Initial State Helicity Correlation in Wide Angle Compton Scattering (E12-14-006)

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Hall-C Collaboration Meeting

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Outline

- Theoretical motivation
- Proposed experiment
    1. Experiment setup
    2. Kinematics and cuts
    3. Expected result
- New improvement
- Summary

WACS: Introduction

Key elements in program of hard exclusive processes:

- RCS
- Elastic nucleon form factors
- DVCS
- DVMP

Common issues:

- Interplay between hard and soft processes
- Onset of asymptotic regime
- Role of hadron helicity flip

A_{LL} (initial-state polarization asymmetry) will provide

- Critical test of the high-t reaction mechanism
- Access to structure functions not available in electron elastic scattering

Why WACS?

First ever measurement of A_{LL}

$$A_{LL}\frac{d\sigma}{dt} \equiv \frac{1}{2}\left[\frac{d\sigma(\uparrow\uparrow)}{dt} - \frac{d\sigma((\downarrow\uparrow)}{dt}\right]$$

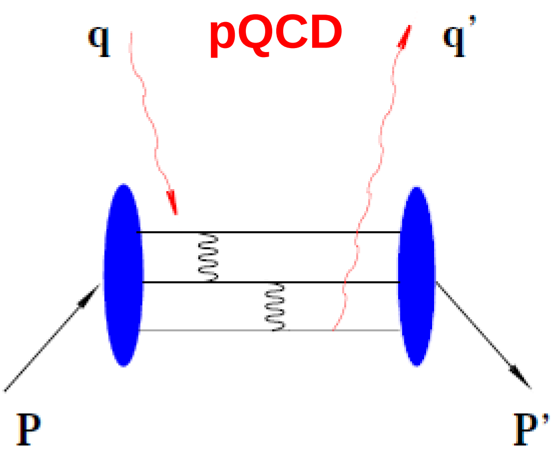
What is the nature of the quark which absorbs and emits photons? Is it a constituent or a current quark?

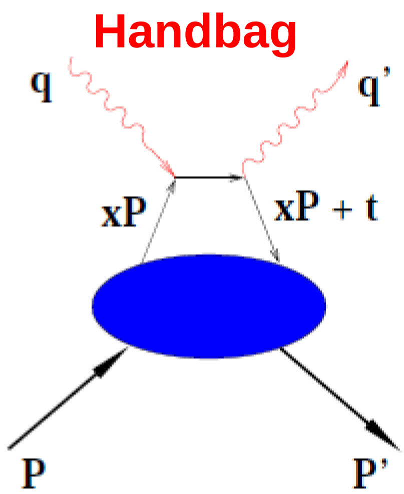
If the GPD approach is correct, is it indeed true that the RCS reaction proceeds through the interaction of photons with a single quark?

A_{LL} will help discriminate between quark helicity flip and non-flip contributions.

Data on A_{LL} will provide constraints on the GPD integrals

Two Reaction Mechanisms





pQCD:
- 3 active quarks
- 2 hard gluons
- 3-body "form factor"
- Constituent scaling: $d\sigma/dt = f(t)/s^6$
- Already proved to dominate at sufficiently high energy
- Predict $K_{LL} = A_{LL}$ (final/initial state polarization asymmetry)
- Measured K_{LL} and $d\sigma/dt$ from E99-114 (6GeV) do not agree with pQCD predictions

Handbag:
- 1 active quark
- 0 hard gluons
- 1-body "form factor": $d\sigma/dt = d\sigma^{KN}/dt * f(t)$

Which one dominates at a few GeV? We will be able to distinguish.

Handbag Mechanism (GPD)

$$\gamma p \rightarrow \gamma p$$

Compton form factors

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

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

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

$$ep \rightarrow ep$$

Elastic form factors

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

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

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

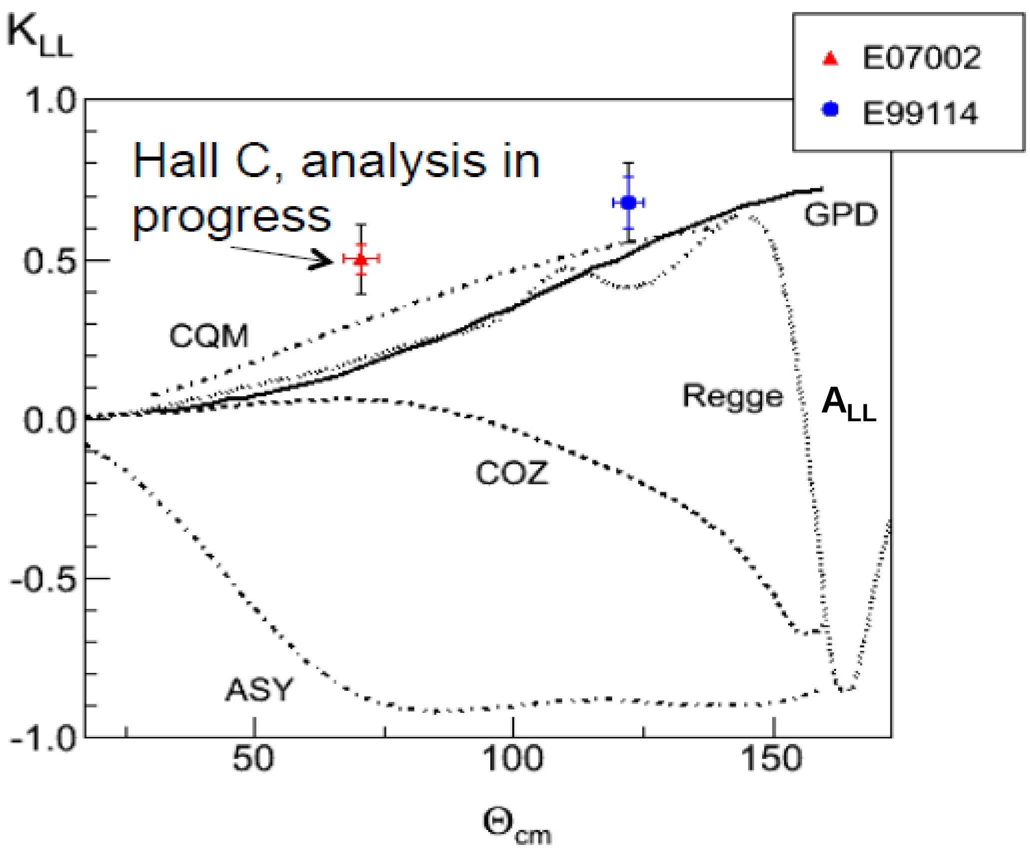
$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}_{KN} \left\{ \frac{1}{2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 + R_A^2\right] - \frac{us}{s^2+u^2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 - R_A^2\right]\right\}$$

WACS is unique compared to elastic form factors:

