POSIPOL 2012

Measurement of Transversely Polarized Beams at the IP

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Why we want Transverse Polarized Beams

- New method of observing CP-violation in $e^{+}e^{-} \rightarrow t\bar{t}$ process [7].
- Using TPOL beams it is possible to discrimination among **large extra dimensions** and **5-dimensional warped geometry theory** gravity scenarios [8].
- To discrimination from standard model background the R-parity violating supersymmetry in the $e^{+}e^{-} \rightarrow b\bar{b}$ [9].

Some of the TPOL Polarimeter Requirements

- Measure the transverse polarization values, near or at the $e^{+}e^{-}$ interaction point ,down to a level of 0.5% or even better.
- The polarimeter should be robust and fast for instant tune-up of spin-dependent machine parameters.
- The polarimeter should not Interfere with the main experiment data collection.

The Main Features of the Compton Polarimeter

1. Turning the direction of the beam from its main trajectory

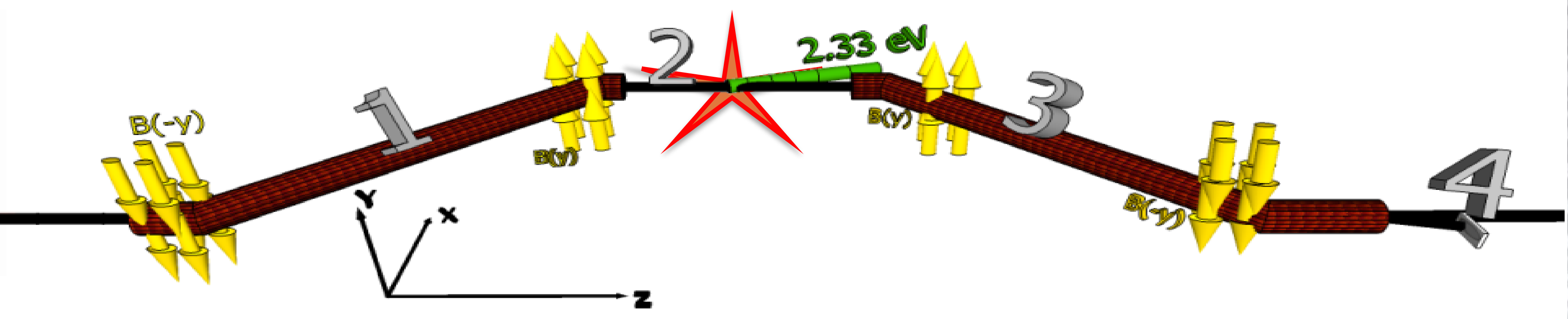
   Beam variables:

   - Beam energy: 250 , 500 GeV
   - Beam horizontal and vertical sizes : 5 μm

2. Compton scattering:
   - Laser Energy: $2.33 \ eV$ (Green)
   - Crossing angle in radian: 10^{-3}

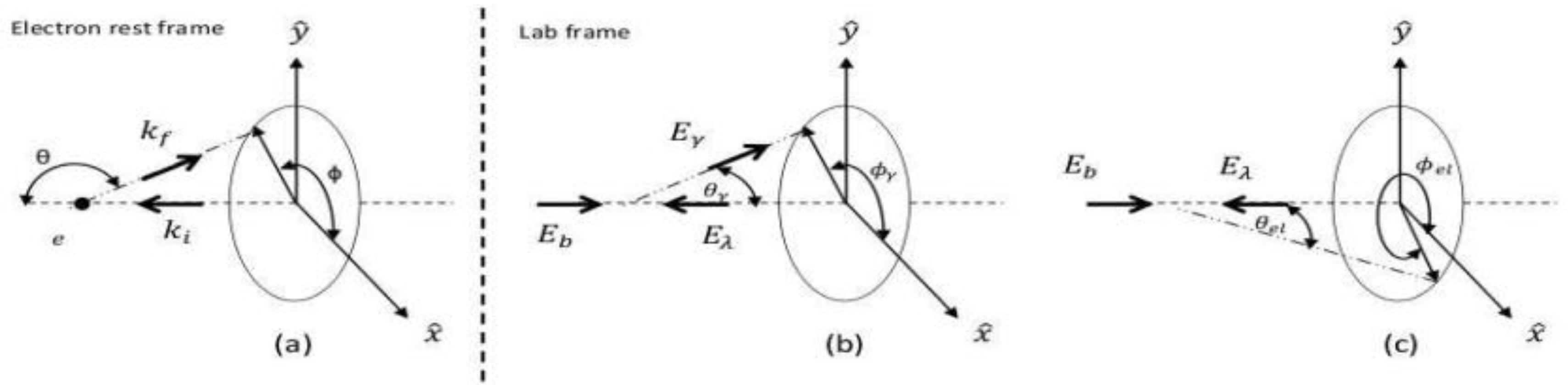
3. Magnetic spectrometer separates the scattered electrons from the main beam (in the $\hat{x}$ direction)
   - Magnetic field strength: 0.097 T

4. Pixel detector recording the (x,y) position
   - Silicon pixel size 400 μm ×50 μm
   - ↪ Detector resolution 115.5 μm ×14.4 μm [6]



Compton Scattering (Barber et al., [1])

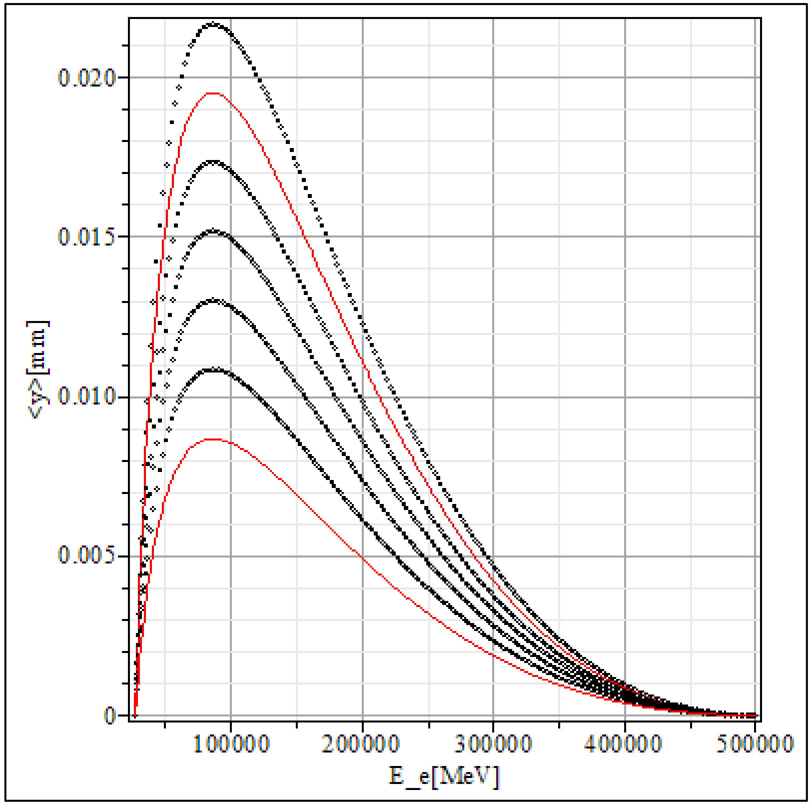
- $\frac{d\sigma}{d\Omega} = \Sigma_0 + S_1\Sigma_1 + S_3[P_y\Sigma_{2y} + P_z\Sigma_{2z}]$
- $\Sigma_0 = C\left[(1+cos^2\theta) + \left(k_i - k_f\right)(1-cos\theta)\right]$
- $\Sigma_1 = Ccos2\phi\ sin^2\theta$
- $\Sigma_{2y} = -Ck_f sin\phi sin\theta(1-cos\theta)$
- $\Sigma_{2z} = -C(1-cos\theta)\left(k_f + k_i\right)cos\theta$
- $k_i = \frac{2\gamma E_\lambda}{m_e} = \frac{2E_b E_\lambda}{m_e^2}$
- $k_f = \frac{1}{(1-cos\theta+\frac{1}{k_i})}$
- $C = \frac{r_0^2 k_f^2}{2k_i^2}$
- $cos\theta = \frac{E_b - E_\gamma(1+\frac{1}{k_i})}{E_b - E_\gamma}$
- $E_\gamma = E_b + E_\lambda - E_e$
- $\theta_e^{lab} = \frac{Y}{1-Y}\frac{m_e}{E_b}\sqrt{\frac{2k_i}{Y} - (2k_i+1)}$
- $Y = 1 - \frac{E_e}{E_b}$
- $y = Dsin\phi\ tan\theta_e^{lab} \xrightarrow{\theta_e^{lab} \ll 1} Dsin\phi\theta_e^{lab}$
- $< y > |_{E_e} = \frac{\int \frac{d\sigma}{d\Omega}\cdot y\cdot d\varphi}{\int \frac{d\sigma}{d\Omega}\cdot d\varphi}$
- $\frac{\langle y\rangle_{S_3=1} - \langle y\rangle_{S_3=-1}}{2} = P_T \cdot \Pi(E_e)$



