— 2d FCC EPOL WORKSHOP —

The VEPP-4M laser polarimeter system

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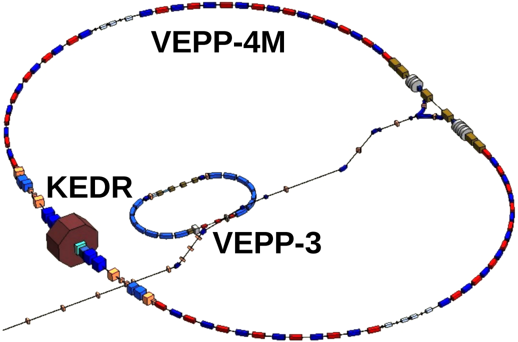
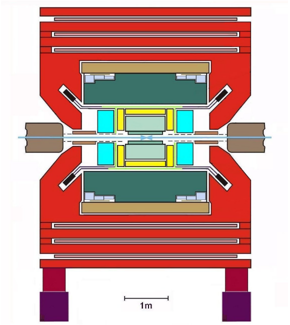
The VEPP-4M collider and the KEDR detector



e^+e^- Collider

- $E_{\text{max}} = 5.5$ GeV
- $\mathcal{L} = 10^{31}$ cm^{-2}s^{-1}

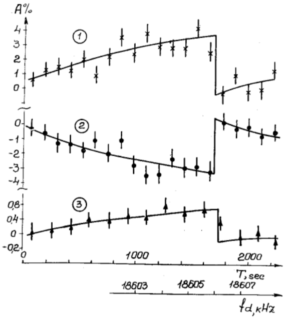


The KEDR detector

- Multipurpose particle detector
- Precise measurements of J/ψ, ψ' mesons and τ – lepton

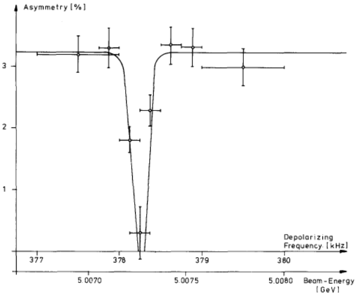
Resonant depolarization history

- 1968: RD method was introduced at BINP
- 1975: First results on absolute energy calibrations with $\delta E/E \sim 10^{-4}$



VEPP4 Event asymmetry for e^- – ① and e^+ – ②

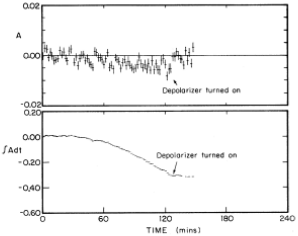
- 1983: $\Upsilon(2S)$ mass measurement by ARGUS and CB collaborations
- $\delta E/E = 4 \cdot 10^{-5}$



Depolarizing frequency scan for DORIS II collider.

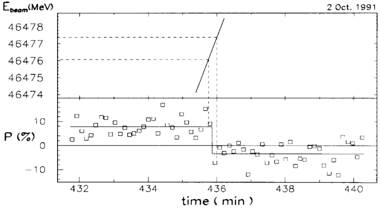
Resonant depolarization history

- 1984: CUSB collaboration measured $\Upsilon(1S)$ mass
- Relative error: $\delta E/E \simeq 1.1 \cdot 10^{-5}$



The experimentally measured time dependence of the polarization in CESR

- 1992: LEP energy measurement at Z–boson region
- Results variability was $\pm 6 \cdot 10^{-5}$



The localization of the depolarizing frequency within the sweep for the LEP collider

Motivation

- Future measurements of the Υ-meson mass and leptonic width
- Expecting 50 keV error for $\Upsilon(1S)$ mass
- High precision energy determination at the interaction point
- Development of the laser polarimeter system