- vary s and t independently
- can help to constrain GPDs through:
  - e_a^2 (charge) weighting
  - independent integral of GPD's, x^{-1} weighting

Existing Data

E07-002:
s = 8 GeV^2
t = -2.1 Gev^2

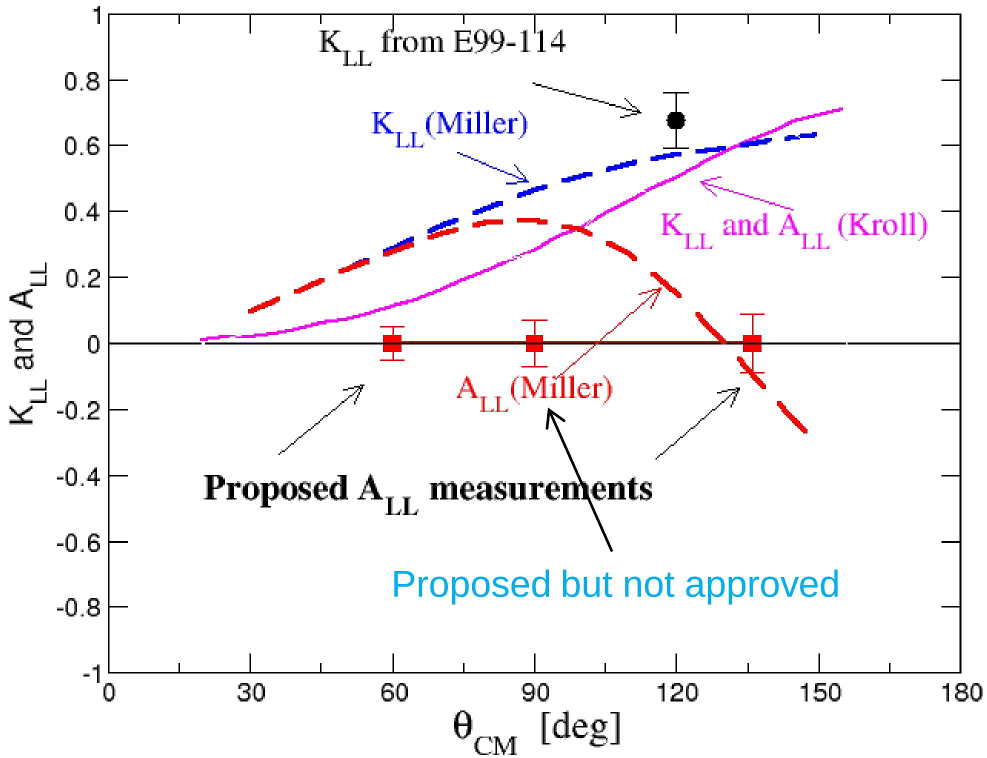


E99-114:
s = 6.9 GeV^2
t = -4.0 Gev^2

K_{LL}: a longitudinal polarization transfer observable, which is related to the helicity of the final proton.

GPD: Huang and Kroll
CQM: Miller's K_{LL}
ASY: Brooks and Dixon
COZ: Chernyak-Ogloblin-Zhitnitsky
Regge: Cano and Laget (A_{LL})

A_{LL} and K_{LL}



A_{LL}: the initial state helicity correlation observables, which involves the helicity of the initial proton

Kroll: $A_{LL} = K_{LL}$

vs

Miller: $A_{LL} \neq K_{LL}$

Miller's Impulse approximation of handbag:

Massive quark

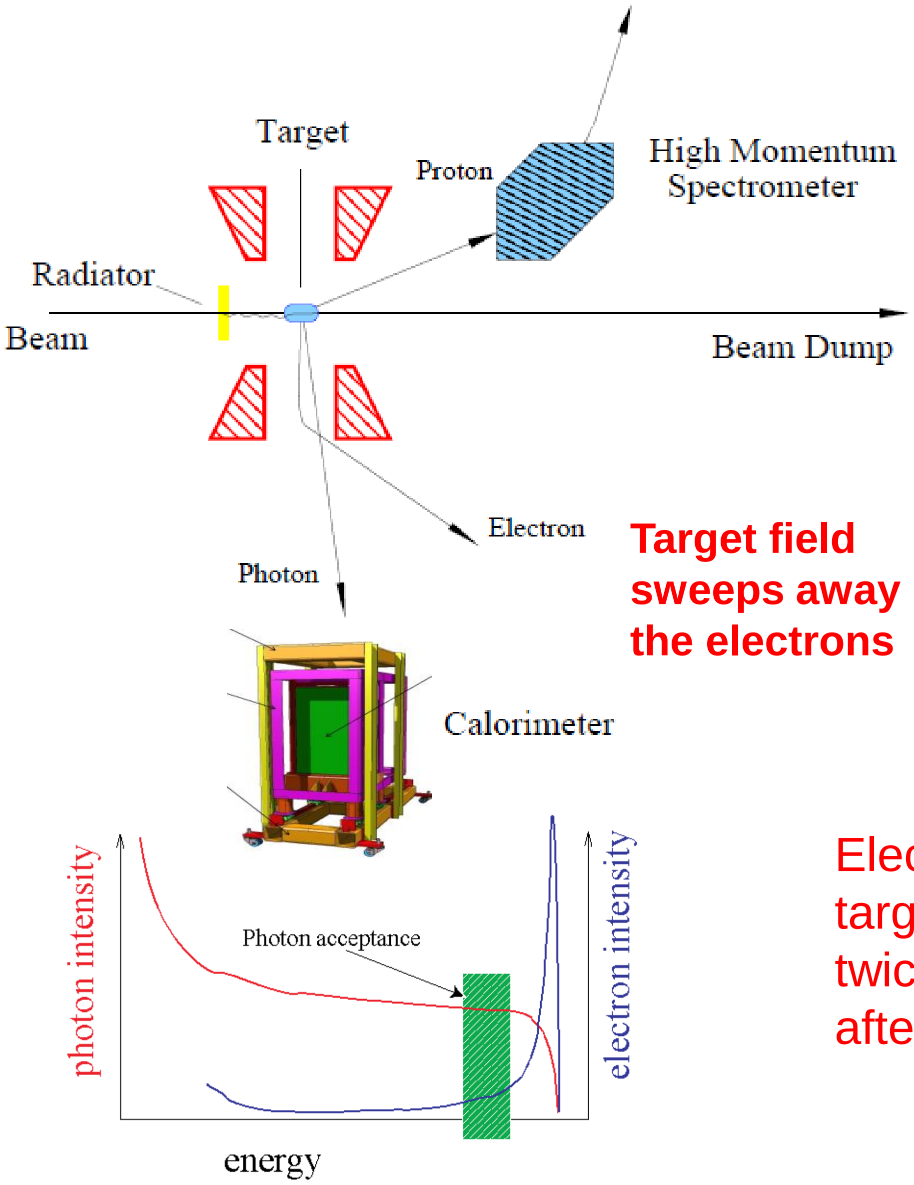
Model wave function same as for E/M form factors

