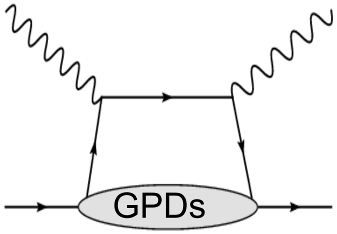


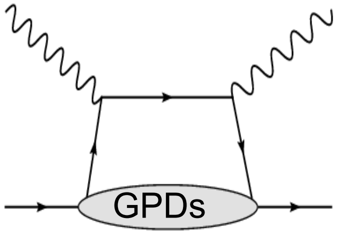
Polarized Wide Angle Compton Scattering in 12-GeV era

B. Wojtsekhowski

What are the issues of hadron physics?

What do we want to do in the ALL experiment?

How will we do the measurements?



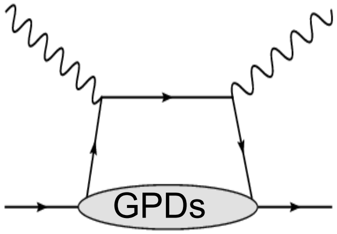
WACS: Introduction

Part of the Hard Exclusive Reactions program

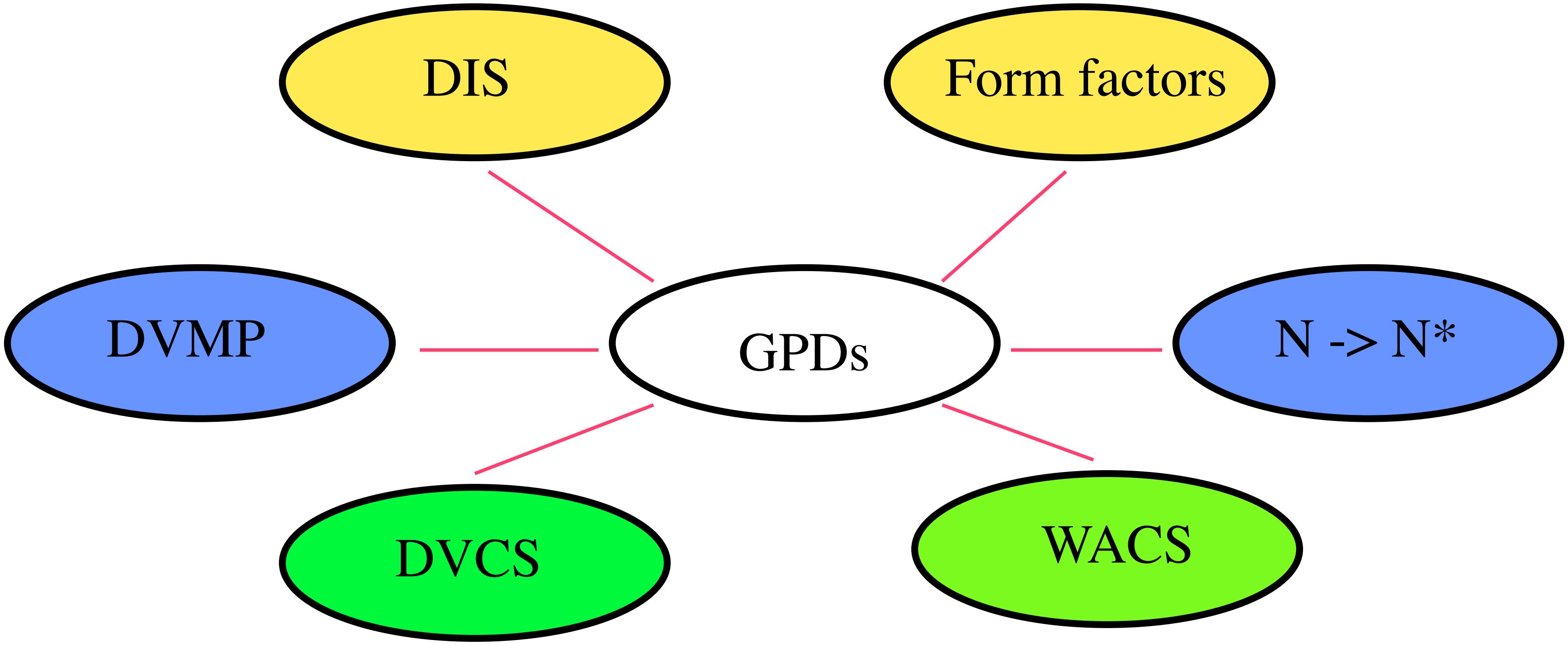
- Elastic Form Factors: GM_P,GE_P,GM_N,GE_N,FF_π
- WACS: high-*t* two-photon reaction
- Deeply Virtual Compton Scattering (DVCS)
- Deeply Virtual Meson Production

Common issues:

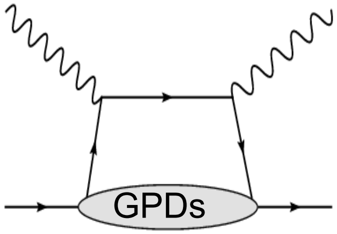
- Handbag diagram
- Interplay between the hard and soft processes
- Threshold for onset of the asymptotic regime
- Role of the hadron helicity flip



Unification of nucleon structure within GPDs



x ξ t



The experiment provides the answer

Test of the reaction mechanism in the cloud chamber.

Arthur

Compton

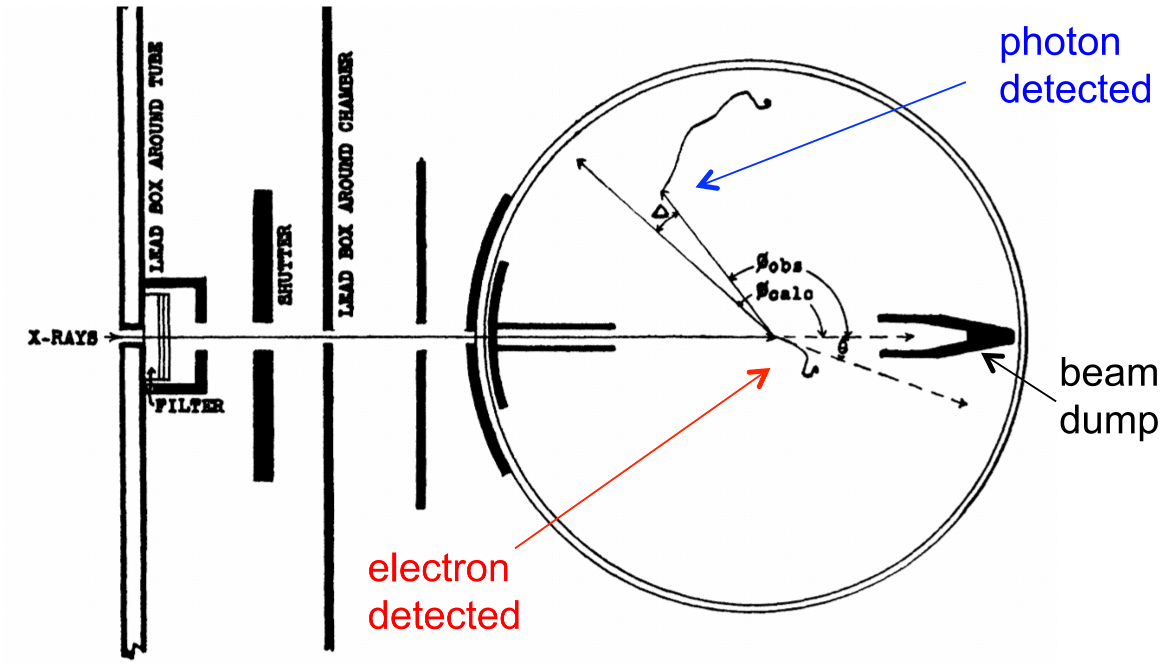
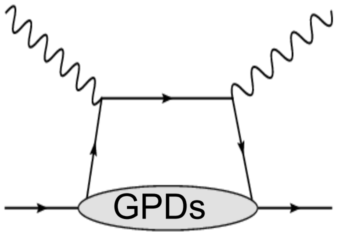


Fig. 1. Diagram of apparatus. On the hypothesis of radiation quanta, if a recoil electron is ejected at an angle θ, the scattered quantum must proceed in a definite direction ϕ_{calc}. In support of this view, many secondary β-ray tracks are found at angles ϕ_{obs} for which Δ is small.

Physical Review (1925)

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.*



GPDs and form factors of WACS

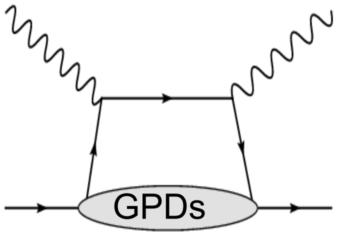
$$\gamma p \to \gamma p \qquad\qquad ep \to ep$$

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

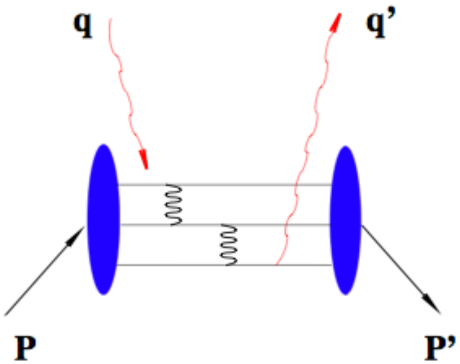
$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} \mathrm{sign(x)}\, \hat{\mathrm{H}}^{\mathrm{a}}(\mathrm{x},0,\mathrm{t}), \qquad G_A(t) = \sum_a \int_{-1}^{1} dx\, \mathrm{sign(x)}\, \hat{\mathrm{H}}^{\mathrm{a}}(\mathrm{x},0,\mathrm{t}),$$

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

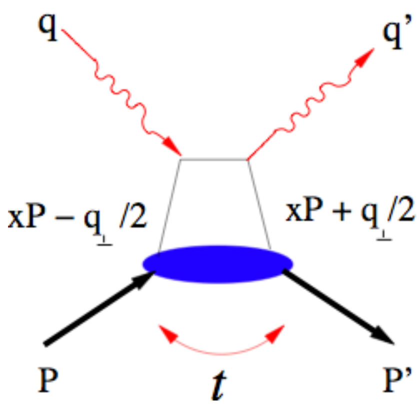
GPD	x^{-1} moment	x^0 moment	$t=0$ limit
$H^a(x,0,t)$	$R_V(t)$	$F_1(t)$	$q(x)$
$\hat{H}^a(x,0,t)$	$R_A(t)$	$G_A(t)$	$\Delta q(x)$
$E^a(x,0,t)$	$R_T(t)$	$F_2(t)$	$2J(x)/x - q(x)$



Cross section of Wide-Angle Compton Scattering



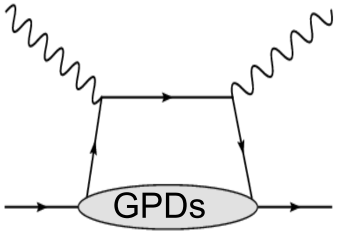
$+ \quad ... \quad + \quad .... \; 336$



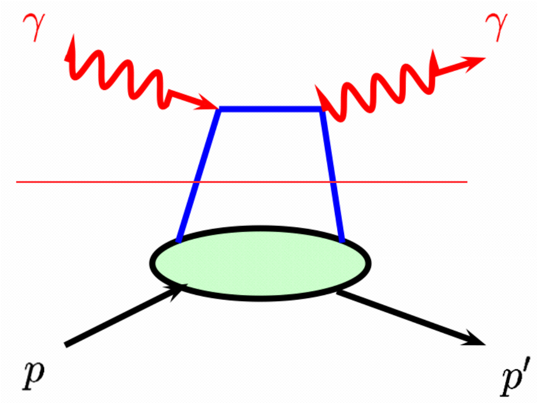
- **Three-quark mechanism:**
  It dominates at "asymptopia".
  Two hard gluon exchanges.
  Constituent counting rules:
  $d\sigma/dt = f(\theta_{CM})/s^6$
  "complicated" polarization observables

- **Single-quark mechanism:**
  "Handbag" diagram dominates.
  Form factors (P. Kroll):