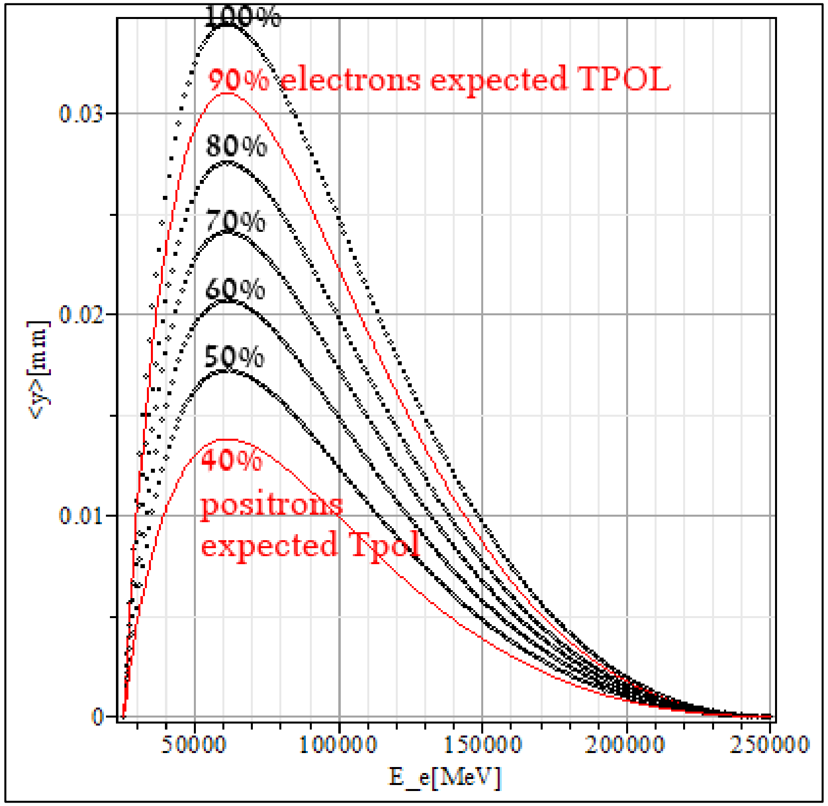
Scattered Electron (Positron) $\langle y \rangle_{E_e}$ Distribution

- Laser energy (pulsed)
  - $E_\lambda = 2.33$ eV
- Laser circular helicity
  - $S_3 = +1$
  - $S_1 = 0$
- Detector distance from the γe IP
  - $D = 37.95$ m