Orbital angular momentum and non-conservation of proton helicity

Good agreement with cross section data But $\mathbf{A_{LL} \neq K_{LL}}$,

At large backward angles: $A_{LL} \simeq - K_{LL}$

Experiment Setup: HMS + NPS



Target field sweeps away the electrons

80% polarized beam at 4.4 GeV
Kinematic Range:
E_{γ} = 4.0GeV, s= 8 GeV^2

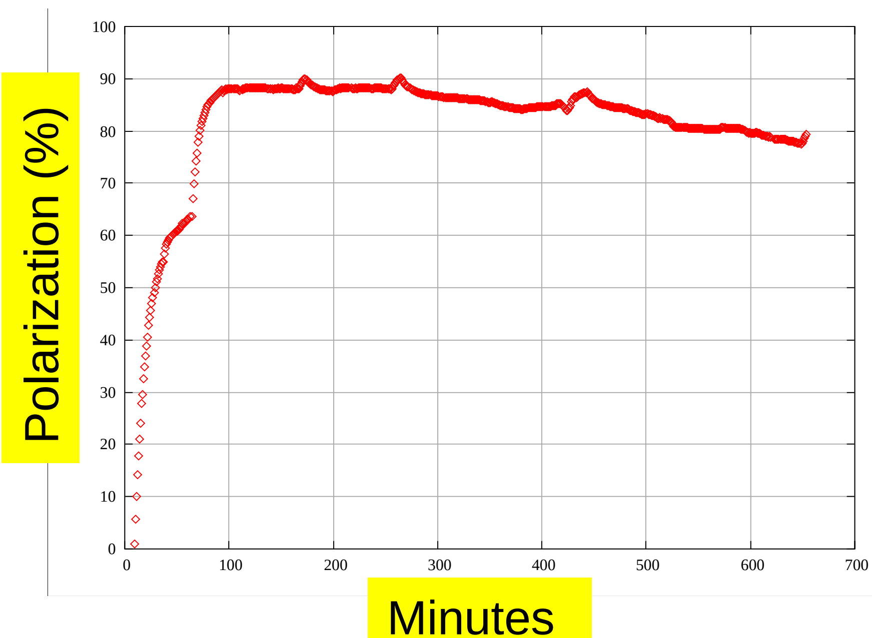
- θ_{CM} = 60° and 136°
- 6% copper radiator
- **mixed e−γ beam**
- polarized target

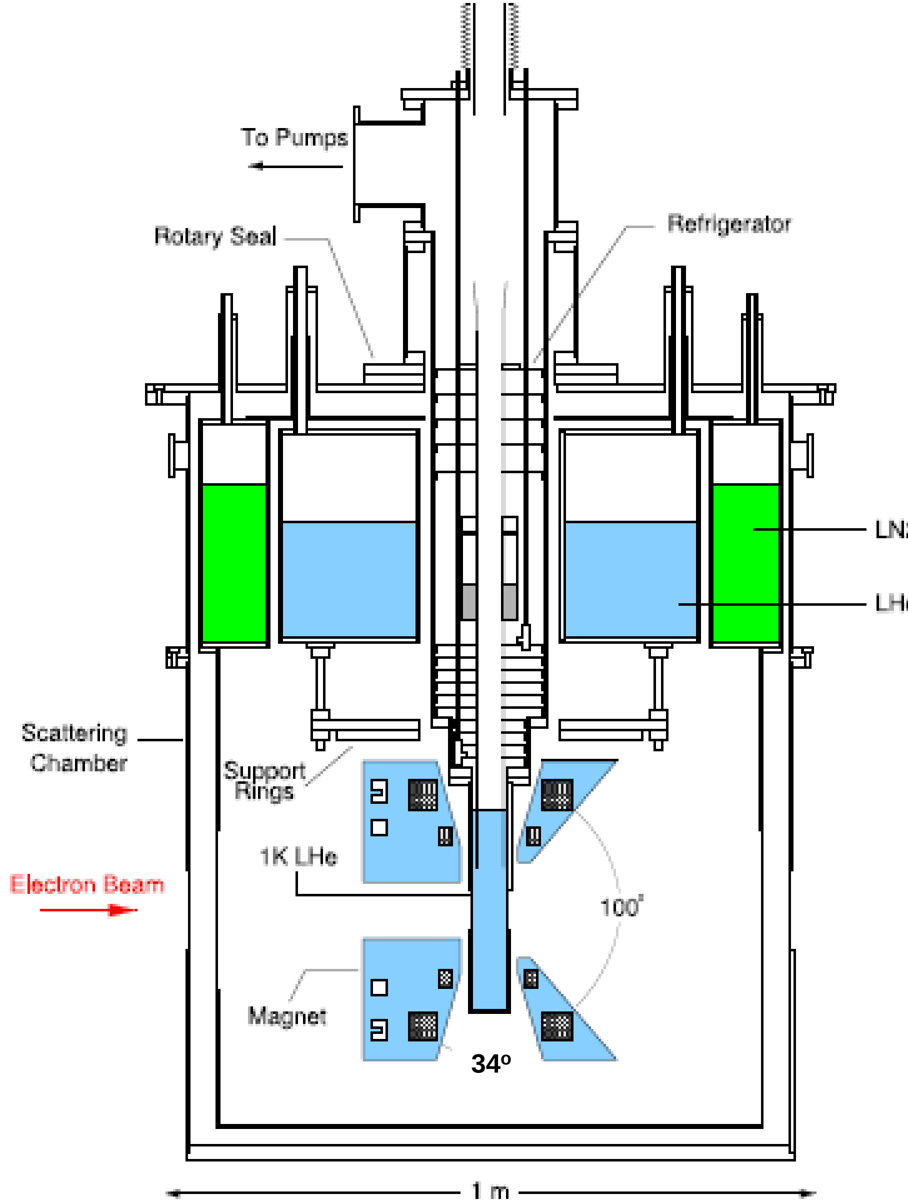
Electron will cause radiation damage to the target which requires annealing once or twice per day and replacing target material after 5~7 anneals. See details in next page.

