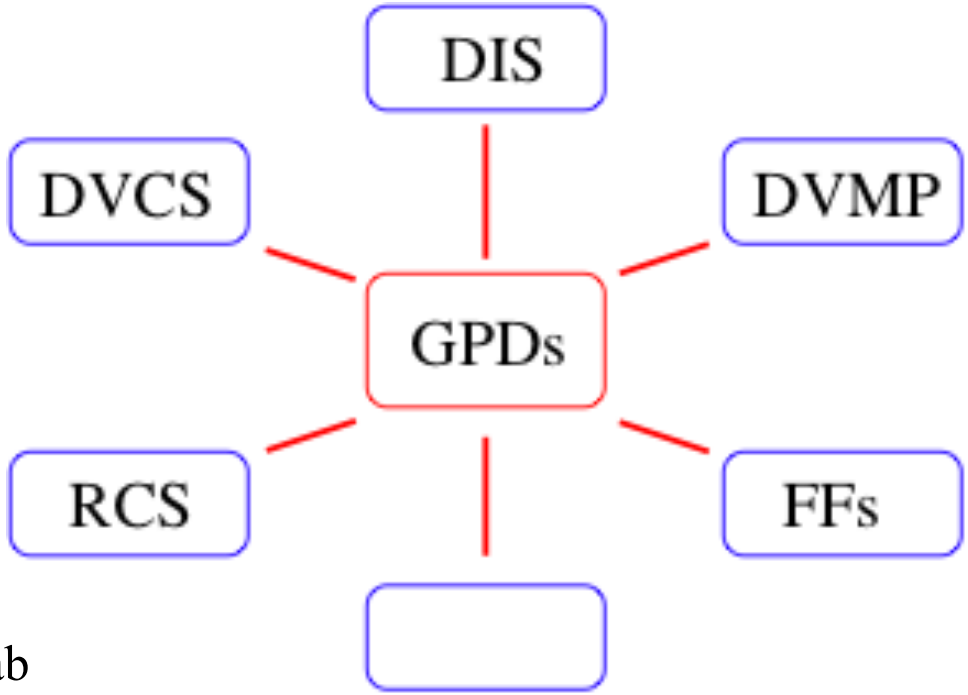
Large Acceptance Wide-Angle Compton Scattering Experiment

Bogdan Wojtsekhowski,
Thomas Jefferson National Accelerator Facility

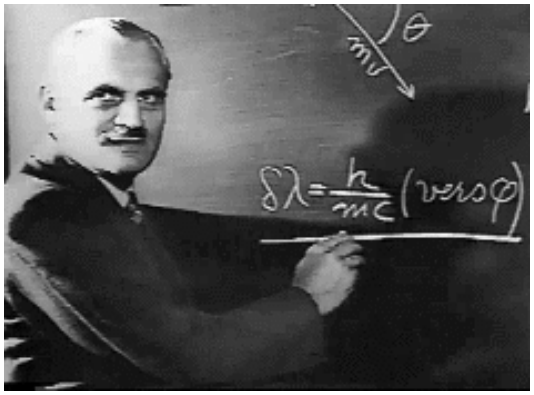
Physics of the nucleon via GPDs



- DIS – a major field, all x, Q^2, u/d, pol.
- DVCS – a main driver for QAM
- DVMP – many experiments @ HERA, JLab
- FFs – a very advanced field, all Q^2, E/M, TPE; SBS program
- RCS – two exp'ts. in "6-GeV era", 18+7 PAC days, dσ/dt with NPS/HMS – 18 days

Rolf: "RCS in WACS regime is the least explored sector"

Experiment is always the answer



Test of the reaction mechanism in the cloud chamber

Arthur Compton,

Physical Review (1925)

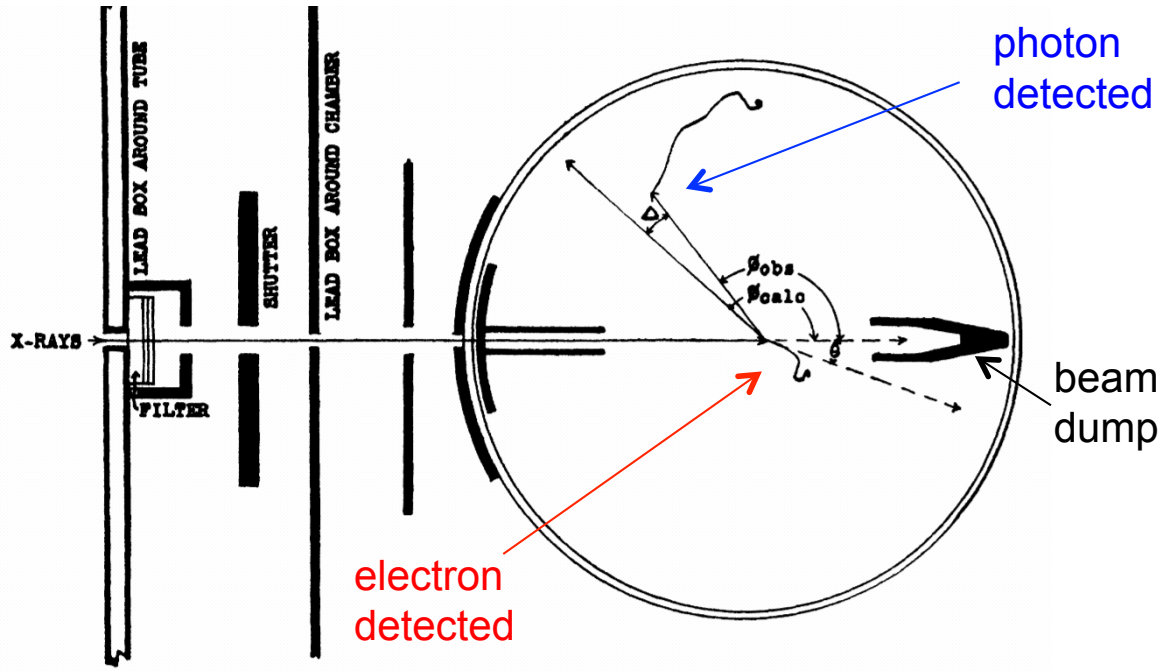


Fig. 1. Diagram of apparatus. On the hypothesis of radiation quanta, if a recoil electron is ejected at an angle θ, the scattered quantum must proceed in a definite direction ϕ_{calc}. In support of this view, many secondary β-ray tracks are found at angles ϕ_{obs} for which Δ is small.

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.*

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

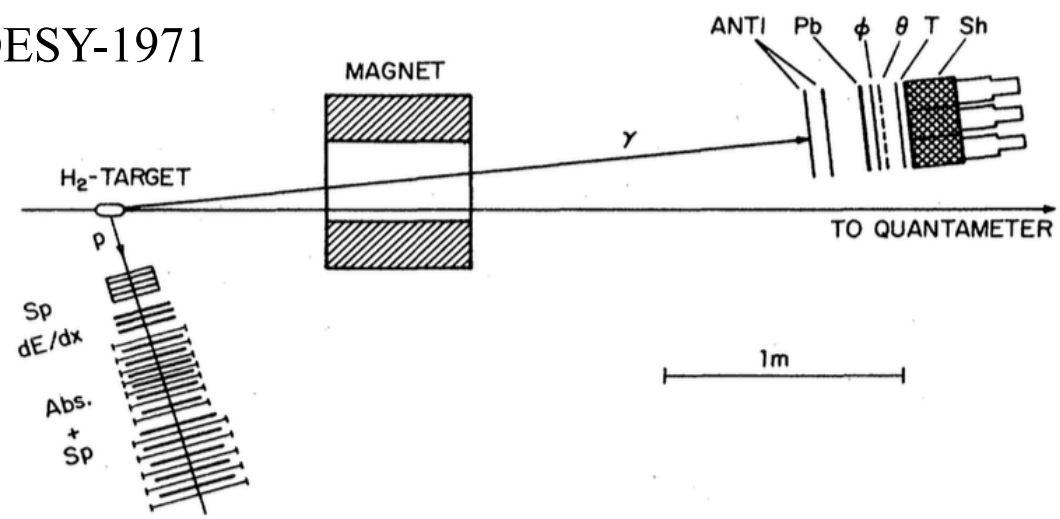


FIG. 44. Diagram of the apparatus used by the DESY group for Compton scattering measurements (from Buschhorn *et al.*, 1971a).

The photon flux is

2 x 10^8 γ/s

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

- Cornell - 1975 → The photon flux is **1.5 x 10^{10} γ/s**

Cornell's experiment

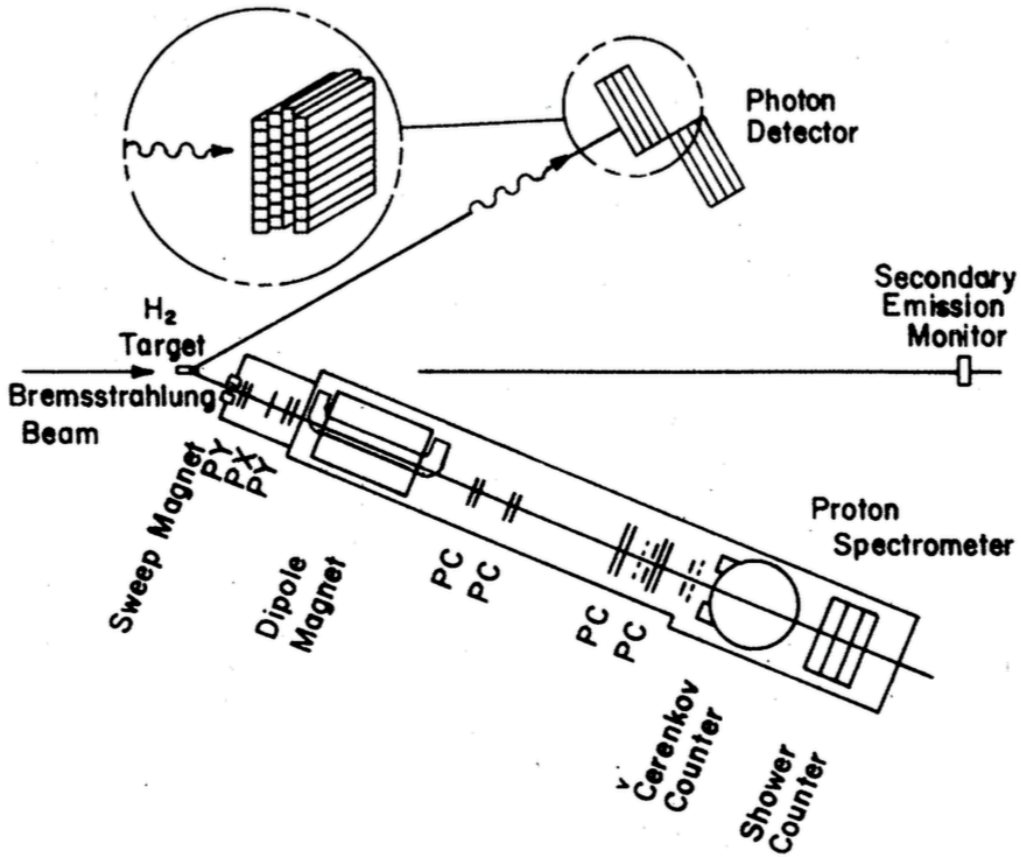

FIG. 1. Schematic floor plan of the apparatus. PY designates a pair of MWPC's with wires at ±7° to the horizontal, PX an MWPC with vertical wires, PC a pair of MWPC's with wires horizontal and vertical, and TH a scintillation counter trigger hodoscope. A perspective view of one of the two lead-glass arrays is depicted in the inset.

