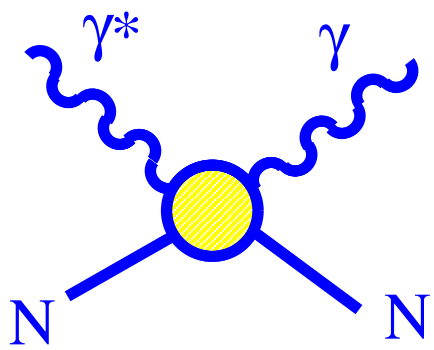
$\gamma^* p \to \gamma p$

Virtual Compton Scattering

BARYONS 2002 Conference
Jefferson Lab, March 3-8

H.Fonvieille
LPC-Clermont-Fd

Virtual Compton Scattering



the simplest electromagnetic process on the hadron after the absorption of a virtual photon

- $ep \to ep\gamma$: **radiative correction to elastic scattering** $ep \to ep$
  (γ emitted from hadronic vertex: $\ll$ electron bremsstrahlung)
- **contains specific information on nucleon structure !**
  (since R.Berg and C.Lindner, Nucl.Phys. 26 (1961) 259).

small $\sqrt{s}$ $(\leq (M_p + M_\pi))$ **any** Q^2	**large** $\sqrt{s}$ $(\gg M_p)$ **large** Q^2 **small** t **(small** $\theta_{\gamma\gamma}$**)**	**large** $\sqrt{s}$ $(\gg M_p)$ **large** Q^2 **large** t **(large** $\theta_{\gamma\gamma}$**)**
VCS at low energy	*Deep VCS*	*VCS in Hard Scattering*
Generalized Polarizabilities of the nucleon (GPs)	**Generalized Parton Distributions (GPDs)**	**Distribution amplitudes (DA)**

(1995 → . . .) **(1996 → . . .)** **(1990 → . . .)**

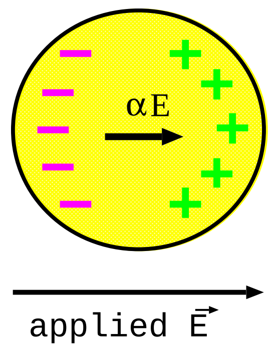
Content

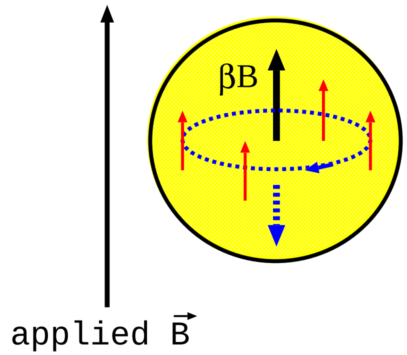
VCS at Low Energy

1. Concepts : GPs (Generalized Polarizabilities)
2. Extraction Method(s)
3. Experiments and Results
4. Future Prospects

Real Compton Scattering at low energy

$\gamma p \to \gamma p$: the final γ plays the role of an applied EM field





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

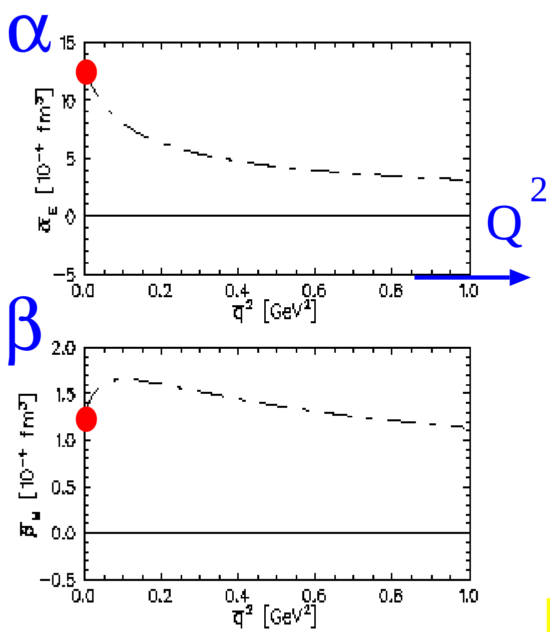
Electric polarizability	$\bar{\alpha} = (\ \mathbf{12.1}\ \ \pm 0.3_{stat} \mp 0.4_{syst})\ 10^{-4}$ **fm**^{3}
Magnetic polarizability	$\bar{\beta} = (\ \mathbf{1.6}\ \ \pm 0.4_{stat} \pm 0.4_{syst})\ 10^{-4}$ **fm**^{3}

- **Proton: very rigid object**

- $\bar{\beta} << \bar{\alpha}$ **: para/dia-magnetic cancellation in** β

Generalization to a virtual photon: $\gamma^* p \rightarrow \gamma p$

idea: $\alpha \rightarrow \alpha(Q^2)$, $\beta \rightarrow \beta(Q^2)$, **(+ other GPs)**



T.Hemmert et al.,
Phys.Rev.D 55 (1997) 2630.
Chiral Perturbation Theory

Generalized Polarizabilities:

measure the polarizability
locally inside the nucleon

(scale given by Q^2)

Goal of Experiments

Good observables to test nucleon structure

Polarizabilities and Resonances

Concept of Polarizability: $\Longleftrightarrow$ the nucleon gets deformed in an applied EM field

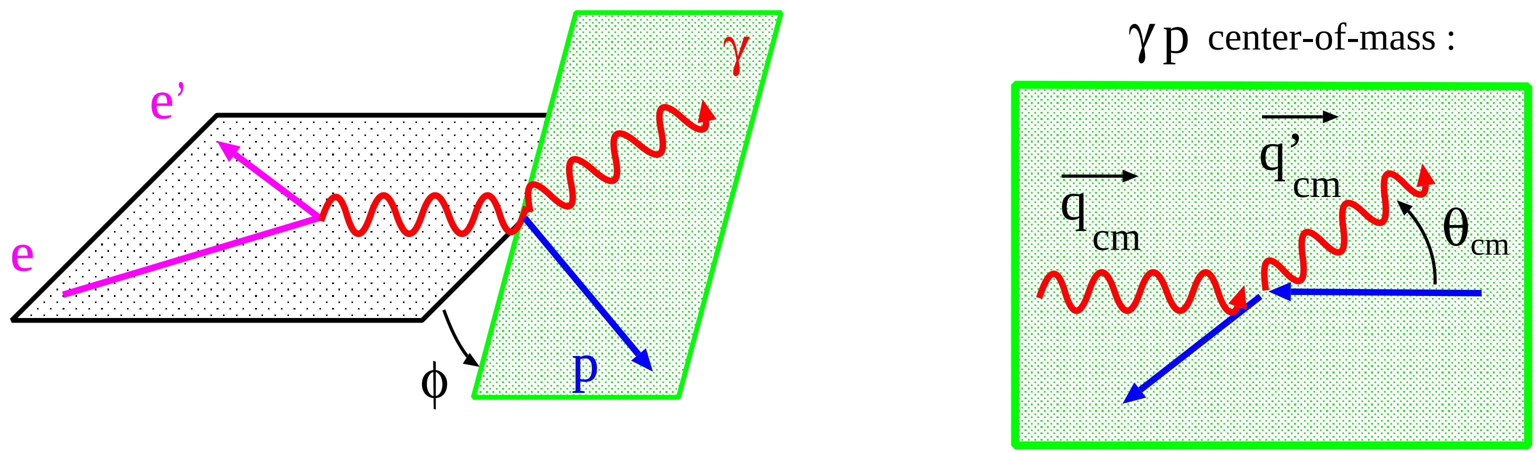
$\Longleftrightarrow$ it can go to an excited state (resonance)

amplitude T_{VCS} = sum over all possible intermediate states: proton (=Born) + resonances (=polarizab.)

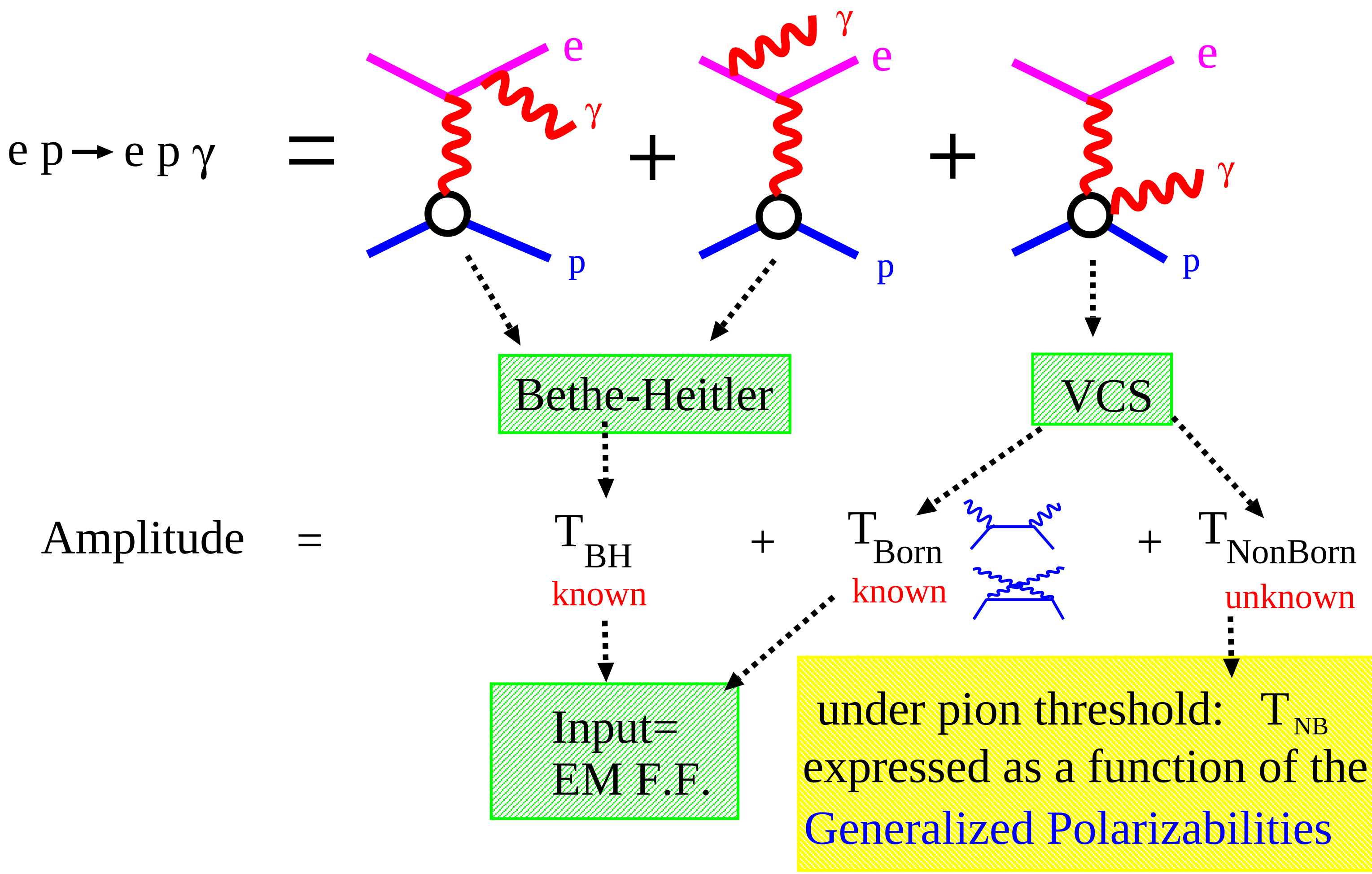
$T_{VCS} =$ real for $\sqrt{s} < (M_N + M_\pi)$ (Resonances contribute virtually)

