Workshop on the Circular Electron-Positron Collider

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Università degli Studi Roma Tre

BEAM POLARIMETER & ENERGY SPECTROMETER

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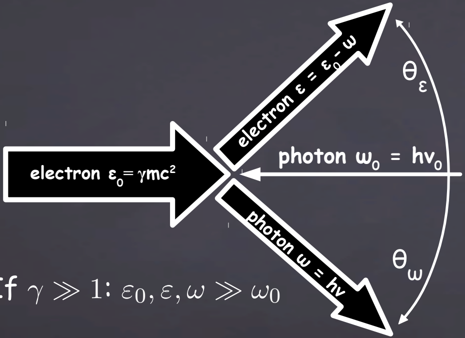
Preface

- Inverse Compton scattering is the traditional approach for beam polarization measurement in lepton machines.
- Eligibility of this method at high energy domain had been confirmed by LEP and HERA experiments.
- Fast measurement of beam polarization allows to use the resonant depolarization technique for precise beam energy determination.

AND

Inverse Compton scattering is already in use for direct beam energy determination in $e^{\pm}$ colliders: VEPP-4M, BEPC-II, VEPP-2000.

Inverse Compton Scattering



If $\gamma \gg 1$: $\varepsilon_0, \varepsilon, \omega \gg \omega_0$

Scattering parameter

$$u = \frac{\omega}{\varepsilon} = \frac{\theta_\varepsilon}{\theta_\omega} = \frac{\omega}{\varepsilon_0 - \omega} = \frac{\varepsilon_0 - \varepsilon}{\varepsilon}$$

is in the range

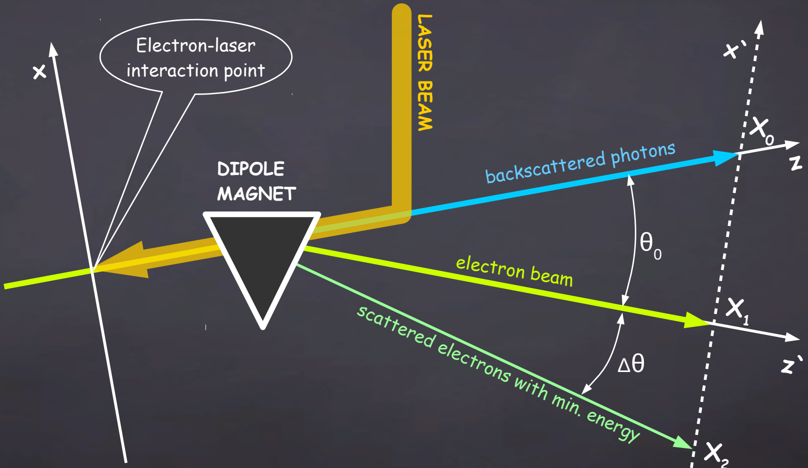
$$u \in [0, \kappa] \text{, where } \kappa = \frac{4\omega_0\varepsilon_0}{(mc^2)^2}$$

$\kappa \simeq 1.53$ if $\varepsilon_0 = 100$ GeV & $\omega_0 = 1$ eV

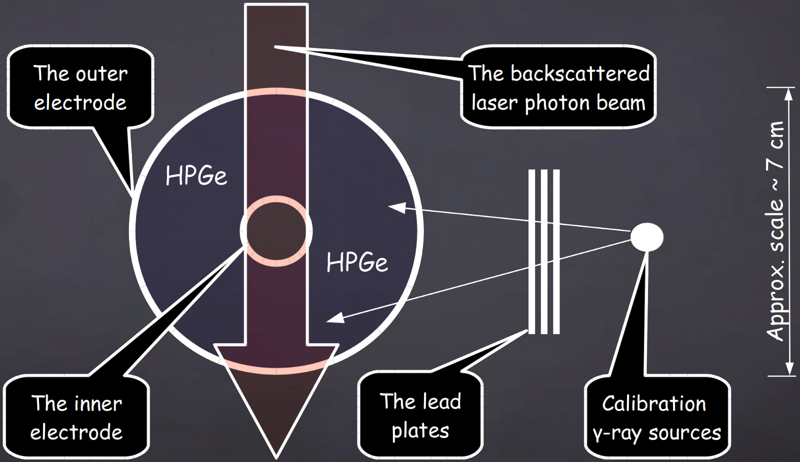
Scattering angles: $\theta_\omega = \frac{1}{\gamma}\sqrt{\frac{\kappa}{u} - 1}; \quad \theta_\varepsilon = \frac{u}{\gamma}\sqrt{\frac{\kappa}{u} - 1}.$

Note: $\max(\theta_\varepsilon) = 2\omega_0/mc^2$ (when $u = \kappa/2$). It is $\simeq 10\mu$rad for green light.