Polarized Target

UVA/JLAB polarized proton target, NH_3
+/- 50 degrees opening in forward
+/-17 degrees opening in transverse side

- Frozen (doped) NH_3
- ^4He evaporation refrigerator
- 5 T polarizing field
- Remotely movable insert
- Dynamic Nuclear Polarization





The RCS Event Rate

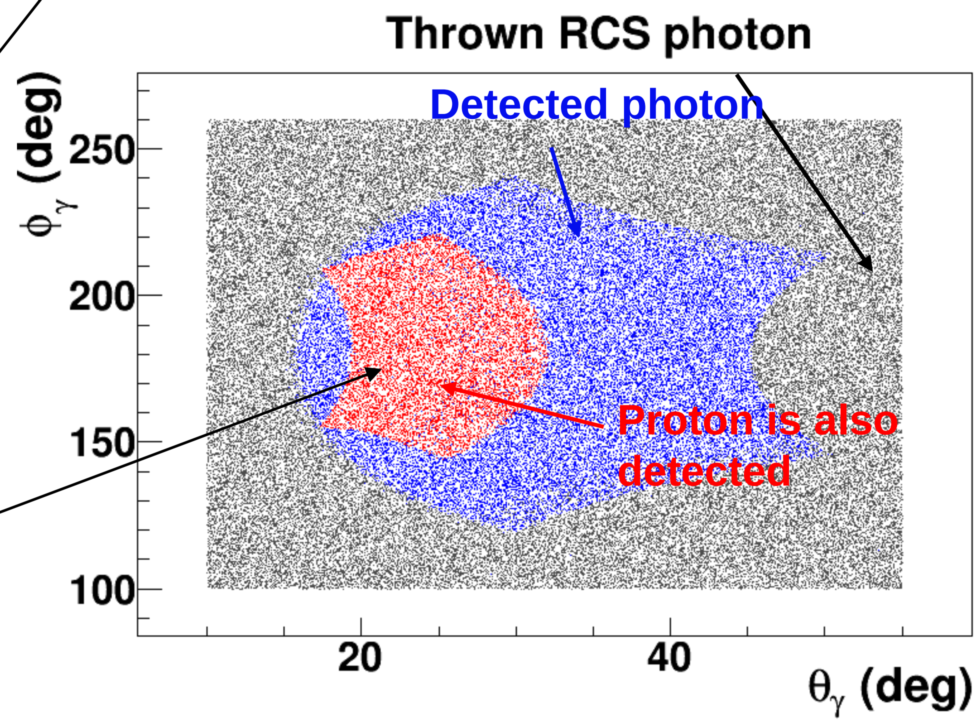
$$N_{RCS} = \frac{d\sigma_{RCS}}{dt} \frac{(E^{f}_{\gamma})^2}{\pi} \Delta\Omega^{lab}_{\gamma p} \, F_{\gamma} \, L_{\vec{ep}}$$

photon# per electron

L_{ep}= 8.0E34

$dt/d\Omega_{\gamma}^{lab}$

From Modified Miller's Model



Red region is the solid angle of the photon detector where the corresponding recoil proton are also detected by the proton arm

Proposed Kinematics

kin. P#	t, $(\text{GeV}/c)^2$	θ_γ^{lab}, degree	θ_γ^{cm}, degree	θ_p^{lab}, degree	E_γ^{lab}, GeV	p_p, GeV/c	L, cm	H, cm
P1	-1.7	22	60	45	2.87	1.56	785	41.2
P2	-3.3	37	90	30	2.00	2.52	445	21.5
P3	-5.4	78	136	13	0.88	3.55	245	10.0

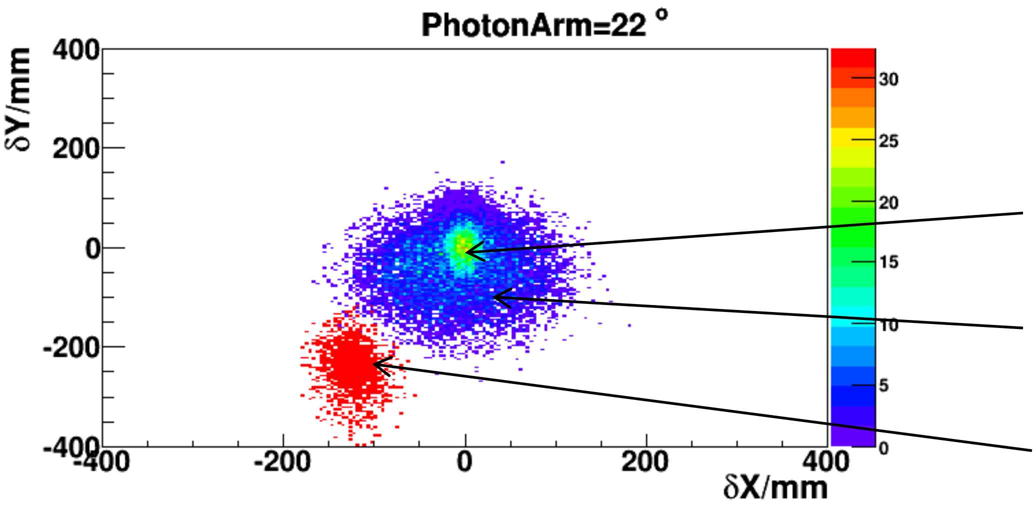
Statistical error:

kinematic	P1	P2	P3
N_{RCS}, events	2333	1666	1404
ΔA_{LL}	0.05	0.07	0.09

Systematic error ~ 8%

Major systematic error sources:
- Beam polarization: 3%
- Packing fraction: 3%
- Target polarization: 3%
- Charge: 1%
- Background: 5%

