Virtual Compton Scattering at MAMI: Polarization Experiments

Halifax, July 16th, 2003

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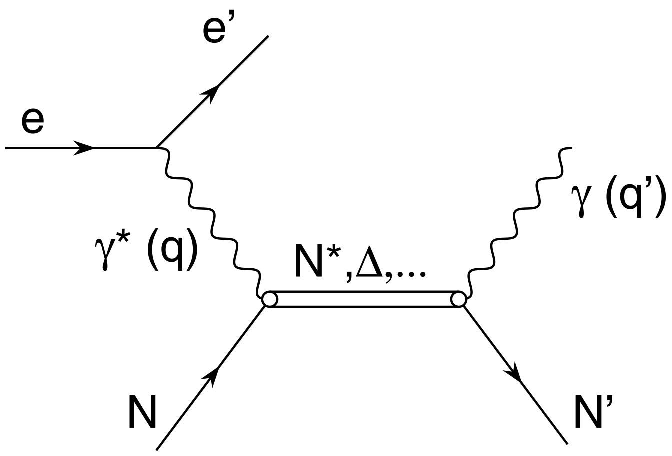
A1 Collaboration

- Introduction
  - Unpolarized VCS
- Double Polarization
  - Beam-Recoil observables
  - Design of MAMI experiment
- Experimental Check of Dispersion Relations
  - Model-dependent analysis of Cross Sections
  - Predictions for Beam Helicity Asymmetry
  - First test experiment
- Summary and Outlook

Virtual Compton Scattering



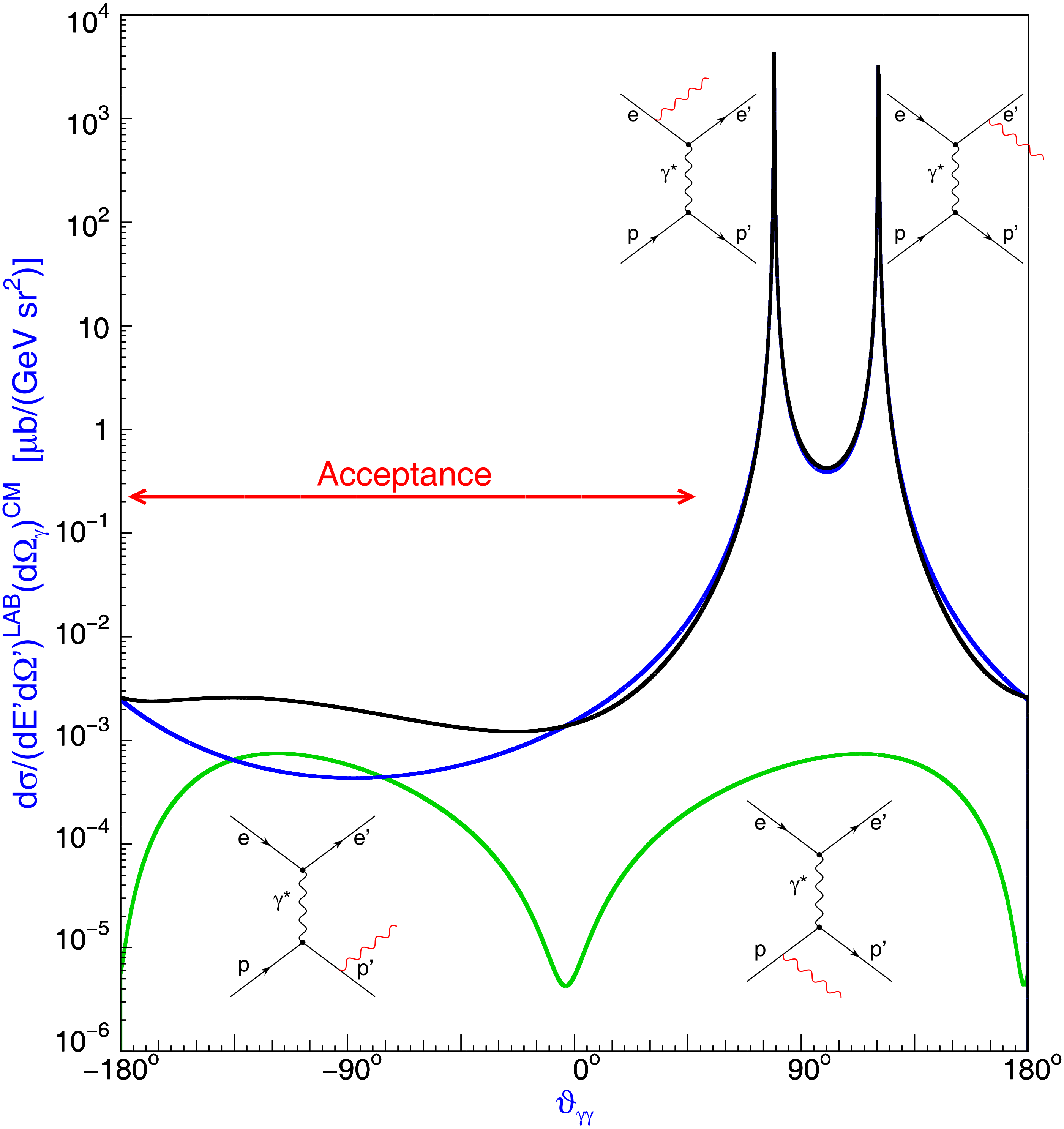
- Low energy expansion

$$\frac{d\sigma}{dE' d\Omega' d\Omega_\gamma^{cm}} = K \left(\frac{\mathcal{M}_{-2}^{BH+Born}}{q'^2} + \frac{\mathcal{M}_{-1}^{BH+Born}}{q'} + \mathcal{M}_0 + O(q') \right)$$

- Non-Born contribution in the limit $q' \longrightarrow 0$
- Multipole decomposition
- 10 (6 independent) Generalized Polarizabilities

VCS	EM transition		RCS	Resonance
$P^{(01,01)0}$	C1→E1	S=0	$-\frac{1}{\alpha}\sqrt{\frac{2}{3}}\,\alpha_E$	D13,S11
$P^{(11,11)0}$	M1→M1	S=0	$-\frac{1}{\alpha}\sqrt{\frac{8}{3}}\,\beta_M$	P33,P11
$P^{(01,12)1}$	M2→E1	S=1	$-\frac{1}{\alpha}\frac{\sqrt{2}}{3}\,\gamma_3$	D13
$P^{(11,02)1}$	C2→M1	S=1	$-\frac{1}{\alpha}\sqrt{\frac{8}{27}}\,(\gamma_2+\gamma_4)$	P33
$P^{(11,00)1}$	C0→M1	S=1	0	P11
$P^{(11,11)1}$	M1→M1	S=1	0	P33,P11

Bethe-Heitler and Born Amplitudes



Unpolarized VCS

$$\frac{d^5\sigma}{dE'd\Omega'd\Omega_\gamma^{cm}} = d^5\sigma^{BH+Born} + \phi q'\Psi_0(q,\varepsilon,\theta,\phi) + \phi O(q'^2)$$

- Unpolarized experiment:

$$\Psi_0 = v_1(\theta,\phi,\varepsilon)(P_{LL}(q^2) - P_{TT}(q^2)/\varepsilon) + v_2(\theta,\phi,\varepsilon)P_{LT}(q^2)$$

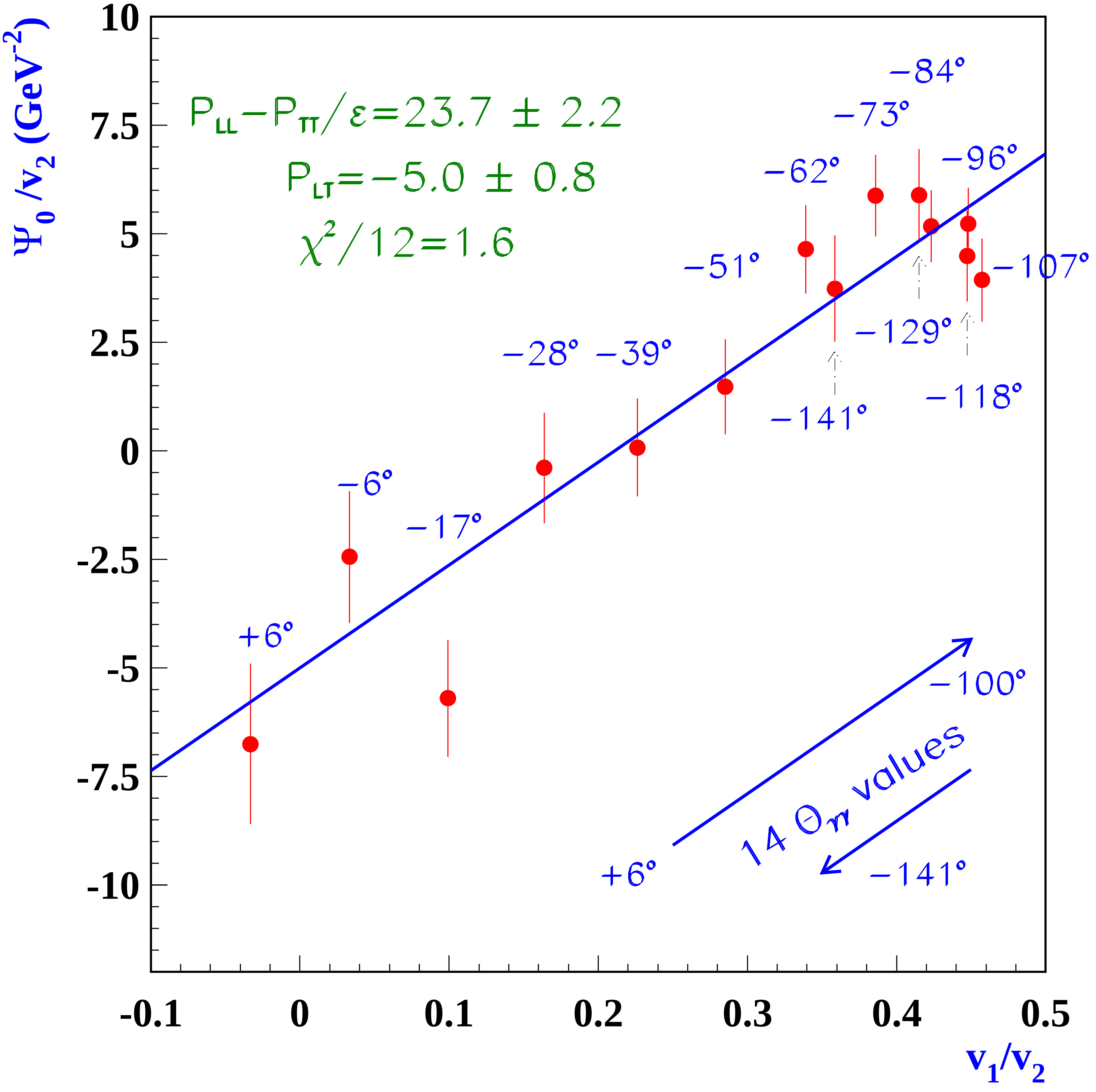
- Structure functions:

