On the reaction mechanism of the Wide Angle Compton Scattering from the proton

WACS experiment with NPS and SBS

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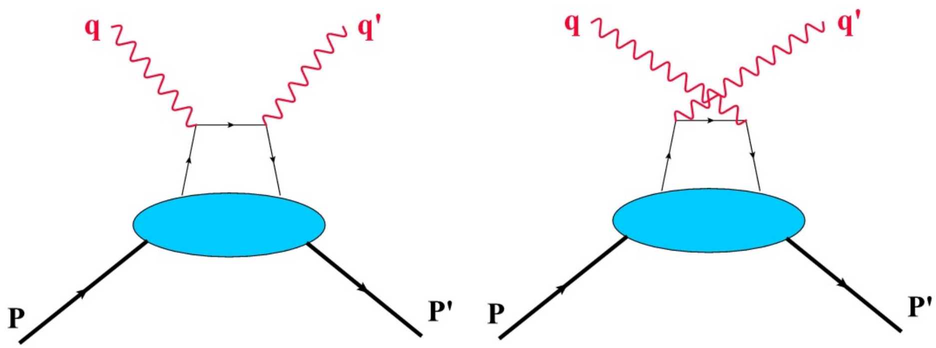
NPS & SBS collaborations

Overview

- Physics motivation
- WACS experimental challenges
- Key components of the experiment
- Projected accuracy

Compton scattering

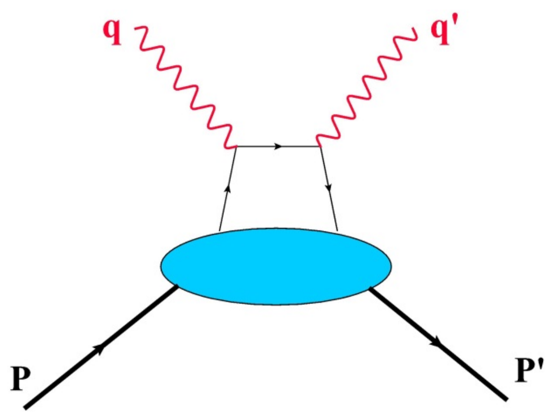


In the GPD approach, interaction goes with a single-quark, and the handbag diagram dominates.

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

- Test of the handbag predictions to the <10% level is an important task.
- The K_{LL}/A_{LL} asymmetry is an observable of choice.
- The NLO corrections are supposed to vary as 1/s (Kivel&Vanderhaeghen).

FF-s, GPD-s and Polarization Observables



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

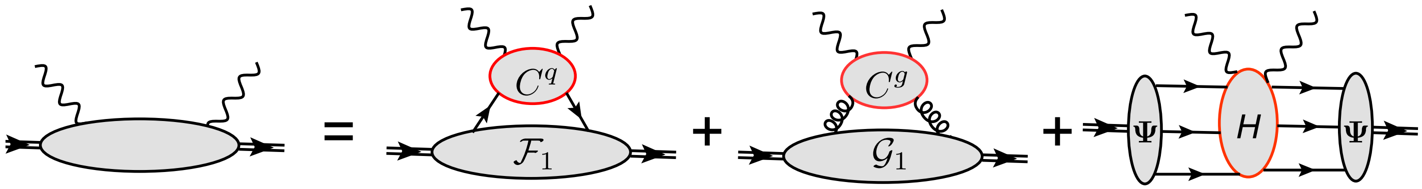
$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} sign(\mathrm{x}) \hat{H}^a(x,0,t)$$

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

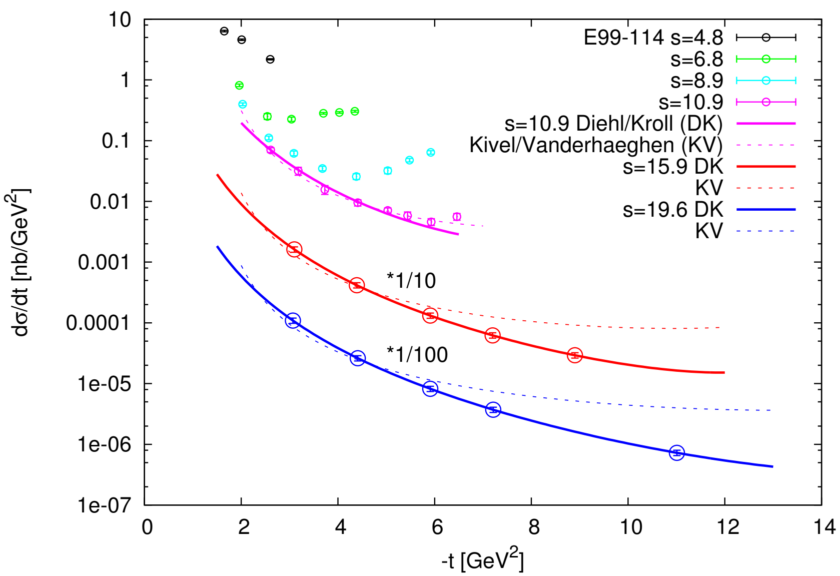
$$K_{LL}^{KN} = \frac{s^2 - u^2}{s^2 + u^2}$$

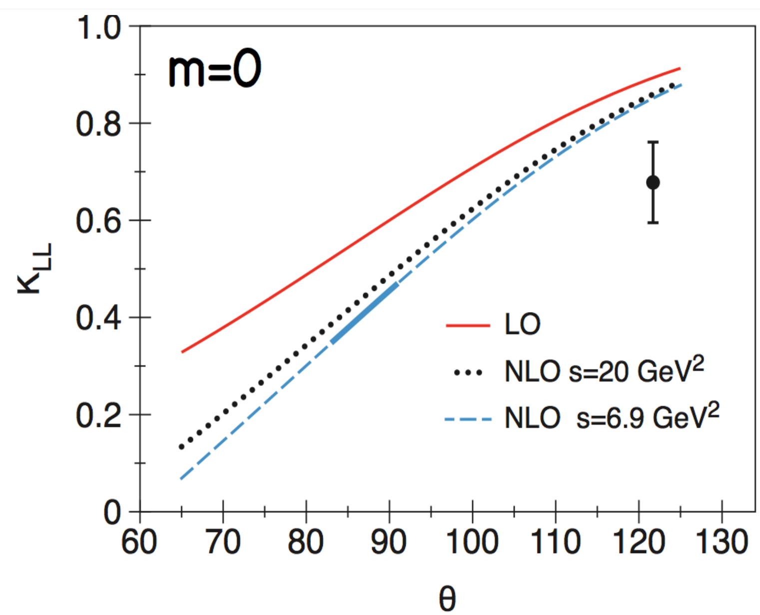
$$K_{LL} \; ; \; K_{LL}^{KN} \frac{R_A}{R_V} \left[1 - \frac{t^2}{2\left(s^2 + u^2\right)} \left(1 - \frac{R_A^2}{R_V^2} \right) \right]^{-1}$$

GEp/GMn and WACS



$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2}{s^2}\,|\mathcal{R}(s,t)|^2(-su)\left(\frac{1}{2}|C_2(s,t)|^2 + \frac{1}{2}|C_4(s,t)|^2 + |C_6(s,t)|^2\right)$$





WACS phenomenology: longitudinal polarization K_{LL}

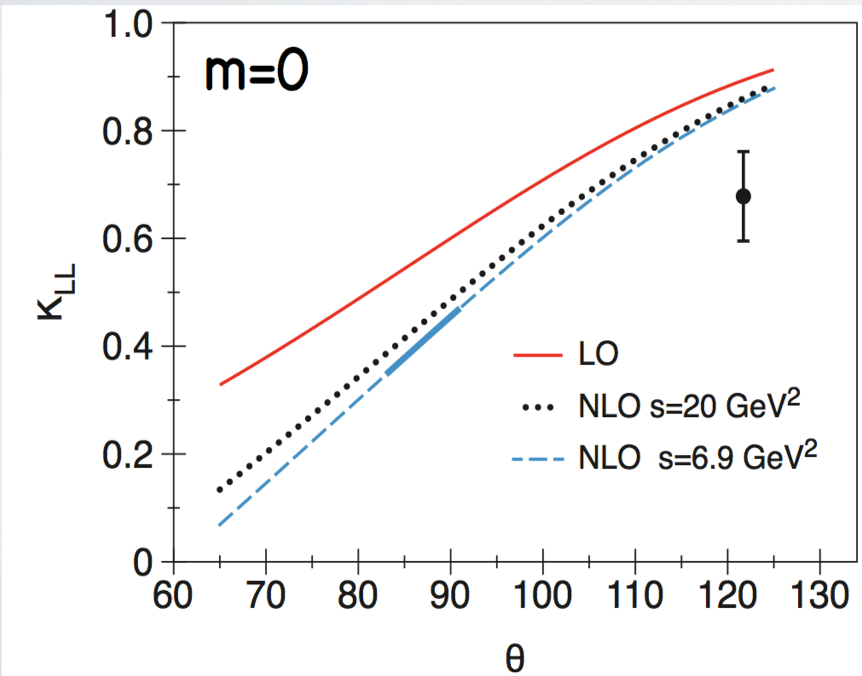
$$K_{\rm LL} = \frac{\sigma_{\parallel}^{R} - \sigma_{\parallel}^{L}}{\sigma_{\parallel}^{R} + \sigma_{\parallel}^{L}} = \frac{s^2 - u^2}{s^2 + u^2} + \frac{\alpha_s}{\pi} C_F K_{\rm LL}^{\rm NLO}$$