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



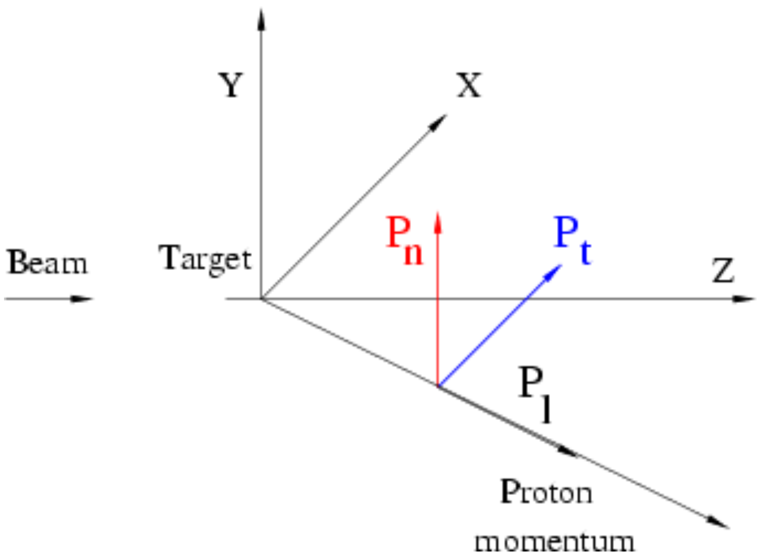
Polarization observables of WACS in GPDs handbag calculations



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

LO:

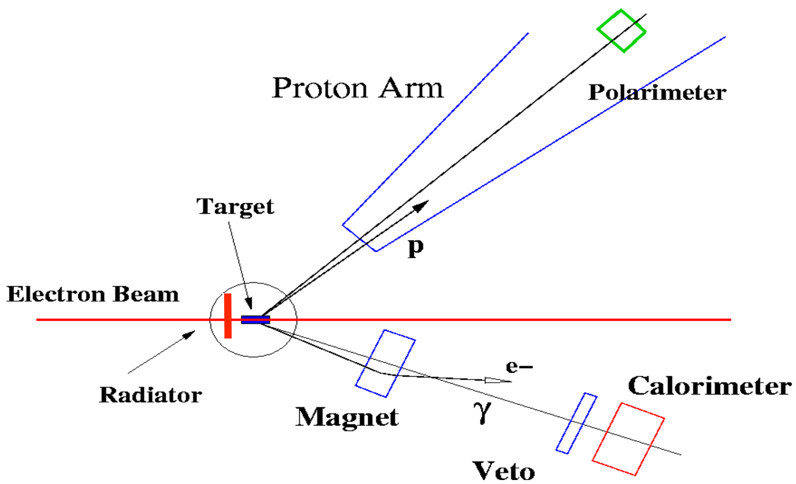
$$\frac{K_{LL}}{K_{LL}^{KN}} = \frac{R_A}{R_V}\left[1 - \frac{t^2}{2(s^2+u^2)}\left(1 - \frac{R_A^2}{R_V^2}\right)\right]^{-1}$$



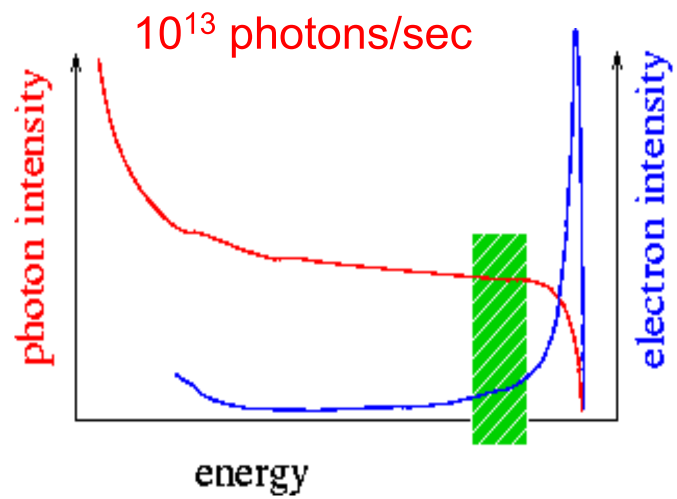
LO + R_T :

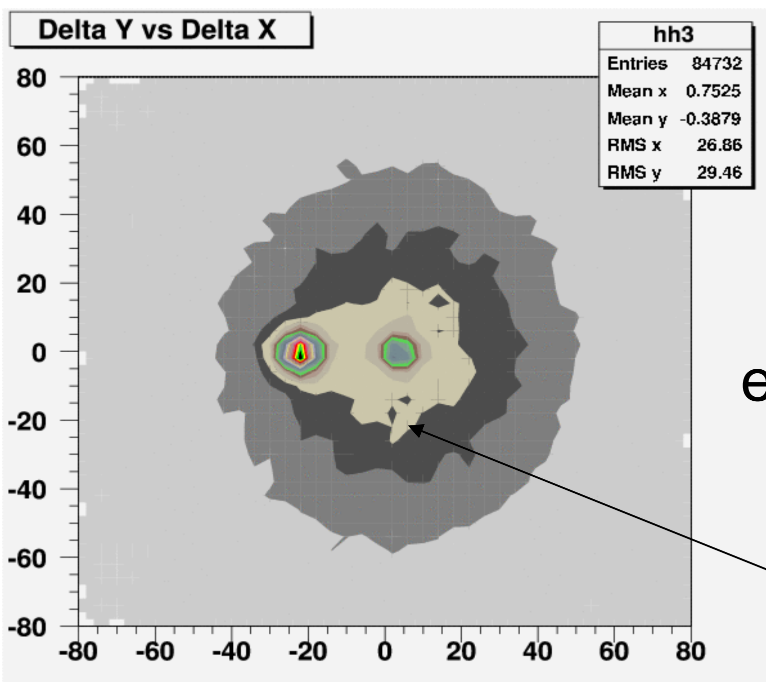
$$K_{LL} = \frac{s^2 - u^2}{s^2 + u^2}\,\frac{R_A(t)}{R_V(t)}\,\frac{1 + \beta\sqrt{-t}/(2m_p)R_T/R_V}{1 - t/(4m_p^2)R_T^2/R_V^2}$$
$$\times\left[1 + \frac{R_A^2 - R_V^2(1 - t/(4m_p^2)R_T^2/R_V^2)}{2R_V^2(1 - t/(4m_p^2)R_T^2/R_V^2)}\,\frac{t^2}{s^2+u^2}\right]^{-1}$$

Mixed e/γ beam –> productivity ***1300*** times higher than the beam of “clean” γ

