Pure Photon Source in 12-GeV Jefferson Lab Hall-C

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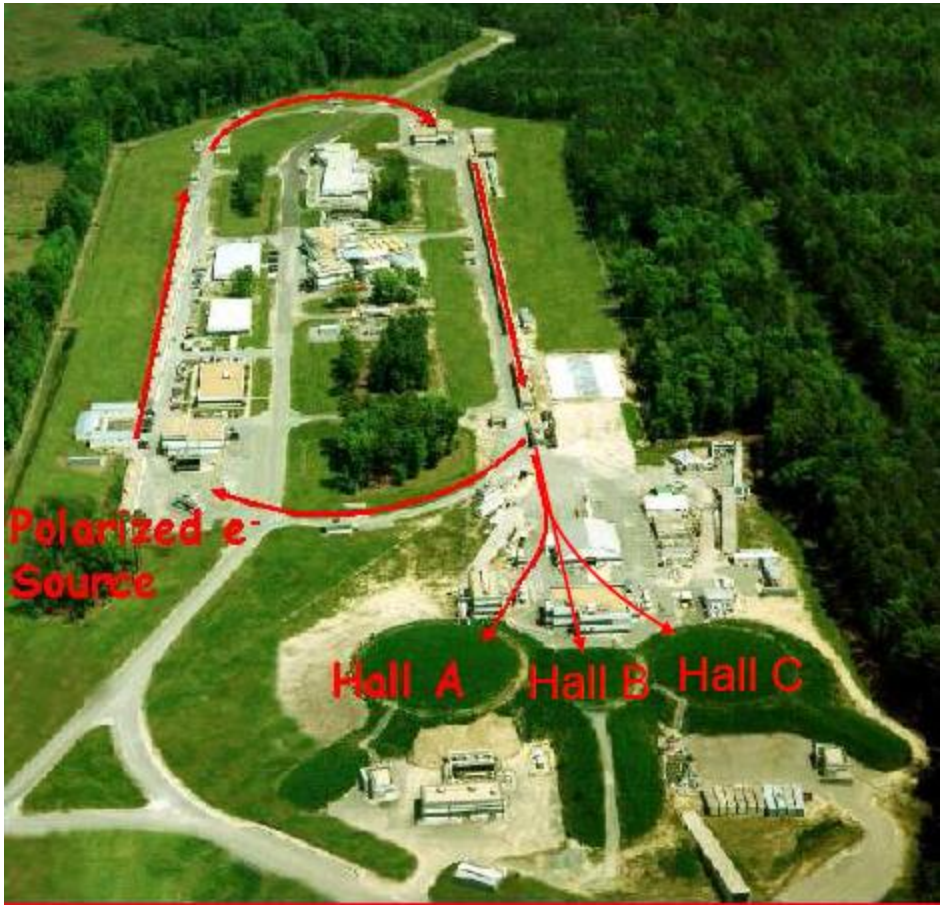
Outline

- Motivation
- Proposed setup
- Summary

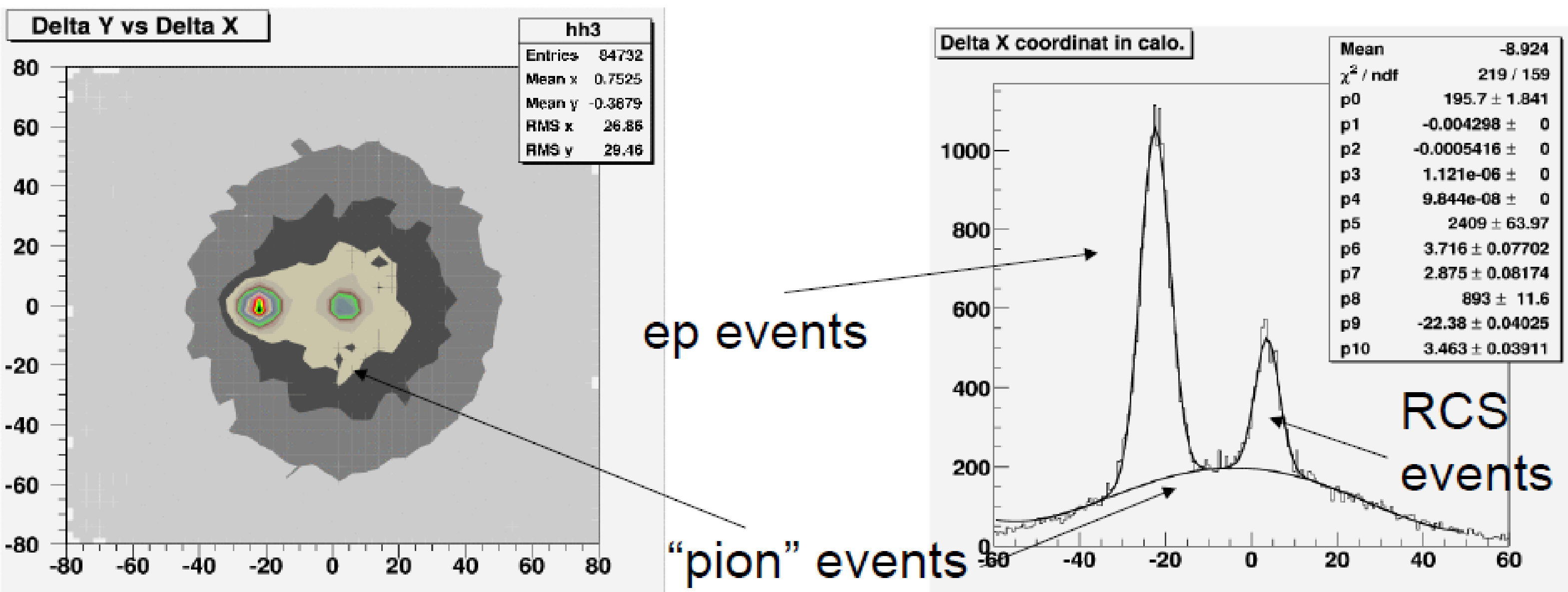
Jefferson Lab Accelerator

- Continuous Electron Beam Accelerator Facility (CEBAF), located at Newport News, VA
- Spin flipped at 30Hz or 1kHz
- Energy: up to 12 GeV
- Polarization: 90%
- Maximum beam current: 180 uA at 6 GeV, or 80 uA at 12 GeV



Photon Experiments in Hall A|C

- Unpolarized WACS: E99-114, E07-002, using e-γ mixed beam
- Future unpolarized WACS: E12-14-003 , using e-γ mixed beam
- **Future longitudial polarized WACS: E12-14-006 , using e-γ mixed beam**
- **Future transverse polarized WACS: Pr12-16-009, using pure photon beam**
- Future TCS in Hall C: LoI, prefer pure photon beam
- Future TCS in Hall A with SoLID: LoI, prefer pure photon beam



From E99-114, using e-γ mixed beam

Why WACS?

First ever measurement of A_{LL} and A_{LS} in RCS:

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

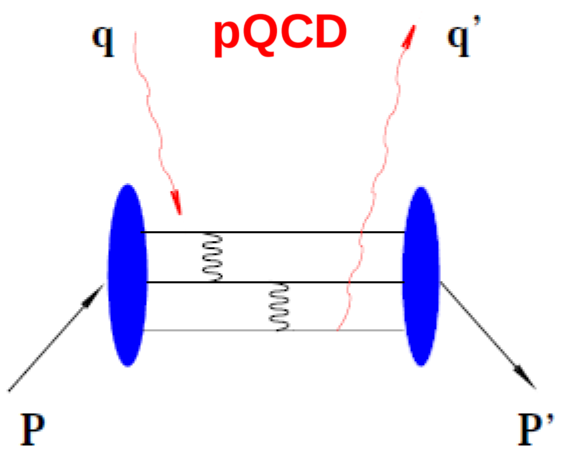
- RCS itself is interesting. It can provide information of nucleon structure.
The reaction mechanism of RCS is not well understood yet.

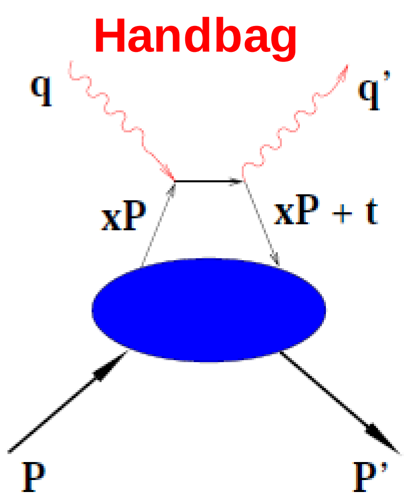
- A_{LL} of RCS will help discriminate between quark helicity flip and non-flip contributions.

- RCS can access GPD. It works in some kinematics regime where DVCS does not apply.
  DVCS: small t and large Q2
  WACS: large t

- According to SCET, RCS can help 1) to constrain the factorization of SCET and 2) to understand TPE effects in e-p elastic scaterring.