m=0

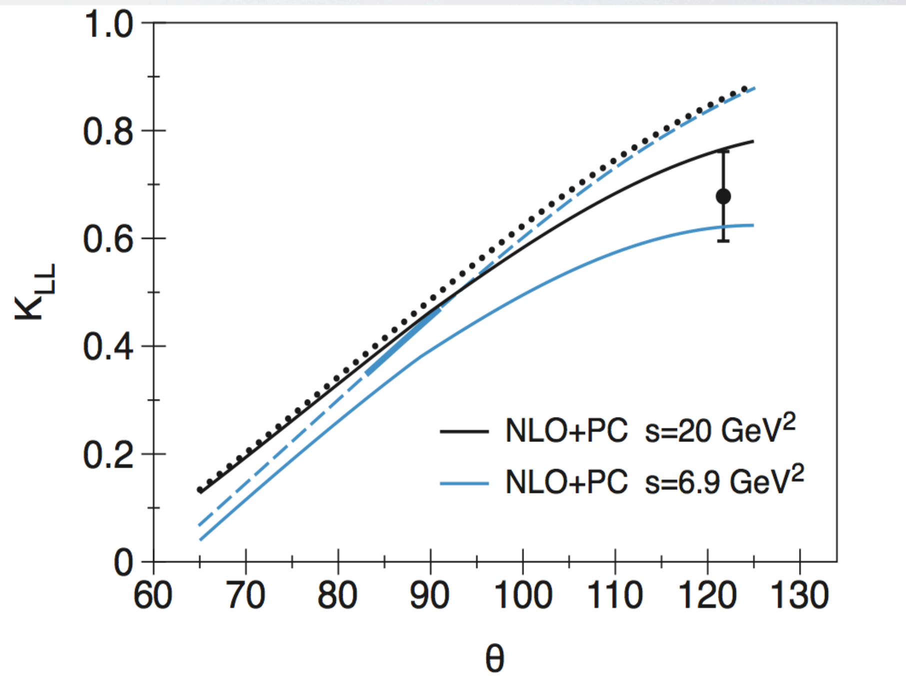
$\Rightarrow$ Does not depend on s & $\mathcal{R}$

NK, Vanderhaeghen, to appear

data: JLab/Hall-A, 2004



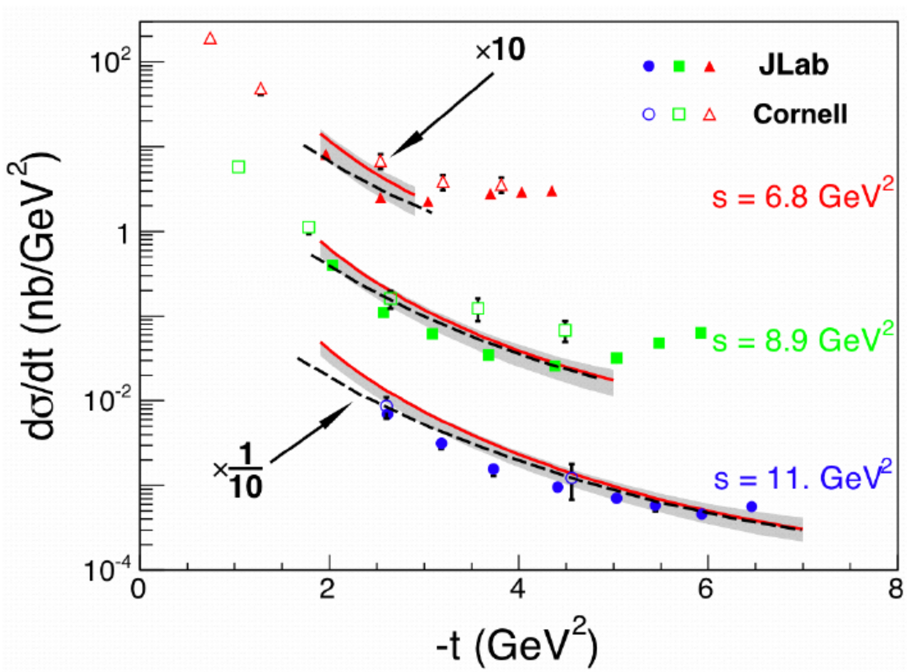
with the kinematical power corr's

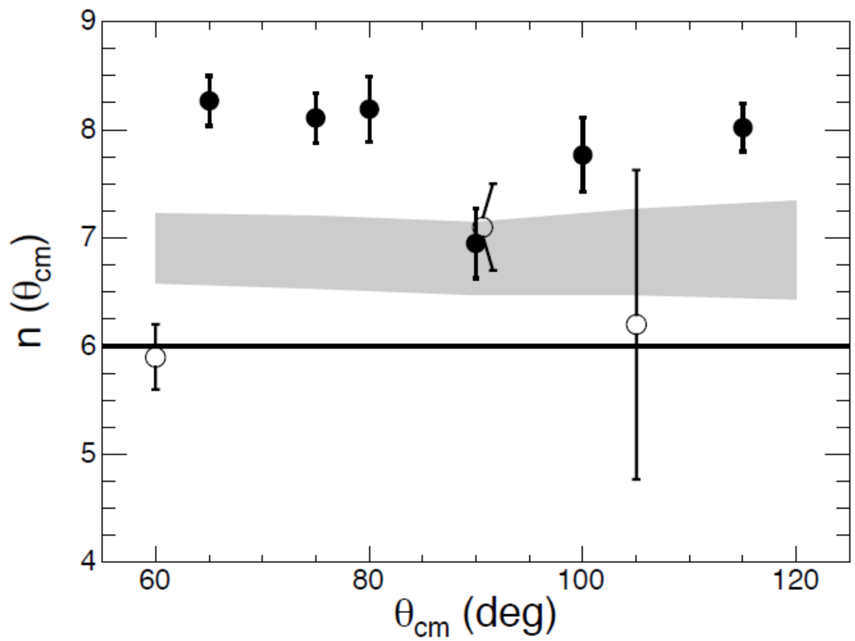


Cross-section and scaling

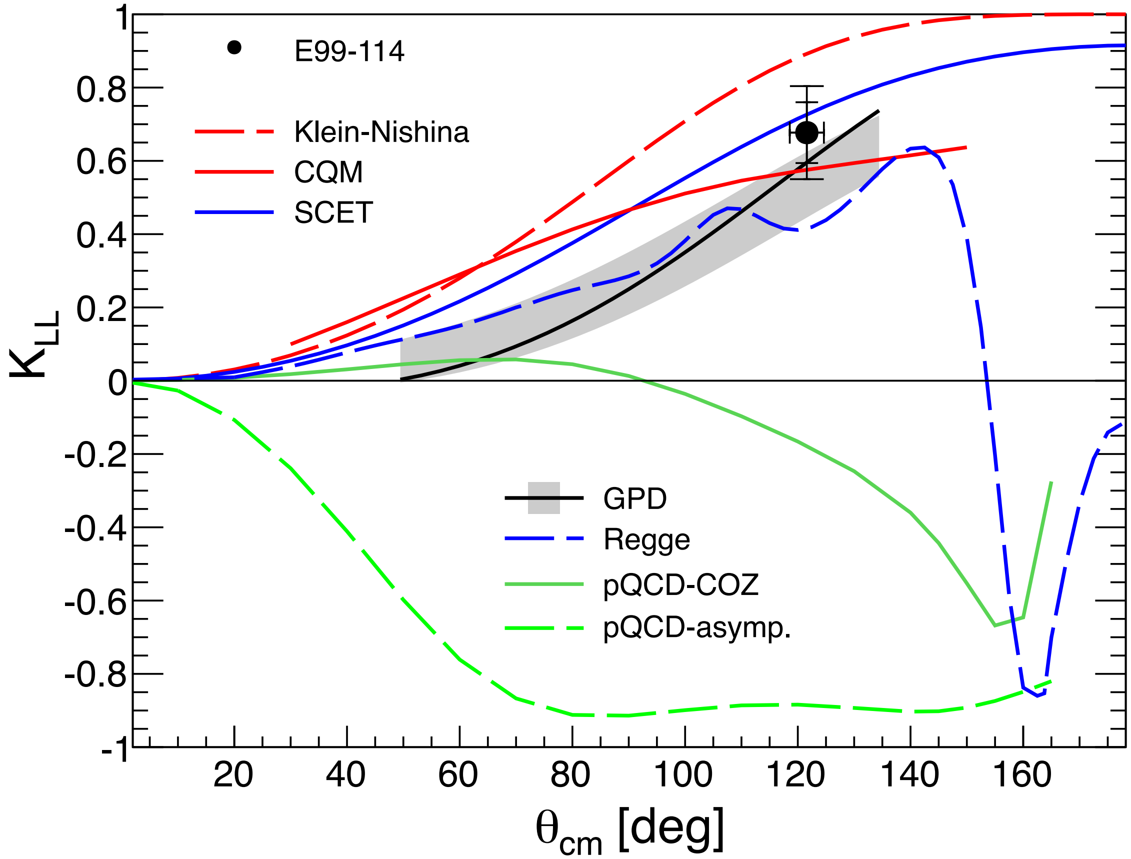
Cross-section results from PRL-98 152001 (2007) show that

