High energy photon polarimetry

B. Wojtsekhowski, JLab

motivated by the DVCS proposal

under development by Maxime Defurne, Saclay

Photon polarimetry

- Neutral pion: π^o decay to $\gamma + \gamma$, polarizations
- Polarimetry for 100s MeV photons beam, e^+e^-
- Astrophysics: Photon of low energy, Compton
- Photon Beam: goniometer – Hall D, e^+e^-
- Astrophysics: Photons of high energy, $\gamma \Rightarrow e^+e^-$
- DVCS: large solid angle, several GeV photons

Pion decay polarimetry

Possible Experimental Determination of Whether the Neutral Meson is Scalar or Pseudoscalar

C. N. YANG
Institute for Advanced Study, Princeton, New Jersey
January 16, 1950

NEUTRAL mesons with a mass of ~300 Mev which decay into two photons have been reported.[1] It can be proved[2,3] on general grounds of rotation-inversion invariance that a particle which dematerializes into two photons cannot have spin 1. Furthermore,[3] if the neutral meson is a scalar meson, the two photons would always have parallel planes of polarization, while if the neutral meson is a pseudoscalar meson, the two photons would always have perpendicular planes of polarization. One is

PHYSICAL REVIEW VOLUME 126, NUMBER 1 APRIL 1, 1962

Measurement of Linear Photon Polarization by Pair Production*

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National Bureau of Standards, Washington, D. C., and Institutt for Teoretisk Fysikk, Norges Tekniske Høgskole, Trondheim, Norway
(Received November 7, 1961)

Photon beam polarimetry

NEW METHOD FOR MEASUREMENT OF γ-RAY POLARIZATION BY DETECTION OF ANGULAR CORRELATION IN PAIR PRODUCTION

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Received 5 May 1972

$$R(\eta_-, \eta_+) = \frac{\dfrac{\partial^3 \sigma_{\parallel}}{\partial E_- \partial \eta_- \partial \eta_+} - \dfrac{\partial^3 \sigma_{\perp}}{\partial E_- \partial \eta_- \partial \eta_+}}{\dfrac{\partial^3 \sigma_{\parallel}}{\partial E_- \partial \eta_- \partial \eta_+} + \dfrac{\partial^3 \sigma_{\perp}}{\partial E_- \partial \eta_- \partial \eta_+}},$$

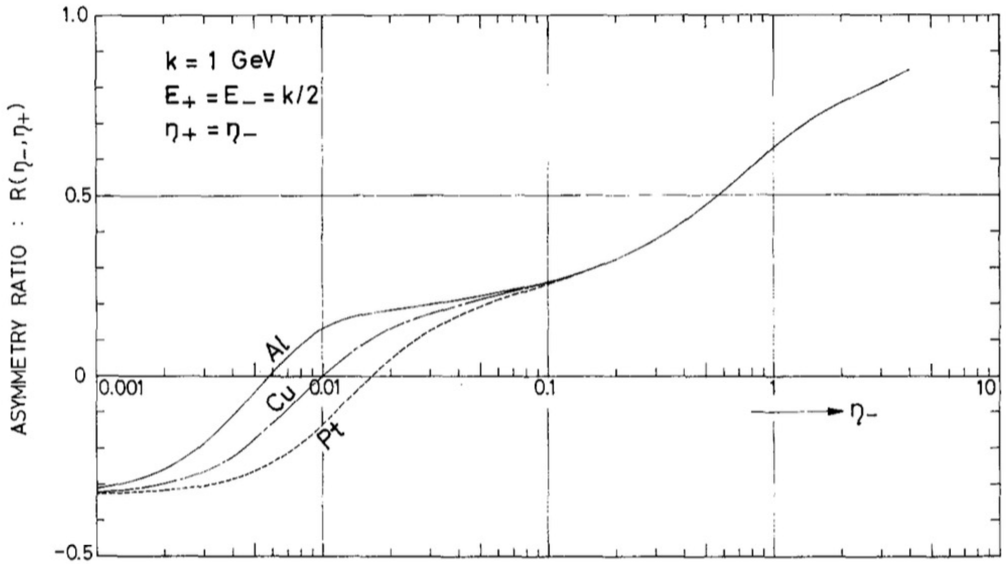


Fig. 6a. $R(\eta_-, \eta_+)$ calculated on the line $\eta_+ = \eta_-$ in different materials.

