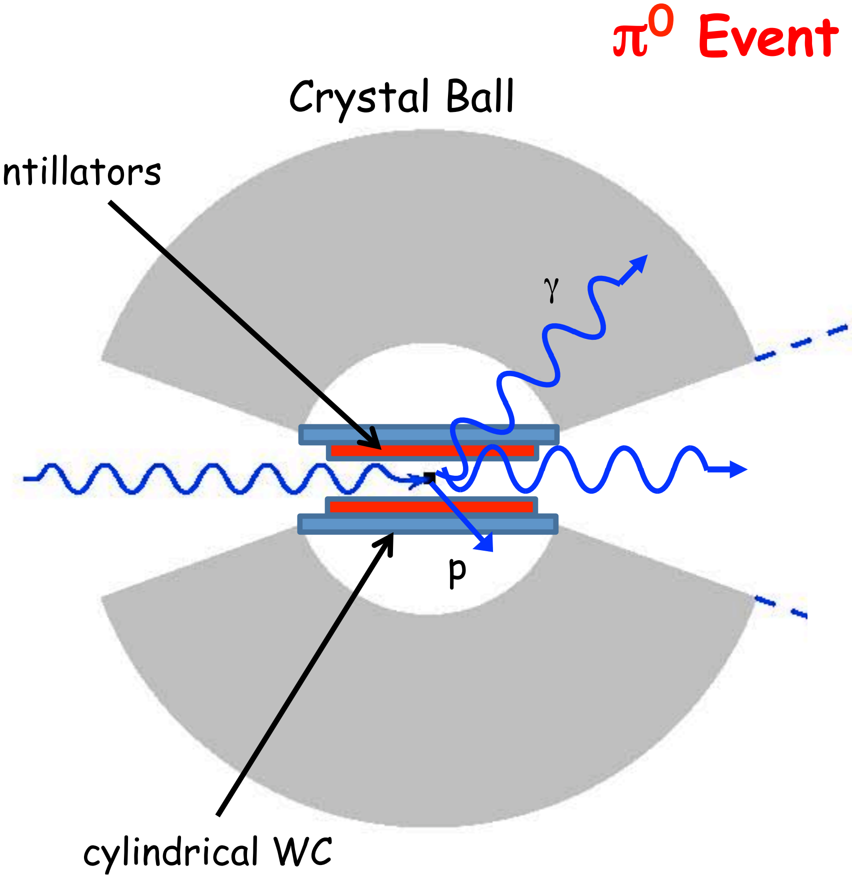


Event Selection



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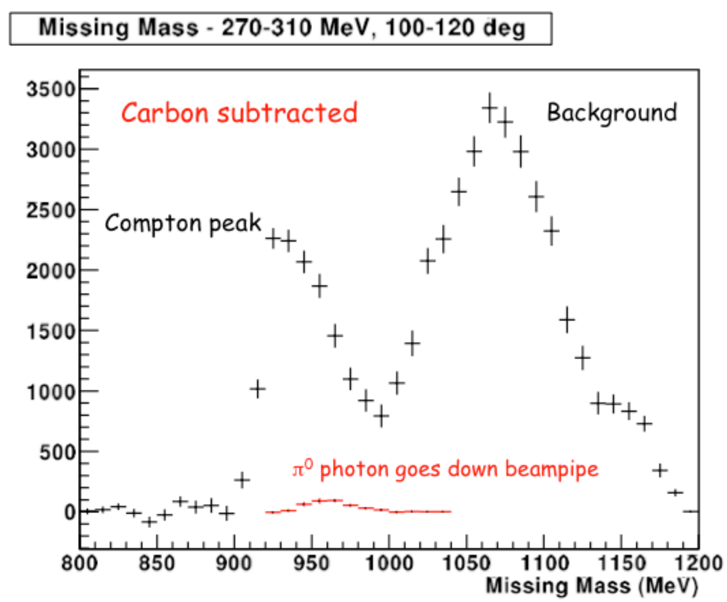
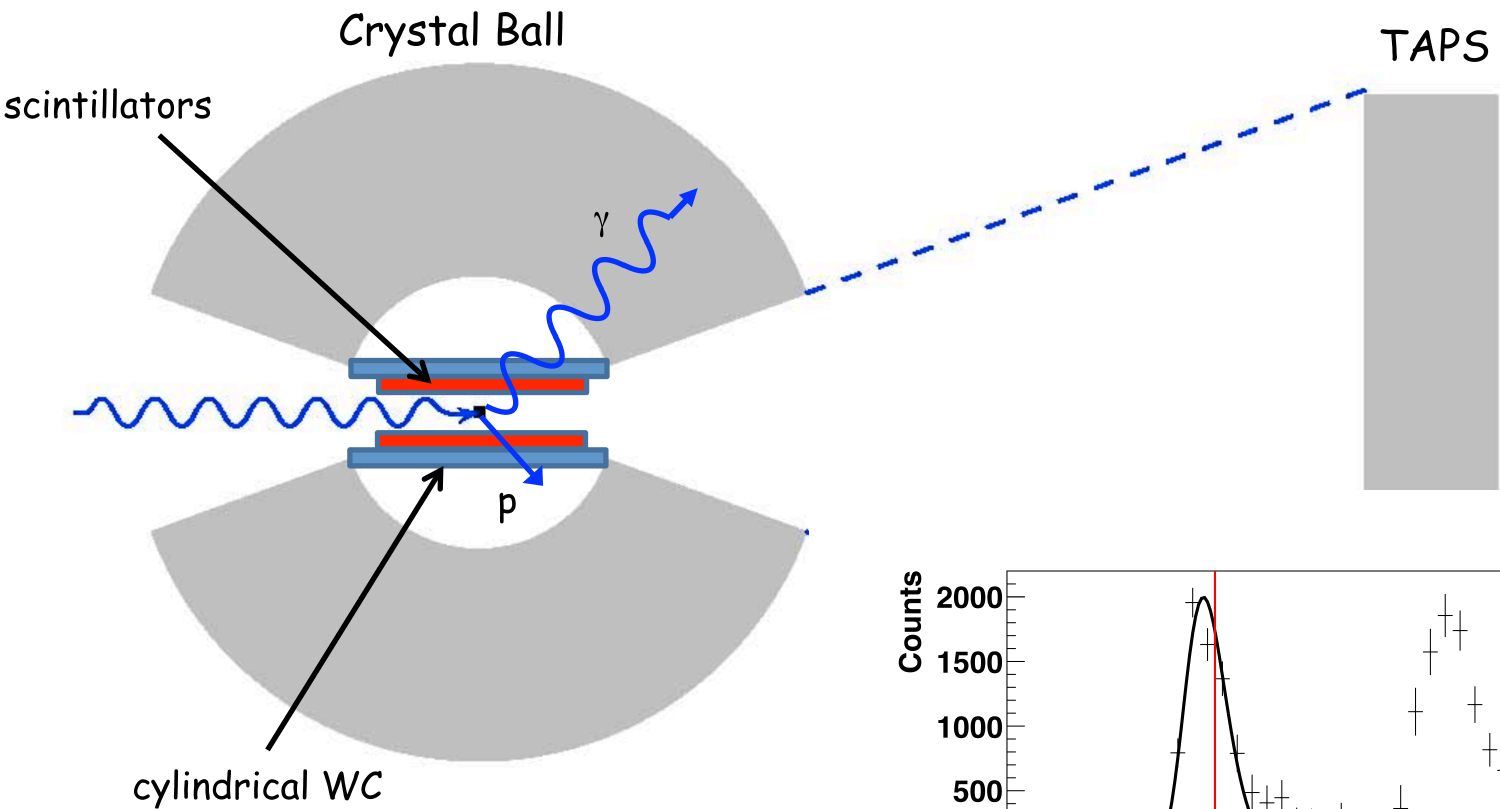
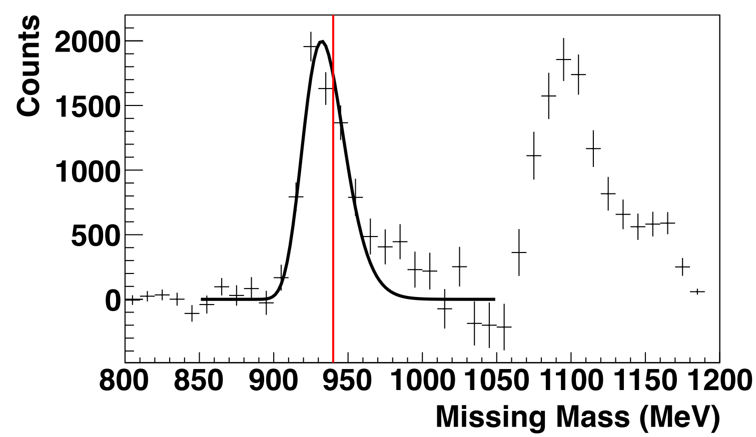


Event Selection

Compton Event





Good match to simulated Compton distribution.