the s scaling parameter n = 7-8, while pQCD predicts n = 6



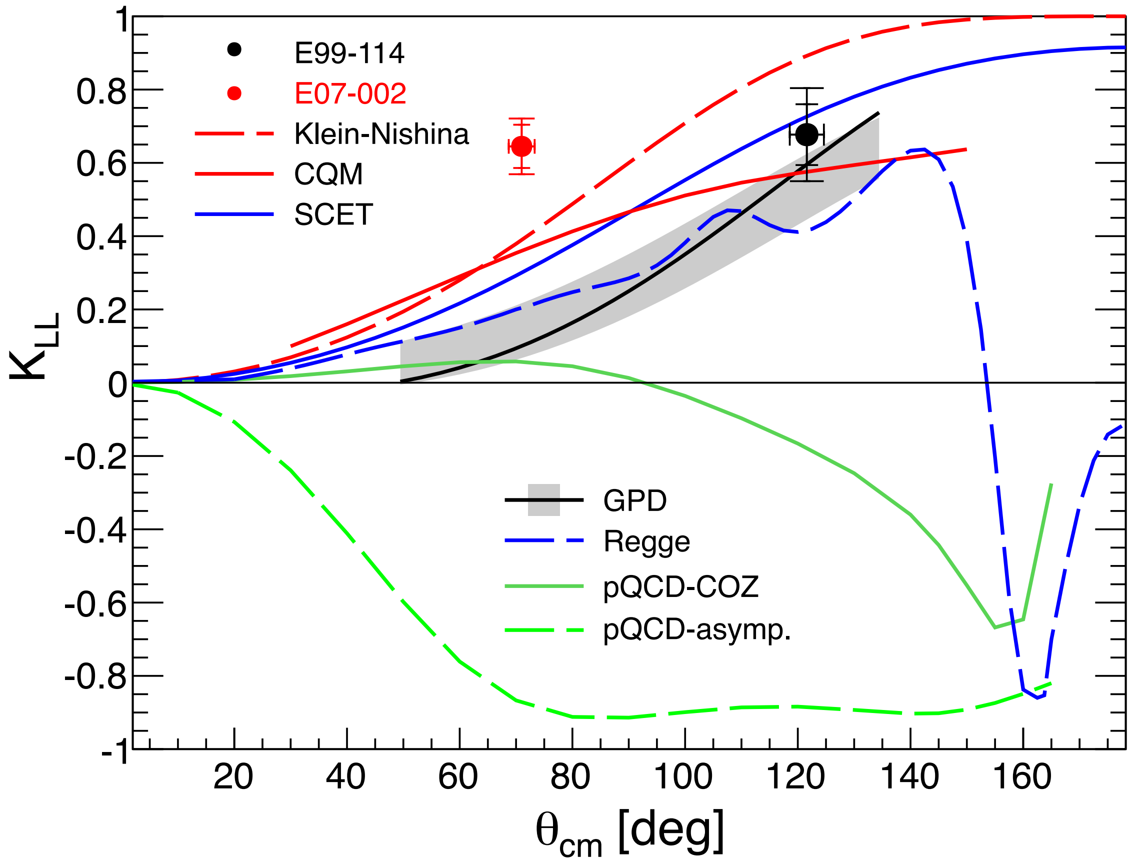


Physics Motivation



E99-114
s=6.9, t=-4.0, u= -1.1 GeV^2

Physics Motivation and Unexpected …



E99-114
s=6.9, t=-4.0, u= -1.1 GeV^2

E07-002
s=7.8, t=-2.0, u= -4.0 GeV^2

New measurements at (**≥ double**) s, t, u values and wide θ_{cm} range are necessary to understand the mechanism of WACS.

