Measurement of Generalized Polarizabilities of the Proton by Virtual Compton Scattering

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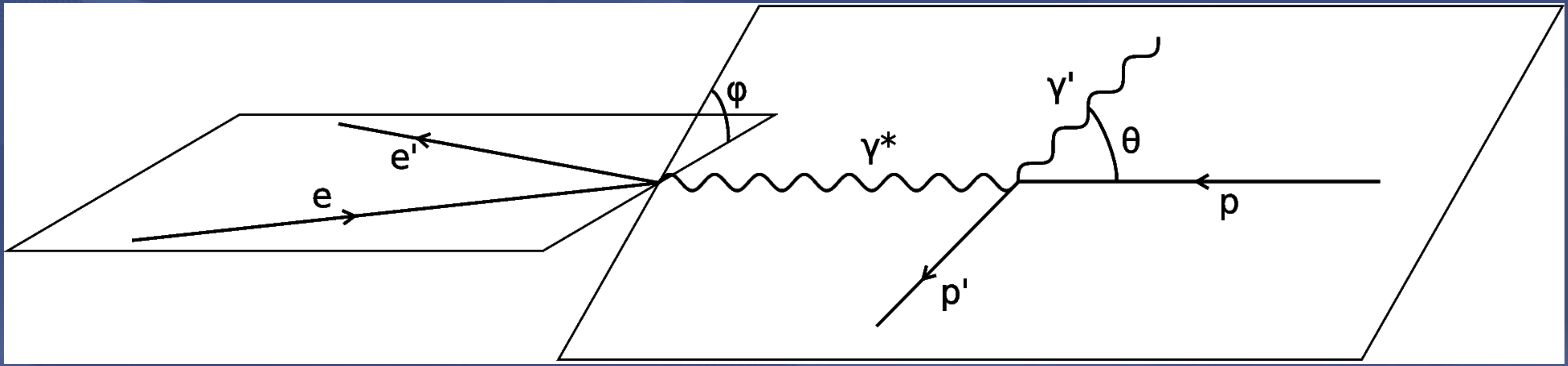
Electromagnetic interaction as a probe

- powerful tool for investigating the nucleon structure
  - relatively weak
  - can be calculated very accurately in quantum electrodynamics
- elastic electron scattering
  - form factors
- deep inelastic scattering
  - structure functions
- real Compton scattering
  - static electric and magnetic polarizabilities
- Virtual Compton Scattering (VCS)
  - generalized polarizabilities

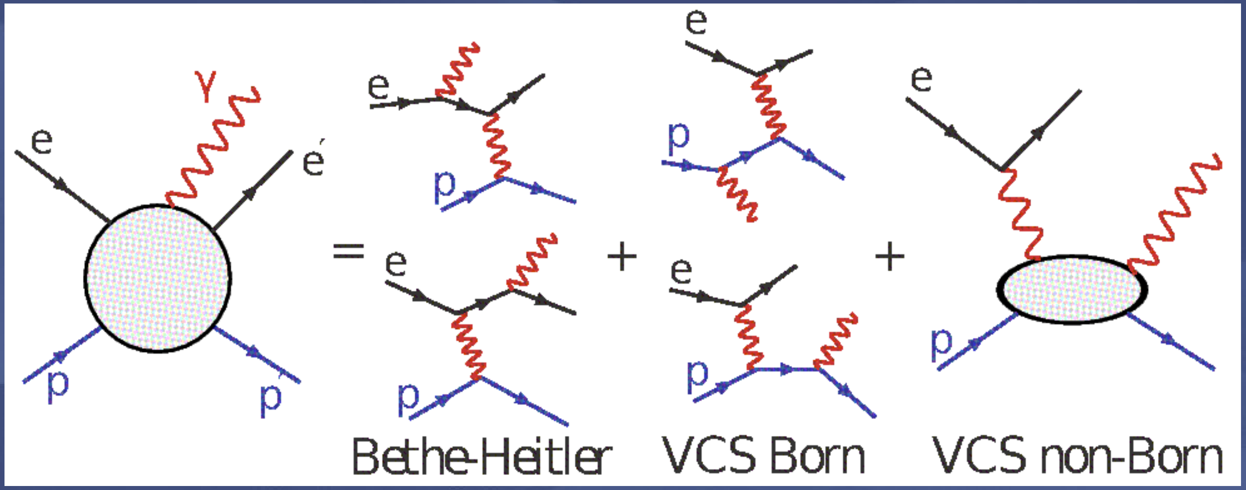
Virtual Compton Scattering on a proton

- VCS is the process: $\gamma^* + p \rightarrow \gamma + p'$
- experimentally accessible via photon electroproduction reaction $e + p \rightarrow e' + p' + \gamma$
- kinematics defined by 5 independent variables
  - e.g.: $(k_{lab}, k'_{lab}, \theta'_e, \theta_{\gamma\gamma cm}, \varphi_{cm})$
  - or: $(q_{cm}, q'_{cm}, \epsilon, \theta_{\gamma\gamma cm}, \varphi_{cm})$



Photon electroproduction - contributions

- amplitude is a coherent sum of the Bethe-Heitler, Born and non-Born contributions
- Bethe-Heitler and Born
  - known
  - depend only on elastic form factors G_E and G_M
- non-Born
  - unknown
  - at low energies parametrized by generalized polarizabilities - GPs



Low-Energy eXpansion or LEX

- expansion in powers of q'_{cm} (low-energy expansion)
- for unpolarized scattering:

$$d^5\sigma(ep\gamma) = d^5\sigma_{BH+B} + (\Phi q'_{cm}) \cdot \left[v_{\mathrm{LL}} \cdot (P_{\mathrm{LL}} - P_{\mathrm{TT}}/\epsilon) + v_{\mathrm{LT}} \cdot (P_{\mathrm{LT}})\right] + O(q'^{2}_{cm})$$

P.A.M.Guichon et al., NPA 591 (1995) 606.