Two Reaction Mechanisms





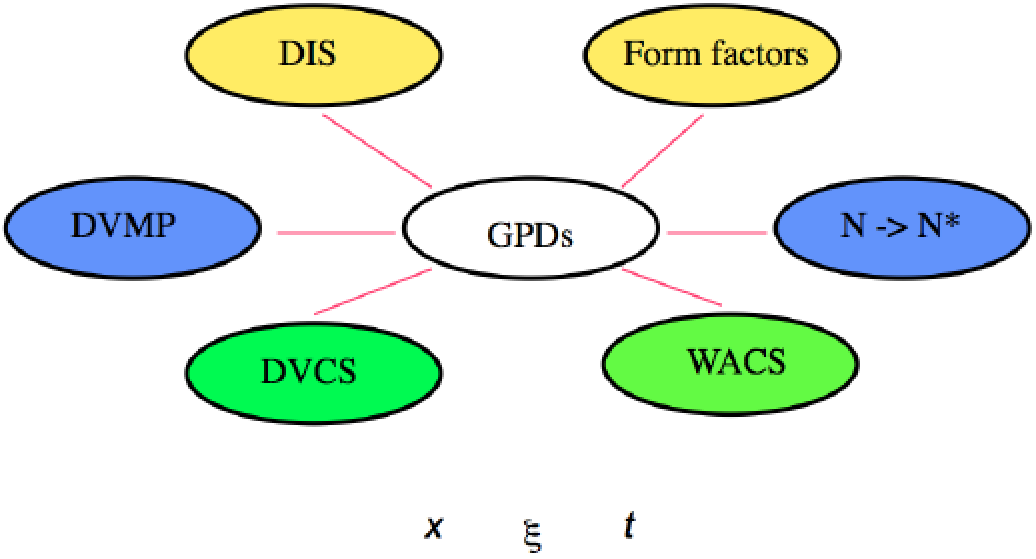
pQCD:
- 3 active quarks
- 2 hard gluons
- 3-body "form factor"
- Constituent scaling: $d\sigma/dt = f(t)/s^6$
- Already proved to dominate at sufficiently high energy
- Predict $K_{LL} = A_{LL}$ (final/initial state polarization asymmetry)
- Measured K_{LL} and $d\sigma/dt$ from E99-114 (6GeV) do not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

Access the GPD

- GPDs are accessed through exclusive reactions, such as DVCS and WACS
- Correspond to the proton wave function in light-front variables
- Description of longitudinal momentum fraction at transverse location



RCS vs EP

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

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:

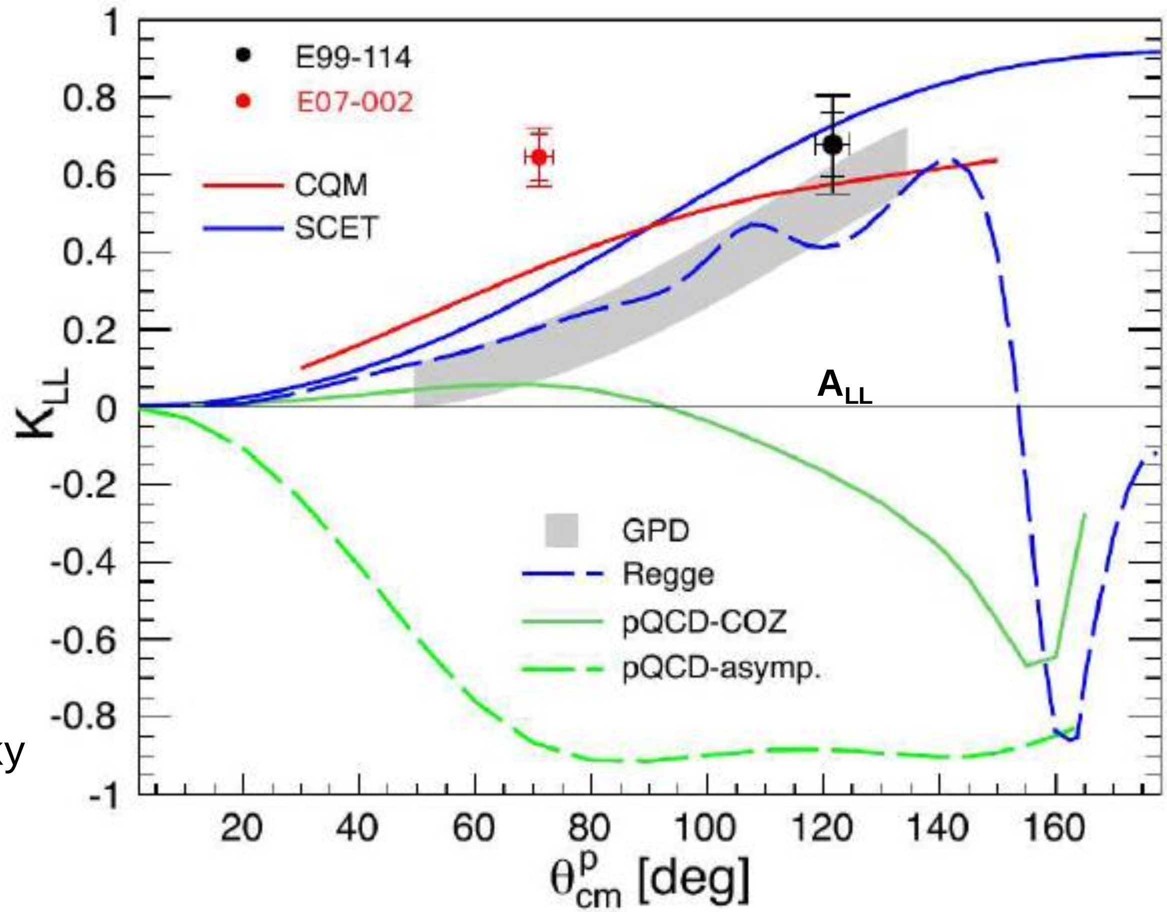
- vary s and t independently
- can help to constrain GPDs through:
- e_a^2 (charge) weighting
- independent integral of GPD's, x^{-1} weighting

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

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



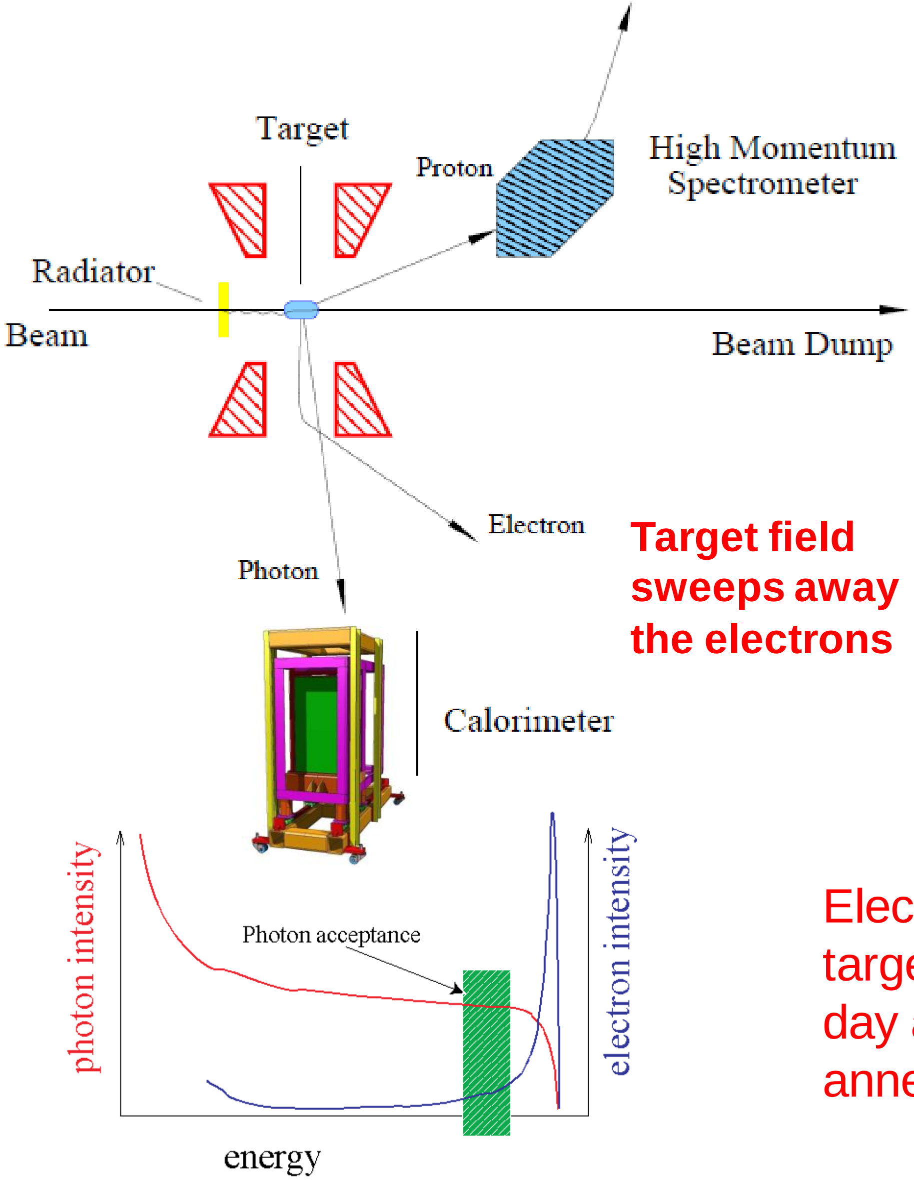
K_{LL}: a longitudinal polarization transfer observable, which is related to the helicity of the final proton.

Existing and Proposed Data

Existing and Proposed WACS Asymmetry Observables

Exp.#	θ_{CM}(°)	s(GeV²)	-t(GeV²)	-u(GeV²)	Observables
E99-114	120	6.9	4.0	1.1	K_{LL}, K_{LS}
E07-002	70	8.0	2.1	4.1	K_{LL}, K_{LS}
E12-14-006	60	8.0	1.7	4.5	A_{LL}
E12-14-006	136	8.0	5.4	0.8	A_{LL}
PR12-16-009	90	7.6	3.0	2.8	A_{LL}
PR12-16-009	90	13.6	5.9	6.0	A_{LL}
PR12-16-009	120	13.6	9.0	3.0	A_{LL}
PR12-16-009	120	13.6	9.0	3.0	A_{LS}

Experiment Setup: E12-14-006



Target field sweeps away the electrons

HMS: High Momentum Spectrometer
NPS: Neutral Particle Spectrometer

80% polarized beam at 4.4 GeV
Kinematic Range:
E_γ = 4.0 GeV, s= 8 GeV^2

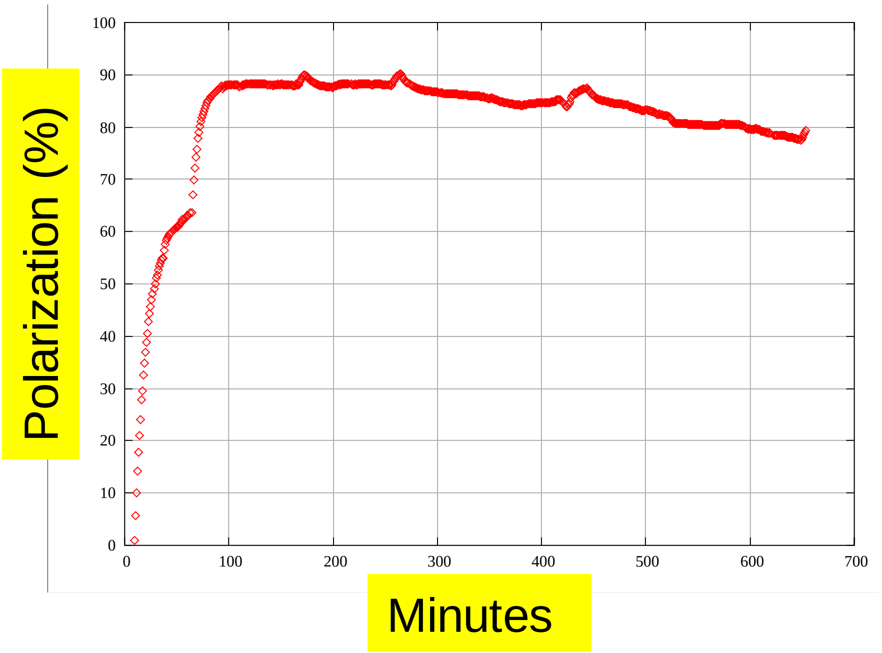
- θ_{CM} = 60º and 136º
- 6% copper radiator
- **mixed e−γ beam**
- polarized target

