Nucleon structure study by polarized virtual compton scattering $(\gamma^* p \rightarrow \gamma p)$

I.K. Bensafa

Nucleon Structure Study

By Polarized Virtual

Compton Scattering ($\gamma^* p \rightarrow \gamma p$)

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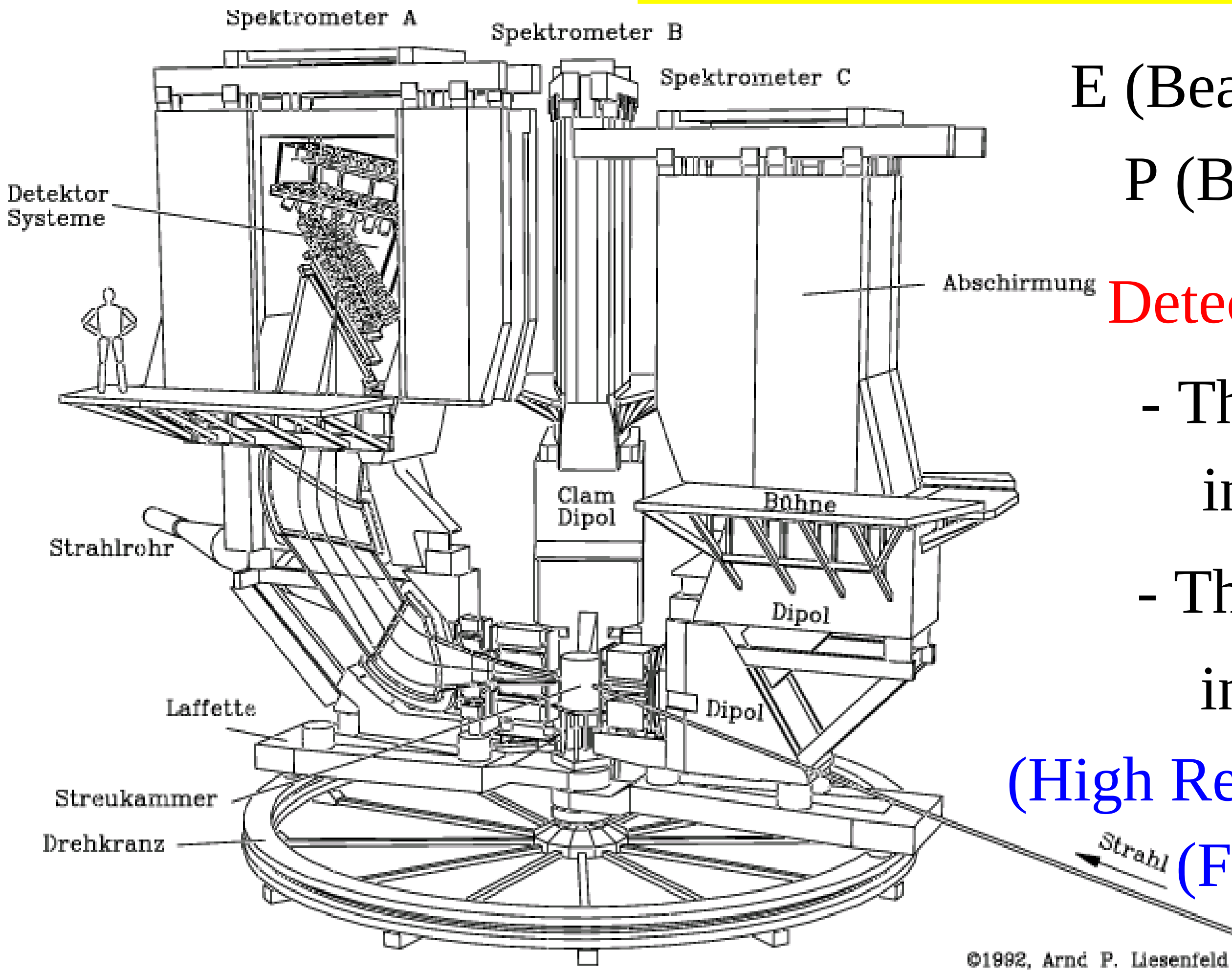
Schematic view of A1 Collaboration, MAMI (Mainz, Germany)

