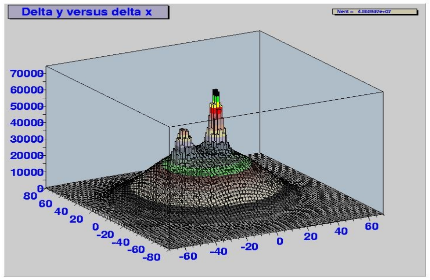


$\gamma p \rightarrow \gamma p$

Wide-Angle Compton Scattering

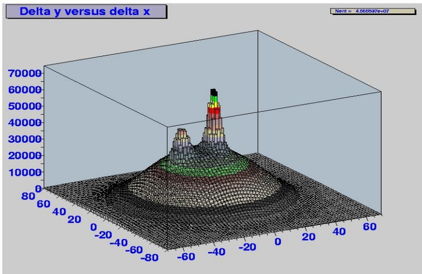
Bogdan Wojtsekhowski, JLab

Outline

- Mechanism of the reaction is a key question

  We can measure the process. What does it mean?

- JLab WACS experiments 2002, 2008
- Experimental results
- Comparison to the LO GPDs calculations



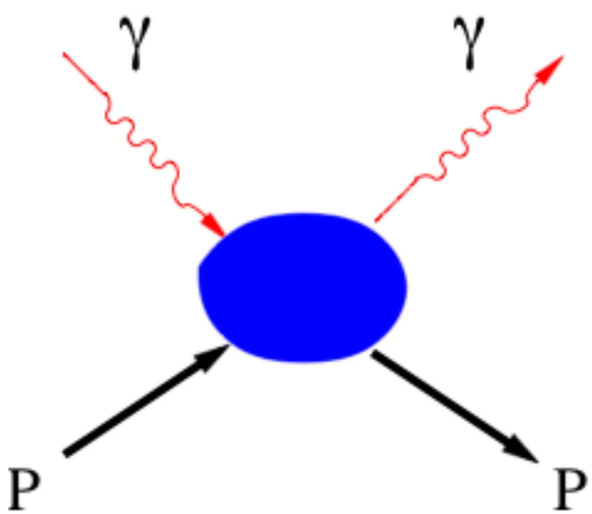
$\gamma p \to \gamma p$

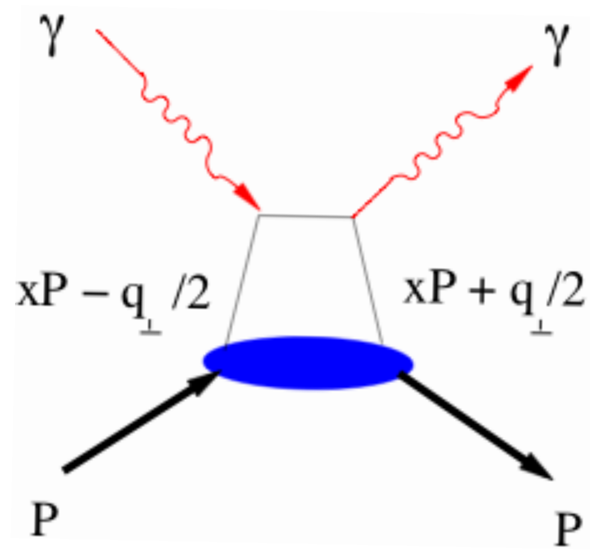
Mechanism of the process

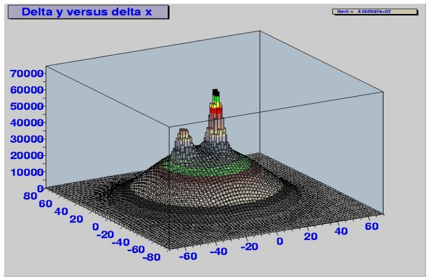
Two basic options for the mechanism:

Collective response - several partons involved in high momentum interaction with the photons

Individual response - one quark absorbs an incident photon and the same quark emits a scattered photon







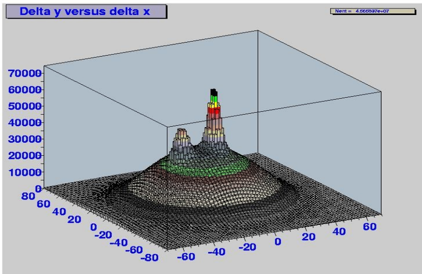
$\gamma p \to \gamma p$

Studies of the RCS process

- Regge poles - VMD - since 1960s …, Laget
- pQCD - two-gluon - Brodsky, …
- Diquark model - Guichon&Kroll 1996
- Leading quark - Brodsky et al 1972,
- GPDs (handbag) - Radyushkin, Kroll et al
- CQM - G.Miller 2004

Main issues:

- Competing mechanisms
- Interplay between hard and soft processes
- Threshold for onset of asymptotic regime
- Role of the hadron helicity flip



Experiment provides the answer

$\gamma p \to \gamma p$

Test of the reaction mechanism in the cloud chamber.

Arthur Compton,

Physical Review (1925)

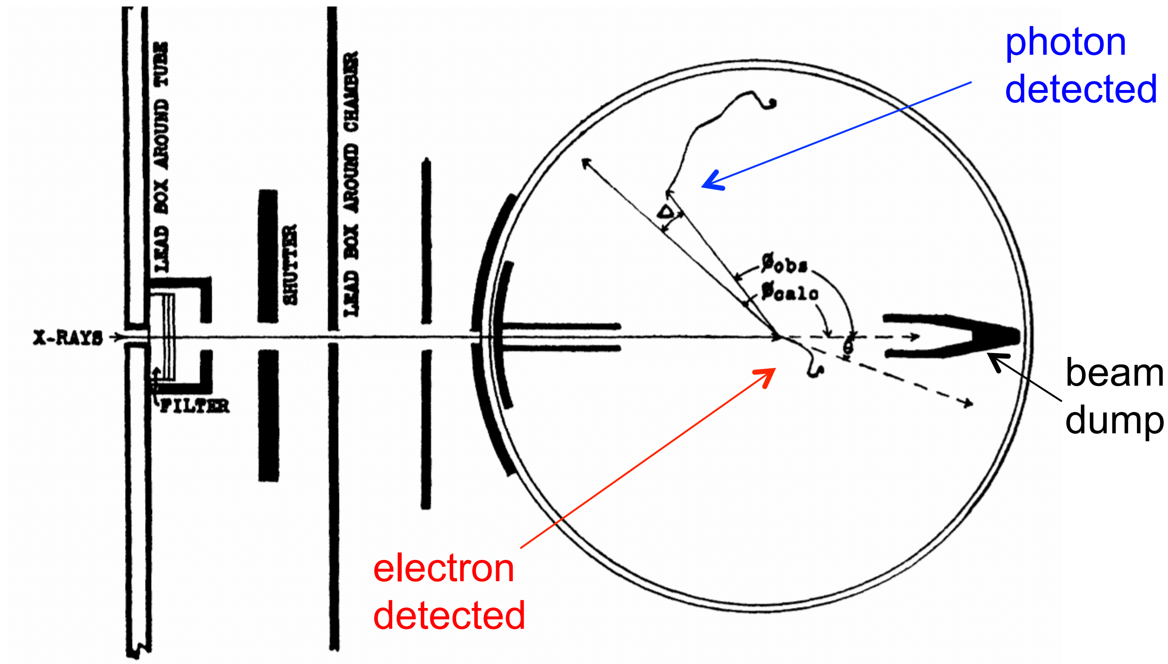
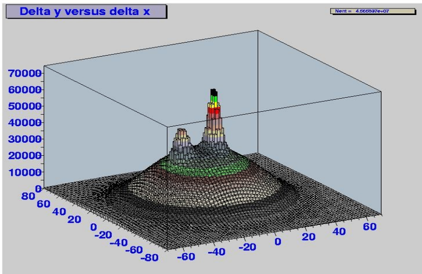


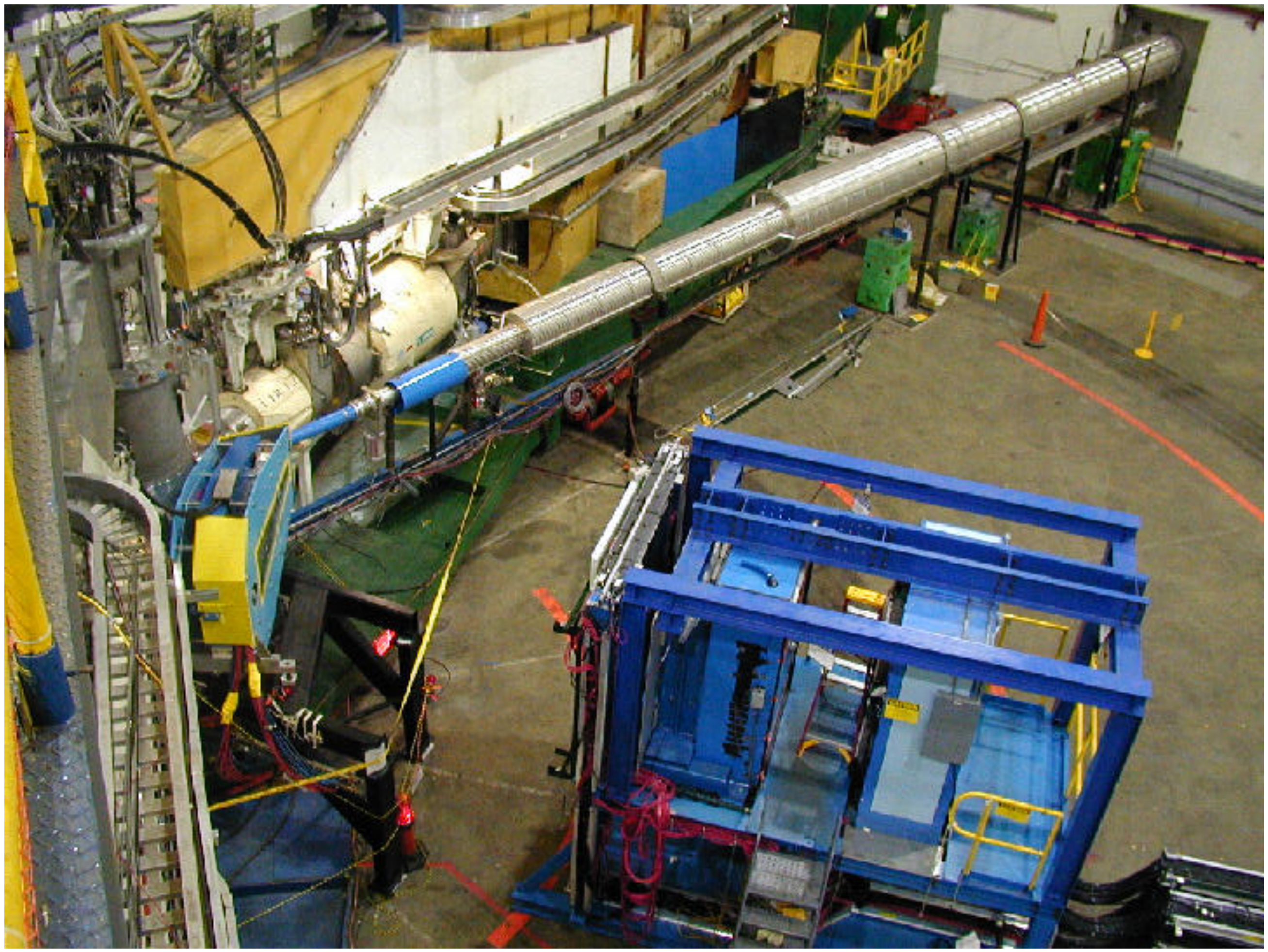
Fig. 1. Diagram of apparatus. On the hypothesis of radiation quanta, if a recoil electron is ejected at an angle θ, the scattered quantum must proceed in a definite direction ϕ_{calc}. In support of this view, many secondary β-ray tracks are found at angles ϕ_{obs} for which Δ is small.