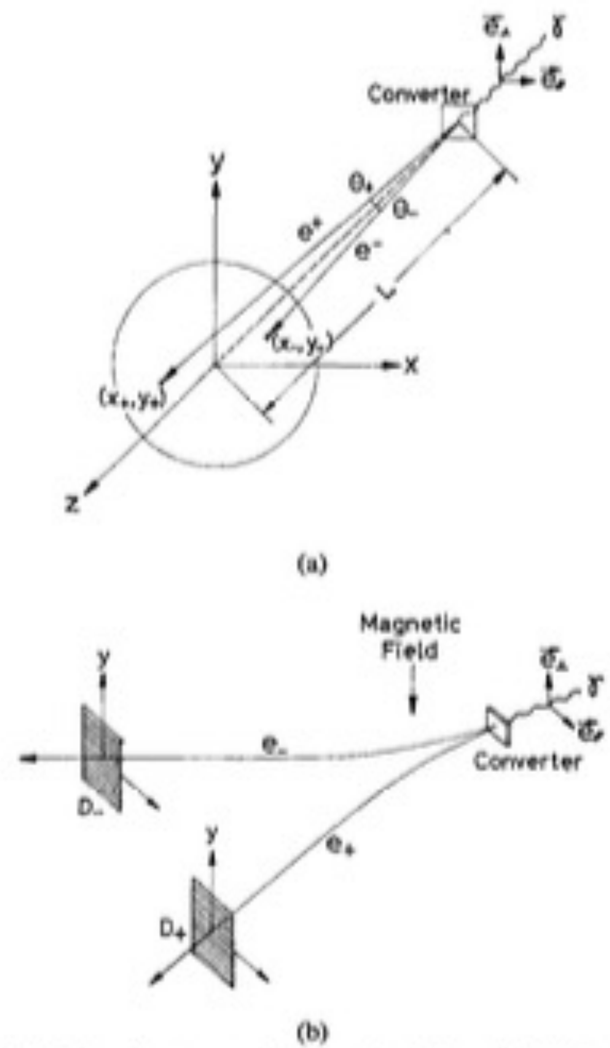


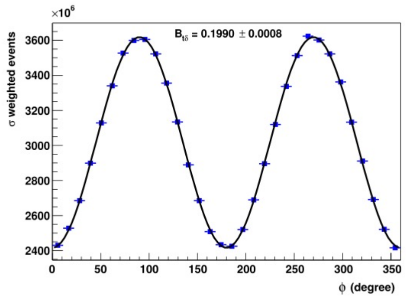
Fig. 1. (a) Coordinates used in the calculation. (b) A sketch of an example of possible experimental arrangements. $D_\pm$ are detectors such as wire chambers or hodoscopes.

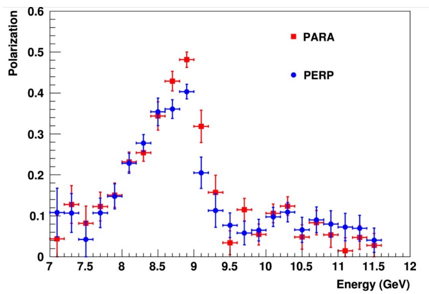
Photon beam polarimetry – triplet

Design and construction of a high-energy photon polarimeter

M. Dugger [a,*], B.G. Ritchie [a], N. Sparks [a], K. Moriya [a], R.J. Tucker [a], R.J. Lee [a], B.N. Thorpe [a], T. Hodges [a], F.J. Barbosa [b], N. Sandoval [b], R.T. Jones [c]

Nuclear Inst. and Methods in Physics Research, A 867 (2017) 115–127





Triplet production: e+e- pair produced from an electron
Cross section => ~ Z
It is a large angle recoil, but low energy electron

After all cuts have been applied, the detector accepts approximately 2% of the total triplet cross section. The design goal for the GlueX photon beam is to have a polarization of 0.4 and rate of 10^8 photons per second within the coherent peak energy range of 8.4–9.0 GeV. Given such a beam incident on a 75 μm thick beryllium converter, the expected TPOL rate surviving all cuts is 75 Hz (and perhaps as high as 10 kHz without cuts for the full incident photon-energy range), leading to an approximate statistical uncertainty in the TPOL determination of polarization of 0.014, after a single hour of production running.

