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Update on Wide-Angle Compton Scattering Proposal

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for Simon Sirca and Bogdan Wojtsekhowski

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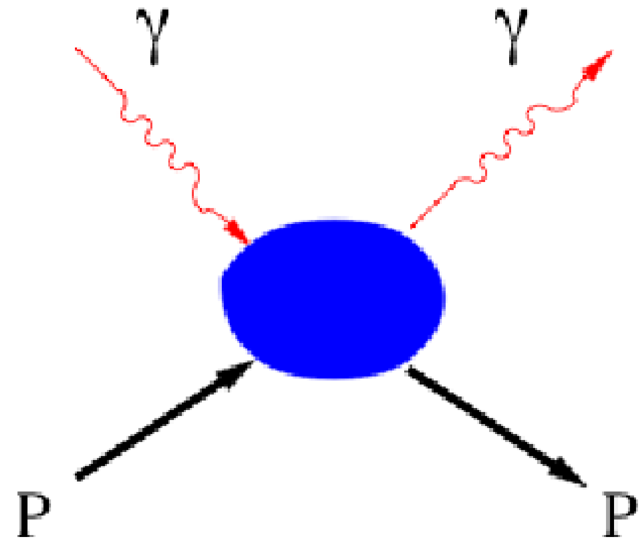
Physics Motivation

- Proton Compton scattering in the wide-angle regime (**$s, -t, -u \gg m^2_{nucleon}$**) is a powerful and under-utilized probe of nucleon structure.

- It is an elegantly simple reactions, involving only a real photon and ground-state nucleon in both initial and final states.

- The physics in play is similar to that in elastic ep scattering or DVCS: **to characterize the electromagnetic response of the nucleon without complications from additional hadrons**.

- It is, however, one of the **least understood** of the fundamental reactions in the several GeV regime.



We propose to measure the differential cross section for WACS at photon energies of 8 and 10 GeV over a wide range -t.

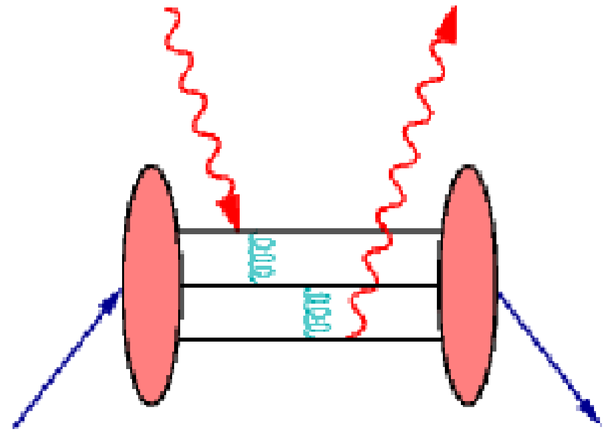
Beamtime Request = 42 days*

* includes time for configuration changes, calibration runs and DAQ/analysis overheads

Reaction Mechanism

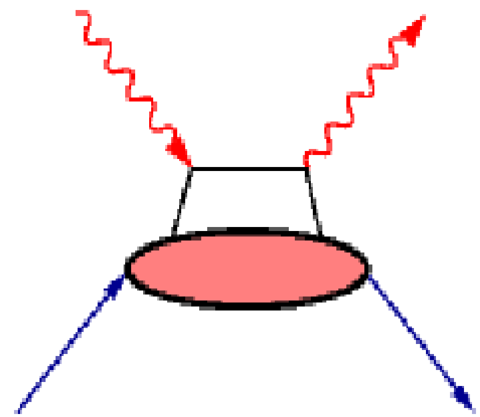
A number of reaction mechanisms for WACS have been proposed over the years:

- **pQCD (two-gluon exchange)**
- **The Handbag Mechanism (GPDs)**
- **Relativistic Constituent Quark Models**
- **Soft Collinear Effective Theory**



The main questions we intend to address are:

- **Does large -t ensure dominance of short-distance physics?**
- **What factorization scheme is valid?**
- **Is it indeed true that the WACS reaction proceeds through the interaction of the photon with an individual quark?**
- **What information can be extracted concerning the structure of the proton from measurements of the WACS form factors?**
- **Given the fact the pQCD is not expected to be valid at this kinematic scale, why are the scaling predictions so close to the observed value?**



Reaction Mechanism: GPDs

M. Diehl and P. Kroll, arxiv 1302.4604

$$\gamma p \to \gamma p$$

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

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

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

$$ep \to ep$$

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

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

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

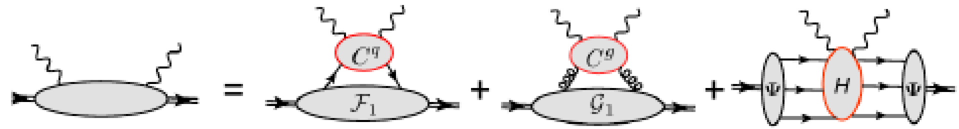
$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}_{KN} \left\{ \frac{1}{2}\left[R_V^2 + \frac{-t}{4m^2} R_T^2 + R_A^2\right] - \frac{us}{s^2+u^2}\left[R_V^2 + \frac{-t}{4m^2} R_T^2 - R_A^2\right]\right\}$$

Studying WACS can lead to constraints on GPDs at large -t and x, which differ from electromagnetic form factors due to 1/x and e_a^2 factors.