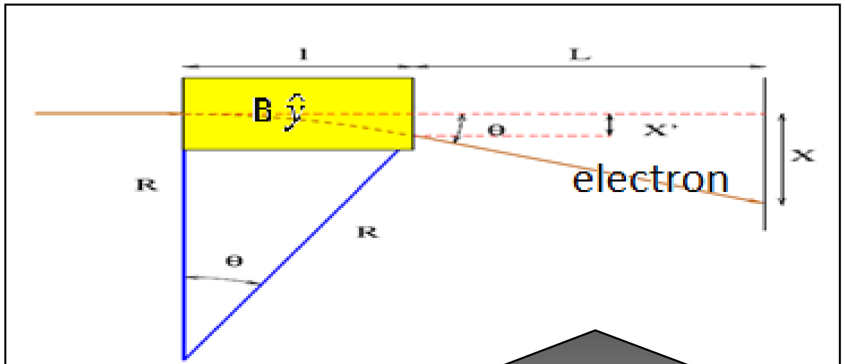
$E_{bean} = 500$ GeV



$E_{bean} = 250$ GeV

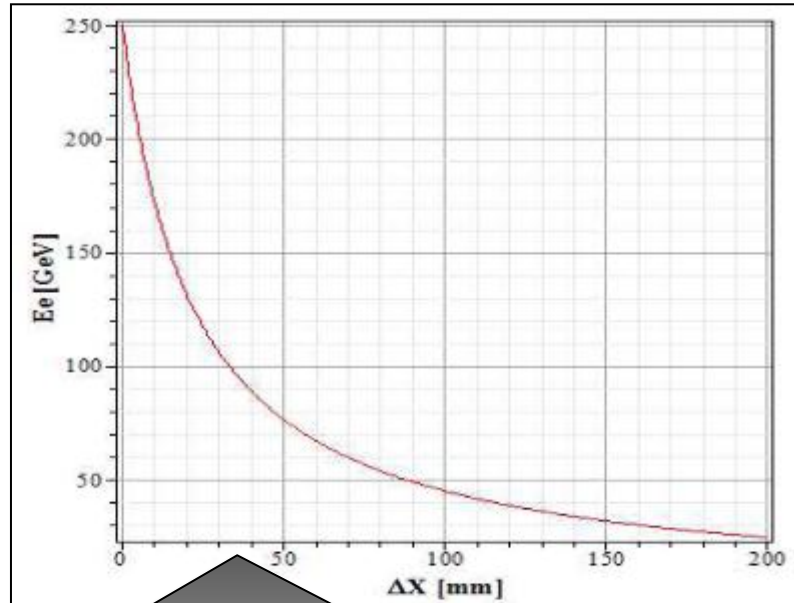


Energy Spectrometer

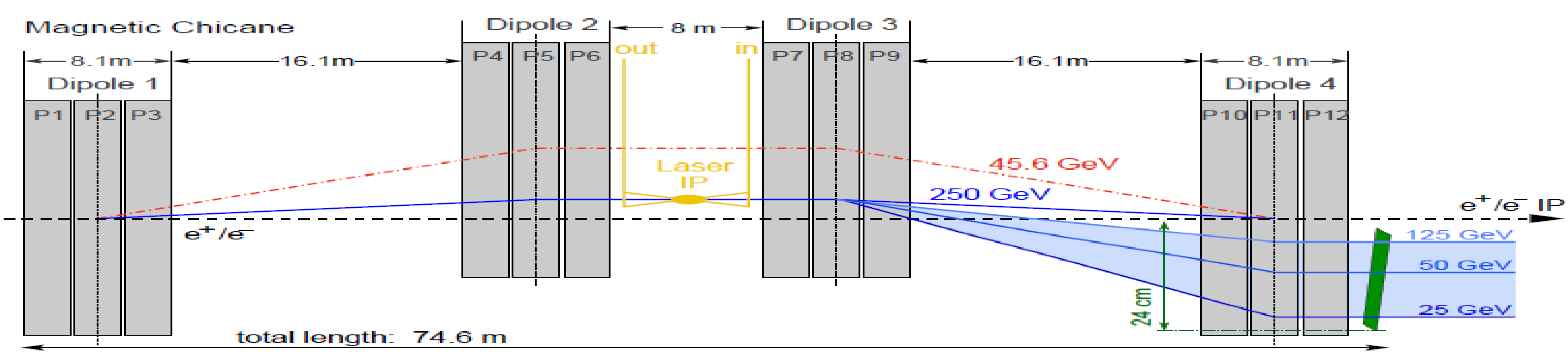


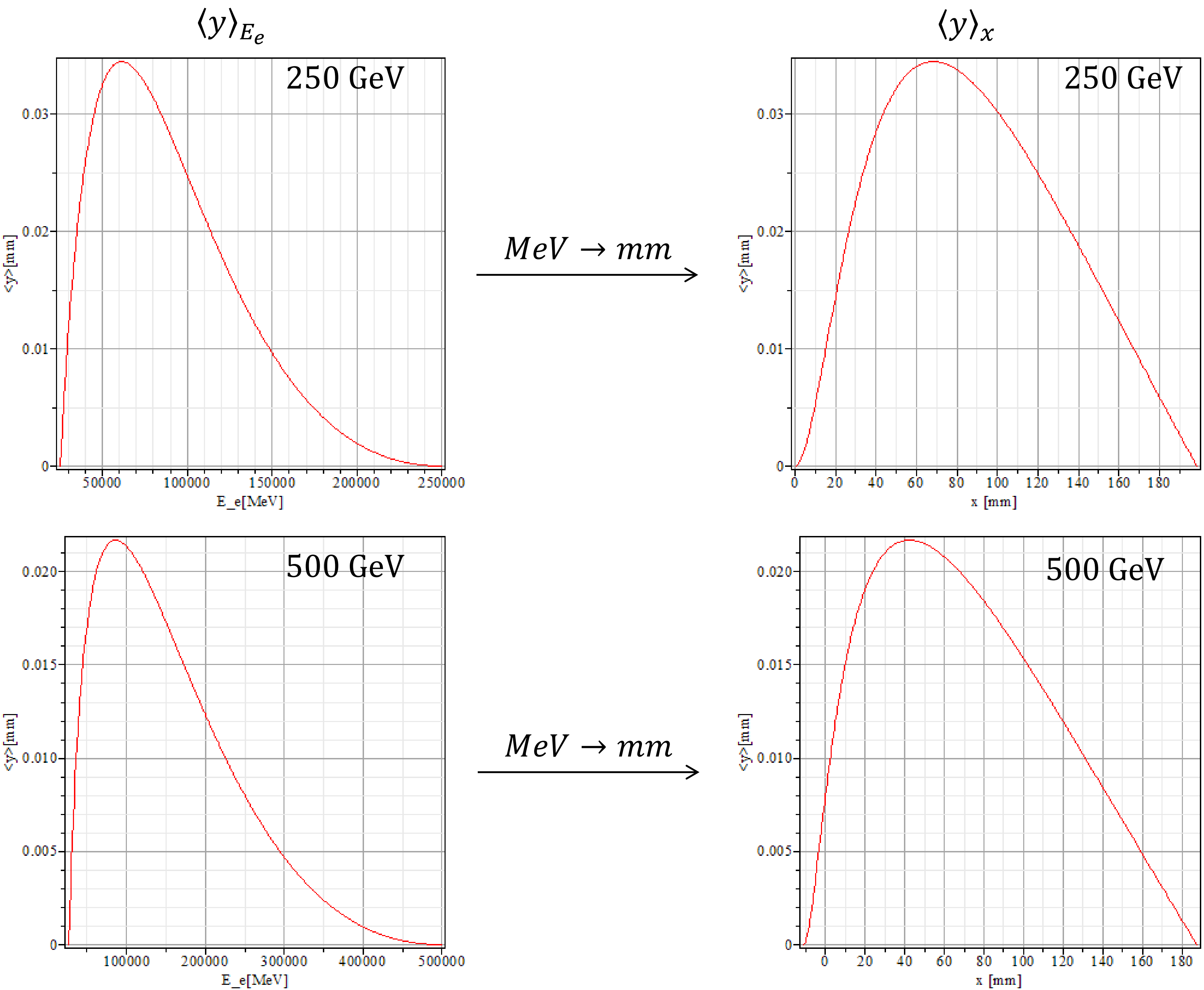
$$R[m] = \frac{p_{\perp}[GeV]}{K_b \cdot B[T]} \cong \frac{E_{el}[GeV]}{K_b \cdot B[T]}$$

K_b=0.2998



$$E_{el}[MeV] = \frac{10^6}{4 + 18.04 \cdot x[mm]}$$



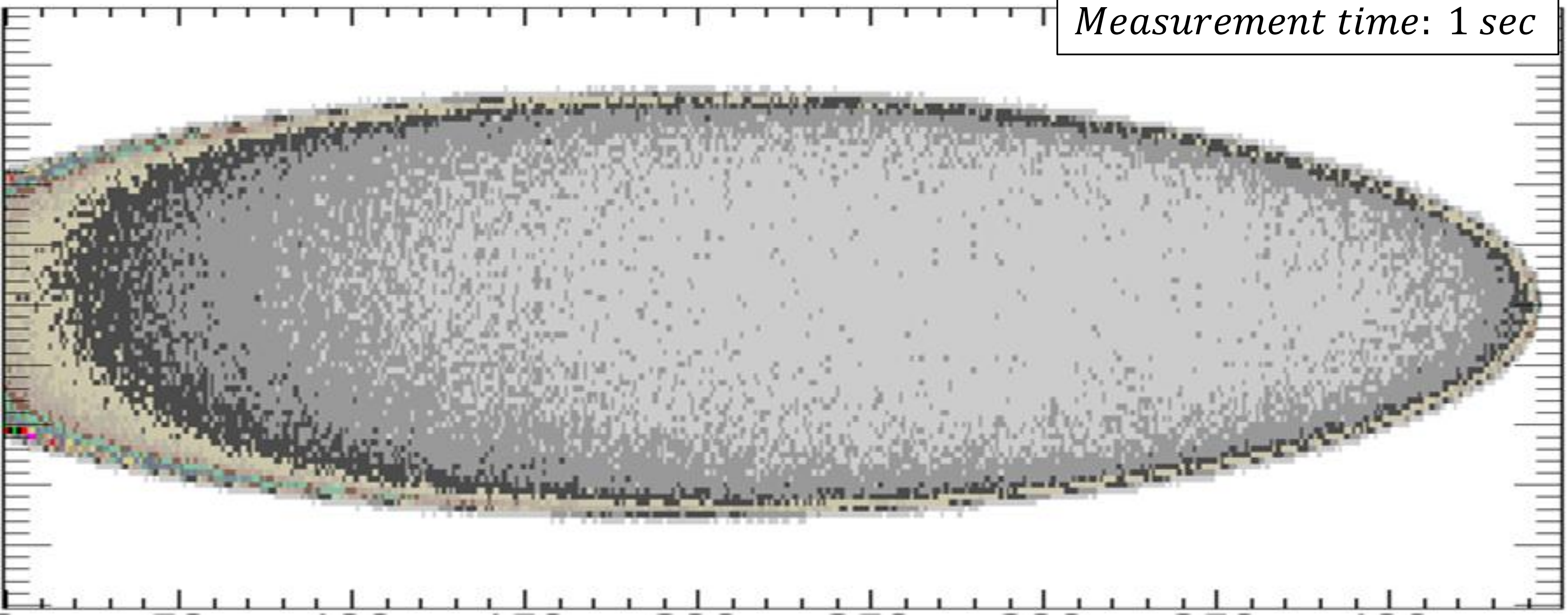


$\langle y \rangle_{E_e}$
$\langle y \rangle_x$
250 GeV
250 GeV
500 GeV
500 GeV
$MeV \rightarrow mm$
$MeV \rightarrow mm$
<y>[mm]
E_e[MeV]
x [mm]

