Wide Angle Compton Scattering

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SBS Collaboration Meeting, July, 2016

Outline:

- *Why WACS?*
- *Theory/Existing Data*
- *Experimental Challenges & Options*
- *Quo Vadis?*

$$\vec{\gamma} + \vec{p} \rightarrow \gamma + p$$

WACS $\vec{\gamma} + \vec{p} \rightarrow \gamma + p$

- *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 6-GeV era WACS experiments (2002, 2008)*
- *Experimental results for polarization K_{LL}* $\vec{\gamma} + p \rightarrow \gamma + \vec{p}$
- *Motivation for further measurements*

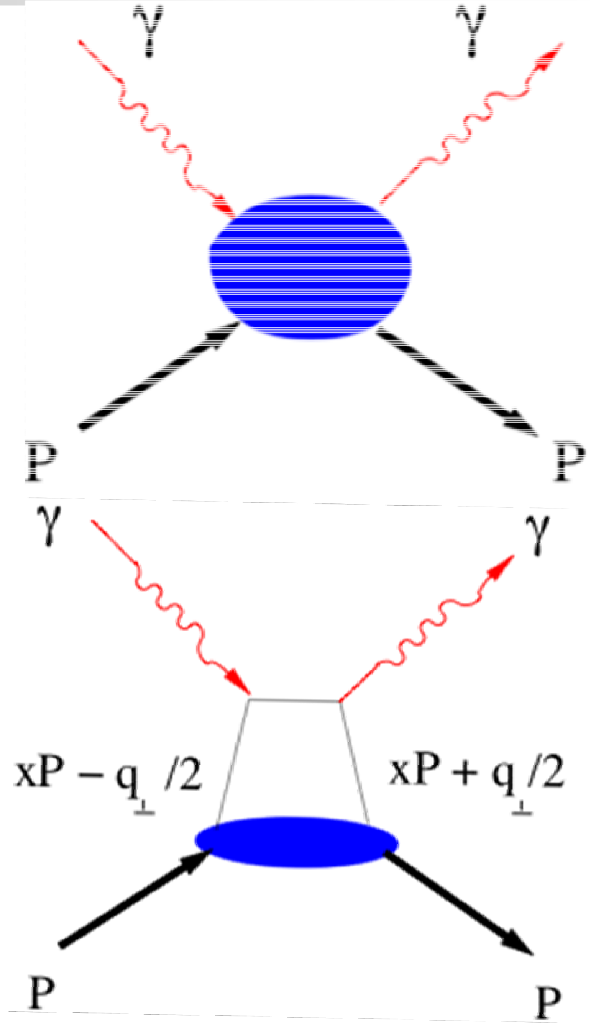
- ***An approach for the most productive A_{LL} experiment***
- ***… and the avenues it might open.***

Mechanism of the RCS Process

Two basic options for the mechanism:

- *Collective response – several partons involved in high momentum interaction with incoming/outgoing photons*

- *Individual response – a single quark absorbs the incident photon and the same quark emits a scattered photon*



Theoretical studies of the CS process

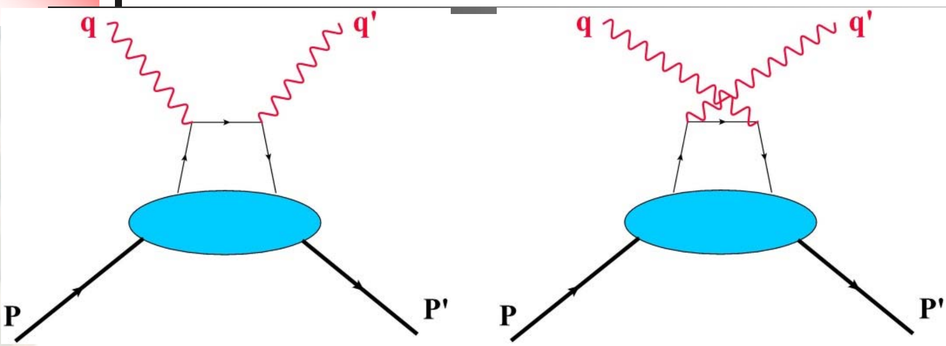
Many different groups, many different ideas…

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*

Compton scattering & GPDs



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

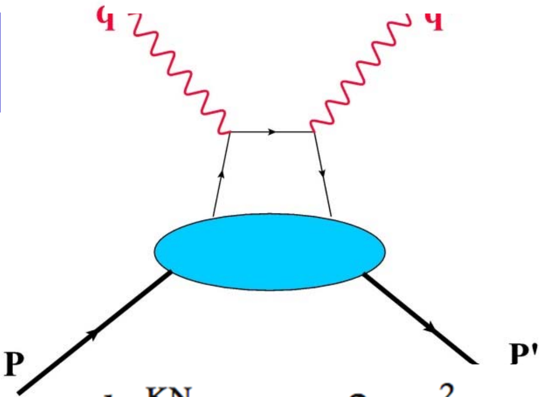
M.Diehl & P.Kroll

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

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

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

FFs, GPDs and Polarization Observables



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

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

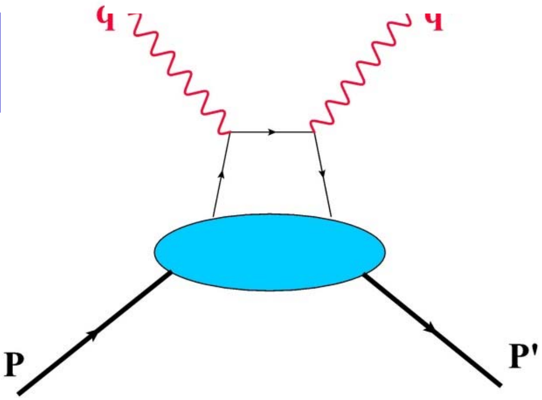
$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t)$$

M.Diehl & P.Kroll

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

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

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

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

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

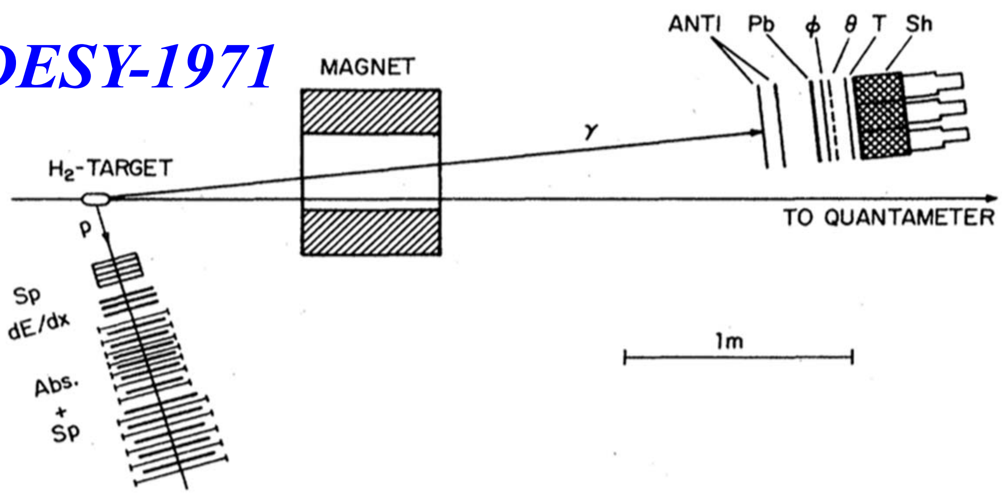


FIG. 44. Diagram of the apparatus used by the DESY group for Compton scattering measurements (from Buschhorn *et al.*, 1971a).

The photon flux is 2×10^8 γ/s

Experimental studies …

experiments with –t > 1 GeV² (WACS regime)

- *Cornell - 1975*
- *JLab (Hall A) - 2002*
- *JLab (Hall C) - 2008*

mixed e/g beam!