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
9460.30 ± 0.26 OUR AVERAGE Error includes scale factor of 3.3.				
9460.51 ±0.09 ±0.05	[1] ARTAMONOV	2000	MD1	$e^+ e^- \to$ hadrons
9459.97 ±0.11 ±0.07	MACKAY	1984	REDE	$e^+ e^- \to$ hadrons
• • We do not use the following data for averages, fits, limits, etc. • •				
9460.60 ±0.09 ±0.05	[2, 3] BARU	1992B	REDE	$e^+ e^- \to$ hadrons
9460.59 ±0.12	BARU	1986	REDE	$e^+ e^- \to$ hadrons
9460.6 ±0.4	[4, 3] ARTAMONOV	1984	REDE	$e^+ e^- \to$ hadrons

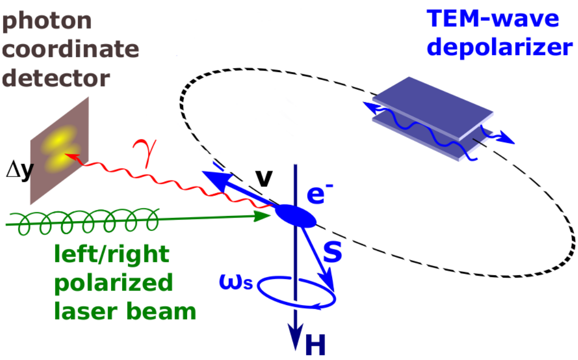
Screenshot from pdglive.lbl.gov: upsilon meson mass summary

Resonant depolarization recap

- Beam polarization by Sokolov-Ternov effect: $P = G\zeta_0(1 - e^{-t/G\tau_p})$
- Applying LFM depolarizing field
- When The resonance is achieved: $\omega_s = k\omega_r \pm \omega_d$
- At this moment the electron beam depolarizes $(\omega_d, \omega_r \to \omega_s)$
- We extract the beam energy from the frequencies relation:

$$\omega_s = \omega_r \left(1 + \frac{q'_e}{q_e}\frac{E}{mc^2}\right)$$

*q'_e and q_e are anomalous and normal part of the gyromagnetic ratio

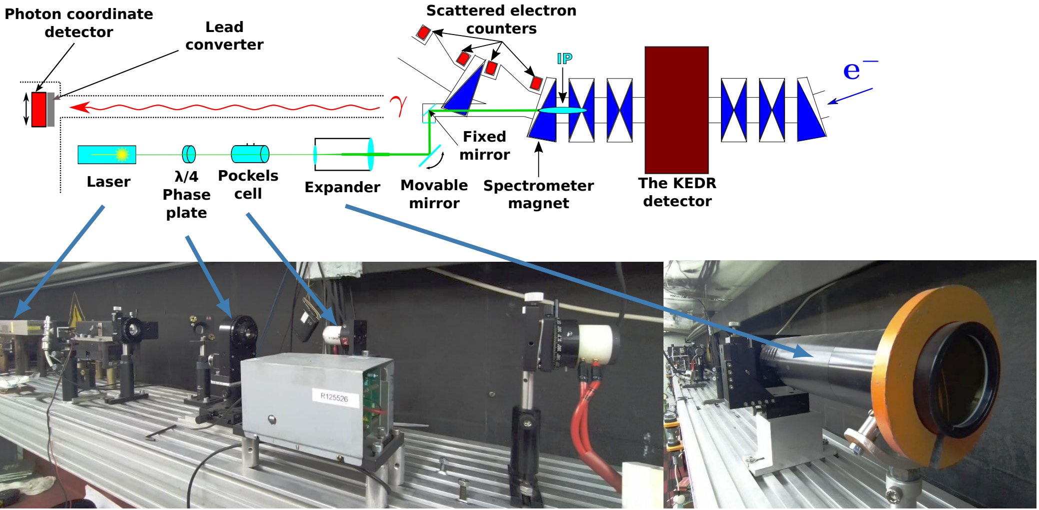


$$\Delta\langle y\rangle = \frac{\hbar\omega_0}{2m_e c^2} P \ell \Delta V$$

e^- polarization

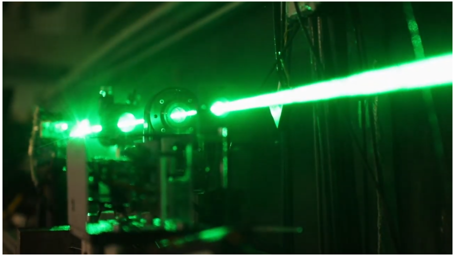
Change in optical circular polarization

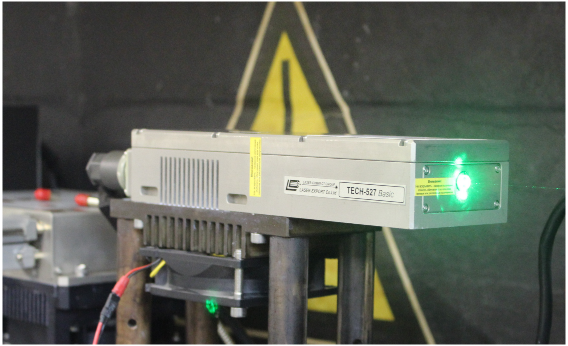
Laser polarimeter optical layout



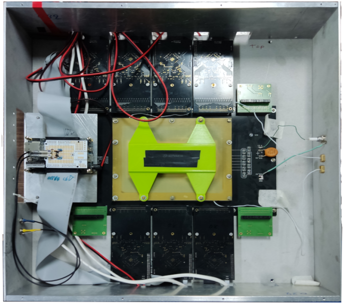
Laser

- Nd:YLF with frequency doubling
- 527 nm wavelength
- Operating frequency up to 4 kHz
- Average power - 2 W
- Pulse width – 5 ns (1.5 m length)

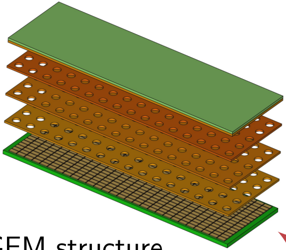




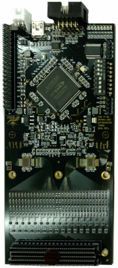
Photon coordinate detector



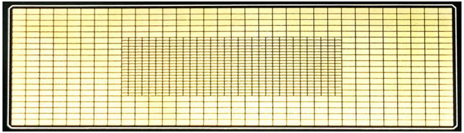
Detector design



GEM structure



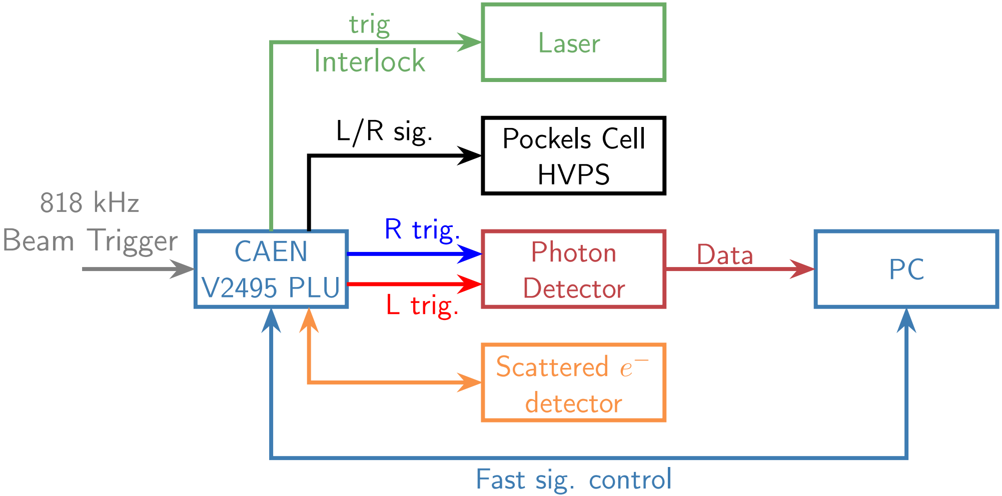
Single readout board



Readout structure

- Amplification structure: 3 GEM electrodes
- Sensitive area: 40×128 mm
- Channel number: 640 (center) $+512$ (side)
- Trigger rate: 4 kHz