Cornell's experiment

sity. The incident photons were generated by an extracted electron beam focused to a spot approximately 3 mm in diameter on a 0.10-radiation-length aluminum target. The electrons in the resulting beam were magnetically diverted into a water-cooled dump. The bremsstrahlung photon beam passed through a collimator, sweeping magnet, scraper, and another sweeping magnet before entering the hydrogen target which was 11.5 m downstream of the radiator. At this point the beam was about 1.3 cm in diameter at the lowest energy. The hydrogen target cup was a cylinder 6.35 cm long by 5.08 cm in diameter oriented with its axis coincident with the beam direction.

Cornell's experiment

The incident beam flux was typically 1.2×10^{10} equivalent quanta per second, close to the maximum available from the synchrotron with our radiator. At this intensity the Compton scattering rate ranged from 50 to 0.1 events per hour; the rate of π^0 events was approximately 50 times the Compton scattering rate. At each data point the beam flux was limited by either singles rates in the proportional chambers closest to the target (2 MHz per wire was the maximum rate allowed in these chambers) or by accidental coincidences. Because of the loose trigger requirements and the high beam intensity, between 40% and 70% of the trigger rate was due to accidentals.

Experimental studies of the CS process

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

- Cornell - 1975 →
- JLab Hall A - 2002 →
- 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 of detector
- Low efficiency & analyzing power of the proton polarimetry
- Low value of the polarized target luminosity

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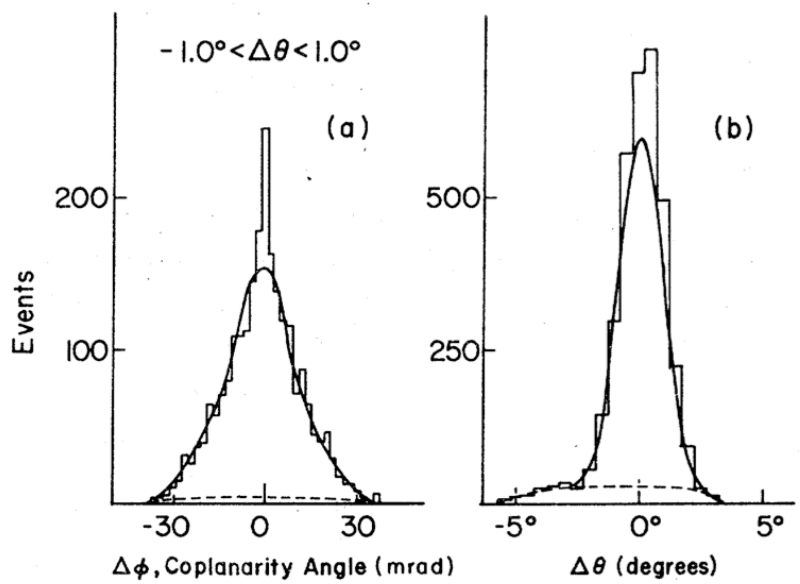
Avoid "a pure photon beam" if possible! or DESIGN IT WELL

Features of WACS

- The WACS cross section at fixed s/t drops fast, about $1/s^{7.5+}$

- An unavoidable aspect of the WACS measurement is the pion background, which could be separated only statistically. It dictates the need for the best angular resolutions and a minimum beam spot size on the target.



This plot shows that Cornell's 1977 exp't had insufficient separation between the RCS and pion processes and has caused confusion about s-scaling and applicability of the 2-gluon pQCD calculations in a few GeV energy regime for 25 years.

Cornell used a 1.3 cm diam. photon beam.

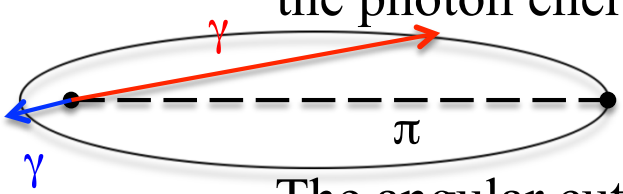
Pion background

There are two simple reasons for a large pion dilution factor:

$$D = \frac{N_{\gamma,\pi} + N_{\gamma,\gamma}}{N_{\gamma,\gamma}}$$

1) Cross section is around 20-100 times larger than the WACS cross section, especially for large scattering angles.

2) When the π^0 decay photon moves along the initial pion momentum (these are the part of events with which we are dealing for the D factor), the photon energy is very close to the full pion energy:



$$E_\gamma = E_\pi \cdot \left[1 - (\gamma_\pi \theta)^2\right]$$

The angular cuts, especially the vertical one, allow us to reduce **D**. However, even with high energy resolution of NPS, only little could be done for **D** in addition to the angular cuts.

Features of WACS; HCPS

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- A concept was presented at the NPS collab. meeting in Oct. 2014; we called it the Hermetic Compact Photon Source. The concept takes into account:
    - The efficiency & compactness of a magnet-assisted beam dump.

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  - A big difference between the γ-beam and radiation shower width

    => **"We can make it hermetic"**.

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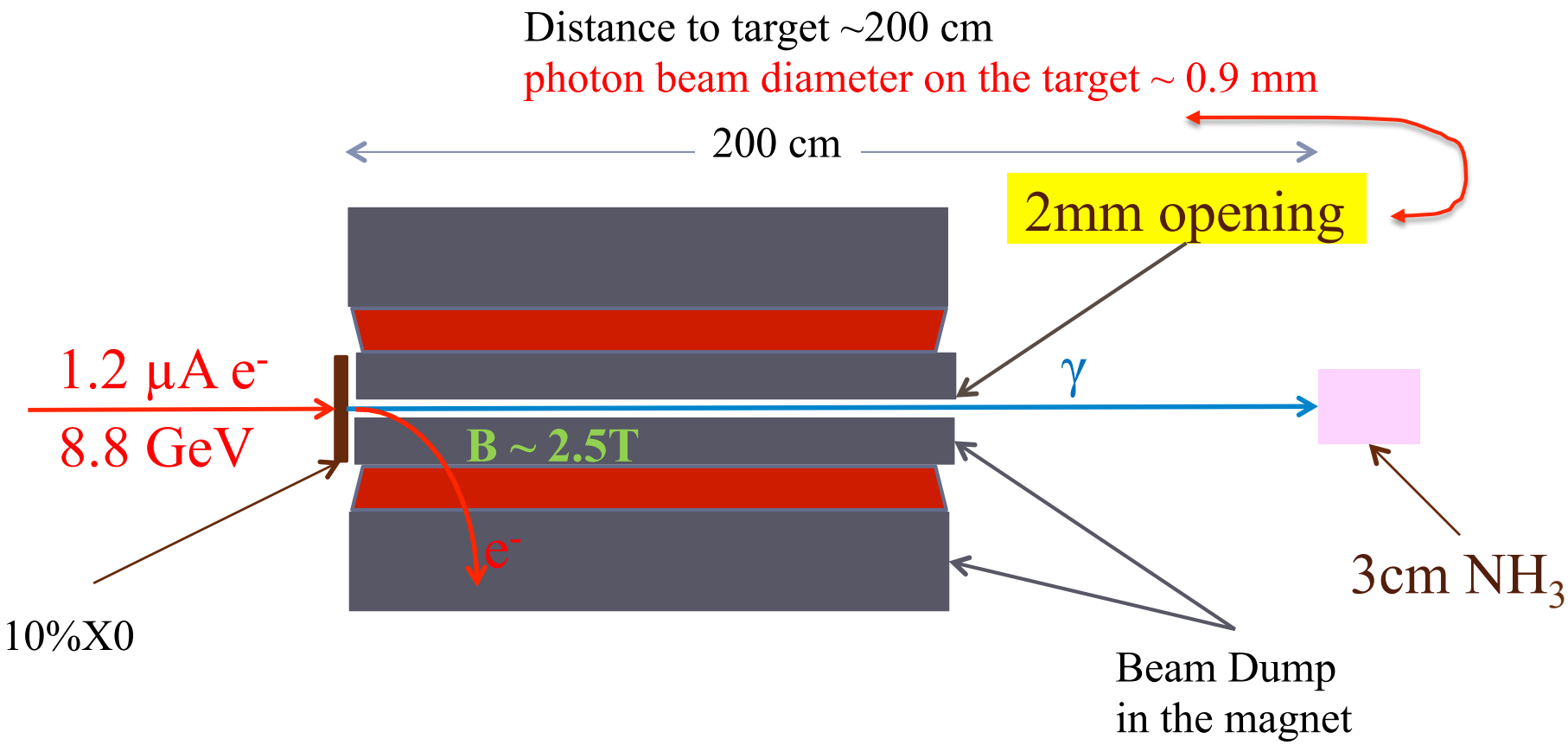
  - The required thickness of radiation shielding around the magnet.
  - A big difference between the γ-beam and radiation shower width => **"We can make it hermetic"**.
  - A big reduction in the shielding weight/cost due to dump's short length.
  - Several design ideas:
    - Narrow slots in a photon channel,
    - Vertical movement of the collimator synch. with beam rastering (could be replaced by the UVA target rotation),
    - Water cooling of the absorbers and magnet coils (total of 100 kW),
    - Reuse of the "green" blocks as an external shielding,
    - Control of a magnetic force on the target solenoid, etc.