$T_{VCS} =$ complex for $\sqrt{s} > (M_N + M_\pi)$ (Resonances formed on-shell)

VCS Kinematics



Virtual Compton Scattering



P.Guichon et al., Nucl.Phys. A591 (1995) 606.
P.Guichon, M.Vanderhaegen, Prog.Part.Nucl.Phys. 41 (1998) 125.
D.Drechsel et al., Phys.Rev. C55 (1997) 424.
D.Drechsel et al., Phys.Rev. C57 (1998) 941.

Photon Electroproduction cross section

$$d\sigma(ep\gamma) = d\sigma(\textbf{BHB}) + \textbf{Interf. (BHB).(NB)} + d\sigma(\textbf{NB})$$

$d\sigma$(BHB) $\downarrow$ *known*

Interf. $\downarrow$ *small*

$d\sigma$(NB) $\downarrow$ *negligible*

below π threshold

$q'_{cm} = 126$ MeV/c

- **Below π threshold:** P.Guichon et al., expansion in q'_{cm} **(LET)** $\Rightarrow$

$$d\sigma(ep\gamma) = d\sigma(\textbf{BH+Born}) + (PhaseSpace) \times \Big([\ \dots\ ] + O(q'_{cm}) \Big)$$

- **Basic Properties :**

$\star$ $d\sigma(ep\gamma) \rightarrow d\sigma(BHB)$ **when** $q'_{cm} \rightarrow 0$

$\star$ **[...] contains 6 GPs** derived from Multipolar expansion of the NonBorn VCS amplitude.

Generalized Polarizabilities

- **Multipole Expansion of the Non-Born VCS Amplitude:**

G.P. = $P^{(\rho' l', \ \rho \ l)S}(q_{cm})$

$\sim$ **limit of Multipole** $H_{NB}^{(\rho' l', \ \rho \ l)S}(q_{cm}, q'_{cm})$ **when** $q'_{cm} \to 0$

ρ, ρ' = photon polarization states (0,1,2= longitudinal, magnetic, electric)
l, l' = total angular momentum of initial (final) EM transition
S = proton spin-flip (S=1) or non spin-flip (S=0)

- **In lowest order term: 6 independent GPs**

final γ	initial γ^*	proton spin flip	$P^{(\rho' l' \rho l)S}(q_{cm})$	$P^{X\to Y}$	$Q^2 = 0$
E1	C1	0	$P^{(01,01)0}$	$P^{C1\to E1}$	$\frac{-4\pi}{e^2}\sqrt{\frac{2}{3}}\ \alpha$
E1	C1	1	$P^{(01,01)1}$	$P^{C1\to E1}$	0
M1	M1	0	$P^{(11,11)0}$	$P^{M1\to M1}$	$\frac{-4\pi}{e^2}\sqrt{\frac{8}{3}}\ \beta$
M1	M1	1	$P^{(11,11)1}$	$P^{M1\to M1}$	0
E1	M2	1	$P^{(01,12)1}$	$P^{M2\to E1}$	γ_3
M1	C2	1	$P^{(11,02)1}$	$P^{C2\to M1}$	$(\gamma_2 + \gamma_4)$

two Scalar GPs (S=0) and four Spin GPs (S=1) (Dipole GPs: l=1)

• Structure Functions:

$$P_{LL}(q_{cm}) = -2\sqrt{6}\ M_N\ G_E(\tilde{Q}^2)\ P^{(01,01)0}(q_{cm})$$
$$P_{TT}(q_{cm}) = -3\ G_M(\tilde{Q}^2)\ \frac{q_{cm}^2}{\tilde{q}_0} \times \left[\ P^{(11,11)1}(q_{cm}) - \sqrt{2}\tilde{q}_0\ P^{(01,12)1}(q_{cm})\ \right]$$
$$P_{LT}(q_{cm}) = \sqrt{\frac{3}{2}}\ \frac{M_N\ q_{cm}}{\tilde{Q}}\ G_E(\tilde{Q}^2)\ P^{(11,11)0}(q_{cm}) + \frac{3}{2}\ \frac{\tilde{Q}\ q_{cm}}{\tilde{q}_0}\ P^{(01,01)1}(q_{cm})$$

• in an unpolarized VCS experiment:

$$d\sigma(ep\gamma) = d\sigma(\text{BH+Born}) + (PhaseSpace)\times$$
$$\left(\ v_1\ [\ P_{LL}(q_{cm}) - \tfrac{1}{\epsilon}P_{TT}(q_{cm})\ ] + v_2\ [\ P_{LT}(q_{cm})\ ] \quad + \quad O(q'_{cm})\ \right)$$

$v_1, v_2 =$ known kinematic functions of $q_{cm}, \epsilon, \theta_{\gamma\gamma cm}, \phi_{\gamma\gamma}$.

• At fixed q_{cm} and ϵ , one measures two structure functions :

$P_{LL} - P_{TT}/\epsilon$ **sensitive to electric GP** $\alpha(Q^2)$

P_{LT} **sensitive to magnetic GP** $\beta(Q^2)$ $\rightarrow$ **to be compared to Model predictions**

Methods to extract GPs from Experiment

from absolute 5-fold differential $(ep \to ep\gamma)$ cross sections:

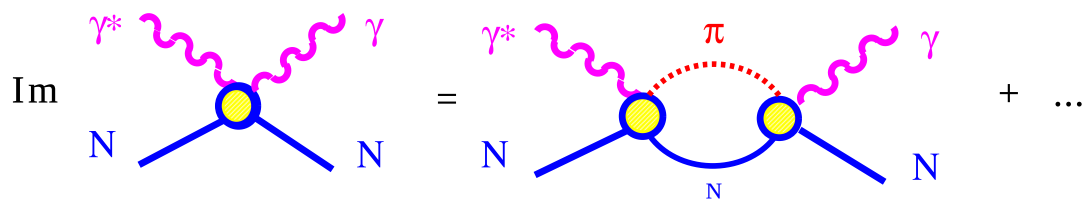
Method A (done at MAMI) below pion threshold only **"LET"**	**Method B** (new) below and above pion threshold **"DR"**
• based on **the LET** *(P.Guichon et al.,NP A 591 (1995) 606)* • in each bin in $(\theta_{\gamma\gamma}, \phi_{\gamma\gamma})$, extrapolate : $(d\sigma_{\text{exp}} - d\sigma_{\text{BH+Born}})/[PhaseSpace]$ to q'_{cm}=0 $\to$ yields $[\ v_1\ (P_{LL} - P_{TT}/\epsilon) + v_2\ P_{LT}\ ]$ • fit two parameters: $P_{LL}(q) - P_{TT}(q)/\epsilon$ and $P_{LT}(q)$	• based on **Dispersion Relation** *(B.Pasquini et al., Eur.Phys.J.A 11 (2001) 185)* • fit two free parameters $\Lambda_\alpha, \Lambda_\beta$ (Q^2-dependence of polarizabilities α and β) by χ^2 min. between $d\sigma_{\text{exp}}$ and $d\sigma_{\text{DR}}$ • then get the model prediction for: $P_{LL}(q) - P_{TT}(q)/\epsilon$ and $P_{LT}(q)$

Dispersion Relation Model for VCS

B.Pasquini, M.Gorchtein, D.Drechsel, A.Metz, M.Vanderhaeghen

(Eur. Phys. J. A 11 (2001) 185)

- Dispersion integrals:



- $\gamma^* N \rightarrow \pi N$ taken from MAID2000
- Asymptotic parts and contributions beyond πN
- two free parameters: Λ_α , Λ_β related to polarizabilities α and β :

$$\alpha(Q^2) - \alpha^{\pi N}(Q^2) \; = \; \frac{\alpha_0^{exp} - \alpha_0^{\pi N}}{(1 + Q^2/{\Lambda_\alpha}^2)^2} \; ,$$