Fast Signal Control System



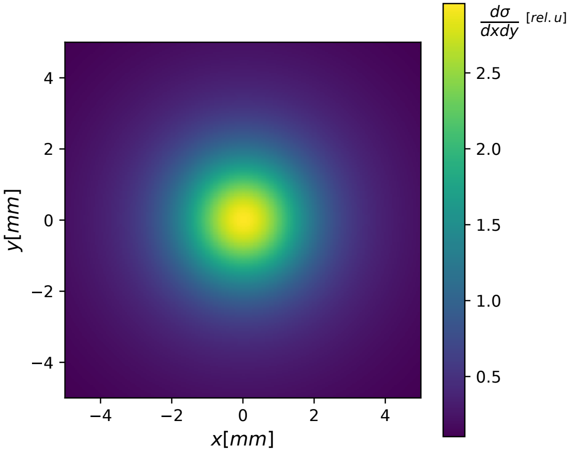
*PLU – programmable logical unit, HVPS – high voltage power supply

How to register e^- beam polarization

- Photon beam asymmetry scale:

$$\Delta\langle y\rangle = \frac{\omega_0}{2m_e} P\ell\Delta V \sim 100\ \mu m$$

- Photon beam size: $\ell/\gamma \sim\ 3.5\ mm$
- Looking at the difference: $\frac{d\sigma_L}{dxdy} - \frac{d\sigma_R}{dxdy}$ it is possible to register vertical asymmetry
- Beam polarization affects the amplitude of this asymmetry



Compton backscattering: theoretical distribution

*P – average e^- beam polarization, ΔV – difference of the circular polarization states ℓ – distance between the interaction point and photon detector

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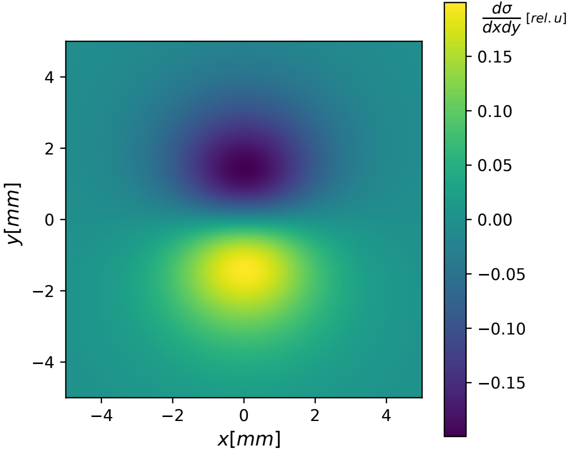


(L-R) difference for compton backscattering

*P – average e^- beam polarization, ΔV – difference of the circular polarization states ℓ – distance between the interaction point and photon detector

How to extract e^- beam polarization state

Distribution asymmetry

$$A = \frac{N[y>0] - N[y<0]}{N[y>0] + N[y<0]}$$

- ✓ Simple and fast method
- × Sensitive to the beam shape and position
- × Detector acceptance causes systematic uncertainty

Projection Fit (1D)

$$\frac{d\sigma}{dy} \bigotimes B(y) \text{ (Blur)}$$

- ✓ Robust when beam shape is controlled
- × Fails to describe the distribution for the elliptically polarized light