10^{11} photons => 0.014 accuracy

or interpolate to 10^9 for 14%

High energy photon beam polarimetry

A pair polarimeter for linearly polarized high-energy photons

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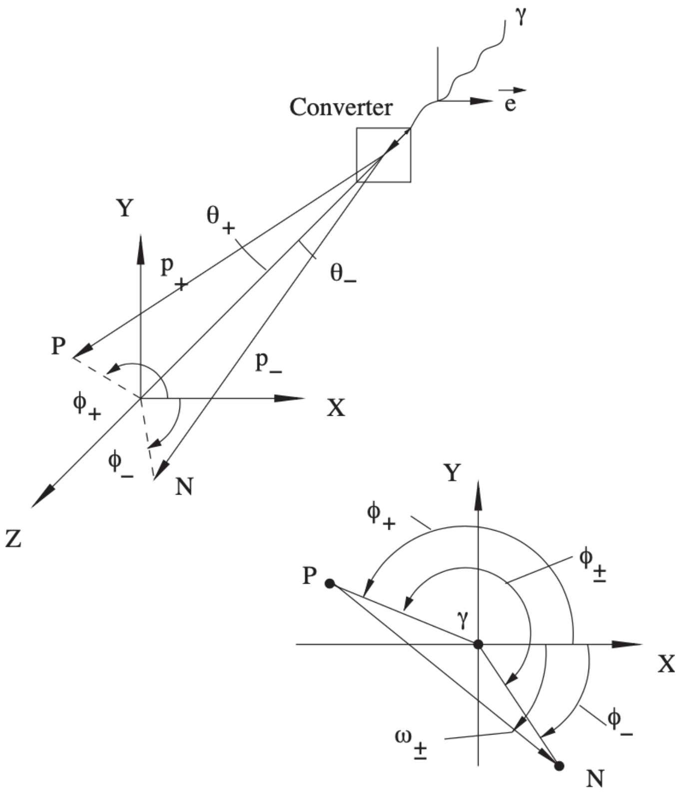
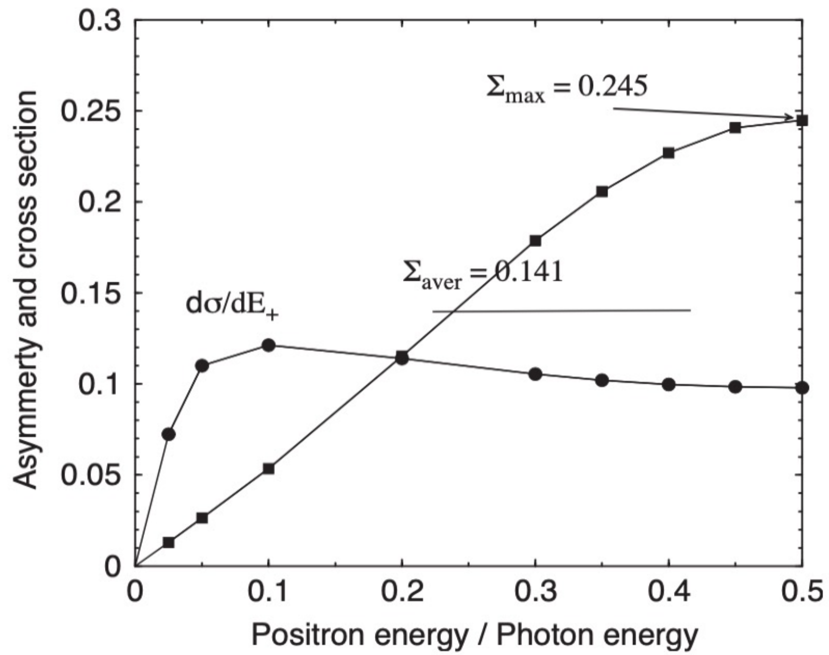
[a] TJNAF, Newport News, VA 23606, USA
[b] University of South Carolina, Columbia, SC 29208, USA
[c] North Carolina Central University, Durham, NC 27707, USA

Received 13 September 2002; received in revised form 16 June 2003; accepted 1 July 2003



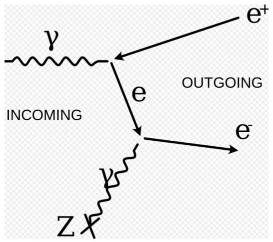


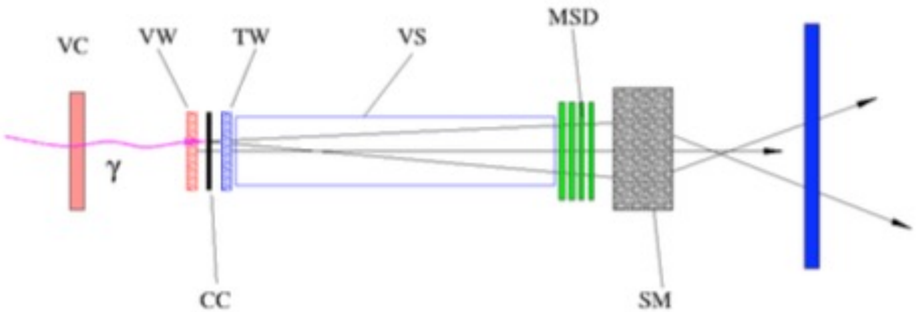
High energy photon beam polarimetry

Eur Phys J A (2004) **19**, s01, 275–278

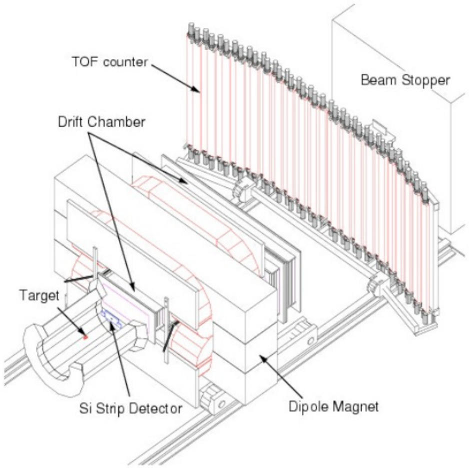
A pair polarimeter for linearly polarized high energy photons