The forward and backward spin polarizabilities

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

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

$$\gamma_0 = \lim_{Q^2 \to 0} \frac{16\alpha M^2}{Q^6} \int_0^1 x^2 \left[g_1(x,Q^2) - \frac{4M^2}{Q^2} x^2 g_2(x,Q^2) \right] dx$$

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

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

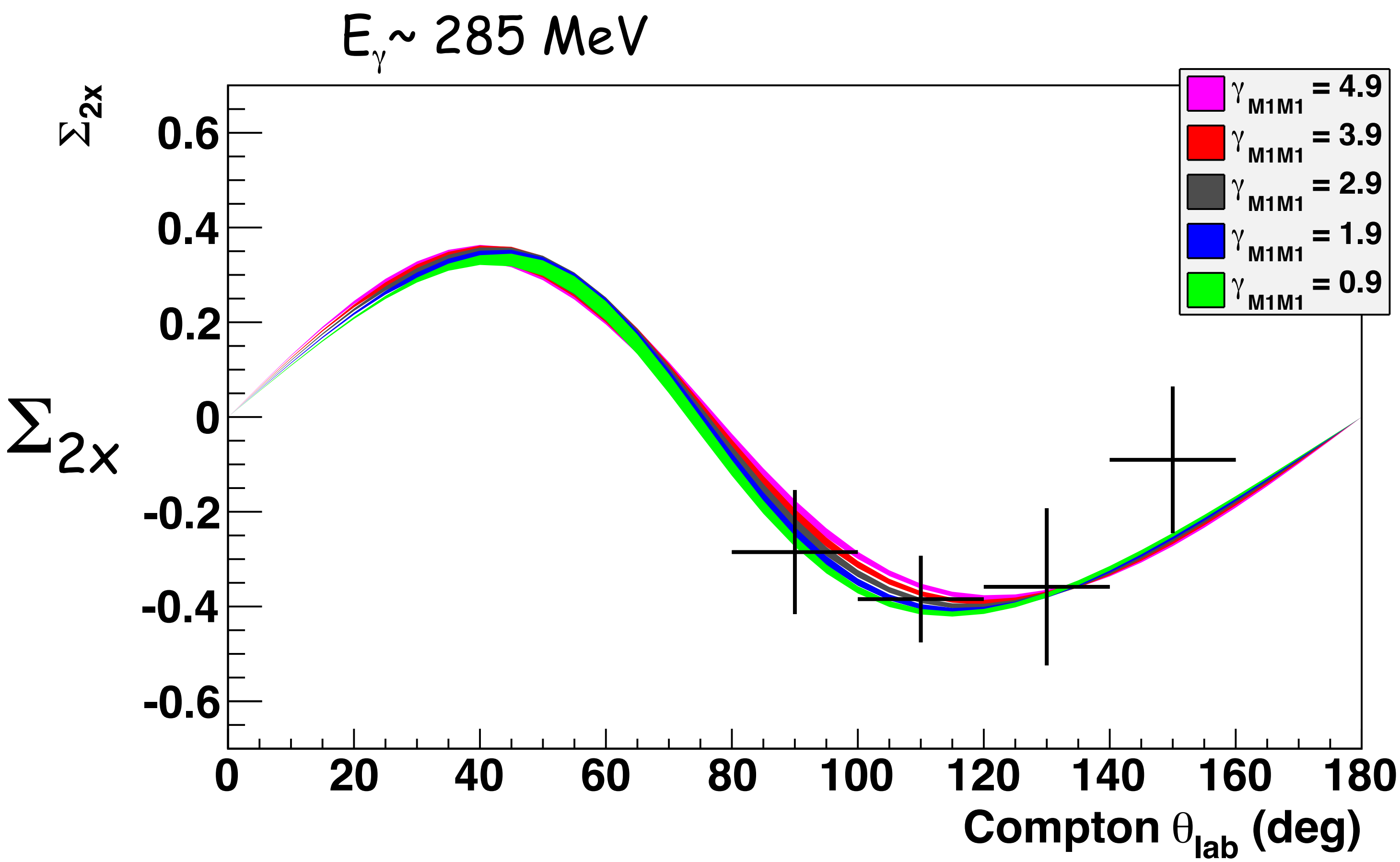
Backward spin polarizability from analysis of backward angle Compton scattering

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

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

The pion-pole contribution has been subtracted from γ_π

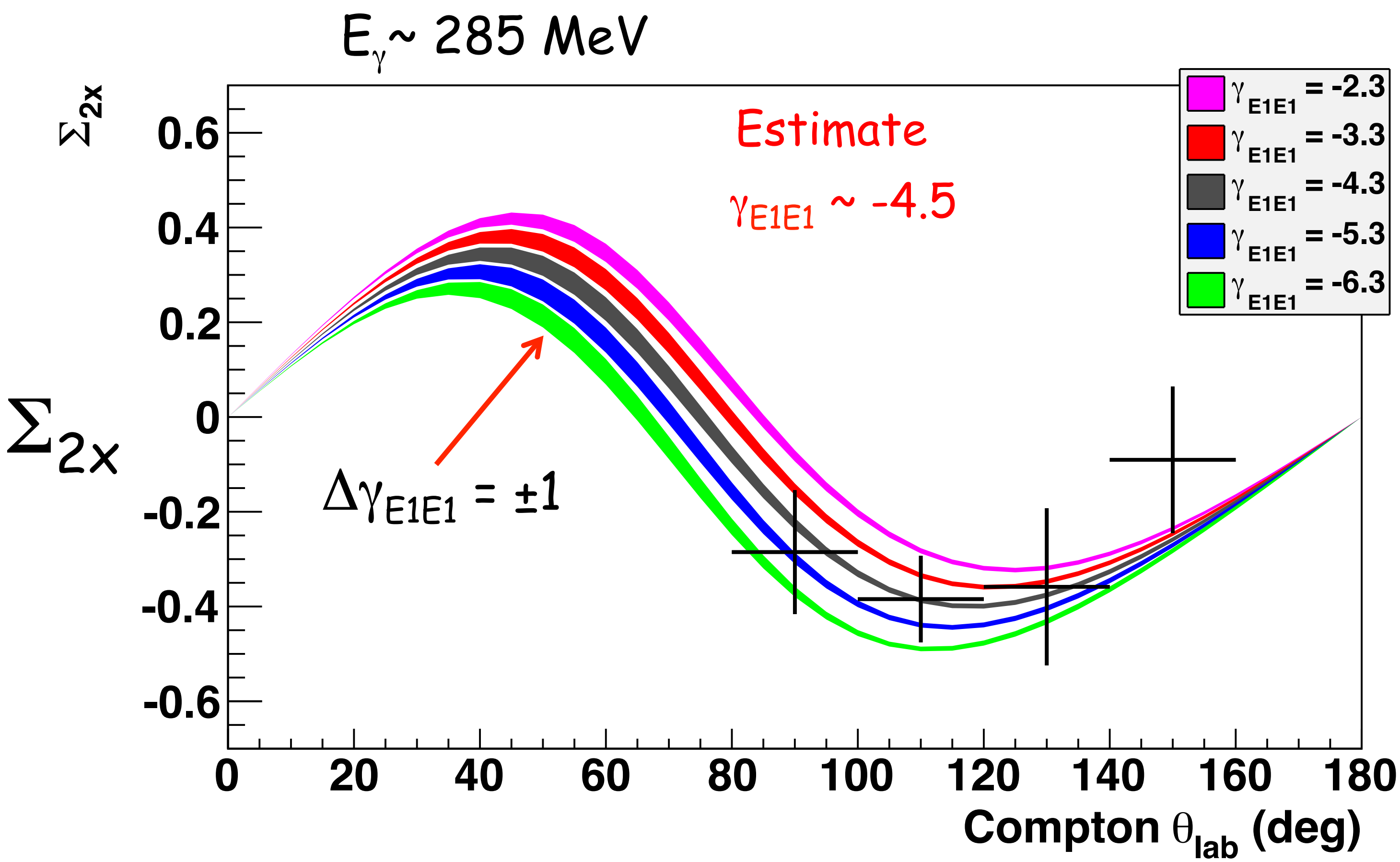
Transverse Butanol Target - Sep 2010/Feb2011