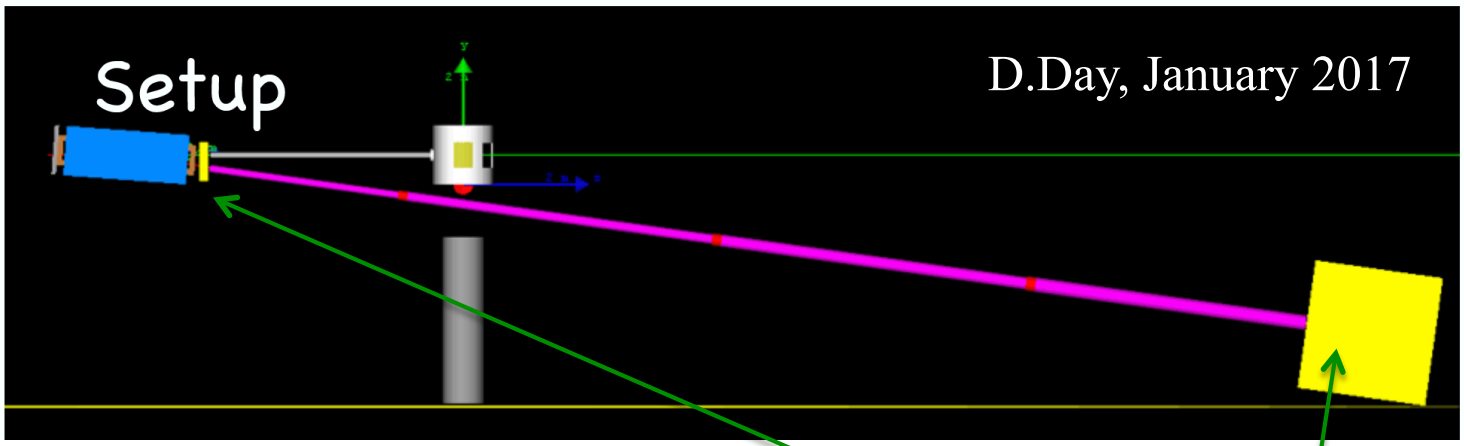
Hermetic Compact Photon Source



Novel concept allows high photon intensity and low radiation in the hall

Regarding a traditional "beam dump" scheme

The shielding a "Separated Function Pure Photon Source" would be difficult and expensive due to the large size of the area which requires shielding and a wide electron energy spectrum.



~ 20 m

25% 75%

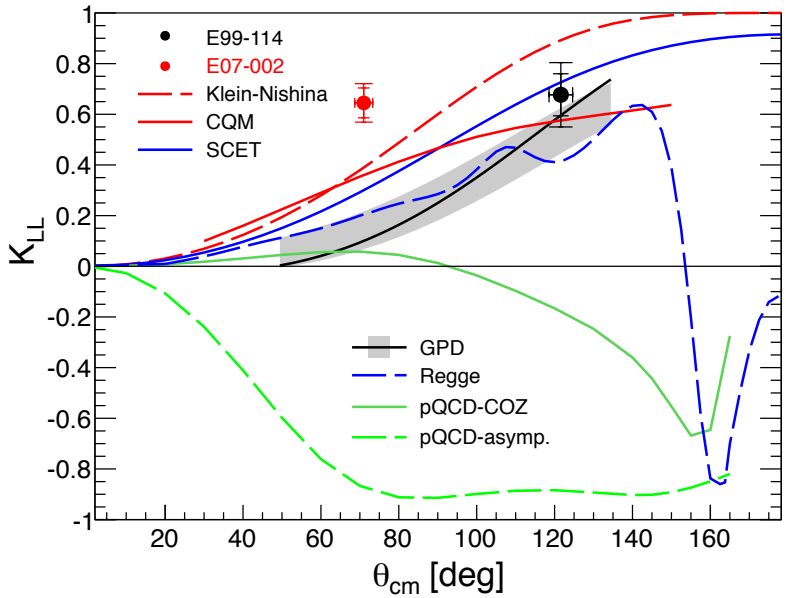
Power in the tail is defined by the integral

$$P_b \cdot t_{rad} \cdot \int_{0.03E_b}^{E_b} \frac{E_b - E_\gamma}{E_b} \frac{dE_\gamma}{E_\gamma}$$

7.5 kW

Why a large acceptance experiment?

For the WACS process far above the resonance region, the cross section drops fast, about $1/s^{7.5+}$. However, the asymmetries are slow functions of s and s/t.



Integration over a 10-20% wide photon energy range and a 20 deg. cm angle range is productive => A_{LL} WACS could/should use a large acceptance detector system. High resolutions are needed mainly for reduction of the pion dilution factor.

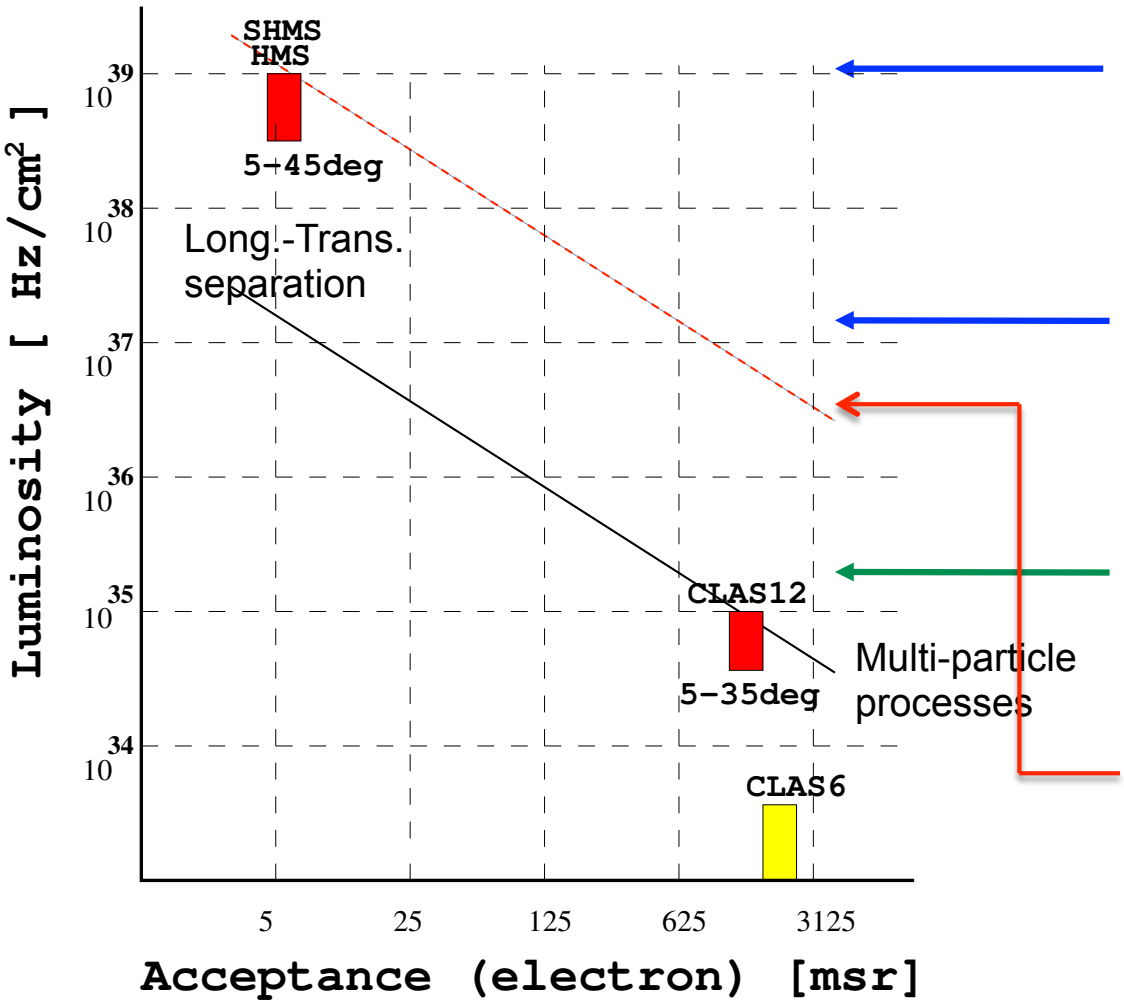
Projected detector single rates with the large acceptance system

- Photon arm detector (100 msr, 2 meters, 28 deg.):
  - NPS trigger (1/4 E_{elas} ~ 1 GeV) ~ 300 kHz
  - NPS energy flow per module – 1 MeV / 100 ns
- Proton arm detector (70 msr, 4-6 meters, 25 deg.):
  - SBS trigger (HCAL) (1/4 T_{elas} ~ 1 GeV) ~ 100 kHz
  - SBS GEM tracker < 1 kHz/cm^2
  - Pion rate and p/π ID π^+/p ~ 10, ID by RICH as in SIDIS exp't

Values are for the total gamma-nucleon luminosity $6*10^{36}$ /cm^2/s

Do we have such a detector?
JLab detector landscape

A range of 10^4 in luminosity.



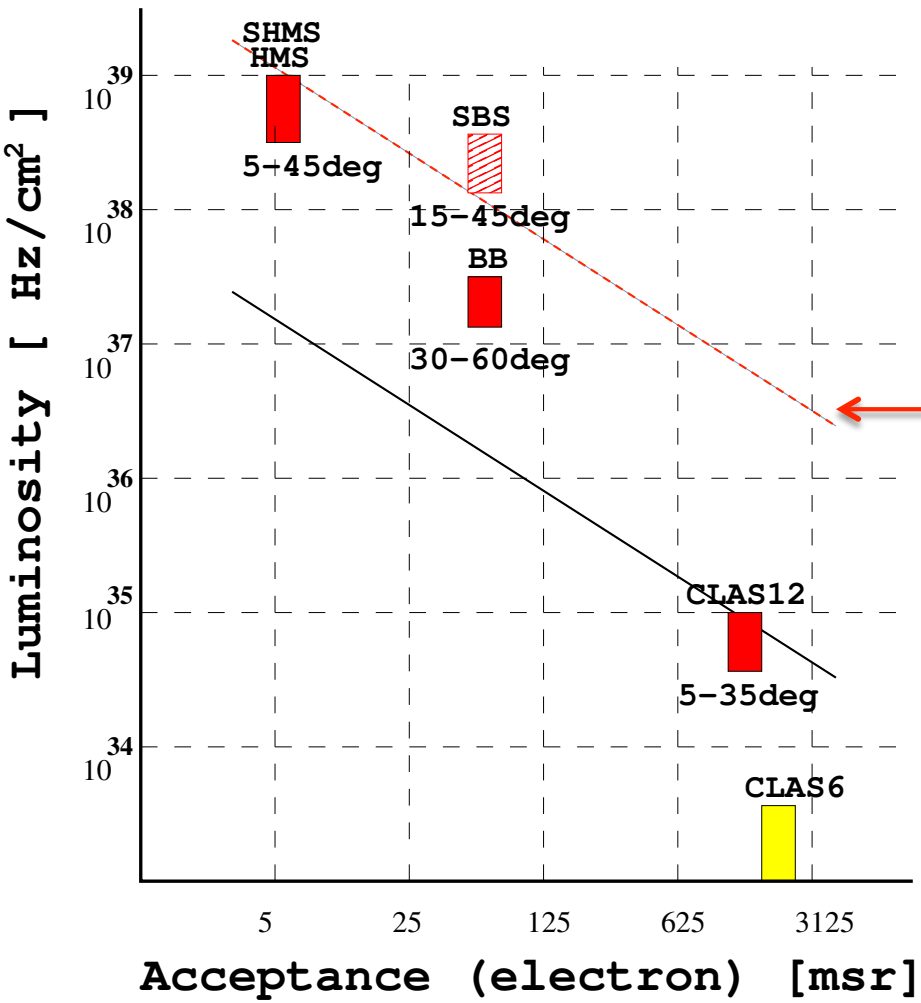
The LH_2 target can be used up to $L_{eN} \sim 10^{39}$

The polarized ^3He at $L_{eN} \sim 10^{37}$

The polarized NH_3 at $L_{eN} \sim 10^{35}$

Pure photon beam: $L_{\gamma N} \sim 6*10^{36}$

JLab detector landscape



A range of 10^4 in luminosity.