Conceptual layout: x-z plane

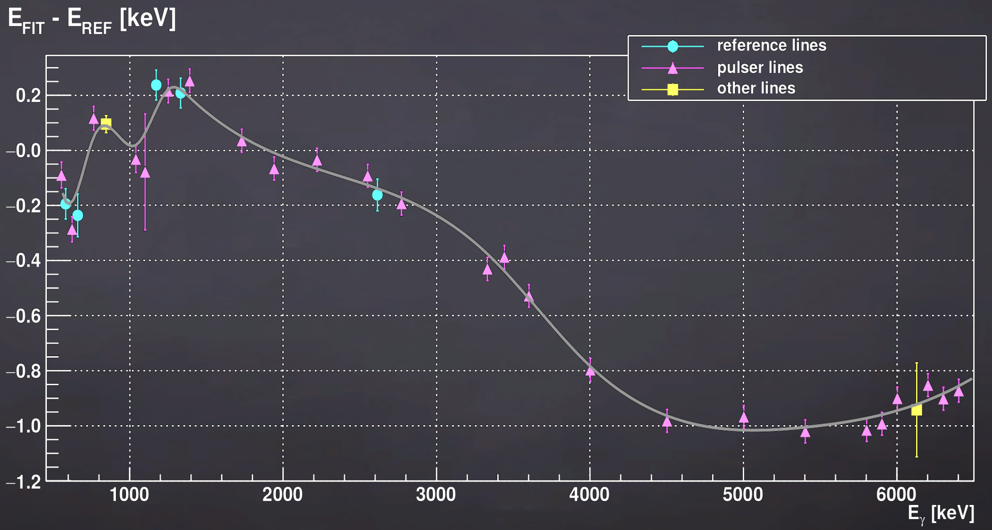


Beam Energy Calibration in $e^{\pm}$ Colliders

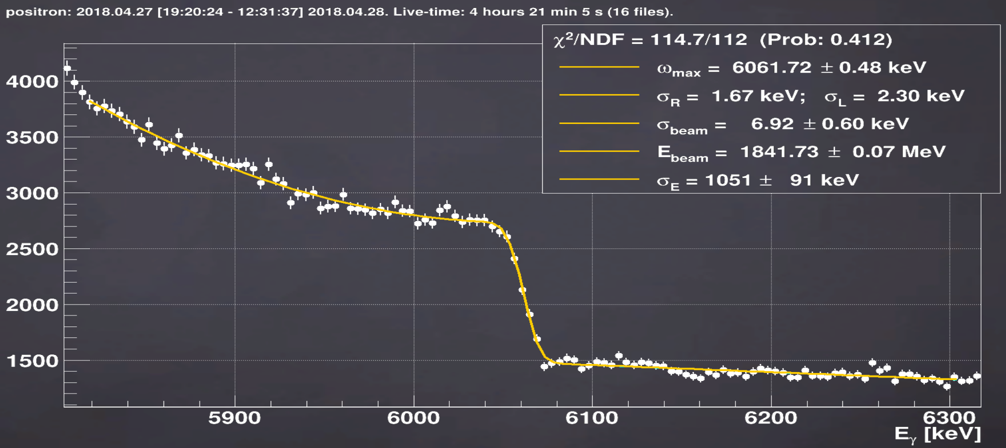


VEPP-4M (2005) ◦ BEPC-II (2010) ◦ VEPP-2000 (2012)