Vary γ_{M1M1}, holding γ_{E1E1} fixed. Little sensitivity to γ_{M1M1}

PhD, Phil Martel, Univ. of Massachusetts

Transverse Butanol Target - Sep 2010/Feb2011



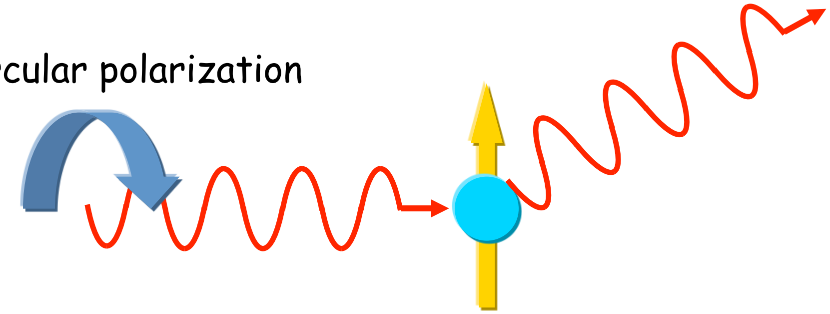
Vary γ_{E1E1}, holding γ_{M1M1} fixed. Good sensitivity to γ_{E1E1}

PhD, Phil Martel, Univ. of Massachusetts

Polarization observables for Compton scattering in the Δ region

Circular polarization

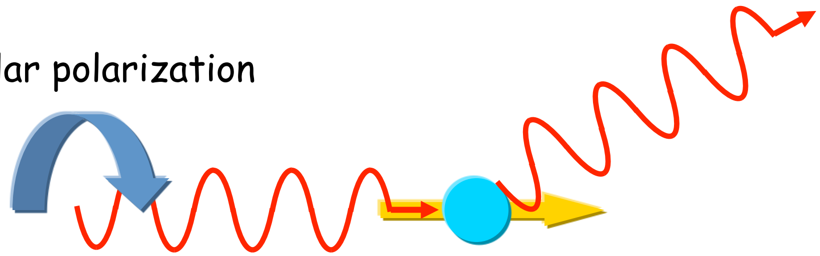
$$\Sigma_{2x} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$



Sensitive to γ_{E1E1}

Circular polarization

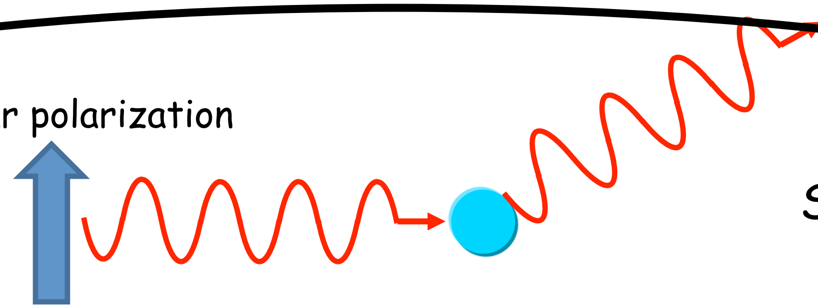
$$\Sigma_{2z} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$



Sensitive to γ_{M1M1} and γ_{π}

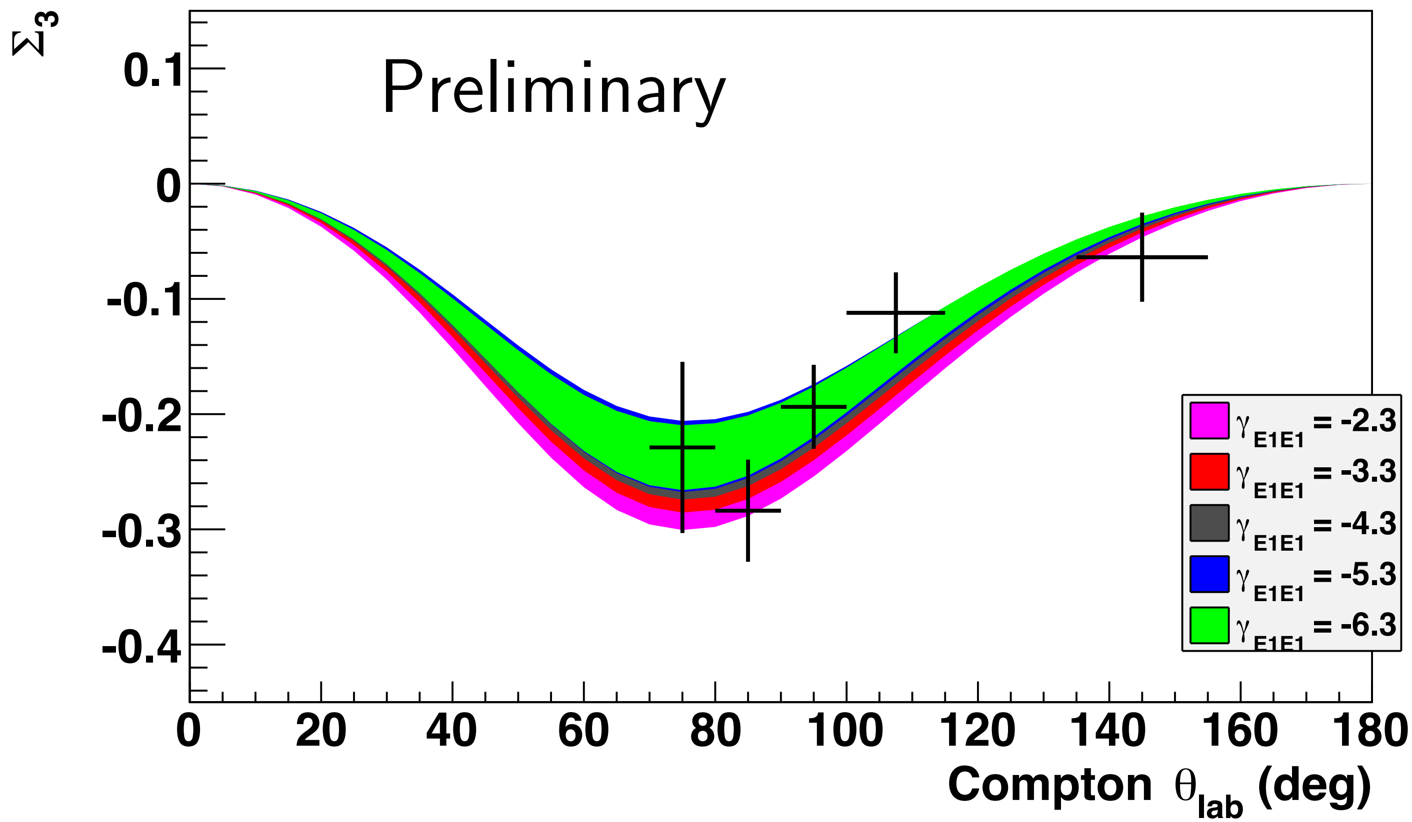
Linear polarization

$$\Sigma_{3} = \frac{\sigma^{\parallel} - \sigma^{\perp}}{\sigma^{\parallel} + \sigma^{\perp}}$$