A big range in solid angle:
from 5 msr (SHMS)

to about 1000 msr (CLAS12).
==========

The SBS is in the middle
with solid angle up to 70 msr.

Pure photon beam: $L_{\gamma N} \sim 6*10^{36}$

A large acceptance spectrometer

Projected parameters of the Super Bigbite Spectrometer

Solid angle =>

$\theta_{central}$, degree	Ω, msr	D, meter	Hor. range, degree	Vert. range, degree
3.5	5	9.5	$\pm$ 1.3	$\pm$3.3
5.0	12	5.8	$\pm$ 1.9	$\pm$4.9
7.5	30	3.2	$\pm$ 3	$\pm$8
15	72	1.6	$\pm$ 4.8	$\pm$12.2
30	76	1.5	$\pm$ 4.9	$\pm$12.5

Resolution:

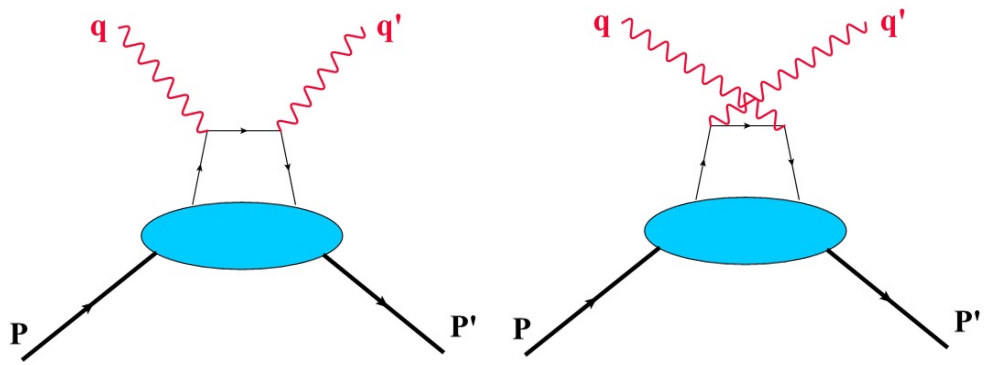
Momentum => $\frac{\sigma_p}{P} = 0.0029 + 0.0003 \times p[\mathrm{GeV}]$

Angular => $\sigma_\theta = 0.14 + 1.3/p$ [GeV], mrad

Momentum acceptance

=> unlimited above 1-2 GeV/c

Compton scattering with GPD



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

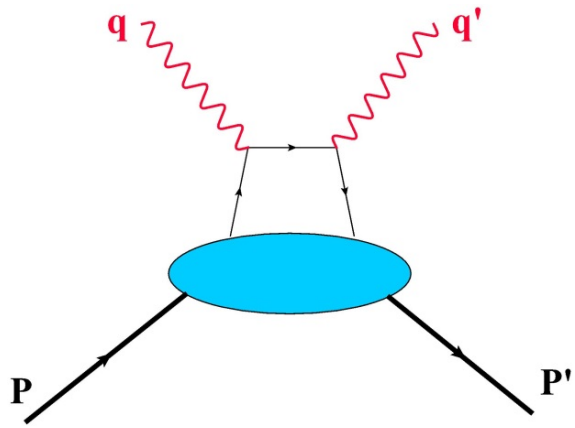
M.Diehl & P.Kroll
Eur. Phys. J. C 8, 409 (1999);
Phys. Lett. B 460, 204 (1999)

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

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

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

FFs, GPDs and Polarization Observables



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

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

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

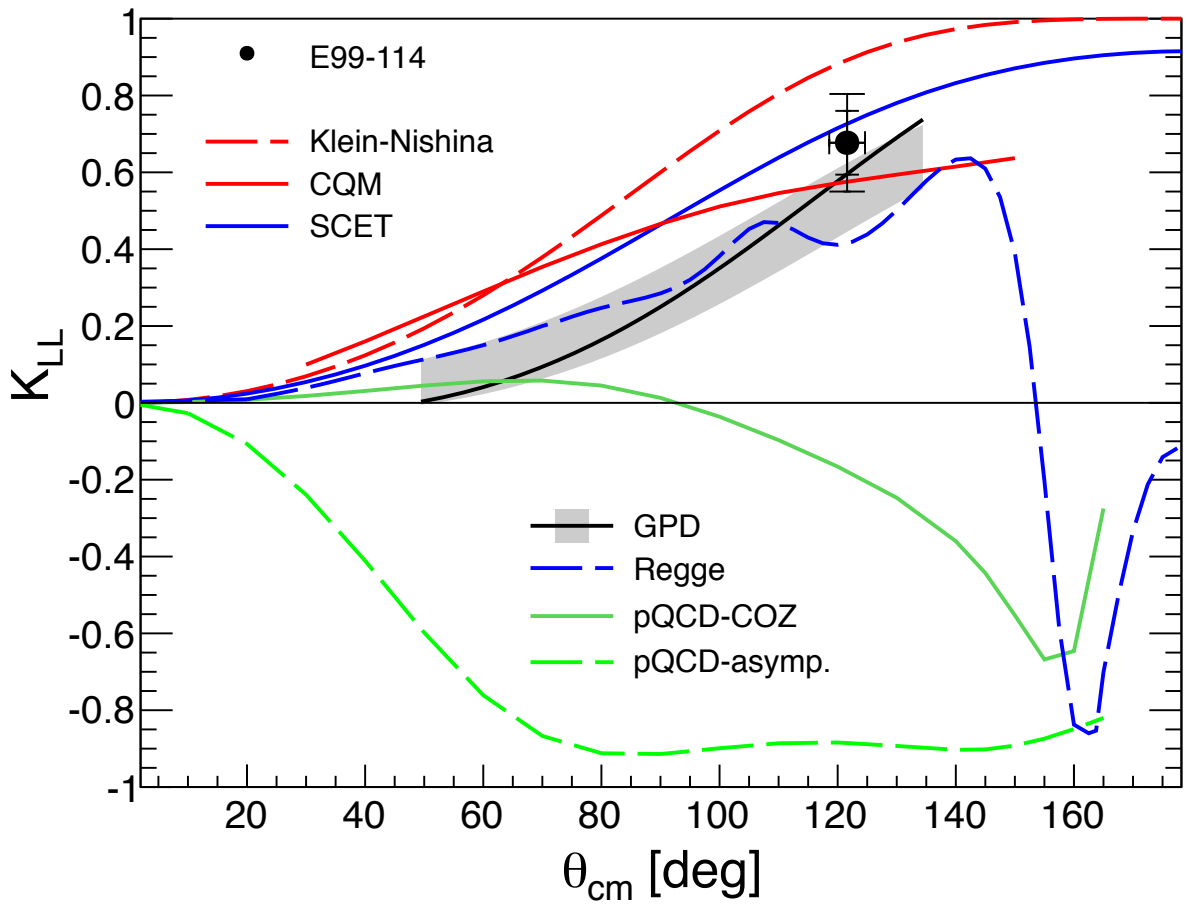
for m=0 $$K_{LL}^{KN} = \frac{s^2 - u^2}{s^2 + u^2}$$

M.Diehl & P.Kroll

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

Based on that, we added the K_{LL} measurement and resubmitted the WACS proposal in 1999

Striking disagreement with a 2-gluon pQCD

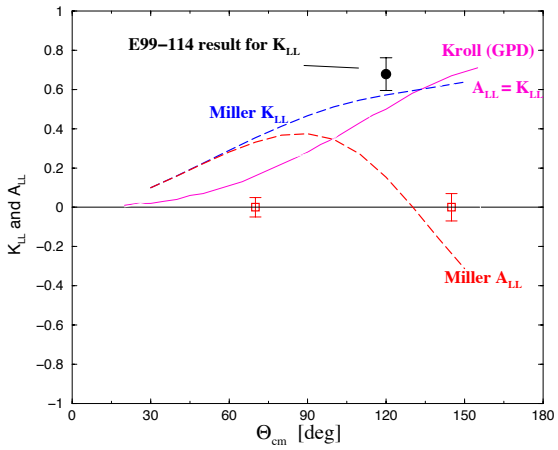


E99-114
s=6.9, t=-4.0, u= -1.1 GeV^2

Strong evidence for handbag mechanism

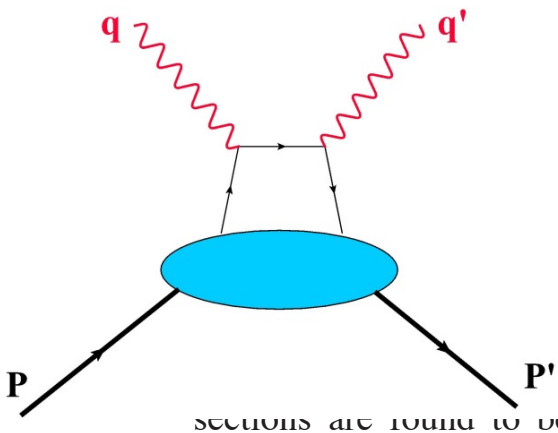
PRL **94,** 242001 (2005)