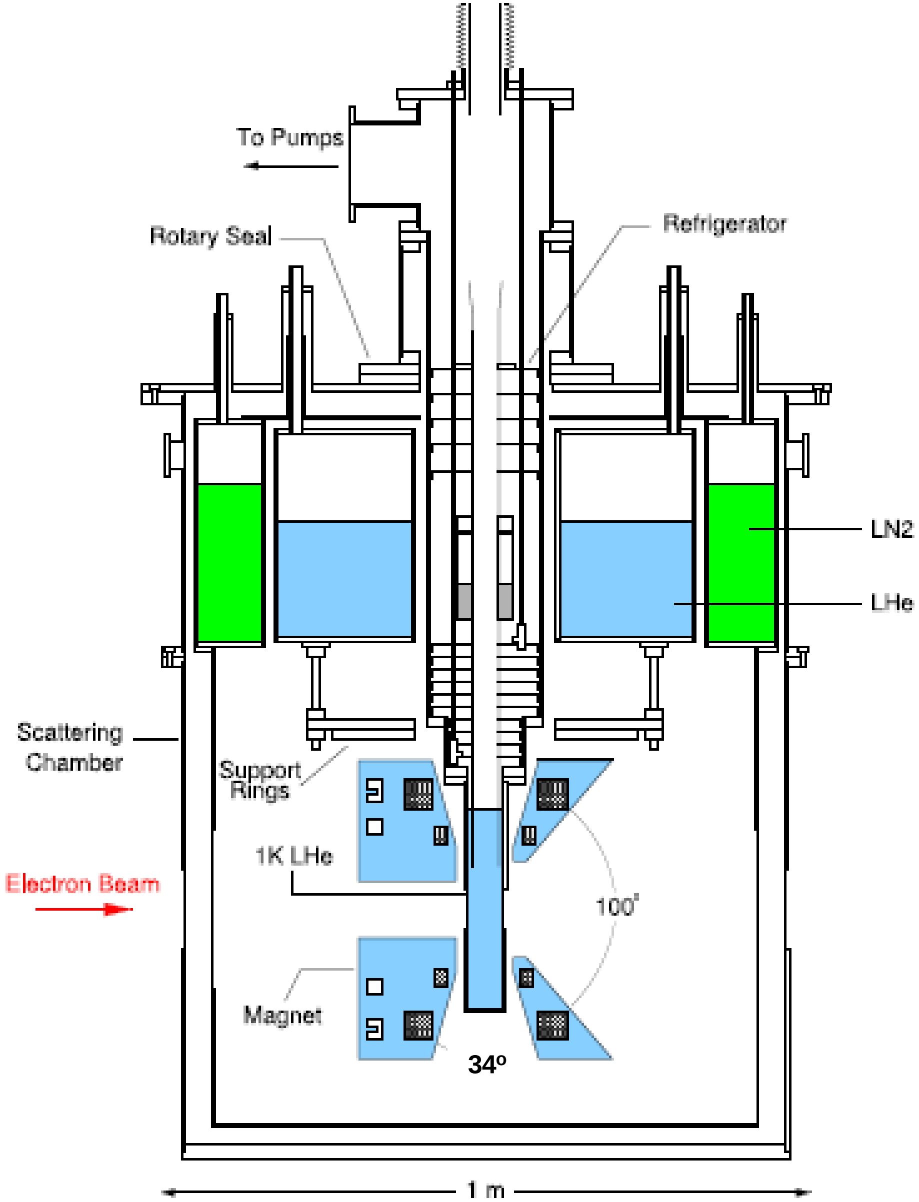
Electron will cause radiation damage to the target which requires annealing once per day and replacing target material after 5~7 anneals.

Bottle Neck: depolarization

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





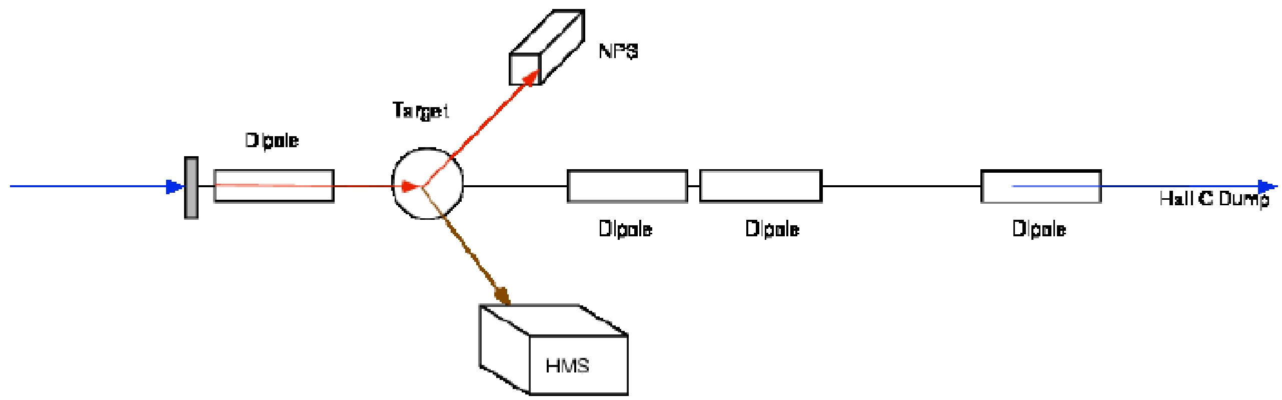
Why Pure Photon Source?

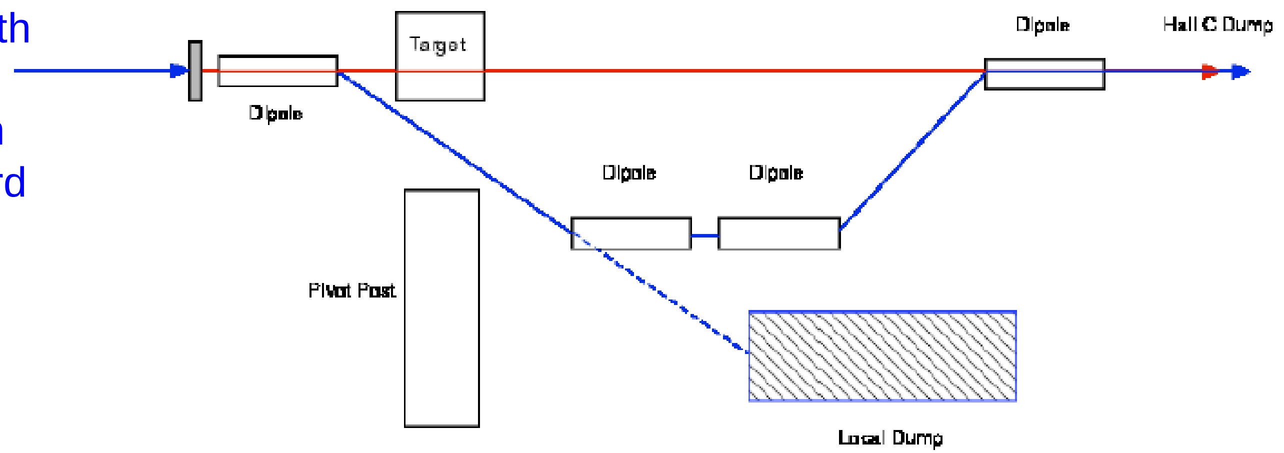
- Eliminate electron backgrounds: e-p elastic and epγ events.
- Target averaged polarization increases from 70% to ~90%, F.O.M increases by ~1.7 (assumming keep electron beam current).
- Heat load from photon beam is much lower than that from electron beam – about 60 times smaller (assumming 10% radiatior and the same electron beam current).
- Collimator will reduce the photon flux, depending on beam energy and distance. For 8.8 GeV beam and 6.33m distance, the photon flux lost is 40.5%.
- Beam current can be increased by a factor of 100 (limited by the cooling power of the beam dump, or radiation budget ,or the heat load in the target).
- Overhead time will be greatly reduced: fewer anneals, target material changes and TE measurements (associated with target changes).

F.O.M could be improved by up to a factor of 60.