Reaction Mechanism: SCET

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

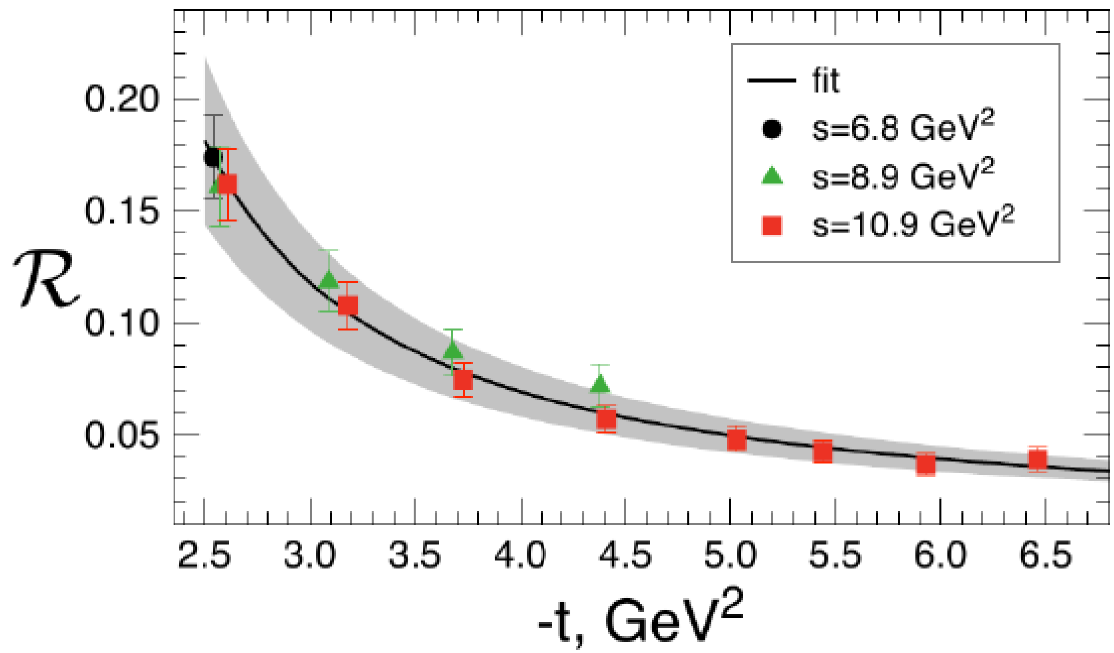
The recent development of the SCET approach has shown the importance of WACS in understanding **Two Photon Exchange (TPE)** effects in elastic ep scattering.



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

Due to universality considerations the **form factor** which describes TPE at high Q^2 can be determined from WACS cross section data.

Extending the measurements of this form factor R(t) to higher s and -t will provide valuable insights into the **validity of factorization** in both WACS and TPE in elastic ep scattering and help learn more about the **soft physics describing proton structure** in the 12 GeV regime.



WACS at Jlab in the 6 GeV Era

Jlab Experiment E99-114 (Hall A, 2002)

Measurements of spin averaged WACS cross section over a broad kinematic range of **$6.8 < s < 11$ GeV², $2 < -t < 7$ GeV²** and polarization transfer K_{LL} and K_{LT} at a single point of **$s = 6.9$ GeV², $-t = 4$ GeV²**.

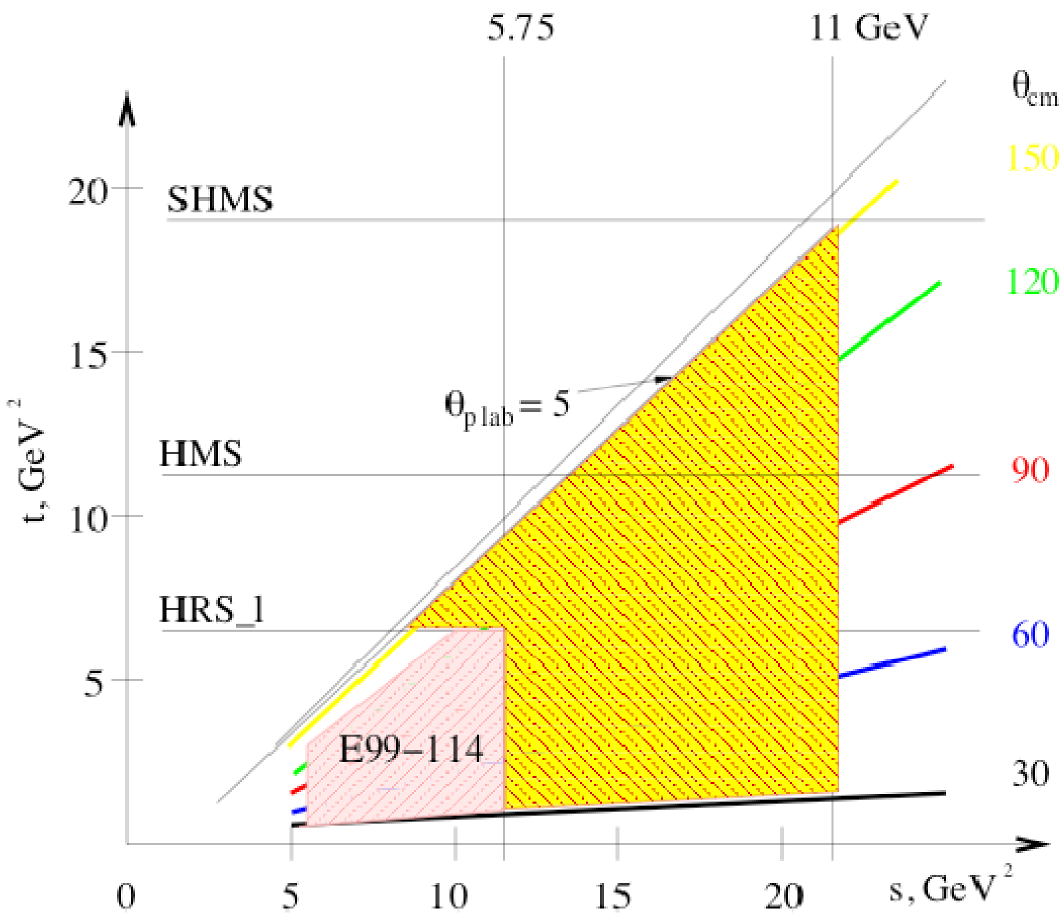
Two publications in PRL and one in NIM.