ALL experiment for WACS



PHYSICAL REVIEW C **69**, 052201(R) (2004)

handbag diagram in Compton scattering on the proton



Gerald A. Miller

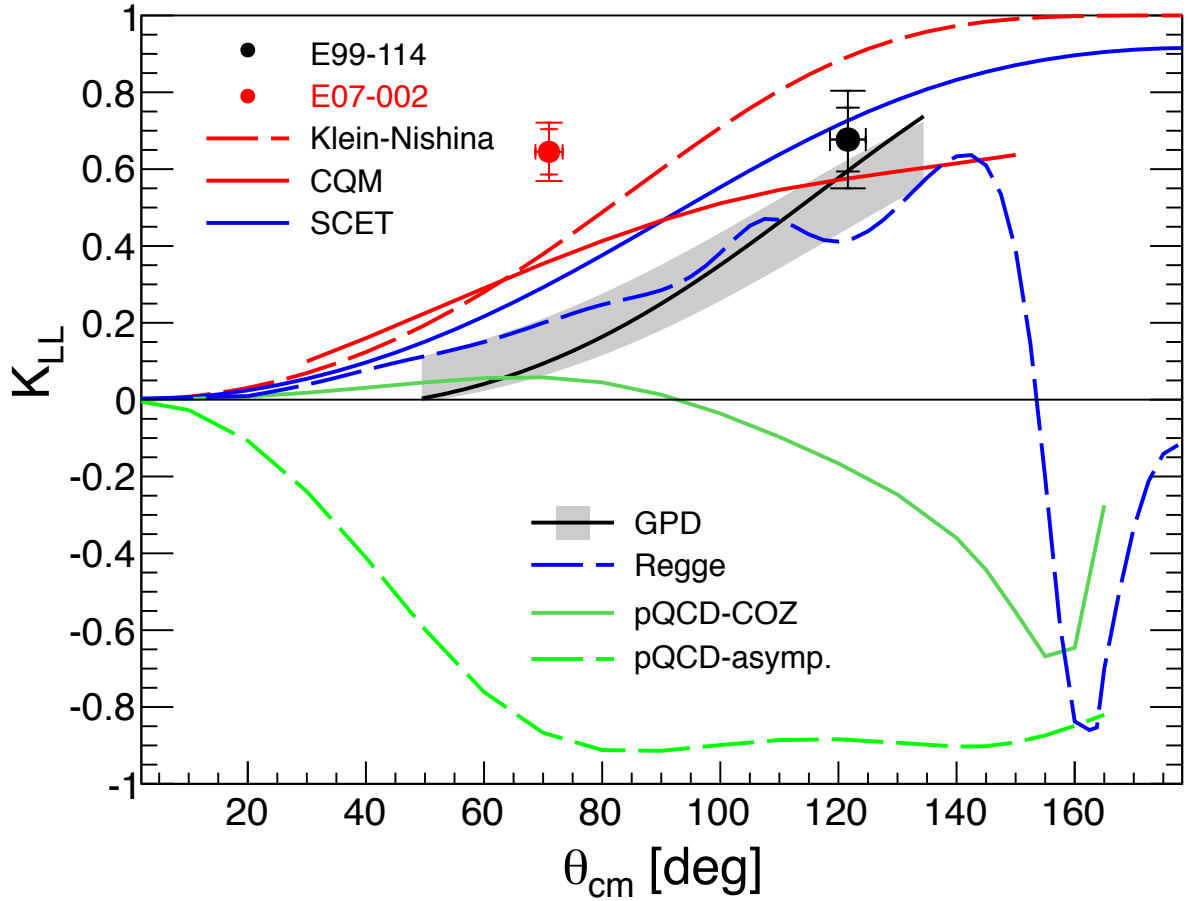
f Physics, University of Washington, Seattle, Washington 98195-1560, USA

(Received 1 March 2004; published 25 May 2004)

;auge invariance, conservation of parity, and time reversal invariance are respected in
›n evaluation of the handbag diagram. Proton wave functions, previously constrained
:asured form factors, that incorporate the influence of quark transverse and orbital
the corresponding violation of proton helicity conservation) are used. Computed cross
sections are found to be in reasonably good agreement with early measurements. The helicity correlation between the incident photon and outgoing proton, K_{LL}, is both large and positive at back angles. For photon laboratory energies of $\leqslant 6$ GeV, we find that $K_{LL} \neq A_{LL}$, and $D_{LL} \neq 1$.

This result of Jerry's nicely shows that A_{LL} is not equal to K_{LL} due to hadronic helicity flip. At the same time, in his recent email Jerry said that CQM is just a toy model, and actual uncertainty (and the role of the hhf) in the prediction for A_{LL} requires a new investigation.

Physics motivation and a surprise



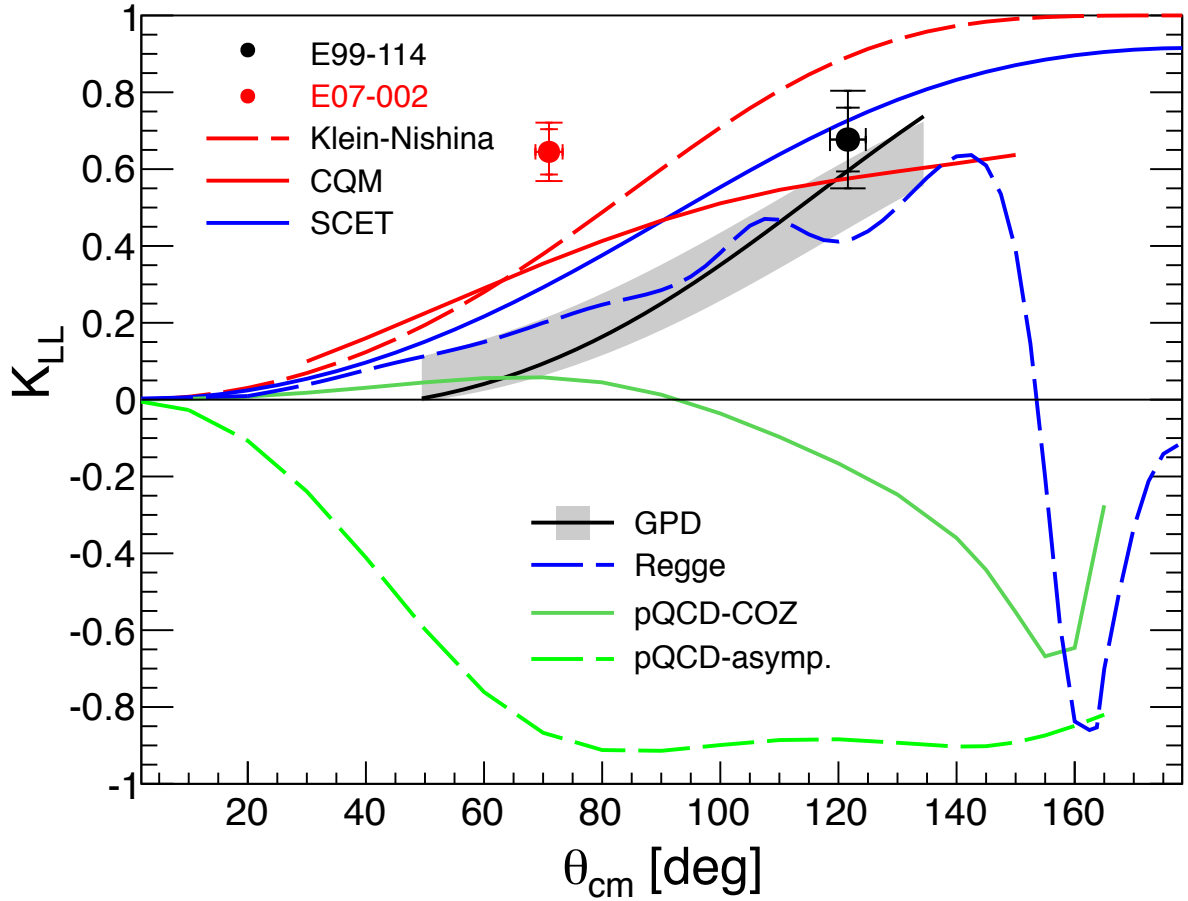
E99-114
s=6.9, t=-4.0, u= -1.1 GeV^2

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

Strong evidence for additional physics?

PRL 115, 152001 (2015)

Physics motivation and a surprise



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PRL 115, 152001 (2015)

New measurement at larger s, t, u values is necessary to clarify the mechanism of WACS and constrain F_A

WACS experimental considerations

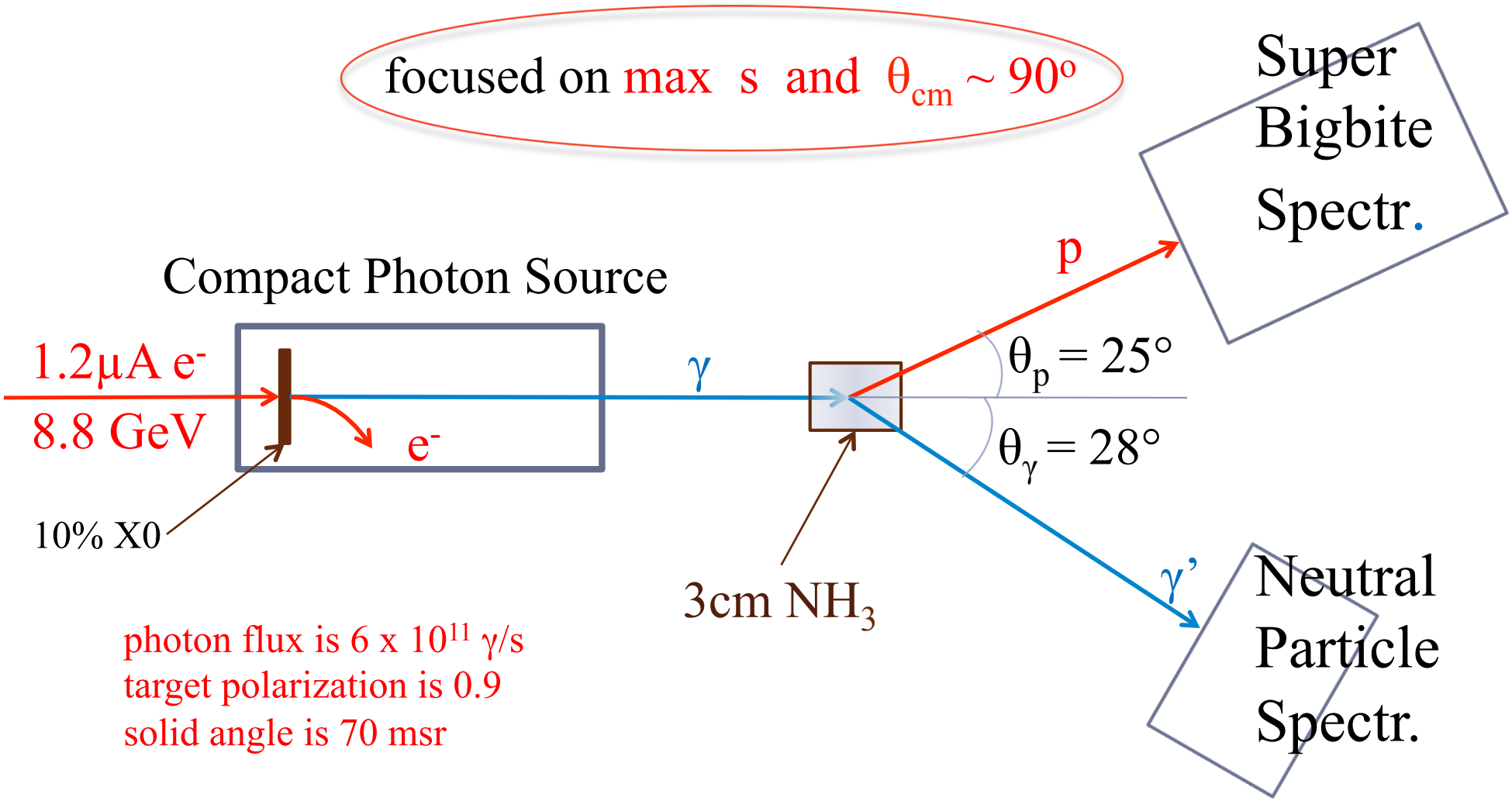
- K_{LL}
  - Beam intensity: 2 x 10^{13} γ/s
  - Polarimeter: figure-of-merit ~ 0.001
  - Solid angle of apparatus: HRS/HMS ~ 6-7 msr