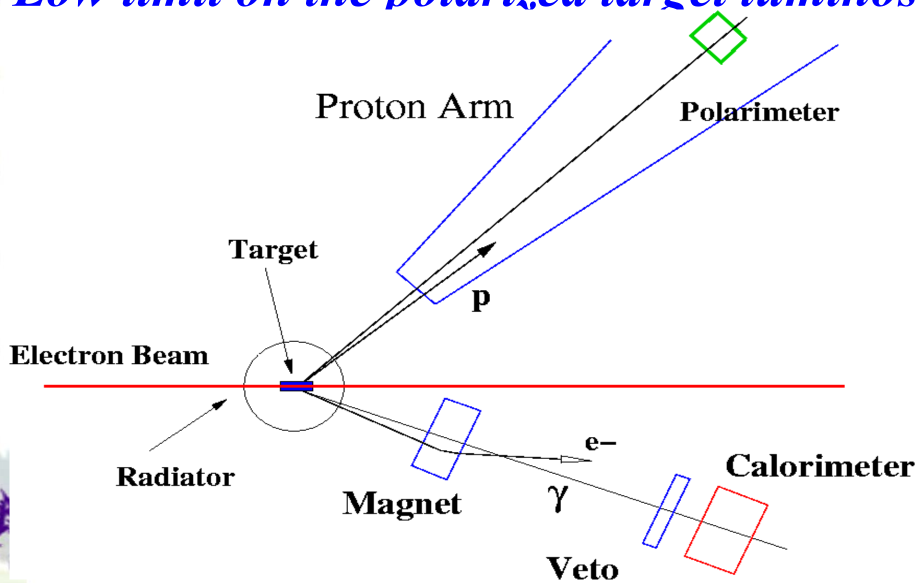
The photon flux is

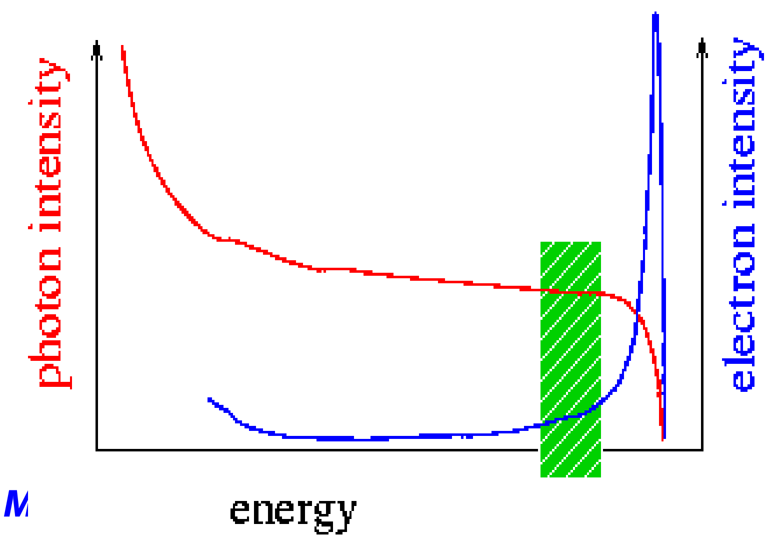
1.5 x 10^{10} γ/s

~2 x 10^{13} γ/s

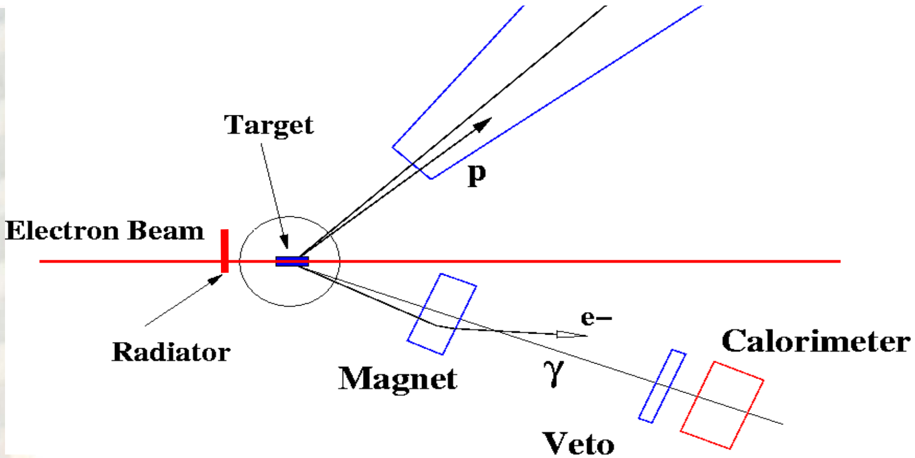
Main issues:

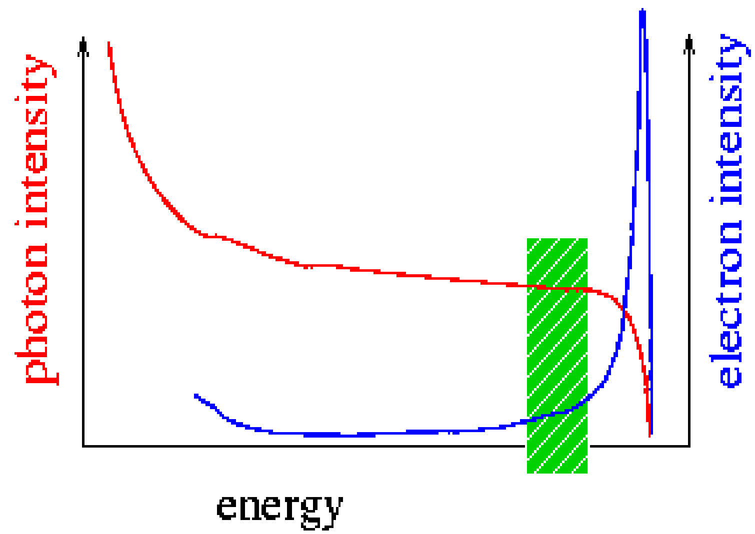
- *Competing reaction – p^0 photo-production*
- *Low cross section and small solid angle*
- *Low efficiency & analyzing power of the proton polarimetry*
- *Low limit on the polarized target luminosity*