- 2 structure functions
  - $P_{\mathrm{LL}} - P_{TT}/\epsilon = \frac{4m_p}{\alpha} G_e^p(Q^2) \cdot \alpha_E(Q^2) + [\text{spin-flip GPs}]$
  - $P_{\mathrm{LT}} = -\frac{2m_p}{\alpha}\sqrt{\frac{q_{cm}^2}{Q^2}} G_e^p(Q^2) \cdot \beta_M(Q^2) + [\text{spin-flip GPs}]$
- for extraction of the scalar GPs, spin-flip GPs need to be fixed using some theoretical model
- not valid over whole phase space
  - only below pion production threshold

Dispersion Relations or DR

B.Pasquini et al., EPJA 11 (2001) 185.

- VCS amplitude is calculated through dispersion integrals
  - calculations use MAID model for pion and photo electroproduction amplitudes
- GPs are directly parametrized by 2 free parameters
- spin-flip GPs are described within the model
- model is valid over whole phase space
- calculations are slow compared to LEX

World data on VCS (unpolarized)

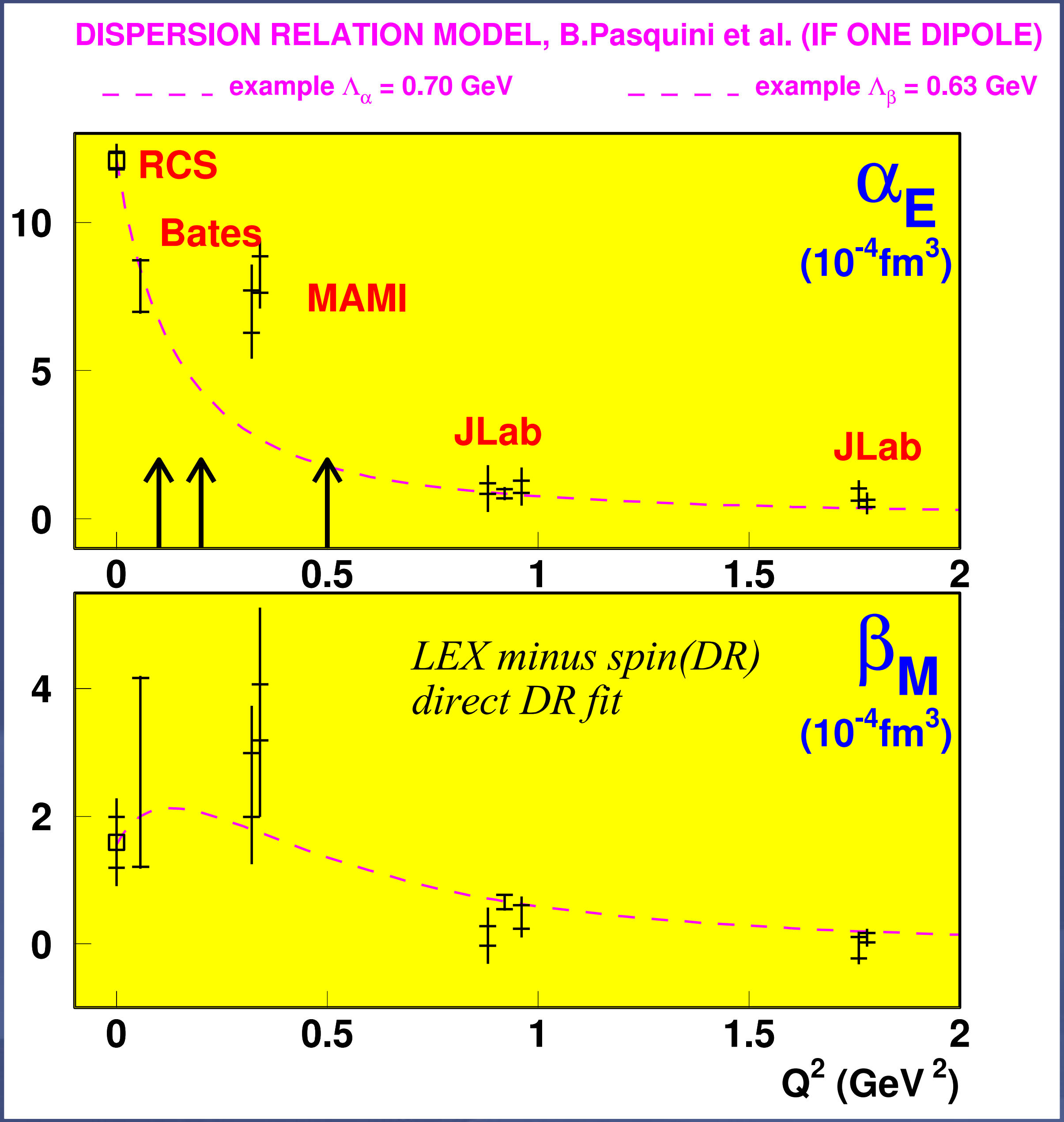
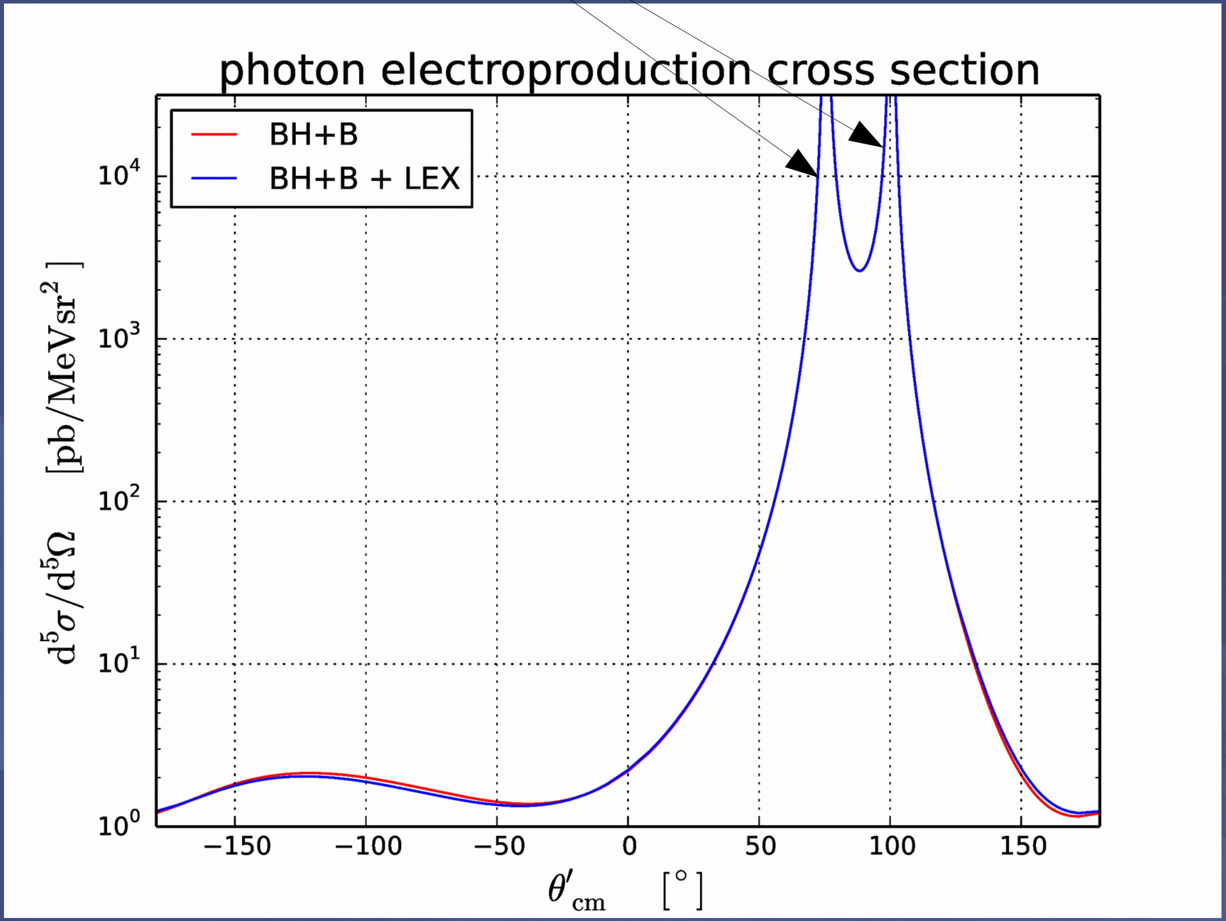