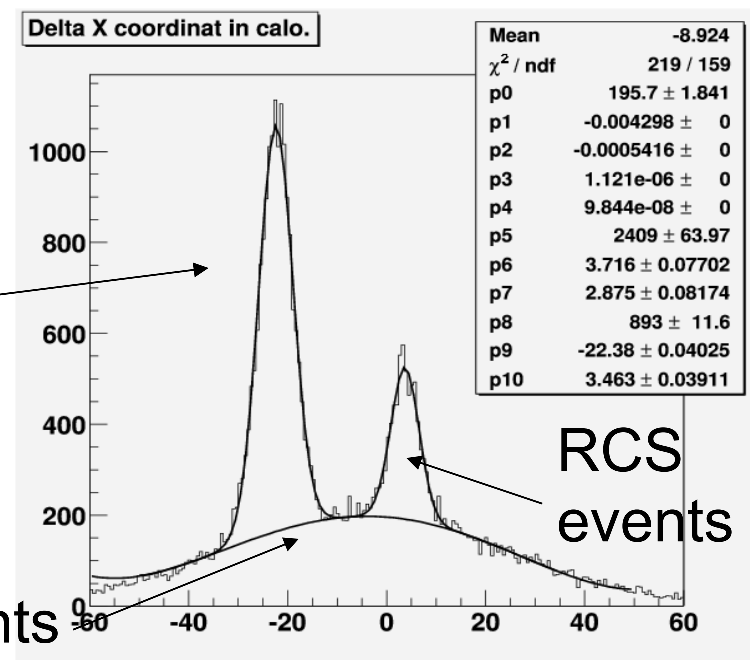


Two body kinematics





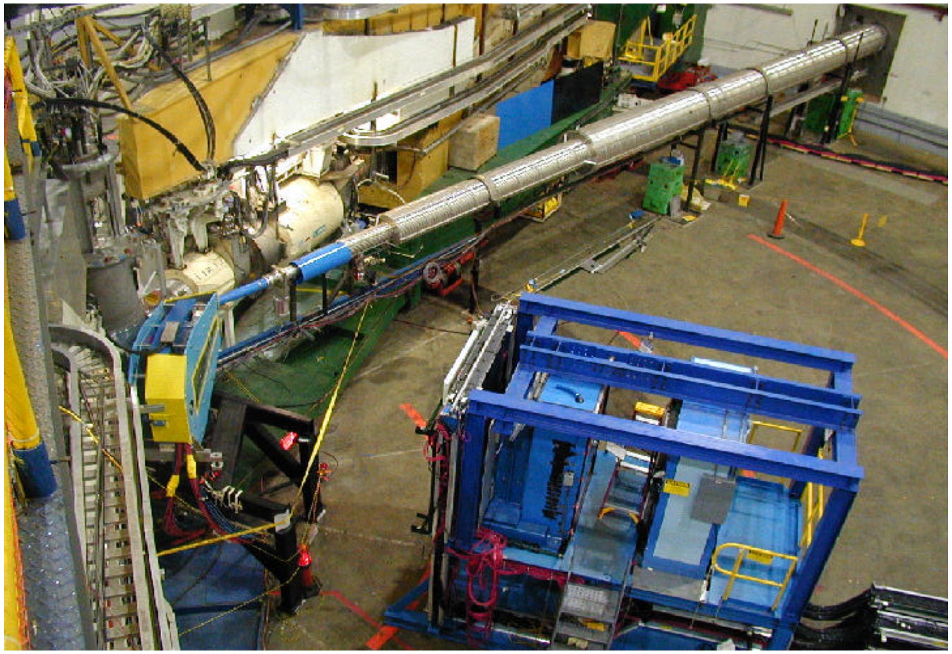
ep events

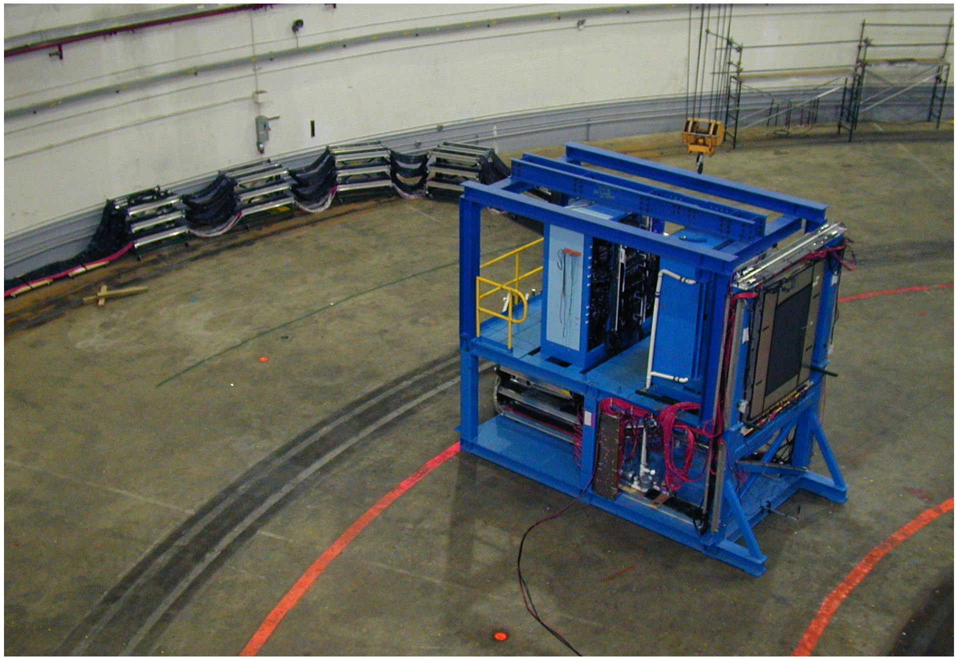


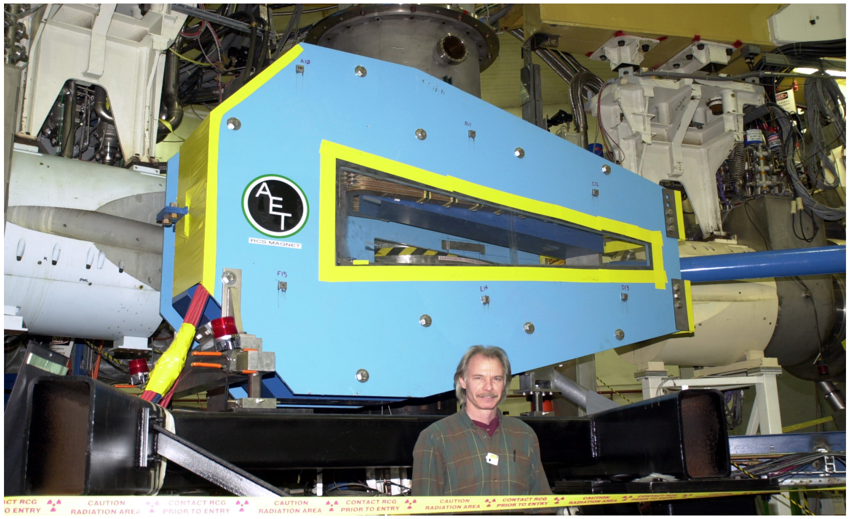
RCS events

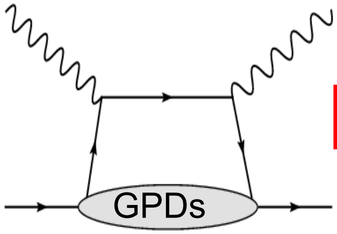
“pion” events

E99-114 experiment in 2002









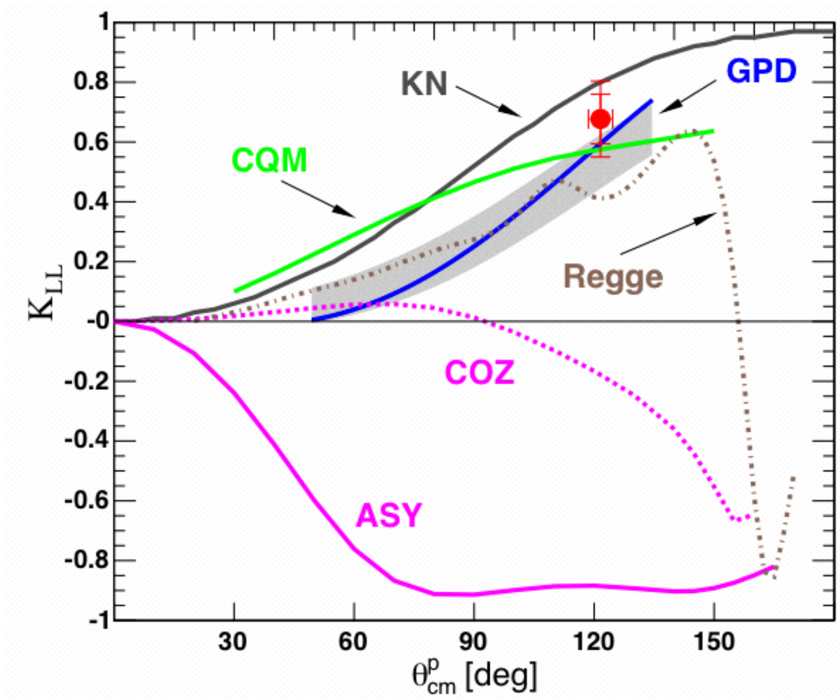
Results of 6 GeV WACS experiment

PRL 94, 242001 (2005)

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

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

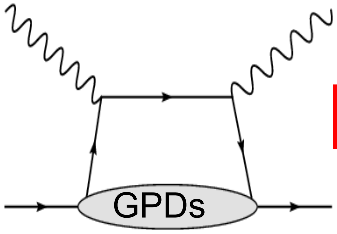
$R_A/R_V = 0.81 \pm 0.11$



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

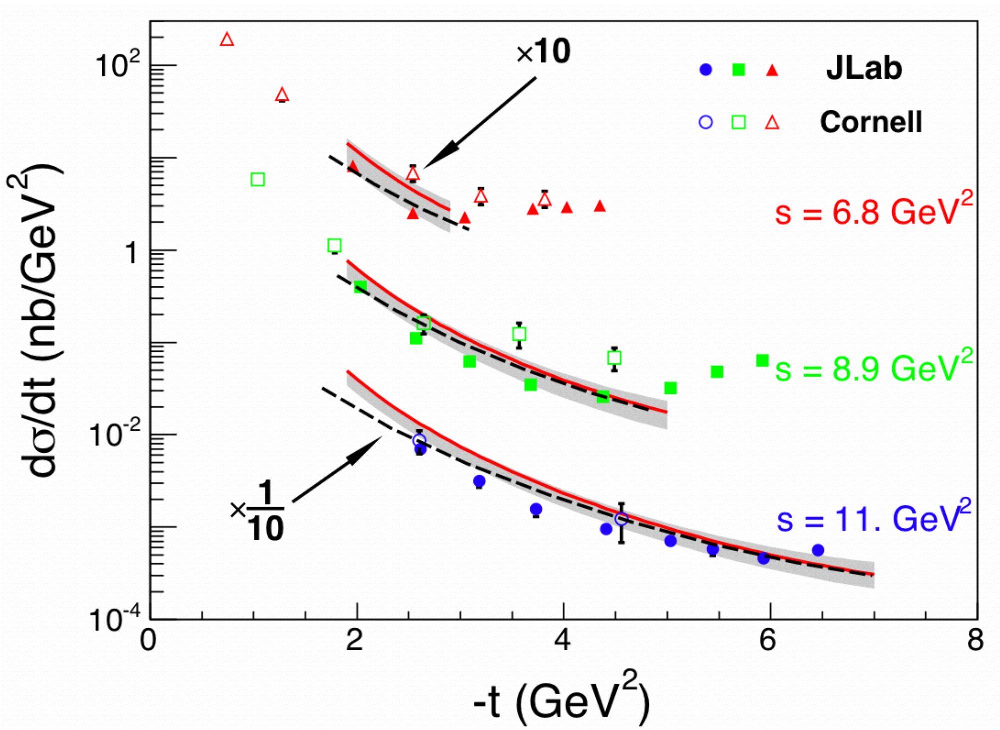
$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x}\, \mathrm{sign(x)}\, \hat{\mathrm{H}}^a(\mathrm{x},0,\mathrm{t}),$$

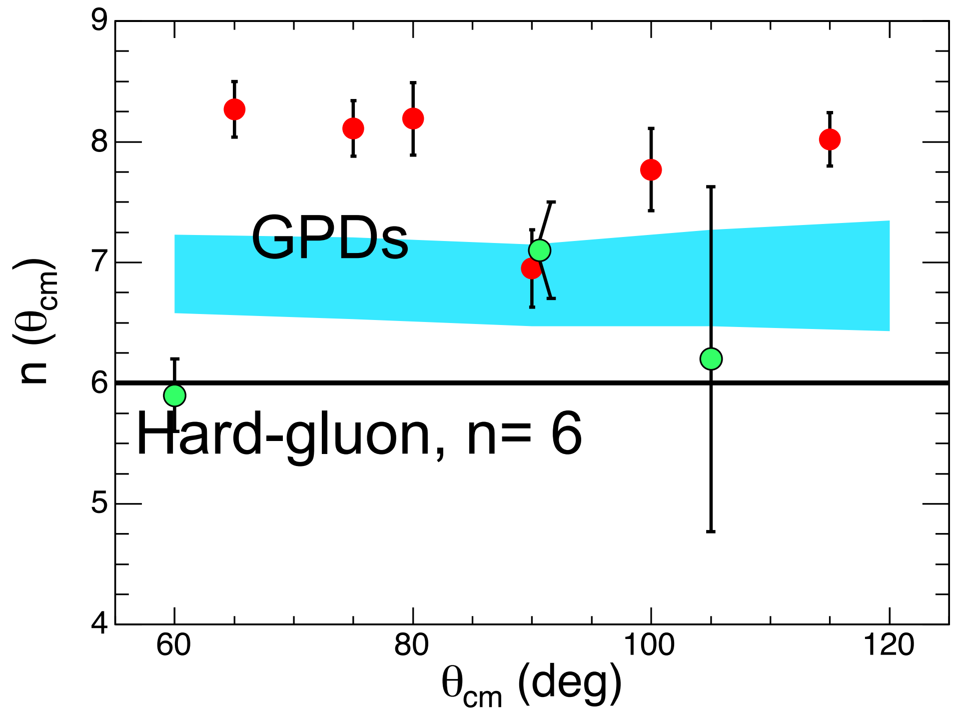
$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t),$$



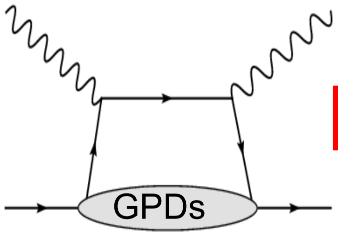
Results of 6 GeV WACS experiment

PRL 98, 152001 (2007)





n = 8.0 +/- 0.2



Results of 6 GeV WACS experiment

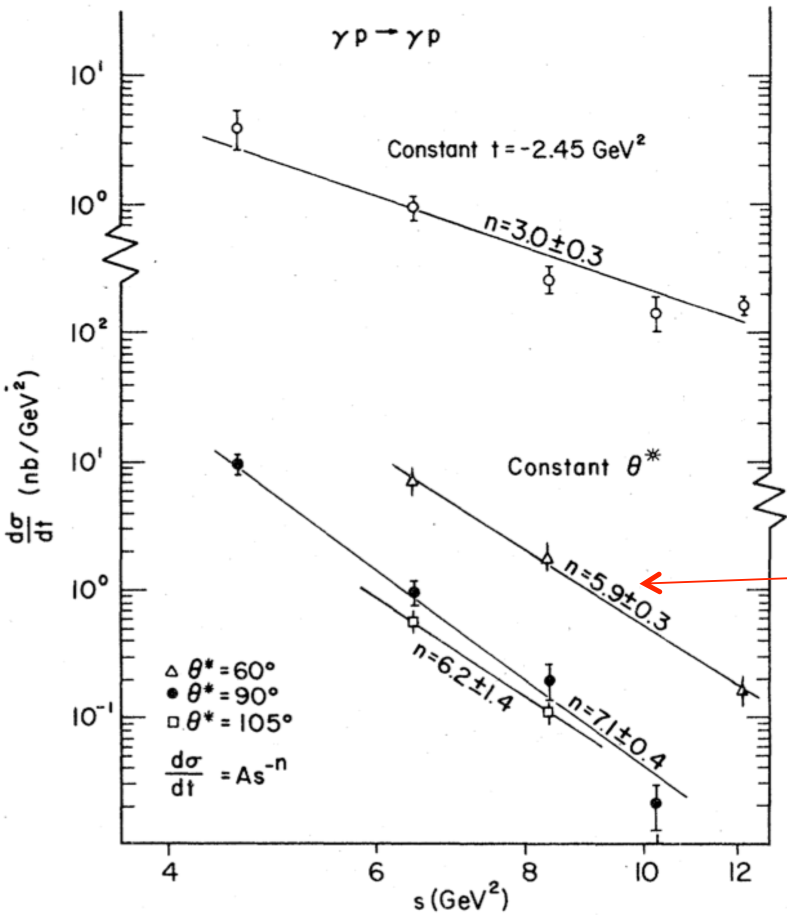
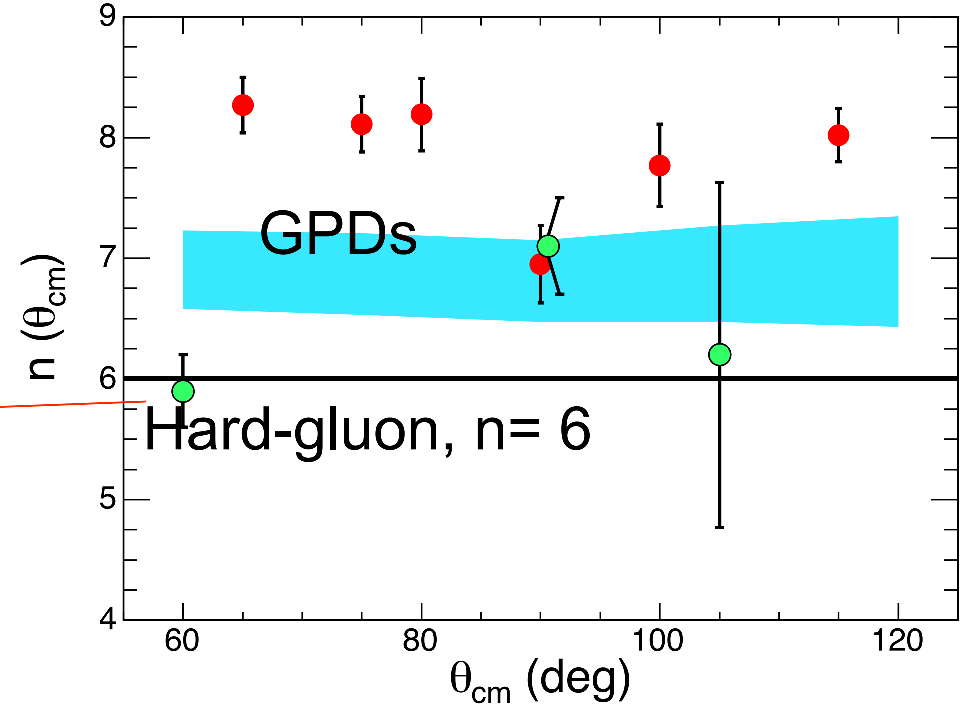
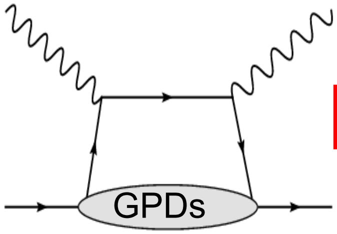