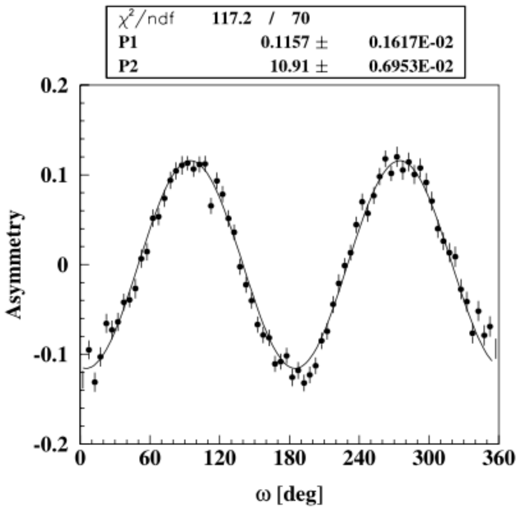
C. de Jager[1], B. Wojtsekhowski[1], D. Tedeschi[2], B. Vlahovic[1,3], D. Abbott[1], J. Asai[4], G. Feldman[5], T. Hotta[6], M. Khadaker[7], H. Kohri[6], T. Matsumara[6], T. Mibe[6], T. Nakano[6], V. Nelyubin[1,2], G. Orielly[5], A. Rudge[8], P. Weilhammer[8], M. Wood[2], T. Yorita[6], and R. Zegers[9]