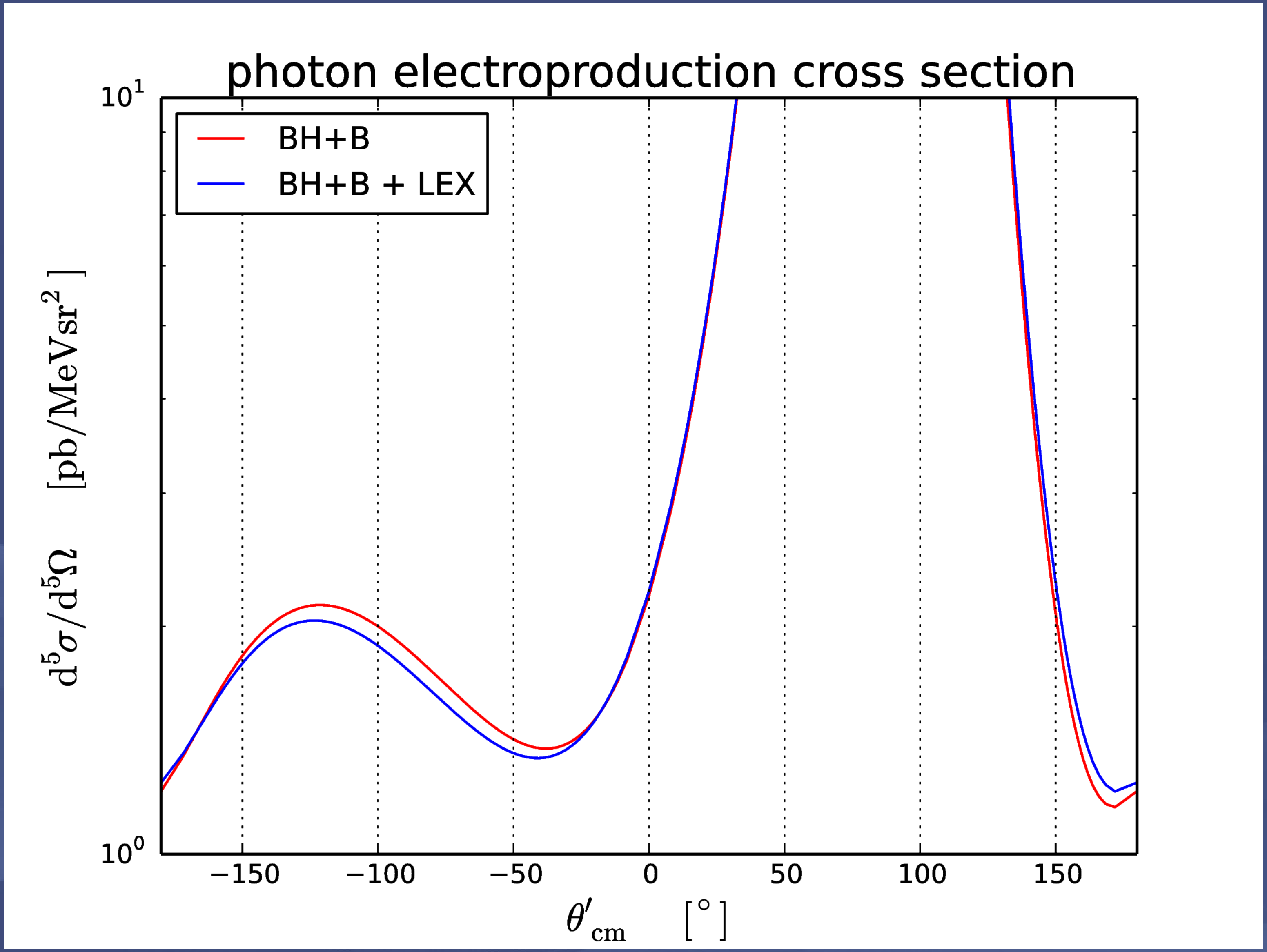
Figure courtesy of H.Fonvieille

Typical cross section

- Bethe-Heitler + Born cross section (+ 1st order LEX)
- characteristic Bethe-Heitler peaks
  - appear when outgoing photon has the direction of one of the electrons (in cms)