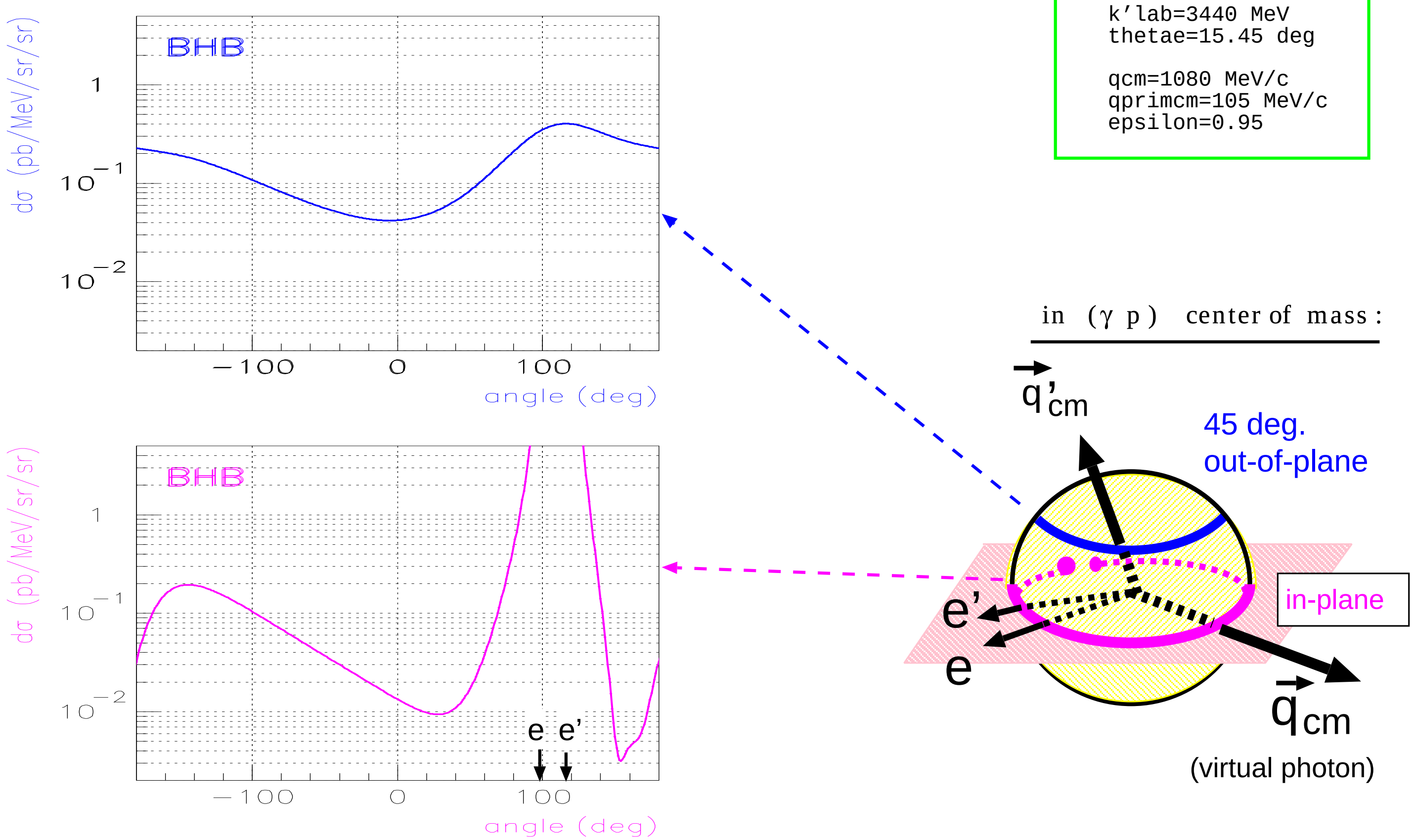
same relation for β

- no q'_{cm} expansion; DR $(\gamma^* p \rightarrow \gamma p)$ cross section includes all orders in q'_{cm}
- limited to $\sqrt{s} = W \leq (M_N + 2m_\pi)$, and not limited to small Q^2

Photon Electroproduction: BETHE-HEITLER + BORN cross section

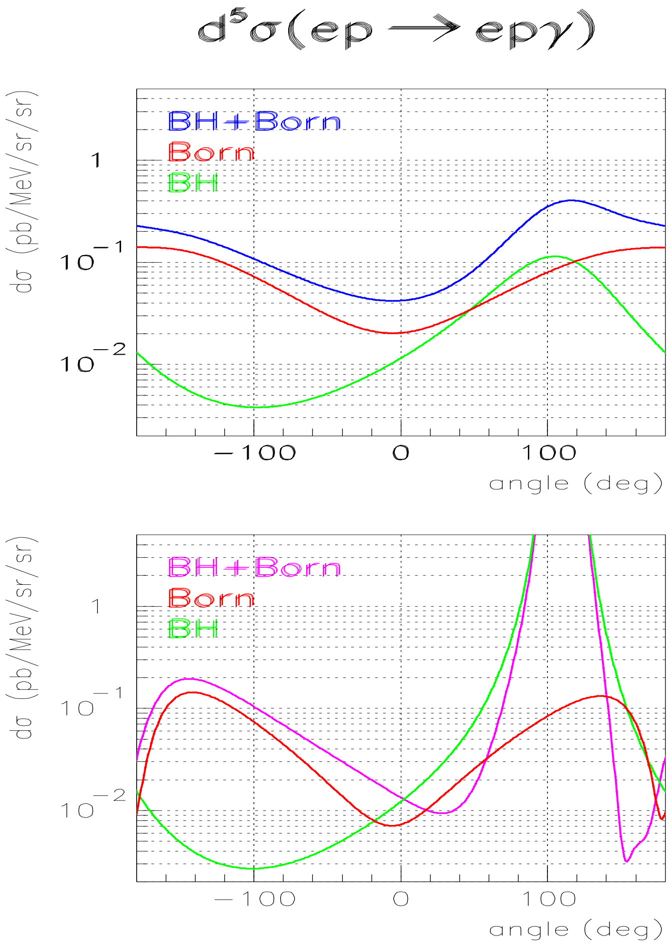
$d^5\sigma(ep \longrightarrow ep\gamma)/dk'_{lab}\, d\Omega_{elab}\, d\Omega_{\gamma\gamma cm}$

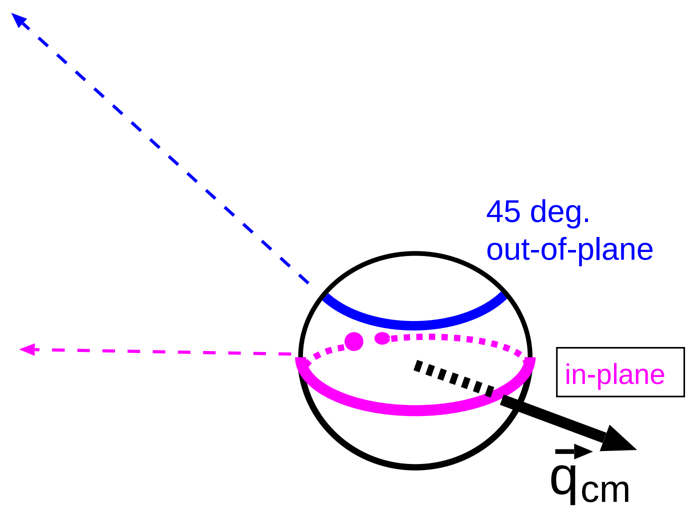
```
Q2 = 1.0 Gev2
klab=4100 MeV
k'lab=3440 MeV
thetae=15.45 deg

qcm=1080 MeV/c
qprimcm=105 MeV/c
epsilon=0.95
```



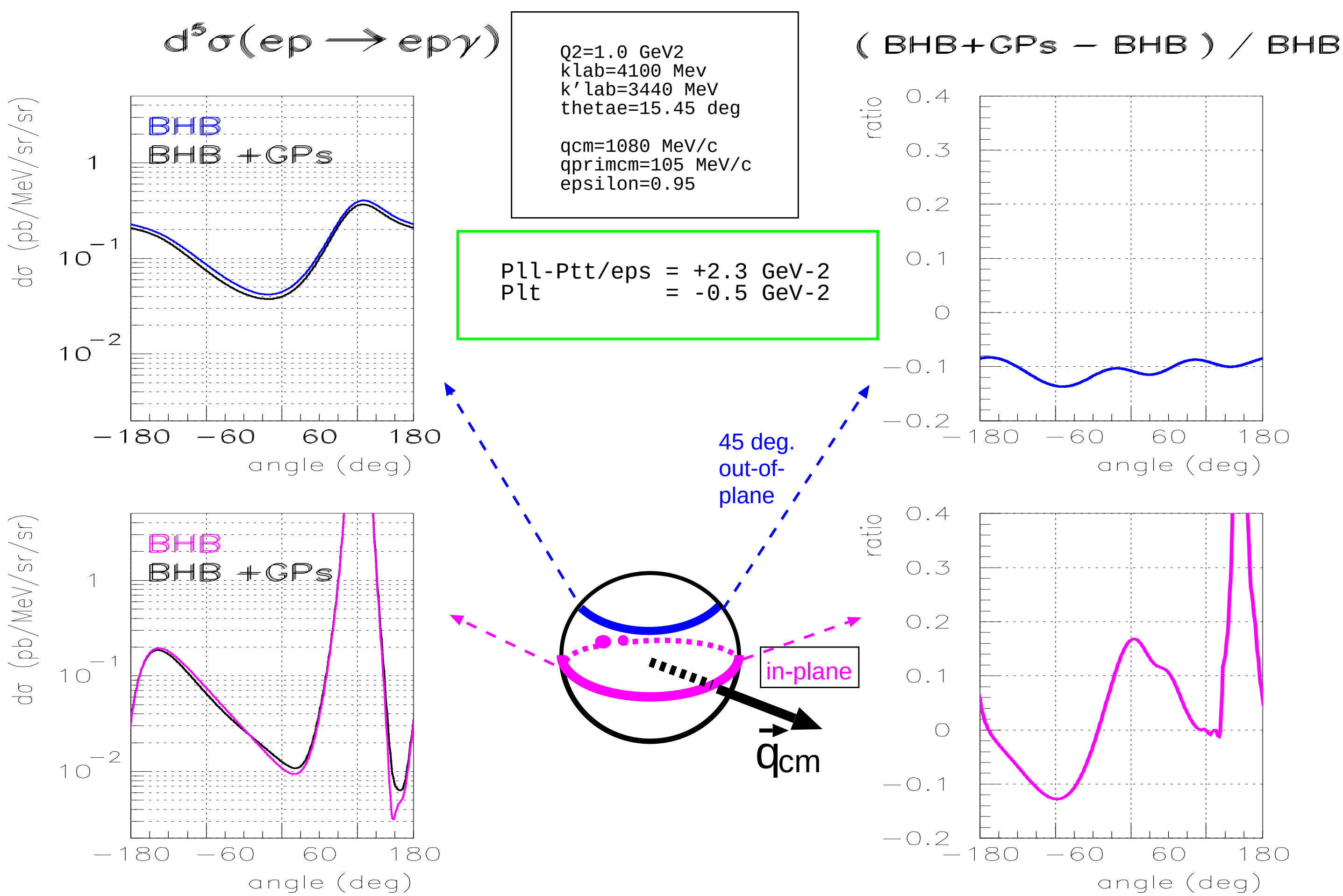
Components of BETHE-HEITLER + BORN cross section