The reaction is : $\vec{e}p \longrightarrow ep\gamma$



E (Beam Energy) = 0.88 GeV

P (Beam Polarisation) ~ 80

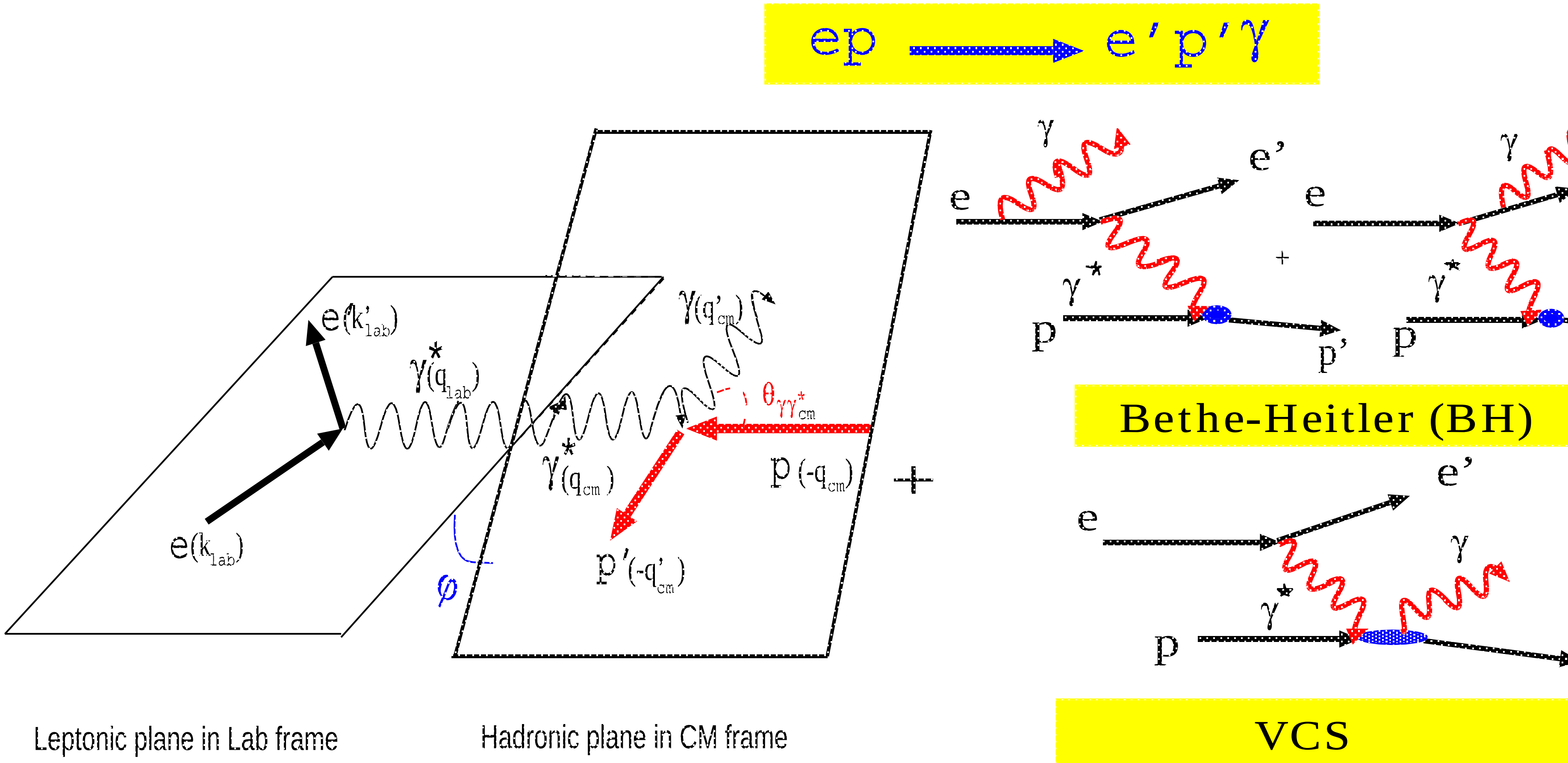
Detection in coincidence of

- The scattered electron in Spectrometer A
- The final proton in Spectrometer B

(High Resolution Spectrometer

(Final γ = missing partic

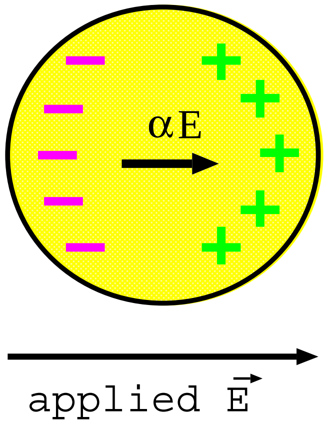
Kinematic of electroprodution of photon ($ep \rightarrow ep\gamma$) and Feynman diagrams