Ongoing PhD thesis work by Johan Sjoegren (Glasgow) on neutral pion photoprodution cross sections.

Jlab Experiment E07-002 (Hall C, 2008)

Measurement of polarization observables K_{LL}, K_{LT}, and P_N at **$s = 8.0$ GeV², $-t = 2.1$ GeV²**.

PhD analysis nearing completion by Cristiano Fanelli (ISS Rome).

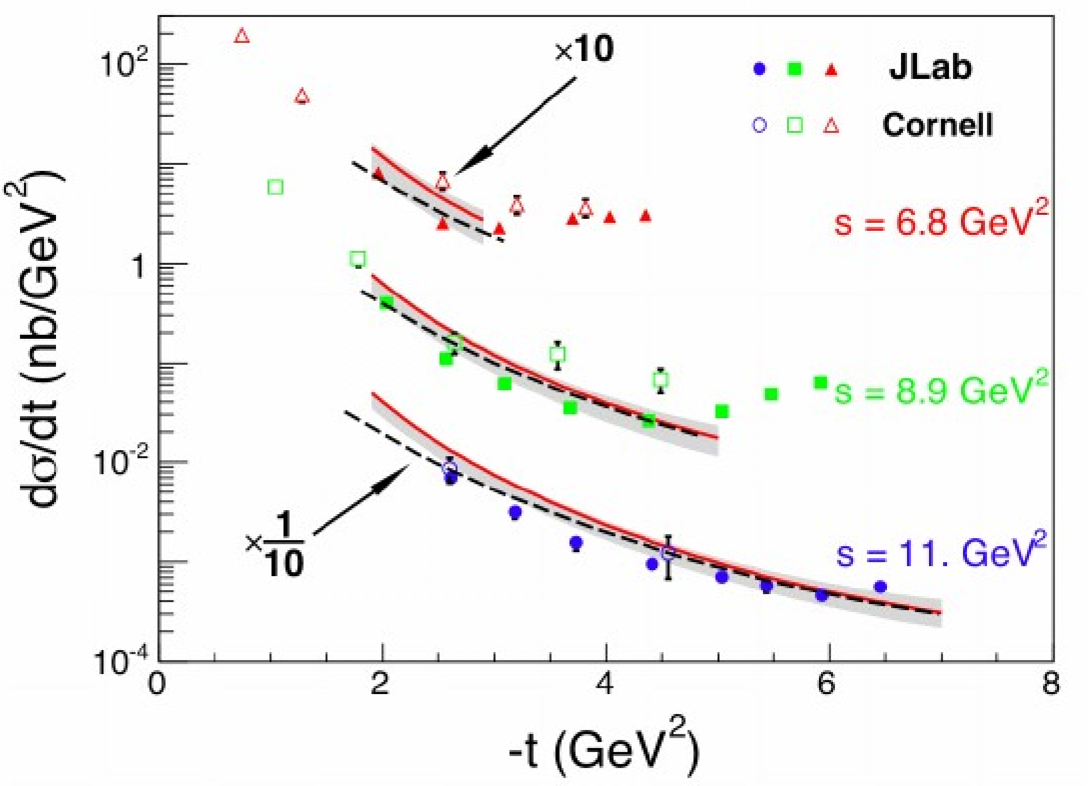


WACS at Jlab in the 6 GeV Era

A. Danagoulian et al, PRL 98 (2007)

The experimental technique represented a **factor of 1000** improvement in productivity ($\mathcal{L}_{\gamma p}$) over the last Cornell experiment.

This allowed for a very significant improvement in precision, and the measurement of **polarization observables** in this kinematic regime for the first time.