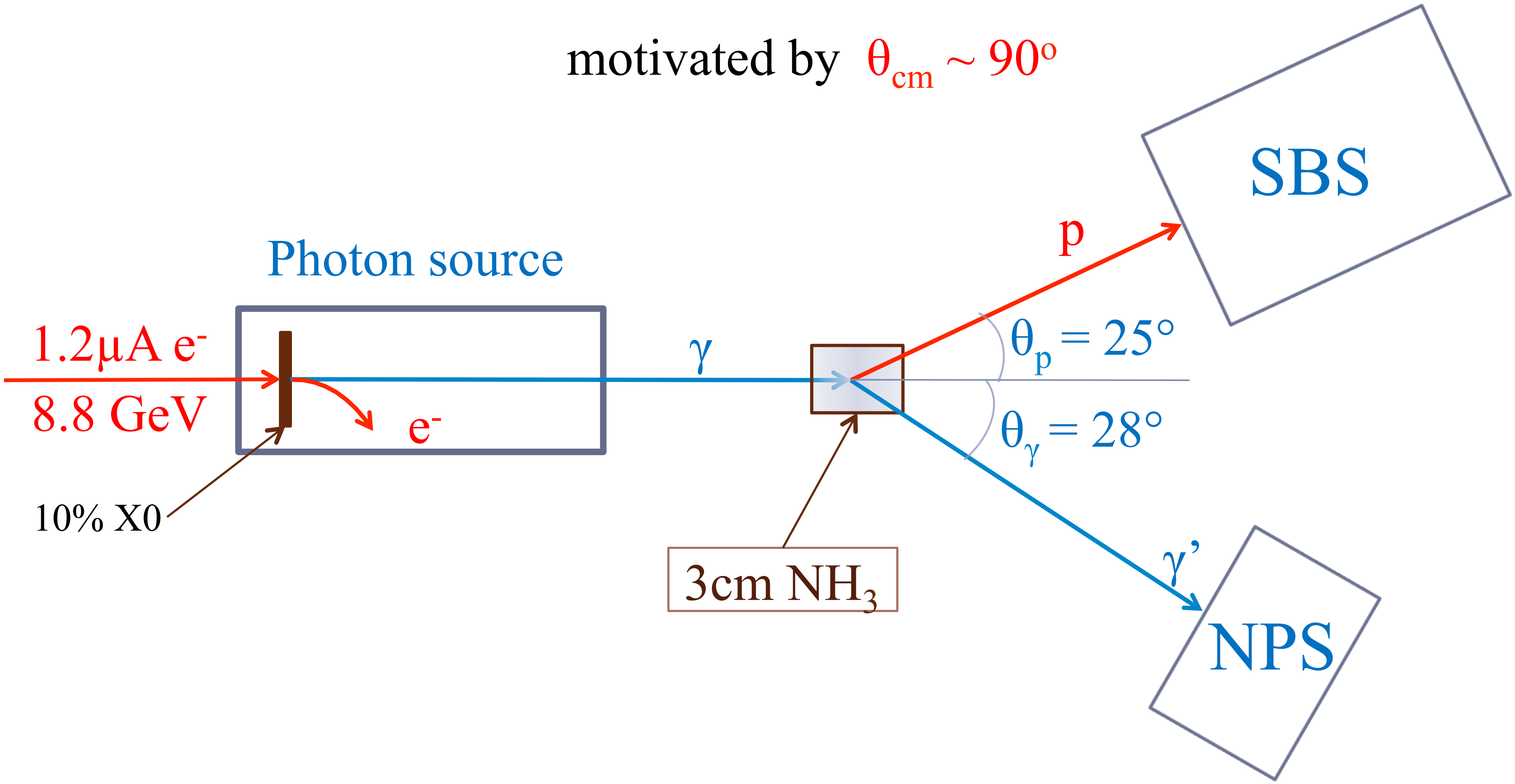
WACS experimental challenges

$$rate \propto 1/s^{7.5}$$

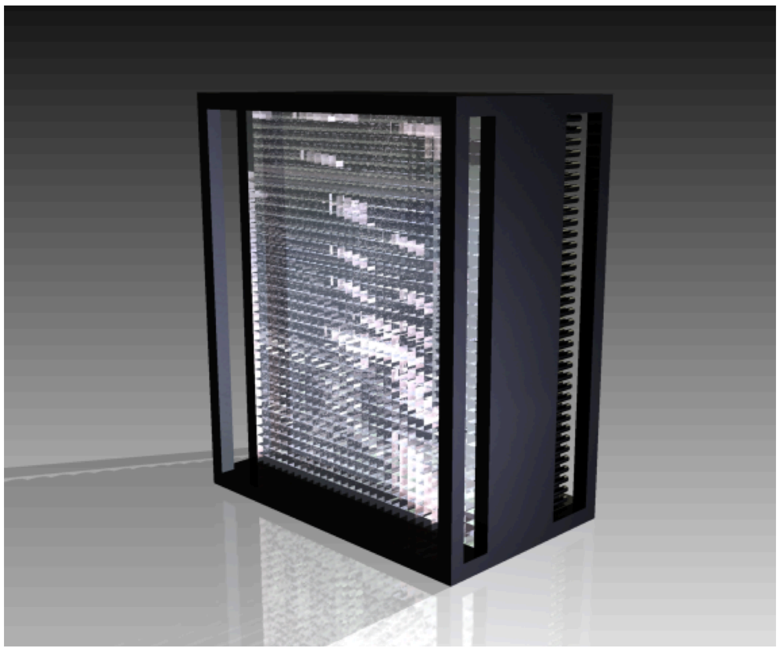
- Beam intensity, clean photon beam, beam dump
- Polarimeter figure-of-merit or polarized target power limit (100 nA electrons)
- Solid angle of apparatus: HRS/HMS vs SBS
- Neutral pion background/dilution: 4-10

New Experimental Setup

motivated by $\theta_{cm} \sim 90^o$



Neutral Particle Spectrometer



NPS collaboration

Catholic University of America,
Ohio University,
Old Dominion University,
Mississippi State University,
University of Virginia,
Jefferson Lab,
Glasgow University (UK),
IPN Orsay (France),
University of Ljubljana (Slovenia),
Yerevan Physics Institute (Armenia).

https://wiki.jlab.org/cuawiki/images/d/dc/NPS_WP_11142014_v3.pdf

Neutral Particle Spectrometer

EXP. NO.	Hall	Title	Spokespersons	Institutions	Beam Days	Rating	PAC	Run Group
E12-13-007	C	Measurement of Semi-Inclusive π^0 Production as Validation of Factorization	R. Ent	JLab	25	A-	40	A
			T. Horn	CUA				
			H. Mkrtchyan	Yerevan				
			V. Tadevosyan	Yerevan				
E12-13-010	C	Exclusive Deeply Virtual Compton and Neutral Pion Cross-Section Measurements in Hall C	C. Munoz Camacho	IPN Orsay	53	A	40	A
			R. Paremuzyan	IPN Orsay				
			T. Horn	CUA				
			C. Hyde	ODU				
			J. Roche	Ohio U				
E12-14-003	C	Wide-Angle Compton Scattering at 8 and 10 GeV Photon Energies	B. Wojtsekhowski	JLab	18	A-	42	B
			D. Hamilton	Glasgow				
			S. Sirca	Ljubljana				
E12-14-005	C	Wide Angle Exclusive Photoproduction of π^0 Mesons	D. Dutta	Miss. State	18	B	42	B
			M. Amaryan	ODU				
			H. Gao	Duke				
			M. Kunkel	ODU				
			S. Sirca	Ljubljana				
			I. Strakovsky	GWU				
E12-14-006	C	Initial State Helicity Correlation in Wide-Angle Compton Scattering	D. Keller	UVa	15	B	42	C
			D. Day	UVa				
			J. Zhang	UVa				

Neutral Particle Spectrometer

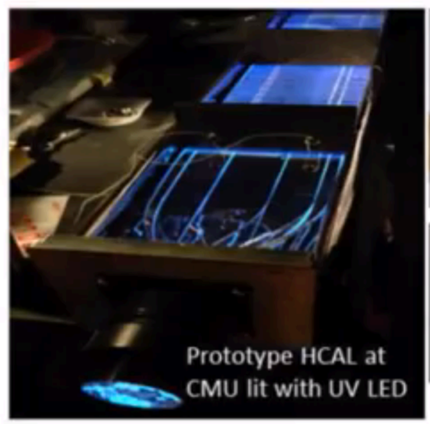
Key parameters

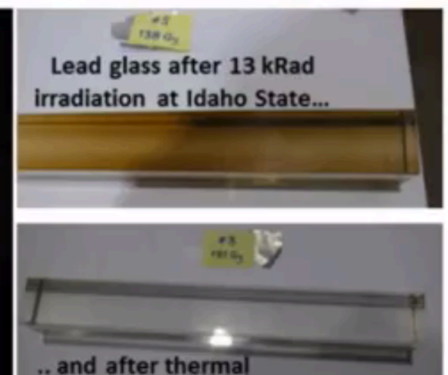
- Energy resolution ~$2\%/\sqrt{E}$
- Radiation hardness PbWO4
- Area/segmentation: 72 cm x 60 cm /1100 crystals
- Coordinate resolution: 2-3 mm

Super Bigbite Spectrometer

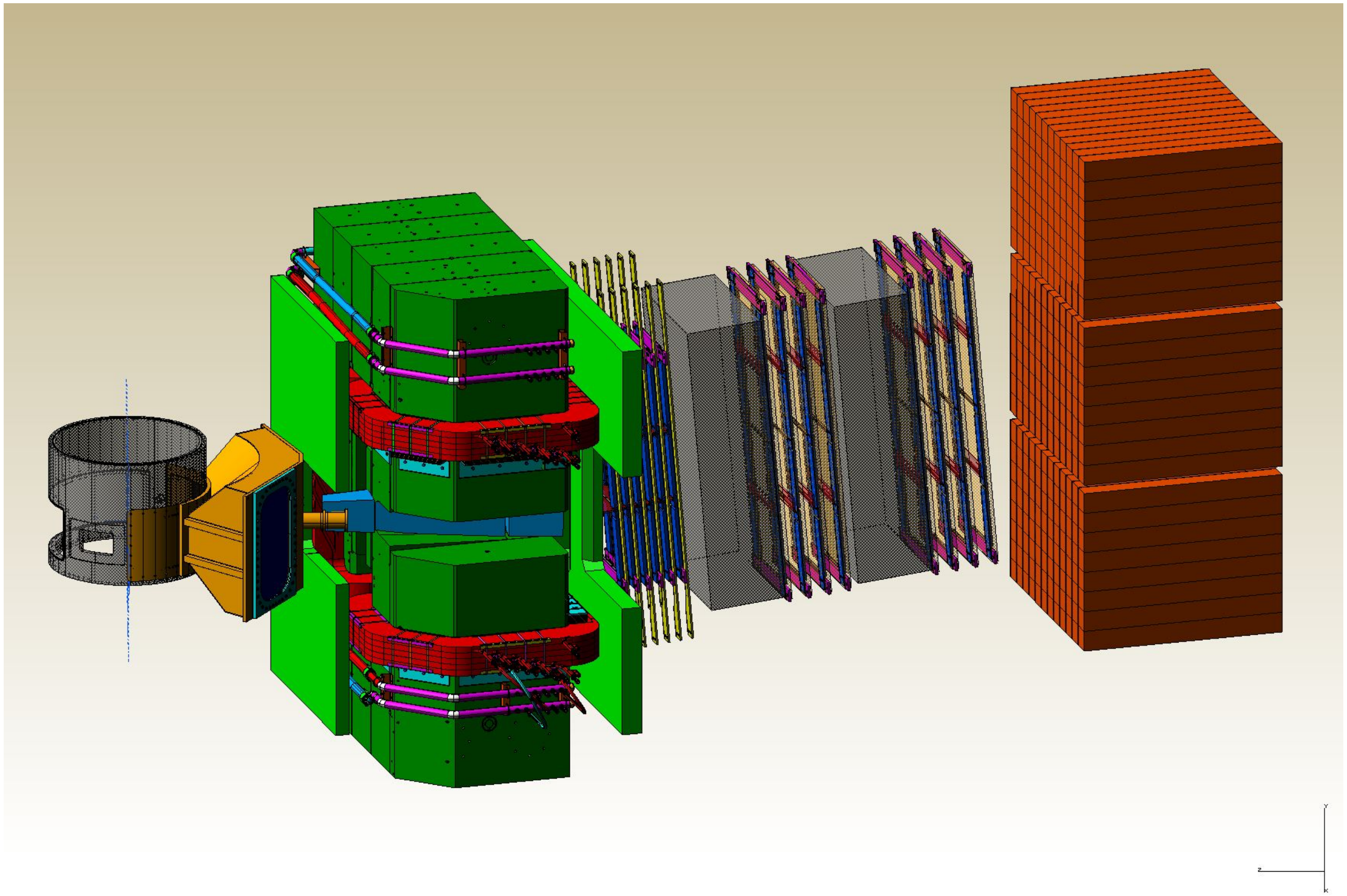
Jefferson Lab Mission: SBS Status

- **Project started October 2013**
  - Successful 2nd annual review 11/2014
  - Some recommendations, but overall very positive, project on track
  - New PMP with WBS 2 re-baseline submitted
  - 67% costed and obligated
- **Spectrometer work at JLab**
  - 48D48 magnet modified, assembled, tested in Test Lab Hi Bay area
  - Power supply in Hall
  - Working on support, stand, beamline
  - Completion within one year
- **Coordinate detector at Idaho State**
- **GEM production underway at UVa, 6 modules completed**
- **Dependencies:**
  - GEM trackers at INFN
  - Hadron Calorimeter (HCAL) at CMU
  - ECAL, thermal annealing at JLab