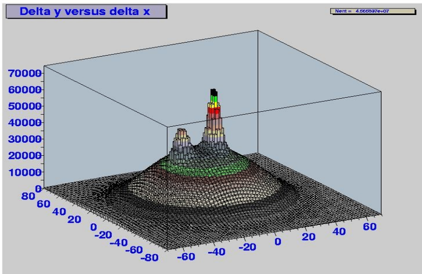
These results do not appear to be reconcilable with the view of the statistical production of recoil and photo-electrons proposed by Bohr, Kramers and Slater. They are, on the other hand, in direct support of the view that *energy and momentum are conserved during the interaction between radiation and individual electrons.*



E99-114 experiment in 2002

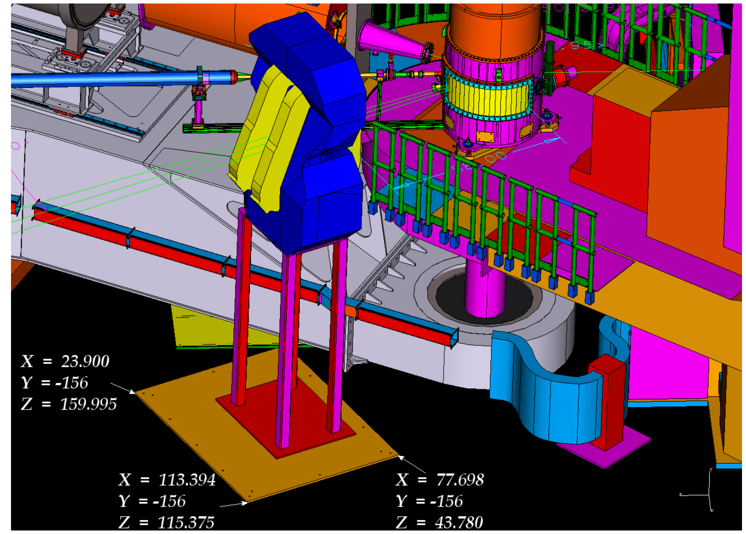
$\gamma p \to \gamma p$



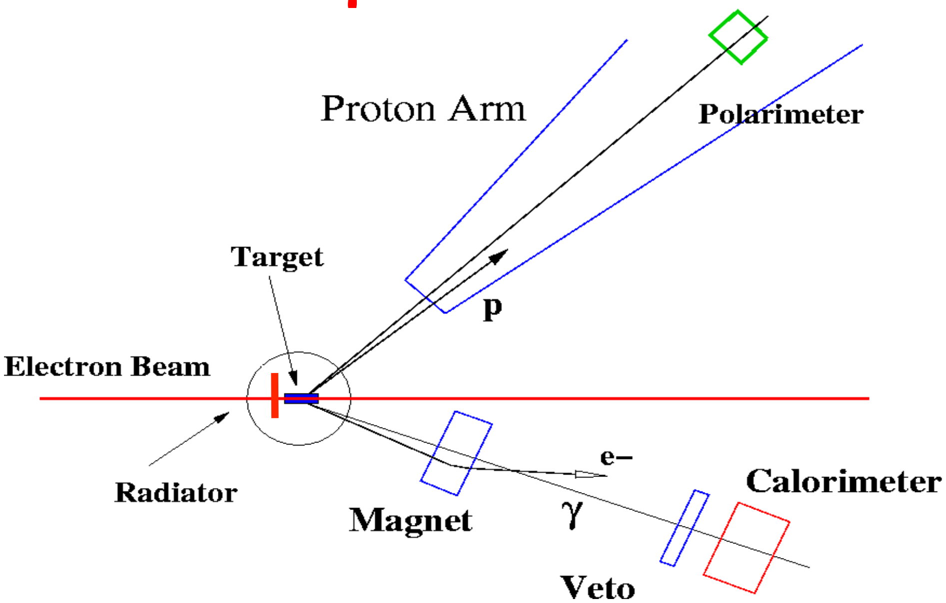


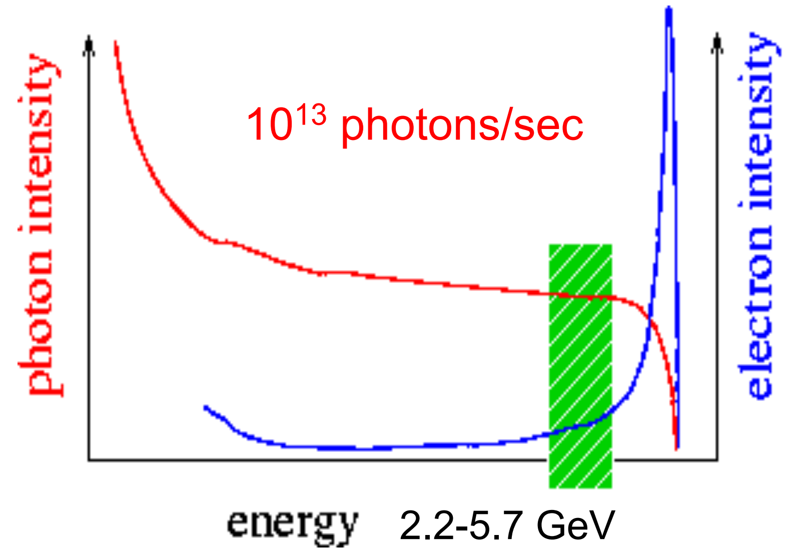
$\gamma p \rightarrow \gamma p$

E07-002
experiment in 2008

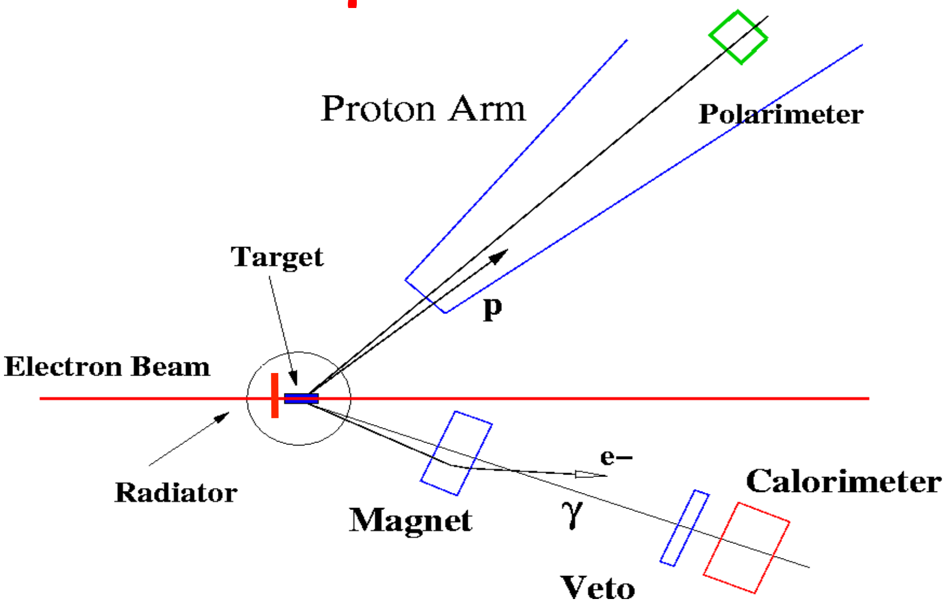


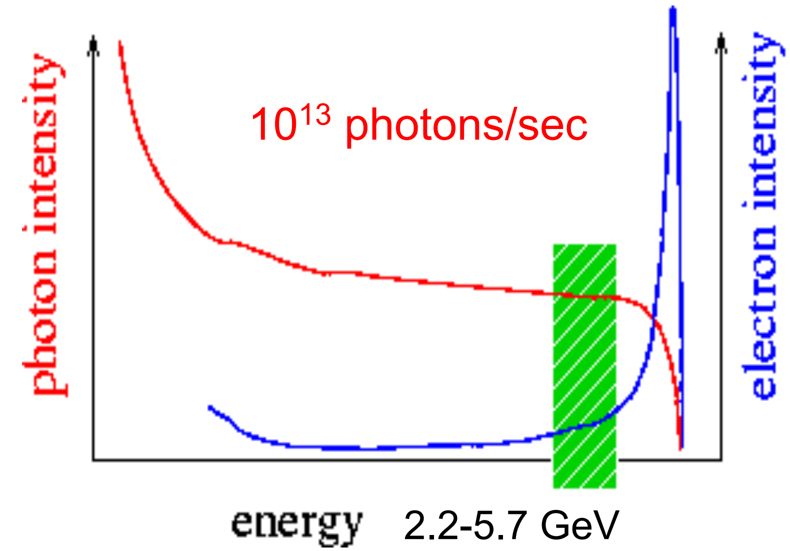
Mixed e/γ beam –> rates ~ 1300 higher than “clean” γ