Typical cross section - zoom



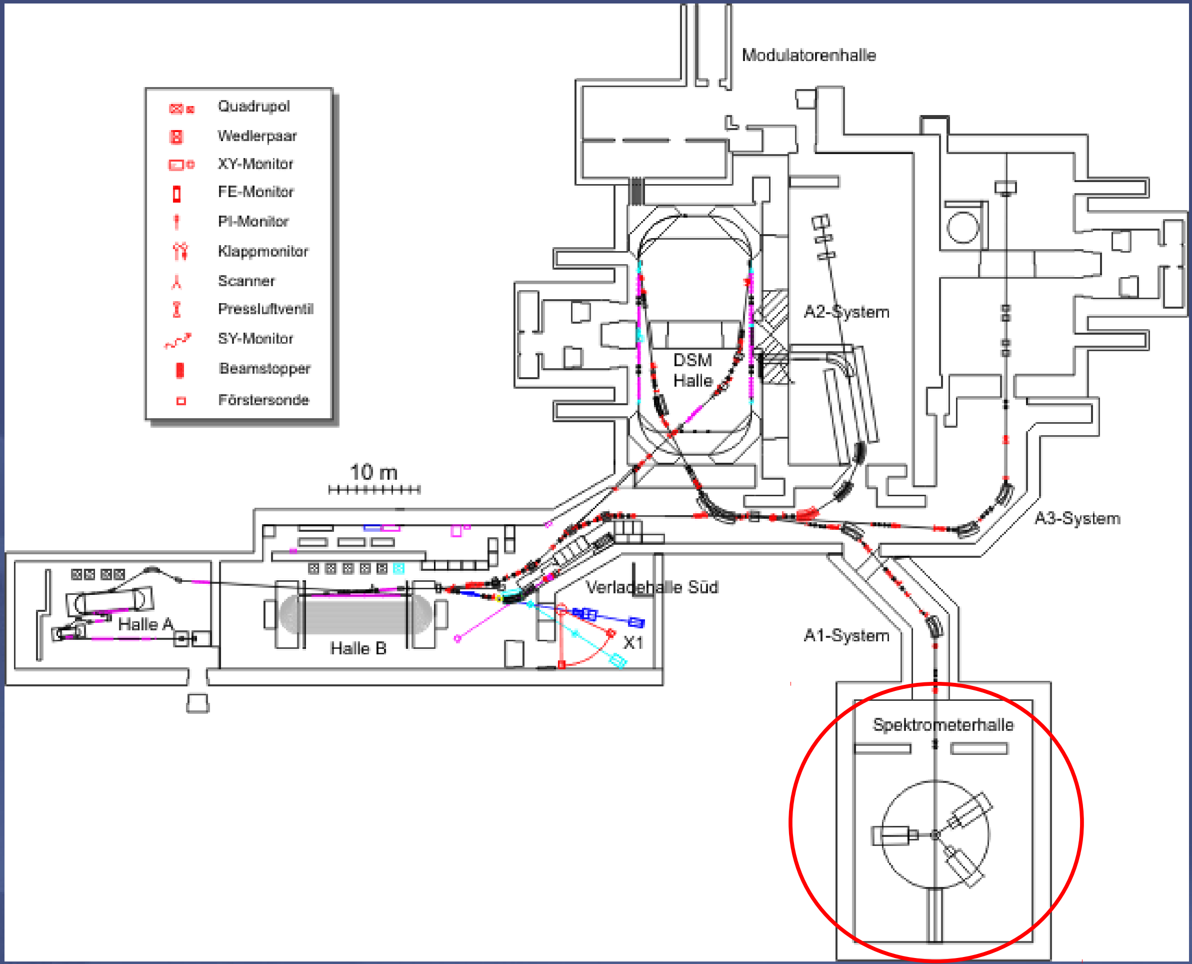
Proposed settings: Proposal MAMI-A1-1-09

- careful selection of kinematics
- blue – my setting: $Q^2 = 0.1\, GeV^2$ data
- red – possible remeasure

setting name	particle in spec.	E_{beam} [MeV]	P_B [MeV/c]	θ_B [°]	P_A [MeV/c]	θ_A [°]
q2-0.1-oop *	e in B	871.7	693	21.9	343	52.6
q2-0.1-inp	e in B	871.7	700	22.9	425	53.1
q2-0.1-low	e in B	871.7	745	22.4	365	58.0
q2-0.2-oop *	e in B	1002.4	766	29.2	486	51.0
q2-0.2-inp	e in B	1002.4	766	30.4	580	51.5
q2-0.2-low	e in B	904.9	723	32.5	462	52.2
q2-0.2-low-bis	e in B	904.9	715	32.5	442	52.2
q2-0.5-oop	e in A	1034.1	750	39.2	647	51.0
q2-0.5-inp	e in A	1034.1	634	32.7	650	51.2
q2-0.5-low	e in A	937.7	713	40.5	645	52.3