FIG. 6. Compton-scattering cross sections at constant t and at constant θ^*. The straight lines are fits to the data. The fits shown here have no energy cuts.

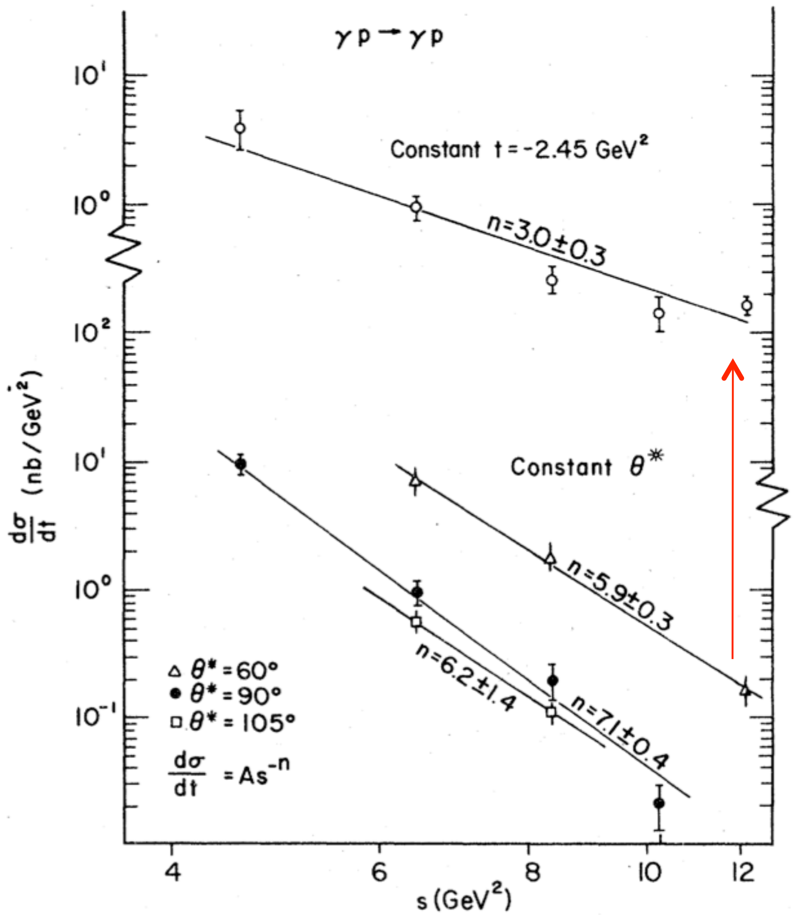
PRL 98, 152001 (2007)



n = 8.0 +/- 0.2



Results of 6 GeV WACS experiment



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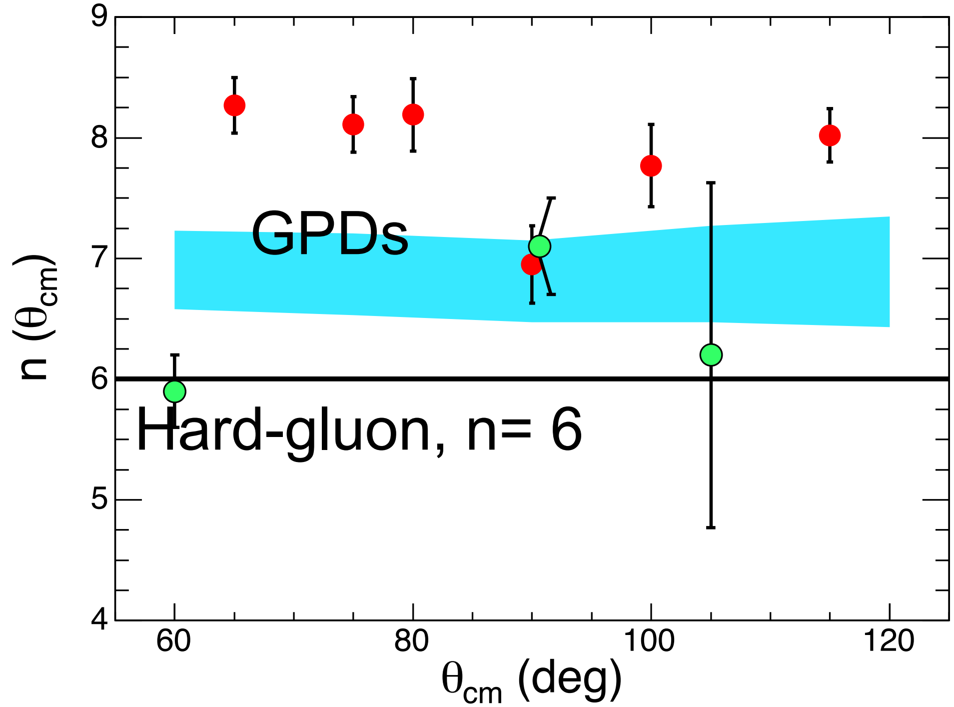
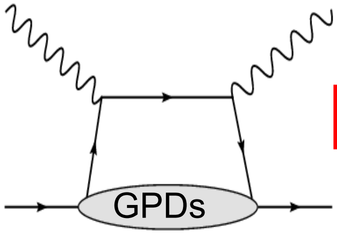
PRL 98, 152001 (2007)



$n = 8.0 +/- 0.2$



Results of 6 GeV WACS experiment

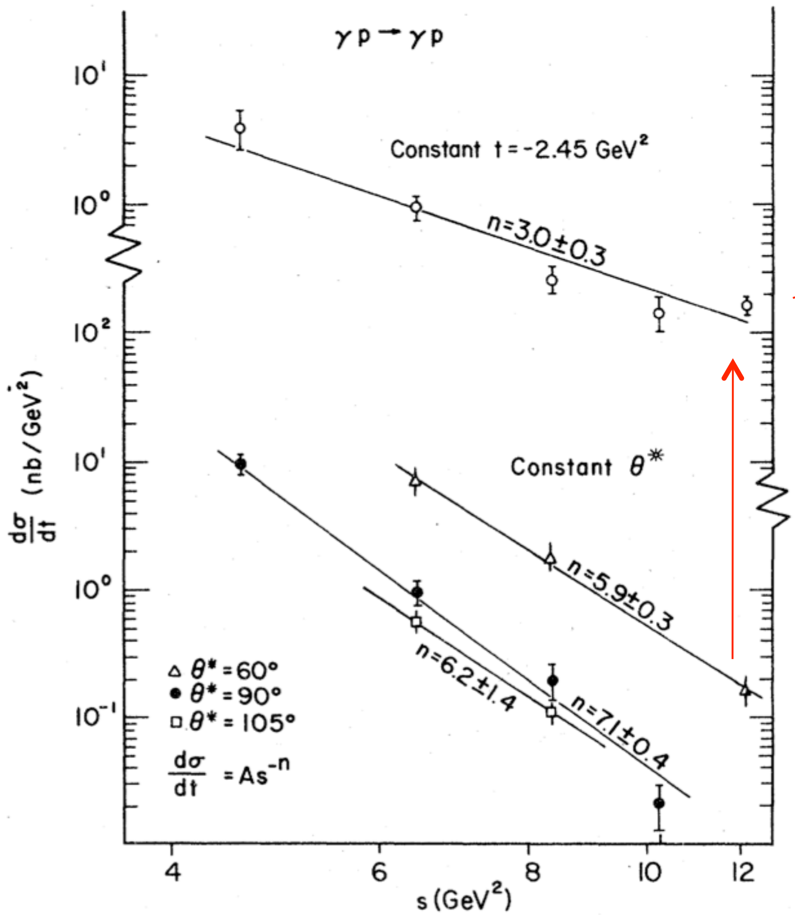


FIG. 6. Compton-scattering cross sections at constant t and at constant θ^*. The straight lines are fits to the data. The fits shown here have no energy cuts.

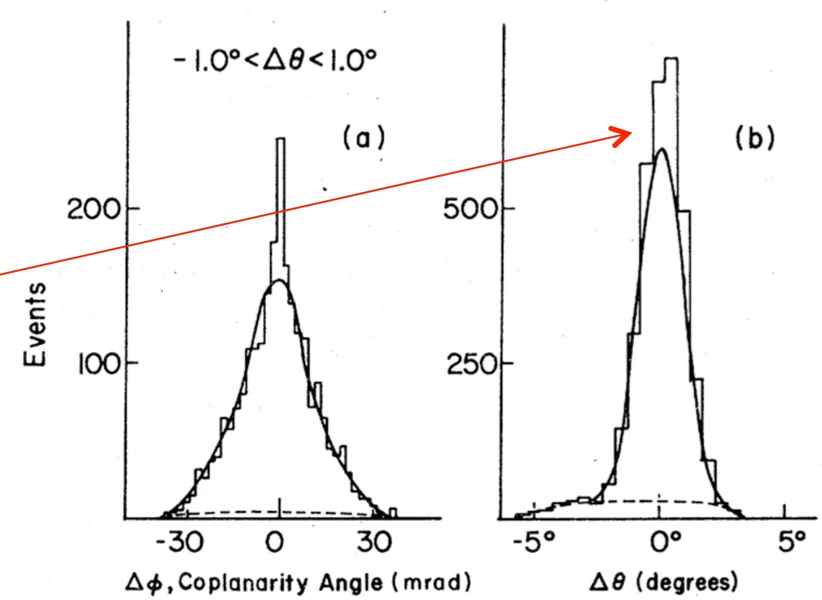
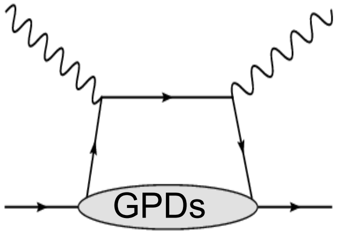
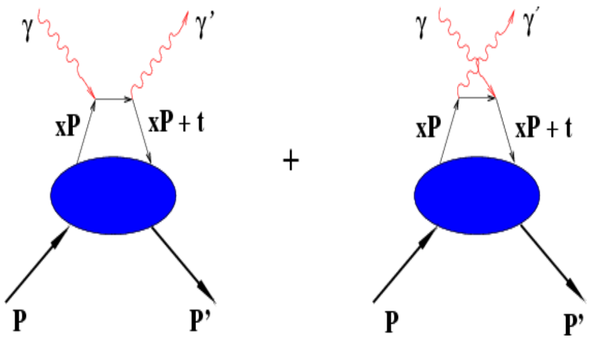


FIG. 3. Angular-difference distribution at 6 GeV and $t = -2.45$ GeV^2. (a) Coplanarity-angle distribution. The solid line is a fit assuming neutral-pion photoproduction, the dashed line is the estimated background from other processes, and the peak at $\Delta\phi = 0$ is due to proton Compton scattering. (b) Angular-difference distribution in the reaction plane. The curves have the same interpretation as in (a). The excess at $\Delta\theta = 0°$ is due to Compton scattering.