The Pixel Detector

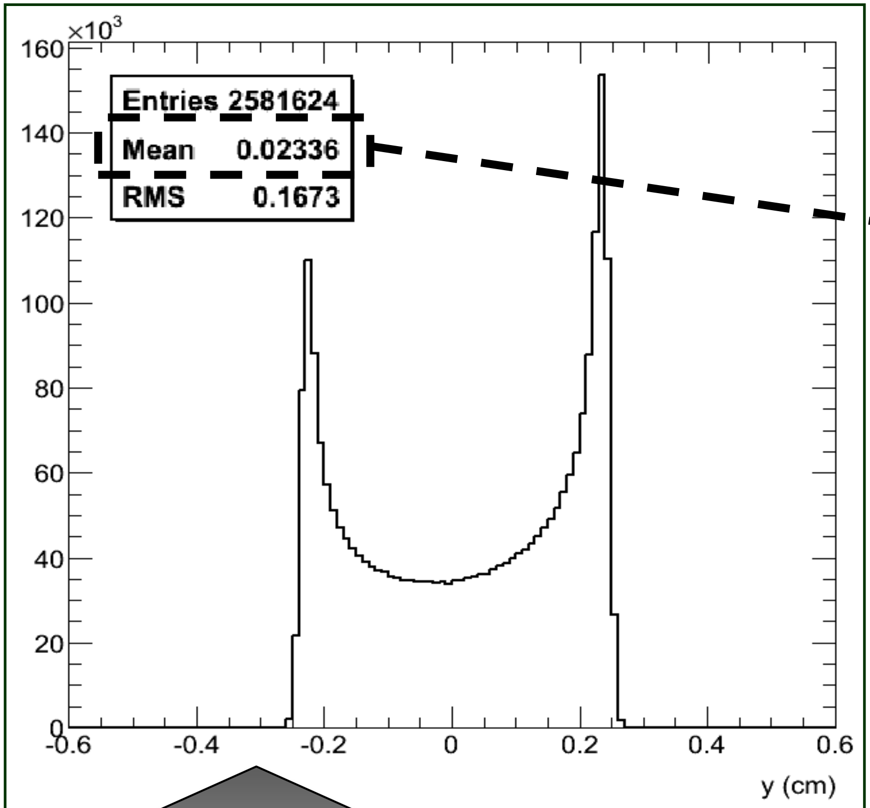
- Silicon pixel detector based on the Atlas one [6] recording the (x,y) position of the extracted scattered electrons.
  - Silicon pixel size $400\ \mu m\ \times 50\ \mu m$
  - ↪Detector resolution $115.5\ \mu m\ \times 14.4\ \mu m$
  - Clock frequency for the pixel readout chips $40\ MHz$

$E_{bean} = 250$ GeV
$P_T = 0.9$
$Measurement\ time$: $1\ sec$

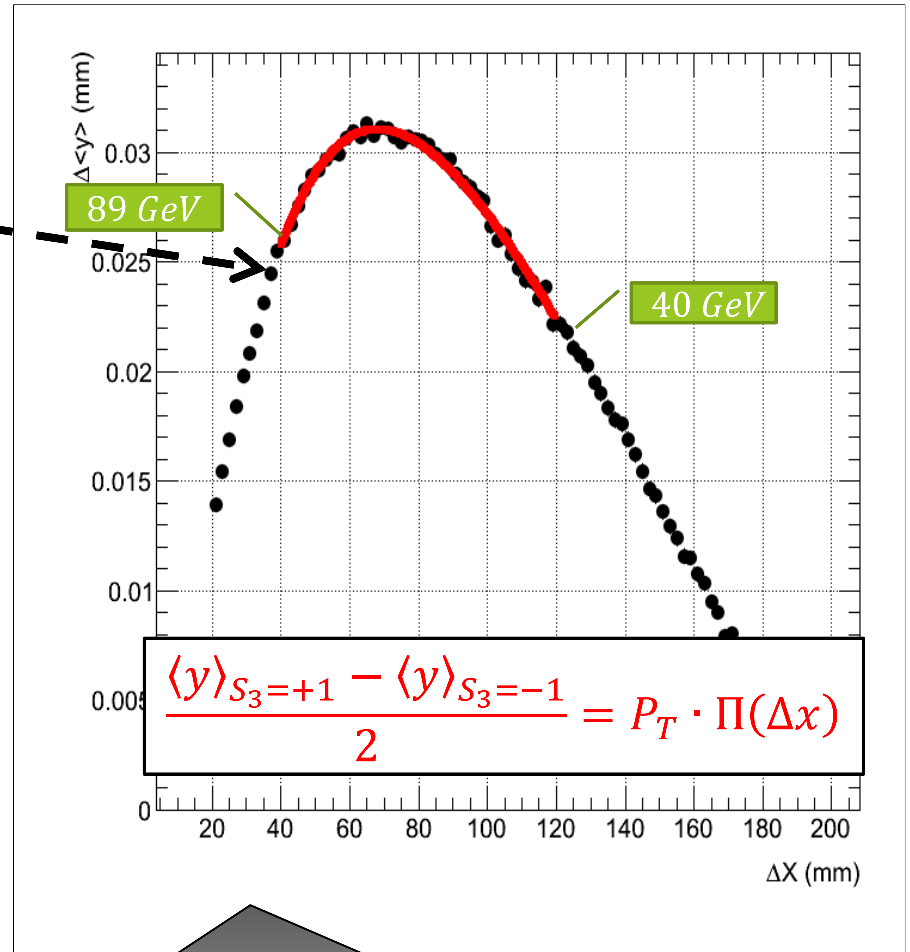


Measurement Result

$E_{bean} = 250$ GeV
$P_T = 0.9$



The distribution of y within the x range of 36 to 38 mm from the electron beam direction with $S_3 = +1$