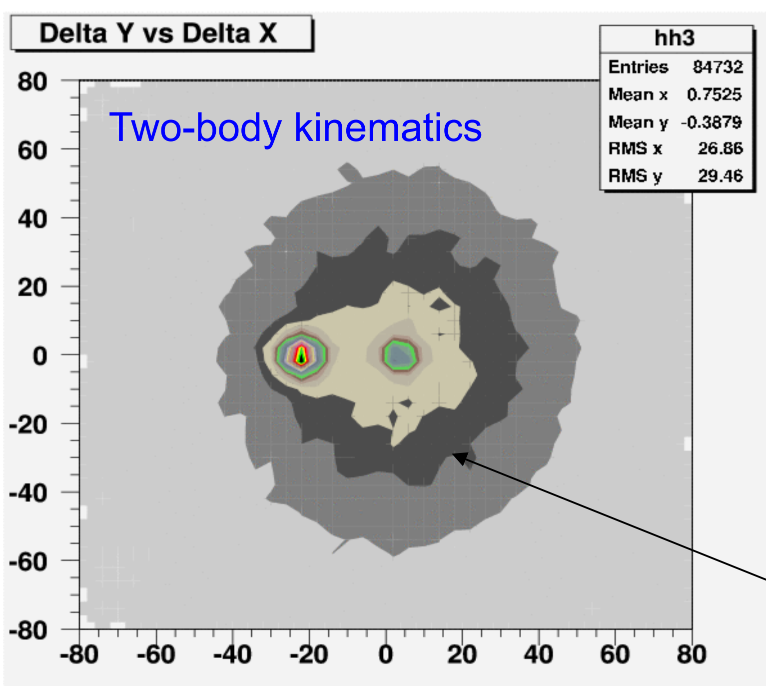




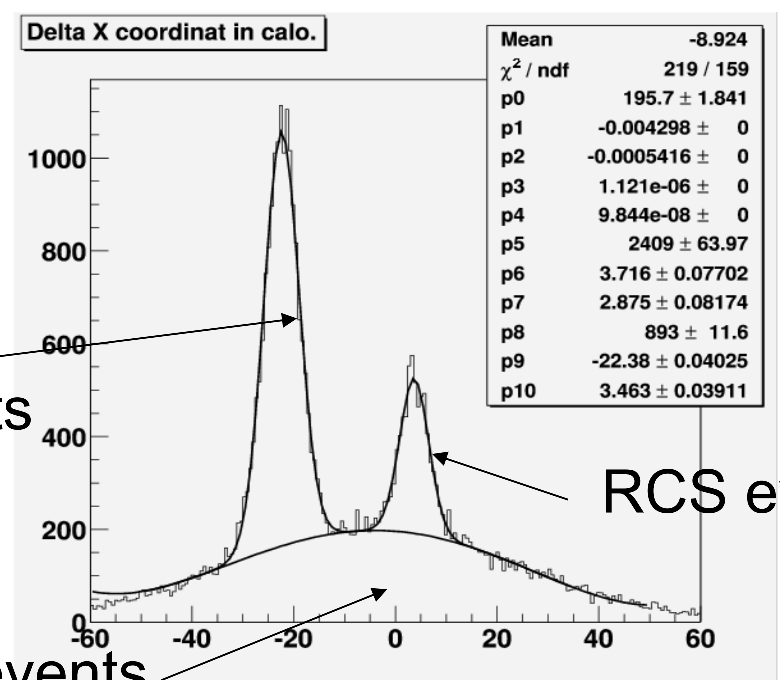
Mixed e/γ beam –> rates ~ 1300 higher than "clean" γ