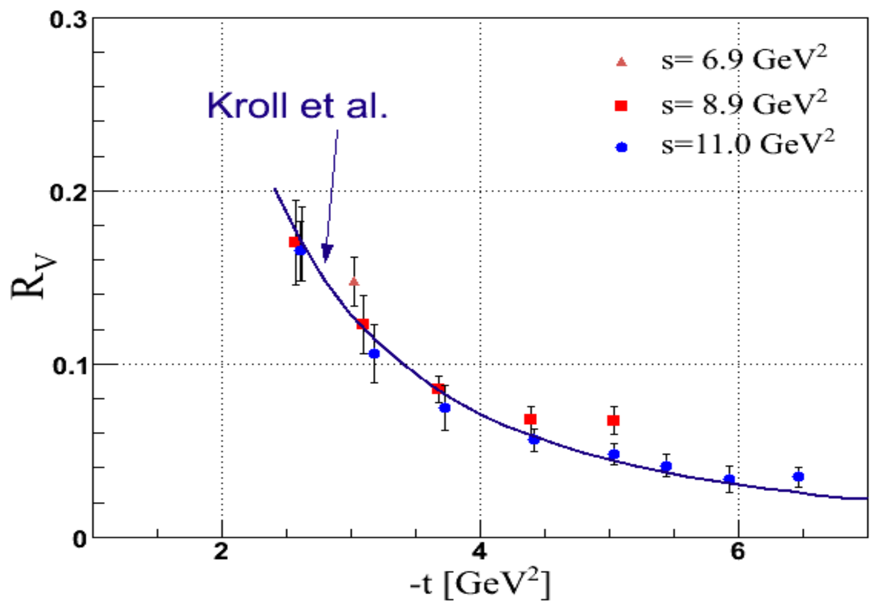
Form factors of RCS and partonic structure of the nucleon

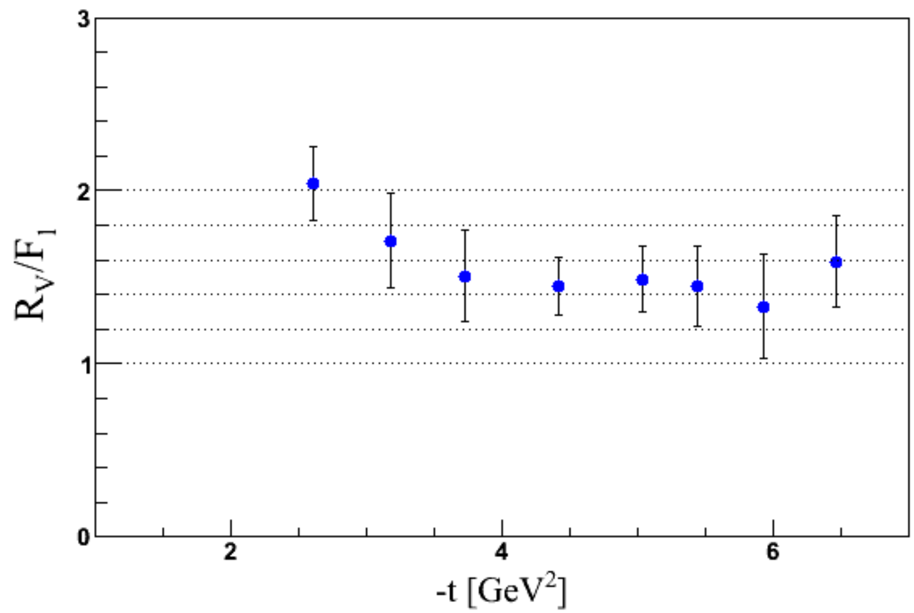


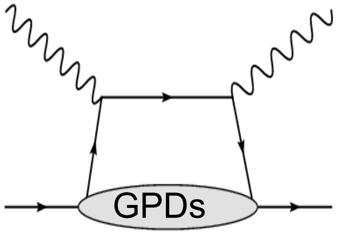
$$\frac{d\sigma_{RCS}}{d\sigma_{KN}} = \frac{(\hat{s}-\hat{u})^2}{\hat{s}^2+\hat{u}^2} R_V^2(t) + \frac{2\hat{s}\hat{u}}{\hat{s}^2+\hat{u}^2} R_A^2(t)$$

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

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

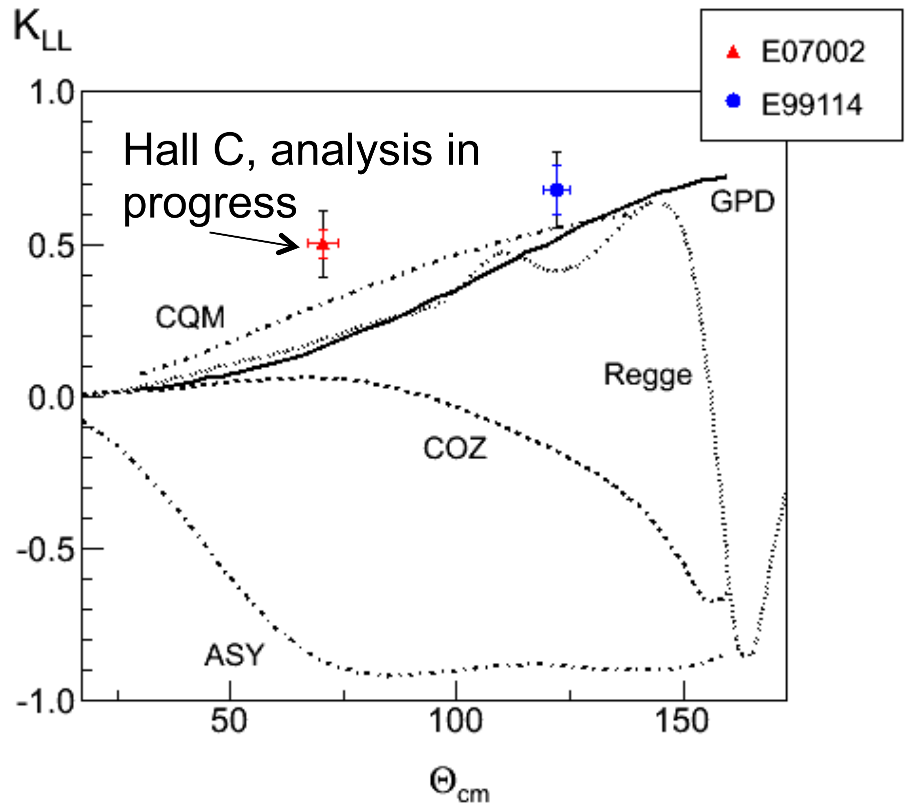


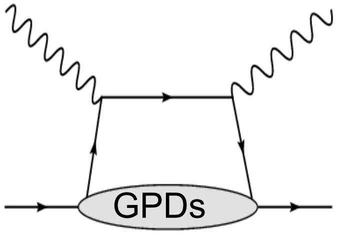




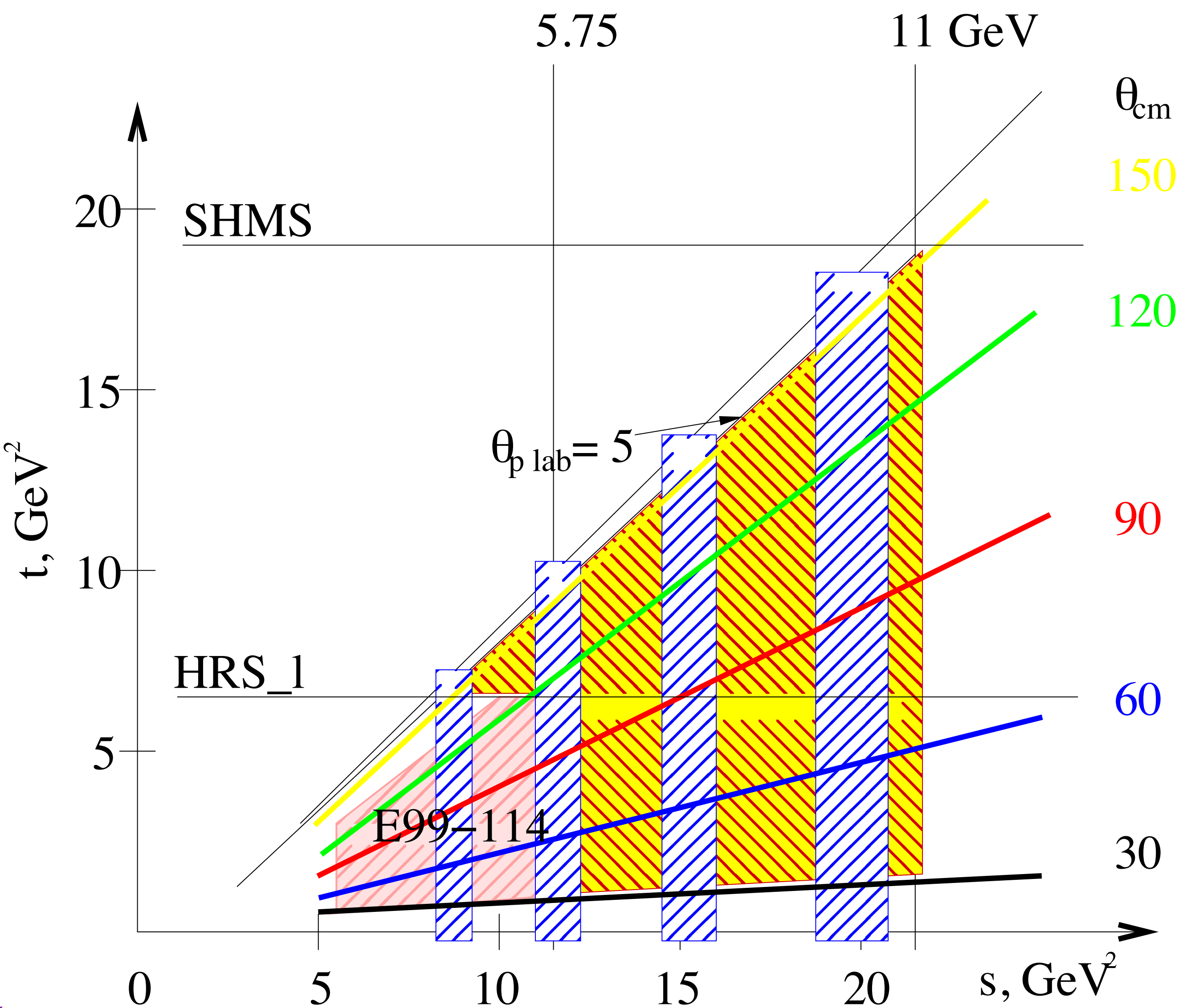
E07-002 K_{LL} result

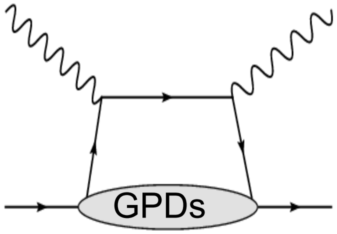
$s = 8.0\ GeV^2$, $-t = 2.1\ GeV^2$, $-u = 4.1\ GeV^2$