NPS dY vs dX

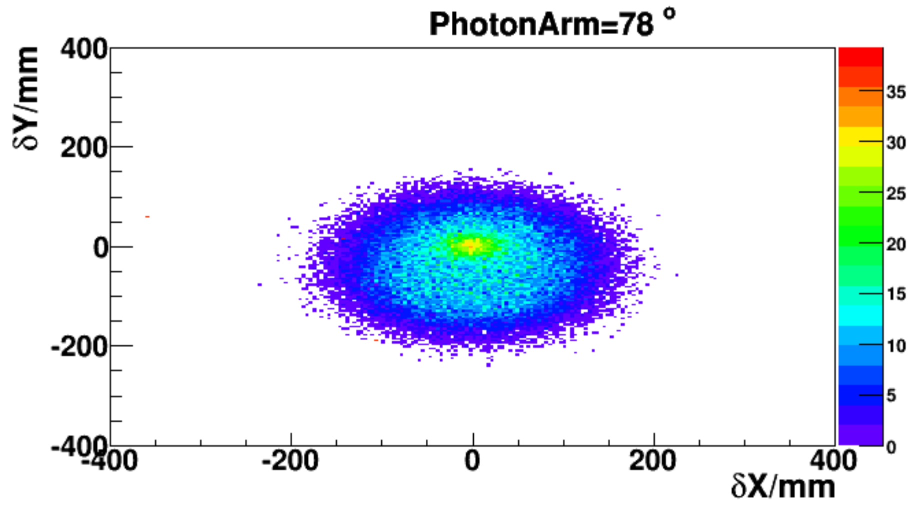


After dE Cut, NO dY cut

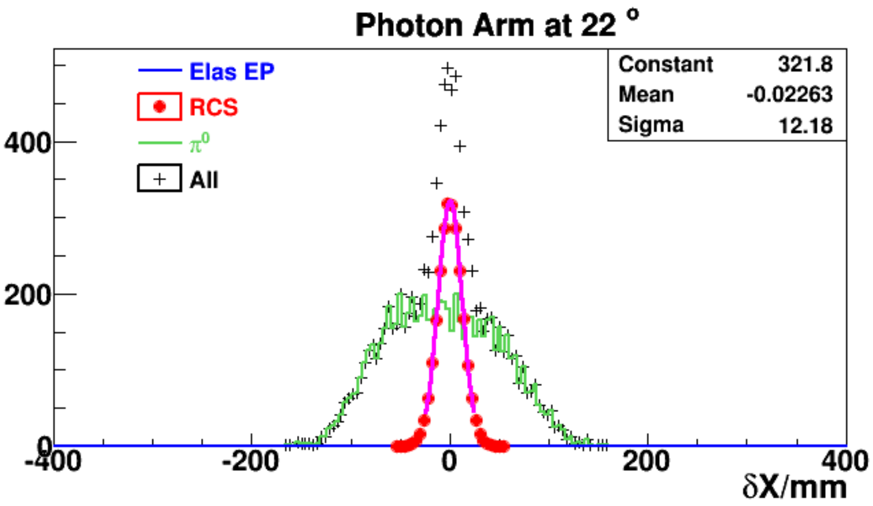
RCS

π^0

ep elastic



dX Distribution

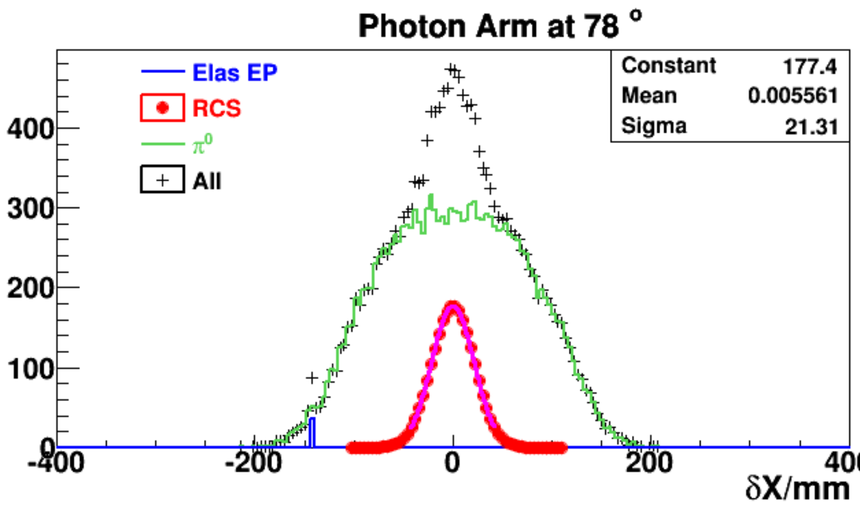


dX: the difference between the measured RCS photon vertical position and the inferred vertical position.

After both dY and dE cuts

Fit Bg+signal to find out dX resolution, then extract dilution (D) of RCS events.

$$N_{RCS, required} = D/(P_e P_p f_{e\gamma} \Delta A_{LL})^2$$



New Improvement

Idea: Use pure photon beam instead of e-γ mixing beam.

How to make pure photon beam?

What are the advantages and what are the concerns?

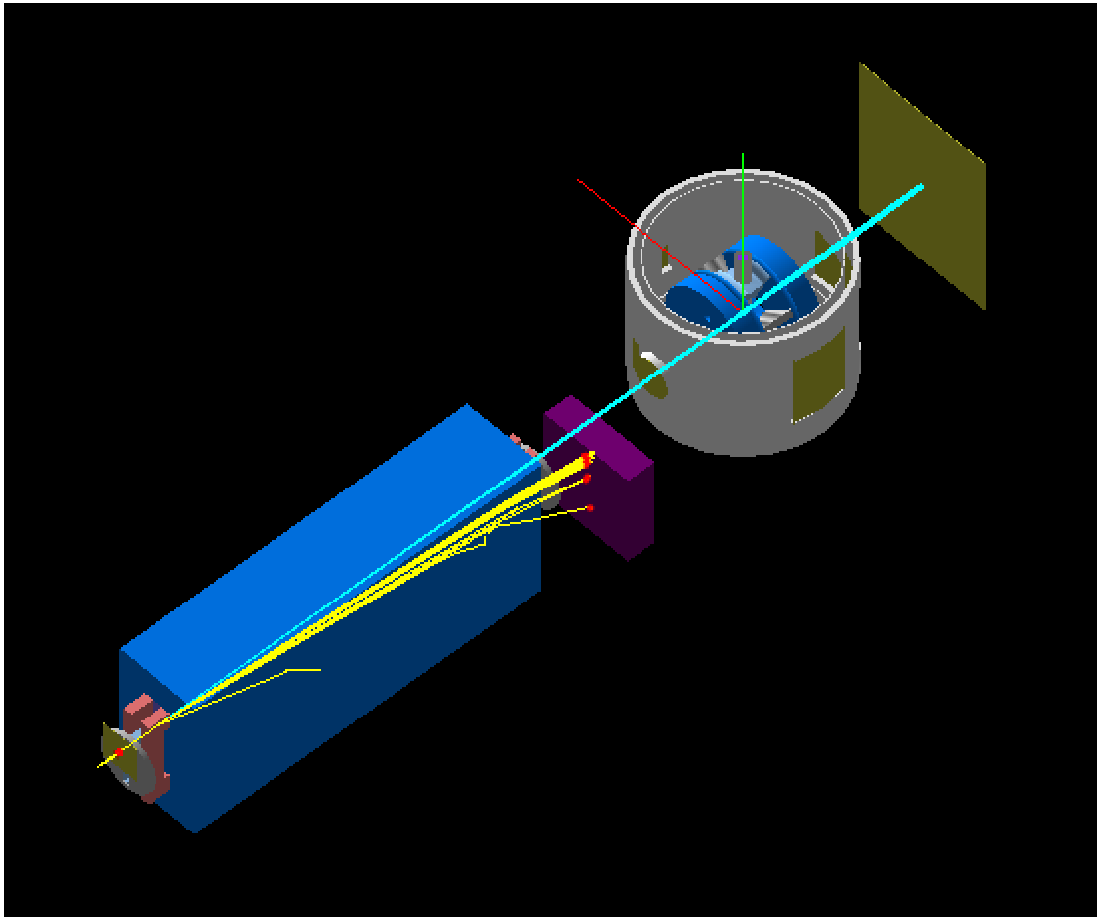
How To Make Pure Photon Beam

Place dipole magnet right after the radiator to bend e^- beam to a 2k-watt local dump

There exists a FZ dipole and a power supply, which was used during G2P experiment.