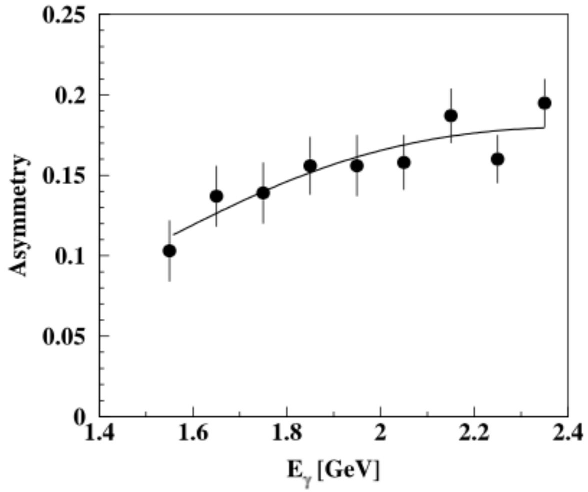




$E_\gamma = 1.6 - 2.4$ GeV







Astrophysics gamma polarimetry

Eγ < 2 MeV

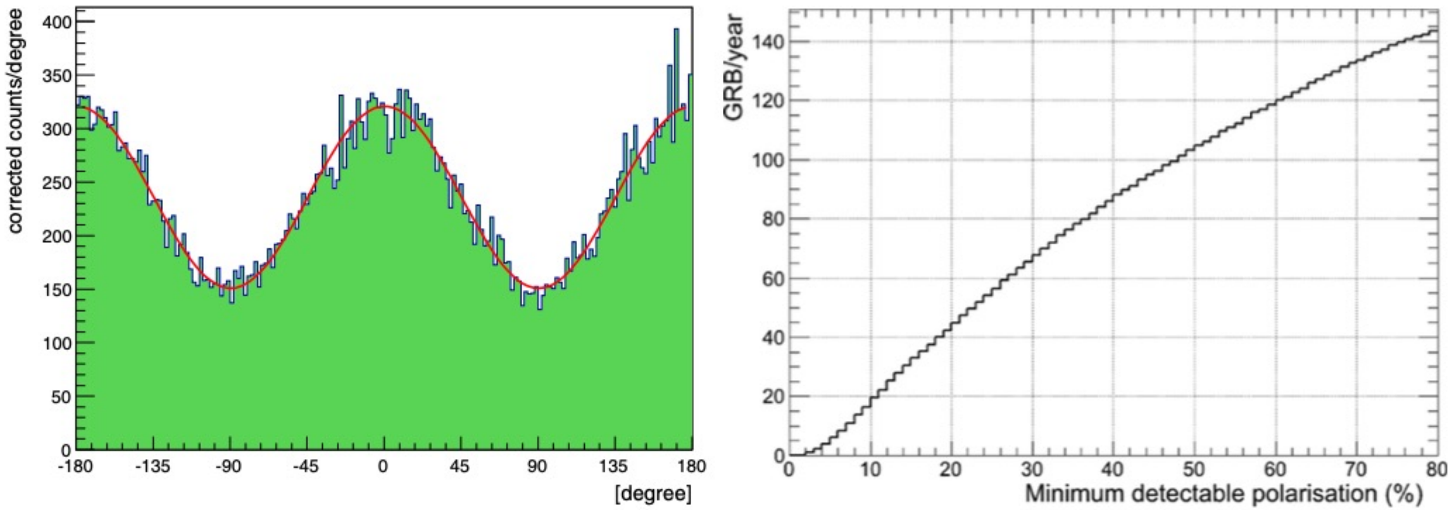


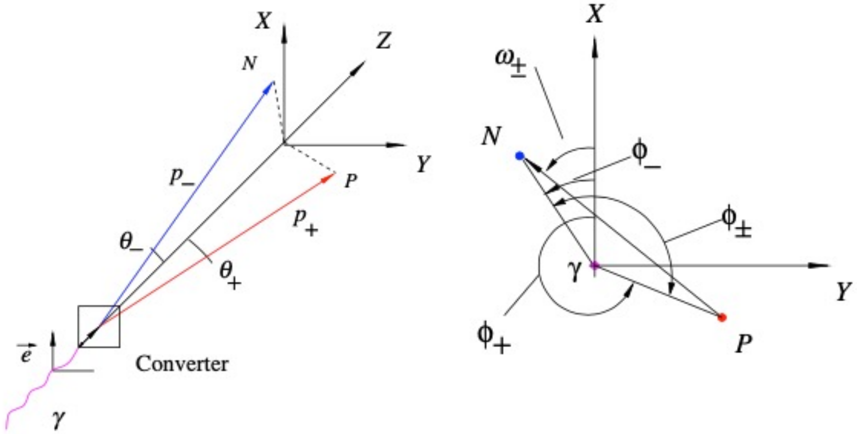
Fig. 20 *Left panel*–e-ASTROGAM polarization response (polarigramme) in the 0.2–2 MeV range for a 100% polarized, 10 mCrab-like source observed on axis for 10^6 s. The corresponding modulation is μ_{100} = 0.36. *Right panel*–Cumulative number of GRBs to be detected by e-ASTROGAM as a function of the minimum detectable polarization at the 99% confidence level

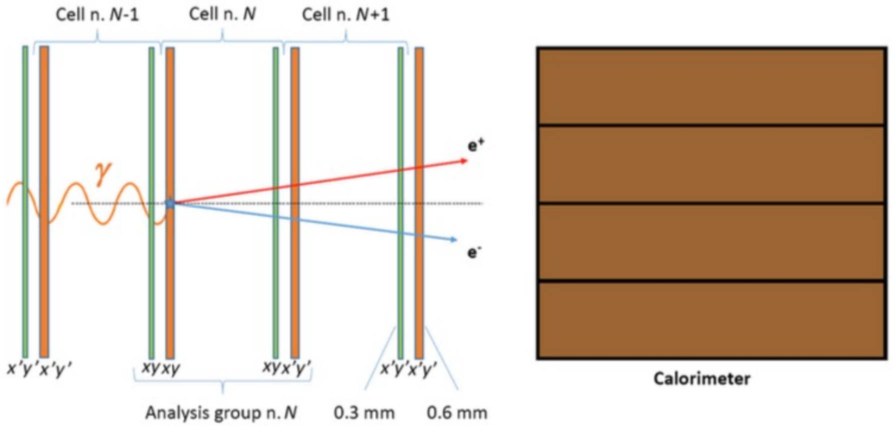
Astrophysics gamma polarimetry: Si MSD

Journal of Astronomical Telescopes, Instruments, and Systems 4(1), 011006 (Jan–Mar 2018)

High-energy photon polarimeter for astrophysics

Maxim Eingorn,[a] Lakma Fernando,[a] Branislav Vlahovic,[a,*] Cosmin Ilie,[b,c] Bogdan Wojtsekhowski,[d,*]
Guido Maria Urciuoli,[e] Fulvio De Persio,[e] Franco Meddi,[e,f] and Vladimir Nelyubin[g]





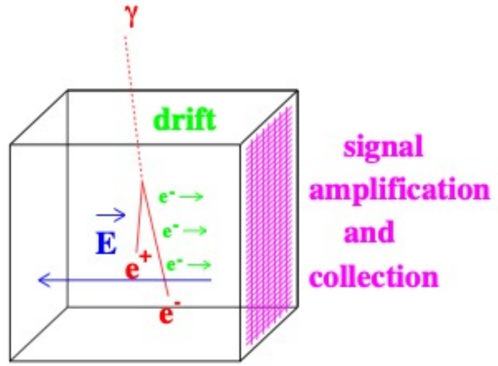
For high photon energy it is better to use MSD due to its coordinate resolution