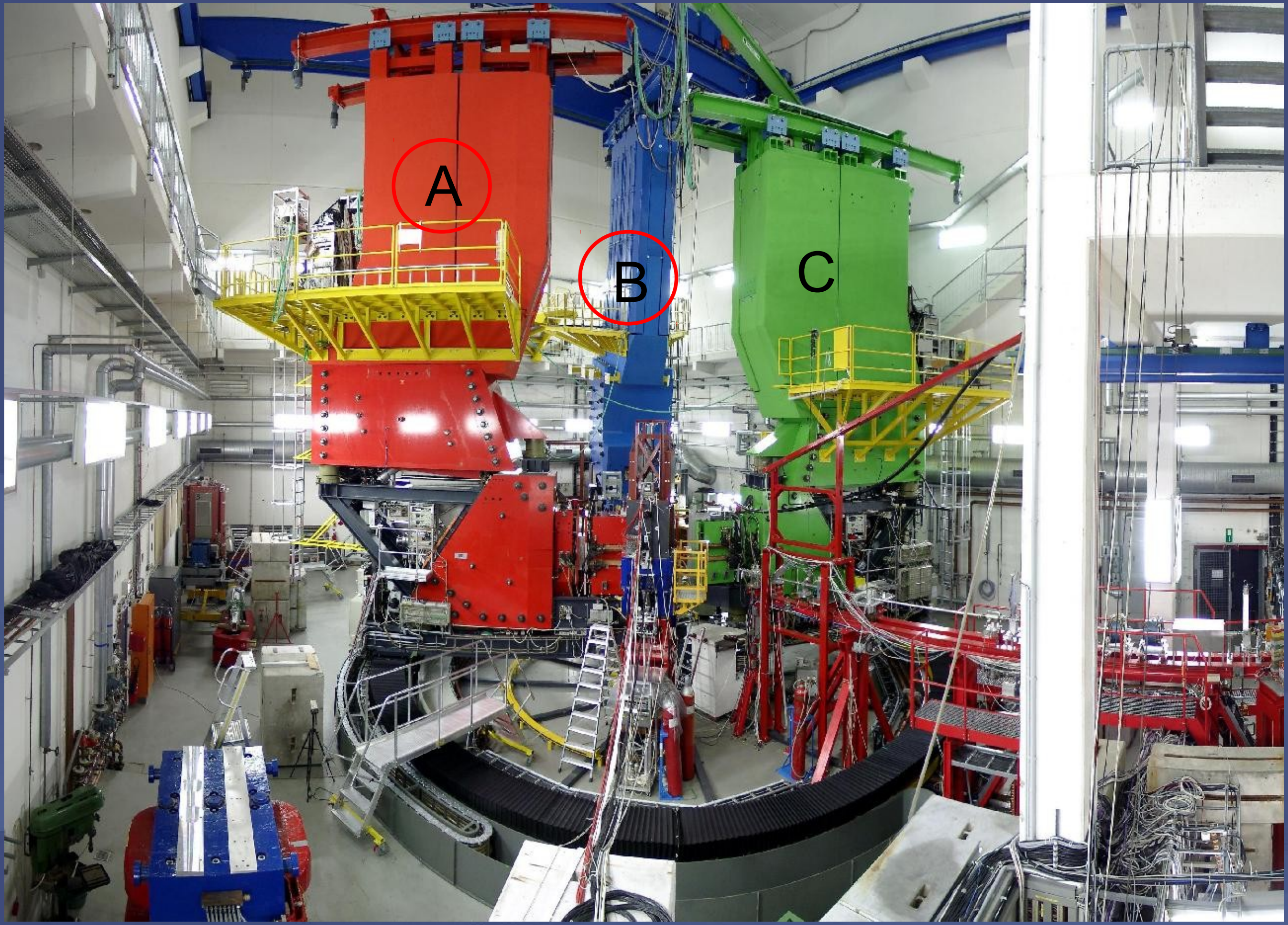
Experimental facility

- Mainz Microtron MAMI
  - Institute für Kernphysik at Johannes Gutenberg Universität
- electron accelerator
  - polarized electron source
  - linac
  - 4 microtrons
  - $E_{max}=1.6\,GeV$
  - $I_{max}=100\,\mu A\,(20\,\mu A)$
- 4 experimental halls
  - A1: electron scattering
  - A2: tagged photons
  - A3: parity violation
  - X1: X-rays



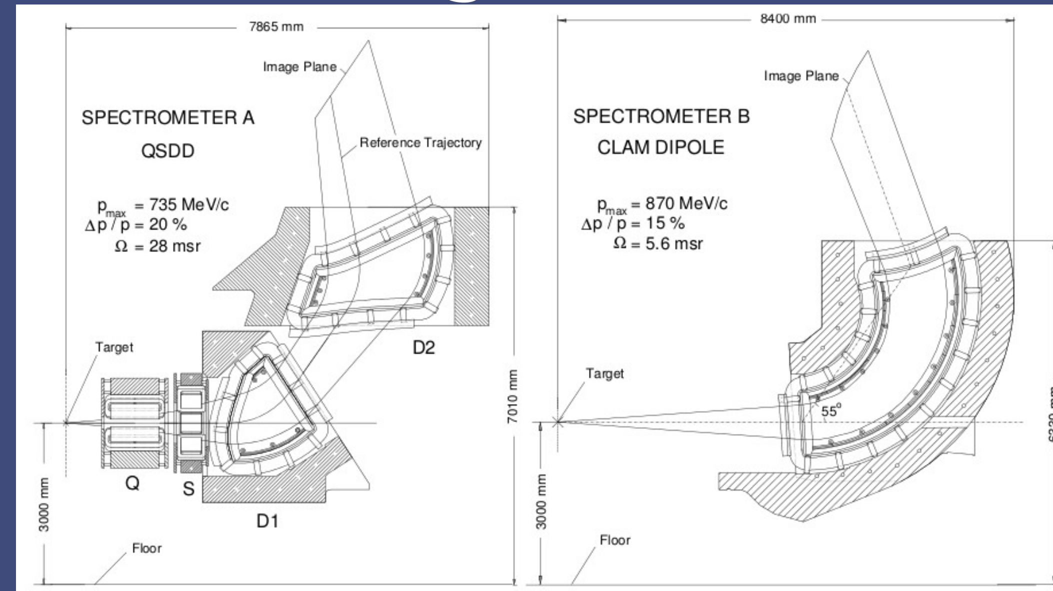
Hall A1

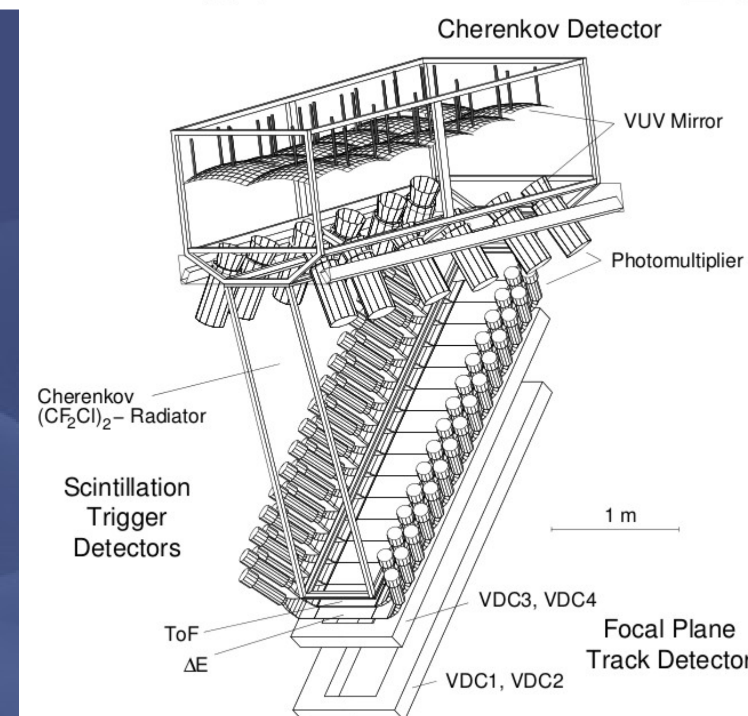
- three spectrometer setup
- we used spectrometers A and B