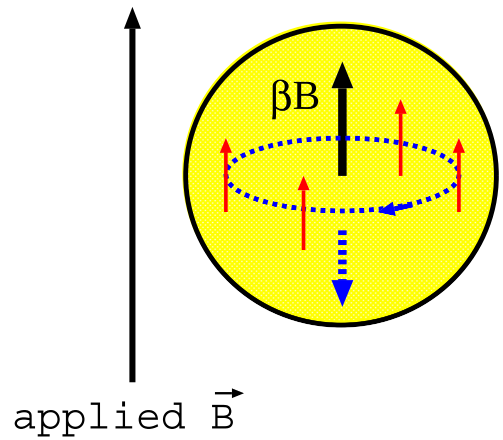


Kinematic variables :

$Q^2 = 0.34 GeV^2$ = **Four-momentum transfer of Virtual Photon**
$q' = 0.23 GeV$ = **CM momentum of final photon**
$W = \sqrt{s} = 1.2 GeV$ = **CM energy of ($\gamma^* p \rightarrow \gamma p$)**

Polarizabilities in Real Compton Scattering





- **World Data:** V.Olmos de Leon et al,Eur.Phys. J. A 10 (2001) 207 [Global Fit, Table 3].

Electric polarizability $\bar{\alpha_E} = (\ \mathbf{12.1} \ \ \pm 0.3_{stat} \mp 0.4_{syst}) \ 10^{-4}$ **fm**^{3}

Magnetic polarizability $\bar{\beta_M} = (\ \mathbf{1.6} \ \ \pm 0.4_{stat} \pm 0.4_{syst}) \ 10^{-4}$ **fm**^{3}

- **Proton: very rigid object**
- $\bar{\beta}_M \ll \bar{\alpha}_E$ **: para/dia-magnetic cancellation in** β_M

Nucleon Generalized Polarisabilities (GPs).

- The (GPs) are the Polarisabilities of the nucleon for $Q^2 \neq 0$

- The (GPs) have been measured up to now by $(ep \to ep\gamma)$ **unpolarized**

1. Below pion threshold : $\sqrt{s} < (m_N + m\pi)$, $q' = 126 MeV/c$

- **Low energy Theorem (LET)**
[P.Guichon et al, Nucl.Phys. A591(1995) 606] :

$$d^5\sigma(ep\gamma) = d^5\sigma(\textbf{BH+Born}) + (PhaseSpaceFactor).q'_{cm}.([...] + O(q'^2_{cm}))$$

$$[...] = 2K_2\{v_1[\epsilon P_{LL}(q) - P_{TT}(q)] + (v_2 - \frac{\tilde{q}}{q}v_3)\sqrt{2\epsilon(1+\epsilon)}P_{LT}(q)\}$$

VCS Structure functions: contain the GPs

$$P_{LL} = -2\sqrt{6}MG_E P^{(L1,L1)0},$$
$$P_{TT} = -3MG_M\frac{q^2}{\tilde{q}_0}(P^{(M1,M1)1} - \sqrt{2}\tilde{q}_0 P^{(L1,M2)1}),$$
$$P_{LT} = \sqrt{\frac{3}{2}\frac{M\,q}{Q}}G_E P^{(M1,M1)0} + \frac{3}{2}\frac{M\,q}{\tilde{q}_0}G_M P^{(L1,L1)1}),$$