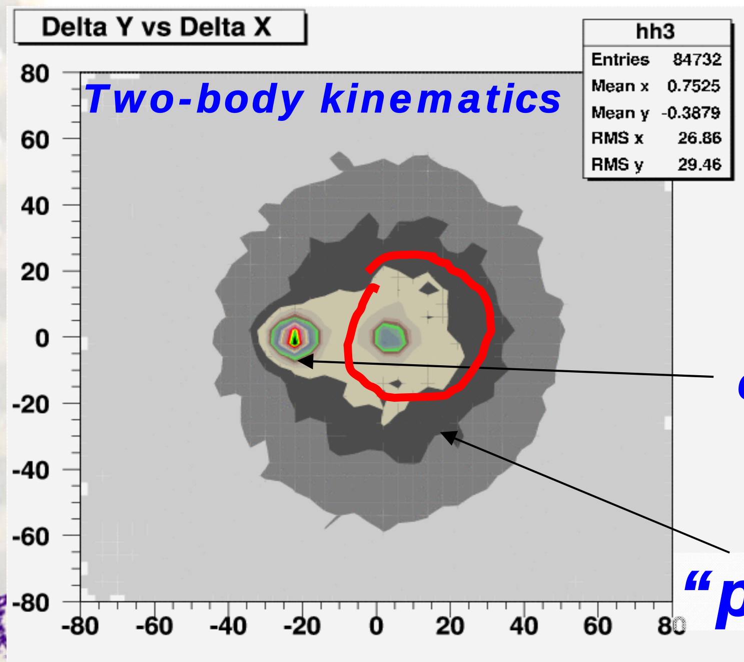




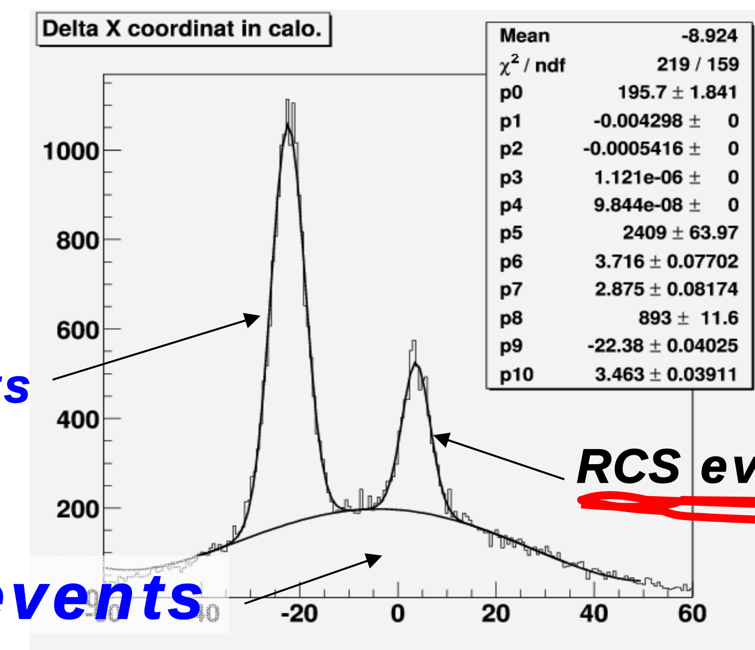
Mixed e/γ beam –> rates ~1300 higher than "clean" γ







ep events

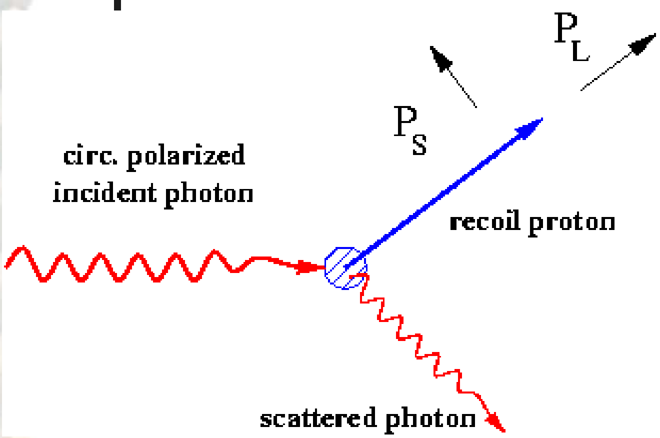


RCS events

"pion" events

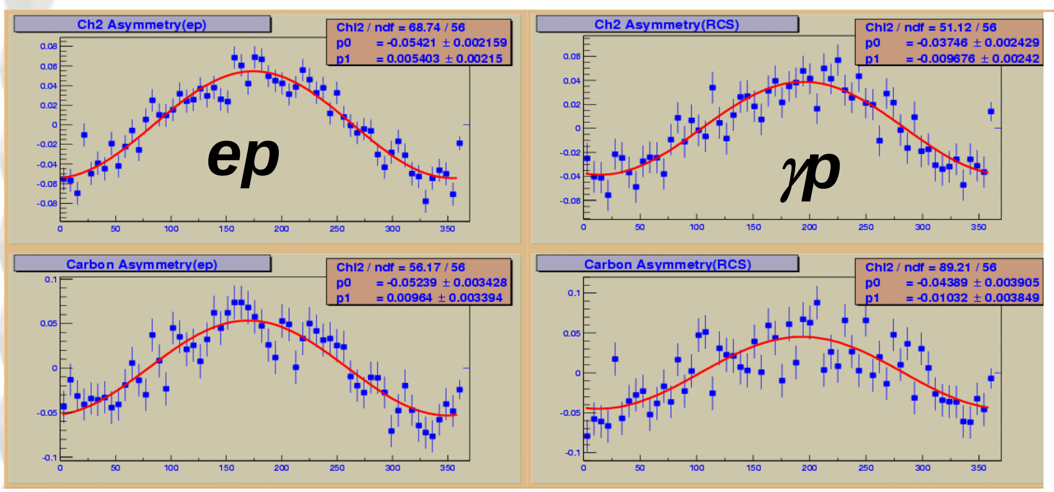
Polarization transfer K_{LL}

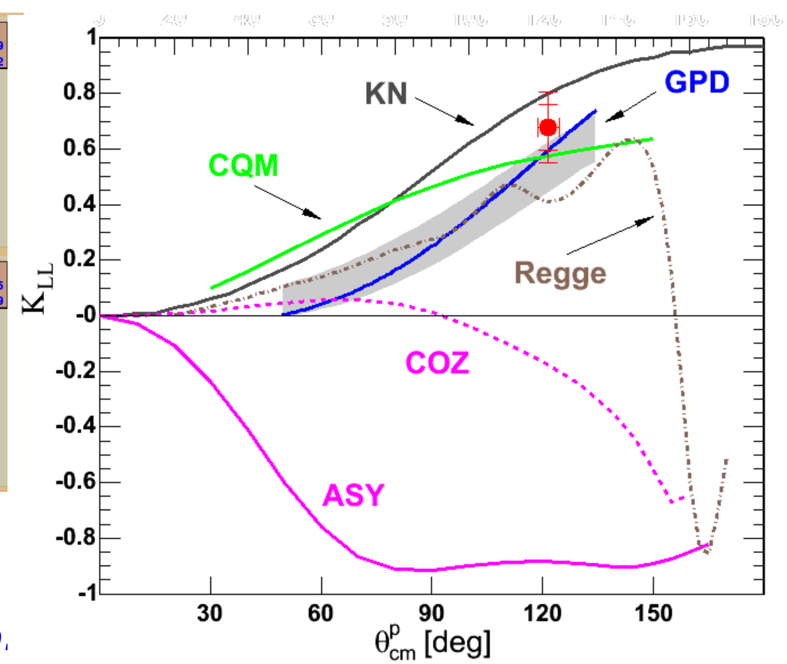
E_γ = 3.2 GeV, θ_{cm} = 120° (s = 6.9, t = -4 GeV^2)



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 ~ 0.05
systematic uncertainty is below 10^{-4}

Collab.