Full shape fit (2D)

$$\frac{d^2\sigma}{dxdy} \bigotimes B(x,y)$$

- ✓ No reduction of dimensionality: utilize all information from data
- × Time consuming
- × Doesn't work on complicated beam forms

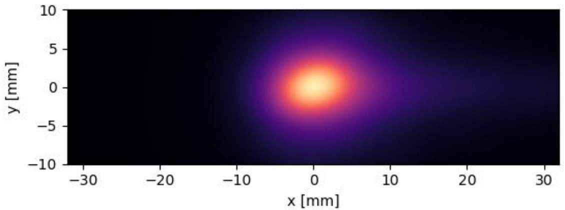
Is it possible to develop beam shape independent method?

What we actually see at the detector?

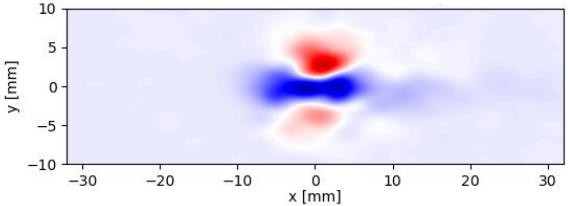
- Scattered photons distribution:

$$D = \varepsilon(x,y) \cdot \left[\frac{d^2\sigma}{dxdy} \bigotimes B(x,y) \right]$$

- It is a convolution of the Compton x-sec and smearing factors:
  - Electron beam emittance
  - Optical intensity distribution
  - Photon scattering and conversion
  - Clusters formation in the detector
- This complicates the analysis
- And decreases the effect extraction stability



Scattered photos coordinate distribution



Scattered photons coordinate distributions difference for the left and right optical polarization

Extracting beam shape from data

- We need to separate Compton distribution from all smearing factors:

$$D = \varepsilon(x,y) \cdot \Big[\underbrace{\frac{d^2\sigma}{dxdy}}_{:=C(x,y)} \bigotimes B(x,y) \Big] \quad \text{(Assumption: } \varepsilon(x,y) = 1)$$

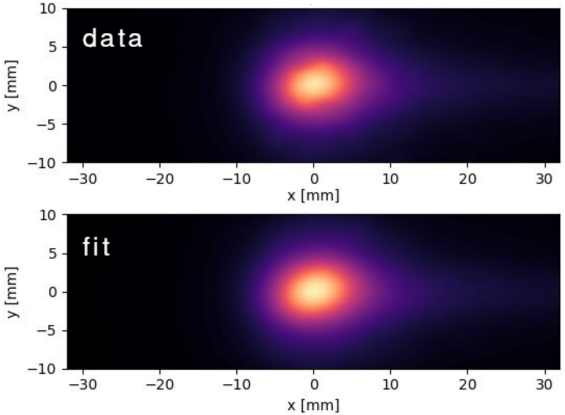
- It is possible to separate two contributions by spatial Fourier transform $\mathcal{F}^+$:

$$\hat{D} = \mathcal{F}^+ \Big[C(x,y) \bigotimes B(x,y) \Big] = \hat{C}(\theta_x, \theta_y) \cdot \hat{B}(\theta_x, \theta_y)$$

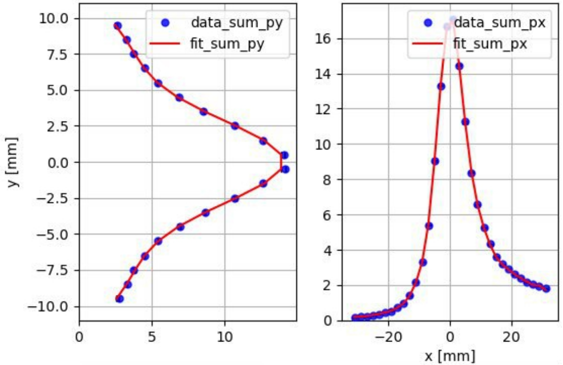
- Extract smearing function from data: $\hat{B} = \frac{\hat{D}}{\hat{C} + \varepsilon} \cdot \frac{|\hat{C}|^2}{|\hat{C}|^2 + k \sum |\hat{C}|^2}$, where k and ε are the regularization coefficients (Wiener filtration)
- Perform the inverse Fourier transform: $B = \mathcal{F}^- [\hat{B}]$
- Make a fit to data using known smearing function: $D_L - D_R = (C_L - C_R) \bigotimes B$

