Polarization in Wide-Angle Compton Scattering

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Wide-Angle Compton Scattering

- Mechanism of the reaction is a key question

  If we can measure the process: What do we learn?
  What do we learn from polarization observables?

- JLab WACS experiments 2002, 2008

- Experimental results for polarization KLL

- Motivation for further measurements

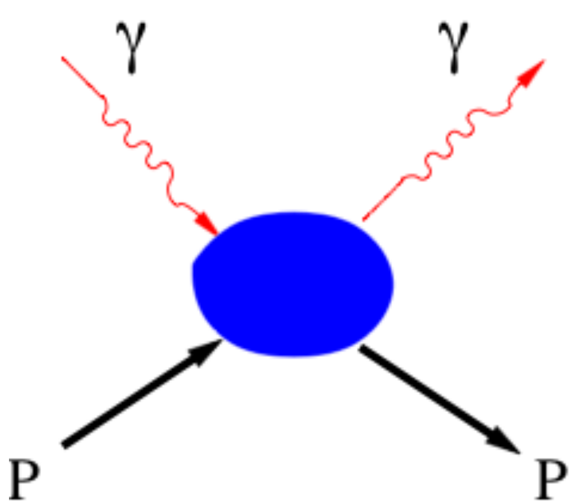
- An approach for the most productive ALL experiment

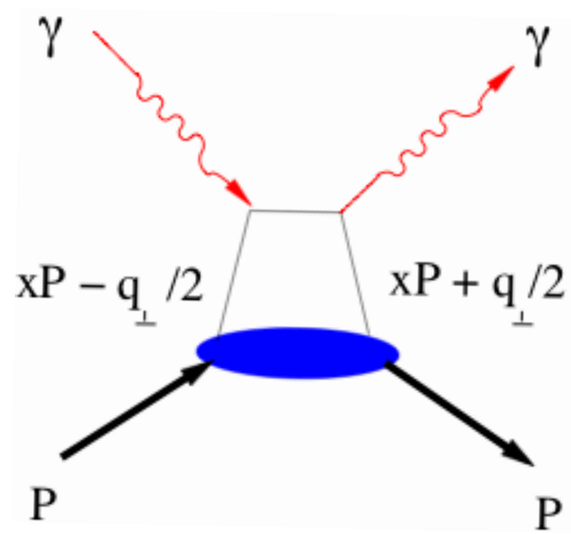
Mechanism of the process

Two basic options for the mechanism:

Collective response - several partons involved in high momentum interaction with the photons

Individual response - one quark absorbs an incident photon and the same quark emits a scattered photon





Theoretical studies of the WACS process

- Regge poles - VMD — since 1960s …, Laget
- pQCD - two-gluon — Brodsky, …, Dixon, MVh,…
- Diquark model — Guichon&Kroll 1996
- Leading quark — Brodsky et al 1972,
- GPDs (handbag) — Radyushkin, Kroll et al
- CQM — G.Miller 2004
- SCET — Kivel&Vanderhaeghen
- DSE — Eichmann

Main issues:

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

Experimental studies of the CS process

experiments with s > 2 GeV^2, low t
Bauer-Spital-Yennie review, RMP 50 (1978)

- DESY - 1971
- SLAC - 1971
- CEA - 1972-73, Deutsch

DESY-1971

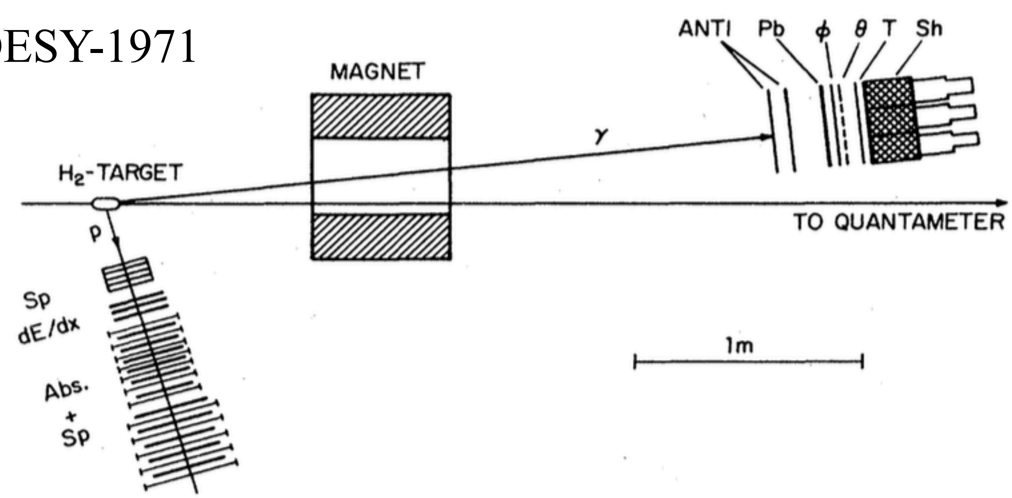


FIG. 44. Diagram of the apparatus used by the DESY group for Compton scattering measurements (from Buschhorn *et al.*, 1971a).

The photon flux is

2×10^8 γ/s

Experimental studies of the CS process

experiments with s > 2 GeV^2, low t
Bauer-Spital-Yennie review, RMP 50 (1978)

- DESY - 1971
- SLAC - 1971
- CEA - 1972-73, Deutsch

experiments with –t > 1 GeV^2 (WACS regime)

- Cornell - 1975 → 1.5×10^{10} γ/s
- JLab Hall A - 2002 → ~2 x 10^{13} γ/s
- JLab Hall C - 2008

The photon flux is

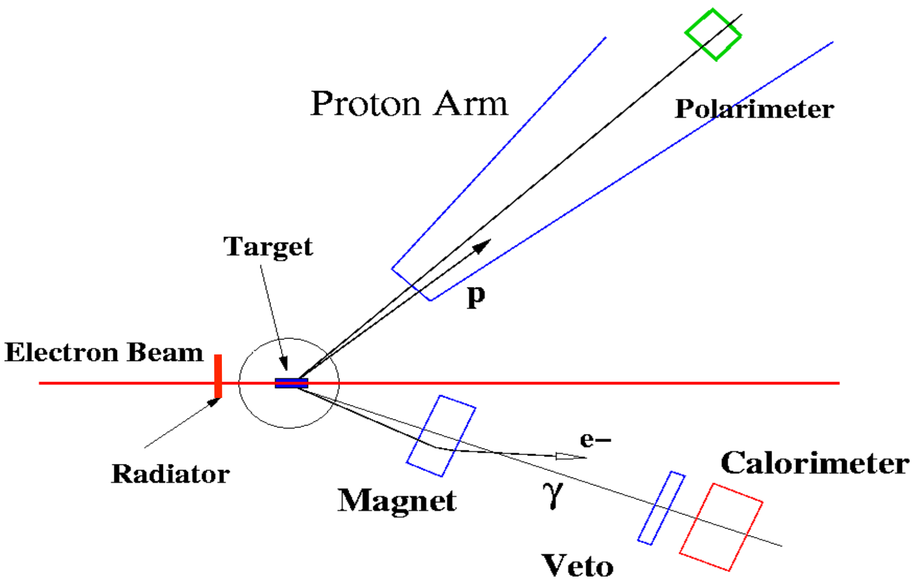
1.5 x 10^{10} γ/s

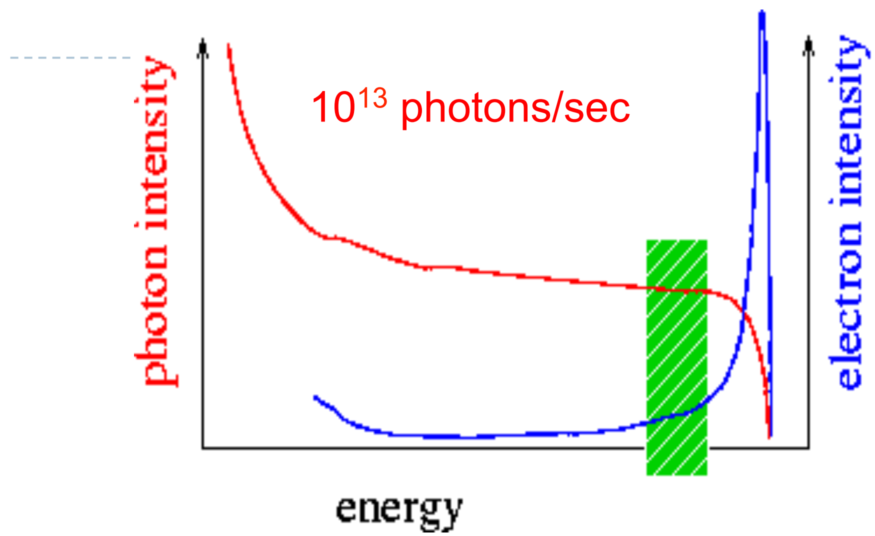
~2 x 10^{13} γ/s

Main issues:

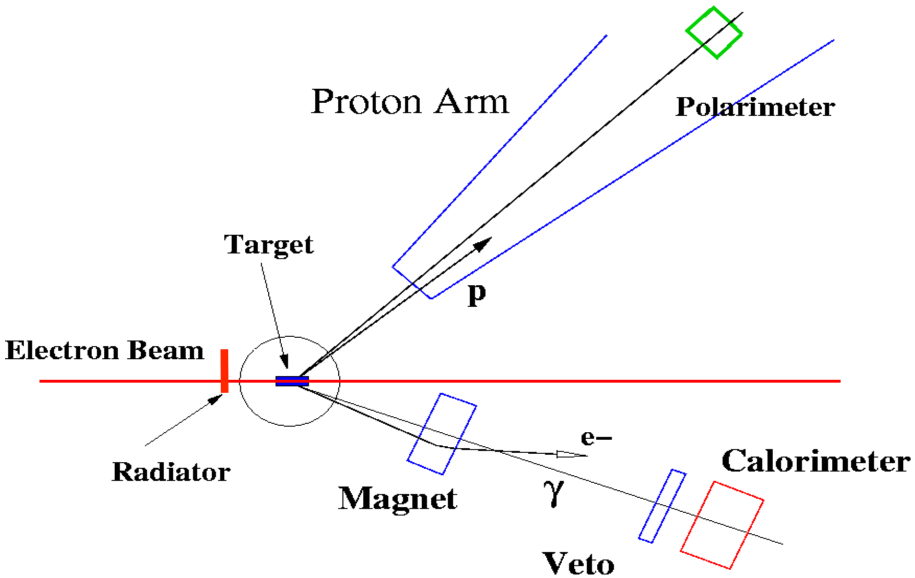
- Competing reaction – pion-0 photo-production
- Low cross section and small solid angle
- Low efficiency & analyzing power of the proton polarimetry
- Low limit on the polarized target luminosity