E99-114 experiment, Hall A, 2002

Proton spectrometer

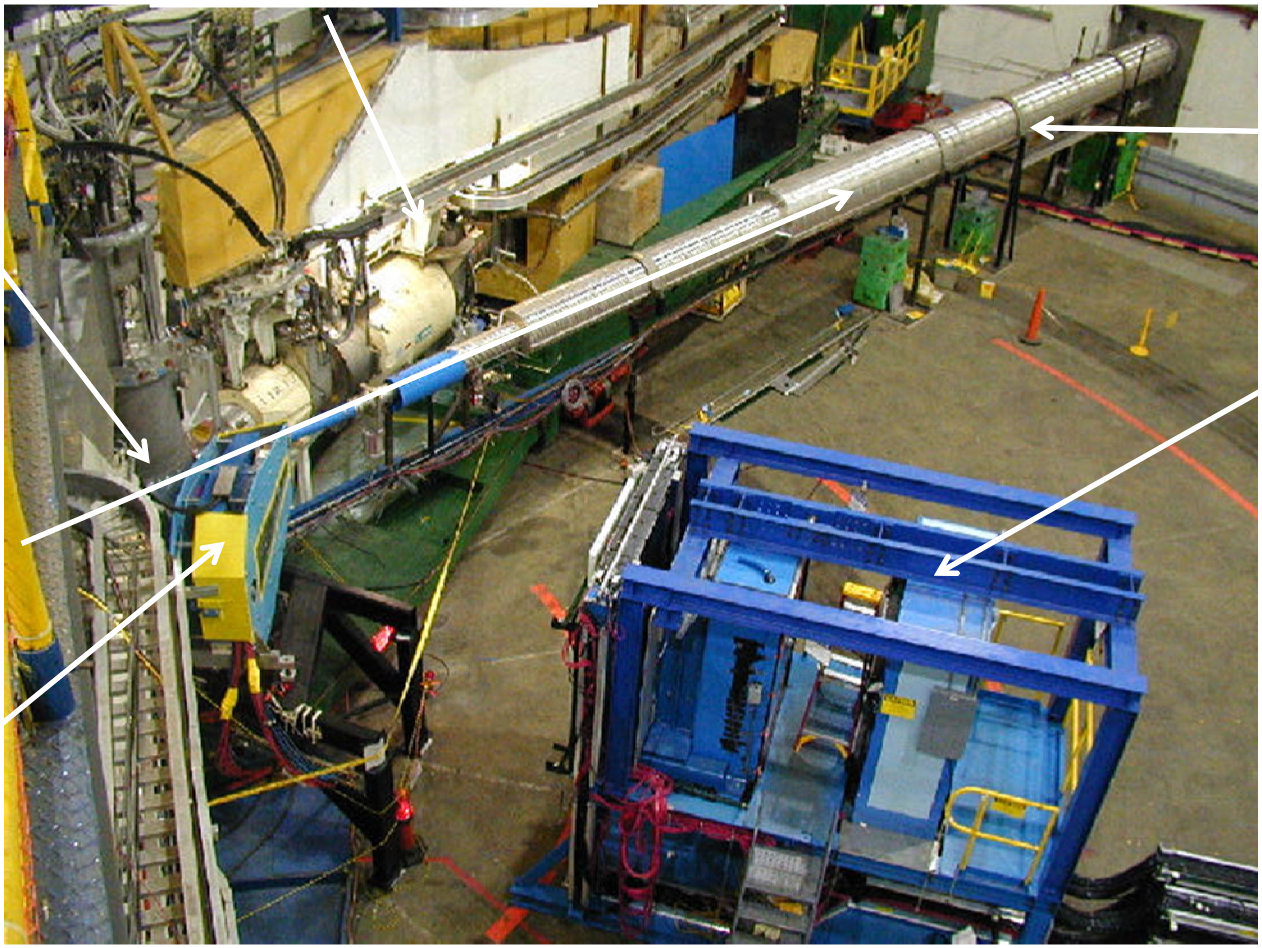
Hydrogen target

Exit beam line

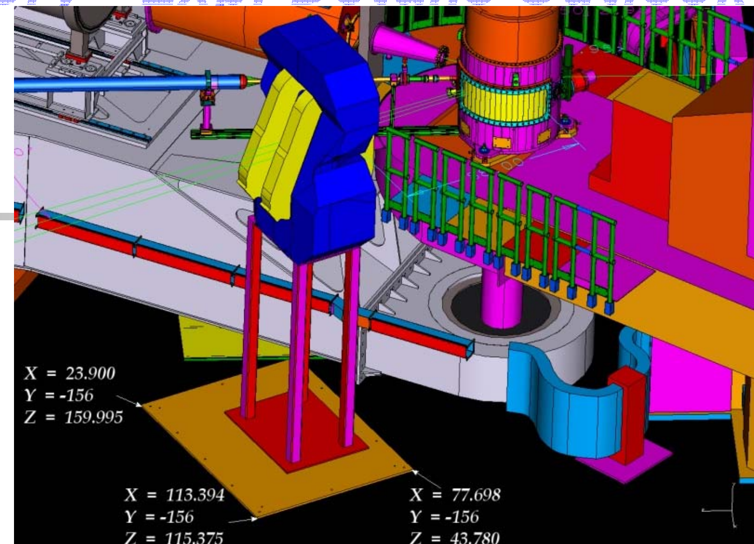
Photon detector

Electron Beam

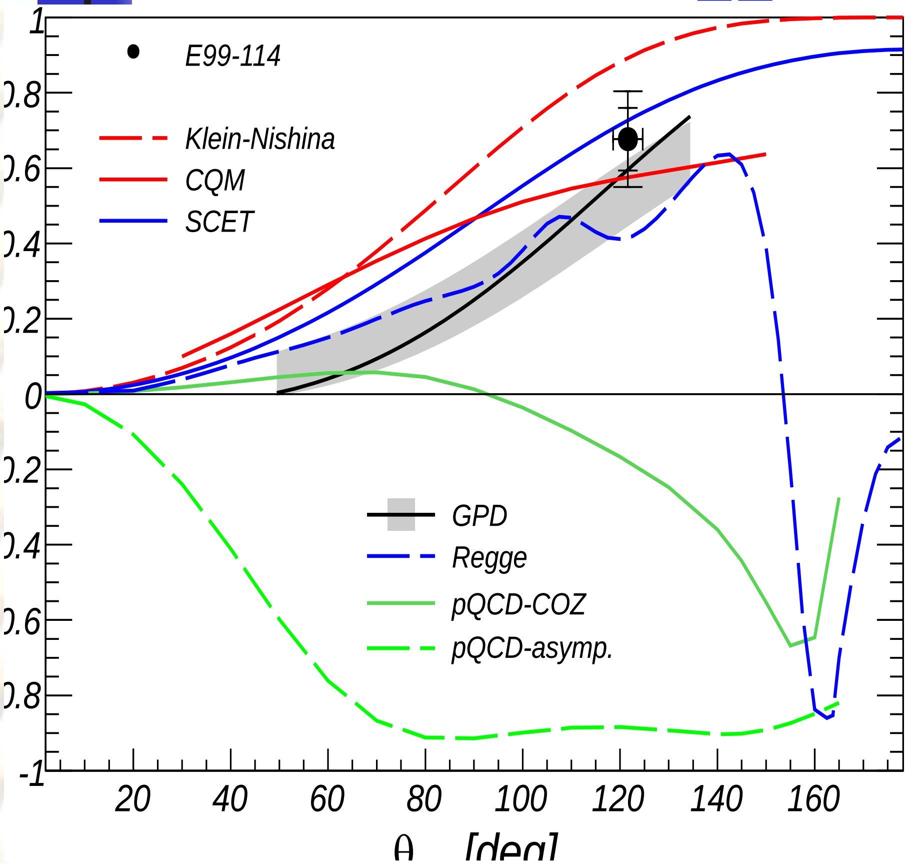
Deflecting magnet



E07-002 experiment, Hall C, 2008



Physics Motivation: study of K_{LL}



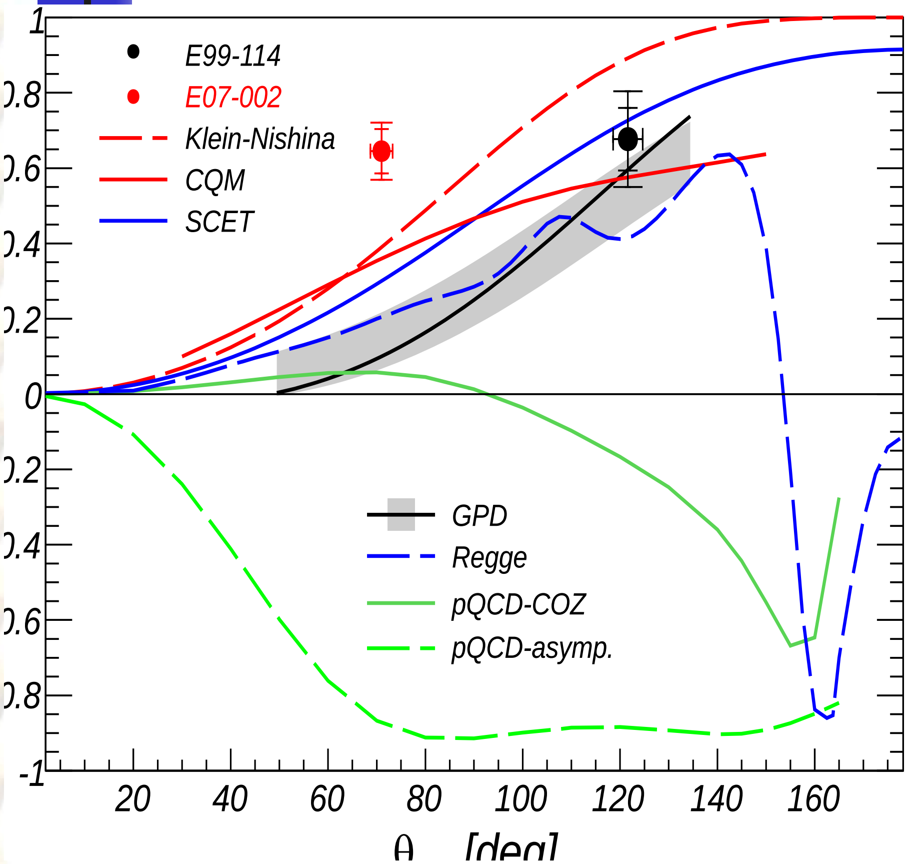
E99-114

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 GeV²

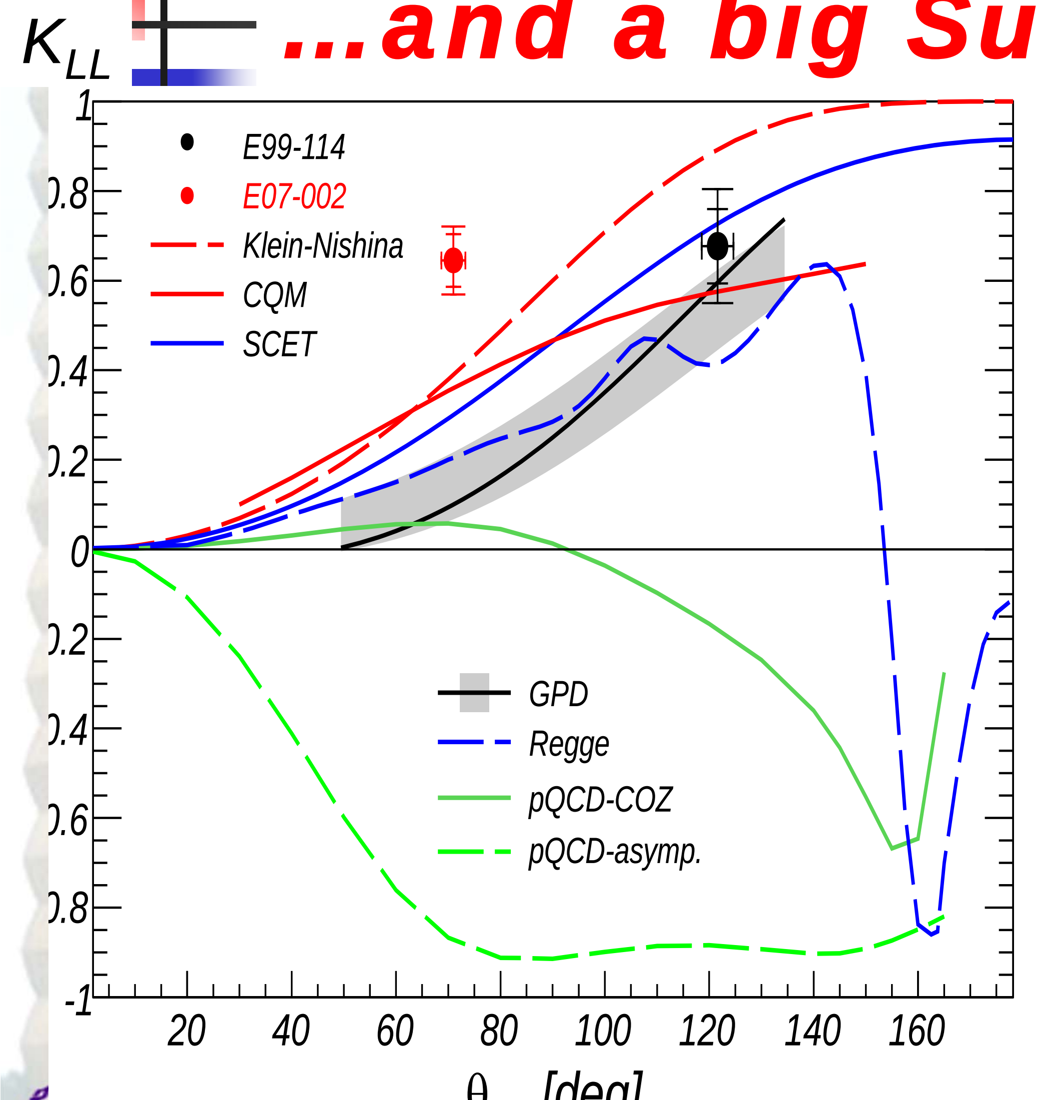
E07-002