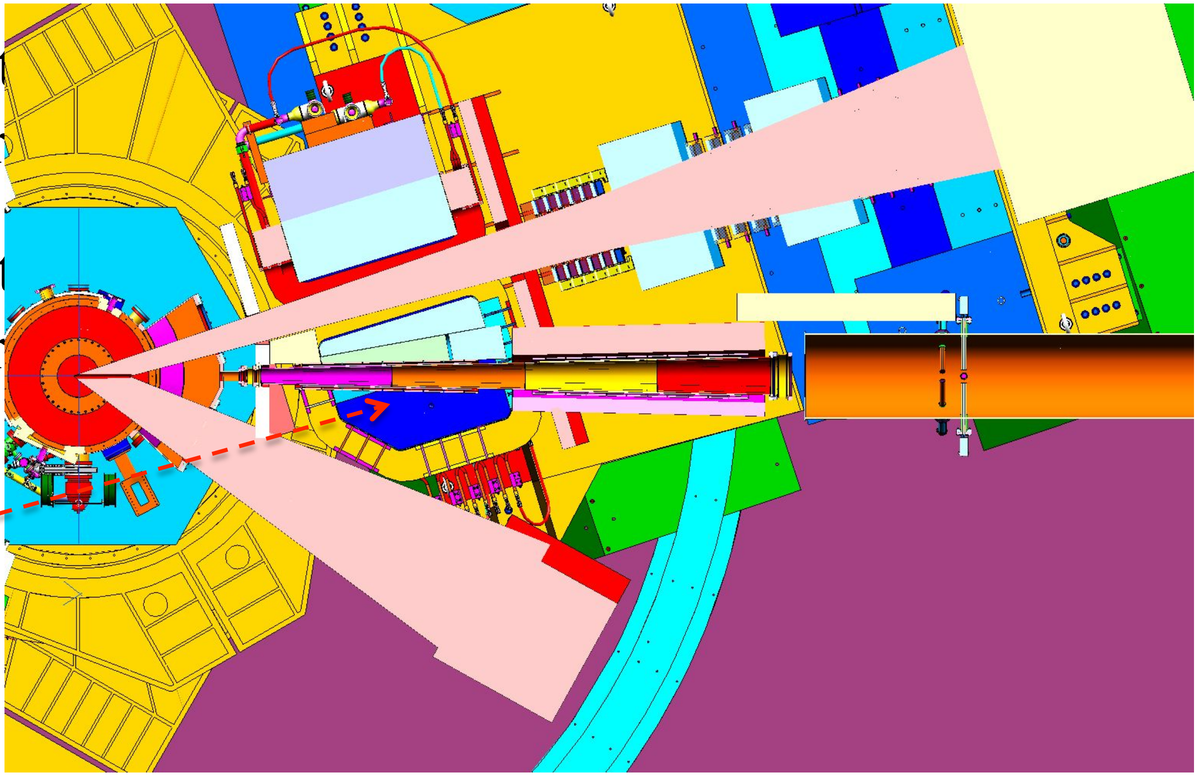
Super Bigbite Spectrometer



Super Bigbite Spectrometer

Key parameters

- Solid angle: 70 msr for angle above 15^o
- Moment
- Angular
- Moment
- Angular



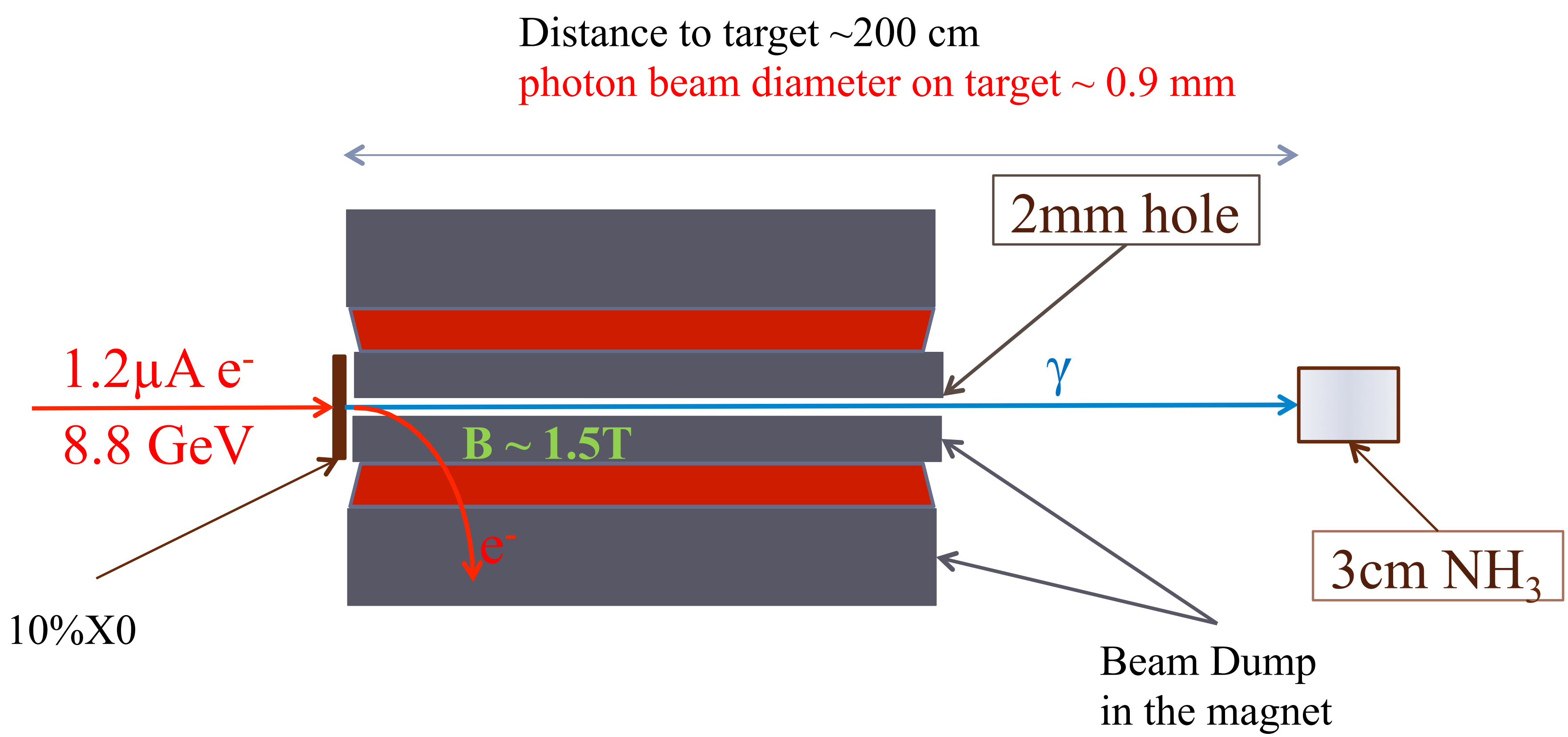
Beam line goes
through the yoke

Super Bigbite Spectrometer

Key parameters

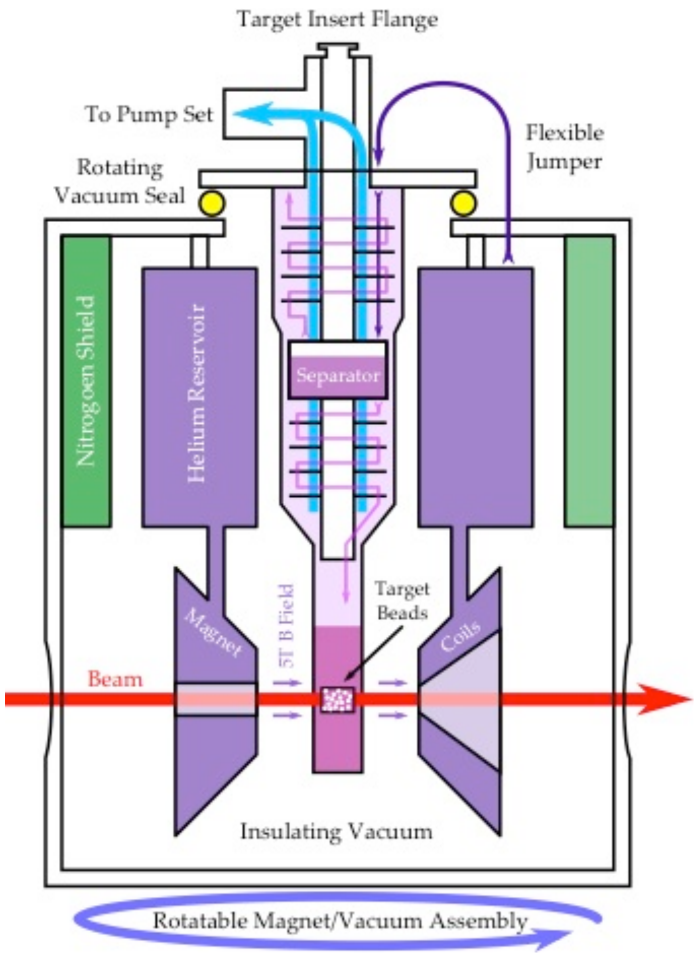
- Solid angle: 70 msr for angle above 15^o
- Momentum acceptance: 2-10, GeV/c
- Angular range: from 5^o (12 msr) to 45^o
- Momentum resolution: 0.29 + 0.03*p, %
- Angular resolution: 0.14 + 1.3/p, mrad

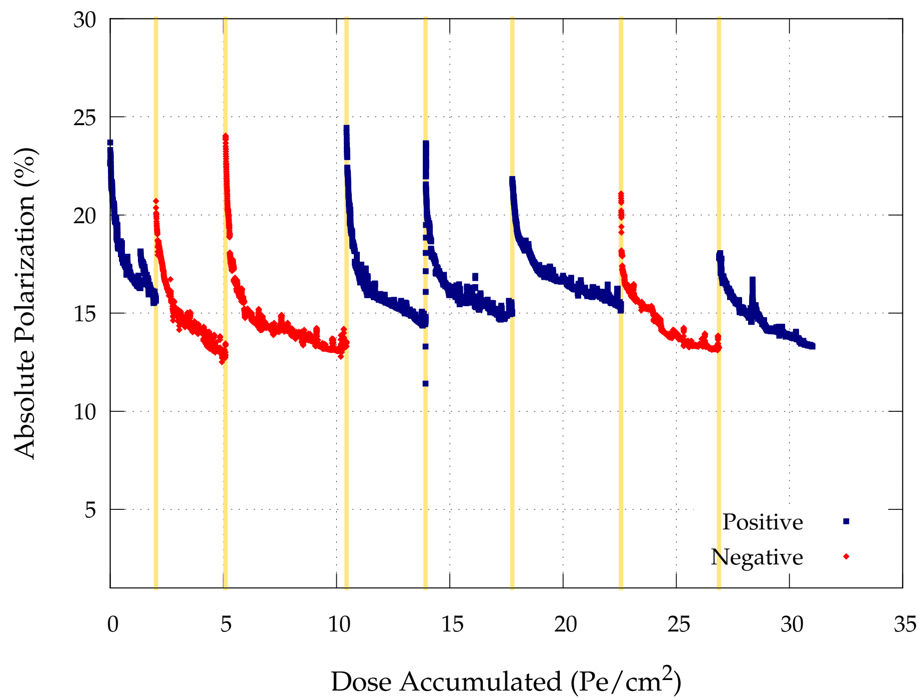
Novel Photon Source



Initial MC simulation shows acceptable background rate on SBS and NPS.
Detailed analysis of the radiation level is in progress.

Polarized target NH_3