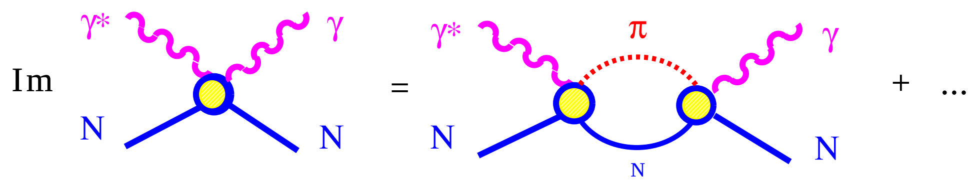
Where :
- P_{LL} proportional to the electric generalized polarisability $\alpha_E(Q^2) \sim P^{(L1,L1)0}$
- P_{LT} contains the magnetic generalized polarisability $\beta_M(Q^2) \sim P^{(M1,M1)0}$

the Dispersion Relations (DR) method

- **above pion threshold:**

The Low Energy Theorem does not hold (T_{VCS} becomes complex)

Dispersion Relation Model, *B.Pasquini et al., Eur.Phys.J.A 11 (2001) 185*
D.Drechsel et al., Phys.Rept.378 (2003) 99



- **The GPs $\alpha_E(Q^2)$ and $\beta_M(Q^2)$ contain free parameters $\rightarrow$ fit them from data, via:**

$$\alpha_E(Q^2) - \alpha_E^{\pi N}(Q^2) = \frac{\alpha_{E0}^{exp} - \alpha_{E0}^{\pi N}}{(1 + Q^2/{\Lambda_\alpha}^2)^2} \quad , \qquad \textit{same for } \beta_M .$$

- **model valid until $\pi\pi$ threshold $\rightarrow \sqrt{s} \sim m_{\Delta(1232)}$ = good region**
- **gives prediction of the Single Spin Asymmetry in ($\vec{e}p \rightarrow ep\gamma$).**

SSA. Theoretical formula of Single Spin Asymmetry (SSA).

- **The SSA is defined by :**

$$SSA = \frac{\sigma(h_e = +\frac{1}{2}) - \sigma(h_e = -\frac{1}{2})}{\sigma(h_e = +\frac{1}{2}) + \sigma(h_e = +\frac{1}{2})}$$

1) SSA in ($\vec{e}p \rightarrow ep\gamma$) above pion threshold:

$$d\sigma(\gamma^* p \rightarrow \gamma p) = d\sigma_T + \epsilon d\sigma_L + \sqrt{2\epsilon(1+\epsilon)}d\sigma_{LT}cos\Phi + \epsilon d\sigma_{TT}cos2\Phi + h\sqrt{\frac{\epsilon}{(1-\epsilon)}}d\sigma_{LT'}sin\Phi$$

$$SSA(\gamma^* p \rightarrow \gamma p) \sim \sqrt{\frac{\epsilon}{(1-\epsilon)}}d\sigma_{LT'}sin\Phi \sim \Im(T_{VCS})$$

SSA measures the imaginary part of the VCS Amplitude
In electroproduction of photon: (Interference with the Bethe-Heitler process)

2) SSA in ($\vec{e}p \rightarrow ep\pi^0$):

$$d\sigma(\gamma^* p \rightarrow p\pi^0) = d\sigma_T + \epsilon d\sigma_L + \sqrt{2\epsilon(1+\epsilon)}d\sigma_{LT}cos\Phi + \epsilon d\sigma_{TT}cos2\Phi$$
$$+ h\sqrt{2\epsilon(1-\epsilon)}d\sigma_{LT'}sin\Phi$$

$$SSA(\vec{e}p \rightarrow ep\pi^0) \sim \sqrt{2\epsilon(1-\epsilon)}d\sigma_{LT'}sin\Phi$$

In both cases, the Asymmetry measures the 5th structure function $d\sigma_{LT'}$

Experimental methods to determine the SSA.

- **Likelihood method:**

  - We make an assumption that the Φ-dependence of the SSA is a pure sinΦ ($\Phi = \Phi_{\gamma\gamma cm}$) :

$$SSA = SSA(\bar{q_{cm}}, \bar{q'_{cm}}, \bar{\epsilon}, \bar{\theta}, \Phi) = K(\bar{q_{cm}}, \bar{q'_{cm}}, \bar{\epsilon}, \bar{\theta}) \times sin\Phi$$

- fit the K factor and its error ΔK by the likelihood method.