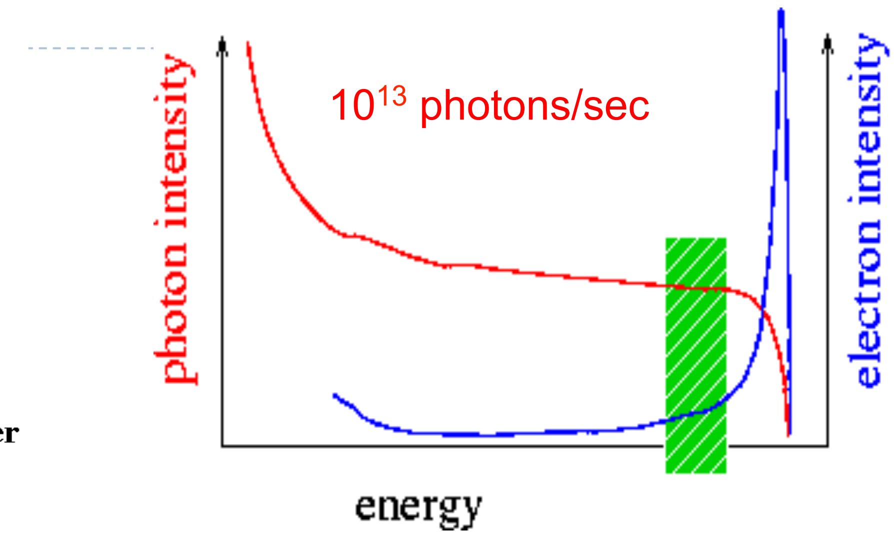
Mixed e/γ beam –> rates ~ 1300 higher than "clean" γ

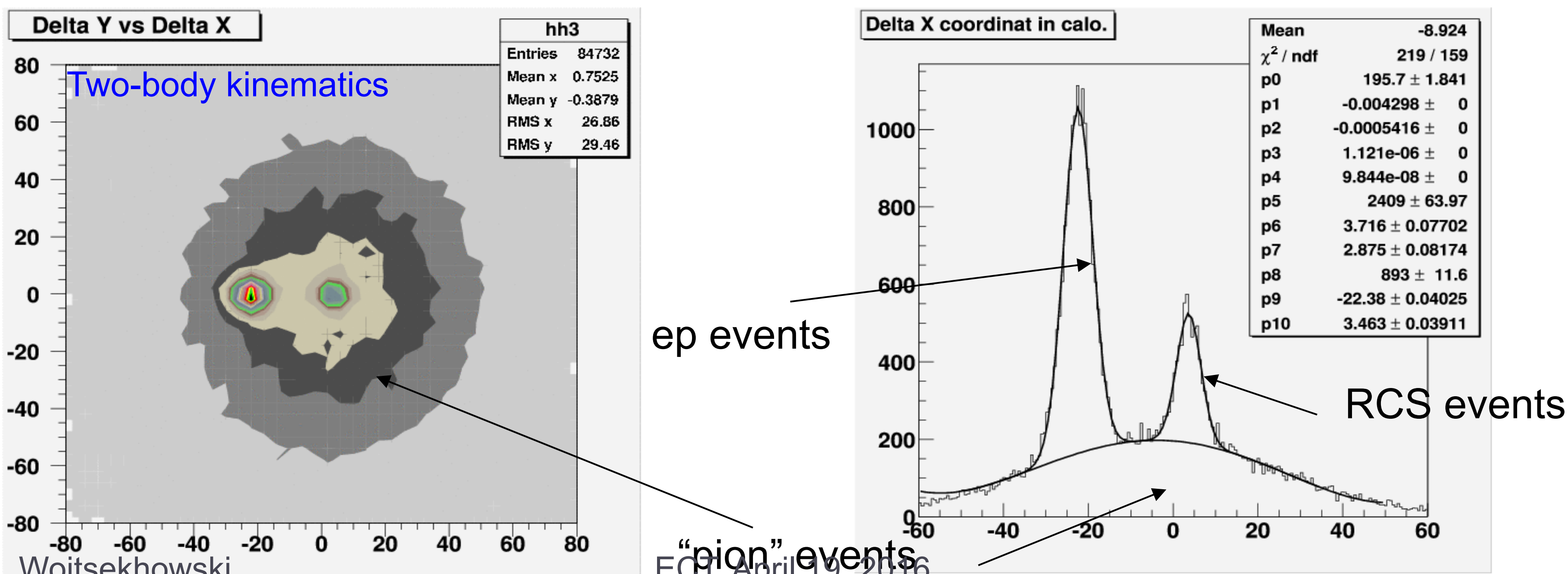




Mixed e/γ beam –> rates ~ 1300 higher than “clean” γ

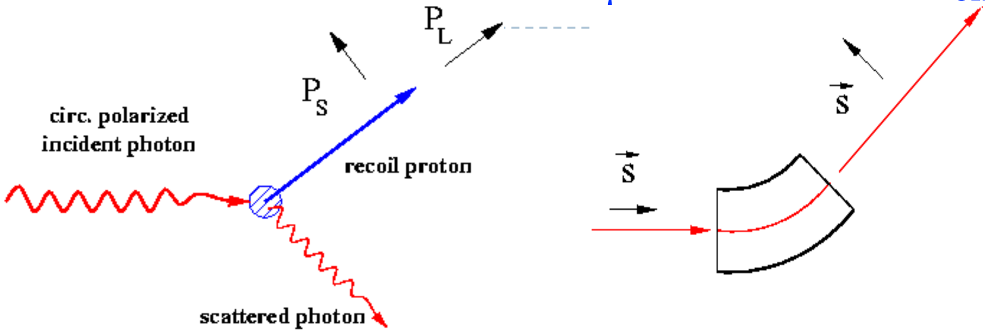






Polarization transfer K_{LL}

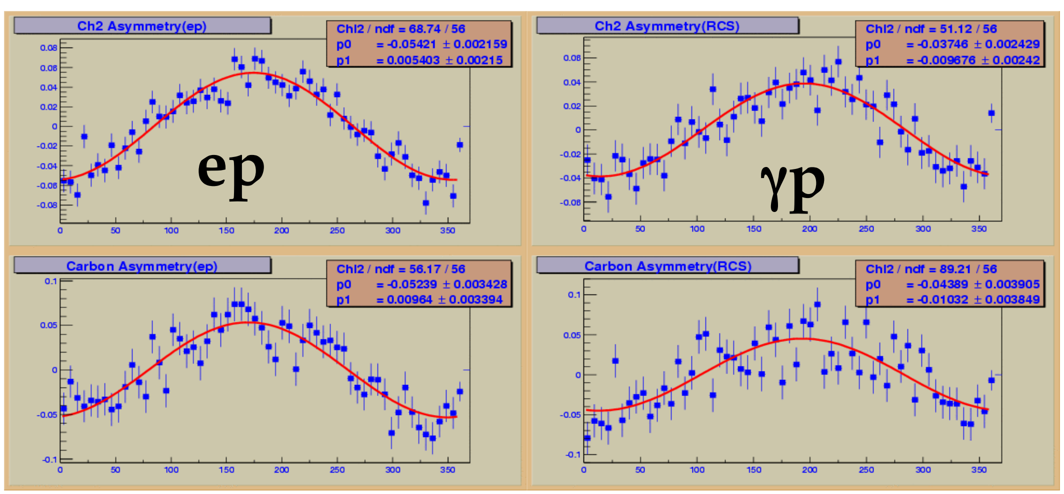
E_γ = 3.2 GeV, θ_{cm} = 120° (s = 6.9, t = -4 GeV^2)

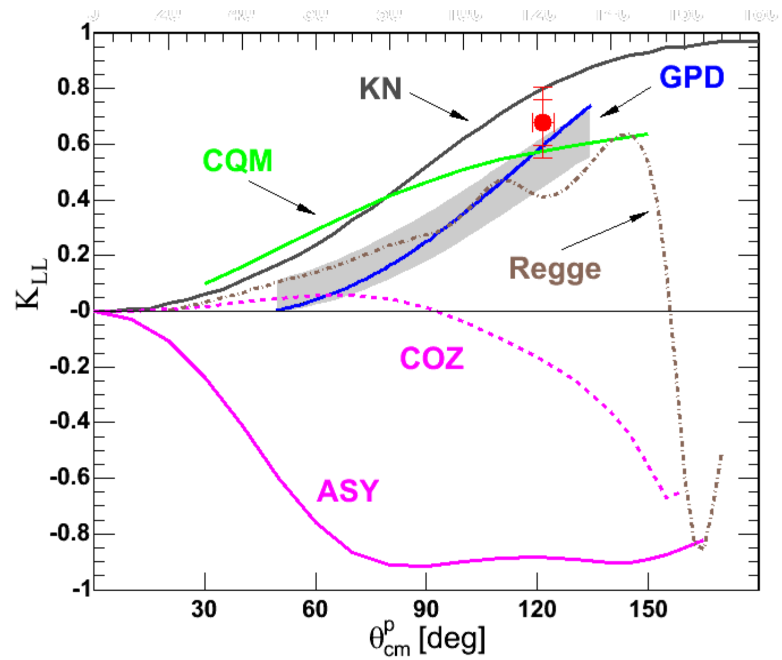


K_{LL} is an average value of the longitudinal proton spin in the γp cm system for 100% circular polarization of incident photon.