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This allowed for a very significant improvement in precision, and the measurement of **polarization observables** in this kinematic regime for the first time.

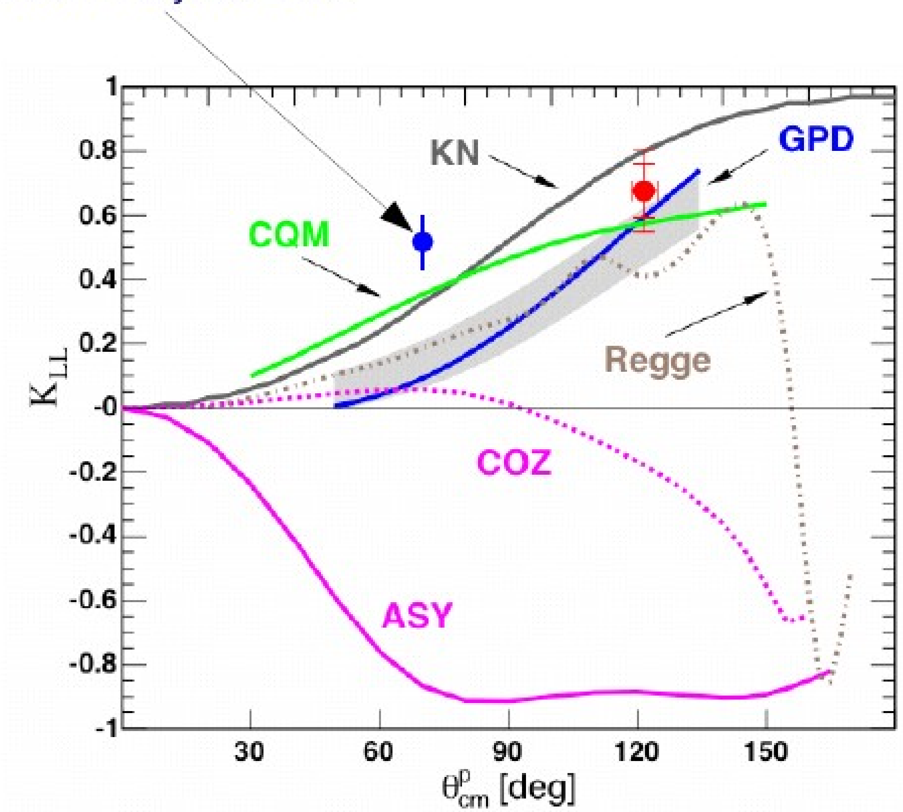
The results show evidence for **factorization of the reaction mechanism**, and dominance of the handbag mechanism.

As with elastic ep scattering results, recoil polarization results have helped gain even greater insight: the results strongly favor a **leading quark mechanism (x ~ 1).**

However, some data-points did not fully meet the wide-angle condition (**$s, -t, -u \gg m^2_{nucleon}$**) because of a low value of -u.