Spectrometers and target

- spectrometers A and B
  - A: QSDD
  - B: D
  - mom. res.: $\leq 10^{-4}$
  - ang. res.: $\leq 3\,mrad$
  - pos. res.: $3-5\,mm$, $\leq 1\,mm$
  - electron and proton coincidence
  - very well known acceptance
  - out-of-plane capability
- spectrometers A and B
  - 4 VDC planes
  - 2 scintillator planes
  - threshold Čerenkov detector
- cryo target filled with liquid hydrogen

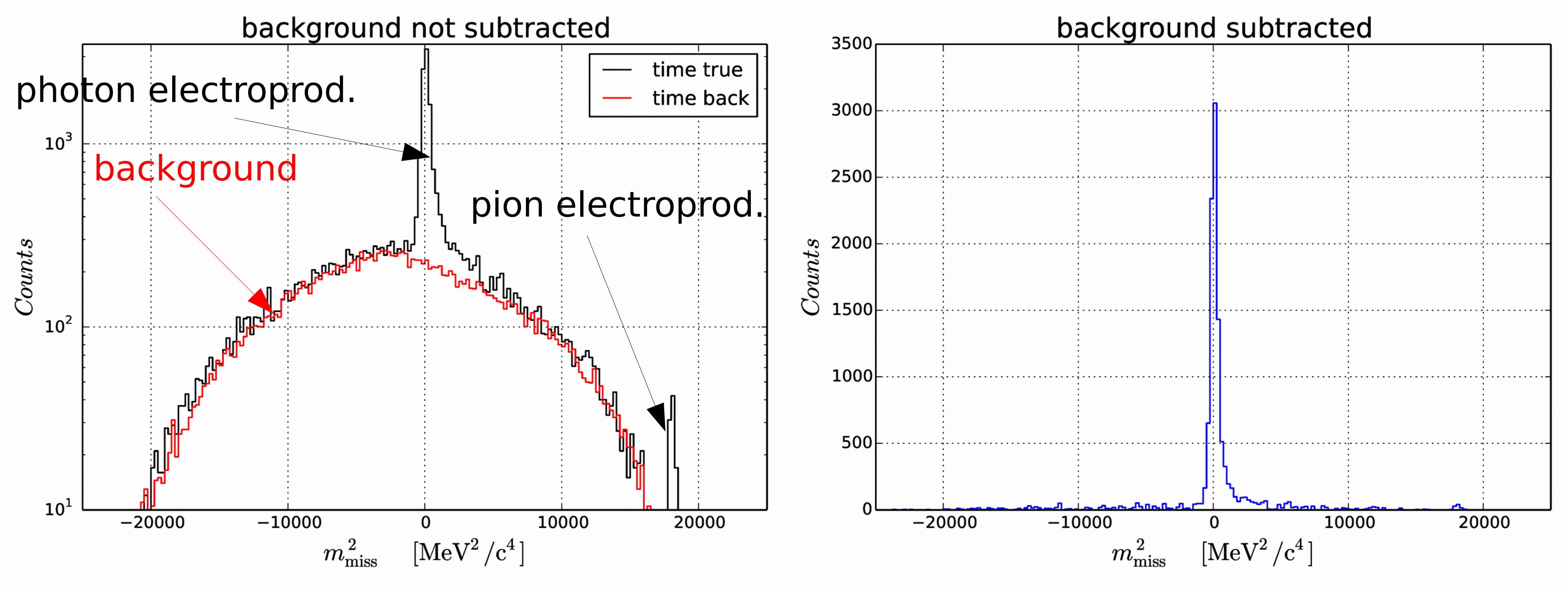




K.I.Blomqvist et al., NIM A 403 (1998) 263.