Absolute Energy Scale: High Accuracy

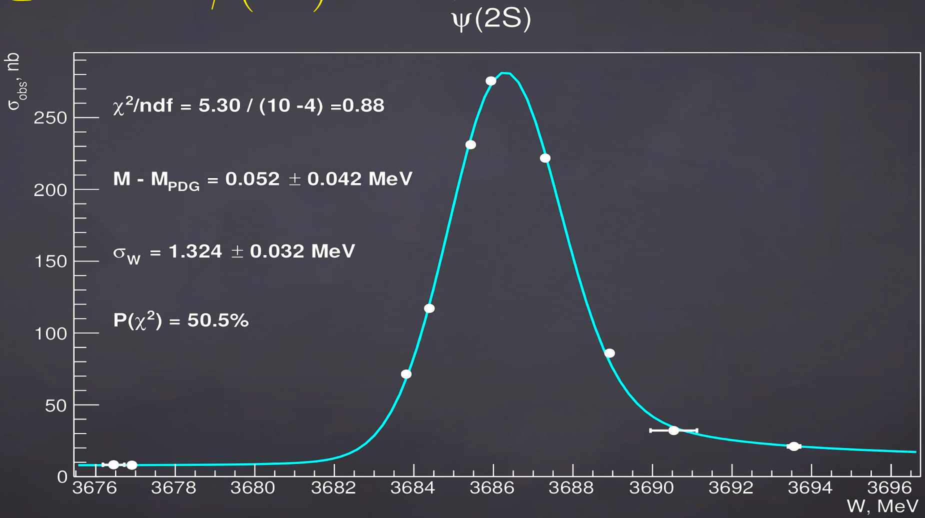


The Edge in the Compton γ-spectrum



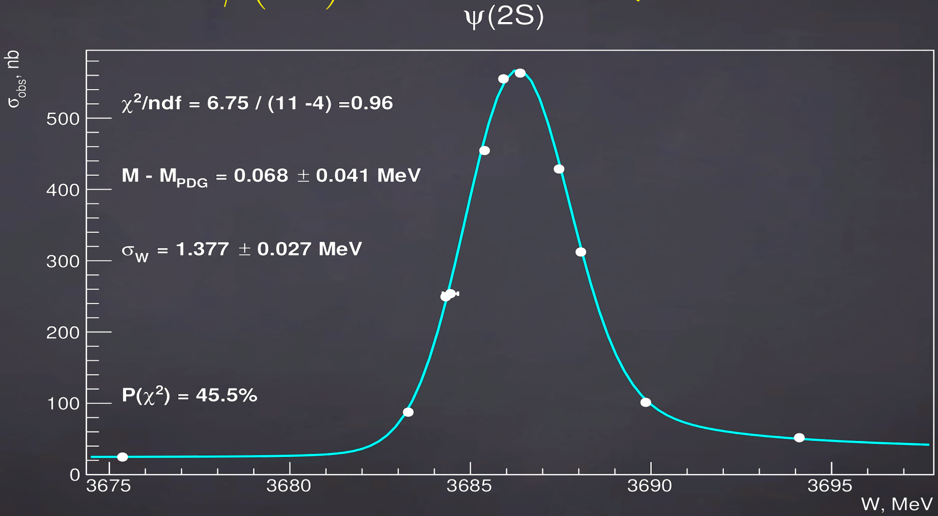
$$E_{\mathrm{beam}} = \frac{\omega_{\mathrm{max}}}{2}\left(1 + \sqrt{1 + \frac{m^2}{\omega_0 \omega_{\mathrm{max}}}}\right) \qquad (\omega_0 = 0.11706523\ \mathrm{eV})$$

BEPC-II $\psi(2S)$ scan 2017



Accuracy is at the level of $\Delta M/M \simeq 2 \cdot 10^{-5}$

BEPC-II $\psi(2S)$ scan 2018 (online hadron cross section)



The new τ-lepton mass measurement was held at BES-III in April 2018.