s=7.8, t=-2.1, u= -4.0 GeV²

Strong evidence for additional physics

PRL 115, 152001 (2015)

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

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

Q: What is the origin of large K_{LL}?

- *Quark OAM?*
- *Diquark u-d correlations?*

WACS experimental considerations

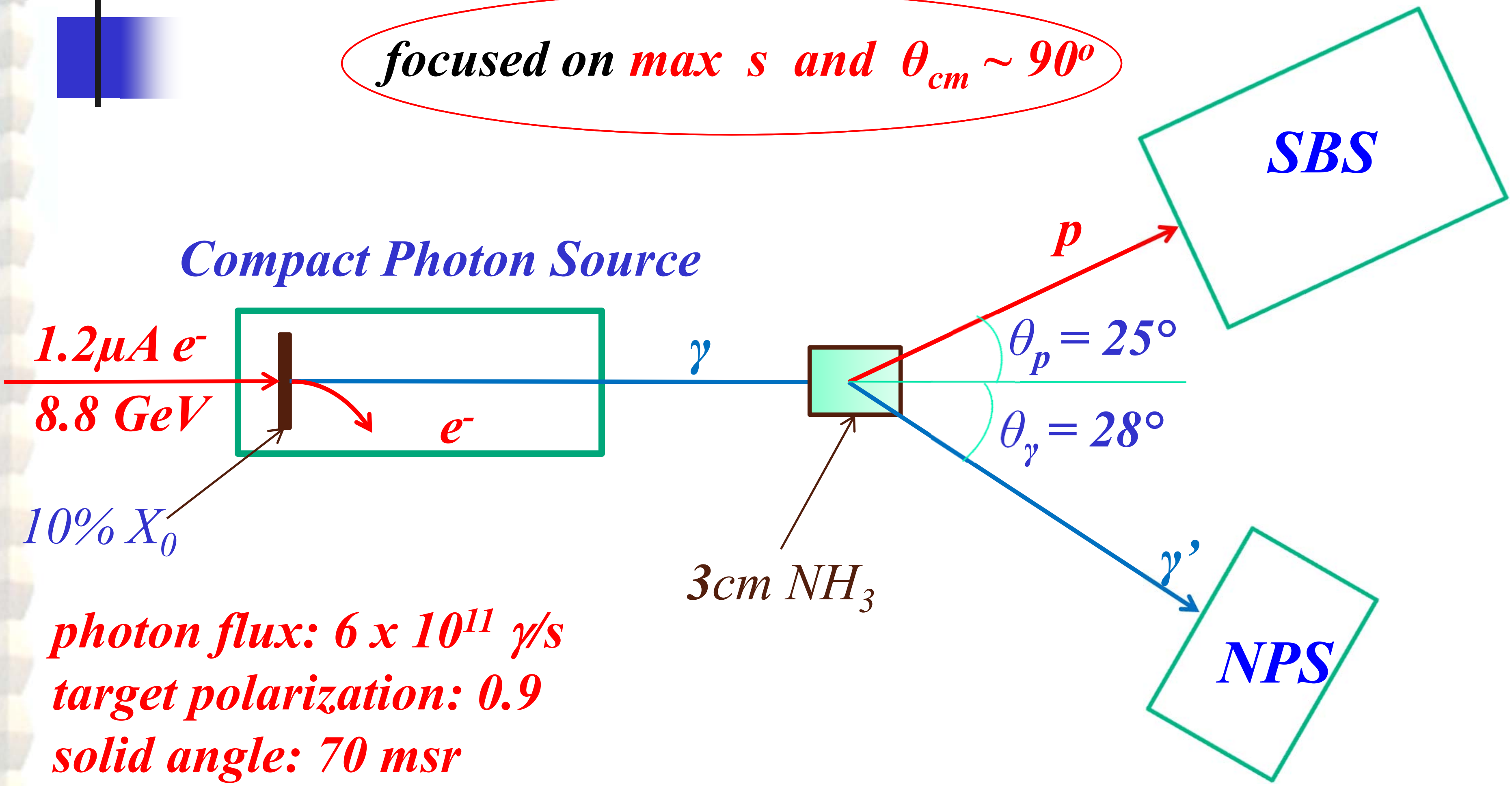
- K_{LL}
  - Beam intensity: 2×10^{13} γ/s
  - Polarimeter: figure-of-merit ~ 0.001
  - Solid angle of apparatus: HRS/HMS ~ 6-7 msr