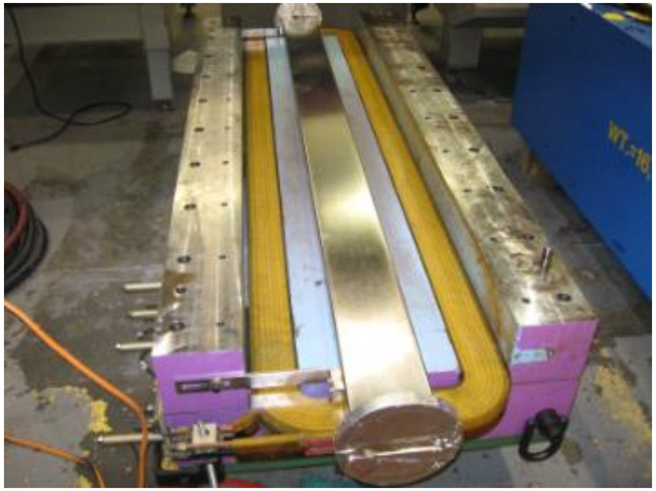
For **BdL=2.2 Tesla-meter,** beam electron deflection is ~ 21 cm at the local dump

Need to setup shielding

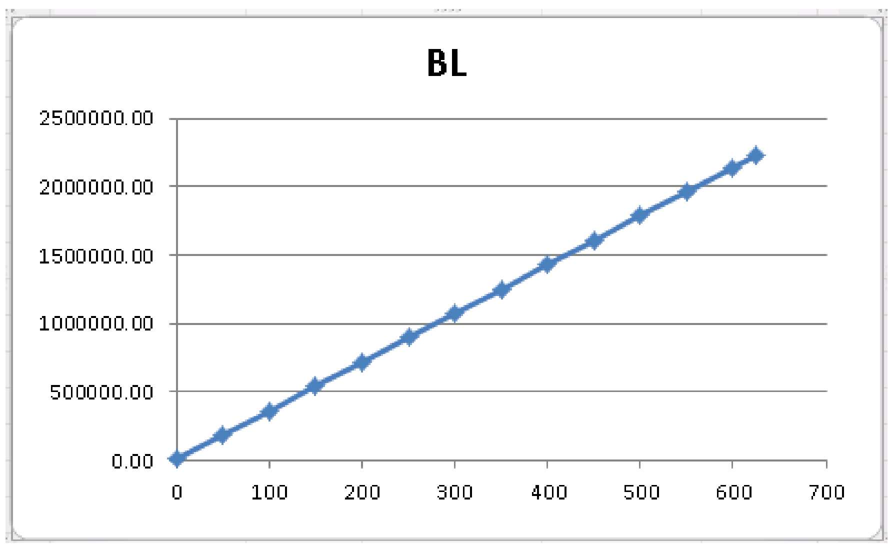


6% copper radiator located at -3.5m (upstream)
FZ magnet located at -2.3m, BdL=2.2 Tesla-meter
Local dump at -0.8m (15 cm lead, ~27 radiation length)

The FZ Magnet



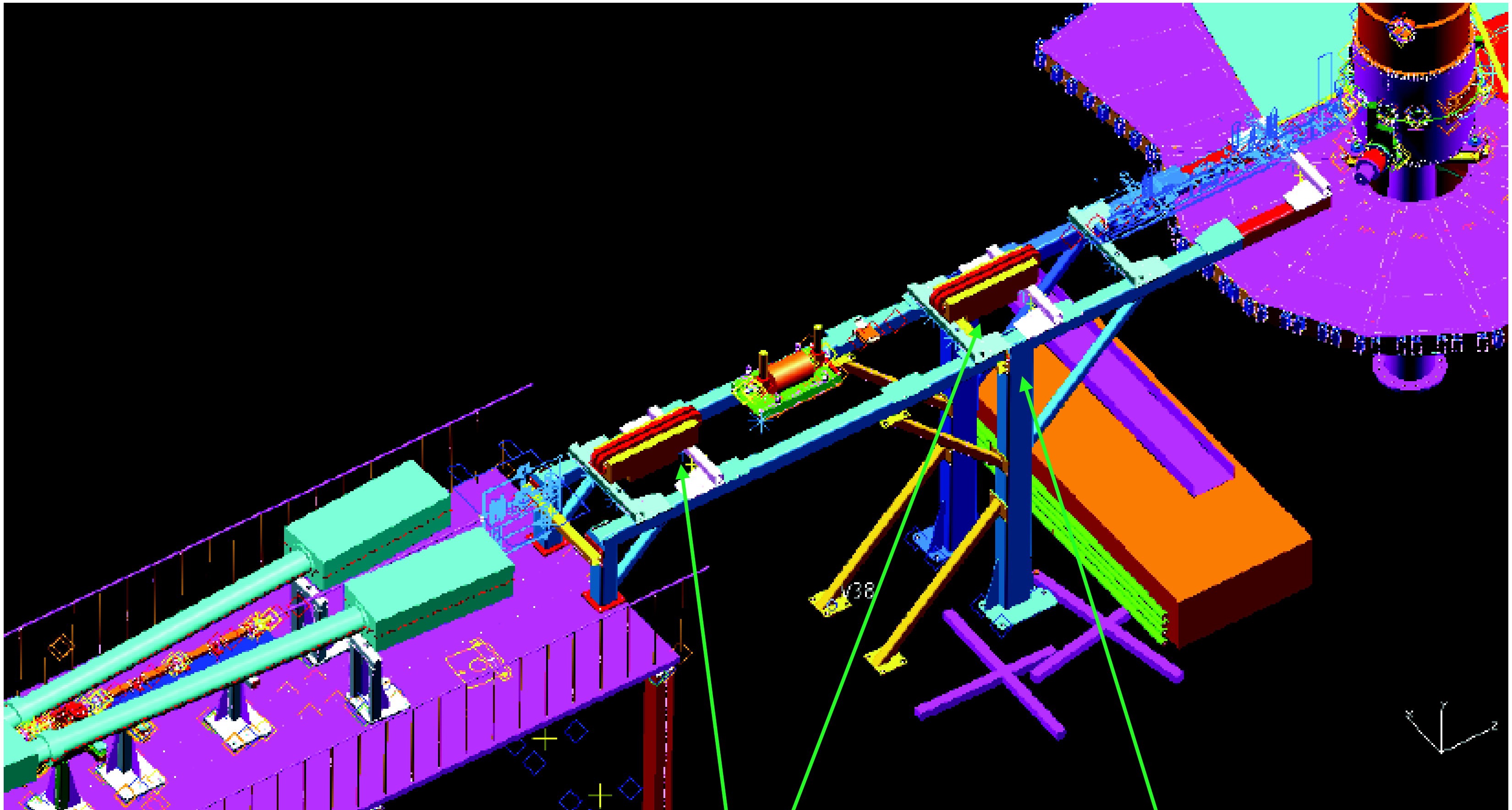
I	BL
625	2226572.57
600	2138123.25
550	1962276.70
500	1785806.00
450	1608779.64
400	1431313.59
350	1254368.74
300	1076461.54
250	897956.19
200	719248.02
150	540379.73
100	361361.02
50	182164.04
0	10832.47



Need to check the cooling power of this magnet.