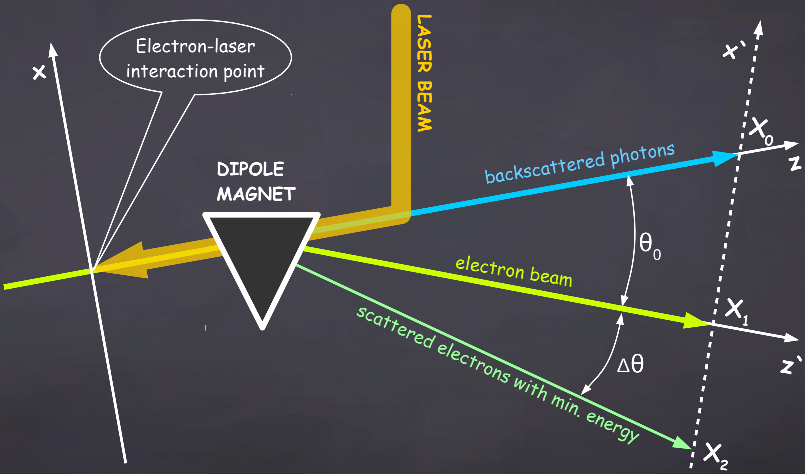
Compton Scattering cross section

for circular polarization of light $\xi_{\circlearrowright} = \pm 1$ depends on both longitudinal $\zeta_{\circlearrowright}$ and transverse $\zeta_{\perp}$ polarizations of the electron:

$$
\begin{aligned}
d\sigma_0 &= \frac{r_e^2}{\kappa^2(1+u)^3}\left(\kappa(1+(1+u)^2) - 4\frac{u}{\kappa}(1+u)(\kappa-u)\right) \quad du\, d\varphi, \\
d\sigma_{\parallel} &= \frac{\xi_{\circlearrowright}\zeta_{\circlearrowright} r_e^2}{\kappa^2(1+u)^3} \quad u(u+2)(\kappa-2u) \quad du\, d\varphi, \\
d\sigma_{\perp} &= -\frac{\xi_{\circlearrowright}\zeta_{\perp} r_e^2}{\kappa^2(1+u)^3} \quad 2u\sqrt{u(\kappa-u)}\cos(\varphi-\phi_{\perp}) \quad du\, d\varphi.
\end{aligned}
$$

For vertical electron (beam) polarization $\phi_{\perp} = \pi/2$

Conceptual layout: x-z plane



Since $\Delta\theta = \kappa\theta_0$ direct beam energy calibration is possible: $E = \frac{(mc^2)^2}{4\omega_0} \cdot \frac{\Delta\theta}{\theta_0}$

Scattered electrons

The energy of scattered electron is:

$$\varepsilon = \frac{\varepsilon_0}{1+u} \to \min(\varepsilon) = \frac{\varepsilon_0}{1+\kappa}$$

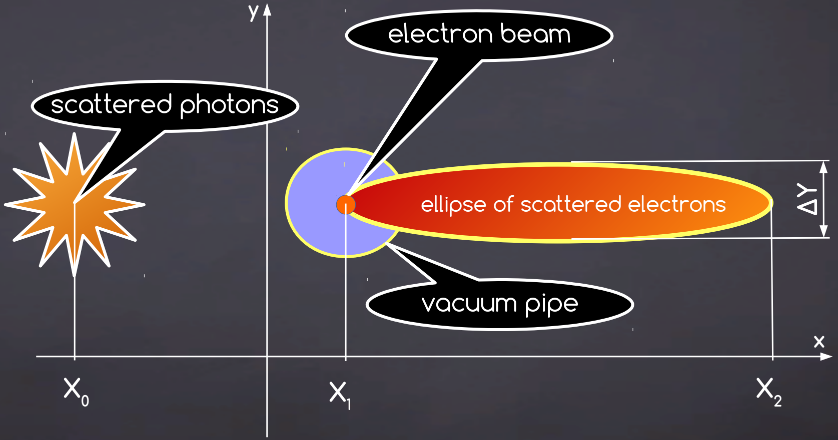
Bending of electron is inverse proportional to its energy:

$$\theta = \frac{B}{\varepsilon} \quad = \quad \frac{B}{\varepsilon_0} + \kappa\frac{B}{\varepsilon_0} \quad = \quad \frac{B}{\varepsilon_0} + \frac{4\omega_0 B}{(mc^2)^2} \quad = \quad \theta_0 + \Delta\theta$$

So the beam energy could be determined as:

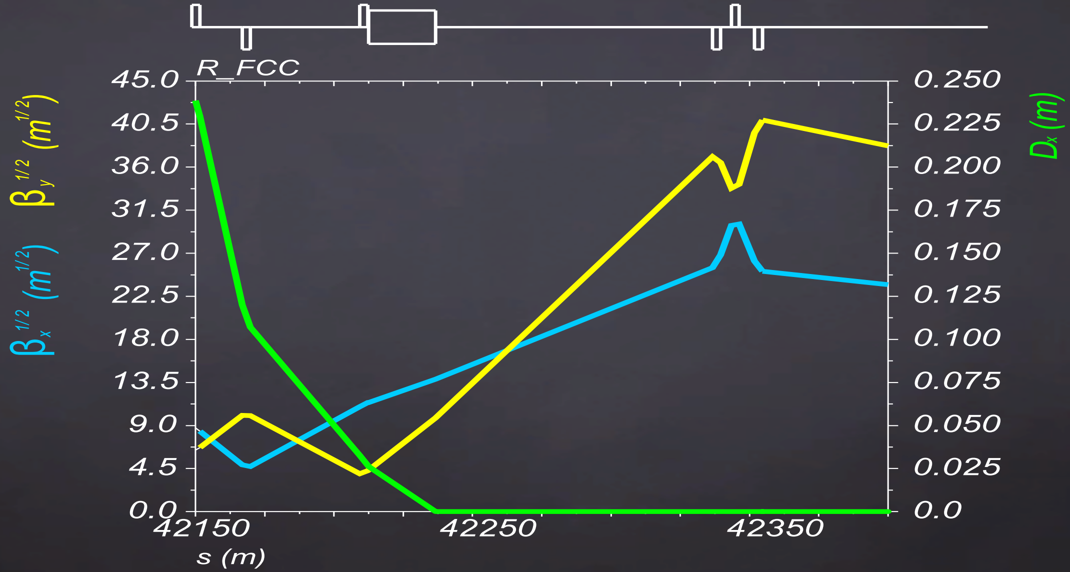
$$\varepsilon_0 = \frac{(mc^2)^2}{4\omega_0} \cdot \frac{\Delta\theta}{\theta_0}$$

Conceptual layout: x'-y' plane

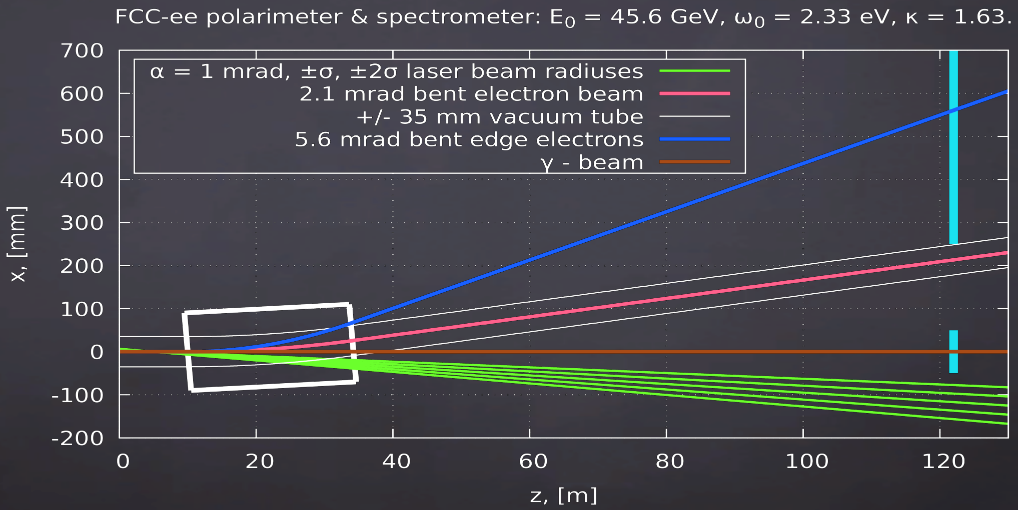


Direct beam energy measurement is: $E = \frac{(mc^2)^2}{4\omega_0} \cdot \frac{X_2 - X_1}{X_1 - X_0}$