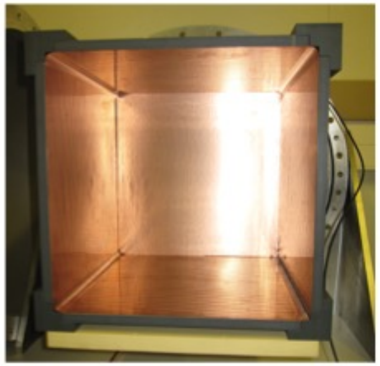
Astrophysics gamma polarimetr: TPC

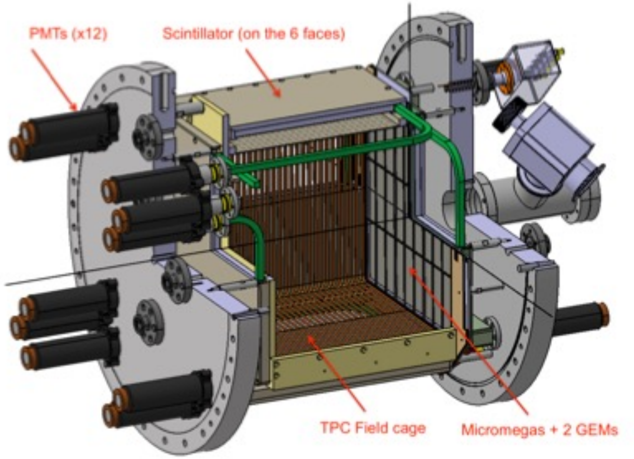
D. Bernard et al. Future Space-based Gamma-ray Observatories Workshop, Goddard Space Flight Center, 2016

HARPO: the Demonstrator

- Time Projection Chamber (TPC)
- $(30\text{cm})^3$ cubic TPC
- Up to 5 bar.
- Micromegas + GEM gas amplification
- Collection on x, y strips, pitch 1 mm.
- AFTER chip digitization, up to 100 MHz.
- Scintillator / WLS / PMT based trigger







NIM A 695 (2012) 71, NIM A 718 (2013) 395

Physics: DVCS photon polarimetry

Gluon tomography in nucleons by γ-polarimetry

Maxime Defurne

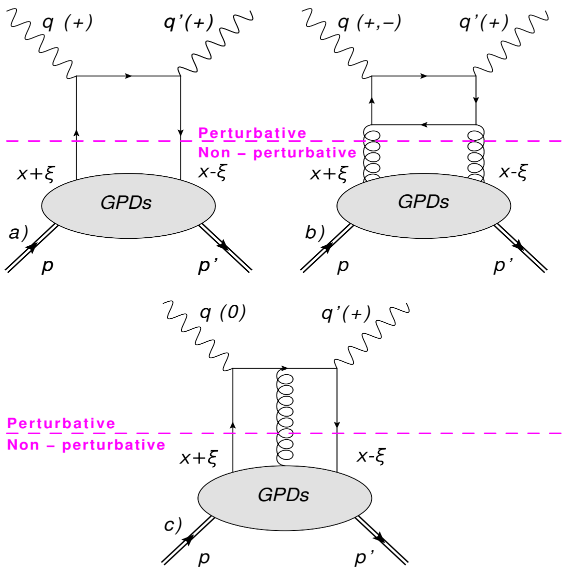
February 11, 2023

We propose to measure the degree of linear polarization of a photon produced by deeply virtual Compton scattering, never considered but rich in terms of new information about the proton structure. Indeed, the photon polarization is rigorously and straightforwardly related to the gluon transversity GPDs, still completely unknown today.

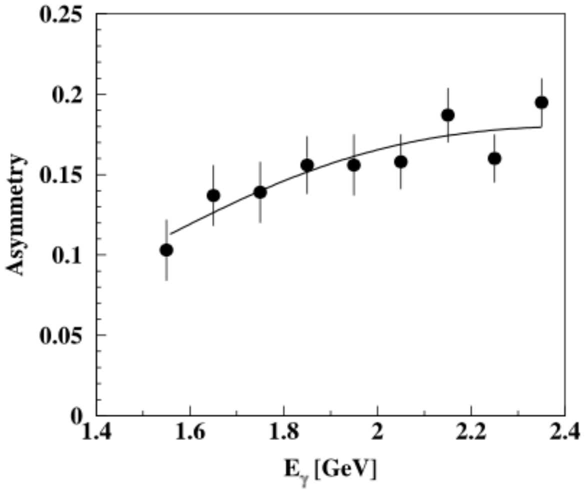
1 From gluon transversity GPDs to γ-polarization