$$P_{LL}(q^2) = -2\sqrt{6}\, M_N\, G_E\, P^{(E1\to E1)0}$$

$$P_{TT}(q^2) = 3\, G_M\, |\vec{q}|^2 \left(\sqrt{2}\, P^{(M2\to E1)1} - \frac{1}{q_0} P^{(M1\to M1)1}\right)$$

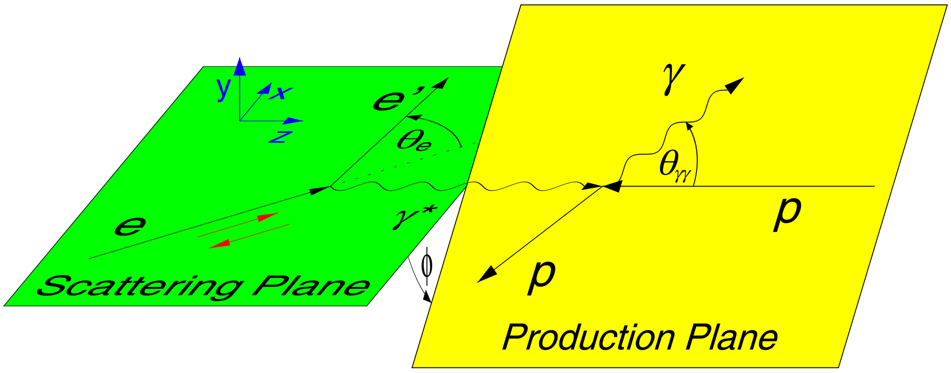
$$P_{LT}(q^2) = \sqrt{\frac{3}{2}\frac{|\vec{q}|}{Q}}\, M_N\, G_E\, P^{(M1\to M1)0} + \frac{3}{2}\frac{|\vec{q}|\, Q}{q_0}\, G_M\, P^{(E1\to E1)1}$$

“Rosenbluth” type separation



⇒ Large error in P_{LT} from unpolarized measurement

Beam-Recoil Polarization



$$P_{x,y,z} = \frac{d^5\sigma^{\uparrow\uparrow} + d^5\sigma^{\downarrow\downarrow} - d^5\sigma^{\uparrow\downarrow} - d^5\sigma^{\downarrow\uparrow}}{d^5\sigma^{\uparrow\uparrow} + d^5\sigma^{\downarrow\downarrow} + d^5\sigma^{\uparrow\downarrow} + d^5\sigma^{\downarrow\uparrow}} = \frac{d^5\sigma^{h\uparrow} - d^5\sigma^{h\downarrow}}{2\, d^5\sigma}$$

$$\Delta d^5\sigma^h_{x,y,z} = \Delta d^5\sigma^{BH+Born}_{x,y,z} + \phi \mathrm{q}' \Delta\Psi_0^{x,y,z} + \phi O(\mathrm{q}'^2)$$

$$\begin{aligned}
\Psi_0 &= v_1(P_{LL} - P_{TT}/\varepsilon) + v_2 P_{LT} \\
\Delta\Psi_0^z &= 4\,h\,[v_1^z\, P_{TT} + v_2^z P_{LT}^z + v_3^z\, P'^z_{LT}] \\
\Delta\Psi_0^x &= 4\,h\,[v_1^x\, P_{LT}^\perp + v_2^x\, P_{TT}^\perp + v_3^x\, P'^\perp_{TT} + v_4^x\, P'^\perp_{LT}] \\
\Delta\Psi_0^y &= 4\,h\,[v_1^y\, P_{LT}^\perp + v_2^y\, P_{TT}^\perp + v_3^y\, P'^\perp_{TT} + v_4^y\, P'^\perp_{LT}]
\end{aligned}$$

6 independent structure functions ⇒ 6 GPs

$$\begin{aligned}
P_{LL} &= aP^{(01,01)0} \\
P_{TT} &= c_1 P^{(11,11)1} + c_2 P^{(01,12)1} \\
P_{LT} &= bP^{(11,11)0} + c_3[P^{(11,00)1} + d_1 P^{(11,02)1}] \\
P_{LT}^z &= c_4 P^{(11,11)1} + c_3[P^{(11,00)1} + d_1 P^{(11,02)1}] \\
P'^z_{LT} &= c_5 P^{(11,11)1} + c_6[P^{(11,00)1} + d_1 P^{(11,02)1}] \\
P'^\perp_{LT} &= [d_2 P^{(11,00)1} + d_3 P^{(11,02)1}]
\end{aligned}$$

Angular Structure

$$
\begin{aligned}
\Psi_0 &= v_1(P_{LL} - P_{TT}/\varepsilon) + v_2 P_{LT} \\
\Delta\Psi_0^z &= 4\,h\,[v_1^z\,P_{TT} + v_2^z P_{LT}^z + v_3^z\,P'^z_{LT}] \\
\Delta\Psi_0^x &= 4\,h\,[v_1^x\,P_{LT}^\perp + v_2^x\,P_{TT}^\perp + v_3^x\,P'^\perp_{TT} + v_4^x\,P'^\perp_{LT}] \\
\Delta\Psi_0^y &= 4\,h\,[v_1^y\,P_{LT}^\perp + v_2^y\,P_{TT}^\perp + v_3^y\,P'^\perp_{TT} + v_4^y\,P'^\perp_{LT}]
\end{aligned}
$$

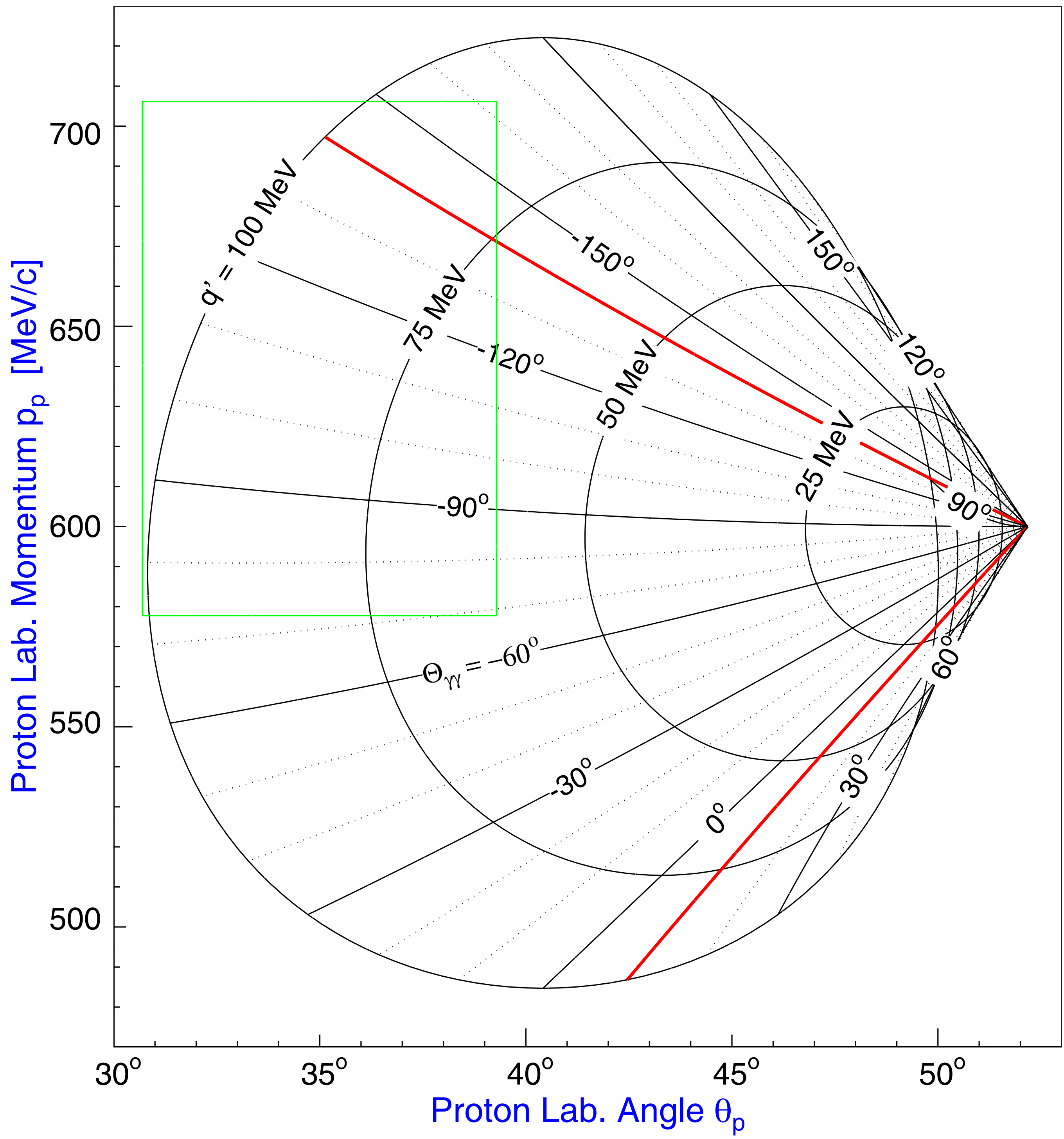
$$
\begin{aligned}
v_1^z &= \sin\theta\,(\omega''\sin\theta - k_T\omega'\cos\theta\cos\phi)\,, \\
v_2^z &= -\,(\omega''\sin\theta\cos\phi - k_T\omega'\cos\theta)\,, \\
v_3^z &= -\,\left(\omega''\sin\theta\cos\theta\cos\phi - k_T\omega'(1-\sin^2\theta\cos^2\phi\right)\,,
\end{aligned}
$$