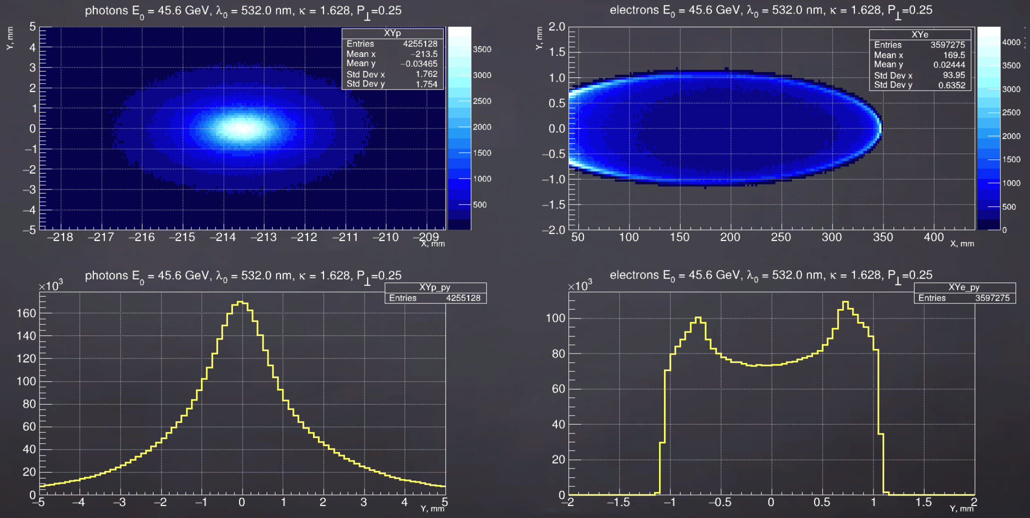
Integration to FCC-ee lattice



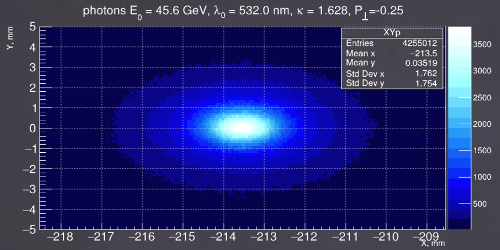
Layout for FCC-ee

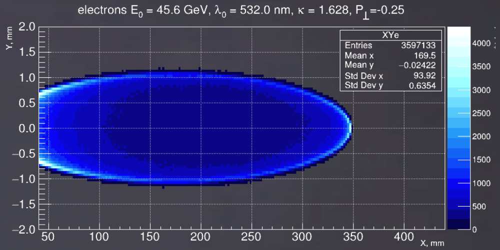


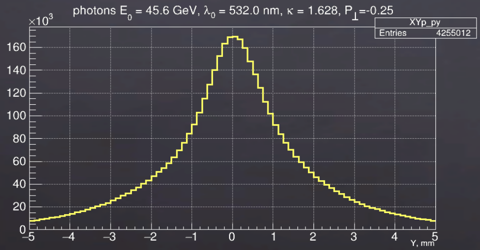
Scattered γ & e: $\xi_{\circlearrowleft}\zeta_{\perp} = +0.25$