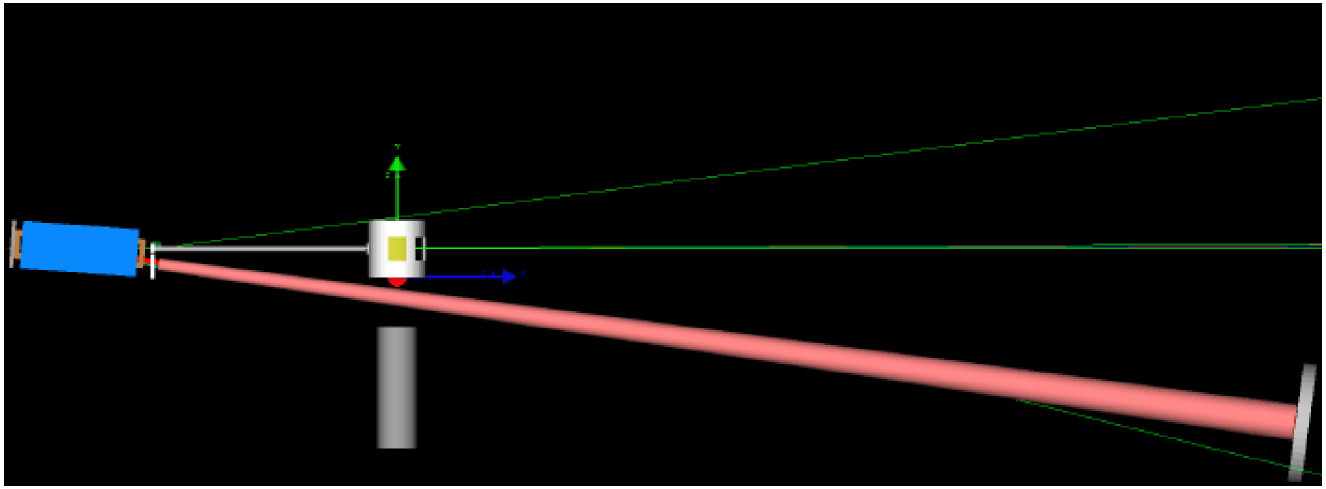
Experiment Setup: PR12-16-009

- Use Pure Photon Beam
- 10% radiator
- 3 uA beam current
- 4 FZ dipoles chicane
- Electron beam go beneath the target chamber, then can go to a local dump in the hall or to the standard Hall C dump.
- Target Field in 275 or -5 degrees





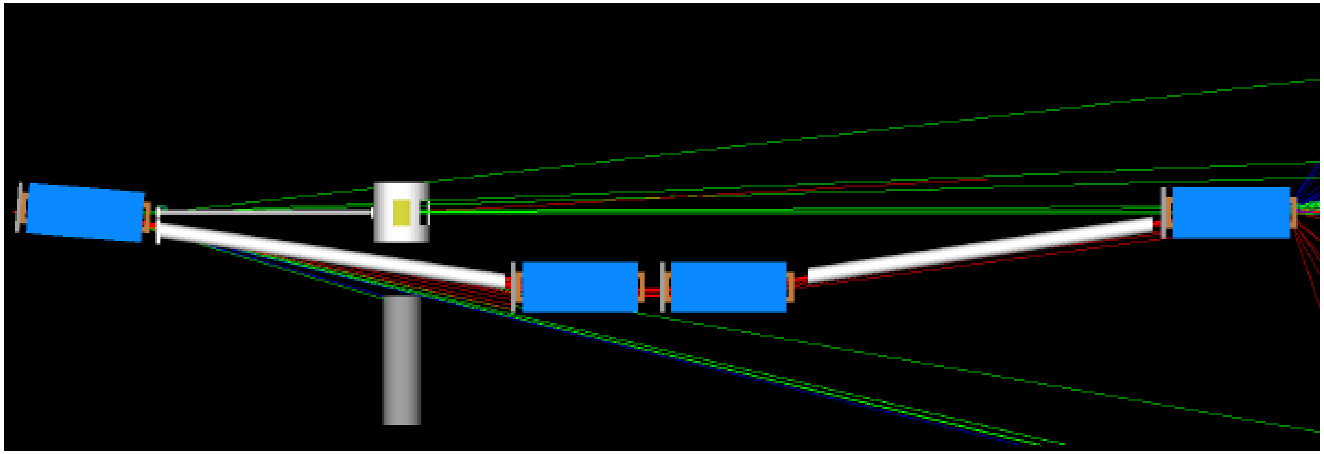
Local Dump Photon Source



- Dipole ends 4.3m upstream of target.
- Large space available to shield radiator, collimator, beam pipe.
- No disruptive magnetic forces on target.
- Opportunity for radiation exposure minimized.
- Distance and shielding minimizes singles background in NPS.
- Hermetic local dump can be made with as many meters of material as necessary - the ‘green blocks’ - the space exists. We proposed 30kW cooling power local dump located at 20 meters downstream on the floor, allowing 3 uA beam current at10 GeV.

For 6%(10%) radiator:
10% (18%) of beam power is lost in radiator/dipole/collimator/beam pipe and
90% (81%) of beam power is lost in local dump or Hall C dump

1-Dipole Chicane Photon



- Dipole ends 4.3m upstream of target.
- Large space available to shield radiator, collimator, beam pipe.
- No disruptive magnetic forces on target.
- Opportunity for radiation exposure minimized.
- Distance and shielding minimizes singles background in NPS.
- Ample space to shield beam line - primarily the absorbers at each dipole.

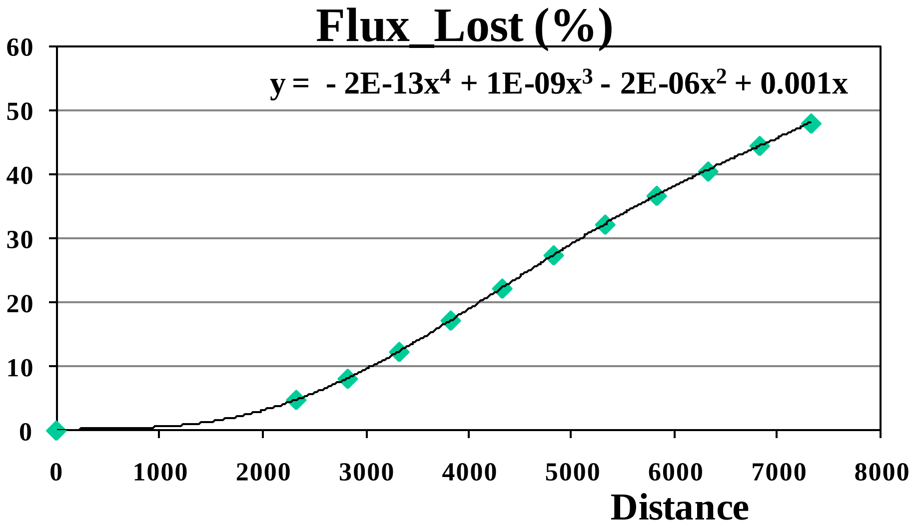
For 6%(10%) radiator:
4.5% (9%) of beam power is deposited in radiator/first dipole/collimator
11% (17)% of beam power in last dipole
75% (60)% of beam power in Hall C dump

Photon Flux Lost

Beam_Energy (GeV)	Distance (mm)	Photon_Flux (x10^11/s/uA)	Flux_Lost (%)
8.8	2330	3.5	4.8
8.8	2830	3.3	8.1
8.8	3330	3.2	12.3
8.8	3830	3.0	17.2
8.8	4330	2.8	22.2
8.8	4830	2.6	27.4
8.8	5330	2.5	32.2
8.8	5830	2.3	36.7
8.8	6330	2.2	40.5
8.8	6830	2.0	44.5
8.8	7330	1.9	48.0

Assumes:

- 10% radiator
- 0.5 < E_γ/Beam <0.95
- spot size at target within 2mm radius



Heat Load in Target

Photon Flux

E	I	RL	D	Lost	γ/s
8.8	3.0 uA	10%	633cm	40.6%	6.6E11

Power Deposition

Ebeam (MeV)	Radiator length(%)	Power deposit 1uA beam (Watts)
4400	6	0.009
4400	10	0.015
6600	6	0.017
6600	10	0.022
8800	6	0.024
8800	10	0.035

Electron experiments use 100nA and 0.36 W are deposited in target: an order of magnitude more than from the photon flux generated by 1 μA on a 10% radiator.

If cooling power was only issue we could put 8-10 μA on radiator to illuminate the PT: target would operate “normally”.

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 source is feasible, which open door for experiments with transverse target field.

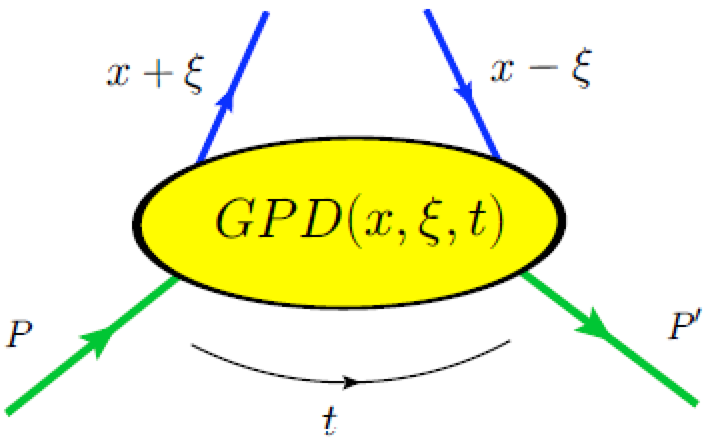
- Our proposed pure photon source could increase the F.O.M by a factor of 30. It allows us to propose new WACS experiment with new kinematics (higher t, higher s) and measuring A_{LS}.

Back up slides

Generalized Parton Distribution (GPD)

GPDs describe the nucleon structure in terms of quark and gluon degrees of freedom

Correlation between transverse position and longitudinal momentum fraction of quark in the nucleon



Relation to total angular momentum (Ji relation):

$$J_q = \frac{1}{2} \lim_{t\to 0} \int_{-1}^{1} dx\, x\, (H_q(x,\xi,t) + E_q(x,\xi,t))$$

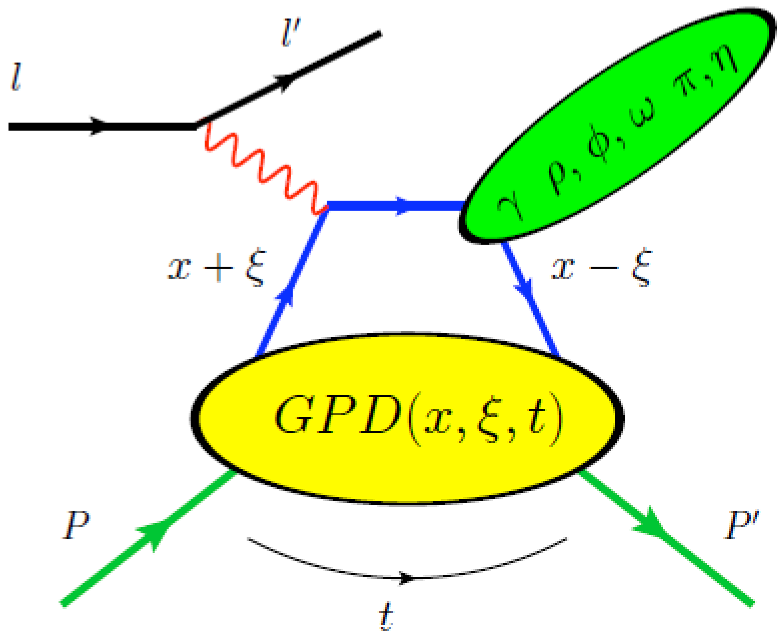
leading-twist, quark chirality conserving		
spin-1/2	unpolarized	polarized
no nucleon hel. flip	H	$\widetilde{H}$
nucleon hel. flip	E	$\widetilde{E}$

Form Factors:
Transverse distribution of quarks in space coordinate.
F(t)=∫dx*GPD(x, ξ, t)

PDFs:
Quark longitudinal momentum fraction in the nucleon.
q(x)=GPD(x, ξ=0, t=0)

How to Access GPD

Hard Exclusive Processes.