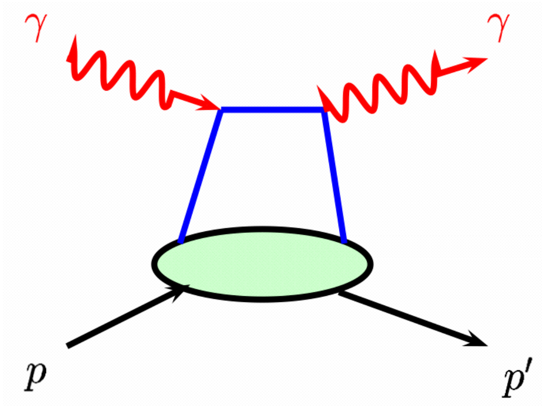
WACS perspective with 12 GeV JLab beam



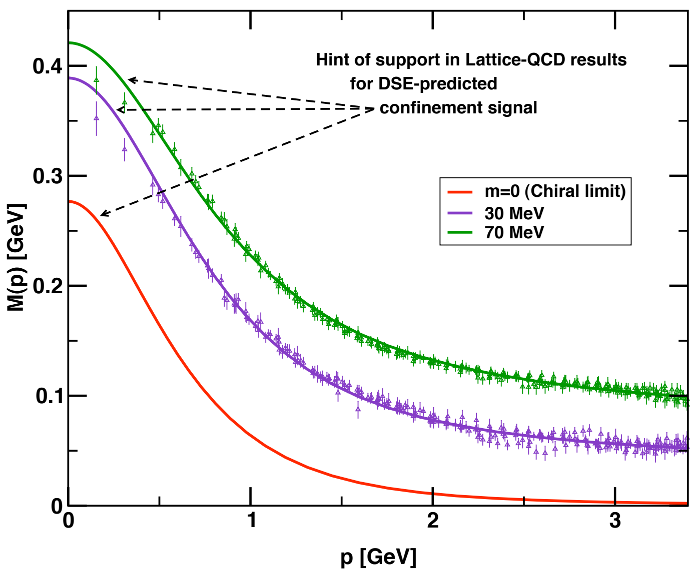


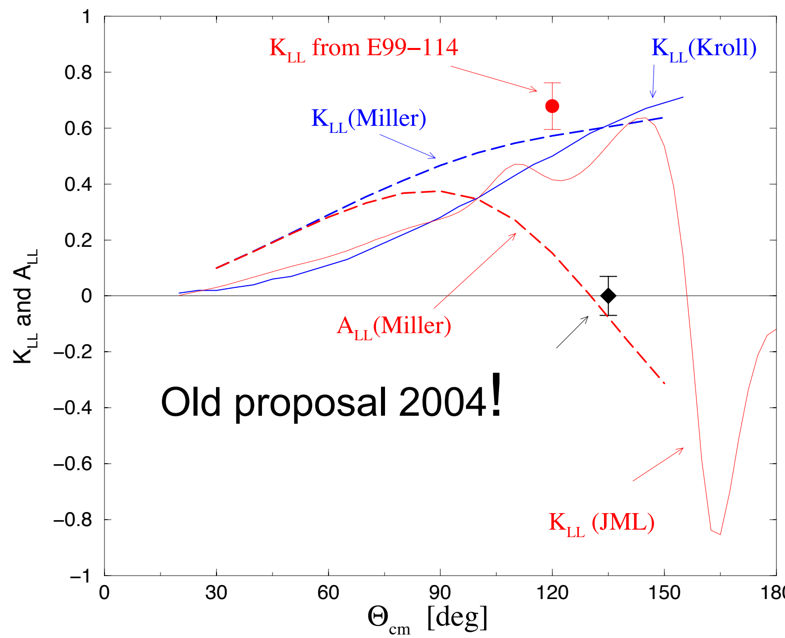
Polarized WACS in 12-GeV era

Initial state double polarization correlation

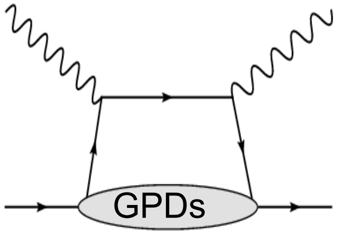


$$A_{LL} = \frac{1}{2}\left\{\frac{\sigma(+\uparrow)-\sigma(+\downarrow)}{\sigma(+\uparrow)+\sigma(+\downarrow)} - \frac{\sigma(-\uparrow)-\sigma(-\downarrow)}{\sigma(-\uparrow)+\sigma(-\downarrow)}\right\}$$

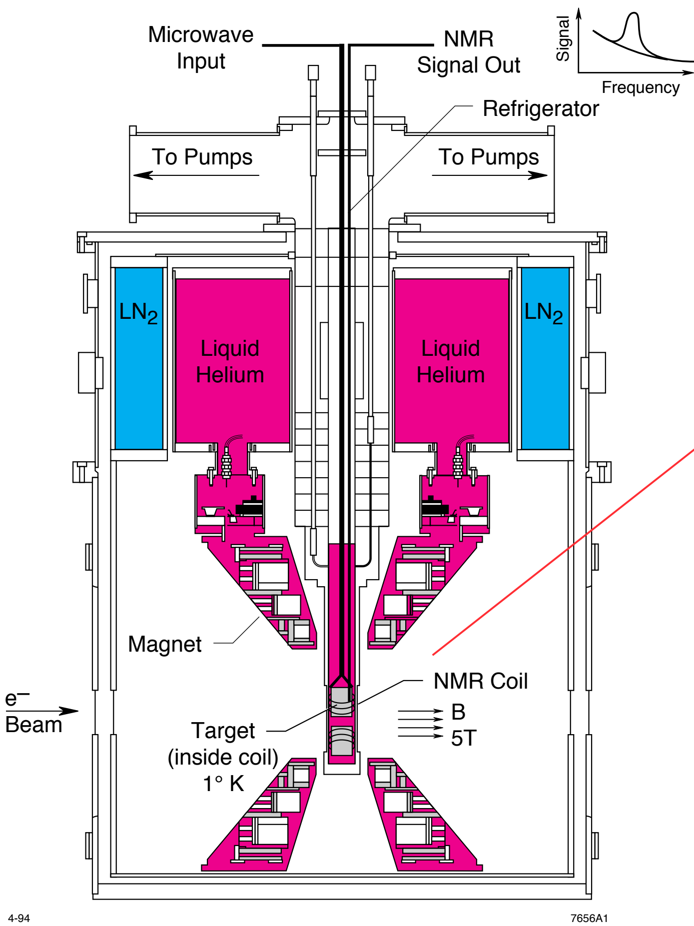




A_{LL} - K_{LL} diff. as a measure of quark spin flip ~ m_q/E_γ



Polarized WACS in 12-GeV era



Magnet C opening polar angle +/- 51^o
and also from 90^o +/- 18^o

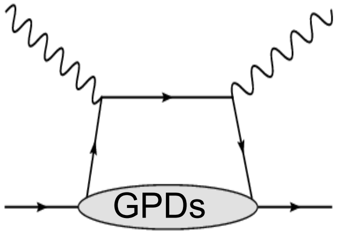
Magnet B opening polar angle +/- 45^o
and also from 90^o +/- 14^o

Electron beam intensity 0.09 μA
10% Cu radiator at 25 cm from target

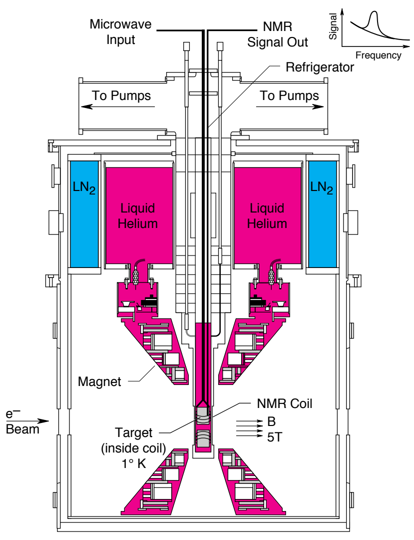
Luminosity: polarized proton: 8×10^{34} Hz/cm^2

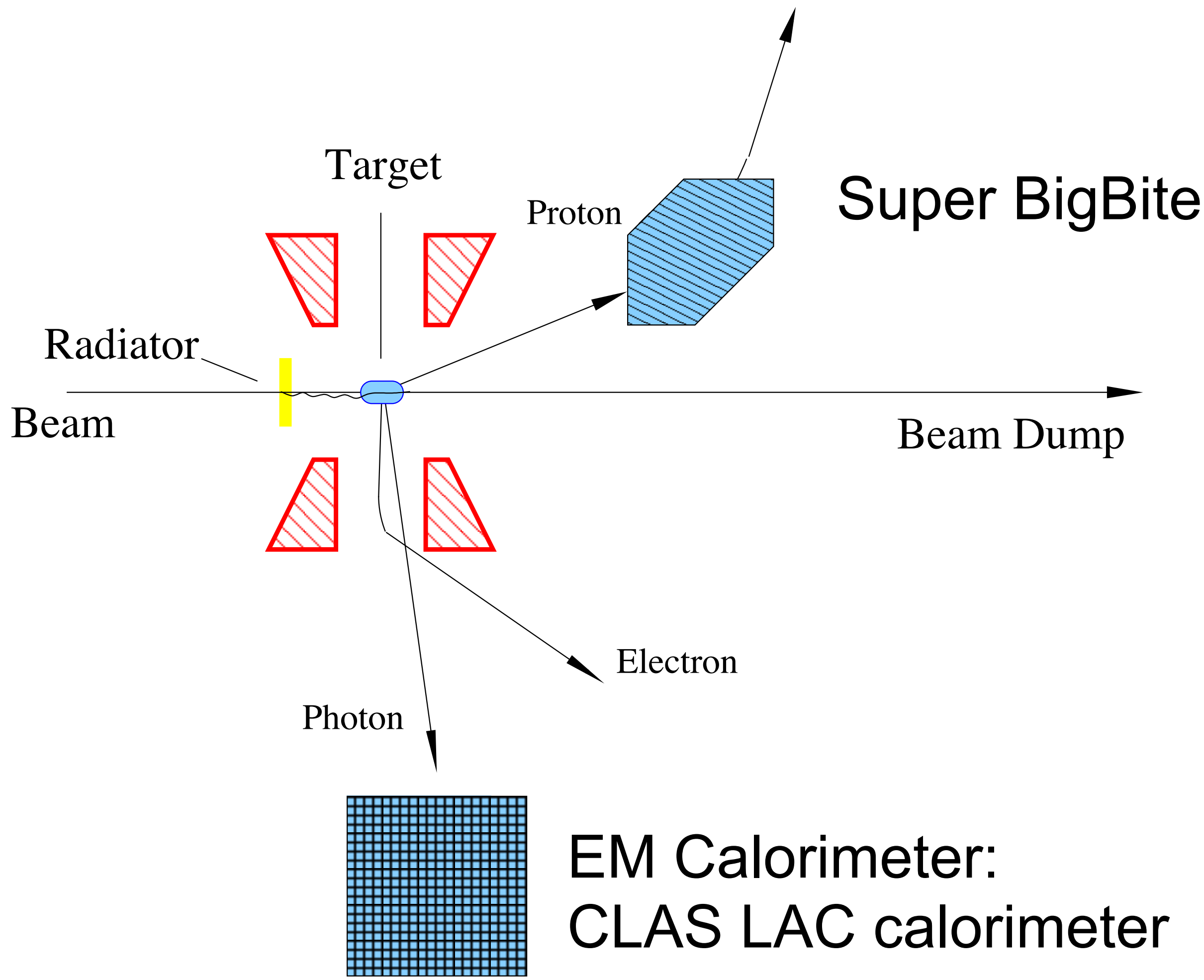
(L_{eN}) total nucleon : 4.8×10^{35}

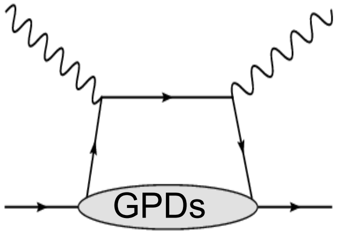
Compare with E99-114, $L_{ep} = 1.2 \times 10^{38}$