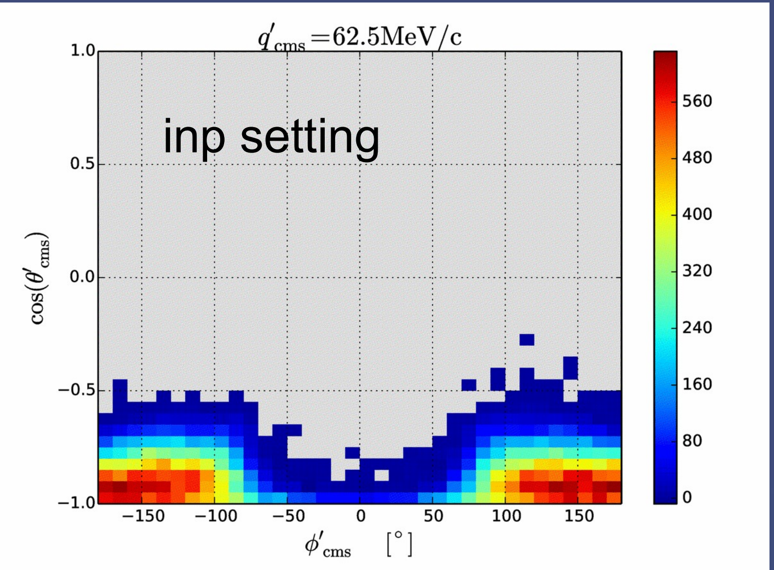
Physics variable: m_{miss}^2

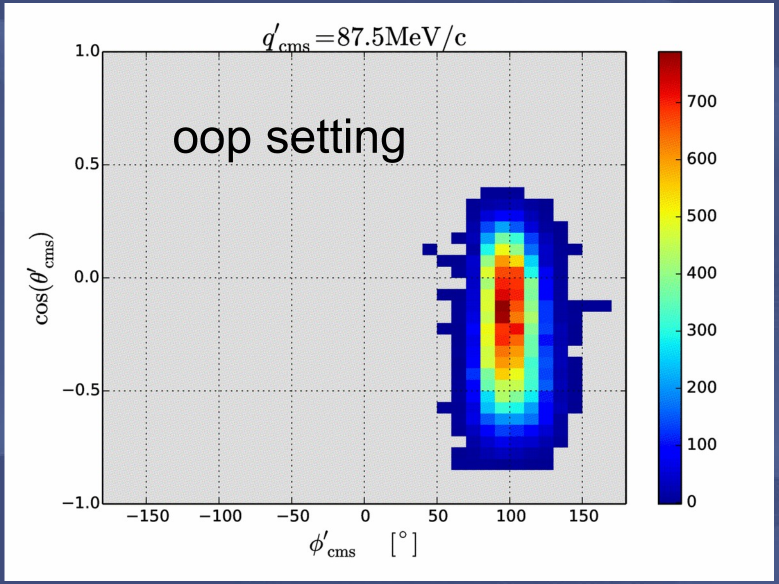
- $m_{miss}^2 = [(k+p) - (k'+p')]^2$
- a test of how well background is controlled
- used for diagnostics
- useful in PID

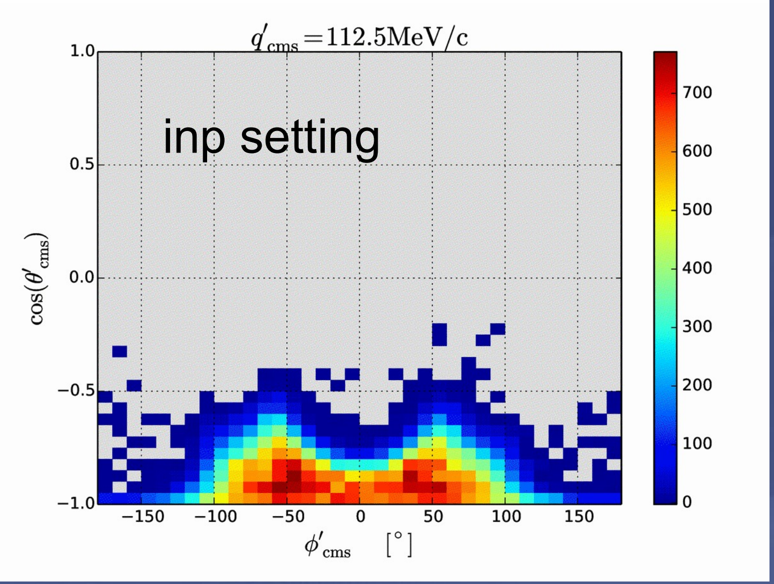


Measured events across the phase space

- kinematics defined by $\left(q_{cm}, q'_{cm}, \epsilon, \theta_{\gamma\gamma cm}, \varphi_{cm}\right)$
- q_{cm} and ϵ are fixed by kinematics
- make bins in other three
  - 5 bins in q'_{cm}
  - 36 bins in φ'_{cm}
  - 40 bins in $\cos\left(\theta'_{\gamma\gamma cm}\right)$