$$
\begin{aligned}
v_1^x &= \sin\theta\cos\phi(\omega''\sin\theta - k_T\omega'\cos\theta\cos\phi) \\
v_2^x &= -(\omega''\sin\theta - k_T\omega'\cos\theta\cos\phi) \\
v_3^x &= -\cos\theta(\omega''\sin\theta - k_T\omega'\cos\theta\cos\phi) \\
v_4^x &= k_T\omega'\sin\theta\sin^2\phi
\end{aligned}
$$

$$
\begin{aligned}
v_1^y &= \sin\theta\sin\phi(\omega''\sin\theta - k_T\omega'\cos\theta\cos\phi) \\
v_2^y &= k_T\omega'\cos\theta\sin\phi \\
v_3^y &= k_T\omega'\sin\phi \\
v_4^y &= -k_T\omega'\sin\theta\sin\phi\cos\phi
\end{aligned}
$$

Out-of-Plane measurement to get $P'^\perp_{LT}$

Spectrometer Acceptance



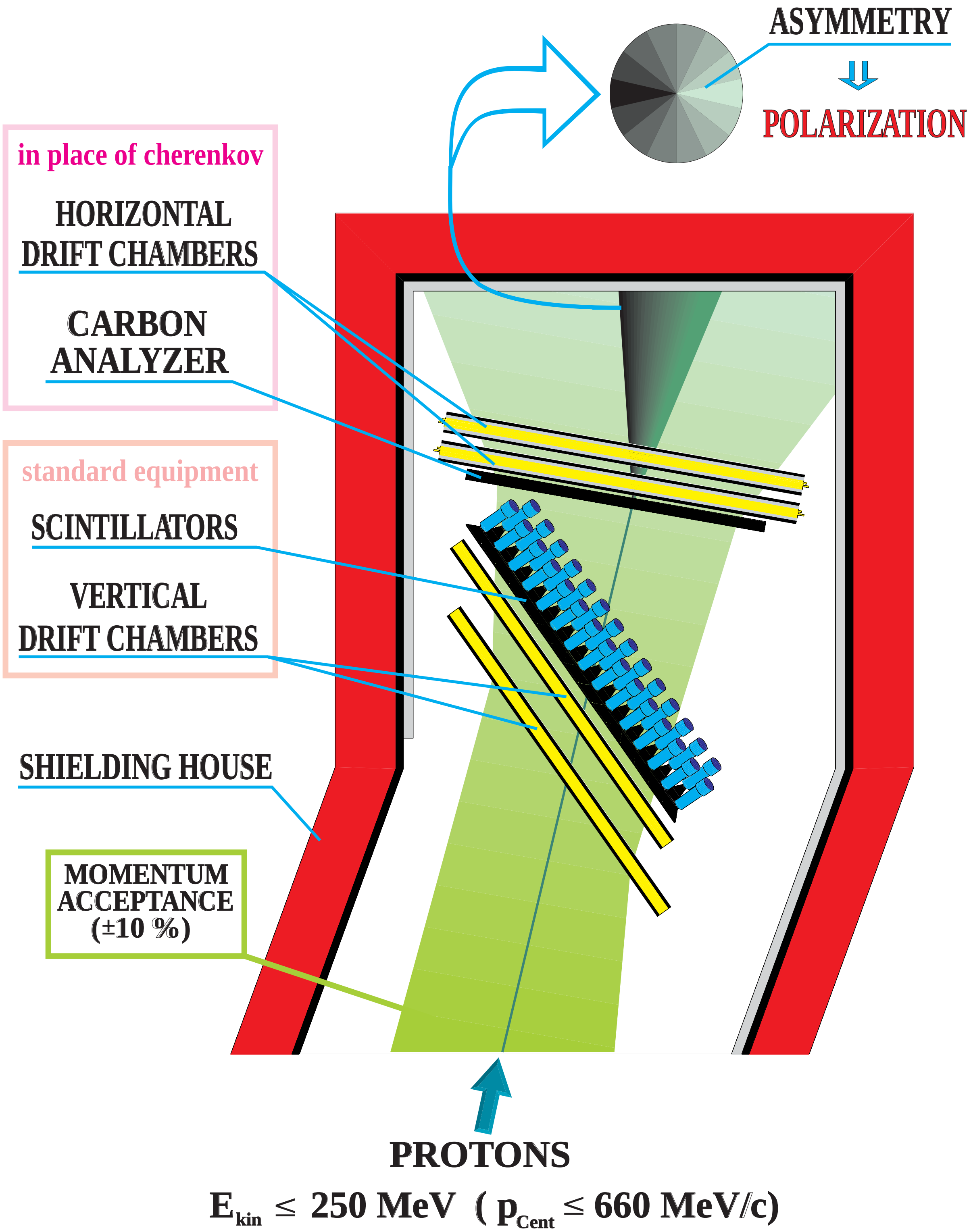
$$E_{in} \leq 855\,MeV \qquad \varepsilon = 0.62$$