- A_{LL}
  - Beam intensity: 6×10^{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}

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



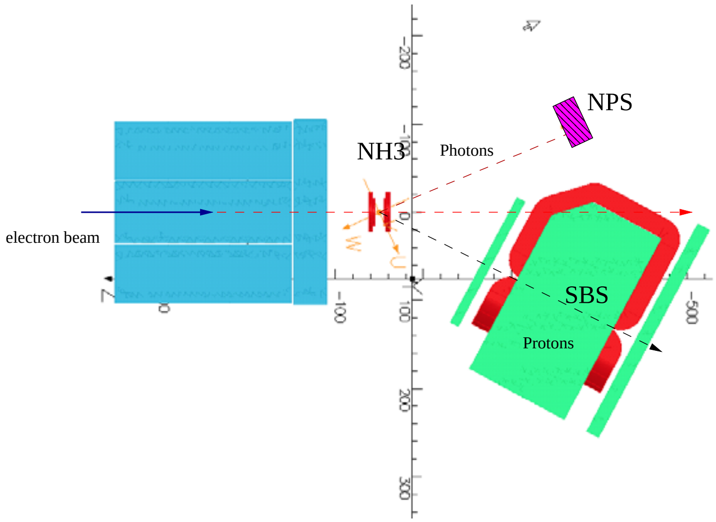
photon flux: 6×10^{11} γ/s
target polarization: 0.9
solid angle: 70 msr

Plan to measure A_{LL}

Key parameters:

NPS:

- *Energy resolution ~* $2\%/\sqrt{E}$
- *Radiation hardness $PbWO_4$*
- *Area/segmentation: 72 cm x 60 cm /1100 crystals*
- *Coordinate resolution: 2-3 mm*



Exp. Setup in GEANT

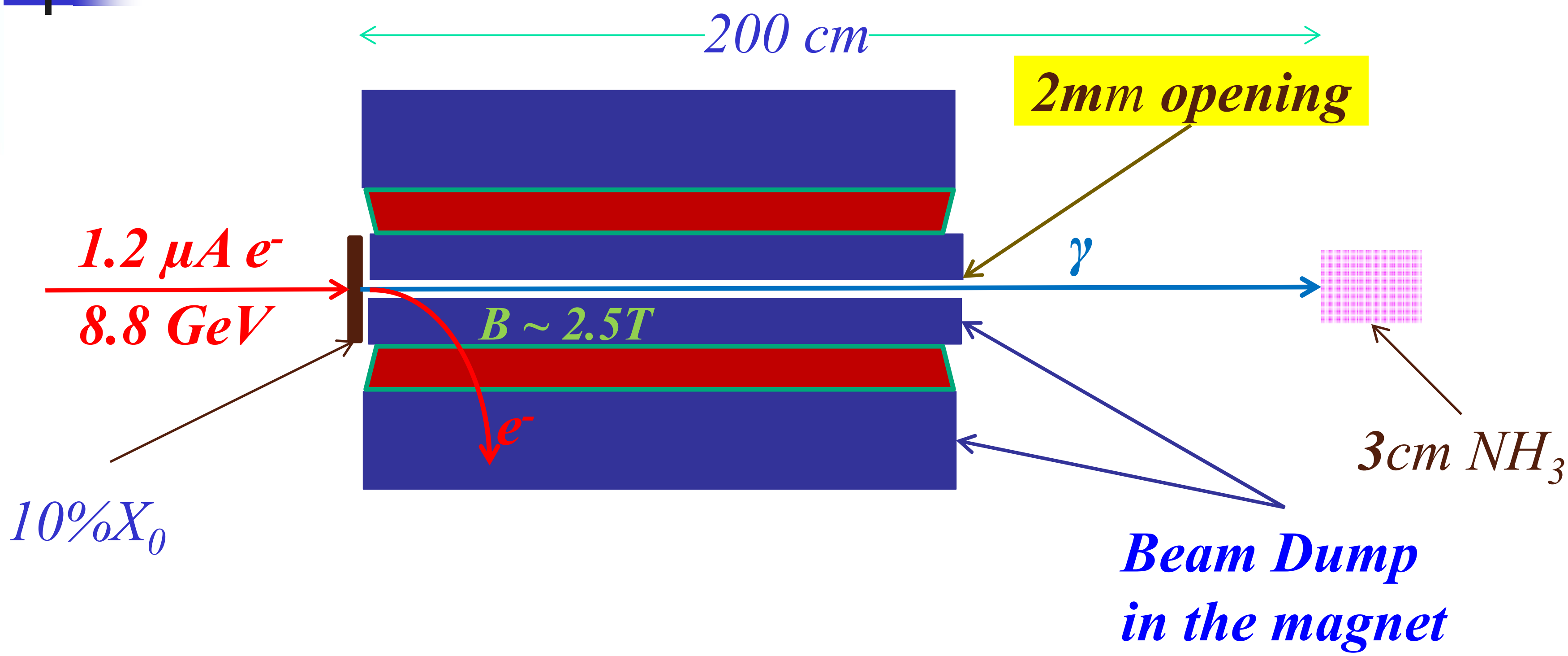
SBS:

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

Compact Photon Source

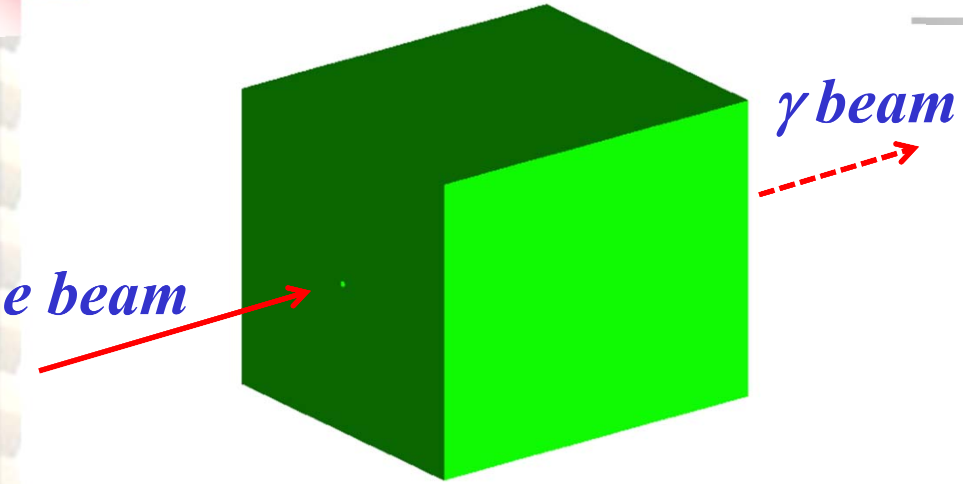
Distance to target ~200 cm

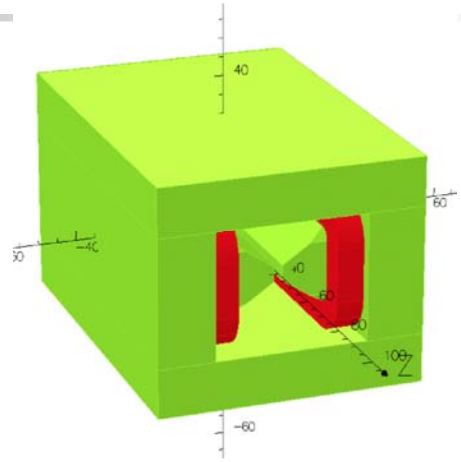
photon beam diameter on the target ~ 0.9 mm