D. J. Hamilton et al, PRL 94 (2005)

Preliminary E07-002



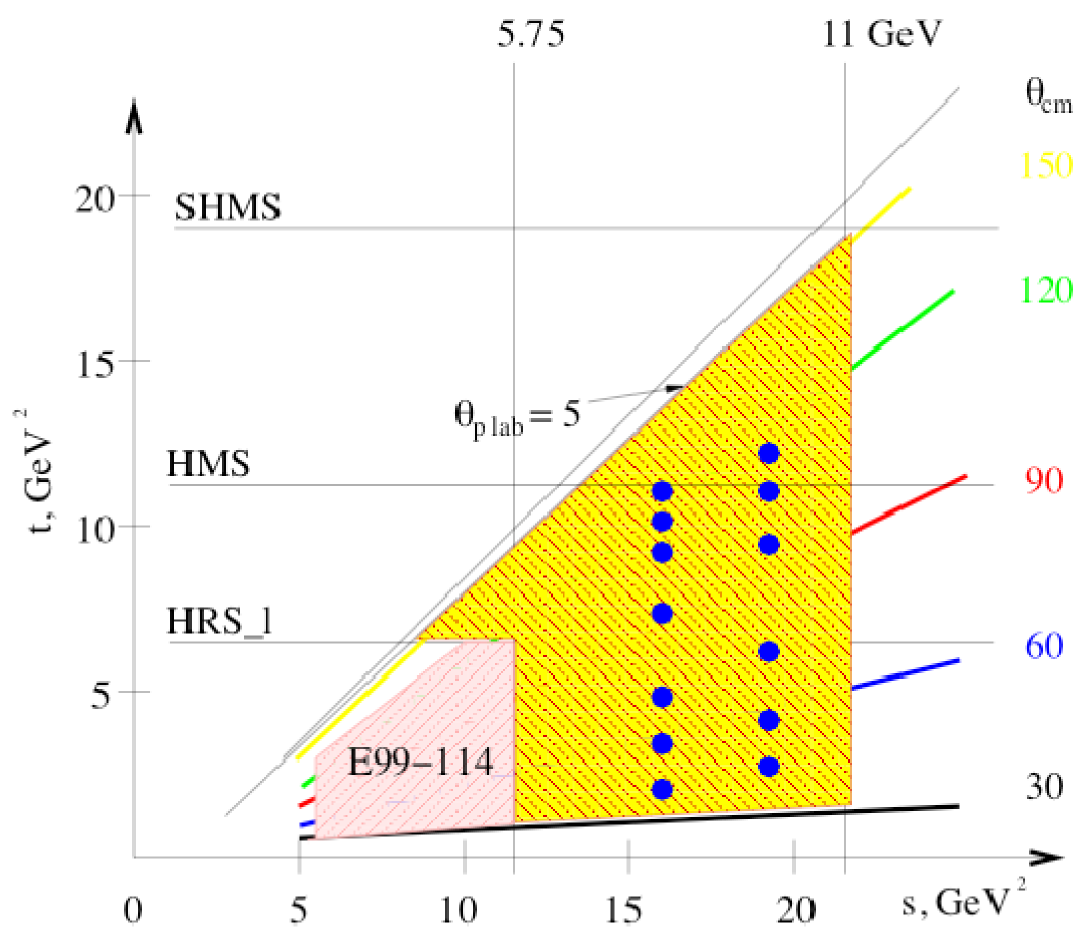
Jlab Proposal PR12-13-009

The current proposal includes measurements of the differential cross section at **13 kinematic points.**

These measurements will allow for a determination of the cross section scaling power n at fixed Θ_{CM} and therefore the **dominant reaction mechanism**.

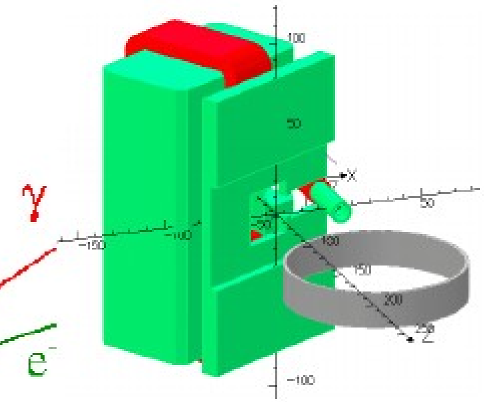
The broad range in -t will allow for extraction of the WACS form factor R(t), providing **direct experimental evidence for factorization** and leading to constraints of GPDs at high x and -t and TPE effects in elastic ep scattering at high Q^2.

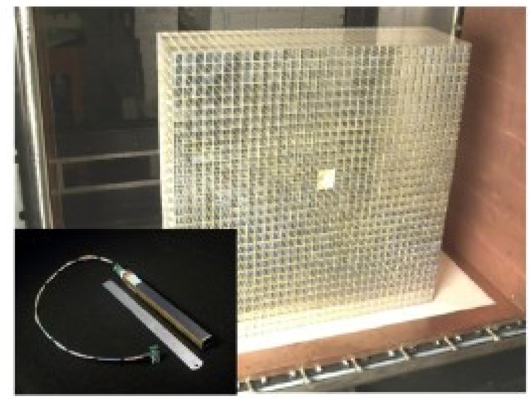
All kinematic settings unambiguously meet the wide-angle condition that **$s, -t, -u \gg m^2_{nucleon}$**