- **Binphi method:**

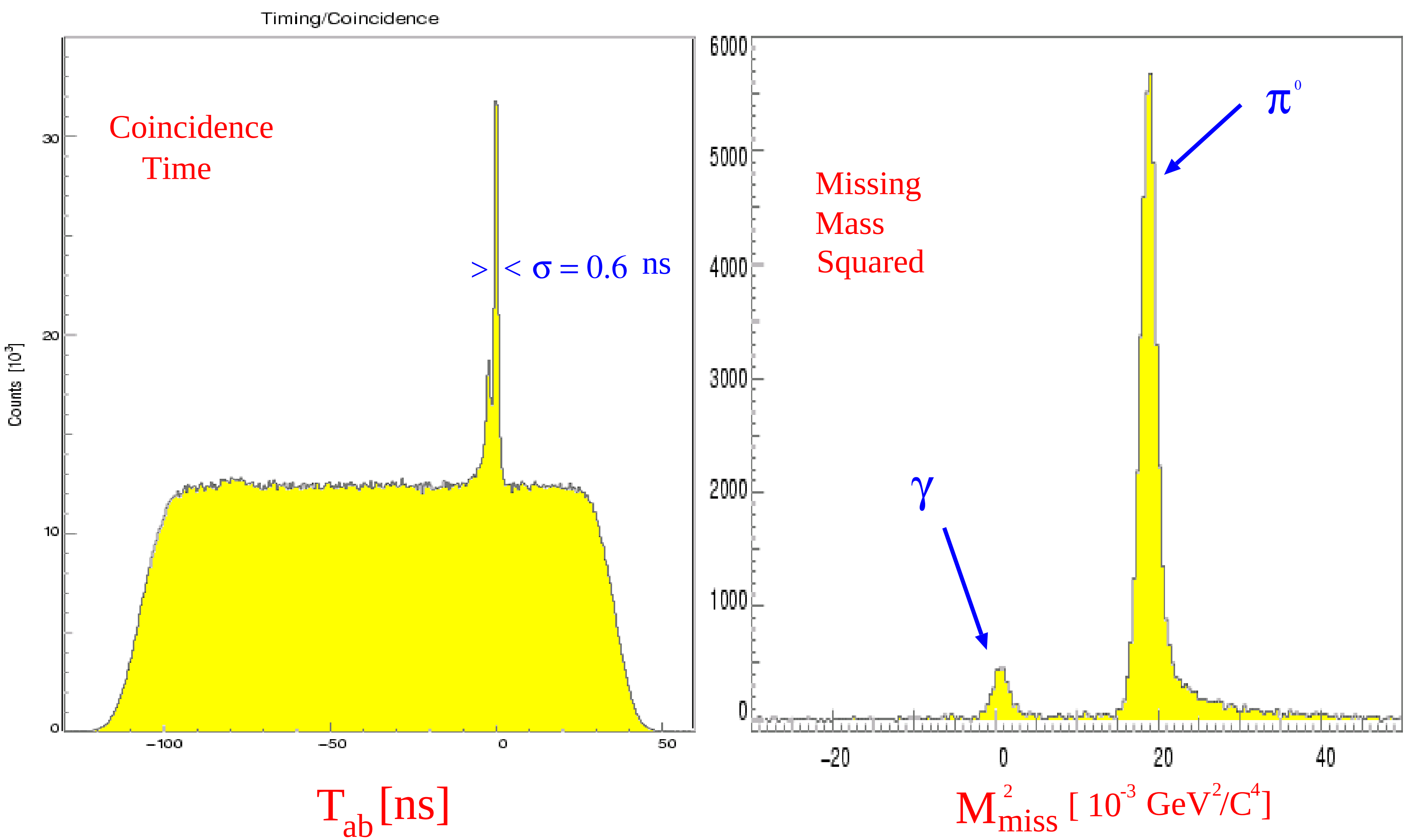
- The asymmetry is given classically from the number of counts in Bins in Φ:

$$SSA = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\frac{N^+}{L^+\Delta\Omega^+} - \frac{N^-}{L^-\Delta\Omega^-}}{\frac{N^+}{L^+\Delta\Omega^+} + \frac{N^-}{L^-\Delta\Omega^-}} \times \frac{1}{|BeamPol|}$$