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

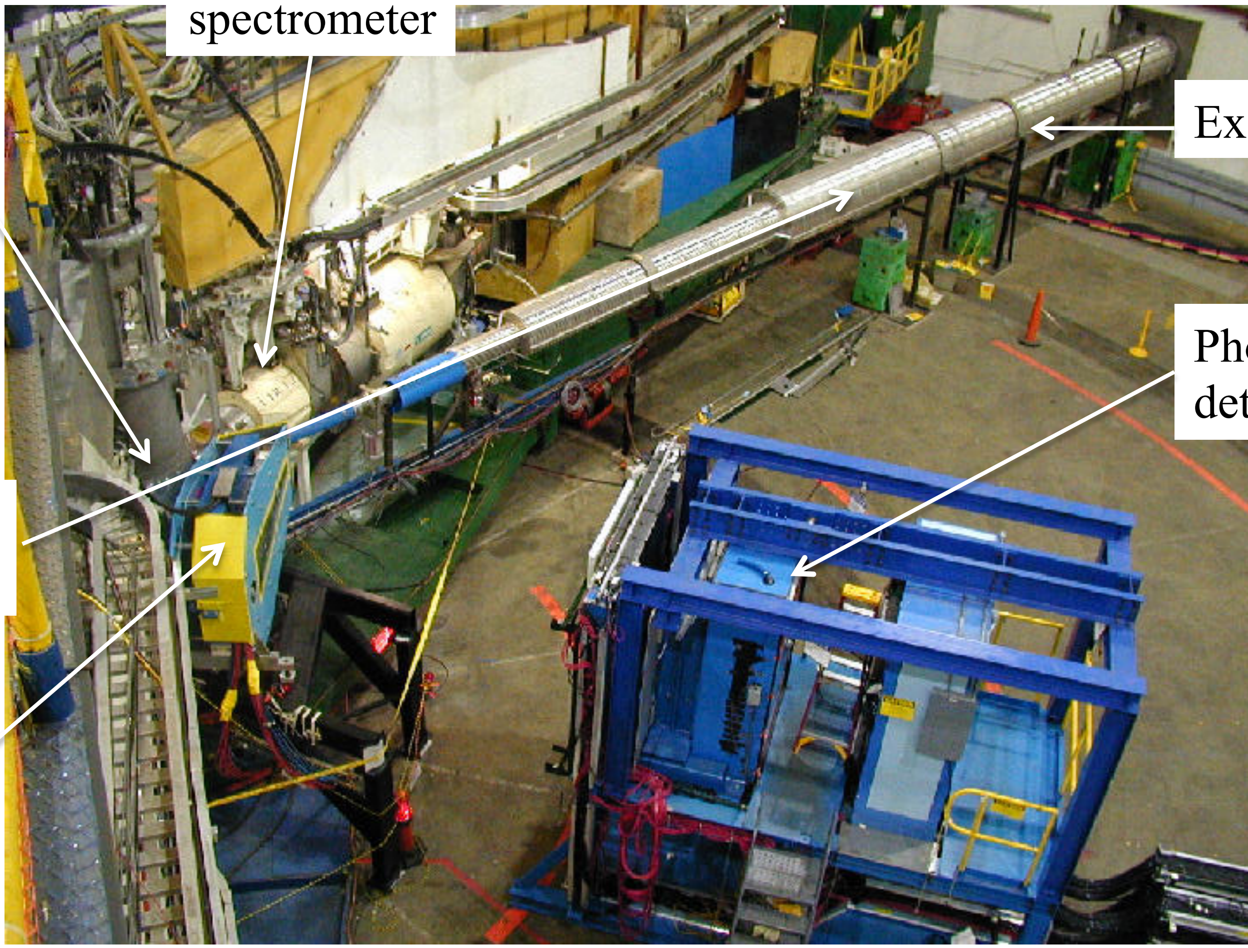
Raw asymmetry for ep and γp events



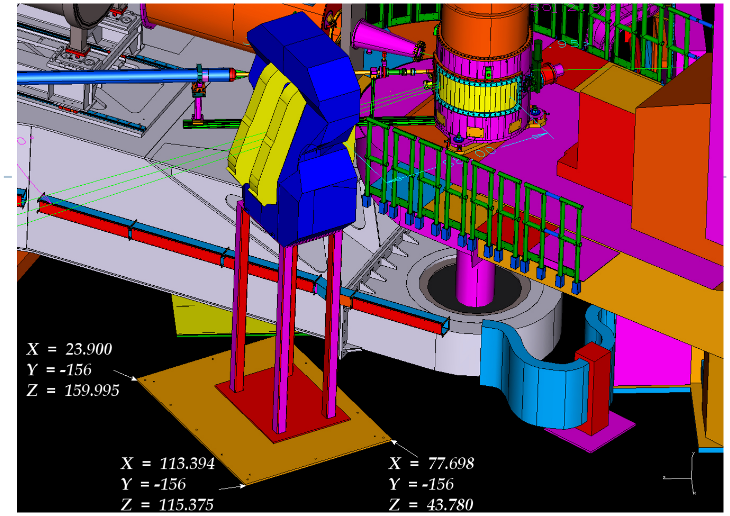


raw asymmetry is of 0.05, systematics is below 10^{-4}

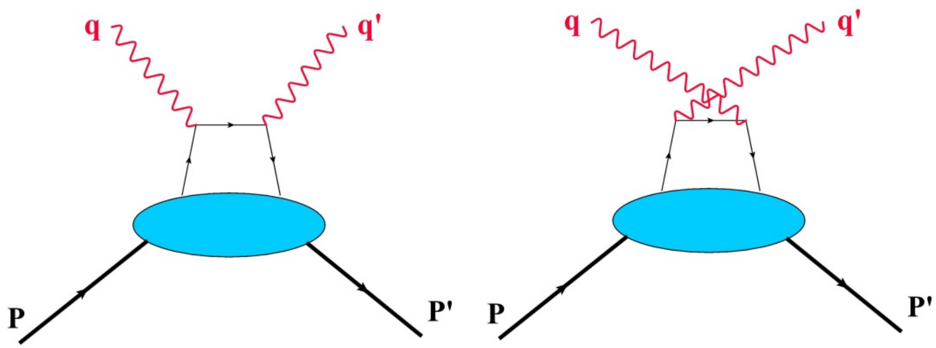
E99-114 experiment in 2002



E07-002 experiment in 2008



Compton scattering



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

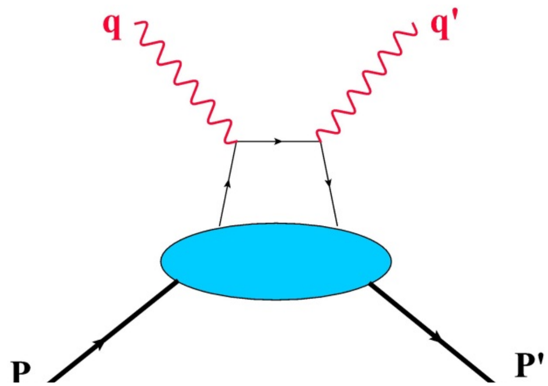
M.Diehl & P.Kroll

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

$$K_{LL} = A_{LL} \qquad K_{LL}\frac{d\sigma}{dt} \equiv \frac{1}{2}\left[\frac{d\sigma(+,\uparrow)}{dt} - \frac{d\sigma(-,\uparrow)}{dt}\right]$$

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

FFs, GPDs and Polarization Observables



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

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

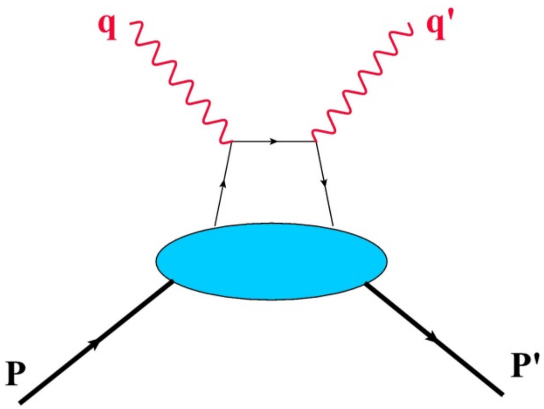
$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t)$$

$$\frac{d\sigma^{\mathrm{KN}}}{dt} A_{LL}^{\mathrm{KN}} = \frac{2\pi\alpha_{\mathrm{em}}^2}{(s-m^2)^2} \times \left[-\frac{s-m^2}{u-m^2} + \frac{u-m^2}{s-m^2} - \frac{2m^2t^2(s-u)}{(s-m^2)^2(u-m^2)^2} \right], \qquad (9)$$

M.Diehl & P.Kroll

$$\frac{d\sigma^{\mathrm{KN}}}{dt} K_{LL}^{\mathrm{KN}} = \frac{2\pi\alpha_{\mathrm{em}}^2}{(s-m^2)^2} \times \left[-\frac{s-m^2}{u-m^2} + \frac{u-m^2}{s-m^2} - \frac{4m^2t^2(m^4-su)}{(s-m^2)^3(u-m^2)^2} \right],$$

FFs, GPDs and Polarization Observables



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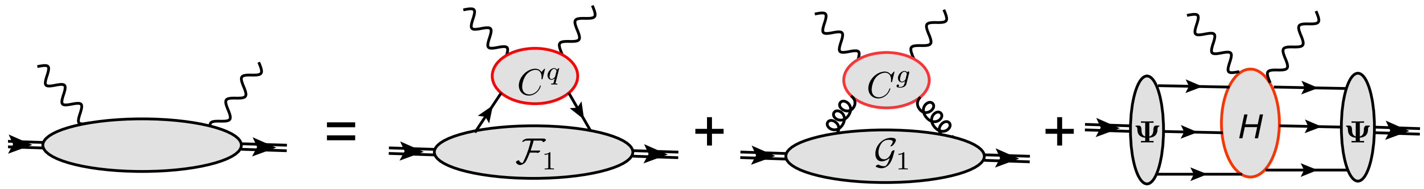
$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t)$$

for m=0 $\quad K_{LL}^{KN} = \frac{s^2 - u^2}{s^2 + u^2}$

M.Diehl & P.Kroll

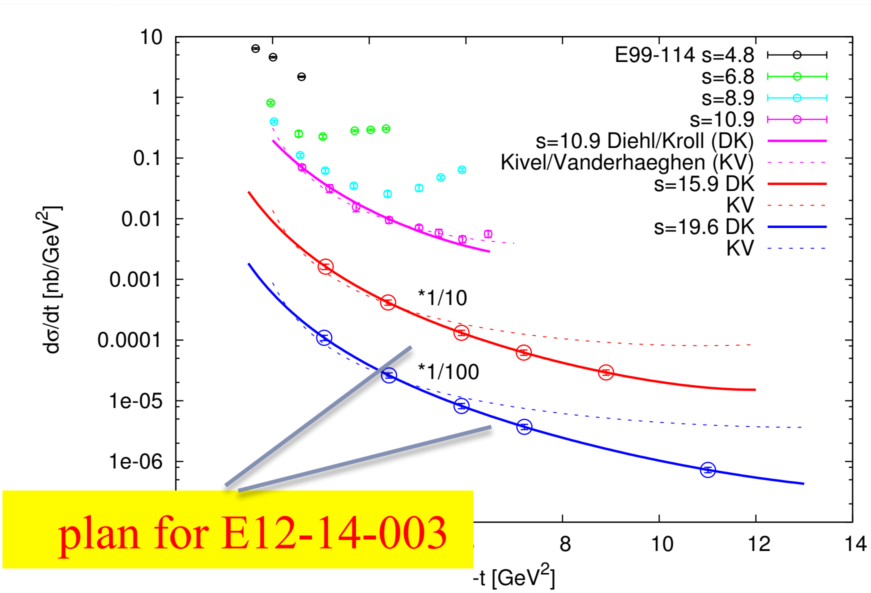
$$A_{LL} = K_{LL} = K_{LL}^{KN} \frac{R_A}{R_V} \left[1 - \frac{t^2}{2(s^2+u^2)} \left(1 - \frac{R_A^2}{R_V^2} \right) \right]^{-1}$$