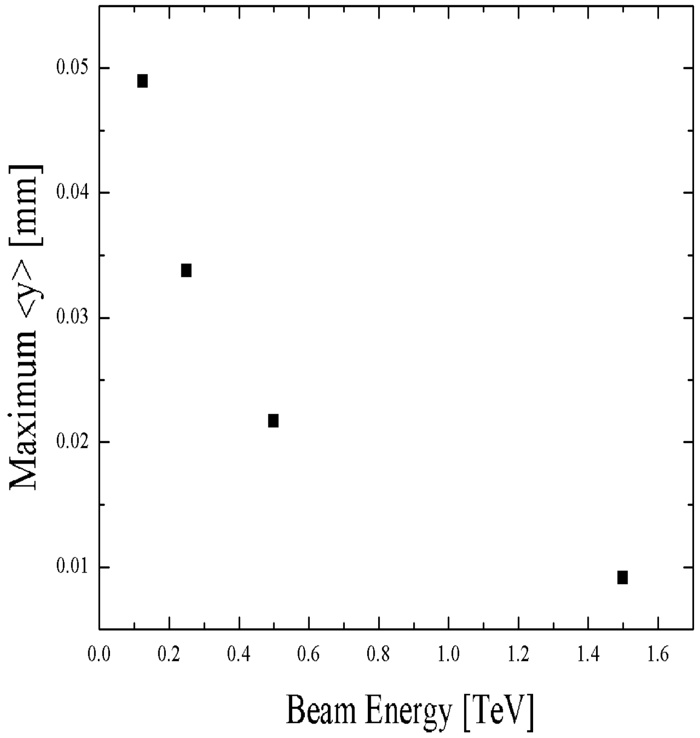


The dependence of $P_T \Pi(x)$ on x evaluated in steps of 2 mm

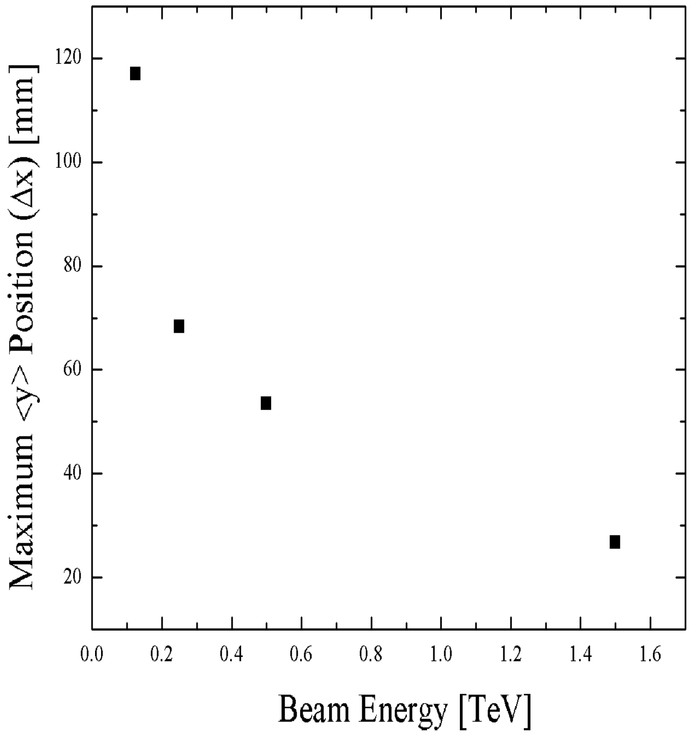
The Maximum of $\langle y \rangle$

at P_T=1.0 with the same setup as before at different beam energies .

The maximum value of $\langle y \rangle$



The position of the maximum value of $\langle y \rangle$



γe Luminosity (Pulsed Laser)

$$\mathcal{L} = f_b N_e N_\gamma g$$

- $f_b(14100)$, the number of bunch crossing per second
- $N_e(2 \cdot 10^{10})$, the number of electrons per bunch
- $N_\gamma(6.24 \cdot 10^{12} \frac{j_\gamma}{\epsilon_\gamma})$, the number of photons per laser pulse
- ($j_\gamma(35\ \mu J)$, $\epsilon_\gamma(2.33\ eV)$ are the laser current and energy)
- g, the geometrical factor which takes in account the spatial overlap of the two beams. For a transvers beam sizes $\sigma_\gamma \gg \sigma_e$ we get

$$\mathcal{L} = 1.68 \cdot 10^{32} \frac{1}{cm^2 \cdot s}$$

ILC Beam Parameters

Parameter	Unit	
Center-of-mass energy range	GeV	200 – 500, 1000
Peak luminosity	$cm^{-2}s^{-1}$	2×10^{34}
Average beam current in pulse	mA	9
Pulse rate	Hz	5
Pulse length (beam)	ms	~ 1
Number of bunches per pulse		2820
RF pulse length	ms	1.6
Typical beam size at IP	nm^2	640×5.7
Electron Polarization		90%
Positron Polarization		40%

Polarimeter Parameters

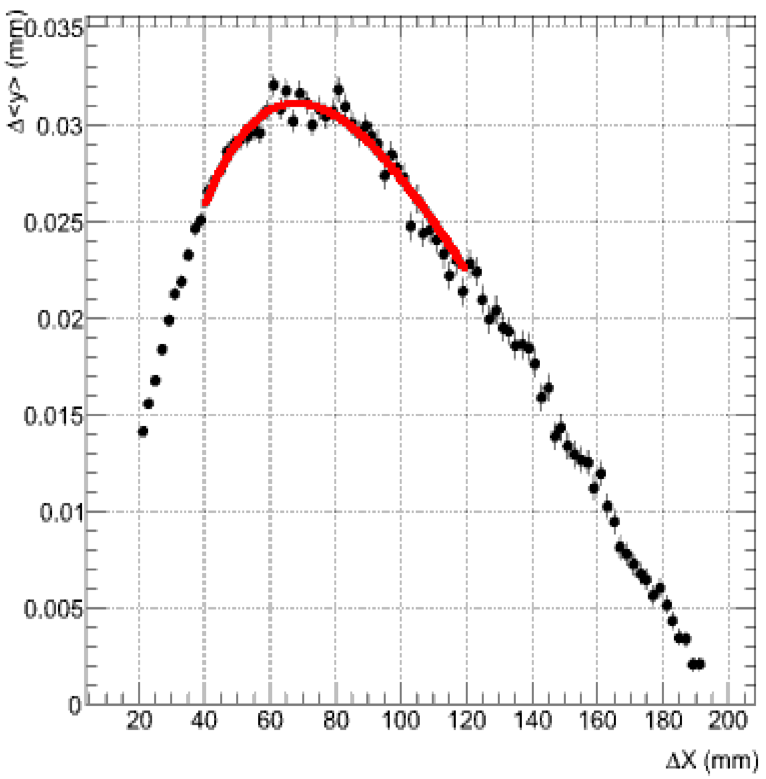
Parameter	Unit	
Detector distance from the γe IP	m	37.95
Laser energy (pulsed)	eV	2.33
Laser crossing angle	radian	0.01
magnetic field	T	0.097
Detector pixel size	μm^2	400×50
Detector pixel resolution	μm^2	115.5×14.4

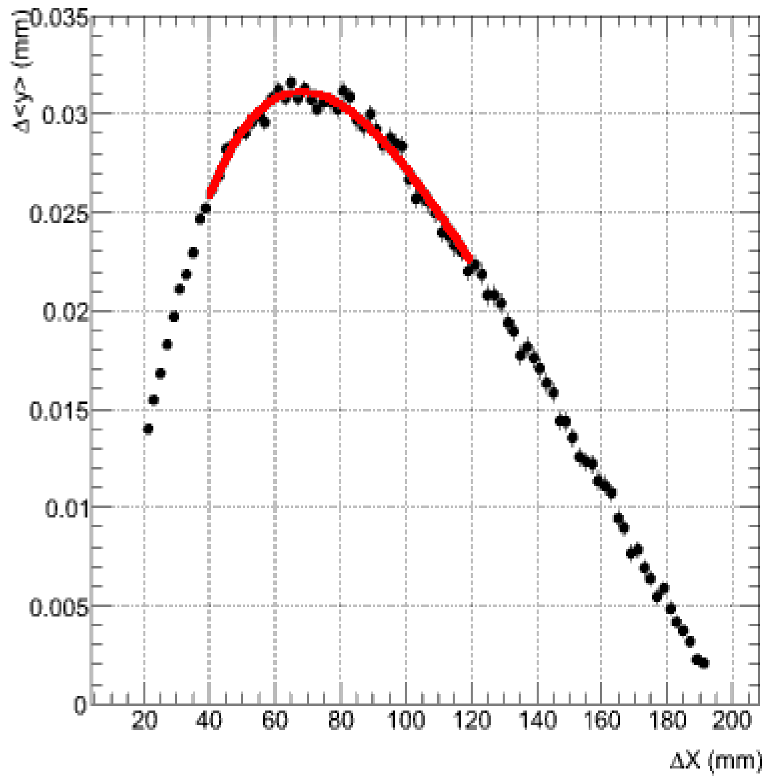
Monte Carlo for the Electrons

$P_T = 0.9\ , E_{bean} = 250\ \mathrm{GeV}$

No. Bunches	14100
Run time	1 sec
$\boldsymbol{P_T\ measured}$	0.8999 ± 0.003 (0.32%)
$\boldsymbol{\chi^2/NDF}$	1.393