$$\left| T_{BH} + T_{Born} \right|^2$$

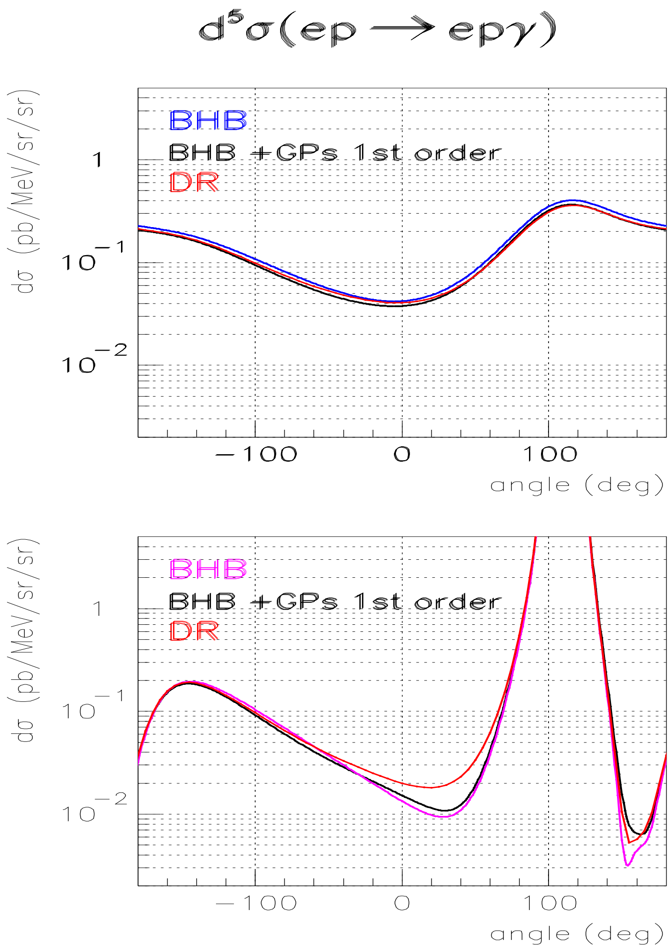




Photon Electroproduction: Effect of GPs at first order



Photon Electroproduction: Higher orders in q'_{cm}

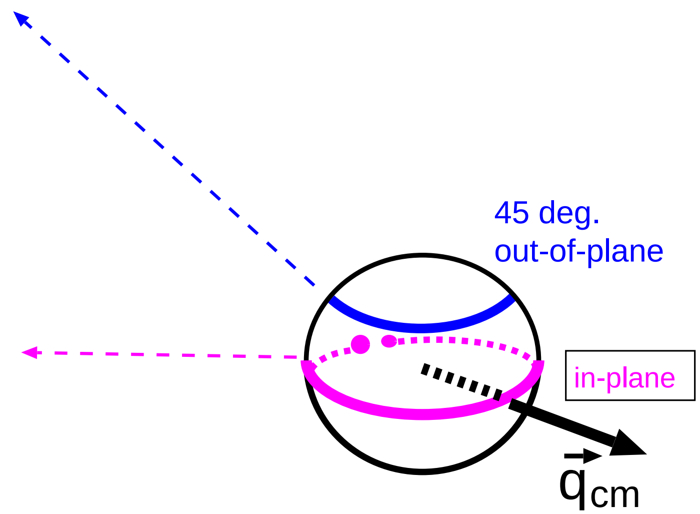


Dispersion Relation Model

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

Λ_α = 0.92 GeV

Λ_β = 0.66 GeV



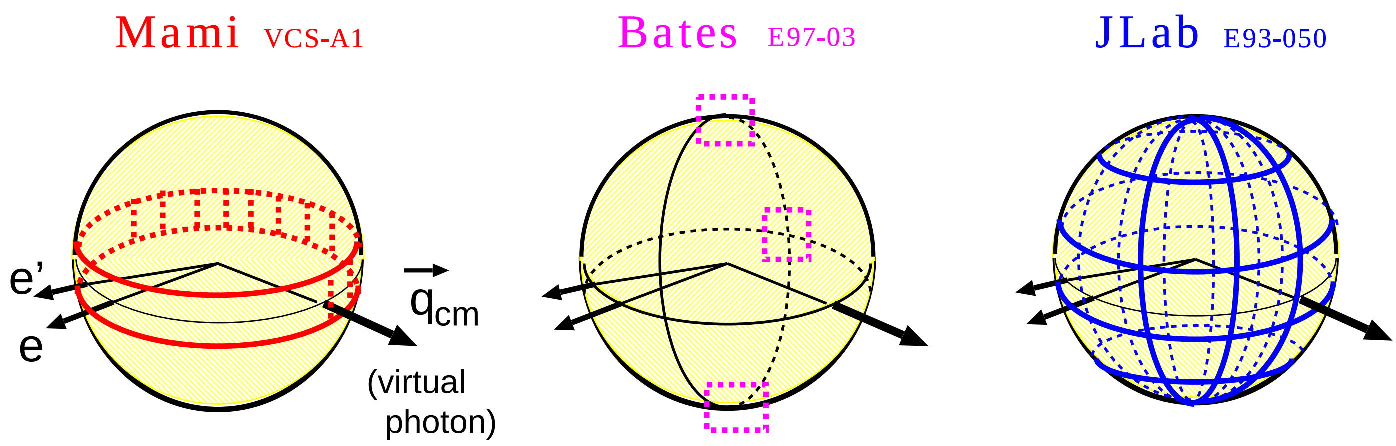
VCS at Low Energy : experiments

where	Q^2 (GeV^2)	$(\gamma^* p)$ c.m. energy $\sqrt{s}$	p cone θ_{pq}	data taking	status (@ end 2001)
MAMI A1 Coll.	0.33	$< (M_N + M_\pi)$	10°	1995+97	published
JLab (A) E93-050	1.0, 1.9	< 1.9 GeV	6°, 3°	1998	final stage
Bates E97-03	0.05	$< (M_N + M_\pi)$	28° OOPS	2000	analysis
Bates E97-05	0.12	~ 1.232 GeV	14-20° OOPS	2001	analysis

- **Detection:** magnetic spectrometers (γ = missing particle)
- **High Resolution:** separate γ and π^0 missing mass peaks
- accurate measurement of **absolute cross sections** $d^5\sigma(ep \to ep\gamma)$

(good knowledge of acceptance) (effect of GPs is small)

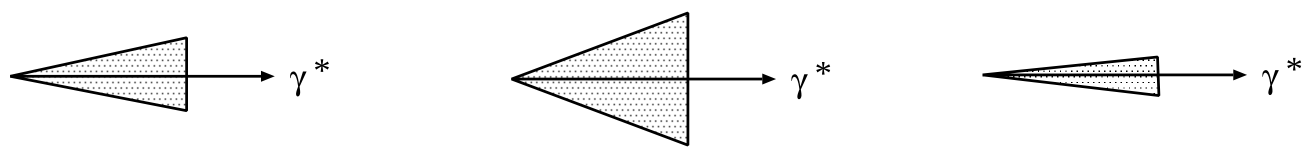
Acceptance in photon angles in $(\gamma^* p)$ center-of-mass



$Q^2 = 0.33$ GeV^2
Proton cone in lab : +/- 10 deg

$Q^2 = 0.05$ GeV^2
Proton cone in lab : +/- 28 deg

$Q^2 = 1$ (2) GeV^2
Proton cone in lab : +/- 6 deg

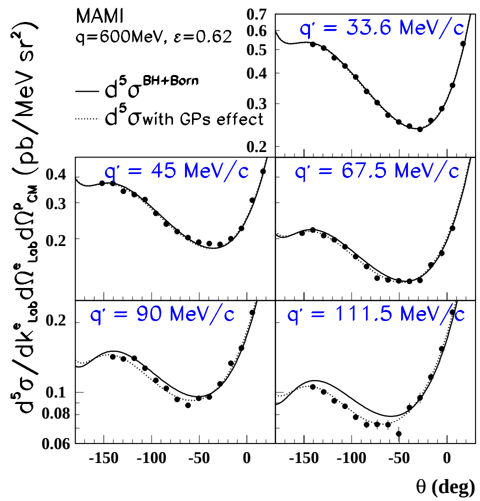


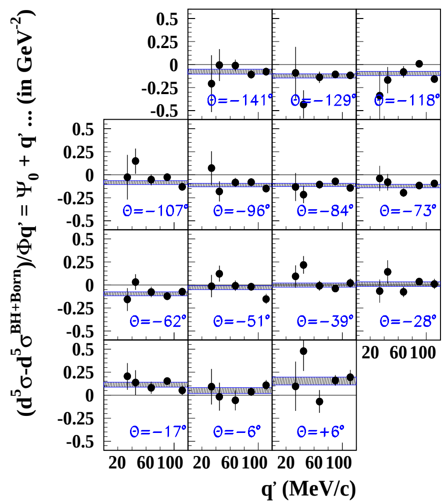
Mainz Experiment (below pion threshold)

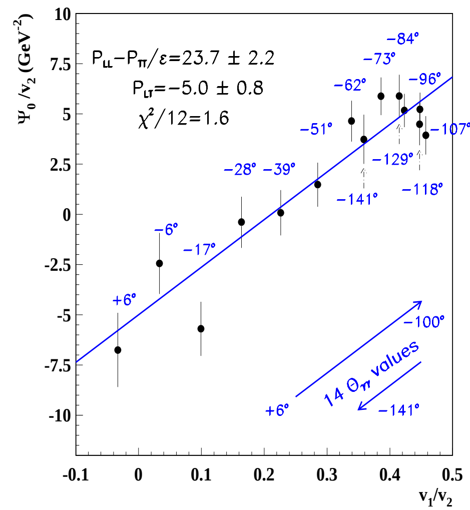
(J.Roche et al., PRL 85 (2000) 708)
(Q^2 =0.33 GeV^2)

$(d\sigma_{exp} - d\sigma_{BH+Born})/[PhaseSpace]$
$\sim [\ v_1(P_{LL} - P_{TT}/\epsilon) + v_2 P_{LT}\ ]$
= [...]