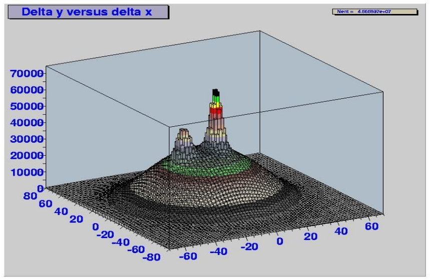


ep events



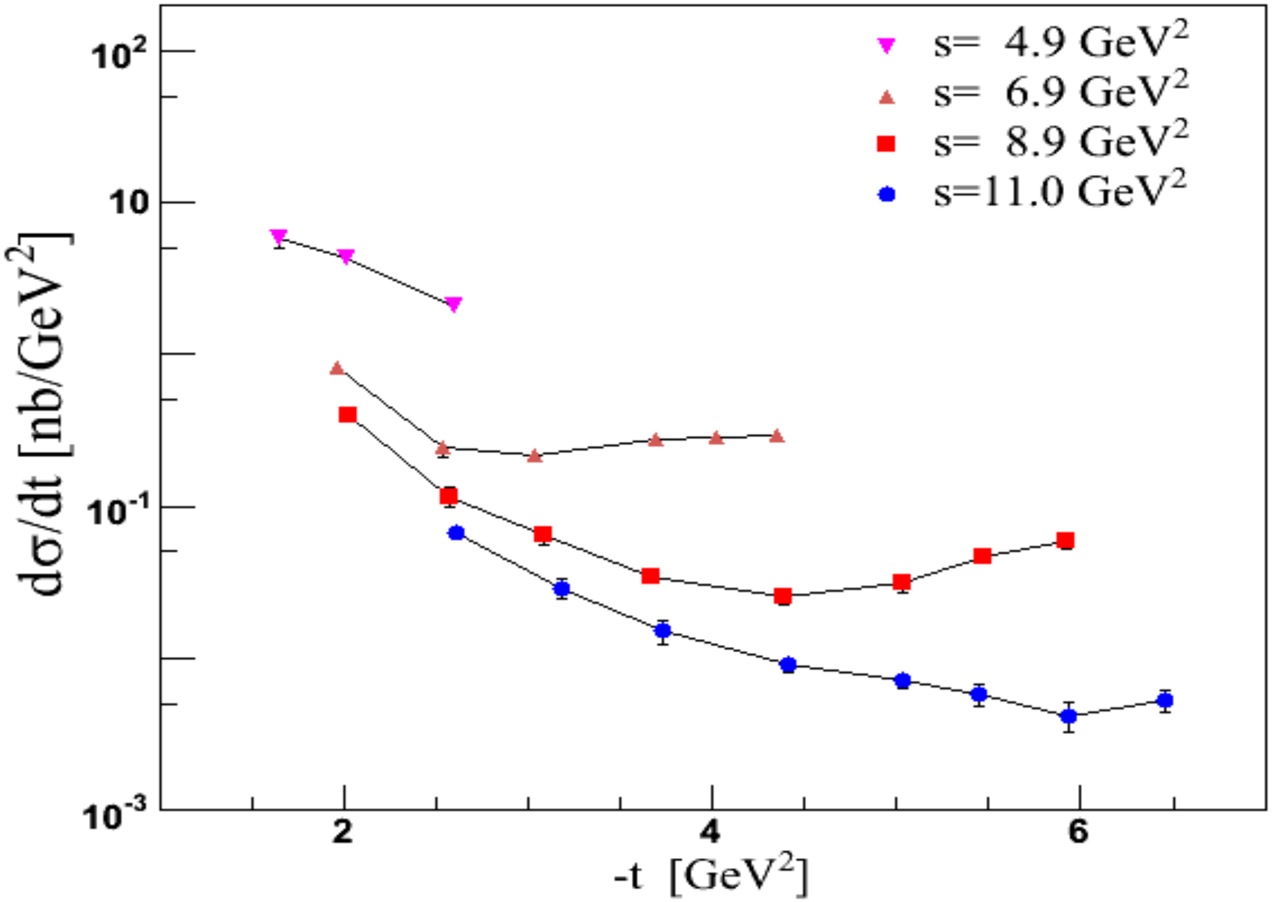
RCS events

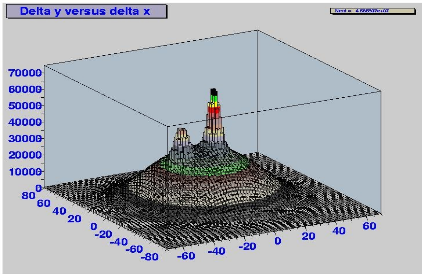
"pion" events



Experimental results: the cross section

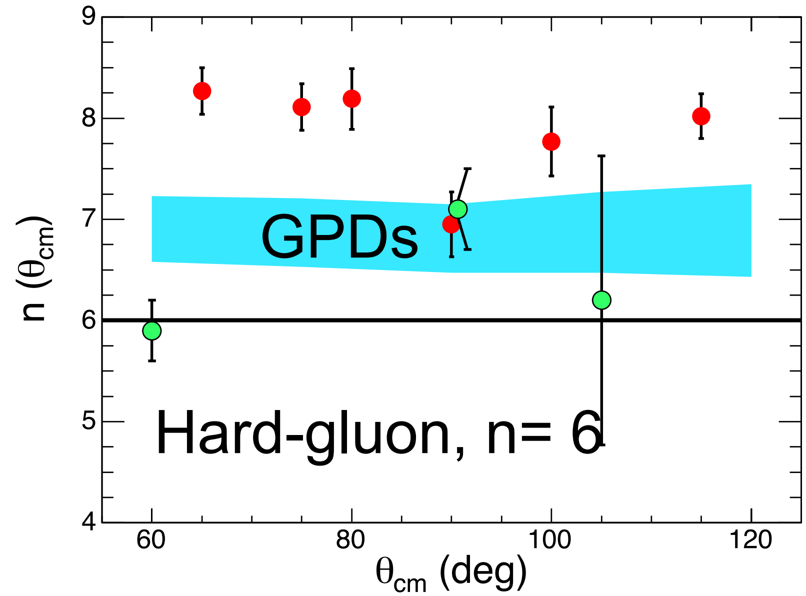
$\gamma p \to \gamma p$





Experimental results: the cross section

$\gamma p \rightarrow \gamma p$

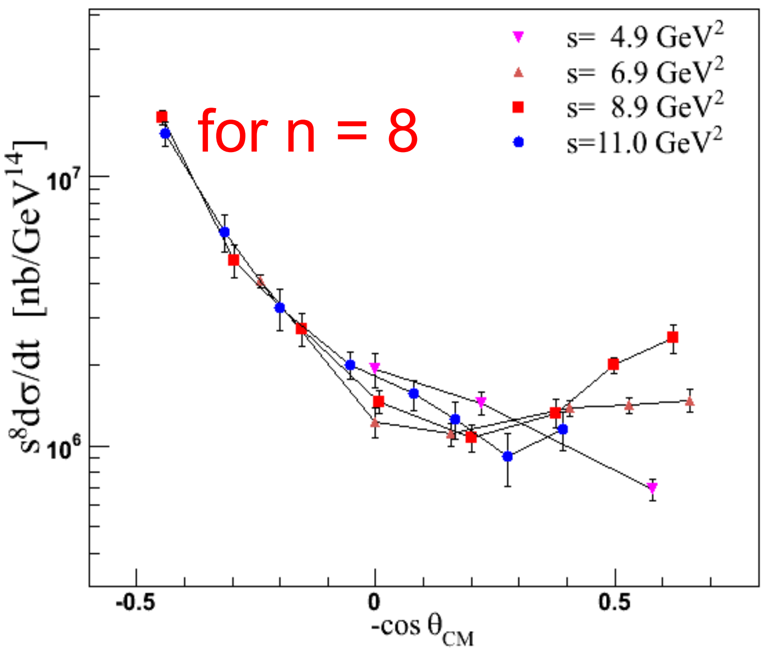


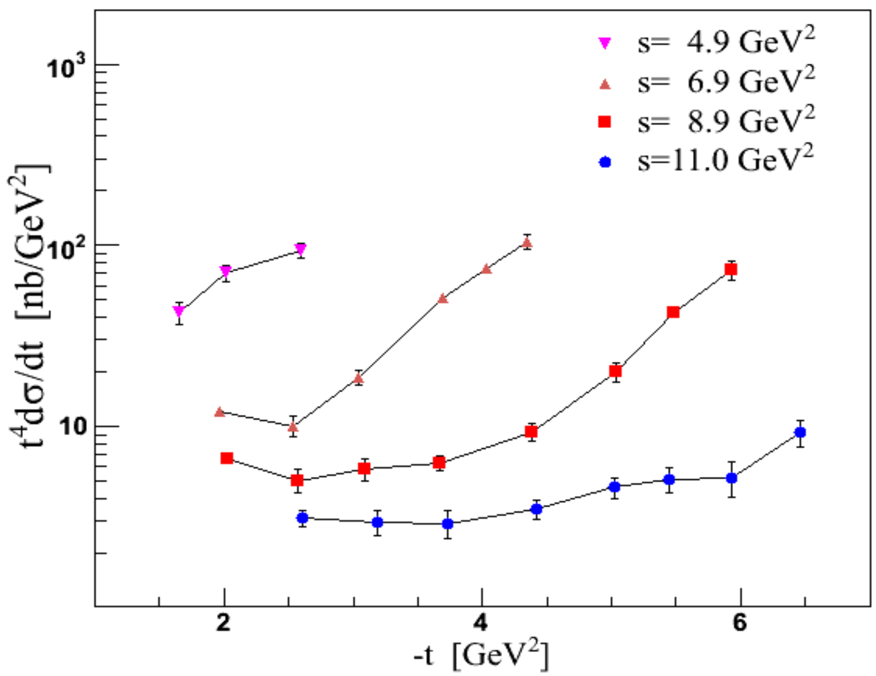
s scaling for the cross section

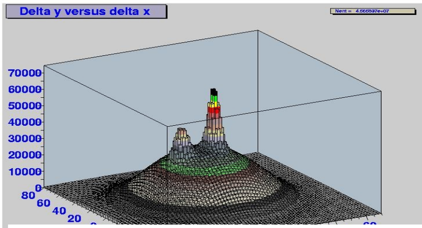
$$d\sigma/dt = f(\theta_{cm})\,/\,s^n$$

pQCD prediction is $n = 6$

$$d\sigma/dt = C\,/\,s^2 t^4$$

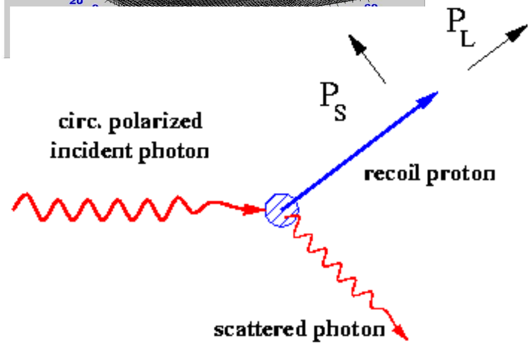


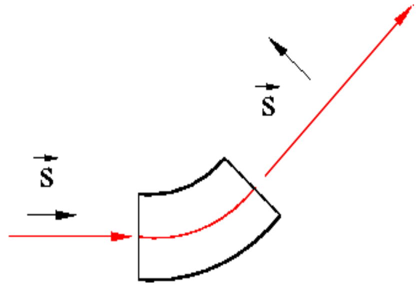




Polarization transfer K_{LL}

E_γ = 3.2 GeV, θ_{cm} = 120° (s = 6.9, t = -4 GeV^2)

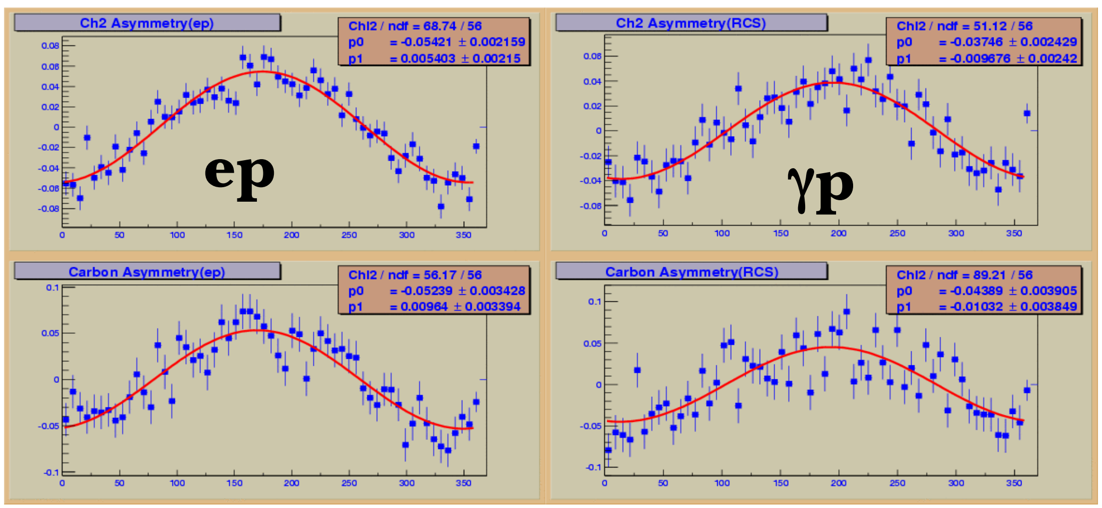


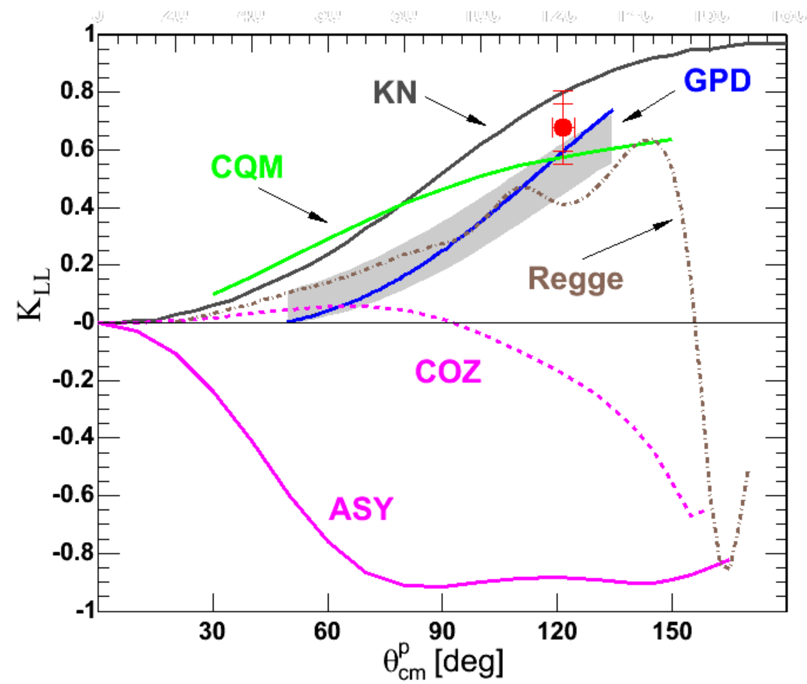


K_{LL} is an average value of the longitudinal proton spin in the γp cm system for 100% circular polarization of incident photon.

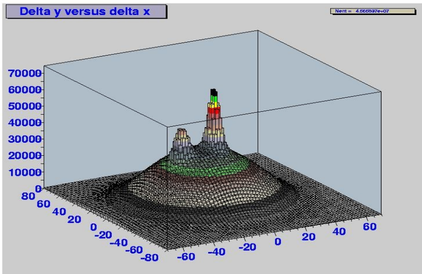
$$K_{LL} = \frac{1}{2}\left\{\frac{\sigma(+,\uparrow)-\sigma(+,\downarrow)}{\sigma(+,\uparrow)+\sigma(+,\downarrow)} - \frac{\sigma(-,\uparrow)-\sigma(-,\downarrow)}{\sigma(-,\uparrow)+\sigma(-,\downarrow)}\right\}$$