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 using magnets to get e to a beam 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

Split the (large) detector acceptance in several kinematic bins (all taken simultaneously)

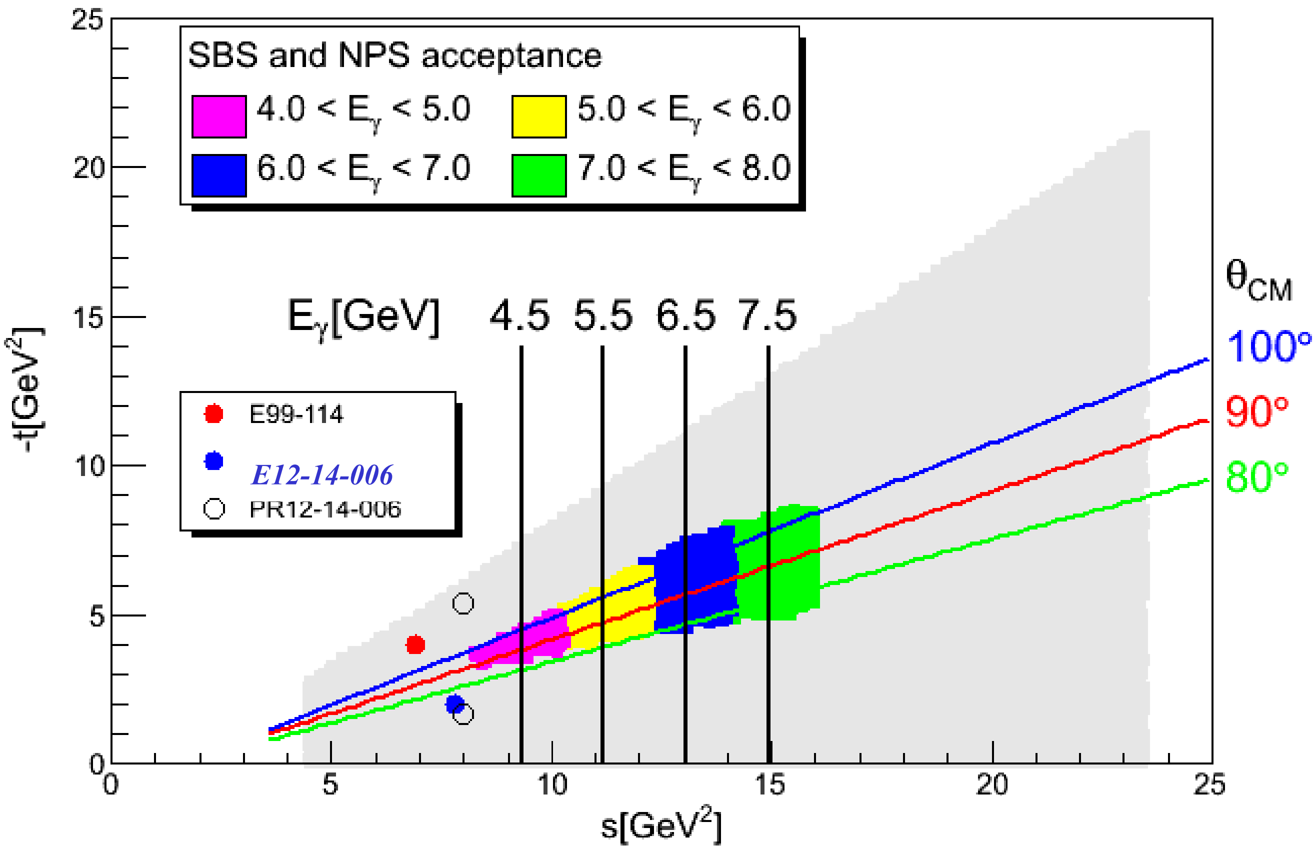
s: 8.0 – 16.0 GeV²

-t: 3.0 – 7.0 GeV²

-u: 3.0 – 7.0 GeV²

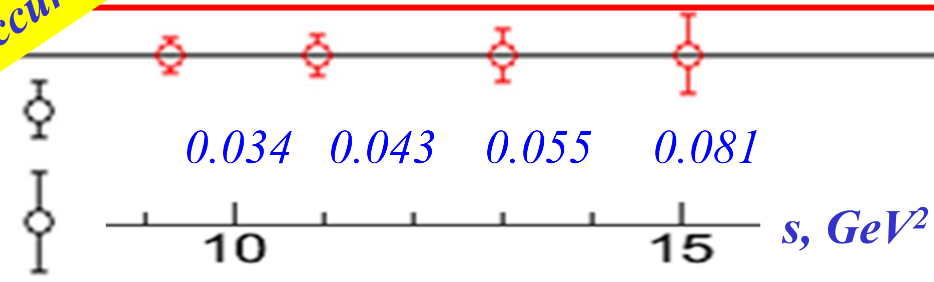
θ_{cm} : 80° – 100°

$<\theta_{cm}>$ ~ 90°



Projected Accuracy

High statistical accuracy



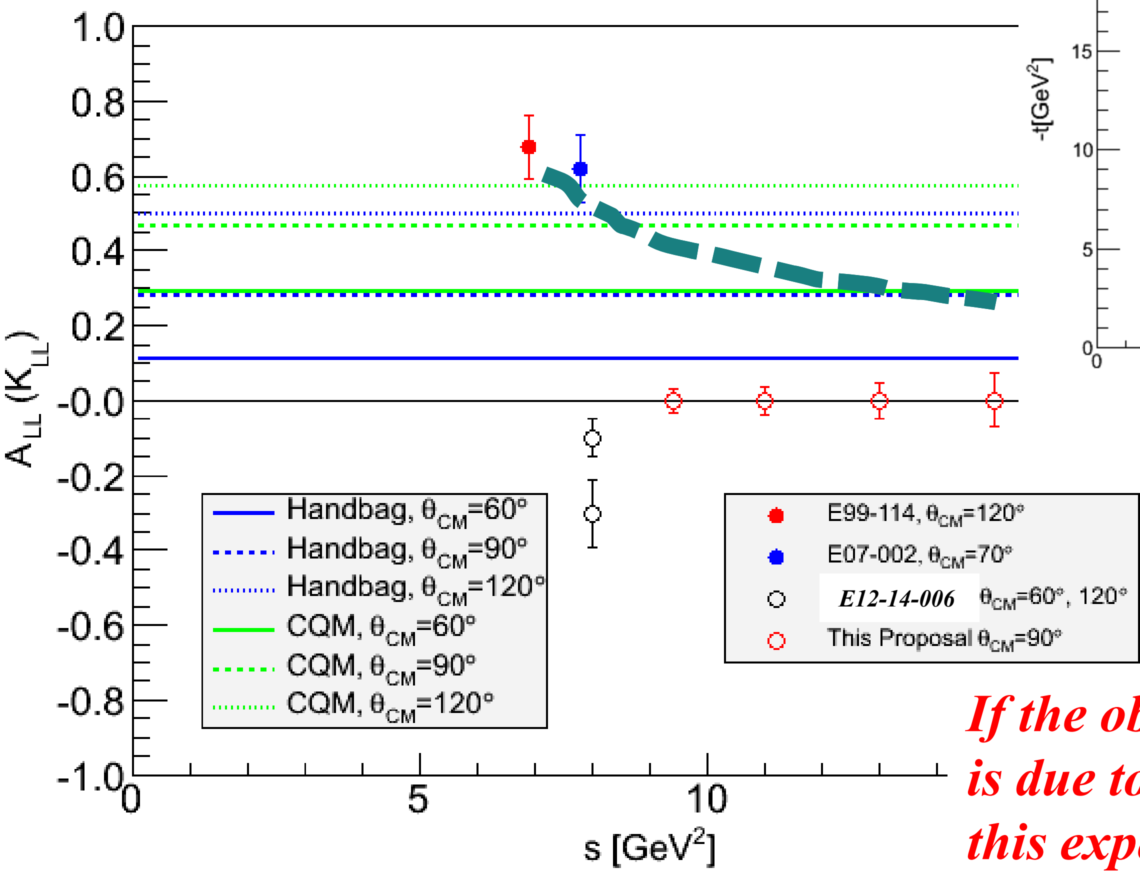
- *This Proposal, $\theta_{cm} = 90^o$*
- *E12-14-006, $\theta_{cm}=60^o, 136^o$ (-u~0.8 GeV^2)*