No. Bunches	28200
Run time	2 sec
$\boldsymbol{P_T\ measured}$	0.9011 ± 0.002 (0.22%)
$\boldsymbol{\chi^2/NDF}$	1.17



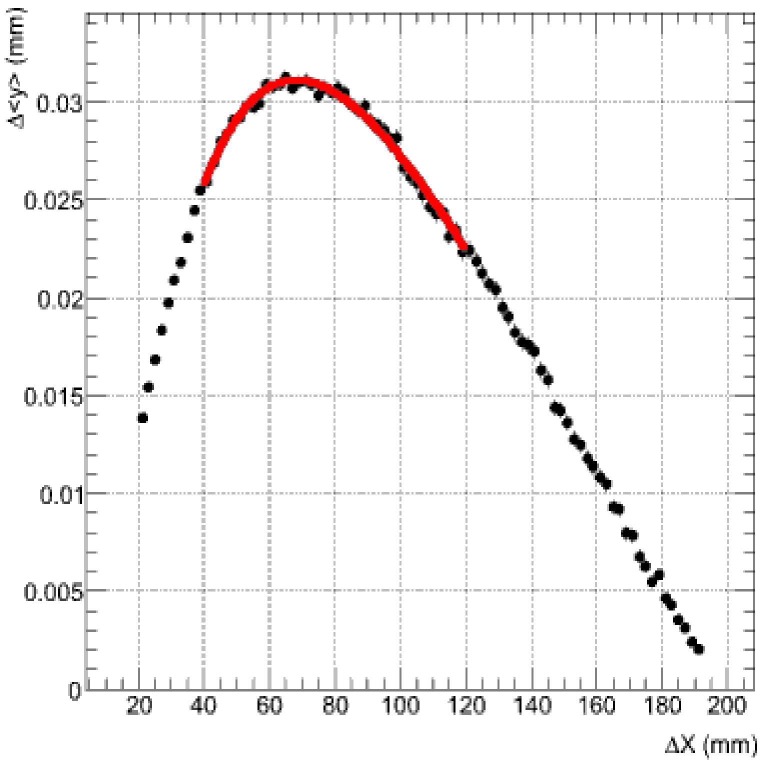


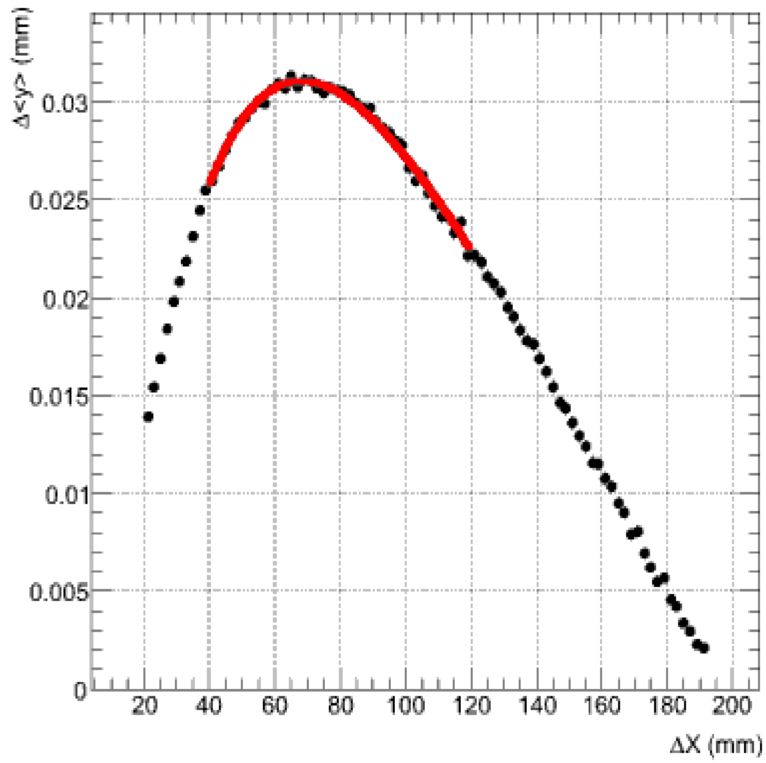
Monte Carlo for the Electrons

$$P_T = 0.9\ , E_{bean} = 250\ \text{GeV}$$

No. Bunches	42300
Run time	3 sec
P_T ***measured***	0.9009 ± 0.0016 (0.18%)
χ^2/NDF	0.805

No. Bunches	56400
Run time	4 sec
P_T ***measured***	0.8996± 0.0014 (0.16%)
χ^2/NDF	0.75