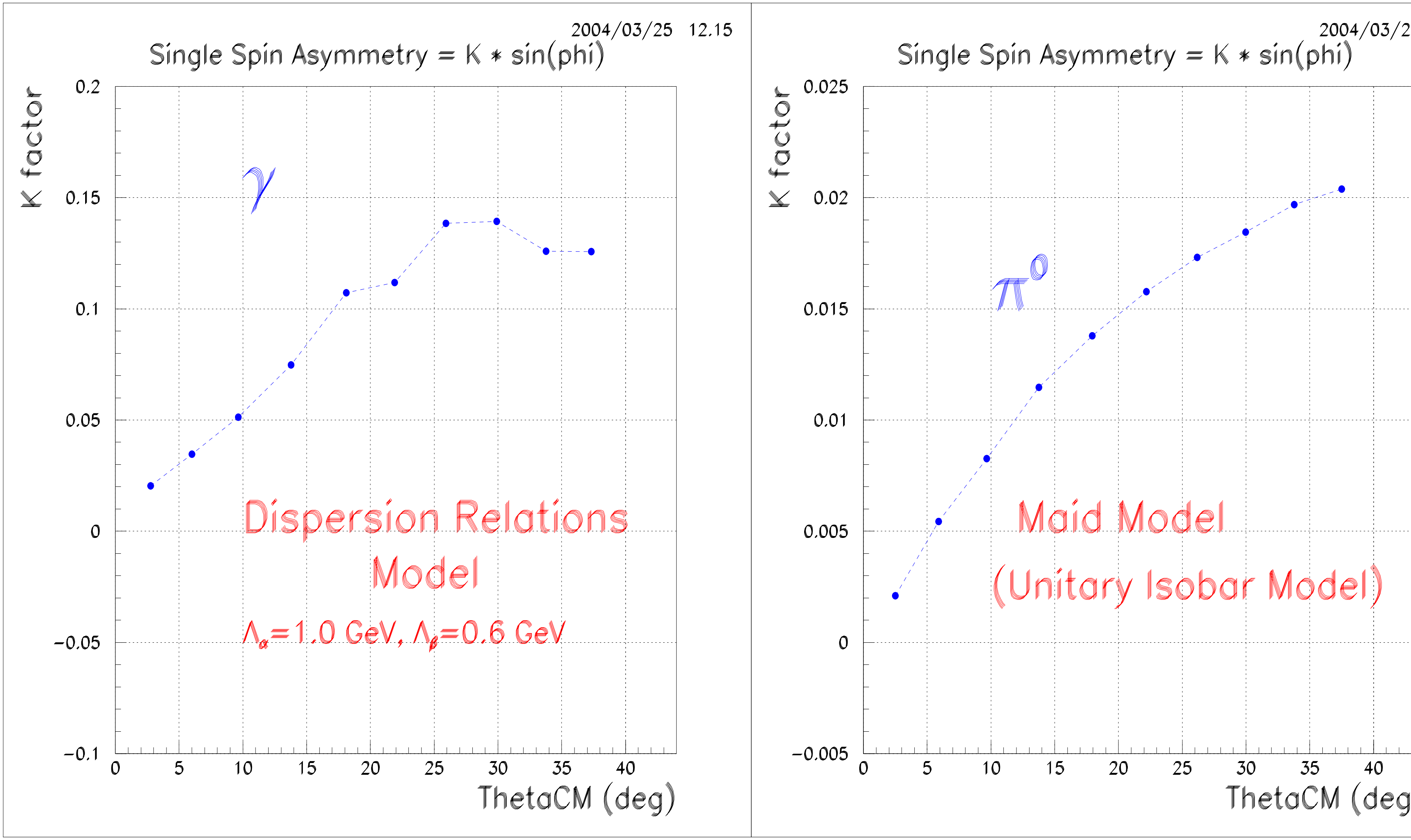
(+,-)=($h_e = +\frac{1}{2}, h_e = -\frac{1}{2}$).