Comparison of cross sections – low setting

$Q^2 = 0.1\, GeV^2$

PRELIMINARY

Fit of Ψ_0 - LEX

- $\Delta M = \frac{d^5\sigma - d^5\sigma_{BH+B}}{\Phi q'} + O(q')$

$Q^2 = 0.2\,GeV^2$

$\Psi_0 = \Delta M(q' \to 0)$

$\Psi_0 = v_{LL} \cdot (P_{LL} - P_{TT}/\epsilon) + v_{LT} \cdot P_{LT}$

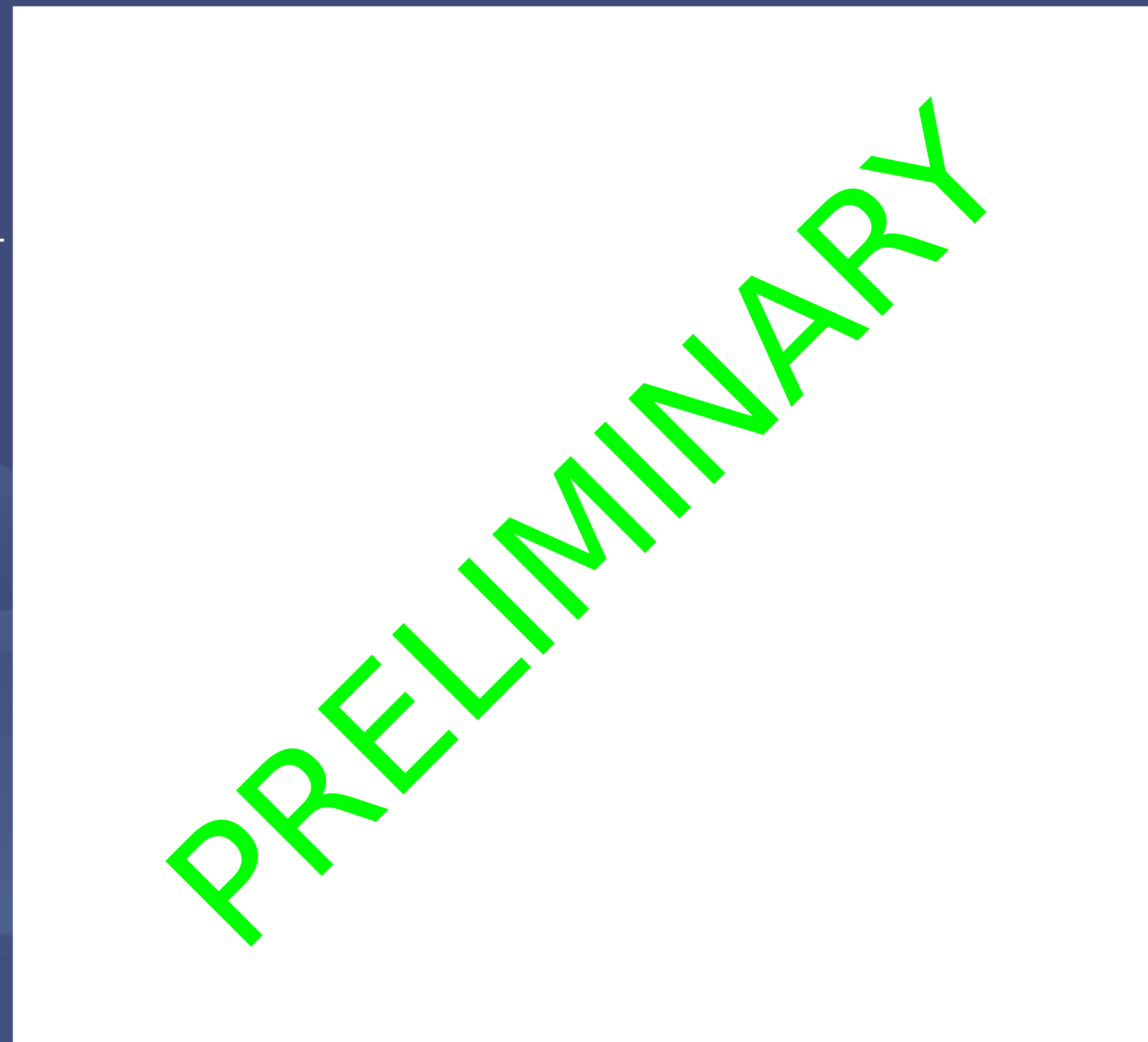


Figure courtesy of L.Correa

Fit of structure functions – LEX

- $$\frac{\Psi_0}{v_{\mathrm{LT}}} = \left(P_{\mathrm{LL}} - P_{TT}/\epsilon\right) \cdot \frac{v_{\mathrm{LL}}}{v_{\mathrm{LT}}} + P_{\mathrm{LT}}$$

$Q^2 = 0.1\,GeV^2$

PRELIMINARY

Generalized polarizabilities fit – DR

- calculate cross section for each bin using DR
- compare calculated and measured cross sections by calculating χ^2
- change α_E and β_M and repeat
- find minimum and contours at
  - $\chi^2_{min}+1$
  - $\chi^2_{min}+2.41$

$Q^2 = 0.5\, GeV^2$

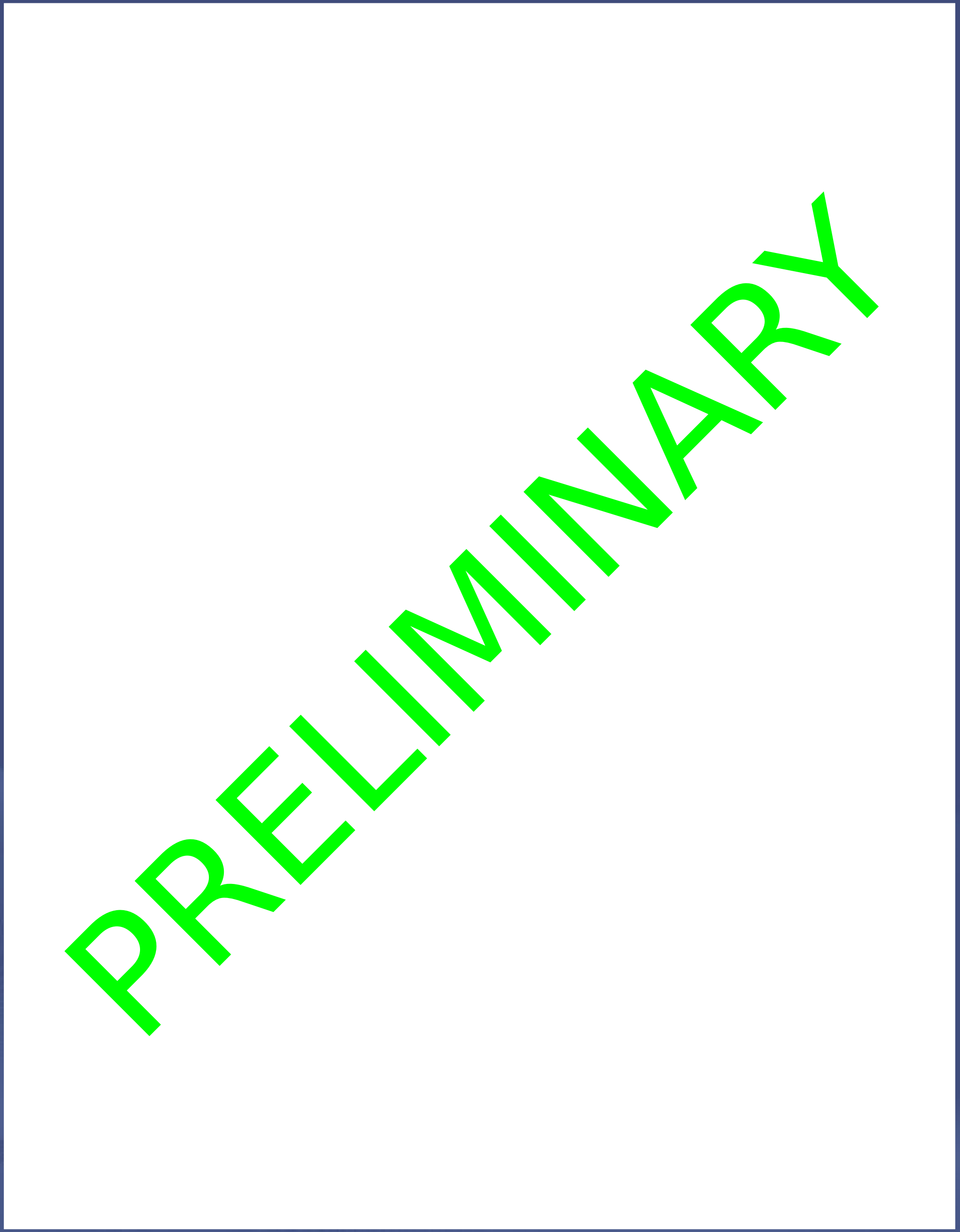


Figure courtesy of H.Fonvieille and M.BenAli

Summary

- electromagnetic interaction is a powerful probe to nucleon structure
- virtual Compton scattering gives us access to generalized polarizabilities
- measure photon electroproduction reaction
  - Bethe-Heitler + Born + non-Born contributions
- analysis via low energy expansion and dispersion relations
- 3 new kinematical points measured in Mainz

  $Q^2 = 0.1;\ 0.2;\ 0.5\, GeV^2$

- TODO
  - possible remeasure of 2 settings
  - finish last pass analysis
  - finalize LEX fix
  - do DR fit

The end

- Thank you for your attention.
- Any questions?