Sensitive to γ_{M1M1}

Unpolarized Hydrogen Target - Dec 2012



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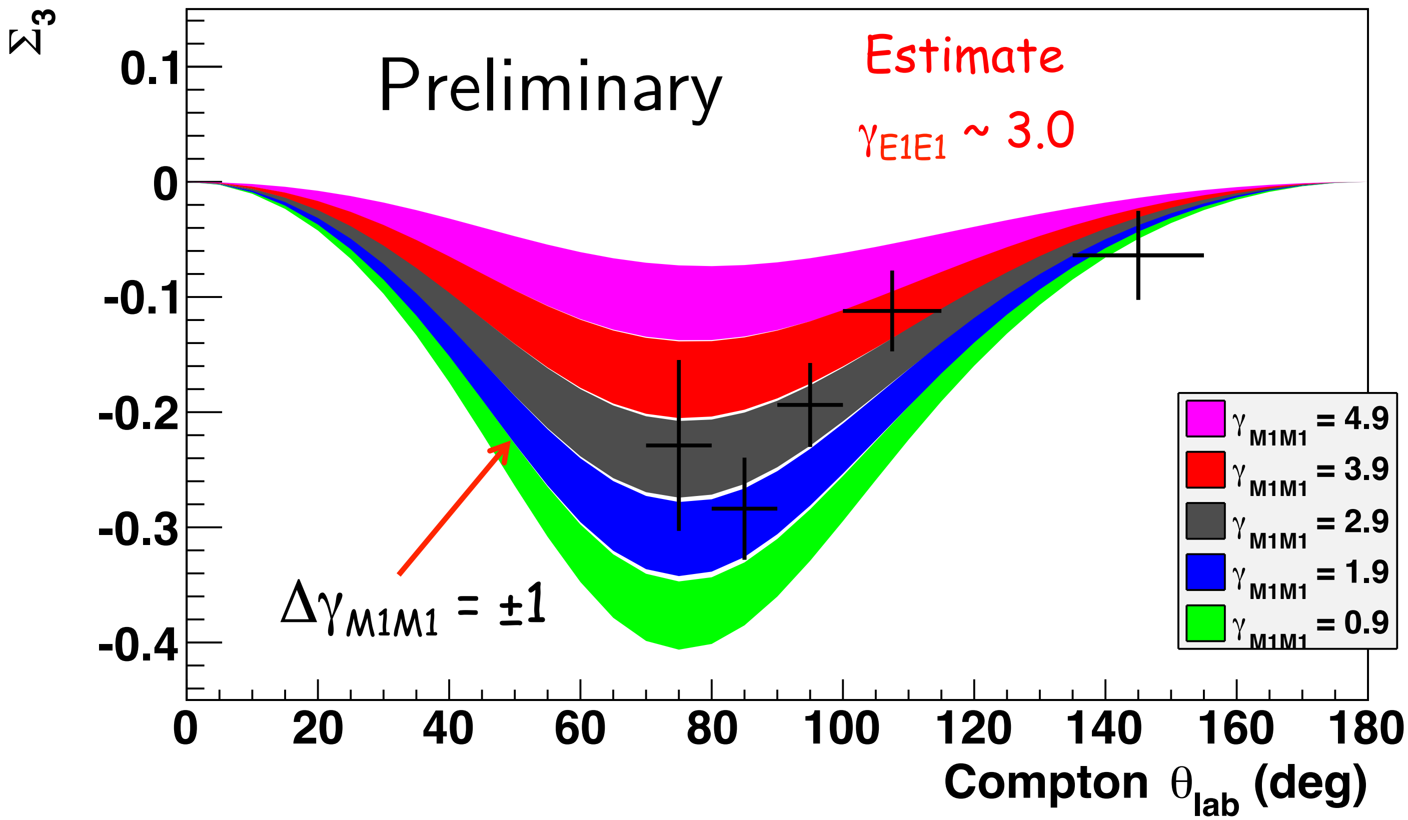
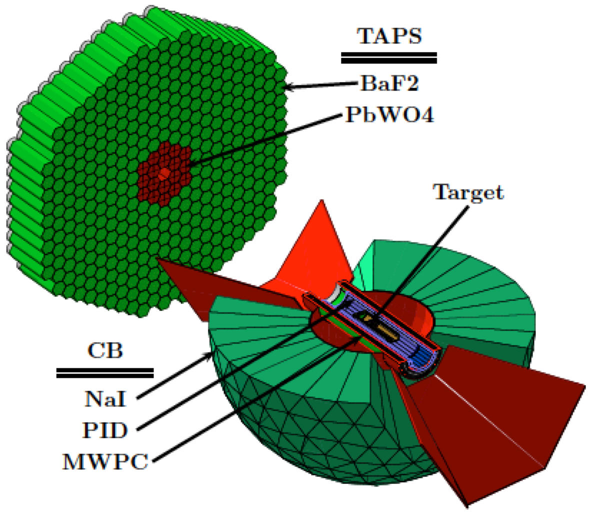
PhD, Cristina Collicott, Dalhousie University NS