[...] / v_2 **vs** v_1/v_2







1.

measure $d\sigma(ep\gamma)$
for bins in q'_{cm}
and in $(\theta_{\gamma\gamma cm}, \phi_{\gamma\gamma})$

2.

extrapolate to $q'_{cm} = 0$
$\Longleftrightarrow$ **Average over** q'_{cm}
($\sim$ **no** q'_{cm} **dependence)**

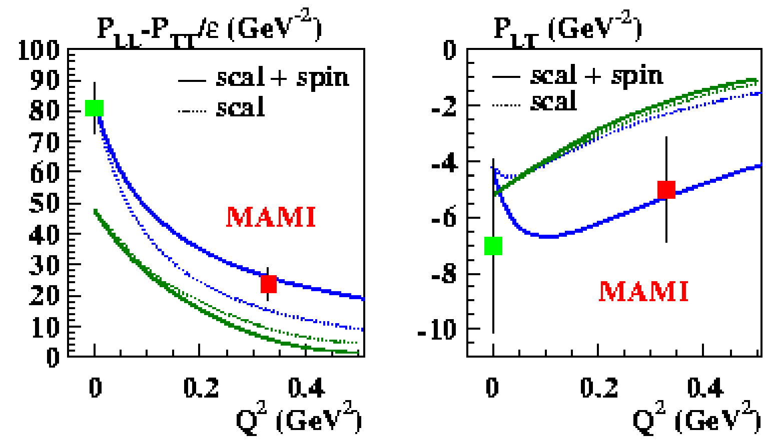
3.

plot extrapolated value versus kinem.factor

$P_{LL} - P_{TT}/\epsilon$ **= SLOPE**
P_{LT} **= INTERCEPT**

Results of VCS Mami (Courtesy: Nicole D'HOSE)

Results unpolarized VCS at $Q^2 = 0.33$



	$P_{LL}(Q^2) - \frac{1}{\varepsilon} P_{TT}(Q^2)$ [GeV^{-2}]	$P_{LT}(Q^2)$ [GeV^{-2}]
MAMI	$23.7 \pm 2.2 \pm 4.3$	$-5.0 \pm 0.8 \pm 1.8$
HBChPT	26.0	-5.3
ELM	5.9	-1.9
LSM	11.5	0.0
NRCQM1	11.1	-3.5
NRCQM2	14.9	-4.5

HBChPT Heavy Baryon Chiral Perturbation Theory
Th. Hemmert, B. Holstein, G. Knöchlein, S. Scherer
Phys. Rev. Lett. **79** (1997), Phys. Rev. **D 55** (1997)

ELM Effective Lagrangian Model
M. Vanderhaeghen, Phys. Lett. **B 368** (1996)

LSM Linear Sigma Model
A. Metz, D. Drechsel, Z. Phys. **A356** (1996), Z.P. **A 359** (1997)

NRCQM1 Non Relativistic Constituent Quark Model
G. Q. Liu, A. W. Thomas, P. A. M. Guichon, Aust. J. Phys. **49** (1996)

NRCQM2 Non Relativistic Constituent Quark Model
B. Pasquini, S. Scherer, D. Drechsel, nucl-th/0008046

BATES E97-03 VCS experiment

Q^2		$\theta_{\gamma\gamma cm}$	$\phi_{\gamma\gamma}$
0.05 GeV^2	q_{cm} = 240 MeV/c	90°	90,180,270 $^\circ$ (out-of-plane OOPS)
	ϵ = 0.92		
$\downarrow$		$\downarrow$	$\downarrow$
test the turn-over of P_{LT}	q'_{cm} = 28-115 MeV/c	far from BH peaks	separate $P_{LL} - P_{TT}/\epsilon$ and P_{LT} by ϕ-dependence

- **Status: analysis in progress** (data taking: year 2000)
  - 2001 spectrometer optics studies (sieve-slit in OHIPS)
    - Missing mass γ peak, proton spectrometers MC studies
  - 2002 MC studies, normalization of data

- **Lab achievement:**
  - 1st use of high duty factor beam in South Hall Ring
  - 1st use of full OOPS system

JLab E93-050 VCS experiment in Hall A

Set I	Q^2 = 1.0 GeV^2	$\sqrt{s}$ mostly below pion threshold	100000 events
Set II	Q^2 = 1.9 GeV^2	$\sqrt{s}$ mostly below pion threshold	46000 events
Set III	Q^2 = 1.0 GeV^2	Resonances: $1.0 < \sqrt{s} < 2.0$ GeV	28000 events

- **Key points of experimental analysis:**

  ⋆ (I,II) vicinity of elastic peak ⇒ **CUTS** (punchthrough protons)

  ⋆ accurate **Monte-Carlo** for solid angle calculation
  - reproduce experimental resolution
  - include radiative corrections
  - use realistic input cross section

- **Advantages:**

  ⋆ Lorentz boost → large acceptance w.r.t. outgoing photon phasespace

  ⋆ several methods to extract structure functions $P_{LL} - P_{TT}/\epsilon$ and P_{LT}

JLab VCS-E93050 Results

Absolute normalisation : under control at the $\sim$ **2 % level**

- Elastic (ep) cross sections
- $(ep\gamma)$ cross sections at low q'_{cm}
  - $\star$ almost no GP effect
  - $\star$ χ^2 test between $[renorm.factor] \times d\sigma_{exp}$ and $d\sigma_{BH+Born}$ (+GPs)
  - $\star$ reduced $\chi^2 \sim 1$ and $|renorm.factor - 1.00| \leq 0.02$

Choice of proton EM Form Factors (in $\sigma_{BH+Born}$) :

$\star$ G_M^p param.of Bosted (P.Bosted, Phys.Rev. C 51 (1995) 409)

$\longrightarrow$ $\star$ G_M^p **param.of Brash et al.** differs by 1.8 (2.4) % at $Q^2 = 1(2)$ GeV^2
(E.Brash et al., hep-ex/0111038)

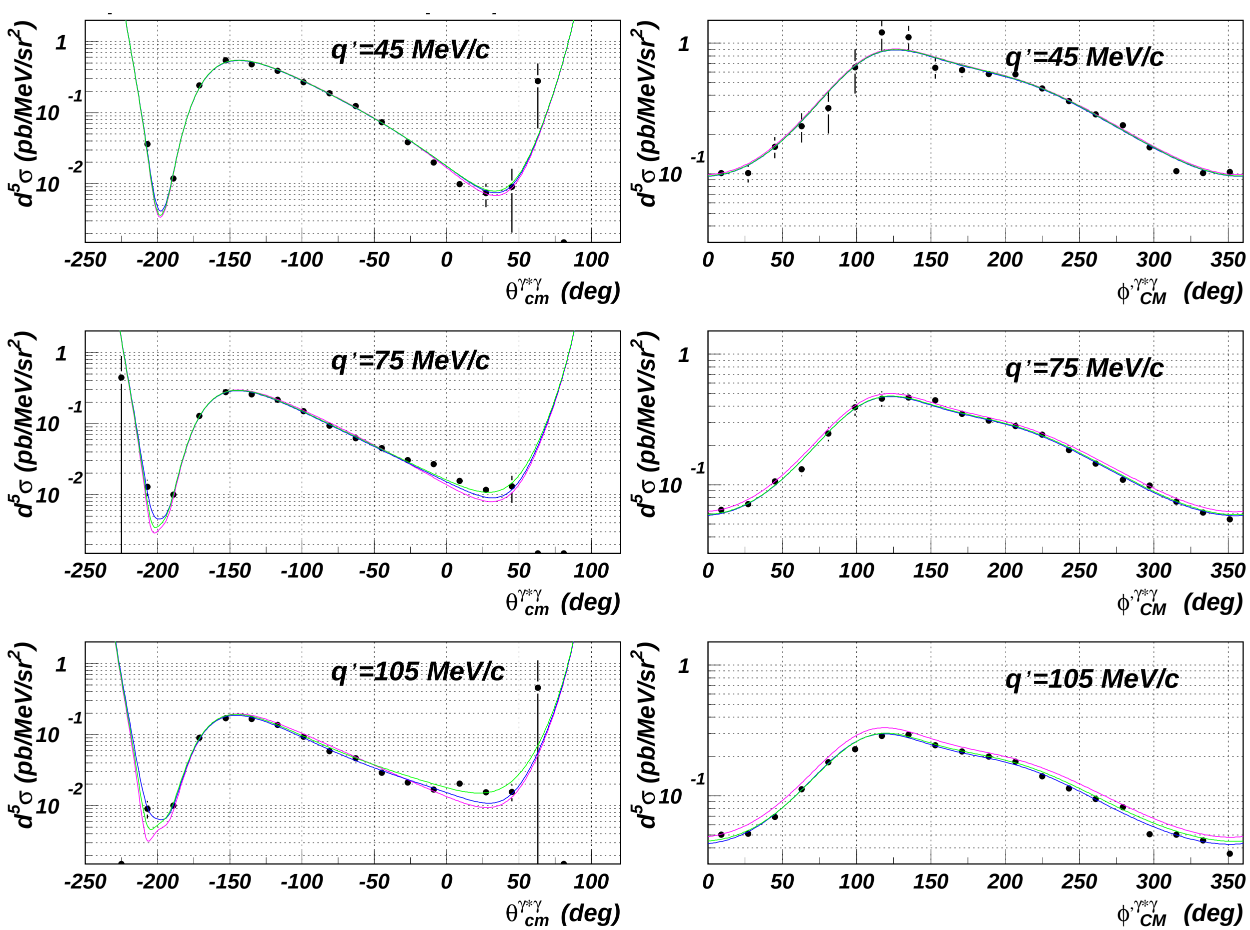
$\longrightarrow$ $\star$ $\mu G_E/G_M$ **from JLab expt** (O.Gayou et al., Phys.Rev.Lett.88:092301,2002)