Deeply Virtual Compton Scattering

- Theoretically the cleanest probe of GPDs
- Theoretical accuracy at NNLO
- GPDs are accessed through convolution integrals with hard scattering amplitude
- Experimental observables: Azimuthal asymmetries
- GPDs $H, E, \widetilde{H}, \widetilde{E}$ are accessed

Vector Mesons

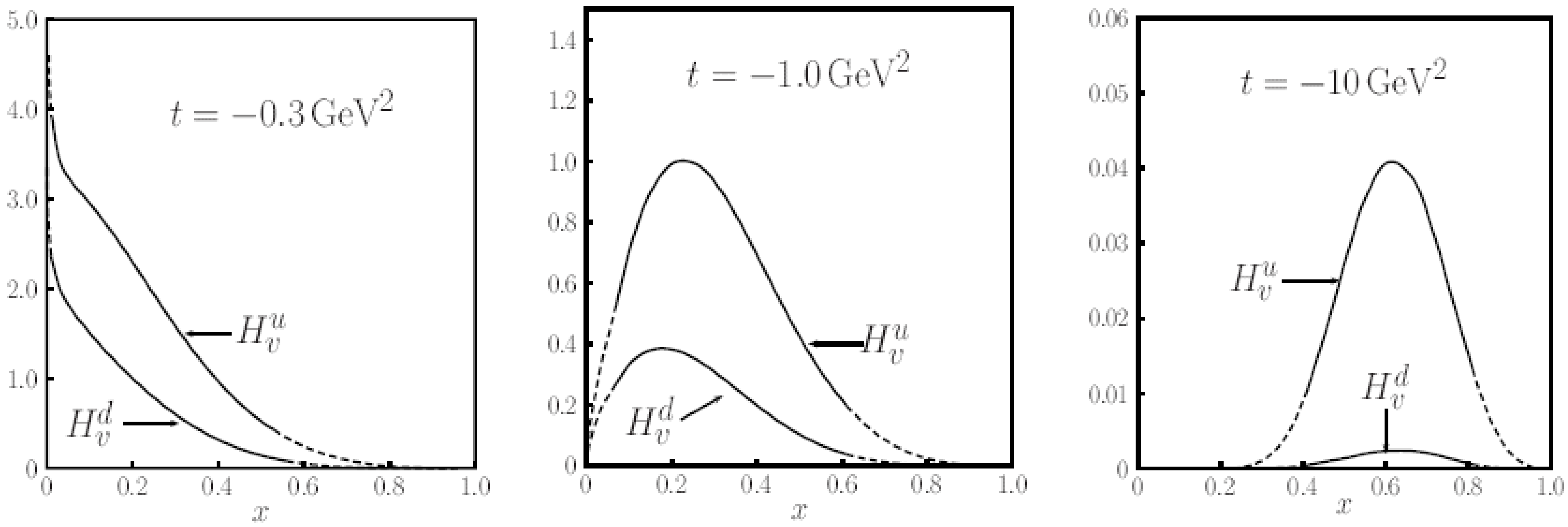
- Factorization for σ_L (to ρ_L, ϕ_L, ω_L) only
- σ_L to σ_T suppressed by $1/Q$
- σ_T suppressed by $1/Q^2$
- Experimental observables: SDMEs, Transverse target spin asymmetries, Helicity amplitude rations
- At leading twist → sensitive to GPDs H and E

Pseudoscalar mesons

- Experimental observables: Cross sections, Transverse Target Spin Asymmetries
- At leading twist → sensitive to GPDs $\widetilde{H}$ and $\widetilde{E}$

GPD and WACS

M. Diehl, T. Feldmann, R. Jakob and P. Kroll, Eur. Phys. J. C **39**, 1 (2005).



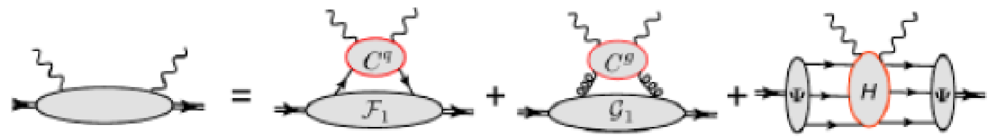
WACS provides constrains on GPDs at high t, which are different from ep form factors due to 1/x and e_a^2 (charge) weighting

RCS (high t) should receive the same level of attention as DVCS (low t) does. They are complementary to each other in probing GPD.

RCS and SCET

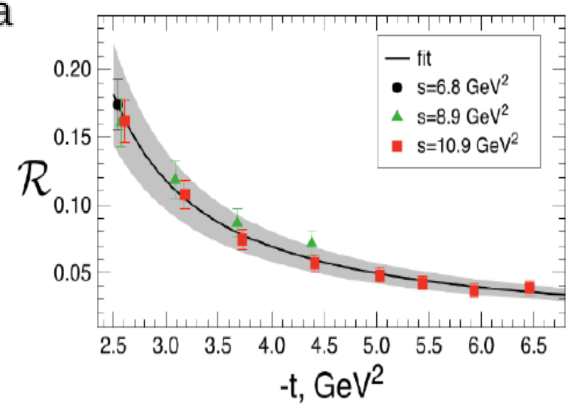
The recent development of the SCET approach has shown the importance of WACS in understanding **Two Photon Exchange (TPE)** effects in elastic ep scattering.

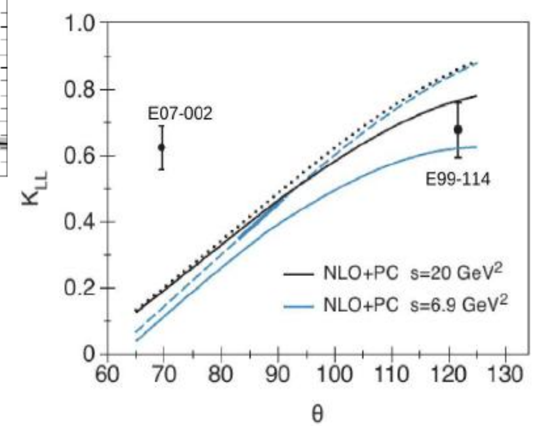
N. Kivel and M. Vanderhaeghen, JHEP 1304 (2013)



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

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

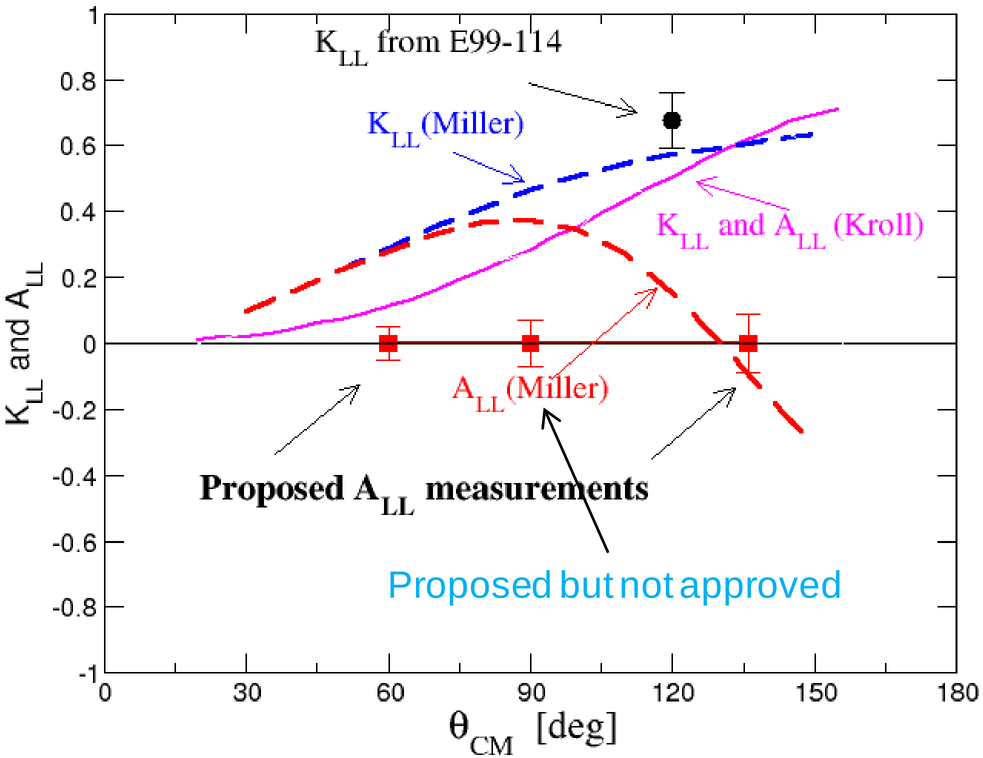




Extending the measurements of this form factor R(t) to higher s and -t will provide valuable insights into the **validity of factorization** in both WACS and TPE in elastic ep scattering and help learn more about the **soft physics describing proton structure** in the 12 GeV regime.

A complete factorization formula for the leading power contribution in wide angle Compton scattering has Recently been developed. Our measurement can provide good constraints to this factorization.