Low energy electrons will deposit ~65w of heat in the iron.

Is there space for the FZ Magnet?



Vertical Chicane using 2 BEs

4.9m to the pivot

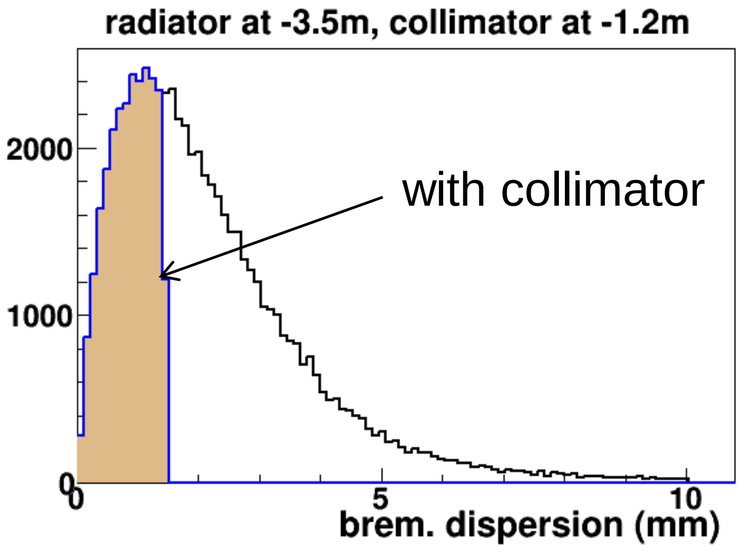
Vertical chicane is used to lift electron beam by ~2.2cm to match the height of the pivot.

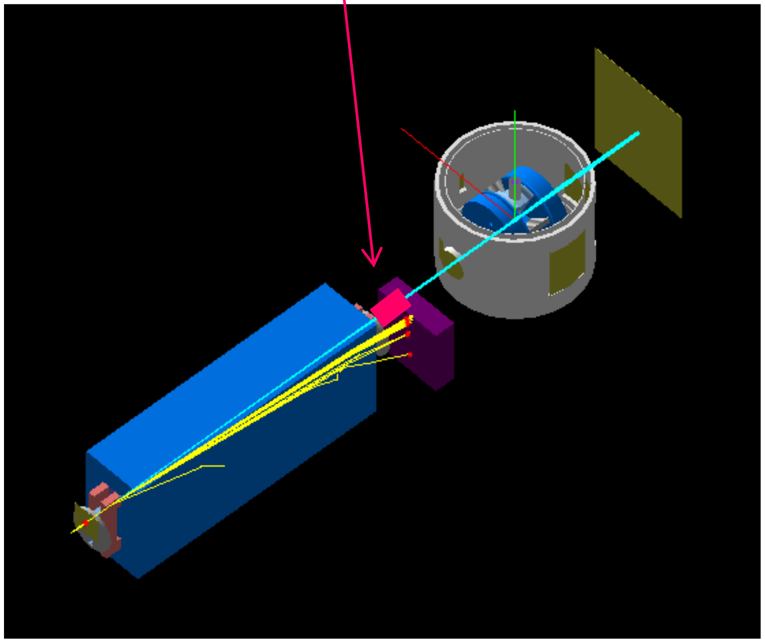
Collimator

When the radiator is 3.5m away from the target, the dispersion of the brem. photon at target is ~5 mm. We do not know the exact interaction position for each event. In order to reconstruct proton and photon precisely, one has to collimate the incident photons.

Need to place a thick collimator with 2 mm diameter hole at z=-1.2m to ensure photons beam spot size at target is within +/- 1.5 mm.

Photon flux loss due to the collimator is ~60%





Advantages and Concerns

1) Eliminate electron backgrounds: e-p elastic and epγ events.

2) Target averaged polarization increases from 70% to ~90%, F.O.M increases by ~1.7 (no loss of target polarization seen in Hall B with FROST).

3) Collimator reduces photon flux down to 40%.

4) Heat load from photon beam is essentially zero – dominant heat load is form microwaves.

5) Beam current can be increased from 100 nA to 400 nA (limited by the colling power of the local dump and radiation budget).

6) Overhead time will be greatly reduced: fewer anneals, target changes and TE measurements (associated with target changes).

Conservatively speaking, the F.O.M could be improved by a factor of 6~8.

Concerns:

- Radiation in the hall
- Shielding need to be applied to protect detector and electronics

Summary

- Polarization observables can provide particularly sensitive tests of the reaction mechanism of RCS.
- E12-16-004 was approved by PAC42 for 15 days of beam time. It would be the first ever measurement of A_{LL}, the initial state correlation asymmetry.
- The measurement of A_{LL} would not only extend the pioneering measurement of K_{LL} , but also shed light on the nature of quark helicity–flip processes.
- A pure photon beam can be achieved with a chicane to dump the electrons in the hall. It appears feasible and would greatly improve this experiment and perhaps open the door for new experiments.

Back up slides

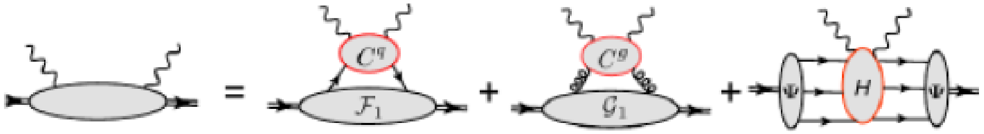
New A_{LL} Calculation Is Coming

•There is some indication that Miller's approach is not complete (photons couple to different quarks and other moments). It is only a model, not a full systematic approach.