JLab-E93050. Cross sections at $Q^2 = 1$ GeV^2 , below pion threshold

$q_{cm} = 1080$ **MeV/c,** $\epsilon =$ **0.95,** $\tilde{Q}^2 =$ **0.923 GeV^2**

_______ BH+Born _______ DR model _______ BH+Born+GPs 1st order (2.3,-0.4 GeV-2)

In-plane 50 deg. out-of-plane

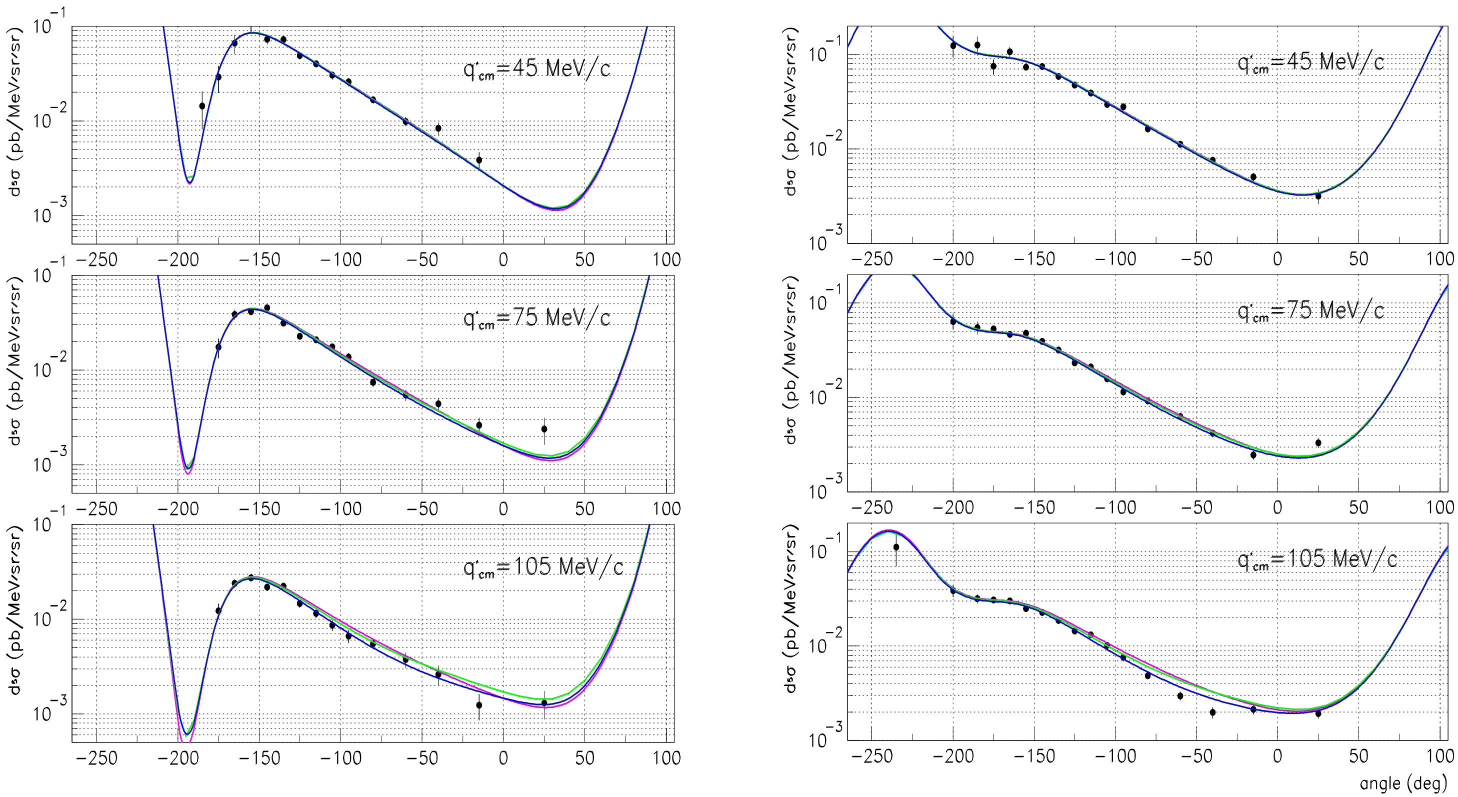


JLab-E93050. Cross sections at Q^2 = 1.9 GeV^2 , below pion threshold

$q_{cm} = 1600$ **MeV/c,** $\epsilon =$ **0.88,** $\tilde{Q}^2 =$ **1.72 GeV^2**

_______ BH+Born _______ DR model _______ BH+Born+GPs 1st order (0.56,0. GeV-2)

In-plane 25 deg. out-of-plane



JLab-E93050. fit of Generalized Polarizabilities by Method A

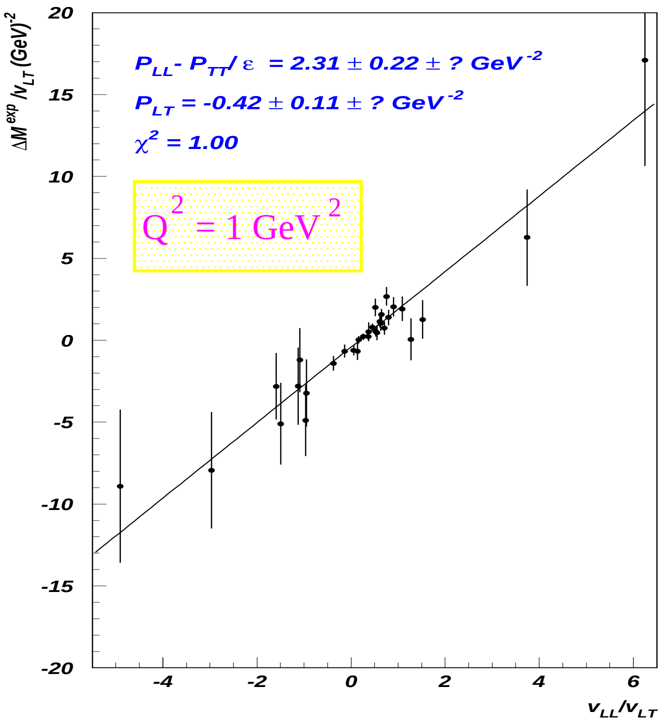
- **LET :** $d\sigma_{exp} = d\sigma_{BH+Born} + (PhaseSpace) \times \left[v_1(P_{LL} - \frac{1}{\epsilon}P_{TT}) + v_2\, P_{LT} + O(q'_{cm}) \right]$
- **no noticeable dependence of** $[(d\sigma_{exp} - d\sigma_{BH+Born})/PhaseSpace]$ **versus** q'_{cm}

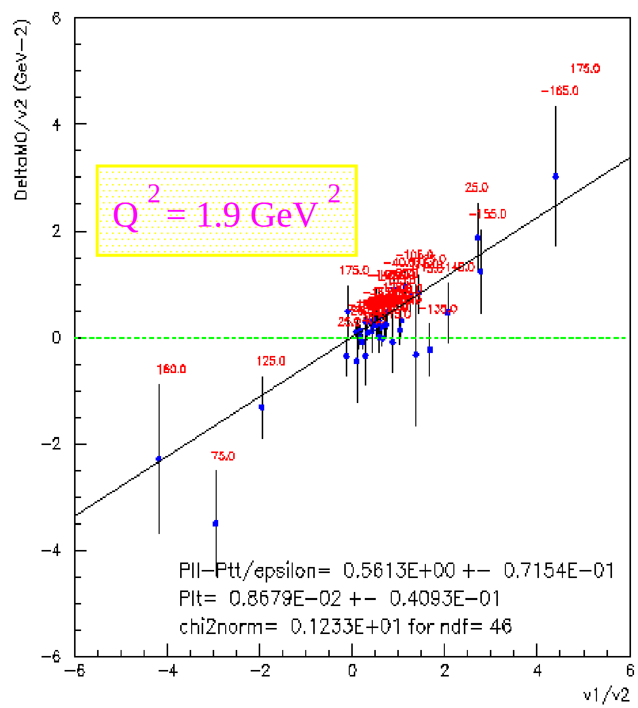
  $\Rightarrow$ **higher orders terms small (below pion threshold)**

  $\Rightarrow$ **average in** q'_{cm} **and make a linear fit with two free parameters**

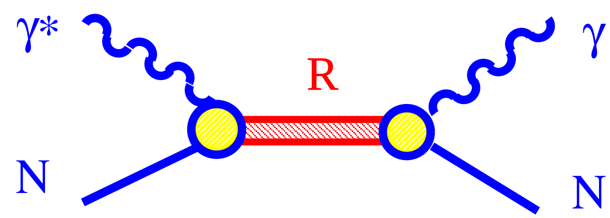
  - **Graphic Representation:** $[...]/v_2$ **versus** v_1/v_2 $\rightarrow$ **intercept** $= P_{LT}$