Polarized WACS in 12-GeV era

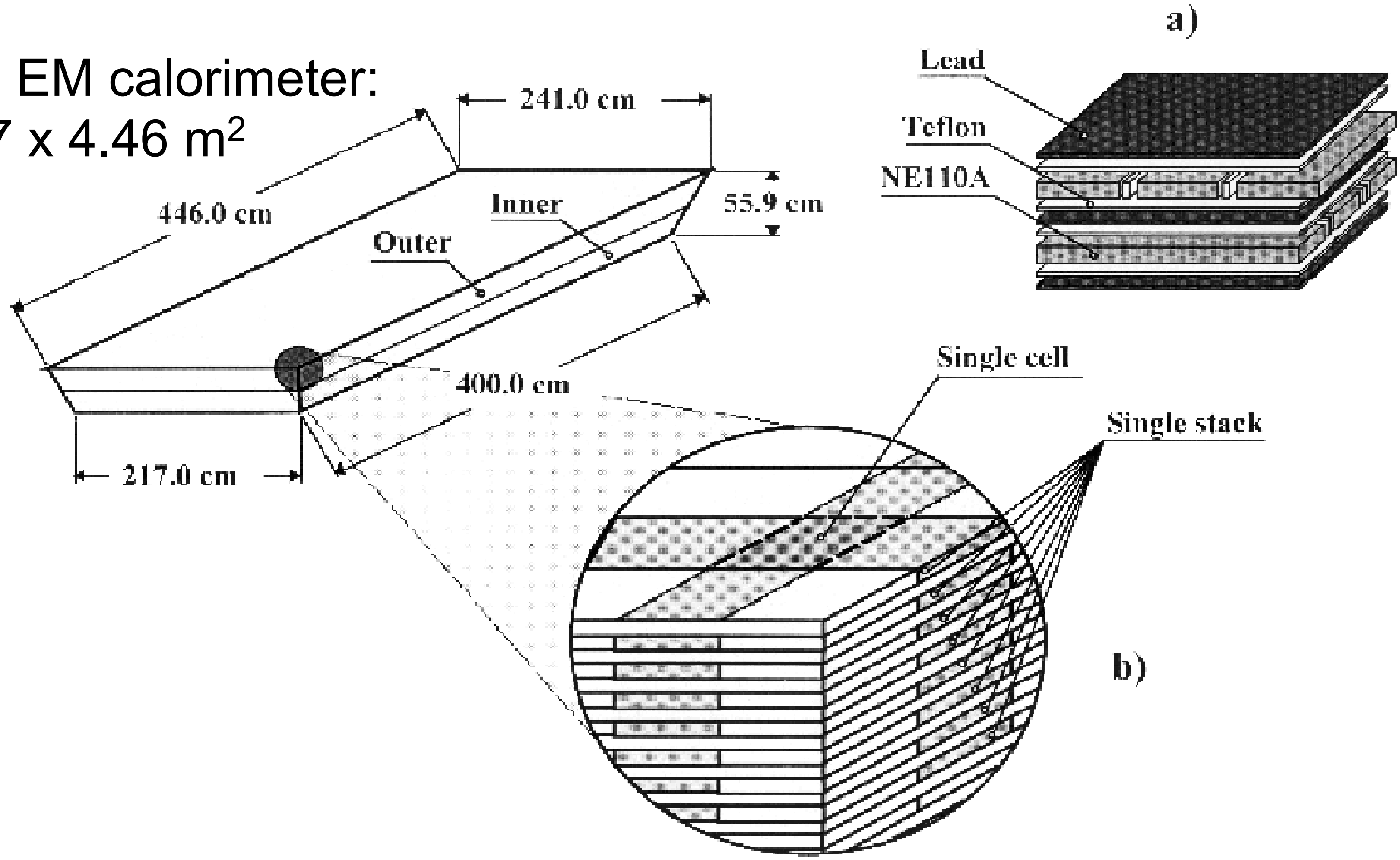


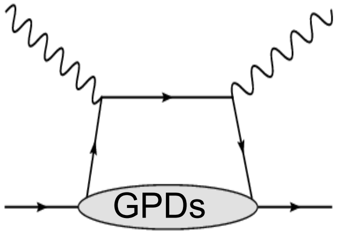




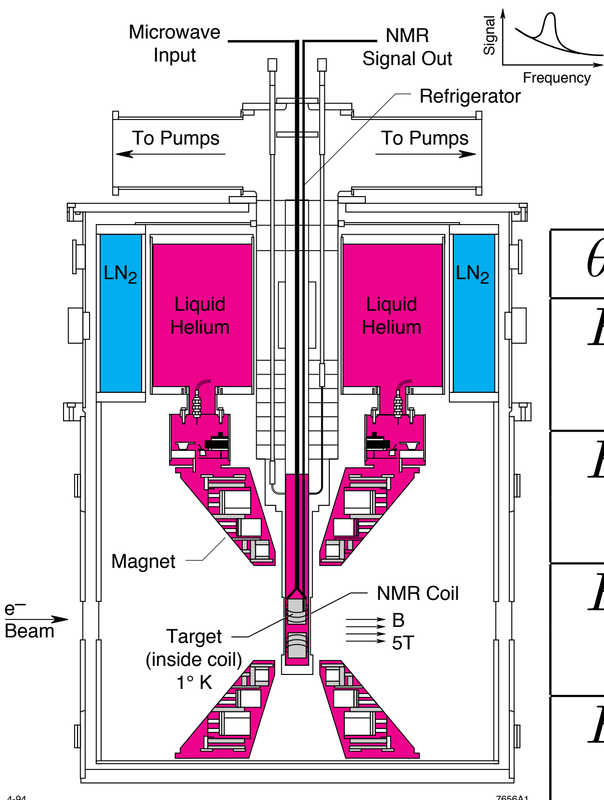
Polarized WACS in 12-GeV era

The EM calorimeter:
2.17 x 4.46 m^2





Polarized WACS in 12-GeV era

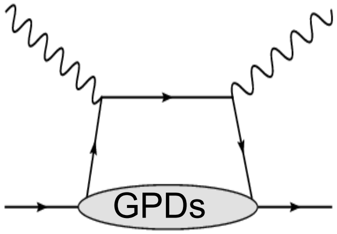


$$\sin\left(\frac{\theta_\gamma^{cm}}{2}\right) = \frac{\sqrt{-ts}}{(s-m^2)}$$

The photon & proton scattering angles (lab)

θ_γ^{cm}, $[deg]$		30	60	90	120	150
$E_\gamma = 4\,GeV$	θ_γ	9.9	21.2	35.9	58.5	101
	θ_p	65.5	45.4	30.4	18.7	8.9
$E_\gamma = 6\,GeV$	θ_γ	8.2	17.7	30.1	50.0	90.3
	θ_p	62.1	41.0	26.7	16.2	7.7
$E_\gamma = 8\,GeV$	θ_γ	7.2	15.5	26.5	44.4	82.5
	θ_p	59.1	37.6	24.0	14.4	6.8
$E_\gamma = 10\,GeV$	θ_γ	6.5	13.9	23.9	40.3	76.5
	θ_p	56.5	35.1	22.1	13.2	6.2

All these points are “kinematically” admissible



Polarized WACS in 12-GeV era

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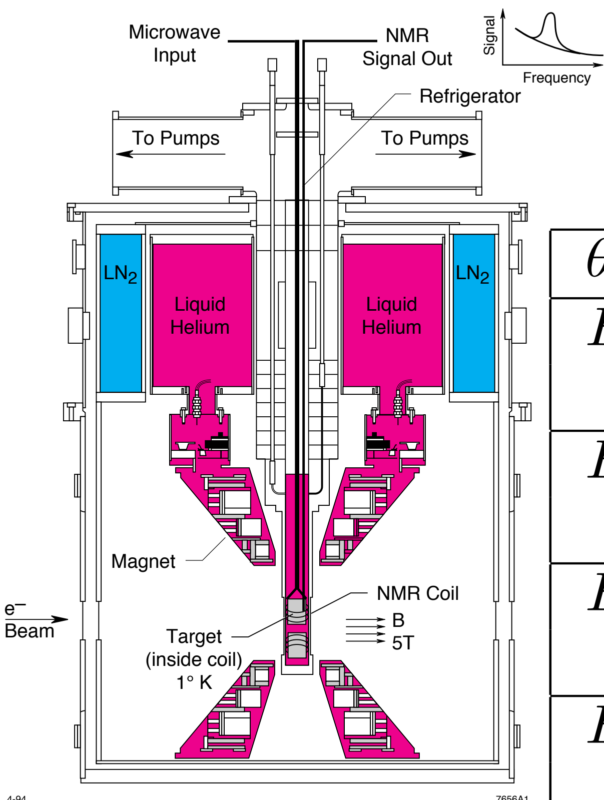

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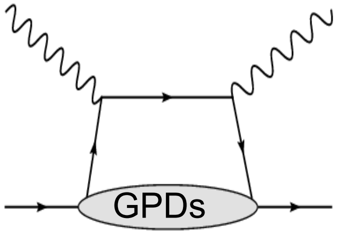
This is also a good GEP data point!



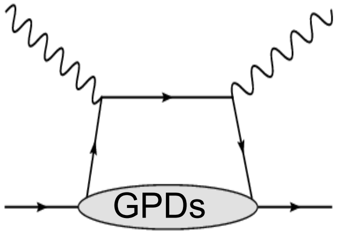
Polarized WACS in 12-GeV era

cross section solid angle photon flux

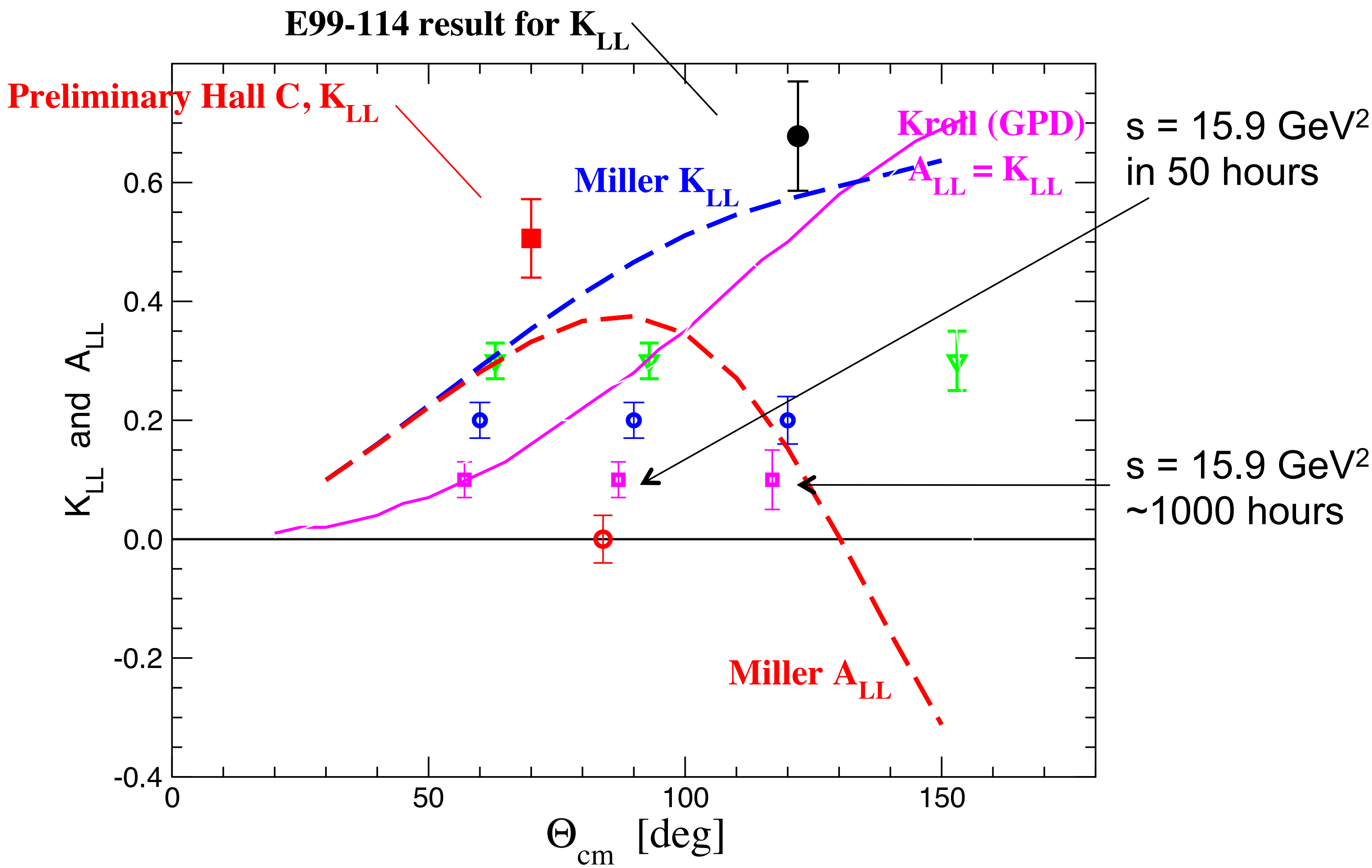
$$N_{RCS} = \frac{d\sigma}{dt}_{RCS} \left(\frac{(E_\gamma^f)^2}{\pi} \Delta\Omega_p \frac{d\Omega_\gamma}{d\Omega_p} \right) f_{\gamma p} \left(\frac{\Delta E_\gamma^f}{E_\gamma^f} \frac{t_{rad}}{X_o} \right) \mathcal{L}_{e\vec{p}}$$