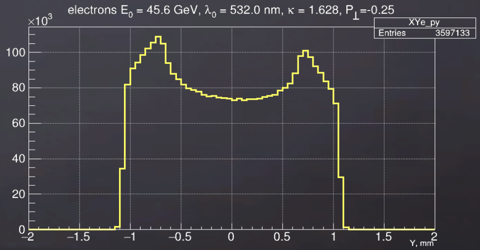


Scattered γ & e: $\xi_{\circlearrowright}\zeta_\perp = -0.25$

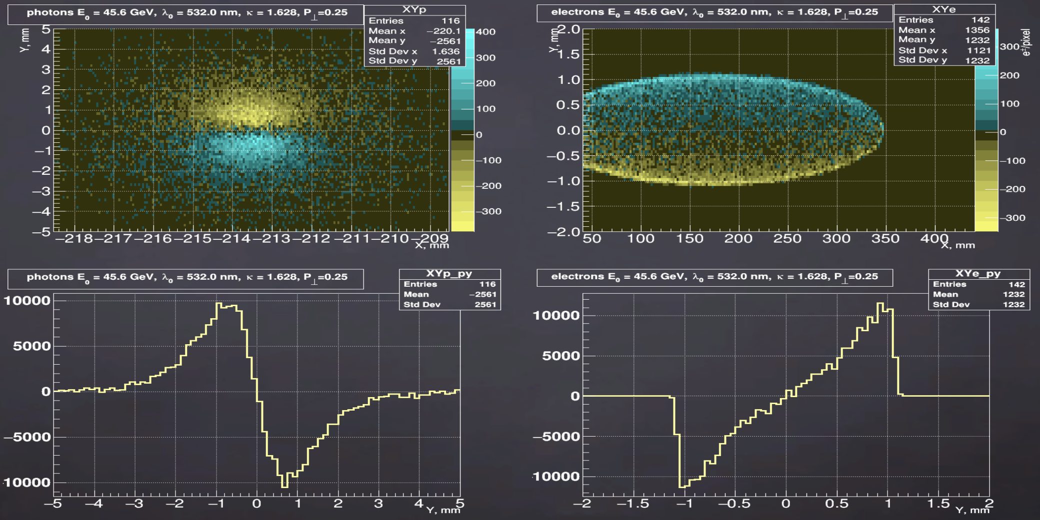




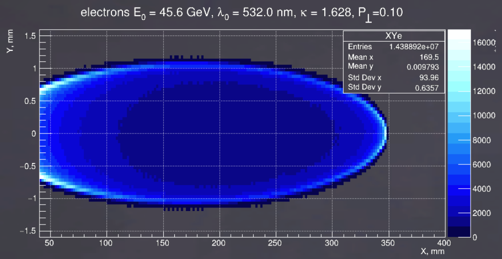




Scattered γ & e: The Difference



Fit: cross section & emittance



χ^2/NDF = 6356.7/6129 | Prob = 0.0208

X_0 = -213.538 $\pm$ 0.000 mm

X_1 = -000.008 $\pm$ 0.010 mm

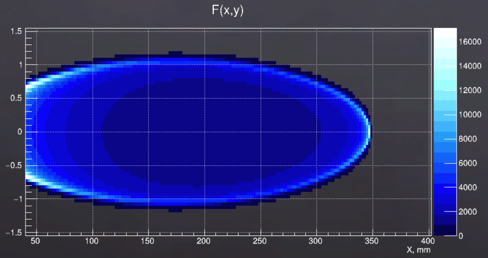
X_2 = 0347.631 $\pm$ 0.003 mm

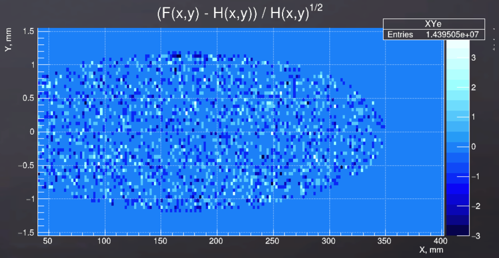
σ_x = 194.8 $\pm$ 4.4 μm

σ_y = 23.69 $\pm$ 0.02 μm

E_{beam} = 45.6032 $\pm$ 0.0035 GeV.

$P_\perp$ = 0.0997 $\pm$ 0.0016





Polarimetry with electrons?

- Scattered electrons propagate to the inner side of the beam orbit: there is no direct background from high energy SR.
- Electrons are ready to be detected by their ionization losses while γ's need to be converted to e^+e^- pairs: this leads either to low detection efficiency either to low spatial resolution.
- The flux density of electrons is much lower due to bending and corresponding spatial separation by energies. Simultaneous detection of multiple scattered electrons thus is much easier.
- Analysis of the scattered electrons distribution allows to measure the longitudinal beam polarization as well as the transverse one.
- Change of laser circular polarization leads to a redistribution of the scattered electron density within a fixed elliptic shape.

Summary

Detecting scattered electrons in the Compton polarimeter:

- allows to increase the reliability & accuracy of polarization measurement
- provides the beam energy spectrometer option, which does not require mandatory neither the B-field measurement nor the BPMs data.
  - Statistical accuracy at the level of 100 ppm / 10 sec
  - Systematical accuracy estimation requires further studies: no limitations were founded yet
  - test of the approach does not require high beam energy and should be performed with low emittance beam at low energy
- allows to measure beam sizes & positions as well