- 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}

We would like to measure A_{LL} not to find a difference between K_{LL} and A_{LL} , which could be as small as 0.01, but because the A_{LL} measurement would be much more efficient than the K_{LL} ones and allow a productive WACS experiment at high s and t.

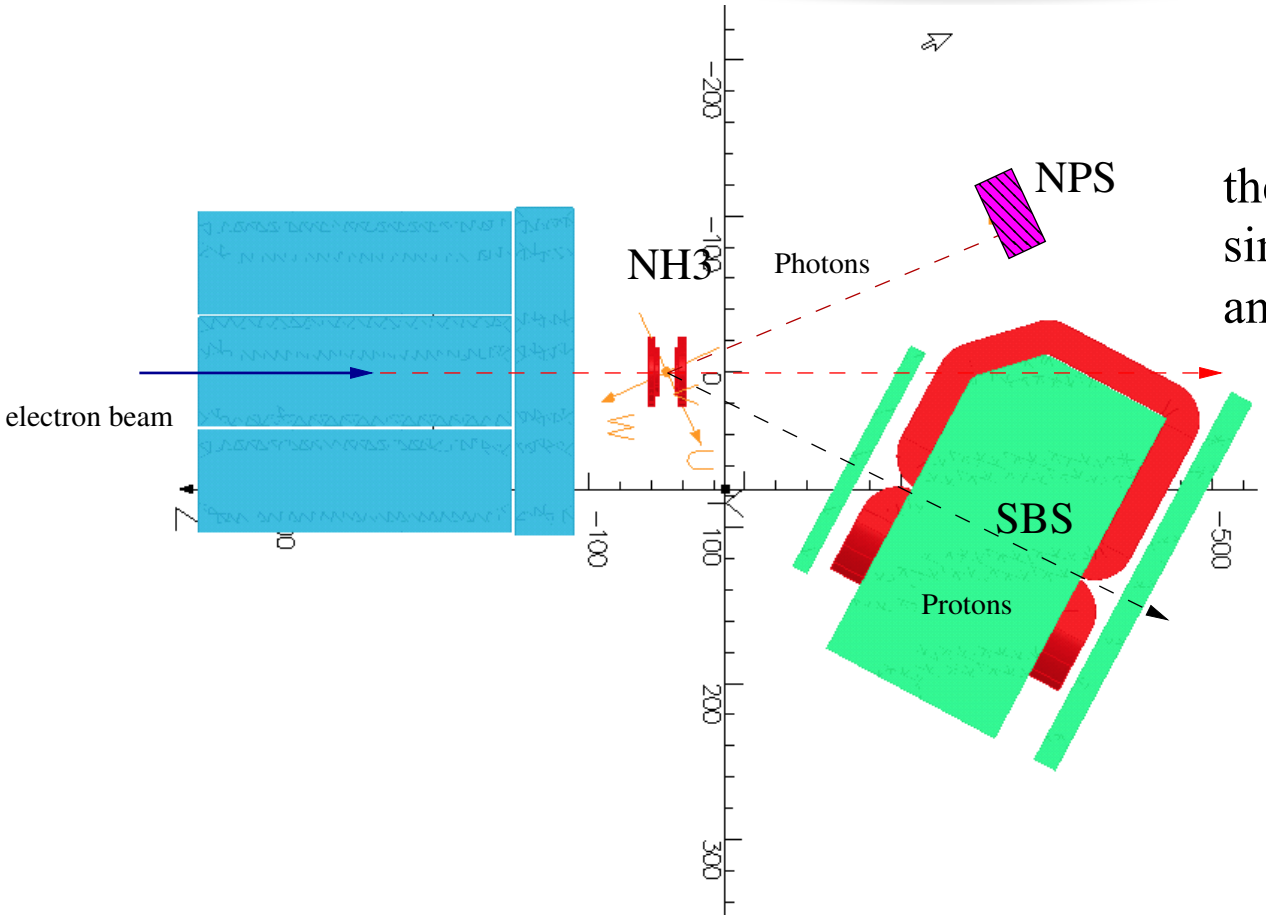
Our plan to measure A_{LL}



photon flux is 6 x 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 the GEANT simulation of physics, radiation and magnetic field calculations