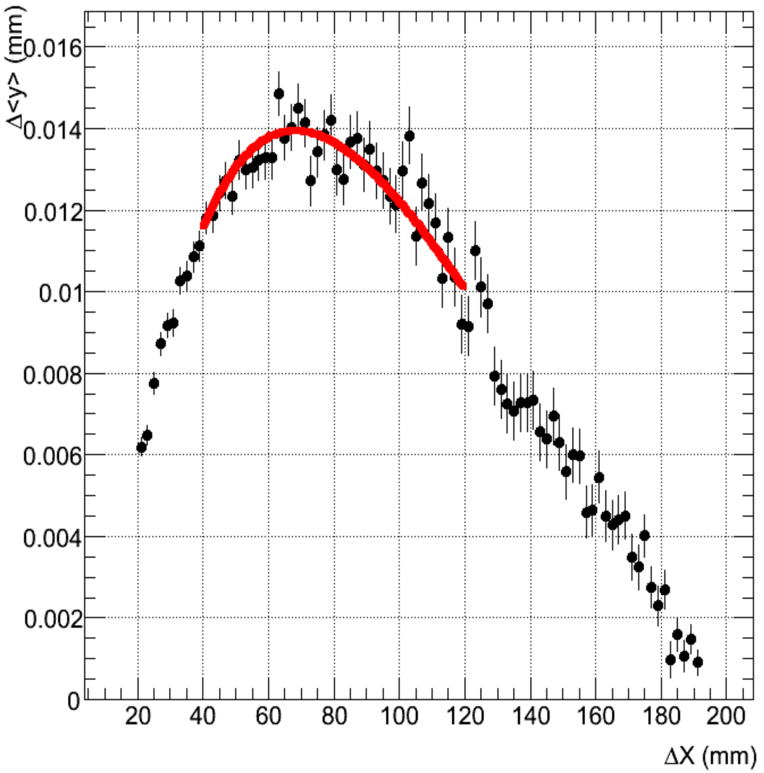


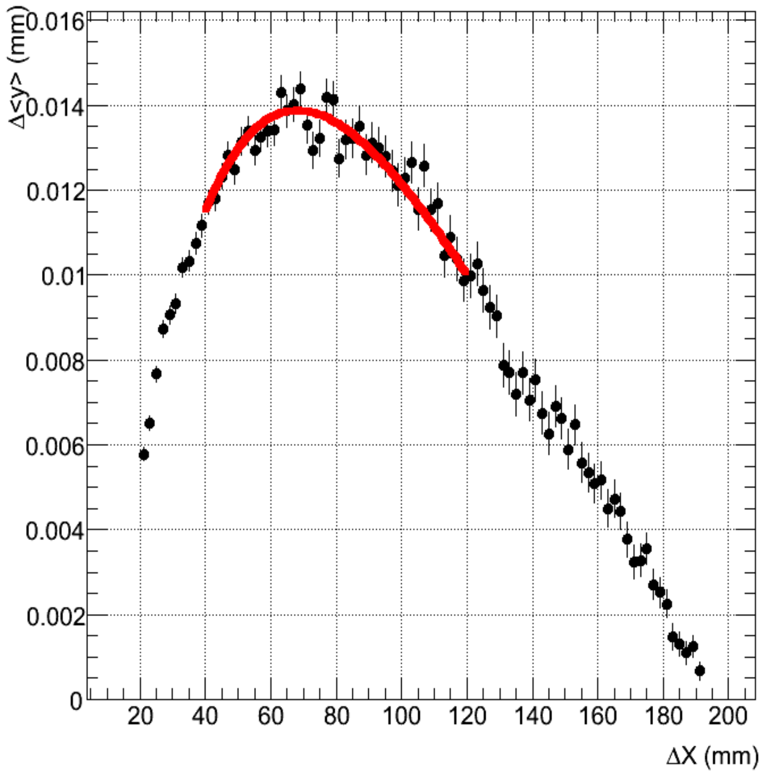
Monte Carlo for the Positrons

$$P_T = 0.4\ ,\ E_{bean} = 250\ \text{GeV}$$

No. Bunches	14100
Run time	1 sec
P_T ***measured***	0.4037± 0.0028 (0.7%)
χ^2/NDF	0.92

No. Bunches	28200
Run time	2 sec
P_T ***measured***	0.4018 ± 0.002 (0.5%)
χ^2/NDF	0.89



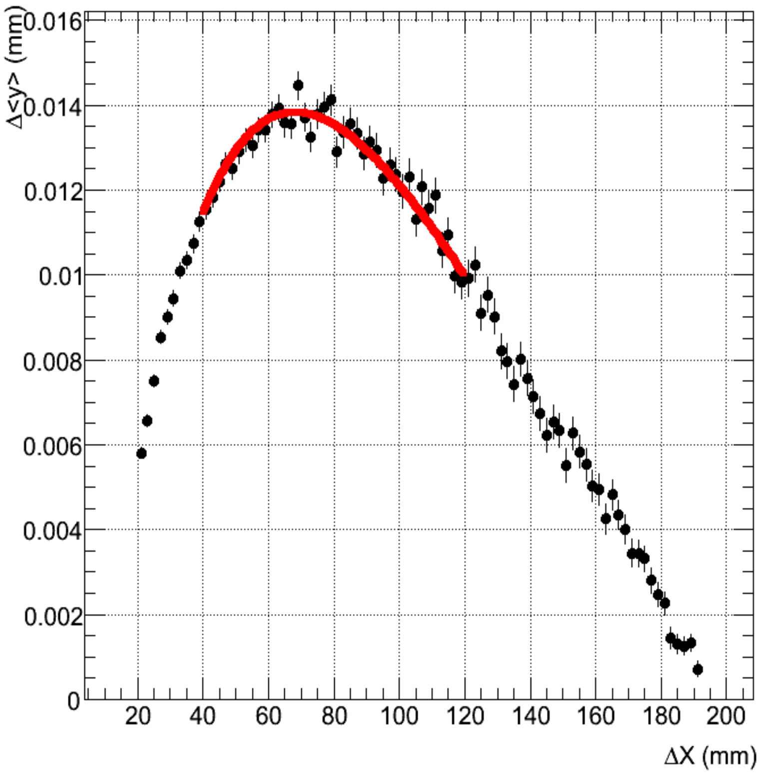


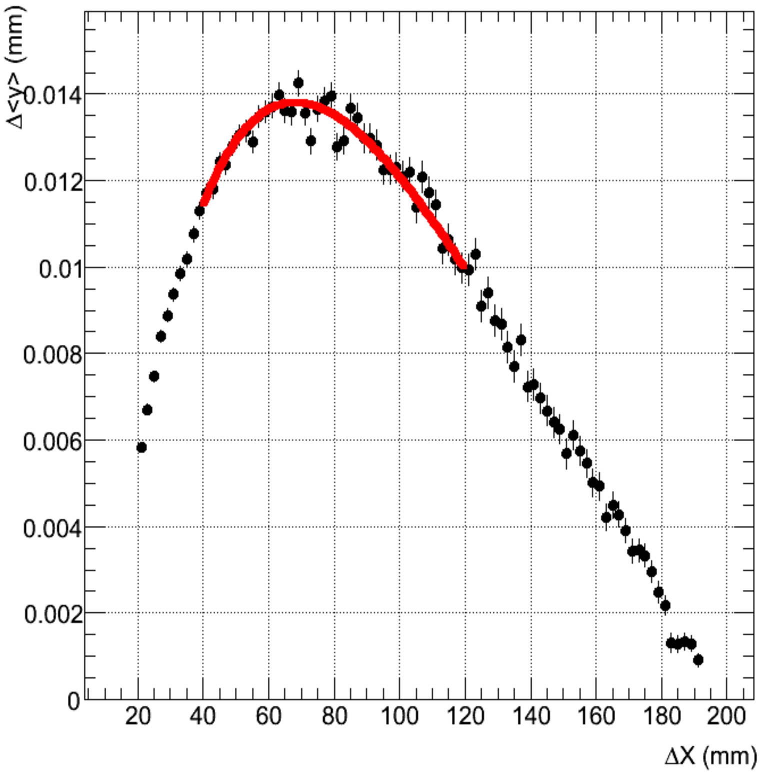
Monte Carlo for the Positrons

$$P_T = 0.4\ ,E_{bean} = 250\ \text{GeV}$$

No. Bunches	42300
Run time	3 sec
P_T *measured*	0.4006 ± 0.0016 (0.41%)
χ^2/NDF	0.80

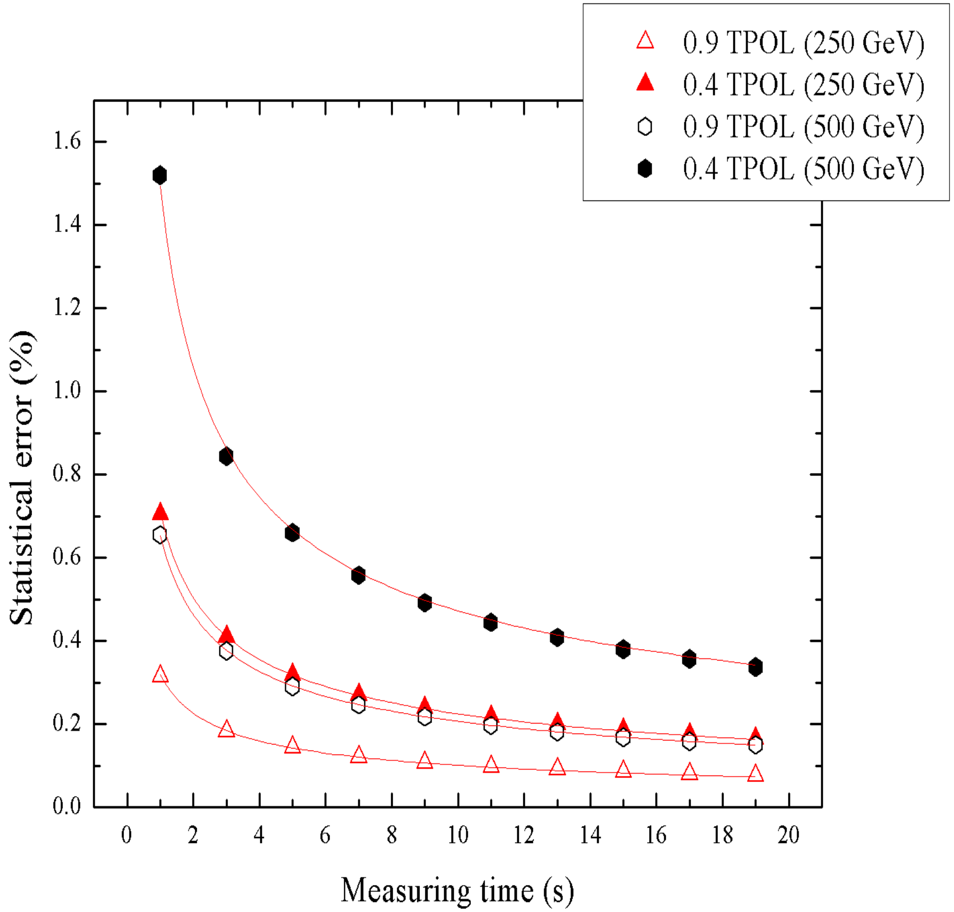
No. Bunches	56400
Run time	4 sec
P_T *measured*	0.3998± 0.0014 (0.35%)
χ^2/NDF	1.07