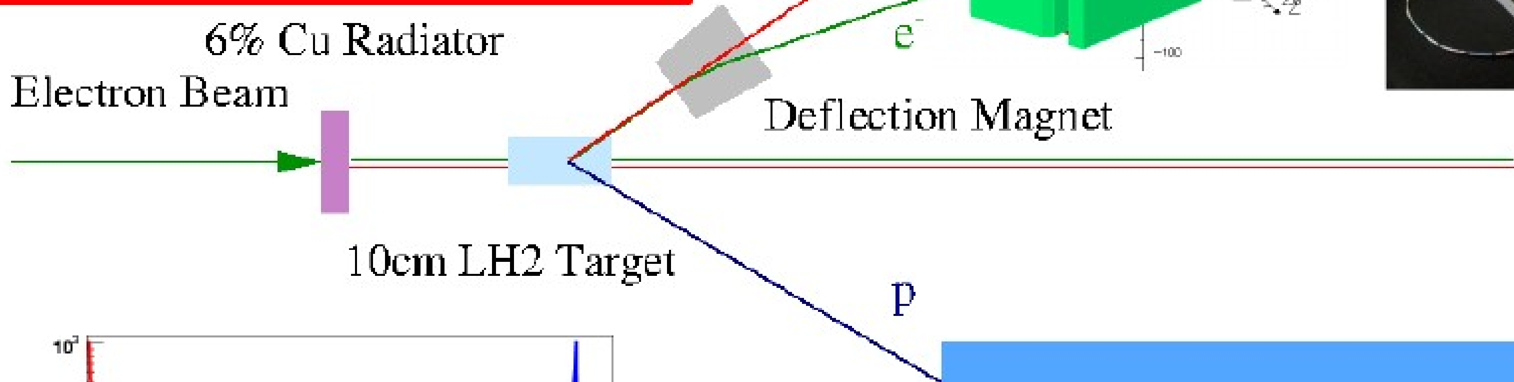


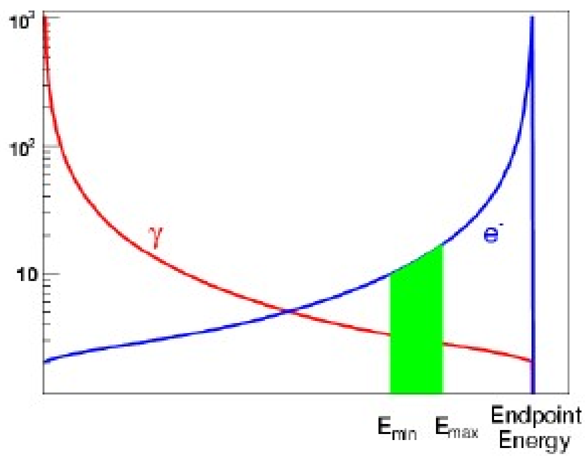
Experimental Set-up

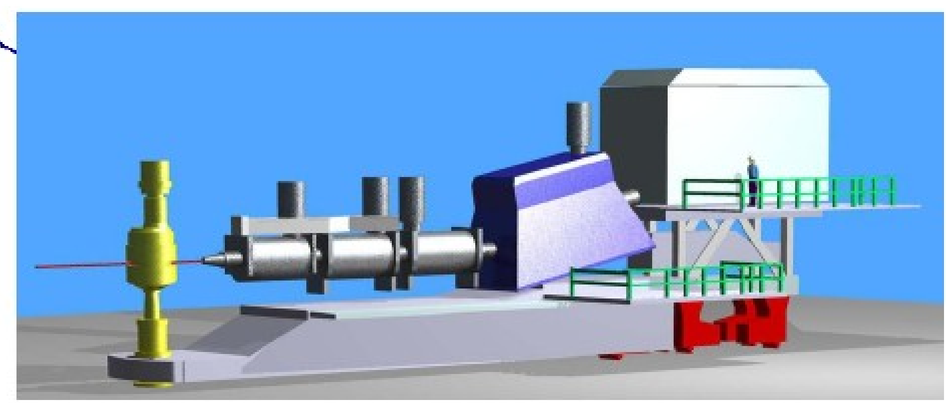
New vertical deflection magnet and 1116 element $PbWO_4$ calorimeter to detect scattered photons.
Simulated with Geant4.