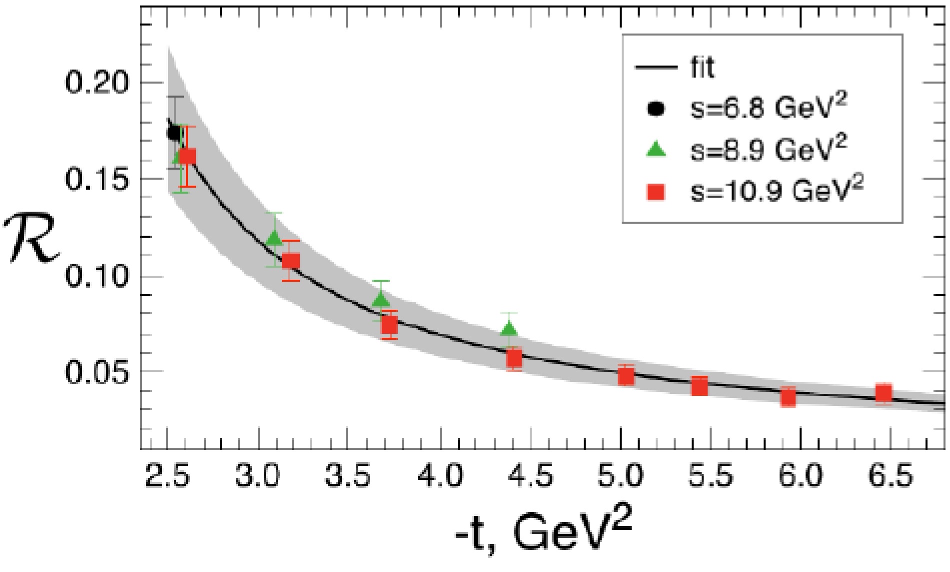
•Helicity flip amplitudes can be incorporated into the SCET(soft collinear efffective theory) scheme and describe the leading-order factorization. In this way A_{LL} and K_{LL} can be related in a very systematic formalism.

•A_{LL} can then be used to clarify the role of the power suppressed helicity flip contribution in WACS (**NEW work underway by N. Kivel**).

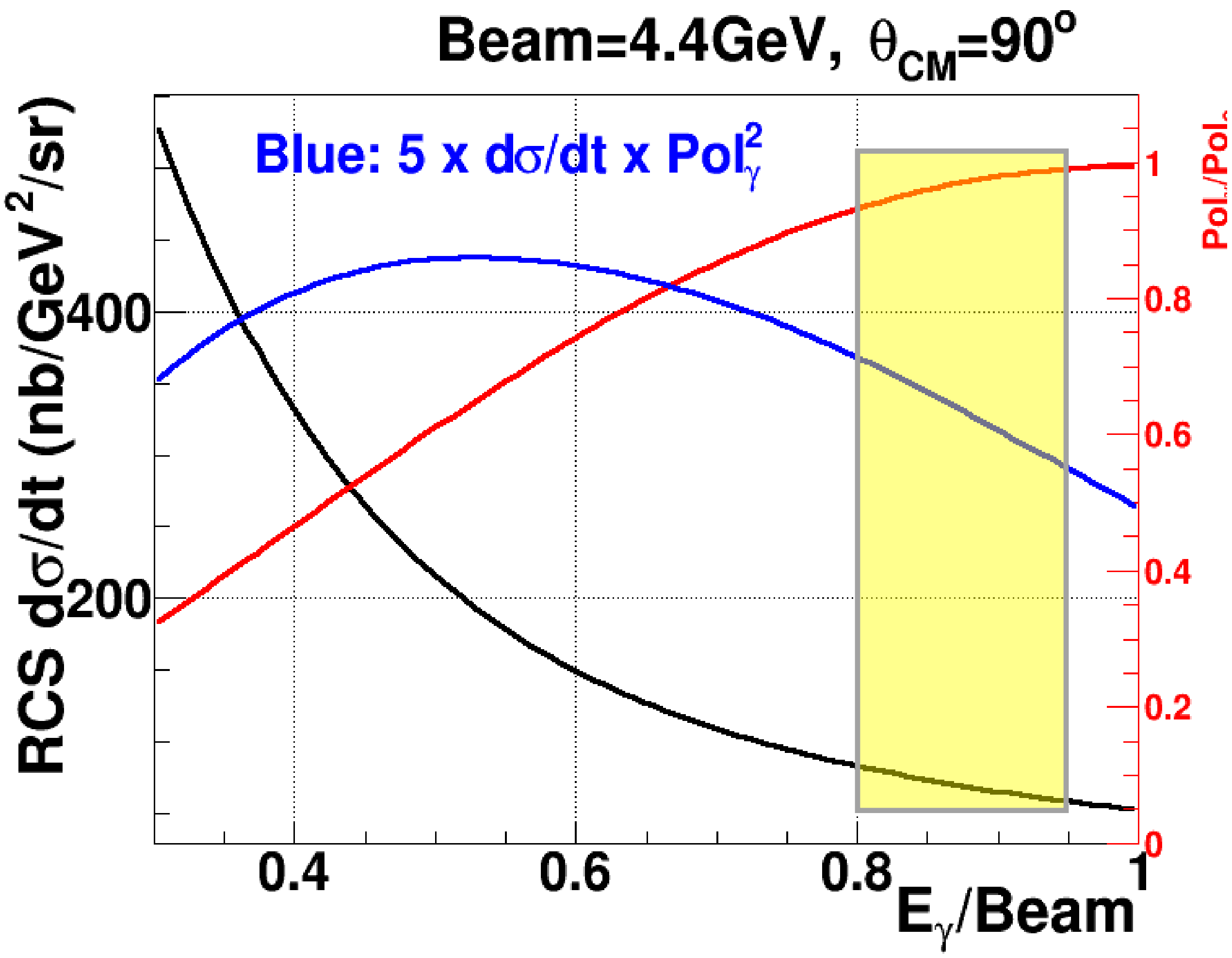
N. Kivel and M. Vanderhaeghen, JHEP 1304 (2013)



$$\frac{d\sigma}{dt} \simeq \frac{2\pi\alpha^2}{(s-m^2)^2}\left(\frac{1}{1-t/s}+1-t/s\right)|\mathcal{R}|^2 = \frac{d\sigma^{KN}}{dt}|\mathcal{R}|^2,$$



Weight RCS Cross Section by Polarization Square



$$\frac{P_\gamma}{P_e} = \frac{4\frac{E_\gamma}{E_e} - \left(\frac{E_\gamma}{E_e}\right)^2}{4 - 4\frac{E_\gamma}{E_e} + 3\left(\frac{E_\gamma}{E_e}\right)^2}.$$

Why just 80%-95%?

Could we also include 50%-80%? The rate from there is much larger. And the photon arm can be optimized to take most of them.

Beam Time Request

Kin. P#	Procedure	beam, nA	time hours
P1	RCS data taking	90	52
P2	RCS data taking	90	293
P3	RCS data taking	90	185
P1	NPS and HMS calibration	1000	8
P2	NPS and HMS calibration	1000	8
P3	NPS and HMS calibration	1000	8
	Packing Fraction	90	22
	Moller Measurements	200	33
	Beam Time		609
	Target Anneals		55
	Target T.E.		25
	Stick Changes		15
	BCM calibration		13
	Optics		13
	kinematics change		12
	Total Requested Time		742

← not approved

15 days were approved