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 **$A_{LL} \neq K_{LL}$,**

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

Beam Time Approved: E12-14-006

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~~

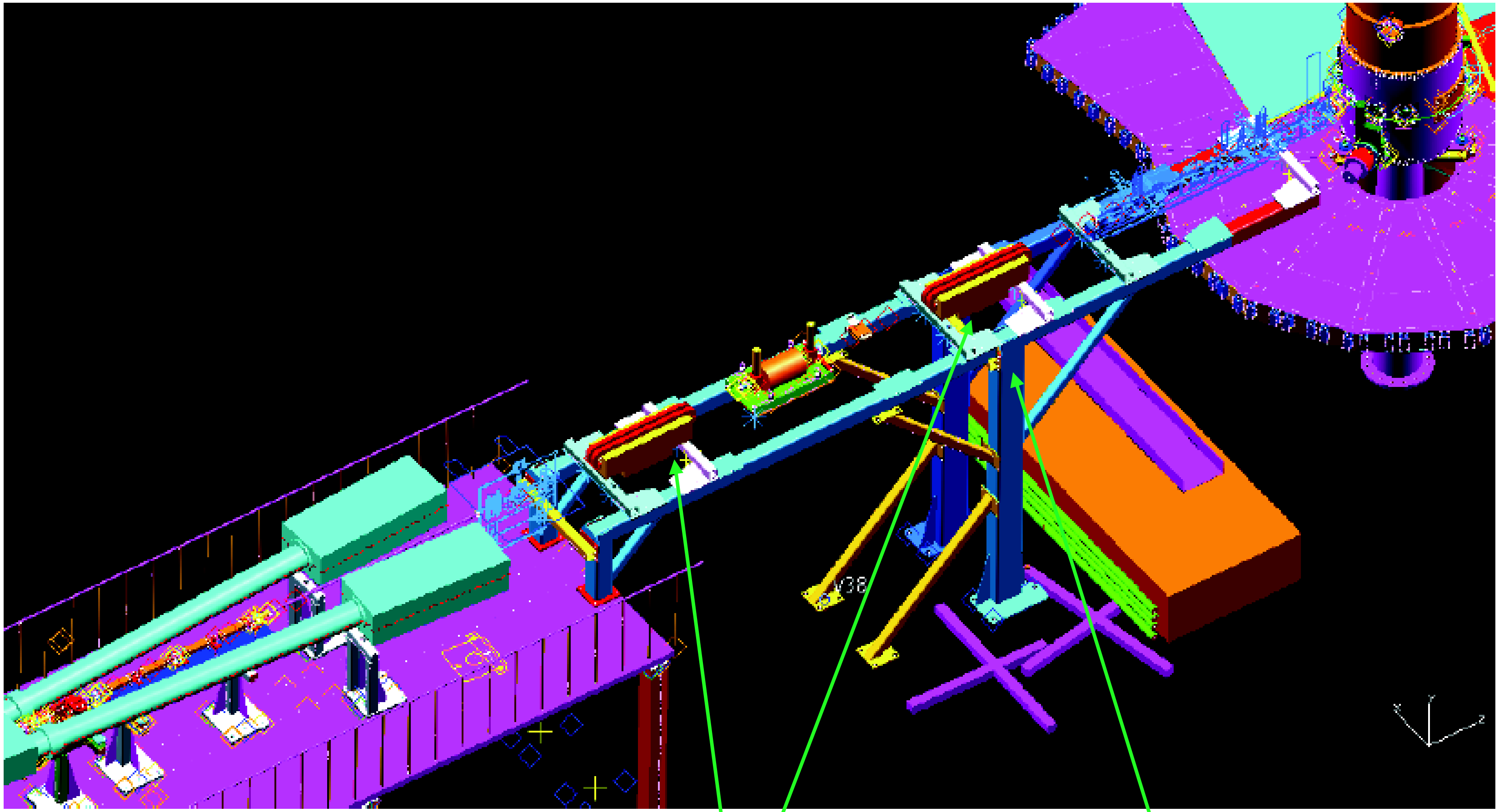
not approved (P2 rows)

15 days were approved

Beam Time Request: E12-16-009

Kin. P#	Procedure	beam, uA	time hours
P4	production	3	58
P5	production	3	292
P6	production	3	106
P7	production	3	158
	Packing Fraction	3	33
	Moller Measurements	1	42
	Data Beam Time		689
	Target Anneals		54
	Stick Changes		24
	Target commissioning		24
	Kinematics change		12
	BCM,BPM calibration		24
	HMS Optics		8
	Beamline commissioning		24
	Total Requested Time		835

Is there space for the FZ Magnet?



Vertical Chicane using 2 BEs

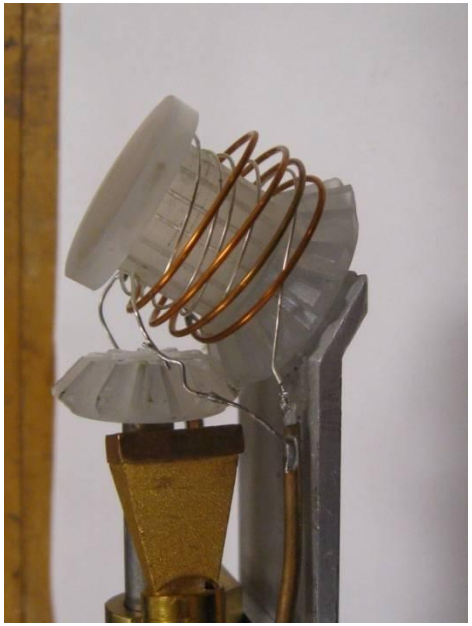
4.9m to the pivot

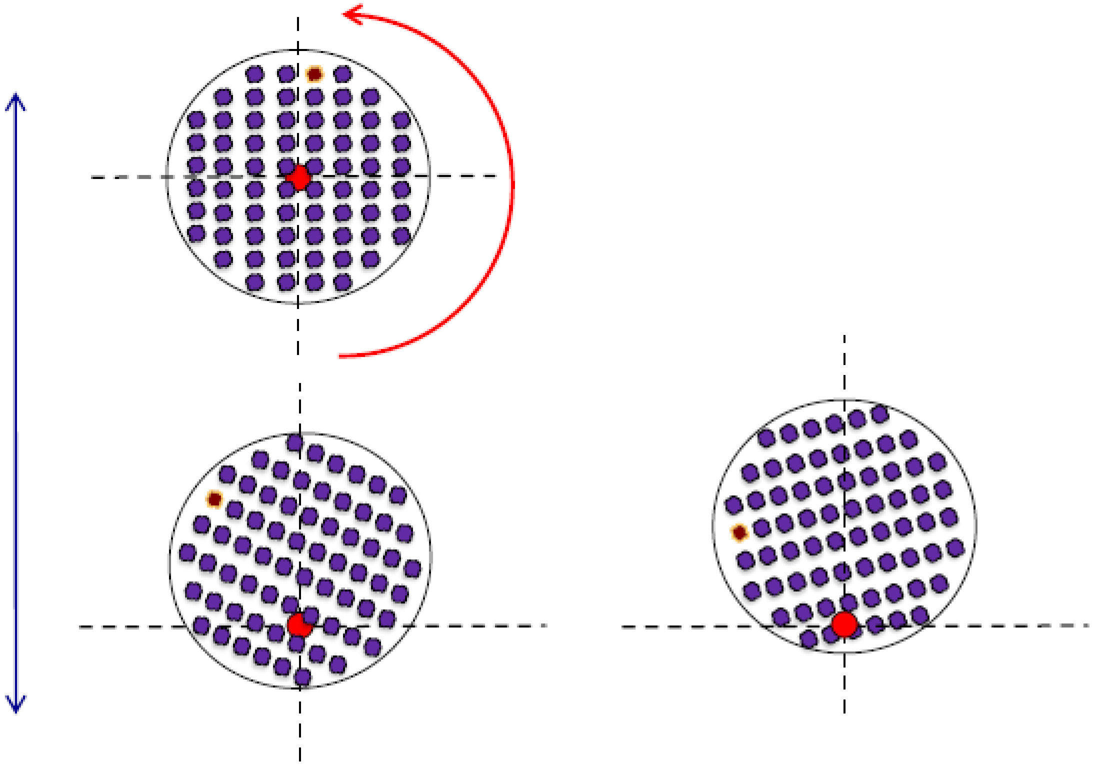
Vertical chicane is used to lift electron beam by ~2.2cm to match the height of the pivot.