Unpolarized Hydrogen Target - Dec 2012

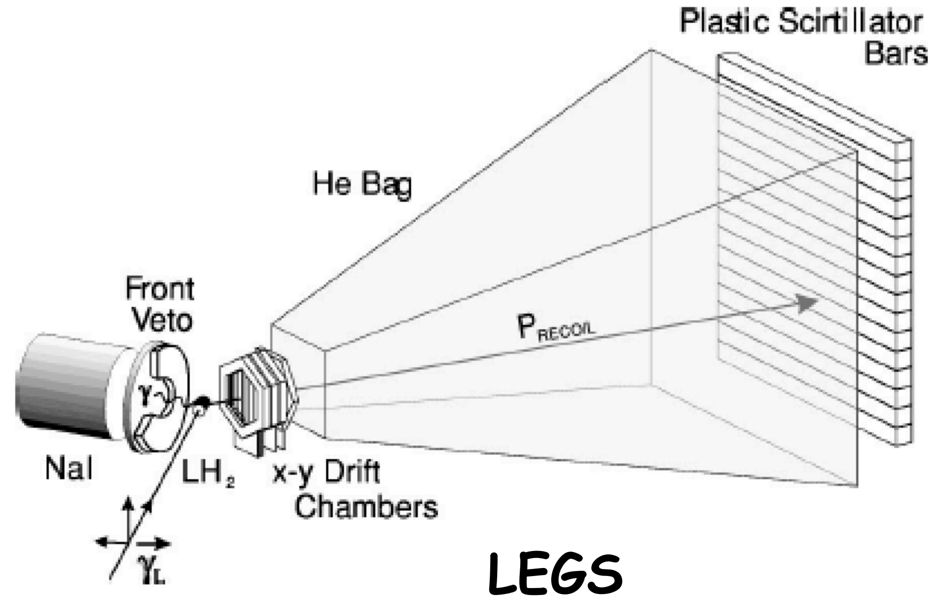


Vary γ_{M1M1}, holding γ_{E1E1} fixed. Good sensitivity to γ_{M1M1}

PhD, Cristina Collicott, Dalhousie University NS

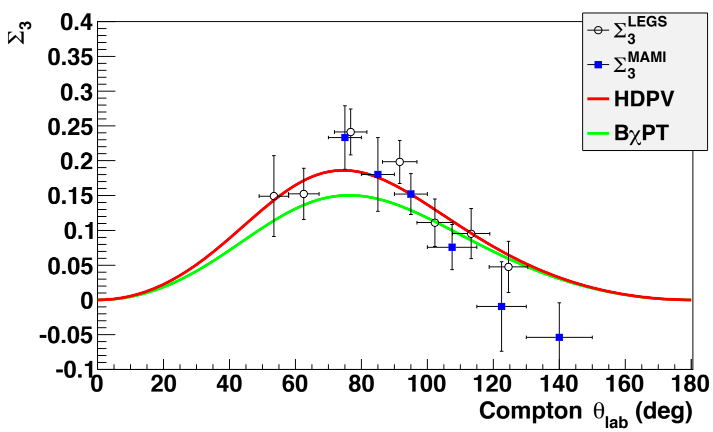


Mainz



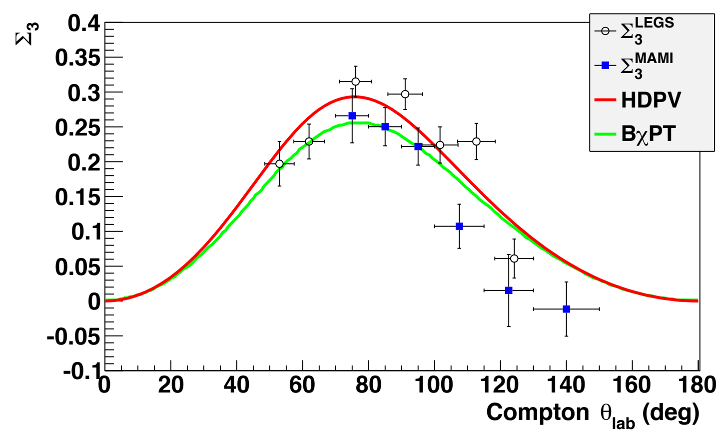
LEGS

Σ_3 - Dec 2012 - E_γ=267.0-287.2 MeV

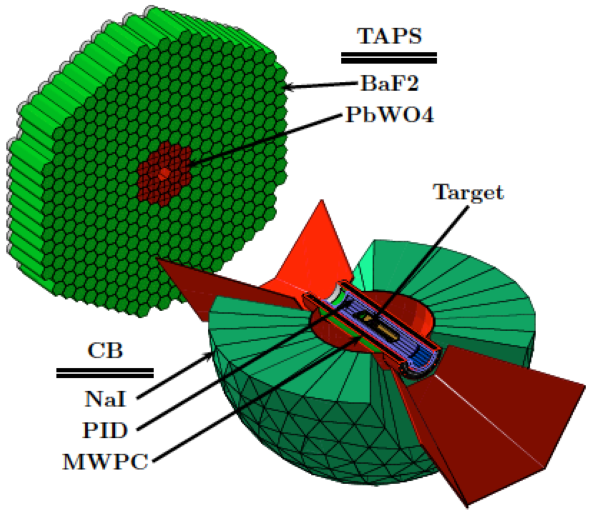


The recent (MAMI) and older (LEGS) Σ_3 measurements along with two theoretical curves using their preferred polarizabilities.

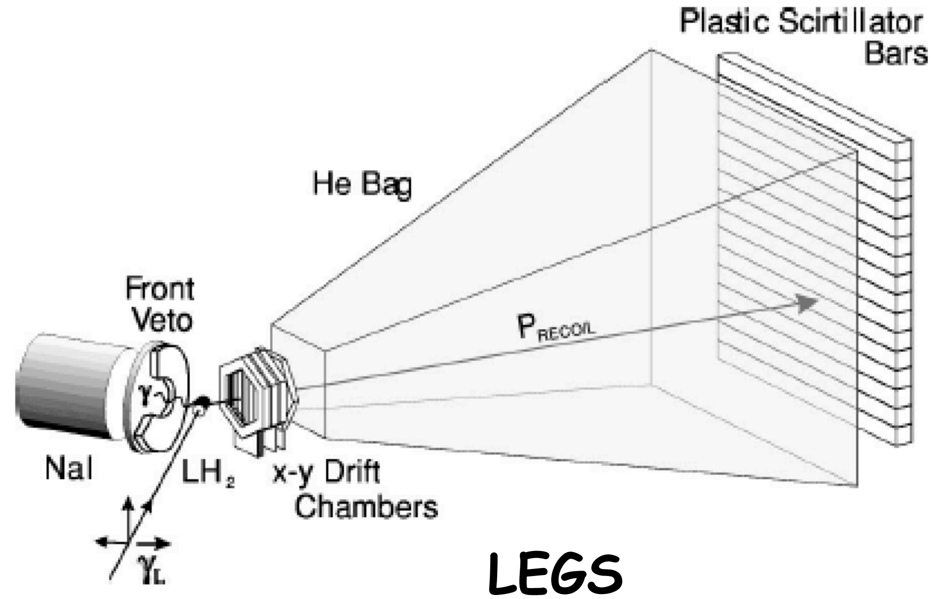
Σ_3 - Dec 2012 - E_γ=286.9-307.1 MeV



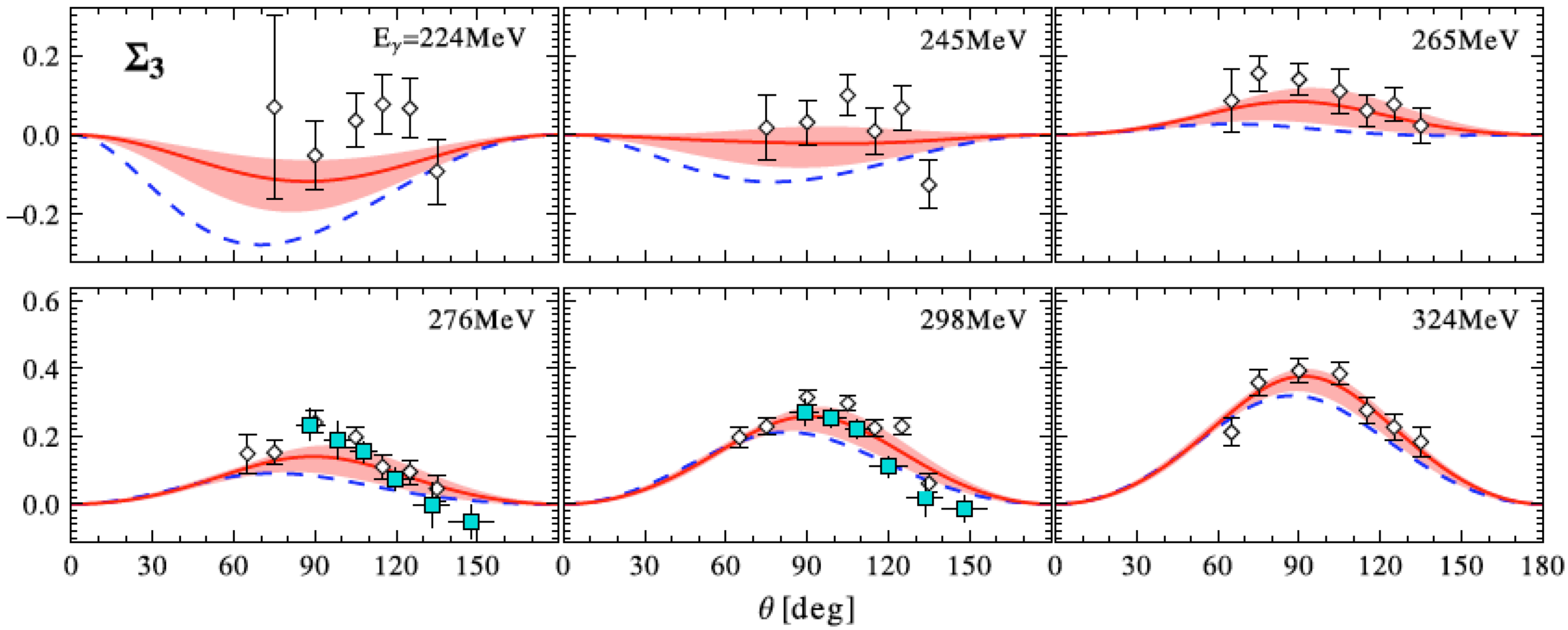
The recent (MAMI) and older (LEGS) Σ_3 measurements along with two theoretical curves using their preferred polarizabilities.