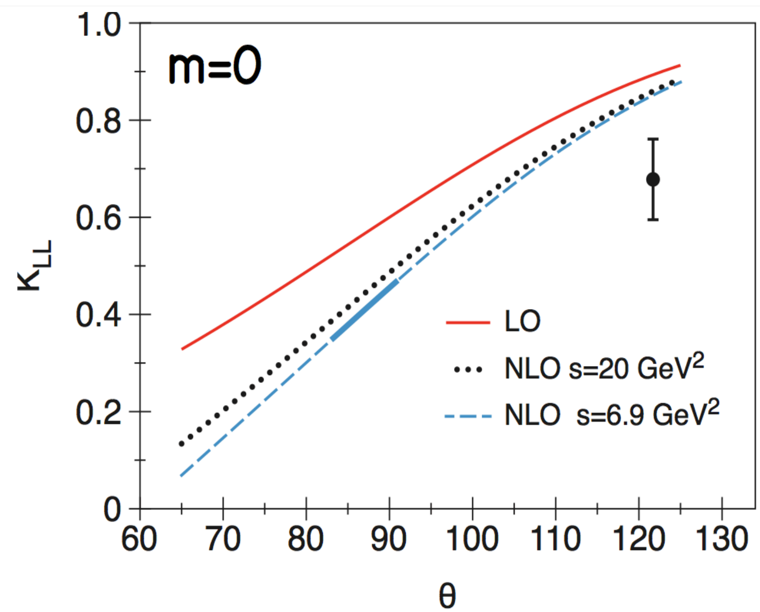
GEp/GMp and WACS in SCET



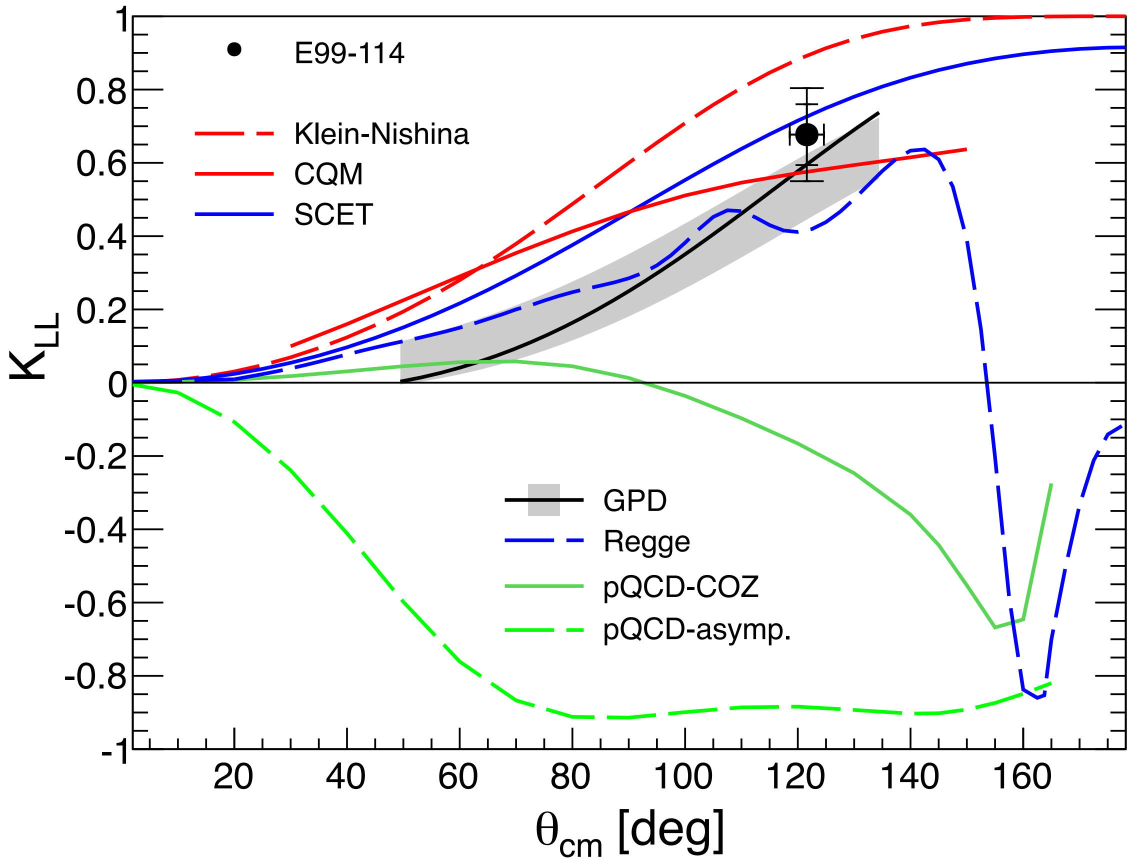
N.Kivel & M.Vanderhaeghen

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





Physics Motivation: study of K_{LL}



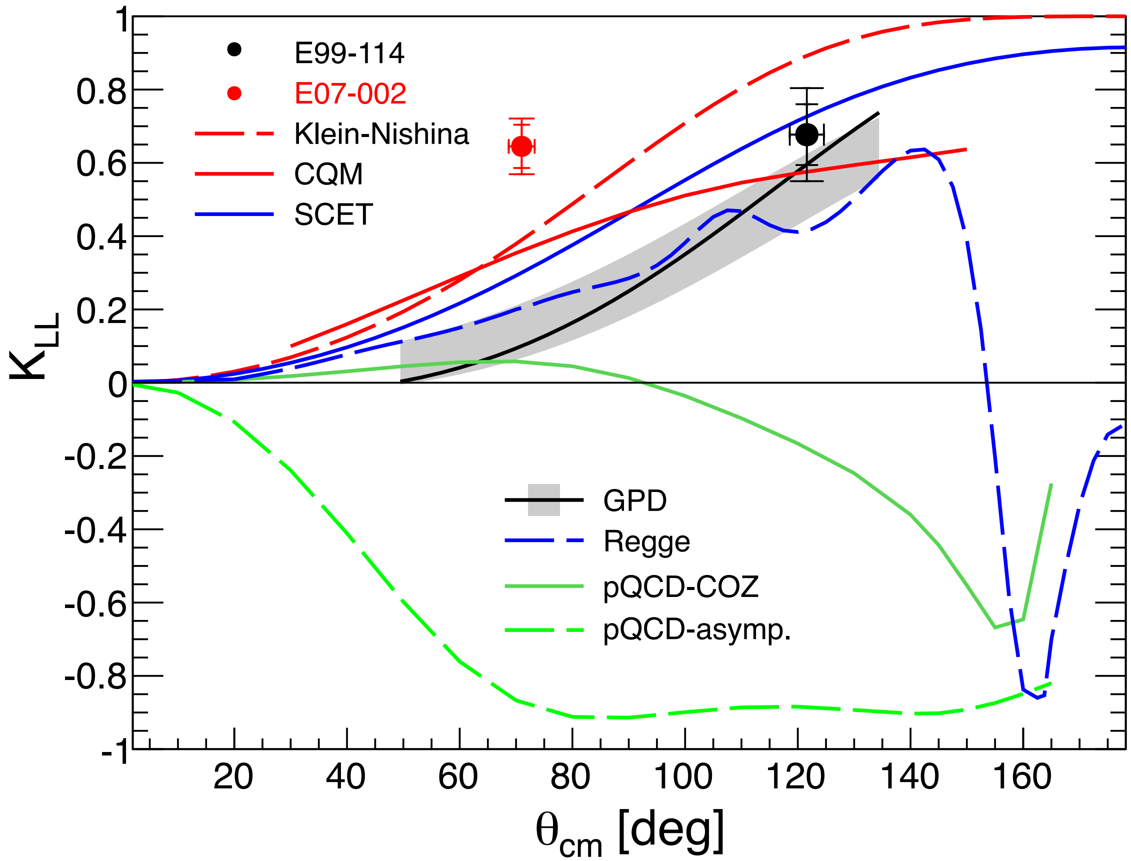
E99-114

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

Strong evidence for handbag mechanism

PRL **94,** 242001 (2005)

Physics Motivation and a surprise



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

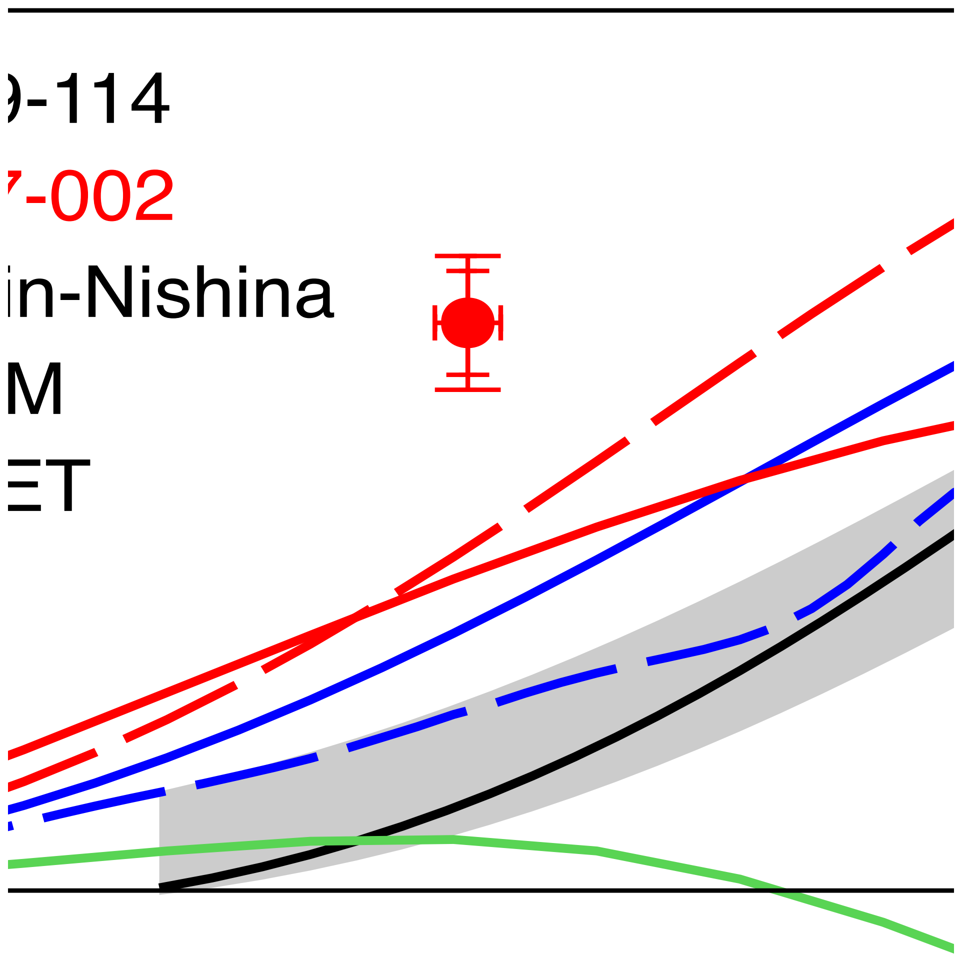
E07-002
s=7.8, t=-2.1, u= -4.0 GeV^2

Strong evidence for additional physics

PRL 115, 152001 (2015)

New measurement at large (doubled) s, t, u values is necessary to clarify the mechanism of WACS.

Physics Motivation and a big surprise

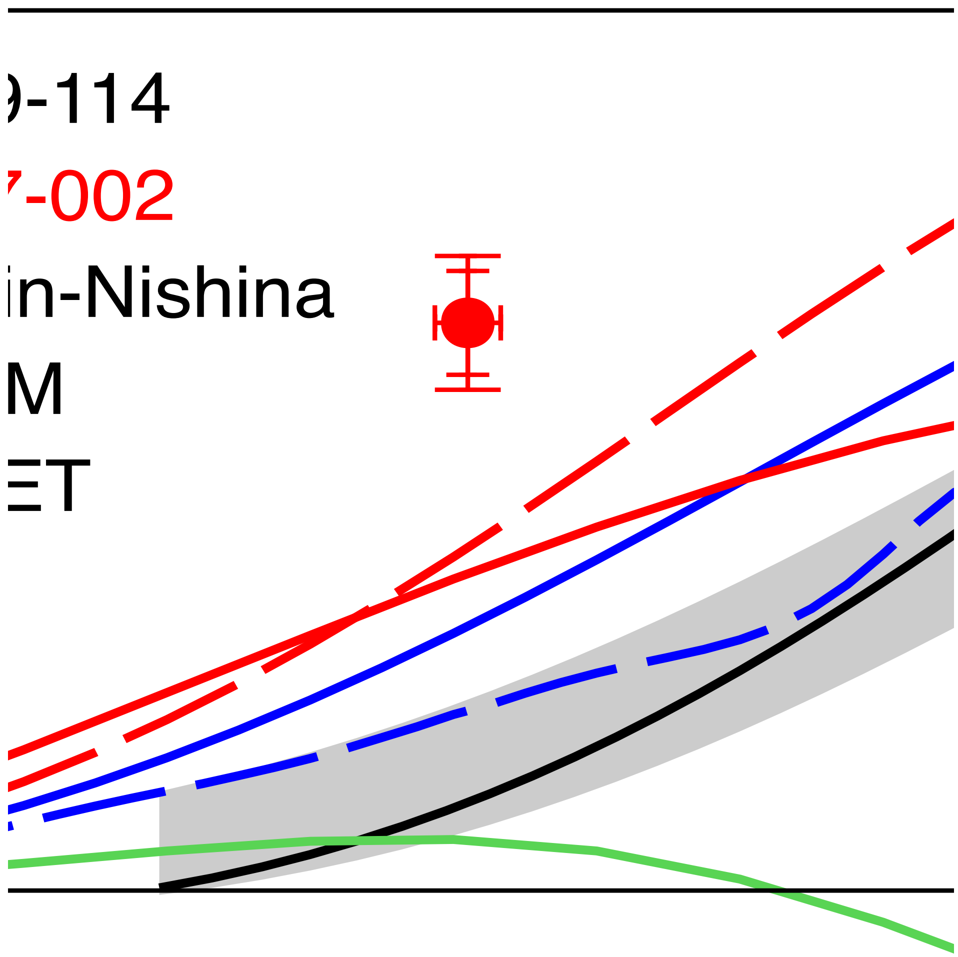


E99-114
s=6.9, t=-4.0, u= -1.1 GeV^2

E07-002
s=7.8, t=-2.1, u= -4.0 GeV^2

3.4 σ from the CQM
5.5 σ from the GPD band

Physics Motivation and a big surprise



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

E07-002
s=7.8, t=-2.1, u= -4.0 GeV^2

What is the origin of large K_{LL}?