Raw asymmetry for ep and γp events



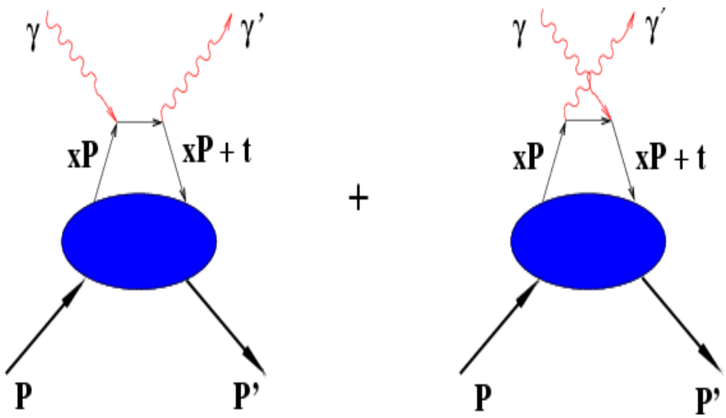


raw asymmetry is of 0.05, systematics is below 10^{-4}



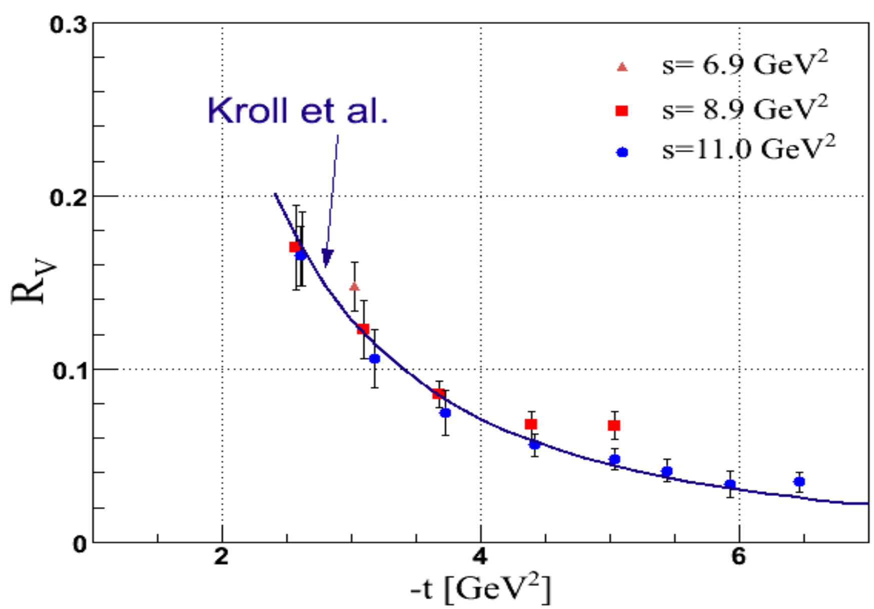
Experimental results: the cross section

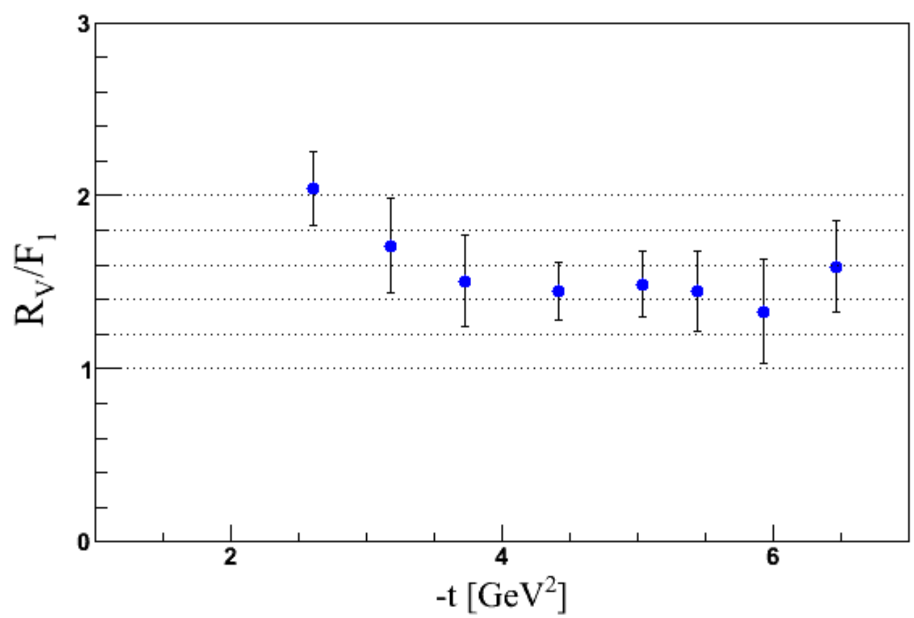
$$\frac{d\sigma_{\mathrm{RCS}}}{d\sigma_{\mathrm{KN}}} = \frac{(\hat{s}-\hat{u})^2}{\hat{s}^2+\hat{u}^2} R_V^2(t) + \frac{2\hat{s}\hat{u}}{\hat{s}^2+\hat{u}^2} R_A^2(t)$$

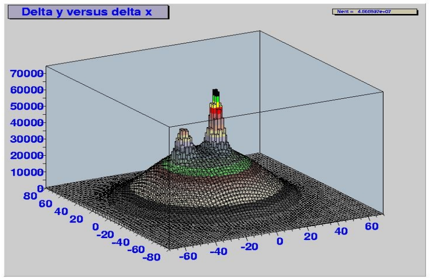


$$R_V(t) = \sum_a e_a^2 \int_{-1}^{+1} \frac{dx}{x} H^a(x;0,t) \quad , R_A(t) = \sum_a e_a^2 \int_{-1}^{+1} \frac{dx}{x} \widetilde{H}^a(x;0,t)$$

$$F_1(t) = \sum_a e_a \int_{-1}^{1} dx\, H^a(x,0,t) \quad , F_2(t) = \sum_a e_a \int_{-1}^{1} dx\, E^a(x,0,t)$$