TAPS
BaF2
PbWO4
Target
CB
NaI
PID
MWPC

Mainz


Plastic Scintillator
Bars
He Bag
Front
Veto
P_{RECOIL}
NaI
LH_2
x-y Drift
Chambers
γ_L

LEGS


Σ_3
E_γ=224MeV
245MeV
265MeV
276MeV
298MeV
324MeV
0.2
0.0
−0.2
0.6
0.4
0.2
0.0
0 30 60 90 120 150 0 30 60 90 120 150 0 30 60 90 120 150 180
θ [deg]

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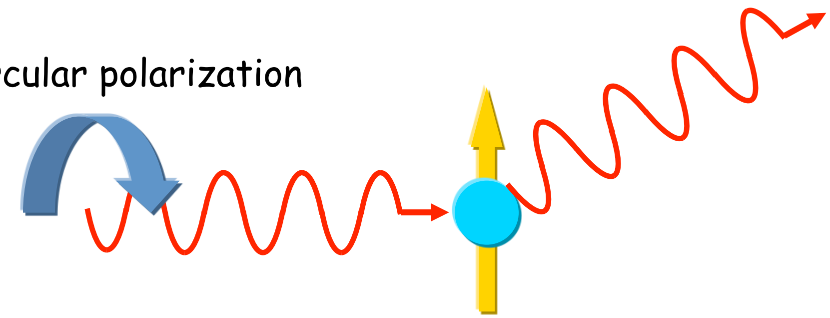
$$\Sigma_{2x} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

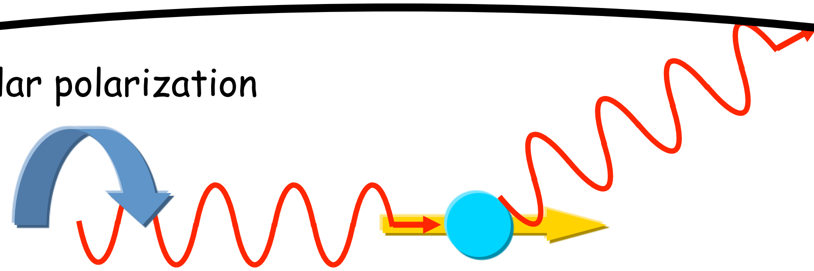
Circular polarization



Sensitive to γ_{E1E1}

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

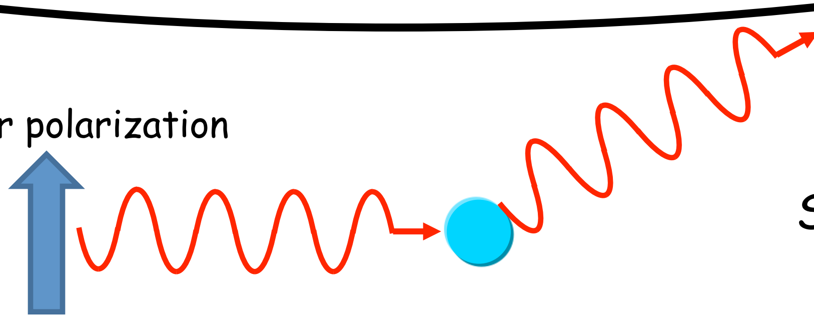
Circular polarization



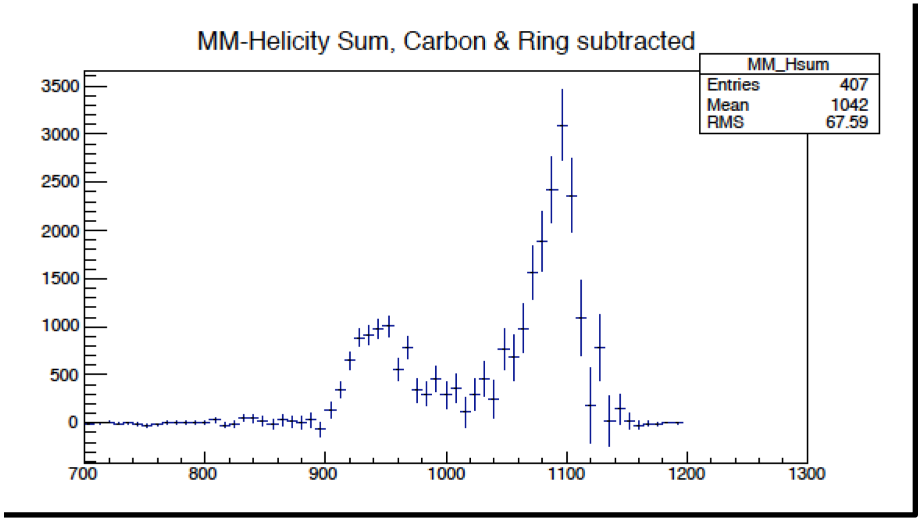
Sensitive to γ_{M1M1} and γ_{π}

$$\Sigma_{3} = \frac{\sigma^{\parallel} - \sigma^{\perp}}{\sigma^{\parallel} + \sigma^{\perp}}$$

Linear polarization

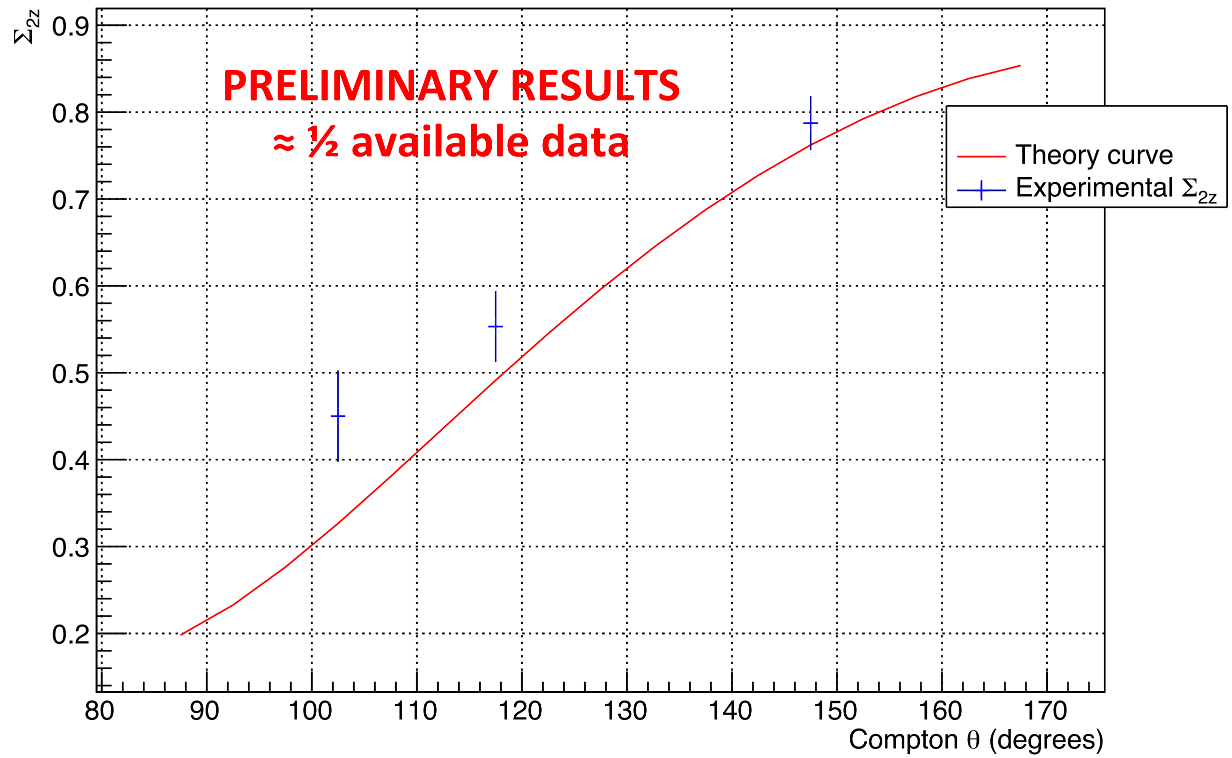


Sensitive to γ_{M1M1}



First Results for Σ_{2z}

Compton Σ_{2z}, Theory vs. Experiment



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Fitting Σ_{2x} (Mainz) and Σ_3 (LEGS) data using the Drechsel, Pasquini, Vanderhaeghen calculation