Quark OAM?

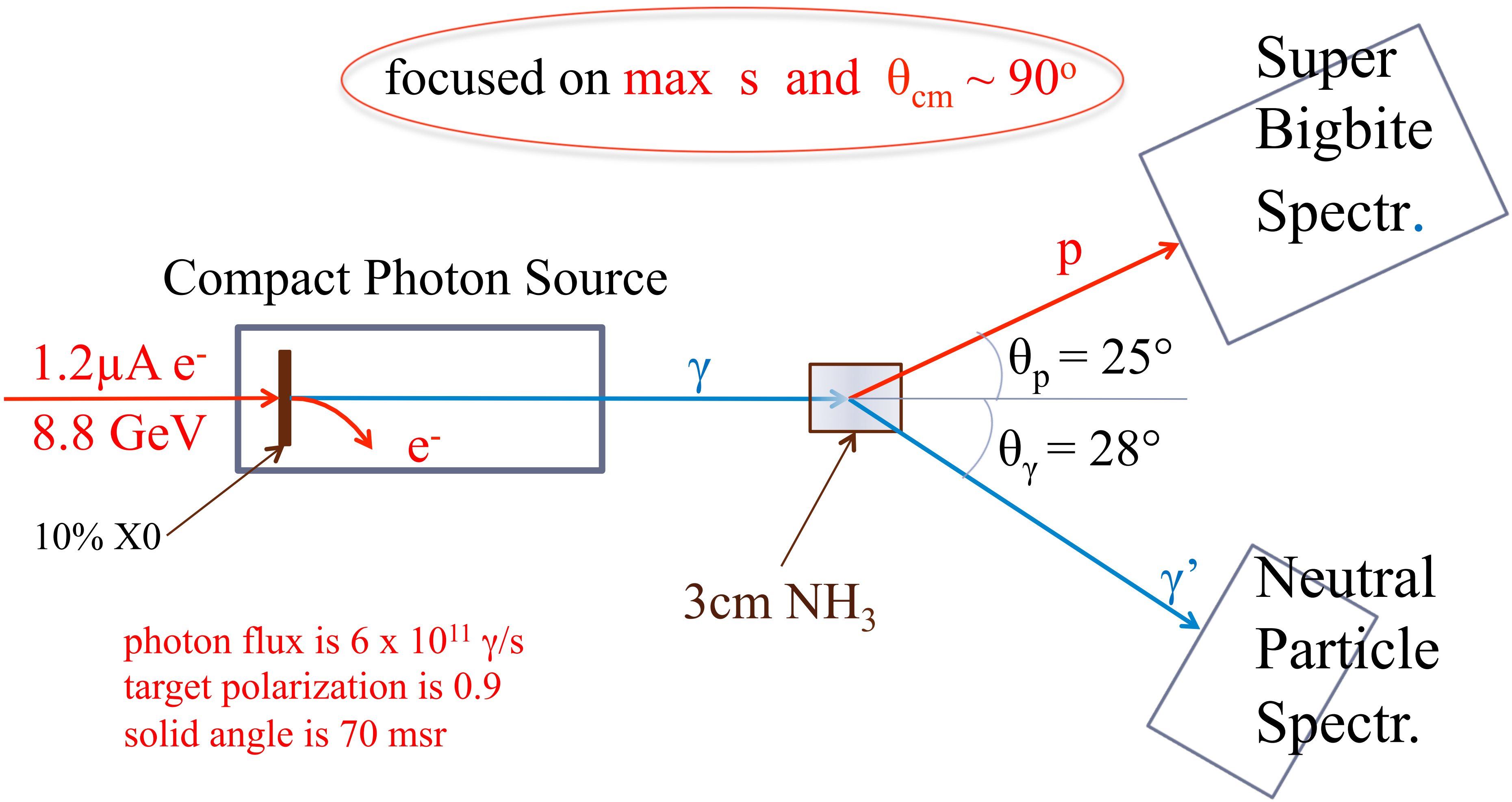
Diquark u-d correlations?

WACS experimental considerations

- K_{LL}
  - Beam intensity: 2 x 10^{13} γ/s
  - Polarimeter: figure-of-merit ~ 0.001
  - Solid angle of apparatus: HRS/HMS ~ 6-7 msr
- A_{LL}
  - Beam intensity: 6 x 10^{11} γ/s (novel source)
  - Target polarization: ~0.9
  - Solid angle of apparatus: SBS ~ 70 msr

Overall performance ~ 250 better for A_{LL}

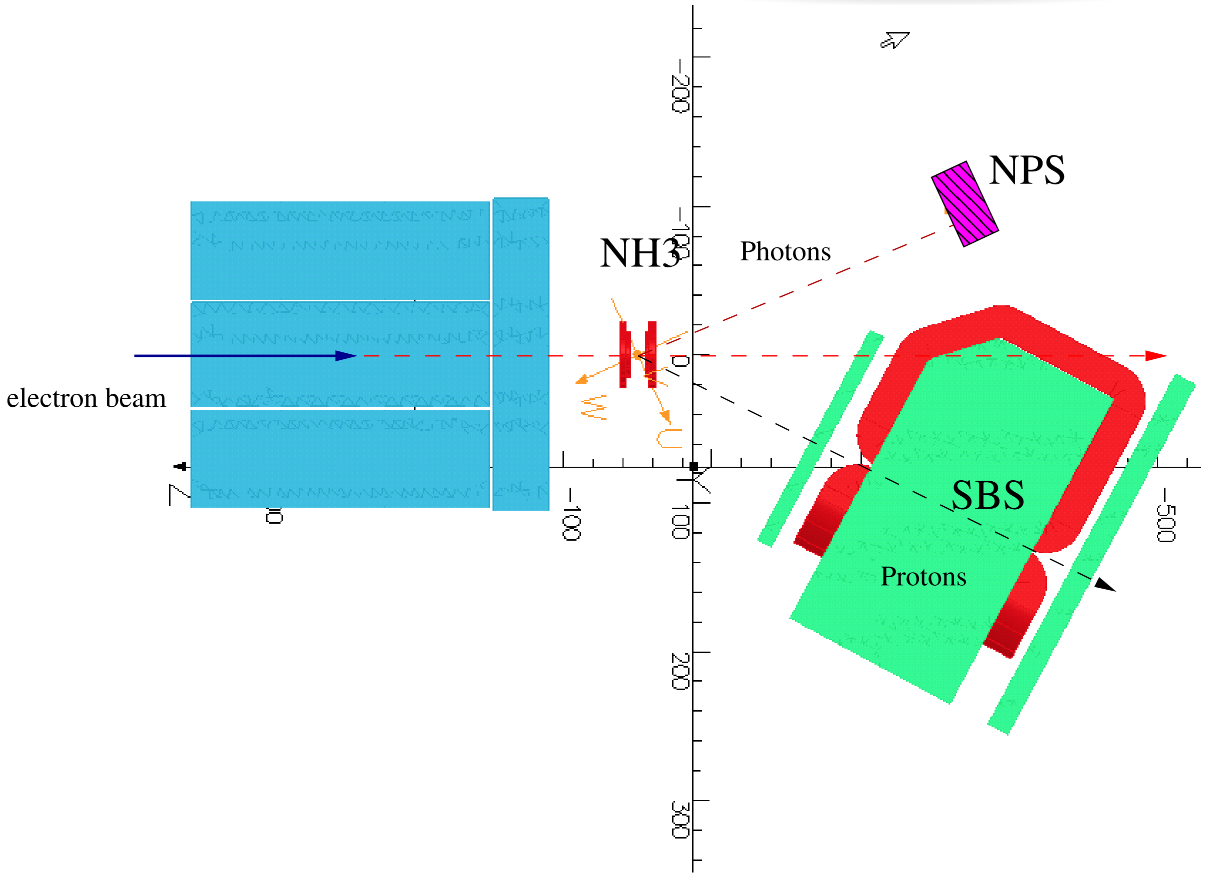
Plan to measure A_{LL}



photon flux is 6×10^{11} γ/s
target polarization is 0.9
solid angle is 70 msr

Proposed Experimental Setup

focused on max s and $\theta_{cm} \sim 90^o$



A floor plan:

the 3D model used in GEANT simulation of physics, radiation and magnetic field calculations

Neutral Particle Spectrometer

Key parameters:

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

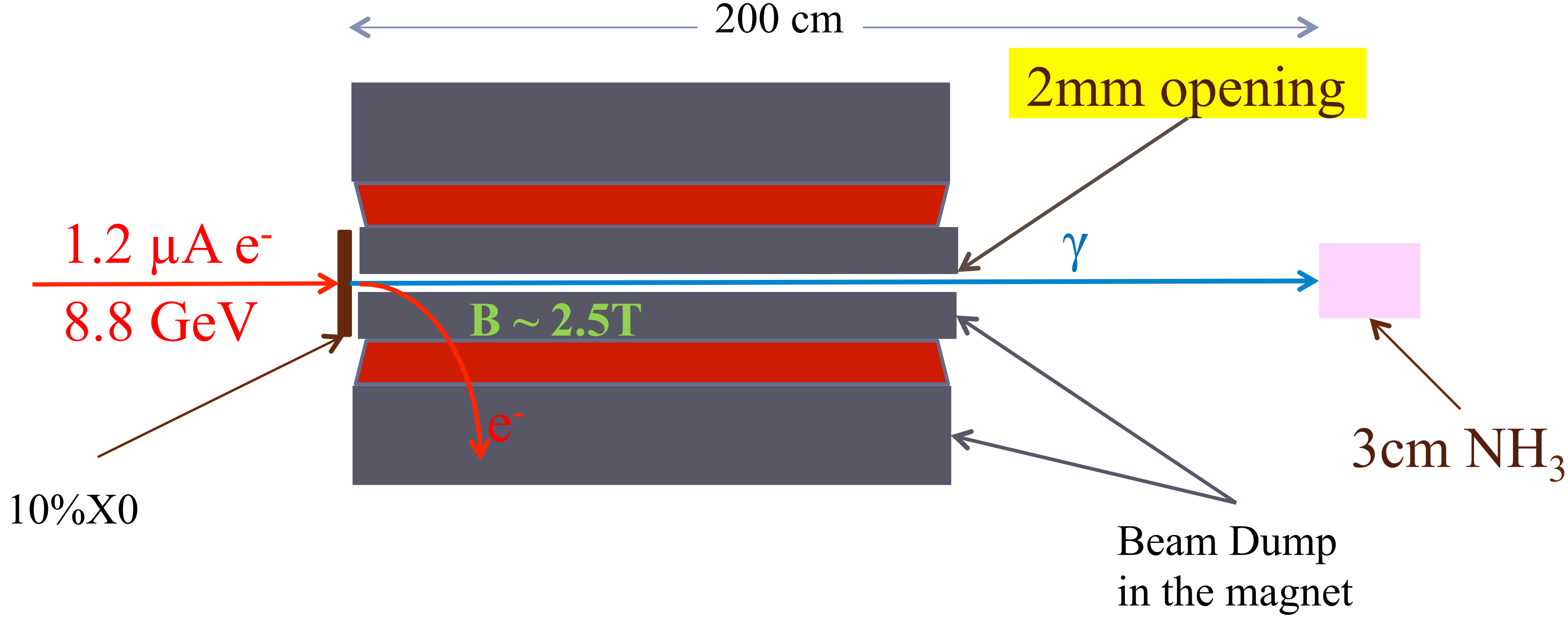
Super Bigbite Spectrometer

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

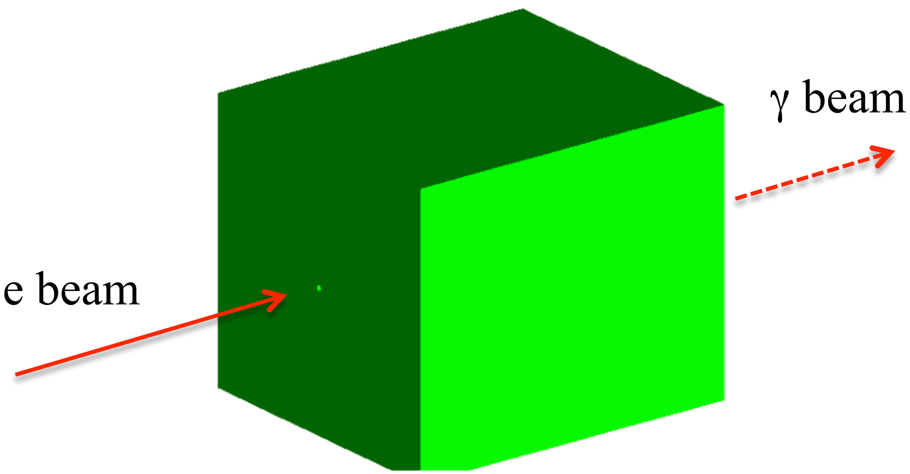
Compact Photon Source

Distance to target ~200 cm
photon beam diameter on the target ~ 0.9 mm

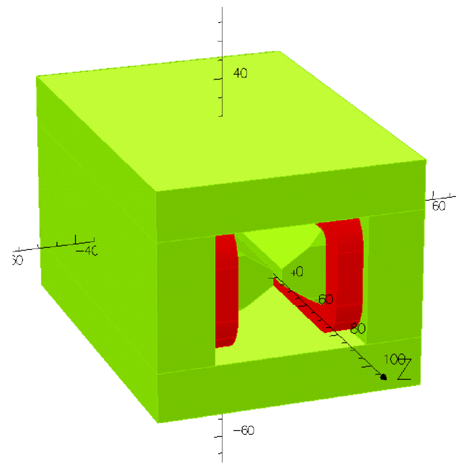


Novel concept allows high photon intensity and low radiation

Compact Photon Source – hermetic concept



2.6 m x 2.5 m x 2.5 m structure



1 m x 0.6 m x 0.5 m magnet

Incident beam has small transverse size
Outgoing photon beam has m/E angular size

} Source could be hermetic!

However, where to send the used electron beam?

- Traditional approach is based on the magnet and the dump =>
  large openings => no hermeticity and large distance from the radiator to the target
- Our new approach is using the magnet as a dump => The problem is solved!

Kinematic range

Detector acceptance will cover wide kinematic range in "one set".