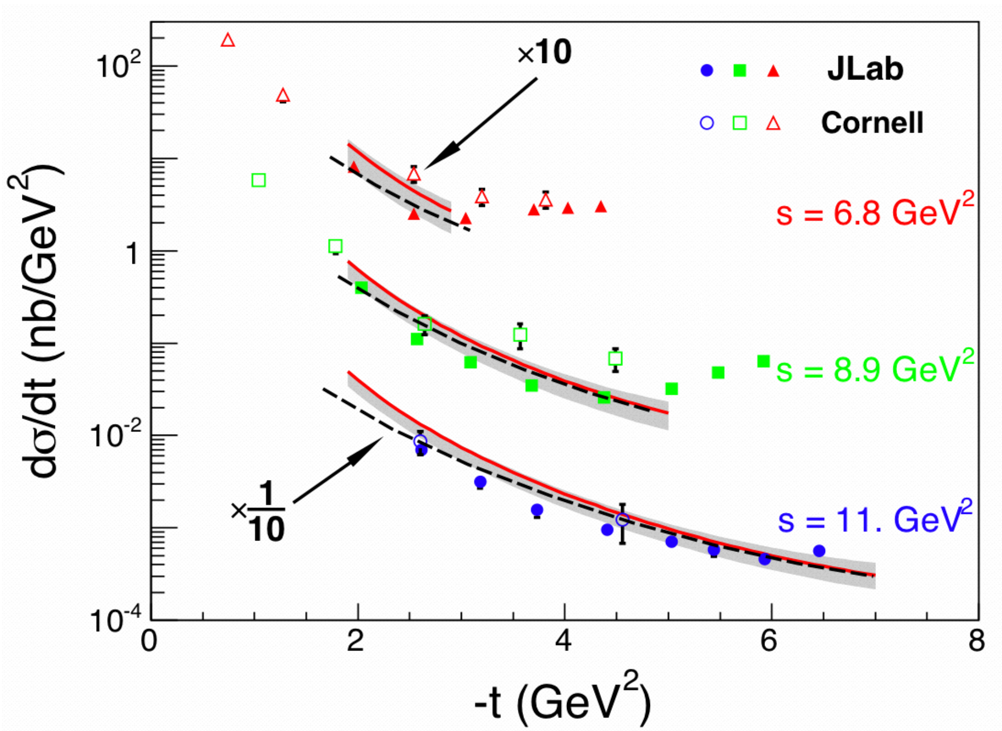




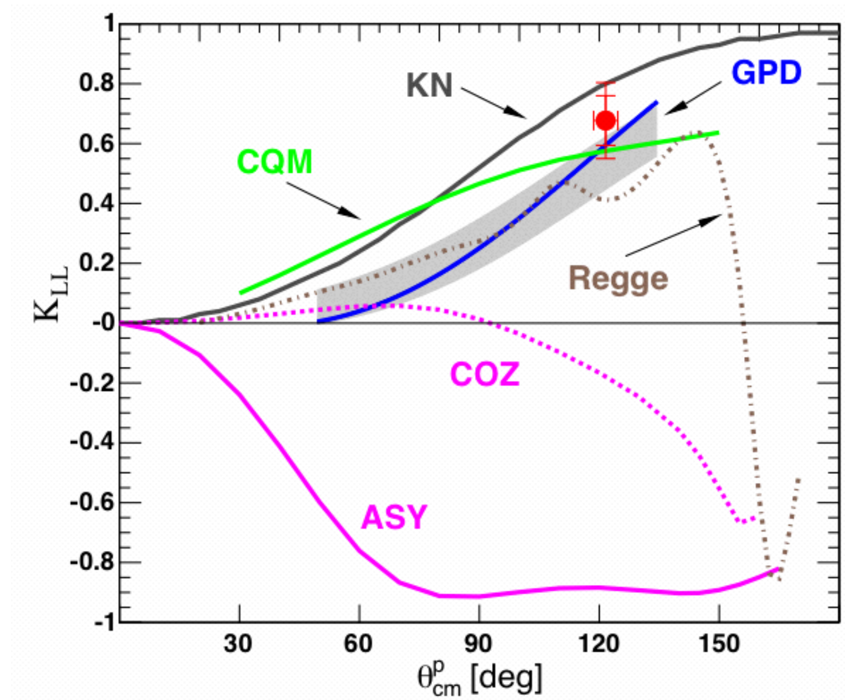
E99-114 results

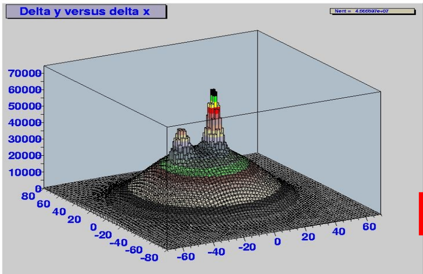
γp -> γp

PRL 98, 152001



PRL 94, 242001 $-u = 1.13\ \mathrm{GeV}^2$



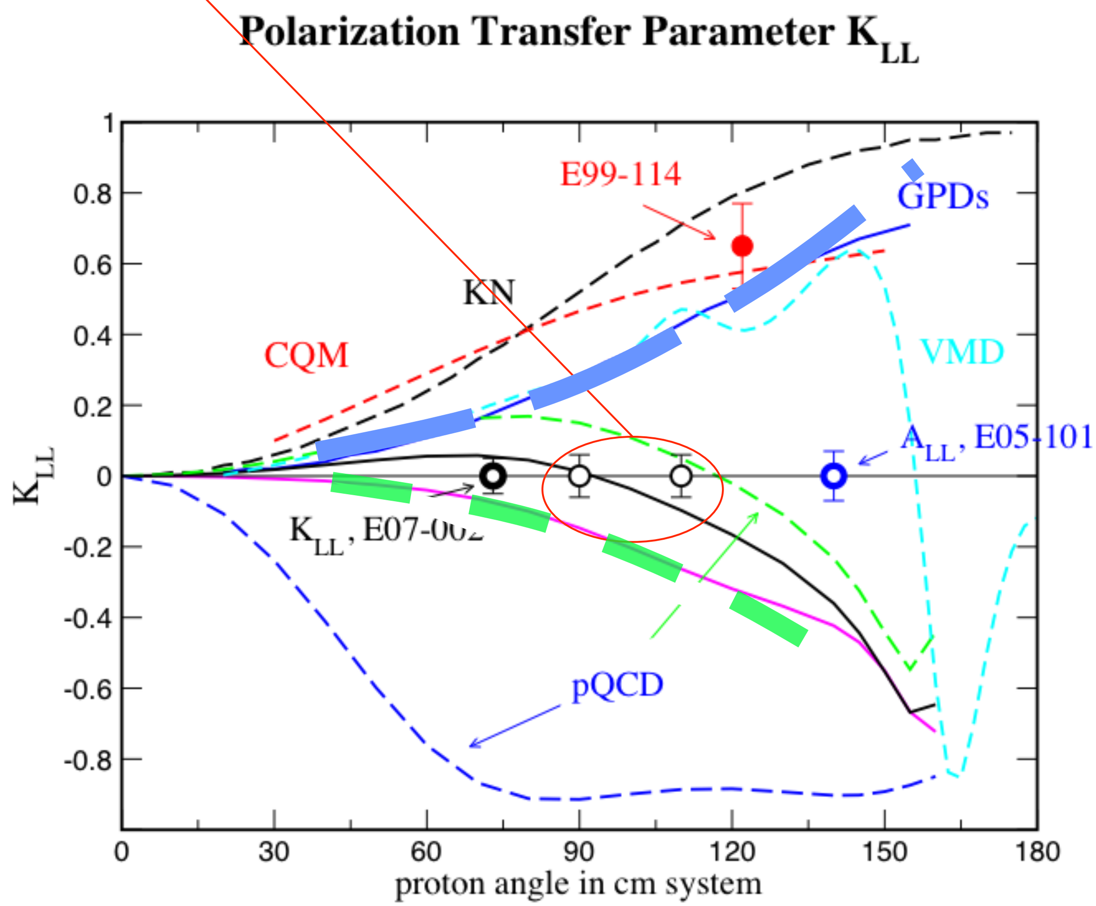


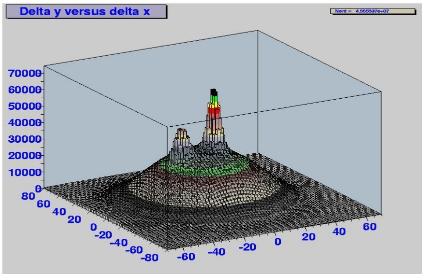
Test of the reaction mechanism

Proposed for E_γ ~ 4.3 GeV for cm angles 90° and 110°

$\gamma p \rightarrow \gamma p$

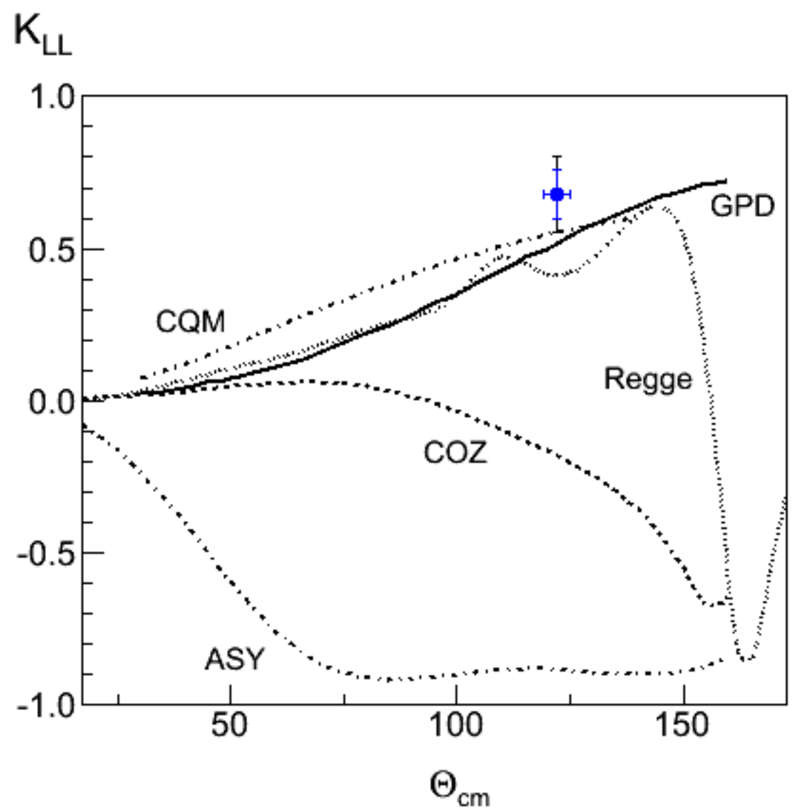
(also for 70° cm in E07-002 and 140° in E05-101 A_{LL})



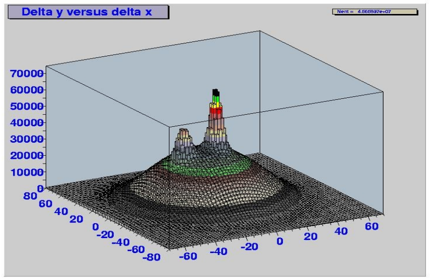


$\gamma p \rightarrow \gamma p$

E99-114 K_{LL} result

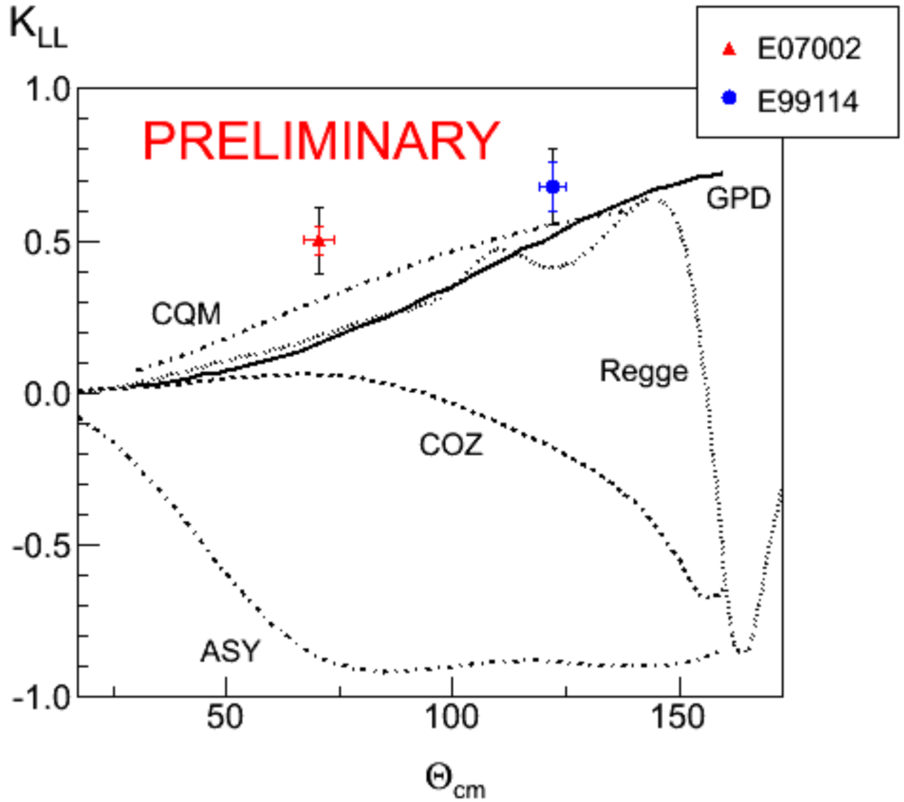


s = 6.9 GeV², = 4.0 GeV², -u = 1.1 GeV²-t

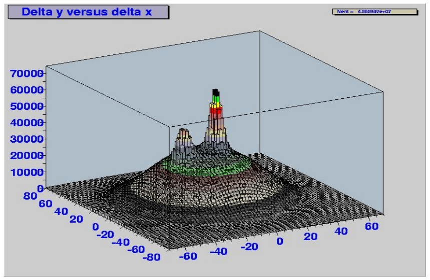


$\gamma p \to \gamma p$

E07-002 K_{LL} result



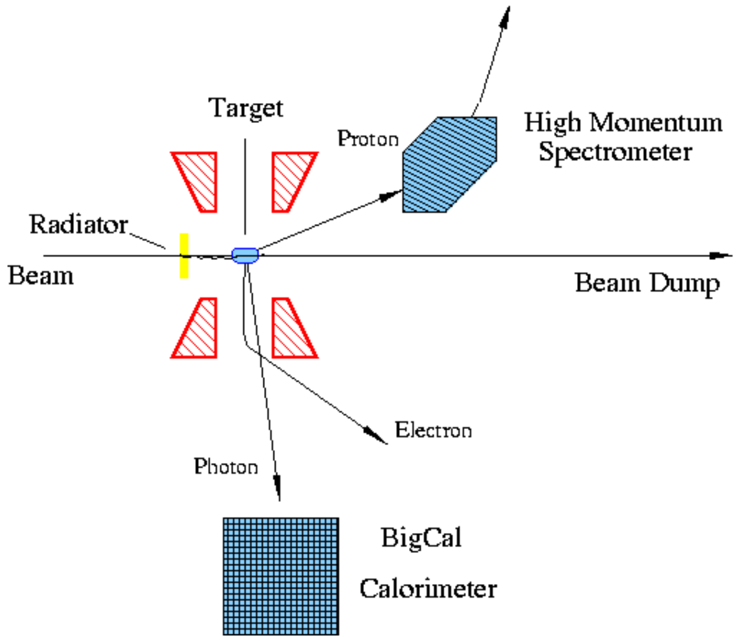
$s = 8.0\ GeV^2$, $-t = 2.1\ GeV^2$, $-u = 4.1\ GeV^2$



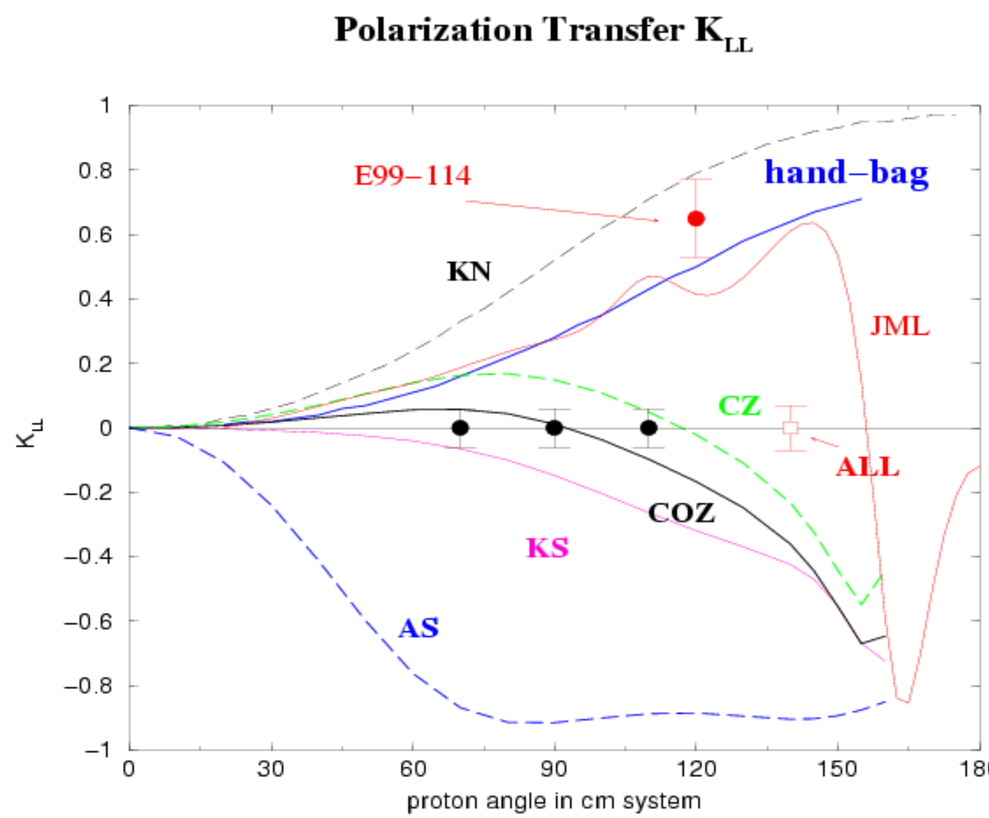
γp -> γp

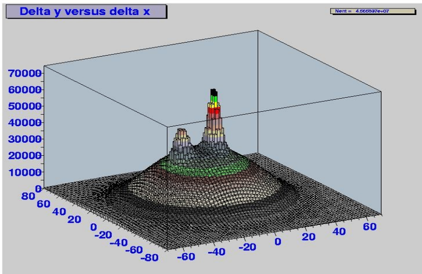
A_{LL}- initial state polarization correlation parameter

$$A_{LL} = \frac{1}{2}\left\{\frac{\sigma(+\uparrow)-\sigma(+\downarrow)}{\sigma(+\uparrow)+\sigma(+\downarrow)} - \frac{\sigma(-\uparrow)-\sigma(-\downarrow)}{\sigma(-\uparrow)+\sigma(-\downarrow)}\right\}$$