$$q = 600\,MeV \qquad q' < 111.5\,MeV$$

$$Q^2|_{q'\to 0} = 0.33\,GeV^2/c^2 \qquad \theta_e \approx 51°$$

$\phi_{OOP} < 10° \Rightarrow$ complete Out-of-Plane coverage

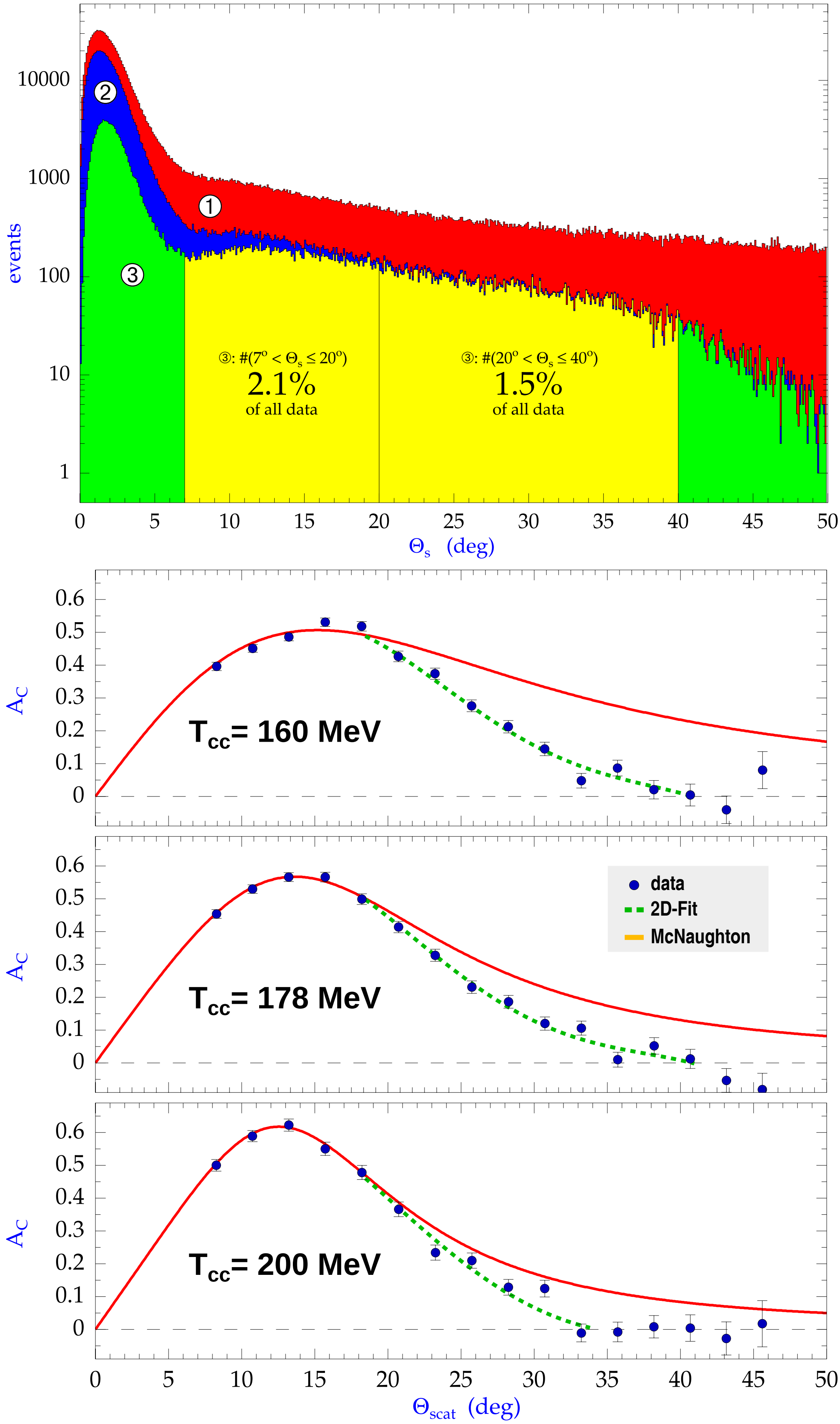
A1 Focal Plane Polarimeter



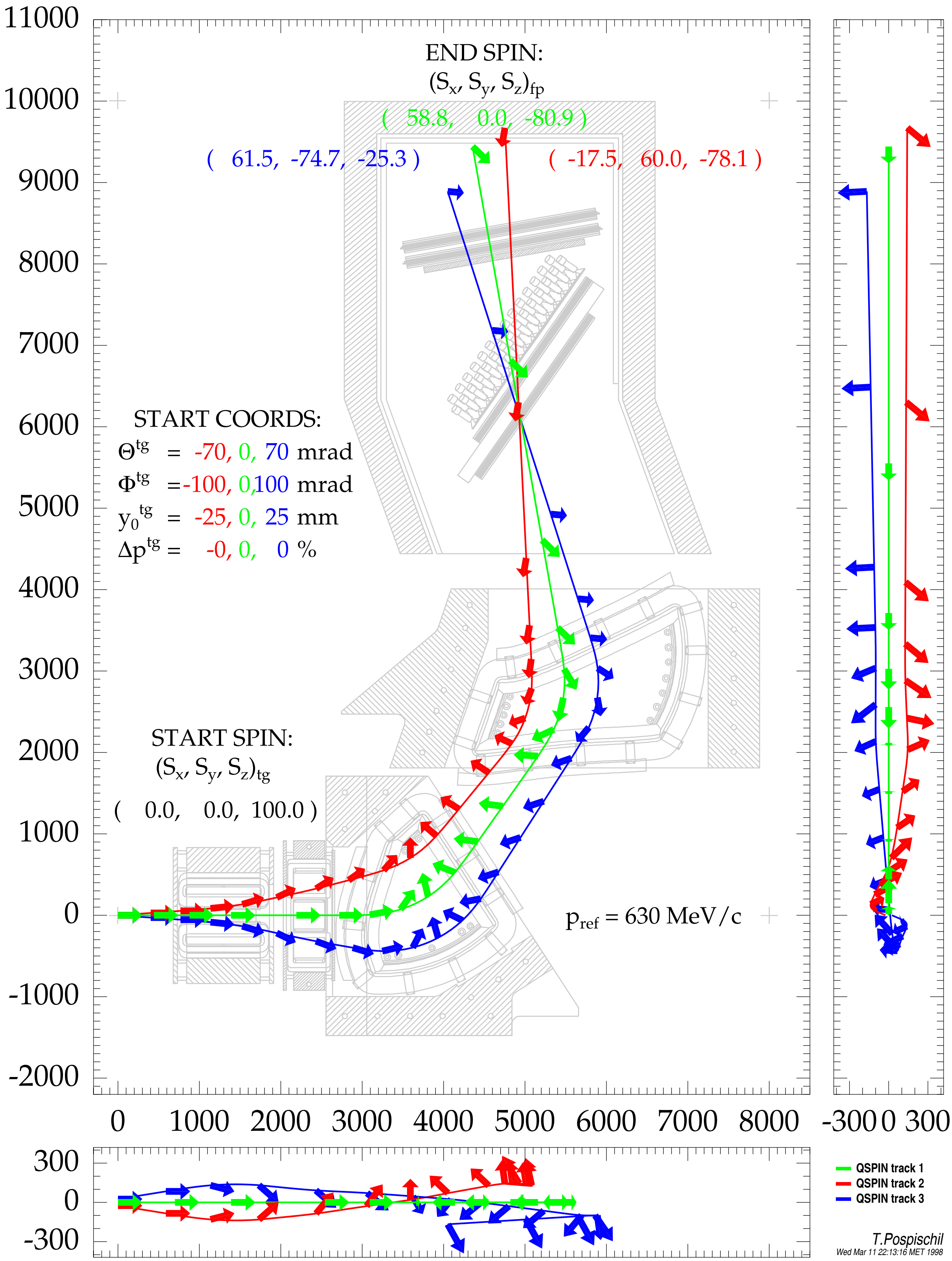
Efficiency for $470MeV < p_p < 740MeV$: 2.5%