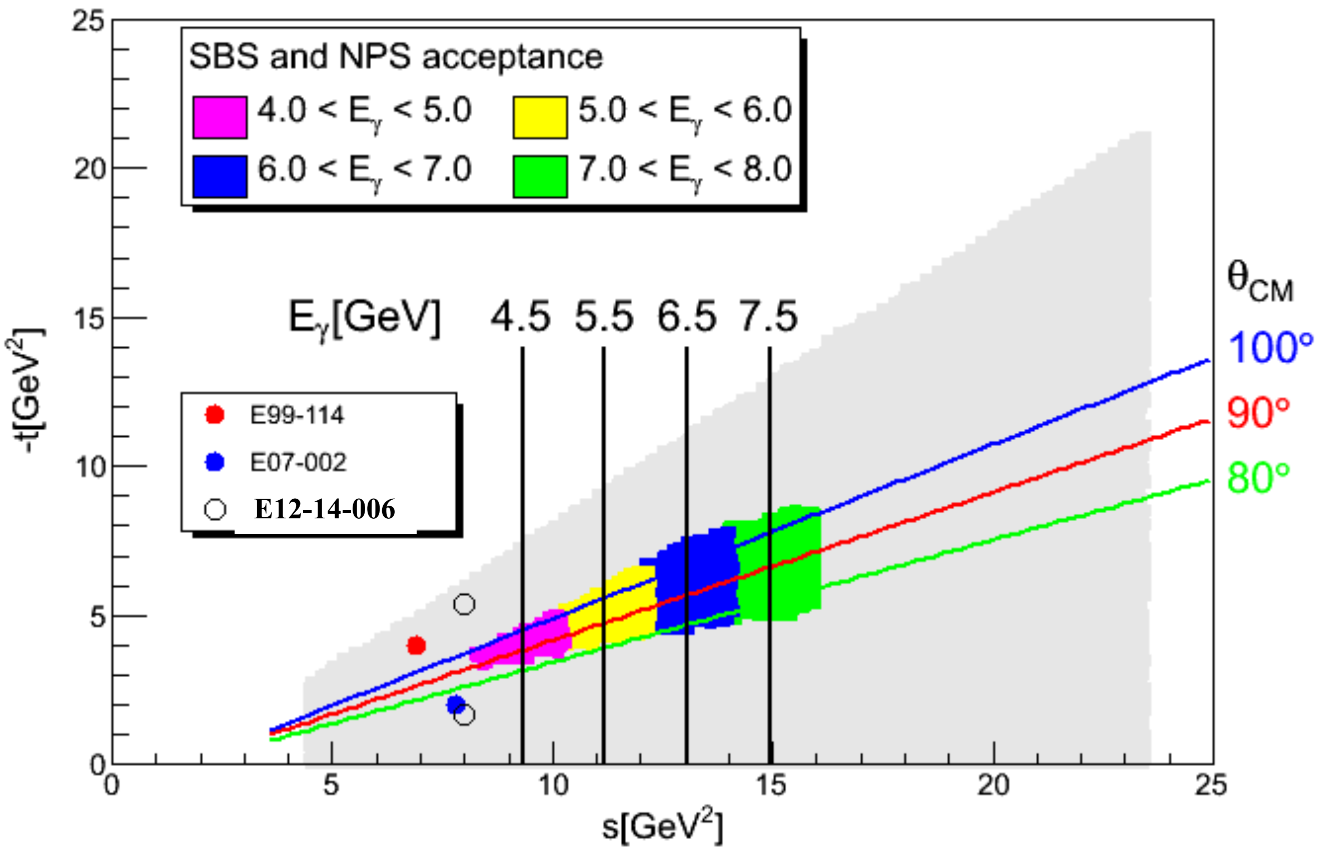
s: 8.0 – 16.0 GeV^2

-t: 3.0 – 7.0 GeV^2

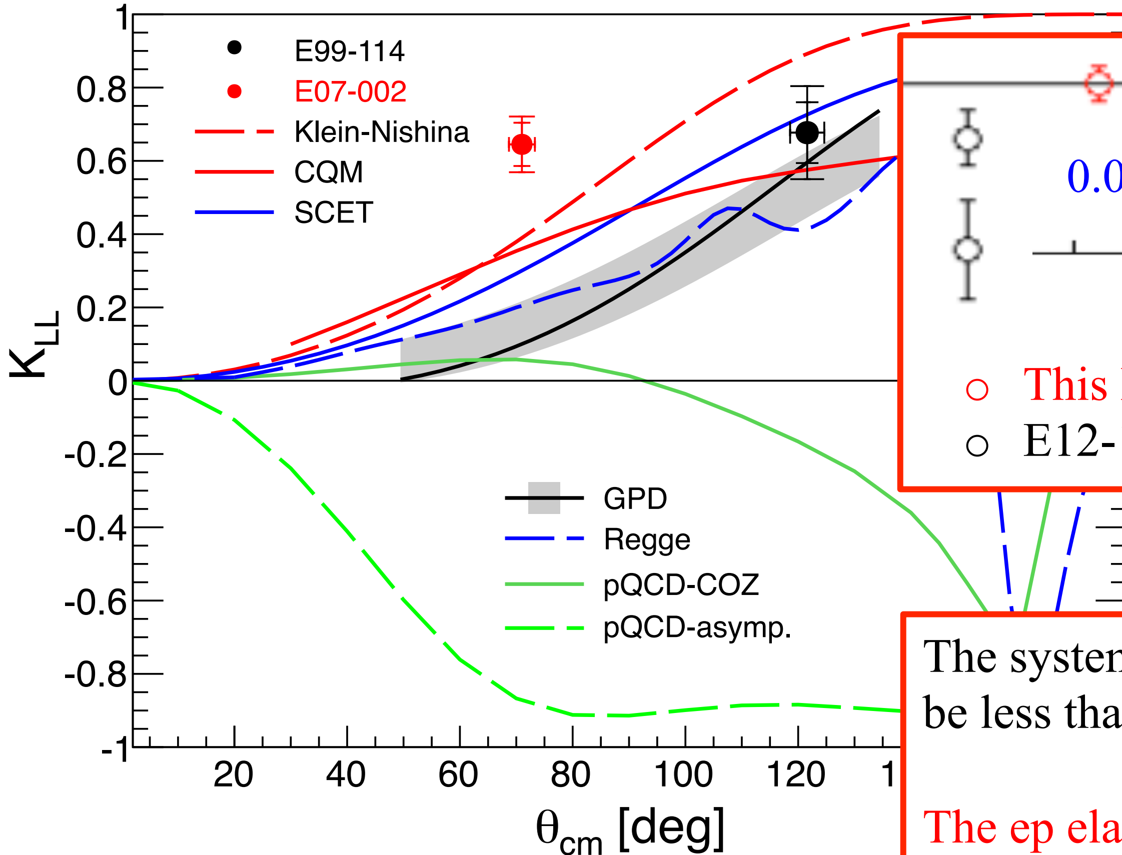
-u: 3.0 – 7.0 GeV^2

θ_{cm} : 80° – 100°

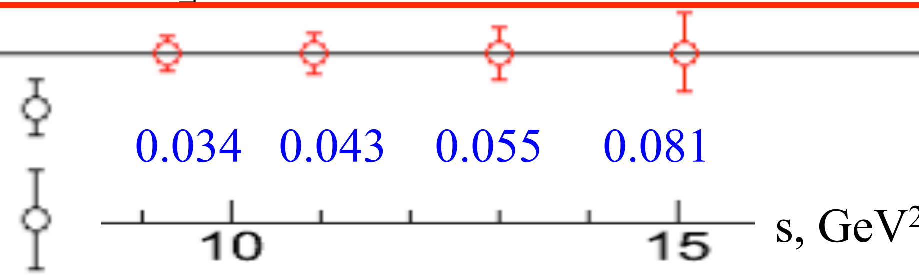
$\langle\theta_{cm}\rangle \sim 90°$



Physics Motivation, projected accuracy



High statistical accuracy



○ This Proposal, $\theta_{cm} = 90^o$

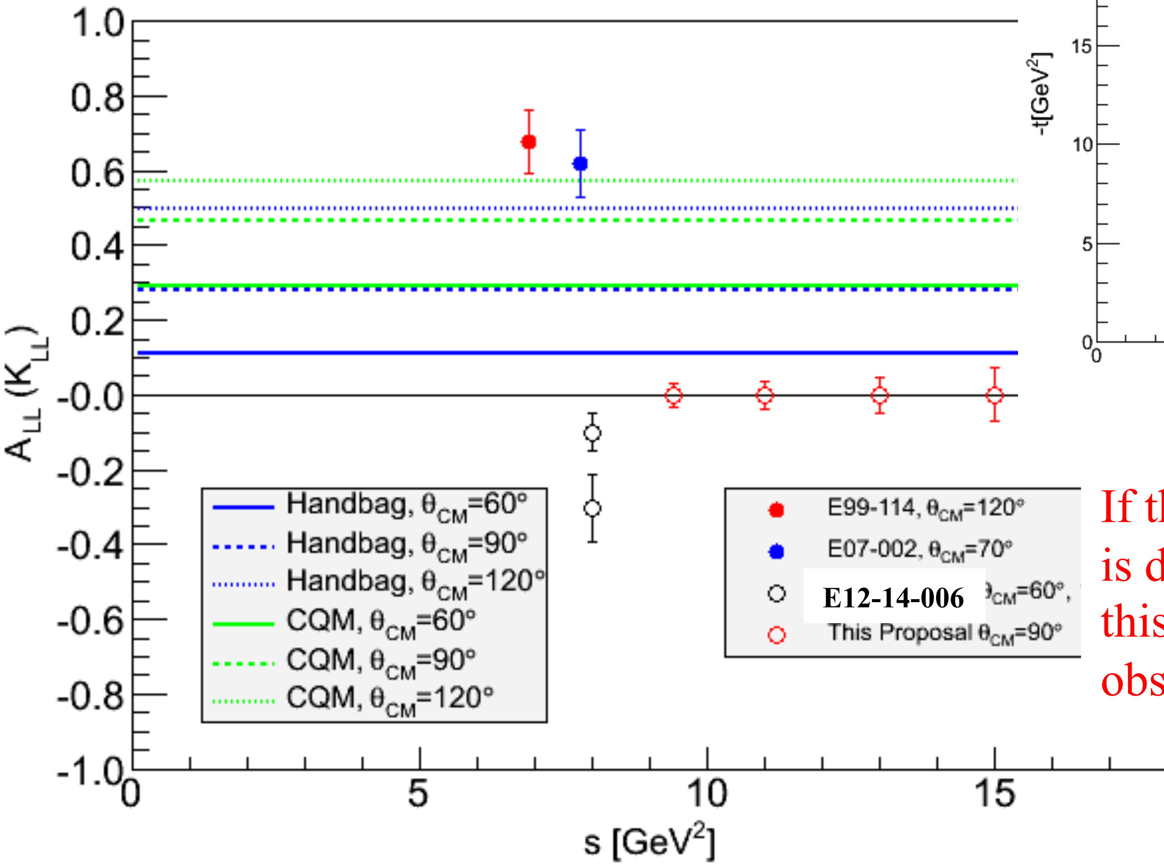
○ E12-14-006, $\theta_{cm}=60^o, 136^o$ ($-u\sim0.8$ GeV^2)

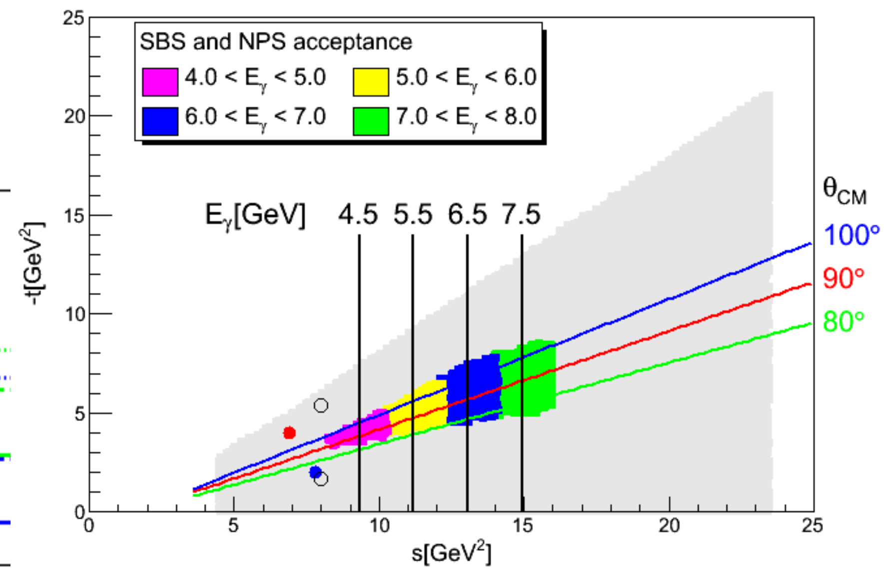
Good systematic accuracy

The systematics for the A_{LL} is projected to be less than 0.03 (absolute):

The ep elastic data A_{LL} –> product of the beam and target polarizations, $\delta(P_t*P_b)\sim 4\%$;
the beam pol. via Moller measurement, ~1%;
the target pol. via NMR, δP_t ~5%.

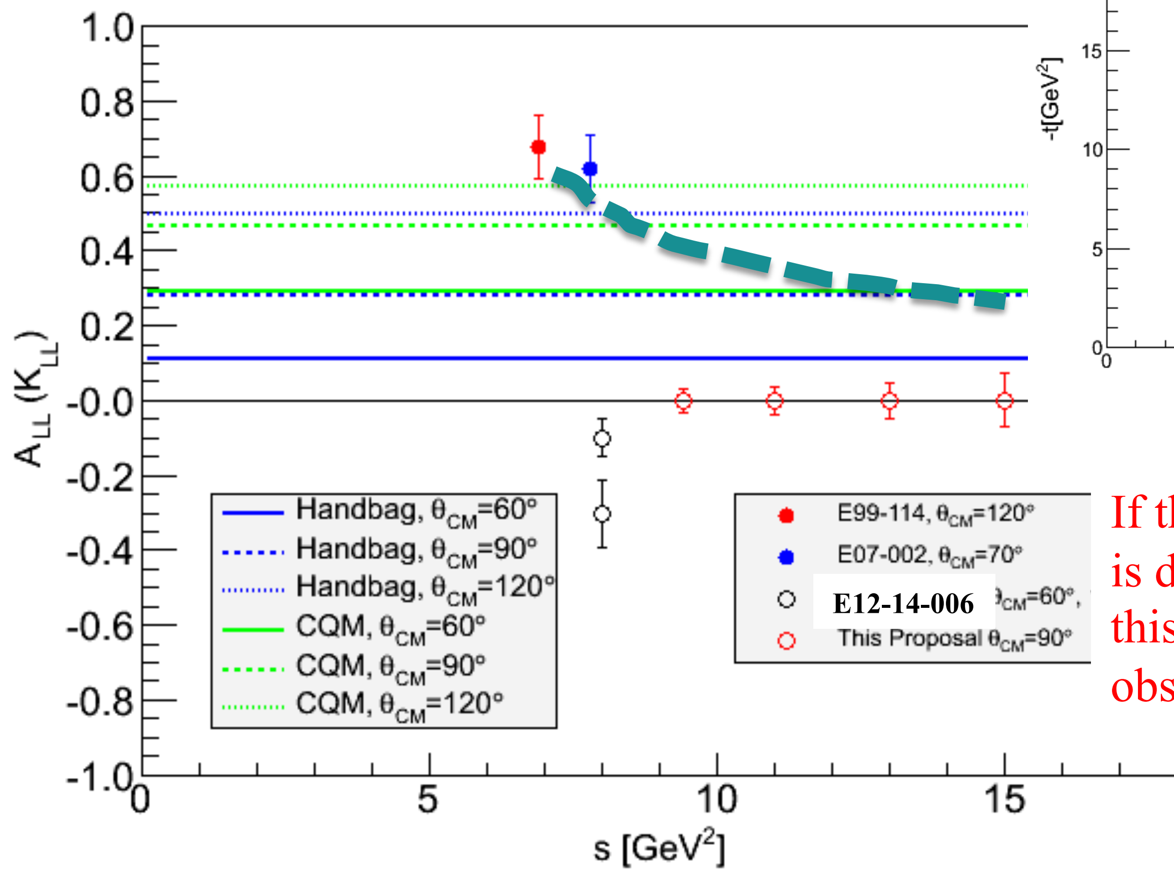
Projected impact of the results

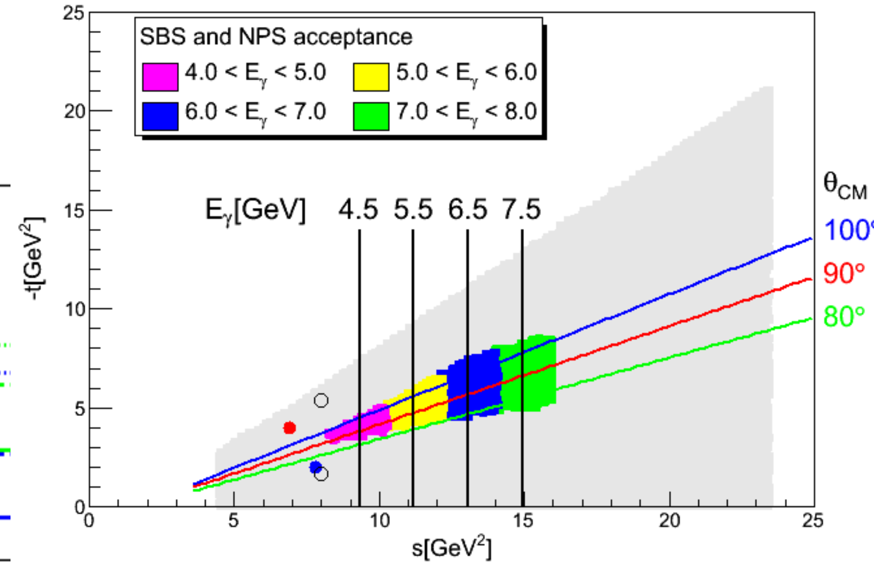




If the observed large K_{LL} at $\theta_{cm} = 70^{o}$ is due to large $1/s$ NLO contributions, this experiment should be able to observe an s dependence.