Martel et al., Phys. Rev. Lett., 114, 112501 (2015)

	$O(\varepsilon^3)$	$O(P^4)$	$O(P^4)$	K-matrix	Disp. theory HDPV	Disp theory DPV	L_χ	HBχPT	BχPT	Experiment
γ_{E1E1}	-1.9	-5.4	1.3	-4.8	-4.3	-3.8	-3.7	-1.1± 1.8 (th)	-3.3	**-3.72 ± .92**
γ_{M1M1}	0.4	1.4	3.3	3.5	2.9	2.9	2.5	2.2±.5 (st) ± .7 (th)	3.0	**2.90 ± .52**
γ_{E1M2}	0.7	1.0	0.2	-1.8	-.02	0.5	1.2	-.4± .4 (th)	0.2	**-.05 ± 1.07**
γ_{M1E2}	1.9	1.0	1.8	1.1	2.2	1.6	1.2	1.9± .4 (th)	1.1	**1.89 ± .50**
γ_0	-1.1	1.9	-3.9	2.0	-.8	-1.1	-1.2	-2.6	-1.0	**-1.01 ±0.08 ±0.10**
γ_π	3.5	6.8	6.1	11.2	9.4	7.8	6.1	5.6	7.2	**8.0± 1.8**

$O(\varepsilon^3)$ small scale expansion, Hemmert et al.
$O(p^4)$ χPT , Kumar et al., and Gellas et al.
K-matrix, Kondratyuk
Dispersion HDPV, Holstein et al.
Disperson DPV, Drechsel et al.
$L\chi$, Gasparyan et al.
HBχPT, McGovern et al.
BχPT, Lensky and Pascalutsa

Experiment confirms that:

i. γ_{E1E1} is negative, and $\gamma_{E1E1} \approx -3$

ii. γ_{M1M1} is positive and $\gamma_{M1M1} \approx -\gamma_{E1E1}$

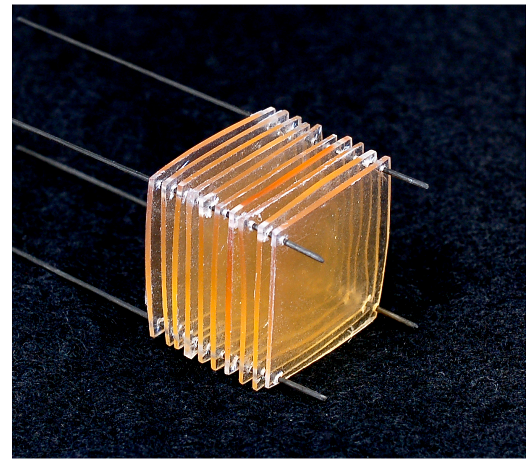
iii. γ_{E1M2} is smallest of SP's

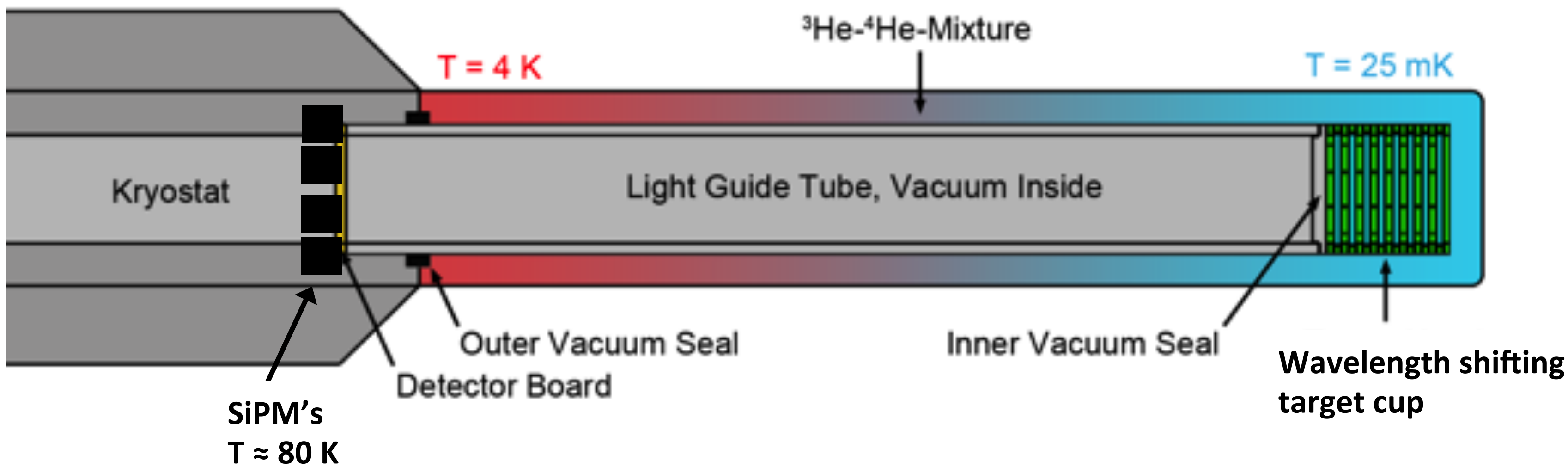
Development of a scintillating polarized target for Mainz

Needed for double-polarized Compton scattering measurements near pion threshold

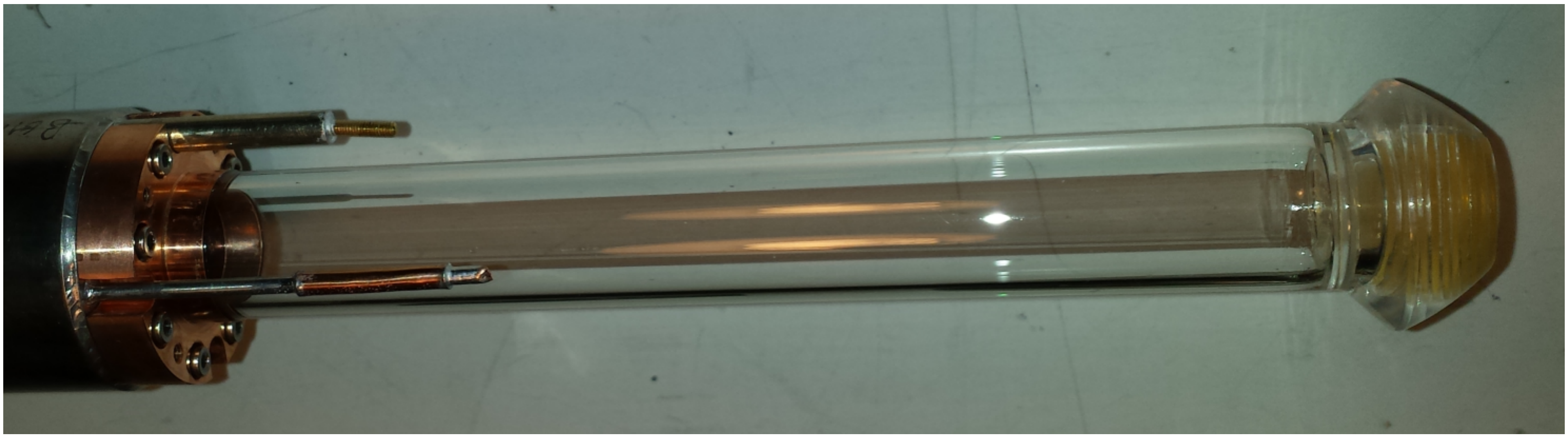
- **Polarizable scintillator developed at UMass**