Analyzing Power: 50%

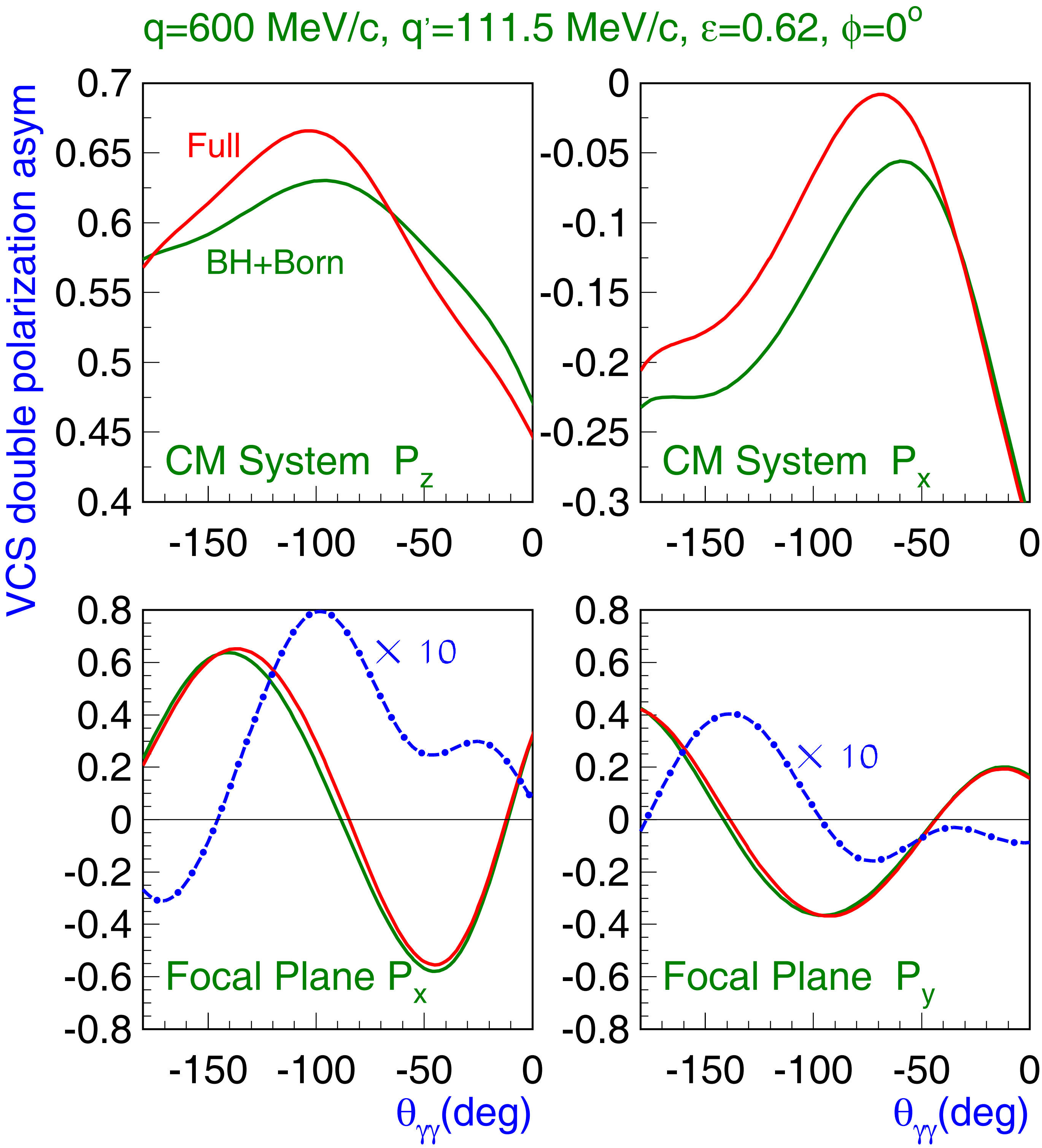
FPP Analyzing Power



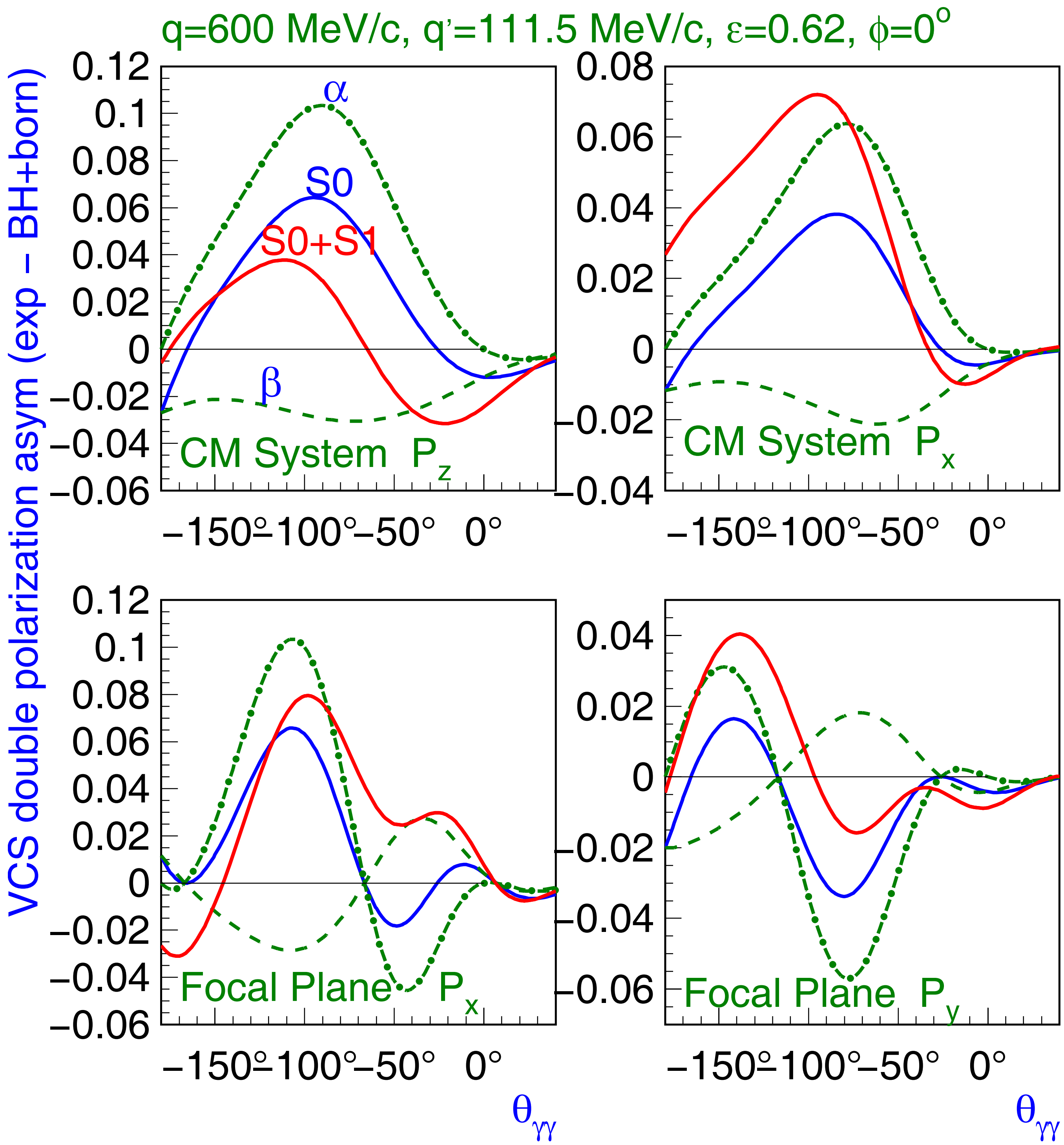
Spin Precession in Spectrometer Field



Beam-Recoil Polarization

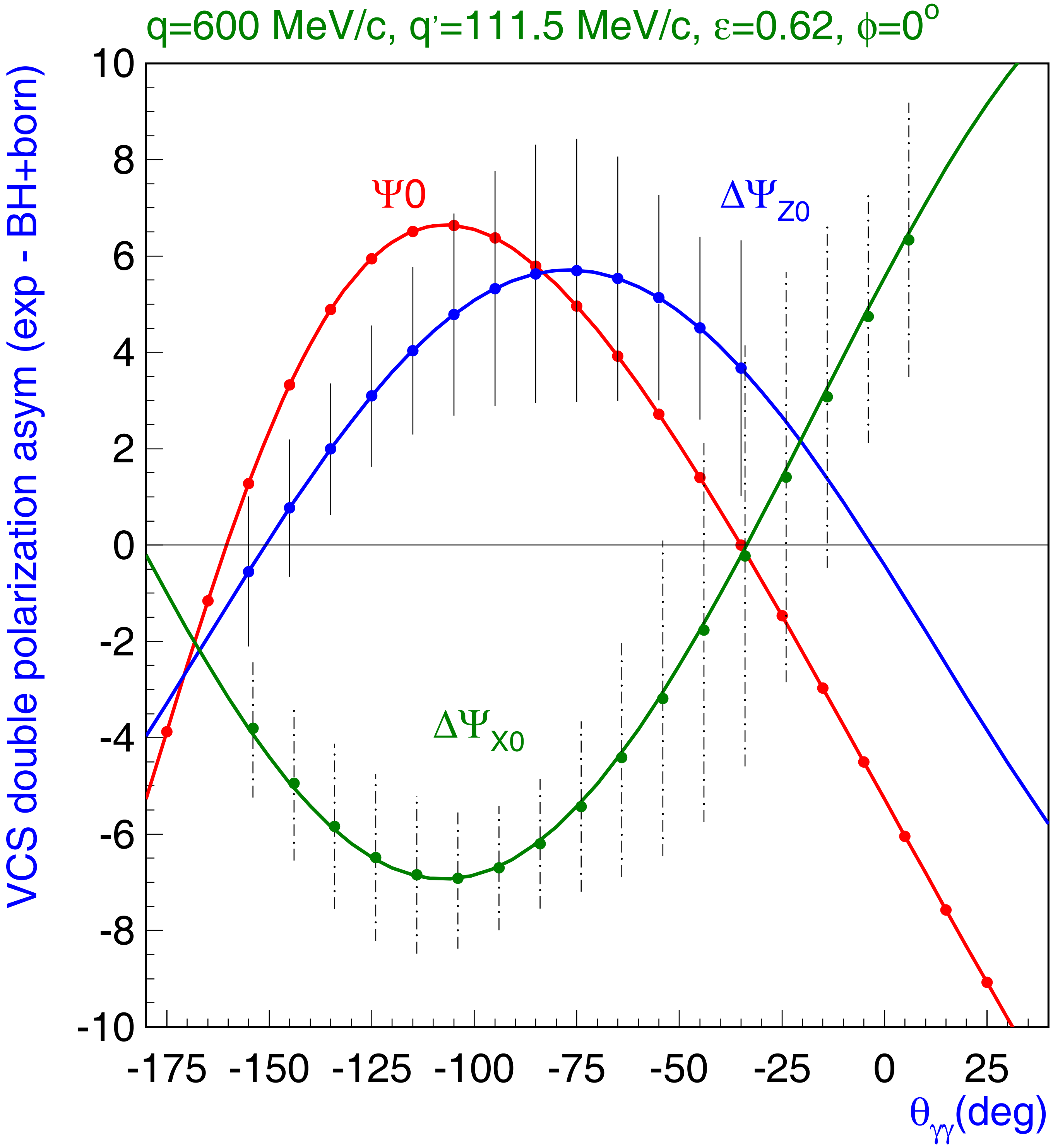


Extraction of Polarizabilities



- No "easy" separation by kinematics
- High dimensional: $(\theta_e, \phi_e, k, \theta_{\gamma\gamma}, \phi_{\gamma\gamma}) \rightarrow (P_x, P_y, P_z)$
- Parametrized by 6 polarizabilities

Projected Errors



Open Questions:

- Simulation of polarizations for complete acceptance
- Systematic errors of FPP, Test measurement

Dispersion Relations (B. Pasquini *et al.*)

Ingrediences

- Crossing symmetry
- π^0 production data above πN threshold (MAID)
- Analyticity

$\Rightarrow$ Unsubtracted, fixed t, Q^2 Dispersion Relations for VCS Non-Born amplitudes F_i^{NB}

$$\mathrm{Re}\, F_i^{NB}(Q^2,\nu,t) = \frac{2}{\pi}\mathcal{P}\int_{\nu_{thr}}^{+\infty} \mathrm{Im}_s F_i(Q^2,\nu',t)\frac{\nu' d\nu'}{\nu'^2-\nu^2}$$

Advantages

- Based on general principles
- Weak “model” dependence
- Tool to extract threshold properties at high energies

But

- Only as good as existing π^0 data
- Fixed Q^2, model for inter- and extrapolation
- Limited Range $q' < 300\,\mathrm{MeV}$

Connection to Generalized Polarizabilities

- Generalized Polarizabilities:

$$F_1^{NB}(Q^2,\nu=0,t=-Q^2) = -\sqrt{\frac{3}{8}}\sqrt{\frac{2E}{E+M}}P^{(M1\to M1)0}(Q^2)$$

...