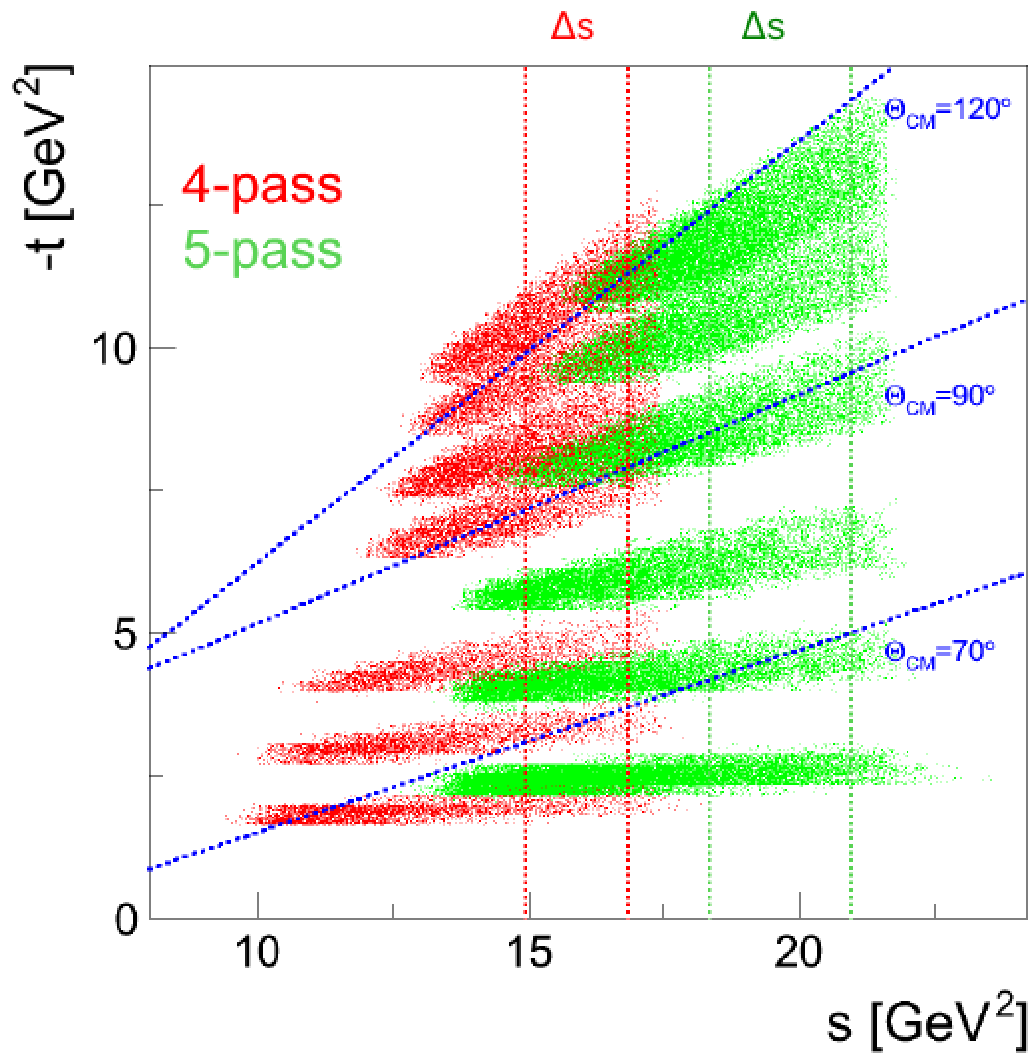
Measurements that were Proposed

- We propose to make measurements at 13 kinematic settings:
  7 points with 4-pass beam (8.8 GeV).
  6 points with 5-pass beam (11 GeV).

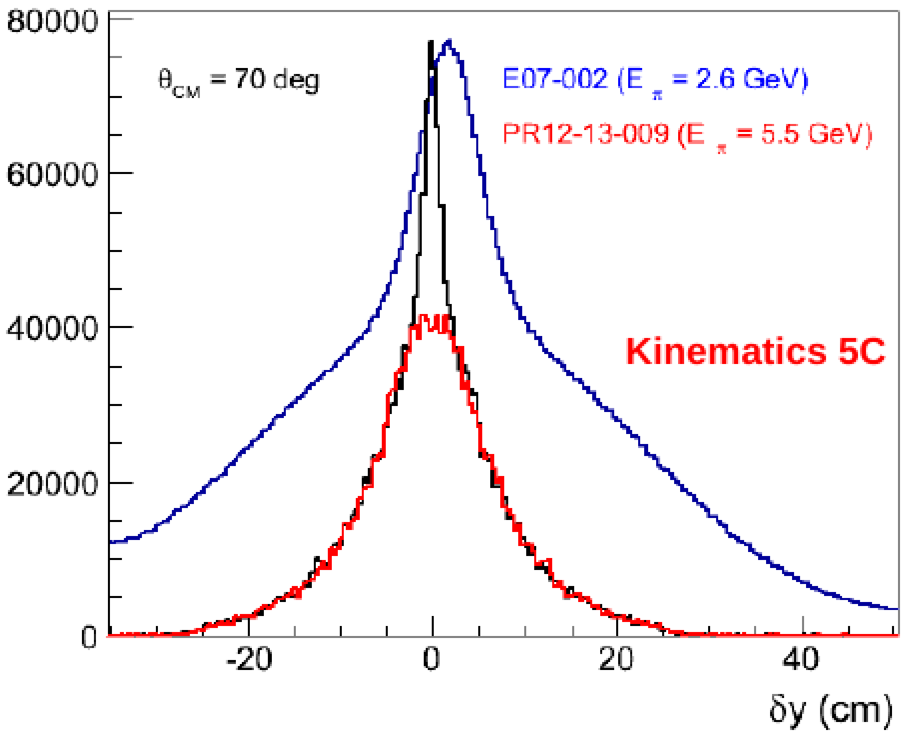
- The corresponding range of incident photon energies used in the beamtime estimate was:
  7.5 – 8.5 GeV for 4-pass settings.
  9.3 – 10.7 GeV for 5-pass settings.

- **Kinematic Setting 5F re-calculated for a proton momentum of 7.3 GeV/c in response to TAC comments.**

- Range of kinematic coverage:
  $15.0 < s < 21.0$ GeV^2
  $2.03 < -t < 12.05$ GeV^2
  $3.05 < -u < 15.30$ GeV^2



The main background to the WACS process is due to the much larger π^0 production process, when one of the decay photons goes undetected. The authors have shown the feasibility of this background subtraction for some settings. Given its crucial importance, the PAC40 would have liked to see a realistic simulation for the background subtraction for each kinematic setting, to avoid the beamtime request from becoming prohibitively large.



Work is already under-way on improved background subtraction techniques.

For kinematic points where the background is very large, a significant reduction is possible by rejecting events in which both decay photons are detected.

A more rigorous approach will allow for less conservative estimates of systematic uncertainties and requested beamtime.

Furthermore, the PAC was also not convinced on the choice of kinematic points to make the strongest physics case. To perform the above mentioned factorization study, the PAC felt that it would be more promising to focus on a fixed intermediate value of –t, combining the s-range from the previous 6 GeV experiment with the proposed extension in s. Several theoretical model approaches have been presented to interpret the result of such WACS cross sections. To interpret a factorization of the s- and t-dependence, the PAC would also like to see a sharpened physics case, indicating how such data would lead to systematic improvements within the specific models.