J. Pierce etal, arXiv:1305.3295

Main Experimental Components

SBS	
Angle	25°
Distance [cm]	371 (to detector) 160 (to magnet)
ΔΩ [msr]	70
δp [%]	0.5%
δθ [mrad]	0.4
δϕ [mrad]	0.4

NPS [60cm x 70cm]	
Angle	28°
Distance [cm]	200
ΔΩ [msr]	105
δp [%]	$2\%/E^{1/2}$
δX [mm]	3
δY [mm]	3

Beam	
I [μA]	1.2
E_e[GeV]	8.8
E_γ[GeV]	4 – 8
P_γ	0.45 – 0.78

NH_3 target	
t [g/cm^2]	2.61
$f_{packing}$	0.6
P_p	0.75

Key Features of the proposed setup

- Photon detector, NPS: E, x and y high resolutions; 100 msr.
- Proton detector, SBS: 70 msr solid angle (10x HRS/HMS).
- Photon flux, local Beam Dump: 10x mixed beam.
- Compact photon spot: 0.9 mm by means of the magnet-dump configuration.

Kinematic range

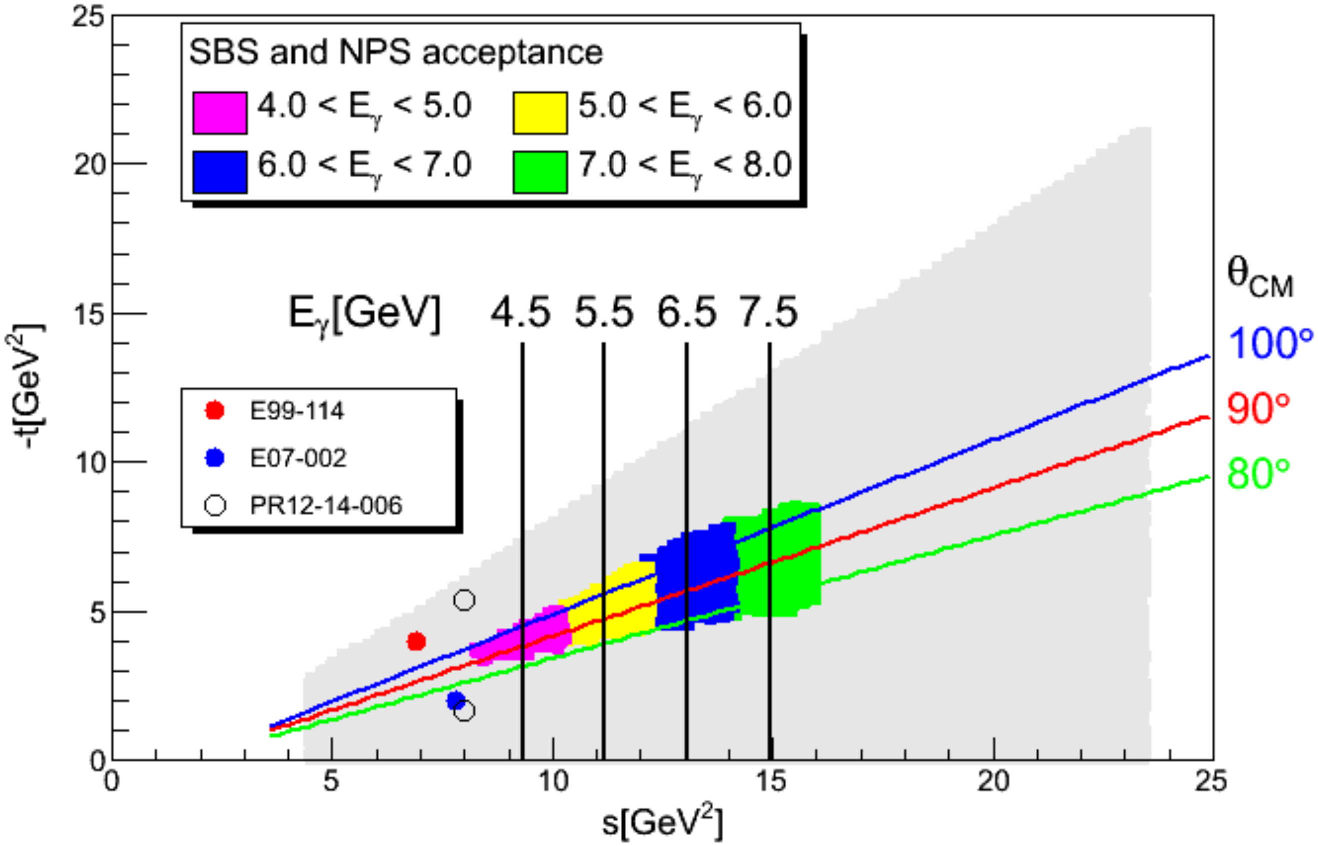
Detectors acceptance will cover wide kinematic range in one set.