- Four GP's from Dispersion Relations
- Parametrization of two GP's

$$P^{(C1\to E1)0}(Q^2) = -\sqrt{\frac{2}{3}}\frac{4\pi}{e^2}\alpha(Q^2)$$

$$P^{(M1\to M1)0}(Q^2) = -\sqrt{\frac{8}{3}}\frac{4\pi}{e^2}\beta(Q^2)$$

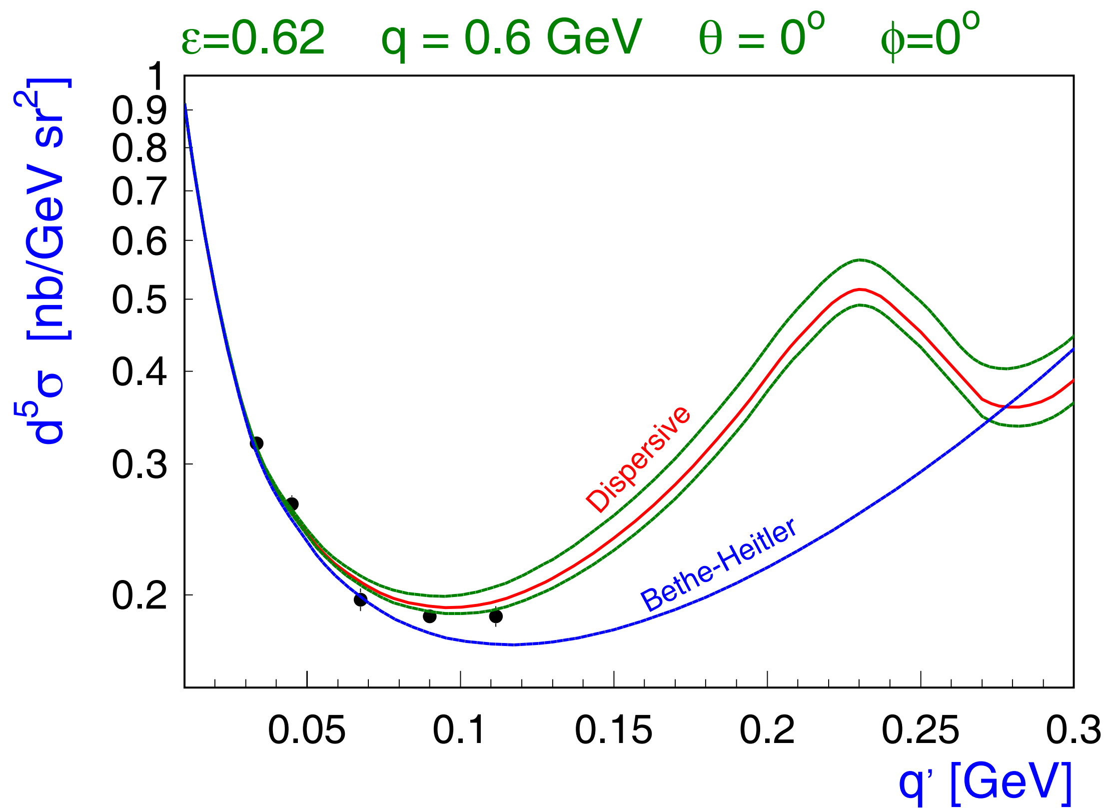
- Arbitray choice: Dipole

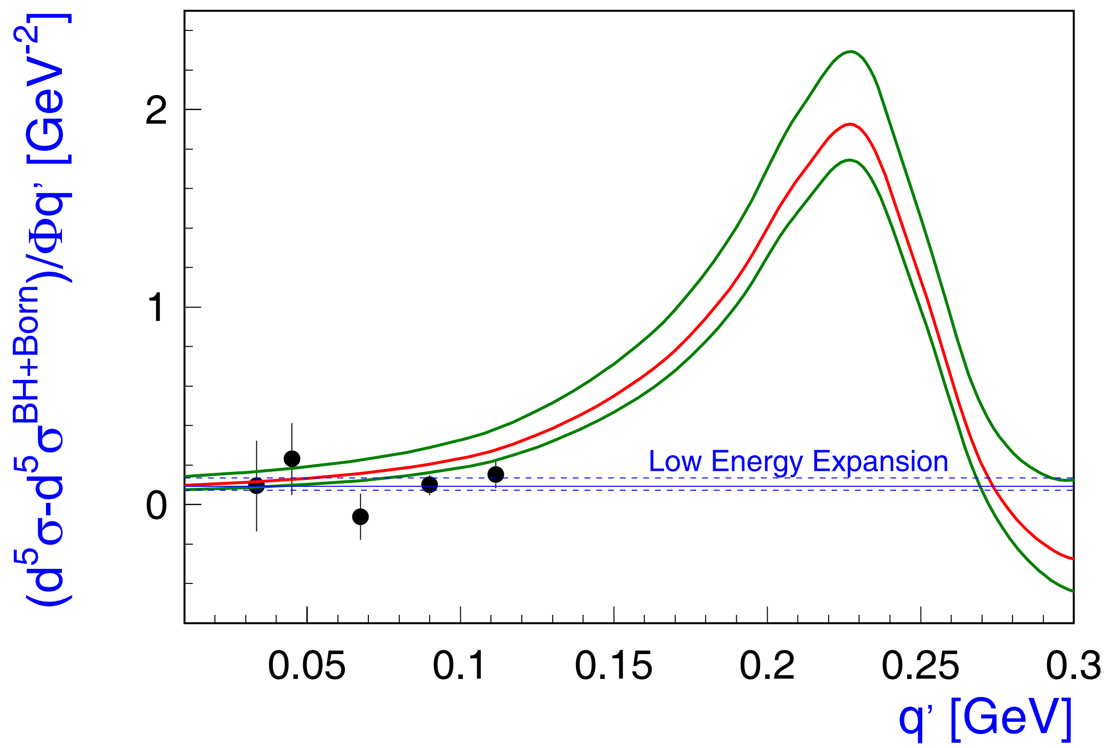
$$\alpha(Q^2)-\alpha^{\pi N}(Q^2) = \frac{\alpha-\alpha^{\pi N}}{(1+Q^2/\Lambda_\alpha{}^2)^2}$$

$$\beta(Q^2)-\beta^{\pi N}(Q^2) = \frac{\beta-\beta^{\pi N}}{(1+Q^2/\Lambda_\beta{}^2)^2}$$

- Fit Λ_α, Λ_β to data at $\nu > \nu_{thr}$, extract GP at $\nu = 0$

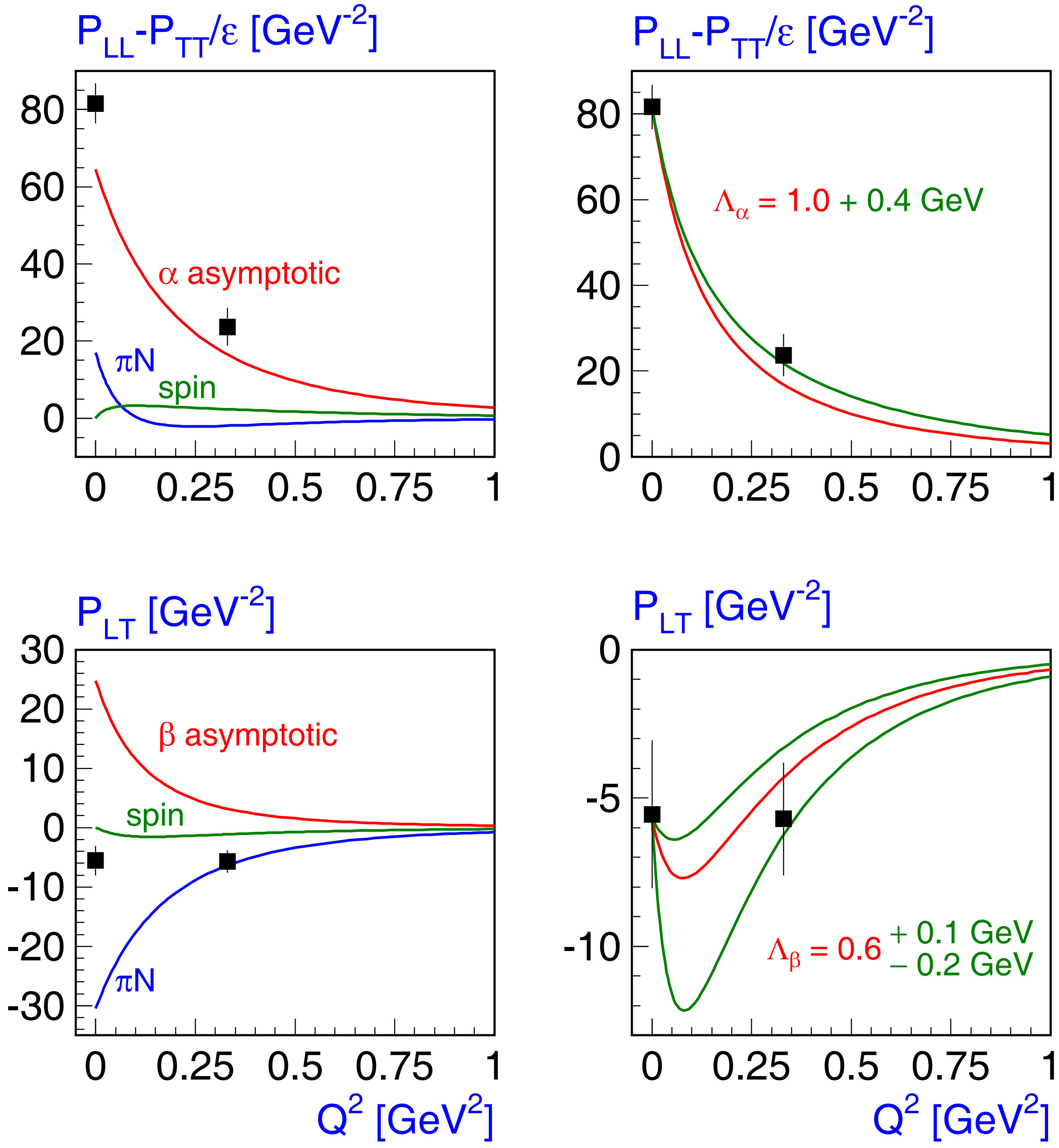
Cross Section





- ● J. Roche *et al.*, Phys. Rev. Lett **85,4** 708 – 711 (2000)
- – B. Pasquini *et al.*, Eur. Phys. J. **A 11**, 185 – 208 (2001)