Measurement Time, Statistical Error

- The statistical error is related to the number of scattered γe per second recorded for the analysis.
- For a measurement with a Gaussian distribution we anticipate a $\Delta P_T \propto \frac{const}{\sqrt{t}}$ behavior.
- Using the Monte Carlo we find that the Fit of a to $\frac{\Delta P_T}{P_T}(t) = \frac{a}{\sqrt{t}}\%$

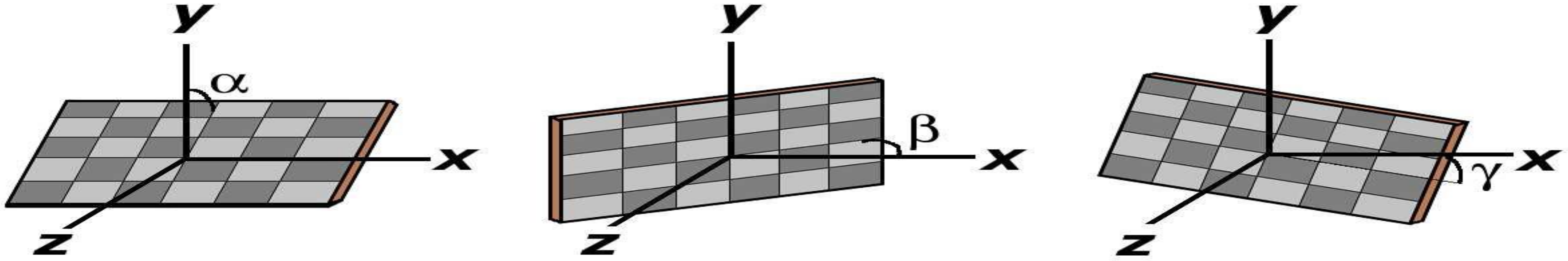


***14100 bunches per sec**

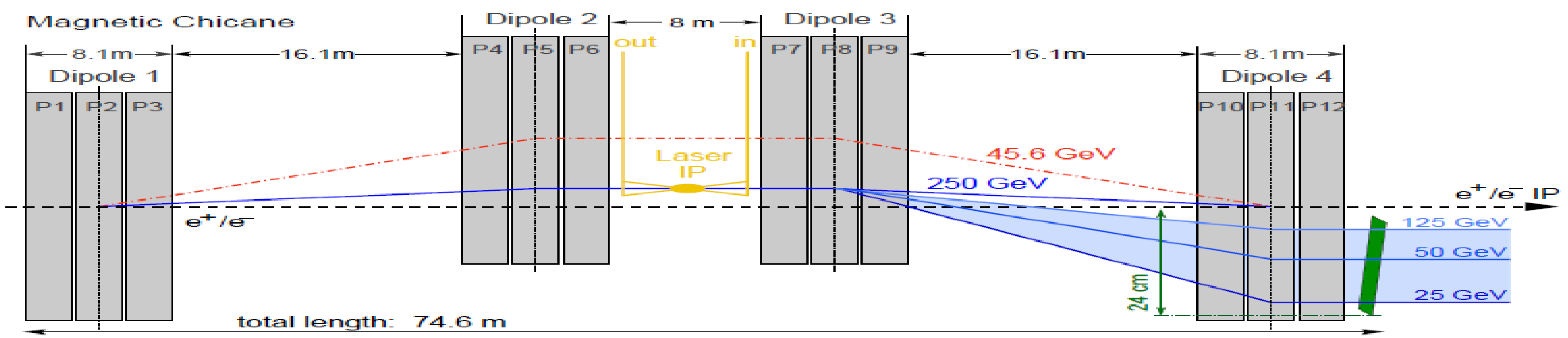
TPOL	a	Δa
0.9 (250 GeV)	0.31889	0.00162
0.4 (250 GeV)	0.71089	0.00194
0.9 (500 GeV)	0.65321	6.21E-04
0.4 (500 GeV)	1.49317	0.0083

List of Systematic Error Considered Here

- Detector and/or γe IP displacements



- Magnetic field of the spectrometer



- beam tremor
- beam energy uncertainty

	σ	$\lvert\Delta P_T\rvert$ 250 GeV	$\lvert\Delta P_T\rvert$ 500 GeV
Δy axis displacement	$\geq 25\ \mu m$	0.12%	0.14%
Δx axis displacement	$0.1\ mm$	0.008%	0.03%
Δz axis displacement	$1\ cm$	0.01%	0.026%
$\Delta\alpha^0$ deviation of the detector	0.1^0	0.001%	0.002%
$\Delta\beta^0$deviation of the detector	0.1^0	0.004%	0.005%
$\Delta\gamma^0$deviation of the detector	0.1^0	0.1%	0.21%
Spectrometer ΔB1	$0.0001\ T$	0.02%	0.05%
Spectrometer ΔB2	$0.0001\ T$	0.005%	0.029%
y Axis Beam Position Tremor	$5\ \mu m$	0.01%	0.011%
x Axis Beam Position Tremor	$5\ \mu m$	0.03%	0.035%
Beam Energy Tremor	0.1% of beam energy	0.025% For $\sigma = 0.25$ GeV	0.03% For $\sigma = 0.5$GeV
Beam Energy $\Delta \boldsymbol{E_b}$	0.1% of beam energy	0.06% For $\sigma = 0.25$ GeV	0.073% For $\sigma = 0.5$GeV
$\sqrt{\sum_i \Delta P_i^2}$		**0.17%**	**0.28%**

Summary

- Transverse Polarized Beams are expected to reveal new physics phenomena at high e^+e^- energy collisions .

- Transverse polarimeter based on Compton scattering is shown here to fulfill the requirements of $\frac{\Delta P_T}{P_T} \leq 0.5\%$ at beam energies of 250 and 500 GeV and in principal can be adjusted even to higher energies.

- In our setup measurement time of about 2 min will be sufficient to achieve negligible statistical errors.

- The systematics errors that have been investigated here yielded the values of 0.17% for $250\ GeV$ and 0.28% for $500\ GeV$ where the main contributions come from Δy and $\Delta\gamma^0$.

Acknowledgment

We would like to thank Drs. Sabine Riemann , Friedrich Staufenbiel and Jenny List for many useful comments and suggestions.

Thank you for your attentions .

תודה רבה.

Main References

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End

The y Centering of the Detector

Using the fact that unlike longitudinal polarimetry, in the transvers polarimetry the difference of <y> between left and right laser helicity is only by their sign, that is

$$\langle y \rangle_L + \langle y \rangle_R = 0$$

So any deviation from the true "y" centering will be cancel when one considers $\Delta\langle y \rangle$ i.e.

$$\frac{\langle y+dy \rangle_L - \langle y+dy \rangle_R}{2} = \frac{\langle y \rangle_L - \langle y \rangle_R}{2} = P_T \Pi(\Delta x)$$