1.1 A *simple* answer to: "Why γ-polarization?"

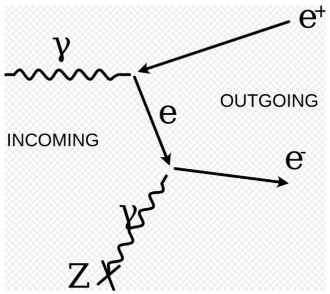
In deeply virtual Compton scattering (DVCS), a highly virtual photon is absorbed by the nucleon and the latter subsequently emits a high-energy real photon. At the partonic level, the process can be described by the diagrams presented in Figure 1. The process can be described in terms of helicity



DVCS photon polarimetry



For photon energies above 100 MeV, the silicon MSD is a preferable option because of the limit on the apparatus's total length. Indeed, considering a 300-cm total length and an energy of 500 MeV, the number of cells is 5 for the drift chamber option, 6 for the TPC/micromega, and 46 for the MSD option. At the same time, the total amount of matter in the polarimeter should be limited to one radiation length or less because of significant absorption of the incident photons, which will reduce the average efficiency per cell. For example, in the MSD option 54% absorption will occur with 46 cells



$L_{pair} = 9/7 \;\; X_0$

	X_0
Scint	400 mm
Si	94 mm
Cu	14 mm

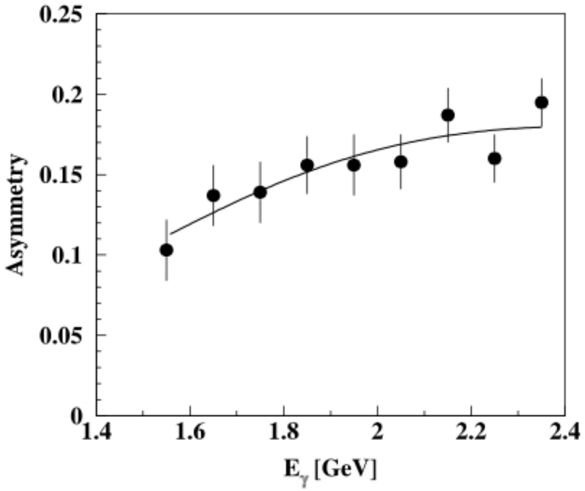
$\Theta_{ms} \sim 1/p$ for 1% X_0 detector

1 GeV, 100 μm => 10 cm spacing between layers

$$\theta_{plane}^{rms} = \frac{13.6\text{MeV}}{p\beta} z\sqrt{x/X_0}\left[1+0.038\ln(x/X_0)\right]$$

The key is a two-track space resolution =>MSD

DVCS photon polarimetry



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- Using projected asymmetry A = 0.15 and desirable accuracy of 10% the statistics of e+e- events of 4k is required.

- With detection efficiency of 1% per detector layer (1%X_0 ~ 100 μm Si) the required number of DVCS events is 0.4M.

Due detector resolution will be some reduction of A, so statistics of 1M is likely a lower limit.

With 46 layers in the statistics of 25k should be sufficient.

Jefferson Lab
Thomas Jefferson National Accelerator Facility

DVCS photon polarimetry

Scintillator fiber systems

Scintillating fiber detectors for the HypHI project at GSI

D. Nakajima[a,b,*], B. Özel-Tashenov[a,c,**], S. Bianchin[a], O. Borodina[a,d], V. Bc
M. Kavatsyuk[e], S. Minami[a], C. Rappold[a,f], T.R. Saito[a,d], P. Achenbach[d], S. A
T. Fukuda[h], Y. Hayashi[i], T. Hiraiwa[i], J. Hoffmann[a], K. Koch[a], N. Kurz[a], O. I
Y. Mizoi[h], T. Mochizuki[k], M. Moritsu[i], T. Nagae[i], L. Nungesser[d], A. Okamu
A. Sakaguchi[k], M. Sako[i], C.J. Schmidt[a], H. Sugimura[i], K. Tanida[i], M. Träger

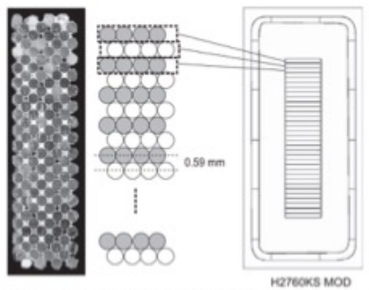
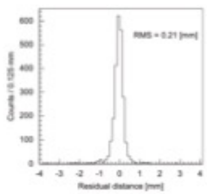


Fig. 2. (a) Cross-section of a 32-channel fiber bundle and (b) corresponding enlarged schematic drawing. The panel (c) shows a scheme of the surface of PMT H7260KS MOD.