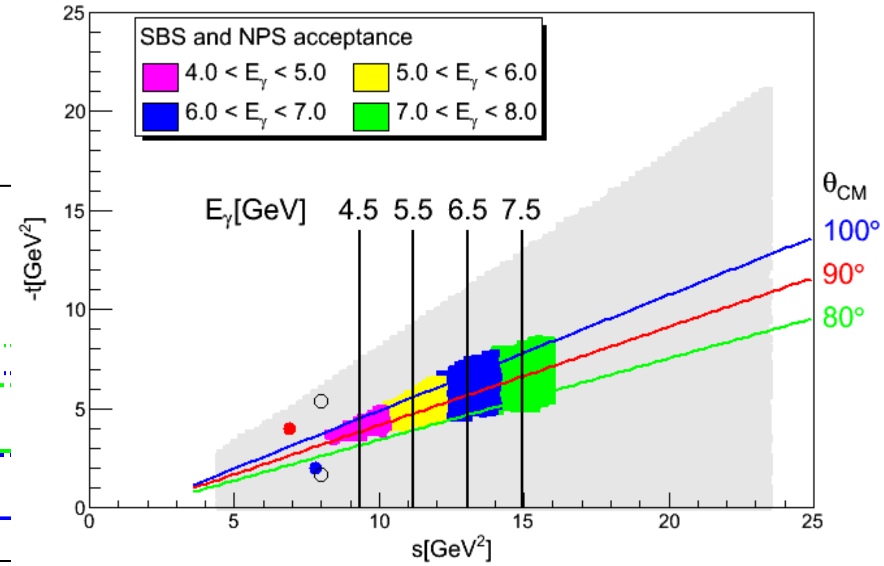
Good systematic accuracy

- ***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, $\delta(P_t*P_b)$~ 4%;***
- ***The beam pol. via Moller measurement, ~1%; the target pol. via NMR, δP_t ~5%.***

Projected impact of the results

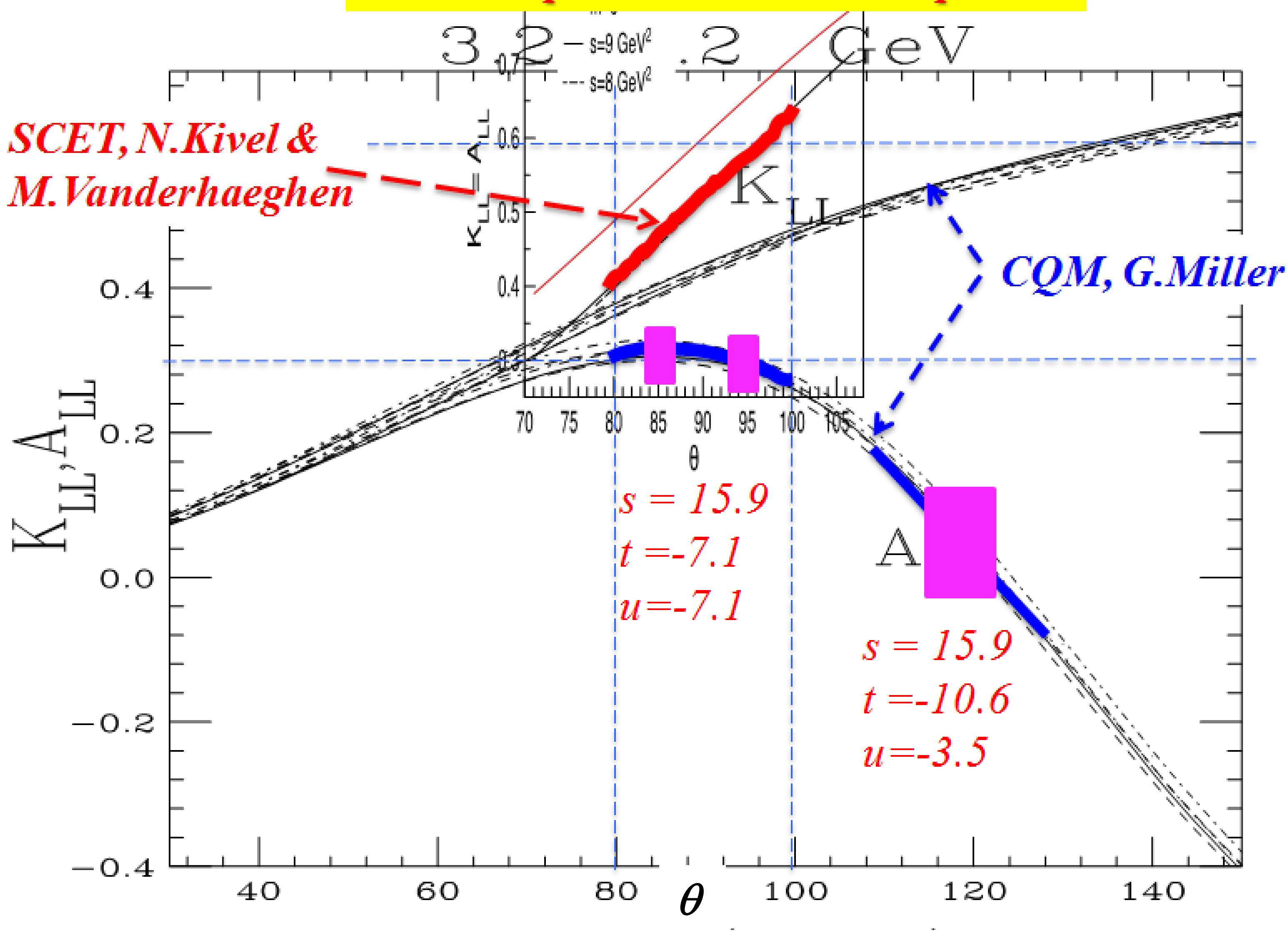




If the observed large K_{LL} at q_{cm} = 70º is due to large 1/s NLO contributions, this experiment should be able to observe an s dependence.

CQM Indicates that ALL != KLL

current quark vs. constituent quark



Quo Vadis?

- ***WACS* mechanism more intricate than previously thought (even in the nominal GPD/SCET range)**
- ***CPS (10x intensity, 100x yield). Reasonably inexpensive.***
- *Allow* A_{LL} *measurements* **s = 9- 15 GeV^2 at θ_{cm} ~ 90^o, 120^o**
- ***… useable for other (polarization) exp.:***
- ***A_{LT} with the same apparatus as A_{LL} (transversely polarized target)~ 20 beam days.***
- ***Σ asymmetry with Hall D apparatus, E ~ 9 GeV, only for low t (below 1 GeV^2) due to flux limitation (10^7 photons/s)***
- ***…***
- ***Thank you!***