	4A	4B	4C	4D	4E	4F	4G	5A	5B	5C	5D	5E	5F
Set-up (beam & detectors)	14	-	-	-	-	-	-	10	-	-	-	-	-
Spectrometer move	-	2	2	2	2	2	2	-	2	2	2	2	2
HMS sieve slit	-	-	-	-	-	-	-	-	-	-	-	-	12
Optics target	1	1	1	1	1	1	1	1	1	1	1	1	1
No radiator	4	4	4	4	8	12	12	4	4	6	8	12	12
Production	8	18	18	27	40	60	110	12	18	42	64	110	150
Total beam-on-target	13	23	23	32	49	73	123	17	23	49	73	123	163
Adjusted beam-on-target	16	28	28	38	58	88	148	20	28	58	88	148	196
Total (hours)	**30**	**30**	**30**	**40**	**60**	**90**	**150**	**30**	**30**	**60**	**90**	**150**	**210**

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Optics target	1	1	1	1	1		1	1	1	1	1	
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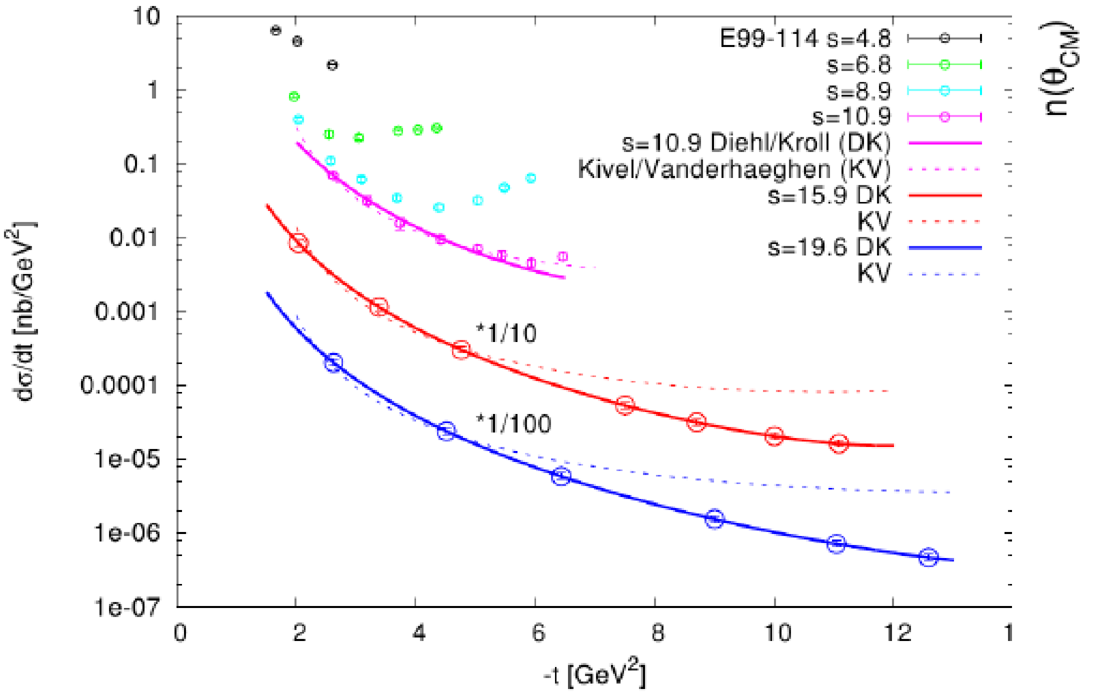

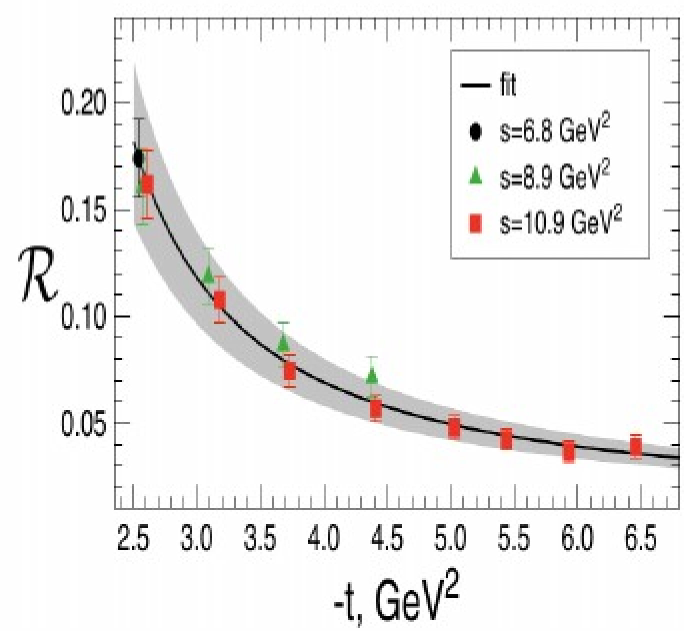

Conclusion and Future Plans

The PAC40 sees a strong potential for the WACS to be a process of choice to explore factorization in a whole class of wide-angle processes. However, the PAC was not convinced that in the present proposal both the π^0 subtraction procedure crucial to extract the WACS cross sections as well as the physics case were optimized.

Our plans for the next PAC are:

Remove the highest -t kinematic settings.

Put together a more optimised set of points at more moderate values of -t (5 settings for each beam energy).

Provide a better physics focus in terms of establishing factorisation and discriminating between models.

Improve background subtraction techniques and make more realistic estimates of systematic uncertainties.

Make less conservative estimates of overheads in order to futher reduce the beamtime request

Work has already begun on these points, with an expected revised beamtime estimate of 20 – 25 **PAC** days.