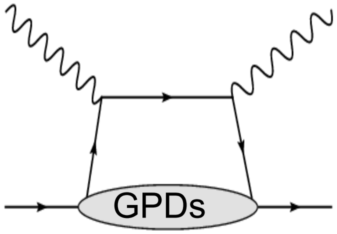
Pion/RCS ratio and cross section for the 4.3 GeV photon energy

kin. 4#	θ_γ^{lab}, degree	t, $(\mathrm{GeV}/c)^2$	θ_γ^{cm}, degree	D	$d\sigma/dt$, $\mathrm{pb}/(\mathrm{GeV}/c)^2$
4A	22	-2.03	63.6	2.13	496.
4B	26	-2.57	72.8	1.54	156.
4C	30	-3.09	81.1	1.67	72.
4D	35	-3.68	90.4	2.75	42.
4E	42	-4.39	101.5	2.80	29.
4F	50	-5.04	112.1	2.42	38.
4G	57	-5.48	119.9	2.83	46.
4H	66	-5.93	128.4	3.89	61.



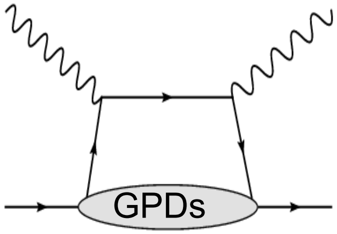
Polarized WACS in 12-GeV era





Collaboration buildup

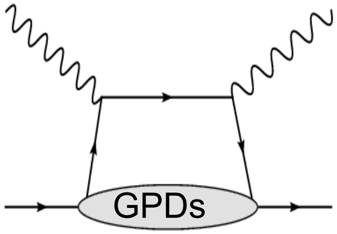
- Polarized experts: JLab/UVa group, D.Keller
- E99-114 Ph.D.: D.Hamilton, V.Mamyan, J.Sjögren
- E07-002 WACS PIs: D.Day, BW
- INFN/JLab LAC PI: P.Rossi



Summary

- The RCS 6-GeV experiment has made an “unexpected” observation of the handbag dominance (KLL result) and the measured s-scaling power value n=8.2+/-0.2

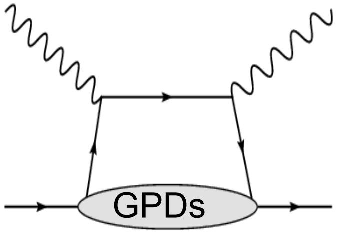
- The ALL 12-GeV experiment will explore handbag dominance and may find a 50-year-old constituent quark in the proton due to “direct” connection between the ALL and the quark mass



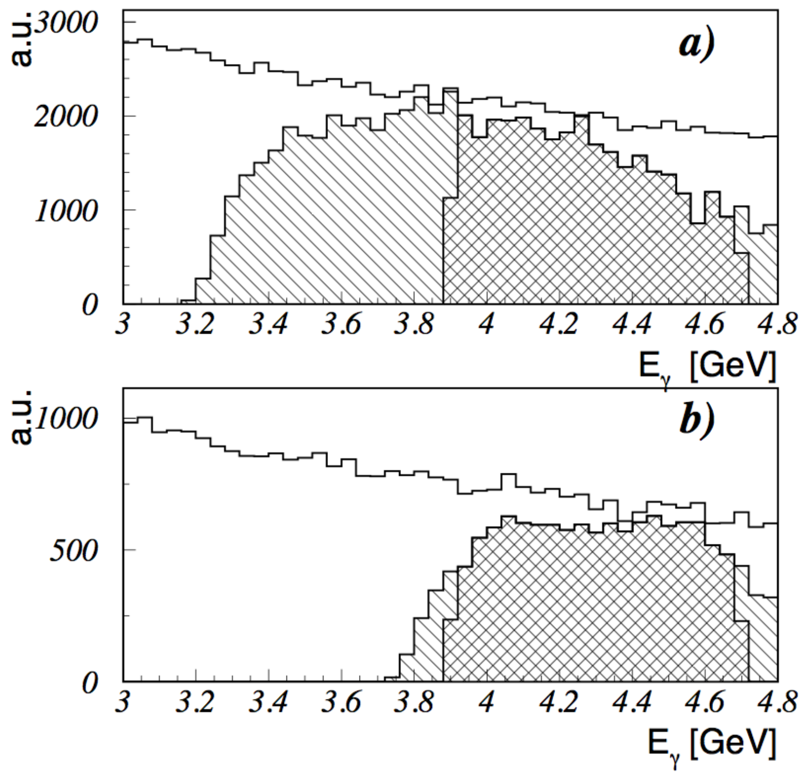
RCS perspective with 12-GeV JLab beam

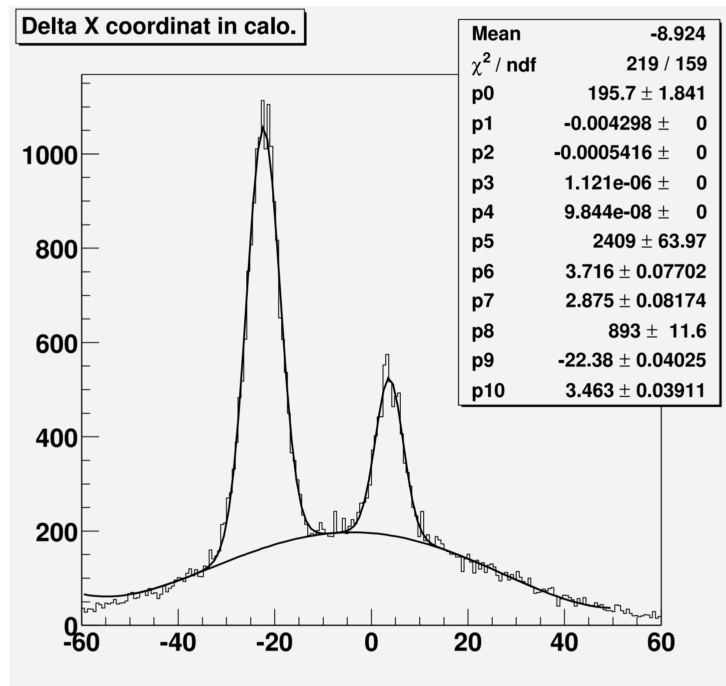
$E_\gamma = 4$ GeV, s = 8.4 GeV^2						
θ'_γ, $[deg]$	14	20	28	37	50	69
E'_γ, $[GeV]$	3.6	3.2	2.7	2.2	1.6	1.1
θ_p, $[deg]$	57	47	37	30	22	16
$J_h \times J_v$	6	3	1.3	0.6	0.2	0.08
P_p, $[GeV/c]$	1.0	1.5	2.1	2.6	3.2	3.8
θ_{cm} , [deg]	42	57	75	92	110	130
$-t$, $[GeV^2]$	0.84	1.5	2.5	3.5	4.5	5.5

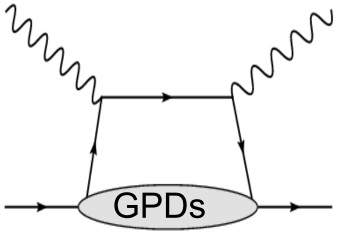
$E_\gamma = 8$ GeV, s = 15.9 GeV^2									
θ'_γ, $[deg]$	7	11	15	19	28	33	40	48	55
E'_γ, $[GeV]$	7.5	6.9	6.2	5.5	4.0	3.4	2.7	2.1	1.7
θ_p, $[deg]$	60	47	39	32	23	30	16	13	11.4
$J_h \times J_v$	25	10	4.5	2.2	0.6	0.4	0.2	0.1	0.06
P_p, $[GeV/c]$	1.1	1.8	2.6	3.3	4.8	5.5	6.2	6.8	7.2
θ_{cm} , [deg]	29	45	58	71	93	103	114	124	131
$-t$, $[GeV^2]$	0.90	2.0	3.4	4.7	7.5	8.7	10	11	11.8



Polarized WACS in 12-GeV era



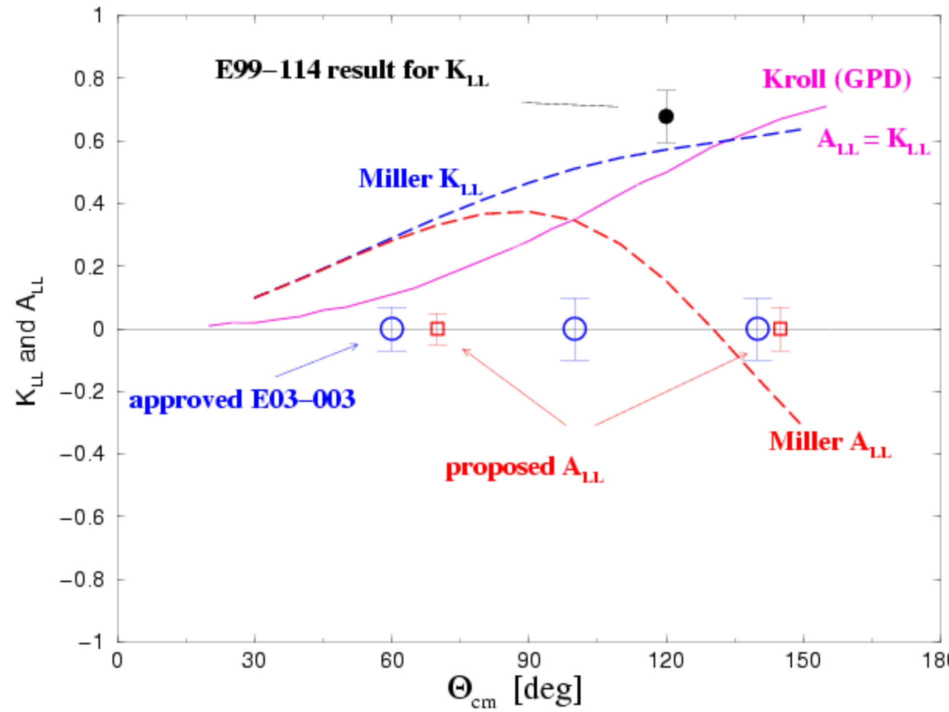




Polarized WACS in 12-GeV era

from the 2004 ALL proposal to PAC27

Kin. P#	Procedure	beam, nA	time hours
P1	BigCal calibration	1000	8
P1	RCS data taking	90	176
P2	RCS data taking	90	240
	Packing Fraction Measurements	90	16
	Moller Measurements	200	18
	Beam Time		458
	BigCal angle change		8
	Target Anneals		52
	Stick Changes		36
	Overhead Time		96
	Requested Time		506



kinematic	P1	P2
N_{RCS}, events	1850	3250
ΔA_{LL}	0.05	0.07