Theoretical Compton x-sec

Fit results

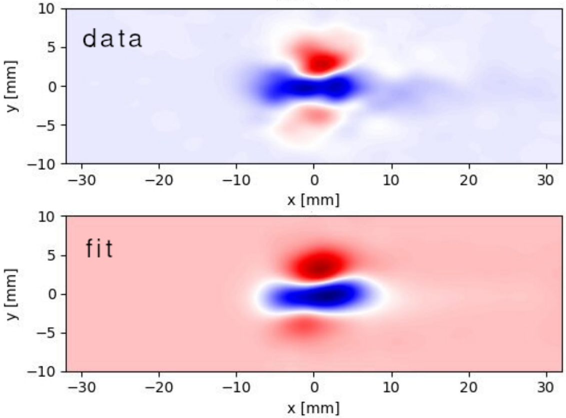


Scattered photons 2D coordinate distributions for data and fit



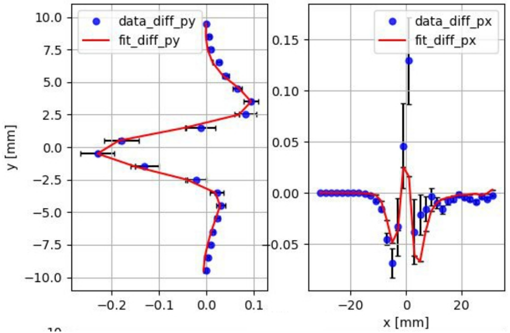
Vertical and horizontal projections for the data and fit distributions (Errors are too small to show)

Fit results:extracting polarization state



Scattered photons 2D differential coordinate distributions for the left and right optical polarization

$\chi^2/\text{ndf} = 1.19$



Vertical and horizontal projections for the data and fit distributions

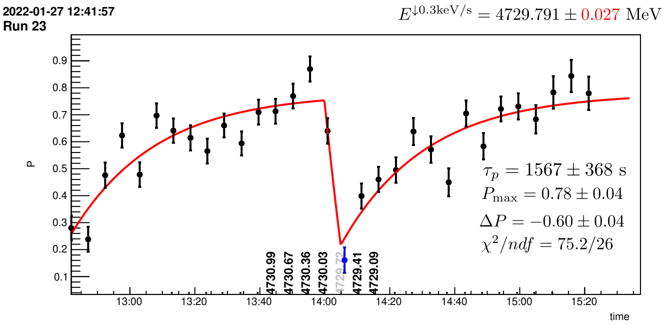
- $P = 0.56 \pm 0.08$ [e^-polarization]
- $Q = -0.21 \pm 0.02$ [linear light]
- $V = 0.97 \pm 0.02$ [circular light]

Measuring beam energy

- We performed $\sim$ 50 beam energy measurements with the new Laser Polarimeter
- Each run takes about 40 min (Statistical constraint)

$\Rightarrow$ Statistical energy error is 0.027 MeV

- $\delta E/E = 5.7 \cdot 10^{-6}$
- $\delta P/P = 5\%$

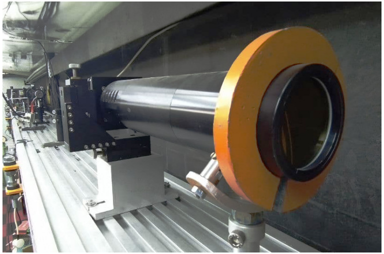


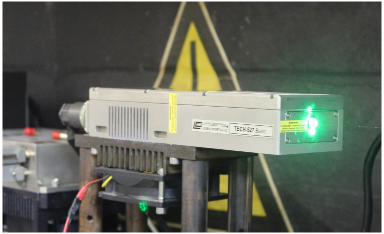
Electron beam polarization state time dependence