    $\rightarrow$ **slope=** $P_{LL} - P_{TT}/\epsilon$





JLab E93-050 VCS in the Resonance Region

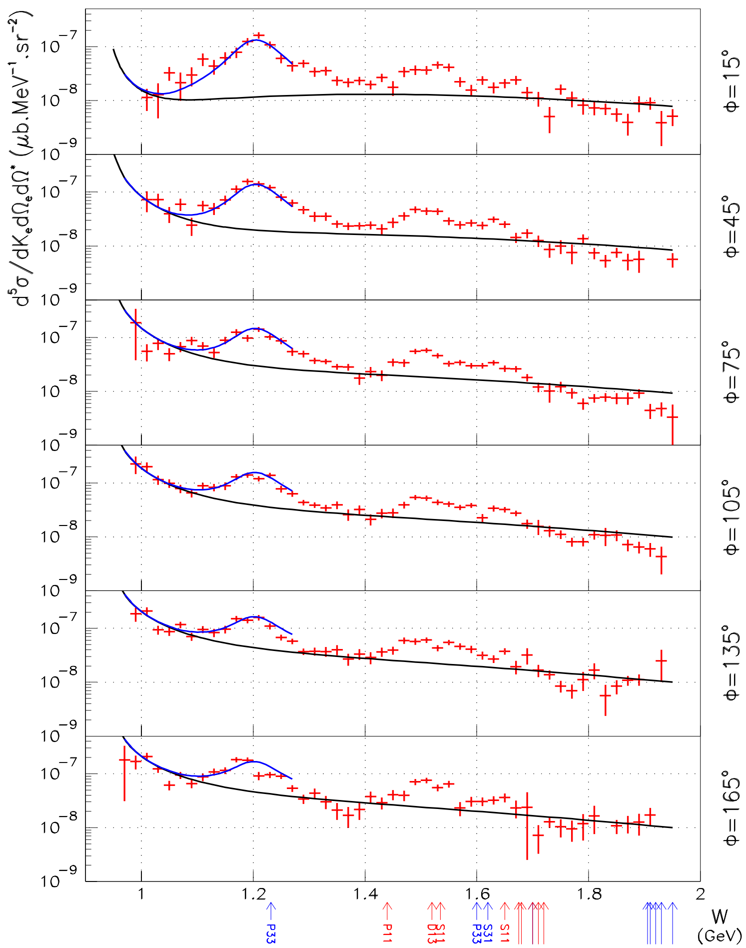


- excitation scan in $W = \sqrt{s}$, from M_N to 1.9 GeV
  - 1st measurement of 5-fold $d\sigma(ep\gamma)$ in this channel
  - see how resonances show up (missing res.?)
  - fixed $Q^2 = 1$ GeV^2
  - backward angle $\theta_{\gamma\gamma cm}$ (keep Bethe-Heitler small)

E93050 - Photon Electroproduction versus Phi and W

5-fold cross section: $d^5\sigma(ep \to ep\gamma)/dk'_{lab}d\Omega_{elab}d\Omega_{\gamma\gamma cm}$

at Q^2 **= 1 GeV^2,** $\theta_{\gamma\gamma cm} = 167.2°$



BetheHeitler +Born

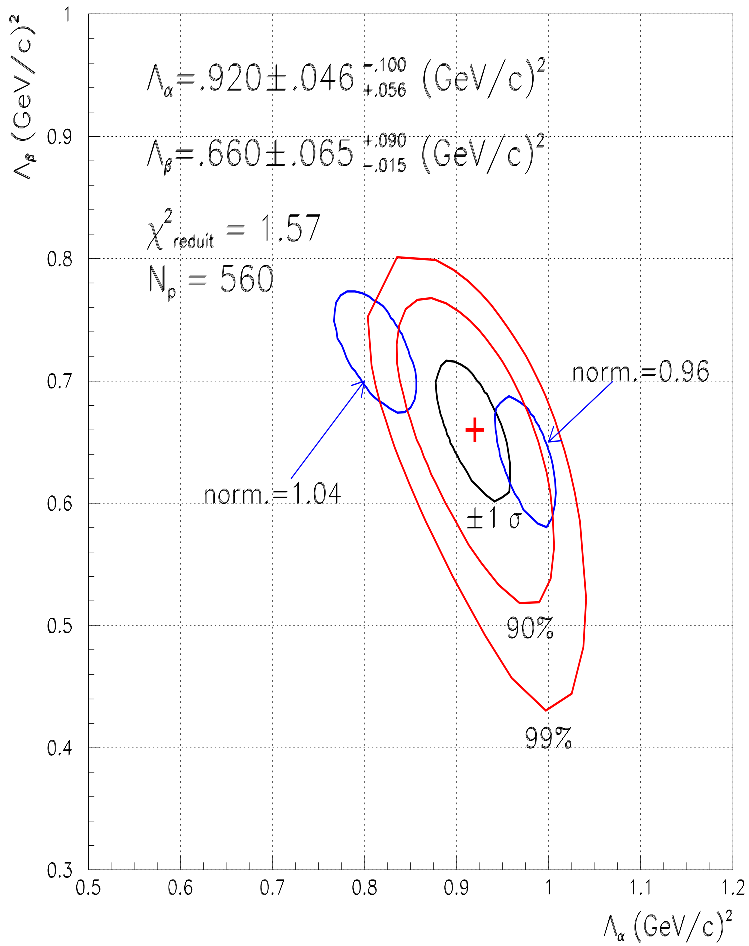
- Dispersion Relation Model for W < 1.3 GeV
  (La=1.00, Lb=0.45 GeV)
- Lack of models for the whole range in W
- phi-dependence: separation of L,T,TT,TL response functions distorted by Bethe-heitler interf.

use DR Model

-> extract GPs

(Method B)

GPs from Analysis in Resonance Region



Principle:

- make a chisquare between experimental cross sections and cross sections given by DR model

- adjust the free parameters by minimizing chisquare

at Q^2 =1 GeV^2 :

P_{LL} = + 1.85 +/- 0.24(stat) +0.30-0.49(syst) GeV^{-2}

P_{TT} = -0.418 GeV^{-2} (given by the model)

P_{LL} - P_{TT} /0.95 = + 2.29 +/- 0.24(stat) GeV^{-2}

P_{LT} = - 0.53 +/- 0.12(stat) +0.16-0.03(syst) GeV^{-2}

Measurements of GPs as of today

(JLab: Preliminary)

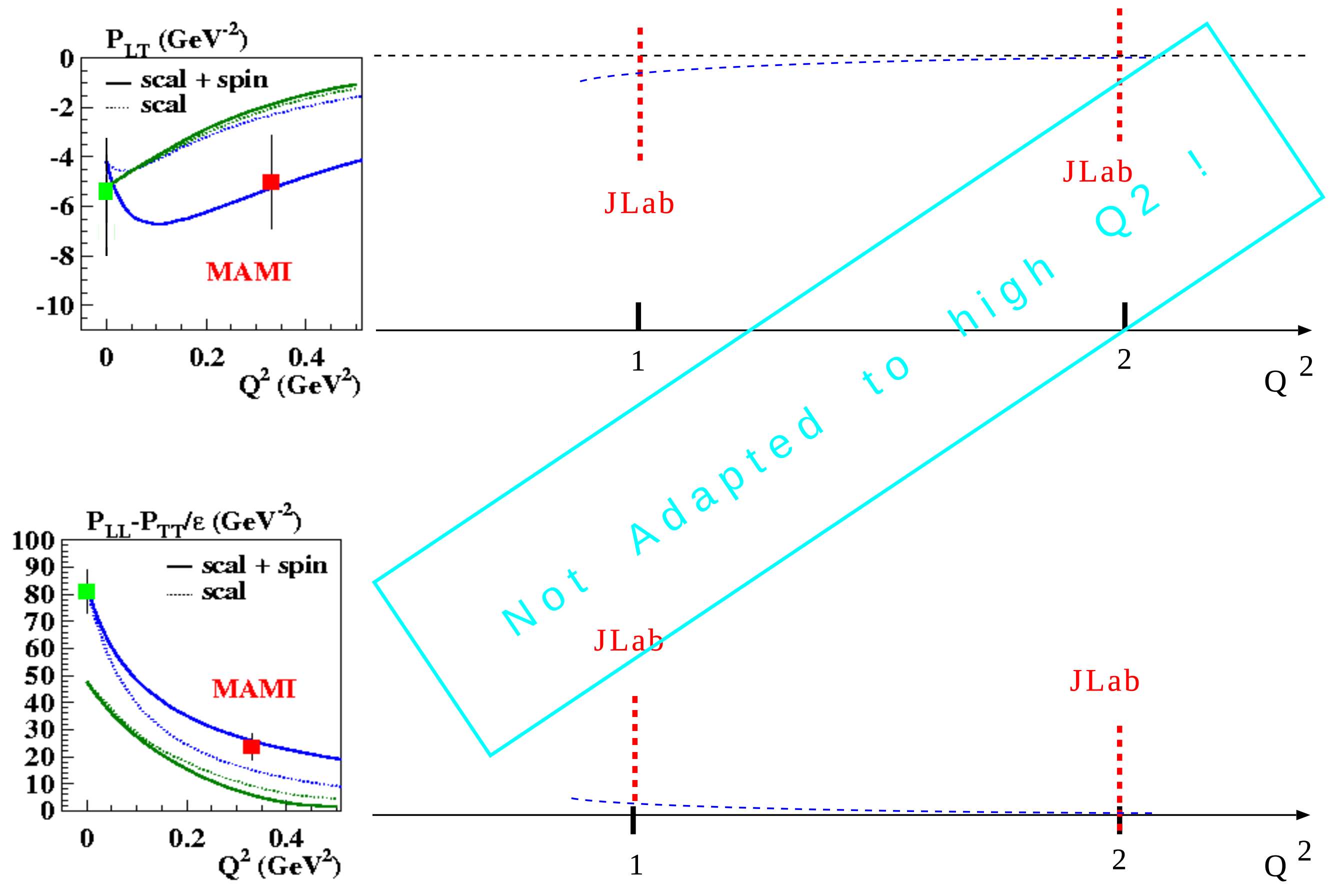
$$P_{LL}(q) - P_{TT}(q)/\epsilon$$

Q^2 (GeV^2)	q_{cm} (MeV/c)	ϵ	Structure function (GeV^{-2})
0.33	600	0.62	LET: +23.7 $\pm$ 2.2 (stat) $\pm$ 4.3 (syst)
1.0	1080	0.95	LET: +2.31 $\pm$ 0.22(stat) $\pm$ 0.35(syst) $\pm$ •
	1133	0.95	DR : +2.29 $\pm$ 0.24(stat) $^{-0.49}_{+0.30}$ (syst)
1.9	1600	0.88	LET: +0.56 $\pm$ 0.07(stat) $\pm$ 0.11(syst) $\pm$ •
	1600	0.88	DR : [+0.43,+0.84]