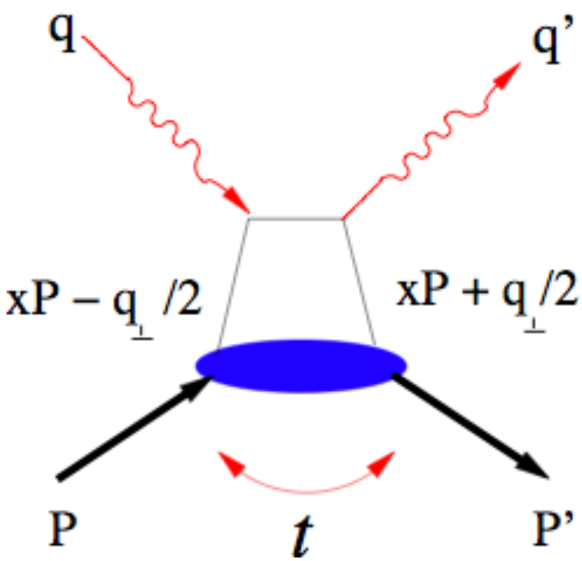
K_{LL}= ?= A_{LL}





WACS in the GPDs approach

γp -> γp



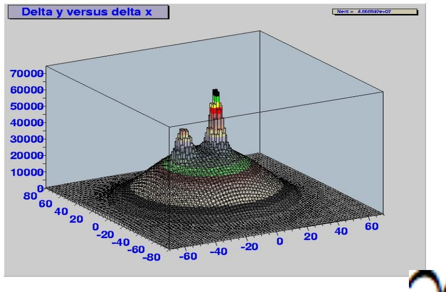
- Single-quark mechanism

  "handbag" diagram accounts for scattering from quark and introduces the FFs for ++,+-, ..

  Form factors: R_V, R_T, R_A
  KN-like polarization observables

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}_{KN} \left\{ \frac{1}{2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 + R_A^2\right] - \frac{us}{s^2+u^2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 - R_A^2\right]\right\}$$

Form factors allow us to fit the cross section



GPDs and the form factors of WACS

γp -> γp

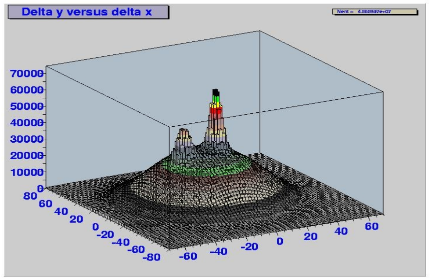
$$\gamma p \to \gamma p \qquad\qquad ep \to ep$$

$$R_V(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} H^a(x,0,t), \qquad F_1(t) = \sum_a e_a \int_{-1}^{1} dx\, H^a(x,0,t),$$

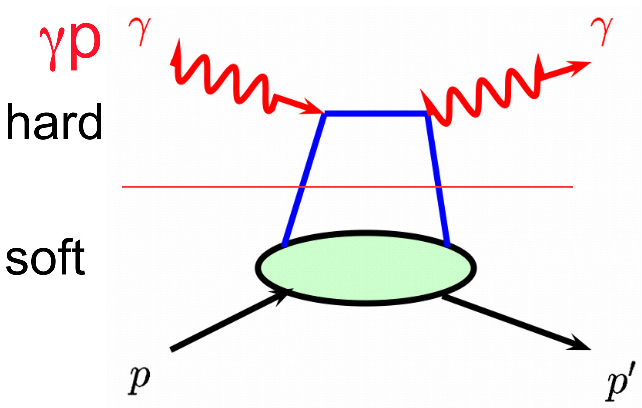
$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} \mathrm{sign(x)}\, \hat{\mathrm{H}}^{\mathrm{a}}(\mathrm{x},0,\mathrm{t}), \qquad G_A(t) = \sum_a \int_{-1}^{1} dx\, \mathrm{sign(x)}\, \hat{\mathrm{H}}^{\mathrm{a}}(\mathrm{x},0,\mathrm{t}),$$

$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t), \qquad F_2(t) = \sum_a e_a \int_{-1}^{1} dx\, E^a(x,0,t),$$

GPD	x^{-1} moment	x^0 moment	$t=0$ limit
$H^a(x,0,t)$	$R_V(t)$	$F_1(t)$	$q(x)$
$\hat{H}^a(x,0,t)$	$R_A(t)$	$G_A(t)$	$\Delta q(x)$
$E^a(x,0,t)$	$R_T(t)$	$F_2(t)$	$2J(x)/x - q(x)$



Polarization observables of WACS in GPDs handbag calculations

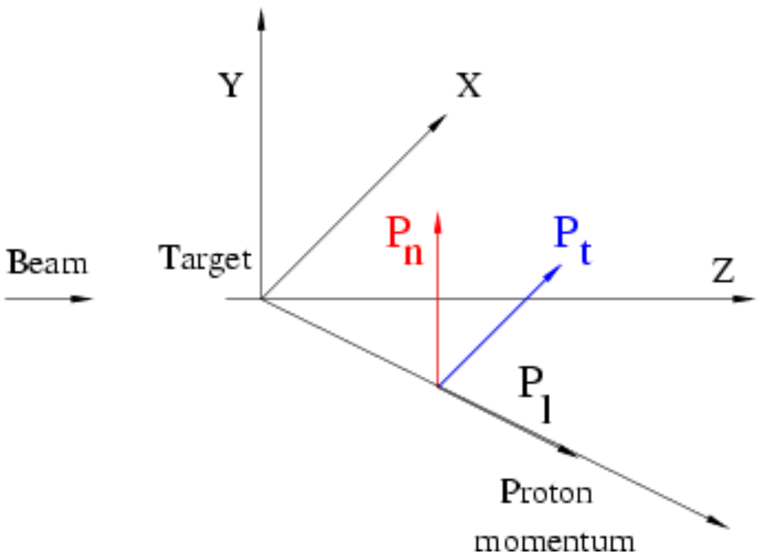


photon helicity and P_L of the recoil proton

$$K_{LL}^{KN} = \frac{s^2 - u^2}{s^2 + u^2}$$

LO:

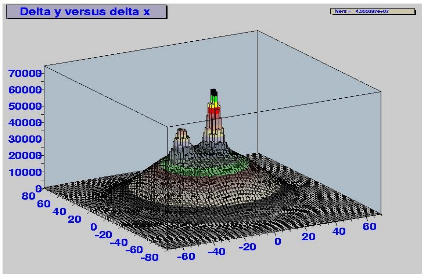
$$\frac{K_{LL}}{K_{LL}^{KN}} = \frac{R_A}{R_V}\left[1 - \frac{t^2}{2(s^2+u^2)}\left(1 - \frac{R_A^2}{R_V^2}\right)\right]^{-1}$$



LO + R_T :

$$K_{LL} = \frac{s^2 - u^2}{s^2 + u^2}\,\frac{R_A(t)}{R_V(t)}\,\frac{1 + \beta\sqrt{-t}/(2m_p)R_T/R_V}{1 - t/(4m_p^2)R_T^2/R_V^2}$$

$$\times\left[1 + \frac{R_A^2 - R_V^2(1 - t/(4m_p^2)R_T^2/R_V^2)}{2R_V^2(1 - t/(4m_p^2)R_T^2/R_V^2)}\,\frac{t^2}{s^2+u^2}\right]^{-1}$$