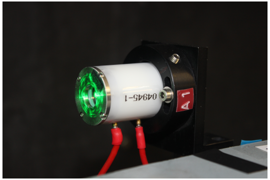
Results & status

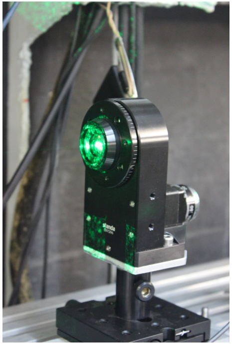
- We are completing the Laser Polarimeter setup for the VEPP-4
- To perform absolute electron beam polarization measurement, a new effect extraction method was proposed:
  - ⇓ Obtain 2d distributions for the scatted photons
  - ⇓ Extract the beam smearing function
  - Make a fit to data using a theoretical x-sec and the smearing function
- Statistical error of the electron beam energy value is 0.027 MeV, that corresponds to $\delta E/E = 5.7 \cdot 10^{-6}$
- We know e^- beam polarization with 5% error and work on improvement of our method

Backup: Laser polarimeter optical elements

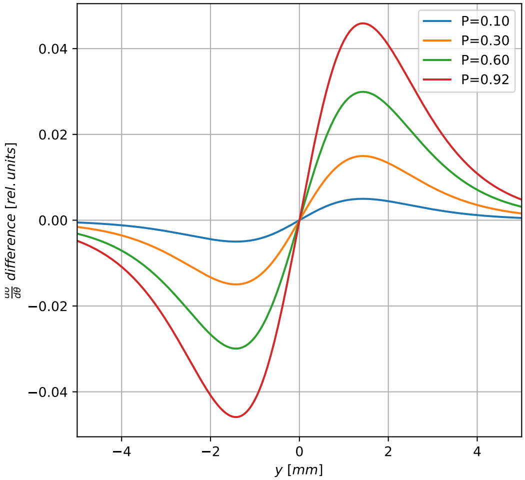




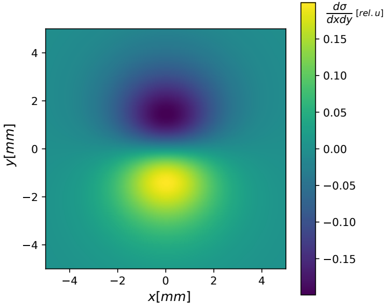




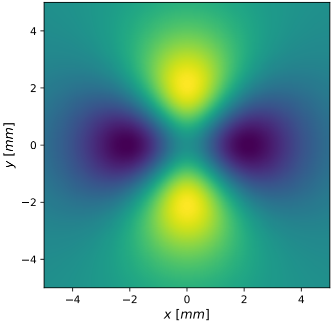
Backup: Compton x-sec for different e^- beam polarization



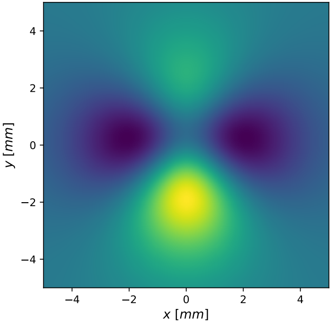
Backup: Compton x-sec for the elliptical optical beam



Differential Compton x-sec for the non-zero electron beam polarization and a circularly polarized optical beam $(P \neq 0,\ V = 1,\ Q = 0)$



Differential Compton x-sec for the linearly polarized optical beam $(Q = 1)$



Differential Compton x-sec for the elliptically polarized optical beam $(P = 0.92,\ V = 0.97,\ Q = 0.2)$