Results of “Rosenbluth separation”



- ● J. Roche *et al.*, Phys. Rev. Lett **85,4** 708 – 711 (2000)
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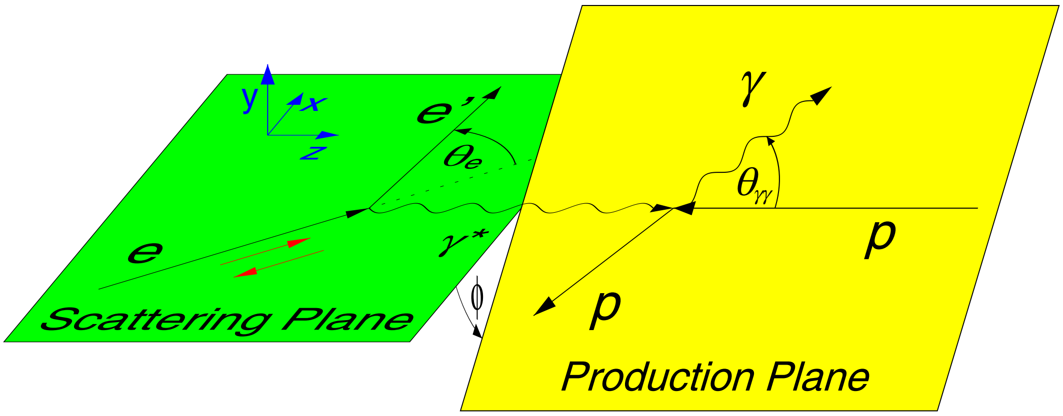
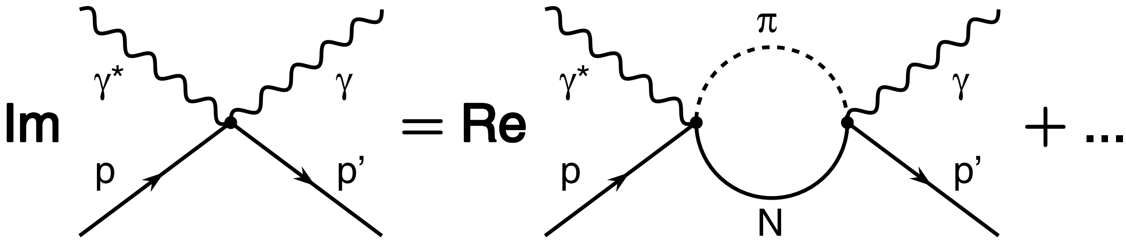
Beam Helicity Asymmetry A_h



- Bethe-Heithler Cross Section: QED $\Rightarrow$ real
- Generalized Polarizabilities at threshold real
- Above πN threshold:

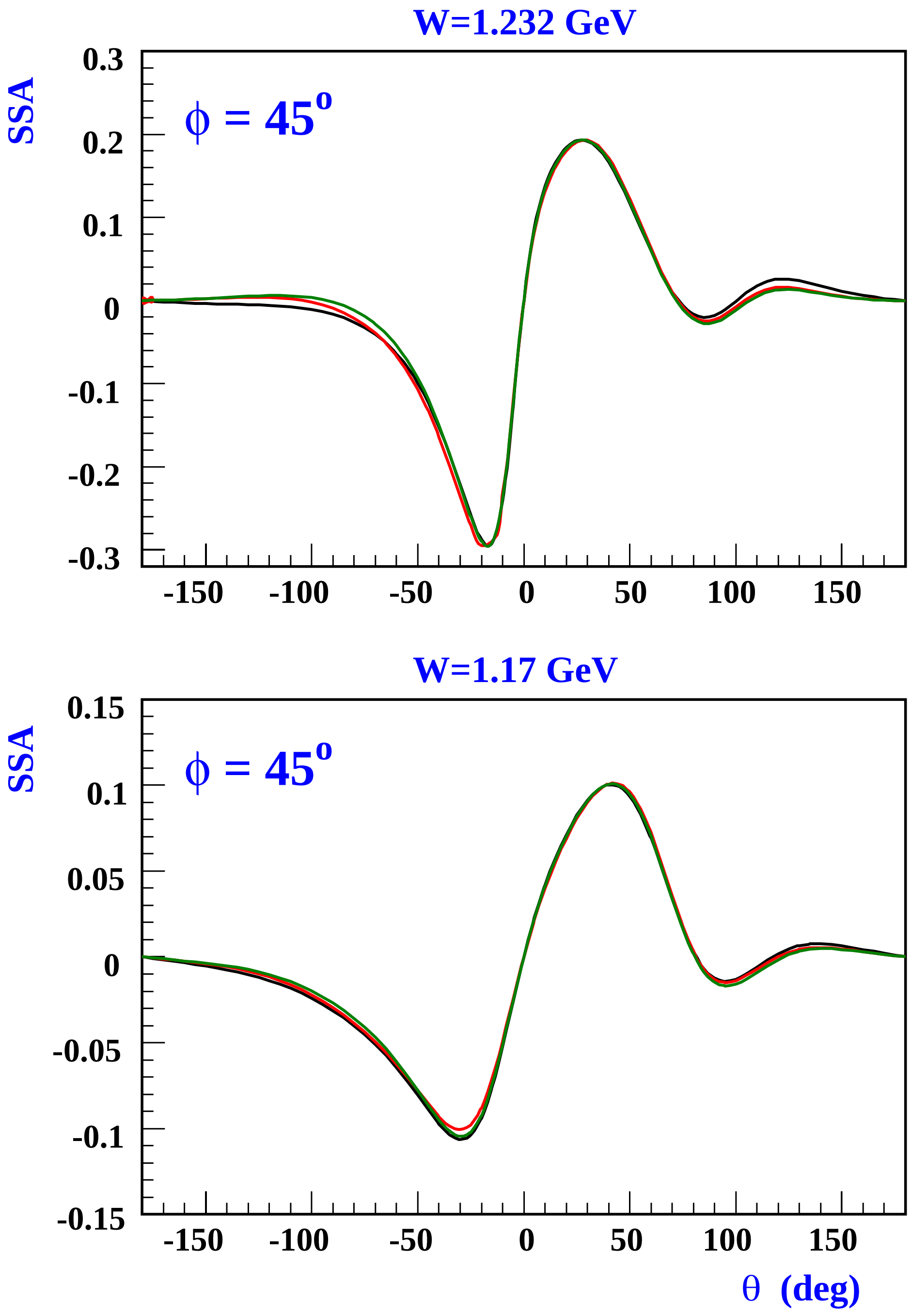


$\Rightarrow$ Imaginary part of Non-Born Amplitude

- Beam Helicity Asymmetry A_h:

Interference Im(Non-Born VCS) – Bethe-Heithler

Prediction Beam Helicity Asymmetry



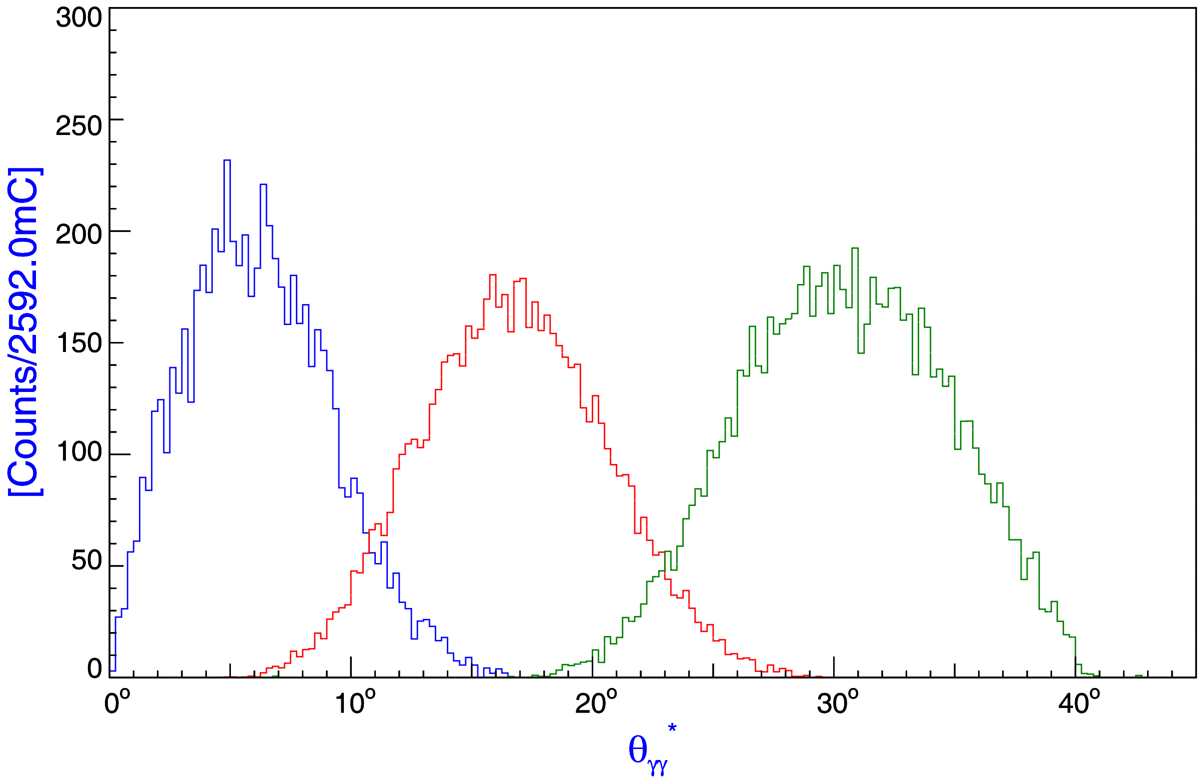
B. Pasquini *et al.*, Eur. Phys. J. **A 11**, 185 – 208 (2001)