Kinematic range

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

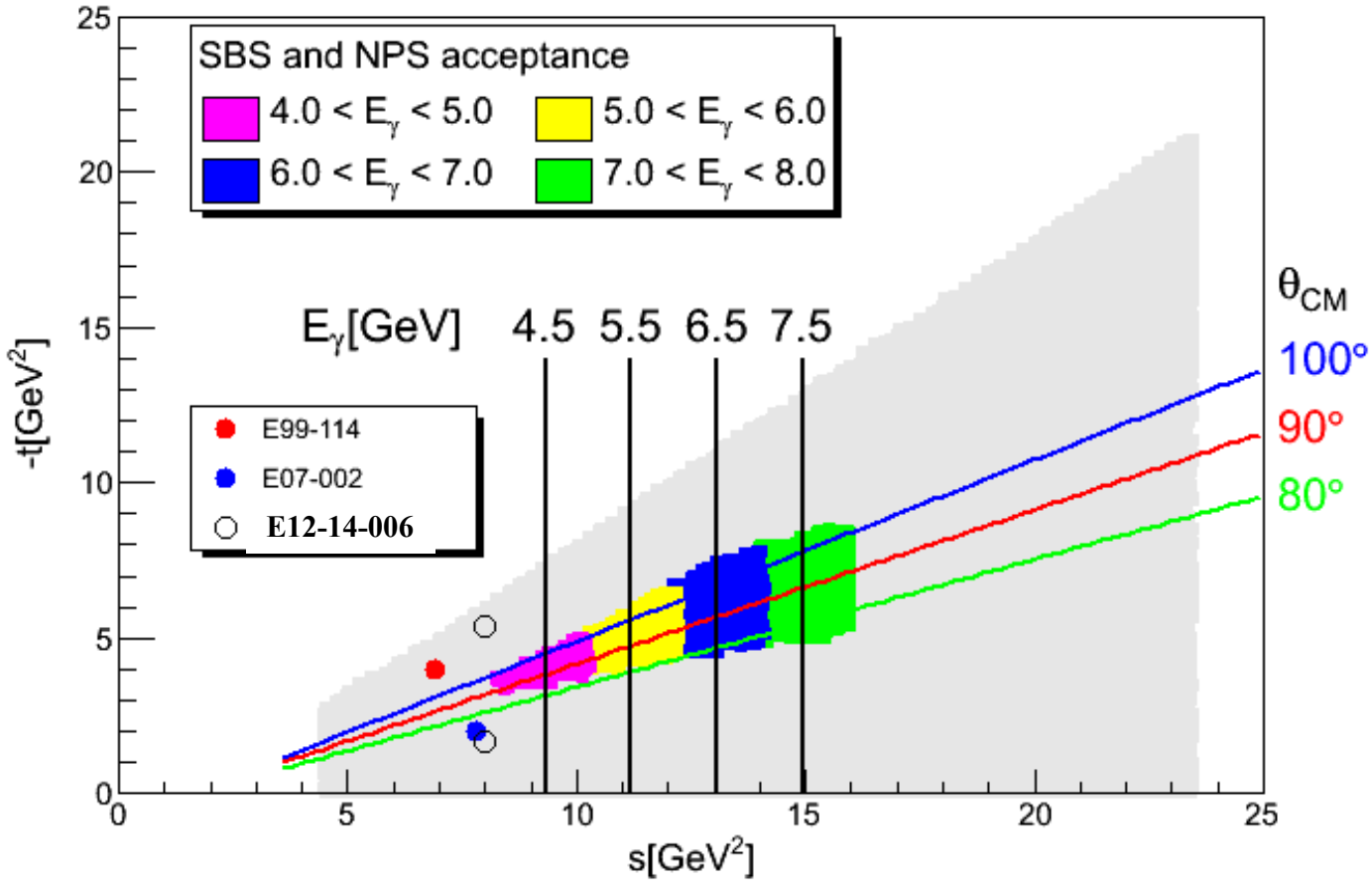
s: 8.0 – 16.0 GeV^2

-t: 3.0 – 7.0 GeV^2

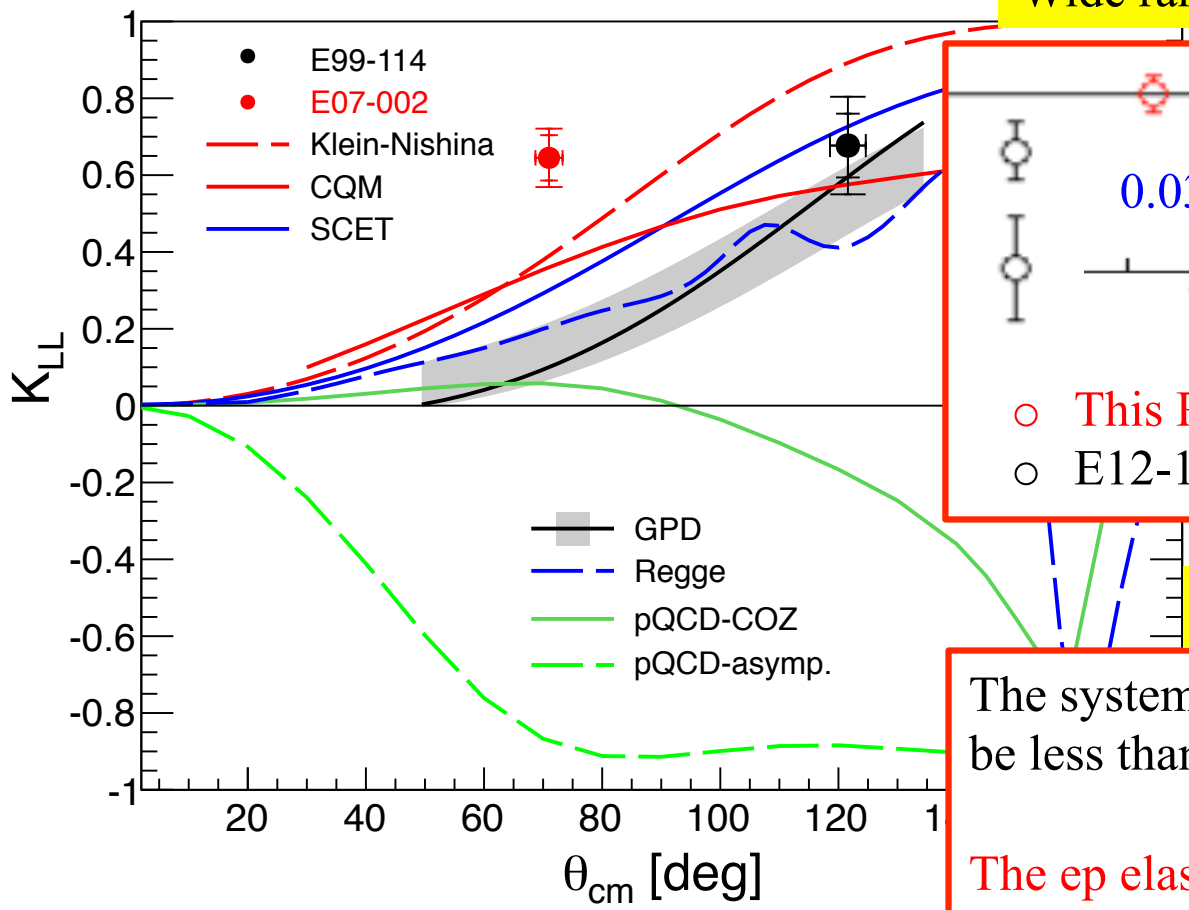
-u: 3.0 – 7.0 GeV^2

θ_{cm} : 80° – 100°

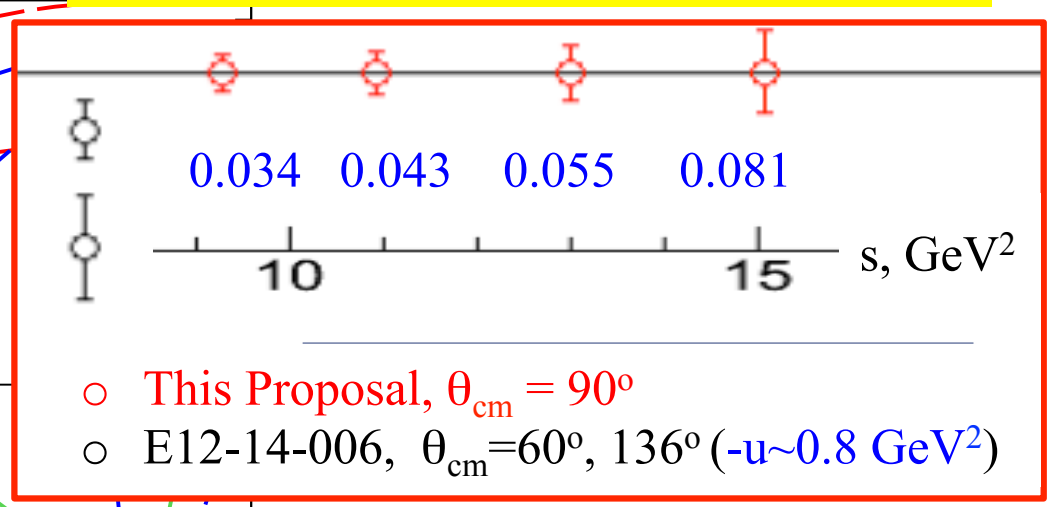
$\langle\theta_{cm}\rangle \sim 90°$



Physics Motivation, projected accuracy



Wide range of s. High statistical accuracy.

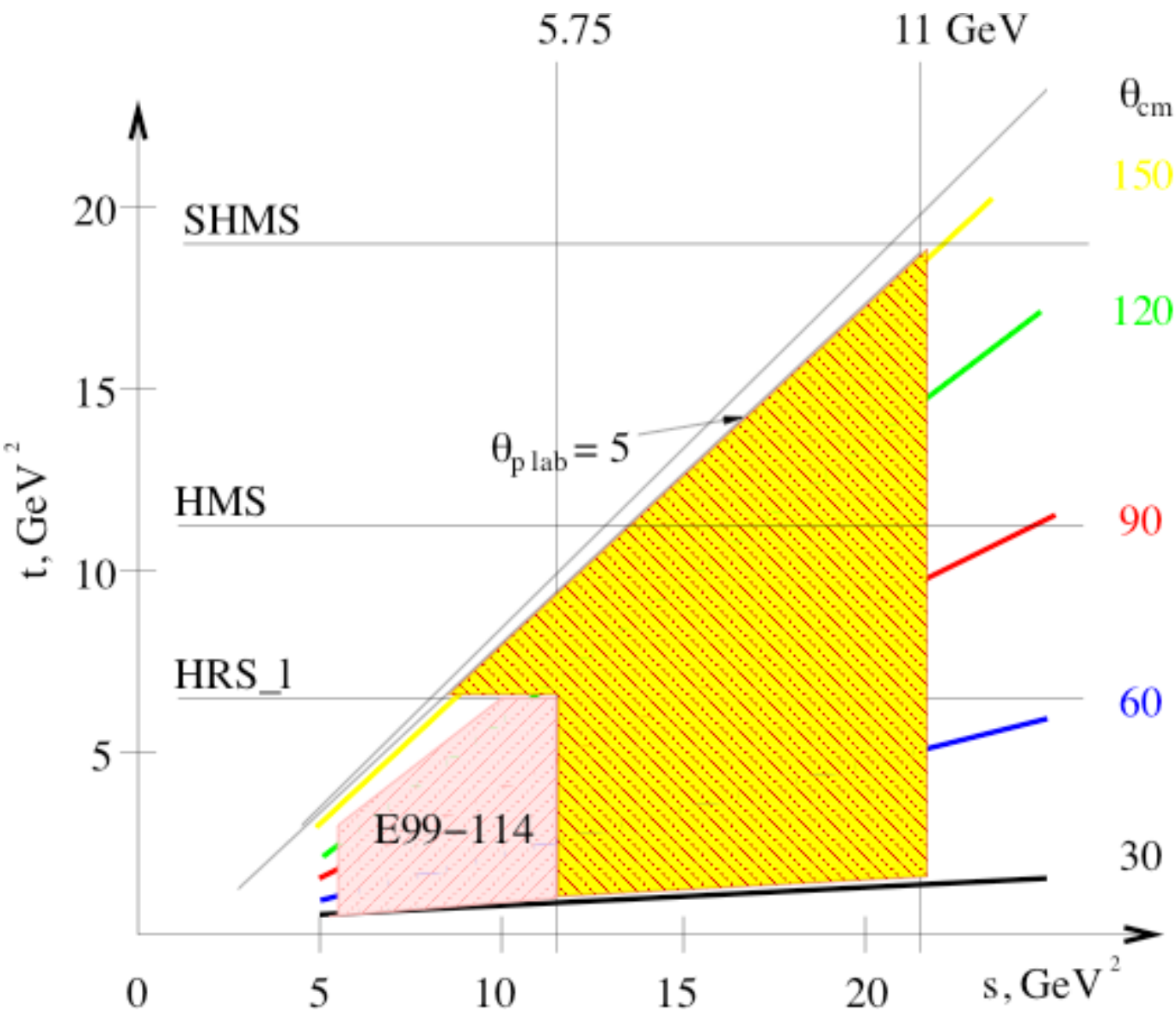


Good systematic accuracy.

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%.