✓ Proton polarization ≈ 70%
✓ Relaxation time ≈ 22 hours
✓ Light output ≈ 30% of standard plastic scintillator
✓ High clarity for thicknesses up to 1 mm



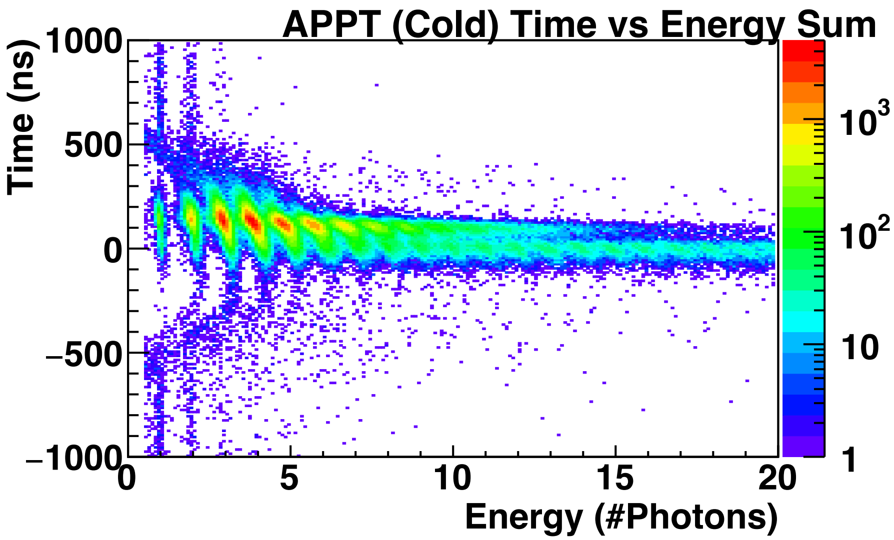


Target assembly

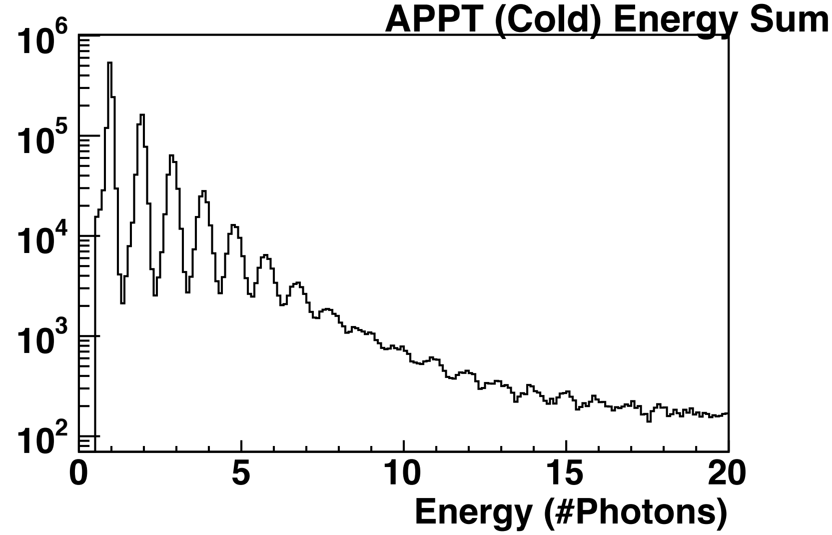


PhD, Maik Biroth, Mainz

Beam test in A2



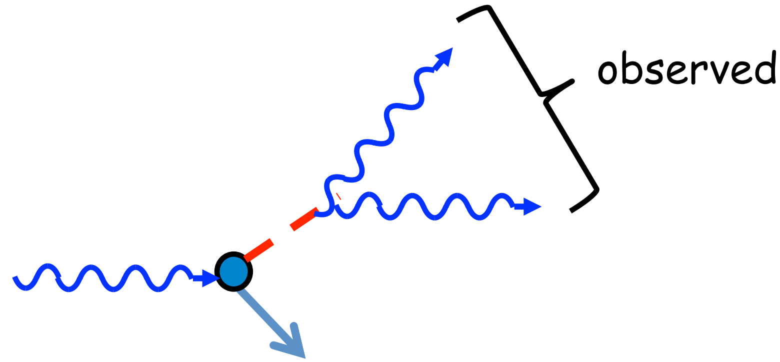
Coincidence with π^0 in the Crystal Ball



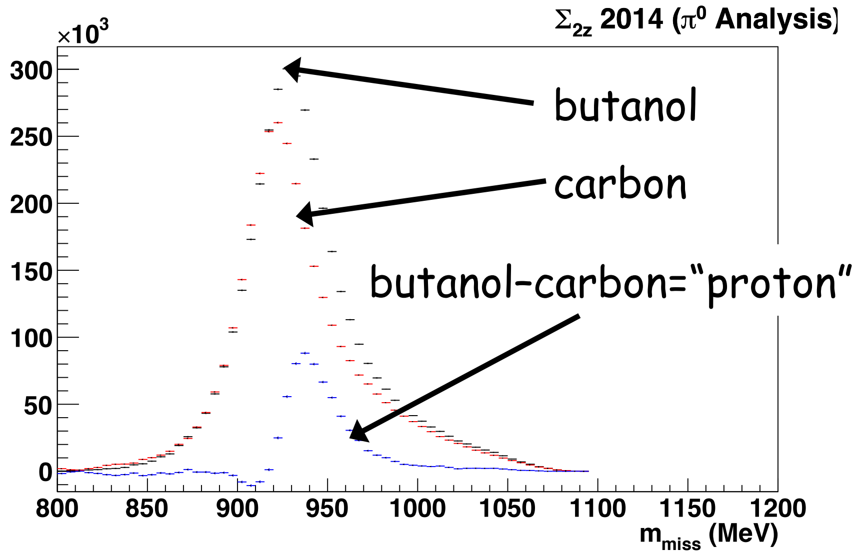
Light output of the target

From P. Martel

π^0 analysis with active target

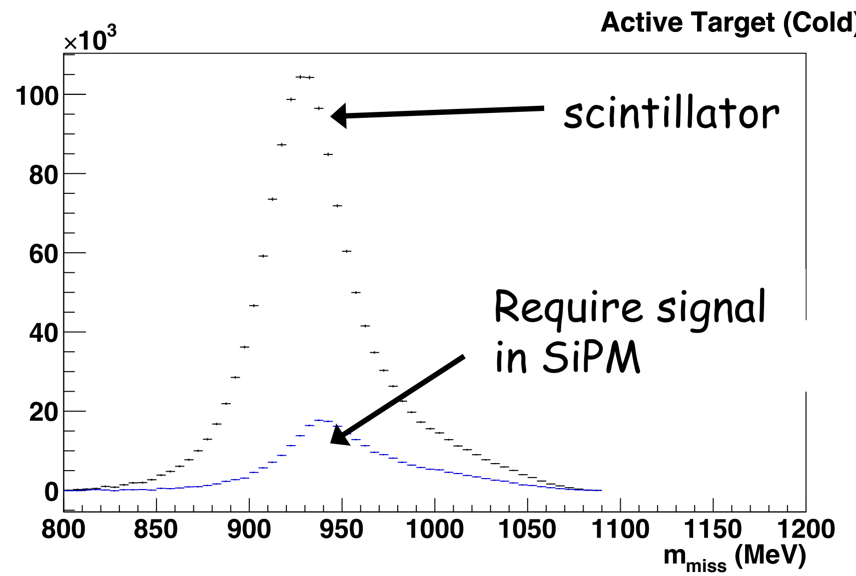


"Standard" π^0 butanol analysis



Missing mass

Active target



Missing mass

Plans for the near future:

- Further studies with the active, polarized target
- Running with linear polarized photons on LH_2 target, Σ_3
  - Δ region: spin polarizabilities
  - π threshold region: scalar polarizabilities, α and β

Thank you !

Especially M. Biroth, C. Collicott, P. Martel, and the A2 collaboration