— $\Lambda_\alpha = 1.0\,\text{GeV}, \Lambda_\beta = 0.6\,\text{GeV}$

— $\Lambda_\alpha = 1.0\,\text{GeV}, \Lambda_\beta = 0.4\,\text{GeV}$

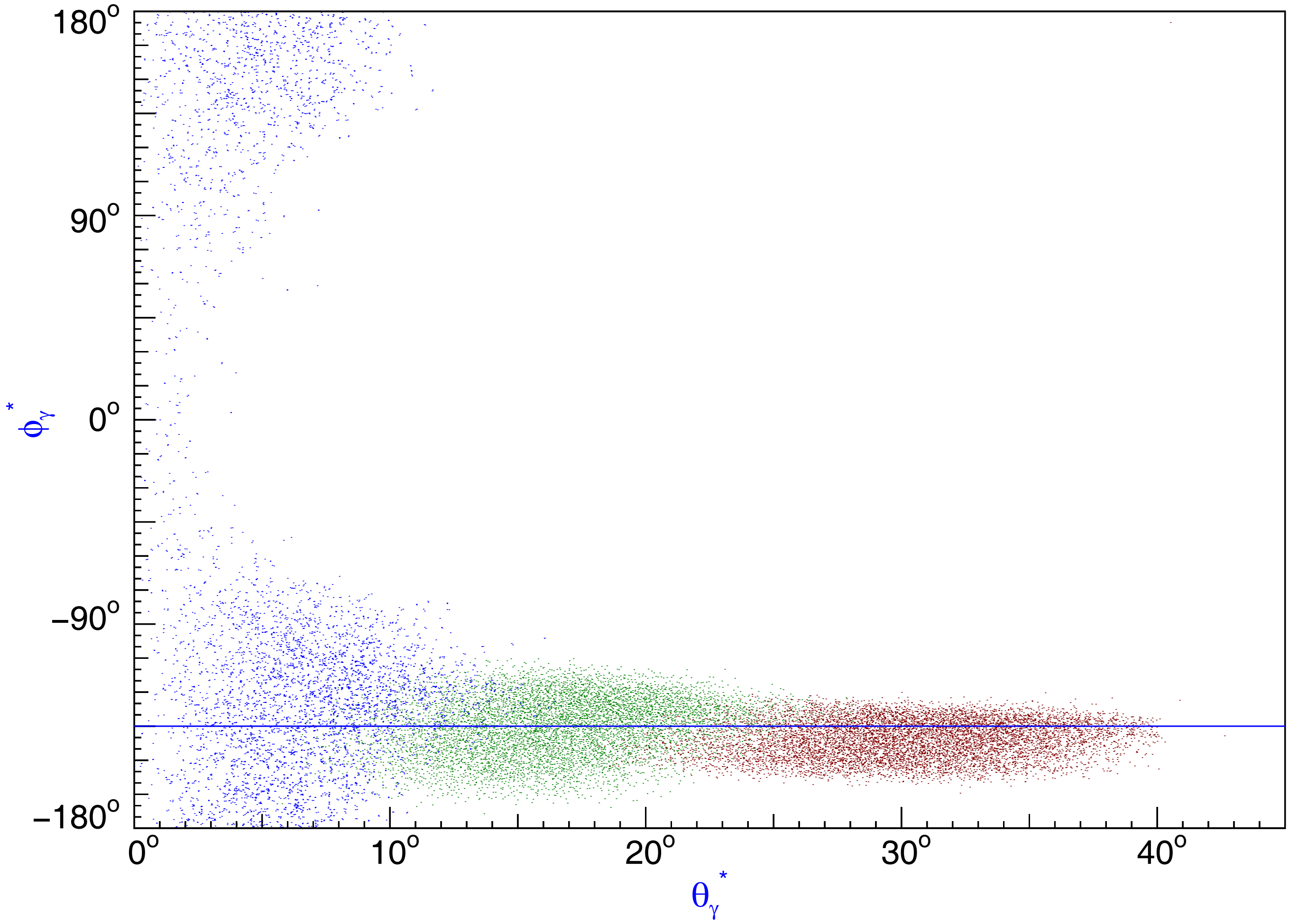
— $\Lambda_\alpha = 1.4\,\text{GeV}, \Lambda_\beta = 0.6\,\text{GeV}$

Coverage in $\theta_{\gamma\gamma}$



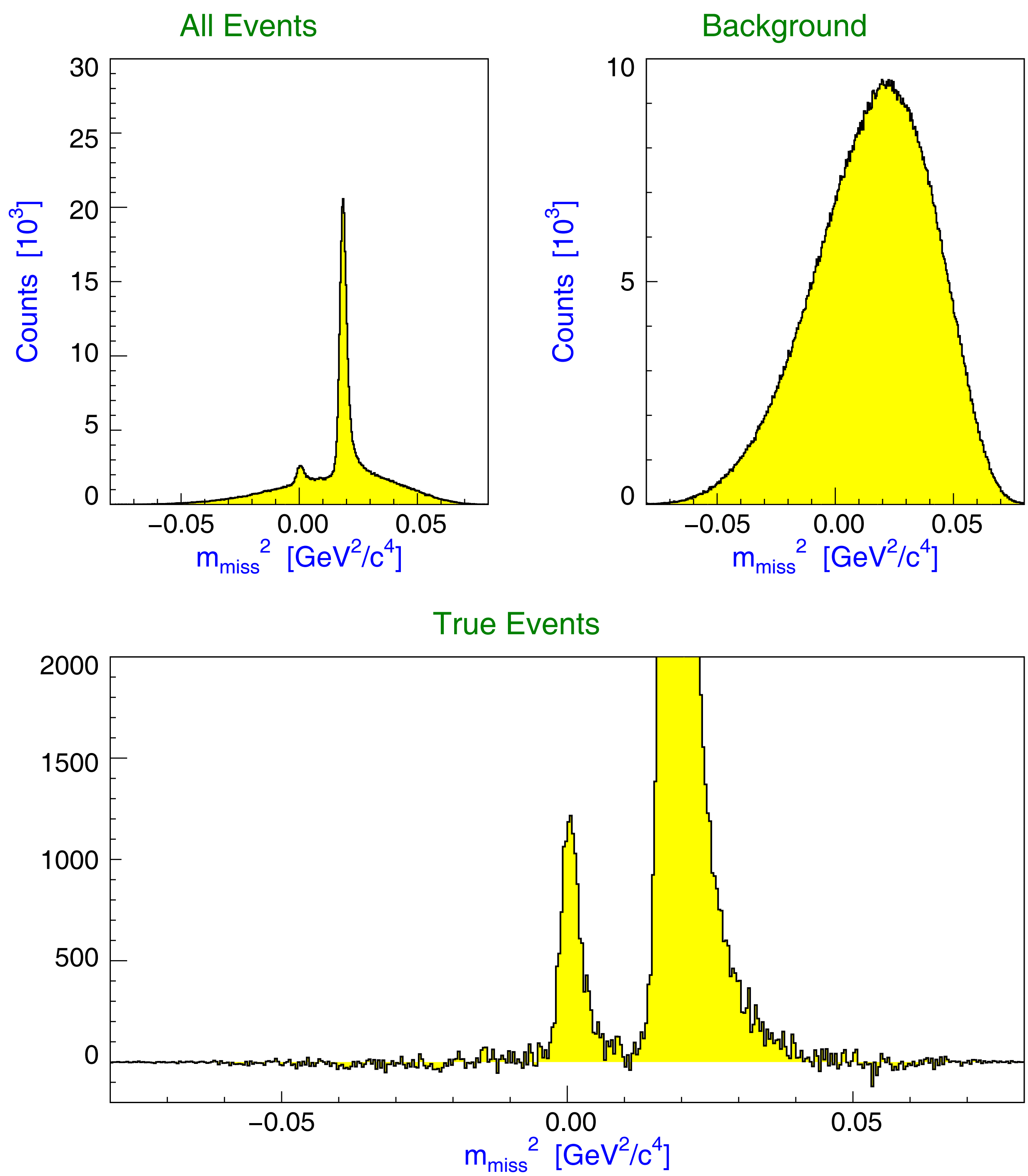
- $\phi_{\gamma\gamma} = -135°$
- Out-of-Plane angle: 2°, 7°, 10°
- One setting: ±5° within spectrometer acceptance

$\phi_{\gamma\gamma}$ Coverage



- Out-of-Plane angle: 2°, 7°, 10°
- Full $\phi_{\gamma\gamma}$ coverage at $\theta_{\gamma\gamma} = 0°$
- Still large coverage at $\theta_{\gamma\gamma} > 30°$

Missing Mass Resolution (Online)



- π^0 background $10\times$ VCS
- Events separated
- Resolution should be improved

Summary and Outlook

- Double polarization
  - 6 gen. polarizabilities can be extracted in principle
  - High resolution and accuracy needed
  - Small statistical error required $\longrightarrow$ long measurement
  - But: Effect might be too small
- Single scattering asymmetry
  - Higher count rates
  - Pion background
  - Model-dependent extraction of 2 independent parameters by dispersion-relations analysis
  - First test experiment carried out