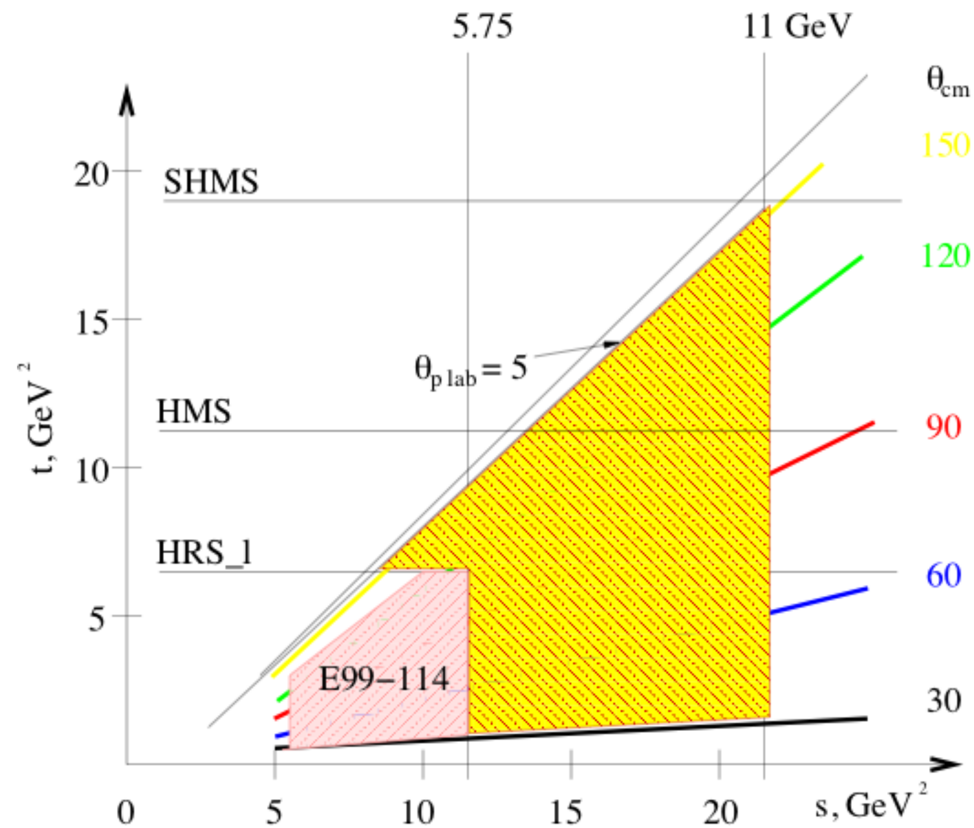


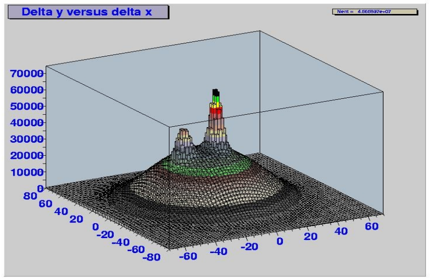
γp -> γp

WACS research program

CS research has a significant chance of discovering an actual reaction mechanism

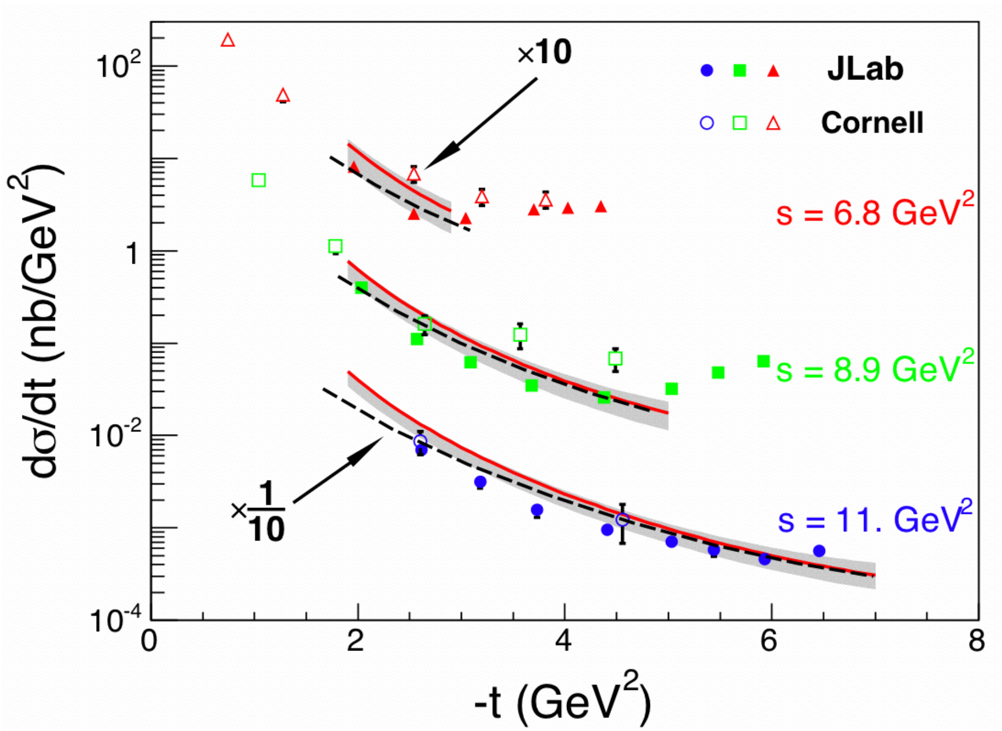
CS research would be extended for cross section up to s = 20 GeV^2 with the 12-GeV upgrade.





WACS and GPDs

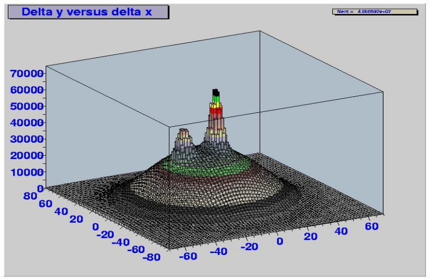
γp -> γp



Smoking issues:

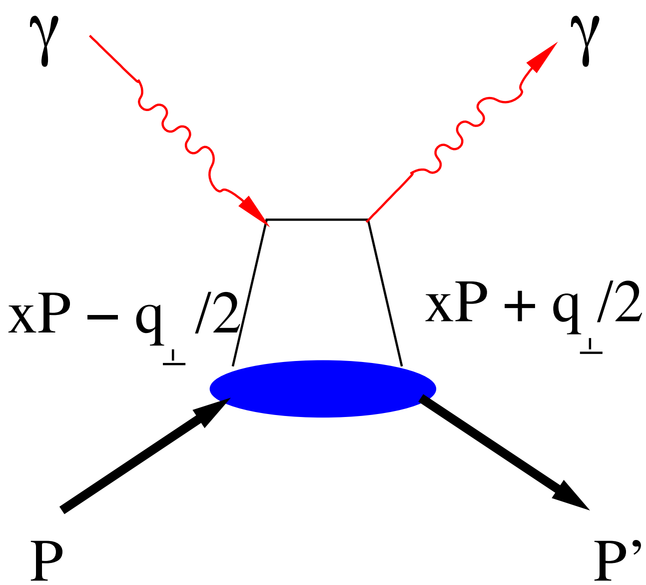
WACS is well described, needs the NLO …

γ p -> π N, cross section much larger (factor of 100) LO GPDs calculation



WACS and GPDs

γp -> γp

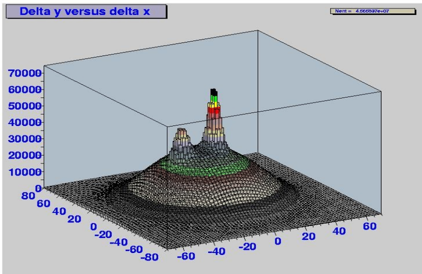


Smoking issues:

WACS is well described, needs the NLO …

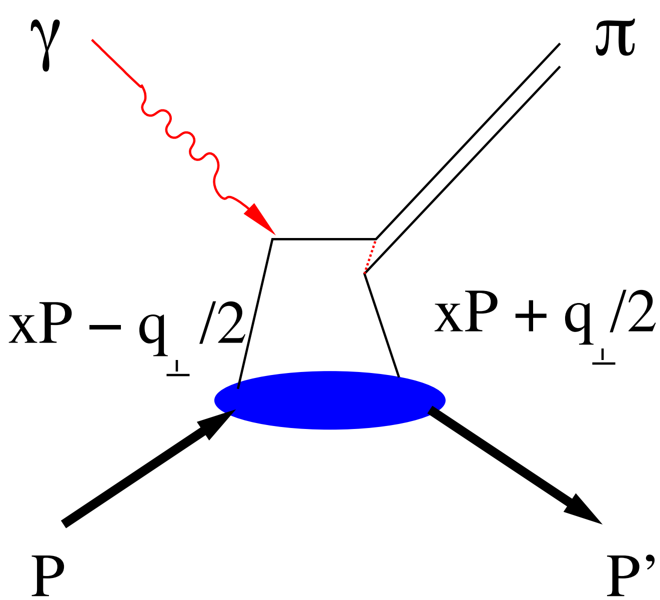
Scaling power n is ~ 8.
It tell us a number of the constituents: 5 => N + M

Does it look like a SSC?



WACS and GPDs

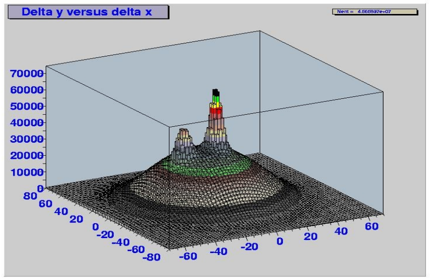
$\gamma p \to \gamma p$



Smoking issues:

WACS is well described, needs the NLO …

γ p -> π N, cross section is much larger (factor of 100) than in LO GPDs calculation



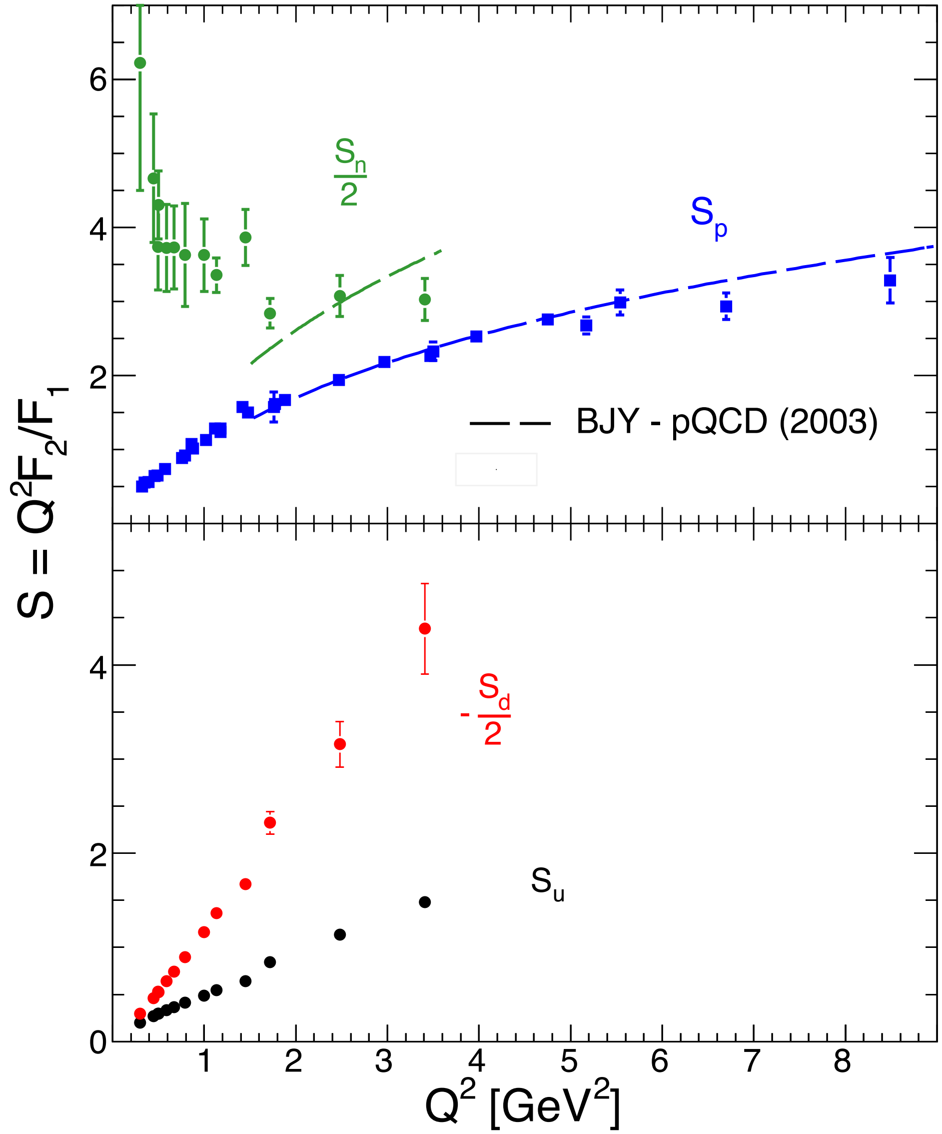
New about nucleon Form Factors

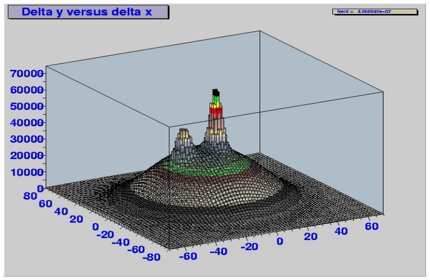
eN -> e'N

arXiv:1103.1808v1 [nucl-ex]

$$F^u_{1(2)} = 2\,F^p_{1(2)} + F^n_{1(2)}$$

$$F^d_{1(2)} = 2\,F^n_{1(2)} + F^p_{1(2)}$$





New about nucleon Form Factors

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