Projected impact of the results

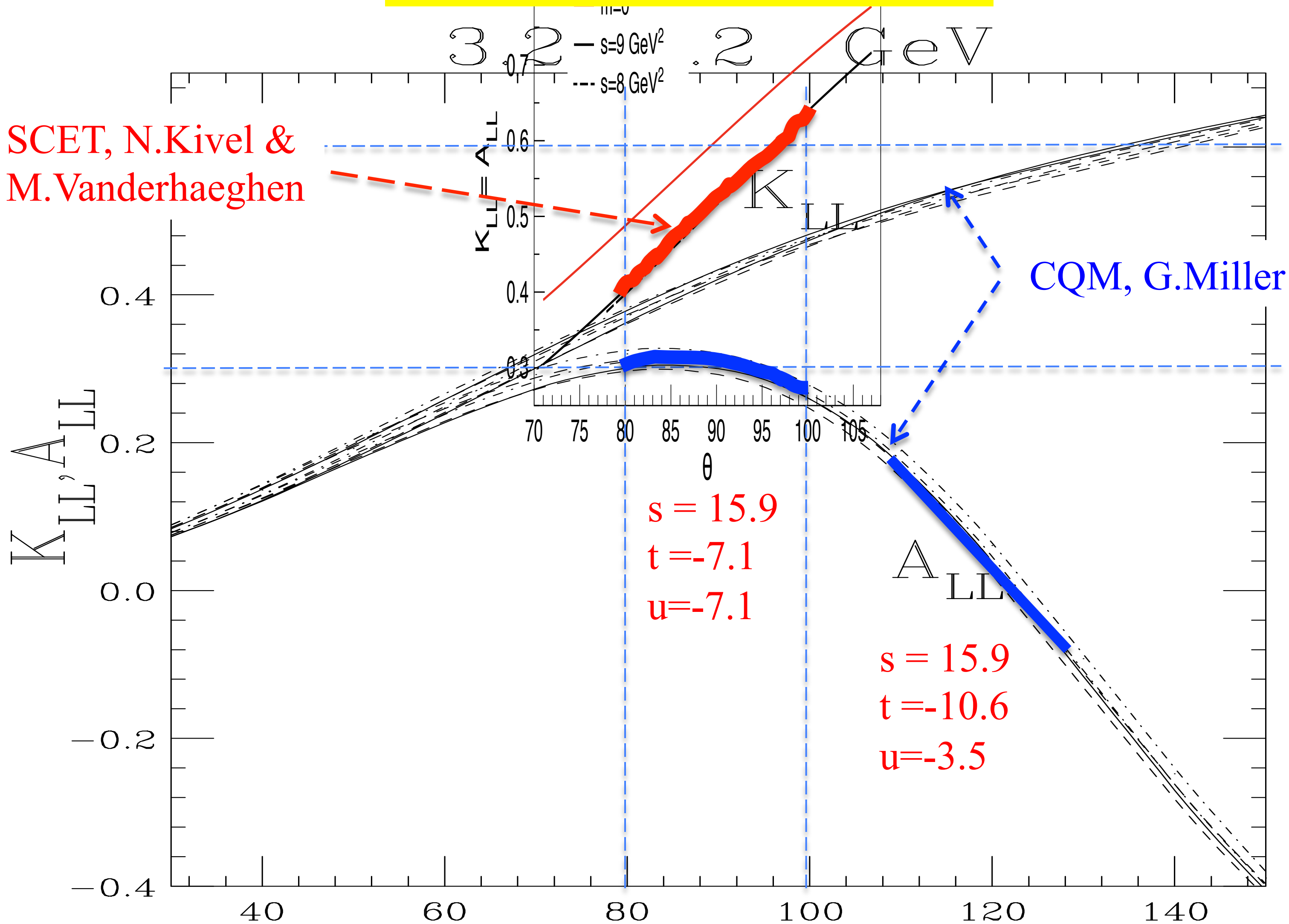




If the observed large K_{LL} at θ_{cm} = 70° is due to large $1/s$ NLO contributions, this experiment should be able to observe an s dependence.

CQM indicates that A_{LL} is not equal to K_{LL}

current quark vs. constituent quark



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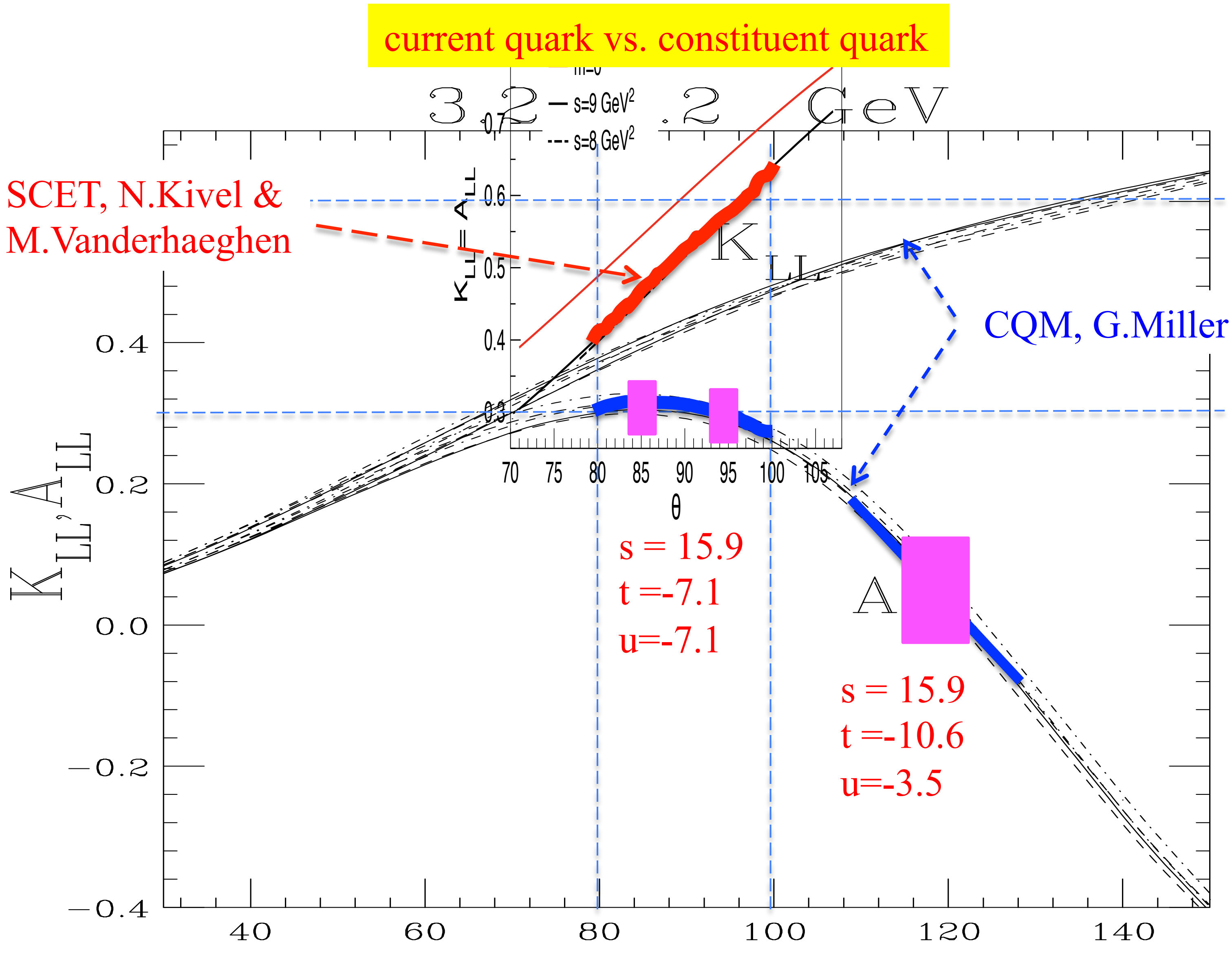

Other polarization experiments

- A_{LT} with the same apparatus as A_{LL}
  but the transversely polarized target
  would require about 20 days of beam time

- Σ asymmetry with Hall D apparatus, $E \sim 9$ GeV,
  However, the flux (10^7 photons/s) limits: $-t < 1$ GeV^2

Experiment is always the answer

Test of the reaction mechanism in the cloud chamber.

Arthur Compton,

Physical Review (1925)

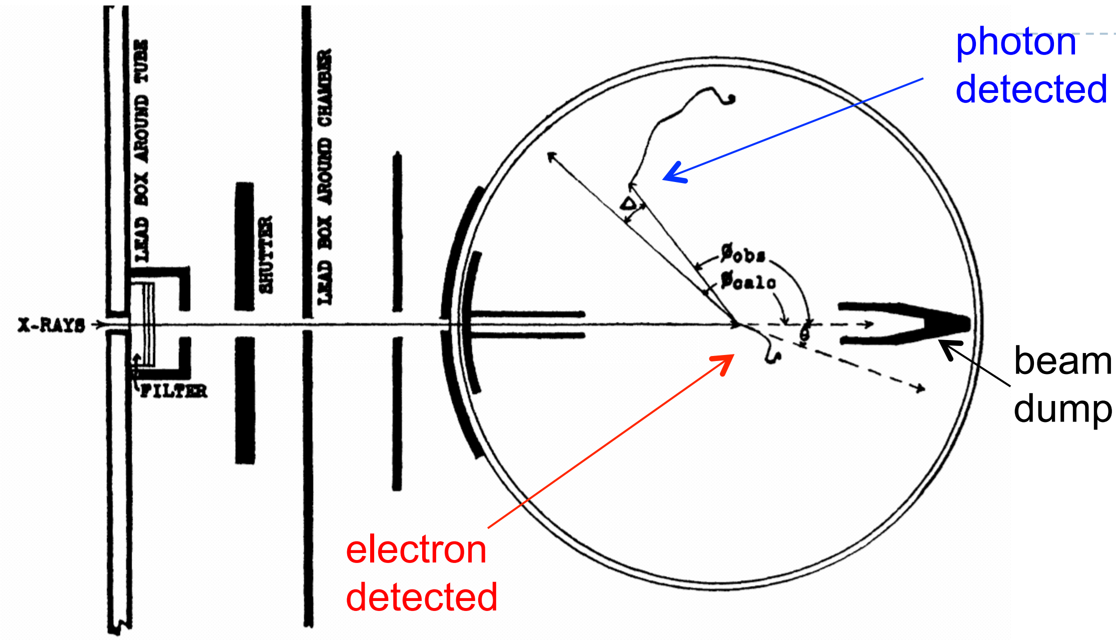

Fig. 1. Diagram of apparatus. On the hypothesis of radiation quanta, if a recoil electron is ejected at an angle θ, the scattered quantum must proceed in a definite direction ϕ_{calc}. In support of this view, many secondary β-ray tracks are found at angles ϕ_{obs} for which Δ is small.

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.*

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/SCET applicability.

  A large acceptance spectrometer and a high resolution calorimeter allow a 10-fold increase in the acceptance.

  A novel scheme of a photon source-electron-dump allows 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 $\theta_{cm} \sim 90^o$, 120^o