s: 8.0 – 16.0 GeV^2

-t: 3.0 – 7.0 GeV^2

-u: 3.0 – 7.0 GeV^2

θ_{CM} : 80° – 100°



Statistics and estimated uncertainty

Scattered photon energy

Cross-Section

Number of protons

$$N_{RCS} = \frac{d\sigma}{dt} \cdot \frac{\left(E'_\gamma\right)^2}{\pi} \cdot \Delta\Omega_\gamma f_{\gamma p} \cdot N_p \cdot N_\gamma$$

Detectors acceptance

Number of photons

$$\Delta A_{LL} = \frac{1}{\sqrt{\frac{N_{RCS}}{D}} P_p P_\gamma}$$

Photon polarization

Dilution due to pion background

Proton polarization

Photon flux and number of protons

$$N_{RCS} = \frac{d\sigma}{dt}\frac{\left(E_{\gamma}^{'}\right)^{2}}{\pi}\cdot\Delta\Omega_{\gamma}f_{\gamma p}\cdot N_{p}\cdot N_{\gamma}$$

$$N_{p} = \frac{Z}{A}\cdot t\cdot f_{pack}\cdot N_{A}$$

NH_3 Target	
t [g/cm^2]	2.61
$f_{packing}$	0.6

$$N_{p} = 1.65\cdot 10^{23}$$

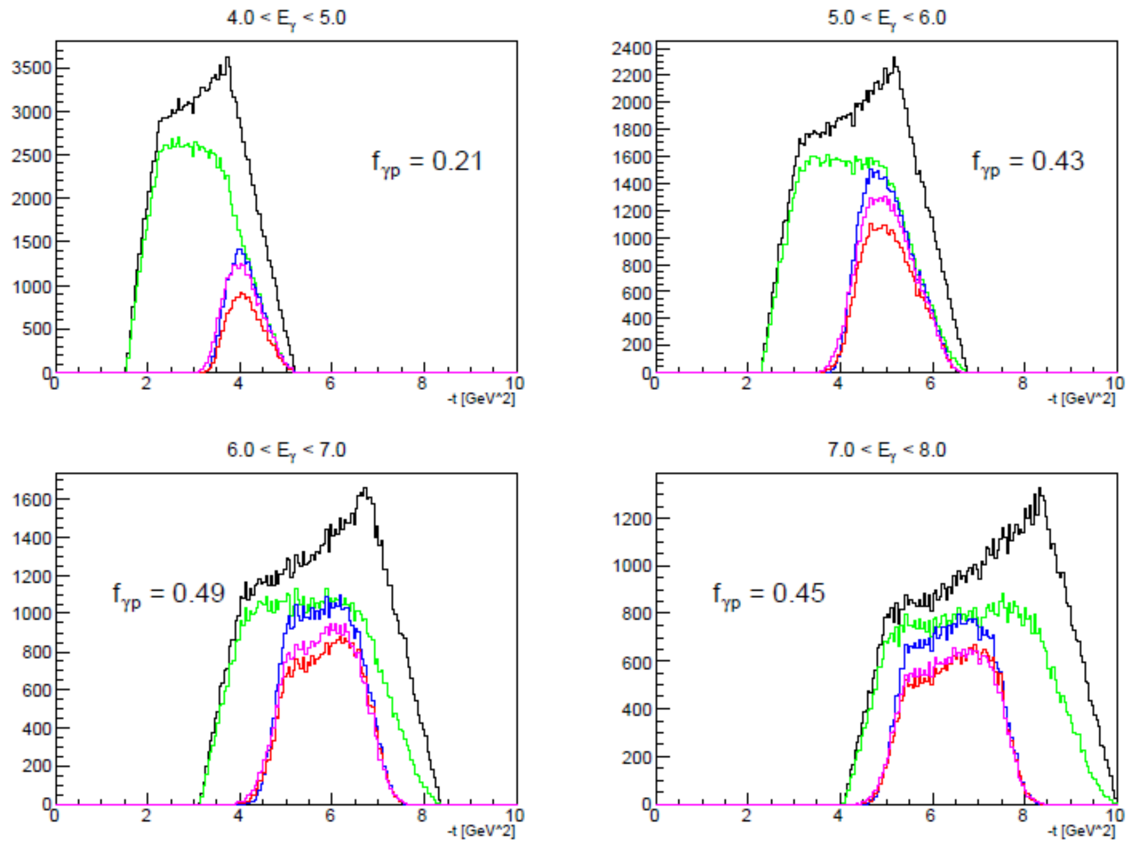
For 1.2 μA beam and 10% radiator

Kin	1	2	3	4
E_γ [GeV]	4 – 5	5 – 6	6 – 7	7 – 8
N_γ (per sec)	$1.5\cdot 10^{11}$	$1.2\cdot 10^{11}$	$1.1\cdot 10^{11}$	$0.9\cdot 10^{11}$

Solid angle

$$N_{RCS} = \frac{d\sigma}{dt}\frac{\left(E_{\gamma}^{'}\right)^{2}}{\pi}\cdot \Delta\Omega_{\gamma} f_{\gamma p}\cdot N_{p}\cdot N_{\gamma}$$

- NPS acceptance
- SBS acceptance (no field)
- SBS acceptance (with field and target)
- SBS acceptance (with field and target, NPS shifted to match)



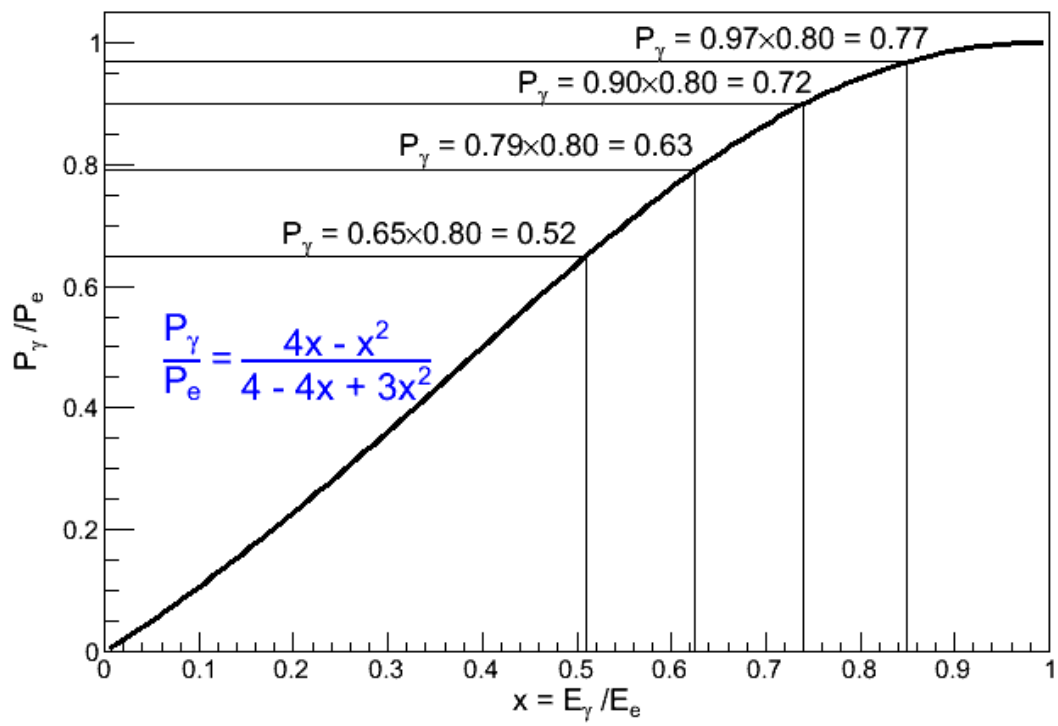
$$\Delta\Omega_{\gamma} = 100 \text{ msr}$$