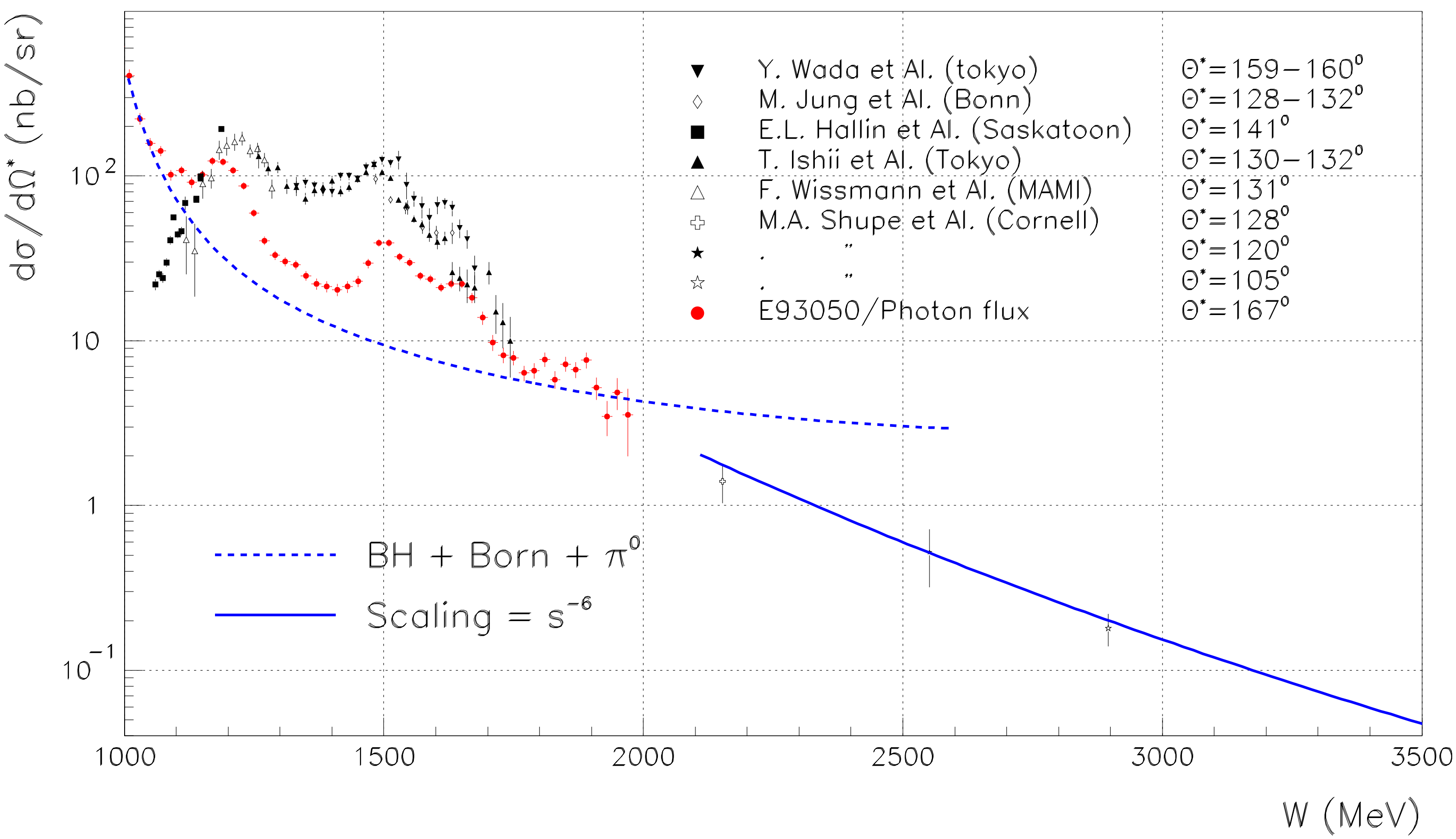
$$P_{LT}(q)$$

Q^2 (GeV^2)	q_{cm} (MeV/c)	ϵ	Structure function (GeV^{-2})
0.33	600	0.62	LET: $-$ 5.0 $\pm$ 0.8 (stat) $\pm$ 1.8 (syst)
1.0	1080	0.95	LET: $-$ 0.42 $\pm$ 0.11 (stat) $\pm$ 0.02(syst) $\pm$ •
	1133	0.95	DR : $-$ 0.53 $\pm$ 0.12(stat) $^{-0.03}_{+0.16}$ (syst)
1.9	1600	0.88	LET: +0.009 $\pm$ 0.041(stat) $\pm$ 0.005(syst) $\pm$ •
	1600	0.88	DR : [$-$0.05,+0.02]

Measured Structure Functions



High W: comparison VCS/RCS



Related topics

- **neutron** Generalized Polarizabilities ?

neutron polarizabilities (at $Q^2 = 0$) poorly known:

$\alpha_n = (1.20 \pm 0.15 \pm 0.20) \times 10^{-3}\ fm^3$ — J. Schiedmayer et al., PRL 66 (1991) 1015

(discussed $\rightarrow \leq 2.10^{-3}\ fm^3$)

$\alpha_n = (0.8 \pm 1.0) \times 10^{-3}\ fm^3$ — L.Koester et al., Z.Phys. A 329 (1988) 229

$\alpha_n = (0.0 \pm 0.5) \times 10^{-3}\ fm^3$ — L.Koester et al., Phys.Rev. C 51 (1995) 3363

$\beta_n =$ **?**

isospin-averaged nucleon polarizabilities:

$\alpha - \beta = (2.6 \pm 1.8) \times 10^{-4}\ fm^3$ — D.Hornidge et al., PRL 84 (2000) 2334

- **nucleus** GPs ?
- **pion** GPs, and **all other hadrons ...**

Future prospects in VCS

- **Low energy (below π threshold): Generalized Polarizabilities**

  $\star$ **unpolarized experiments:**
  improve the mapping in Q^2
  separate P_{LL} and P_{TT} using lever arm in ϵ
  $\star$ **polarized experiments:** $\vec{e}p \to e\vec{p}\gamma$
  separate the six GPs entering at first order
  planned at MAMI at $Q^2 = 0.33$ GeV^2, and Bates

- **Resonance region ($W < 2$ GeV): GPs & Resonance Study**

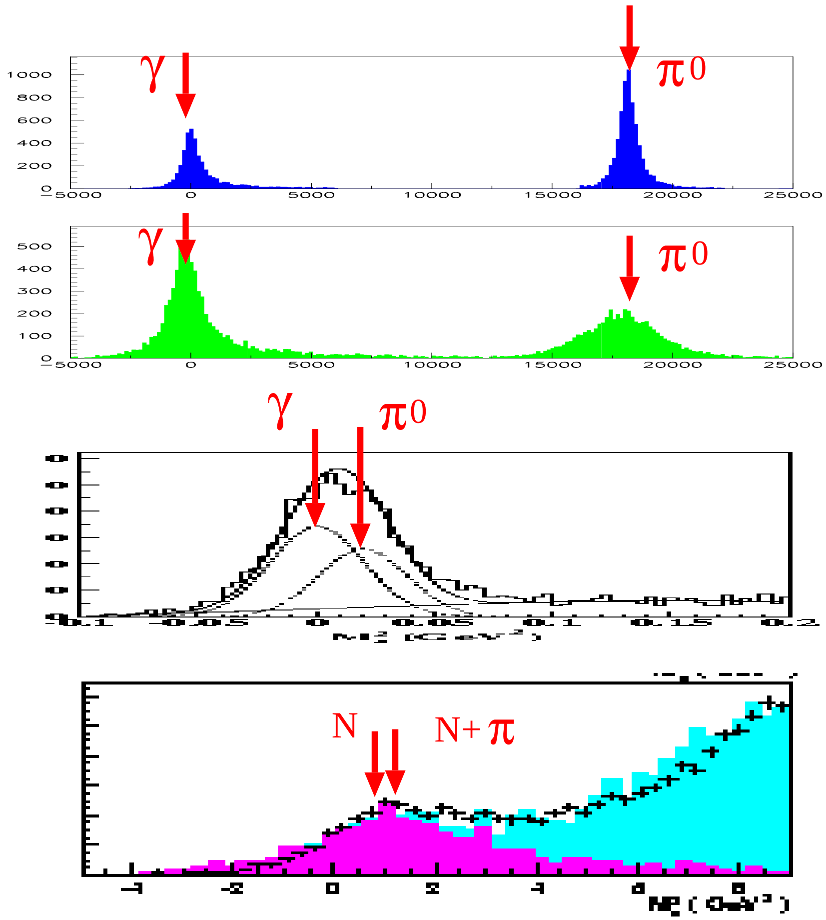
  JLab VCS-E93050: demonstrated feasibility
  sensitivity to GPs $\to$ measure at higher Q^2
  $\star$ **unpol. and polarized experiments**

- **Higher energies: Deep VCS and the GPDs**

  $\star$ **polarized** $\vec{e}p \to ep\gamma$ $\to$ **SSA: very active field!**
  published: Hermes (28 GeV), JLab Hall B (4 GeV)
  future: JLab Halls A and B (E=6 GeV), Hermes and Compass

Challenges for Detection

Missing mass Squared M_X^2 :



epX MAMI — Ebeam = 855 MeV, spectrom.resol = 1.e-4

epX JLab Hall A — Ebeam = 4 GeV, spectrom.resol. = 1.e-4

epX JLab Hall B — Ebeam = 4 GeV, mom. resol . = 1.e-2

eγ X HERMES — Ebeam = 28 GeV

High energies: need to detect all three particles