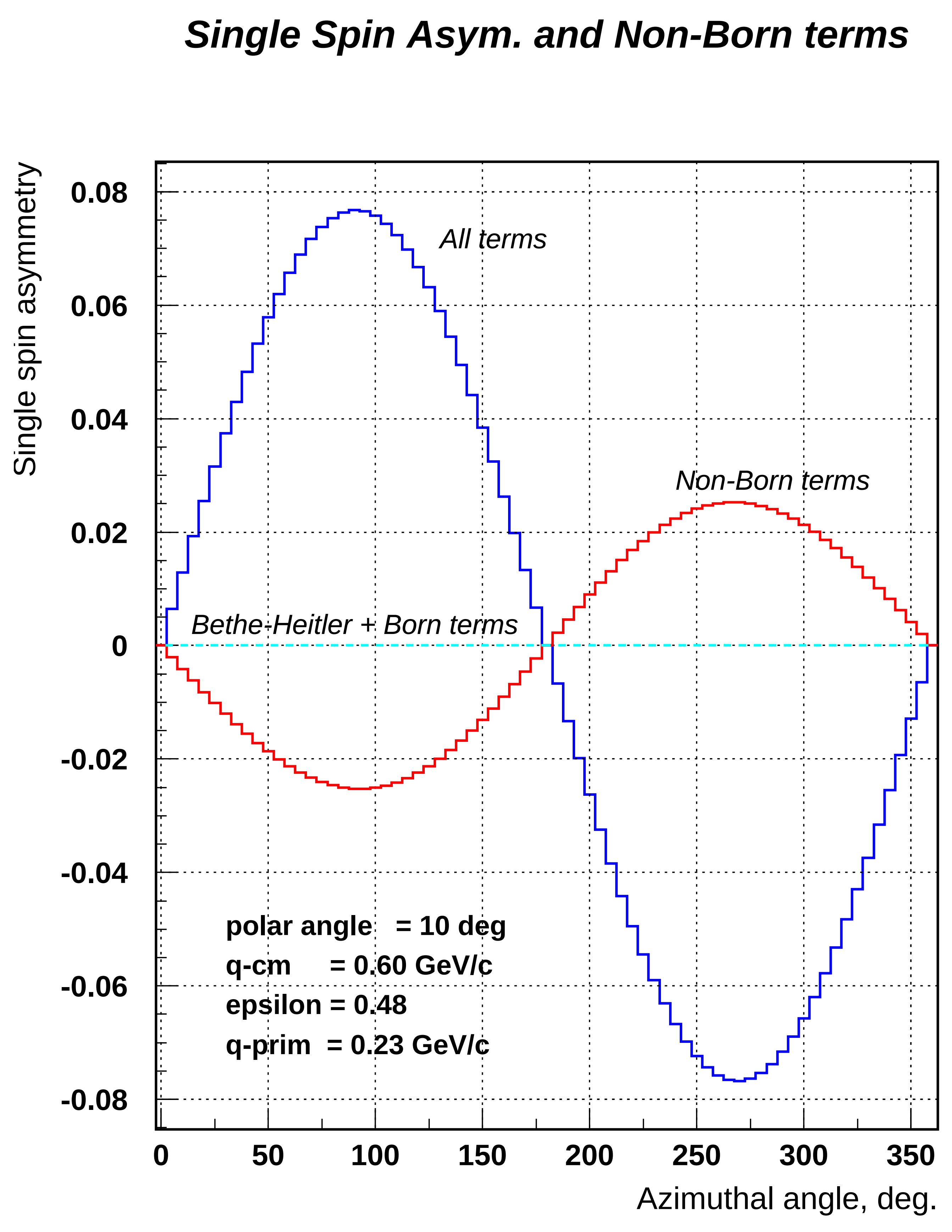
compute the model predictions and compare with our measurement.

Coincidence time and Missing Mass Squared of ($\vec{e}p \to epX$).



Single Spin Asymmetry of $\vec{e}p \rightarrow ep\gamma$ and $\vec{e}p \rightarrow ep\pi^0$.





Single Spin Asym. and Non-Born terms
Single spin asymmetry
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
All terms
Non-Born terms
Bethe-Heitler + Born terms
polar angle = 10 deg
q-cm = 0.60 GeV/c
epsilon = 0.48
q-prim = 0.23 GeV/c
0
50
100
150
200
250
300
350
Azimuthal angle, deg.

Conclusions.

- **VCS: new field to study nucleon structure**
- **My experiment: SSA $\longrightarrow$ test models**
- **Also in my thesis work: do theoretical calculations.**