Kin	1	2	3	4
$f_{\gamma p}$	0.21	0.43	0.49	0.45

Proton and photon polarization

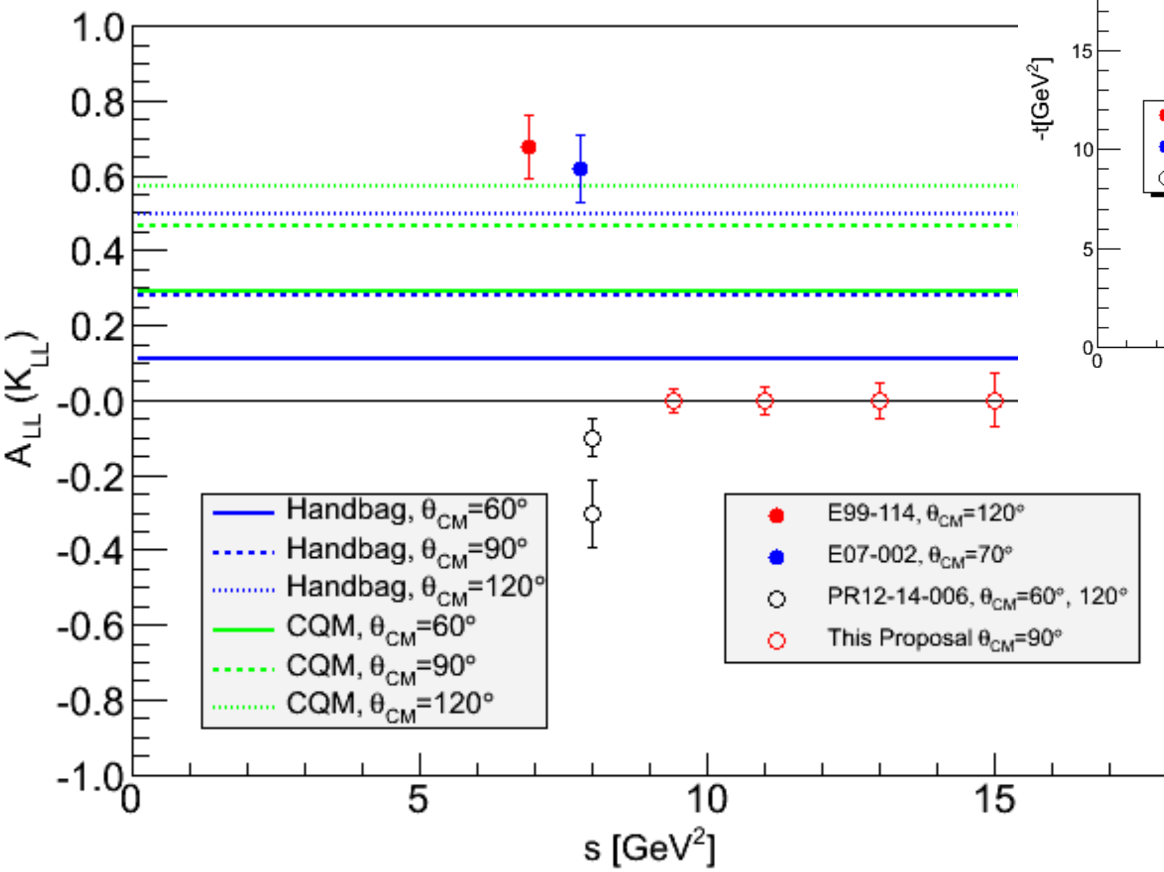
$$\Delta A_{LL} = \frac{1}{\sqrt{\frac{N_{RCS}}{D}}P_p P_\gamma}$$

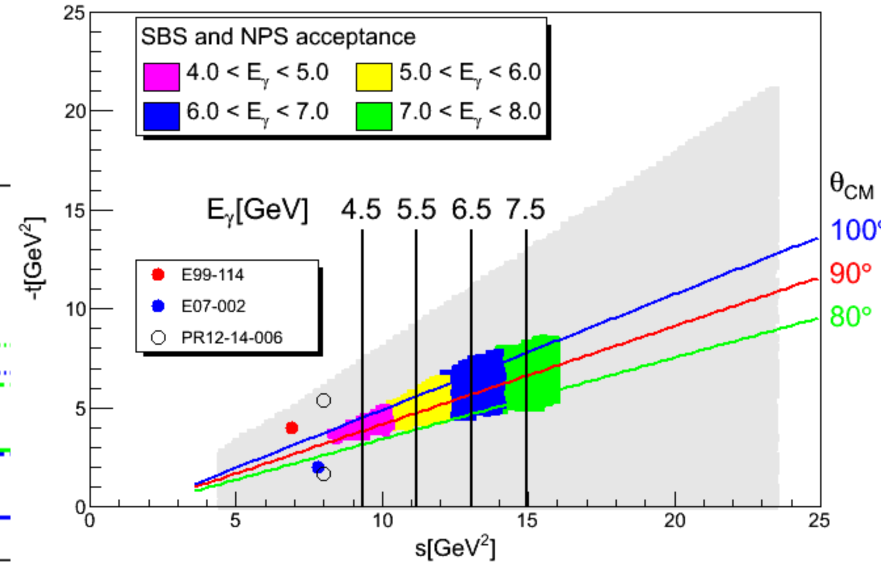
$$P_p = 0.75$$



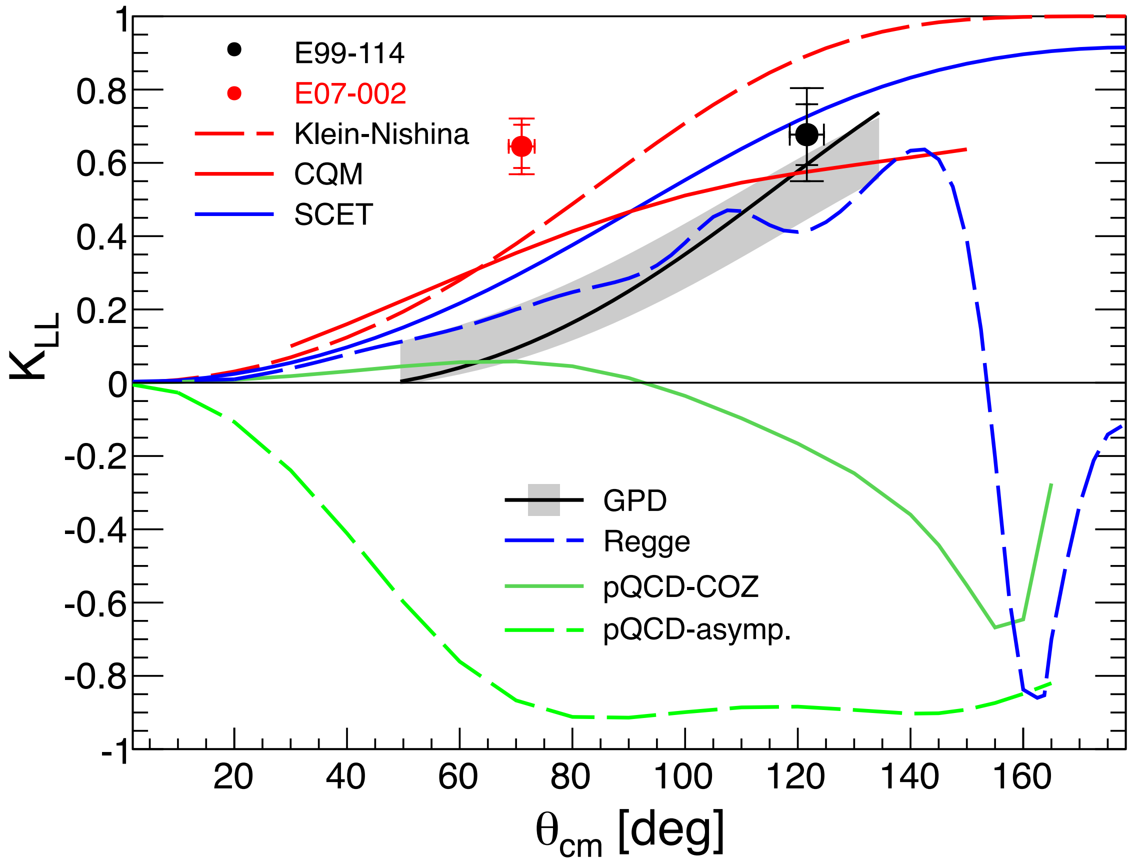
	Kin 1	Kin 2	Kin 3	Kin 4
P_γ	0.52	0.63	0.72	0.77

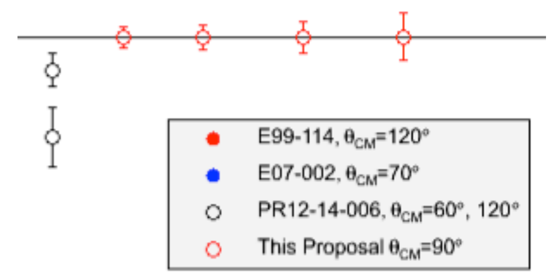
Projected impact of the results





Physics Motivation and Unexpected …





New measurements at (**≥ double**) s, t, u values and wide θ_{cm} range are necessary to understand the mechanism of WACS.

Summary

- Large K_{LL} at $\theta_{cm} = 70^o$: WACS is not as simple as expected, even in the range of s/t/u projected GPD applicability.

- A large acceptance spectrometer and a high resolution calorimeter allow for a 10-fold increase in the acceptance.
- A novel scheme of the photon source-electron-dump allows for a 10-fold increase in the photon intensity.

- With a factor of 100 of productivity gain, the A_{LL} could be measured at s = 9 & 11 &13 & 15 GeV^2 at $\theta_{cm} \sim 90^o$.