Improving the Polarized Target

No need to raster electron beam
Full and uniform irradiation of target

Photon spot fixed in space, target cell is moving up and down with rotation





UVa group already rotating target for other studies

dX Distribution: PR12-16-009

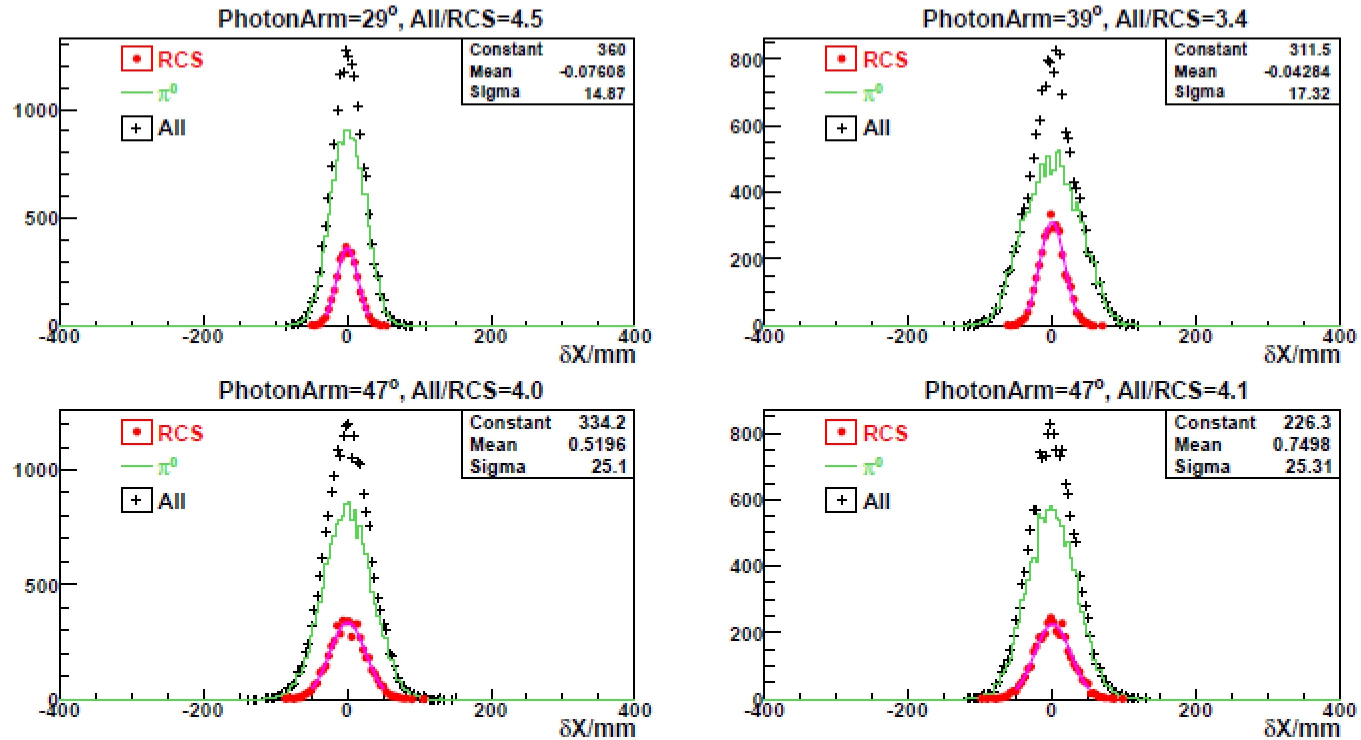
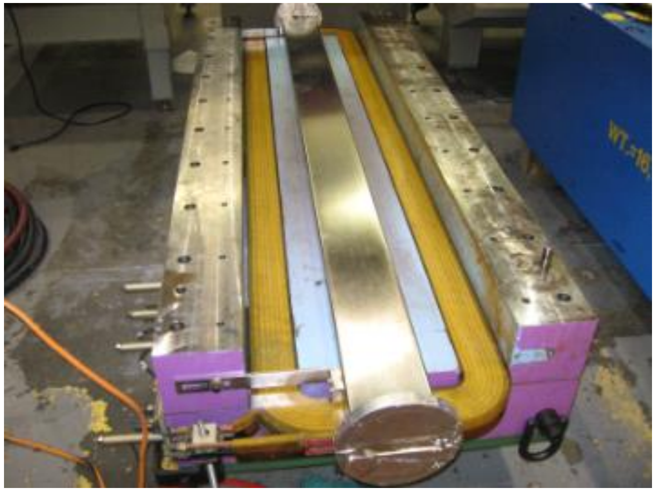
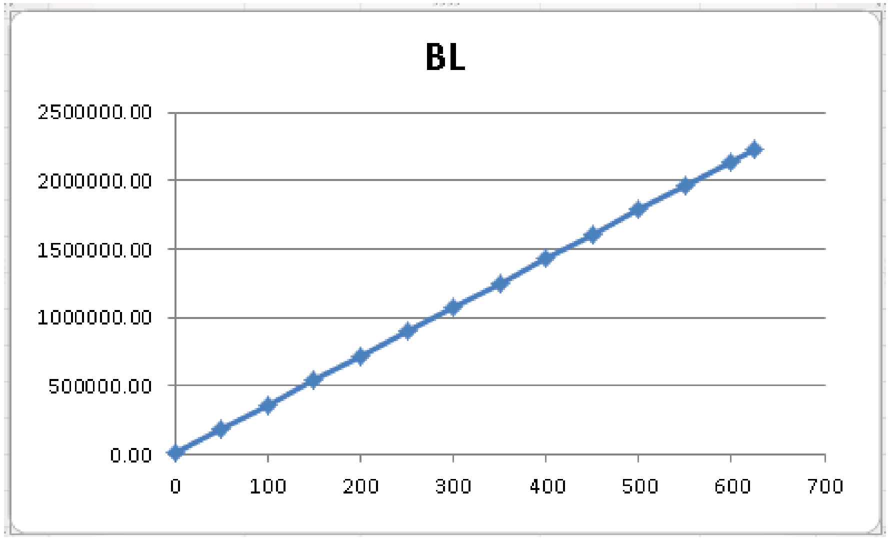


Figure 35: δX distributions after both δE and δY cut, for kinematics P4(top-left), P5(top-right), P6(bottom-left) and P7(bottom-right). The pure RCS signal is red curves, with a gaussian fit (pink) on top of it. The fitted parameters are labeled in the upper right corner of each panel. The π^0 background are ploted as green curve. The total (RCS+π^0) are present as the black points. Also present in the title are the Dilution values.

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

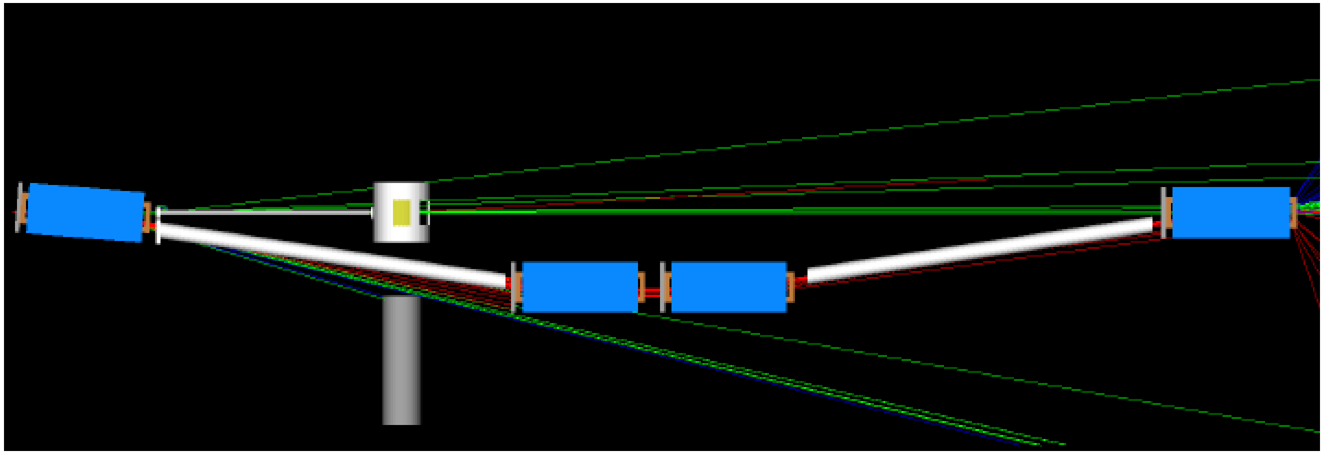


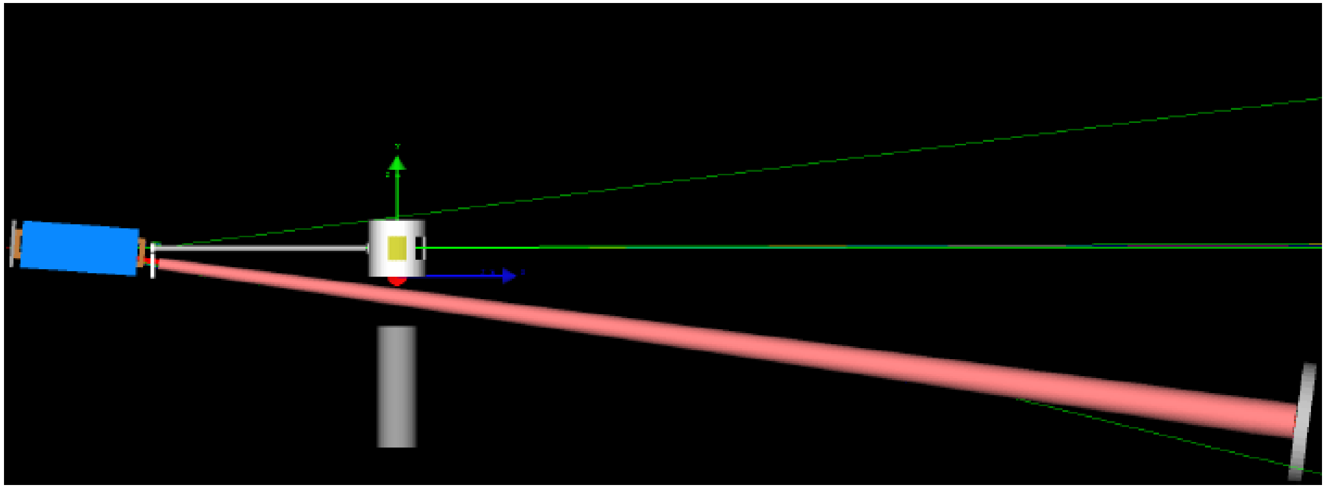
Need to check the cooling power of this magnet.

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

Photon Source Equipment

- 10% radiator, located at about -633 cm
- 30kW cooling power local dump located at 20 meters downstream on the floor, allowing 3 uA beam current at10 GeV.
- Electron beam go beneath the target chamber, then can go to a local dump in the hall or to the standard Hall-C dump.