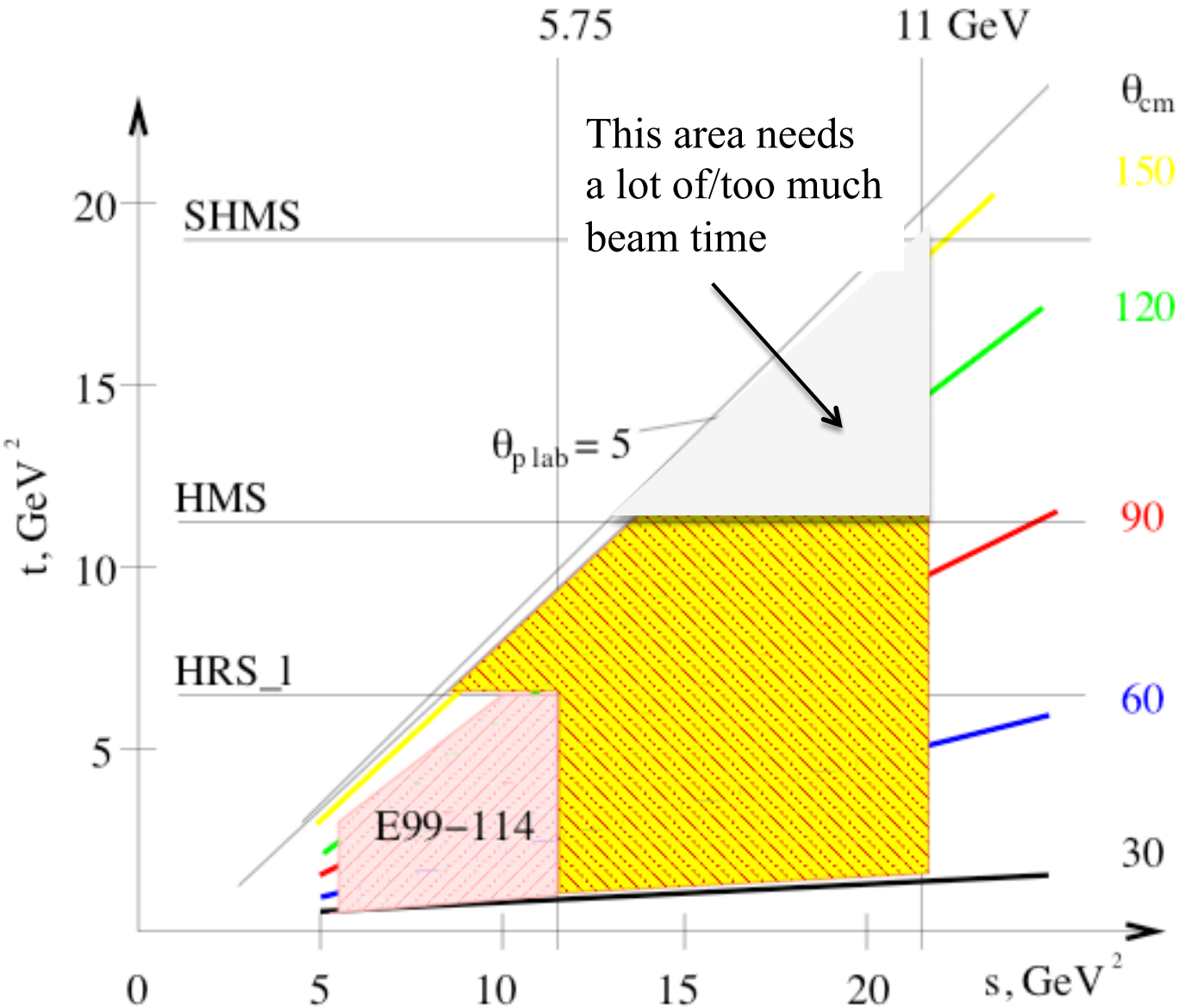
Kinematical s-t map



$d\sigma/dt \propto 1/s^{7.5}$

at fixed θ_{cm} doubling of s costs 180 in rate .

Kinematical s-t map



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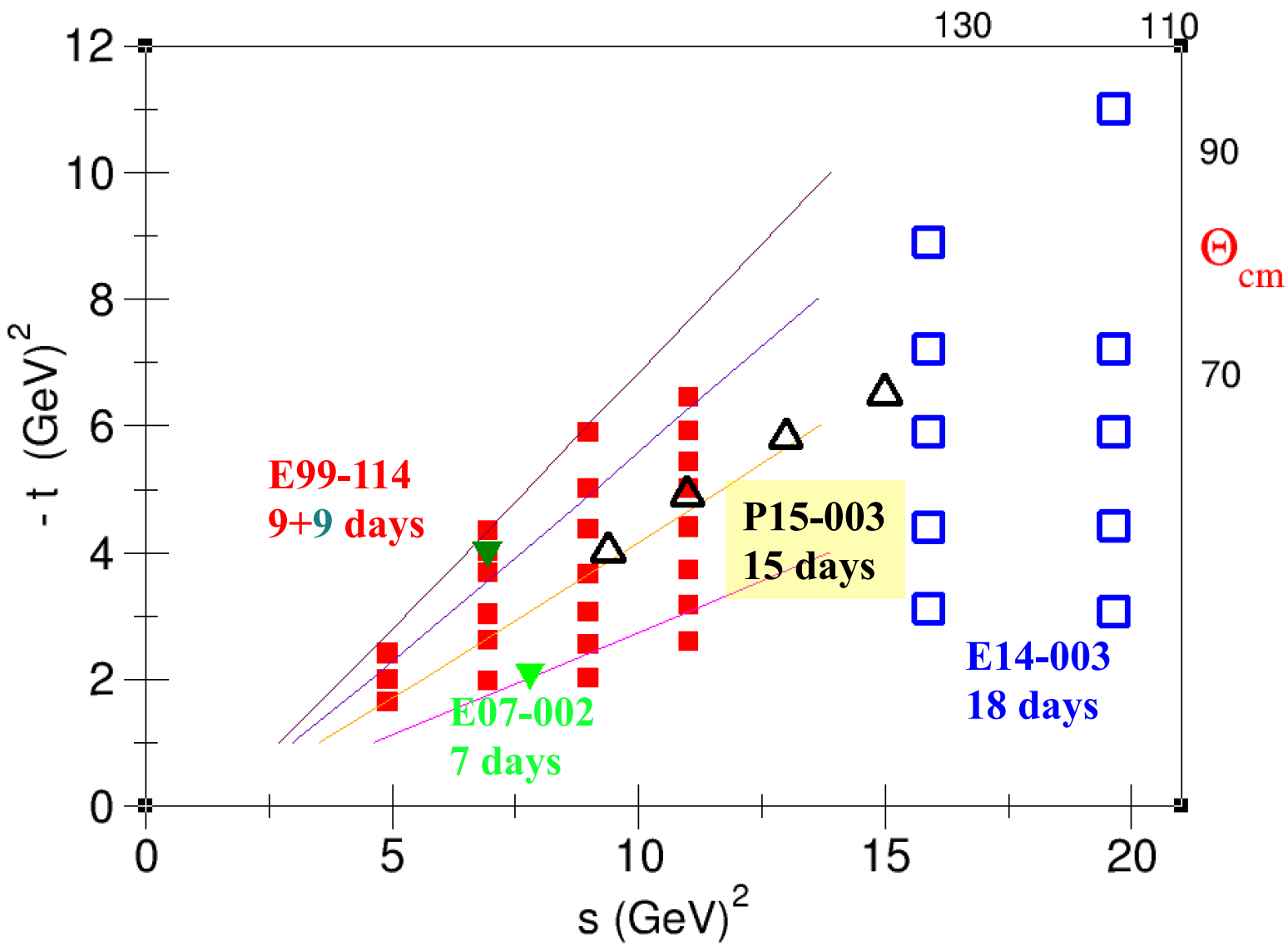
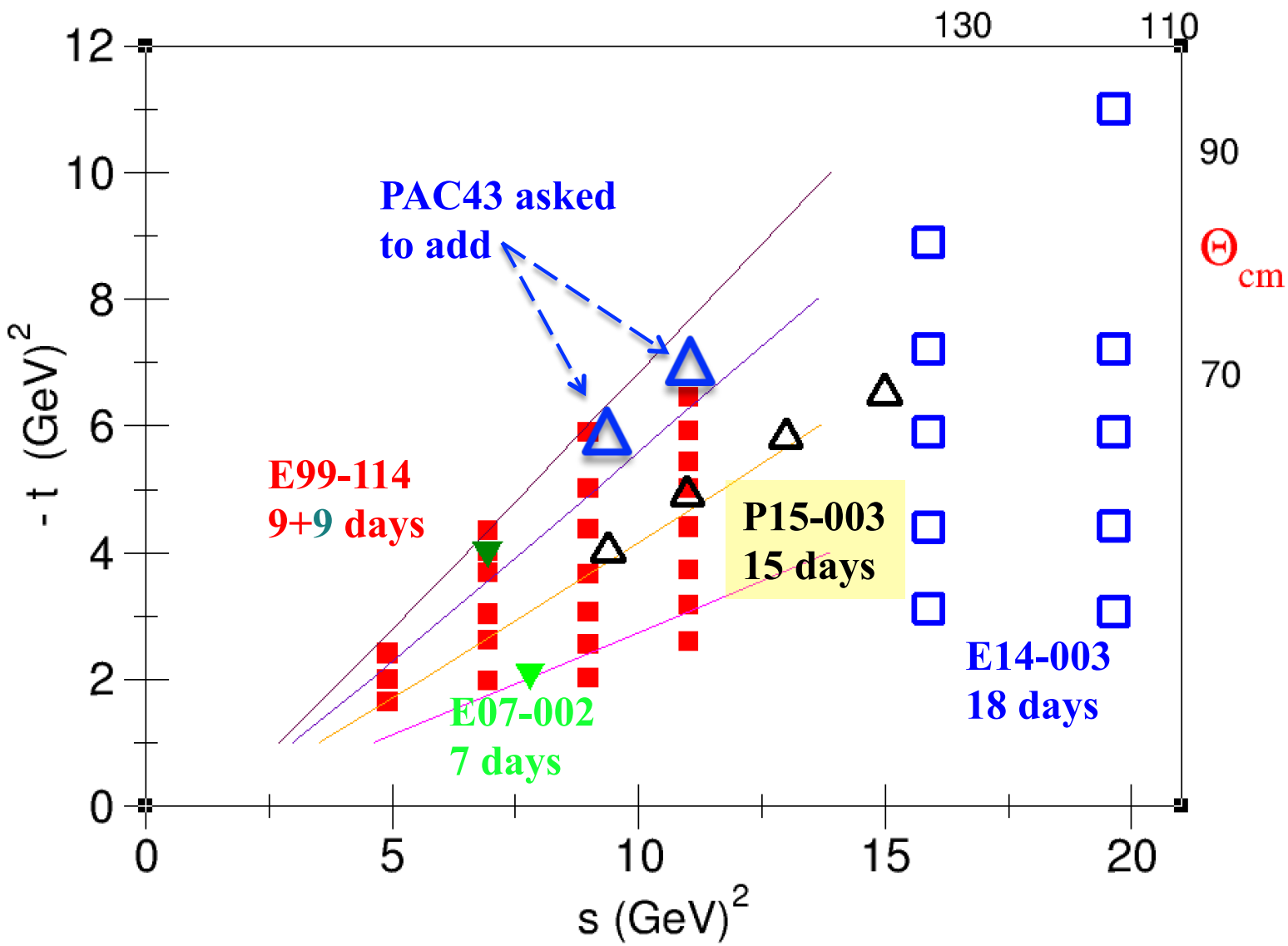
Kinematical s-t map



Kinematical s-t map



Summary

- The measurement of WACS asymmetry should be done with a large acceptance spectrometer and a high resolution calorimeter which allow a 10-fold increase in the acceptance.

- A novel scheme of a photon source "electron-dump" allows a 10+ 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 $\theta_{cm} \sim 90^o$ in a relatively short period of beam time (15 days). Additional time would allow the measurement at $\theta_{cm} \sim 120^o$.