A two-dimensional scintillation-based neutron detector with wavelength-shifting fibers and incorporating an interpolation method

T. Nakamura[a,*], K. Toh[a], T. Kawasaki[a], M. Ebine[b], A. Birumachi[b], K. Sakasai[a], K. Soyama[a]

3.3. Spatial resolution

Fig. 7 shows the spatial resolution measured while scanning the collimated beam over the detector. The spatial responses were fitted with a Gaussian function to extract the variance (σ) for each incidence position. The spatial resolution, which was calculated as the full width at half maximum (FWHM) by 2.35σ, was better when the neutron beam was incident on top or near the WLS fiber than when it was incident between the fibers. Measurements made over a distance of 10 mm revealed a periodicity in the spatial resolution of 2.5 mm for all of the MPC logics, which reflected the pitch of the WLS fibers. These observations were consistent with the spatial responses shown in Figs. 4 and 5.

The average FWHM spatial resolutions were 3.3 ± 0.3, 2.7 ± 0.1, and 2.5 ± 0.1 mm for standard-, half-, and quarter-pitch logics, respectively. The spatial resolution improved from 1.2- to 1.3-fold

noise. At a single photon threshold the SiPM suffers from the same problems as a GAPD. Current state of the art SiPMs have thermal noise rates[6] at $\mathcal{O}(100\,\text{kHz})$[7] at single photon level. This value depends on the temperature and the bias voltage. The typical pixel sizes of SiPMs are between $25 \times 25\,\mu m^2$ and $100 \times 100\,\mu m^2$. One single device can cover active areas up to $6 \times 6\,mm^2$ (fig. 3.9).

Two-track coordinate resolution of the scintillator fiber-based system is not sufficiently good

DVCS photon polarimetry

J. Derré et al. / Nuclear Instruments and Methods in Physics Research A 459 (2001) 523–531 527

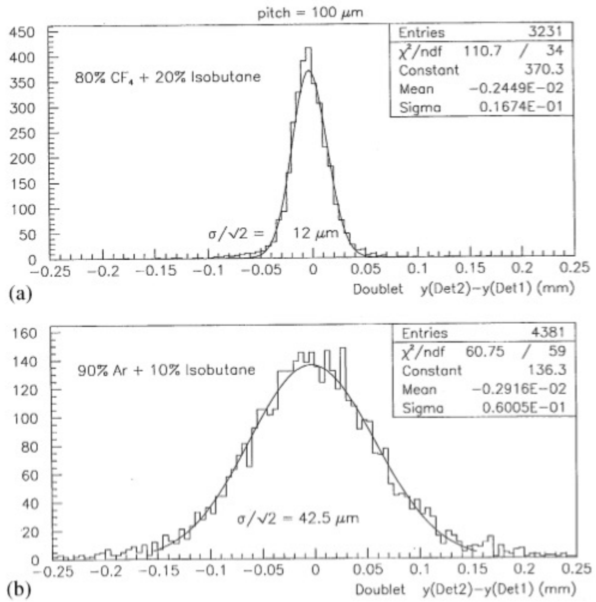


Fig. 3. The difference between the intercept of tracks in the two detectors of a Micromegas doublet for a gas mixture of (a) CF_4 and isobutane, (b) argon and isobutane. The fitted lines are gaussian distributions.

This observation is related to the behavior of the transverse diffusion in the gas. A similar effect has been observed [5] for the longitudinal diffusion.

4.2. Other gas mixtures

The spatial resolution of Micromegas has also been studied for other gas mixtures. For comparison with the above results, the corrected position difference distribution in a doublet operated with our standard gas mixture Ar–isobutane (90%,10%) is shown in Fig. 3(b). The measurement shows a clear degradation of the accuracy which is 42.5 μm (standard deviation divided by $\sqrt{2}$).

Table 1 summarizes all the results obtained with a doublet of detectors. For each gas mixture we give the measured resolution and the transverse diffusion coefficient. The transverse diffusion coefficient results from an adjustment in our simulation to reproduce the charge and cluster size distributions shown by the data.

The spatial resolution improves when the amount of quencher is increased in the gas mixture and the amount of CF_4 is large. The best result was

Layers of micromega chamber could be the best detector for the DVCS polarimeter due to high coordinate resolution also good two-track resolution.

Detector setup for DVCS polarimetry

150 cm x 150 cm area coordinate detector
25 layers in 500 cm depth – 25% efficiency
EM calorimeter for event selection behind

Located 5 m from the target: 90 msr solid angle

70 msr SBS spectrometer as an electron arm

With 10 μA beam on 15 cm long LH2 target