For 6%(10%) radiator:
10% (18%) of beam power is lost in radiator/dipole/collimator/beam pipe and
90% (81%) of beam power is lost in local dump or Hall C dump

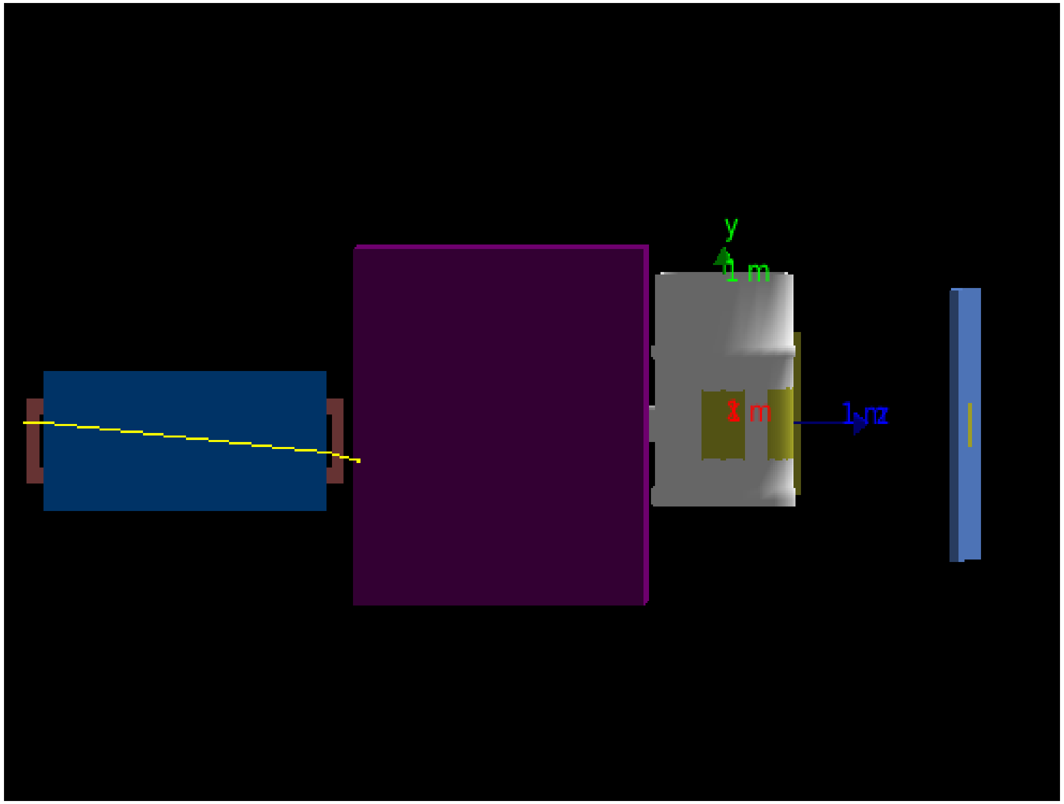
Separate Function Photon Source

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

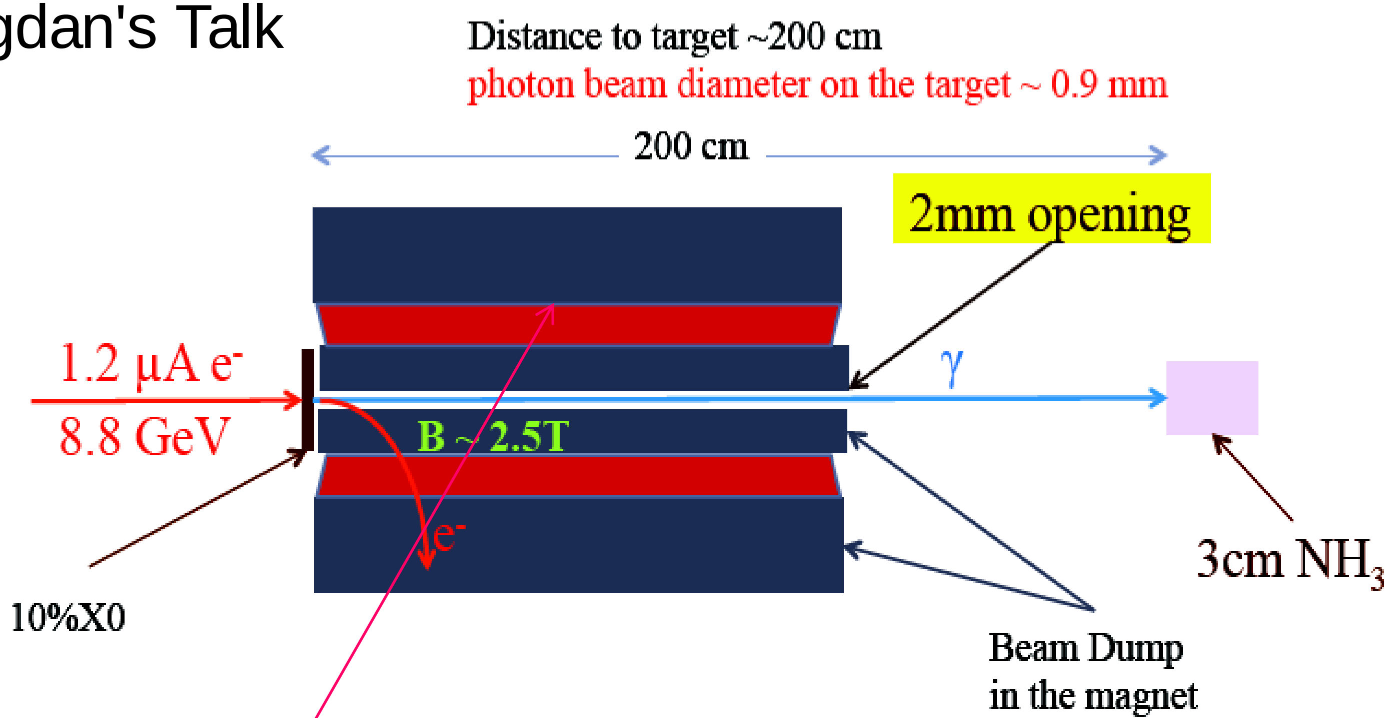
Problem: too high activated radiation level in the target platform. Need to setup very thick shielding. Need to wait several hours for the radiation to cool down. Not safe to operate the target.



The radiator is located at -370cm (upstream)
FZ magnet is located at -270cm
Local dump at -102cm (15 cm tungsten core, 100 cm including shielding)

Compact Photon Source

From Bogdan's Talk



Note: The total z length of magnet+shielding is 2.6m. That says, there will be 80cm thick shielding between the magnet and the target chamber. Therefore the distance from the radiator to the target should not less than **2.32** m. (Target chamber entrance window is 0.52m to target).

Problem:

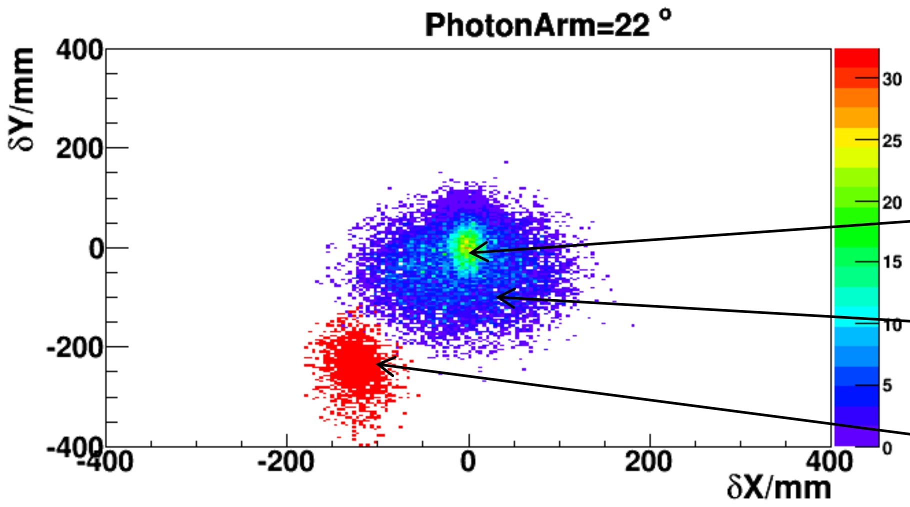
1)electron beam is dumped into the magnet, radiation is high, need very thick shielding needed.

2)10 kW cooling power allows no more than 1.2 uA beam current.

3)Very challenge in engineering

4)Magnet is one time use only. If it fails, no way to save the experiment.

NPS dY vs dX

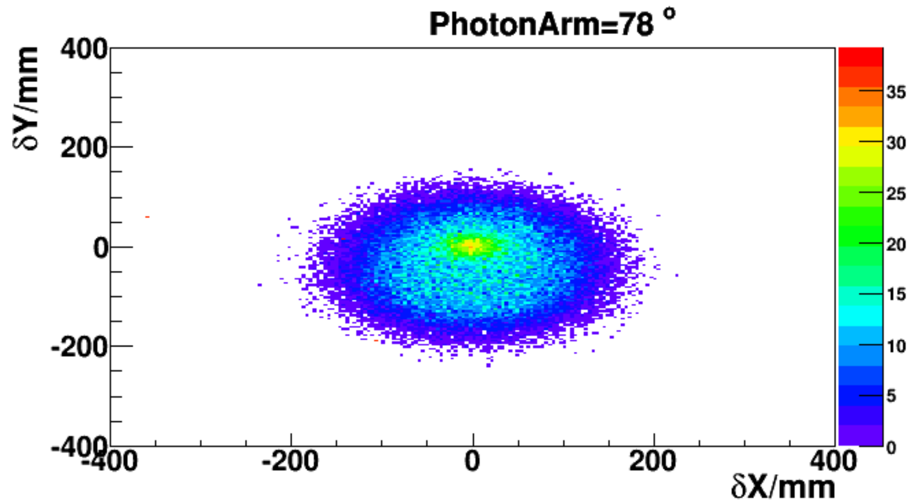


After dE Cut, NO dY cut

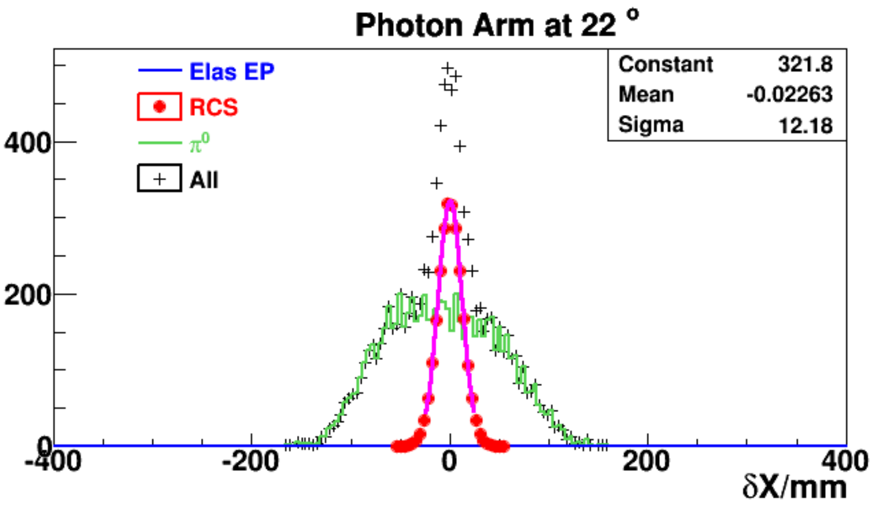
RCS

π^0

ep elastic



dX Distribution, E12-14-006



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.

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